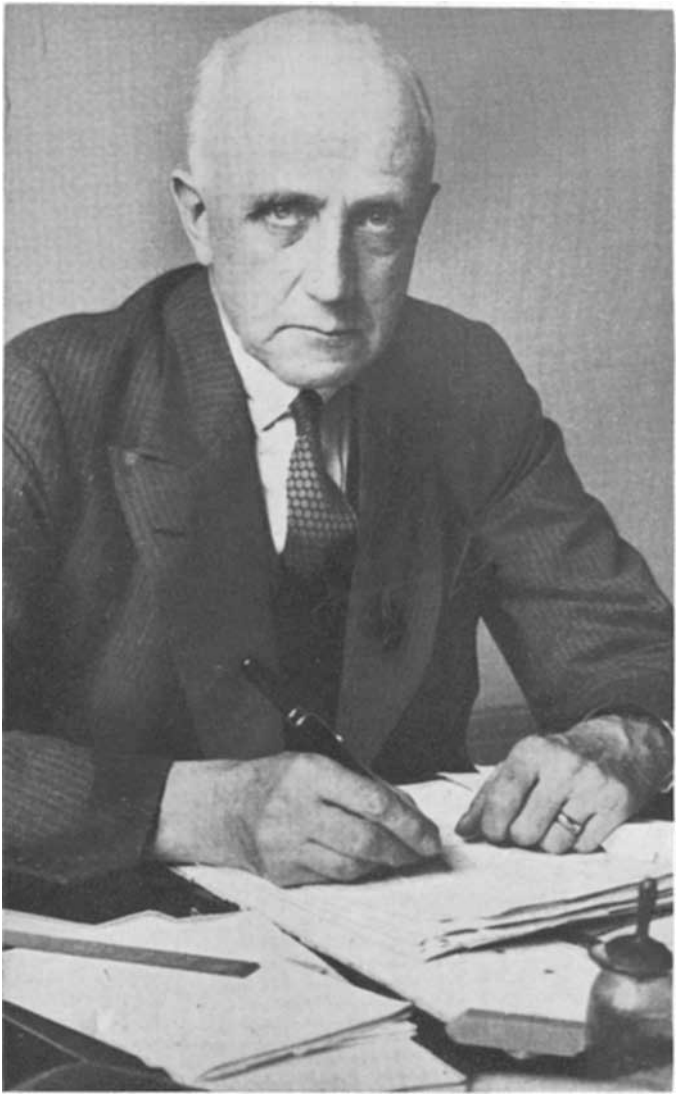

DR. G. F. HERBERT SMITH, M.A., D.Sc.
President of the Association.

THE JOURNAL OF GEMMOLOGY

AND PROCEEDINGS OF THE GEMMOLOGICAL ASSOCIATION OF GREAT BRITAIN

Vol. 1 No. 1 JANUARY 1947

THE appearance of the Journal of Gemmology in its new and independent guise marks a definite turning point in the history of the Gemmological Association of Great Britain. Its examinations have long gained an international reputation, but it is now something more than an examining body; more and more it is engaging in activities of value and interest to the Fellows and Members. The Council propose, in addition to chronicling their proceedings, to publish from time to time theses which have been successfully submitted for the Research Diploma and possibly other original work. The Association goes from strength to strength; it is a privilege which I greatly value to have been connected with the movement from the very start, and I hope that it may be my good fortune to aid its progress still further. May the Association continue to flourish!

G. F. Herbert Smith

ALL PEARLS are not what they seem!

A. E. ALEXANDER, Ph.D.
Gem Trade Laboratory
New York

IT has been six years since the writer published his first paper dealing with ways and means of differentiating Japanese cultured pearls from the genuine pearls of commerce ([1], [2], [3]).

Since 1939, several hundred thousand individual pearls have been fluoroscoped, radiographed, X-ray diffractioned and otherwise scientifically tested and examined.

To the layman, a pearl is a pearl. To the scientist, a pearl on examination may prove to be a pearl and then again it may turn out to be something quite different. Pearl testing is no job for an amateur jeweller, or even a retail jeweller who thinks he is an "authority" on pearls. The toughest synthetic ruby or sapphire is easy to determine by any standard when compared to **some** undrilled pearls that have come to the writer's attention.[4]

The Japanese cultured pearl is a good example with which to start. Mineralogists, as well as most dealers in pearls, have come to accept one very salient fact about Japanese cultured pearls, viz., that for the most part these biologically synthesized pearls contain a large, round mother-of-pearl head encased by pearl nacre not over a half-millimetre thick, and that this bead measures from 80-90 per cent. of the total linear diameter of the pearl ([5], [6]). The question has been asked: Are there any Japanese cultured pearls which do not contain round mother-of-pearl beads? Unfortunately for the pearl tester, exceptions do occur.

The writer uses the radiographic method almost exclusively to test pearls ([3]). The round, mother-of-pearl bead of a Japanese cultured pearl is usually well defined on the X-ray film. To cite a case: In 1946, two different pairs of fine quality earring button pearls, all cultured, representing 20 and 30 grains weight each, respectively, were found to contain not round mother-of-pearl beads, but large, **oval** shaped mother-of-pearl beads. Ordinarily, on the basis of the radiographic negative alone, these pearls would

have been classified as "genuine." They "looked" cultured, however, and for that reason the request was made to have the pearls removed from the setting so that additional tests could be made. On the basis of non-radiographic tests, the pearls were positively identified as being cultured.

The Japanese use fresh water shell for manufacturing their mother-of-pearl beads. Mussel shells are found sufficiently thick to permit the extraction of large beads. This material has been found to fluoresce under X-ray radiation. The fluorescence is due to the presence of a trace of manganese associated with the calcium carbonate and organic matter of the shell. Until recently, of the thousands of Japanese cultured pearls subjected to X-ray radiation, none had ever failed to fluoresce, and similarly, no genuine Persian Gulf salt-water pearl had ever been found to fluoresce.

In the past several months, however, a few exceptions to this rule have been noted. The pearls in question weighed approximately 20 grains each and were undrilled. The writer had to resort to other tests to determine the cultured character of these pearls. If the Japanese were to use salt-water shell for mother-of-pearl beads, assuming that they could get shells of this kind in sufficient number and of satisfactory thickness, the phenomenon of fluorescence as an **indication** of a cultured pearl would not exist and the ingenuity of the pearl tester would be taxed still further.

And now for another case history. Some time ago, several undrilled fresh-water pearls of three and four grain size were brought to the writer's laboratory. These particular pearls had been pronounced genuine. The writer, using special techniques, found they had been cultured. Further investigation revealed that in truth they had been. The pearl culturist had taken a genuine, one grain fresh-water pearl and placed it in a fresh-water mussel, leaving it there for a period of years to grow. The final product

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[2] A. E. Alexander: *Gems and Gemmology*, *3*, Pt. 1, 2, 169-172, 184-188 ; 1941.
[3] A. E. Alexander: *The Gemmologist*, *10*, 113, 45-48 ; 1940.
[4] A. E. Alexander: *J. Chem. Ed.*, *23*, 9, 418-422, 459 ; 1946.
[5] A. E. Alexander: *Sci. Am.*, *160*, 4, 228-229 ; 1939.
[6] A. E. Alexander: *Sci. Am.*, *160*, 5, 294-297 ; 1939.
[7] A. E. Alexander: *Horology*, *7*, 2, 11-16 ; 1940.
[8] A. E. Alexander: *Horology*, *7*, 4, 11-23 ; 1940.

was a pearl of three or four grain weight. In this particular instance, radiography did not conclusively reveal the thin line of organic matter initially deposited on the genuine pearl insert.

In an earlier paper, the writer described the fine, undrilled fresh-water cultured pearls which were found to contain glass beads as nuclei ([2]). Pearls of this kind were found to have the same specific gravity of genuine pearls. An X-ray diffraction pattern characteristic of a genuine pearl was obtained from these pearls. Radiography, however, easily detected the glass bead.

Mention already has been made of certain genuine fresh-water pearls which will produce cultured-pearl X-ray diffraction patterns with reasons given for this anomalous condition ([1]). The problem becomes even more involved when Japanese cultured pearls having very small mother-of-pearl beads measuring 50 per cent. or less of the total linear diameter, yield genuine pearl X-ray diffraction patterns. (Such pearls are very much the exception to the rule, as has been stated before.) This condition results from the fact that the mass of genuine pearl matter greatly exceeds the mass of mother-of-pearl shell matter in pearls of this type.

A fine imitation pearl can cause trouble if a large number of genuine pearls are tested at the same time. Imitation pearls, made of glass, are generally composed of three types: (a) a solid glass sphere ; (b) a hollow glass sphere ; (c) a hollow glass sphere filled with some organic or inorganic material designed to give weight to the pearl. The sphere is covered with a substance usually organic in composition having the appearance of pearl nacre. On occasion, however, a remarkable simulation is achieved with the imitation pearl possessing the " life," lustre and look of a genuine pearl.

The solid glass bead may be of a variety of glass compositions. If the glass is a lead glass, the radiograph reveals this fact at once. On the other hand, some glass beads have a composition that will yield a shadowgraph identical or very close to identical with that obtained from pearl or mother-of-pearl substance.

Furthermore, if X-ray fluorescence is used as a preliminary test for cultured pearls, the tester must not be surprised to find some imitation pearls fluorescing, with equal intensity. Again, some imitation pearl necklaces that have been submitted to the writer for test produce no fluorescence whatsoever.

That still other simulations may be forthcoming, as from the field of plastics for example, can be accepted as a foregone conclusion.

SOME PHOTOGRAPHS FROM THE LABORATORY

No. 1.—PEARL SECTIONS

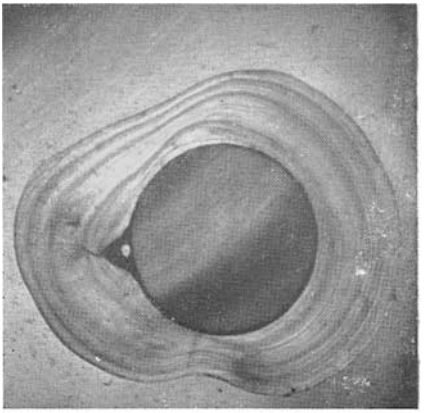

1. Section of a baroque cultured pearl with an unusually thick skin.

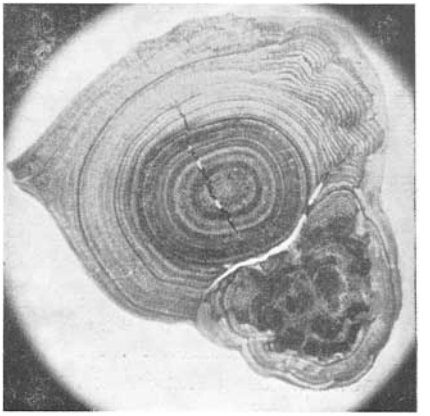

2. Section of an irregularly-shaped fresh-water pearl.

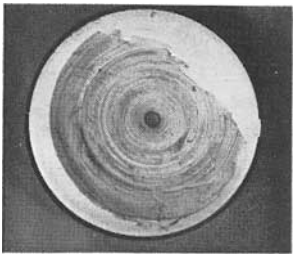

3. Section of an oriental pearl.

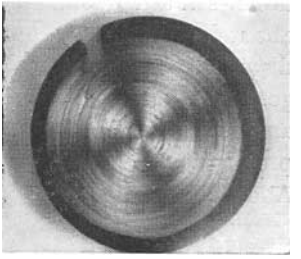

4. Section of an oriental pearl viewed between crossed nicols showing the "extinction cross."

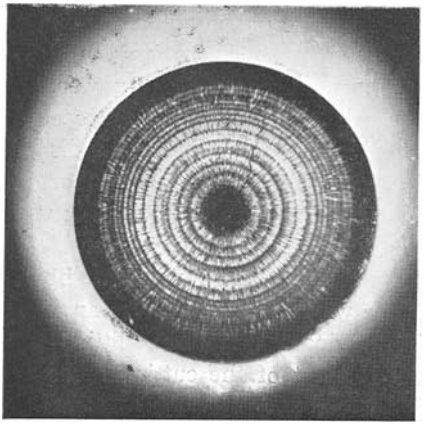

5. Section of a fresh-water pearl.

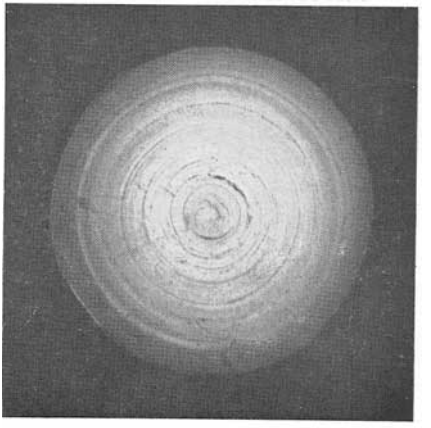

6. Section of an oriental pearl.

(Photos by B. W. Anderson, B.Sc., F.G.A.)

Jade Picture

by ELSIE RUFF, F.G.A.

IT is easier to reconstruct a neolithic jade cutter's shop than it is to visualize accurately a contemporary one. And not because it is impossible to prove or disprove the ancient. One is the result of research . . . an aggregation of facts, a logical working out, a corroboration of this and that as experience progresses.

Generally our approach to jade has been a little theatrical. Its symbolism is so complicated and the authorities on the subject so few that we stand in awe of a jade figure. Any jeweller would rather sell a diamond than a piece of jade. He is not even clear about its mineralogy. And while there is hardly a question on diamonds he cannot deal with, there are many on jade that must go unanswered. Yet actually there is little difference between it and our early silverwork. Both the silversmith and the jade carver produced within a religious aura. It was the life of their day. And Buddhism is not much older than Christianity.

To go back-stage to the Chinese jade cutter's shop is to emerge feeling that another illusion has been destroyed and the way once more cleared for unbiased thinking. No limousine will take you there. A rickshaw coolie might jolt you down one of those thoroughfares that are a series of wide shallow steps. Finally you proceed on foot—along some gloomy alley where the cutter's shop will likely be in the dirtiest part. Unless it is exceptional, the shop's machinery will not be electrically controlled. Man-power, on the old treadmill principle, is still the custom. Wooden clogs standing empty—and rather pathetic—at the side of the treadmills proclaim that while bare feet do one job hands are free for another. Almost certainly the shop will be artificially lighted, for little enough daylight can penetrate a hole or two in the wall. If the holes are filled in with glass the glass will be grimy and light that much more reduced. Nor will the whitewashed walls be anywhere near their original white. The Chinamen will wear little—perhaps only slacks—for the climate in most of the cutting areas

is warm and humid. A dozen or more men under such conditions, in a space just large enough to take two or three rows of treadmills side by side, is anything but agreeable. By comparison with our modern factories the jade cutting workshops might be described as a dungeon on the alley level.

For jade is a serious business and the Chinaman, if he gets half a chance, a good business man. And men must work and eat and sleep too. Some sleep on the premises of just such a workshop, with bunks, upper and lower, running round the top of the walls. There they breathe the abrasive and human laden air. And there, incredible as it seems, with the noise of the treadmills and the incessant chatter of his co-workers, the jade cutter does sleep. Perhaps it's his only chance of bed-space, a valuable commodity in the East. The workshop may be open from 8 a.m. to 12 p.m., and no trade unions control working conditions. During that period the workers doubtless have some time off and presumably take their turn in the bunks. Yet, despite conditions, the Chinese business man still has plenty of labour to draw upon, experienced and inexperienced only too anxious to learn.

The logical question to ask it: What can a man produce under these conditions? Well, there's a large slab of jade on one of the benches and an almost emerald green gemstone is being marked off for cutting. It is to come from a thin vein of green near the boulder's crust, separated only by a tapering ochre strip. But it will be valuable. The West has a taste for it. Large blocks will presently be marked off that will eventuate as jade figures. Variegated material should give the carver scope for some originality. But as likely as not he will draw on the past, particularly the Ming period (A.D. 1368-1644), for it was a time of great technical virtuosity, though not of spontaneous work. The Mings are credited with having imitated the earlier periods.

It cannot be denied that the jade carver has a realistic contact with the world in which he lives. He is up against it from birth. But good health and vitality—or at least phases of these—are also essential for creative work. And as a third factor there must be some degree of leisure in which to experiment and interpret. Most assuredly the contemporary jade cutter or carver sees his work in terms of rice. And the terms are not easy. An empty bowl is always imminent.

By Norman A. Harper, F.R.G.S., F.G.A.

SCIENCE or EMPIRICISM ?

INFORMED experience is a faculty of considerable value in any walk of life and knowledge gained by experience remains more firmly embedded in the minds of most people, than does knowledge culled from books or acquired at lectures.

Unfortunately, the human senses are not always capable of analysing their observations, with the result that experience is frequently ill-informed, and thus of little value.

For countless centuries men experienced the diurnal journey of the sun round the world, and, having a prejudice in favour of a geocentric universe, never suspected that in reality the rôles were reversed, it being the earth which was the "wanderer."* By means of the scientific method, the measuring, analysing and indexing of experienced observation, it was possible, however, to arrive eventually at this now almost universally known truth.

In every branch of knowledge the scientific method has proved its indispensability, and scientific instruments which measure and analyse human observations have become so numerous that a book† of some three hundred pages is required to describe briefly the forms and uses of the more important of them.

There is still, however, a remarkable disinclination or reluctance among many to use such instruments, or rather to acquire the technique enabling them to be used. This may be due to a mistaken idea that these instruments require a technique that can only be achieved by long and painful practice and study. If this is so, it had better now be stated that while such study is necessary to grasp thoroughly the scientific principles underlying the use, say, of the telescope, much valuable and accurate knowledge can be gained by anyone, completely unversed in the science of optics, who knows which end to place next to the eye.

Few advances in knowledge have had such beneficent effects upon humanity as those associated with medical science, and few sciences can equal it in the number of the instruments to which its practitioners have recourse. The instruments of physics, of optics, of chemistry, of electricity—to all these the physician turns for aid.

It is hard to imagine a doctor without a thermometer, a stethoscope, and a hypodermic syringe, yet it is possible for him purely by experience and the use of his hands to tell whether or not a patient is feverish, or by his unaided ear to hear the rhonchi or râles which mark successive stages of bronchitis ; it is also possible for him to introduce drugs into the body without a hypodermic syringe, but who will deny that the use of such instruments makes these operations so much more accurate and certain, besides their having other uses and a much wider application.

What, one may ask, is the object of this long preamble? The answer is contained in another question. Does the jewellery trade make sufficient use, in the hands of its numerous practitioners, of the scientific instruments which are available for the determination of the nature of the materials in which it deals?

The writer has within the past few weeks encountered three pieces of jewellery in which there were green stones which experience told him were emeralds, and not only his own experience, but the experience of three other jewellers of no mean capabilities, to whom they were shown. By the use of scientific methods and scientific instruments, however, these " stones " were proved to be extremely good imitations. As they were mounted in association with diamonds of considerable value, they might have escaped suspicion had not three very simple scientific tests been utilised to determine their true nature. Needless to say, the results of the investigations were a grave disappointment to their owners, who had vigorously asserted their genuineness.

In such cases the empirical method is generally employed, with the result that the truth is never discovered.

There are few trades where such mistakes can be more costly and few trades where accurate diagnosis is so often necessary. Every purchase from the public (and sometimes even from the " trade ") and every valuation, for whatever purpose, pre-supposes an exact knowledge on the part of the buyer or appraiser of the true

nature of the constituent materials of the object to be bought or valued. Yet, in spite of the growing number of competent gemmologists, a census of the jewellery establishments in which a bottle of dilute nitric acid and a smooth faced file were the only instruments available (and in a few enlightened cases, one Chelsea colour filter), might engage a large number of enumerators.

In such establishments it is not possible to differentiate between unmarked platinum and unmarked white gold, or, for that matter, between either of those metals and stainless steel, and even an approximation of the quality of unmarked yellow gold would be with difficulty arrived at.

But when it comes to the determination of gemstones, the difficulties which beset such establishments would cause shivers of apprehension in a gemmologist.

Of course, jewellers in that position can always say that it is possible to " play safe " ; " when in doubt, don't buy "—or sell? " When not sure, allow nothing for the coloured stone." . . . " Buy it as 9 carat (or when it is obviously better than that . . . 15 carat)." But surely that is unethical and dishonest. What would be thought of a doctor who said " I can't be sure whether it is colic or appendicitis, so we had better operate "?

A knowledge of gemmology and the purchase of a little equipment would resolve most, if not all these doubts. In the case of precious metals, the expenditure of a few shillings and an hour of time with Selwyn's " Retail Jeweller's Handbook " are all that is necessary to banish them for ever. Precious stones require a little more attention, but the possession of a few scientific instruments and an easily acquired knowledge of the technique of their use constitutes all that is necessary to transform an empiricist into a scientist, or one who guesses into one who knows.

The cost of these instruments might deter the individual, as it is in the region of thirty to forty pounds, but it should not, under any circumstances, deter a business, or an individual if he happens to be the proprietor of a small business, as this equipment will in a few years pay handsome dividends if used with knowledge and imagination. In any case, the increased confidence to be gained from their use will manifest itself inevitably in more and more successful sales-talk.

" I don't want to turn my showrooms into a laboratory " is a remark occasionally heard, but a consultation in Harley Street will be conducted in the atmosphere of a cultured 18th century salon, with gastroscopes, cystoscopes, and even such a pleasant instrument as the microscope, kept well in the background. No one doubts their existence and possible proximity, however, and the certainty that the consultant will take every advantage in diagnosis they offer, makes his advice invaluable as compared with the advice of the greatest physician of medieval times.

What equipment will benefit the jeweller? Here is a list of instruments in the order in which they should be purchased, in the opinion of the writer:—

1. The Refractometer. (Tully, Herbert Smith, or Rayner.)
2. Heavy Liquids. (Bromoform, Methylene Iodide, Clerici Solution.)
3. Petrological Microscope.
4. The Dichroscope.
5. The Spectroscope. (4 and 5 can be in the form of Microscope accessories.)

The method of their use is fully explained in text-books written specially for the jeweller, but the first essential is a competent knowledge of gemmology.

* *Planet : Greek.—Planētēs—Wanderer.*

† Scientific Instruments: *Edited by Herbert J. Cooper, B.Sc., A.R.C.Sc.I., A.M.I.E.E. Hutchinsons.*

The Gemmological Association Exhibition

By Gerald Carr

GEMS from every part of the world, many of them so rare that they had seldom or never been seen by the ordinary person, were on display in all their beauty and with all their interest at the first Gemmological Association exhibition to be held in the Hall of the Worshipful Company of Goldsmiths.

On January 8th and 9th, the two days of the exhibition, these gems, some unique, many rare and others costly, delighted the expert eyes of the gemmologist. They looked their best in the settings which had been designed for them as they glittered or revealed their fine markings beneath the twin lighting of electricity and the hundreds of candles in the great candelabra of the Hall. From the spoken comments of the less expert of the visitors it was clear that the exhibition had aroused their enthusiasm, given them a glimpse into new fields of knowledge and almost converted them on the spot to take up the study of gemmology.

Apart from gems and instruments of the Association, leading organisations and firms associated with gemmology contributed their own well presented displays and notable, too, were some of the displays and collections of the Fellows of the Gemmological Association. Many important members of the trade travelled far to visit the exhibition, and I understand that the members of the Design and Research Centre who visited it on the second day were impressed by its scope and variety.

Amid the filled Hall with beauty everywhere, it is difficult to know where to start in reporting the exhibition. But perhaps the diamond, still holding pride of place in value if not in rarity, gives the clue, and this display caught the eye first. Two cases told the story of this and its associated gems with a liberal display of fine diamonds ranging from gems of several carats to mixed melee.

There was a piece of Kimberley blue ground with a diamond embedded in it, and from that the visitor could see the future stages in the production of a brilliant from the rough. They were shown by models, mathematically correct ; by photographs showing stages of the work and by the diamonds themselves.

The models showed the diamond in its perfect octahedral form as mined, then sawn in half and then " bruted " into its round shape. Then the polishing began and following models showed the successive stages from the polishing of the first two pavilion and top facets until all 56—or 57—facets had been done.

Above this were pictures of some of these stages being carried out by the workers, while at eye level where vision could be aided by a magnifying glass, was a wonderful example of this craftsmanship carried out on a fully-faceted gem of only .07 cts. While for contrast by its side was a £7,000 diamond of 7.3 carats.

A section of the Exhibition from balcony

Then in the second case the visitor found that a diamond mine was not wholly composed of diamonds. Many other useful minerals and semi-precious stones were mined, such as bronzite, gypsum, limonite, molybdenite, garnet, olivine and zircon. Examples of these and others were given, but again the attention of most visitors was caught by the groups of diamonds of different varieties, lit from below and including a fine 72 ct. large cape and a 90 ct. large maccle stone in which the lateral division line marking these " two-in-one " stones could be noted.

Neat little piles of diamond wealth made up the other varieties. There were yellow stones and blue, small extra blue maccles, green stones, sand and brown stones and mixed melees.

And naturally, the world's two remarkable diamond finds, the Cullinan and the Jonkers, the latter found only three miles away from the site of the former and both bearing a common resemblance, were not left out of this exhibition. Glass models of the two diamonds were on view, together with models of some of the stones which were cut from the rough.

The Geological Survey and Museum presented a good display of mainly semi-precious stones which included an attractive one of sphene in its different colours and also tourmaline in its multi-coloured form. There were also some fine quartz and opal specimens and a lovely blue topaz. The contrast between the rough and polished stones was also underlined with specimens of each.

A fine 76 ct. scapolite was also among the display together with a large peridot and a number of those always attractive zircons. Other lesser known stones—as far as the jeweller, but not the gemmologist, is concerned—were danburite, spodumene, orthoclase, apatite and phenakite.

For even more unusual gem stones, however, the gemmologist had not to seek far. They were presented in a profusion which almost seemed to give the lie to the comparative scarceness of many. There was the most recently discovered, Brazilianite, of a yellowish colour and named after the country in which it was found. There was a case of different varieties of sphene and examples of phenakite, cyanite, idocrase and cassiterite.

An exhibit prepared by Thorold Jones, F.G.A.

Here again there was rivalry between the popular and lesser known stones, and the fine 100 ct. " Queen of Australia " opal, glowing with deeply contrasting lights in the forefront of the case, captured a lot of attention. This opal, reputed to be the finest found at Lightning Ridge, had been loaned to the exhibition by the Duke of Devonshire. A number of water opals also made a nice display here, as did a 114 ct. aquamarine. A varied collection of rough and cut stones from the Moguk Stone Tract in Burmas was pleasing and admired by the many Fellows present.

Another case which told the story of the manufacture of synthetic sapphires was greeted like an old friend by many gemmologists who had heard an Association lecture on this subject in the same hall last year. Here, among the modern exhibits, was an historic one of a synthetic ruby made by Fremy in 1890.

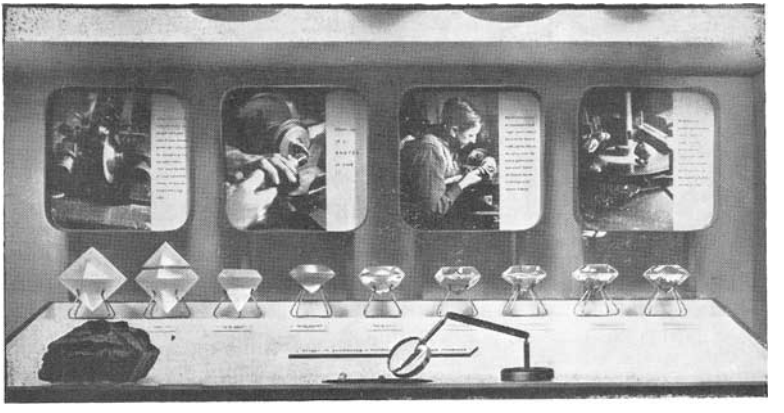

Stages in producing a brilliant from a rough diamond

Memories of the Stalingrad Sword were evoked by the stand of Gregory Bottley and Co., who supplied the quartz crystal for the Sword, and who exhibited some lovely varieties of minerals. Here the jeweller and gemmologist met the scientist, for quartz has a new use to-day in timekeeping and radio control. Here, too, the gemmologist was again reminded of the resources, now so much diminished, of his own country. Quartz from Cornwall was there, but in greater quantities was quartz from Brazil.

Another glimpse into the romance of gemmology was afforded by an exhibit of scapolite, discovered by an expedition that tried to find the missing Amazon explorer, Col. Fawcett. An exhibit of cassiterite from Uganda gave visitors a chance to see a very rare stone.

Yet, as if the beauties of these minerals were not sufficient on their own, Mr. Bottley made them take on a new charm as he displayed their fluorescent qualities under ultra-violet light.

This exhibition presented almost as many facets of gemmology as there are to be found on the cut diamond. So it was not surprising to find that Mr. Thorold Jones, F.G.A., showed yet another facet in his presentation of gemmology at war.

Here he showed how gemmology helped to give us the finest sparking plug in the world, adopted by the United States for all their war planes. Corundum insulation was an important secret

in these plugs and his exhibit showed by actual examples, by photographs and microphotographs, just how success was gained in this field in producing the now well-known " Corundite " plug.

The visitor, impressed by these microphotographs showing the structure of the material, was even more impressed when he turned from this exhibit to another and realised that such pictures might be taken by a 5s. camera. That was the theme of the display by one of the Fellows, Mr. J. Vincent. They were fine pictures of gems that had been taken with a " Brownie " camera and a 60-year-old microscope. Certainly, as the exhibit suggests, they hold out the prospect of enabling the " thumb print " of gems to be taken for a few pence and the gemmologist is likely to want to know more about this avenue of study.

The evolution of pearl testing was shown with many of the early and original instruments by those leaders in the field, Mr. B. W. Anderson, B.Sc., F.G.A., who has helped so many gemmologists to gain their degree, and his able co-worker, Mr. R. Webster, F.G.A., and Research Fellow of the Association.

R. Webster, F.G.A., demonstrating at the pearl testing stand

The principal of the majority of the testing instruments lay in differentiating between the radial structure of the real pearl and the layer structure of the mother-of-pearl bead in the cultured pearl. Many different means were used in the past to do this, methods which seemed as ingenious as they were practical. Thus there was the magnetic method which registered the interference caused by the bead to the magnetic lines of force. Another used the differing heat conductance of the real and cultured pearls to denote which was which and there was a complicated one using mercury to observe the inside of the pearl through a microscope.

Visitors could try all these and, of course, the modern endoscope instrument, or the inexpert could look at two pearls fluorescing under ultra-violet light and guess which was the real and which the cultured.

It might be thought that the ramifications of gemmology had by then been exhausted, but a new one, " medico-gemmology," to coin a fresh word, was introduced in the exhibit of Sir James Walton, K.C.V.O., F.R.C.S., F.G.A., whose exhibits of fluorspar specimens revealed that some of them had been given him as a result of an operation upon a man who was doing research work on lesions of the lung experienced by quartz workers. The gemmological knowledge of this famous surgeon was of aid in clearing up the difference in the crystalline structure of the quartz. The exhibit, made interesting by the surgeon's notes, included crystals, cut stones and manufactured articles.

More home produce in the form of the famous Scottish jewels of cairngorm and Scotch peeble agates was to be seen in another display of silica in its various forms, where there were also glass models of the crystal systems of a number of gems, including the rhombic topaz and peridot and the hexagonal corundum, quartz and sapphire.

Nor was ivory and its related materials forgotten. Mr. M. T. Hindson and Mr. E. R. Levett showed a display from the Netsuke collection of finely carved ivories, many of mammoth origin, and there was also carvings on walrus, elephant, hippopotamus and vegetable ivory. This led gradually from some finely fashioned pieces in bone, to celluloid, buttons and modern plastics.

Books on gemmology dating from the 17th century made an interesting display, one especially catching my eye that was dedicated to Cæsar Borgia.

Finally, there was a good display of the tools of the gemmologist—the well-known series of Rayner refractometers ; of spectrometers and dichroscopes, spectroscopes and microscopes, which must have caused a buying urge in many.

Did I write finally? There was one exhibit that seemed to be out in the cold and overlooked by many. It was of a jadeite boulder and it was in the entrance hall, downstairs. Maybe the hard-working gemmologists who were responsible for the finest gemmological exhibition that has ever been seen in Britain were too tired to carry it upstairs!

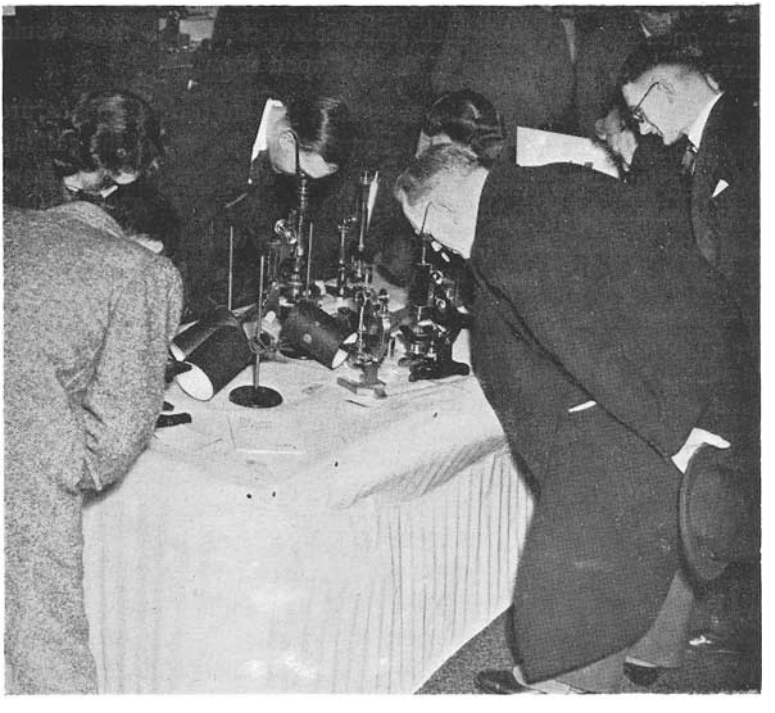

Viewing inclusions in natural and synthetic stones

By Robert Webster, F.G.A.

Some Aspects of Fraud

VALUE is an essential concomitant of that type of criminal offence which the legal mind terms " stealing by false pretences," and the jeweller trading in precious stones is a fitting target for this type of trickery. The following notes, based on factual reports and personal experiences, may make interesting and informative reading, and may in some measure prevent others suffering loss through the same pitfalls. Although all the episodes mentioned may not have been fraudulently conceived, most would have, or had, the stricture of the law upon them.

Perhaps it would be wise to remark that no trick of this nature would be effective unless some preparation in the way of the gaining of confidence were first engendered. To walk into a shop, place a four carat zircon on the counter and say " I want £700 for this diamond " would not get a rogue very far with the hard-headed business man of to-day ; but with confidence established suspicion is lulled and almost anything may happen. Indeed, it can be given as an axiom that one is never caught except when haste is the " jade," a " breezy " type of personality or a pretty face and a trim figure be the distraction, or when the desire for profit overcomes common sense.

It is fitting that the diamond be the first stone to consider, for that is the gem most handled by the jeweller and the most likely to be the stone whose simulation leads to chicanery. The substitution of a diamond by a paste imitation does not, at first sight, appear a likely cause of loss, for only an **imitation** jeweller would come to grief with this fake ; it is the amateur who falls for a piece of glass. What member of the trade has not heard of the wonderful bargain bought in a public house for a song? Inevitably it is the jeweller who has the unenviable task of supplying the denouement.

Most jewellers have encountered false diamonds which they glibly term " jargoons," " doublets " or " white sapphires," often totally unaware of the correct interpretation of the names they use. In most of these cases the fake has been the colourless zircon which owes its lack of colour to heat treatment and has a high dispersion. Exhibited in a " half-light," such stones do show an appreciable resemblance to diamond—providing one does not look for the strong double refraction. Time and time again these zircons have caught the unwary, often the same operator working the same fraud for months on end until Nemesis finally overtakes him.

The diamond doublet, although so often mentioned, does not appear to be so prevalent as is generally supposed. Of three authentic cases known to the writer, one consisted of a crown of true diamonds and a base of glass ; in another the base was probably rock crystal ; the third, a stone with a two carat spread and mounted with " roman " or " gipsy " setting in a heavy gold ring, caused the jeweller who bought the ring (at dusk, when the light was bad) to lose many pounds. This stone, which the leaders of the jewellery trade considered to be such a dangerous fake that they instituted a " broadcast " caution, was found to have a base of synthetic white spinel.

It is doubtful whether the synthetic white sapphire has ever caused much difficulty, but mention must be made of the artificially produced colourless spinel, if only to comment on the journalistic enthusiasm which caused the " diamond scare " of 1935. These " Jourado diamonds," generally " emerald-cut," a style which was then beginning to be favoured for diamonds, did momentarily cause confusion, but only for the few hours before the report of the Laboratory Experts was published by press and radio. That these synthetic white spinels have not been entirely neglected by the unscrupulous is recalled by the recent conviction of the Dutchman, Winnser, but this was probably more in the nature of substitution than in direct simulation.

Comparatively early in the writer's career he met with the " painted " diamond. Shown a single-stone diamond ring which had been pledged by a gentleman prominent in the theatrical profession, he noticed something " not quite right " about the stone, but lack of experience precluded a definite reason. The opinion

of an experienced diamond broker confirmed this suspicion ; he washed the stone in hot water, thereby removing the dye from the rear facets, and returned an off-coloured yellowish diamond instead of the " white " stone submitted to him. The method used to restore the stone to a white colour need not be considered here.

It is questionable whether the inducing of a green colour in a diamond by radium emanations, so easily detected by autophotography and spinthariscopic observation, can be called fraudulent, for, in the case of the heat treatment of zircons and topazes and the staining of agate, the alteration of hue is not considered to be wrong providing the stone is sold as such ; but how often is the radium-treated diamond so sold?

Although having little application to the retail jeweller, the imitation of diamond crystals goes to show to what length the crook fraternity will go in their endeavour to make money by fraud. There have been three authentic cases of " diamond octahedra " which had been found to have been artificially shaped from base material. In two of these cases the material used was synthetic colourless corundum, and for the third case colourless quartz was used.

Most jewellers, knowing all too well the synthetic production of the corundum gems, ruby and sapphire, are wary of dealing with such stones unless they have sound reasons or are backed by a laboratory report, and it is rare that loss is occasioned by such an artifice. That fraud can occur, even with an experienced trader, was made apparent recently when a three-stone ruby ring was bought for some hundreds of pounds, it being discovered later that the most important centre stone was a synthetic.

With respect to emerald, the most likely cause of trouble is surely the composite stone better known as the soudé emerald, but, despite the undoubted fine effect of this counterfeit, the writer cannot recall a single case of fraud involving this stone. The true synthetic emerald which is now being made in America has as yet not invaded this country, and when it does, as surely it will, more care still will be required by the members of our trade.

The painting of the rear facets of pale rubies, sapphires and emeralds in order to enhance their colour is too patent and too well known to cause much difficulty, and the same may be said for the

older type of garnet-topped doublets. The imitation of the alexandrite by the synthetic version of corundum and spinel does not now appear to worry the trade as it has done in the past, nor, for that matter, do the opal doublets ; on the other hand, the orange-red synthetic corundum, sometimes called the " padparadscha," is still confused with the fire opal by some people less informed than their neighbours.

Before bringing these few notes to a close, reference must be made to gem pearl, for, although the cultured pearl is so well known and so difficult in some cases to detect at sight, that risk is rarely taken. It is with the black pearl that trouble may occur, for artificial colouration may be particularly good, and, rather surprisingly, that hoary text-book fake, the polished haematite sphere, has quite recently shown itself. What probably was the most unusual fake that the writer came across was a necklace of pink beads, bought as coral, which turned out to be vegetable ivory appropriately stained.

With the spread of the science of gemmology, most, if not all of these tricks should never succeed, and those enemies of society who perpetuate them be for ever put out of their nefarious business —but for the frailty of human nature.

AMERICAN GEM CONCLAVE

The first American Gem Society conclave since the war will be held at the Hotel Stevens in Chicago on March 30th, 31st, and April 1st. Arranged by the International Committee of the A.G.S. under the leadership of Carleton C. Broer, International Chairman of the Society, the three-day session will include instruction in gemmology as well as business meetings of the Society.

The educational programme will, as in previous conclaves, be conducted and planned by Robert M. Shipley, Jr., formerly educational director of the Gemmological Institute of America. Lecturers and instructors will include many prominent educators and Certified Gemmologists, and a special session of advanced gemmological instruction may be arranged for the latter on the day preceding the opening of the conclave.

This conclave will be an innovation in that it will be the first wholly national and international meeting of the Society. In previous years two conclaves have been held each spring, one for members of the Eastern Division and another for members of the Central Division. Because of the greatly increased membership of the American Gem Society, an attempt is being made to provide educational accommodation for 500 members, which is twice as many as pre-war.

American Gem Society, 541, So. Alexandria Avenue,
Los Angeles 5, California.

A Lecture, illustrated by a film, delivered to Fellows and Members of the Association by R. P. Rooksby, B.Sc., F.Inst.P., of the G.E.C. Research Laboratories

SYNTHETIC CORUNDUM

INTRODUCTION

I SUPPOSE the manufacture of precious stones has been an attractive proposition for centuries. Certainly there are several records during the nineteenth century of attempts to make both sapphires and diamonds. I think we have to distinguish these attempts to synthesize crystals, chemically and physically similar to natural ones, from efforts directed merely in imitation of the genuine article.

For a crystal to be valued as a gem stone it should have other properties besides rarity. Rarity is, of course, a prime reason for valuing crystals, but the mineral must have certain other attractions as well.

Clarity, hue, high refractive index for light, and hardness stand out as properties desirable in a gem stone. Of these, hardness is important, because, once cut and polished, or otherwise finished, a jewel should not be easily scratched or blemished. Of natural minerals diamond is the hardest known. Sapphire, though much less hard than diamond, is nevertheless near the head of the list.

For industrial applications we must have chemical stability, but a high value of hardness is a quality that will make a crystal of considerable practical utility. So that, besides the original objective to produce diamonds and sapphires for the gem trade, we have another strong incentive to produce for use in industry. It was not until the beginning of the century that the problem of manufacture of sapphire was solved, and we shall be discussing some of the developments that have taken place since that time.

THE NATURE OF SAPPHIRE

First of all, let us examine the nature of the material we call sapphire. Sapphire, ruby, corundum are all chemically and structurally similar, consisting of the α-crystal form of aluminium oxide. Originally the term sapphire described the characteristically blue and clear natural crystals of alumina valued as gem stones. Corundum was at one time used to describe the less attractive white or opaque forms, but it is now customary to refer to single crystals of alumina of a high standard of perfection as white sapphires.

In the applications with which we are concerned the single crystal character of sapphire stones, whether natural or synthetic, is important. For satisfactory working of the material the perfection of the crystal structure must be high, and stones that comprise a heterogeneous assemblage of crystal fragments are unacceptable.

Blue sapphires and rubies are similar to white sapphires but coloured by the presence of certain specific impurities which enter the crystal lattice.

We find that the hardness of sapphire or corundum is put at 9 on Mohs' scale, higher than, say, quartz at 7, but lower than diamond at 10. One must be clear, though, that this does not mean that sapphire is nine-tenths as hard as diamond, for Mohs' scale is not quantitative, and is simply an old accepted means of placing materials in order of hardness.

Diamond would naturally be the ideal material to use for instrument and meter bearings. However, the hardness of sapphire is adequate for a very long life, and sapphire jewels have an enormous advantage in cost over diamonds. To-day the jewels of watches and the bearings of all good-quality instruments are cut from sapphire, synthetically grown to be crystallographically and chemically similar to the best examples of the natural mineral.

THE VERNEUIL PROCESS FOR THE SYNTHESES OF CRYSTALS OF SAPPHIRE

Our aim, then, is to manufacture homogeneous single crystals that can be subsequently cut and fabricated as required. At first glance we might imagine that the process would not be very difficult. Could we not simply melt the alumina at high temperature

in a suitable container and allow it to crystallize slowly during cooling? This does not work. Too many points of crystallization occur, and it is found impossible to prevent the development of a number of crystal nuclei. Then on solidification we obtain a multi-crystalline agglomerate, which, although it may be suitable for some purposes, is certainly unsuitable for the preparation of jewel bearings.

We must endeavour to confine the crystallization to a single point or nucleus, if the product of crystallization is to be a good homogeneous single crystal. It was Verneuil in 1902 who discovered the solution to the problem.

He dropped finely powdered alumina through the flame of an oxy-hydrogen torch on to a refractory support rod. The contact with the rod was reduced to the minimum possible area consistent with mechanical strength. From this point contact, the single crystal was built up very slowly by feeding the powder through the flame in small increments, which were individually melted and merged with the parent crystal.

The basic form of Verneuil's apparatus has not been modified to any great extent to this day. Improvements have been made, so that the crystals that can be grown now are much larger than the small ones with which Verneuil was content, but the principal features are unchanged.

The crystals are called boules, from the French word for "ball," because the original specimens made by Verneuil were spherical in shape.

The finely powdered raw material is held in a canister whose bottom is a 40-mesh sieve ; the container is like an inverted pepper-pot. When the apparatus is in action, taps from a hammer above the canister give it a periodical shake, so that puffs of powder pass through the sieve. Oxygen is fed into the annular space surrounding the container by means of a pipe, and the gas stream carries the powder downwards through a long tube to the furnace. Hydrogen is fed in lower down through a concentric tube and mixes with the oxygen at the jet.

The furnace itself is formed of two specially shaped refractory bricks, small portions of which are cut away to form an inspection window. The powder falls on to a refractory rod or candle entering the lower end of the furnace. This support can be raised or lowered by turning a handwheel.

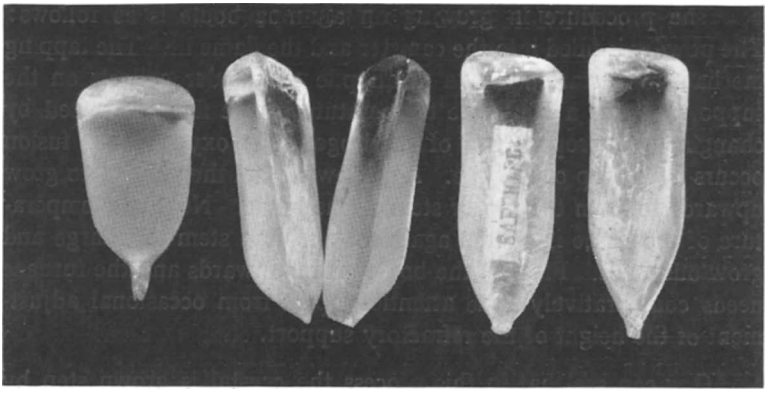

FIG. 1.—*Typical sapphire boules, showing "splitting."*

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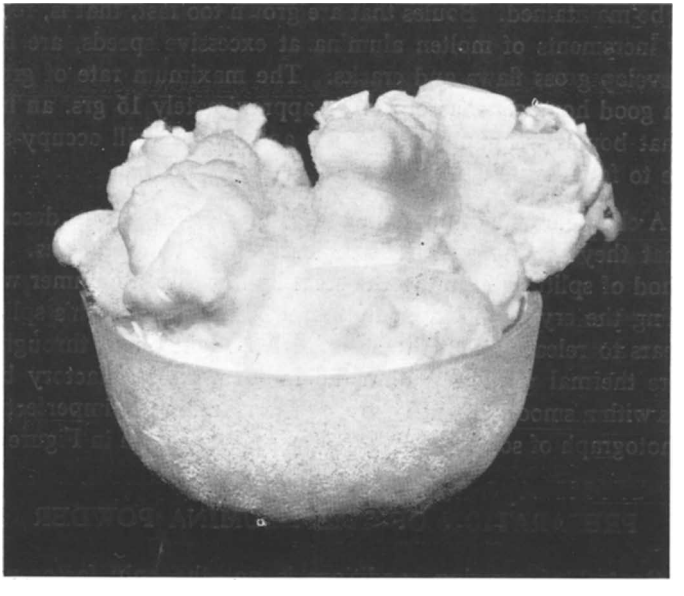

FIG. 2.—*Dish containing γ alumina prepared by decomposition of ammonium alum at 1000°C.*

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The procedure in growing an alumina boule is as follows: The powder is filled into the canister and the flame lit. The tapping mechanism is started and a small pile of powder collects on the support. After a while the temperature of the flame is raised by changing the proportions of hydrogen and oxygen until fusion occurs at the top of the pile. A narrow crystal then begins to grow upwards to form the pip or stem of the boule. Next the temperature of the flame is altered again to cause the stem to enlarge and grow outwards. Finally, the boule grows upwards and the furnace needs comparatively little attention apart from occasional adjustment of the height of the refractory support.

One can see that in this process the crystal is grown step by step by the addition of small increments of molten alumina. As each increment falls on to the growing surface there is an interval before the next increment arrives for the thin layer to assume the structure and crystallographic orientation of the underlying material. Experience shows that there is a maximum rate of growth which must not be exceeded if the homogeneity of the boule crystal is to be maintained. Boules that are grown too fast, that is, receive their increments of molten alumina at excessive speeds, are liable to develop gross flaws and cracks. The maximum rate of growth for a good homogeneous crystal is approximately 15 grs. an hour, so that boules weighing between 45 and 60 grs. will occupy some three to four hours' furnace time.

A characteristic of alumina boules grown in the way described is that they readily split longitudinally into two portions. One method of splitting is to tap the stem lightly with a hammer whilst holding the crystal firmly in the palm of the hand. This splitting appears to release strain in the crystal brought about through the severe thermal gradient within the furnace. A satisfactory boule splits with a smooth surface showing the minimum of imperfections. A photograph of some of these split crystals is shown in Figure 1.

PREPARATION OF THE ALUMINA POWDER

Control of growing conditions is not the only factor which has to be considered in the preparation of good white sapphires. The quality of the powder used has a most profound influence on the quality of the boule.

A powder of irreproachable purity is naturally required, but it must also have special physical properties. For instance, it has to be of low bulk density, and it should have free flowing properties, so that it does not pack down solidly in the container.

The alumina is prepared from ammonium alum crystals by firing in an electric or gas fired muffle furnace at 1,000° C. The charge swells up during firing to a meringue like cake. Figure 2 shows the typical appearance of the fired product. This is anhydrous alumina in the γ crystalline form, and it has a sponge-like texture. The fired product is broken up to powder by a tumbling process.

PROPERTIES OF THE SAPPHIRE BOULE

I want now to refer to some of the characteristics of the sapphire crystals prepared in the way you have seen. We have to consider, for example, such items as crystallographic orientation, perfection of crystal structure, and the presence or absence of flaws.

Dealing first with orientation, this is of importance because of the influence on the wearing properties of finished jewels. As will be mentioned later, the direction of the crystal axes with respect to the bearing surface have a significant effect on the rate of wear. If the orientation of the boule is known, cutting can be devised so as to avoid unfavourable orientations in the finished jewels.

The crystal structure of sapphire can, for our purposes, be thought of as being based upon the hexagonal system. Hexagonal crystals have four axes. Three of these are equal and intersect at 60° to define the base of a hexagonal prism, whilst the fourth is at right angles parallel with the height of the prism. The prism axis is commonly referred to as the optic axis, and it has three-fold symmetry. Its direction in a crystal of unknown orientation can be found by optical means, using polarized light, or by X-rays. The direction of the other axes, which have only two-fold symmetry and are therefore described as diad axes, can only be determined conveniently by X-ray methods. A hexagonal crystal would be completely defined by specifying one of the diad axes and the optic axis.

We have seen that sapphire crystals grown in the Verneuil furnace split longitudinally. It does not appear that this is a crystallographic cleavage ; a principal crystal plane is not normally

involved. The split occurs because of strain in the crystal resulting from the manner of growth.

But we do find that the split surfaces invariably contain the three-fold or optic axis. The optic axis lies in the plane of splitting, but, on the other hand, its direction does not bear any steady relation to the growth axis. All angles between 0° and 90° with the direction of growth seem to be found when a number of boules are examined.

It is a particularly lucky freak of fortune that the optic axis is located in this way, since it is this direction that we need to know when we come to make jewel bearings. We shall come back to this point in a moment.

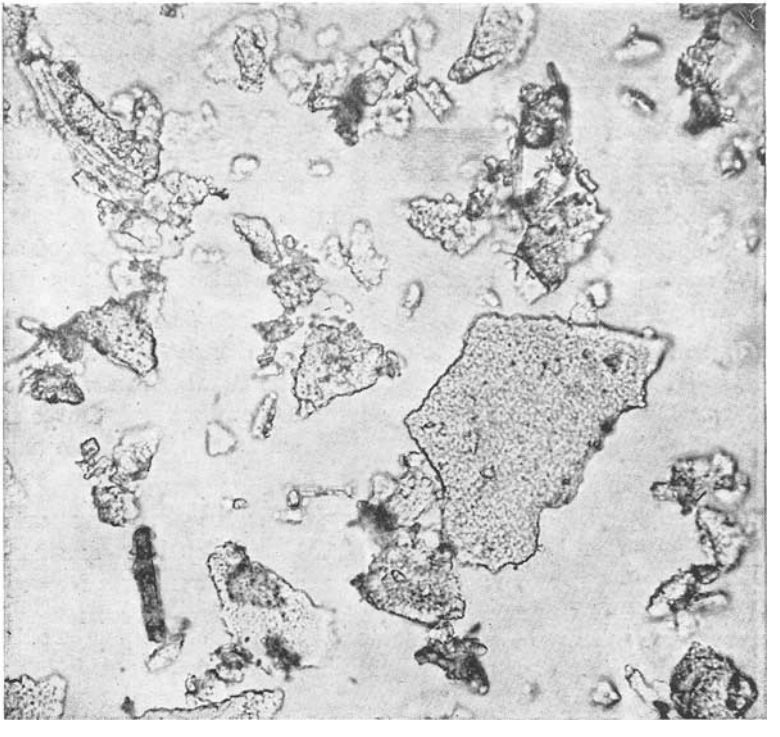

FIG. 3.—*Photomicrograph (x 275) of alumina powder used for synthetic sapphires.*

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The next aspect of the synthesized crystals we have to consider is the perfection or homogeneity of structure. How well does the synthetic boule conform with the single crystal ideal? It is difficult to devise scientifically based criteria of quality, and what is usually done is to base acceptance largely on the perfection and smoothness of the split surface. When the surfaces are rough or irregular and striated the crystals seem to have a greater tendency to develop cracks or other flaws during subsequent processing than when the splits are smooth and even. In bad cases, of course, the boule does not split regularly at all, and is cracked in several places, so that it is quite unsuitable for cutting. This may happen if the rate of growth is excessive, when presumably some discontinuities in the steady development of the single crystal structure have been introduced. Figure 4 shows several half boules in which the varying nature and degree of perfection of the split surface may be observed.

The only other flaws that are troublesome in the synthetic crystal are small bubbles that sometimes develop in parts of a specimen. Gases may be trapped either in the powdered particles passing down on to the growing surface or as the particles merge with the surface. Insufficient refining of the molten alumina before solidification, then, means that a few bubbles may become permanently fixed in the crystal. Although a few bubbles may be tolerated, large numbers are very objectionable as they may lead to flaws in the bearing surfaces of the finished jewels.

CUTTING AND SLICING BOULE FOR INSTRUMENT JEWELS

Now let us pass on to the cutting of the boule for practical use.

The boule is first of all sliced either parallel or perpendicular to the long axis. The slices are then cut again to give pieces of square section. A third cutting operation gives segments of the required thickness. By turning on a centre, rondels or discs are obtained.

The bearing surface now has to be prepared. Originally the recesses or cavities were made by hand, but to-day complete mechanization of the recessing and finishing processes is effected. A wide range of dimensions and shapes is required. For instruments the Vee jewel and the cup jewel are mostly employed, but other designs are utilised for watches.

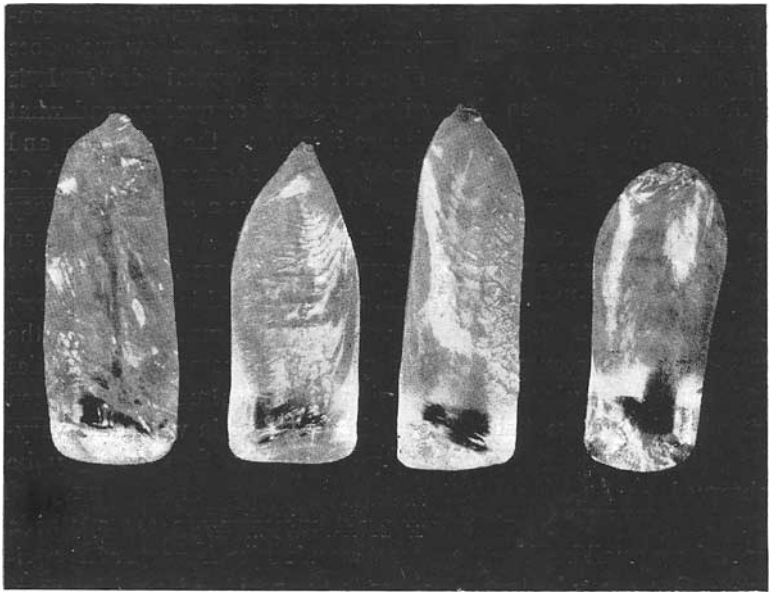

FIG. 4.—*Half boules of synthetic sapphire, showing variations in character of split surface.*

(Reproduced by courtesy of Royal Society of Arts)

One of the most important parts of the recessing operation is the final polishing of the surface on which the pivot runs. The preparation of a highly polished cavity has a profound influence on the wearing properties. Polishing is usually done with diamond dust, which is carefully selected and graded for the purpose.

There is probably quite a deal to be learnt about the structure of the polish layer. For instance, there may well be a difference in structure between a polish layer produced by " flowing " the surface and that produced by mere abrasion. However, there is general agreement that the surface of the recess must be perfectly smooth and free from all flaws and imperfections that can be detected under a microscope.

Another question with which we have to be deeply concerned is the crystallographic orientation in the jewel crystals. Verney Stott, working at the National Physical Laboratory, first drew attention to its importance in connection with the wear on meter jewels. Stott indicated that for maximum wear the orientation

selected should be such that the optic axis of the sapphire crystal lay in or near to the tangent plane to the bearing surface. It is a common practice to specify the orientation of meter jewels by the angle between the optic axis and the normal to the tangent plane. Stott's work showed that 90° jewels were the best. 0° jewels would be expected to give a rather poor account of themselves in comparison.

Now why should this be so? Remembering our earlier remarks about the crystal structure of alumina the optic axis is, of course, the C— or prism axis of the hexagonal form. Now it appears that crystal planes parallel to the prism base, i.e. perpendicular to the optic axis, are planes of weakness in alumina. Alumina exhibits what is sometimes called basal parting. This is the most prominent parting. Because of the relatively weak bonding across these parting planes, crystals of alumina tend to fracture along the basal plane rather than along any other crystal plane.

We could thus regard sapphire crystals as having a laminated structure, the laminas being perpendicular to the optic axis. Some diagrams illustrating the form this laminated structure might take in meter jewels of varying orientations are shown in Figure 5. In the 0° case, with the optic axis vertical, the weak planes are in an unfavourable orientation, as the revolving pivot may well tear laminated fragments out of the surface. In the 90° case, on the other hand, the weak planes intercept the bearing surface at a steep angle, and consequently fragmentation is not so likely to occur.

Another aspect of the laminated structure is illustrated in the photograph, Figure 6, of some wooden models representing meter jewels of similar orientations to the above. The form of these models is due to Mr. Shotter, of the North Metropolitan Power Supply Co.

More evidence has been collected since Stott's early work, and it does seem that a specified orientation has to be envisaged as an essential item in meter jewel selection. As it happens, the specification in the case of boule is not really very difficult to meet. This is because it has been found that the optic axis invariably lies in the plane of splitting, and with this as a known consistent direction cutting procedure can be devised so as to ensure a favourable orientation in the finished jewel.

SYNTHETIC SAPPHIRE IN OTHER FORMS

So far we have thought of the synthesis of sapphire in terms of the boule form. But it has to be admitted that for jewel bearings much material is wasted in the cutting processes and these processes themselves are most expensive on such a hard material. If a single crystal of small circular cross-section could be synthesized, the cutting might be reduced to a relatively simple process. A great economy of labour and material would be effected by slicing rondels or discs of the right thickness.

These considerations have influenced development work in both this country and America, with the result that sapphire crystals can now be produced in the form of rod. I must emphasize the point that these rods are just as much single crystals as are boules. It may seem a little strange if we still cling to the conception of crystals with regular external faces and symmetry. But we have to accept the idea that the external form is of little moment, provided the internal make-up in respect of atomic configuration is that of the single homogeneous crystal.

Single crystal rod is grown in much the same way as the boule, furnace size being scaled down to confrm with the narrow cross-section of the crystal being synthesized.

One may ask what about the orientation of the crystal? There is a technique for controlling the orientation aspect of the structure. This is by seeding with a small crystal of the desired orientation and growing the rod on to this. The method has been developed particularly in America, where it is claimed that, with the seed-crystal technique, rods can be grown consistently with the same predetermined orientation.

Not only is the rod form of synthetic crystal an economic form to use for jewel bearings, but, remarkably enough, it can be shaped and bent under controlled heat treatment conditions. It has been demonstrated in America, for example, that the sapphire rod can be drawn to quite small diameters, provided the conditions are carefully controlled. Proper deformation and working of the sapphire rod can, for example, only be done for a limited range of crystal orientations.

Bending and twisting of sapphire rod open up a variety of applications in which the hardness of the sapphire would be a practical advantage. It has been reported that hooks and rings are made for use as fibre or thread guides, these having a much longer

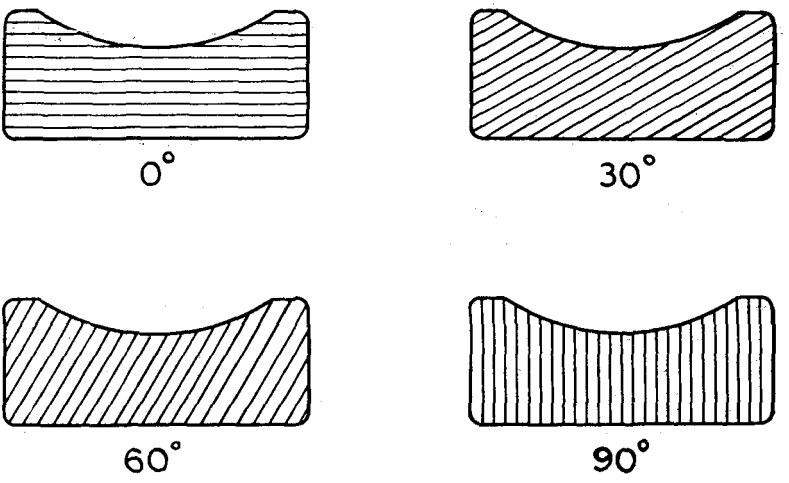

FIG. 5.— *Diagram illustrating "laminated" structure of sapphire jewels of different crystallographic orientations.*

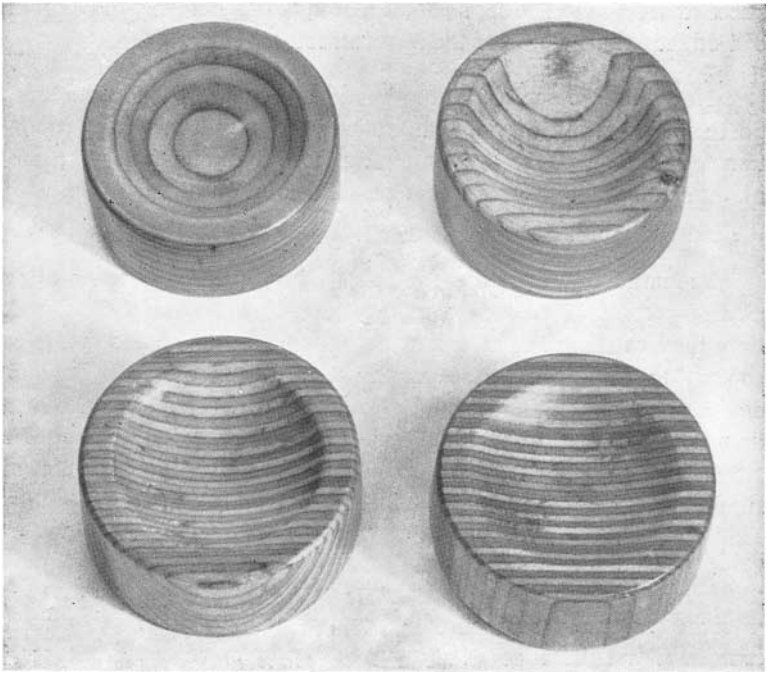

FIG. 6.— *Wooden models of sapphire meter jewels, illustrating changes in direction of "laminated" structure with crystal orientation. The orientations correspond with those in the diagrams of Fig. 10.*

(Reproduced by courtesy of Royal Society of Arts)

life, and less deleterious effects on the fibres than materials previously used.

THE MANUFACTURE OF SPINEL CRYSTALS

There is another crystal that can be prepared by a similar method of growth to sapphire. This is the magnesia/alumina compound known as spinel. Ideally spinel crystals contain equimolecular parts of magnesia and alumina, but, since spinel and alumina are to some extent mutually soluble in one another, the term spinel, when used to describe synthetic crystals, does not necessarily refer to the one-to-one molecular composition. In fact, it is quite common to make spinels containing three or four molecular parts of alumina.

The structure of spinel differs from that of alumina. It is a cubic crystal and magnesium aluminate is the analogue of a whole series of crystals of similar structure. Magnetite, the magnetic oxide of iron, for example, is of the same structural class.

Now the γ form of alumina has ideally a spinel-like structure. So this is probably why we can make spinels with varying proportions of alumina. A spinel containing more than one molecular part of alumina can be looked upon as a solid solution of γ alumina with the conventional $MgO.Al_2O_3$.

Preparation of powder for spinels involves the incorporation of an appropriate amount of magnesia with the alum. One finds that the growth of good spinel boules is a little more difficult to control than the growth of sapphires. Boules tend to become opaque or crack if grown too fast or too large. Spinel boules also do not split as do sapphires. The shape tends towards a rectangular cross-section, instead of the round cross-section characteristic of sapphire.

As regards applications, spinel is appreciably less hard than sapphire, but because of this it is more easily worked. When lower hardness can be tolerated the advantage of ease of working might be worth while. It is also possible that use can be made of a relatively tough crystal which has a complete absence of the crystallographic basal parting characteristic of synthetic corundum.

COLOURED BOULES

Both alumina and spinel can take impurities into solid solution which confer attractive colours upon the crystals. Coloured boule is perhaps mainly valued for gem stone purposes, but there are some practical industrial uses for coloured jewels. For instance, the colour may be wanted because it leads to simple distinction and differentiation between jewels to be used in different parts of an instrument. Watchmakers, too, have a preference for rubies because they are more easily seen than white sapphires.

For gem stones we would want to be most careful and precise about our selection of the exact shade or hue of colour. The gemmologist has very definite notions on the precise hue which is going to be acceptable and attractive. In industrial applications one is, perhaps, less influenced by these considerations, but a good depth of colour is desirable. Red or ruby, and blue, are the most usual colours, though by altering the ingredients it is possible to make alumina and spinel with a whole range of colours, to include red, orange, green, and blue.

In red corundum or ruby the colouring ingredient is chromium oxide, and amounts from about one half of 1 per cent. to 5 per cent. may be incorporated in the alumina powder. We can follow what happens to the chromium oxide by X-ray analysis of the resultant crystal. The chromium oxide forms a solid solution with the alumina, and one measures an expansion of the average interatomic distances.

The method of growth of synthetic rubies follows much the same course as for white sapphire, but generally speaking the size of boule is rather smaller. The best blue sapphire is made with two added impurities, namely, iron oxide and titania. Iron oxide alone gives a green crystal.

Cobalt oxide gives a very strong blue colour in spinels, but gives disappointing patchy effects in alumina. In practice it seems generally easier to make coloured spinels than sapphires, and this is probably attributable to the differences in crystal structure.

CONCLUSION

There, I think, we shall have to leave the story of the syntheses of sapphire and spinel crystals. It is worth remarking that before 1940 synthetic jewel production seems to have been largely in the

hands of Swiss, German and French manufacturers. It was following the break with the Continent that we had to ensure the supply of jewel bearings by developing the process quickly. Only by careful co-ordination of research and manufacturing experience was progress made, and it can now be justly claimed that British sapphire boule is the equal of that of Swiss origin.

Manufacture under controlled conditions ensures a consistency of quality and predictability of physical characteristics which would be difficult to obtain in a natural product. This is one of the important features we can claim for the synthetic material, and for practical use in industrial work this is naturally a property of great importance.

Finally, I would like to make perfectly clear to you that I am merely the spokesman of a group of people who have been working on this subject. Without their assistance and generous help this talk could not have been given. May I mention particularly the names of my colleagues Mr. Dauncey and Mr. Chirnside, and for the preparation of the film I have to thank Miss Hobbs and Miss Anthony.

NEW GEM TESTING METHOD

An exact and conclusive method of identifying gem mineral species which is a major advancement in the field of determinative gemmology has been discovered as a result of an intensive research project conducted by staff members of the Gemmological Institute of America in their laboratory.

In the science of gemmology, this discovery is comparable to the introduction into mineralogy of the X-ray powder method which gave to the mineralogist his final and conclusive test. The new X-ray technique of identification of gemstones will determine with absolute accuracy the nature of opaque to transparent gems, whether they are mounted, unmounted, faceted, cabochon, carved or rough, regardless of size.

By a revolutionary departure from old techniques which required reduction of the specimen to a powder, the new X-ray method produces the same results without harming the gem in any way. The discovery will be used especially as a deciding test in cases where previously known methods do not yield conclusive results.

Gemmological Institute of America, 541, So. Alexandria Avenue, Los Angeles 5, Calif.

Synthetic Sapphire & Spinel Production in Germany

(Extracted from the Final Report No. 355 of the Office of Military Government for Germany (U.S.). The Final Report written by Mr. H. Barnes of the Joint Intelligence Objectives Agency)

1. There are two plants in Germany which produced synthetic sapphire and spinel boules during the war, the I. G. Farben plant at Bitterfeld and the Wiedes Karbid Werke at Freyung. Both plants employ the basic Verneuil process. The details of German apparatus and process have been revealed for the first time, since this information was always held as a strict trade secret before the war.

2. The German sapphire plants depend on highly skilled, low wage labour for their successful operation. The boule growth process is considered an art, and little or no attempt has been made to mechanize the process or to introduce production aids.

3. The Wiedes Karbid Werke boule plant has a capacity of 60,000 carats per day. This plant specializes in the production of spinel boules.

4. While it was not possible to visit the I. G. Farben plant at Bitterfeld, information from other sources indicates that this plant has about 300 burners with a boule capacity substantially greater than that of the Wiedes Karbid Werke. The I. G. Farben plant specializes in the production of clear sapphire and ruby boules.

5. There was never a shortage of synthetic sapphire boules in Germany during the war, but there was a shortage of diamond powder for cutting them. This led to the development of a process for hardening spinel bearings such that their performance approached that of sapphire, and only one-quarter as much diamond was needed for fabrication. Except for this spinel bearing development, no new applications for sapphire or spinel were found that were not known before the war.

6. The German synthetic sapphire and spinel boules are considered inferior to those made in France and Switzerland by the gem cutters at Idar Oberstein.

The only process known for the production of synthetic corundum and spinel crystals of appreciable size was invented by Verneuil about 1902. It is an oxy-hydrogen flame process in which the crystals, or boules, are produced by a layer on layer growth. For 25 years before the war, the world production of synthetic corundum and spinel was centred in Switzerland, France, and Germany. Before the war, the United States imported millions of jewel bearings annually for watches, watt-hour meters, and precision instruments of all types. In addition, the market for semi-precious gem stones of corundum and spinel in America was considerable.

While the general process for the production of synthetic corundum and spinel was known in the United States, details of European plant equipment and process control were closely guarded trade secrets. It was the purpose of this investigation to learn these details of equipment and process as practised in German plants.

It has been found that there were only two plants in Germany producing corundum and spinel by the Verneuil process. They are the I. G. Farbenindustrie plant at Bitterfeld and the Wiedes Karbid Werke at Freyung. The Wiedes plant is in operation and was visited by this investigator. It was not possible to observe the operations of the I. G. Farben plant, but a number of people were interrogated who had access to information concerning the Bitterfeld operations.

DEFINITIONS AND BACKGROUND INFORMATION

Before discussing the specific detailed information gained on this investigation, for purposes of completeness, it appears appropriate to set down here the following definitions and well-known background information relative to the production of corundum and spinel crystals by the Verneuil technique.

A corundum boule is a single crystal of alpha aluminium oxide (Al_2O_3), normally produced in diameters between $\frac{1}{2}$ and 1 inch and lengths from 1 to $2\frac{1}{2}$ inches, usually weighing between 100 and 200 carats (20 to 40 grams). If the boule is coloured red by the addition of .5 to 3.0 per cent. chromic oxide, it is ruby with essentially the same chemical composition as the natural stone. The addition of small amounts of titania and iron oxide results in a blue sapphire crystal. The clear, uncoloured corundum crystal is usually designated as clear or white sapphire.

Synthetic spinel ($MgO : 3.5\ Al_2O_3$) is clear, but may be coloured a wide variety of tints and shades by the addition of small percentages of the oxides of cobalt, chromium, titanium, nickel, iron, and vanadium. Perhaps the most popular coloured spinel stones for gem purposes are the blue and aquamarine, for which the principal colouring oxides are cobalt and nickel, respectively. Other oxides are often added in small quantities to give more desirable shades of these colours.

The basic process for growing corundum and spinel boules is essentially the same in the I. G. Farben and the Wiedes Karbid Werke plants. The powdered oxides are held in a hopper with a fine mesh screen bottom. Tapping the hopper causes the powder to be fed intermittently into the oxygen stream and carried down through the central tube of a diffusion type oxy-hydrogen burner. Hydrogen is fed to the flame through an annular passage surrounding the central oxygen-powder tube. The tip of the oxy-hydrogen burner discharges the flame into a cylindrical ceramic furnace, usually split down the middle for easy opening and with a small rectangular slot in one side for viewing the boule during the growth process. The boules are grown on a ceramic pedestal, centred in the refractory furnace, and supported by a table with vertical screw adjustment.

At the start of the boule growth process, the powder feed rate is adjusted somewhat higher, and the flame intensity lower than for steady boule growth conditions. A fritted mass is built up on the end of the pedestal, and soon a single crystal begins to emerge from the mass if the flame conditions are favourable. By careful control of flame intensity, this single crystal is made to grow out of the sintered mass until it is about the diameter of a matchstick and $\frac{1}{4}$ to $\frac{1}{2}$ inch long. At this point the flame intensity is increased and a small ball is made to form on the end of the rod, which is progressively broadened to resemble a mushroom. When the diameter is increased to that desired for the boule being grown, the growth conditions, including powder feed, flame intensity, and boule lowering rate, are adjusted to give a uniform diameter cylindrical section. These steady conditions are maintained until the boule is of the desired length, and then the growth process is abruptly stopped. As a general rule, the clear stones are easier to grow than the coloured ones ; and the greater the amount of colouring agent added, the

more difficult is the fusion and the greater probability of the boule cracking when the flame is shut off at the end of the growth cycle.

WIEDES KARBID WERKE—PLANT ORGANIZATION

The boule plant of the Wiedes Karbid Werke is located at Freyung in the Bayrischer Wald. Hydroelectric power is available, and an electrolytic plant consisting of two 250 KW cells furnishes the necessary oxygen and hydrogen for boule production. The hydrogen capacity was said to be 4,000 cubic metres per day. Boules have been produced in this plant for 20 to 30 years. The plant was shut down by the Allied Forces on April 27th, 1945. Operations were resumed on a limited scale on October 27th, 1945, by a contract agreement between American and French Military Governments. This agreement provides that aquamarine spinel boules be grown at Freyung and shipped to Idar Oberstein in the French Zone for cutting into gem stones.

POWER PRODUCTION

The alumina and alumina-magnesia spinel powders used as starting materials in the boule process are prepared by the calcination of aluminum ammonium sulphate and magnesium ammonium sulphate. These alums are purchased from Merk in Darmstadt and usually are of satisfactory purity as received. However, occasionally it is necessary to wash the alum crystals in a centrifuge with distilled water before they are sufficiently pure for boule purposes. No purity standards or tests are applied to the alum except the actual making of a boule from a calcined grab sample of the material.

Spinel powder is prepared by the mixing by hand of 729 grams of magnesium ammonium sulphate with 6,075 grams of aluminum ammonium of sulphate. This was said to give a ratio of $MgO:3.5\ Al_2O_3$ in the finished powder. The mixed alums are calcined in quartz dishes in the same manner as the sapphire powder except at a slightly higher temperature. As in the case of the ruby powder, the spinel colouring agents are added to the alum in each quartz dish just prior to calcination.

The calcining furnace in the Wiedes plant is coke fired and contains six full muffles made of silicon carbide. The muffles have

a hearth space of 78 cm. x 44 cm. and an arched roof with a maximum height of 25 cm. A single thermocouple in the back wall of the central muffle is used for temperature control. Each muffle will accommodate a charge of 8 quartz dishes.

After cooling, the alumina in the quartz dishes is in the form of a light friable cake which is dumped into steel drums for transfer to the screening room. The powder is brushed through brass screens (approximately 65 mesh per cm.) with rotating bristle brushes. Wooden hoppers feed the powder to the screen. The powder is then ready for use in the boule burners. No special aging or humidifying treatment is given to the powder to improve its flowing properties.

BOULE APPARATUS

A concentric two-tube diffusion-type burner is employed with a water-cooled skirted tip, having an inside diameter of 3 cm. The oxygen-powder tip has a diameter of 4 mm., and the water-cooled cast iron skirt extends beyond this tip for a distance of 6 cm. The overall length of burner is 30 cm.

The powder hopper is 8 cm. in diameter and 20 cm. long with a 30 mesh per cm. brass screen on the bottom. The hopper is supported from a phosphor bronze diaphragm, which is sufficiently flexible to transmit the tapper blow to the hopper. The casing enclosing the hopper is 10 cm. in diameter and 42 cm. long, the bottom half being in the form of a conical approach to the central oxygen-powder tube.

The bottom of the water-cooled burner tip is just flush with the top of the high alumina refrectory furnace in which the boules are actually grown. This furnace is split into two halves with tongue and groove joint to permit opening for easy access to the finished boule. A vertical slot $5\frac{1}{2}$ cm. long and 1 cm. wide is provided for viewing the boule during the growth process. The furnace is $16\frac{1}{2}$ cm. high with an outside diameter of 14 cm. and an inside diameter of 4 cm. The life of these furnaces was said to be about 18 boule growth cycles, after which they are too badly cracked and the inside wall is melted down. The furnaces are purchased from Marktredwitz at a cost of 1.30 Reichsmark per pair of furnace halves.

The boule burners and furnaces are mounted with clamps to an angle iron frame, 17 burners in a row with a space of about

18 inches between burners. There are twelve such banks of 17 burners each in the plant, making a total of 204 burners. When operating at maximum capacity, only one-half these burners are actually used to grow boules at any one time. The remaining burners are in the process of cooling down from a previous run or are being serviced. Powder is added to the hoppers after each three boules. The individual tapping hammers for dispensing the powder from the boule hoppers are actuated by a camshaft running the length of the burner bank. This camshaft is driven by a variable speed DC motor with rheostat control. Individual mechanical adjustment of the tapper height, and hence the powder feed, is provided for each boule burner. A simple manual screw adjustment is employed to raise and lower the boule in the furnace.

Oxygen and hydrogen are fed into the individual burners from a gas header made of 3-inch pipe running the length of the boule bank. Each burner is provided with needle valves on the oxygen and hydrogen lines for individual adjustment of gas flows. However, it is the present practice to control an entire bank of 17 burners by master valves on the gas headers rather than by the individual burner needle valves. The needle valves are used only as metering orifices for balancing the gas flows of the various burners. The oxygen and hydrogen are supplied to the boule banks at a pressure of approximately 10 cm. H_2O by means of belt-driven rotary compressors.

BOULE PRODUCTION

The operations in the Wiedes boule plant are dependent upon highly skilled, low wage labour. The entire process is manually controlled with practically no effort being made to mechanize any phase of the operation. For example, no metering devices are used for setting the burner gas flows which are regulated manually by a rather crude valve on the gas headers for each bank of 17 boules. The adjustment depends on the judgment of the " melter " as he looks at the boules being grown. Balancing of the gas flows to individual burners by the small needle valves to make all boules grow under identical conditions is also left to the judgment of the melter without the aid of any gas metering device. About one year is required to train a boule melter, provided he is capable of learning

the art at all. Each melter develops his own individual system of control, and no two melters employ the same.

When operations were at their best, the capacity of the plant was 60,000 carats per 24-hour day. This figure, which includes cracked boules as well as first quality ones, is considered poor by this investigator for a plant with 204 burners. At the present time, because of the lack of skilled operators and an insufficient quantity of alum, the plant is making only about 40,000 carats per 24-hour day. On aquamarine spinel (90 per cent. of the production now), the following data on growth conditions were provided:—

Boule size	150 to 200 carats
Boule growth time	4 to 5 hours
Cooling time in furnace ...	½ to 1 hour
Tapping frequency	60 to 80 per minute
Hydrogen consumption ...	4 cubic meters per hour
Hydrogen-oxygen ratio ...	2 to 3
Overall powder utilization ...	60 per cent. approximately

The average size of the ruby and sapphire boules made in this plant is only 80 to 125 carats. The growth time for boules of this size was said to be about 2½ hours with a first quality yield of 50 to 60 per cent. The above yield figures apply only for 1.3 per cent. Cr_2O_3 ruby and clear sapphire.

INSPECTION, GRADING AND SELLING

Boules are inspected with a bright incandescent lamp in a darkened hood. No liquid immersion or other means is used to minimize surface reflection. All boules are placed into one of three grades with no special regard for boule size. Corundum boules are always split before inspection by pinching the foot with a pair of pliers. Boules are graded in the Wiedes Karbid Werke corundum plant according to the following standards:—

First Quality—Boules which show no major cracks and which are free from cores, feathers, and large bubbles. Minor cubic foot cracks in spinel boules are common and acceptable in this classification.

Second Quality—Boules which exhibit cores, feathers, and bubbles, but which do not have major irregular cracks.

Third Quality—Badly cracked boules irrespective of their internal quality.

In normal good operation, the yield of boules is 60 per cent. first quality, 20 per cent. second quality, and 20 per cent. third quality. At the present time, the entire production of the plant, about 40,000 carats per day, is being sold to Gebrüder Kaucher, the plant representative in Idar-Oberstein. Since resuming operations two weeks ago, the wholesale price of boules (lots greater than 25,000 carats) has risen 50 per cent.

I. G. FARBENINDUSTRIE AT BITTERFELD—PLANT OPERATIONS

Fortunately, Dr. Konrad Schad in Höchst was using a boule burner from the Bitterfeld plant for a special research which will be discussed in detail later. This burner is quite similar to the Wiedes burner, the principal difference being that the I. G. Farben burner does not employ a water-cooled skirt. The ceramic furnace used experimentally by Dr. Schad was improvised from an ordinary clay crucible and obviously did not represent boule plant practice. The ceramic boule support for the I. G. Farben apparatus was mounted on a rotating table. However, Dr. Schad insisted that this feature was used only for centring the ceramic pedestal at the start of the operation and the boule was not rotated while being grown.

Alum for calcining to alumina is purchased from Merk in Darmstadt. The purity of this material as received is satisfactory for making ruby and clear sapphire, which are the principal products of this plant. Very little spinel is produced. The alum is calcined in two-litre fused quartz dishes at a temperature of 1,000° C. for eight hours, according to Dr. Schad. While ruby boules can be grown from powder containing as much as 5 per cent. Cr_2O_3 in the alumina powder, the standard ruby powder contained between 1.2 and 1.5 per cent. C_2O_3. The Cr_2O_3 was added to individual dishes of alum in the form of a sulphate solution just before calcination.

The best information indicates that the Bitterfeld plant has approximately 300 boule burners with a production several times that of the Wiedes Karbid Werke. According to Dr. Konrad Schad, boules of about 200 carat size are grown in four to five hours.

It was the opinion of Mr. Richard Bohlenger that the ruby boules made at Bitterfeld were not equal in quality to those made in the Swiss and French boule plants.

SPINEL JEWEL BEARINGS

The most interesting work on jewel bearings found in Germany was related to this investigator by Dr. Wilhelm Eppler. Since 1942, Dr. Eppler has been working with Dr. Maucher and Prof. Kaden at the University of Strasbourg on the problem of minimizing the use of diamond powder in the production of jewel bearings.

Since spinel has a Mohs hardness of 8 as compared with 9 for sapphire, it is much easier to work and requires considerably less diamond powder to fabricate than sapphire. However, the lower hardness makes spinel somewhat less satisfactory for jewel bearings than sapphire. Dr. Eppler has developed a process for hardening the synthetic spinel after the spinel bearings have been fabricated through all the steps except the final polish.

The spinel hardening process depends on the fact that synthetic spinel contains a considerable amount of excess alumina held in solid solution " in the gamma form," according to Dr. Eppler. On heating the spinel to a temperature of 950 to 1,050° C. for 12 hours, " part of the excess alumina is precipitated and converted to an alumina form intermediate between gamma and alpha." The clear spinel stone is made quite cloudy by this treatment, and at the same time the hardness is measurably increased. Heating to a higher temperature (above 1,075° C.) was said to result in conversion of the excess alumina completely to the alpha form accompanied by a weakening of the stone structure and the destruction of all the desirable properties obtained by the lower temperature treatment. After the jewel bearing is heat treated, the final polishing of the bearing surface is effected with diamond powder in the usual manner. While coloured spinel can be used for bearings and can be improved in performance by the heat treating process, it is considered inferior to the clear material and is not recommended by Dr. Eppler.

According to Dr. Eppler, he has made extensive comparative tests on sapphire, spinel and glass bearings. A sand blast wear resistance and hardness test was devised from which the following

comparative performance index was obtained, based on loss of weight of a standard polished sample:—

Quartz	100
Clear Spinel	400— 600
Heat Treated Spinel	1,400—4,500
Sapphire	2,000—3,800

Vibration tests made on instruments with sapphire, heat treated spinel, untreated spinel, and glass bearings gave results which indicated that the heat treated spinel bearings were equally as satisfactory as the sapphire ones ; the untreated spinel bearings were not acceptable but were better than the glass bearings. The elasticity of spinel was said to be 30 to 40 per cent. greater than that for sapphire.

The heat treated spinel bearings were tested by Paul Backes and Degussa. Both companies found the bearings satisfactory and comparable with sapphire, according to Dr. Eppler. However, only the Paul Backes company actually made the bearings in production. About 900,000 heat treated spinel bearings were made for airplane instruments in the last year of operation of the Backes plant. A diamond powder saving of 75 to 80 per cent. was made by the use of spinel instead of sapphire. Dr. Eppler indicated that Degussa would have produced heat treated spinel bearings had it not been for pressure by I. G. Farben, who make sapphire and practically no spinel boules.

Dr. Eppler stated that all of his records and reports on this development had been taken from Strasbourg by the U.S. Army in May or June of this year.

GEM STONES

Before the war, gem stones of synthetic corundum and spinel were cut in large quantities at Idar Oberstein and at Hanau. However, according to Dr. Willi Holstein, who is head of the Chamber of Commerce at Idar Oberstein, no gem stones have been cut there in the past four years because of the lack of boule stock and diamond powder. Diamond powder is still very scarce, and for this reason, the limited gem stone cutting now being done is confined to spinel, which requires a minimum of diamond for cutting. Spinel can be rough cut with silicon carbide and can be finished polished with aluminum oxide. Diamond is required only for grinding the facets on the stones and rough polishing them.

It is interesting to note that a large part of the production of the Wiedes Karbid Werke boule plant during the war was in coloured boules for gem stones. This would indicate that there was never a shortage of sapphire for jewel bearings in Germany during the war. Why the major part of the coloured spinels made by Wiedes were cut in Czechoslovakia instead of at Idar Oberstein or Hanau could not be ascertained.

As far as could be learned, there have been no major improvements in the methods of fabricating gem stones from corundum and spinel. The stones are all cut by hand and the quality depends entirely on the artistic ability of the worker. Most of the facet work is done by eye, requiring the development of a high degree of manual skill. Diamond impregnated horizontal copper laps are used almost universally for shaping and faceting the stones. Tin and other " secret alloy " soft laps with very fine diamond powder or alumina are used for the polishing operations.

NEW SAPPHIRE AND SPINEL APPLICATIONS

Except for the heat treated spinel jewel bearings, no new applications for synthetic sapphire or spinel were found in Germany which were not known before the war. As far as could be learned, sapphire has not been used for plug or ring gauges in Germany. While the value of sapphire and spinel as a thread guide material was recognized, practically none of these guides were fabricated in Germany. No new applications for corundum as a wear resistant surface or for optical uses were found.

No evidence was found that the German plants had developed corundum or spinel in rod form, such as is now being made in the United States. It was the opinion of all persons interrogated, including Dr. Wilhelm Eppler, that corundum in rod form in small diameters would be of no value because it would always split down the middle and lose its cylindrical shape. The Germans apparently are not aware that a corundum rod in the order of one-tenth inch in diameter has been developed in the United States which does not split.

A Summary of the
RESEARCH THESIS
by Robert Webster, F.G.A.

Entitled: "AN INVESTIGATION INTO THE PROPERTIES OF IVORY ; THE MATERIALS USED IN ITS SIMULATION, AND INTO METHODS WHEREBY THEY MAY BE SEVERALLY DISTINGUISHED."

IVORY is described as the body substance of the teeth of all mammals, and, for commercial purposes, that material obtained from the tusks of the elephant ; from the hippopotamus ; from the walrus ; from the narwhal, and to a lesser extent from the tusks of the boar and the teeth of the cachelot whale.

The structure shown by visual inspection and by the examination of thin sections, illustrating the undulatory character of the fine canals, were found to give some evidence of the origin of the ivory. The hardness (about $2\frac{1}{2}$ Mohs) was ascertained by scratch and hardness indenter methods. The low refractive index (mean of 1.53) is ascribed to the organic content of the substance and the density was found to differ in respect of the ivory from the elephant and mammoth (1.70 to 1.85) from that of the coarser textured material from the other animals (1.85 to 2.00). Micro-chemical tests for the presence of calcium and phosphate and other chemical and flame tests are indicated.

The substances used in the simulation of ivory are discussed with reference to their structure, physical and optical characters and in their reaction to chemical reagents in order to compare these with the corresponding properties of the genuine material. Among the substances discussed are bone, deer horn, vegetable ivory and those materials of artificial nature termed " plastics."

The summing up describes suggested methods whereby the different materials may be distinguished from each other using the data obtained from the investigation, and illustrated by a series of original photomicrographs showing the various types of structure, assisting a fuller understanding. The thesis concludes with a short list of references.

The DIAMOND INDUSTRY in 1945

(Extracted from the Jeweler's Circular-Keystone.)

IN its 2,500 or more years of existence, the diamond industry has never had such a prosperous year as 1945. Production reached an all-time peak, some 14,250,000 carats, the decided increase over recent years being due to marked up-turns in output of crushing bort in the Belgian Congo and of gem stones in the Union of South Africa. Notwithstanding this, stocks were further depleted by the fact that the Diamond Trading Company's sales of rough were £24,500,000, a figure never before attained. Demand, for the fourth successive year, greatly exceeded production, and hereafter diamond cutters and users of industrial diamonds must look largely to current production for their raw product, and wholly so far as some sub-types of it are concerned.

Sales of cut diamonds, in the United States at least, also were of record proportions, due to high wages during the war and to accumulated wartime savings and, during the past four years, to the American stock market boom.

Wholesale prices of industrials did not advance, although it is rumoured that the quality of shipments deteriorated somewhat due to depleted stocks ; prices of rough increased, and retail prices of cut diamonds have never been higher, although not out of line with other commodities.

Shares of diamond mining companies on the London Stock Exchange showed a gain of 17 per cent., an increment scarcely commensurate with the long-term outlook of the industry.

The diamond cutting industry continued its growth, largely through the remarkably rapid revival of the Belgian industry. There are now over 26,000 cutters widely scattered over the world. The industry is geared too high for the amount of gem rough which presumably will be available, and much unemployment is likely to result.

Prices of both cut stones and diamond shares temporarily dropped, with the German collapse, presumably because optimists inferred that there would immediately be a larger supply of consumer goods and an immediate restoration of international economic stability. When it was realized that neither of these inferences was correct, diamond prices snapped back. Inflation still looms ; hence the gem diamond continues to have its normal investment position, due to its proved value through the years, its ease of transport, and its international market.

The British Empire for over 75 years has had the dominant position in the diamond industry, and is likely to retain it for many years to come. She is not, however, too content to have it rumoured that she may lose administrative control of two of her minor producers, South-West Africa and Tanganyika Territory, both mandated areas. In the first, among the white are a certain number of irreconcilable Nazi sympathizers ; in the

second, only loyal British colonists. The Union of South Africa does not propose to give up its mandate over South-West Africa, but the British Government has voluntarily offered to relinquish its 25-year-old mandate over Tanganyika Territory, a position which receives little support in South African diamond circles.

Early in 1945 the Anti-Trust Division of the Department of Justice of the United States brought an anti-trust suit against certain diamond producers and selling companies.

World War II established for the industrial diamond a place in the sun. In 1945, while improvement of diamond-set tools were made, no new uses were developed. With the end of the fighting, many war contracts were cancelled, but nevertheless imports of industrials are holding up satisfactorily. Year by year, the differentiation between the gem and the working diamond is strengthened. Henceforth different subsidiaries of the Diamond Corporation are to handle the sale of gem and industrial diamonds.

Now that the war is over, the industry may be congratulated on the fact that at no time during the war were the United Nations short of one of the most important of strategic minerals, the industrial diamond, without the use of which no important munition of war was made ; nor was the industry subsidized, nor did it sell its product under a premium price plan. Further, all industrials were sold throughout the war at pre-war prices.

The future of the industry is bright. Producers now have two products to sell, of first importance, gem stones, and of somewhat less importance, industrials. Stocks are depleted and demand exceeds current production. Unlike most mining industries, capacity was not greatly increased during the war and further plants now being installed can scarcely come into production for some three years. At worst, enough gems, particularly the smaller sizes, the bread and butter of the trade, should be sold to make the trade reasonably prosperous for some years. Further, with to-day's economy, if I see it rightly, many will have money to buy small diamonds who never did before, and at some future date China, Russia and many other countries may once again buy diamonds. Moreover, the producing companies are financially in a strong position and can, if necessary, ride out a normal depression.

ROUGH MARKET

The Diamond Corporation purchases in normal times 95 per cent. of the world's production in dollar value, indeed all production except part of that of Brazil, British Guiana, Venezuela and of some of the South African alluvial diggers. These stones its subsidiary, the Diamond Trading Company, sells to brokers and cutters. The Diamond Corporation has £5,000,000 in ordinary shares, 80 per cent., it is understood, being owned by De Beers and 20 per cent. by Consolidated Diamond Mine of South-West Africa. The Diamond Trading Company's capital (£3,000,000) is wholly invested in rough diamonds and as sales are made the proceeds are re-invested in rough. The Diamond Corporation's report is available only to its stockholders but the firm pays in good years, it is understood, handsome dividends. (1944 Diamond Corp., 10 per cent., and Diamond Trading Co., 12½ per cent.)

The main office of the Diamond Trading Co. is at Kimberley, but while sales are made there to the South African trade, its more important sales agency is in London. From mid-1942 until recently the company was under order of the Diamond Controller of Great Britain, but since the war's end this control, with others in the British diamond market, has doubtless been eliminated.

As late as 1934 total sales of the Diamond Trading Company were only £3,719,242, a year of depression in the industry and one in which few industrial diamonds were sold. More recent sales follow:—

Year	Total Sales	Gem Stones	% of Total	Industrials	% of Total
1939	£5,865,000	—	—	—	—
1940	6,144,314	—	—	—	—
1941	7,414,420	£5,500,000	74	£2,000,000	26
1942	10,694,671	6,250,000	59	4,240,000	41
1943	20,400,634	14,973,000	73	5,428,000	27
1944 (Est.)	17,000,000 +	13,000,000	76	4,000,000	24
1945 (About)	24,500,000	19,600,000	80	4,900,000	20 +

Sales in 1945 reached an all-time peak ; indeed, sales would have been larger had the company been in a position to offer more goods, as at most of the sights customers' needs could not be satisfied.

Stocks continue to decrease and that of the Corporation is low. Each year sales are more and more from current production. Sales in 1945 largely exceeded production (Sir Ernest Oppenheimer values gem production at £16,000,000 yearly) and it is doubtful whether 1946 sales will be as great as those of 1945, although higher prices, especially for industrials, may keep the value of sales from decreasing too markedly. For the next two years no increase in production can be expected.

During the year the Corporation extended all of its purchasing agreements with the producers, which expired at the end of the war.

The increases in prices of rough during the year, Sir Ernest Oppenheimer stated, are less than the increases of the index of commodity prices in the United States and South Africa and future price increases will not exceed such figures.

During the year the Diamond Trading Company was split into two companies, one under the original name to handle gem stones ; the second, Industrial Distributors (1946), Ltd. (capital £1,000,000), registered in Pretoria, to deal in industrials. The producers are the principal shareholders in the new company, although Anglo-American Investment Trust has an interest. Mr. Otto Oppenheimer is managing director. The price of industrials will be based on the value of each grade to industry and will be wholly uninfluenced by gem price fluctuations. Assortment will be according to uses in the industry. It will be remembered that to assist the United Nations prices of industrials were reduced just before the war and no price increases occurred during the war.

During 1945 the Diamond Trading Co. held a number of " sights," most of them gem grades. The quantity offered was disappointingly small, largely because the Corporation's stocks were becoming depleted, although partly because of a shortage of sorters. Due to stock shortages, quality, it is rumoured, fell somewhat. Many " askers " left with only a small part of their needs supplied. In the February, 1945, sight prices were some 8 per cent. over those of November, 1944. The lucky bidders were able, immediately after the sights, to re-sell their diamonds at a mark-up of as much as 19 per cent., it is said.

During the war, the old London office of the Corporation (8, Charterhouse Street) was destroyed by bombs ; it is now in St. Andrew's Building at the very centre of the diamond merchants' quarter.

In April industrials were sold. Retail prices of industrials were raised previously thereto, in expectation of appreciably higher prices for roughs.

Rough prices since before World War II, say November, 1939, to February, 1945, have increased, according to one merchant, appreciably on first quality goods, 1 to 13 carats about 120 per cent., while second quality stones have doubled in value. The advance for 1-carat to 5-carat stones has been from 135 to 160 per cent., that of 8-carat stones only about 100 per cent. The advance in rough under 1 carat has been appreciably less.

SYNTHETIC DIAMOND ATTEMPTS

Due to a shortage of industrial diamonds, German scientists during the war carried on extensive researches as to the production of synthetic diamonds (Guenther, P. L. ; Geselle, C., and Rebentisch ; Zeitschr Anorgan e. allgem Chemie, Vol. 99, 1943, pp. 357, 72. Excellent digest Industrial Diamond Review, Vol. 6, February, 1946, pp. 42-46). In summary, the possibility of diamond synthesis is discussed ; Moisson's experiments were repeated and improvements thereof tried, with disappointing results. Further, graphite and coal blocks were heated in about 6 seconds to a temperature of 3,000 deg. C. and then exposed to a pressure of 1,707,000 lbs. per sq. in. ; failure resulted.

WORLD PRODUCTION

For the sixth year, because of the war, even fairly accurate figures of world diamond production are not available. The 1945 figures are necessarily in part estimates, but the total, 14,257,157 carats (3,129 short tons), is probably a close approximation. The value at the mines was some $64,750,000. Caratage and value were respectively some 21 per cent. and 35 per cent. greater than the 1944 figures (revised value for 1944, $48,000,000). Of the total, gem rough made up about 18 per cent., a less percentage than last year because of the large produtcion of crushing bort by BCK, a Belgian Congo producer. By weight, some 5,125 pounds were industrials and 1,130 pounds gem stones.

The Belgian Congo was the leading producer, by weight (72.7 per cent.), but, because much of its production was crushing bort, it represented only 13 per cent. of the value of world production. On the other hand, the British Empire, which accounted for only 19.2 per cent. of the weight, represented 71 per cent. of the value.

The South American producers (Brazil, Venezuela and British Guiana) accounted for 2.09 per cent. of the world's production by weight and 9.6 per cent. by value.

Compared with 1944, the Belgian Congo increased its production, by weight, 38 per cent. The South African pipe mine production increased markedly, thanks to greater activity at the DeBeers mines. While Premier and New Jagersfontein are being reopened, they can scarcely get into production for two years longer. South African alluvial production increased appreciably. Tanganyika Territory continued its gain in production and, in consequence, DeBeers sent representatives to look over the field. The Venezuelan production continued to decrease, and that of Brazil probably was less than in 1944.

The following table shows, as accurately as available statistics permit, world production for the past four years.

Production, 1942-45, by Countries, in Metric Carats (Including Industrial Diamonds)

	1942	1943	1944	1945
Africa:				
Angola	791,850	794,980	800,000	786,000
Belgian Congo ...	6,018,236	4,881,000	7,540,000	10,386,000
French Equ. Afr.	*20,000	*20,000	*5,000	*5,000
French W. Africa	1,500	35,000	*60,000	*60,000
Gold Coast ...	*1,000,000	*1,000,000	*1,000,000	*500,000
Sierra Leone ...	*850,000	*850,000	*700,000	*800,000
South-West Afr.	56,420	88,000	154,000	156,000
Tanganyika ...	41,000	52,998	90,667	115,666
Union of St. Africa:				
Mines ...	—	175,885	639,000	878,713
Alluvial ...	118,821	126,444	270,000	262,527
Total ...	118,821	302,329	909,000	1,141,240
Brazil	*300,000	*275,000	*370,000	*275,000
British Guiana ...	22,208	18,272	13,911	17,251
Other Countries**	40.836	29,650	34,000	15,000
Grand Total ...	9,260,781	8,347,239	11,676,578	14,257,157

* Estimated.

** Includes Venezuela (12,769 carats) ; Borneo, India, New South Wales, U.S.S.R.

(Reprinted from the Jewelers' Circular-Keystone.)

TEXTBOOKS ON GEMMOLOGY

Now available :

" Practical Gemmology," by R. Webster, F.G.A.
New and revised edition, 1946 (published by N.A.G. Press, Ltd.). Price 10s. 0d.

" Key to Precious Stones," by L. J. Spencer, C.B.E., F.R.S. (Blackie & Son.) Price 7s. 6d.

" Gems and Gem Materials," by E. H. Kraus, Ph.D., Sc.D., and C. B. Slawson, Ph.D.
Fourth edition (1941), (McGraw-Hill). Price 17s. 6d.

To be published shortly :

" Gemstones," by G. F. Herbert Smith, M.A., D.Sc.
New and revised edition, 1947. (Methuen & Co., Ltd.)

" Gem Testing," by B. W. Anderson, B.Sc., F.G.A.
New and revised edition. (Heywood & Co., Ltd.)

" Gemmologists' Compendium," by R. Webster, F.G.A.
New and revised edition. (N.A.G. Press, Ltd.)

Orders for the above books may be sent to The Gemmological Association.

R.I. Determination by the shadow method

by
Lt.-Col. G. M. SPRAGUE
A.M.I.Mech.E., F.R.G.S.

THE purpose of this article is to describe a method of working which, though not met with in the standard textbooks on gemstones, nevertheless gives excellent results and is very easily applied. It is particularly useful when, as at present, refractometers are scarce. It is also available for stones which are cut en cabochon or for uncut stones which are too rough for examination with the refractometer. The method is described in textbooks on Mineralogoy for use with small grains of sand, but may be applied equally well to large stones. All that is required is a simple microscope without substage or condenser and a set of suitable liquids of known R.I.

Unlike the Becke test, which is described in most textbooks on gemstones, the shadow method works best with low power, say 2 ins. or 1 in. Ample working distance is therefore obtainable.

The procedure is as follows:—

The stone to be tested is made to rest on its table facet or any suitable surface, and is placed in a glass bottomed cell in a liquid of known R.I. The microscope is then focussed on the bottom edge of the stone, which is illuminated by means of the mirror to give as far as possible even illumination of stone and liquid (Fig. 1). A card is introduced above the mirror and below the stage and is moved in towards the edge of the stone as seen through the instrument (Fig. II). As the card moves, a shadow will appear on the side opposite to that from which it is put in and will move across the field. Now comes the test. If the stone has a higher R.I. than the liquid, darkness will develop all round the edge of the stone while the liquid around it is still lighted up (Fig. III). If, however, the stone has a lower R.I. than the liquid, the reverse will be the case, and the edge of the stone will remain light whilst the liquid all round is in shadow (Fig. IV).

I

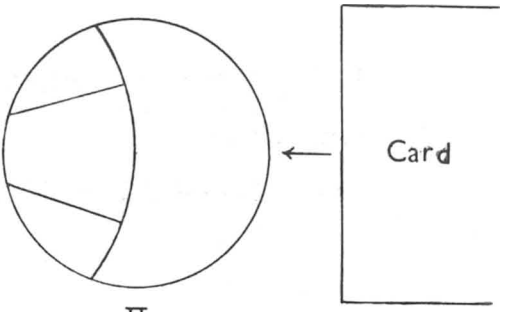

II

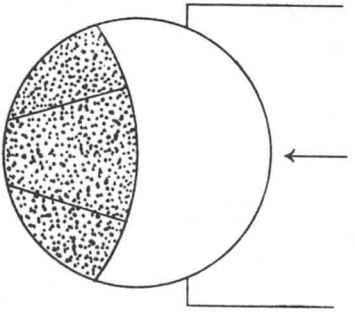

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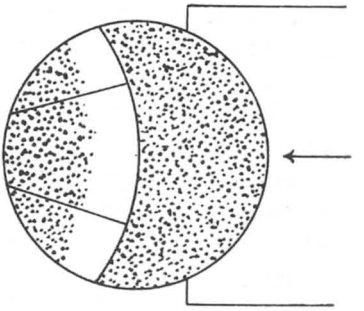

IV

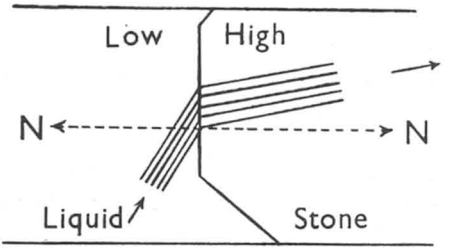

(a) Rays spread out by refraction on entering stone.

V

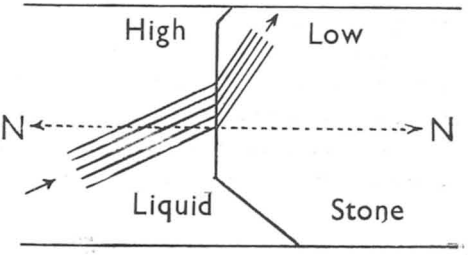

(b) Rays concentrated by refraction.

In both the above cases, if the card is put in from the opposite side the effect is reversed, i.e., if the stone showed a shadow in the first instance it will now show brightness.

The description may perhaps sound a trifle complicated, but the method is simple to use and after it has been tried once or twice will be performed without difficulty.

If the R.I. of the stone approaches that of the liquid to within, say, 2 or 3 units in the second decimal place, it will be found that a blue fringe will appear at the edge of the stone nearest the card. If the card be inserted from the opposite side, a red fringe will be seen at the edge of the stone, the shadow effect, of course, being reversed as before (i.e., if the stone showed in the first instance a shadow with a blue edge, it will now show brightness fringed with red).

Usually, as with testing in liquids for S.G., it will be sufficient to determine limits between which the R.I. must lie. A suitable set of liquids for this purpose might include Bromoform (R.I. 1.59), Monobromonaphthaline (1.66), Methylene Iodide (1.74) and Meth. Iodide saturated with sulphur (1.79). These will be found sufficient for all normal work in conjunction with other tests.

If complete accuracy is required, monochromatic light must be used. A method of obtaining this is given on page 21 of B. W. Anderson's excellent book, "Gem-Testing for Jewellers." Two liquids, one of R.I. above and one of R.I. below that of the stone are mixed until no shadow effect can be observed, the shadow passing across the field in the same way as if the stone were not there. Incidentally, the stone should now, of course, be invisible in the liquid except for such impurities as it may contain. The R.I. of the liquid will then have to be measured by refractometer or otherwise, so that there is little point in going to the trouble of mixing the liquids except in cases where the stone has no flat polished surface to allow of direct measurement by the refractometer.

For those who are interested in the why and the wherefore of such phenomena it may be explained that the effects described above are caused by the fact that a ray of light is bent towards the normal when travelling from a rarer into an optically denser medium. The effect of inserting the card is to cause the illumina-

tion to fall obliquely on the surface joining the stone and the liquid (Fig. V). If the stone has the higher R.I. the rays are spread out by refraction and so lose intensity on entering it. A shadow is therefore produced at the edge of the stone. If, however, the stone has a lower R.I. than the liquid, the rays will be concentrated by refraction and brightness will be produced, giving the opposite effect. The side on which the light falls is, of course, the side of the stone away from the card, but the microscope reverses the image so that the effect is seen on the side which appears nearest the card. It can be shown that the same effect is produced when the surface joining the stone and liquid is oblique instead of vertical, which explains why the method works well with any shape or size of stone.

The colour fringes are due to the relative dispersions of the stone and the liquid. Where these are seen, it is certain that the two R.I.s are close together. It is usually obvious which is the higher if one examines the edge with the card inserted first one side and then the other. The brightness may be more marked than the shadow effect, or vice versa, depending on whether the R.I. of the stone for red or for blue light is closer to the R.I. of the liquid.

Official Notices *(Continued.)*

MEMBERSHIP

Fellows and Members who may be aware of former members whose contact with the Association has lapsed during the war years, are requested to submit names to the Secretary of the Association.

GIFTS TO THE ASSOCIATION

The Council acknowledges, with deep appreciation, the following gifts and donations:—

£50 0s. 0d.—B. W. Anderson, Esq.
£26 5s. 0d.—M. Crombie, Esq.
125 gem mineral specimens—G. F. Andrews, Esq.
Gabochon Almandine Garnet (283 carats)—A. J. Fox, Esq.
Specimen of Tiger's Eye—Gems of the World, S. Africa.

MEMBERS' NOTICES

WANTED.—Good cut specimens of (a) light yellow fluorspar, (b) pink or red fluorspar, preferably table cut.—Ref. G/1.

OFFICIAL NOTICES

AWARD OF RESEARCH DIPLOMA

The Council of the Association, upon the recommendation of the Examiners, has awarded a Research Diploma in Gemmology to Mr. Robert Webster, F.G.A., for his thesis entitled "An investigation into the properties of ivory and of the materials used in its simulation, and into methods whereby they may be severally distinguished."

In his thesis Mr. Webster has studied a subject which has hitherto received little systematic attention. His work contains the record of much original research, and for the first time the physical properties of the natural substances which rank or pass as ivory and of their plastic imitations have been systematically determined and compared with one another.

MEMBERS' MEETING

Notice is given that a Meeting of Fellows and Members of the Association will be held on Thursday, 27th February, 1947, at 6.30 p.m., in the Hall of the **GEOLOGICAL SOCIETY OF LONDON, BURLINGTON HOUSE, W.1.**

The Meeting will be followed at 7 p.m. by short lectures and discussion on selected gemmological subjects.

LECTURE

It is hoped to arrange a lecture, illustrated by lantern slides, entitled "Gemstone Inclusions," to be given by Dr. E. Gubelin, Ph.D., F.G.A., C.G., of Lucerne, Switzerland, some time in March. Further details will be announced later.

1947 EXAMINATIONS IN GEMMOLOGY

The 1947 Examinations in Gemmology will be held in June.

PROVISIONAL DATES :

Preliminary Examination—Wednesday, 25th June.
Diploma Examination (Theoretical)—Thursday, 26th June.
Diploma Examination (Practical)—Friday, 27th June.

Examination entrance forms may be obtained from the Association's offices.

ENTRY DATES :

Overseas candidates—no later than 15th March.
Provincial candidates—no later than 10th May.
London candidates—no later than 24th May.

Candidates overseas should make early application, in order that arrangements can be made. Where proper facilities are available the Diploma practical examination may be taken oversea.

All candidates are required to qualify in the Preliminary Examination before sitting for the Diploma Examination.

ENTRY FEES :

Preliminary—£1 1s. 0d.
Associate—£3 3s. 0d.
Diploma (Fellowship)—£3 3s.0d.

All enquiries in respect of the Examinations should be addressed to the Director of Examinations, Gemmological Association of Great Britain, Audrey House, Ely Place, London, E.C.1.

THE EXAMINATIONS

The Association's Examinations in Gemmology are held normally in June of each year. Candidates are admitted for examinations at the discretion of the Council.

PRELIMINARY EXAMINATION

Theoretical papers only. A certificate is awarded to qualifying candidates. Entrance fee: £1 1s. 0d. The Examination may be taken provincially or abroad by arrangement.

A prize of books, to the value of £3 3s. 0d., is awarded annually to the candidate submitting the best papers in the examination which, in the opinion of the Council and Examiners, are of sufficiently high standard to merit the award.

DIPLOMA EXAMINATION (Fellowship)

Theoretical and Practical papers. A diploma is awarded to qualifying candidates (subject to their having qualified in the preliminary examination). The Diploma Examination is held normally in London, but may be taken provincially or abroad, provided that proper facilities are available. Entrance fee: £3 3s. 0d.

The " Tully Memorial Medal " is awarded to the candidate submitting the best papers in the Diploma examination which, in the opinion of the Council and Examiners, are of sufficiently high standard to merit the award. In addition to the award of the medal, the " Rayner Prize," a refractometer presented by Messrs. Rayner & Keeler, Ltd., is awarded to the winner of the Tully Medal.

The " Anderson Prize," a spectroscope presented by B. W. Anderson, Esq., is awarded to the candidate submitting the best papers in the practical examination, subject to the papers being of sufficiently high standard to merit the award.

Successful candidates in the Diploma Examination may be admitted as Fellowship Members of the Association.

ASSOCIATESHIP EXAMINATION

Open only to candidates who, having passed the Preliminary Examination, are unable to sit for the Fellowship Examination for reasons acceptable to the Council and Examiners. The examination, which may be taken in London, provincially or abroad, consists of theoretical papers of Diploma grade only. Entrance fee: £3 3s. 0d. Associates may qualify for Fellowship by passing practical examinations of Diploma grade subsequently. Entrance fee: £1 1s. 0d.

The practical examinations for Associates must be taken at the normal date of the examinations.

Syllabus of Examinations

I.—PRELIMINARY

1. Crystallography.

Nature of crystals. Crystal systems.

2. Physical Mineralogy.

Hardness, cleavage. Specific gravity ; its determination by hydrostatic weighing and approximate determination by heavy liquids. Reflection, refraction, total-reflection, double refraction. Refractive index ; its determination by refractometer. Colour, lustre, sheen, opalescence, iridescence, asterism, chatoyancy, dispersion, dichroism.

3. Elementary Use of Apparatus.

Refractometer, dichroscope, lens, " Chelsea " colour filter, balance.

4. Description of Gem Materials.

(*a*) NATURAL GEMSTONES. Chemical and physical properties of—beryl (including emerald and aquamarine), chrysoberyl (including alexandrite), corundum (including ruby and sapphire), diamond, garnet family, jade, quartz (including chalcedony), spinel, topaz, tourmaline, turquoise, zircon.

(*b*) SYNTHETIC AND IMITATION STONES. Synthetic corundum and spinel ; composite and paste stones.

(*c*) ORGANIC PRODUCTS. Native, cultured and imitation pearl ; their formation and structure ; base system of calculating the value of pearls. Amber.

5. Fashioning of Gemstones.

Styles of cutting.

II.—DIPLOMA

1. Crystallography.

Crystal morphology and habit. Crystal structure. Isomorphism and isomorphous replacement.

2. Physical Mineralogy.

Specific gravity ; its determination by hydrostatic weighing and by heavy liquids (advanced technique). Estimation of weight. Optical properties of crystals. Refractive index ; its measurement by refractometer and by other methods. Polarized light. Colour and its artificial alteration. Interference and diffraction of light. Spectroscopy and absorption spectra. Luminescent and electrical properties. Application of X-rays to gem testing. Inclusions and other internal features.

3. Advanced Use of Apparatus.

Construction and use of—refractometer, dichroscope, spectroscope, spectrometer, microscope (including polarizing type), endoscope, balance.

4. Description of Gem Materials.

(*a*) NATURAL GEMSTONES.

(i) Chemical and physical properties, mode of occurrence and localities of—beryl, chrysoberyl, corundum, diamond, feldspar family, fluor, garnet family, jadeite, lazurite (lapis Lazuli), nephrite, olivine, opal, quartz (including chalcedony), sphene, spinel, spodumene, topaz, tourmaline, turquoise, zircon.

(ii) Chief chemical and physical properties of—andalusite, apatite, axinite, azurite, benitoite, calcite, cassiterite, cordierite, danburite, diopside, enstatite, epidote, haematite, idocrase, kornerupine, kyanite, malachite, phenakite, prehnite, pyrites, scapolite, smithsonite, sodalite, variscite.

(*b*) SYNTHETIC AND IMITATION STONES. Synthetic corundum, spinel, and emerald. Composite and paste stones ; plastics.

(*c*) ORGANIC PRODUCTS.

(i) Native and cultured pearl ; their formation, structure and occurrence, and methods of distinguishing them. Imitation pearl.

(ii) Amber, coral, jet ; ivory, tortoise-shell.

5. Fashioning of Gemstones.

Cleaving, slitting, cutting and polishing. Machinery used. Styles of cutting.

INSTRUCTION CENTRES

LONDON

Chelsea Polytechnic, Manresa Road, S.W.3.

Evening lectures and practical work. Preliminary, Diploma and post-Diploma Courses. Senior Lecturer: Mr. B. W. Anderson, B.Sc., F.G.A. Junior Lecturer: Mr. T. G. Jones, F.G.A. Assistant Lecturer and Demonstrator: Mr. R. Webster, F.G.A.

Courses commence in September each year. Prospectus and enrolment forms may be obtained from the Secretary of the Association.

BIRMINGHAM

Jewellers' and Silversmiths' School, Vittoria Street.

Evening Lectures. Preliminary Course. Lecturer: Mr. N. Harper, F.G.A., F.R.G.S. Details may be obtained from Principal of the School.

EDINBURGH

Heriot-Watt College.

Evening courses of Preliminary grade. Lecturer: Mr. D. Ewing, F.G.A. Details may be obtained from the Principal of the College.

CORRESPONDENCE COURSES

The courses cover Preliminary and Diploma work. Enrolments must be made in August and September of each year. The courses are conducted by the Association's official Instructors, Mr. B. W. Anderson, B.Sc., F.G.A., and Mr. C. J. Payne, B.Sc., F.G.A. Full particulars may be obtained from the Secretary of the Association.

RESEARCH DIPLOMA

Regulations for the Research Diploma:—

1. Candidates for the Research Diploma of the Gemmological Association shall either have gained the Fellowship Diploma with distinction, or satisfy the Board of Examiners that they possess the qualfications necessary for undertaking such work.

2. Candidates shall either select their own subject or follow a line suggested by the Instructor. The intended scope of the investigation shall be submitted to the Board of Examiners for approval at an early stage.

3. The candidate's own account of the investigation shall be submitted (in triplicate) to the Board of Examiners in the form of a typewritten or printed paper. In addition, the Board of Examiners may require the attendance of the candidate for an interview.

4. In order to qualify for the Research Diploma the paper must form a distinct contribution to Gemmology, and afford evidence of originality, shown either by the discovery of new facts or by the exercise of independent critical power.

5. The investigation may be carried out either at a suitable Institute or in approved cases at home. Candidates will be expected to show that they are familiar with the work of previous investigators on the subject selected.

6. Each successful candidate will be awarded a Research Diploma, and be entitled " Research Gemmologist."

7. The copyright of the papers of successful candidates shall be the property of the Gemmological Association, at whose discretion they may be published.

THE JOURNAL OF GEMMOLOGY

AND PROCEEDINGS OF THE GEMMOLOGICAL ASSOCIATION OF GREAT BRITAIN

Vol. I No. 2 APRIL 1947

AT the time when the diploma scheme was being formulated there was no question but that the correct name for the science of gemstones was *gemmology*, inasmuch as this word was introduced with this meaning early in the nineteenth century, though it is only since the inception of the examinations and especially the foundation of the Gemmological Association of Great Britain that it has come into common use. There is an alternative word, *lithology*, which etymologically might have been considered apt, meaning as it does the science of stones, but it was at one time in fairly general use for the science of stones or rocks, though it has been displaced by *petrology*.

The only point at issue, which did give rise to discussion, was the spelling. In America the form *gemology* is preferred. This, however, is a hybrid word, being composed of an English word and one derived from the Greek, and is the kind of word which, according to the canons governing the formation of composite words recognized in Britain, should be avoided. *Gemmology*, on the other hand, is a combination of a Latin word, but of Greek origin, and a Greek word. It may be remarked that it is invariably pronounced with a double *m*.

The Latin word *gemma* appears to have been based upon a Greek word meaning to be full or to swell up, and was first applied to the bud of a plant—indeed, such words as *gemmate* and *gemmation* were once common in English in that sense—and was later applied to precious stones, especially when fashioned, the treatment accorded to them apparently suggesting to the Romans the effect of budding, and subsequently, as with our *gem*, it was used

to denote an ornament of specially high quality. In the sense of precious stone the word passed into French as *gemme* and was absorbed into English with some such spelling as far back as the ninth century, the simplified form not being introduced until the eighteenth century.

The second part of the word is directly based upon a Greek word, which is derived from one meaning to say or to speak, and is used in two distinct senses: saying or speaking, and the matter said or spoken (sciences or subjects of study). The former group, which is much the smaller, includes words such as *eulogy* (speaking well of a person) and *tautology* (saying the same thing). The latter group includes words such as *theology* and *astrology*, which are taken from actual Greek words, and others such as *geology* and *zoology*, which might have been similarly taken had such words existed. Many words, such as *sociology* and *terminology*, are hybrids. *Mineralogy* also must be accounted a hybrid, since the first part comes from the medieval Latin word *minerale*. The Romans used for minerals of all kinds *metallum*, a word taken from the Greek which originally meant the place of searching, and later acquired the meaning of mine or quarry, and finally also the extracted material. The different termination *-alogy* is explainable by the fact that the word is a contraction of *mineralology*.

G. F. Herbert Smith

WORLD GEMMOLOGICAL ORGANIZATIONS

Swedish Gemmological Association.
Founded 1946.

The Gemmological Association of Australia.
Founded 1946.

The Swiss Gemmological Association.
Founded 1942.

Gemological Institute of America.
Founded 1931.

The Gemmological Association of Great Britain.
(Founded in 1908 as the Education Committee of the National Association of Goldsmiths, reconstituted in 1931 as the Gemmological Association.)

EQUIPPING a Gem Testing Laboratory

by F. E. ULLMAN, F.G.A.

HAVING closed my business at the outbreak of war in order to take up a Government appointment, I disposed of nearly all my gem testing instruments. On restarting to trade one of my first tasks, after finding suitable office accommodation, was to set about re-equipping my laboratory, as I consider scientific gem testing to be even more important now than it was previously owing to the prevailing conditions of being compelled to deal almost entirely in merchandise purchased from the public. The proof of this fact is clearly demonstrated by an experience I had recently. One day a lady called at my office with a view to selling me some coloured stones. She approached the matter in a most business-like way and produced a neatly typewritten valuation which she had obtained from a large provincial jeweller, to whom she had paid the full scale valuation fee. The amount involved was not inconsiderable. Imagine the lady's consternation when I was obliged to tell her that all her specimens were synthetic spinels!

My first post-war purchase was a Chelsea colour filter at a cost of 5s. At that time a good second-hand dichroscope came my way for £2, and I was also fortunate enough to acquire from a friend of mine a really accurate and almost new balance for £10. My next purchase was some laboratory glass, half a dozen wide-necked stoppered bottles, a few glass mixing rods, a funnel, three glass cells, some microscope slides, a beaker or two, and one or two other odds and ends completed my requirements in this line. I also bought small quantities of benzine, bromoform, bromonaphthalene, methylene iodide, and clerici solution, the latter at that time costing £2 per ounce. My total expenditure on laboratory glass and chemicals ran into some £10. It is now possible to

purchase, I believe, the heavy and highly refractive liquids needed for gem testing at much lower prices than I was obliged to pay.

I then started to look for a decent microscope ; after not much trouble I picked up a good modern second-hand Beck fitted with a sub-stage condenser and iris diaphragm for £25. It has two eye-pieces and four objectives, and although not of the polarizing type, I have found it a first-class general purpose instrument. I also bought a second-hand bulls-eye condenser in mint condition for 25s.—an always useful accessory. On being shown a fine brown zircon by a colleague, I logically began to think of absorption spectra, and soon purchased a new Beck spectroscope for £5. My next worry was to obtain a good source of illumination for my spectroscopic work, and I thus acquired a 500-watt, pre-focus, miniature cinema projection lamp, which, together with a holder and a special housing I had professionally made, cost £8.

One night when working at Chelsea I was shown some new " Polaroid " discs. I was so impressed by their almost complete extinction that I ordered from an instrument maker I know a polariscope made of this new " Polaroid," mounted and arranged with a rotating stage so as to be suitable for gemmological work. As this device was especially built to my own requirements, I was obliged to pay a fairly high price for it, the whole thing costing me £10. I now had to buy a laboratory table, and after searching round for several weeks I found just what I wanted for £9 15s. in an old second-hand shop ; I also picked up a nice bench stool for 10s.

At the time of writing I have only just received my Rayner refractometer and colour filter ; with the aid of this latter one obtains what is virtually monochromatic light, so that the necessity of purchasing a sodium vapour lamp for doing accurate work no longer arises. The refractometer cost £13 and the filter 16s., and no words of mine can express my pleasure at possessing these wonderful instruments.

My greatest piece of luck was that I recently found a practically unused endoscope for £15! I bought a new filament resistance for this instrument at a cost of £6 15s. And finally, a good bench lamp at a cost of £2 10s., which, together with an electrician's bill of £8 for wiring, made a total expenditure of £127 15s. for fitting my laboratory to date.

SOME PHOTOGRAPHS FROM THE LABORATORY

No. 2.—INCLUSIONS IN GEMSTONES

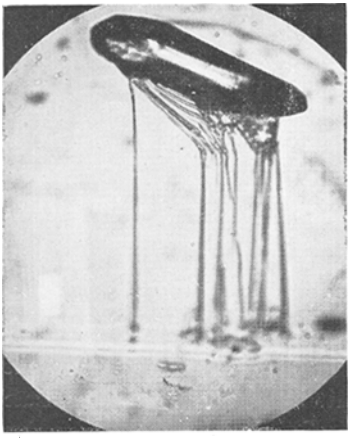

"The Barrage Balloon"

An inclusion in Emerald.

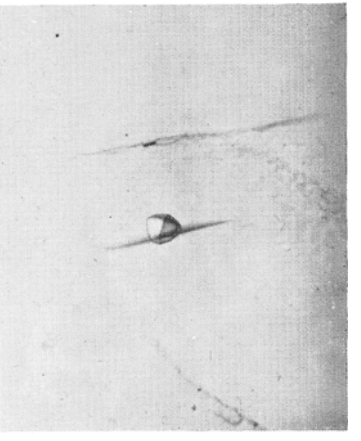

"The Raider"

Zircon crystal in Ceylon Yellow Sapphire.

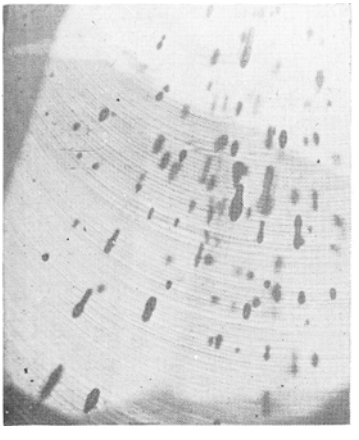

"The Bombs Fall"

Elongated bubbles in synthetic Ruby.

"The Bombs Burst"

Inclusions in Burma Ruby.

Gemmology and Sir Thomas Browne

by E. BURBAGE, F.G.A.

IT would be misleading to present a gemmological collage from the writings of Sir Thomas Browne as indicative of the state of knowledge of the average 17th century Englishman, for, in the width and profundity of his intellectual curiosity, Browne stands apart from his contemporaries, and would have been remarkable in any age. In a famous passage in the Religio Medici, Browne claims with justice, " I am of a constitution so general, that it consorts and sympathizeth with all things," and this catholicity of interest is reflected in his writings. One feels, however, that the good Doctor had a keener interest in living things than in inanimate nature, and that he had a livelier affection for that famous garden which Evelyn called a Paradise, and for the birds and beasts of the Norfolk fields and seashore, than for those Hungarian minerals which his son Edward contributed to the extensive Brownian collections. At any rate, the occasional notes on minerals which are scattered throughout Browne's writings are not of the first importance, but they are not without interest to the gemmologist.

Of these passages, the most considerable occurs in his Pseudodoxia Epidemica, Browne's longest work, published during the Commonwealth. In his Second Book, Browne examines " Sundry popular Tenets concerning Mineral, and vegetable bodies, generally held for truth ; which examined, prove either false, or dubious." The first of these " vulgar errors " is " that Crystal is nothing else but Ice or Snow concreted, and by duration of time, congealed beyond liquation." Following a citation of those authorities assenting to the proposition, and of those rejecting it, Browne controverts it on various grounds by arguments whose validity is often suspect in the light of later knowledge. Browne's mineralogy postulates the existence of " mineral spirits " as essential to the formation of crystalline bodies, and he makes a rigid distinction between " conglaciation " and true crystallization to which a modern physicist would be reluctant to subscribe. He further

differentiates between ice and crystal by considerations of melting points (" In this way may be effected a liquidation in Crystal, but not without some difficulty ; that is, calcination or reducing it by Art into a subtle powder—but Ice will dissolve in any way of heat, for it will dissolve with fire, it will colliquate in water or warm oyl ") ; also, by specific gravity (" Crystal will sink in water, as carrying in its own bulk a greater ponderosity then the space in any water it doth occupy ; and will therefore only swim in molten Metal and Quicksilver "). But we need not pursue the Doctor further upon this subject, excepting to note that although his chemical guesses are lamentably wide of the mark, his morphological observations are correct enough.

In the second book of the Vulgar Errors, a disproportionately large section is devoted to magnetism, and it is evident that his findings are solidly based upon extensive personal observations, although the works of Gilbert, Sir Kenelm Digby, Descartes, and many others are employed. From his correspondence, it appears that amber cast up on the Norfolk coast reached Browne from time to time, and in these pages he writes about the substance with the confidence of personal knowledge. He lapses into error in discussing its origin, for he writes, " It is likewise probable the Ancients were mistaken concerning its substance and generation ; they conceiving it a vegetable concretion made of the gums of Trees, especially Pine and Poplar falling into the water, and after indurated or hardened, whereunto accordeth the Fable of Phaetons sisters: but surely the concretion is Mineral, according as is delivered by Boetius." On included insects in amber he notes that Bellabonus discovered them to be not real, but representative (reminding one of the analogous views by which Philip Gosse, the naturalist, reconciled palaeontological contradictions with the chronology of Bishop Ussher), but here Browne suspends judgment, remarking that " hereunto we know not how to assent, as having met with some whose reals made good their representments."

Of various superstitions concerning the magical properties of gemstones, Browne make short shrift elsewhere in the Pseudodoxia. " That Lapis Lasuli hath in it a purgative faculty we know ; that Bezoar is Antidotal, Lapis Judaicus diuretical, Coral Antipileptical, we will not deny. That Cornelians, Jaspis, Helio-

tropes, and Blood-stones, may be of vertue to those intentions they are implied, experience and visible effects will make us grant. But that an Amethyst prevents inebriation, that an Emerald will break if worn in copulation. That a Diamond laid under the pillow, will betray the incontinency of a wife. That a Saphire is preservative against inchantments ; that the fume of an Agath will avert a tempest, or the wearing of a Crysoprase make one out love with Gold ; as some have delivered, we are yet, I confess, to believe, and in that infidelity are likely to end our days." On the existence of self-luminous gemstones, he hedges, merely recording the opinions of Milius and Boetius that this is not a property of the carbuncle.

Purists whose ears are offended by the pinchbeck sound of that much-debated substantive "gemmologist" may prefer Browne's variant in "Plants in Scripture," although Time has falsified the general truth of the passage in which it occurs: "Gemmarie Naturalists reade diligently the pretious Stones in the holy City of the Apocalypse: examine the Breast-plate of Aaron, and various Gemms upon it, and think the second Row the nobler of the four: they wonder to find the Art of Ingravery so ancient upon pretious Stones and Signets ; together with the ancient use of Ear-rings and Bracelets."

In another posthumous tract, "An Account of Island, alias Ice-Land, in the yeare 1663," we are told that "They have some large well grain'd white pebbles, & some kind of white cornelian or Agath pebbles on the shoare, which polish well. Old Sr. Edmund Bacon of these parts made use thereof in his peculiar Art of Tinging & colouring of stones." It would be interesting to know more of the technique employed by the ingenious Sir Edmund ; possibly some Norfolk gemmologist of antiquarian tastes can inform us on this point.

The diverse and uneven character of Browne's occasional notes about gemstones form too insecure a basis to venture any generalizations about the level of gemmological knowledge in his day. Although sharing the Baconian ardour for experiment, Browne retained too much of a scholar's respect for authority fully to subscribe to that novel and daring maxim, "Nullis in verba," and by reason of this he ranks, on a strictly scientific assessment, below contemporaries of lesser versatility and learning. (It is significant that in spite of painstaking services per-

formed for the new Royal Society, and several none-too-subtle hints conveyed to its Secretary in the correspondence which passed between Browne and Oldenburg, the former never realized his ambition of election to membership—possibly this residual deference to authority may have been a major factor in his rejection.) Although Browne's supreme contribution is to literature rather than to science, in that wonderful Renaissance of the spirit of free enquiry which flowered between the Restoration and the death of Newton, his name merits consideration for his work in the exantlation of truth (to borrow his own characteristic Latinism). To return to gemmology, it is fervently to be wished that a general survey might be undertaken to collect and discuss the investigations made during this period into the gem minerals, for the wide field of enquiry presented by the history and progress of gemmological knowledge has had far less attention than it merits.

OUR AFFILIATED ASSOCIATION
THE GEMMOLOGICAL ASSOCIATION OF AUSTRALIA

The Gemmological Association of Australia, which became affiliated to the Gemmological Association of Great Britain in 1946, is broadening the scope of its activities in a most encouraging and enterprising manner. Branches are being established in selected centres of the Commonwealth, and classes will be conducted in Sydney and Melbourne. 1947 will see the holding of the first Diploma Examinations.

The Australian Association has decided upon the affix "F.G.A.A." for its Fellowship, thus wisely avoiding confusion with the "F.G.A." of the British organization.

Reports of the G.A.A.'s proceedings are contained in "Gemmology Review"—a section of the "Commonwealth Jeweller and Watchmaker." The institution of lectures, formation of a reference library and the appointment of further qualified instructors indicate the enthusiasm and determination of those interested to ensure that Australia adequately caters for all concerned with Gemmology.

The following have been appointed Officers for the ensuing year:—

Patron : G. D. Osborne, D.Sc., Ph.D., Sydney University.
President : D. P. Mellor, D.Sc., Sydney University.
Vice-Presidents : Messrs. A. E. Tombs, G. Proud, L. Goldring, J. T. Hinkley, W. J. Saunders and J. H. Pope, F.G.A.
Chairman : Mr. A. E. Tombs.
Treasurer : Mr. F. Kirkby. *Secretary :* Mr. J. S. Taylor.
Librarian : Mr. A. Wirth.
Instructors : H. F. Whitworth, M.Sc., and R. O. Chalmers.

The Chelsea Filter

WHEN the " Chelsea " Colour Filter was devised it was primarily intended to provide a rapid aid in distinguishing between genuine emeralds and the pastes and doublets which resemble them. Subsequent investigation showed that the filter was also useful in other ways.

The filter is designed to transmit only deep red and yellow-green light, and the best results are obtained when stones are examined under a strong electric light. It is sufficient to hold the filter close to the eye with the stone or stones (for a number can be examined at one time) receiving as much light as possible.

Under these conditions emeralds (absorbing in the yellow green) usually appear distinctly red or pinkish in colour, the actual tint varying from merely pinkish in the case of pale stones, to a rich almost ruby red for better coloured specimens. On the other hand, most imitations of the genuine stone (pastes, doublets, soude emeralds) retain a green appearance. In rare cases certain emeralds, notably those from South Africa, may not show any pinkish reaction. Synthetic emeralds (at present only produced in Germany (pre-1939) and in the U.S.A.) react in the same way as genuine stones, though the residual red colour is more brilliant. Generally, green synthetic spinels display green under the filter, though some stones, probably coloured by chromium, show red.

A reliable indication of ruby (both natural and synthetic) is given by a characteristic brilliant red seen through the filter, synthetic rubies being on the whole more brilliant than the genuine.

Synthetic blue spinels, which are intended to imitate aquamarine and sapphire, appear yellowish-orange or red when examined, while the stones they are intended to represent appear green or greenish-grey.

Cobalt-glass imitations of sapphire show a deep red, though some other blue glass imitations, coloured by iron, etc., do not display any red reaction. Green pastes show green.

The lens, microscope, refractometer and spectroscope are the principal instruments upon which the gemmologist relies for gemstone identification, but the " Chelsea " Filter, though it has some limitations, when used intelligently, is a most valuable aid.

Some Notes on
JAPANESE CORAL & JET

by E. R. LEVETT, F.G.A.

AT the recent Gemmological Association's Exhibition, a case of Netsukes attracted attention as illustrating certain varieties of ivory not commonly used in art or commerce.

The Netsuke carver, although principally attracted to varieties of wood or ivory as the most suitable and pleasing media for his work, developed a taste for, what was to him, the unusual and used examples of jadeite, malachite, turquoise, the quartz and chalcedony groups, coral, jet, and tortoiseshell, but only some of these materials are found in or around Japan.

Both the pink and black corals are found along the coastline of Southern Japan, and, apart from the obvious one of colour, are quite distinct from each other.

The black or " horny " coral is found principally along the coast of the Iwami Province and is known as " sea pine " (Japanese Umimatsu).

Although one of the coral polyp class known as *Coelenterata*, it is of another order, namely, *Antipatharia*. It differs from the white and pink coral in that the polyp skeleton is horny and does not contain a spicule of $CaCO_3$.

It forms a similar tree-like or dentritic structure, but the size varies with the temperature of the water, and only in warm waters are the stems large enough to serve when dried as objects for carvings, the largest stems being about 1½ in. in diameter.

The refractive index is approximately 1.55 and the specific gravity I find is low, between 1.30 and 1.33, which is very similar to the figure of 1.34 suggested by R. Webster for Indian Ocean black coral (see " Practical Gemmology," page 148). The material usually has concentric drying cracks

FIG. 1.—*Umiregi. Copy of a stele with a side inscription which reads "preserved at Kofukuji."*

FIG. 2.—*Umimatsu. Cicada on branch carved by Kwanman Iwami No Kuni (of Iwami Province).*

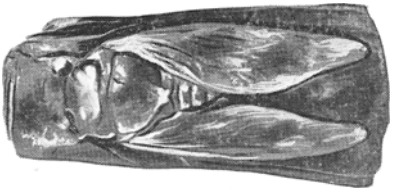

FIG. 3. - *Umimatsu. Cicada, in which the golden patches have been used by the carver to imitate the markings found on the insect's wings and head.*

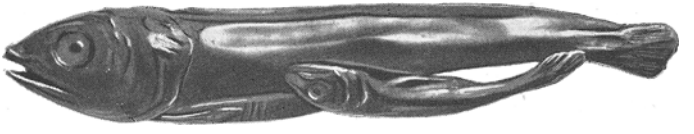

FIG. 4.—*Umimatsu. Two Gomane carved by Hokkyo Setsusai.*

and it is difficult to avoid all air bubbles in hydrostatic weighing.

It takes a higher polish than the pink, and when the dark body is interspersed with patches or veins of a golden colour, the effect is very pleasing. Also found in reddish black colour which is translucent at the edges.

The best pink is found in Tosa Bay, off the Island of Shikoku, but the beds are practically extinct.

It is found in larger masses than usual, but is rarely uniform in colour, having whitish patches and a broken texture. The S.G. is lower than that for pink coral, being approximately 2.50.

The usual acid tests for coral apply to the pink type, and though the pink will be easily distinguished, Umimatsu may be more difficult to identify ; but I have only found examples amongst Netsukes, Ojimes and as one of the materials used in " Shiba-yama " and similar inlay work.

" Buried pine " (Japanese Umiregi) is a variety of jet found only, it would seem, in the Sendai district near Tokyo and in seams of not more than 3 in. in thickness.

It has a S.G. of 1.33, which is similar to the European jet figure, but the R.I. is distinctive, being 1.61 approximately, as against the usual figures of approximately 1.65 to 1.70.

It is not such a dense black as Whitby jet, and when the surface is broken up by carving it has been erroneously labelled as ebony ; but its lower S.G. and sectility would distinguish the latter.

The Gemmologist and The Public

by T. H. BEVIS-SMITH, F.G.A.

UNDER " To-day's Arrangements," " The Times " of the 8th and 9th January, 1947, reported that the Gemmological Association were holding an Exhibition at the Goldsmiths' Hall. The more sensational press confined itself mainly to giving misleading reports about the value of the Exhibition: the lowest was under £1,000, the highest over £100,000.

What was the reaction of the public to these reports? Did they gather, as perhaps many readers of " The Times " did, that it was possibly a Scientific Society? Did the readers of the sensational press understand that the members of the Association were also in the main members of the jewellery trade?

The dictionary would be of little help if an enquiring public tried to find out about the habits of the gemmologist.

However, the Exhibition did arouse a certain amount of public interest. A friend of mine, a member of the Association, told me that on the Wednesday, while travelling on the Underground, he heard two girls discussing the Exhibition. He listened with great interest, but was rather stunned when one of the girls announced with authority that she knew what Opal was. On being asked what it was by her friend, she said proudly, " Hydrated Silicosis."

The public can hardly be blamed, least of all the girl in the Tube train, for being ignorant if so many members of the trade maintain their present attitude towards gemmology, believing it to be entirely a waste of time. I have been told, many times in various ways, that gemmology is purely an academic study of no practical use. This attitude is defensive in its nature and is in some people the reaction to Applied Science Why not tell the public that gemmologists have undertaken this specialized training in order to serve it?

Perhaps Members and Fellows of the Association can eventually overcome this deplorable attitude. Practical demonstrations do help, but it must be pointed out that although the gemmologist is scientific by training, he is not too academically minded to realize that he has three important functions:—

1. To protect the public.
2. To protect his firm.
3. To protect himself.

The public now demands—mainly through the efforts of the examining bodies—that everyone who tests eyes is properly qualified. I hope the time will come when every jeweller will employ on his staff at least one gemmologist who can be consulted by the public in his laboratory when the occasion arises.

Many jewellers believe that there is no point in carrying a large stock of coloured stones because there is only a small demand for them. The mainstay of the jewellery trade is alleged to be diamond rings—usually engagement rings—but why must the jeweller sell diamonds and bits of glass which are trying ever so hard to be diamond? I feel that jewellers, and particularly gemmologists, should sell only real stones. No watchmaker worthy of his name would sell a pin pallet watch. I don't see how the jeweller can compete with the chain stores, and particularly the large departmental store, when cheap costume jewellery is the article being sold. Costume jewellery is most effectively sold as accessories to clothes.

The gemmologist's answer should be the less expensive stones mounted in gold, silver and silver gilt, but let attention be given to design. Each stone, no matter how cheap, is capable of being mounted to the best advantage. Nearly everybody prefers something that is real to something which is imitation.

The public to-day, as a result of the war, is at the mercy of the retailer, and many unscrupulous persons are taking full advantage of the situation. This state of affairs cannot last for ever. The history of retailing has proved two things: that the prosperity of all successful businesses has been built on fair trading and service. Why not tell the public about gemmology? Why not point out that not only are stones guaranteed as genuine, but they have been tested scientifically by specialists?

PYRANDINE—

a New Name for an Old Garnet

by B. W. Anderson, B.Sc., F.G.A.

NOMENCLATURE in gemmology, as in other sciences, has always been a thorny and controversial matter, and who approaches the subject must tread with care, lest he cause more harm than good. Particularly is this so when, as here, a new name is suggested. The stone in question is not a new mineral nor even a new variety. On the contrary, it is a very old and common gem—a red garnet having a refractive index between 1.75 and 1.78 and density between 3.80 and 3.95, and which is thus neither an almandine or a pyrope. Admittedly there is *no* pure pyrope found in nature and *no* pure almandine, but the terms serve very well for those specimens which are predominantly the one or the other. For a large number of the red garnets used in jewellery there is no compelling reason why they should be called either of these names since they contain almost equivalent quantities of iron and magnesium, and in an attempt to give an accurate description one either has to use the circumlocution " a red garnet of the almandine-pyrope series " or shorten that to " an almandine-pyrope." Having got so far as the hyphenated term it seems a reasonable step to coin a portmanteau word, and of various possibilities in this direction *pyrandine* seems the neatest, and the derivation should be obvious even though, for the sake of euphony, the first syllable must be pronounced short, as in Pyrenees.

The name " rhodolite " has been used for a garnet of intermediate type, having R.I. 1.76 and density 3.84, but was intended only to apply to a peculiar rhododendron-red variety found in North Carolina. The term is thus not of universal application and has the additional drawback of being easily confused with the manganese silicate rhodonite, the two names being as prone to misinterpretation as are lazurite and lazulite. There is no other mineral name with which pyrandine is likely to be confounded. The organic chemical pyridine has a closely similar sound, but the context should preclude any possible trouble on this account.

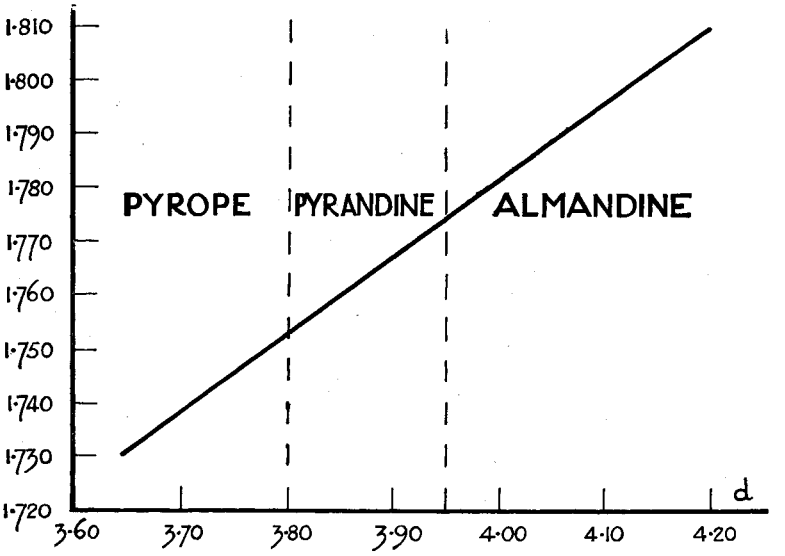

It is hoped that this short article will serve to " put up the banns " for the proposed name, so that any who know of any just cause or impediment may declare against it forthwith before " pyrandine " is on its way to become common currency.

The limits chosen are admittedly quite arbitrary, but are intended to exclude from the pyrandine region those well-established pyropes from Bohemia, Kimberley and Arizona, and at the other end of the scale almandines of the distinctive colour associated with the name so often cut as " carbuncles " in hollow cabochon form. The graph (kindly drawn by Mr. Robert Webster) gives an approximate idea of the proposed division. The R.I./S.G. slope must not be taken as exact for all red garnets, since in addition to the pyrope and almandine molecules grossular and uvarovite are often present and modify the constants.

It is worth recalling that the theoretical values for the " pure " garnets, as calculated by W. E. Ford, are as follow:—

	Density	Ref. Index		Density	Ref. Index
Pyrope ...	3.51	1.705	Spessartite ...	4.18	1.800
Almandine ...	4.25	1.830	Andradite ...	3.75	1,895
Grossular ...	3.53	1.735	Uvarovite ...	3.7?	1.870

These figures are often quoted out of their context, which is dangerous, as they do not represent values found for any actual specimen.

The New RAYNER REFRACTOMETER

Reviewed by B. W. ANDERSON, B.Sc., F.G.A.

FOR the gemmologist, two instruments beyond all others are essential: the microscope and the refractometer. Since microscopes are used by practically all the Sciences, many thousands are in circulation, so that second-hand instruments of a sort (and at a price!) have been procurable throughout the war ; but for five or six grim years jewellers' refractometers have been virtually unobtainable, and a waiting list of eager would-be purchasers has been steadily growing on the files of the manufacturers.

" Hope deferred maketh the heart sick " expressed the feelings of many keen gemmologists as delay after unavoidable delay prevented the promised arrival of the first post-war refractometers, but now at last they really are here, and in very fair quantity.

Though in essentials the new " Rayner " remains the same as the popular pre-war model, there are some significant improvements.

The shape is more squat than formerly, the instrument standing firmly on its base. The shield for protecting the stone from overhead light is larger and is domed, so that it will not foul the culet of even a large stone while it is being tested. In the previous model the corresponding shield, even when tilted back, prevented a reading being obtained where the polished base of a carving was concerned or a stone set in a bulky ornament. This disadvantage no longer obtains with the new " Rayner," since the whole superstructure can be removed in a second, leaving the upper surface of the refractometer free to receive the largest conceivable article of jewellery.

As for the readings obtainable, they are a sheer delight, especially where one of the dense yellow filters (provided as an extra by the makers) is used. This filter transmits a narrow band of light of effective wavelength about 5875A with only a faint red transmission centred near 6800A ; shadow edges are thus practic-

ally as sharp as with sodium light and barely .001 lower—a difference which will not in the least affect identifications.

The particular instrument examined was splendidly calibrated, being correct to three places of decimals with standard specimens of known index. To eyes accustomed for years to expect only faintly discernible shadow-edges on battle-scarred instruments the density and clarity of the effects seen on the brand new refractometer are intensely satisfying and make one vow never to spoil the surface of the glass by careless handling of the stone or by leaving any surplus liquid to crystallize thereon!

In addition to the filter, another useful accessory is a polaroid cap which enables each of the two edges in a birefringent stone to be studied separately. Polaroid is quite as effective as a nicol prism for this purpose, and far less cumbersome. A supply of liquid of refractive index 1.81 is provided with each instrument. There is an acute shortage of dropping bottles of suitable type for containing this liquid, but these will doubtless be available eventually.

There has inevitably been an increase in price compared with the pre-war "Rayner," but the cost of £13 for the instrument is very reasonable and there may well be many occasions when it will save or benefit the user to an extent many times its cost price. The cost of the yellow filter is 16s. extra, and the polaroid cap £1.

By SIR JAMES WALTON, K.C.V.O., F.R.C.S., F.G.A.

Refraction of Light in Gem Minerals

HAVING commenced the study of Gemmology many years after my training in physics and mathematics, I found that an understanding of the optical characters of minerals was beset with considerable perplexity. This was, I think, in part due to the fact that most of the text-books tended to assume that their readers possessed a knowledge of general physics which but few had obtained. I am therefore emboldened to write this article in the hope that, although it contains nothing new or original, I may be enabled, by logical development, the use of the simplest, non-technical language and by the employment of simple line diagrams, to make the subject of interest and easy understanding even to those who have no previous knowledge whatever of physics or mathematics.

Light travels in waves through the surrounding medium, the ether, vibrating in all possible directions at right angles to the path of travel. If travelling with equal velocities in all directions, the wave surface is a sphere.

The *wave length* is the nearest distance between two particles on the wave surface in the same position and travelling in the same direction. The *wave amplitude* is the distance between the crest and trough of the wave. (Fig. 1.)

White light is a mixture of red, orange, yellow, green, blue, indigo and violet rays, each having different wave lengths, red having the longest, around 7,000 Angstrom units (each unit $=10^{-7}$ m.m.), and violet the shortest, around 4,000 Angstrom units.

The velocity of light in air is approximately 186,000 miles per second, but in a denser medium it is slower. It is also slower with a short wave (violet) than with a long wave (red), i.e., in a diamond the velocity of the red light approximates to 77,000 miles a second, and that of blue light to 75,000 m.p.s. Therefore the *velocity varies directly with the wave length.*

If a ray of light passing through the air enters a sheet of glass at right angles to its surface, that is, along the normal, its velocity through the glass will be diminished, but it will emerge on the opposite side with its path and characters unaltered. If, however, it enters the glass obliquely, that is, at an angle to the normal, it will be bent towards the normal and is said to be *refracted*. On emerging on the opposite side it will again be bent away from the normal to an equal degree so that its new path will be parallel to the old but laterally displaced. (Fig. 2.)

The path of the refracted ray obeys definite laws. If *SOS'* represent the surface between two media air and glass and *N,N'* represent the normal with the incident ray *IO* and the refracted ray *OR*, then if equal distances be measured off on *IO* and *OR* and perpendiculars be dropped on to the normal, then in the two triangles *i* will be the angle of incidence, and *r* the angle of refraction. The two laws of refraction (Snell's laws) are:—

(a) The incident ray, the refracted ray and the normal all lie in the same plane.

(b) The angle *i* which the incident ray makes with the normal is related to the angle *r* which the refracted ray makes with the normal by the equation $n \times IN - = n' \times RN'$ where n and n' = the refractive indices of the two media.

Snell's Law actually states that $n \sin i = n' \sin r$, but the sine of an angle in a right angled triangle = the side opposite the angle divided by the hypotenuse, and since in our figure the two hypotenuses are equal, it becomes $n \times IN = n' \times RN'$.

This is true whatever be the nature of the two media in contact. The refractive index of air is taken as unity and hence in our diagram the refractive index of glass will be $n' \times \frac{IN}{RN'}$ and RN' being less than IN it will be greater than unity. (Fig. 3.)

The refractive index is a constant for each medium and is an expression of the optical density of the medium.

The refractive index is different for each coloured ray, but when the rays emerge from a plate with paralleled sides they again combine to form white light. If, however, the ray of light passes through a prism the rays will be further refracted on emerging (Fig. 4), so that the emergent ray forms a spectrum of all the colours. In this spectrum the red ray with the longest wave length

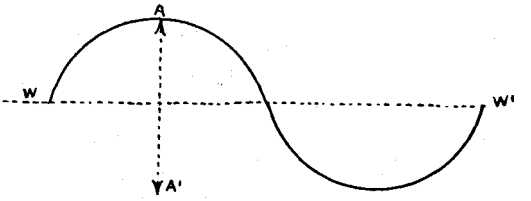

FIG. 1.—*Length and amplitude of lightwave.*
A—N = Amplitude. W—Wl = Wavelength.

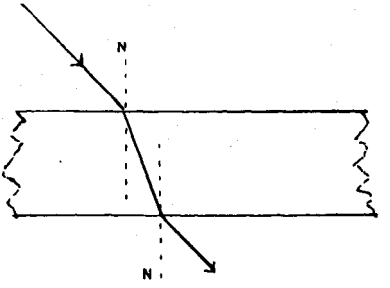

FIG. 2.—*Refraction of light through a parallel sided sheet of glass.*

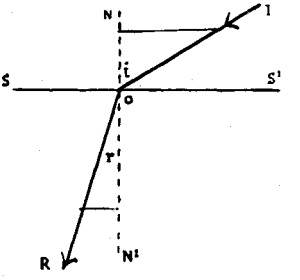

FIG. 3.—*Snells laws of refraction.*

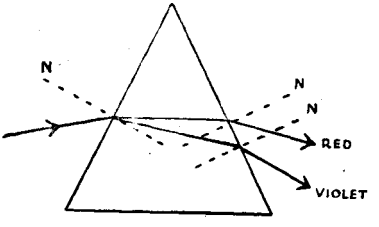

FIG. 4.—*Path of ray of light through prism.*

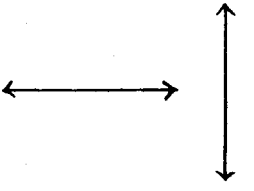

FIG. 5.—*The wave vibrations in two rays of polarised light*

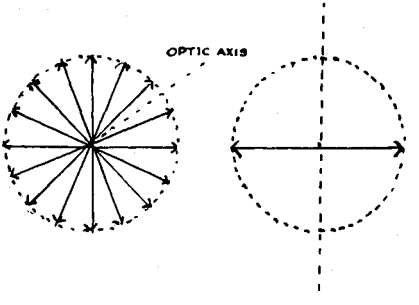

FIG 6.—*Wave fronts of an ordinary ray.*
Left : Travelling along optic axis.
Right : Travelling across the optic axis.

and the greatest velocity is refracted to a lesser degree than the violet with the shortest wave length, and the slowest velocity. The refractive index therefore varies inversely with the velocity and the wave length.

The width of the spectrum varies, but as a rule increases as the refractive index of the medium increases. It is known as the colour dispersion, which is expressed by the difference between the refractive indices of the red and blue rays, the distance being usually taken between the B (6807Ā) and the G (4308Ā) Fraunhofer lines of the solar spectrum or between the C (6563Ā) and F (4861Ā) lines which are used for optical glasses. The difference in the refractive indices of the rays increases more rapidly as the violet end of the spectrum is reached.

It is the amount of colour dispersion which determines the fire of the stone, and since in general the dispersion increases with the refractive index, the stones in which it is most marked—Blende, Cassiterite, Demantoid, Sphene and Diamond—all have high refractive indices.

Varieties of Refraction. Light traversing transparent substances may pass as one ray or be split up into two rays. The substances which transmit the light as one ray are known as *singly refracting* or isotropic. Those which split the incident ray into two rays having different paths are known as *doubly refracting* or *anistropic*, and they again are of two varieties, *uniaxial* and *biaxial*.

Isotropic Substances

These consist of the amorphous substances, glasses, resine and all liquids and all crystals of the cubic system, i.e.:

Diamond	Garnet	Fluorspar	Cobaltite
Spinel	Hauynite	Blende	Rhodizite
Pollucite	Sodalite	Pyrites	

The wave vibrations travelling through them are in all directions at right angles to the path of the ray and the light travels with the same velocity in every direction through the substance. Therefore the wave surface is a sphere. The optical properties show no variation with the direction of the ray within the substance or crystal.

Anistropic Substances

In anistropic substances the vibrations of the wave front, probably owing to the nature of the atomic packing, are limited

to directions at right angles to one another and are not free to move in any direction. They of course also only vibrate in directions at right angles to the path of the ray. It has been pointed out that a ray of light passing from air through a denser medium has its velocity reduced. In anistropic substances the reduction of the velocity varies with each vibration direction. Hence there is not a compound ray vibrating in two directions at right angles to one another, but two separate rays having different velocities, and therefore different refractive indices. The maximum difference between the refractive indices is known as the *birefringence*. In each ray the wave vibrations, unless the ray is travelling along the optic axis, can only take place in one direction at right angles to the path of the ray, and the vibration directions in the two rays are at right angles to one another. Such light with the vibrations in the wave front moving in only one direction is said to be *polarized* or *plane polarized*. (Fig. 5.)

There are two varieties of anistropic substances, uniaxial and biaxial.

Uniaxial Substances. These consist of crystals of the tetragonal and hexagonal systems.

Tetragonal.	**Hexagonal.**	
Zircon	Corundum	Apatite
Cassiterite	Quartz	Dioptase
Scapolite	Beryl	Phenakite
Idocrase	Tourmaline	Benitoite
Rutile	Calcite	Willemite
Anatase	Haematite	Smithsonite

If a ray of light is travelling along the vertical axis of the crystal its wave front can vibrate in any direction. Along this vertical axis the crystal is isotropic, and this path of single refraction in a doubly refracting stone is known as the *optic axis*. In uniaxial crystals it always corresponds to the principal crystallographic axis (c).

In all other directions through the crystal one ray is vibrating at right angles to the principal crystallographic axis, that is, the optic axis. This ray, whatever its direction, has the same velocity for light of one colour in the same kind of crystal, and therefore its refractive index, which is denoted by *o* or *w*, is constant. It obeys the ordinary laws of refraction and it is therefore known as the *ordinary ray*. (Fig. 6 a and b.)

(To be continued)

STANLEY F. BONES, F.G.A., makes

A Confession

I HASTEN to explain that this " confession " has not been extracted from me by " coaxing " or even suggestion, but is quite a voluntary effort made in the hope it may prove an incentive to others.

There are doubtless many who have entered for the highly esteemed Diploma of the Gemmological Association and have failed to earn the standard of marking that carries the award of " F.G.A.," and many more who, on account of age, might be " hovering on the brink " of attending a Course in Gemmology at the various classes or through the Correspondence Courses.

Based on my own experience, to the former I would say " Try and try again," and to the latter " Do not hesitate another minute."

It is unfair to keep the reader in further suspense after giving such a title to this article . . . therefore my confession is that, having attended gemmological classes at Chelsea Polytechnic during the years 1943-4-5-6, I entered three times for the Diploma examination and did not succeed until the third attempt.

In pre-war years one often heard the phrase " too old at 40," which has always stimulated me to the possession of greater knowledge and to a fuller life, and to endeavour to prove (at least to myself) that there is practically no age limit to the acquisition of knowledge of a variety of subjects.

Amongst other interests, just prior to the War, one evening I found myself signing up as a student at evening classes in one of the London Schools of Art—in the delightful company of students who in the main were 30 years my junior. I had no previous experience of drawing or painting.

A chance meeting with a friend who turned out to be a mineralogist gave me my first interest in gemmology. He suggested I might find a course at Chelsea Polytechnic a means of acquiring greater knowledge of the subject. I first called at Audrey

House, where it was my pleasure to meet Mr. G. F. Andrews, who quickly put me at ease and assured me of a welcome in the classes. I commenced at Chelsea Polytechnic in 1943.

The War years were anything but conducive to study and I well remember with very mixed feelings those regular wailing sirens and the disturbing influence of the sound of falling bombs and gunfire. The times when we left the lecture room for a point of more comparative safety were many and instruction was carried on under the greatest difficulty.

One evening the plan might be for practical work with refractometers, microscopes, spectroscopes, etc., but one perhaps drifted to the examination of Mr. Webster's new Sten gun.

Uniforms were much in evidence, and naval ratings, privates and airmen shared their heavy liquids with Admirals, Generals and Air Marshals in the pursuit of gemmological knowledge! I recall an American G.I. who stayed a short while with us and who used to sit directly in front of me. This was rather disturbing, as evidently one of his colleagues had drawn in crayon on his waterproof jacket a most attractive figure of a girl, and other members of the class were inclined to look at the back of the G.I. instead of the blackboard!

Mr. B. W. Anderson, I recollect, had National Fire Service duties heavily carried on top of his normally extremely busy day. Just how Mr. Anderson retained his characteristic charm, patience, and great ability to impart his profound knowledge under such trying conditions will ever remain a matter of wonderment to me.

Mr. R. Webster, radiant with enthusiasm and with a positive appetite for work, also did much to keep the classes going.

Mr. Andrews, as Director of Examinations and Secretary of the Gemmological Association, also put in frequent visits to Chelsea and did valiant work in the interests of the students, but he was called to the R.A.F. just after I joined the classes.

I admit frankly I should not have entered for the Diploma examination in 1944 as I had not had the opportunity to acquire the necessary knowledge, but it was good " fun " to try.

The following year I made another attempt and in failing learned my lesson.

I have been told I possess a vivid imagination ; this prompted me to write pages on the aspect of a subject which did not carry

marks! I was "carried away" by the intriguing properties of the colour change in alexandrite when alternatively exposed to daylight and artificial light, to the profound beauty of colour of the emerald and ruby, or by the human side of the fishers of pearl!

1946 brought the return of Mr. T. G. Jones, F.G.A., to Chelsea, and in his person an added stimulant to effort on my part. Refractometers were re-polished, heavy liquids duly strained and brought up to a high standard of S.G. accuracy. What an excellent team of instructors were now available to us.

The classes in 1945-46 were able to be run on two nights a week and greater concentration was possible. In this period I realized that there were so many actual facts to record that there was no time to elaborate on one's own personal reactions to the aspect of a particular problem, and that brief and concise definitions would bring the fullest reward.

The many books of Dr. Herbert Smith, M.A., D.Sc., Mr. Basil Anderson, B.Sc., F.G.A., and Mr. Robert Webster, F.G.A., all provide many examples on which to base a full yet brief answer to most questions likely to be set by the examiners, and Mr. Anderson's lectures provided the final key to the solution of being the holder of the high award of a Fellowship Diploma.

The return of Mr. T. G. Jones gave me an opportunity to "invent" another "Mr. Jones." I gave him the name of "L. S. Jones," which enabled me to memorize some of the Monoclinic gemstones, which in order are as follows:—

Lapis **S**phene **J**ade **O**rthoclase **N**ephrite **E**uclase **S**podumeme

I also found "TAK" most useful to recollect some of the Triclinic gemstones, Turquoise-Axinite-Kyanite, whilst "ZIC" did good service to bring to mind some of the Tetragonal gemstones, Zircon-Idocrase-Cassiterite.

In conclusion, based on my own experience, I would recommend everyone in the jewellery and allied trades (whatever his or her age or previous training) to attend a course at Chelsea, Birmingham or Edinburgh, or where this is impossible to take the Correspondence Courses, and gain that Fellowship Diploma at any cost of time involved. It was a great experience and worth every minute and effort expended.

The Gemmological Association's

Speakers :
Mr. H. Rayner
Dr. W. F. P. McLintock, D.Sc., F.R.S.E.
Mr. P. Grodzinski, A.I.M.Mech.E.

FEBRUARY MEETING

THE presentation of Rayner refractometers, won by students in the Gemmological Association's preliminary examinations held during the war, took place at Burlington House, London, W.1, on Thursday, 27th February. The instruments have not been available during the war years.

Dr. Herbert Smith, the President, referred to the fact that the Association would soon, he hoped, become Incorporated and thus acquire higher status. He was glad that Mr. H. Rayner had been able to attend to present the refractometers.

Mr. Rayner confessed his small knowledge of gemmology, but pointed out that as a member of the optical industry he was concerned with providing instruments that were of aid to mankind. Every trade and profession needed magnifying instruments of differing powers. The refractometer was a means of measuring the physical characteristics of a substance. It was just as informative when applied to oil, fats, butter or any sugar solution as it was to the crystal substances in which the members of the Association were most interested.

Difficult to define or trace were the colourings of, say, a diamond. Whether it was, for instance, yellow or blue, and by how much. Various printed charts of colours or glasses have been used by industry, but they are essentially arbitrary standards. None can be exactly reproduced and it is doubtful whether they are sufficiently finely divided to serve in this industry. However elaborate the charts, the precise hue you seek to match is not always there ; but now, given an electric lamp bulb, filters and apertures, it becomes possible to mix the colours to match any colour, and this process can be repeated—that is, you can repeat the colour.

At present the colourometer is in its infancy, but he had hopes that it may be available to gemmologists in the future.

Mr. Rayner referred to the friendship which had existed between his late father and Mr. B. J. Tully, whose work and that of his contemporaries had been so fruitful.

To come out top in the Association's examinations was an honour marked by the award of the Tully medal. Mr. Rayner said he proposed at the next examination to present a Tully refractometer to the Tully medallist and he hoped that could be repeated in future years. In addition, he looked forward to giving a Rayner refractometer to the best students in the preliminary examinations. The refractometers were then presented to:—

MR. S. G. MOULD (1941).
MR. LIONEL WALFORD (1943).
MR. E. R. LEVETT (1945).

Mr. R. W. Hester (1942), Mr. R. R. Cox (1940) and Mr. D. P. Guest (1944) were unable to be present.

During the evening Mr. P. Grodzinski gave a talk on his recent visit to the diamond mines of South Africa, in which he gave interesting facts concerning their present-day operations.

In the questions that followed this talk, Mr. Anderson expressed qualms at the highly mechanized state of the industry. Might not this mechanical pounding seal the fate of another Cullinan? The crusher would destroy it. Mr. Grodzinski thought, however, that such a large stone would probably reveal itself after blasting.

Mr. Braunfeld asked for more information concerning the coloured stones found with diamonds, to which the lecturer replied that they were often used on pathways and tennis courts. Occasionally a large garnet or zircon was found, but it seldom showed good crystallization.

In closing the meeting, Mr. F. H. Knowles Brown, Chairman of the Association, thanked Mr. Rayner for his long interest in the Association and the encouragement given to the students, Mr. Grodzinski for his talk, and expressed appreciation of the delightful and interesting manner in which Dr. McLintock had spoken. A vote of thanks to the Geological Society for the loan of their hall was proposed by the President.

A summary of Dr. McLintock's talk appears on page 29.

40 YEARS OF GEMMOLOGY

by DR. W. F. P. McLINTOCK, D.Sc., F.R.S.E.

FOR some forty years Dr. W. F. P. McLintock, D.Sc., F.R.S.E., Director of H.M. Geological Survey and Museum, has been a gemmologist, yet it was only last February that he actively participated as a speaker at the meeting of the Gemmological Association of Great Britain in the Rooms of the Geological Society, Burlington House, London, W.1.

His talk revealed that in his years of work, both out in the field and in the museum, gemmology has provided romance and humour as well as much interest in the daily round.

Dr. McLintock was able to stake his claim to being a gemmologist a year before the Association was founded, when he joined the staff of the Geological Survey and entered on his duties at the Geological Museum, then in Jermyn Street, S.W.1. There he found a collection of precious stones and the scientific instruments left by his predecessor. These included a balance that swung horizontally and a laboratory that was a dark and dirty cupboard.

At that time mineralogy took a new turn with the discovery of the fact that recognition of transparent stones could be made by their refractive index ; this was made practicable for gemstones by the use of the Herbert Smith refractometer, which had just made its appearance. Armed with this new instrument, he re-examined the collection and found only two wrong attributions. One of his first tasks was to prepare a Guide to the collection at the Museum.

He soon found that visitors upon his predecessor had included Duchesses and other ladies of title, and even less respected ladies. They came for advice about their gems. He recalled one attractive lady who asked him about a fine and large blue stone in a pendant. In those days the synthetic sapphire was just coming

on to the market and he had not the slightest difficulty in detecting the striae and air bubbles.

" Rather to my surprise when I told her this," said Dr. McLintock, " she replied, ' You are quite right. That is exactly what I bought it as.' "

She then wanted an estimate of its value, and after pointing out that as a Government representative he was disinclined to value it, Dr. McLintock suggested 15s. a carat, the stone weighing 4½ cts.

" ' The rascal, the rascal,' was the lady's exclamation," said Dr. McLintock. " ' He told me it was an extremely fine synthetic sapphire and I paid £35.' "

These synthetic stones, added Dr. McLintock, were at the beginning of their introduction being sold at considerably beyond their market value.

A year or so later, Dr. McLintock recalled seeing in a Piccadilly jeweller's window a notice: " The dream of the alchemist realised. Synthetic diamond is now a reality. The stones exhibited in this window are superior to the natural diamond in hardness and brilliance and fire." Below was a tray full of beautifully cut white stones.

As an enthusiastic gemmologist, Dr. McLintock went in the shop, only to have the salesman look at him and say: " You are from the Museum in Jermyn Street, aren't you? "

The salesman, however, continued to claim that the stones were harder than diamonds.

" I picked up a 6-7 ct. stone and pulled a diamond point out of my pocket, saying, ' If it is harder this point will not scratch it.' But the salesman quickly replied, ' Give me the stone back.' "

This was not the end of the Doctor's " synthetic diamond " experience, for he told his audience how, a few days later, Mr. Doyle Heaton, a gemmology lecturer, came into the Museum and told him that the jeweller was now claiming that his artificial diamonds had been vouched for by him. " Eventually I put a stop to the swindle by threatening to publish a statement in ' The Times,' " said Dr. McLintock, adding that there was a similar ramp in 1935 with synthetic white spinel.

Pointing out the greater difficulties of the gemmologist, the speaker said that the mineralogist could always turn for identifica-

tion in the last resort to the chemist or crush his specimen and examine it under a microscope. The precious nature of the gemmologist's material limited his method of attack.

For a short time Dr. McLintock went to Edinburgh, and on returning to Jermyn Street in 1921 he had to organize the move to South Kensington. This took about 14 years, partially owing to difficulties with the Treasury.

There he planned to do something for gemmology, though he found that the claims of other sections of palaeontology and petrology were strongly put by their various adherents. Though he had travelled in Europe and seen most of the collections, he had not seen one in which the gemstones were separate from the minerals. He had set his heart on doing this and succeeded, and claimed that the curved glass used in the showcase gave almost no reflection from the overhead skylight.

Mentioning that he had never yet found a dealer selling a real stone as a synthetic, though in his long experience he had sometimes known the reverse, he said he had known dealers make a mistake to their disadvantage. He cited the case of a friend who was left some jewellery, including an antique ring in which was mounted a flawless emerald of 2 carats. It was believed to be genuine, but on probate the valuer said it was worth £5. Despite being told that the ring had been in the family 100 years, the valuer insisted it was worth only that. A jeweller dismissed it as paste. Then it was unmounted and found genuine, but so fine and flawless that it " deceived " the other experts.

Dr. McLintock pointed out that it was right and proper that in London, one of the principal gemstone markets of the world, there should also be a good collection of gemstones for study and an active Gemmological Association. The greatness of the market depended very largely upon confidence, which was founded on scientific knowledge. The Gemmological Association were the " vigilants " of the gem market. If there was not constant watchfulness, the undermining of confidence was bound to happen.

The market had withstood the synthetic stone and the cultured pearl, thanks largely to the efforts of their members, and so there should be no need to worry about the synthetic emerald. Dr. McLintock paid a tribute to Dr. Herbert Smith for his leadership and his pioneer work for gemmology.

From the Association's

LIBRARY

THE illustration here is taken from the oldest book in the library of the Gemmological Association. The title of the book is as follows:—

The HISTORY OF JEWELS, and of the Principal Riches of the East and West, Taken from The Relation of Divers of the Most Famous Travellers of Our Age. Attended with Fair Discoveries, conducting to the knowledge of the Universe and Trade.

London. Printed by T.N. for Hobart Kemp, at the Sign of the Ship in the Upper Walk of the New Exchange. 1671.

The style of the book, which is a delight to read, is indicated by the following passage:—

> "First of all then they have discovered four Fishing Places for the Pearl in the East, the most considerable is performed in the Isle of Behren in the Persian Golph ; the which appertains to the Sophy of Persia, who receives whence a great revenue. While the Portugals were Masters of Ormus and Mascati, every Vessel which went to fish was obliged to take a Passport from them at a dear rate ; and they maintained five or six small Galleys in the Gulph, to sink those Barks which took no Passports ; but at present they have no farther power upon those Coasts, and each Fisher payeth to the King of Persia not above one third of what they gave to the Portugals."

It will be interesting to know whether any member has an older book in his or her collection. Other interesting books in the Gemmological Association's library will be featured in future editions of the Journal.

monds of great value fifteen dayes together, without comeing to ſee them, and by that means affording them all the leaſure they can wiſh to conſider well their marchandiſe, ſo that it is their own fault if they be cheated in it.

The ſecond Mine is called *Conllour* in the Perſian Language, and the Idolaters of the Countrey call it *Gany*. This is a large Town, near a great River, and they dig from the River to a Mountain about two Leagues from thence, and in the Mountain it ſelf. This Mine hath been

been diſcovered but within 50 or 60 years, and is the place where they find the moſt part of the great Stones, whereas before that time they rarely met with any above twelve Carrats; but that at this day ſome are to be ſeen of threeſcore, an hundred, and of two hundred Carrats, *Mirgimola* Chief Miniſter of State, and General of the Armies of the King of *Golconda*, a man of great parts, much believed of his Maſter, who gave him the Title of Prince of Princes, though at length he proved a Traitor, preſented the *Great*

By GEORGE SWITZER, Ph.D., Director of Research, Gemmological Institute of America, and RAPLH J. HOLMES, Ph.D., Instructor in Mineralogy, Columbia University, New York City

The Identification of Gems by X-Rays

THE present known methods of gem testing in certain unusual cases make it impossible for one to positively identify an unknown stone without powdering a portion of it for chemical or X-ray analysis. This is especially true of opaque substances, where the only property that can be determined without the possibility of damaging the gem is that of specific gravity, and if the gem is mounted, even this test cannot be made without first removing it from the setting.

To a lesser extent non-opaque materials can prove to be very troublesome, especially if they are cut with all curved surfaces, so that their index of refraction cannot be determined with accuracy. With curved surface gems, even the property of single or double refraction cannot be determined by either the polariscope or the polarizing microscope if the gem is in a solid-backed mounting, or if it is semi-translucent.

There has been a definite need, therefore, for a method of gem identification which will yield positive results on all gems, and especially on opaque or semi-translucent materials, mounted or unmounted. Hence at the suggestion of Robert M. Shipley, such a method of gem identification by means of X-rays has been developed in the laboratory of the Gemological Institute of America which fulfils this need.

The design of the instrument to be described is based upon a suggestion made by Dr. Samuel G. Gordon, Associate Curator, Academy of Natural Sciences of Philadelphia. Work was begun in the Los Angeles laboratory in April, 1946, to develop and construct an X-ray camera of a special type that would make it pos-

sible to identify gemstones by a method of X-ray diffraction. After preliminary work by Switzer the problem became the joint effort of Switzer and Holmes in the summer of 1946.

REQUIREMENTS TO BE MET

Before describing the actual camera design it will be advantageous to review briefly the requirements that must be met by an instrument which will make it possible to identify an unknown gem by means of X-rays.

Crystalline substances, and all gem materials except opal, jet, amber, obsidian, moldavite, glass and some plastics, are made up of atoms having an orderly arrangement. This orderly atomic arrangement causes a crystalline substance to act as a three dimensional diffraction grating, with the result that when an X-ray beam strikes it, secondary beams of X-rays are generated. This diffraction effect, for simplicity, may be thought of as reflection of the X-ray beam by planes of atoms within the crystal.

Any crystalline substance will produce a diffraction pattern if placed before a narrow X-ray beam and a sheet of film is put in proper position to record the secondary X-ray beams generated by the orderly atomic arrangement of the specimen. In the general case, when the specimen is stationary and having a random orientation, a pattern is obtained consisting of an unsymmetrical network of spots. A pattern of this type is known as a Laue pattern.

In general a Laue pattern is taken of a *single crystal*. A single crystal is a homogeneous crystalline body and may be one having natural crystal faces, or a cut gem where the natural crystal faces have been removed by the lapidary. In any case, to be most useful a Laue pattern must be taken with the X-ray beam parallel to an axis of the crystal. Then a symmetrical pattern is obtained which indicates the crystal system to which the material belongs. In other words, to obtain a usable diffraction pattern from a stationary cut gem (single crystal) such as corundum, topaz, or beryl, it must be set before the X-ray beam with one of its crystal axes parallel to the X-ray beam. Since in cut gems the naturally occurring crystal faces (which lie parallel to the crystal axes) have been removed, to locate the direction of a crystal axis is extremely difficult, or in some cases impossible, and therefore impractical.

A more useful type of diffraction pattern is obtained if the specimen is rotated or oscillated about an axis of the crystal. Here again, however, unless the position of a crystal axis is known, and the crystal carefully placed before the X-ray beam in a particular position, the resultant pattern is useless for purposes of identification.

The most useful type of X-ray diffraction pattern for the identification of minerals is the so-called powder pattern, first developed by Debye and Sherrer in 1916. A pattern of this type is ordinarily obtained by finely powdering the material under investigation and cementing the powder into a small rod-shaped specimen. The sample thus prepared is made up of a large number of randomly oriented crystals, so that the position of the sample in the X-ray camera is now of no consequence. Powder patterns consist of a group of concentric circles recorded on the film, and are in a sense a " fingerprint " since every crystalline material gives its own characteristic grouping of circles or lines.

It is evident from the foregoing discussion that the ideal condition for identification work is to have available a powdered sample. However, this cannot be done without damaging the specimen, and cannot be considered as a practicable method of identification of a cut and polished gem. The new X-ray camera was therefore developed, so that a *powder-type* diffraction pattern may be obtained from a cut gem, whether it be cut from a single crystal, or from an aggregate of many crystals.

As stated above, a large number of randomly oriented grains are required in order to obtain a powder-type pattern. In the new instrument an analogous condition is obtained *without powdering the sample* by giving to the specimen a combination rotatory and oscillatory motion.

The new instrument, or *X-ray diffraction camera,* is shown schematically in Figure 1. On the extreme right is indicated the X-ray tube. The X-ray beam passes through a pin-hole system which serves to confine it to a narrow pencil of essentially parallel X-rays. The X-ray beam then passes through a hole in the film holder and film and strikes the specimen. Secondary X-ray beams are generated by reflection of the primary beam from planes of atoms within the specimen and are reflected back to the film to produce an X-ray diffraction pattern. The primary X-ray beam

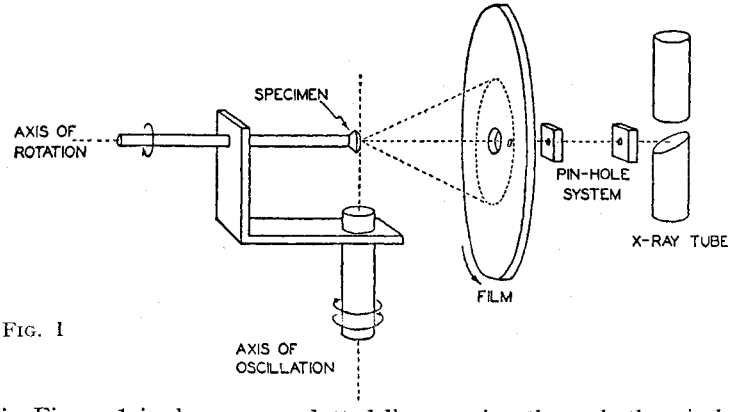

FIG. 1

in Figure 1 is shown as a dotted line passing through the pin-hole system, through the centre of the film, and striking the specimen. The secondary X-rays generated by the orderly atomic structure of the specimen are shown as dotted lines leading back to the film. The dotted circle on the film indicates the manner in which concentric circles are recorded on the film. A pattern obtained in this way is referred to as a *back-reflection* diffraction pattern, since the secondary X-rays are reflected from the specimen back to the film.

The motion imparted to the specimen is of particular importance. As has already been pointed out, diffraction patterns usable for identification work cannot in general be obtained if the specimen is motionless, or if it is given a simple rotatory or oscillatory motion. However, *powder-type* patterns are obtained when the specimen is simultaneously rotated about one axis and oscillated about another axis at 90 degrees to the first. Referring to Figure 1, the specimen is rotated continuously about the horizontal *axis of rotation*. At the same time it is oscillated to and fro through a 90-degree arc about a vertical axis, the *axis of oscillation*.

The motive power is supplied by clock motors, the horizontal rotation taking place at the rate of one revolution per minute, and the vertical oscillation at one degree per minute. As a result of this " oscillating fan " type of motion given to the specimen, a large number of atomic planes are brought into reflecting position, with diffraction patterns such as those shown in Figure 2 being the result.

A third motion may be introduced, this being a rotation of the *film* about the X-ray beam as an axis.

RESULTS AND USES

Typical results obtained with the new X-ray diffraction camera consist of a family of concentric circles. The spacings and intensities of the circles vary according to different gem materials.

The X-ray method of gem identification described is intended for use primarily in especially difficult cases, or in cases where identification by all other means has led to dispute as to the gem's true identity. Its advantages are as follows: (1) It can be *used on all specimens regardless of size,* depending on camera design. The present model can accommodate specimens up to 10 centimetres in diameter. (2) It can be used on any specimen, *regardless of shape or contour of surface.* (3) It can be *used on mounted or unmounted gems.* (4) It will give a positive identification of *opaque as well as non-opaque material.* (5) It will work equally well *on a single crystal* such as ruby, emerald, or marcasite, *or upon fine grained crystalline aggregates* such as onyx, lapis, haematite, jadeite or nephrite.

The results described herein are the first obtained with the new X-ray camera. Eventually a catalogue of standard patterns will be made, one for each gem mineral species, and routine identifications will be made by direct comparison of the standard film with those obtained from unknown specimens. Since this is a back-reflection camera, it is not possible to make a direct comparison of these patterns with those obtained in an ordinary type powder camera.

Extracted by courtesy of "Gems and Gemology"

Post-Diploma Students at Chelsea

NOW that the 1946-47 term has reached its last stage it seems opportune to become personal for once and discuss some of the personalities who help to make the classes in gemmology at the Chelsea Polytechnic so successful.

We will consider only the instructors and the enthusiastic group of Fellows who are continuing their studies, after an enforced war-time interruption, for the third, sixth—or is it twelfth year?

The teaching staff is headed by B. W. Anderson, B.Sc., F.G.A., who was appointed as Senior Lecturer in 1933. At the present time he is assisted by Thorold Jones, Junior Lecturer, who obtained his diploma in 1926, and Robert Webster. B. W. Anderson is well known as the Director of the Gem Testing Laboratory of the London Chamber of Commerce, and as author of " Gem Testing," which is now in its fourth edition. Thorold Jones is in charge of the Preliminary Class and his return to Chelsea, after doing a great deal of gemmological work in the war effort, has brought about the reunion of the quartet of Fellows which has assisted the classes for so many years. Webster, an example of a gemmologist capable of carrying out research work from start to finish (he was awarded a Research diploma recently), is also a writer, and his " Practical Gemmology " and " Compendium " are trusty companions of students.

So far we have mentioned three names ; the fourth member of the quartet is G. F. Andrews, a 1931 diplomatist, who is Secretary of the Association. He is the " family " critic—reading page proofs of the works of Anderson, Webster and others, ascertaining views of students, and generally collating and disseminating views for the benefit of the students.

There are at least fourteen " inveterate " gemmologists now working at Chelsea, among them L. F. Cole, who gained his diploma in 1937, R. K. Mitchell (1934), F. Eade (1933), Ross Popley (1934), F. Ullmann (1938), V. Levett (1946 Tully Medallist), T. Bevis-Smith (1936), W. West (Tully Medallist for 1940), Sir James Walton (1945), A. Kemp (1936), Audrey Newman (1946), Vera Benson (1946, first winner of the Anderson prize in the practical examination) and Mrs. A. M. Sharpe (1945).

They are all sound gemmologists and their deep enthusiasm is a great encouragement. They come along to Chelsea to learn something new and consort with old friends. It is good to have some of these Fellows return to Chelsea after the war, and it is hoped that those now studying will be inspired to follow in the footsteps of these workers. By so doing a really efficient school of post-diploma gemmologists can be maintained. Possibly, from the hundred odd students at Chelsea and the centres in Edinburgh and Birmingham, more Fellows will have the desire to continue their studies.

Gem Testing Laboratory Achieves its Majority

PRESENTATION TO MR. B. W. ANDERSON, B.Sc., F.G.A.

AT a meeting on 6th March of the Standing Committee of the Diamond, Pearl and Precious Stone Trade Section of the London Chamber of Commerce, the occasion was taken to make a presentation of a silver waiter to Mr. B. W. Anderson, the scientist in charge of the Section's Laboratory at 55, Hatton Garden, to mark the twenty-first anniversary of its establishment and of Mr. Anderson's long and devoted service.

It may be recalled that in 1925 the Committee of the above Section representing the leading merchants, brokers and manufacturing jewellers in London, decided that the most effective way to protect the trade agaist the fraudulent use of cultured pearls would be to establish a Laboratory where pearls could be scientifically tested and certificates issued as to the nature of any goods submitted.

The work started in a small fourth-floor room in Diamond House, Hatton Garden, the pearl testing equipment consisting at first of a " Lucidoscope," which was not a very satisfactory instrument, and a diamond balance being practically the only other apparatus in use.

In the following year the endoscope appeared, pearl testing becoming a matter of scientific certainty, so that the work of the Laboratory steadily increased and extended to the testing of precious stones of all kinds and to the issue of certificates of weight in cases of dispute.

The number of pearls tested rose rapidly from 4,000 in 1926 to 49,000 in 1928, and to cope with the extra work the staff was increased and the Laboratory moved in 1929 to larger premises at 55, Hatton Garden, where special X-ray equipment was installed to enable undrilled or part-drilled pearls to be tested—the endoscope being suitable only for drilled pearls.

The world-wide trade depression of 1930-1931 and the consequent falling-off in testing work afforded an opportunity for research, which included a long series of investigations on the density of pearls from different localities and the accurate measurement of the density and refractive index of all manner of gem materials. The data thus obtained confiicted in many cases with text-book figures and the first-hand knowledge so gained has been of the greatest service.

In 1935 the value of the Laboratory to the trade was brought to the fore in connection with an alleged " synthetic diamond " discovery which obtained much publicity in the Press. Specimens of these stones were examined in the Laboratory and found to be nothing more than colourless synthetic spinels having a composition and properties entirely different from diamond. In order to reassure the market an official statement by the Section was published and broadcast, stating the true nature of the fraud.

Apart from the early years of the last war, increasing use of the Laboratory has been made by members of the trade, and at the end of 1944 a revision of the charges for testing became possible, with the result that for two years now it has not been necessary to call upon the Guarantors to the Fund set up some years ago by members of the Section to finance the work. It is very much hoped that this state of affairs will continue.

In the year 1946, when the Laboratory " came of age," all records were broken, over 62,000 pearls and over 100,000 stones being tested and nearly 1,700 reports issued.

The Laboratory staff has been greatly increased, and is now in a position to cope with a much greater volume of work, and it is intended to provide improved accommodation as soon as circumstances permit.

Letters to the Editor

The Secretary

We congratulate you on the issue of your interesting Journal, and send our best wishes for the future. At the same time we wish to draw your attention to a reference on p. 16, para. 1, regarding the quartz

crystal supplied for the Stalingrad Sword. We supplied the piece of crystal for the pommel and also cut and polished the crystal in our workshops.

Afterwards the two craftsmen employed by us were invited to attend the Russian Embassy, and each was presented with a magnificent casket in appreciation of their share in producing the sword.

Yours truly,

14, Hatton Garden,
E.C.1.

C. MATHEWS & SON.

Dear Mr. Andrews,

I feel I must congratulate you on yet another outstandingly successful meeting of the Gemmological Association ; you are indeed setting yourself an alarmingly high standard which it will be difficult to maintain, let alone succeed.

The decision of Mr. Rayner to offer a Tully refractometer to the winner of the Tully medal was a very pleasant surprise. The award is splendidly appropriate, since it forms yet another commemorative link between the Gemmological Assocation and the late B. J. Tully, who did so much to further the cause of gemmology in its early beginnings. The announcement was doubly welcome in that it afforded proof that the production of an improved model of this form of refractometer will not be long delayed.

Of Dr. McLintock's talk it would be difficult to speak too highly. I think Sir James Walton expressed the feelings of us all when he said that it was one of the most delightful to which he had ever listened. It was heartening to learn that even to the Director of the Geological Survey the optics of biaxial crystals presented certain difficulties, and that he found the mathematical treatment of the subject in Dr. Herbert Smith's " Gemstones " a little hard to follow. In paying a well-deserved tribute to our President's famous text-book Dr. McLintock touched only very lightly on his own short " Guide to the Gemstones in the Museum of Practical Gemmology," which first appeared in 1912 and was revised in 1923. This most readable and accurate introduction to gemmology, costing only one shilling, was for years the recognized companion to the standard text-book amongst students at the Chelsea classes. I was glad to learn that Dr. McLintock is seriously contemplating the production of a new edition of the " Guide " which, in addition to general matter, will contain information about some of the magnificent stones to be seen in his Museum.

Mr. Grodzinski's first-hand account of the South African Diamond mines was exceedingly interesting and informative. One envies his opportunity to see for himself the processes about which one has read so much. As Mr. Braunfeld remarked, it does seem a pity that the interesting secondary minerals are apparently discarded as waste when (to judge from examples one has seen) some at least of the pyrope and enstatite could be cut into attractive gemstones.

Altogether it was a splendid meeting, and I am sure we all went home with the satisfied sense of an evening well spent.

Yours sincerely,

B. W. ANDERSON.

OFFICIAL NOTICES

AMERICAN AWARD TO MR. M. D. S. LEWIS, B.Sc., F.G.A.

The American Gem Society has awarded the title of Certified Gemmologist to Mr. Malcolm D. S. Lewis, a jeweller, 33, Conway Street, Fitzroy Square, London, W.1, England, who undertook and successfully completed the final examinations for the four-year gemmological course offered by the Gemological Institute of America in Los Angeles.

Mr. Lewis, who is an F.G.A. and the winner of the Tully Medal in 1944 for the highest grade, is now further to be credited with being the first in England to receive the C.G. title. He has also been awarded the first Research Diploma of the Gemmological Association of Great Britain for noteworthy research in the field of gemmology, an accomplishment comparable to a Research Membership in the Gemological Institute of America, an honour awarded so far to but one man, Dr. E. Gübelin, Ph.D., F.G.A.

Mr. B. W. Anderson, B.Sc., F.G.A., the noted British gemmologist, Director of the Gemmological Laboratory in London, acted as proctor for Mr. Lewis.

FIRST ANNUAL DINNER

The first annual dinner of the Association will be held on Thursday, 15th May, 1947, at the Waldorf Hotel, Aldwych, London, W.C.2.

Tickets and details of the dinner, which is being held to mark the Incorporation of the Association, are obtainable from the Secretary.

OBITUARY

It is with great regret that the Council has to record the death on 21st February of Victor William Clarke.

Mr. Clarke, who was in his 81st year, was chairman of Wilson and Gill, Ltd., and his wide knowledge of the jewellery trade enabled him to perform valuable work in Trade Association activities. He was Vice-Chairman of the National Association of Goldsmiths in 1920 and 1921, Chairman in 1922 and 1923, President in 1927, and Treasurer from 1931 to 1942.

During his term of office with the National Association Mr. Clarke took a considerable interest in the work of the National Association of Goldsmiths' Gemmological Committee, which in 1931 became the Gemmological Association. In recognition of his work he was made the first Honorary Fellow of the Gemmological Association in this country in 1943. He was Chairman of the Association from 1943-1946 and held the office of Honorary Treasurer from 1931 until his election to the Chair. He was admitted to the Livery of the Worshipful Company of Clockmakers in 1925.

By the death of Mr. Clarke the Gemmological Association has suffered a great loss. He was always prepared to place his great knowledge of the jewellery trade at the disposal of the younger members, and his kindly interest and advice will be greatly missed.

The Association was represented by Mr. F. H. Knowles-Brown, Chairman, and Mr. G. F. Andrews, Secretary, at the funeral ceremony which took place at the Golders Green Crematorium on 25th February.

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THE JOURNAL OF GEMMOLOGY

AND PROCEEDINGS OF THE GEMMOLOGICAL ASSOCIATION OF GREAT BRITAIN

Vol. I No. 3 JULY 1947

THERE can be no doubt that the most practical method available to the gemmologist for determining the specific gravity of his specimens is by the use of heavy liquids. For stones of low density the relatively harmless and inexpensive liquids bromoform and acetylene tetrabromide are available, but for values above 2.9 either methylene iodide or Clerici solution (thallium malonate and formate in water) must be employed, and these are both poisonous and expensive. Moreover, even the most concentrated Clerici solution has at room temperatures a density not much higher than 4.2, which provides only a " negative " result for some of the denser gem materials and for the precious metals.

In a short article in the February issue of the " Jeweler's Circular—Keystone," Dr. A. C. Hawkins describes a series of viscous colloidal fluids or " gels " which he has produced to replace the customary heavy liquids. He claims that the new gels are clean, non-poisonous, water-soluble and inexpensive, and that they enable the user to discriminate even between materials of high density such as platinum and other white alloys or between 22 carat and 18 carat gold.

In these ingenious preparations it is the viscosity and not the density of the fluids which keeps stones afloat or regulates their rate of fall. Rate of fall, indeed, is the important factor in using these gels, and must be measured and compared with stones of known density and of similar size to the stones tested—for stones

of larger size sink more rapidly in the viscous medium than smaller specimens of the same density.

Herein seems to lie a weakness in the new method: density values in which the size and shape of the stone must be taken into account are unreliable unless accompanied by comparative tests, and these comparative tests must necessarily take some time, even supposing appropriate specimens for the comparison are readily available.

The reviewer recalls how in 1935 Mr. R. K. Mitchell carried out some experiments at his request in which it was hoped to show that the rate of fall in tall columns of bromoform would serve to distinguish between stones of density considerably higher than that of the liquid. A graduated burette was used to provide the long column needed, in which the time of fall between two agreed points could be accurately measured with a stop-watch. It was found, however, that not only did style of cutting affect the result, but that even with spinel octahedra of identical density and form the larger specimens sank more rapidly than the smaller. The experiments were then (perhaps prematurely) abandoned.

While on the subject, it may be suggested that there is room for experiments on the possibilities of heavy sands in place of liquids, in which heavy gems would sink on shaking while lighter stones remained at the surface. Accurate results could not be expected, but separation, for instance, of cassiterite from zircon, or of zircon from sphene by such a method might well be possible. Heavy zircon and garnet sands are available in nature in large quantity, while modern technology might be capable of providing tiny pellets of glass or of metals covering a wide range of density, which might serve the purpose even better.

To return to Dr. Hawkins' gels: he recommends a set of four, contained in glass tubes, with each of which a wire spoon is provided for the easy removal and draining of specimens tested. The function of each can be briefly stated:

(a) A gel of low viscosity in which opal (2.00) will sink below the surface in about 10 seconds. Even slower rates of fall will be found in amber (1.08) and the various plastics (around 1.3).

(b) In this, opal will float, while quartz (2.65), diamond (3.52) and spinel (3.60) will sink in successively shorter periods of time.

(c) A gel suitable for stones with density 3.00-5.00.

(d) A highly viscous gel suitable for tests on haematite, pyrites, etc.

A paragraph in Dr. Hawkins' paper with which few gemmologists will agree reads as follows: " Synthetic stones may have included bubbles of air or other gas and when such bubbles are present in excessive quantities these stones are definitely lower in density than the genuine. This important difference is usually shown by the slower rate of sinking of the synthetics." Actually, in modern synthetics the proportion of included gas bubbles is exceedingly small and the resultant lowering of density may well be exceeded by the cavities and low-density inclusions found in some natural corundums. In the rare cases where large gas bubbles do exert a significant effect on the density the synthetic would so readily be detected by a glance under the microscope or even with a pocket lens as to render a delicate density test an entire waste of time.

Dr. Hawkins' gels are being marketed in the U.S.A. by Cargille Scientific, Inc., New York—a firm for which Dr. Hawkins is laboratory consultant. It is to be hoped that the fluids will before long be available in this country, for they seem to open up very interesting possibilities.

B. W. ANDERSON, B.Sc., F.G.A.

NEWS FROM AMERICA

The American Gem Society has recommended to its members that the term " semi-precious " be discontinued. The term is said to be meaningless and confusing to the public, as many fine quality so-called " semi-precious " stones are actually more valuable than a precious stone with imperfections and of inferior grade.

Surface Tension and Air Bubbles in Hydrostatic Weighing

by G. M. SPRAGUE

THERE is on the market a " Wetting Solution " which is intended to promote the free flow of liquids and to prevent the formation of air bubbles on photographic plates and films during processing.

It achieves this result by lowering the surface tension of the (aqueous) liquid to which it is added, and it occurred to me that the solution would be of use in carrying out a hydrostatic weighing, both in eliminating air bubbles and in lessening the pull on the wire due to surface tension. The usual method of obtaining these results by the use of toluol instead of water is at best a smelly and somewhat inconvenient business.

The surface tension of water is of the order of 75 dynes per cm. and that of toluol is of the order of 30 dynes per cm. The addition of 20 drops of wetting solution to each fluid ounce of water (or, say, one dessertspoonful to a half pint) reduces the surface tension to about 40 dynes per cm.

This quantity of solution has a negligible effect on the Sp. g. of the water, and it will be found that the degree of accuracy obtainable is as great as is compatible with the fineness of working of the ordinary balance. The main benefit, however, is the ease with which troublesome air bubbles are eliminated, even those which usually lurk in corners under the wire cage and refuse to disappear. If any should be seen when the stone is first immersed, they are easily dislodged by gentle shaking. Temperature corrections may be made, if desired, in the normal way.

The data given above are based on information supplied by the makers, Messrs. Burroughs Wellcome & Co. The solution is obtainable through any photographic dealer.

By ROBERT WEBSTER, F.G.A.

An Interesting ETCHED DIAMOND

SOME notes on a diamond which recently passed through my hands may have an interest for readers of the *Journal of Gemmology*. The stone, having a spread of about 2 carats, was mounted, with diamond baguettes, in a platinum mount as a solitaire ring and had been severely damaged by fire ; a fire which must have been slow and not intense, for the platinum mount had suffered no damage, although the whole surface of the diamond, and the baguettes, had taken on a frosted appearance.

When the stone was examined under the ultra-violet lamp a reddish mauve fluorescence was observed ; a fluorescent hue characteristic of many rough diamonds. Confirmation that the stone was a diamond was made by examination of the absorption spectrum which showed the band at 4155Å recorded by Walter in 1891. However, when the rough, soda-like surface was examined under a low-power microscope a most beautiful pattern of triangular depressions, reminiscent of the " trigons " so often seen on the octahedral faces of natural diamond crystals, was observed.

The etch marking by fire of a diamond surface is no new thing, but problems arising from these natural and artificial cavities have intrigued scientists the world over. Sir William Crookes[1] mentions Gustav Rose[2] as having pointed out that triangular striations appear on the surface of diamonds burnt before the blowpipe, and from resemblance to the " trigons " on natural diamond faces Rose assumed the probability that natural diamonds had at some previous time been exposed to incipient combustion.

Crookes repeated this burning experiment on a clean diamond and obtained this triangular pitting, but pronounced that in his opinion the pits had a different character to the " trigons " on the natural crystal faces.

A vast amount of work and consideration of the subject of etch and growth cavities has been carried out by Fersmann and Goldschmidt[3] ; by Friedel[4] and Sir Robert Robertson[5] amongst many others. J. Parry at the De Beers Laboratory made an examination of artificially formed etch markings on diamond by using a fusion of potassium nitrate (saltpetre $=KNO_3$) at 900° C. ; the result of immersing a diamond in such a fusion mixture is that oxidation of carbon takes place and the diamond therefore dissolves. (References and comments on the action of heat and chemicals on diamond are given by Grodzinski[6].) A. F. Williams, in his work *The Genesis of the Diamond*[7] has correlated all the previous work (1932) and has added information and deductions from his own experiments.

Fig. 1 — Magnification 380x

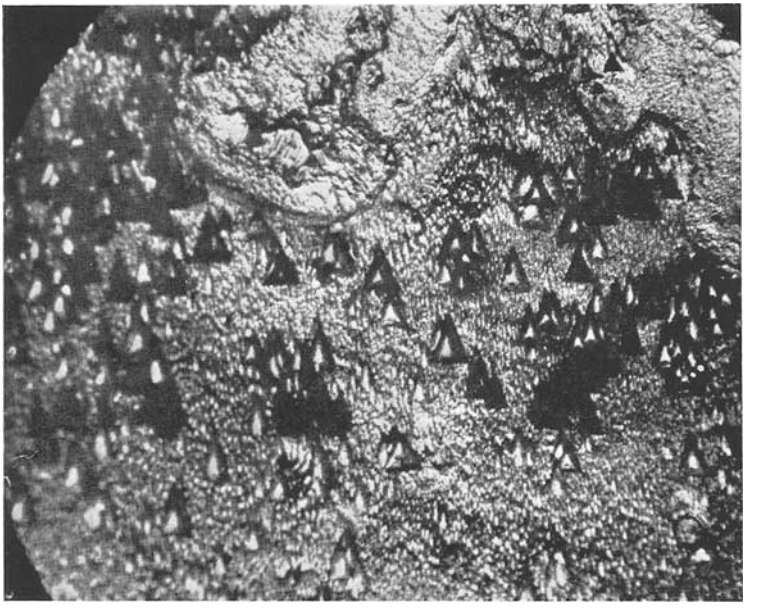

Fig. 2 – Magnification 38x

It has been pointed out by Sutton[8] and other workers that the corners of the " trigons " on an octahedral face of a diamond crystal point towards the edge of the octahedron face, while the triangular cavities etched by solution (or fire) are conformable to the face of the octahedron (that this is always so has been disputed. *Editorial note to Kayser*[12]). The argument whether the " trigons " on natural faces are due to etching or to growth, a debate which has been going on for some fifty years, has not yet been clearly decided. Briefly, Rose[2], Fersmann and Goldschmidt[3] and Miers[9] favour the etch theory, while Crookes[1], Sutton[8], Honess[10], Van der Veen[11], Williams[7] and Friedel[4] take the view that these pits are due to growth.

Quite recently the new technique of interferometry has been applied to the problem of these triangular pits, Kayser[12] using the two-beam method and Tolansky and Wilcock[13] the multiple-beam method. The latter workers suggest that they have at last proved that the depressions are due to growth.

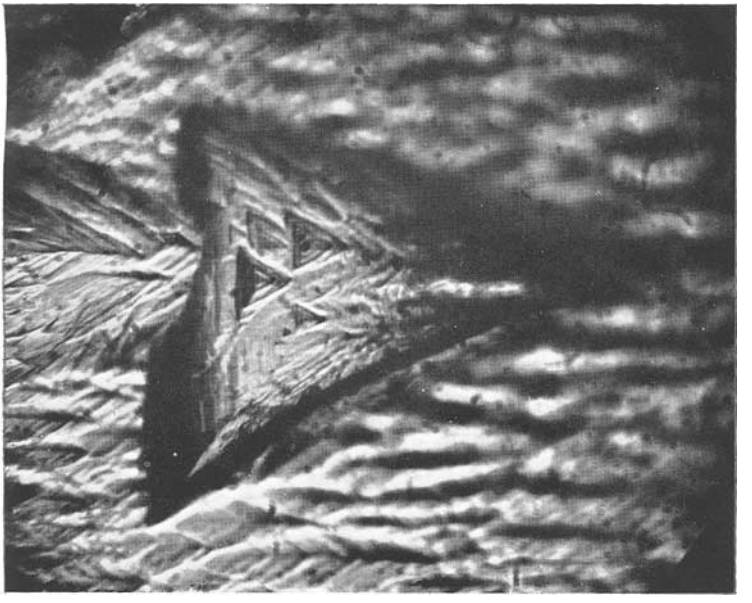

Fig. 3 — Magnification 380x

In this short resumé I hope to have told something about an interesting stone ; something, too, about the work which goes on in scientific circles in the attempt to unravel the mystery of the genesis of the diamond. Small as they are, these depressions can have an absorbing interest, and for that very reason I have attempted to give as full a list as possible of the references to literature. The written word alone could scarce convey the beauty of the marks on the damaged diamond, but fine photography can ; therefore, I conclude in offering thanks to Dr. W. Stern, of Industrial Distributors (1946), Ltd. (Diamond Research Department), who kindly took the photomicrographs.

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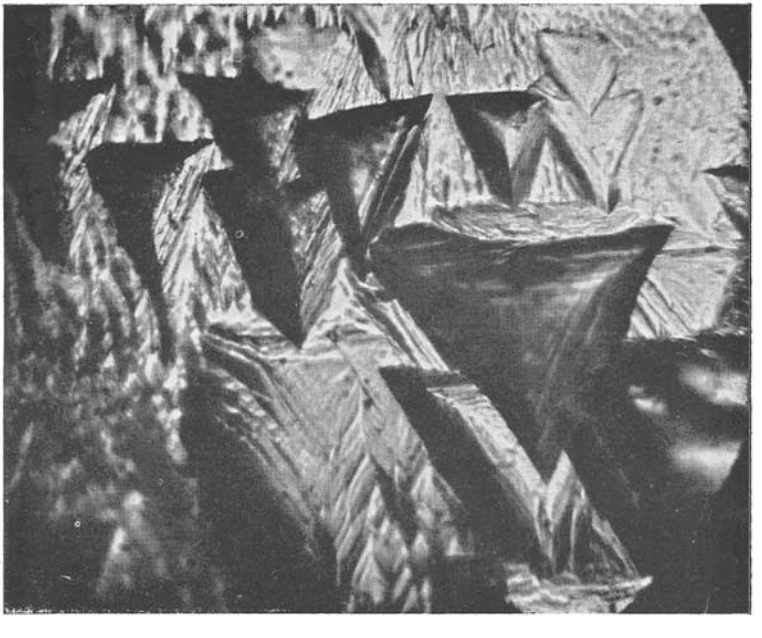

Fig. 4 — Magnification 380x

NOTES BY D. S. M. FIELD ON THE

Crystallinity of OPAL

ALTHOUGH opals are widely believed to be truly non-crystalline gemstones resulting from the solidification of an amorphous silica gel, laboratory experiments have shown that in both the precious and common varieties the atomic arrangement is not entirely random.

Dwyer and Mellor in Australia, and Levin and Ott in the United States—among others—point out that most opals give definite X-ray diffraction patterns which are identical with that of β— cristobalite ; whilst in a number of instances only a broad diffuse band characteristic of amorphous substance is obtainable.

It has been shown, however *(v. Randall, Rooksby, and Cooper, "Zeitshrift für Kristallographie"* LXXV, 201, 1930) that vitreous and precipitated "amorphous" silica produces a broad band and it is in the position of the most intense line of the diffraction pattern of either α or β— cristobalite. These scientists believe that the band is due to the presence of β— cristobalite crystallites with diameters ranging from 10^{-6} to 10^{-7} cm. It is therefore suggested that the broad band of apparently non-crystalline opals is due not to irregularity in the atomic structure but to the presence of an infinite number of crystallites of cristobalite of colloidal dimensions.

Kreji and Ott *("Jour. Phys. Chem.," XXXV, No. 7, 1931)* found that freshly prepared silica gel shows distinctly the presence of ultra-microscopic crystallites of the aforementioned mineral. This would appear to indicate that the tendency towards a regular arrangement of the atoms of the opal takes place during the formation of the gel.

Thermal study of cristobalite shows that the inversion point of α— cristobalite to the β— form lies between 198° and 275° Centigrade (Dana—Ford). We may assume, therefore, that all opals giving the diffraction pattern of β— cristobalite have been heated in nature above the temperature at which the inversion takes place. This assumption is borne out by the fact that opals which have been formed in association with volcanic rocks, for example, opals from Quéretaro, Tintenbar, and Ballina, etc., all show sharp β— cristobalite diffraction patterns, whilst those found associated with sedimentary shales and limestones (Lightning Ridge, White Cliffs, Coberpedy, etc.) do not. *(Dwyer and Mellor.)*

Further proof of the crystallinity of opal is given by Talliaferro *("Amer. Jour. Science," November, 1935)*. Experiments carried out by Dr. Talliaferro have indicated that the values of the refractive index and specific gravity, when plotted against water content, lie between the curves of the systems amorphous silica-water and cristobalite-water. He states:

> " The departure of both index and density from the theoretical silica-water curve is due to the tendency toward atomic arrangement in the direction of the β— cristobalite modification."

He further states that no traces of actual cristobalite crystals or of any crystalline material were found in the opals examined. Their presence has been noted, however, in a few instances by other authorities *(v. Sosman, "Jour. Amer. Chem. Soc.," LIX, 3015, 1932; Grieg, Ibid LXXVI, 300)*.

It is interesting to note that loss of colour-play seems to occur only in opals which have been formed at high temperature. This would seem to indicate that the colour play depends to some extent upon the presence of cristobalite in the β form.

Dwyer and Mellor found that " β— cristobalite prepared (in the laboratory) from opals by fluxing at 800° C. persisted up to six months, while specimens prepared from the same opals at 1,500° C. inverted promptly on cooling. In all cases the persistence became more marked as the temperature of fluxing was

lowered. It is considered, therefore, quite possible that the cristobalite produced at the relatively low temperatures of magmatic waters, often as low as 200° C., should show great stability." *(Proc. Roy. Soc., N.S.W., 1934).*

Another point of interest to gemmologists is that certain specimens of precious opal were heated for six to eight hours at approximately 1,000° C., yet lost none of their play of colour. The specimens came from Tintenbar and Coberpedy *(Proc. Roy. Soc., N.S.W., 1932).*

Baier *(Fortschritte der Mineralogie, Kristallographie und Petrographie, XV, 1931, and Zeitschrift für Kristallographie, LXXXI, 1932)* attributes the iridescence of precious opal to pseudomorphosis after rhombohedra of calcite, the lamellar twinning structure of which has been preserved in the opal as thin films which produce optical interference. The excellent photomicrographs which accompany his second paper show clearly the presence of a crystalline structure or pseudomorphous crystallinity.

Summary.

(a) A crystalline or pseudo-crystalline structure—most probably that of α— cristobalite—is possessed by the silica gel from which opals are presumably formed.

(b) An inversion of the α— cristobalite to the β form has occurred either during the formation of the gel or subsequent to its deposition in all cases where opals have been subjected to the thermal action of magmatic waters during lava flows.

(c) The atomic arrangement has sufficient regularity to give in many cases definite β— cristobalite X-ray diffraction patterns, and to cause the departure of both R.I. and S.G. from the theoretical amorphous silica-water curves.

(d) Loss of colour play occurs only in opals which have been subjected to high temperatures during formation of the gel.

With the exception of brief mention of Baier's hypothesis by Smith (*Gemstones*) and Webster (*Practical Gemmology* and *Introductory Gemmology*), I have not found any reference to the crystallinity or pseudo-crystalline structure of opal in gemmological literature

Experimental Photomicrography • Photospectrography • Interference Figure Photography

By JOHN VINCENT, F.G.A.

AS a prelude to these notes which give an account of certain experimental work carried out in the Laboratory attached to Messrs. John Vincent, Ltd., of Weymouth, it must be stressed that the writer is fully cognisant of the fact that many would-be practical gemmologists have neither the facilities nor the encouragement to develop their knowledge to the commercial benefit of their various firms. It is a sad fact that the science of gemmology is still regarded as " Black Magic " by many Captains of Industry in the jewellery trade and consequently any suggestion regarding the allocation of window space for special displays of gemstones or small grants for the purpose of purchasing gemmological instruments are dismissed as being " non-commercial " and " totally unnecessary." The writer of this article has had plenty of first-hand experience of this attitude and would point out that such a short-sighted policy must inevitably retard that enlightened day when every retail jeweller of standing will be possessed of the necessary knowledge and equipment appertaining to the buying and selling of precious stones, thus raising the trade to new high levels and automatically increasing the confidence of his customers.

Knowing full well that the average keen practical gemmologist has not great finances at his disposal, and that, in any case, grants allowed for the purchase of equipment would probably be small, the laboratory has conducted a series of experiments with the object of finding out just what can be done and how far one can go by using the least expensive and minimum amount of apparatus. Most of the instruments used have been bought second-hand ; difficulties both large and small have arisen from time to

time, but improvisation combined with a lot of faith and blind hope have overcome most of them. Welcome encouragement has attended some of the experimental work in the form of acceptance by the Gemmological Association of some photomicrographs of the internal structures of gemstones for the recent exhibition held at the Goldsmiths' Hall early this year and publicity gained through favourable write-ups in the newspapers of gem displays featured in past months. It is not proposed to describe the inauguration of the gem laboratory, as this has been done in a previous article ; it is enough to say that so far it has been an unqualified success and is a substantial handle for argument with the " steel file-cum-guesswork " jewellers and their ilk.

The two main themes for experiment were photomicrography and photospectrography, using black and white and colour film. Interference figure photography of cut gemstones in convergent monochromatic polarized light was also attempted and results of a sort were obtained. The apparatus used throughout these experiments consisted of a microscope (1880 vintage), a second-hand Brownie box camera and a Beck pocket spectroscope, including various complementary home-made equipment. These experiments will now be discussed separately.

PHOTOMICROGRAPHY

The microscope used for this work was located in an attic where it had lain for a considerable time. After the instrument had been thoroughly cleaned and made ready for use, it was found that the stage consisted of a platform with a circular hole in the centre and was minus condenser and reflecting mirror. Three screw-on objectives accompanies the microscope, ½ in. (cracked), 1 in. and 2 in. The camera which it was proposed to use in conjunction with the microscope was in an extremely poor condition, having an ill-fitting body, cracks in the woodwork and a jammed shutter. The setting up of the apparatus was as follows:

A concave metal shaving mirror was utilised for the purpose of reflecting light through the central aperture of the stage and into the body of the microscope. To regulate the strength of light, a circular disc of black cardboard was cut about four inches in diameter in which was pierced a series of holes of varying size.

PROTOTYPE MICROGRAPHS TAKEN IN THE LABORATORY

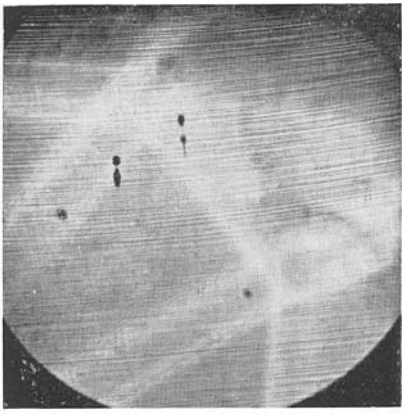

Fig. 1 — Synthetic Ruby. One inch objective. Panchromatic roll film. 150 watt pearl. 12 secs. exposure.

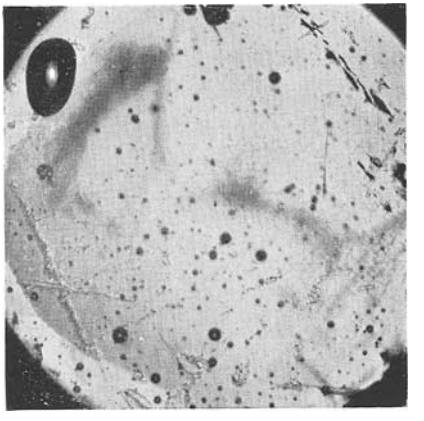

Fig. 2 — Silk and Bubble layer in Almandine Topped Doublet Panchromatic roll film. 150 watt pearl. 6 secs. exposure.

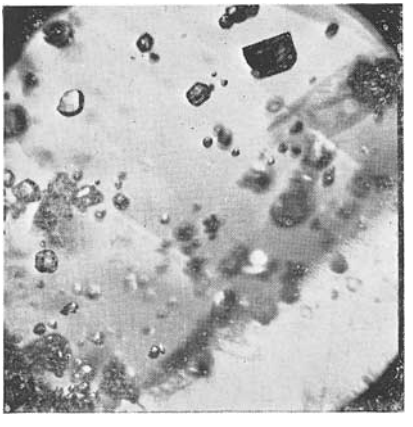

Fig. 3 — Inclusions in Ceylon Sapphires. 500 watt Nitrophot flood. ½ inch objective. 10 secs. exposure. Pan. roll film.

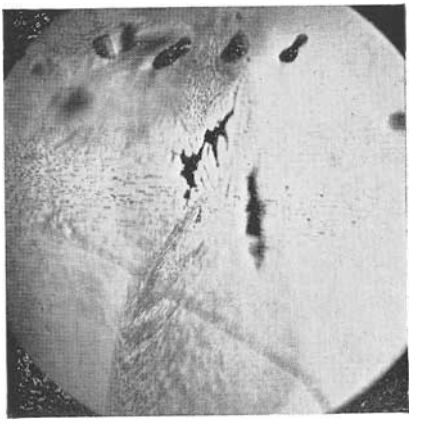

Fig. 4 — Inclusions in Ceylon Sapphires. 500 watt Nitrophot flood. ½ inch objective. 10 secs. exposure. Pan. roll film.

This was then attached underneath the stage in such a way that the disc could be rotated, thus bringing the holes into line with the aperture. A glass slide was then laid across the stage, and this in turn supported a glass inkwell filled with highly refracting fluid. With a stone immersed in the liquid, the microscope objective was focussed in the normal way, correct lighting being obtained by rotating the disc at the bottom of the stage.

Having rendered the camera lightproof by sticking insulating tape over the cracks in the body and repairing the shutter, the back of the camera was then prised off and a ground glass screen laid across the instrument. It was found that when the camera was superimposed over the microscope eyepiece, a small, ill-defined image appeared on the improvised screen. By inserting a cardboard tube of certain length containing a series of supplementary spectacle lenses as between camera and microscope, it was seen that " infinity " had been produced and that a clear image formed itself on the screen. In order to combine the largest possible image with the minimum wastage of film, the distance between the lens had to be varied until an image was obtained of such a size as to let its outer arcs be tangential to the bounding edges of the proposed film. This latter was only attained after great difficulty, but once the correct distance was obtained, it was found that the resultant focus was constant for the particular objective used for the experiments, irrespective of the movement of the objective towards its own point of focus.

The back of the camera was then nailed down and the camera loaded. Laboratory retort stands were used to support the camera over the lens tube and microscope, and exposures effected in the normal manner. The advantage of using roll film was obvious. Exposures could be made in sequence by merely winding the film on without disturbing the apparatus in any way supposing different exposures of the same specimen were required ; eight pictures could be taken on a standard film roll. Standard panchromatic super double X film was used in these experiments, exposure times varied from 2 seconds to 3 minutes and light source varied from 150 watt pearl gas-filled bulbs to 800 watt Nitrophot flood laps for very dark stones. Once the apparatus was set up, ex-

posures could be made at the rate of 15 minutes per film roll supposing eight different specimens were photographed in sequence.

Most of the stones for test were mounted as rings and the best way of dealing with these was to suspend the ring stone uppermost in the liquid by hooking a bent metal hairpin through either side of the ring shank and bending the ends over the lip of the container. The objective could then be racked down on to the stone without fear of damaging the objective itself. Examples of prototype micrographs accompany this article.

SPECTROGRAPHY

Obtaining results in spectrography using the limited apparatus available proved to be rather more difficult than was at first anticipated. The instruments employed in this work were the microscope as previously described, the Brownie Box camera and a Beck pocket spectroscope. In the absence of a condenser, a twenty dioptre spectacle lens held in a clamp served the purpose, and light was passed by a concave metal shaving mirror as in the micrograph experiments. A hole was drilled in the stage of the microscope and a peg inserted which held a metal collar. This in turn held a six-inch brass rod with a dop cup at one end and a spring clip at the other. The clip held a ring by the shank for examination and the dop cup held a lump of wax in which an unmounted gem could be set for test. The rod enabled either the ring or stone to be positioned in the central aperture of the stage, it could be moved up and down the collar and was also rotatable about its longitudinal axis, thus facilitating transmitted light from the stone under test to be passed through into the body of the microscope tube.

It was found that the best results were obtained by using a ½ inch objective for stones with small facets and a 1 inch for cabochon and larger specimens. The pocket spectroscope was screwed on to a ball and socket head with tripod attached, and by this means the instrument could be clamped in any position over the microscope tube. When the camera was placed over the spectroscope, the same difficulty occurred in the correct spacing of the spectacle lens in the auxiliary tube in order to obtain the

correct focus. When the focus had been attained and a trial " take " had been effected, it was seen that the resultant spectrograph negatives showed a cut off at either end of the spectrum at 6,500Å and 4,300Å respectively. In an attempt to overcome this new snag, the eyepiece of the spectroscope was unscrewed and the tube containing the lens series was brought down and almost into contact with the prism. A cardboard collar was placed around the junction of the spectroscope tube and lens tube to exclude extraneous light and a further sequence of exposures made. The cut-off remained as before and, in addition, a flooding of the red end of the spectrum spoilt the negatives. In either case, with or without the spectroscope eyepiece, the over-exposure was always present. To try to combat this difficulty half filters were placed between spectroscope and camera with the object of slowing down and holding back the red portion of the visible spectrum, while giving the violet end a chance to register on the film. This latter proved to be another failure and during six months of experimenting with various ideas no real headway was made in eliminating the cut off and flooding. By altering the lighting, better results were obtained but there was room for considerable improvement. It is only during the last few days that real progress has been achieved by using a different technique, which will be the subject of a further article in the future.

Light source for these experiments varied from 150 watt pearl bulbs to 1,600 watt double Nitrophot flood lamps. Exposure times also varied from 2 seconds to 100 seconds. Panchromatic super double X film was found to be the most successful for this type of work, being sensitive to the whole visible spectrum range. Work carried out with Dufay colour film was spasmodic, due to the acute shortage of colour film, which was even more difficult to obtain than pan. film. The Dufay colour transparencies do not show the true colours of the spectrum, a fact concerning which the makers are at pains to inform would-be users of this particular type of film. Results therefore did not cause such misgivings as would have been felt otherwise. The exposure factor in the colour photography was 4x approximately. It was found that accuracy in exposure times was infinitely more essential than when exposures were being made with panchromatic film. The time lag for colour film was only a second each way compared with the ten

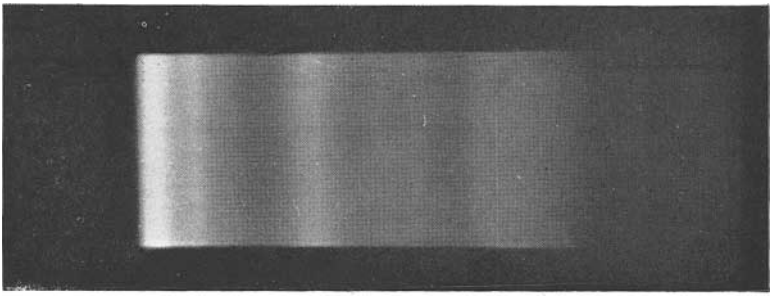

Fig. 5 *Spectrum of Natural Blue Spinel. 1600 watt Double Nitrophot flood. ½ inch objective. Pan roll film. 75 secs. exposure.*

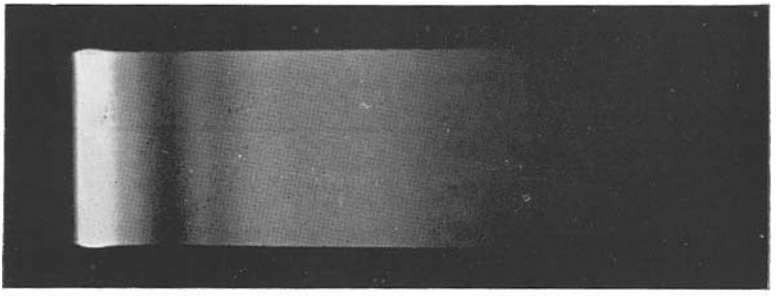

Fig. 6 — Spectrum of Synthethic Blue Spinel. 800 watt Nitrophot flood. ½ inch objective. Pan. roll film. 68 secs. exposure.

seconds lag for the panchromatic film. At present Dufay film is the only colour film obtainable in England and is not recommended by the writer for this work. The ideal colour film is the new American Kodachrome, which is not on sale in this country as yet.

By suitably masking the back of the camera, it was found that twenty-five exposures could be made on a standard roll film. Thus the cost of producing the spectrographs was considerably less than the micrographs and would have been less still but for the short life of the Nitrophot lamps, which averaged about half an hour's burning time. Further improvements in the cost of production enabled a photomicrograph and photospectrograph of the

customer's gemstone to be included in a special laboratory folder together with the routine certificate of testing. A charge of five shillings was made for the folder complete with certificate and two photographs, and many clients availed themselves of this innovation.

The micrograph serves as a fingerprint photograph of the gemstone and is useful in the case of loss or theft as identification by comparison is the work of a moment, no two gems having identically placed inclusions. The spectrograph, while not essential, is tangible evidence of scientific examination and cannot fail to give a favourable impression and a sense of confidence.

The laboratory aims at a forty-eight hour service for clients, but developing and printing difficulties and shortage of photographic materials render preparation of the complete folder impossible in under seven days at present. It is hoped to remove production bottlenecks in the near future.

INTERFERENCE FIGURE PHOTOGRAPHY

Besides the routine testing and preparation of photographs in conjunction with certificates issued, recent work has been concentrated on photographing interference figures of cut gemstones in convergent monochromatic polarized light, for the purpose of incorporating the finished pictures in a series of new gem displays, now a permanent feature of the firm. A brief note on the setting up of the apparatus and difficulties encountered during these experiments may be of interest to readers.

Two series of condensing lenses were purchased for a few shillings and these were mounted in a cardboard roll and cemented in position, thus making a home-made double-bank condenser. The polarizer from the microscope was then taped to the bottom of the condenser series by insulating adhesive and the whole contraption supported under the stage by means of a laboratory retort stand. Two spectacle lenses were then fixed together and lodged half-way down the body of the microscope tube, thus acting as a Bertrand lens. By this means the interference figure could be viewed without having to remove the eyepiece of the microscope and also gave a larger image. The camera and lens tube were

Red 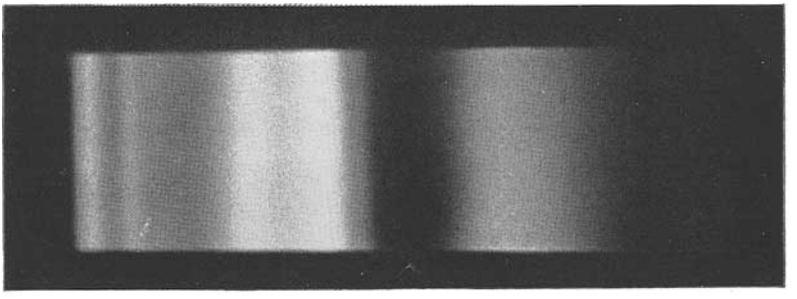 Violet

Fig. 7 — Spectrum of Natural Blue Australian Sapphire. 800 watt Nitrophot flood. 1 inch objective. Pan. roll film. 45 secs. exposure.

Red 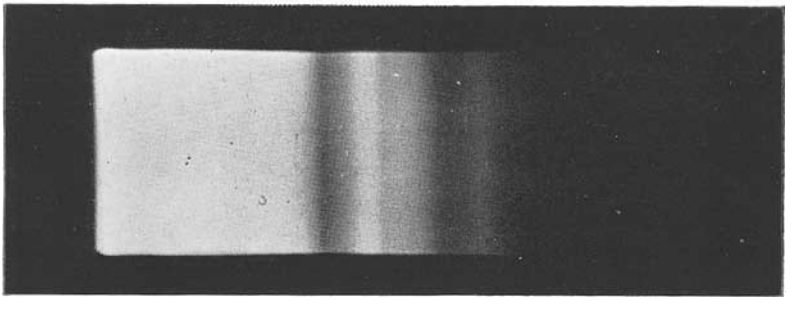 Violet

Fig. 8 —Spectrum of Peridot. 1600 watt double Nitrophot flood. 1 inch objective. Pan. roll film. 25 secs. exposure.

rigged up over the microscope and an Ilford Spectrum Yellow filter was inserted between eyepiece and tube to give a sodium light effect, thereby making the concentric rings which appeared coloured in white light, black and well defined. The focussing difficulty proved to be even more of a headache than was previously experienced in other instances and several rolls of precious film were wasted before printable negatives were secured. Difficulty with lighting and positioning of the stone was also experienced, and it was found that to get anything worth the trouble of photographing, many minutes had to be spent in getting the scene " just right " for the final " take." As no thin plates of material were available, perfect figures were unobtainable, but pictures of cut and facetted stones from the firm's collection were taken in the

laboratory, and although much remains to be done in this direction, a start has been made and this particular work has been found to be an all-absorbing study, mainly on account of the difficulties encountered.

In concluding these notes it may be worth mentioning that since the inauguration of the laboratory there have been many instances where its foundation has been fully justified. A few incidents from the laboratory Case Book may now be quoted. These happenings are perfectly true and may be vouched for ; each case has occurred within the last six months.

Case No. 1 is that *rara avis*, the case of the dealer who sold a real stone for a synthetic. A stone was recently shown by a dealer who described it as a " Synthetic fancy Sapphire " ; the specimen proved to be an "Almandine " Spinel of over 40 carats. Advantage was taken of the dealer in this instance as it was considered that a man should know his stock ; also, there were, and are, facilities for gaining knowledge regarding precious stones which are open to all members of the trade. If a man is either too lazy to avail himself of the opportunities afforded him by the trade educational organization or thinks that " He Knows It All," then he should take the consequences. The next case was that of a traveller belonging to a well-known firm offering for sale, in all good faith, a canary yellow diamond of over a carat in weight. As a result of a routine check, it was found that the diamond was a yellow sapphire and the traveller was recommended to send the ring to the Hatton Garden Laboratory for test. A letter was later sent from the firm in question apologizing for their mistake and offering the yellow sapphire ring for sale at a fraction of the original price asked.

The third case was of an old and valued client whose family had been customers for many years. Interested in the new gem displays and the laboratory photographs, she proffered a pretty green stone set in an antique ring for examination and test. The pretty green stone turned out to be an almost flawless Colombian Emerald and an approximate value of two thousand pounds was placed on it. This ring was subsequently sold for this figure in a London sale room, an account of which appeared in " The

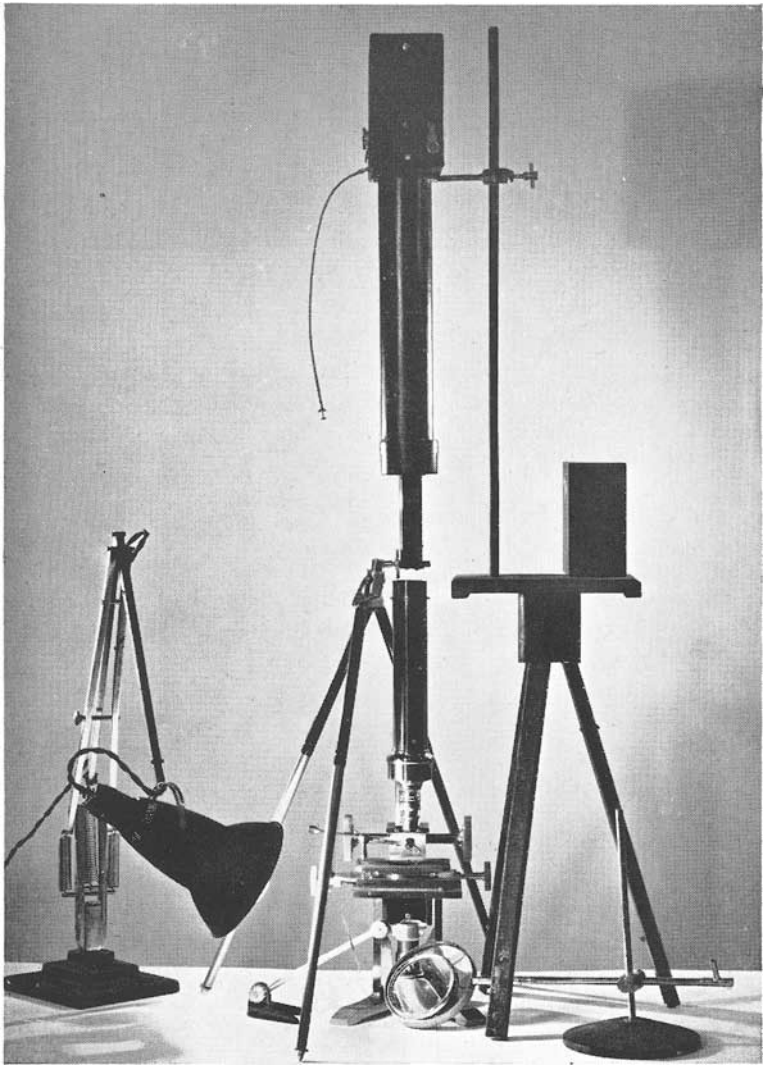

Fig. 9 — Prototype apparatus for photographing absorption spectra of gemstones, using roll film, Brownie camera, spectroscope and microscope.

Times " recently. The benefit to the firm from this incident was considerable. The customer, moving in highly influential circles, did not keep her good fortune to herself.

The last case is a bad one and, unfortunately, is not isolated. A self-styled " Dealer " offered a twelve carat Alexandrite for sale at £86. On being informed that the Alexandrite was a vanadium-tinted synthetic corundum, he did not seem in the least surprised and gave the impression that he had failed to " put it over." Such behaviour does incalculable harm to the trade in general, as the base creature would hawk the ring until he found some avaricious half-wit who traded under the name of " Jeweller," who would throw the small amount of discretion he might possess to the four winds (a twelve carat Alexandrite for £86!), and pay out the money for a comparatively worthless article. The public would suffer in the end, of course, but then so would the trade when the unfortunate purchaser's confidence in the jewellery trade had been blasted for ever. As has been said, all these cases happened to one provincial firm in this country in six months. Multiply these few instances by many thousand, and it appears obvious that much remains to be done in the way of educating everyone up to higher standards in the gemmological world.

Thus the work of a provincial gem laboratory progresses and continues to safeguard the interests of employers and clients alike. If this account of work which has been done and is being done in this laboratory has fired any embryo gemmologists with the necessary enthusiasm to branch out along similar lines, then the time taken in the compilation of these notes will not have been wasted.

By DAN E. MAYERS, Mining Geologist

The Gems of MEXICO

FOR a country so abundantly blessed with natural resources, Mexico is rather deficient in gems. This is due largely to the thick beds of Cretaceous limestone which blanket much of the region ; fabulously rich replacement deposits of lead and silver are found in this limestone, but gem-bearing pegmatite veins, so characteristic of Brazil and Madagascar, are absent. The pattern of Mexico's mineral wealth is particularly well demonstrated in her jewellery, emphasizing rich and massive designs of silver and gold with stones used merely to highlight the silversmith's skill.

This article touches only upon gems of commercial importance ; the subject of Mexican Jade (the genuine kind rather than the currently-plentiful analine-dyed limestone) is chiefly of archaeological interest.

OPAL

Precious opal from the State of Queretaro (kay-ray-ta-ro) is a truly outstanding stone, when of fine quality, but mining and distribution, carried out in the haphazard manner typical of Latin America, have combined to give the stone a poor name. Particularly notable are the Mexican opals contained in the display of the Smithsonian Institute ; these stones have magnificent fire, equalling the finest white opals of Australia and Hungary. Mexican opal appears to glow with a sort of internal warmth and pulsating colour reminding one of an enormous rainbow-hued pearl ; it lacks the harshness of colour characteristic of Australian and Nevadan stones.

Opals are widely distributed throughout the State of Queretaro and adjoining regions, occurring in small nodules and veins in brown to white trachytic porphyry, the opal usually coinciding in colour with the porphyry. Opaque white opal resembling the Australian, but of inferior fire, is found occasionally in masses of considerable size.[1]

Though Queretaro opal is plentiful, few mines produce genuinely fine durable stones. Opals from most of these localities, though pretty at first, have a strong tendency to crack on ageing. This has been well advertised by the lapidaries of Queretaro City (the State's capital), who usually keep a liberal supply of these stones in oil for sale to tourists. Due largely to this far-sighted business practice Mexican opal labours under a reputation for cheapness and brittleness ; nevertheless, discriminating opal connoisseurs appreciate its true worth.

At present the Carbonero Mine, located north-east of San Juan del Rio, near Tequisquiapan (tay-keys-kee-yáp-pan) is the chief source of good stones. The mine is just now in an ugly state of disrepair as the result of a five-year suit over its ownership. The dispute was recently settled and it seems likely that the mine may resume production shortly. More opal would be recovered in usable form if dynamite were used less prodigally.

The price of Queretaro opal varies enormously. Small stones showing little fire bring from 5c. to 50c. each. Truly fine stones are very rare and bring as much as $7.50 per carat in Queretaro.

It is to be hoped that the gem trade will eventually appreciate good Mexican opals, for they are fine stones and deserve a higher regard than they now enjoy.

AMETHYST

Little or no flawless Amethyst occurs in Mexico. However, in the mountains near Taxco (Tass-go)—a town once famous for its silver mines and now noted for the picturesqueness of its streets and the artistry of its silversmiths—are numerous veins which yield Amethyst of fair to excellent colour, though almost opaque from numerous flaws. Individual crystals are several inches long and up to an inch in diameter ; due to intense intergrowth, cementation, and flaws they do not possess the beauty of comparable specimens from Brazil or Uruguay. Only rarely is a portion of a crystal sufficiently clear to allow the cutting of a flawless stone of more than a few carats' weight.

These crystals are shipped from Taxco to Queretaro City, the lapidary centre of the nation. Here the amethyst is cut and polished ; most is cut en cabochon, but some of the better material is carved into rudimentary figures—miniature frogs, for example

—suitable for a better grade of silver jewellery. Most of the cut stones eventually find their way back to Taxco, where they are mounted.

Amethyst also occurs in Guanajuato (wann-a-watt-to) in some quantity ; although more pleasing as mineral specimens than is the Taxco material, Guanajuato amethysts are vastly inferior in size, colour and transparency.

The author received, on one occasion, some small, flawless, pale doubly-terminated amethyst crystals from an unknown locality in Sonora ; they greatly resembled Herkimer quartz in appearance. No more is known of this occurrence.

OTHER STONES

Turquoise occurs in several places in Mexico: Northern Chihuahua ; Concepcion del Oro, Zacatecas ; Lower California. These deposits have been worked sporadically for the past fifty years with decreasing success. Turquoise produced tends to be greenish, light in colour, small in size, and rather soft.

A flawless one-carat emerald crystal was recently shown the author by a fairly reliable miner. The miner claimed to have discovered it in the State of Oaxaca (wa-ha-ka) in a region noted for its unfriendly Indians.[2]

During the war a flourishing business in Queretaro City was based on the manufacture of coloured glass in imitation of precious stones. Magnificent large " aquamarines," " amethysts," " topazes " and " emeralds " made their appearance, not inexpertly cut on home-made faceting machines (jam-peg cutting is unknown in Mexico). The glass stones had unpolished girdles, as the average Mexican thinks this the sign of a genuine stone. Rings mounted with these well-authenticated stones were sold widely and some even found their way into the United States. The merchants who supplied the coloured glass in sheets received amazing prices for " gem rough " of a particularly choice shade.

[1] This opal is frequently converted into a " black " opal of improved fire by raising the stone to a high temperature in the presence of organic material, causing the deposition of carbon in its pores. Such a stone, unfortunately, loses its colour on repolishing.

[2] Many foreigners do not appreciate that access to certain parts of Mexico is not feasible owing to the presence of actively hostile Indians.

KAURI GUM

By ELSIE RUFF, F.G.A.

ABOUT one hundred years ago white men were invading a sub-tropical forest that was part of the extreme north of New Zealand's North Island. In so doing they were almost certainly re-living a scene of bygone ages. But this was a kauri forest, and the kauri gum or kauri pine (*agathis australis*) is a columnar, resiniferous tree ranging from 80 to 150 feet in height, its trunk anywhere from 4 to 24 feet in diameter, and with a round bushy head. These grey giants, rising out of a thick undergrowth alive with insect life, sheltered a remarkable range of birds. And over all was a sub-tropical sun and the hush of nature alone, in command. It could hardly have differed from the amber forests of, say, a million or more years ago. And the gum for which men dig (gum-diggers the men are actually called) is largely a fossil variety from the sites of previous forests. (New resin that may be picked from the trunks of living trees as a result of some perhaps slight abrasion is relatively of little value and the process of tapping the tree for this purpose has long been abandoned.) The age of previous forests may be gauged by the fact that present trees running to 24 feet in girth are already over 4,000 years old.

Like everything else, gum that once oozed from the kauri pine is in a process of change—of becoming—and given another million years, which it will not now have, New Zealand might have exported amber in place of the £20 million worth of resinous substance that has proved so satisfactory for varnish, for shellac, and in the manufacture of linoleum.

In recent years the New Zealand Government has exercised some control over the marketing of kauri gum and the wages of the diggers, but up to that time the industry had little or no organization. It was perhaps analogous to opal mining in Australia. The life was an arduous one, particularly because it was an isolated life, and small settlements grew and flourished and died

rather as they did in gold-mining areas. (During 1913 as many as 7,000 diggers were engaged in this work, among them Maoris, Croats and Dalmatians.) Some of the home-made contraptions used for recovering the gum from the soil have been classified *Heath Robinson.*

But gum digging has changed. Formerly only large pieces were retained, often as large as a man's head. Since then ground has been worked a second and a third time. To-day, small chips and even dust are considered profitable. For not only is the gum being worked out, the kauri forest itself is disappearing. Early destruction and accidental fires and the present encroachment of civilization is merely repeating another old story. And the death knell of kauri gum was sounded when a synthetic product appeared on the market, a product adequate because of " its purity, dependable quality, certainty of supply, lower productive cost, and proved suitability. . . ." A recent Government report sums up the situation: " The Kauri Gum Industry is . . . deteriorat-

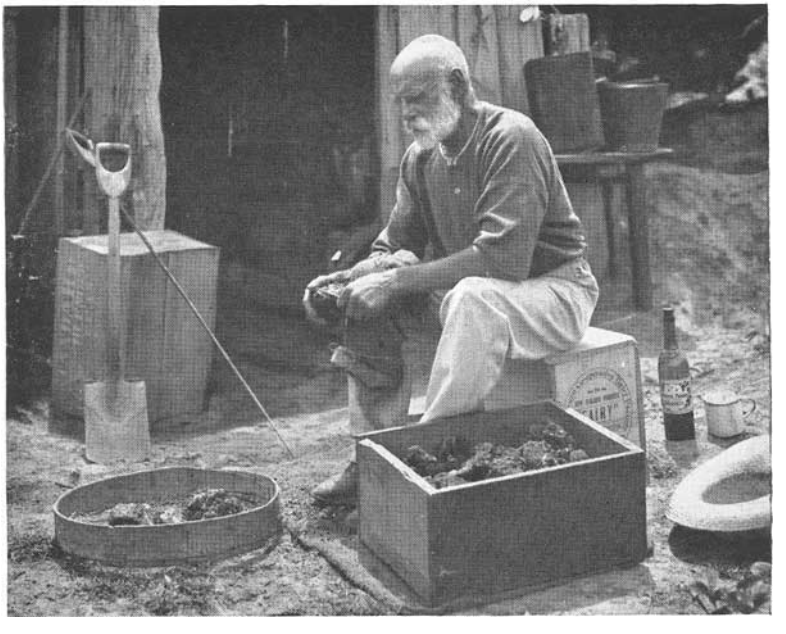

An old gum digger of Hohoura, North Auckland, North Island, New Zealand (with acknowledgements to the High Commissioner for New Zealand)

ing as the gum bearing areas are being rapidly worked out. The principal method of gum extraction now in use is by washing the gum soil through a series of sieves in a type of machine constructed for the purpose. This enables even the fine particles of gum to be recovered. . . . There are still recoveries of larger gum, but only in small quantities and in isolated localities. . . . It is expected . . . that with the increasing use of synthetic substitutes the overseas demand will fall and prices will not be maintained. . . ."

The possibility of using kauri gum as jewellery has not been overlooked and many a gemmologist must have been confused by this amber-like substance that also closely resembles the copal gum of Africa. (Captain Cook, who seems to have missed nothing, referred to kauri gum in his Journal of 1769.) Several small attempts have in fact been made to launch the material as New Zealand amber, but always its softness, even compared with amber, has baulked such a venture. Pendant pieces are nevertheless sold to the tourist. A substance easily scratched with the finger nail (amber varies from 2½ to 3 on Mohs' scale) is at too great a disadvantage. But resemblances to amber do at times call for a considered decision. In colour the gum ranges from colourless (and translucent) to yellow and a pale and sometimes deep sherry tint. Its specific gravity is around 1.05 and therefore not discriminative, though Herbert P. Whitlock (*The Story of the Gems*) states that by dissolving common salt in water kauri and copal gum will float while true amber will sink, and that this is " a simple and reliable test to distinguish old fossil amber from a more recent gum." Moreover, he writes that " In addition to the gravity test in brine . . . Kauri gum is distinguishable by being more soluble in alcohol than is true amber. A drop of alcohol will cause a certain stickiness to develop on the surface of kauri gum, whereas several moments are required for a similar effect to appear on the surface of an amber piece." Mr. B. W. Anderson (*Gem Testing*) gives as distinguishing features of kauri or copal gum compared with amber, " . . . its readier fusibility when a hot needle is placed on some inconspicuous part of the specimen . . . and by its greater solubility in ether. When a drop of this liquid is placed on copal resin it becomes quite sticky, and a dull spot is left on the surface when the liquid has evapo-

rated." In R.I. kauri gum actually covers amber—my own readings varied from 1.52 to 1.54. Like amber, too, it is warm to the touch and easily electrified by friction. But according to another authority[1] kauri gum has no trace of amber's characteristic succinic acid.

As in true amber, the odd insect or leafy fragment has sometimes found its way into the resin before hardening, and doubtless this suggested stimulating tourist-interest by melting the material (it melts at a temperature of 360° to 450° F.) and pouring it over some unfortunate bug. For wherever the visitor wanders in New Zealand, more especially in the North Island, he is confronted with lumps of kauri gum in varying shapes and sizes complete with insect or flora inclusions, sometimes more than one inclusion to a lump. Magnificent beetles, moths, even minute lizards, caught up in life, are beautifully preserved till the gum itself meets disaster. It is, in fact, merely a question of choosing your insect. Most jewellers stock this gum and souvenir shops go in for it in a big way—or did before the war. Recalling the rarity of an insect in amber and the speculation that is part of the amateur's discovery, one's first reaction to kauri gum and its inclusions is to wonder whether insects of the Antipodes are more gullible than in other parts of the world. The next surprise is to find that nobody, not even the jeweller, knows or cares to admit how it is done and where. One or two might talk of a secret process and the man said to be responsible is always in some other town. If you go to this town and make the same enquiries he is back in the one you came from. When I eventually met the responsible party it was to learn again that the process was secret but that all insects were mercifully chloroformed before the operation.

Due to the fact that this type of gum will one day be extinct (unless other gums are discovered or the copal gum of Africa becomes an issue), and also due to its necessarily short existence in use, it is one of the substances that should bother the gemmologist less and less. But, like medicine, for every satisfactory cure of one disease there are two new exciting diseases ready and waiting. And if man has cut gum short in its efforts to become amber it is almost certain that something else far more complex is in nature's crucible.

[1] *The Book of Amber.* G. C. Williamson.

Two Fellows of the Association have reported that they possess a copy of a book on Precious Stones printed in London in 1652, of which the title page reads:—

A Lapidary of The History of Pretious Stones

With cautions for the undeceiving of all those that deal with Pretious Stones.

By Thomas Nicols, sometimes of Jesus College in Cambridge.

Inest sua gratia parvis

Cambridge: Printed by Thomas Buck, Printer to the Universities. 1652.

The following extract from a chapter dealing with the "adulteration of Gemms" will, no doubt, interest readers.

"Any thoroughly transparent tinctured gemm what ever, may be adulterated by two Saphires, or with two Crystalls, having a foyl betwixt them. But such duplicated gemms, which are tinctured either with a foyl of Mastick, or with other coloured foyls in their intermediate space, are thus ordinarily and usually discerned by Jewellers ; they will take the gemm and put it upon their thumb nail, and then direct their sight betwixt the plain of the gemm and of their nail ; and if the upper part of the gemm be white, and no colour be added (which lying hid under the sides of the cistæ can there be perceived) then the upper part of the gemm will plainly appear white as it is, and so it will discover it self to be an adulterated gemm instead of the naturall one. This is a very easy way to discover factitious gemms from naturall ones. But those factitious gemms which consist of many angles fitted for this purpose, by various sections, hollowings, and excavations cannot so easily be perceived, because the reflections from the angles, do give tincture from the foyl in every part of the superficies of the gemm. Another kind of ingenious fraud there is, by which gemms are adulterated, and that is when as cunning Artists do excavate a gemm, as a white Saphire, or a Crystall, in the lower part of it with a very small foramen, and then infuse into it a drop of some transparent liquour, which being artificially done, will very excellently diffuse its colour through the body

of the whole gemm: Thus the idea's of true Rubies, Saphires, Samaragdes are produc'd. There is another kind of way of subtill fraud in gemms, when as cunning sophisticatours do macerate gemms in coloured or tinctured waters, or so tincture them in fire, or by any other means, that the tincture or colour may enter the body of the gem. These frauds can no otherwise be discovered, but by taking the gemms out of their cistis, enclosures or settings, and so taking a naked view of them with full sight. As for other gemms which are dissembled with tinctured glasse, these for the most part seem to have a pellicula or little film in their superficies, as if they were anointed with oyl, which is never to be found in true gemms. There are factitious gemms made of Crystall, and of flints, and lead, which will be harder then the common glass, and transparent as Crystall, in the making of which, to tincture them, cunning artists are wont to adde metalls to it or tinctures, or colours of metalls, and thus they being committed to the fire, by the operation of the heat upon them, will be produced a gemme scarcely to be discerned from the true gemm, have only by the atomes in the middle of their bodie, and by those small bullæ which are often caused in them by the unequall working of the fire upon their matter, or by the extreme behemencie of its heat. Of these kinds of factitious gemms there are some so perfect, and free from the small bullæ and atomes, as they can no wayes be discerned from the true gemms but by the use of the file ; for these may be filed, the true ones cannot, except onely the Topaz and Samaragde: and by their gravities, weight and ponderosity ; for these factitious stones are much heavier then the true, as consisting of lead and metalls, which are very ponderous and weighty ; and by their pining, dead, fading look, which if they be long beheld, do afford no pleasure to the eye by feeding it ; whereas in true gemms there is always a lively splendour, which by reason of the reflections of the severall tables or sides of the superficies, gives it self forth with the more sparkling delight.

Another way of adulteration of gemms there is, very subtill, and more excellent then any of the former, which is this, Cunning Chymists will make a lapidifick water mineralls, and then poure of it into waxen forms, which forms they will immerge for some time in an indurative water, and thus produce a gemm not unlike to the true."

OFFICIAL NOTICES

HONORARY FELLOWSHIPS

The Council of the Association has awarded Honorary Fellowships to William Francis Porter McLintock, D.Sc., F.R.S.E., F.G.S., Director of H.M. Geological Survey and Museum, and Walter Campbell Smith, M.C., T.D., M.A., Sc.D., F.G.S., Keeper of Minerals in the British Museum of Natural History, for the services that they have rendered in connection with the study of gemmology.

EXAMINATIONS

The 1947 Examinations in Gemmology were held in Great Britain on June 25th, 26th and 27th at various cities, and also in Australia, Canada, U.S.A., Mexico, India, Ceylon, Denmark, Hong Kong, Holland, Palestine, Siam and South Africa.

1947/1948 COURSES IN GEMMOLOGY

The 1947/48 Classes and Courses in Gemmology will commence in the last week of September, 1947. Classes will be conducted at the following centres in Great Britain:—

London. Chelsea Polytechnic, S.W.3.
Edinburgh. Heriot-Watt College.
Glasgow. Stow College.
Birmingham. Jewellers' and Silversmiths' School.
Plymouth. Plymouth Technical Institute.

The Correspondence Courses (Preliminary and Diploma) will be conducted on the usual world-wide basis.

Information about the Classes or Courses may be obtained from the Secretary of the Association.

GIFTS TO ASSOCIATION

The Council records with appreciation the following donations that have been made to the Association during the first six months of 1947:—

Mrs. Gwen Parry, £21.
Sir James Walton, £4 4s.
John H. Pope (Australia), £5 5s.
M. D. S. Lewis, £2 2s.
A. S. Murray, £2 2s.
H. R. Gooch, £1 1s.
F. Bryan, £1 1s.

AUTUMN DANCE

An Association Dance will be held at the Victoria Halls, Bloomsbury, London, W.C.2, on Thursday, October 16th, 1947, from 7 p.m. until midnight. Further details will be sent to all members in due course.

FIRST GENERAL MEETING

The First General Meeting of the Association, since the date of Incorporation, was held on Thursday, June 19th, 1947, in the Hall of the Chemical Society, Burlington House, London, W.1. The Officers and Council of the Association elected for the ensuing year are:—

Officers.—President: Dr. G. F. Herbert Smith, M.A., D.Sc. Chairman: Mr. F. H. Knowles-Brown, F.S.M.C. Vice-Chairman: Dr. G. F. Claringbull, Ph.D., B.Sc., F.G.S. Honorary Treasurer: Mr. S. F. Bones.

Council.—Sir James Walton, K.C.V.O., Messrs. B. W. Anderson, R. Blott, G. Clarkson, M. L. Crombie, T. G. Jones, R. Webster, J. H. Stanley, E. R. Levett.

During the discussion that followed the Meeting it was advocated that post-diploma students might prefer to work to a set course rather than to study individually. Suggestions made included the holding of specialist lectures, talks given by Fellows and provision for refresher courses. The Council will endeavour to meet these needs according to the accommodation available.

Helpful suggestions regarding the *Journal of Gemmology* were made, the general impression being that members desired the articles to be of academic nature.

In the Autumn the history of the Association from 1908 will be brought up to date, as well as statistical information, and will be published in a Year Book containing the Constitution and Bye-Laws and a list of Fellows and Members.

TALKS BY FELLOWS. JANUARY-JULY, 1947

February.—S. T. Solomon, F.G.A., Launceston Rotary Club, February 17th. Subject: "Gemstones." F. Leak, F.G.A., Bristol and West of England Jewellers' Association (Western N.A.G. Section), February 20th. Subject: "Science of Jewellery."

March.—J. Gilloughley, F.G.A., Paisley Philosophical Institution, March 18th. Subject: "Gemstones." T. H. Bevis-Smith, F.G.A., Talks for staff training purposes, March 13th and 20th. Subject: "Synthetic Gemstones." A. R. Popley, F.G.A., staff training talk, March 21st. Subject : "Jewellery Manufacture."

April.—F. Leak, Toc H, Mark IX Group, April 14th. Subject: "Science of Jewellery." S. T. Solomon, F.G.A., Plymouth Soroptomists, April 11th. Subject: "Gemmology." R. Webster, F.G.A., London Central School of Arts and Crafts, April 25th. T. G. Jones, F.G.A., London Central School of Arts and Crafts, April 18th.

May.—F. Leak, F.G.A., Bristol Toc H (Women's Section), May list. Subject: "Science of Jewellery." W. A. Peplow, F.G.A., Stourbridge Inner Wheel Club, May 13th. Subject: "Jewels."

ASSOCIATION DINNER

The President, Dr. G. F. Herbert Smith, M.A., D.Sc., presided at the First Annual Dinner of the Association, which was held at the Waldorf Hotel, London, W.C.2, on Thursday, May 15th, 1947. Dr. W. F. P. McLintock, D.Sc., F.R.S.E., Director of H.M. Geological Survey and Museum, Sir Lewis Fermor, O.B.E., F.R.S., former Director of the Geological Survey of India, Dr. W. Campbell Smith, M.C., M.A., Sc.D., Keeper of Minerals, British Museum of Natural History, Mr. G. R. Hughes, C.V.O., Clerk to the Worshipful Company of Goldsmiths, Mr. I. Short, President of the British Jewellers' Association, Mr. J. Lees, Chairman of

the London Wholesale Jewellers' Association, Mr. R. D. Dale and Mr. C. D. Sonn, of the Diamond Trading Company, Mr. H. B. Southam, M.B.E., Mr. J. Pike and representatives of the Trade Press were present as guests of the Association.

Members present, representing kindred organizations, were Mr. J. J. Holgate, Chairman of the National Association of Goldsmiths, and Mr. A. W. Blott, Chairman of the London Jewellers' Council.

The Chairman of the Association, Mr. F. H. Knowles-Brown, proposed the Toast of the Guests, and Dr. W. F. P. McLintock responded. Sir Lewis Fermor proposed the Toast of the Association and the reply was given by the President.

Fellows and Members present included:—R. V. Blott, S. F. Bones, J. Blott, E. Bamber, T. H. Bevis-Smith, G. Blythe, M. L. Crombie, T. P. Cuss, D. Corfield, W. B. Crombie, Mrs. H. Corfield, J. K. Cairncross, H. Cropp, Miss V. M. Benson, E. C. Cull, H. C. Diss, M.B.E., J. F. Croydon, F. E. L. Clarke, Miss K. Dyson, G. F. Claringbull, Ph.D., B.Sc., Mrs. E. Holdsworth, N. Harding, O. D. Fahy, T. G. Jones, Mrs. M. Meisl, J. S. Miles, G. Lindley, Mrs. G. Lindley, T. L. Ellis, R. Lucas, R. K. Mitchell, E. H. Neale, N. A. Harper, A. Kermeth, A. G. Nicol Smith, D.S.O., W. N. Kennedy, M. D. S. Lewis, B.Sc., Mrs. G. Parry, B.Sc., K. Parkinson, S. F. Redknap, J. W. Reynolds, Mrs. A. M. Sharpe, A. W. Peplow, A. R. Popley, T. G. Shenton, J. H. Stanley, J. H. Saunders, E. Trillwood, S. C. Sears, W. A. Perry, S. T. Solomon, Sir James Walton, K.C.V.O., H. Wheeler, D. Wheeler, F. Waller, Miss C. Watson, R. W. Yeo, J. B. Mennie, R. Webster, G. F. Andrews, Dr. W. Stern, F. E. Ullmann, Miss W. Willis.

AUSTRALIAN VISITOR

The Association recently had the pleasure of a visit from Mr. M. Stevenson, F.G.A., of Adelaide, Australia. Chairman of the South Australian Branch of the Gemmological Association of Australia, Mr. Stevenson was extremely interested in the activities of the British organization. He gave encouraging news of the rapid expansion of the Australian Association.

Mr. Stevenson is one of a small band of Australian Jewellers who have qualified in the British Association's Examinations. In addition to Mr. Stevenson, who is a 1927 Diploma holder, there is Mr. J. H. Pope, of Melbourne, Diploma 1946, and Mr. J. Henderson, also of Melbourne, who is an Associate.

AMERICAN VISITOR

On his return to America from a visit to the Middle East Dr. A. E. Alexander, Ph.D., Director of the Gem Trade Laboratory, New York, broke his journey at London to visit the London Gem Testing Laboratory and to discuss experiences with Mr. B. W. Anderson. During his visit Dr. Alexander found time to visit the Gemmology Classes at Chelsea Polytechnic, where he was interested in the work of post-diploma students, and also to visit retail jewellers in the West End of London. He also had an opportunity for meeting his war-time counterpart in Mr. T. G. Jones, as both were then engaged upon similar work connected with the insulating of sparking plugs, Dr. Alexander's visit has been much appreciated by all those who had the pleasure of meeting him during his brief stay in London.

THE JOURNAL OF GEMMOLOGY
AND PROCEEDINGS OF THE GEMMOLOGICAL ASSOCIATION OF GREAT BRITAIN

Vol. I No. 4 OCTOBER 1947

TWO NEW EDITIONS

TWO outstanding personalities of British Gemmology have recently published new editions of their books.* In each case the book is enlarged and enriched and in each case there is the omission of a qualifying phrase from the former title.

There are two extremes in the writing of scientific books, with all degrees of combinations in between. One extreme is the compendium type of book, which at its best is a carefully prepared dossier composed of relevant information from all sorts of sources. When made by an expert with access to many sources and with the knowledge necessary to select, arrange and present the material gathered, the result can be a reference book of great value and a distinct contribution to the literature of its special subject.

Mr. Anderson's "Gem Testing," formerly "Gem Testing for Jewellers," belongs to the opposite extreme. In this class of book a man who has devoted a great part of his working life to the subject pours out all the knowledge and wisdom accumulated as the result of his personal study and experience. A man can write only one general book of this class in a normal lifetime, although, of course, more detailed treatises on specialized aspects may well appear from the same pen.

* "Gem Testing," by B. W. Anderson, B.Sc., F.G.A., 4th Edition. Heywood & Co., Ltd., London. Price 17s. 6d.

"Gemmologist's Compendium," by Robert Webster, F.G.A., 2nd Edition. N.A.G. Press, Ltd., London. Price 15s.

Mr. Anderson is a scientist by education, a specialist in the study and identification of gemstones by profession and a lecturer and teacher of exceptional renown: and it is abundantly clear to the serious reader of this great book that here is the genuine article straight from the fountain head. In a work of this calibre, packed with the knowledge and understanding which could only be accumulated by a first-class mind with exceptional opportunities, faults of diction and arrangement could well be forgiven, but we have here a book brilliantly written and admirably planned, with an index which is a joy to use.

Perhaps the most striking feature is the way the author leads his readers to appreciate and employ scientific methods. The distaste and mental paralysis liable to seize the ordinary person plunged into a flood of scientific and sometimes pseudo-scientific jargon are absent, because the scientific principles and terms are presented in a way which is at once the admiration and despair of writers of popular science.

The numerous illustrations are an integral part of the book. The frontispiece is a colour plate of nine typical absorption spectra, and practically all the instruments mentioned or described throughout the text are illustrated. But the great majority of the illustrations are photographs of the author's own taking, showing just what to look for when examining a stone through the microscope. These effects are quite impossible to convey in words, and to have an expert select a specimen, adjust the instrument and invite the reader to study the image at leisure is tuition at its best. This is precisely what, in effect, these remarkable illustrations do.

Only the author could find ways of improving the earlier editions ; just what more can be done when a fifth edition becomes due for consideration is a mystery which we shall look forward to seeing solved.

Mr. Robert Webster's 1937 " Gemmologist's Pocket Compendium " has now reached its second edition, and is so much enlarged that the word " Pocket " is wisely dropped. My copy of the original little red book is soiled, frayed and worn: dumb testimony to the constant usage it has had.

This book is an example of the type first mentioned, inasmuch as it is compiled rather than written. It presents in tabloid form

a most comprehensive survey of the whole field of Gemmology and its neighbouring districts. Essentially a reference book, it is so complete and all-embracing that there is scarcely a question can occur to the gem student but the answer will be found, not by patient searching, but at first sight. The amazing Mr. Webster has achieved an unassailable position in the gem world by immeasurable industry and an infinite capacity for taking pains, coupled with sheer native intellect of a high order. His Compendium is an indispensable book built on the same basis.

As before, the book is divided into an alphabetical Glossary of Definitions, and a Part Two comprising general data in tabular and other concise forms. Besides a number of line illustrations, the new edition contains fourteen half-tone blocks and ten beautiful colour plates, all on art paper. Special interest and value attaches to the twenty typical Absorption Spectra. Five-figure logarithmic tables are included for convenience in making any necessary calculations. One questions whether some of the chemical data dealing with valency, atomic weights and atomic numbers, and especially the periodic classification of the elements, will be very much used ; but they are there if needed.

One notices minor discrepancies between the Spectra for alexandrite and blue spinel as given in " Gem Testing " and the " Compendium," but in spectroscopic work so much depends upon the individual specimen, the illumination, the instruments used, and above all on the personal observation factor, that such slight differences will always occur. The one thing to be condemned in scientific books is the perpetuation of errors by successive authors who blindly copy earlier works, and one finds no trace of this mischievous and all too prevalent practice in the Compendium.

G. T. CLARKSON, F.G.A., M.B.H.I.

NEW OFFICES OF THE ASSOCIATION

The Gemmological Association of Great Britain and the National Association of Goldsmiths of Great Britain and Ireland have now moved to

93-94, Hatton Garden, London, E.C.1.

The telephone number remains unaltered.

MICROCHEMICAL TESTS CAN BE USEFUL

by

Robert Webster, F.G.A.

THE employment of chemical tests usually infers the partial destruction of the specimen and is therefore considered to have little application in practical gemmology. A number of chemical tests can, however, be carried out on the micro-scale ; where only small scrapings from the specimen are required, small quantities of chemical reagents used, and the resulting reactions studied under the microscope. The value of these tests may perhaps best be illustrated by relating an actual case where their use afforded confirmatory evidence of the nature of a substance, and where the more usual optical methods could not be employed.

The article, a necklace of irregularly-shaped ivory-white beads, came into the hands of the writer, not necessarily for testing but as an item of interest, for they were described as being the milk teeth of a young animal. As a point of interest rather than for a more pertinent reason it was decided to carry out tests for calcium and for phosphate. It is well known that the teeth of all mammals consist mainly of calcium phosphate, and if both calcium and phosphate were found to be present, there could be little doubt that the material was as described. To unstring the beads was considered unnecessary so tests by the microchemical method were carried out.

The test for calcium was made by scraping a small quantity of the material from the edge of the string canal on to a 3 x 1 glass microscope slide, drawing the powder into a heap in the centre of the slide and adding a drop of dilute hydrochloric acid from the end of a glass rod. After allowing a minute for the acid to combine with the suspected calcium of the substance, a drop of dilute sulphuric acid was added, and the action studied under the microscope.

Fig. 1 — Calcium Sulphate Crystals resulting from microchemical test (approx. x 20).

With such a test, if calcium be present, a white precipitate of calcium sulphate is formed which, under the microscope, is seen as bunches of acicular crystals of gypsum (*selenite*) ; the singular beauty of these radiating crystal groups can be best appreciated by reference to the photomicrographs. This crystalline precipitate was clearly evident in the test carried out on the beads, hence, calcium was confirmed as being part of their composition.

The presence of phosphate in a material may be determined by the yellow precipitate which is formed when a solution of ammonium molybdate in water is added to a solution of the material in nitric acid. This test was therefore carried out on scrapings from the beads ; the scrapings placed on a glass slip, nitric acid added followed by the drop of aqueous solution of ammonium molybdate. NO REACTION WAS FOUND TO TAKE PLACE. To prove that neither the method nor the reagents were at fault a check test was carried out with scrapings from a known ivory. In the check test a canary-yellow precipitate formed, which under the higher powers of a microscope was seen to consist of small yellow octahedral crystals (*see photomicrograph*). This yellow precipitate, ammonium phospho-molybdate, forms much more quickly if the slide is warmed, but in practice the heat from the microscope lamp is sufficient to ensure copious precipitation.

Thus, the microchemical tests tended to disprove the contention that the beads were " the milk teeth of a young animal." The beads were then unstrung and a density taken to obtain further evidence as to the nature of the material. A bead weighing 7.72 carats gave a specific gravity for the material of 2·82, a value which agrees with that of the calcareous shells of certain mollusca. Final confirmation was carried out by X-rays, a lauegram giving a picture comparable to that shown by fibrous aragonite ; in fact, a typical cultured pearl picture. From the evidence obtained from these experiments the material was identified as marine shell, probably waterworn pieces of the thick central pillar of spiral shells.

It can be seen that microchemical tests (and there are many chemical reactions which can with advantage be studied under the microscope) can have a distinct value to gemmologists. This is particularly true in the case of certain opaque substances which do not easily lend themselves to optical methods. A word of caution must be given concerning the ammonium molybdate test for phosphate, for arsenates produce the yellow precipitate of ammonium arseno-molybdate indistinguishable from ammonium phosphomolybdate. However, in the very complete tables given by Dr. Herbert Smith in *Gemstones*, arsenic does not enter into the composition of any gem material so far encountered. That an arsenate mineral may turn up in the future cannot be overlooked ; the writer, during an investigation of turquoise, once came across a green mineral labelled *kalait*, which was identified by Dr. Bannister as *erinite*, a copper arsenate, and the sky-blue to verdi-

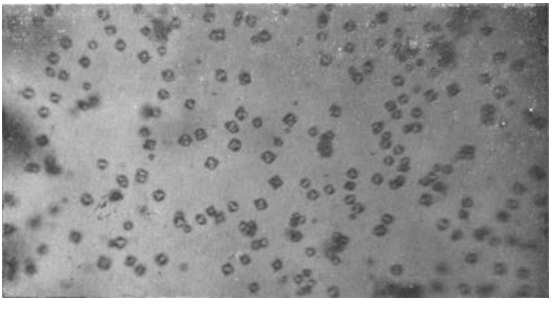

Fig. 2 — Ammonium Phospho-Molybdate Crystals resulting from microchemical test (approx. x 85).

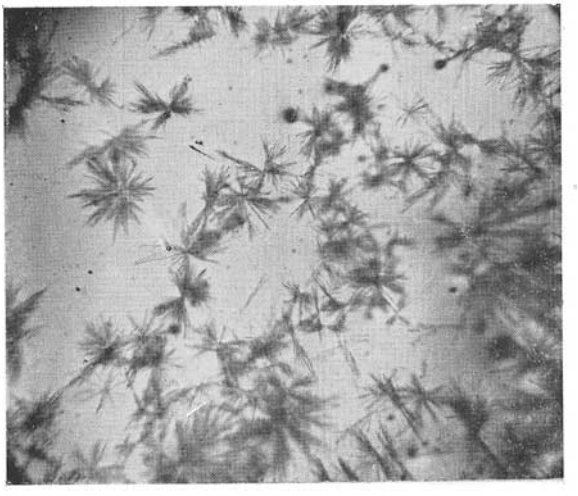

Fig. 3 — Calcium Sulphate Crystal resulting from microchemical test (approx. x 50).

gris-green mineral *liroconite,* a hydrated arsenate of aluminium and copper, is always a possible " turquoise."

To carry out known microchemical tests is a fascinating experience ; for those versed in chemistry to devise fresh reactions a perfect joy, and those with only an elementary knowledge of that science, whose only experiments must of necessity be on the " hit or miss " principle, can enjoy an intriguing hobby.

THE WORK OF THE GEMMOLOGICAL CENTRES

Enrolments at the various Gemmology Centres in Britain and in the Correspondence Courses continue to remain high. Over 55 have applied to attend at Chelsea Polytechnic for the Diploma (second year) Class, while 100 have entered for the Preliminary. Enrolments in the Correspondence Courses total 75 Preliminary and 51 Diploma. Figures for other centres are: Edinburgh, 30 Preliminary and Diploma ; Plymouth, 20 Preliminary ; Birmingham, 40 Preliminary and Diploma ; Glasgow, 64 Preliminary.

By D. S. M. FIELD

CANADIAN AMBER

IN the report of the Canadian Geological Survey for 1876-77, Dr. B. J. Harrington records that results of the examination of samples of fossil resin from the north Saskatchewan River, the Peace River, and from the Nechacco River south of Fort Fraser. The occurrence of amber at Cedar Lake, Saskatchewan, has also been known for many years. It is only comparatively recently, however, that fine quality " gem " amber has been noted in a quantity sufficient to warrant commercial recovery.

In December, 1921, a considerable amount of fossil resin was recognized in the waste dumps at the Coalmont Collieries, Coalmont, B.C., and a sample of lignite containing 10 cubic inches of opaque resin was submitted to the Department of Mines, Ottawa, for identification. It proved to be amber. This specimen fluoresced strongly in sunlight—reflecting a brilliant apple-green from the conchoidally fractured surfaces.

Most of the amber from Coalmont is transparent to translucent, varying in colour from pale yellow through brown to bottle-green and black. The darker specimens are almost invariably opaque. Some pieces are quite transparent and free from flaws, and are a bright, pleasing cherry-red colour. These resemble clear Mexican and Nevada opal of a similar tint..

Fragments of Coalmont amber submitted for test to Mr. R. T. Elsworthy, of the Mines Department, yielded only a small amount of succinic acid, and on this basis the resin was classified mineralogically as retinite.

It occurs close to the edge of seams of low-grade lignite, between the coal and slate contact, or as isolated, irregular fragments.

It is quite brittle and in common with all amorphous mineral substances or gem materials has a conchoidal fracture. There are, of course, no cleavage planes.

The hardness of Coalmont amber varies somewhat. Most pieces will readily scratch the better grades of Baltic amber (H. 2.0—2.5), but none will scratch calcite (H. 3). The hardness is therefore about 2.75 on the Mohs scale.

Owing to the presence of numerous gas bubbles, the specific gravity (hydrostatic and "heavy" liquids) varies within the limits 1.031—1.168. It softens at 180° C. (5 gm.)—200° C. (25 gm.), with melting point 250° C.—270° C. and 270° C.—297° C., respectively. The percentage by weight of oil distilled during the Government experiments ranged from 60 to 76.

Coalmont amber is much less soluble in ether than is the Prussian variety. Experiments carried out by the Mines Branch, in which the resins were powdered and subjected to the boiling solvent (in special flasks) for several hours, gave the following figures:—

Solvent	Per cent. soluble Coalmont	Per cent. soluble Prussian
Ether	5.0 ...	... 18.8
Absolute alcohol ...	8.7 ...	... 14.3
Acetone	10.8 ...	... 23.3
Chloroform	38.4 ...	... 17.3

The finer grade selected pieces are quite suitable for beads, pipe stems, cigar and cigarette holders, small carved objects and the like. Smaller fragments, and inferior material, might be pressed into "block amber" or employed in the manufacture of lacquers and varnishes.

An increased number of synthetic stones have recently been submitted for testing, including the synthetic sapphire that simulates alexandrite.

■ ■ ■

It was reported to the Association that an embryo gemmololist had, on looking at a natural amethyst through a colour filter, diagnosed the stone as a synthetic. Thus do the inexperienced falter.

SELECTIVE REFLECTION and its possible bearing on Gemmology

By M. D. S. LEWIS
A.R.C.S., B.Sc., F.G.A., C.G.

PALE emeralds or even colourless quartz when closed at the back are often foiled, a process which if skilfully performed can impart quite a good emerald colour to virtually colourless stones. When recently examining a piece of this green foil the writer was surprised to find that it showed slightly red through the Chelsea Filter. A white paste or quartz when placed on the foil and viewed from certain directions appeared definitely pink. This is probably an example of the phenomenon known as " Selective Reflection."

Most transparent coloured substances appear approximately the same whether viewed by transmitted or reflected light. If we hold an emerald between our eye and a source of light it appears green because the rays during their journey through the stone have suffered some preferential absorption. If we now move the emerald so that light is reflected from it to our eye it still appears green for the same reason. A small proportion of the white light falling on the stone is reflected at the surface still as white light, but the majority of the rays enter the stone. Some are there scattered by inhomogeneities and others are reflected at the back facets to reach our eye. In both cases the light has travelled an appreciable distance through the stone. This is an important condition, implying that substances of this type have small absorbing power, or as physicists say a low " coefficient of absorption." Red glass when finely ground yields a white powder, the particles of which, being small, cannot impose sufficient absorption on white light to produce colour. For the same reason the froth on beer appears white.

There exists, however, another class of substance, of which the organic dyestuffs are typical, characterized by intense colour, high coefficient of absorption, and bands in the visible spectrum of almost metallic intensity. In these, light cannot penetrate more than a wavelength or so and they possess the peculiar property of appearing differently coloured according to whether they are viewed by transmitted or reflected light. If the dyestuff methyl violet be dissolved in alcohol an intense violet coloured solution results. A drop placed on a glass slide soon evaporates, leaving a thin film of dye which is violet by transmitted light, but green by reflected light. This strange behaviour—known as selective reflection—is due to abnormal changes of refractive index occurring in the neighbourhood of an intense absorption band.

In idealized form a graph connecting the Refractive Index of such a substance and the wavelength of the different rays would probably take this form:—

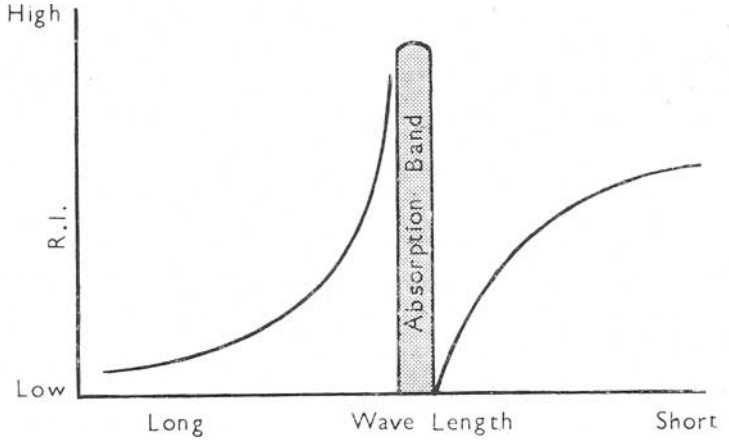

It will be observed that on the long wave (red) side of the absorption band the R.I. becomes very large and on the short wave (blue) side very small. Now the reflective power of a substance depends on its R.I. For light incident perpendicularly, the proportion reflected is given by the expression $\left(\frac{n-1}{n+1}\right)^2$ where "n" is the R.I. (If we substitute the values 2.42 and 1.5 respectively, we find that diamond reflects about 17% and glass 4%—hence the far greater brilliance of diamond.) It follows, then, that those rays

with high R.I. on the left hand side of the absorption band will be predominantly reflected whilst those with low R.I. on the right hand side will be mainly transmitted and almost entirely absent from those reflected at the surface. Suppose the absorption band is in the green, then the rays reflected at the surface will have a very strong yellow component but almost no blue. The transmitted light will be strong in blue and deficient in yellow. This is the cause of the difference between body colour (due to transmitted light) and surface colour (due to selective reflection) although a certain amount of the former is always present with the latter.

By this stage many readers may have become distinctly uneasy, because when the absorption band occupies a central position in the visible spectrum the rays of long wavelength, say orange, have a greater refraction than those of short wavelength, say blue, all of which is quite contrary to gemmological teaching. This apparently peculiar behaviour is known as " anomalous dispersion," but actually there is nothing very strange about it. If now we turn to " Herbert Smith "—always a wise procedure in gemmological discussions—we find on page 23 a quite impeccable, well behaved dispersion curve for diamond (reproduced below).

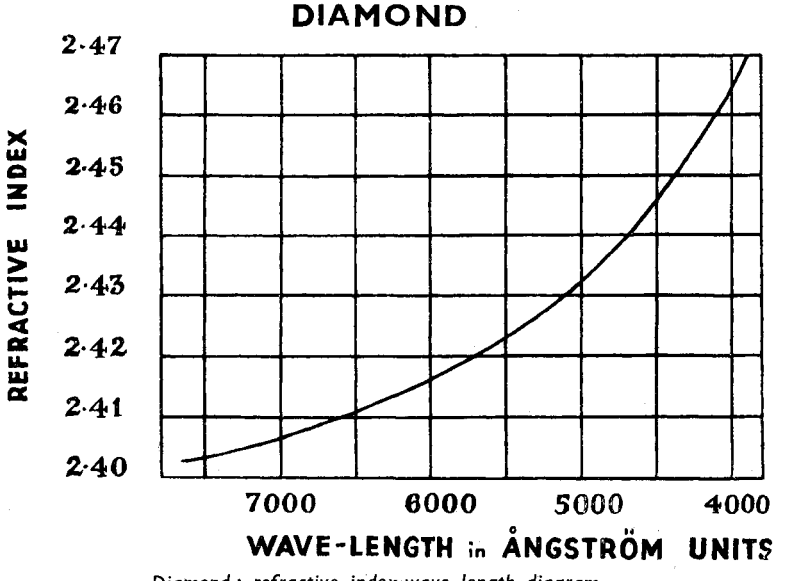

Diamond: refractive index-wave length diagram

It will be noted, however, that on the right the curve is beginning to rise very steeply and the R.I. has already reached a high value. It is probable that an absorption band is being approached, to the left of which the R.I. will be very high and if the graph is sufficiently extended the curve will reappear somewhere low down to the right of the band. We may, therefore, here only be looking at a part of the picture. In fact, the suggestion has been made that most substances show anomalous dispersion if considered over a wide enough range of wavelengths, the so-called " normal " dispersion being merely a special case of the anomalous, over a comparatively small range of wavelengths. Unless the absorption band is really intense and in the visible spectrum, we do not notice any abnormal effects.

Returning to our green foil, which will probably be found to consist of a thin sheet of bright copper covered on one side with a film of green dye. Most of the rays pass through the latter and are reflected at the metal, emerging as transmitted light of a predominantly green colour. At certain angles, however, we catch the selectively reflected rays—in this case red. Although it is just possible that colourless stones thus foiled might show red through the Chelsea Filter, a spectroscopic test (by reflected light) at once shows that the green colour is not due to chromium and that the stone is therefore not an emerald.

There remains one further aspect of " selective reflection " with a possible bearing on gemmology. We have seen how the whole phenomenon turns on R.I., but this is always dependent on *two* substances in contact. Thus, when we speak of the R.I. of a gemstone we really refer to the gemstone-air boundary. If the stone is immersed in a liquid the R.I. is different, because here we are dealing with the gemstone-liquid interface. The colour then selectively reflected from a dye may vary according to the substance on which it is deposited. If we look at our spot of methyl violet (deposited on a glass slide) by reflected light it appears green at the dyestuff-air interface. If now we reverse the slide so that the spot is underneath and again view it by reflected light it appears quite another shade of green because here we are dealing with the dyestuff-glass interface. The difference of R.I. between glass (1.5 approx.) and air (1.0) produces this change of tint. The

writer had hopes that white stones of varying R.I. (diamond, zircon, corundum, quartz, etc.) might show different colours when a selectively reflecting dye was deposited on them. Although numerous dyes were experimented with, no tangible results were obtained with the unaided eye, but there remain perhaps theoretical possibilities. One difficulty is due to the appearance of interference colours of typical " thin film " type which tend to mask slight changes of tint. It is of interest to note that the normally reflected rays are almost completely plane polarized at Brewster's angle and can therefore be extinguished by a Nicol prism, but the selectively reflected rays cannot thus be removed as they are elliptically polarized. Readers interested in this subject should consult the articles on " Selective Reflection " and " Anomalous Dispersion " in Wood's " Physical Optics," Preston's " Theory of Light " or Bowen's " Chemical Aspects of Light " (2nd edition).

THE TERM " SEMI-PRECIOUS "

In connection with the Gemological Institute of America's recommendation that the term " semi-precious " should no longer be used, it is interesting to quote from the Retail Jewellers' Course of the National Association of Great Britain: " The term ' semi-precious ' is often used in the jewellery trade to describe those gemstones that remain after diamond, ruby, sapphire and emerald have been grouped as ' precious.' It is not a fair division and not even logical. It is true that in many cases there is a drop in prices per carat after the ' precious ' varieties named due mainly to the fact that other gemstones are often found in great quantity, but this fact should not allow the jeweller to prejudice public interest (or even his own) in lesser known gemstones, some of which are very beautiful.

The term ' semi-precious,' being open to misunderstanding, should be discontinued, and all real stones referred to as ' gems ' or ' gemstones.' "

Some Vagaries of BIREFRINGENCE

by R. KEITH MITCHELL F. G. A.

IT is a simple matter to consider refraction in gems from an elementary viewpoint ; to use white light for refractometer work and to be content with readings from diffracted shadow edges, hazily accurate to two places of decimals at most. But the deeper one goes into gemmology the more necessary it becomes to work accurately ; to use monochromatic light to estimate that third decimal place which is important for the determination of many of the lesser-known gem minerals. The advanced worker soon realizes that the so-called " constants " of a gem are in fact averages around which there can be quite considerable variation ; a fact exemplified more in the refractive indices than in most other physical characteristics. It is evident that in many cases the behaviour of the readings as the stone is turned on the refractometer is of great importance as a diagnostic feature.

In order fully to understand the fluctuations which may be observed in the indices of doubly-refractive stones it is necessary to remember one or two facts about the instrument. Although the shadow-edge is ingeniously projected on to a scale giving a direct reading of the R.I., it is in actuality a projection of the shadow occasioned by the critical angle for the two media (the optically dense glass and the stone under test). That is to say, the angle of incidence within the glass which produces an angle of refraction in the stone of 90° to the normal. It therefore follows that the instrument cannot give the R.I. for any direction other than those in the plane of the facet under test. And since the light is

FOOTNOTE.—It should be emphasized that the word " direction " is used expressly in its strict meaning, and although a direction may be represented in a figure by a single line, the optical properties described will apply equally to light passing through any part of the stone or crystal in a path parallel to that line.

travelling in a parallel path through the instrument, any given reading will be for a direction parallel to the optical axis of the instrument and to the facet under test. The principle of the refractometer (Fig. 1) will illustrate these points.

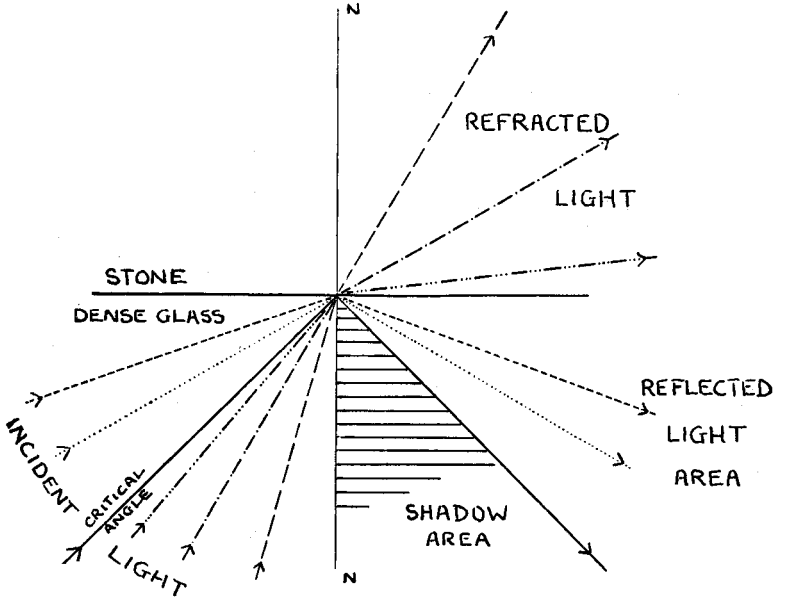

Fig. 1 — Principle of the Refractometer. Incident light entering at the critical angle will graze the surface dividing the glass from the stone. Light entering at a greater incident angle will be totally reflected within the dense glass.

Cubic or isotropic gems tested in monochromatic light and rotated on the instrument will show no variation in their single refractive index, since light is refracted equally in all directions within the stone and no plane polarization takes place. Singly refractive gems are not numerous and are widely distributed on the scale of refraction. When once the slight possibility of confusion with paste is eliminated, there is no further difficulty unless an abnormally high spinel reading be mistaken for an equally abnormal low reading for garnet.

In gems belonging to the other systems of crystal symmetry the case is different. The incident light is split under the influence

of the atomic structure of the crystal into two rays plane-polarized at right angles to each other, and having different velocities and hence different refractive indices. In tetragonal and hexagonal crystals there is one direction or axis of single refraction which is parallel to the long or *c* axis of the crystal, and they are known as "uniaxial." Orthorhombic, monoclinic and triclinic crystals are optically biaxial, having two directions of single refraction.

When tested, gems of these five systems give two readings which in most cases show a fluctuating amount of birefringence as the stone is rotated. The manner and degree of movement of the shadow edges depends in part upon the orientation of the testing facet to the optic axis or axes.

In the uniaxial gems of the tetragonal and hexagonal systems one of the two readings, that for the ordinary ray, will not move, while that for the extraordinary ray will generally move as the stone is turned. The birefringence being greatest when the direction of test is at right angles to the optic axis. If the movable shadow-edge gives the higher reading, the stone is optically positive and vice-versa.

Figure 2 shows a stone cut from a hexagonal crystal with its table facet parallel to the optic axis. In tests on this facet the extraordinary reading will fluctuate between the position of greatest birefringence and the position of the reading for the ordinary ray as the stone is rotated. So that in two positions the stone will appear to be singly refractive.

In Figure 3 the stone is cut with the table at right angles to the optic axis of the crystal. All tests on this facet will therefore be in directions at 90° to that axis ; the extraordinary reading will remain at the position of greatest birefringence and neither shadow edge will move as the stone is rotated. A test on another facet would be necessary before the optic sign could be determined.

Figure 4 gives us a case between these two extremes. The table is inclined to the optic axis and therefore in no position of this facet can a test be made parallel to that axis. In two positions of the stone, however, the readings will register the full birefringence of the stone. The readings for the extraordinary ray will therefore fluctuate from the optimum position to one approaching that of the ordinary ray, but will not coincide with it. The

degree of movement will vary with the angle made by the table facet with the direction of single refraction.

In the biaxial gems of the remaining three systems the effects seen are more complicated.

There are two directions of single refraction and three principal optical directions generally indicated by the signs α, β and γ. α and γ are the two bisectrices of the optic axes and β the direction perpendicular to the plane in which they lie. α and γ correspond to the least and greatest refractive indices while β corresponds to their optical (not mathematical) mean. If the index for β is nearer that for α than that for γ the optic sign is positive, and vice-versa. In a negative crystal α, and not γ, will be the acute bisectrix. These optical directions are indicated in Figure 5 in their relation to the directions of single refraction. The behaviour of the refractive indices can be more directly referred to them than to the optic axes.

If a gem be tested in any one of these principal optical directions the readings will correspond to those for the remaining two directions. Thus light passing through the stone parallel to β will be plane-polarized at right angles, the wave motions being in the directions α and γ respectively, and the readings obtained will be for the least and greatest indices. It will be obvious, then, that complicated results may be expected as the orientation of the testing facet changes with regard to the principal optical directions.

In Figure 6 we have the case of a stone with its table facet parallel to the plane of the optic axes (and incidentally to α and γ) and perpendicular to β. It should be a simple matter to see that as the stone is rotated through 360° there will be four positions in which it will be apparently singly refractive, with a reading corresponding to the mean R.I. (β); two readings for the least (α) and mean (β) R.I.'s ; and at right angles to these two more giving the mean (β) and greatest (γ) R.I.'s. In effect, then, one shadow edge will remain steady and give the mean index, while the other will cross the first as it fluctuates between the least and greatest readings.

The stone depicted in Figure 7 has its table facet parallel with the plane of β and γ and perpendicular to α. If this facet is

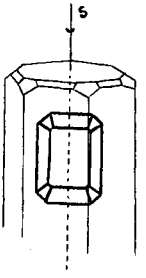

Fig. 2.

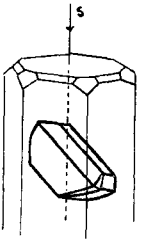

Fig. 4.

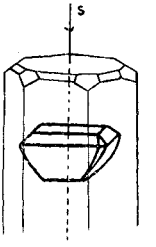

Fig. 3.

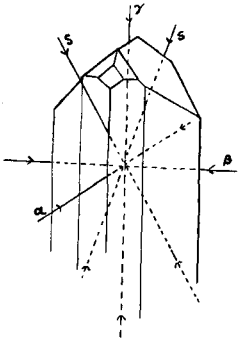

Fig. 5.

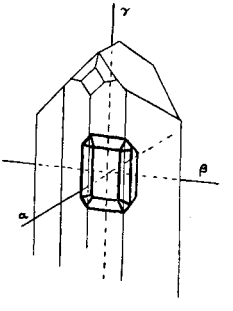

Fig. 7.

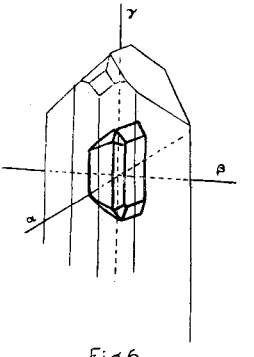

Fig. 6.

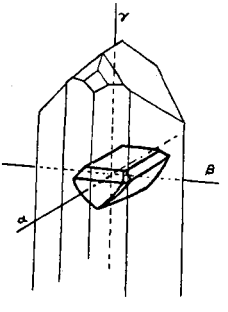

Fig. 8.

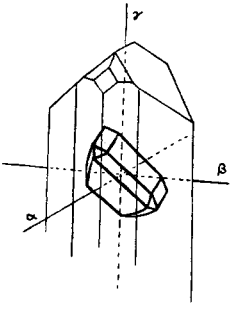

Fig. 9.

In Biaxial Negative Crystals positions of α and γ are reversed.

tested and the stone rotated, two positions will give readings for the least and greatest refractive indices ; and at right angles to these two more giving the least and mean indices. That is to say, one shadow edge will remain steady at the lowest reading while the other will fluctuate between the greatest and mean positions, giving the effect of a uniaxial positive stone! A test on another facet will reveal the biaxial nature of the gem.

Figure 8 illustrates the opposite case to Figure 7. The testing facet is perpendicular to γ and parallel to the plane of α and β Here the upper shadow edge will remain stationary while the lower will fluctuate between the lowest and the mean positions, giving the effect of a uniaxial negative stone.

A table facet inclined haphazardly to the main optical directions, as in Figure 9, will give readings rather more difficult to interpret. As the stone is rotated on the table of the instrument the direction of test will be vertical to each of the main optical directions in turn but never to two at the same time. Thus each of the principal refractive indices will be reached by one or other of the shadow edges at different positions of the stone. In practice it is difficult to determine the exact reading for β, but α and γ are simple enough. Both shadow edges move and it is a matter of taking the lowest reading reached by the lower and the highest reached by the higher edge to determine the full birefringence of the stone. Generally the optic sign may be obtained by noting which of the two shadow edges passes the half-way mark between the highest and lowest readings. If it is the upper one the stone is positive, and if the lower it is negative.

In practice the majority of cut biaxial stones seem to have their table facets cut in accordance with this last example. Perhaps because lapidaries tend to take a large natural facet as a convenient starting point in shaping their stone. Thanks to the peculiarities of the crystal symmetry of the three biaxial systems, such facets are not often found parallel to two of the main optical directions.

R·E·S·U·L·T·S of the 1947 Examinations

IN the 1947 Examinations in Gemmology 28 candidates entered for the Diploma Examination, in Great Britain and Overseas. A record number of entries was received for the Preliminary Examination, 21 from overseas and 119 in Great Britain, making a total of 140.

On the recommendation of the Council two Tully Memorial Medals have been awarded. One of the medallists, Lt.-Col. G. M. Sprague, has also been awarded the " Anderson " Prize for the best work in the practical examination.

The names of the successful candidates are:—

DIPLOMA

Tully Medal
Rutland, Dr. Ernest Hugo (London).
Sprague, Lieut.-Col. George Martin (Edinburgh).

Distinction
Farn, Mr. Alexander Edward (London).
Levinson, Mr. Leslie Harold (Bournemouth).
Meisl, Mrs. Rose Rachel (London).
O'Callaghan, Mr. Harold (London).
Redknap, Mr. Samuel Frederick (Twickenham).
Stern, Dr. Werner (Wembley).
Wheeler, Mr. Henry James Blackburn (Hornchurch).

Qualified
Ash, Mrs. Gladys Violet (Wembley).
Clark, Mr. Herbert Austin (London).
Diggan, Mr. Gerald (London).
Hancock, Mr. Gerald Arnold (Cheshire).
Livsey, Mr. Geoffrey (Blackpool).

PRELIMINARY CERTIFICATE

Rayner Prize
Bowen-Evans, Mr. H. P. (London).

Qualified
Ackerhalt, Mr. Robert (London).
Alderson, Mr. John Aubrey (Huddersfield).
Allan, Mr. Wallace Stewart (Ayr).
Bailey, Mr. Brian Oswald (Birmingham).
Bailey, Mr. Joseph Arthur (Southall).
Baker, Mr. Leonard Alfred (Seven Kings).
Barrie, Mr. Andrew (Edinburgh).
Baxter, Mr. Douglas (Blackpool).
Bennett, Mr. Ronald Leslie.

Benson-Cooper, Mr. Peter (London).
Bolton, Mr. Leslie (Leeds).
Buckingham, Mr. William Charles (Ilford).
Buckle, Mr. Robert (Edinburgh).
Cairncross, Mr. Alastair Duff (Perth).
Cameron, Mr. David (Edinburgh).
Carmichael, Mr. George Latus (Hull).
Christie, Mr. Edwin (Dundee).
Clarke, Mr. Raphael Victor (London).
Conway, Mr. Arthur Douglas (Birmingham).
Cooper, Mr. Edward George (Ilfracombe).
Cooper, Mr. Walter Thomas (London).
Corbin, Mr. Anthony Bazille (Wickford).
Crombie, Mr. Walter (London).
Cumming, Mr. George Richardson (Edinburgh).
Davenport, Mr. Charles Edward (Sutton).
Davidge, Mr. Kenneth Charles (Sevenoaks).
Dawkins, Mr. Charles Edwin Thomas (London).
Day, Mr. Norman Harry (Salisbury).
Dean, Mr. Alan Arthur (Cheltenham).
Eames, Mr. Richard Harry Bateman (Stourbridge).
Ewen, Mr. James Spence (Castle Douglas).
Forsyth, Mr. Adam (Edinburgh).
Gaggs, Mr. John Christopher (Blackpool).
Gilmer, Mr. Denis Arthur Gordon (Bath).
Godfrey, Mr. Kenneth Ernest (Winchester).,
Hale, Mr. Sidney John Warwick (Maidstone).
Hall, Mr. Ronald Albert (E. Grinstead).
Hedges, Mr. Frederick Charles (London).
Hession, Mr. Cyril William (Rugby).
Higgins, Mr. Thomas Francis (Birmingham).
Higgs, Mr. Paul Henry (Stourbridge).
Hodge, Mr. John (Campbelltown).
Inches, Mr. Ian Hamilton (Edinburgh).
Jenkinson, Mr. Herbert Arnold (Birmingham).
Jones, Mr. Ellis (Leicester).
Jutson, Mr. Allan Harry (Sandwich).
Kent, Mr. David George (London).
Kino, Mr. Richard Charles (London).
Kirtley, Mr. Dennis Campbell (Sunderland).
Knowles, Mr. Walter Herbert (Woking).
Laidlaw, Mr. Francis John (Edinburgh).
Law, Mr. Thomas Cunningham (Edinburgh).
Levett, Mr. Leonard (London).
Levy, Mr. Harry J. (London).
Llewellyn, Mr. Graham David (Ilford).
Lines, Mr. Harold Thomas (London).
Martin, Mr. Roy (Southall).
May, Mr. Claude William (Ilford).
Meade, Mr. John Arthur Morby (London).
Meek, Mr. David L. (Edinburgh).
Mortimer, Mr. Richard Thomas (London).
Murray, Mr. Arthur Stuart (Edinburgh).
Nicholson, Mr. John William (Edinburgh).
Page, Mr. John Albert Robert (Orpington).
Pastor, Mr. Hynek (London).
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Pyman, Miss Joan Mary (Letchworth).
Ricketts, Mr. Leslie (London).

Roberts, Mr. Ian Phillip (London).
Rossiter, Mr. Donald Frank (Clevedon).
Rostron, Mr. Norman James (Chiswick).
Ruddock, Mr. John Wharton (St. Albans).
Salisbury, Mr. Frederick Charles (Hanwell).
Sanitt, Mr. Leonardo (London).
Scanlon, Mr. Frank (Manchester).
Scarles, Mr. Basil Percival (London).
Spero, Mr. Douglas Marcel (London).
Stein, Mr. Nathan (London).
Stern, Dr. Werner (Wembley).
Stewart, Mr. Aulton (Bournemouth).
Stollery, Mr. Ernest William Renton (Glasgow).
Stone, Mr. Ernest George (Hove).
Stonley, Mr. Henry Gerald (Wembley).
Tugwood, Mr. Ralph H. (London).
Ungerson, Mr. Daniel (London).
Vanstone, Mr. Michael John (Plymouth).
Wade, Mr. Michael Balfour (London).
Walker, Mr. James (Edinburgh).
Weeks, Mr. Herbert William (Woking).
West, Mr. Laurence (Leicester).
Wheeler, Mr. Douglas (London).
Wigdorczyk, Mr. Hirsz (London).
Winnert, Mr. George Muir (Edinburgh).
Woolrych, Mr. Peter (Burton-on-Trent).
Worthington, Mr. Eric (Blackpool).
Young, Mr. Robert (Edinburgh).

OVERSEAS CANDIDATES

DIPLOMA

Distinction

Benson, Mr. Lester B., Jnr. (Los Angeles, U.S.A.).
Collison, Mr. William Tilghman (Los Angeles, U.S.A.).

Qualified

Bonebakker, Mr. Adrianus (Holland).
Mackenzie, Mr. Kenneth Fraser (Canada).
Porter, Mr. Maurice John (India).

PRELIMINARY CERTIFICATE

Bawden, Mr. Frederick Charles Michell (S. Africa).
Benson, Mr. Lester B., Jnr. (U.S.A.).
Bodes, Mr. P. N. J. (Holland).
Bond, Mr. Clyde Herbert (U.S.A.).
Bonebakker, Mr. Adrianus (Holland).
Collison, Mr. William Tilghman (U.S.A.).
Dave, Mr. Jatashanker Naranji (Pakistan).
Dragsted, Mr. Ove (Denmark).
Field, Mr. Dean Sterling Mark (Canada).
Hemachandra, Piyasiri (Ceylon).
Hutchings, Miss Mabel (Australia).
Mackenzie, Mr. Kenneth Fraser (Canada).
Mayers, Mr. Daniel Eric (U.S.A.).
Peresypkin, Mr. Oleg Paul (Hong Kong).
Porter, Mr. Maurice John (India).
Short, Lieut.-Col. George Valentine (India).
Wood, Mr. Mervyn John (India).

WORLD GEMMOLOGICAL NEWS IN BRIEF

■ ■ ■

AMERICA

Two members of the staff of the Gemological Institute of America, Mr. Lester B. Benson, Jnr., and Mr. William T. Collinson, qualified with distinction in the 1947 Diploma Examinations of the British Gemmological Association.

The G.I.A. has recently produced a miniature news-sheet for students called " The Loupe." It provides a popular digest of gemmological news items of interest to American readers and is more personal than the G.I.A.'s excellent quarterly " Gems and Gemology."

The appointment of an Editorial Board for " Gems and Gemology," the quarterly journal of the Gemological Institute of America, has been announced. The Board includes B. W. Anderson, London ; Dr. S. H. Ball, New York ; Dr. W. F. Foshag, Washington ; Dr. G. Switzer ; and Dr. E. Gubelin, Switzerland.

We are awaiting receipt of a new publication, " Handbook of Gem Identification," written by Richard T. Liddicoat, Jnr., of the G.I.A. We understand that the book, which contains a foreword by Dr. Edward H. Kraus, Dean Emeritus of the College of Literature, Science and Arts, University of Michigan, outlines simply and concisely methods for identification of all coloured stones and pearls. Thus it seems to run parallel with B. W. Anderson's " Gem Testing." A review of this new book will be given as soon as possible.

SYNTHETIC STAR STONES

The first man-made star sapphires and star rubies, to the layman undistinguishable from expensive naturally occurring gems, were recently put on display by Dr. F. H. Pough, curator of geology and mineralogy, at the Museum of Natural History.

The synthetic gems were made by the Linde Air Products Company in an oxy-hydrogen flame. They are the result of extensive war-time efforts to replace natural stones with synthetic substitutes for use as bearings in clocks and sensitive electronic and optical instruments.

A synthetic star ruby shown at the museum weighed about ten carats. It was shown in comparison with a natural star ruby of the same size. The natural ruby was estimated to be worth from $50,000 to $100,000 and the value of the synthetic ruby, similar in all physical and chemical properties but with some unapparent differences in internal structure, was estimated in the hundreds of dollars.

Linde Air Products Company representatives said that the production of the synthetic stones was a laboratory process which could not be adopted to large-scale production.

(Extracted from New York Times).

It is understood that the synthetic star stones show gas bubbles and striæ under microscope. The star is believed to be produced by crystallographically oriented needles of Rutile, which have been caused to grow in the boule. The perfection and brilliance of the star is reported to be good.

Rutile has recently been synthesized in the U.S.A. and is available in transparent, colourless boules.

DENMARK

The President of the Danish Goldsmiths' Association (Faellesrepraesentationen for Danske Guldsmede), Mr. Ove Dragsted, was a successful candidate in the 1947 Preliminary Examinations of the Gemmological Association of Great Britain.

OFFICIAL NOTICES

CHANGE OF ADDRESS

Members are requested to note that the Association's registered office is now at 93-94, Hatton Garden, London, E.C.1. Telephone: Holborn 1839.

GIFTS TO ASSOCIATION

The Council of the Association acknowledges the gift of a copy of "A Lapidary of the History of Pretious Stones," by Thomas Nicols, Cambridge, 1652, from Mr. John Vincent, F.G.A., of Weymouth. This book was the subject of an article in Vol. 1, No. 3, of the Journal.

A further gift has been made by Mr. R. Webster, who has presented the Association's Library with a copy of Mohs' "Treatise on Mineralogy." The work, in three volumes, was translated from the German by William Haidinger, F.R.S.E., and published in 1825.

Mr. Dan E. Mayers, of New York, has kindly given the Association an Andalusite from Brazil, and specimens of Mexican white opal and black opal, made by treating identical white opal mentioned in his article in Vol. 1, No. 3.

The Council records with appreciation the gift of instruments (including a Herbert Smith Refractometer, Spectroscope and Dichroscope) and books by Mr. Henry R. Gooch, F.G.A., of Worthing.

NOVEMBER MEETING

A meeting of members will be held at 6.45 p.m. on Thursday, 13th November, 1947, at the British Council Cinema, 3, Hanover Street, London, W.1. The meeting will include the showing of two films and a demonstration talk on diamonds. Accommodation is limited and members should notify the Association if they intend being present.

TALKS BY MEMBERS

S. T. Solomon (Hon. Regional Secretary, Devon and Cornwall). Subject: "Gemmology." September 1st, Whitchurch Women's Institute; September 29th, Rotary Club of Honiton.

EXTRACT FROM MINUTES OF COUNCIL MEETING

A meeting of the Council was held on Thursday, 14th August, 1947, at 93-94, Hatton Garden, London, E.C.1, under the Chairmanship of Mr. F. H. Knowles-Brown.

The report of the 1947 Examinations in Gemmology was submitted by the Senior Examiner. The Council accepted the report and agreed to award the Tully Medal and Rayner Prize as recommended by the Examiners.

It was decided that in future, in the event of two candidates submitting papers that made award of Tully Medal or Rayner Prize difficult, a further test should be arranged. Further agreed that a candidate who sat for the Preliminary and Diploma Examinations in the same year should not be eligible for Rayner Prize.

The Council appointed Messrs. B. W. Anderson, R. Webster, T. G. Jones and G. F. Andrews to submit recommendations on gemstone nomenclature to next meeting of Council.

Sir James Walton, K.C.V.O., was appointed Curator of the Association's gemstone and gem mineral collection, and Mr. H. Wheeler was appointed Librarian.

Arrangements for the November meeting of members were approved.

The following Fellows were re-elected:—

Thomas A. Hahn, London.
Albert Shackman, London.
Mrs. G. Lindley, London.

The following Ordinary and Probationary Members were elected:—

ORDINARY:

Zoltan White, London.
J. Lovell Baker, Montreal.
Jack Batty, Keighley.
John A. Hardy, New York.
H. Paul Juergens, Chicago.
Veronica Mileson, London.
Stanley C. Sears, London.

PROBATIONARY:

Leon Shapshak, Johannesburg.
Richard C. Kino, London.

The next meeting of the Council will be held on 27th November, 1947.

LETTERS

to the Editor

Dear Mr. Editor,

I have been puzzled for some time at the apparent dual mentality of some gemmologists. On one hand everyone tries to assert his or her intense desire for labour-saving gadgets, whilst on the other there is an undoubted inherent love of complications.

The latest example of this is shown in the report (July Journal) of the use of a wetting liquid whilst ascertaining specific gravity by the hydrostatic method. This implies that the air is conveyed into the water by the stone and wire cage. My observations suggest that the stone and cage attract the air that has been entrapped in ordinary tap water during filtration and pumping. The formation of such bubbles can be prevented by using water that has been boiled.

I use distilled water. After all, the standard definition of specific gravity does mention "pure water." And perhaps I, too, have a dual mentality.

Yours faithfully,

F. E. LEAK.

Dear Mr. Editor,

I feel that Mr. Leak's letter is a tribute to his careful and cleanly methods rather than to a great advantage gained by the use of distilled water.

Surely, in this "latest example" the complication is of Mr. Leak's own making, in that he infers that by some mysterious process the air which is present in finely distributed form in a glass of tap water will concentrate of itself to form bubbles as soon as an object is immersed in the water.

Is not the usual explanation the simpler one, namely, that air in small pockets is entrapped in corners, and on uneven or dirty surfaces, as the stone and cage are immersed? Hence the recommended use of a liquid of low surface tension, such as toluol, which will penetrate into these places and drive out the air.

Yours sincerely,

G. M. SPRAGUE.

Dear Sir,

Where did the term semi-precious originate? It is not, apparently, aged. Perhaps even as young as the early part of this century. Was it used as a selling-aid by some jeweller who could not honestly dispose of a particular stone as *precious*—by the then precious standard—and so raised the status of what otherwise would have been just a gemstone? And was this repeated by his assistants till its continuity was assured? One guess is as good as another, but it does not make the term any less naïve or meaningless. It is therefore interesting to learn that the American Gem Society has recommended its discontinuance. Any enthusiastic gemmologist finds all gemstones precious. If the public could see him pass up a diamond, because it happens to be fairly easily identified on sight, they might wonder which was precious.

From the commercial point of view—assuming it began that way—the prefix *semi* has not really helped. It has merely extolled a handful of stones—by emphasizing the preciouness of a few—at the expense of many. It is a division between gemstones that is arbitrary. Not even on grounds of hardness may we divide. I recall a beautiful topaz once shown to a gemstone admirer. He studied it for a while, grew quite enthusiastic, and then said: "But it's only semi-precious, isn't it?" The implication was that he had said something knowledgeable. One searches in vain for an analogy. It is rather like saying of an *objet d'art*, "It's only half-precious." And you say "Why?" And the answer is: "Because it comes within the half-precious group."

Yours sincerely,

ELSIE RUFF.

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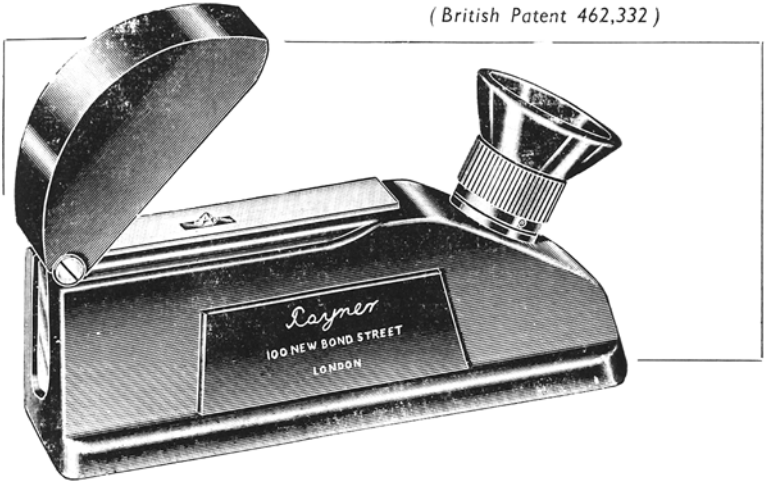

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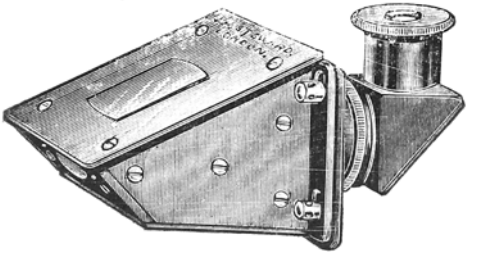

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THE JOURNAL OF GEMMOLOGY
AND PROCEEDINGS OF THE GEMMOLOGICAL ASSOCIATION OF GREAT BRITAIN
Vol. I, No. 5 JANUARY 1948

SYNTHETIC STAR SAPPHIRES

THE new star corundums manufactured in America by the Linde Air Products Co. have already been briefly described in the last issue of the " Journal of Gemmology." Gemmologists and dealers in precious stones all over the world are naturally intensely interested in obtaining more exact information concerning these startling new products of the Verneuil furnace. Thanks to the kindness of a leading importer of precious stones, the writer has been enabled to examine two fine specimens of synthetic star sapphire, weighing 9.20 and 7.31 carats respectively, and permission has been granted for the results of this examination to be published.

In appearance the synthetic star-stones differ perceptibly from natural star corundums. They are a bright pale blue in colour with a sharply-defined star, but the artificial " silk " (one is tempted to write " rayon ") is confined to a relatively thin layer near the crown of the stone, with the result that the arms of the star do not reach the base of the stone, which is quite clear and transparent.

In natural star sapphires the stones are usually either full of silk throughout, heavily zoned in hexagonal formation, or are so cut that the silk is concentrated towards the base of the stone with the upper part relatively clear.

Under the microscope, the usual signs of the Verneuil synthetics (curved lines of colour and included bubbles) are abundantly present. The curved lines, which can be seen with the naked eye when the stones are viewed sideways, are at right angles to the symmetry axis of the cabochon, giving rise to the surprising conclusion that the " silk " was concentrated at one side of the original boule, *not* near the upper surface as one would expect. The " silk " itself consists of short needles, dark by transmitted light, and intersecting at angles of 60°. Presumably they consist of rutile though as yet there is no proof of this. The needles are so small and fine that they are not easily discernible, though they appear quite clearly in the photomicrograph reproduced below, taken under a magnification of 60 diameters (Fig. 1). For comparison, the zonal structure of the silk in a typical natural Ceylon star sapphire was also photographed (Fig. 2).

Some idea of the relative sharpness of the asterism in the synthetic and natural stones is given in Figs. 3 and 4. These were taken under low magnification (7 diameters) by light reflected from a Beck " Intensity " microscope lamp, throwing an almost parallel beam. The specular reflection of the beam from the polished surface of the stone gives rise to the bright spot seen in each photograph. The distortions apparent in the rays of each stone are not

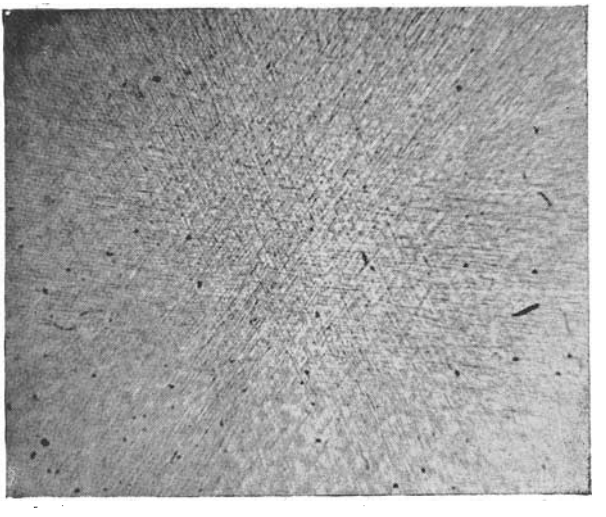

Fig. 1 — Silk in Synthetic Star Sapphire

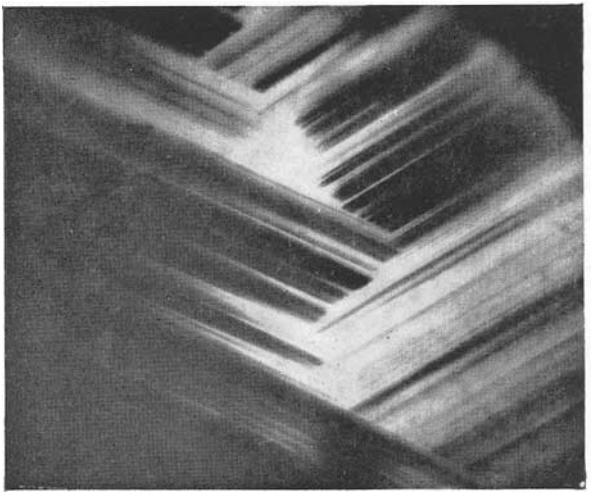

Fig. 2 — Zoned Silk in Natural Star Sapphire

noticeable when viewing the stones under ordinary conditions. The curious feathering of two of the rays in the natural stone gives an interesting indication of the underlying zonal structure.

Careful density determinations were carried out on the synthetic specimens by hydrostatic weighing in ethylene dibromide, and also on their natural counterparts. As expected, the results showed no significant differences: they are indeed chiefly notable for their consistency and are remarkably near the value 3.989 which is the density of pure corundum. For purposes of record the density figures are given below:—

Specimen		Carats		Density
Synthetic blue	...	9.205	...	3.985
Synthetic blue	...	7.316	...	3.982
Ceylon pinkish	...	9.928	...	3.984
Ceylon blue ...	...	7.485	...	3.989
Ceylon pale ...	...	7.895	...	3.986
Ceylon pale ...	...	7.945	...	3.987
Ceylon blue ...	...	15.132	...	3.987

The eye of the expert will probably be able to differentiate the synthetic star sapphires from the natural by their unusual colour, glassy appearance, and clear base. The gemmologist will

be wise to examine the internal structure of any doubtful stone under the microscope, immersing the specimen (complete with setting if necessary) in a dish of monobromo-naphthalene.

With the present stars at least the following simple test is effective. Place a small drop of methylene iodide or bromo-naphthalene on the rough base of the stone and view the droplet under a single bright light. Natural stones will show a clear-cut star in the drop owing to the underlying silk, whereas the synthetics will give a null effect.

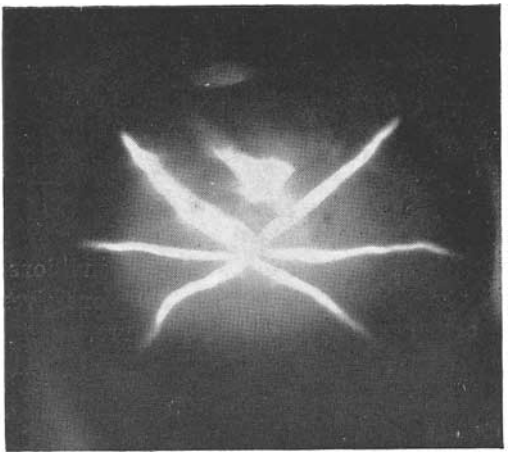

Fig. 3
Synthetic Star Sapphire
(x 7)

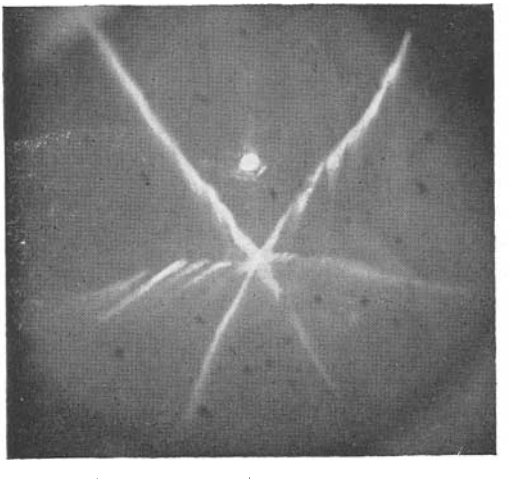

Fig. 4
Ceylon Star Sapphire
(x 7)

A TALK ON DIAMONDS

BY R. DAVID DALE

given at a Members' Meeting on 13th November, 1947, at the British Council Cinema

I VERY much appreciate being invited by your Association to be here this evening to give you some impressions on the subject of diamonds.

I may say at once that I feel certain that you, as members of the Association, and your students, know a great deal more about the technical side of diamonds than I would presume to profess, and therefore, having regard to some of the many awkward questions that I am likely to be asked at the conclusion of this, what I should like to call " entertainment," I have asked a member of our Research Department, who is one of your Fellows, to give me a great deal of moral and practical support. I refer, of course, to Dr. Stern of the Research Department of Industrial Distributors (Sales) Ltd., the company charged with the responsibility for distributing industrial diamonds. But I have used the word " entertainment " and I want to present to you this evening, not only some of the technical aspects of diamonds, but to bring before you some practical examples of the subject and to offer for your consideration some of the background of the history of diamonds. This is a subject which, as yet, has by no means been thoroughly examined.

RECOVERY OF DIAMONDS

Diamonds originated, according to the best accepted theories, in the times, some eons ago, when the eclogite or strata some many miles beneath the earth's surface erupted in molten form and passed through the crust of the earth. The resulting lava flowed over the earth's surface and in it were tiny particles of carbon which were subjected to an atomic degree of pressure and heat. It was these particles which were thus converted into diamonds, and today you have at a number of points on the earth's surface—Brazil, Venezuela, British Guiana, Gold Coast, Sierra Leone, Portuguese West Africa, Belgian Congo, Tanganyika and last, but by no means least, the Union of South Africa and the mandated territory of

South West Africa, what are known as alluvial diamond deposits. These in pursuance of the theory are assumed to be the diamonds which remained after the lava had been weathered away. By contrast, in South Africa, Tanganyika, the Belgian Congo, you have what are known as the actual diamond pipes composed of blueground or Kimberlite, which are vertical cylinders descending into the earth's surface and which are that portion of the lava which cooled in position when the eruptions ceased.

ROMANCE OF BLUEGROUND

I have brought a film with me which was produced by a news reel company in South Africa. It is called " Romance of Blueground " and illustrates far more graphically than I can describe the processes by which diamonds are actually extracted from these pipes. I would particularly draw your attention to this amazing property of diamonds whereby they have an affinity for grease or adhere to grease while none of the other minerals to be found in the blueground do so adhere, with the result that the process of extraction is one of the simplest methods of mineral recovery.

CHINESE LEGEND

It is rather interesting to contrast this property of diamonds, which was only discovered early in this century, with a legend from ancient Chinese mythology in the days when China was Cathay and India was unknown, at any rate to the ancient Chinese. They had a theory that far away to their west in what must, in fact, have been India, there was a mythical valley of diamonds, and they tell of how carcases were rolled down into this valley and in due course eagles swooped down into the depths of this almost bottomless pit and bore off morsels of the fat flesh from the carcases. Specially detailed parties of men traced the eagles to their eyries and there, from among the remnants of the fat flesh, found stones which were diamonds. It seems quite clear to me that, in common with those to-day who wish to conceal simple processes, the discoverers of the affinity of diamonds for grease hid their knowledge very well under the cloak of allegory.

Now, with this rather strange story in your minds, I will not detain you further from seeing this film, and I give you the film produced with the full co-operation as technicians of De Beers Consolidated Mines Limited, " Romance of Blueground." (Here the film was shown.)

I hope that that film has given you an insight into the methods of recovery of diamonds.

I think you would like to know that at the moment another film of general interest on the subject of diamonds is being produced, which will carry the same message with one or two stories, which we consider to be eminently worthy of record. Our organization is supplying the technical advice.

INDUSTRIAL DIAMONDS

Now that you have a picture of the recovery of diamonds in your mind, I want to show you a few practical examples and I propose to deal first with the industrial diamond, the diamond which represents some four-fifths of the weight of all diamonds recovered and which is so much in demand in industry to-day. There is no difference structurally, of course, between the industrial diamond and the gem diamond. It is only classified as the former when, for reasons of colour or flaw, it is unsuitable for use as a gem. But please do not have the idea that all industrial diamonds are flawed. On the contrary. The stones which are required for jobs involving great stress have to be flawless, although the colour is immaterial. The best example of what I mean is the Die stone, of which you see some here, stones which will be drilled by means of an oscillating needle dressed with diamond dust bound in olive oil. These dies are used for drawing wires of great fineness. All the electric light bulb filaments in this room will have been drawn through a diamond die. Wires used in connection with the valves of radio and for numerous radar operations are drawn by diamond dies, and I have got here a spool of the finest wire drawn in this country, a shade over a 2,000th part of an inch in diameter, and for purposes of comparison it is affixed to a card alongside one of my own hairs, which is approximately nine times as thick as the wire in question. It was, I think, Winston Churchill who, during the war, asked a girl operative engaged on drawing these wires, " Do you find your work interesting? " Her reply was, " Yes, I do, but it is rather difficult putting a wire you cannot see through a hole you cannot feel."

Another instance of the power of the diamond, this time in the form of powder, was illustrated by the competition which existed between the War Production Board of America and the

Ministry of Supply in this country during the recent war. Whenever there was any new development on either side, they tended to send it across to the other with some such message as " Can you beat that? " I am told that an American firm sent across an ordinary steel drill bit of the unusually small diameter of one-sixty-fourth of an inch. After consultation with one of our engineering firms who used a fine needle dressed with olive oil and diamond dust, they were able to return it to the Americans drilled neatly through the centre from one end to the other with the comment, " What do you know about that? "

TURNING MOTOR CAR AND AEROPLANE PISTONS

But, of course, the use of the industrial diamond is by no means confined to stunts such as this, and it would be impossible in the time at my disposal to go into the many and practical uses of the industrial diamond. But one example I should refer to—that of turning pistons for motor car and aircraft engines—a use which had a very great bearing on the results of the recent war and which is of great importance in the world to-day. I have brought with me as an illustration the piston of a Rolls Royce Merlin engine. When you examine it you will be able to see from the inside the normal surface of the whole piston as delivered in the rough by the casters. The finish, as shown, is obtained by the diamond in one operation on each surface ; special diamond tools are used for the piston ring grooves and the great beauty of the use of the diamond is the very low pressure necessary to carry out the turning, which results in a mirror finish, so that, in fact, there is a negligible amount of burring at the corners of the piston ring grooves when the tool passes across them.

FUNCTIONS AND CLASSES OF INDUSTRIAL DIAMONDS

Without going into too much detail, I will explain some of the functions and the classes of industrial diamonds which you see before you.

Crushing Boart, which in itself represents four-fifths of the total industrial output, is in every way a diamond, but cannot be used except in crushed form as diamond powder of various sizes. In this form it is used for impregnating into bonded abrasive wheels, as I have already indicated, bound in olive oil for drilling purposes

and in the same form for sawing through gem diamonds and for polishing them. You will see here a model of a diamond saw. The actual method is that the phosphor bronze disc (about 3/1000ths inch thickness) revolves at 4,000 r.p.m. ; the edge of the disc is kept dressed with olive oil and diamond dust, and it is actually the diamond dust which cuts its way through the diamond to be sawn. The perspex models which you see illustrate what happens at this stage.

(Mr. Dale then described the cutting of an octahedral diamond into a brilliant, using the models by way of illustration.)

GEM DIAMOND CUTTING (STYLES)

We have thus brought ourselves to the gem diamond. The style of cutting which you see illustrated here is the " brilliant," with 32 facets and the table on the top and 24 facets on the pavilion or under part. What is known as a " culet " used to be cut across the bottom, but modern practice has eliminated this as it tends to give the impression of a small hole or black spot at the base of the stone. This style of cutting is in conformity with the mathematical angles which give the greatest effect to the diamond's power of light refraction, the angle on the top 41° between the girdle and the edge, and between the girdle and the pavilion 39°.

But, of course, gem diamonds are by no means always cut in the brilliant style. Broadly speaking, the factor which guides the cutter when deciding the method of cutting any particular rough diamond is: what is the largest clean stone or stones that he can get out of the particular piece of rough. In this regard people have sometimes asked me why a larger stone than the pear-shaped brilliant of 516½ carats was not cut from the 3,106 carat Cullinan. The answer is that there were two spots of carbon in the otherwise perfect blue-white stone and the cutters had to cleave the stone through these spots, and, for your interest, I have here a photograph showing the Cullinan cleaved into three, the pear-shaped brilliant having been made from the largest piece. There is also the original agreement between King Edward VII and Messrs. Levy Brothers appointing them as inspectors of the cutting of the Cullinan.

To revert to the styles of cutting, I would like to say that throughout these styles, however unusual, the cross section through the stone will reveal the same use of these angles between the upper

portion of the stone and the girdle, and the lower portion of the stone and the girdle. The most usual style after the brilliant is the emerald-cut or square type of cut with corners off, thus giving it eight sides, and the square-cut, which has pointed corners. Both the emerald-cut and the square-cut are found either in the square shape with equal sides or the oblong shape with length and breadth. I may say that there are three off-shoots of the brilliant —the pendeloque or pear-shaped to which I have already referred and which you see in the model of the large stone from the Cullinan ; the marquise, which is boat-shaped as if the brilliant had been pulled outwards from diametrically opposite points, and the rarer type—the half moon—where a brilliant would appear to have been cut in half, being given facets down the edge which is cut.

Some of the French cutters specialize in a wide variety of fancy shapes, three, four, five and six sided. The latter are particularly useful to the manufacturing jeweller who wishes to execute mosaic or floral designs.

DIAMONDS AS DOLLAR EARNERS

The diamond appeals to the eye, it is rare, is readily portable and its value remains reasonably constant in normal times and tends to increase almost in direct sympathy with the depreciation in currency values at a time of inflation. This is one of the reasons why to-day, in America particularly, and in many countries throughout the world which are obsessed with troubles, such as India and China, the demand for diamonds has never been higher. This state of affairs explains why the sales which have been taking place in recent months have been maintained at a rate which constitutes a record for any similar period in the entire history of the Diamond Industry. A high proportion of these sales are made direct to the U.S.A. for dollars. Indirectly, the rough diamonds that go to other centres in the sterling area where cutting takes place (South Africa and Palestine), also earn dollars for the sterling bloc, as 75 per cent. to 80 per cent. of the resulting cut stones go to the dollar area.

Diamonds in 1946 exported from this country to the United States were by far the highest dollar earner and brought in rather more than one quarter of all the dollars earned by goods exported from this country to America.

FILM

On a previous occasion I was charged by my directors with the task of organizing a film show for our own staff, with a certain amount of commentary where necessary, and they felt with me that it would be interesting to have a short film on the subject of an industry which is very closely allied with our own, an industry which was built up late in the 19th century in South Africa by the pioneers who had built up financial resources as a result of the diamonds found in Kimberley. Therefore, I present for your entertainment and interest a film on Goldmining. (Here followed Walt Disney's " Donald's Gold Mine," a R.K.O. Donald Duck film.)

CONCLUSION

With the conclusion of that highly instructive film, I would like you to regard my remarks as being at an end, but Dr. Stern and I would welcome any question from you, either technical or of general interest, on the subject of diamonds, and between us we will do our best to answer them.

I suggest that with the chairman's permission, when the questions have been concluded, those people who wish to examine the exhibits at closer range come forward and ask any questions on these of our staff who are here to assist you.

Thank you very much for having given me the opportunity of coming here to-night and I hope that what I have said will provoke some discussion among you.

" COCO - NUT PEARLS "

A report in *Nature* (Vol. 160, No. 4071, November, 1947) gives details of recent work of Dr. A. Reyne, who has published " On the Structure of Shells and Pearls of *Tridacna squamosa* (Lam.) and *Hippopus hippopus* (Linn.) " (*Arch. Neerl. Zool.*, 8, 206 ; 1947).

Dr. Reyne points out that the so-called " Coco-nut pearls " claimed to have been found in a coco-nut are true *Tridacna* pearls, the chief inorganic component being aragnoite. It is thought that deception by local natives on Celebes was responsible for the original claim that pearls had been found in coco-nuts.

A Useful Aid to GEM SPECTROSCOPY

By
R. KEITH MITCHELL
F.G.A.

THANKS largely to work done in this country, absorption spectroscopy has achieved a very important place in gemmology. An invaluable and speedy aid to the identification of many gems, the small hand-spectroscope ranks to-day with the refractometer and the microscope in importance among gemmological instruments.

Up to now the most generally successful method of using the instrument has been to employ the lens system of a microscope to pass light through the specimen and collect the resultant light for examination. Briefly, this method consists of placing the stone on the microscope stage and passing a concentrated beam of light through it by means of a substage condenser. This transmitted light is then collected in the objective and the draw tube of the microscope becomes filled with its bright glare. The spectroscope is then used in the place of the normal microscope eyepiece.

An alternative method is to use the scattered light obtained when the stone is placed table down on a suitable surface with a strong beam of light directed into it from one side at an angle of approximately 45° ; the spectroscope being held at a similar angle with the slit close to the stone on the other side. This method is obviously less elaborate and, since the light path within the stone is longer and because less extraneous light reaches the instrument, it tends to give somewhat more intense spectra. They are, however, much marred by transverse lines caused by the close proximity of the spectroscope slit to the stone. The holding and directing of the instrument also calls for some small skill and can give rise to difficulties.

These objections to the method have now been almost entirely overcome by the construction of a simple stand for the instrument. This, as will be seen from the accompanying illustration, holds the instrument steady at an angle of 45° with the slit directed at the

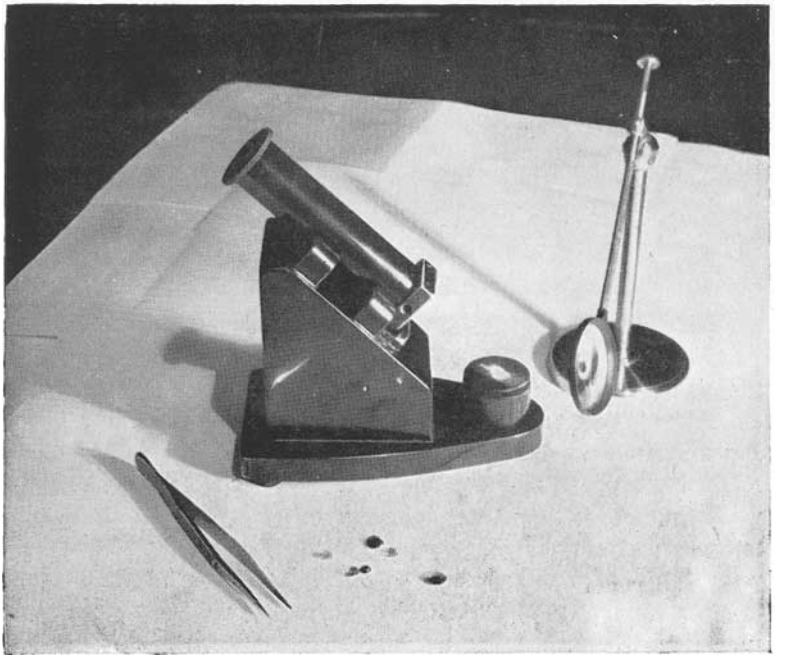

centre of a small rotatable table. The stone to be examined is placed table-facet down on this surface and a strong beam of light focused on it by means of a bull's-eye condenser and an intensity lamp or other suitable source. Light is reflected internally from the table-facet and emerges in the direction of the instrument, where its spectrum can be examined.

The fact that the spectroscope is removed some 2-3 inches from the stone eliminates to a very great extent the troublesome transverse lines experienced when ordinary scattered light method is used. One beam of light is examined at a time and the stone may be rotated on the stand to obtain the clearest spectrum.

A limited number of these stands have been made up and are available at 18s. 6d. each. They are constructed to take the Beck spectroscope No. 2458 recommended by Mr. B. W. Anderson in "Gem Testing," but will take other instruments of the same tube diameter. Slight alterations can be made to take other tube diameters. The stands are strongly constructed of wood and admirably finished in black lacquer.

X-RAYS and the JEWELLER

By JOHN VINCENT, F.G.A.

THE following may be of some interest to practical gemmologists. In the course of business, a ring was brought in to the laboratory of Messrs. John Vincent Ltd., of Weymouth, for examination and test. The ring in question was a large diamond cluster with an opaque black stone cut in the form of a brilliant of approximately five carats with a metallic lustre. This stone was reputed to be a black diamond, but there was some doubt as to whether this was so. Apart from a negative reading on the refractometer and a test for hardness the instruments in the laboratory were of no use. The stone being opaque, it was impossible to test in polarized light ; the spectroscope was of no use for the same reason, and the specific gravity could not be obtained owing to the fact that the stone was mounted. A definite decision had to be obtained without delay as it was a question of the owner obtaining redress if the stone was found to be other than a diamond.

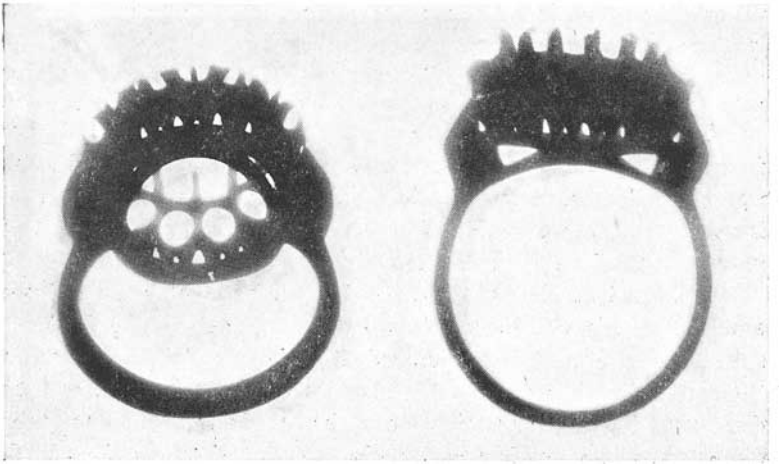

Fig. 1

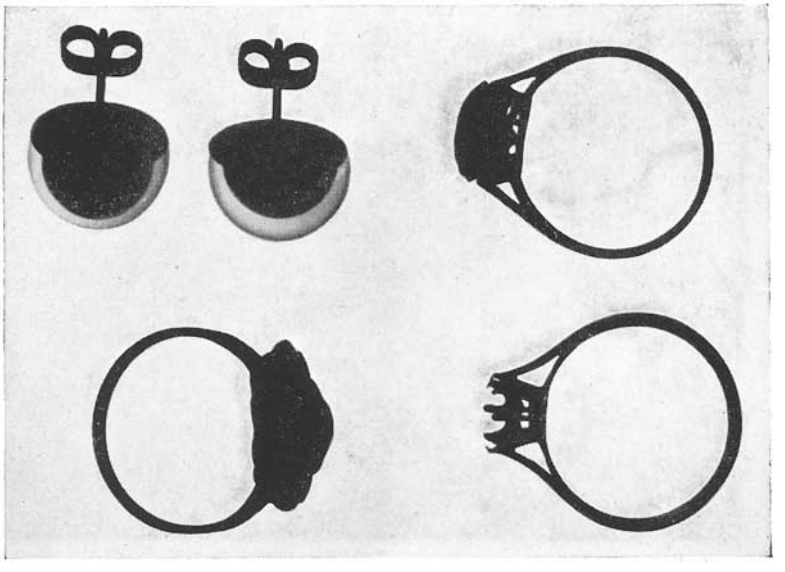

Fig. 2

A local dental surgeon was contacted by phone and it was explained to him that an X-ray photograph was required of the ring, the situation was discussed, and he agreed to help. The ring, together with a copy of Mr. Anderson's " Gem Testing " marked at page 111, was sent round to the surgery, with the result that the dentist, intrigued by the test put forward in the text-book, brought the X-ray negatives of the ring round to the shop premises himself within half an hour. Prints were quickly obtained from the negatives and it was seen that the large central stone was indeed a diamond.

When the customer returned in a few hours, the result of the test was explained to him by means of the photographs and the text-book. The photographs are figured herewith and show the transparency of the central black diamond and the surrounding diamonds quite clearly.

(The exposure for Fig. 1 was 1 second, anode distance 9.5 inches, film—Pan super XX Dental.)

Further experiments have been carried out on various articles of jewellery. Fig. 2 shows a single-stone diamond ring, a colourless zircon ring, a paste cluster ring, and a pair of cultured pearl ear-studs. (Exposure time 1.5 seconds, anode distance 11 inches.)

HANDBOOK
of
GEM IDENTIFICATION

By RICHARD LIDDICOAT

Reviewed by B. W. Anderson, B.Sc., F.G.A.

THE author of this new " Handbook "* is Director of Education in the Gemological Institute of America, and has been assisted in his project by his colleagues Robert M. Shipley and Drs. Holmes and Switzer ; thus there should be no doubt that this book represents the authentic voice of the G.I.A. in the matter of gem identification. At first sight the book seemed to conform so closely not only in its scope but in its general arrangement to the recent British work " Gem Testing " that the reviewer might be excused for supposing that the book was deliberately modelled on his own production.

Closer inspection, however, revealed considerable differences. American gemmology, after leaning at first rather heavily on pioneer work done chiefly in Germany and Britain, has been in the last decade developing its own ideas, its own techniques and its own instruments. In this " Handbook," for instance, the first American-made jewellers' refractometer is described and illustrated. This instrument, the " Erb and Gray," would seem to compare very well with our own " Tully," which it resembles in having a rotating hemisphere, though in this case supported by a pedestal from below. Its price (a matter of purely impersonal interest to present-day Englishmen) is given as approximately $140.

Other gem-testing equipment, for the most part devised and issued by the G.I.A., which is mentioned and illustrated includes the Diamondscope (a binocular microscope fitted with special sub-stage lighting, giving either direct or dark-ground illumination ; the Gemolite (a simplified monocular version of the above) ; the

* *Published by the Gemological Institute of America. Los Angeles, 1947*

Shipley hand polariscope ; and the new G.I.A. Pearloscope—a microscope equipped for the endoscopic and pearlometric types of test for drilled pearls with facilities for the simple examination of pearls by transmitted light which the French employed in the old " Lucidoscope " and which the Americans call " candling."

The book opens with chapters on the determination of hardness, specific gravity, and refractive index. The use of " Carbona " (commercial carbon tetrachloride) is suggested as an alternative to water for hydrostatic weighing. Despite its low surface tension, this liquid is not really suitable for the purpose, as its great volatility upsets the stability of the balance. Moreover, the undiscriminating use of a single correction factor of 1.59 when using this liquid is hardly conducive to accurate results, as even in pure carbon tetrachloride the density varies appreciably with temperature, and even at a fixed temperature commercial samples will inevitably vary considerably.

Mr. Liddicoat is rightly very insistent on the careful handling of the refractometer and gives meticulous instructions on how to avoid causing damage to the delicate glass of the hemisphere or prism during use. Immersion methods for refractive index determinations are also briefly described. A good chapter on " Magnification " is followed by " The Use of Characteristic Imperfections as a Means of Gem Identification." This forms a useful introduction to one of the most beautiful and valuable techniques available to the gemmologist. It is well illustrated by photomicrographs from the incomparable collection formed by Dr. E. Gübelin.

The book indeed is plentifully illustrated throughout, but there is much duplication, the most curious case being Figs. 84 and 85, where anomalous double refraction in synthetic spinel is pictured on successive pages from prints apparently taken from the same negative in reversed position. The photograph used for Figs. 69 and 83, showing flask-shaped bubbles in synthetic spinel, is both ugly and unrepresentative, while the chain of bubbles shown in Fig. 77 is far more typical of paste than of synthetic ruby.

There is a chapter on Pearls where simple tests are described and a brief account is given of endoscopic and X-ray methods.

" Instruments Essential to Gem Testing " is the title of the last chapter in the first section of the book. The refractometer, polariscope, magnification, and specific gravity are listed as essen-

tial tests, while " less frequently used " instruments include the " Gemological " (i.e. polarizing) microscope, ultraviolet lamp, the dichroscope, emerald filter, spectroscope, hardness points and plates, sodium lamp, and X-ray equipment.

To the spectroscope Mr. Liddicoat devotes only one brief paragraph: " . . . Its principal use is the distinction between spinel and pyrope when their properties overlap. Since its applicability to gem testing is limited and its manipulation rather exacting, it has not been widely used in this country."

Herein lies probably the greatest difference between the American and British schools of gemmology. In this country we have come to regard the spectroscope as the third most important gem-testing instrument, the other two, of course, being the microscope and refractometer. Its value lies in its low cost, portabliity, and above all in its ability to provide the most rapid positive means of identifying the gemstones most used in jewellery, whether these be mounted or unmounted, cut or rough. It provides in many cases a most valuable means of separating natural from synthetic sapphire, and is operative on stones such as zircon and demantoid garnet which are beyond the range of the refractometer.

The use of the spectroscope would vastly simplify and shorten the painstaking systematic schemes laid down for the identification of gems in their different colour groups which are given in the second portion of the " Handbook."

For the jeweller the practical value of the book is reduced by the author's assumption that the stones under test will always be available in the unmounted state. It may indeed be sometimes necessary to remove a stone from its setting to enable a decisive optical or density test to be made, but to the true gemmologist this must always be regarded as something of a defeat.

The values for refractive index and density given in the book are for the most part unexceptionable, but there are some which require revision. The reviewer well knows the near impossibility of deciding on a single representative figure for each species in the tables of these constants, but in choosing such a figure for stones which show considerable variation, it is often a mistake to use a value which is the arithmetic mean between the extreme limits of the recorded range—such a reading is apt to be quite unrepresenta-

tive. For example, the great majority of peridots have a density near 3.34, and the fact that certain brown or yellow iron-rich types may be as high as 3.48 does not justify 3.40 as an average value, as given here. In the same way, the yellow and pink gem varieties of topaz have refractive indices 1.630 and 1.638, values for the colourless stones being in the region of 1.61-1.62. The figures 1.619-1.627 given in this book tally neither with one nor the other. Again, a refractive index of 1.726 is definitely higher than normal for natural spinel and is indeed very near the usual value for the synthetic material. Concerning the latter, Mr. Liddicoat is not correct in stating (p. 111) that the ratio $1MgO : 1Al_2O_3$ " is usually true of synthetic spinel, but in some cases it is made with a ratio as high as five parts of aluminium oxide to one part magnesium oxide." Such syntheses can admittedly be made, as we learnt from a classic paper by Rinne,* but in practice the German and Swiss manufacturers find that boule growth is best with a ratio of $1MgO : 3.5Al_2O_3$ in the initial materials and adhere closely to this ratio in commercial practice. For this we have not only the authority of Dr. W. F. Eppler,† who for years has been associated with its manufacture, but also the cumulative evidence of innumerable refractometer readings on this very common synthetic gem, which show practically no variation. One has less occasion for frequent determinations of the specific gravity of synthetic spinel, but all such, of whatever colour, that have been measured have been very near to 3.63, and the values 3.7 to nearly 3.75 suggested by Liddicoat seem improbably high.

The book concludes with a useful summary of the properties of the gem species with a column suggesting those gems with which each may most readily be confused. There is also an excellent index.

We hope that Mr. Liddicoat will consider it a compliment that his book has been accorded a long and critical review. The subject is one which closely concerns the readers of this journal, and a just consideration of the merits and demerits of the " Handbook " could hardly be given in shorter space.

* F. Rinne, " Neues Jahrbuch Mineral, etc., Abt A.," 1928, vol. 58, pp. 43-108.

† W. F. Eppler, " Industrial Diamond Review," September, 1947, p. 259.

Canadian Gems and Gem Localities

Part I

GEMS OF THE BAY OF FUNDY

By D. S. M. FIELD

A descendant of an old United Empire Loyalist family which migrated to the Bay of Fundy region of Nova Scotia in 1873, the author of this series was born in 1917, and spent much of his boyhood collecting and studying the minerals and gem crystals found in great abundance along the Bay. Much of the information given in Part I is based upon personal observations.

BLOMIDON

THE Bay of Fundy region of Nova Scotia yields some of the finest gem crystals of amethyst and other minerals to be found in Canada. This is particularly true of Blomidon, not far from Parrsboro, N.S.

Blomidon, and indeed all the North Mountains extending from Brier Island to Cape Blomidon ; three of the Five Islands, Two Islands, Isle Haute, and all the capes on the north shore of the Bay of Fundy, are composed principally of basaltic trap resting upon amygdaloid, which in turn rests upon a new red sandstone.

This latter peculiarity, wherein a hard, compact rock rests upon a soft and yielding material of more recent formation, may also be noted in several localities in Scotland and Mexico.

The name " Blomidon " (allegedly derived from the words " Blow me down," in allusion to the high winds frequently encountered there in the stormy seasons) is locally applied to the great mural precipice extending for a distance of some fifteen miles between Capes Blomidon and Split (see illustration and map).

Here may be seen some of the most picturesque scenery in the Province. Great vertical columns of basalt crown the summit of the precipice, which rises in some places over six hundred feet above the sea, its face washed here and there by lace-thin waterfalls cascading gracefully to the narrow beach beneath.

Lower down, the trap becomes declivous, permitting small bushes and trees to cling precariously to the slope, and to the heaps of débris lying at the foot of the cliffs, washed at their base by the sea.

The majesty of the towering heights, and the silence of the lonely place (broken only by the intermittent screams of seagulls) is almost frightening. Here and there along the sandy beach one may come upon tiny, abandoned fishermen's shacks, but they are few, and because of the sad state of disrepair into which they have fallen they can offer the collector little shelter from the winds and rains which drive in so frequently and unexpectedly, to lash the coast in the spring of the year. Although the vernal season is the most dangerous time to search for gems on storm-swept Blomidon, it is also the season which affords the hardy collector his most lucrative harvest.

Every spring great masses of gem-freighted rock, weakened by the frosts of the preceding winter, make avalanches which cover the narrow beaches to the sea with fragments of rock and crystals of amethyst, cornelian and moss agates, jasper and hornstone, bloodstone and spar, and many others. These minerals thus may

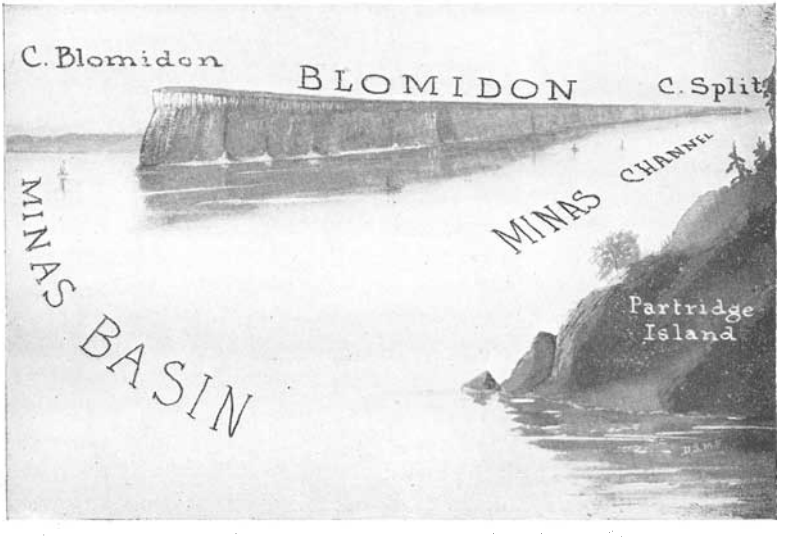

Fig. 1 — Blomidon, as seen from Partridge Island, Parrsboro, N.S.

be conveniently collected from the loose piles of rock at the base of the cliff, and indeed each spring one may find eager collectors searching the débris for specimens which, except along the Bay of Fundy, would cost them great labour and expense.

Here may be found some of the prettiest specimens of moss agate in the world, and of a transparency and perfection elsewhere unknown. Some pieces are so fine when polished that it is difficult to believe that the dendritic stainings are not actually organic plants embedded in blocks of crystal plastic.

Huge pieces of agate—including the comparatively rare fortification and scenic varieties—are also to be met with. Some of this material compares favourably in its natural state with the artificially stained agate from other countries ; for the ribbons of red cornelian in much of the Blomidon material contrast sharply with adjoining layers of cream and white chalcedony.

Eye agates, in large masses weighing nearly a hundred pounds, are also of frequent occurrence. Dr. Abraham Gesner, of Parrsboro, N.S., writing in 1836, gives an interesting account* of his discovery of some of this material, following a great avalanche from the top of the precipice, in the spring of 1834:—

> " The noise of the downfall was heard many miles along the opposite coast. Being acquainted with the circumstance, we hastened to the spot, and were richly rewarded for our trouble. . . . Among the numerous and beautiful minerals obtained during the first visit to this interesting locality was the onyx agate. A large mass, weighing upwards of eighty pounds, had been dislodged, and lay among the ruins of the cliff. This agate exhibits distinct and parallel zones of different colours ; these zones consist of circles of white cacholong, alternating with small rings of pale red cornelian. When these agates are polished they are extremely beautiful, and resemble the eyes of certain animals."

Dr. Gesner goes on to describe the amethyst-lined geodes, vugs, and surfaces also to be found there:—

> " Large blocks of amethyst had been broken by the downfall of the cliff, and lay among the broken masses. In several instances perfect geodes of that beautiful mineral were obtained. These geodes, when whole, appear like balls of

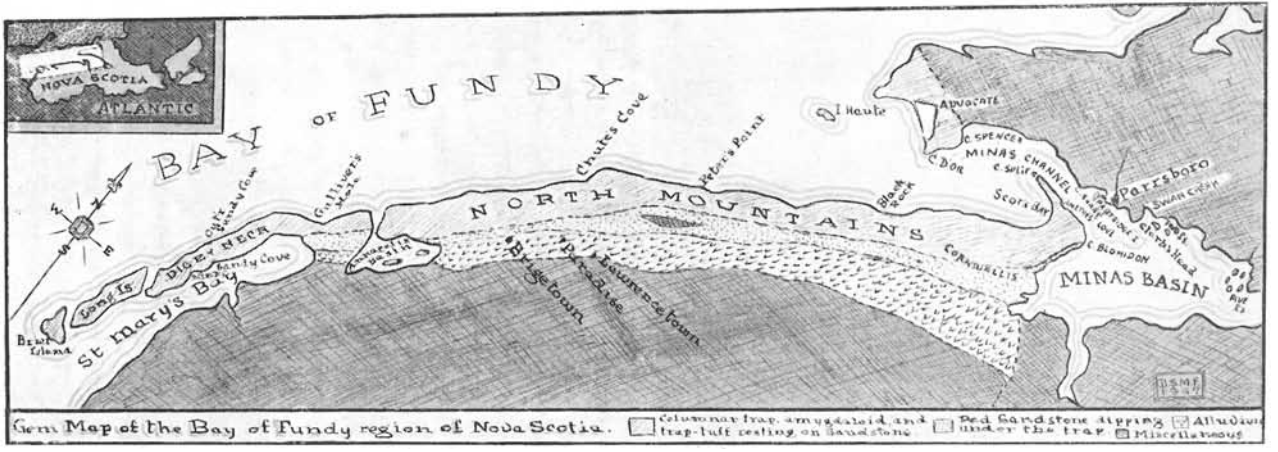
NOVA SCOTIA
ATLANTIC
BAY OF FUNDY
NORTH MOUNTAINS
Chutes Cove
Peter's Point
Gulliver's Hole
Black Rock
I. Haute
Advocate
C. SPENCER
MINAS CHANNEL
C. DOR
C. Split
Scots Bay
Parrsboro
Swan Creek
Partridge I.
Cattle Cove
C. BLOMIDON
Two Rivers
Starr's Head
CORNWALLIS
MINAS BASIN
DIGBY NECK
Sandy Cove
St Mary's Bay
Long Is.
Bear Island
Annapolis Basin
Bridgetown
Paradise
Lawrencetown
Gen. Map of the Bay of Fundy region of Nova Scotia.
Columnar trap, amygdaloid and trap-tuff resting on sandstone
Red Sandstone dipping under the trap
Alluvium
Miscellaneous

Fig. 2

quartz, indented all over their external surfaces with botryoidal cachalong, which often encloses the geode ; but when broken the mass often presents large crystals of amethyst, of a deep violet-blue colour. Frequently also the shell of the geode is composed of riband jasper or agate. The amethyst also occurs in cavities in the amorphous trap ; a single block when opened with a blow of the hammer, presented a surface a foot square, perfectly covered with splendid crystals of that mineral: some of these crystals measure an inch in diameter, and when they are perfect are six-sided prisms, terminated by six-sided pyramids. The amethyst found along this shore is seldom surpassed in beauty. . . .

Apophyllite . . . also appears, partially filling the cavities in geodes of quartz and amethyst ; the pearly lustre of the apophyllite, contrasted with the purple crystals where it is embedded, forms a pretty variety, and furnishes rich and elegant specimens. Amethyst, agate, and apophyllite, are sometimes found combined, each affording an instance of the singular process by which they have arranged their particles during the process of crystallization. Almost all the geodes containing this mineral, and those in the neighbourhood, are coated and curiously indented with botryoidal cacholong."

Quantities of amethyst, cacholong, and agate pebbles, worn smooth by the attrition of the waves, lie scattered among the sands of the beaches ; so it is rare indeed that even the veriest tyro departs from Blomidon without a goodly variety of specimens for his collection.

Unlike the opaque, encrusted specimens so characteristic of Canada's Lake Superior region, the amethyst crystals of Blomidon contained in freshly opened vugs and geodes, are possessed of a high natural polish.

Most are transparent in part and are a deeper shade of purple toward the end of the crystals. Some cavities in the rock are dressed or covered with minute, closely crowded crystals of rich colour, giving a rough spiked surface with many reflecting facets. These surfaces are often roughly fashioned along the edges and set locally in their natural state.

Many specimens of amethyst from this district are sold to tourists—principally from the United States, but little or no credit

is given the country of origin once the crystals have been cut and polished into gems or worked into ornamental objects.

Geodes and vugs lined with splendent amethyst crystals are utilized quite commonly for fireplace decorations in the summer cottages at Parrsboro and other tourist resorts along the Bay. The writer has seen geodes weighing twenty pounds or more used as doorsteps or garden decorations in Parrsboro and vicinity.

The local inhabitants place little value upon even the finest specimens ; consequently they unknowingly fall easy prey to the tourist in search of " bargain " specimens. The writer recalls having seen a portion of a geode from Blomidon entirely composed of snow-white opaque cachalong marked with lemon-yellow circles or eyes, and containing a cavity lined with splendent drusy amethyst crystals, each slightly less than a quarter inch in diameter. This specimen weighed approximately four pounds, and was sold to a visitor from the United States for about as many dollars.

A woman living on Victoria Street in Parrsboro has a necklace of deep purple, faceted amethyst set in antique natural gold The rough was collected at Blomidon by her daughter, and cut in the United States. The largest gem in this graduated necklace measures about five-eighths of an inch across, and the smallest is about one quarter inch in diameter. The necklace is composed of about forty round brilliant-cut stones in all.

With the exception of those striped with red cornelian and white chalcedony, the agates of Blomidon exhibit softer colours than do those from other American localities. Many are of a deep seal brown colour grading in portions to a pale translucent brown or buff colour. When cut in the domed form (the so-called " cabochon " cut), and set in rings, brooches and pendants, they make extremely attractive jewels—particularly if natural gold be utilized for the mounting. Dr. Gesner mentions a variety found at Blomidon imitative of the gay dancing figures made by our Indians with the quills of the porcupine on boxes made of birch bark.

Bloodstone and prase are rarely found at Blomidon, but specimens from that locality do turn up occasionally.

A slight curve in the wall of the mighty precipice, between two projections of basaltic rock—nearly opposite Cape Sharp—is known locally as Amethyst Cove ; and it is here that the greatest variety of crystals and masses are generally found. However, its reputation as the ideal collector's spot is hardly true with regard to the summer visitor, since it is principally in the spring of the year that the best crystals are to be found here. By summer time the piles of rocks have long since been picked over and looted of the most important specimens. Occasionally falls of rock occur during the summer also, so the itinerant collector and tourist would do well to visit any part of the cliff.

The most eligible and only really efficient mode of exploring the Bay of Fundy is by means of a small motor boat ; for aside from the difficulty of transporting large specimens, the collector is constantly endangered by a combination of insurmountable precipices and rapidly flooding tides, which rise in some places as much as sixty feet and more. This is the highest rise and fall of tide in the world.

Apart from the ever-present danger of being caught by the tide and having the doubtful privilege of clinging precariously for hours to a crevice above a raging sea, near Cape Split a mass of basalt extends out into the sea, so that it cannot be passed by way of the narrow beach—even at low tide—without the aid of a boat.

While it is the writer's purpose to describe only gems and ornamental materials of interest to the gemmologist-collector, justice to this locality cannot be done without appending a short list including other outstanding Blomidon minerals.

The following list,† prepared by Dr. Henry How (1827-1879) —Professor of Chemistry and Natural History in the University of King's College, Windsor, N.S.—may now be found somewhat imperfect, since the havoc wrought by the tremendous tides of the Bay of Fundy is continually changing the outlines of the coast and exhausting the old localities, but at the same time bringing to light others equally rich in mineral treasures.

The names of those minerals which can be obtained in good specimens are italicized:—

Analcime, agate, amethyst, apophyllite, calcite, *chalcedony,* chabazite, gmelinite (ledererite) (rare), faröelite, hematite, magne-

tite, *heulandite*, laumonite, fibrous gypsum, malachite, *mesolite*, native copper (rare), *natrolite*, *stilbite*, psilomelane, thompsonite, *quartz*.

PARTRIDGE ISLAND

Six miles north of Cape Blomidon, across the Bay of Fundy —and four miles east of Cape Sharp—rises lofty Partridge Island, celebrated for its numerous minerals, its summer hotel, and picturesque scenery.

Like Blomidon, this island (which, incidentally, is really a peninsula, linked as it is to the mainland by a stretch of solid beach) is composed principally of basaltic columns resting upon amygdaloid and sandstone.

On the western side, the three-hundred foot cliff has become undermined in several places by the action of the waves at high water, and hangs frowning accusingly upon the collector who dares to loot the treasures hidden among the fragments at its base ; for was it not at Partridge Island that the Great Glooscap, God of the Micmac Indians, cached his bowls of precious beads when the hated pale-faces intruded into his domain?

Situated some two miles from the thriving port of Parrsboro, and connected with the mainland by a motor road along the beach, Partridge Island enjoys the unique feature of ready accessibility by automobile from Parrsboro to the very base of its eastern cliff.

The minerals and gemstones found at this storied locality enjoy a world-wide reputation, not only for their variety and perfection, but also for their astonishing beauty as cabinet specimens.

As long ago as 1605, ten large crystals of deep purple amethyst were sent from Partridge Island, by the early colonists of Acadia, to Henry IV of France. This king, greatly impressed by the magnificence of the material, caused the crystals to be fashioned into jewels for his crown, and they maintained their exalted place in the French regalia for several centuries.

On rare occasions, opal and semi-opal have also been found there. The writer has two outstanding specimens (one of which has been partially cut and polished into a 12 x 15 mm. gem) which exhibit a splendid play of brilliant greenish gold colour with overtones of pale violet. Were it not for the iridescence of the speci-

mens, they might be taken for pieces of ordinary beeswax. The rough piece is entirely free of matrix and measures approximately 20 x 23 x 10 mm. Dr. Gesner mentions having found nodules of opal similar to these during one of his visits to Partridge Island in the 1830s. Specimens of fine quality are extremely scarce, however, and as far as is known, this is the only occurrence of precious opal in the Dominion.

Several veins of jasper and hornstone are to be found on the western side of the island, and botryoidal cacholong—a variety of opal which will adhere to the tongue—is obtainable with ease, in rich and striking patterns.

Splendidly marked cacholong frequently encloses geodes of amethyst and moss agate, cornelian, etc. Large specimens of hornstone may also be picked up along the shore. These would doubtless yield attractive collector's gems if cut and polished in cabochon form.

Good amethyst is now becoming rather scarce at Partridge Island, and nothing but an avalanche from the top of the cliff will replenish the dwindling supply of good material. Generally speaking, the Partridge Island amethyst has never been so fine as that from Blomidon. However, specimens of exceptional size—if not of quality—may still occasionally be found there.

The amethyst most frequently found at Partridge Island now might better be termed amethystine quartz, for it is in the form of masses of straight concentric crystals, banded with quartz and agate, and is suitable only for sawing into ornamental slabs. This variety—if strengthened with plate glass or plastic sheets on the back—would make beautiful jewel caskets or facings for clock cases, and if made thin enough, the slabs thus fortified could be utilized as panels for modernistic lampshades and other artistic objects of a similar nature.

In addition to the purely gem material mentioned above, the following striking cabinet specimens are of notable occurrence at Partridge Island:—

CALCITE.—As large and regular crystals, often transparent and of a light straw to golden yellow colour. Sometimes as perfect rhomboids an inch and a half in diameter.

STILBITE.—In large, wine-coloured crystal bundles, curiously studded with crystals of calcite, or tipped with delicate bright red heulandite.

CHABAZITE.—In colourless, transparent, rhombic crystals ; also in colours, varying from golden yellow to a bright red, which, although rather soft (H. 4-5), would furnish matchless and quite unusual cabinet gems if cut and polished.

OTHER BAY OF FUNDY LOCALITIES

CAPE D'OR.—Exceptionally fine, large crystals of apophyllite ; fair quality Malachite (often with dendritic veins of shining native copper running through it) and obsidian ; also good quality, richly patterned red and yellow jasper, especially as beach pebbles at Horseshoe Cove. Large cavities in the amygdaloid of this district are frequently occupied by transparent crystals of analcime.

Whilst the cliffs at Cape D'Qr cannot compare in height with those at Blomidon (although at one point they reach 400 feet), the rugged grandeur of the headlands, bluffs, and arches in the vicinity of Horseshoe Cove provide some of the most beautiful scenery in America. This beauty, combined with a wealth of mineralogical specimens not mentioned in this paper, make Cape D'Or a veritable paradise for the tourist—mineralogist and general collector.

SPENCER'S ISLAND.—Ideal crystals of clear quartz in prisms and bi-pyramids ; ribbon jasper ; and hematite in shining crystals and crystal groups.

CAPE SHARP.—Deep violet amethyst in geodes and vugs.

CLARK'S HEAD.—Hematite in fair quality ; also dark green prehnite in fine crystals.

SWAN CREEK and TWO ISLANDS.—Colourless and wine, yellow and red chabazite (acadialite) in crystals of exceptional quality and size. These would supply splendid cabinet gems, if cut. Analcime enclosing native copper and fine moss agate are also found here.

MCKAY'S HEAD, just east of Two Islands.—Siliceous sinter replacing crystals of amethyst or quartz (rock crystal), in delicate cherry red and pale amethyst colours. The groups of this mineral found at McKay's Head are unrivalled by any in the world.

CAPE SPLIT.—Exceptionally large geodes of rock crystal ; red thompsonite banded with green rings ; also bloodstone.

SCOT'S BAY.—Very fine moss agate, sagenite, and chalcedony ; also amethyst in fair to good quality.

THE NORTH MOUNTAIN COAST.—Amethyst, agate, chalcedony, jasper, bloodstone, hornstone, opal-agate, etc. Exceptionally fine apophyllite is found at Peter's Point and Chutis Cove.

PARADISE, BRIDGETOWN and LAWRENCETOWN.—Smoky quartz in immense crystals buried in the topsoil. Some are perfectly

transparent, with only a tinge of colour ; others are of a rich yellow colour (natural citrine) ; but most crystals are brownish yellow grading to purple-brown, and in this respect resemble specimens from the Cairngorm Mountains in Aberdeenshire, Scotland.

Crystals also occur in weathered pegmatite or coarse granite which, as it decomposes, leaves the ends of the immense crystals sticking out of the rock, from which they can easily be prised loose with the aid of a pen-knife or chisel.

Specimens weighing 100 lbs. or more were once upon a time piled up with the common stones of the fields ; but few, if any, remain. Dr. Henry How (" Mineralogy of Nova Scotia," 1869) mentions having examined a smoky crystal from this locality, which measured 13 inches in height and six in diameter. Shortly after their discovery in the early part of the 19th century, many were sent to the United States and Scotland, where they were highly esteemed. A single crystal yielded an Edinburgh cutter gems to the value of £400.

DIGBY NECK.—Fine amethyst, agate, hematite, chabazite, stilbite, rock crystal, etc. The hematite is in splendent " museum-type " crystals and crystal groups. Quartz " cat's-eye " may also be found here ; and yellow and red striped jasper is abundant. At Mink Cove, chabazite in one-inch crystals is of frequent occurrence.

* Gesner, A. H.—" Remarks on the Geology and Mineralogy of Nova Scotia," Parrsboro, Nova Scotia, 1836.

† From: " How, Henry.—" Mineralogy of Nova Scotia," King's College, Windsor, Nova Scotia, June, 1868." This list is not by any means a complete one for Blomidon.

WORLD GEMMOLOGICAL NEWS IN BRIEF

■ ■ ■

BRITAIN

A New Gemstone

E. P. Bottley, the well-known Chelsea mineralogist, showed, at the exhibition and reunion of the Geologists' Association held at the Geological Museum, South Kensington, on Friday, November 7th, four faceted gemstones cut from an albite/oligoclase feldspar found in Kenya.

The specimens, three trap-cut and one mixed-cut, were nearly colourless with a tinge of blue or of yellow. They contained crack-like flaws which were probably due to incipient cleavage, as the mineral is known to have three directions of cleavage—a perfect basal, a good one parallel to the brachypinacoid and a poor cleavage parallel to the prism. The lustre was seen to be vitreous tending to pearly and the stones appeared to be much inferior to quartz in brightness.

As yet no opportunity has been afforded to examine the properties of this gem, but from the information that the mineral is an albite/oligoclase much can be assessed. Albite, the soda feldspar ($NaAlSi_3O_8$) is one end member of the soda-lime feldspars known as the plagioclase series, while anorthite, the lime feldspar, is the other end member. Replacement of the albite molecule by anorthite in all proportions produces a complete series. If not more than 10 per cent. of anorthite be present it is correct to call the mineral albite ; if between 10 per cent. to 30 per cent. of anorthite is incorporated the mineral is the variety oligoclase.

It may be assumed that the new gemstone contains approximately 10 per cent. to 15 per cent. of anorthite, and, as both the specific gravity and the refractive indices rise with increase of the anorthite molecule a fair estimate of the constants of the stone may be made. Pure albite, or rather the purest found in nature, has refractive indices of 1.525-1.536, with a specific gravity of 2.62, while the values for anorthite are 1.576 to 1.588 and 2.76 respec-

tively. Oligoclase with 20 per cent. of anorthite has refractive indices of 1.538-1.547 and density of 2.65 ; therefore, assuming 15 per cent. of anorthite in the composition of the new gemstone, the refractive indices would be 1.535-1.544 and the density 2.64.

As the optical orientation of the plagioclase feldspars changes with the composition the sign of refraction alters, being positive for albite, turning to negative when 16 to 17 per cent. of included anorthite molecule is reached and reverting again to positive when the anorthite molecule reaches 40 per cent. The probability, therefore, is that the sign of refraction of the new gemstone is positive. The plagioclase feldspars crystallize in the triclinic system and have a hardness of $6\frac{1}{2}$.

That the gem can be anything but a curiosity cannot be gainsaid. For the collector, yes ; for the jeweller it can have no claim.

Since the above note was penned there has come to our notice that such a stone was known some seven years ago. In March, 1940, the late Major H. J. Beadnell obtained in Nairobi a pale bluish-white trap-cut stone weighing $3\frac{1}{2}$ carats. The stone was in appearance similar to the Bottley stones, and, like the last mentioned, the locality where it was found was Kenya. It was further stated to be a mineral known to geologists as albite/oligoclase. This Beadnell stone was carefully examined and the following data obtained: refractive indices $= \alpha 1.535, \beta 1.539, \gamma 1.544$, positive in sign and a 2V of 83° to 86°. The density was found to be 2.63. Thus the stone has approximately 90 per cent. of albite and 10 per cent. of anorthite, and the Bottley specimens will probably be in agreement with this.

AUSTRALIA

Our affiliated organization, the Gemmological Association of Australia, has recently widened its constitution in order to provide better facilities for the teaching of gemmology. Control of the Association is now vested in a Federal Executive which consists of representatives elected from each State Branch and the Secretary.

The rapid growth of the Association in Australia is most encouraging, and it is hoped that the revising of its Constitution will prove of benefit to all interested in gemmology.

By R. Dick-Larkam, B.Sc. (Eng.), A.M.I.Mech.E., F.G.A.

Cameo and Intaglio

THE art of engraving and carving stones is of great antiquity and was indeed known to primeval man, as it was he that discovered that a scratch could be made on one stone by means of another. Without doubt it did not take him long to find out that if he then pressed this piece of stone on some soft, plastic substance, such as a lump of clay, that an impression would be left which was identical to the scratch, except that it was raised instead of being sunken.

In all probability it was in some such way that the principle that underlies the seal was first discovered. It was this discovery that has made possible one of the articles that have been almost indispensable to mankind ever since.

Seals were even more a necessity to the ancient races than they are to-day. Previous to the Roman period the idea of the lock and key was not evolved, and it was only by means of affixing the impression of some hard object which had previously been carved with some recognizable design, that the privacy of property could be maintained.

Quite naturally different races and peoples of the earth, having different arts, signs and symbols, evolved seals in various shapes and applied their separate arts of decoration. The two most common are doubtless the " Scarab " and the " Cylinder " or modifications of the latter.

The scarab was to the Egyptians a symbol emblematic of eternity, and took the shape very similar to our beetle (which in actual fact it was copied from, beetles being by the ancient Egyptians worshipped as gods). It was oval, and on the underside, which was flat, it had engraved any particular pattern or cypher which the owner might think unique. The cylinder seal, as the name implies, was not unlike a miniature garden roller, and around the outside was engraved the pattern or subject which the seal was to impose

upon the wax or other soft substance. In operation, as can be readily understood, the principle was similar to an ordinary garden roller, usually having a hole through the axis of the cylinder in which to insert a stick.

Naturally these seals were made of a hard material and for the aristocratic classes valuable stones of the day were often used. Such stones as garnet, feldspar, lapis, turquoise, cornelian, amethyst, emerald, and in the East jade, were perhaps the most common. Although in the East also, calcite, soapstone, serpentine, and other soft stones were used, but it may be assumed that owing to their softness they were not so highly prized, although, due to the same property, the engraving was often of a much superior character.

The art of incising hard stones with elaborate designs reached the highest degree of perfection at the hands of the Greek artists. Upon stones which as a rule were almost flat they engraved representations of personages and incidents of their beautiful mythology in such a remarkably clever manner as to place the work on a par with many of the contemporary arts. The engraved stone or intaglio was often literally a subject picture displayed by hollowed out and carefully shaped incisions made upon the surface of the stone, and the subject was seen to even greater advantage in bas-relief upon any soft substance against which the object was pressed. These stones, although of great beauty, were in principle intended as articles of utility for sealing.

In contrast to these it was not until later that the cameo, or stone carved in bas-relief, was first executed. This stone was not utilitarian, but merely an ornament, and very likely owed its origin to the delightful impressions of the intaglios appealing to some wealthy personage of ancient days as an object of adornment if carved in hard stone.

It was in the Roman era that cameos first came into their own, as these people had a great love for them, employing the Greek craftsmen for their execution. They were produced in great numbers, portraying subjects connected with pagan mythology, and were distributed in quantities throughout Europe and handed down from generation to generation through the middle ages. In Roman times it does not seem to have been the habit to carve the portraits of living people, although a few are of warriors and celebrities.

Through the middle ages the art waned and, as with all things connected with arts, languished in Europe ; although many old cameos and intaglios were kept, and often used for adornment and sealing. In spite of the fact that the ancient carving depicted mythological and pagan superstitions, these were now translated into some Christian or kindred meaning.

It was not until the 15th century that the arts showed signs of renewed vigour, and with this movement came the rebirth of the carving of hard stones. At first copies of old works were undertaken, then after it had regained stimulus the production of original works were begun. During the 16th century the cameo received a very prominent place in jewellery and was often very exquisitely set.

During this period many royal and notable personages caused their portraits to be carried out in bas-relief upon hard stone, and many may still be seen in collections of art works. But the renaissance soon died, for in the seventeenth century all that was produced was in both technique and artistic skill far inferior to that which had preceded it.

The apeing of all things classical that became an obsession in the eighteenth and nineteenth centuries brought about another great revival of the cameo and intaglio, and it was at this time that many of the more wealthy people started forming collections of ancient carvings, which, of course, included any cameos or intaglios that could be procured. As can be expected, this led to innumerable forgeries of the original works being disposed of as Greek or Roman.

On account of the great demand there appeared craftsmen who were in many cases undoubtedly equal in skill to their classical precedents, and could no doubt have produced original works of equal merit with those previously executed ; but, however, they mostly contented themselves with sedulously copying the old engravings, even if their productions were not sold fraudulently as the ancient articles. There were, however, a few artists who resisted the temptation of being copyists and of making a great deal of easy money by clever forgeries by declaring that their work was of equal merit with any of a previous age and must necessarily be paid for accordingly. These men made their names famous by taking up this attitude, and their carvings are recognized as being entirely equal to those of any previous time.

It is sad to think that the glyptic art which existed from a date which history fails to reach, with only the short eclipse during the middle ages, down to modern times, should be allowed to flicker practically out, but this was its sad fate in the thirties of the last century ; and although isolated cases of its revival have been made, there is no general tendency in that direction. This may be due to the fact that the severity of the modern day in reaction to the Victorian and pre-Victorian lavish adornment has little place for the intaglio and less still for the cameo, which in themselves usually present the appearance of fancifulness.

Association Notices

(continued from opposite page)

PROBATIONARY:

N. H. Day, Salisbury ; Ove Dragsted, Copenhagen ; A. Elzingre, Karachi ; M. Field, London ; C. F. Haberer, London ; J. M. Lister, Birmingham ; J. A. Meade, London ; Miss J. M. Pyman, Letchworth ; Miss G. Richards, New York ; F. C. Salisbury, Northolt ; F. Scanlon, Manchester ; W. G. Seymour, London ; W. G. Solomon, London ; D. L. Steyning, Hampton ; P. J. Thomson, Thundersley ; D. Ungerson, London ; M. B. Wade, London ; F. Wolfers, Brussels ; E. Christie, Dundee.

TALKS BY FELLOWS

W. A. Peplow. Stourbridge Soroptimist Club, November 5th, 1947 Title: "Gemstones."

H. A. Reese. Southport Scientific Society, 13th November, 1947. Title: "Gemstones." Also Liverpool Geological Society, January, 1948.

James Gilloughley, Greenock and District Catenian Association, Gourock, 13th November 1947. Title: "Diamonds."

T. Bevis-Smith, Central Y.M.C.A., London, 29th November, 1947. Title: "Synthetic Stones."

ANNUAL SUBSCRIPTIONS

Fellows and Members are reminded that Annual Subscriptions became due on 1st January, 1948. Remittances should be sent to the Secretary of the Association according to the following rates:—

Fellows, £1 1s. 0d.
Probationary Members, 10s. 6d.
Ordinary Members, £3 3s. 0d.

Cheques should be made payable to the "Gemmological Association of Great Britain."

THE JOURNAL OF GEMMOLOGY
AND PROCEEDINGS OF THE GEMMOLOGICAL ASSOCIATION OF GREAT BRITAIN

Vol. I, No. 6 APRIL 1948

GEMSTONE NOMENCLATURE

In 1936 the National Association of Goldsmiths of Great Britain, which represents the retail jewellers of the country, approved for trade usage standard gem descriptions. These descriptions were themselves adapted for use in Britain from the 1936 International Congress of Jewellery Associations.

The Gemmological Association has now revised the 1936 list, and in so doing has discarded and disregarded altogether misleading names which have become outmoded and can be considered "dead and done with," and only singled out for condemnation terms still commonly mis-used in the trade to-day. Thus reference is not made in the list to misnomers now obsolete, such as "oriental amethyst," when mauve sapphire is the correct description. Names which, while not incorrect, have an indefinite meaning have also been avoided. As an example may be quoted the term "chrysolite," which has been often used to designate yellow chrysoberyl, but is used by American mineralogists as the species name for Olivine.

It is emphasized that the modifications made to the 1936 list have been made for use in Britain. It is hoped that the recommended revised British List will provide a basis for discussion and agreement between other countries which possess gemmological and jewellery organizations that are fully alive to the importance of the use of correct gem descriptions.

Mineralogical Species and Variety	Colour	Correct Trade Name
DIAMOND:		
	Bluish white, white yellowish white. Yellow, brown, green, pink, red, mauve, blue, black	Diamond
	Brilliant; Rose. *These terms are commonly applied in the trade as synonyms for diamond of appropriate cut. Unless followed by the name of the species, however, the terms are not free from ambiguity.*	
CORUNDUM:		
Ruby	Red	Ruby. *If description is given, i.e., Burma Ruby, seller to be responsible for correct place of origin.*
	Red, with 6- or 12-point star effect	Star Ruby
Sapphire	Blue	Sapphire. *If description is given, seller to be responsible for correct place of origin.*
	Blue, grey. etc., with 6- or 12-point star effect	Star Sapphire
	Blue, with shimmering stripe	Sapphire Cat's Eye
	Pale bluish white	White Sapphire
	All colours other than the above to be called by their colour	Yellow Sapphire, Green S., Pink S., Mauve S., Orange S., etc.
	Incorrect Descriptions: *Coloured Sapphires should not be called "King Topaz, Oriental Topaz, Oriental Amethyst, Oriental Aquamarine."*	
CHRYSOBERYL:		
Chrysoberyl	Yellow - yellowish - green, green, yellowish - brown, brown	Chrysoberyl (Term "Chrysolite" should not be used)
Cat's Eye	Translucent honey-coloured to greenish or brownish, showing chatoyancy.	Cymophane Chrysoberyl Cat's Eye
	Note: *Term "Cat's-eye" should not be used on its own but qualified by name of species, i.e., Chrysoberyl Cat's Eye.*	
Alexandrite	Green to greenish-brown by daylight, red to reddish-brown by artificial light	Alexandrite

Mineralogical Species and Variety	Colour	Correct Trade Name
SPINEL:	All colours, other than dark blue, and black to be called . . .	Spinel; or Red S., Pink S., Orange S., Purple S., Violet S., Mauve S., Blue S. or Green Spinel, respectively.
	Black, or very dark green	Pleonaste, or Ceylonite
	Zinc-rich blue spinel	Gahnospinel
	Note: *Terms spinel ruby, ruby spinel, rubicelle, alamandine spinel cause confusion, and should not be used.*	
TOPAZ:	All colours	Topaz
	Species to be called by colour, e.g. Yellow Topaz	White, Pink, Blue, etc., Topaz respectively.
	Note: *Term Topaz should only be applied to this mineral and not applied to yellow quartz.*	
BERYL:		
Emerald	Bright green (coloured by Chromium)	Emerald
Aquamarine	Pale blue Pale greenish-blue	Aquamarine
Beryl	Green (other than emerald green)	Beryl
	Golden, Yellow	Heliodor (Golden beryl)
	Pink or Rose	Morganite (Rose Beryl, Pink Beryl)
ZIRCON:	All colours	Zircon
	White (colourless)	White Zircon
	Blue	Blue Zircon
	Green	Green Zircon
	Note: *The terms "jacinth" and "hyacinth" should not be used.* Incorrect Descriptions: *White Zircon should not be called "Matura Diamond." The term "Jargoon" is fast becoming obsolete and may well be dispensed with.*	
TOURMALINE:	Colourless and all colours The colour should prefix name, i.e. Red tourmaline, Green tourmaline, etc.	Tourmaline
	Chatoyant	Tourmaline Cat's Eye
	Incorrect Descriptions: *Green Tourmaline should not be called "Brazilian Emerald", Yellow-green Tourmaline not "Brazilian Peridot": Red Tourmaline not "Siberian Ruby": Greenish-blue Tourmaline, not "Brazilian Sapphire."*	

Mineralogical Species and Variety	Colour	Correct Trade Name
GARNET:		
	All colours	Garnet
Almandine	Violet-red	Almandine Garnet
	Incorrect Description: *Almandine should not be called "Ceylon Ruby," "Arizona Spinel" or "Kandy Spinel."*	
Pyrandine	Violet-red, density range 3.80 to 3.95	Pyrandine Garnet
Rhodolite	Pale Violet (Intermediate types between Almandine and Pyrope)	Rhodolite Garnet
Pyrope	Brownish red to crimson	Pyrope Garnet
	Incorrect Descriptions: *Pyrope should not be called "Arizona Ruby," "American Ruby," "Adelaide Ruby," "Bohemian Ruby," "Colorado Ruby," "Cape Ruby."*	
Spessartite	Brownish-red, orange-red	Spessartite Garnet
Grossularite	Pale Green	Green Garnet Grossularite Grossular
Hessonite	Orange-reddish-brown	Hessonite
	Incorrect Descriptions: *Massive Green Garnet should not be called "Transvaal Jade": Hessonite not "Jacinth."*	
Andradite	Yellow	Andradite Garnet
	Green, Yellowish - green, Olive-green	Demantoid
	Black	Melanite Garnet
	Incorrect Descriptions: *Demantoid should not be be called "Olivine" or "Uralian Olivine."*	
Uvarovite	Emerald green	Uvarovite
IOLITE:		
Iolite Cordierite Dichroite	Blue and pale brown, strongly dichroic	Iolite, or Cordierite or Dichroite
	Incorrect Descriptions: *This gemstone should not be called "Water Sapphire" or "Lux Sapphire."*	
PERIDOT, OLIVINE:		
Peridot	Yellowish-green	Peridot
	Olive Green	Peridot
	Yellow, brown	Peridot
	Incorrect Description: *Peridot should not be called "Evening Emerald."*	

Mineralogical Species and Variety	Colour	Correct Trade Name
QUARTZ:		
Rock Crystal	Colourless, milky, also slightly coloured	Rock Crystal
	Incorrect Descriptions: *Rock Crystal should not be called "Bristol Diamond", "Cornish Diamond."*	
Amethyst (natural colour)	Light to dark mauve Violet	Amethyst
Amethyst (heat-treated)	Shades of brown and yellow	Citrine
Citrine	Yellow, yellow-brown	Citrine
	Incorrect Descriptions: *Amethyst heated to a topaz colour should not be called "Topaz," neither should the naturally-coloured Citrine be called "Topaz." Yellow or Brown Quartz should not be called "Topaz," "Madeira Topaz," "Scotch Topaz," "Spanish Topaz," "Occidental Topaz," "Quartz Topaz," etc.*	
Smoky Quartz	Smoky or brownish-yellow to black	Smoky Quartz
	Brown	Cairngorm
	Smoky brown or blackish	Morion
Rose Quartz	Milky rose pink	Rose Quartz
QUARTZ (with inclusions)		
Prase	Leek green	Prase
Quartz Cat's Eye	Chatoyant Whitish-grey Greyish-green Greenish-yellow Brownish-red Blue	Quartz Cat's Eye
	Incorrect Descriptions: *Quartz Cat's Eye should not be called "Cat's Eye" without the qualification "Quartz."*	
Aventurine Quartz	Yellowish-browny-red Yellow, brown, red or green, spangled with green or reddish flakes	Aventurine Quartz
	Incorrect Description: *"Indian Jade," for green Aventurine Quartz "Aventurine" should not be used for a glass melt containing crystals of copper, sometimes known as "Gold Stone."*	
Rutilated Quartz	Colourless, with rutile inclusions	Rutilated Quartz
Tiger's Eye (Crocidolite)	Golden-brown chatoyant	Tiger's Eye (Crocidolite)
Falcon's Eye	Like Tiger's Eye, but greyish-blue	Falcon's Eye

Mineralogical Species and Variety	Colour	Correct Trade Name
QUARTZ (Crypto-crystalline):		
Chalcedony (translucent)	Grey to bluish	Chalcedony
	Incorrect Descriptions: *Chalcedony stained blue or green should not be called "Blue Moonstone" or "Chrysoprase" respectively.*	
Chrysoprase	Apple - green and light green	Chrysoprase
Cornelian	Red in various shades	Cornelian
Heliotrope	Dark green with red spots	Bloodstone Heliotrope
Jasper	Opaque, whitish, yellow, red, green, brown, etc.	Jasper
	Incorrect Description: *Jasper when chemically stained blue, should not be called "German" or "Swiss Lapis."*	
Plasma	Leek Green	Plasma
Agate	White, yellow, grey, red, brown etc., usually in concentric strata Also stained in various permanent colours	Agate
	Milky with green or brown moss-like inclusions	Moss Agate
	Velvety black, single coloured	Black Onyx
	Stained or unstained Agate with two strata of black and white or red and white	Onyx, Sardonyx
SPODUMENE:		
Spodumene	Yellowish-green Pale yellow	Spodumene
Hiddenite	Bright green	Hiddenite
Kunzite	Rose, Pink, Lilac, Violet	Kunzite
JADEITE:		
Jadeite	White or parti-coloured, also mauve, brown, orange, translucent to opaque	Jadeite or Jade
Chloromelanite	Dark green or nearly black, with white flecks, opaque to translucent.	Chloromelanite or Jade
NEPHRITE:		
Nephrite	Green, White, self-coloured or spotted, translucent to opaque	New Zealand Jade, Nephrite, Greenstone, Jade

Mineralogical Species and Variety	Colour	Correct Trade Name
OPAL:		
Opal	Milky with quickly shimmering rainbow-like play of colours	Opal White Opal
	The same on dark background	Black Opal
Fire Opal	Pale to dark orange	Fire Opal
Opal	Transparent, colourless or pale yellow with internal play of colour	Water Opal
Opal Matrix	Flecks of Opal in Matrix	Opal Matrix
FELDSPAR:		
Orthoclase	Colourless Yellow	Adularia Yellow Orthoclase
Moonstone	Whitish with bluish wavy lines of light	Moonstone
	Whitish green	Microcline
	Opaque green	Amazon Stone, Amazonite
	Incorrect Descriptions: *Moonstone or Adularia should not be called "Ceylon Opal": Amazonite or Amazon Stone, not "Colorado Jade."*	
Oligoclase and Orthoclase	Brownish-white with gold flakes	Sunstone Aventurine Feldspar
Labradorite	Ashen grey with gleams of colour	Labradorite
	Transparent type	Black Moonstone
LAPIS-LAZULI:		
	Fine blue (opaque), often with brassy specks of Pyrites, sometimes with white patches	Lapis-Lazuli
TURQUOISE:		
	Sky - blue, bluish - green, greenish, opaque	Turquoise
	Containing veins of brown limonite matrix	Turquoise Matrix
FLUORITE, FLUORSPAR:		
Fluorite, Fluorspar	Green, yellow, red, blue, violet, etc. Transparent to translucent	Fluorspar, Fluorite, Blue John for blue veined massive variety
	Incorrect Description: *Fluorspar should not be called "African Emerald" or "Emerald Matrix."*	

Mineralogical Species and Variety	Colour	Correct Trade Name
PYRITES:		
	Note: *Actual mineral Marcasite is not used in jewellery, as it decomposes too readily. So-called Marcasite is really Pyrites.*	
Pyrites	Brassy yellow with a metallic sheen	Pyrites Marcasite
	Not to be confused with faceted steel or other metal.	
OBSIDIAN: (a volcanic glass)	Dark green, or black, grey, red, brown, etc.	Obsidian
	Note: *The term "Obsidian" is sometimes wrongly applied to bottle glass.*	
MOLDAVITE (a meteoric glass)	Dark green to brownish green	Moldavite
	Note: *The term "Moldavite" is sometimes wrongly applied to bottle glass.*	
MALACHITE	Green, veined, banded	Malachite
SERPENTINE:	Greenish-yellow to green	Serpentine
	Serpentine should not be described as "Jade."	
PSEUDOPHITE:	Green	Pseudophite
	"Styrian Jade" is a misnomer.	
AMBER:	Pale yellow to brown	Amber
	Transparent to opaque, also also cloudy	
	Amber chips reassembled under heat and pressure	Pressed Amber
	Stained Amber	Stained Amber
JET:	Black	Jet
CORAL:	Varies from pure white to dark red	Coral

Mineralogical Species and Variety	Colour	Correct Trade Name
PEARL:		
Pearl	Creamy - white, pink, yellow, green-blue, etc.	Pearl
	Black	Black Pearl
Pearl (Cultured)	Creamy-white to pink-white, with artificially inserted nucleus	Cultured Pearl
	The Designation "pearl" without qualification must only be used for the natural product of a mollusc unaided in any way by human agency.	
	Pearls which have been produced with the intervention of human agency must bear the designation "Cultured Pearls."	
Conch Pearl	Pink, white, porcellaneous	Conch Pearl Pink Pearl
Clam Pearl	Black, non-nacreous	Clam Pearl

To the Editor

May I comment on Elsie Ruff's exposition concerning "semi-precious stones" in the "Journal of Gemmology," Vol. 1, 1947, p. 28, a theme which is at present debated by the gemmologists of the U.S.A. and of Britain?

If memory serves me right, the expression "semi-precious stones" (Halbedelsteine) was first used in Germany in a treatise published at Heidelberg in 1824. I cannot submit more specific details, especially not the name of the author, as I lost my papers through war-action, but I remember that the author probably chose this expression in order to have —according to his opinion—a better possibility of classifying gemstones. Although it requires some effort, one can imagine that some 125 years ago the then new conception did not have the same significance and especially not the same effect as to-day. Neither the African diamond localities nor the very rich gem occurrences of Brazil and Madagascar were known at that time ; the quantity of gems on the market must have been very small and their price correspondingly higher than at later times. Apart from gems from Ceylon, India, Russia and Britain, there were practically known only Bohemian garnet, amber, and agate and jasper from Idar-Oberstein. Considering the relative rareness of gems, the expression "semi-precious stones" could not have had the most undesirable effect which it has to-day at a time when jewellery is in great demand and gems are abundant.

In Germany the expression "semi-precious stones" has practically disappeared since about 20 years. No doubt, constant explanation and the tireless efforts of Prof. Brauns (Bonn) and of my late father, Dr. Alfred Eppler, have contributed to this end. I wish the same success to the gemmologists of the U.S.A. and of Great Britain. The designation "semi-precious stone" does not make sense.

U.S. Zone, Germany. W. F. Eppler.

EXPERIMENTAL RESULTS with the Hawkins Density Gels

By B. W. ANDERSON, B.Sc., F.G.A.

A BRIEF reference to the Hawkins density gels has already appeared in this Journal (Vol. I, No. 3, page 1). Now, thanks to the generosity of Dr. A. C. Hawkins in sending me a complete set of his gels, it is possible to offer a more detailed report on this interesting variation on the heavy liquid theme.

The resistance offered to the fall of stones in these liquids depends not upon their density (which is less than that of water) but upon their viscosity. In appearance they resemble hair-cream (a substance actually used, Mr. G. T. Clarkson tells me, in some experiments on these lines he carried out some years ago), and they are contained in glass cylinders some 8 inches high and 1½ inches in diameter, graduated in 100 divisions. Neatly made wire spiral " spoons " serve to raise the specimens to the surface after a test has been made, and the gels, though somewhat messy, are non-poisonous, non-corrosive and water-soluble.

The fluids are graded A, B, C and D in order of increasing viscosity. Those most suitable for gemstones of average size and density are grades B and C, and with these two gels careful and extensive experiments were carried out for me by Dr. W. Stern, Mrs. G. V. Ash and Mr. H. A. Clark in the Post-Diploma classes at Chelsea Polytechnic.

Dr. Hawkins in his own description of the gels had already uttered a warning that the rate of fall increased not only with the density of the specimen but also with its weight ; also that the style of cutting had some influence. In order to obtain more precise information about the importance of these factors, our experiments were mainly directed to discover the rate of fall of

(a) Specimens of the same density but varying in size and weight.

(b) Specimens of the same shape and size but differing in density.

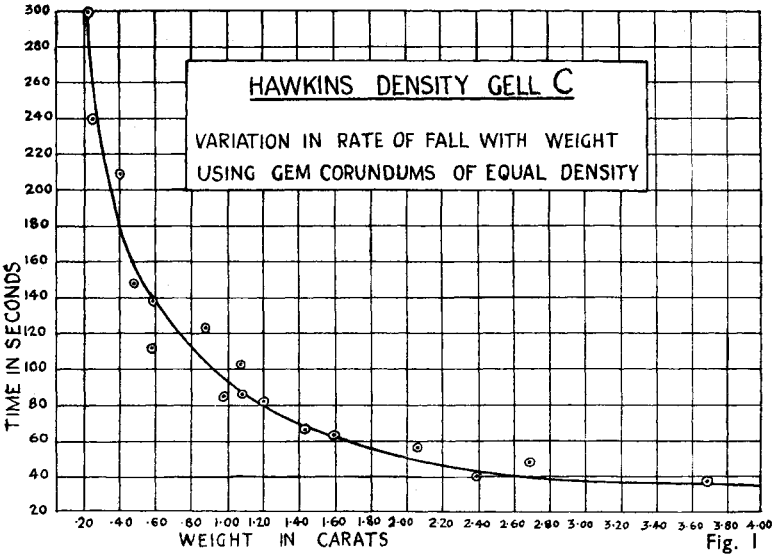

Fig. 1

For experiments (a) corundums were chosen, some natural and some synthetic, ranging from 0.21 carat to 8.56 carats. As expected, there was no evidence of the slower rate of fall in synthetics compared with natural corundums of the same size, a claim surprisingly put forward by Dr. Hawkins on the basis of the lightening effect of included bubbles. The time taken for the specimen to fall from 0 to 50 and from 50 to 100 divisions was measured by two observers using stop-watches, and each stone was timed twice. No acceleration was observed in the falling specimens when once they had started to sink, the time taken to fall from 0-50 being equal to that for the 50-100 interval. The time for the complete fall, plotted against the weight of the respective specimens, was found to form a rough curve (see Fig. 1), very steep in the smaller weight region, but flattening out for the larger stones. The actual time variation was very great: 300 seconds for a corundum weighing 0.21 carat to only 23 seconds for one weighing 8.65 carats. The tremendous influence of weight (as distinct from density) is alarming enough when one considers trying to use the method for discriminating between stones of different density, but even more disconcerting were the inconsistencies within the curve, which made one despair of the gels being in any way a practical proposition. Records were kept of the dimensions and style of cutting of each

stone, but no clear correlation could be made between the shape and rate of fall of two specimens equal in all other respects. Brilliant-cut stones were found to turn over in falling and then to remain steady in the sideways position. This having been observed, later stones were introduced into the liquid in this most favoured position, to ensure a steady fall.

In experiments (b) a set of Rayner density indicators made from optical glass was chosen, as these give a wide range in density and at the same time are of almost exactly the same shape and size (rectangular slabs, some 10 × 10 × 5 mm.). Here time of fall was plotted against density, resulting in the crude curve indicated in Fig. 2. Again there were many anomalies, and the line drawn in is only an attempt to guess the correct position.

A number of other tests were carried out with the gels, but, with the best will in the world, one was left with the conclusion that to place any reliance on a density figure assessed from the rate of fall in these fluids one would have to carry out so many comparative experiments with stones closely similar in size and density that it would be both quicker and safer to use the hydrostatic method or the normal heavy liquids.

In conclusion, my thanks are due to Dr. Hawkins for so kindly sending the gels over from America, and to the small team of workers mentioned above who carried out the experiments.

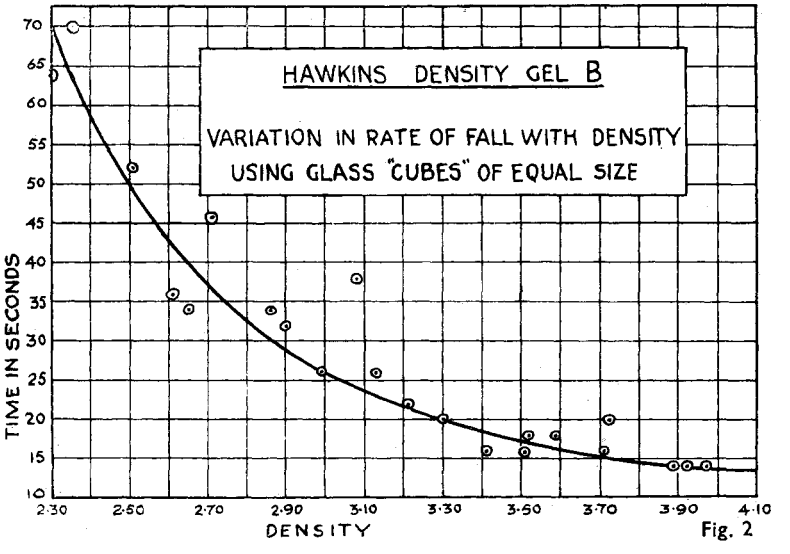

Fig. 2

Canadian Gems and Gem Localities

Part II

GEMS OF QUEBEC AND ONTARIO

By D. S. M. FIELD

THE rocks of Quebec and Ontario are so varied and the deposits of gem material so numerous that the writer has chosen to give in this chapter only a brief, general outline of the geology of the country, and to classify the gems according to their respective names rather than by specific localities.

The Canadian Shield—technically known as the Laurentian Plateau—stretches like a giant horseshoe around Hudson Bay. All the Labrador peninsula is occupied by the Shield. It skirts the north shore of the St. Lawrence River almost to the city of Quebec. It occupies the whole northern part of Ontario and reaches down to the shores of Lakes Superior and Huron, and borders the eastern side of Georgian Bay. It projects across the International Boundary in a narrow belt east of Lake Ontario, and in a wide zone between Lake Huron and Lake-of-the-Woods. Its western boundary is formed by the chain of lakes which includes Lake Winnipeg, Lake Athabaska, Great Slave, and Great Bear Lakes.

The Canadian Shield (Pre-Cambrian) has the oldest surface rocks to be found anywhere in the world. These consist of a series of sedimentary and volcanic formations, and igneous intrusives of great variety.

Mountains, some of which, before the Great Ice Age, were miles in height, have been completely eroded by the combined actions of weather, icefields, glaciers and other agents, until the average elevation does not exceed 1,500 feet, and few areas—except in the north-east—exceed 2,000 feet in height.

Since most of the rocks now exposed were of plutonic origin, ideal conditions for the growth of crystals—such as slow cooling,

the presence of mineral solvents to keep the mass liquid, and cavities large enough to allow free growth—were present during the formation of many of the crystalline rocks of the country. As a result, exceptionally large and well-developed crystals of gemstones occur in several localities. Unfortunately, however, when the rocks now exposed were deeply embedded, they were subjected to great strain, re-heating and crushing, which tended to destroy the internal perfection of most crystals which might otherwise have furnished cut gems of good size and colour.

In this chapter I propose to describe in some detail those gems of Canada which may be of interest to gemmologists and collectors generally, either because of their beauty as gems, or on account of the size and perfection of the specimen crystals obtainable.

Grateful acknowledgment is made to the Librarian, Bureau of Geology and Topography and National Museum of Canada, who has given generous co-operation in the provision of geological and mineralogical references, and information.

ZIRCON.—Dr. George Frederick Kunz, in his book, " The Gems and Precious Stones of North America," called the zircons of Ontario " the most remarkable known for beauty, size, perfection, and richness of colour."

The crystals from Lake Clear, Renfrew County, Ontario, are generally cinnamon red in colour, with an adamantine to resinous lustre. They range in length from about one-half to four inches, and are frequently twinned. This locality furnishes what are generally acknowledged to be the choicest twinned crystals of this mineral in the world. Several splendid twins from Canada are in the British Museum collection, and one of these is shown, in colour, in Selwyn's " Retail Jewellers' Handbook " (Plate VII).

Some of the individual zircons from the townships of Brudenell and Sebastopol, Ontario, are nearly a foot in length and from three to four inches in diameter.

The fine-grained rock in which they occur is composed almost entirely of feldspar, and has been classified as a syenitic-aplite. On account of the toughness of the gangue, the crystals can rarely be secured except by blasting, and this hopelessly shatters much of what might otherwise be good material.

The crystals are uniformly distributed throughout the rock, and it has been estimated that the diggings will yield a crystal more than an inch and a half in length for every three tons of rock removed. Crystals weighing from two to fifteen pounds are of fairly common occurrence. No crystal of less than one-half inch in length has been observed at this locality. (Parsons, A. L.—" The Mode of Occurence of the Giant Zircons from Brudenell Township Ontario," in " Contributions to Canadian Mineralogy," 1931.)

Large zircons are also found at many places at the contacts of crystalline limestone and the granite-gneisses, in the district north of Kingston, Ontario.

At best, only small portions of these huge crystals are fit for cutting into gems, and the finished stones, although of very fine quality and colour, rarely exceed a carat or two in weight ; but many thousands of dollars worth of the crystals have been sold as specimens.

For really promising gem material one must go to Burgess, Ontario, and adjoining townships. Here, smaller but exquisite crystals—in splendent, highly modified forms—occur, and at Templeton and near Grenville, P.Q., still smaller, but transparent cherry red crystals occasionally yield hyacinth gems.

SPHENE.—The huge crystals of sphene found in Canada also have a world-wide reputation, not only for their perfection as specimens, but also for their colour and general appearance. They occur in several localities in Ontario and Quebec, but perhaps the best known deposit is on Turner's Island in Lake Clear, Renfrew County, Ontario.

The crystals from Turner's Island are, in general, deep chocolate brown in colour, with an amazingly brilliant adamantine lustre. They average about two and one quarter inches in their greatest dimension, but crystals of giant size are quite frequently met with. Dr. Kunz (op. cit.) mentions a twinned crystal from this locality which weighed upwards of eighty pounds.

Unfortunately, like the large zircons described above, few of the crystals of sphene from Turner's Island are transparent enough to furnish even a small gem ; but many thousands of dollars worth of specimen crystals have been sold to collectors and museums.

The finest crystallographic specimens are found in Brudenell and Sebastopol townships, also in Renfrew County, Ontario. Both of these localities furnish huge sphenes of both the twinned and simple types.

Honey-yellow crystals of gem quality are occasionally found in the township of North Burgess, Lanark County, Ontario ; and fine crystals have been found in the townships of Buckingham, Hull, and Wakefield, P.Q.

A very rare, almost white variety from Brome, P.Q., is among the many fine specimens in the Geological Survey Museum at Ottawa. The Royal Ontario Museum of Mineralogy houses what is probably the best collection of sphene crystals from Lake Clear.

WHITE GARNET.—Among the less spectacular, but exceedingly rare and interesting gems of Canada, are the colourless and white grossular garnets found in some abundance in Lots 6 and 14, Wakefield township, near Hull, P.Q.

These gems occur in veins and vugs in crystalline limestone, associated with hessonite, idocrase, and pyroxene ; galena, pyrites, and zinc.

This locality is the most remarkable known for this particular type of garnet. It yields crystals up to two inches in diameter, often in large groups of twenty or more individuals, measuring as much as a foot across (Kunz, op. cit.). Some of the smaller transparent crystals have keen cut into gems of from one to two carats in weight. A number of the crystals are of a pale sherry tint—grading to light olive green—and these also furnish small, but bright and attractive faceted stones.

Although sporadic attempts to mine these garnets were made some seventy-five years ago, no market could be found at that time, and the work was abandoned altogether. The extent of the deposits is not known, but their systematic exploitation would undoubtedly yield some good gem material.

UVAROVITE.—Not the least of the Canadian gemstones are the small, transparent uvarovite garnets from the township of Orford, P.Q.

These gems, although rarely measuring more than four millimetres across, rival in colour and clarity the best of the emeralds

from Muzo, and are quite matchless anywhere. If it were not for their small size, the bright velvety-green dodecahedra would furnish faceted gems of the very highest rank.

The crystals are found in association with chrome diopside and millerite, lining cavities in crystalline limestone.

Uvarovite also occurs in the township of Wakefield, P.Q. Here the crystals are larger, but as a rule are opaque or only feebly translucent. The larger specimens measure nearly a half inch across, and therefore rival in size the uvarovites from the Ural Mountains. The crystals are of a deep emerald green colour externally, grading to yellow at the centre. Some of them might furnish cabochon gems.

GEM SCAPOLITE.—Until the recent discovery in Canada of several promising deposits of this rare mineral, Brazil, Madagascar and Burma were thought to be the only producers of gem scapolite.

In Canada, the crystals and masses exhibit a wide range of colours.

Scapolite occurs in fine lemon-yellow masses in the township of Grenville, P.Q. Cabochons exhibiting a well-defined, sharp chatoyant line have been cut from this material, and these have been classified as true scapolite cat's-eyes. Some of these cabochons are on display in the Royal Ontario Museum of Mineralogy.

Clear, transparent fragments are also met with occasionally at the Grenville deposit, and authorities believe that it may some day yield transparent material suitable for cutting into faceted gems.

Mr. G. G. Waite, a Toronto gem collector, has acquired a number of transparent specimens of scapolite from other Canadian localities. His collection now contains a pale green, step-cut stone from a newly discovered occurrence at Khartum, in the township of Griffith, Renfrew County, Ontario. This was cut from a fragment of a large, single crystal. Another recently discovered deposit at Drag Lake, Dudley township, Haliburton County, Ontario, has provided him with a very clear, pale yellow, triangular mixed-cut stone.

DIOPSIDE.—Transparent diopside (a variety of pyroxene) is found near Laurel, Argenteuil County, P.Q., and many crystals

have been cut in both the cabochon and faceted forms. The diopside from this locality ranges in colour from sherry-drab to greyish-green. The former colour provides surprisingly attractive and unusual gems. A number of cut specimens of this material are on display at the Royal Ontario Museum of Mineralogy.

Emerald-green diopside crystals, approaching gem quality, have also been found in Lot I, Concession XI, in Cardiff, Haliburton County, Ontario ; and it occurs abundantly as a rock constituent in the Laurentian area.

Diopside crystals up to six inches in length occur at Calumet Falls, P.Q., but these are seldom clear enough to be cut into gems.

A rich emerald-green chrome diopside is found at Orford, P.Q., associated with the uvarovite garnets described above. This is occasionally transparent and affords beautiful cut stones.

Diopside in a light green colour occurs at Bird's Creek in the township of Herschel, Hastings County, Ontario. Some of it is transparent and of gem quality.

A lilac-colour variety of pyroxene, resembling kunzite, is found near Grenville, P.Q., but it unfortunately does not admit of a high polish, and it is consequently seldom fashioned into gems.

VESUVIANITE (IDOCRASE).—Transparent, gem-quality vesuvianites, of a cadmium yellow to golden brown colour, are found at Laurel, P.Q. The Royal Ontario Museum collection contains two flawless and exceedingly attractive cut gems, of the esteemed cadmium tint, from this locality. These stones were apparently fashioned from fragments of a large, transparent crystal which was shattered either by natural forces or by blasting. The fine quality of a piece of rough which accompanied the cut specimen would seem to indicate that further search may reveal crystals from which stones of large size may be cut.

Rich amber to seal-brown crystals occur in white calcite, in the township of Wakefield, P.Q., and at Calumet Falls large brown crystals of vesuvianite are known to occur in considerable quantity.

Mr. G. G. Waite possesses a fine, golden brown, oblong brilliant cut from part of a large crystal from Laurel, P.Q., as well as

a golden brown aventurescent cabochon, measuring 14 by 12 by 8 mm., from the same locality.

MONAZITE.—This mineral, called Monazite from the Greek μονάζειν, to be solitary, in allusion to its rare occurrence, is a phosphate of cerium, lathanum, praseodymium, neodymium, etc., with thorium, ythrium and silica usually present. It has a high specific gravity (S.G. 4.9-5.3), and crystallizes in the monoclinic system, the crystals being commonly small and flattened. It is relatively soft for a gem (H. 5-5½), but might afford quite attractive cabochons.

In colour, it ranges from hyacinth red through clove brown to yellow and yellowish green, with a resinous to vitreous lustre.

Monazite is occasionally found as large crystals in the township of Villeneuve, Ottawa County, P.Q. A part of a huge crystal taken from this locality weighed nearly fourteen pounds, which makes this one of the most remarkable occurrences known.

LABRADORITE.—Since its discovery, nearly a century and a half ago, the several occurrences of this universally admired variety of what might be termed Canadian feldspar have been so fully described in mineral texts that little need be added to what has already been written.

The finest known specimens come from Ford's Harbour (near Nain), Paul's Island, and Black Island, off the coast of Labrador. It also occurs in Ontario, along the shore of Lake Huron, at Cape Mahul, and at Abercombie, P.Q., and in large cleavages showing rich colour at Morin, P.Q.

APATITE.—The apatite of Canada, like so many of the other gem minerals described in this paper, is found in finer crystals and in greater abundance than in any other country (Kunz, op.cit.).

Magnificent crystals—one of which weighed 550 pounds—are found in the Emerald* Mine at Buckingham, P.Q. Others of rich colour, measuring several feet in length, occur throughout eastern Ontario, at Lake Clear and Sebastopol and other localities in the Counties of Renfrew, Lanark, Leeds, and Frontenac, Ontario ; and in the townships of Hull, Wakefield, Templeton, and Portland in Ottawa County, P.Q.

* So called because of the green colour of the apatite crystals.

Crystals from these localities are all shades of flesh-red, purple-brown, steel blue, and green. In Ottawa County, rich deep green apatite occurs in considerable quantity. The crystals are frequently partly transparent, and could be fashioned into ornaments or cut as cabochons.

Transparent gem apatite—considered to be equal in colour to the finest known—is found near Wilberforce, in the township of Monmouth, Haliburton County, Ontario. The rich bluish-green crystals from this locality are strongly dichroic. It is quite unlike the universally familiar type of material found in abundance elsewhere in Ontario and Quebec, although a poorer grade apatite of similar colour occurs near Cheddar and Tory Hill, Ontario. The Wilberforce crystals occur in veins of calcite, and provide very attractive faceted and cabochon stones.

TOURMALINE.—Gem quality tourmaline is rather scarce in Canada, but the occasional crystal provides small faceted stones of fine colour, and in some respects superior to those once taken from the celebrated deposit in the United States, near Paris, Maine.

Green and red tourmaline of gem quality occurs in the townships of Villeneuve and Wakefield, P.Q. Mr. G. G. Waite has a green triangular-cut stone from Wakefield which matches in colour the best of the tourmaline from Brazil. He also possesses a mixed-cut stone from a newly discovered deposit at Wilberforce, Monmouth township, Haliburton County, Ontario. This gem exhibits very dark green and crimson colours, and closely resembles the andalusite-like tourmaline from Ceylon.

Rich brown and yellow tourmaline crystals of gem quality are found imbedded in pink crystalline limestone in the township of Ross, Ontario, and at Calumet Falls, Clarendon, and Huntertown, P.Q.

The greater part of the crystals from the localities mentioned above, and the green tourmaline found in Chatham township, P.Q., are either cloudy or fractured in part, so that faceted gems of only a few carats can be cut from them. It is possible, however, that crystals now deeply imbedded may yield larger cut stones of excellent colour and quality.

Fine, large and well developed crystals of blackish green and blue-black tourmaline, and schorl of no gem value, are frequently

met with in the Laurentian limestone at localities too numerous to mention in this paper.

AQUAMARINE.—Large and well-developed prismatic beryl crystals—one of which measured five inches in diameter and twenty in length—occur in a small pegmatite dyke in Lot 23, Concession XV, in the township of Lyndoch, Renfrew County, Ontario. This dyke, which averages ten feet in width, is exposed for a length of only 150 feet, but numerous outcroppings indicate that its extent is considerably greater.

The dyke consists principally of an intimate mixture of gem amazonite albite, and the white, smoky, and rose varieties of quartz. Considerable black tourmaline and large crystals of red garnet are also present.

The beryl crystals are distributed rather thickly throughout the dyke, but are generally fractured and of a greenish shade. Occasionally, however, the larger crystals furnish gems of blue colour. A very fine, large blue aquamarine, cut from Lyndoch material, is in the Royal Ontario Museum collection of Canadian gems. It is the largest faceted aquamarine yet cut from Canadian beryl.

Gem quality aquamarine of fine blue colour occurs sparingly near Quadville, Renfrew County, Ontario, and a number of quite large faceted stones have recently been cut from it.

A newly discovered deposit, near Kearney, in the township of Butt, Nipissing District, Ontario, has also yielded stones of the esteemed blue shade.

GOLDEN BERYL.—Translucent to opaque golden beryl, suitable only for cabochons, occurs in Lot 13, Concession IV, in the township of Calvin, Nipissing County, Ontario. To the writer's knowledge, none of this material has yet been fashioned into gems. However, it is possible that transparent crystals of gem quality may some day turn up at this locality.

AMAZONITE.—Amazonite is found in the township of Lyndoch, in association with the aquamarine crystals described above. Unlike the watery green amazonite from other countries, the beads and cabochons which have been cut from the Lyndoch material are of a rich, nearly emerald green colour, with contrasting stripes or bands of creamy white. A magnificent necklace cut

from the amazonite from this locality is in the Royal Ontario Museum collection.

Amazonite of good colour has also been found in the townships of Monteagle and Sebastopol, Ontario, and near Hull, in the Province of Quebec.

SODALITE.—Perhaps no gem material found in Canada is better known than the rich cornflower and deep royal blue sodalite found near Bancroft, in the township of Dungannon, Hastings County, Ontario.

Sodalite is a complex silicate mineral, closely related in composition and properties to Lazurite, the principal constituent of lapis-lazuli.

The most attractive material found in Canada is laced and mottled with included minerals of bright red and white colours, and in this respect approaches very closely the true lapis-lazuli in composition. Indeed, no sharp line of demarcation can conscientiously be drawn between the two materials, since lazurite itself belongs to the isometric group of sodalite minerals.

Both the pure and the mottled varieties of Canadian sodalite take an excellent polish and furnish most attractive beads and cabochon gemstones.

Larger pieces of the Bancroft material have been cut into slabs and utilized in the arts for inlays, panels, etc. The collection of gems in the Royal Ontario Museum of Mineralogy contains several polished specimens from Bancroft, including carved figures, cabochons, and ornamental panels.

Sodalite of good colour also occurs in the counties of Peterborough and Haliburton, Ontario, and in small quantities in the rocks of Mount Royal, in the city of Montreal, P.Q.

The Redpath Museum at McGill University, Montreal, contains several pieces of the rare purple variety from Ontario ; and Mr. G. G. Waite, of Toronto, has secured a large flawless and translucent double cabochon of rich blue colour from the Bancroft deposit.

MALACHITE.—Malachite has been observed in Canada at practically every locality where native copper or its ore occur, but gem quality material is comparatively scarce. Some fine malachite does turn up occasionally, however, especially near Sutton, P.Q.

AN ASPECT OF GEMMOLOGY

ELSIE RUFF, F.G.A.

THROUGHOUT the English-speaking world—and in other countries also—is an increasing and enthusiastic column of gemmology students. One writes *students* with intention, because the qualified or practising gemmologist almost invariably takes the scientific view, despite the fact that he is a hybrid—part trade, part science, part devotee. One wonders less at gemmology itself and more at this growing body of adherents who have more to offer than the present jeweller appears to need. Maybe the jewellery trade is about to experience a sort of metamorphosis.

Curious of the part played by gemstones, from the dawn of man's existence, the gemmology student must perforce ask himself what all the fuss is about. Imperial Institute's " Gemstones " introduces the subject with a statement: " . . . it is said . . . some fourteen different varieties were known more than seven thousand years before the Christian era." Sydney H. Ball states that the Red Men alone used at least eighty-four different kinds of gems and stones, yet while fashion, custom, and even habits change, we continue to fuss over the emerald, not only as a species but in the main over a particular green. The same may be said of the ruby and many another stone. Some generations like their amethysts a little paler. Some their sapphires a little darker. Even those with an aversion to gemstones as ornamentation may nevertheless indulge in a personal collection, or exhibit an interest in collections.

The familiar formula, *Beauty, Durability,* and *Rarity,* at least provides a ready-made explanation that is generally satisfactory. But Durability, to take the second word first, used to mean more than it does to-day. No one particularly wants an old-fashioned Rolls Royce, even with petrol. No one really wants the furniture of a previous generation—if the furniture could somehow skip a hundred years it would be acceptable in a different way. Save for the reactionary, no one really wants an Edwardian house with a

scullery. So, if one's gemstones and pearls last a life-time it is, to be quite frank, all one wants or needs. Rarity, the third point, is something most of us innately understand. Deep down there is a desire for exclusiveness—if one cannot be exclusive about one's possessions or mode of living one tries to be exclusive about one's intellectual attainments or one's virtues. Yet the diamond is not rare. It is not possible to be exclusive in the possession of it. Furthermore, because one's neighbours on both sides possess diamonds, it does not make the diamond less desirable—rather it's an urge for the Smiths to keep up with the Joneses. Very few gemstones, in fact, are rare and at the same time attractive for ornamental purposes. Fine specimens are often rare, but these affect only the discriminating, not the great majority. At one period on the American Continent, where the public has been educated to desire fine diamonds and the average standard is higher, there was a craze for Jager diamonds. "Pay a little more and buy a Jager," one would hear. Neither the adviser or the advised could have recognized a Jager from any other diamond. The jeweller's word was enough. And from the moment of purchase the new owner would talk confidently about her Jager. Julian Huxley wrote recently: " . . . Are we to try to hold up the march of events on the ground that rarity is a good thing, and that the natural must always be better than the synthetic ; or are we to go to the opposite extreme and try to bring rarities and luxuries down to the level of commonplace and everyday abundance? It is a curious problem, which is new in human history. The answer in any case is not an affair of science, but of economics and of human nature. So I shall content myself merely with stating it, and leaving you to the question: Whether you would rather all of you be able to wear diamonds, if diamonds only cost little, or would prefer that diamonds should be luxuries for almost everyone, and by their very rarity confer some kind of glamour on the world? " Linked with Rarity is, of course, the investment factor, more acute to-day than for some time past. But that again affects only the few. The average buyer knows that his small investment, in a crisis, is neither here nor there. So, to sum up, Rarity, like Durability, does not make a big case for the gemstone.

Undoubtedly Beauty has the strongest vote, but beauty is relative. And to the gemmologist, bent on discovering the secret

—if there is one—it is not enough. Why all the fuss, he still asks, about that *emerald* green, that *pigeon's blood* red, that *royal* blue? Nature is lavish with colour. Even a pauper may satiate himself with it. One need not spend a thousand pounds to enjoy colour—superb colour!

We can hardly dismiss this discussion without reference to the part magic and superstition have played, though in our present sceptical world little of this remains. And the therapeutic aspect of gemstones is now historic or pre-historic, save for a few isolated instances. Nor do gemstone collectors, who have been constant throughout, elucidate the mystery, if mystery it is. Rather do they further confuse, for so often the particular is lost in the mass.

Scintillation is no help either, for most gemstones do not scintillate, and those that do, effectively, owe their sparkle to a comparatively modern technique. All forms of scintillation certainly fascinated primitive man, just as they do the baby. Our Christmas decorations are based on this appeal to the young. But though there are periods where scintillation plays a rather more important rôle, by and large man has grown out of it.

Added together, Beauty, Durability, and Rarity give a fairly substantial result. Maybe it is entirely satisfactory to the layman. For the gemmology student, however, it is still not enough. Beauty, Durability, and Rarity might quite conceivably, in primitive times, have been applied to teeth, often worn as necklets or ear or nose ornaments. But there is no vestige of the tooth cult left, unless it is the first baby tooth mounted in gold for an adoring parent.

It is possible that many a gemmology student, by a fluke of circumstances denied a scientific career, here finds his safety valve. It is possible, too, that the artistic, denied expression in other fields, also finds satisfaction here. The artist and the scientist have much in common for they more nearly approach that most exhilarating and precious of treasures, an open mind. For the rest, it is possible that the gemmology neophyte is first astonished at the vast field of knowledge concerned with these little scraps of nature that conform to law. It is possible that he gets caught up in this study as one may with any such work, pin-pointing life as it were. And was it not a famous scientist who said that any serious study must bring one to just this point?

R. Dick-Larkam, B.Sc.(Eng.), A.M.I.Mech.E., F.G.A., discusses

The Problem of NOMENCLATURE

●

IT is interesting indeed to review the names of gemstones, as they form such a conglomeration of misnomers and misuses that it is remarkable that more confusion does not occur. In 1929-1930 a conference was held in London in an endeavour to clear up some of the errors and misrepresentations in the naming of stones, and this was followed by an international meeting in 1936. These, no doubt, did good and valuable work for the jewellery trade as a whole, but it is indeed difficult to make a man suddenly forget a number of names which he has been using for many years and start again on systematic and sensible lines.

This process will only mature after several generations have passed and grown accustomed to a more scientific treatment of the gemstone than has been used in the past.

A great deal of confusion is undoubtedly due to a large number of stones having been known to the ancients, who named them haphazardly after any particular property that they possessed or were claimed to possess. Many of these names come down to us from the dead languages ; others are of Arabic, Persian, Hebrew or Indian origin.

In some instances the meaning of the words can be traced and it generally is indicative of some particular colour ; without doubt, anciently, many gems of a totally different nature were included under the same name because they resembled one another in appearance. In some cases, however, a name has a different meaning, as for instance the word *garnet* comes from the Latin word meaning " grain-like " ; *euclase* from the Greek, indicating " to break easily " ; and we get the name *turquoise* from the French, indicating that the gem was obtained from the merchants of Turkey.

Many of the older names of stones give a peculiar euphony, which seems to suggest beauty, and in fact are quite poetic in their inspiration, such names as beryl, chrysoberyl, spinel, and topaz, all of which fall easily, smoothly and beautifully from the tongue. This cannot be said of the more recent names, however, which are more scientific, being terminated by the suffix " -ite," indicative of a mineral. Such names as hiddenite and kunzite, for the green and pink varieties of spodumene, are not particularly poetic, nor is morganite, the name given to pink beryl. The two former take their names from two eminent American mineralogists, while the latter was named after Mr. Pierpont Morgan, a great collector of objects of beauty.

Yet another prominent stone named after a great man is that variety of chrysoberyl called alexandrite, which changes colour from green by daylight to red by artificial light. This stone thus displays the national colours of the old Russian Empire, and as it was discovered in Russia on Czar Alexander I's birthday, it no doubt has every right to the name which it has been given.

One of the chief difficulties which beset the student of gemmology is the complicated nomenclature of the subject. The gems have received their names in past ages without any regard to their relationship one with another and with an utter disregard of method. For instance, few but those in the trade and students of the subject realize that emerald and aquamarine are in reality one and the same, namely, beryl, and that a further variety, as mentioned above, is morganite. Surprisingly enough, almost as few realize that Ruby and Sapphire are brothers in the family of Corundum. There is really no reason why they should ; the names do not indicate in in any way.

In addition to this, partly through ignorance and partly for other reasons, the names of certain gems have become in course of time attached to stones of an altogether different nature, which they somewhat resemble, and which are in many cases of less value and importance. An extremely good instance of this is Topaz, which is a mineral found in yellow, blue, brown, pink and colourless varieties, but unfortunately the name is often given, not by any means always fraudulently, but merely out of ignorance, to the yellow variety of quartz (citrine), which has less value. It is sometimes, but by no means always, wrongly hyphenated with the word *Quartz*. *Scotch* or *Spanish*, etc.

All the confusions and misnomers so far mentioned are ones which have arisen by accident or by chance, owing to either their being many centuries old or to sheer ignorance on the part of the people who handled them. There is yet another and far more dangerous cause of confusion, and one which seems to have been rife in the gem trade a decade or so ago, and still often practised in the East, namely, that of fraud. Many ordinary cheap stones were given fancy names, to which they had no right or bearing, purely in order to sell them to an unsuspecting public, who did not know the difference between one mineral and another.

By the foregoing it is not meant that, for instance, a piece of crystal was sold as a diamond, but it would be called a " Cornish diamond," or " Bristol," " Brighton," " Briançon " diamond. A garnet would be sold as a " Cape Ruby," "Australian Ruby," or "Adelaide Ruby," etc. ; a spinel as a " Balas Ruby " or massive green garnet as " Transvaal Jade," and very many more. Fortunately, the use of such names has greatly decreased.

To dealers in gems these names have become known, and when, for example, a Balas Ruby is referred to, he does not think of ruby, but of spinel. The danger and confusion really lies with the uninitiated, who only too naturally believe it to be a particular kind of ruby and value it accordingly.

Hyphenated names have come into being for numbers of stones, such as " ruby-spinel," which is an ordinary spinel with a colour similar to ruby, to which it has no other connection. In the past the term " Rubicelle " has been used for orange-red spinel, and similarly the word " Rubellite " is often used for red tourmaline. Both should be disregarded.

For the green garnet found in the Urals there is a perfectly good name which it has all unto itself, namely, demantoid, and yet, peculiarly enough, the gem dealers of the past had to call this stone olivine, a name used by mineralogists for the gem mineral of which peridot is a variety. This leads to a great deal of confusion, and it is not at all uncommon to hear someone asking for olivine garnet, using two words where merely demantoid would suffice and be much more correct ; even when correctly used, the term olivine is liable to be misunderstood in the trade and peridot is thus a better name for the gem material.

" Oriental " and " Occidental " are words sometimes used in gemmology, but it is indeed encouraging to see that these terms are being used less and less. They are very confusing and are best discontinued. Oriental is a term which has grown to mean corundum, and as there are no special names for any of the colours other than red or blue, oriental topaz, oriental emerald and oriental amethyst, etc., have incorrectly grown to mean yellow, green and mauve corundum respectively. To-day the much more sensible habit of calling them yellow sapphire, green sapphire, etc., has come into being.

Jade is yet another very loose term which is used to cover numerous varieties of minerals ; it can almost be safely said that any green stone from soft steatite to the relatively hard Jadeite is called jade. Actually, according to the 1936 International Jewellers' Conference, this should, however, only cover Jadeite and Nephrite, two extremely similar minerals.

The recently revised Gemmological Association list should be helpful in further impressing upon all interested in gemstones of the importance of nomenclature.

ASSOCIATION NOTICES

JANUARY MEETING

On January 28th, 1948, the Association was honoured by a talk by Dr. W. Campbell Smith, M.A., D.Sc., Keeper of Minerals, British Museum (Natural History). His subject was " Gems and Gemmology at the Natural History Museum," and Dr. Campbell Smith discussed the history of his department between the period

Following Dr. Campbell Smith's talk, Mr. B. W. Anderson commented upon some recent problems in gemmology, including synthetic star corundums, synthetic emeralds and synthetic spinel boules, which showed twinning. Specimens of the various synthetics were available for examination.

GIFTS TO ASSOCIATION

The Association wishes to record the gift of five parcels of stones from Mr. C. T. Gilmer, Bath.

TALKS BY FELLOWS

January 17th, 1948.—" Identification of Gemstones." H. Reese, F.G.A. Liverpool Geological Society.

February, 1948.—" Gemstones." T. Ratcliffe, F.G.A. Buxton Youth Club.

GEMMOLOGY CLASSES IN EDINBURGH

In January officials of the Association visited the gemmology classes conducted at the Heriot-Watt College, Edinburgh, by Mr. D. Ewing, F.G.A. A special two-day course of practical instruction was undertaken by the visiting officials. The facilities at the College are excellent, and the Edinburgh and East of Scotland Goldsmiths' and Jewellers' Association are sponsoring the purchase of additional gemmological equipment for use in the classes.

1948 GEMMOLOGICAL EXHIBITION

The 1948 Gemmological Exhibition, organized by the Association, will be held at Goldsmiths' Hall, Foster Lane, London, E.C.2 (by kind permission), on the following days:—

Tuesday, 11th May, 2.30 to 8.30 p.m.
Wednesday, 12th May, 2.30 to 8.30 p.m.
Thursday, 13th May, 2.30 to 8.30 p.m.
Friday, 14th May, 2.30 to 7.30 p.m.

Admission will be by ticket only, and will be open to all members and their friends and members of the jewellery and allied trades. A limited number of tickets will also be available to the general public.

MARCH MEETING

In March the Association was honoured by a visit from Dr. Edouard Gubelin, F.G.A., C.G., of Lucerne, Switzerland. On Tuesday, 9th, and Wednesday, 10th March, at 6.45 each evening, he gave a lecture (in two parts) on "Inclusions in Gemstones" to Fellows and Members of the Association, at the Medical Society of London, Chandos Street, W.1. The principal feature of the lecture, however, was the showing of about seven hundred coloured photomicrograph slides of gemstone inclusions prepared by the lecturer. It was the first occasion that members in this country had had an opportunity of seeing part of Dr. Gubelin's unique collection of coloured photomicrographs. A full report will appear in the next issue of the Journal.

Mr. B. W. Anderson, who recorded a vote of thanks, said that mere words were inadequate to describe the debt that gemmologists owed Dr. Gubelin for the vast amount of work he had done on this particular aspect of gemmology.

ANNUAL MEETING

At the second Annual Meeting of the Incorporated Association held at Chelsea Polytechnic, London, S.W.3, on Wednesday, 24th March, 1948, the following Officers were re-elected:—Chairman, Mr. F. H. Knowles-Brown; President, Dr. G. F. Herbert Smith; Vice-Chairman, Dr. G. F. Claringbull; Treasurer, Mr. S. F. Bones. Messrs. J. H. Stanley, R. Webster and E. R. Levett were re-elected to serve on the Council. Messrs. Watson Collin & Co. were re-appointed as Auditors.

EXAMINATIONS IN GEMMOLOGY

The 1948 Examinations in Gemmology will be held as follows:—

PRELIMINARY (Britain and Overseas): Wednesday, 23rd June.

DIPLOMA (Overseas): Theory papers, Thursday, 24th June; Practical papers, Friday, 25th June.

DIPLOMA (Britain): Theory papers, Thursday, 24th June; Practical papers: London, Friday, 25th June; Edinburgh, Monday, 14th June; Birmingham, Friday, 18th June.

MEMBERSHIP

The following were elected to membership at a meeting of the Council held on Thursday, 26th February, 1948:—

FELLOWS:

A. E. Farn, London.
G. A. Hancock, Hazel Grove.
G. Livsey, Bradford.

ORDINARY:

E. G. Ashwin, London.
Douglas Benson, London.
C. G. Biggs, Maidenhead.
Arthur G. Batty, Liverpool.
A. W. Byron Brook, Edinburgh.
H. Cartier, London.
C. D. Dyson, Windsor.
R. H. Eames, Stourbridge.
G. B. Falconar, Singapore.
J. C. Ginder, London.
C. T. Gilmer, Bath.
J. W. Isaac, London.
A. A. Julius, London.
R. W. Kemp, Bristol.
T. W. Lightfoot, Kingston-upon-Thames.
J. G. Lucas, Leamington Spa.
James R. Ogden, Harrogate.
A. Sondheimer, London.

PROBATIONARY:

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P. Benson-Cooper, London.
H. P. Bowen-Evans, London.
A. D. Cairncross, London.
E. Christie, Aberdeen.
E. O. Hack, Birmingham.
G. D. Llewellyn, Ilford.
C. W. May, Ilford.
V. R. Pleasance, Worthing.
C. M. Robb, New Zealand.
L. Sanitt, London.
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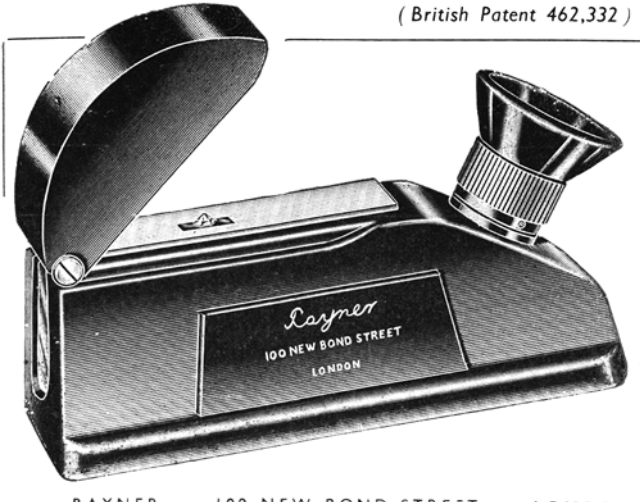

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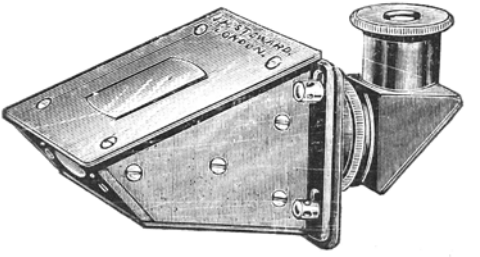

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THE JOURNAL OF GEMMOLOGY
AND PROCEEDINGS OF THE GEMMOLOGICAL ASSOCIATION OF GREAT BRITAIN

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GEMMOLOGICAL EXHIBITION

1948

Reviewed by *Gerald Carr*

COULD they do it again?

It was with this thought in my mind that I walked into the Goldsmiths' Hall on May 4th, the opening day of the second exhibition by the Gemmological Association. I was wondering if the Association could repeat the success of their first big exhibition. Had that been partially obtained because it had never been done on that scale before? After all, there was little fresh that could be shown in gems. No startling discovery of a new variety could be expected, no novelty for the next season.

In a few moments I realised that the Association had done it again—and better. An exhibition of gemstones had been presented which was not only fresh but lovelier, more interesting than the previous one. A year ago I had been fascinated by the beauty of many of the exhibits. Now I was fascinated by the beauty of the whole exhibition.

Queen Mary was an early visitor and the officers of the Association were presented to her. It was no wonder that she, with her expert knowledge of jewels and antiques, spent almost an hour looking at the exhibits. Or that she wanted to handle and feel the perfection of some of the delicate pieces of carved jade.

Every display case presented a different aspect of beauty and interest in its exhibits which reached a peak in the centre stand with its remarkable collection of flawless gems, large in size and fine in colour. Here were stones that would be the pride of any collector. As I looked at them, it occurred to me that the finest stones are too good to be with anything less fine than in an ornament of the best design made by skilled craftsmen. Such gems as the 68 ct. Brazilian topaz with its square cut or the oval fancy cut topaz from the Urals or the lovely black opals and beryls, were sufficient unto themselves, needing nothing else to emphasize their splendour. So with the Spodumenes—what an ugly name for such fine clear examples—which included a unique Kunzite, the pinky 93 ct. tourmaline or the 67 ct. aquamarine.

A principal attraction of the Exhibition was a fine collection of rubies, sapphires and emeralds. The corundum varieties were grouped according to locality, and visitors were able to compare Siam with Burma rubies, Ceylon sapphires with those from Kashmir, Siam and Burma. Ingeniously lighted were a specimen Star Ruby and a magnificent deep blue Star Sapphire.

A section of the Exhibition.

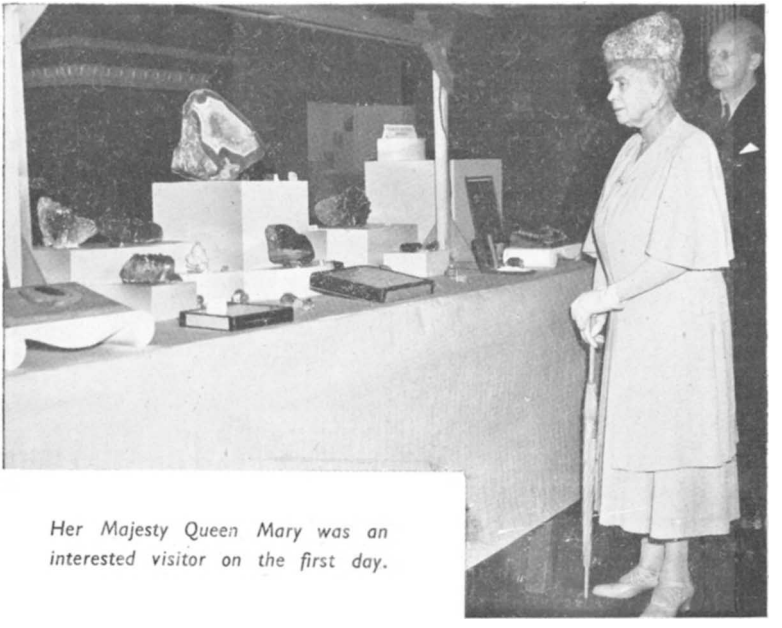

Her Majesty Queen Mary was an interested visitor on the first day.

Yet it might be unwise to despise the work of the craftsman, for after all, though nature's forces first provided these stones, it was his skill in cutting and polishing that had brought them to perfection. So that even in the more common mineral such as quartz, the beauty of life had been uncovered by his hands.

How much more, perhaps, was the craftsman to be praised in the examples to be noted in the jade collections. And this does not mean only the modern craftsman who has the resources of science and the tools of a century of industrialisation. A collection of jade ornaments, emblems and clubs showed the art that could be attained by a native working without any metal. It might take him a lifetime to finish, but the objects made by those New Zealand Maories have a permanence far extending a human's span. Though even to-day the exact significance of the " hei-tiki " ornaments is not known, their appeal is instantaneous. The war clubs, also, or " mere pounamu," apart from their obvious efficiency and excellence as weapons, are fine examples of the craft of necessity which produces functional beauty.

Then there were the examples of how man had used his artistic imagination in making the natural patterns of nephrite fit into the things he wanted to make, such as snuff bottles or the realistic green apple, even slightly bruised, that made one think of the cheapness of Victorian wax imitations. Delightful, too, were the jadeite miniature carvings of elephants which demonstrated the range of colour.

Star stones always have a special interest, and here the Gemmological Association had a cleverly arranged rotating collection, each stone coming below a spotlight to display its stars. The stones included a 12-ray sapphire, a cat's-eye, garnet and—a neat piece of workmanship—a rose-quartz doublet. Just to remind visitors that gemstones often do finish up in a mount, one display case showed examples of this. It included the unusual example of a sphene and diamond ring and brooch and also had a lovely pink topaz in a gold bracelet.

Another case had a collection of cut sphene and showed interesting examples of natural opal formations that resembled an oak tree, a boot and other objects. While here again man had made nature's " lapses " serve his purpose in carving vases and bottles from amethyst, aquamarine and tourmaline.

Jade window shows varieties of colour ranges and styles of carving.

An operational laboratory enabled visitors to make intimate observations of gem testing technique.

Then in this Aladdin's cave of gems, one saw the great possibilities existing in even a single specie because of the great colour variations. There were beryl stones ranging from white to brown and pink to sea green, and corundum, too, in many colours.

In that case also was a 26 oz. piece of polished amber. A lovely piece of mineral and one that was recalled by the Royal visitor to the exhibition the moment she saw it. For Queen Mary had presented it to the Geological Survey and she was interested to see it once again.

Queen Mary also expressed surprise at the wide variations of colour and the unfamiliar colours found in the minerals exhibited in this case. She, too, in her tour round the exhibits with Dr. Herbert Smith, Dr. G. F. Claringbull and Mr. B. W. Anderson as her expert guides, had been particularly interested in the star stones and the jade, especially the snuff bottles, of which she has a collection.

Though these things were, perhaps as I thought, the high lights of the exhibition, there were many others of great interest. There

was the comprehensive diamond exhibit with its strange collection of " freak " diamond crystals described by complicated names which mean all to the expert, such as " interpenetrating cube " and " twin octahedra." To the expert they were fascinating examples of nature's pranks.

The Association even allowed synthetics to present themselves there, though these man-made " gems " seemed out of place amid the splendours of the natural and large sized stones. There was an example of synthetic rutile, the only one in Britain, together with other imitation and synthetic stones dating in some cases from the first specimen made in the last century.

Finally, on many of the stands one could indulge in a grand orgy of gem testing and comparison. There were batteries of Chelsea colour filters, Rayner refractometers, spectroscopes, and other gem testing equipment and a display of elements periodically classified. And a helpful touch to the budding gemmologist was a stand showing what was needed and how the set-up might be arranged of a modest gem testing laboratory. Can the Gemmological Association repeat its success again? I think so.

* * *

The Council of the Association expresses its deep appreciation of help received from the following:—

ORGANIZERS: G. F. Andrews, R. Webster and H. Wheeler.

STEWARDS: Messrs. B. W. Anderson, S. F. Bones, L. F. Cole, A. T. Kemp, E. R. Levett, R. K. Mitchell, Dr. W. Stern, F. Ullmann, D. Wheeler and A. Farn.

EXHIBITORS: Diamond Trading Co., Geological Survey and Museum, Pittar, Leverson & Co. Ltd., Liberty & Co. Ltd., Jade Dragon Ltd., Crombie (Fine Jewels) Ltd., J. H. Lucas, R. W. Yeo, Waters & Blott, Albert Hahn & Son Ltd., Rayners Ltd., Wilson & Gill Ltd., W. Nathanson, Major W. Kennedy, R. W. Hester, Kenneth Parkinson, Mrs. Virginia Courtauld, Steinfels Ltd., A. E. Farn, Sir James Walton, Hancock & Co. Ltd., Dr. E. H. Rutland, J. R. Vincent, and Gemmological Association.

And to the Wardens of the Worshipful Company of Goldsmiths for so kindly placing the Hall at the disposal of the Association.

GEMSTONE INCLUSIONS

By DR. EDWARD GUBELIN, C.G., F.G.A.

GEMSTONES are generally considered either as a means of adornment or as a sort of capital investment. Very few people realize that in these jewels they have the revelation of natural monuments of a past that reaches back beyond the excavations of archaeologists in Mexico, Egypt and Mesopotamia, to many, many thousands of years. To those who are able to explore their secrets precious stones relate a story as interesting as that of the huge Pyramids erected by the Pharaohs at Luxor, and it would seem that their sublime internal spheres might best be called " The Fingerprints of God." If we wish to study the history of the origin of gems and to understand more fully the progress of our own mother earth, we must delve into the great book of Nature. Due to their great durability, precious gems are the finest proof of the continuous and timeless epochs of development to-day as well as in the illustrious ages when the old Kings of Egypt were flourishing in their splendour. Careful research and study of gems is as valuable to mankind as the ancient history of the Egyptians, and each small inclusion left behind from the primaeval age gives us a sign of its origin and creation, which is vitally important to natural history. The microscope alone is able to probe their innermost secrets and it is recognized as one of the most important instruments for revealing the internal features of gems. Through the eyes of this remarkable assistant we are able to see those peculiar characteristics and formations of other minerals, liquids, gas bubbles, flags, and feathers which we term inclusions and which are extremely important for distinguishing natural and synthetic stones, and for ascertaining a stone's provenance. On these guardians of the age-old secrets we shall to-day place our attention.

Of course, it would be impossible to give you here and now a complete layout of all the characteristics of inclusions which one could meet during the study of genuine stones and their synthetic or artificial counterfeits. Thus, the best way of gaining knowledge

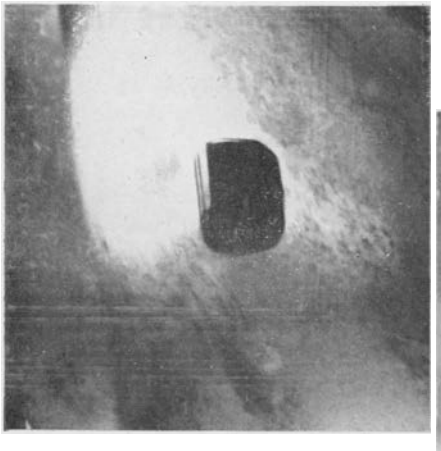

FIG. 1.

Well developed idiomorphous Rutile crystal in a Burma Corundum. 100 ×

FIG. 2.

Well developed crystals of Rutile in a Burma Ruby. 75 ×

FIG. 3.

"Venus-hair," i.e. Rutile needles in a Quartz. 120 ×

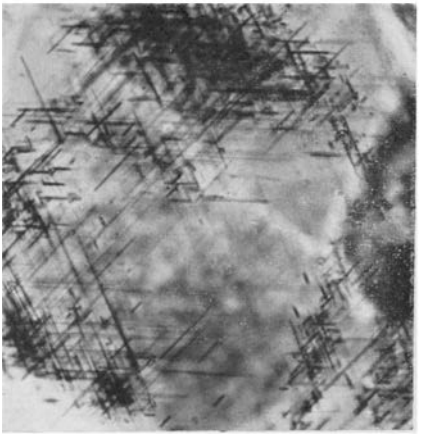

FIG. 4.

Patches of Rutile needles in a Burma Ruby. 75 ×

is for each one to examine personally as many stones as possible and through this experience will quickly follow an ease in distinguishing the natural from the synthetic, and eventually one may quite easily know them by their typical marks of their place of origin. In this following lecture I shall deal with the most important aspects of this question and those problems which will be most likely to occur with you.

We owe a great debt of gratitude to the researches of Sir David Brewster, H. Vogelsang, H. Geissler and Henry Clifton Sorby, who were among the first to discover the great importance of inclusions in the study of minerals. They established the fact that in many gemstones one could observe various liquid inclusions consisting of carbonic acid, water, or carbon dioxide and water.

In connection with this brief lecture and description of inclusions I feel obliged to mention one authority—Prof. Dr. H. Michel from Vienna—who is worthy of the outstanding merit of being the first pioneer to recognize the gemmological importance of the many inclusions in gem stones in differentiating between natural and synthetic stones. He dismissed the idea that inclusions were only flaws on the beauty of a stone and turned scientific interest on to these so-called imperfections. He was a true promoter of modern investigation of inclusions, and from his research substantial facts have been effectively developed.

An inclusion is any substance incorporated in another material —particularly in a crystal. Inclusions may be of the same chemical compound as the enclosing mineral, foreign chemical compositions or empty cavities. Perfect conditions during the growth of a crystal such as uninterrupted growth, absolutely pure mother-liquor, steady pressure and heat, etc., are very rarely found in nature. Therefore any gem may be considered as having some imperfection, even if it be so minute as to be hardly visible to the human eye.

While the fanciful inclusions, the liquids, the crack-like formations and irregular feathers within gemstones fire the imagination and stimulate one's curiosity, they represent a scientific value over and above their fascinating appeal. Mineralogists and gemmolo-

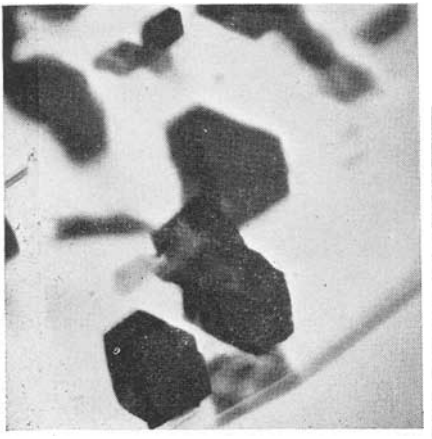

FIG. 5.

Biotite scales in a Peridot. 50 ×

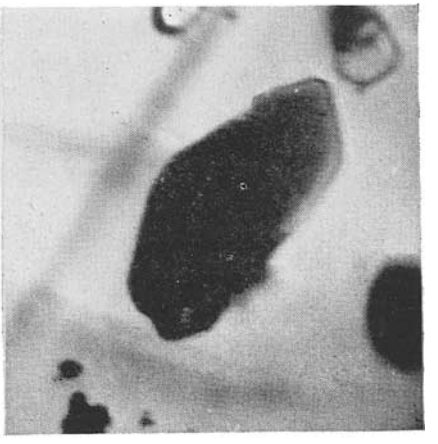

FIG. 6.

Scale of Phlogopite in a Ceylon Sapphire. 75 ×

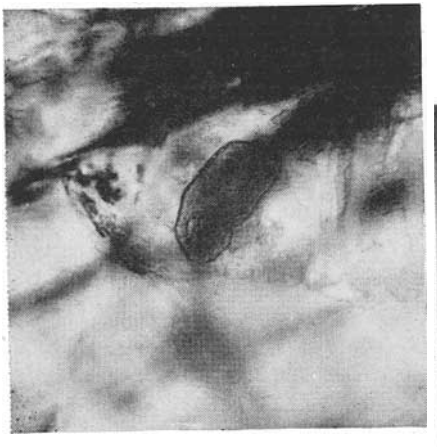

FIG. 7.

A xenomorphous flake of mica in a Siberian Emerald. 50 ×

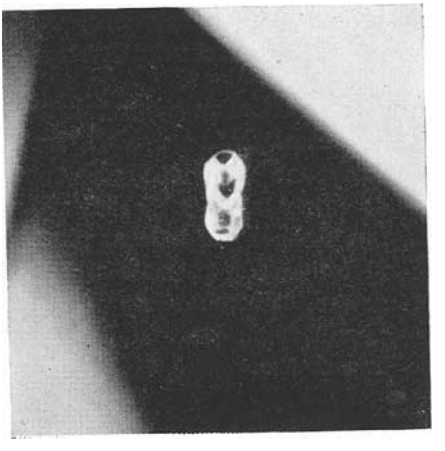

FIG. 8.

Resorbed Quartz crystal in a Diamond. 100 ×

gists will be interested in the genetic problem of the occurrence and from this point of view inclusions may be classified as:—

Pre-temporary inclusions which consist mostly of solid enclosures—crystals and amorphous or earthy matter—whose substance belonged to a previous phase of formation. As a gem grows, layer after layer of molecules is deposited on its surface, i.e. the growing planes, and any foreign minerals which exist in the mother-liquor may become embedded.

Con-temporary inclusions may either be drops of the mother-liquor or rising gas bubbles which were surrounded by the growing host mineral. Also minerals belonging to the same or foreign mineral species may crystallize simultaneously with the host mineral and deposit themselves on its accretion faces. Such impurities which come in contact with faces of the growing jewel are finally enclosed by succeeding molecules which build up around the pollutions. This is called a formation of inclusions during growth.

Post-temporary inclusions develop after a mineral has formed, when they may be produced by chemical alteration of certain parts or areas or by recrystallization in a different form of the chemical element of which the mineral is composed, or internal cleavage cracks may form long after the gem has been gathered from the earth.

As the geologist or mineralogist will study gem inclusions in minutest detail for their revelations of age-long development, the jeweller and gemmologist will appreciate them for their highly diagnostic importance and conclusive distinction between genuine stones, and between these and their counterfeits. Thus the enchanting world of inclusions appeals to the sense of beauty and imagination of the gemmologist, and offers him as well very valuable opportunities for practical application. Consequently, he will especially study and rely upon the phenomenological pictures of internal paragenesis.

What, then, is the nature of inclusions found in precious stones? We may distinguish between the following types:

1. Solid Inclusions (Inclusions of same or foreign minerals).
2. Internal Cavities (Liquid or gaseous inclusions).

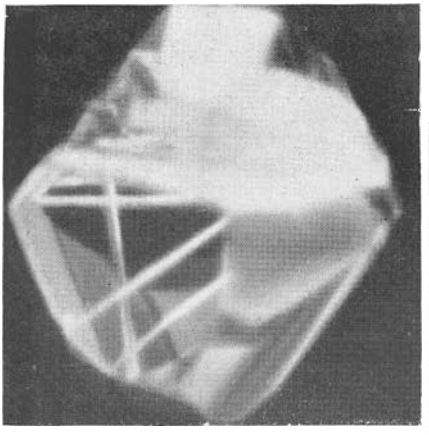

FIG. 9.

Included corundum crystal enclosing rod-like foreign minerals, in a Ceylon Sapphire. 100 ×

FIG. 10.

Opaque corundum crystal surrounded by a liquid feather in a Siam Ruby.

FIG. 11.

Cluster of Pyrites in an Emerald from Colombia (El Chivor Mine). 40 ×

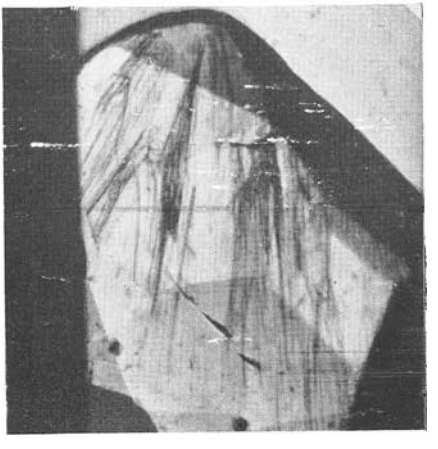

FIG. 12.

Byssolite fibres in a demantoid. 40 ×

3. Feathers and Flags (Cracks and fissures filled with gas or liquid).
4. Growth Phenomena (Zonal structure and irregular distribution of colour).

These internal peculiarities, which are used for purposes of distinction, are thus the traces imprinted upon the stones by the process of formation. This process not only differs in the case of natural and synthetic stones, but is somewhat different in stones of the same species and variety according to their place of origin. Moreover, these inclusions are also typical of the various species themselves.

1. **Solid Inclusions** (Inclusions of same or foreign minerals) may be of the most varied form, type and colour. In distinguishing between those enclosed minerals the difference in nature is not of general importance, which is fortunate, as this usually presents a difficult problem. Sometimes they are large and distinct, and can be referred to known mineral species, but more generally their true nature is difficult to determine. The term " microlites " is often used to designate the minute enclosed crystals ; they are generally of needle-like form, sometimes quite irregular, and often very remarkable in their arrangement and groupings. Crystallites is an analogous term to cover those minute forms which have not the regular exterior form of crystals, but may be considered as intermediate between amorphous matter and true crystals. Sometimes included crystals can readily be identified by means of their habit, their colour, or their arrangement and form of crystal faces. It has been possible up to date, therefore, to ascertain the existence of the following foreign minerals in gemstones:

1. Coarse crystals or long slender needles of Rutile. (Figs. 1-4.)
2. More or less good idiomorphic tablets of mica (biotite, phlogopite, muscovite). (Figs. 5-7.)
3. Well-developed crystals of quartz, corundum, pyrite, sillimanite, byssolite, zircons, garnets, magnetite, diopside. (Figs. 10-16.)
4. Zircon inclusions with radio-halos. (Fig. 17.)
5. Stalked actinolite, hornblende and augite. (Figs. 18-20.)
6. Rhombohedral iceland spars or precipitation of calcite. (Figs. 21-23.)

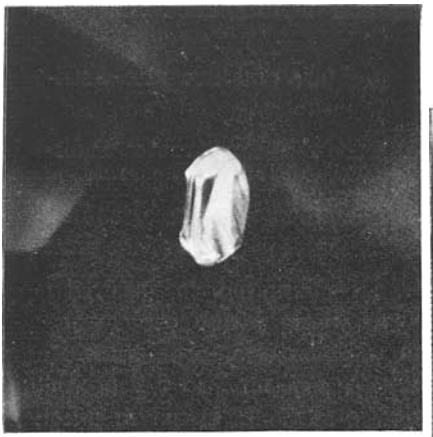

FIG. 13.
A zircon crystal embedded in a Diamond. 100 ×

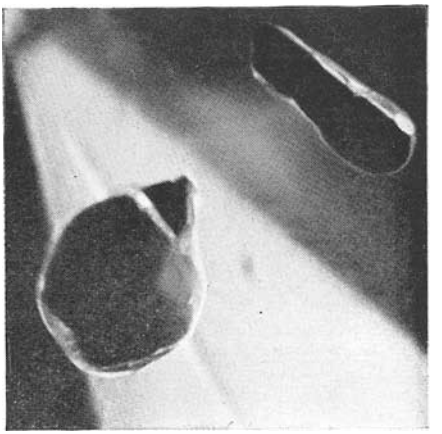

FIG. 14.
Pebbles of Garnet in a Diamond. 100 ×

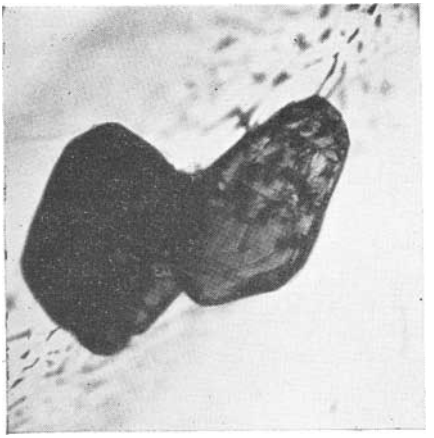

FIG. 15.
Rounded grains of garnet in a Ceylon Sapphire. 125 ×

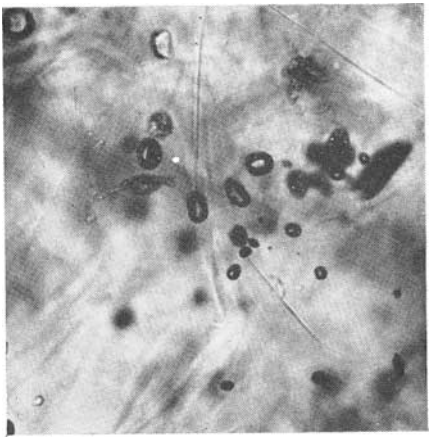

FIG. 16.
Diopside and zircon crystals and swirls in a Hessonite. 75 ×

In addition to these most frequently occurring foreign minerals one may encounter:

Prismatic crystals of tourmaline, tabular crystals of hematite and ilmenite, sharply defined octahedrons of spinel and diamond, dendritic formations of manganese and iron oxides, moss-like inclusions of chlorite, further on anatase, goethite, yellow copper ore, and so on. (Figs. 24-27.)

The most interesting among these inclusions are the rutile needles and the zircon inclusions. (Figs. 28, 29.)

The rutile needles appear chiefly in sapphire and ruby, where they lie according to the hexagonal structure, i.e. parallel to the prisms of the second order of these stones at angles of 60 degrees and can easily be distinguished from inclusions of a different nature. These rutile needles serve as the best hall-mark of the genuine corundum in contrast to the synthetic. Arranged very closely together and of very delicate habit, they are one cause —so-called " silk "—of the six-rayed stars in star-sapphires and star-rubies. Even in their precious shell the enclosed zircon crystals remain radio-active, emitting radium rays and thus producing a radio halo in the surrounding substance. Such zircon inclusions, with radio halos, are a typical mark of corundums from Ceylon.

In the shape of the bounding surface it is often possible to find crystal faces which show that at this point one small idiomorphous crystal is enclosed by the other, called the host. Such well-formed outlines permit the crystal to be classified according to crystal system. Often, on the other hand, the shape is that of ellipsoidal or rounded grains with merely one crystal face here and there, or even quite without any. The boundaries between these solid mineral inclusions and the host are sharply demarcated, and if the refraction of light is about the same, few or no total reflection phenomena present themselves ; that is to say, they are transparent. The colour may vary greatly. With dark ground illumination it is frequently possible to observe the red interior reflections of the hematite tablets. In the case of a colourless mother-gem there is, of course, no confusing element and the inclusion is visible in its own colour.

Among solid inclusions, microscopic, irregularly formed glass inclusions play a special part. They resemble in shape an irregular

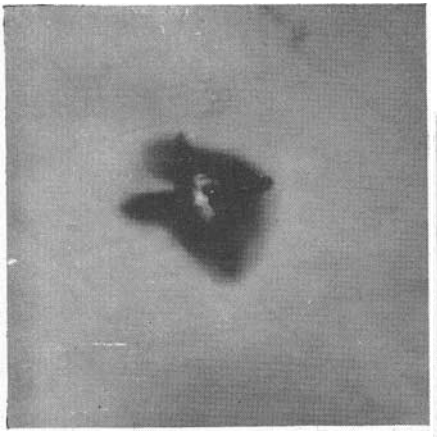

FIG. 17.
Radio-active zircon surrounded by a radio-halo in a Ceylon Sapphire. 25 ×

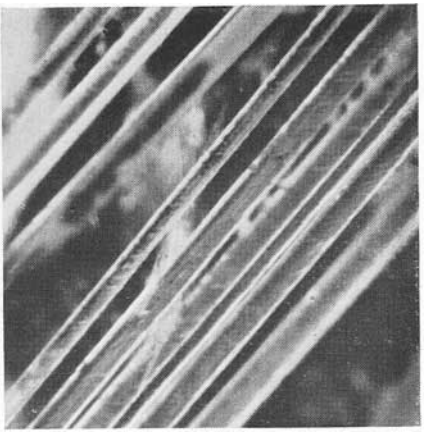

FIG. 18.
Rods of Actinolite in a Quartz. 20 ×

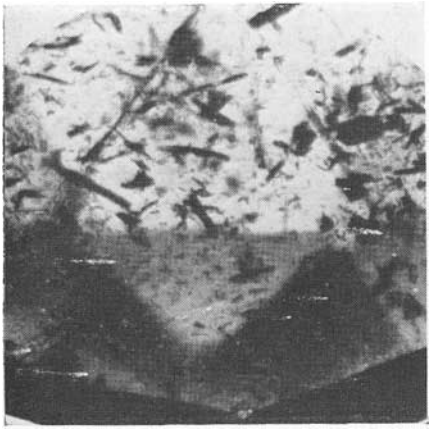

FIG. 19.
Amphiboles in an Almandine from Trincomali, Ceylon. 40 ×

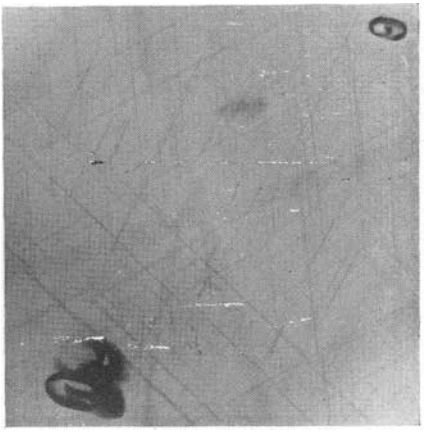

FIG. 20.
Needles of an Amphibole variety and grains of radio-active Zircon in a Ceylon Almandine. 25 ×

solidified drop of previously molten glass and may very often remind one of the gas bubbles in artificial materials. They provide sure proof that the minerals in which they are found have solidified in the presence of a molten mass. Glassy inclusions of this sort are sometimes embraced by obsidian, peridot, feldspar, and garnet.

Besides all the afore-mentioned inclusions there exists another sort of most curious solid inclusion, which is the product of post-growth precipitation within the host mineral and sometimes indicates the commencing of a chemical and subsequent alteration of the mineral from its inside. (Fig. 30.)

2. **Internal Cavities.**

A.—LIQUID INCLUSIONS.

Liquid inclusions are of very different nature, both in origin and appearance. They include the solution from which the gem was formed, or water, carbon dioxide, carbonic acid and other liquids. Such cavities arise in a growing crystal when in the process of growth free spaces remain open and are enclosed by the growing substance in accordance with the crystallographic laws. The law of the growth of a crystal is portrayed in its confined form by crystal faces which coincide with the crystallographic directions of the mineral ; this same law asserts itself in the enclosure of a free space. Once again crystal faces are formed, but these are turned inwards in the embracing crystal and surround the cavity in the form of its walls. Such a cavity walled by crystal faces is called a "negative crystal." (Fig. 32.) These negative crystals appear in many gems and their filling can be of varied nature. It is either a gas or a liquid (it is doubtful that a true vacuum ever occurs in a mineral ; during formation there should be some gas present—if only water vapour or carbonic acid—to fill any such space), and in both cases these have no colour of their own, so that they are seen in the hue of the enclosing mineral. In the case of a gas filling the total reflection phenomena at the boundary of host and gas are so strong that broad dark seams appear, or the negative crystal may become altogether black and opaque. In the case of a liquid filling the difference in the refraction of light is not so great, so that the black reliefs are much narrower. Liquid inclusions need not always contain pure solutions, but they may also be a mixture of liquid and gas, and consequently one may clearly recognize rounded gas

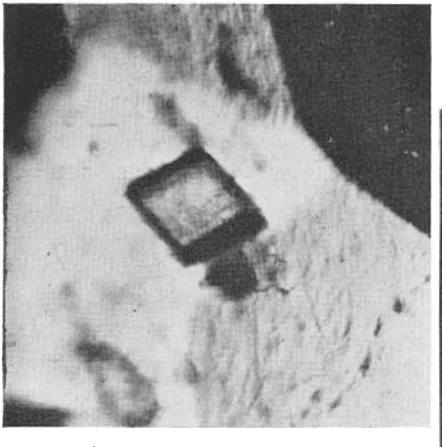

FIG. 21.

Idiomorphous rhombohedron of Iceland spar in a Colombian Emerald (Muzo Mine). 75 ×

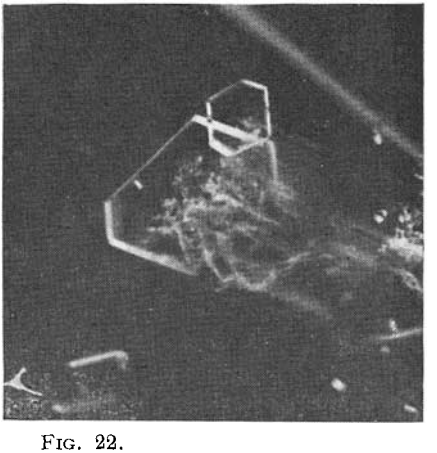

FIG. 22.

Calcite tablets in a Ceylon Sapphire. 75 ×

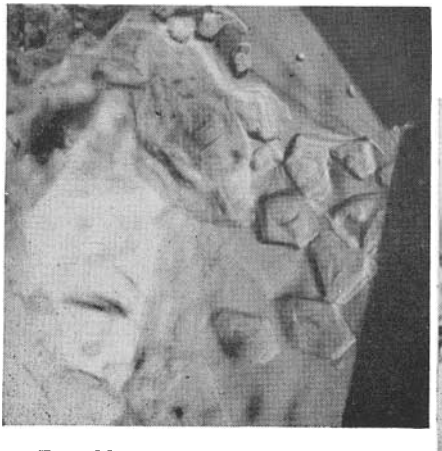

FIG. 23.

Precipitation of calcites formed by exsolution in a Colombian Emerald (Muzo Mine). 50 ×

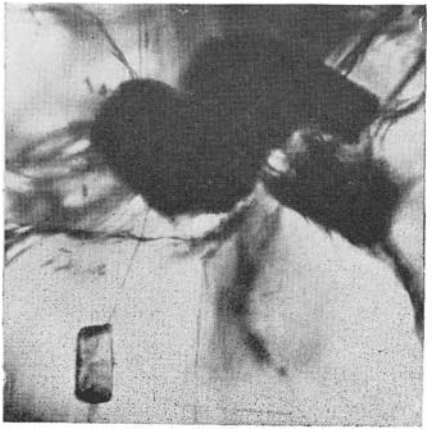

FIG. 24.

Brookite crystals in a Cordierite. 30 ×

vesicles which float in the liquid, such as in a spirit level, and which are called " libella " in liquid inclusions. Well idiomorphously developed negative crystals are not the rule ; on the contrary, irregularly formed cavities are more usually encountered in gemstones. (Fig. 33.)

To determine the chemical constitution of these liquid inclusions is of the first importance for both mineralogy and gemmology. It is now known that the great majority consists of water or dissolved salts—no doubt tiny quantities of the mother lye in which the stones came into existence. Some also contain gas in a content consisting mainly of water, part of which has been proved to be liquid or gaseous carbonic acid. (Fig. 34.) Chemistry has ascertained that the " critical temperature "—e.g. the temperature above which carbonic acid can exist only in the gaseous state—is that of 31.1 degrees C. By various other methods (spectral investigations) as well, the presence of carbonic acid in negative crystals has been set beyond doubt. (Fig. 35.)

The gaseous phase does not always occur in the form of a bubble. If a quantity of liquid diminishes in a cavity, the liquid may take the shape of a drop surrounded by a border of vapour against the walls of the enclosure. The gas may fill wide parts of the space and such inclusions seem to be typical for topaz and tourmaline and beryls.

As I have told you previously, these liquid inclusions, which are such a fascinating and important feature within gemstones, are not always pure, and especially interesting are inclusions which consist of two or more non-miscible liquids in one and the same cavity. The behaviour of the enclosed liquids in the surrounding liquid is very similar to that of gas bubbles. Their shape is usually long, and as a result of very slight differences of light refraction between the individual liquids the borders are very fine. In almost all cases these liquids consist of water and carbonic acid and they may be encountered in practically all gemstones. (Figs. 36-39.)

A still higher development of the filling is provided by the three-phase inclusions. These are cavities which contain the three states of aggregation (e.g. the three phases of matter) at once, that is when one or more crystals and one or more gas bubbles are bedded in the liquid which fills the cavity. Such three-phase inclusions have taken form particularly in beryls and are both the

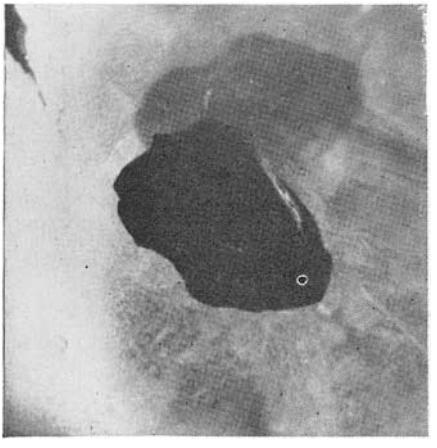

FIG. 25.
Parcel of haematite tablets in a Ceylon Corundum. 75 ×

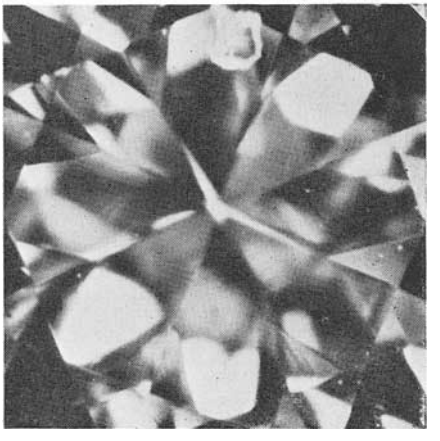

FIG. 26.
Diamond octahedron in Diamond. 100 ×

FIG. 27.
A distorted diamond octahedron in a Diamond. 100 ×

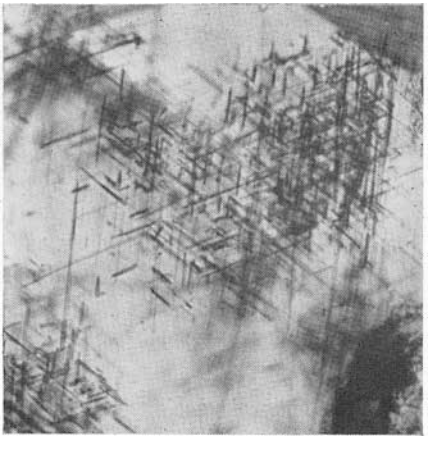

FIG. 28.
"Silk" formed by acicular rutile crystals in a Burma Ruby. 75 ×

most important characteristic for this species, as well as the essential feature for disinguishing between Colombian and Ural emeralds. One never ceases to wonder at the many beautiful forms of these three-phase inclusions, which are such a gorgeous sarcophagus of God's most delicate wonders. (Figs. 40-42.)

Occasionally one may have the lucky chance of finding a gemstone with the very rare type of inclusion in which the included liquid substance is actually in the state of re-crystallization. This interesting process of forming new microscopic crystals of unknown nature often takes place in flat liquid filled cavities in Siam sapphires and chrysolites from the island of Zebirget in the Red Sea. (Figs. 43 and 43a.) The chapter on internal cavities ought not to be concluded without mentioning the ingenious arrangement of parallel, hollow or liquid filled tubes in chrysoberyl which are responsible for the flattering wavy sheen of the cat's eye.

B.—Gaseous Inclusions.

In natural crystallized stones gas appears only in negative crystals, either alone or with liquid, and in the latter case gives simultaneous proof that the cavity in question contains a liquid. In natural glasses of volcanic origin, such as moldavite and obsidian, in synthetic stones, glass imitations and doublets, there occurs a very special type of cavity—the gas bubble. These gas bubbles trapped in synthetic stones and air bubbles imprisoned in glass imitations and in the conjunction plane of doublets and triplets, are unintentionally mingled with the artificial substance. Because of strong total reflection they are always black with at the most one bright spot in the middle. (Figs. 44, 45.)

In man-made glass the appearance of air bubbles is somewhat different, and therefore it is not difficult to differentiate between natural and artificial glass. Gas or air bubbles occur in synthetic stones in a considerable range of form and size, the bubbles appearing as small black dots either singly or in groups, sporadic medium-sized or more rarely bigger bubbles up to coarse and very large bubbles may often be seen. In addition to these bubbles occurring singly or in groups, one may frequently observe whole clouds of very fine vesicles and the entire stone may be densely filled with small gas bubbles, interspersed here and there by individual bubbles of larger size. In assembled stones (doublets and

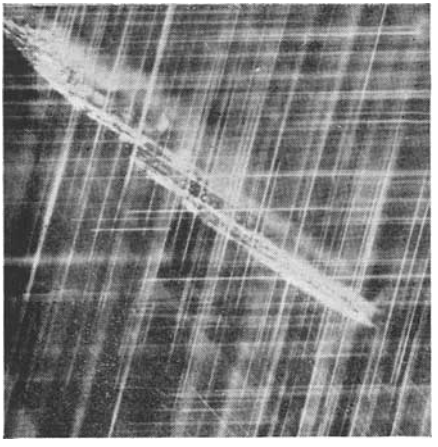

FIG. 28a.
"Silk" consisting of fine tubes in a Ceylon Ruby. 100 ×

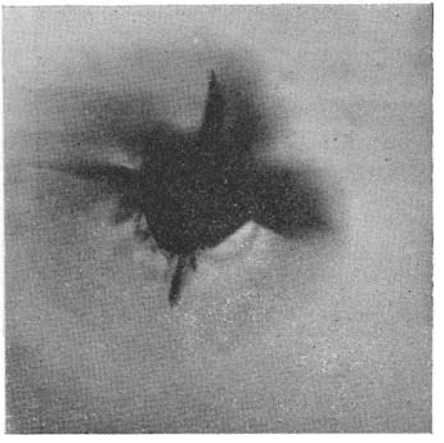

FIG. 29.
Radio-active zircon surrounded by a radio-halo in a Ceylon Sapphire. 50 ×

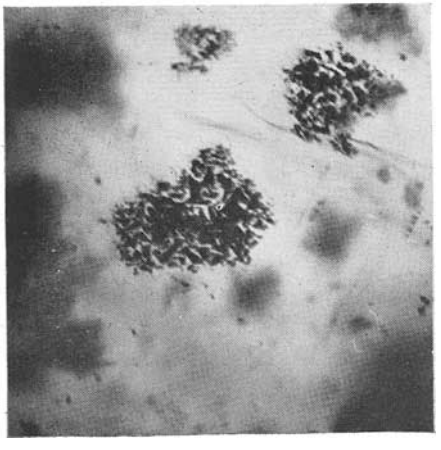

FIG. 30.
Beginning of pinitisation (chemical alteration) in a Cordierite. 50 ×

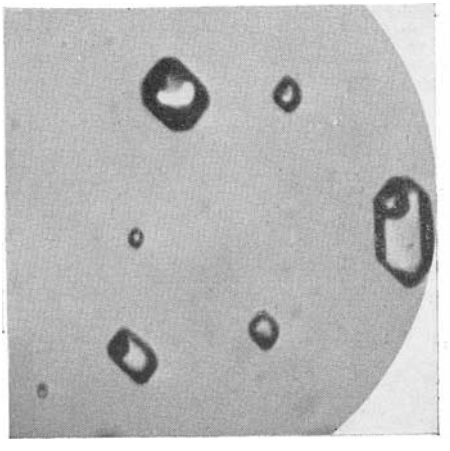

FIG. 32.
Negative crystals filled with liquid and a libella in a Cairngorm. 75 ×

triplets) air bubbles are usually found in the cement layer which pastes the two or three parts of the stone together. These air bubbles always lie in one plane, thus immediately betraying the stone as one which has been assembled. These round or elongated gas and air bubbles are the most typical marks of imitation jewels, whether synthetic or artificial. (Figs. 46-52.)

3. **Feathers and Flags** (cracks and fissures filled with gas or liquid).

Internal cleavage cracks and fractures may also be considered as inclusions. Many of them are more likely to occur after the formation of the mineral than during growth. The lack of cohesion between the atomic planes in certain directions results in cleavages between such planes. External blows or expansion and contraction resulting from changes in temperature may cause a separation to start along a cleavage plane. At other times, a separation which starts to develop along such a cleavage may break across adjoining atomic planes, producing internal fractures or feathers in directions other than cleavage directions. Such inclusions may be increased by alteration after the completion of growth of a crystalline substance. Liquids or gases may enter along slightly developed cleavage planes and alter the chemical composition or molecular arrangement within the stone, thereby forming inclusions. These feathers and flags are of the most varied form, size and position. They either radiate from the surface of the stone or they are shut in on all sides within the stone and cannot develop further. Enclosed air, liquid or newly-separated mineral substance may be found. The liquid is mostly distributed in the form of small drops which may assume the queerest forms. Generally it looks as though the whole flag had been decorated with very finely designed exotic hieroglyphs. The drops of liquid are often most bizarrely shaped or vermiform, hose-shaped, rod-like or formed in the shape of a tube. Whole broad systems of irregular channels of various non-miscible liquids may traverse the gems and may knit the most delicate mesh pattern. No lady's knitting could be fine enough for such a subtle work. The sum total of these drops —which is known as a flag or feather—is often similar to insects' wings in form and finish. If the single drops are studied under very high enlargement small libellas can be found in them. Fine films of air or liquid on the cleavage cracks and fractures are

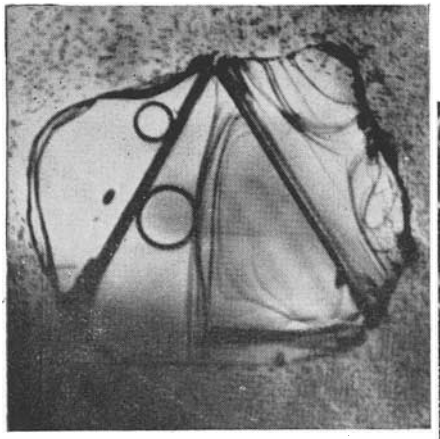

FIG. 33.

Flat cavity filled with liquid and libellae in a Ceylon Sapphire. 75 ×

FIG. 34.

Cavities filled with CO_2 in an Aquamarine at ordinary room temperature. 50 ×

FIG. 35.

Same cavities after Aquamarine was heated above 31.5°C. All liquid carbon dioxide has evaporated (no bubbles visible). 50 ×

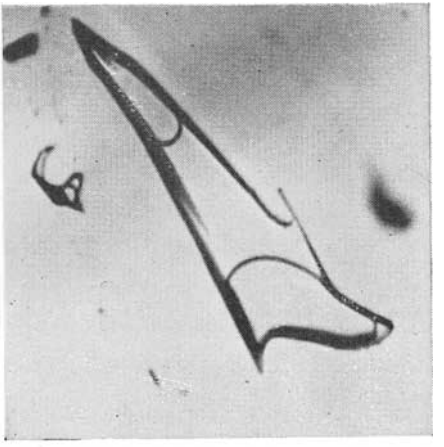

FIG. 36.

Large cavity with non-miscible liquids in a Topaz. 75 ×

noticeable by reason of their total reflection phenomena. If such air or liquid filled fissure be examined under the microscope from above, and by looking perpendicularly through it, nothing at all will be seen except the delicate border of the film. If the stone is turned with its flag so that one may look obliquely through the air or liquid layer from the side, one will notice a brownish hue present. (Figs. 53-60.)

As I have just been talking about the fissures, I would like to mention a peculiarity of Cashmere sapphires—the well-known " haziness " which contributes to the attractive beauty of these stones. This hazy appearance is caused by curious and interesting veil-like formations which consist of wavy filaments reminiscent of a fine tissue woven in a hexagonal pattern, the single twines intersecting at angles of 60 degrees respectively 120 degrees. However, these are not rutile needles, as can be easily established. Increased magnification shows the individual fibres as consisting of tiny and subtle fissures, or hollow tubes of a slightly brownish colour generally lying across the direction of the wavy threads.

In emeralds, air-filled cracks or fractures often have a dendritic design and one has to be careful not to confuse them with enclosed solid inclusions of similar forms. American-made synthetic emeralds, as well as those from the German Dye Trust Industry, display liquid feathers of their own which are very easily recognized and which firmly betray the synthetic origin of these stones. Liquid inclusions shaped as feathers are the most characteristic type found in synthetic emeralds. These appear as most delicate, wisp-like, veil-shaped formations resembling cracked lacquer or scroll pattern. As we are at present dealing with the synthetic emerald I may mention another kind of typical inclusion which is a small, irregularly shaped solid inclusion sprinkled throughout the stone, probably particles of colouring matter. It must always be remembered that it is very easy for an expert to distinguish between genuine and synthetic emeralds as their specific inclusions are so different. (Fig. 61.)

4. **Phenomena of Growth.**

A.—TWINNING.

Crystals of the same nature or also of different substances may so intergrow that the crystallographic axis of one individual is parallel to those of the others. In twin crystals the individuals

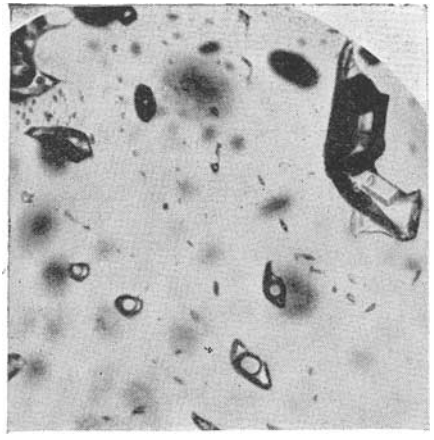

FIG. 37.

Cavities with non-miscible liquids in a Topaz. 75 ×

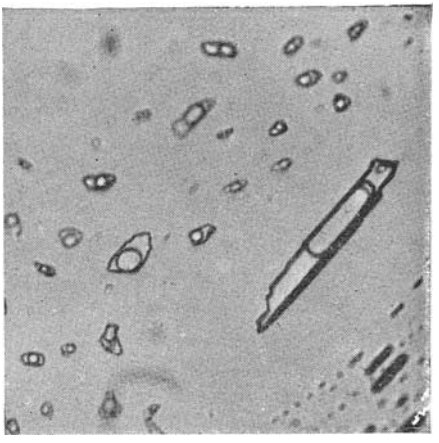

FIG. 38.

Cavities with non-miscible liquids in a Topaz. 100 ×

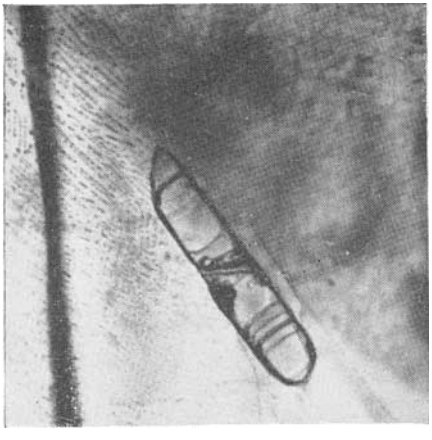

FIG. 39.

Typical long cavity with non-miscible liquids in a Ceylon Sapphire. 75 ×

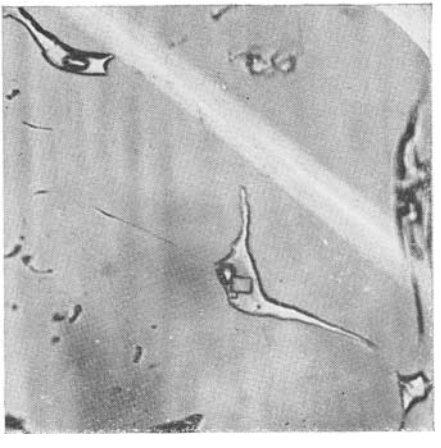

FIG. 40.

Beautiful three-phase inclusions in a Colombian Emerald. 75 ×

have intergrown in a definite manner, known scientifically as "according to a definite law." Parallelism of the separate individuals is not essential. There are two types of twins—contact twins and penetration twins. As the name implies, contact twins are those in which two crystals are in conjunction with one another. The two parts of such a twin have grown side by side and are so related that one part may be considered as having been rotated through 180 degrees around an axis known as the twinning axis. Penetration twins are those in which two individual crystals are so intergrown that they penetrate one another. A twin may consist of more than two individuals. This is the result of repeated twinning and polysynthetic twins are formed this way. Polysynthetic twinning frequently gives rise to characteristic fine, parallel lines, called twinning striations. These represent the boundaries between individual crystals, thus forming lamellae. Cohesion between twin planes is sometimes weak in corundum, in which species such lamellae frequently occur, and parting or false cleavage then results, very similar to true cleavage. (Figs. 62, 63.)

B.—ZONING.

One must not imagine that the growth of a mineral from its mother solution proceeds in such a continuous manner as the prenatal growth of a living creature within the protective tissues of the womb before birth. The flow of a solution from which the crystal grows is liable to have long or short interruptions and to be subjected to chemical alterations such as changes in the proportional amount of colouring agents. This is quite feasible, as the liquid in the immediate neighbourhood is variable in quantity and nature, and the character of the accompanying foreign particles is also liable to change. Therefore growth phenomena arise in nature from the continually varying new substances being deposited on the strictly flat faces of the growing crystal. For this reason the "striae" arising are always parallel and always absolutely straight, and they often meet at angles in groups arranged in parallel fashion among each other. Under the microscope one may thus notice a layered or banded structure which indicates the results of interrupted growth or continuously altering composition in the amount of the colour elements. This grouping is said to be a zoning structure. The zones may often be marked by layers of inclusions, as, for instance, rutile needles. (Figs. 64-68.)

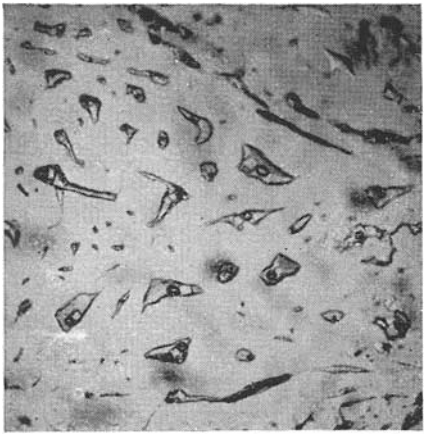

FIG. 41.

Three-phase inclusions in a Colombian Emerald. 40 ×

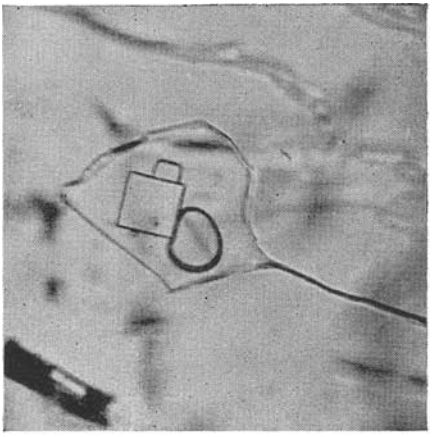

FIG. 42.

Three-phase inclusions in a Colombian Emerald. 250 ×

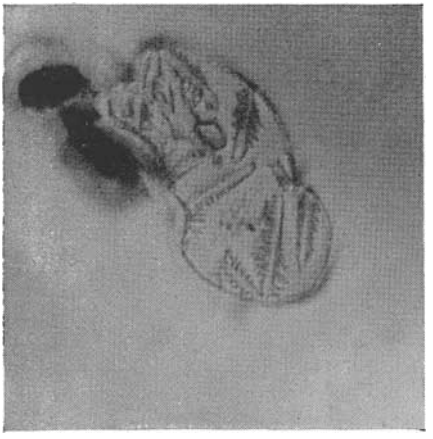

FIG. 43.

Recrystallisation in the liquid inclusion of a Siam Sapphire. 125 ×

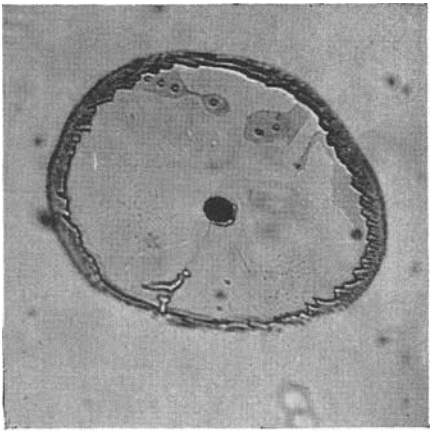

FIG. 43a.

Post-temporary formation of a solid inclusion in a Chrysolite (from Zebirget Island, Red Sea). 125 ×

In the case of a coloured mineral the banded or zoned structure is usually obvious by reason of differences between the colour or depth of colour of the neighbouring layers. With corundums, emeralds, tourmalines and other gemstones, zoning is frequently present. It quite frequently happens that the pigment of allochromatic minerals is unevenly distributed, or the colour may occur in irregular patches or blotches, as is often the case with amethyst, sapphire and Burma rubies. (Fig. 69.) The signs of interrupted growth we have just mentioned can be an important means of distinction between natural and synthetic stones, and for this reason I will treat them in detail. The synthetic ruby, sapphire and spinel grow in the form of a boule, and are thus quite different from the crystal habits of the natural gems. The new deposits of the substance in the case of such a boule, which generally has no distinct crystal form, are made on the flatly arched dome of the boule, and so the striae are also curved. They are distinct in synthetic corundums, but never appear in synthetic spinels. (Figs. 70-79.)

It is now said that a factory has succeeded in producing straight striae in synthetic rubies and sapphires, so I give you the following method for the distinction of natural and synthetic stones: straight striae are not common, but when they occur in groups meeting in a knee-fashion at an angle conforming to natural laws, you have an absolutely certain sign of the natural origin of the stone. In emeralds, where the layers are always straight, this rule does not apply, as in synthetic emeralds which are produced under conditions similar to those prevailing in nature ; one also finds straight striae. The safest means of microscopic detection for synthetic emeralds are the wrinkled wisp-like feathers of microscopically fine drops of liquid.

You have now heard much of the mystery and fascinating beauty of those wonderful formations of God's own magnificent designs in His most precious gifts to mankind. We so much admire the beautiful inclusions in natural gemstones, and I hope you now understand better how to distinguish these from the ugly inclusions found in man-made counterfeits.

My studies have drawn me more and more towards the conclusion that sooner or later gemmologists will abandon the orthodox present-day method of first examining gemstones for genuineness by tests for specific gravity, refraction and dichroism in favour of

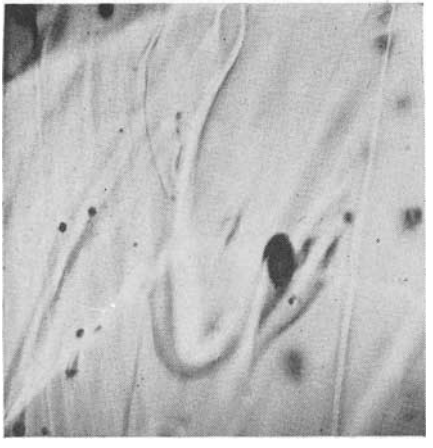

FIG. 44.

Swirl marks and gas bubbles in a Moldavite. 30 ×

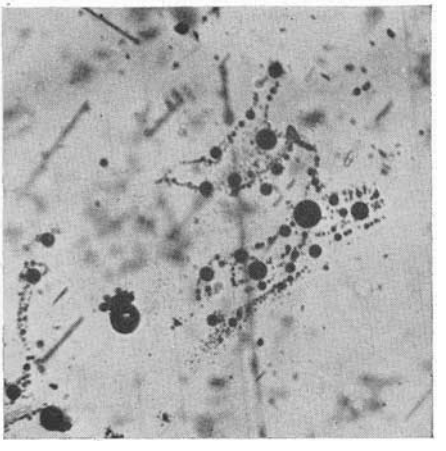

FIG. 45.

Typical air vesicles in the glass body of a doublet. 75 ×

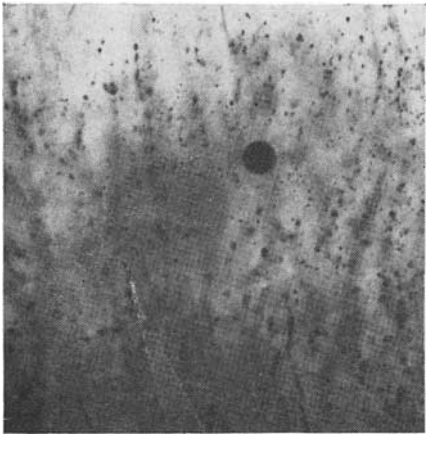

FIG. 46.

Dense cloud of gas bubbles in a synthetic Corundum. 50 ×

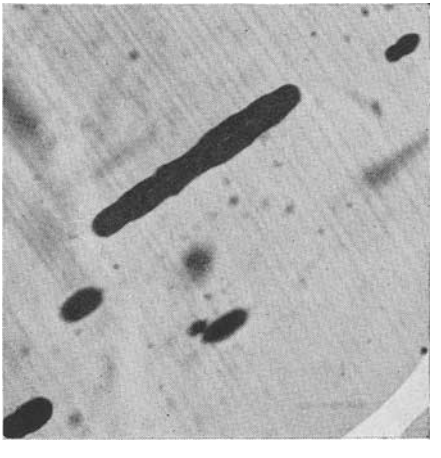

FIG. 47.

Long stretched gas bubbles and curved striae in a synthetic corundum. 75 ×

an approach through study of their inclusions, and I consider this means of identification amongst the first three most important gem-testing methods: the other two, of course, being the determination of refractive index and of absorption spectra.

Among all properties and characteristics of gemstones only inclusions are useful as an absolutely sure means of identification which can also be documented through photomicrographs. Weight, cut and external blemises of a stolen or lost stone can be completely altered, but the formation of typical interior inclusions remain always significant for a given stone, so that later identification of any stone accompanied with a photomicrograph is always ensured.

In a few outlines, then, I have sketched the nature of a branch of gemmology which is still in its youth—the study of inclusions. It owes its new impetus, though not its birth, to the necessity for creating some reliable methods of distinguishing between natural and man-made stones as well as between stones of different origin and provenance. This study will form the basis for the testing methods which the future will see employed in the realm of the gemstones. A great deal of work will still have to be done by mineralogists and gemmologists, as well as by chemists and physicists, if the numerous problems which inclusions conceal in their costly sealed up mansions are to be brought to their final and complete solution. But in return gemmology may await from the new discoveries among the internal parageneses of gemstones valuable results in many directions, both for itself and for the general benefit of jewel-loving mankind.

(See further illustrations on pages 32-39.)

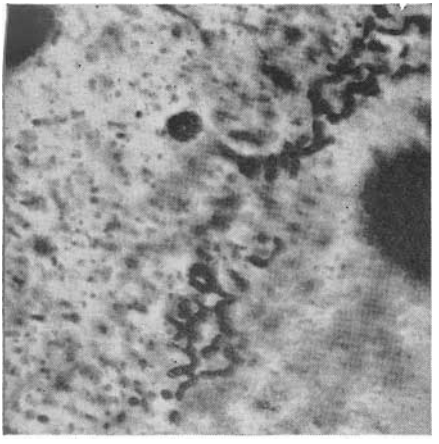

FIG. 48.

Gas bubbles and irregular gas filled hoses in a synthetic Corundum. 125 ×

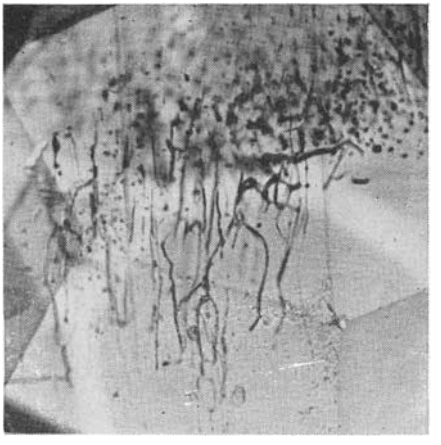

FIG. 49.

Irregular gas-hoses in a synthetic Corundum. 75 ×

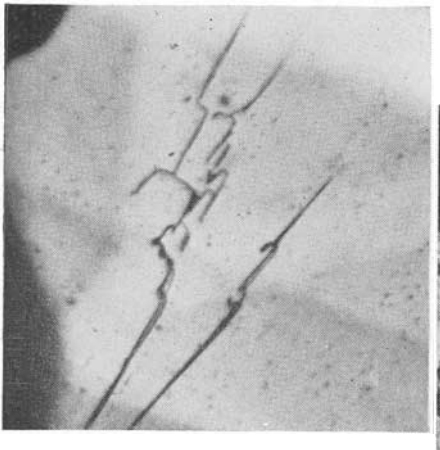

FIG. 50.

Irregular gas inclusions in a synthetic Corundum. 75 ×

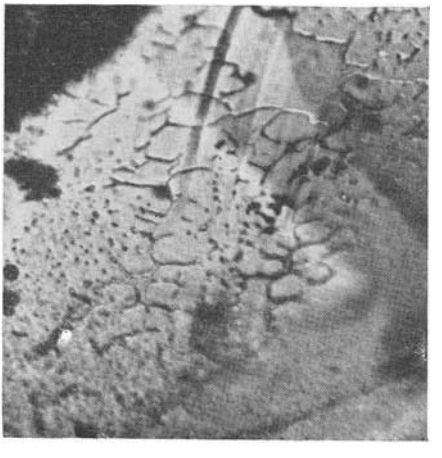

FIG. 51.

Irregular, net-like, gaseous inclusions in a synthetic Corundum. 125 ×

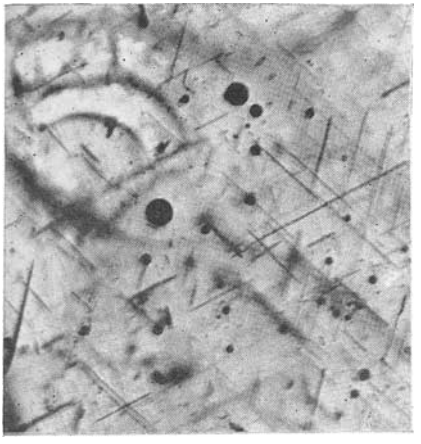

FIG. 52.
Phenomenological view of the inclusions in a doublet, i.e. rod-crystals of amphiboles in garnet-top and gas bubbles in glass pavilion. 75 ×

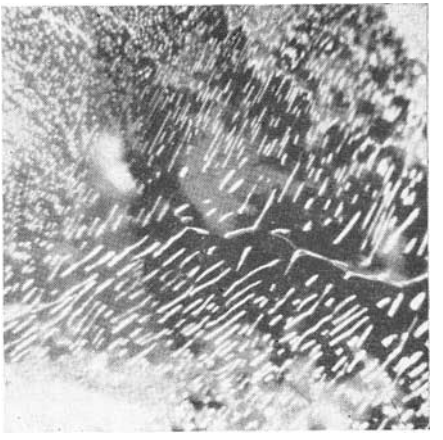

FIG. 53.
Liquid feather in a Ceylon Sapphire. 40 ×

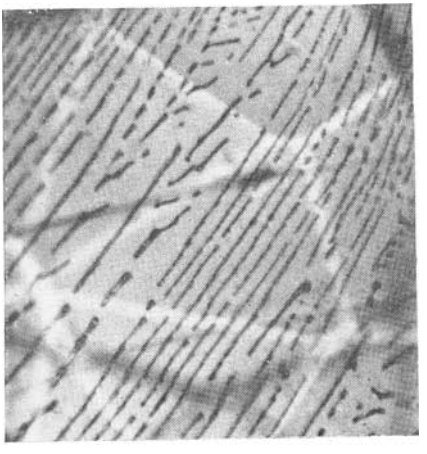

FIG. 54.
Typical feather in a Ceylon Sapphire. 75 ×

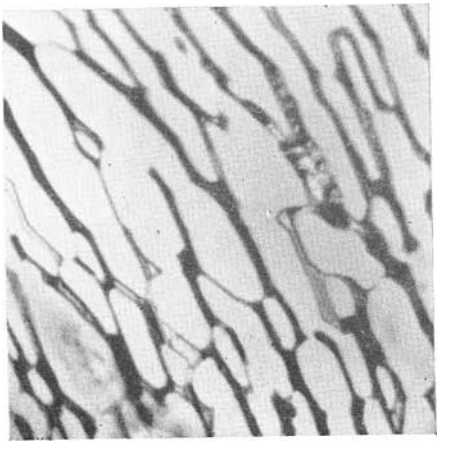

FIG. 55.
Liquid feather highly magnified in a Ceylon Sapphire. 125 ×

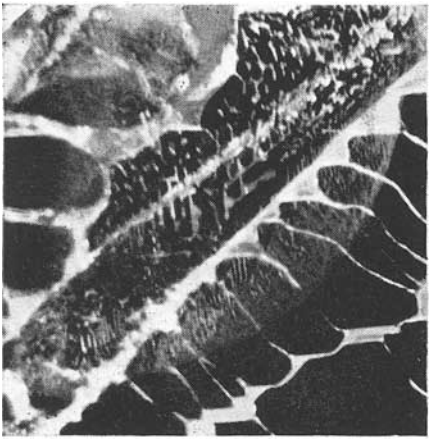

FIG. 56.

Strong magnification of intercommunicating channels forming a feather in a Ceylon Sapphire. 150 ×

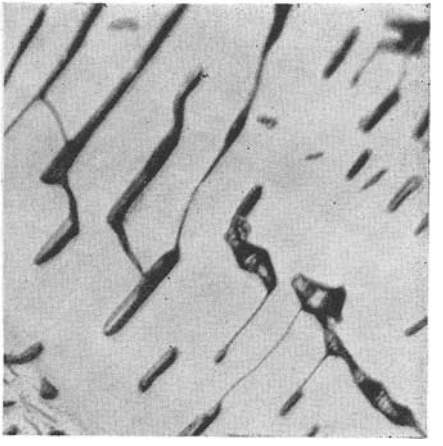

FIG. 57.

Single drops of fluid forming a feather in a Ceylon Sapphire. 250 ×

FIG. 58.

Scriptine-like design of a feather in a Siam Ruby. 50 ×

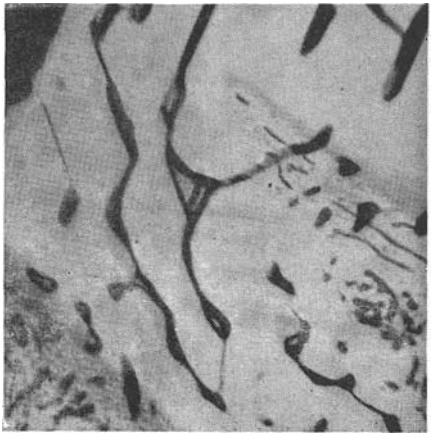

FIG. 59.

Liquid feather in a Ceylon Sapphire. 250 ×

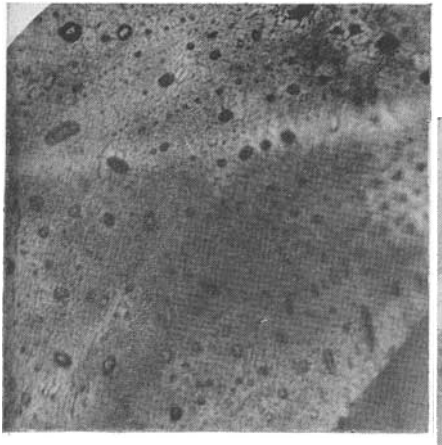

FIG. 60.

Liquid feather overlaid by a feather of crystals in a Burma Sapphire. 50 ×

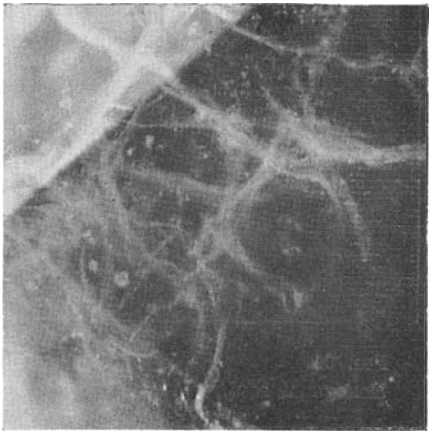

FIG. 61.

Wisp-like feathers in synthetic Emerald. 20 ×

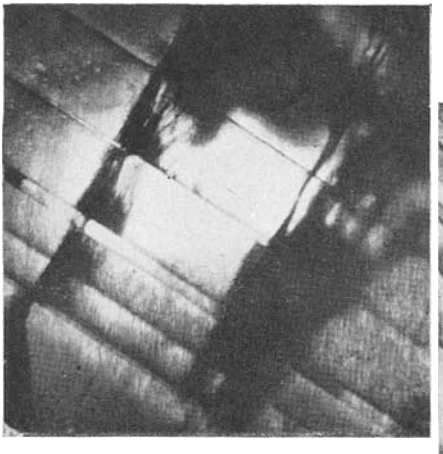

FIG. 62.

Chequered pattern of polysynthetic twins of Siam Rubies. 40 ×

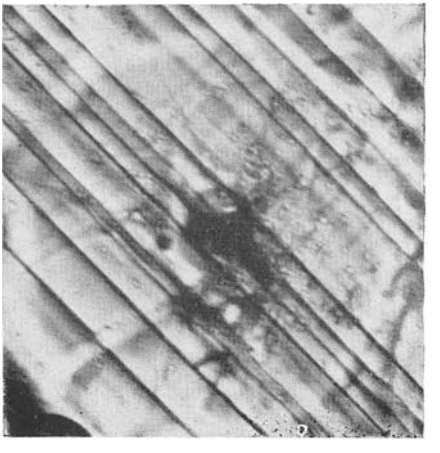

FIG. 63.

Lamellae caused by polysynthetic twinning in a Ceylon Ruby. 75 ×

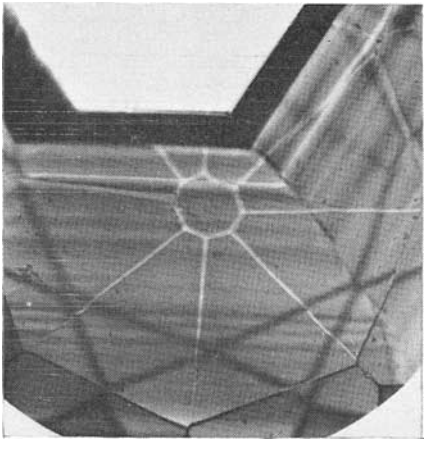

FIG. 64.
Hexagonal zoning in a Burma Sapphire. 40 ×

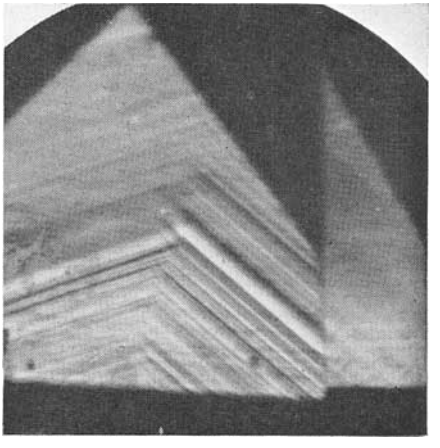

FIG. 65.
Angular meeting of zonal striae in a Burma Sapphire. 40 ×

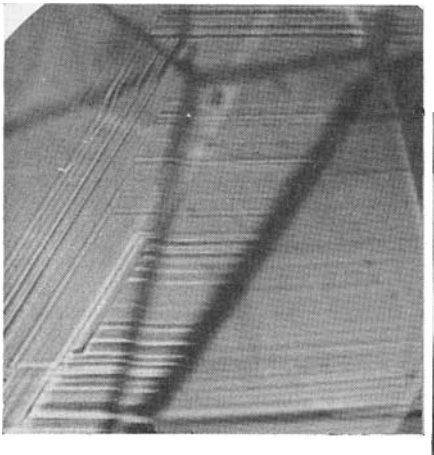

FIG. 66.
Typical zoning in a Ceylon Ruby. 40 ×

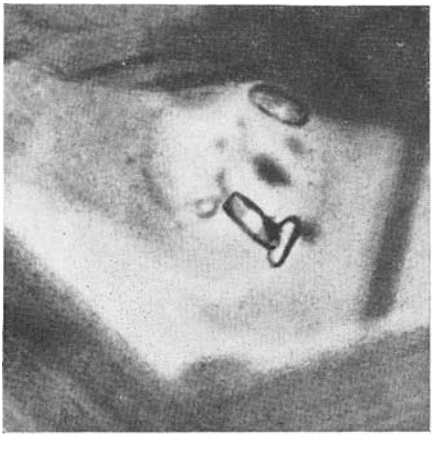

FIG. 67.
Zonal structure strongly marked by deposition of rutile silk in a Burma Ruby. 75 ×

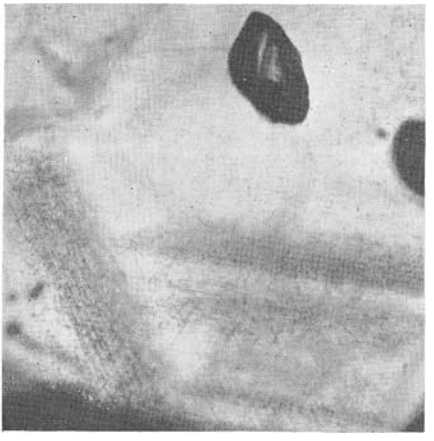

FIG. 68.

Zonal structure accentuated by a deposition of rutile needles in a Burma Ruby. 75 ×

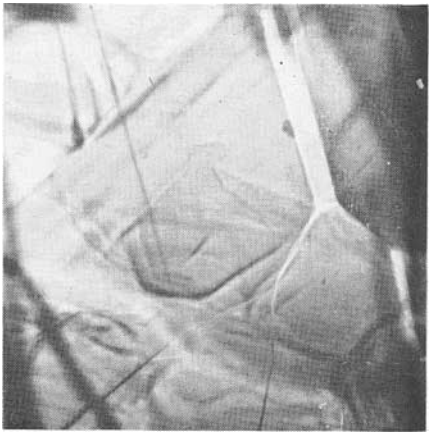

FIG. 69.

Distinctive colour swirls in a Burma Ruby. 30 ×

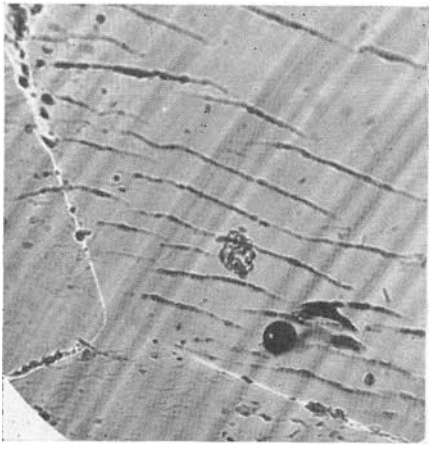

FIG. 70.

Surface cracks, curved striae and gas bubbles in a synthetic Corundum. 50 ×

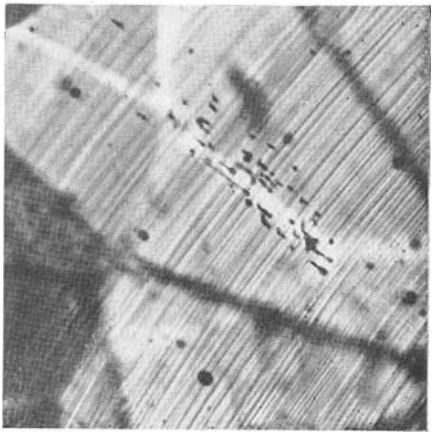

FIG. 71.

Curved layers and gas bubbles in a synthetic Corundum. 75 ×

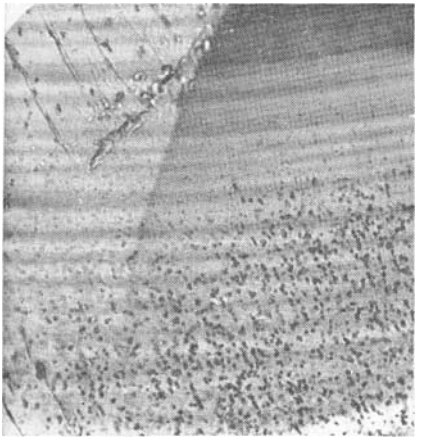

FIG. 72.
Curved striae and gas bubbles in a synthetic Corundum. 50 ×

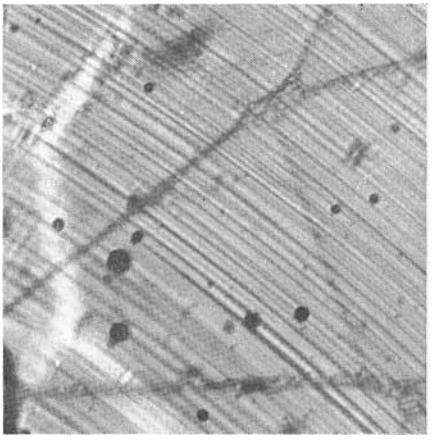

FIG. 73.
Curved striae and gas bubbles in a synthetic Corundum. 75 ×

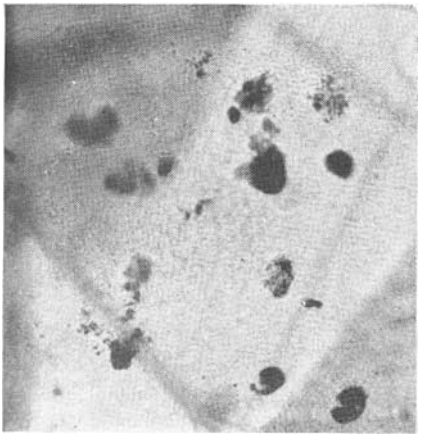

FIG. 74.
Undissolved (unfused) particles of colouring matter in a synthetic Ruby. 40 ×

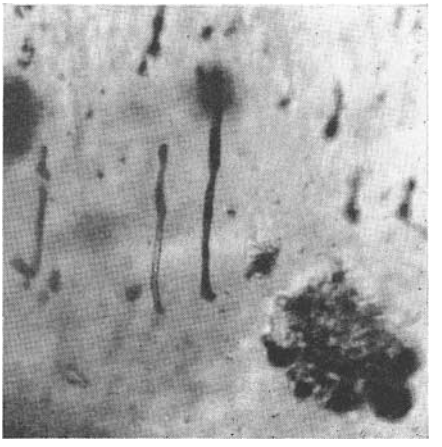

FIG. 75.
Gaseous inclusions and impurities in a synthetic Ruby. 125 ×

FIG. 76.
Anomalous extinction of synthetic Spinel. 10 ×

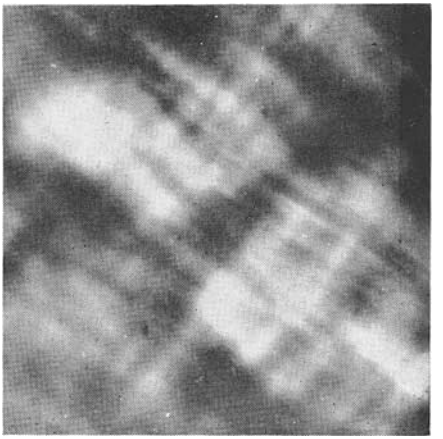

FIG. 77.
Anomalous extinction of synthetic Spinel. 10 ×

FIG. 78.
Anomalous extinction of synthetic Spinel. 10 ×

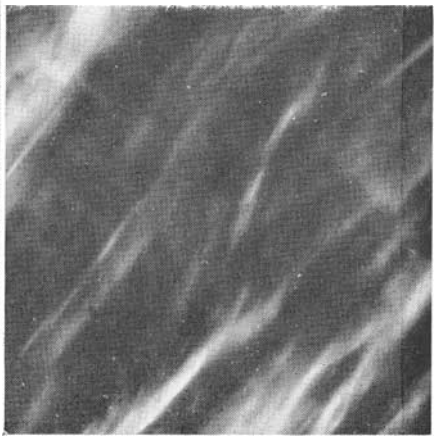

FIG. 79.
Anomalous extinction of synthetic Spinel. 10 ×

ASSOCIATION NOTICES

GEMMOLOGICAL PRIZEMEN AT THE BIRMINGHAM SCHOOL

A small exhibition of Gemmology was shown recently at the Birmingham School for Jewellers and Silversmiths on the occasion of the Annual Prize-giving at the School and this exhibit attracted considerable attention. Two students, Mr. A. D. Conway (Final Year) and Mr. Stephanides (Prelim.) received prizes of Five Pounds and Three Pounds respectively. The prizes were given in the presence of a large gathering by the Lady Mayoress of Birmingham, after speeches by the Lord Mayor, Mr. Cuthbertson, the Headmaster, Mr. Albert Carter and Mr. Ivan Short. The prizes in Gemmology will be awarded annually to students of the Birmingham School.

TALKS BY FELLOWS

Lecture entitled "The Romance of Gemstones," given by John F. Croydon, F.G.A., to St. Andrews Youth Club, Colchester, on 9th April.

N.W. Hull Conservative Association, 6th May, talk on Gemstones, K. Parkinson, F.G.A.

EXAMINATIONS IN GEMMOLOGY

The 1948 Examinations in Gemmology were held in June as follows:—

PRELIMINARY: Wednesday, 23rd.

London, Edinburgh, Glasgow, Birmingham, Plymouth, Perth, Belfast, Manchester, Bristol, Bournemouth, Dublin, Surat (India), Calcutta (India), Crawley (W. Australia), Vancouver (Canada), Hilversum (Holland), Edmonton (Canada), Oporto (Portugal), Karachi (Pakistan), Johannesburg (S. Africa), New York (U.S.A.), Los Angeles (U.S.A.), Jos (Nigeria), Youngstown (U.S.A.), Miami (U.S.A.).

DPLOMA (Theory): Thursday, 24th.

London, Edinburgh, Birmingham, Dorchester (Canada), Hilversum (Holland), Johannesburg (S. Africa), Chihuahua City (Mexico), Hong Kong, Colombo (Ceylon), Crawley (W. Australia), Los Angeles (U.S.A.), Jos (Nigeria), Miami (U.S.A.).

DIPLOMA (Practical): Friday, 25th.

London, Hilversum (Holland), Johannesburg (S. Africa), Hong Kong, Colombo (Ceylon), Los Angeles (U.S.A.).

DIPLOMA (Practical): Monday, 14th. Edinburgh.

DIPLOMA (Practical): Friday, 18th. Birmingham.

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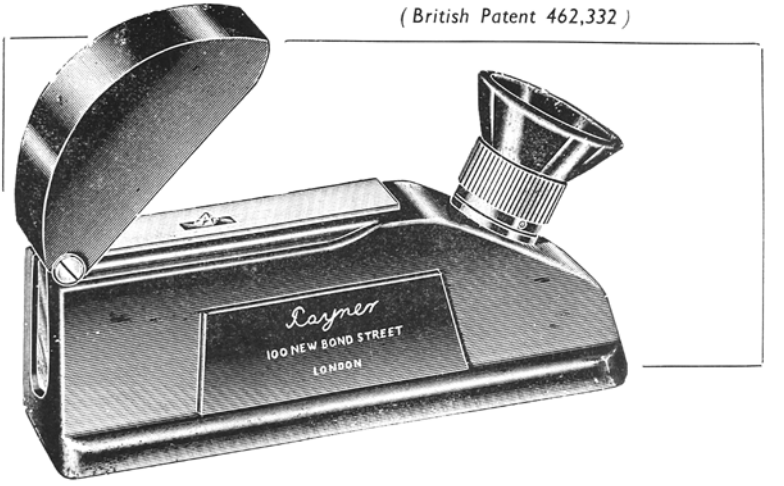

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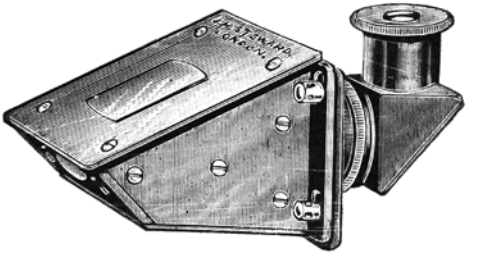

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THE JOURNAL OF GEMMOLOGY
AND PROCEEDINGS OF THE GEMMOLOGICAL ASSOCIATION OF GREAT BRITAIN

Vol. I, No. 8. OCTOBER 1948

THE MINERAL GALLERY REOPENS

MEMBERS of the Gemmological Association will be pleased to read that part of the Mineral Gallery of the Natural History Museum at South Kensington has been reopened to the public. Great efforts on the part of the Keeper of Minerals (Dr. Campbell Smith) and his staff have produced an exceptional show of the most attractive specimens selected from the vast number in the great National Collection in their care. The re-opening was timely in view of the International Geological Congress held in London during August: that the exhibits held the interest of our overseas visitors was indeed evident to our representative, who noticed many of the visitors to the gallery wore the " crossed hammer " badge of the Congress.

With such a splendid show it is difficult to know where to start, but a gemmologist will at once be attracted by the case of cut gemstones which meet the eye on entering the door of the gallery. An entirely new type of display has been given to this show of specimen coloured stones, now segregated together. The stones are displayed inset in a colourless " perspex " sheet which is held some inches above a self-colour fabric background. The effect is intriguing and made further so by the grouping of the gems into colours ; the blue stones being at the top left, the reds at the top centre, and the browns and yellows at the top right ; the greens below had the darker shades in the centre with the bluish-greens on the left to merge with the blues and the yellowish-greens on the

right to blend with the yellow group ; the whole making an attractive display of colour.

The stones are neatly labelled with the species name and a number which by reference to a key at each bottom corner additional information could be obtained. It is an open secret that our Vice-Chairman, Dr. G. F. Claringbull, was responsible for this fine show of stones, which included the two large beryls ; topazes, tourmalines, spinels, and fluorites in all hues ; and the more unusual andalusite, kornerupine, fibrolite, hiddenite, scapolite and many others.

The diamond display shows the various occurrences of this gem ; a number of fine diamond crystals and a range of cut stones and crystals showing the various hues, also a number of crystals illustrating the characteristics of the various mining fields. The precious metals, platinum and gold, in native state and many worked pieces of ornamental minerals from the Hans Sloane collection were on view.

The general exhibit showed the finest of the crystal and mineral specimens, beautifully spaced and set out. It would be unfair to select specimens for special mention, but the gemmologist can hardly fail to spot the fine aquamarine crystal from Pinqueira Mountain, Brazil, and the fine emerald crystals, including the 1,384 carat " Duke of Devonshire " emerald. Among the tourmalines two slices of tourmaline crystal from Antsirabé, Madagascar, cut parallel to the basal plane, showed pronounced and unusual zoning, while other crystals from Pala, Brazil and Ava, Burma, made an impressive sight. Fine topaz crystals, too, are well evident, including the striking magenta-coloured variety from the Sanaka River, U.S.S.R.

The fine group of pseudo-hexagonal alexandrite crystals need to be seen to be fully appreciated, and how much more precious is an opal which replaces the humerus of a plesiosaurian. A sincere prayer was offered that no examinee at a future G.A. practical examination would meet the ruby crystal with " octahedral " habit. Space forbids description of the many more fine crystals, but two recent acquisitions, a fine group of doubly-terminated crystals of greenish yellow colour and complex crystals of rose beryl, both from Minas Gerais,* and the brazilianite crystals deserve mention.

* The old name Minas Geraes has been replaced by the corrected spelling—Minas Gerais.—EDITOR.

Other exhibits show the range of colour that may be found in a single species (fluorite) ; early mineral treatises and crystal models and a very excellent show of models illustrating Crystal Chemistry. One must not forget, too, the grand show of uranium and radio-active minerals, far better as mineral specimens than as fuel for the God Mars.

In the outer corridor are seen exhibits showing large crystals of beryl and calcite ; the meteorites and a series showing the formation of minerals by precipitation of mineral matter from charged waters producing stalactites and stalagmites which show concentric structure. Calcite, rhodochrosite, " Gibraltar stone " and a limestone cavern illustrate the effect. The ultra-violet light fluorescence exhibit is again in operation so that one can see the intense blue fluorescence of fluorspar ; the green of willemite and the yellow of scapolite. The old display of the ornamental stones is still in place, but a fine show of " British Minerals " has caused the smaller mammals to retreat along the corridor.

Thanks, Dr. Campbell Smith and your staff, for again giving us a sight of the old familiar pieces, and so many new ones, in such a finely arranged display.

CORRESPONDENCE

From Sir Lewis Fermor, O.B.E., F.R.S.

Bristol.
4th August, 1948.

The Editor,
" The Journal of Gemmology."

Dear Sir,

I notice that on page 15 of Volume I, No. 2, of your Journal, Mr. B. W. Anderson proposes a " New Name for an Old Garnet," namely *pyrandine*.

He will probably be interested to learn that a somewhat similar name for this same garnet, namely *pyralmandite*, was proposed by me as long ago as 1926 in a paper " On the Composition of Some Indian Garnets,"* and that the general question of the nomenclature of garnets was discussed by me in a later paper on " On Khoharite, a New Garnet, and on the Nomenclature of Garnets."†

You will find from the latter paper that I have been using similar compound names for garnets since 1909, the earliest example being " *spandite*," the composition of which the reader can easily guess.

With reference to the pronunciation of the first syllable in pyralmandite or Mr. Anderson's variant thereof, it should, of course, be pronounced long, as in pyrope, and not short, as in pyrrhotite.

Yours faithfully,

L. L. FERMOR.

* " Records, Geological Survey of India," LIX, p. 205 (1926).

† *Op. cit.*, Vol. 73, pp. 145-156: specially pp. 151 and 156 (1938).

Spectrochemical and Spectrophotometric Analyses of RUBIES and SAPPHIRES

by

A. E. ALEXANDER, Ph.D.

Director, Gem Trade Laboratory, Inc., New York, N.Y.

DURING the course of a comprehensive investigation of rubies and sapphires, the writer felt that an accurate series of spectrochemical analyses might prove very useful in an undertaking of this kind. The results of the initial analyses made on both genuine and synthetic rubies are now available for study and comparison. At a later date, a similar spectrochemical analysis will be made on the sapphire. (1), (2), (3)

Preparing the samples for spectrographic analysis posed a problem, due to the excessive hardness and toughness of all corundum. To reduce outside contamination as much as possible, a boron carbide mortar was used to grind the rubies. The gems are cleaned with, and ground under, acetone to remove handling contamination. The excitation of the samples in the spectrograph was performed under conditions specified by the Harvey Method for semi-quantitative analyses. The writer is indebted to Dr. Harold P. Klug and Mr. William L. Weeks of the Mellon Institute of Industrial Research for making these tests.

The percentages listed in the table below have been calculated on a basis of the elements' oxides, assuming that all the elements existed in the oxide form in the samples. Though this is not strictly true, the variation caused by some of the elements existing in the form of silicates falls well within the range of accuracy of the method.

(1) A. E. Alexander, "Genuine and Synthetic Rubies and Sapphires," Jour. Chem. Education, Vol. 23, 418-422, 459, 1946.

(2) A. E. Alexander, "Fluorescence in Synthetic Stones," Jewelry Magazine, March 15th, 1948.

(3) A. E. Alexander, "Linde Synthetic Star Stones," National Jeweler. "NJ." November, 1947.

TABLE I

Spectrochemical analyses of four rubies, two genuine, two synthetic

Oxide		Specimen A	Specimen B	Specimen C	Specimen D
Al_2O_3	...	98.8%	97.5%	96.5%	97.3%
Cr_2O_3	...	.945	1.81	1.915	2.58
SiO_2	...	.137	.542	.410	.464
CuO	...	.00237	.00160	.00483	.00308
CdO	...	.0168	.0351	.00937	.01121
MgO	...	.02265	.0328	.0170	.0625
MoO_3	...	.00448	.0117	.0142	.01725
V_2O_5	...	.0320	.0582	None	None
Fe_2O_3	...	.0147	.0252	.0215	.0409

Specimen A—Genuine ruby, light in colour.
Specimen B—Genuine ruby, dark in colour.
Specimen C—Synthetic ruby, light in colour.
Specimen D—Synthetic ruby, dark in colour.

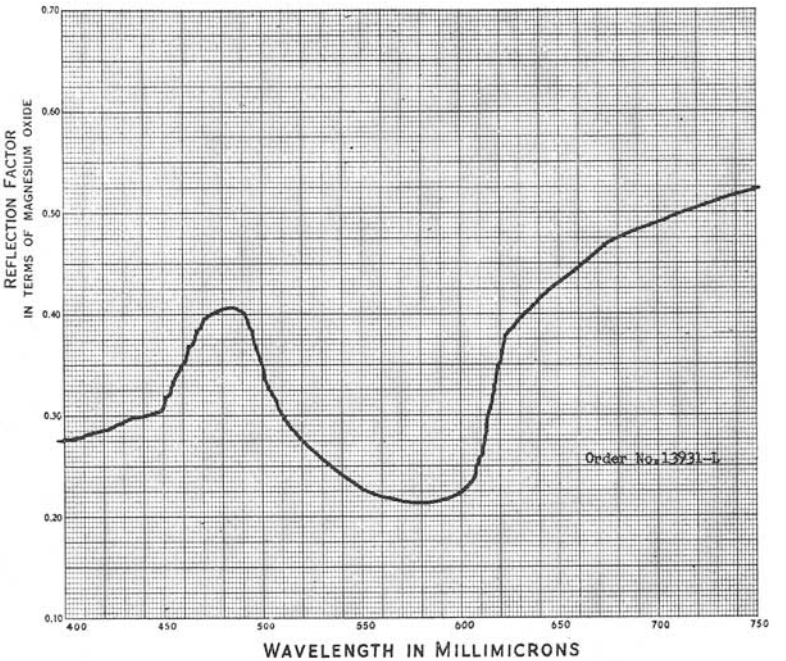

SPECTROPHOTOMETRIC TEST

Spectral Reflection Factor in the Visible Region of Genuine Ruby (Dark)

The following elements were sought in all samples but were not found: K, Li, Be, Sr, Cb, Bi, Pb, Ru, Ce, Rb, Cs, Ag, Ni, Co, Ti, Sn, Sb, Mn, Te, W.

The keen interest aroused at the time Linde synthetic star stones came on the market resulted in a decision to have spectrochemical analyses made of this material. Since petrographic examination of the star producing medium suggested titania, a detailed analysis for this component was undertaken(3). For this test, only synthetic star ruby was employed. Linde star sapphire was not available at the time. The results obtained are noted in Table II.

TABLE II

Spectrochemical analyses of sections of a Linde synthetic star ruby

Sample	Mg	Cr	Si	Ti
Core	.024%	2.54%	—	.064%
Core, plus outer layers ...	.023%	2.63%	—	.070%
Outer layers alone ...	.080%	2.48%	.31%	.162%

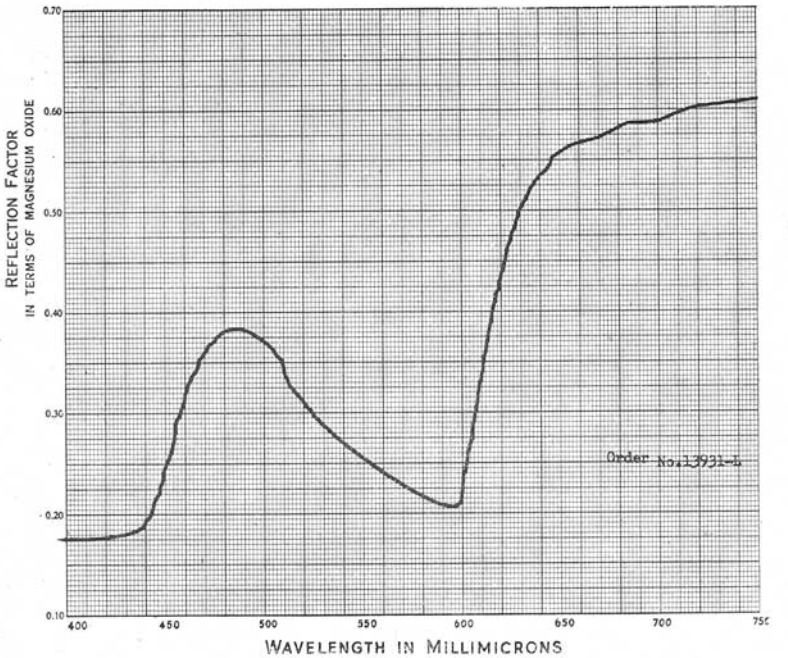

SPECTROPHOTOMETRIC TEST

Spectral Reflection Factor in the Visible Region of Synthetic Ruby (Dark)

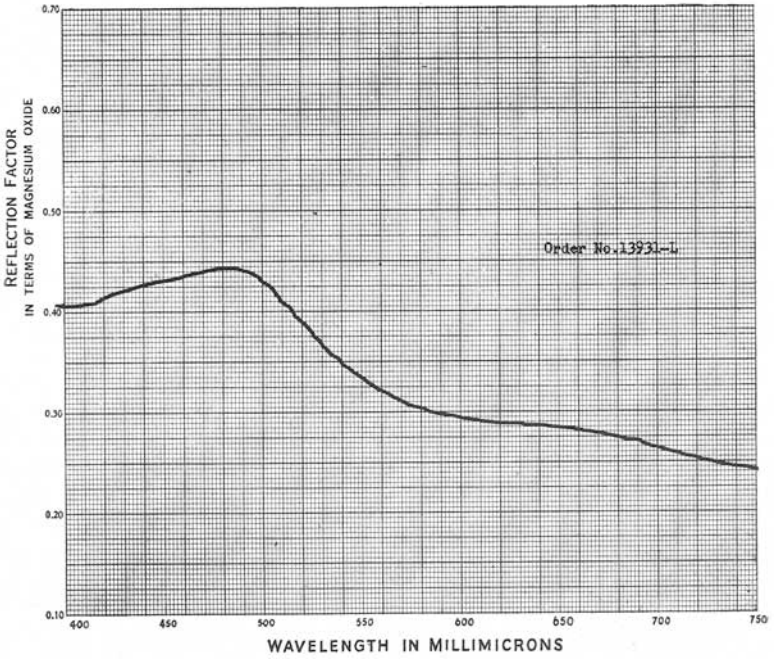

SPECTROPHOTOMETRIC TEST

Spectral Reflection Factor in the Visible Region of Genuine Sapphire

NOTE: " Core " means centre or clear part of this particular stone. " Outer layers alone " means area around apex of this stone, which contained the crystalline material which produces the star effect.

Noteworthy is the finding of increased titanium in the area characterized by the presence of dense, interlocking crystals. Their resemblance to rutile needles in the star synthetics, when compared with those noted in Burma rubies, for example, has been described elsewhere(1), (3).

In line with another part of the corundum investigation, a series of spectrophotometric tests were deemed necessary. To undertake this work necessitated the preparation of special material. Several small plates of both synthetic and genuine ruby and sapphire were made. These measured 2 millimetres square and 1 millimetre thick and were highly polished. All measurements

were obtained from a Hardy recording spectrophotometer. The graphs which accompany this report are interesting in that spectral reflection curves show a similarity of pattern. One would expect this, since the chemical and physical properties of genuine and synthetic corundum are, for all practical purposes, identical.

These graphs were subsequently submitted to the research laboratories of the Eastman Kodak Company, Rochester, N.Y., with the idea that a special filter might be developed which could be used in the Laboratory to quickly differentiate genuine corundum from its synthetic counterpart. As yet, with research incomplete, no wholly satisfactory filter of this type has been obtained.

In connection with this research, Gem Trade Laboratory, Inc., is indebted to Mellon Institute of Industrial Research and Eastman Kodak Company for their co-operation and interest ; and to Tiffany & Company, Inc., for generously furnishing the genuine rubies and sapphires used in the experiments.

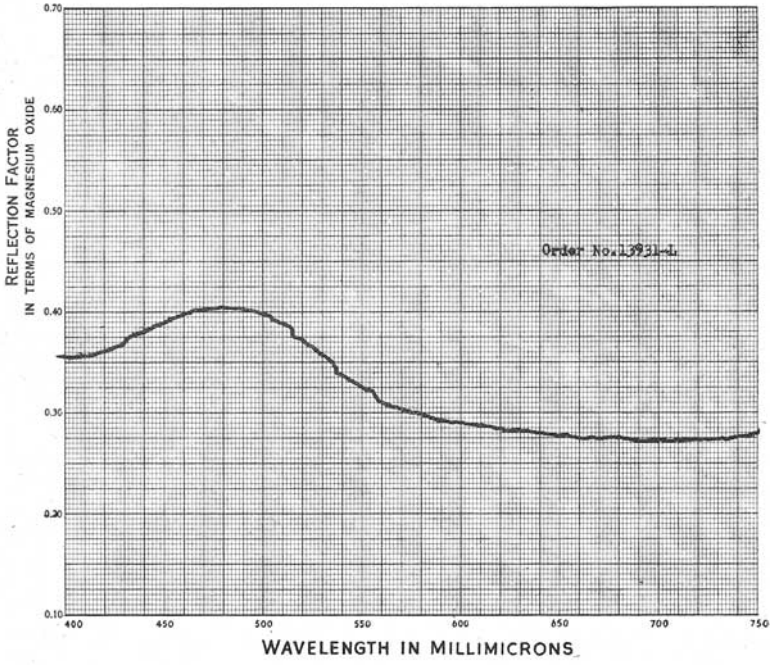

SPECTROPHOTOMETRIC TEST

Spectral Reflection Factor in the Visible Region of Synthetic Sapphire

M. D. S. LEWIS, A.R.C.S., B.Sc., F.G.A., C.G.

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SPECULATIONS ON LUSTRE

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THIS is not an article purporting to explain lustre ; it is no more than the title suggests—an expression of thoughts and speculations (many of which, on further reflection, may prove unsound or at least highly controversial) on one of the most mysterious of gemmological phenomena. Some time ago Mr. B. W. Anderson drew attention to the fact that it was difficult to explain lustre in terms of the known characteristics of light and in the standard textbooks it is barely mentioned. Simply defined as " the effect produced by light reflected from the surface of a stone " or as " the appearance of a surface in reflected light," lustre becomes a most difficult problem when one realizes that physically this light is completely described by three properties—intensity, wave-length (or frequency) and state of polarization. Intensity needs no explanation, wave-length determines colour, whilst state of polarization is not normally detected by the unaided eye and so drops out of the picture. When, therefore, we describe lustre in terms of intensity and colour, have we said all there is to say, or does there remain some further imponderable quality—wholly subjective, psychological, perhaps physiological?

Before considering this question I think we must revise our definition of lustre, because the light which produces that effect in our minds has not only been reflected from the surface. It is always mixed with rays which have travelled into the interior of the stone, from which they have been scattered or reflected back to reach our eyes. As a matter of fact, only a small proportion is reflected from the surface and the greater part of the light we receive from the stone has travelled some distance through it and has thus undergone modification.

Recently, Dr. G. Gardam, of the Jewellery Trades' Design and Research Centre, recommended me to read two references, which to my mind place the whole subject in quite a new perspective. The The first is a series of articles, " Colours of Colloids," in the American publication " Journal of Physical Chemistry " (1919, Vol. 23), in which W. D. Bancroft discusses at great length the lustre of many substances, including gemstones. The second is a book, " Definition and Measurement of Gloss," by Dr. V. G. W. Harrison (published by The Printing and Allied Trades' Research Association). The author summarizes the scattered literature on the subject and deals in attractive but erudite manner with the three principal aspects of the problem—the physical basis, the very difficult mathematical attempts at evaluation and, perhaps most interesting of all, the psychological angle. It is, of course, written from the point of view of the paper technologist and it is difficult to decide how far his " gloss " differs from our " lustre," but there is no doubt they are so closely related that they can be considered side by side. Most dictionaries infer that " gloss " and " lustre " are synonymous, but I think that gloss seems to be a measure of " shine," whilst the gemmologists' lustre carries in addition to " shine " some vague mental description of the appearance of the stone. To illustrate the psychological or physiological aspect of lustre Dr. Harrison cites several phenomena. Black glass is always judged more lustrous than white glass of the same properties and polish. It is a quite general experience that if two identical diagrams on fairly rough paper are viewed through a stereoscope, the flecks in the paper stand out above the plane of the paper and look like *small bubbles in a block of glass ;* one gets a " glassy " sensation, which has remained unexplained in spite of long investigation by physicists and psychologists. When two stereoscopic prints are examined singly they may have little lustre, but there nearly always appears an increase when the two are combined in the instrument. The connection between stereoscopic effect and gloss is too marked for it to be ignored as a factor in the quality of lustre, or perhaps as a cause of " pseudo-lustre." In the last century, H. W. Dove, also experimenting with the stereoscope, made another strange discovery. If two identical geometrical figures are drawn, both on matt surfaces, one in black lines on a white background, the other in white on black, and both are viewed through a stereoscope, the resulting picture is invested with a lustre

reminiscent of polished graphite or pewter. These two diagrams are shown in Dr. Harrison's book and would have been reproduced here if the paper of this journal were matt instead of glossy, as many people can get the effect even without the aid of a stereoscope. (By looking fixedly at the pair of diagrams for a few moments and then relaxing the attention and diverging the eyes, four pictures are seen, the inner two coalescing.) The undeniable increase of lustre accompanying stereoscopic vision suggests that in some cases lustre is due to our looking simultaneously at two surfaces, one behind the other. Dr. Harrison calls this the "parallactic effect" and in his theory it is one of the primary causes of lustre. Possibly this may be the reverse of the process by which "glare" (a form of high lustre) produces a feeling of strain in the eyes. When the eyes are strained in a certain way, e.g. by having to look at one surface through another, we may "suggest" to ourselves that lustre is present.

Dr. Harrison refers all cases of gloss to his "gloss complex," of which there are three primary constituents—mirror images, changes in intensity, and parallactic effect. The first is purely a physical property depending mainly on refractive index and smoothness (with consequent specular reflection), the second introduces a time factor, and together with the third may be psychological or physiological or both. In the same way as any tint can be matched by mixing three primary colours in suitable proportions, so can any state of gloss be obtained by a suitable variation of the three ingredients of the gloss complex. Every gemmologist knows it is often impossible to distinguish one stone from another by visual judgment of colour. An emerald and a green paste may look almost exactly the same shade, but their absorption spectra will be very different and from the physical point of view the light which has emerged from the two stones is not the same. Different wave-lengths have been absorbed, the residual rays have different composition, but yet their integrated effect on our senses is the same in each case and we think the colours identical. In the same way, our final sensation of gloss is the integrated effect on our senses of the three primary constituents of the "gloss complex."

A plane glass mirror gives high specular reflection and superlative mirror images but is not considered glossy, since the other two factors are not present. A varnished piece of furniture, say a

piano top, is glossy because here we have all three causes in operation. The intensity of light specularly reflected is not large and the mirror images not particularly good, but as we move about we get changes of intensity as lights or windows are brought into reflection. One can also see the surface of the wood through the varnish layer, which thus provides the parallactic effect.

Now let us turn to gemstones and see if Dr. Harrison's theory (with modifications) can be applied. Before doing so, however, let us convince ourselves that lustre is not wholly a physical property depending on refractive index, hardness, smoothness and other measurable qualities. Suppose we are looking from a fixed position at a motionless diamond in perfectly still surroundings. Should we experience the characteristic lustre of this stone? Undoubtedly not, since movement and changes of intensity are inseparable from the lustre of a diamond, which we appreciate partly by the flashes and colour effects as we view the stone from different angles. Neither would we get the true lustre of a diamond if it were cut in the form of a perfectly flat plate, even if we were to move about in front of it. We would miss the effect of the side facets, in spite of the fact that the purely physical properties of a diamond plate are no different from those of a perfectly cut brilliant. Obviously, then, we must introduce a time factor into lustre, involving changes of intensity or colour. I know nothing of paper technology, but assume that (with the exception of titanium oxide) the usual materials involved do not have very high or variant refractive indices. Although gemmological surfaces do often provide very good reflection they are relatively so small that " formation of mirror image " properties do not seem very applicable to them. Light does not travel very far into the majority of papers, which are thin and opaque, whereas most gemstones are transparent and of considerable depth. For these reasons I would like to try the effect of resolving Dr. Harrison's three primary ingredients into a few more fundamental ones. I would like as a first choice to select refractive index, smoothness, changes of intensity, dispersion and parallactic effect as the essential constituents of the " lustre complex." There may very well be others in addition, perhaps opacity and texture, but these would be difficult factors. Refractive index, of course, plays a large part in lustre, since it determines the proportion of light reflected from the surface. For light incident

normally on an average paste only about 5 per cent. is reflected at the surface, the remainder passing in to the stone. With diamond the proportion rises to about 17 per cent ; thus stones with high refractive indices tend to have good lustre, e.g. diamond, zircon, sphene. Needless to say, a high refractive index by itself will not ensure a good lustre, e.g. the unpolished diamond crystal.

Smoothness of surface is a dominant factor in lustre, as if the inequalities approach half a wave-length, the light falling on the surface is mainly diffused instead of being specularly reflected. It is only really smooth surfaces which can be very lustrous and some authorities consider that this largely determines variation in lustre between stones. The ability of a stone to take a good polish is mainly dependent on its hardness and cleavage properties ; needless to say, mere flatness by itself does not confer lustre, for, as Dr. Harrison points out, the crinkled surface of orange skin is quite glossy, whereas the dead smooth surface of egg shell can be extremely matt.

If refractive index and smoothness were solely responsible for lustre, we might just as well cut our gemstones in the form of thin highly polished plates, backed by metal mirrors, and we would then get excellent specular reflection and mirror images. There may be very sound purely optical reasons for the disposition of the small facets on the front of a brilliant, but I would like to suggest that it is also in a psychological or physiological way that their effect is appreciated. It is mainly through them that we get the " time " factor—the changes of intensity which are so essential to lustre. No one who picks up a stone holds it motionless ; it is always moved and tilted so that light plays on the small side facets from which we get intermittent flashes of varying intensity. An emerald is not prized for its lustre ; in fact, we try to diminish it so that we are not dazzled and can then better appreciate the beautiful colour. To do this we deliberately enlarge the table at the expense of the side facets, which thus become smaller in size, number and importance. The " change of intensity " effect is thus reduced and lustre declines—hence the " emerald cut."

I think it must be admitted that dispersion affects lustre. The characteristic lustre of diamond includes its high dispersive effect—

the constantly changing coloured gleams from the surface. Dispersion seems to make a lively lustre. Benitoite, although much softer than sapphire, has a better lustre, in spite of similarity of refractive index, whilst demantoid is outstanding among garnets probably for this reason.

Now we come to the most interesting of all the ingredients of the lustre complex—the parallactic effect. We look simultaneously at the surface and through it into the body of the stone. If we immerse a stone in liquid to diminish the surface reflections we certainly get none of the characteristic lustre. Neither can we appreciate it by focussing a microscope past the surface down into the interior (even using dark field illumination so as to obtain the minimum of direct transmitted light), and if we hold the stone at such an angle that we get practically only the light specularly reflected from the surface it looks like little more than a bad mirror, also with poor lustrous effect. It is clearly essential that our eyes shall simultaneously receive light reflected from the surface in addition to the transmitted light in order to appreciate the lustre. The parallactic effect may perhaps be the principal cause of stones of similar physical properties having different lustre. Quartz and phenacite have refractive indices and hardness of the same order, yet the lustre of the latter is far higher. (Phenacite is definitely a problem on account of its unusual silvery lustre.) A synthetic white corundum is less lustrous than synthetic white spinel in spite of superior hardness and refractive index ; yellow orthoclase and yellow apatite are sometimes quite lustrous stones despite moderate refractive index, low hardness, and (in one) cleavage difficulties. These anomalies are difficult to explain on purely physical grounds because lustre is not a physical property ; it is an effect on our senses, which cannot be measured like refractive index, and among the constituents of our lustre complex the parallactic effect is one of the psychological factors which perhaps " take care " of these anomalies. It would be tempting to try to connect the " parallactic effect " with double refraction, by which " two of everything " sometimes appear and some doubly refracting stones have good lustres (sphene, zircon). If there were any correspondence, however, hambergite with its enormous birefringence should be lustrous, but the only specimen I have seen was singularly unlustrous in appearance.

The parallactic effect has been the subject of prolonged discussion and is dealt with at some length in Bancroft's paper. Some authorities infer that it arises when two surfaces are seen simultaneously, one closely behind the other. Others consider it due to the combination of two " masses of light," and if it is of significance in gemmological lustre it must be regarded in the broadest possible way. The light reflected from the surface of a gemstone is not much changed, but that from the interior is often greatly modified. Preferential absorption of some wave-lengths may take place and others may be preferentially scattered. It is in this way that texture and opacity can be brought into the picture as contributory causes of lustre.

The gemmologist seems to divide lustre roughly into three classes. The adamantine or extremely brilliant, I think, infers that we are so dazzled by the specular reflections that we cannot see very clearly into the stone. When these specular reflections diminish, our eyes are no longer dazzled and we can easily observe the interior. If it is featureless we call it glassy or vitreous, but if we observe any " texture " we instinctively compare it to other substances and say the lustre is greasy, silky, pearly, etc. Now how can the appearance of a gemstone possibly resemble that of grease? The two substances are totally different—in composition, structure and physical properties, but yet with a polished zircon one does get the feeling that the surface looks somewhat greasy. Some authorities consider it due to inequalities on the surface, which in parts may have failed to respond to the polishing process —a theory which receives some support from the experience of lapidaries who find zircon a difficult stone to polish. Since a poor polish on a stone of low refractive index does not usually result in a similar lustre, it must be inferred that on this theory the greasy lustre of zircon is due to a combination of poor polish on a substance of high refractive index, but a poorly polished diamond (e.g. a native cut stone) does not look greasy. Dr. Harrison (in a private communication) says: " As far as I can judge, a greasy appearance depends on the existence of a weakly reflecting slightly irregular layer on a stronger, more regular layer," and asks whether there is a possibility of there being minute faults beneath the surface of zircon which, acting as weakly reflecting planes, create a somewhat similar condition. My knowledge of mineralogy is far

too small to answer this question. Some white zircons do show a tendency to turn milky owing to the formation, perhaps, of minute light scattering particles. The only answer, of which I can think, is that if we consider grease on the one hand and a zircon on the other against the background of the lustre complex the total integrated effect on our senses is similar in each case and we almost imagine the zircon to be covered with a film of grease.

Finally, a few words on the difficult subject of metallic lustre, which hardly enters gemmology except, perhaps, with marcasite, haematite, and graphite. Optically, metals are peculiar substances, and differ greatly from others, due, no doubt, to their internal structure. In most of them the atoms or ions are closely packed together and share electrons, which can be imagined to form a loosely held " froth " extending round the structure. The closely packed atoms account for the high density of metals and the ease with which they can slide or glide over each other confers ductility and malleability. The electrons, being fully mobile, convey electric charges when in motion—hence the good electrical conductivity. Under the stimulus of light (of long or medium wave-lengths) these electrons obsorb energy, but having no fixed positions about which they can vibrate, do not retain but re-radiate it. Hence metals are very good reflectors—far better than other substances. Even a diamond reflects only 17 per cent. of normal incident light ; metals can reflect over 70 per cent. The structure of graphite somewhat resembles that of metals in that there is considerable sharing of electrons—hence the metallic lustre of this substance. There is practically no penetration of light into metals, so what we see is almost all surface reflected light. Now in gemstones light reflected at the surface is white ; the coloured component comes from within, where light suffers some preferential absorption, becomes residually coloured and is scattered or reflected back to our eyes. Light reflected from a metal surface—the lustre—is, however, coloured. This raises the interesting question as to what are the real colours of gold and silver. In thin films gold leaf is purple and silver blue by transmitted light. We might perhaps be justified in saying that these are really bluish metals having a golden or silvery " lustre."

The principal characteristics of metallic lustre are, therefore, the very high proportion of light reflected from the surface, great opacity and the ability to reflect coloured light, so if for any reason

these should occur with a non-metallic substance it assumes a " metallic " lustre. For example, a small bubble of air imprisoned in water appears silvery in certain directions where there is a high concentration of reflected rays owing to total internal reflection. As Dr. Harrison points out, the silvery streak of the moon reflected in ruffled water appears metallic, because owing to inclination of the wave there is not much penetration of light and we get a high intensity of reflection from the surface, which thus appears opaque. In a previous article in this journal* it was explained how some very intensely coloured substances show selective reflection—that is, they appear to be differently coloured according to whether they are viewed by transmitted or reflected light. This arises from the fact that for certain wave-lengths of light these substances have very high refractive indices and for others very low. The former are therefore mainly reflected at the surface, whilst the latter are mainly transmitted through the substance. The component reflected at the surface is coloured and thus tends to confer metallic lustre. Many solid dyestuffs and the plumage of some birds also exhibit this phenomenon.

In short, many non-metallic substances assume metallic lustre ; somehow they suggest to our minds they are like metals, whereas in fact there is not the slightest " physical " resemblance, which again underlines the strong psychological aspect of lustre.

In conclusion, I would like to re-emphasize the warning I made at the beginning. This is no " authoritative article "—even if it were possible to write one. The problem of lustre has baffled physicists, psychologists, and physiologists for nearly a century and still remains unsolved. I have merely tried—perhaps unwisely —to apply a very attractive theory from another branch of technology to our own rather more complicated subject. I think, however, that Dr. Harrison's qualifications together with his long and probably unique preoccupation with the subject do justify the attempt.

* " Journal of Gemmology," p. 10, No. 4, Vol. I.

A GEM LABORATORY IN HOLLAND

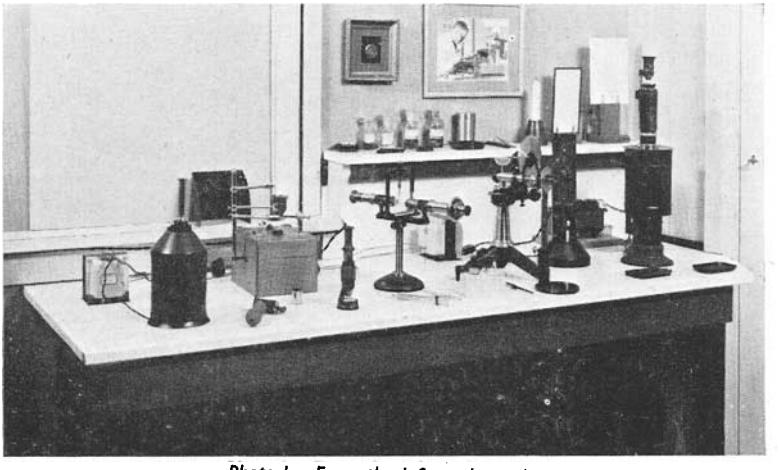

Photo I. From the left to the right.
Spectroscope with illumination and lamp transformer. Detectoscope with screen. A small Zeiss microscope, magnifies 280 times; this instrument to be used for studying and examining slides and microscopical crystals. Horizontal Conoscope, instrument to examine the interference figures of optical uniaxial and biaxial gemstones and crystals. Bolman syst. Pulfrich-Zeiss Refractometer, with polarizer and monochromatic (Medium) lamp. The hemisphere with a R.I. = 1,90116. Pearloscope (Bolman syst.) with transformer.

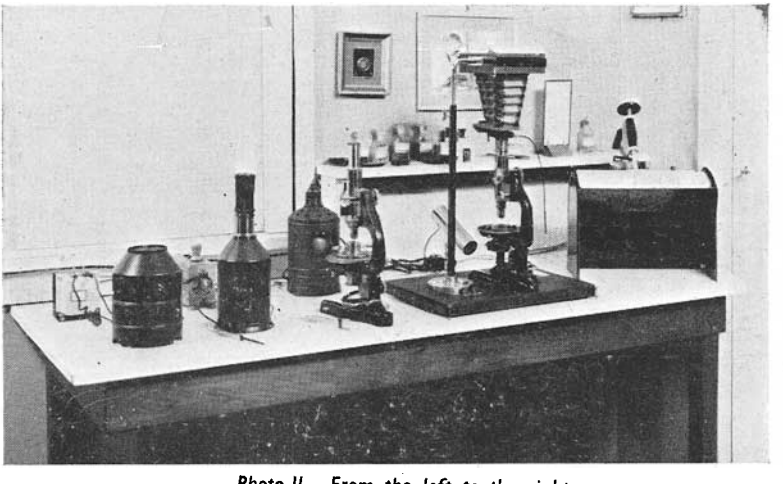

Photo II. From the left to the right
Brillantoscope, Bolman syst. to examine the angle—and double refraction besides the dispersion in faceted stones. This instrument is also used to make refractograms of a gemstone. Polarizing Microscope with apparatus for making photomicrographs. Ultra violet illumination in box to examine fluorescence. (Photos: Dr. J. Bolman, Gem Laboratory, Hilversum).

MARGINALIA

Informal notes on points of interest and opinions of a controversial character compiled by Fellows of the Association. The contributor in this issue is Edgar J. Burbage

IT has been suggested that with the advance in fame and reputation of the Gemmological Diploma, a time may come when it may achieve University recognition. It cannot be denied that under the aegis of such a body, the Association's examinations would gain greatly in prestige, but the advantages and snags of such an elevation in status seem to be pretty well balanced. The University would not unreasonably expect to take a hand in framing the syllabus, in setting the examination papers, and in selecting the examining body. Personally, I should be reluctant to see any of the activities of the G.A. becoming subject to outside control, however benevolent in intention. Also, the traditional functions of an English university do not include the provision of technical education of this sort, and I hope they never will do so.

* * * *

Evidence of the extent of recent work on the fine structure of diamond has been given by the publication of papers forming a symposium on the subject. Although of considerable importance to physicists, the gemmologist may be forgiven for knowing little of the progress and scope of this research, as it does not touch him closely, and the subject is somewhat too recondite for a non-specialist to follow from the original papers. It is to be wished that a " popular " account could be written in terms intelligible to the average gemmologist, and in a publication normally accessible to him. The name of Dr. Kathleen Lonsdale suggests itself as the ideal expositor of this subject, to which her own research work has contributed so greatly.

* * * *

Here is a mystery of a minor sort, which I confess has proved beyond my capacity to unravel. In Meade Falkner's best-known novel, " Moonfleet," Elzevir Block and John Trenchard are in Amsterdam trying to sell the Mohun diamond to a Dutch dealer, but the latter tells them that the stone is false and so acquires it without payment. For the purpose of the deception the dealer

purports to show the vendors a chemical test proving that the stone is paste. He says: " Against high chymic tests no sham can stand ; and first it is too light in weight, and second, when rubbed on this Basanus of Black-Stone, traces no line of white as any diamond must. But third, and last, I have tried it with the hermeneutic proof, and dipped it in this most costly lembic ; and the liquor remains pure green and clear, not turbid orange, as a diamond leaves it." Now, I need not be reminded that there is no simple chemical test for diamond, and certainly none that was known in the eighteenth century ; also, the alchemical blarney may be intentionally meaningless. But I have a suspicion that the passage describes a garbled version of an operation which the disciples of Robert de Fluctibus, Lillius, the Dees, and other students of " the Matter " believed to furnish a test for diamonds. That this is probable becomes evident from a careful examination of the loving care which Falkner has taken over his pastiche elsewhere (as in " The Lost Stradivarius "), and recent reassessments of the writer and his work tend to strengthen this probability. Perhaps some erudite F.G.A. can provide confirmation for my theory by running to earth the source employed by Falkner.

* * * *

A scrutiny of a recent issue of the " B.P.C." confirms a suspicion that medicaments compounded from the gem minerals no longer form part of the stock-in-trade of the modern pharmacist. His predecessor of three centuries ago rated sundry decoctions from the gemstones as of medicinal value equal to preparations of Egyptian mummy and of salves employing Sir Kenelm Digby's famous Sympathetick Powder. Apparently a faith in the efficacy of gem preparations survives in the East, for within recent years an order has been received from India by a London jeweller, requiring a supply of diamond dust for medicinal purposes. Having regard to the former sinister employment of this substance, it was considered advisable to tell the inquirer that the powder was unobtainable. Among gem substances formerly employed in medicine, lapis-lazuli had some popularity ; I find that Brasavolus in " De Medicamentis Purgantibus " commends its employment as a purge. No doubt a competent pharmacist could translate his somewhat esoteric formula into reality, should some curious gemmologist wish to hazard a test of it, but I suspect that Epsom salts would be vastly more effective at a fraction of the cost.

Canadian Gems and Gem Localities

Part II
(continued)

GEMS OF QUEBEC AND ONTARIO

By D. S. M. FIELD

CORUNDUM (Gem Var.: Ruby and Sapphire).—An account of the Canadian occurrences of corundum which should be of special interest this year, for it was exactly a century ago that it was first discovered in Canada.

Dr. T. Sterry Hunt, Chemist and Mineralogoist to the Provincial Geological Survey, discovered the mineral while making an examination of the rocks in which is now the township of Burgess, Ontario. In April, 1848, the following report was submitted to the Provincial Geologist:—

> ". . . Not far from the locality of the apatite, on the land of Mr. George Holliday, on the second lot of the ninth range of Burgess, is a deposit of copper pyrites. It occurs in the crystalline limestone, but the explorations, which had consisted only in two or three small blasts, had not developed any well defined vein. . . .
>
> " Among the masses of rock thrown out in blasting, were some consisting of silvery mica, with quartz, feldspar or albite, and calc-spar, which contained imbedded masses of a delicate emerald green and almost transparent pyroxene of rare beauty, and crystals of a dark honey-yellow sphene The mica is often aggregated in masses of small crystals having a columnar arrangement ; imbedded in this, and indeed disseminated throughout the rock, were a great number of small crystalline grains of a transparent mineral, varying in colour from a light rose-red to a deep sapphire-blue. Their hardness, which is so great as to enable them to scratch readily the face of a crystal of topaz, showed them to be nothing else than the very rare mineral corundum, which from the colours is referable to the

varieties known as the *oriental ruby* and *sapphire*. The grains obtained were small, none indeed larger than a pepper corn,* but at the time I was on the spot they were not noticed, and the specimens were collected for the pyroxene, in only two or three of which I have since detected the corundum. It is probable that further examinations may develop larger and more available specimens of these rare and costly gems. . . .

"Those of the sands of Ceylon, which have supplied the market of the world with these gems, are derived from a similar crystalline limestone. . . . I am indebted for this interesting fact to the courtesy of Major Lachlan, now of this city,† a gentleman who spent many years of his life in India, and, ever alive to the interests of natural science, made a fine collection of the minerals and other natural curiosities of Hindustan and Ceylon. Among these is a fragment of white crystalline limestone, containing small crystals of sapphire, with grains of chondrodite. The latter mineral . . . is quite characteristic of these peculiar limestones . . . and although I have not yet observed it in place in Canada, I have seen a specimen in the hands of Dr. Holmes . . . [of *Montreal*] which was broken from a boulder near Bytown [*Ottawa*], and which contains crystals of spinel, with chondrodite, in limestone."

In 1876, the largest known deposit of corundum was discovered in Lot 3, Concession XVIII, in the township of Raglan, Renfrew County, Ontario. The corundum from this locality—now known as Craigmont—is found in large barrel-shaped crystals, but unfortunately, few, if any, of them would yield cutting material. This is true also of the crystals found in the several Canadian deposits later discovered, one of which has been traced for over 100 miles, with few interruptions, through several counties in the province of Ontario.

In Lot 12, Concession XIV, in the township of Dungannon, Hastings County, the syenite is rich in corundum crystals of a translucent grey to pale blue colour, some of which—although almost invariably traversed by fine cracks—are transparent in the centre and of a rich, deep sapphire-blue colour.

* Small pea. † Montreal.

One of these splendid crystals was classed a true sapphire, and was exhibited along with other Canadian gem minerals at the Pan-American Exhibition of 1901.

In more recent years, some little attention has been given this and other deposits with a view to obtaining flawless gem material for cutting purposes. The crystals found by itinerant prospectors are larger than any previously discovered, and being of much finer quality—in so far as cracks are concerned—offer considerable promise.

In 1924, the late Dr. H. V. Ellsworth, of the Geological Survey of Canada, published a short report* on the Bancroft sapphire, part of which is given below:—

> " Usually the discoverers do not wish to divulge the exact location of their finds. The writer visited one such occurrence under promise not to mention the exact locality, and obtained some specimens. . . .
>
> " The corundum crystals occur in a gneissoid micaceous phase of the so-called syenite, in which but little nephelene was apparent. The crystals are externally a pale greyish colour and are more or less translucent so that sometimes indications of an internal blue colouration can be seen from the outside. The larger blue-coloured areas are usually found in the centre of the crystals, but many crystals contained only sporadic blue spots. The specimen illustrated was one of several obtained in place by the writer in person. The two portions taken together represent about half of the original crystal, which was broken across, normal to the C axis, by repeated blows of a heavy hammer. The half crystal was sawed in two in a direction normal to the C axis giving the specimens illustrated here. These are 2 × 1½ in. in diameter over all, the coloured areas being 1½ × 1 in. in diameter. The colour is a very fine deep cobalt blue."

Dr. Ellsworth submitted the specimen to the late Dr. George Frederick Kunz, who stated that if it were not for the aforementioned defects, each half would have been worth 10,000 dollars.

Blue corundum is also found in the township of Methuen, Peterborough County, Ontario. Here the crystals are generally imbedded in muscovite, with no indication of their presence until

* In "Can. Mining Jour.," October 10th, 1924.

the books of mica are broken open. The crystals from Methuen township are often rounded in form, due to their alteration into the mica.

Very little work has been done anywhere in Canada with a view to obtaining gem sapphire, the specimens so far obtained having been found practically at the surface of the deposits. A few of the grey-blue crystals have yielded quite large star stones of medium quality, but the pre-Cambrian rocks of the district have been so badly deformed by secondary heating and pressure that the constituent crystals so far uncovered are capable of yielding only small fragments, hardly suitable for cutting into faceted stones. It is possible, however, that some of the larger now deeply-imbedded crystals may have a flawless, deep blue central core from which large gem sapphires could be cut.

The Craigmont deposits also yield a bronze-coloured corundum and some of the crystals have been cut, by amateur lapidaries, into cabochon gems. These have no particular appeal to the general public, however ; consequently it would be rather difficult to find a ready market for them in Canada.

SPINEL.—Although very few perfectly transparent crystals of spinel have been found in Canada, several deposits might yield material suitable for cutting into cabochon stones.

In the Seigniory of Daillebout, Joliette County, P.Q., fine blue translucent octahedra of spinel are found in a micaceous crystalline limestone. Some of these might possibly yield star stones.

Opaque, light blue, cube-shaped crystals, nearly an inch across, and translucent pink and dark blue cubes—usually slightly rounded in form—are sometimes found near Wakefield, P.Q.

Splendent crystals of black spinel (the so-called pleonaste), measuring as much as two inches in diameter, occur abundantly in a vein of crystalline limestone, in the townships of Burgess and Bathurst, Lanark County, Ontario. This vein is over a mile in length.

TREMOLITE.—Tremolite is a calcium-magnesium amphibole which was originally discovered in the Tremola Valley, on the south side of St. Gothard, Switzerland. It is closely related to actinolite, differing only in that it contains little or no iron.

Tremolite is generally somewhat fibrous in structure, and of a white to dark grey colour. It is rarely transparent.

Small, deep blue and brilliant emerald-green stones have recently been cut from fragments of crystals found near Wilberforce, in the township of Monmouth, Haliburton County, Ontario.

The tremolite from this locality is associated with chrome diopside, and the green had previously been mistaken for that mineral.

Greyish-green, grey, greenish-grey and brown tremolite is found in some abundance in the same County, near the town of Haliburton. Several dozen fine tremolite cat's-eyes have been cut from this material.

The writer has cut a number of these cat's-eyes—the best of which are deep bottle-green in colour, and display razor-sharp, silver-white lines of light.

WILSONITE.—Rich purplish-red wilsonite is found in large masses, in association with scapolite, in the townships of Bathurst and Burgess, in Lanark County, Ontario ; and in Ottawa County, P.Q.

The material is susceptible of a splendid polish, and this, together with its great beauty, makes it one of the most interesting of the rare gem minerals of Canada (v. Kunz, op. cit.).

PERIDOT.—This lovely gem is found as a constituent of many of the rocks of Ontario and Quebec, but as yet no good material has been discovered.

The nearest approach to gem peridot are the small, imperfect crystals found in the rocks of the ancient volcanic mountains of Montarville, Mount Albert, and Rougemont, which rise abruptly from the plain within a fifty-mile radius, south-west of the city of Montreal, P.Q., and including Mount Royal, in the heart of the city itself.

The peridot crystals or grains average one-half inch in diameter, and range in colour from amber to olive-green. Few of them are transparent enough to furnish gems, and the majority are full of feathers and inclusions.

CANCRINITE.—A string of beads and a couple of attractive pear-shaped pendants cut from cancrinite are exhibited in the gallery of the Royal Ontario Museum of Mineralogy. The material from which the specimens were fashioned occurs in pure lemon-

yellow to orange-yellow masses, in association with sodalite, at Bancroft and French River, in the province of Ontario.

Cancrinite has a hardness of 5 to 6, and a sub-vitreous to pearly lustre. It derives its name from Count Cancrin, Minister of Finance in Imperial Russia, where it was originally discovered.

SPHALERITE.—The only gem sphalerite that has yet been reported from Central Canada comes from a small deposit near Wiarton, Bruce County, Ontario. A Toronto collector has a six-carat round brilliant, cut from a twinned crystal found at this locality. It has a rather patchy, golden brown colour and a resinous lustre.

PHENACITE.—Very brilliant, transparent crystals of colourless phenacite have been noted in pegmatite dykes near the Kewagama River, Temiskamingue County, P.Q. These may yield faceted stones.

CHRYSOBERYL.—Tabular crystals of chrysoberyl have been found in pegmatite dykes near the forks of the Rivière du Poste, a branch of the Matawin River, in the Province of Quebec ; but no further details are at present available. It also occurs in Renfrew County, Ontario, but none of the crystals so far discovered there are of gem quality.

PERISTERITE.—Although some thirty mineral species have been originally described from Canadian material, only a few gem-stones have enjoyed that distinction. Among these is peristerite, or pigeon-stone, a beautiful, iridescent variety of feldspar, with a composition near to that of albite.

Much of the peristerite from Canada is white or colourless with a celestial-blue opalescence characteristic of the best grade of moonstone ; but perhaps the most attractive varieties have a cream to fawn or brownish-pink body colour, and display a brilliant iridescence rivalling that of a good opal.

The most beautiful peristerite known is found in the township of Monteagle, Hastings County, Ontario. It displays prismatic colours of exceptional brilliance, and when cut as beads, or into cabochon gems, it makes exceedingly attractive jewellery.

Good specimens of ivory-white peristerite have been found in considerable quantities in the Villeneuve Mica Mine, Labelle County, P.Q., and in the township of Buckingham, P.Q. It is also found in crystals of many tints, and in large cleavable masses —often weighing a ton or more—in a pegmatite dyke, in Lot 19,

Concession IX, in the township of Bathurst, Lanark County, Ontario ; and as large crystals near the mouth of Eel Creek, on the north shore of Stony Lake, in the township of Burleigh ; and in the township of Bromley, Renfrew County, Ontario.

The large cleavages from Bathurst might well be adapted for use in the arts, and attractive jewellery sets could doubtlessly be cut from them.

Some of the best of the peristerite from the township of Monteagle has been cut and polished, and is on display in the gallery of the Royal Ontario Museum of Mineralogy, Toronto.

PERTHITE.—Perthite, which derives its name from the town of Perth, Ontario, the site of its first discovery, is another ornamental mineral originally described from Canadian material. It consists essentially of both the potash and soda feldspar, the component minerals having been miscible to form a homogeneous compound at high temperatures, but one having been thrown out of solution at a lower temperature to form an interlaminated combination.

If the cutter takes care to orient the stone properly before cutting, the resultant gems will exhibit a rich golden labradorescence against a flesh-red to reddish brown, or white, background. The mineral is susceptible of a high polish and furnishes very beautiful ornamental panels and tallow-topped cabochons.

Perthite is also found in large masses in Lot 20, Concession X, in the township of Dungannon, Hastings County, Ontario ; in Lot 3, Concession VI, in the township of North Burgess, Lanark County ; and in association with Amazonite in the township of Cameron, Nipissing District, Ontario.

In the Province of Quebec, high grade, white perthite occurs at the Villeneuve Mine, in the township of Villeneuve, Papineau County ; and the mineral is found in several shades of grey, cream, white and pink at the Leduc Mine, Wakefield township, P.Q.

An exhibit of cut and polished Canadian gems and ornamental stones in the National Museum at Ottawa includes several specimens of perthite from the provinces of Ontario and Quebec.

SUNSTONE.—Sunstone is a transparent to translucent variety of sodic plagioclase characterized by minute, disseminated particles of red oxide of iron, which cause fiery flashes of colour from the interior of the stone.

Some very fine crystals of sunstone have been found in several places near the contact of the Bancroft sodalite and nephelene syenite in Hastings County, Ontario, and near Perth, in Lanark County. Attractive specimens also occur in the township of Sebastopol, Renfrew County, Ontario ; and sunstone of a brownish-pink colour is found in a pegmatite dyke some twenty miles east of French River, on the north-east side of Lake Huron.

Many splendid cabochons—some of which are chatoyant—have been cut from Canadian material. The most attractive of these have a translucent, golden brown body colour, and resemble the " goldstone " imitation which was popular before World War I.

Another deposit has recently been discovered at Drag Lake, in the township of Dudley, Haliburton County, Ontario. A Toronto collector has acquired a large taupe cabochon from this locality which shows minute fiery flashes and a blue moonstone flame.

There would seem to be two distinct colour varieties of this mineral. The writer possesses two cabochons, one of which weighs approximately sixty-five carats, and is of a light fawn colour with pale bluish-mauve moonstone flame ; the other is of a much darker brown, and displays a white moonstone flame. It weighs forty carats. Both colour varieties display good aventurescence—the deeper colour being superior in that respect.

A less attractive, grey-to-white variety of plagioclase from Norway, with similar inclusions, is known as aventurescent feldspar, or, simply, aventurine.

FLUORSPAR.—Fine cubic crystals of transparent green fluorspar occur in the Mica mines of Quebec, north of Ottawa, Ontario, and a green, compact variety is found at Baie St. Paul and near Murray Bay, P.Q.

Deep purple-to-violet crystals of fluorspar occur in association with the amethyst and smoky quartz crystals of the Lake Superior district of Ontario, and in small, splendent crystals lining geodes at Niagara Falls, Ontario.

CHLORASTROLITE.—This mineral is a silicate of aluminium, calcium, etc. It occurs, in Canada, as small stellated masses in the basic ignerus rocks of Michipicotem Island, in Lake Superior ; and chlorastrolite pebbles may be picked up on the beaches of this island, and at other points along the shores of the lake.

Chlorastrolite is frequently chatoyant, and this, together with its attractive mottled green colour, makes it eminently suitable for cutting into cabochon stones. It takes a fine polish, and is locally called " Lake Superior Greenstone."

Chlorastrolite is also found on Isle Royale, a U.S. island at the south side of the lake. These are the only known deposits of this rare and attractive gem material.

In order to halt the wholesale exploitation of the deposits by tourists and local collectors, it is reported that measures have been instituted to limit the collection of specimens—which each year are becoming increasingly more difficult to find.

PREHNITE and ZONOCHLORITE.—Closely related to chlorastrolite is the mineral prehnite, a hydrated silicate of aluminium and calcium. This, and the chemically impure variety known as zonochlorite, are found at a number of points on the north shore of Lake Superior, and in spherical masses of crystals in the trap rock along the Kaministiguia and Slate Rovers, in Ontario.

The prehnite from these localities is translucent and of a rich emerald-to apple-green colour, and resembles prase or first-quality Burma jade.

The zonochlorite variety is only feebly translucent, and if of a much darker shade of green. It is, however, beautifully veined and mottled with contracting shades of green, and since it admits of a high polish, the mineral is cut into cabochons and sold at tourist resorts along the lake.

Prehnite and zonochlorite with inclusions of native copper are found at Simpson's Island, in Lake Superior.

THOMSONITE.—Thomsonite is a hydrated silicate of alumina, lime and soda, which owes its beauty and value as a gem material to concentric rings or bands of flesh-red, white, yellow, and green colours. Some fairly large specimens are found on the beaches of Michipicoten Island, in Lake Superior, and while it occurs in more striking colours along the north shores of the lake (especially in the amygdaloid basalt at Cape Gargantua and Point Mamainse), the pebbles found there rarely exceed an inch in their greatest dimension.

Thomsonite takes a splendid polish, and in the past great quantities were cut and sold to tourists and collectors ; but, like the chlorastrolite described above, good material is not plentiful now.

The most attractive thomsonites have, when polished, bright green zones of lintonite (an uncrystallized form of the same mineral) framed by concentric rings or bands of contrasting green or pink colours. Such specimens are very beautiful, and are readily saleable at good prices.

AMETHYST.—Great quantities of splendid amethyst crystals are found in the vicinity of Thunder Bay, and at other points along the north shore of Lake Superior ; also on the shores of Lake Nipigon, and at the mouth of the MacKenzie River.

Dr. George Frederick Kunz* described the Lake Superior amethyst as follows:—

> "Amethyst is found in some form in nearly every vein cutting the cherty and argillaceous slates around Thunder Bay. . . . At Amethyst Harbour this mineral constitutes almost the entire vein, and numerous openings have been made to obtain it for tourists who visit the spot. Thousands of dollars' worth are annually sold here, and as much more is sent to Niagara Falls, Pike's Peak, Hot Springs, and other tourist resorts, as well as to the mineral dealers. Surfaces several feet across are often covered with crystals from one quarter to five inches long, rich in colour and having a high polish. Sometimes, especially when large, the crystals have a coating of a rusty brown colour, owing to the oxidation of the included goethite. This is one of the most famous occurrences of this mineral, regarded as mineral specimens. . . ."

In common with the Bay of Fundy amethysts described in Part I, the colour is not evenly distributed throughout the crystals. But, whereas the Bay of Fundy stones are often transparent, the amethyst crystals from Lake Superior are generally opaque. Occasionally, however, a portion of a crystal is clear enough to be cut into transparent, crimson-shaded amethyst gems of rare beauty.

SMOKY QUARTZ occurs in fine groups, with the amethyst described above. The crystals are of about the same general quality.

ROSE QUARTZ.—Rose quartz of gem quality has been found in the Villeneuve Mica Mine, in Labelle County, P.Q., and in the township of Lyndoch, Renfrew County, Ontario. The material from these localities is frequently opalescent, and when cut in the

* See Kunz: "Gems and Pr. Stones of N. America," 1892.

cabochon form shows a six-rayed star. The Lyndoch rose quartz ranges in colour from a pale rose to pale purplish rose-pink, and quite large flawless pieces are plentifully distributed throughout the pegmatite dykes of the district. A rich, deep pink variety of excellent gem quality occurs in Manitoba. (The Manitoba material will be further described in Part III.)

MASSIVE QUARTZ.—Agates, onyx, carnelian, etc., are found in great abundance at nearly every point along the shores of Lake Superior. The masses exhibit a wide range of colours—green, red, blue, brown, etc.—and furnish cut gems to equal the finest from other countries. This is especially true of the banded agates found in the trap rock and along the beaches at Michipicoten, Ignace, and Simpson Islands. At these localities the colours are exceptionally vivid. and the stones, when cut, seldom require artificial staining to enhance their beauty.

Agates of good quality are rarely met with in the Province of Quebec. However, the agate pebbles found along Chaleur Bay, in Gaspé County, P.Q., are sometimes cut for the tourist trade.

JASPER.—Dr. Kunz (op. cit.) gave an excellent account of the jasper deposits of Ontario:—

> " Jasper conglomerate exists in mountain masses, along with the quartzite masses of the Huronian Series, for miles in the country north of the Bruce Mines, on Lake Superior north of Goulais Bay, on the St. Mary's River about four miles west of Campment d'Ours, and at two places on the east shore of Lake George, and on Lake Huron, Ontario. It is a rock consisting of a matrix of white quartzite, in which are pebbles often several inches across, of a rich yellow, green, or black jasper, and smoky or other coloured chalcedony, which form a remarkably striking contrast with the pure white matrix. It is susceptible of a very high polish, and has been made into a great variety of ornamental objects, such as vases, paperweights, etc. Some very beautiful mosaics have been produced by using the rock and included pebbles. The stone occurs in thick bands which extend for miles, and large boulders of it are scattered along the shores of the lakes and rivers. Within half a mile of the northern extremity of Goulais Bay, Ontario, there is a ridge containing several varieties of it. . . .

"Considering the abundance of this jasper it seems strange that so beautiful an ornamental stone should have been so long neglected, but the recent improvements in sawing and polishing hard stones for ornamental purposes will doubtless bring it into extensive use in the near future."

Fine jasper also is to be met with in Quebec Province, associated with chalcedony along the Rivière Quelle ; also near Sherbrooke ; and rich red material occurs in large quantities in the township of Hull, P.Q.

BANDED JASPILITE.—The Royal Ontario Museum of Mineralogy recently secured specimens of a banded jaspilite of exceptionally fine colour which were taken from a small deposit on an island in McInnis Lake, Patricia District, Ontario. Several extremely attractive cabochons were cut from this material and, although care must be taken to achieve an even polish, it offers considerable promise as an ornamental stone or gem material.

EPIDOTE.—This mineral is found in veins traversing a fine-grained red-coloured gneiss in the township of Ramsay, Ontario ; also at the Mingam River falls in the Province of Quebec. The epidote is generally cut with the matrix into cabochon stones and ornamental slabs.

The epidote from these localities is usually pea-green in colour, and since both it and the reddish matrix take a good polish, the cabochons and slabs cut from it are of very great beauty.

Epidote is also found with quartz along the Matane River in Quebec ; in association with flesh-coloured feldspar in the trap rock of the Lake Superior region, Ontario ; and in huge masses in the Shickshock Mountains, Gaspé County, P.Q.

The epidote from all these localities takes a good polish, and, if cut with the matrix, would make an excellent ornamental material and furnish attractive and unusual cabochon gems.

ILMENITE.—Ilmenite containing small grains of green feldspar and imbedded acicular crystals of rutile is found near St. Urbain and Baie St. Paul, P.Q. It makes an excellent ornamental stone when polished.

SERPENTINE.—This beautiful ornamental stone is found at Kilmar, P.Q., in association with magnesite. Some of the material is beautifully mottled, and ranges in colour from oil-green through pea-green to citrine-yellow, and it is quite distinct from any of the serpentines found elsewhere. A few attractive ornamental objects have been fashioned from it, and it would doubtlessly furnish pretty cabochon stones.

Precious serpentine is also found in large quantities in the eastern townships of Quebec, and in other parts of the province, and large slabs of rich colour have been taken out.

PORPHYRY.—This rock forms a twenty-foot dyke running east and west through the townships of Chatham and Grenville, P.Q. It consists of a compact, dark green to brownish-black base in which are imbedded crystals of red orthoclase feldspar. Polished sections of this rock produce a distinctive mottled design of great beauty.

COBALTITE.—Shining cubic crystals of this metallic silver-pink mineral occur in and around the town of Cobalt, Ontario. These are sometimes cut as cabochons, or faceted like pyrites and marcasite.

DATOLITE.—Compact, opaque masses of beautifully mottled datolite, cometimes containing inclusions of native copper, are found in association with prehnite in veins and cavities in the Lake Superior copper district. The material, which resembles delicately tinted meerschaum when polished, is sometimes cut into cabochon stones and ornamental slabs.

DIAMOND.—Although small diamond crystals were believed to have been discovered in the chromite of Rheume township, Ontario, and in the massive chromite near Black Lake, Megantic County, P.Q., their existence has not been definitely confirmed. But in the glacial drifts south of Lake Superior—especially in the State of Wisconsin—diamond crystals are occasionally found.

Were these U.S. diamonds transported there, during the Glacial Period, from the vicinity of Hudson Bay? Nobody knows. But the supposition sends engineers and prospectors incessantly deeper into Canada's vast uncharted North ; for if, as many believe, the diamonds of Winconsin came originally from Canada, then rich pipes may lie somewhere in this northland, undiscovered.

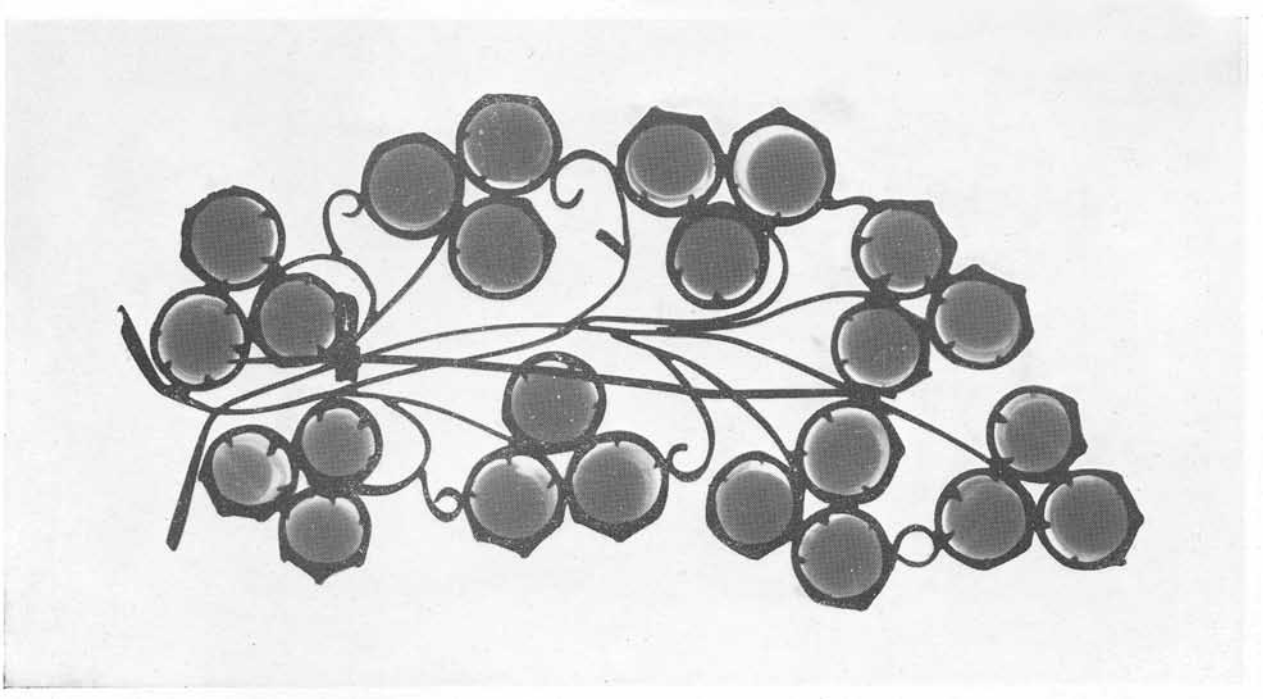

Photograph of a cultured pearl floral brooch taken by direct radiography (slightly enlarged).

ASSOCIATION NOTICES

MEMBERS' MEETINGS

12th October, 1948: At Geological Society's Hall, Burlington House, Piccadilly, London, W.1, 7 p.m. Dr. Kathleen Lonsdale, F.R.S. "The Atomic Structure of Diamond."

2nd November, 1948: At British Council Cinema, 7 p.m. "Golden Harvest of the Witwatersrand," a sound film showing the mining of gold in S. Africa.

24th January, 1949: At British Council Cinema, 7 p.m. "Atomic Physics," a remarkable sound film dealing with a topical subject.

EXTRACT FROM MINUTES OF COUNCIL MEETING

A meeting of the Council was held on Thursday, 5th August, 1948, at 93-94, Hatton Garden, London, E.C.1, under the Chairmanship of Mr. F. H. Knowles-Brown.

A report of the 1948 Diploma examinations was submitted by the examiners and approved by the Council. (The list of qualifiers appears hereunder.) The Council discussed the possibility of forming a European Gemmological Federation and agreed to ascertain views of other Associations.

The following Fellows were elected:—

T. G. Balson (Rickmansworth) (re-election).
M. J. Stevenson (Adelaide).

The following Ordinary and Probationary Members were elected:—

Ordinary: M. I. A. Khalik (Singapore), R. E. Lee (Uttoxeter), J. Pike (Thames Ditton), Miss L. Willis (London).

Probationary: D. Baxter (Blackpool), J. R. H. Chisholm (Leverstock Green), Mrs. L. M. Chisholm (Leverstock Green), N. A. Clayton (Birmingham), G. Croston (Liverpool), R. J. Dudfield (Oxford), Miss J. E. Fitch (Vancouver), D. N. King (Birmingham), R. W. Lowe (N. Rhodesia), N. Masso (Barcelona), A. H. Parfitt (Bristol), E. D. Rainbird (Bedford), W. A. Rance (High Wycombe), J. Sais (Barcelona), S. G. Stephanides (Birmingham), G. W. Whitehead (Surbiton).

AMERICA

It is reported that the Diamond Council of America has appointed Prof. Paul J. Storm, University of Pennsylvania, to conduct two correspondence courses for members of the Council and their employees. The courses include a general study of gemstones and a special one on diamond, with appropriate certificate awards. Myer B. Barr, of Philadelphia, is President of the newly formed Diamond Council, and Clement J. Wyle, Executive Director. The Council's objects are stated to be the promotion of the study of gemstones and maintenance of a code of ethics.

The Gemological Institute of America has opened an Eastern Headquarters office at 5, East 47 Street, New York. This will be the first time the Institute has had an Eastern Headquarters since the closing of the Boston office following the death of Dr. Edward Wigglesworth in the spring of 1945.

In August the Association had the pleasure of calls from Dr. Frederick Pough, Curator, American Museum of Natural History, and Dr. Ralph J. Holmes, of Columbia University. They visited this country in connexion with the International Geological Congress held in London in August.

Dr. Pough very kindly arranged to show members of the Association the technicolour film "Paricutin and Mexico's Volcanic Area." This was done on Monday, 20th September, at the British Council Cinema. Dr. Pough explained the film as it was shown, and his interesting and entertaining talk impressed members as much as the vivid and exciting film.

AUSTRALIA

The Association has received news of the passing of A. E. Tombs, Federal Chairman and State President of the Gemmological Association of Australia. Mr. Tombs was one of the founders of the Association in Australia and his work and knowledge will be sadly missed.

SWITZERLAND

Recently Dr. A. E. Alexander, of the Gem Trade Laboratory, New York, and Mr. B. W. Anderson, from this country, met Dr. E. Gübelin in Lucerne and spent an enjoyable week discussing and working out various gemmological problems.

Dr. Alexander visited this country on his return journey to America.

INSTRUCTORS, 1948-49

Mr. B. W. Anderson, B.Sc., and Mr. C. J. Payne, B.Sc., continue as the Association's Instructors in the Diploma and Preliminary Correspondence Courses. The following have been appointed as Instructors in the various Gemmology Classes by local Education Authorities:—

London (Chelsea Polytechnic): B. W. Anderson, T. G. Jones and R. Webster, assisted by R. K. Mitchell and L. F. Cole.

Birmingham (Jewellers' and Silversmiths' School): N. A. Harper and W. A. Perry, assisted by A. D. Conway.

Edinburgh (Heriot Watt College): D. Ewing.

Glasgow (Stow College of Engineering): A. T. Dollar, Ph.D., B.Sc. and Dr. Holgate.

Plymouth (Technical Institute): S. T. Solomon.

TALKS BY FELLOWS

Miss M. J. Biggs: Women's Provisional Club (20th July, 1948). Subject: Gems.

F. E. Leak: Toc H, Brislington (Bristol) Branch (3rd May), Clifton (Bristol) Arts Club (20th May). Subject: The Science of Jewellery. St. Edmund's Church (Bishopston, Bristol) Youth Club (21st April). Subject: Pearls.

RESULTS

of the 1948 Examinations

FOR the 1948 Diploma (Fellowship) Examinations of the Gemmological Association of Great Britain an unprecedented number of candidates, 95 in all, presented themselves, of whom 81 sat in Great Britain and 14 overseas ; of these 6 did not take the practical part of the examination and could qualify for Associateship only. Upon the recommendation of the examiners no award of the Tully Medal has been made. The Anderson prize for the best work in the practical examination has been awarded to Mr. D. M. Spero.

A record number of entries was received for the Preliminary Examination also, 20 from overseas and 156 in Great Britain, making a total of 176. The Rayner Prize has been awarded to Mr. E. H. Gudridge.

The following is a list of successful candidates, arranged alphabetically:

DIPLOMA

Qualified with Distinction

Crowningshield, George (Los Angeles, U.S.A.)
Dragsted, Ove (Copenhagen, Denmark)
Hodge, John (Campbeltown, Argyll)
Kirtley, Dennis C. (Sunderland)
Llewellyn, Graham D. (London)
Spero, Douglas M. (London)
Stevenson, Malcolm J. (Adelaide, Australia)
Stonley, Henry G. (London)
Wade, Michael B. (London)

Qualified

Allan, Wallace S. (Ayr)

Baker, Leonard A. (Seven Kings)
Bawden, Frederick C. (Johannesburg, S. Africa)
Bodes, Pieter N. (The Hague, Holland)
Bolton, Leslie (Leeds)
Buckingham, William C. (Goodmayes)
Buckle, Robert (Edinburgh)

Cairncross, Alastair (Perth)
Conway, Arthur D. (Birmingham)
Cooper, Walter T. (London)
Crombie, Walter (London)

Davenport, Charles E. (Sutton)
Dawkins, Charles E. (London)
Dembo, Victor A. (Bristol)

Forsyth, Adam (Edinburgh)

Godfrey, Kenneth E. (Winchester)
Goldschmeding, W. (Amsterdam, Holland)
Hammes, Johan (Zeist, Holland)
Harkness, Leslie (Halifax)
Hayman-Joyce, Mrs. B. (Eastbourne)
Hedges, Frederick C. (London)
Higgs, Paul Henry (Stourbridge)

Jenkinson, Herbert A. (Birmingham)
Jones, Ellis (Leicester)
Jutson, Allan Harry (Sandwich)

Kent, David G. (London)
Kennedy, Nigel W. (Tadworth)
Kino, Richard C. (London)
Knowles, Water H. (Byfleet)
Knowles-Brown, Miss E. (London)

Levett, Leonard (Romford)

Martin, Roy (Southall)
Meakin, Peter G. (London)
Miller, Grant (Los Angeles, U.S.A.)
Murray, Arthur S. (Edinburgh)

Page, John A. (Orpington)

Peresypkin, Oleg (Hong Kong)
Plas, Joseph (London)
Pyman, Miss Joan (Letchworth)

Ricketts, Leslie (London)
Roberts, Ian (London)
Rostron, Norman J. (London)
Rossiter, Donald F. (Clevedon)
Ruddock, John W. (St. Albans)

Stein, N. (London)
Stone, Ernest G. (Hove)

Trumper, Leonard C. (Devizes)
Tugwood, Ralph H. (London)

Ungerson, Daniel (London)

Weeks, Herbert W. (Woking)
Wheeler, Douglas (London)

Diploma (Associateship) Examination

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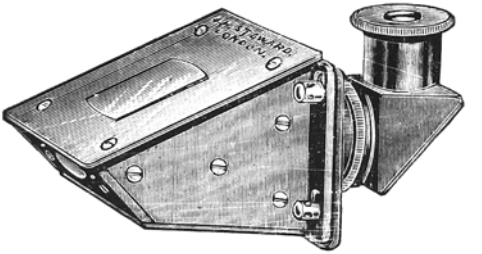

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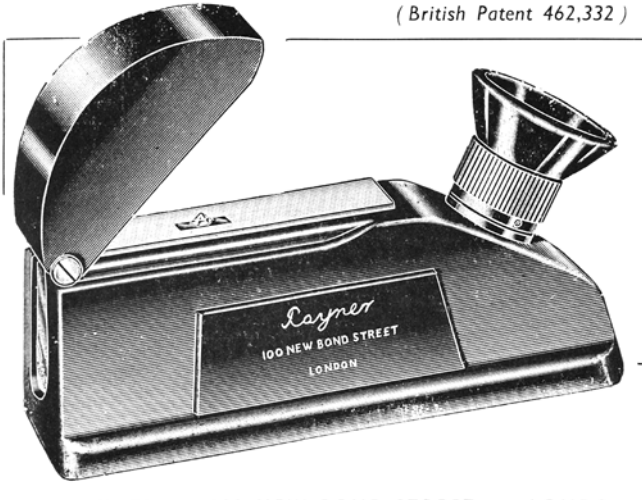

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THE ATOMIC STRUCTURE OF DIAMOND

IN October last Dr. Kathleen Lonsdale gave a delightful lecture to the Gemmological Association on "The Atomic Structure of Diamond," in the rooms of the Geological Society. In welcoming the lecturer from the chair, Dr. Herbert Smith mentioned that she had returned only the day before from an extensive lecture tour of the Scandinavian countries under the auspices of the British Council. Dr. Lonsdale spoke without reference to notes and in so skilful a manner as to make the difficult subject (in which she is a specialist) understandable to all who were present. The lecture was illustrated by lantern slides and by helpful blackboard drawings. The following is a brief paraphrase of Dr. Lonsdale's talk, given as accurately as the memory of one interested listener can make it, aided by notes made at the time.

Diamond has, in past years, been the subject of investigations by many of the world's most famous scientists. The work still continues, and still there seems to be no prospect of the final word being said on the mystery of its structure and properties. It almost seems that no two diamonds are quite alike, and the problem therefore becomes in part a statistical one. This is realized by Sutherland, now working at Cambridge on the infra-red spectrum of diamond, who has sorted through many thousands of stones in the course of his investigations.

As an example of the variability of diamond may be cited the work of Chesley, who submitted 33 diamonds from 14 different localities to an elaborate spectrochemical analysis. Traces of aluminium, silicon, calcium, magnesium, copper, barium, iron, strontium, sodium, silver, titanium, chromium, and in one case lead, were found in varying amounts.

When considering the structure of a crystal in the fullest sense one has to consider the following three aspects:

1. The arrangement of the atoms,
2. The crystal texture,
3. The dynamics of the crystal lattice.

So far as the arrangement of the atoms in diamond is concerned, this was investigated by W. H. and W. L. Bragg in 1913, using the newly-discovered technique of X-ray crystal analysis. They found that in diamond there are endless chains of carbon atoms in which each carbon is linked to four others arranged tetrahedrally round it. The unit cell in such an arrangement of atoms can be described as a face-centred cube within which four further atoms are disposed at the centres of four of the eight smaller cubes enclosed by the cell. Expressed differently, the structure consists of two interpenetrating face-centred cubic lattices. Such a structure is by no means a close-packed one—were it so, the density of the mineral would be about 7.6 instead of 3.52—but it is very strong from the " engineering " point of view. Further, since in long-chain hydrocarbons the highest refractive index is found along the length of the chains, so the chains of carbon atoms which extend in all directions in diamond may account for its high refractivity. Other remarkable properties of diamond include its high thermal conductivity (higher than some metals) and low coefficient of expansion. Thanks to these properties, a diamond at red heat can be plunged into liquid nitrogen without harm, whereas almost any other non-metallic mineral would be completely shattered.

By crystal " texture " is meant the perfection or imperfection in alignment found in the minute crystallites of which the whole crystal is built. In a " perfect " crystal there is complete homogeneity, whereas in a " mosaic " crystal the tiny units are slightly " staggered " like the bricks in a badly-made wall, or may even

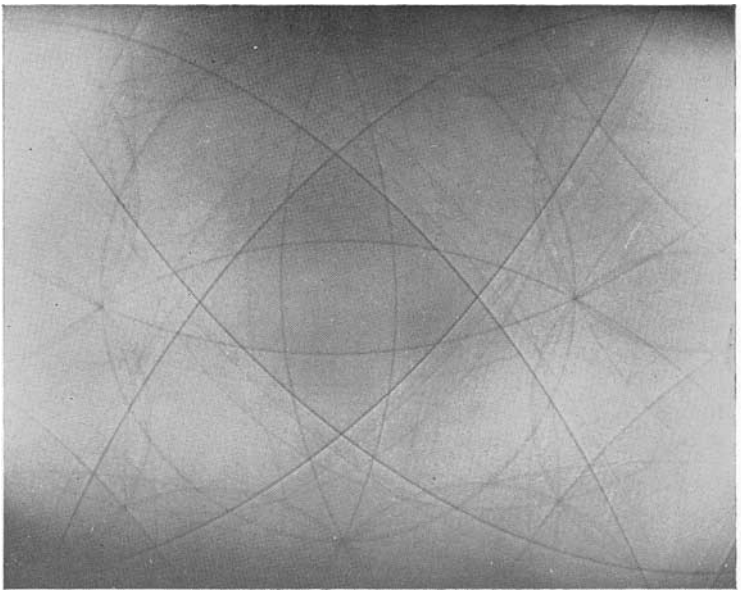

Photograph of a diamond, taken with a divergent beam of X-rays from a copper target. The film was perpendicular to a four-fold axis (cube edge) of the structure.

have a spiral arrangement. A model made from a stack of identical cards stitched together with elastic threads can be used to illustrate this. X-ray patterns of a crystal give information about this mosaic structure. " Perfect " crystals give feeble X-ray reflections, since interference of the rays reflected from the deeper layers of atoms prevents their contributing to the strength of the reflected beam, whereas in a mosaic structure the whole crystal can contribute and the reflected beams are thus far stronger. This is particularly true of the " divergent beam " photographs (a technique much favoured by Dr. Lonsdale) in which a small crystal is placed close to the source of a strongly diverging beam of X-rays, which then fall on to a photographic film or plate. The directions in which reflections at the atomic layers have removed certain of the rays are marked on the negative as pale lines against the darker fogged background, and the symmetry and orientation of the specimen can be gauged with extreme accuracy. Such photographs are extremely beautiful and the exposure time is extremely short. In the example reproduced in Fig. 1 the film was parallel to a cube

face, and the four-fold symmetry can be clearly seen as in a stereographic projection. Copper "α" radiation was used and the exposure time was only a few seconds. This type of photograph permits very accurate measurements to be made of the mean distances between the carbon atoms. This distance averages 1.54451Å, but shows a real variation between 1.54440 and 1.54465Å, possibly due to the effect of a few "foreign" atoms present in the lattice.

The "dynamics" of the lattice include the study of the heat-vibrations which the atoms undergo about their mean positions. These are considerable even at room temperatures and at 1600° C. (in absence of air) are violent enough to allow the diamond structure to be converted into the more stable graphite formation.

Dr. Lonsdale alluded in passing to the strain under which some diamonds exist. Spontaneous explosions are very rare, but two authentic cases were known to the lecturer, and a slide showing the specimens concerned was shown. One stone (belonging to Prof. W. T. Gordon) was complete when placed in the safe but had exploded before the next day. This was found to contain a smaller diamond crystal enclosed within the first—possibly the cause of the strain.

The lecturer also had something to say about Hannay's artificial diamonds. It was Dr. Lonsdale who, with Dr. F. A. Bannister, subjected the tiny fragments in the British Museum collection to searching X-ray tests and proved all but one of them to be diamond. Hannay claimed some success in only three out of eighty difficult and even dangerous experiments. There are those who doubt the authenticity of Hannay's results because they have repeated his experiments without success. Dr. Lonsdale asked, cogently enough, whether any of these workers followed Hannay in attempting as many as *eighty* experiments on these lines.

In thanking Dr. Lonsdale for her most interesting lecture, Mr. F. H. Knowles-Brown said that he had experienced a shock of disappointment when she broke off her lecture on account of time, when there was so much more of the story of diamond that she could tell and we should like to hear. He hoped that Dr. Lonsdale would consent to address the Association on some future occasion.

B. W. A.

UNUSUAL INCLUSIONS *in* *Almandine Garnet*

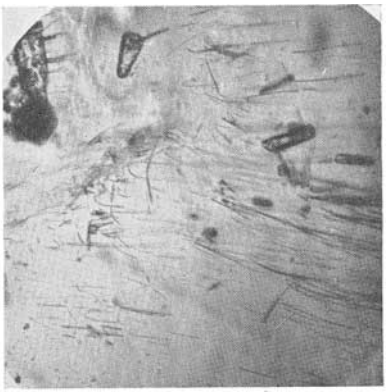

Fig. 1. Fibrous inclusions in an almandine garnet. x 25.

DURING the examination of a parcel of almandine garnets, a specimen was found which showed inclusions reminiscent of the asbestos fibres usually associated with the demantoid variety of garnet. Subsequently a similar stone from another parcel also showed rather similar inclusions.

Photomicrographs of the inclusions shown by both stones, and also one showing the asbestos fibres (byssolite fibres, according to Dr. Gübelin) in a demantoid garnet, are shown in Figs. 1-3.

Both the red stones were cut en-cabochon and were small, so that the constants of specific gravity and refractive index could not be conveniently determined ; they both showed the typical absorption spectrum of almandine garnet.

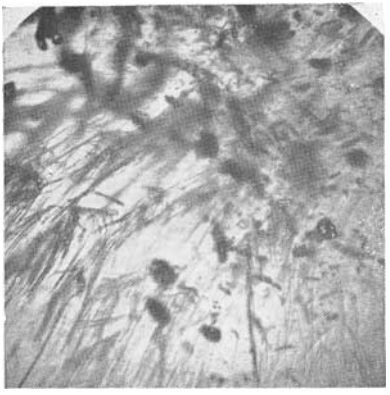

Fig. 2. The inclusions in Mr. Kino's almandine garnet. x 25.

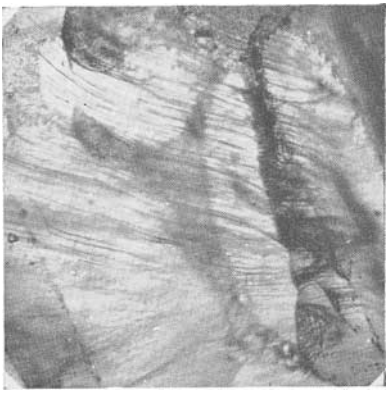

Fig. 3. Asbestos fibre inclusions small almandine garnet. x 25.

Canadian Gems and Gem Localities

Part III
(conclusion)

GEMS OF BRITISH COLUMBIA

By D. S. M. FIELD

ALTHOUGH the gem species of Western and Northern Canada are fairly numerous, only a few deposits have yielded cutting material. Generally speaking, prospectors and engineers have been concerned only with minerals of economic importance, and no extensive search for gems has been made.

In the more accessible parts of Northern Manitoba, for instance, pegmatite dykes and sills are numerous, and some of the few examined for gemstones have yielded quite good material. Similar discoveries may be made when the rocks of other sections of this northland are carefully searched for cutting specimens.

While the writer has made every effort to list only the localities which have at one time or another yielded gem material—or those which seem to offer considerable promise—it should be borne in mind that in a country the size of Canada, thousands of miles may separate the various deposits ; and in regions such as the far north, only the most daring collector can hope to secure specimens at their source. For such reason, one must rely, for the most part, upon the word of persons often not too well qualified to judge the material by a gemmologist's standard of quality. Since many species and very many deposits mentioned in Government reports are not listed herein, the writer does not infer that this paper exhausts the known resources, let alone the unknown possibilities.

It is proposed to publish supplements to this article as further discoveries are made.

AGATE, CHALCEDONY, CORNELIAN.—Handsome specimens of these minerals occur in considerable abundance throughout British Columbia, especially in the Ashcroft, Kamloops, Nicola, Omineca and Queen Charlotte mining divisions. Some of them are found in the Miocene-Tertiary volcanics ; others are found as rolled pebbles along the shores of lakes and rivers, and on the beaches of the

coastal islands. Large masses of good colour occur at Aspen Grove Camp, in the Nicola mining division. The rolled pebbles are particularly abundant on the Queen Charlotte Islands. On Vancouver Island, agate is found to a small extent in the volcanic rocks of which this island is largely composed.

In the North West Territories, olive-green chalcedony (chrysoprase) is found in small veins on Belanger Island, on the east coast of Hudson Bay.

ALMANDINE.—Fine almandine crystals (" the most beautiful in the world . . ."—Kunz) occur in mica schist, and in the gravels derived from this, on the Skeena and Stickeen Rivers, B.C. Some years ago, Mr. E. R. Flewwelling, a Vancouver manufacturing jeweller, had a cabinet containing several hundred cabochon and faceted specimens of this garnet, many of which were examined by the writer. Athough of fine colour, most of the stones—some of which weighed over ten carats—contained numerous dendritic inclusions of foreign matter. The crystals, when found imbedded in the matrix, are very nearly perfect in form and polish ; and though few of them are transparent enough to cut, they make striking cabinet specimens. The crystals are so closely spaced that a cubic foot of matrix might contain two dozen or more crystals—many over an inch across. Some of these crystals, in the matrix, are on display at the Vancouver City Museum, and at other museums in British Columbia and elsewhere.

Several specimens of gem quality almandine were collected (circa 1915) in Baffin Land on Garnet Island (Long. 78° 30′, Lat. 63° 45′) by an official of the North Lands Exploration, Limited. A few of them were cut into hollow cabochons and roses for the Royal Ontario Museum of Mineralogy Collection. This garnet is not found as individual crystals, but as rounded crystal masses, sometimes as great as four inches in diameter. Almandine also occurs in Baffin Land, at Albert Harbour ; and good crystals were brought from that locality (circa 1908) by Captain J. E. Bernier.

Almandine is of widespread occurrence throughout the West and North, but the localities described above are the only ones known to have yielded gem material.

AMBER.—This fossil resin is of frequent occurrence in the coal-fields of British Columbia. The most promising deposit (at Coalmont, B.C.) was described in some detail in a previous article (Field, D. S. M. " Canadian Amber." " Journ. Gem." October, 1947, Vol. I, No. 3). However, at none of these localities are the grains or nodules of sufficient size to furnish any but the smallest type of ornament—although many of the pieces are transparent and show a wide range of colours.

Another variety of Amber (called " Chemawinite," in allusion to a nearby Hudson Bay Post) occurs in the sand and gravel along the shore of Cedar Lake, Manitoba ; but the largest piece found was only slightly more than an inch in diameter. The beach on which the Chemawinite occurs is from eighty to one hundred and twenty feet wide and about a mile long. Mr. J. B. Tyrrell, of the Geological Survey of Canada, sank test pits to ascertain the depth of the deposit, and estimated that the upper two feet (in which the proportion of the amber is fairly uniform) contain nearly a million and a half pounds of the resin. Some of the pieces have been cut en cabochon and placed on display at the Royal Ontario Museum of Mineralogy, Toronto.

Amber also occurs in both Saskatchewan and the Yukon, but the deposits are of minor importance.

Only a few of the Canadian fossil resins contain succinic acid, but it should be borne in mind that this qualification for amber was propagated by the German Government—which controlled the mining and manufacture of their Baltic product—rather than by gemmological authority (v. " True Amber." Shipley. " Dict. Gems and Gemology," 1945).

AMETHYST.—Amethysts are known to occur in the trap rock of Dubawnt Lake, N.W.T. (quality unknown).

ANDRADITE (DEMANTOID).—This rare variety of garnet is found in pale, honey-yellow to brownish-yellow crystals ; and in yellowish-green masses, in association with a fibrous white tremolite, on Texada Island, B.C. (Malaspina Copper, Cornell and Marble Bay Mines). It also occurs quite commonly as a gangue mineral in the Alberni, Kamloops and Lillooet Mining Divisions. The Texada Island andradites are large enough to furnish gems, if any can be found clear enough for this purpose.

ANHYDRITE (SULPHATE OF CALCIUM).—This beautiful mineral occurs in large quantities north-east of Gypsumville, Manitoba. It is hard enough to take a fine polish, and shows attractive bluish-grey and red tints. It has been suggested for use as an ornamental stone.

APOPHYLLITE.—Apophyllite occurs in fine specimens of a beautiful pink colour at Le Roi Mine, Centre Star Mine, and at other mines in the Rossland area of British Columbia (Trail Creek Mining Division) (Johnston. " List of Can. Min. Occur.," Geol. Survey, 1915).

AXINITE.—Fine hair-brown crystals and crystalline masses of axinite occur on the west slope of Nickel Plate Mountain, Osoyoos Mining Division, B.C. (quality unknown).

AZURITE AND MALACHITE.—Several specimens of azurite from B.C. are on display at the Vancouver City Museum. This mineral usually occurs, in Canada, as druses, stains or coatings, seldom thick enough to cut. Malachite of fine colour is found in both the crystal and massive forms at the head of Copper Creek and Boundary Creek, Greenwood Mining Division, B.C. It also occurs as crusts and as small, radiating acicular crystal groups at several other localities in that province. Typical botryoidal specimens of malachite are on display at the B.C. Mining Building, Vancouver.

BERYL.—Transparent crystals of aquamarine, of good colour, occur in the pegmatite dykes of the Bernic Lake district of Manitoba. Dr. Goodwin (" Geol. and Min. of Man., 1929) suggests that these may prove to be of gem quality.

CALCITE (VAR. ICELAND SPAR).—A cleavage rhomb has been found on a dump at the " You-Know-Me " Claim, at Whiskey Point, Lardeau Mining Division, B.C. Good specimens are found, too, in association with the copper-bearing rocks of the province.

CHIASTOLITE.—The Chiastolite variety of Andalusite from Great Slave Lake (N.W.T.) is outstanding for size and pattern. Chiastolite also occurs on the hills west of Armstrong, B.C.

CHRYSOCOLLA (HYDROUS SILICATE OF COPPER).—Chrysocolla occurs in connection with the copper ores of both the Greenwood Mining Division and Yale District, B.C. ; and with limonite in the Whitehorse Mining Division of the Yukon.

CHRYSOPRASE.—(See Agate, etc.).

CORUNDUM.—A celandon-green, transparent corundum has been observed in the gold washings of the Pend d'Oreille River, West Kootenay District, B.C. (Geol. Survey Can. Rep't. New Series, IX-15R) ; and small rubies have been noted in the gravels of certain creeks tributary to the Tulameen River, B.C. (Johnston, op. cit.).

DIAMOND.—" Microscopic diamonds have been found in scattered groups and minute veinlets in connexion with chromite and chrompicotite occurring in dunite at two localities in the province (B.C.):

" Clinton Min. Div.—' With the chrompicotite of Scottie Creek, Bonaparte River " (Mines, G.S. Br., Sum. Rept., 1911, 360).

" Similkameen Min. Div.—' With the chromite of Olivine Mountain ' (Ibid., 1910, 112-113) " (Johnston, op. cit.).

DIOPSIDE.—Three-inch crystals of diopside, with very fresh, brilliant surfaces in the prism zone only (the ends being rounded and corroded), occur in the calcite on MacDonald Island, Baffin Land. The material is described as being olive-green in colour, and much brighter and fresher than the diopside found at Calumet Falls, P.Q. (Walker, Dr. T. L. " Min. of Baffin Land," Ottawa Naturalist, Aug.-Sept., 1915).

EPIDOTE.—This mineral is found in magnificent crystals (some of gem quality) on Prince of Wales Island, Alaska (U.S. Territory) ; and similar material occurs on the neighbouring (Canadian) islands, and in the Boundary District of B.C. It occurs, too, on the west coast of Vancouver Island. The material is rather dark in colour.

Epidote is also found at the mouth of Loon Lake, on the east side of Lake Winnipeg, Manitoba ; not of gem quality, however (although cut with the rock, it might provide an ornamental stone).

In the Whitehorse Mining Division of the Yukon, Epidote crystals occur abundantly ; and some of them might furnish gem material.

FLUORSPAR.—At Five-Mile Point, just east of Troup Junction, Nelson Mining Division, B.C., a band of bluish and purplish fluorspar, having a maximum thickness of fourteen inches, occurs along the foot of a tunnel cut in granite porphyry.

Fluorite suitable for quite large ornamental objects may also be obtained at "Rock Candy" Mountain, B.C., and crystals of fluorspar occur at the west end of Baker Lake, Dubawnt River, N.W.T.

GROSSULARITE.—This variety of garnet is found on Texada Island (Nanaimo Min. Div.) and at Lepaz Bay, Graham Island, B.C. The Lepaz Bay grossularites occur in fine trapezohedra, but there is no report as to quality.

A crystalline, massive form of grossularite—probably similar to the so-called "Transvaal Jade" of South Africa—occurs in the Whitehorse Copper Belt, Yukon.

HORNBLENDE.—A blackish-green, fibrous aggregate occurs near Foster Bar, Fraser River, B.C., and at Ash Inlet, Big Island, Baffin Land.

IOLITE.—Excellent crystals of first-grade gem iolite occur in some abundance eighty miles N.W. of Great Slave Lake, N.W.T. Some of this has yielded rich blue stones of from one to four carats or more in weight.

Deep blue, gem quality iolite also occurs in Baffin Land, on Garnet Island (Long. 72° 30′, Lat. 63° 45′). Here the mineral is found in association with a feldspar rock, and probably also occurs as lenses in gneiss. Some irregular fragments, only very slightly flawed, were brought out (circa 1915). Some of these measured as much as two inches in diameter (Walker, op. cit.).

JASPER.—Good specimens, in the form of rounded pebbles, occur in the Atlin Mining Division, and in the Boundary District of B.C. ; in the Grass River and Rice Lake Districts of Manitoba ; at the east end of Great Slave Lake, N.W.T. ; and, with magnetite and hematite, as float in the wash of Bonnet Plume and Snake Rivers ; and at Patterson Mountain and Tagish Lake, Yukon.

KYANITE.—Occurs in British Columbia, with beryl, in the mica vein south of Tête Jaune Cache, and in the Kamloops, Nelson and Vernon Mining Divisions (no report on quality). In the Kamloops Division it occurs in the form of radiated columnar aggregates of a pure blue, bluish-grey and greyish-green colour, on the North Thompson River.

LAZULITE.—This mineral is found in quartz, three-quarters of a mile east of the Churchill River, Northern Manitoba. It pos-

sesses a rich blue colour (similar to lazurite) and takes a good polish. Some of the Churchill lazulite is on display at the Royal Ontario Museum of Mineralogy, Toronto.

MARCASITE.—Marcasite is found in British Columbia in some of the mines at the head of Kettle River, and in Manitoba, on the banks of the Assiniboine, and as nodules in boulders of white sandstone on various islands in Lake Winnipegosis.

NEPHRITE.—This variety of jade occurs as water-worn boulders, near Lytton, in the valley of the Fraser River, B.C. Some of the specimens from that locality have been examined by a Toronto lapidary, and were found to be of too dark a shade of green to make attractive gemstones. Nephrite also occurs as water-worn boulders on the Lewes River, a tributary of the Yukon, Yukon Territory.

OBSIDIAN.—Obsidian occurs in both large and small masses on the higher eastern slopes of Il-ga-chuz Mountain ; also in large quantities on Anahim's Peak (also named Beece), an isolated peak between the Il-ga-chuz and Tsi-tsutl Mountains, in the Upper Blackwater Country, British Columbia. In addition to these localities, obsidian is found on a small island north-east of Tas-kai-guns, on the upper part of Masset Inlet, Queen Charlotte Islands, B.C., and at other points in the province.

OPAL.—Some specimens of this mineral—approaching precious opal in character—have been found near Dropping-water Creek, about two miles N.W. from the head of Stump Lake, B.C.

White, pale greenish-white and apple green, translucent opal occurs in the Tertiary agglomerate of Savona Mountain, B.C., and common opal and semi-opal occur in the Quesnel, Similkameen and Slocan Mining Divisions, B.C.

PERIDOT.—This variety of the mineral Olivine is common in the eruptive rocks of British Columbia, especially in the dunite of Scottie Creek, Clinton Min. Div., and at Olivine Mountain, Similkameen Min. Div. Gem quality material occurs, sparingly, in geodes at Timothy Mountain, B.C. Some of this has been cut.

PREHNITE.—Excellent prehnite, of a fine green colour, occurs at the Le Roi Mine, Rossland, in the Trail Min. Div of B.C. A beautiful green prehnite similar to this is found in veins at Admiralty Inlet and Adams Sound, and (with copper) at Copper Mountain, N.W.T.

ROSE QUARTZ.—Dr. A. L. Parsons (Director Emeritus of Min., Royal Ontario Museum) describes the rose quartz of Manitoba as follows: " The Manitoba material . . . is a deep pink and is well suited for all purposes for which rose quartz is adapted. When taken out of the deposit with care, it is equal to the best rose quartz from other countries " (Contrib. Can. Min., 36—Univ. Toronto).

This material is found in a pegmatite dyke in the Oiseau River area. A large ornamental rose, cut from Manitoba material, is on display in the Royal Ontario Museum. This is shown in colour in the educational bulletin cited above.

Rose quartz is also found in Amadjuak Bay, Baffin Land. The surface deposit is very pale in colour, while the embedded material is a deeper pink, giving support to the claim that rose-quartz fades when exposed to bright sunlight.

SCAPOLITE.—White scapolite, having a vitreous lustre, occurs in large crystals at MacDonald Island, Baffin Land. Some of these crystals measure as much as five inches in diameter.

SILICIFIED WOOD.—Excellent specimens of silicified wood are found near the elbow of the South Saskatchewan River, Alberta ; also in the vicinity of Ross Coulée. Fine specimens have also been found in British Columbia, on Agate Mountain, on the Similkameen River, and on Wolf Creek, Similkameen Min. Div. This makes a beautiful ornamental stone when highly polished.

SMITHSONITE.—Smithsonite has been found in the Slocan Min. Div. of B.C., but no report on the quality is available at present.

SODALITE.—Large specimens of a very beautiful, light cornflower blue sodalite occur, in abundance, in the vicinity of Ice River, a tributary of the Beaver-foot, in the Golden Mining Division of B.C. Polished slabs of this sodalite are on display at the Royal Ontario Museum of Mineralogy.

SPHALERITE.—Widespread in British Columbia, but it is doubtful that any of the deposits would yield gem material.

SPINEL.—A beautiful lilac-coloured spinel occurs in Baffin Land, but all the pieces collected proved to be too badly fractured for gems.

SPHENE.—Sphene occurs in small, yellowish crystals in the granite of the coastal range of British Columbia.

STAUROLITE.—Staurolite is found on the west side of Slocan Lake, Slocan Min. Div., B.C. The mineral also occurs, as huge crystals, at Snow Lake, Manitoba. Some of these crystals are transparent in part. The stones are dark reddish-brown in colour, but will yield cabochons, and possibly faceted gems.

TOPAZ.—Transparent, pale yellow and pale blue topaz pebbles have been observed in the gravel of a small river west of Jasper House, Jasper Park, Alberta. Topaz is also found in British Columbia, at Mica Mountain, Tête Jaune Cache (Cariboo Min. Div.), and in Manitoba, in pegmatite dykes of the Oiseau River area.

TOURMALINE.—Rather fine crystals of tourmaline have been noticed in the pegmatite of the Oiseau River district of Manitoba, and some may prove to be of gem quality.

Tourmaline also occurs in the Ainsworth, Nelson, Skeena and Slocan Mining Divisions of B.C., but no reports on quality are available at present.

TREMOLITE.—Very pretty specimens of tremolite occur in a light bluish-grey calcite at Deadwood Camp, Greenwood Mining Division of B.C. These are white in colour, and possess a fine fibrous structure. Some of them would undoubtedly furnish cat's-eyes.

Tremolite also occurs, in association with copper ores, on Texada Island, in the Nanaimo Mining Div., and on Vancouver Island it has been noted in several localities,, associated with limestone.

UVAROVITE.—This handsome, but extremely rare variety of garnet, occurs as small bright emerald-green, transparent, imperfectly shaped crystals, associated with white quartz, white scapolite, and grey, greyish-green, and greyish-brown pyroxene, near the southern end of Upper Arrow Lake, on the west side, and between Despatch Island and the point opposite Nakusp, on the east side of the lake, in the West Kootenay district of B.C. These crystals will furnish gems, if any can be found that are large enough to cut.

VESUVIANITE (IDOCRASE).—Fine crystals of Vesuvianite occur at Marble Bay, Texada Island, B.C. Some of these may be of gem quality.

ZIRCON.—Small, but very well developed crystals of this material have been noted in the pegmatite of Wilson Creek, Slocan Mining Division, British Columbia.

REFERENCES.

References to Canadian Gem minerals are scattered through so many official Canadian geological reports that it would be an immense task to list them all. However, the following fourteen authoritative references contain much of interest on Canadian gems and gem localities:—

(1) BAILY AND JACK.—" The Woods and Minerals of New Brunswick " (1876).

(2) GESNER, A.—" Geology and Mineralogy of Nova Scotia " (1836). (An excellent account of the minerals of the Bay of Fundy.)

(3) GOODWIN.—" Geology and Minerals of Ontario " (1929).

(4) GOODWIN.—" Geology and Minerals of Quebec " (1929).

(5) GOODWIN.—" Geology and Minerals of Manitoba " (1930).

(6) HOFFMAN, G. C.—Part I, Ann. Rept. G.S.C., Vol. 5 (1888-89). " Annotated List of the Minerals Occurring in Canada." (A good general descriptive list.)

(7) HOW, HENRY.—" Mineralogy of Nova Scotia " (1868).

(8) HUNT, T. S.—G.S.C., Report of Progress (1847-48). (An entertaining account of early exploration in virgin territory (Ontario and Quebec).)

(9) JACKSON AND ALGER.—" Remarks on the Mineralogy and Geology of the Peninsula of Nova Scotia " (1832).

(10) JOHNSTON, R. A. A.—Memoir 74, G.S.C. (1915). "A List of Canadian Mineral Occurrences." (The most comprehensive list ever published.)

(11) KUNZ.—Part " S," Ann. Rept. G.S.C. (1887). The Precious Stones of Canada."

(12) KUNZ.—" Gems and Precious Stones of North America " (1892).

(13) PARSONS, A. L.—" The Utilization of Semi-Precious and Ornamental Stones of Canada " (Univ. Tor.-Geol., Series 36) (1934).

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Reviewed by Dr. A. S. Alexander
(Gem Trade Laboratory, New York)

A New Method for Fingerprinting Diamonds

AN instrument has been invented by Mr. Bruce D. Eytinge, of the Manhattan Research Laboratories, 352, East 82nd Street, New York, which will in a matter of a few minutes photographically record the light that is reflected from the facets of a gemstone. The device (Fig. 1) consists, briefly, of a metal cylinder, at the bottom of which is a fixed light source (a 6 or 12 volt lamp will suffice). The light is projected by a simple lens system through the tube on to the table of the stone to be " fingerprinted." Just below the optical glass plate on which the stone is placed is a holder which contains the photographic film. Film of the type used for back reflection X-ray work can be employed, since this particular film already has a circular hole in the centre.

Each facet reflecting light at a fixed angle will impinge itself on the film, producing as a result a series of irregular " spots." Should the same stone be photographed at a later date, an identical spot reflection pattern will, of course, be obtained.

By placing the second negative over the first, or original, and then viewing the two superimposed negatives in front of a convenient light source, it can be seen that the spots exactly coincide. If the stone is a different one, or should the original gem be re-cut or re-lapped, a wholly different spot reflection pattern will be reproduced.

Since the facets of no two stones of the same weight and cut are ever fashioned *absolutely* mathematically alike, no two reflection spot patterns of identical design and orientation are possible. The device will handle faceted stones of any cut, as well as gems of any colour or species.

Using ordinary commercial film, an exposure of 12 to 14 seconds sufficed to register the light reflected from the facets of a gemstone. Patent is pending on this invention.

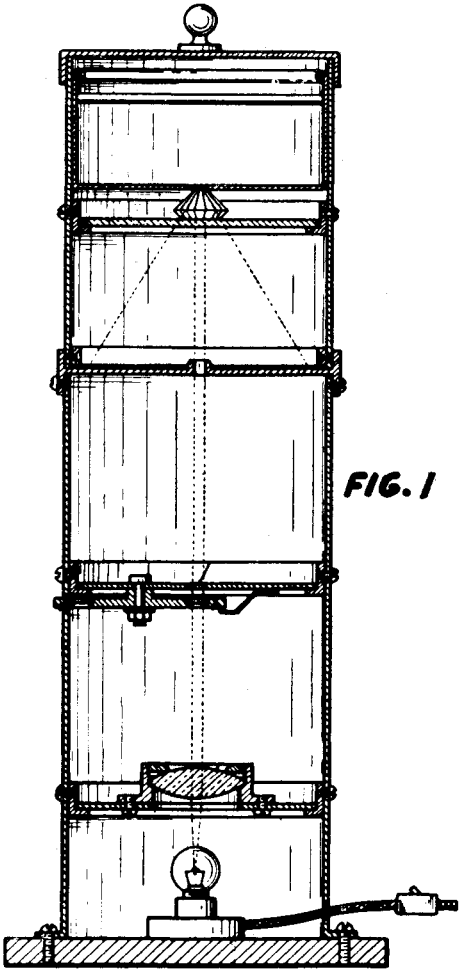

The writer has personally tested this " camera." It is very simple to operate and it supplies a means of fingerprinting gemstones in a manner not hitherto possible (compare this method with X-ray diffraction and the time and cost involved).

The Gem Trade Laboratory, Inc. (New York) is considering installing an Eytinge camera so that all stones, loose or mounted, coming in for test can be " fingerprinted " and recorded for future reference. Comments from British gemmologists are invited.

A film shown to members on 2nd November, 1948, by courtesy of the High Commissioner of South Africa

GOLDEN HARVEST OF THE WITWATERSRAND

ON November 2nd at the British Council Cinema, London, W.1, members of the Gemmological Association were shown a film entitled " Golden Harvest of the Witwatersrand." A running commentary accompanying the film described the various operations carried out in the 40 mines which produce half the world's gold, from the time the natives are signed on to work in the mines to the time the gold in commercial ingots is shipped abroad.

Most natives work in the reefs with European supervision. Europeans are also employed in the mines on work other than actual mining. The welfare of the natives, of which there are a quarter of a million working in the various mines, is looked after very well. They are housed in compounds under the control of a Central Board in Johannesburg. The European workers which number some thirty thousand are encouraged to take part in outdoor sports and games. Shower baths are supplied at the mine head. Simple amusements mean a lot to the native workers and native dancing to music reminiscent of the rhythm of the mine machinery is one of their pastimes.

The actual blasting of the rock is done by Europeans who hold Government certificates for that work and every day before the natives commence work, a supervisor precedes them examining the structure for loose rocks likely to cause accidents and if any faults are found they have to be put right. The natives go 3,200 ft. below ground to do the preparatory work in connection with blasting. For every ounce of gold won, three tons of rock are blasted. Air, water, electricity and chemicals play their part in the daily working

of the gold mines in which ten thousand drilling machines are used. Water, 2½ million gallons of which is used daily in the various processes carried out, is a big factor in keeping down dust in the mines, thus overcoming to a great extent the disease which used to attack so many mine workers. The number of electricity units used in the mines in a year is equal to that used in Glasgow, and the amount of explosives used in blasting the rock is 27,000 tons. Factories have been built in the Cape and Natal for the purpose of manufacturing the explosive material. Safety measures are strictly enforced in the mines and whilst the actual blasting is in operation the natives are sent to places of safety.

The day after blasting has been carried out the men go down the mine and shovel the loose rock down a chute which loads it into trucks which are taken away and tipped into a train of railway trucks. This train takes the rock over to another part of the mine where it is sorted by natives—the gold bearing rock being placed on a conveyor and transported to the crushers and the waste rock is thrown away ; the small dust is passed through a fine screen. Thus begins the various processes of separating the gold from the rock which by this time has been reduced to fine sand. At one point in the procedure the gold concentrate is mixed with mercury and is known as amalgam. At other points cyanide and sulphuric acid are added. By the time the smelting house is reached the ingots contain 60 per cent. mercury and 40 per cent. gold, but after passing through the retort furnace the mercury is vaporized and subsequently recovered for further use. When the bars reach the refinery they are weighed and usually contain about 80 per cent. gold, 9 per cent. silver and the balance in other metals such as copper, lead, etc. Chlorine is added and after the chlorine leaves the crucibles the refining process is completed. The refined gold is placed in a furnace and thoroughly stirred and after that it is sampled and made into 400 oz. bars suitable for the bullion market. One million ozs. of silver are reclaimed each year from the processing of gold by the rand refinery.

(Extracted, by permission, from the " Jeweller and Metalworker," Vol. LXXIV, No. ixcc.)

MARGINALIA

Informal notes on points of interest and opinions of a controversial character compiled by Fellows of the Association (Contributors in this issue are members of the office staff)

FROM time to time we have heard of some strange results being obtained from use of Chelsea colour filter. Subsequent investigation has revealed that it has been the user and not the filter that has been at fault. Therefore it seems timely to caution would-be gemmologists to regard the filter as an *aid* to testing and not always as a conclusive test.

In experienced hands the filter can be very useful, but when we hear of a student gemmologist airing the knowledge he has yet to acquire by declaring that an amethyst is a synthetic spinel because it appeared red under the filter, it is necessary to urge intelligent use of the filter. We do know that a filter and a lens are the only stock in trade of many dealers, but in the majority of cases they are only concerned as to whether a stone shows " red or green." Unlike traffic lights, it is green that sometimes indicates danger, and what these knowing ones will do if they ever encounter a synthetic emerald we shudder to think. It will be a case of *Nimium ne crede colori.*

* * * *

The suggestion reported by Edgar J. Burbage in the October, 1948, " Marginalia," that a time may come when University recognition will be given to the gemmology diploma is likely to remain a suggestion. Although there are many non-trade gemmologists it must always be remembered that the majority of students, in the U.K. at least, are engaged in various branches of the jewellery and allied trades, and who would have little opportunity for achieving a University standard in gemmology.

In fact, it has often been commented that qualification in the study of gemmology, whilst expanding as fresh knowledge is gained, should not race away from the general requirements of the persons for whom it caters. We commend this opinion, often expressed, to those lecturers, instructors and examiners concerned.

A member recently brought to the notice of the Association that white synthetic spinels have been invoiced as " synthetic zircons." It was alleged that the term " synthetic zircon " in reference to these synthetic spinels was a standard trade practice! There does not appear to be any good reason for this kind of nomenclature, and we should be interested to hear of any other instances of this kind. Possibly gemmologists in other parts of the world can instance even more exaggerated misnomers.

* * * *

When reading " They Struck Opal," by E. F. Murphy, two rather interesting points arose dealing with opal formation. Murphy remarks that the colour in the opal is always horizontal and keeps on an absolutely flat level. In whatever position the opal lies in the ground, the *colour* will cross it quite level. Even if there is a vertical seam, that is, one leading to the surface, it does not matter at what angle the opal in the seam may be, the colour crosses it horizontally, quite level. In fact, the author alleges that one can always tell opal that comes from a vertical seam by the way the colour crosses the stone.

The other point was that when following a seam of potch, that is, opal without commercial value, it suddenly turns into a patch of saleable opal with good colour. It may be a small or large patch, but eventually becomes potch again. Now the whole seam of opal is the same age, was deposited at the same time, and both potch and colour patch contain the same ingredients by analysis, but what causes the change from potch to colour? One might think that the colour part cooled more quickly or slowly to account for the difference, but when a patch of opal is found with a bar of good colour running through the centre of the stone, the top portion is white milky potch and the lower portion also white milky potch, it is more difficult to believe this theory. If the stone is lying flat the bar of colour will run through from end to end. No matter what position the stone may be in, the colour bar will continue its course absolutely level.

Perhaps readers may have some theories to explain the phenomena mentioned above.

Gemmological Abstracts

NOTES ON RECENT RESEARCH

ULTRA-VIOLET Transparency of Corundum. In an article in " The Gemmologist " for October, 1947, G. O. Wild and H. Biegel recorded the results of some experiments on the transparency of various natural and artificial sapphires to ultra-violet rays. They found that one of their specimens, an off-white synthetic sapphire, showed a considerably greater range of transparency than any of the natural or other artificial stones tested.

B. W. Anderson and C. J. Payne have followed up this interesting result with more extensive experiments, and have shown that not only do synthetic colourless and yellow corundums transmit much more light in the deep ultra-violet than their natural counterparts, but also that synthetic pink and red corundums show the same trend, though in a less marked fashion. Only in the blue corundums is the transmission in synthetic stones limited to the same extent as in natural corundums.

These results are scientifically interesting, and may have some practical importance where internal features are lacking. The authors point out that visual observation of these effects is possible with a Beck ultra-violet spectroscope in which the ultra-violet spectrum is seen on a fluorescent screen. More exact details will be found in the original paper (" Gemmologist," October, 1948).

Synthetic Rutile.—Descriptions of the new synthetic rutile which is now being manufactured by two firms in the U.S.A. have appeared in several gemmological journals. In " The Gemmologist " for last July Anderson and Payne give their data for a small rose-cut synthetic rutile kindly loaned to them by D. S. M. Field, an Associate of the Gemmological Association resident in Canada, who is already known to readers of this Journal as a contributor.

The rutile was off-white in colour, had a high lustre and tremendous display of fire. At a casual glance the stone had a superficial resemblance to a Cape diamond, but the strong doubling of the back facets prevented any likelihood of this impression surviving a closer examination. The most plausible error would be to mistake the stone for sphene, but an intense absorption band in the violet at about 4300 Å is seen in place of the weak didymium lines usually discernible in sphene. In loose stones the density of the rutile (4.23) is also distinctive.

A figure of 0.1070 for the partial disperson 6708Å-5350Å (Li-Tl) was established for the rutile, which makes the corresponding figure of .0171 for diamond seem very low. For the usual B-G range the dispersion figure for the ordinary was estimated to be about .300, and for the extraordinary ray even higher than this. The ordinary index for sodium light was 2.6104 for this specimen. For the upper ray, 2.8729 was the highest measurable with the angles available, so that the full birefringence of 0.287, as given in the literature, was not observable.

We understand that blue synthetic rutile is also obtainable ; this should be a striking gem, and would be all the more welcome for not resembling any natural gemstone except, perhaps, the very rare benitoite.

Coated Stones.—The latest fashion in the practical faking of stones is to coat their upper facets with a thin film of lower refractive index, either by sputtering, etching or controlled application of plastic resin. The principle behind their process is the same as that of the coated lenses now so much in vogue for binoculars and cameras. A quarter-wavelength film of suitable refractive index lowers considerably, by interference, the percentage of light reflected at the surface, and a correspondingly greater amount of light passes into the body of the substance.

The writer was shown samples of various stones treated in this manner when visiting Dr. Gübelin last summer, and reports from New York indicate that they are already known in America. J. de Ment is patenting a " Gemcote Process," and has written an article in the November " Mineralogist " (the Oregon Journal), pp. 547-556, in which he endeavours to explain why coated stones should display enhanced brilliance. It is doubtful whether stones faked in this manner have any real advantage over the ordinarily

well-cut gems, and they are unlikely to have any place in good-class jewellery. They look decidedly " phoney " and show interference tints at certain angles. The coating has a nuisance value in that it prevents one from obtaining readings on the refractometer. Should a refractometer test be necessary a brisk rub with a wash-leather charged with jeweller's rouge will usually clean the film from the surface.

Structure of Tourmaline.—Tourmaline is the last important gemstone to yield the secrets of its structure under the persistent inquiry of the X-ray crystallographers. The increasing number of gemmologists who are becoming interested in the atomic configuration of the gem minerals will find the main features of the complex tourmaline structure explained in a paper by Hamburger and Buerger in the " American Mineralogist " for September-October, 1948. Working with a colourless sodium magnesium tourmaline from de Kalb, N.Y., having an " ideal " formula of $Na\ Mg_3\ B_3\ Al_6\ Si_6\ O_{27}\ (OH)_4$, the unit cell dimensions are found to be a = 15.951 Å, c = 7.24 Å, and the space-group R 3 m. Clear diagrams are included in the paper showing the structure as seen in the direction of the trigonal axis.

B. W. A.

General

" Diamonds: The Diamond Industry in 1947. Twenty-third annual review. Sydney H. Ball. " Jewelers' Circular-Keystone," New York, 1948, reprint, 25 pp.

World production during 1947 was slightly less than for preceding year, 9,754,231 carats against 10,212,573 carats, the loss being mainly in industrial grades. The British Commonwealth accounted for 31.1 per cent. of the weight and 68 per cent. of the value, while the Belgian Congo was the leading producer by weight with 56 per cent., although it produced only 12 per cent. of the value.

Scientists of many nationalities studied the diamond in 1947, notably G. N. Ramachandran—photoelastic qualities ; K. S. Lonsdale—divergent beam X-ray photography ; A. Guinier—abnormal diffusion of X-ray in diamond. Synthesis of diamond was attempted but no progress made.

G. F. A.

" Emeralds: The Muzo Emerald Zone, Colombia, S.A." Victor Oppenheim. Econ. Geol., 1948, Vol. 43, pp. 31-38.

A general account of the emerald mines in the Muzo district. Work is expected to recommence soon at the Muzo and Coscuez mines. None of the mines has been worked since 1939. The author, pointing out that the origin of emerald is still doubtful, comments upon the presence of salt beds and the finding of emeralds in salt mines.

G. A.

" Emeralds: Emeralds in Mewar." H. Crookshank. Indian Minerals (Geo. Survey, India), 1947, Vol. I, pp. 28-30.

Occurrence of emeralds at Mewar in Rajputana, from which good gems have been cut.

" Spodumene: Lithium—its sources, properties and uses." V. S. Swaninathan. " Canada's Weekly," October 29th, 1948, p. 126.

Brief account of a recently located deposit of spodumene some 90 miles north-west of Winnipeg, Canada. The report deals with the commercial uses of lithium and there is no mention of spodumene in crystals of gem quality.

H. W.

" Silicon Carbide: New gem superior to diamond." Jack de Ment. " The Mineralogist " (U.S.A.), April, 1948, pp. 211-218.

Report of use of silicon carbide, for many years produced commercially as an abrasive, as a gem material. Properties given are: Mean R.I., 2.668 ; H., 9.5 (Mohs' scale) ; S.G., 3.17. Its identification is not likely to present such difficulty as the author suggests.

SiC can be produced in hexagonal and cubic forms, and its easy colouration suggests use as a future possible substitute for various gems.

" Silicon Carbide." " Gems and Gemology," Vol. VI, No. 2, 1948.

The Gemological Institute of America does not consider that development of SiC as a gem material will take place in the near future, though admits that if process is developed to produce larger crystals the synthetic product could become an important gem material.

V. B.

Publications

" They Struck Opal." E. F. Murphy. Assoc. Gen. Pubs. Pty., Ltd., Sydney. 191 pp., 3 colour plates and numerous sketches. 12s. 6d.

An account of early days in opal mining. Murphy, who was an important opal buyer, describes conditions in the opal fields. The book, though of general interest, does not deal with any technical problems.

H. W.

" Popular Gemology." Richard M. Pearl. New York: John Wiley & Sons, Inc. London: Chapman & Hall, Ltd. 1948. 316 pp. 116 illustrations. 24s.

A well-written popular volume on the principles of gemmology and of the gem species. The nature, chemistry and crystallization of gem minerals are discussed, and, with the fundamental backgrounds, the methods of gem testing are outlined. Shortened tables of constants taken from Dr. Herbert Smith's " Gemstones " are the only determinative tables given ; the values for many of the species discussed are not recorded nor mentioned in the text. An unusual scheme is used for the classification of the species which are first divided into three groups—" Faceted gems " ; " Cabochon and carved gems " ; and " Gems of the silica group "—the subdivision being in accordance with that of the new edition of Dana's System. The gem descriptions are mainly historical and topographical, but contain no technical information. Chapters on organic gems and on man-made gems, which includes the synthetics, doublets, pastes and artificially coloured stones, are adequate ; cultured pearl is also discussed in this section. An unusual feature is the inclusion of a complete chapter on luminescent phenomena and the equipment used in the production of ultra-violet light. The book is extremely well illustrated, has a good index, and is printed on art paper. There are few errors and omissions. A book for the general reader rather than the specialist.

R. W.

ASSOCIATION NOTICES

SWITZERLAND

A Course in Gemmology has recently been inaugurated at the Kunstgewerbeschule of Zurich. This Course is in addition to the classes held in goldsmithing and silversmithing.

AUSTRALIA

The 1948 Diploma Examinations of the Gemmological Association of Australia were held on the 12th and 13th November. The theoretical and practical papers comprised papers of three hours each.

This is the second occasion that diploma examinations have been held in Australia. The Association's Constitution has been slightly modified to allow it to work more efficiently, and there is no doubt that the Australian Gemmological Association is painstakingly laying the foundations of an organization which will bring great credit and benefit to all gemmologists.

TALKS BY FELLOWS

B. W. Anderson: "Gemstones"—B.B.C. Third Programme, 25th November, 1948.

S. T. Solomon: "Gemstones"—Women's Institute, Gittisham, near Honiton, 4th November, 1948.

H. S. Reese: "Salesmanship of Gemstones"—Merseyside and District Branch of the National Association of Goldsmiths, 29th October, 1948. "Synthetic Gems"—ibid., 22nd November, 1948.

R. Webster: "Gemstones"—Southend jewellers, 11th November, 1948 (demonstrator, L. F. Cole).

T. H. Bevis-Smith: "Precious Stones"—London Central Y.M.C.A., 27th November, 1948.

MEMBERS' MEETINGS

A meeting of members was held on Tuesday, 2nd November, 1948, at the British Council Cinema, Hanover Street, London, W.1, when the film "The Golden Harvest of the Witwatersrand" was shown. The Council of the Association is indebted to the High Commissioner for South Africa in once again making the film available to the Association.

COUNCIL MEETING

At a meeting of the Council held at 94, Hatton Garden, London, E.C.1, on Wednesday, 24th November, 1948, the following were elected to membership of the Association:—

FELLOWS

W. S. Allan (Prestwick)
L. A. Baker (Seven Kings)
F. C. M. Bawden (Johannesburg, S.A.)
L. Bolton (Leeds)
W. C. Buckingham (Goodmayes)
R. Buckle (Edinburgh)
W. T. Cooper (London)

W. Crombie (London)
G. R. Crowningshield (New York, U.S.A.)
C. E. Davenport (Sutton)
V. A. Dembo (Bristol)
A. Forsyth (South Queensferry)
W. F. Goldschmeding (Amsterdam, Holland)
J. Hammes (Zeist, Holland)
L. Harkness (Halifax)
Mrs. B. C. Hayman-Joyce (Eastbourne)
J. Hodge (Campbelltown)
H. A. Jenkinson (Birmingham)
E. Jones (Leicester)
D. G. Kent (London
W. H. Knowles (West Byfleet)
L. Levett (Romford)
Roy Martin (Southall)
Grant W. Miller (Pasadena, U.S.A.)
A. S. Murray (Edinburgh)
I. H. McLean (Bushey)
J. A. R. Page (Orpington)
O. P. Peresypkin (Hong Kong)
J. Plas (London)
L. Ricketts (London)
I. P. Roberts (London)
D. F. Rossiter (Clevedon)
N. J. Rostron (London)
J. W. Ruddock (St. Albans)
H. G. Stonley (Wembley Park)
R. H. Tugwood (London)
H. W. Weeks (Woking)

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A. Cairncross (Perth)
A. D. Conway (Birmingham)
C. E. Dawkins (London)
Ove Dragsted (Copenhagen, Denmark)
P. H. Higgs (Wollaston)
A. H. Jutson (Sandwich)
Nigel W. Kennedy (Tadworth)
R. C. Kino (London)
D. C. Kirtley (Sunderland)
G. D. Llewellyn (Ilford)
P. G. Meakin (London)
Miss Joan Pyman (Letchworth)
D. M. Spero (London)
N. Stein (London)
E. G. Stone (Hove)
L. G. Trumper (Devizes)
D. Wheeler (London)

ASSOCIATE

A. E. Horn (Nigeria)

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S. J. Hale (Maidstone)
D. E. Mayers (Cambridge, U.S.A.)

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F. M. Cunningham (Toronto, Canada)
G. Denton (Clacton-on-Sea)
M. Kussman (London)
C. A. Piek (Amsterdam, Holland)
F. O. Soughton (Terrace Bay, Canada)
Miss M. L. Sprankle (Oklahoma City, U.S.A.)
Mrs. J. M. Thomas-Ferrand (Bury St. Edmunds)
R. F. H. Wakeley (Swindon)
G. T. Wright (London)

ORDINARY

Siu Man Cheuk (Hong Kong)
A. B. Hemachandra (Colombo, Ceylon)
B. C. Lowe (Birmingham)

The Council has received with regret the resignation of Mr. E. R. Levett, who has taken up residence in Rhodesia. At its November meeting the Council recorded appreciation of Mr. Levett's services to the Association while he served as a Councillor. Mr. R. K. Mitchell was appointed to serve on the Council in the place of Mr. Levett until the next General Meeting.

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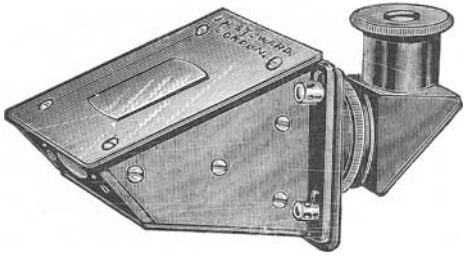

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GEMMOLOGICAL ASSOCIATION OF GREAT BRITAIN

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OF GREAT BRITAIN
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THE GEMMOLOGICAL ASSOCIATION OF GREAT BRITAIN (INC.)

(Originally founded in 1908 as the Education Committee of the National Association of Goldsmiths, reconstituted in 1931 as the Gemmological Association)

OFFICERS AND COUNCIL

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THE FINE CUT OF SYNTHETIC RUTILE

by
W. F. Eppler, Ph.D.

IN more than one way the announcement of the synthetic rutile was a great surprise to all gemmologists. Although this synthesis concerns a long-known mineral, which, moreover, has for some time been produced synthetically for technical purposes (in small and tiny crystals), it was so far unknown in a size and quality suitable for jewellery, and it therefore constitutes a great novelty. Moreover, this new synthetic stone is a material which by its optical properties far surpasses all known synthetic and natural stones and which by its extremely strong refraction in its effect excels even diamond. Lastly, the wealth of coloration in which synthetic rutile can be produced is an additional and very remarkable innovation in synthetic stones. Undoubtedly the manufacturers, the Linde Air Products Company, of Chicago, U.S.A., have opened up new paths and have thus added further ornamental possibilities, but at the same time have increased the difficulty of identifying and testing stones. The importance which synthetic rutile is able to attain as a precious stone is subject to certain restrictions owing to its relatively low hardness.

Without in any way examining the commercial or aesthetic value of this new synthesis, it should be stated that synthetic rutile is a material with remarkable optical properties. These necessitate a suitable cut to yield the optimum effect. It is unlikely that a cut which is usual and effective in other stones can be applied to rutile without modification of the dimensions and angles. On the contrary, it appears indispensable in view of its abnormally high refraction to work out a special cut for synthetic rutile. In doing so, one will have to start from experience with diamond, which has shown the brilliant shape to be the most suitable one, and to adapt its proportions to the refractive indices of rutile.

At first the calculation so successfully carried out by Tolkowsky* for the brilliant cut of diamond was tentatively applied to rutile. First of all, in every research on cutting of precious stones it must be postulated that all the light entering the cut stone from above shall be totally reflected by the facets of the base and shall leave the stone through the crown in an effective direction. Therefore the angle of inclination γ of the pavilion facets towards the plane of the girdle is the most important angle and at the same time is the angle determining any shape.

Tolkowsky calculates this angle by the equation

$$\gamma = (180^\circ - x)/4$$

the auxiliary angle x being obtained from the formula

$$\sin x = \sin 45^\circ / n,$$

where n stands for the refractive index, which (least and greatest value) is 2.62 and 2.90 for rutile. For these two values the following angles of inclination are obtained:—

$$\gamma\,(2.62) = 41.1^\circ,\ \gamma\,(2.90) = 41.5^\circ,$$

from which the height of the base hb can be found from the equation

$$hb = 50 \times \tan \gamma,$$

the diameter of the girdle of the brilliant shape being assumed to be 100. For the two refractive indices of rutile the heights of the base are obtained:—

hb (2.62) = 43.6, hb (2.90) = 44.2 per cent. of the diameter of the girdle.

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* Tolkowsky, M. "Diamond Design." E. & F. Spon, Ltd., London, 1919.

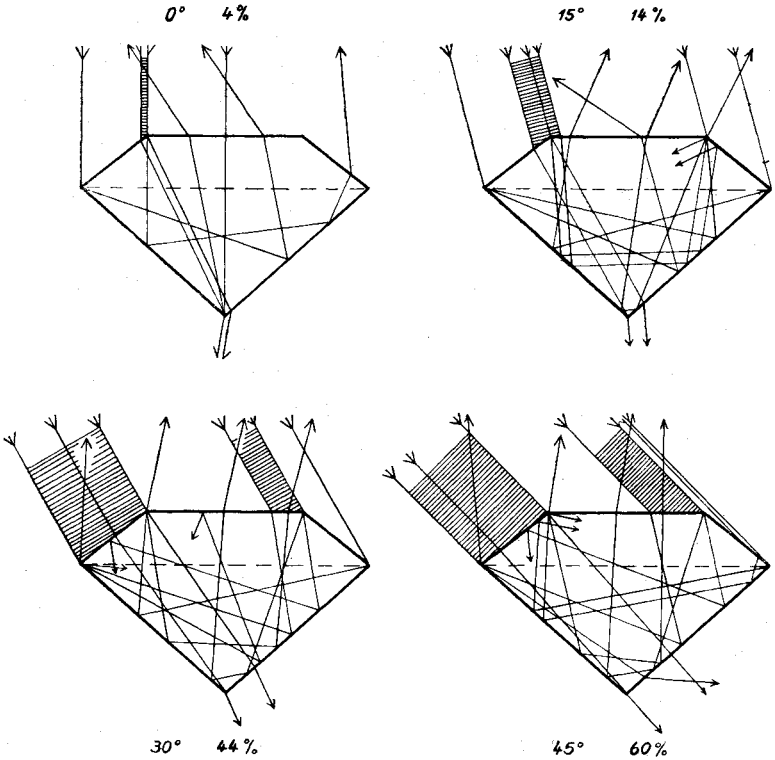

FIG. 1.—Cross-section showing path of rays for synthetic rutile (n = 2.90) in Tolkowsky cut for various inclinations of the entering light. The shaded parts indicate the regions of light losses.

The additional values which determine the brilliant shape have been worked out graphically on the basis of the Tolkowsky values for diamond:—

Bezel facets φ (2.62) = 36.0°, φ (2.90) = 38.1°, inclination to the plane of the girdle ; Diameter of Table T(2.62) = 53.5°, T(2.90) = 54.3 per cent. of the diameter of the girdle ; Height of crown hc (2.62) = 16.9, hc (2.90) = 17.9 per cent of the diameter of the girdle.

These values determine a brilliant cut of synthetic rutile, since the remaining facets, namely star, cross and half facets, are only accessories in the cut, important though their effect may be.

It is now essential to ascertain the effect of such cutting. This question can be reliably done by studying whether, and to what

extent, light rays incident upon a rutile cut according to these values are utilized for brilliancy. For convenience the path of the light rays is followed out on a cross section of the cut (which is known to be permissible in such examinations), and that cross section is chosen which runs through the greatest diameter of the table and through the middle of the main facets of crown and base. The following light-losses have been established in this way for the two refractive indices of rutile, caused partly by escape at the back, partly by undesirable internal reflections:—

TABLE 1.—Light-losses in percentage proportion of the entering quantity of light in Tolkowsky brilliant cut of synthetic rutile:—

Inclination of entering light towards the normal	Light-losses $n = 2.62$	$n = 2.90$
0°	0°/₀	4°/₀
15°	15	14
30°	35	44
45°	43	60
mean	23.3°/₀	30.5°/₀

The cross sections for refractive index, $n = 2.90$, are shown in Fig. 1 ; the path of rays which enter vertically and obliquely can be seen in them. The shaded parts indicate the regions of the entering intensities of light which are lost for the brilliancy of the cut.

The investigations by graphs for this and the ideal cut, discussed below, have shown, moreover, that the individual values of a cut, at steeply rising refractive indices, do not change as much as at low refractive indices. This becomes obvious also by comparing the values of the Tolkowsky cut for the two refractive indices, the difference of which, especially in γ and φ, is so small, that for γ at least lies within the latitude of cutting. It therefore appears warrantable to take account in the calculations not of both refractive indices but only of their mean, $n = 2.76$. This simplification has been proved by diagrammatic proof to be admissible.

The light-losses of the rutile in the Tolkowsky cut, as shown in Table 1, appear rather high. It has therefore been studied whether the ideal cut, proposed formerly by Johnsen and by Rösch* for diamond and other precious stones, can be applied to rutile. The

* See W. F. Eppler, "Die Brillianz durchsichtiger Edelsteine. Fortschritte der Mineralogie," etc., vol. xxiii, 1938, pp. 1-40 (containing references).

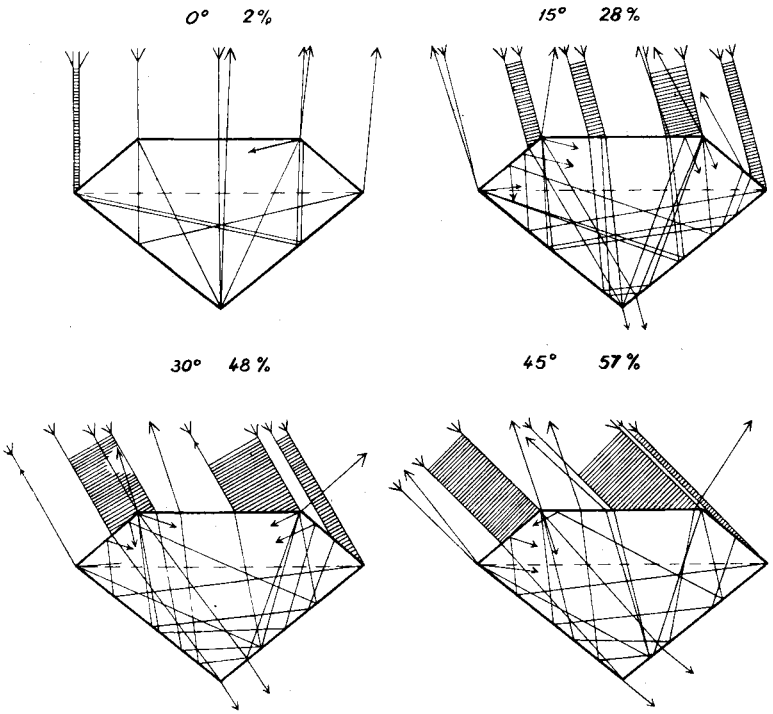

FIG. 2.—Cross-sections showing path of rays for synthetic rutile (mean, $n = 2.76$) in the ideal cut for various inclinations of the entering light. The shaded parts indicate the regions of light losses.

required values for the high average refraction of rutile have been established sufficiently exactly by graphs ; they are set out in Table 2.

TABLE 2.—Values of dimensions and angles of the ideal cut for $n = 2.76$:—

Pavilion facets	$\gamma = 38.5°$	inclination towards plane of girdle
Bezel facets	$\varphi = 40.1°$	
Height of base	$hb = 39.8$	per cent. of diameter of girdle
Height of crown	$hc = 18.5$	
Diameter of table	$T = 56.1$	

Fig 2 shows the method of examining the extent to which light rays entering vertically and obliquely are used, while Table 3 contains the light losses as compared with those of the Tolkowsky cut for $n = 2.90$.

Table 3 as well as Fig. 2 show very clearly that the loss of light in the ideal cut is even greater than that in the Tolkowsky cut. Neither form therefore appears to be advantageous, and the question arises whether one has to put up with such high, at least high for this type of refraction, losses of light. To answer this question the following method was used:—

TABLE 3.—Light-losses in percentage proportion of the entering quantity of light in synthetic rutile in the Tolkowsky ($n = 2.90$) and ideal cuts ($n = 2.76$):—

Inclination of the entering light towards the normal	Light-losses Tolkowsky cut	Ideal-cut
0°	4%	2%
15°	14	28
30°	44	48
45°	60	57
mean	30.5%	33.7 5%

In the Tolkowsky and ideal cuts the angles of inclination of the pavilion facets have been calculated by the authors under different assumptions. Tolkowsky based his calculations on oblique incidence of the light, whilst the ideal cut takes account of light only which enters vertically i.e. at right angles to the table and therefore to the plane of the girdle. With regard to the use of cut stones Tolkowsky's version is preferable. By his method of calculation and by using the formulae given above one obtains for $n = 2.76$ an angle of inclination, $\gamma = 41.3°$, to which angle a height of the base, $hb = 43.9$ per cent., is correlated. These two values determine the base, but there are difficulties in the case of the crown. Those angles of inclination of the bezel facets which are obtained by graphs cause either losses of light by escape through the pavilion facets or no less undesirable internal reflexions in the crown. Critical deliberations lead to the result that because of the high refraction a very small range of angles only is available for the exit of the light-rays in the crown. At the most, as can be proved by drawing and calculation, this is not more than the critical angle t of total reflexion. According to the equation, $\sin t = 1/n$, a critical angle of $t = 21.25°$ corresponds to the refractive index $n = 2.76$. The light, coming from the interior, must fall on the main bezel facets within this range of angles, if it is to leave the stone at all.

As a second requirement which must be satisfied, light which emerges from the crown must leave the stone in directions which

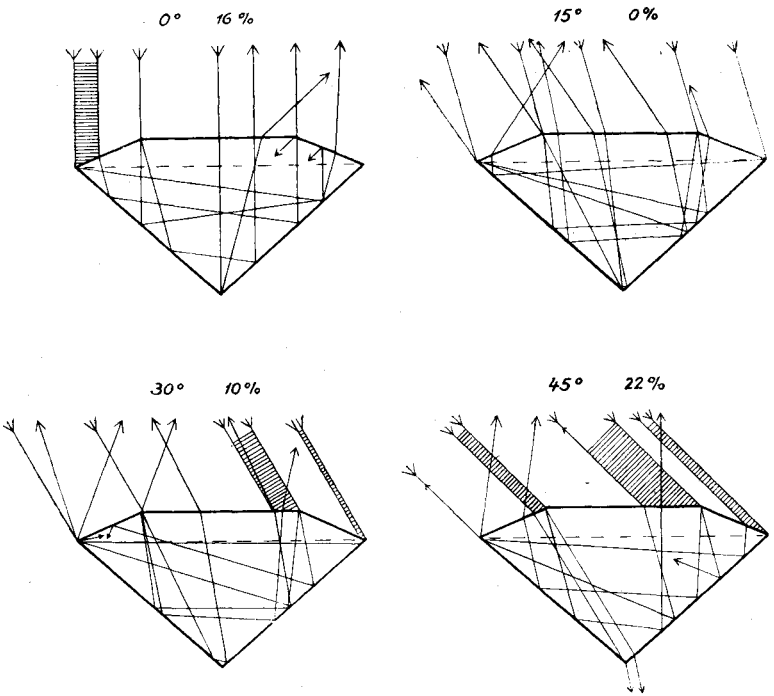

FIG. 3.—Cross-sections with path of rays for synthetic rutile (mean, $n = 2.76$) in fine cut for various inclinations of the entering light. The shaded parts indicate the regions of light losses.

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are still effective. The angle of the emergent light with the normal (i.e. a line at right angles to the table) should therefore not be too large and should after an approximate estimation not exceed about 50°.

These two requirements for the angle of inclination φ of the bezel facets depend, as can easily be understood, on the refractive index n and the angle of inclination γ. From them we obtain by means of trigonometrical calculations, upon which we need not enlarge, the following formulae for a suitable angle of inclination φ:

$\varphi = \alpha + \beta$, where $\cot \alpha = (n - \cos \beta)/\sin \beta$, and $\beta = 180° - 4\gamma$. For refractive index $n = 2.76$ and for $\gamma = 41.3°$ the required angle of inclination can be worked out as $\varphi \doteq 23.0°$. The height of the

crown *hc* depends, if φ is known, on the diameter T of the table. The very low value of the angle φ requires a low crown ; the table should then be as small as possible. On the other hand, a small diameter of the table is not particularly favourable for the path of the rays, as it might bring about additional losses of light. At any rate, the somewhat complicated calculations, which are beyond the scope of this paper, give us a diameter of the table T =31.1 per cent., and thus a height of the crown *hc* = 14.5 per cent. of the diameter of the girdle. It appeared useful nevertheless to plan the table somewhat larger than as calculated, and in analogy with the accepted ideas about the brilliant cut a diameter of the table, T = 54.0 per cent., was chosen. The height of the crown thus has the extraordinarily low value *hc* = 9.8 per cent. of the diameter of the girdle, a value which otherwise can be justified with stones of very low refractive properties only, such as opal and fluorspar. As an additional precaution the path of the rays in a cross section has been followed out in both forms, that with the calculated smaller table and greater height of the crown as well as the more conventional cut with larger table and specially low crown. The light-losses thus found as a criterion are shown in Table 4.

TABLE 4.—Light-losses in percentage proportion of the entering light quantity in the fine cut for $n = 2.76$:—

Inclination of the entering light towards the normal	Light losses at cross section with a small table	a large table
0°	35°/₀	16°/₀
15°	13	0
30°	17	10
45°	37	22
mean	25.5°/₀	12°/₀

It can clearly be seen that the conventional cut with a large table is definitely to be preferred because of the reduction of the light losses to about half the amount. As can be seen also in Fig. 3, the light losses in this form are so extraordinarily small and *vice versa* the light yield is so surprisingly large that this cut must be expected to be especially effective in rutile. It is suggested therefore to give it the designation " fine cut."

To give an overall idea, the values for a Tolkowsky cut, for an ideal cut (from Table 2) and for the suggested fine cut of rutile are

compared in Table 5. Table 6 enables a comparison of the light yields of these three forms to be made, a comparison which underlines by graphical means the specially favourable conditions of the fine cut.

TABLE 5.—Values of lengths and angles for three cuts of synthetic rutile:—

		Tolkowsky cut	Ideal cut	Fine cut	
Pavilion facets	γ	41.5°	38.5	41.3°	inclination towards plane of girdle.
Bezel facets	φ	38.1°	40.1°	23.0°	
Height of base	hb	44.2	39.8	43.9	per cent of diameter of girdle.
Height of crown	hc	17.9	18.5	9.8	
Total height	h	62.1	58.3	53.7	
Diameter of table	T	54.3	56.1	54.0	

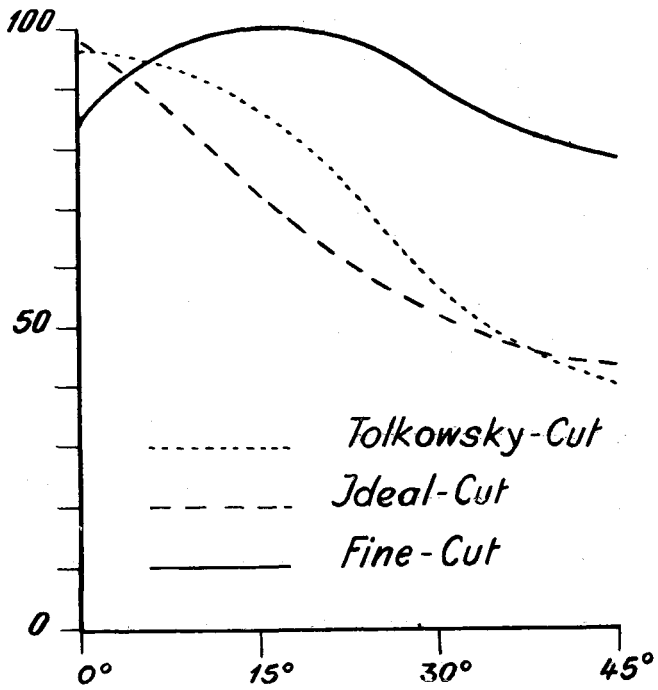

FIG. 4.—Graphical representation of the light yields for synthetic rutile in the Talkowsky cut, ideal cut and fine cut, according to the inclination of the entering light.

TABLE 6.—Light yields in percentage proportion of the entering light quantity for three cuts of synthetic rutile:—

Inclination of the entering light towards the normal	Tolkowsky cut	Ideal cut	Fine cut
0°	96	98	84
15°	86	72	100
30°	56	52	90
45°	40	43	78
mean	69.5	66	88

There remains the calculation of the small facets, i.e. of the angles of inclination of the star facets and of the cross and lower half facets. For the time being it was not considered necessary to work out their values, as they cannot influence the basic form of the fine cut. Moreover, in practice, the unusually low crown may make different values appear more suitable than those usual in the brilliant cut. If they are arranged as customary in the brilliant cut, the following values may be proposed:—

Star facets	...	8°-10°	inclination towards plane of girdle
Cross facets	...	25°-27°	
Half facets	...	43°	

In working out these values, it has been taken into account that the length of the star facets should be about a third of the distance from the table to the girdle and the edge between each two cross facets about two-thirds of that distance. For the length of the half facets half the distance from the culet to the roundist has been used. It will be interesting to see to what extent these values will be proved satisfactory in practice.

The preceding calculations are based upon the assumption that the girdle has no thickness, which, however, even in well-cut brilliants amounts to about 1.5 to 2 per cent. of the diameter of the girdle. With regard to the thickness of the girdle it can only be recommended to keep it as small as possible, as it exerts, like a culet in the brilliant cut, an unfavourable influence upon the brilliancy by causing additional losses of light.

The measurements and dimensions supplied above are applicable not only to the brilliant cut of rutile but also to every other form of it In these cases they apply to the smallest cross-section of the cut in question.

A. E. ALEXANDER, Ph.D.,
Director, Gem Trade Laboratory Inc., New York, discusses

A Remarkable Inclusion in a Burma Ruby

RECENTLY a Burma ruby was brought to my attention in which was so unusual an inclusion as to warrant special comment. This ruby contains an aggregate of rutile needles which—in my mind—form, in profile, something of the likeness of the head and headdress of an " Egyptian Deity," and illustrates the vagaries of nature showing to what extent crystallization can deviate from the theoretical or ideal.

The story of this ruby goes back to 1938, when Mr. Charles Murray, well-known New York pearl and stone dealer (with whom I went to the Middle East in 1947), was on an extensive trip to the Far East. Among other places, he had been at Mogok visiting the ruby and sapphire mines and taking motion pictures of the natives at work. Leaving there, he had returned to the Irrawaddy River, to the boat on which he was soon to leave.

The boat was scheduled to leave at dawn and Mr. Murray was awakened at 2 a.m. by someone loudly calling his name. The pilot of the craft, also aroused by the commotion, went on deck to ascertain the nature of the disturbance. There was a native demanding to see Mr. Murray, who by that time was also on deck and recognized the man as a worker from one of the mines at Mogok. He was permitted on the boat, and excitedly told his story: Shortly after Mr. Murray had left Mogok, this native found the remarkable ruby shown in Fig. 1. Elated with his find and believing the figure in the stone to be a good omen, he wanted the American to have it. So he set out at once on the two-day trip from the mines to Mr. Murray's boat.

Now, according to Burmese religious beliefs, the person finding a large, rare, or an unusual gem is grateful to Buddha for his discovery. To express his gratitude he erects at the site of the " find " a pagoda, which may be small or large, simple or ornate, inexpensive or very costly, according to his financial ability. So

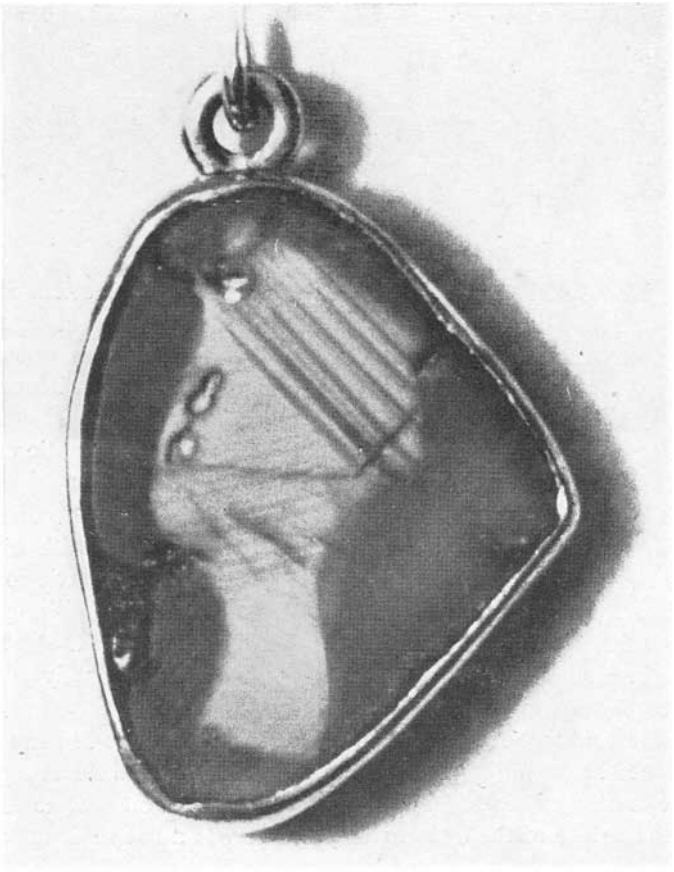

Photo: Courtesy of Cartier, Inc.

to-day, should you visit Mogok, you would undoubtedly find a Buddhist pagoda built in honour of this ruby, its discoverer, and its present owner.

Perhaps because, to his mind, he would be displeasing Buddha and would bring misfortune and grief upon himself and his family, the Burma native would under no circumstances sell the stone. It was a gift for Mr. Murray—a gift that would bring him, or anyone thereafter who possessed the gem, good fortune.

As for the ruby, it weighs approximately five carats. The colour is good. The photograph reproduces the outline of the head and headdress exceptionally well. This figure consists of a dense mass of rutile needles, in addition to several growth or colour bands

Photo: Courtesy of Katherine Cornell Productions Inc.

which help to accentuate the " design " in the headdress. The stone has never been polished or otherwise fashioned.

I have included a picture in this story of Katherine Cornell and Godfrey Tearle as they appeared in Shakespeare's " Anthony and Cleopatra " (Fig. 2). With a little imagination, the similarity between the figure in the ruby and the Egyptian headdress in the photograph is apparent.

In conclusion, I wish to thank Messrs. Cartier, Inc., for kindly taking the photograph of the ruby, the Katherine Cornell Productions, Inc., for their interest and co-operation, and Helen DeVore Alexander for her advice and constructive criticism.

"GEMSTONES"

by Dr. G. F. Herbert Smith goes to Tenth Edition

THE tenth edition of "Gemstones," by Dr. G. F. Herbert Smith, is expected to appear very shortly, after a long delay that originated from the coal crisis. The previous edition, which was published in May, 1940, became exhausted soon after the end of the war Its scope had been expanded to a considerable extent, because students of gemmology, for whom from its beginning in 1912 the book has been primarily intended, wished to delve ever deeper into the subject. Even then their thirst for knowledge was not assuaged, and in the new edition the opportunity has been taken to enlarge certain parts and to introduce additional matter. For instance, the chapter on crystals has been lengthened until it has become almost a treatise on crystal morphology in itself, and the discussion on the crystal form of diamond has been widened so as to include its intimate structure. Despite the limitation which the title of the book might logically be supposed to impose upon its contents, pearl has always found a place in it, but a new chapter on ivory and tortoise-shell has now been added ; with the inclusion of pearl there is no logical reason for the omission of ivory. Tortoise-shell is, however, another matter, and the justification for its inclusion is that for many purposes it is allied to ivory. Another new chapter is on resins. The artificial resin known as celluloid has long been used in imitation of ivory, but the great development of what are now known as plastics is increasingly leading to their use in place of glass imitations of gemstones. This chapter may appear unnecessarily comprehensive, but it would have been difficult and perhaps even undesirable to draw a line. Dr. Herbert Smith's book has for long been recognized as the standard work on gemmology in the English language, and the new and revised edition, with its wealth of information, will undoubtedly make it the best text-book available.

"Gemstones," by G. F. Herbert Smith, D.Sc., M.A. (Tenth edition, revised), 1949. Published by Methuen at 35s. (postage and packing 1s.). Copies may be ordered from the Gemmological Association of Great Britain, 93-94, Hatton Garden, London, E.C.1.

ATOMIC PHYSICS

ON Monday, January 24th, the Gaumont-British film on Atomic Physics was shown to members of the Association at the British Council Cinema. The film dealt with the story of a remarkable scientific achievement based on the work of scientists of many nations, but owing most of all to the work of Lord Rutherford and the school of Nuclear Physics which he developed. The final achievement of the release of nuclear energy for war was due largely to the scientists and engineers of the United States stimulated and helped by British Physics.

The film recalled the emergence in 1826, when John Dalton propounded the Atomic Theory of Chemistry, of a scientific theory of an idea of matter which had existed for over two thousand years as a belief unsupported by experimental proof.

Scientists have now the task of using the immense power of nuclear energy for peaceful purposes—for the production of radioactive materials for medical and biological research, and for the generation of heat and power. With their present knowledge it is possible to design nuclear power stations, which will produce power at a moderate efficiency. Until operating experience of these plants is acquired it will not be known how economical they will be, nor will scientists be sure of overcoming all the technical difficulties which will occur in large scale development of nuclear power.

Nevertheless, there is a real promise that over the next few decades world power resources can be greatly increased and that the very great benefits to be obtained will do much to increase standards of living. It is the hope of every scientist that this will lead to the establishment of a work organization for the effective control of all weapons of mass destruction and through this to the abolition of war.

From Dalton's theory of 1826 to atomic power is a long road but the landmarks are clear.

With the Atomic theory as a basis a pretty complete picture of the elements of our material world was fitted together during the 19th century.

The discovery of electrons, the realization of the nature of positive rays, the strange powers of X-rays revolutionized conceptions of the nature of matter and of the atom itself.

The study of radioactivity, investigated by Becquerel and the Curies, led Lord Rutherford to make the greatest single advance in atomic theory. He pictured a small heavy nucleus in the atom, round which the electrons revolved.

In 1919 Rutherford discovered how to change one element to another by bombardment with alpha-particles.

He suggested that the nucleus of the atom might contain protons and uncharged particles of about the same mass.

In 1932 scientists could say with certainty that the atom contained electrons, carrying unit negative charges—and a nucleus, built up of protons, carrying unit positive charges and of neutrons, uncharged particles equal in mass to protons, whose existence was proved by Sir James Chadwick. In 1932 also Cockcroft and Walton split the lithium atom by bombardment with protons and found that mass could actually be translated into energy in perfect accord with Einstein's Theory of Relativity.

Atomic disintegrations provoked by great machines became a commonplace of well-equipped physics laboratories.

In 1939 Uranium fission was first noted and the possibility of a self-sustaining chain reaction suggested the wholesale release of energy. Controlled chain reactions were achieved in the atomic pile.

The imagination of the world has been stirred by the prospect of adapting such piles to use as sources of heat energy, and as sources of radioactive materials for use in medicine.

In research laboratories the scientists are even now writing fresh pages in this unfinished story.

But over all, the smoke of the atomic bomb hangs like a pall. If we are to reach the future that promises so bravely, the peoples of the world must see that this new power is wisely used.

By ROBERT WEBSTER, F.G.A.

STAINED PEARLS and X-RAYS

RECENTLY during the routine testing of pearls by the direct radiographic method (skiagrams), the writer was interested to notice a " reversal " effect in a photo of a necklet of black pearls which under test was found to be cultured. The effect was considered to be due to the pearls having a black colour induced by staining, probably by silver nitrate ; and to obtain further confirmation that this might be the case an experimental coloration was carried out.

Before considering this " reversal " it will be as well to discuss the principle underlying the testing of pearls by the direct radiographic technique and the limitations of such a method. Skiagrams —the pictures obtained when an object is photographed by a wide beam of X-rays—are really shadowgrams. This was one of the earliest applications of X-rays, being immediately taken up by the medical profession, who early foresaw its value in the location of metallic foreign bodies and in the diagnosis of fractures in the skeletal framework. The method depends on the differential transparency to X-rays of the various components of the body examined, and quite soon after Röntgen's classic discovery of these radiations it was found that, in general, the higher the atomic weight of the elements composing the material the more opaque was the material to the rays ; thus aluminium (*atomic weight of 27*) is very transparent, and lead (*atomic weight of 205*) very opaque ; and similarly flesh, consisting mainly of the light elements carbon, hydrogen and oxygen, are more transparent than the bones which contain the heavier calcium and phosphorus atoms.

As the operative value of a skiagram depends upon the differential transmission (or absorpton) of the incident X-rays, in theory,

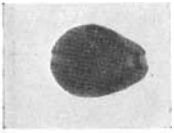

Direct radiograph of a cultured pearl.
Positive print about twice natural size.

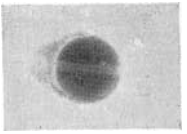

" A," before staining.

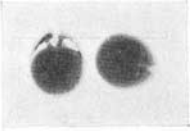

" B," after staining with $AgNO_3$, showing the " reversal " effect.

Direct radiograph of the two " rosée " cultured pearls showing the " reversal."
Positive print natural size.

a radiograph of a pearl would be expected to show little, for the organic constituent—conchiolin ($C_{30}H_{48}N_2O_{11}$), is so intimately incorporated with the $CaCO_3$ crystallites that the structure would not show. In practice, however, pearls are often found to depart from this ideal condition, particularly between the concentric layers of the structure. This being due to the oyster depositing, either in a complete concentric layer or in patches in such a layer, a variable thickness of the organic constituent ; this will show up in an X-ray negative as lines of deeper density (due to the greater transmission of the X-rays through the organic layers affecting the photographic emulsion to a greater extent than those rays which have been partially stopped by the mineral crystallites). In the case of cultured pearls the skiagram method may give adequate distinction owing to a similar effect ; for the oyster very often deposits a thick layer of conchiolin round the bead nucleus. The deposit may be irregular and thus form baroque pearls, or, if concentrated in any one area will produce a drop pearl. The layers normally show up as a dark circular ring, either complete or partial, which has a sharp inner edge and possibly a diffuse outer edge ; while the central bead shows, perhaps surprisingly, no structure. This effect is diagnostic but requires considerable ability to interpret correctly.

When the radiograph of the black pearl necklet was examined it was noticed that, in the case of a few pearls, instead of the black circle on the negative. which, as has been previously mentioned, so often occurs surrounding the bead nucleus, the circle was seen to be, in part, white on the negative ; this being especially noticeable near the string canal *(the photograph of this necklet is*

Direct radiograph of cultured pearls, showing the white ring *(this is black in the negative)* surrounding the bead nucleus.

Positive print natural size.

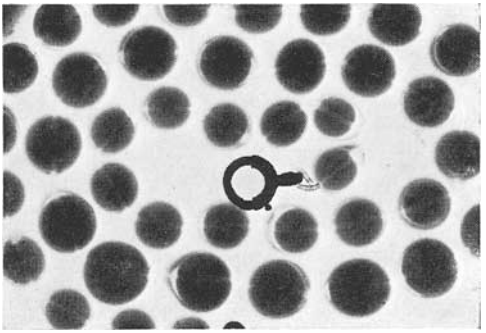

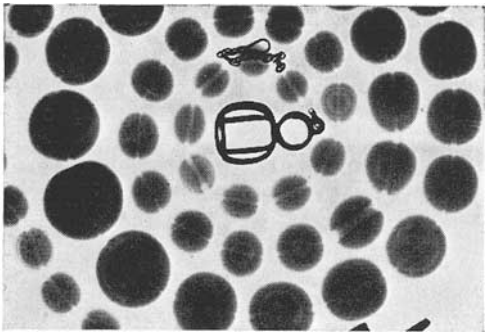

Direct radiograph of natural pearls, showing the structure exhibited by natural pearls. Some of the pearls are seen to have the appearance of cultured pearls in this picture; this shows the difficulty of complete diagnosis by the direct radiographic technique.

Positive print natural size.

unfortunately unsuitable for reproduction). The inference is that the white line may be due to colouring by stain containing heavy atoms.

That a black colour may be induced in pearls, both natural and cultured, by staining, has long been an accepted fact, but the methods by which this may be carried out are, perhaps for good reason, not disclosed. Experiment has shown that soaking a pearl in a strong solution of silver nitrate ($AgNO_3$) would turn it to a bronze or black colour—the silver nitrate being reduced by the organic (conchiolin) content to finely divided metallic silver which is black in colour. In order to ascertain whether such a coloration would in fact cause the " reversal " of the black line to white, a direct radiograph of a cultured pearl was taken which gave the typical " cultured " black ring on the negative ; the pearl was then

immersed in a strong solution of silver nitrate in a test tube, boiled for about thirty minutes and allowed to stand overnight. During this treatment the pearl first turned to a golden bronze shade and then to a bronze black. On taking an X-ray picture after this treatment the " reversal " was clearly evident.

This experiment, while not proving that silver nitrate is in all cases the stain used, does give credence to the supposition that if such a " reversed " effect is observed the pearl is stained. It must be further remarked that while this " reversal " has been clearly seen in stained cultured pearls I have been unable to detect similar effects in natural pearls which I have good reason to suppose to be artificially coloured.

More recently, during routine testing, a further case of " reversal " came to light ; this time, however, the pearls were not black pearls, but white, or more correctly " rosée." These pearls, which on being tested were found to be cultured, showed on the negative the " reversal " extremely strongly. Whether this was caused by some form of staining, or due to some other factor, such as doctoring of the bead used as a nucleus in order to produce a faster deposition of nacre—and such treatment has been credibly reported—could not be determined. The " rosée " staining of cultured pearls has long been known, and the stain employed was always considered to be an organic dye. To further test this point a radiograph of a known " rosée " stained cultured pearl was taken —this showed *no* " reversal," thus in this case the real reason for the effect cannot yet be proven.

NEW REFRACTOMETER

The Gemological Institute of America has announced the production of low priced refractometer (approx. £6 to £7). The instrument is small, measuring about 2 in. x 2 in., with a base width of under one inch. It is claimed that the new instrument is accurate in performance, though it is not expected to replace the larger instruments already on the market. A further claim is that it gives readings for cabochon cut stones. The main features seem to be its low price and, possibly, the fact that it can be carried in a waistcoat pocket. Its accuracy will be more properly assessed when a sample instrument is received in this country.

The Gem Industry at Idar-Oberstein

ALREADY in 1936 at Idar-Oberstein there existed a Gemmological Institute connected with the University of Frankfurt. During the war the activity of the Institute stopped, and when the technical school of gem-cutters was destroyed most of the instruments and books were lost. In 1947, Professor K. Schlossmacher, author of "Edelsteinkunde," was called to Idar-Oberstein to re-establish the Institute. As a first task, the few instruments which are still at hand have to be repaired and, above all, a library has to be brought together. By the kindness of foreign countries' Institutes and Associations the Idar Institute now gets the most important gemmological journals. Professor Schlossmacher has the task of instructing the members of the gem industry by lectures and to make them acquainted with the newest investigations. In the time a series of lectures concerning gem sources is given. Besides that, he instructs at the technical school of gem-cutters. As soon as a laboratory is established he will be able to begin with scientific investigations, too. There are many scientific and technical problems which are of importance for the industry and there exists an especial interest in the question of the origin of agates and for the chemical and physical conditions of agate colouring Reports on the results of investigations and many other questions are given in the gemmological journals of Germany and foreign countries. Professor Schlossmacher has now begun to prepare a new fourth edition of his important book "Edelsteinkunde."

The gem industry at Idar-Oberstein has developed out of the manufacturing of native agates, which were found in the time of the Romans, 2,000 years ago. Modern times has brought about an important development by opening the trade. From all over the world rough stones were imported and cut stones were exported to many countries So a many-sided industry developed, which depends completely on the world market. Dealers of rough stones

from Idar in foreign countries searched for gem sources and they visited the rough stone markents. In Idar these stones were cut and the smaller part of them sold in Germany, the larger part being exported. In connection with this industry, in the neighbouring quarter of Oberstein there developed a jewellery and hardware industry. By this development the fate of the industry in import as well as in export is connected very closely with the markets of foreign countries. Already the first world war had caused a severe interruption of these relations. Since 1933 political economy has added to these difficulties. When in 1939 the second world war began the connections with foreign countries were interrupted completely. It is true that on the market in Germany there could be sold a small quantity, but therewith it was broken into the stocks, because import of rough stones was impossible. So for 15 years the industry had to work under conditions which were opposed to its whole development and structure. The post-war years have not brought any improvement. The reform of currency has decimated the money and now by a law for taxes on property this will be continued. Thus stocks and money are lost more and more. Besides that, the dealer of rough stones will meet a market abroad in which prices have risen enormously in comparison with former times. The whole industry, however, depends on the import of rough stones. It is true that the blockade of stocks and the system of contingencies for the trade within Germany were diminished during the last time and partly they even were repealed, so the market in Germany is free to-day, but a luxury industry is without prospects in Germany to-day. Without a connection with the world market the industry isn't able to live. One hopes at Idar that this question will be answered in the near future, and then the industry will win back its old place by its acknowledged quality.

Gemmological Abstracts

" Crystals and X-rays." By Kathleen Lonsdale, D.Sc., F.R.S. Bell, London, 1949. 199 pp. Illustrated. 21s.

Fellows of the Gemmological Association who recently had the privilege of listening to Dr. Kathleen Lonsdale's talk on the structure of diamond will be interested to learn that her book on the determination of crystal structure by means of X-rays has just been published.

The book is based on a course of lectures given at University College, London, in 1946. It opens with an interesting historical introduction, pivoting on the year 1912—the year of the famous Laue experiment, from which all the vast superstructure of X-ray crystal analysis stems. This is followed by a clear account of the generation and properties of X-rays. The next chapter, on " The Geometry of Crystals," opens with the X-ray crystallographer's answer to a question familiar to students of gemmology, " What is meant by a crystalline substance? " " One in which the internal atomic or molecular arrangement is regular and periodic in three dimensions over intervals which are large compared with the unit of periodicity." Thereafter follow some pages describing the symmetry of the seven crystal systems, and notes on crystal drawing and projection. Of the conventional drawings of crystals in parallel perspective Dr. Lonsdale, with a typical flash of humour, remarks: " Such drawings are also made as if the eye were looking down from a little above and slightly to the right . . . like a benevolent Conservative government."

The author then describes how the introduction of planes, axes, and inversion axes to the seven systems leads to the 32 crystal classes ; how the addition of glide planes and screw axes increases the number of possible frameworks to 230 space groups ; and how, even when the space group of a crystal has been determined, this is still only the bare bones of the crystal, into which ions, or atoms, or molecules can be introduced in an infinite variety

of ways. To correct the idea that any actual rigid framework exists, Mrs. Lonsdale writes: " The space lattice is quite imaginary ; there is no actual framework. The atomic model is quite imaginary ; the crystal is much more like a quivering jelly full of vibrating pips."

Next, the information which can be derived from Laue photographs, powder photographs, divergent beam methods (so powerfully developed by Dr. Lonsdale) and rotation photographs is described, and the notion of the " reciprocal lattice "—the periodic distribution of the reflecting power (to X-rays) of a crystal—is explained. There is a long chapter on " Atomic and Electronic Distribution " which gives an account of the difficult and time-consuming methods by which the actual spatial distribution of the atoms in a crystal is determined, followed by a chapter on " Extra-structural Studies." which deals with such topics as crystal texture and imperfections of structure, thermal vibrations, and so on. In the final chapter are given some of the achievements in different departments of science of the methods of X-ray crystallography. There is an adequate index.

The book is short—under 200 pages—and the subject a vast and complex one. Dr. Lonsdale has done wonders to compress so much into so little space, but there is naturally little room for concessions to the inexpert reader. However, for anyone who is not afraid of thinking mathematically in three dimensions Dr. Lonsdale's book provides as excellent and up to date a survey of the subject as can be imagined. The book is well illustrated with photographs and diagrams, the latter in particular being very helpful.

B. W. A.

" Dictionary of Gems and Gemology. By R. M. Shipley and others. 4th edition. 261 pp. Published by G.I.A.

An expanded edition of a very helpful gem dictionary, containing much additional information. It is a pity that some minor errors of former editions have not been corrected.

General

" Silicon Carbide Refractometer." By Jack de Ment. The Mineralogist (Oregon), February, 1949, p. 99.

A postulation of the use of beta-silicon carbide in refractometers. Should such a refractometer be produced it is not likely to be of significance to the gemmologist.

" Improvement in the Colour of Precious Stones by Heat Treatment." By K. F. Chudoba. " Achat," 1949, Vol. 2, No. 1, pp. 9-12.

The appearance of natural gemstones has always been improved by grinding and polishing, but it is also possible to improve their colour. Apart from colour improvement one may aim at removing spots and streaks. The desired change may be obtained by heat treatment, sometimes by cooling and frequently by radium, X-ray or other radiation. It is well known that yellow, red or brown zircons can be heat treated at about 300° C., the product being a colourless stone, and which is sometimes given misleading names. About 1921 zircons of a beautiful blue colour from Siam were put on the market ; blue zircons were up to then unknown and it was found that this colour, too, was obtained by heat treatment. Amethyst-coloured quartz can be heated to resemble topaz (about 500-600° C.), light green beryl can be coloured blue (aquamarine) by heating the stone to about 400° C., when it loses all colour, becoming blue as it cools off. Yellow and brown topaz may become pink (350-450° C.), while dark green tourmaline may obtain a more pleasing light green colour. Some of these enhanced colours are not permanent ; they fade with time. Some zircons lose their colour in ordinary daylight, while other stones regain their original colour by cathode or X-ray radiation (treated pink topaz, treated citrine). Many problems relating to these colour changes are still unsolved.

E. S.

" Violet Filter as Tester for Emeralds." By S. v. Gliszczynski. " Achat," 1949, Vol. 2, No. 1, pp. 13-14.

There are many colour filters for the identification of emeralds, the best known being the Walton Loupe and the Chelsea Colour Filter. These filters are dichromatic, i.e. they only transmit two spectral colours. Genuine emeralds viewed through these filters appear red. Dr. F. Vandrey-Goettingen has developed another filter for emerald testing consisting of a violet film sandwiched between glass squares of 4.5 x 5.5 cm. size. Green tourmaline and olivine appear blue under this filter, which is preferably used under artificial light. In order to spot green glass imitations, appearing red under the filter, a hardness test with a steel file is recommended. (This test would be unfair to a genuine emerald and is to be deplored.—Ed.)

E. S.

MARGINALIA

Informal notes on points of interest and opinions of a controversial character compiled by Fellows of the Association (Contributor in this issue is F. E. Leak).

WILL ever the topaz-quartz controversy come to an end? The managing director of one provincial organization apparently made this a doubtful proposition when he complained, " The trouble with you gemmologists is that you are too honest." But, coming from a man who runs his business with unquestionable integrity, surely this remark is in itself an indication regarding the ultimate solution of the problem? On the other hand, it has become more than apparent since the foundation of the West of England Gemmological Laboratory that some jewellers in this country are ignorant of their trade. The number of puzzling specimens tested has been infinitesimal compared with those that almost reveal their identity by appearance alone. These are the people who, when they get the worst of a bargain, have been known to condemn the business methods exploited by a few unscrupulous dealers and traders. Surely they should blame themselves.

The Gemmological Association recently appointed a committee to consider the vexatious question of misnomers. I can remember three such committees set up by various organizations, one at international level, and I daresay there have been even more. Have they achieved anything concrete? Certainly, this continued publicity, if it reaches the required quarters of the trade, must have some success—when the diehards and others die out. It must not be forgotten that simultaneously with the publication of the report of the G.A. Committee, the Association found it necessary to make a statement regarding " Synthetic Zircons." The outlook does not seem to be propitious since there is undoubtedly a lack of unanimity throughout the trade on this subject, and until that is brought about there can be no possibility of enacted control. The present legal position as exemplified by the existing Appraiser's Licence that can be purchased without examination or proof of ability is ridiculous. For the payment of £2 any inexperienced person is entitled to set up in business as a house agent and at the same time to value any-

thing under the sun. It is reputed that certain undesirables find this a profitable sideline to their legitimate business.

Returning to the original query, is its insistence due to our laziness in speech? It is so much easier to pronounce the monosyllabic word. The same might apply to the demantoid-olivine business, in which case the sound of the latter is much softer. The majority of the remainder of the high-sounding misnomers take up so much time and wind to pronounce, and this may be the cause of their declining popularity. Other excuses have, I know, been put forward. Recently the Gemological Institute of America has advocated the use of " topaz-quartz " in preference to " quartz-topaz." This is confusion worse confounded.

* * * *

Surely it is time that some effort is made to amend the colour descriptions applied to gems, and apparently slavishly copied from one text-book to another, even from the generally accepted standard works downwards. As the matter now stands it is fair play for the facetious or imaginative mind. What happens if the Board of Standards intervenes? I picture Mr. B. W. Anderson proudly exhibiting his latest acquisition, the standard specimen of pigeon's blood, and religiously renewing it at prescribed intervals. But the highlight of this nonsense must be achieved when the University lecturer in forestry informs his bewildered students that the pistachio nut is epidote-coloured. None of my raspberries have, thank goodness, ever looked, whether in an under-ripe, mature or putrid state and either raw or cooked, like an alexandrite in artificial light. I was on one occasion reminded by the managing director of a well-known City firm, a keen hunting man and presumably *au fait* in all the accessories that accompany this sport, that there is more than one colour for sherry.

Crude sarcasm without a doubt. But surely the absurdity of this position deserves nothing more. Here is further work for the G.A. Committee on nomenclature and work that will be certainly breaking fresh ground. No one will raise the slightest objection to the many sensible colour descriptions that have been employed, provided they are truthful. The difficulty will be to find an expression that will be acceptable throughout the length and breadth of the country. Even such an innocent sounding expression as straw-yellow is liable to countless mental interpretations. Some years ago

an instrument called the Colorimeter was described in one of the trade papers. This analysed scientifically the colour of any material in terms of the proportions of the three primary colours contained. Maybe this would also provide a basis on which a range of shades of colour applicable to all varieties of gemstones could be classified. At present, who is to say when a pale green beryl becomes an emerald, or a ruby degrades into a pink sapphire? Its application under normal trading conditions would be almost an impossibility, but it would achieve a standard and no doubt the Association would serve, if necessary, as arbitrator.

* * * *

I recently had a ruby set up on the stage of a microscope in the approved manner for observing absorption spectrum. The bench not being a model of neatness and order, by mistake I placed a dichroscope down the tube of the microscope. The effect seen was quite startling and the twin colours were quite vivid.

Since then I have experimented with stones the dichroism of which is generally regarded as weak, and have found the arrangement most helpful. It is a snag, I know, if light happens to be passing through the stone, from table to culet, in a direction of single refraction, but in doubtful cases it certainly seems worth the effort of sticking the stone into plasticine so that the girdle is at right angles to the glass slip.

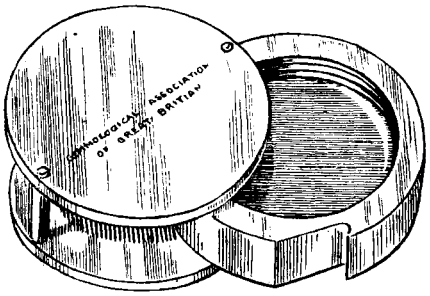

CHELSEA COLOUR FILTER

The Chelsea Colour Filter is now available in aluminium casing which is neater and more compact than the older type of mounting. The accompanying illustration shows the new type of filter.

Obtainable from the Gemmological Association of Great Britain, 93-94, Hatton Garden, London, E.C.1, the filter costs 8s. 6d., post free.

Though it has certain limitations, the Chelsea Filter has proved to be a very useful aid to gem-testing.

ASSOCIATION NOTICES

TALKS BY FELLOWS

F. E. Leak: "Pearls"—Toc H, St. George (Bristol) Group, January 27th, 1949. "The Science of Jewellery"—Mina Road (Bristol) Junior Mixed School, Parent-Teacher Association, February 16th, 1949. "Pearls"—St. Mary's Church, Shirehampton (Bristol), Youth Fellowship, February 20th, 1949.

H. S. Reese: "The Identification of Gemstones"—Southport Scientific Society, December 16th, 1948.

R. Webster: "Pearl"—L.C.C. School of Arts and Crafts, January 14th, 1949.

James Gillougley: "Diamonds"—Film-lecture to Geological section of Paisley Philosophical Institution, March 15th, 1949.

A lecture, "Gemstones of to-day and yester years," was given by Prof. W. T. Gordon, M.A., D.Sc., F.R.S.E., at the Museum Lecture Theatre, University Road, Bristol, on February 9th. F. Leak, F.G.A., assisted at the lecture and arranged a special exhibit which was shown at the Museum the week before and the week after Prof. Gordon's lecture.

GEMMOLOGICAL EXHIBITION

The Exhibition will be held from October 4th to 7th, 1949, at the Goldsmiths' Hall, London, E.C.2.

AMERICAN NOMENCLATURE

The Educational Committee of the Gemological Institute of America has recommended that the term "topaz-quartz" be used as a satisfactory synonym for citrine. The term "topaz," when used for citrine or "quartz-topaz," was outruled. The Institute is preparing a complete list of Nomenclature of Gemstones and it will be interesting to compare its recommendations with those that the British Organization published in Volume I, No. 6, of its Journal.

The Gemmological Association considers that while the term "topaz-quartz" is preferable to "quartz-topaz," the expression "topaz" is undesirable as a colour adjective, and that this controversial subject requires a bold and logical decision.

GIFTS TO THE ASSOCIATION

The Council of the Association acknowledges gifts of specimen stones from Wilson & Gill (London), Theo Stern (London), M. Weinstein (London), W. Steinfels, Ltd. (London), J. H. Underdown (London, W. Nathanson (London), and a donation from E. W. Maton (Cardiff).

CORRECTION

Vol. II, January, 1949, p. 5, fig. 3. For "almandine" read "demantoid."

Ibid., p. 16. For "A. S. Alexander" read "A. E. Alexander."

AUSTRALIA

A conference of the Lecturers in Gemmology of the State Branches of the Gemmological Association of Australia was held in Sydney on Saturday, 5th February. Those present were: Dr. D. P. Mellor, President of the G.A.A.; Mr. A. Wirth, President, N.S.W. Branch; Mr. J. S. Taylor, Secretary of the G.A.A.; Mr. Whitworth, N.S.W. Lecturer; Mr. R. O. Chalmers, N.S.W. Lecturer; Mr. H. E. E. Brock, S.A. Lecturer; Mrs. S. G. Whincup, Victorian Lecturer; and Mr. Robinson, Queensland Lecturer.

In opening the Conference, Dr. Mellor pointed out that this Conference was the result of a recommendation made at the last Federal Conference.

Dr. Mellor referred to the extension of the Diploma Examination and that the centres of study were widely separated and the Lecturers had the problem before them of sorting out any difficulties or discrepancies which might occur in the Syllabus or lecture material. He stated how important he thought it was to keep the standard of the examination high and comparable with the British standard, and said that he fully realized what a difficult problem it was to keep the same standard from year to year, as he had found from his own experience in other fields.

The President then touched briefly on the Post-Diploma Courses and Research Diploma, and repeated the remarks that he made on the same subject at the Federal Conference, in which he emphasized the importance of making this Research Diploma cover something in the nature of original work, preferably but not necessarily in the nature of some original investigations into Australian gems.

Dr. Mellor then turned the conduct of the meeting over to Mr. Wirth, the Chairman, who endorsed the welcome given by Dr. Mellor and thanked the Lecturers for the co-operation they had given to the Association. He pointed out that without the assistance of the Lecturers the Association would not be where it was to-day, and he knew that this fact was appreciated by all concerned.

The conference went on to discuss the many subjects of the agenda. Revisions were made to many of the lecture papers of the Preliminary and Diploma courses; some subjects are to be re-written and amendments added to bring them up to date to include recent development and discovery.

Among the subjects continued and discussed was the advisability of:

(*a*) Post-Diploma study.

(*b*) The need for more equipment and specimens.

(*c*) Text and reference books to be recognized and recommended.

(*d*) The possibility of a Research Diploma.

It was recommended that the Diploma practical examination time be extended to four hours and that the theory examination should remain at three hours to be held on a night prior to the practical. It was also recommended that a Conference of Lecturers should, if possible, be held at regular intervals and in different capital cities.

A highlight of the conference was an able demonstration by Mr. H. E. E. Brock, F.G.A.A., of a number of ingenious instruments and aids to more simple and rapid gemstone determination and investigation.

Results of Australian 1948 Diploma Examination

November, 1948, saw the second Diploma Examination held in Australia and the Association is happy to announce that they had a record number of 94 candidates (including one correspondent student), covering the four states of the Commonwealth.

Following is a list of successful candidates arranged in alphabetical order and in their respective States, who have qualified for a Fellowship Diploma of the Association:

NEW SOUTH WALES

Cambridge, J.
Casey, A. K.
Davies, E.
Freeman, A.
Garvin, J.
Green, L.
Greene, K.
Giles, R.
Jeremy, Miss R.
Jopling, A. V.
Merrington, A. W.
Messenger, W. F.
Morris, B.
Plowman, E. J.
Proud, S.
Stuart, B.
Tofler, Miss S.

QUEENSLAND

Acton, C. F.
Arthus, J. H.
Evans, H. D.
Hay, C. A.
Johnston, J.
Lewis, A. R.
Maxwell, D.
Morrow, A. S.
Nissen, C. E.
Nissen, L. W. R.
O'Neill, R. L.
Parker, G. H.
Shaw, A. E.
Steele, A. G.
Steinmuller, G. S.
Wheatley, Miss P.

MELBOURNE

Aiyard, F. A.
Bilney, J. F.
Black, R.
Burrows, M.
Feltham, C.
Funston, W. E.
Locke, K.
Newland, W. G.
Rumbold, S. D.
Vanderkelen, P. W.

ADELAIDE

Abbott, A. M.
Bartram, Miss E.
Brock, H. E. E.
Burgess, C. R.
Campbell, P. C.
Dunbar, W. R.
Earl, A. W.
Heath, R. D.
Ibbotson, K. B.
Jenkins, M. A.
Kavanagh, L. R.
Leak, K. M.
Lyons, J. B.
McCabe, P.
Offe, Miss J.
Quilliam, A.
Roder, A. E.
Shiels, J.
Stead, R. A.
Williams, L.
Zeising, R. C.

Mr. John H. Pope, of Melbourne, who qualified in the Fellowship Examination of the Gemmological Association of Great Britain in 1946, was also successful in obtaining qualification in the 1947 Diploma examinations of the Gemmological Association of Australia.

ANNUAL GENERAL MEETING

The 18th (third since incorporation) Annual General Meeting of the Association was held on Wednesday, March 23rd, 1949, at 7 p.m., in Prince Henry's Room, 17, Fleet Street, London, E.C.4. Mr. F. H. Knowles-Brown, who presided, welcomed members and referred briefly to the history of the 340-year-old room in which the meeting was held.

On the proposal of Mr. R. Popley, seconded by Mr. J. H. Stanley, the adoption of the Annual Report and Accounts was unanimously approved. Mr. Popley referred to the good work done by the Association during the year under review, and specially mentioned the Gemmological Exhibition, Dr. Gübelin's lecture on "Inclusions in Gemstones," and the various interesting films that had been shown. He also emphasized the need for the Association to continue to work for the benefit of the jewellery industry.

The President, Dr. G. F. Herbert Smith, remarked that H.M. Queen Mary had been most impressed with the Exhibition, and that it had undoubtedly enhanced the prestige of the Association.

The following Officers were elected for the ensuing year:—

President—G. F. Herbert Smith, M.A., D.Sc.; Chairman—F. H. Knowles-Brown, F.S.M.C., F.G.A.; Vice-Chairman—G. F. Claringbull, Ph.D., B.Sc., F.G.S.; Treasurer—S. F. Bones, F.G.A.

The following Fellows were re-elected to serve on the Council: Messrs. R. V. Blott, M. L. Crombie, T. G. Jones and R. K. Mitchell.

Messrs. Watson Collin & Co. were re-appointed as Auditors to the Association.

The Chairman thanked the Officers, Council, Members and staff for their support during the past year which had been most happy and beneficial to the Association.

The general meeting was then declared closed, and Mr. Knowles-Brown instituted a discussion on future activities of the Association. It was recommended that instructive films on general subjects should be shown during the forthcoming year, and that more information should be made available about gemstone inclusions. Other matters relating to the 1949 Exhibition, close co-operation with the jewellery industry, general policy and social activities were referred back to the Council.

A vote of thanks to the Chairman was proposed by Mr. S. F. Bones, seconded by Mr. R. V.Blott, and carried with acclamation.

EXAMINATIONS IN GEMMOLOGY

The 1949 Examinations in Gemmology will take place as follows:—

Preliminary—Wednesday, June 15th.

Diploma (Theory)—Thursday, June 16th.

Diploma (Practical)—

Edinburgh—Monday, June 6th.
Glasgow—Tuesday, June 7th.
Plymouth—Thursday, June 9th.
Birmingham—Friday, June 10th.
London—Friday, June 17th.
Overseas—Friday, June 17th.

All entries should reach the Director of Examinations, Gemmological Association of Great Britain, 93/94, Hatton Garden, London, E.C.1, not later than May 4th.

"OPERATION DIAMOND"

On Monday, March 14th, a recently produced film, "Operation Diamond," was shown to members of the Association at the British Council Cinema. The film told two interesting and true stories in which diamonds were the centre of interest and around which the story of diamonds from the mine to jewellery was told.

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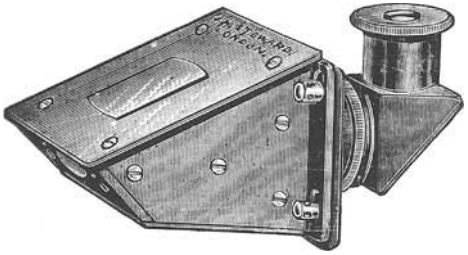

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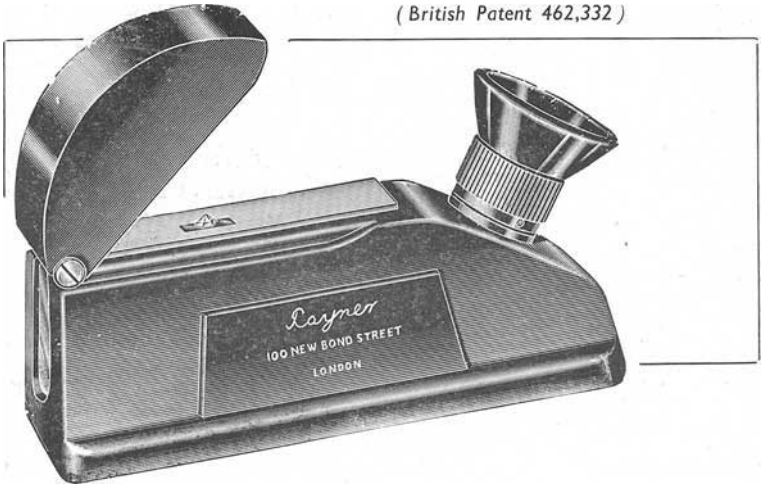

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PROCEEDINGS OF THE

GEMMOLOGICAL ASSOCIATION OF GREAT BRITAIN

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THREE GLIMPSES OF THE PAST

by

B. W. Anderson, B.Sc., F.G.A.

BROWSING amongst the writings of older mineralogists is a pleasant and often a profitable exercise for the present-day gemmologist. Many a forgotten or half-forgotten fact is brought to light again and a fascinating insight is provided into the state of knowledge and the indefinable climate of thought of past generations.

The progress of Science has, of course, been enormous during the past century, and we can, from the vantage-point granted us by time, smile with unwarranted but pardonable condescension at the troubles experienced by even the masters of the past in distinguishing gemstones where advances in knowledge or the invention of new instruments or techniques have made these an easy exercise for the beginners of to-day. But, on the other hand, it might be argued that (partly due to the vagaries of fashion, which operate in Science as in all human activities) for every new technique developed an old one has been lost, or has become so rusty and dusty from disuse as to be practically unavailable to the modern worker.

These thoughts have been prompted by the re-reading of three quite unconnected papers written respectively some seventy, fifty and forty years ago, each of which has its own peculiar interest for the gemmologist of to-day.

The first and earliest of these papers formed the Presidential Address given by H. C. Sorby to the Mineralogical Society in 1877, and was published in Vol. 2 of the Mineralogical Magazine. Sorby described a simple method of determining the refractive indices of transparent mineral plates by measuring their real and apparent depth under the microscope, and some curious optical phenomena discovered while making such determinations. The principle of this method had already been given (unknown to Sorby) by the Duc de Chaulnes as early as 1767, but Sorby's investigations were far more thorough, embracing as they did the peculiar behaviour of light in doubly refractive minerals. Quite apart from their theoretical interest, his findings are of first-rate practical importance for anyone who is tempted to use this seemingly straightforward method of refraction index determination. It will be remembered that the method involves the measurement of the vertical difference of focus between the upper surface of a transparent body placed on the microscope stage and the surface of the glass on which it rests, both as seen through the specimen (" apparent depth ") and through air (" real depth "). For isotropic substances the formula R.I. = real depth / apparent depth holds to a close approximation.

With a standard petrological microscope the vertical displacement of the focus can conveniently be measured by means of the calibrated wheel of the fine adjustment, but this has a limited range and the thread, unless very well made, suffers from backlash, so that a more satisfactory arrangement is to have a scale and vernier attached to the stand and body of the microscope. Sorby had such a scale fitted, reading to 1/1000th inch, and by using a No. 2 eyepiece and 2/3 inch objective on isotropic specimens some ¼ inch deep was able to obtain refractive index readings with only slight errors in the third place of decimals.

By the same simple formula the *ordinary* ray of a uniaxial stone can be obtained, *but this is not true for the extraordinary ray nor for either of the two rays in a biaxial mineral.*

Instead of using dust particles or scratches on the glass plate supporting the specimen, Sorby found it more convenient to focus

on the image of a ruled grating, limited by a small circular diaphragm, which he fixed below an achromatic substage condenser with a small stop, the image being thrown just below the surface of the glass plate. It was by using this arrangement that the truly " extraordinary " behaviour of the extraordinary ray forced itself on his attention. He found that there were two foci for this ray. In neither was it possible to obtain an undistorted image of the circular hole or the grating, and in neither was a true refractive index figure given by the simple real/apparent depth formula! In biaxial minerals *both* images are found to be bi-focal and again the indices obtained by the formula were in no case true. Sorby demonstrated these phenomena at a Soirée of the Royal Society and the matter greatly interested Sir George Stokes, who investigated the problem energetically from the theoretical standpoint and was able a little later to publish a full explanation of the observed facts. (Proc. Roy. Soc., 1877.)

Thanks to Stokes's explanations, Sorby was able, with suitably oriented crystal plates, to calculate from the data obtained by his method both of the indices in uniaxial stones and all three indices in biaxial stones. Moreover, he could assess the sign and extent of the double refraction. In his hands, in fact, the method became of considerable power and flexibility.

And yet, after being rescued and brought to a new pitch of accuracy by Sorby more than a century after it was first discovered, the whole process was again and almost immediately relegated to the limbo of forgotten things. Relegated, astonishingly, even by Sorby himself ; for after preparing a detailed manuscript on the subject which was intended for the Royal Society, he shelved it for thirty years and only re-edited it for publication shortly before his death. This fuller account of his experiments was published posthumously (1909) in the Mineralogical Magazine ; but the most readily accessible account of Sorby's technique and results is in that valuable source-book, Tutton's " Crystallography and Practical Crystal Measurement " (1922 edition, pp. 1177-1183), which is to be found on the shelves of most Public Libraries.

I have myself always been attracted by the method and have used it from time to time with fair success when, for instance, a rough check was needed on the refractive index of diamond octahedra, for which the technique is more suitable than any other.

Not long ago Dr. E. H. Rutland carried out some tests for me in which the microscope objective remained stationary and the stone itself was raised or lowered into focus on the table of a small spherometer. This worked very well, but was rather cumbersome, and tricky in operation. Recently I have had a millimetre scale and vernier fitted to the body and tube of a Beck No. 10 London Stand which enables readings to 1/20 mm. (roughly 1/250 inch) to be made quickly and accurately. When time permits I hope to indulge in a more detailed explanation of the possibilities and snags for the practical gemmologist of this attractively direct method.

The second of three papers to which I referred above is of far more general interest to readers of this Journal. It forms the text of the two Cantor Lectures on " Precious Stones " delivered by Professor Henry Miers before the Society of Arts in 1896. Sir Henry Miers, as he later became, honoured us in his old age by becoming the first President of the Gemmological Association. At the time these lectures were given he was already one of the leading mineralogists in the country—and it must be remembered that the mineralogists were the gemmologists of those days. These lectures, therefore, give a very clear résumé of the state of gemmological knowledge in this country at the end of the nineteenth century.

In this same year, it may be noted, Bauer's great book, " Edelsteinkunde," was published in Germany, and though it is obviously unfair to compare the exhaustive treatment of the subject possible in a text-book with the brief summary required in two popular lectures, one is afforded an intriguing glimpse of the different methods of approach to the determination of gemstones adopted by contemporary mineralogists of the two nations.

In his first lecture Miers introduced his audience to a number of the lesser known gemstones, including sphene, andalusite, axinite, idocrase, phenakite, cordierite, spodumene and diopside, and projected them on the screen " by reflected light," i.e. by means of what to-day is called an epidiascope. He then gave a brief review of the methods by which stones can be discriminated, starting with hardness, to which he refers in the best modern manner. " It is not a character capable of any accurate measurement, neither is it to be recommended for use by inexperienced persons. I hope to show as I go on, that we have now accurate methods of testing at our disposal which render the trial of hardness quite unnecessary." He then passed on to brilliancy, total internal

reflection, dispersion, and the use made of these properties by the lapidary in enhancing the beauty of the rough material. This was followed by an attack (so often made by mineralogists) on colour as a basis for gem distinction ; and one cannot but agree with the instance chosen. " There are, for example, certain red stones which the most skilful experts cannot by their colour alone refer with certainty to ruby, garnet or spinel." But he does *not* add that " ruby, garnet and spinel " just about exhaust the possibilities for gems of this particular shade of red, and that the colour has, in fact, by enormously reducing the field, assisted greatly in the eventual identification of the stones.

Miers then (and this will surprise many readers) proceeds to describe the use of the spectroscope in identifying almandine and zircon—the two minerals in which absorption bands were first discovered by his friend, Professor Church. It seems curious that in the thirty years which had elapsed since Church first announced his discovery, the spectra shown by so many other gemstones should have remained unnoticed. The lecturer knew the value of observation by reflected light, for he says: " . . . it is not necessary to look *through* the stone, it is quite sufficient to place it in a strong light and look *at* it through an ordinary pocket spectroscope. . . In this way we are enabled to identify a jargoon or an almandine merely by looking at it. *There is no test so simple or so easy of application.*" I have to confess that the italics of that concluding sentence are mine.

To summarize the data for specific gravity and refractive index values of the various gems, Professor Miers presented them in the form of a graph showing the close relationship existing between these two properties in the majority of minerals, the main exceptions to the straight line ratio being diamond and sphene, in which the refractivity is high in relation to their density, and topaz, in which it is low. (Two other exceptions, demantoid and fluorspar, are not included in his diagram.) There is a link here between Miers and Sorby, since Sorby at the end of his paper gave, in addition to an excellent table of refractive indices, a list of the values for what he called the absolute refracting power of minerals, and it is very noticeable from this table that the values for $\frac{n^2-1}{d}$ are very nearly constant for the silicate minerals, to which group

most of the gemstones belong. The simple graphical representation of specific gravity and refractive index is to be commended to students who find remembering such data a troublesome business.

Miers' first lecture concluded by describing how the specific gravity of an unmounted stone could be determined by means of an accurate chemical balance, Westphal Balance, or by means of heavy liquids. For use in the latter method, methylene iodide was recommended, and for denser stones the fused mixture of thallium and silver nitrate, then recently discovered by Dr. Retgers. This mixture melts at 75° C. to a clear colourless liquid in which zircon just floats ; and, like the more convenient Clerici solution which we favour nowadays, is miscible in all proportions with water.

Miers' second lecture opened with an account of the optical methods of gem discrimination. He first described the minimum deviation method, in which facets of the stone to be measured are made to act as a prism on the table of a goniometer, and then referred to a primitive " reflectometer " of the Bertrand type, which was the crude prototype of the jeweller's refractometer which Dr. G. F. Herbert Smith was to design ten years later.

A curious time-lag is noticeable here. Professor Miers stated that the reflectometer could only measure refractive indices up to 1.66, this being " the greatest index of refraction yet obtained in any transparent liquid." The liquid to which he refers is, of course, bromonaphthalene. It is surprising that so well-informed a mineralogist should have been unaware of the much higher index of that same methylene iodide which he knew and recommended as a heavy liquid, since this value had been established by W. H. Perkin some years previously and was well enough known to Bauer, whose book, as already stated, was published in the same year that Miers gave his lectures.

The delayed-action effect of published information is admittedly not uncommon. Clerici solution, for instance, was first described in 1907, but did not come into regular use until nearly thirty years later ; and only now, more than 100 years after Brewster observed the absorption bands in cobalt glass, orpiment and other coloured substances, is the usefulness of the absorption spectrum method of identification becoming accepted by more than a few enthusiasts.

Miers proceeded by describing dichroism and the dichroscope, double refraction and polarized light, and by means of a projection polariscope showed his audience uniaxial and biaxial interference

patterns on the screen. To him, as a mineralogist, this technique seemed obvious and simple, though with faceted stones he admitted that immersion in a liquid of similar refractivity was generally necessary to enable the interference figures to be visible. Pyro-electricity, that curious property shown strongly only by tourmaline amongst the gem minerals, was included by Miers as a practical test, which he carried out by sifting through muslin a mixture of sulphur and red lead on to the specimen while it was cooling after being heated in the flame of a spirit lamp. " This test I have frequently applied and have never known it to fail," he stated. One wonders whether, had a practical gemmology examination been held in 1896, students would have been provided with a supply of powder, muslin sieve and spirit lamp as part of their routine equipment.

The newly discovered X-rays were mentioned briefly as affording a means of distinction between certain gems and their imitations. " True ruby or sapphire or true turquoise are like flesh —transparent to the X-rays ; but their imitations are like bones—opaque to them."

Miers was writing, of course, before the days of the Verneuil synthetics, but Frémy's synthetic stones were familiar to him. " Large numbers of artificial rubies are now used in jewellery. The only respect in which they differ from the natural stone is that they have been formed by a different process. If we desire to distnguish them it can only be by some feature resulting from the manner in which they have been made. From my own limited observations I think it is generally possible to see in the artificial rubies, by means of the microscope, a certain streakiness and also little cavities like bubbles which one does not see in the natural stones." (Those Frémy crystals which I have examined have shown features quite unlike anything seen in natural or Verneuil synthetic rubies ; the gemmologist's skill in recognizing characteristic inclusions seems for some reason not easily acquired by the mineralogist.)

Miers ended his lecture with so powerful a plea for scientific gemmology that I feel I must quote him at some length.

" In bringing to a close these imperfect and fragmentary notes on precious stones, I must call attention to the chief point which it is my desire to emphasize. I have indicated how I should myself

set to work to determine the nature of a precious stone. Each observer can use his own contrivances, but they must be in accordance with the principles which I have illustrated. The methods are those of physical science—and they are accurate ; personally, I should hesitate to assert positively the nature of any precious stone except by means of the scientific tests, although I might have an opinion. It may be my own want of expert knowledge which prevents me from feeling confidence in any but these methods ; at any rate, I claim for them that they enable anyone with a little practice to determine with absolute certainty any precious stone even when it is facetted, and, moreover, they supply, not an opinion, but a proof.

" Considering the number of serious mistakes which are made in the trade, and the curious errors which prevail, jewellers would surely do well to learn these methods, to acquire especially such a knowledge of crystal optics as will enable them to determine the refraction of any transparent material. . . The jeweller's trade stands almost alone in failing to realise that such a knowledge has a real commercial value, and ignoring the aid of physical science."

The irrefutable good sense of this appeal was slow in bearing fruit, but there must have been some present at these Cantor lectures who were later to help in the founding of the Gemmological movement in this country.

The third paper on which I wish to comment is also the reprint of an address, not this time by a scientist, but by a well-known dealer in precious stones, J. Chaumet, of Paris. His communication, entitled " Le Rubis," was delivered in 1904 before fellow-jewellers and merchants of the Chambres Syndicales. It gives a most interesting picture of what must be considered the more enlightened views on the subject which held in the Trade at that time.

Chaumet divided rubies into two main categories: natural and manufactured. Natural stones he further divided into (1) Oriental ruby, or simply " ruby " ; (2) Siam ruby ; (3) Balas ruby ; (4) Spinel ruby. Manufactured stones he classified into (1) Reconstructed stones ; (2) Manufactured or synthetic stones proper.

He quoted as an ancient authority the following passage from a book entitled " Dénombrement, facultés et origine des pierres précieuses," by M. L. D. S. D., published in Paris in 1667: " Le vrai rubis est une pierre diaphane, rayonnante et rougissante, teinte

d'une couleur écarlate et de la laque indique (indienne) ; son écarlate tire sur la sinople On découvre fort peu de couleur azurée dans le bout de leur feu ; car si l'on en découvre beaucoup, ils seraient appelés balai ; quand ils pesent plus de vingt carats, ceux qui sont parfait meritent le nom d'escarboucles. Les Indiens l'appellent tozez ou menea ; les Perses et les Arabes l'appellent iacu. Il y a quatre genres de rubis: le veritable est appelé rubis ; le rubacelle ; le balai ; le spinelle."

" Sinople " was a word of many meanings, but the reference here is probably to vermilion. That a stone should be called by a different name when it is over 20 carats was to me a new suggestion.

Chaumet recognized as Oriental rubies fine transparent examples from Burma or Ceylon which had the desired pigeon's blood or ox-blood red sometimes tinged with pink. He dismissed from further consideration balas and spinel ruby, which he recognized as having a different composition and which he and his colleagues had no difficulty in distinguishing. But on Siam rubies which (and this was news to me) had made their first appearance on the market between 1870 and 1880, he dealt at some length because of the great difference in value existing between these and Oriental rubies from which, on occasion, they could with difficulty be distinguished.

Chaumet referred to an actual dispute on a ruby of doubtful nuance which was sold as an Oriental ruby for 35,000 francs. The purchaser, suspecting that the stone was not, in fact, a Burma ruby and was thus worth far less than he had paid for it, wished to annul the sale. The matter was brought to court and submitted to the arbitration of the Chambre Syndicale, who, after minute examination of the stone, decided that the ruby was a Siam stone and that the sale should be annulled. The vendor appealed against this and the Court designated three experts to make a report on the specimen. Presumably Chaumet was one of the experts, since the examination was carried out in his laboratory.

He astonished and impressed his colleagues by exposing a Burma and a Siam ruby to the violet rays from an arc lamp ; the Burma stone glowed like a red-hot carbon, the Siam stone remained virtually inert. Examination in a phosphorscope gave a similar result, and by such means the stone under dispute was confirmed as being a Siam stone—even the vendor being satisfied that he had made an error.

How Chaumet projected violet rays (" ultra-violet " is not mentioned) on to the stones is not explained—presumably through some form of prism. Since his day ultra-violet light has been continuously used and widely regarded as a means for distinguishing between rubies from the two localities. The reason for the lower intensity of fluorescence in Siam stones is that they usually contain more iron than Burma stones, which has a quenching effect on the fluorescence. Dark Burma rubies, however, also show weak fluorescence and the method is, in fact, hardly more accurate or sensitive than judgment by eye on a colour basis. The atmosphere of scientific magic surrounding a test in ultra-violet light in a darkened laboratory is, however, far more impressive to the uninitiated and hence carried more weight. Actually, a far more accurate and scientific means of distinction is afforded by examination of internal structures under the microscope.

Chaumet then proceeds to undermine our faith in his scientific ability by quoting the results of his density determinations on the different categories of ruby. We are, alas! only too accustomed to seeing inaccurate figures for the density of precious stones quoted and re-quoted in books of the not-so-distant past, but Chaumet's figures, derived from his own experiments on " more than a hundred " specimens of Oriental, Siam, synthetic and reconstructed rubies, are not merely inaccurate, but show fairly consistent and well-marked divergencies between each group, where no such divergency does in fact exist. May I remind readers that the density values for gem quality corundum are very constant ; to two decimal places 3.99 is the figure for pure corundum and the variation does not exceed the limits 3.98—4.01. Remembering this, what can Chaumet have done to obtain the following results?

Oriental Rubies.—Minimum, 4 ; maximum, 4.06 to 4.08. Very rarely 4.08.

Siam Rubies.—Minimum, 4.20 ; maximum, 4.26 to 4.28. Very rarely 4.28. " I have never met a Siamese ruby giving 4.00."

Synthetic Rubies.—Minimum, 3.60 ; maximum, 3.75 to 3.80. Very rarely 3.80. " On one occasion only a synthetic stone gave me 4.00."

Reconstructed Rubies.—Minimum, 3.70 ; maximum, 3.76, a single case giving 3.87.

Chaumet's figures for " Oriental " rubies are what one might expect, since when using water for hydrostatic weighing there is always a tendency for results to be rather high, and the figure 4.08 has been obtained even by reputable mineralogists.

The values for Siam rubies, however, are quite inexplicable, unless he was working not with rubies at all, but with dense almandine garnets. Unfortunately, though he publishes photo-micrographs of inclusions seen in Burma rubies he does not show any of his " Siam " stones, which might offer a clue as to their authenticity.

With the synthetic and reconstructed stones, the only reason for figures so far below normal could be the inclusion of bubbles of fantastic size and number. One of his photo-micrographs of a reconstructed stone shows something of this kind, but a photograph of a synthetic specimen given for comparison shows the usual cloud of very small bubbles typical of a Verneuil stone.

Incidentally, this is the only clue one has to the fact that Chaumet is referring in his text to Verneuil synthetics and not to the Frémy rubies, as the name Verneuil does not appear anywhere in his paper. The paper in Comptes Rendues in which Verneuil first announced the success of his process had appeared two years previously (1902).

After pointing out quite clearly the main internal features by which natural and synthetic rubies could be distinguished under the microscope, Chaumet made the suggestion that with any important ruby a certificate of authenticity should be issued stating its provenance, weight, shape, colour, density, fluorescence, and notable internal features. With such a certificate could be issued a photograph of the mounted stone together with photo-micrographs of its inclusions. In making this suggestion (and carrying it out in practice in his own business) Chaumet was well ahead of his time. Very similar certificates are issued at the present time by the Paris Laboratory.

My account of these three addresses has already taken more space than was originally intended. I can hardly dare hope that I have interested others as profoundly as the papers themselves have interested me.

A Collection of United States Gems

OVER a number of years, Mrs. Virginia Hinton, of Houston, Texas, the first woman jeweller to receive the coveted awards of Certified Gemologist, of the American Gem Society, and of Fellowship of the Gemmological Association of Great Britain, has collected rough and cut gemstones found only within the confines of the continental United States. This started on a Western trip, where (as she says) a few poor garnets, a broken piece of aquamarine, some quartz and some blue topaz were found and they inspired the idea of a collection. She thought that a possible fifteen varieties might be available. That was the first step ; her American collection now has ninety-two species and varieties and might go to a ninety-six or a vaguely possible one hundred.

Some of this material she has actually dug herself on prospecting trips, some she has purchased from " mountain folk or plains people," and some from reliable mineral dealers. No one, that has not done it, can know the effort required to make such a collection. Each summer and sometimes in fall and winter (she explains the spring is not a good time), long trips have been made by automobile or train to obtain a single good specimen. Hundreds of letters have been written to other collectors and many disappointments have been encountered. Hard trips have been made on horse or mule back to sections where this is the only means of travel, where snakes, mostly rattlers, were very prevalent, and to what has been termed " Our Last Frontier," which is a hideout for those wanted by the Law. She has met many lovable characters and some not so lovable, some with most exceptional education and some with almost no education. This has woven itself into a richness of experience that has endeared each stone to her and often wrapped it up in a story of real life. Some people might think it is only a stone collection, but to Mrs. Hinton it is evidently palpitating and very much alive.

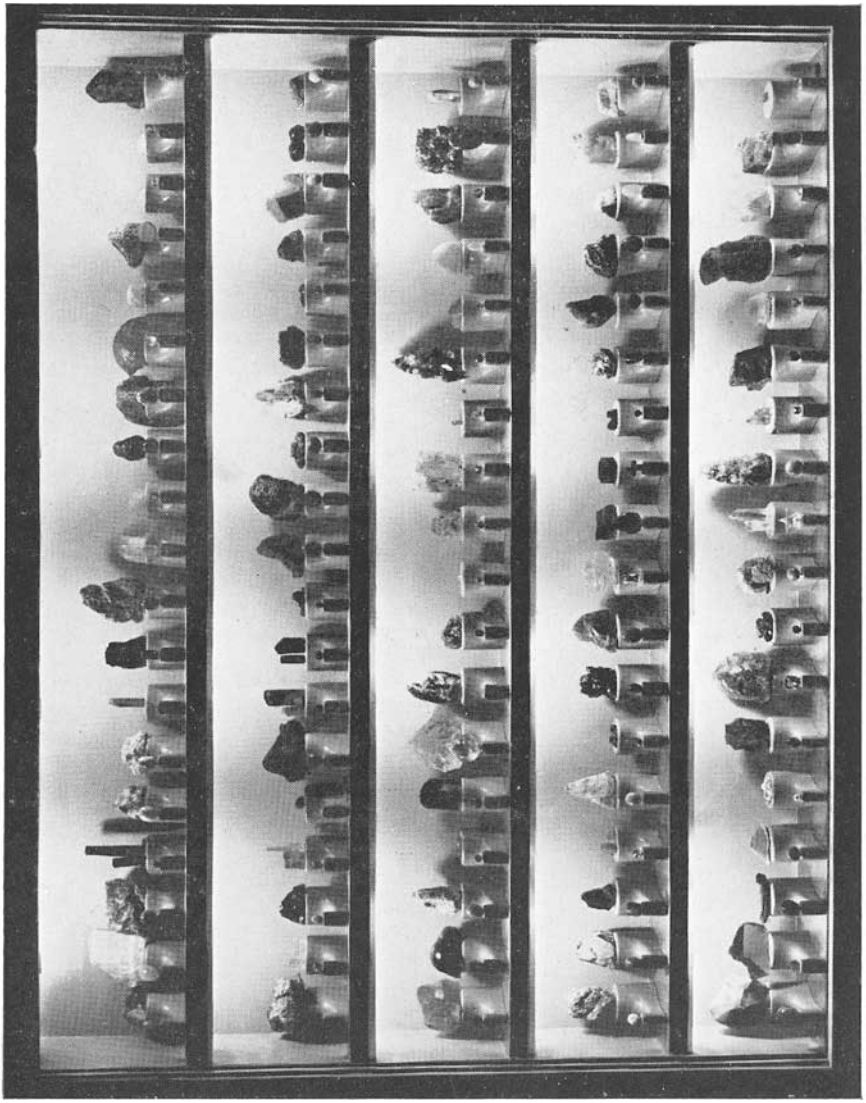

From a professional point of view the collection has been of great value, to this soft-spoken lady of the Southland, in her appreciation and actual knowledge of rare gems, and she is always ready to talk about the beauty, colour, form and

crystal structure of her specimens. Her great enthusiasm for gems and for perfection in her daily work as a jeweller led her into the study of display, and she designed unique cast aluminium stands showing the rough material and the cut stone directly in front of it ; also, after many cabinets were built, she now has one that has a series of lights under each shelf. The writer has had the pleasure of seeing and examining this American collection ; the colours were beautiful and the crystal forms varied and interesting. It also made him proud to know that there are so many gems in the United States.

The following is a list of the gems in her collection:—

Amber
Apatite
Azurite
Augelite
Beryl—Aquamarine, emerald, golden, Morganite
Beryllonite
Benitoite
Celestite
Cancrinite
Chiastolite
Chlorastrolite
Corundum—Ruby, sapphire
Diopside
Datolite
Diamond
Epidote
Feldspar—Moonstone, oligoclase, Amazon stone, sun stone
Fluorite
Garnet—Pyrope, hessonite, rhodolite, spessartite
Hæmatite
Howlite
Iolite
Jade—Nephrite
Jet
Kyanite
Lapis Lazuli
Lazulite
Malachite
Opal—Colours, opalized wood.
Obsidian—Colours, silver sheen
Pearl
Peridot
Phenacite
Phenite
Quartz—Rose, moss agate, mocha stone, iris agate, dumortierite, rutilated, Myrikite, chrysocolla, moonstone, hornstone, smoky, jasper, amethyst, rock crystal, fortification agate, plasma, blood stone, carnelian, aventurine
Rhodonite
Rutile
Scapolite
Smithsonite
Shattuchite
Spodumene—Kunzite, yellow, Hiddenite
Staurolite
Spinel
Sillimanite
Serpentine
Topaz—Brown, blue
Tourmaline—various colours
Turquoise
Variscite
Vesuvianite
Willemite
Zeolite—Messacite, Thomsonite

Mrs. Hinton is now trying to replace specimens with finer ones, thus building the quality of her collection. As in all collecting, whether it is silver, pictures or anything else, there are some pieces one never gets, but she says we always have the possibility of new finds being made or some new gem such as Benitoite or Brazilianite being discovered, and if so she hopes to be there.

Mrs. Hinton is manager and buyer for the fine jewellery department in a department store in her city.

SOME TESTS for PLASTIC IMITATIONS

by ROBERT WEBSTER, F.G.A.

THE gemmologist has for some thirty years known of plastic imitations of amber, and has equally well known of the use of a strong saline solution as a means of distinction one from another ; the " light " specimens being deduced as amber and the " heavy " pieces, by implication, as " bakelite." In those early days of gemmology, when any colourless stone which " looked like " diamond was glibly called a " jargoon," so any imitation which was not patently glass was called " bakelite," and truth to tell little damage was done. To-day the position is vastly different, for the chemist has given to art and industry many more materials, and older types in new guises. Indeed, this is truly a " plastics age," and the serious worker is not now content to just describe such pieces as " imitations," as " plastics," or even more crudely as " bakelite." He wants his diagnosis to be completely truthful and accurate, however base the material and however worthless it may appear to be, and this article is the record of some chemical tests, and other data, which experiment has shown to be useful in the distinction between various plastics.

" Plastics," an omnibus name used for a whole collection of synthetic products, are, in general, rigid substances which at some period in their production are plastic, hence the derivation of the " general " name. Only a small number of these substances have an application in gemmology, the majority being used as a vehicle for colour finishes in the paint industry, and these " lacquers," except in two particular cases, are of no concern to the student of gemstones. These materials, most of which can be truthfully described as synthetic resins (and here it may be pertinent to mention that in industry the natural resins are referred to as *rosin,*

while the term *resin* implys a synthetic production), are in one classification divided into two divisions, the *thermoplastic* and the *thermosetting* types. The thermoplastic types are characterized by their being plastic when hot and rigid when cold, while the thermosetting types, after once having been moulded by heat and pressure, remain rigid, however much further heat, within reason, is applied.

My discussion on plastics must suppose some knowledge of organic chemistry, a subject upon which the average gemmologist knows little ; therefore a few remarks on organic chemistry in so far as it applies to plastics, or synthetic resin formation, is indicated. Organic chemistry, unlike the better known inorganic branch of that science, utilizes relatively few elemental substances, the chief of which are carbon, hydrogen and oxygen ; indeed, organic chemistry has been described as " the chemistry of the carbon atom," and it is partly due to the incredible number of ways in which these three elements can combine together that the enormous variety of organic compounds are possible. Nitrogen, sulphur, phosphorus, the halogens and some metals (the latter having no significance in plastics chemistry) complete the list of chemical elements which enter into compounds in this chemistry of " life." Early chemists, owing to their inability to synthesize organic compounds, concluded that a mysterious agency—the so-called " vital force "—was an essential factor in organic composition, a view that was broken down by the synthesis of urea, a truly organic compound, by Wöhler in 1828.

One of the first things which strike a reader of text-books on organic chemistry, and in articles on plastics, is the peculiar system of shorthand used as formulae. We are all conversant with the formulae employed to show the composition of inorganic chemical compounds—and minerals, e.g. Al_2O_3 (aluminium oxide) ; a molecular formula representing one single substance only. In organic chemistry this does not hold good ; for instance, C_2H_6O represents both the molecule of a colourless gas—dimethyl ether, and the molecule of ethyl alcohol, a colourless liquid better known by the shortened form *alcohol*. That is, they are *isomers* of one another, and the difference is expressed by the use of the typical " glyptic "

formulae of organic chemistry, i.e.:—

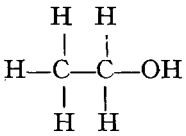

ethyl alcohol

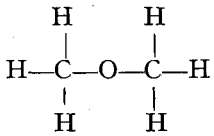

dimethyl ether

or put into another form which is often employed:—

$CH_3{\cdot}CH_2{\cdot}OH$ (*ethyl alcohol*) or $CH_3{\cdot}O{\cdot}CH_3$ (*dimethyl ether*).

In organic chemistry everything turns on the fact that carbon is tetravalent, that is, has four " bonds " or " arms " available for attaching to other like or unlike atoms, such as the univalent hydrogen with one " arm," or oxygen, which is divalent and therefore has two " arms." Thus methane, CH_4, may be written

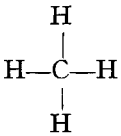

and acetylene, C_2H_2, is written as H—C≡C—H, the valency of carbon being satisfied by a triple " bond " between the two carbon atoms. This is known as an " unsaturated " compound, and although on paper this " triple bond " appears to be a stronger linkage it is actually not so. This is because the four " arms " of the carbon atom must be considered as reaching out in three dimensions at equal angles from the centre, that may be explained as reaching out to the points of a hypothetical tetrahedron (*Figure* 1),

FIGURE 1.

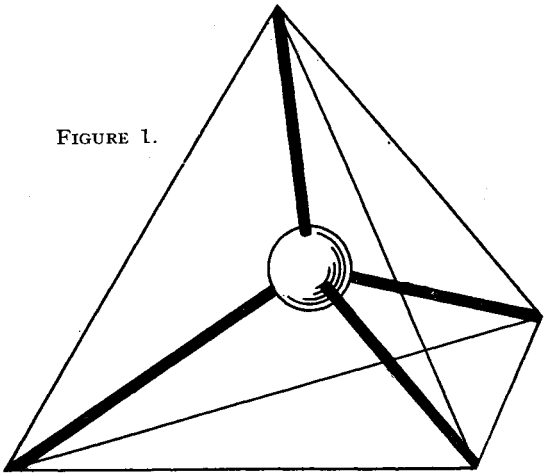

in fact the tetrahedral arrangement of carbon atoms in the atomic structure of diamond, and to bring two or more " arms " together must in fact produce strain. Formaldehyde, H—CHO, a compound of some importance in plastics chemistry, is expressed as:—

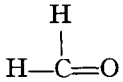

where the valences of oxygen and the two single valencies of hydrogen " satisfy " the four " arms " of the carbon atom.

It is now necessary to consider the structure of benzene, C_6H_6, and its symbol, the hexagon, so characteristic of organic formulae, which was postulated by Kekulé in 1867. This worker suggested that the six carbon atoms formed a closed ring in which " double " and " single " bonds occur alternately, thus:—

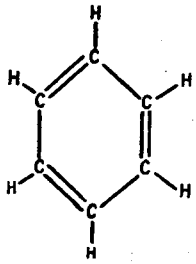

or represented simply as:—

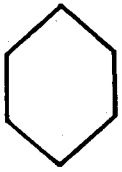

The observant will see in Kekulé's benzene ring an apparently unsaturated compound, whereas benzene is known to be very stable, and it is suggested that the bonds are satisfied in some internal manner connected with the natural angle of the hexagon. Further, any of the hydrogen atoms may be replaced by atoms of other elements and " radicals," such as the hydroxyl (—OH), the ethyl (—C_2H_5), the amino (—NH_2) and the carboxyl (—COOH) among many others. Thus the structure may branch in one of many different ways. Phenol or carbolic acid (C_6H_5OH) is one such substitution, the " graphic " formula of which is:—

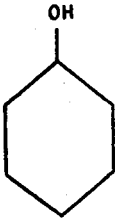

The fundamental processes of plastics depend upon the formation of " macro " molecules in long " chains " or " nets," which, except in the cellulosic plastics, are artificially formed. This formation of long chain molecules is carried out by either " condensation " or " polymerisation." Condensation may be briefly described as the attachment of two (or more) chemical groups by the elimination of water or other simple molecules, and may be illustrated by the formation of resin by the interaction of phenol and formaldehyde:—

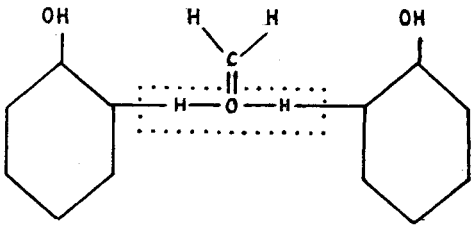

gives:—

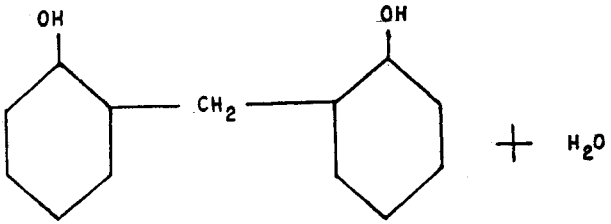

which by extension gives the net molecules of phenol/formaldehyde resin (the bakelite plastic), which, it must be remembered, are in three dimensions and not two as implied by the drawings in the plane of the paper. Certain condensations, however, particularly demonstrated by the polyamides produce long chain molecules of exceptional length, in fact fibres ; this being popularly known as *nylon*. The final product, Bakelite C, would have a net possibly like:—

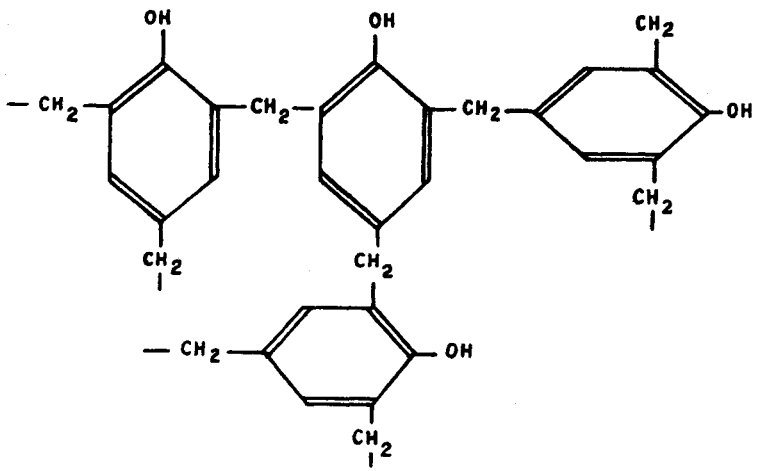

Polymerisation produces a chain extension of simple molecules by the joining up of molecules containing " double " bonds, e.g. ethylene, C_2H_4 or $CH_2{=}CH_2$, forms:—

$$CH_2{-}CH_2{-}CH_2 \longrightarrow CH_2{-}CH_2{-}CH_2,$$

which is formed by, what can best be described as, the spare bond in each " double " bond of the ethylene molecule swinging over to satisfy a similar bond in the carbon atom of the neighbouring ethylene molecule. This " polymerisation " being started by energising agents, such as heat or ultra-violet light, yielding *polyethylene*, a white, tough, but flexible, solid known as "Alkathene " or " Polythene."

The reader will now see that the problems of identification of a given plastic must depend upon the identification of groups or " radicals," because, unlike the compounds in inorganic chemistry, there are no metals to isolate. Indeed, it is to these " radicals " or compounds formed from them by reagents that identification by chemical means is obtained. Particularly is this the case where odoriferous or colourful compounds are produced, and the record of some of the methods which have been found of value experimentally is given in these notes, together with relevant physical and optical data.

THE CELLULOSIC PLASTICS.

CELLULOID.

Nitrocellulose, commonly miscalled cellulose nitrate, is made by the nitration of cotton linters or wood pulp, these being a pure cellulose which consists of naturally formed chain structures produced by the joining of " glucose ring " molecules. The cellulose is treated with sulphuric and nitric acids till the nitrogen content is about 11 per cent., and is " lubricated," or as it is termed " plasticized," with camphor. It is well known that celluloid is extremely inflammable, leaving a fibrous ash, and when rubbed or worked emits the smell of camphor. The density for the purer material is 1.35, but may rise to 1.80 or over when containing " fillings," and the higher values are particularly evident in the ivory and white colours. The refractive index has a range between 1.495 and 1.520, and the hardness, in common with all the plastics, is low, about 2 on Mohs's scale, and further, the material is readily sectile.

Peelings of celluloid heated in a closed tube (a test tube) give off fumes which are acid to litmus and are negative to a test for hydrogen sulphide. The most conclusive test for celluloid, however, is a delicate one for the detection of free nitric acid ; it is a test requiring little preparation and does *no* damage to the specimen providing the spot of reagent is removed immediately after testing. The test is carried out by placing a spot of a 5 per cent. solution of diphenylamine in concentrated sulphuric acid (sufficient quantity for years of use may be made by dissolving .5 gram, that is 2.5 carat, of the diphenylamine in 10 c.c. of sulphuric acid) on to the surface of the specimen to be tested ; if the material is celluloid the pale brownish coloured liquid turns to a deep blue. No such change of colour was found to be produced by any of the other plastics, or by the natural products, amber, ivory, etc.

This test is also available for the detection of the " solid glass bead " type of imitation pearl ; for nitrocellulose is nearly always used as a vehicle for the guanine (fish scales). No colour change is found when the liquid is applied to the surface of real or cultured pearls, but to use this liquid on such material is hazardous, for the acid will tend to remain between the interstices or the crystallites and react with the calcium carbonate with detriment, which,

although not being immediately apparent, may become evident at a future time. Likewise, a negative result will be obtained with the hollow-glass sphere type of imitation pearl, unless the reagent is able to penetrate between the inner surface of the glass and the wax filling in order to get at the cellulosic/fish scale essence. NOTE: sulphuric acid should be kept from contact with the skin.

SAFETY CELLULOID.

Owing to the inflammability of ordinary celluloid a " safety celluloid " has been produced, in which the cellulose is " acetylated " by acetic acid and not " nitrated," thus producing a cellulose acetate which burns much less readily with a characteristic blue-edged flame, with the formation of droplets of fused material and the emission of a vinegary smell. The density of the pure material is lower than that for ordinary celluloid ; it is 1.29, which may be increased by " fillers " to 2.00. The range of refractive index was found to be just lower than for celluloid of the ordinary type, that is, from 1.490 to 1.510.

Peelings heated in a closed tube behave like celluloid in giving off fumes which are acid and negative for hydrogen sulphide, and, again like celluloid, the safety material softens with acetone, but *not* with amyl acetate, which does soften ordinary celluloid. The most conclusive test (if a positive result can be obtained) is one depending upon the production of the " ester " ethyl acetate when peelings of the specimen are placed in a test tube with a small quantity of ethyl alcohol (ordinary methylated spirits will do), a drop of sulphuric acid added and the mixture gently heated, when, preferably after cooling and perhaps decanting into water, the characteristic apple-like smell of ethyl acetate becomes apparent, the chemical reaction being:—

$$\underset{\textit{acetic acid.}}{CH_3COOH} + \underset{\textit{ethyl alcohol.}}{C_2H_5OH} = \underset{\textit{ethyl acetate.}}{CH_3COOC_2H_5} + \underset{\textit{water}}{H_2O}$$

OTHER CELLULOSIC PLASTICS.

In recent years several new modifications of cellulose plastics have been produced, such as the mixed ester of aceto-butryate cellulose and the cellulose ethers of ethyl, methyl and benzyl. Of these plastics, none of which have been experimentally worked upon by the author, little can be told as far as the scope of this article is concerned. From manufacturers' literature ethyl cellulose

and benzyl cellulose are insoluble in triacetin, whereas celluloid and safety celluloid dissolve in this chemical. Ethyl cellulose is made by the reaction of ethyl chloride upon alkali cellulose and the pure material ; a granular white product is said to have a density of 1.14 and a refractive index of 1.47. How these values would be affected by processing and plasticizing will only be known when experimental determinations are made on finished products.

PROTEIN PLASTIC.

FORMALIZED CASEIN.

The familiar horn-like plastic which is variously known as " Galalith," " Lactoid," " Ambroid," " Sicaloid " (French), and " Casolith " (German), is a product of the formalization of milk, skimmed milk being coagulated by rennet or acid, pressed or extruded, and finally " cured " by formaldehyde (a pungent gas, but actually used as the 40 per cent. aqueous solution known as " formalin "). The density of the casein plastic is more restricted in range than are the cellulosic and bakelite plastics, it being nearly constant at 1.33 (range is 1.32 to 1.39) and the refractive index is 1.55.

Casein chars but does not burn, a smell of burnt milk being perceptible. In the closed tube peelings of casein give off fumes which are alkaline to litmus and positive for hydrogen sulphide. It may be appropriate to mention at this stage a method whereby these fume tests may be easily and accurately carried out with small quantities of test material ; this is by closing the end of the test tube containing the test peelings by a bored cork fitted with a short glass tube (the pourer corks with glass nozzles supplied with bottles of lighter petrol are eminently suitable) into which is inserted a small strip of the moistened test paper—red litmus paper if alkaline fumes are anticipated or blue paper if the fumes are suspected to be acid (both papers could be put in the tube together) ; a strip of filter paper moistened with lead acetate solution (sugar of lead) will detect hydrogen sulphide, the test paper turning brown if the evil-smelling gas is evolved. (*See figure 2.*) This method ensures that all the fumes pass the test paper and thus allow small quantities of material to be used. It is preferable to use as small a test tube as possible.

With casein, however, there is a test more easily carried out and which is quite characteristic for this plastic. A spot of concentrated nitric acid (the jeweller's *aqua fortis*) applied to the surface of casein produces a permanent yellow stain due, presumably, to the production of xanthoproteic acid, and may be analogous to the similar action of nitric acid on the skin. NOTE: Do not test any plastic with diphenylamine solution on the spot where a nitric acid test has been carried out, for some of the free nitric acid will have remained and give a positive blue coloration to the diphenylamine solution, which is a very delicate reagent.

A protein plastic has been made from soya bean, but has been used solely in association with phenol for motor car parts by the Ford organization. No notice is taken of this " hybrid " type as its use appears to be contra-indicated for an ornamental plastic likely to be encountered by the gemmologist.

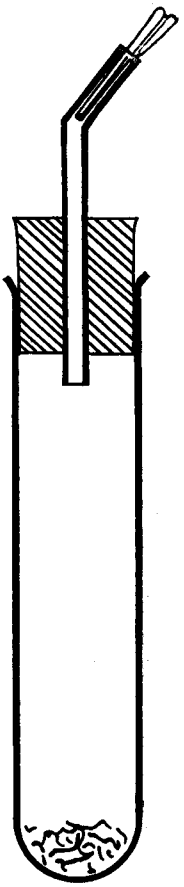

Figure 2.
Test tube containing peelings with "restriction" tube fitted and test paper inserted.

THE BAKELITES.

PHENOL/FORMALDEHYDE RESIN.

The plastic to which the name " bakelite " is normally applied is the phenolic resin, which has until quite recently been the one outstanding plastic with which the jeweller had to contend, for most amber imitations are made from this material, and many fine, colourful and transparent stones and " ornamentals " are made from " Catalin," a type of phenolic resin which is cast and not pressure moulded, as are most of the dark coloured bakelites used for utility articles. The chemical composition of this resin has been discussed in the introduction and needs no further comment, nor will it, for the purposes of this article, be necessary to discuss the complex methods employed in the manufacture of the bakelite resins. It may be as well to note that in bakelite condensation the formaldehyde could be replaced by furfural, giving a

furfural/phenol polymer which is employed in the United States for a " bakelite " which is sold under the trade name " Durite."

The only two tests known to gemmologists for distinguishing bakelite are those of density and refractive index, and these can be completely successful only when the values of both constants can be obtained and, one might add, with ease. How often can both these values be determined in " set " conditions or when carved? Less sectile and slightly harder than the celluloids, the density of bakelite ranges from 1.26 to 1.67, the higher values being due to " filling," while the cast resin has, according to makers' literature, a density range of 1.27 to 1.35 (experimental determinations on a number of pieces of " Catalin " gave an even more restricted range of 1.32 to 1.34). The refractive index varies betyeen 1.57 and 1.70, but is usually restricted to between 1.61 and 1.66.

Phenol bakelite chars but does not burn, the characteristic odour of phenol (carbolic acid) being given off. Fragments heated in the closed tube give off fumes which are, strangely enough, strongly alkaline to litmus. It would be thought that they would be acid, as phenol is known as carbolic acid, but it is an extremely weak acid and, moreover, is in combination with formaldehyde. The fumes are found to be negative for hydrogen sulphide. There are several satisfactory chemical tests for free phenol and one would expect the distinction of the phenol in bakelite to be comparatively easy, but this is not so, for the phenol is so tightly held in the molecule that insufficient can be released to influence the usual chemical reactions required to determine phenol. It is known, however, that phenol may be detected, even if in very small amounts, by the use of 2.6 dibromoquinone-chlorimide, a bright yellow powder, and experiment has shown that phenol bakelite may be easily identified by testing for the minute amount of free phenol that has been leached out by water, a method which does not cause damage to the specimen.

The method found most effective is to boil the specimen, if small, in a small quantity of distilled water contained in a suitable vessel (say a boiling tube) ; or, if the specimen be large, to take a peeling or scraping and similarly boiling in 1 or 2 c.c. of water in a small test tube (3″ x $\frac{1}{4}$″), allowing to cool and then dropping in the water a *very* small pinch of the yellow powder 2.6 dibromoquinone-chlorimide, and then, from the end of a glass rod, allow

to trickle into the tube a *very small* drop of caustic soda solution. The production of a blue colour (bromchlorphenol blue) indicates free phenol and therefore bakelite. Care should be taken to use only the merest trace of caustic soda solution, for phenol blue is an indicator and is only blue between very definite limits of alkalinity (pH 5.5 and pH 4.5), below which the liquid turns green and then yellow, and if acidified a red colour is produced.

AMINO PLASTIC.

UREA/FORMALDEHYDE RESIN.

These resins are obtained by the condensation of urea—$CO(NH_2)_2$, sometimes called *carbamide* (or its sulphur analogue—*thiourea*, $NH_2 \cdot CS \cdot NH_2$), by formaldehyde ; that is, instead of phenol, urea is used, the condensation producing a network structure as in the case of the phenol bakelites, but of a type not definitely understood. Better known under the trade names "Beetle," "Pollopas" and "Scarab," the amino plastics produce colourless resins which can be tinted delicate pastel shades.

Except perhaps in the white coloured material, the urea/formaldehyde resins are rarely incorporated with "heavy" fillers, hence the density is rather more constant, the values being 1.48 to 1.55, although Morrell (*Synthetic Resins and Allied Plastics*, 1937) gives values to 1.60, and the pure material at 1.48. A few pieces of "Beetle" tested for specific gravity gave values not far removed from 1.50, with white material reaching to 1.54. The refractive index has a range of from 1.55 to 1.62 ; here again Morrell gives the higher figure of 1.66 for the upper limit. The hardness is just about 2 and, like bakelite, tends to chip rather than peel, being thus differentiated from the celluloids.

In a flame the urea resin chars and gives off a smell not unlike that of casein, but distinctly more pungent. When destructively distilled, fumes are given off which are alkaline to litmus and show a positive reaction to the lead acetate test for hydrogen sulphide. Ammonia is also given off which can be detected by filter paper wetted with Nessler's solution (an alkaline solution of potassium mercuric iodide which turns brown when ammonia is present and is a delicate test for this compound). The question of separating casein from urea resin is easy, for despite the similarity of these

reactions, for urea/formaldehyde resin does not give a yellow stain with nitric acid as is the case with the protein plastic.

ACRYLIC RESIN.

POLYMETHYLMETHACRYLATE.

Well known as " Perspex," the water-white glass-like material so much used for aircraft windows, this plastic can also be obtained in many transparent and opaque colours, and has been used to some extent as " gemstones " for costume jewellery and for the " core " of solid imitation pearls. The resin is a methylated acrylic acid, derived from ethylene, and is polymerized into long chain molecules.

Perspex is very sectile and has a very constant density of 1.18 to 1.19 in the transparent white or coloured material, thus will float on a saturated solution of salt in water. As experiments have been carried out solely on transparent material it is not known with accuracy whether higher densities occur with the pigmented or " filled " material. Text-books seem to give no information on this point, but, by analogy with the rise in density due to " fillings " in the case of other plastics, nothing greater than .2 increase in the density values should be possible. The refractive index of Perspex is near to 1.50.

The acrylic resin burns with a spluttering flame, giving off a sickly, sweet-smelling odour, and when heated in the closed tube gives off a heavy white inflammable vapour which is denser than air, and a liquid, first considered to be water, condenses on the cooler part of the tube. However, experiments with anhydrous copper sulphate proved this liquid not to be water, and by fitting a cork and bent delivery tube to the closed tube, the distillate was collected in a second test tube. It was found to be an amber-coloured mobile oily liquid with a similar smell to the heated plastic. Indeed, what happens is that the polymer (the resin), when heated to about 300° C., softens and undergoes rapid depolymerisation to the monomer—methyl methacrylate. Perspex is known in the United States as " Plexiglass."

POLYSTYRENE (Poly vinyl benzene).

In this plastic, a glass-like material which, like " Perspex," is used for the production of " costume gems " by the injection moulding technique, and for the cores of imitation pearls, the hypothetical group *vinyl* $CH_2 = CH—$ (which is ethylene with one hydrogen atom removed) takes the place of one hydrogen atom in the benzene molecule. This is *styrene* or *vinyl benzene,* and by polymerisation long chains of over 100 styrene molecules are formed, giving to the world a plastic with many outstanding properties—electrical and optical. The British material is known as " Distrene " and trade names for American manufactures are " Styron," " Lustron " and " Victron," and there is a post-war manufacture at the I.G. Farbenindustrie plant at Schkopau.

Polystrene has the remarkably low density of 1.05 (1.05 to 1.07 according to " Lustron " information circular) ; this is slightly less than for amber. The refractive index is 1.59. The material burns with a smoky flame giving off a sickly aromatic odour, and in the closed tube the plastic melts, gives off heavy white fumes which if ignited burn fiercely with a sooty flame. The fumes are neutral to litmus test papers and give a negative result to the test for hydrogen sulphide. However, distinction is made easy owing to the ready solubility of this plastic in such liquids as benzene, toluol, amyl acetate (but not acetone), bromoform, methylene iodide and α-monobromonaphthalene. After immersion in any of these liquids for a second or two the surface becomes sticky, an effect at once diagnostic and destructive, for the refractometer liquid will " do in " the surface of a specimen.

THE ALKYD RESINS (The glyptals).

These resins have an importance in the paint industry and, as far as gemmology is concerned, have, at the moment, no application. The inclusion of this resin is because these alkyds have to some extent superseded the cellulose lacquers, and there is every reason to suspect that they may be used as a vehicle for the fish scale guanine for coating imitation pearls.

The resin is formed by the esterfication of a polybasic acid, usually phthalic acid, and a polyhydric alcohol, such as glycerol (glycerine). By controlling the relative amounts of glycerol and

phthalic acid various polymers of different properties may be obtained, but the final polymerisation produces an infusible, brittle glass-like material insoluble in most solvents. These resins are easily tested, for if a small peeling be mixed with twice its quantity of resorcinol and moistened with concentrated sulphuric acid (the mix can be prepared on a 3 x 1 glass slip with the aid of a glass rod on to which the mixture sticks). The end of the rod with the mixture adhering to it is heated over a small flame until the sticky mass on the end of the rod becomes a dark reddish-brown colour. The rod is then stirred round in a beaker of water containing one pellet of caustic soda. The production of fluorescein (the water becomes a fluorescent yellowish-green in colour) indicates the presence of phthalic acid and therefore a glyptal resin.

A SCHEME OF TESTING.

In testing a suspected specimen for the various types of plastic, one, of course, will be influenced by first observations and will duly make such a test as is necessary for proof. If, however, no idea at all is obtained from first impressions, it is suggested that the tests are carried out in this order: *1.* Place a spot of the diphenylamine/sulphuric acid solution on the specimen—if a blue colour is produced the material is *celluloid*. *2.* If previous test was negative, try a spot of nitric acid—a yellow spot indicates that the specimen is *casein*. *3.* If previous tests negative, try the solubility with benzene or toluol ; if soluble then the plastic is *polystyrene*. *4.* If all previous tests negative, try sectility ; if the specimen peels easily Perspex or Safety celluloid is indicated. Try a spot of acetone, and if specimen is soluble the plastic is *Safety celluloid*. *5.* If result of previous test shows no quick solution by acetone, then prove for Perspex by seeing if a small peeling sinks or floats on a saturated salt solution. If it floats, as it should do if all other tests have been carried out correctly, the specimen is proved to be *Perspex*. *6.* If the specimen was found to chip rather than peel, the resin is probably either the phenol bakelite or the urea resin. Carry out the test with the 2.6 dibromoquinone-chlorimide ; a blue colour to the test water proves that the specimen is *phenol bakelite*. The test for ammonia will prove the plastic to be *urea resin*, all other tests having proved negative.

The glyptal resin would only be used as a coating for pearl essence, and here it might be mentioned only celluloid has so far been detected as the vehicle for fish scale guanine. One plastic which has sprung up in recent years has not been considered in this article. It is *poly vinyl chloride*, better known as P.V.C., and has been omitted from this work as it does not form solid rigid substances, but only rubbery coatings ; hence its inclusion was not warranted.

It has been the writer's intention to try and formulate " spot " tests for all the important plastics ; although this has not met with complete success, it is confidently suggested that all the plastics used in imitation jewellery can be differentiated by the tests given, and in the case of the important phenol bakelite, celluloid and casein, new and powerful methods are suggested which do not damage the specimen. In conclusion, it is my pleasurable duty to thank Mr. Harold Lee for his ready help and advice.

A LETTER TO THE EDITOR

Dear Sir,

With reference to the comments in " Marginalia " in Volume II, No. 1, in the Journal, two points about the colour of opal are raised in connection with Murphy's book, " They Struck Opal " :—

(1) Why the colour is always horizonal.

(2) Why the potch turns suddenly to colour.

The answers are not too difficult. The colour is always (with few exceptions) horizontal because opal is a solidified jelly—a silicate gel—found in the viscous state from a colloidal solution and it naturally assumes a horizontal bedding as does a jelly in a household jelly-mould.

Potch changes to colour because the conditions which produce the effect are intermediate between those which produce milky or dark potch and those which result in water opal or hyalite. When these conditions vary only a little the reflections are not possible.

Yours truly,

Australia. (Signed) G. Frank Leechman.

The Question of
DIAMONDS in CANADA

by D. S. M. Field, A.G.A.

FOR more than half a century geologists and mining engineers have debated the possibility of discovering diamond deposits in Canada.

Interest and curiosity in this question have been aroused by recent claims that gem diamonds have indeed been found in this country ; and in July, 1948, the " Gemmologist " published an account of a proposed expedition into Canada's northlands to be made by international geologists in search of a deposit of diamond-bearing rock.

That the alluvial diamonds found in the northern United States occurred in glacial drift carried thence from Canada has been conclusively established. So, before dealing with the question of Canadian diamonds *in situ,* let us consider the great continental glaciers which, radiating from three main centres in Canada during the Pleistocene epoch, deposited the debris in which the diamonds were found.

Many of us think of the Pleistocene epoch as a period of continuous glaciation and refer to it as the great " Ice Age." There were, however, several other important glaciations in the earth's history, the greatest of which took place in the Permo-Carboniferous period. Moreover, during the Pleistocene, there was not one but a series of glaciations—sometimes separated by long spells of warmth during which the climates of certain sections of Canada was more temperate than it is to-day.

At least four million square miles of North America were covered with glaciers during the Pleistocene epoch ; and the accumulation of ice and snow was so great that, in certain areas, its weight created depressions hundreds of feet in depth. Geologists estimate that some glaciers, at least, were two miles or more in

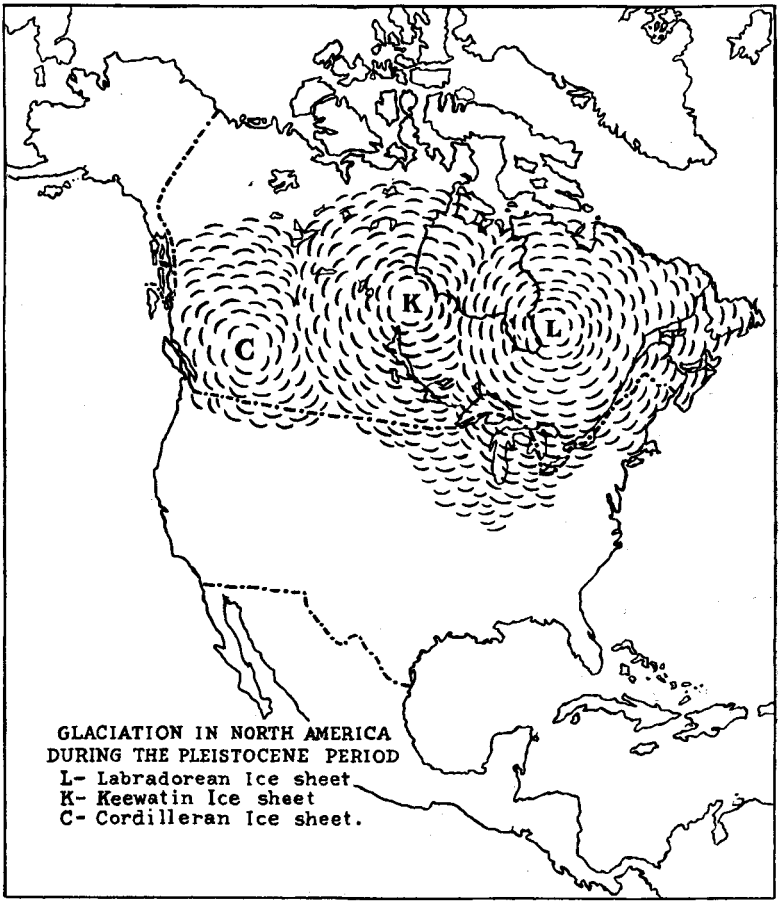

thickness ; and one has only to glance at a photograph of Greenland, as it is to-day, in order to get a realistic picture (on a lesser scale) of the topography of Canada during the Ice Age.

The glaciers of North America were developed by the precipitation of enormous quantities of snow over a large section of Canada ; but what caused the accumulation is not yet fully understood. Geologists are generally agreed, however, that not one but many circumstances were responsible, the most important of which was increased altitude ; for the epoch that immediately preceded the Pleistocene was one of uplift in many areas of North America.

As in the case of the Greenland ice-cap of modern times, the continental glaciers of Canada radiated in all directions from a centre of glaciation. There were three such centres during the Pleistocene, and these have been named the Keewatin (K), Labradorean (L), and Cordilleran (C), according to their geographical position (see map).

A fourth centre existed at one time in what is now the Patricia district of Ontario ; but with the advance of the Keewatin and Labradorean ice sheets, the centre was overwhelmed and obliterated.

The Keewatin ice sheet is estimated to have been well over a mile in thickness, with its centre just west of Hudson Bay. Its south-eastern flow joined the Labradorean sheet and extended far into the United States. The south-western border of the Keevatin ice sheet corresponded to what is now the valley of the Missouri River.

The Labradorean ice sheet had its centre just west of James Bay—to the south-east of Hudson Bay—in Ungava territory, Province of Quebec. From this centre it radiated outwards in all directions, extending southward into the United States as far as the city of St. Louis, Missouri. In some areas, the glaciers of the Labradorean ice sheet over-rode mountain peaks upwards of two miles in height ; and are themselves estimated to have been over two miles in thickness—at their centre.

The Cordilleran sheet had its centre in the Rocky Mountain region, from which it extended in all directions. But since it deposited none of the moraines in which diamonds have been found, the Cordilleran glaciers are of little interest to the gemmologist.

Because of the great thickness of the Pleistocene glaciers, many persons mistakenly entertain the belief that they were responsible for the removal of thousands of feet of solid rock from the Canadian Shield.

It is true, of course, that volcanoes and mountains, possibly two or three miles in height, at one time occupied parts of Canada which are now entirely mountainless ; but is a grave misconception to believe that these mountains were destroyed wholly by glacial action. For, while glaciers will most certainly erode rock faster

than weather and running water, these subtle agents of destruction were at work for a vastly greater length of time ; and geologists now agree that the mountains of the Canadian Shield were eroded away long before the Pleistocene, and that not more than a few tens of feet of solid rock were removed by glacial action.

Altogether, there were four recognized glaciations during the Pleistocene, each interspersed by periods of glacial recession during which parts of Canada were much warmer than they are at the present time.

During the interglacial stages of warmth, all glaciers (except the alpine glaciers in the mountains of the Cordilleran region of Western Canada) seem to have completely melted away. Evidence of this is to be seen in many parts of the Dominion, especially in the Don Valley and at Scarborough Cliffs, near the city of Toronto, Ontario.

This evidence is in the form of *till sheets* (composed of unstratified rock-flour and boulders), variously weathered and eroded, and with layers of sediments of intermediate deposition lying between them. In each case the sedimentary layer represents an interglacial period.

Some geologists who have made a special study of glaciation in North America believe that we are even now living in an interglacial stage ; for only about twenty-five thousand years (a period roughly one-eighth as long as some of the interglacial stages in the Pleistocene) have elapsed since the disappearance of the last of the continental glaciers from Canada. The question is, of course, beyond the scope of this article, but it is an interesting one.

The glaciers of the Labradorean and Keewatin ice sheets pushed great quantities of mud, sand, gravel, boulders, etc., of every size and shape, ahead of them as they advanced across the land, in south-westerly and south-easterly directions, respectively.

Thus armed, the destructive force of the glaciers increased ; for, frozen into the lower surface of the ice, the gravels, sands, and muds first ground, then polished the subjacent solid rock, and there are even yet many examples of a beautiful red jasper with almost a mirror polish still to be seen in parts of the Canadian Shield.

The softer rocks over which the glaciers passed were deeply grooved and scratched, the depth of the markings being in some measure an indication of the hardness of the rocks bearing the marks. Thus the ice-embedded stones left for us a well-marked trail to show the course of the glaciers that bore them far from the place of their origin.

Many of the stones embedded in the ice sheets were completely worn out ; others only partially so, or not at all. Many that survived the ordeal show numerous striae, often running in several directions across the stone, and indicating that its position in the ice was changed several times during its hazardous journey across the land.

The accumulations of debris carried by continental glaciers and deposited during the retreat of the ice (or otherwise) are known as moraines. Some of these deposits are of special topographical form and bear special names ; but these are of interest only to the geologist. It is sufficient to state here that many moraines deposited by the Labradorean and Keewatin glaciers exist in both Canada and the United States, especially in southern Ontario and in the State of Wisconsin, and it is in these moraines that diamonds have been found. . . .

The first official notice of the finding of a diamond in the United States was given by the late Dr. George Frederick Kunz(1). The diamond in question was uncovered at a depth of sixty feet by a well-digger in Eagle, Waukesha County, Wisconsin. The crystal was yellowish-white in colour, and weighed about 15 carats. The year was 1876.

Commenting on the nature of the gravel among which the diamond was found, Dr. Kunz wrote: " Having carefully examined a quantity . . . I have failed to find anything but the regular debris of glacial drift."

According to the late Professor William Herbert Hobbs, of the University of Wisconsin,(2) the woman on whose property the diamond was discovered kept the Eagle crystal for seven years as a curio, after which (not knowing it to be in fact a diamond) she sold it to a Milwaukee jeweller for a dollar.

(1) Kunz, in " Mineral Resources of the United States," 1883-84.

(2) Hobbs, in " Journal of Geology," May-June, 1899.

Later, when the identity of the crystal was established and the find made public, the woman offered to buy it back for a dollar and ten cents, and when her offer was refused she brought a suit against the jeweller for the full value of the gem.

In due course, the case was decided by the Supreme Court of the State of Wisconsin—in favour of the jeweller ; inasmuch as he was judged by the Court to have been as ignorant of the identity and value of the stone (when he made the purchase) as was the woman in whose well it had been found. (Obviously this jeweller lived in the Gemagnostian epoch—before the establishment of the Gemmological Association of Great Britain and the Gemological Institute of America.

Eventually, the Eagle diamond was purchased by the jewellery firm of Tiffany's Incorporated, New York City, and it is presumably still held in the Tiffany gem collection.

In 1886, a similar but larger Wisconsin diamond, weighing slightly more than 21 carats, was uncovered near Kohlsville by a farmer while ploughing his field.

During the next three years (1887-89), no fewer than ten small alluvial stones—weighing from 50 to 200 points each—(as well as a number of microscopic crystals) were found by gold prospectors in the gravel of Plum Creek, Wisconsin. These diamonds ranged in colour from yellowish-white through colourless to pale bluish-white.

No further finds of diamonds were reported in the State of Wisconsin until 1893, when two stones were picked up about twelve miles south of the city of Madison, and near Burlington, respectively. The former was a white stone of 4 carats in weight, but no description of the Burlington diamond is now available.

Three years later (in 1896), a 6½ carats white diamond was found in the possession of a German-American farmer living in Saukville, Wisconsin. It should be mentioned, however, that this stone had been in the farmer's possession for fifteen or sixteen years, making the year 1880 the probable date of the find.

Diamonds of gem size and quality have also been found in the States of Michigan and Ohio. In 1894, an 11-carat crystal was picked up in glacial drift near Dowagiac, Michigan, and another stone (colour and weight not given) was found at Milford, near the city of Cincinnati, Ohio. The Milford diamond is the last discovery mentioned by Professor Hobbs.

Said he: " No less than seventeen identified diamonds, varying in weight from ½ to 21 carats, have been discovered in the region of the Great Lakes of North America. That a considerable number of others have been found, which have not been reported because they have escaped identification, hardly admits of reasonable doubt, when it is borne in mind that three (3) of the stones found (including the two of largest size) remained in the hands of the farming population, without their nature being discovered, for periods of eight and a half, seven, and over fifteen years, respectively. If it were possible to visit all the houses of the lake region, I have no doubt that many diamonds would be discovered in the little collections of pebbles and local curios which accumulate on the shelves of country farmhouses."

All the diamonds described above were found in glacial drifts, except those found in the gravel of Plum Creek, which is very close to glacial deposits. The area in which the crystals were found measures about 600 miles in length and about one-third of that distance in breadth, with the geographical centre at Milwaukee, Wisconsin. In each case the diamonds were found in or near to glacial moraines composed, at least in part, of rocks and stones peculiar to the districts in Canada north of the Great Lakes.

Their exact place of origin is, however, uncertain ; but geologists are generally agreed that the diamonds of Wisconsin came from an unlocated Canadian source. Glacial moraines very similar to the ones found in Wisconsin occur in many parts of Ontario, but they have not yet been examined for diamonds.

The late Dr. Andrew C. Lawson, of the Geological Survey of Canada, suggested that diamonds *in situ* may occur in the Rainy Lake region of Ontaria. Commenting on this district, he said:

" The occurrence of bosses of serpentine suggests the possibility of diamonds, and some enterprising prospector may yet be rewarded for a close examination of the vicinity of the serpentine rocks . . . or of others that may be discovered, particularly if they be found near the cargonaceous schists that sometimes occur in the Keewatin."(3)

Dr. Lawson goes on to say that at several points in the Keewatin rocks he found evidence of extinct volcanoes, several of which were of immense size.

(3) Lawson, in " G.S.C. Report," 1887.

Carbon-bearing slates are of widespread occurrence in the Keewatin, and on the north shore of Lake Superior, at Thunder Cape, there is a thickness of at least 1,000 feet of carbonaceous slate traversed by dykes of diorite.

In 1900, a writer for the Ontario Bureau of Mines commented on the Thunder Cape area as follows:

" In conditions like these, where carbonaceous slates have been subjected to the influence of molten rock in the form of dykes and sills under great pressure, I think one ought to look for diamonds and expect to find them. The likelihood is not less in a large dyke in a volcano neck, if one of the theories of the origin of diamonds is true ; and we have been treated to too many surprises by new discoveries within the last ten years in Ontario to be deterred or dismayed by the man who says a diamond has never yet been found in a dyke or a sill in a formation of carbonaceous slate. But there are numerous other localities in northern Ontario besides the region of Thunder Cape where in like circumstances diamonds might possibly occur. I mention only one, the township of Balfour, near Sudbury, where a vein of anthracite carbon was discovered four years ago in a formation of fissile slate. Analyses made by Dr. Ellis showed the vein matter to give 7.42 per cent. of fixed carbon and the slate 6.8 per cent. Samples of slate from the same origin, recently analyzed, gave as high as 13 per cent. of carbon."

The actual existence of Canadian diamonds has not yet been definitely confirmed. Canadian geologists are apparently more interested in the search for metals and radioactive minerals. Years ago, microscopic diamond crystals were believed to have been discovered in the massive chromite of Black Lake, Megantic County, Quebec, and in the chromite of Reaume township, north of Porcupine, Ontario ; but in both instances the discoveries still lack official confirmation.

The same is true of the microscopic diamond crystals reported to occur in scattered groups and minute veinlets in connection with chromite and chrompicotite occurring in dunite in the Clinton and Similkameen mining divisions of British Columbia.

In 1948, several reports came out of northern Manitoba and Saskatchewan to the effect that diamonds had been discovered there ; but these, likewise, have never been confirmed.

The Saskatchewan " find " was reported as follows:—

" Saskatchewan may shortly be looked upon as a second South Africa if five diamonds, recently discovered in a wall of blue clay within 100 miles of Flin Flon, prove genuine. A northern prospector, John J. Johnson, has made application to the Department of Natural Resources for ' exclusive prospecting rights for diamonds ' in the province. He claims he has found five diamonds, one as big as a marble. He said a jeweller valued the rough stone at about 300 dollars.

" The Government is giving serious consideration to his request. W. J. Buchan, Director of Mineral Resources, points out that if the diamonds are genuine, it will mark the first time in Canada's history that these valuable stones have been found in this country. They were discovered in ' Kimberlite,' a blue stone in which diamonds are usually located."(4)

Since the above report was published, the writer has made extensive enquiries into the truth of the alleged find of diamonds in Saskatchewan. Here is what was learned:

The government of Saskatchewan drew up an agreement offering the prospector a tax-free concession of 300 acres, with the diamond deposits at the centre, providing that he could show them *one* diamond *in situ*. He refused the offer. If he were sane (and in the opinion of many he was not), this would seem to be too good an offer to refuse.

With regard to the report printed in the " Gemmologist," July, 1948, and based upon an article published in the London " Sunday Express," the Government of Canada has no information whatever relative to the " group of international geologists " who were supposed to be planning a trek into Canada's north country in search of diamonds.

The possibility of diamonds " somewhere east of James Bay " has long been discussed, however, and while the Canadian Government has taken no action as yet, the writer has been officially informed that something may be undertaken within the next two years.

What the results of such an investigation will be, no one can say. Are there diamonds in Canada? Many Canadians would like to find the answer to that question.

(4) " Trader and Canadian Jeweller," July, 1948.

PUBLICATIONS

The reappearance of "Gemstones," by Dr. G. F. Herbert Smith, is an event which has been eagerly anticipated for some time. Important additions and revisions have been made to the new tenth edition, which further strengthen its position as the most comprehensive and scholarly text-book on the subject—at least in the English language. Most striking is the chapter on crystallography, which has been expanded until, in the author's own words, it almost constitutes a treatise on crystal morphology. The section on organic products now includes ivory (animal and vegetable), bone, tortoiseshell, and in addition to amber, many other resins, both natural and synthetic. Extended treatment has been given to the subjects of synthetic emerald and absorption spectra. The new gemstones, brazilianite and synthetic rutile, are mentioned for the first time, as well as the interesting mineral, zincite. Several pages on the precious metals are added, but somewhat surprisingly no tests of identification or crude assay are given. Also little mention is made of the value and use of the microscope as a gem-testing instrument.

If any further criticism can be made, it is that while much space and time have been devoted to the external form of crystals, their internal architecture has been largely neglected. This is perhaps regrettable, as the properties of gemstones are best understood in the light of their atomic structure. Nevertheless, the field covered is astonishingly wide, extending from the analytical geometry of ellipsoids on the one side to the subtleties of classical translation on the other. Within, lie most of the important facts of some eighty or ninety gemstones and gem materials—their geography and composition, physical properties and identification, their origin and fashioning, history and romance, their counterfeits and trade significance. In this diversity of aspect—a reflection of its author's rare intellectual stature—is to be found the appeal of "Gemstones" to all whose interest in the subject is more than superficial. It is, of course, the indispensable companion to all serious students, particularly those proceeding to F.G.A. standard and beyond.

M. D. S. L.

Gemstones: G. F. Herbert Smith, Methuen & Co., Ltd., London, 1949, 10th edition (revised), XIX + 537 pp., 4 plates in colour, 40 in monotone, 145 text-figs., 35/-.

ASSOCIATION NOTICES

1949-1950 COURSES IN GEMMOLOGY

The 1949-1950 Classes and Courses in Gemmology will commence in September, 1949. Classes will be conducted at the following centres in Great Britain:—

London.—Chelsea Polytechnic, S.W.3.
Edinburgh.—Heriot-Watt College.
Glasgow.—Stow College of Engineering.
Birmingham.—Jewellers' and Silversmiths' School.
Plymouth.—Plymouth Technical Institute.

The Association's Correspondence Courses (Preliminary and Diploma) will be conducted on the usual world-wide basis.

Information about the Courses may be obtained from the Secretary of the Association. Inquiries regarding Classes should be made direct to the schools concerned.

GEMMOLOGICAL EXHIBITION

The 1949 Gemmological Exhibition will be held at Goldsmiths' Hall, Foster Lane, London, E.C.2 (by kind permission of the Wardens), on Tuesday, Wednesday, Thursday and Friday, October 4th to 7th, from 2 p.m. until 8 p.m. each day. Admission will be by ticket, for which application should be made after 15th August.

TALKS BY FELLOWS

B. W. Anderson: "Gemstones." Brighton and Hove Branch of the National Association of Goldsmiths, April 11th.

R. Webster: "Gems of the Sea" (Pearls and Coral). Central Y.M.C.A.; assisted by T. H. Bevis-Smith, March 26th.

K. Parkinson: "Testing Gems for Identification and Genuineness." B.H.I. demonstration talk, Estate Exchange, Manchester, April 19.

Mrs. G. I. Parry: "Precious Stones." Inner Wheel, Cardiff, May 9th.

E. H. Rutland: "Gemstones—their origin and uses." Artworkers' Guild, 6, Queen Square, W.C.2., June 10th. (Also the "Cutting and Polishing of Stones," by Mr. Bull-Diamond to the Guild on the same day.)

G. A. Blythe: "Gemstones." Southend Toc H., June 7th.

MEMBERS' MEETINGS

The Association is indebted to Sir James Walton, K.C.V.O., for an extremely interesting talk on the "Structure of Quartz," which was given at the Medical Society of London's Hall on Thursday, April 21st, 1949. Subsequently Sir James presented to the Association the models that he had used to illustrate his talk.

On Saturday, May 14th, the Association's Vice-Chairman, Dr. G. F. Claringbull, showed a party of members some interesting features of the mineral department of the British Museum (Natural History).

MEMBERSHIP

The following were elected to membership on May 4th, 1949:—

FELLOW:

M. B. Wade, London.

ORDINARY MEMBERS:

C. H. Bond, Virginia, U.S.A.
A. R. Harid, Colombo, Ceylon.

PROBATIONARY:

J. Best, Hereford.
M. J. C. Brocklehurst, Chorley Wood.
M. L. Butterfield, Leeds.
R. F. Cassidy, Worcester.
Miss M. Hutchings, Perth, W. Australia.
D. B. Mackay, Glasgow.
L. Penn, Birmingham.
V. S. Talbot, London.
D. F. Byrne, Chessington.
J. E. Campion, Plymouth.
C. Robson, Manchester.

GIFTS TO ASSOCIATION

The Council of the Association is indebted to T. Harding, 22, Gt. Pulteney Street, London, W.1., Messrs. Drewell & Bradshaw, Ltd., 25, Hatton Garden, London, E.C.1, for gifts of gemstones, and to Sir James Walton for a gift of models of quartz crystal structure.

AMERICA

At a meeting of the Board of Governors of the Gemological Institute of America in April, Edward H. Kraus, Dean Emeritus of the College of Literature, Science and the Arts of the University of Michigan, was elected for his fourth term as President of the Institute. At the same time, Fred J. Cannon, Vice-President of Koke-Slaudt & Co., Los Angeles, who served previously as a member of the Operating Committee, was elected Secretary-Treasurer of the G.I.A. to succeed C. I. Josephson, Certified Gemologist, of Moline, Illinois. Robert M. Shipley continues as Director of the Institute, which is located in Los Angeles, California, with Eastern Headquarters in New York City.

Elected to the Chairmanship of the Board for the second term was Paul H. Juergens, Certified Gemologist, Juergens & Andersen, Chicago. J. Lovell Baker, Certified Gemologist, J Henry Birks & Sons, Ltd., Montreal, will again serve as Vice-Chairman of the Board.

Members of the Board of Governors of the Gemological Institute of America are elected from the Sustaining Members of the Institute, numbering 89 at the present time. In a broadening programme to parallel the widely increasing demand for gemmological knowledge among jewellers and their customers, and in order to increase the number of eligibles from whom such officers may be elected, thus giving greater representation among progressive jewellers of the country, the Board voted to increase its Sustaining Membership by approximately 50 each year in the future.

PRESIDENT HONOURED

Dr. G. F. Herbert Smith, President of the Association, has been awarded the C.B.E. in the June, 1949, Honours List. It is a well-merited recognition of his services in connection with the preservation of the flora and fauna of the British Isles. Dr. Herbert Smith has for many years been Honorary Secretary of the Society for the Promotion of Nature Reserves as well as maintaining an active interest in the Gemmological Association, of which he was made President in 1942.

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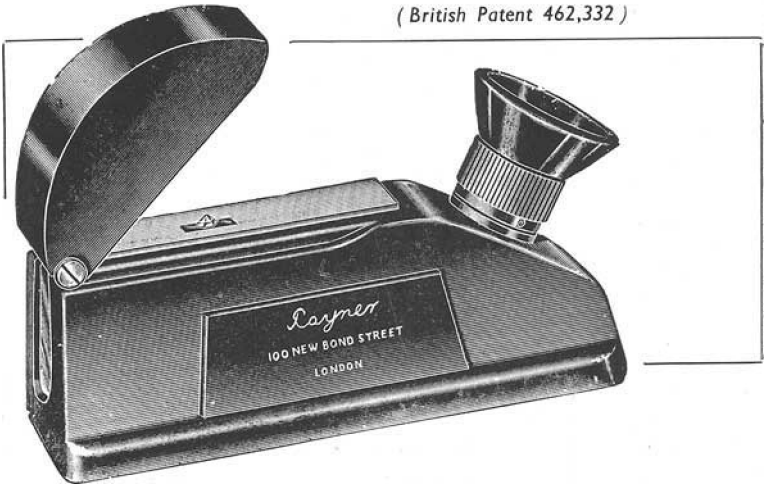

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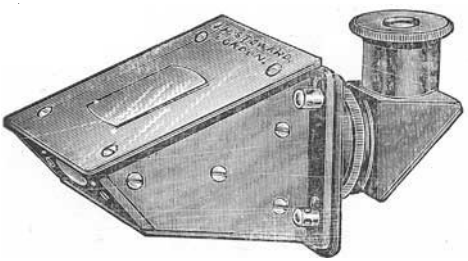

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Vol. II No. 4 October 1949

THE JOURNAL OF GEMMOLOGY

and

PROCEEDINGS OF THE

GEMMOLOGICAL ASSOCIATION OF GREAT BRITAIN

THE GEMMOLOGICAL ASSOCIATION
OF GREAT BRITAIN
19/25 GUTTER LANE, LONDON, E.C.2

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THE JOURNAL OF GEMMOLOGY
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Vol. II, No. 4. OCTOBER 1949

REFRACTOMETER ADVANCES in the U.S.A.

By B. W. Anderson, B.Sc., F.G.A.

UNTIL quite recently, the refractometers used by gemmologists in the U.S.A. were all of British manufacture. While these well-made and satisfactory instruments were available in plenty there was not sufficient incentive for any of the American optical firms to enter this specialized field.

The War altered all this. The manufacture of refractometers, even in normal times, is of course only a small side-line for firms engaged primarily in ophthalmic or other important work. In Britain, the vast demands of Government war-work, which claimed all the time of the most skilled workers, together with the lack of special materials such as the dense lead glass used for hemispheres and prisms, brought the production of refractometers completely to a standstill for several years. We in Britain had no alternative but to wait for better days, and " queues " of orders hundreds deep gathered on the files of the principal makers. The standard " Rayner," considerably improved, has mercifully been with us again for some time, also the perennial " Herbert Smith," but we still await the new model of the " Tully " and that useful accessory type, the Spinel refractometer.

Americans also had to wait ; but before the post-war supplies of the new " Rayner " had reached them they had evolved at least one model of their own, the " Erb and Gray." This incorporates

a very simple optical system of hemisphere, totally reflecting prism, scale, and eyepiece, the latter mounted on a swivel to traverse the scale. This has been followed by a still simpler instrument designed by Robert Shipley, Junior, and issued by the Gemological Institute of America. This sells for only 29 dollars in the U.S.A., and is by far the lowest priced refractometer on the market to-day. This makes use of a narrow hemicylinder in place of the usual hemisphere or prism, and the scale itself is curved. The latest American refractometer of which we have knowledge is the handsome-looking instrument with built-in lighting made by the Polarizing Instrument Co. to the design of the well-known mineralogist and gemmologist, Dr. F. H. Pough.

Unfortunately, a critical assessment of the performance of these American refractometers cannot yet be given, as the dollar position virtually bars their entry into this country. Whatever their merits or faults, their development seems to have made American gemmologists refractometer-conscious, and several notable papers on refractometer technique have been published which deserve our attention.

The "Distant Vision" Method

The most important of these are two articles by Lester Benson and by G. R. Crowningshield, published in "Gems and Gemology," the attractive quarterly journal of the Gemological Institute of America.(1) These describe what can appropriately be called the "distant vision" method of using the refractometer, whereby readings can be obtained with cabochon stones and with faceted stones too small to give any visible shadow-edge in the ordinary way.

Essentially the method is quite simple, though practice and concentration are needed before reliable results can be obtained. The first essential is to apply only the smallest possible droplet of contact liquid to the refractometer table, and then to allow the stone to rest with its point of contact as near as possible to the centre of the glass. With a cabochon stone, the liquid droplet slightly enlarges the apparent area of contact, and this can be seen as a little disc as viewed by reflection from below if the eye be withdrawn some twelve inches from the eye-piece of the instrument while retaining the correct line of vision.

When this contact disc is viewed in the lower refractive index region of the scale it appears dark, since light is here striking the

stone at less than the critical angle and is not totally reflected. As the eye travels in a vertical sense towards the higher readings a position will be reached where total reflection at the contact point will begin, and part, and finally the whole, disc appear bright and merge into the bright background of the scale. With care, the critical position can be found where the contact disc is exactly bisected by the shadow. By a slight readjustment of the eye's focus one can read almost simultaneously the position where the line of demarcation lies on the refractometer scale, thus obtaining a close approximation at least to the refractive index of the stone.

A certain amount of distortion seems to occur near the lower and upper limits of the scale, the middle readings being more clearly defined. It has not so far been possible to measure birefringence by this means.

Even if an exact index is not obtainable it is quite simple to separate minerals of similar appearance but widely differing refractivity since the change-over of the disc from dark to light takes place in quite obviously different parts of the scale. A good example of this is given by quartz and chrysoberyl cat's eyes. Fine specimens of quartz cat's eyes are very difficult to distinguish with certainty from not very good examples of cymophane ; and though absorption spectra, dichroism, inclusions, lustre and hardness may all provide information, where the stone is mounted and one cannot take the density one feels the need for a more conclusive test. The distant vision method on the refractometer provides this, quite definitely.

Another advantage of the method is that it enables readings to be obtained with poorly polished surfaces and with almost opaque substances like turquoise, which give no visible shadow-edge, or a very indistinct one, in the normal way.

Exact readings of the scale and disc are more easily harmonized by using a reading lens of lower power and larger diameter than the usual eye-piece lens, and it is quite possible that the makers will later be able to provide special facilities for using the new method.

The workers in the G.I.A. to whom we owe the idea are to be congratulated on widening the scope of the refractometer to such an important extent.

(1) Lester Benson, "Gems and Gemology," Summer, 1948. G. R. Crowningshield, ibid., Summer, 1949.

THE 1949 GEMMOLOGICAL EXHIBITION

Reviewed by
Gerald Carr

"GEMMOLOGY Made Easy," might have been the title of the third exhibition held by the Gemmological Association at the Goldsmiths' Hall in the first week of October. For it was the kind of exhibition which, while it contained plenty to interest the knowledgeable, also had much to attract the ignorant and to make them converts to gemmology by easy stages. A typical example of the way the displays fascinated those to whom the very word " gemmology " was new was shown by one of the men engaged to guard the gems. He returned to the Hall on his afternoon off, bringing his wife as well.

Members of the Association acted as stewards, ready to explain to the novice what it was all about and to tackle the technical questions fired at them by experts. They were not kept too busy, because most of the exhibits were displayed in a form that was self-explanatory. They told a story that gave a deeper insight into the gems they showed. There was beauty, too, of course. A beauty of fine and common crystals immediately apparent to all, though its significance and wonder may have been better understood by the experts. And for those who delved really deep into the subject there was an array of instruments.

Dominating in size, at least, the centre stand of gems, was the famous Devonshire uncut emerald of 1,383.95 cts. An aquamarine, cut and also large, had a fine clear colouring and the beauty of quartz and fluorspar made them quite worthy to mingle in this stand with spinels, topaz and stones of the tourmaline family. Fine specimens of the more unusual gems were those of danburite, a fine green olivine, apatite and sphalerite in yellow and brown-red.

The export drive was—very happily—put into reverse to allow visitors to see on another stand a widely gathered and representative collection of gems found in Canada. Crocidolite in its rough and polished state showed how its popular name of " tiger's eye "

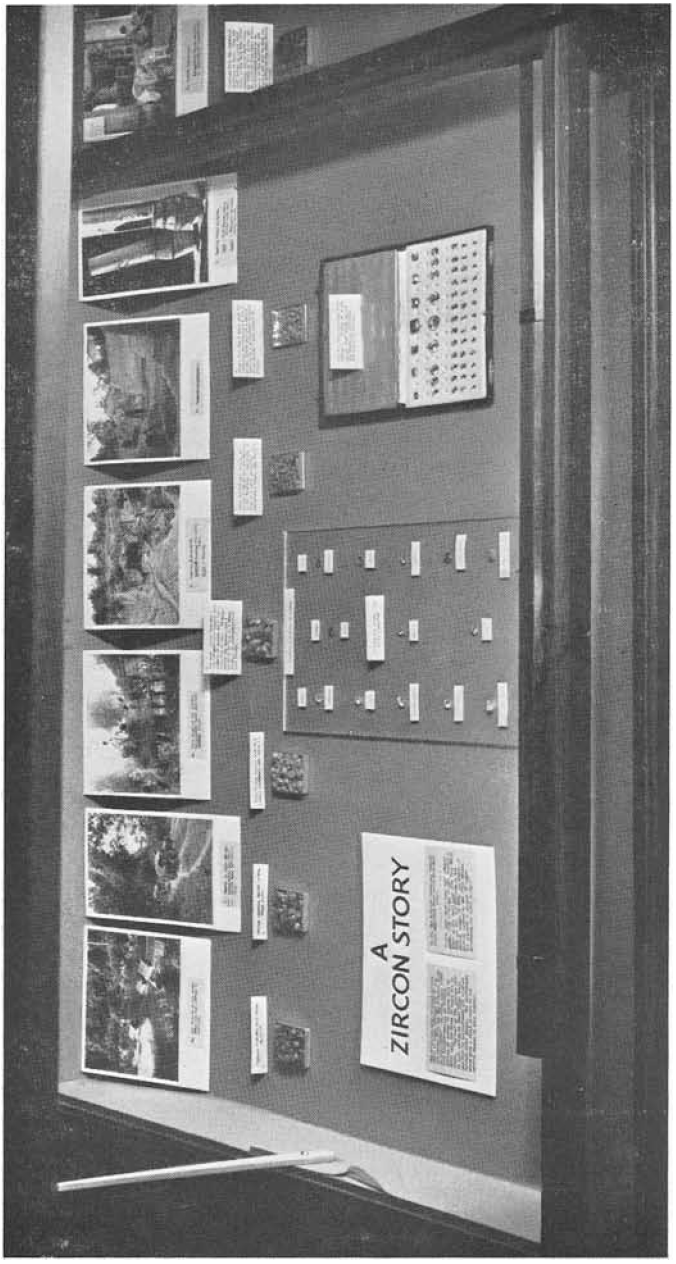
A
ZIRCON STORY

had been adopted, and apart from many gemstones found in most parts of the world, there was Thomsonite and the more felicitously named Patricianite, called after the daughter of the finder. Pyrites had that golden look which has trapped many a " get-rich-quick " amateur, and there was a lovely collection of spherical and polished stones, including several of the star varieties. The beauty of malachite in rough was seen in one specimen where a forest seemed to be depicted.

Finely made models of diamonds that are world-famous attracted many visitors, who thus had their first and probably only chance to see what names such as Cullinan, Jonker, Blue Tavernier, and Dresden Green really meant. Incidentally, nearby was another interesting and imaginative exhibit in which a student had reconstructed what may have been the original form of the Cullinan and shown the line of cleavage parallel to the octahedral plane.

The stand also gave a clear idea of the stages in the production of a brilliant from the rough and the many styles in which a diamond may be cut—an aspect which may have given some of the young and feminine non-gemmologists an idea or two regarding an engagement ring. On another stand were the rarities and freaks of the diamond world, a unique collection of diamonds in strange shapes, unusual colours and with queer inclusions. Their shapes seemed to defy their fundamental atomic and crystalline structure. As for their colours, ranging from port through to yellow green and back to pink, well, that was a surprise for the non-gemmologist, while the expert was happy to study these beautiful coloured

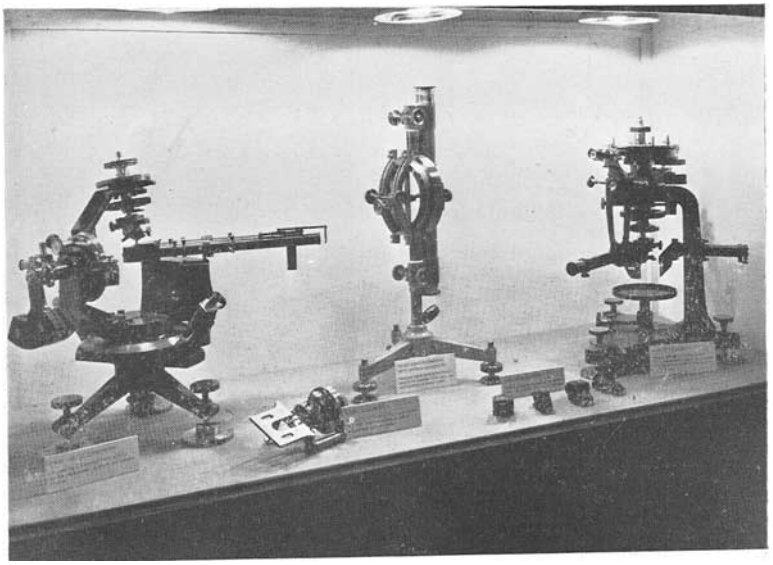

diamonds. And behind were samples of the blue ground with diamonds embedded in them so that it made it appear an easy task to find these gems in the richness of Mother Earth.

From the sublime to the " poor relation " that tries so hard to imitate his natural born superior. The United States specimens of synthetic rutile and of emerald crystals were on view, but nearby was a reminder that " there is little new " with a synthetic ruby made by Fremy in 1890. British attainments in this field were not forgotten, a complete range of synthetic stones made in the North of England from home-produced aluminium and chemicals underlining the fact that industry has not far to look for these goods. Another series of cases contained a wide range of synthetic sapphires, rubies and spinels, while dominating these exhibits was the queer rod-like erection, the Verneuil furnace, which started and still continues much of the work of synthetic making. The " tricks " that can be played by using X-rays to change the colour of some of the synthetics were also shown in the " before and after " manner.

Jewellers—and the public—may well have appreciated two display cases which showed combinations of well-known and lesser-known gems in jewellery and the contents of a jeweller's " junk

box." There was a water opal and sapphire bracelet, the stones arranged on wax to give the public an interesting glimpse into how a jeweller tries out his ideas. A pair of drop earrings using sphenes were attractive and so was a carved tourmaline and fluorite necklace. Moonstones were used for another wax mounted bracelet and a pink diamond was an interesting mounted piece. A rare euclase necklet was another novelty and so was another piece using a huge aquamarine and morganite. This exhibit was well displayed and many retail jewellers who saw it were extremely impressed. The " junk box " represented a collection of gems gathered in the " gold rush " of the nineteen-thirties. They had lain almost forgotten down the years, but they were certainly not without considerable value to-day. I wonder if many other jewellers have such a forgotten Aladdin's cave? Here also were specimens, and fine ones, too, of black diamonds, fine cut rubies and emeralds from various parts, and garnets, spinels and zircons.

May I say that I was glad to see a case was devoted to specimens of opals, those rich stones which demand isolation. Here were black opals, fire opals and water opals forming a striking contrast with their particular displays of colour, some still in the rough, others polished, and some made up into jewellery. Then there was the fascinating story of the zircon, told in detail with photographs and examples of the stones from various mining districts in various stages of treatment, from the rough to the various colours and their final cutting and polishing. Another of the many stands which told a story and also gave examples of more

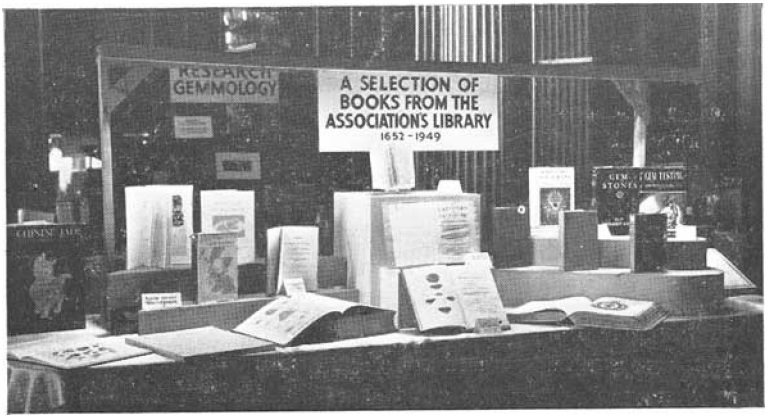

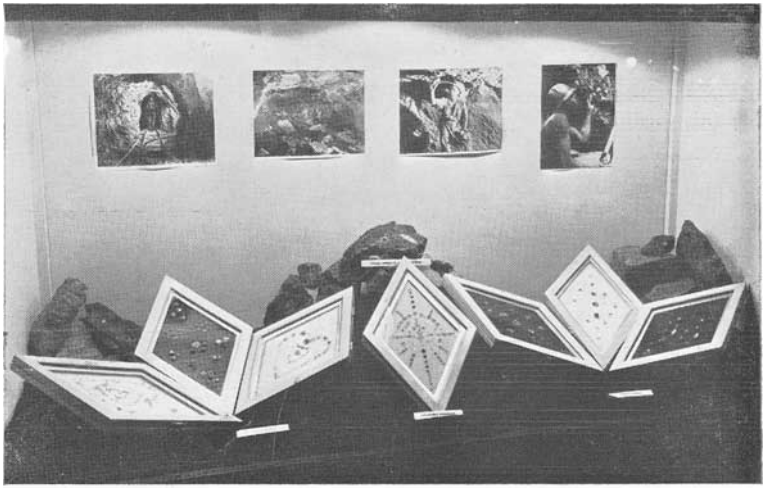

fine gems was that which illustrated the Mohs' scale of hardness of minerals, the different stones being shown in their rough and polished state, their hardness numbers indicated from one to ten and intermediately.

The beauties of crystalline structure were not exhausted by these precious gems. There was a lovely range of quartz, agate and fluorspar. One specimen of quartz must have had a wonderful group of more than fifty crystals and there was an egg-shaped piece of fluorspar. Different beauty was evoked on a " rockery garden " of crystals seen under ultra-violet rays so that they fluoresced, and a rock crystal made a delightful ornament lit from below with changing colours.

Many gemmologists must have had memories of the past evoked by the exhibition of Diploma No. 1 of April, 1913, gained by Mr. Samuel Barnett, who, it will be remembered, died only a few months ago, and commemorated his long association with the Association by mentioning it in his will. Then there was the impressive list of countries, twenty-three in number, in which the examinations have been held. Another indication of the leading part played in gemmology by the Association was in the display of some of the books from their library, undoubtedly unique in its range and selection and dating from 1671 to the latest book of Dr. Herbert Smith.

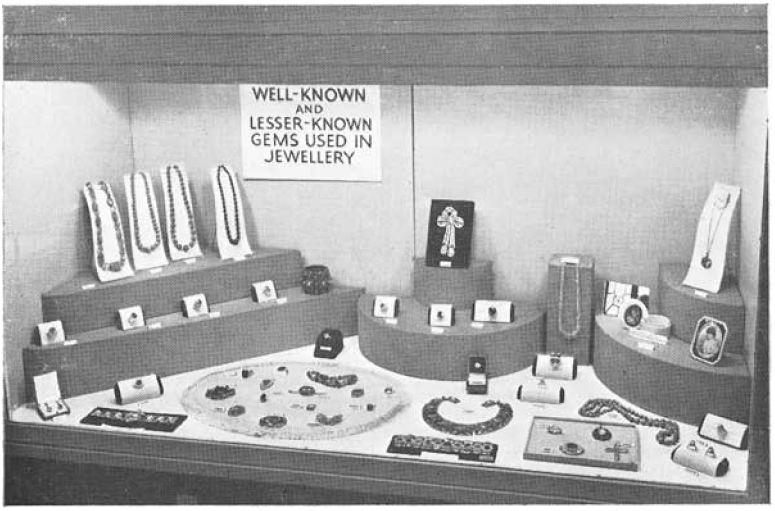

Then there were the technical exhibits, reminders of the important work done by the Association and its students over the whole field of gemmology. The interesting models of crystal formation used in the various gemmological classes, the G.A. papers themselves and the vast range of instruments devoted to the work. Of these, it was pleasant to see that the ever-useful tool, the Chelsea colour filter, has been produced in a handier and less austerity finish. There was a range of refractometers, not forgetting the early Herbert Smith model, and a new and ingenious specific gravity balance.

The working of the endoscope in pearl testing was demonstrated and the range of microscopes had interesting specimens below them that could be observed. Near at hand was the "sea-shore" with its specimens of pearls and coral and mother-of-pearl. For the advanced specialists there was a spectrometer and the development of plastic imitations has, it could be seen, easily been met by the scientist aided by micro-chemical testing, the various chemicals used being displayed. Various refractometers were also, of course, displayed, one with a diamond prism to give the widest possible readings.

The 1949 Exhibition attracted a record attendance and among the many distinguished visitors were Queen Mary, Princess Alice and the Lord Mayor of London.

Formation and Properties of Single Crystals of SYNTHETIC RUTILE

by Charles M. Moore, Jr., member A.I.M.E.

Reproduced by permission of the American Institute of Mining and Metallurgical Engineers (Mining Transactions, Vol. 184, pp. 194-199, June, 1949).

Introduction

IN the study of the properties of rutile pigments it became apparent several years ago that certain physical and optical properties could not be determined on particles of pigmentary size. Since reflected light is the dominant type which reaches the eye from small particles, the true colour of pure rutile was not known. Most rutile pigments are acicular in habit, elongated parallel to the " *c* " axis. It was considered important to know the nature and tone of light transmitted, for example, by a basal plate. Further, as shown by spectrophotometric curves, there is a very strong absorption of light of 4000 Å as measured on particles with random orientation. It would be interesting to see whether this absorption position varied with predetermined and selected orientations. Also, since the behaviour of titanium pigments in a vehicle is important, a knowledge of the surface wettability of single crystals by various media should prove very fruitful. Finally, the optical properties of rutile are such that it should show, in a single pure crystal, greater fire and brilliance than the diamond. Mineralogists had long speculated that this would be the case and curiosity was strong to produce a single crystal large enough to cut.

In light of the above, a project was initiated for the formation of single crystals of rutile.

Method of Formation of Rutile Single Crystals

Fortunately, purification of TiO_2 produced from both titanium tetrachloride and titanyl sulphate solutions had reached the stage where spectrographically pure starting material could be made. Spectographic analysis of the feed material used in the initial experiments is compared with the present feed material in Table 1. It is apparent that the present large scale purification is approximately as good as the original experimental, small scale purification.

Verneuil(1) produced synthetic ruby and corundum in 1904 by the well-known flame fusion process, which to-day bears his

name. Except for mechanical improvements the present commercial production of synthetics by flame fusion is essentially unchanged from his initial method. His burner consisted of an inner orifice through which was fed the feed material and oxygen. Surrounding this was a larger outer orifice through which was fed hydrogen at lower pressure. This arrangement consists then of a lance of oxygen burning in an atmosphere of hydrogen. The proportions of hydrogen to oxygen usually used in corundum production is about 3:1, providing there is sufficient temperature to reach the 2050° C. required for the fusion of alumina.

From work done in the Titanium Division Laboratories(2) and from the published work of Erlich(3) it was known that rutile appears to lose oxygen near its melting point and that it would not be possible to grow single crystals in a strongly reducing environment. Consequently, in order to determine whether single crystals could be grown at all, an Airco oxygen-acetylene torch with twin nozzles was set up. A hopper, consisting of a 6 in. length of mullite furnace muffle 1½ in. in diameter was mounted vertically, with the bottom covered by a 100 mesh wire screen. A glass funnel leading to a copper tube was mounted below the hopper, with the end of the feed tube terminated an inch above the junction of the flames from the two tips. The feed material was vibrated through the screen by means of a small magnetic vibrator attached to the side of the hopper.

The tips of the torch were bent 45°, so that they faced each other. They were wound with 1/16 in. copper cooling coils and inserted through holes cut into a porous refractory brick. A hole was cut in the centre to admit the feed material and the brick cemented to the torch with sodium silicate cement.

A preliminary furnace shell with an inside diameter of 2 in. was cast from the standard clay mix and the brick top with the torch inserted was rested upon it. In order to lower the fused material away from the flame, the furnace assembly was placed upon a scissors automobile mechanical jack, and the furnace lowered by hand. Small crystals, approximately 1 to 2 mm. in diameter and 4 to 5 mm. in length were grown with this apparatus. This showed that in spite of its tendency for very rapid crystallization rutile single crystals could be grown by the flame fusion method. It was obvious, however, that with a point fusion zone, no crystals of appreciable size could be grown and that any crystals

produced would be so badly strained as to be useless. In consequence we designed a burner which would provide the minimum reducing environment and which would enlarge the area of constant temperature, to yield a broader fusion zone without a horizontal thermal gradient.

Where hydrogen and oxygen burn, an intense heat is created at the zone of mixing of the two gases. Turbulence of the gases broadens the zone but it is still a single reaction area. However, if an envelope of oxygen is made to surround the hydrogen to yield a three component, or three envelope, nozzle burning flame, there are two reaction zones with sufficient turbulence so that a constant temperature is maintained over the effective diameter of the nozzle. In addition, the outer oxygen envelope prevents excessive reduction of the TiO_2. A 0.5 in. nozzle diameter burner was built according to this design and single unfractured crystals of pure rutile, 1 in. long and 0.45 in. in diameter, were grown. The burner is virtually fool-proof, and the only critical factors are the relative space velocities of the three gas streams.

In order to prevent periodic cooling of the flame by the showers of feed material produced by the customary tapping of the hopper, a very sensitive hopper was designed and a vibrator employed in place of the tapper commonly used on commercial burners. The constant flow of feed not only prevented the strain in the crystal which had formerly resulted from periodic cooling of the flame, but also eliminated the layer structure characteristic of Verneuil Process synthetic crystals. This layer fusion had been deemed by Verneuil as an essential part of the flame fusion technique.

It was also felt that the hand lowering of the growing boule must contribute to strain in the crystal, since any operator must of necessity lower the boule a minimum of several millimeters if he is to keep up with the rate of boule growth and hold the fusion zone at a constant position in the flame. Therefore, a variable speed motor was attached to a worm gear and the pedestal lowered automatically. A provision was made also for a variable speed rotation of the pedestal in the event this was found to facilitate crystal growth.

The control of flow of oxygen and hydrogen to the burner is of the greatest importance. This was accomplished, in the 0.5 in. burner, by reduction valves on the tanks followed by low pressure

diaphragm valves in the line ; and which were followed in turn by needle valves in front of the rotometers. A simultaneous shut-off valve also was used. A filter of Spanish moss placed in the line removed excess moisture from the gases, but is not considered essential when gases of normal purity are used. Pigtails connecting two tanks each of hydrogen and oxygen gave sufficient capacity of gas so that a 6-hour run could be made without shutting off, and without marked gas fluctuation.

The final burner design is essentially the same, except for engineering improvements, as the 0.5 in. nozzle burner. The present burners are 0.75 in. nozzle diameter and on which the hopper and lowering mechanism have been materially improved. These burners are connected to fixed lines which are fed from a series of 5 hydrogen and 5 oxygen tanks.

Table 1. – Comparison of Original and Present Feed Material

	Original Feed Material	Present Feed Material
SiO_2	< 0.02	0.04
Fe_2O_3	< 0.001	< 0.001
Al_2O_3	< 0.001	0.001
Sb_2O_3	< 0.002	< 0.002
SnO_2	< 0.001	< 0.001
Mg	0.0005	0.0005
Cb	< 0.005	< 0.005
Cu	< 0.0001	0 0001
Pb	< 0.002	< 0.002
Mn	< 0.00005	< 0.00005
W	< 0.005	< 0.01
V	< 0.0005	< 0.002
Ca	< 0.01	
Cr	< 0 0001	
Ba	0.001	

Mechanism of Growth.

A congruently melting compound which has a melting point within the range of the temperature of combustion of hydrogen and oxygen is quite simple to grow as a single crystal. The only absolutely essential features are accurate control of gases, a burner which will yield a fusion zone with a low horizontal thermal

gradient, and a perfectly straight spindle under the pedestal. The control of particle size and shape is essential for a commercial operation, since the particles must be absorbed into the molten surface and melted completely as rapidly as possible.

Single crystals of rutile are grown in the following manner. The burner is cut on, the sintered alumina furnace ($2\frac{1}{2}$ in. id) is closed and the chamber allowed to heat for several minutes. The pedestal, consisting of any sufficiently refractory ceramic material, usually alumina or stabilized zirconia, is raised until it is just below the hot zone of the flame, which has a very steep vertical gradient. The vibrator is then turned on and the feed material drops on the pedestal. The temperature of the flame is held below the melting point of the compound by holding the hydrogen content of the flame low. A steep sintered cone is built up until the tip is approximately 1 mm. across. The hydrogen flow rate is then increased and the tip melted. If frozen at this point the tip is found to consist of 3 to 5 crystals with various orientations. If not frozen, it is allowed to grow up into the hottest zone of the flame. It is essential at this stage that the flow of feed be very concentrated, since the " foot " must be kept narrow. This is necessary in order for one crystal to assume dominance and " freeze out " the others. After the foot has grown to a height of 4 to 6 mm., which takes about five minutes, the gas velocity is increased, the automatic lowering turned on and the width of the growing crystal is increased. This increase in velocity is continued until the desired width is obtained. The lowering rate is then synchronized with the rate of crystal growth and the mechanism is allowed to run until a boule of requisite size is attained, when all gases are cut off simultaneously. After cooling in the furnace for 30 minutes the boule is removed. Although boules of large size can be grown, because of the increase in strain with size, the boules are restricted to approximately 100 carats.

Growth from a seed crystal is much simpler since the very critical " foot " stage is eliminated. However, this is not considered a desirable technique for commercial production because of the manpower-time requirements. Seed are usually cemented to the pedestal by an alumina-clay cement. The crystallographic orientation obtainable by growth from a seed does not appear necessary with rutile. Crystals grown from cones have the " *c* " axis less than 20° off the vertical axis of the boule.

Table 2.—Hardness of TiO_2 Crystals by Knoop Microindentation Method

Sample	Orientation				Pyramid Face Cut 45° to "c" Axis	Standard		
	Basal Plane Perpendicular "c" Axis		Prism Face Parallel "c" Axis			Mineral	Mohs Hardness	Indentation No.
	Parallel One Prism	Parallel Other Prism	In Direction of "c" Axis	Perpendicular to "c" Axis				
Perfectly orientated colourless cube	898	898	805[a]	840		corundum	9	± 1,800
Yellowish over-oxidized crystal					940	topaz	8	± 1,200
Light blue partially reduced cube	750	850	831[a]	835	890	quartz	7	790 710
Dark blue cube	766	840	859[a]	885		orthoclase	6	600—690
Black	940	950	1,000[a]	767				

a Indicates erroneous readings caused by excessive brittleness.

Characteristics of Single Rutile Crystals

Rutile single crystals grown by the above process are opaque black when removed from the furnace. However, because of the outer oxygen envelope, the rutile structure holds and there is no increment of Ti_2O_3 in the entire structure. A measurement of the unit cell of this black material is nearly identical with that of the fully oxidized rutile structure, both having a tetragonal unit cell. The colourless crystals show 4.5815 and 2.9509 Å, and the black shows 4.5820 and 2.9510 for the *a* and *c* directions respectively.* This black material is a strong semiconductor, and has a specific gravity of 4.268. It is possible to convert this material to colourless rutile by heating in a stream of oxygen. The oxygen addition to the crystal is directly proportional to the size of the crystal being reoxidized and the temperature used. The degree of reoxidation is readily checked by colour changes, as the material goes from black through deep blue to light blue to green to colourless with a yellow tone. The specific gravity of the clear material has been found to vary between 4.29 and 4.30.† As will be shown, this variation in optically identical material was also noted in the dielectric measurements.

* Measurement made by W. F. Sullivan, of Titanium Division, Research Laboratory.

† Measurements were made by the volume displacement method.

Table 2 shows hardnesses of the oxidation states of TiO_2 single crystals, measured by the diamond indentor, commonly known as the Knoop microindentor.

The synthetic material as measured by the Knoop microindentation method is universally harder than natural rutile, in that the latter is reported having a hardness of 6 to $6\frac{1}{2}$ Mohs scale, while the synthetic is as hard or harder than quartz in all directions. However, hardness measured in the direction of the " *c* " axis on the prism face exhibited a " butterfly " fracture effect around the indentation. This indicates a relief of stress in a sharp angle cone, with the length of the indentation correspondingly shortened. This is brought about by an excessive brittleness in this direction, making the indentation measurements in the direction of the " *c* " axis unreliable. Such a phenomenon would be expected to occur if there exists an atom deficiency in the planes parallel to " *c* " leaving many broken bonds, or if the atoms are slightly displaced along these planes, creating a state of strain.

Table 3 shows the dielectric measurements of single rutile crystals. These data show a marked change in dielectric properties, corresponding to the degree of " reduction " of the crystals. The measurements were made by the Crystal Section of the Naval Research Laboratory,([4]) using a General Radio 716 capacity bridge in conjunction with a simple sample holder. All samples were colourless material reduced by H_2 at 600° C. for the various time intervals. The samples were held at five-minute intervals for the first five steps, 10-minute intervals for the next two steps and 30-minute intervals for the last three steps (with the latter held at 700 to 800° C.). It was observed on making the reduction tests on the oriented cube, that the cube was coloured a faint blue in the region of the basal faces after 10 minutes while still colourless in the central portions. As reduction time increased the blue zone moved into the crystal from both basal planes. This supplements the evidence shown by the hardness tests that the greatest loss of the oxygen upon reduction is in the direction of the " *c* " axis. Since TiO_2 is teragonal, one would expect, if the change from colourless to black is caused by loss of planes of oxygen atoms, that this loss would be in a preferred direction. This is indicated by the evidence.

In light of the physical data, certain facts are noted concerning the single crystal rutile structure:

1. It is possible to vary these crystals from clear to opaque black without apparently affecting the volume or dimensions of the tetragonal unit cell.

2. There is a distinct difference in bonding between the planes of atoms parallel to the " *c* " axis and those in other directions.

3. Differences in hardness, brittleness, specific gravity and dielectric constant occur in crystals which are identical in colour.

4. A given crystal can be taken through a complete cycle from colourless to a black semiconductor, apparently identical with the original furnace product, and back again to colourless, at least four times without materially affecting its properties. After six to eight cycles, the crystal becomes embrittled. The ability of the crystals to reduce and oxidize without structural change indicate an elasticity of structure not generally recognized.

The concept that removal of oxygen atoms brings about a darkening of the colour upon reduction, to yield an increasing increment of Ti^{+3} may be correct, but it is difficult to apply to oxidation. A structure for the clear rutile analogous to FeO and FeS_2 should be considered as a possibility. These compounds exist as stable lattices with nonstoichiometric proportions of constituents. The strong covalent bonds necessary for such a cation deficient structure to exist have been shown, by dielectric studies, to occur in rutile.(5)

Rutile pigments show a strong absorption of light at 4000Å to yield a higher increment of longer wavelengths in the transmitted light which results in a yellow tone. Single crystals of rutile are opaque to all wavelengths of light between 2100 and 3200Å and transparent from 4100 to 6800Å at 77°K.(6)

Synthetic Rutile as Gemstones

The indices of refraction of synthetic rutile, measured by a three circle goniometer on a 20° prism cut parallel to the "*c*" axis showed 2.605 ± 0.004 for the ordinary ray and 2.901 ± 0.004 for the extraordinary ray. Sodium light was used. Measurements made by B. W. Anderson and C. J. Payne(7) on a cut rutile gem show very similar results. These values are within the range of the refractive indices of natural rutile. The refractive index, the marked dispersion, and the extremely high birefringence yields a

Table 3.—Change of Properties Upon Reduction

No. of Reduction Exposure	Crystallographic Direction	Oriented Cube		Rectangular with Long Direction Parallel to "c" Axis		Rectangular with Long Direction Parallel to "c" Axis	
		Dielectric Constant	Resistivity (ohm cm)	Dielectric Constant	Resistivity (ohm cm)	Dielectric Constant	Resistivity (ohm cm)
0	a	655	3.14×10^{2}	149	15.0×10^{12}	187	3.79×10^{12}
	a	275	4.5×10^{10}				
	c	83.5	1.55×10^{10}				
1	a	4.9×10^{4}	1.7×10^{5}	4.68×10^{4}	1.13×10^{5}	2.34×10^{4}	4.73×10^{5}
	a	3.88×10^{4}	4.82×10^{5}				
	c	3.16×10^{4}	6.33×10^{3}				
2	a	5.7×10^{4}	3.82×10^{4}	5.35×10^{4}	2.35×15^{6}	3.01×10^{4}	7.12×10^{5}
	a		1.92×10^{4}				
			3.0×10^{4}				
3	a	4.58×10^{4}	4.2×10^{4}	4.15×10^{4}	3.39×10^{5}	2.22×10^{4}	9.5×10^{5}
	a	4.58×10^{4}					
	c		1.55×10^{4}				
4	a	4.42×10^{4}	1.275×10^{5}	2.95×10^{4}	2.82×10^{6}	1.59×10^{4}	2.37×10^{7}
	a	4.24×10^{4}	2.24×10^{5}				
	c	3.64×10^{4}	1.55×10^{5}				
5	a	4.31×10^{4}	2.55×10^{4}	3.17×10^{4}	2.62×10^{6}	1.62×10^{4}	1.66×10^{6}
	a	4.37×10^{4}	4.82×10^{4}				
	c	4.8×10^{4}	2.64×10^{4}				
6	a	4.2×10^{4}	2.12×10^{4}	3.22×10^{4}	2.82×10^{5}	1.79×10^{4}	9.47×10^{5}
	a	3.53×10^{4}	7.06×10^{4}				
	c	4.7×10^{4}	2.18×10^{4}				
7	a	4.25×10^{4}		3.27×10^{4}	9.42×10^{5}	1.81×10^{4}	
	a	3.88×10^{4}	8.02×10^{4}				9.47×10^{5}
	c	5.67×10^{4}	4.97×10^{4}				
8	All samples indicate strong decay of dielectric constant during measurement.						
9	Cannot measure dielectric constant—resistivity too low.						

brilliance and fire unrivalled by any other gem. The birefringence gives rise to a marked phenomena in the cut stones. The well-known illustration of the double refraction for different optical orientations is clearly shown by the single, overlapping double and apparently separate culets at the base of the stones.

Even though the stone measured by Anderson and Payne was not cut to yield maximum values, the dispersion of the lowest index

of refraction (0.2851) is six times that of a diamond. This dispersion of the extraordinary ray is even higher. This, of course, accounts for the tremendous " fire " of the material.

The standard brilliant or diamond cut is satisfactory for rutile. Since this type of cutting is designed to give total reflection of light by the facets of material with a critical angle of 24° (diamond) it will, of course, also serve for material with a critical angle of a maximum of 18° (rutile). However, if desired, the 6° advantage rutile has over diamond could be utilized to allow a wider bottom internal angle (100° is critical for diamond) yielding a larger diameter stone for its weight.

Since the colourless rutile is not a duplication or imitation of a natural stone as are the other synthetics, it is probably the first truly new gem since the advent of modern jewellery. It is the first material whose optical properties are such that it is superior to diamond in both brilliance and fire. Its future in this industry at least seems assured.

Acknowledgment

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By M. D. S. Lewis, A.R.C.S., B.Sc., F.G.A., C.G.

PASTE

SOME gemmologists and jewellers dismiss "paste" as unworthy for consideration in the same class as gemstones because it is "imitation," "glassy," or amorphous. As a matter of fact, the "glassy" or vitreous condition is of far greater rarity and more difficult of achievement than the crystalline state, which is the one normally assumed by most ordinary inorganic solids from table salt to rubies. Whilst the gemmologist enthuses over the high crystallinity of diamond the glass technologist considers this property most objectionable and one to be avoided at all costs. The crystalline state is now believed fairly well understood, but the glassy state still remains to a certain extent mysterious and difficult to define. As will be seen later, it is almost a fourth state of aggregation—something between solid and liquid —analagous to the twilight through which day passes into night.

Older than the jewellery trade itself, paste in historical importance far transcends all other gemstones. In the same way that modern chemistry had its roots in mediaeval alchemy, so glass technology owes much to the early lapidaries for their work on paste gemstones, which were actually the first articles to be made of glass. Representing a technical achievement of the highest order, they were more treasured than gems, which they surpassed in rarity and the acquisition of which merely required diligence in searching.

The earliest known glass—a moulded amulet of deep lapis colour—probably dates back to 7,000 B.C. Many of the so-called "gemstones" of historical significance are undoubtedly paste, including the "Sacro-Catino" emerald bowl, from which Christ is said to have partaken at the Last Supper and the "emerald" slab through which Nero watched the gladiators in the glare of strong sunlight. Many of the "garnets" used in Byzantine jewellery of the 5th and 6th centuries were also probably paste.

Until fairly recent times paste and, in fact, all glass was invariably coloured and often opaque, colourless glass being a comparatively modern invention. At the courts of Louis XIV and Louis XV, when France led the rest of the world in culture, pastes were freely mixed with real stones, emphasis being placed on artistic effect rather than on intrinsic value. Flemish crosses of this period were sometimes set with large pastes in front, whilst the backs were ornamented with small diamonds, which thus played quite a subordinate role.

The manufacture of paste as a separate industry may be said to have begun in 1758, when the Viennese jeweller, Joseph Strass, opened his workshop in Paris. Even now, in some countries paste is still called " Strass." Rapid success seems to have rewarded his efforts, for in 1762 Pouget, a French jeweller, wrote: " Women wear nothing else but Strass," and five years later a Corporation of " Joailliers-faussetiers " was established in Paris. Paste is, of course, a glass rich in lead and it is somewhat surprising that its manufacture was never established on a large scale in England, for in the 18th century English lead glass was supreme in quality and favour throughout the world.

In order that a liquid may form into a glass, two main requirements must be met. Firstly, the electrically charged ions which are present in the liquid must have a tendency to join up with each other to form endless chains in three dimensions, and secondly, the liquid must become highly viscous near the point of solidification. In a liquid, the ions are in violent motion and constantly changing their position relative to each other, and their kinetic energy is so high that their electric charges—through which they are attracted to or repelled from each other—are insufficient to impose a stable arrangement. As the temperature falls their energy of motion becomes less and at a certain point these electric charges gain the upper hand and the ions usually form together in more or less fixed positions in orderly symmetrical fashion. In other words, the melting (or freezing) point has been reached, and the substance has solidified in the crystalline state. Now, if when the ions are joining up near this critical temperature the liquid becomes very viscous, they cannot—through lack of movement—arrange themselves in an orderly crystalline pattern. In other words, the molten or high temperature configuration will be " frozen " in the structure, even in the solid (low temperature) state, and the result is a

glass. Water turns into crystalline ice because near the freezing point the liquid remains highly mobile ; molten silica often turns into silica glass because at this point the " melt " is highly viscous. Thus glass, although a " solid," still retains some of the random arrangement which is characteristic of liquids and is often described as a " super-cooled " liquid. The properties of a crystal are always the same however it is formed, but obviously those of a glass will depend on the temperature at which the viscosity has overcome the natural tendency to crystallize and are therefore governed by the thermal treatment. If two glasses are made from precisely similar materials, mixed in identical proportions, but submitted to different heat treatments, the results may differ widely.

Like most gemstones—with the important exceptions of diamond and fluorspar—the structure of any normal glass would appear to be dominated by its oxygen atoms. In nearly every transparent glass—no matter what, or how many constituents there may be—the total weight is practically equal to the sum of the weights of the " oxides " of all the elements it contains and it may be significant that liquid oxygen near its freezing point becomes a highly viscous fluid.

As in all silicate gemstones, the fundamental building brick of any normal glass is the SiO_4 tetrahedron. Imagine four oxygen ions compactly arranged in tetrahedral fashion—three at the base all in contact with each other forming an equilateral triangle—and one placed on top in contact with the three below. The central hole which is thus left is very small, compared in size to an oxygen ion, and can only be occupied by another element if the ionic size is very much less than that of oxygen. Furthermore, this central ion must possess a high positive electric charge to confer stability and prevent the negatively charged oxygen ions from flying apart through mutual repulsion. Silicon is therefore the ideal glass former because its ion is both small and highly charged and there are only a very few other elements, e.g. boron, arsenic, phosphorus, etc., which possess these two essential properties and can thus form glasses. SiO_4 tetrahedra cannot exist separately but may join up with each other to share all four oxygen corners and thus endless chains of Si—O—Si—O atoms are obtained. Since each oxygen is shared by two silicons the overall formula reduces to SiO_2, which, of course, is that of silica. Now there is more than one way of joining these SiO_4 tetrahedra corner to corner. Imagine two such

tetrahedra " hinged " together through a common oxygen ion so that the Si—O—Si angle can vary, at the same time bearing in mind that each oxygen ion throughout the structure must be a " hinge " connecting two adjacent tetrahedra. When this angle is 145° the quartz structure results (Fig. 1), and when 180° the cubic crystalline form of silica—cristobalite—is obtained (Fig. 2).

In each case two SiO_4 tetrahedra are joined through sharing an oxygen corner. The silicon atom lies vertically below the topmost oxygen of each tetrahedron. The same linkage is repeated at each oxygen corner throughout the system.

Now it has been established by X-ray diffraction that the structure of vitreous silica—which is the simplest and most perfect glass—is somewhat similar to that of cristobalite ; in fact a blurred or distorted modification of it. Thus, if molten silica cools under

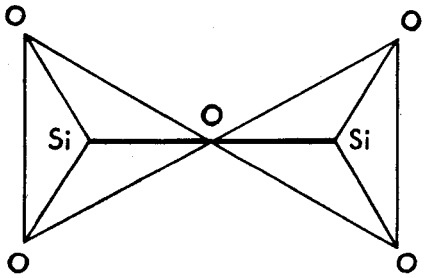

FIG. 1
Linking of SiO_4 tetrahedra in Quartz Structure.
Si—O—Si angle = 145°

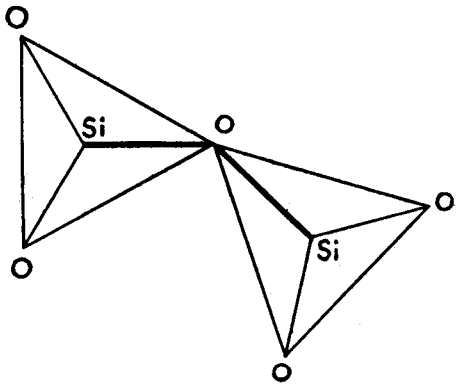

FIG. 2
Linking of SiO_4 tetrahedra in Cristobalite Structure.
Si—O—Si angle = 180°

In each case the fourth oxygen must be imagined iimmedately above or below the silicon. A similar link occurs at each oxygen atom throughout the structure.

suitable conditions, the ions begin to form crystalline cristobalite, but before they can reach this state they are frozen solid and remain in disorder.

Fortunately, the glass maker has no need to juggle with silicon and oxygen ions, as they exist in enormous quantities on the earth's surface, combined in just the required proportions in the form of sand (quartz), which is, therefore, the starting point of all normal glasses. If, then, by the simple process of melting sand and allowing it to cool, perfect silica glass can be obtained, why look further and seek other types? Firstly, because quartz only melts at a very high temperature and the attainment of the enormous heat required for fusion is expensive. Secondly, because molten silica, through its high viscosity—the very property which confers its glass forming qualities—is awkward to mould and work. Thirdly, because it is difficult to colour. By fusing sand with alkali (soda or potash) two of these problems are solved, as fusion occurs quite easily and the viscosity is greatly reduced, but a fatal complication intervenes—the glass is soluble in water. To counteract this, a third component, usually lime, magnesia or alumina, is added, giving a three component glass of the type SiO_2—Al_2O_3 – Na_2O, although all three metals may be replaced to a varying extent by others. This, then, is the usual pattern of glasses, although the proportions may be altered and yet more elements introduced to obtain special properties.

It has just been stated that the fusion of quartz with soda reduces the viscosity and this happens through the rupture and sealing off of Si—O—Si—O chains ; the more chains which are broken the less viscous is the " melt " (Fig. 3).

The closeness of silica glass structure to that of crystalline cristobalite has also been commented on and this illustrates the peril which always confronts the glass maker, because if conditions permit, every glass tends to " devitrify " and become crystalline. This is a disastrous fate for glass as it does not, of course, crystallize in one piece, but in innumerable crystallites which scatter the light and destroy transparency and strength. Aluminium is a particularly good stabilizer, resisting devitrification for the following reason. Its ion is somewhat larger than that of silicon, which it can replace at the centre of an SiO_4 tetrahedron, but the substitution distorts the structure and introduces further randomness of

FIG. 3

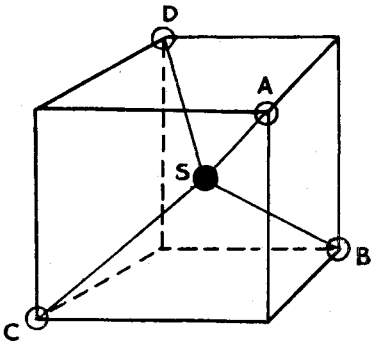

Diagram of Silicon-oxygen Tetrahedron. Silicon atom at centre of cube and oxygen atoms at corners ABCD.

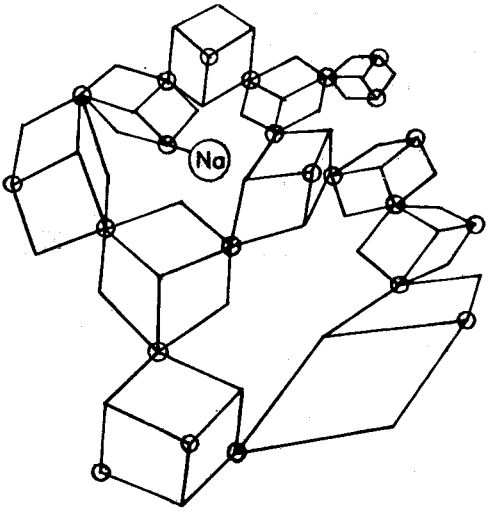

Sketch of Random arrangement of atoms in glass. The silicon atoms are at the centre of each distorted cube.

Representation of glass structure by R. W. Douglas
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arrangement. By itself, aluminium cannot possibly replace silicon as it has not such a high positive charge, but the deficiency can be made good by the simultaneous introduction of a sodium ion, thus preserving electric neutrality. (Silicon has 4 positive charges, aluminium 3 and sodium 1 ; thus Si^{++++} is balanced by Al^{+++} plus Na^{+}.)

Further reference to Fig. 3 shows that the glass structure is a fairly open one dominated by groups of large oxygen ions and two

types of " holes " will be seen to exist. There is the very small hole within each oxygen tetrahedron, usually occupied by silicon, which can be replaced by a few other elements. An element within this tetrahedral hole is called a network former as it plays an essential part in the structure. Between each tetrahedral group of oxygens there are also much larger holes of approximately octahedral shape and of varying sizes, and these may, or may not, be filled by other atoms, each of which will then be surrounded by at least six or eight oxygens. Elements within these larger holes play only a secondary part in the structure and are therefore called network modifiers. Some elements, notably aluminium, titanium and iron can occupy either type of hole, acting as network formers or modifiers. Titanium, often added to raise refractive index, is interesting because if in a tetrahedral hole it is surrounded by four oxygens and absorbs in the visible blue part of the spectrum, conferring an objectionable yellow colour on the glass. If, however, the titanium ions can be shifted to the octahedral holes they will each be surrounded by six or more oxygens, when the absorption band moves to the ultra-violet, outside the visible spectrum, and no colour results. To achieve this, the glass maker adds zinc or cadmium also, as these ions have a marked preference for the tetrahedral holes which they occupy and so force the titanium ions into the vacant octahedral holes.

In the course of its 9,000 years' existence the glass making industry has solved most of its problems by patient and laborious methods of trial and error, with little knowledge of the scientific principles involved. One of its greatest difficulties was the preparation of colourless glass because sand, the all-important primary material, is nearly always coloured by iron impurities, which impart a green or red tinge. The principle decolourizers used were manganese dioxide and arsenious oxide, both of which tend to oxidise the highly coloured green ferrous iron to the paler ferric yellow. At one time it was thought that manganese dioxide assisted the decolourizing process through its violet colour, which is complementary to the yellow of iron. It is also possible that arsenic combines with some of the iron to form colourless ferrous arsenate. Arsenic has always been a favourite ingredient for glass making, and Mr. W. B. Honey, the eminent authority on antique glass, attributes the " mellowness " of old paste to the presence of this element. It is difficult to find any scientific basis for this

view ; it may perhaps be due more likely to a " patina " of lead sulphate which has probably formed on the surface.

Of all the elements which may be added to improve the appearance of glass, lead is unique and really good paste nearly always contains large amounts. Although the hardness of such a glass—as measured by scratch tests—may be low, it possesses other " wearing " qualities which more than compensate. The enhancement of optical properties resulting from the addition of lead has long been known, but the reason has only been ascertained in the last few years. The refractive index of glass or silicate gemstones is usually determined by the oxygen atoms. They are large and the outer electrons relatively far from the stabilizing influence of the nucleus. The incoming light waves, which may be regarded as electrical in character, interact with these loose electrons and are thus slowed down. Most metallic ions used in glass or found in gemstones are small and contribute little to refractivity, but the lead ion is so large and unsymmetrical that it is easily distorted or polarized and its interaction with the light waves is correspondingly drastic. W. A. Weyl, the American authority on glass, has also found that lead confers a chemical inertness to the surface which reduces friction and solubility in water, thus improving wearing properties. The outer layer of the lead ion in glass has only two electrons, which being relatively far from the nucleus and weakly held will therefore be repelled from negatively charged bodies. Consider a lead ion at a glass surface, below which lie the negatively charged oxygen ions. Strong polarization will result, the two outer electrons being repelled, producing a very inert top side which may be crudely expressed thus:—

Pb^{++}	$\longrightarrow$	$\frac{1}{2}Pb^{++++}$	+	$\frac{1}{2}Pb^{\circ}$
lead ion		highly charged underneath		neutral at surface

The inertness arises from the zero electric charge—there is no force of attraction extending to other ions—hence the diminution of friction. Glass which does not contain lead readily attracts water, which gradually dissolves the alkali constituent, and then this alkaline solution attacks the remaining silica, thus breaking down the entire structure. Some time ago the writer conducted experiments on the spreading of drops of water on pastes and other gemstones. Contrary to expectation, complete spreading (zero

contact angle) was not obtained and the writer attributed this to inability to remove the last traces of dirt from the surface, but it now appears that lead glass surfaces are inherently hydrophobic (the reverse of water attracting) and a zero contact angle is theoretically unobtainable. It is hardly correct to describe this as water-repellent, as no special repulsive forces reside in the surface —it is merely inert or neutral and the particles of water are more attracted to themselves than to the surface. The high polarizability of the lead ion is also responsible for the stability of lead glasses, as the effect of polarization is to reduce the symmetry of the structure, thereby increasing resistance to crystallization. By reducing friction, solubility, and tendency to devitrification, lead thus confers improved wearing qualities which may counterbalance lack of hardness and the magnificent appearance of fine old paste after two or three centuries' use is probably due to a reasonably high lead content.

It is not proposed in this article to discuss the normal physical properties of paste, which are fully dealt within the usual textbooks, but the following points may be of interest, although of little gemmological significance.

Paste, being amorphous, is fundamentally isotropic, but a glass can be made which is so anisotropic that it is used as a polarizer. E. H. Land, of " polaroid " fame, has patented a process whereby glass containing lead oxide is exposed before solidification to the reducing action of hydrogen. Droplets of metallic lead are formed and the semi-solid glass is stretched to give elongation in one direction, and marked anisotropy results.

The refractive index of paste is usually between 1.5 and 1.7, but by incorporating rare earth oxides and titanium oxide, glasses have been made having a refractive index of well over 2.0. By carefully treating a glass surface with hydrofluoric acid some of the oxygen ions can be replaced by fluorine, but still leaving a sufficiency of Si—O bridges to retain the glass structure. The decomposition products are very soluble in water, and if leached away a skeletonized glass surface remains which gives the phenomenally low refractometer reading of 1.28 (less than that of water).

Only glasses containing soda are appreciable conductors of electricity—due to the small size of the sodium ions which can therefore move through the holes and channels to produce an electric current. (The only other ion small enough to do this is

lithium.) As most pastes contain some soda, a suitably devised conductivity test would probably differentiate them from many other gemstones.

Except in the case of those containing rare earths, the absorption spectra of pastes will be usually " woolly " and diffuse, in contradistinction to the sharp lines and bands shown by many gemstones. In a crystal the environment of atoms is constant and consequently absorption of certain frequencies intense and sharp, but in glasses the environment varies and absorption takes place with less intensity on a broader front. Rare-earth glasses still show sharply defined spectra as absorption in this case is due to electron transitions taking place in inner " protected " orbits which are insensitive to chemical environment.

It would probably be easy to produce a " dichromatic " effect in paste by the inclusion of rare earth oxides, and the famous Moser factory at Karlsbad rather specialized in the production of so-called "Alexandrite " glass. This glass contains neodymium and other oxides, which by absorption in the yellow green sharply divide the light into two components—red and blue—the latter predominating to give a blue colour in thin layers. As, however, blue light is more easily absorbed or scattered, the red component eventually predominates and imparts this colour to thick layers.

The writer would have liked to conclude this article by a definition of " glass " and more particularly " paste," but glass technologists cannot agree among themselves on this point. Indeed, one of them once abandoned the attempt in despair, saying: " Glass is that which, if there were none, we should have to make bottles out of something else, such as goat-skins." The same authority (Dr. F. W. Preston), in a less pessimistic mood, has, however, offered the following:

> " A glass is obtained from a liquid by cooling it (without crystallizing it) until its viscosity has become so high that the configuration remains fixed at a state not corresponding to the equilibrium configuration, but one determined by the heat treatment and the time elapsed."

If the gemmologist wishes to substitute " paste " for " glass " he must also specify the presence of positive ions of large size and polarizable nature.

A SOURCE OF LIGHT FOR SPECTROSCOPY

by D. J. Ewing, F.G.A.

WHEN dealing with the use of the spectroscope, text-book writers invariably describe and recommend the microscope technique as the most convenient.

Although methods based on the use of transmitted light are, in the writer's opinion, preferable to those using scattered light, nevertheless there are disadvantages attached to the use of the microscope. Firstly, microscope objectives are comparatively inefficient as transmitters of light, especially those of low power. Secondly, the magnification obtained results in still more loss of light. Another disadvantage is the discomfort of heat and glare through the necessity of using a 250 or 500 watt projection lamp, apart from the fact that only a fraction of the length of the filaments of such lamps can be used with ordinary optical systems.

A diagram of apparatus is given which has been successfully tried by the writer and, in his earnest opinion, is much more convenient to use. The construction is a circular metal container, such as a double-sized cocoa tin 7 inches in height and 4½ inches in diameter. A condensing lens is fitted midway between top and base and the source of light is a 12-volt 24-watt car headlamp bulb. The top of the container should have a small aperture similar in size to those seen in hand dichroscopes. A more efficient result is given if the metal top is covered with thin glass. This enables the specimen to be slipped into place more easily.

When the stone is placed over the aperture light is directed through the specimen from the source of light below and a choice of positions with regard to holding the spectroscope may be made. It may be held directly over the stone with ½ inch to 1 inch working distance. Alternatively, in some crystals it might be more advantageous to examine stones in several directions, since the absorption may be more apparent in certain directions than in others.

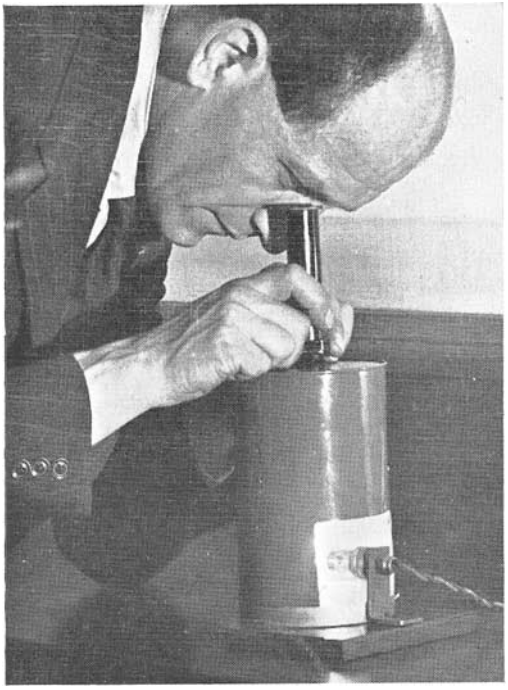

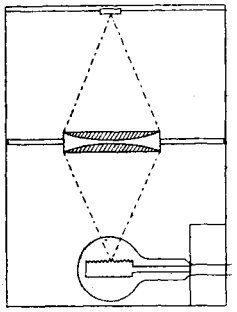

Numerous modifications may suggest themselves to the enthusiastic spectroscopist. For instance, since many gemstones are dichroic, it is advisable to place a polaroid between stone and spectroscope which helps immensely to bring out the finer points of the absorption. Similarly, by placing a transparent dish containing a little toluene or similar liquid over the aperture a stone may, in certain instances, be immersed in such liquid and examined in the manner described above.

For workers who wish to examine the stone for a lengthy period in the one position a retort stand will serve the purpose.

Gemmological Abstracts

" Artificial Colouring of Agate." By K. H. Biegel and G. O. Wild. " Achat," 1949, Vol. 2 (3), pp. 116-118.

To the colouring of agate apply the general hints applicable to the colouring of carneol given in " Achat," 1949, Vol. 2, p. 3. (1) Test samples must be taken. Generally speaking the larger the molecules of the dye the more porous should be the agate. (2) The grain should run vertical to the surface to allow the dye to enter easily into the pores. (3) The stones must be clean and should be boiled in nitric acid to remove iron (except when the stone is to be dyed red) and in soda to remove paraffin used as cooling agent. Only dyes which are practically light, heat-proof and insoluble are used, therefore they must be formed in the stone by heat or the reaction of two solutions. Aniline colours are not used as they fade when exposed to air and light. The only good dye not using a metal salt is the black sugar dye. The agate for black stones must be " soft," i.e. very porous. Honey is better often to use than sugar. The colour is to be preferred to that of cobalt sulphide. The usual colouring processes are as follows:

I. BLACK.

a. 1. Solution: lukewarm concentrated sugar or honey solution.

2. Solution: sulphuric acid ; boil 20 minutes to two hours.

b. 1. Solution: cobalt nitrate ($Co(NO_3)_2$.

2. Solution: ammonium rhodanide NH_4SCN.

The stones are treated, either first with solution 1 then solution 2, or the two solutions are mixed. The black cobalt sulphide only is formed in the stone through subsequent firing.

II. RED.

The dye is iron nitrate. It can be made at home by dissolving rusty nails in concentrated nitric acid.

III. GREEN.

1. Solution of potassium bichromate $K_2Cr_2O_7$ or (better) chromic acid.
2. The saturated stones are next put into solid sal-ammoniac (ammonium chloride), heated for two weeks, then fired. This method has been modified, but no details can be given.

IV BLUE.

1. Solution: yellow prussiate of potash $K_4(Fe(CN)_6)$.
2. Solution: iron sulphate $FeSO_4$ with a few drops of sulphuric and nitric acid, so that a dark blue hue results.

The dyeing sometimes takes several weeks, then the stones are dried, washed and fired. Careful drying at 120° C. is important as traces of water in the pores tend to crack or burst the stone through steam pressure during firing. The old method of firing makes use of covered earthenware jugs on a stove, but more suitable are electric furnaces giving a temperature of about 350° C. With the above methods it is possible to obtain quite useable colours in agate and jasper, but for commercial purposes one needs long experience and thorough knowledge of the material.

E. S.

"Tourmaline Tester according to F. Vandrey." By S. von Gliszczynski. "Achat," 1949, Vol. 2 (3), p. 109-111.

The simplest determination of a tourmaline makes use of a polariscope. The most popular instrument used to be the dichroscope, but this is too expensive as it requires Iceland spar, which becomes quite rare. At the moment "herapatite" and "bernotare," which are used as polarizing foils, are not available and are replaced by a set of glass plates. These are inclined by 57° towards the incident light beam. Vandrey's newly developed tourmaline tester consists essentially of an aluminium cylinder, height 3.2 cm. (1.3 in.), diameter 3.9 cm. (1.6 in.), containing the glass set. Two openings 0.8 cm. (0.3 in.) wide in the cylinder base and top allow viewing along the cylinder axis. If the instrument is held between eye and stone and rotated quickly through 90° around the cylinder axis, dichroism is observed in tourmalines. Green tourmalines display green and olive green colours, reds show darker and lighter shades, brown and blue stones behave likewise. The application of the instrument is not restricted, of course, to tourmalines, but may be usefully extended to any pleochroic material.

E. S.

" Determination of Silver in Pearls which have been dyed Black." By G. O. Wild, R. Papke and K. H. Biegel. " Achat," 1949, Vol. 2 (3), pp. 111-112.

Natural and cultured pearls can be coloured dark brown to black by dipping them into a solution of silver nitrate. The artificial colouring is very difficult to determine by chemical means, but spectographically the determination is possible. Silver shows three marked lines in the spectrum if only small quantities are present as contained in matter scraped from the drill hole of the pearl. Two lines are in the ultra-violet part of the spectrum, the third, which is the least intense, lies between the ultra-violet and the visible part. The following wavelength (in Angstrom units) are given:

Iron	3441 Å
Silver	3383 Å
Silver	3281 Å
Copper	3274 Å

The third silver line at 4055 Å is not visible with small quantities, so that the use of a quartz spectograph is required. Spectra of matter from an artificially coloured natural pearl illustrate the short article.

E. S.

" Handbook of Fluorescent Gems and Minerals." By Jack DeMent. Mineralogical Publishing Company, Portland, Oregon, U.S.A. First Edition 1949. 68 pp. Price $1.50.

A useful paper-covered handbook dealing with fluorescence production and its effects. Contains an excellent survey of radiation sources, including X-rays, cathode rays, grenz rays and ultra-violet light. The book contains valuable information on the various filters which can be used to isolate different wave-lengths of ultra-violet light. Some thirty gem species, including pearl, are remarked upon with reference to their reactions and fluorescent colours, and likewise some 230 minerals are discussed. The appendices contain a not very helpful set of tables based on the fluorescent colours and a useful bibliography. A number of the author's remarks on fluorescence effects are open to criticism and there are many typographical errors and mis-spellings. Garnierite is not a green garnet as stated.

R. W.

" A Report on a Radio-active Diamond." By John A. Hardy. " Gems and Gemology," Vol VI, No. 6, pp. 167-170.

Relates the experiments carried out on a green diamond and on other diamonds. The stone, .71 carats in weight, was, in 1938, of a lively green colour. After some alteration of the shank (in 1940) the stone was found to have turned a rich golden-yellow—possibly due to heat. The stone, which showed neither fluorescence nor phosphorescence, was found to be strongly radio-active by autophotography (three illustrations). Tentative theories as to how the radio-activity may have been induced are given. Experiments in 1940 and in 1941 at the University of Michigan by the use of an electrometer and Wilson Cloud Chamber produced the suggestion that the radio-activity is due to one of the daughter products of one of the radio-active series, and that there were indications that the radio-activity comes from atoms inside the diamond lattice. No decision was arrived at as to whether this was a natural phenomenon or had been artificially produced. In 1942 the radio-activity was about the same and the stone was then subjected to deuteron bombardment by cyclotron, when the stone regained its original green colour which it has since retained. Cyclotronic bombardment by deuterons showed that nearly all diamonds colour green if the bombardment be not too intense, but brown if too intense ; the latter is considered to be a heating effect rather than due to the deuterons. After such treatment the diamonds were found to be highly radio-active, but the effect drops almost to zero after an hour or two. The colouring of cyclotronic treated stones are, so far, apparently permanent, but is thought to be a purely surface effect. A note of warning is given on the wearing of radio-active radium treated diamonds, for in the case of the stone examined, radio-activity was detected in the wearer's finger after the ring had been removed.

R. W.

" A Handbook of Precious Stones." By L. A. N. Iyer (Foreword by W. D. West). Calcutta (Baptist Mission Press), 1949.

A conventional book on gemstones, with particular reference to gems and gem workings of India, Burma and Ceylon. The references are not altogether reliable.

G. A.

" Mineral Collectors' Handbook." By Richard M. Pearl. Colorado Springs (Mineral Book Co.), 1948-1949. First edition, 297 pp.

Written by a Fellow of the Association, this is an excellent book for the amateur mineral collector. Chapters are devoted to care, cleaning, preservation and labelling of minerals, and the chemistry, chemical tests and physical properties are comprehensive enough for the scope of the book. There are competent lists of museums and books dealing with mineralogy and a vocabulary.

G. A.

" Symposium on Reconstructed Rubies." By A. E. Alexander, E. J. Gubelin and B. W. Anderson. " Gems and Gemology," Vol. VI, No. 6, pp. 184-190.

Reports on the examination of a reconstructed ruby and on a specimen artificially produced. The symposium contains notes on the history, the physical and optical properties and the internal structure of these and other reconstructed stones. The density, refractive indices, absorption spectra and fluorescence (under ultra-violet light and X-rays) were found to be similar to natural ruby. The structure showed remarkably curved " swirl marks " of short radii which are markedly irregular when compared to the striations seen in synthetic ruby. Confusing " genuine-like " gaseous inclusions are also seen in association with isolated round bubbles. The colour is similar to Burma rubies but show the greater transparency in the ultra-violet (to 2700 Å) that has been observed in synthetic, but not in natural, ruby.

R. W.

" Oriented Zoning in Synthetic Corundum." By W. Plato. " Edelsteine u. Schmuck," 1949, 1 (9), pp. 193-194.

Apart from the straight colour bands in genuine corundum and the curved lines in synthetic stones, the author points to another phenomenon in synthetic corundum. When a synthetic corundum is viewed between crossed nicols along the optical axis zoning, intersecting at 60° or 120°, due to anomalous double refraction can be seen in nearly every case. This zoning is quite distinct from the straight colour bands in genuine stones and is particularly useful when colourless or very pale stones are examined.

E. S.

" Progress in the Synthesis of Diamonds." By K. F. Chudoba. " Edelsteine u. Schmuck," 1949, 1 (8), pp. 163-165.

Attempts to synthesize diamonds are enumerated and discussed, especially those of Moissan, Hannay, Günther and coll., Bridgman. The author arrives at the conclusion that the problem will not be solved in the near future as the technical and scientific basis has not yet been ascertained.

E. S.

" Emeralds and Rubies—Why so Scarce? " By Prof. Dr. K. Schlossmacher. " Edelsteine u. Schmuck," 1949, 1 (8), pp. 166-168.

Rubies and emeralds are formations of the pneumatolyic phase of the solidification of sial magma, emeralds being nearer to the pegmatic and hydrothermal phase. The colouring matter—chromium—does not belong to this formation. It only enters as colouring matter into corundum and beryl when carried from chromium deposits in sima stones by rising melts and solutions.

E. S.

" From Synthetic Ruby to Synthetic Rutile." " Achat," 1949 2 (5/6), pp. 205-209.

A historical review mentioning the work of A. Gaudin (1837), E. Frémy (1891), A. Verneuil (1902), G. A. Duabrée (1849), E. Ebelmann (1851), H. de Senarmont (1851), and others.

E. S.

" Fluoroscope for the Classification of Genuine Rubies." By S. von Glisczynski and F. Vandrey. " Achat," 1949, 2 (7/8), pp. 270-272.

Instead of employing a comparatively expensive ultra-violet light outfit, the authors used with good success an ordinary 15 watt lamp or preferably a 40 or 60 watt lamp in combination with two complementary colour filters. The light passes through a blue-green on to a red filter. The specimen is placed between the filters. No visible light from the lamp passes through the red filter. The blue-green light, however, which has passed the first filter, excites red fluorescence in a suitable specimen, which can be observed through the second filter. Examples of identification are given.

E. S.

OBSIDIAN OR MOLDAVITE ?

By Robert Webster, F.G.A.

EVEN in quite well-informed circles some difficulty is often found in distinguishing between the so-called "natural glasses," *obsidian* and *moldavite*, despite the fact that examination of the internal structure clearly differentiates between the two materials. The difficulty probably results from misconception in early days, when the green glassy lumps found along the Moldau river in Bohemia were thought to be a type of obsidian and were sold as such.

Indeed, looking back through the literature, one can see that the misconception must have started early, and with the mineralogist, who, in fairness, quickly corrected the error. Moldavites, which had been known before 1787,(1) were not referred to in the second edition of Phillip's "Mineralogy" of 1819,(2) but in the fourth edition of that work(3) are referred to as a variety of obsidian ; a similar version being given in Mohs's "Mineralogy" of 1825.(4) In the 1852 edition of Phillip's "Mineralogy" (revised by Brooke and Miller),(5) moldavite is not included—the mineralogist had apparently decided against the pieces being volcanic glass, although as late as 1894 F. Rutley(6) still terms moldavite a variety of obsidian.

The gemstone literature seems to have been much later in clearing up the discrepancy, for we find that as late as 1909 Wodiska(7) classed moldavite as obsidian. Many of the earlier works (Claremont, Cattelle, Emanuel and Church in his first edition) ignore the material altogether. Church(8) in the 1905 edition clearly states that moldavites are not a volcanic glass, and in the last edition he writes: "The material differs in intimate structure, in fusing point, and in chemical composition from any kind of glass. It is not identical with obsidian."

Further, many text-books describe obsidian as having a leaf-green colour, a shade rarely, if ever, found in the natural volcanic

glass. Therefore it can be little wondered at that the gemmologist, with all this initial misunderstanding, finds himself at a loss over these materials. Maybe these few notes will clear away some of the ambiguity.

For convenience it may be as well to give initially some notes on the moldavites themselves. These glassy pieces are found in lumps having peculiar surface markings and are of a deep leaf-green in colour—they are faceted in the usual styles for marketing. The origin of the pieces is wrapt in mystery ; they have been variously described as being the remains of a prehistoric glass works, or to have a celestial origin, and as such have been grouped with the *tectites*.

Moldavites have a range of density, according to Herbert Smith, of 2.30 to 2.50 ; eight determinations reported by the writer(9) on cut and rough specimens gave values between 2.32 and 2.38. The refractive index, the material being a glass and therefore isotropic has only one index of refraction, is given as 1.48 to 1.52. Here again the writer found from the specimens available, the more restricted range of 1.49 to 1.50. There is no absorption spectrum pronounced enough to be of use in identification. However, it is by examination of the internal structure that the most conclusive evidence can be obtained, for the large and profuse round gas bubbles combined with peculiar swirl markings are typical of the material and totally unlike the swirl striae and gas bubbles seen in glass imitation gems.

Obsidian, a volcanic glass, results from the rapid solidification of volcanic lavas, which, if slowly cooled, would assume a crystalline structure ; e.g. granite. Most obsidian does show incipient crystallization, generally known as *devitrification*, which is evident by the texture or microstructure showing crystallites. These are spherical, rod-shaped or hair-like bodies, the different forms being given specific names ; thus the droplike bodies are termed *globulites*, the rod-shaped ones *belonites* and the coiled and twisted hairs *trichites*(10), and globulites in chains are termed *margarites*, probably in fanciful analogy to a string of pearls. It is by this texture that obsidian may be clearly differentiated from moldavite, and further, a sort of preferential parallelization of the crystallites —probably due to flow structure—produces a silver or golden sheen.

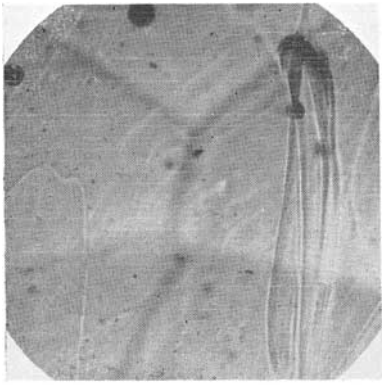

FIG. 1

Gas bubbles and swirl marks in moldavite. X25.

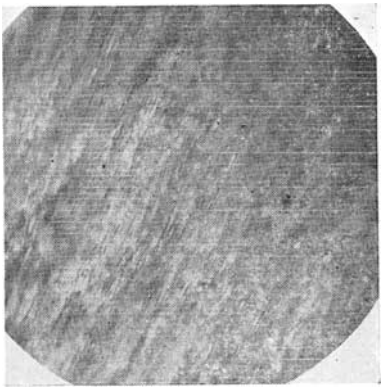

FIG. 2

Microscopic crystallites in parallel orientation in an obsidian. X25

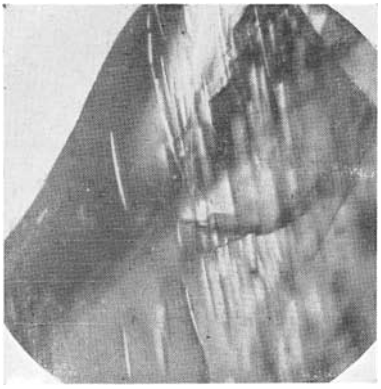

FIG. 3

Torpedo-shaped vesicles in obsidian. X25.

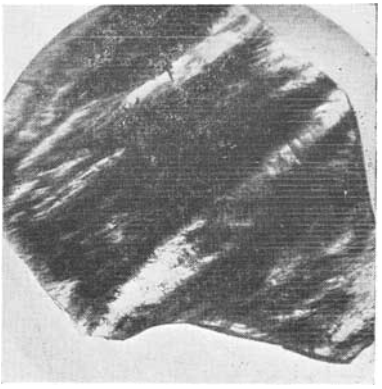

FIG. 4

Colour bending appears to be composed of microscopic crystallites in "Mountain mahogany obsidian." X25.

Obsidian is generally dark grey or black in colour, or may be brown and black, the two colours being banded and showing a very definite flow structure. The obsidian used as a gem material is usually the iridescent variety showing a golden or silver sheen ; and perhaps for some occasions the black and brown striped material is fashioned. The name " mountain mahogany " has been applied to this black and brown material.(11) The hardness of obsidian is about 5 on Mohs's scale, and the material has a pronounced conchoidal fracture producing sharp knife-like edges—a character which has endeared obsidian to Stone Age Man.

The density of obsidian, according to Herbert Smith,(12) is 2.33 to 2.47, a value range which the writer's personal determinations fully confirm and which for completeness are appended:—

" Mountain mahogany "	2.338
" Mountain mahogany "	2.341
" Mountain mahogany "	2.343
" Mountain mahogany "	2.345
" Mountain mahogany "	2.347
Black	2.356
Golden iridescent	2.358
Golden iridescent	2.361
Black	2.361
" Mountain mahogany "	2.381
Silver iridescent	2.393
Black	2.399
Silver iridescent	2.41
" Mountain mahogany "	2.414

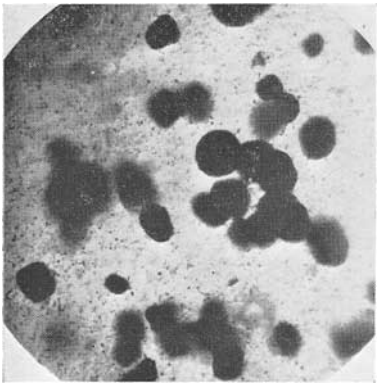

FIG. 5
Spherulites and small globulites in obsidian. X25.

The refractive index is given as 1.48 to 1.51, and thin fragments viewed between crossed nicols are generally completely isotropic, unless fairly large crystallites, or rather *microlites*(13) are included, which show up as bright points of light and which are also seen to show sharp extinction.

Observation of thin slivers under the microscope, even with low magnification (x25), will clearly distinguish obsidian from moldavite. In obsidian the texture observed may vary considerably from the crystallites already mentioned to torpedo-shaped, or cigar-shaped, vesicles ; the latter often in association with belonites or other types of crystallites—which may require a much greater magnification to resolve. It is hoped that the accompanying photomicrographs will illustrate the structures more clearly.

The obsidian used in jewellery is mostly obtained from the United States, important localities being the Glass Butte, Oregon ; Obsidian Cliff, Yellowstone National Park, and in a number of localities in California. A variety, miscalled " Iceland agate," is found, as the name implies, in Iceland. Many other localities throughout the world are known, mainly, though, through the interest they hold as being the sources of material used for ancient artifacts.

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(10) Hatch (F. H.). " Petrology of the Igneous Rocks," 7th Edn., p. 32. London, 1914.

(11) Bauer (M) (trans. by L. J. Spencer), " Precious Stones," p. 446. London, 1904.

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TWO USEFUL HOME-MADE POLARISCOPES

by R. Keith Mitchell, F.G.A.

IN response to one or two inquiries from Chelsea students early last session, I had some one-inch squares of polaroid mounted between glass for supply to such students as wanted them. Two of these squares, held in a crossed position with a space between them, in the left thumb and forefinger, formed, with a little practice, a crude but none the less effective polariscope. The stone under test being placed between them and moved as required by means of corn-tongs held in the right hand, light being reflected from a strongly illuminated sheet of white paper and side light excluded by the position of the thumb and forefinger.

It was at first intended that these sets of polaroids should be used in this way and be available for refractometer work and any other uses to which polaroid may ordinarly be put. But two students have independently elaborated on the simple idea to build permanent and useful polariscopes at remarkably small cost.

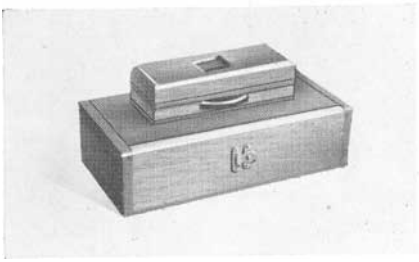

FIG. 1

The first of these, made by W. Frake and illustrated in Figure 1, is a very simple little instrument. The main body, which houses a pocket torch lamp and battery, is made from one end of a cigar box with a sliding lid to allow easy access to these items. The polarizer (glass-mounted polaroid) is recessed into a $1\frac{1}{4}$ in. square hole in the sliding lid. Above this is a metal rimmed glass disc, sandwiched between three rectangles of plywood, with its edges projecting fore and aft, so that it may be rotated at will. The plywood is screwed and glued into place on the box lid. A

further sandwich of three layers of glued ply holds the polaroid analyzer, and is pivoted on the first by means of a screw at one corner.

In use, the top section swings out to allow a stone to be placed on the glass disc. It is then swung back into place, when the polarizer and analyzer are in crossed position. The stone is illuminated from below by means of the lamp and viewed through the square hole at the top of the instrument, the glass disc being rotated as desired. An ordinary brass jewel box catch has been cleverly utilized as a switch for the lamp.

FIG. 2

The second instrument, illustrated in Figure 2, was made by F. Kench, and is a considerably more elaborate job. It consists of a rectangular wooden box housing batteries and switch, surmounted by a square wooden tube containing bulb, diffusion screen, polarizer, rotating glass, analyzer and lens. Again the construction is mainly from cigar-box wood. The tube is hinged to allow a stone to be placed on the rotating disc. Further hinges give access to the bulb and batteries respectively. The top wooden plate can be unscrewed for cleaning the back of the lens and the analyzer. A rather complicated inner lining (not shown in the diagram) gives similar access to the glass disc and polarizer. By hinging the instrument immediately above the glass disc this complication could be avoided.

In use, this instrument gives similar results to those obtained with the first one, with the additional advantage of a small degree of magnification. Three two-volt batteries are used, giving somewhat stronger illumination. The lamp housing is painted white inside, while all above the polarizer is painted black.

Both instruments are intended for use with loose stones, but the larger one would accommodate a mounted ring of reasonable size if necessary. The student originally thought of devising some means of immersing the stones in a suitable fluid, but this would seem impractical in view of the damage that might result from spilled liquid.

These, no doubt, are far from being the first home-made polariscopes to be constructed by gemmologists, but they are of interest as illustrating some degree of enterprise and also of the fact that no more than about ten shillings was expended on each.

COMMENT ON "THE FINE CUT OF SYNTHETIC RUTILE"

By W. F. Eppler, Ph.D.

There are two approaches open to the student in analyzing the design of gem cuts. Dr. Eppler has followed the usual path. The less common method is to set the stone up on a special optical bench and physically examine the light lost out the back, the pattern thrown on the screen and by pin-hole or mask trace the ray paths. No simplifying assumptions such as render the results of a drawing-board analysis doubtful are necessary.

I would like particularly to point out in Dr. Eppler's paper that the only facets considered (except for 0° incident light) are those cut by the plane of the paper. For these facets his argument is on sound ground. It is inadmissible to use the results for these facets for the remainder of the area of the gem presented to the light at other than 0° and compute thereby percentage of light lost for the whole gem.

If memory serves me right, Dr. Eppler in his 1938 article develops his whole series of "Ideal" cuts on the basis of 0° incident light. Unfortunately, this angle of presentation to a light source is rather impractical unless one wants to use a surgeon's forehead lamp when examining gems. Dr. Eppler apparently recognizes the greater rationality of Tolkowsky's oblique illumination in his current article.

I have cut and examined, on the optical bench, a number of Synthetic Rutile Gems. As a result, I have abandoned the standard round Brilliant-cut for these stones where the finished weight exceeds 8 or 9 ct. The largest cut to date weighs 27 ct. The cut I have found to be superior to the standard round brilliant is the Jubilee-Cut. The crown is shallow, there is no table. The angles to the plane of the girdle are:—

Main Pavilion Facets	−40°
Point Pavilion Facets	−35°
Main Crown Facets	−30°
Star Crown Facets	−10°

For what my judgment is worth, I would say that Dr. Eppler's Fine Cut points to improvement in gem design. I can only hope that he will come to analyze gem designs on the optical bench and report his findings.

GRIFFIN GRANT WAITE, Toronto 12.

ASSOCIATION NOTICES

FIRST GEMMOLOGICAL CHAIRMAN DIES

The Council regrets to announce the death in London on June 21st of Mr. S. Barnett, the first Chairman of the Gemmological Association. Mr. Barnett was born in Swineshead, Lincs, in 1874, and served an apprenticeship with his father, a watch and clock maker.

After experience with a number of firms, in 1902 he went as manager to Butt & Co., Ltd., of Chester, and on the death of Mr. A. W. Butt became managing director, a position he held until 1920, when he bought a business at Brighton. Two years later he purchased a business in Peterborough and carried on there until his retirement in 1943.

Throughout his career Mr. Barnett was keenly interested in trade education. In 1901 he became a Fellow of the Spectacle Makers' Company, and was that year granted the Freedom of the City of London. In 1912 he qualified as an F.B.H.I. At the Annual National Association of Goldsmiths' Conference in Manchester in 1908, he proposed on his own initiative that the teaching of gemmology should be one of the objects of the N.A.G. and that the Association should hold examinations in the subject. After four years of work in furthering the scheme, the first examination was held in 1913. Mr. Barnett sat for the examination and was awarded Diploma No. 1.

Prior to the formation of the Gemmological Association in 1931, of which he was the first Chairman, Mr. Barnett acted as chairman of the N.A.G. Education Committee for three years. In his will (subject to probate) he bequeathed £100 free of duty to the Gemmological Association.

GIFTS TO ASSOCIATION

The Council wishes to express its appreciation of the following gifts that have been made to the Association: A text-book on Gemmology, in Finnish, presented by the author, H. Tillander, Esq., F.G.A.; the "Armytage Collection of Maori Jade," by K. Athol Webster, Esq.; a collection of synthetic sapphire and spinel boules by Wiedes Carbidwerk.

MEMBERS' MEETING

A meeting of Fellows and members will be held in the Medical Society of London's Hall on Tuesday, November 15th, 1949, at 7 p.m. The speaker will be R. K. Mitchell, F.G.A., whose subject will be "Cleavage and the structure of gem minerals."

BIRMINGHAM POST-DIPLOMA CLASS

A post-Diploma class in gemmology has been instituted at the Jewellers' and Silversmiths' School, Vittoria Street, Birmingham, and Fellows of the Association who may be interested should address inquiries to the lecturer, Norman Harper, F.G.A., at the school.

MEMBERSHIP

The following were elected to membership of the Association at a meeting of the Council held on August 10th, 1949:—

FELLOW:
Thody, J. T., Bedford.

PROBATIONARY:
Katz, Arnold, S. Africa.
Katz, Basil, S. Africa.
MacKillip, A. J., Ardrossan.

ORDINARY:
Helzberg, Barnett C., Kansas City, U.S.A.
Law, Leslie, London.

DR. A. E. ALEXANDER

Messrs. Tiffany & Co. announce that Dr. A. E. Alexander, authority on gemstones and pearls, will join their organization in an executive capacity on October 1st. Dr. Alexander recently resigned the directorship of the Gem Trade Laboratory, Inc., New York.

RESULTS OF THE 1949 EXAMINATIONS

For the 1949 Diploma (Fellowship) Examinations of the Gemmological Association of Great Britain a record number of candidates, 111 in all, presented themselves, of whom 96 sat in Great Britain and 15 overseas ; of these seven did not take the practical part of the examinations and could qualify for Associateship only. Upon the recommendation of the examiners the award of the Tully Medal has been made to Mr. P. J. Thomson, of The Jade Dragon, Ltd., for the competent knowledge of the subject displayed in his papers. It has also been recommended that two Anderson Prizes be awarded, one to Mr. E. T. Hartland, of A. E. Poston & Co., Ltd., and the other to Mr. F. C. L. Salisbury, of W. C. Mansell, for papers of equal merit in the practical examination.

A large number of entries was received for the Preliminary Examinations also, 14 from overseas and 112 in Great Britain, making a total of 126. The Rayner Prize has been awarded to Miss S. G. Warnes, of Messrs. Speed & Son.

The following is a list of successful candidates, arranged alphabetically:

DIPLOMA

Qualified with Distinction

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Butler, Miss J. M. (Greenford)
Butterfield, M. L. (Leeds)
Davis, K. C. (London)
Day, N. H. (Salisbury)
Dresme, D. (Amsterdam, Holland)
Feitelson, P. ((London)
Franklin, L. (London)
Gudridge, E. H. (Perranporth)
Harkins, T. (Johnstone)
Hartland, E. T. (London)
Heetman, J. G. (Rotterdam, Holland)
MacDonald, E. W. (Bearsden)
McDonald, Miss T. (Edinburgh)
Newman, J. A. (London)
Rosas, M. M. R. P. (Oporto, Portugal)
Sanitt, L. (Ilford)
Stephanides, S. G. (Birmingham)
Thomson, P. J. (Thundersley)
Whitehead, G. W. (Surbiton)
Winnert, G. M. (Edinburgh)
Wright, G. T. (London)

Qualified

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Backers, F. C. M. (The Hague, Holland)
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Campbell, K. J. (Thornton Heath)
Cook, G. O. (London)
Croston, G. (Liverpool)
Cutts, Miss P. E. (Birmingham)
Dickson, R. W. (Glasgow)
Dougan, R. W. (Deal)
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Fitch, Miss J. E. (Vancouver, Canada)
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Haussler, Miss J. (Amsterdam, Holland)
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Leng, H. H. (Birmingham)
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Lowe, R. D. (Wickersley)
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Penn, L. (Birmingham)
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Pinn, R. L. (Cape Town, S. Africa)
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Rack, M. P. (London)
Rance, W. A. (Widmer End)
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Salisbury, F. C. L. (Northolt)
Salloway, J. M. S. (Lichfield)
Saunders, C. K. (Sutton Coldfield)
Scanlon, F. (Manchester)
Shearer, E. H. S. (Edinburgh)
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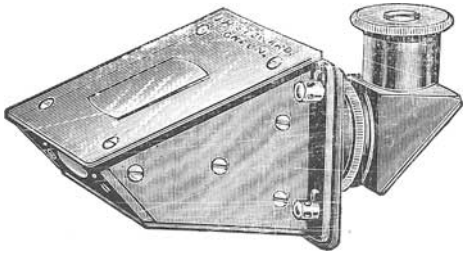

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Vol. II No. 5 January 1950

THE JOURNAL OF GEMMOLOGY

and

PROCEEDINGS OF THE

GEMMOLOGICAL ASSOCIATION OF GREAT BRITAIN

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THE JOURNAL OF GEMMOLOGY
AND PROCEEDINGS OF THE GEMMOLOGICAL ASSOCIATION OF GREAT BRITAIN

Vol. II, No. 5 JANUARY 1950

THE MINING AND HEAT TREATMENT OF ZIRCONS

by

W. C. BUCKINGHAM, F.G.A.

The collection of zircons, together with the photographs described in this article, were shown at the 1949 Gemmological Exhibition in London.

The writer's thanks are due to Messrs. George Lindley & Co. (London) Ltd., for the opportunity of examining the stones, and also for much of the information used as a basis for the article.

THE recent arrival in London of a large collection of zircon crystals and waterworn pebbles is affording an interesting opportunity for further research into the gemstone.

The parcels of stones making up the collection have been given a preliminary inspection, and a general description of them appears in this article, together with brief notes on their origin. They have been numbered for ease of reference.

Commercially, zircon is steadily regaining its pre-war popularity as an inexpensive yet real stone, and it is well known that the main source of the familiar heat-treated material is French Indo-China, via the cutting centre of Bangkok. From a gemmological point of view, however, there has been some difficulty in obtaining specimens which are definitely known as coming from a

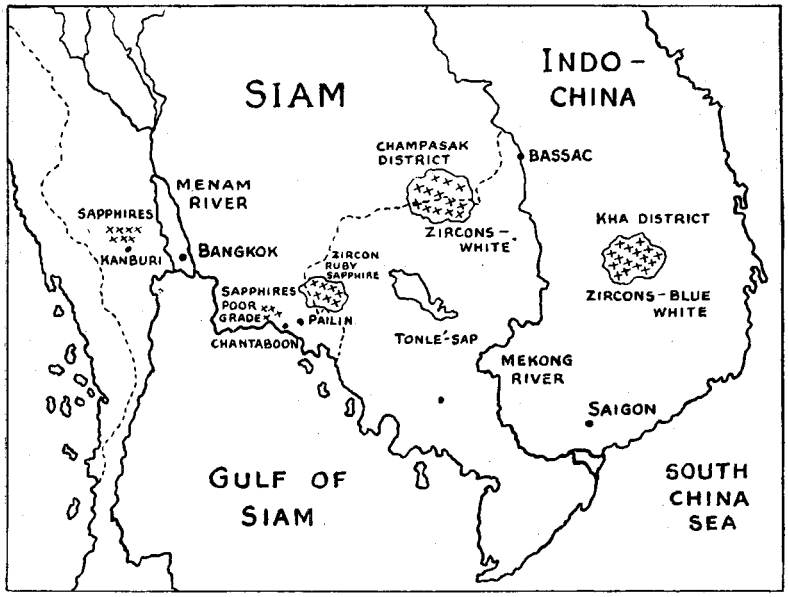

Fig. 1.

certain area or mine. This is perhaps the most interesting feature of the present collection under review. It has arrived with each of its twelve parcels of rough and semi-finished stones marked with the district of origin, and, in two cases, with the names of the mines where the crystals were obtained. Thus it is possible to study the characteristics of the rough, both before and after heat treatment, and to note any variation between specimens from each district.

The sketch map (Fig. 1) showing the southern areas of both Thailand (Siam) and Indo-China gives the locations of the zircon mines in three well-defined groups, or districts, which are, in probable order of commercial importance, the Kha, Champasak, and Pailin districts. The main concentration of mines is in Indo-China, although the two latter districts lie actually on, or across, the border line of that country and Thailand.

In addition to being the chief source of zircon, the Kha district is of particular interest because it is the only area where the mined rough produces both blue and golden or colourless stones after suitable heat treatment. This group of mines is situated east of the

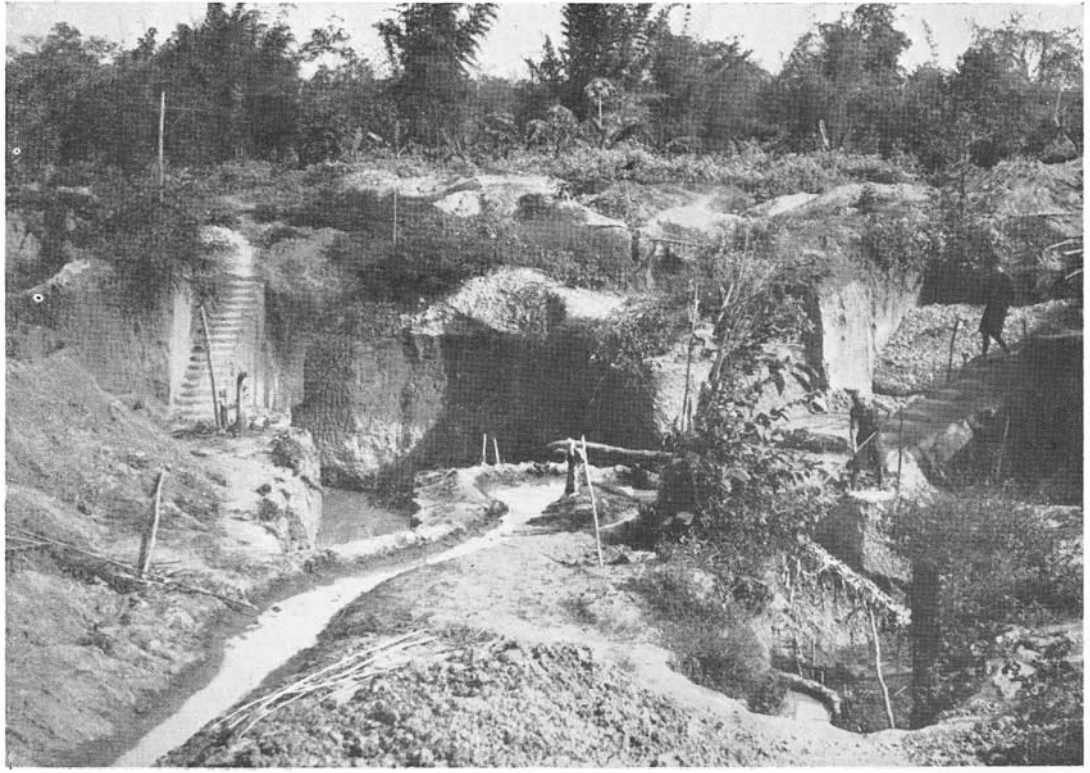

Fig. 2. — Typical zircon mine. Right — digging. Centre — washing earth away.

Mekong River and about 150 miles north of Saigon. There is a very definite backbone of mountainous country down the whole length of the east coast of Indo-China. Peaks rise almost to 7,000 feet near the coast, but there is a rather gradual descent in the west, towards the Mekong valley. Lying in the foothills the mines are only readily accessible from the river. This disadvantage of the rugged country is perhaps offset by the fact that the mountains seem to act as a definite check to both the S.W. and N.E. monsoons. Thus a fairly constant rainfall of over 60 inches a year ensures the all-important water supply for both domestic and mining purposes. The use of water for the preliminary excavation and removal of the zircon bearing ground is well illustrated in Fig. 2.

A journey to the Kha district from Bangkok is not lightly undertaken since it entails an arduous trek for eleven to twelve days, of which only the first few hours can be made in any degree of comfort by train. The rest of the travelling must be accomplished partly overland by bullock cart and elephant (Fig. 3), and partly by water in small boats along the Mekong and one of its tributaries, the Sé-San.

The mines in this district are about 10-20 miles from each other, and it is from one of these, the Looi mine, that parcel 1 originated. This parcel consists of about 30 per cent. worn pebbles and 70 per cent. pieces clearly showing traces of crystal form. Unfortunately, the conditions of growth or method of digging have resulted in almost every piece being fractured, or showing imperfect cleavage planes. Only in the largest crystal, weighing about 6.5 carats and used for a preliminary density test, is it possible to see part of the tetragonal dipyramidal terminations together with two adjacent prism faces. The colour of this parcel varies from a pale straw to a deep red-brown translucency. The fractured surfaces display the peculiar lustre of zircon, best described as adamantine but yet possessing a certain greasy quality even in the rough.

Zircon crystals from the Kha district produce blue, white and golden stones after heat treatment, but it would appear that the colour is determined primarily by the actual mine of origin. The rough from the Looi mine (as in parcel 1) will change, with suitable period and degree of heating, firstly to blue and then to white or golden stones, whilst crystals from another mine in the same district will give only colourless zircons after treatment.

Fig. 3.—The elephant journey takes six days through jungle.

Parcel 2 represents a similar collection of specimens to those in parcel 1. They come from the same mine and have undergone the initial heating. The resultant colour varies in shade from pale sky-blue to deep blue-green, whilst the fractured surfaces seem to have a rather higher degree of lustre than the untreated red-brown stones. The fact that the worn surfaces have a more pronounced " satin " appearance than before heating is probably due to the slight increase in brittleness which occurs in all zircons during the firing process. Two specimens selected for comparative density tests were, firstly, a completely fractured and partly worn pebble of medium sky-blue weighing 12.33 carats, and, secondly, an interesting crystal of almost perfect form showing the intermediate pyramid faces in addition to the usual pyramidal terminations, together with three prism faces. The remaining face is distorted due to conditions of growth. This second crystal is of clear medium sky-blue colour and weighs 8.78 carats.

Although B. W. Anderson, in his summary of Dr. W. E. Eppler's findings,* places the actual degree of heat at 900-1,000° C. for a period of 1½-2 hours, it would appear that these two factors

* " Gemmologist," Vol. VII, No. 75, October, 1937.

vary considerably according to the source of the rough, and the operator. It is quite definite, however, that the heating of such rough as this from the Looi mine is done in a small fireclay crucible which is closed to give a reducing atmosphere. Somewhat primitive stoves are still in use for this purpose, as shown in Fig. 4. They are provided with suitable apertures and grates for draught and contain the crucible holding about a kilogram of zircon, the crucible itself being surrounded by small coal or charcoal. A tall funnel, as seen on the left of the photograph, can be added to increase the draught and thus raise the temperature as required. Both crystals and worn pebbles undergo the same treatment and achieve similar percentages of results in change of colour.

The wastage in this firing stage is very high, over 70 per cent. of the rough having to be rejected as not up to gem standard. All clear, but pale blue stones from the treated parcel are given a further prolonged period of heating in the closed crucible which has the effect of bleaching the poor blue, resulting in colourless material. The temperature for this stage is critical, and must be determined after long experience, since underheated stones tend to fade from white to a brown shade, whilst overheating means an undesirable cloudy appearance.

Parcel 3 consists of specimens from this bleaching process and the stones are of clear to cloudy white with fused black particles, together with possible galena, adhering to the fractured surfaces.

Some of the rough from the initial firing will show the intrinsic characteristics of golden zircon, and these pieces undergo their second heating in a perforated crucible which allows free access of oxygen. From such crystals are cut the lesser known but equally beautiful red to golden-brown zircons which, save for their higher lustre and " steely " aspect, are very close in colour to the various shades of citrine.

This range of colour is well seen in parcel 4, which is of roughly shaped round stones varying from pale orange to reddish-orange and golden yellow. Exact determination of colour and purity is difficult at this stage owing to the frosted surface imparted by the carborundum shaping wheel.

Whilst dealing with the Kha district material it is interesting to take note of the Hua Tek mine. Although this source has been completely exhausted for many years, a small supply of crystals mined there is included in the collection under parcel 5. The rough

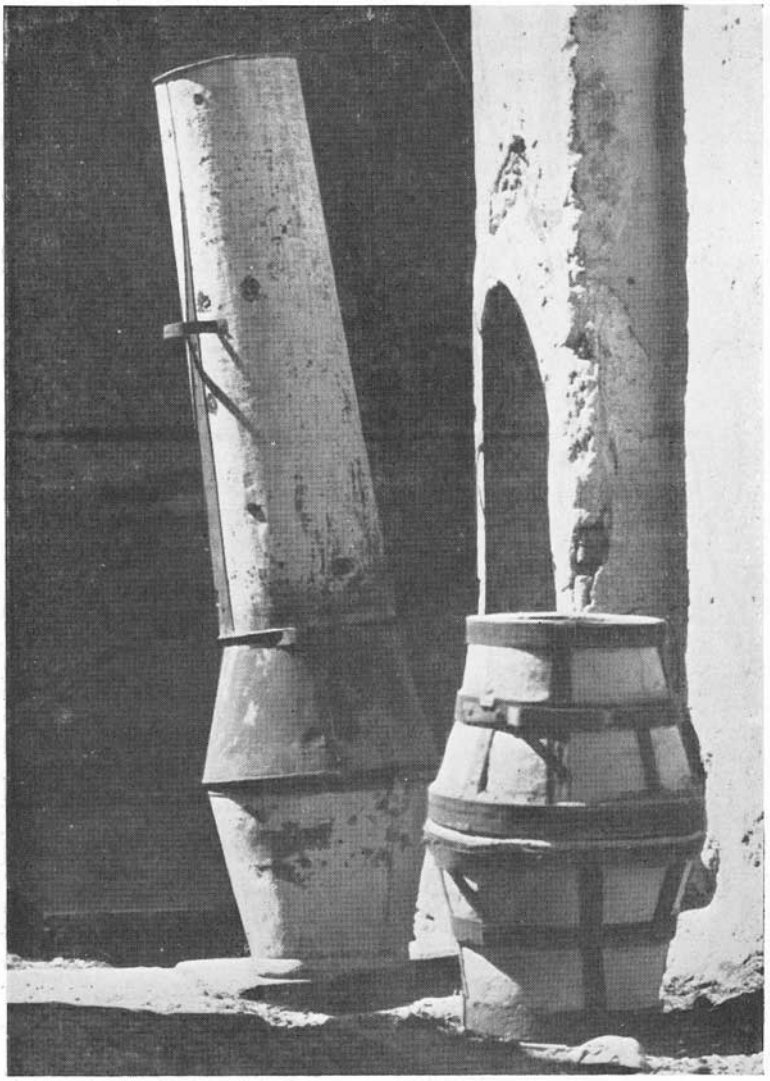

Fig. 4. Heating rough zircons. Left—Tall funnel filled with coal; Right—1 kilogram of rough being heated.

from this mine was considered to produce the finest white zircons of all, possessing a higher degree of brilliancy than stones from other diggings. This belief is well borne out by the appearance of the zircon in this parcel, since even in the rough unheated state this is very bright clear material ranging from the natural colourless to a pale straw colour. The average size of this rough is extremely small—905 stones in the parcel weigh only 416.25 carats, and the largest, a tabular crystal, weighs only 0.8 carat.

Leaving the main area of production, the next in importance is the Champasak district, which lies partly in Thailand and partly in Indo-China. It is almost due west of Bassak, a town on the Mekong, and is centred chiefly on a ridge of high ground, the Dang-Bek, rising in this part to 1,000 feet. The Dang-Bek range separates the Eastern basin of Thailand from Cambodia in Indo-China, and the frontier follows it very closely, from Watana in the west, to the Mekong. Although Cambodia is supplied with water in the dry months from the natural reservoir of Tonlé-Sap (inland lake) and the small streams which feed it, the Eastern basin is notorious as a very dry area. The long period of drought influences the mines in the Champasak area in that they can only be worked for about two months in the year during the rains.

The parcel, No. 6, containing specimens from this district, is not attributed to a definite mine, but consists of pieces averaging a rather larger size than those from the Kha mines. They are a consistent dark opaque brown in colour, and the largest crystal, used for density tests, is one with long prism faces and one termination showing two pyramid faces very pronounced in a wedge shape. The piece weighs 39.40 carats. This material produces only colourless stones after heating, and before the main firing process it is pre-heated to increase its transparency and facilitate inspection for cracks and inclusions. The inspection stage is represented by a further parcel, No. 7, whilst the stones in parcel 8 show the appearance after the final heating. Treated zircons from the Champasak mines are a much clearer white than those from other districts, and they never fade to brown. However, the temperature during firing must be closely watched, as underheating results in a blackish cast in the crystals.

The final and least important present-day source of commercial zircons is the Pailin district, very close to the mines from which come the well-known dark blue sapphires. This area is just above

Fig. 5. Native lapidaries. Rough shaping of crystals on handwheel.

Chantabun, a town on the northern coast of the Gulf of Siam, also a centre of poorer grade sapphires. The zircon rough from this district, represented in parcel 9, gives a colourless stone after treatment and only in sizes suitable for producing small brilliant-cut stones. The untreated rough is a fairly constant clear light red-brown colour averaging about 4.0 carats per piece. It is estimated that another year or two will see the chief Pailin mine completely worked out.

The remaining parcels of specimens in this new collection show the process of cutting and polishing the rough from different districts. This work is done almost exclusively in Bangkok. A preliminary stage is the shaping, which is carried out against a small vertical carborundum hand wheel, as in Fig. 5. This is followed by a smoothing operation on a horizontal wheel, also of carborundum, turning in water-filled enclosure.

The actual facet cutting and the final polishing are done on the normal type of steel lap, the same wheel being used for both operations. This is well shown in Fig. 6. Boart is used for cutting and polishing, and a facet cut on the inner portion of the lap face is immediately polished on the outer rim.

The finished gemstones are carefully graded for colour and purity, chiefly into three classes for both white and blue. Special quality blue stones are the deepest and most prized colour, whilst the white are particularly clean and brilliant. First quality blue zircons cover a good average range from medium sky-blue to deep steel-blue, and the commercial or lowest quality in both varieties provides stones particularly suitable for grouping "en masse."

In conclusion, it is of interest to record one or two points regarding change of colour in finished zircons. These are exposed to strong sunlight in a current of air for 48 hours after polishing, and stones which then show a tendency to revert to their original colour are rejected before shipment. Experience proves that this treatment cuts down the proportion of subsequent colour changes to a very small amount. A draught, or a damp atmosphere, will often cause a blue zircon to undergo an apparent reversion to brown or green-blue. This change is only temporary, however, and if the stone is wrapped and left in the dark for a short period its original shade of blue is restored. White zircons sometimes show a tinge of yellow after they have been wrapped and stored for a long time,

but when unwrapped and exposed to the air they regain their normal white brilliancy in a matter of minutes.

It is hoped to carry out extensive density and optical tests on specimens from this collection, and any interesting results will be recorded in a future article.

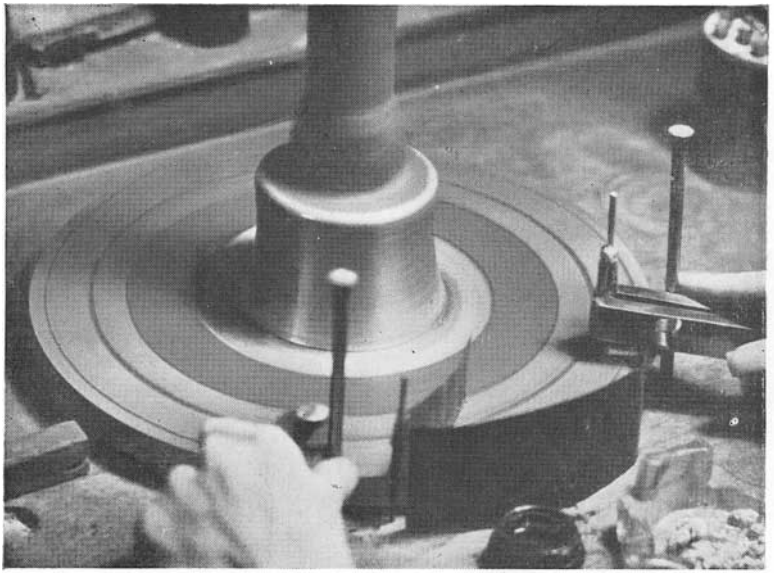

Fig. 6. Right hand—cutting facets ; Left hand—spreading surface of lap with boart inserted in a lead rod.

CANADIAN GEMS AND GEM LOCALITIES *(continued from page 194)*

UVAROVITE.—A number of small green crystals, too small to cut.

WALRUS IVORY.—Two tusks from Baffin Land. Also a replica of a seal carved from walrus ivory by the Esquimaux.

WILSONITE.—Several fine reddish-to-purple cabochons, from Minden, Ontario.

ZIRCON.—Several brilliant- and mixed-cut stones in fine orange and red colours. Cut from fragments of large crystals. This material turns colourless when heated. Renfrew County, Ontario.

ZONOCHLORATE.—A number of fine cabochons from the islands off Nipigon Harbour, Ontario.

Canadian Gems and Gem Localities

SUPPLEMENT to Parts I & II Vol. I Nos. 5, 6 and 8

By D. S. M. FIELD

ALMANDINE (Province of Quebec).—Labelle County, Joly Township, Range 1, Lot 16, two miles west of Labelle Station. Transparent and deep red masses, weighing up to a hundred pounds, occur in several parallel four-foot veins of solid pyrrhotite. This has been given the highest official rating of any Canadian red garnet. (G.S.C., No. 677 (1927), pp. 19 and 32.)

AXINITE (Ontario and Quebec).—Some fine crystals of axinite were found, many years ago, in a primitive rock boulder, near Hawksbury, Prescott County, Ontario. (G.S.C., New Series, IV, 22T.)

Axinite has also been found, in place, by Dr. R. Bell, in small veins in trap rock, about one and one-half miles south of the mouth of Little Whale River, on the east coast of Hudson Bay, in Quebec Province. The mineral is found in association with epidote, calcite and quartz. The colour is a fine purplish brown.

BLOODSTONE (Nova Scotia).—This mineral has been found, in place, by C. W. Willimott, at Two Islands, Bay of Fundy Region, Nova Scotia.

CHIASTOLITE (New Brunswick, Nova Scotia and Quebec).—Good specimens of Chiastolite occur in a fine-grained micaceous schist at Moore's Mills, Charlotte County, N.B. ; in Compton, Frontenac and Stanstead Counties, P.Q. ; and in fair macles at Geizer's Hill, Halifax County, N.S.

DEMANTOID (Quebec).—Occurs sparingly, in good-sized light green crystals (transparent in part), on the dumps adjoining the Chrome pits, Black Lake Region, P.Q. (Priv. Comm., Dr. Carl Faessler, Université Laval, Quebec City). (This garnet was first identified as Demantoid by Dr. Faessler in 1941.)

EMERALD (Ontario).—Small crystals of emerald occur in Northern Ontario, but none have been found which are large enough to cut.

HOWLITE (Nova Scotia) (Hydrous Silico-borate of Calcium). —This beautiful ornamental mineral was first identified as a new species by Dr. Henry How, of King's College, Windsor, N.S. (circa 1860), and was described by him as a silicoborocalcite. Howlite is ivory white in colour, but usually has veins of other colours—often jet black—and attractive dendritic markings. It occurs, in Nova Scotia, in the form of nodules, ranging in size from that of a pigeon's egg to that of a man's head. (V. Johnston, Memoir 74, G.S.C.) These nodules are found embedded in gypsum, or anhydrite and gypsum, at Brockville, Newport Station, Noel, Wentworth, etc., all in Hants Co., N.S. The mineral takes a high polish, and is therefore well adapted for extensive use in the Arts.

JET (Nova Scotia).—Jet is found, in fine pieces, at Pictou, N.S. It is less hard than the famous Whitby material, but it takes a good polish.

PEARLS (New Brunswick and Quebec).—Fresh-water mussels (Uniondae) are to be found in practically all Canadian streams where fish may be found, but there has not been much pearl hunting done in this part of the Continent.

Some years ago, a unio containing a fine round pink pearl, weighing about 30 grains, was taken near the City of St. John, N.B. This was acquired by George Renolts, Esq., of Toronto, Ontario.

The writer possesses a remarkably good egg-shaped " black " pearl, found last year by Mr. R. T. LeBlanc in a qua-hog clam (Venus mercenaria) in Westmorland County, N.B. This gem weighs about 16 grains and ranges in colour from deep blackish violet on the larger end to light brownish mauve on the other, with a small, slightly opalescent round spot of white at the very tip. This pearl lacks orient, but possesses a high lustre and is without blemish. It is by far the finest specimen of its kind the writer has seen. Viewed with the smaller end up, the pearl resembles a good star-sapphire—as seen in diffused light.

In the Province of Quebec, lumbermen sometimes catch unios for food by fastening small branches to the rear of their rafts when travelling down the rivers in the early Spring. The mussels, touched by the ends of the branches, quickly close their shells, and some at least are caught on the leaves and twigs. When a sufficient number of them become attached, the branches are hauled up and

the molluscs removed. Some of these unios contain good pearls, but the majority are baroques.

ROCK CRYSTAL AND MORION (Ontario and Nova Scotia).—A great deposit of rock crystal of the finest optical quality was recently discovered near Black Rapids, North of Gananoque, Ontario. Several tons of choice crystals—some of them sixteen inches in length—were mined and stockpiled during the summer of 1947.

Morion quartz and rock crystal of great size occur at Joe Bell Brook, Chester, and near Lake Ramsay, Nova Scotia. One crystal from the last-named locality measures twenty-six and three-quarters inches in length. It is in the Provincial Museum, Halifax, Nova Scotia.

ROSE QUARTZ (Nova Scotia).—Occurs in the form of pebbles near the town of Shelburne, N.S.

SPHALERITE (New Brunswick).—Honey-yellow, gem sphalerite (blende) occurs with galena, in veins traversing dolomite, at Frenchman's Creek, Lancaster County, N.B. The zinc mines of New Brunswick are quite well known as a source of this rare gem material.

A PRIVATE COLLECTION OF CANADIAN GEMSTONES AND ORNAMENTAL MINERALS

Descriptions and remarks are based on information furnished by the owner of the Collection, an amateur gem collector and lapidary of Toronto, Ontario.

AGATE.—Several hundred cabochons, many showing fine patterns. Chiefly from Michipicoten Island, Lake Superior (Can.). This locality furnishes a great plenty of colourful material of highest quality. (See also Cornelian, Chalcedony, Jasper, Eye-Agate, etc.)

ALMANDINE.—Rough material from Baffin Land (Can. Arctic). This will furnish good faceted stones.

AMAZONITE.—Several cut specimens of fine quality from Renfrew and Parry Sound Districts of Ontario. This material is found in all shades of green, the best of which approaches good emerald colour, with white stripes.

AMETHYST.—Several mixed- and step-cut stones. Deep violet with crimson shades. Thunder Bay, Lake Superior (Canada). Also a small deep-purple brilliant from Blomidon, Nova Scotia.

ANDALUSITE (var.: CHIASTOLITE).—Polished slab. Brown and black with fine chiastolite pattern. Great Slave Lake, N.W.T. (Canada). Great Slave Lake material is outstanding for size and pattern.

APATITE.—Brilliant- and mixed-cut stones (green). Wilberforce, Haliburton County, Ontario. Dichroic.

AQUAMARINE.—Brilliant- and mixed-cut stones from Butt Township, Nipissing District, and from Quadville, Renfrew County, Ontario. The fine blue colour and the clarity of these stones matches the best from Brazil.

AVENTURINE—FELDSPAR. (See " SUNSTONE.")

BLOODSTONE.—Small narrow cabochon from Bay of Fundy, N.S. This material is of fine colour and quality, but is scarce in large sizes.

CELESTITE.—The collector has facet-cut the translucent orange from Ontario and says that transparent blue (similar to that found in New York State) occurs in the Niagara limestone.

CHALCEDONY.—Large grey double cabochon with brown spot and markings, from Blomidon, Nova Scotia.

CORNELIAN.—Red cabochon from west end of Michipicoten Island ; also others from Lake Superior (Can. side) ranging from pale rose to deep brick red.

CORUNDUM. (See " SAPPHIRE.")

DIOPSIDE.— Light green and pale green step- and mixed-cut stones ; a sherry marquise-brilliant, and a smoky sherry cabochon with blue moonstone flame ; from various places in Ontario and Quebec.

EYE AGATE.—Some of the Lake Superior agates yield eyes, and the collector has cut some of these.

FLUOR.—Some of the Madoc (Ontario (fluorspar)) is clear and brilliant enough to facet. It is usually colourless, pale green, and (rarely) pale pink and pale blue. One stone has been cut from a portion of the material in this collection. The perfectly limpid crystals from the Niagara limestone—often pale blue—are equal to any, but seldom greater in size than half-inch cubes. There are some in this collection, but not cut as yet. " Rock Candy " Mountain (B.C.) furnishes some suitable for ornamental objects. The collector has a fifteen-pound piece suitable for a lamp.

IDOCRASE (VESUVIANITE).—Amber and golden brown cabochons ; also oblong brilliant and novelty mixed-cut stones of the same colour. (From Quebec Province.)

IOLITE.—Blue, facet-cut transparent stones of very fine colour, from Great Slave Lake (N.W.T.) ; also uncut material (of faceting grade) from Ontario.

JASPER.—Red stone from New Brunswick and a cabochon or two from Ontario and Quebec provinces.

JASPER CONGLOMERATE.—Some fair material is found in Ontario, but the pattern is often so coarse that it can be utilized for large objects only, such as book-ends.

KYANITE.—Sometimes a small stone of indifferent quality can be cut from crystals found at Parry Sound in Georgian Bay.

LAZULITE.—One small cabochon. Found near Churchill, Manitoba.

MESOLITE.—A white cabochon from Nova Scotia.

MOSS AGATE.—Several cabochons from Agate Islet, Quebec Harbour, Michipicoten Island. (Discovered by the collector.) Also a round tallow-topped cabochon with good pattern against an almost transparent background. From Bay of Fundy, N.S.

NARWHAL IVORY.—One tusk from Baffin Land, about 50 ins. long.

NEPHRITE.—Some dark green pieces from the Fraser River, B.C. (uncut). These are not of good quality, however.

OPAL.—Two small and one medium size tan coloured cabochons from Partridge Island, N.S. These show a brilliant, metallic golden-green play of colour with pale mauve overtones. Precious opal from this locality is extremely rare, not more than a half-dozen pieces having been found.

PEARL.—A number of baroque white pearls from the Province of Quebec. These were collected many years ago, probably in the Saguenay River.

PERIDOT.—Two small, grass-green, triangular cut stones of good colour. Timothy Mountain, B.C.

PERISTERITE.—Several yellow-white cabochons from the Parry Sound district of Ontario. This material is less transparent than Ceylon Moonstone but has a more brilliant (yellow) flame.

PETRIFIED WOOD. (See " SILICIFIED WOOD.")

PORPHYRY.—Fine specimens.

PREHNITE.—Several cabochons showing inclusions of native copper. Often associated with zonochlorite. (Simpson Island, Lake Superior, Ontario.) Also a number of other fine cabochons from this same province.

PROUSTITE.—One ruby-red, facet-cut stone from the Keeley Mine in Northern Ontario (rare).

ROCK CRYSTAL.—Last summer several tons of the finest quality Rock Crystal were mined and stockpiled near Black Rapids (North of Gananoque, Ont.), and the owner of this collection has cut three roses from this for a set of dress studs. Crystals up to sixteen inches in length and up to four inches in cross section were taken out, many doubly terminated. This lapidary has also cut some Rock Crystal from Baffin Land.

ROSE QUARTZ.—Pale pink cabochon. Renfrew County, Ontario. This material is plentiful, but is not so fine in colour as the Manitoba Rose Quartz ; it is more translucent.

SAPPHIRE.—Grey-blue star stone, but with poor star. Also very fine blue cut stone, but showing many structure lines. North-East of Bancroft, Ontario. The grey-blue, blue and bronze types occasionally yield star stones.

SCAPOLITE.—Small, step-cut, triangular step-cut and triangular mixed-cut stones in colourless, pink, pale green and pale yellow colours. Renfrew and Haliburton Counties, Ontario. Also large fluorescent cabochon from Point-au-Chene, P.Q. Also a scapolite cat's-eye from Bancroft, Ontario. (The colourless Canadian scapolite turns a lovely amethyst colour when exposed to radium emanations.) (Experimented by the collection owner.)

SEAM AGATE.—" The east end of Michipicoten Island has agate seams running for thousands of feet in straight lines across the bare headlands, and crossing each other at angles up to ninety degrees. These seams are from one-eighth of an inch to three inches in width—widening and narrowing. In places they stand above the rock ; in others, they run down under the lake. In some instances they are in the bottom of grooves as much as ten feet deep and from one to three feet wide—the edges of the veins of agate always protruding from the bottom of the chasms. . . . Red and white colours predominate." (Priv. Comm.)

SELENITE.—The selenite crystals from Alberta are perfect and water clear and can be cut.

SERPENTINE.—Several cabochons cut from Ontario material.

SILICIFIED WOOD and DINOSAUR BONE.—Several cut specimens from Alberta.

SODALITE.—A deep blue, translucent and flawless double cabochon (17 x 13 x 8 mm.) from Dungannon Township, Hastings County, Ontario. Most of the Canadian sodalite is laced with included materials ; pure pieces are quite rare. Also a number of lovely cabochons in both midnight blue and pale blue translucent to transparent varieties. Also one facet-cut stone. All from the Bancroft District, Ontario. (NOTE: Contrary to most text-books, Sodalite is almost never opaque.)

SPHALERITE (BLENDE).—A six-carat, round, golden-brown brilliant (colour not uniform) from Bruce County, Ontario. (Good sphalerite is also found in New Brunswick.) (See Supplement.)

SPHENE.—A small golden-brown brilliant from Westport, Ontario. This stone contains several flaws.

STAUROLITE.—" The staurolites from Snow Lake, Manitoba, are sometimes huge. Good masses are obtainable, and I have the fragments of a big crystal ($\frac{3}{4}$ x 3 inches) that have some transparent regions. This will definitely yield cabochons, and perhaps a facet-cut stone. It is a rather dark reddish-brown, but no darker than my facet-cut Swiss specimens." (Priv. Comm. Collection Owner.)

SUNSTONE.—Several nice cabochons, some of which show a moonstone effect—and even a cat's-eye effect—in addition to aventurescence. Haliburton and Renfrew Counties, Ontario.

THOMSONITE.—Large, red-brown cabochon, showing typical pattern but lacking contrasting colours. Michipicoten Island.

TOURMALINE.—Mixed-cut stones from Wilberforce, Ontario, and Wakefield, Quebec. These are very dark green and crimson and good green respectively. The colour of the former is similar, but darker than the andalusite-like tourmaline from Ceylon, while the lighter green matches good Brazilian tourmaline. Also a golden brown, triangular mixed-cut stone from Enterprise, Ontario, duplicating best Ceylon material.

TREMOLITE.—A number of small brilliant- and step-cut stones (emerald green, grass green, deep blue, brownish-lavender, etc.). Also some fine cat's-eyes in various colours. the best of which show a razor-sharp line of light. This material comes chiefly from Haliburton and Renfrew Counties, Ontario. (Colourless facet material in collection, but not cut as yet.)

(continued on page 187)

ELUSIVE SPECTRA

by

R. Keith Mitchell, F.G.A.

ONE of the initial difficulties experienced by students when confronted with the spectroscope is to reconcile spectra seen with those very excellent but idealized versions illustrated in current text-books. These " gongs," as one ex-Service student has dubbed them, are extremely useful so long as the practical discrepancies of observed spectra are recognized and expected.

Spectrum colours are, of course, pure, and direct photographs by the normal three-colour process are precluded by the obvious limitations of the method. Therefore the illustrations are photographed from paintings and are idealized and, so far as possible, perfect representations.

It is difficult to devise an easy to use set-up for obtaining unblemished spectra. The microscope-spectroscope method gives suitable out-of-focus light which is normally free from transverse lines, but the spectra are usually less well defined than in the so-called " scattered light " method, and in both methods care has to be taken to avoid masking the effect by undue glare. In either case it is essential to ignore all transverse lines, which may be due to irregularities in the light reaching the slit, or to dust, and to keep the slit as narrow as possible. A wide open slit does not give a stronger absorption spectrum, it merely lets in more light to overlap and obscure the fine lines for which we are looking.

Probably one of the major differences between the illustrated and the observed spectrum arises from the fact that the illustrations are of equally spaced spectra as seen with the diffraction grating instrument ; while the instrument recommended and provided for students' use is usually the Beck 2458, a prism train instrument giving a clearer spectrum but with greater spread in the blue and considerable bunching at the red end. In other words, the wavelengths in the illustrations are spaced on a regular arithmetical scale, while those in observed spectra, with this instrument, increase in accordance with a geometrical progression.

The increase in the dispersion angle of glass prisms is unfortunately not completely rational, and in some instances the spread of the blue, although greater than for the red, is actually less than for an equal wavelength range in the yellow-green. It is therefore difficult to draw an exact picture of the spectrum as seen with a prism-train instrument. With the Beck 2458 something near a true geometrical progression is reached, however, and I have found the following method a good way of obtaining an approximate wavelength scale upon which to draw the absorption bands seen with this instrument.

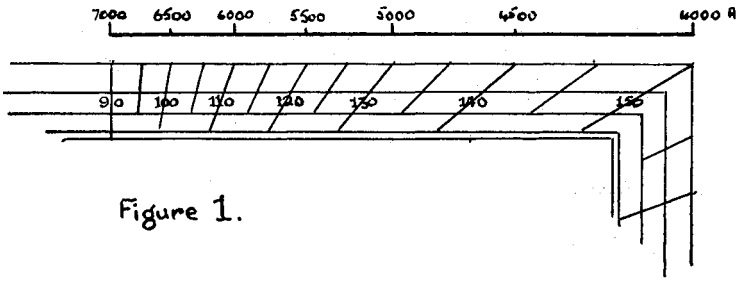

Figure 1.

On an ordinary 6 in. x $1\frac{3}{4}$ in. rectangular protractor, use the 90° mark to represent 7000Å and use each further 10° marking to represent 500Å as shown in Figure 1. An even more accurate scale can be made by projecting these measurements from 0, as in Figure 2, and using their points of intersection on a line PQ inclined at about 20° to the original base line. This provides a scale which gives reasonably accurate visual comparison, although it exaggerates the extreme blue. Within the limits of B—G, the normally visible spectrum, the degree of error is small. Points of intersection on any line parallel to PQ will give an equivalent scale of any convenient size. These scales are arrived at empirically but are sufficiently near for the purpose of illustration.

Another difficulty lies in the immensely variable spectrum of zircon. In a few very rare cases magnificent spectra of some 30 to 40 lines have been observed. But in the vast majority of zircons used in modern jewellery even the ten or so lines shown in textbook illustrations will not be seen. The only line which can be relied upon to turn up with almost infallible regularity is the famous one at 6535Å. Most specimens will show two, three, four or more other lines, in varying degrees of clarity and fineness ; but

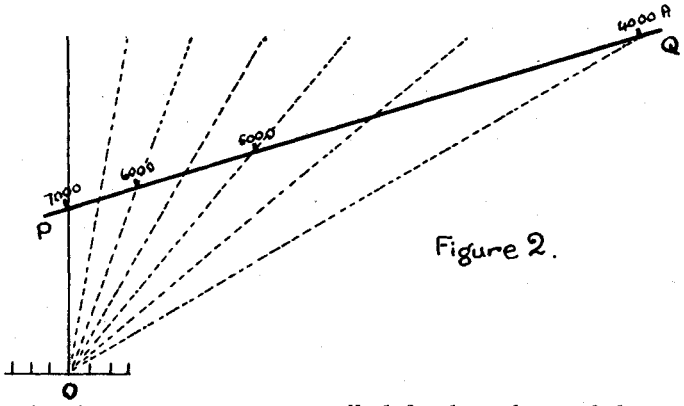

Figure 2.

stones showing spectra even as well defined as those of the text-books are exceptions rather than the rule.

It is also well to remember that the green low-type zircon has a distinctive variation of the normal zircon spectrum. The 6535Å line appears as a much broader line than usual, and is often clear-cut on the side towards the red and fuzzy on that towards the lower wavelengths. Like most other spectra, this one is easily recognized when once seen and identified.

Even the classic example, almandine, can prove difficult to the unpractised eye. The full spectrum shows three main bands and two or more less definite ones. The latter are not always seen, while the three main bands can be so intense and broad as to merge into each other. In garnets containing only a small amount of the almandine molecule all except the third of these three bands may be missing. This one, centred at 5050Å, persists while the almandine molecule is present. In some cases the almandine spectrum is practically masked by that of pyrope, which, being due to chromium, has a broad absorption from 6200Å to 5200Å.

Peridot, in its paler manifestations, will not always give the well-known three bands in the blue which are usually illustrated. Often the only indication will be the faint suggestion of an " edge " at the beginning of the blue. If this is seen and recognized it can, however, be very diagnostic. At the other extreme is the peridot with the three bands so broad and intense as to almost merge into one.

Most other spectra can vary enormously in intensity, generally in direct ratio to the depth of colour of the gem. Colourless stones do not usually give absorption spectra, but the white zircon is an

exception and almost always shows a faint trace of the 6535Å line. It is possible that some other gems normally showing rare earth spectra may still show traces of the same spectra in their colourless varieties.

An insufficient source of light may be responsible for confusion between the fluorescent line in the red in ruby and the very similar fluorescent lines in the rose-red spinel. Both are due to chromic oxide, but whereas the ruby line appears to be a clear-cut single line of bright light (it is, in fact, a pair of lines so close as to appear as a single narrow line), the spinel spectrum has a series of about five such bright lines sufficiently separated to be distinguishable if the lighting is strong enough. Inadequate lighting, however, may result in a spectrum in which only the brightest of the bunch is seen and an erroneous identity be given to the stone. Fortunately there is another check, the two lines in the blue observed in ruby (the left-hand one is, in fact, a doublet, and may be seen as such in well-defined spectra). These are entirely absent in red spinel.

The majority of students find observation of lines at the blue end of the spectrum somewhat difficult. This is due in part to an actual decrease in the sensitivity of the eye to this part of the spectrum, and in part to the spreading of the lower wavelengths by the prism instruments. Also the relatively greater intensity of the closely bunched red, orange and yellow creates glare and renders the blue obscure and difficult to see. This can be overcome to some extent by moving the eye slightly to one side until the edge of the eye-piece aperture screens the brighter part of the spectrum. After a moment or two the eye becomes accommodated to the lower intensity and details of the blue can be seen more easily.

The chief aid to absorption spectroscopy is practice. No amount of poring over text-books will replace it. When using the instrument as much light as possible, without producing glare, should be directed through the stone. *The slit of the instrument should be kept as narrow as possible,* and the stone moved to give the best possible spectrum. Very faint lines may sometimes be seen more readily if the stone is moved into position while a complete spectrum of the light source is under observation.

Finally, the absence of an absorption spectrum is not necessarily a negative test ; but if one is seen and correctly recognized it *is* an absolutely positive test.

BROADENING HORIZONS OF GEMMOLOGY

by RICHARD M. PEARL, M.A.

THE original meaning of the word *gem* as applied to a substance made of stone is lost in antiquity, though the word itself goes back to its Latin root, *gemma*. The Oxford English Dictionary says that " in Middle English the word was adopted afresh (or refashioned after) the French form *gemme* " and traces its history through the literature.

The earliest usage of which we are certain referred to a cut and polished stone, and hence it was a lapidary term. The next meaning (first recorded in English in 1638) was that of an engraved stone ; this was the chief significance of the word during recent past centuries, when it would have been redundant to speak of a carved or engraved gem. The word then reverted back to meaning a stone or related substance cut for personal adornment, and finally it was expanded to include various ornamental applications. (The phrase *gem material* suggests the " rough " from which the finished product is fashioned.) Always the lapidary use has given the cue to the meaning.

Classification is a different story, and it is here that the writer should like to express some personal opinions. The foolishness of the term *semi-precious*, which has now properly fallen into disfavour, was first unwittingly revealed in 1896 by Max Bauer, who in the first edition of his classic book " Edelsteinkunde " listed as " precious " eighteen kinds of gems, some of which were quite unknown to all except mineralogists and a few jewellers. Recent contributions to the " Journal of Gemmology " by Elsie Ruff, W. F. Eppler and others have expressed the modern viewpoint on this subject, which is also the official attitude of the several national gemmological organizations. It would be tilting with windmills to argue the matter further, though plenty of opportunity still exists for educating jewellers in this terminology.

Yet if there be no legitimate distinction between precious and semi-precious stones—and there is none—why should we continue to pay respect to a discredited idea by using classifications based

upon supposed relative value in our textbooks? Now that the tenth edition of Dr. G. F. Herbert Smith's " Gemstones," certainly the best book in English, has abandoned this distinction between precious and semi-precious stones, the opportunity presents itself for a thorough revision of our approach to the subject.

In B. W. Anderson's discerning review of " Gemstones "* he reveals the hesitation which all of us, including no doubt the author, must have in accepting an arrangement of gems based upon several sorts of relative value. For it is not scientific thinking to depend upon an increasing or decreasing " importance "—whatever that means!—most ordinary jewellery stores, making up the backbone of the trade, do a larger total business in amethysts than in alexandrites.

The arrangement in the excellent standard American textbook, " Gems and Gem Materials," by Edward H. Kraus and Chester B. Slawson, though indifferently approved by Mr. Anderson, is scarcely better inasmuch as it travels the route of decreasing " value " for a while and then strikes off across country in a different direction, following the alphabet.

In contrast, my own book, " Popular Gemology," is divided first according to the major style of cutting (facet or cabochon) which is generally most appropriate for each gem ; this cutting (again a matter decided by the lapidary) in turn depends upon the inherent properties of the gem. Within the individual chapters I have adopted, as closely as possible for the mineral gems, what I consider to be a truly scientific arrangement, which is the mineralogical classification of the new Dana system ; this when completed will without question be the international authority until a drastically new method of considering minerals is discovered.

This adoption would not be justified if I did not believe that gemmology is most properly a branch of mineralogy. It is largely because they are primarily professional mineralogists that such men as Herbert Smith, Kraus, Alexander, Pough, and others of that high calibre qualify as gem experts. Otherwise the only gem experts would be practising jewellers, who, after all, were making a livelihood from their untechnical knowledge of gems long before science invaded the field.

The chief objection that has been offered to this new arrangement has been that it makes necessary the use of the table of

* " Gemmologist," Vol. XVIII, 1949, pp. 165-167.

contents and the index to find a given gem in the book—which is precisely why indices and tables of contents were invented: only a dictionary can presume to get along without them. In the preface to "Popular Gemology" I wrote: "Diamond, by fortunate coincidence, occupies the first position in either a commercial or a scientific succession." If I were rewriting that to-day, I might omit the subjective word *fortunate*; the book could as well begin with garnet or sphene. Aesthetically, if not commercially, all kinds of gems are equal, and any preferences are a matter of individual choice—to quote Dr. Herbert Smith, "*de gustibus non est disputandum.*"

In the same review Mr. Anderson said: "In an era when some collectors will have any mineral cut in gem form, regardless of its suitability, another difficulty facing the author was to decide which minerals to include and which to omit." This difficulty will, of course, always exist and must be resolved arbitrarily. Nevertheless, the "collectors" to whom he refers rather slightingly are effecting changes in the scope of gemmology that are as pronounced as those that accompanied the evolution of the meaning of *gem* from a cut to an engraved stone.

The conservative student of gems, particularly outside the United States, may be shocked to learn of some of these changes in usage that are now comfortably accepted by at least a few score thousand lapidaries in this country. Though originally hobbyists, they are not entirely "amateurs," for a large proportion of their product reaches the market and constitutes an increasing share of the jewellery business. They have as much right to be taken seriously as have craftsmen in the home industries of any other nation. Their viewpoint, if only because of their numbers, cannot be casually overlooked.

A good example of this modern American usage concerns opal. *Gem opal* has heretofore meant opal with a play of colours; specimens without this beautiful optical phenomenon were called *common opal.* Now, however, gem opal refers to pieces that are solid enough to be cut into stones for jewellery, whether they have any other attribute or not. Surely good "common opal," with its delicate bands of faint colour, is as "suitable" for this purpose as ivory, which has been given much space in recent British books and articles on gemmology. Similarly, opaque specimens of otherwise transparent minerals are regarded in these American circles as

gems, if only they are not too friable to be cut and polished.

Such an expanding definition of a gem seems as acceptable as one which includes synthetic and imitation minerals. Incidentally, the declining availability of natural specimens has caused an increased interest in the United States in synthetic material, which has been given added impetus during recent months by the introduction of the new synthetic rutile.

This shortage of supply also tempts some amateur lapidaries to try their skill with plastics. Plastics have received especial attention among gemmologists lately through the diligent work of Robert Webster, and so ought to be worthy of consideration by these same lapidaries. Nevertheless, such an interest can readily get out of hand, at the expense of the natural substances that give lapidary work its real meaning, and therefore it is satisfying to state that at the annual exhibits of the California Federation of Mineralogical Societies—the largest of such regional organizations in the United States, with about 4,000 active members—competitive entries for awards are accepted only for natural materials.

Attempts to adhere to any rigid list of gems, established in past years and destined never to change, were shown in their ultimate absurdity in "American Gem Cabochons," by William C. McKinley. Passing from a homogeneous rock, obsidian, to rocks that are aggregates of minerals, he included granite as gem material. If granite, why not syenite, its quartz-free equivalent? Hence it was included also. Then why not any or all of the thousands of kinds of rocks as classified by petrographers? This suggestion, and the presentation of fashioned specimens of granite and syenite as gems, brought Mr. McKinley considerable ridicule, yet he was more logical than his critics, if only because he showed the impossibility of setting up an iron curtain around the field of gemmology.

It seems as reasonable for the gemmologist—the student of the *science of gems*—to consider these attractive lapidary specimens, unfamiliar though they be in jewellery stores, as it is to devote pages in his books to the superstitions of gems and other attendant nonsense. The use of the critical faculty is necessary, of course, in order to restrict the field of gemmology to practicable limits, so that we can concentrate on the most necessary aspects. No harm is done in this, so long as we recognize that all classifications are arbitrary ; Nature knows no such distinction. Above all, there is no natural boundary, either in time or place, to the study of gems.

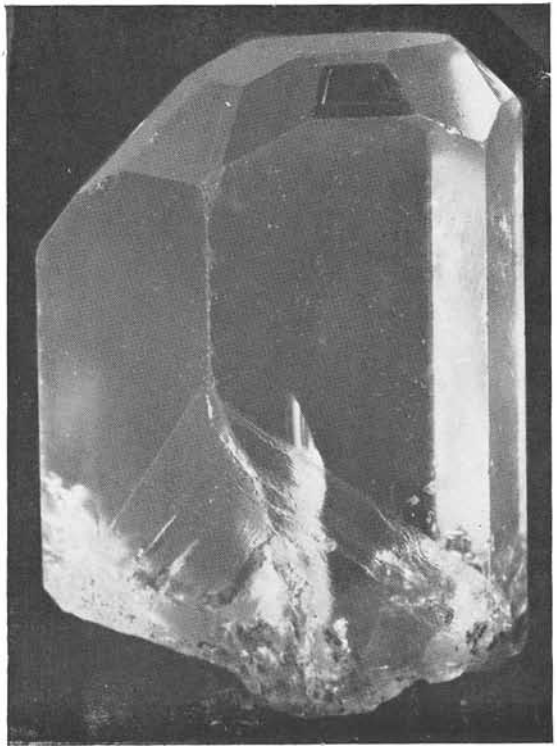

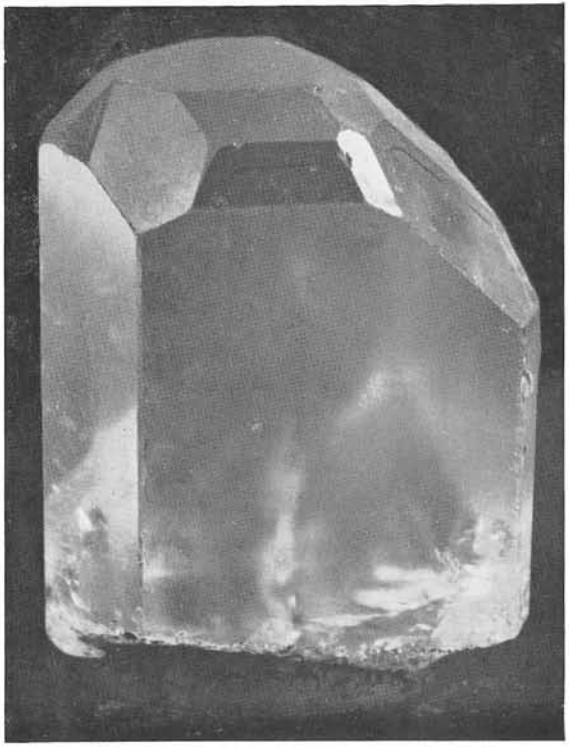

A beryl crystal (light green in colour and transparent) from Minas Gerais, showing terminations and etch markings. Weight 248.20 grams (1,241 carats), height 78 mm.

Photos: Courtesy of Paul Bessem.

Gemmological Abstracts

" Agate and Quartz Glass." By R. Nacken. " Natur und Volk," Berichte der Senckenbergischen Naturforschenden Gesellschaft, Frankfurt/Main, 1949, Nos. 1-3 ; " Edelsteine und Schmuck," 1948, *1*, 243-244.

Experiments with quartz glass have thrown new light on the genesis of agate. The conventional theory of the formation of agate nodules through hot aqueous solutions of silica seems wrong if one realizes that a litre (0.22 galls) of water dissolves about 2.5 g. (37.58 grains) of silica at a temperature of 500 deg. C. (932 deg. F.) and a pressure of 2 to 3,000 atmospheres (29,460-44,190 lbs./sq. in.). The formation of an agate nodule of 1 kg. (2.2 lbs.) would require 400 litres of water (88 gallons). Agate must have been formed, therefore, in a different manner. (Nacken found the first indication when investigating the syntheses of quartz crystals.) He heated quartz glass and some water under pressure to a temperature of 400 deg. C., at which temperature water has a particularly high mineralizing effect. Under these conditions the quartz glass is transformed into a mass of quartz fibres (chalcedony). The crystallization begins at the surface of the piece of glass and progresses towards the interior. Bands are formed parallel to the outer faces. When the transformation is completed, a central cavity remains which is filled with water, as seen in enhydros. The contents of the water are of great importance. Acidy solutions prevent germ formation. Alkaline solutions even of the weakest concentration favour the formation of germ crystals at the glass surface. Raising of the temperature has the same effect. The density of quartz glass being 2.2, that of quartz crystal 2.65, a considerable loss of volume must occur during crystallization, amounting to more than 10 per cent. Between the fibres capillary cavities are formed through contraction, and these allow the progress of the transformation. Additions of metals or metal oxides produce

coloured bands. The quartz glass in the genesis of natural agate rose probably in the form of drops (resembling gas bubbles in shape) from the depth of the earth. This seems likely as the density is 2.2 to 2.3, whereas that of the surrounding lava must have been 2.6 to 3.

E. S.

" Oriented Zoning in Synthetic Corundum." By W. Plato. " Edelsteine u. Schmuck," 1949, *1* (12), 266.

Photomicrograph showing anomalous double refraction of synthetic corundum when viewed between crossed nicols along the optical axis, refers to earlier article on this phenomenon in " Edelsteine u. Schmuck," 1949, *1* (9), 193-194 ; " Journal of Gemmology, 1949, *2* (4), 157.

E. S.

" The Diamond Industry in 1948." Twenty-fourth annual review. " Jewelers' Circular-Keystone," New York, 1949, reprint 18 pp. (prepared from papers of the late Dr. Sydney H. Ball).

World production of diamond during 1948 is estimated at 11,859,200 carats, against 9,754,231 for 1947. Operations were resumed in several S. African mines. Further research work was undertaken by many scientists, including S. Bhagavantam—dielectric constants ; G. O. Wild—fluorescence ; and D. S. Lewis.

G. A.

" Emeralds in India." By Prof. K. Schlossmacher. " Edelsteine u. Schmuck," 1949, *1* (2), 238-239.

Prospecting financed by Sir Bagchand Soni and the emerald dealer Seth Banjilal Thulia near Kaliguman, a small village between Amet and the old fortresses of Kumargarth (in the State of Rajputana), led to the discovery of emeralds of $\frac{1}{2}$ to 4 inches length and about $1\frac{1}{4}$ inch diameter. The quality is said to be comparable to Russian emeralds. The emeralds occur in layers of biotite slate sandwiched between hornblende slate. Mining to a depth of 200 ft. is envisaged. The yield contained eight stones of about 6 cts., the colour of which is said to be extremely good. On the whole, the quality is disappointing. The author, who received this information from the Geological Survey of India, concludes that most of the stones will contain biotite inclusions, and that fine stones will be scarce.

E. S.

" Zircon and its Characteristics." By K. F. Chudoba. " Edelsteine u. Schmuck," 1949, *1* (2), 235-238.

Wide variations in the physical constants of zircon ($ZrO_2.SiO_2$) are not due to isomorphous replacement but constitute particular characteristics which deserve to be reviewed. Density and colour are of special interest. The spread of *density* values led to the following terminology (after R. Köchlin, 1903):—

high types above S.G. 4.6
low types below S.G. 4.2
intermediate types between S.G. 4.2 and 4.6.

Frequently the high types are called " normal " zircons because they possess the typical crystal structure, as revealed in X-ray diffraction patterns. Investigation of a zircon of S.G. 3.945 showed that instead of crystalline $ZrSiO_4$ the products of the broken-down crystal structure were present, namely amorphous SiO_2 and amorphous ZrO_2. Intermediate types are mixtures of crystalline and amorphous zircon. Bauer, Chudoba and others also found cubic ZrO_2 whih is present before the amorphous modification is formed. Vaughan H. Scott (1945) investigated a zircon of S.G. 3.965 and showed that monoclinic ZrO_2 was present with amorphous SiO_2. This modification was also observed when zircons of various S.G.s were heated to 1,580 deg. C. and rapidly cooled. It can be assumed that the break down of the crystal lattice is caused in nature by radioactive matter in the zircon. Of great importance is the possibility of recrystallization of amorphous zircon through heating. This process is characterized by an increase in S.G.-values and corresponding change in refractive index, double refraction, and hardness. There is a connection between structure and *colour*. Low types are nearly always green, sometimes yellow-green or brownish-green. High types are never green, but mostly brown, brown-red, pink or red. When low types are recrystallized the colour changes from green to yellow, pale yellow or blue. Other types, too, change colour on heating. Brown Tasmanian zircons become colourless through moderate heating. Blue zircons from Siam are heat treated. In this case the improvement in colour is connected with pigments in the stone. Brown-red zircons are heated in reducing atmosphere to 900-1,000 deg. C. and become blue or colourless. Heating in air to 850-900 deg. C. produces colourless, yellowish or reddish-yellow crystals. When blue zircons

become pale in time the deep blue colour can be restored through heating in air to 400-600 deg. C. Heating to temperatures over 850 deg. C. produces a yellowish hyacinth colour ; these stones become blue again when heated in reducing atmosphere. Some hyacinth-coloured zircons may be bleached through sunlight, but they become coloured again on heating. Not all zircons behave in the described manner.

E. S.

Dr. S. von Gliszczynski, lecturer of mineralogy at the University Muenster, Germany will lecture on gemmology during the winter term and direct practical exercises in the identification of precious stones at the Meisterschule des Gestaltenden Handwerks (Master School of Creative Arts and Crafts) at Muenster—" Juwelier," 1949, No. 9-10, p. 30 (September-October).

E. S.

The German periodical " Achat " has been reorganized and is published now under the new name of " Der Juwelier " ; its sub-title, " Zeitschrift für Schmuck und Edelsteine," indicates that it is devoted to jewellery and gems.

" New Test for Cultured Undrilled Pearls." By G. O. Wild. " The Gemmologist," Vol. 18, No. 221, p. 285, December, 1949.

It is suggested that cultured pearls may be distinguished from natural pearls by allowing a narrow beam of X-rays to brush over the surface of the pearl, which is then slowly raised into the beam. Observation, in a suitably placed fluorescence screen, of the shadow of the pearl shows, in the case of a cultured pearl, a flash of light on the screen when the beam reaches the edge of the cultured pearl core. A real pearl does not show this effect.

R. W.

" Pearls under the Microscope." By W. Plate. " Der Juwelier," 1949 (11/12), 17, 18.

Distinction between natural, cultured and imitation pearls facilitated by microscopic inspection. Eight good photomicrographs (45 to 534 x mag.) of pearl surfaces convey well the points the author wants to stress.

E. S.

" Pearl Essence Finishes: What they are and how to use them." (No author quoted.) " Product Finishing," Vol. 2, No. 8, pp. 14-18.

Although written essentially for the paint industry, there is much information of interest to the gemmologist on the history, properties and production of the iridescent essence used in the coating of imitation pearls. Fish scales for use as a pearly coating first discovered by Jacquin in France, where, up to the beginning of the Second World War, the manufacture of pearl essence was principally carried out, is an industry which has since been lost to America. The method of recovery of the scales, an offshoot of the American sardine industry, and the processing to obtain the colourless transparent guanine crystals is told. The iridescence of the pearl essence is stated to be due to the play of colour from the minute and thin crystals (0.1 by 0.02 by 0.001 mm.) and to the high refractive index, the double refraction and polarization of the light which, passing successively through two of the crystals, being broken up into brilliant colours by the twisting of the polarized beam. The density of the guanine crystals is given as 1.6 and their resistance to chemical attack is noted. Very full information is given as to the best methods of using pearl essence and how coloured finishes may be produced.

R. W.

" Problems of Colour." By M. D. S. Lewis. " Gemmologist," Vol. 18, No. 219, page 233, October, 1949.

An exposition of the theories of Prof. W. A. Weyl that colour may arise from a disturbance or lack of balance in the electric field caused by oppositely charged ions. Some five factors are mentioned and discussed as being the possible causes of the ionic distortion.

R. W.

" The Diamond Syndicate and their Successors." By R. M. Shipley. " Gems and Gemology," Vol. 6, No. 7, page 199. Fall, 1949.

A review of the history of the diamond industry from 1884 to the present day, and of the steps taken for the control of the market. A summary of the principal organizations which control the diamond market is given.

R. W.

" Aventurine: Glass, Feldspar and Quartz." By R. Webster. " Gems and Gemology," Vol. 6, No. 7, page 207. Fall, 1949.

Aventurine glass is explained as being copper crystals induced to form in a glass matrix, and not copper filings as commonly reported. The characters of the material are compared with natural aventurines (quartz and feldspar). The structure of the three kinds of aventurine is remarked upon and illustrated by photomicrographs. Polarized light proves that the green aventurine quartz has the chrome mica (fuchsite) flakes in a granular quartz matrix. The so-called sunstone from Modoc Co., California, is not oligoclase but labradorite with included crystals of metallic copper.

V. B.

" The Cause of Colour in Turquoise." By F. B. Wade and W. C. Geisler. " Journal of Chemical Education," Vol. 26, page 436, August, 1949.

A report on a series of experiments undertaken to discover the cause of the blue colour of turquoise. From chemical and isotopic analysis the colour is considered to be due to complex amino copper ions which is probably organic in origin.

R. W.

" Staining Turquoise." By F. B. Wade and W. C. Geisler. " Gemmologist," Vol. 18, No. 217, page 187, August, 1949.

The report of a final experiment of a series of researches on the cause of colour in turquoise (previous experiments reported in " Gemmologist," May, 1947, January, 1949, and June, 1949, and in " Journal of Chemical Education," August, 1949). Having found that the colour is possibly due to a complex amino copper ion, it was decided to experiment with poor quality porous turquoise to see whether the amino copper ion would stain the material to better colour. The result was successful and a good colour induced.

R. W.

" The Oiling of Turquoise to Deepen the Colour." " Gems and Gemology," Vol. 6, No. 7, page 221. Fall, 1949.

A résumé of the " oiling " techniques used to " fraudulently(?) " deepen the colour of turquoise. The accidental production of a " lavender " coloured turquoise owing to the stone being impregnated with red dopping wax which had not been completely cleaned off with alcohol as is customary after polishing.

R. W.

"The Transparency of Chromium Aluminium Alums and of their Solutions." By C. H. Rehberg. "Neues Jahrbuch f. Mineralogie, etc., Abhandlungen," A, 1949, *80*, 1-35.

Object of the paper was to investigate the relation between transparency and colouring matter in a series of mixed crystals, and to check the application of Lambert-Beer's law. The range of potassium chromium aluminium alums was chosen. Crystals of different concentration were grown and the chromium content determined by quantitative iodometric analysis. Investigation of the light refraction showed linear relationship. The transparency (between 4,000 and 8,000 A.U.) was measured with the light electric apparatus of the Koenigsberg Mineralogical Institute (micro-selenium photo element S. 12 by Dr. Lange). Starting from Lambert-Beer's law a general formula for mixed crystals was developed and the agreement of measured values with the formula shown, thus proving the validity of Lambert-Beer's law for this case. If the formula was expressed in logarithms a linear relationship between transparency and concentration resulted. In the same fashion mixtures of colourless potassium aluminium alum solution and violet potassium chromium alum solution were investigated, and also mixtures of violet and green potassium chromium alum solution. The formula developed for the mixed crystals was applicable also in these cases. To investigate the influence of the alkali metal on the transparency a rubidium chromium alum was grown, and complete agreement was found between its transparency curve and that of the potassium chromium alum. At nearly equal mol-volume of both alums, the conclusion was reached that the transparency depends on the trivalent metal and is the same for equal mol-volumes.

E. S.

"Recognizing Double Refraction of Precious Stones by Simple Means." By G. O. Wild. "Der Juwelier," 1949 (11/12), 19, 20.

Stone is held very near to the eye and rotated whilst light source or illuminated object is viewed through it. Double refrection is indicated by doubling of part of object outline and shifting of effect when stone is rotated.

E. S.

A GEMMOLOGIST'S LAMP

A gemmologist's and microscopist's lamp has recently been produced by Chards (Reg.).

The instrument is composed of a tubular body on a solid base with an adjustable lamp holder. The front part of the lamp is for use with the microscope and is fitted with a filter carrier which is designed to take the standard Selo filters, 2 in. x 2 in., for use in connection with refractometers and other instruments needing filters.

A feature of the lamp is a circular recess at the top holding a revolving transparent optically finished 3 in. Perspex cell formed into two concentric recesses. Four small knobs are fitted to the edge to enable the cell to be conveniently revolved.

Below the cell is a large iris diaphragm controlled by a lever on the top of the edge.

The Perspex cell enables stones to be immersed in any of the liquids used by gemmologists and is an advantage when testing a number of cut or uncut transparent stones. The concentric recesses enable the recognized stones to be removed from the mass into the outer recess. The overall efficiency of the lamp is much better in a darkened room. It is attractively finished in chromium plate and cream enamel.

ASSOCIATION NOTICES

AMERICAN GEM TESTING LABORATORY

The Gemological Institute of America, Inc., and the Gem Trade Laboratory, Inc., New York, have announced the consolidation of the Gem Trade Laboratory, formerly located at 36 West 47th Street, and the Gemological Institute's Eastern Headquarters Laboratory at 5 East 47th Street, effective 5th October. The new laboratory will be operated under the name of the Gem Trade Laboratory of the Gemological Institute of America.

All equipment, including that for pearl testing of the Gem Trade Laboratory, has been added to that at G.I.A. Eastern Headquarters, where a laboratory has been operated in conjunction with the educational Institution's classes and other functions since August, 1948. The laboratory will be under the directorship of Richard T. Liddicoat, Jr., assisted by G. Robert Crowningshield, and Gilbert Cakes, of the G.I.A. staff.

The combined facilities of the Gemological Institute and the Gem Trade Laboratory, under the new name of the Gem Trade Laboratory of the Gemological Institute of America, will be made available to laboratory members, the jewellery trade and the public.

MEMBERSHIP

The following were elected to membership of the Association at a meeting of the Council held at 19/25 Gutter Lane, London, E.C.2, on Wednesday, 23rd November, 1949:—

FELLOWS

Miss W. M. M. Allan, Prestwick.
D. Blanshard, London
D. C. Blatchford, Plymouth.
T. L. Boston, Colchester.
A. Bowden, Plymouth.
Miss J. M. Butler, Greenford.
K. J. Campbell, Thornton Heath.
G. O. Cook, London.
Miss P. E. Cutts, Birmingham.
K. C. Davis, London.
R. W. Dougan, Deal.
J. S. Ewen, Castle Douglas.
J. H. Feinmesser, London.
P. Feitelson, London.
H. C. Gale, Isleworth.
E. H. Gudridge, Perranporth.
T. Harkins, Johnstone.
E. T. Hartland, London.
Miss J. Haussler, Amsterdam, Holland.
J. G. Heetman, Rotterdam, Holland.
T. J. F. Johnson, Watford.
H. H. Long, Birmingham.
R. D. Lowe, Rotherham.
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Miss T. McDonald, Edinburgh.
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ACKNOWLEDGMENTS

The Association has received a miniature collection of rough gem specimens from W. Constantin Wild & Co., Idar-Oberstein.

TALKS BY FELLOWS

G. A. Blythe: "Gemstones." "Round Table" Club, Southend, 11th October.

J. F. Croydon: "Gemstones." Ipswich Rotary Club, 20th October; Ipswich Junior Chamber of Commerce, 10th November.

L. Penn: "Use of Microscope in Gem Testing." Birmingham Natural History and Philosophical Society, 1st November.

Harold S. Reese: "Gems." Liverpool Geological Society, December 10th.

NETHERLANDS GEMMOLOGICAL ASSOCIATION

Gemmologists in the Netherlands have recently formed the Nederlandsch Edelsteenkundig Genootschap. Membership is open to Fellows of the Gemmological Association of Great Britain and such persons as may be invited to become members. The first President of the new organization is Ing. J. Hammes, Zeist, while D. Dresme, Amsterdam, and C. A. Piek, are acting as Treasurer and Secretary respectively.

"PASTE," BY M. D. S. LEWIS

Mr. M. D. S. Lewis wishes to make a correction to his article on "Paste" (Vol. II, No. 4, "Journ. Gemm."). Views on the role of arsenic were wrongly attributed to Mr. W. B. Honey instead of another authority. The author wishes to apologize to Mr. Honey for the inaccuracy.

MEMBERS' MEETINGS

On January 17th a meeting of members was held at the British Council Cinema, 6, Hanover Street, London, W.1, when the following films were shown:—

"Looking Through Glass." The story of glass production from raw material to the cutting and polishing of lenses for scientific instruments.

"Steel." A film in technicolour showing all stages in the production of steel.

"The Story of Money." Development of the present monetary system from days of barter and the goldsmith-banker.

The following arrangements have been made for February and March, 1950:—

March 2nd, at 7 p.m., at the British Council Cinema. Film show which will include "The History of Man" and a film dealing with the production of Palladium for use in jewellery.

March 22nd, at 5 p.m. Annual General Meeting of the Association at the Holborn Restaurant, London, W.C.2.

March 22nd, at 7.30 p.m. Association Dinner and Reunion of Members to be held at the Holborn Restaurant, London, W.C.2. Full details of this function may be obtained from the Secretary of the Association.

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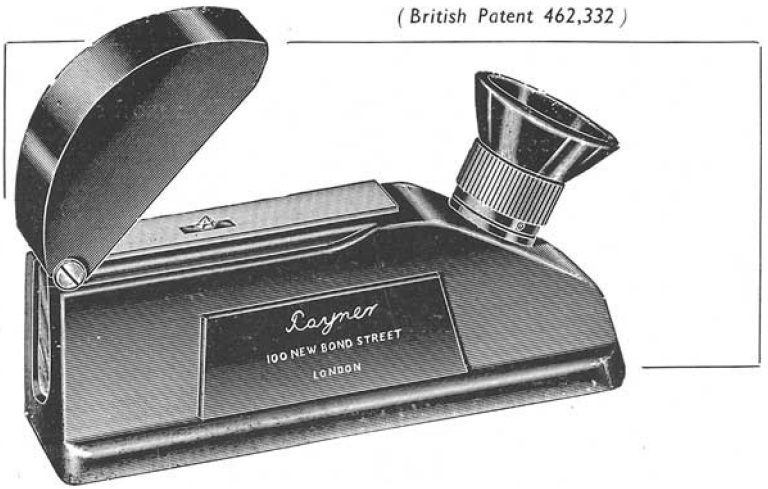

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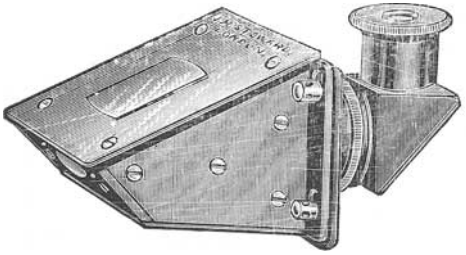

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Vol. II
No. 5
January, 1950

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Vol. II No. 6 April 1950

THE JOURNAL OF GEMMOLOGY

and

PROCEEDINGS OF THE GEMMOLOGICAL ASSOCIATION OF GREAT BRITAIN

THE GEMMOLOGICAL ASSOCIATION
OF GREAT BRITAIN
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THE JOURNAL OF GEMMOLOGY
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Vol. II, No. 6 APRIL 1950

HARDNESS TESTS

by

M. D. S. LEWIS, A.R.C.S., B.Sc., F.G.A., C G.

ALTHOUGH hardness tests are not employed where other means of identification are available, the subject remains of interest as hardness is one of the principal factors to be considered in assessing the durability of a stone. There may also be rare occasions where optical examination is not feasible and an unusual diamond might be quickly identified by ability to scratch corundum. Since stones are set with steel instruments a paste is often indicated where scratch marks are visible on the setting edge.

From the theoretical aspect hardness is not a simple subject and is difficult to define or assess quantitatively. One cannot measure absolute hardness like temperature ; it depends on the test employed. When two substances are pressed together it is usually the softer one which gives way ; its atoms are more easily separated and in general hardness is considered as a measure of resistance to separation of the atoms under pressure. Obviously, then, the hard substances must have very strong interior binding forces.

The attraction between two oppositely charged bodies depends both on the magnitude of the charges and the distance between them, and is greatest when the former are big and the latter small. Thus the loosely packed bivalent barium oxide is about as hard as closely packed monovalent lithium fluoride. A substance, therefore, can only be hard if its constituent ions are highly charged (tri- or quadrivalent) and at the same time small (and hence light), so that when in contact with each other the distance between their centres of gravity is a minimum. These two requirements narrow down the choice of elements to very few: carbon, silicon, aluminium, boron, etc. In crystals, simplicity of composition is also called for, since where there are more than two elements, the variat ons in ionic size tend to make the structure less compact, increasing interionic distances and so decreasing hardness.

Atoms tend to become separated by heat. Through increasing thermal agitation the ions move further away from each other and the force of attraction between them decreases. Eventually they part company and the substance melts. Strong interionic binding forces oppose this process and for the same reason most hard substances have high melting points.

A closer examination of hardness(1) shows that it may embrace many properties, some very closely related to each other, e.g., resistance to abrasion, resistance to scratching, ability to cut other materials, resistance to plastic deformation, high modulus of elasticity, high yield point, high strength, absence of elastic damping, brittleness, cleavage, lack of ductility and malleability, chemical inertness, etc.

Any one test will, in general, call into action only some of these factors and the " hardness value " arrived at is the integrated effect of just those particular factors. Another type of test may involve quite a different set and thus give another result. Roughly speaking, however, hardness phenomena may be resolved into two main classes exhibiting deformation and fracture respectively.

There are at least three types of deformation: immediately reversible (springy metals), permanent (many plastic materials) and an intermediate variety which develops slowly and is ultimately recovered. All three may be present in the same experiment. In

(1) " Strength of Plastics and Glass," by R. N. Haward.

tests to measure " fracture hardness " the surface is broken when the stresses set up exceed the breaking stress of the material *under the conditions of the test.* If the point of loading is moved the rupture becomes a scratch.

It is impossible to mention more than a few of the numerous tests employed for assessing hardness and, as already indicated, they do not give uniform results. Quartz(2), by the indentation or scratch tests, is much harder than brass, but softer according to abrasion tests. Some plastics would appear to be harder than mild steel under a rebound test.

A ball may be dropped on the material under test and the indentation measured. Alternatively, the height of rebound may be observed ; obviously a ball dropped on soft lead will deform the metal and thereby lose much of its energy, whereas the rebound will be higher from a hard elastic surface which does not suffer permanent deformation or indentation in the process. A hard pointed substance (e.g. a diamond pyramid) may be pressed on the substance and the penetration measured. Deformation tests are primarily suitable for metals, a characteristic of which is the ease with which the atoms glide over each other (malleability). It is interesting to note that the metals of highest symmetry—copper, gold, silver, etc.—are soft and malleable owing to the larger number of planes of symmetry on which gliding may take place. Conversely, metals of lower symmetry—chromium, vanadium, molybdenum, etc.—are hard and brittle. The introduction of foreign atoms in alloys disturbs regularity of arrangement, impedes gliding, and for this reason impurities generally cause hardness. The supreme position occupied by iron among the metals is due to its ability, through heat treatment, to adopt either a symmetrical soft form, or a harder variety, consequent upon lower symmetry. Since deformation occurs within the material under test, chemical influences play no part, but in some cases cleavage effects might be noticed. The usual gemmological minerals are, however, not easily deformed because their atomic structure is so different from that of metals, and deformation tests of this type are less suitable for them. Massive glass (as distinct from thin sheets or fibres) exhibits elastic deformation, but irreversible deformations are almost impossible to

(2) " Industrial Diamond Review," December, 1949, W. V. Engelhardt, p. 369.

measure at ordinary temperatures and the same probably applies to most ordinary gemstones.

Another test for hardness depends on abrasion resistance, the loss of volume being measured after grinding. Since diamond cannot be scratched by any other material, this is the only feasible test for measuring its variations in hardness with crystallographic direction. Here again absolute hardness cannot be assessed, comparative values only being obtainable, because the amount abraded depends on the lubricant used. The chemical forces at play between abrasive, sample and lubricant largely determine the amount of attrition. In this process the polishing grains remove small particles of material, not by simple pressure as would be involved, say, by snapping off a protuberance, but rather by causing a series of fractures in different directions. F. W. Preston has found(3) that when glass is ground, the abrasive grain causes stresses in the brittle material which eventually lead to fractures running partly in the direction of and partly crosswise to the movement. When these intersect chips are broken out and the loose material comes away. There is reason to believe that quartz and other crystalline materials behave similarly, and this illustrates the difficulty of defining hardness, because the fundamental process here seems to be the reduction of the sample to powder. Yet this same result is also easily obtained merely by hammering in the case of crystals with suitable cleavage. According to P. Grodzinski(4), 5 carats of diamond can be reduced to powder by repeated hammering (hand operated hammer) in a mortar within 30 minutes. If hardness were solely defined as " resistance to separation of atoms " the hardness of jadeite might exceed that of diamond if assessed in this manner.

In the scratch tests, a sharply pointed substance, usually diamond, is moved under constant load and speed over the various surfaces and the amount of material removed or depth of penetration measured. The crudest scratch test is, of course, that of Mohs' and strictly speaking this should only be performed between dissimilar substances, otherwise chemical forces can give quite anomalous results. Practically all ordinary glasses will scratch each other—whether they be hard or soft—and it will no doubt occasion

(3) " Industrial Diamond Review," December, 1949, W. V. Engelhardt, p. 367.

(4) " Industrial Diamond Review," January, 1950, p. 24.

some surprise that glass will often scratch gemstones of greatly superior " hardness." If an ordinary solid glass rod (hardness about $5\frac{1}{2}$ and easily marked with a steel file) be rubbed hard against a polished quartz, beryl, tourmaline or other gemstones of hardness about 7, a definite scratch is left on the stone. Harder gems, such as topaz, are less easily marked. This is due to similarity of structure ; when two substances of similar constitution (in this case silicates) are brought into sufficiently close contact with each other they weld together, and if fractured the break does not necessarily take place at the original join. Of course, any substance may wear away another much harder one by continued friction. Some stone steps are worn away by leather shoes or even bare feet, and who has not heard of the bronze foot of St. Peter's statue in Rome which has partly vanished merely through the touch of millions of lips? This phenomenon, however, is somewhat different, as a hard steel file merely slides off a polished quartz, whereas the softer glass rod " bites " on the surface with quite a different feel and sound.

In the study of gemmology the approach to hardness is usually via Mohs' test, which, although derided from a purely practical point of view, still remains a background against which the property is judged. It is still held to be theoretically sound, even if not prudent, to employ on account of possible damage to a costly stone. When topaz is stated to be harder than quartz, a subconscious picture probably forms of a pencil-like piece of topaz being drawn across the surface of the softer material, leaving a satisfactory scratch. Actually, this view is valid only under very limited conditions. Mohs' test does not solve the hardness problem ; it merely assesses resistance to fracture using *suitably shaped instruments*. If a cut topaz were pressed hard against a quartz it is quite possible that the thin girdle or culet might chip owing to cleavage and the hard stone thus suffer more " abrasion " than the softer one. When a hardness value is stated, the conditions of the test should be specified. The fact that a pencil-shaped piece of topaz produces a scratch on quartz does not automatically guarantee that topaz will suffer less abrasion than quartz under another process—say, perhaps, on a grinding wheel. In many questions of gemmological hardness, cleavage is a factor never far in the background. This makes a definition even more difficult than is the case with other materials. The best is probably that of R. N. Haward(1), which

states that it is " the capacity of a surface of the material in question to remain unaltered in shape when subject to relatively concentrated mechanical forces which do not break the specimen as a whole."

The durability of a stone depends mainly on abrasion resistance, freedom from cleavage, chemical inertness and texture. A porous substance gives a lower hardness value than a compact one, whilst gaseous or liquid inclusions may impair the stability of a stone. Some American gemmologists integrate all these factors into the property of " toughness," and Briggs' " Encyclopaedia of Gems " contains a comparative table, headed by diamond, followed by cassiterite, jadeite, ruby, etc. Topaz, in spite of its hardness, is well down the list, below quartz, due, no doubt, to its easy cleavage.

IMPROVEMENTS in the PRODUCTION of SYNTHETIC QUARTZ

(continued from page 227)

thick-walled steel chamber by a supporting bar (see diagram). The bottom of the chamber is filled to a depth of several inches with finely powdered silica, which provides the nutrient, and the remaining space is filled with an aqueous alkaline solution. Growth of the quartz crystal commences when the temperature at the bottom of the chamber reaches 750 degrees F., and the pressure 15,000 pounds to the square inch.

This combination of heat and pressure dissolves the powdered silica, and when the diffused molecules reach the cooler region at the top of the chamber they deposit one by one on the quartz " seed," producing, in due course, a flawless, transparent crystal of synthetic quartz.

Up to the present, no attempt to produce coloured gem crystals has apparently been made, but this could conceivably be done without much difficulty through the introduction of suitable colouring agents.

The largest crystal so far produced weighs about a quarter of a pound and took two weeks to grow.

It is very probable that some variation of the process described above is employed by Chatham in the production of his synthetic emerald crystals.

D. S. M. F.

IMPROVEMENTS in the PRODUCTION of SYNTHETIC QUARTZ

FOR the first time, clear crystals of synthetic quartz (rock crystal) are being produced in quantities sufficiently large to warrant more than the passing interest of the gemmological world.

Announcement of the achievement was made, late in February, 1950, by Dr. Albert C. Walker, of the Bell Telephone Company laboratories, before a gathering of scientists in Ithaca, N.Y.

Dr. Walker described the method of production and told how Bell Company engineers have improved upon the German process developed during World War II, until it is now possible to produce quarter-pound crystals of water-clear quartz in a short time and at relatively low cost.

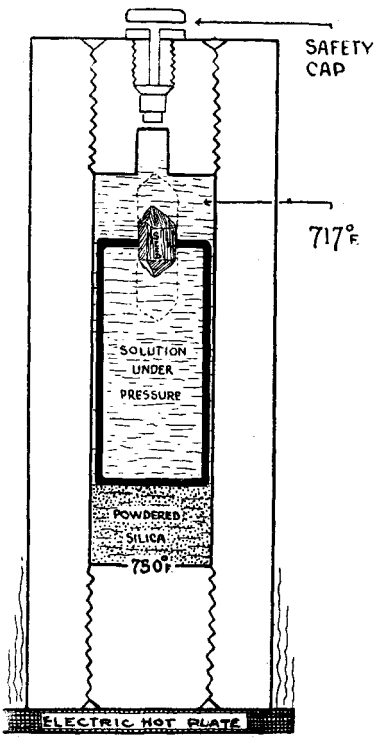

The process differs entirely from that utilized for the synthesis of corundum, spinel and rutile. These man-made gem materials require furnaces patterned after the inverted blowpipe constructed by Auguste Verneuil, the French chemist who successfully synthesized the red variety of corundum, called *ruby*.

The quartz crystals produced in the Bell laboratories (for use in the electrical industry) are grown from a small natural "seed" crystal or fragment of quartz, held near the top of a

(continued on page 226)

SOME OPTICAL NOTES

by D. S. M. FIELD, A.G.A.

On Choosing a 10x Objective

THE working distance of a microscope objective is the distance between the foremost lens of the objective and the object, when the microscope is in sharp focus. This is always considerably less than the stated focal length, which is that for a single lens of similar magnifying power.

When purchasing objectives for gem testing, the buyer should be aware that working distance is of the utmost importance, particularly in the case of the higher powers ; for the longer the working distance, the greater will be the reachable depth.

The advantage of long working distance can be fully appreciated only by one who has tried to focus into a transparent gem, only to have the foremost lens of his objective touch the table facet before any appreciable depth has been reached.

In practice, of course, the careful worker would *raise* the focus from a point nearly touching the table facet, in order to avoid physical contact with the gem and possible resultant damage to the outside lens of his objective ; but if the stone should be fairly thick and the working distance short, it would be impossible at that point to bring the culet or lower pavilion facets into focus.

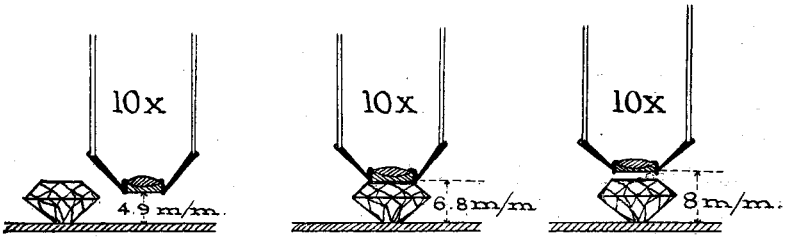

Relative working distances of 10x objectives by various makers.

It might be supposed that all objectives of a given power or focal length possess the same amount of working distance. This is not always the case. The writer has lately consulted the catalogues and descriptive price lists of a number of manufacturers in Great Britain, Continental Europe and the United States, and has found that there is a wide variation not only in working distance but in price, both of which are important considerations for many gemmologists.

The 10x objective of one of the foremost North American manufacturers has a working distance of only 4.9 mm. (too short for stones above a carat or so in weight), while a new model recently introduced by a second well-known firm has a working distance of 6.8 mm.—apparently the longest available in America.

In this respect, one British maker at least seems to have produced the most efficient objective for use in gem testing, for, without any appreciable sacrifice of resolution, the firm in question has achieved a working distance of 8 mm. for its objective of the same focal length and magnifying power. The stated numerical aperture —which, in practice, means simply resolving power—is also similar (0.25).

When powers below 10 are used, little thought need, of course, be given to the working distance, since this is in all cases great enough to permit one to explore the entire stone, regardless of its size or refracting power.

The above notes apply to achromatic lenses employed on monobjective binocular or monocular microscopes of standard (160 mm.) tube length.

With few exceptions, prevailing high prices for microscopes and accessories manufactured in the United States makes it virtually impossible for the Canadian student of modest means to acquire even second-hand American equipment for gem testing.

A fine microscope purchased from the United States costs the Canadian consumer at least twice as much as its British counterpart, and the prices of American-made accessories range from 100 to 200 per cent. above those of similar fittings manufactured in Great Britain.

Fortunately, all microscopes and microscope accessories valued at 50 dollars or more are admitted to Canada free of duty and are exempt from the Consumption or Sales Tax.

Great Britain, through the Royal Microscopical Society, has set the universal standards in the manufacture of optical equipment for microscopy, and, as might be expected of the acknowledged leader in this field for nearly a century and a half, her post-war instruments and accessories are second to none on the market to--day.

An Aid to Gem Spectroscopy

A small but extremely useful accessory attachment that can be used to facilitate the examination of tiny stones is supplied by Messrs. R. & J. Beck, Limited, for use in conjunction with their standard makes of spectroscopes. The attachment consists of a cylindrical lens conveniently mounted in a metal fitting held in place by two clamping screws.

This inexpensive accessory (No. 2496—£1 5s.) concentrates and extends the transmitted or scattered light, so that it completely fills the adjustable slit on the front of the instrument. This results in clear and brilliant absorption spectra, even when very small stones are examined.

Threaded holes for the accommodation of the attachment have been provided in all modern Beck spectroscopes of standard design —excepting the small fixed-slit and Beck-Hartridge reversion models.

A New Eye Shade

Messrs. Bausch and Lomb (Canada), Ltd., are offering an attractively designed black zylonite microscope eye-shade [priced at about one dollar (Can.)] to cover the eye not in use when looking through a monocular microscope. This accessory relieves completely the strain of suppressing the vision in the eye not in use, thereby adding greatly to the comfort of the user.

The shade is firmly held in place by a flexible plastic loop encircling the eyepiece of the microscope. It is equally effective when used in conjunction with the Beck hand spectroscopes, and creates the illusion of binocular vision.

Gemmological Abstracts

PUBLICATIONS

" Welke Edelsteen is dit? " J. Bolman, 105 pp., 2 plates, Leiden, Netherlands, 1950.

This publication consists mainly of tables giving principal physical properties of gemstones. An informative glossary (59 pp.) is arranged in five columns, the first giving the correct gem name, the second unusual or misleading names, the third the correct mineralogical designation, the fourth the degree of transparency and the fifth additional remarks. Tables of specific gravity and refractive indices are subdivided according to the colour of the gems. Special tables are provided dealing with translucent and opaque stones, stones displaying asterism, chatoyancy and glittering inclusions. A mineralogical list (14 pages) in the more conventional form in nine columns gives the chemical and physical properties of interest to the gemmologist. Other tables refer to crystal systems, double refraction, dispersion and other information usually found in the standard works on gemmology. The publication should be of considerable value to the growing number of gemmologists in the Netherlands.

" Die Enstehung der Agate "—the genesis of agates. Prof. K. Schlossmacher.

Article expounding new theory that volcanic magma consisted mainly of basic melt in which were included non-miscible drops of acid melt rich in silica. The drops, which were of lower specific gravity than the surrounding magma, are our agates. " Schmuck und edles Geraet," 1950, 1, 23-26 (No. 1, January). E. S.

" The Genesis of Agates," By Prof. Schlossmacher.

Continuation of article in preceding issue, pp. 23-26. " Schmuck und edles Geraet," 1950, *1*, 55-57. E. S.

The monthly periodical " Edelsteine und Schmuck," for which Prof. K. Schlossmacher was responsible, has ceased to appear. Papers and information relating to gemmology and gem industry will be published under the heading " Edelsteine und Edelsteinindustrie," editor Prof. Schlossmacher, in the new periodical, " Schmuck und edles Geraet " (publishers: Rudolk Grimm Verlag, Frankfurt/Main).

" Jeweler's Pocket Reference Book." R. M. Shipley, 1950. Ed. U.S.A.

A fourth edition of a reference book intended for jewellers in the U.S.A. and Canada. The gemmology section is good but it is regrettable to see that the term topaz-quartz is advocated for yellow and brown quartz. Topaz and quartz should be regarded as distinct gem species. A list of incorrect names for gemstones contains many that have long been regarded as obsolete in the U.K.

A. G.

" Edelstenen." By P. Terpstra, 178 pp., 34 figs., The Hague, 1949.

Written in Dutch, this is a small book following conventional form of text-books on gemstones. Physical and optical characters of all important gemstones are dealt with, but no reference is made to gem materials of organic origin. Modes of occurrence and chemical composition are also omitted. A. G.

" How Synthetic Rutile was Produced in Czechoslovakia." By Dr. J. Kasper, D.S. " The Gemmologist," Vol. 18, No. 221, p. 291. December, 1949.

A report on the production of rutile single crystals in Czechoslovakia during the years 1942 to 1945 (during the German occupation of that country) and the commencement this year of industrial production. R. W.

" Grinding Hardness and Possibilities of Influencing It." By K. F. Chudoba. " Schmuck und edles Geraet," 1950, *1*, 57-60.

The gemmologist is mostly concerned with scratch hardness. The gem cutting industry is interested in the resistance to grinding. This grinding hardness can be affected by using different lubricants. This article reports mainly on investigations by W. v. Engelhardt (1942-1946), who experimented with various lubricants and gem materials. The grinding hardness of four gem materials (basal plane) varied as follows:—

	Benzine	Water	Octanol-2
Quartz	103	100	59
Tourmaline ...	68	61	68
Topaz	55	52	55
Rutile	137	105	105

E. S.

" Synthetic Star Rubies and Star Sapphires." By John N. Burdick and John W. Glenn, Jr. (to Linde Air Products Co.). U.S. 2,488,507, November 15th, 1949.

A process is described for developing asterism in single crystals of ruby and sapphire containing oxide of Ti ; for obtaining gemstones from the non-asteriated single crystals containing oxide of Ti ; and for intensifying asterism in asteriated ruby and sapphire crystals. Synthetic ruby and sapphire of gem quality are made by the Verneuil process. Asterism is developed in a single crystal of gem-quality ruby or sapphire which contains Ti oxide dissolved in alumina. The crystal is heated between 1100° and 1500°, and kept at such a temperature until a compound of Ti ppts. along prominent crystallographic planes of the crystal. The length of the heating period required varies as an inverse function of the temperature, e.g. asterism was produced successfully in both synthetic ruby and synthetic blue sapphire boules after 72 hours at 1100°, after 24 hours at 1300°, and after 2 hours at 1500°. Below 1100° no asterism developed. Above 1500° there was no pptn. of the Ti oxide. For best results, the alumina powder should contain not less than 0.1 per cent. and not more than 0.3 per cent. of TiO^2. In gems prepared by this process the ppt. of Ti compound concns. in a surface skin, while the inner part of the

boule is almost free from pptd. Ti compound. After cutting the asteriated stone, the visibility of the star can be intensified by heating from 1100° to 1500°. The synthetic asteriated crystals, both cut and uncut, have curved growth lines and microscopic or submicroscopic oriented acicular crystals. Also they often show curved striae in the cloudy ppt. zone. The star effect is believed to be caused by refraction and interference-diffraction of reflected light from the oriented ppt. crystals.—Abstract from "Chemical Abstracts," Vol. 44, No. 5. G. S. M.

BOOK REVIEWS

"The Armytage Collection of Maori Jade." By Webster K. Athol. Photography by John Queenborough, A.R.P.S. The Cable Press, London.

Other than fiction, the success of any book, surely, is the ability of the author, figuratively speaking, to take the reader by the hand and show him round. The word *success* means here, primarily, the appreciation of the reader . . . the feeling that not only was the book worth its weight in time (one of our most precious commodities to-day), it awakened an interest in a subject that adds up to individual understanding. A *success* book, therefore, must not just amuse or skim the surface of one's attention, however knowledgeably ; it must cause the reader to sit up and take notice. Many subjects to-day are so specialized that there is a tendency to ignore them entirely, feeling that ninety-five per cent. of one's fellow creatures will do the same. A few question the integrity of these subjects, and have a right to do so, since they make demands on one's time. It is a question of whether there is not an aptitude to specialize for the sake of specializing.

To anyone other than a student of the Maori race, "The Armytage Collection of Maori Jade, by K. Athol Webster, a slim, illustrated monograph of Maori jade artifacts, might pass as only of interest to collectors or specialists. Yet as an introduction to the subject one can think of no better type of approach. Here is a representative and carefully described collection, pictorially, before one's eyes. The author tells us that this was probably one of the finest private collections of Maori jade items in existence. For this

reason it is possible for the layman to be taken by the hand and shown round. One doesn't have to listen to some collector's running commentary even, nor elbow one's way over a museum case. When Edward Armytage died in 1946, his studiously acquired collection showed every evidence of going the way of many another collection. Mr. Webster's efforts saved it from this dreary end. Finally the jade went home, and the collection may now be scrutinized in New Zealand museums.

To make a study of Maori jade is to brush against several Sciences. And any such study must contribute to gemmology. Could the illustrations in this monograph have appeared in colour, since the range covers whitish grey-green to dark green, with brownish-greens and blackish-greens thrown in for full measure, the gemmologist would have been treated indeed. Maori jade is essentially a study of neolithic jade—not based on some airy hypothesis but on something contemporary man has discovered, and is still discovering.

" Brillanten und Perlen (Brilliants and Pearls)." By W. Maier, 188 pp., 17 tables, 80 illustrations. E. Schweizerbart, Stuttgart, 1949.

The author is a mineralogist who has occupied himself for several years with gems. His disregard for conventional terminology is most irritating. Brilliants, thus, are not only diamonds but all gem materials that shine. The two outstanding sections of the book are concerned with the different cuts of gems and with the registration methods for outer and inner reflections. The description of cuts is called " Brilliantography " (Brillantographie) and the section on reflections is headed " Brillianceometry " (Brillanzométrie) and the instrument used is a " brillianceoscope " (brillanzoskop). Apart from these formidable words, the two sections are interesting and useful. In 14 tables, 100 different cuts are depicted, nearly always in plan and elevation. The author has evolved a sort of shorthand description, giving together with the drawings the number of facets on crown and pavilion, the symmetrical arrangement and the shape of the facets. The instrument to register reflections consists of an upright glass cylinder which is either covered with a transparent screen or photographic paper.

The cut gem is held in the centre of the cylinder, the crown usually facing the light beam, which is directed horizontally through an opening in the cylinder periphery. Described also is a method of observing the light path in a stone which is placed in a smoke chamber. Other sections of the book are either conventional or no improvement on existing presentations. The section on natural gems, in which the author enumerates individual gem varieties, could be omitted altogether, as so many good reference books are available. Colour prints in this section are extremely poor. The section on synthetic gems gives an incomplete survey. In contrast to the author's opinion, the specific gravity of synthetic spinel is a clue to the genesis. An interesting suggestion is contained in a patent held by the author, allowing synthesis in a Verneuil type furnace but under pressure and in selected atmospheres. Nothing is said about any practical results. The suggestion to use large corundum bearings in industry (p. 147) and not only rubies in watches reveals that the author is neither familiar with the jewel bearing nor with the machine-producing industries. Should a second edition be contemplated, no doubt many errors will have to be rectified. Ruby, for instance, does not display light and dark green pleochroism (p. 4). Sapphire is the unhappy choice for the demonstration of double refraction (p 19), while Asterism in ruby is mentioned when probably corundum is meant (p. 32). The word cape-ruby is mis-used for garnet (p. 37). In the section on cutting, a saw for machining diamonds is represented as gem-sawing machine (p. 58). The diamond polisher's scaifes consist of cast-iron, not steel (p. 61), the method of charging the scaife is wrongly described, and in illustration 45 the tail-end pin holding the tang in position is omitted. The claim that theoretical considerations allow determination of the most favourable grinding direction on a particular diamond facet (p. 67) has not been substantiated yet in practice. Boron crystals are not as hard as diamonds and also boron carbide is softer (p. 146). The fact that diamond can be abraded slowly with boron carbide is certainly a very misleading argument, as in many instances the harder material is polished with a softer abrasive. Gem testing by means of hardness pencils (p. 150), however discretely applied, ought to be strongly discouraged. In the paragraph on pearl testing (p. 178) reference to the endoscope is omitted.

W. S.

CLEAVAGE
AND THE STRUCTURE OF
GEM MINERALS

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By R. KEITH MITCHELL, F.G.A.

THE long-standing problem of the causes of cleavage belongs rather to the broad science of mineralogy than to our own specialized subject of gemmology. The very nature of the property renders those minerals exhibiting it strongly undesirable in jewellery, since they violate the elementary requirement that a gem should be durable. There are, in spite of this, several gems, such as diamond and topaz, which possess perfect cleavage in one or more directions. Fortunately, the property cannot be said to be facile in these cases, since a fairly considerable force is generally required to produce it.

Usually described by mineralogists as "the result of the grained structure of minerals," cleavage is by no means an uncommon property among crystalline substances. The great majority of minerals possess it in some degree or other. Some, like quartz, exhibiting it scarcely at all, while others such as the micas are so easily cleavable that the property achieves major utilitarian importance.

From the time of the French mineralogist Haüy, who first recognized that the cleavage of a crystal was characteristic and common to all crystals of the same mineral, many theories have been formulated to explain the phenomenon, none of which can be said to apply universally. This seemingly simple structural property of crystalline minerals must, in fact, be due to highly complicated causes intimately connected with the atomic and electronic structure and forces of the mineral. The further we delve into the theories and facts of modern crystal chemistry, the more evident it becomes that cleavage is far from having a simple explanation.

Bravais, in 1881, explained the phenomenon on a purely geometric basis, stating that cleavage was most easily obtained parallel to those planes of the crystal lattice which contained the

most atoms per unit area. In other words, parallel to the planes of greatest net density. And, since the distance between planes is inversely proportional to the net density of the planes, he gave as an alternative that cleavage will be found to occur parallel to the net planes most widely separated. Minerals exhibiting more than one crystallographic direction of cleavage were held to possess facility of cleavage in direct proportion to the degree of compliance with the above requirements.

This is a neat and logical explanation which would be very convenient if true, but unfortunately it has been shown that although many mineral cleavages apparently comply with Bravais' theory, there are many others which do not.

Other workers have carried the theory further to apply to conditions in which atomic layering exists as in the double tetrahedral arrangement of atoms found in mica. The atoms being held together by bonds other than those in the direct atomic plane parallel to which cleavage may be expected. Again complete agreement has not been found.

In 1912 the experiments of Max von Laue on the diffraction of X-rays led to the discovery by Sir William Bragg of the methods of examining the spacing and positions of atoms in the crystal lattice. For the first time scientists were able to " see " by means of direct calculation the structure of crystalline matter. The regular lattice or net patterns which had been deduced crystallographically were now capable of being proved, corrected and measured with considerable accuracy. The far-reaching effects of this discovery upon the whole of science cannot be over-estimated, and from that time on, crystallography has been enriched by research which has revealed lattice details of mineral after mineral. New light has been thrown on the comparatively unimportant matter of cleavage and new facts have been provided upon which to formulate further theories.

Some investigators have summed the electrons in the atoms of given planes and layers, thus elaborating on the theories of Bravais without advancing greatly towards a satisfactory answer to the problem.

Another line of thought has occupied itself with the question of atomic bonds and valencies, it being suggested that cleavage will take place in directions in which the fewest bonds are broken.

However, this approach is complicated by the nature and strength of the bonds concerned.

M. L. Huggins concluded, among other things, that cleavage faces should be electrically neutral, and that weak bonds (i.e. those between the most widely separated planes) would be ruptured before strong bonds.

Other workers have carried the question still further, recognizing that differences in bond types have considerable bearing on the subject ; calculating the forces binding atoms across various possible cleavage planes and considering those with the lowest value to be the most cleavable.

Several writers, including Wooster and Shappell, separate ionic and covalent (or homopolar) minerals as requiring different treatment. Shappell has calculated the bond strengths and the relative " cleavability " between given crystal planes, basing his findings upon the facility of cleavage rather than on the perfection of surface obtained. His calculations are based on broad approximations, and although the percentage of agreement with observed cleavages is high, there are several discrepancies among the 25 minerals treated that are not easily explained.

General Survey

A survey of cleavage throughout the mineral kingdom reveals certain facts that are indisputable.

The property is exhibited to a greater or lesser extent by almost all crystalline minerals. It is closely related to the primary crystallographic directions and can be referred to facial indices of low order, as (111) for the cleavage of diamond or fluor. It takes place parallel to existing or possible crystal faces or forms, and if present parallel to one face of a form, must be equally present parallel to all other faces of that form. Thus in the cubic mineral diamond, cleavage parallel to a set of two opposite octahedral faces necessitates identical cleavage parallel to each of the other three sets of faces.

In the cubic system it is therefore impossible to have less than three directions of cleavage (cubic (100) as in galena), if the property is present at all. While four directional (octahedral (111), in diamond or fluor) is quite common, and six directional (dodecahedral (110) as in zinc blende) is possible.

In all other crystal systems a single pinacoidal direction of cleavage is possible, or the tendency may be present in two or more directions parallel to one or more forms.

Cleavage quite obviously does not depend exclusively upon chemical composition, as consideration of such polymorphs as calcite and aragonite, cyanite, fibrolite and andalusite will show. Nor can it be said that similar crystal lattices yield similar cleavage. The case of diamond and zinc blende is an example of geometrically similar lattices which yield totally different cleavages.

INTER-ATOMIC BONDS.

It is customary to refer the bonds between atoms to four main types. Such division is largely arbitrary and one of convenience, since, according to Sir W. Lawrence Bragg, mathematical methods of lattice calculation show no fundamental difference between them.

The four bond types are known as ionic, covalent, metallic and Van der Waals, and they may be regarded as predominating in inorganic and organic compounds, metals and the inert gases respectively. Although any one or more of them may be present in varying degrees in one compound.

Generally mineral bonds consist of either or both of the first two types, ionic or covalent, and a brief description of the characteristics of each is necessary. But before going on to the complexities of atomic bonding some basic idea of the structure of the atom may be helpful.

The present state of knowledge and theory of atomic structure has been reached by observation, experiment and mathematical calculation largely based upon such direct information as may be obtained by X-ray diffraction methods and other less complex physical and chemical measurements. In the course of the past few decades, as we know too well, immense strides have been made in atomic physics, with the result that the atom, which was once regarded simply as a combination of electrons and protons, now has been found to contain other less simply explained charges, such as neutrons, deuterons, mesons, etc.

However, it will be sufficient for the immediate purpose if the simple picture is understood, and the atom considered as a central nucleus bearing a positive charge and surrounded by one or more

orbital " shells " of electrons whose negative charge balances the positive charge of the nucleus.

The electron shells are normally designated as K, L or M shells, and so on, up to Q shell, the latter being found only in a few of the heaviest radio-active atoms, notably radium and uranium. These shells are in turn divided into sub-shells.

It is the electron configuration of the outer shell or shells that largely determines the chemical activity of the atom, and it has been found that atoms possessing eight electrons in their outer shell are those of the chemically inactive " inert " gases, neon, argon, krypton, and others. These are in a state of electronic stability, while atoms possessing numbers of electrons other than eight in this outer shell are unstable, and tend to reach the stable configuration by an exchange of electrons, combining with another element. Since in the heavier atoms the outer shell can contain more than eight electrons, it has been found that stability is also reached when there are eighteen electrons in that outer shell. It is of interest to note that such inactive elements as gold, platinum, palladium and iridium are all very close to this latter condition.

Either of these states of stability may be reached by shedding the odd one, two or three electrons of the outer shell, reducing the atom to the completed penultimate shell of eight or eighteen electrons ; or by adding one or two electrons to complete the outer shell. Therefore we have the fact that an atom when in chemical combination with another atom has either more or less electrons than when in a balanced state of electrical neutrality (a state not often found in nature). It has become an electrically charged atom, or an " ion." If it has acquired electrons it is a negative ion or " anion," since the negative electrons more than balance the positive charge of the nucleus. An atom which has parted with electrons is a positive ion or " cation," since the nucleus now has a greater charge than that of its surrounding electrons.

Anions are generally considerably larger than metallic cations and tend to assume close-packed structures as though they were spherical bodies of definite radius. The shape of a crystal structure is in the main due to the sizes and relative forces of the cations filling the interstices.

The difference of charge between anion and cation constitutes the ionic bond, the first of the bond types with which we are concerned. It is often illustrated by the instance of fluor, CaF_2.

In this mineral the calcium atom has two electrons in its outer shell. By losing them it attains the stable configuration of the inert gas argon. The fluorine atom is one electron short of the configuration of another inert gas, neon. Interchanges take place leaving Ca^{++} cations and F^{-} anions. These charges may be expressed alternatively in terms of valency.

The Ca atoms, carrying a double charge (divalent) are able to combine with twice their number of singly charged (univalent) F atoms. Hence the composition CaF_2.

Crystals having purely ionic bonds are generally transparent to visible light and often possess good cleavage. Colour is frequently idiochromatic. They are of moderate hardness and refractivity.

In some elements the outer electron shell is so balanced between two stable configurations that no exchange of electrons is possible. In such cases two or more atoms share their outer electrons by forming electron-pair bonds. This is the case with diamond, each carbon atom sharing its four outermost electrons with four neighbour-atoms in the structure. Bonds of this type are generally known as covalent or homopolar and are usually of considerable strength. This bond is probably responsible for such physical attributes as hardness, transparency and high refractivity.

The remaining two bonds, metallic and Van der Waals, are of little importance to the mineralogist. The former, as its name suggests, is the bond responsible for the cohesion of metals. It is generally characterized by extreme electronic fluidity giving rise to malleability, ductility and other properties common to metals and is responsible for their high electrical and thermal conductivity.

The Van der Waals bond is a very weak force and is responsible for, among other things, the slight cohesion that occurs when an inert gas or a molecular gas is liquified. It is the residual force holding molecules one to another when all direct bonds are satisfied within the molecule. It is found in minerals in a few instances only, graphite and talc being two outstanding examples.

An important factor in mineral structures which has a profound effect on cleavage is the composite negative ion. This is a group of atoms held together by partly covalent bonds, which act collectively as the negative ion in a predominantly ionic bond with another cation. A good example is provided by the SiO_4 tetrahedron of the silicates, in which four oxygen atoms are strongly

bonded to a central silicon atom. Such composite ions, in some cases known as acid radicals, are generally considered incapable of being broken by cleavage.

While on the subject of negative ions, it should be emphasized again that anions are generally considerably larger than cations and tend to assume close packed structures as though they are spheres of definite radius cemented together by small cations in the holes between. By far the commonest anion is oxygen ($O^{=}$), which forms the main part spatially of the vast majority of crystal structures. Other important anions are fluorine (F^{-}) and the hydroxyl ion (OH^{-}). In the latter, half of the normal double charge of the oxygen anion has been taken up by the absorption of a hydrogen atom. Another anion found occasionally in mineral structures is chlorine, but it is rarely present in gem minerals.

Minerals consisting of approximately close-packed oxygen anions may be expected to have densities of 3.50 or more. In minerals of lower density the oxygen structure has been distorted out of the close-packed formation and gaps are left in the structure. Good examples of this are to be found among silicates of low density. In cases where the holes are sufficiently large they accommodate water molecules of crystallization, and even, as in the case of the zeolites, allow the free passage and interchange of large cations.

Before discussing individual mineral structures in relation to cleavage, it should be mentioned once more that the majority of minerals contain both ionic and covalent bonding, and that a bond may be partly covalent and partly ionic. Also, since an ionic bond is due to electrostatic attraction, the number of bonds between a given cation and its surrounding anions is limited only by their relative sizes, while the number of covalent bonds between, say, a silicon cation and oxygen, can only be four, since there are only four spare electrons in the outer shell of the silicon atom. Other covalent cations are similarly limited by the number of their outer electrons.

The Cleavage of Gem Minerals.

In the following descriptions of gem mineral cleavages no attempt is made to explain the phenomena on mathematical grounds. Such work would be almost impossibly involved and would probably serve very little purpose. Certain conclusions have

necessarily been drawn, for direct information on cleavage as such is scarce. The references listed at the end have been used freely both for information on structures and as sources of structure drawings upon which to base most of the present illustrations.

The problem of conveying an adequate conception of complex crystal structures in two dimensional drawings is a considerable one, and it is often only possible to indicate some of the probable cleavage directions. For the sake of clarity the drawings for the most part represent atoms as small circles connected by lines indicating bonds. It is important to remember that, in fact, atoms behave as though they are spheres *in contact,* and that generally in bond directions little or no space between them exists.

DIAMOND.

The crystal lattice of this hardest of all minerals was among the first to be investigated. It was chosen because, being an element and having very high symmetry, its laue pattern was comparatively simple to interpret. Results have shown that the lattice is not only simple in form but is also remarkably perfect. The X-ray diffraction photographs are sharply defined and argue a perfection far above that of other crystals.

The unit cell of diamond consists of two interpenetrant face-centred cubes, the one displaced from the other by a quarter of the cube diagonal, as shown in Figure 1. This puts each carbon atom at the centre of a regular tetrahedron of four other carbon atoms.

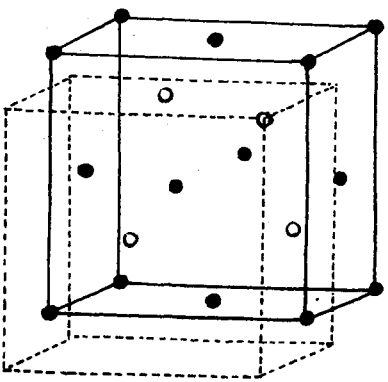

FIG. 1 (*a*)
The basic structure of diamond can be related to two interpenetrant face-centred cubes.

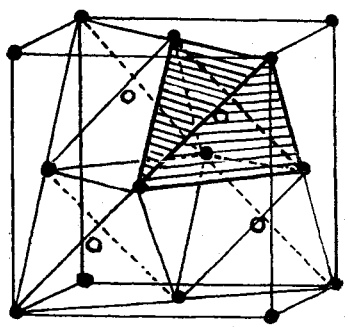

FIG. 1 (*b*)
Demonstrates the intimate relationship of tetrahedral and octahedral forms to the diamond structure.

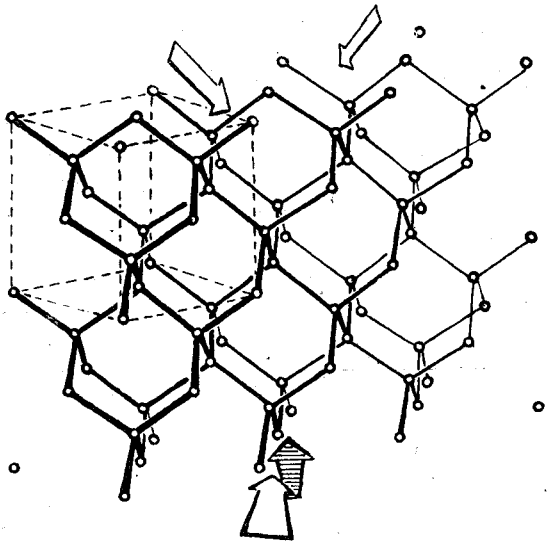

FIG. 2

Six unit cells of the diamond point lattice. The two cleavage directions indicated at the top of the diagram are clearly seen. The remaining two follow exactly similar paths although they are somewhat obscured by the perspective of the drawing.

Since the crystal consists only of carbon atoms and is not metallic, it follows that the bonding is covalent. There are four electrons in the outer shell of the carbon atom and therefore four bonds may be expected from each atom. This bonding is strong and in its perfection is responsible for the immense hardness of the gem.

In Figure 2 six unit cubes have been placed together and it is possible to see the layering of the atoms in the octahedral planes between which perfect cleavage may occur. Such cleavage is normal to and breaks only one bond from each tetrahedral group. This cleavage in four directions is generally recognised as the only one found in diamond, but the writer was recently informed by Sir C. V. Raman, of Bangalore University, that he has detected other cleavage planes in minute fragments of diamond, notably dodecahedral (110) and cubic (100) planes. These are directions of atomic layering but such cleavages would break more than one bond in each tetrahedron. It therefore seems obvious that if such cleavages exist they can only be obtained with difficulty and are, in ordinary conditions, completely masked by the perfection and comparative ease of the octahedral cleavage.

GRAPHITE.

This, of course, is not a gem mineral in any possible sense, but in the consideration of cleavage is of such interest as to warrant its

inclusion. It is a soft, black and opaque mineral, the very antithesis of diamond, and has a cleavage so pronounced that a complete crystal has probably never been found.

The carbon atoms are arranged in flat hexagonal rings (Figure 3) similar to the puckered rings of diamond, but in this case, although each atom is surrounded by only three other atoms, the direct bonds are apparently satisfied within the layers. The carbon atoms within the layer are closer than in diamond, but the distance between layers is considerably greater. Bonding between layers is probably of the very weak type known as Van der Waals, and the sheets of carbon atoms part, slip or glide under the slightest pressure. To this property graphite owes its remarkable usefulness as a dry lubricant.

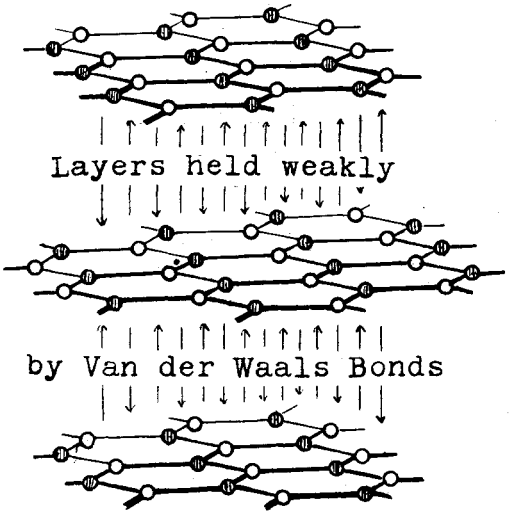

FIG. 3
The layered six-sided rings of graphite.

The high electrical conductivity, opacity and peculiar lustre of the mineral argue an essential difference in the bonding within the layers as compared with the bonding in diamond. The suggestion is that in the case of graphite the fourth electron pair is shared by a condition known as resonance, between the three main bonds. This argues a certain fluidity of electrons which would account for the good electrical conductivity of the mineral.

Charcoal has been found to possess the same bonding as graphite, but without the ordered layering of the atoms. The

amorphous order results in many unsatisfied bonds which in turn account for the remarkable absorptive properties of this form of carbon.

It will be noted that in both diamond and graphite the carbon atoms form hexagonal rings (in diamond they are puckered by the tetrahedral formation). This hexagonal ring of carbons dominates the whole vast family of hydrocarbons and is probably responsible for the lubricant properties of so many of them. In the case of diamond it undoubtedly explains the affinity of that stone for grease.

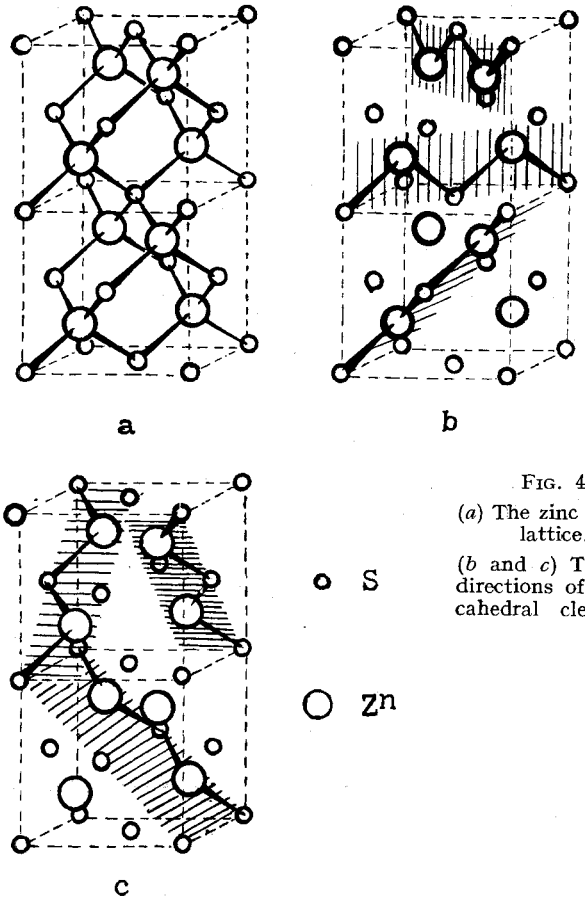

FIG. 4
(*a*) The zinc blende lattice.
(*b* and *c*) The six directions of dodecahedral cleavage.

ZINC BLENDE. ZnS. Cubic, hemihedral. Cleavage: Dodecahedral (110).

Not normally a gem mineral, zinc blende has occasionally been cut to provide those collectors' stones so dear to the heart of the keen gemmologist. It is another of the simple structures which were investigated in the early days of X-ray crystal analysis, and since it provides a fairly straightforward picture of atomic structure it is worth while including in the present discussion. It should, perhaps, be pointed out that these simple lattices for the most part contain no oxygen, and are by no means so typical of the mineral kingdom as a whole as are the more complex structures based on the oxygen anion. The underlying principles of nature may be simple, but the edifice built upon those principles is usually complex to an extreme.

The space lattice of zinc blende is the same as that for diamond except for size. Each zinc atom is at the centre of a regular tetrahedron of sulphur atoms, and vice versa. It is generally considered as an illustration of the transition between the covalent and ionic types of structure. The high refractive index of the mineral (often a feature of sulphur compounds) suggests that the bonding is, in fact, mainly covalent.

The cleavage is parallel to the six dodecahedral planes and is very easily produced. The planes are indicated in Figure 4. It will be noticed that they are the most widely separated planes containing equal numbers of both zinc and sulphur atoms. Separation

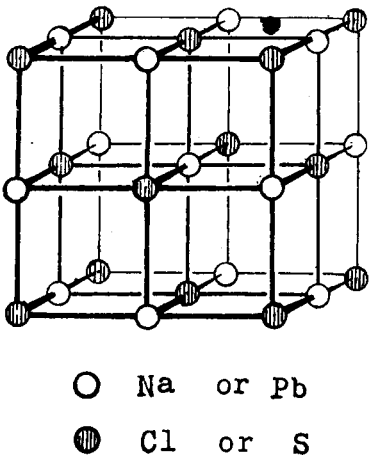

FIG. 5

The cubic lattice of rock-salt or galena. In either mineral cleavage parallel to the cube faces will separate like planes of mixed atoms.

(Reproduced by permission of the Clarendon Press, Oxford, from A. F. Wells's "Structural Inorganic Chemistry.")

parallel to the cube planes would involve leaving one face of zinc atoms and one of sulphur atoms—an impossibility in cleavage. Puckered octahedral layering exists as in diamond, but here the sheets are polar (which accounts for the hemihedral crystal habit), with zinc to one side and sulphur to the other, a condition which would leave cleavage surfaces similar to those obtained if the cleavage were cubic.

GALENA (PbS) AND ROCK SALT (NaCl). Cubic. Cleavage: Cubic (100).

Other simple cubic crystal lattices are those of galena and rock salt. Neither is gem material, but both provide excellent examples of cleavage in simple structures. They both comply with the lattice shown in Figure 5. The cubic cleavage leaves like planes containing equal numbers of anions and cations. Octahedral or dodecahedral cleavage would not meet this requirement.

FLUOR. CaF_2. Cubic. Cleavage: Octahedral (111).

Although a mineral of small importance to the jeweller, fluor is a well-known feature of the gemmologist's curriculum, possessing

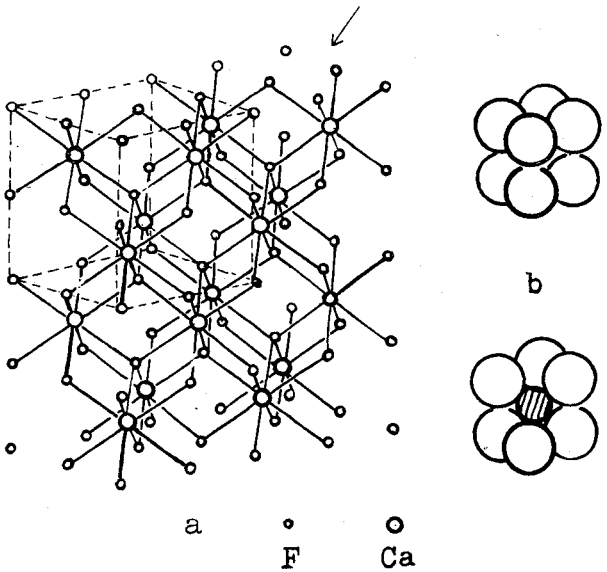

FIG. 6

(*a*) Four unit cubes of the fluor point lattice. Only one direction of octahedral cleavage is indicated

(*b*) Demonstrates that cleavage will remove one fluorine from the cube formation, leaving calcium cations exposed at a lower level.

as it does a well developed and highly characteristic crystal habit and a facile, although hackly, octahedral cleavage.

The crystal lattice is a simple one, on the lines of that of zinc blende, but since fluorine is univalent there are twice as many F atoms as there are sulphur in blende. This leads to an 8:4 co-ordination, each Ca^{++} cation being surrounded by eight F^- anions at the corners of a cube, and each F^- by four Ca^{++} at the corners of a regular tetrahedron (see Figure 6). These additional fluorine anions remove the polarity of the octahedral planes which exists in the blende structure, make the crystals holohedral and allow the octahedral planes as possible cleavage directions. The planes exposed would consist of identical sheets of F anions with Ca cations partly exposed at a lower level. The dodecahedral planes would also consist of like sheets of mixed F and Ca atoms, but would involve the breaking of twice the number of Ca-F bonds if cleavage took place in that direction. Since the bonding is ionic it is to be expected that the cleavage will be, as in fact it is, octahedral.

SPINEL. $MgAl_2O_4$. Cubic. S.G. 3.50. Cleavage: Octahedral (111), imperfect.

Chemically, the mineral spinel is not as simple as its formula might suggest, and it is, in fact, one of an important isomorphous series of some dozen or so minerals in which the magnesium and aluminium cations may be partly or wholly replaced by Fe^{++}, Zn or Mn, and by Fe^{+++}, Mn^{+++} or Cr respectively ; and in the case of artificial spinels, by several other metallic cations.

The oxygen structure of the mineral is approximately that of cubic close packing. The available diagrams do not give a sufficiently clear conception of the layer structure to form a definite conclusion regarding cleavage, but it is evident that the aluminium cation is at the centre of an octahedral group of six oxygens, while the magnesium atom is surrounded by a tetrahedral group of four oxygens. The Al-O bonding is strong and, according to A. F. Wells, partly covalent. It is therefore in all probability stronger than the essentially ionic Mg-O bond, and is unlikely to be ruptured by cleavage. It appears likely, therefore, that the octahedral cleavage follows planes containing Mg cations, and is largely influenced by the AlO_6 octahedra. The matter is further complicated by the isomorphous replacement of either of the cations, and

by the fact that a second type is known in which some of the metal cations have changed places. It is, perhaps, significant that, as in the case of some other isomorphous mineral series with close-packed structures (e.g. tourmaline and garnet), the cleavage is difficult and imperfect.

An interesting feature of synthetic spinel is that it often has a tendency to cleave parallel to the cube directions. This may be in some way due to an excess of γ alumina in the structure.

CORUNDUM. Al_2O_3. Hexagonal, trigonal. S.G. 4.00. Parting: Basal pinacoid (111) and rhombohedral (100).

This mineral raises the question of parting as opposed to cleavage, and it is perhaps as well to explain the difference between them. The general conception of " parting " is a splitting along planes of twinning or other comparatively coarse structural faults or defects. Cleavage, on the other hand, is due to the actual atomic structure of the crystal and can, in theory, be carried down to atomic dimensions.

It has been suggested that the accepted definition of splitting in corundum as " parting " is open to query, and that it is, in fact, true cleavage. Sir Henry Miers states:—

> " . . . . the parting or apparent cleavage parallel to R (the (100) or rhombohedral faces) seems to be due to . . . lamellar twinning, which may perhaps be in many cases secondary, and caused by pressure, planes parallel to R acting as glide planes. The parting parallel to the basal plane (111) appears to be due to incipient decomposition. Crystals of corundum often exhibit a pearly lustre on the base and a platey structure parallel to the same ; these are due to microscopic cavities produced along horizontal planes (111) which are therefore to be regarded as ' solution-planes ' along which corrosion takes place most easily. Somewhat similar, though less distinct, is a third parting, parallel to the hexagonal prism (101)."

The oxygen structure is approximately hexagonal close-packed, and the aluminium cations, as usual, occupy octahedral positions at the centres of groups of six oxygen anions. All three directions of parting are parallel to main directions of atomic layering.

The Al-O bond, as has already been stated, is strong, and the parting/cleavage is not produced easily in most gem specimens. Crystals showing the twinning and partial decomposition upon

which the property is apparently conditioned are obviously unsuited for gems.

γ alumina is a polymorphous form of the oxide which can be produced synthetically, and which crystallizes with the spinel structure. This fact was used to considerable purpose by German technicians during the recent war. By using an excess of alumina in the manufacture of spinel, boules were obtained containing γ alumina in solid solution. These were capable of being worked into various forms for use as abrasion or cutting tools for industrial use and were then hardened by a process which caused the alumina to expand into the corundum structure (α alumina). The resultant material possessed considerable toughness and little or no tendency to cleave. Its use to a country short of industrial diamonds and other super-hard abrasives is obvious.

CHRYSOBERYL. $BeAl_2O_4$. Orthorhombic. S.G. 3.71. Cleavage: (010) and (011), imperfect.

It is a recognized fact that chrysoberyl has considerable resemblances crystallographically to the magnesium silicate, olivine. The crystal habits and dimensions are practically the same, and one of the two cleavage directions is identical. X-ray analysis has shown that they are fundamentally the same in structure. The positions occupied by Al and Be cations in the one being taken by Mg and Si atoms in the other.

In chrysoberyl, BeO_4 tetrahedra take the place of the discrete SiO_4 tetrahedra in olivine, while Al atoms, being larger, take their usual place between six octahedrally placed oxygens. The bonding of Be and Al to oxygen is covalent to about the same degree, but, since the beryllium atom is smaller, the bond strength is greater and is shared with only four oxygens, while the Al cation is shared with six. It is therefore to be expected that the cleavage planes will be those between oxygen anions bound by aluminium cations. An examination of the diagram of the olivine structure (Figure 10), which serves also for chrysoberyl, will show that in the case of the brachypinacoidal (010) cleavage such conditions do exist.

The case of the second cleavage (011) is not so clear, especially as it apparently does not occur in olivine. The possible reasons for a discrepancy will be dealt with under that heading.

THE CLEAVAGE OF THE SILICATES.

Practically all the remaining gem minerals of importance are to be found in the vast mineral family known as silicates. The only notable exception is quartz, which, with its polymorphs tridymite and cristobalite (not gem minerals), is normally considered with the oxides. The distinction is man made, however, and in the natural order of things quartz may be regarded as the end species of all the immense series of minerals classified as silicates. The Si-O bond is of such importance in its bearing on cleavage that the inclusion of the three silica minerals under this heading is logical.

It has been estimated that the two elements silicon and oxygen together comprise more than 70 per cent. of the earth's crust, and that the latter consists practically entirely of silicates and silica, the weights of other ores of metals being insignificant in comparison. That being the case, we are justified in concluding that the two elements have a very strong affinity for each other and that the bond between them is strong.

Silicon is the second element in the periodic table to have the four electron outer shell and, with oxygen, it forms four bond tetrahedra which are reminiscent of the tetrahedra of diamond. According to Pauling, the bonding is considered to be 50 per cent. covalent, which undoubtedly adds to its strength.

An interesting compound of the two elements carbon and silicon exists in the artificial abrasive carborundum (SiC). This substance crystallizes in some half-dozen forms, at least three of which are referable to the diamond lattice. It is interesting to note that carborundum is second only to diamond in hardness. Silicon itself, however, exhibits no outstanding hardness.

From a structural point of view silicates are generally divided into several main groups according to the type of Si-O composite ion involved. These are, briefly:—

(*a*) The orthosilicates, in which discrete SiO_4 tetrahedra occur. No oxygen atom in this type of structure can be common to two such tetrahedra. (Figure 7a.)

(*b*) Structures in which pairs of SiO_4 tetrahedra are linked through one of their oxygens, but are otherwise discrete. (Figure 7b.)

(*c*) Structures in which the SiO_4 tetrahedra each share two oxygens and are linked up to form closed three-fold, four-fold and six-fold rings. (Figure 7c.)

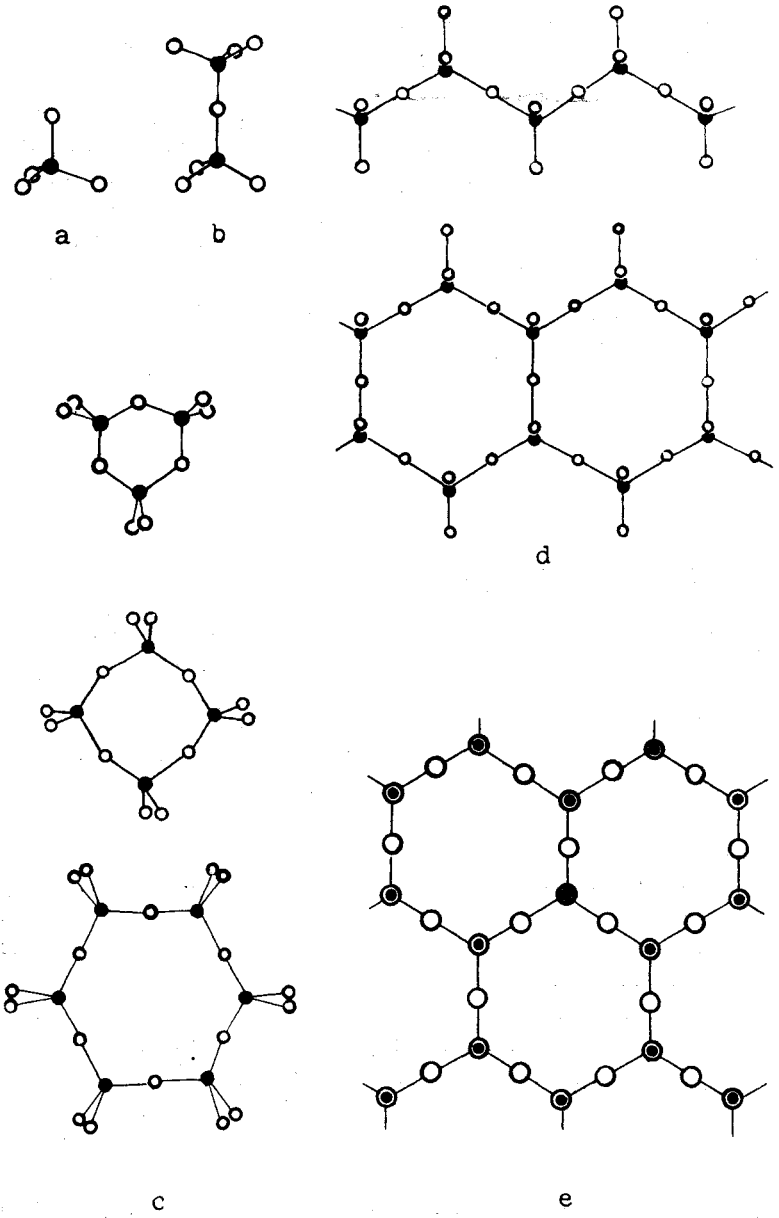

FIG. 7

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(*d*) Fibrous structures in which the SiO_4 groups are linked as in (*c*) by each sharing two oxygens with neighbouring groups, but in which endless chains are formed. (Figure 7d.)

(*e*) Structures in which the SiO_4 tetrahedra each share three oxygens to form infinite sheets. (Figure 7e.)

(*f*) Structures in which each oxygen atom is shared by two tetrahedra to form an infinite three-dimensional framework. This type in its pure form gives us quartz and its polymorphs. But many instances occur in which the structure includes other metallic ions and the framework is of mixed tetrahedra. The feldspars and zeolites are of this latter type.

ORTHOSILICATE GEMS.

Under this heading we find such well-known gems as topaz, zircon, peridot, tourmaline and the garnets ; and others less known, as andalusite and its polymorphs, and the rarely cut euclase, epidote and phenacite.

In all these gem structures the silicon-oxygen tetrahedra are isolated from each other and are connected only through metallic cations. It follows that the influence of the strong Si-O bond is not so obvious as in the chain and layered silicate structures.

TOPAZ. AlF_2SiO_4. Orthorhombic. S.G. 3.55. Cleavage: Basal (001), perfect.

After diamond, topaz is probably the most cited instance of cleavage in gem minerals. It possesses the property to a remarkable degree when its use as a gemstone is considered, and careless handling in setting or in use has resulted in badly damaged stones.

It is one of the few silicates to contain fluorine anions, and although the cleavage is due in part to the strength of the silicon-oxygen bonds, its facility and perfection can be attributed to the presence of the fluorine, or of the hydroxyl anions with which they are sometimes replaced.

These anions are both univalent, as opposed to the divalent oxygen anion. Their sizes are not dissimilar and replacement of F by OH occurs, with a consequent increase in the refractivity of the crystal. This may perhaps be considered rather as a lowering of the refractive indices due to the increase of fluorine content, an

influence which is noticeable in all substances containing that element. In gem topaz the yellow, brown and pink stones contain more hydroxyl than do the blue and white specimens.

This replacement has no appreciable effect on the cleavage. The absorption of the single electron hydrogen atom into an oxygen anion reducing the composite ion to the same univalent state as fluorine. The mass of the hydrogen atom is small and makes no apparent difference to the size of the resultant ion.

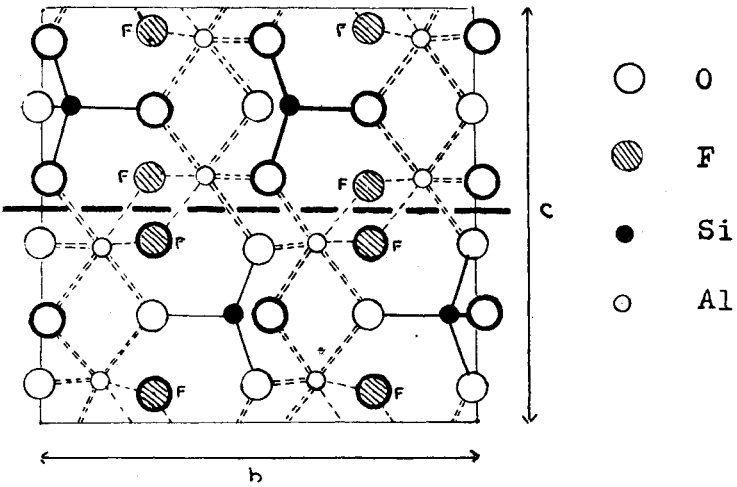

FIG. 8

The topaz structure projected on a plane normal to the *a* axis. Al-O bonds are indicated by double dotted lines and those between Al and F atoms by single ones. The heavy broken line and the top and bottom edges of the drawing indicate possible cleavage planes.

The actual structure of the gem is not simple to interpret in diagram form. Figure 8 shows the lattice projected on the plane normal to the *a* axis. The cleavage is indicated by the broken heavy line. The top and bottom edges of the diagram are also lines of possible cleavage. Al-O bonds are indicated by double dotted lines and the Al-F bonds by similar single lines. It will be seen that cleavage separates two layers of aluminium cations and breaks only Al-O and Al-F bonds. The staggered and alternated positions of the SiO_4 tetrahedral groups preclude the possibility of any other cleavage.

ZIRCON. $ZrSiO_4$. Tetragonal. S.G. 4.00 to 4.70. Cleavage: Prismatic (110), imperfect ; Pyramidal (111), less distinct.

Zircon is an instance in which X-ray investigation has confounded the original allocation of axes in the crystal, so that the true lateral axes of the unit cell are at 45° to those to which faces are normally referred. Thus the normal crystal forms, which are also the cleavage directions, should be prism (100) and pyramid (101).

The perspective diagram of the unit cell is fairly easy to interpret (Figure 9). The silicon-oxygen tetrahedra are there as usual, while each zirconium atom, being larger than silicon, is surrounded by eight oxygens: four from vertically situated silicon groups and four from laterally situated groups. These are indicated only in the case of the centre zirconium atom in the diagram.

Although the *c* axis of the unit cell has been shown to be shorter than the *a* axis, the vertical zirconium-oxygen bonds are somewhat longer than the lateral ones. However, the prismatic (100) cleavage will separate sheets of silicon-oxygen tetrahedra and zirconium atoms, only zirconium-oxygen bonds being broken. The more difficult pyramidal (101) cleavage undoubtedly separates the double sheets of zirconium atoms which occur in these directions.

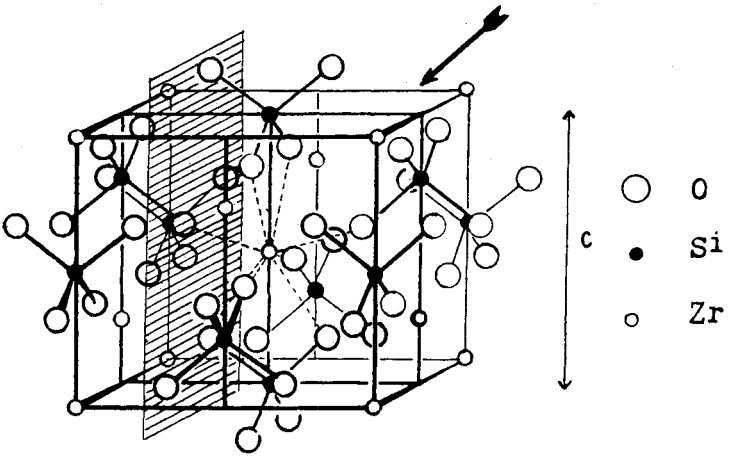

FIG. 9

The unit cell of zircon. The shaded vertical plane indicates one of the prismatic (100) cleavages, breaking only one of the eight Zr-O bonds from each Zr cation. For the sake of clarity these bonds are shown only in the case of the centre Zr atom. The (101) pyramidal cleavage (indicated by the arrow) separates layers of Zr cations, breaking three Zr-O bonds from each Zr atom.

This involves the breaking of more bonds than in the first instance, hence the increased difficulty of the cleavage.

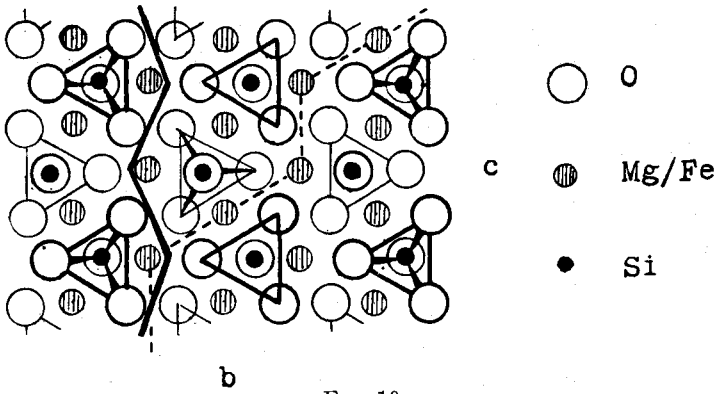

FIG. 10

The idealized olivine structure projected on a plane normal to the *a* axis. The (010) cleavage would probably follow the zig-zag path indicated, Mg/Fe atoms alternating on the exposed faces. The (100) cleavage would be parallel to the plane of the paper and is obscured by the alternation of the SiO_4 tetrahedra.

Chrysoberyl, which is almost identical in structure, can be referred to this diagram. The (010) cleavage is the same as in olivine, but the lesser (011) cleavage marks a divergence in the two structures and possibly follows the path indicated by the dotted line.

OLIVINE (Peridot). $(MgFe)_2SiO_4$. Orthorhombic. S.G. 3.40. Cleavage: (010) and (100), imperfect.

The similarity of the structure of this gem to that of chrysoberyl has already been mentioned.

From the diagram (Figure 10) it will be seen that, although the SiO_4 tetrahedra are discrete, they do in fact group themselves into sheets separated by Mg/Fe cations which are in contact with octahedral groups of six oxygens. This grouping is responsible for the (010) cleavage parallel to the brachypinacoid. It is not a facile or a perfect cleavage because the Mg-O bond is far from a weak one, and although in the idealized plan of the structure the division is clearly defined, the actual positioning of the atoms at the cleavage face is not planar, as will be seen from the second illustration (Figure 11).

The second cleavage direction is parallel to the macropinacoid (100). From the available diagrams it seems that the silicon-oxygen tetrahedra are pointed in alternate directions, and the

cleavage planes are even less planar than in the previous instance. This cleavage is difficult and obscure, as is the (011) cleavage of chrysoberyl, and it is these cleavages that mark the divergence of otherwise very similar structures. The difference is probably due to the smaller sizes of Al and Be cations when compared with those of Mg and Si.

The fact that twinning, which has been referred to (011) planes, is a frequent feature of chrysoberyl and a very infrequent one of olivine may have some indirect connection with the subject.

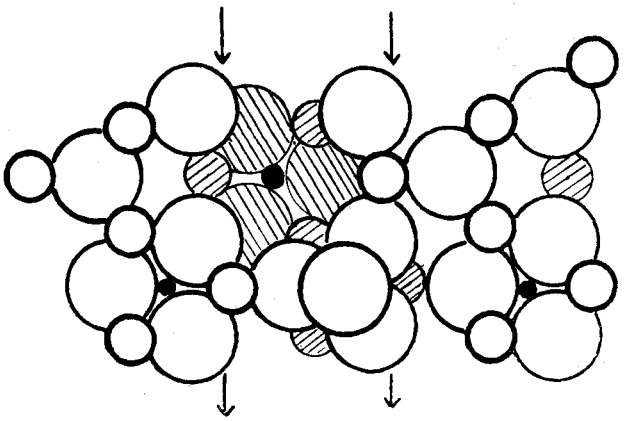

FIG. 11

The olivine/chrysoberyl structure, drawn to show the spacing of atoms (after Bragg). The atoms along the (010) cleavage path are to some extent interlocked, which probably reduces the facility with which the cleavage may be produced.

(Figure reproduced from W. L. Bragg's "The Atomic Structure of Minerals" by permission of the Cornell University Press and the Oxford University Press.)

TOURMALINE. A complex boro-silicate of several metals. S.G. 3.05. Hexagonal, trigonal. Cleavage: Parallel to flattened pyramid and prism faces, very imperfect.

The complexity of the composition of the tourmaline series is a byword among gemmologists, and the degree of isomorphous interchange of cations known in the mineral is almost impossible to understate. F. Machatschki published in 1929 ("Zeit. Krist.," 70, 211) a list of 28 analyses of the NaCaMgAl tourmalines. Added to this we have to consider replacement of Na by K, Mg by Fe^{++} or Mn, Al by Fe^{+++}, Ti or Cr, and hydroxyl by fluorine. The

possible combinations appear to be almost limitless, and it is easy to realize that the structure is not yet fully understood. It is thought, however, that when analysed it will prove comparatively simple, as have other seemingly endless series.

The cleavage of the mineral is not by any means marked and probably is observable only in thin sections. There may be some variation in its degree of perfection and facility as the formula varies. The same may be said of other isomorphous series, although, except in the cases of mica and feldspar, data in evidence are apparently not available.

THE GARNETS. Cubic. Isomorphous series of silicates of bivalent and trivalent cations. S.G. 3.40 to 4.20. Cleavage or parting: Dodecahedral, difficult and imperfect.

This is another good instance of the homogeneity of structure in some isomorphous series. The unit cell has been determined by X-ray diffraction methods, but available drawings do not assist greatly in the matter of cleavage.

There is a difference of opinion among mineralogists as to whether the occasional and imperfect splitting along dodecahedral planes is in fact cleavage, or is parting due to coarser imperfections. The possibility of lamellar twinning cannot be overlooked, although, since the mineral is isotropic, except for strain patches, it would be difficult to prove.

Altogether, it seems evident that the bi-, tri- and tetravalent metal cations of the garnets establish a very effective balance of bond throughout this highly symmetrical cubic lattice. The somewhat doubtful cleavage is difficult and probably only observable in thin sections.

KYANITE. Al_2SiO_5. Triclinic. S.G. 3.60. Cleavage: Pinacoidal, (100) perfect, (010) less perfect.

ANDALUSITE. Al_2SiO_5. Orthorhombic. S.G. 3.15. Cleavage: Prism (110) distinct, pinacoidal (100) less perfect, (010) traces only.

FIBROLITE. Al_2SiO_5. Orthorhombic. S.G. 3.25. Cleavage: Pinacoidal (010), very perfect.

These three minerals provide an interesting example of polymorphism, for, although they are chemically identical, they are in fact minerals of very different appearance and widely variant physical properties.

The essential difference in their atomic structure lies in the number of oxygens surrounding the Al cations. Half the latter are at the centres of octahedral groups of six oxygens while the remainder are surrounded by six, five or four oxygens in kyanite, andalusite and fibrolite respectively.

A characteristic of all three is the existence of chains of Al-O octahedra parallel to the *c* axis in each mineral. These are no doubt contributory to the fact that none of the cleavages cut this axis.

Kyanite, with its close-packed oxygen structure, is the densest of the three, and the perfect (100) cleavage apparently occurs between layers of oxygen anions sparsely bonded by aluminium cations. The less perfect (010) cleavage is not well defined and apparently follows a more step-like path in which again Al-O bonds only are broken.

The structures of andalusite and fibrolite are slightly more open and have the higher symmetry of the orthorhombic system. In fibrolite the Al-O octahedral chains are paralleled by chains of alternate Si-O and Al-O tetrahedra. The single pinacoidal direction of cleavage is not easily traced in diagrams of the structure. The name, *fibro*lite, suggests that a secondary cleavage may exist, but mineralogical text-books make no reference to it.

Andalusite, which is the best known of the three to gemmologists, possesses a structure between those of kyanite and fibrolite. The unusual position of half the aluminium atoms, between five oxygens, complicates the lattice and makes planes of possible cleavage hard to locate in the existing diagrams. It seems probable, however, that the more pronounced cleavages follow planes of oxygen layering.

SPHENE. $CaTiSiO_5$. Monoclinic. S.G. 3.50. Cleavage: (110), (100) and (112), imperfect.

The monoclinic symmetry of this mineral is undoubtedly due in the main to the large size of the calcium cation which occupies a position between seven oxygens. The lattice is thereby distorted a little from the close-packed condition, although the specific gravity might suggest otherwise, the density of the titanium cation being high.

The unit cell is complex and difficult to interpret from a two-dimensional drawing, but it is noticeable that the metallic cations

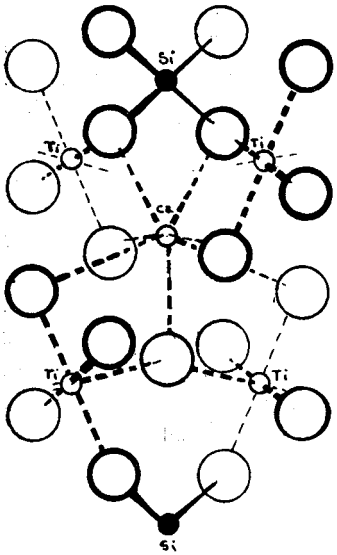

b

FIG. 12

The sphene structure projected on a plane normal to the *a* axis. Showing the interrupted Si-O-Ca sequence, which may contribute to one or more of the cleavages. This monoclinic structure is difficult to interpret from diagrams, but it is probable that models, if available, would show that bond angle and gaps in the structure are largely responsible for the weaknesses that produce the rather imperfect and ill-defined cleavages.

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are layered parallel to the three main pinacoid directions. Layers of Ti between six oxygens alternating between mixed layers of Si between four, and Ca between seven oxygens. This might be pre-supposed to indicate cleavage in all three of these planes. But, in fact, only the (100) plane of the three is a cleavage direction, and this between the least widely separated cation planes. It seems likely that in this direction the gap structure due to the large Ca atoms produces a weakness which, together with changes in bond angles, results in imperfect cleavage.

In the direction of the *b* axis there appears at first sight to be a chain of alternate Si-O and Ca-O structures. Closer examination shows (Figure 12) that the chain is interrupted by the seventh oxygen around the Ca cation, and bonding proceeds by laterally placed Ti cations., It seems probable that this diversion of bond contributes considerably to the (110) cleavage. It is to be noted that none of the three cleavages are at all prominent.

Si_2O_7 STRUCTURES.

Few minerals have this type of silica structure, and idocrase and danburite are the only gem minerals among them.

IDOCRASE. $Ca_{10}Al_4(MgFe)_2Si_9O_{34}OH_4$. Tetragonal. S.G. 3.40. Cleavage: (110) indistinct, (100), (001) less distinct.

The unit cell of this mineral contains 252 atoms and is an example of the complexity of structure which can be unravelled by X-ray diffraction methods. Some parts of it can be directly related to parts of the garnet structure.

Of the nine silicons in the formula only four form Si_2O_7 groups, the remainder forming discrete SiO_4 tetrahedra.

Diagrams of this structure are extremely complex, and show no obvious cleavage directions. The presence of the large Ca cations and weak hydroxyl anions no doubt contributes in some way.

DANBURITE. $CaB_2(SiO_4)_2$. Orthorhombic. S.G. 3.00. Cleavage: (001) very indistinct.

This gem has been compared to topaz on the strength of its appearance, crystal system and similarity of formula. The presence of the Si_2O_7 complex radical does not help the comparison, although the occurrence of very poor basal cleavage may be an argument once more in its favour. It is perhaps due to a layering of oxygen anions parallel to the basal plane, but lacks the weak fluorine-aluminium bonds of topaz to make it perfect.

Si_3O_9 THREEFOLD RINGS.

This is a very rare type of silicon grouping and occurs only in the rare barium titanium silicate, benitoite, and in the calcium silicate, wollastonite. The former has been cut to yield small and rather beautiful blue gems.

BENITOITE. $BaTiSi_3O_9$. Hexagonal. S.G. 3.65.

The mineralogies consulted do not mention cleavage in connection with this gem, and I think that it may be assumed that it is not a strong feature. The threefold Si-O rings lie parallel to the basal plane, and, as in beryl, they are bound both laterally and vertically by the remaining cations, titanium and barium. It is therefore possible that difficult basal cleavage may occur.

Two other observations may be made. Firstly, that the threefold ring is most obviously reflected in the trigonal symmetry of the mineral, and is an excellent example of the immense influence

of the silicon-oxygen bond on the crystallography of silicates. Secondly, since the threefold ring formation, unlike the sixfold rings of beryl, does not create gaps at the centres of the rings, the specific gravity may be expected to be higher than that of the latter gem. The heavy barium and titanium atoms contribute greatly to this, but the S.G. of 3.65 must indicate a fairly close oxygen structure.

Si_6O_{18} RINGS.

These, of course, are the silicon-oxygen rings found in beryl and so obviously reflected in the symmetry of that gem.

BERYL. $Be_3Al_2Si_6O_{18}$. Hexagonal. S.G. 2.70. Cleavage: Basal, (0001), very indistinct.

The profound effect of the Si-O bond on symmetry is very obvious in this mineral. In Figure 13 two layers of sixfold rings of

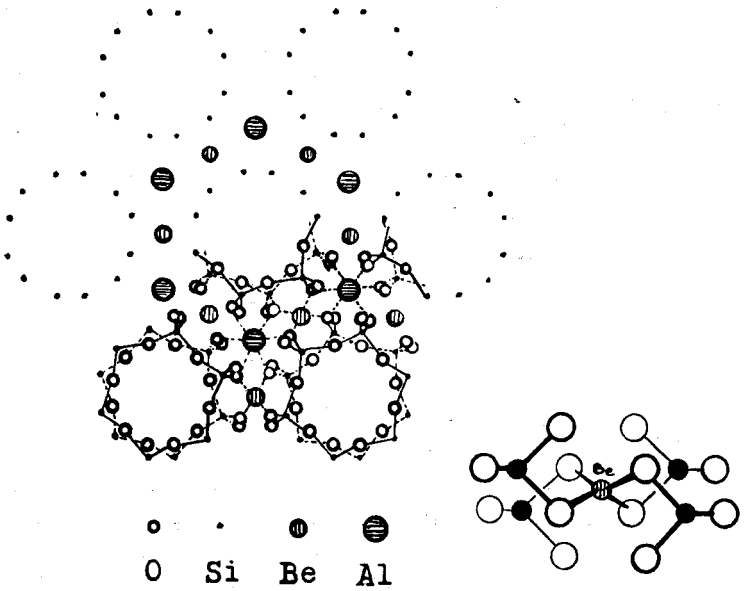

FIG. 13

The hexagonal Si-O rings of beryl. Rings at adjacent levels alternate in position, giving the impression of being 12-sided. To emphasize the perfect hexagonal symmetry the positions of further rings are shown by dots representing their silicon atoms only. The rings are strongly cemented vertically and laterally by the Al and Be cations between them, as seen in the smaller diagram.

tetrahedra are shown, and in order that the hexagonal repeat pattern may be understood the positions of further rings are indicated by dots representing the silicon cations.

The silicon-oxygen rings are layered parallel to the basal pinacoid and would probably lead to strong cleavage were it not for the positions of the other metallic cations. From the smaller drawing it will be seen that these serve to bind the rings tightly together both laterally and vertically.

Both Al and Be are fairly small cations and their bonds with oxygen are strong, being partly covalent. Between them they achieve a strength of bond which cancels out the possibility of vertical cleavage and leaves the basal (0001) cleavage poor and very ill-defined.

The low density of the mineral is in part due to the presence of two light metals, Al and Be ; but it is decreased by the gap structure occasioned by the open centres of the Si-O rings. The gaps are insufficient to accommodate water molecules or other such " fillings " found in more open structures.

SI-O CHAINS.

This type of structure is represented by two large families of minerals, the pyroxenes and the amphiboles, the former having single chains of tetrahedra and the latter double chains.

The pyroxenes include, among other minerals, the gems spodumene, diopside and enstatite. Jadeite is a massive pyroxene with a characteristic fibrous structure.

Amphiboles are represented among gems by the massive nephrite and the fibrous mineral crocidolite, which, when oxydized and partly replaced by quartz, provides the chatoyant golden stone known as Tiger's Eye. Asbestos is perhaps the best example of the amphiboles, and amply illustrates their fibrous and facile cleavage.

SPODUMENE. $LiAl(SiO_3)_2$. Monoclinic. S.G. 3.18. Cleavage: (110) perfect.

ENSTATITE. $(Mg,Fe)SiO_3$. Orthorhombic. S.G. 3.27. Cleavage: (110) easy.

DIOPSIDE. $CaMg(SiO_3)_2$. Monoclinic. S.G. 3.29. Cleavage: (110) rather perfect.

These three are not of great importance among gems, although spodumene in its lilac-coloured variety, kunzite, has appeared

occasionally in modern jewellery. The ready cleavage may account for this to some extent, but the rarity of good gem quality specimens is probably the main reason for their lack of popularity.

The silicon-oxygen chains in each case are a simple sequence of tetrahedra each joined by two corners to neighbouring tetrahedra. They invariably run parallel to the *c* axis of the crystal, and are bound laterally by the remaining metallic cations. The sizes of these cations control the symmetry of the crystal, the Mg and Fe of enstatite giving balanced orthorhombic symmetry, while the larger Ca cations of diopside and the smaller Li and Al cations of spodumene both shift the arrangement of silica chains to give monoclinic symmetry. The cations between the chains are in positions of six or eight co-ordination with the oxygen anions of the chains. The bonds in each case are mainly ionic and are weaker than the Si-O bonds within the chains.

The (110) prismatic cleavage is quite typical of pyroxenes and is entirely due to the comparative strength of the silica chains. The angle between the two prism planes is invariably about 93° and is the result of a step-like path between the chain structures, as shown in Figure 14.

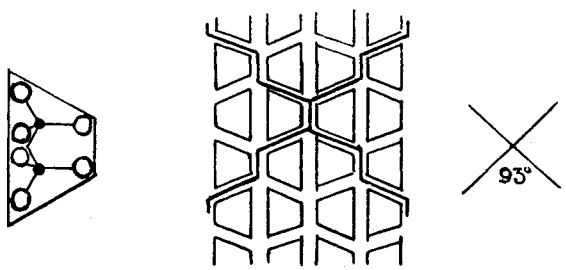

Fig. 14

Pyroxenes.—An end-on view of the Si-O chain formations, looking down the *c* axis of a pyroxene crystal. The step-like prismatic cleavage paths are indicated, intersecting at 93°.

In enstatite the (010) direction has also yielded cleavage. Possibly the slight shift of cations due to the lower symmetry prevents this in the other two gems.

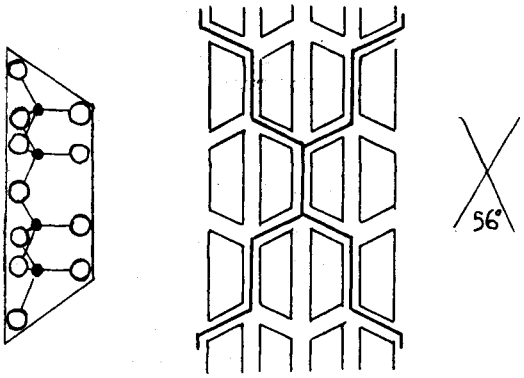

FIG. 15

AMPHIBOLES. — End-on view of the double chains. The "steps" of the cleavage paths are steeper than in pyroxenes and result in cleavage planes inclined at 56°.

(Figures 14 and 15 are reproduced by permission of the Cornell University Press and Oxford University Press from W. L. Bragg's "The Atomic Structure of Minerals.")

THE AMPHIBOLES.

The (110) cleavage of the amphiboles follows a similar path to that of the pyroxene cleavage, but since the silicon-oxygen chains are double the step-like path is steeper (Figure 15) and the angle between the two prism directions is about 56°.

Regarding amphiboles, A. F. Wells states that they invariably contain some hydroxyl and that aluminium may replace some of the silicon in the double chains. Isomorphous replacement is very common.

Crysotile, which is often used commercially as asbestos, is closely related to the amphibole group, but contains more hydroxyls and more Mg, with the result that the chains are coated with OH anions. Bonding between chains is usually between Mg and OH or water molecules, and separation of the fibres in this mineral is facile to an extreme.

Si_2O_5 SHEETS.

Having digressed to deal briefly with the amphiboles, the writer may perhaps be excused for going on to an even less gem-like family—the micas. A family, nevertheless, of vast importance in the consideration of cleavage. The clay minerals and talc are also examples of this type of layered Si-O structure.

The simplest form of the structure is an infinite sheet of Si-O tetrahedra, each linked to its neighbours by three oxygens (Figure 7e). In the clays and talc the remaining negative charge of the fourth oxygen is taken up in various ways with hydroxyl

and Al groups forming layers which have no residual charge and hence no outside cations to bind them together. They are held only by the small residual charges known as Van der Waals bonds and can slip, glide, cleave or break with a minimum of applied energy. This is a factor which contributes greatly to the slipperiness of clays and to the lubricating qualities of talc.

In the micas the structure is more complex. The layers consist of two single layers of SiO_4 tetrahedra with their vertices pointing inwards and bonded together by Al or Mg cations and OH anions. One in four of the tetrahedra in the structure is centred by aluminium instead of silicon. The resultant double sheets carry a negative charge and the hexagonal holes which are apparent in Figure 7e accommodate large potassium or other alkali atoms which bind the sheets together. These large K atoms are univalent and are situated between twelve oxygens. The bonding between layers is therefore not only comparatively sparse, but also very weak when compared with the bonds within the layers. From this fact arises the cleavage for which mica is so well known. Figure 16 is an idealized picture of the layered structure.

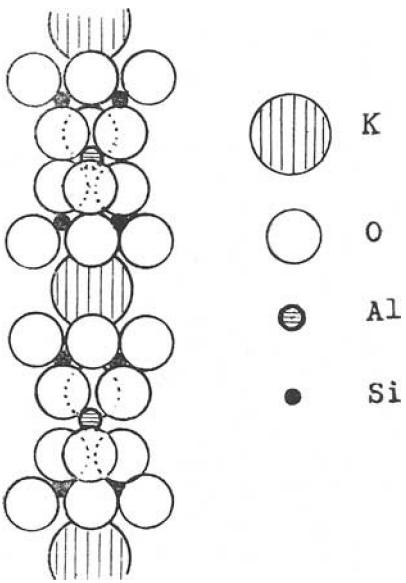

FIG. 16

The sequence of the atom layers in mica. Two of the six anions surrounding the Al cations between the SiO tetrahedral layers are hydroxyls.

Cleavage separates the sheets which are weakly held by large alkali cations.

A group known as the brittle micas has equal numbers of Al and Si atoms in the double layers, with the result that they carry twice the normal negative charge. The atoms between the layers are then smaller bivalent calciums, and the layers are held more strongly. This, combined with the weakening of the layers by the additional aluminium atoms, causes the mica to be harder, and brittle and rather less cleavable.

Three-Dimensional Silicate Frameworks.

Structurally the various forms of quartz and its polymorphs are examples of this type of lattice, but before we discuss these there is one other gem series to be considered.

There are actually three important mineral classes possessing " framework " silicate structures: the feldspars, zeolites and ultramarines. The two latter do not greatly concern us, although lapis lazuli is a massive mixture of three ultramarines. The zeolites are of importance as water softeners, the gaps in their structures being of sufficient size to permit the free interchange of large sodium and calcium atoms.

The Feldspars.

These are the commonest of all rock-forming minerals and are of great importance in that connection. But, being rather soft and of low density and refraction, they have not achieved much importance as gems. They are known in this connection only by moonstones, microcline, labradorite and occasional cut specimens of yellow orthoclase, blue oligoclase and other colours.

Broadly the feldspars are divided into monoclinic (the orthoclase feldspars) and triclinic (plagioclase feldspars), the latter consisting of an isomorphous series between the sodium-feldspar, albite, and the calcium-feldspar, anorthite. The small size of the Na and Ca cations when compared with the K and Ba atoms of the monoclinic group is responsible for the lower symmetry.

The fundamental structure of all feldspars is a complex chain of Si-O tetrahedra (best described as fourfold rings of tetrahedra joined vertically by alternate edges (Figure 17)). The external oxygens of such chains connect directly to other silicon atoms in other such chains, so that the entire crystal is filled with a three-dimensional network of silicon and oxygen atoms which is in effect one vast negative ion.

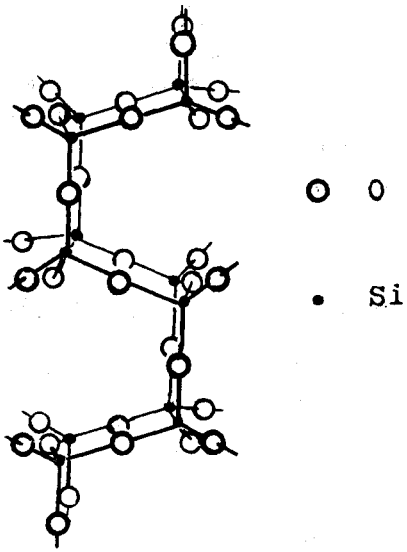

FIG. 17

An idealized version of the feldspar Si/Al-0 chain. Chains of this type run parallel to the *a* axis in feldspar crystals and are held one to another by comparatively sparse Si-O bonds and weak alkali-oxygen bonds.

(Reproduced by permission of the Clarendon Press, Oxford, from A. F. Wells's "Structural Inorganic Chemistry.")

The fact that the structure is negative needs some explanation, since, if it consisted only of silicon and oxygen, there would be no surplus negative charge to take up other cations in the structure. The reason for the charge is that in feldspars, as in micas, trivalent Al cations replace one in four of the tetravalent silicons in the network. (In anorthite the ratio is 2:2.) It has not so far been possible to assign definite positions to these Al atoms, although everything points to an orderly rather than a haphazard arrangement.

The chain structure obviously gives rise to considerable gaps capable of accommodating the large K, Ba, Na and Ca cations which are present to balance the negative charges. It is noticeable that the smaller cations, such as Fe, Mg and Cr, so common in other minerals, find no place in the feldspar formulae. The available spaces are all too large.

The low density of the feldspars is further evidence of the considerable departure from a close-packed oxygen structure.

Treated simply, the feldspar crystal consists of comparatively strong chains of Si/Al-O tetrahedra running parallel to the *a* axis. Laterally these chains are held together by a lesser number of Si/Al-O bonds and by the very much weaker bonds to the larger

alkali metal ions. Cleavage, which is parallel to these chains, necessarily involves breaking some Si-O bonds as well as those weaker ones between alkali and oxygen.

The cleavage of plagioclase feldspars is to some extent affected by the alteration of symmetry, and the two pinacoidal cleavages are not equally defined. There is another imperfect cleavage apparently cutting across the chains in the sodium-feldspar, albite. All of these triclinic feldspars are brittle and it seems probable that this factor increases and ease of cleavage lessens as the anorthite end of the series is approached, owing to the greater proportions of Al and Ca cations.

The X-ray analysis of the feldspars is by no means complete and many puzzling factors have yet to be solved. The problems of twinning, intergrowths and near isomorphism are among the many that are still only partly understood.

QUARTZ. SiO_2. Hexagonal, trigonal. S.G. 2.65. Cleavage: Pyramidal (1011), difficult and seldom observed ; prismatic (1120), more difficult ; basal (0001), more difficult.

TRIDYMITE. SiO_2. Hexagonal, trigonal. S.G. 2.30. Cleavage: Prismatic (1010), not distinct.

CRISTOBALITE. SiO_2. Cubic. S.G. 2.35. Cleavage: None observed.

Finally, we come to the most concentrated " silicate " of them all, the pure oxide quartz. No longer are any silicons replaced by aluminium, allowing the inclusion of other metal cations. The framework structure consists simply of an infinite lattice of silicon-oxygen bonds, every silicon bound directly to four oxygens and every oxygen to two silicons. The 2:4 co-ordination has been reached.

As may be expected, the unity of bond type in every direction throughout the structure produces a strong crystal. But when the comparative strength of the Si-O bond and the Al-O bond is considered, the low hardness of quartz (7) is perhaps difficult to understand. However, the densities of quartz, and of polymorphs, tridymite (2.30) and cristobalite (2.35), are low and indicate structures in which the oxygens are not close-packed. This is undoubtedly due to the *small* size of the silicon cations, and is probably the reason for the lower hardness of these minerals when

compared with that of corundum (9), in which the structure is close-packed.

At the same time, the strength of the Si-O bond is effective in the matter of cleavage. Quartz shows an obscure pyramidal cleavage, very difficult to produce, and two others even more difficult. No cleavage has been observed in cristobalite, and only one indistinct direction is known in tridymite. All these are probably due to the distortion of the lattices into gap structures.

It has been suggested that the three minerals, the exceedingly common quartz and the very rare tridymite and cristobalite, are temperature modifications of each other. Each of them certainly has a low and high temperature form, and quartz, when sufficiently heated, can be made to change slowly to tridymite and finally to cristobalite. The change is a difficult and complex one involving the breaking and reshuffling of Si-O bonds. This difficult transition accounts for the fact that all three are known at ordinary temperatures. Neither tridymite nor cristobalite have been found in crystals large enough to warrant their being cut as gems. Their only claim to gemmological fame lies in the fact that it has been suggested that the fissures in the silica gel, opal, are lined with cristobalite.

In quartz, the silicon-oxygen tetrahedra are joined in spirals parallel to the *c* axis. The right- or left-hand twist of these spirals is responsible for the right- and left-handed crystals which are a feature of the mineral.

Quartz is well known for its invariability of physical constants. This may be taken as further evidence of the strength of the Si-O bond, which permits no isomorphous intrusions of other cations. Coloured varieties are allochromatic and contain the colouring matter as colloidal inclusions in no way assimilated into the chemical structure of the crystal.

The difference between the three minerals lies basically in the way in which adjoining SiO_4 tetrahedra are related. This is best seen in Figure 18.

The conclusions and inferences which may be drawn from this discussion of cleavage are necessarily broad, for the analysis of atomic structures is still in its youth, and a great deal of research will be needed before anything like a complete understanding can be reached. Many of the structures discussed have not been com-

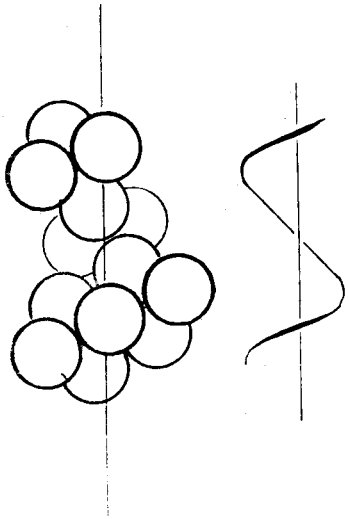

FIG. 18

Diagrams showing the linking of silicon-oxygen tetrahedra in the structures of quartz, tridymite and cristobalite.

The spiral sequence in quartz is responsible for that mineral's unique rotatory polarization. This is the most close-packed SiO_2 structure and has the highest specific gravity (2.65).

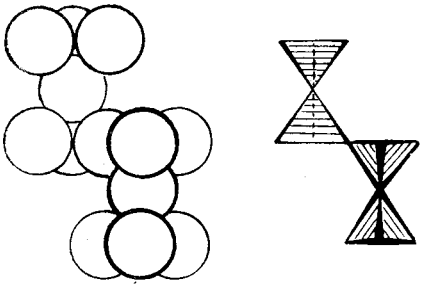

In tridymite the Si-O-Si angle has straightened from the 145° of the quartz spiral to 180°, with a resultant opening-out of the lattice, lowering the S.G. to 2.30.

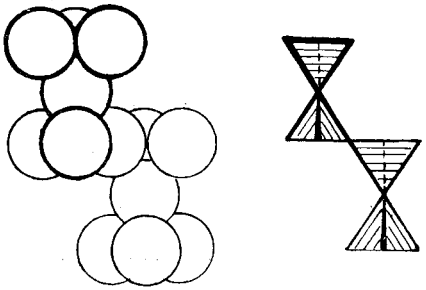

In cristobalite the Si-O-Si angle is again 180°, but the inversion of juxtaposed tetrahedra closes up the lattice a little, and the S.G. is slightly higher at 2.35.

Such cleavage as exists in these minerals must be due to the gap structures and possibly, in the case of the pyramidal direction in quartz, to direct oxygen layering.

pletely analyzed, and in many cases the texts available take little or no account of their cleavage.

However, certain general rules seem to apply, and it may, for instance, be assumed that cleavage surfaces are neutral, that the smaller cations tend to be more strongly bonded to their anions than are the larger ones. The importance of the silicon-oxygen complex ion cannot be over-emphasized. The inclusion of fluorine or hydroxyl anions generally produces weak planes in a crystal structure. Gap structures are obviously not as strong as close-packed ones, a fact reflected in both hardness and cleavage.

A perfect crystal structure probably does not exist, although diamond approaches that state. Other minerals are far from perfect either chemically or crystallographically and their cleavage is undoubtedly affected thereby.

There is still an enormous amount of work to be done before the structure of crystalline matter is fully understood. And while atomic physicists are side-tracked at the other end of the periodic table tracing down bigger and better destructive agents among the radio-active elements, it will probably be a long time before sufficient work is done on the common elements, which largely comprise our mineral heritage, to enable final and conclusive arguments to be made.

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ASSOCIATION NOTICES

ANNUAL MEETING, 1950

The twentieth (fourth since date of Incorporation) Annual General Meeting of the Association was held at the British Council Cinema, Hanover Street, London, W.1, at 5.30 p.m., on Wednesday, March 22nd, 1950.

Mr. F. H. Knowles-Brown, Chairman, who presided, welcomed members and expressed regret at the inability of the President to be present because of indisposition.

The Annual Report and Accounts for the year ended December 31st, 1949, were presented to the meeting and it was moved from the Chair "That the Report of the Council and the audited Accounts for the year ended December 31st, 1949, be and are hereby approved and adopted." Mr. Gordon Blythe, Southend, seconded the resolution and expressed appreciation of the work of the Association. The resolution was unanimously approved.

There being no other nominations, the following Officers were declared to be re-elected:—

President: Dr. G. F. Herbert-Smith.
Chairman: Mr. F. H. Knowles-Brown.
Vice-Chairman: Dr. G. F. Claringbull.
Treasurer: Mr. S. F. Bones.

Mr. J. H. Saunders and Mr. A. S. Braunfeld were appointed to act as scrutineers for the postal ballot for election of Fellows to serve on the Council. As the result of the ballot, Mr. B. W. Anderson and Sir James Walton were re-elected and Mr. A. R. Popley and Dr. W. Stern elected.

Messrs. Watson Collin and Co., Chartered Accountants, were re-appointed as Auditors to the Association.

After the Annual Meeting a short film was shown dealing with the Microscope. Following this, Mr. F. H. Knowles-Brown gave a review of some of the more important gemmological developments during 1949. He referred to the technique of measuring curved surfaces on the refractometer which had been developed by a member of the Gemological Institute of America. He also referred to the question of synthetic stones. It seemed that man was struggling all the time to do something as well as, if not better than, nature. Why should there be this curious desire to produce something which nature does? It should be realized that of diamond, sapphire, ruby, emerald and pearl only one was not produced

synthetically or artificially. The Chairman dealt at length with the production of synthetic emerald in the United States and submitted that the people in this country were not likely to be enamoured with the recently produced synthetic rutile. He felt it was too gaudy for the average British taste.

Reference was also made to various instruments devised by Fellows of the Association, the most outstanding being the balance made by Sir James Walton. This had been on show at the Association's 1949 Gemmological Exhibition and later in the evening Sir James himself explained the balance to members. Two students at Chelsea had devised simple and inexpensive polariscopes. One in Scotland—Mr. D. J. Ewing—had experimented with light sources for absorption spectra tests.

Mr. Knowles-Brown continued: "I personally was particularly interested to read and also see details about the heat-treating of zircons. When I was much younger and studying gemmology, all I was told was that the colour of blue and golden zircons was caused by heating, but it was not until this year that I was made aware of what really went on, and I am sure we are grateful to Mr. Lindley and Mr. Buckingham for making this information available to us."

After referring to new books published on gemmology, both in this country and elsewhere, the Chairman thanked those Fellows of the Association who had given talks to institutes, clubs and similar organizations. He felt that their work in telling the public about gems was an influence for the good of the jewellery trade. Specifically he added: "I mention jewellery trade, for it must always be remembered that it was from the jewellery trade that this Association has emerged and our roots extend long and deeply into the trade."

In concluding his remarks, Mr. Knowles-Brown referred to the extent that the technique of testing by absorption spectra was used in this country and to the debt which was owed to Dr. E. Gübelin, of Switzerland, for making us more aware of the diagnostic importance of gemstone inclusions.

Mr. B. W. Anderson spoke at length on the new technique of obtaining refractive indices of cabochon stones on the refractometer, and acknowledged the debt we owe to the two members of the Gemological Institute of America—Lester B. Benson and R. Crowningshield—who had developed it. It was a simple method which required care and practice. A drop of liquid was placed on the refractometer and then the curved surface of the stone was applied as if it were an ordinary flat surface. The eye was withdrawn from the eye-piece to about ten inches, when there should be seen a little disc in the eye-piece, representing the contact of the stone with the refractometer. What the viewer had to do was to poise his eye to divide the area into dark and light sections and then to focus on the scale to see at what point the division takes place. To do that is easier if the eye-piece was removed and a low power lens used.

There was more in this use of the refractometer than that. Sometimes it was difficult to get a reading on a stone with a flat facet, particularly with paste. The distant vision method did enable a reading to be got where the ordinary method failed. The same applied with quite small stones. One limitation was still the detection and measurement of double refraction. Probably with a polaroid disc this might be achieved.

Mr. Anderson ended with a few further guiding words. Be sparing with the contact liquid. Get the stone surface positioned in the centre of the refractometer table. The rest was largely a matter of practice. It was best to start with a synthetic cabochon in the middle register. At the lower and upper ends of the scale there was some optical distortion. Finally, persevere.

Sir James Walton then spoke about his balance, saying for many years they had been trying to get an instrument which would give an accurate reading of specific gravity, easily and quickly. Apparatus now existing had to be corrected often or was slow. He then described his balance, a working one being on the table, which would handle from one up to forty carats and could also be quickly adapted as an ordinary balance to give a reading up to two places of decimals.

The meeting concluded with the showing of a film in technicolour on the making of "Optical Glass."

COUNCIL MEETING

At a meeting of the Council of the Association held on Wednesday, February 15th, 1950, the following were elected to membership:—

FELLOWS:

R. J. Barker, London.
C. M. L. Carr, Montreal, Canada.
D. Dresme, Amsterdam, Holland.
J. M. Duncan, Glasgow.

PROBATIONARY:

R. W. Batty, Liverpool
M. A. N. Caffoor, London.
H. A. Clarke, London.
R. H. Corfield, London.
E. G. H. Drury, Birmingham.
F. L. D. Ekanayaka, Colombo, Ceylon.
H. C. Fishberg, Edgware.
Miss B. M. Henn, Bridgnorth.
H. Myhre, Ljan, Norway.
John F. Scott, Lincoln.

ORDINARY:

Kurt Decker, Stockholm, Sweden.

GIFTS

The Council of the Association acknowledges with grateful thanks small parcels of gemstones for the Association's collection from Mr. F. E. Lawson Clarke, Chairman of the National Association of Goldsmiths, and Mr. W. E. Payne, Bromley.

TALKS BY FELLOWS

F. E. Leak: "The Science of Jewellery." January 19th, the "Ark" Club, Westburn Park, Bristol; February 6th, King Street (Bristol) Methodist Church Youth Club; February 14th, Eastville (Bristol) Townswomen's Club. "Diamonds." March 13th, "20/40" Club, Bristol.

R. Webster: "Pearls." January 27th, Central School of Arts and Crafts, London, W.C.1.

Letters to the Editor

HORIZONS OF GEMMOLOGY

Dear Sir,

Regarding Mr. Pearl's article in your January issue, "Broadening Horizons of Gemmology," we think it a pity that his very reasonable plea against the imposition of arbitrary limits to gemmology should be vitiated by a sample of the patronage which the mineralogist too frequently inflicts upon the gemmologist. We refer to the passage, "It is largely because they are primarily professional mineralogists that such men as Herbert Smith, Kraus, Alexander, Pough, and others of that high calibre qualify as gem experts; otherwise the only gem experts would be practising jewellers, who, after all, were making a livelihood from their untechnical knowledge of gems long before science invaded the field."

However true this may be in the States, it certainly doesn't apply over here, where the pioneers of gemmology were persons actively engaged in the trade, such as Tully and Barnett. In those early days mineralogists, with a few honourable exceptions, regarded the infant science with aloof distaste, and it is only since the jewellers have lifted themselves up by their own shoe-strings (so to speak) that mineralogists have as a body developed an interest in the subject. In any case, even if one holds the view implicit in Mr. Pearl's article, that jewellers are in general an ignorant lot whose amateur gropings in gemmology require external guidance, it is arguable that the tutelage of the physicist is likely to be more profitable than that of the mineralogist. Certainly the work and teaching of a physicist and chemist, Mr. B. W. Anderson, have been so outstanding in gemmology that his name alone serves to confirm this in no uncertain fashion.

The cavalier dismissal of research into the mythology of gemstones as " nonsense " is oddly discordant with Mr. Pearl's general thesis. We agree with him in having but a lukewarm enthusiasm for this facet of gemmology, but consider nevertheless that it is an integral and valuable department of that subject.

Yours sincerely,

THOROLD JONES.
E. J. BURBAGE.

26, Wolseley Gardens, W.4.

Dear Sir,

I regret that my article should have tended in any way to provoke an unfavourable reply from Messrs. Thorold Jones and E. J. Burbage, whose purposes in advancing the field of gemmology are fundamentally the same as my own. I had hoped that instead it would lead to a re-orientation and broadening of our viewpoints and a furthering of the interests of gemmologists the world over.

The term " untechnical knowledge " should not offend anyone except those who make a pretence to information and training they do not possess, an error not committed by those who are formally associated with the Gemmological Association of Great Britain. We all have an untechnical knowledge of every subject except our own specialty. Most jewellers, even to-day, even in Britain, have an untechnical knowledge of gems. Messrs. Jones and Burbage belong to a distinguished minority.

Everyone, I believe, who cares to exert himself can become a capable gemmologist, be he jeweller, mineralogist, chemist, or poet. It is, however, the mineralogist—because of his required basic training in physics, chemistry, and geology—who happens to be in the best position, through no fault of his own, to qualify as a gemmologist. Your correspondents were not justified in interpreting my statement as a slur upon the worthy members of the jewellery trade. There should be no occasion for any hard feelings in this matter ; I apologize sincerely for any that may have arisen.

The last criticism is likewise the result of a misunderstanding, a confusion of words. I defined gemmology as the *science of gems*, hence the superstitions, folk-lore, and old wives' tales are not a part of it. They are indeed entertaining and interesting nonsense (so is "Alice in Wonderland ") —but they are not gemmology. As I said originally, if we can spend time on such things, we should consider also the many minerals and rocks that deserve a place in gemmology even if they are not sold in the jewellery stores. This is part of the broadening horizon.

Yours sincerely,

RICHARD M. PEARL.

Colorado College.

FINE CUT OF SYNTHETIC RUTILE

Dear Sir,

I should greatly appreciate if you could publish the following note on Mr. G. G. Waite's " Approaches to the Fine Cut of Synthetic Rutile " (this Journal, Vol. II, No. 2, April, 1949, pages 35 to 44).

Mr. Waite's suggestions are based on practical investigations of synthetic rutile. My suggestions for a suitable fashioning of synthetic rutile had been made from optical considerations and calculations. For conventional reasons the brilliant-cut was adopted, and I concluded with the words: " It will be interesting to see to what extent these values will prove satisfactory in practice."

The quesion will easily find its objective answer as soon as synthetic rutile, cut according to calculated values, can be compared with the cut now in vogue, as well as that suggested by Mr. Waite. " Reflectograms," which I myself cannot at present provide yet, would greatly facilitate such a comparison.

As for the Jubilee-cut of synthetic rutile, optical theory appears to indicate some alterations of the angles suggested by Mr. Waite ; his values are set out below together with the revision: —

TABLE

SUGGESTION FOR THE JUBILEE-CUT OF SYNTHETIC RUTILE
(angles of facets with the girdle plane)

	Mr. Waite's values	Suggestion for improved new values
Main pavilions	40° ...	45.0°
Point	35° ...	41.3°
Main crown	30° ...	23.0°
Star	10° ...	9.0°

Yours sincerely,

Freyung v. W., Germany. W. F. EPPLER.

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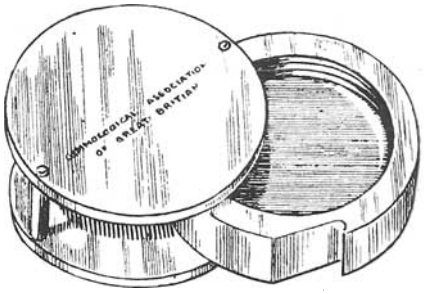

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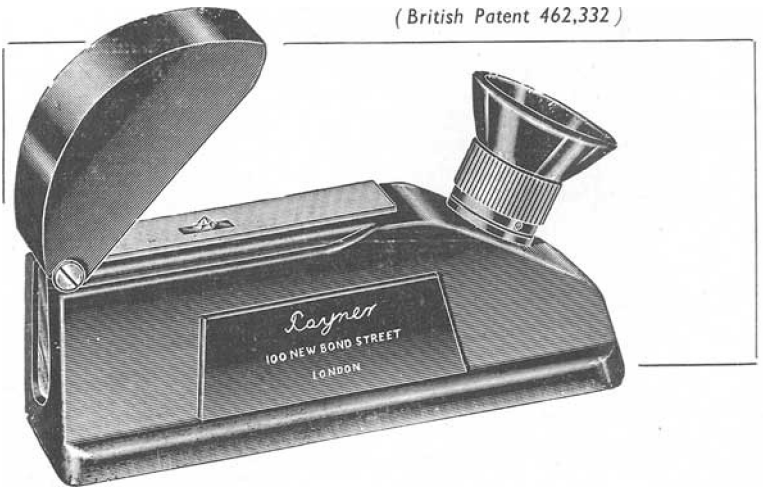

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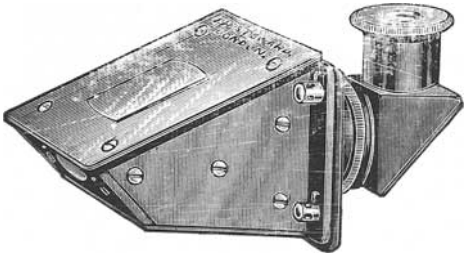

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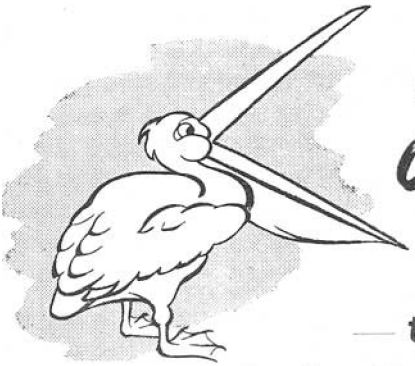

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THE JOURNAL OF GEMMOLOGY

and

PROCEEDINGS OF THE

GEMMOLOGICAL ASSOCIATION OF GREAT BRITAIN

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DIAGNOSTIC IMPORTANCE OF INCLUSIONS IN GEMSTONES

By EDWARD GUBELIN, Ph.D., F.G.A., C.G.

IN the previous paper on gemstone inclusions, published in the "Journal of Gemmology," Vol. 1, No. 7, a general survey on inclusions was presented ; the exquisite beauty of the fairylike landscape scenery, sunlit garden corners, bizarre forms and fantastic shapes appeared to consist of foreign particles of matter which could be solid, liquid or gaseous ; they could consist of cavities filled with liquid or crystals within crystals of the same gem species ; and the veracity and significance of Pliny's assertion that in gems we admire nature's majesty in miniature was substantiated and will remain unchallenged.

An intensive study of gemstone inclusions is as essential to any gemmologist as a thorough knowledge of the other properties of gemstones, such as refractive index, density and absorption spectrum, since this study enables him to become capable of determining any gemstone by its inclusions as quickly and as accurately as by its spectrum or refractive index. The identification of gemstones by their inclusions as a means of revelation and as a field of

scientific investigation therefore ranks on a par with the two other principal examinations, that of the refractive index and that of the absorption spectrum.

Apart from the ordinary observation of inclusions for their splendour, or as a means of distinction from synthetic stones, plastics and pastes, they are of greatest value in the discernment and classification of genuine stones. Inclusions are beginning to attain increased significance in crystallography, and are also receiving close attention in genetic mineralogy and stratigraphy.

It may certainly be taken as a merit of the youngest branch of mineralogical science, namely gemmology, that, out of the need to evolve new identification methods for its objects of study, since the standard methods are often not sufficient for identifying a gemstone, it has made a considerable contribution to the increase of knowledge about inclusions and their use in identification, at any rate, of gemstones. The invention of a new type of dark field illumination for binocular microscopes in connexion with a new rotation device has enabled considerable progress to be made. This apparatus makes it possible in a practical way to examine gemstones and their inclusions in dry condition from all angles, and proves especially advantageous for investigating the crystallization form of enclosed crystals. Systematic studies have shown that the inclusions of the different kinds of gemstones differ to such an extent that they offer a reliable means of separating them.

Rightly recognizing that the differing chemical and physical conditions during crystallization of different species of minerals in separated deposits have left their unmistakable traces in most gemstones, the diagnostician turns mainly to the phenomenological picture of the inner paragenesis. (Phenomenology is used in the sense of the science of the visible, and a phenomenological picture is one which characterizes a stone and leads to its identification.)

The diagnostic value of inclusions lies not so much in the single occurrence of the various kinds in the various species of gemstones, but rather in their regular appearance in a certain species of crystal (byssolite fibres in demantoids), in their manner of arrangement and distribution (" silk " in corundums, or amphibole needles in almandines), their phenomenological pictures in conjunction with peculiarities of structure (diopside crystals in the streaky distribution of colours in hessonites), their unique

appearance or development (jagged liquid inclusions in beryls, three-phase inclusions in emeralds, tetrahedron cavities in fluorites), or the typical relationship of the inner paragenesis with a known exterior association (metamict zircons in Ceylon stones, enstatites and garnets in diamonds, spinels in Burma rubies, etc.). The inclusions specific for many kinds of minerals are just as characteristic as oak leaves for the oak trees ; indeed, in their profusion of forms individuals are just as different from one another as two oak leaves are never exactly identical.

The knowledge about the diagnostic value of inclusions in gemstones so far obtained from gemmological research already is so extensive and is confirmed with certainty by numerous examples, that the time seems to have come to give the gemmologist a comprehensive summary.

Diamond. Although the diamond is often considered as a gemstone free from inclusions, and although exaggerated ideas of the common occurrence of pure diamonds are widely held, its inclusions are extraordinarily characteristic. A diamond with inclusions can easily be distinguished from other gemstones which may appear similar. An interesting abundance of different, but always typical, pictures of inclusions presents itself to the person through whose hands numerous diamonds pass. As the diamond owes its formation to unique conditions, a peculiar type of formation characteristics may be expected.

Among the solid inclusions we find more or less well-developed zircons, varieties of pyropes (Fig. 1), quartz (Fig. 3), haematites (as single tablets or grouped into " iron roses "), enstatites, diopsides, graphite and other less important minerals. These inclusions may be pre-temporary or con-temporary. Furthermore, crystal splinters, rarely particles of coal, and earth-like substances have been found to be included. Some of the fissures that sometimes occur in diamond are caused by included zircon crystals (Fig. 4) whose thermal expansion coefficient is higher than the diamond's. Many of the inclusions are minerals of the outer paragenesis of the diamond. Especially the occurrence of enclosed, usually distinctly euhedral crystals of diamond, frequently octahedral, may be regarded as an unequivocal recognition characteristic (Fig. 2). Not merely the presence of these microlites but often quite as much the type of distribution and arrangement are equally of diagnostic importance. " Carbon

spots " is a favourite term in the jewellery trade for the dismissal of any apparently dark-coloured inclusions within a diamond, though in my opinion carbon is very rarely present.

Liquid inclusions occur as filling of cavities with or without libellas or as a kind of foggy cloudiness, caused by a microscopically dense accumulation of the finest droplets of liquid. Liquid inclusions are none the less very rare ; the well-known feathers of other gemstones, which will be discussed later, appear to be entirely absent from diamonds.

On the other hand, gaseous inclusions, usually microscopic bubbles, which as a rule are accumulated in dense clouds and as such often assume interesting shapes, are very frequent, and can serve as an instructive source of information about the crystal form of the host crystal which has been lost in cutting. Thus a cloud of octahedron shape displays the original position of the natural crystal faces and their angular relation to the cut stone (Fig. 5). Cross-shaped clouds are sometimes found enclosed in Golconda diamonds, clouds which are surrounded by one or several foggy frames (Fig. 6). Such structures were formed by dense clouds of gas bubbles settling during the growth of the diamond on its temporary surface. The present cross shape of the cloud indicates that these bubbles settled on the crossing edges and on the surfaces forming the re-entrant angles of interpenetrating twin cubes. On approaching the surfaces of the crystal the cloud was parted by the edges and assumed the shape of a cross above the re-entrant angles. In addition to these genuine inclusions there are straight-running clefts, which offer a less interesting picture, and which must be distinguished from the conchoidal, stepped-up fissures through breakage and the jagged cracks. Both these and the rather frequent fissures through tension may also be considered handy characteristics for recognizing diamond.

It is quite impossible to give an even approximately exact description of the profusion of forms and of the multiplicity of distinctive inclusions in diamonds and all other gemstones. The present account has therefore been illustrated by as large a selection as possible of typical pictures of inclusions, from which can be read what cannot be expressed in words.

Corundums are to the student of inclusions an inexhaustible source of charmingly beautiful pictures of inclusions with manifold types of inclusions and a hardly imaginable wealth of forms. Usually the expert gemmologist can at once recognize the species of corundum under the microscope on account of their characteristic inclusions. In addition to the always distinctive peculiarity of the inclusions of all corundums, a differentiation according to their occurrence is obvious. Thus the corundums from the three main deposits, Burma, Ceylon and Siam, differ markedly from one another.

Well known and often described is the type of inclusions called " silk " by the gemmologist, which in Burma corundum consists of fine rutile needles (Fig. 7) and in Ceylon corundum of a loose accumulation of tubes which permeate the whole gemstone (Fig. 9). Here the group-wise arrangement of the short, black, rutile needles in Burma corundum is distinctive as compared with the penetration of colourless capillaries through the whole stone in Ceylon corundum. Rutile needles and canals are orientated according to the direction of the edges of faces $(0001)/(10\bar{1}1)$ and $(10\bar{1}1)/(11\bar{2}0)$; thus they are, so to speak, " two-dimensionally " embedded in sagenite arrangement parallel with the basal plane, and they are contemporaneous coalescence-inclusions. In Burma corundums together with the " silk " there occur a host of crystal inclusions, inter alia normal zircons, coarse rutile crystals (frequently in knee-shaped twins), spinels (usually as euhedral octahedra), corundum crystals, and glassy melted drops (Fig. 8). In Ceylon corundums, on the contrary, one finds calcite plates, either single or in packets, muscovite lamellae, garnets, and metamict radio-active zircons. The latter are typical guests not only of the corundums but also of numerous other minerals of the Ceylon deposits, and the radio-halo which always surrounds them is to be considered as a distinctive character of the locality. These halos are formed by the destructive radiation of alpha rays by the radio-active element uranium, which is contained in metamict zircons (Fig. 14).

Liquid inclusions are seldom found singly, and then in Ceylon sapphires only. They fill up hose-like cavities with step-like grooves, the shape of which cavities is so distinctive that one can always recognize them if one has observed them once (Fig. 10).

Much more numerous are the so-called feathers of liquid, which consist of a host of microscopic liquid droplets and the whole of which may be compared with wings of insects (Fig. 12). This type of inclusion, too, is typical of Ceylon corundums (Fig. 13). If strong magnifications are used, the microscopist is always surprised by the most magnificent patterns formed by the droplets of these clouds (Fig. 11). Clouds of liquid of the type and aspect found in the corundums have so far not been discovered in any other gemstone.

The inclusions of Siam corundums differ entirely from those so far discussed. In Siam rubies are found opaque, brown-black to black, hexagonal crystals, surrounded by flat liquid halos with concentric structure (Fig. 15). The nature of the hexagonal crystals has not yet been established with certainty ; preliminary examinations suggest opaque corundum crystals. Feathers of liquid, which occur singly and are not tied to the opaque crystals, show a hieroglyphic pattern (Fig. 16).

In Siam sapphires the picture of the inclusions is characterized by opaque black prismatic crystals, which are accompanied by films of a brownish liquid containing iron (Figs. 17 and 18). As the colouration of the Siam sapphires is almost always very dark, the study of their endogenesis is rendered so difficult that the nature of the prismatic crystals could not be determined.

The milky or foggy opaque appearance of the Kashmir sapphires is caused by microscopically small, short cracks or channels, which often occupy the whole crystal.

Beryls. Among the beryls the emeralds and aquamarines can be recognized and distinguished from similar different gemstones by their inclusions.

In **emeralds** the liquid inclusions are of the first importance ; they as a whole make up the so-called " jardin." True, not the narrow, sinuate or crumpled feathers, but the individual droplets of liquid, and especially their shape and contents are decisive for the diagnosis. These single droplets of liquid have an irregularly jagged shape with acutely pointed extensions (Fig. 19), and their contents have reached the highest stage of liquid inclusions, as the three phases of matter are represented in them side by side (Fig. 20). The liquid in the cavity surrounds a gas-libella and one or several

small crystals. Because of these contents such inclusions, typical of emeralds, are called three-phase inclusions (Fig. 21).

It is interesting that the emeralds from the two most important localities, the Urals and Colombia, can be separated by the diversity in the general appearance of the enclosed small crystals, the crystals in Colombian emeralds being always cubic, those in Ural emeralds of rhombic crystal shape. Nobody has yet succeeded in determining the nature of these small crystals beyond dispute, although in several small cubical crystals blue spots have been observed similar to those in rock-salt containing a surplus of Na. In addition to the three-phase inclusions Colombian emeralds frequently contain calcite inclusions, which either take up the whole stone or part of it as more or less massed separation inclusions or occur as single distinctly rhombohedral crystals. Well developed pyrite crystals are not seldom present as single loosely dispersed microlites or assembled into aggregates. In contrast to typical Colombian endogenesis, in Ural emeralds single mica scales, or whole bundles of them, are found. Mica has also been found in Transvaal emeralds.

The distinctive inclusions in **aquamarines** consist of straight tubes, which are filled with a liquid containing iron. They always run parallel to the *c* axis (Figs. 23 and 24). Inclusions which under low magnification are reminiscent of snow stars, and which therefore are called " snow-star inclusions," furnish magnificent pictures (Fig. 22). In every instance they are arranged parallel to the prism surfaces of the host crystals. Under high magnification it is seen that these inclusions consist of a microlite, which is surrounded by a halo of single small droplets of liquid. It is very obvious to assume that extraneous melted drops, not soluble in the mother liquor of the aquamarine, have joined as a consequence of positive adsorption the growth surfaces of the aquamarine, and that the microlites now visible have very quickly separated from the melted drops by ex-solution, leaving residue droplets in their closer proximity.

It has been impossible so far to discover distinctive inclusions in yellow, green and pink beryls.

Garnets. Green andradite contains typical inclusions, which occur again and again, and which can be discovered in 99 per cent. of all demantoids. These are hair-fine brown or colourless byssolite

crystals, which are arranged in wavy bundles or which radiate from a common centre (Fig. 28) ; in many demantoids, however, they intersect each other in confused irregular tangles. It is a peculiar and interesting fact in the occurrence of these byssolite fibres that the fine fibres are not by any means enclosed in a compressed and bent condition, but extend freely, being obviously unaffected by the substance of the crystal, as though they projected freely into the air like free fibres (Fig. 27).

Red Pyrandine garnets, comprising **Pyrope, Almandine** and the mixed crystal **Rhodolite,** which is intermediate between them, cannot easily be separated from each other by means of their inclusions (nor is this of great importance, as they belong to the same isomorphous series). Nevertheless, they too contain quite characteristic interior parageneses, which form a decisive criterion for distinguishing them from other red, brownish-red, or purple-red gemstones. The best-known kind of inclusions in these three closely related red garnets are black needle-like amphibole crystals, which permeate the host crystal in accordance with the edges of the rhombic-dodecahedron (Fig. 25). The feature discriminating between these needles and the small rutile needles called " silk " in rubies is their arrangement. In garnet these fine needles are distributed in a distinctly three-dimensional order, often occupying all the interior of the stone ; the silk in rubies, on the other hand, is arranged bi-dimensionally, i.e. the needle-shaped crystals have been deposited in a sagenite-like way on the growth surfaces of the rubies. In red garnets, however, they lie apparently in promiscuous disorder (Fig. 26), and only after careful examination the way in which their directions are governed by crystallographic laws can be recognized. The expert is hardly surprised to find that the typical locality characters of Ceylon gemstones, namely metamict zircons with radio-halos, occur also in almandines from Ceylon. Here, too, these black-margined, usually xenomorphous zircon inclusions with their halos supply the unequivocal proof of provenence. The halos are not always circular, even less spherical, but frequently they are developed on one side only or in star-like rays.

Every expert is familiar with the somewhat granular appearance of the **hessonites.** Herein lies to hand a distinguishing character though it is as a rule not so distinct that with the unaided eye one could rely on it alone. If this granular appearance be in-

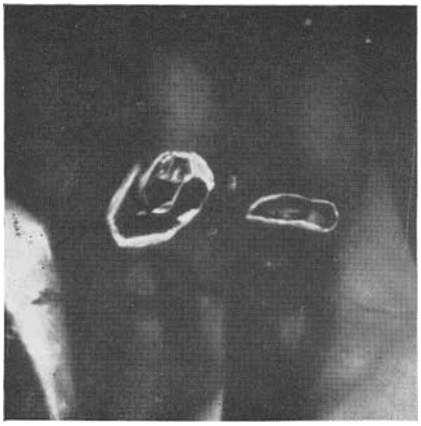

FIG. 1.
Garnet crystals in diamond. 150 ×

FIG. 2.
Diamond octahedron in diamond. 150 ×

FIG. 3.
Resorbed crystal inclusions in diamond. 75 ×

FIG. 4.
Zircon crystal in a diamond form. 20 ×

vestigated more closely with the aid of a microscope, it will be found that inclusions again play an interesting part in it. They consist of a multitude of diopside crystals, which are irregularly distributed over the whole of the stone, and are often very distinctly idiomorphous. Diopside often accompanies the hessonite during formation, which means that it also shares the exterior paragenesis with it. Moreover, hessonite is permeated by peculiar streaks, which give its interior an oily appearance (Fig. 29).

A pretty but rare occurrence is **spessartite,** a manganese-alumina garnet, rarely of gem quality, and which also shows characteristic inclusions. These consist of irregularly arranged feathers of fine, bizarre liquid droplets (Fig. 30). Such feathers are embedded singly in the spessartites, or, aggregated in bundles, spread over them in various directions. This special type of feathers of liquid does not occur in any other garnet or any other gemstone resembling spessartite.

In the species of gemstones not so far mentioned the inclusions and their appearances are less complicated, and only one type of inclusion is characteristic of each species. In many cases even some experience is needed for recognizing the distinguishing features of apparently similar inclusions in different kinds of gemstones. The similarity in appearance of the liquid inclusions with libellae in aquamarines, topazes, kunzites, and beryllonites is confusing, and only a detailed knowledge of their specific appearance will permit of their differentiation.

In **tourmalines,** no matter what variety, irregularly arranged threadlike capillaries, the so-called trichites supply a reliable character for identification. Strong magnification reveals them to be canals, which may run in any direction, and which are filled with a liquid and contain a libella (Figs. 31, 32 and 35). They occur singly or amalgamated into nets. Trichites occur in all varieties of tourmalines, but the red tourmalines are, in addition, almost always permeated by long, perfectly straight phases, which occur singly or united into dense bundles.

The **spinels** contain innumerable well-developed small spinel octahedra, which as contemporaneous crystallizations are merged with the growth surfaces of the host crystals. They are grouped densely in parallel rows, which run in wavy directions (Figs. 33 and 34). Sometimes also they are grouped in nests. From Ceylon

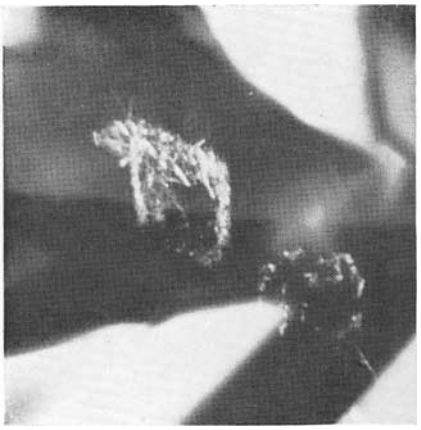

FIG. 5.

Cloud of small gas bubbles in a diamond, oriented according to (110). 150 ×

FIG. 6.

Cloud of gas bubbles according to (110) in a diamond twin. 250 ×

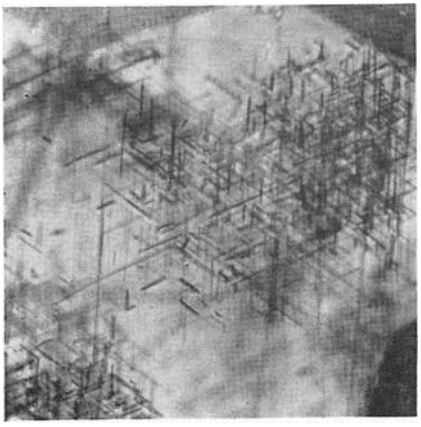

FIG. 7.

Patches of short, oriented rutile crystals in a Burma ruby. 250 ×

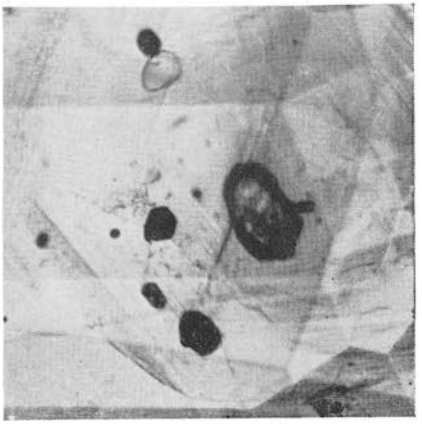

FIG. 8.

Characteristic inclusion picture of Burma ruby. 150 ×

spinels the locality character, radio-active zircons with radio halos, is seldom absent.

In **moonstones,** fine figures of stress-fissures develop along the twin planes of polysynthetic twin lamellae. As a rule these figures, which may suggest incipient albitization, consist of a more or less straight-running principal cleft from which short fissures branch off on both sides (Figs. 38 and 39). These systems of stress fissures usually occur singly, though sometimes they are amalgamated into more complicated combinations. In spite of individual diversity their appearance is always so unmistakably distinctive that in every case it can be regarded as a valuable characteristic of moonstones.

Andalusite. There does not appear to be any inclusion which may be regarded as occurring typically in andalusite. Stones from Ceylon have revealed minute rod-like crystals of varying crystal habit and in some instances it has not been possible to determine their nature. In andalusites from Brazil inclusions frequently take the form of dense clouds of extremely minute particles which (Fig. 47), under very strong magnification, have proved to be liquid drops of an elongated kind and fissures. These densely massed, though extremely fine, inclusions are typical of andalusites mined in Brazil, and thus provide a clue to their origin which andalusites from Ceylon do not do. In addition to these useful diagnostic inclusions, Brazilian andalusites sometimes show narrow parallel striations which, but for their straightness, are not unlike the striations seen in some synthetic rubies (Fig. 48).

Green Metamict Zircons. It has often been remarked that green zircons sometimes have their colour slightly marked by an internal sheen-like effect. The cause of this phenomenon appears to be due to the edges and corners of isomorphous layers which are present in the stones. The phenomenon is quite characteristic of this type of green zircon (Figs. 40 and 41).

Kyanite. This mineral is rarely cut as a gemstone and the many tubular or flat fissures seen may perhaps not interest the gemmologist quite so much. These inclusions are highly characteristic and correspond to the crystal's two cleavage directions (Figs. 42 and 43).

One of the finest examples of diagnostically important inclusions is furnished by the **fluorites,** which contain, no matter whence

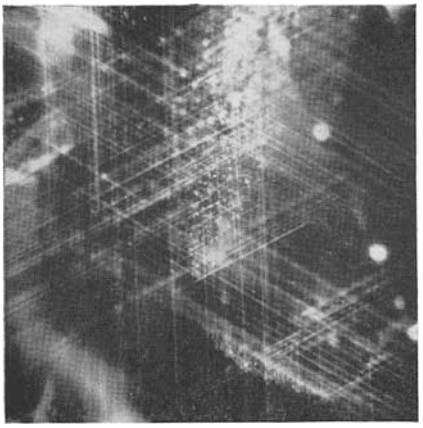

FIG. 9.
"Silk," fine oriented capillaries in a Ceylon sapphire. 150 ×

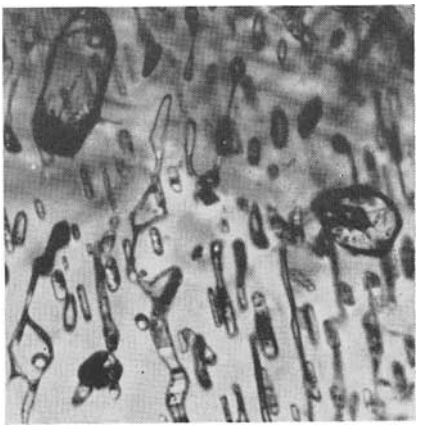

FIG. 10.
Small area, strongly enlarged, of feather consisting of liquid inclusions in a sapphire from Ceylon. 250 ×

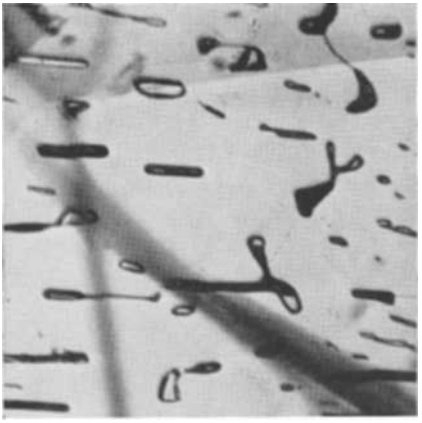

FIG. 11.
Typical liquid feather in Ceylon sapphire greatly magnified to disclose single liquid drops and their bizarre shapes. 350 ×

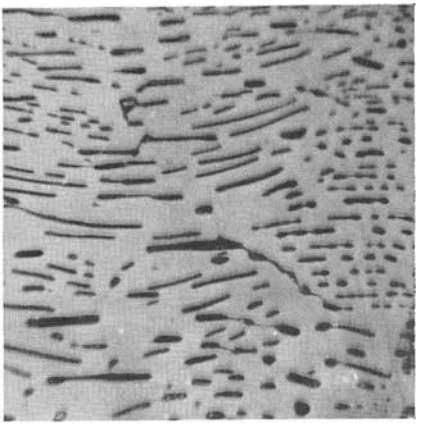

FIG. 12.
Liquid feather in sapphire from Ceylon. 150 ×

they come, a few single, or dense crowds of innumerable tetrahedral liquid inclusions. These are negative crystals in the shape of tetrahedra, filled with a liquid and a libella, which moves as the stone is being turned (Fig. 36). As natural crystals do not only occur in ideal forms, these tetrahedral cavities have not in every case assumed the geometrical ideal shape (Fig. 37). Usually they are distorted in some way or otherwise interrupted in their development. The presence of such tetrahedral cavities is so characteristic of fluorite that it can always be recognized by them.

It must not be supposed that the preceding descriptions deal with every kind of inclusion that has been observed. There are still many more which can be used less well or not at all as identification characters. An attempt has, however, been made in specific examples selected for the purpose to portray, with brief descriptions relating to the most essential characters, the distinctive inclusions of a few common species of gemstones and to point out their diagnostic significance. The study of inclusions is a young branch of gemmological and mineralogical science, and much work will have to be done by mineralogists, crystallographers and gemmologists if the numerous problems which the inclusions of the most different gemstones will present to-day are to reach an indisputable solution. An interesting field for fruitful collaboration between mineralogy and gemmology is opened up here. Out of it, thanks to possibilities presented by its objects and methods of research, gemmology can make lasting contributions of new observations to mineralogy for the use of both sciences, so that from the knowledge so gained valuable conclusions in the direction of genesis and diagnosis may be hoped for.

(EDITORIAL NOTE.—It is hoped that the two articles by Dr. E. Gubelin that have appeared in the " Journal of Gemmology " will prove a useful introduction to his comprehensive forthcoming book on Gemstone Inclusions which is shortly to be published by the Gemological Institute of America.)

(See further illustrations on pages 295 - 303)

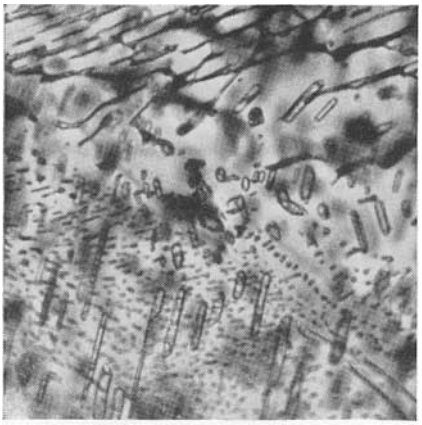

FIG. 13.
Liquid feathers in a sapphire from Ceylon. 250 ×

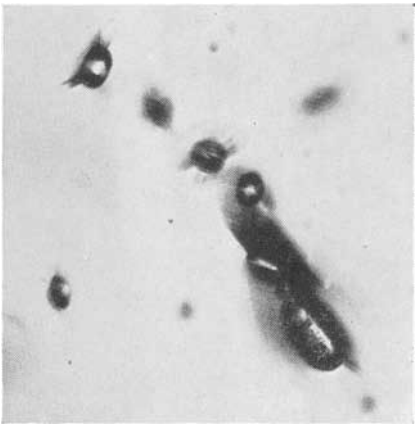

FIG. 14.
Metamict zircons surrounded by halo in Ceylon sapphire. 125 ×

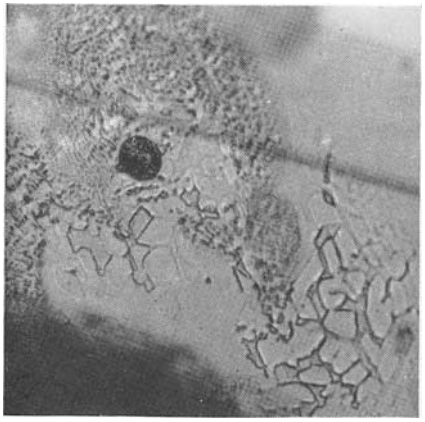

FIG. 15.
Diagnostic inclusion picture of ruby from Siam. 150 ×

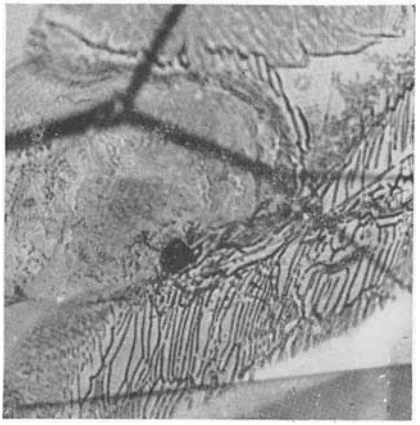

FIG. 16.
Characteristic inclusion picture of Siam ruby consisting of black crystals accompanied by large script-like liquid feather. 150 ×

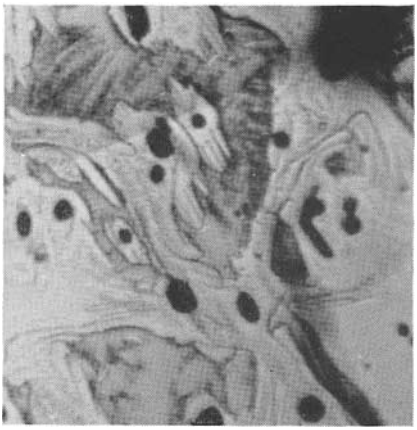

FIG. 17.

Typical phenomenological picture of inclusions in Siam sapphire. 250 ×

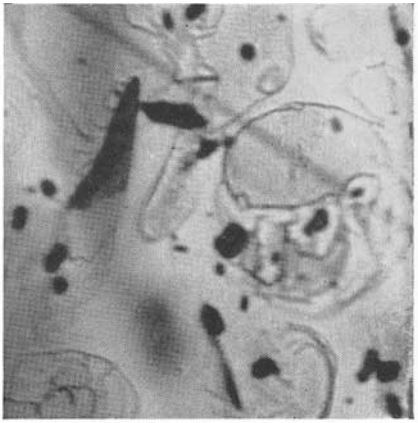

FIG. 18.

Characteristic inclusions in Siam sapphire. 250 ×

FIG. 19.

Jagged irregularly shaped liquid and three-phase inclusions in emerald. 200 ×.

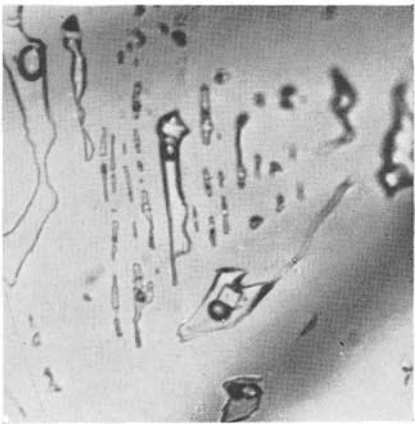

FIG. 20.

Irregular liquid and three-phase inclusions in Emerald. 200 ×

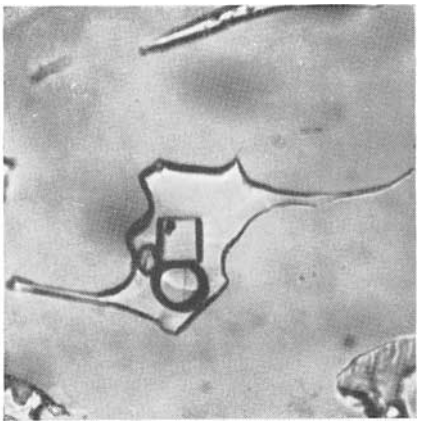

FIG. 21.
Three-phase inclusion in a Colombian emerald. 500 ×

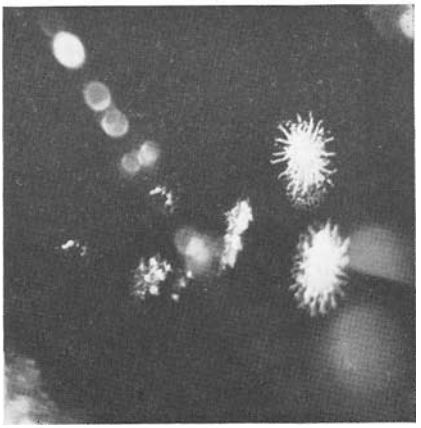

FIG. 22.
Typical "snow-star" inclusion in aquamarine. 150 ×

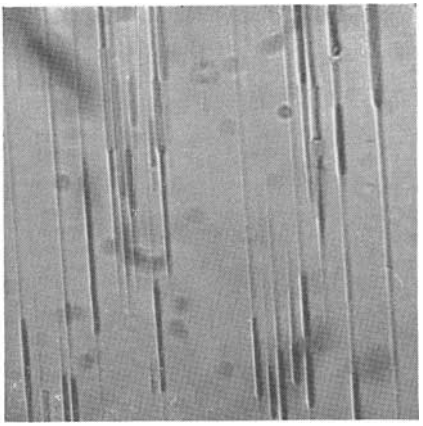

FIG. 23.
Liquid filled canals in aquamarine. 200 ×

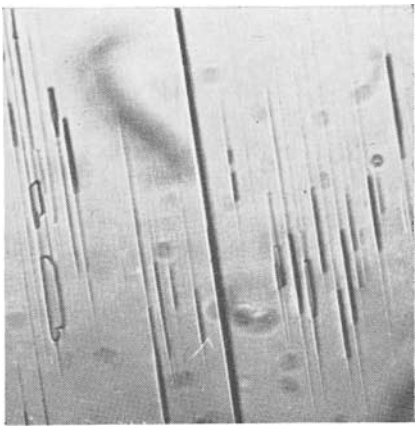

FIG. 24.
Liquid filled canals in aquamarine. 250 ×

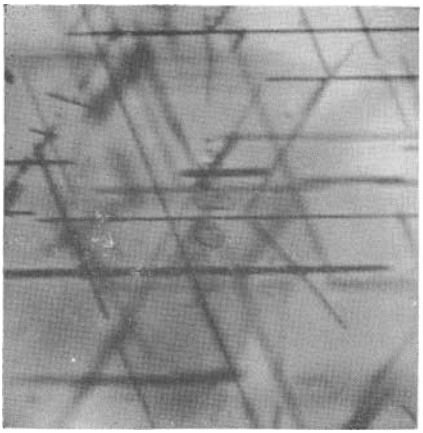

FIG. 25.
Amphibole needles in almandine. 250 ×

FIG. 26.
Three-dimensional arrangement of needles in almandine. 250 ×

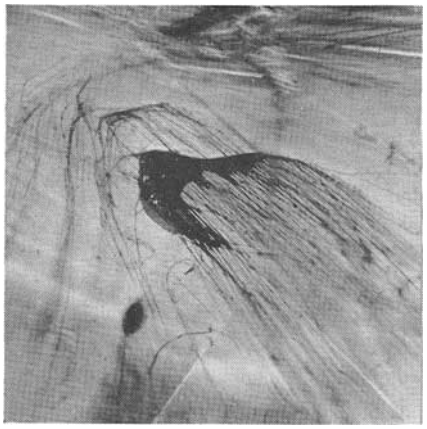

FIG. 27.
Byssolite fibres in demantoid. 75 ×

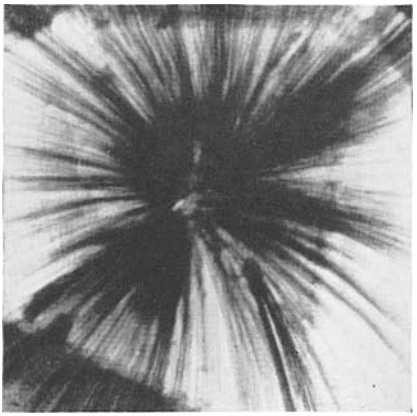

FIG. 28.
Radially arranged byssolite fibres in demantoid. 100 ×

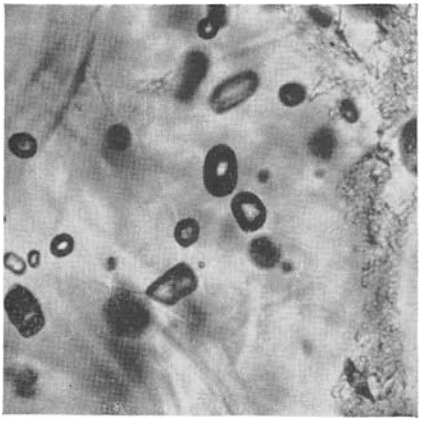

FIG. 29.

Diopside and zircon crystals embedded in swirly structure of hessonite. 250 ×

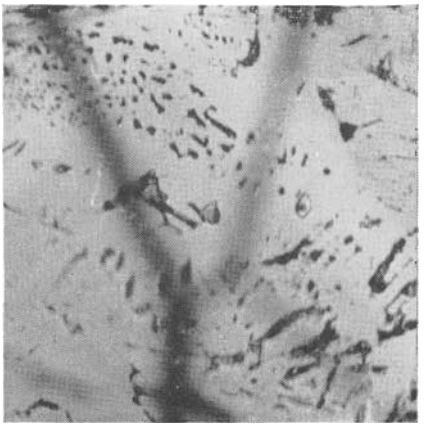

FIG. 30.

Typical cloud of liquid droplets in spessartite. 250 ×

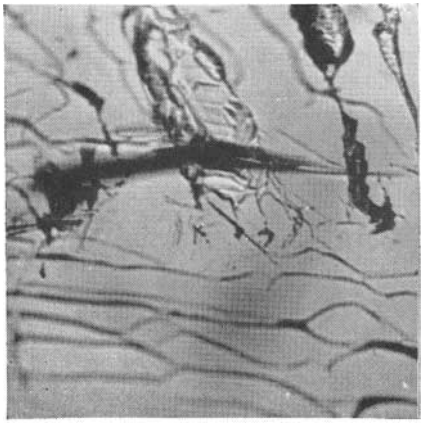

FIG. 31.

Liquid filled trichites in green tourmaline. 250 ×

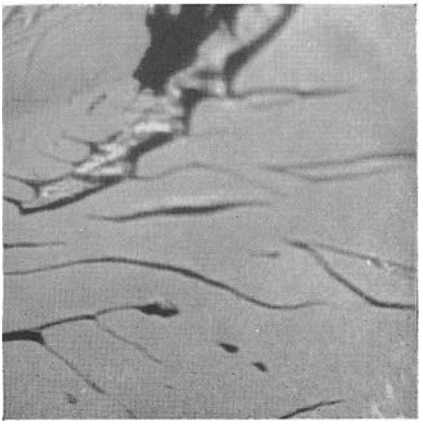

FIG. 32.

Greatly magnified capillaries (liquid filled so-called trichites) in green tourmaline. 300 ×

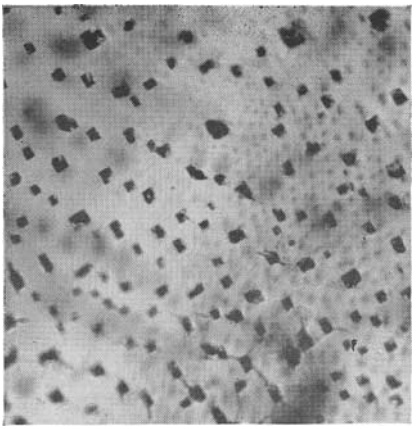

FIG. 33.

Rows of euhedral spinel octahedra in a spinel from Burma. 150 ×

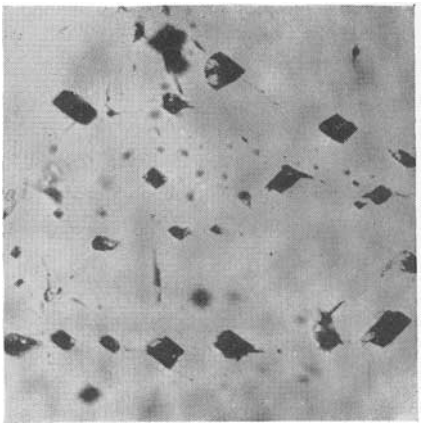

FIG. 34.

Series of spinel microlites in a spinel from Burma. 150 ×

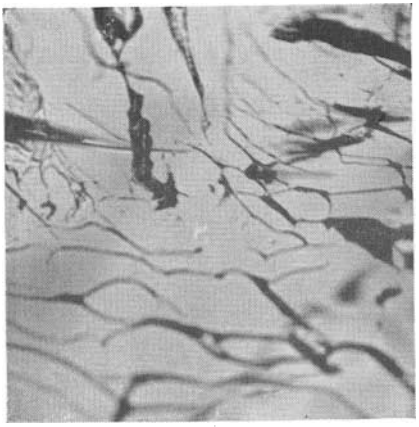

FIG. 35.

Liquid filled trichites in green tourmaline. 250 ×

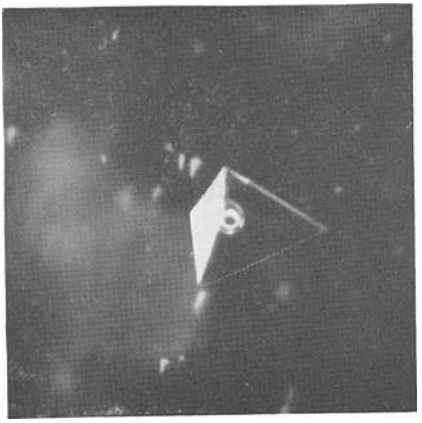

FIG. 36.

Positive diagnostic inclusion in fluorspar consisting of a cavity in the shape of a cubic bisphenoid with liquid and a movable libella. 400 ×

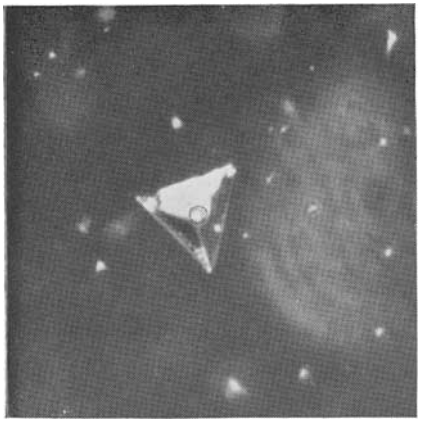

FIG. 37.

Cubic bisphenoid filled with liquid and libella in a fluor-spar. 350 ×

FIG. 38.

Fissures and metamorphous deposits along polysynthetic twin-lamellae in moonstone. 250 ×

FIG. 39.

Fissures and metamorphous deposits along twin-lamellae in moonstones. 150 ×

FIG. 40.

Angular markings, which are characteristic of green metimact zircons from Ceylon. 300 ×

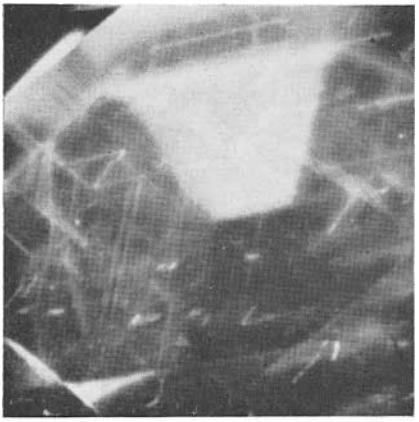

FIG. 41.
Metamict zircon with typical angular markings. 100 ×

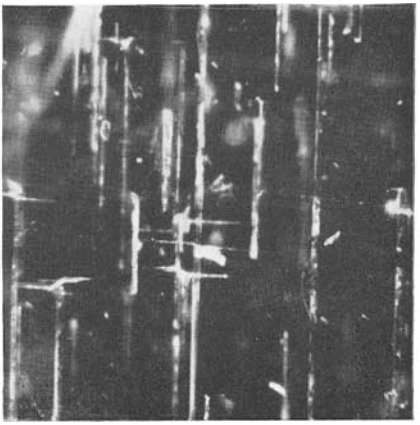

FIG. 42.
Typical fissures in kyanite. 100 ×

FIG. 43.
Greatly magnified picture of characteristic fissures in kyanite. 300 ×

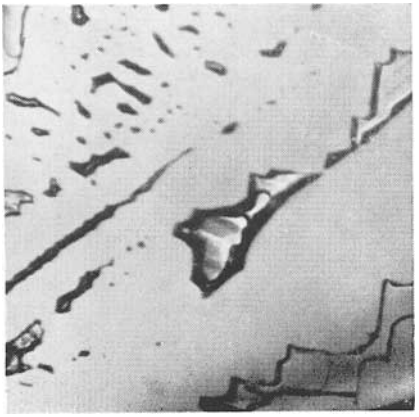

FIG. 44.
Typical inclusion picture of topaz consisting of cavities filled with non-miscible liquids. 100 ×

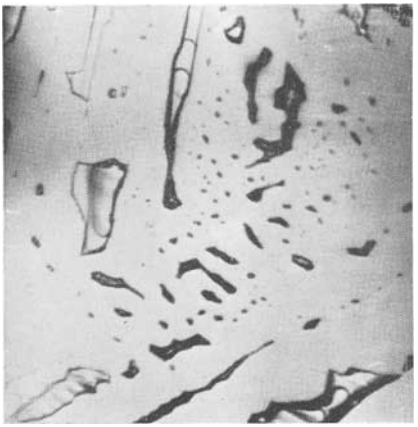

FIG. 45.

Characteristic inclusions in topaz consisting of cavities filled with non-miscible liquids. 100 ×

FIG. 46.

Irregular cavity filled with non-miscible liquids in topaz. 150 ×

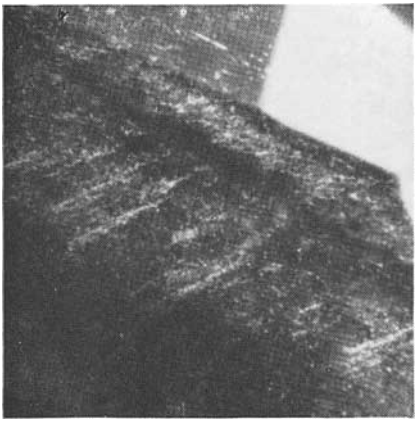

FIG. 47.

Clouds of dust-like inclusions in Brazilian andalusite.

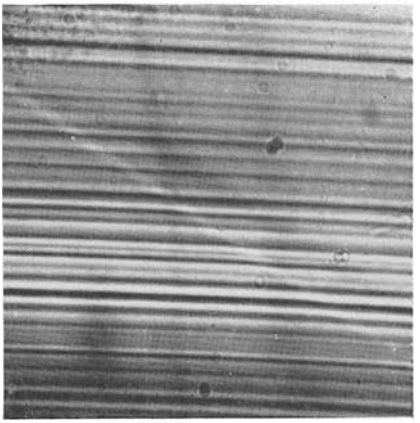

FIG. 48.

Straight and parallel striations and clouds of dust-like inclusions in Brazilian andalusite. 100 ×

OPTICAL ORIENTATION IN UNIAXIAL GEMSTONES

by

E. BURBAGE and T. G. JONES, FF.G.A.

BEING less well-informed on Platonic matters than Dr. Joad, we cannot tell whether the philosopher is correctly reported in that famous passage which credits him with regarding knowledge as " but remembrance ; intellectual acquisition but reminiscential evocation ; and new impressions but the colouring of old stamps which stood pale in the soul before." We confess that our present enquiry can pretend to no status more elevated than a refurbishment of this sort, as we have not adventured beyond an application of a law of crystal optics which has been known for a century. Curiously enough, this application appears to have escaped the attention of gemmologists. Whilst no search has been made through the literature of mineralogy and related subjects to discover whether earlier papers have been published on this subject, we are fairly confident that with the exception of a brief reference in an earlier article upon another subject by one of the present authors, nothing relevant has appeared in gemmological books and journals.

The proposed method uses extinction directions to determine the optical orientation of a gemstone. To those who are familiar with petrological techniques, it will be apparent that it is in a sense a three-dimensional generalization of the extinction criteria by which a petrologist distinguishes minerals in thin sections. With a gemstone, where one does not normally have a cleavage to employ as datum line, it is convenient to use instead a direction related to the symmetry of the cut stone. Except in cases such as the rose and cabochon cuts where another choice becomes obligatory, the obvious direction for this purpose is the normal to the table facet. Now, given two further axes forming a system such that all three are mutually at right angles, one has a sufficient framework of reference for the intended purpose.

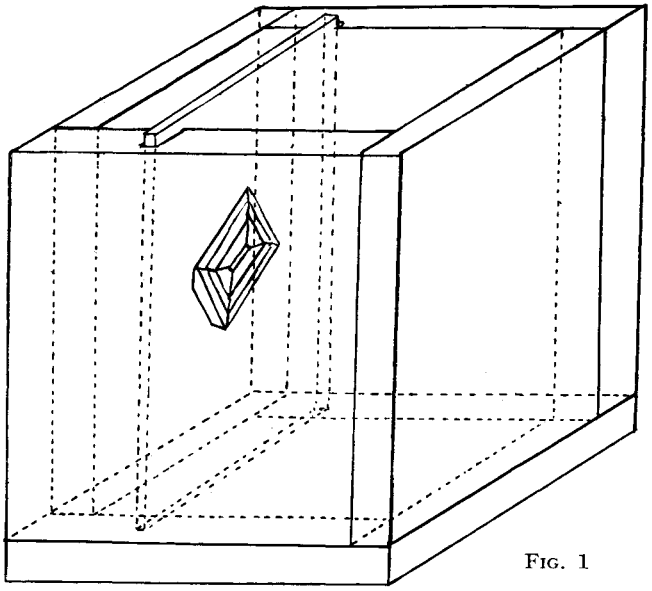

FIG. 1

To translate this project into actuality, we constructed an immersion cell of transparent plastic, having initially checked that the material was isotropic. Two sides of this cell were slotted vertically to hold a square of glass, resulting in a gadget as sketched in Fig. 1. We then related the principal directions of the glass slip to the axial conventions of three-dimensional co-ordinate geometry ; that is, we called its vertical direction in the initial position the Z-axis, the normal to its surface the Y-axis, and the direction at right angles to these two the X-axis, and postulated the usual sign conventions, as shown in Fig. 2.

It is advantageous to standardize one's working routine, and our own procedure has been as follows: The gemstone is mounted table downwards on the glass slip by means of Perspex cement, and the cell is filled with a liquid whose refractive index is a reasonably close match to that of the stone. Inserting the slip in a vertical position in the cell, the latter is placed on the revolving stage of a petrological microscope between crossed Nicols, with the stage at the zero position, the edge of the glass slip lined up in a N.S. position and with the stone on the E. side of the slip. Then, rotating the stage in a clockwise direction, the angle through which

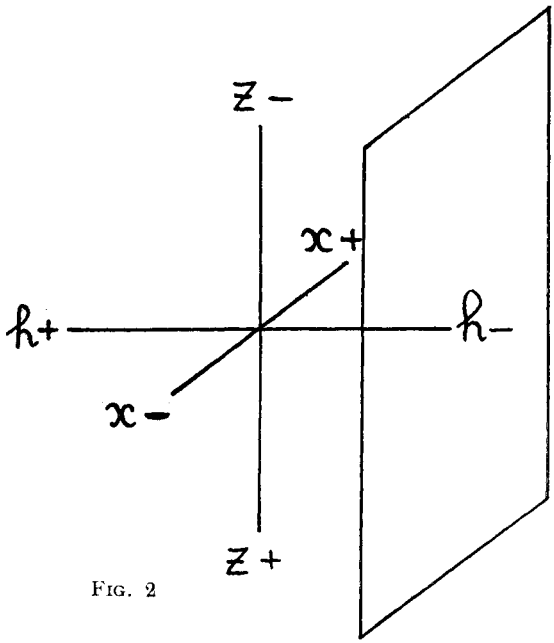

FIG. 2

one must travel before reaching the first position of extinction is noted. The slip is then lifted, rotated through a right angle in a clockwise direction, if the slip is viewed from the side at which the stone is attached. Then the stage is returned again to zero, and the edge of the slip again to the N.S. position, and the extinction angle determined as before. Lastly, the slip is rotated back to its former position, and lifted and placed in a horizontal position in another larger cell, lining up the original upper edge in a N.S. position, and a third extinction angle is determined.

In addition to each of the determined directions, there are, of course, extinctions at right angles to these, giving, in all, a set of six, and it is necessary to compare them to reject unwanted values before finding the direction components of the optic axis. We can best illustrate this process from an actual set of readings. The extinctions of a faceted gemstone (a pink beryl) were found to be as follows: First position, 79° ; second position, 26° ; and the third (horizontal) position, 68°. The relations of these angles with the planes containing the co-ordinate axes are shown in Fig. 3.

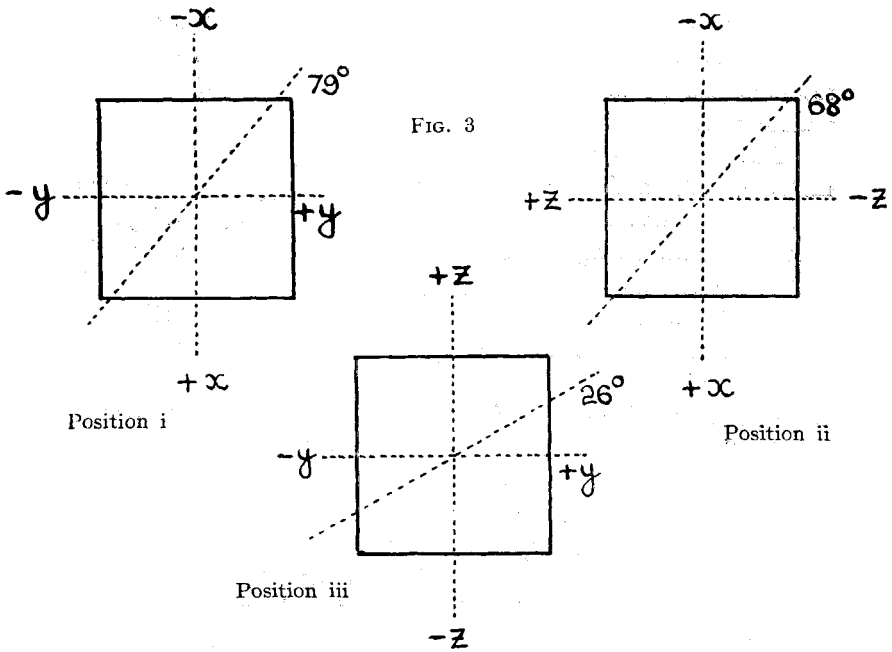

FIG. 3

Positions (i) and (ii) furnish a set of four possibilities for the direction components of the optic axis:—

$$L:M:N = -\tan 79^\circ : 1 : \tan 26^\circ$$
$$\text{or} \quad \cot 79^\circ : 1 : -\cot 26^\circ$$
$$\text{or} \quad \cot 79^\circ : 1 : \tan 26^\circ$$
$$\text{or} \quad \tan 79^\circ : 1 : \cot 26^\circ$$

From position (iii) $L:N = \sin 68^\circ : \cos 68^\circ$
or $\cos 68^\circ : -\sin 68^\circ$

Thus the four values of the ratio $\frac{L}{N}$ derived from positions (i) and (ii) are -10.548, $-.095$, $.398$, and 2.509, and the two derived from position (iii) are 2.475 and $-.404$. The last value is clearly one which does not match any of the first four, but, allowing for experimental errors, the 2.509 and 2.475 match very well. Accepting the former value as *the* true one, the ratio of the direction components is given by $L:M:N = \tan 79^\circ : 1 : \cos 26^\circ$, and dividing these values by the normalizing factor $\sqrt{L^2+m^2+N^2}$, the direction cosines of the optic axis are given as $l = .915$, $m = .178$, and $n = .355$. The cosine of the angle between the normal to the

table facet and the optic axis is equal to the value of m, giving this angle as about $79\frac{3}{4}°$. If one uses the other value of $\frac{L}{N}$, 2.475, the resultant change in this angle is very small, approximately one minute of arc.

Described at length, the calculations appear somewhat formidable, but, in fact, a table of the logarithms of the trigonometrical functions enables them to be performed very quickly, the process of normalizing, itself quite simple, being the most lengthy part of the calculations. Superficially, it would seem that one could shorten the work to some extent by normalizing the L:N value derived from extinctions in position (iii), as this ratio is a simple trigonometrical expression, but this is an error, for, unlike the corresponding value chosen from the first set of four, the essential proviso that $M=1$ has not here been observed.

In order to clinch the validity of this method, we decided to try it out in circumstances where an independent check was possible. In a uniaxial crystal having pyramid and either or both prism and pinacoid faces, the angle between the normal to a pyramid face and the optic axis can be found by this extinction method, and compared with the interfacial reading determined on a goniometer or quoted in the textbook data. For instance, a crystal of apatite was mounted on the glass slip with a pyramid face in contact, and, from direction cosines obtained from extinctions, the two values of the angle made by the normal to the pyramid face with the optic axis were 42° 24′ and 42° 10′. These were very satisfactorily close together, and about 2° removed from the value of 40° 18′ quoted by Herbert Smith as the angle between the basal pinacoid and appropriate pyramid, a disparity no doubt resulting from a somewhat imperfect cementation between stone and glass giving rise to a small amount of " play " between them. A further trial with a crystal of beryl (aquamarine) yielded the two results $44\frac{1}{2}°$ and $45\frac{1}{2}°$, of which the mean, 45°, was coincident with the angle measured on the spectrometer and quoted in the textbooks as that between the basal pinacoid and the (1121) pyramid.

In this, as in most enquiries involving measurements of angles, lengths, physical constants, and the like, one has to consider at the outset the tolerance limits imposed by one's initial requirements. For ourselves, the purpose which we had in view required readings of the angles between normals to the tables of gemstones,

and their optic axes, in which errors up to $\pm 3^\circ$, say, would be permissible, and it was therefore pointless to strive for an exactitude in our results of an order of minutes of arc. If this were required, one's obvious course would be to ensure that the cell construction permitted an examination in positions which were very accurately 90° apart, to check carefully that contact between stone and glass was as nearly perfect as possible, and to seek methods to define very sharply the extinction positions and to measure the angle of rotation with more precision than the graduated stage of the microscope normally affords.

The use of a petrological microscope is not essential for this work, and if the standard of accuracy required is not too great, it should be possible to assemble a polariscope for this purpose, although really accurate results would probably demand precision engineering beyond the scope of the amateur's workshop. It should be noted that in a home-made polariscope, the routine which we have described would need modification if any departure from the N.S., E.W. convention of the crossed Nicols or Polaroids were made. It is interesting to note that in his " Crystallography " (1922), Tutton, for whom extinctions had to be accurate in terms of minutes of arc, advances the claims of the Fuess stauroscope over the petrological microscope on grounds of its greater accuracy. As, however, the gemmologist is seldom likely to have either the need to work with such precision, or access to the stauroscope recommended to attain it, a good petrological microscope remains first choice for work involving extinctions.

Corresponding to the law of Malus, which we have employed in this method, there is that of Biot for biaxial media, which could be used similarly in dealing with orientation of biaxial stones. Unfortunately, one's requirements when dealing with the latter are seldom satisfied with the mere knowledge of the bisectrices and Biot does not help one to go beyond this to ascertain the value of 2V, in which one is more likely to be interested.

It is hoped in a later paper to describe an enquiry in which this method has been employed. We wish gratefully to acknowledge the advice and encouragement of Mr. B. W. Anderson in connexion with this work.

NEW BOOKS REVIEWED

"An Easy Guide to Stones in Jewellery." By G. M. Sprague, A.M.I.Mech.E., F.G.A. Cairo, 1949. 77 pp., illustrated.

An elementary book on gem identification for the jeweller, with special reference to the use of simple apparatus. Explanation of the three main types of stones is given. The use of the dichroscope, hand lens and the Chelsea colour filter is discussed, and how to correlate the information obtained from their use in a possible identification. The microscope and refractometer are adequately treated, but, perhaps wisely in such an elementary book, the spectroscope is not mentioned. The list of suggested heavy liquids could be improved by the inclusion of a tube of undiluted bromoform, especially as its use is specifically mentioned in subsequent pages. Discussion of the species is divided into colour groups, a method which is having an increasingly greater vogue, and, indeed, for such an elementary work, is more or less essential. A short but clearly expressed chapter on synthetic stones, pastes and doublets concludes the first part of the book. Part 2 contains chapters on non-transparent stones and how they may be detected. Specific gravity, hardness and surface structure as seen by the lens are emphasized as useful tests, which, in conjunction with the description given in the text, should give identification. The book concludes with a set of useful tables as appendices and a good index. No rare stones are mentioned ; there are a few typographical errors. Also goldstone might have been included in the text rather than in the index only. The description of the curved lines seen in synthetic ruby as " gramophone record lines " is most expressive. The note on imitation pearls, in the section on organic gems, is ambiguous ; a clear description of the solid glass bead type which is the type now commonly employed would have been more useful.

The book is a simply expressed introduction to gem testing and may well inspire the jeweller to a better understanding of the different gemstones.

P. B.

"*Chinese Jade Carving.*" By S. Howard Hansford. Lund, Humphries & Co., Ltd., London. Illustrated. 132 pp. 32 pls.

" Chinese Jade Carving " could, so easily, have added to the endless controversy of Chinese symbolism. It does not. It is a direct contribution to gemmology. Its theme, as the title indicates, is the work of the lapidary. And not only is much of the given information a result of close contact, the author has, in certain instances, carried out his own experiments—that of testing a particular abrasive, for instance, or drilling nephrite by means of a short stick of bamboo and ordinary builder's sand. In trying to arrive at a common abrasive used in early jade carving, Mr. Hansford develops the sand theme and mentions in particular corundum and garnet sands which he believes would have been too painstaking, as a rule, to crush fine enough for abrasive purposes. It may be of interest, therefore, to mention certain " ruby sands " in a little place called Crepuke in Southland, New Zealand. These sands are minute garnet crystals and, though there is no evidence that the Maoris made use of this as an abrasive for jade work, it would suggest that some similar natural product, requiring no processing, may have been available in early Chinese times.

The student of jade will find himself frequently comparing this book with Dr. Laufer's " Jade." The author, too, compares and pays tribute to Dr. Laufer. Nevertheless, at times he is at considerable variance with him. And whereas Dr. Laufer's large volume was more or less a series of notes on his findings—for which he apologized—the more literary quality of Mr. Hansford's book makes for pleasant reading.

To all but the specialist, Chinese jade may be divided roughly into four sections. One, the Neolithic. Two, the creative, and perhaps tradition-bound, Han to Sung dynasties (though Mr. Hansford gives this a slightly earlier date). Three, the highly ornamental Ch'ien-lung period that would seem to be the Eastern counterpart of our gilded Louis XIV. And, like Louis XIV, of

course, masterpieces in craftsmanship. Mr. Hansford points out here that despite the drawbacks of this period, speaking aesthetically, it was freer of tradition and willing to decorate almost any piece of jade for almost any purpose. One thinks of it in relation to the renaissance of Europe, when the artist began to break with the traditions of the Christian church and found a world full of possibilities beyond. To quote the author: " The rugged workmanship of the jade carver of over two thousand years ago shows none of the refinement to which we are accustomed in the sophisticated productions of the Ch'ien-lung period and of the present day. Yet, as regards tools and tactics the craft had reached its maturity by the end of the Chou Dynasty." To illustrate sections two and three, one may study, among the beautiful plates at the end of this book, a vase of the Sung Dynasty (No. XXVI b). It is cylindrical in shape, 6¼ inches high, and with an elongated animal that creeps almost to the top of the vase and forms a handle. It is a piece one could contemplate without satiety, a vastly different proposition from the rather " heady " efforts of the Ch'ien-lung. Plate XXVI (a) must be of extraordinary interest to any collector. Here is another Sung piece in grey jade, a two-handled bowl, for all the world like an old silver fluted sugar bowl. Perhaps it is prejudice, but the Sung period gives us, surely, far better design, even if limited—by tools or technique or tradition—than the florid let's make-money insincerity of the Ch'ien-lung. Section four brings us to the present day—as far as the jade worker is permitted to operate—and here Mr. Hansford, perhaps influenced by the graciousness with which he was admitted into this inner circle, has more than a kind word to say.

Mr. Hansford begins his exposition with a list, not only of the Principal Chinese Dynasties, always a help, but, with what is still more valuable to the occidental placing these periods, the comparative dates in world events.

Chapter Two is pure gemmology. It covers colour, structure, chemical composition, hardness, specific gravity, refractive index, and, of absorbing interest, the associations and ramifications of the word Yü, including jade as part of medicine. There is also a reference to industrial diamonds, which, Mr. Hansford believes, were used by the Chinese as early as the 4th and 3rd centuries B.C.

In the final chapter of this work—actually the last page but one—the author mentions the fascination of the *feel* of certain jades that are usually carved from suitable nephrite pebbles. He describes it thus: " It must be held in the hand, viewed from every angle, and then *fondled.*" Since nearly every writer on jade mentions this point, one is left wondering whether each has experienced it for himself or whether it is referred to as part of the build-up of the Chinese jade picture. In Western psychology this is something permissible perhaps only to women still subconsciously regarded as a lower form of the species. To a man, and a Britisher, capable of a well-documented investigation, it reads a little like sudden exposure and stamps him a man of courage. In the last paragraph but one, however, is another psychological point with which one feels inclined to take issue. " Yet no account . . . could close," writes Mr. Hansford, " without a tribute of admiration to those humble perfectionists for whom, it seems, the only reward of a thing well done was to have done it." Surely it should read " in the doing of it." No job, however well done, satisfies for long, certainly not in proportion to the amount of time and work involved. Mr. Hansford may find that his own book, not long off the press, is already of the past and in the back of his mind he is writing another. Then, perhaps, we may be treated to a phase of the subject that was the only disappointment of " Chinese Jade Carving "—some light on the " missing link " of jade. This link will unite Stone Age tools wrought by a race that Dr. Laufer and others feel were not Chinese (or Mongol even) at all, and the Chinese who are supposed later to have occupied the land. The Maoris of New Zealand travelled in their amazing canoes. This race—Chinese possibly—scaled mountains, the Pamirs it is thought. Yet neither travelled light. Wrought jade was part of their equipment.

E. R.

" The Art of the Lapidary." By Francis J. Sperisen. The Bruce Publishing Co., Milwaukee, 1950. 382 pp., 406 illustrations.

From the very nature of his craft, the lapidary has a peculiarly intimate knowledge of gemstones. His judgment must be brought to bear on each stone, first as a rough crystal or pebble, and then

through all the stages of its shaping and polishing. Such matters as hardness, brittleness, cleavage, flaws, inclusions, colour distribution, dichroism, reaction to heat, are all of vital concern to him. An error of judgment before beginning operations hardly less than a fracture during cutting may rob him of profit or reputation.

Small wonder, then, that before (and even after) the advent of the trained gemmologist it was to the lapidary that dealers and jewellers turned for expert advice on the nature of any stone that was in doubt. The lapidary, of course, was usually right in his judgments ; but sometimes he was rather surprisingly and disastrously wrong—relying too much on empirical knowledge and on the way in which the stone reacted " on the wheel " and scorning the quite simple scientific tests which would have saved him from error.

Things are slowly changing. The modern lapidary has probably no more empirical knowledge than his fathers, and no greater manual skill. But he has better apparatus for his craft and, if not himself a gemmologist, he is at least aware of the possibilities of the science in matters which are outside his ken. Manual dexterity, skilled judgment, and " touch " can be better taught by apprenticeship to a master craftsman than by means of the printed word, and the small but important details of technique which have been learned from experience or handed down from father to son are regarded as " secrets of the trade," and as such not to be lightly imparted to the amateur or general public. For these reasons the lapidary is usually reticent in matters affecting his craft.

In many ways, then, " The Art of the Lapidary " forms an unusual and welome addition to the literature of precious stones. Francis J. Sperisen is a successful lapidary of some 35 years' standing, who can speak with an authority based on personal experience on all the techniques of cutting gemstones. In his work he has handled rare and unusual gem materials in addition to the usual commercial stones, and is able to suggest the special treatment necessary in the case of some of the more " difficult " minerals. Mr. Sperisen has also interested himself in gemmology and in the history of lapidary work and jewellery in past ages, which gives his book a greater richness and depth than would be found in a

mere technical manual. Moreover, the book is very well written and plentifully illustrated.

The first three chapters give a brief introduction to the nature of gemstones and to the characters by which they may be identified. The treatment is unconventional, full of original observations, and given from the lapidary's point of view ; it thus makes refreshing reading for the gemmologist who has become too familiar with the usual type of text-book. Since the lapidary deals largely with rough and always with unset stones, there is a natural emphasis on density tests, particularly on those which are suitable for large specimens. The reviewer has seldom seen the measurement of displaced water from what is sometimes amusingly known as an " Eureka Can " recommended as a density method for gem materials. However, though crude in appearance, there is no reason why such a simple contrivance should not yield good results on large specimens.

Optical properties, on the other hand, are dismissed far too briefly, since these, too, should serve the lapidary well on occasion. Less than a page, for instance, is devoted to the refractometer, and the enormously important phenomenon of double refraction receives four lines. The third chapter, entitled " Classification of Gems," is, for the gemmologist, the strongest and most interesting in the book. It deals largely with characteristic inclusions (including those in synthetic stones) and is illustrated with some thirty carefully selected photomicrographs taken by the author. Mr. Sperisen has special knowledge of the Chatham synthetic emeralds, as he has cut so many, so that his observations on these stones are well worth reading. Synthetic rutile, rather strangely, is not included in the book.

With Chapter IV, " Tools and Equipment," we come to grips with the main subject of the book, a subject on which the reviewer is hardly competent to comment. Thereafter are chapters dealing with all aspects of cutting, including diamond cutting, and engraving, carving and sculpturing. The illustrations help the reader to form a very clear picture of the processes involved. Chapter XIII, with which the book ends, would be better named an appendix, since it contains a medley of reference lists, tables, glossary, etc. One of the lists, headed " Stones Requiring Special Care in Hand-

ling, Cementing and Working," indicates the wide range of materials used for cutting by the author. Naturally, the easily cleaved minerals, euclase, spodumene and fluorite, are in this list (though not fibrolite) but also brazilianite, benitoite, and the rare mineral augelite, which is better left as a charming crystal than cut as a gem, having no colour to commend it. Other lists useful to the lapidary or would-be lapidary are those of stones having granular texture, coarse or uneven grain, and stones difficult to polish.

One may disagree with Mr. Sperisen on certain points of detail, but on the whole the book is remarkably free from error for a first edition, and a most valuable volume for those interested in the theory and practice of the lapidary's art. It is gracefully dedicated " To the Amateur—may his tribe increase." In America the tribe *is* on the increase, and has already reached what to us seem very large proportions. This book should serve still further to swell their number.

B. W. A.

" The Jewelers' Dictionary." Second Edition. Jewelers' Circular-Keystone (Chilton Co.), New York, 1950. 262 pp., illustrated.

This very useful dictionary contains definitions of over 5,000 terms used in the jewellery trade, and covers not only gemmology (contributor Dr. F. H. Pough) but also watches, clocks and jewellery manufacture (John J. Bowman) and metals (Miss C. M. Hoke). The three contributors are all authorities on their subjects, and the result is far more than a mere compilation derived from other people's work.

The gemmological entries are naturally those which concern us most here, and in these Dr. Pough's forthright style often brings entertainment as well as enlightenment. He scores some shrewd hits against trade nomenclature where this is at fault, and since this work is likely to be consulted widely by American jewellers at least, his strictures should exert considerable influence on the right side. Of the misuse of the term " olivine " to mean demantoid garnet, Dr. Pough remarks that this is " probably the only instance

in gemology where the jewelers have perpetuated an error to their disadvantage."

Authoritative information on the localities of gemstones is also to be found in the dictionary. For instance, under Mexican turquoise, where the entry reads " A misnomer ; no important turquoise occurrence is known in Mexico. . . ." Dr. Pough is also able to correct certain misconceptions as to colour ; thus under phenakite we find " Usually colorless or slightly yellow ; never rose-red, brown or yellow."

The constants of the gem materials are usually, but not always, given as part of their description in the text. The reason for their occasional omission is not very clear ; it would certainly be more convenient for the reader for the figures to be given in every case. There is a table of " Gemstone Characteristics " in an appendix at the end of the book, but this is limited to a single page, giving room only for sixteen species. A mysterious feature of this table is that two adjacent columns are each headed " gem hardness."

Amongst other valuable features of the appendix section are diagrams of various styles of cutting, and " exploded " views of all the parts of a watch.

All in all, this is a very useful work of reference which well deserves a place on every jeweller's bookshelf alongside Shipley's " Dictionary of Gems and Gemology " and Webster's " Gemmologists' Compendium."

B. W. ANDERSON.

"A Roman Book of Precious Stones." By Sidney H. Ball. The Gemological Institute of America. Los Angeles, 1950. 338 pp.

Caius Plinius Secundus, better known as Pliny the Elder, was born at Novum Comum (Como) in that part of Northern Italy then known as Transpadane Gaul, in the year A.D. 23. Author of many works, only one of which, the celebrated " Historiae Naturalis " in 37 books, is extant to-day. Dedicated to Titus, son of Vespasian and his successor as Emperor, the Natural History comprehends a greater variety of subjects than we now regard as included under that title—the 37th book treating with precious stones. Pliny's

work is often criticised as having little philosophical arrangement or scientific merit and that the observations are nearly all taken second-hand and show small discrimination in selecting the true from the false. But it cannot be denied that the work is a great monument of industry and research and most valuable in supplying us with details on a great variety of subjects as to which we have no other means of information. This is particularly true in respect to precious stones as they played such an important part in the life of the Roman Empire of the 1st century. This is the background of the present volume.

Pliny's Natural History has been translated into almost all European languages, and one of the best in English is that by Philemon Holland, published in London in 1601. It is on this translation that Dr. Ball's book is based. Pliny's original, and Holland's translation, are not easily available, and, further, one requires a knowledge of Latin, while the other, printed in the Old English style, is not too easily read. That is only part of the difficulty ; much of Pliny's meaning is obscure, the names of gems and localities are different, and much of the original material requires, as far as may be possible, some clarification and explanation. This is what Dr. Ball has set out to do. The result is a volume full of interest.

" A Roman Book of Precious Stones " is divided into three parts. The twelve chapters of Section 1 being a description of Pliny's career, the credibility of the authorities he quotes and the story of gems and jewellery of his day. Roman jewellers, Roman commerce and Roman taxes are discussed in this section as well as gem occurrences, known and surmised. Information on the mining of gems, on imitation and treated stones and on the industrial uses of gems is given. The section concludes with a general survey, complete with two excellent tables, of the attempts to correlate the stones described by Pliny with those of to-day.

The second section is a modernized version of Philemon Holland's translation of the 37th book of " Historiae Naturalis," with the one difference that the chapter headings have been changed to the more numerous and logical headings used in the Latin edition of Jean Hardouin. In this section the " foreign " mineral names are printed in italics and marginal notes are made of the probable modern name of the gemstone. The third section contains notes

and additional information explaining and elaborating those details in the translation which are ambiguous. These are referenced by the use of superior numbers in the text.

The book is extremely well printed and is handsomely bound in linen cloth. The text is thoroughly annotated with the references placed in the wide margin in preference to the more usual positions at the foot of the page or at the end of the chapter. With the great number of references involved this method has much to commend it. In imitation of old parchment the second section—the translation—is printed on yellow India paper and each page of text is panelled with a border of a rolled scroll design. The text is often overprinted on this design and it is doubtful whether the scroll effect adds to the appearance of this section. The book concludes with an excellent index containing over 450 entries.

" A Roman Book of Precious Stones " is a volume that should be on every discerning gemmologist's bookshelf for Pliny's work is quoted by many writers on gemstones. The 37th book, indeed, gives the earliest collected knowledge of gem materials and has at last been edited by a lover of gemstones and one who knew the subject. The great pity is that Dr. Ball did not survive to see the completion of his great work, which was finally completed and launched by Kay Swindler. The Gemological Institute of America is to be congratulated in making available this splendid work to all English-speaking people.

R. W.

"Jade of the Maori." By Elsie Ruff. Gemmological Association of Great Britain, London, 1950.

A review of this work, which deals with New Zealand Jade used by the Maori, will be given in the October, 1950, issue of the Journal.

Gemmological Abstracts

"New Process of Artificially Beautifying Gemstones." By E. J. Gubelin. "Gems and Gemology," Vol. VI, No. 8, pp. 243-248. Winter, 1949/50.

A survey of the surface treatment (coating) of gemstones in order to reduce surface reflection. The optical reasons underlying the effect are explained and the reason why the refractometer will give a false reading, or none at all, with such coated stones. A number of spot chemical tests for the detection of the films are given. P. B.

"Diamond Mining in Brazil." By T. Draper. "Gems and Gemology," Vol. VI, No. 8, pp. 241-242. Winter, 1949/50.

The first instalment of a series to be published on this subject. This instalment tells of the history of the Brazilian mining ; of the "garimpeiros"—the nomad miners ; their habits and their methods of mining. An interesting and informative article profusely illustrated with photographs. It seems to be the prelude to the most comprehensive survey of the Brazilian diamond fields yet written. P. B.

"New Data on Brazilianite." By B. W. Anderson. "The Gemmologist," Vol. XIX, No. 226, pp. 89-90, May, 1950.

A slightly higher value of specific gravity for material from the original source and from the new-found occurrence at Grafton Co., New Hampshire, U.S.A., has been determined by Frondel and Lindberg, Anderson and by Trumper. The new values are tabled:

Author	S.G.	Refractive Indices		
Frondel and Lindberg:				
U.S.A.	2,985	1.602	1.609	1.623
Brazil	2.980	1.602	1.609	1.621
Anderson:				
Brazil	2.990	—	—	—
Brazil	2.994	1.6019	1.6117	1.6228
Trumper:				
Brazil	2.994	1.598	—	1.619

Pleochroism is feeble, liquid-filled "feathers" a common inclusion and the mineral does not fluoresce and has no distinctive absorption spectrum.

" Identifying Synthetic Sapphires." By G. O. Wild. " The Gemmologist," Vol. XIX, No. 226, p. 102, May, 1950.

Experiment showed that the colour induced by irradiation of colourless sapphire by X-rays from a tube with a molybdenum target and run at 40 kV. and 20 mA., to be different for natural sapphire to synthetic colourless sapphire. Natural white sapphires quickly turn to a canary yellow colour, while, after five minutes' irradiation, no colour appeared in the case of the synthetic white sapphire. Fluorescence colours induced by X-rays were found to be of little diagnostic value. Suggestion is made that the synthetic stones are under some strain, for the interference figure shown by natural stones is perfect ; that of synthetic stones is distorted. R. W.

" Neutron Treatment of Precious Stones." "Atomics," 1950, *1*, 79, 83.

Changing the properties of diamonds. Extract from recent patent by N. E. Nahmias, of Chatenay-Malabry, France (Engl. Pat. 13986/1949). The method consists in the use of neutrons to produce permanent colour change by reaching the pigments in the nuclear structure, modifying permanently physical and chemical properties, thus achieving transmutation *in situ*. (The method is based on theoretical deductions, not on practical experiments.—Ed.) The speculation is that by neutron radiation more valuable colours may be secured in gems, and that the hardness in industrials may be improved, following the determination of the nature of the impurities and their modification. Existing piles would have to be used. E. S.

" Die Bedingungen der Edelsteinentstehung." (Conditions of gem formation.) By Prof. Dr. Schlossmacher. " Schmuck," 1950, 87-88 ((No. 3).

Geographically, the most important gem occurrences will be found in a wide belt on both sides of the equator. The beauty of a gem depends on its optical properties, its purity and size. The question is, what conditions are favourable for the formation of such pure crystals of sufficient size? A table shows that most gems

are formed in the pegmatitic phase of Sial, the next important is the pneumatolytic, then the hydrothermal phase. The cause is found in the volatile constituents and mineralizers of these magmas and solutions. E. S.

" Der rumänische Bernstein." (Rumanian amber.) By A. Lenard. " Schmuck," 1950, 89 (No. 3).

Enumeration of occurrences of amber in Rumania, and description of physical properties.

" Another Test for Pearls." By G. O. Wild. " The Gemmologist," Vol. XIX, No. 223, p. 23, February, 1950.

Report on a test for drilled pearls based on the X-ray induced fluorescence of the mother-of-pearl bead in cultured pearls. Oblique examination is made, by a suitably placed low-power microscope, of the inner wall of the string canal of the pearl under test. The pearl being in the beam of X-rays. In the case of a cultured pearl the bead nucleus will be seen to fluoresce, while the non-luminous shell will remain dark. The line of demarcation of the core and nacreous shell is said to be in most cases very distinct. E. S.

" Titania now Made as Doublet." " Gems and Gemology " (Gemological digest), Vol. VI, No. 8, p. 257. Winter, 1949/50.

Report that composite stones having a crown of coloured corundum and a base of titania (synthetic rutile) have been made. All colours of synthetic corundum have been used and very little loss of brilliancy or " fire " is reported. The notion behind their manufacture is to provide a better wearing face, but the practicability of the method has not yet been proved.

" Progress in Diamond Synthesis." By K. F. Chudoba. " The Gemmologist, Vol. XIX, No. 224, pp. 62-65, March, 1950.

A review of the various experiments which have been carried out in the attempt to synthesize diamond. Mention is made of the two leading ideas upon which these experiments are based, i.e. high pressure (diamond having a higher density than the more stable graphite) and by quick cooling to obtain the unstable diamond modification of carbon (backed by Ostwald's grade rule). Discussion of theoretical and experimental considerations throws doubt on the validity of the assumption. R. W.

" Amethyst Colour Induced in Clear Quartz by Cyclotron." " Gems and Gemology " (Gemological digest), Vol. VI, No. 8, p. 255. Winter, 1949/50.

Extracted (by G. Switzer) from " Note on Removing the Deuteron-induced Colour from Quartz Plates " (A. A. Schulke and R. E. Nuelle) in " Review of Scientific Instruments," August, 1949. Transparent colourless quartz plates are employed in aligning the target assemblies in a cyclotron. They fluoresce a bright blue under the deuteron bombardment. These plates were found to turn a deep purple after a relatively short bombardment. The colour change is stable under normal conditions but is destroyed by heat treatment at 300° F. to 400° F. (150-200 deg. C.) with the emission of a strong blue thermoluminescence. Suggestion is made that this amethystine colour may have some bearing with the, as yet unknown, cause of the colour of amethyst. R. W.

" A Curious Polishing Effect." By M. D. S. Lewis. " The Gemmologist," Vol. XIX, No. 222, pp. 64-66, January, 1950.

The production of an anisotropic layer on isotropic solids by polishing in one direction is discussed. Experimentally polishing, in opposite directions, two halves of a glass slide and then dripping an alcoholic solution of methylene blue on the slide and igniting produced markedly different tints in the two halves when the slide was viewed through a piece of polaroid. Full references are given to the works of other authorities on this " anti-Beilby layer " and associated phenomena. R. W.

" Properties of Gem Varieties of Minerals." By Edward Wigglesworth, 1948. Gemological Inst. of America.

Published in memory of the author, this book consists of record cards listing the physical properties of varieties of minerals suitable for cutting as gemstones. The figures of optical and physical constants from works of eminent gemmologists and mineralogists are a valuable feature of the Wiggleworth tables. The loose leaf binding of the book is a useful feature.

It is a pity that some unfortunate variety names are suggested, such as " topazolite " for demantoid garnet, " padparadscha " for corundum, and " peredell " for topaz ; it is praiseworthy to note that confusion between names given to varieties of quartz and topaz has been avoided. A. G.

ASSOCIATION NOTICES

OVERSEAS VISITORS

During April, May and June the Association was honoured to receive visits from gemmologists from overseas. One of the first was Mr. Kenneth G. Mappin, F.G.A., C.G., of Mappin's, Ltd., Montreal, who is Vice-President of the American Gem Society. Mr. W. A. Catanach, President of the Victoria Branch of the Gemmological Association of Australia, brought greetings from the G.A.A. and also attended an Association meeting on May 18th. Another visitor from Australia was Mr. J. B. Lyons, President of the South Australia Branch of the Gemmological Association of Australia. Mr. D. Dresme, of Amsterdam, Treasurer of the newly formed Netherlands Gemmological Association, called to discuss problems connected with the establishment of a new organization. From Oslo came Mr. Hans Myhre, also interested in the formation of the new Norwegian Gemmological Association, and Mr. O. Modahl.

MEMBERS' MEETING

A meeting of members of the Association was held on Wednesday, May 18th, 1950, at Goldsmiths' Hall, Foster Lane, London, E.C.2, at 7 p.m. A paper by Dr. E. Gubelin, F.G.A., C.G., on the "Diagnostic Importance of Gemstone Inclusions" was read by Mr. G. F. Andrews. After the reading Mr. B. W. Anderson described a series of photomicrographs of gemstone inclusions shown on lantern slides, and emphasized some of the points made by Dr. Gubelin in his paper.

NORWEGIAN GEMMOLOGICAL ASSOCIATION

The Association is glad to record the formation on May 9th, 1950, of a Norwegian Gemmological Association (Norges Gemmologiske Selskap) with headquarters in Oslo. The Norwegian Association has been founded along similar lines to that of the Gemmological Association of Great Britain and two representatives of the newly formed organization have visited London and discussed future co-operation between the two Associations.

GEMOLOGICAL INSTITUTE OF AMERICA

Edward H. Kraus, Dean Emeritus, College of Literature, Science and the Arts, University of Michigan at Ann Arbor, has been elected President of the Gemological Institute of America. This is the fifth term as President for Dean Kraus.

H. Paul Juergens was elected for a third term as Chairman of the Board of Governors of G.I.A., and J. Lovell Baker, C.G., R.J., of Henry Birks & Sons, Ltd., Montreal, Canada, again serves as Vice-Chairman of the Board.

New members of the Board of Governors include Carleton E. Broer, C.G., R.J., of the Broer-Freeman Company, Toledo, Ohio; C. I. Josephson, Jr., C.G., R.J., of C. I. Josephson Jewelers, Moline, Illinois; and William P. Kendrick, R.J., William Kendrick Jewelers, Louisville, Kentucky.

Robert M. Shipley remains the Director of the Institute.

1950 EXAMINATIONS IN GEMMOLOGY

The Examinations of the Gemmological Association of Great Britain were held in Great Britain and Overseas as follows:—

Preliminary.—June 7th: Birmingham, Bristol, Darlington, Edinburgh, Glasgow, Harrogate, Ibsley, Liverpool, London and Plymouth.

Overseas: Cambridge (U.S.A.), Ceylon, Egypt, Holland, Indore (India), Jaipur (India), Los Angeles (U.S.A.), Ontario (Canada), Saskatchewan (Canada), Singapore, S. Africa and Toronto (Canada).

Diploma.—June 8th and 9th: London.

Overseas: Australia, Ceylon, Holland, Hong Kong, Los Angeles (U.S.A.), Northern Rhodesia, Ontario (Canada), Saskatchewan (Canada), S. Africa and Toronto (Canada).

June 8th and 12th: Edinburgh.
June 8th and 13th: Glasgow.
June 8th and 14th: Plymouth.
June 8th and 16th: Birmingham.

1950—1951 CORRESPONDENCE COURSES IN GEMMOLOGY

The 1950-1951 Correspondence Courses in Gemmology will commence in September, 1950, and will be conducted on the usual world-wide basis.

Information may be obtained from the Secretary of the Association, and the last date for receiving enrolments from United Kingdom residents is August 31st. Prospective Overseas students should send in their applications prior to August 14th.

TALKS BY FELLOWS

Mrs. Kathleen G. Warren: "'Gemstones," Townswomen's Guild, Bromley, Kent, Tuesday, June 13th.

D. J. Ewing: "Gem Testing," Edinburgh and East of Scotland Association of Goldsmiths, Silversmiths and Watchmakers, Edinburgh, March 15th.

Letter to the Editor

Dear Sir,

I have read with much interest the letters of Messrs. Jones, Burbage and Pearl regarding the latter's recent article on the broadening horizon of gemmology.

I have found from personal experience that while mineralogists in general are able to identify gems by destructive methods, usually only outstanding specialists can correctly identify all cut and polished natural and synthetic gems without injury to the stones.

This is where the knowledge possessed by the trained gemmologist exceeds that of the *average* mineralogist, who quite naturally has received training in the identification of minerals in their natural uncut state, or in thin section.

Not many years ago, before I had the opportunity to study the courses offered by the Gemmological Association of Great Britain, I had occasion to submit a parcel of cut synthetic rubies for a check test by a well-known Canadian mineralogist, at that time head of one of the departments of a Canadian University. In due course, this gentleman successfully identified the stones as red corundum, but was unable to say whether natural or synthetic. Furthermore, although aware of the curved lines in synthetic corundum, he had never been able to detect them in known synthetics he had examined.

This failure was due to no lack of mineralogical knowledge. On the contrary, the man possessed a very high University degree in geology and mineralogy, and since then he has won universal acclaim for his discoveries in the field of geology.

Prior to the establishment of the organized courses in gemmology, scientific gem testing was practically unknown, and to-day only a very few mineralogists have sufficient knowledge of modern (non-destructive) gem-testing methods to qualify them as specialists in precious stones ; for every book or course in mineralogy treats only briefly of gems, and always, of course, in the rough form, or in thin section.

The mineralogist is a great scientist who has to deal with thousands of species. The gemmologist, on the other hand, is a specialist who, ordinarily, deals with less than 90 varieties, and can therefore be much more thorough than the mineralogist.

The specialist in gems has developed the scientific study of gemstones far beyond that of mineralogy. He has conceived new instruments and new methods whereby it is now possible for him to identify any natural, synthetic or imitation gemstone, and without injury to the specimen.

Mineralogists and geologists, chemists and physicists, jewellers and laymen *who possess such knowledge* are gemmologists, whether or not they hold certificates or diplomas of the various accredited associations and institutes specializing in scientific gem study.

The great advance made in the study of gems during the last quarter of a century have been due to *specialization.* While I agree with Mr. Pearl that many unusual North American minerals and ornamental stones worked by private lapidaries should be recognized as gemstones, I feel that non-gem substances such as the plastics, bone, gold, silver, etc., have no place in gemmology, and no *intensive* study of such materials should be required of the student. These are not now and never have been gem materials, nor have they ever been effective imitations of gem materials.

The gemmologist is not necessarily a jeweller, albeit many jewellers are outstanding gemmologists. Why, then, should the student be required to study the properties of silverware, gold-plated ware, and other merchandise sold by the jeweller?

With all due respect for those who have made a special study of such material, it is surely sufficient for the gemmologist to state that a plastic is a plastic, without entering into a detailed discussion of the physical and chemical properties thereof.

If the horizons of gemmology continue to broaden at their present rate, I hazard the opinion that the time will not be far distant when the gemmologist will again be a general practitioner, or else a mental giant specializing in a dozen sciences—some of which, like plastics, are only remotely related to gemmology.

It matters little whether an imitation of turquoise is a stained beef bone or part of the fibula of an elk. It is bone. That moulded brooch in plastic ; does it matter much whether bakelite B or C or polystyrene? The latest carved cameos are being cut from wood. Must one, then, study the hundreds of varieties of wood to qualify as a gemmologist, or shall we simply state " It is a wood carving " and let it go at that?

Let us hope that the educational boards of the future will not make the specialized study of other sciences a required part of gemmological training, and let us not confuse the gemmologist with the jeweller—nor, again, with the specialists in other fields, who may or may not be gemmologists.

In short, let us stick to our wares.

Yours sincerely,

D. S. M. FIELD.

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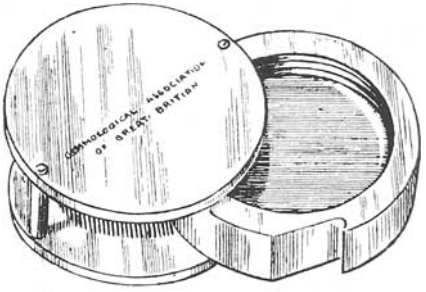

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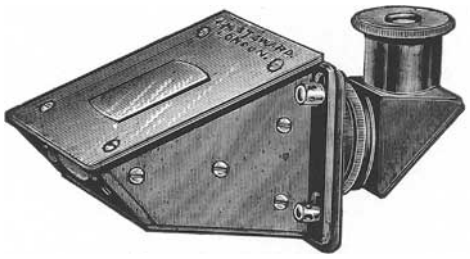

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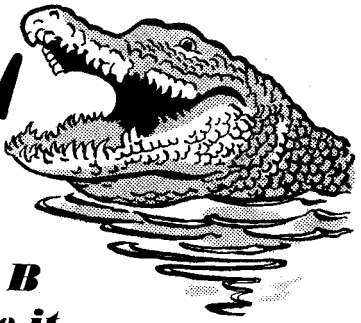

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THE JOURNAL OF GEMMOLOGY

and

PROCEEDINGS OF THE

GEMMOLOGICAL ASSOCIATION OF GREAT BRITAIN

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Vol. II, No. 8 OCTOBER 1950

MOUNTING A GEMSTONE COLLECTION

By L. C. TRUMPER, B.Sc., F.G.A.

MY interest in precious stones dates back to 1925, when as a schoolboy old enough (as I then thought) not to want to play on the sands at Newquay, and not old enough to want to do anything else, I bought a 5s. set of inexpensive stones mounted in a cardboard box. I still have that box.

The next and inevitable phase—being on holiday in Cornwall—was to hunt the beach for stones and also inevitably take them to that same jeweller's shop to be cut! I still don't know whether the poor amethyst pendants and somewhat roughly shaped cornelians did or did not come from the pebbles we found, but certainly the innumerable rock crystal pendants that appeared at the shop after a lapse or four or five days did not.

There then followed a period (akin to the dark ages) during which the mind was filled with the more pressing need somehow to carve out a career.

A latent interest in minerals, stones and fossils evidently remained and this, together with an interest in all things scientific, probably prompted me during the dark days of the war to turn once again to the possibility of adding a good collection of minerals to my other many but modest collections of nearly everything except postage stamps.

So it was that for my Christmas present in 1943 I decided to treat myself to a collection of minerals from Gregory Bottley & Co., Church Street, Chelsea. They built up for me a very good collection, nicely set out in cardboard boxes in well made wooden trays, arranged to lift easily out of an equally well made box, 17 ins. by $10\frac{3}{4}$ ins. by 12 ins. deep, six trays $16\frac{1}{4}$ ins. by $9\frac{1}{2}$ ins.

Now the interest of this collection was greatly enhanced by those minerals of approaching gem quality being polished on one side and by quite attractive and generous specimens being provided. This part of the collection soon revived my interest in gemstones, and not many days passed before I decided to embark on the acquisition of one of Gregory Bottley's standard collections of uncut and cut stones.

The first set to arrive was that of 50 uncut stones ; these were all in small glass-topped pill boxes, each one numbered and the whole in a small box about 6 ins. by 12 ins. with a list of the names and localities affixed to the lid.

What a glorious array of colour that collection was! Quite good specimens, too, almost all of which still find a place in my collection. Hour after hour of a dark and blacked-out evening I used to gaze at that collection, and day after day I waited for its counterpart, the set of 50 cut specimens.

At last that day arrived ; no doubt I had set my standard too high, for I must confess that I was rather disappointed at some of the specimens. Perhaps, however, in the long run it was a good thing as otherwise I might not have been so keen to improve upon it.

The stones as supplied were mounted on white cotton wool in similar pill boxes with glass lid. Somehow, all jammed up together in a box they did not look right, and I soon removed them and tried them on a single piece of cotton wool with a sheet of glass over the lot. I was still not entirely happy about it, however.

About this time I was introduced to a copy of " A Key to Precious Stones," by L. J. Spencer. This was my first introduction to the real possibilities of gemmology, and absorbing every word over and over again I resolved then and there to pursue it as a hobby. I also resolved that my collection should comprise side by side a specimen of the rough and a specimen of the cut or polished stone. I am sure that my real reason for this went back to my

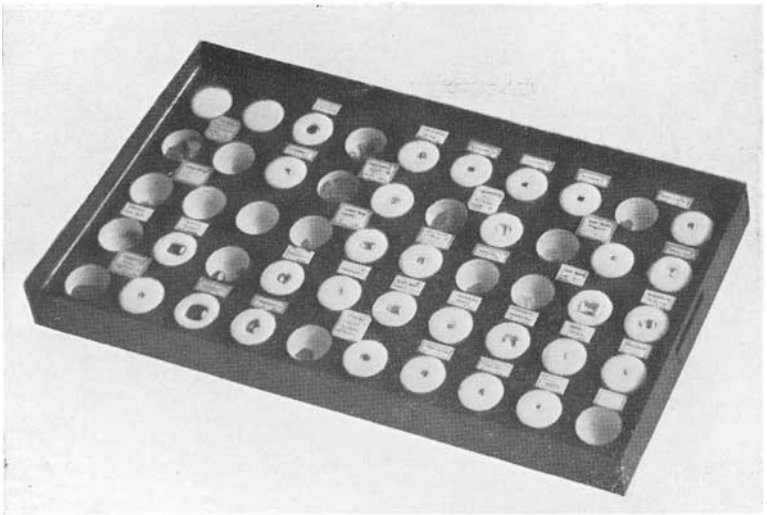

experiences of 1925, because, so struck was I with the difference between the presumed rock crystal pebble and the apparently resultant rock crystal pendant that I had been bold enough to ask them to polish one half of a pebble and leave the other in its natural state. Needless to say, this was never obtained and every possible explanation was given as to why they could not possibly accede to my wishes.

Thus it was that with the aid of Spencer's " Key to Precious Stones " I concluded that my collection could and should comprise 100 specimens of rough and 100 specimens of cut or polished stones. I further decided that these should be contained in four trays, fifty specimens in each, and that each tray should be of a size that would go into the standard size of box as supplied by Gregory Bottley & Co., who kindly supplied me with a further box to match their others for the purpose.

Thus it was that I evolved my standard tray of overall dimensions $16\frac{7}{8}$ ins. by $9\frac{1}{2}$ ins. by $1\frac{3}{4}$ ins. deep. Now, as will be seen from the illustration, each tray was constructed by drilling holes $1\frac{1}{8}$ in. diameter through a piece of $\frac{3}{4}$ in. thick wood (actually several were drilled simultaneously), then glueing and nailing a base on one side and sides and ends to complete the tray.

The insides of the cells, $1\frac{1}{8}$ in. diameter by $\frac{3}{4}$ in deep thus formed, were painted with flat white paint and the whole of the rest of the tray flat dead black.

The boxes previously mentioned will hold seven of these trays. As will readily be seen, rough material, or wherever possible rough crystals of gem quality go into the cells as they are, and the cut specimen is placed upon a firm wad of white cotton wool, carefully pressed into the appropriate cell. In the case of black opals and a few other stones such as diamond, black cotton wool has been found to be preferable.

Each cell or group of two cells is labelled in Indian ink, giving the name of the stone, its number in the collection and, if room, the S.G. or R.I.

The whole of the tray is then covered with a sheet of clear white glass, giving clearance of 1/16th in. to $\frac{1}{8}$ in. from the sides and ends of the tray. This is quite heavy enough to keep all the cut stones firmly down on the cotton wool.

A slit in the ends of the tray is essential, not only to lift the tray in and out of the box, but also to enable the sheet of glass to be removed by lifting clear with the blade of a knife.

The general effect of the specimens in a small white circle against a matt black background is very good and the spacing of the specimens is just enough to allow the eyes to look at one at a time instead of seeing a jumbled mass.

In providing for a collection of 100 specimens I very soon found that I had not made allowance for colour variations, and after subsequently getting my hands on every possible publication on gemmology, I began to appreciate how wide of the mark this idea was ; indeed, I already have thirteen trays in occupation and others standing by in readiness for further eagerly sought specimens to turn up.

The size of cell has (perhaps wisely) set a maximum to the size of specimen to be collected, but I have since felt compelled to make a few trays with cells $1\frac{1}{2}$ in. by 1 in. deep particularly to take specimens of rough too large to fit into my standard cells.

My method of mounting has not blinded me to the possibility of better methods, and my first visit to the Gemmological Exhibition had as its prime objective the investigation of what I hoped might be better ones. In this I was disappointed, but realized that

selected specimens for general exhibition called for a different treatment where ample showcase space was available.

Mr. B. W. Anderson suggests that a gemmologist's collection should be kept indexed in the usual folded papers ready for instant examination or comparison. There is much to be said for this if one's collection is confined to cut stones only, and this is essentially portable. It is not so suitable for rough specimens and I do not like the idea of one's collection being all hidden away.

A method in its essentials not dissimilar to my own is that used at Prague at the Bohemian National Museum and well illustrated on page 264 of Vol. 17, 1948, of " The Gemmologist."

Another excellent method may be seen at the Natural History Museum at South Kensington, and was ably described by Mr. Robert Webster in the same volume of " The Gemmologist." This consists in supporting a thin sheet of clear perspex some inches above the base of a box, the inside of which is in an off-white colour. The gemstones are supported in carefully shaped holes cut in the sheet of perspex and have the appearance of floating in mid-air.

So struck was I with this method that I went to a great deal of trouble and some expense to make a series of similar boxes, cut from opal and black perspex. The latter for stones calling for a black background, particularly opals and colourless stones.

I found that it was necessary to generate a matt surface by sandpapering to eliminate unwanted reflections. Perspex can be obtained in various thicknesses and my object was to obtain both a white and a black that would be as permanent as possible. White opal perspex, after sandpapering with very fine glass paper, produces a very good matt surface that is as near snow white as it is possible to get. Incidentally, if you wish, such a matt surface can be written on with Indian ink.

Perspex is moderately easy to saw, file or shape and can be polished with metal polish ; it is, however, very tough and it is well worth while in the long run to get the supplier to cut it to size for you, which they will do no matter how many small pieces are required, and the additional charge is more than saved by eliminating wastage from larger sheets. (In working out the measurements, do not forget to allow, where necessary, for the thickness of the material.)

Suitable boxes can be made up in this way very easily indeed by joining up with Tensol No. 2 Cement, which can be obtained from the perspex supplier, and by masking with gummed paper invisible joints can be made.

After completing a number of such boxes of sizes to fit suitably into a display cabinet that I had picked up in an antique shop, and after carefully arranging a number of stones, I nevertheless came to the conclusion that it was not suitable for my collection. For a jeweller's shop, yes ; for a museum display of specimen stones, particularly coloured ones, yes ; but not for a collection such as mine, with rough as well as cut, and small stones as well as large ones, and indeed often indifferent stones, in the collection for a specific purpose, for their inclusions for instance. No, it just would not do.

There is another most important consideration to be borne in mind: normally one sees a gemstone by reflected light ; that is, the light enters the stone by the table facet, traverses the stone and re-emerges at the front ; the light has, in fact, passed through the stone twice.

Now if the stone is floating on perspex against a white background some distance from the stone, most of the light will, in fact, be reflected from the background through the stone to the eye and the light will have thus traversed the stone once only. The result is that the stone looks washed out as the depth of colour is roughly halved.

Some stones, quite apart from this, look entirely different by transmitted light from what they do by light reflected mostly from the surface layers. Here, then, are further reasons why such a method has its limitations.

For exhibition purposes it is, of course, common practice for the stones to rest on an off-white velvet, but such a method, though admirable for an exhibition, a museum or a high-class jeweller's display, is not compact enough for the collector.

Yet another interesting method is that adopted by Mrs. V. Hinton, of Houston, Texas, U.S.A., and well shown in Vol. 2, No. 3, of the " Journal of Gemmology," on pages 84 and 85. Here again we have a method that is confined in the main to large specimens and on more or less permanent display within a glass cabinet.

Thus my more or less original method continues to reign supreme. That it has some disadvantages I am well aware, but they are not very serious ones.

One objection is that after you have arranged a number of stones in one or more rows and duly labelled them, a fresh specimen turns up that has to go somewhere in the middle where there is no space. Usually one can slip it in by making a few alterations only, carefully removing the labels and replacing them, but sometimes there is nothing for it but to re-arrange in an entirely new tray. When this happens the old tray is cleaned up and repainted ready for some other move or extension ; laborious, but after all part of the fun of the thing.

With a view to getting over this particular problem I have long designed a unit system of blocks, each of a size to allow for a label and the appropriate cell. By means of inserts, it would be possible to have a white or a black cell or a solid white or black disc which could be countersunk to take the stone ; such a mount would be permanent and they could be shuffled about in a tray to take, say, 40.

Such a method would call for die cast perspex or other plastic components and the cost would be prohibitive unless a very large number could be made at a time.

Finally, as white cotton wool, which I have not been able to improve upon so far, unfortunately does not remain white indefinitely, it is interesting to note that in America gemmologists can already obtain a plastic substitute termed " Snow foam," which I imagine will be more permanent. I have no knowledge of such a product being on the market in this country, however.

The successful mounting of a collection is one of the most important parts of any hobby, and I hope I may have contributed some helpful suggestions to an aspect that has not received nearly enough attention.

GEMMOLOGICAL NOTES

A SMALL GEM LABORATORY

FINE instruments are important, not only because of their superior performance but also from the standpoint of pride of ownership. Cheap goods are never satisfactory.

This does not necessarily mean that it is necessary or even desirable to make huge expenditure to outfit a costly laboratory before efficient work can be done. On the contrary, if the beginner accumulates his instruments slowly, a few at a time, and uses a little imagination and initiative in improving both their efficiency and their appearance, his collection will become, in a surprisingly short time, a source of pride and satisfaction.

A small gem laboratory in the process of evolution is shown in the accompanying photograph.

The following brief description of the instruments of which it is comprised may be of interest.

(Left to right): Bull's-eye condenser with variable focus. Lenses were purchased from war surplus. Stand adapted from a *Beck* dissecting arm.

Rayner refractometer with polaroid and monochromatic light filters.

Beck prism spectroscope on inclined stand with chromium-plated and black suede turntable. Barrel of instrument is covered in black English morocco. Ancillary apparatus includes chromium-plated eye-shade attached to metal collar, Beck cylindrical lens attachment for flooding slit with light, and universal post for small bull's-eye condenser. This post formed part of the dissecting arm mentioned above.

Instrument made to special order, embodying Chard dichroscope. The stand has a tilting handle and inclines through 90°. It can be fixed at any convenient angle by tightening the milled head. The instrument is finished in polished chromium plate and black English morocco leather.

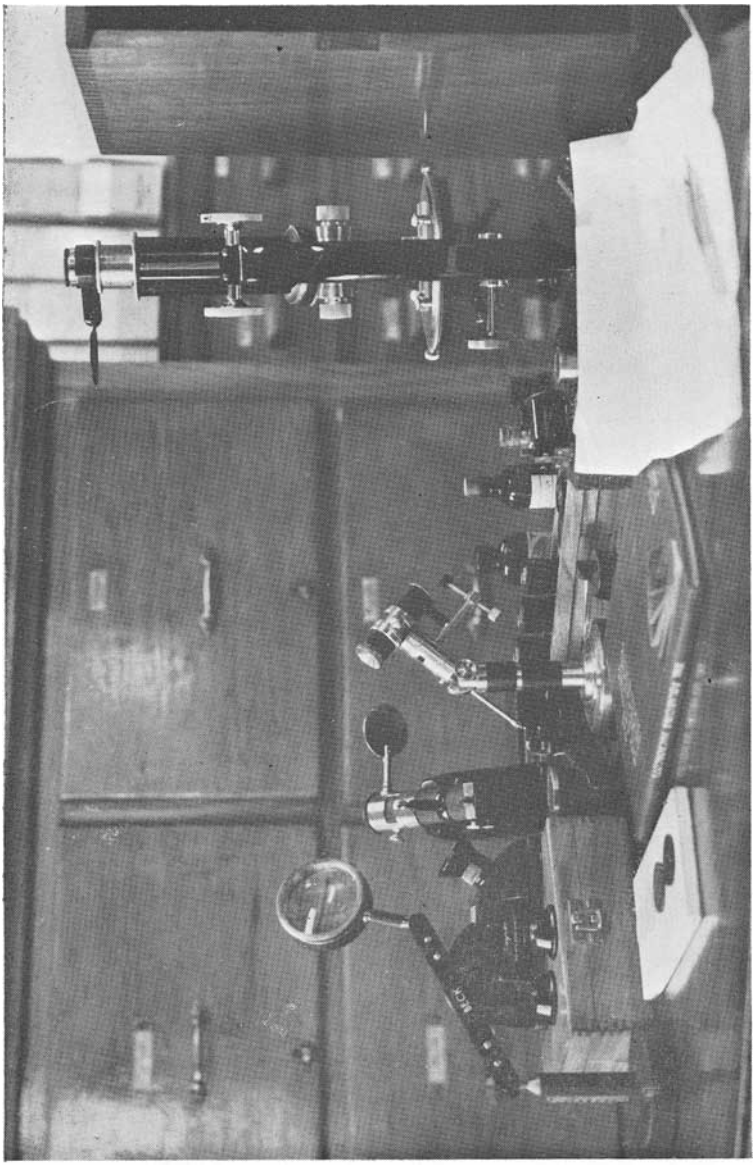

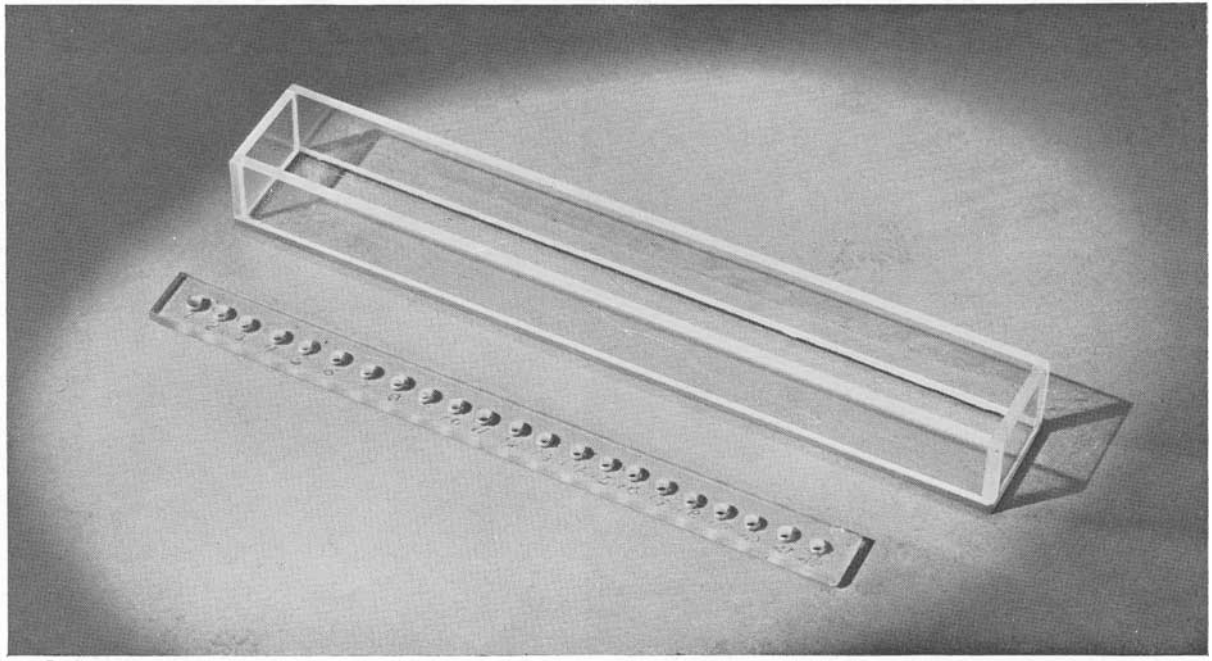

Photo: A. E. Alexander, Ph.D., Tiffany and Co., New York

Microscope accessories, including prism projector, dark-ground stops, eyepieces, filters and immersion liquids.

Beck grating spectroscope.

Polarizing microscope constructed to order by Messrs. R. & J. Beck, Limited. This instrument is equipped with quadruple revolving nosepiece, rack and pinion focussing and centring sub-stage and centring revolving stage calibrated in degrees and numbered at 10° intervals, with vernier. Each division of the calibrated fine adjustment equals 0.005 mm. of movement. The 10 × (16 mm.) objective is of special construction, giving a working-distance of approximately 13 mm., and a sharp, colour-free image. For these reasons, it is unusually suitable for the study of inclusions in gemstones, where working-distance is frequently the prime requisite. The black " zylonite " eye-shade is a product of Messrs. Bausch & Lomb (Canada), Limited.

D. S. M. Field, A.G.A.

GLASS CELL FOR EXAMINING DIAMONDS

The accompanying photograph shows an optical glass cell especially constructed so as to be liquid tight. The inside dimensions of the cell measure 6 inches in length, three-quarters of an inch in width, and five-eighths of an inch in depth.

Also shown in the photograph is a glass plate, 5½ inches long, containing 22 evenly spaced holes, each slightly under one-eighth of an inch in diameter. This plate is laid in the bottom of the glass cell and the diamonds to be examined are placed, one in each hole, with table and crown facets up. (The stones rest easily in the holes, pavilion facets down.) If larger stones are to be examined they should be placed in every other hole. Any colourless, inert, immersion liquid (the writer prefers dibutyl pthalate) is then poured over the glass plate, sufficient enough to just cover the table of the diamonds.

Using a binocular microscope, it is then possible to examine the diamonds quickly, one by one, by merely moving the glass cell from left to right.

Use of the liquid aids in cutting down annoying internal reflections which tend to mask any minute carbon or white spots present.

Photo : A. E. Alexander, Ph.D., Tiffany and Co., New York

Photograph of a flawed diamond. The inclusion is close to the culet and the reflections in and around the nearby facets give the appearance of birds or flies in flight.

In general, it is better to first look for flaws at a higher magnification than 10 ×. The author uses 22.5 ×. Then adjust the optical system to 10 ×.

If an inclusion seen at the higher magnification cannot be seen at the 10 × magnification, the diamond is adjudged perfect.

A. E. ALEXANDER, Ph.D.
Tiffany & Co., New York.

DOUBLE REFRACTION AND THE DISTANT VISION METHOD

One of the curious features of the valuable distant vision refractometer technique, developed by Lester Benson and G. R. Crowningshield for taking readings with cabochon stones, is that generally only one shadow-edge can be seen crossing the contact disc even in doubly refractive stones. This represented a considerable drawback compared with the standard method of reading the refractometer which is possible with stones having a flat contact facet. Under these conditions, as is well known, maximum and minimum refractive indices for the stone can readily be obtained by appropriate orientation of the contact surface.

Some weeks ago, Sir James Walton informed the writer that he had been able to detect two distinct edges on a cabochon peridot, using the distant vision method with a Herbert Smith refractometer. More recently still, Mr. C. J. Payne, while using this method on a large cabochon specimen of chatoyant scapolite, noticed an unmistakable double shadow-edge. That this effect was indeed due to the birefringence of the stone was confirmed by use of a polaroid disc, which, when appropriately set, enabled first one and then the other edge to be seen as a single dividing line crossing the contact disc. It was found possible to take fairly accurate readings of the two edges on a spinel refractometer, the figures being approximately 1.56 and 1.58.

The scapolite had a very highly polished surface, and trials were accordingly made with other well-polished cabochons. A clear double edge was seen, *inter alia*, with a flat cabochon of quartz, but with several other stones one had to confess to failure.

Conditions favourable for the double edge seem to be (i) a highly polished surface, (ii) a monocrystalline specimen, (iii) not too steep a curvature of the surface. A fairly large contact disc is here desirable to allow space for both dividing edges to be seen in the same field ; it is not so necessary, therefore, to limit the contact liquid to the tiniest possible droplet.

These experiments, though not thorough or complete, are reported in the hope that others may be encouraged to make attempts in this direction, perhaps with greater success.

B. W. ANDERSON.

NEW BOOKS REVIEWED

"*Leitfaden fur die Exakte Edelsteinbestimmung*" (Guide to the Exact Determination of Precious Stones). By Professor Dr. Schlossmacher. Schweitzerbart'sche Verlagsbuchhandlung, Stuttgart, 1950. 174 pp., illustrated.

This is the first new book on determinative gemmology to appear in Germany since the beginning of the war. In this ten-year interval many discoveries of importance to the science have been made, particularly in America and Switzerland, and it is interesting to note how far Professor Schlossmacher has succeeded in his avowed aim of incorporating the new knowledge in a text-book of less than 200 pages.

Though many new instruments are mentioned and briefly described, there are considerable omissions. Thus, no account is given of the important "distant vision" technique developed by Benson and Crowningshield in America, whereby refractometer readings are made possible with cabochon stones, and neither the spectacular new synthetic rutile nor synthetic star corundums are mentioned, though both were publicized before the book was completed.

The balance of the book is curious in many ways. Crystallography is entirely omitted, and the word "Kristall" does not even appear in the index. The detection of double refraction by means of the polarizing microscope is fully treated, but the very important and practical observation of the "doubling" effect with a pocket lens is nowhere mentioned, nor is sufficient stress given to the great diagnostic importance of accurate measurement of birefringence on the refractometer.

Again, dichroism and the dichroscope receive unusually handsome treatment: no less than eleven pages in the text and a very fine four-page table of the pleochroic colours shown by different species at the end of the book. This is excellently done, but it shows

a false sense of proportion to devote 15 pages to a method whereby no single gemstone can be positively identified, and then to accord less than four pages to the spectroscope, with which so many unequivocal determinations can be made. One could understand this being done for simplicity's sake, but this plea loses force when one finds several pages and an illustration are given to the Zeiss Abbe-Pulfrich total reflectometer. This beautiful and accurate instrument is invaluable for laboratory research, but is quite unsuited for the jeweller, owing to its complexity, cost, and liability to damage, particularly if an attempt is made to test mounted specimens upon its very vulnerable hemisphere.

In a good chapter on specific gravity determination, Professor Schlossmacher points out the fallacy of quoting a density result to four places of decimals in cases when, from the known accuracy of the weighings, a result correct to only one place can be assured. He points this moral with two tables in which the effects of a weighing error of 1.0 milligram and of 0.1 milligram is shown for stones of different weights and densities. These considerations lead the author to suggest that results to one place of decimals are all that can normally be expected by the hydrostatic method, and that such are usually all that are needed for purposes of identification. Though there are sound reasons for this view, the keen gemmologist will always strive to obtain at least second-place accuracy, as it is only in the second place of decimals that the figures become interesting either by their constancy or their diversity.

Professor Schlossmacher is right in ascribing greater accuracy (for small specimens at least) to flotation methods in heavy liquids, backed by indicators or the Westphal balance, the latter instrument being well described and illustrated in this book. It is curious, however, that the poisonous and messy Thoulet's solution (potassium mercuric iodide) should be recommended for the lower ranges, and no mention made of bromoform or of acetylene tetrabromide, which are so much cleaner, more mobile and relatively inexpensive. An upper density value of 4.6 is given for Clerici's solution. This figure can be attained or even exceeded by heating, but at room temperatures 4.15 is about the limit for this useful though unpleasant fluid.

In the chapter on the microscope a good account is given of the instrument specially designed by the author for the examination of

precious stones. The main feature of this microscope is that it is horizontal, which means that a stone, gripped in a vertical holder, can be immersed and rotated with great ease in a cell of liquid placed on a small platform in front of the objective. Observations can be made either in ordinary or in polarized light.

The only descriptions of particular gemstones in the book are those in a short " dictionary " of the gem minerals given towards the end. There are other tables of species arranged according to colour, S.G., R.I., etc., as well as the excellent table of pleochroic colours already mentioned. Exact figures for birefringence, and also the wavelengths of important absorption bands might usefully be incorporated in a future edition. At the end of the volume there is an attractive selection of photo-micrographs of gem inclusions from Dr. Gübelin's incomparable collection.

In conclusion, it may be said that the book is most interestingly written, and, as one would expect from such an author, contains much of value for the keen gemmologist who can muster sufficient German to read the text.

B. W. ANDERSON.

"Jade of the Maori." By Elsie Ruff. Gemmological Association of Great Britain, London, 1950. 89 pp., illustrated.

Books about jade, of which one or more seem to be published each year, are usually distinguished by their lavish use of illustration, their slender text, and their high cost. Often they are little more than picture-books, in which superb museum pieces of carved jades appear in sumptuous but rather monotonous succession. Works embodying original research and true scholarship, which really contribute to our knowledge of the subject, are rare indeed.

One of these, Howard Hansford's " Chinese Jade Carving," was reviewed in the last issue of the " Journal." The importance of this unpretentious book will grow rather than diminish with the years, and it must always remain of value as a source-book of accurate information on the origins of jade and the technique of jade carving.

As its title suggests, Hansford's book was concerned primarily with jade as it affects the Chinese. Elsie Ruff's little volume attempts much the same task with another jade-loving people—the Maori of New Zealand. This, too, is the result of years of patient

research carried out while actually living amongst the people concerned, and should add considerably to our appreciation of a rather neglected material (New Zealand nephrite) and to our knowledge of its historical and prehistorical background.

The book opens with a chapter emphasizing the tremendous importance of jade to early cultures, comparable to the importance of gold in more modern civilizations. The author shows how jade was used for weapons, for tools, for ornament, and as a medium of exchange. She relates how the search for this coveted mineral served as a stimulus for adventure and exploration, in particular amongst the Polynesian peoples and amongst the ancient cultures of South America from which (as the Kon-Tiki Expedition has suggested) some of the Polynesian cultures may have been derived. These pages make one realize that the modern Western appreciation of jade is but a pale shadow of the mystical near-adoration accorded to the material by ancient man, to whom, indeed, the modern thirst for gold would have seemed grossly materialistic.

Next comes a chapter on nomenclature, in which the three minerals, jadeite, chloromelanite and nephrite, are accorded formal permission to use the coveted name. Nephrite was undoubtedly the original jade: the use of jadeite, despite its present popularity, is comparatively recent, while chloromelanite is nothing more than an iron-rich variety of jadeite, though it appears to have some importance in archaeology. The Maori word *pounamu*, like our word jade, is a collective term, since it covered nephrite, bowenite, and possibly other green serpentines used by the old craftsmen.

In the third chapter the author discusses the occurrence of the jade minerals ; a peculiarly difficult subject on which some of the greatest authorities have gone astray. Although nephrite is widely distributed, the only authenticated source of jadeite seems to be in Upper Burma, and these mines were not in contact with the civilized world until trade with China began in the eighteenth century.

The remainder of the book is concerned more specifically with the nephrite of New Zealand—the primitive methods by which it was cut, and the names given by the Maori to the various qualities of the jade and to the weapons and ornaments fashioned from it. The principal weapon was the *mere*, an implement about a foot long, pierced at one end to allow a thong to pass through it and

round the wrist. This was used either for striking or for thrusting, with distinctly lethal effect. The most important tool was the axe, or adze, used for felling timber and the construction of wooden canoes. The general form of neolithic axes with their curved cutting edge varies very little, but the dimensions ranged from that of a small chisel which could be suspended from the ears to monsters of five, seven, or even sixteen pounds in weight.

Of the ornamental jades of the Maori, the curiously formed *hei-tiki* (i.e. a *tiki* to be worn round the neck) is at once the most famous and the most mysterious. This is usually a contorted squatting figure with enormous owl-like eyes in a head which is set peculiarly awry. The head is pierced to allow the figure to be suspended from the neck.

Being limited to tools far more primitive even than those used by the ancient Chinese, the work of shaping, polishing, and particularly of drilling these artifacts must have been incredibly laborious. But Miss Ruff points out the deep satisfaction derived from the work, which (apart from the specialist) could be carried on by almost any member of the tribe in their leisure moments, as is knitting by the modern woman.

In his first look through " Jade of the Maori," the gemmologist will inevitably be attracted to Chapter VIII, headed " In the Laboratory," where the author gives a good account of the colours, composition, physical and optical properties of the jade minerals. Though listing fourteen minerals (and even more might be added) which resemble jade more or less closely, she is probably wise in singling out only one of these—serpentine—for description. Bowenite, a pale-green, unusually hard form of serpentine, is particularly likely to be confused with jade, and was in fact thought to be nephrite by the Dr. Bowen after whom it was later named. Bowenite is particularly relevant to Miss Ruff's theme, since the material is found in Milford Sound, in the South Island, and was extensively use for carvings by the Maori.

The book ends with a short bibliography and index. In the bibliography it is a pity that no dates or other particulars are given for the books mentioned.

" Jade of the Maori " is obviously written by a true jade-lover, and, moreover, by one who is interested in the philosophical implications of the jade story. The writing is lively, and in many

passages really excellent, but is sometimes marred by over-use of the full stop. This tendency to over-punctuate, added to the rather wide spacing between the paragraphs, gives an air of discontinuity, of scrappiness, to (for example) the opening of the first chapter and the close of the last.

For the rest, the book is well printed on good paper: it is adequately illustrated and neatly bound. It represents altogether a creditable achievement on the part of the Gemmological Association in its first essay in the field of book production.

B. W. ANDERSON.

"*Handboek voor Edelsteenkunde.*" By J. Bolman. H. J. Paris, Amsterdam, 1950. 1,037 pp., illustrated, 4 pp. colour.

An elaborate book which adds little to the existing gemmological literature. It has been reviewed in the Netherlands not too favourably. That such a large book should lack an alphabetical index is hardly credible, and throughout the text there are inaccuracies and inconsistency of spelling. There are four excellent colour plates.

S. F. K.

DIAMOND PIPE DISCOVERED IN INDIA

According to "Indian Information Services," Ottawa, a diamond bearing pipe—believed to be of volcanic origin—has been discovered near the town of Panna, in Central India.

Reporting on the find, the Geological Mining and Metallurgical Society of India says that recent work has resulted in the exposure of the pipe which consists of a basic igneous rock in which diamonds have crystallized and occur as a primary mineral.

It is believed that this occurrence may be one of several primary sources supplying diamonds deposited in conglomerates of the adjoining areas.

Diamonds from the deposits worked in Panna for several centuries have been extracted from rocks known as conglomerates and are regarded as of secondary origin. The primary source from which these diamonds were transported and deposited in conglomerates had not previously been known.

The surface exposure of the newly discovered diamond pipe is oval in outline with irregular boundaries, and has an area of 150,000 to 200,000 square feet.

D. S. M. FIELD.

NOTES ON AN ULTRA-VIOLET RAY CABINET

By T. H. BEVIS-SMITH, F.G.A.

THE behaviour of gem minerals and other substances when exposed to the influence of ultra-violet radiation is a subject well worthy of serious study by gemmologists and students.

Fluorescent phenomena, the emission of visible light rays of various wave-lengths (colours) by certain substances when exposed to invisible ultra-violet radiation (that is, radiation lying beyond the violet end of the spectrum and having a wave-length between 1,000 and 3,800Å), is a familiar one nowadays. Most museums which house important gem and mineral collections exhibit an ultra-violet cabinet. This is a darkened showcase in which are placed certain selected minerals. By means of simple switch-gear controlling an ultra-violet light source and also filament lamps, the visitors are allowed to examine the specimens under ultra-violet and ordinary light. The minerals, some of which are often gem minerals, are usually carefully chosen and arranged so that the exhibit as a whole presents an uncanny and startling panorama to the lay public. Most gemmologists will recall the uncanny effects that are achieved on the stage by the use of fluorescent dyes.

To the "working" gemmologist these practical applications of the fluorescent effect are interesting, but they do not provide him with a means of studying the phenomena for himself, and with this idea in mind and appalled at the cost of a proper analytic lamp, I evolved a fairly satisfactory ultra-violet cabinet which cost about £2 10s. The idea is not original ; its first practical application so far as gemmology is concerned was in the first post-war Gemmological Exhibition, when B. W. Anderson and Robert Webster used the idea to demonstrate the fluorescence of natural and cultured pearl. But one of its most practical applications was in the recent war, when it was used for the illumination of fluorescent aircraft instrument markings. The Woods glass filter filament lamp holder, using ordinary aircraft filament lamps, replaced most successfully a low voltage ultra-violet lamp of the mercury discharge type,

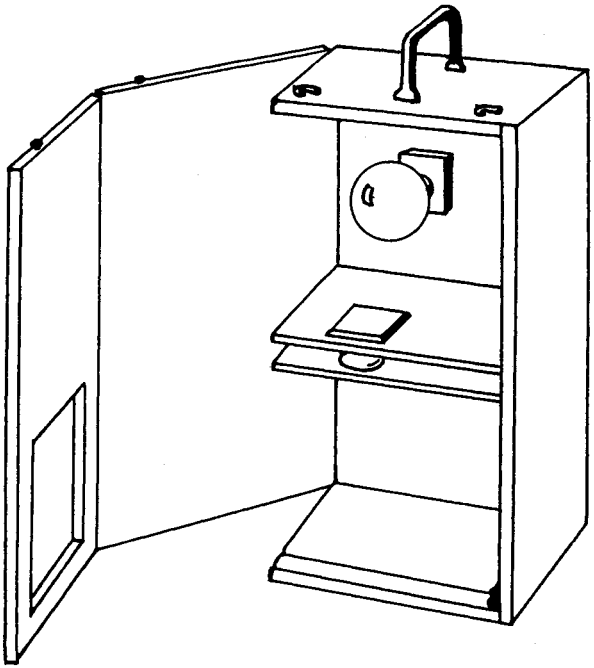

which was both expensive and in short supply. Fluorescent instrument markings were found to be more restful to the pilots' eyes than the more conventional luminous (phosphorescent radium compound) markings. And possibly, what is quite as important, the fluorescent preparation, which I believe was a zinc compound, was nothing like so dangerous to the health of those who had to apply the compounds to the instrument dials.

Sources of ultra-violet light of this nature do not possess the penetrating power of a proper quartz mercury discharge tube lamp like the Hanovia Analytic lamp or a carbon arc source using specially prepared carbons like the Kelvin Bottomley and Baird ultra-violet apparatus.

If the gemmologist feels inclined to invest, say about £10, possibly a better proposition than the apparatus described would be the purchase of a Phillips or G.E.C. Ultra-Violet Filter Mercury Lamp, together with the auxiliary equipment ; even with this equipment a quartz lens is a most useful auxiliary. Whatever the type of ultra-violet light source, the fluorescent effects are best seen in complete darkness.

It is most important to remember that prolonged exposure to ultra-violet radiation is harmful, particularly to the eyes. Some form of dark cabinet fulfils a dual purpose ; it prevents undue exposure to the extremely penetrating rays and shields the specimens, if required, from direct daylight or overhead lighting.

A photoflood lamp No. 1 is used as the light source in the apparatus for three main reasons—at the time it was built (1946-7) the Phillips or G.E.C. special lamp was not available, and secondly a photoflood lamp is cheap and easily obtained. Thirdly, the electrical connections are of the simplest and the lamp can be plugged directly into a light socket or point without the need for a separate switch. The lamp is readily available in all standard voltages, with a Bayonet or Edison Screw Cap.

Technical data of the lamp is as follows:—

270 watt ; 33 lumens per watt ; life 2 hours ; operating temperature of filament 3,250° to 3,300° Kelvin or 3,525° to 3.573° C. Bulb envelope—soda lime glass.

In actual practice the life of the lamp is much more than two hours, but the manufacturers will only guarantee an efficiency of 33 lumens per watt for this period.

The No. 2 lamp is not such an efficient generator of ultra-violet because it operates at 31 lumens per watt.

As it will be seen from the diagram, the cabinet is of very simple construction ; it consists essentially of a light-tight box 9 ins. by 7 ins. by 13 ins., divided into three compartments. The upper compartment contains a No. 1 Photoflood Lamp, the emission from which is very rich as compared with normal filament lamps in " actinic " or ultra-violet radiation. Let into the floor of compartment is a piece of " Woods " glass, 2 ins. by 2 ins., which is opaque to visible light rays (4,200Å to 7,800Å) but allows the invisible ultra-violet rays, mostly 3,750Å, to pass. In the top of No. 3 compartment is a 2 ins. quartz, double convex converging lens. Quartz, as it is very well known, is transparent to the short ultra-violet light rays. No. 1 compartment is painted with a white heat-resisting enamel and the other two compartments blacked with optical black. The type of lamp holder is not important.. I prefer the Edison screw type, but it is important that the filament should be in the centre of the filter.

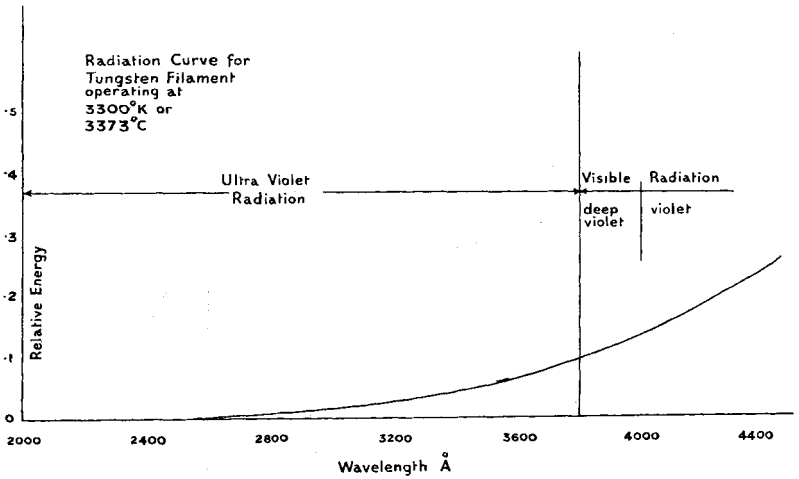

In use, a piece of black velvet or cloth (non-fluorescing) is placed in the bottom of No. 3 compartment. The box is then closed up, the specimen placed under the lens and the lamp switched on. A 4 ins. by 4 ins. opening is the most convenient size.

For diagonostic purposes the apparatus should be used with care. A dull violet colour should not be confused with a violet fluorescence as most filters let through a little visible violet light which is reflected by the plane surfaces of minerals and other gemstones and this can obscure very weak fluorescence effects. It has been suggested that a silver coin also placed in the ultra-violet beam will enable the observer to detect the difference between reflected visible violet light and violet fluorescence.

It is difficult, if not impossible, to enumerate the results that can be expected from the apparatus ; many writers have detailed specific results with certain minerals, but I would suggest that an attempt should be made to read papers on fluorescence as a whole and not confined to those upon gemstones. As with the spectroscope, a negative result does not necessarily mean the stone will not fluoresce under other conditions.

Most gemmologists would be well advised to study the appearance of a diamond brooch under an ultra-violet lamp. Experience in this field, as in most others, often pays handsome dividends.

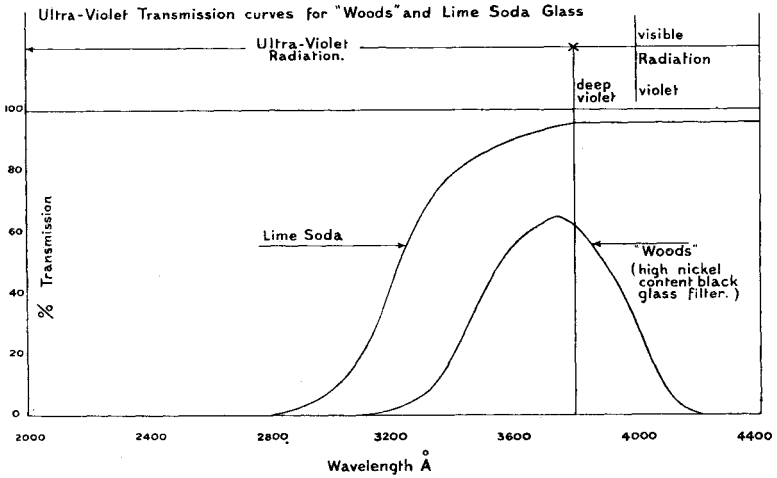

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Gemmological Abstracts

GÜBELIN (E. J.). ***Are synthetic red spinels available?*** Gems and Gemology, Vol. VI, No. 10, pp. 307-309 and 332. Summer, 1950.

A review of the reasons why synthetic red spinel is not a commercial proposition. The Verneuil process does not lend itself to the manufacture of spinel of normal equimolecular composition, and synthetic spinels have the composition $MgO\ 3.5Al_2O_3$, with the excess alumina in the cubic form of gamma-alumina. Due to the distinct difference in the chemical compounds of synthetic corundum and synthetic spinel, the addition of chromic oxide produces a red colour in corundum and a green colour in spinel. On heating ruby to 500-600° C. it assumes a green colour and reverts to its original red on cooling. On heating a synthetic green spinel to 950-1,050° C., part of the excess alumina is precipitated and the stone becomes cloudy. Raising to 1,075° C. results in weakening the spinel's structure with destruction of transparency—but the stone becomes red. The mechanism of these colour changes is fully discussed. Synthetic ruby red spinel can only be made if the ratio of Al_2O_3 to MgO is 1:1. Mention is made of experiments to produce a manufactured ruby red spinel with equimolecular proportions of alumina and magnesium oxide coloured with chromic oxide with the result that the tiny boules produced are cracked and shattered and no material suitable for cutting is obtained. Twelve references are given.

R. W.

SCHMIDT (P.). ***Der lapislazuli.*** (The lapis lazuli.) Uhren, Schmuck, und edles Gerät, 1950, pp. 235-236 (8).

Short historical review. Mentions important rôle played by lapis lazuli with the Sumerians (about 2030-2575 B.C.), the Egyptians, the Babylonians. It was also the favourite stone of Louis XIV of France and Ludwig II of Bavaria.

EHRMANN (Martin L.). ***Bombarded diamonds.*** Gems and Gemology, Vol. VI, No. 10, pp. 295-297 and 318. Summer, 1950.

Records the results of experiments on the colouring of diamonds by cyclotronic bombardment, the cyclotrons at the University of California and those at Harvard and Columbia Universities being used for the tests. Early experiments showed that the colours produced on Cape stones by two to six minutes' exposure to deuteron bombardment were light green to dark brown. The initial colour of the stone did not influence the resultant colour. A suggestion is made that the difference in induced colour may be due to any one of the trace elements which have been found to be present in diamond.

In the early experiments it was found that the colouring was only skin-deep but permanent. Small burn marks, shown as black pin-points, were seen throughout the stone. An initial radio-activity persists for thirty minutes to twenty-four hours, after which the stone ceases to show any sign of radio-activity. Slight recutting restored the original colour.

Ten diamonds placed in the cyclotrons for seven to eight days outside the area of the beam were found to be all coloured a light green by the gamma and neutron radiation. Such colouring was found to fade gradually to the original colour on exposure to daylight.

Some irradiated diamonds, showing fluorescence before treatment, were found to have lost all trace of it after they had been bombarded. Some retained their fluorescence. A diamond accidentally dropped in the cyclotron and left for about two weeks was found to have assumed a ruby-red colour which turned to a dirty brown when the radio-activity ceased.

Four diamonds subjected to a five-minute alpha particle bombardment with a 2 micro amp. beam current and 40 million volt energy showed that two of the stones turned whiter and the other two to a brown colour. With increase of current to 15 micro amp. and a four-minute exposure, another diamond turned to a tourmaline green colour. Ten stones bombarded with deuterons from a 10-15 micro amp. beam at 20 million volt energy produced colours ranging from olivine green, tourmaline green, bluish zircon green and light to dark browns. After recutting these stones kept their

new colour, and it is therefore considered that the higher energy and current produce complete penetration of the stone. R. W.

DRAPER (Thomas). ***The origin and distribution of diamonds in Brazil.*** Gems and Gemology, Vol. VI, No. 10, pp. 298-306. Summer, 1950.

The second part of an interesting series of articles includes a general survey of the diamond localities in Brazil. Geological theories are mentioned and discussed and a comparison made of the associated minerals with those of the South African sources. Fourteen diamond fields are individually reviewed. Eight illustrations and one map. R. W.

FISCHER (W.). ***Etwas von Nephrit.*** (Something about Nephrite.) Gold und Silber, 1950, 18-19 (No. 7).

Historical review mentioning especially finds of tools made of nephrite in primitive paling huts on the Swiss seas. The material is still available in Europe, i.e. " Jordansmüller Nephrit " from Silesia.

TAYLOR (H. E.) & HILL (D. K.). ***The identification of stones in glass.*** Journ. Soc. Glass Technology, 1950, *34*, 25-39 (No. 156).

Techniques used in Department of Glass Technology, University of Sheffield, for identification of stone inclusions in glass are preliminary examination of the stone with a hand lens, microscopic examination of stone when immersed in liquid of refractive index similar to that of surrounding glass, microscopic examination of thin sections, and examination of X-ray diffraction pattern. Features which provide information at any stage as to the identity and origin of stone are indicated, and relative applicabilities of visual and X-ray tests discussed. E. S.

CHUDOBA (K. F.). ***Der synthetischen Edelsteine Entwicklung und Fortschritt.*** (Development and progress of synthetic gems.) Gold und Silber, 1950, 3, 18-19 (No. 5).

The principle of the Verneuil furnace is shortly described and the present stage of gem synthesis discussed, mentioning synthetic corundum, spinel, star corundum and rutile. Attention is drawn to the rod-boule. Also dealt with is the emerald synthesis by I.G.

Farben and by Carrol F. Chatham. Not mentioned are means of distinguishing between synthetic and genuine stone. E. S.

TRUMPER (L. C.). ***Measuring Dispersion.*** Gemmologist, Vol. XIX, 230, p. 199.

Describes an attempt to measure dispersion on a simply constructed instrument. The main purpose was not accomplished, but a good guide to the dispersive power of gems was obtained.

K. T.

KENNEDY (N. W.). ***The Genesis of Gemstones.*** Gemmologist, Vol. XIX, 230, p. 191 (Part 1).

A simply expressed article dealing with the formation of gems in the earth's crust in greater detail than K. Schlossmacher's recent article (Schmuck, 1950, 3—Journ. Gemmology, Vol. II, 7, p. 321).

K. T.

FIELD (D. S. M.). ***Arctic Gems.*** Gemmologist, Vol. XIX, 229, p. 177.

A restatement of details of some gem minerals found in Arctic regions originally published in Geological Survey of Canada Report, New Series, Vol. XI, and the Ottawa Naturalist (1915). A. G.

CROLL (I. C. H.). ***The Opal Industry in Australia.*** Commonwealth of Australia, Dept. Supply and Develop. Bulletin No. 17, 1950.

A description of the opal industry in Australia, with some suggestions for its stabilization and improvement. The bulletin emphasizes that opal production is less than 0.05 per cent. of the total mineral production in the Commonwealth and that there is no commercial use for the mineral other than as a gem. Part II of the bulletin (Part I deals with occurrence and production), dealing with cutting and marketing, is of interest for its comments on the controversies that exist regarding opal doublets. Opals seen in many Australian jewellers' windows are of inferior quality and create an unfortunate impression with the public. A proposal that a Committee of Control be set up to safeguard interests of all sections of the industry is made, though it is considered that it is the responsibility of the industry itself to carry out necessary improvements.

H. G.

ASSOCIATION NOTICES

EDITORIAL JUBILEE

In October this year Dr. L. J. Spencer, C.B.E., F.R.S., completed 50 years as Editor of the "Mineralogical Magazine," the publication of the Mineralogical Society. The December, 1950, number of the "Mineralogical Magazine" will be a special number in honour of the Editor.

The Council of the Association has extended its congratulations and good wishes to Dr. Spencer.

GIFTS TO ASSOCIATION

The Council of the Association acknowledges the gift of various packets of gemstones, the generosity of Mr. E. S. Campbell, Jeweller, Brompton Road, London, S.W.7, a member of the National Association of Goldsmiths of Great Britain.

TALKS BY FELLOWS

K. Parkinson: Various talks to audiences in Ceylon, April to September, 1950. Mr. Parkinson has recently had a six months' visit to Ceylon and has obtained much information and experience regarding the methods of mining, cutting and marketing of the gems that are found in the Island.

G. A. Blythe: "Gemstones," Southend Inner Wheel, July 3rd, 1950. "Gems," at Westcliff-on-Sea, Monday, October 2nd.

1951 EXAMINATIONS IN GEMMOLOGY

The 1951 examinations in Gemmology will be held as follows:—

Preliminary: Great Britain and Overseas—Wednesday, June 6th.

Diploma: Theoretical papers—Great Britain and Overseas, Thursday, June 7th. Practical papers—London and Overseas, Friday, June 8th. Edinburgh, Monday, May 28th; Glasgow, Tuesday, May 29th; Birmingham, Friday, June 1st.

Examination entry forms are obtainable from the Association Offices and all applications for entry into the examinations must be received and registered before (*a*) Overseas, March 1st; (*b*) Great Britain, April 30th.

CEYLON

In August, Mr. Kenneth Parkinson, F.G.A., who has just completed a six months' visit to Ceylon, received a commission to rearrange the well-known gem museum of Messrs. Abdul Caffoor, the jewellers of Colombo. Mr. Parkinson received carte blanche to do the rearranging as he thought

fit. Apparently the Museum has been somewhat neglected since its partial use by naval units during the last war and the task of sorting out the many superb gem specimens from the more dubious varieties is one which would appeal to any gemmologist.

AMERICA

The Gemological Institute of America have appointed Mr. R. M. Shipley, Jnr., to be an Honorary Research Member. The only other person to be accorded this distinction by the Institute is Dr. Edward J. Gübelin, of Lucerne.

COUNCIL MEETING

A meeting of the Council of the Association was held at 19-25, Gutter Lane, London, E.C.2, on Wednesday, August 16th, 1950. Mr. F. H. Knowles-Brown presided and welcomed Messrs. A. R. Popley and W. Stern, two new members of Council.

The following were elected to membership of the Association:—

FELLOWS

S. C. Dixon (Reigate).
E. E. Foskett (London).
Hans van Starrex (Colombo, Ceylon).

PROBATIONARY

D. K. Lynch, (London, S.W.).
Miss S. G. Warnes (King's Lynn).

ORDINARY

Heinz Goebeler (Munster, Germany).
Meyer Rosenbaum (Detroit, U.S.A.).

The Council set up a sub-committee to consider and report on the working of the Association since the date of Incorporation, with special reference to the examination awards, subscriptions, adequacy of Articles of Association and Bye-Laws and the improvement of services to members.

ASSOCIATESHIP

In view of the increased facilities that exist overseas for sitting for the practical section of the Association's diploma examinations, it has been decided to discontinue the Associateship examination. Entries for this examination have always been small and it has been found that nearly all candidates who have had a temporary difficulty in taking both sections of the examination in the same year have preferred to wait and enter for the Fellowship examination.

In future no award will be made except after qualification in the complete Diploma examination. A sub-committee of the Council is now considering the advisability or otherwise of permitting the theoretical and practical parts of the Diploma examination to be taken in different years.

1950 EXAMINATION RESULTS

A LARGE number of entries was received for the Preliminary Examinations of the Gemmological Association of Great Britain, 19 from Overseas and 120 in Great Britain, making a total of 139. Upon the recommendation of the examiners the Rayner Prize has been awarded to Mr. I. N. Instone, of Messrs. Biggs of Farnham, Ltd.

Ninety-eight candidates presented themselves for the Diploma (Fellowship) Examinations, of whom 81 sat in Great Britain and 17 Overseas ; of these, two did not take the practical part of the examinations and could qualify for Associateship only. The award of the Tully Medal has been made to Mr. H. L. Zwirs, of Messrs. N. V. Begeer van Kempen en Vos, for the knowledge of the subject displayed in his papers. The Anderson Prize has been awarded to Mr. A. Schaap, of Messrs. S. Spyer, for the best work in the practical section.

The following is a list of successful candidates, arranged alphabetically:

DIPLOMA

Qualified with Distinction

Akehurst, H. R. (Saskatoon, Canada)
Coote, J. W. (Los Angeles, U.S.A.)
Corfield, R. H. (London)
Gunters, H. D. (The Hague, Netherlands)
Jennings, J. D. (Windsor, Canada)
Katz, B. (Johannesburg, S. Africa)
O'Donoghue, T. J. (London)
Phillips, J. A. (Los Angeles, U.S.A.)
Schaap, A. (Amsterdam, Netherlands)
Schunk, J. E. (Los Angeles, U.S.A.
Shapshak, L. (Johannesburg, S. Africa)
Zwirs, H. L. (Utrecht, Netherlands)

Qualified

Aspinall, T. R. (London).
Aston, G. R. C. (Gt. Missenden)
Bailey, B. O. (Birmingham)
Batty, R. W. (Southport)
Best, J. (Stourbridge)
Boyes, K. A. (Scholes, Leeds)
Brady, R. C. (Ipswich)
Bruton, E. M. (Wembley).
Cassidy, R. F. (Worcester).
Chapman, V. K. (Perth)
Chisholm, J. R. H. (Leverstock Green)
Cornelius, A. R. (London)
Crosthwaite, S. A. (Glasgow)
Davidge, K. C. (Otford)
Davison, P. J. F. (Goodmayes)
Denton, G. W. (Clacton-on-Sea)
de Rosa, R. (London)
Doidge, R. J. (Tavistock)
Dyce, S. B. (Perth)
Falconer, H. S. (Edinburgh)
Fishberg, H. C. (Edgware)
Fishberg, J. M. (London)
Frake, W. J. (London)
Garner, L. W. (London)
Gribben, A. T. (Birmingham)
Hanslip, M. J. (Torpoint)
Hathaway,, Miss A. H. (Stratford-on-Avon)
Heighes, C. E. (Los Angeles, U.S.A.)
Hemachandra, P. (Colombo, Ceylon)

Henn, Miss B. M. (Bridgnorth)
Hollander, Miss J. C. (London)
Hurst, J. C. (Olton)
Hyde, J. L. (Hounslow)
Inch, A. R. (Currie)
Jarvis, C. A. (Ilford)
Jones, O. D. (Burton-on-Trent)
King, R. F. (Welling)
Modahl, O. (Oslo, Norway)
Pellett, W. (London)
Quartermain, J. F. (Westgate-on-Sea)
Raymond, P. (Kenton)
Rillstone, R. (Benalla, Australia)
Sawyer, J. B. (London)
Shaw, J. R. (Great Bridge)
Shipster, T. R. (London)
Siu, M. C. (Hong Kong)
Snell, J. S. (Ramford)
Speed, P. G. ((London)
Thomas-Ferrand, Mrs. J. M. (Bury St. Edmunds)
Tindall, E. H. (Pool-in-Wharfedale)
van der Loo, J. A. M. (Rotterdam, Netherlands)
van Starrex, B. (London)
Wainwright, F. (Hutton)
Warnes, Miss S. G. (King's Lynn)
Warren, F. W. (Bristol)
Watkins, A. G. (London)
Whitehead, M. W. (Surbiton)

Diploma (Associateship) Examination

Cunningham, F. M. (Toronto, Canada)
Lowe, R. W. (Broken Hill, N. Rhodesia)

PRELIMINARY

Akehurst, H. R. (Saskatoon, Canada)
Alexander, D. (Glasgow)
Armstrong, A. H. G. (Stirling)
Austin, W. F. (Rugby)
Belton, C. G. (Southend-on-Sea)
Bishop, E. A. (Southend-on-Sea)
Bowden, F. A. (Plymouth)
Bradbury, D. S. (London)
Bradfield, W. H. (London)
Bridges, R. J. (London)
Broadbent, Miss S. A. (Farnham)
Brotherton, C. (Buxton)
Browne, P. C. (Nottingham)
Caffell, E. W. (Old Woking)
Caffoor, M. A. N. (London)
Cater, C. W. (Thornton Heath)
Caudell, P. M. (London)
Clark, Miss J. M. (Sutton Coldfield)
Clark, L. D. S. (Surbiton)
Collinson, D. E. (Leicester)
Coote, J. W. (Los Angeles, U.S.A.)
Craik, E. D. (Edinburgh)
Crook, Miss W. E. (London)
Cuss, F. C. (London)
Cutler, M. (London)
Davis, G. W. (Birmingham)
Denyer, B. C. (Kenton)
Ekanayaka, F. L. D. (Colombo, Ceylon)
Fine, H. D. (London)
Franks, A. B. (Brighton)
Gauton, G. W. (Hadley)
Goodbody, R. F. (Petersfield)
Gulian, K. (Cairo, Egypt)
Gunters, H. D. (The Hague,, Netherlands)
Gush, Mrs. I. N. (Johannesburg, S. Africa)
Harris, D. I. (London)
Harrison, Miss M. A. (Lichfield)
Hattle, R. G. (Helensburgh)
Heighes, C. E. (Los Angeles, U.S.A.)
Hodges, J. F. (Chester)
Hunt, P. (London)
Instone, I. N. (Farnham)
Jackson, F. W. (London)
Jennings, J. D. (Windsor, Canada)
Jones, A. E. (London)

Kibe, V. R. (Indore, Central India)
Knowles-Brown, P. (London)
Kolb, H. F. (London)
Kutock, M. (London)
Leech, R. A. (Ilford)
Lerman, A. (Toronto, Canada)
Lewis, Miss B. E. (Bristol)
Lumsden, Miss J. G. (Edinburgh)
Lynch, D. K. (London)
MacDonald, D. (Airdrie)
MacDonald, H. F. (Glasgow)
MacDonald, Mrs. M. E. (Airdrie)
McIntosh, C. (Glasgow)
MacKenzie, I. (Greenock)
Martin, W. E. (Hull)
Mason, S. (Harrogate)
Mitchelson, A. (Gateshead)
Morris, H. (Edinburgh)
Mountain, Miss D. J. (Worthing)
Myers, G. (Wembley)
Myhre, H. (Ljan, Norway)
Neerincx, Miss R. (London)
Perry, J. A. (Southend-on-Sea)
Phillips, J. A. (Los Angeles, U.S.A.)
Pilling, Miss E. M. (Keston)
Pratt, Miss L. D. (London)
Rae, J. W. (London)
Randall, J. A. (Bath)
Russell, B. T. (London)
Schaap, A. (Amsterdam, Netherlands)
Schroeder , Miss V. (Birmingham)
Schunk, J. E. (Los Angeles, U.S.A.)
Scott, J. F. (Lincoln)
Sena, W. (Singapore)
Shepherd, G. T. (Birmingham)
Spence, C. R. (Taunton)
Stockwell, J. C. (Middlesbrough)
Stol, D. (Amersfoort, Netherlands)
Swettenham, G. W. (London)
Towe, E. G. (Edinburgh)
Turnbull, K. (London)
van der Loo, J. A. M. (Rotterdam, Netherlands)
van Loo, J. (Zeist, Netherlands)
Wakelin, R. J. G. (Birmingham)
Watkins, A. G. (London)
White, W. (Wembley Park)
Witherall, H. P. (Dunstable)
Wood, Miss E. A. A. (Edinburgh)
Wright, T. J. (London)
Wyatt, J. (Bromley)
Zwirs, H. L. (Utrecht, Netherlands)

REUNION OF MEMBERS AND PRESENTATION OF AWARDS

Over one hundred Fellows and Members of the Association met at Goldsmiths' Hall, Foster Lane, London, E.C.2, on Wednesday, October 11th, 1950, at a reunion gathering. Following the reunion the presentation of prizes and diplomas in connection with this year's examinations was made in the Livery Hall. Mr. F. H. Knowles-Brown, Chairman of the Association, introduced Mr. F. E. Lawson Clarke, Chairman of the National Association of Goldsmiths of Great Britain, who presented the awards. Dr. G. F. Herbert Smith, President, proposed a vote of thanks to Mr. Clarke and to the Wardens of the Worshipful Company of Goldsmiths for use of the Hall. The winner of the Tully Medal, Mr. H. L. Zwirs, and of the Anderson prize, Mr. A. Schaap, made a special journey from Holland, together with another diploma winner, Mr. H. D. Gunters, in order to receive their awards. It was the first occasion that the Tully Medal had been awarded to an overseas candidate, and Mr. D. Dresme, Treasurer of the Netherlands Gemmological Association, also attended to support his colleagues.

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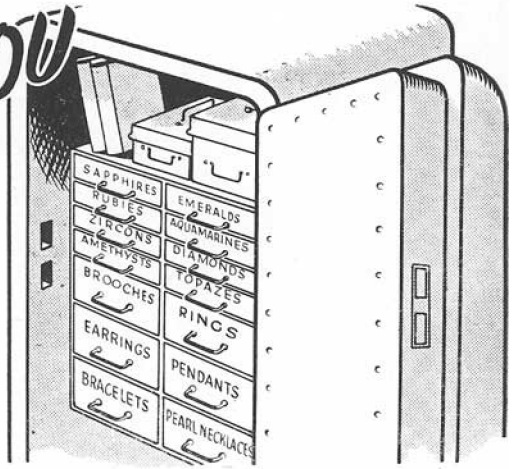

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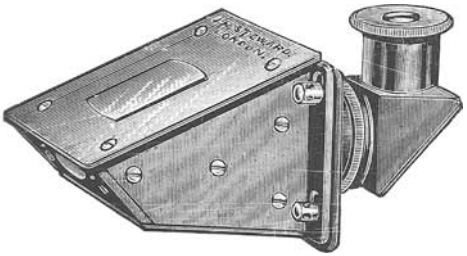

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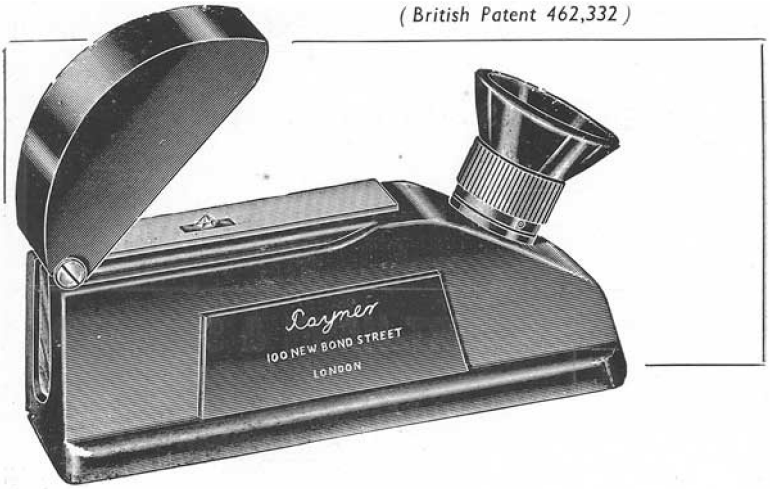

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No. 8
October, 1950

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THE JOURNAL OF GEMMOLOGY
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Vol. III, No. I JANUARY 1951

BRAZILIANITE

by

L. C. TRUMPER, B.Sc , F.G.A.

THE discovery of a new mineral and at the same time a new gemstone is something of an event, and, as is now quite well known, that was the distinction attaching to well-formed greenish yellow crystals found late in 1944 at a locality variously described as near Arrasuahy, near Corrego Frio, or near Divino in the Conselheira Pena district of Minas Gerais, Brazil.

The mineral was first described by F. H. Pough and E. P. Henderson in 1945 and named brazilianite by them in honour of the country in which it was found.

When first discovered, the crystals were mistaken for chrysoberyl, to which they have some resemblance in colour, but not otherwise.

A further source was discovered in July, 1947, by C. Frondel and Mrs. M. L. Lindberg at the Palermo mine, North Groton, in Grafton County, New Hampshire, in the U.S.A.

So far as is known, the most exact description of the original Brazilian source has been provided by Sr. M. Pimental de Godoy, who says that " The deposit is an altered pegmatite dike about one metre in width between walls of biotite schist.

" The brazilianite appears to be associated with mica, feldspar and quartz. The locality is the south slope of a hill which divides the Rio Doce and the Rio Sao Matheus, near the head of a small tributary of the Divino river, which runs in turn into the Laranjeiras and then joins the Rio Doce.

" The deposit belongs to the mica group of the Conselheira Pena district in the eastern part of the State of Minas Gerais."

In addition to those minerals mentioned above, two further phosphate minerals new to science are associated with brazilianite, since named scorzalite and souzalite, and also albite, muscovite, apatite, zircon and tapiolite, the pegmatite having a central and border zone.

The second occurrence has been described in great detail by Clifford Frondel and Mrs. Marie Louise Lindberg.

The Palermo Mine at which the discovery was made has been worked for mica since 1863. It is at present being worked for beryl and feldspar and will again be worked for mica at a later stage.

The number one Palermo pegmatite is a lens-shaped dike well zoned internally into approximately three main zones. The outer zone contains quartz, biotite, feldspar and black tourmaline. The intermediate zone, in addition to the above, contains perthite, beryl, lazulite, other phosphates and small amounts of sulphide minerals (it is this zone which is being worked). The central zone is essentially a quartz core, but contains other minerals, particularly at the edge, notably triphylite, perthite and some beryl.

The brazilianite crystals were found in cavities at the contact of the intermediate and central zones and appears to have been formed by hydrothermal action on the triphylite with the formation of other associated minerals as apatite, ludlamite, whitlockite, siderite and triploidite.

MATERIAL.

A large crystal of 973 grams is in the Canfield collection of minerals at the U.S. National Museum in Washington. Crystals of 868 and 852 grams are to be found in the American Museum of Natural History in New York, and other crystals in the Divisao do Geologia e Mineralogia at Rio de Janeiro, and in the mineral gallery at the Natural History Museum, South Kensington, London.

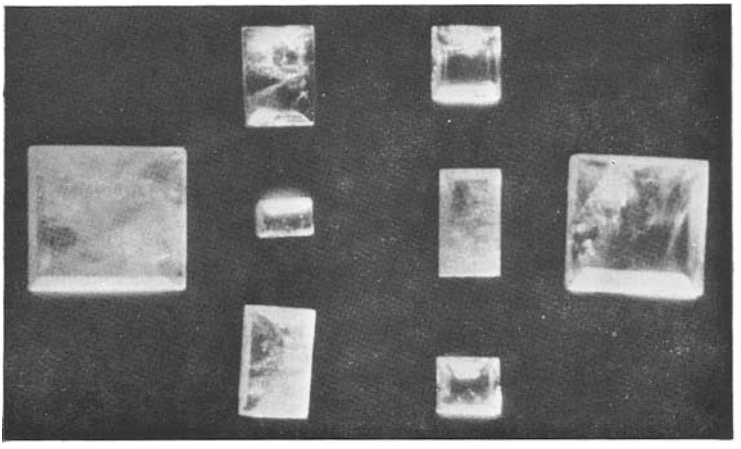

Above: Gemstones cut from 89 carat brazilianite crystal.

PHOTO-MICROGRAPHS OF BRAZILIANITE

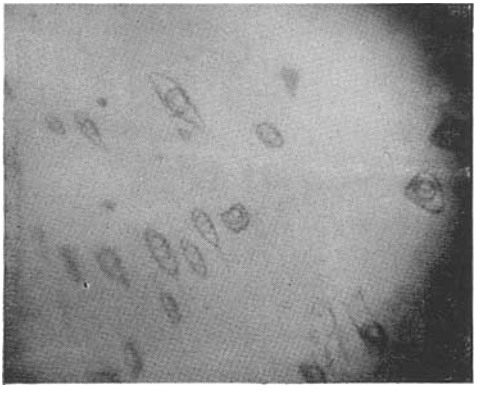

Above: Liquid and gas filled inclusions in brazilianite. × 80

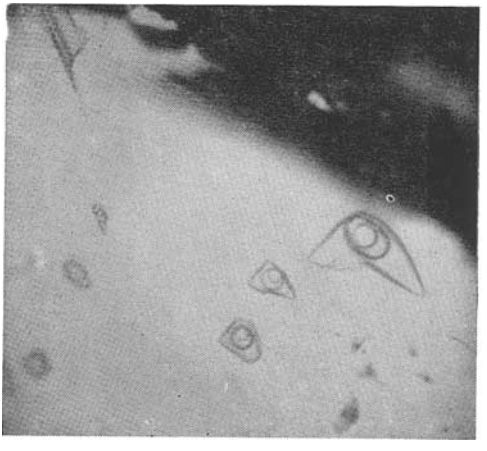

Right: Cavities in brazilianite filled with non-miscible liquids and gas bubbles. × 100. (Kodak verichrome film, 8 secs. exposure, $\frac{2}{3}''$ objective, X10 ocular.)

An emerald-cut stone of 23 carats is in the collection of the Divisao do Geologia e Mineralogia in Rio de Janeiro and an oval brilliant of 19 carats is in the American Museum of Natural History in New York.

Mr. B. W. Anderson has two crystals and the writer obtained early in 1950 a crystal of 63 carats, partly clear and partly translucent by reason of flaws and liquid inclusions, the locality being given as " Corrego Frio, N. of Sao Tome, Minas Gerais, Brazil." (Sr. M. P. do Godoy quotes: " Corrego Frio, Municipio de Conselheira Pena, Minas Gerais.")

Later in the same year a further crystal of 89 carats was obtained, part of which was of superb gem quality ; the locality of this crystal was given as near Conselheira Pena, Rio Doce, Minas Gerais, Brazil.

After making full-scale drawings, photographing in natural colour and taking various measurements, this crystal has since been cut in Birmingham by a lapidary of Shipton & Co., Ltd., under the personal supervision of Miss P. E. Cutts, F.G.A., into the following stones:—

(1) A baguette of 2.988 carats. S.G. 2.997. R.I. 1.600, 1.620. Containing one flaw and numerous liquid fingerprint inclusions.

(2) A square cut stone of 1.507 carats. S.G. 2.998. R.I. 1.600, 1.620.

An almost clean stone, very brilliant and attractive, containing a few liquid fingerprint inclusions, cut from the cleanest part of the crystal. This would have been a much larger stone, but unfortunately a piece flew off which was recut into a smaller stone.

(3) A large square cut stone of 11.13 carats. S.G. 2.997. R.I. 1.601, 1.621.

Transparent to cloudy due to enormous numbers of liquid filled inclusions.

(4) A small square cut stone of 1.02 carats.

Clear, transparent with a slight flaw in one corner with a few liquid filled inclusions and some minute incipient cleavages.

(5) A baguette of 2.215 carats.

Mainly clear and transparent, slightly paler, but numerous incipient cleavages and filimentous canals, typical liquid filled

PHOTOMICROGRAPHS
OF
BRAZILIANITE

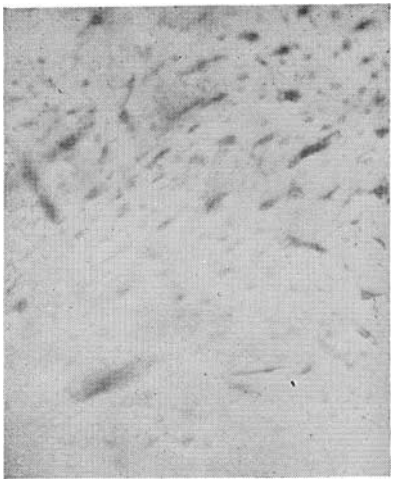

Liquid filled inclusions in brazilianite. × 20.
($1\frac{1}{2}''$ objective X6 ocular.)

Liquid and gas filled inclusions in brazilianite. × 100.
($\frac{2}{3}''$ objective X10 ocular.)

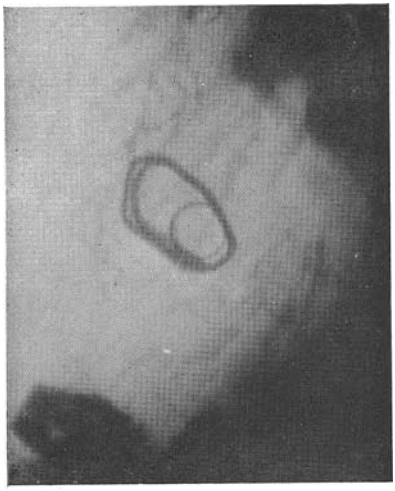

Large liquid and gas filled inclusions in brazilianite.
× 80.

Cavities in brazilianite filled with liquid gas and bubbles.
× 80

inclusions and a few larger cavities partly filled with liquid and a movable gas bubble.

(6) A small oblong fancy step cut stone of .415 carats.
Clear, transparent, paler than the average, no typical inclusions, flawed at base.

(7) An inferior oblong flat of 1.57 carats.
Clear, transparent and with many most typical liquid filled inclusions.

(8) A large square cut stone of 8.22 carats.
Mainly clear, transparent, with liquid filled inclusions, but unfortunately spoilt by a portion of the base of the stone cleaving away.

CUTTING.

The lapidary reports that cutting brazilianite is very similar to cutting zircon. Having had no previous experience of cutting this stone, it was necessary to experiment to see which surface would take the best polish. This was found to be along the cleavage plane. Using this plane as the table facet, cutting was considerably easier and gave better results.

The cutter found that cleavage was more pronounced in the clear gem portions of the crystal than in the inferior or feathery part.

The friction of the cutting powder produced cleavage more readily than the polishing powder, which is, of course, smoother. Further, the heat of the cement used to mount the stones upon the lapidary's stick tends to produce cleavage.

An interesting feature of the cutting of brazilianite is the peculiar smell generated in the process. Careful interrogation with the lapidary resulted in this smell being agreed as akin to that of fireworks or gunpowder.

CRYSTALLOGRAPHIC SYSTEM.

From what has already been said it will be apparent that brazilianite is not only noteworthy as a new mineral, but also for the perfection and size of its crystals, which belong to the Monoclinic system.

The Brazilian crystals are found in two different habits: the smaller number, of which the 868 gram crystal previously mentioned is an example, are prismatic, the prisms being slightly

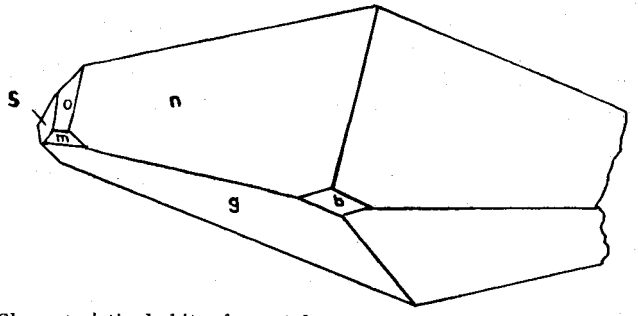

Characteristic habit of crystals from Palermo mine, North Groton, U.S.A. Grafton County, New Hampshire.

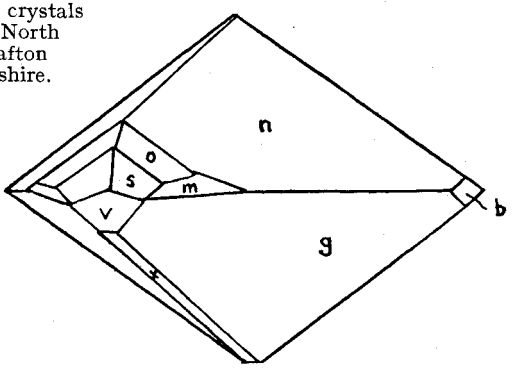

Coventional projection.

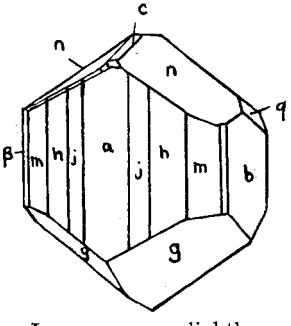

Less common slightly prismatic habit of brazilianite

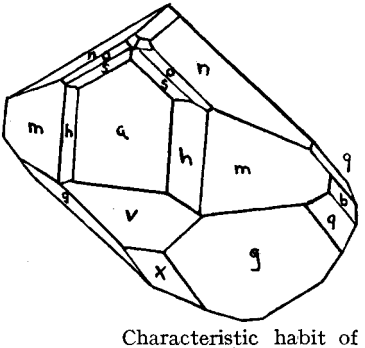

Characteristic habit of brazilianite

From Conselheira Pena, Minas Gerais.

elongated and striated and the crystals somewhat rounded in outline.

More frequently the prism zone is much narrower with the principal development in the 100 zone.

The crystals from the Palermo mine, on the other hand, show an entirely different habit, this being almost the only difference between the minerals from the two sources.

The prism zone is almost entirely suppressed, whilst the *n* (011)) and *g* ($\bar{1}11$) forms are strongly developed, thus giving the crystals an elongated four-sided appearance ; the crystals are attached to the matrix by one end of the 100 axis, as is frequently the case with the Brazilian crystals also.

The prism forms, which are characteristically striated parallel to the *c* axis, are not as noticeable as the clinodome *n*, and the negative bipyramid *g* ; *v* is a common form. The negative orthodomes X and W are rare but present in about half of the cases as a slender truncation between the faces of *g*. The prisms *m* and the pinacoids *a* and *b* are always observed. Other forms observed are *c*, *i*, *h*, *j*, *z*, *p*, *o*, *s* and *q*.

CLEAVAGE AND HARDNESS.

Brazilianite has a perfect cleavage parallel to the side pinacoid *b*, and incipient cleavages may frequently be observed parallel to this face throughout the crystal. Cleavage is more pronounced in the clear, gem part than in the inferior or feathery part of the crystal.

This cleavage is not too easily set going and does not unduly interfere with or prevent the satisfactory cutting of gemstones, provided due care is taken.

In spite of the well-marked cleavage referred to above, breakage more easily occurs as a conchoidal fracture. The mineral is brittle.

Unfortunately, brazilianite is not a hard mineral, though quite suitable for brooches, earrings and pendants, the hardness on Mohs's scale being $5\frac{1}{2}$.

COLOUR, TRANSPARENCY AND LUSTRE.

The colour is somewhere between Chartreuse yellow (B.C.C. 75) and Chartreuse green (B.C.C. 171) ; in the writer's opinion closer to the latter and matched very closely by the Wilson colour

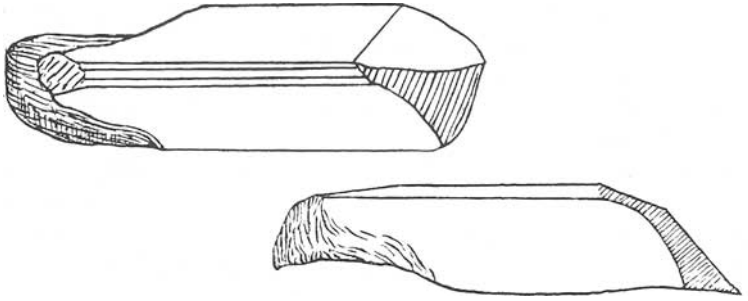

Part crystal of gem quality of 89 carats from Conselheira Pena, Minas Gerais, since cut into a number of stones.

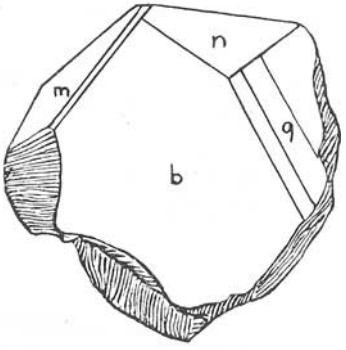

Part crystal of 63 carats from Corrego Frio, N. of Sao Tome.

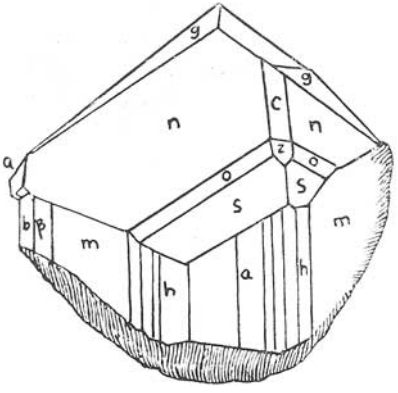

Well formed crystal from Brazil.

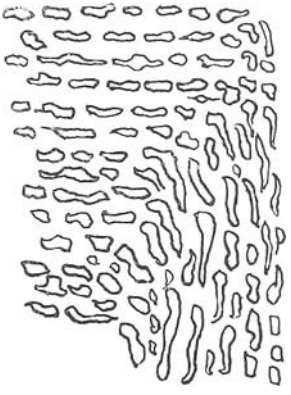

Typical liquid filled inclusions.

chart tint 663/2 of Chartreuse green. This tint is equivalent to British Colour Council Chartreuse green No. 171 and to Ridgeway Green-Yellow 27b, there being no equivalent in the Repertoire or Ostwald systems, nor any recognized equivalent Horticultural tint.

Measured on the Tintometer, the readings average: Blue .4 units, yellow 4.0 units ; equivalent to .4 units of green and 3.6 units of yellow, for the rough ; and on a cut stone, blue .5 units and yellow 3.5 units ; equivalent to .5 units of green and 3 units of yellow. The colour varies slightly in the same crystal and the Palermo material is slightly lighter in tint than the Brazilian and slightly less green.

Brazilianite occurs in transparent crystals well suited to the cutting of gemstones, though it is frequently semi-transparent to translucent either wholly or in part due to flaws and also to very frequent liquid filled inclusions.

The lustre of brazilianite is vitreous. On cutting, the stone takes a very high polish and has quite a slippery feel.

There is no change of colour under the Chelsea colour filter, and the reaction to ultra violet light is negative.

There is very slight dichroism observable as a change of shade only.

OPTICAL PROPERTIES.

The original readings of F. Pough and E. P. Henderson have since been shown to be too low by about .003. Recent readings have been as follows:—

Frondel and Lindberg ...	Brazilian	1.602	1.621
	Palermo	1.602	1.623
Anderson	Brazilian	1.602	1.623
Trumper	Brazilian	1.599	1.619
	Brazilian	1.602	1.622
(Cut stones)	Brazilian	1.600	1.620

Brazilianite is biaxial and positive in sign and the indices would appear to be (*a*) 1.602, (*b*) 1.609, (*c*) 1.622 and the double refraction .020 in extent. The dispersion is low, around .014. In a private communication, Mr. B. W. Anderson states that careful comparison with topaz and tourmaline as viewed through red and blue glasses on the spinel refractometer show brazilianite to have a distinctly lower dispersion than tourmaline (.017) and very similar to that of topaz (.014).

SPECIFIC GRAVITY.

The original determinations of F. Pough and E. P. Henderson again seem to have been on the low side, for recent determinations including on the original material are as follows:—

Frondel and Lindberg	... ...	Brazilian	2.980
		Palermo	2.985
Anderson (73.88 cts.)	... ...	Brazilian	2.992
(54.81 cts.)	... ...	Brazilian	2.993
Trumper (89.27 cts.)	... ...	Brazilian	2.993
(63.6 cts.)	... ...	Brazilian	2.990
11.13 cts. and 2.998 cts.	... ...	Cut stones	2.997

There is no difference between the Brazilian and Palermo mine sources and the Specific Gravity may be taken as 2.992 $\pm$.005.

ELECTRICAL PROPERTIES.

After rubbing strongly, brazilianite attracts small bits of cotton, and similar material, but only weakly.

CHEMICAL COMPOSITION.

Determinations by E. P. Henderson and M. L. Lindberg, the latter on both the original and Palermo mine occurrences, show that the mineral is a hydrous sodium aluminium phosphate, conforming very closely to the formula Na_2O, $3Al_2O_3$, $2P_2O_5$, $4H_2O$. Only a very minute trace of impurities was found, including a trace of Cl and Mn, but no fluorine, arsenic or vanadium.

Brazilianite is distinct from any known mineral and is in a group of its own. Its nearest approach is to Turquoise, CuO, $3Al_2O_3$, $2P_2O_5$, $4H_2O$, which is of interest to gemmologists, and to a phosphate mineral, Fremontite, which it was at first thought to be.

SPECTROSCOPIC EXAMINATION.

Examination with the direct vision type of spectroscope fails to disclose any absorption bands.

INCLUSIONS.

In the course of their detailed examination F. Pough and E. P. Henderson reported on the numerous flaws to be found as well as many flawless areas, but the only other inclusions they noted were some slender crystals of green tourmaline and muscovite.

Examined in oblique light, however, brazilianite is found to contain numerous liquid filled fingerprint type of inclusions which

do not appear to be in any particular zone, but buckled up as if composed of thin veil-like material freely suspended in a liquid of similar density.

Careful examination of these liquid filled inclusions under high magnification reveals that they are of a most interesting type. The cavities are partially filled with what appears to be a double bubble one inside the other. Both inner and outer bubbles are round except where in some cases the outer bubble of liquid is too large to assume this shape, when it conforms to some exxtent with the outline of the cavity.

What appears to be an inner bubble of liquid is, in fact, a bubble of gas and is spherical or oval in every case so far observed. There is little apparent difference between the refractive indices of the two concentric bubbles.

As far as can be ascertained, every single cavity, even long cracks or narrow filaments which are occasionally observed, contain these double bubbles of liquid and gas, which are colourless. Literally hundreds of them can be seen if the magnification is sufficiently high.

So far, in only a very few cases have larger cavities been found and these also contained the same contents, and here, on rocking the stone, the inner bubble of gas can be seen to float to the highest point in the liquid bubble surrounding it. Indeed, in the micro-photographs the inner bubbles may be seen all at the same end.

The liquid bubble has not been seen to move and invariably occupies the middle of the cavity.

The presence of the gas bubble is peculiar since the liquid bubble in no case completely fills the cavity, though the surrounding space between may be filled by a non-miscible liquid.

Careful examination of these inclusions, using the Becke line test under a moderately high power in parallel light, showed definitely, as was to be expected, that the body of the mineral was of higher R.I. than the inside of the cavity.

Further, the inner and presumed gas bubble has a lower R.I. than the liquid in which it occurs, again as was to be expected. It does, however, appear that the remainder of the cavity has a higher R.I. than the liquid and may thus be occupied in fact by a non-miscible liquid of higher R.I. than the liquid bubble occupying the middle of the cavities.

As each of these liquid filled formations is not wholly in any one plane, it is difficult to bring this characteristic out in microphotographs. In addition to flaws which are similarly buckled about at random, incipient cracks can frequently be seen parallel to the side pinacoid *b*, owing to the perfect cleavage of the mineral parallel to this face.

Slight variation in the depth of colour has already been noted.

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LETTER TO THE EDITOR

Dear Sir,

The article "Notes on an Ultra-Violet Ray Cabinet," by Bevis-Smith ("Journal of Gemmology," Vol. II, No. 8) was most interesting. It is to be hoped that more practical hints of this nature will be published during the coming year.

I would suggest the use of a "Transpex" lens in place of the rather expensive 2″ quartz affair. This would bring the cabinet within the reach of all.

The "Transpex" lens is produced by a London firm and is made by casting acrylic optical resin in accurately worked glass moulds. This process permits of aspherical surfaces—a type of correction seldom met with in glass lenses, owing to the prohibitive cost of manufacture.

For general use, an added advantage is that "Transpex" can readily be drilled and sawn, thus greatly facilitating the mounting of the lens.

D. S. M. FIELD.

Canada.

EMERALDS from the AJMER District, India

A. E. ALEXANDER, Ph.D., Tiffany & Co., New York

The writer recently examined several Indian emeralds which for colour rivalled those of Muzo origin.

The emeralds came from a section of India referred to as Ajmer. The gems under study weighed approximately one-half carat each, and were for the most part quite clear. Three-phase inclusions were identified and one remarkable group was photographed. (See Fig.)

The indices of refraction were high for emerald, being 1.581 and 1.591. In this respect the mineral resembled emeralds of Russian and South African origin. The density was found to be 2.75-2.76. Negative fluorescence was noted when the emeralds were subjected to ultra-violet and X-ray irradiation. Dichroism was found to be strong: emerald-green and blue-green. Chromium lines were identified with the Gübelin absorption spectroscope. Readings of 7050Å and 6550Å differ to those measurements obtained by Anderson and Webster for chromium lines in the emeralds they have examined.

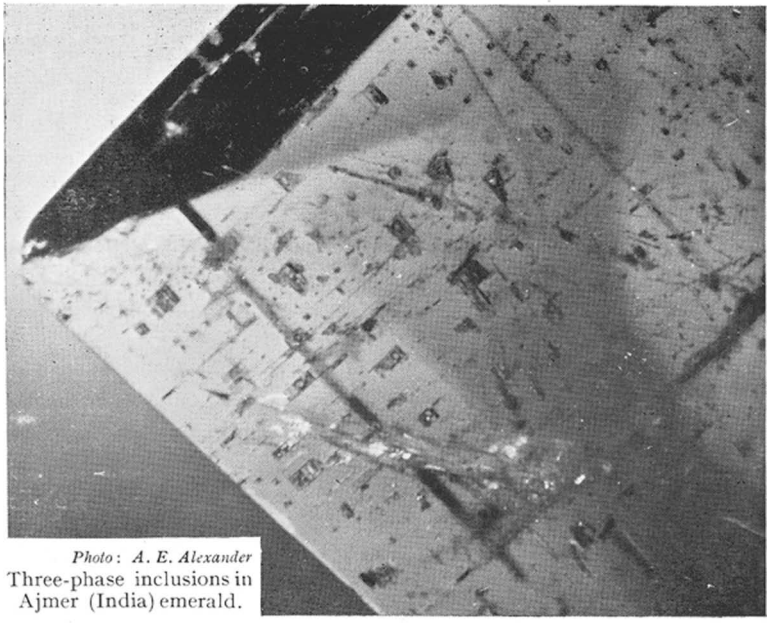

Photo: A. E. Alexander
Three-phase inclusions in Ajmer (India) emerald.

The James Bay Diamond Syndicate

by D. S. M. FIELD, A.G.A.

IN the " Journal of Gemmology," July, 1949, the writer reported on the known finds of diamond crystals in glacial drift which, according to international geological authorities, originated in the wilderness of Canada, somewhere north of the Great Lakes.

Further information regarding the possible existence of deposits of diamonds in that area has kindly been furnished by Mr. J. C. Honsberger, a well-known consulting mining engineer and geologist, who has had extensive mining experience in the hinterlands of Canada.

In February and March, 1950, Mr. Honsberger, in association with Mr. Norman Vincent, of Toronto, formed the James Bay Diamond Syndicate, with holdings consisting of a solid block of twenty-eight mining claims totalling two thousand acres, located in the Vassan-LaCorne-Pressiac area of north-western Quebec Province, approximately fifteen miles by road north-west of the celebrated mining town of Val d'Or, and five miles south of the LaCorne Molybdenite Mine. The property consists, for the most part, of level farm land with a few rock outcroppings, and is readily accessible to transportation, power and water.

Mr. Honsberger is of the opinion that a diamond of good commercial size has been located in a serpentinized peridotite on the southern half of the property, and extensive development work is now under way. In a letter dated 31st July, 1950, he informed the writer that " in a matter of several weeks, the Quebec Department of Mines will do a milling test on 100 tons of the believed diamond-bearing rock from Vassan Township at their testing plant at Val d'Or."

The suggestion of a diamond deposit in the Vassan area developed when news reached Mr. Honsberger that two well diggers had encountered unusual difficulty in sinking a vertical hole on the farm of Alvida Duval on 27th March, 1948. Details of the incident are contained in their sworn statement, given below:—

CANADA. Province of Quebec.

We, Peter E. Allard, of the town of Val d'Or, in the District of Abitibi, Province of Quebec, diamond driller, and Osias Allard,

of the Town of Val d'Or, in the District of Abitibi, Province of Quebec, diamond driller, do severally make oath and say

To Wit:

1. That we have been diamond drill runners in the Provinces of Quebec and Ontario for the past twenty years, during which time the years 1930 to 1944, inclusive, were spent in the employ of N. Morisette Diamond Drilling Company, of Haileybury, Ontario, and/or its predecessor.

2. In 1944 we established our own diamond drilling firm, known as Allard Bros., Reg'd.

3. During the past three years we have been drilling water wells at intermittent periods for the Department of Colonization of Quebec.

4. On March 27th, 1948, we were drilling a water well on the Duval farm, which is located on the south half of lot 14, Ranve VII, Vassan Township, County of Abitibi East, Quebec, within a few hundred feet north of the highway between Val d'Or and Amos. We had no employees on this job and operated the drill ourselves.

The Hole was a vertical hole which required sixteen feet of casing. After collaring the hole drilling was commenced with EX bits and we drilled steadily through a soft rock to a depth of sixty feet. At this point the advance of the rods stopped and the machine began to rise with its foundation. We immediately shut off the power and placed two barrels of water on the machine foundation. The machine was then started several times but the bit refused to advance whatsoever. Never in our twenty years of drilling experience had we encountered such a condition in drilling. The rods were then pulled and the bit was examined. The diamonds on the face of the bit were polished smooth and the bit was useless for further drilling. We then put on a new bit and tried to drill again. The rods refused to advance any distance that could be measured, and when the rods were pulled the second bit was found to be polished off as smoothly as the first, after a few minutes of use. We then went to Val d'Or and sharpened our chopping bit and on March 28th we went back to the drill, put on the chopping bit, and chopped down about two inches. Before commencing to chop we tied a sludge bag on to the T of the casing and thereby collected all the choppings. This sludge was placed in a small brown bottle and taken to our office in Val d'Or.

After the chopping operation a third new bit was installed and the hole was driven to a vertical depth of 121 feet with no difficulty whatsoever. At this point the hole was abandoned as no water was encountered. A second hole was started within a few feet of the first hole. This was also a vertical hole and was driven to a depth of sixty feet without any difficulty. The hole was then abandoned as no water flow was encountered. In the drilling of these two holes no attempt was made to lay the core in boxes as we were not

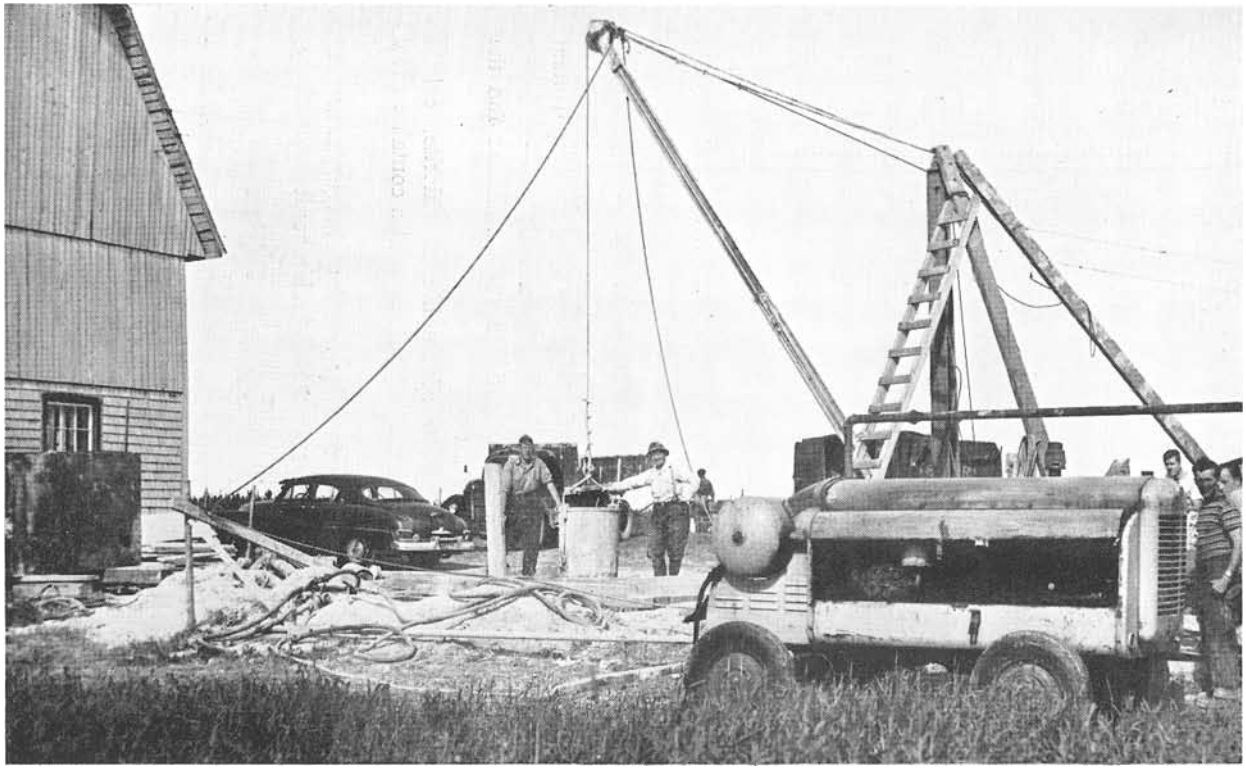

Photo: Courtesy of J. C. Honsberger, Esq.

Shaft sinking on the Duval farm, at the property of the James Bay Diamond Syndicate, Vassan Township, P.Q., August 2nd, 1950.

required by law to save the core. The core was dumped haphazardly beside the shack upon removal from the core barrel.

5. In February, 1949, Osias Allard called on J. C. Honsberger, mining engineer and geologist, at his office at Room 208, Lalonde Building, Val d'Or, P.Q., and related the aforegoing facts. These facts were later confirmed by Peter E. Allard. At Mr. Honsberger's request Osias Allard presented him with the sludge bottle and also, at Mr. Honsberger's request, they returned to the drill site and picked up, from the ground, what fragments of diamond drill core remained, amounting in all to about five feet of core, which was given to Mr. Honsberger.

NOTARIAL SEAL	Sworn before me at the village of St. Cyrille, in the District of Arthabaska, this 22nd day of March, 1950. (signed) "L. S. JOYAL."	(signed) "OSIAS ALLARD" .....
NOTARIAL SEAL	Sworn before me at the Town of Val d'Or, District of Abitibi, this 28th day of March, 1950. (signed) "ARMAND GILBERT."	(signed) "PETE E. ALLARD" .....

On 26th March, 1949, Mr. Honsberger submitted the bottle containing the choppings to Mr. B. T. Denis, Chief of the Mineral Deposits Branch of the Quebec Department of Mines. On 22nd April, Mr. Maurice Archimbault, Director of the Department of Mines Laboratories, Quebec City, replied as follows:—

"The sample submitted by you has been examined and the following results were obtained:—

"The sample is composed of amphibole, chlorite, calcite associated with a little mica and iron pyrites. It also contains a few grains of diamond."

The pieces of ore, recognized by Mr. Honsberger as serpentinized peridotite, were submitted to Mr. Archimbault on 6th May, 1949, with the request that the Department of Mines determine the origin of the rock and if microscopic diamond crystals occurred in it. The findings of the Department were detailed in a memorandum, dated 28th May, 1949. The rock was indeed a serpentinized peridotite, but no diamonds were found in the samples of core submitted.

When it is considered that the production in South Africa averages approximately one carat of diamond per eight tons of processed rock, this report is not at all surprising. Indeed, it is said

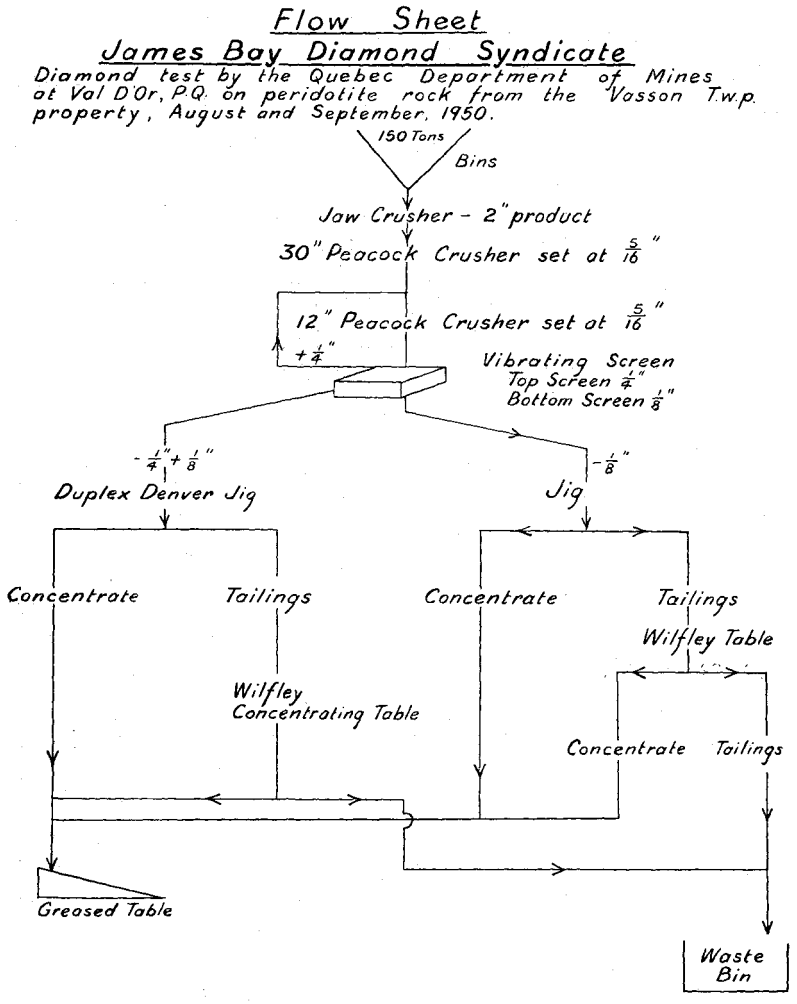

that some of the South African natives have worked a lifetime in the mines without ever having once observed a diamond *in situ*.

For this reason, it was decided that the examination of a large bulk sample of the peridotite from the Quebec property would be the only practical way to determine a possible diamond content.

Mr. Honsberger comments on the topography and geology of the area as follows:—

" During the past few years, the area has been mapped in detail by the Geological Survey of Canada, aided by the fact that hundreds of miles of good colonization road extends east and west and north and south through many parts of the area. The area lies parallel to, and fifteen to thirty miles north of the Cadillac-Malartic-Bourlamaque areas.

"A large mass of granodiorite, 28 miles long east-west, with a maximum width, north-south, of 12 miles, has been intruded, the basal rocks consisting of altered volcanics and sediments. A number of north-easterly trending diabase dykes cut all other formations. A number of peridotite and serpentinized peridotite intrusives have also been noted associated with the granodiorite and other intrusive rocks and widely interspersed in the volcanics.

" A wide range of metallic and non-metallic minerals have been found in the area, and during the war two mines—the Indian Molybdenite Corporation and the LaCorne Molybdenum project—produced molybdenite. The latter mine is about five miles north of the James Bay Diamond Syndicate's Vassan Township property. The LaCorne area is potentially capable of being a large producer of lithium ore (spodumene). Beryl, columbite, tantalite, etc., have also been found.

" . . . The extreme north-east corner of the . . . (Syndicate's group of claims) . . . is underlain by sedimentary rocks of the Kewagama group, consisting of greywacke, minor amphibolite, tuff and breccia. The remainder of the group is underlain by volcanic rocks, mostly andesite, intruded by several small granitic intrusives, a number of diorite dykes with numerous small outcrops of peridotite. The large LaCorne granodiorite batholith lies about 1,500 feet north-east of the north-east corner of the group. The percentage of rock outcroppings on the entire group is under two per cent., but it is believed that the overburden in many places is light."

In addition to the 2,000-acre property purchased by the Syndicate, considerable ground in the vicinity has been staked by private interests, including several " Big Names " in Canadian mining. It is estimated that a total of some 14,000 acres have been located.

Development of the Syndicate's holdings commenced late in July. At the present writing, a test shaft 9½ feet x 6 feet is being sunk to a depth of 65 feet. The contract for the sinking of the

shaft was awarded to Patrick W. Harrison & Company, of Noranda. This company will remove approximately 100 tons of rock from the shaft and truck it to the Val d'Or plant of the Quebec Department of Mines, where it will be thoroughly examined for diamonds. The machinery and equipment for the test was assembled by Mr. E. H. Bronson, a consulting metallurgist of Toronto, in co-operation with the Quebec Department of Mines. As a matter of fact, the flow sheet has been worked out by Mr. Grainger Grant, B.Sc., metallurgist for the Quebec Department of Mines, at their test plant in the Val d'Or area.

Should the test mentioned above disclose the presence of diamonds, a company will be formed for the purpose of testing and assessing the economic importance of the property.

FROM THE LABORATORY

An X-ray photograph of a shell of the pearly nautilus mounted in gold as a pendant.

The pearly nautilus (Nautilus pompilius), a mollusc of the order Tetrabranchia, of the class Cephalopoda, a relative of the cuttle fish, is found in the Indo-Pacific.

Although in some ways resembling a snail, it belongs to a different order, and has the shell divided into sections by "septa," which clearly show in the photograph.

The animal occupies the last compartment and the septa between the compartments are traversed by a shelly tube, the siphuncle, which in life contains a prolongation of the tissues of the mantle. This tube is also discernible on close inspection of the photograph.

Chinese creature of good augury, Ch'i-lin, probably 19th century. The figure is unusual in being carved from quartzite.

Classification of Colours in Gemmology

by Professor K. Schlossmacher

THE colour of precious stones is one of the most interesting problems yet also one that has attracted only little attention in gemmology. Colour lends the chief beauty effect to most gems and is most important in gemmology. It is rich in theoretical and experimental difficulties, which explains to some extent why it has attracted so little attention.

The science of gem colour can be divided into four branches which belong to different fields of physics and chemistry. The primary conditions of the colour effect are the colouring substance and the crystal accommodating it, the so-called " host." Investigating the nature and constitution of the colouring substance two directions of research result, in which chemistry and mineralogy participate equally. Chemistry and its branch, spectroscopy, must determine the chemical nature of the substance. Mineralogy, together with crystallography, must investigate the arrangement in space and the accommodation in the " host " ; occasionally other mineralogical properties are of interest. After determining the colouring matter another field of science is entered, namely, that of atomic physics. The colour is caused through changes in the inner structure of the atoms of the colouring substance, being transformations of energy when light passes through. Research here enters one of the most difficult subjects of atomic physics and one can understand easily why up to now gemmology has not entered this field, especially as there are many other questions of gem coloration to be solved as well. The research problems mentioned so far relate to the pigment or colouring substance. There is also quite a different complex of questions concerning changes in the light itself which occur by its contact with the colouring substance. Here optics must be considered and, as most gems are crystals, crystal optics. The most important problem here is the absorption of the light intensity which is suffered by each indi-

vidual colour when passing through a coloured stone (which may also appear to be colourless to the eye). Measuring this absorption is the concern of photometry and the result is an exact colour analysis. In this case the object of research is the colour phenomenon. To these two fields, the substantial and phenomenological research, there is added an appendix (belonging to both) and relating to the changing of colour in gems by physical or chemical treatment. These problems, which are of great importance to the gem industry, can be solved only by simultaneous substantial and phenomenological research. This is the reason why they are particularly difficult. Many experiments have been made because of the economic importance, but basic research has hardly been attempted.

Every descriptive exact science has as one of its objects a system of classification. The colouring substance of gems can be classified according to various points of view. Genetically, the obvious classification is according to the colour-spending chemical elements, which determine the absorption in the interior of the atom and the external optical effect. This system, however, does not carry us very far, as there are only a few elements which could be considered. Most important of these is iron, which probably takes up the largest percentage of all colouring substances, not only in gemmology but also in mineralogy. This is not surprising, as in our earth crust iron is the most common of all metals, the oxygen combinations of which are coloured. After iron in a certain distance follow chromium, copper, nickel, manganese, perhaps titanium and a few other doubtful metals. Such a classification according to colouring matter would not mean very much as our present knowledge of the subject is not sufficiently advanced. The colouring substance, which usually is only present in minute quantities, has in many cases not yet been determined, so that such a system would have many gaps.

Much more satisfactory at present is a system using the relation of the colouring substance to the host. It differentiates between idiochromatic and allochromatic colours and the latter are classified according to the type of accommodation. Idiochromatic are those gems whose colouring substance is an inevitable constituent of their chemical composition. Malachite is idiochromatic, as it cannot exist without the colouring copper in its chemical formula. Allo-

chromatic colours are found in corundums, beryls and other gems, wherever whole series of colours are found in the same gem type. In this case there is a further classification according to the relation of colouring matter and host crystal. A simple case is that of replacement in the crystal structure. An example is the ruby (Al_2O_3), in whose crystal lattice some of the aluminium atoms are replaced by chromium. The presence of chromium has been proved chemically. But with our present resources we cannot yet say how these atoms are distributed in the lattice and whether they follow distinct rules. The next group of colouring substances comprises inclusions, which exceed atomic and molecular size, where the colouring substance is found in the form of individual crystals. These small crystals need not consist of the colouring metal only but may be a compound in which non-colouring elements participate. An example is the chrysoprase, whose basic substance is chalcedony and whose colouring substances are nickel-silicate grains. Only the nickel is the colouring substance, not the other components such as silicon, magnesium, oxygen and hydrogen. In this group of accommodation one can hope occasionally to see the colouring substance by microscopic or other suitable methods. In the case of sapphire, for instance, it is said that the pigment can be seen under the ultra-microscope (optical microscope with side illumination). This class of crystalline colouring substances can be further sub-divided according to the orientation of the crystallite in relation to the host crystal. In the case of oriented accommodation the crystallite lies with one of its main axes parallel to any one main axis of the host crystal. An example is the star ruby, where three sets of rutile needles, which cause the star, are arranged parallel to the hexagonal axes of the ruby, i.e. at 60° to each other.* Generally speaking, one can say that wherever chatoyancy is present there are parallel inclusions which are orientated in relation to the crystal structure of the host. There is, however, a group of non-orientated accommodations, a macroscopic example being the rock crystal with the rutile needles included in random directions. This classification is partly deduced from observation of gems, but to a greater extent it is derived from general knowledge of mineralogy and theoretical considerations. It is to be hoped that modern development of science, with the help of the newest microscopic

* The star effect is not strictly a colour effect.—Ed.

methods, will bring in the next few years valuable knowledge and with it an extended classification of colouring substances in gems.

A classification of the phenomenological part of the science relating to gem colours would be most important for the gem industry and trade. A beginning has been made in the colour measuring and classification of the diamond with new instruments, such as the Colorimeter, Diamolite and Coloriscope. But essential for the classification of gem colours is the exact definition of colour, which cannot be given subjectively by the mere impression of the eye, but needs physically exact measuring. In this field, however, only the first beginnings can be noted. Fault lies with optical photometry where the measuring instruments depend too much on the human eye, which is not sufficiently sensitive to light and colour. The ideal solution of light-electrical colour measuring has caused great technical difficulties. Investigations with a new light-electrical apparatus, built during the last decades in the Mineralogical Institute of the University of Koenigsberg, have shown the interest of this research work for gemmology. In a theoretical investigation the author has suggested a classification of one-colour, two-colour, and multi-colour systems, and in the case of the two latter has calculated and experimentally proved the compound effect of the two, respecting three colouring substances. But only when the absorption curves of a great number of gems have been measured can a classification system for gem colours be compiled and new points of view found for it.

GEMMOLOGICAL ABSTRACTS *continued from page 30*

FOSHAG (W. F.). ***Exploring the World of Gems.*** The National Geographic Magazine, Vol. XCVIII, No. 6, pp. 779-810.

A well-written, popular article on gemstones, excellently illustrated with 24 Ectachrome and Kodachrome colour plates and 12 in monochrome. The fact that the author is Head Curator of Geology of the U.S. National Museum, and is on the Editorial Board of the Gemological Institute of America, ensures the soundness of the statements made. Trade errors in nomenclature are decried, and synthetic stones, while mentioned, are not elaborated. Curiously, the fine blue sapphires from Burma and Siam are not mentioned, the only blue sapphires referred to being those from Montana. A useful article enhanced by beautiful illustrations.

R. W.

Gemmological Abstracts

"*Kleiner Wegweiser zum Bestimmen von Edelsteinen*" Small Guide for the Identification of Precious Stones). By G. O. Wild, K. H. Biegel. 32 pp., illustrated. Frankh'sche Verlagshandlung, Stuttgart, 1950.

The publication is most probably useful to the German worker who has to identify precious stones practically without any instruments. It is doubtful, however, whether anybody can make good use of it unless he is an experienced gemmologist. The authors mention in the introduction that a good 8 × aplanatic lens and a pair of scales are powerful means of detecting gem properties, and that with the addition of a dichroscope and two small polarizing filters most problems of identification can be solved. This is certainly correct. The beginner, however, will be much better served with a refractometer, an instrument which is not mentioned, although it should be within reach of the jeweller for whom the booklet is written. Determining the refractive index with the help of immersion liquids as recommended requires no apparatus, but more skill. The authors may have had the particular circumstances in mind which made it difficult to procure instruments in Germany, and with due regard to this position the booklet has probably filled a gap. To the initiated gemmologist in this country, if he can read the German text, it is interesting to note how the " fun " of discarding one or the other instrument in gem determination can become a serious necessity.

The determination of the following constants are dealt with: (1) Density (hydrostatic and heavy liquid methods). Only water is mentioned as immersion liquid in hydrostatic weighing, although much trouble due to surface tension could be avoided by using one of the liquids which are suggested for the determination of the refractive index (for instance, toluol). (2) Hardness. Mohs's scale and abrasion resistance referring to quartz = 100 are given. The

discreet use of a steel file is not discouraged. (3) Refractive index (immersion method). Ten immersion liquids are listed. (4) Double refraction. (5) Dichroism. A few pages are devoted to synthetic stones and good photomicrographs illustrate the text. The booklet concludes with a page on glass imitations and an index. The mainstay of the publication is three tables of constants and properties classifying the conventional gem materials into those of "distinct dichroism," those of "lacking or imperceptible dichroism" and into "colourless stones." According to this arrangement the authors seem to recommend the use of the dichroscope as first test, followed by the determination of double or single refraction. W. S.

CHUDOBA (K. F.). ***Farbumwandlungen bei Schmuck- und Edelsteinen.*** (Colour changes of precious stones and gems.) Gold und Silber, 1950, *3*, 19 (No. .10).

The colour of most gems is not dependent on the chemical constitution but on some additional pigment, as easily seen in case of corundum where different pigments with same constitution produce red rubies or blue sapphires. Such gems are termed allochromatic. The allochromatic colouration of a stone is easily influenced by higher temperatures or treatment with X-rays or other rays. Best known is the heating of amethyst-coloured quartz at 500-600 deg. C. to a yellow-red colour. When red-brown or reddish zircons are heated in a reducing atmosphere to 850-900 deg. C. they become colourless or blue, the latter hue not being present in natural crystals. Zircons can be treated with radio-active uranium or thorium, which destroys their lattice—they become green. When these "autoisotropic" zircons are heated to 1,450 deg. C. they resume their original lattice and become brown or yellow. Colourless diamonds when treated with cyclotrons obtain a green hue. If gems were treated systematically with various rays many other colour changes would result. E. S.

GÜHLER (U.). ***Studies of precious stones in Siam.*** Siam Science Bulletin, Bangkok, 1947, Vol. 4, No. 1, pp. 1-39.

Details of the Bo Ploi sapphire mines are given, together with references to gem gravels of Krat and Chantaboon. The main feature is the detail given of qualities and prices of rubies and sapphires. A. G.

GÜBELIN (E. J.). ***Ein neues Verfahren zur Erhöhung der optischen Wirkung von Edelsteinen.*** (A new method of increasing the optical effect of gems.) Uhren, Schmuck und Edles Gerät, 1950, 267-268 (9).

For some years the optical industry has made use of a method consisting in covering (" blooming ") optical glasses with a transparent film. This thin film has a certain thickness so that there are interference phenomena of the reflected rays in the air-film and film-glass border. Thus surface reflection is reduced and more light enters the glass. Similar experiments have now been made with 53 gems. It is shown that not only oblique light rays are strongly reflected and thus lost for the brilliance effect, but that also other light rays sacrifice a good part of their energy to the surface reflection. By the use of this thin anti-reflection film a great amount of the light which would otherwise be lost can be let into the stone, thus reducing reflected light. In order to reduce the loss of light to a minimum, the covering film must have a refractive index which lies between that of air and that of the stone ; it is best if that R.I. equals the root of the R.I. of the stone. A few examples are given. The thickness of the film must be a quarter of the wavelength of the used light, which, of course, is only easy in the case of monochromatic light. But with daylight the rule need not be followed too closely. There are four metal fluorides whose R.I.s make them usable for a number of gems: BaF_2, CaF_2, MgF_2 and Na_3AlF_6 (cryolite) ; TiO_2 can also be used. To protect the film, silica is used (hardness a little under 6). The two last substances are insoluble in water. There are three methods available for bringing the film on to the stone, two chemical and one physical. The chemical methods which dissolve part of the surface of the stone cannot be used for gem purposes. In the physical method the fluoride is powdered and evaporated in high vacuum on to the stone. It has been shown that in the case of diamonds the anti-reflection film can increase the entering light by 5 per cent., which improves the brilliance markedly. (Cont.) E. S.

The Diamond Industry in 1949. (25th annual review.) Jewelers' Circular-Keystone, New York, 1950.

This well-known review has been continued by W. F. Foshag and George Switzer. Details of mining, exports and imports for various countries are again given.

CHUDOBA (K. F.). ***Das Problem der Diamantsynthese.*** (The problem of diamond synthesis.) Gold und Silber, 1950, *3*, 8-9 (No. 8/9).

A query as to the use of " synthetic industrial diamonds " in Russia. Short historical review, mentioning H. Moisson (1900), M. K. Hoffman (1931), P. L. Günther (1942), and the repetition of Hannay's (1880) experiment by C. A. Parson (1919). There are two schools of thought: one according to Ostwald's law tries synthesis by quick cooling of carbon in gaseous, liquid or soluble form to obtain the unstable diamond modification—the results have been negative. The other way is to change graphite into diamond under high pressure, as diamond has a higher specific gravity than graphite. P. W. Bridgman used this method, but even pressures of 45,000 kg/sq. cm. were unsuccessful. It seems most unlikely that Russia has solved the problem ; it can be assumed that they have found new diamond deposits or are using very hard carbides. The possible use of atomic energy in relation to diamond synthesis must not be forgotten.

E. S.

GÜBELIN (E.). ***Perlen.*** (Pearls.) Gold und Silber, 1950, *3*, 11-13. No. 10.

Pearls are perfect when found. Chief properties are lustre and opalescence. They are found in three colours: white, including rosé ; black, including grey ; dark green, navy, as long as they have a metallic lustre, and coloured, which includes golden, copper, green, blue, even red. Colour is influenced by geographical position of occurrence. The production of cultured pearls by inserting a small mother-of-pearl bead into the living oyster is described, as is also the differentiating between real and cultured pearls. Six rules are given with regard to treatment of pearls: do not wear them in the bath, take them off when you are hot, remove the dust frequently by rubbing over them, have the necklace restrung every six months, do not let them come into contact with diamonds, do not throw them carelessly on the dressing table. It must also be mentioned that they need air and light and should not be kept for years in a safe.

E. S.

(continued on page 26)

SYNTHETIC QUARTZ CRYSTALS EXAMINED

by B. W. ANDERSON, B.Sc., F.G.A.

THERE is to-day a large and growing demand for crystals of quartz for use in the telephone and other industries. Advantage is taken of the marked piezo-electric properties of the mineral in controlling the frequency of signals to a high degree of accuracy, the quartz being cut for this purpose into thin plates of definite crystal orientation and thickness.

It so happens that, of the quartz found in nature, only a small percentage of crystals have the necessary purity and freedom from twinning which are essential for these technical uses. Thus, despite the abundance of the mineral in almost every country of the world, attempts are being made by scientists to grow pure quartz crystals artificially, using small, untwinned natural "seed" crystals or plates to ensure that the completed crystals shall be of the quality needed. Success has been reported in this endeavour from many laboratories, but it is in America, notably in the laboratories of the Bell Telephone Company, that the largest crystals are now being manufactured.

Thanks to the kindness of Mr. D. S. M. Field, three specimens of artificial quartz crystals grown in the Bell laboratories have been made available to the Gemmological Association for study. Though these have, of course, no importance as gemstones, a brief description of these crystals may be of interest here.

First, something may be said as to the method of preparation. A diagram illustrating the conditions under which such crystals are grown was published in an excellent article on synthetic crystals in the August number of "Fortune," an expensively produced American periodical not easily obtainable in this country. According to this diagram, the quartz plates acting as "seeds" are suspended in an alkaline solution rich in silica, enclosed in a high-pressure columnar reaction chamber under a pressure of 15,000 pounds per square inch. The lower part of this vessel, containing

quartz chips as " nutrient," is maintained at a temperature of 750° F., while the upper part of the column, where the seeds are suspended, is at a lower temperature, about 715° F.). In the same article a photograph is reproduced of the largest quartz crystal so far made by Bell—a transparent specimen weighing five ounces.

The most interesting and perfect of the specimens submitted by Mr. Field is a beautiful crystal about 1 inch long by $\frac{5}{8}$ inch broad, weighing 15.16 carats. The habit is remarkably simple ; the only faces developed being six faces of the positive rhombohedron $(10\bar{1}1)$ and six faces of the hexagonal prism $(10\bar{1}0)$. No trace of the negative rhombohedron can be seen, and there are none of the customary horizontal striations on the prism faces. This simple habit is figured in Dana's " System," but is very seldom encountered in nature.

The faces show a faint iridescent tarnish, and attractive growth markings of slightly raised discs (dimples in reverse, so to speak) can be seen on the rhombohedral faces. The plate which formed the original " seed " can be seen as a " ghost " within the crystal, parallel to one face of the rhombohedron, and the metal hook by which this was suspended is partly embedded in the crystal.

One of the rhombohedral faces was sufficiently smooth to give good shadow-edges on the Abbe-Pulfrich refractometer, and, as would be expected, these were found to coincide exactly with those shown with a polished surface of natural colourless quartz.

Of the other two specimens, one was a doubly-terminated crystal weighing 117.95 cts., the other being a much smaller (.30 ct.) tapering prismatic crystal with only one rhombohedral termination. The larger crystal was relatively imperfect but more normal in habit than the one described above. Both positive and negative rhombohedra were present, and also trapezohedral faces, showing the crystal to be a left-handed specimen. Externally this crystal had a dull, slightly etched surface, and internally there were cavities in bizarre shapes, containing liquid and bubbles of gas.

In conclusion, one may express the hope that eventually the success achieved in growing artificial crystals of quartz will be sufficiently great to put a halt to the wastage and destruction of fine specimens of the natural mineral which has been going on for many years.

CHALCEDONY
photographed in ordinary and polarized light.

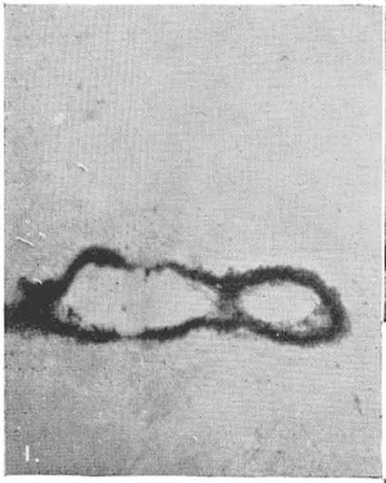

Ordinary light.

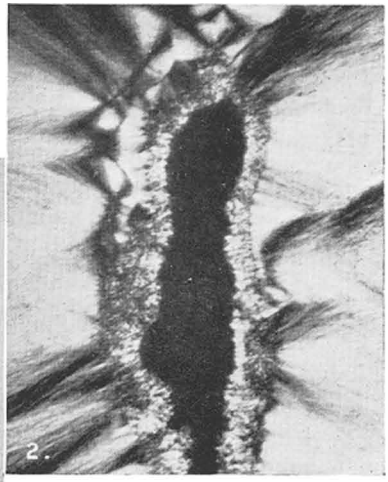

Polarized light.

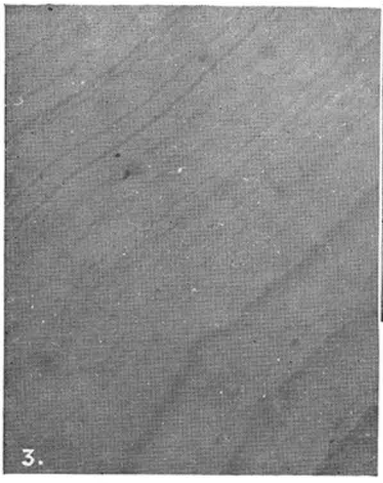

Ordinary light.

Polarized light.

Photos 3 and 4
STRIPED AGATE

STATISTICS and GEMMOLOGY

A Survey and Trial Enquiry

by E. BURBAGE and T. G. JONES, FF.G.A.

AMONG the questionable advantages of maturity must be reckoned the jettisoning or transformation of many of the agreeable fables which beguiled one's youth, by which process, in the cautionary anecdotes of Strewwelpeter, a covert Freudian undercurrent presents itself, Hy. Brasil fades, and Dr. R. Lloyd Praeger, armed with a vasculum and a geological hammer, deflates St. Patrick's Purgatory. Thus, we have cherished for many years the agreeable picture (in Wells's " Food of the Gods ") of Redwood's investigation of the Diurnal Variation of the Butting Frequency of the Young Bull Calf (an enquiry, it will be remembered, which discommodated the teaching staff to some extent, but which yielded curves of a most interesting nature). Now, unfortunately, a very slight acquaintance with statistical methods has punctured the Wellsian fantasy: if a paper describing the successful achievement of this research has not yet reached the sober pages of Biometrika, it is not, we conjecture, because the research is inherently unsuitable for statistical handling—c.f. (as the textbooks say), the classical Poissoniam distribution of casualties from the kick of a horse in a Prussian army corps (1875-94), described by Quetelet and von Bortkiewicz. In fact, a grounding in Statistics teaches one to regard with a coldly sceptical eye any plexus of events which on rule-of-thumb commonsense criteria would be relegated to the limbo of " unrelated " or " random " happenings. For instance, a gemstone whose cutting is unrelated to the crystal symmetry of the original material we had previously been content to consider as having random orientation. We now regard the term " random " with some dubiety, and deplore the incurious acceptance of an almost total lack of information as to the relationship between crystal orientation and that imposed by the lapidary.

The question presents itself in two forms: (i) in those gemstones where there is cleavage, dichroism, or some other factor to influence the lapidary's choice of direction for cutting, to what extent does this external factor operate? For instance, when there is a direction of " best colour " with what frequency and precision is this reflected in the cutting? (ii) In minerals where no evident compulsion exists to bias the lapidary in any particular direction, does a statistical enquiry show that there is, in fact, an even distribution of directions of cutting?

The field of enquiry presented by these two questions is a very extensive one, but large areas of it are probably inaccessible to the statistician by reason of the impossibility of collecting the necessary data. For instance, the relationship between the fashioning of isotropic gemstones and the original crystal symmetry cannot usually be discovered. Also, however one reduces the labour involved in collecting the data required by simplifying one's methods, it still remains considerable. Ideally, this is a chore suitable for collective handling, and here one could do well to borrow from our American friends the practice, common in their societies and clubs, of launching a " project," a joint enterprise of a group of members. Our own effort is only by way of a trial sortie, open to criticism on both gemmological and statistical grounds, and we claim no especial merit for it other than the virtue of indicating a fresh field of enquiry to persons with more leisure and better facilties than we possess.

In an earlier paper in this journal* we described a method, using extinctions, to determine the orientation of an uniaxial gemstone with respect to the optic axis. Having decided to use this technique in our statistical work, we had to select a suitable gemstone from the uniaxial group, a group which, although large, contained a great number of stones which were for various reasons inacceptable for our purpose. Thus, rarities were " out," for two reasons: first, that it would have been difficult to procure sufficient specimens to give results of any significance in a statistical enquiry, and secondly, because a great number of unusual stones are cut to the specific instructions of a collector, and are consequently special cases lying beyond the scope of our enquiry. Quartz, an obvious choice, was rejected in view of the complication introduced by the rotation of the plane of polarization. Tourmaline filled the bill on

* Burbage and Jones. " Optical Orientation in Uniaxial Gemstones." " Journal of Gemmology," Vol. II, pp. 304 to 309 (July, 1950).

the grounds of the accessibility of specimens, and it would, indeed, be interesting to consider this gemstone as furnishing a multivariate distribution on the basis of colour. Since Mr. R. W. Yeo's pioneer paper* relating specific gravity and colour in tourmalines, work on this gemstone has not been extensive, and this relative neglect provided an additional inducement to use it for our purpose. We reluctantly abandoned the idea, as the number of stones we needed to consider would have had to be far greater than when dealing with a univariate distribution. In addition, colour is a subjective business which does not readily lend itself to statistical handling.

Finally, we decided to work on aquamarines. The material for our purpose consisted of 45 faceted stones, cut in a variety of styles, including briolettes, mixed-cut, and step-cut, and ranging in size from .6 to 17 carats, of which few were of good, and none of fine colour. We need not recapitulate our earlier description of the method used for finding the angle between the normal-to-table direction and the optic axis. For a number of stones it was not easy to interpret the results from the first set of readings, and it proved necessary to remount them to get a second set ; in other stones, patchy extinction presented a difficulty. Our final results, expressed as a frequency histogram, are shown in Fig. 1.

It will be appreciated that, for a complete picture of the situation, one would need to plot a frequency surface in three dimensions, for, although our method enabled the angle made by the normal-to-table with the optic axis to be determined, its direction remains unknown, and, indeed, unknowable, at least by any elementary means. Such a surface would be contained within two boundary planes intersecting at 30°, one of which will contain the histogram corresponding to normal-to-facet directions lying in the plane containing the optic axis, and cutting a prism face at right angles, and the other will contain the histogram corresponding to those directions lying in the plane containing the optic axis and emerging at the junction of prism faces, the other points on the frequency surface being furnished by planes lying between these two extremes. As hexagonal prism faces are similar in the same crystal, and one cannot therefore establish a correspondence between any particular faces in a set of aquamarine crystals, this hypo-

* Yeo, R. W. " Gemstones and Specific Gravity." " Gemmologist," Vol. No. 1, August, 1931, pp. 16-20.

Fig. 1 DISTRIBUTION OF CUTTING - ORIENTATIONS IN PARCEL OF 45 AQUAMARINES.

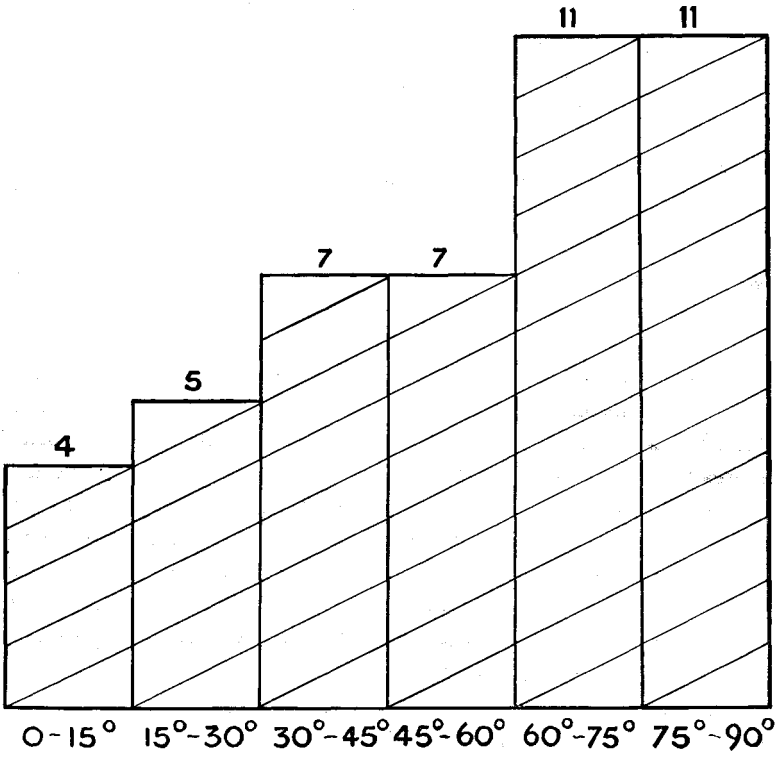

thetical frequency surface would necessarily be confined to the 30° sector described. We do not believe that the surface would be one of revolution, but failing the impracticable method of surveillance of the actual process of cutting, one cannot hope to establish this.

Our data provided us with the values of the angles made by the normal-to-table direction with the optic axis, without providing an indication of sign, which would in any event be meaningless, and in consequence our histogram departs from the usual form in peaking at the end instead of in an approximately central position. One would intuitively reject the hypothesis that here we have a group of stones in which the fashioning has been purely random with respect to the crystal symmetry, and it is not difficult to obtain

a fairly decisive quantitative confirmation of this impression by means of the Chi-squared distribution. As grouped in our histogram, the frequencies are too low to use with any confidence for this purpose, and therefore we used the broad groupings of 0-30°, 30°-60°, and 60°-90°. Setting up the hypothesis of an equal distribution, we then had as " observed values " 9, 14 and 22 respectively, as against an " expected value " of 15, giving a Chi-squared total of 5.73. For the two degrees of freedom concerned, this figure is near the 5.99 of the 5 per cent. confidence level, showing that the probability of a Chi-squared as great or greater than the value calculated being given by random sampling is about one in twenty—a probability sufficiently low to rule out the hypothesis. Having thus rejected fairly decisively the hypothesis of equal distribution, one then asks what alternative hypothesis can replace it, and that of a normal distribution immediately suggests itself (using the term " normal " in the restricted statistical sense in which it describes a class of single-humped curves defined by an algebraic expression involving the exponential function). Unfortunately, the same difficulty presented by small frequencies in a six-class classification again presents itself to render impossible the fitting of a normal curve, and one would not attempt to do so for a lesser number of cells, for which in any case the additional constraints involved would limit the degrees of freedom too greatly to permit a Chi-squared test for goodness of fit.

We would note incidentally that in a characteristically brilliant feat of gemmological expertise, Mr. B. W. Anderson, from whom we had invited an opinion before starting this enquiry, had correctly predicted that our findings would be as stated. As previously noted, there were few stones of good colour among those examined ; a fortiori, with specimens of fine colour one would reasonably expect an even greater majority to be cut so that the normal-to-table directions made large angles with the optic axis.

It would certainly be interesting to have data of this sort for the more important gemstones. and we think it likely that it would be of value in their study. In the strictly practical business of identification, ancillary information of this sort has its merits. This would be more especially true when a number of stones of one kind were in question. For instance, if one had a " normal " frequency curve of a particular gemstone, one would have the means of

assessing if a particular random set is likely to have been drawn from this species. For example, if it could be established that the relationship between the cutting and the crystal orientation were significantly different in synthetic and natural rubies, and if the distributions of both were known, one could use the multiplicative properties of the relative probabilities to give a fairly conclusive answer as to whether a set of rubies, not necessarily very many in number, were natural or synthetic. Although it may be objected that the gemmologist has by now taken the measure of synthetic corundum without the need to call upon unorthodox criteria of this sort, it is possible that when dealing with other gemstones, maybe in circumstances limiting the application of standard tests, information about cutting orientations would be of value.

It is a little surprising that, while in so many sciences and branches of learning common ground has been found in which amateurs of these studies have either contributed to, or been indebted to, gemmology, Karl Pearson and his co-workers and successors might never have existed as far as the impact of their work on gemmology is concerned. If we may imagine the appointment of a statistician to the staff of a gem research laboratory, how, we may ask, could his abilities and technical training be most profitably employed? One rather prosaic and unexciting but unquestionably useful job which he could tackle would be to impose some kind of statistical order upon the published data on the physical constants of gemstones. Twenty years ago a text-book would confidently assert that a particular gemstone X had a specific gravity of 3.63 (say). Nowadays, in a text-book having any claim to a reasonably full treatment, the s.g. of our hypothetical gemstone X is likely to be dealt with as follows: " The spec. grav. varies from 3.617 to 3.638, except in the metamict types, where it may be as low as 3.605, and in the iron-rich variety from Paraguay, where it may rise to 3.67." Confronted with such a plethora of information, the student may well sigh for the dogmatic half-truths of the 1930 text-book, and in point of fact, a statement in the form quoted (which could without difficulty be matched by actual quotations from modern text-books) is not very helpful. One does not need to know anything of such matters as frequency distributions, variance and kurtosis to feel that a statical presentation would bring order to this hodge-potch of facts. Our

hypothetical statistician could profitably wade through the mass of readings upon which the text-book statement was based to provide answers to the following questions: Is the distribution " rectangular " within the range quoted? If not, where and how steeply does it " peak "? How likely is it that one should come across stones having very high or very low s.g.'s? If the variation in s.g. is accompanied by a variation in r.i., what degree of correlation can be established between them, and can both be related to variations in composition?

An important contribution which the statistician could make to gemmological studies is in the assessment of the results of experiments, and in testing the significance of observations. It is difficult arbitrarily to invent situations where tests of this sort would be applicable, but they are of value in circumstances where, having various possible hypotheses to test, observations are on immediate inspection not sufficiently weighted one way or the other to enable a decision to be made. Here there are techniques available which permit an actual comparison of the relative probabilities of correctness.

ASSOCIATION NOTICES

GIFTS TO ASSOCIATION

The Council of the Association is indebted to Mr. L. C. Trumper, B.Sc., F.G.A., for two cut specimens of brazilianite.

Mr. D. S. M. Field, A.G.A., has recently sent to the Association three specimens of synthetic quartz. He obtained them, through the courtesy of Dr. A. C. Walker, from the manufacturers, the Bell Telephone Company, and the Council of the Association is grateful for this addition to its collection.

MEMBERS' MEETING.

A meeting of members was held at the British Council Cinema, London, W.1, on Thursday, 16th November, 1950. Mr. J. R. Knight, B.Sc., A.I.M., deputizing for Dr. E. C. Rhodes, who was unfortunately ill, described and discussed the manufacture of jewellery in palladium and its handling and treatment when carrying out repairs. The talk was followed by a film, in colour, which showed the various stages of production of palladium and how well it was suitable for making fine pieces of jewellery.

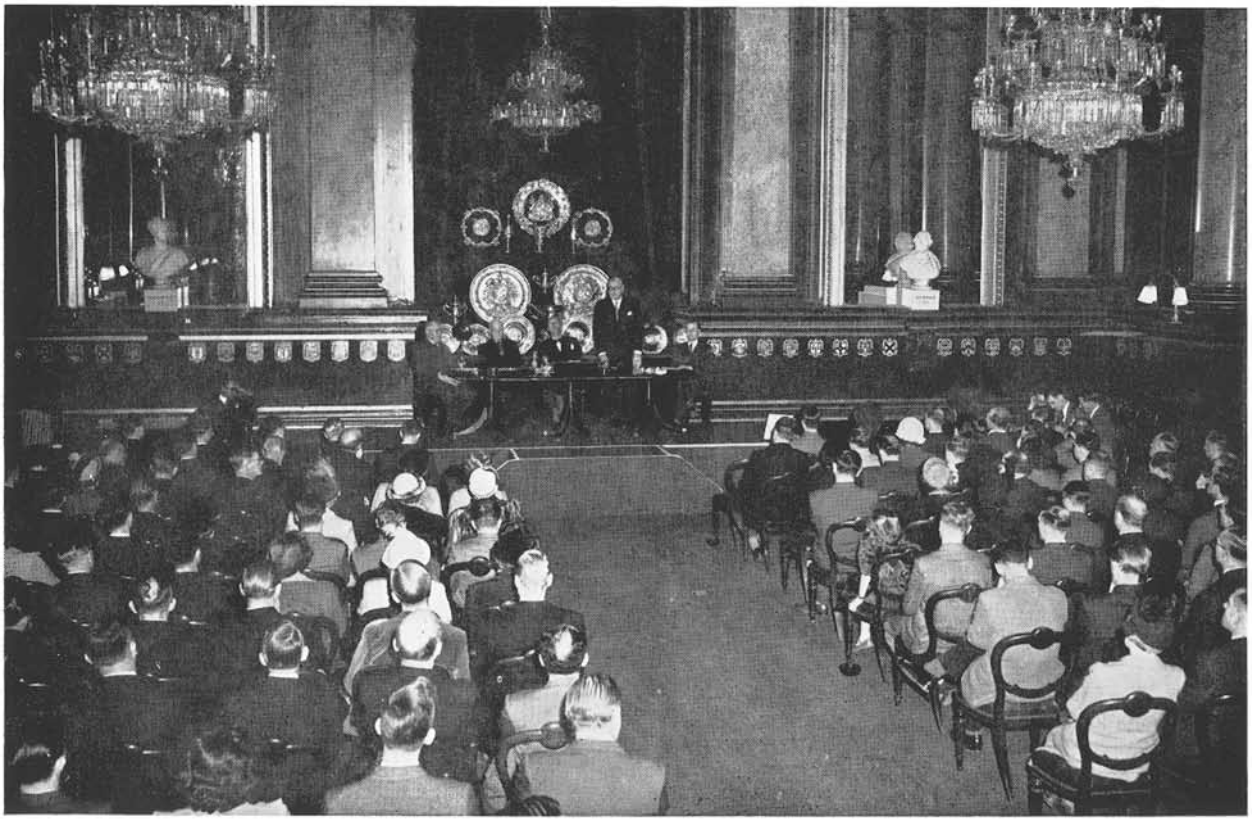

Scene at Presentation of Awards at Goldsmiths' Hall, London, October, 1950.

COUNCIL MEETING

At a meeting of the Council held on Wednesday, 11th October, 1950, at 19-25 Gutter Lane, E.C.2, the following were elected:—

FELLOWS

Akehurst, H. R., Saskatoon, Canada.
Aston, C. R. C., Gt. Missenden.
Bruton, E. M., London.
Chapman, V. K., Perth.
Crosthwaite, S. A., Glasgow.
Davidge, K. C., Otford.
Doidge, R. J., Tavistock.
Dyce, S. B., Perth.
Falconer, R. S., Edinburgh.
Frake, W. J., London.
Garner, L. W., London.
Gribben, A. T., Birmingham.
Gunters, H. D., The Hague, Holland.
Hanslip, M. J., Torpoint.
Heighes, C. E., Los Angeles, U.S.A.
Hurst, J. C., Olton.
Jarvis, C. A., Ilford.
Jones, O. D., Burton-on-Trent.
van der Loo, J. A. M., Rotterdam, Holland.
Modahl, Oivind, Oslo, Norway.
O'Donoghue, T. J., London
Quartermain, J. F., Westgate-on-Sea.
Raymond, P., Kenton.
de Rosa, R., London.
Sawyer, J. B., London.
Schaap, A., Amsterdam, Holland.
Snell, J. S., Romford.
Speed, P. G., King's Lynn.
Tindall, E. H., Harrogate.
Warren, F. W., Bristol.
Whitehead, M. W., Surbiton.

PROBATIONARY

Mason, S., Harrogate.

FELLOWS TRANSFERRED FROM PROBATIONARY

Corfield, R. H., London.
Katz, B., Johannesburg, S. Africa.
Bailey, B. O., Birmingham.
Batty, R. W., Southport.
Best, J., Stourbridge.
Boyes, K. A., Scholes.
Cassidy, R. F., Worcester.
Chisholm, J. R. H., Leverstock Green.
Cornelius, A. R., London.
Davison, P. J. F., Goodmayes.
Denton, G. W., Clacton-on-Sea.
Fishberg, H. C., Edgware.
Fishberg, J. M., London (Life Member)).
Hathaway, Miss A. H., Stratford-on-Avon.
Henn, Miss B. M., Bridgnorth.
Hollander, Miss J. C., London.
King, R. F., Welling.
Pellett, W., London.
Siu, M. C., Hong Kong.
Thomas-Ferrand, Mrs. J. M., Bury St. Edmunds.
Warnes, Miss S. G., King's Lynn.

ASSOCIATES TRANSFERRED FROM PROBATIONARY

Cunningham, F. M., Toronto, Canada.
Lowe, R. W., Broken Hill, N. Rhodesia.

OBITUARY

We regret to record the death of Professor W. T. Gordon, M.A., D.Sc., F.R.S.E., Professor Emeritus of Geology, University of London. To gemmologists he will be remembered for the delightful talks that he gave to members before the last war. An appreciation of Professor Gordon will be included in the next issue of the Journal.

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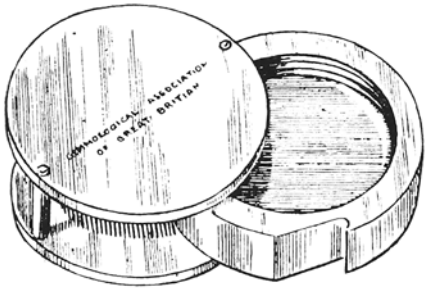

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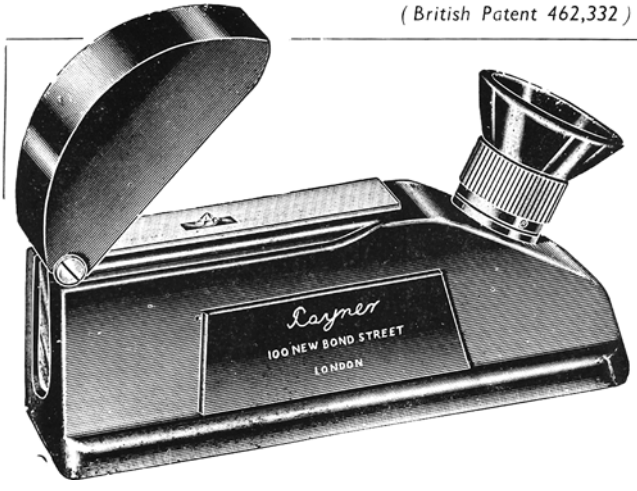

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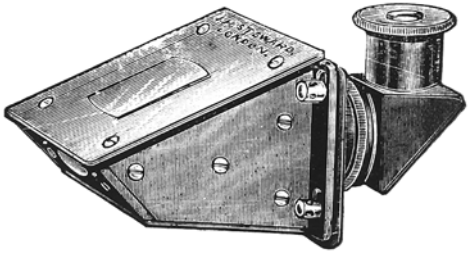

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THE JOURNAL OF GEMMOLOGY
AND PROCEEDINGS OF THE GEMMOLOGICAL ASSOCIATION OF GREAT BRITAIN

Vol. III, No. 2 APRIL 1951

A SPECIFIC GRAVITY BALANCE

By Sir James Walton, K.C.V.O., F R.C.S., B.Sc., F.G.A.

THE determination of the specific gravity has tended to be neglected by gemmologists, for the hydrostatic method is rather prolonged and tedious and the use of heavy fluids requires constant control of the accuracy of the fluids.

For some time I have been experimenting to produce a balance which in a few minutes would give a direct specific gravity reading sufficiently accurate for diagnostic purposes. The following is a description of a model which has been able to meet these requirements. It differs from an ordinary balance in that the arms, instead of moving only for a few degrees, have to traverse an arc of 90° and the position of the centre of gravity has to be altered.

Two arms (B) extending for 32 mm. from the centre of a pinion (A) terminate in grooved quarter circles (C). In the grooves lie silk threads which on the left support two scale pans united by thin tantalum wire and on the right a counter weight (E). Hence the horizontal distance of the points of suspension from the centre of

the pinion does not alter as each arm moves through 90°. A long pendulum with a screw thread cut on its lower part is also attached to the pinion ; at its lower end a weight (F) can be moved up and down the threaded portion, and a counter-weight (G) is attached to the upper end of the pendulum bar. The whole of this unit must be of the lightest weight possible commensurate with rigidity or a high modulus of elasticity. After many experiments perspex was found to be the most satisfactory material. The pinion is supported by a strip of razor blade or a narrow agate wedge (H) which passes through it at an angle of 45° with the horizontal. It rests on either side in two short lengths of glass or pyrex tubing, so that it rotates around its edge with hardly any friction.

Below the lower scale pan is a beaker resting on a stage which is capable of being raised or lowered by an eccentric wheel. When lowered the fluid in it is below the lower pan ; when raised this pan is entirely submerged. The counter-weight (E) consists of a hollow duralumin tube with a screw top. It contains lead filings of an amount necessary to give an accurate balance. The scale has two series of gradations, the lower giving the weight and the upper the specific gravity.

The principle of the balance is that the point of suspension is above the centre of gravity and is in such a position that if L is the length of the balance arm, 6 carats the weight to be placed in the pan, W the weight of the pans, balance arms and counter-weight, and X the height of the point of suspension above the centre of gravity, then $WX=6L$, and since W and L can be measured X is easily estimated. When on such a position, and a weight of 6C is placed in the upper pan, the balance will swing round until the centre of gravity lies in the same horizontal line as the point of suspension. In this position the balance is unstable, therefore only 5/6ths of the arc is used ; that is, the scale is graduated up to 5C and a stop placed above this. The distance between the point of suspension and the centre of gravity will be inversely proportional to the weight of the perspex unit and its appendages. These, therefore, must be made of the lightest possible materials in order to give a working distance. Even with the extremely light materials used in this model it was only 2.25 mm.

The pendulum weight (F), made of brass, is screwed up to a convenient position on the pendulum ; a counter-weight (G), also

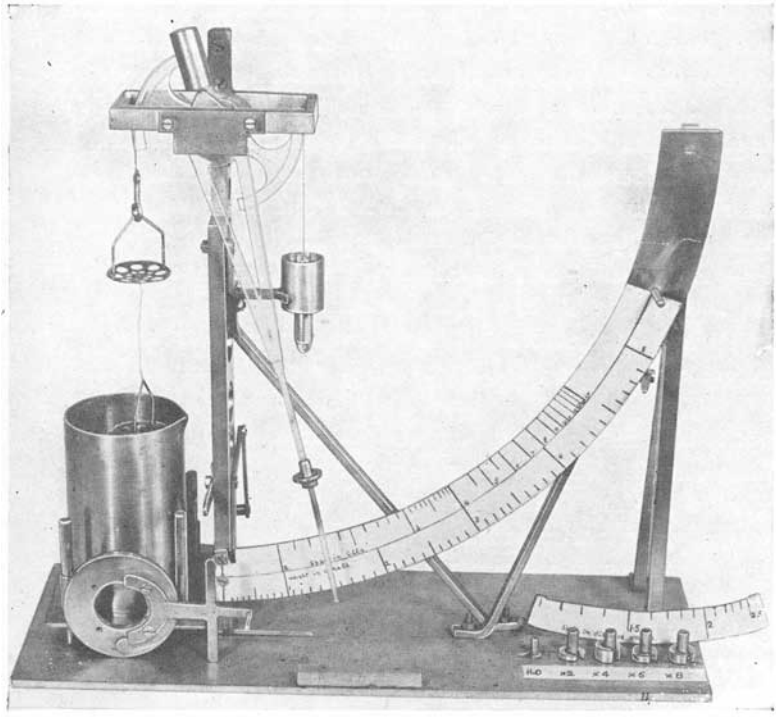

A new type of specific gravity balance. The upper scale gives sp. gr. 2-15, using carbon tetrachloride. The lower scale gives weights 1-5 carats. The smaller supplementary scale gives sp. gr. 1-2.5, using water.

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of brass, is made of such a size that when screwed home on the upper end of the pendulum and the latter placed on a knife edge running through the point of suspension, an accurate balance is obtained. The pans and their counter-weight are weighed against one another, with the lower pan suspended in carbon tetrachloride, on an ordinary hydrostatic balance, lead filings being added to the counter-weight until they balance accurately. The pendulum is then permanently fixed to the pinion with perspex solution in such a position that when hanging vertically the balance arms form an angle of 45° with the horizontal (Fig. 4).

With the lower pan in the fluid (carbon tetrachloride) the pendulum will hang vertically and will thus be the zero point on the

scale ; when a 5-carat weight is placed in the upper scale pan the pendulum will swing round for 5/6ths of the quarter circle, i.e. 75° from the vertical, if not, a slight adjustment of the pendulum weight (F) is made. The stop (S) is screwed up to it and fixed with perspex cement ; the rest of the scale is then graduated.

In use the beaker is raised so that the lower pan is submerged, the specimen placed in the upper pan, the pendulum released and will swing along the scale to give the correct weight. The pendulum weight (F) is slowly screwed up and so gradually raises the position of the centre of gravity. As a result the pendulum slowly rises, the adjustment being made so that it comes to rest exactly opposite the figure 5 on the lower scale. The pendulum is then placed back at the zero point and fixed. The beaker is lowered, the specimen placed in the lower pan, the beaker again raised, and when the pendulum is freed it will register the correct specific gravity on the upper scale.

The principle is that whatever the weight (up to 5 carats), the raising of the pendulum weight makes it register 5 unknown units ; then, since the weight of fluid displaced is always a fixed proportion of the weight in air, the correct specific gravity will be given on the upper scale, e.g. corundum of specific gravity 4 will lose a quarter of its weight in water, whatever its weight may be ; hence, if it is made to register 5 unknown units, it will, when weighed in water, lose a quarter of its 5 units, so that the mark 4 on the upper scale will be opposite the 3.75 on the weight scale. The specific gravity scale can therefore be estimated, but it is controlled by the use of minerals of known specific gravity.

The upper limit of the scale is 5 carats, but four extra weights are made which slip over the pendulum weight (Fig. 6). They are very carefully graduated so that when in use the scale has to be multiplied by 2, 4, 6 and 8 respectively, and hence the range of the instrument is extended to 40 carats. The lower limit is about 1 carat, for below this the viscosity and surface tension of the fluid, even when carbon tetrachloride is used, makes the movement of the pendulum so sluggish that the specific gravity readings are uncertain.

Certain substances of very low specific gravity, such as amber, jet, ivory and the plastic imitations, will float in carbon tetrachloride and hence distilled water will have to be used. Different readings

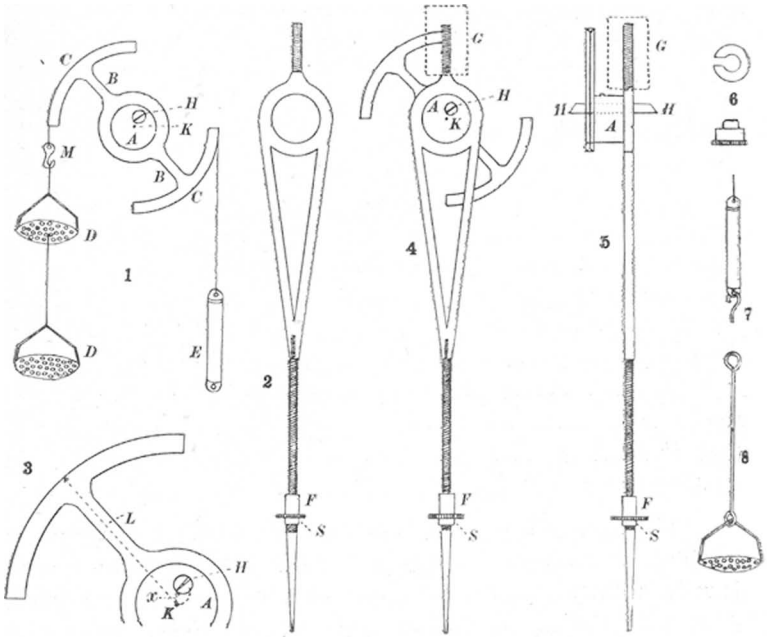

FIG. 2.—Parts of the specific gravity balance. (1) Arms, pans and counter-weight ; (2) pendulum ; (3) razor edge pivot of arms and pendulum ; (4) front view of assembled perspex unit ; (5) side view of unit ; (6-8) accessories.

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of the specific gravity will then be given, therefore a small accessory scale is provided reading up to 2.5 which slips over the fixed scale, and since the specimen weighs more in water than in CCL4, an extra weight in the form of a small hook (Fig. 7) is hung on to the counter-weight.

The instrument may also be used as a delicate simple balance. The beaker is removed and the double scale pan replaced by a single one (Fig. 8), which in air correctly balances the counter-weight (E). The pendulum will then swing over and give the correct weight of a specimen in the pan and thus avoid trial with several weights as in an ordinary balance.

The instrument is being manufactured for me by Messrs. Rayner and Keeler, of 100 New Bond Street, W.1.

THE MOST EFFECTIVE DISPLAY OF GEMSTONES

By *Nigel W. Kennedy, F.G.A.*

MODERN writers seem to disfavour the use of quotations, probably because, like the writer, they find some difficulty in remembering them, yet there is no doubt that a quotation sometimes contains a lot of common-sense. One old adage states that "What is worth doing at all is worth doing well," and another warns us "not to spoil the ship for a ha'p'orth o' tar."

Both sayings apply very strongly to the *display* of gemstones, whether in the form of a private or public collection, or in a jeweller's shop window, and this does not refer to the general scheme of the lay-out which may vary with the precise object in view. For example, three different schemes might have as their purposes (a) A comparison of colour varieties; (b) Examples of cut and uncut gems in their species; (c) Uses to which gem materials may be applied.

In *all* cases the main object of the display is almost certainly to attract attention and interest in the gems.

Now the writer is a mineralogist (of sorts) and used to be considered as the possessor of a very sound knowledge of crystallography, but after having tried to wade intelligently through Phillips' "Crystallography," and to absorb some of its fascinating data, has regretfully come to the conclusion that his own knowledge of the subject must be very elementary. However, the conviction is still retained that some of the most perfect examples of crystals whether produced in nature's marvellous laboratory, or that of the humble chemist, will compare with any faceted gem, and even transcend some gems in beauty of form, proportion, and colour.

It is conceded with little reserve that when a mineral is cut, polished, and faceted it acquires a new status, and any inherent

features of beauty are enhanced, particularly if cut correctly, polished with care and viewed under the best conditions.

Clearly such ideal conditions are not attained in complete darkness or even a dim light, and it is not necessary to be colour-blind to be unable to tell the difference between an emerald and a ruby under such conditions.

The beauty of form of a mineral can be appreciated even by a blind man through the sense of touch, but in the case of a gem each feature of beauty is purely visual, and therefore the effect of light. Now, what are the several features upon which the beauty of a gemstone depends? These have been formulated as colour, lustre, and transparency, and each of these in kind, and from a maximum to a minimum intensity, are further modified by the specific optical properties of refractive index, single and double refraction, dichröism and dispersion.

In order that the full effect of these properties should be produced it is necessary that certain laws should be followed in the method of cutting and faceting most stones.

The various popular cuts are not accidental but have been selected to give optimum optical effect, cabochon for opaque gems and translucent stones, asterias, chatoyants et cetera; deep trap cut for transparent coloured stones, and a much shallower mixed and brilliant cut for lighter or achroic gems. The lapidary knows that the best results are only obtained by cutting a stone in relation to its crystallographic and optic axes, and in special cases, by the exact angles of the facets above and below the girdle, so as to obtain a maximum reflection and refraction of light rays entering through the top facets, thus producing the maximum scattering of the emergent analysed rays, producing the desired "fire."

The beneficial effect that more careful consideration of the correct cut has had upon the improvement of gems is most marked when one compares the old-fashioned rose and double-rose cuts of 200 years ago with the brilliant cut, especially as now developed on mathematical lines, and a more recent and equally remarkable example was the dull and waxy appearance of the early synthetic rutiles compared with those now faceted more correctly, and dazzling with brilliance.

Since the skill of the lapidary is only concerned in producing the best results from a given mineral, subject to the gem being given an opportunity to display its charms under the best conditions, the entire effect may be marred by lack of attention to the essential detail of correct lighting.

As not merely light, but the best form of illumination that can be adapted to bring out the characteristic optical properties of each type of gem, is so obviously of paramount importance, it will no doubt be an advantage to discuss in greater detail some of these properties.

THREE MAIN PROPERTIES

The first is of course *colour* covering the whole range of the visible spectrum, and including achroic stones, as well as those of white, greyish, brown, purplish and black tones. That is, stones with definitely selective absorption; those which transmit light of all wave-lengths with equal facility and little or no absorption; those which reflect a complicated colour combination which we speak of as " white "; and finally those which reflect certain mixtures of light or absorb all colours.

It is clear that the source, intensity and direction of light used for highly refractive achroic gems is not of necessity the best for denser coloured stones.

Then *lustre*, which is actually a common property enough, but one of which little appears to be understood; this is a feature which again varies very considerably, and is definitely related to the nature of internal inclusions and their orientation, dimensions and number, and their distance from each other and from the surface. This fascinating subject has already been very excellently dealt with by Mr. M. D. S. Lewis in his article " Speculations on Lustre," " Journal of Gemmology," Vol. I, No. 8, Oct., 1948, which is well worth re-reading.

He raises an interesting point, with which the writer does not agree, that lustre may be due to a stereoscopic effect. Now this effect is only observable, surely, when two (usually different) images are superimposed on each other, and seen by a *pair* of eyes. Therefore, if lustre is a stereoscopic effect it should not be apparent when the object is seen with one eye, which is not the case, particularly in metallic lustre. But possibly the writer has misread or misinterpreted Mr. Lewis's hypothesis.

For the purpose under discussion lustre may be divided into three convenient categories, metallic and sub-metallic, adamantine and vitreous; and resinous, waxy, oily, greasy, pearly, silky and opalescent.

The third main feature, *transparency*, may be considered under two heads; transparent and sub-transparent, translucent and sub-translucent in one, and opaque and semi-opaque in the other.

Now as to the specific optical properties which modify the effect of the above three features, refractive index is common to all ; single and double refraction are best seen in achröic or pale stones, and not at all in opaque minerals: dichroism is limited to coloured stones, and dispersion is at its best when the maximum proportion of the incident light is reflected and refracted through the facets on the upper side of the stone, while " fire " is a scintillating effect only to be observed when either the gem or the eye of the observer is subjected to a sudden lateral displacement across the path of the incident ray, and line of sight. A stationary stone may exhibit dispersion but cannot show " fire " or scintillation which is an effect of movement. It is next necessary to consider the method of illumination, the intensity and kind of light to be selected, and its location with reference to the mineral and the observer.

The writer should add at this point that if anyone should feel that this seems to be wasting a lot of time over a simple matter, he should try some simple experiments on the proper illumination of gem stones, and even if it does not carry him far, he will begin to understand why some jewellers' window displays, often of fine gems, appear to be of very indifferent glass or plastic. As will be seen later, this problem is quite a complicated one.

The writer possesses a very modest collection of gems, which are simply representative of their various species and colour variants, types, et cetera, and as there is no very great likelihood of adding really expensive specimens, he decided to concentrate upon effective display rather than perfection of exhibits, and it seemed very obvious that correct lighting for each type of mineral was essential. In order to discover what improvements could be made in this direction the schemes of lighting of several celebrated collections were examined.

IMPORTANCE OF LIGHTING

Any apparent criticism of the lighting or general scheme of display of such well known gemmological collections as those of the Geological Survey Museum, or the Natural History Museum at South Kensington, may seem presumptuous, but any inferred criticism is made constructively and is in no sense derogatory. The fact is that having set up certain standards as ideals in this connection, the writer has discovered that no collection so far examined has achieved them.

In the first of the above collections the general conception of the display, and the illumination on an average basis, is excellent, and the idea of covering the cabinets with modern " invisible " glass was a happy inspiration and adds much to the pleasure of inspection. Yet the fact remains that the fixed top lighting, and the diffused illumination, is too soft and allows too little for the best effects of reflection and refraction in the case of faceted gemstones. In addition, coloured stones are rarely so placed that their depth of tint is fully developed as it should be, by transmitted light, and in many cases no attempt has been made to select a suitable background. A soft, diffused light is quite the worst for many stones, and asterias in particular require a special " spot " light, and for optimum effect, may even have to be shrouded to prevent cross-lighting, and it is no exaggeration to state that with the diffused system of illumination adopted it is practically impossible to see the star effect in what are probably magnificent specimens of asterism.

This is reminiscent of an experience of a married friend who served in India during the recent War, and on returning brought with him a number of gemstones which he had " picked up " while there. As usual, some 75% were synthetics of one kind or another, but he had one quite nice pale translucent Star Sapphire, which was soon mounted in a ring for his wife, who very much admired it. Quite a long time afterwards they were in their garden one very bright afternoon when his wife suddenly let out a little squeal of surprise and delight—" Oh, do look! " she exclaimed, " There's the most wonderful star in my ring." She had only examined it previously by artificial light and never near a single bright light, but under ideal conditions with the sun as a spot light she saw the perfect six-rayed star for the first

time! Readers may remember the beautiful star sapphire and star ruby each of about 15 carat, exhibited at our first Exhibition by Pittar, Leverson, which were displayed to full advantage by the use of individual spot lights invisible to the observer, but focussed on to the centre of each gem, thus producing magnificent stars—probably the finest ever seen in this country.

Let us turn now to the remarkable collection of coloured gemstones, most of them of incredible size, and representing very unusual mineral species, which have been on view for some time at the British Museum's (Natural History) Mineral Gallery, and which have been carefully arranged and fitted into spaces in a curved sheet of transparent " Perspex " so as to allow full colour development by transmitted light, the effect aimed at being that of stones suspended in mid air. In actual fact, lack of attention to what may have been considered as a minor detail, has resulted in the effect being merely that of some beautiful stones resting on a sheet of curved plastic, because no attempt has been made to conceal the margins of the sheet, and the view extends over and beyond the limits of the sheet. The background is neutral and has been sympathetically selected, and if it had been continued right round the collection, to the top of the case, the sheet being gripped tightly between shaped panels, the desired effect would easily have been attained, and the illusion of suspension in space would, in the writer's opinion, be an aesthetic improvement.

The reader may be excused for asking, and in fact, is quite entitled to ask, if the writer has arrived at any definite conclusions as to the optimum conditions for effective display of gemstones, and of the best methods of obtaining such desirable results.

The reply is, certainly, as it seems obvious that particular attention must be paid to the correct kind of illumination to be adopted, and this is qualified by several essential conditions, namely, the type of stone displayed, which automatically controls the nature of the background, the other important points being the source, type and position of the illumination in relation to the exhibits.

In the case of achroic gems such as diamond, zircon, synthetic rutile, possessing high R.I's and abnormal dispersion, a fairly intense source of white light is necessary and this should be so placed that the maximum effect is obtainable from the top facets,

and the highest degrees of refraction and maximum reflection by the back facets, so that entering rays are analysed in traversing the stone and emerge with maximum dispersion.

Since such stones are cut so as to reflect as near 100% light as possible it is theoretically impossible to see through the back of such stones, or for light from the back to enter them; therefore, no purpose is served by having any light behind them, particularly as it is not essential to develop body tints, which are absent. For the same reasons a sharp contrast is required as a background and in the writer's opinion, this is provided by the almost matte yet " warm " surface of a deep blue or black velvet.

Soft, diffused light is useless for the effective display of faceted jewels, particularly achroic stones, and it is a grave and extraordinary error that fashion in adopting modern diffusion lighting should have overlooked this important psychological fact. Far too many restaurants and popular rooms used for dinners and evening entertainments are illuminated by some form of diffused light, the worst examples of course being the concealed cornice and wainscoting lights, under which a woman is lucky if her most precious jewels look like anything but indifferent paste or plastic

Another essential feature which is taken for granted by most people, is that " fire " or scintillation are inherent properties of a stone, but it actually results from movement in the path of a ray of fairly bright light. Now, it is women who wear most gems, and on whom they look their best, but much of their beauty (that is, of course, the beauty of the gems!) is due to the fact that when thrilled or excited—as most women are when conscious of being well and expensively dressed, and of wearing beautiful jewellery—they are never still, and therefore, ear-rings, pendants, tiaras, chokers, bracelets and rings, are in a constant state of movement, intercepting countless rays of light, if they are provided, and disintegrating and dispersing it in all directions and producing the maximum dispersion and " fire."

This is clearly demonstrated when one stands before the average jeweller's window, particularly one that is badly lighted, when it will be noted that in spite of the fact that the gemstones on view may be the best of their kind, there is no display of " fire " so long as one remains stationary, and scintillation is only apparent when one makes a quick movement to either side across

the line of sight. This clearly indicates that, in order that this very important feature be developed, it is essential that a lateral displacement of this nature must take place. Obviously the observer cannot be requested to bob his head about, as in a crowd this might cause complications, so that either the exhibits or the lights must move. In some rare instances this problem has apparently been appreciated and solved by the provision of small turntables in the showcase on which a number of selected stones revolve so that dispersion and " fire " may be viewed from all points.

In the case of coloured transparent faceted gems a similar system of top lighting should be employed, although it is probable that a somewhat softer illumination will be more effective, but where possible, the gems should be mounted so that soft light from below may be transmitted through them, thus giving prominence to their body colour.

Cabochon stones probably look their best in a moderately soft light, particularly if opaque, but this does not apply to asterias, chatoyants, and moonstones, which require very particular care for their effective display. When a star is visible by reflected light a spot-light of suitable intensity should be provided in the best position in front of the stone (or stones, if there are several, as one such light will serve for a number of stones if properly arranged), and screened from the observer, and the stone should stand out against a suitable background, such as black velvet. In the case of minerals like star mica, a plate of rose quartz, or some almandine garnets which may only show asterism by transmitted light, the observer should be able to view the source of light (a spot light) through the specimen which should preferably be mounted in a holder, which may be rotated on the axis of the light.

Generally speaking a neutral, or cream, or flesh-tinted velvet background will give excellent results with coloured stones.

Although lighting is of paramount importance in the effective display of gemstones it seems doubtful if any collection so far exists in which full attention has been devoted to this factor, and it is obvious that in the course of time much improvement will be achieved in this direction. The results of such carefully planned illumination will certainly be fully appreciated by all

genuine gemmologists, and in fact, by anyone having a cultivated sense of beauty.

If the reader had been interested enough to read so far, it is likely that another question has arisen in his mind, namely, whether or not the author has been able to evolve any positive scheme of effective display of gemstones on the lines advocated above, and if it is sufficiently practicable to be utilised?

Yes. The origin of this investigation, as has previously been explained, was a desire to discover a method by which a rather indifferent collection could be displayed to the greatest advantage. This laudable ambition was preceded by some considerable amount of soul-searching mental queries: "What am I collecting?" "What is the aim of my collection?" Probably few people collect gemstones methodically and it was essential to have some definite objective in view before deciding upon effective display, but once this constructive decision was made, it formed a basis upon which the whole fabric of the collection will rest.

The specimens were to be arranged first as a general collection in species of gemstones, and sub-divided as occasion arose, so that ultimately, each species may have its own separate section, with special sections for particular kinds of stones. This obviously meant that, unless due care was taken in anticipation of it, such a collection might be in a perpetual state of flux "under re-arrangement" which is a perfectly hopeless state of affairs.

One of the first schemes was to use a sheet of transparent "perspex" with counter-sunk apertures for each stone (long before this idea was first seen in the British Museum (Natural History)), but this presented several disadvantages for an impermanent, mobile collection. That is to say, one in which the specimens were liable to be exchanged for others, and which had to be mobile for use at lectures and demonstrations.

If it was requisite to substitute one stone for another, it would usually be necessary to alter the shape of the aperture, which would mean dismantling the collection temporarily; in addition, stones merely resting in such setting could not be safely moved for any distance, and it was impracticable to cement them in position. This scheme was therefore scrapped in favour of an improvement on it. In the meantime the idea of supporting each

stone in 3-prong flexible holders was considered, but the cost of these gadgets seemed rather prohibitive, although, no doubt, one of our Fellows who has a genius for intricate metal work would have solved this problem simply and neatly.

After further brain-searching which spread over a period of years, a scheme was eventually evolved which seemed to allow for easy accessibility of individual gems for dismantling or replacement, combined with extreme portability, and (it is profoundly hoped) an exceptionally efficient system of illumination and display. Of course most of these provisions refer to cut and faceted, polished stones, rather than to crystals and uncut minerals.

The general scheme as finally adopted was to start with a small mixed collection of cut and faceted stones, arranged in a series of vertical rows, in their several species, and disposed horizontally according to their colour. This should allow of an easy comparison between the colour and " fire " of stones of similar appearance. The top row consists of achroic stones, which are sharply displayed against a background of soft dark-blue velvet. The remaining rows are respectively, red, orange and yellow, green, blue, violet, with odd stones on the last row. The background is cream velvet as a foil for the transparent coloured gems above it.

The system of illumination has been the cause of much more trouble and perplexity than anyone who has not tackled the same problem would have thought possible, and it is still in the experimental stage. It is a top-lighting at present consisting of several small electric lamps mounted on a pivoted bar in such a way that it can oscillate horizontally across the specimens from end to end, so as to provide the essential scintillation from the faceted stones.

Transmitted light is provided by a small opaque (opal) strip light lying below and at the back of the coloured stones, giving a soft illumination through them, but screened from the " white " stones.

The method of mounting the stones is quite simple, and, to the best of the writer's knowledge, is unique, each stone being lightly yet firmly gripped in a suitable ring of transparent colourless " Perspex " split at one side, and slotted to grip the

bezel, and reinforced by plastic where necessary. Rings of several diameters are used, and of varying wall thickness. The tension, or " spring " of each ring is sufficient to ensure that there is little likelihood of a stone slipping out of its setting, but at the same time, any stone can be withdrawn quickly.

The rings are cemented, six in a row, to curved strips of the same material. The cement is quite strong, yet if it is necessary to remove a ring, it can be snapped off at once, and another substituted, with a drop of cement.

The strips are 9 in. long with a curve of about 20 in. radius so that it has a " focus " at a point in front and above the cabinet at which one's eyes are normally likely to be. These curved strips are cemented to several straight horizontal strips 12 in. long, and the whole inclined towards the front at an angle of about 45°.

The display is protected in front by an " invisible window " of the same product and in the front of the cabinet an aperture 12 in. x 6 in. had been cut, forming a protective flap, which can be let down in front. The inside of this flap will be covered with cream velvet, on which the names of the specimens will be given, in position, engraved on black ivorine in white letters.

This first section requires particular care in order to produce the desired effect, but as the collection grows, other similar cabinets will be provided. In addition to these there will of course be special displays for opaque cabochon stones and flat ornamental stones, with suitable illumination.

Star Stones and moonstones, chatoyants and others, will be provided for in the way already outlined for these specimens, and the collection will include such things as a rotatable rhomb of Calcite to demonstrate the effect of polarized light.

The striking double refraction of zircon, compared with the single refraction of spinel will be demonstrated in an illuminated cabinet with a screen and spotlight, and further improvements which will add to the pleasure of examining the exhibits, will be added in due course.

In this way it is hoped that even a most modest and unassuming collection of gems can be so displayed as to enhance its inherent beauty and to provide a definite cultural entertainment to an average interested small audience, as well as a considerable amount of pleasure to the owner.

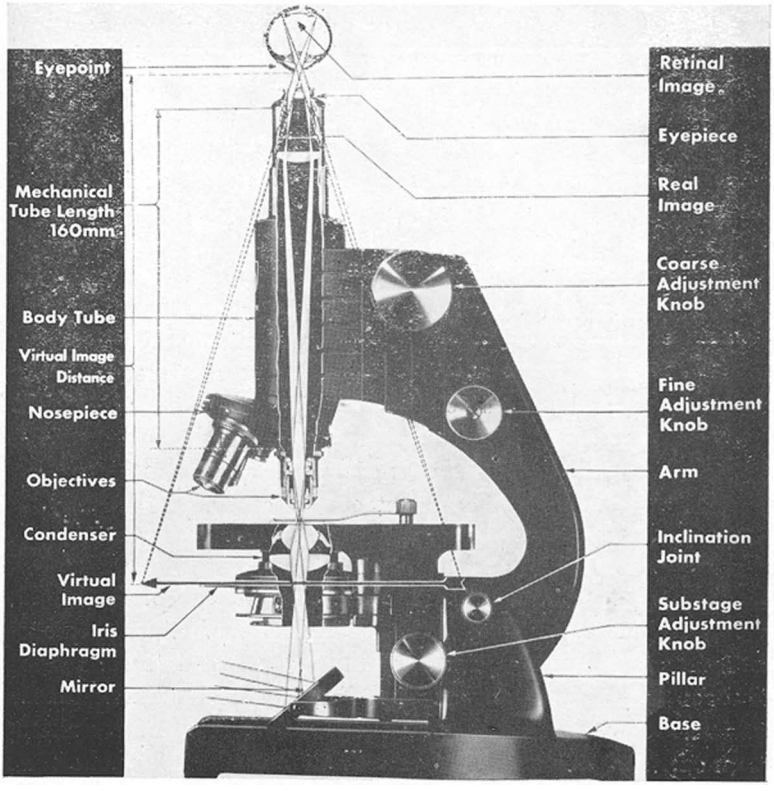

Courtesy of American Optical Co.

FIG. 1.—A moderately priced Modern Microscope with parts named.

OLD vs NEW MICROSCOPES

By D. S. M. FIELD

A MODERN MICROSCOPE DEFINED

For all practical purposes, the name "Modern Microscope" may be given to all short tube instruments manufactured during the first half of the present century; and, in the case of the petrological type with long tube, those of somewhat older vintage may be so qualified. These include (1) microscopes which, while old in years, are functionally the equals of those of recent manufacture, and (2) the very latest post-war types.

It might be said at once that age alone does not determine the value of an instrument. Quite a number of petrological

microscopes (e.g. those manufactured by Swift & Son) have been in continuous daily laboratory use for more than sixty years and still render satisfactory service. Indeed, a well made old stand —constructed piece by piece with infinite care and pride of workmanship—is often found to be superior in mechanical performance to some of the later products of the machine age.

Determining the Age of a Stand

The serial number definitely establishes the age of a microscope stand; but if this cannot be traced, there are several other means whereby the gemmologist can determine the age with reasonable accuracy. For instance, several makers, such as Crouch, are no longer in business, having retired from the field around the turn of the century.

We know, then, that the very latest Crouch models are more than fifty years old, and many others are considerably older.

The Finish

The type of finish is also a clue to the age of the stand; providing, of course, that it is the original one. Instruments of the nineteenth century were universally constructed of solid brass or of brass plated metal, with a highly polished or matt finish, coated with clear lacquer to prevent tarnishing. Later, microscopes with black japanned cast-iron bases began to make their appearance; and when it was found that this was a more durable and effective finish, black japan was gradually adopted as the finish of all parts of the instrument excepting the adjustment screws and trim—which remained lacquered polished brass.

In the late twenties and early thirties, black and brass were superseded by black and chromium or rhodium plate. Occasionally, a light grey and brass or chromium finish is met with—the latter, especially, in some of the newer models. Undoubtedly the grey *shows* less dust than the conventional black enamel ; but whether or not this may be considered a virtue is questionable

In recent years, too, a wrinkle finish is much in evidence. This does not require so much care in the machining of the metal surfaces prior to the application of the enamel; consequently, it is generally to be found on the lower priced " students' " instruments.

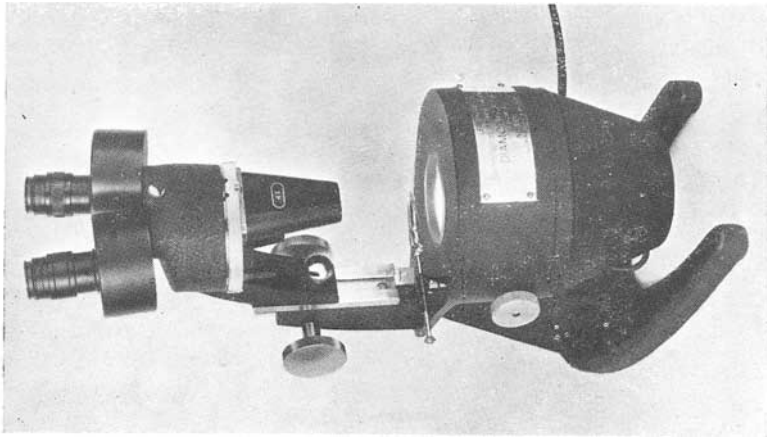

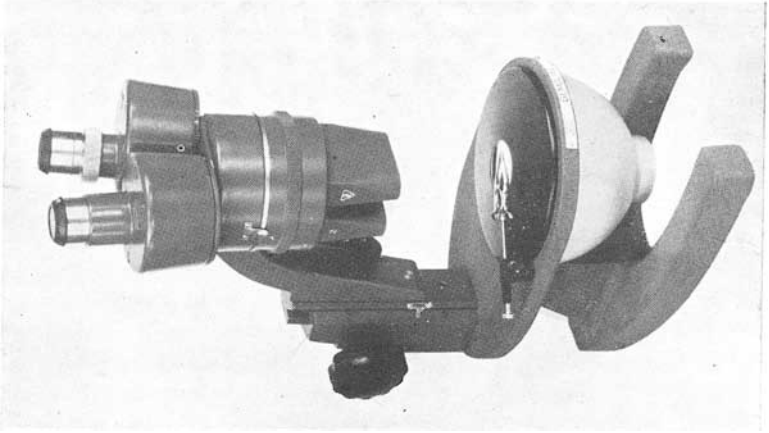

FIGS. 2 and 3.—Greenough - type stereoscopic microscopes with special lighting features developed for the testing and grading of coloured stones and diamonds.

Courtesy of The Gemological Institute of America.

Noteworthy exceptions are the gem-testing microscopes pro-produced by the Gemological Institute of America, and shown in Figs 2 and 3. These beautifully designed instruments feature a matching shade of dark grey or black fine-grained wrinkle finish in combination with non-reflecting smooth enamel. The two

finishes provide a pleasing contrast; but in the writer's experience, the ordinary coarse-grained wrinkle finish is liable to become shabby looking in the course of time. It is also somewhat difficult to clean thoroughly, unless one uses a fairly stiff brush; while simply wiping with a soft cloth or chamois will at once remove most of the dust and grime from the regular smooth surface.

The Fine Adjustment

Another feature indicative of the age of a microscope is the position of the fine adjustment. Older instruments were generally equipped with fine adjustment actuated by a horizontally operated milled head located on top of the limb; while in the case of practically all microscopes manufactured since World War I, the fine adjustment is controlled by a milled head on either side of the limb, with the same direction of motion as the coarse adjustment.

The older form, when well made, is very smooth in operation, and in the better class instruments is capable of giving accurate reading to 0·0025 m/m. of movement; hence, while the side fine adjustment has now become almost universal in application, there is actually little difference, if any, between the two types insofar as the quality of performance is concerned. Indeed, there are many experienced microscopists who would rather welcome the return of the earlier form, with its large, easily read dial.

The Base or Foot

The high tripod base sometimes encountered on instruments still in use, and designed to provide greater stability than the early horseshoes forms, seems also to have lost favour, and bases of modified horeshoe shape have largely replaced it. Some manufacturers now concentrate the weight in the front toes to ensure maximum stability in all positions from the vertical to the horizontal.

As in the case of the fine adjustments mentioned above, there is little to choose between the two, and the final choice would seem to depend solely upon the personal taste or preference of the purchaser. Generally speaking, a lower table is required for a microscope with tripod base.

The Nose-Piece

The multiple nose-piece or revolving objective changer is still

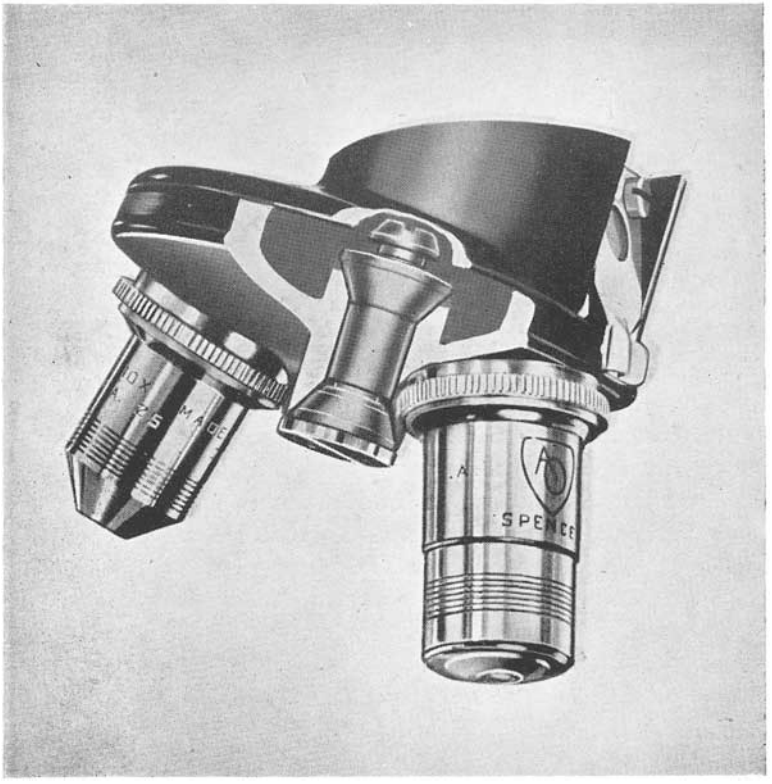

Courtesy of The American Optical Co.

FIG. 4.—The Spencer "Dual-cone" nosepiece with rounded top and automatic centring device.

another part of the microscope that has undergone a radical change in design—in this case, unquestionably for the better.

In the older models—that is, in models produced before the first World War—the dust guard covered the extra object glasses only when they rested in the stationary position. Thus the back of the objectives were exposed to floating dust particles when changing from one power to another. With the advent of the circular guard, this fault was entirely eliminated.

Since that time, the circular revolving nose-piece has undergone numerous modifications with respect to design and accurate centring, but the basic principle remains the same. The accompanying photograph—Fig. 4—shows a multiple nose-piece that is

undoubtedly the last word in beauty of design and functional excellence. This nose-piece is manufactured by the American Optical Company, Buffalo, New York, and is standard with the new line of Spencer microscopes. Having a rounded top, it is particularly easy to keep free of dust particles and lint, and its streamlined appearance constitutes a decided advance over the conventional form with concave top. Unfortunately, however, the new model cannot be used on other than the latest Spencer microscopes which were specially designed to accommodate it.

The Body Tube

The length of the body tube of all standard modern microscopes, excepting the so-called petrological instruments still employing nicol prisms, is about 140 m/m; but when the instrument lacks a draw-tube and is provided with a revolving object changer, the distance from the top of the objective to the eyepiece rest (the mechanical tube length) is fixed at 160 m/m.

On the more advanced instruments, an inner sliding drawtube for varying the mechanical tube length is commonly provided. This allows the separation between objective and eyepiece to be changed at will, and has several distinct advantages over the tube of invariable length, which in recent years, has regrettably been adopted as a standard, by several makers.

The inside diameter of the modern eyepiece tube is 23·3 m/m. —as laid down by Royal Microscopical Society Standard. This will receive all regular sized eyepieces of recent manufacture (23 m/m. diam.*) as a sliding fit.

The lower end of the body tube is fitted with the standard R.M.S. screw thread, which will accommodate modern objectives of British, Continental or American manufacture, as well as the objective changers described above.

When purchasing second-hand instruments and accessories, care should be taken to see that the threading of both tube and objective glasses conform to this standard, the specifications of which are as follows:

The Society Thread

Diameter: 0·800 in. (20·3198 m/m.)

Pitch: 36 threads to the inch (14·7 to the centimetre)

* Wide diameter eye-pieces are still often encountered in petrological microscopes of recent make.

Form: Whitworth screw—a V-shaped thread having the sides inclined at a 55 degree angle to each other, with one-sixth of the V rounded off at both the top and bottom of the thread.

Length of Objective Thread: 0·125 inch (3·1750 m/m.)

Length of Plain Fitting Above Thread: 0·1 in. (2·5400 m/m.)

Diameter of Plain Fitting Above Thread: not more than 0·759 in. (19·2784 m/m.)

Length of Screw in Tube or Nosepiece: Not less than 0·125 in. (3·1750 m/m.)

OBJECT GLASSES

When Abbe, in 1886, designed the first of the apochromatic objectives, near perfection in the correction of the object glass was achieved. Since that time, only very slight improvements have been made in either the achromatic or apochromatic series; consequently, many of the older objectives compared very favourably with those manufactured in the present day, providing that they are used with the tube length for which they were computed,* and are in good condition.

Since only the lower powers are required for gem testing, the achromatic rather than the expensive apochromatic series should be chosen by the gemmologist.

In recent times, the trend in object glass design has been toward a plain cylindrical barrel, with individual sleeves for each lens, none of which can be unscrewed from the outside. This form is attractive and easily kept clean; moreover, it obviates the danger of damage or improper assembly of the indivdual components by persons who like to "take things apart," but who lack the technical knowledge and skill to put them properly together again.

However, in view of the high quality and ready availability of many of the older types, the writer is preparing a separate paper covering their choice for gemmological work, and outlining methods for determining the total magnification of a microscope equipped with either the old or new forms.

THE CONDENSER

Although much has been written about the optical deficiencies

* Although not of so much importance in gemmology, where only comparatively low powers are utilized, old objectives optically corrected for a ten-inch tube length should not be used with a modern short-tube microscope unless the draw-tube is fully extended.

of the well-known two-lens Abbe condenser, this unit is unquestionably capable of supplying with complete efficiency the ordinary requirements of microscopy, and no expensive achromatic model need ever be purchased by the gemmologist.

A sub-stage rack and pinion focussing adjustment is more commonly to be found on old stands than on new ones; for, in recent years, many manufacturers have sought to cut down manufacturing costs by omitting refinements that were formerly standard to all but the simplest models. Furthermore, it has been clearly shown by Mr. Robert Webster, in his recent microscope series for the " Gemmologist " that a focussing arrangement to the condenser is a very desirable feature, where the microscope is intended for gem testing.

BINOCULAR VISION INSTRUMENTS

Binocular microscopes are undoubtedly more comfortable and less fatiguing to use than the monocular types—and in the case of the binocular Greenough models, stereoscopic vision combined with an erect image greatly enhance their value to the practical gemmologist and student.

Figures 2 and 3 illustrate two microscopes of this type designed by the Gemological Institute of America especially for use in the testing of gemstones without immersion; and the special lighting features their construction thus incorporates set them apart from most Greenough instruments designed primarily for biological or industrial application.

Alternately, it is possible for the student to purchase microscopes equipped with binocular bodies (or binocular eyepiece attachments for almost any type of monocular microscope of standard make manufactured during the past fifty years); but, with gems, it is hardly possible to achieve the same degree of stereoscopic relief when using the attachments so far developed by the various makers.

Years ago, the Wenham type binocular microscope described by Mr. Webster* was a very popular instrument—although, by modern standards, somewhat odd in appearance. However, the writer has been assured by good authority that the Wenham, equipped with a set of low-power achromats, is a very effective

* Webster, R.—" Gemmologist," Nov., 1950, pp. 246-49

instrument for the testing of gems. Furthermore, many of these instruments are equipped with circular, revolving stage and polarizing equipment.

Since, owing to the nature of their construction, Wenham-type binocular microscopes cannot function with the high power object glasses now demanded for biological and medical research, their manufacture has long since been discontinued, and those formerly in use have been replaced by high power instruments. This condition is greatly to the advantage of the gemmologist, who, not requiring high initial magnifications, can acquire second-hand Wenhams at comparatively low cost.

Wenham orthoscopic microscopes of very fine quality and heavy construction are readily available from many London dealers in good used optical equipment (such as, Chards (Reg.), at prices ranging from about twenty-five to forty pounds sterling. These prices include suitable objectives and several sets of eye-pieces ; as well as a great variety of ancillary apparatus—though mostly of a biological nature. A few have retractible prisms or separate monocular body tubes.

As always, the inexperienced student would be well advised to consult a competent established dealer when purchasing a microscope of this type, in order that the instrument selected will be guaranteed in good condition throughout, and be suitably equipped for gemmological work.

Personal Comfort

When using any type of microscope, the gemmologist should take care to avoid unnecessary fatigue resulting from adverse working conditions. Consideration should first be given to the height of the instrument or the chair upon which he is to sit. A cramped, awkward position is neither conducive to enjoyment of the task at hand nor to an accurate interpretation of the inclusions or structure present in a given gemstone under test.

Since inclusions are best observed when gems are immersed in a liquid of similar R.I., the stage must of necessity be in a horizontal position. Under this condition, an inclined eye-piece tube (not at all a costly accessory) or built-in binocular body, or separate binocular eyepiece attachment, will add considerably to the personal comfort of the worker.

Since all inclined attachments are set at a fixed angle to the body tube, the relative heights of the worker's chair and the table on which the microscope rests are quite critical; hence, when such attachments are employed, even more attention should be given to the height factors. The ideal combination can only be found by trial and error, and will depend entirely upon the height and idiosyncrasies of the individual worker.

Many authorities have recommended that the user of a monocular instrument keep both eyes open in order to prevent undue fatigue to the muscles of the inactive eye. However, most of them have failed to point out that good work is impossible when the inactive eye is allowed to perceive light in a passive manner.

This condition has been alleviated by using one of the eye shields specially designed for use with the monocular microscope. Such shields are usually available from manufacturers of optical instruments, or one may be constructed at home from black zylonite, hard rubber, or other suitable material. A very attractive and effective shield manufactured by Bausch & Lomb was described in an earlier paper.* This shield is now in use not only on the writer's microscope, but also on his spectroscopes, dichroscope, and refractometer.

Contrary to the popular notion, but in obedience to the natural law of use and disuse, the proper use of the microscope is beneficial rather than harmful to the eyesight. It has now been conclusively established that, after a time, the eye used for microscope work develops markedly better vision than the inactive one. It is imperative, however, that no stronger light be employed than is absolutely necessary for clarity of detail. This rule obtains particularly where ultra-violet light is being emitted by the light source, as when using arc or quartz mercury vapour lamps, or strong daylight. Needless to say, transmitted direct sunlight must *never* be employed as a light source, unless a suitably dense filter is inserted below the condenser, both as a means of filtering out the harmful ultra-violet rays, and to lessen the intensity of the visible light.

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* Field, D. S. M.—" Journal of Gemmology," Vol. II, No. 6.

A TALK ON JADE

By S. Howard Hansford

THE fascinating story of Chinese jade from its earliest manifestations was told by Mr. S. Howard Hansford, Lecturer in Chinese Art and Archaeology at the Courtauld Institute of Art, University of London, when he spoke to members of the Gemmological Association at the British Council on January 31st.

He said that among the many expressions of the Chinese artistic genius with which we were now familiar in the West there was one in which the Chinese occupied a position of unique and unchallengeable superiority, the carving of gems and ornaments from semi-precious stones. The fashioning of stones, harder than any known metals, into tools and ornaments had been practised in many parts of the world, but nowhere with such success and in such a continuous tradition as by the Chinese. Jade, the most precious stone known to them, had been their speciality. Throughout the formative period of Chinese civilisation jade had furnished the material for insignia and ceremonial objects and shared with bronze the function of providing the material for ritual symbols.

In China, as elsewhere, the stone-age man found that jade made excellent tools. A slide showed some of the neolithic tools found in China by Dr. J. G. Andersson, of Sweden. Whilst, however, in other lands jade went out of use, as stone tools were superseded by those of metal, in China it acquired the status of a precious stone, and the jade carver a position analogous to that of the goldsmith in Europe.

Mr. Hansford showed an early example of a pi, a disc of jade with a circular hole in the centre, which represented the deity "Heaven." The central hole probably portrayed the sun shining

in the vault of heaven. It appeared to have been carved without metal tools, he said, the orifice being drilled out from opposite sides with a length of bamboo and quartz sand. The piece was probably not much less than 3,000 years old.

The true jade prized by the ancient Chinese so highly was nephrite, a mineral harder than steel and made up of minute crystalline fibres, which accounted for its toughness and durability. It came from the region of Khotan in central Asia which appears to have been the source from the earliest times It was a long way from the ancient centres of population in China, something like 2,000 miles by caravan, the hazardous journey being alone sufficient to account for the high price. At first it was obtained only in the form of pebbles and boulders from the beds of rivers. An illustration from an old Chinese book showed one of the rivers being searched for jade.

Because jade was believed to be a product of Heaven, it was thought to be highly charged with creative force. Supernatural powers of healing the body and conferring immortality were attributed to it and jade amulets were buried with the dead to preserve the corpse. Women were said to have been used to search rivers for jade because it represented the male force in nature. The Chinese, explained Mr. Hansford, believed that everything in nature was male or female. Heaven, for example, was regarded as male, and Earth as female. Therefore women were supposed to exercise special attraction upon jade and, so likely to be specially successful in the search for it.

From the 18th century onwards the other jade mineral jadite, had been entering China from Burma. He showed micro-photographs of thin sections of nephrite and jadeite which showed the fibrous structure of the former and the granular crystals of jadeite. The mere possession of jade and its contemplation was supposed to impart fine qualities of character, especially the white jade with its typification of morality and all the virtues. The lecturer told how Confucius was asked why jade was esteemed more highly than marble. His reply was a little homily in which he compared the natural qualities of jade, one by one, with the most admirable human virtues, concluding with the remark, " Like the Way of Truth and Duty, jade is reverenced by all."

Certainly a beautiful object in white jade might well inspire such words. Nephrite was in fact being carved in China long before the time of Confucius. Pictures of objects were shown, some of which were made in the second millennium B.C. The holes in some were probably bored with pencils of bamboo used with an abrasive such as sand. The work must have been very laborious. Jade was not known to exist in the natural state within the eighteen provinces of China proper and appeared never to have done so. Mr. Hansford mentioned that he had marshalled the guidance for and against native jade in his recent book on Chinese Jade Carving, and had reached the conclusion that in the light of our present knowledge there was no reason to suppose that jade had ever been found in China.

From about 1400 B.C. onwards it was much used as ornaments for clothing and for fittings of utensils. Bronze tools were used to make most of these. From about the 4th century B.C. when the craft was reaching its maturity, it was applied to new purposes, sword furniture, accoutrements and vessels.

An illustration of an excavated tomb showed a first century A.D. jade scabbard fitting found attached to the weapon in Korea, which was then a colonial settlement of the Chinese. Later hollow vessels were carved in jade, though he did not think these were made much before the 3rd to 4th Century B.C., or well into the iron age.

Mr. Hansford went on to deal with the craft and its methods, saying that as jade was harder than metal, it had to be cut and ground by an abrasive. The first to be used was probably quartz sand, later superseded by powdered garnets and corundum. Fortunately nature had given the Chinese a perfect drill in the form of the bamboo. He had recently drilled holes in nephrite using the old Chinese method. Gradually metal tools were introduced and iron rotary tools operated by treadles were in general use as today. Illustrations showed the modern jade carver at work, the abrasive now-a-days being powdered carborundum known as " black sand " imported from the United States. It would take a week or more to cut a fair sized piece of jade in two. The fact that the Chinese craftsmen practised intense specialization gave them their supremacy. After the jade had been roughly

Continued on page 76

Stress Figures in AMBER

by Robert Webster, F.G.A.

SEVERAL pieces of clear amber fashioned as pendants or as beads for necklaces have been seen to contain large "inclusions," often coloured green or red, which are reminiscent of nasturtium leaves (Figure 1). Such pieces are often described as being "Sicilian amber," and the second illustration in the coloured frontispiece to Dr. Williamson's book on amber, which seems to be of this type, is stated to be Latvian in origin, While such ascriptions may in some cases be correct, the presence of these leaf-like structures cannot be taken as proof that the amber comes from any one locality since they can be artificially induced, as will be described.

Recently, whilst examining a ring set with a cabochon-cut amber stone mounted in a closed-back setting, it was noticed that small uncoloured "nasturtium-leaf" inclusions were present near the base of the stone, and also a number of bubbles on the base The history was that these inclusions were not present before the ring had been to the repairers in order that the shank be enlarged. It was considered possible that the heat employed in the re-sizing had been the cause of the blemishes now present in the stone, and to prove this point a number of experiments were carried out.

Preliminary tests by heating a piece of amber on a copper plate held over a Meker burner gave clear evidence of the production of the leaf-like figures. These are undoubtedly caused by stresses set up in the amber by heating, or maybe in some way by a change or release of stress, for as Herbert Smith mentions (1), "but it (amber) is always in a state of strain sufficient to show bright interference colours in polarised light."

The likeness of these "induced" inclusions to those seen in the fashioned pieces just mentioned, suggested further experiments on the lines of controlled heating. A number of pieces of block amber were prepared, so that at least one side had a crudely polished face, and various methods of heating were tried out. As was quite expected, heating in boiling water (100°

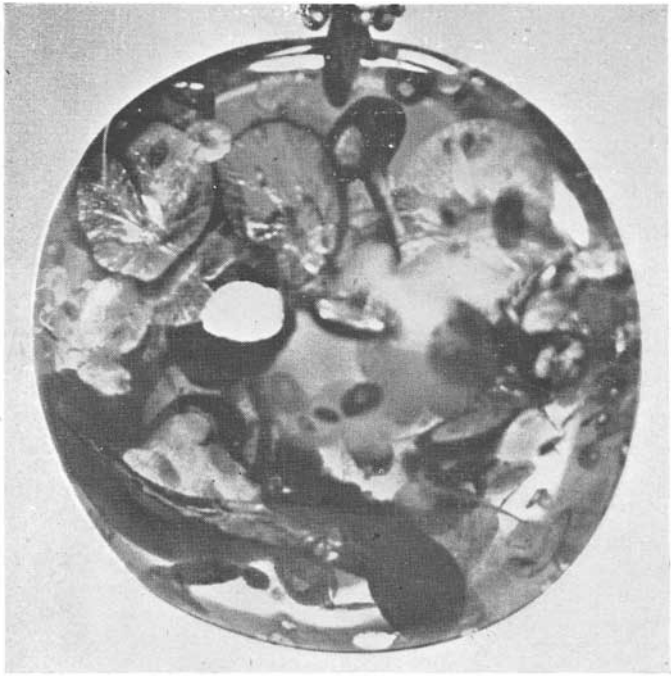

FIG. 1.—A very fine example of amber containing green coloured stress figures.

From the collection af B. W. Anderson.
Photo by G. A. Plastow, Wimbledon Photographic Society

C) for thirty minutes produced no effect and the amber was not altered in any way. Neither was any change in structure observed when the amber was packed in powdered blackboard chalk in a porcelain crucible and heated for a short time at about 200° C, but in a subsequent experiment on similar lines with longer and stronger heating, the stress figures appeared.

Repeating the earliest experiment; first by heating the amber in a lidded porcelain crucible, and secondly by heating on a wire gauze, until the amber tended to decompose, i.e. started to give off smoke (about 270° C), again produced the stress patterns. These patterns, however, were nowhere near so large as seen in the commercial material. Similar heating followed by rapid cooling in coloured inks (red and green) showed that the stress figures took up the dye and appeared similar to the coloured

figures in the marketed pieces. However, as was expected, much cracking occurred by this method—much more than when the amber was heated after being packed in powdered chalk.

Max Bauer (2), referring to the process used in clarifying cloudy amber by employing controlled heating in rape seed oil (oil expressed from the seeds of the rape—*Brassica napus*), states the following:—" Unless the greatest care be taken the operation of clarifying amber results in the development of peculiar cracks which in some respects resemble fishes scales. They are at first so small as to be scarcely visible, but gradually become more and more conspicuous and begin to show iridescent colours until towards the end of the operation they become quite obvious as shining golden cracks. These are known to the amber workers as ' sun spangles,' and their presence often serves to distinguish a clarified from a naturally transparent specimen of amber."

FIG. 2.—Leaf-like stress figures artificially induced in amber.

In view of this note of Bauer's, a series of experiments was carried out using rape seed oil. Pieces of amber were placed in the oil contained in a porcelain crucible which was heated until the oil was near decomposing point—evident by the strong smelling fumes which were evolved. During the heating the amber specimen was occasionally turned to ensure that different sides were at the bottom of the crucible where heating was strongest. In these experiments the amber was not removed and rapidly

cooled, but was allowed to cool slowly in the oil. On removing the specimen a large number of stress figures were noticed. These were somewhat larger than those induced in the earlier experiments, and, moreover, were oriented at all angles just like those seen in the commercial article. Figure 2 shows a group of these heat-induced stress figures.

Experimental colouration was attempted by various methods, such as by inducing stress figures by heating in rape seed oil and then dropping into cold water, coloured by red or green ink. The figures were found to take up the colour, more effectively with the green solution that with the red, but much cracking occurred due to the rapid cooling. The use of a hot solution (near the boiling point of water) did not lessen this tendency to cracking.

An attempt to use alcoholic solutions of fuchsine and methyl green to dye the rape seed oil directly showed that the two liquids (alcoholic dye and rape seed oil) were not readily miscible. However, the green dye acted quite well but tended to colour the whole of the amber when heated in the coloured oil as well as the stress figures produced by the heating. The red dye became decolourized during the heating and little staining occurred. The very slightly coloured piece of amber was then dropped into a cold alcoholic solution of rhodamine, which, like the coloured ink experiments, dyed the stress figures but caused much cracking. On inspection it was seen that some of the stress figures were stained with the red fuchsine dye and rather more with the rhodamine which has a different shade of red.

The sum total of the experiments, although not producing the magnificent effects seen in the commercial articles, does show that some method of controlled heating and staining can produce the nasturtium-leaf effect. It is most probable, therefore, that the pieces offered for sale are " treated," although no proof can be given that the effect cannot be produced by nature.

Parallel experiments on pieces of bakelite " B " and " C " did not give the typical stress figures shown by amber. A recent copal resin (probably from Zanzibar) softened when heated on a gauze and when so treated in rape seed oil and no stress figures were induced. Finally, small leaf-like figures were seen after pieces of pressed amber (Ambroid) were similarly treated.

In conclusion; a visit to the collections at the British Museum (Natural History), and the Geological Survey Museum, showed that no specimens of amber having these leaf-like stress figures were exhibited. In the case of the British Museum (Natural History) no amber is as yet shown in the Mineral Gallery, and the only exhibit of amber is a fairly comprehensive one in the the Fossil Gallery, but which does not show a specimen of Sicilian amber. The Geological Survey Museum shows several specimens of fluorescent amber from Sicily, but as far as could be observed through the glass case, no stress figures were present. Enquiry from trading merchants gave the general impression that the marketed material had definitely been "treated," but how and where was not known. Perhaps someone more knowledgable may be able to throw more light on this mystery.

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(1) Herbert Smith (G.F.), " Gemstones," 1949, p. 488. Methuen. London.
(2) Bauer (M.), Trans. Spencer (L.J.), " Precious Stones," 1904, p. 539. London.

JADE (*continued from page 71*)

shaped by the revolving disc worked by a treadle, the edges would be ground down by a large grinding wheel. Much ingenuity was used to make the design fit the natural peculiarities of the stone.

The tools for the treadle lathe are made in a great variety of shapes, but they may all be separated into the three categories of grinders, gouges and drills. Mr. Hansford showed slides made from photographs which he had taken in the Peking jade workshops and which illustrated many of the processes. His audience was thus able to realize how, after months of patient cutting, grinding and drilling, a superb vessel emerges from this apparently intractable material polished to the semblance of the softest wax, with delicately undercut carving and loose ring-handles of faultlessly regular shape. He concluded his lecture by showing slides, some in colour, of a number of outstanding masterpieces in jade, executed within the last two centuries by such simple tools and skilful methods as he had described.

A New Gemstone

By C. J. Payne, B.Sc., F.G.A.
Diamond, Pearl and Precious Stone Laboratory of the London Chamber of Commerce.

ON Saturday, 17th March, 1951, a letter appeared in "Nature" from Dr. G. F. Claringbull, B. W. Anderson and the writer, describing a new gemstone. Several newspaper enquiries have been made since and it seems appropriate to describe the circumstances of the discovery in greater detail.

The honour of discovering this new stone is due to Count Taaffe, of Dublin, a keen amateur gemmologist, collector and connoisseur. In 1945 he was examining a parcel of spinels in his collection under the microscope, and to his eternal credit he noticed that one of them, a pale lilac stone, showed a very slight doubling of the back facets. At that time he did not possess a refractometer and so had no means of measuring either the refractive index or confirming the birefringence. So he sent the stone to the Laboratory, where it was soon established that it had the following properties:—

Refractive indices $n_{D\omega}$ 1.723, $n_{D\varepsilon}$ 1.719, $n_{\omega}-n_{\varepsilon}$ .004.
Specific gravity, 3.62. Hardness, 8. Uniaxial negative.

A search through the literature failed to reveal any mineral with similar properties and the stone was submitted, with Count Taaffe's permission, to the British Museum experts. Dr. Claringbull declared that he could not identify it and so we had to ask the owner if he would allow us to saw a piece off for identification and analysis. He very kindly gave permission and Dr. Claringbull was able to declare that X-ray analysis had shown that it was a new mineral. We were surprised and so was he. Nowadays new minerals are very rare and then generally only small incrustations, so a solid hard crystal actually cut as a gemstone was a very remarkable discovery.

The stone was a pale lilac colour and its hardness was the same as spinel, and refractive index and density were also very near to

it. The student of gemmology may pause a moment and consider. It has the hardness and general appearance of spinel, and the birefringence is so small—.004—that it would be unnoticed unless sodium light was used, and being small, only 1.41 carats, no density could be relied on unless elaborate technique was used, though anyone possessing a sample of Clerici's Solution could have seen that the density was very near to that of spinel. The stone showed a perfectly good uniaxial negative interference figure.

Dr. Claringbull set to work on the sawn off piece and established that the mineral was hexagonal. In fact, he discovered that it belonged to a very rare class of the hexagonal system, the hexagonal trapezohedral or hexagonal holoaxial class. The symmetry of this class consists of all the axes (holoaxial implies this), i.e. the vertical hexagonal axis and the six digonal axes but no plane of symmetry at all. The word " trapezohedral " refers to the general form of this class, the hexagonal trapezohedron. However, in the few crystals belonging to this class this face or form has never been seen. Until recently no mineral had been known belonging to this class, but in 1942 Dr. Bannister described a mineral from Kenya called Kalsilite which belonged to it, and now this new mineral has come to make it two. Curiously, they both belong to the same space group. A minor point is that among the few artificial crystals barium aluminate has been found to belong to it. Since this new mineral has been found by spectrum analysis to be a magnesium beryllium aluminate, it seems that there might be a connection between the two.

Some idea of the price Count Taaffe had to pay in the cause of science is shown by the fact that his stone originally weighed 1.419 carats and after sawing and recutting 0.55 cart. His only consolation is that Mr. Bull-Diamond, of Charles Mathews (Lapidaries), Ltd., has made, as usual, a very good job of it and the stone now looks much brighter and more attractive.

As far as composition is concerned, we know that it contains magnesium, beryllium and aluminium and very little else. The amount reserved for chemical analysis is so small that we have to wait patiently for that brilliant mineral microanalyst, Dr. M. H. Hey, of the British Museum staff. It was thought at first that the stone contained boron, which is very troublesome in a microanalysis, but a further examination showed this to be absent.

It might be added that the writer tried very hard to establish the refractive index of the ordinary ray by means of the minimum deviation method and found it to be 1.7230 ± .0001 for sodium light.

In October, 1949, the writer was testing a case of stones which consisted mainly of green sapphires and pale spinels. One of the green sapphires turned out to be a very nice Ceylon kornerupine, and finally, when nearly all the stones had been tested, one pale lilac spinel was found to have a rather higher refractive index than the others. It was in no way different from them in colour or general appearance, but these pale spinels had as usual a refractive index of 1.715, whereas this stone was 1.720 or 1.721. The refractometer was in very bad condition and our other one on show at the Gemmological Association's Exhibition, so it was not possible to see birefringence ; but it was possible to obtain the interference figure and to the writer's surprise and great delight it showed a uniaxial figure which proved to be negative. A few days later better refractometers were available and the birefringence was established definitely. The purchase of this stone was negotiated not without difficulty.

Dr. Claringbull took an X-ray rotation photograph and pronounced it to indicate a stone similar to Count Taaffe's. In the meantime we had acquired a Zeiss Abbé Pulfrich refractometer and a new X-ray set with a more powerful tube. We had the table facet enlarged and better polished and obtained the following data: $n_{D\omega}$ 1.7208, ε 1.7167, $\omega-\varepsilon$ .00412. The stone before re-cutting weighed .87 carat and after .860 carat, so it had not lost much.

This stone was paler than Count Taaffe's and this accounts for the slightly lower indices, due probably to less iron in the composition. The density was taken in Clerici's Solution by the refractive index method. It was found to be 3.61, again a little lower than the first. We submitted this stone to Dr. W. Stern for indentation hardness tests, and he found that it was slightly harder than natural spinel and slightly softer than synthetic spinel. In Mohs's scale it was 8. This is, of course, unusually hard for a mineral ; only chrysoberyl ($8\frac{1}{2}$), corundum and bromellite (9), moissanite (" meteoric carborundum ") ($9\frac{1}{2}$) and diamond (10) are harder.

Our hopes were raised when we found that the stone had a green fluorescence in X-rays though it showed nothing under ultraviolet light. Unfortunately, the spinels in the case in which it was

found also showed a green fluorescence, particularly those most resembling it in colour.

This stone was too pale to show any real absorption spectrum, but Count Taaffe's stone showed a vague band in the blue very near and exactly like the band shown by blue spinel, a band due to ferrous iron at 4,580 Å.

It is unfortunate that the locality of this mineral is unknown. Count Taaffe's specimen was obviously cut in the East ; in fact, one might almost certainly say Ceylon. The second stone, together with the other stones in the case, was cut somewhere in Europe, possibly Idar-Oberstein. It was certainly associated with many Ceylon stones, but obviously not all. We cannot say for certain where this new mineral comes from though we suspect the gem gravels of Ceylon.

As the only two specimens have been cut as gemstones we do not know the habit. They are too pale to show dichroism.

Summary of properties:—

Crystal System—Hexagonal. Class 62. Hexagonal trapezohedral.

Cell structure—Space group $C6_32$. Unit cell a, 5.72; c, 18.38 A.

Habit—Unknown.

Chemical Composition—Contains Mg., Be., Al. and Fe (trace).

Absorption Spectrum—Vague band at 4,580 A.

Fluorescence—Green in X-rays, inert U.V.L.

Dichroism.—None apparent.

	H	ε	ω	ω—ε	*D*
Count Taaffe's stone ...	8	1.719	—1.723	.004	3.62
B. W. Anderson's stone	8	1.7167	—1.7208	.0041	3.61

It only remains to express thanks to Mr. Bull-Diamond (Charles Mathews (Lapidaries), Ltd.) for his kindness and trouble in re-cutting and re-polishing both stones ; to Dr. W. Stern for the indentation hardness tests ; and finally to Mr. I. E. Pressman for his co-operation in obtaining the second specimen.

Gemmological Abstracts

GÜBELIN (E. J.). ***Ein neues Verfahren zur Erhohung der optischen Wirkung der Edelsteine.*** (A new method of increasing the optical effect of gems.) Uhren, Schmuck und Edles Gerät, 1950, *10*, 294-295 (cont. Journ. Gemm., 1951, *3* (1), 29).

Anti-reflection films can enhance the appearance of a good spinel so that it looks like a fine ruby. The possibility of fraud cannot be excluded but the film can sometimes be detected with the unaided eye, and it can be dissolved in acids. The fluor in the film can also be detected by micro-chemical methods for inst. zirconium-alizarin reaction or the " etch test." The detection of barium and magnesium is also described.

E. S.

SCHLOSSMACHER (K.). ***Nieuwe problemen van de synthetische edelstenen.*** (New problems relating to synthetic gemstones.) Edelmetaal, 1950 (10), 221-223.

Article in Dutch mentioning (apart from synthetic corundum) synthetic emeralds (I.G. Farben, C. T. Chatham) and synthetic rutile. The latter are already encountered in the trade, covered with a thin film of corundum to improve the surface hardness.

E. S.

MCLINTOCK (W. F. P.). ***A Guide to the collection of gemstones in the Geological Museum.*** Revised by P. A. Sabine.

A third edition of this inexpensive (price three shillings) yet very valuable publication follows much the same lines as the original. It has been brought up to date and has benefited by Mr. Sabine's revision and Dr. Phemister's editorship. As it deals with the properties and cutting of gemstones and the imitation, treatment and artificial formation of them, and gives, in addition, a series of identification tables, the booklet is a text-book as well as a guide to the gems in the museum. Gemmological students of the 1915-1935 period remember the first edition with affection.

CROWNINGSHIELD (G. R.). ***Reports on Brazilian heated green quartz.*** Gems and Gemology, Vol. VI, No. 11, p. 346.

In a vein of quartz, mined near Montezuma in the District of Rio Pardo, Minas Gerais, is found, with sparse amethyst, a partially opaque quartz having a yellowish cast, which on proper heat treatment (process not given) various shades of green are induced. Colours resemble green beryl, green tourmaline and a dark peridot green. It is suggested that the possibility of producing green quartz was discovered accidentally through the prevalence in Brazil of applying heat treatment to all types of stones. The colour is said to be permanent and stones up to twenty carats have been cut in Rio de Janeiro, where the gem is called " Prasiolita."

R. W.

KOHN (J. A.). ***Observations of the Slijper diamond.*** Gems and Gemology, Vol. VI, No. 11, p. 347.

A discussion on the orientation of the included diamond in a diamond crystal of 7.25 carats in relation to twinning. No convincing results obtained. This diamond was reported upon by R. T. Liddicoat in " Gems and Gemology," Vol V, No. 12, 1947, pp. 492-493.

It is interesting to recall that E. Trillwood, in 1934 (" The Gemmologist," Vol. 3, No. 30, January, 1934, pp. 186-189), reported on a diamond crystal with a similar large inclusion of diamond. This diamond, then said to weigh 7½ carats, may have been the same stone.

P. B.

MITCHELL (R. K.). ***Two rarities from Ceylon.*** Gemmologist, Vol. XX, No. 235, February, 1951, pp. 28-30.

A report on an unusual chatoyant aquamarine of silky blue colour and on a slaty-blue star stone (flesh pink by transmitted light) which was identified as a remarkable asteriated quartz.

R. W.

ALEXANDER (A. E.). ***Restoring moisture to pearls.*** Gemmologist, Vol. XX, No. 234, January, 1951, p. 1.

Discusses the loss of water by pearls over a period of time with detriment to the pearls. Experiment showed that by placing the pearl in a dessicator containing water in its base the pearl took up moisture and rejuvenation is suggested by using the method.

R. W.

ASSOCIATION NOTICES

MEMBERS' MEETINGS

January: At a members' meeting held at the British Council Cinema on January 31st, 1951, Mr. S. Howard Hansford, Lecturer in Chinese Art and Archæology at the Courtauld Institute of Art, University of London, gave an illustrated talk upon the occurrence and working of jade.

February: On February 20th, Dr. G. F. Claringbull, Vice-Chairman, described a unique colour film dealing with the formation of the Mexican volcano Paricutin. This film was first shown to members in 1948 and caused so much interest that an opportunity of showing it again was welcomed.

The Council of the Association is grateful to Dr. G. H. Pough, of the American Museum of Natural History, for making this possible.

March: On March 15th, at Goldsmiths' Hall, Mr. Nigel Kennedy gave an extremely interesting talk to members on the subject of "Gold in Britain, and illustrated it with slides that he had prepared himself. The talk will be reported in the next issue of the Journal.

PUBLICATIONS

Fifty-two pages have been added to the new edition of the "Handbook of Gem Identification," by R. T. Liddicoat, first published by the Gemological Institute of America in 1947. This increase in size is largely due to the addition of a comprehensive chapter which gives detailed descriptions and property ranges of all the important gemstones, as well as many of the minor ones.

In the elaborated new edition, recently developed testing instruments are described and their purposes and importance outlined; the "spot method" of refractive index determination is more fully discussed than in previous editions; and explanation is given of the radiographic and fluorescence methods of pearl examination. Additional gemstones have also been added to the tables and flow charts, plus a Cleavage and Parting Table in the Appendix. Tables already included in previous editions are Specific Gravity, Refractive Index, Hardness, Optic Character, Pleochroism, Birefringence, Colour, Dispersion, and Property.

There are 117 illustrations in the book, including an abundance of photomicrographs showing characteristic inclusions useful in the identification of gemstones.

TALKS BY FELLOWS

Gordon A. Blythe: "Gemstones." Townswomen's Guild, Southend-on-Sea, Thursday, January 11th, 1951; Townswomen's Guild, Prittlewell, Tuesday, March 13th, 1951.

Mrs. G. I. Parry: Nursing Staff of Llandudno Hospital, Cardiff, Wednesday, February 28th, 1951.

Dr. G. F. Claringbull: B.B.C. Home Service—Science Survey. Thursday, April 5th, 1951.

THE LATE PROF. W. T. GORDON

The sudden death of W. T. Gordon, emeritus professor of Geology in the University of London, has already been briefly recorded in the last issue of this Journal.

He was in his earlier years chiefly noted as a palæo-botanist, but in his long period of work at King's College, first as lecturer and later as professor, he developed so many interests that he was widely known as an expert in many fields, including the study of diamonds, synthetic corundum, and gemstones generally.

Both B. W. Anderson and C. J. Payne were students of his in the early twenties, and in a personal note Mr. Anderson writes:—

" My own memories of Prof. Gordon date back for more than 25 years, when I was a chemistry student at King's College. Drs. A. W. Wells, S. W. Wooldridge, and L. D. Stamp were my lecturers in Geology and Mineralogy, which I took as a subsidiary subject for my degree: Prof. Gordon lectured to me only in palæontology, and even his enthusiasm and skill as a lecturer failed to make this branch of geology very interesting to me.

" It was outside the lecture hours, browsing through his splendid mineral collection and on other informal occasions that I learnt most from Gordon and came to know him well. It was he who recommended me for the job of starting the Precious Stone Laboratory of the London Chamber of Commerce, and it was at his hands that I had my first lessons in distinguishing natural from synthetic corundums, and in the use of the refractometer. I well remember Mr. S. A. Phillips (an enthusiastic and knowledgeable F.G.A.) and I foregathering late in the evening at King's and poring through petrological microscopes at synthetic corundums immersed in methylene iodide, with Prof. Gordon similarly engaged at our side. Thus early was the smell of methylene iodide associated with gemmology in my mind.

" Prof. Gordon allowed himself no respite and no recreation. He gave generously of time and trouble in helping past and present students ' out of hours.'

" His own work suffered in consequence, but lives on in that of many of his former students, who will always remember him with admiration and affection."

GIFTS TO THE ASSOCIATION

The Council of the Association acknowledges with gratitude the following gifts:

Large pink tourmaline crystal, A. Sandhurst, Esq.; parti-coloured cabochon tourmaline, Miss M. J. Biggs.

ANNUAL MEETING

Annual Meeting, 1951. The twenty-first (fifth since incorporation) Annual General Meeting of the Association was held at Goldsmiths' Hall, Foster Lane, London, E.C.2, at 7 p.m. on Wednesday, April 4th, 1951. Mr. F. H. Knowles-Brown, the Chairman, presided.

The audited accounts for the year ended 31st December, 1951, were presented and commented upon by the Treasurer, Mr. F. E. Lawson Clarke. Mr. Knowles Brown, in submitting the annual report, thanked the Officers, Council and Committees for their work throughout the year end expressed appreciation of the work carried out by many Fellows. It was moved from the Chair—" That the Report of the Council and the audited Accounts for the year ended December 31st, 1950, be hereby approved and adopted." Mr. N. Kennedy seconded the resolution, which was unanimously approved.

Mr. R. Webster and T. G. Jones were re-elected to serve on the Council and Miss E. Ruff elected to serve in the place of Mr. J. H. Stanley.

Messrs. Watson Collin & Co., Chartered Accountants, were re-appointed as Auditors to the Association.

After the election of these Fellows, Dr. G. F. Herbert Smith, President, asked Mr. Stanley to accept from the Council a case of two briar pipes as a token of the Council's appreciation of his long and useful service to the Association. Mr. Stanley acknowledged the gift with gratitude.

Dr. Herbert Smith also presented to Col. G. M. Sprague a refractometer that he had won as co-Tully medallist in the 1947 examinations. A special welcome was extended to Mr. Siu Man Cheuk, a Fellow of the Association from Hong Kong.

After the meeting members took light refreshments in the Livery Hall where members had an opportunity for informal discussion.

COUNCIL MEETING

At a meeting of the Council of the Association held on January 31st, 1951, the following were elected to membership:—

FELLOWS:

Coote, James W., Pasadena, U.S.A (D.1950)
J. L. Hyde, Hounslow (D.1950)
Jennings, John D., Windsor, Canada (D.1950)
Rillstone, R., West Leederville, Australia (D.1950)
Shapshak, Leon, Johannesburg, S. Africa (D.1950)
Shaw, J. R., Great Bridge (D.1950)
Shipster, T. R., Abadan, Iran (D.1950)
Wainwright, F., Hutton (D.1950)

ORDINARY MEMBERS:

Rait, R. L., Winsford

PROBATIONARY MEMBERS:

Lawrence, J. F., St. Albans
Wheelock, H. J., Birmingham
Randall, J. A., Bath
Shepherd, G. T., Birmingham

GEMMOLOGICAL EXHIBITION IN EDINBURGH

An Exhibition is to be held at the Heriot-Watt College, Edinburgh, on April 25th, 26th and 27th, from 6 to 9 p.m. each evening. Aarrangements are in the hands of Professor W. H. J. Childs, D.Sc., F.Inst.P., of the Physics Department at the College, and Mr. D. J. Ewing, F.G.A., the Instructor of the Gemmology Classes.

There will be a display of minerals, cut gemstones and books, but the principal theme will be actual gem testing methods and it is intended to demonstrate the various instruments to the public

GEMMOLOGICAL ASSOCIATION OF AUSTRALIA 1950 DIPLOMA EXAMINATION RESULTS

The following are the members who have qualified in the 1950 Diploma Examination for Fellowship. The first three positions in Australia were filled by:-

K. N. S. Hall (N.S.W. Branch)
G. A. Tombs (N.S.W. Branch)
B. J. Skinner (South Australia)

The best students in each State were:—

NEW SOUTH WALES: K. N S. Hall. QUEENSLAND: Miss H. Mole
VICTORIA: B. McMaster SOUTH AUSTRALIA: B. J. Skinner

The Australian Prize has been presented to Mr. K. N. S. Hall and the Stevenson Award to Mr. J. B. Campbell.

The complete results are as follows:—

N.S.W. BRANCH

Armitage, C. C.	Engel, Miss C.	Redman, Miss J
Barnett, Miss Nella	Farley-Thew, R.	Russell, R. F
Becker, J. B.	Gerrard, W. A.	Symons, N.
Bellwood, E. J.	Gumbley, C.	Tombs, G. A.
Blair, J.	Hall, K. N. S.	Vernon, E.
Brandman, H.	Humphries, Mrs. R.	Whiteman, R.
Cliff, R. H.	Leadbeater, Miss E.	Wilkinson, D. E.
Castle, L. F.	Lowe, E. E.	
Durst, T.	Massa, C.	

VICTORIA

Brook, B.	Durkin, J.	McMaster, B.
Brown, R.	Ezard, H.	Turvey, G.
Caulfield, R.	Feore, N.	Wynde, L.
Cramp, J.	Hall, N.	
Davey, L.	Hood, D.	

QUEENSLAND

Gardner, J. W.	Mole, H. (Miss)	Staines, E. H.
Herdsman, L. P.	Quain, M. (Miss)	Virgo, R. A.
Isaacs, K.	Squires, S. J.	

SOUTH AUSTRALIA

Campbell, J. M.	Howeler, D. C.	Skinner, B. J.
Congdon, W. R.	Moss, J. A.	Stapledon, D. H.
Foskett, C. W. K.	Noble, G. E.	Wilson, J. G.
Hale, J. E.	Richardson, W. M.	

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INSTRUMENTS FOR GEMMOLOGY

We give below a list of the instruments and accessories for gemmology now being made, and, as far as is possible, of which stocks are maintained. The accumulation of orders for some of these instruments and the continued high demand cause occasional delays in supply, and reduce the rate at which we can increase the range of our manufactures.

	£	s.	d.
Rayner Refractometer	14	0	0
Polarising filter for refractometer	1	0	0
Yellow filter for refractometer		16	0
1.81 Refractometer fluid per oz.		15	0
Rayner dichroscope	4	4	0
Specific gravity indicators, per set	3	3	0
Hardness pencils, Mohs' 6–10, per set	2	0	0
Hardness pencils, Mohs' 1–10, per set	3	0	0
Spectroscope grating	4	0	0
Spectroscope d.v. prism	5	10	0
Spectroscope, grating, w.l. scale	12	10	0
Lamp, high intensity, on stand with transformer, for microscope, spectroscope, refractometer	7	7	0
Stone holder, three spring prong		9	0
Wood's glass, 2 ins. × 2 ins.		5	0
Chelsea filter		8	6
Immersion cell		7	6
Loupe, double lens, 8x		5	0
Loupe, triple lens, achromatic and aplanatic, 8x, 10x, 12x, 15x, 20x ... from £1 12s. 6d. to	2	15	0
Methylene Iodide, S.G. 3.32, Nd 1.742		5	10
Monobromonaphthalene, S.G. 1.49, Nd 1.66 ...		2	4
Bromoform, S.G. 2.86, Nd 1.59		1	6
Clerici Solution, S.G. 4.33 at 40° C. ... ... (Prices per ounce, bottles 8*d.*)	1	4	0

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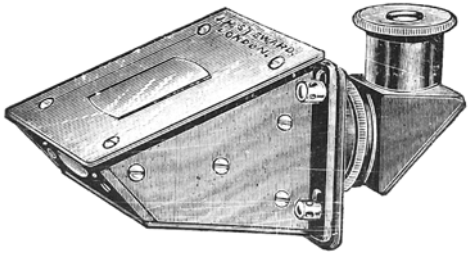

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THE JOURNAL OF GEMMOLOGY
AND PROCEEDINGS OF THE GEMMOLOGICAL ASSOCIATION OF GREAT BRITAIN

Vol. III, No. 3 JULY 1951

Simple Photomicrography as applied to Gemstone Inclusions

By Norman H. Day, F.G.A.

LIKE many who gained their first knowledge of gemmology from reading Mr. B. W. Anderson's "Gem Testing," I have always enjoyed using a microscope to study the wonderful and beautiful inclusions that occur within gemstones and have long cherished the idea of taking photographs of these for myself.

After becoming a Fellow of the Association, I turned to the subject of photomicrography and took a course in the Elementary Theory and Practice of Photography at the local technical school.

In looking for books on the subject, I found that there are a great many on photomicrography, but none that approach the subject from the point of view of the gemmologist.

Gemstones are quite different in shape and size from the very thin petrological slides of rock formations or the mounted sections of organic substances, made for use with the critical lighting and high magnification of the modern microscope.

The most useful books I have read are:—

1. " The Ilford Manual of Photography," by James Mitchell. Chapter XXIII deals with photomicrography and the other chapters give useful information on all photographic problems.
2. " Amateur Photomicrography," by Alan Jackson. Gives a clear idea of the problems and describes simple apparatus that can be easily constructed.
3. " Practical Photomicrography," by Barnard and Welch. An advanced and very thorough book on the subject. Because it is some years since the last edition was published, certain of the lighting and photographic equipment described has been superseded by later and more efficient types.

Turning to the equipment required, any microscope that is suitable for the study of gemstones can be used, though the type with a revolving stage and centering-screws has many advantages over the instrument with a fixed stage.

The laboratory making a large number of photomicrographs of high magnification uses a special camera which has long extension bellows, which is held vertically above the microscope by a rigid stand ; the shutter is worked by a cable release and at the top it has a ground glass focusing screen and a dark slide plate holder. Some cameras will take roll film and have the focusing screen at the side, which works on the reflex principle. For this type of work there are special eye-pieces for the microscope called projection-oculars ; these often have an extra observing eyepiece at right angles to the optic axis.

Very good results can be obtained with a plate camera with lens removed, preferably with double or treble extension bellows. It should be held over the microscope with a very rigid stand.

Certain miniature cameras can be used, the lenses being replaced by a special observing eyepiece which fits to the ocular of the microscope.

Satisfactory photomicrographs can be obtained with an ordinary roll film box camera using a supplementary lens, and this method was described by Mr. John Vincent, F.G.A., in the " Journal of Gemmology," Vol. I, No. 3, July, 1947.

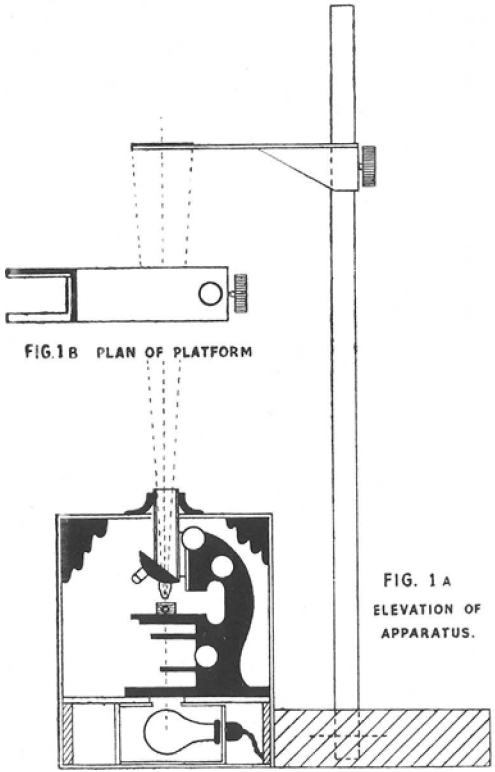

FIG. 1B PLAN OF PLATFORM

FIG. 1A ELEVATION OF APPARATUS.

Nº	GEMSTONE				EXPOSURE	PLATE		LIGHTING				"CAMERA LENGTH" OC POSITION TO PLATE			MAGNIFICATION	DEVELOPMENT			RESULTS
	SPECIES	COLOUR	DEPTH	RI OF		TYPE	SPEED	LAMP	CONDENSER ON OR ILLUMINATED		FILTER	OB	OC			TYPE	TIME	TEMP	
1	SPINEL	BLUE	5½	M1	16	ORTHO	O800	100	—		—	32	—	490	27	RYTOL	7	65°	GOOD
2	"	"	"	"	40	"	"	"	DG		—	32	—	"	"	"	"	"	GOOD (REQUIRES MORE DEPTH OF FOCUS)
3	RUBY	DARK	4	M1	20	PAN	P1200	"	—		—	50	—	520	14	"	4½	65°	SLIGHTLY OVEREXPOSED

FIG. II RECORD SHEET.

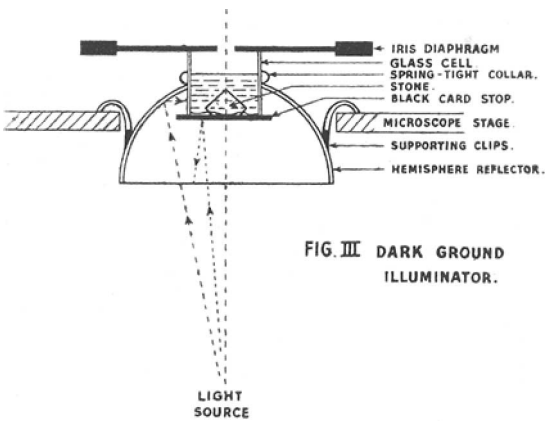

FIG. III DARK GROUND ILLUMINATOR.

By working in a dark room it is possible to take photomicrographs without using a camera. The lighting unit and the microscope are housed in a light-tight box with only the eyepiece protruding from the top ; a rigid stand holds a platform horizontally at " camera length " above the eyepiece. This platform carries the focusing screen, which is replaced with the photographic plate, which after exposure is immediately developed.

It is this last method that I have used to gain experience.

When using the microscope to examine inclusions the focus is often altered to observe a feature and to get a proper idea of its shape, but in the case of a photomicrograph only one plane can be in focus ; therefore it is necessary to use an objective that will give sufficient depth of focus in order that the true shape of the whole inclusion or plane of inclusions may be seen in one picture.

In general, it is true to say the longer the focal length of the objective the greater the depth of focus. Objectives 16 m/m, 25 m/m, 32 m/m or 50 m/m give sufficient working distance, therefore one should be chosen which gives the required depth of focus necessary for the problem in question.

For work of low magnification it is not necessary to use an eyepiece ; extra magnification can be obtained by using extra camera length. The extra magnification requires an increase in the power of the lighting source, otherwise the exposure will be unduly long.

The Setting-Up of the Apparatus

A light-tight box (see Fig. 1a) can be made from a cardboard carton strengthened with wooden battens, and the front opening covered with strong light-proof black-out curtains, draped to include all light but loose enough for the microscope to be adjusted for focus through the curtains.

The microscope is placed on a rigid wooden three-legged stand giving a clear space underneath for an asbestos box in which is mounted a 100-watt opal bulb. The asbestos box and the wooden stand have holes cut in them and are arranged so that the bulb is in alignment with the microscope.

In the top of the carton, cut a round hole large enough for the body tube of the microscope to pass through. A light-tight union is made from a collar of black-out material fixed to the carton with paper clips and to the body tube with a strong elastic band.

The eyepiece and draw-tube of the microscope are removed and in place of the draw-tube is placed a tube of black paper or, better still, a paper tube lined with black velvet ; this prevents unwanted reflections.

On the bench at the side of the light-tight box is placed a stand with vertical pillar, such as the stand of a vertical photographic enlarger. One can be easily made from $3\frac{1}{2}$ feet of one-inch water-pipe held vertically in a 12 ins. by 12 ins. by 3 ins. block of concrete, and clamped to the vertical pillar is an adjustable bracket which carries a horizontal platform on which rests the ground glass focusing screen and, later, the photographic plate. A screw knob allows it to be fixed at the height required.

Should it be decided to use $3\frac{1}{2}$ ins. by $2\frac{1}{2}$ ins. plates, the platform should be made from a piece of 3-ply wood, 12 ins. by 3 ins. (see Fig. 1b). A space $3\frac{3}{8}$ ins. by $2\frac{1}{4}$ ins. is cut from one end, and two strips, one 3 ins. and one $3\frac{1}{2}$ ins., of wood or thick cardboard $\frac{1}{4}$ in. wide are glued as indicated ; these act as stops. In having only two stops it is quite easy to feel the correct position for the plate in the dark.

Give the whole platform a coat of matt black paint ; the type called poster paint is very good.

The ground glass focusing screen is the same size as the plate to be used, and for this type of work one with a medium grain is quite satisfactory ; a very fine grain requires much stronger lighting.

To avoid knocking or shaking the apparatus at the beginning of the exposure, the switch for the light inside the box is screwed on to the bench some distance from the rest of the apparatus.

The Method of Using the Apparatus

On the microscope stage lay an Iris diaphragm and open to about 5 m/m diameter. On this place a plain glass slide, and on this slide stand a glass cell containing the stone to be photographed.

Cover the stone with a highly refractive liquid, its refractive index being near that of the stone, using, say, a 32 m/m objective racked down until it nearly touches the liquid. Place the focusing screen ground side downwards on the platform, switch out all room lights except a photographic safelight, if one is being used, drop the curtains in front of the box, switch on the light under

PHOTOMICROGRAPHS
OF
CRYSTAL INCLUSION
WITHIN A
DARK BLUE SPINEL

Dark Blue Spinel
RI 1.715

Oval Brilliant Cut 1.00ct.

Photographs on this page
are ×55 32 m/m
Objective

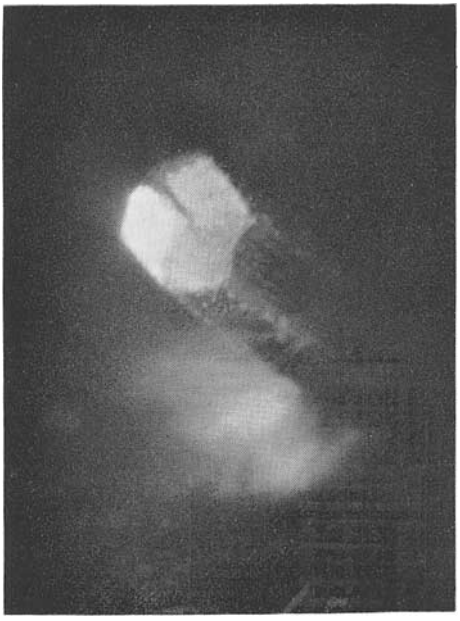

(Using dark ground iliumination)

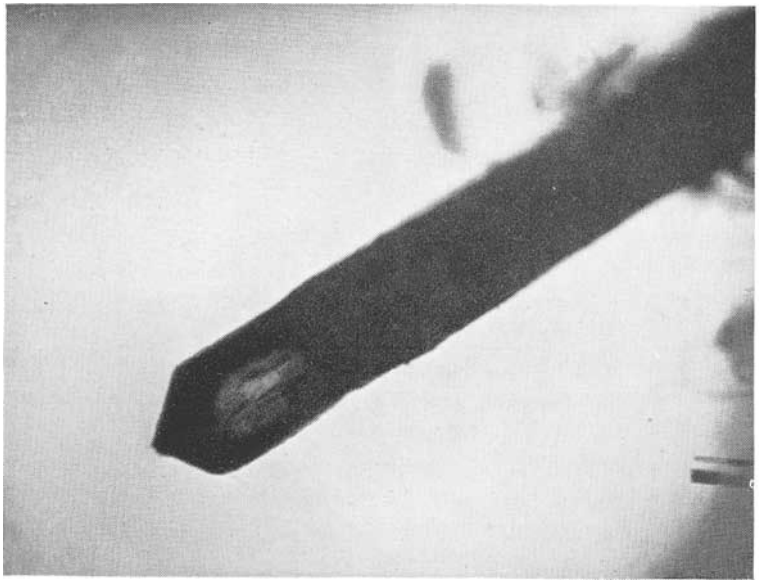

(Using direct lighting)

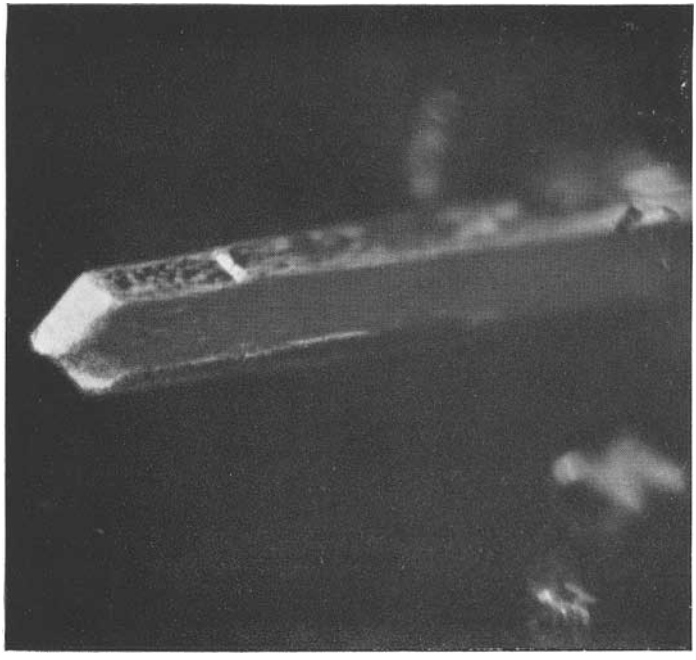

× 55 32 m/m objective (Using dark ground illumination)

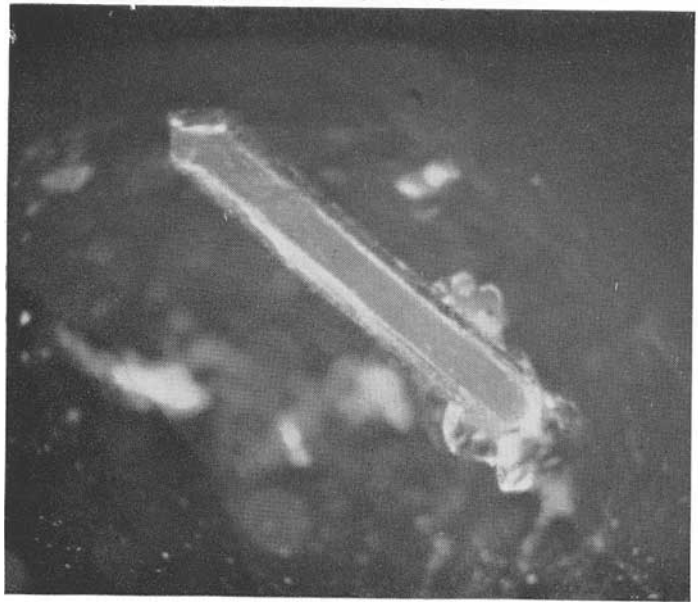

× 35 50 m/m objective (Using dark ground illumination)

the microscope, and raise the objective ; watch the focusing screen until that part of the stone required is in focus.

Now raise or lower the platform until the whole or that part of the picture it is proposed to photograph covers the whole of the screen. Adjust the diaphragm on the microscope stage so that it passes sufficient light to illuminate the picture. Should the diaphragm be open too much, the excess light will tend to spoil the definition of the picture.

It is often an improvement to place a second diaphragm on the top of the cell, which will control undesirable reflections from the cell itself.

If Iris diaphragms are not available, very good substitutes can be made from 2-in. discs of thin copper or brass, with a round hole cut in the centre and painted matt black. A useful set would have holes 4 m/m to 10 m/m diameter.

Use a watchmaker's eyeglass and, observing the focusing screen, adjust the focus until the picture is really sharp. A low-powered magnifying glass mounted on three legs and stood on the focusing screen can be very handy for this final adjustment.

See that no light is showing outside the box except that shining on to the screen ; switch out the light.

It is as well to have the light shining in the box only when adjustments are being made, because the 100-watt lamp gives out sufficient heat to boil the immersion liquid if left on too long, and should methylene iodide be used this will turn brown quite quickly.

With all lights, except the safelight, out, take a photographic plate from the packet of plates ; see or feel that the remainder are properly wrapped and returned to the packet. Replace the focusing screen with the photographic plate the emulsion side downwards.

The emulsion side can be identified by touching the corner of the plate against your moistened lip ; the emulsion side will stick slightly, the " backed " side will not.

Now switch on the light within the box, time the exposure, using a dark room clock placed near the safelight, or in total darkness count the seconds.

Switch out the light, remove the exposed plate and develop immediately in chemicals already prepared.

The Choice of Photographic Material

Photographic plates can be obtained in a great many sizes. I have found $3\frac{1}{2}$ ins. by $2\frac{1}{2}$ ins. useful for most work.

There are three main groups of photographic emulsion: *Ordinary*, which is colour sensitive only to violet and blue. *Orthochromatic*, sensitive to violet, blue, green and yellow, and *Panchromatic*, sensitive to all colours, but not in the same ratio as our eyes, which record yellow-green as the strongest colour. All photographic plates are most sensitive to blue light.

Some plates, usually panchromatic, are said to be "fast," that is, very sensitive to light, but for photomicrographs of gemstone inclusions it is better to use medium or slow material which has a smaller grain size.

Safelights for ordinary and orthochromatic material are much easier to see and work by than those for panchromatic material. When using panchromatic material it is often better to work in complete darkness.

It is important for this type of work to use "backed" plates. These have the back of the plate covered with a coloured film which absorbs light passed through the emulsion and prevents internal reflections within the glass plate which would produce undesirable effects. The "backing" of the plate dissolves during the developing process.

I have had good results with Kodak Ultra Speed Orthochromatic Plates O 800 and Kodak Super Panchro-Press Plates P 1200. Both are quite fast, but are types that are easily obtained.

Exposure

Exposure depends upon a great number of factors:—

(*a*) The *type of plate* and its speed.

(*b*) The *quality of the light and its quantity*, governed by the type of lamp, its wattage, and the shape of the filament, as well as the light transmitting qualities of the substage-condenser, diaphragms and filters if they are used.

(*c*) *Magnification* depends on the power of the objective and the "camera length" or the power of the objective with the eyepiece and the "camera length."

(*d*) The *stone being photographed*, its colour, the depth of colour, transparency and the refractive index of the immersion liquid.

Using the apparatus for the first time, it is possible to get a good idea of the correct exposure by using a stone with an all-over pattern of inclusions, such as Hessonite Garnet. Make an envelope of black opaque paper which covers three-quarters of the unexposed plate and expose this for 16 seconds. Turn out the light, move the envelope to cover only half the plate, expose 8 seconds, proceed by covering only a quarter of the plate, expose 4 seconds, remove envelope and expose 4 seconds. Then develop the plate which has been given a step exposure of 4:8:16: and 32 seconds. One step should cover the exact exposure, but if all the steps are over-exposed (the plate practically all over black) place a sheet of ground glass or flash opal glass over the opening of the asbestos box and try another step expose.

Should the first attempt have been under-exposed (showing only a weak outline of the picture), try two steps 64 seconds and 128 seconds ; but should the factors of the " set up " be such that an exposure of over 100 seconds was necessary, the picture would be very difficult to focus sharply on the screen because the picture would be very dim.

Because most gemstones make a mono-coloured picture, I have found that exposure can have a very large latitude and there is very little difference in the results of exposures of 20 seconds and 30 seconds.

The results of every exposure, with full details of all the factors, should be kept on a record sheet (see Fig. 2).

Once the record shows the results from exposures, using the same lighting, magnification and type of plate, with the main colour groups of gemstones, it is possible to estimate fairly well a correct exposure from a given gemstone and a given set of factors.

The Development of the Plate

There are numerous formulæ for making photographic plate developers and there are many first-class ready-made developers on the market, but for the gemmologist who only occasionally requires one, ready to hand and in a fresh condition, Messrs. Burroughs Wellcome & Co.'s " Tabloid " photographic developers, marketed by Johnsons, of Hendon, Ltd., are very satisfactory.

The type of " Tabloid " called Rytol is most suitable for general work. Using $3\frac{1}{2}$ ins. by $2\frac{1}{2}$ ins. plates and one pair of tablets with 4 ozs. of water in a $4\frac{1}{4}$ ins. x $3\frac{1}{4}$ ins. dish will give sufficient depth of developer, which should be kept at an even temperature and at 65° F. if possible.

With development temperature and time are the important factors.

In a second $4\frac{1}{4}$ ins. x $3\frac{1}{4}$ ins. dish mix " Acid-Hypo Fixing Salts " that will give 4 ozs. of liquid, or mix plain Hypo (Sodium Thiosulphate Crystals) 2 ozs., with 5 ozs. of hot water, adding when cool $\frac{1}{8}$ oz. potassium metabisulphite or $\frac{1}{8}$ oz. sodium bisulphite.

Between these two dishes have a dish or basin of plain water. Take the exposed plate the emulsion side upwards, slide under the developer and gently rock the dish. Remove when the time given on the instruction leaflet for that type of plate is reached, rinse in the water and slide emulsion side upwards into the hypo fixing and rock the dish for three minutes. Take out and switch on the main light, look at the result, return to the hypo and cover the dish with a cardboard box lid. Then leave another seven minutes, take out and wash in running water for one hour. Because the emulsion is now soft, hold the plate in a form of rack to prevent scratching while washing, especially if several plates are being washed together.

Take out and shake off superfluous water and allow to dry in a place free from dust, but with a free circulation of dry air.

Prints can now be made from the negative in several ways, though often it is as well to let a professional photographer make the prints, for he has a wide range of graded papers. Photomicrographs are best printed with a glazed finish. A good negative can be enlarged, which brings out the detail, and is one way of increasing magnification without loss in the depth of focus.

Variations in the Lighting

When making photomicrographs of inclusions within stones with strong double refraction, the double refraction phenomenon may be undesirable and may be eliminated by placing a polaroid filter in the filter holder under the microscope stage and turning the filter until the picture on the focusing screen shows no double refraction.

The very interesting twin-planes seen in corundums when observed between crossed nicols can be easily photographed. First place a polaroid filter under the microscope stage and a second polaroid filter on the top of the body tube, adjusting the two filters until they are in a crossed position. Then bring the stone in the cell into the optic axis and turn until the maximum effect is observed.

Dark-ground Illumination

With the transmitted lighting many interesting photomicrographs can be made, but with transmitted light certain inclusions will only photograph as silhouette, and to show their true shape dark-ground illumination or a type of side lighting must be arranged.

For this I have made a unit (see Fig. 3). From a round disc of 6 S.M.G. sheet silver, 3 ins. diameter, is raised a hemisphere. This can be accomplished by using a doming block and doming punches, and frequent annealing of the silver. A silversmith friend will usually oblige if the tools are not to hand. The exact size of the hemisphere will be governed by the size of the hole in the microscope stage. Now obtain a small glass cell about ½ in. diameter and ½ in. high: the lower part of a cachou tube or medical phial can be cut off at the required height with a carborundum slip and the top edge ground smooth and level.

In the top of the hemisphere is cut a hole ½ in. in diameter or the size that will allow the cell to pass through. Make a metal collar that holds spring tight round the cell to prevent it dropping right through.

Fix clips that will suspend the hemisphere in the stage. Cut a circle of black cardboard ⅝ in. in diameter and cement to the base of the cell. Durofix heat-proof cement is quite satisfactory for this. Now cut a disc of lead foil or pewter that fits inside the cell and bend it to hold the stone in the position required. The stone is covered with a highly refractive liquid.

Below the stage is an opal 100-watt bulb. The amount of light transmitted through the sides of the cell is governed by the depth that the metal collar allows the cell to pass into the hemisphere. The best results are obtained by illuminating only that plane within the stone that is being photographed.

It is an improvement to place a diaphragm on the top of the cell to prevent extraneous light reaching the objective.

Conclusions

When Dr. E. Gübelin's unique photomicrographs of gem inclusions, many of which were taken in colour, are studied, it is soon realised that he controls his lighting perfectly, so that even with the high magnification he obtains each type of inclusion is given the correct lighting and shows maximum detail.

Using the simple apparatus that I have described, it is apparent that a great improvement would be made by using a Pointolite or a type of lamp with a small but powerful light source in conjunction with a sub-stage condenser and so obtain critical lighting.

Having improved the lighting, there are many other ideas for the improvement of the apparatus described in the books I have mentioned. These must be tried to assess their value when applied to the photomicrography of gemstones:—

1. The fitting of tube-like diaphragms behind the objectives to increase the depth of focus.(3)
2. The use of filters to increase the optical performance of the microscope.(1 and 3)
3. The use of the "Parallax" method of focusing on a clear glass screen with black cross lines.(2 and 3)
4. The use of photo-electric exposure meters to measure exposure times.
5. The whole field of colour photography.(2)

I hope that this description of a successful method of making photomicrographs will encourage others to approach this interesting subject which plays such an important part in the study of gemstone inclusions, and maybe other workers will publish details of their experiences with other methods and apparatus.*

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(1) "The Ilford Manual of Photography." By James Mitchell. Henry Greenwood & Co., Ltd., London, 1950.

(2) "Amateur Photomicrography with Simple Apparatus." By Alan Jackson. The Focal Press, 6th edition, 1948.

(3) "Practical Photomicrography." By J. E. Barnard and F. V. Welch. Longmans, Green & Co., 3rd edition, 1937.

* A further article on the subject of photomicrography will be published in a subsequent issue of the Journal.

From the Laboratory . . .

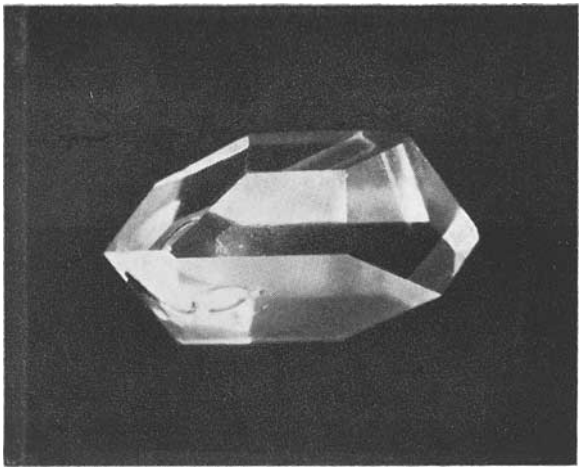

Photographs of a synthetic quartz crystal made in the Bell Telephone Laboratories and described in Vol. 3, No. 1.

(*Above*) Natural size, showing development of the positive rhombohedron at the entire expense of the negative (R. K. Mitchell).

(*Below*) Magnified about 10 ×, showing wire hook embedded in the "seed" plate.

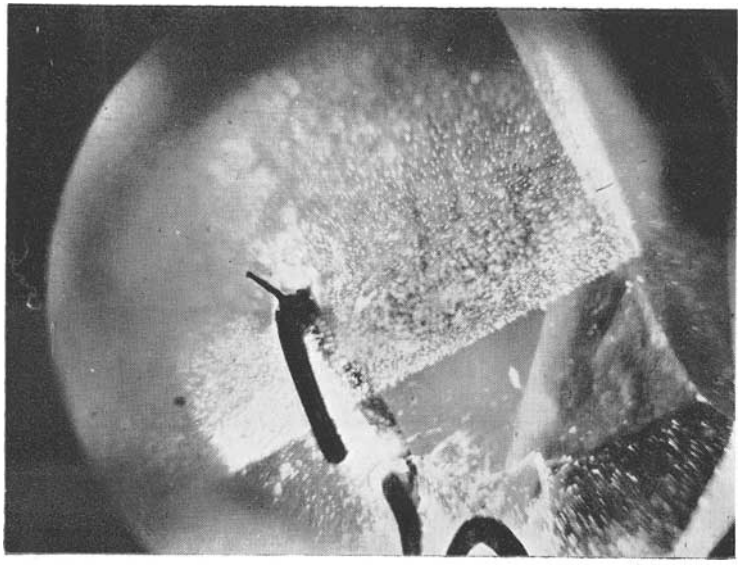

Gold in Britain

By Nigel W. Kennedy, F.R.S.A., F.G.A.

I.—Introduction

GOLD has been so absent from circulation in Britain for thirty-six years that two generations are unable to visualise a time when gold coinage, from the half-sovereign upwards, was in common use by all classes of the community.

For countless generations gold has been almost venerated as a precious metal, sometimes reputed to possess occult powers, and partly owing to its comparative rarity and to the fact that it is not easily destroyed or harmed by fire or normal chemical action, it has been accepted the world over as a moderately portable medium of exchange in comparison with many other forms of wealth. This attribute of preciousness is so closely associated with gold that one instinctively compares personal and other qualities with those of the Noble Metal, as in the phrases " As precious," or " as costly," or " as pure " or " as good as gold," and until comparatively recent times gold was regarded as the King of Metals, and even now many people believe gold to be the most costly metal.

Latterly, however, Platinum, Palladium, Iridium and Rhodium have commenced to replace gold in many ways.

Copper is actually rarer than gold in nature, for not only is it less widely distributed through the earth's crust, but there is actually less of it ; but while Copper is often found in more or less isolated patches of considerable size and richness, gold is widely distributed, usually in a finely divided state, and the high cost of extraction adds to its price.

Gold occurs native or almost pure in some places, or in the form of ores in combination and association with other minerals in veins and lodes traversing rock formations. Associated metals may include Platinum, Palladium, Osmiridium, as well as Silver, Tin,

Lead, Copper, Iron, Bismuth, Antimony, Zinc, with Arsenic, Sulphur, Tellurium and Selenium. Many of the minerals we prize as gemstones are included in those associated with gold ores as *rarer accessory minerals*, such as Blende and Cassiterite.

During the course of time chemical processes cause gold to be released from its ores, when it may be transported by streams and deposited as scales, threads and nuggets in their beds. Mountain torrents in spate transport it, but since gold is 19 times heavier than water it is soon dropped and retained in hollows and cracks. Shepherds in olden times discovered that the woolly fibres of the sheep's coat, lying in a stream, might collect spangles of gold, and fleeces were left deliberately for the removal of gold dust from streams, thus giving rise to the legend of the Golden Fleece. Some dried-up beds of streams are incredibly rich sources of gold, e.g. the placer deposits of Kalgoorlie and Coolgardie in Australia.

Most countries have possessed such deposits, but they have usually been quickly worked out, although the original source of the gold is sometimes traced by prospectors.

Gold is usually obtained by mining its ores, and Witwatersrand at Kimberley is a famous mine, another being Mount Morgan, in Australia, where the hill was said to be practically composed of rich auriferous copper ore.

Sometimes gold-winning is relatively simple, but its production is usually laborious and costly, and may involve danger to health or life. It is probably true that more gold has been invested in gold mines than has come out of them, but this has largely been due to rank dishonesty and human greed, the desire to obtain an unduly high return for a small outlay.

Another source of gold is sea water, and many years ago the Russian scientist Dmtri Ivanovitch Mendelejeff estimated that each cubic mile of sea water contained £60,000 worth of gold, and since the earth supports 300 million cubic miles of water there is sufficient gold to interest any Chancellor of the Exchequer—only it would cost more to extract it. River sands are often rich in gold, and in 1846 the French savant M. Dubré suggested that the bed of the Rhine should be worked for the precious meal, estimated at 36,000 tons.

II.—A Brief Historical Sketch of the Occurrence of Gold in Britain

Britain is an auriferous area and has produced quantities of the precious metal from pre-Roman times up to the present day.

There is no reason whatever to suppose that our gold resources have been anything like worked out, but there is a good deal to support the theory that vast amounts of gold ore in very rich veins

SKETCH MAP OF THE BRITISH ISLES

The approximate positions of the Gold Mines formerly operating, and localities in which native Gold is stated to have been discovered. The approximate location of various gold objects which have been found at times is also indicated by the appropriate symbol.

still await the miner's pick in Wales and Ireland, and possibly Cornwall and Scotland.

In August, 1947, when the Press was full of news about the approaching wedding of H.R.H. Princess Elizabeth, some prominence was given to the hope that sufficient native Welsh gold would be forthcoming for her wedding ring. It was stated that the proprietor of a Welsh mine (which was the only gold mine then operating in Britain) hoped to have enough gold, and that Welsh gold had been used for wedding rings for her royal mother, Queen Elizabeth, and her august grandmother, Queen Mary.

Anyone reading this would naturally infer than the finding of native gold in Britain was rare, but in 1938 it was reported that in one month 225 ounces of gold, worth £1,500, had been extracted at the reopened pre-Roman mine of Ogofau, at Pumpsaint. The official Report of 1939 to the Secretary of Mines states that in 1938 2,428 ounces of gold were mined in Wales, valued at £20,000. Since then a sort of Iron Curtain has descended on production, which is under the ægis of the Ministry of Supply.

At one time we find British gold mines referred to in all good faith as a possible new El Dorado which would put Klondyke or Coolgardie in the shade, and at another the suggestion that there ever has been gold of any value in Britain is received with howls of derision.

In order to get some sort of picture as to where we have arrived in the story of the production of gold in Britain, we shall have to delve a long way back into the depths of history. The story commences in the distant past, over 2,000 years prior to the birth of Christ. It is not too easy to locate the parts of the historical mosaic and to fit them into a picture, but by searching through the local Reference Libraries, the Geological Survey Library, and by visits to the British Museum, Science Museums, Geological Survey Museum and Victoria and Albert Museum, I have at least managed to discover many fragments.

We have abundant evidence that metal workers had reached a high degree of skill in pre-Roman Britain. It is stated that gold was mined in Essex by both Boadicea and Cymbeline, whose name appears on at least 40 gold coins of different design, and also that gold coins were in circulation in Britain circum B.C. 200, and much earlier than that in Ireland.

In Saxon times King Athelstan conquered Wales and it is stated that he imposed an annual tribute upon the Welsh princes amounting to 300 lbs. silver and 200 lbs. gold (weight). This alone gives one something to think about, for since in such early days trade was carried on mainly by barter, and money was dear, the value of any gold coin must have been very great, and the heavy tribute referred to represents a tremendous figure in modern currency ; but it must have come out of native gold, either found in river beds or from ancient mines, in Britain or Ireland.

Ireland was a very rich alluvial gold area and the early Bronze Age inhabitants acquired considerable skill in the fabrication of laminated and drawn objects, such as Gold Lunulæ and Tara Torcs, for which the ductile and malleable properties of gold are very suitable. It is probable that the Druids smelted gold and guarded the secret, but whoever was responsible for the production of the excellent Irish gold ornaments dating back to before 1,300 B.C., as will be seen from some of the maps I have located, Irish gold objects

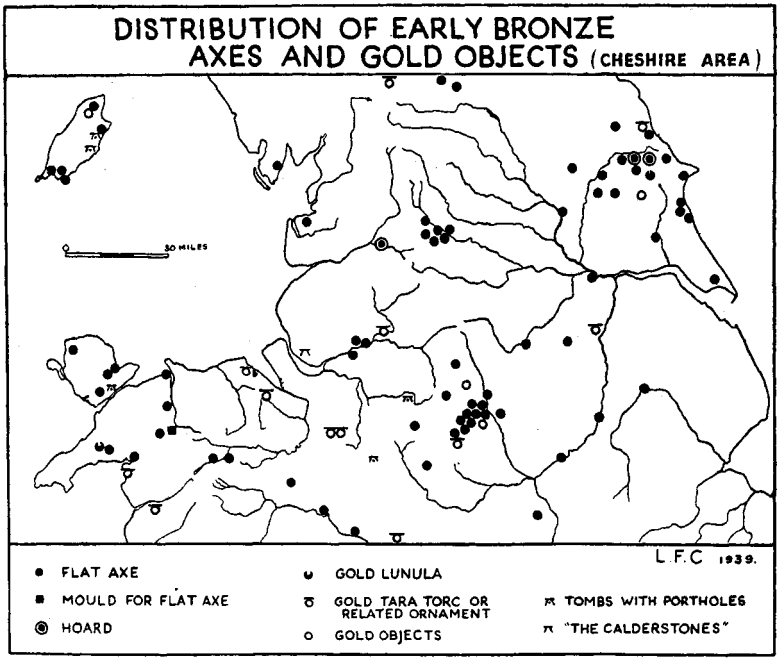

Reproduced from "Prehistoric Cheshire" (1940) by permission of the Cheshire Rural Community.

were obviously known and traded all over Britain and the West of Europe.

The impression left by these durable relics of a bygone age is of a people of high cultural attainment, with the ability to make the best use of materials at hand, and in this we have much to learn from lost peoples.

Anyone interested in early gold ornaments of Britain should visit the King Edward VII Gallery, British Museum, where two cases will be found containing some 160 objects having a total weight of at least 10 lbs. (160 ounces). They include Ear-rings, Rings, Bracelets, Ring-money, Lunulæ and Tara Torcs, and some of these weigh 18 to 27 ounces. It is certain that many more of these objects have been found than are recorded, and that many may have been melted down, and it is obvious that they were relatively common articles of commerce.

We know that the Phœnicians carried on trade with Cornwall for the tin required to make bronze, and that the source of the metal was kept secret. Herodotus refers to Britain as " Cassiterides," which I understand originally meant " The wooded place," but was the Greek name for Tin, and is still retained in the name Cassiterite for a valuable tin ore which in gem quality is occasionally cut and polished. Some writers believe that gold was the real attraction which drew the hardy rovers beyond the Pillars of Hercules to discover the source of gold in the west.

They left another name behind, for the Scilly Isles bear an ancient name which sometimes provides a puzzle, being named after Scylla, the six-headed monster which sat over a dangerous rock in the Straits of Messina, opposite the whirlpool of Charybdis, giving rise to the saying " Between Scylla and Charybdis " in reference to a choice of two evils. It is likely that a similar tidal race also existed near the Scillies.

The Romans knew that Britain was an auriferous country, for we are told that Agricola, addressing his legions in the Grampians in the Scottish campaign and urging them on to fight the stubborn Scots, reminded them that " Britain produces gold, silver and other metals, the booty of victory." Calvert, writing in 1853, states that there are proofs that the Romans worked many gold mines in Britain: Poltimore Mines in Devonshire ; Ogoufou Mine, Pumpsaint, Carmarthenshire (reopened successfully in 1938); Gold Scoop

Mid-WALES.
Pumpsaint
Gold Mines,
Carmarthenshire
(right).

IRELAND
County Wicklow
Gold Mining
Areas (*below*).

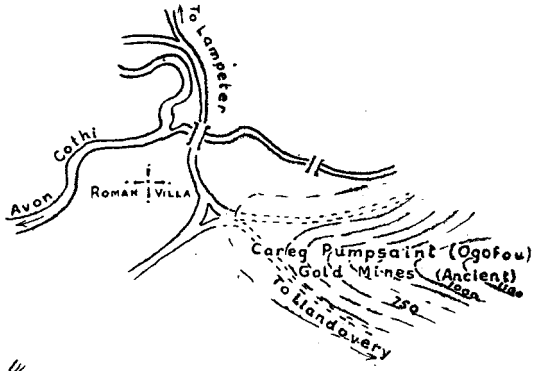

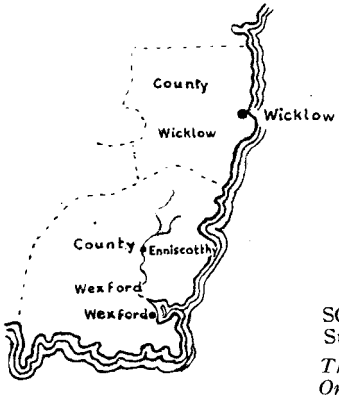

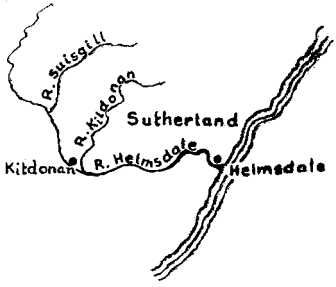

SCOTLAND—Kildonan Gold Mine area, Sutherland (*above*).

Three sketch maps copied from the one-inch Ordnance Survey map, with the sanction of the Controller of H.M. Stationery Office.

Mines, Cumberland ; and the Lanarkshire Leadhills, which were encircled by Roman camps as though under military protection. In the Merionethshire Gold Belt there is a Roman camp near Moel Siabod in the north-east, and another close to the Clogau Gold Mine north of Dolgelly, while a significant feature of the Pumpsaint map is the inclusion of a Roman villa near the site of the old mine.

After the departure of the Roman legions in the IVth century, little or nothing is known of the history of our islands for another four hundred years, until we learn of the coming of the Saxon Kings, and under Alfred culture and learning were encouraged and history commenced to be recorded. Cultural progress would be mainly centred in Winchester, Lincoln, York and other ancient Saxon cities, but the impression one has is that most of the country was covered by dense forests, and that the people had relapsed after the departure of the Romans into ignorance and darkness, in which

cities like Chester fell into ruins and were covered by many feet of soil. Under the Saxons, however, the smelting of iron and manufacture of glass made much headway, as seen by the many beautiful objects left by them, and it is certain that they were able to smelt gold and silver, so that it is equally certain that some gold mines were operating, for there is absolutely no reason to suppose that gold was at that time imported into this country. Trade did not justify it, and probably barter and exchange was sufficient in most cases.

Now one thing is certain, and that is that the Saxons were persecuted by raiders from Scandinavia—Norway, Jutland and Denmark—who ravaged the coast and pillaged the coastal towns and villages, until in the time of Ethelred II (The " Unready ") they were bought off by a levy known as the " Danegeld " and still exacted in Norman times long after the Danish raids had ceased. I have always maintained that this levy was paid in British gold, hence its name, which is different from any other imposition since—customs, tax, duties, rates, tithes, tributes, fines, etc.—but the word " gold " is never so used, and in my opinion its use was deliberate and that the Danes demanded payment in gold because they knew that Britain had rich gold resources.

This view is strengthened by the Welsh tribute imposed by Athelstan, but real corroboration is met in a reference(1) which states that in 866 A.D. Turgesiw, King of Norway, conquered Ireland and imposed a heavy tribute requiring every head of a family in the whole of Ireland to pay one ounce of gold annually or to suffer mutilation.

Although it is stated that coinage existed in Britain long before the Roman invasion, and that the Romans insisted on the use of their coinage, money was so dear in Saxon times that it is unlikely that much was in circulation, and although some of the coins have the same names now, in purchasing value one cannot compare them. Even 500 years ago a penny would purchase 40 or more eggs, and although a shilling may have been equivalent to 12 or 13 pence, they do not have much in common with the modern penny.

It is not necessary to plod century by century through mediæval times to trace the story of Gold in Britain, and indeed it might be difficult to obtain enough data ; but one can take outstanding events through the years, and so we learn that in the

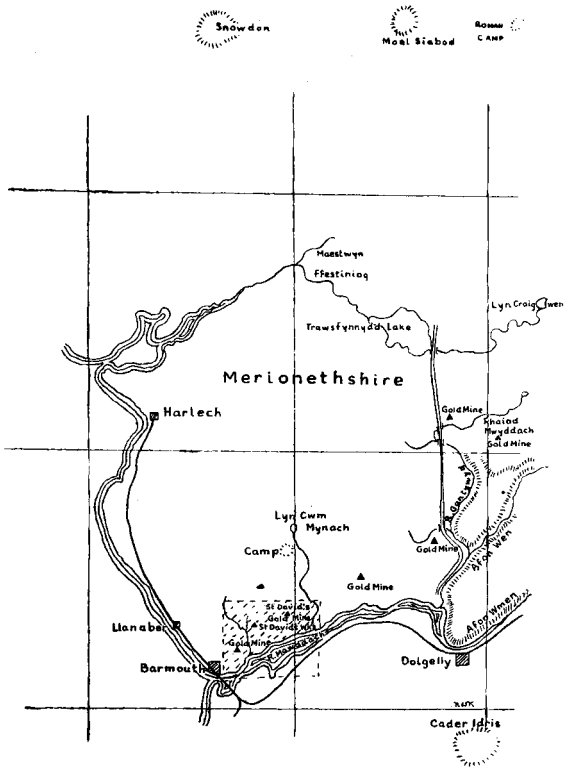

Left : Sketch map copied from one-inch Ordnance Survey Map, New Series, showing location of Gold Mines as indicated on Maps Nos. 51, 52 and 44. *(Reproduced from the Ordnance Survey Map, with the sanction of the Controller of H.M. Stationery Office.*

Below : Enlargement of shaded area of above, showing position of rich Gold Ore Lodes. Thirteen lodes are indicated on this map, some of which have proved enormously rich in Gold Ore. *Copied from a drawing by A. R. ANDREW in his paper on "The Dolgelly Gold Belt", Geological Magazine vol. VII, (1910) p. 208. Reproduced by permission of the Geological Magazine.*

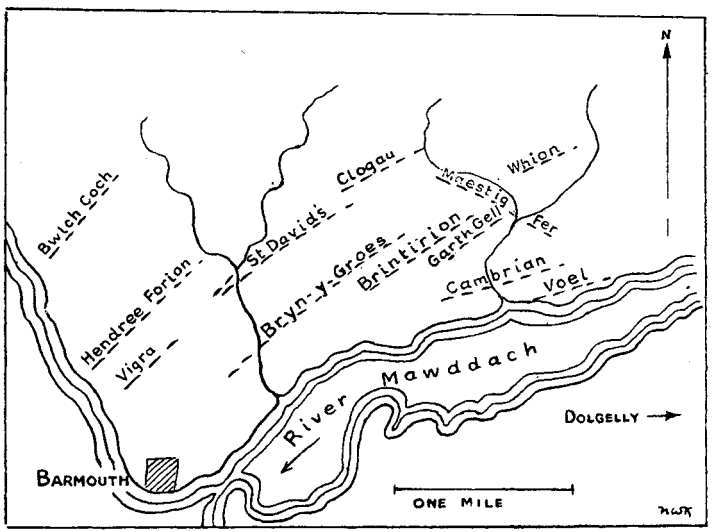

colourful times of King Henry VIII the gold mines at Keswick were worked, and that during his reign £300,000 in gold was forthcoming, although it is not definitely stated that it all came from Cumberland.

Several writers refer to Sir James Myddleton, who flourished in the reign of James I and died in 1631. He was the founder of the New River Company and paid the Crown £400 per annum rental for gold mines at Skibery Coed, Cardiganshire (which I have failed to locate), and that he cleared a profit of £2,000 per month which was devoted to the bringing of water from the New River from Ware to London. This is not strictly accurate, as I have since discovered that the mines were worked for silver as well as gold, and it is impossible to state now what proportion of each was refined.

About this time public interest was centred on speculation overseas, in gold and other Colonial produce often more valuable, and hence attention was drawn from local mining enterprise and possibilities, and so far as I can see this apathy has been popular ever since. This may account for the fact that I have not seen much mention of British production of gold from that time until the middle of the last century, when an Australian prospector named Calvert visited Britain about 1840 with the intention of investigating the possibilities of gold mining in Britain, which he felt should be a rich auriferous area. In 1853 he wrote a most interesting book(1) explaining his views and aims and the result of his investigations all over the country. He states that in his time the amount of gold found all over Britain was much greater than was supposed, for most people he spoke to told him that gold had been found on their estates at one time or another, and he came to the conclusion that owing to the excessive greed of the Government, discovery of gold in Britain was kept secret, although by law it is supposed to be reported. He particularly mentions County Wicklow, in Ireland, where nuggets of 22 ozs., 18 ozs., 9 ozs. and 4 ozs. had been found, and where worked articles weighing 17 and 27 ounces had been discovered.

III.—Production of Gold in Britain

Calvert seems to have been among the earliest writers to give details of production, and is followed by many others, but, unfortunately, even the official returns issued by Government

Departments do not agree in detail with each other, which seems inexcusable. It may be that the references are not quite to the same places nor to exactly the same periods, but it is puzzling.

Vanderbilt (2) in 1888 states that Clogau Gold M.ne produced 1,260 tons ore in 1862, from which 8,186 ounces gold were refined, which is a remarkable return, as will be seen later. Andrew,(7) in 1908, gives the figures as 804 tons ore, producing 5,299 ounces gold. Both figures may be correct, as one may include another lode near Clogau. Readwin(2) states that in 1887 the production of ore from five mines was 12,137 tons, yielding 14,667 ounces of gold valued at £57,000 sterling. Vanderbilt also states that Mr. Pritchard Morgan commenced crushing ore at Gwynfyndd Mine in 1888 in workings which had been abandoned and extracted 4,108 ounces gold in four months.

Coming now to the year 1908, MacLaren (4) states that gold production in the United Kingdom to that date had been:—

PRODUCTION OF GOLD IN BRITAIN

(These figures are quoted by several writers.)

ENGLAND		
North Molton, Somerset	£581	Period not stated
WALES	£417,183	" Since 1844 "
SCOTLAND		
Leadhills	£100,000	Period not stated
Sutherland	£3,000	1868/9
IRELAND	£28,855	Period not stated
Total	£549,619	Sterling

Present value at current price of gold not less than £1,400,000.

TONNAGE OF GOLD ORE MINED IN BRITAIN

The tonnage during some periods is unknown and for others is incomplete.

Period	EXTRACT FROM ANNUAL REPORT TO THE SECRETARY OF MINES: Gold Ore Auriferous Quartz	Corrected Figures	Gold Production in Merionethshire only (Andrew Geol. Mag. 1910) Incomplete 1860—1907
1860—1872	Not stated	— ,,	15,167 Tons
1873—1882	" Cannot be stated "	— ,,	22 ,, (plus)
1883—1892	3,570 Tons	35,667 Tons	35,667 ,,
1893—1902	10,252 ,,	10,252 ,,	
1903—1912	11,988 ,,	11,988 ,,	78,566 ,, (plus)
1913—1922	648 ,,	6,476 ,,	98,777 ,, To 1907
1923—1932	230 ,,	230 ,,	—
1933—1938	? ,,	? ,,	—
	26,688 Tons	64,613 Tons	228,199 Tons

All Totals incomplete.

PRODUCTION OF SILVER IN BRITAIN

From 1920 to 1938 was nearly one million ounces worth £110,000.

YIELD OF GOLD

DOLGELLY GOLD BELT

Between 1860 and 1907

GREATEST TONNAGE of Gold Ore mined in one year:—
1902—29,303 Tons ore.

SMALLEST TONNAGE:—
1887—1 Ton.

LARGEST PRODUCTION of Gold during one year:—
1904—19,653 ounces Gold valued at £73,925 Sterling.

GREATEST YIELDS OF GOLD per Ton of Ore:—
(1) 1887—1 Ton Ore mined yielding 58 ounces.
(2) 1920—1 Ton Ore mined yielding 34½ ounces.
(3) 1879—22 Tons Ore mined yielding 20 ozs./Ton.

SMALLEST YIELDS per Ton Ore:—
During 1883 and 1885 904 Tons Ore were mined yielding 69 ounces Gold, or 0.08 (or 1/12th) ounce/Ton.

NOTE.—Since the figures available are incomplete for some years above data refers only to available figures.

Average Yield of Gold apears to have been approximately ½ ounce per ton of ore.

On reference to the same Report (8) for 1921 I found detailed figures for gold ore mined between 1913 and 1921 totalling 6,476 tons, which is ten times the figure quoted in the same Report a year later. Little gold mining was in progress between 1932 and 1938, but the yield from an unstated tonnage of ore was 2,906 ounces, valued at £20,230, mostly mined in 1938, according to the last Report of 1939.(8).

While reading through Andrew, who was a careful writer and gives the sources of his information, I discovered another similar error. He gives detailed tonnages of ore mined in Merionethshire, with yield in gold in ounces and value, for every year between 1860 and 1907, and for the period between 1893-1902 the total is 35,667 tons ore, or again ten times more than is stated in the Return in 1932.

A. R. Andrew's articles on " The Dolgelly Gold Belt " are most informative, and his several tables and useful maps are very instructive. His figures show that during the 47 years covered, no ore was mined in this area during eight individual years, and that figures are lacking for nine other years, although the yield of gold is given.

Some of the figures are remarkable: thus the normal yield of gold appears to have been about ½ ounce per ton of ore ; the smallest yields were in 1883 and 1885, when 900 tons ore only gave 69 ounces or about 1/12 ounce per ton. The ratio of tons of ore to

ounces of gold is, of course, unknown for the nine incomplete years. In 1862 the yield from 800 tons is given as 5,400 ounces or 6.6 ounces per ton, but this is eclipsed in 1879 when 22 tons yielded 441 ounces or 20 ounces per ton. The most spectacular figure is for 1887, when the one ton mined gave 58 ounces gold, which compares with 1920, when one ton yielded 34½ ounces. In view of such figures there appears to be every justification in stating that our Welsh goldfields can compare favourably in grade of return with Klondyke and the Yukon, or indeed any known mines.

The tables compiled by Andrew refer mainly to the production of the St. David's and Clogau Mines and there seems no reason to question the statement that during the 47-year period a total of some 120,000 ounces (or something like 3½ tons of pure gold) was produced in Merionethshire alone, with a current sterling value of some £440,000, representing possibly £1,400,000 to-day.

IV.—What Constitutes a Paying Yield in a Mine?

There must be some relationship between the tonnage of ore mined and the yield of gold refined from it, but the question, however, is not a simple one, for much depends upon the type of mine, accessibility, availability of water and power, cost of labour, cost of plant, and, of course, the current price and demand for gold, not to omit the ever-open voracious jaws of the State.

Some prospectors have stumbled upon El Dorados of unbelievable wealth, such as Coolgardie, where two men literally picked up a tent-full of gold lying on the surface in a small area, but it was an arid desert, and temperature, lack of water and transport rather spoiled the picture.

Then in Papua an immensely rich deposit was found in a remote valley beyond forest and jungle covered mountains peopled by head-hunters. Everything had to be transported to and from the spot by special aeroplanes.

The more usual source of gold is a mine where it is normally associated with many other valuable ores, and often is only present in minute quantities. Thus at Witwatersrand the yield is stated to be one ounce of gold in 200,000 ounces of ore (about five tons), or approximately one-fifth of an ounce per ton ; yet in spite of the high cost of mining, which includes raising the ore 6,000 to

8,000 feet and air-cooling at the rate of one ton of air per minute, this mine manages to pay its way.

In Britain, small quantities of gold are still known to be washed down in mountain streams, and there may be much more beneath some mountain bogs, but it is doubtful if panning any stream would pay commercially.

There is no doubt that Wales is a very rich auriferous locality and properly financed and organized prospecting and mining should produce a high yield of gold, but production has had to contend with many difficulties. First of all, Calvert states that the phenomenal discoveries of gold abroad diverted public attention from British mines, and that, in addition, there was, and always had been, a bitter antipathy on the part of the Cornish miners, who for some extraordinary reason seemed to resent any sort of competition with Cornish tin. He states that although gold and silver were known to occur with their tin ores no attempt was made to refine it, and apart from that, they either did not or could not recognise gold, unless it occurred native, and anything which was not tin, copper or lead might be dumped. It is true that many valuable finds have since been made in neglected Cornish tip-heaps from which tungsten, uranium and radium have been obtained.

To an investor, the main object of a gold mine is to produce gold and pay a dividend, but I cannot help feeling that in Wales the main object of gold mining has been to relieve unemployment irrespective as to whether the undertaking paid or not.

Then MacLaren ([4]) draws attention to another factor which, if it still operates, would certainly make it impossible for any gold mine to pay in this country. He states that the Kildonan Gold Mines, operating in 1868/9, paid the State royalties on a declared production of £3,000 at 10 per cent., namely, £300, but that he believes the real production to have been more like £12,000, and that much was concealed by employees and others. At one time 400 men were employed, and a Government tax of £1 per head per month was levied. If one assumes that 200 men were constantly employed over a year, this tax would amount to £2,400, so that the State would receive £2,700 out of a total return of £3,000, leaving £300 to cover all charges for wages, plant and, of course, dividend! Personally, as a Scot, I fervently hope that my country-

men did find £12,000 worth of gold, on which the State charges would still be far too high. Any Government making such an imposition encourages the law-breaker.

Lewis,[10] writing in 1930, evidently tried to discover what return had been made from British gold mines, and, like myself, he found it difficult to compare one set of official figures with another, and after comparing three sets of figures covering production during the same periods, he observes: —

" It is difficult to reconcile these conflicting statements ; the fact that stands out quite clearly is that, whatever the yield, it did not pay expenses involved."

My own opinion is that there appears to be abundant evidence that very large quantities of gold exists in a definite goldfield in Wales, in rich but erratically distributed lodes, and that it seems worth while, with the resources of modern science and mining equipment, to locate the precious metal in the Snowdon area, and to operate with a moderate staff, and with a much more restricted levy by the State, paid on profits not upon total yield.

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The Relation between Lustre and Stereoscopic Vision

By G. T. Clarkson, F.G.A., C.M.B.H.I.

AT the outset, it is wise for the writer to say what he understands by lustre, which word is used as a technical term in gemmology and is also a commonly used word in less specialized matters. It is not thought that the specialized use differs in any important way from the general use, and it is taken to mean the quality of "shiny-ness." It depends entirely upon the way the surface concerned reflects light falling upon it, and this in turn will depend upon (a) the nature of the substance and (b) the quality of the surface, by which is meant the geometrical regularity of the surface and the degree of smoothness or polish applied to it. The reflections of incident light that lustre is concerned with occur at or near the surface (say within the top hundredth of an inch) ; it is not concerned with internal reflections. It is highly probable that the nature of the substance is involved in the question of lustre only so far as it affects the degree of smoothness it permits the surface to accept. Obviously, blotting paper could not be given a polished surface like metal or glass.

The meaning of the term "stereoscopic vision," or, more properly, the stereoscopic effects of binocular vision, is equally clear in most people's minds, but it will have to be dealt with a little more fully. Cyclops, having but one eye, would see objects at any one time from one viewpoint only. Without moving his head, he would be completely unable to ascertain and grasp the solidarity of an object ; any "depth" dimensions, along his line of sight, would not exist. A normal person, however, gets two separate and different views of one object, one with each eye. The difference between these views depends upon the difference in perspective resulting from a change of view point. For near objects the difference is considerable, but for distant objects it is only slight. The apparent movement of objects relative to each other which results from a change of viewpoint is known as "parallax," and this term also covers the change of perspective which occurs with each change of viewpoint, since the principle of relative movement still applies when the objects are selected points on a single object.

The ordinary person receives on his two retinas two flat pictures which, if superimposed, would not fully coincide. One of the functions of the brain is to explore these two images, note the amount of parallax in various places and from this data calculate the " depth " along the line of vision. This it does with amazing rapidity and efficiency, thus giving a single solid or stereoscopic picture which reveals the complete form of the object and its placing relative to other objects within the field.

This is true stereoscopic vision, and every point made above can be proved by making drawings of a real or imagined object from two viewpoints, laterally displaced relative to each other, and by simple experiments involving the use of one eye at a time. Zeiss made hundreds of stereoscopic pairs of drawings, and there is nothing difficult about it, as the writer has satisfied himself. It is also quite possible for a normal person to use these pairs stereoscopically, to achieve depth and solidity, without using a stereoscope. Now Cyclops, with one eye—and there are lots of people about having only one useful eye each—will hotly deny, with perfect truth, that he is unable to " see solidly." This is because of nature's resourcefulness and because of nature's deep desire, strengthened by millions of years of evolutionary development, to see in depth as well as in the flat. It is of the utmost importance for a living being if he is to stay alive to be able to judge of the complete form of an object in all three dimensions and also to judge its placing in depth (or distance from the eye) relative to other objects. Robbed of the " stereoscopic pairs " of flat pictures, nature therefore falls back upon such other expedients as (a) slightly moving the head laterally and (b) taking advantage of the movements of the objects themselves, and also (c) drawing conclusions from the size the object appears—just as a distant car can easily be hidden by a visiting card pasted on the windscreen of one's own vehicle. It is very unlikely that the depth perception of one-eyed people is appreciably inferior to that of normal beings, but it is also unquestionable that one-eyed people can easily be deceived in the matter of depth dimensions if the circumstances are such as to rob them of the aids mentioned in (a), (b) and (c) above.

To return to the question of lustre. It is obvious that the higher the degree of lustre of any surface, the more perfect will be the reflections in that surface of surrounding objects and light sources. Thus the image of a small light source—say a candle

flame or an electric bulb—will be clear and sharply defined in a lustrous surface. A one-eyed person, so long as both he and the object remain still, will gather his appreciation of the lustre of a surface purely from the sharpness and vividness of the reflections. Just as the perspective of an object varies with each change of viewpoint (and *only* with a change of viewpoint), so the apparent position of each reflection will change with the viewpoint. And just as the parallax brought about by the lateral separation of the two eyes, applied to the perspective, gives the effect of solidity in the viewer's eyes and brain, so the effects of parallax applied to the relative positions of the various reflections from the surface give the effect of lustre. And thus lustre is largely a stereoscopic effect. A one-eyed observer will, however, see lustre just as (or almost as) vividly as a normal person, but he will depend upon the expedients already mentioned instead of a stereoscopic pair of flat pictures embodying reflections.

If the reader desires proof, let him set up a large stone in a fixed near position with one or two light sources conveniently placed and, holding the head quite still, cover each eye alternately whilst examining the stone. He will find that just as the perspective varies for each eye, so does the position of the reflections of the lights from the stone's surface. Because the stone is assumed to be of high lustre, the reflections will be sharp and clear and the apparent changes in their shapes and positions for each eye will be abundantly clear. For further proof, it would be a simple matter to incorporate in hand-drawn stereoscopic pairs reflections whose parallax corresponds with the perspective parallax, and unquestionably the effect would be one of lustre.

We may sum up by saying that just as a one-eyed person gets a flat, two-dimensional, and very imperfect grasp of the solid form of an object, so he would also get a very imperfect idea of the lustre of its surface *except* that, by long practice and by intense desire, he would bring in " parallax of reflections " so skilfully, though probably quite unconsciously, that he would see the lustre almost or quite as well as others: just as he normally uses this method to correct and amplify his understanding of the solid form of the object.

The James Bay Diamond Syndicate

by D. S. M. FIELD, A.G.A.

A PRELIMINARY report on the newly formed James Bay Diamond Syndicate, whose holdings are located in the Vassan-LaCorne-Pressiac area of North Western Quebec Province, Canada, was published in the " Journal of Gemmology " in January, 1951 (Vol. III, No. 1).

At that time work had commenced on the sinking of a shaft for the removal of a bulk sample of rock for testing at the Val d'Or plant of the Quebec Department of Mines.

Details of the test and the findings of the Mines Department are contained in a second report recently made available to the writer by J. C. Honsberger, Esq., B.Sc., of Val d'Or, who, together with Mr. Norman Vincent, of Toronto, formed the Syndicate in March of last year.

The rock was shipped as mined from a shaft sunk to a depth of 65 feet in Range VII, Vassan Township, Abitibi District, in the Province of Quebec. The shaft followed a vertical diamond drill hole in the drilling of which the bit had encountered a substance it could not penetrate at a depth of 60 feet. Examination of some of the choppings from the hole at that depth showed the presence of a few particles of diamonds. All rock mined from a depth of 43 feet to the bottom of the shaft at 65 feet was shipped for treatment and amounted to 147.6 tons. The rock consisted of both peridotite and amphibolite, the latter being encountered in the lower part of the shaft. The peridotite was both massive and sheared and contained a good deal of fine magnetite. Pyrite occurred in well-formed crystals, a few of which with edges 1½ in. in length.

Crushing

After a study of the sizes of diamonds found in Arkansas, at Prairie Creek and the Arkansas Mine, and at the Premier Mine in South Africa, it was decided to crush all the rock to minus ¼ inch. The average weight of 3,000 stones found at the Arkansas Mine was 0.4 carat. Seventy per cent. of the stones found at the Premier Mine are below ¼ carat in weight. A 1.2 carat stone of fairly

regular shape easily passes through a $\frac{1}{4}$ inch screen. It was realized that any large stones above $\frac{1}{4}$ inch diameter would be fractured, but as the main purpose of the test was to prove the presence or otherwise of diamonds, crushing to $\frac{1}{4}$ inch seemed to be a safe procedure. Coarser crushing would have added greatly to the cost of the test and would have been difficult to carry out with available equipment.

Primary crushing was done in a 9 ins. by 14 ins. jaw crusher ; $1\frac{3}{4}$ inch secondary crushing in a 30 ins. Peacock differential crusher set at 5/16 in. opening. The product of the 30 ins. crusher went to a 12 ins. Peacock crusher with the same opening. The smaller diameter of the cone of the 12 ins. Peacock crusher broke up slabby pieces of rock without crushing too fine. The product of the 12 ins. crusher went to a Dillon double-deck vibrating screen. The top screen had $\frac{1}{4}$ inch openings (square) ; the bottom screen had $\frac{1}{8}$ inch square openings. Plus $\frac{1}{4}$ inch material was returned to the 12 ins. crusher.

A screen analysis of the finished screen products was as follows:

Mesh	Per Cent.	Per Cent. Cumulative
$-\frac{1}{4}$ in. plus $\frac{1}{8}$ in.	49.8	49.8
$-\frac{1}{8}$ in. plus 10	10.5	60.3
-10 plus 20	11.8	72.1
-20 plus 35	7.3	79.4
-35 plus 65	4.9	84.3
-65 plus 100	1.7	86.0
Minus 100	14.0	(100)

The two finished products from the screen, namely $-\frac{1}{4}$ in. plus $\frac{1}{8}$ in. and minus $\frac{1}{8}$ in., were jigged separately.

The jig used was a 12 ins. x 18 ins. Denver Duplex, with a bottom screen of wedge wire type with 1/16 in. slotted openings. A bed of 3/16 in. steel shot, about 2 ins. in depth, lay on the jig screen. Jig stroke was 3/16 in. Feed to the jig was by pump at the rate of 1,300 pounds per hour. Naturally, any diamonds with a diameter of over 1/16 in. would be retained on the jig screen. The screen was cleaned off several times during the run, and the material collected was considered concentrate.

As a safety precaution, jig tailings passed over a Wilfley Standard Sand concentrating table, where a fairly wide cut was made to insure that any diamonds present that might escape the jig would

not pass into the Table tailings. Table tailings were stockpiled outside the mill, where they could be reclaimed for further treatment, if such were deemed necessary. Table concentrates were collected for treatment on the grease table with the jig concentrates.

The weight of the concentrates obtained was as follows:

Jig Concentrates: 8,800 pounds.

Table Concentrates: 4,200 pounds.

Approximately 5 per cent. of the concentrates was pyrites.

Grease Table Work

Before any grease table work was done, advice was obtained from the Government Metallurgical Laboratories in Johannesburg, South Africa, as to the type of grease to use and its application. This was a mixture of approximately 20 per cent. Petrosene and 80 per cent. Light Amber Petroleum Jelly. The composition was varied according to the temperature of the air and water in the mill. It was found that at plant temperatures very little Petrosene made the grease too hard.

To test the efficiency of the grease table, natural rough South African diamonds, about 1/10 carat in weight, were put in with the concentrate, or put over the table after a run of concentrate. Results were never satisfactory. The grease became contaminated even after as little as ten pounds of concentrate was put over the table, and the diamonds generally rolled over ; although there were occasions when 50 pounds were tabled and the diamonds were still held by the grease.

In South Africa, stationary as well as vibrating tables are used. Both were tried at the Val d'Or plant. The first table was built on top of a Wilfley sand table, was 2 feet wide, and had a slope of 7 degrees. Grease was applied ¼ in. thick for a length of 6 feet. The table was fed by hand, evenly and slowly. Stroke was 3/32 in. and speed 300 per minute. The grease rapidly took up a film of fine magnetite and other minerals, and the test diamonds soon rolled over. A microscopic examination of this film showed that 40 per cent. was magnetite and the remainder talc, chlorite, amphibole and fine pyrite. Tests were then run on small lots, with as much of the magnetite as possible removed by electro-magnet. Results were still unsatisfactory. A stationary grease table was built, 24 ins. wide, 6 feet long, and with a slope of 12 degrees.

This table was carefully fed by hand, with varying water temperatures and grease mixtures, with no better results being obtained.

An account of the poor results of the tests was submitted to the Diamond Research Laboratory in Johannesburg. Their recommendation was to remove as much magnetite as possible, to screen out all minus 20 material and to spray-wash the remainder to remove soft mineral particles. They stated that, in any case, it would be very difficult to remove any diamonds found in the minus 20 mesh range from the grease table. Their final recommendation was to resort to hand sorting if satisfactory results were not obtained with other methods. It was also suggested that the PH of the water should not be above 9. The PH of the water used at the Val d'Or plant was found to be 7.

Removal of the minus 20 mesh fraction and spray-washing, as recommended, did not improve the results, so hand sorting was resorted to.

Hand Sorting

Hand sorting of 6½ tons of concentrate would have been an endless procedure with the few men available at the Val d'Or plant, so steps were taken to reduce the bulk of the concentrate. About 28 per cent. reduction was obtained by screening out the minus 20 mesh material. The remainder was jigged four times. Material remaining on top of the jig screen was carefully removed after each jigging operation and considered as concentrate, together with all material passing through the jig screen into the hutch. It was confidently felt that no large free diamonds would be lost in the jig tails when the operation was repeated so often. Any diamonds less than 1/16 in. diameter would, of course, pass into the jig hutch. By this means the concentrate to be hand sorted was reduced to approximately 2,200 pounds.

For hand sorting, reading glasses with a magnification of 4 × were used, under hooded lights. Sorting was one at the rate of about three pounds of concentrate per hour. As such was a tedious operation, men were limited, generally, to only a few hours' sorting at one time, and it was for this reason that the operation covered a period of about five months. Owing to the very small amount of quartz, calcite and other minerals in the concentrate, which might have been mistaken for diamonds, sorting was not as difficult as

might be imagined. Particles of quartz, calcite, garnet, ilmenite, etc., stood out very prominently, and for this reason it is difficult to imagine any diamonds over twenty mesh in size being missed. The quartz found was glassy, milky-white, light green or rose coloured.

Any particles that had the slightest resemblance to a diamond were tested by squeezing by hand between two silver coins, since it was reasoned that a diamond would not fracture under such pressure. The only minerals sorted which did not fracture, or did so with difficulty, under this test were garnets and ilmenite. About 12½ grams of garnet and 12 grams of ilmenite were picked out. The ilmenite particles were rounded and worn, and it is felt that these had remained in the jig from a previous operation and worked out of crevices during the test. The garnets were probably native to the rock. Their colour was generally brownish-red, rose or yellowish. The average weight of the garnets was about 20 milligrams.

The above report is based upon the official report of G. S. Grant, Esq., of the Quebec Department of Mines Plant at Val d'Or.

CONCLUSIONS

Although no diamonds larger than 20 mesh were found, the matter is not closed. One of the shareholders, a mining engineer from California, with many years of diamond mining experience in South Africa, is planning to make further tests during the summer months.

Incidentally, it may be of interest to record the fact that competent scientific examination of the huge (world's largest) circular crater only recently discovered in Ungava Territory, in the extreme north-west corner of Quebec Province, indicates that it resulted from the impact of a meteorite striking the earth approximately 3,000 years ago.(1) This knowledge disproves the originally propounded theory that the Ungava crater is similar in nature to the diamond pipes of South Africa, and the possible source of the alluvial diamonds carried to the United States during the Ice Age. The whereabouts of Canada's diamond treasure is still very much a mystery, and only time will solve it.

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(1) For a detailed and first-hand account of the expedition to the crater and the discoveries made there, read " The Secret of Ungava," by Ken W. MacTaggart, in " World Wide " Magazine (Tower House, Strand, London, W.C.2), June, 1951.

Gemmological Abstracts

WALKER (A. C.). ***Laboratory synthesis of quartz crystals.*** Gems and Gemology, Vol. VI, No. 12, pp. 359-361. Winter, 1950/1.

A description of the apparatus used for the synthetical growth of quartz crystals in alkaline solution with a note on the applications of piezoelectric crystals in telephony and radio communication. Two illustrations.

See also Journal of Gemmology Vol. 2. No. 6. p. 227 and Vol. 3. No. 1. p. 31.

R. W.

CROWNINGSHIELD (G. R.) and HOLMES (R. J.). ***Synthetic red spinel.*** Gems and Gemology, Vol. VI, No. 12, pp. 362-268. Winter, 1950/1.

The description of a synthetically produced spinel crystal of octahedral form, the origin of which is not known. The crystal, an unusually well-formed octahedron with 13.5 mm. edge, has been grown on a metallic disc, probably of palladium, and with a crystal encrusted loop attached. Microscopic examination showed the presence of triangular pits on the crystal faces and numerous internal imperfections and inclusions, giving the whole crystal a cloudy effect. Examination by the electron microscope showed uniformly distributed sub-microscopic triangular markings on the octahedral faces and in some areas markings in the form of rosettes having a possible six-fold symmetry. The hardness was found to be greater than natural spinel or synthetic spinel grown by the Verneuil method. The density to be greater than 3.63 and less than 3.98 (misprint for 3.68 ?). Both large crystal and the smaller incrusted crystals adhering to the metallic disc and wire loop showed marked zonal colour distribution. The material is singly refracting and shows no anomalous double refraction. The R.I. was found to be 1.75. The absorption spectrum is discussed in relation to natural red spinel and to ruby. X-ray powder diffrac-

tion patterns of the material and of natural red spinel were taken, and patterns of Verneuil synthetic pink spinel and red corundum are compared with the others. The unit-cell size for the natural red spinel was found to be 8.089 A.U., for the synthetic red spinel under discussion to be 8.084 A.U., and for the Verneuil pink spinel 7.975 A.U. A spectrogram showed that this synthetic spinel is an aluminium and magnesium compound containing appreciable chromium and is similar to a spectogram of natural red spinel. Nothing is known as to how this unique specimen was produced—hydrothermal method of growth suspectecd. Six illustrations.

R. W.

DRAPER (T.). ***The gemstones of Brazil.*** Gems and Gemology, Vol. VI, No. 12, pp. 369-375. Winter, 1950/1.

A popular and historical article on the mining of gemstones in Brazil. The discovery of the gem fields may be said to have commenced in the 16th century, when expeditions were organized to search for emeralds which had been reported to exist in the then remote regions of Brazil. Tables of the gemstones found in the different zones of the country, and of the largest diamonds found in Brazil, are given. Six illustrations.

R. W.

ANDERTON (R. W.). ***Report on the Chivor emerald mines.*** Gems and Gemology, Vol. VI, No. 12, pp. 376, 377 and 379. Winter, 1950/1.

A general article by a former Manager of the mines on the working and recovery of emeralds from the Chivor mine in Colombia.

R. W.

SCHLOSSSMACHER (Prof. K.). ***Die internationale Edelstein-Nomenklatur.*** (The international nomenclature of gems.) Gold und Silber, 1951 (5), 13-14.

In the beginning gems were named according to colour, causing much confusion, which is still encountered occasionally. In 1935 an international gem nomenclature was published in Berlin. The American Gem Society is now working on a new nomenclature. The term " semi-precious " is discredited.

Sachverstandigenkonferenz der BIBOA in Idar-Oberstein. (Congress of BIBOA experts at Idar-Oberstein.) Gold und Silber, 1951 (5), 14.

Experts of the BIBOA met at Idar-Oberstein on April 3rd-5th, 1951. Among other items, the publishing of a new international nomenclature for gems was discussed, as was also the measurement of colour and definition of purity in a diamond, experiences with new synthetics and new methods of examining gems and pearls.

E. S.

ROBB (C. J.). ***Irish pearls.*** Gemmologist, Vol. XX, No. 237, pp. 96-97. April, 1951.

A short history of the river pearl fisheries of Ireland (Eire). The early methods of fishing are discussed. Fishing practically ceased after the 18th century and now industrial pollution has destroyed many of the pearl mussel beds. Some rivers are still mussel bearing and may be revived at a future time.

R. W.

ANON. ***Westphal balance.*** Gemmologist, Vol. XX, No. 238, pp. 104-107. May, 1951.

An informative article on the operation and use of the Westphal balance. The balance itself is first described and the arrangement and method of using the weights discussed. Examples are given. The application of the balance to the determination of the density of gemstones and of liquids is explained.

R. W.

WRIGHT (L. A.). ***The gemstones of California.*** Gemmologist, Vol. XX, No. 238, pp. 117-121. May, 1951. ***Reprinted from Department of Natural Resources, Department of Mines, Bulletin No. 156 "Minerals of California."***

A full Governmental report on the gemstones and ornamental minerals found in the State of California.

R. W.

SCHLOSSMACHER (Prof. K.). ***Die Farben der Edelsteine.*** (The colours of gems.) Gold und Silber, 1951 (4), 11-14.

The article discusses the properties on which the colour in gemstones depends. The phenomenon of absorption is described in detail. Lambert's law (referring to the thickness of the absorbing material) and Beer's law (referring to the colour density, i.e. relative quantity of pigment in the material) are mentioned. Generally speaking, colouring matter in gems is supplied by eight elements only, namely, Nos. 22-29 in the periodic system (titanium,

vanadium, chromium, manganese, iron, cobalt, nickel and copper), which have remarkably small atomic volumes. They are all paramagnetic. The eight elements have the same number of electrons in the K, L and N orbits ; in the M orbit, however, the number of electrons increases from 10 to 17. This might be the reason that these elements can absorb light.

E. S.

SCHLOSSMACHER (Prof. K.). ***Ende der Halbedelsteine.*** (The end of semi-precious stones.) Gold und Silber, 1951 (3), 10-11.

The name " semi-precious " stones lead to many misunderstandings and difficulties. It was first used by H. F. Benedikt Brückmann in 1773 (?). In 1949, E. H. Kraus suggested to the American Gem Society that " members should not employ the term ' semi-precious ' in referring to any gemstone."

CHUDOBA (Prof. Dr. K.). ***Bestrahlung von Edelsteinen mit "schnellen" Elektronen.*** (Treatment of gems with " fast " electrons.) Gold und Silber, 1951 (3), 12-13.

The use of new, energy-rich electron, proton or deuteron rays, as obtained with the betatron and cyclotron, opens a new field of research in gemmology, the results of which, for instance, in the case of cyclotron-coloured diamonds, are not only of importance scientifically, but also practically. Diamonds, which are treated with deuterons, become strongly radio-active, which property fades after about an hour. They become green, but the colour is located in the surface only. On polishing a treated diamond loses its colour or becomes brown. Many gems such as tourmaline, zircon, rock crystal, synthetic ruby, etc., display luminescence when exposed to betatron rays.

E. S.

JACOBSOHN (W.). ***Diamond Tool Patents IV, Polishing of Gem Diamond.*** Price 12s. 6d. Industrial Diamond Information Bureau, Industrial Distributors (Sales), Ltd., London, E.C.1. October, 1950.

A patent survey has been made by Industrial Diamond Information Bureau of the patents issued during the last 60 years on improvements in diamond polishing, leading to semi-automatic and automatic machines. These have been published as a brochure of 40 pp., containing a large number of illustrations. A short abstract

is given of each patent, indicating the main features. Patents in England, U.S.A., Germany, Switzerland, Belgium and France are covered. In addition to the main section on diamond polishing, patents relating to diamond bruting are dealt with in an appendix. A publication of this kind has long been needed in this field, as every inventor and designer has had to compile his own list of patents in order to evaluate correctly the new ideas which he wanted to put forward. This new publication, compiled by W. Jacobsohn, A.M.I.Mech.E., gives the inventor the chance of studying, relatively inexpensively, exactly what has been done in this field, and of evaluating new potentialities. Obviously many of the patented ideas described have not been realized, and at present only a few diamond works use automatic or semi-automatic machines of the kind considered in these patents. The expert diamond polisher has the tendency always to revert to the simplest tool, which is, as a matter of fact, more universal than all improved tools, i.e., to the solder dop with copper stalk and wooden tang. But with progressing engineering developments it should be possible to overcome this point of view and to introduce more elaborate and sensitive operating tools which will bring diamond polishing into line with other high-class engineering activities.

A. G.

ASSOCIATION NOTICES

COUNCIL MEETING

A meeting of the Council of the Association was held at 19/25 Gutter Lane, London, E.C.2, on Wednesday, May 23rd, 1951, at 4.30 p.m. Mr. F. H. Knowles-Brown presided, and welcomed Miss E. Ruff, who was attending a meeting for the first time.

The sub-committee appointed to consider the working of the Association since the date of incorporation was further charged with reporting upon all matters appertaining to the examinations in gemmology. Mr. R. K. Mitchell was appointed to the committee to serve in the place of Dr. G. F. Claringbull. It was agreed that the examiners should be co-opted to the committee for the purpose of considering the syllabus of examinations.

GEMMOLOGY IN SCHOOL

Mrs. L. H. Knight, B.Sc., who is a science teacher at a High School in the East Riding of Yorkshire, writes to tell us that in her school timetable she has fifth form, with which she chooses her own subject in which she has a special interest. She chose a short, simplified course in gemmology and has found the students most interested. Last year Mrs. McKnight took the gemmology classes at the Stow College of Engineering, Glasgow, and it is very praiseworthy that she has elected to introduce the subject of gemmology to students before they leave school. Such teaching can be valuable in interesting students in jewellery sufficiently for some of them, perhaps, to express a desire to enter the trade on leaving school. Whatever the result, this interest in the beauty and science of gems at an early age will be beneficial.

TALKS BY FELLOWS

Mr. H. C. Fishberg: Broadfields Park Residents' Association, Hendon. "Precious Stones," April 30th.

Mr. G. A. Blythe: Rochford Women's Institute. "Gems," May 9th.

AMERICAN GEM SOCIETY

Mr. Kenneth G. Mappin, C.G., F.G.A., of Mappin's, Ltd., Montreal, has been elected as President of the American Gem Society. Mr. Mappin is the first Canadian to be elected as President, and the Council of the Gemmological Association of Great Britain has sent him their good wishes for a successful term of office.

1951 GEMMOLOGICAL EXHIBITION

A Gemmological Exhibition is being arranged by the Association, to be held at Goldsmiths' Hall, Foster Lane, London, E.C.2 (by kind permission of the Wardens of the Company) on October 8th, 9th, 10th and 11th, between 2 p.m. and 8 p.m. each day. Admission will be free.

CORRECTION

In connection with the article "A New Gemstone," by C. J. Payne, which appeared in the last issue of the Journal, Messrs. Chas. Mathews (Lapidaries), Ltd., have pointed out that it was Mr. Chas. L. Arnold, a director of the Company, who cut the new gem.

OVERSEAS VISITORS

During May the Association was honoured by visits from several overseas gemmologists, including Mr. A. Stromdahl (Secretary, Sveriges Gemmologiska Forening, the Swedish Gemmological Association founded in 1946). Mr. Stromdahl welcomed the opportunity of discussing gemmological matters with various members of the Association.

Other Swedish visitors were Mr. E. Gewers and Mr. Inglebert, members of the Gemmologiska Riksforbundet (a Swedish Gemmological Union founded last year). The Association was advised that Mr. H. Tillander, F.G.A., C.G., of Finland, gave a lecture-demonstration to the Union on May 27th, when its annual meeting was held. The Association was also pleased to receive a further visit from Mr. Hans Myhre, of the Norwegian Gemmological Association.

LONDON CONGRESS OF B.I.B.O.A.

The 1951 Congress of B.I.B.O.A. (Bureau Internationale de la Bijouterie, Orfèvrerie, Argenterie et Horlogerie) was held in London from May 23rd to May 26th.

Eight commissions were appointed to consider international problems connected with the jewellery, silverware and horological trades, and probably the most interesting was the one dealing with gemstones.

The Diamonds, Pearls and Precious Stones Commission was presided over by Mr. G. Fontana (France), and the British delegates were Mr. R. Klean and Mr. A. Triefus. The Commission included Dr. G. F. Herbert Smith (representing the Gemmological Association of Great Britain), Mr. F. H. Knowles-Brown and Mr. G. F. Andrews (the National Association of Goldsmiths), and Mr. B. W. Anderson was one of the representatives from the Pearl and Precious Stone Section of the London Chamber of Commerce. Among Fellows of the Association from overseas were Mr. A. Bonebakker (Netherlands), Mr. O. Dragsted (Denmark), Ing. J. Hammes (Netherlands), Dr. E. Gübelin (Switzerland) and Mr. W. Goldschmeding (Netherlands). Mr. G. Göbel, Head of the Precious Stone Section of the Paris Chamber of Commerce, who is an Honorary Fellow of the Association, acted as Secretary of the Commission.

Dr. E. Gübelin presented a paper on the present state of research in gemmology. He particularly mentioned the method of distinguishing between natural and synthetic corundum by means of the ultra violet light absorption spectroscope. Another part in his extremely interesting paper dealt with the changes of light at various times of the day and season that affected diamond grading by the naked eye and the importance, therefore, of grading by the use of a binocular microscope. Dr. Gübelin particularly urged the setting up of an international colour grading for diamonds.

A paper by Professor K. Schlossmacher (Germany), who was unable to attend the Congress, was read by Mr. Göbel. It dealt with the recognition of various gem testing laboratories by B.I.B.O.A. and of the importance of adhering to the gemstone nomenclature that had been agreed by the countries of Western Europe.

Mr. B. W. Anderson, in an *ex tempore* talk, referred to the history of gemmological development in the United Kingdom, and emphasized the importance of the pioneer work of the National Association of Goldsmiths, Dr. Herbert Smith and others interested in gemstones.

He dealt at length with the early and latest methods used to distinguish between natural and cultured pearl and mentioned that the origin of natural pearls was not yet fully understood in many cases.

The attestation for diamonds, pearls and precious stones, regulation of the correct use of designations and the services offered by the Paris Gem Testing Laboratory were described by Mr. G. Göbel.

After the presentation of the various papers a number of resolutions were approved, the significance of which was not of importance. Mr. G. Fontana and Mr. G. Göbel were re-elected as President and Secretary of the Commission with acclamation.

Interested visitors to the Exhibition

EDINBURGH
Gemmological Exhibition

APRIL 25th, 26th and 27th, 1951

A THREE-DAY Exhibition showing the scientific methods of testing gemstones in action was recently held at the Heriot-Watt College, Edinburgh. The exhibition was open to the general public for three hours for each of three consecutive evenings and over a thousand people attended.

The purpose of the exhibition was to show, since the popular coloured varieties of gemstones occurred in many species, that it was necessary for jewellers to call in the aid of science to identify stones. It was hoped to make clear that such aids, when properly applied, identified stones accurately and without ambiguity.

A particular feature of the exhibition was that all visitors were conducted round each exhibit by members of the Association and present students. At the entrance a brief introduction to the purpose of the exhibition was given to each small group of visitors

before they were subsequently handed over to the operators of the various gemmological instruments.

Apart from the display of cut and uncut gemstones and the usual gem-testing apparatus, a series of mock instruments was set up to enable the layman to appreciate better the principles of the various instruments he saw in use around him.

For the refractometer a special ray board was set up which had the advantage of showing a ray of light entering a hemisphere of dense glass. This hemisphere was movable and it was therefore an easy matter for an operator to illustrate the critical angle of total internal reflection.

Similarly, for the spectroscope a lantern directed a beam of light through a prism, causing a spectrum to be shown on a small screen. This was particularly helpful in explaining the function of the spectroscope.

Another lantern and screen was also provided with two polaroids and served as an excellent medium for demonstrating polarized light.

Finally, an ultra-violet lamp was available for those who wished to take advantage of seeing the effects of this light on the various natural and cultured pearls and other gemstones.

A party from the North of England Jewellers' Association (Newcastle), headed by Mr. J. Wadham Grant, Chairman of the National Association of Goldsmiths, attended on the first evening. The visitors were much impressed with the exhibition.

Among those who contributed to the success of the Exhibition were: Professor H. B. Nisbet, Ph.D., D.Sc., F.R.I.C., Principal of the College, for kind permission to hold the exhibition and for arranging the necessary publicity ; Professor W. H. J. Childs, Ph.D., D.Sc., F.Inst.P., Head of Physics Department, for advice and guidance and invaluable help in the general layout of the venture. Mr. J. Allen, Mr. G. Cummings, Mr. A. Inch, F.G.A., Mr. J. Kinnear, Miss J. Lumsden, Mr. A. McAlpine, Miss T. McDonald, F.G.A., Mr. E. Shearer, Mr. E. Towe, Mr. J. Walker, Mr. G. Winnert, F.G.A., and Miss E. Wood, stewards during the exhibition, and Mr. D. J. Ewing, Lecturer in Gemmology at the Heriot-Watt College. Several Edinburgh jewellers kindly loaned specimens, jewellery and show cases for what was a most valuable contribution towards making the public aware of the importance of gemmological study to the jeweller.

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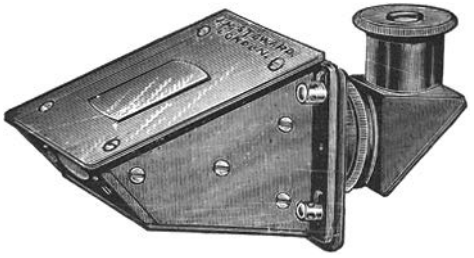

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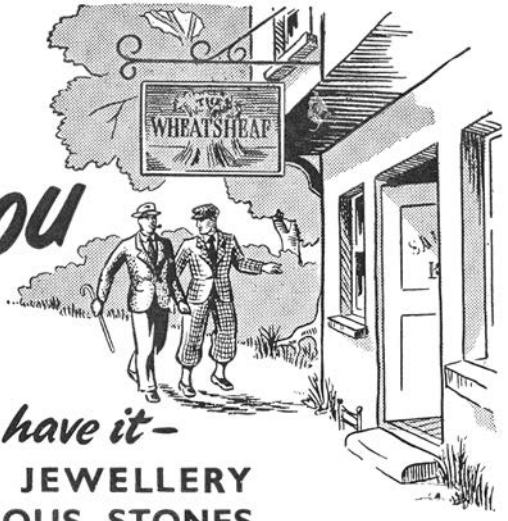

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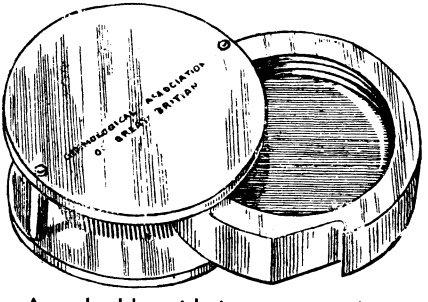

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Vol. III, No. 4 OCTOBER 1951

GEMMOLOGICAL EXHIBITION

Reviewed by 1951 *GERALD CARR*

THE spirit of the Festival of Britain was re-animated in the Goldsmith's Hall on October 9 to 12 when the Gemmological exhibition was presented by the Gemmological Association. Once again, as in earlier exhibitions held to celebrate the Festival at the Hall, there were visitors from all over the country and even from abroad. The theme of one hundred years provided the idea for several of the stands where one could study and marvel at the great progress that has been made in gemmology, little known as a word in 1851.

Once again Queen Mary honoured the Association by spending an hour looking at the exhibits and there were many other distinguished visitors. A further feature was the record attendance and the fact that the majority of the visitors were not connected with the trade. The 1951 exhibition is probably the best so far.

The range of exhibits was so wide that there was much to interest everybody from the happy and amusing idea of goldfish set amid ultra-violet rays and swimming against a background of lovely fluorescing minerals to the grim reminder of present day problems still unsolved, made by pieces of quartz fused from the sand of New Mexico when the first atom bomb was exploded. More educative, perhaps, but no less interesting were the exhibits

showing the different styles of cutting, excellently carried out by an amateur lapidary, or those illustrating with specimens the stages of production of gem stones from the raw material.

Many of the exhibits had been devised and prepared by Fellows of the Association and bore the hallmark of enthusiasm and care. Although in most cases the exhibits were self-explanatory, or could be understood from the adjacent descriptions, the presence of stewards, always ready to help both the expert and the tyro, was another mark of the keeness of members which made the exhibition leave a more than fleeting impression on the visitor and enabled all to get the most out of it.

The West of the exhibition room was mainly occupied with a series of displays showing the use of stones from primitive days to the present. Here there was much to interest students of many lores. Beauty and cruelty were combined in the finely shaped war club of nephrite once used by the Maori. Wielded by them, I believe, they could scalp an opponent as neatly as any American Indian. But, of course, they used their nephrite for more peaceful purposes as well, as could be seen from the ornaments they made from it. Another war-like exhibit came from India, a sword and a dagger handle in quartz, again shaped and finished so well as to possess inherent beauty. Other ornaments of the past were a Graeco-Roman ring with a sard intaglio of Eros of the 3rd century B.C. and a delightful Graeco-Egyptian gold mask decorated with garnets. The peaceful uses of stones were aptly demonstrated, and brought to date by an adze and mallet used by the Eskimos up to the 19th century. So, pausing a moment before the intervening case which showed attractive examples of native gold and diamonds, the visitor was ready to inspect the use of gems in jewellery during the past hundred years. Here the Victorian jewellery did not noticeably clash with the modern, though the latter naturally stood out with its greater use of diamonds and open setting. One piece used a fine golden sapphire as its focal point and another made good use of a moonstone, while a third exhibit showed a fine suite of garnets. Another interesting aspect of the past was that of a diamond polishing table similar to those which were used in the 18th century. Here the experts were amused to note that it showed little difference from those used now, with the exception of the dops—and the driving power. Then

Queen Mary at the Exhibition with the President and Sir James Walton (left).

the tables were turned by women, operating a large wheel by a ratchet device. Now, of course, electric motors do the work. And the diamonds that are polished? There were several displays which told of their story, showing them in the blue ground, telling of the 33 tons that are mined and pulverized and sifted before probably a single carat's worth of stones are claimed. There were specimens of fine diamonds and such unusual ones as a 50¾ ct. dark brown one and a 65 ct. green stone, together with the handmaiden of industry, the industrial diamonds so necessary in practically every engineering workshop for their tools. In another case was an exhaustive range of faceting styles, some thirty in number, listed and carried out upon synthetic spinels.

But I am getting away from one of the fascinating aspects of gemmology, the study of the manifold varieties of stones. Everyone knows of diamonds and the stones that are commonly seen and worn. Only the gemmologist has the secret key to understanding and knowing about many equally beautiful stones of which only their names fail to suggest glamour. Kyanite, epidote, thomsonite, tremolite, sodalite. Thank goodness the scientists,

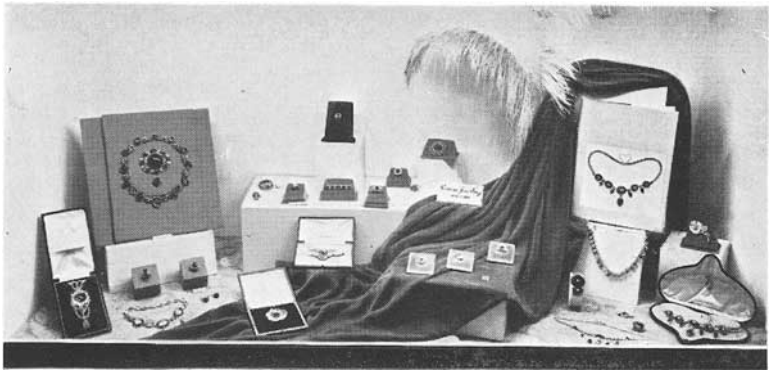

Gems in Jewellery during the past hundred years.

yes, even the gemmologists, were not there when the older stones were named! The visit of Princess Elizabeth to Canada was brought to mind by an exhibit of Canadian gem materials, for probably she will see some of these in her travels. Here were some of the " ites " and also purple bloodstone, cat's eyes and agates. The latest " ite," shown in Collector's Corner, naturally attracted interest. These were the only two specimens of Taaffeite yet found and here were other rare stones such as colourless Hessonite and Datolite, while other attractive specimens with their fantastic patterns of quartz and topaz showed the beauty of the commoner stones. These wonders of nature were renewed again with their beauty of pattern that could provide a theme for any designer in the display of mineral forms and in the examples of rocks in which gems occur. The man-made models of these crystal forms may have pointed the lesson, but they could not

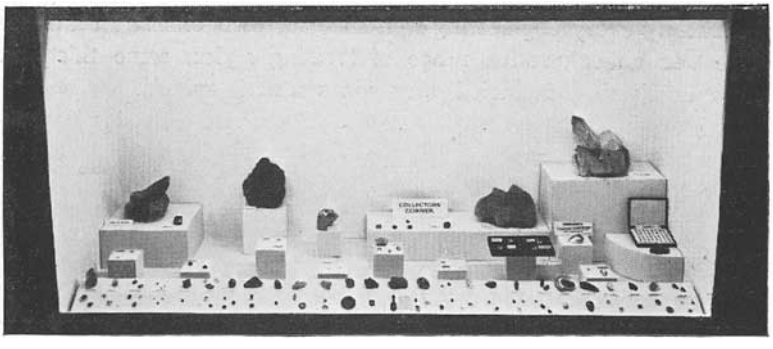

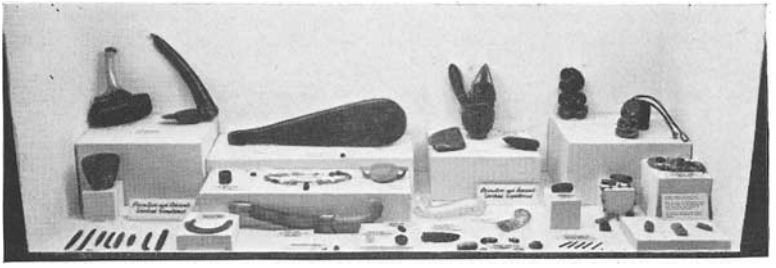

Primitive and Ancient worked Gemstones.

capture the free flow and variety of frond-like growth; of fan-like crystals; of stalactitic growth; and plant formation frozen into rock showed by these exhibits. Here the interests of gemmologists and geologists began to merge and one wished for a hammer and a " rock " holiday in the West.

Then back from stones in their beginnings to stones in their endings—though they hardly ever have an end—and the fine collections of gems loaned by various Fellows and friends of the Association. First, because I have a weakness for them, I should like to comment on the lovely collection of opals, notably the huge 74.93 ct. triangular specimen, the water opals and the intricately carved opal matrix depicting Cupid and Psyche in the clouds at the approach of dawn, and the specimens from Australia with their varied hues and colours. Then there were diamonds from South Africa, rubies from Burma, pearls from the Persian Gulf and elsewhere. Incidentally, there was a delightful " push

Dr. E. Gübelin (right) explains his new Spectroscope.

button " set-piece linked up with a map of the world from which visitors could find out, on pushing the button bearing the name of a gem, from where the gem came.

Special exhibits of particular stones had a particular interest, because each of them added a little bit of extra knowledge concerning that stone. One, it was true, proclaimed a mystery still to be solved. How the stress figures that made a necklace of amber beads so attractive, had been produced? It appeared that it had been done artificially by some unknown manufacturer, but it has not yet been possible to duplicate the results. The Beryl group had a display to themselves, showing the wide range of colour varieties. Or there was the story of two gems, diamond and ruby, and the various stages of design, arrangement and planning which led to the first drawing, the wax mount, the metal mount and the setting that ended with a modern piece of jewellery featuring these gemstones.

The story of synthetic gem stones could not be omitted, and here the gemmologist could study the huge colour range produced and some of the first examples of synthetic rutile made experimentally in a British laboratory. What a contrast is this laboratory controlled production from the actual mining, so well shown in the colour film, taken by a Fellow who had recently visited Ceylon, which was shown at frequent intervals during the day.

Getting closer to the science of gemmology was the exhibit which dealt with the specific gravity of gems and with stones both rough and cut, from the garnet and chalcedony groups, gave their s.g. Then there was the display of enlarged pictures of inclusions found in various stones, the " finger prints " of a gem. These exhibits brought one naturally to the stands on which stood all the complicated apparatus in use today for delving into gems. Here the story of 100 years of gemmology could be seen in the

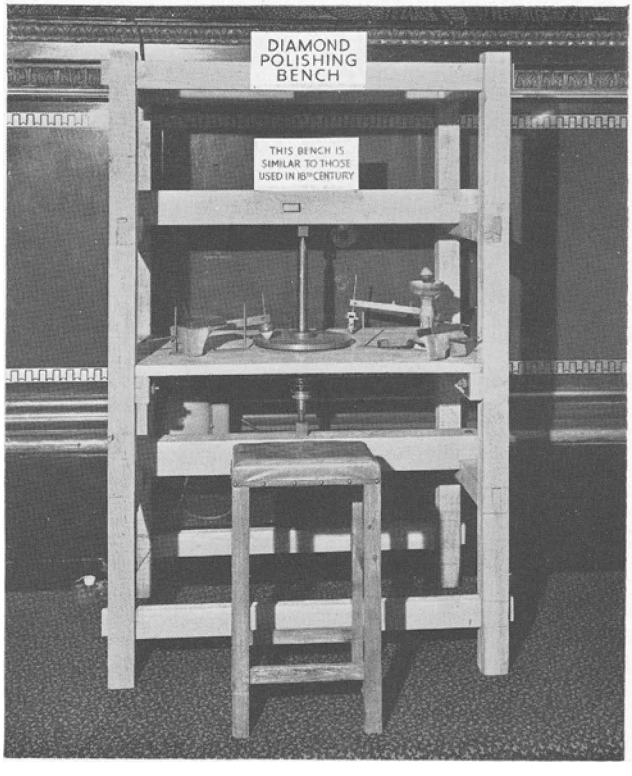

development of new devices, whose introduction was necessarily urgent with the arrival of synthetic and other types of artificial stones. Those early instruments, brought out from the cupboards and the years of dust swept off them have looked clumsy and strange, but they did their job. They were an efficient front line defence against the early synthetics and they must have saved jewellers hundreds of thousands of pounds. Not so many of us can remember those days in the beginning of the century, but they were to be duplicated after the first world war when cultured pearls were marketed, quickly to be followed by the invention of an instrument that could explore their interiors.

* * *

The Council of the Association is grateful to the Wardens of the Worshipful Company of Goldsmiths for kindly making the Hall available for the exhibition and to the following persons, companies and organizations for assistance with technical advice, the loan of exhibits or participation in the exhibition as stewards or organizers:

Messrs. B. W. Anderson, K. A. Webster, R. Webster, H. J. B. Wheeler, D. Wheeler, K. Parkinson, O. Fahy, G. Clarkson, L. F. Cole, R. F. Corfield, K. Pellett, R. W. Yeo, R. L. Rait, N. Deane, A. M. Ramsay, H. Lee, F. E. Lawson Clarke, M. L. Crombie, A. R. Popley, L. C. Trumper, P. Grodzinski, A. Stokes, Kelsey Newman, I. Whetstone, W. Nathanson, A. Monnickendam, H. C. Fishberg, D. S. M. Field, N. H. Day, A. Coleman, Charles Mathews, J. C. Ginder, Ltd., Mrs. A. M. Sharpe, Miss W. Allan, Mrs. M. Chisholm, Miss M. G. Biggs, Miss K. Gibson, Mrs. G. Parry, Mrs. G. Ash, Messrs. Spink & Son, Ltd., Research Laboratory of G.E.C., Chelsea Polytechnic, J. W. Benson, Ltd., H. A. Byworth, Ltd., Australian Pearl Co., Ltd., Chas. Mathews & Son, Sybil Dunlop, Wilson & Gill, Ltd., Crombie (Fine Jewels), Ltd., R. W. Yeo, Ltd., British Museum (Natural History), H.M. Geological Survey & Museum, Rayner & Keeler, Ltd., The Diamond Trading Co., Ltd., Chance Bros., Ltd., Wood & Whitelaw, Cartier, Ltd., Dr. G. F. Claringbull, Dr. W. Campbell Smith, Dr. E. H. Rutland, Dr. J. Phemister, Dr. W. F. Fleet, Sir James Walton, Lt.-Col. G. N. Sprague, Dr. W. Stern, Dr. E. Gübelin, and G. F. Andrews.

CURVED COLOUR BANDS

By B. W. ANDERSON, B.Sc., F.G.A., and R WEBSTER, F.G.A.

GEMMOLOGISTS are familiar with the curved colour bands in synthetic blue corundum which follow what were formerly the surface contours of the growing boule. In synthetic blue spinel, for reasons not properly understood, the colour is nearly always homogeneous, so that no striae of any kind can be seen.

We were surprised, therefore, to receive from Mr. Hans Myhre of Oslo a specimen of synthetic spinel showing very clearly curved bands of cobalt blue. The stone weighs 8.34 carats, and is cut in fancy style with large triangular facets set at a low angle. The properties are quite normal, the refractive index being 1.7271 for sodium light and the density 3.629: a cobalt spectrum could be seen.

Since the colour bands are somewhat diffuse and widely separated they would not show up well in a photomicrograph, so we decided to photograph the bands by less conventional means. The left photograph reproduced here was taken by direct radiography at 48 kV., and shows fairly clearly, as we hoped, the slightly greater opacity of the coloured bands to the X-rays owing to the greater concentration of cobalt within the bands. The second photograph was taken without apparatus, by simply immersing the stone in a plastic dish containing monobromonaphthalene placing underneath a piece of printing paper, and exposing to an overhead light. The resulting picture is rather charming, and the bright line effect makes one wonder whether this simple process might not have some practical value in the visual demonstration of the principles of the well-known immersion methods of refractive index determination. It should be remembered that in both these photographs it is the *pale* bands that represent the dark bands of colour in the actual stone.

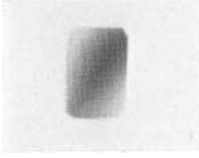

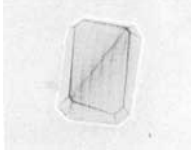

In concluding this brief note, we should like to express our thanks to Mr. Myhre for presenting us with this interesting stone.

Bookstall Discovery

By A. E. FARN, F.G.A.

I AM one of those people who can never resist the lure of a curio shop or a " junk " stall and am quite an inveterate bargain hunter who has at times found minor bargains, and also a few " white elephants."

Browsing over some secondhand books recently I was interested in a book which seemed to be a veritable miscellany of general scientific information and write-ups of all types. The book was entitled " Curiosities and Wonders of Nature, Science and Art or The Intellectual Observer " was published by Groombridge & Sons, Paternoster Row, and contained many prints in colour. It was chiefly these which caused me to purchase it for a few shillings.

Keener interest was aroused when I found therein a letter from (then) Professor Church, telling of his experiments with the microspectroscope and announcing his discovery of the absorption spectra of Almandine Garnet and Zircon. I showed the volume to Mr. B. W. Anderson who was thrilled with it and at once asked the date of the book. To our astonishment there was no date on its title page, or indeed anywhere in the volume except incidentally in the text where several references to the year 1865 were found.

Enquiries made from the Chief Librarian of the British Museum elicited the information that they had no copy of the book. On the suggestion of Mr. Anderson I ventured somewhat diffidently to the Patent Office Library and looked it up there. The volume was checked page by page and found to be Volume 9, February—July, 1866. There were volumes of the same journal published from 1862 to 1868. Before that it was known as " Recreative Science " and later it continued as " Student." For the interest of readers of the Journal the pages showing Professor Church's historic letter are reproduced here.

MICRO-SPECTROSCOPE INVESTIGATIONS.

LETTER FROM PROFESSOR CHURCH.

THE Editor has received the following interesting letter from Professor Church.

"Have you tried the experiment with chloride of cobalt, which I mentioned to you? If you take the saturated cold solution of this salt it will give the spectrum roughly sketched in Fig. 1,* a *thinner* film of the *same* solution, heated (on a glass slide with thin cover) over the candle or lamp gives the spectrum drawn in Fig. 2.† You will notice two black bands, I had almost said lines, in the red. As might be predicted from the change of colour on heating, the solution is afterwards much more transparent to rays beyond D. The chloride of copper and nickel also give very interesting results.

But I think you will be most pleased with the experiment I have now to relate. I have worked lately on the spectra of pleochroic minerals and salts. Among the minerals recently examined were several fine specimens of the true zircon or jargoon, a silicate of zirconia. These gave a beautiful and most characteristic system of seven dark bands quite different from those belonging to any other substance yet examined. They are roughly sketched in the following figure. Zircons as colour-

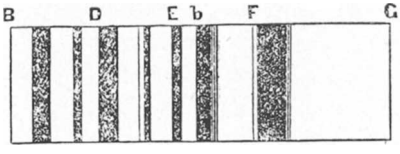

less as common glass shew these bands as well, perhaps better, than those possessed of colour. They are to be observed with zircons which have been ignited as well as with those still in their natural condition. But some zircons show the phenomenon better than others, this difference not being due apparently to the colour of the stone or the thickness through which the light traverses. I am not quite sure, but I incline to think that those zircons which have come from some localities shew the bands better than those from others. Several Expailly specimens scarcely exhibit anything of this kind; all

* The Figure alluded to shews the red darkened, the orange light, and a broad dark band commencing to the right of the yellow and extending beyond the line F, the remainder of the spectrum is cloudy.

† Fig. 2 shows the narrow black bands in the red, modified tints replacing the broad dark band of Fig. 1, the blue coming out clear. The experiment is a very beautiful one.

those from Ceylon and Norway show the bands well. From this observation I am induced to hazard the conjecture that it may be, after all, the presence of Swanberg's *norium* which determines the difference. You are aware that the orange jacinth, a variety of zircon, is very precious, and that the essonite of cinnamon-garnet is constantly sold for it. Curiously enough, the cinnamon-garnet, or essonite, (a lime-garnet), has no conspicuous dark absorption-bands at all, and so the spectroscope may be brought to bear upon the discrimination of these two stones. We have thus a much more ready process than that of taking the density of the specimens. The lime-garnet is of comparatively small value. The iron-garnet of different shades (carbuncle, almondine, etc.) gives a beautiful and very characteristic spectrum with several intensely deep absorption bands.

I write these particulars of my experiments at once, for I thought you might like to make a little paragraph about them for the readers of the INTELLECTUAL OBSERVER.

I ought to add that the absorption bands of zircon resemble those of didymium, discovered by Gladstone, in their sharpness and in their being produced by the passage of light through a colourless medium. Silica, the other constituent of zircon, gives no bands.

Professor Church's letter reproduced from "Curiosities and Wonders of Nature Science and Art or the Intellectual Observer." Groombridge, London.

Gemmological Abstracts

ANON. ***New gem substitute resembles emerald.*** Gems and Gemology, Vol. VII, No. 1, p. 29. Spring 1951.

A " soudé " emerald in which the more usual quartz crown and pavilion is replaced by synthetic (white?) spinel; the usual green cement joining the two halves. The spinel is flawed (probably by heat), which gives the completed composite stone the appearance of a slightly flawed emerald.

R. W.

TRUMPER (L. C.). ***Lighting for the gemmologist.*** Gemmologist, Vol. XX. No. 239, pp. 129-132. June 1951.

A resumé of suggested lighting equipment for the gemmologist. The sodium discharge lamp (Street lighting type) for use as a source of monochromatic light; the " Black lamp," a type of high-pressure mercury discharge lamp with a Woods glass outer bulb, as an ultra-violet light source and the low-pressure fluorescent discharge tubes for colour matching are discussed. A suitably housed 250 or 500 watt projection bulb is mentioned as being a suitable source of continuous spectrum light source for absorption spectroscopy. Three wiring diagrams are given and a short and not wholly accurate table of fluorescent colours is appended.

R. W.

GUBELIN (E. J.). ***Some additional data on Indian emeralds.*** Gems and Gemology, Vol. VII, No. 1. Spring 1951.

An excellent resumé on the Indian emerald. The localities of the mines, type of occurrence and methods of mining of the Udiapur emeralds are given. The external appearance of typical specimens of these emeralds are commented on, and the physical and optical properties determined by the author and other workers, are listed. The absorption spectrum is discussed in relation to the lack of a red residual colour through the usual

emerald filter. A very full investigation has been made of the characteristic inclusions. Mica tablets are found to lie always parallel to the basal plane and in conjunction with them are rectangular or square-shaped cavities, often with movable libella, in a direction at right angles to the plane containing the mica plates, that is they are parallel to the direction of the optic axis. Under low power these cavities are further characterized by a projection at one corner. Under higher magnification, and better with dark-ground illumination, these " comma-like " cavities are shown to be negative crystals of emerald habit, the comma effect being caused by the joint formation of such negative crystals, one of which is longer and more slender than the cluster of shorter companions. 10 photomicrographs: 1 absorption spectrograph and 1 map.

R. W.

POUGH (F. H.) and SCHULKE (A. A.). ***The recognition of surface irradiated diamonds.*** Gems and Gemology. Vol. VII, No. 1, pp. 3—11. Spring 1951.

A general survey of the distinguishing factors, as far as observation on available specimens allows, of diamonds coloured by radiation. A short historical background is given and also the negative result of placing diamonds (also yellow sapphire, kunzite, and pale yellow scapolite—which did colour in a similar manner as they do when bombarded by x-rays). The negative result in the case of diamonds being ascribed to the fact that the radium was packed in brass and glass containers which let through only the gamma radiation and not the alpha and beta rays which are known to cause colouring in diamond. Some notes on the cyclotron and on the methods of mounting the diamonds in the beam (deuteron, protron and alpha particle beams being used) are given. Green colours usually obtained by cyclotron bombardment, but if the beam be intense a golden brown colour may be induced. This brown coloration being ascribed to the heat of the beam at higher intensities. Colour penetration is only a surface effect, and in the case of alpha particle and proton experiments the colour was found to have only about one half the depth of the deuteron coloration. Alpha particle bombardment seemed to give more brown than green colours, but whether this was due to higher intensity—thus higher temperature, or is a constant characteristic

of the particle used, has not been decided. Crown-treated stones show, when viewed on a white paper with the culet up, a dark ring around the stone between the table and girdle. Pavilion-treated stones similarly placed do not show this ring, but do so if viewed table facet uppermost. In all cases a careful lens examination shows a cubistic pattern of reflections that show varying intensities of green colour. 7 illustrations. R. W.

DIXON (C. G.). ***Report on investigations in the Kurupung and Meamu diamond fields,*** British Guiana. Rep. Geol. Survey British Guiana, 1949, pub. 1950, pp. 5-25.

The Kurupung and Meamu river are tributaries of the Mazaruni river and the report deals with the numerous diamond workings in the area of these tributaries. The main source of diamonds is the alluvial deposits of the streams. A. G.

G.R.C. ***Inclusions in Synthetic Emeralds.*** The Loupe, Vol. IV, No. 3, 1951.

The occurrence of a fingerprint of a two-phase inclusion in synthetic emerald is reported. The stone examined, approximately three-quarters of a carat in weight, also contained a transparent colourless crystal. Refractive indices were 1.558-1.563. The stone fluoresced strongly under ultra-violet light. G. A.

RICHARD M. PEARL. ***Colorado Gem Trials.*** Sage Books, Inc., U.S.A. 1951, 141 pp., 15 photos and various sketch maps.

Here is a book by an assistant professor of geology and an enthusiastic gemmologist which will entertain and interest the gem collector even though an opportunity of taking a Colorado gem trail does not come his way. Mr. Pearl has provided an extremely useful guide that will prove invaluable for those fortunate to go. The author has been at pains to provide would-be collectors with much information about local travel land ownership and collecting conditions. Information about gem and mineral societies that may be contacted. It may well encourage the production of similar books about other localities.

The text is pleasantly readable and not spoiled by comments, which would have detracted from its usefulness as a guide. The photos show the type of country likely to be encountered but are otherwise not very helpful. The sketch maps would have been more useful if their scale had been indicated adequately.

GUBELIN (E.). ***Edelstein-Einschlüsse als Art-Merkmale.*** Gem inclusions as family characteristics. Gold und Silber, 1951, 4 (6/7), 36-38.

In modern gemmology the study of inclusions is of as much consequence as measuring refraction and observing the absorption spectrum. Admixtures and inclusions in gems permit not only determination of the gem family but also of the individual member and of the origin. Inclusions are formation characteristics which lately have become of increased importance for crystallography, genetic mineralogy and especially for the study of deposit distribution. Solid, liquid and gaseous inclusions from characteristic patterns. Twelve typical and extremely beautiful photomicrographs show inclusions in diamond, Burma ruby, Ceylon sapphire, Siam ruby, Siam sapphire, Colombian emerald, aquamarine and demantoid.

—— Ibid. Gold und Silber, 1951, 8, 10-12 (cont. from 6/7, pp. 36-38).

The article brings six further interesting photomicrographs depicting tourmaline, green zircon, topaz, moonstone, African peridot, and andalusite. Apart from these species, descriptions are given of microscopic inclusions and other characteristics in garnets, spinels, Colombian, Ural, and Indian emeralds. E. S.

SCHLOSSMACHER (K.). ***Neues uber Edelsteine.*** News about gems. Gold und Silber, 1951, 4 (6/7), 39.

In a lecture about new gem developments, Prof. Schlossmacher mentioned the importance of American inventions, i.e., the synthetic emerald, the synthetic rutile and the synthetic star sapphires and star rubies. The second part of his lecture dealt with the more exact methods in gem determination and examination, i.e., the colorimeter, the diamolite and the coloriscope. The diamondoscope was mentioned and the importance of examining cultured pearls by x-ray luminescence apart from the classical method of x-ray interference pictures. E. S.

HARDY (E.). ***The literature of the pearl.*** Gemmologist, Vol. XX, No. 240, pp. 152-153. July 1951.

A useful survey of the literature of the pearl. Listing works on the formation, the fisheries and legends. R. W.

Colour Filters for Gem Testing

By L. C. TRUMPER, B.Sc., F.G.A.

GEMMOLOGISTS will be familiar with the Chelsea filter and its use in checking a parcel of emeralds. Illuminated by a strong electric light source (not fluorescent) emeralds appear pinkish to a strong red, depending upon the quality of the emerald, whereas paste remains green.

It is true that other green stones exhibit the same colour change, notably green zircon, green fluor, alexandrite, green chrysoberyl and demantoid garnet, due to the fact that in these cases the colour as in emerald is due to chromium—these stones can however be eliminated quite easily by other simple tests. Other remarkable colour changes are also brought about, thus synthetic stones or paste coloured by cobalt which are deep royal blue in colour turn bright cherry red. Synthetic spinels of deep aquamarine colour turn bright red. Amethysts, purple sapphires, etc., turn red and almost colourless aquamarines take on a peculiar blue/green colour which is most characteristic.

The following table gives a comprehensive list of the colour changes observed:—

COLOURS OBSERVED THROUGH CHELSEA FILTER USING 60 WATT ELECTRIC LIGHT

Green Stones	Colour Observed
Alexandrite	bright red
Avanturine quartz	brown
Andalusite	green
Apatite	greenish
Aquamarine	distinct apple green even if very pale stone
Chrysoberyl	red
Demantoid Garnet	red or bright pink
Dioptase	deep emerald green
Doublets	green
Diopside	blue green
Emerald	red or pink
Euclase	reddish

Green Stones	Colour Observed
Enstatite	green
Epidote	dark green
Fluor	red
Hiddenite	genuine Hiddenite shows pink
Nephrite	green
Paste	green
Peridot	green
Sapphire	blackish green
Smithsonite	greenish
Stained green chalcedony	red
Pale apple green stained chalcedony	green
Synthetic corundum to imitate Alexandrite	bright red
Synthetic green sapphire	red
Synthetic green Spinel	green (may show red)
Tourmaline	green
Variscite	grey
Zircon	reddish

Red Stones	Colour Observed
Almandine garnet	dark red
Almandine/Glass doublet	dark red
Kunzite (pink spodumene)	flesh pink
Paste	dark red
Pyrope garnet	dark red
Pink Scapolite	flesh pink
Magenta Tourmaline	pale purplish
Pink Tourmaline	brownish
Morganite (pink Beryl)	bright pink
Ruby	bright fluorescent red
Rubellite Tourmaline	bright pink
Rhodochroisite	pink
Rose quartz	pink
Spinel	bright fluorescent red
Pink Topaz	bright pink
Pinkish golden Sapphire	bright pink
Zircon	red

Blue Stones	Colour Observed
Apatite	blue
Aquamarine	distinctly apple green
Deep blue Beryl	green
Fibrolite	dirty pink
Fluor (mauve)	red
Iolite	brown
Kyanite	navy blue
Doublets	red or greenish
Euclase	pink

Blue Stones	Colour Observed
Sapphire	black
Purple Sapphire	red
Spinel	reddish brown
Synthetic Spinel	bright red or orange
Smithsonite	yellow green
Sodalite	grey
Tourmaline	bluish green
Topaz	greenish blue/colourless
Turquoise	greyish
Zircon	greenish

Brown Stones	Colour Observed
Brown Zircon	reddish
Hessonite garnet	red

Purple and Violet Stones	Colour Observed
Amethyst	cherry red
Mauve Sapphire	red
Purple Sapphire	red
Purplish Tourmaline	blackish
Purple Zircon	reddish purple
Violet Sapphire	blood red
Mauve Sapphire	yellow

Yellow Stones	Colour Observed
Amber	yellow or orange
Apatite	pale yellow
Beryl	pale green
Brazilianite	yellow
Citrine (yellow quartz)	golden yellow
Chrysoberyl	yellow
Danburite	pale yellow
Fluor	yellow
Heliodor (golden Beryl)	yellow
Orange Zircon	orange
Orthoclase	yellow
Fire Opal	orange
Scapolite	pale yellow
Smithsonite	yellow
Spodumene	yellow
Spessartite	orange
Sphene	pinkish yellow
Topaz	yellow
Tourmaline	slightly pinkish
Yellow Zircon	yellow

So useful a guide is the Chelsea filter that in the Winter of 1946/47 the writer set about designing and constructing a viewing

box, full details of which were published in the Gemmologist Vol. XVI., 1947, p. 97.

This enables rapid observations to be made at any time in any light by merely inserting the stone on the tray, closing the drawer, switching on the light and viewing with binocular and stereoscopic vision shielded from extraneous light under ideal conditions. (It may be pointed out here that the panel shown on the front is not a window but a framed and glazed copy of the printed instructions issued with the Chelsea filter).

Many gemmologists have since constructed similar viewing boxes. Suggestions in certain quarters that there would be a ready market for commercially made viewing boxes were however met with the comment " That the idea would be still better if it could be extended to a range of useful filters and why did I not do something on these lines."

This set me thinking. First of all such a filter to be useful to the ordinary jeweller needed to apply to stones in popular demand. Emerald being already adequately covered and with it some others, what about ruby? Now I reasoned out that the only filter that could possibly exactly match the wavelengths emanating from a ruby suitably illuminated was another ruby and by inference any other stone must look somewhat different.

The first step therefore was to have made a flat of synthetic ruby as large as possible to form a filter. I managed to get one made ¾in. x ½in. and 3 mm. thick. This was then mounted to fit into one eyepiece of a viewing box, specially made up for filter experiments so that the filters could be changed rapidly.

There is no doubt but that the results are somewhat as had been anticipated. Rubies look exactly the same as without the filter, though perhaps a little deeper in tint as a result of additional thickness being superimposed. Red spinel, however, and red paste it must be admitted do not appreciably change in tint. The other stones take on a rather more orange hue. With many stones, some quite interesting changes do occur.

My next step was to superimpose Wratten colour filters over the ruby filter—some 100 different filters were tried and the changes which are set out below were noted in the case of those filters listed. For this particular test only red stones were examined and as far as possible stones were chosen where the colour was a reasonably close match to natural rubies. The stones used being

FIG. 3.—ORIGINAL CHELSEA FILTER VIEWING BOX. Construction of the light-tight box with shield, simple lamp house and switch, operating instructions on the front panel and the tray containing a number of selected gemstones for comparative purposes, together with spaces available to accommodate the stone under test (*on left*).

FIG. 4.—EXPERIMENTAL FILTER VIEWING BOX. Standard type of viewing box with simple lamp house, switch and light-tight shield, but with special provision for testing the 1½ inch square filters mounted between glass covers, one of the large number of Wratten and other filters employed in the tests (*on right*).

a Burma ruby of good colour, a synthetic ruby with a distinct carmine/magenta tinge, two pale rubies, a deep red spinel, a pale red spinel, two deep red zircons, two almandine garnets, a pyrope garnet and an almandine/glass doublet.

IN THE TESTS WHICH FOLLOW, THE RUBY FILTER 3 MM. IN THICKNESS WAS SUPERIMPOSED UPON THE WRATTEN FILTER

Filter No.	Name	Colour Changes Recorded and Other Remarks
25	A (Tricolor Red)	Ruby, lightened; remaining stones darkened
29	F	Ruby approaching a very pale tint—remaining stones unaltered in appearance
34	D (Light)	Difference outstanding, ruby pale rose red, remaining stones very much darker
35	D	Similar
36	Methyl Violet B.R.R.	Ruby pale rose red; spinel similar, remainder much darker
38	Toluidine blue	Ruby imperial purple; rest red
38 A	Dark Toluidine blue	Ruby violet/blue, spinel dark red, pale pink spinel mauve, rest dark red (quite good)
40	Ciné Green 1	Ruby imperial purple; rest definitely red
40 A	Ciné Green 2	Ruby deeper purple, rest red—the advantage that background is white
43	Minus Red 2	Rubies purplish, pale rubies blue, pale pink spinel blue
44	Minus Red 4	Ruby violet, rest dark red except pale pink spinel which is mauve
44 A	Minus Red 5	Similar but ruby a deeper violet
60	P	Ruby violet, rest dark red
64	Minus Red 3 (light)	Rubies violet or deep blue, red spinel red, pale red spinel pink, rest dark red or brown
65	Minus Red 3	Ruby violet, dark red ruby deep violet
67	Filter blue-green	Ruby less violet, pale spinel pinkish/mauve, rest red or brownish black
68	Fast green-blue shade	Rubies violet, rest deep red
70	A (Contrast R)	Rubies almost colourless. Remainder dark
71 A	B	Similar
75	N	Rubies deep violet—rest dark red
89	Signalling Red (light)	Rubies nearly colourless, remainder dark

USING THE SAME RED GEMSTONES, ALL THE FILTERS WERE THEN TRIED WITHOUT THE RUBY SLICE

Filter No.	Name	Colour Changes Recorded and Other Remarks
29	F	Rubies pale red, pale pink spinel pale, remainder darker
30	Rose Bengal	Bright red colour of ruby accentuated
30 A	Q	Bright red colour of ruby accentuated
31	Minus Green 1	Bright red colour of ruby accentuated
34 A	—	Rubies and spinel pale fluorescent red, dark red spinel dark red
38 A	Dark Toluidine blue	Rubies deep violet; dark red spinel very deep purple; pale spinel mauve
38	Toluidine blue	Rubies magenta; pale spinel similar, remainder red
44	Minus Red 4	Rubies violet, zircon a dirty violet; pale spinel pale violet, rest dark red
45 A	Blue-Green	Rubies blue; pale spinel slightly reddish, rest dark red
47	C5 Projection blue	Rubies dark green, rest dark
40	Ciné Green 1	Rubies violet, pale ruby blue; pale spinel darker, rest dark
40 A	Ciné Green 2	Rubies beetroot purple, pale ruby paler violet/blue, pale pink spinel pinkish, rest dirty red
35	D	Rubies bright fluorescent red, rest dull and dirtier
60	P	Rubies deep violet/blue, pale spinel bluish, rest dark or dark red
67	Filter Blue-Green	Rubies deep violet, pale pink spinel slightly mauve, rest dirty brown
97	Dichroic filter	Rubies fluorescent red, rest dark red; pale spinel very similar to ruby
57	B2 (light)	Close to 40 A, pale pink spinel not quite so pink as red spinel not so distinctly red, rest red or brownish
34 A	—	Rubies and spinel pale fluorescent red. Deep red spinel still dark red
59	Projection green	Almost identical to 40 A, very good colour change

IN THE FOLLOWING TESTS, TWO WRATTEN FILTERS WERE SUPERIMPOSED UPON ONE ANOTHER

Filter Nos.	Colour Changes Recorded and Other Remarks
38 A and 31	Rubies pale green; pale spinel reddish, rest red.
40 A and 31	Rubies lilac, rest brownish.
68 and 31	Rubies fluorescent red, rest dark red or brownish.
70 and 31	Rubies nearly colourless, rest dark.
38 A and 34	Rubies dark green—quite good.

Filter Nos.	Colour Changes Recorded and Other Remarks
36 and 68	Rubies bright fluorescent red.
35 and 40 A	Rubies almost colourless, rest dark; pale pink spinel slightly darker.
46 and 40 A	Rubies almost colourless, rest dark; pale pink spinel slightly darker.
38 and 40 A	Rubies deep violet, pale ruby blue, pale pink spinel mauvish, rest darker.

The most difficult separation was found to be the pale spinel though frequently almandine/glass doublet came very close indeed to the Burma ruby. The other red stones usually appeared quite different and usually a blackish tint of red or dark brown.

Concurrent with the above tests, I started to develop the prototype of a " Filter viewing Box " providing for rapid interchangeability of colour filters. A similar type of viewing box was built to those previously designed comprising a light tight box with base 7in. x 7in. and about 7½in. high with a drawer fitting into the base to take the stone or stones under test.

A simple lamp housing carries a 60 watt tungsten filament gas filled electric lamp with provision for changing the bulb with the lamp arranged to strongly illuminate the interior of the box without any direct light reaching the eyes.

A light-tight viewing shield is built into the front of the top centred so as to provide the correct angle of vision to the centre of the base of the tray.

Rectangular apertures about 1in. x ¾in. about 2in. centres apart are provided in the top of the box and a similar pair about ½in. above and built into the viewing shield. Between these two, provision is made for a circular disc about 4½in. diameter with a milled edge capable of rotation about a central pivot, which pivot is removable to enable the discs to be removed or changed. This disc carries four pairs of colour filters mounted between glass covers ½in. x ¾in. and spaced 53 mm. centres apart.

At first glance it might have been supposed that a better shape for the pairs of filters would have been round or square. The oblong shape was decided upon solely to provide for variation between the width of the eyes in different individuals. This shape clearly allows for a variation of at least ¼in. between a possible minimum and maximum. All that is necessary is to rotate the disc with the finger by means of the milled edge to bring each of the four filters successively into position. A small slot in the cover

FIG. 1

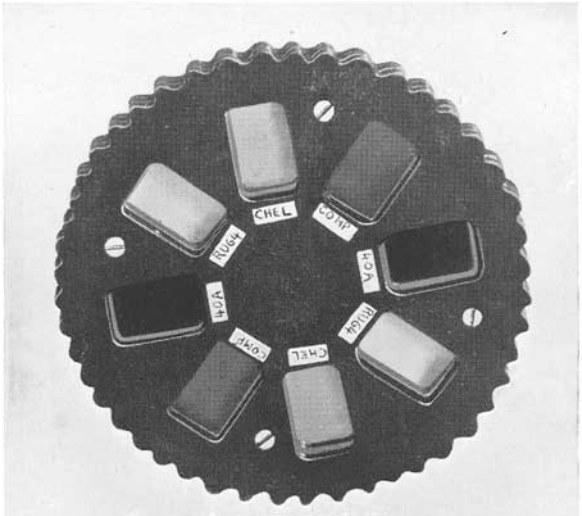

FIG. 2

Interchangeable disc of filters. Construction of the rotating disc carrying the four pairs of viewing filters.

The Trumper Interchangeable Filter Viewing Box. Left of the lamp house is the lever for bringing the complementary blue filter over the light source. Within the light-tight viewing shield between the two eyepieces, which in the commercial model will be fitted with lens and prisms, is the pin for withdrawing the rotating pairs of filters. Above the pin is the window through which appears the name of the filters in position. To the front of the viewing shield may be seen part of the knurled rotating disc of filters.

enables the name of the appropriate filter to appear as it is rotated. The switch at the side of the box enables the light to be switched on and off promptly thus preventing over heating of either the box or the filters.

Most colour filters are stable, but some do change after prolonged exposure to daylight. It will be seen, however, that three of the four pairs of filters will at any one time be covered both sides from the light and an added precaution would be to have a simple dust cover with a small handle that could be placed over the eye pieces when the viewing box was not in use.

The advantages of such a viewing box will bear repeating. Immediate availability of the appropriate illumination screened from daylight or any other source of illumination and the great benefit of both binocular and stereoscopic vision. To this has now been added the availability of alternative colour filters. To make my final choice of filter for the testing of rubies, I next selected a number of rubies of varying tints and depths of colour and checked these up along side a number of red spinels also of varying tints and depths of colour.

The following table shows the results using the most likely filters selected in the earlier examinations which I was satisfied already differentiated sufficiently from the remaining red stones.

FINAL FILTER TESTS

Filter No.	Name	Colour Changes Recorded and Other Remarks
64 + Ruby	Minus Red 3 (light) + Ruby	Rubies violet, pale rubies blue, deep red spinel deep red, medium red spinel pale purple, pale pink spinel distinctly pinkish or purplish, red zircon brownish red, garnet black or distinctly red, almandine/glass doublet deep red. On the whole this is the best filter for differentiating ruby from other red stones
67 + Ruby	Filter blue green + Ruby	Rubies violet tinged slightly with purple, pale rubies blue, deep red spinel dark red, pale pink spinel slightly mauvish. Red zircon inclined to be purplish black or brown, garnets distinctly red. Doublet deep red. This filter is practically as good as the one above for determining rubies

Filter No.	Name	Colour Changes Recorded and Other Remarks
40 A or 59	Ciné Green 2 Projection Green	Rubies distinct beetroot purple, pale rubies greyish blue, deep red spinel dark blackish red, garnets and zircon reddish brown to almost black. Deep Bohemian pyrope almost black, pale spinel distinctly pink, medium red spinel pale blackish red. This filter is quite a good one for identification of ruby.
38 A	Dark Toluidine Blue	Rubies violet or deep blue, zircons dirty brown or blackish, pale spinel deep mauve but difficult to determine, red spinel a deep blackish purple, garnets brownish red. Almandine/glass doublet deep red. This filter could be used with practice
40 A—38	Ciné Green 2 + Tolluidine Blue	Rubies a very deep violet, red spinel black, garnets and zircons dark brown, pale pink spinel brownish. Almandine/glass doublet very deep red. Garnets black or dark brown
38 A—31	Dark Toluidine Blue—Minus Green 1	Rubies dark to very dark green tinged with red. Pale spinel pink, all other stones distinctly red. Not a sufficiently marked colour change
40 A—67	Ciné Green 2	Rubies deep violet or deep blue, pale pink spinel pinkish brown, all other stones black or dirty brown. This combination of filters also provides a reliable separation with some practice

My final choice fell upon the 3 mm. slice of synthetic ruby with Wratten filter No. 64 Minus red 3 (light) superimposed thereon. With this filter rubies appear distinctly violet whilst all other stones are generally deep red. blackish or purplish.

Spectroscopic examination of this compound filter to which I have given the Code Number RU64 shows as was to be anticipated complete absorption of the violet up to about 4,500 angstroms, the usual lines in the blue attributable to ruby namely a line at 4,700 and a doublet around 4,770, considerable absorption in the green between 5,300 and 5,700 and complete absorption above 6,200 Angstroms.

The resultant colour of the filter is a pale blue and in general it will be seen that the light transmitted is blue and orange with a trace of red.

I also considered it worth while to include in the first disc of interchangeable filters, Wratten filter No. 40A (No. 59 is in fact nearly identical and may supersede No. 40A). With this filter rubies appear distinctly a beetroot or maroon purple, pale Siam rubies appearing a greyish blue whilst deep red spinel shows dark red, pale pink spinel distinctly pinkish and other red stones blackish, brownish or distinctly red.

Spectroscopic examination of the filter 40A shows that there is complete absorption in the violet and in part of the blue up to 4,580 angstroms with some absorption in the red, complete between 6,500 and 6,680.

Whilst both of these filters have been specifically chosen for their value in identifying rubies, colour changes do occur in many other gemstones. It has in particular been observed that both filters change the colour of peridot to a distinct brown whereas without exception all other green stones remain a similar green colour when viewed through the filters.

The full list of observations follow.

THE TRUMPER INTERCHANGEABLE FILTER VIEWING BOX—COLOUR CHANGES OBSERVABLE

Green Stones	RU64 Filter	40A Filter
Alexandrite	greenish blue	emerald green
Andalusite	dark green	green
Aquamarine	bluish	sea green
Aventurine quartz	green	green
Apatite	dark green	green
Chrysoberyl	green	green
Chrysoprase	leek green	leek green
Chalcedony (stained green)	green	green
Demantoid garnet (emerald green)	yellow green	bluish green
Demantoid garnet (bluish green)	bluish green	bluish green
Demantoid garnet (yellow green)	yellow green	green
Diopside	dark green	green
Dioptase	dark emerald green	dark emerald green
Doublets (simulating emerald)	green	green
Enstatite	green	green
Epidote	blackish green	dark green

Green Stones	RU64 Filter	40A Filter
Euclase	bluish green	bluish green
Emerald (of good colour)	emerald green	emerald green
Emerald (pale colour)	bluish green	green
Fluor	yellowish green	green
Hiddenite (emerald green spodumene)	dark green	green
Kornerupine	brownish green	dirty green
Malachite	dirty green	dirty green
Nephrite	green	green
Paste	green	green
Peridot	light brown	light brown
Sapphire (natural)	green	green
Sapphire (some synthetics)	green	green
Spinel (natural)	green	green
Spinel (synthetic)	green	green
Synthetic Corundum simulating alexandrite	blue	blue
Smithsonite (Bonamite)	greyish	greyish green
Tourmaline	green	green
Variscite	green	green
Zircon	olive green	olive green

Blue Stones	RU64 Filter	40A Filter
Apatite	blue	blue
Aquamarine	pale blue	sea green
Azurite	royal blue	royal blue
Beryl (deep blue)	blue	greenish blue
Benitoite	blue	yellowish green
Euclase	bluish green	bluish green
Fibrolite	pale blue	grey
Iolite	dark green	dark green
Kyanite	royal blue	blackish
Lapis lazuli	dark blue	dark greenish blue
Lazulite	bluish	greenish blue
Sapphire (Burma)	black	blackish
Sapphire (Ceylon)	blue	greenish blue
Sapphire (Kashmir)	deep blue	inky green
Sapphire (Montana)	blue	bluish green
Sapphire (Australia)	black	black
Sapphire (Synthetic)	black	black
Spinel (natural)	inky blue	inky blue
Spinel (synthetic)	blue	blue
Smithsonite	greyish blue	greenish
Sodalite	blue	greyish
Topaz	pale blue	sea green
Turquoise	bluish	greenish
Tourmaline	blue	greenish blue
Zircon	blue	pale green

Red, Purple and Violet Stones	RU64 Filter	40A Filter
Almandine garnet (red)	very dark red	black
Almandine garnet (pink)	Imperial Purple	blackish
Almandine garnet (purple)	purplish/black	dark brown
Almandine/Glass doublet	red	orange red
Amethyst	deep blue	grey
Carnelian	chocolate	pale chocolate
Fluor (mauve)	pale blue	bluish green
Kunzite (lilac spodumene)	pale greyish	yellowish pink
Morganite (pink beryl)	greyish blue	pale yellow
Paste	red	red
Pyrope garnet	very dark red	black
Red Jasper	chocolate	chocolate
Rhodochroisite	fawn	fawn
Rose quartz	grey	colourless
Ruby (Burma)	deep violet	beetroot purple
Ruby (Siam)	violet	pale beetroot purple
Ruby (pale)	pale violet	purple
Sapphire (Amethyst colour)	medium blue	pale violet
Sapphire (purple)	inky blue	violet
Sapphire (violet)	violet	violet
Sapphire (mauve)	grey	grey
Scapolite (pink)	colourless	colourless
Spinel (deep red)	deep red	blackish red
Spinel (medium red)	purple/maroon	blackish pink
Spinel (pink)	pale purple	pinkish
Spinel (purple)	Imperial Purple	brownish
Tourmaline (rubellite)	amethyst	pink
Tourmaline (pink)	mauvish brown	brown
Tourmaline (magenta)	purple	red
Tourmaline (purple)	Imperial Purple	dirty brown
Topaz (pink fired)	greyish blue	colourless
Zircon (red)	blackish brown	blackish brown
Zircon (purple)	purple	greyish

Orange and Yellow Stones	RU64 Filter	40A Filter
Amber (reddish)	brown	brown
Amber (yellow)	yellow	yellow
Apatite	colourless	colourless
Beryl	pinkish yellow	yellow
Heliodor (Golden Beryl)	pinkish yellow	yellow
Brazilianite	pale yellow	pale yellow
Chrysoberyl	flesh pink	yellow
Citrine (yellow quartz)	pale brown	yellow
Danburite	colourless	colourless
Fluor	yellow	yellow
Hessonite garnet	reddish brown	reddish brown

Orange and Yellow Stones	RU64 Filter	40A Filter
Orthoclase	colourless	pale yellow
Opal (Fire Opal)	orange	orange
Sapphire	flesh pink	yellow
Scapolite	colourless	pale yellow
Smithsonite	yellow	yellow
Spessartite garnet	orange brown	pale brown
Sphene	flesh pink	yellow
Smoky Quartz (Cairngorm)	brown	brown
Spodumene	colourless	yellow
Topaz	pale yellow	pale yellow
Tourmaline	greenish yellow	yellow
Zircon (yellow)	colourless	yellow
Zircon (orange)	orange	orange

I also decided that it was convenient to add still further to the value of the viewing box by providing a means of examining rubies and spinels for fluorescence by the use of two complementary filters as developed by S. Von Glisczynski and F. Vandrey and reported on in " Achat " 1949, 2 (7/8), pp. 270-272.

In this method two filters are employed one filter passes wavelengths from 3,200 A to 5,800 A, that is including the ultra violet and the other filter passes wavelengths from 5,800 A upwards.

With both filters superimposed in front of the light source, practically no light passes but if the rubies are placed between the filters then the bright red fluorescence excited in rubies and spinel by the light passing through the blue green filter is visible through the red complementary filter everything else remaining dark.

The viewing box is therefore provided with a Wratten Filter No. 44A, Minus Red 5, 2½in. square mounted between glass covers masked with black velvet and so arranged that by pressing a lever at the back of the box, it is brought over the light source—a ring of black velvet ensuring that no extraneous light escapes into the viewing box. Thus only light which passes this filter can illuminate the box. When not in use the filter drops out of the way. This filter is moderately stable and is unaffected by the heat of the lamp ; it is of course only in use for a matter of seconds.

The appropriate complementary filters are mounted in the rotating disc being Wratten filter No. 25A, Tricolour Red.

Finally, Messrs. Rayner have accepted the interchangeable filter viewing box for commercial production still further improved by the provision of combined lenses and prisms over the eyepieces.

PORTABLE DIRECT READING SPECIFIC GRAVITY BALANCE

By O. LeM. KNIGHT, B.E., Assoc.M.Inst.C.E., A.M.I.E.Aust.

IN the identification of gem stones, particularly in the rough, two of the most important properties are hardness and specific gravity. A knowledge of these, coupled with observed details of colour, crystal habit and mode of occurrence is sufficient, in most cases, for the identification of the stone.

In the field hardness can be readily found, but an accurate determination of specific gravity is not so easy, as none of the accepted forms of balance are very portable. To overcome this difficulty, the writer has developed a readily portable balance which reads specific gravity directly without calculation to a degree of accuracy that is sufficient for all practical purposes.

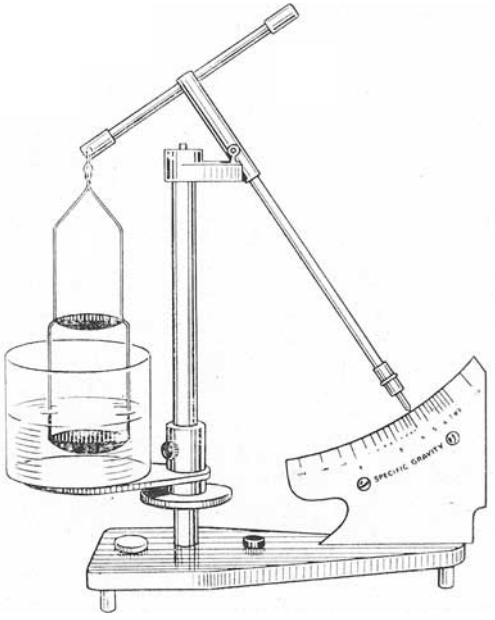

FIG. 1

The principle of the balance is simple. It consists of two pans, the lower immersed in water, carried on the one end of a balance

arm, the other end of which moves in an arc and carries a suitable sliding counterweight. The stone to be tested is placed in the upper pan and balanced by the counterweight against a fixed point on the scale. The stone is then transferred to the lower pan, which is immersed in water, and the arm carrying the counterweight moves to a new position, where it just balances the reduced weight of the specimen. (Fig. 1)

If the balance arm and pans are so designed that they are in perfect balance for any position of the arm, the depth of immersion of the lower pan being kept constant, the amount of movement of the arm is proportional to the loss of weight of the stone when immersed in water and the scale can be suitably graduated to indicate the specific gravity.

It may be well to outline briefly the mathematics involved.

Fig. 2 shows the balance in its initial position with a specimen, weighing W, in air, in the upper pan, balanced by a counterweight C. The initial position, for various reasons, has been taken at 45°. L is the length of the balance arm to C and l the distance from the pivot O to the pan support.

Taking moments about the centre O we have

$$W\ l \cos. a = C\ L \sin. 45°$$

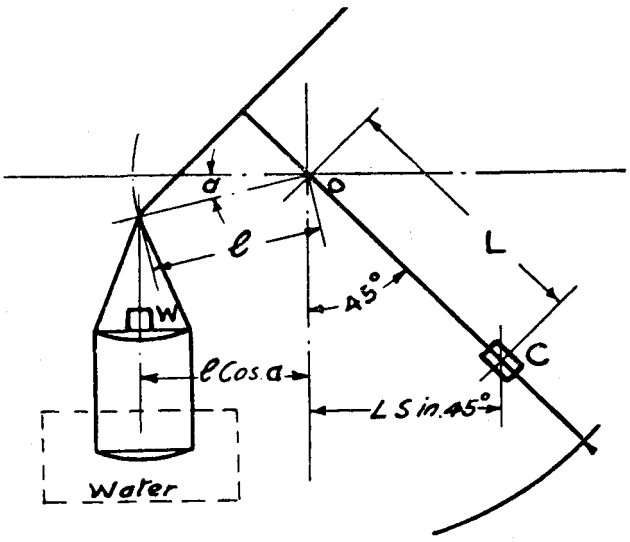

FIG. 2

The angle a is fixed by the design of the balance so that the pan support moves, over its useful range, approximately equal distances below and above the horizontal line through the pivot O.

From the above equation we see that

$$W = \frac{C\ L\ \text{Sin. } 45^\circ}{l\ \text{cos. } a}$$

Fig. 3 shows the position when the specimen has been transferred to the lower pan and now has an apparent weight of w. The balance arm has moved through an angle b to a new position and again taking moments about the centre O we have

$$w\ l\ \text{cos. } (b-a) = C\ L\ \text{Sin. } (45^\circ - b)$$

From this equation we see that

$$w = \frac{C\ L\ \text{Sin. } (45^\circ - b)}{l\ \text{cos. } (b-a)}$$

Now since

W = the weight of the specimen in air

and

w = the weight of the specimen in water

$$\text{the specific gravity} = \frac{W}{W-w}$$

substituting values for W and w from the two equations above we get

$$\text{Sp. gr.} = \frac{W}{W-w} = \frac{\dfrac{C\ L\ \text{Sin. } 45^\circ}{l\ \text{Cos. } a}}{\dfrac{C\ L\ \text{Sin. } 45^\circ}{l\ \text{Cos. } a} - \dfrac{C\ L\ \text{Sin. } (45^\circ - b)}{l\ \text{Cos. } (b-a)}}$$

This rather formidable looking expression reduces to

$$\text{Sp. Gr.} = \frac{\text{Cot. } b + \text{tan. } a}{\text{tan. } a + 1}$$

As mentioned before, the angle a is fixed by the design of the balance and is a constant value which can be substituted in the above equation, leaving the specific gravity proportional only to the co-tangent of the angle b.

For the dimensions of the balance made by the author the angle a was 12°, and as tan. 12° equals .21256 the formula can be written

$$\underset{(\text{Sp. gr.})}{g} = \frac{\text{Cot. } b + .21256}{1.21256}$$

A more useful form of the equation for calculating the scale is

$$\text{Cot. } b = 1.21256\ g - .21256$$

From this formula the angle corresponding to any value of g can be calculated.

So much for the theory of the balance. There are a number of practical considerations that are of importance, particularly if the balance is to be accurate when testing very small stones.

1st.—The whole of the moving parts, balance arm and pans, must be in perfect balance at any position on the scale, the lower pan being always immersed in water to the same depth.

This can be assured by balancing these parts about the pivot point in two positions: one with the arm in the vertical position and one with the arm in the horizontal position. If balanced in these two positions the moving parts will be in balance in any intermediate position.

This balance must be calculated when drawing up the design and finally corrected experimentally after making and assembling the parts.

2nd.—Friction at the pivots must be reduced to a minimum. The writer used hardened steel pivots working in sapphire jewels for the main pivots. The sapphire jewels were let into the cross

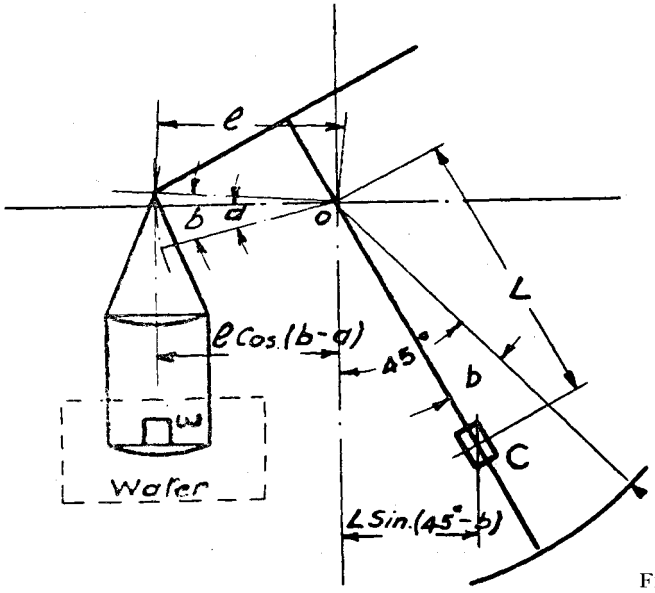

FIG. 3

spindle on the balance arm so that the pivot points were exactly at the centre of this spindle.

The pan suspension consisted of a wire hook suspended over an agate knife edge.

3rd.—The depth of immersion of the bottom pan must be maintained constant for any position of the balance arm. This can be arranged by a vertical screw adjustment for the bracket carrying the water container and a line marked around the container giving the level of the bottom of the pan.

4th.—It is advisable also to reduce the inertia of the working parts to a minimum. This can be accomplished by making the balance arm and pan supports of duralumin tube and the pans of thin aluminium sheet stiffened by pressing to dished form. Stiff wire for the pan supports can be made by drawing duralumin tube through a die plate.

5th.—The balance should be truly horizontal when in use and the insertion of a small bubble level in the base will permit this to be adjusted accurately.

In the balance illustrated the balance arm can be lifted off the pivots when not in use for ease and safety in packing. The pivot points are let into a U-shaped bracket and are $\frac{3}{4}$ inch apart.

The radius from the pivot to the scale is 5 inches and the distance from pivot to pan support is $2\frac{1}{4}$ inches. Pans are $1\frac{1}{4}$ inches diameter and are stamped from aluminium sheet .01 inch thick.

Weights are made to slide on the balance arm with a friction grip which permits of rapid adjustment. The actual value of the balance weights is unimportant, it being necessary only to have a range of weights that will balance the specimens likely to be tested.

Specimens from 2 grains to an ounce or more in weight can be handled rapidly and accurately in the field on this balance, though for stones less than one carat in weight considerable care is necessary.

The total weight of the balance packed in a case for transport is four pounds. The top of the case is provided with a screw for clamping the base of the balance when in use.

(Extracted with permission from the Commonwealth Jeweller and Watchmaker, May, 1951.)

ASSOCIATION NOTICES

REUNION OF MEMBERS AND PRESENTATION OF AWARDS

A reunion of Fellows and Members of the Association will be held at Goldsmiths' Hall, Foster Lane, London, E.C.2, on Wednesday, 7th November, 1951, between 6.15 and 7 p.m.

Following the reunion the presentation of awards gained in the 1951 examinations will take place at 7.15 p.m. Professor Kathleen Lonsdale has very kindly consented to present the awards.

TALKS BY FELLOWS

Kibe, V. R.: B.B.C. Overseas programmes. "Study of Gemmology" with special reference to the Gemmological Association of Great Britain, August 28th. "Gemmology," September 15th. (Recorded talks in the Marathi language.) Mr. Kibe is the first Indian to obtain the Fellowship diploma.

Warren, Mrs. K. G.: "Gemstones," Bromley Town's Women's Guild August 14th.

Blythe, G. A.: "Gemstones," Southend Rotary Club, August 21st. Baptist Church Guild, Southend, October 2nd. Prittlewell Evening Guild, October 3rd. Thorpe Bay Townswomen's Guild, October 4th. Royal College of Nursing (Southend and district, Rochford Hospital), October 8th.

Ash, G. A. (Mrs.): "Precious stones and the stories of some famous gems," Palmers Green and Southgate Townswomen's Guild, October 4th.

COUNCIL MEETINGS

JUNE

A meeting of the Council of the Association was held at 19/25, Gutter Lane, London, E.C.2, on Thursday, June 21st, 1951. Mr. F. H. Knowles-Brown presided.

The Council received with regret the resignation of Mr. Thorold G. Jones as a member of Council. He felt that he was unable to continue to serve because of the prior claims of his present work. The Council recorded its great appreciation of Mr. Jones' work for the cause of gemmology and the Association.

A report of the sub-committee appointed to consider matters appertaining to the examinations was presented and, after amendment, adopted. Among other matters the Council decided that the examiners for the time being should be co-opted as members of Council. During the previous Council meeting Dr. G. F. Herbert Smith announced that he felt that the time had now come for him to hand over the task of being Senior Examiner to some one younger. The Council decided to invite Mr. B. W. Anderson to act as an examiner with Dr. Claringbull.

The sub-committee also submitted that amendments should be made to the syllabus of examinations and these, mostly affecting the diploma examination, were agreed.

* * *

AUGUST

Mr. F. H. Knowles-Brown presided at a meeting of the Council held at 19/25, Gutter Lane, London, E.C.2, on Wednesday, August 29th, 1951.

Mr. B. W. Anderson formally accepted his appointment as co-examiner in gemmology and in so doing expressed the appreciation and thanks of the Council to Dr. Herbert Smith for his great work as examiner to the Association and its predecessors since 1912. It was work the value of which could not be adequately expressed in words and had set a standard that had earned international repute.

The examiners presented their report on the 1951 examinations and the Council agreed to the award of prizes. (The examination results are set out in these notices.) In view of the difficulty of assessing the award, Mr. Anderson agreed to withdraw the prize given in connection with the practical section of the diploma examination.

The following were elected to membership:—

FELLOW:

Phillips, J. A., Los Angeles, U.S.A. (D. 1950).

PROBATIONARY MEMBERS:

Connolly, J., Auckland, New Zealand.

Sena, W., Singapore (D. 1951).

GIFTS TO ASSOCIATION

The Council of the Association acknowledges with gratitude a gift of gemstones from Dr. E. Rutland.

GERMAN GOLDSMITHS' MEETING, 1951, AT AUGSBURG

Over 400 jewellers, gold- and silversmiths attended the Augsburg meeting, and foreign delegates from France, Belgium, Switzerland and Austria participated again. Within the framework of this meeting, a number of lectures were given. Dr. E. Guebelin, of Lucerne, talked about "The introduction into gemmology" using coloured slides. Prof. Dr. K. Schlossmacher, of Idar-Oberstein, gave an illustrated lecture on the "colours of gemstones." The well-known art-historian, Father Dahm, of the monastery Maria Laach, gave a public lecture on "enamel, gold and gem objects, ecclesiastical and secular." The importance of the meeting is shown by the fact that its patron was the Bavarian Minister of State for Economics, Dr. Hanns Seidel, who opened the meeting on June 30th in the Small Golden Hall of Augsburg. Numerous discourses dealt with apprenticeship and examination, experts' problems and propaganda.

The main feature of the meeting was the opening of the exhibition of "gemstones, ornaments and precious utensils" in the historic halls of the Maximilian Museum of Augsburg. The exhibition was open until June 25th and showed historical Augsburg goldsmith craft, a gem exhibition from Idar-Oberstein, and a separate section under the heading "From apprentice to master."

Several resolutions were passed, directed to the States government. Strong protest was raised against the luxury tax, and it was urged that the State should initiate an emergency program (including important orders) for the gold- and silversmiths' workshops, which are especially hit by the economic crisis.

THE TECHNOLOGY OF DIAMOND AND OTHER HARD SUBSTANCES

After the successful conclusion of the first nine-lecture course on this subject at the South East London Technical College, the Mechanical Engineering Department has arranged for a second ten-lecture course on the Technology of Diamond and Other Hard Substances, commencing Monday, October 8th, 1951, with lectures every other Monday until February 18th, 1952. The lectures deal practically with all technical applications and try to give fundamental knowledge on the diamond as technical material. Special lectures are provided on Shaped Diamond Tools, Diamond Truing Tools, Diamond Dies, Production and Use of Diamond Powders, Production and Use of Diamond Grinding Wheels, Diamond Rock Drilling, and Production of Sapphire Bearings. The lectures will be given by experts in this field, including J. C. Dawkins, P. Grodzinski, F. C. Jearum, G. R. Leeds, J. D. McClure, B. Morgans and N. Smith. Applications should be sent to the South East London Technical College, Lewisham Way, London, S.E.4. Telephone: Tideway 1421.

GEM CLASSES IN BRISTOL

Classes in gemmology have recently been commenced at the Fairfield Grammar School, Bristol. Students will be prepared for the examinations of the Association. Mr. F. E. Leak has been appointed lecturer.

MEMBERS' MEETINGS

On Thursday, 11th October, at Goldsmiths' Hall, London, Dr. E. Gübelin, F.G.A., C.G., of Lucerne, gave a talk to members on the inclusions that occur in diamond. His talk, which was illustrated by coloured slides of photomicrographs, will be reported in the January, 1952, issue of the Journal.

* * * *

A meeting of members will be held at the British Council Cinema on Tuesday, 20th November, 1951, at 7 p.m., when, in response to demand, a further showing of the film "Atomic Physics" will be given. Tickets are required for this meeting.

1951 EXAMINATIONS IN GEMMOLOGY

The Association's 1951 examinations in gemmology were held in the United Kingdom, the United States of America, Canada, the Netherlands, Singapore, the Union of South Africa, Norway, Sweden, India, Switzerland, Ceylon and the Commonwealth of Australia.

One hundred and forty-seven candidates sat for the preliminary examination and ninety-two for the diploma. Upon the recommendation of the examiners the Tully Medal (Diploma examination) was awarded to Mr. J. D. Wade, Glasgow, and the Rayner Prize (Preliminary examination) to Mr. C. I. Belcher, Johannesburg.

The following is a list of successful candidates, arranged alphabetically:

PRELIMINARY

Aarons, A. (London)
Allen, H. (Newbridge, Scotland)
Andersen, A. T. (Toensberg, Norway)
Andriessen, D. J. (Bergen-op-Zoom, Netherlands)
Austin, L. F. (London)
Barker, Miss J. B. (Birmingham)
Bartram, Miss E. M. (Woodville West, S. Australia)
Belcher, C. I. (Johannesburg, S. Africa)
Blake, Miss D. I. (Plymouth)
Bochatay, A. (Geneva, Switzerland)
Boudreau, G. A. (Harrow)
Bould, D. R. (Plymouth)
Boundy, D. B. (Leamington Spa)
Bowditch, Mrs. P. E. (Bristol)
Boxall, W. J. (Edinburgh)
Brandsma, A. H. (Maastricht, Netherlands)
Brooks, Miss B. B. (Birmingham)
Bushell, J. C. (Oldbury)
Cameron, A. D. (Glasgow)
Cannon, J. (Gerrards Cross)
Carter, Mrs. N. E. (Bristol)
Chalmers, A. (Glasgow)
Clarke, C. L. (Hatfield)
Clay, Miss E. V. (Birmingham)
Clutterbuck, Miss M. E. (Birmingham)
Cohen, S. (Amsterdam, Netherlands)
Coxhead, R. M. (London)
Cranfield, A. S. (Croydon)
Craven, B. R. (Blackburn)
Cross, R. (Glasgow)
Crossingham, A. W. (London)
Crouchley, D. (London)
Cummins, W. G. (Blackburn)
Cutler, R. (London)
Davies, G. H. (Birmingham)
Davies, J. W. (High Beech)
Davis, A. W. (Potters Bar)
Denham, F. J. (Harrow)
Doulis, L. N. (Detroit, U.S.A.)
Dove, D. K. (London)
Drury, E. G. (Birmingham)
Dunk, L. A. (Morden)
Edwards, J. (Manchester)
Evans, Miss F. M. (London)
Fifield, L. J. (St. Albans)
Flood, F. (London)
Foreman, V. L. (Stockton-on-Tees)
Frenkel, A. O. (Montreal, Canada)
Furse, T. S. (Tavistock)
Grahame-Ballin, Miss A. M. (St. Albans)
Grantham, Miss L. O. (London)
Green, Miss P. D. (London)
Hall, J. A. (London)
Hardwick, D. G. (Burton-on-Trent)
Harper, A. J. (Swansea)
Harsheim, O. (Oslo, Norway)
Henderson, Miss A. I. (Houston, Scotland)
Hodne, H. (Kristiansand, Norway)
Hogervorst, Mrs. T. (The Hague, Netherlands)
Hudson, J. S. (Birmingham)
Hval, J. O. (Oslo, Norway)
Isaacs, D. (Glasgow)
Jacobs, R. E. (London)
Johnson, D. R. (Toronto, Canada)
Jones, A. D. (Birmingham)
Jones, V. G. (Sutton)
Kinnear, D. I. (Edinburgh)
Krashes, B. (New York, U.S.A.)
Lardeur, K. J. (London)
Levett, R. V. (Thorpe Bay)
Lewis, E. G. (Woking)
Light, D. A. (Sutton Coldfield)
Lubin, G. (London)
Lurcott, T. (London)
McAlpine, A. W. (Edinburgh)
McKay, Miss J. (Glasgow)
McRae, A. J. (Glasgow)
Mearns, Mrs. M. A. (Brisbane, Australia)
Mellish, E. (London)

Messer, R. C. (Edinburgh)
Middlemiss, A. E. (Erith)
Miller, L. R. (San Rafael, U.S.A.)
Oostwegel, L. H.
(Heerlen, Netherlands)
Paterson, W. (Edinburgh)
Payne, L. (Bournemouth)
Peel, F. A. (Edmonton, Canada)
Pollington, K. I. (Welling)
Pye, D. T. (Methil, Scotland)
Rhodes, J. (Birmingham)
Rice, Miss J. M. (Birmingham)
Rice, R. A. (Birmingham)
Roe, A. J. (Newton Abbot)
Russell, W. E.
(Port Alberni, Canada)
Short, Miss E. A. (Twickenham)
Siedle, L. C. (Colombo, Ceylon)
Silver, B. (Edgware)
Small, J. G. (Los Angeles, U.S.A.)
Smith, J. E. (Reigate)
Solomon, D. N. (Tavistock)
Spray, A. J. (London)
Stanton, A. I. (London)
Stevens, R. E. (London)
Sunde, G. (Oslo, Norway)
Svensson, K. W. (Lidingö, Sweden)
Tillander, A. B.
(Helsingfors, Finland)
Towells, Miss M. J. (Bristol)
Urquhart, I. R. (London)
van der Heyden, C. J.
(Zoeterwoude, Netherlands)
van der Velden, J.
(Amsterdam, Netherlands)
Voyce, R. K. (London)
Walsh, J. F. (Birmingham)
Wardall, C. H. (Chester)
Watton, J. E. (Birmingham)
Wheelock, H. J. (Birmingham)
Whelan, K. (Hainault)
Woolley, T. W. (Birmingham)
Yaghobi, H. (London)

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Brandsma, A. H.
(Maastricht, Netherlands)
Breebaart, A. J.
(Arnhem, Netherlands)
Crook, Miss W. E. (London)
Davis, G. W. (Birmingham)
Doulis, L. N. (Detroit, U.S.A.)
Gush, Mrs. I. N.
(Johannesburg, S. Africa)
Kolb, H. F. (London)
Lumsden, Miss J. G. (Edinburgh)
Palmer, J. V.
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Scott, J. F. (Lincoln)
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van Loo, J. (Zeist, Holland)
Wade, J. D. (Glasgow)
Wright, T. J. (London)

Qualified

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Armstrong, A. H.
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Bradbury, D. S. (London)
Bridges, R. J. (London)
Broadbent, Miss S. A. (Farnham)
Browne, P. C. (Nottingham)
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Cater, C. W. (London)
Clark, L. D. (Surbiton)
Clarke, Miss H. A. (London)
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Russell, W. E.
(Port Alberni, Canada)
Stockwell, J. C. (Middlesbrough)
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Swettenham, G. W. (London)
Tillander, A. B.
(Helsingfors, Finland)
Towe, E. G. (Edinburgh)
Turnbull, K. (Harold Wood)
van der Heyden, C. J.
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Wacker-Wakelin, R. J.
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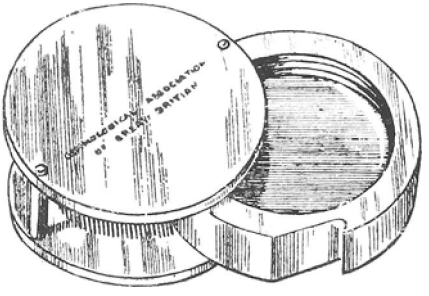

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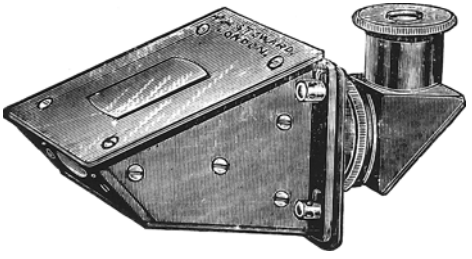

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THE JOURNAL OF GEMMOLOGY
AND PROCEEDINGS OF THE GEMMOLOGICAL ASSOCIATION OF GREAT BRITAIN

Vol. III, No. 5 JANUARY 1952

INCLUSIONS IN DIAMONDS

by E. Gubelin, Ph.D., C.G., F.G.A.

INCLUSIONS in diamond have not attained their rightful recognition. That gemmologists have not brought them into the limelight may be due to the fact that the diamond has been regarded as being free from inclusions of particular interest, except for what is known in the diamond trade as " carbon spots," " feathers," and " cracks," and the absence of any form of synthesis was also responsible for the lack of interest in investigating the characteristic inclusions in diamond. The term " carbon spots " may have a double meaning ; according to Mr. B. W. Anderson, any inclusion consisting of carbon or a carbonaceous compound may be logically called a " carbon spot," be it a diamond or graphite. In the French and German translation it refers to and means " coal." I am convinced that coal never occurs in diamond whereas carbon inclusions in either of the dimorphous forms of graphite or diamond may be found quite frequently.

Indeed, black specks, " carbon spots " as they are termed in the diamond trade, are so plentiful that I decided to delve into the study of these inclusions, and consequently found most of them to be either amorphous aggregates or broken particles of the original magma or any of the minerals subsequently referred to. It may be mentioned that in bad light almost any inclusion in diamond appears

INCLUSIONS IN DIAMONDS

DIAMOND 1
Diamonds included in diamond

DIAMOND 2
Enclosed garnet crystal

DIAMOND 3
Enclosed enstatite crystal

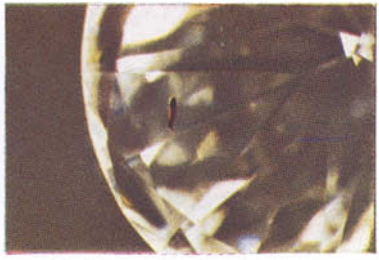

DIAMOND 4
Enclosed garnet crystal

DIAMOND 5
Enclosed enstatite crystals

DIAMOND 6
Enclosed zircon crystal

DIAMOND 7
Three Generations

DIAMOND 8
Three Generations

Photo micrographs: E. Gubelin.

black ; diamonds should always be examined in the best available light, preferably in dark-ground illumination which really causes the inclusions to reveal their true nature. The most common inclusion in diamond is a black mineral, which may be graphite or some ore, such as hematite, magnetite or ilmenite, but besides these there are many other colourless, transparent or coloured inclusions which are much more intriguing.

Diamond inclusions may be classified in the same groups as the inclusions in other gemstones. Thus we have solid, fluid and gaseous inclusions, and with reference to the time of formation of the host diamond we may discern inclusions which were formed either before the diamond was born (known as pre-temporary), or at the same time as the diamond (con-temporary), or after the diamond was completed (post-temporary inclusions).

Since the purport of this paper is to discuss critically the so-called " carbon spots," particular concentration will be focused on the solid inclusions. Solid inclusions may be either particles of the original magma, as already stated, or crystallized bodies. The amorphous particles of the magma appear as shapeless, irregular grains, crumbs, clusters or lumps of black colour. Sometimes they are surrounded by cracks due to strain, which may also appear black when the diamond is so inclined as to cause the transmitted light to be totally reflected on the crack. As to the type of mineral inclusions in diamond, one can expect to encounter any of the accessory minerals present in the original magma. There is strong evidence that some diamonds had crystallized out of the magma before eruption and occasionally even before the consolidation of the peridotite and pyroxenite rocks, because diamonds are sometimes found in these rocks. Furthermore, it has been ascertained that the majority of carbon, in some form or other and under conditions in which it could crystallize into diamond, remained in the magma long after the solidification of the peridotite and pyroxenite rocks. Therefore we may find mineral inclusions which are con-temporary in the first born diamond and pre-temporary in the younger diamonds. This may account for the fact that we encounter both well-developed, euhedral and on the other hand xenomorphous, worn or broken specimens of the same mineral species, e.g. zircon and garnet, within diamond.

Investigations have proved that many of the solid inclusions in

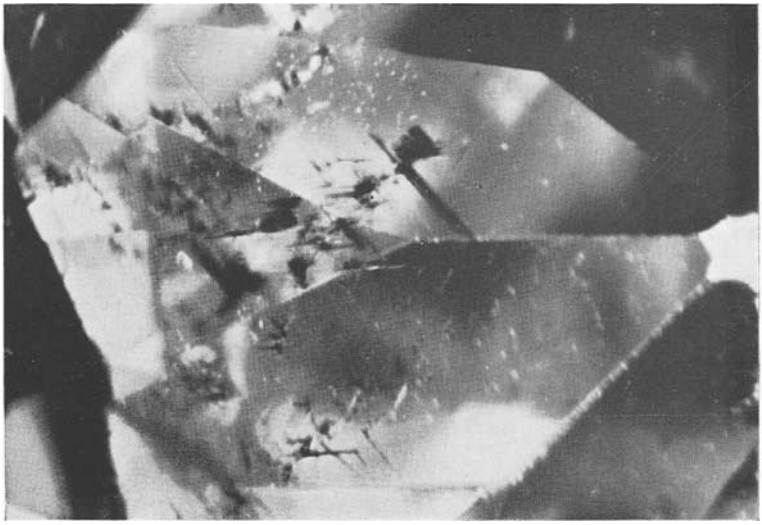

Masses of stalked crystals of graphite in a diamond from South Africa. 100 ×

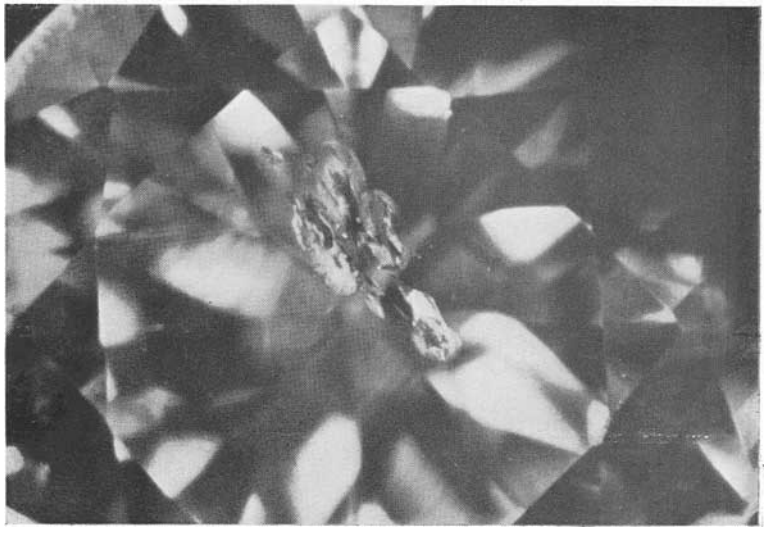

Crushed particles of the magma. They form irregular black crumbs which may be mistaken for "coal" inclusions. 75 ×

the diamond are those occurring as primary crystals in the magma from which the diamond crystallized ; these solid inclusions were probably present in the magma before its eruption and its eventual consolidation into the rock now called Kimberlite. It is therefore only reasonable to assume that among the pre-temporary solid inclusions occurring in diamond we may expect to find those minerals which crystallized out of the magma before eruption, and in addition to graphite there are garnet, magnetite, chlorite, enstatite, chrome-diopside and biotite inclusions ; olivine, phlogopite, and zircon also belong to this group. These pre-temporary inclusions may be recognized on account of their strongly xenomorphous, resorbed, worn or broken bodies. Sometimes they are covered with some black foreign substance which may be graphite, chlorite or crusts of the original magma.

That many inclusions crystallized out of the magma at the same time as the formation of the diamond took place is unequivocal, because it is not uncommon to find diamonds with inclusions of both garnet and chrome-diopside, while, on the other hand, garnet and chrome-diopside occasionally occur as host minerals of diamond. These as well as other con-temporary mineral inclusions such as magnetite, ilmenite, hematite, zircon, graphite and perhaps enstatite, usually display well-developed, euhedral crystal habits.

Apart from the minerals referred to above, the diamond itself forms a very important inclusion. There are numerous instances of a diamond crystallizing around another diamond, the inner diamond usually differing in crystal form, orientation and colour from the outer crystal. By far the most common habit is the rounded octahedron ; sharp-edged diamonds as inclusions are less frequent, but " macles " have been observed.

The enclosed embryonal diamonds portray all the same crystallographic characteristics, such as growth marks, rounded edges, a frosted surface and even inclusions, exactly as their fully-fledged " adults " and mothers. They may vary in colour, but are usually darker than the host diamond. The inner diamonds are sometimes coated or surrounded by some alien black material which may be magma or graphite. The growth of the embryo was not necessarily one continuous process ; in frequent cases the crystallization was interrupted and before it restarted the tiny diamond may have been chemically or mechanically attacked, thus frosting or slightly resorb-

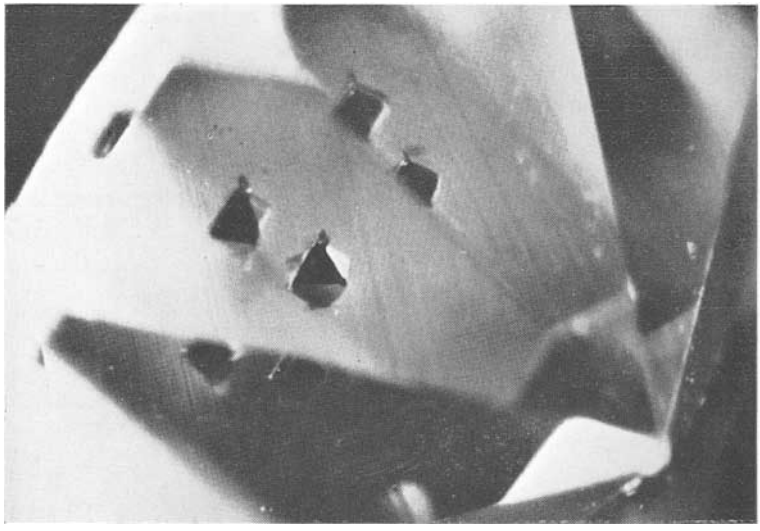

Beautiful, euhedral octahedron of magnetite (mirrored several times by the facets of the brilliant-cut host diamond) in a diamond. 75 ×

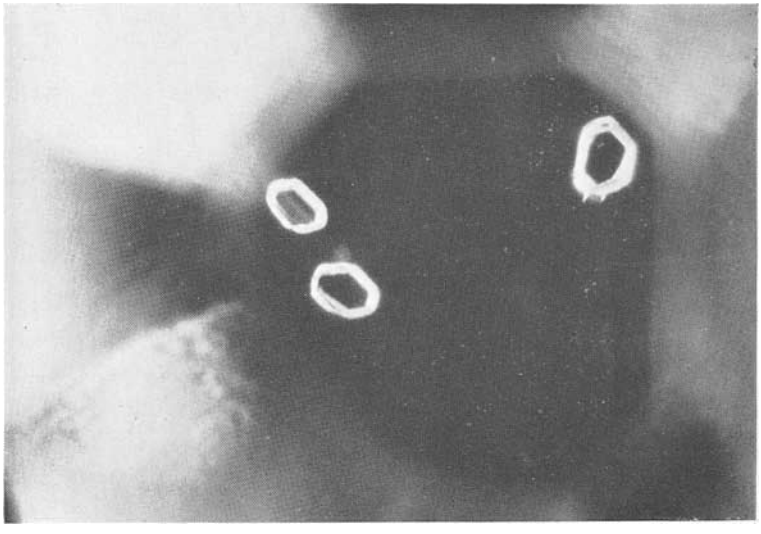

Group of euhedral quartz crystals in a diamond from Brazil. 75 ×

ing its body, or it may have been coated with some foreign matter. The formation of the second embracing diamond did not absolutely assume the same crystal habit nor orientate after the crystallographic directions of the primary diamond. The latter, therefore, rarely acted as a seed crystal with regard to the second diamond, but usually was just embedded like any other foreign mineral inclusion. The fact that the included diamond is generally of darker colour may imply that colour, particularly yellow to brown, denotes a greater age. It is a rare but thrilling occasion to meet with a diamond displaying " three generations," so aptly termed by Mr. B. W. Anderson and depicted in the colour plate. The first diamond to crystallize was a yellow specimen, which was shattered before it was enclosed by the second, hemi-octahedral crystal, a so-called " flat " of colourless transparency, both of which were later on re-embedded in a third diamond which grew unmolested to a size sufficiently big to be cut into a brilliant.

Zircon, an inclusion of some significance and of local diagnostic value, which is present in many gemstones, commands special attention as an inclusion in diamond. It may exist as a fresh euhedral crystal or a resorbed broken pebble ; these crystals or pebbles may be associated in groups or occur singly. Of course, the size of the enclosed specimens varies in accordance. Quite often these zircon crystals are found to lie in direct contact with a tension crack or to be embedded in the centre of several such cracks radiating from the zircon into the body of the embracing diamond. It is obvious that the zircon crystal is responsible for such internal strain and ensuing cracks ; usually these fissures are minute and confined to small areas, but in larger diamonds and with bigger inclusions they may be noticed with the naked eye.

Now, diamonds containing solid inclusions of foreign matter are liable to break easily, especially when the inclusion is a zircon, because the zircon has a remarkably higher coefficient of thermal expansion. When the diamond becomes hot on the cutting lap, the enclosed zircon reacts to the transmitted heat by expanding, thus creating strong internal strain which may result in the formation of fissures. Many a diamond cutter remembers the unlucky incident when a diamond exploded while being cut because it could no longer bear its internal tension. Investigations have proved that zircon

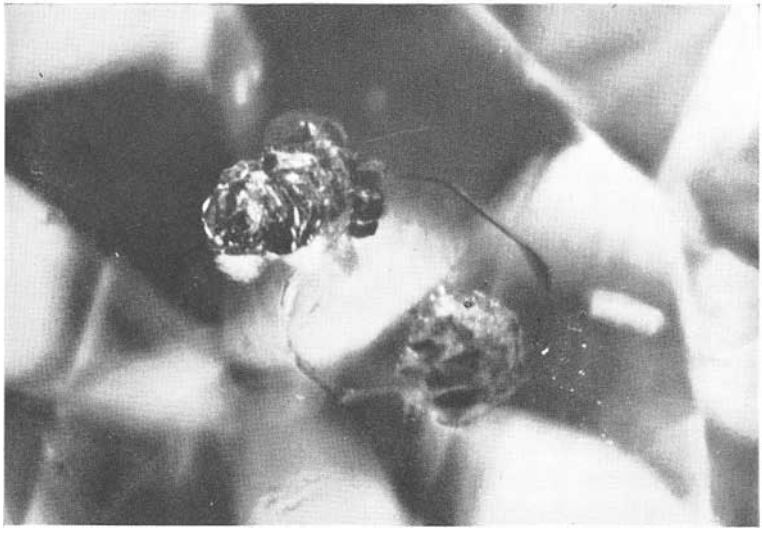

Two "iron-roses," one of which is particularly well-developed by forming a long cluster of minute hematite tablets. 75 ×

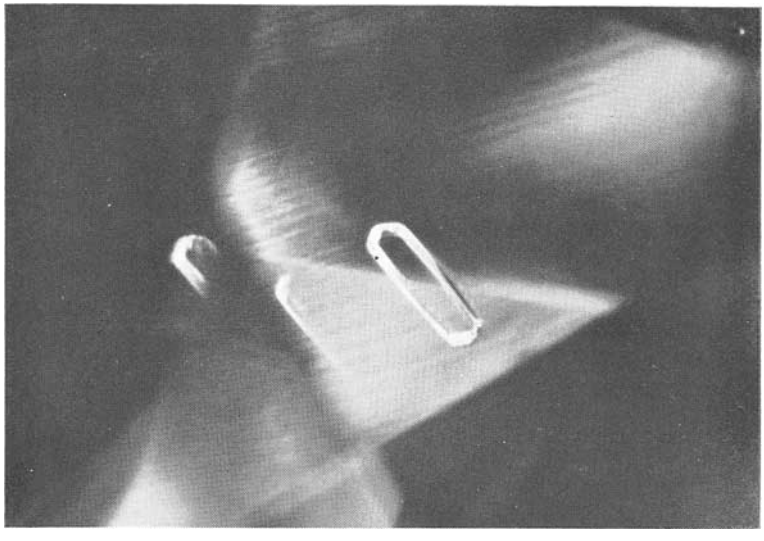

Well-developed, slender crystal of quartz included in a diamond from Brazil. 40 ×

inclusions mainly occur in African damonds, yet are absent in Brazilian diamonds.

The garnet found in the kimberlite and in the cognate inclusions—the peridotite and pyroxenite rocks—never shows any crystal faces. In all of these rocks the garnets are enclosed by kelyphitic shells.[1] These rounded garnets are often very badly cracked and in the process of recovery they are broken into sharp-edged irregular pieces. If, as is contended, the diamond crystallized out of the magma in exactly the same way as the garnet, then one would expect to find garnet inclusions in diamonds showing crystal faces and sharp edges. Indeed, careful microscopic research has proved that minute garnet and possibly zircon crystals do occur in diamonds as inclusions and that some of these crystals show smooth faces and sharp edges. Garnet inclusions afford a very characteristic feature of South African diamonds.

The black spots, which are of such frequent occurrence in diamond, must be ascribed to graphite or magnetite or hematite or some other ore.

G. Friedel[2] concluded that they consisted of carbonaceous material, since, when exposed on a cleavage surface, they instantly disappear when touched with a blowpipe flame. This was supported by later experiments of G. Friedel[3], who affirms that the material is graphite. The existence of graphite as an inclusion in diamond proves that conditions prevailed in the same magma which permitted the carbon to crystallize either as diamond or graphite. Whether the conditions were the same and whether the diamond and the graphite crystallized simultaneously is difficult to say. Graphite probably belongs to an earlier phase, for, although graphite exists in diamond, diamond is not known to form an inclusion in pure graphite. Moreover, graphite never displays idiomorphous crystals in the diamond. But then, we know of many a case where an enclosed older diamond was covered by a graphite coating.

J. R. Sutton[4], referring to a special case, mentions that it was the first time he discovered an inclusion that was highly magnetic ; thus the proof was given that magnetite is really a mineral which belongs to the internal paragenesis of the diamond. Magnetite very often gives evidence of Dr. Sutton's findings in that it usually has beautifully preserved its octahedral crystal form even as an inclu-

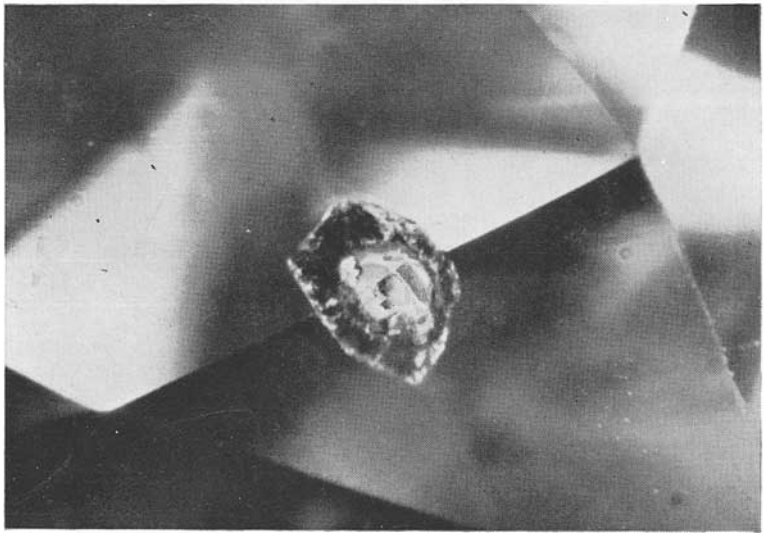

Included crystal of zircon surrounded by a large tension crack. Zircon having a higher coefficient of expansion may often cause the host diamond to crack when it is heated during the process of cutting. 80 ×

DIAMOND. This interesting picture shows a broken morsel of kimberlite with a diamond octahedron still embedded in its matrix trapped by the secondary diamond. 80 ×

sion in diamond. In all these cases magnetite may be regarded as a con-temporary inclusion.

Both hematite and ilmenite have also been proved to exist as inclusions in diamond. Of course, besides these minerals just mentioned, black inclusions in diamond may also be formed by the presence of chromite, picotite, ironcarbide or even metallic iron. Dr. Sutton remarks that the black inclusions in diamond are difficult to extract, and the material usually comes out in fragments.

Quartz has never been found as an inclusion in any of the African diamonds, but it has been found in diamonds from Brazil. It may be queried why quartz inclusions should be found in Brazilian diamonds in the face of the fact that the diamonds were formed in ultra-basic magma while the formation of quartz was confined to acid rocks. T. Draper[5] asserts that an ultra-basic magma is not essential to the formation and growth of diamonds and this would appear to substantiate the occurrence of quartz inclusions in diamonds from Brazil and explains why quartz inclusions are found in such stones.

Draper further asserts that in Brazil the formation of diamonds was not necessarily limited to ultra-basic rocks, and this reveals why quartz inclusions do not occur in diamonds from South Africa, where diamonds are only found in ultra-basic rocks.

Besides solid inclusions, it is possible for diamonds to contain gaseous and liquid types. The gaseous inclusions, which are more common than liquid, are usually microscopic bubbles. They usually occur as dense patches and frequently take shapes consistent with growth stages of the crystal. Information about the crystal form of the host crystal which has been lost in cutting can often be obtained by structures formed by dense clouds of gas bubbles settling on a temporary surface during the growth of the diamond.

It is interesting to note that Bauer and Spencer[6] state that: " The enclosures of diamond do not invariably consist of solid matter ; not infrequently there exist cavities in the substance of the diamond which may be vacuous or may contain liquid ; these fluid enclosures are, however, usually of microscopic size. The liquid they often contain does not, as a rule, completely fill the cavity, part of the space being occupied by a bubble of gas, which is sometimes fixed in position and at other times movable, thus clearly indicating the fluid nature of the contents of the cavity. In some

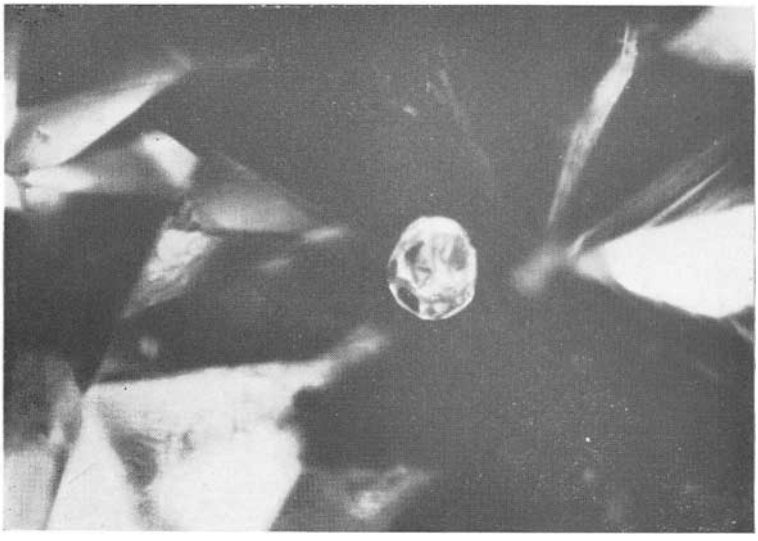

Garnet crystal, which although slightly rounded still displays euhedral crystal faces. It is enclosed in a diamond from South Africa and belongs to the contemporary phase of formation of inclusions. 75 ×

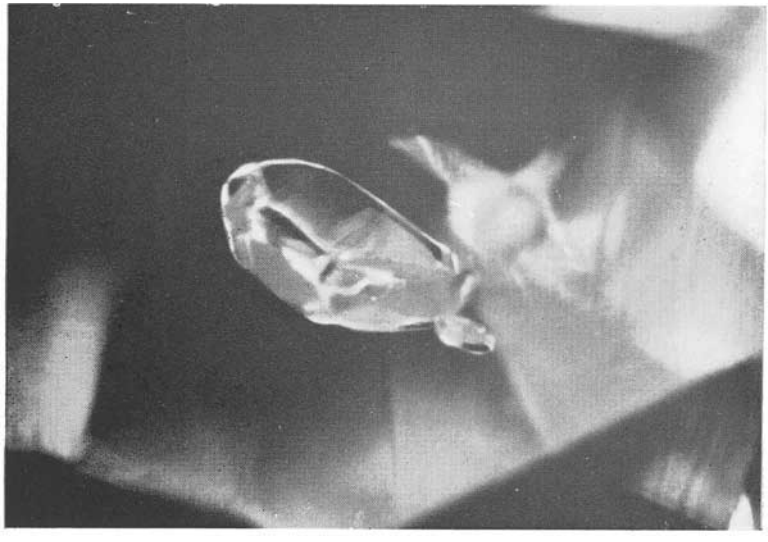

Well-developed idiomorphous zircon crystal embedded in a diamond from South Africa. 100 ×

cases it can be safely inferred from the behaviour of the liquid when the diamond is heated that it is liquid carbon dioxide. In other cases the properties of the liquid point to its being water or a saline solution."

Other cavities are quite empty, or only filled with gas ; like the fluid enclosures, these are by no means rare, and, when present at all, occur in large numbers. When observed under the microscope they appear quite black, especially at the visible margins ; this is owing to the fact that the rays of the light travelling through the stone are almost totally reflected at the surface of separation of the substance of the diamond and the bubble of gas ; they therefore fail to reach the eye and the cavity appears dark. This is a fruitful source of error, for such appearances are liable to be mistaken for solid enclosures of a black colour. Such mistakes may be avoided, however, by careful observation, for the outline of cavities is usually rounded, while that of a solid enclosure is irregular and angular ; moreover, most cavities allow the passage of some light, at least, in the centre ; they will therefore appear to have a bright centre surrounded by a dark border, which would not be the case with solid enclosures. The presence of these cavities is of practical significance, since to them is due the cloudiness of the diamond and those faults which are also known under the name of " Silk."

In most cases they cannot be detected through a pocket lens in ordinary light and they are particularly treacherous to the one who handles rough diamond as it is most difficult to observe them through the rough crystal faces. In concentrated light, however, they brighten up remarkably, causing some sort of " Tyndall effect."

In addition to solid, gaseous or liquid inclusions, diamonds are also found to enclose straight-running clefts, incipient cleavage cracks, and often irregular tension cracks. In the jewellery trade these inclusions are known as feathers, fractures, cracks or cleavage, depending upon their appearance.

All the inclusions described above, which are all very characteristic of diamond and therefore of great diagnostic value, might appear as black spots or patches if they were not examined with adequate light conditions. Much harm has been done to the diamond by ignorance and by wrong description and designation of the diamond inclusions and by exaggerating the fact that they affect

Octahedral crystal of a diamond enclosed in a secondary diamond. 75 ×

the beauty and value of diamonds. The purpose of this paper has been to show that " coal " does not occur as an inclusion, that even black spots in a diamond may be formed by rare or interesting minerals, and that many of the mineral inclusions in diamonds display some intriguing beauty of their own. It may be hoped that a more intense study and a better knowledge as well as more adequate description of diamond inclusions will contribute to the glory of this gem of gems.

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NEW and IMPROVED INSTRUMENT STANDS

by D. S. M. Field, A.G.A.

ALTHOUGH individual ideas of personal comfort vary far too much for anyone to give definite rules regarding ideal working conditions, no experienced research worker will deny that the position, height, and inclination of an optical instrument are all factors which must be considered if its use is to be a continual enjoyment.

The photographs on the opposite page illustrate how two of the gem testing instruments in common use by the gemmologist have been improved both in appearance and usefulness by the addition of specially constructed laboratory stands.

The spectroscope stand shown in Fig. 1 is a modification of the small but very useful inclined stand designed by R. Keith Mitchell, F.G.A., and distributed in limited quantities by the Gemmological Association. The newer version differs from the Mitchell pattern only in that height (for comfort) and weight (for stability) have been added. Constructed from a solid hardwood block, the stand illustrated is heavily lacquered and hand-rubbed to an instrument finish. The turntable is of chromium-plated brass with a $\frac{1}{4}$ in. x 4 in. wobble-free metal shaft. It is topped with black suede leather.

The refractometer stand (Fig. 2) is of original design, the main purpose of which is to bring the eye-piece of the Rayner instrument up to eye level when the worker is in a normal sitting position ; also to provide greater stability in laboratory use. This stand, too, is constructed of solid hardwood with a hard black lacquer finish. The sides and fitted accessories box are covered with black English morocco leather, which enhances the general appearance of the unit.

Both instruments may be removed or attached to the stands at will as they are required to be used on field trips or in the laboratory.

FIG. 1 (*on left*).

Stand for
Beck Prism Spectroscope.

Designed and executed by
D. S. M. Field, 1951.

(Based on the Mitchell
Spectroscope Stand.)

FIG. 2 (*on right*).

Stand for
Rayner Refractometer in
Laboratory use.

Designed and executed by
D. S. M. Field, 1951.

Natural or synthetic ?

by B. W. Anderson, B.Sc., F.G.A.

THE curious form which included-bubbles can take presents a fascinating study—and moreover a study of great practical importance to the gemmologist. With experience, it should be possible to recognize the characteristic shape and grouping of gas bubbles in synthetic corundum, synthetic spinel, natural and artificial glasses, as well as the flattened bubbles in the junction plane of a doublet.

Distortion into rod- or hose-like forms of bubbles in synthetic corundum is not very uncommon, but the specimen illustrated by the photomicrograph reproduced in Fig. 1 showed a patterning which was altogether exceptional—reminiscent of " feathers " in Siam ruby or in natural red spinel, and might well pass as a natural

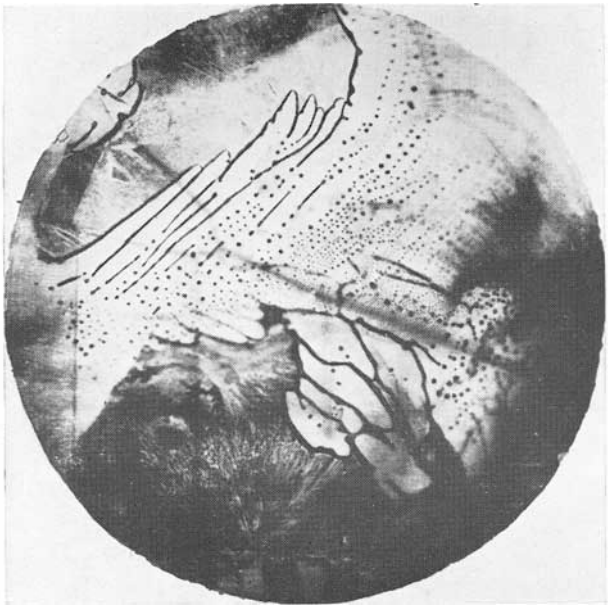

FIG. 1

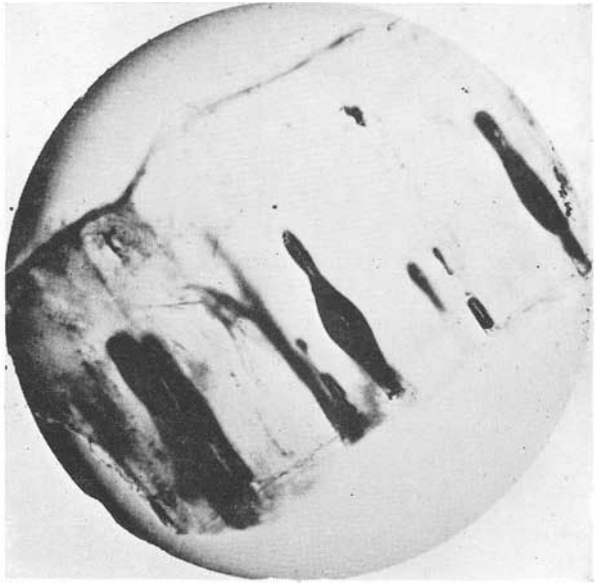

FIG. 2

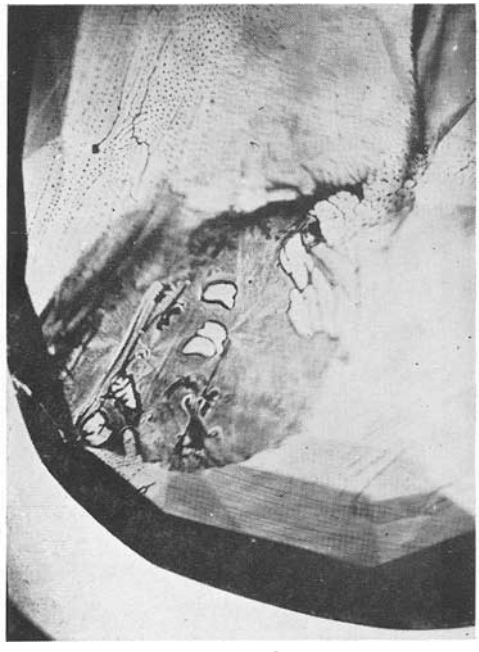

FIG. 3

stone if examined by a beginner. In other directions, the typical curved lines of a Verneuil ruby could be clearly seen: traces of these lines can be seen in the photomicrograph reproduced in Fig. 3.

On the other hand, bubble-like forms are sometimes met with in natural gemstones: notably in blue apatite from Burma and peridot from Hawaii. The elongated bubble-like cavities shown in Fig. 2 are an instance of this kind of deceptively artificial-looking structure in an undoubtedly natural and crystalline mineral. These particular cavities were observed in a yellowish, transparent plagioclase feldspar having the physical properties of labradorite, but with practically no schiller. The density of this small irregular piece was near 2.67, with refractive index 1.563, as determined by immersion. The cleavage angle was approximately 86°, as measured with an eyepiece goniometer.

It is hoped that these photographs will interest experienced gemmologists and serve as a warning to beginners not to interpret inclusions too quickly at their immediate face value.

A NEW GEMSTONE

In a paper read to the Mineralogical Society on Thursday, 24th January, 1952, by Dr. G. F. Claringbull and Dr. W. Hey, it was disclosed that many of the brown and yellow gemstones supposed for many years to be Olivine (peridot) have proved to be a new mineral. The mineral, called Sinhalite, has a composition $Mg.Al.Bo_4$ and refractive index readings for various stones have showed a range 1.667-1.712 (peridot 1.654-1.690) and densities observed have ranged from 3.475-3.496. For the gemmologist it would seem that the first clue to distinguishing peridot and sinhalite in one's collection would be provided by a density test.

The stones so far examined have come from Ceylon.

LARGE SYNTHETIC RUTILE

A magnificently cut synthetic rutile weighing over 29 carats has recently been acquired and placed on display by the British Museum (Natural History). The stone, which is the largest in the United Kingdom at the moment, was cut by Messrs. Charles Mathews (Lapidaries) Limited.

Gemmological Abstracts

CHAMBERS (R. O.). ***Australian gemstones*** Gems and Gemology, Vol. VII, No. 3, pp. 83-88. Fall, 1951.

A discussion of the major gemstones found in Australia, with special reference to opal. Sapphires from Anakie and Inverell are from alluvial deposits and probably originated as a rock-forming mineral in a basalt. The sapphires are found in blues, greens and yellow colours ; the yellows and greenish-yellows usually have a distinct golden tinge which is peculiar to Australian stones. Emeralds are found at Ammaville, New South Wales, and in the Western Australian goldfields. Some gem beryl has been found at Harts Range in Central Australia. The topaz found in New South Wales has a prevailing colour of a pale blue or green. Zircons, in yellows, browns and reds, are found in Anakie and New South Wales. Tourmaline is obtained from only one locality—the Kangaroo Island off the South Australian Coast. The tourmalines are found in red, blue and green colours. The opal fields of Queensland, New South Wales and South Australia are discussed. Diamonds were first discovered in New South Wales in 1851. The stones are small and generally " off-coloured " and are mostly used industrially. The superior hardness of Australian diamonds is discussed. Sixteen illustrations. R. W.

BATCHELOR (H. H.). ***Prospecting for opal matrix.*** Gemmologist, Vol. XX, No. 243, p. 205. October, 1951.

First-hand information on the types of opal found along the upper reaches of the Diamantina river of Queensland. Some opal matrix is so soft that it crumbles away in the hand ; some is as hard as jadeite. R. W.

ANON. ***New development increases range of effective heavy liquids.*** Gems and Gemology, Vol. VII, No. 3, p. 103. Fall, 1951.

Suspension of finely divided solids in methylene iodide are said to produce a density range from 3.32 to 7.5. The liquids are opaque and the solids settle on standing and require stirring before use.

R. W.

GOEBELER (H.). ***Von edlen Steinen.*** On precious stones. Published by the author, Beckum, Germany, 1951, 51 pp., index, bibliography.

The author calls his book an introduction to gemmology and a guide for the amateur. It does not pretend to be a mineralogical treatise.

About eight pages are devoted to general remarks on the formation of minerals, cutting, the history and simple methods of determination, mentioning especially specific gravity, hardness, refractive index, double refraction and pleochroism. Twenty-seven pages deal with the individual gem species, giving chemical composition and physical constants, and the concluding pages contain a few remarks and lists on the stones of the months, misleading names, doublets and synthetic stones. On the whole, although not much is said in the booklet, the stated facts are correct ; in a few instances wrong impressions could be made. Only a small percentage of diamonds can be used as counters for gamma-rays ; corundum belongs to the rhombohedral, not to the rhombic system. The booklet may make interesting reading for the amateur.

E. S.

SCHLOSSMACHER (K.). ***Der neue synthetische Smaragd.*** (The new synthetic emerald.) Gold und Silber, 1951, 4 (9), 10-11.

The new synthetic is the Chatham emerald. Thus the Igmerald, first marketed in 1935, is already relegated to history. In 1849 the first reconstructed emeralds were made by fusing powdered emerald and boric acid and the synthesis proper succeeded in 1888 (Hautefeuille and Perry). The method is called hydrothermal, because crystals are formed from solution at several hundred degrees C. and under a pressure of about 1,000 atmospheres (14,700 lbs. per sq. inch). To-day crystals of several centimetres diameter are made (1 centimetre—0.3937 inch) ; the colour

is a very attractive emerald green, although the expert may detect a slightly bluish tint. Not more than 1,000 cts. monthly are released from Chatham's factory and the price for the cut stone is 15 to 100 dollars per carat. The stones are cut in the U.S.A. and at Idar-Oberstein, Germany.

The distinction between genuine and synthetic emerald is comparatively simple. The refractive index and double refraction values are as follows:—

Origin	Mean ordinary ray	Mean extraordinary ray	Mean double refraction
Synthetic	1.564	1.561	0.0035
Colombia	1.576	1.571	0.0055
Russia	1.583	1.577	0.0065
South Africa	1.590	1.583	0.0070

Instead of determining the R.I. on the total refractometer, the author observes the Becke effect on his gem microscope, making use of benzoic-acid-benzyl-ester as immersion liquid. Its refractive index of 1.569 lies between those of the synthetic and genuine emeralds.

Specific gravity, too, is a means of differentiation, with the following values:—

Origin	Mean S.G.	Range
Synthetic	2.655	2.645-2.665
Colombian	2.70	
Russian	2.73	
South African	2.76	

The author recommends making use of Thoulet's solution, which is diluted with distilled water until the emerald to be tested is suspended ; the S.G. of the liquid is then determined with a Westphal balance.

Microscopic observation of the characteristic inclusions is another means of disclosing the pedigree. A further indication is luminescence in ultra-violet light, synthetic stones displaying an intense raspberry-red fluorescence. Most genuine stones do not fluoresce at all, but a few exceptions are fluorescent. A similar uncertainty remains after inspection through a suitable colour filter—genuine stones appear deep red to red, whereas synthetics are more orange red. This method requires experience, however, and, in addition, confirmation by one of the above-mentioned means.

E. S.

KENNEDY (N.W.). ***The genesis of gemstones.*** Part VII. The mechanism of mineral formation. Gemmologist, Vol. XX, No. 241, pp. 181-183. August, 1951.

The continuation of the series under this title. The formation of the glassy rocks and the granitic rocks is discussed. The formation of microlites and crystallites in both natural and artificial glasses. The peculiar conditions existing at the centre of the earth ; the probable happening when the internal fluid magma is ejected to the outer layers, or the surface of the earth, and the types of crystallization which may occur. R. W.

SWITZER (G. S.). ***"Rockhounds" uncover earth's mineral beauty.*** The National Geographic Magazine, Vol. C, No. 5, November, 1951.

An entertaining article on amateur rockhunting in the U.S.A. written by a mineralogist who is also well known in the world of gemmology. Diverse subjects mentioned, such as the Paracutin volcano ; how minerals are formed ; equipment required for rockhunting—perhaps better known to us as mineral hunting ; minerals from outer space ; famous collectors and collections ; and some mention of lapidary work. Fluorescence of minerals under ultra-violet light and the preparation of " micromounts," small well crystallized specimens mounted in a small box for examination under a low-power microscope with the aid of top lighting. Illustrated by six pictures in monochrome and 16 pages in colour. R. W.

Division of Mines, Department of Natural Resources, State of California. Three special reports: 10A, Nephrite jade and associated rocks of the Cape San Martin region, Monterey Co., California. 10B, Nephrite in Marin Co., California. 10C, Jadeite of San Benito Co., California.

These three reports (separately bound) give a very full account of the history and geology of the jade minerals found to date in the State of California. Much of the nephrite is in association with serpentine. The jadeite is found in and around Clear Creek, San Benito Co., California, San Luis Osbispo Co. and Sonoma Co., California. R. W.

DRAPER (T.). ***The diamond mines of Diamantina—past and present.*** Gems and Gemology, Vol. VII, No. 2, pp. 49-57. Summer, 1951.

The first part of a series on the diamond mines of the Diamantina area. The history of the diamond mining since the beginning —some two hundred and twenty years ago—is given. Most of the historical survey is taken from Mawe's " Travel in the interior of Brazil." Eleven monotones and one map. R. W.

—— IBID. Part 2. Gems and Gemology, Vol. VII, No. 3, pp. 89-98. Fall, 1951.

Continuation of the historical survey. Discussion of the high-level massa mines and their geology. The story of the companies who have operated in the fields—their successes and failures. Eleven illustrations and one map. R. W.

KRAUS (E. H.). ***Nomenclature of gems.*** Gems and Gemology, Vol. VII, No. 2, pp. 58-67. Summer, 1951.

A standardized list of acceptable gem names arranged for use by the American Gem Society. The list is divided into four groups, viz., Important gemstones ; Organic gem materials ; Other gem materials ; and Synthetic gem materials, which are then tabled under three headings: Species ; Description ; and Correct Names. The list does not materially differ from the European versions. Under Feldspar Group (labradorite variety) is appended " Transparent or opaque black—Andradite garnet or andradite " ; this is an obvious typesetting error and should be on page 60. Some of the colours given for nephrite are certainly not well known for that mineral. It would have been better to have mentioned that clam pearls are not nacreous. The use of the term " Topaz quartz " for citrine is recommended. Synthetic almandine spinel and synthetic amethystine sapphire and spinel, which are recommended for the mauve or purple colours of synthetic spinels and corundums, are not in keeping with the rest of the nomenclature ; of the synthetic stones, " reddish purple synthetic spinel " for the " synthetic almandine spinel," and likewise " purple " or " mauve " for amethystine, would be better prefixes. R. W.

SCHLOSSMACHER (K.). ***Neue Wege in der Edelsteinuntersuchung.*** New methods in gem examination. Gold und Silber, 1951, 4 (10), 28-29.

Before the first world war only the dichroscope and the measuring of hardness were known to most jewellers. This article deals with the uses of the total reflectometer and the spectroscope. Both these instruments are explained in detail. E. S.

WEINSTEIN (M.). ***Scarabs.*** Gemmologist, Vol. XX, No. 241, pp. 169-170. August, 1951.

A general article on the history and nature of the carved representations of the sacred beetle of Egypt. The materials used for the ancient scarabs were steatite, faience, glass, wood, ivory, amber and metal. During the later periods amethyst, rock crystal, obsidian, lapis lazuli and amazonite were employed. About 1400 B.C. carnelian, sard, jasper and hematite were the minerals employed. A note is given on the Greek scarabs and on the imitations. R. W.

JAHNS (R. H.) and WRIGHT (L. A.). Gem and lithium bearing pegmatites of the Pala District, San Diego County, California. Special Report, 7A Division of Mines, Department of Natural Resources, State of California. June, 1951. San Francisco, U.S.A., 72 pages.

A very complete survey of the geology of the gem-bearing pegmatites of the Pala District. The history of the discovery of tourmaline, beryl and spodumene which are found in the district and accounts of the occurrences, localities and varieties of these species is given. Pale rose and peach-coloured morganite is reported, with pale blue, green, yellow-green, deep blue and golden yellow beryls. Some occurrences produce beryls with greenish cores and pinkish rims. Green, yellow and colourless gem varieties of spodumene are found besides the lilac-pink kunzite variety. All colours of tourmalines, except brown, which is rarely found in the pegmatites. Many variations of parti-coloration are said to occur. The paper-covered book is well illustrated by monochromes and by eight coloured plates of cut stones and crystals. Many references are given and the book is furnished with an index. There are three maps in pocket attached to back cover. R. W.

NEW SPINEL DOUBLET

by Robert Webster, F.G.A.

AN opportunity to examine the new synthetic spinel doublets of emerald colour now on the market, first reported in American gemmological literature,[1] allows a fuller description of these " emeralds " to be now given.

The stones examined were of the usual emerald-cut and were of good colour and weighed just over 4 carats each. They were of French origin and are exported from that country under the name *soudé sur spinelle.*

In all cases the crown and the pavilion of the stone gave a refractive index reading of 1.728 indicating the material to be synthetic spinel. The stones show a green residual colour through the Chelsea colour filter and no distinctive absorption spectrum could be seen.

That the stones were composite was evident when they were immersed in liquid, for then the top and bottom halves of the stone were seen to be colourless and the junction to consist of a thin layer of coloured material estimated to be about .4 mm. in thickness. Probably due to the smaller critical angle of spinel compared with that of quartz, the colourless portions of these new stones are not so evident as in the case of the quartz soudé emeralds.

The stones examined were fairly clean and did not show " flaws " or " feathers " like so many of the quartz soudées, although the American report mentions that some stones examined by them showed " flaws " or cracks in the crown which they suggest was caused by heat treatment. Included bubbles were observed, sometimes in one plane, which indicates that they lie in the coloured layer, and between crossed nicols the characteristic " tabby " extinction of synthetic spinel was observed.

Under the long-wave (3650 Å) ultra-violet lamp there did not seem to be any particular effect, but under the short-wave (2635 Å) ultra-violet rays the coloured layer showed up fairly strongly as a

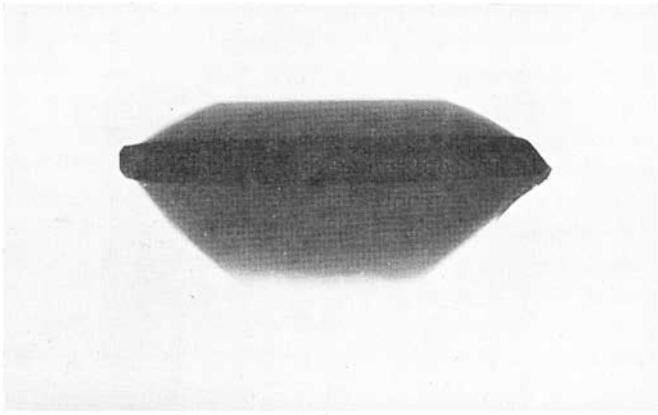

Radiograph of a synthetic spinel soudé emerald showing the lack of penetration by X-rays of the central coloured layer. (Owing to the stone not being set in perfect alignment with the X-ray beam the opaque layer appears to be much thicker than it actually is.) Operating characteristics: Exposure 50 seconds, target to film distance 8 inches, Machlett tube with Mo, target and Be windows tube running at 48 pkV and 18 mA.

dark non-fluorescing line against the pale misty fluorescence of the spinel crown and pavilion. This observation agrees in principle with those of Liddicoat,[2] who remarked that the quartz " triplets " (soudées) showed no fluorescence effect as the quartz does not fluoresce and there would be nothing to throw into relief the non-fluorescent coloured layer. When irradiated with X-rays the typical green fluorescence of the colourless synthetic spinel[3] was seen, but the dark line of the coloured layer was not observed. This may well be due to the difficulty of completely seeing the rim of the stone through the observation window of the X-ray apparatus. In comparison the quartz soudées are quite inert under X-rays.

Anderson[4] reports that the usual quartz soudé emeralds have a remarkably high density, near to 2.8, and that author ascribes this to the use of a heavy lead-glass, coloured green, for the central layer which " colours " the stone emerald green. The knowledge of this high density of the quartz emerald doublets prompted an early determination of the density of these new synthetic spinel

soudé emeralds. The result showed an enhancement of density above that for synthetic spinel—the values for the four stones determined were found to lie between 3.66 and 3.69, as against 3.63 for synthetic spinel. The increase in density for the quartz soudées is approximately 0.15 and for the spinel soudées 0.045 ; these figures seem to imply that a similar coloured layer is in the new synthetic spinel composite stones as is used for the quartz soudé emeralds, and that it might well be a slice of coloured lead glass. To obtain further information an X-ray direct picture was taken to see whether the central layer was to any extent opaque to the rays. As the radiograph (reproduced) shows, the central layer is very opaque to X-rays and must thus contain heavy atoms. This result tends to confirm the likelihood of the layer being lead glass, but the thinness of the layer must to some extent make this doubtful.

The nature of the actual composition of the layer must remain, at present, unproved. It is interesting to note, however, that some fragments of the substance removed from the edge at the join in a quartz soudé indicated that the substance could scarcely be glass. A spectogram kindly taken by Mr. Anderson clearly showed that copper was present in the material of the layer. Further investigation will be needed in order to elucidate the mystery of the increased density and the nature of the colouring matter, but it is tentatively suggested that an organo-metallic dye in a plastic base may be the answer.

In conclusion, it is pertinent to mention that these composite stones are also being made in small " calibré " sizes.

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3. Luminescence and photocoloration of synthetic white corundum and spinel. Webster (R.). " Gemmologist," pp. 113-115, Vol. XIX, No. 227, June, 1950. London.
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Some speculations on

AN UNUSUAL ZIRCON

by R. K. Mitchell, F.G.A.

BY the courtesy of a very good friend in Ceylon I recently acquired a rectangular-cut zircon of somewhat unusual appearance. Although not of good gem quality and certainly far from clean, the stone is parti-coloured, one portion being a pale but typical zircon green, while the other part is an equally characteristic orange or golden colour. There is a clear-cut division between the two sections, and although it was thought at first that this might be a twin plane, it proved not to be so.

Parti-coloured gems are not uncommon among tourmalines, corundums and some other mineral species, but if zircon occurs commonly in this form it is not often cut. The full interest of this particular gem was not realized until Mr. C. J. Payne, using a diamond refractometer, checked its refractive indices. It was then found that the differently coloured sections of the stone were each differently refracting, the green portion giving values of 1.853 and 1.863, and the orange part higher readings at 1.866 and 1.876. This at once puts one portion in a lower zircon category than the other, although both can be broadly included in the intermediate group.

A check of the absorption spectra showed that the two parts were again different, the green section having a sharper and better developed spectrum than that for the orange part. Both are rather fuzzy and very far from the well-defined spectra of normal zircons. The stronger definition of the green section of this stone argues that that part may be richer in the radioactive material responsible for the phenomenon.

These facts about two parts of the same stone may not appear significant until we consider the generally accepted theory that the descent from normal or high zircon through the intermediate type to low zircon is due to the inconceivably slow disintegration of the crystal lattice by the radioactive emanations from uranium atoms occurring as impurities in the mineral.

Low zircon has so far been found only in Ceylon and it has been suggested that this is primarily due to the fact that the strata from which the mineral has weathered are immensely older than other

known sources of the gem. Geologically, the rocks are very much pre-cambrian and probably among the world's oldest formations.

Now, what are we to conclude from this? That the Ceylon zircons which have not reached the low condition are much younger than those which have, or that the green zircon, by reason of some impurity which at the same time influences its colour, has proceeded further in disintegration than crystals of different colours? Or is it possible that the disintegration in the low type stones has been occasioned by radioactive emanations from a source outside the crystal? This seems unlikely and is in the nature of a personal speculation.

Examining these three possibilities in the light of the present example, we apparently have these conditions. Either the initial portion, that which is now green, has acted as a " seed " crystal around which a later deposit of material, now orange, has formed, or the two parts are of the same age but contain different amounts of radioactive material, causing the green to disintegrate more rapidly than the orange. Or one part of the crystal has been subjected to stronger radioactive emanations than the other.

The evidence of the spectra seems to point to the second of these conditions being, in fact, correct. But against this we may pose the problems of the normal zircon from Burma. These have exceptionally well-developed, sharp spectra of more than 20 lines, arguing a comparatively high percentage of radioactive substance in the crystal lattice, and yet the Burma zircon shows not the slightest sign of disintegration.

Reasoning from this, we come back once more to the fact that the degree of disintegration must be proportional to two things, firstly the age of the crystal and secondly the amount of radioactive substance present. Other and unknown influences may also have some bearing on the matter. One thing is certain. Whatever the influences causing the phenomenon, this specimen establishes that they can produce it to different degrees in one crystal.

Finally, it is interesting to reflect that another branch of radiology has recently come into being in which measurement of the infinitely small residual radioactivity of rocks is used to date them in terms of tens of millions of years. I wonder what the exponents of this new science would make of this present specimen?

The crystalline STRUCTURE OF QUARTZ *and its polymers*

by Sir James Walton

QUARTZ is the commonest of all minerals, but in its diversity of form and structure presents more interest and fascination to the physicist and mineralogist than perhaps any other mineral. Many of its crystals are of remarkable beauty and, being very durable, are attractive to the jeweller. Being inexpensive and occurring in almost innumerable varieties, it forms by itself an object of profound interest to the collector ; indeed, there are many collectors who specialize in this subject alone.

The chemical formula is simple, being silicon dioxide (SiO_2) or silica. Although containing no hydrogen and showing none of the characters usually assigned to acids, it is regarded as an acid owing to its power of combining with many metals to form silicates, and all igneous rocks containing an excess of silica, such as granites, quartz porphyries, rhyolites, obsidian and pumice, are known as acid rocks. It occurs to a lesser degree in quartz diorite, tracheite and andesite.

Atomic Structure

The nucleus of silicon contains 14 protons, and since the atomic weight is 28 there are also 14 neutrons. Around the nucleus are the 14 electrons, and, as usual, the inner two shells are complete with 2 and 8 electrons. In the outer shell, therefore, there are only 4 electrons (Fig. 1), which is four short of the stable gas argon. In the oxygen atom there are 8 protons and 8 neutrons in the nucleus and the electronic formula is 2 in the inner shell and 6 in the outer (Fig. 1), which is two short of the stable gas neon. To obtain the stable argon structure the silicon atom combines with four oxygen atoms by homopolar or covalent bonds, each oxygen atom sharing an electron with the silicon atom. The silicon atom thus obtains, in all, the necessary 8 electrons, but each oxygen is left with only 7.

The deficiency is made good by each oxygen combining with a second silicon atom (Fig. 2). Each oxygen atom is thus linked up to two silicon atoms resulting in the formula SiO_2.

Silicon is only known to form either four or six bonds arranged either tetrahedrally or octahedrally (Wells). The latter is rare and in silica and nearly all silicates the arrangement is tetahedral, the silicon atom being surrounded by the four oxygen atoms by bonds which are equal in strength and the angles between each pair of bonds of equal degree (Fig. 3). The size of the two atoms is, however, very different, that of the oxygen atom being 2.7 Å and that of the silicon only .6 Å. That is, the oxygen atom is $4\frac{1}{2}$ times the size of the silicon. If a model be made of spheres of these proportionate diameters, it will be seen that the silicon atom fits snugly into the space between the four oxygen atoms (Fig. 4).

Crystal Packing

One of the most interesting facts about silica is that it exists in three disinct crystalline forms, namely quartz, tridymite and cristobalite, which are stable at very different temperatures, thus:—

$\longrightarrow$ 870° $\longleftrightarrow$ 1470° $\longleftrightarrow$ 1710° C. (Melting point)

Quartz Tridymite Cristobalite

As Wells points out, when once the material is molten recrystallization of the liquid is difficult, the mass usually solidifying as a glass with an extremely small coefficient of expansion and a high softening point, which make it very useful in the formation of crucibles and cooking utensils.

The different forms are not easily converted from one to the other and thus all three are found in nature ; but it is interesting to note that both tridymite and cristobalite usually occur in volcanic rocks, and also that in some of the methods of the artificial production of quartz, quartz crystals separate out below a temperature of 700° C., while at higher temperatures cristobalite is formed. All three varieties also exist as α and β forms which are respectively high and low temperature modifications.

Each variety is made up of the characteristic tetrahedra so linked that each oxygen atom is united to two silicon atoms and thus they all have the formula SiO_2, but the tetrahedra themselves are linked together quite differently in the three forms. The α and β forms

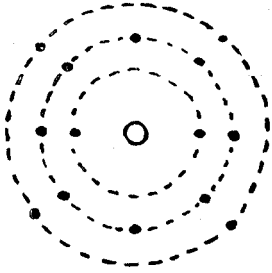

Scheme of silicon atom.

FIG. 1

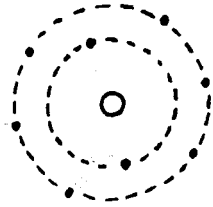

Scheme of oxygen atom

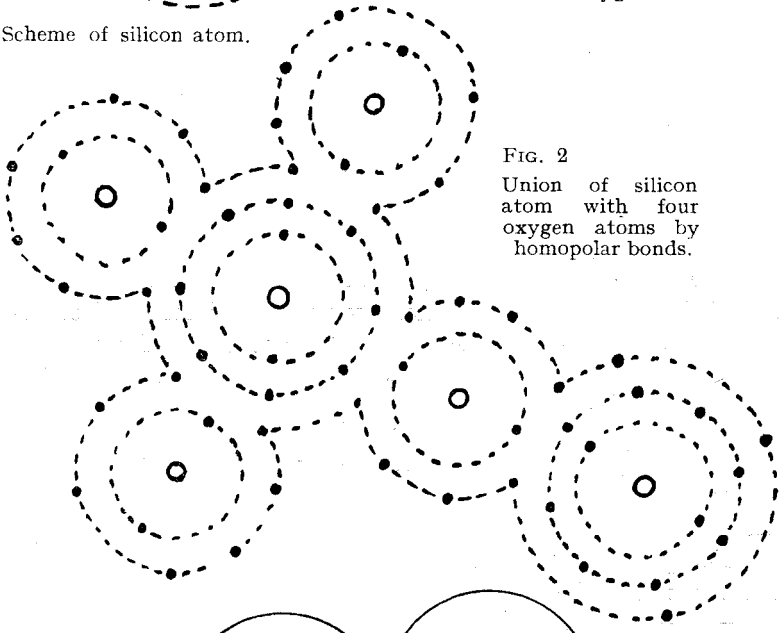

FIG. 2

Union of silicon atom with four oxygen atoms by homopolar bonds.

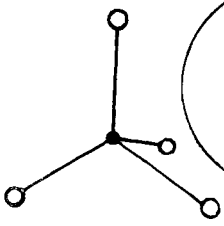

FIG. 3

Tetrahedral arrangement of four oxygen atoms around one silicon atom.

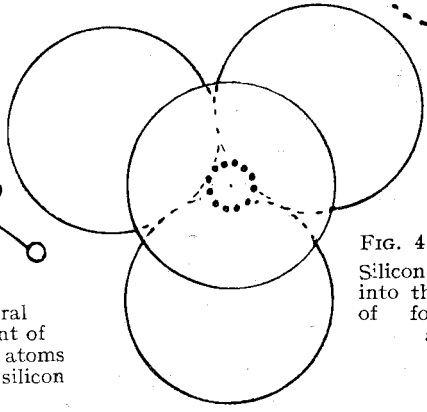

FIG. 4

Silicon atom fitting into the interstices of four oxygen atoms.

differ only in detail with the tetrahedra showing only a slight rotation relative to one another, and hence conversion from one form to another is relatively easy and is reversible. The piezo electric characters are altered with such a change but, as will be shown later, the nature of the optical activities of the and β forms remains constant.

β *Quartz*. This is a much rarer form than α quartz, but it is convenient to consider it first as it has a higher degree of symmetry. It occurs in nature in graphic granite, in granite pegmatites and in porphyries. Crystals belong to the hexagonal division of the hexagonal system and are of the Trapezo-hedral or hexagonal holoaxial type. That is to say, they have one axis of hexagonal symmetry corresponding to the C axis and six axes of digonal symmetry coresponding to the three horizonal crystal axes and lines midway between them ; thus it more closely approaches the beryl class, but it has no centre or planes of symmetry. With this symmetry the oxygen atoms are arranged in hexagonal close packing.

The unit cell is a parallelipiped, three of which are united to give the hexagonal form (Fig. 5). Each horizontal side of the unit cell is 4.88 Å long and the vertical sides 5.37 Å (Sir William Bragg). Each unit cell contains three molecules which lie in three equidistant layers and are arranged in a spiral about a vertical axis so that the crystal has trigonal symmetry (Fig. 6). It is this spiral arrangement which gives the crystals the power of rotating polarized light, for if the grouping of atoms is such, that it cannot be superimposed on its mirror image it is said to be enantiomorphous and rotates polarized light. It is clear that with the spiral arrangement of the silicon atoms this condition will hold. It is also clear that the spiral may be right or left handed when it will rotate the light to the right or left.

The tetrahedral arrangement of the oxygen atoms around the silicon atoms is maintained, the silicon atoms lying in the three equidistant planes and the oxygen midway between these planes. Each oxygen atom has as its neighbours two silicon atoms, but the three do not lie in the same straight line, the lines joining the oxygen atom to the two silicon atoms making with each other an angle of 155° (Fig. 12) (Sir William Bragg).

If the position of the silicon atoms be projected on to the basal plane the resulting figure will show symmetrical hexagons and pairs

of small triangles symmetrically arranged one to the other and the hexagonal symmetry is thereby apparent (Fig. 7).

If α quartz be heated to 573° C. it will be converted into β quartz, the crystal angles altering and the change being associated with a sudden marked lowering of the refractive indices and the birefringence.

α *Quartz*. This is much the more common variety and is the form used in industry and in the fashioning of gems. When the term quartz is used with no distinguishing prefix it refers to this variety. It is extremely widespread in nature, forming about 12% of the constituents of the rocks of the earth's crust. Together with the silicates, silica forms about 28% of the lithosphere.

It has a lower degree of symmetry than β quartz. It belongs to the trigonal division of the hexagonal system and in this division to the trapezohedral or trigonal holo-axial class. Crystals therefore have a vertical axis of only trigonal instead of hexagonal symmetry, corresponding to the C axis, and only three axes of digonal symmetry corresponding to the three horizontal crystal axes. There is no centre and there are no planes of symmetry. The arrangement of the tetrahedra shows only a slight change of rotation from those of β quartz. This is well shown in the figure given by Sir William Bragg (Fig. 8), which depicts the projection of the position of the silicon atoms on the basal plane. It will be seen on comparison with

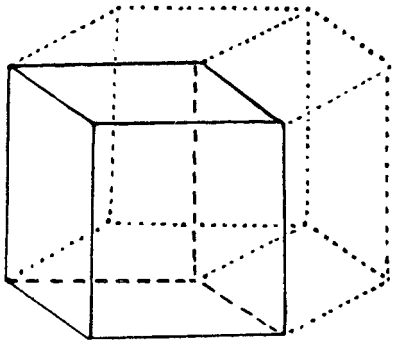

FIG. 5
The unit parallelified cell of quartz united to two others to give the hexagonal form.

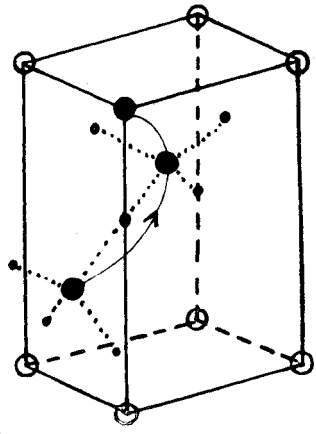

FIG. 6.
The unit cell of quartz. The three silicon atoms forming the spiral are shaded ● The other silicon atoms unshaded form the tetrahedra of adjacent cells. The tetrahedral arrangement of the oxygen atoms around two of the spirally arranged silicon atoms is shown ●

the same figure for β quartz (Fig. 7) that the alternate angles A.A.A. may be regarded as having been pulled out while the intermediate angles have been pushed in. This causes a rotation of the small triangles so that they are not symmetrically placed as regards the atom at their apices. The six-sided spaces are no longer regular hexagons, but show alternate sharp and blunt angles like the base of a scalenohedron of the calcite class. Each set of three of these figures runs across an axis with their three sharp angles directed towards the Angles A.A.A. which have been pulled out. Thus the ends of each axis are different and the crystal would therefore be expected to show piezo electricity. This is exactly what happens, for it is well known that if two opposite prism edges of an α quartz crystal be compressed an electric field is developed along that line, one end of the axis showing positive and the other negative electricity.

When a quartz is heated the small triangles swing round and become symmetrical and the six-sided figures become regular hexagons. There is no lack of symmetry and the piezo-electricity disappears. It may happen that when β quartz is converted back again into a quartz some of the small triangles may swing one way and some the other, for, as Sir William Bragg says, it must be largely a matter of chance which way the triangles turn and it may be that some remains of previous crystallization or some small intrusion may determine which way they turn. If it should so happen that they are turned in different directions this would readily account for the piezo-electric twinning which so commonly occurs.

Since in this change from β to α quartz the spiral arrangement of the silicon atoms is unaffected, the optical characters will not change, the crystal remaining dextro or laevo rotatory as before.

If it be considered that the change is due to pulling out of the alternate angles and the pushing in of the intermediate angles, then a model can be made to show this effect. The silicon atoms are represented by small beads mounted by pivots on small strips of brass accurately drilled at equal distances which represent the bonds. The beads at each angle of the regular hexagon are fixed to jointed levers lying behind the base and connected at their central ends eccentrically with a circular metal disc which can be partly rotated by a lever. When the lever is at its mid point the perfect hexagonal symmetry of Fig. 7 is presented. When pulled down to its full extent the position of the atoms is changed and the resulting figure

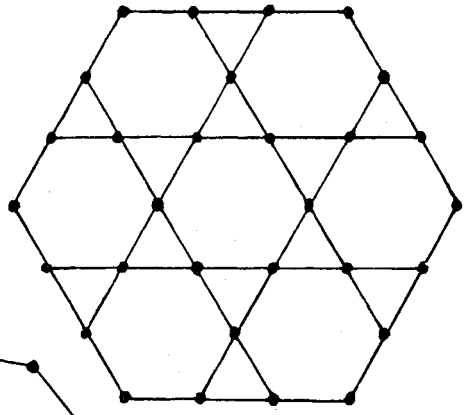

FIG. 7
Projection of the position of the silicon atoms in β quartz on to the basal plane showing the hexagonal symmetry.

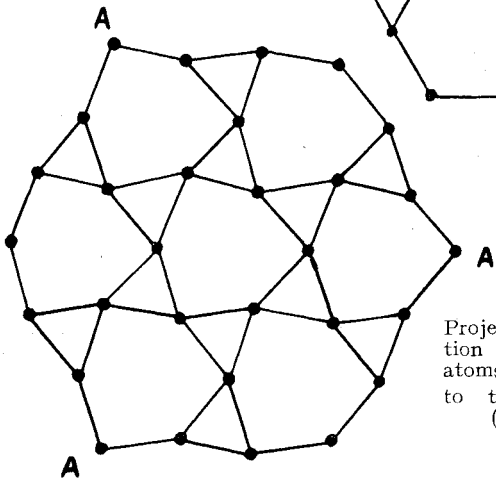

FIG. 8
Projection of the position of the silicon atoms in α quartz on to the basal plane (after Bragg).

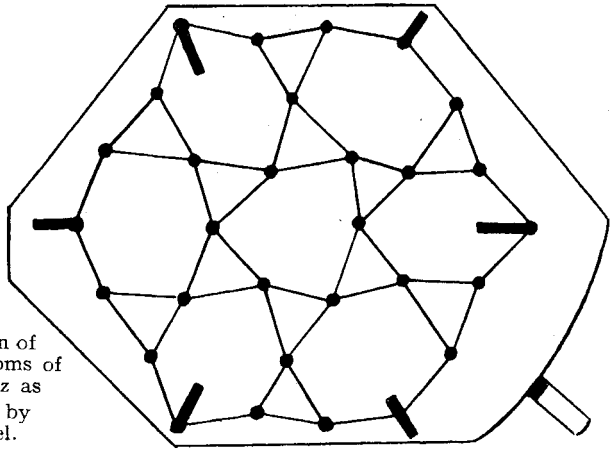

FIG. 9
Position of silicon atoms of α quartz as shown by model.

has an external form which is an exact replica of Sir William Bragg's figure (Fig. 8), but the arrangement of the internal atoms is somewhat different (Fig. 9). The small triangles are rotated in the opposite direction and the larger spaces, instead of all resembling the base of a scalenohedron, are made up of two different figures, of which there are three of each. One is somewhat diamond-shaped and the other somewhat barrel-shaped. The central space alone resembles the base of a scalenohedron. Of the two forms of figure, one of each is placed at the opposite ends of an axis, the acute angle of a diamond-shaped figure forming the pulled out angle. If the lever is pushed up to its full extent the exact opposite figure is obtained, the extended angles become retracted and vice versa ; at the same time, the diamond-shaped figures become barrel-shaped. In fact, the figure represents a piezo-electric twin. The figure having the two kinds of spaces arranged alternately gives a representation of the ditrigonal symmetry of quartz and the different kind of space at each end of an axis represents the piezo-electric character of the crystal. Yet it does not agree with the results of X-ray crystallography, although the bonds, being made of rigid inelastic brass, must show accurately the mechanical effects of expansion and compression of the alternate angles. Dr. Claringbull has given an ingenious explanation of this discrepancy which would seem to be the most likely. He suggests that the model represents the effect of forces on only a small group of atoms, while in the crystal there are many other atoms around, which may give, as it were, extra thrusts and pulls resulting in a change of pattern.

In addition to the piezo-electric twins described above, there is another variety, the structure of which is made very clear by Sir William Bragg's figures. It occurs in both α and β quartz. If a model (Fig. 10a) of a right-handed quartz crystal be cut in a slanting plane the two parts will show the arrangement of the internal atoms as in Fig. 10b, while in a left-hand crystal they will be as in Fig. 10c. It is evident that b and c cannot be fitted together if the axes are in the same straight line, but they can be if fitted as in Fig. 10d, when the angle between the two parts is 84° 33′. This will give a twin, one part of which is dextro and the other laevo rotatory. The fit is not absolutely perfect and a certain amount of strain occurs at the junction. If it were not so there would be, as Sir William Bragg states, no reason why a crystal should ever grow regularly.

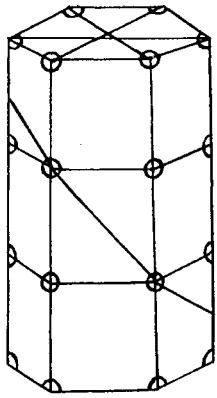

FIG. 10 (after Bragg).

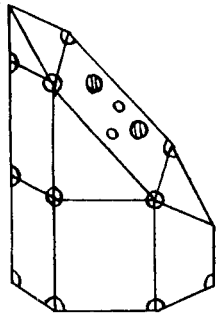

A.

B.

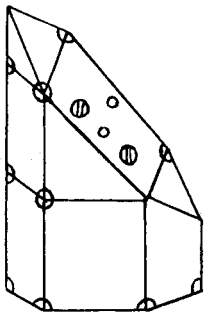

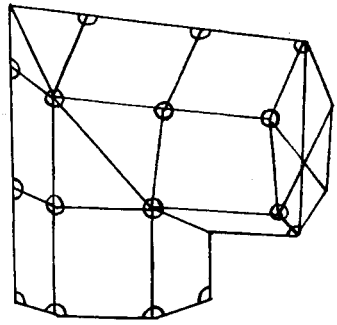

C.

D

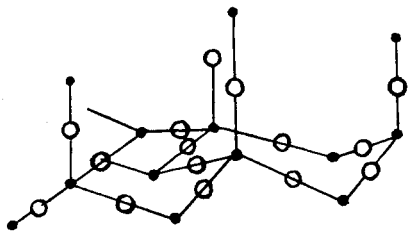

A (after Gibbs).

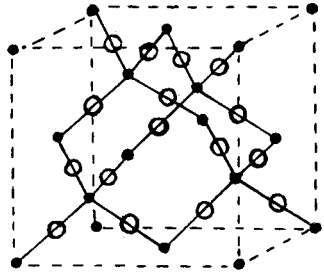

B. (after Wyckoff)

FIG. 11

The structure of β tridymite (a) and β cristobalite (b) Si = ● O = o.

Twinning about a pair of prism faces with interpenetration, which is extremely common, is also associated with a difference in the individuals of their optical activities.

Tridymite. This is a comparatively rare form which, like quartz, exists as α and β varieties, the α variety being orthorhombic and the β hexagonal. It occurs chiefly in acidic volcanic rocks such as rhyolite, trachyte, and andesite, and less often in dolerite ; the crystals are usually minute, thin and tubular, being parallel to the basal pinacoid (0001). It often occurs as twins and the crystals may be united to form fan-shaped groups. Its properties differ considerably from quartz, the specific gravity being only 2.28-2.33 and its refractive indices 1.469 and 1.473 (Dana and Ford). Parting may be present parallel to the c axis and prismatic cleavage may occur.

Cristobalite. This is also relatively rare but exists in both α and β varieties, the former being probably tetragonal and the latter cubic. Hence β cristobalite has the same relation to β tridymite that zinc blende has to wurtzite, one showing cubic and the other hexagonal close packing. The crystals occur as white octahedra. It occurs with tridymite in andesite, in lava and also in meteorites. Its specific gravity is 2.27 and its refractive index 1.480 (Dana and Ford).

The crystalline structures of tridymite and cristobalite differ considerably from quartz. In tridymite the oxygen atoms lie midway between two silicon atoms, and although the tetrahedra are definite the hexagonal figures are not evident (Fig. 11a). In cristobalite the tetrahedra lie in a cubic cell with silicon atoms at each corner and in the face centres, the oxygen atoms being again placed midway between two silicon atoms. The main difference is that, whereas in quartz the lines joining an oxygen atom to two silicons form an angle of 155° with each other (Fig. 12), in both tridymite and cristobalite all three atoms are in the same straight line. Wells points out, however, that this linear arrangement in cristobalite gives a distance between the oxygen and silicon atoms of only 1.54 Å, whereas, since the diameter of an oxygen atom is 2.7 Å and that of the silicon atom is .6 Å, the distance between them should be 1.65 Å. He states that Barth suggests that the oxygen atoms actually rotate around the lines joining the nearest silicon atoms, giving a more satisfactory distance of 1.63 Å.

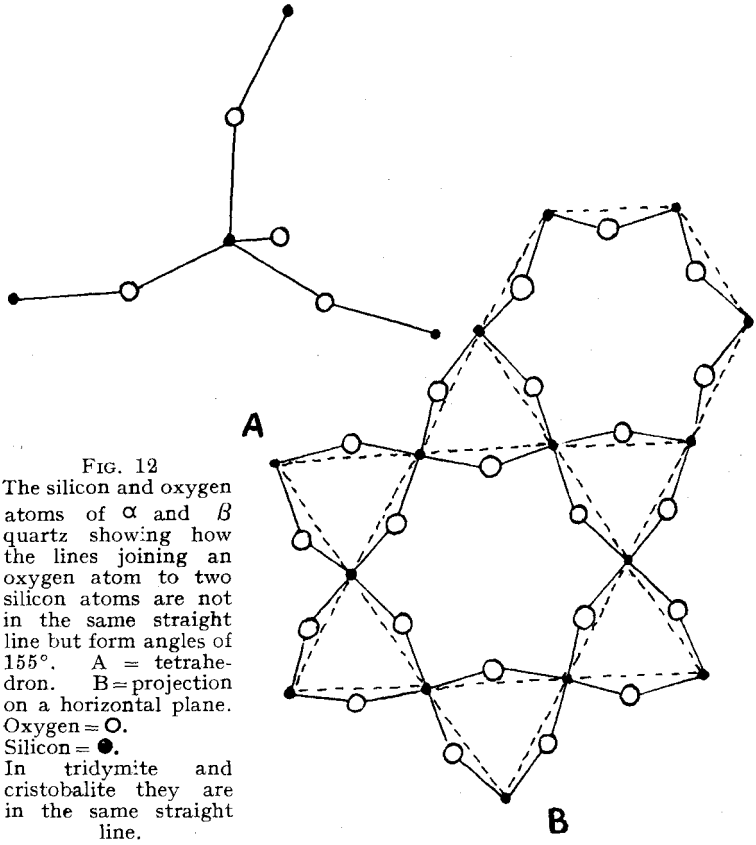

FIG. 12
The silicon and oxygen atoms of α and β quartz showing how the lines joining an oxygen atom to two silicon atoms are not in the same straight line but form angles of 155°. A = tetrahedron. B = projection on a horizontal plane. Oxygen = O. Silicon = ●. In tridymite and cristobalite they are in the same straight line.

Silica also exists in nature in an amorphous form as opal, natural glass and sinter, but these are in no sense of the word quartz and their physical characters are entirely different from crystalline and massive quartz or from crypto-crystalline chalcedony.

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ASSOCIATION NOTICES

REUNION OF MEMBERS AND PRESENTATION OF AWARDS

Dr. G. F. Herbert Smith, the President, described the prize giving held at the Goldsmiths' Hall on November 7th as the climax of the Association's year, when the candidates who were successful at the examinations in June came to receive tangible evidence of their success. The importance of the occasion was, he thought, generally recognized by the large number that were present. Many had come long distances, even as far as Scotland.

It afforded him much pleasure to see present an old friend of his and the Association in Mr. Irvine Jardine. It was thirty years ago that he undertook the very responsible position of official instructor. In those days, when comparatively little was known of gemmology, he had to start the students on the right course.

They were also fortunate in having with them to hand over the Diploma and Certificates, Professor Kathleen Lonsdale, who was well known in X-ray work and crystallography. Due to the brilliant work of early pioneers and the Braggs, father and son, X-rays were a powerful weapon of investigation and Prof. Lonsdale was fortunate in serving her apprenticeship with Sir William Bragg.

Professor Lonsdale then presented the awards and was thanked by the Vice-Chairman, Sir James Walton. He said that she had travelled from Hull to be present that evening. Her wonderful work, he went on, became even more remarkable when it was realized that it was only within recent years that the doors of science had been open to women. She was one of the first women to be made a Fellow of the Royal Society.

Many of those present had heard her lecture on the atomic structure of the diamond. It had made such an impression upon him that now when he looked at a diamond he felt he could almost see its structure. He hoped that Professor Lonsdale would honour them again with a lecture.

To all gemmologists the work of the Professor had been of special value in raising the scientific trend of gemmology. Some might decry that approach and say it was not in accordance with practical gemmology, but the same thing happened in many branches of science and was essential for advancement.

Throughout the ages, Sir James continued, mankind had always been seeking happiness. Some through marriage, wealth or health. Provided one has found a measure of happiness one of the chief ways of gaining a permanent form was to have an interesting, an enthralling hobby. Such a hobby made one impervious to the worries and annoyances of modern life. With such a hobby as gemmology there was no retiring age, though perhaps there should also be a more active hobby to give exercise. To many of

those present there was the opportunity, the most glorious of all, that they might be able to make of their life work their hobby also.

Professor Lonsdale said she was honoured by the list of her predecessors who had presented prizes and the fact that Sir William Bragg had been a Past President of the Association. She had had the privilege of working with him for twenty years. Sometimes people wanted to know what was the use of pure science. Surely scientists had the same feelings as an artist? His pleasure was great and of the same kind in its reward for the study of the order and beauty of nature. People did not ask what was the use of a violet under a hedgerow. She found pleasure in studying crystals, but of course it did not finish there. Crystals came into every phase of life. Every kind of solid material was crystalline. They were studying the same kind of arrangement in diamonds as in saucepans.

The U.S. Government had recently given her a Fellowship to travel in America under the auspices of a health research scheme because crystals came into medicine. She was now a Professor of Chemistry and knew the importance of crystals in such substances as penicillin. They even came into the study of permanent waving, because hair was partially crystalline and in waving it the arrangement of the atoms had to be changed. Thus the subject had repercussions in almost every field. Gemmologists could feel that they were part of a very great company.

Professor Lonsdale congratulated those who had received the awards for which they had worked so hard. Their work had made them better citizens because they had studied scientific methods. Particularly was this so if they used those methods in everyday life. Many young people could not distinguish between fact and fiction. It was important to be able to distinguish truth from error ; the proved from the unproved ; real from artificial. They had learned how to do this and she hoped they would continue to practise it not only in gemmology but in all the affairs of life.

Miss Elsie Ruff, member of the Council, then presented the Professor with a bouquet, after which the Chairman, Mr. F. H. Knowles-Brown, made another, and surprise, presentation. He said that since the birth of the Association their President had always been closely associated with it, giving it his constant attention and encouragement. In the early days it was difficult to train students because of the lack of a textbook. Dr. Herbert Smith wrote one which had become a standard work on the subject. He also designed his refractometer. From the earliest examinations he was the chief examiner and his influence was such that he set a very high standard to start with. This had been maintained so that the Diploma was desirable to have not only in Britain but throughout the world. Mr. Knowles-Brown said he was, therefore, glad to offer a tribute to the services of the President, who had recently given up work as senior examiner to the Association, in the form of a portrait of him. As he said this he lifted a piece of velvet to reveal a portrait of Dr. Herbert Smith, wearing his University robes and C.B.E. decoration. The painting had been done, unknown to the President, by Miss Betty Byrne, working from photographs.

In his thanks, Dr. Herbert Smith said it had been laid down that virtue was its own reward, but the pleasure of it was enhanced when it was recognized in such a manner.

COUNCIL MEETING

A meeting of the Council of the Association was held at 19/25 Gutter Lane, London, E.C.2, on Wednesday, November 7th, 1951, at 5.15 p.m. Mr. F. H. Knowles-Brown presided.

The following were elected to membership:—

Fellows

Alexander, D., Glasgow.
Armstrong, A. H. G., Stirling.
Belton, C. G., Southend-on-Sea.
Bishop, E. A., Southend-on-Sea.
Breebart, A. J., Arnhem, Netherlands.
Broadbent, Miss S. A., Farnham
Bridges, R. J., London.
Browne, P. C., Nottingham.
Caffell, E. W., Woking.
Cater, C. W., London.
Cohen, S., Utrecht.
Crook, Miss W. E., London
Davis, G. W., Birmingham.
Denyer, B. C., Harrow.
Dew, R. G. J., Croydon.
Fine, H. D., London.
Goodbody, R. F., Petersfield.
Harris, D. I., London.
Hogervorst, Mrs. T., The Hague, Holland.
Instone, I. N., Bexhill-on-Sea.
Kibe, V. R., Indore, India.
Kirkpatrick, M. R., Harrow.
Kolb, H. F., London.
Knowles-Brown, P., London
Leech, R. A., Ilford.
Lumsden, J. G., Edinburgh.
Miller, L. R., San Rafael, California.
Myers, G., Wembley.
MacDonald, H. F., Glasgow.
Mackenzie, I., Greenock.
Oostwegel, L., Heerlem, Holland.
Palmer, J. V., New Westminster, British Columbia.
Perry, J. A., Southend-on-Sea.
Rae, J. W., London.
Russell, B. T., London.
Russell, W. E., Port Alberni, Canada.
Stockwell, J. C., Middlesbrough.
Towe, E. G., Edinburgh.
Turnbull, K., Romford.
Wacker-Wakelin, R. J. G., Birmingham.
Wade, C. D., Paisley.
Wade, J. D. S., Glasgow.
Walker, J., Edinburgh.
West, Miss M. D., Theale, Berks.
Wood, E. A. A., Edinburgh.
Wright, T. J., London.
Wyatt, J., Bromley.

Fellows transferred from Probationary

Bartram, Miss E. M., West Woodville, South Australia.
Clarke, Miss H. A., London.
Doulis, L., Detroit, U.S.A.
Ekanayaka, F., Colombo.
Gush, Mrs. I., Johannesburg.
Lynch, D. K., London.
Myhre, H., Ljan, Norway.
Scott, J. F., Lincoln.

PROBATIONARY

Hessling, F., Birmingham.
Light, D. A., Sutton Coldfield.
Rogers, D. S., Belmont.
Spiro, F., Indonesia.
Andriessen, D. J., Bergen, Holland.

ORDINARY

Sheehan, W. W., Brazil, South America.
Jardine, I. G., London.

An invitation from the British Standards Institution asking the Assotion to appoint a member to serve on a diamond tools and powders committee was received. Mr. B. W. Anderson was invited to represent the Association.

Correspondence concerning the two Swedish Gemmological Associations was considered, the Council expressing the opinion that the cause of gemmology would best be served if a satisfactory means of amalgamation could be agreed.

TALKS BY FELLOWS

R. H. Corfield: "Gemstones." Mill Hill Rotary Club, October 30th, 1951.

P. Knowles-Brown: "Gemstones—their origin and use in jewellery." Twenty Club, Temple Fortune, November 21st, 1951.

J. F. Croydon: "Gemstones." Woodbridge Rotary Club, January 12th; Ipswich Inner Wheel, February 5th; Leiston Women's Institute, July 10th; Southwold Women's Institute, September 20th; Ipswich Round Table, November 19th.

MEMBERS' MEETINGS

January 23rd: British Council Cinema, Hanover Street, London, W.1, 7 p.m. "Art of the lapidary and the problems of cutting and polishing," by C. L. Arnold and G. E. Bull-Diamond of Messrs. Charles Mathews, Ltd.

March 26th: Twenty-second annual general meeting, Goldsmiths' Hall, Foster Lane, London, E.C.2., 6.45 p.m.

NORWEGIAN GEMMOLOGICAL ASSOCIATION

On September 14th, 1951, the Norges Gemmologiska Selskap arranged a lecture for their members at which Mr. Pike, of Messrs. Rayner & Keeler, Ltd., was the speaker. Members of the Goldsmiths' Association of Oslo were also invited.

Mr. Pike read a paper which dealt with the simplest and more complicated gem testing instruments, and a demonstration which followed greatly interested the audience. The lecture was translated by Mr. Hans Myrhe, Oslo.

The Chairman of the Association, Mr. O. Modahl, in thanking Mr. Pike, said that the lecture would further increase the interest of gemmology in Norway.

The following day members of the Association were shown the mineral collections at the Museum of Natural History in Oslo.

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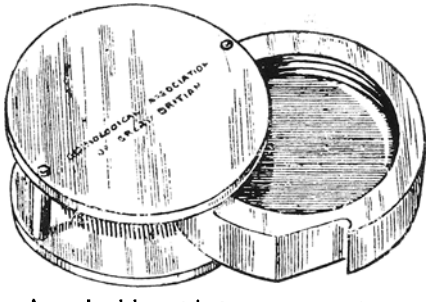

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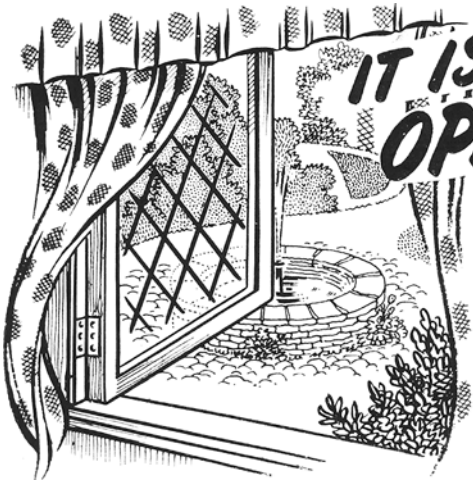

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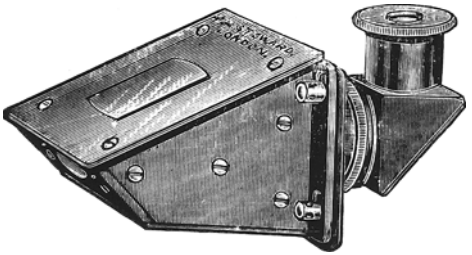

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Vol. III, No. 6 APRIL 1952

IMMERSION CONTACT PHOTOGRAPHY

A Simple New Technique

by B. W. Anderson, B.Sc., F.G.A.

"PHOTOGRAPHY without a camera" would perhaps have been a more attractive title for this article, but the phrase would not have described so exactly the nature of the process involved, and even the simplest process must have a descriptive name attached—if it is to be spoken of at all.

The first immersion contact photograph was made last autumn, at my suggestion, by my colleague, Robert Webster, to act as an illustration in a short article on curved colour bands in synthetic spinel.* On that occasion the stone was immersed in monobromonaphthalene in a shallow plastic dish, a piece of printing paper placed underneath the dish, and the whole exposed to light from an overhead electric lamp. The resultant image, though on printing paper, was, of course, a negative picture of the stone, showing the curved bands of colour as pale instead of dark, and a narrow bright rim round the specimen which really represented a black border due to internal total reflection at the edges of the stone, as the spinel had a higher refractive index than that of the surrounding liquid.

* B. W. Anderson and Robert Webster. "Curved bands in synthetic spinel." "Journal of Gemmology," Vol. 3, No. 4, October, 1951.

The result of that preliminary experiment was sufficiently attractive and promising (though it did not reproduce well) to make me determine to carry out further experiments with other stones and other liquids when the opportunity arose. Some further trials have now been carried out, though very spasmodically, as the urgent demands of routine testing have afforded no chances lately for continuous and careful work. Nevertheless, the results have been even more interesting and fruitful than expected. Not only is a very clear indication of the refractive index provided, even when only a single liquid is used, but the pictures are also æsthetically pleasing. Moreover, since an exact record is given of the outline of the stone, of the disposition of the facets, and even of any notable internal features such as feathers, flaws, zoning or large inclusions, these contact photographs would serve very well as a means of identification of individual important stones, for which expensive and time-consuming photomicrographical methods have hitherto been employed.

All that is needed in the way of equipment (one could hardly call it apparatus) is a glass or plastic cell, a few selected immersion liquids of known refractive index, and " gaslight " printing paper, bromide paper, or slow, fine-grained flat film, according to the taste and needs of the experimenter. My first results were with printing paper, giving an exposure time of 20 or 30 seconds, but the photographs reproduced here were taken on Ilford " Line " film, and enlarged prints made from these negatives in order to show the effects " in their true colours," so to speak, i.e. as positives. The following liquids would form a useful range for most purposes: Toluene (1.50), ethylene dibromide (1.54), bromobenzene (1.56), bromoform (1.59), iodobenzene (1.62), bromonaphthalene (1.66) and methylene iodide (1.745). Several of these will already be in the hands of most gemmologists.

For most of the tests described here the same group of five stones was used. These were initially rather hastily picked out as being sizeable, transparent stones, colourless or pale in tint, roughly comparable in size, and of different refractive indices. Had all the specimens been brilliant cut this would in some ways have been better, as the inclination of the facets would have been more nearly the same in each case ; but, on the other hand, the different shapes of the five stones chosen make it more easy to recognize them in the several pictures. Here is a list of the stones: —

Stone			Carats	Ref. Indices
Oval mixed-cut quartz	...	...	7.60	1.544—1.553
Long oval topaz ...	...	...	7.72	1.630—1.638
Step-cut spodumene	...	...	6.30	1.664—1.679
Mixed-cut chrysoberyl	...	...	10.33	1.748—1.757
Round white zircon	...	...	16.16	1.926—1.985

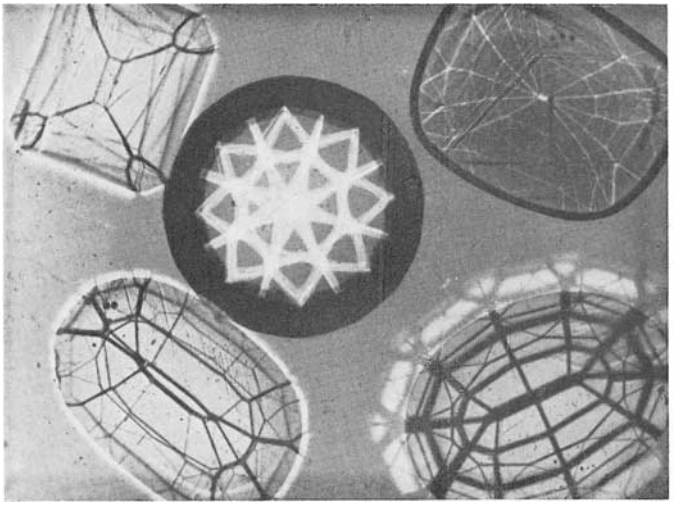

Fig. 1 — Immersion contact photograph of quartz, topaz, spodumene, chrysoberyl and zircon in monobromonaphthalene. Enlarged about 2¼ ×.

Fig. 1 is a slightly enlarged immersion contact positive of these five stones in monobromonaphthalene. The quartz is in the bottom right hand corner followed in a clockwise order by the topaz, spodumene and chrysoberyl, with the round zircon in the middle. An attempt was made to arrange the stones in some semblance of order and symmetry, which would greatly have enhanced the appearance of the picture. But in the dim light of the dark-room lamp the stones were virtually invisible, and the slight movement of the cell as the film was inserted below was enough to disarrange them. Another defect is overcrowding of the specimens owing to the small size of the cell. The stones should ideally be well separated from one another and from the containing sides, where the meniscus caused noticeable distortion. Despite these faults the picture shows in how striking a manner the different refractivity of the specimens influences their appearance in the photograph. The

quartz, with an index far lower than the liquid, has a broad pale border extending beyond its true outline, and the junctions of the facets are strongly marked in black. With the topaz, where the index is not much below that of the immersion medium, these features are less pronounced. The mean index of the spodumene would slightly exceed that of the liquid for sodium light, but the greater dispersion of the monobromonaphthalene ensures that for the blue and violet light for which this film is most sensitive the index of the liquid is still slightly greater than that for the stone. With chrysoberyl the reversed effect becomes clearly apparent, resulting in a narrow *black* border and *white* outlines to the facets ; while in the zircon the heavy dark border and broad white facet edges form a striking demonstration of its high refractive indices. Here the strong double refraction adds to the complexity of the pattern formed by the facets.

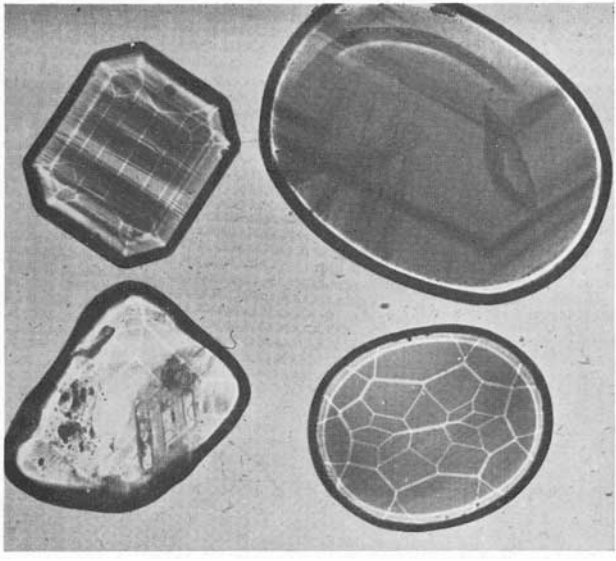

Fig. 2 — Immersion contact photograph of three natural sapphires and one synthetic sapphire in monobromonaphthalene. Enlarged about 2 ×.

In Fig. 2 three natural sapphires and one synthetic sapphire are shown immersed in monobromonaphthalene. In this case the stones were chosen to demonstrate how clearly internal features are revealed by this simple process. The colour zones of the top two

flat stones are plainly seen. The irregular stone on the bottom left is a Ceylon sapphire containing large three-phase inclusions, while the oval synthetic sapphire shows only faintly its curved colour bands, merely because the angle of rest of the stone in the dish is not the most favourable direction for displaying these features. Note the approximately equal dark rim which surrounds these stones, despite their very different styles of cut. Careful inspection of the other photographs will reveal internal markings in some of these stones also.

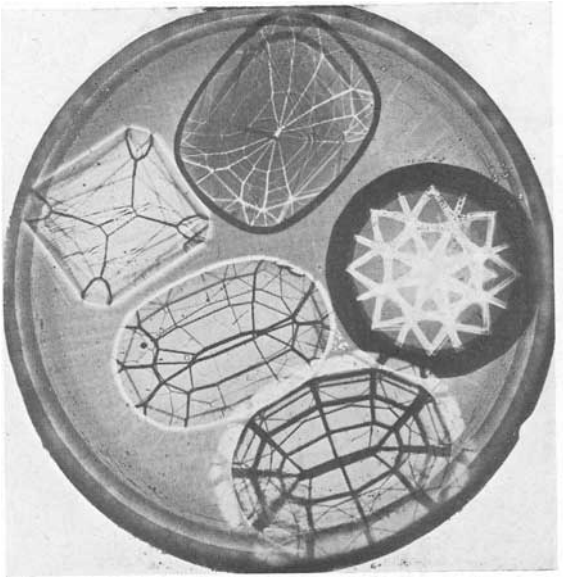

Fig. 3 — Immersion contact photograph of quartz, spodumene, chrysoberyl and zircon in monobromonaphthalene. Enlarged 2×.

These first two pictures were taken on Ilford " Line " film (a slow and fine-grained emulsion) at about 4 feet below a 60 watt frosted bulb, the exposure time being 3 seconds. In the remaining two pictures shown an attempt was made to obtain sharper results by using a cell with a thinner glass base than the rather massive Whilems cell used in the other experiments, and by masking the light with black paper, allowing only a narrow beam from a 1-inch aperture to reach the immersion cell. Comparison of Fig. 3 with Fig. 1 will show that there is, in fact, a slightly better definition of the facet edges. In Fig. 4 the same five stones are shown immersed

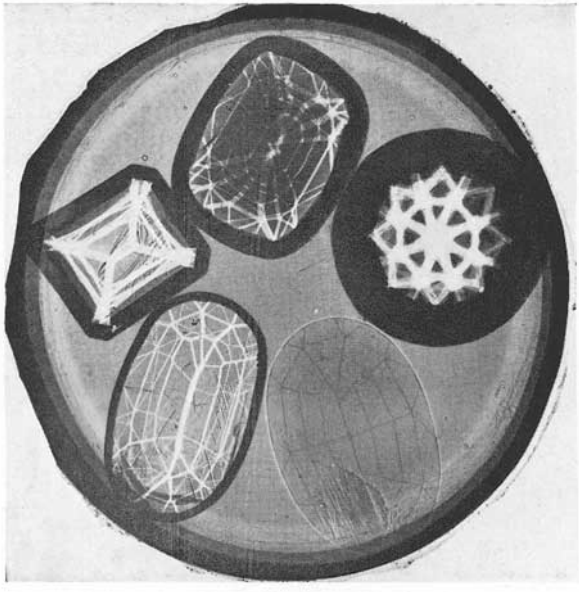

Fig. 4 — Immersion contact photograph of same five stones in ethylene dibromide.

in ethylene dibromide, the lower index liquid causing them to show very different relief. Ethylene dibromide matches quartz almost exactly in sodium light, but its higher dispersion makes its index just a fraction higher than that of the stone for blue-violet actinic light to which the film is most sensitive ; hence the faint bright rim and fine dark facet edges displayed by the specimen. The other stones show increasingly wide dark borders, as expected, except that the steepness of the facets in the spodumene makes it appear to have about the same refractive index as chrysoberyl in this picture.

One further photograph is reproduced in Fig. 5, in this case to indicate the sensitivity of the immersion contact method. The stones in this instance are synthetic emerald (the larger stone) and South African emerald immersed in bromobenzene. Here the liquid is clearly shown to have a higher index than the synthetic (for the operative wavelength) and a lower index than the natural emerald. The difference between the mean index for the two stones as measured on the refractometer is about 0.035.

I am hoping, as time permits, to carry out many other experi-

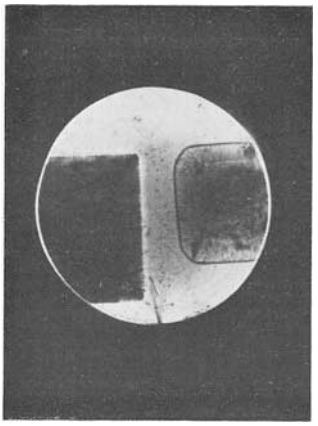

Fig. 5 — Synthetic emerald (left) and South African emerald in bromobenzine. About 3 ×.

ments with this method, and to try out various possibilities. If monochromatic light were used it would sharpen the effects considerably, since there is continuous variation of the relation between the refractivity of the stones and the liquid with the wavelength of the light. With suitable colour-filters and liquids of known dispersion a fair range of indices could be covered without having to use a multiplicity of liquids. Results under ultra-violet light also might be revealing in certain cases. However, such elaborations are only suitable for the laboratory worker, and it should be emphasized that perfectly effective photographs giving a clear guide to refractive index, and forming a record of the size and the disposition of the facets of any unmounted stone can be obtained without any equipment beyond a glass cell, a few liquids and a packet of contact paper.

Nor is a dark-room really necessary ; any room in which a single overhead light can be switched on and off will serve after dusk, since contact paper is not unduly sensitive. It must be remembered that the results on contact paper, as on a film before printing, will be the exact reverse of those shown in the illustrations to this article.

It is not, of course, suggested that the contact photograph method can replace other immersion techniques for refractive index determination, of which there are several variations particularly suited to the needs of gemmologists ; but for its simplicity, the unequivocal nature of its results, its beauty, and its value for purposes of record, I am confident that the process has much to commend it.

NOTAE — UT INFRA

by D. S. M. Field, A.G.A.

DESPITE the efforts of the American Gem Society and other praiseworthy American trade organizations to discourage such practices, another name has been added to the long list of fanciful and often misleading trade terms for synthetic rutile. The word " *Diamothyst* " is now appearing in advertisements sponsored by a New Jersey (U.S.A.) firm engaged in the retailing of the opal-like synthetic gemstone. Many of the claims made in the advertisements are grossly exaggerated and scientifically inaccurate: " Harder than zircon . . . Diamothyst is .7 on the Moh's (sic) scale of hardness, and diamonds are .9 . . . a stone that only an *expert* working under a *good light* can detect from a real diamond." In conclusion, the advertiser assures the buyer that: " Legally, we cannot refer to the Diamothyst as a *diamond*, so we ask you to order in the three most popular *diamond* shapes . . ." (The italics are the advertiser's.) Of course, no mention is made of the fact that the so-called " Diamothyst " is nothing more startling than synthetic rutile.

Incidentally, increased production and improved faceting machinery have brought about a sharp drop in price to five dollars per carat for cut rutile—purchased in wholesale lots of a dozen stones. Indications are that the American price will eventually stabilise rather above the level of synthetic blue sapphire, the most expensive of the synthetic corundums.

A Toronto firm is currently outfitting with furnaces, etc., for the production of synthetic rutile in Canada. The source of their raw material will be the huge titanium deposits in the Province of Quebec. The Toronto factory, which is scheduled to commence operations on a small scale this year, will be the first of its kind to operate in Canada.

* * *

Lo! The archaic jargoon. Taking advantage of the publicity enjoyed by the synthetic rutile hucksters, at least one New York dealer is seeking to promote the sale of white (colourless) zircon

under the old and obsolete name "jargoon." His advertisements read something like this:—

> "NATURAL JARGOON—rivals diamond in brilliance and fire. NOT A SYNTHETIC STONE! Nature *is* always right . . . and the Jargoon . . . a natural mined gemstone proves it! Two hundred million years in creation, the jargoon is so white, so fiery . . . yes, so *brilliant* that it is the closest rival of the diamond! Mined from the gem-bearing gravels of Ceylon . . . it glows on your finger with the same splendour that made it a favourite with Sultans . . . caused it to be included in the British Crown Jewels!" (The humble Indo-Chinese zircon blushes—and hangs its modest head in shame!)

* * *

A report from Brazil tells of a little-known thermal colour change in gems: blued golden beryl.

The colour of the treated stones is said to be pale blue, similar to that of the best aquamarines. It is not known whether *all* golden beryls are so affected when subjected to controlled heat treatment. The treated stones came from Minas Gerais.

* * *

Advice from Brooklyn, New York, regarding a top-secret synthetic diamond project in Russian territory, will be found in the following letter published in an American magazine for men:—

> "I wish to pass on some information given me by a Russian citizen when I was with the American Occupation Forces in Vienna, Austria. . . . About eighteen months ago I became acquainted with a Russian girl also stationed there. . . . Once she noticed my diamond ring and said, 'What if I told you that diamond might be worthless very soon?' She went on to say that her brother was a mathematics professor in Moscow. He had been on a secret project based at the mouth of the Yakutsh River . . . left his wall safe unlocked one afternoon and she went through his private papers. She learned that the project was to manufacture diamonds out of raw carbon, with the aid of an atomic explosion . . . on the theory that, under heat and pressure, carbon—in the form of graphite—could be made to rearrange its structure to conform to the crystalline pattern of the diamond. The diamonds were

in chunks weighing up to hundreds of kilograms. . . . At a certain spot in the Arctic Ocean there is a great subterranean (sic) valley about four miles deep and the pressure is tremendous. . . . When an atomic explosion occurs at these depths strange forces come into play. . . . Their modus operandi called for huge buoys, to which were attached long cables. . . . At the bottom were the containers holding the graphite, placed in moulds. I asked my girl friend if she didn't feel she was breaking her brother's trust. She said that he had died of pneumonia six weeks before. . . ." (The letter was unsigned.)

* * *

Notwithstanding the fact that neither the edible oyster nor the clam is capable of producing a pearl desirable for use as a gem, stories of alleged finds of valuable pearls in oyster stews and clam chowders quite frequently appear in the sensational press.

As every gemmologist knows, true pearls are to be found in only two types of shell-fish: the fresh-water mussels (Unionidae) of North American and European streams, and the pearl-bearing molluscs (Margaritifera) of tropical and sub-tropical seas. An exception to this rule is the abalone (Haliotidae) ; but the lovely vari-coloured pearls of this strange shell-fish are rare indeed and seldom met with in the trade.

The confusion in the public mind no doubt stems from the fact that the popular name given to the margaritifera is " oyster," when actually the animal does not belong to the same zoological family as the edible oyster (Ostrea edulus), and is entirely different in shape and size of shell and in the type of pearl it produces. The concretions produced by the edible oyster and the clam are similar in form to pearls, but, as they are not nacreous, are of *no value as gems* and should not be classed as such.

The heat of cooking has frequently been given as the cause of the " dead " appearance of " pearls " found in stews and chowders. Actually, however, while the cooking certainly would not enhance their appearance, it is their natural lack of nacre that causes them to appear lifeless and dull and to be unsuitable for jewellery use. It is, therefore, sheer nonsense for an " expert " to say that a pearl of this nature would have been valuable had it not been subjected to cooking heat.

Proprietors of certain sea-food establishments have been known to introduce cultured pearls (sometimes ready drilled!) into edible oysters before serving them to customers, perhaps hoping to profit from the ensuing newspaper publicity. (Newspaper reporters seem to love this sort of thing!) And we often hear of jewellers (who should certainly know better) setting fabulous prices on them. So a fallacy persists and, despite refutory articles in responsible trade journals, the stories continue to plague the gemmologist and conscientious jeweller whose job it is to present the *facts*, even when it means that the sale of a setting is lost and a customer is disillusioned.

Consider, for instance, the let-down a certain citizen of Rochester, New York, is going to experience when he tries to sell a " black pearl " that he reportedly found in a restaurant dish called " Clams Casino." It is said that an " expert " has valued it at 11,000 dollars. Evidently this " expert " has never heard of the G.I.A. and the American Gem Society, whose efforts over the past two-score years have done so much toward eliminating a good deal of the ignorance and misrepresentation in the North American jewellery trade.

* * *

With further reference to the American Gem Society, their official approval of the term " *topaz-quartz* " for citrine is apparently confusing not only to the public, but to some jewellers as well. In Canada, a well-intentioned member firm is advertising " Genuine topaz (quartz)," a construction which would possibly mislead some persons to believe that *genuine* topaz *is* quartz, which is certainly not the case.

In this instance, the adjective " genuine " is undoubtedly used for the sole purpose of differentiating the natural stone from the synthetic varieties advertised on the same page. Nevertheless, in the writer's opinion, it should have been borne in mind that " citrine " is an attractive and quite proper name for the particular gemstone represented, and, while *topaz-quartz* is admittedly a somewhat happier choice than " quartz-topaz," the use of qualifiers that are actually the names of distinctive gem varieties is bound to be confusing to the lay mind.

THE DIAMOND INDUSTRY 1950

*by W. F. Foshag and George Switzer**

THE year 1950 was a record-breaking one in the diamond industry. Sales of diamonds by South African and other producers were the greatest in history, with total sales nearly one-third greater than the previous record year in 1948, and nearly double those of 1949. In his Christmas message, Sir Ernest Oppenheimer reported: " The year 1950 has been a most prosperous one for the Diamond Industry. The demand for both gem and industrial stones has exceeded all expectations and previous records, and the buoyancy of the market has taxed the ability of the producers to maintain an adequate supply. Even with the help of the reopened Premier and Jagersfontein mines production has not been able to meet all demands."

The rapid changes in the world situation have brought about a decided change in the diamond industry, both in the gem and industrial fields. The early lethargy of the market was changed to one of avid demand by the outbreak of the Korean War. Even before this event an improvement became noticeable, due in part to the stabilizing effects of the Diamond Trading Company's action to maintain prices upon the devaluation of sterling currencies in 1949, and to the moves by various governments, notably that of the Union of South Africa, to eliminate the manipulations between hard and soft currencies, the so-called switch operations, as they affected the diamond market. Political uncertainties and the fear of inflation induced a rapid increase in the demand for gemstones. This demand fluctuated with the vagarious changes in the military outlook, interest waning somewhat upon Allied successes, and increasing upon Allied setbacks.

In the industrial field, too, the outbreak of the Korean War again emphasized the importance of the diamond in industry.

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* Extracted from " The Diamond Industry, 1950," by permission of the Jewellers' Circular-Keystone.

American and other rearmament programmes greatly increased the demand for industrial stones. By 1950, reserve stocks were reduced to eight million carats. No general serious shortage developed during the year, although the market tightened on some types, notably crushing bort. The present outlook is for greatly increased demand, which will be partially offset by increased production from the Belgian Congo, and the reopening of the Premier Mine. The reopening of the Premier Mine was a fortunate move, increasing the supply of higher qualities of industrials.

Other factors, such as the development of the Alberta, Canada, oilfields, created new demands for industrial stones. New recovery processes, heavy, media and electrostatic, have now proved their value, resulting in more efficient recovery of stones and lower recovery costs. They will undoubtedly find wide application in the mining industry. Not only will producing mines improve their recovery, but marginal producers may become profitable.

The diamond cutting industry shows some progress toward a more desirable degree of stability, but is still beset with difficulties, due in part to a disparity in manufacturing costs between various centres. Unemployment in some centres, notably Antwerp, remains a disturbing factor. A decided tendency for the dispersal of the manufacturing industry from the old-established centres is evident.

Diamonds in Fashion

Fashions in 1950 showed relatively little basic change. Diamond jewellery was light, flexible and mobile. Designed on the theory that diamonds in motion look bigger than diamonds in repose, mountings were hinged to move loosely and large single stones were made to sway in pendant fashion or in rows as a shimmering fringe.

In mountings, curved lines were the most popular, but with fewer naturalistic flowers and abstract objects. The butterfly motif began to emerge towards the close of 1950.

In forms of diamond jewellery, the necklace remained the most important single piece. Earrings changed from the long pendant type to large button clusters on the lobe. Diamond wrist watches became increasingly popular.

In 1950, the most significant motif in precious jewellery was the cluster, a large centre stone surrounded by one or more rows of brilliants in matched sizes. The cluster mountings may be marquise, square, oval or round. The metal tops are made rather

elaborate, so that with the addition of a few small diamonds, a fairly large piece may sell for a comparatively low price, some for under $100. The most popular usage of these clusters was as dinner rings.

Towards the end of the year, the metal restrictions imposed or on the horizon made new designs uncertain. Gold was being used extensively due to the shortage of platinum.

More fancy cut diamonds were used this past year than at any time since the 1920's. Ample supplies were available of unusual shapes such as pentagon, kite, trapeze, triangle and half-moon. The bulk of the diamond jewellery sold in America, however, is mounted with the standard brilliant, the emerald cut, occasionally the marquise, and the baguette.

World Production

Accurate figures regarding diamond production are not available for all countries. Exact figures received from official sources are given in most instances. Where estimates are given they are believed to be fairly reliable.

WORLD PRODUCTION OF DIAMONDS, 1947-1950,
BY COUNTRIES, IN METRIC CARATS
(Including Industrial Diamonds)

Country	1947	1948	1949	1950
Africa:				
Angola	799,201	795,509	769,981	538,867
Belgian Congo ...	5,474,469	5,824,567	9,649,896	10,147,471
French Equatorial Africa	107,076	[4]118,300	[4]122,928	111,460
French West Africa ...	53,749	77,970	94,996	126,346
Gold Coast	[1]852,493	[2]850,000	[1, 4]972,976	[2]950,000
Sierra Leone	605,554	465,518	494,119	655,474
South-West Africa ...	179,554	200,691	280,134	488,422
Tanganyika	92,229	148,169	191,787	195,274
Union of South Africa:				
Lode	918,042	[2]930,000	964,266	1,516,194
Alluvial	[3]286,692	[2, 3]270,000	[3]289,756	[3]231,674
Total Union of South Africa ...	1,204,734	[2]1,200,000	1,254,022	1,747,868
Brazil[2]	275,000	250,000	250,000	200,000
British Guiana	24,669	36,562	34,790	37,462
Venezuela	61,634	75,513	56,362	60,389
Other Countries[2]	3,500	3,500	3,000	3,000
Grand Total (Round Figures)	9,734,000	10,047,000	[4]14,174,991	15,262,033

[1] Exports
[2] Estimated.
[3] Includes an estimated 100,000 carats for State Mines of Namaqualand.
[4] Revised Figure.

Cutting—England

A rapidly expanding diamond cutting industry has developed in the past ten years in England. The industry was formed in 1940 when refugees came from Amsterdam and Antwerp. It has now been firmly established and is allotted regular sights by the Diamond Trading Company.

The industry employs approximately 700 men, principally in London and nearby districts. The diamonds cut are mostly the larger sizes, ranging from one carat (rough) upwards.

Industrial Diamonds

Developments during 1950 in the field of industrial diamonds centred chiefly about greatly increased use by manufacturers geared to production for defence requirements, and a resultant short supply. Because of these factors there has been a sharp rise in prices.

At the beginning of World War II there existed a huge stock-pile of industrial diamonds throughout the world. Heavy demands during and subsequent to the war reduced this stock to a low level.

The world production of industrial diamonds in 1950 was approximately 12,500,000 carats, an increase of about 15 per cent. over 1949. Of this amount some 9,600,000 carats were mined in the Belgian Congo. Reopening of the Premier Mine in South Africa should materially increase the supply of high-grade industrials.

Scientific Research

Experiments on the colouration of diamonds by irradiation by radium and in the cyclotron were reported on by Martin L. Ehrmann (" Gems and Gemology," Summer, 1950, p. 295) and Frederick H. Pough and A. A. Schulke (" Gems and Gemology," Spring, 1951, p. 3). Colour changes brought about by cyclotron bombardment are usually from pale brown to green, white to bluish green, and yellow to yellow green. Occasional changes from yellow to golden brown were observed. The colour appears to be permanent but is only present as a surface skin. No permanent induced radioactivity was observed.

Diamonds subjected to neutron bombardment in an atomic pile were stated to have been quickly blackened but passing through an intermediate green colour. (Reported by Pough and Schulke as a personal communication from D. E. Blackwell, Cambridge, England.)

Further Notes on

TAAFFEITE

by C. J. Payne, B.Sc., F.G.A.

IN Vol. III, No. 2, of this journal the writer described a new mineral, but at that time the analysis had not been completed. Since then the mineral has been described in the "Mineralogical Magazine," Vol. XXIX, No. 215, pp. 765-772.

It has been decided to call this mineral Taaffeite in honour of its discoverer, Count Taaffe, much to the relief of the writer, who had been calling it that since about 1946. Various other suggestions were made but none of them were satisfactory. Naming a new gemstone is not easy and it should be borne in mind that most stones have very ancient and time-honoured names which are really pleasant. Minerals, on the other hand, frequently have horrible unpronounceable names, which do not matter perhaps, because the ordinary public do not come into contact with them.

The refractive indices of Count Taaffe's specimen have been taken again (previously only ω could be measured accurately). The two stones had the following indices:—

Count Taaffe's: ω 1.7230 ; ε 1,7182 ; ω—ε 0.00475.
B. W. Anderson's: ω 1.7208 ; ε 1.7167 ; ω—ε 0.00412.

Dr. M. H. Hey made an analysis on 6 mgs. (i.e. 0.3 cts.) of the stone as follows ("Min. Mag.," XXIX, 215, p. 772):—

Al_2O_3	...	...	70.0
Fe_2O_3	...	...	5.9
MgO	...	...	13.4
BeO	...	...	11.0
			100.3

This gives a rough formula $MgBe(Al_2O_4)_2$ if the iron is ignored. It shows that Taffeite is intermediate in composition to spinel and chrysoberyl.

The ideal formula given according to the contents of the unit cell is $Mg_4Be_4Al_{16}O_{32}$.

The formula for spinel giving the content of the unit cell is $Mg_8Al_{16}O_{32}$, and of chrysoberyl $Be_4Al_8O_{16}$. Setting these formulæ

out together they appear like this:—

Spinel: $Mg_4Mg_4Al_{16}O_{32}$ cubic
Taaffeite: $Mg_4Be_4Al_{16}O_{32}$ hexagonal
Chrysoberyl: $Be_4Be_4Al_{16}O_{32}$ orthorhombic

and one can see the relation between the three.

More careful densities have been made on the two stones, giving for Count Taaffe's 3.613±.002. B. W. Anderson's stone was slightly lighter—3.60.

The complete data on the mineral can be summarised:—

Name: Taaffeite.
Composition: $Mg_4Be_4Al_{16}O_{32}$.
Habit: Unknown.
Crystal System: Hexagonal Trapezohedral (Class 62).
Cell dimensions: c/a 3.21 a 5.72Å c 18.38Å.
Space group: D_6^6—$C6_3$ 2.
Hardness: 8.
Refractive indices: ω 1.723-1,721, ε 1.718-1.717, uniaxial negative.
Specific gravity: 3.61-3.60.
Origin: Unknown (believed to be Ceylon).
Remarks: Only two specimens known. The ratio of c/a 3.21 is virtually the same as the ratio of crystal axes ; these cannot be measured until a crystal is found giving the pyramid and prism necessary. B. W. Anderson's stone, weighing 0.86 carat, is on view at the Natural History Museum, South Kensington.

A POCKET POLARIZER

A pocket-sized polarizing apparatus designed for gem testing. The apparatus consists of a tube, about 3½ inches long, equipped with a reflection mirror at one end above which is a lens and a polarizer employing a sheet of polaroid. The top of the tube contains a rotatable cell for liquid and stone, over the top of which can be swung to a second polaroid disc to act as the analyzer. The apparatus is to be marketed. Three illustrations.

From Gemmologist, Vol. XXI, No. 246, pp. 1–3. January, 1952.

PHOTOMICROGRAPHS

by L. C. Trumper, B.Sc., F.G.A.

AN interesting side of gemmology is the creation of a collection of photomicrographs of inclusions in gemstones. Since no two stones can possibly be the same in this respect, the number of variations is infinite. Large numbers of most excellent photomicrographs have already been published by Dr. E. J. Gübelin, a master of this particular technique, and by many others also.

As it is possible that most gemmologists look upon this as a difficult job, it is the main purpose of the present article to show not only that this is not so but that in fact the procedure is a very simple one. Briefly, it consists in focussing the microscope correctly and then centring the camera (any camera) with the lens as close to the ocular or eyepiece of the microscope as possible. The lens of the camera is focussed at infinity (in the case of a box camera there is nothing to do) and then it is merely a question of a little experimenting to find the best exposure.

Now to elaborate the simple procedure outlined above so that the best possible results may be obtained. Clearly the first essential is a means of satisfactorily and firmly holding the camera over the microscope so that the axis of microscope and camera are in the same line, that is, correctly centred. Let it be said at once that since the gemstone will in most cases be immersed in a fluid it follows that both microscope and camera will need to be vertically one above the other, and therefore the stand will have to provide accordingly unless a totally reflecting prism is employed above the microscope eyepiece or ocular.

My own first experiment (Fig. 1) was to construct a rigid wooden stand for the purpose with a fixed position for both microscope and camera which automatically did the necessary centring. This can only be built after careful measurement of the height of microscope focussed upon an average stone with camera superimposed. The disadvantage of this method is first the difficulty of initial focussing, because the stand is in the way, and secondly the

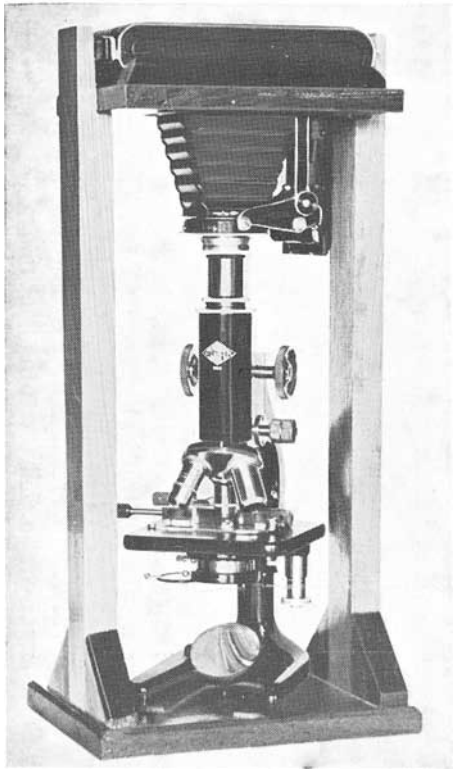

Fig. 1 — Fixed Stand for Photomicrography.
Camera: Kodak Special.
Film size: $2\frac{1}{2}'' \times 4\frac{1}{4}''$.

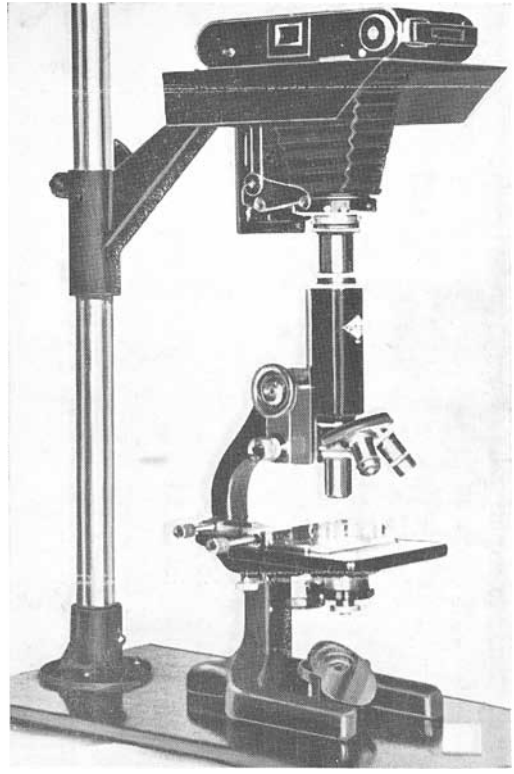

Fig. 2 — Adjustable Stand for Photomicrography.
Camera: Kodak Special.
Film size: $2\frac{1}{2}'' \times 4\frac{1}{4}''$.

severe limits to anything but a very small raising or lowering of the micropscope tube and the necessity of keeping to the same power of objective and ocular. The rigidity is, however, a great advantage. The rigid wooden stand has been superseded by a stand adapted quite simply from standard photographic enlarger parts. As will be seen, this stand (Fig. 2) consists of a good-sized and rigid baseboard, vertical pillar and a sliding arm with a clamp and clamping screw. A suitable metal table with a rectangle cut out of it was made and attached to this sliding arm into which my camera could be lowered and which thus held it firmly. The metal table must be dead horizontal.

As to the camera, any camera will do so long as the aperture is not smaller than F.11 and " time " control is used so that exposures in the region of 10-20 secs. can be employed using any suitable average speed film.

If, however, you intend buying a camera for the purpose, then get a size that will take photographs as nearly square as possible, such as $2\frac{1}{2}$ in. x $2\frac{3}{4}$ ins. or $2\frac{1}{4}$ ins. x $2\frac{1}{4}$ ins., as this will economize in film. A good lens is always desirable, but neither complicated focussing nor shutters are any advantage. Actually, the lens plays no part at all and for this reason an aperture of not less than about F.16 should be used to avoid the risk of cutting off part of the microscope field.

If you stop down, this will not enable a longer exposure to be made as in photography generally, but will have the effect of gradually reducing the field photographed and, instead of a clean circular edge, will result in a partially fogged border. On the other hand, too large an aperture, i.e. larger than that of the ocular, will result in unwelcome reflections which may partially fog the film.

As to the film, the only recommendation I would make is to keep to the same make and speed and always make a detailed record of every photo taken, giving (a) the subject, (b) the film, (c) the focus (it will always be infinity for photomicros, of course), (d) objective, (e) ocular (should these latter two be variable), (f) exposure, (g) stop, (h) light at time, (i) date and time, (k) remarks.

In the remarks column, after the film has been developed, indicate any faults so that you will build up a record which will

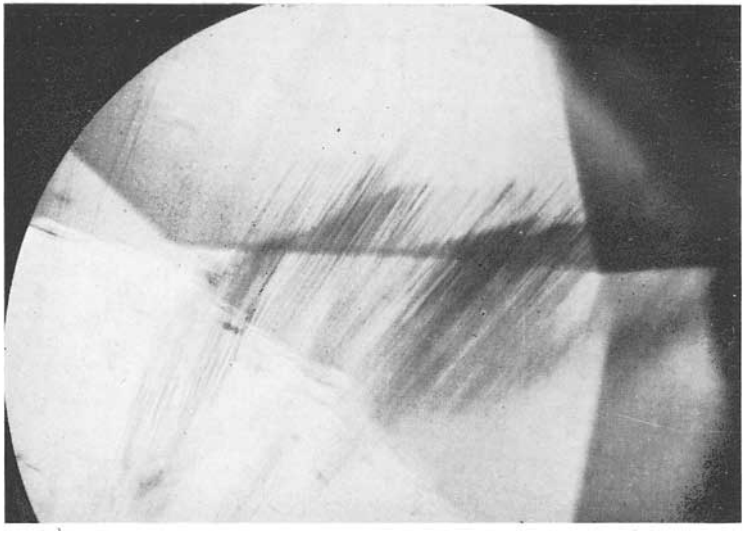

Demantoid Garnet — Stop F.16 : Focus — Infinity : Exposure 20 secs. : Film — Kodak Verichrome : Objective 2/3 : Ocular ×6.

tell you at any time exactly what exposure to make, which lenses to use and so on.

Again, any microscope will give results. I have taken first-rate photomicrographs with a microscope built about 1880 and bought for 25s. Here again, however, better equipment will give better results, so that the more orthodox type will be dealt with here. The microscope is focussed in the ordinary way. Use the concave mirror in preference to the plane mirror and the abbé sub-stage condenser, if so fitted.

Lowering the condenser will frequently enhance the definition, particularly of transparent inclusions.

The most useful objectives for gemmological work are $1\frac{1}{2}$ ins. and $\frac{2}{3}$ in., as these allow sufficient working distance. Eyepieces or oculars of ×6 and ×10 will meet most requirements. Some experimenting will be essential to get the best results. If possible, arrange camera and microscope with a suitable object and, with the back of the camera off, fit either a piece of ground glass or stretch tightly a piece of thin tissue paper or greased paper in the position normally occupied by the film.

Shielding from extraneous light by using an opaque sheet over head and camera, try every possible combination of objectives and oculars and record the fields of view obtainable. It will be found that a given combination will just fill the largest possible circle of film, whereas a higher powered ocular will result in part of the circular field being cut off.

Using a Kodak 616 size camera with $2\frac{1}{2}$ ins. x $4\frac{1}{4}$ ins. film, the following magnifications were obtained experimentally:—

Objective	Ocular	Diameter of Microscope Field	Area covered on Film	Magnification Direct Print	Magnification On enlargement to 4″ Diameter
$1\frac{1}{2}$″	×6	22/100″	$2\frac{1}{4}$″ dia.	×10.5	×18
$1\frac{1}{2}$″	×10	17/100″	3″ (part)	×17	×23
$\frac{2}{3}$″	×6	83/1000″	$2\frac{1}{4}$″ dia.	×27	×48
$\frac{2}{3}$″	×10	63/1000″	3″ (part)	×47	×63

The stone whose inclusions are to be photographed is immersed in a glass cell containing a liquid having as nearly as possible the same R.I. as the stone. Glass cells specially made for this purpose comprising a ring of glass fused to an optically flat glass slide may be obtained from Rayners.

Suitable liquids are the following:—

Toluol	R.I. 1.49
Clove Oil	1.54
Bromoform	1.59
Acetylene tetrabromide	1.63
Monobromonaphthalene ...	1.66
Iodonaphthalene	1.70
Methylene iodide	1.74

A liquid not too near in refractive index that of the stone will give some contrast and will show up the facets to some extent should this be required, thus showing the position of the inclusions relative to the stone itself. Furthermore, if you have not got the most suitable liquid almost any liquid is better than none.

To get the desired inclusions in focus takes a good deal of patience and repeated positions of the stone must be tried. When all is ready with the microscope in the correct position on the baseboard, give the exact focus a final check and then very carefully

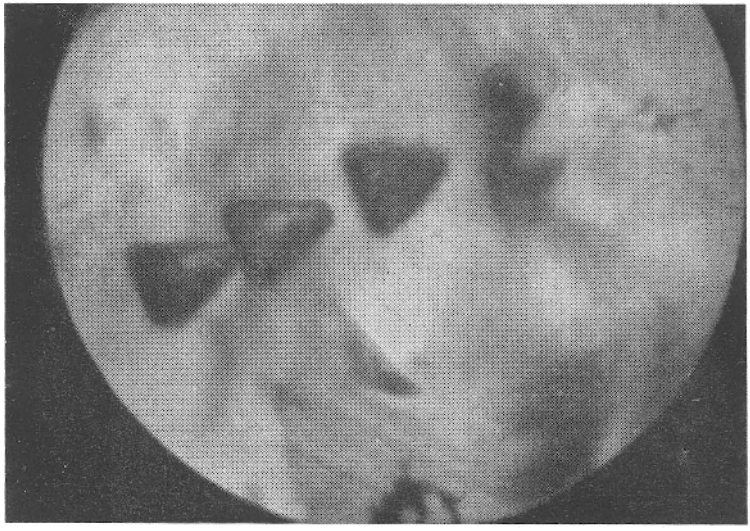

Fig. 4 — Ceylon Sapphire — Stop F.16 : Focus — Infinity : Exposure 3 secs. : Film — Ilford Fast Ortho : Objective 2/3 : Ocular × 6.

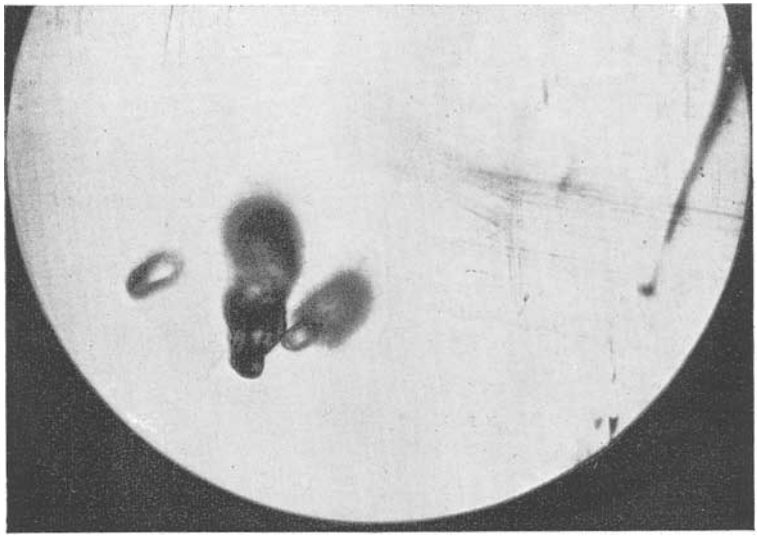

Fig. 5 — Almandine Garnet — Stop F.16 : Focus — Infinity : Exposure 20 secs : Film — Kodak Verichrome : Objective 2/3 : Ocular × 6.

swing the camera into position with the lens of the camera as close as possible to and immediately above the ocular of the microscope. This must be done with the greatest possible care otherwise the stone may be jolted out of position. This can easily occur as inevitably the immersion liquid and stone being of nearly the same density as well as of the same refractive index the stone may be almost in a state of suspension in the liquid.

Even if this does not occur, the slightest jar may upset the very critical focus, particularly with high powers.

Assuming that all is well, all that remains is to make the appropriate exposure, again taking care not to shake either camera or microscope whilst so doing. On completion of the exposure, carefully swing the camera back out of the way and at once look into the microscope to see that during the process nothing has moved and that the inclusions are still in focus. If movement has occurred, then there is only one thing to do and that is try again. In any case, after checking turn on the film before doing anything else. Always turn on the film after taking a photograph.

Clearly the chosen exposure depends on many factors, including light at the time, film speed, objective, ocular in use and the colour and depth of the stone itself The following may, however, serve as a guide:—

Kodak Verichrome film, 1½ ins. objective, ×6 ocular, average light from daylight (not direct sunlight):

Colourless Stones	4 secs.
Pale Blue Stones	5 secs.
Medium Blue Stones	6 secs.
Medium Yellow Stones	7 secs.
Medium Green Stones	8 secs.
Deep Orange Stones	9 secs.
Pale Red Stones	12 secs.
Medium Red Stones	15 secs.
Deep Green Stones	20 secs.
Deep Red Stones	30 secs.

For Dufaycolor film double the above exposures, though only in exceptional circumstances is there little, if any, point in colour film for photomicrographs, due to the fact that the higher power washes out the body colour and very few inclusions are coloured.

EXPERIMENTS WITH THE SOXHLET EXTRACTION APPARATUS

by Kenneth Parkinson, F.G.A.

WHILST in attendance at the Association's Gemmological Exhibition last October, I was attracted on more than one occasion to the exhibit of a Soxhlet Extraction Apparatus, which was working continuously all the week with the object of improving the colour of a faded turquoise.

At the end of the week, I could see no improvement in the colour of the turquoise and so dismissed the idea of obtaining such equipment for myself as being unnecessary and useless. After reading Mr. Webster's article on the matter in " The Gemmologist " and realizing that it was not an expensive item, I decided to obtain similar equpment, even if only to " play with " ; but my very first experiment convinced me strongly of the possibilities and I felt satisfied that it would pay for itself in very short time.

Some time ago, a friend of mine, after having repaired a small diamond ring, had dropped the ring whilst still hot into some cold acid and found on removing it that, owing to capillary action, some of the filth in the acid had entered an external flaw or fracture.

The fracture, though only just noticeable in the first place, was very distinctly visible after having been in the dilute acid and was, in fact, so bad that it had to be replaced by another stone, as all attempts to restore its former appearance had failed.

Knowing all the details of the trouble, I asked for this diamond on which to experiment and, using carbon tetrachloride only, found after about fifteen hours that the stone had improved to such an extent that I was sure the experiment had been a success. There was still a trace of the impurity but an improvement was obvious.

I gave up the experiment on this stone as reasonably satisfactory as I wanted to try the apparatus with other stones, not thinking at the time that it would have been quite in order to put two or three stones in the Soxhlet tube at once.

I took a fair-sized turquoise from my stock and another one of smaller size but of exactly the same faded colour so that I should

have a colour shade to go by later, and putting the turquoise in the Soxhlet tube, decided to attempt restoration of the colour, again using pure carbon tetrachloride.

After refluxing had taken place for a whole day, I removed the stone and put it alongside the smaller one which had been of the same shade of colour, and found that it had improved to the extent of about two or even three shades, but I was disappointed to find that several ugly dark stains had appeared on the surface which were not apparent in the first place and for which I could find no explanation.

A little water from the condenser had found its way into the carbon tetrachloride due to the rubber tubing not having been a tight enough fit on the inlet. As this might have caused the stains for some reason, I ran off the water and started again with clean solvent.

Two days later there was little or no further improvement in the colour and the stains were still present. As the stone had been subject to refluxing for over twenty-four hours, this was also put on one side, although the colour had definitely improved, and I could only put the stains down as being caused by the stone being more porous in some places than others.

Some years ago I heated some pieces of rock crystal and then plunged them whilst still hot into red and green dye to give them an iris effect, and as I still had some of these I thought they would prove easy and interesting items on which to experiment further.

After a full day in carbon tetrachloride, I was sorry to find the dye still there, though possibly not quite so deep in colour, although there seemed to be no trace of the dye in the solvent.

This seemed to be a definite failure, although I thought that perhaps prolonged action might improve them but it would hardly be worth the time and trouble.

I turned again to the small diamond which I had tried with some definite degree of success in the first place, but this time I tried concentrated hydrochloric acid, with the result that after only three or four hours not a trace of the impurity could be seen.

I might mention that the fumes which managed to escape were so choking at first that I had to stop, but by plugging a wad of wet

cotton wool in the top of the condenser the trouble was overcome to a great extent, but was still too choking to use in a closed room.

This naturally gave me the encouragement to try hydrochloric on the rock crystals, but before doing so I was advised by a chemist to try glacial acetic acid.

This is solid at normal temperatures, but after thawing it out I was pleased to find that after only three or four hours again, all trace of the red and green dye had disappeared and the stones were as clean as could be possibly expected in view of the numerous fractures due to being plunged into cold liquid whilst still very hot. All the fractures were there, of course, but the stones were once again white and clean.

My attention again turned to the turquoise, but realizing that treatment with either hydrochloric acid or glacial acetic acid would probably result in complete disintegration of the stone, I decided to try methylated ether. The fumes from the glacial acetic acid were just as bad as the hydrochloric acid.

The foregoing experiments were carried out with the old type of Soxhlet apparatus with an external looped tube and a badly fitting cork through which the water in the first place had entered, and realising that a more modern type with an enclosed looped tube would be better, I purchased a different but simple type of Soxhlet extractor with a loose inner tube and syphon to take a 22 x 80 mm. thimble. This allows the rising vapour to keep the condensed liquid and the stone at a much higher temperature.

Owing to the highly inflammable nature of methylated ether, I had to keep an eye on the experiment all the time, and, even so, gave up the experiment after two or three hours in case of accident, especially as no improvement was apparent.

The stains were still in the turquoise but the colour was about three or four shades better, but I put it on one side again and decided to experiment with some other material.

It was a week before I saw the turquoise again, when, much to my delight, I found that the stain had completely disappeared but the stone had almost returned to its original colour. The stains had apparently been due to some minute cracks on the surface into which the solvent had penetrated and showed deeper colour than the rest of the surface and had taken a week to dry out.

Gemmological Abstracts

CHUDOBA (K. F.). ***Charakteristische Bestimmungsmerkmale der Diamanten.*** (Characteristics of diamonds.) Gold und Silber, Vol. V, No. 2, pp. 14-15, February, 1952.

Unset stones are easily recognizable as diamonds by their hardness, specific gravity and optical properties. Difficulties may arise in distinguishng cut and set diamonds from other colourless stones. The following characteristics help in the determination. " Fire " (dispersion)—only zircon displays a similar " fire." Rutile is suspect because of excessive dispersion. Hardness leads to sharper and more durable edges on cut diamonds than on other stones. It also accounts for a better surface which reflects a clear image when used like a mirror. Good surfaces, however, are also found on zircons. In many cases rough parts are seen on the girdle of brilliants showing sometimes growth marks. Internal signs of cleavage are also characteristic in diamonds. Apart from these details the overall effect of the optical properties is significant, especially the effect of high and single refractivity which reduces the apparent depth of the stone. In addition, the " total reflection " is apparent in well cut brilliants. The author does not mention one important characteristic the connoisseur looks out for, namely the polishing marks on brilliants which indicate that no " flow layer " has been formed. E. S.

SCHLOSSMACHER (K.). ***Die Williamson Diamant Mine.*** (The Williamson Diamond Mine.) Gold und Silber, Vol. V, No. 2, pp. 15-16, February, 1952.

Details of the locality and workings of the Williamson Mine. Daily production 535 cts. Yearly production:—

1947	...	...	12,229 cts.
1948	...	...	148,169 cts.
1949	...	...	191,787 cts.
1950	...	...	195,274 cts.

Estimated value of the 1950 production: £2,100,000. E. S.

LIDDICOAT (R. T.). ***Heavy media separation proved effective.*** Gems and Gemology, Vol. VII, No. 4, pp. 116-119. Winter, 1951-2.

A suspension of ferrosilicon which is kept at a specific gravity of 2.87 at the top, and at the bottom at 2.97 to 3.05. The ferrosilicon has a density of about 7, but when ground to proper grain size and mixed with water acts similarly to a heavy liquid. Diamond-bearing material crushed to less than 1 inch to plus ten mesh, which constitutes about 80% of the feed from crushers, is fed into the heavy media (ferrosilicon suspension), when the blue ground, with a density of about 2.7, is floated off, while the heavier diamond, zircon, garnet, etc., sinks. Method said to be highly effective. Other methods of recovery described. Six illustrations.

R. W.

CROWNINGSHIELD (G. R.) AND ELLISON (J. G.). ***The determination of important optical properties without instruments.*** Gems and Gemology, Vol. VII, No. 4, pp. 120-124. Winter, 1951-2.

The detection and estimation of double refraction, and the dispersion, of gemstones without instruments. The stone is held up to the eye and light from a small bright source examined through the stone. In doubly refractive stones the spectra of the source may be seen doubled and their separation allows estimation of the amount of birefringence. The length of the spectra indicating the dispersion. A modification of the sunlight and card test. Two llustrations.

R. W.

STRATTON (V.). ***Australian sapphire fields not fully exploited.*** Gems and Gemology, Vol. VII, No. 4, pp. 125-128. Winter, 1951-2.

A general survey of the conditions in the Central Queensland sapphire fields. Seven illustrations.

R. W.

TRUMPER (L. C.). ***Rhodolite and the pyrope almandine series.*** Gemmologist, Vol. XXI, No. 247, pp. 26-30. February, 1952.

The results of an examination of a number of rhodolite garnets and comparison with other garnets of the pyrope-almandine series. The occurrence of rhodolite at Macon Co., N. Carolina, is described and mention is made of another occurrence in Greenland. Eight photomicrographs, one graph and one table.

R. W.

PARKINSON (K.). ***Kashmir sapphires.*** Gemmologist, Vol. XXI, No. 248, pp. 39-40. March, 1952.

The term " Kashmir sapphire " so often seen in jewellers' windows are more likely to be good Ceylon stones. The term " Kashmir sapphire " being used in a similar manner to " Burma ruby " and " Siam ruby " as an adjective for colour rather than for locality. True Kashmir sapphires are not plentiful for the mines are inaccessible for most part of the year. The few sapphires mined are of fine quality. R. W.

SCHLOSSMACHER (K.). ***Synthetische Sternrubine und -saphire.*** Synthetic star rubies and sapphires. Gold und Silber, Vol. V, No. 2, p. 16, February, 1952.

Hitherto these synthetics contained rutile needles in a surface layer only. Now a titanium containing compound is added to the raw material. The boule is heat treated afterwards at 1,000-1,500 deg. C., when the titanium oxide crystallizes in the form of needles within the whole structure of the corundum lattice. E. S.

SWITZER (G.). ***Present states of the turquoise industry.*** Gems and Gemology, Vol. VII, No. 4, pp. 113-115. Winter, 1951-2.

A report on the sources of gem turquoise and the quantity and value of the rough material. Now only Iran (Persia) and the U.S.A. important producers. A note on imitations is given. Two illustrations. F. T.

WEBSTER (R.). ***The Soxhlet extraction apparatus.*** Gemmologist, Vol. XX, No. 244, pp. 224-227. November, 1951.

A description of the apparatus devised by Franz Soxhlet for the extraction of a soluble substance by a continuously re-distilled solvent and its suggested employment for removing extraneous matter from cracks and flaws in gemstones. Three illustrations. P. B.

LEWIS (M. D. S.). ***The diamond—before and after.*** Gemmologist, Vol. XXI, No. 246, pp. 4-8. January, 1952.

Before the 16th century diamonds were not employed in jewellery, and the trend was in coloured stones and enamels. When the fashioning of diamonds became an art the styles of jewellery changed. The history of the fashioning of diamond and its use in the Renaissance, 17th and 18th centuries is given. Rock crystal not used for gems in mediaeval times. Three illustrations. R. W.

COLOUR PERCEPTION IN GEMMOLOGY

by M. D. S. Lewis, B.Sc., F.G.A.

MOST gemstones owe their colour to selective absorption. Light enters the stone where some wavelengths are absorbed, the residual rays being reflected back to the eye in which they have the property of causing the sensation of colour. What happens within the stone is a matter of physics and chemistry which can be accurately specified and measured, but when the light reaches the observer's eye two other factors—physiology and psychology—must also be taken into account.

Suppose a lady in an attractive orange-coloured dress and wearing a magnificent emerald brooch makes a dramatic entry into a room. A keen male gemmologist might perhaps only " see " the deep velvety green of the emerald and remain quite oblivious to the colour of the dress, in spite of the fact that orange light is entering his eye. A fashion writer might probably enthuse over the orange-coloured dress and remain only vaguely aware of a large ornament accompanying it. A female gemmologist would probably " see " both green stone and orange dress. In each case the physics of the light is identical ; the same proportions of green and yellow light enter all three pairs of eyes, yet the colour perceptions are different. " Colour," says R. M. Evans, is often a matter of " attention, intention and memory." This difference in " colour perception " arising through varying mental attitudes is not the only one. Assuming each of the three observers to have normal sight, the male gemmologist will experience the " normal " green of the emerald and the fashion writer will likewise see the " normal " orange colour of the dress, but the female gemmologist will experience neither. By gazing simultaneously at green stone and orange fabric the " adaption " of her eyes will change and she will probably experience the phenomenon known as " simultaneous colour contrast." To her, the emerald will seem more " bluish " green and the orange of the dress will appear to contain a greater amount of red.

Already a difference has arisen between " colour " and " colour perception," but at this stage the impatient reader will probably declare that he does not care about the female gemmologist's eyes ; everyone knows that this emerald is green and the dress is orange-coloured. This is reasonable enough, because the word " colour " has come to be identified with the appearance to an average observer in daylight under normal conditions. The colour actually perceived, however, may be quite different under varying circumstances. Although we may prefer to imagine that the redness of a ruby resides in the stone rather than in our own eyes, this is, of course, not the case. If the illumination on a ruby be gradually reduced the colour changes through brown to black ; if it is illuminated by blue light it will probably appear blue, whilst in spectrally pure green light it may appear black. Obviously redness is not a constant property of ruby.

To elucidate some problems of colour we must therefore examine them against the wider background of " colour perception." In doing so we transfer the scene from the gemstone to the observer's eye where, in addition to the physics of the light, we must take circumstances into account. Theoretically and practically the subject is of importance in gemmology. The purchaser of a coloured stone does not usually care about the position of absorption bands, but is interested in the colour actually perceived. An understanding of the subject would be essential in any workable system of colour specification and measurement. It embraces theories of cutting, illumination and colour contrasts, whilst it provides an explanation of a number of gemmological phenomena.

It is generally accepted that there are three aspects or attributes of " colour perception." In gemmology obviously the most important is " hue," which is largely determined by spectral distribution. This is the attribute by which green is distinguished from red, blue from yellow, and so on.

Now consider two synthetic red corundums each made by adding chromic oxide to alumina. Suppose that one contains a very minute quantity of colourant and is pale pink, whilst the other is deep red owing to a larger content of chromic oxide. In both cases the absorption spectrum will be typical of chromium and obviously spectral distribution is similar, yet we get two quite different colour effects. The " hue " is the same but something

else varies. This second attribute is known as " saturation " and refers to the intensity or concentration of hue.

Now imagine a well-kept grass lawn of uniform texture illuminated by strong sunlight. The colour will be bright green and at every point " hue " and " saturation " will be constant. Suppose a large tree to throw a deep shadow in one part ; within this area, yet another colour effect—dark green—is seen. This third attribute is " brightness " and is connected with the total quantity of light reaching the eye.

Colour perception has thus three attributes—Hue, Saturation and Brightness—and all three are needed to specify the appearance of any colour. Hue and Saturation are purely mental concepts and cannot be measured outright. No one can define exactly how " blue " is a sapphire ; it can only be compared in blueness to another blue object.

HUE.

As already stated, " Hue " is the attribute of colour perception by which we distinguish red from blue, green from yellow, etc., and is dependent on spectral distribution. The great importance of absorption spectra in practical gemmology naturally focuses attention on the position of absorption bands, but what really determines colour is not the light absorbed, but that which is transmitted. An absorption spectrum seen in the spectroscope or as a photograph often gives little indication of the actual colour. The areas of red, blue, etc., are quite arbitrary, depending on the instrument used. Partial absorption can take place over a wide range without producing an obvious band and a photographic plate is mainly affected by blue and violet rays, whereas the eye is most sensitive to yellow-green light. What really counts as regards colour perception is the relative energy of the transmitted rays. This is measured by placing a suitable receptor in successive parts of the spectrum so that the energy in the various wave bands is converted into heat or electricity and measured. A graph is then drawn to connect wave length with relative energy. Fig. 1 shows the spectral distribution of light from a hypothetical purple gem. The most important feature in this type of graph is the area underneath the curve. Between 4,000Å and 5,000Å this is larger than under any other 1,000Å stretch of curve, so " blue " energy will predominate

Fig. 1

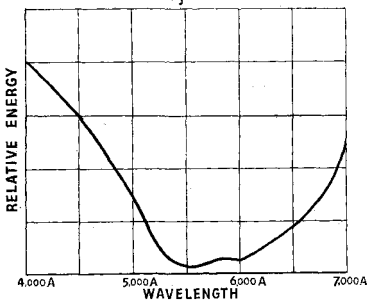

Relative energy curve for light transmitted through a hypothetical purple gemstone.

Fig. 2

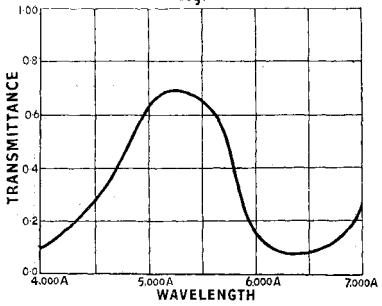

Transmittance curve of hypothetical green gem material.

Fig. 3

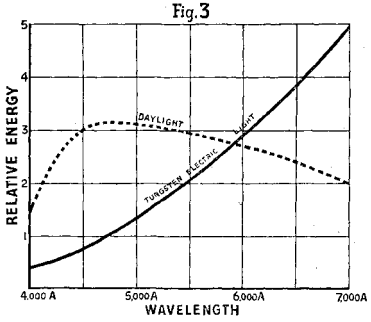

Spectrophotometric curves showing relative energy distribution for daylight and tungsten electric light.

Fig. 5

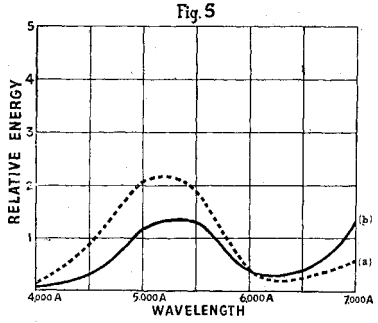

Approximate relative spectral distribution curves of:

(a) Daylight transmitted through gem material of Fig. 2.

(b) Tungsten electric light transmitted through gem material of Fig. 2.

(a) Will probably appear blue-green, whilst (b) will appear yellow-green.

These are the approximate product curves of Figs. 2 and 3.

admixed with a lesser amount of orange and red (approximately 6,000Å-7,000Å). The area under the graph in the green and yellow wavelengths (approximately 5,000Å-6,000Å) is relatively very small so the colour impression will be bluish-purple. At this stage a distinction must be made between coloured objects and coloured light. The above graph merely depicts the quality of the light which has

passed through and left the gemstone. As will be seen later, it does not necessarily completely define the selective absorption characteristics of the stone. Whilst we speak of the energy of light we cannot do so of an object. In this case we relate percentage transmission with wavelength and this is done by measuring in series, the percentage absorption of monochromatic lights and again drawing a curve. Such a graph is seen in Fig. 2 and this would correspond with the Relative Energy-Wavelength curve for the transmitted light, only if light falling on the gemstone had equal energy in each region.

The absorption spectrum of a gemstone shows that some wavelengths of the incident light are absorbed whilst others are permitted transit. If these permitted wavelengths are not present in the incident light there naturally cannot be any transmission in these regions. For this reason the colour displayed by a gemstone depends on the illumination. There are three main types of illuminant in general use—sunlight or daylight, tungsten electric and fluorescent light. Fig. 3 shows the spectral composition of daylight and tungsten electric light, from which it will be observed that daylight is fairly well balanced in energy distribution whilst electric light is relatively poor in blue and rich in red rays. The amount of blue energy in sunlight or daylight is variable, depending on time, place and atmospheric conditions. Fig. 4 shows that fluorescent lamps can have almost any kind of spectral distribution. To evaluate the resultant effect of any illuminant on a coloured transparent object one must combine the Relative Energy curve of the incident light with the transmission curve of the substance. This is done by multiplying for each band of wavelengths percentage transmission by relative energy. Fig. 5 shows the different effects of daylight and electric light on a gemstone. The two relative energy curves in Fig. 3 have been respectively combined with the transmittance curve in Fig. 2 and the resultant product curves are shown in Fig. 5. These specify the spectral distribution of daylight and electric light after transmission through the stone, which will appear bluish-green by day and yellow-green by electric light. The actual hue assumed by a gemstone must therefore depend both on the spectral distribution of the illumination and its own absorption characteristics. For this reason it is possible a gemstone might appear in some quite unnatural hue under fluorescent light. For

Fig. 4

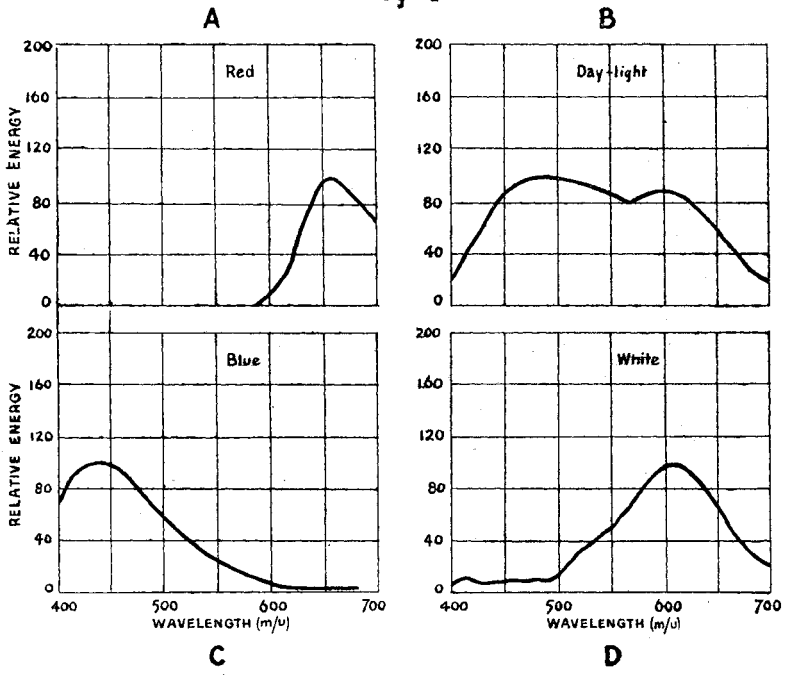

Spectral distribution curves for several types of fluorescent lamps. From "An Introduction to Colour" by Ralph M. Evans (Chapman & Hall Ltd.).

example, a good alexandrite, green by day, will appear red under tungsten electric light, but if the illumination were provided by a fluorescent light of spectral composition corresponding to Figs. 4B or 4C, it would certainly not change in colour but might even appear more green.

Assuming an isotropic stone to be perfectly uniform in colour, it might be supposed that the " hue " or spectral composition would be constant for all directions of view and independent of the depth or thickness. This is not necessarily so, particularly if there is more than one absorption band. The relationship between thickness and " hue " is governed by Lambert's Law, from which it may be deduced that where " T " is the transmission for a particular wavelength for a particular layer, then T^n is the transmission for " N " layers. Thus, if for a certain thickness the transmission

Fig. 6

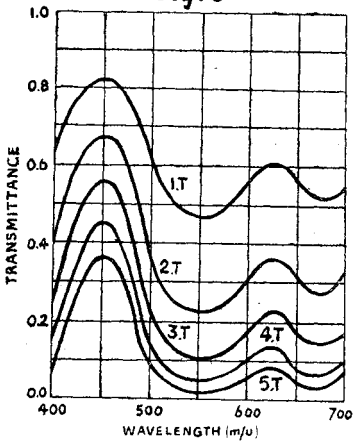

Transmittance curves of five thicknesses of a coloured transparent material.

From "An Introduction to Colour" by Ralph M. Evans (Chapman & Hall Ltd.).

Fig. 7

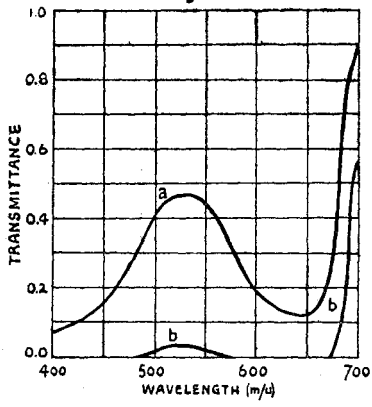

Transmittance curves for a selective material of (a) a given thickness and (b) five times the thickness.

From "An Introduction to Colour" by Ralph M. Evans (Chapman & Hall Ltd.).

of a certain wavelength is 20%, it will fall to 4% for a double layer. If for another wavelength it is 50%, then the transmission for the double layer will only fall to 25%. In other words, the shape of the transmission curve may change with increasing thickness. This effect is not to be confused with the increase of saturation which naturally accompanies increasing depth ; even with constant hue a thin layer of the darkest material will appear pale in colour, but here the difference is only one of intensity, not of spectral distribution. In Fig. 6 curve IT represents the transmission of one thickness of coloured material. It will be seen that "blue" energy is predominant, there is a deficiency of green and considerable reinforcement of orange and red, which will probably produce a violet-purple colour. Curve 5T shows the percentage transmission of five thicknesses. Here green and red have almost vanished so the resulting hue must be nearly pure blue. Fig. 7 shows this change more strikingly. Curve (a) obviously refers to a green object, but in a piece five times as thick the area under the red end has become greater than that under the green region, so the overall colour impression will change from green to red.

Although this phenomenon must occur to some extent in most transparent substances, it is insignificant in normal gemstones, firstly because they do not absorb very strongly and secondly because they are not thick enough. Some glasses incorporating rare earth oxides do show this phenomena and are markedly "dichromatic," the colour changing with thickness.

There are two ways of causing or modifying "hue"—subtractively or additively. The colour of gemstones is subtractive because some part of white light is subtracted to leave a coloured residue. Thus, if a stone absorbs strongly, say, in the middle part of the spectrum, it amounts to a subtraction of green and yellow from white light, leaving substantially blue and red transmission, which gives the sensation of purple. Physics by itself cannot forecast the precise colour sensation of a subtractive mixture. In the case of more than one subtractive process the only wavelengths finally appearing are those common to both transmissions. Suppose a blue stone to be examined through a yellow glass, what hue will be likely to result? Blue stones usually transmit blue and a certain amount of green light. A yellow glass will probably transmit in addition to yellow some red, orange and green rays. Green transmission is the only one common to both systems and this would therefore be the hue of the light which reaches the eye.

Additive hue results from the combined effects of coloured *lights* which reach the eye simultaneously. Any colour can be matched by the mixture of three primaries—e.g. red, green and blue—in suitable proportions, although white light may have to be added to the original. This is a fact of the utmost importance and is the basis of widely used systems of colour specification and measurement. Suppose two approximately monochromatic lights are mixed. If they are far apart on the spectral scale, i.e. one in the red and the other in the blue, their effect is to give purple. If nearer together—say one in the orange and one in the blue, or one in the red and the other in the blue-green—the tendency is to give white or grey. If closer still, say one in the red and one in the yellow, we get an intermediate—in this case orange colour.

Additive colour enters gemmology in questions of illumination. It is important to remember that when coloured light is reflected at another coloured surface it remains unchanged in hue. Thus, green light reflected from a yellow surface will still remain green.

Fig. 8.

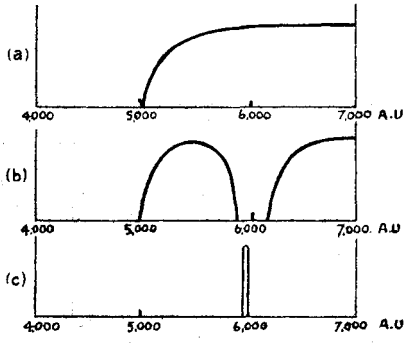

(a) A subtractive yellow — e.g., a solution of yellow dyestuff.

(b) A subtractive yellow, obtained by adding a neodymium salt to (a) and so removing all the true yellow from the transmitted light.

(c) Spectral yellow, such as is obtained by suitably filtering light from a mercury arc lamp.

Three yellows which under suitable viewing conditions would be undistinguishable by the human eye.

From "Colour in Theory and Practice" by H. D. Murray and D. A. Spencer (Chapman & Hall Ltd., London, W.C. 2).

If a room is illuminated by sunlight through a window, outside which stands a leafy tree, an extra amount of green light will mix with that of the sun. If within the room there are yellow walls and a red carpet, these will also add their quota of yellow and red energy to the general illumination. The spectral distribution of light may therefore vary greatly from room to room and for this reason dealers usually prefer to examine stones in their own offices where they have become accustomed to the vagaries of the light.

The unaided eye has very little power to analyse light. Fig. 8 shows the spectral composition of three different yellow lights which are visually indistinguishable from each other. Light represented by curve 8 (b) is particularly interesting as it contains no yellow rays whatever of wavelength approximately 6,000Å, yet monochromatic light of precisely this wavelength will cause identical yellow sensation.

The dependence of "hue," not only on the spectral characteristics of a stone but also on the nature of illumination, has already been mentioned. It has also been seen that illuminants differ very widely in spectral composition. It must therefore seem strange that, after all, the hue of most stones does not appear to vary greatly under normal conditions. An emerald usually looks like an emerald in daylight, electric light, fluorescent light, fog, twilight, etc., in spite of the fact that light transmitted by the stone

under all these extremes of illumination must vary greatly in spectral composition. Why, then, does the " appearance " (that is to say, the colour perception) remain so constant?

This brings us to one of the most important facts of colour perception—the adaptation of the eye.

Without attempting to discuss physiology, it can be said that as regards colour the eye behaves as though it were governed by three receptors sensitive to Red, Green and Blue respectively. If it receives a blue stimulus the sensitivity of this receptor is depressed, whilst that of the green and red receptors increases relatively. It would appear that the eye is normally adapted to daylight and when we change over, say to electric light, which has excess of red energy, there is a change of adaptation and we become relatively less sensitive to red and more so to blue and green, thus tending to neutralise the change. Whenever there is a change of illumination the eye tries to adapt itself in such a way as to keep the appearance that of daylight. It must be stressed that this is purely a physiological and psychological effect. If we were to make a strictly physical examination of the light transmitted by a stone in daylight and again in artificial light, we might get very different results, but within limits the actual appearance would remain fairly constant due to the ready adaptation of our eyes to changed conditions. In the case of alexandrites and some synthetics the shift of hue with changing illumination becomes too strong for adaptation to cope with and quite a new appearance results. The adaptation of the eye is surprisingly great and often dominates situations in which colour is involved. Some electric light is decidedly yellow, yet a sheet of white paper illuminated by it still looks white. If the light reflected by the paper were examined spectrophotometrically it would show high relative energy in those wavelengths which normally produce a " yellow " stimulus. From every physical point of view the paper should look " yellow," yet the eye adapts itself in such a way that we still obtain the " normal " daylight impression of whiteness.

Adaptation accounts for the phenomena known as " after images " and " colour contrasts." At the beginning of this article a somewhat far-fetched and hypothetical situation was described in which a female gemmologist experienced colour sensations

different from those of her less observant companions. When she looked at the emerald the sensitivity of her green receptor was depressed and her blue and red receptors became relatively more active. The orange-coloured dress reflected mainly red and yellow light. This red component then exerted greater effect on her perception through increased activity of her red receptor. Therefore she " saw " the dress in a redder light than the others. When she looked at the orange dress her red receptor became depressed by comparison with her blue receptor. The emerald therefore appeared more blue-green. The effects of surroundings on colour can be worked out in this way from first principles. Suppose we have some greenish-blue turquoise and wish to make it appear more blue. We can do this by decreasing the sensitivity of our red and green receptors, thereby increasing blue sensitivity. Spectral red and green lights unite to give yellow-orange ; therefore by surrounding a greenish-blue turquoise with yellow-orange its apparent blueness should increase. These few remarks on adaptation emphasize the subjective nature of colour.

This may perhaps be the place to mention " white, grey and black," which actually are not colours as they have no hue. Strictly speaking, the term " white " can only be applied to a surface which reflects all wavelengths of the visible spectrum with no change in spectral distribution or intensity. If the spectral distribution of the reflected light remains unchanged but its intensity is less then greyness will result. Blackness is experienced when the intensity is too low to produce a stimulus on our visual mechanism.

There are three stages in the perception of " hue." Firstly, some kind of illumination must enter the stone as without illumination there is no colour. The physical properties of this light can be stated unambiguously. The second stage is the interaction between light and stone and the result depends both on the spectral distribution and energy of the light and the absorption properties of the stone. The modified light which issues from the stone can also be completely defined in physical terms, but when it enters our eyes we leave physics behind because we are in the field of physiology and psychology, where another and most important factor has now to be considered—the differential sensitivity of the eye to various wavelengths. The " Relative Energy-Wavelength " curve should always be " weighted " by optical sensitivity in order truly to

evaluate colour sensation. This, however, involves the more difficult concept of luminosity, a discussion of which will be left until later. To quote R. M. Evans* once again: " Colour is what you *do* see, not what you are supposed to see."

SATURATION.

Saturation is that attribute of " colour-perception " which differentiates between shades and tints of the same hue. It may also be defined as " percentage of hue " or, in the case of pigments, " freedom from white." Consider again the making of a batch of synthetic red corundums in which the same colouring matter is used throughout but in decreasing quantities. A series of red stones will result, all alike as regards spectral composition and hue but varying in intensity of colour. Those containing a relatively high proportion of chromic oxide will be deep red, but as the amount of colourant is reduced the colour will fade to pale pink. The saturation of the colour refers to its place in this scale.

Saturation is probably the most interesting attribute of gemmological colour and, like hue, is largely subjective, often depending on circumstances. If a stone has a certain hue—due to its spectral composition—there is not much to be done about it ; it can be made to appear slightly different through physiological or psychological agencies, but a sapphire cannot be made to look like an emerald. It is of greater importance and often easier to alter the apparent saturation of a stone—to change a poor ruby red into a deeply saturated one. This is not to infer that the stone has to be " faked." It has been repeatedly stressed that colour perception is a mental sensation, depending not only on the stone but also on what goes on in our eyes.

At this stage we must pause to consider what we really want in a gemstone as far as appearance is concerned. The fundamental and primary reason for the wearing of jewellery was (and probably still is) the attraction of attention to parts of the human body. Attention is always drawn to something which is changing relative to its surroundings or to something which is already different from its environment. The colourless gemstones compel notice through their ceaseless variations in reflective and dispersive effects, whilst the deeply coloured gems differentiate themselves from their surroundings through outstanding saturation of colour. Some stones,

of course, attract attention through chatoyancy, asterism or adularescence.

In all questions concerning the appearance of gemstones it is essential to realise that two different kinds of light always travel from stone to eye. No gem is normally viewed solely by transmitted light except when under microscopic examination. It is always seen by a combination of reflected and transmitted light. Of the light which strikes the surface, some is reflected immediately back to the eye without change. Normally this is white (or, more correctly, colourless), but if not, it undergoes no change in colour on reflection at the surface. If one arranges red, blue and green stones so that an electric light bulb is reflected in the tables, the image has substantially the same yellow colour in each case and by concentration on the image one can become quite oblivious to the colour of the reflecting surface. The remainder of the incident light—that is to say, those rays which are not reflected at the surface—penetrates the stone and there undergoes selective absorption or dispersion before reflection back to the eye. These rays which have penetrated into the stone are essentially transmitted light, in spite of ultimate reflection from the back facets. The all-important point to remember is that this transmitted light is never seen in its original purity. Before it can reach the eye it is always diluted by light reflected at the surface, which is, of course, the unchanged illuminant.

In the case of colourless stones the properties most valued are "brilliancy" and "dispersion." Brilliancy is mainly provided by light reflected at the surface and to a certain extent must increase with the number of facets on the stone. It is essential that at least one facet shall reflect light strongly to the eye from whatever position the stone is viewed. Dispersive effects (fire) are provided by light which has penetrated the surface. If only brilliancy were concerned it would be advantageous to cut the stone in such a way that the maximum proportion of light is reflected at the surface, but from the point of view of "dispersion" as much light as possible should enter the stone. It is the function of the lapidary to dispose the facets in such a way as to keep a nice balance between these two often conflicting properties in a colourless stone. It is reasonable to assume that the larger the table the more light can enter the stone, and if the incident rays were always vertically

parallel and the table of the stone always horizontal this would certainly be the case, athough other factors such as total area of surface must exert influence. The table of a stone can, however, be enlarged only at the expense of the side facets and therefore with some detriment to brilliancy.

With pale coloured stones a very interesting situation develops. The colour is not sufficiently saturated to satisfy by itself and a certain amount of brilliancy is needed in addition. This is probably why aquamarines and pink topazes, etc., are cut with a large table and numerous small side facets. The former allows maximum entry of light to provide colour and the latter tend to increase brilliance.

With densely coloured stones everything is different. We want deep saturation above all, not brilliance, which now becomes a definite nuisance. Surface reflections are here undesirable, firstly because they distract our attention from contemplation of colour and secondly because they dilute a saturated colour through the addition of white light. The greatest compliment we can pay an emerald is to say that it is of a " deep velvety " green. Now velvet is a material reflecting the minimum of white light. The incident rays are trapped in the long tapering fibres, repeatedly reflected downwards to the interior of the fabric, undergoing additional selective absorption each time. Thus, a velvet green is a deeply saturated colour.

If we have a rough emerald, how can we ensure that when cut it will show maximum saturation? Only by preventing as far as possible dilution with white light. To do this we must provide it with smooth, well-polished facets, *few in number*. We may be unlucky to see a reflection in one facet, but by moving our head slightly we shall avoid it, whereas if there were many facets there would be no position from which some reflection could not be seen. By sacrificing side facets we can also have a large table to allow maximum entry of light. It is suggested that this is the theory underlying the " emerald-cut." Some readers may now perhaps wonder why smooth, well-polished facets are essential for maximum saturation of colour. Why not leave the stone rough and so avoid these brilliant but unwanted surface reflections? The answer is that we *cannot* do away with surface reflection, which must always

occur to some extent when light strikes any surface. Consider the simplest possible case in which a well-cut and polished emerald is illuminated by parallel light from the sun falling on the table facet. In one direction, and *one direction only*, we shall get specular reflection. We shall probably see an image of the sun, we shall be dazzled, our attention will be distracted and we may even become quite oblivious to the colour of the stone. Even if we do see some colour it will be quite desaturated through heavy admixture with white light. All of these unpleasant effects, however, will only occur in one unique position. There will be almost an infinity of other positions from which we can enjoy the full saturation of colour without dilution with white light. Of course, the situation is never as ideal as this. Even if the sun is shining strongly a large proportion of diffuse illumination from the sky and surrounding objects will also be present. Neither does indoor illumination usually provide parallel rays and, even if it did, diffused light would come by reflection from walls and ceiling, etc. Nevertheless, it is a fact that a single concentrated source of light gives maximum saturation which decreases rapidly as illumination becomes more diffuse. It is also true that maximum saturation is obtained when a coloured surface is viewed perpendicularly, because in this direction our eyes will receive the minimum of surface reflected light.

This explains why a badly worn stone improves in colour on repolishing. A rough surface is one containing numerous tiny facets scattering light at all angles. There is no position from which undiluted colour can be received. By repolishing we accept these annoying surface reflections as inevitable but " canalise " them in one direction. We then step aside and by-pass them. For the same reason a faint layer of dust will desaturate a colour out of all proportion to its obscuring power. The minute particles scatter white light in all directions.

It should be noted that stones of relatively low refractive index should show maximum saturation. Surface reflection increases with refractive index. A diamond will reflect about 17% of the light striking the table perpendicularly ; with emerald the proportion drops to about 5%. The effect is therefore cumulative, for not only does more light enter an emerald to produce colour, but it is also less diluted after emergence from the stone. Even if a diamond were found naturally coloured green by chromium, or a synthetic

rutile were made in an emerald green colour, the saturation could not equal that of a good emerald because the very high refractive indices of these two stones would cause too much surface reflection.

Assuming that colour is due to the interaction between a ray of light and a colouring ion, it seems obvious that " more " colour will result by increasing the number of colouring ions. In most natural stones this can be attained by cutting them as deep as possible. The same result, however, is often achieved more easily by making the rays of light travel greater distances within the stone so as to meet more colouring ions in their path. By a suitable disposition of the back facets the rays of light which have entered the stone are repeatedly internally reflected, thus lengthening the light path and increasing saturation. Indian lapidaries are very skilful in bringing out this effect. By cutting an almost colourless stone in such a way that a small coloured area is located near the culet, most of the rays which enter the stone are made to pass, perhaps many times, through this spot, thus emerging effectively coloured.

One way of improving saturation would be to cut the material in concave form. The interior of a coloured bowl tends to show greatly enhanced saturation as the rays of light are repeatedly reflected from one side to the other before emergence, and with each reflection increased selective absorption occurs.

Fig.9

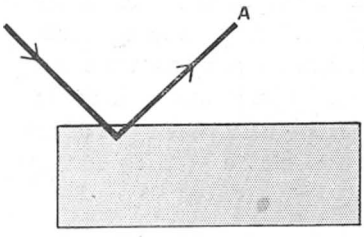

Rays of light undergoing selective absorption in a coloured substance. The ray "A" has only been reflected once and may therefore show incomplete saturation.

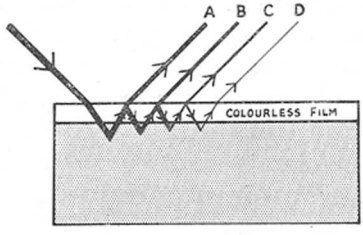

The addition of a colourless film to a coloured surface increases saturation. Through repeated selective absorption the reflected rays "B," "C," "D" become progressively more saturated.

Another method would be to deposit a layer of colourless material on top of a coloured surface (Fig. 9). Many of the rays

which would otherwise escape from the coloured material are then reflected downwards at the air-film interface into the coloured medium again, thus acquiring increased saturation. This effect is even more marked when the original coloured surface is rough as the newly added film substitutes a smoothly reflecting surface.

If a stone is badly worn and it is required to form an estimate of the colour after repolishing, a good, though perhaps optimistic, idea could thus be obtained by placing a drop of liquid on the surface. This effect is really quite different from that obtained in the new-coated stones on which the film is so thin that interference colours result, or, in other words, a new hue is produced. When the added layer is comparatively thick there is no change in hue, merely increased saturation.

Adaptation of the eye plays an important part in saturation. The " colour-contrasts " and " after-images," referred to earlier, result from the depression of one or two of the colour receptors in the eye. In effect this usually induces a complementary sensation. Thus, if we gaze at a blue object and then look at a neutral background the complementary colour of yellow is seen. To display coloured stones to their best advantage they should in theory be shown against a background of complementary hue, which will provide the most effective contrast. Thus, an emerald would seem to require a purple background since this colour gives an " after-image " of green, which, when added to the normal hue of the stone, increases the apparent saturation. Likewise, a green background might be most suitable for amethysts. It is, however, an unexplained fact that a grey background often seems to improve saturation.

Any very thin piece of gem material will appear pale in colour since the light path is not sufficiently long to provide complete selective absorption. As the depth increases the colour becomes more and more saturated until a certain point is reached when added thickness produces no further improvement but only darkens the stone. At this point of maximum saturation, all those wavelengths which the stone is capable of absorbing have been abstracted from the illuminating rays. The absorption bands are fully defined and complete. Added thickness now only reduces the intensity of all wavelengths impartially. General absorption supervenes on

selective absorption, the total amount of light reaching the eye begins to diminish and the stone darkens. This brings us to the third attribute of " Colour-Perception."

BRIGHTNESS.

"Brightness" is the attribute of colour by which we distinguish between lighter tones and darker shades of the same hue and it varies with the physical intensity of the light which produces it. The saturation of a hue indicates its position on a scale at the extremes of which are spectral purity on the one hand and colourlessness or whiteness at the other. The brightness of a hue defines its position on another scale, at one end of which is maximum transmission or reflectance and at the other—blackness. A Burma ruby, pink sapphire and Siam ruby all have the same hue, viz., red." The first two vary in saturation, but the two rubies differ from each other in brightness. The Burma ruby woud be accounted as being of medium brightness, whilst that of the Siam ruby would be decidedly lower and its redness, therefore, would be tinged with brown. Most transparent objects of maximum saturation, including the majority of valuable coloured gems, are moderately bright. If attempts were made to increase their brightness by forcing more light through, their saturation would decrease.

Whilst luminous transmission or luminous reflectance can be measured, the actual sensation of brightness is almost entirely comparative. If one looks at an incandescent light at night the effect is one of blinding brightness, yet the same lamp in daylight appears quite inconspicuous. If the illumination in a room be gradually reduced, there is little diminution in brightness of the objects within, particularly if some little time is allowed to elapse, so that the eye can adapt itself to the new conditions. It, however, the illumination on one object only is reduced, it will assume a " grey " appearance by contrast with the others. Brightness is the most puzzling aspect of colour. If the illumination on a white surface be reduced to half it will probably still appear white, yet if instead black is added so that its reflectance is reduced to a half it will appear a decided grey. In both cases the physical stimulus is the same but the eye reacts to them differently.

It has already been stated that the most deeply coloured stones should be cut to a depth just sufficient to allow maximum

saturation. Beyond this, increasing depth merely decreases brightness and the colour begins to move towards black via grey or brown. In some stones which absorb more strongly, however, saturation must be sacrificed for brightness if a pleasing appearance is to result. This applies particularly to red garnets, which from the æsthetic point of view should always be cut thinly and set closed at the back, over some brightly reflecting material. General absorption is so heavy that every device should be used to return as much light as possible to the eye.

The concept of brightness may not present many difficulties to the paint technologist, who deals with opaque surfaces viewed solely by reflected light. Nor perhaps to those who are concerned with transparent objects such as coloured signal glasses or stained glass windows, which are viewed only by transmitted light. To the gemmologist it presents a more difficult problem since a gemstone is always viewed both by reflected and transmitted light. It is difficult to disentangle the brightness of a gemmological colour from what is usually called the brightness of the stone and which is partly determined by the form in which it is cut.

To sum up, colour cannot be defined in physical terms. If it could, then a blind person might know as much about it as anyone else, which would be absurd. It is largely a mental sensation and must, therefore, be assessed against a " psycho-physical " frame of reference. It is determined by the three attributes of Hue, Saturation and Brightness, but these seem such fugitive qualities one might well despair of ever being able to measure them. It says much for the ingenuity of colour physicists that methods have been found of specifying a colour in figures. How this is done and whether it could be applied to gemmology may possibly perhaps form the subject of another article.

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THE ART OF THE LAPIDARY

MEMBERS of the Gemmological Association learned some of the secrets put into practice by the craftsmen who make gems when they heard two of the leading lapidarists at the British Council Cinema on January 23rd, 1952.

The two craftsmen were Mr. C. L. Arnold and Mr. G. E. Bull-Diamond, both of Charles Matthews, Ltd., the first being a cutter and the second a polisher.

Mr. Arnold began by having a picture of himself at work thrown on the screen and describing the tools he uses. The first thing to consider in cutting a stone, he said, was to study it and decide just what should be done: whether it should be round, oval, trap-cut and so on. Unlike the mathematical methods used in cutting a diamond, coloured stones had to be cut according to the disposition of the colour in them. That was the main factor to be borne in mind, though there were others. The hand and the eye were the important tools. Accuracy had to be judged by the eye and feel guided the worker with his cutting wheel, which was turned by hand.

Demonstrating with two rough pieces of sapphire and ruby how the disposition of the colour lay, Mr. Arnold said a stone could be ruined merely by trying to make it as large as possible. The density and the disposition of the colour determined how the cutting should be done. But after viewing a piece of gemstone and perhaps deciding how it might be cut, the worker did not go right ahead with the cutting. He would rough it up first, and he might change his mind after that, several times, before coming to a final decision.

Mr. Arnold went on to deal with the placing of the facets. The first and most important thing was to have the stone mounted absolutely horizontal to the stick so that the table was straight. The cutting started with the forming of the first facet next to the

table, then the one opposite. Then came two more on each of the other sides, and finally an octagon was made and the basic facets were then done. The rest of the cutting was "fairly simple." The most difficult was getting the first square of facets. The cutter could not use any measuring tools and had to rely upon the skill of his eyes and hand. On the back of the stone each facet should be opposite the ones on the front. All the lines of the facets should run straight towards each other, otherwise there would be distortion and the stone would not look at its best.

A carborundum wheel was used for the first roughing up of the stone, but hard stones had to be cut on a steel or copper wheel charged with diamond, which had to be evenly spaced. Examples of unpolished stones which had gained awards at the Crafts competitions at the Goldsmiths' Hall were shown on the screen and Mr. Arnold added that the cutter's work was not necessarily confined to precious stones. Compass bearings and scientific instruments needed by ships, aircraft and land vehicles had agate or knife bearings which had to be made.

Mr. Arnold closed by referring to the new stone, synthetic rutile. He was the first man here to cut it, he believed. It was an entirely new material. At first no one quite knew how to treat it or the best way to cut it. It could not be dealt with like an ordinary stone because it did not respond in the same way, but he believed now that more had been discovered about it than was known in the United States, and having worked out his own method he did not think it could be improved upon. He had seen a number of rutiles that had been cut in America and he could not learn anything from them. The boules varied and he had yet to find one which would cut all the same coloured stones, though the colour might look the same in the boule. He had cut them all ways from the boule, not necessarily through the axis.

Some people might think that only the front of a stone mattered, but it was his experience that the back was most important. It was a mistake to concentrate on the front. The back must be in proportion and the back needed special treatment according to the colour of the stone. More facets were needed on the back for a light stone like aquamarine, while a dark stone might need facets planned to keep the colour out. A pale stone could be made darker by the placing of the back facets.

Mr. Bull-Diamond then spoke on the art of polishing. For this the light touch and hand-driven wheel of the cutter gave way to a firmer pressure and a power-driven wheel. That was why, as a rule, the cutter and the polisher were two different persons, each specialising in one branch of the craft, though they could often do either job. The polisher with his power-driven wheel sometimes used a control to vary its speed. It was important to keep the wheel clean. Dirt would scratch and a scratch on one facet would be multiplied many times. The wheel, running at about 400 r.p.m., must be absolutely true. The wheel was " sharpened up " with sandstone to get " bite," and the polishing was done by rotten stone and water. Copper wheels were general, though a lead or pewter one might be used for a soft stone such as fire opal or rutile and a softer abrasive than rotten stone.

The first and one of the hardest things to do was the table. The table was mounted at 45 degrees to the stick. It might be necessary to grind out cutter's scores. After that the stone could be put straight and the polisher started on the inner facets, first doing the square and then filling this up with the other four. For oval or cushion stones a slightly different routine would be followed. However, after finishing the octagon, the polisher went on to the broads. Sometimes the cutter might not get these facets quite true and would leave it to the polisher to do this.

Mr. Bull-Diamond, after showing some prize-winning examples of polished stones, said that sometimes the polisher had to close a flaw in a stone. It might not be possible to polish a flawed stone in the orthodox way, for a flaw could not be ground out. The whole secret of polishing lay in holding the stone so that the facet was flat. Clean facets, flat facets, true facets. Those were the aim of the polishers. though there were other things that had to be borne in mind. Thus, a zircon had cleavage facets and care might have to be taken. Sometimes, with a tricky stone, Mr. Arnold would put the eight facets on and he would put the rest. Such co-operation made for perfect results.

For a cabochon cut the polisher might use a smoother wheel, working down to a wooden one. Only a small amount of polishing would be done at a time with fine diamond powder until a lovely velvet finish was obtained. Mr. Bull-Diamond showed an 1850 crystal of 3.4 cts. which won a medal then. It had 43 facets, front

and back. A crystal, he said, was a difficult stone to polish being, like all quartz, soft and inclined to scratch. For such soft stones pumice might be used on a felt wheel. He went on to speak of the crystal pommel of the Stalingrad Sword which he and his workmate had helped to make. Here the difficulty was in coming down from the oval to the round at the base and the metal that had to go through the centre.

Mr. Knowles-Brown, the Chairman, asked about the heat generated on the wheel, and Mr. Bull-Diamond said it was necessary to keep it cool with water. If the wheel went dry, the stone might be fired. A single mistake could flaw or fracture a stone. He added that rutile behaved differently from any other stone in this respect and it was not the same throughout as were synthetic rubies or sapphires. Like zircon, rutile had hard and soft patches, which were liable to fire. It could not be smoothed out like an ordinary stone by the cutter, and it must be done by the polisher.

Answering another question about the closing of flaws, he said that the lapidary went with the flaw and closed the material to it. It would open more if it was worked across, thus behaving like the grain in wood if it was planed the wrong way. A flaw might go half-way through a stone. The whole flaw was not closed, only the surface. He described how he had closed a flaw in an emerald. It was like a terrific gash to begin with, but when closed on the surface it looked little more than a hair-line.

Replying to a question about wastage, he said it would be about two-thirds of a parcel of stones, assuming that each stone was cuttable. Stones did not lose weight in polishing, which made it appear that a flow took place in the process. Water, sometimes diluted with sulphuric acid, was used to ascertain where the colour was in a stone. The colour, if it was to be retained, should lie across the culet. The colour band should not be penetrated. Then even the smallest amount of colour would still reflect.

Concerning the handling of star stones, Mr. Arnold said these were difficult. The art was to get it absolutely true, otherwise there would be a wave in the legs of the star. On the question of how long it took to cut and polish a stone, he said this varied. It might take half a day or two days. Sometimes a stone might be cut two or three times before it was satisfactory. The polishing of an intaglio was done with tools which the craftsman made himself.

ASSOCIATION NOTICES

GEM TESTING LABORATORY

It is gratifying to report that more pearls were tested at the Diamond, Pearl and Precious Stone Laboratory of the London Chamber of Commerce in 1951 than in any previous year. The grand total of pearls examined now stands at rather more than 900,000, and it is anticipated that the millionth pearl will be tested during 1953.

The number of reports issued during 1951, viz., 1,973, constituted an all-time record and there can be no doubt that the services of the Laboratory are being more widely sought after, despite the difficult times through which the trade is passing. A clear idea of the extent of this growth can perhaps be obtained by a comparison of the above figure with that of the best pre-war year, i.e. 1937, when the number of reports issued was 898.

The demand for tests on samples of diamond powder for industrial use has increased and the technique in dealing with problems of this nature has been improved. The quartz spectrograph has proved of great service in this particular work.

In the brief intervals between routine tests work has continued on the luminescence of gem materials. In addition to the standard "Wood's Glass" filter for the quartz-mercury lamp, the Laboratory has now a short wave filter, which increases the range of these investigations.

In 1949 it was reported that a second specimen of a new gem mineral resembling spinel had been found, the first and only other specimen having been brought to the notice of the Laboratory by Count Taaffe, of Dublin, in 1945. The chemical and X-ray analysis of this mineral (which has been named "Taaffeite" in honour of its discoverer) has now been completed in the Mineral Department of the British Museum.

TALKS BY FELLOWS

Solomon, S. T.: "Gemstones," Tavistock Toc H., November, 1951; Plympton Townswomen's Guild, January 8th, 1952; Erdington Townswomen's Guild, Birmingham, February 28th, 1952.

W. A. Peplow: "Gemmology." Scientific Society, King Edward School, Stourbridge, March 4th; "Gems," Business and Professional Women's Association, Stourbridge.

J. Gillougley: "Diamonds," Industrial Life Offices' Association, Paisley and District, March 20th.

Webster, R.: "The Problem of Synthetic Gemstones," Scottish Association of Watchmakers and Jewellers, March 26th, 1952.

GIFTS TO THE ASSOCIATION

The Council acknowledges with gratitude the gift of a parcel of 30 gemstones from Messrs. George Lindley & Co. (London), Ltd., St. Andrew's House, London, E.C.1.

SINHALITE—A NEW GEMSTONE

In connection with the note of a new gemstone, which appeared in Vol. III, No. 5, the co-author with Dr. G. F. Claringbull of a paper read to the Mineralogical Society on January 24th was Dr. M. H. Hey and not Dr. W. Hey, as reported. The chemical composition of the new mineral is $MgAlBO_4$.

COUNCIL MEETING

A meeting of the Council was held at 19/25 Gutter Lane, London, E.C.2, on Wednesday, February 6th, 1952, at 4.30 p.m. Mr. F. H. Knowles-Brown presided.

The following were admitted to membership:—

FELLOWS:

Clark, L. D. S., Oxshott (D.1951)
Dickson, R. W., Glasgow (D.1949)
Dimmer, G., Junr., Chester (D.1933)
Lerman, A., Toronto, Canada (D.1951)
Van der Heijden, C. J., Zoeterwoude, Holland (D.1951)

PROBATIONARY:

Austin, L. F., London
Brack, A. J., London
Caudell, P. M., London
Crouchley, D., London
Denham, F. J., Harrow
Edwards, J., Manchester
Hawtin, S. J., London
Urquhart, I. R., London
Yaghobi, H., London

ORDINARY:

Lee, H., London

The Council decided that it was necessary for all its examinations to be held under the ægis of a University, Education Authority or a recognised Gemmological Association and that arrangements should be made in connection with the two centres where this had not been the custom in the past. It was further decided to amend the bye-laws to enable the examiners for the time being to be members of the Council and, in addition to the officers, to allow the election, in accordance with the Articles of Association, of not more than nine other members, three of whom should retire annually. The audited accounts for the year ended 1951 were submitted and approved for presentation to the twenty-second annual general meeting to be held at Goldsmiths' Hall on April 2nd.

ANNUAL MEETING

The twenty-second annual general meeting of the Association was held at Goldsmiths' Hall, London, E.C.2, on Wednesday, April 2nd, 1952, at 7 p.m. Mr. F. H. Knowles-Brown presided.

Mr. F. E. Lawson Clarke (Treasurer) presented the audited accounts for the year ended December 31st, 1951, and the Chairman, after commenting briefly about the work of the year and annual report, which had been

previously circulated, moved that " the audited accounts and report of the Council for the year ended December 31st, 1951," be adopted. Mr. N. Kennedy seconded the motion, and the proposition was unanimously approved.

The following officers were re-elected: President, Dr. G. F. Herbert Smith ; Chairman, Mr. F. H. Knowles-Brown ; Vice-Chairman, Sir James Walton ; Treasurer, Mr. F. E. Lawson Clarke. The President suitably acknowledged the confidence given to the Officers on their re-election.

As the result of a postal ballot the following Fellows were elected to serve on the Council: Messrs. W. C. Buckingham, N. A. Harper and E. H. Rutland. Messrs. R. V. Blott and R. K. Mitchell were re-elected.

Messrs. Watson Collin & Co., London, were reappointed as auditors.

DR. G. F. HERBERT SMITH

Arrangements have been made to entertain to dinner Dr. G. F. Herbert Smith, C.B.E., M.A., D.Sc. (whose eightieth birthday will be on May 26th), in the Prince Consort Room, Royal Albert Hall, London, on Tuesday, May 27th, 1952.

The Chair will be taken by Lord Hurcomb, G.C.B., K.B.E., President of the Society for the Promotion of Nature Reserves. The Gemmological Association will be represented by Mr. F. H. Knowles-Brown and Sir James Walton, K.C.V.O., Chairman and Vice-Chairman respectively of the Association, and other Fellows.

Tickets (price ten shillings each) may be obtained from Miss F. O. Elwood, British Museum (Natural History), London, S.W.7.

AUSTRALIAN EXAMINATIONS

The Gemmological Association of Australia has announced the following results in connection with its 1951 examinations in gemmology:—

NEW SOUTH WALES

Beale, C. H.	Connelly, D. J.	Goldring, M. G.
Beckenham, N.	Cromack, R. H.	Hansen, W. R.
Bunker, Miss Shirley	Evans, Mrs. D. P.	Kelemen, Miss Eva
Cameron, Miss M. E.	Fisher, K.	Rouse, A.

VICTORIA

Klepner, F.	Rodgers, M. S.	Wylie, J.
Koller, T.		

QUEENSLAND

Herdsman, Mrs. R.	Joyce, N. O.

SOUTH AUSTRALIA

Cox, G. M.	Grove-Jones, P.	Herring, K. W.
Forster, B.		

WESTERN AUSTRALIA

Elliott, R.	Parker, R.	Wilson, Alan F.
Frost, Michael P.	Perry, R. H.	Wilson, R. W.
Jorgeson, W. L.	Playford, P. E.	Woodall, R.
Lawrence, R.	Russell, F. G.	

The Australian Prize has been awarded to Mr. P. Grove-Jones.

Crystal Specimens

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FOR THE COLLECTOR

FOR THE STUDENT

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Material of gem quality and cut stones are not included.

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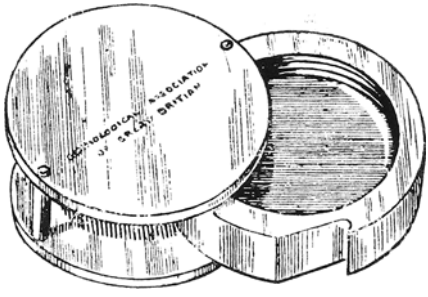

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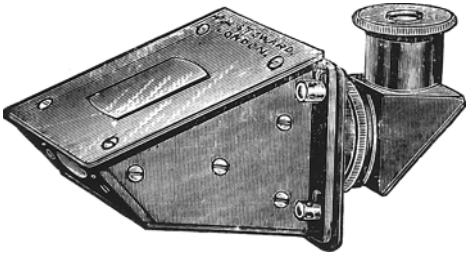

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THE JOURNAL OF GEMMOLOGY
AND PROCEEDINGS OF THE GEMMOLOGICAL ASSOCIATION OF GREAT BRITAIN

Vol. III No. 7 JULY 1952

SOME INCLUSIONS IN MOONSTONE

by R. Webster, F.G.A.

THE appearance of the moonstone variety of feldspar is so characteristic and inimitable that the testing of such stones, and therefore the observation of the inclusions, is rarely necessary. Indeed, except for a short reference to the inclusions given by Dr. E. Gübelin,[1] very little is written on the subject in gemmological literature.

Most moonstones used in jewellery emanate from Ceylon and show a type of inclusion which is typical for the variety. These inclusions have been adequately described by Edmondson Spencer[2] who made a study of the moonstone from Ceylon and other areas. Spencer writes : " The large isolated inclusions appear as thin lath-shaped lamellae or cavities. Their length is 10 mm. or less and the breadth 1 mm. or less. A section cut parallel to the plane of these inclusions (100), shows them as narrow laths parallel to the vertical axis (c) with numerous branching lines or cracks which extend a short distance (0.2 mm.) on each side of the inclusion in the direction of the b axis after which they taper off in an oblique direction. In addition to these lath-shaped lamellae numerous shorter cigar-shaped inclusions are visible. These vary in length

Fig. 1 (*below*). "*The centipede.*" *A rather large, but typical stress fissure in a moonstone.* 27 ×.

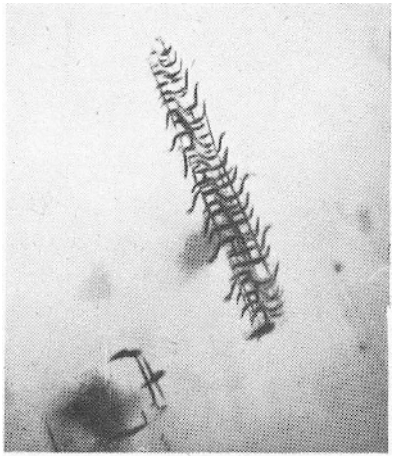

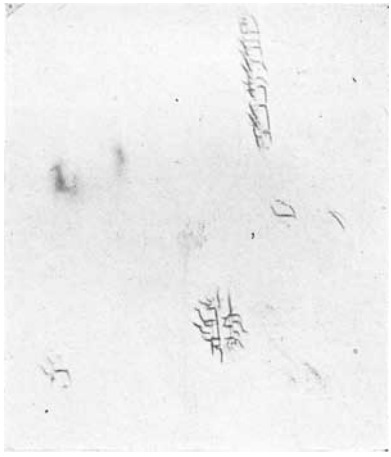

Fig. 2 (*above*). "*Chinese aeroplanes.*" *Typical stress fissures in a moonstone.* 22 ×.

Fig. 3 (*below*). *A group of fissures seen in a moonstone.* 15 ×.

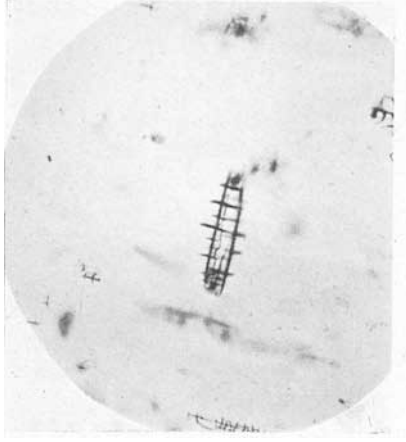

Fig. 4 (*above*). *This stress fissure seems to have turned broadside on.* 15 ×.

from a few millimetres downwards, and are usually clear and devoid of branching cracks. Many of these inclusions are, in reality, very thin cavities as can be demonstrated by taking fragments cleaved across the direction of the cavity and boiling them in strong dye solutions, when the dye penetrates for some distance along the cavity."

Gübelin (loc. cit., p. 292) states that these " fractures " are stress fissures developed along twin planes of poly-synthetic twin lamellae and may suggest insipient albitization.

Some of these inclusions are large enough to be visible to the naked eye, and under the magnification normally used in gemmological practice may appear to resemble centipedes, or, in the case of the shorter cracks, to show a resemblance to the older type of bi-planed aircraft.

The accompanying photomicrographs illustrate some of the patterns which these crack-like stress fissures assume. Figures 1 and 2 show the more usual types of pattern seen in moonstones while figure 3 shows an interesting group of such fissures. Study of the central inclusion in figure 4 will show that this fissure has " lost its direction " and is at right angles to the direction taken by the other stress fissures in the stone. Although they may possibly be of a similar nature to the stress fissures so far illustrated, a slightly

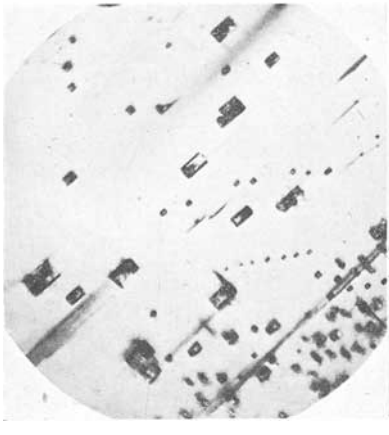

Fig. 5. In this moonstone the inclusions appear to be similar to negative crystals. 22 ×.

Fig. 6. The same set of inclusions as shown in the preceding picture but taken at a higher magnification. 55 ×

different formation may be seen in some moonstones. Figures 5 and 6 illustrate these inclusions in which the main " body " of the crack seems to adopt the form of a cavity or negative crystal.

As far as is known the specimens photographed are of Ceylon origin. No opportunity has been given to examine moonstones known to have come from Madagascar or Tanganyika Territory. The Burmese moonstones do, however, seem to adopt a different type of inclusion altogether. These are short needles running in one, but generally two or even more, definite directions, and are somewhat reminiscent of the needle inclusions seen in many garnets. Figure 7 shows this type of inclusion.

The beautiful blue shimmering light of moonstone obscures the hidden glory within the stone—fascinating beauty which the microscope alone can bring to view. May these few pictures throw a new light on a Cinderella among gemstones.

In conclusion, thanks are tendered to Mr. B. W. Anderson and Mr. L. W. Pooley for the selection and loan of the specimens used in taking the photomicrographs.

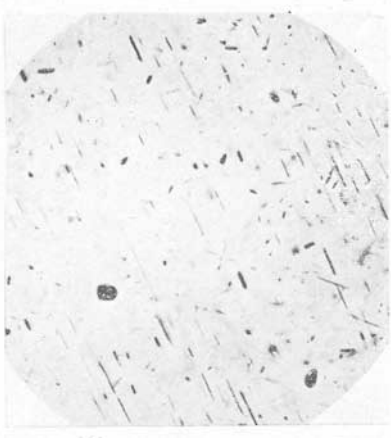

Fig. 7. The typical needle inclusions seen in a Burmese moonstone. 15 ×.

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1. Gübelin, E. " Diagnostic Importance of Inclusions in Gemstones." Journ. Gemm., Vol. 2, No. 7, pp. 292 & 301. July, 1950.

2. Spencer, E. A contribution to the study of moonstone from Ceylon and other areas and of the stability relations of alkali felspars. Min. Mag., Vol. 22, No. 130, p. 303. Sept., 1930.

LIVE-BOX TECHNIQUES

by

J. R. H. Chisholm, M.A., F.G.A.

AS a gemmological tiro I experienced some difficulty in mounting cut gem-stones satisfactorily for examination under the microscope. While no doubt immersion in a liquid of similar refractive index gives the best results,[1] it is liable to be messy unless time and care are spent ensuring cleanliness and it also necessitates the microscope being used in a vertical position, which does not make for comfort. For most purposes it is sufficient to examine a stone without immersion, provided it can be fixed on the stage with the table uppermost and approximately at right angles to the optical axis of the microscope : sufficient light to illumine a considerable part of the stone then enters via the culet. Similarly it may be examined through any other facet, if it can be satisfactorily held with that facet uppermost and parallel to the stage, provided there is an approximately parallel facet at the under side of the stone through which sufficient light is admitted.

Apart from holding the stone in one's fingers[2]—only practicable with stones of a certain size and with low magnifications—my gemmological reading suggested only Anderson's plasticene technique[3] and I naturally began with that. It still appears to be the best general purpose method, but it has certain drawbacks, especially for small stones. It needs no little skill and patience to prop up a really small stone on its culet with a blob of plasticene without at the same time either blocking out some of the light or covering the stone (and the slide) with plasticene. Moreover, if the microscope is at all close to a strong illuminant giving off appreciable heat, the plasticene becomes semi-liquid — πάντα ῥεῖ, to quote Heraclitus— and the result is a mess.

Searching round therefore for some other method of holding a stone with its uppermost facet parallel to the stage, as simple as the plasticene technique but without its disadvantages, I found that for all but very large stones the biologist's " live-box " or " live-cell "[4] provided a satisfactory answer. For this purpose a rather narrow but deep live-box as shown in Figure 1 is required.

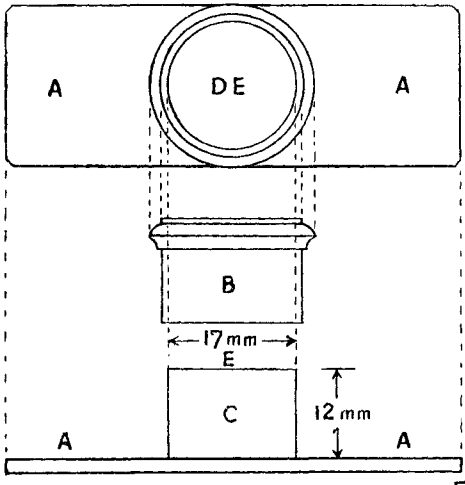

FIG. 1.

The depth of the live-box governs the depth of the stone it can accommodate, so for this purpose the more usual wide but shallow cell is useless, although it can help the gemmologist in another way mentioned later.

The method of use is to place the stone table-down inside and

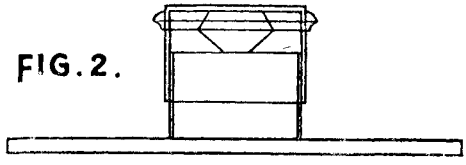

FIG. 2.

at the centre of the inverted top of the live-cell, insert the lower part of the cell into the top until the stone is firmly held as in a vice between the glass top and bottom of the cell—taking care, of course, not to break the glass—and then turn the whole cell the right way up and place it on the stage (see Figure 2). It is usually possible to clamp the stone in position with other facets uppermost if desired. As the stone is held at a considerable distance above the stage—depending on the height of the cell—it is advisable for the focus of the substage condenser to be raised appropriately, which may involve the removal of the top lens of a two-lens condenser, but even without adjusting the condenser the stone can be examined without difficulty under low-power magnification.

Mounting a stone in this way also facilitates the determination of its refractive index by the Duc de Chaulnes' method.[5] The apparent depth is measured by the travel of the fine adjustment while the tube is raised from focus on the culet to focus on the table, and the real depth is similarly measured from the top surface of the bottom-glass of the cell to the under-surface of the top-glass. It is,

of course, desirable to keep the glass of the cell clean, but just a little dirt may facilitate accurate focusing of these surfaces.

If the stone is well centred in the cell and has a reasonably pointed and central culet, then if the top of the cell is carefully rotated with the fingers the stone will rotate with it, pivoting on its culet, while the lower part of the live-box is held motionless by the stage-clips. With suitable stones, therefore, the live-box thus serves as a rotating stage and can be successfully used to show whether the stone is isotropic or not between crossed polaroids or nicols. This is, however, liable to scratch the lower glass of the cell and stones with eccentric culets or with culets shaped rather as a line than as a point are difficult to revolve satisfactorily.

A reasonable substitute for a revolving stage for any size or shape of stone—and for any size or shape of microscope—is provided by a wide and shallow live-box—say, 7 mm. depth and 35 mm. diameter. With its base firmly clipped to the stage this may easily be rotated by the fingers without disturbing the stone, which may be mounted by the plasticene method on the top (outside) or immersed in a glass cell either placed on or (preferably) cemented to the top of the live-box. Accompanied by two discs of polaroid this type of live-box may therefore be a most useful adjunct to a portable microscope or at any time when a microscope with a revolving stage is not available : while for quick examinations I have found the deep live-cell a most useful accessory.

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   R. Webster. " Practical Gemmology," (N.A.G. Press), p. 78.
2. B. W. Anderson. *op. cit.*, p. 88.
3. B. W. Anderson. *op. cit.*, p. 87.
   G. M. Sprague. " Easy Guide to Stones in Jewellery " (Schindler's Press, Cairo—1949), p. 25.
   cf. Dr. G. F. Herbert Smith. " Gemstones," 10th ed. (Methuen—1949), p. 68.
4. Rev. J. G. Wood. " Common Objects of the Microscope," 3rd ed. (Routledge & Kegan Paul—1938), pp. 16-17.
   R. M. Allen. " The Microscope " (Chapman & Hall—1940), pp. 176, 265.
   R. F. E. Miller. " The Amateur's Microscope " (Percival Marshall—1951), pp. 64-65.
5. Dr. G. F. Herbert Smith. *op. cit.*, p. 69.
   R. Webster, *op. cit.*, p. 60.

GEMSTONE RECORDS for the COLLECTOR

by L. C. Trumper, B.Sc., F.G.A.

A COLLECTION of gemstones can provide a great deal of interest whether neatly mounted, or filed away in pockets, with little more than the species of the stone marked on the label or pocket. How much more interesting it becomes however, if reference can be made to the gems inner and hidden story.

A certificate of identification is of course something quite different and not to be confused with gemstone records in any way. For this purpose it is only necessary to state the stones correct name and the barest evidence supporting its identification such as refractive indices, specific gravity and other data.

A collector's record on the other hand will tell a great deal about the stone, quite apart from its standard properties. Such records may be relatively simple in character or extremely elaborate depending to a large extent upon the equipment at the collector's disposal and the time he is prepared to devote to any one stone.

A very good illustration of the simple type of record form is that used by Mr. G. G. Waite of Toronto who is particularly interested in the cutting of his own stones from rough material. Here is the form he uses :—

Variety	No.
Cut	Source
Color	Dealer
Weight or size	Price of Rough
Remarks	

GEM STONES

No. 400

Stone ..... Collection No. .....

Type of cut ..... Purchase Price £ .....

Weight ..... grams ..... carats Date of Purchase .....

Locality .....

Occurrence .....

Lustre ..... Degree of Lustre .....

COLOUR.

Hue ..... Shade ..... Tone ..... Intensity .....

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Refractive Indices ..... Double Refraction .....

Dispersion ..... Optical Properties and sign .....

Pleochroism ..... Colours .....

Crystallographic System ..... Form .....

Cleavage ..... Fracture .....

Hardness ..... Structure ..... Habit .....

Electrical Properties ..... Heat Conduction .....

Chemical Composition ..... Formula .....

SPECIFIC GRAVITY.

Weight of Stone in air ..... grams Weight of Stone + Suspension in Water ..... grams

Weight of Stone in Water ..... grams Weight of Suspension in Water ..... grams

Loss in Weight in Water ..... grams Weight of Stone in Water ..... grams

$$\text{Specific Gravity} = \frac{\text{Weight of Stone in Air}}{\text{Loss in Weight in Water}} = \frac{\qquad}{\qquad} =$$

INTERNAL APPEARANCE OF STONE UNDER THE MICROSCOPE.

Flaws ..... Inclusions .....

Cavities ..... Air Bubbles .....

Doubling of back facets .....

Examination in Polarised light .....

Spectroscopic Examination .....

At the other end of the scale is the type of form that I use, which I have deliberately made as comprehensive as possible, though even this is by no means the possible limit.

I have explained my methods many times to my friends. Gemstones, after all, are rather expensive, so the great thing is to get as much interest out of them as possible. What better way than to systematically work through such a record form as that set out below ?

The filling up of such a form ensures that stage by stage every physical property will be worked through after examination by instrument after instrument, and when all has been done that can be done, any remaining gaps will be filled in by reference to text books and works of reference.

In this way, several hours can be enthusiastically employed on a single gem, every minute of the time being full of interest.

The actual form illustrated is of foolscap size and can be suitably punched with holes for inserting in a binder.

When all this has been done, or as much as can be done, and only then, does the stone go into its alloted place in the trays already described in this Journal.* The records themselves are kept in binders and it is surprising how useful these are. Frequently in an article there is a reference to a certain stone and perhaps for example some reference to unusually high specific gravity. I can at once refer to my records to see whether any of my specimens show the same abnormality.

Similarly when checking a stone, it is interesting to see how it compares with others already investigated and recorded.

* Journ. Gemmology, Vol. 2, No. 8, 1950, pp. 229 - 235.

NEW SYNTHETICS

Reports have been received of a new synthetic strontium-titanite, which is said to be no harder than rutile but very much like diamond in appearance. This development of synthetic rutile no doubt arises from the somewhat yellowish appearance of most of these stones, though this, too, has been the subject of experiment and is now being produced in a tint that is not quite colourless but almost so.

NOTAE—UT INFRA

by D. S. M. Field, A.G.A.

THE *Illustrated London News* for April 5, 1952, contains a supplementary set of two remarkably fine colour plates of gemstones in the collections of the Geological Museum in London.

Much wisdom has been shown in the choice of specimens : the ubiquitous plate gems, ruby, diamond, emerald and sapphire were omitted in favour of stones less familiar to the general public.

Remarkably good examples of diopside, phenakite, brazilianite, scapolite, apatite, danburite and orthoclase are shown ; and the various colour varieties of fancy corundum, tourmaline, topaz, garnet, zircon and other gems are well represented.

Each of the two 9 x 11 in. plates shows twenty-five specimens, well balanced and in actual size, with only one or two minor duplications. The set is, therefore, unique, and of interest and value to all lovers of precious stones. Since the apparent demise of the splendidly illustrated 4to books on gems, which were so popular during the latter half of the 19th century, large plates of gems in colour have become collectors' items ; and not a single plate of this calibre has been available during the past fifty years. Fine colour-photo prints do occasionally occur in magazines ; but they are generally spoiled for framing by intrusive hands or so-called " leg-art."

* * *

Gemmologists who frequently utilize monobromonaphthalene for gem testing might do well to bear in mind its toxic properties. Since 1950, at least a half-dozen American children have died from severe haemolytic anaemia that resulted from the eating of naphthalene moth-balls. Poisoning can also occur though the substance is not taken into the mouth. According to Dr. Edward T. Wilkes, an American medical specialist, a six-day-old infant developed acute anaemia which was traced to the use of diapers, that even though they had been rinsed, still possessed a *strong odour* of the moth-balls in which they had been stored.

The symptoms of naphthalene poisoning are sudden vomiting, abdominal pain, diarrhoea, pallor, and dark wine-coloured urine.

A simple clear polaroid cap, slipped over the eye-piece of the spectroscope, will permit anyone interested in the finer points of

gemmology to examine the differential absorption spectra of the various gems to which this property appertains. The eye-cap, when rotated through a 90-degree angle, separates the rays quite effectively. Emerald and alexandrite, among the uniaxials and biaxials, respectively, show the most striking change when examined in this manner. (Vide : SMITH, " Gemstones "—11th Edition, pp. 107-108).

* * *

There is a growing number of persons in Canada and the United States who are not gemmologists but unqualified characters posing as such.

Even small-town watch repairers (" jewellers ") with no testing equipment other than a file and 3x eye loupe, and who do not know the difference between a synthetic and an imitation, and who probably believe that " specific gravity " is the force that causes the rise and fall of tide in the Pacific Ocean, have been known to class themselves " gemmologists " and insert this title into their advertising. Such characters very often operate within the very trade itself, and the jewellery industry publications that are more concerned with advertising revenue than with the welfare of the industry take no action to prevent such impersonation—though thousands of dollars may be involved in a single transaction.

For instance, a year or two ago, the sum of 6000 dollars was paid for four rings set with emerald-cut synthetic white spinels, after they had been passed by a Connecticut " jeweller " as genuine diamonds. The fraud was uncovered only when the rings were submitted to the G.I.A.'s Gem Trade Laboratory in New York.

Similarly, in Alberta, a dozen or more synthetic rutiles were mistaken and bought and sold for diamonds by self-styled jeweller " experts," until qualified persons brought the matter to their attention—and to the attention of the police.

The public quite reasonably expects its jewellers to be thoroughly familiar with gemstones, and to be able to identify and correctly evaluate any gems or jewellery submitted to them. Consequently, the existence of pseudo-experts in the jewellery trade undermines the reputations of qualified jewellers and gemmologists alike—and seriously endangers public confidence in the industry as a whole.

In Canada, at present, all that is required to become a " jeweller " (an " expert in gems ") is the necessary capital to

purchase stock, pay the rent, and buy a licence. It is high time that aspiring jewellers be required to show proof of their qualifications to identify the gems they buy and sell, before licences are issued to them. Failing that, they could always obtain the services of an accredited gemmologist . . .

* * *

Anyone who has experienced the difficulty involved in examining gemstones with a lens of short working-distance under poor lighting conditions will appreciate the self-illuminating magnifiers *Lumag* and *Luminex*. These loupes are manufactured by Messrs. R. & J. Beck Limited, and distributed by both Beck and Messrs. Rayner & Keeler.

The Lumag loupe has a field of view of 1.25 inches (31 mm.), and, with a magnification of 5x, will be found quite suitable for the casual inspection of gemstones.

The Luminex is available in magnifications of 10, 15, and 20 diameters.

Two models of the 10x loupe are available, one having a fixed focus and the other adjustable. The 15x and 20x instruments are always fitted with a focusing adjustment to the lens. All models give an undistorted image to the very edge of the field of view.

Since a 10x loupe has been more or less universally adopted as the standard for precious stones, the 10x Luminex magnifier will be of particular interest to the gemmologist.

One model is equipped with a focusing adjustment and ancillary 10 mm. numbered scale divided into 100 parts. Hence, it is possible to measure accurately to 0.1 mm. the size of gemstones and their inclusions, and to record such information for reference and identification purposes. When the measuring unit is unscrewed from the loupe, the field of view is increased from approximately 10 mm. to 25 mm.—which is ample for gems of normal size.

The magnifying unit consists of two non-achromatic lenses, which provide a clear, flat field but show a small amount of colour. The writer therefore intends to replace the present 10x unit with a compound lens of the same power—but corrected for both spherical and chromatic aberrations, thus increasing the usefulness of the instrument and bringing it up to the approved standard for diamonds.

One of the most interesting features of the Luminex loupe is the focusing adjustment to the lens. When the measuring-scale unit is removed and the lens raised to its full extent, the magnifier is focused on the gem when the latter is well within the instrument and illuminated from the side. This condition results in a dark-ground lighting effect not greatly inferior to that produced by much more elaborate and costly apparatus.

The light is contained within the handle of the instrument and controlled by a switch. Gems held in tweezers or three-prong spring stone holder are consequently always observed under ideal lighting conditions, every detail being visible.

The illuminating unit is powered by two standard dry-cells, one-half inch in diameter and two inches long. The lamp is a standard 2.5 volt flashlight bulb.

For prolonged use in the laboratory, a mains-type unit (comprising a small transformer which plugs into an electrical outlet and has a lead attached to the handle of the magnifier) can be supplied at somewhat higher cost.

With the lens unit removed, Luminex can also be used in conjunction with the microscope for the examination of opaque gemstones and pearls under much higher magnification than is normally required.

* * *

> " Our (Canadian) universities are now loaded down with such trade school curriculae as gemology, real estate, forestry, physical culture, journalism, commerce and countless other subjects having the same intrinsic value as the square root of nothing, as far as ' education ' is concerned . . ."

The above somewhat startling statement appeared in an article entitled, " *Don't* Send Them to College," by Hugh Garner, a writer for *New Liberty Magazine* (Toronto).

Subsequent investigation carried out by the present writer has shown that an alleged course in gem(m)ology offered by a university in the Maritime Provinces is actually a very elementary course in the lapidary arts—misnamed " gemology " by the university. It would be interesting to learn whether students who complete the course will consider themselves to be gemmologists duly certified or diplomated by the university in question ?

MEASUREMENT OF COLOUR

by

M. D. S. Lewis, B.Sc., F.G.A.

IT is estimated that about ten million different colours can be distinguished by the average human eye. In gemmology the number normally occurring probably runs in thousands, yet until quite recently there has existed no precise method of measurement or even specification. It is true we speak of " pigeon-blood " rubies, " sherry-coloured " topazes, etc., but in doing so we are only making a mental comparison with some object we may previously have seen ; we are attempting to describe colour in terms of our own private personal experiences. Through this lack of objectivity each observer has probably a different standard and although we can specify unambiguously the weight, density, refractive index and other properties of a gemstone, we have been at a loss accurately to describe what is often the most important feature—colour.

The advantages of a universally adopted system of colour specification and measurement are obvious. From the theoretical point of view there are many unknown fields to be explored. What is the exact difference between a " blue white " and other diamond ? How can the fading of a stone be measured ? What are the relationships between Burma, Ceylon and Montana blues ? Is there some unique difference between the yellow of topaz and that of citrine ?

In practical gemmology colour measurement might well yield valuable results. Some jewellers and dealers with a highly developed optical sensitivity can distinguish between many stones through colour alone. If asked to define the difference in colour between a good synthetic and a natural stone they could probably not do so. It is too subtle—it defies definition but is nevertheless present. A stone might conceivably be distinguished from another through a numerical evaluation of colour alone.

Probably the greatest benefits from colour specification and measurement would accrue in the commercial field. It would be very advantageous for an auctioneer to be able to specify in his catalogue the colour co-ordinates of a valuable stone (in addition to weight and certificate of genuineness) so that a prospective-purchaser in another country could form a good idea of its appearance. The colour grading of diamonds can only be successfully achieved through a scientific method of colour measurement.

By 1931 the need in industry for a universal language of colour had become so strong that an international convention met at Cambridge and formulated the C.I.E. system (Commission Internationale de l'Éclairage). In America it is referred to as the I.C.I. system (International Commission on Illumination). Rarely can any international conference have produced such unanimity and prescience of future requirements and there is no doubt that the conventions adopted will remain unchanged for many years The C.I.E. system is rapidly pervading all fields in which colour is of importance and it is only a matter of time before it impinges on gemmology. We may, in the not distant future, hear of a customer warning his jeweller that the " chromaticity " of the ruby he is seeking for an engagement ring must lie within a certain area on the C.I.E. chromaticity chart. The purpose of this article is to describe briefly the C.I.E. system and to discuss its possible application to gemmology. Although the mathematics involved is simple the subject as a whole is not exactly easy to grasp at first because of new and strange concepts. Whilst much has been known of colour for three centuries the technique of colour measurement is less than thirty years old. Before proceeding further it may be as well to ask what is required of such a system.

It will be assumed that the reader is familiar with the article in the previous issue* on " Colour Perception." The observance of colour is a mental sensation influenced by three attributes :—

(a) HUE, by which we distinguish red from blue, green from yellow, etc.

(b) SATURATION. Concentration of hue, intensity, purity, or freedom from white.

(c) BRIGHTNESS (the most difficult attribute), depending on the total amount of light entering the eye. If we have two

* Journ. Gemmology, Vol. 3, No. 6, 1952.

identical red surfaces and add black to one, the colour sensation moves towards brown. Hue and Saturation have remained constant but less light is reflected from the blackened surface causing the eye to register a different sensation.

Whatever arithmetical results a system yields they must be such that some correlation with these three attributes is possible, for it is only through them that a colour is appreciated. They should also be capable of graphical representation to show the relationship of one colour to another and, furthermore, the system must be sufficiently simple for manipulation by comparatively unskilled operators. The C.I.E. system fulfils all these requirements and remains the master pattern to which any other subsidiary system should be capable of reference if it is to remain valid.

The difficulty of the subject is best appreciated by considering the sequence of events which must precede the observance of colour. First there must be some illumination—without light there can be no colour. When this illumination passes through a gemstone it becomes modified to an extent depending on the absorption properties of the stone. The " colour " of a gem is mainly the " colour " of the illuminating light after it has been modified by passage through the stone. So far everything that has happened can be defined in physical terms. The coloured light travelling from stone to eye can be analysed by spectrophotometers, etc., and its spectral composition and relative energy measured. This, however, is the last word which physics can say because it cannot forecast what effect will be produced on the eye. The relative energy of the various rays gives no more than the crudest idea since the sensitivity or response of the eye is not the same for all wavelengths. Radiation of energy so great as to cause actual burning, may yet totally fail to stimulate the colour mechanism of the eye. We must therefore now leave our comfortable world of straightforward measurement in grams, centimetres, degrees, etc., and move to another sphere in which human sensations are involved. The bridge between the purely physical and what the Americans call the " psycho-physical " is the " International Equal-Energy " Luminosity Curve (Fig. 1) which records the inverse of energy required at each wavelength to produce a visual sensation of constant magnitude.

Suppose the light travelling from gemstone to eye has been analysed and that Fig. 2 records the result given by spectrophotometers. The light is obviously very rich in " blue " energy but that does not mean to say that it will appear blue since these rays have low luminosity. If we multiply curves I and II we obtain another curve (Fig. 3) which gives the actual visual response to the coloured light. It will be observed that energy has dropped out of the picture and has been replaced by visual sensation. In spite of the physical instruments having recorded a preponderance of " blue " energy the eye experiences a yellow green sensation, practically devoid of blue.

How then is this visual sensation to be specified and measured ? It may be said that skilled colour physicists can do so by manipulation of graphs of this type and express the result in C.I.E. terms. This " analytical " method, however, is lengthy, requiring a thorough knowledge of the subject, very high technical skill, costly apparatus and laborious calculation. For those less experienced, a simpler method is called for, but before embarking on details it may be helpful to consider an analogous though fanciful situation.

Suppose we are in a café and have in front of us a cup of tea, the sweetness of which we are asked to measure. Our first instinct may well be that it is impossible—sweetness is a sensation of the palate, a private experience—and whereas we can roughly compare sweetnesses, we can no more say that one cup of tea is twice as sweet as another, than we can proclaim that we are twice as happy or half as miserable as someone else. On reflection, however, we may realize that sweetness is due to sugar and if we can find the quantity of sugar in the cup of tea we can say that the sweetness is that of, say, a teaspoon of sugar. By this specification we can stimulate an equivalent sweetness sensation whenever required. To find the amount of sugar we could apply the " analytical " process, but this would require the services of a skilled chemist and his procedure would be unsuitable for use in a café. A much simpler method presents itself for less skilled operators. We can call for a second cup of tea, identical with the first, except that it must be unsweetened. We then add sugar in carefully controlled amounts until both cups of tea taste equally sweet to us. We can then say that the sweetness of the first cup is also that stimulated by say, a teaspoon of sugar. At this stage a supercilious waitress who

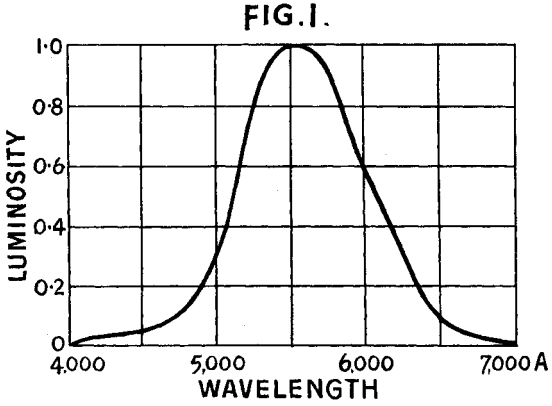

Fig. 1. International "Equal-Energy Luminosity" curve showing the relative response of the average eye to the different wavelengths of the spectrum.

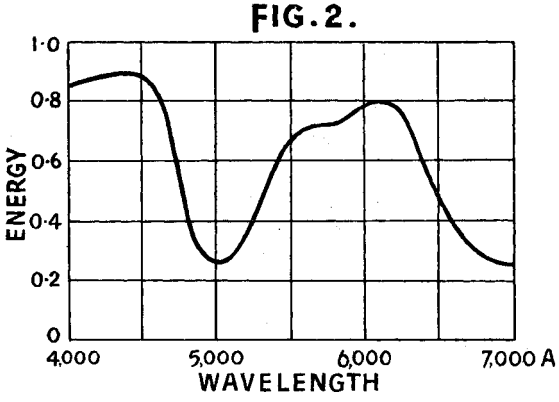

Fig. 2. "Relative Energy — Wavelength" curve of light from a coloured gemstone.

Figs. 2 & 3 adapted by permission of the author and publishers from "The Measurement of Colour," by W. D. Wright (Hilger, London).

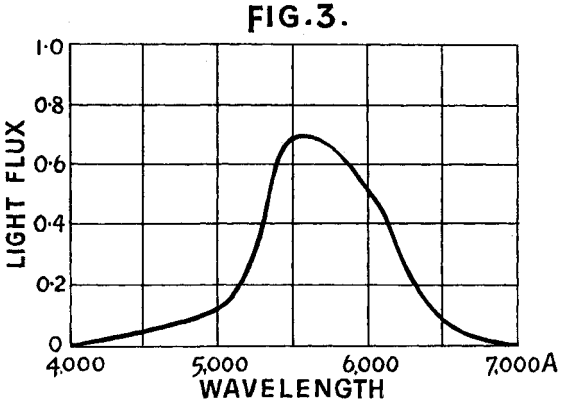

Fig. 3. The product of curves in Figs. 1 and 2 giving the actual response of the average eye to the coloured light represented by Fig. 2. "Light Flux" is a measure of luminosity.

has been observing the whole affair may intervene to point out that our premises are entirely wrong. Owing to sugar shortage there was none at all in our first cup—she had substituted a saccharine tablet. This would be immaterial so long as some skilled observers before us had, through repeated tests, ascertained the relative amounts of sugar and saccharine necessary to produce on the average person the same sensation of sweetness. This could then be expressed either in sugar units or saccharine units by a simple arithmetical transformation or, if economy in the use of sugar were desirable, it could be expressed as so many sugar units plus so many saccharine units.

The analogy with colour is quite close if not pushed too far. The problem colour is thrown on a screen and another colour patch is built up adjacent to it by mixing lights of known physical properties until a complete match is obtained. When this occurs the line of demarcation vanishes. The eye, like the palate, cannot analyse its sensations but is very sensitive to *differences* of colour and quickly recognises when two patches of colour are identical in all respects. When this has been done we " measure " the colour by stating that it is the sensation produced on an average observer under the stimulus of certain lights of known physical properties. This technique of " synthesis " is known as " colorimetry " and the instrument which synthethises an equivalent stimulus is called a colorimeter.

The C.I.E. system and the whole subject of colorimetry rest on the remarkable fact that most colours can be matched by the mixture in suitable proportions of three primary colours. Usually a red, green and blue are chosen, but no special combination is essential ; there are an infinite number of triplets which can be used. Only two conditions are attached to this statement. Firstly, the three primaries, if mixed in certain proportions, must produce white and secondly, no one primary may be matched by any mixture of the other two. As a matter of fact, even monochromatic lights are not essential and some colorimeters employ composite colours, obtained by passing white light through filters.

In order not to break the continuity of what follows certain axioms may be stated beforehand. They are either self-evident or can be proved by theory or experiment. For the present it must

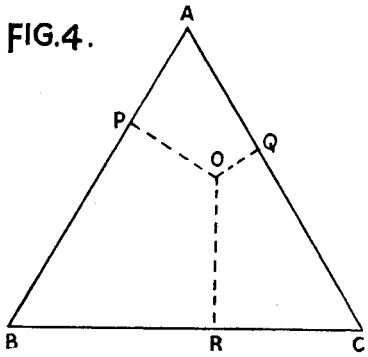

Fig. 4. Equilateral Triangle. Wherever " O " may be OP + QR + OR = the distance of A from BC. The distances OP, OQ, OR are called co-ordinates of the point " O ".

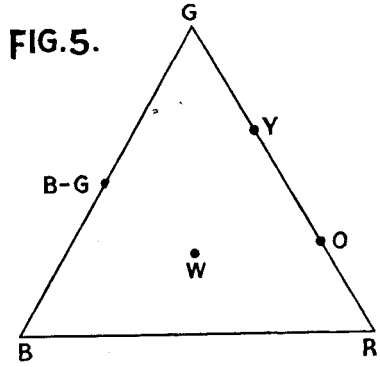

Fig. 5. Equilateral Triangle showing colours of spectrum (Red, orange, yellow, green and blue) arranged round sides. At the centre is the white point " W ".

also be assumed we are dealing with coloured lights (not surfaces or objects).

(a) The hues appearing in the spectrum are the purest normally obtainable and no greater saturation is possible under ordinary circumstances.

(b) If two primary colours are mixed to produce an intermediate colour—say red and green to produce yellow—the addition of a third primary (blue) does not necessarily produce a different hue but rather at first tends to desaturate the mixture. Thus the addition of blue to green and red tends to give a desaturated yellow. This might be argued from first principles. The first small amount of blue added combines with small amounts of red and green to give white which automatically desaturates the yellow mixture.

(c) If the height of an equilateral triangle is unity the sum of the perpendiculars from any point within to the three sides is also unity. Thus if the height of triangle ABC (Fig. 4) is unity then OP + OQ + OR = 1. The position of the point " O " is fixed if any two of these distances (co-ordinates) are known, and the value of the third co-ordinate can always be found by subtraction from unity.

The fact that most colours can be matched by the mixture of three primaries immediately suggests the use of Maxwell's Triangle

as a frame of reference. In Fig. 5 imagine spectrally pure red, green and blue lights to shine inwards from the corners of an equilateral triangle. By definition these three primary colours are the purest, most saturated obtainable. If one travels along the perimeter from R to G the various colours resulting from the mixture of red and green are met with—first orange and then yellow. At G there is pure unadulterated spectral green and proceeding thence towards B the intermediate colour of " Blue-Green " is found, whilst further along at B there is pure spectral blue. In other words, all the hues of the spectrum are met with along the two sides RG and GB. Between B and R lie the purples and magentas, which are not spectral colours but which result from the mixture of blue and red. Immediately one leaves the perimeter for the interior the third primary begins to exert influence and therefore some desaturation will occur (axiom b), whilst at the centre of the triangle is the white point " W " where equal quantities of the three primaries—red, green and blue—co-exist.

Is then this simple triangle a suitable frame of reference within which any colour may be plotted ? The position of a point relative to the perimeter would seem to indicate the hue and its distance from the white point " W," a measure of saturation. Unfortunately further investigation shows that a triangle of this nature cannot contain all possible colours.

FIG.6.

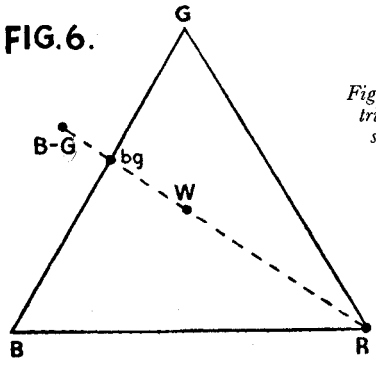

Fig. 6. In this equilateral triangle " R " represents pure spectral red, " W " white, " bg " the blue-green obtained by mixing blue and green. Spectral " blue-green " can only be obtained outside the triangle at BG.

In Fig. 6, consider the colours met with along the line RWbg. At " R " there will be pure spectral red, the saturation of which may be called unity. At the white point " W " the red is only one-third

as strong and here the saturation may be called one-third. At " bg " it will be zero but experiment shows that no mixture of blue and green lights can give the saturation of spectral blue-green. It appears that to obtain this we should have to move further away from the white point to a point " BG " outside the triangle. As the amount of red has decreased from unity at R to zero at " bg " it follows that at BG it must have become a negative amount. Physically this means to say that a match can be made between spectral " blue-green " on the one hand and any mixture of blue and green lights on the other, only if the *spectral* colour is desaturated by the addition of red light. (Subtracting a quantity from one side of an equation is equivalent to adding it on the other side). Similarly all the pure saturated colours must be outside the triangle except at the points RGB. Fig. 7 shows them joined by a curve which is known as the Spectral Locus.

Whilst an experienced colour physicist would have no more difficulty in handling negative colours than a mathematician has in dealing with negative numbers, it was felt that for a system to be

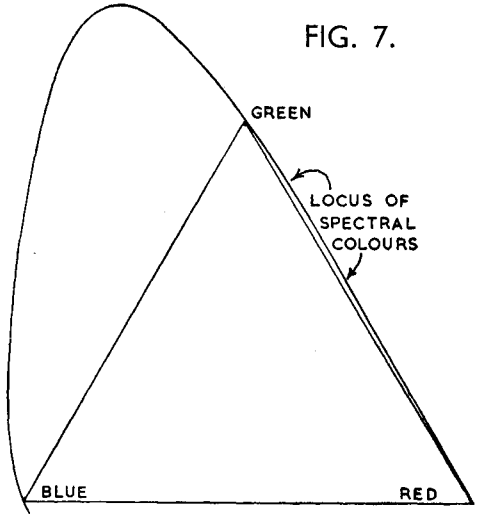

Fig. 7. The position of all pure spectral colours relative to the equilateral triangle of Fig. 6 have now been plotted and joined by a curve known as the " spectral " locus.

Reproduced from "The C.I.E. International Colour System Explained," by G. J. Chamberlin, by permission of the publishers, The Tintometer Ltd., Salisbury.

used generally all positive colours were preferable. Obviously, the only way to get all colours within our frame of reference is to enlarge our triangle and this has been done in Fig. 8, RGB having to be discarded for three new entities XYZ. If RGB represented

primary colours of spectral purity what can XYZ represent ? They can only be imaginary colours of super saturation not capable of being realised in practice and since they are hypothetical they are no longer referred to as colours but as " stimuli."

We now seem to have jumped from the frying pan of negative colours into the fire of imaginary colours, but this need not worry us for the mathematicians have arranged matters so that any real colour can be expressed in terms of XYZ (and vice versa) by a simple arithmetical transformation. Thus, if in a colorimeter a colour is matched by a mixture of red, green and blue lights in certain quantities the corresponding proportions of X, Y, Z can usually be obtained from tables. The expression of tangible

FIG. 8.

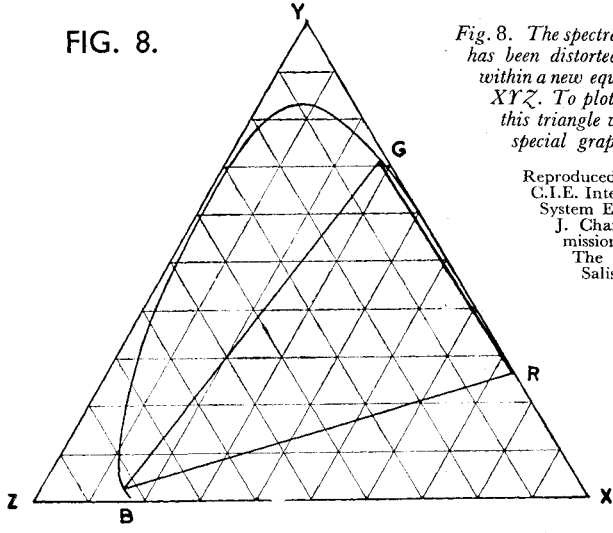

Fig. 8. The spectral locus of Fig. 7 has been distorted to fit wholly within a new equilateral triangle XYZ. To plot positions within this triangle would necessitate special graph paper.

Reproduced from "The C.I.E. International Colour System Explained," by G. J. Chamberlin, by permission of the publishers, The Tintometer Ltd., Salisbury.

quantities in unreal units is not so far-fetched as it might at first seem. The engineer often expresses " power " in terms of horses which do not exist and the whole structure of classical physics rested mainly on the existence of an imaginary aether. The exact specification of these XYZ stimuli was a problem in mathematics and physics but need not concern us here ; their great virtue is that they are the alphabet of a universally accepted language of colour. Thus in one laboratory a colour may be matched by a mixture of deep red, yellow and blue lights whilst in another those worked

with might be medium red, green and blue. When, however, the necessary arithmetical transformations had been made they would both give the same XYZ specification.

The quantities of XYZ stimuli in any colour are known as the tristimulus values and are usually written in the form of an equation known as the tristimulus equation. Thus the C.I.E. specification of the colour of a piece of turquoise might perhaps be given as follows :—

$$C\ (\text{Colour}) = 15.51X + 21.33Y + 38.64Z$$

which is a statement of fact that the colour of the light from this stone would be matched by 15.51 units of X stimulus, plus 21.33 units of Y stimulus, plus 38.64 units of Z stimulus. Although XYZ are imaginary stimuli the actual match would have been made with real colours and the result transformed to the above by easy calculation or through the use of tables. The tristimulus equation in its final form specifies both quantity and quality of a colour for a given illumination. It should be noted that the value of Y is of particular interest, for reasons which will be explained later.

Having now succeeded in labelling a colour—for no other can have these particular tristimulus values—the whole subject for some purposes might perhaps be left here. To do so, however, would leave much of value unsolved. Except to an operator very experienced in colour physics the mere statement of tristimulus values would not convey more than a crude idea of colour and no connection of the three essential attributes—hue, saturation and brightness is yet obvious. Suppose the turquoise were " treated " in some way and re-measured for colour, the new tristimulus values being $25.85X + 35.55Y + 64.00Z$. In which way has the colour changed ?

The answer to these questions lies in graphical representation but the equilateral triangle of Fig. 8 is not an easy frame of reference to deal with, requiring triangulated graph paper and considerable mathematical knowledge. If, however, the three variables XYZ could be reduced to two, the usual rectangular co-ordinates of ordinary graphs would be employed. To do this we can divide the three tristimulus values by their sum, which converts them from actual amounts into proportions, adding up to unity. Thus if a certain colour were specified in C.I.E. terms as $uX + vY + wZ$ we should divide throughout by $u + v + w$ and an equation written

FIG. 9A.

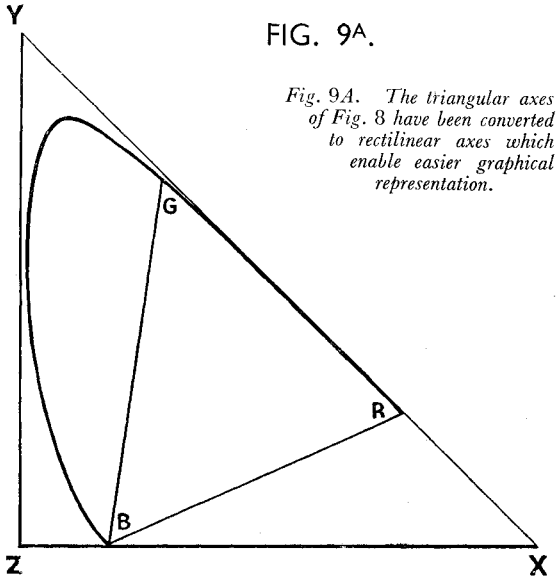

Fig. 9A. The triangular axes of Fig. 8 have been converted to rectilinear axes which enable easier graphical representation.

FIG. 9B.

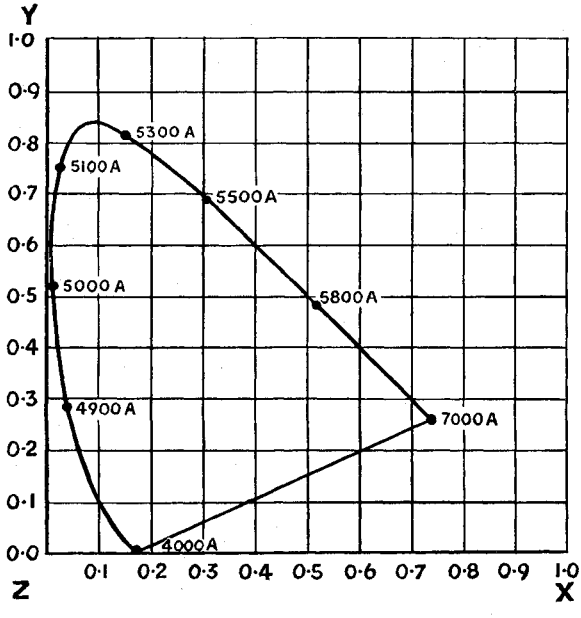

Fig. 9B. All traces of the original triangle have now been obliterated and the axes calibrated. Wavelengths have been marked on the spectral locus which has been adjusted to the new rectilinear axes. This is the standard C.I.E. Chromaticity Chart.

$$c = \frac{u}{u+v+w}X + \frac{v}{u+v+w}Y + \frac{w}{u+v+w}Z$$

Where " c " is one unit of the colour

$$\text{Let } x = \frac{u}{u+v+w}; \; y = \frac{v}{u+v+w}; \; z = \frac{w}{u+v+w}$$

$$\text{Then } c = xX + yY + zZ.$$

$$\text{Where } x + y + z = 1.$$

This equation is called the unit trichromatic equation and the coefficients x, y, z are called the trichromatic co-ordinates. It will be noted they represent not the amounts of X, Y, Z present but their proportions and always add up to unity. If, therefore, two of them are known the third can always be found by subtraction from one. Since the sum of the co-ordinates in the equilateral triangle of Fig. 8 can also be assumed unity, it is mathematically justifiable to convert the curve of Fig. 8 to rectangular co-ordinates and the result is shown in Fig. 9A. In Fig. 9B the last triangular traces have been obliterated and scales provided to both rectangular axes to give the most important diagram of all—the " C.I.E. Chromaticity Chart " in which we can plot every possible hue by using the trichromatic co-ordinates of the unit equation. Any two of the coefficients could be used—though x and y are invariably chosen.

In Fig. 10 the writer has crudely indicated the positions which might be occupied by some of the typical gemstones. The dependence of colour on illumination has been repeatedly stressed and in accurate colour measurement the precise illuminant used is of paramount importance. In the C.I.E. system three standard sources are used corresponding to tungsten electric light, sunlight and north sky light—consistency being achieved by use of standardised lamps and filters. The trichromatic co-ordinates of these standard illuminants are, of course, accurately known and their position fixed on the C.I.E. chromaticity chart.

In Fig. 11 the chromaticity chart is reproduced with one of these illuminants indicated by the point S. Suppose the unit

FIG. 10.

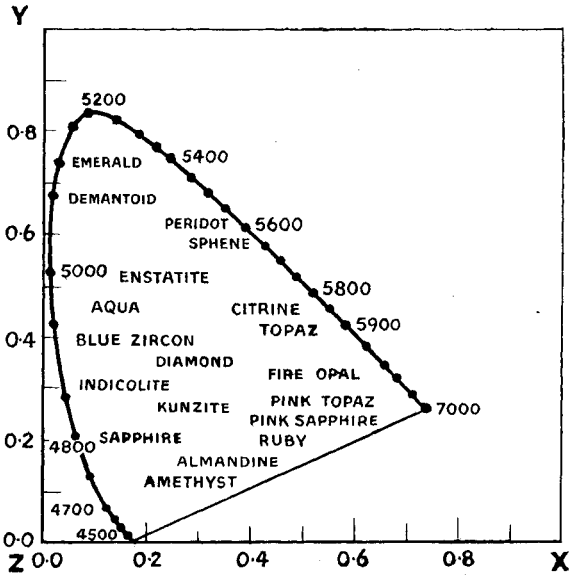

Fig. 10. The average position of some typical gems has been very roughly indicated on a C.I.E. Chromaticity Chart. The exact position of any particular stone would be found by reference to the X and Y axes.

trichromatic equation of a colour has been found by experiment to be :—

$$c = .50\,x + .35y + .15z$$

The coefficients of x and y which are .50 and .35 respectively become the co-ordinates on the C.I.E. chromaticity chart and are plotted at the point " C." These two points S and C are now joined by a straight line which is produced to meet the spectral locus at D. This immediately gives the dominant wavelength, approximately 6,000A—that is to say, the monochromatic light which when suitably mixed with white light, or rather the illuminant, will match the colour under observation. Those with no knowledge of the subject would probably refer to it as "the" colour. Expressing it another way, one could say that the hue of the monochromatic light represented by point D on the spectral locus is the hue of the colour which is being examined. The ratio SC/SD is called the "Excitation Purity" which corresponds with saturation. The combination of Hue and Saturation of a colour is referred to as its "quality" or "chromaticity" and whilst they themselves (Hue and Saturation) remain mental sensations which cannot be measured as such, they are very closely correlated with dominant Wavelength and Excitation Purity which can be expressed numerically.

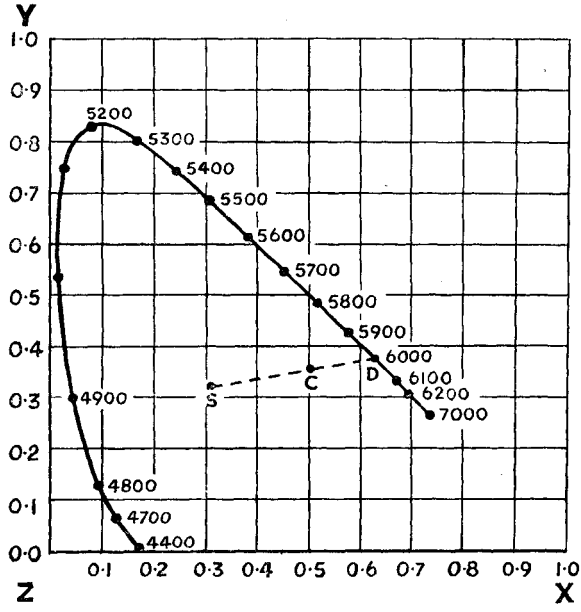

FIG. 11.

Fig. 11. A C.I.E. Chromaticity Chart showing the position of an illuminant "S". The tri-chromatic coefficients of a colour have been found to be $x = .50$, $y = .35$ and the position plotted at "C". The line SC produced to D meets the spectral locus roughly at 6000A, which is the dominant hue of the colour. The ratio SC : SD corresponds to the saturation on a scale in which zero would represent colourlessness (or rather the colour of the illuminant) and unity would represent spectral purity.

Thus emerges one of the outstanding advantages of the C.I.E. system. Suppose it were desired accurately to describe the colour of a gemstone to someone in another country. Without such a method one could only photograph the absorption spectrum or take a large number of measurements of relative energy in the transmitted rays, recording them on a graph. Neither of these methods —though perhaps physically accurate—could possibly convey more than the vaguest conception of actual colour. Under the C.I.E. system the dominant wavelength could be quickly found and isolated in the spectrum whilst the "depth" or "paleness" of hue could be assessed from the Excitation Purity.

The all important aspect of brightness does not yet seem to have been catered for in this C.I.E. specification and it will be seen that a difficulty will arise if the line SC produced meets the straight line at the base of the diagram as no spectral colours are located here. These matters will be discussed in the next article on the subject. In the meantime, however, it may be helpful to summarise very briefly the fundamental steps in the simplest method of colorimetric evaluation.

(i) Coloured lights of known physical properties are mixed in controlled amounts until they match exactly the unknown colour.

(ii) The amounts of these real coloured lights are transformed into units of the imaginary stimuli XYZ giving a tristimulus equation of the form

$$C = uX + vY + wZ$$

(iii) To plot the colour on the C.I.E. chromaticity chart, divide the three coefficients u, v, w by their sum " u + v + w " which will give the unit trichromatic equation of the form

$$c = xX + yY + zZ$$

This merely specifies the quality or chromaticity of the colour, not the amount or brightness, but by finding the point on the C.I.E. chromaticity chart with the co-ordinates x, y, the colour is accurately charted in relation to other colours.

(iv) By joining the illuminant point to the colour point and producing the line to the spectral locus, the " dominant wavelength " and " excitation purity " are quickly found. These two quantities are closely correlated with Hue and Saturation.

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The C.I.E. International Colour System. Explained by G. J. Chamberlin. (A Tintometer Publication).

Trans-Optical Society, 1931-32, 33 Smith & Guild, p. 73.

(*The second part of this article will appear in Vol.* 3, *No.* 8, 1952, *of the Journal.*)

Some More
UNUSUAL GEMS

by R. K. Mitchell, F.G.A.

IT might almost be said that, within the framework of the natural laws, nothing is impossible in the mineral kingdom. In my own experience it seems necessary only to be dogmatic over the colour or crystal habit of a mineral for the exception to turn up and confound one's most forthright pronouncements. Minerals have established habits but their behaviour in formation is subject to a myriad outside influences so that, while complying with certain rigid laws, very considerable variation may be found.

The island of Ceylon is no exception in this matter of producing the unusual, and a recent parcel of 10 cabochon cut stones yielded no fewer than three exceptional specimens.

The first of these flatly contradicted a statement I had made quite recently to my friend in Ceylon. I said that gem enstatite occurred only in an intense green. The present stone was a glassy grey and, although it was sent to me as an enstatite, I was inclined to doubt it and at first thought it might be the closely similar mineral diopside, which, incidentally, should also be green.

I was able to get a rather hazy refractometer reading from a partly polished flat on the back of the stone and, finding that the absorption spectrum showed a distinct line at 5060A (a line seen in both these minerals) and another fainter one at 5510A, I still plumped for diopside. It remained for Mr. B. W. Anderson, guide, mentor and friend to so many bewildered gemmologists, to point out that the 5060A line in this instance was in fact a single line (characteristic of enstatite) while that for diopside should be a doublet. A specific gravity test served to confirm this finding.

Now enstatite, according to Dana Ford, does occur in glassy grey forms, but it seems that these have not, until now, been cut

as gems. The reason the present specimen has been so treated is almost certainly the presence of a faint but definite chatoyant streak. This, of course, is yet another unusual feature of the stone.

Considering the absorption spectrum we have another significant fact. The line at 5060A has, until now, been considered to be due to the presence of iron, which imparted the normal green colour to both enstatite (enhanced by chromium) and diopside. In this instance we have the absorption spectrum and no vestige of the green colouring. The next specimen throws further light on this discrepancy.

This stone proved to be an unusually fine specimen of chatoyant tourmaline, a pale honey yellow in colour with a vivid streak rivalling and even surpassing that of a fine cymophane cats-eye. The specific gravity of 3.10 was quite normal, but the birefringence of 0.015, obtained from a polished flat on the back of the stone, was distinctly low for this species.

Tourmaline is not as a rule a very profitable source of absorption spectra, but this specimen yielded two faint but definite lines which, when measured, proved to be at the same wavelengths as those in the enstatite described above. This is a matter for some comment.

It is known that the elements responsible for the intrinsic colour in minerals belong to a group known as gap elements. That is to say their outer structure, consisting of a series of electron " shells," has one of the inner shells incomplete. The absorption spectra produced by these elements when present in a mineral, consist characteristically of rather broad dark bands (chromium is an exception, producing, apart from the broad absorption in the yellow-green, fine clear-cut lines). The position of these bands is also variable from mineral to mineral, suggesting that the colouring element is itself radically influenced by the structure of the host mineral.

Two other groups of elements also have gap structures ; the heavy radio-active elements and the rare-earth group. Both have interesting effects on absorption spectra, although it is uncertain whether they greatly influence colour.

The first of these groups contributes uranium to our list of absorption spectrum producers. Its effect is seen in the highly

developed and very characteristic spectra of the various types of zircon ; the spectrum being generally clear cut and apparently quite fixed in position.

The second group comprises those elements generally referred to as rare-earths. These provide absorption spectra in which the lines are again fairly narrow and are stable in position to within the limits of the small spectroscope.

It now seems likely that the lines seen in these two gems (one of them occurring also in diopside) must be due to the presence of one of these rare-earth elements. Some comparison may perhaps be made with the yttrium line at 5505A seen, in conjunction with others in the same region, in Brazilian andalusite ; while neodymium shows a line near the 5060A position. Both these elements normally show much richer absorption spectra than are seen in these minerals, but it must be born in mind that data on their typical spectra are usually obtained from solutions of their salts, generally a more prolific source of absorption lines.

Regretfully, I have had to return this parcel of gems to Ceylon and the two specimens are not available for further work. The fact remains that there are now three minerals which have shown very similar, if not absolutely identical absorption lines. An occurrence sufficiently unusual to justify comment.

My third specimen was less startling in appearance but was sufficiently out of the ordinary to warrant discussion. It was simply a deep brown chrysoberyl cats-eye in which a second and rather fainter streak crossed the first at right angles, making, in fact, a four-ray star stone. It is the first I have seen, but I suppose there is really no reason why the " silk " should not be parallel to one of the lateral axes as well as to the vertical axis.

The mineral is, of course, orthorhombic in symmetry. The axes are unequal and the atom sequence is therefore different in each axial direction. The fact that one of the chatoyant streaks is much fainter than the other is undoubtedly due to this variation in lattice pattern. The fibrous inclusions producing the reflected streak are probably denser parallel to the C axis.

The presence of fibres parallel to two *unequal* axes is unusual. Normally such inclusions are parallel to axes or directions which are equal, as in corundum or garnet, or parallel to a unique direction (the C axis) as in quartz cats-eye and normal chrysoberyl cats-eye and others. Another instance of this occurrence of two separate and different groups in one specimen was seen in the strongly asterated quartz which I have described elsewhere (Gemmologist, Feb., 1951). In that instance a strong six-rayed star due to submicroscopic fibres parallel to the normal lateral axes, was supplemented by a series of much fainter four-rayed stars caused by sparce but coarser inclusions, possibly related to one or other of the rhombohedra.

In conclusion I must own my usual indebtedness to Mr. F. L. D. Ekanayaka (who identified them all correctly) for the sight of these and other most interesting gems ; and to Mr. B. W. Anderson for his advice in the matter of the enstatite.

LETTER TO EDITOR

DEAR SIR,

With reference to the article by Mr. L. C. Trumper under the heading of " Photomicrographs " in Volume 3, No. 6, of the Journal of Gemmology, April, 1952, I venture to suggest that the difficulty of focusing referred to in the fourth paragraph of the article can be very simply got over by the insertion of a thin cover glass at an angle of 45 degrees at the appropriate position behind the back glass of the objective, coupled with the addition of a tube to hold a second ocular to act as a watching and focusing eyepiece. This will enable focusing to be carried out with the camera in its normal position at the normal ocular end.

In case facilities are not available, any of the microscope manufacturers will make the alteration very cheaply. The main expense is in the use of the second ocular which should be twice the power of the normal ocular.

I should add that the loss of light for photographic purposes is only about 10% of that available.

Yours faithfully,

E. MACKIE.

23, Mount Park Crescent,
Ealing, W.5.

May 6th, 1952.

Gemmological Abstracts

BENSON (L. B.). *Gem Trade laboratory instals new testing equipment.* Gems and Gemology. Vol. VII, No. 4, pp. 107-112. Winter, 1951-2.

Intended primarily as a report on the new X-ray equipment for pearl testing at the New York laboratory the article gives a summary of the requirements of microradiography and X-ray luminescence of pearls. The methods discussed are confined to the direct radiographic process and X-ray fluorescence. It is suggested that better radiographic results may be obtained by completely immersing the pearls in carbon tetrachloride and employing very soft X-rays (25 kV) with longer exposure times and using fine grain film. A full description of the apparatus used ; the methods of operation and the safety precautions taken are given. It has been found that by using this technique the layers of the mother-of-pearl bead in cultured pearls may show up on the shadowgraph when oriented correctly with relation to the X-ray beam. An ingenious plastic dish with nylon net is used to keep loose pearls in position when being radiographed. The microradiographic (and magnification) technique could with advantage be better explained. A trenchant revue of the current American practice in pearl identification by X-rays. R.W.

DAY (N. H.). *Finding refractive index by direct measurement.* Gemmologist, Vol. XXI, No. 249, pp. 57-58. April, 1952.

A description of the direct measurement method of refractive index determination when employing a microscope which has no calibrated fine adjustment or vernier scale. A small square of celluloid is rested on its edge on the top of the limb of the microscope. With a sharp point the celluloid square is marked at the positions taken up by the top of the rack on the body tube when the microscope is focused on the three positions necessary, the distances of these three points are then measured

by placing the celluloid square on the stage with a suitable stage micrometer. Simple calculation of the ratios gives the refractive index. F. A.

LENTZ (M.). *Emeralds of Chivor.* Gemmologist, Vol. XXI, Nos. 248/249, pp. 49-51 ; 58-60. March/April, 1952. (*Reprinted from The Lapidary Journal, U.S.A.*).

The writer tells of his visit to the emerald hoard at the bank at Bogota, and his journey to the mines of Chivor, which, known some 250 years ago had been lost and not rediscovered until 1905. No machinery is used at Chivor, the emeralds being searched for along narrow terraces—a form of open-pit mining—and by making low untimbered tunnels into the rock. The water necessary for the mining operations is brought along a wooden aquaduct from 16 miles away just as it was so brought during the earlier mining during the 16th and 17th centuries. The emeralds are found in veins varying from several inches to a few feet in thickness. The emerald pockets are indicated by the presence of *moralla* an uncrystallized (massive ?) form of green beryl. Many of the emerald crystals are encrusted with iron oxide which completely obscures the green colour. The article concludes with a general survey of the recent history of the mines—that is from 1905—and some notes of the mineralogy of beryl. R. W.

GAINES (R. V.). *The Sapphire Mines of Kashmir.* Rocks and Minerals, Peekshill, N.Y., Vol. 26, pp. 464-472, 1951.

Sapphire occurs in metamorphosed rocks and associated minerals include kyanite, tourmaline and andalusite. The article describes mines which are near Kudi. F. A.

REIS (E.). *Description of third largest diamond discovered in Brazil.* Gems and Gemology, Vol. 7, pp. 26-27, 1951.

The diamond weighed 407.6 carats when found in 1949 in the Douradinho river, Coromandel, Minas Gerais. Named the " Presidente Enrico Gaspar Durta " it has since been cut into 36 stones ranging from .55-9.60 cts., with a total weight of 136 cts. F. A.

ANDERSON (B. W.). *Stokes on Fluorescence.* Gemmologist, Vol. XXI, No. 250, pp. 77-80. May, 1952.

A centenary tribute to George Gabriel Stokes the 19th century English physicist who carried out so much of the earlier work on the

understanding of fluorescence. A colourful resumé of the work of this great scientist. R. W.

BARLOW (C. H.). *Ancient Pharaonic turquoise mines of Sinai.* Rocks and Minerals, Peekshill, N.Y., Vol. 26, pp. 348-353, 1951.

The turquoise occurs in Nubian sandstone and the article gives a description and a brief history of the mines. F. A.

COGGIN BROWN (J.). *More about Golconda.* Gemmologist, Vol. XXI, No. 249, pp. 72-75. April, 1952.

The history of the ancient State or Kingdom of Golconda and of the capital city of the same name, the latter of which was only the mart for the diamonds found in the southern parts of the state—and elsewhere in India. Some notes on the diamondiferous areas and the localities of the mines are given, and something is told of the famous Indian diamonds. R. W.

CHUDOBA (K. F.). *Neue Schmuck-und Edelsteinmineralien.* New gem materials. Gold und Silber, Vol. 5, 1952, (3), p. 16.

Short survey of new gem materials discovered during the last 50 years, mentioning kunzite, benitoite, brazilianite, and taaffeite. Not yet mentioned is sinhalite. E. S.

H. C. D. *Benitoite Mines Open.* Mineralogist, March, 1952.

A note on the re-opening of the benitoite mines of San Benito, California. Gem specimens are available in limited quantities. A. G.

P. G. *The Diamond Tool Industry in* 1951. Pamphlet, 12 pp. Published by Industrial Diamond Information Bureau, London.

A survey of the chief scientific and industrial developments that took place during 1951, as reported in various periodicals and publications, as well as in patent literature.

SCHLOSSMACHER (K.). *Unterscheidung von echten Perlen und Zuchtperlen durch Röntgenschattenbilder.* Differentiation of genuine and cultured pearls through radiography. Gold und Silber, 5, 1952, (No. 4), p. 10.

The X-ray radiogram technique developed in America and in this country has been tried out by Siemens Reiniger-Werke, A. G., Erlangen. After further tests in Mr. Saller's laboratory in Munich, the Idar-Oberstein Institute is now ready to introduce this efficient method. E. S.

ASSOCIATION NOTICES

COUNCIL MEETING

A meeting of the Council was held at 19/25 Gutter Lane, London, E.C.2, on May 19th, 1952, at 4.30 p.m. Mr. F. H. Knowles-Brown presided.

The following were elected to membership :—

Fellows

Farn, A. E., London. D.1947 (re-election).
Schunk, J. E., Sheridan, U.S.A. D.1950.
Small, J. G., Los Angeles. D.1951.

Probationary

Boudreau, A. G., Harrow.
Branford, E. V., Beccles.
Cummins, W. G., Blackburn.
Foreman, V. L., Stockton-on-Tees.
Forman, E. M. (Mrs.), Buckingham.
Freedman, L., London.
Furness, G. V. (Mrs.), Reading.
Gerling, C. W., Gloversville, U.S.A.
Keay, G. E., London.
Lachowich, V. A., Astoria, U.S.A.
Leese, P. F., Northwood.
Marshall, A., Hull.
Porter, L., Preston.
Ross, R., Edinburgh.
Rudell, J. J., Birmingham.
Sacks, Dr. L., London.
Sandlan, J., Nairobi, Kenya.
Shackman, J., London.
Smith, S. N., Amesbury.
Spray, W. F., Norwich.
Strömdahl, Ake, Stockholm, Sweden.
Thomson, D. M., Dumfries
Towells, M. B. (Miss), Bristol.
Wardall, C. H., Chester.
Watson, P. J., London.
Wood, B. M. (Miss), London.

Ordinary

Brown, J. E., Dewsbury.
Carrington & Co., London.
Dunstall, S. G., London.
Hamilton, J. J., Edinburgh.
Hill, F., Chesterfield.
Hyde, T. H., Sleaford.
Harkness, L.
Hyman Bros., Ltd., Blackpool.
Illingworth, R., Halifax.
Mitchell, B., Harrogate.
Pressley, H. J., Worthing.
Ruffell, E., Tunbridge Wells.
Sanders, G., London.
Sargent, G. T. (Mrs.), Launceston.
Sawyer, F. (Mrs.), South Shields.
Scott, W. S. & A. M., Lincoln.
Sims, B. W., Southend-on-Sea.
Slingsby, J. T., Bradford.

The Council felt that it was desirable to include a member from Scotland on the Council and it was decided to invite Mr. D. J. Ewing (Edinburgh) to serve as a co-opted member. The Council also agreed that where it was felt to be necessary local branches of the Association should be established. The proceedings of the twenty-second annual general meeting held at Goldsmith's Hall on April 2nd, 1952, were approved.

EXAMINATIONS IN GEMMOLOGY

The 1952 examinations of the Association were held as follows :—Preliminary (Great Britain and overseas), Wednesday, June 4th ; Diploma (Theoretical) (Great Britain and overseas), Thursday, June 5th ; Diploma (Practical) (London and overseas), Friday, June 6th ; Monday, May 12th—Plymouth ; Friday, May 16th—Birmingham ; Monday, May 26th—Edinburgh ; Tuesday, May 27th—Glasgow.

The results of the examinations will be notified to all candidates on 27th August.

Applications for the 1952/53 Course should be made no later than as follows :

Overseas—1st August, 1952.

Great Britain—15th August, 1952.

The Course commences for overseas students on 8th September and for home students on the 22nd September.

GEMOLOGICAL INSTITUTE OF AMERICA

Dr. Edward H. Kraus of the University of Michigan has been re-appointed as President of the Gemological Institute of America for the seventh consecutive year.

At the same time Charles Peacock III, C. D. Peacock, Inc., Chicago, was elected to the office of Vice-President which has been vacant for several years. Fred J. Cannon, Slaudt-Cannon Agency Company, Los Angeles, was retained as Secretary-Treasurer.

John S. Kennard, Kennard & Company, Inc., Boston, was chosen to succeed H. Paul Juergens who retired as Chairman after having held that position on the G.I.A. Board for the past four years. Carleton G. Broer, Broer-Freeman Company, Toledo, will serve as Vice-Chairman to the Board, replacing J. Lovell Baker of Henry Birks & Son, Ltd., Montreal.

The retirement of Robert M. Shipley as Director of the Gemological Institute of America was announced on March 31st. In his retirement he can look back with pride and satisfaction upon the important organisation which he was largely responsible for bringing into being and to the status it has to-day. It was during the years of his operation of a large retail jewellery shop that he became conscious of a lack of centralised source to obtain all the information and background that he needed. After visits to factories, shops and museums in various European countries he studied the courses of the Gemmological Association of Great Britain which were, at the time, the only ones available on the subject.

On his return to America and series of lectures to groups of interested jewellers and eventually the Gemological Institute of America became a reality in 1931. No project of this magnitude could have come about through the effort of one man (in 21 years over 10,000 students have been enrolled) but Robert Shipley's leadership and imagination played a dominant part in the building up of a responsible gemmological organization.

Richard T. Liddicoat, Jr., has been appointed to succeed Mr. Shipley as Director of the Institute. He joined the Institute in 1940 and has had wide experience of its many activities. He is author of a " Handbook of Gem Identification " and is well equipped to direct the future activities of the Institute.

GERMAN GEMMOLOGICAL SOCIETY

A German Gemmological Society (Die Deutsche Gesellschaft fur Edelsteinkunde) has recently been established with Headquarters in Idar-Oberstein. The Society aims at furthering the study of gemmology and its objects are very similar to those of the British organization.

PROF. SCHLOSSMACHER

Prof. Dr. Karl Schlossmacher, the well-known German gemmologist, will celebrate his 65th birthday on July 10th, 1952. Until 1945 he was Professor of Mineralogy and Petrography in the University of Königsburg ; since 1948 he has been Director of the State-controlled Institute for Precious Stone Research in Idar-Oberstein. His chief publications have been the third edition (1932) of Max Bauer's great text-book " Edelsteinkunde " ; " Die Plaxis der Eedlsteinbistiminung" (1935) ; and " Lietfaden der exacten Edelsteinbistiminung " (1951). Prof. Schlossmacher has been an Honorary Fellow of the Gemmological Association of Great Britain since 1939. He was recently elected an Honorary Fellow of the Gemological Institute of America. In Germany he is Honorary Fellow of the Central Union of Jewellers, Goldsmiths and Silversmiths.

TALKS BY FELLOWS

G. Blythe : " Gemstones." Crowstone Social Society, Westcliff-on-Sea, March 12th ; " Historical Diamonds." Southend Baptist Senior Fellowship, March 18th.

Joyce Ferrand-Thomas : " Gemstones and Jewellery." Married Families Wives Club, R.A.F. Station, Honnington, Suffolk ; *ibid*, Bury St. Edmunds Townswomen's Guild, March 10th.

G. N. Sprague : " Identification of Gemstones." Quekett Microscopical Club, Royal Society's Lecture Hall, April 8th.

J. M. Duncan : " Gemstones." Rover Scouts of St. James's Church, Paisley, April 11th.

G. M. Parry (Mrs.) : " Gemstones." Royal College of Nursing (Cardiff Branch), April 30th.

D. J. Ewing : " Gemmology—Its application to Police Inquiries." Edinburgh, Newcastle, South Shields and Sunderland C.I.D. and members of Northern Section of the National Association of Goldsmiths (North of England Jewellers' Association), Heriot Watt College, Edinburgh, April 23rd.

F. Warren : " Science of Jewellery." Young Conservatives Assn., Bristol Bishopsworth Branch, April 23rd.

G. Parry (Mrs.) : " Gemstones." South Wales and Monmouth Branch of British Horological Institute, May 29th.

S. T. Solomon : " Gemstones." Buckland Monochorum Women's Institute, July 2nd.

DIAMOND TOOL INDUSTRY IN 1951

The Industrial Diamond Information Bureau has issued a small brochure summarising articles and patents that have been published during 1951, and that have a special bearing on the development of industrial diamonds. Copies of the brochure are available, free of charge, from the Industrial Diamond Information Bureau, 32-34 Holborn Viaduct, London, E.C.1.

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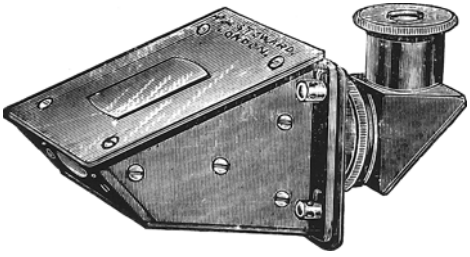

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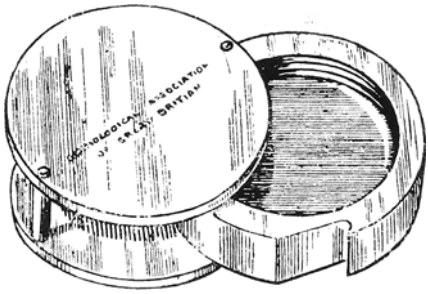

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THE JOURNAL OF GEMMOLOGY
AND PROCEEDINGS OF THE GEMMOLOGICAL ASSOCIATION OF GREAT BRITAIN

Vol. III No. 8 OCTOBER 1952

SINHALITE

— another new gemstone

by B. W. Anderson, B.Sc., F.G.A.

AT a meeting of the Mineralogical Society held on 24th January, 1952, for the second time within a year a new gem mineral was described.

On the former occasion only two small cut specimens of the mineral (taaffeite) were on view, these representing the whole of the world's known supply ; whereas in describing sinhalite Dr. G. F. Claringbull was able to produce a score of cut examples, some of them of considerable size. There was also one small pebble of rough, recovered by Dr. E. H. Rutland from samples of illam held by the lapidaries, Charles Mathews & Son.

Sinhalite, in actual fact, is new only in the sense that its true nature has only just been discovered. Several specimens of the species (all cut as gemstones) were already in the collections of the British Museum (Natural History) and of the Geological Survey Museum, and there is little doubt that there are examples waiting to be re-labelled in most considerable museums of the kind throughout the world.

Private collectors, too, will hold a number of these stones. In the Laboratory we have a fair number of specimens obtained by

gift and by purchase during the past 20 years, and several sinhalites have recently been found in mixed parcels of Ceylon stones (mostly labelled " zircons ") submitted for testing in the ordinary course of business. One of these was a giant of nearly 75 carats—the largest so far recorded.

The aliases of sinhalite have been many and various. When appearance has been the only guide the faceted stones have been plausibly represented as chrysoberyl (which it closely resembles in colour), tourmaline, zircon, or beryl.

When tested by the usual methods, the refractive indices, birefringence, and density agreed sufficiently well with the values to be expected from an iron-rich olivine of the forsterite-fayalite series for the stones to be classified as " brown olivine " or " brown peridot." Brown peridot does indeed exist, but the few so far examined have properties near those of the ordinary green variety, and appear to be a good deal rarer than sinhalite itself.

The chief anomaly with sinhalite when considered in relation to the olivine group is the value of the β refractive index which is quite close to the maximum (γ) index—revealing that the mineral is strongly negative in its optical character with an optic axial angle of about 55°, whereas in olivines the angle is near 90°, resulting in a value for β almost exactly mid-way between the maximum and minimum indices. My colleague C. J. Payne, who had made many accurate determinations both on these brown stones and on green peridots from different localities, had noted this anomaly, and we were both also worried by the very pale colour of some of these " brown peridots " which was hardly to be expected in an iron-rich olivine. However, both axial angles and depth of colour are apt to be variable factors, so suspicions were allowed to slumber. In this connection it is interesting to note that as long ago as 1912 Dr. A. F. Hallimond examined a sinhalite in the Geological Survey collection and altered its description from chrysoberyl to chrysolite, adding the significant words " This stone is to be further examined."

In June, 1950, Dr. George Switzer of the Smithsonian Institution in Washington blew the accepted olivine hypothesis sky-high; the powder used for this explosive act being scraped from the stone itself and the detonator being an X-ray beam.

In more prosaic language, Switzer took an X-ray powder photograph of scrapings from the girdle of a so-called " brown olivine " gemstone in the collection of the United States National Museum and obtained spacings which clearly differed from those of a true olivine. In March 1951, having learned from Mr. Kenneth Parkinson that I had forestalled him in purchasing a large cut specimen of " brown peridot " which the latter had brought back from Ceylon, Dr. Switzer wrote to me for particulars of this stone and any others of the kind which we had measured. In sending him the required data I tentatively offered him one of my smaller specimens for analysis should it seem necessary.

Some time later Dr. W. F. Foshag, Switzer's chief in the National Museum, paid a visit to this country. While being shown round the Mineral Gallery in the British Museum (Natural History) he suggested to Dr. Claringbull that a brown cut gemstone exhibited as olivine had perhaps been incorrectly determined. This was a challenge to which Dr. Claringbull reacted energetically. He took powder photographs of five stones in the Museum collection and in each case obtained a diagram which, though bearing a certain similarity to that of olivine, clearly belonged to a different mineral.

A pale, broken specimen was presented by Mr. Robert Webster to the Museum to assist this research (a typically generous gift of his only specimen) and part of this was crushed and used both for more thorough X-ray analysis and for the chemical analysis which was later carried out by Dr. Claringbull's colleague, Dr. M. H. Hey who, it may be remembered, had earlier analysed taaffeite.

Preliminary spectrographic tests showed the presence of aluminium, magnesium and boron, and the surprising *absence* of silica. The presence of boron always complicates things for the analyst, but, after an unsatisfactory trial, good results were obtained on a sample of only 6.4 mg. Sinhalite, unlike peridot, is practically insoluble in all acids except hydrofluoric. The crushed sample accordingly fused with caustic soda and the fusion dissolved in dilute hydrochloric acid. Aluminium and magnesium were precipitated together by 8—hydroxy quinoline and ammonia and later dissolved and separated by reprecipitation in acetic acid. The boron was determined by titration and iron estimated colorimetrically.

The results of Dr. Hey's analysis were as follow, the figures calculated for pure $MgAlBO_4$ being given alongside :—

		Found	*Calculated*
B_2O_3	...	24.2	27.60
Al_2O_3	...	41.0	40.44
MgO	...	32.3	31.96
Fe_2O_3	...	2.0	—
H_2O	...	0.3	—
		99.8	100.00

Sinhalite is thus a magnesium aluminium borate containing inessential traces of iron. The analyst assumes this iron to be in the ferric state, but from the close similarity of the absorption spectrum with that of peridot (discussed below) in which the iron is undoubtedly ferrous, the writer would beg leave to doubt the correctness of this assumption.

As may be said of most gemstones, sinhalite is allochromatic and would be colourless if a specimen could be found which conformed exactly with the " ideal " formula. Many of the stones are, indeed, very pale in colour, having only a tinge of brownish yellow. At the other end of the range are brown stones as dark and lacking in charm as brown tourmalines—these undoubtedly contain more iron than the 2 per cent. found by Dr. Hey in the pale sample analysed. Between these extremes are sinhalites of golden brown, or greenish brown, closely resembling chrysoberyl in appearance, and these are decidedly attractive gems.

Once its properties are understood sinhalite is not a difficult stone to identify. The birefringence is strong enough to cause very distinct doubling of the back facet edges when these are viewed through the crown of the stone with a 10X or 8X lens. The strength of the birefringence is nearly the same as with peridot—that is, half-way between that for tourmaline and for zircon. It is more dichroic than zircon and less so than brown tourmaline. The pleochroic colours in a typical specimen are pale brown, greenish and dark brown.

On the refractometer, the readings are nearly two units in the second place higher than for olivine, while the birefringence is higher than for diopside. With loose stones, the speed at which it sinks in methylene iodide at once separates it from peridot.

Sinhalite is usually remarkably " clean " and transparent : though isolated mineral inclusions have been observed none seem particularly characteristic, and it lacks the " feathers " seen in so many peridots, chrysoberyls and tourmalines.

As for the absorption spectrum, this bears a remarkable resemblance to that of peridot, but is sufficiently characteristic, when one is familiar with it, to serve as a useful diagnostic feature. The similarity in position between the sinhalite and olivine bands is strong evidence both of the cause for each being the same (ferrous iron) and for the atomic structure surrounding the absorbing atoms being very closely related despite the very different-seeming chemical formula.

With pale sinhalites practically no bands can be seen, while (in common with other brown stones) there is strong general absorption of the blue and violet in the darker specimens, so that it is difficult to see some of the discrete bands in the gloom.

Wavelengths of the main absorption bands in the mineral are given below, alongside those for peridot. In each case there are

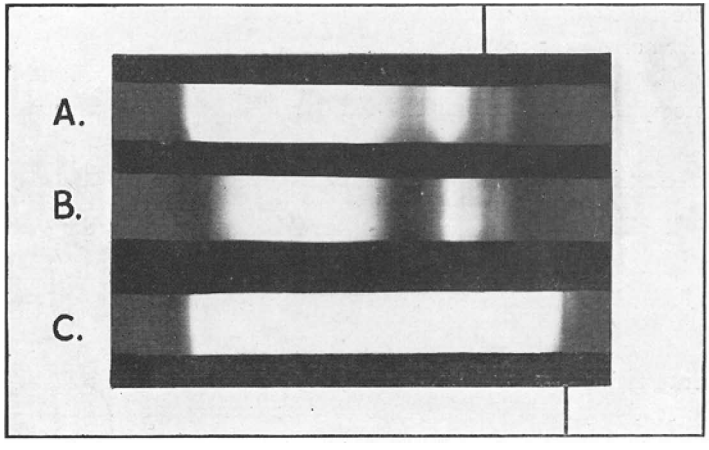

Absorption spectra of sinhalite and peridot taken with a diffraction grating spectrograph, using Ilford "long range spectrum" plates. a. *Sinhalite ;* b. & c. *Peridot. In* a. *the "extra" band at* 4630A *is marked ; it will be seen that this is missing in the peridot spectrum below. In* c., *a deliberate over-exposure of the plate enables the strongest of the ultra-violet absorption bands in peridot* (3970A) *to be observed. The apparent broad absorption bands in the green region seen in* a. & b. *are chiefly due to the insensitivity of the panchromatic emulsion in this region—one reason why photographs of absorption spectra are seldom really satisfactory.*

differences in detail for each of the three pleochroic rays, but in general all the bands mentioned can be seen under good lighting conditions.

	Sinhalite.		*Peridot.*
5260A	weak, vague.	5290	weak, vague.
4930	mod. strong, narrower.	4930	strong, complex.
4750	mod. strong, narrow	4730	moderate, narrow.
4630	mod. strong, broader.	——	
4520	moderate, similar.	4530	moderate.

It will be seen from the above table how most of the absorption bands in the two spectra correspond closely in position, though there are subtle differences in their character that description cannot easily convey. The main difference consists in the presence of a band at 4630A in sinhalite which is missing in peridot. Even without measurement this gives a sufficiently altered pattern to the practised eye to enable one species to be distinguished from the other by this means. Another difference, revealed only on the photographs taken of the spectra, is the presence of two strong, rather narrow absorption bands in the near ultra-violet in the case of peridot (at 3970 and 3850A approx.) which are not found in photographs of the sinhalite spectrum.

For the convenience of readers, I will conclude this article by giving a complete summary of the characters of sinhalite, so far as they are known. The only known locality so far is Ceylon, and the name chosen for the stone indicates this fact. But, just as brazilianite is not confined to Brazil nor andalusite to Andalusia, so sinhalite will almost certainly be found in other countries before long, now that its existence and its properties are known. It will be interesting to see whether petrologists can trace its presence in rock sections, and give us some clue as to its genesis.

Properties of Sinhalite

Composition. Magnesium aluminium borate ($MgAlBO_4$).
Crystal System. Orthorhombic. (Class not yet determined).
Hardness. $6\frac{1}{2}$. (Not yet accurately determined).
Colour. Pale yellow, shades of brown and greenish brown.
Pleochroism. Distinct : Pale brown, greenish brown, darker brown.

Refractive indices, birefringence and density (typical values)

Colour	α	β	γ	$\gamma - \alpha$	*Density*
Pale yellow ...	1.6667	1.6966	1.7048	.0381	3.47
Brown ...	1.6691	1.6988	1.7069	.0378	3.48
Dark brown...	1.6708	1.7000	1.7081	.0373	3.49

Dispersion. B—G .018.

Absorption spectrum. Main bands are in blue, at 4930, 4750, 4630, and 4520A, with general absorption of violet.

The refractive indices given above were measured by C. J. Payne in sodium light on an Abbe-Pulfrich refractometer. The corresponding densities were determined by the writer by hydrostatic weighing in ethylene dibromide, and reduced to two places of decimals. The properties of the more than 20 sinhalites measured in the Laboratory are remarkably consistent, showing merely a slight increase in refractive indices and density with increasing depth of colour. There is a slight but definite tendency for the birefringence to be lower in the stones with the highest indices.

Fuller details of individual specimens, and of the X-ray investigation, will be found in the original paper by Claringbull and Hey, published in the Mineralogical Magazine for June, 1952.

One last note should perhaps be added, though for most readers of this journal the warning should not be necessary. The terms " olivine " and " peridot " in this paper must be taken as broadly equivalent terms for the same mineral, though to mineralogists the name olivine has a wider significance than has the term peridot to the jeweller. If this is not understood, much of what has been written above will prove confusing to the reader.

LETTER TO EDITOR

DEAR SIR,

The article on using a ' live box ' for holding stones (Journal of Gemmology, Vol. 3, No. 7, 1952, p. 279) made me wonder if the idea I have used for years is of interest. It is an ordinary insect holder which fits in place of one of the microscope stage clips. The cork inset is removed and replaced with plasticine on which the stone to be examined is lightly pressed. It can be turned and examined in nearly all directions.

Yours faithfully,

E. W. MATON.

Queen Street, Cardiff.
10*th September*, 1952.

Feature of

AMETHYST AND CITRINE INCLUSIONS

by Norman H. Day, F.G.A.

AMETHYSTS and citrines often contain flaws which are usually known as " feathers." These may be discussed under the term Inclusions, though a true inclusion is foreign to the host crystal. Many gemmologists must be attracted by the beautiful and bold effect of these " feathers," often reminiscent of a mackerel sky of light Cirro-cumulus clouds.

Stones containing large " feathers " are rejected from use in high-class jewellery, but the presence of small and inconspicuous ones give an important diagnostic feature. The so-called "feather" inclusions found in topaz, sapphire and tourmaline do not show the same striped pattern that is seen in many amethysts and citrines.

My interest in these inclusions was aroused some months ago, when Mr. K. Parkinson of Hull sent me a collection of stones that would provide good subjects for photomicrography. Among these was a square cut pale amethyst of about three carats and just under and parallel to the table facet was a " feather " which gave the whole stone what may be described as a " tiger skin " effect. (Fig. 1.)

The stone was immersed in Clove Oil ; an Ilford ordinary plate was used, with a single polaroid filter orientated to cut out any double refraction effect and an Ilford micro-filter No. 2 to cut out ultra-violet and deep violet light to which these plates are very sensitive. The result can be seen in Figs. 2 and 2A, which show part of this " feather " magnified 80 × and 130 × .

These photomicrographs show that the units in one band of the " feather " are parallel to the units in alternate bands, while the units in the intervening bands are parallel but orientated at 60° to the direction of the other units.

Fig. 1. *The "Feather" parallel to the table facet in Amethyst.* 12 ×.

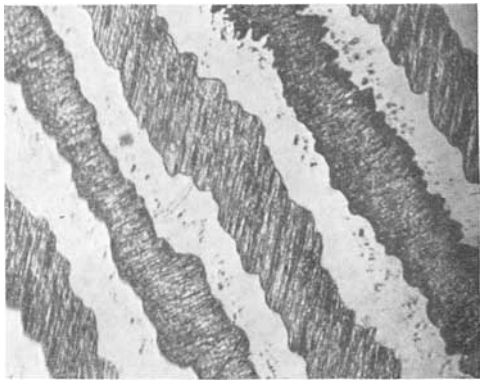

Fig. 2. *Enlargement of part of the "Feather" of fig.* 1. 80 ×.

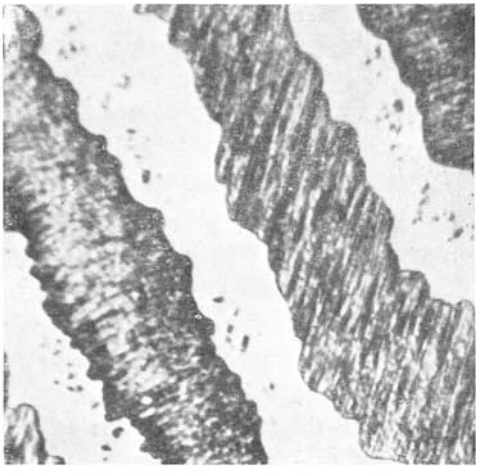

Fig. 2*a*. *Enlargement of part of the "Feather" in fig.* 1. 130 × .

Having noted this phenomenon, I proceeded to examine " feathers " in a large number of amethysts and citrines (usually pale stones), with a low-powered microscope. There appear to be two main types :—

(i) A type in which the bands are evenly spaced and the whole " feather " is in a flat plane ; there may be other flat " feathers " in the stone while they all appear parallel to possible faces of the crystal ;

(ii) Those that do not form a flat plane but are the shape of a conchoidal fracture of the type that shows interference colours in some quartz. The bands of these " feathers " are uneven and do not show the orderly form of type (i).

Using a higher magnification to observe the structure of the bands, it is found that only a few " feathers " have the orderly arrangement seen in Fig. 2, often the units are arranged parallel in every band and only an odd one or two have the alternate arrangement. Fig. 3 shows this, and Fig. 4, which is the same plate enlarged, shows a grain structure which might at first be taken for double refraction ; this remains however the polaroid filter may be adjusted, so that it must be part of the " feathers " structure. " Feathers " of type (ii), showing a grain structure without parallel form, can be seen in Figs. 5 and 6.

Many bands appear opaque because of internal reflection, as do some in Fig. 5. It is usually difficult to obtain quickly a good view of a " feather " for naturally the lapidary does not cut the stone so that it is parallel to the table facet, as in the case of Mr. Parkinson's stone, but he cuts it so that there is an angle of 45° to 90° between the " feather " and the table facet.

After showing Mr. L. C. Trumper the photomicrograph (Fig. 2) he drew my attention to F. J. Sperisen's book[1] " The Art of the Lapidary " in which, among the numerous illustrations, are two photomicrographs of " feathers " within Brazilian amethyst, one 30 × and another 70 ×, the second showing the alternate orientation of the units in the bands very clearly.

In a private communication Dr. E. Gübelin comments on Sperisen's photos and my photomicrograph (Fig. 2) : " They are very much alike indeed and somehow I have the feeling that they

Fig. 3. *A typical evenly spaced "Feather" of group ii.* 36 ×.

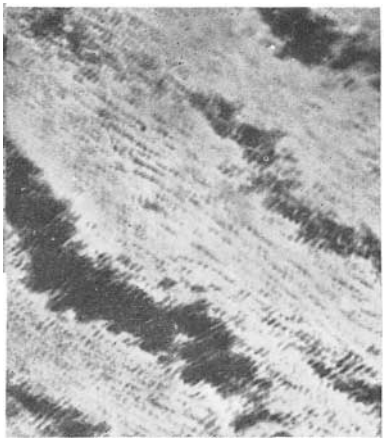

Fig. 4. *Part of plate fig.* 3 *with further enlargement.* 96 ×.

Fig. 5. *Typical "Feather" of group ii.* 36 ×.

Fig. 6. *"Feather" of group ii with complex arrangement.* 55 ×.

are ' scrape ' marks of a crack which partly healed with time, or then they might be marks caused by the shifting of the atomic planes which happened under mechanical strain (what is generally known as ' translation ')."

It is interesting to note that Church[2], Spencer[3], and Herbert Smith[4] all state that they consider these feathery inclusions and ripple fracture characteristic of amethyst to be due to twinning.

Spencer refers to " feathers " as " thumb prints," a name which might easily be adopted for these inclusions in amethysts and citrines, because of the wide application of the term " feathers " for so many types of inclusions.

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The temporary building which houses the Headquarters of the National Association of Goldsmiths, British Jewellers' Association, the National Jewellers' Association and the Gemmological Association of Great Britain. Behind is the facade of Goldsmiths' Hall.

NOTAE — UT INFRA

by D. S. M. Field, A.G.A.

THE writer has just received an interesting parcel of greenish-yellow scapolite from a new deposit opened up in the Township of Grenville, Argenteuil, Quebec. This material is quite compact and should cut good cabochons, although it is not sufficiently transparent for faceting.

Chief interest in the newly discovered variety of scapolite rests in its remarkable reaction to ultra-violet radiations. It fluoresces a slightly paler colour than the better-known type from that locality ; but is phosphorescent as well as fluorescent.

An authority in the United States who has studied the duration of phosphorescence in a large number of minerals reported that this particular scapolite has the longest phosphorescence of any—approximately *fourteen-hundred hours*. That is to say, a specimen exposed to ultra-violet light for a given time would affect a photographic film for a period of about three months thereafter.

Specimens are, in general, all rock, containing on the average from 40 to 60 per cent. scapolite in single individual crystals up to one-half to one-inch in size.

* * *

A considerable upswing in the price of moonstone above five carats in weight has resulted from the almost complete exhaustion of the Ceylon moonstone mines.

Gems that a year or two ago sold for a few shillings per carat are now being quoted in some circles in pounds sterling. Small gems, material for which is still relatively abundant in the gem gravels of certain districts of the island, are still available at the old prices ; but large stones of flawless quality are fast becoming collectors' items, and are practically unobtainable from Singhalese dealers in precious stones.

An advance in price is also expected in quotations for tiger-eye crocidolite. The South African deposits located near Griquatown, north of the Orange River, are now reportedly almost worked out. Fine specimens of this attractive mineral may, therefore, become unavailable when dealers' present stocks are exhausted.

* * *

The mad rush of manufacturers, cutters and dealers to unload synthetic rutile in Canada and the United States has apparently somewhat subsided. Fewer and fewer advertisements extolling the virtues of the brilliant gem have been appearing in trade papers, and in journals designed for the reading public.

* * *

Something new in interference figure slides is now being manufactured in North America. The slides are designed for the aid of teachers and students of optical mineralogy, and might therefore be of interest to the gemmologist.

Each slide provides oriented plates of six different minerals—permitting study of the interference figures without change of focus.

The following orientations are contained in a given slide : Quartz (uniaxial positive) perpendicular to C ; Topaz (bi-axial positive) perpendicular to Bxa ; Muscovite (Biaxial negative) perpendicular to Bxa ; Epidote, optic axis ; Barite, perpendicular to Bxo ; and Topaz, cut half-way between optic axis and Bxa, so that one axial emergence point and the centre of Bxa are in the field simultaneously.

Other slides of interest to the scholar are also available. These include multiple-orientation grain-thin sections of the following gem minerals : albite, andalusite, apatite, beryl, calcite, chalcedony, diopside, enstatite, epidote, idocrase, kyanite, labradorite, opal, orthoclase, peridot, prehnite, rock crystal, rutile, sphene, topaz, tourmaline, and zircon.

A relief slide is also of interest. This slide contains grains of six separate gem species mounted in the form of a star. They are : fluor, orthoclase, quartz, beryl, apatite, and garnet. The grains

are arranged close enough together to allow the centre of the star and all six of the minerals to be viewed at one time in the field of a 10x (16 mm) microscope objective.

* * *

An American gem company has sold more than ten million carats of a new imitation turquoise material for use in the manufacture of novelty jewellery. Misnamed " synthetic turquoise," much of the output is utilized for facsimile American-Indian jewellery, and sold to tourists, principally in the southern and south-western sections of the United States.

* * *

A few black cultured pearls—probably stained by silver compounds—are occasionally reported ; and the writer has identified an exceptionally clever imitation bloodstone intaglio. The latter is of dark green opaque or sub-translucent glass with very realistic specks of opaque red " jasper." Considering the low cost of bloodstone, a clever imitation of this nature (with hand engraved figure) is most unusual, and hardly worth the effort its manufacture must have entailed.

* * *

Ugly Victorian-type cameos, wrist-watch bands and other tasteless jewellery items patterned after the styles popular during the latter half of the 19th century, seem to be the current vogue in North America—particularly with regard to the so-called " popular " items. The emphasis—perhaps mirroring the current international diplomatic situation—is definitely on the synthetic and the loud. Huge, heavy appearing (hollow-shoulder) rings with atrocious scissor-cut, patently synthetic " octagon " stones, for men ; and hanging drop trash jewellery for women. It is therefore to be hoped that the trend will eventually develop toward the quiet designs and standard cuts that were so popular during the first quarter of the present century ; and that, with a renewed sense of the worth of genuine things, the public will abandon its mad chase after the gaudy, and begin to share with the gemmologist his love for and appreciation of the quiet beauty of genuine, natural coloured stones.

Unusual Two and Three Phase

INCLUSIONS IN CEYLON SAPPHIRE

by L. P. Hoagland

OF increasing importance in the study of gemmology is the determination or verification of variety or species of gemstones on the basis of internal inclusions. In addition to being informative, the study of gemstone inclusions will occasionally bring the student into contact with an unusual or fascinating deviation from the expected.

Such a deviation is the occurrence of two- and three-phase inclusions in sapphire which alter to single- and two-phase inclusions of different character under the influence of heat. In the Summer and Fall, 1943, issues of Gems and Gemology, and in the Journal of Gemmology for July 1948, Dr. E. J. Gübelin presented findings on two-phase inclusions in a variety of gemstones. His researches established that those inclusions in which the liquid component altered to gas at a critical temperature usually contained carbonic acid, or carbon dioxide in liquid and gaseous forms.

In the inclusions studied by Dr. Gübelin, the application of heat resulted in the gradual expansion of the gas bubble, with a straightening of the meniscus or curved line of demarcation between the gas and the liquid. At the critical temperature of 31.1 degrees centigrade, when the meniscus formed a nearly straight line, the liquid component of the inclusion was vaporized and the cavity was occupied by gas only.

The inclusions herein reported on are similar in some respects to those noted by Dr. Gübelin, and were discovered in a single cabochon Ceylon sapphire during microscopic examination in the laboratory of Tiffany & Co., New York. Almost by chance, an active but short-lived turbulence within the stone was noted and it was set aside for further examination.

Figure 1 shows the effect of gradual heat applied to an inclusion of the type described by Dr. Gübelin. At room temperature the gas bubble is enclosed by the concave surface of the liquid, and a cluster of small black crystals is lodged in the corner of the cavity which forms an oblique angle. As heat is gradually applied the successive stages of enlargement of the bubble and loss of curvature

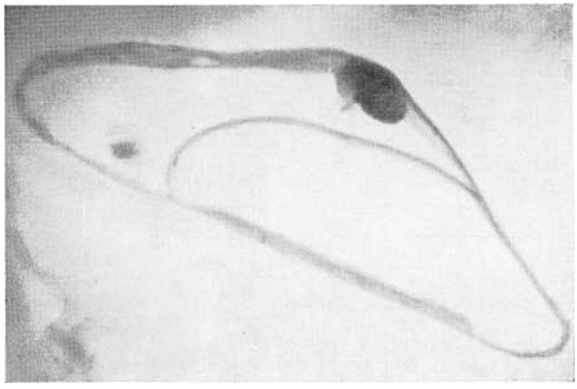

Fig. I

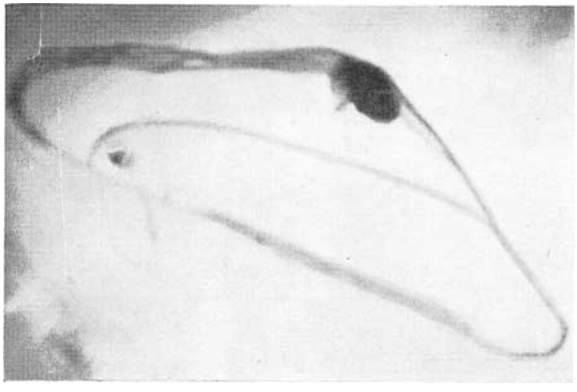

Fig. I a

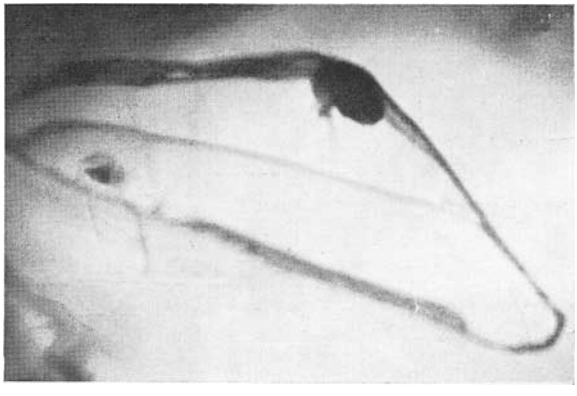

Fig. I b

of the meniscus are shown. Just prior to the sudden and complete alteration of liquid into gas, the meniscus is a thin, faint, nearly straight line of demarcation. In the final stage the liquid is vaporized and the cavity is occupied only by gas and the crystal cluster.

Heat from a microscope lamp is sufficient to cause this change which may also be accomplished merely by placing a finger on the stone for a few moments. To reverse the reaction, removal of the finger or turning off the lamp is sufficient. Dr. Gübelin mentions that on removal of heat and reversal of the reaction, the insides of the inclusions studied by him were momentarily filled with a cloud or mist which obscured the view of the interior. The inclusions discussed herein showed instead a sudden partial liquification of the gas, followed by a relatively violent separating out of additional small gas bubbles from this liquid. This separation continued for a brief period of time until a state of equilibrium seeming to correspond to the temperature of the stone was reached. It was found that a drop of alcohol placed on the stone and allowed to evaporate hastened the reversal of the reaction and reappearance of the gas bubble.

Further examination of this stone reveals that there is an entirely different type of reaction to heat to be found in inclusions of this type. On the basis of appearance, the nature of the reaction and the critical temperature involved, it seems certain that the constituents of the inclusions are the same or closely similar even though the two types of reaction are complete opposites.

Figure II shows a roughly triangular cavity containing liquid, a small black crystal, and a gas bubble. The stages of reaction to heat are shown by the gradual decrease in size of the gas bubble and a greater degree of curvature of the meniscus. When heated above room temperature, small gas bubbles form on the surfaces of the crystal and float upward through the liquid to join the original bubble. At first, this bubble increases in size with the addition of new bubbles but thereafter contracts as more small bubbles are added. This contraction continues until the large bubble has entirely disappeared, at which point no more small bubbles are formed on the faces of the crystal and action within the inclusion ceases. What had been a three-phase inclusion has altered to two-phase and contains not the crystal and gas which might be expected, but rather the crystal and a liquid.

Fig. II

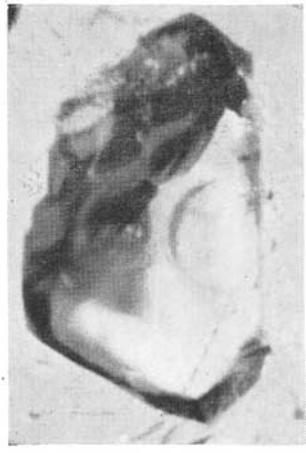

Fig. II a

Fig. II b

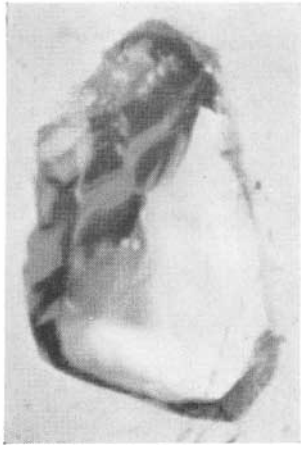

Fig. II c

Figure III shows a larger inclusion of the same type which proved much more active and versatile than the one just discussed, although considerably more difficult to photograph. By moving the stone, it was possible to position the gas bubble in a remote corner of the cavity where the stream of bubbles forming about and rising from the cluster of included black crystals could not reach it. These small bubbles were then seen to form a single new bubble which gradually increased in size. As the new bubble grew, the original decreased and was eventually completely absorbed in the liquid. On its disappearance, the second bubble ceased growing, and as more small bubbles reached it, gradually grew smaller and

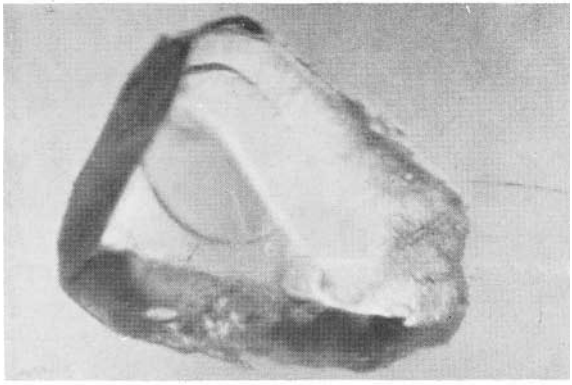

Fig. III

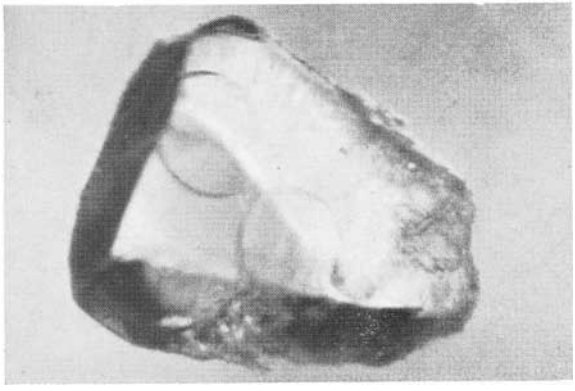

Fig. III a

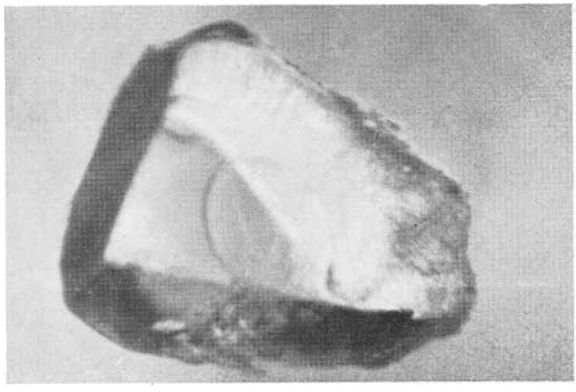

Fig. III b

disappeared. At this point, the generation of small bubbles on the faces of the black crystals came to an end and activity within the inclusion ceased.

An interesting sidelight to this type of reaction lies in the behaviour of the cluster of crystals in this latter inclusion. With the formation and release of gas bubbles on the sides of the crystals (possibly due to a more rapid absorption of heat by them than by the other constituents of the inclusion) these crystals were agitated, danced erratically about the interior of the inclusion, and on occasion floated to the surface of the liquid.

Also interesting to note with respect to the function of these crystals is a two-phase inclusion (gas and liquid) in the same stone which became single-phase (liquid) on the application of heat. (Fig. IV). The absence of a crystal component was paralleled by the absence of a stream of released gas bubbles as a feature of the reaction. The end result, liquification of the included gas, was the same as previously noted.

In each of these inclusions where the gas was liquified, the reversal of the reaction followed the same pattern. At a lowered temperature, a mass of small gas bubbles was seen to separate out from the liquid, rise to the surface, and form the gas bubble characteristic of the inclusion at room temperature. This reaction was particularly apparent in the violent movement within the larger inclusions. Depending on the position of the stone the resulting gas bubble might be seen as one, two, or three separate bubbles.

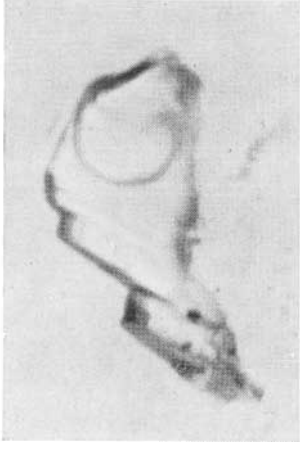

Fig. IV

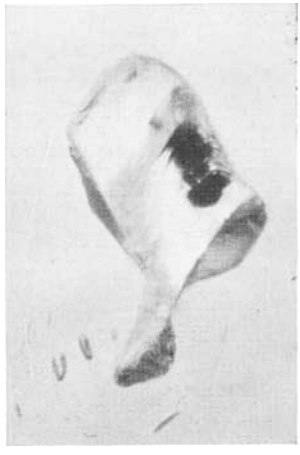

Fig. V

Figure V represents what on examination seemed to be a two-phase inclusion within the same stone and containing only liquid and the familiar black crystals. Since a reduction in heat had been seen to cause gas to separate out from the liquid in the previous inclusions, it seemed worthwhile to find out if a greater reduction below room temperature would have the same effect on this inclusion. The reasoning involved was that perhaps unusual pressures within the cavity were affecting the critical temperature of the solution.

To effect cooling, the stone was packed in dry ice with only the portion above the inclusion open for observation. To prevent frosting and preserve visibility, this portion of the stone was kept wet with alcohol. The effect of freezing was found to be similar for all of the inclusions discussed above. In those containing gas bubbles, the bubble showed an initial increase in size. At another critical temperature which it was not possible to measure, the gas and liquid components went through a rather spectacular change. With a violence resembling a small explosion, the remaining liquid became gas and almost simultaneously froze in a layer of ice crystals on the inner surfaces of the cavity.

On removing the stone from the dry ice, no gradual melting of the ice crystals of any significance was noted. As the critical temperature was again reached, a sudden violent reaction returned the gas and liquid components to the interior of the cavity.

In the case of the inclusion which had prompted the freezing, a gas bubble was formed in the liquid, but with inconclusive results. On warming the stone to room temperature, this bubble was found to be still present and thereafter reacted as had those previously discussed. It seems likely that the bubble may have been present, although not visible, in the small extension of the inclusion which was not susceptible of thorough examination. The freezing and melting just referred to may then have relocated the bubble in an area where it could be more easily seen.

It is realized that the pictures accompanying this report may not be as clear or detailed as might be wished. However, the rapidity of the reaction when coupled with the time required for exposure makes it extremely difficult to reproduce on film all of the interesting aspects of this phenomenon. In closing, the writer wishes to acknowledge the valuable assistance and advice furnished him by Dr. A. E. Alexander.

Gemmological Abstracts

BENSON (L. B.). *Many "reconstructed rubies" found to be synthetic corundum.* Gems and Gemology. Vol. VII, No. 5, pp. 139-144. Spring, 1952.

It is the author's opinion that many stones identified as reconstructed rubies are either cut from early Verneuil boules or from the bottom tip (stems) of boules. What is known of the processes of reconstruction is discussed. Considerable work has been carried out on the examination of the various internal structures of boule tips and the summing-up is mainly based upon these examinations. 12 illustrations. R.W.

CAHN (A. R.). *Pearl culture in Japan.* Report No. 122. Natural Resources Section, General Headquarters, Supreme Commander for the Allied Powers, Tokio. October 1949. *Reproduced by permission of the Civil Affairs Division, United States Department of the Army.*

Probably the most complete report on the cultured pearl industry of Japan. The early beliefs of the cause of the formation of pearl and the history of the experiments which led to the present mass production of cultured pearls. The biological aspects of the pearl oysters—the term *pinctada* is used instead of the older *margaritifera*—particularly that of *pinctada martensii* which is used to produce the cultured pearl. The rate of growth of the animal, the functions of the mantle and the structure of the shell and the origin and development of the pearl—both natural and cultured are discussed. Some information on the staining of cultured pearls to a rosée shade is given but nothing about the black coloration which is so often found in the case of cultured pearls. The collection of spat and the farming of the oysters, with the localities of the various farms (complete with maps) and the various types of rafts used in these farm processes are explained. Full information is given on the techniques of nucleus insertion and the types of instrument used in the operation. The fishing and the operative measures are carried out by girls. The nature of the biological enemies of the pearl oyster is given, special mention being made of the nature of the "red tide" which is said to be due to an abundance of members of the *dinoflagellata* and *distomacea* which colour the water red. The recovery and grading of the cultured pearls is

fully explained. Information is given of the production of non-nucleated pearls by cultivation of the freshwater clam *Hyriopsis schlegeli* at Biwa-ko, Shiga prefecture, which, although experiments have been carried out for some 20 years, has resulted in pearls of good colour and lustre, but of irregular shape, only since 1945. The report is completed with a number of appendices including a summary of the patents relating to pearl culture ; the production of cultured pearls from 1926 to 1946, and other valuable statistics. 91 pages. 23 illustrations. R.W.

HUNT (G. C.). *Greenstones of the Maoris.* Gemmologist, Vol. XXI, No. 251, pp. 102–104. June, 1952.

A short article on the New Zealand nephrite (reprinted from the New Zealand Watchmaker and Jeweller). It commences with a short introduction to the history and legend of Maori jade. Native cutting is discussed. The material is found as boulders in the rivers of Westland (misspelt Westerland). The native names for seven varieties of New Zealand jade are given. Tangiwai from Milford Sound is not nephrite but bowenite (a variety of serpentine). It is stated that nephrite from China (presumably material carved there) and sold as New Zealand jade for the export market commands a better price than the true New Zealand material. Scheerer's analysis showing the New Zealand material to have more iron and less magnesia than the material from China is mentioned. It is suggested that the New Zealand greenstone should be given its true name — jade. *This article called forth a letter from Prof. C. Osborn Hutton (Gemmologist, No.* 253, *p.* 139. *Aug.*, '52) *who pointed out that the one analysis of each jade made by Scheerer was not acceptable in view of later work and could have little value. He also criticised the spelling of the name Teremakau for the river in Westland where much New Zealand jade is found. Prof. Hutton says the correct spelling should be Taramakau. It appears that most English gazetteers use the " e."* R.W.

WEBSTER (R.). *Secrets of synthetic emerald.* Gemmologist, Vol. XXI, Nos. 252–3, pp. 117–121 and 140–145. 1952.

A resumé of the history of emerald synthesis. It is suggested that the synthesis may be analogous to the growth of quartz crystals by hydrothermal method. The characters of the natural and the synthetic emeralds are given and compared. The value of the Chelsea colour filter and ultra-violet light fluorescence

discussed. The typical inclusions of natural and synthetic emerald illustrated by photomicrographs. P.B.

HARRISON (A. R.). *Occurrence—mining and recovery of diamonds.* Gems and Gemology, Vol. VII, No. 5, pp. 154–161. Spring, 1952. Also *Diamond mining and recovery.* Gemmologist, Vol. XXI, Nos. 252/3, pp. 123–126 and 155–157, and 254, pp. 164-166, 1952.

The author commences with a historical survey of diamonds mining and gives notes on the occurrences. The Indian diamond fields and the methods of working them are told. The pipe mines of Kimberley area ; the alluvial deposits of Belgian Congo, Angola, Tanganyika Territory and Sierra Leone deposits are reported on. The methods used in the recovery of diamond being given for each locality. R.W.

WEATHERBY (E. W.). *Diamond sorting and valuation.* Gemmologist, Vol. XXI, No. 253, pp. 146–148, and Nos 254, pp. 173-176, 1952. Reprinted from *Optima.*

An informative article written by a man who has spent his lifetime in the diamond trade as sorter and valuer. The basic idea of sorting is discussed with relation to the buyers' requirements. Smaller and lower priced stones, even if slightly flawed, are more economical for the production of small brilliants than larger stones. Value of the sawing technique for well-shaped octahedral crystals in order to save weight is explained. The Central Office of the Diamond Producers Association in Kimberley deals with the classification and the basic value of the mined diamonds. The Diamond Trading Company breaks up the valued stones into suitable " parcels " to sell to the cutters. R.W.

GARRELS (R. M.). *The synthesis of quartz.* Gems and Gemology, Vol. VII, No. 5, pp. 151–153. Spring, 1952.

A general note on the growing of quartz single crystals. The theoretical consideration of the problems of quartz synthesis due to changes in crystal structure at different temperatures. A discussion of the constant temperature and the temperature gradient methods for the production of quartz crystals. Crystallographic orientation of the quartz seed plate is of much importance. Resultant crystals are untwinned and unstrained and inclusions (two-phase) are minute. Author states that it appears possible to grow coloured material quite readily. R.W.

BARBER (R. J.). *Jade in Mexico.* Gems and Gemology, Vol. VII, No. 5, pp. 147–150, and 166. Spring, 1952.

The origin of the material used for the archæological jades of Mexico is discussed. The theory that the jadeite, for most of these pieces are made of jadeite, was not indigenous to Mexico and came, and was possibly carved, in China, is discredited. Analysis showed that the ancient jadeite pieces had replacement of parts of the soda and silica by lime and magnesia and was therefore a diopside-jadeite. The history of Mexico from these ancient times is given as an explanation why sources of jade minerals in Mexico have not so far been found. Ancient pieces representing all Mexican cultures are found in many parts of the country during excavations of tombs and temples and by being washed out by rain action. The true artifacts are sold to dealers but much of this "archæological" carved work and also carved pieces for feminine adornment are merely modern imitations of green glass. R.W.

ANON. *Gem industry of the Jura Mountains.* Gemmologist, Vol. XXI, No. 253, p. 149. August, 1952.

The industry is said to have originated in Geneva during the XVth century. Gives a short history of the Jura lapidaries from those times. Topazes, amethysts, rubies, sapphires and emeralds were cut during the 19th century. A diamond cutting centre was established at Saint Genis in 1874, and later spread to other villages around the Gex district. Before 1929 there were some 200 diamond cutters in the Jura, but the industry has fallen and now only about 10 diamond cutters are in Saint Claude the main centre of the Jura lapidary workers. R.W.

FIRSOFF (V. A.). *Gems of Arran.* Gemmologist. Vol. XXI, No. 251, pp. 97-101. June, 1952.

A general geological outline of the rocks of the island of Arran off the Firth of Clyde. Gem materials found in the island are red jasper, agate, rock crystal, citrine, smoky quartz and some amethyst—most quartz crystals marred by inclusions and carbon-dioxide gas bubbles. Aquamarine, white to deep honey yellow topaz, black (and green) tourmaline and garnet are also found. There is an occurrence of sapphire but the blue crystals are usually thin hexagonal plates containing inclusions of foreign material and unsuitable for jewellery. R.W.

MEASUREMENT OF COLOUR

by

M. D. S. Lewis, A.R.C.S., B.Sc., F.G.A.

IN the previous article it was explained how the " dominant wavelength " and " excitation purity " of a colour can be found on the C.I.E. Chromaticity chart. These two measurable quantities correspond adequately, though perhaps not precisely, with the mental sensations of hue and saturation respectively. It is first necessary to plot the position of the illuminant on the chart by means of its trichromatic coefficients, which normally are accurately known. Those of the colour will have been ascertained by use of a colorimeter and the position also marked on the chart. A straight line is drawn from the illuminant point to the colour point and produced to meet the Spectral Locus, on which the point of intersection gives the wavelength of the hue.

No difficulty will be experienced if the colour point lies anywhere above the dotted lines BS and RS in Fig. 1. If, however, the colour " C " is located within the triangle BSR which represents the purple area, the line SC produced cannot meet the Spectral Locus, as purple is not a spectral colour. To cope with this situation an artificial device is employed and the line joining the colour point to the illuminant point is extended backwards to meet the Spectral Locus in the green region. Thus in Fig. 1 if CS produced cuts the Spectral Locus at " d " (say 5150A) the dominant wavelength is given as " complementary to 5150A " and is sometimes expressed as C5150 or minus 5150A. The " excitation purity " is still defined as the ratio CS/DS.

By joining any colour point not in the purple area to the illuminant point and producing this line until it meets the Spectral Locus on the *opposite* side, the complementary hue is quickly found. This information may be useful for " killing off " an unwanted colour since admixture with its complementary results in desaturation. A knowledge of complementary colour is useful in questions concerned with colour contrasts and display generally.

By defining the colour of a gemstone in terms of C.I.E. co-ordinates and thereby plotting its position on the C.I.E. chromaticity chart the whole aspect of gemmological colour assumes a precise meaning, particularly as regards nomenclature. There could be internationally agreed areas on the chart within which any particular gemstone could be designated as " fine " (as regards colour). Precise and even legal meaning could be given to terms such as " pigeon-blood " rubies, ordinary " rubies," pink sapphires, etc., whilst the grading of diamonds might merely resolve itself into a statement of trichromatic coefficients. The C.I.E. system embraces the whites and " off-whites " as well as the more saturated colours. If colour grading is to be applied to diamonds or any other stone there can be no better way of doing it than to delineate some specific area or areas on the C.I.E. chromaticity chart and so give objective meaning to what we are trying to say.

The simplicity and success of the C.I.E. system derive largely from its separation of " quality " from " quantity " of light, thereby presenting the problem in two dimensions, which can be dealt with by elementary arithmetic and simple co-ordinate geometry. Unfortunately, however, colour is dependent on quantity, and nothing illustrates this better than the new fluorescent paints which stand out so vividly from others. Some may do this through an unusual hue—different from those surrounding and perhaps unexpected. Possibly some show enhanced saturation, but the principal cause is usually increased " luminosity." They send *more* light to the eye than non-fluorescent paints and therefore have a different colour.

For some purposes—particularly in gemmology—these difficult concepts of Brightness, Luminosity and Lightness may be disregarded, for provided two colours have the same chromaticity (hue and saturation) they can be brought to equality by adjusting the intensity of illumination on one of them. Brightness, like Hue and Saturation, is a subjective phenomenon greatly influenced by the state of adaptation of our eyes. The motor car headlamp, so blindingly brilliant by night, seems quite feeble in daylight in spite of its physical intensity remaining unchanged. When we apply the concept of " brightness " to a primary source—such as a lamp—we refer to it as " luminosity " but when dealing with secondary sources such as surfaces or transparent objects we speak of

" lightness." Fortunately in gemmology we are mainly concerned with secondary sources and our immediate problem is to find some measurable entity which is correlated with " lightness " in the same way as dominant wavelength and purity are related to hue and saturation. Actually the eye (within limits) perceives a surface or transparent object to be light or dark according to the fraction of total light which it reflects or transmits. This is called the " luminance " factor.

It will be recalled that the tristimulus values usually obtained in colorimetry are merely proportions. If no adjustment had been made the specification of a colour might equally be written as

$$20X + 30Y + 40Z \text{ or } 40X + 60Y + 80Z.$$

In other words we can give any value we choose to the coefficient of Y (or, indeed, to those of X or Z) provided the other two are altered in the same proportion. When the C.I.E. system was inaugurated the clever suggestion was made that the final co-efficient of Y should equal the " luminance factor." The exact specification of the X, Y, Z stimuli was made in such a way that the total luminosity of all three was to be regarded as concentrated in the Y stimulus. Thus if the final Tristimulus Equation of the colour of a light transmitted by a glass filter were given as

$$C = 24X + 36Y + 20Z$$

it could be immediately inferred that this glass filter transmitted 36% of the total incident light. If we convert this equation to unit form by dividing throughout by 80 (the sum of the coefficients) we get $c = .30X + .45Y + .25Z$. The complete colour specification of this filter would then usually be given as $x = .30$, $y = .45$, $Y = 36$, in which the values of x and y are the trichromatic co-ordinates and the value of Y the transmittance (luminance) factor. It goes without saying that the precise illuminant used must also be stated in any specification. By these means a colour is satisfactorily specified in its three dimensions of Hue, Saturation and Brightness through the measurement of the corresponding entities of Dominant Wavelength, Excitation Purity and Luminance Factor.

We are now in a position to consider the relative colours of the turquoise mentioned in part 1 of this article. It was supposed that

the original stone had been examined in a colorimeter, the final Tristimulus Equation having been found to be

$$C_1 = 15.51X + 21.33Y + 38.64Z.$$

After " treatment " in some way it was remeasured for colour which was then found to be given by

$$C_2 = 25.85X + 35.55Y + 64.00Z$$

In which way had the colour changed ? Comparing Y coefficients we can immediately say that the " treated " stone was very much brighter. In fact it reflects 35.55% of the total light incident upon it whilst in its original state the percentage was only 21.33. To determine chromaticity or quality we must divide by the sum of the coefficients in each case, i.e. by

$$75.48 \text{ in } C_1 \text{ and } 125.40 \text{ in } C_2$$

yielding the unit equations

$$c_1 = .21x + .28y + .51z$$
$$c_2 = .21x + .28y + .51z$$

which are identical, showing that the hue and saturation had not changed. Probably the stone had just been re-polished. To assess the actual hue and saturation we should find the point on the C.I.E. chromaticity chart with the co-ordinates .21, .28 and then by the simple graphical methods already described proceed to make our evaluation. Alternatively and perhaps preferably, the two colours could be specified as .21x, .28y, 21.33Y and .21x, .28y, 35.55Y respectively.

Mathematically the luminance factor is conceived as the ratio of the Y value of the reflected or transmitted light to the Y value of the incident light. Graphically it is represented by the ratio of the areas under the " Light Flux—Wavelength " curves representing the reflected or transmitted light and the unchanged illuminant. The actual determination of luminance factor, where necessary, is often a problem of photometry rather than colorimetry but in view of its importance in colour calculations most colorimeters employ devices for its direct measurement.

To a first approximation it may be said that the X, Y and Z values roughly represent the relative proportions of red, green

and blue respectively present. A perfectly white or colourless substance would therefore have the trichromatic coefficients,

$$x = .333, \; y = .333, \; z = .333.$$

A perfectly colourless diamond might be expected to have these co-ordinates. A yellow diamond would show some deficiency in blue and hence a lowering of the z value compensated for of course, by an increase in z and y values. If a " blue-white " were really more blue than a colourless stone the measurements would show a z value greater than .333, with x and y values correspondingly less. A perfectly reflecting surface (never attained in practice but approached by white magnesium oxide) would have a Y value of 100 whilst increasing greyness would be accompanied by a fall in Y value reaching zero when black was attained.

Among the best known English colorimeters are the " Donaldson " and the " Tintometer " both in general use in a wide variety of industries. The former is probably more suited for fundamental research, employing three coloured lights of standard quality which can be mixed in any desired proportions. One half of the field is filled with light, say from a coloured gemstone and the other with a mixture of the three radiations, the quantities of which are varied until a complete match is obtained. To ensure thorough mixing they are first directed into an integrating sphere, the interior of which is lined with white magnesium oxide. After multiple reflections at this surface they emerge through another hole as one homogenous beam. From the amounts of the three radiations used and reference to tables issued by the manufacturers the chromaticity of any colour and, if necessary, the luminance factor, are quickly found.

In the " Lovibond-Schofield " Tintometer a series of coloured glass slides are available for placing in the path of the incident light, bringing it to equality as regards chromaticity with the colour under test, whilst an ingenious " obturator vane " enables " luminance factor " to be determined at the same time. Theoretically the accuracy of measurement is limited by the fact that colours can only be varied in discrete steps but for all practical purposes the sensitivity is more than adequate. It also has the advantage of being extremely simple in operation and robust in

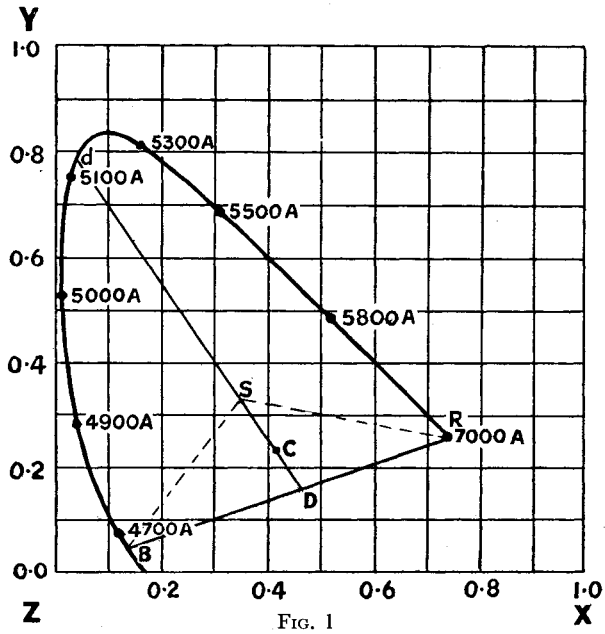
Y
1·0
0·8
0·6
0·4
0·2
0·0
Z
0·2
0·4
0·6
0·8
1·0
X
5300A
d
5100A
5500A
5000A
5800A
S
4900A
R
7000A
C
D
4700A
B

FIG. 1

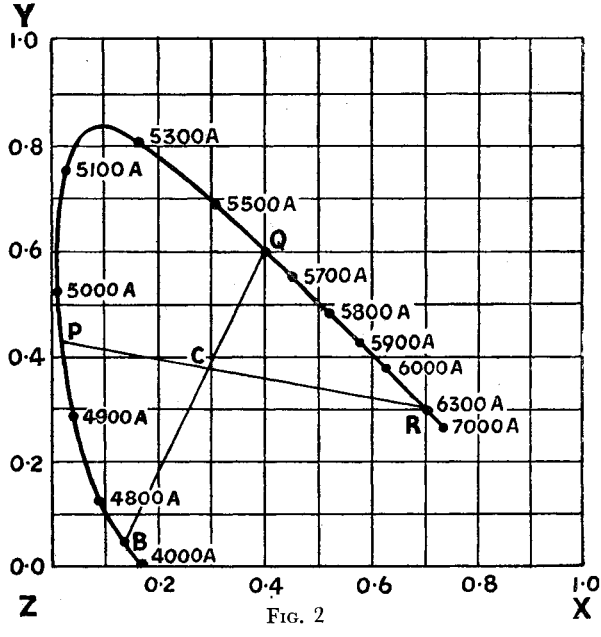
Y
1·0
0·8
0·6
0·4
0·2
0·0
Z
0·2
0·4
0·6
0·8
1·0
X
5300A
5100A
5500A
Q
5700A
5000A
5800A
P
5900A
C
6000A
6300A
4900A
R
7000A
4800A
B
4000A

FIG. 2

structure, yielding direct results in C.I.E. terms through an easy graphical procedure.

Before leaving the subject of colorimeters mention may be made of an attractive technique suggested by J. Guild (Trans. Opt. Soc., 27, 139, 1925) and summarised by Dr. W. D. Wright in his book " Measurement of Colour." Known as Guild's Vector Method it would enable chromaticity to be measured with no computation whatever, although no colorimeter has yet been particularly designed to operate the technique. The requirements would be a primary red radiation, a primary blue radiation and an apparatus for filtering off a narrow band of light from any part of the spectrum. The wavelengths of the two primary radiations would, of course, be known whilst the spectrum would be provided with a scale from which the wavelength of the selected beam could be read. The C.I.E. chromaticity chart is again reproduced in Fig. 2 and the positions of the two primaries are indicated by the points R and B. First the colour is matched by a mixture of the primary red and light from the opposite end of the spectrum the wavelength of which is noted—say P. The colour under test will be on the line RP. Next the operation is repeated, using the primary blue and light from the other end of the spectrum—say Q, the wavelength of which is also noted. The colour then is fixed by the intersection at C of the lines RP and BQ. The co-ordinates of " C " are, of course, the trichromatic coefficients.

So far two broad principles of colour measurement have been mentioned. There is the fundamental analytical procedure of the expert colour physicist who uses spectrophotometers, relative energy curves, luminosity curves, etc., to make calculations of C.I.E. co-ordinates. Then there is the synthetic method, described at some length, using colorimeters and more suitable for those with little knowledge of colour theory. There remains a third method—that of comparison—using colour atlases, deceptively alluring through the fact that virtually no intellectual demands on an observer appear to be made. Every paint manufacturer issuing a chart showing half a dozen of his colours makes use of this principle. There are, however, three fundamental requirements which must be met before a colour atlas can be considered as a suitable vehicle for measuring colour. The design must be in three dimensions corresponding with the properties of Hue, Satur-

ation and Brightness. The samples must be spaced in such a way to show regular and consistent gradations of these properties and their " specification " should be capable of expression in C.I.E. terms. Furthermore they must be absolutely permanent in colour. This last condition is exceedingly difficult to ensure as most coloured surfaces change through age, dirt, corrosion, etc. Bearing in mind that some millions of different colours can be experienced it is also obvious that a colour atlas should contain a very large number of specimens—if it is to be reasonably discriminatory—a requirement which tends to make it bulky and expensive. Yet another complication lies in the fact that it is almost impossible to compare coloured surfaces if they are of widely different texture. Thus a colour atlas used, say, in the silk industry would be unsuitable for gemmology.

In spite of these limitations two well-known Colour Atlas systems—those of Munsell and Ostwald—have been widely used for some years. Of these the Munsell system is better known and extensively employed in America. In theory Munsell conceived a solid frame of reference roughly in the shape of a cylinder. The vertical axis represents the scale of brightness at the base of which is black and at the top white. Considering any horizontal circular section, the hues of the spectrum joined by purple are disposed round the circumference—Blue, Green, Yellow, Red and Purple. The distance of any colour point from the centre is a measure of saturation. The Munsell system has its own notation to define the position of a colour within this imaginary solid, a number of selected points being specified by appropriately coloured " chips," the C.I.E. co-ordinates of which have been calculated. Whilst at first the number of colours which can be measured by means of a Munsell Atlas would seem to be severely restricted by the necessarily few specimens it could contain, a considerable extension of usefulness is achieved by a process known as " disc colorimetry " which enables intermediate colours to be interpolated. If two differently coloured chips are placed on a neutral disc which is rapidly rotated an intermediate effect is obtained. By adding white or black segments to a certain coloured segment on this circle and again rotating rapidly, further assessments of saturation and brightness may be obtained. Estimates of brightness might also be made by controlled changes in illumination.

Throughout these articles certain assumptions are implicit. It is, of course, obvious that no person suffering from any form of colour blindness can be expected to make accurate colour measurements, but in view of the subjective nature of colour perception it might be doubted whether any two persons—however normal their sight—could be relied on to reach identical conclusions in colour matching. Fortunately experience has shown that remarkable unanimity is achieved by about 80–90% of the population ; their judgment approximates very closely to that of the " standard observer " of the C.I.E. system. It has been further assumed that the three attributes of colour perception—hue, saturation and brightness—are independent variables. Strictly speaking this is not so. In theory the addition of black to a colour should produce no change in hue yet this does not apply to some greens and yellows. Nevertheless the interdependence of Hue, Saturation and Brightness is not sufficient to vitiate the usefulness of the C.I.E. system.

It must be confessed, however, that there seem formidable difficulties in the general application of colorimetry to gemmology. There is the average small size of gemstones, making observation difficult in some colorimeters which require an area of at least one square centimeter for observation. In general, colorimetry does not deal with specularly reflecting surfaces but concerns itself primarily with diffuse reflectors or transparencies. Anisotropic gemstones display different colours according to the direction of view and the greatest disquiet must always exist whether the colour actually measured in a colorimeter is " the " colour seen under normal conditions. In the article on colour perception[1] it was pointed out that a gemstone in use is always viewed by a mixture of transmitted and reflected light. If we attempt to exclude one of these beams we obtain an unnatural colour effect.

Nevertheless it would not be unreasonable to suppose that the colour measured in a colorimeter under some standard procedure would bear a definite relationship to the colour normally seen. What form this standard procedure would take could only be decided on after extensive experiment. Possibly the stone might be illuminated by a beam of light passing from culet to table, or alternatively it might be illuminated from above and the scattered light collected by a system of lenses to give an out of focus image. Observance of the form or texture of the surface would preclude proper colour

observations. In addition, the specimen might be spun on a rapidly rotating holder to " integrate " varying colour effects from different angles and to obliterate surface structure. This is quite a usual procedure in colorimetry. The reflection from the surface of a normally cut gemstone and the transmission of light within are such complex processes it is doubtful whether the term " luminance factor " can have much meaning in gemmology. The concept is of great importance, as the relative transmission of a stone is often a vital factor in its colour, but the difficulties in the way of measuring it by conventional methods seem colossal.

Very recently the writer's attention has been drawn to a remarkable article which appeared in " The Gemmologist " of September, 1933 (Vol. 3, No. 26), on the " Measurement of the Colours of Precious Stones." A description is given of the Guild Trichromatic Colorimeter (now superseded by the Donaldson instrument) and of the calculations determining the colour quality of a stone. A fascinating and ingenious technique of measuring the light path in a gemstone is also described. It is astonishing to find that even 20 years ago—within two years of the inauguration of the C.I.E. system—a London firm of scientific instrument makers was ready with an apparatus for the measurement of gemmological colour. Unfortunately the ground was not sufficiently fertile for the idea to take root.

1. Colour perception in gemmology, Vol. III, No. 6.

ASSOCIATION NOTICES

COUNCIL MEETING

The Council of the Association met at 19/25 Gutter Lane, London, E.C.2, on Tuesday, 26th August, 1952. Sir James Walton (Vice-Chairman) presided.

The report of the examiners in respect of the 1952 examinations in gemmology was received and the award of prizes approved.

The presentation of awards was arranged to be held at Goldsmiths' Hall (by kind permission of the Wardens) on Wednesday, 22nd October, 1952, at 7.15 p.m., the presentation to be preceded by a reunion of Members at 6 p.m.

It was agreed that Sinhalite be added to the syllabus of examinations.

The Council approved rules for the use of Branches of the Association that were being established. It was announced that the inaugural meeting of the Midland Branch would be held in Birmingham on 30th September.

The following were elected as members of the Association :

FELLOW

Winnert, George M., Edinburgh. D.1949.

ORDINARY

Kumi, Emmanuel A., Accra, Gold Coast.
Martin, John, London.
Mason, Cyril T., Lahore, Pakistan.
Mills, Frederick W., London.
Warrender, Stanley, Redhill.
Mitchell, James J., Edinburgh.

PROBATIONARY

Donn, Leslie, Manchester.
Embleton, Joseph, Darlington.
Grahame-Armstrong, Stanley J., Singapore.
Jason, Lewis, Bulawayo, S. Rhodesia.
Jayawardana, Col. Christopher P., Colombo, Ceylon.
Mehra, Pashupatti N., Calcutta, India.
Sunde, Gunnar B., Oslo, Norway.
Aitken, Mrs. Elizabeth, Edinburgh.
Galloway, John, Edinburgh.

EXAMINATIONS IN GEMMOLOGY

The 1952 examinations in gemmology were held in May and June at centres in the United Kingdom and Overseas. In the Preliminary examination the Rayner Prize has been awarded to Mr. Trevor M. Brook, of Lincoln.

The Diploma examination was held at five centres in the United Kingdom and in Australia, Canada, Ceylon, Malay States, Netherlands, Switzerland and the United States of America. Forty-five candidates qualified, thirteen with distinction. The Tully Medal has been awarded to Mr. Louis C. Siedlé, of Messrs. Louis Siedlé, Ceylon.

The following is a list of successful candidates (arranged alphabetically) :—

Diploma

Qualified with Distinction

Austin, Leslie Frank, London.
Denham, Francis John, Harrow.
Edwards, John, Manchester.
Kochel, Ann, Alpine.
Lardeur, Kenneth John, London.
Mason, Stanley, Harrogate.
Parsons, Charles Jay, El Cajon.
Payne, Leslie, Bournemouth.
Rice, Jean Mary, Birmingham.
Siedlé, Louis Cochrane, Colombo (Tully Medal)
Spence, Christopher Roy, London.
Svensson, Kurt Wilhelm, Lucerne.
Vos, Dirk, Wassemaar.

Qualified

Allen, Herbert, Newbridge
Boudreau, Guy Armand, Harrow.
Boxall, William John, Edinburgh.
Cannon, John, Gerrards Cross.
Caudell, Peter Miller, London.
Chisholm, Marie-Louise, Leverstock Green.
Crouchley, David, London.
Cuss, Francis Charles, London.
Davies, George Henry, Birmingham.
Davies, John William, Loughton.
Drury, Ernest George Henry, Birmingham.
Evans, Freda Margaret Maude, London.
Fifield, Lawrence John, St. Albans.
Flood, Frank, London.
Green, Phyllis Daphne, London.
Hval, Jens-Olav, Oslo.
Johnson, Douglas R., Toronto.
Light, Donald Ashton, Sutton Coldfield.
McKay, Jane, Glasgow.
McRae, Arthur John Hutchieson, Glasgow.
Paterson, William, Edinburgh.
Pollington, Kenneth Ian, Welling.
Pye, Davis Trann, Methil.
Roos, Leo, Lucerne.
Rudelsheim, Henri Salomon, Amsterdam.
Scott, Maxine O., San Diego.
Short, Elsie Andrina, Twickenham.
Silver, Bernard, London.
Smith, Jack Edwin, Reigate.
Velden, Johannes van der, Amsterdam.
Whelan, Kenneth James, Hainault.
Yaghobi, Hadi, London.

Preliminary

Qualified

Aitken, Elizabeth, Edinburgh.
Bache, Samuel, Old Hill.
Baglee, Gordon, Monkseaton.
Baker, John Thomas, Bristol.
Banister, Halcyone Judith, London.
Barry, Joan Doreen, Birmingham.
Bowen, Walter William, Birmingham.
Brack, Alfred John, London.
Brook, Trevor Martin (Rayner Prize), Lincoln.
Brown, Justin Rowland Caney, Durban North.
Burnett-Ham, Dorothy, London.
Charles, Arthur Edmund, London.
Charles, Helen M. L., London.
Collyer, Rodney Frederick, Birmingham.
Cooper, Paul Gilbert, London.
Ekanayake, Brian Edmund Rodney, Colombo.
Endal, Sverre, Oslo.
Forsey, John Norman, Sutton Coldfield.
Fox, Robert Cecil, London.

Furness, Gwendoline Vivienne, Reading.
Galloway, John, Edinburgh.
Gerling, Chester William, Gloversville.
Goad, Michael J., Sutton.
Graham, Sadie Dickson, Irvine.
Grey, Elmer, London.
Harrison, David John Le Grew, Amersham.
Hessling, Frederick, Birmingham.
Jason, Lewis, Bulawayo.
Jones, Roger Ward, Cirencester.
Keay, Graham Edward, London.
Kell, Ronald George, London.
Kemp, Anthony Lionel, Bristol.
Kemp, John Brian, Bristol.
Kochel, Ann, Alpine.
Korn, Cyril David, London.
Lachowich, Vladymir A., Astoria.
Lambert, Norman Alfred, London.
Leese, Peter Francis, Northwood.
Lennie, David Gemmell, West Kilbride.
Levy, Eric, Glasgow.
Lipman, Maurice, Johannesburg.
Mokrow, William George, Birmingham.
Neerbye, Erling, Oslo.
Niemans, Hendricus Johannes, Amsterdam.
Noye, Leonard George, Ipswich.
Oliver, Richard James Neville, Eastleigh.
Parsons, Charles Jay, El Cajon.
Porter, Lawrence, Preston.
Potter, Byron Allen, Vancouver.
Pyne, Eileen Bridget, South Woodford.
Redmayne, Kenneth, Gateshead-on-Tyne.
Renton, David Alexander, Edinburgh.
Ritson, Ronald, Newcastle-on-Tyne.
Rogers, Dermot Stephen, Belmont.
Roos, Leo, Lucerne.
Roth, Raphael Isaac, London.
Rudell, Justin John, Wolverhampton.
Rudelsheim, Henri S., Amsterdam.
Sacks, Leopold, London.
Scott, Maxine O., San Diego.
Shackman, Julian, London.
Spragg, Ronald, Bristol.
Spray, William Frank, Norwich.
Summerfield, Jane, London.
Summers, William Hamilton, Burnham.
Swan, Winifred Margaret, New Barnet.
Thomson, Douglas Marshall, Dumfries.
Thomson, Roger Ian, London.
Tugwell, Ronald Frank, Thornton Heath.
Vos, Dirk, Wassenaar.
Waites, Leslie Phillip, Birmingham.
Walden, Derek, Enfield.
Watson, Peter Jervaise, London.
Watts, Sidney Frederick, Birmingham.
Wells, Leslie Nield, Chadderton.
Whitehead, Jack, Dudley.
Wickens, Colin Sidney, London.
Wijnhoven, Jos, Eindhoven.
Wilson, Malcolm Edward, Birmingham.
Wood, Beatrice Mary, London.

NOTICE

Volume I (Symmetry Groups) of the International Tables for X-ray Crystallography, published for the International Union of Crystallography, is now ready. The text and tables (in English) have been planned to be of the maximum practical usefulness in the determination of crystal structures and in allied problems, but their value for teaching purposes has also been kept in mind. The price is £5 5s. (five guineas) inclusive of postage and packing; cloth binding, 558 + x pages, 237 figures, with dictionary in English, French, German Russian and Spanish. Members of the Gemmological Association of Great Britain may obtain one copy for their personal use only at the subscription price of £3 post free by using a special order form available, with the prospectus, from the Kynoch Press, Witton, Birmingham, England.

Volumes II and III, which are in preparation and which will be sold separately, will cover Mathematical, Physical and Chemical Tables used in X-ray Crystallography.

TALKS BY FELLOWS

N. Kennedy : " Gem Minerals of the British Isles." Merseyside and District Branch of the National Association of Goldsmiths, 6th October.

C. A. Jarvis : " Gemstones." Methodist Youth Club, Cranbrook Park, Essex, 18th September.

L. Penn : " Gemstone Inclusions." Birmingham Microscopical and Naturalist Society, 23rd April.

Mrs. J. Thomas-Ferrand : " Gemstones." Bury St. Edmunds Inner Wheel, 16th July ; Bury St. Edmunds Ladies' Luncheon Club, 30th September.

F. Leak : " Science of Jewellery," Fellowship of St. Barnabas Church, Warmley, Bristol, 23rd September, 1952.

FIRST ASSOCIATION BRANCH

The President of the Association, Dr. G. F. Herbert Smith, gave the inaugural address when the Midlands Branch of the Association was constituted in Birmingham on Tuesday, 30th September, 1952. Mr. F. H. Knowles-Brown and the Secretary were also present. The first Chairman of the Branch is Mr. Trevor P. Solomon and Mr. J. Best is Honorary Secretary. A full report of the inauguration of the Branch will be given in the next issue of the Journal.

A NEW PUBLICATION

The Vice-Chairman of the Association, Sir James Walton, has recently had published " Physical Gemmology." It is dedicated to Her Majesty Queen Mary.

Without technical language or mathematical formulæ, this new book achieves a notable success in explaining the scientific facts behind the physical phenomena of gem minerals. It begins with an up-to-date account of atomic theory and atomic structures, and goes on to deal with the formation of crystals, microscopic and optical characters, colour and general physical properties. There is a concluding chapter on the fashioning of gems.

A work of over 300 pages, with 400 illustrations, it should be of practical value to those with a professional interest in the subject, and of absorbing interest to those indulging a hobby.

The book has been published by Sir Isaac Pitman & Son Ltd., and copies may be obtained from the Association, 19/25, Gutter Lane, London, E.C.2., price 30/- (postage 9d.).

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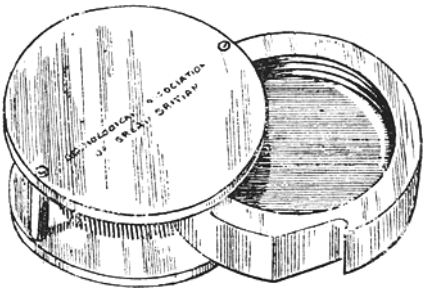

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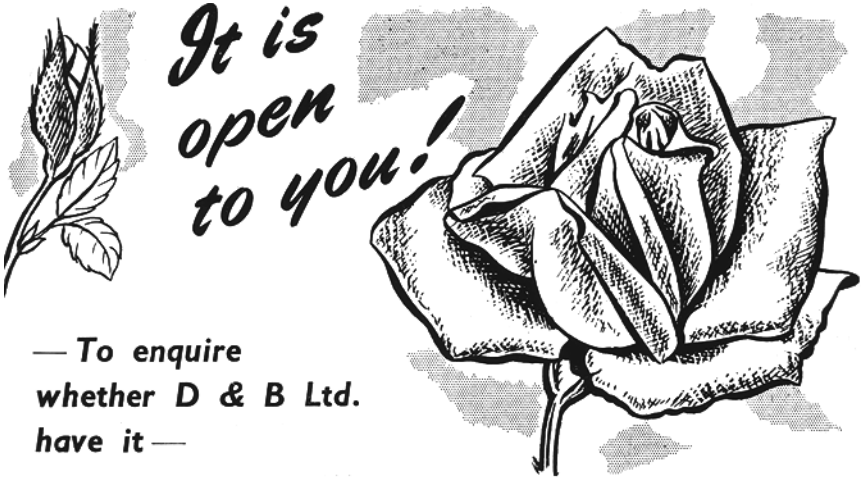

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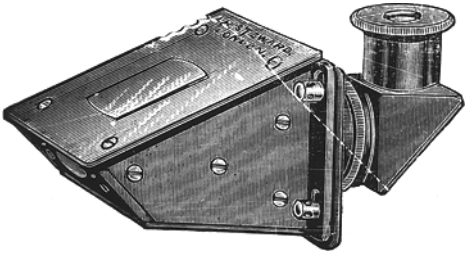

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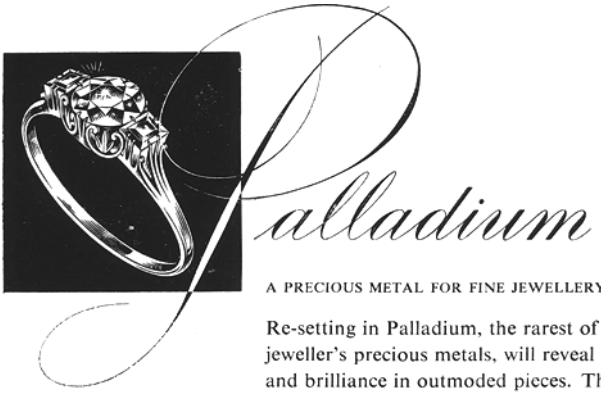

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"RECONSTRUCTED RUBIES" FOUND TO BE SYNTHETIC CORUNDUM

by Lester B. Benson, C.G., F.G.A.

RECENTLY a number of stones have appeared on the market that were thought to be reconstructed ruby. Although the exact process used for the commercial production of synthetic corundum has been known for many years, the degree to which synthetic material may overlap in appearance the reconstructed stone is given little attention in present text books. In fact, little information has been published concerning the exact method used to produce reconstructed ruby.

This also applies to the characteristics of synthetic stones that were produced during the period of transition which led to the commercial production of synthetic ruby by the Verneuil process. Failure to record characteristics of these early stones is due largely to the fact that suitable equipment for photomicrographs (that could reveal and record the characteristics of cut gemstones to full advantage) was not available at that time. Although it has been implied that large quantities of reconstructed stones were produced, securing such material for study has always proved extremely difficult.

By standard U.S. definition, reconstructed stones were made of fragments of genuine stones sintered together under intense heat

with or without pressure. By the method of manufacture necessary to fit such a definition, the ruby fragments would have to form a mosaic joined by fused sections that may or may not have assumed a crystal structure upon cooling. Natural characteristics would be expected in the unmelted portions of the ruby fragments.

Only a few such rubies have been reported in gemmological literature which combine in any way the characteristics of natural material and material that had been melted. One of these was the one reported by Anderson.[1] This had the characteristics of a synthetic ruby but obviously had been grown from a natural seed crystal. A re-examination of the characteristics of so-called reconstructed rubies reported in recent years—together with stones offered recently to the G.I.A. as reconstructed—suggests a need of a revaluation of the whole reconstructed problem.

Although experiments on the reconstruction or synthesis of rubies began in the early 1800's, apparently it was not until approximately 1882 that a few stones appeared on the market labelled "reconstructed." According to an unconfirmed report these were thought to have been made by a priest in a small town in Switzerland, and the report stated that the stones were produced by binding together small particles, or chips, of genuine ruby by fusing small particles of quartz. Obviously, a strict definition would not permit such stones to be considered reconstructed but, instead, merely silica bonded rubies. At any rate, these stones supposedly duplicated the appearance of fair quality rubies and were sold at relatively high prices.

The essential identifying characteristics of such stones would be variable hardness due to the amorphous and soft nature of the bonding agent, in contrast to the corundum fragments and a lack of extinction characteristic of a doubly refractive crystal when rotated in the polariscope. This would result from the random crystallographic orientation of the silica bonded fragments. However, if such stones *were* ever made on a commercial basis they could not have gained much importance since none have been encountered, or at least reported.

In 1877 the first synthetic corundum was produced, but it was not of gem quality. Gem quality material, according to one report, did not appear on the market until about 1886. If this is

[1] B. W. Anderson : *Reconstructed Rubies*, Gems and Gemology, Summer 1949, page 187.

correct, they were undoubtedly confused by some jewellers with the first so-called " reconstructed " stones, and sold as such.

Between 1880 and 1890 a Swiss engineer was supposed to have produced true reconstructed rubies from ruby sand on a commercial basis. These were referred to as " Geneva " rubies and the boules were stated to have been about the size and shape of a shoe button. (A similar description is applied to the first synthetic boules produced by Verneuil).

Whether all of these " Geneva " rubies were made by fusing together ruby powder only, or whether they were just bonded fragments, is unknown. The definition referred to earlier would cover bonded fragments only. However, we are led to believe that these stones were made from powdered natural rubies with the addition of chromic oxide in the later stones to improve their colour.

Actually, since the possibility of producing synthetics had been made known in 1886, there seems little likelihood that any great amount of time was devoted to the production of reconstructed ruby when gem quality natural ruby, even in small sizes, is relatively scarce and costly. This indicates the possibility that much of the so-called " reconstructed " ruby produced prior to 1900 was, in reality, synthetic.

For some reason, the characteristics which have been associated with synthetic corundum in the majority of gemmological publications are those common only to boules formed by the Verneuil process as we know it to-day. The implication is that rubies produced prior to the Verneuil announcement were reconstructed. However, investigations to date have not verified this. On the contrary, there is strong evidence indicating that rubies were made by accretion of molten material, grown into a single crystal long before the Verneuil process was announced.

From study of material that fits the description given to " reconstructed " stones at that time, it seems evident that such accretion can form a single crystal even though the deposition is interrupted or uneven over the surface. The existence of a structure which is divided into several areas (Fig. 1) each containing symmetrical and closely spaced curved striae, but with the general orientation of the striae in each area differing from that of the adjoining area, is not necessarily indicative of reconstructed stones.

On the contrary, such stones could have been produced by fusing alumina powder, but with haphazard and changing orientation of the boule in relation to the direction from which the powder was deposited. In this latter instance, the uneven surface growth will result in low angle to even high angle intersection of the growth lines at the points where each of these areas are grown together. This is not encountered in a boule grown with the assistance of a mechanical apparatus that provides constant orientation of the boule and even distribution of Al_2O_3 powder on the growing surface. This is accomplished in the modern Verneuil oven.

Stones produced by sintering natural fragments would possess very irregular striation, particularly for the adjoining areas of the fragments. Obviously, there would be little advantage in powdering grains of natural ruby to obtain the powder necessary to produce a well-formed boule when the resultant stone, in appearance, could be duplicated with commercially prepared powder at a much lower cost. It should be noted that intersecting striae do not indicate a structure composed of several individual portions, each with a different crystallographic orientation. Instead, intersecting striae generally indicate the direction of growth only for each of the given portions.

The latest group of "reconstructed" rubies submitted for examination were on the average of one half to three fourths carats in weight and possessed numerous erratic gaseous inclusions and pronounced intersecting curved striae (i.e., all the characteristics often associated with so-called reconstructed stones). Many of the gaseous inclusions are developed into elongated and angular forms similar to the gaseous inclusions seen often in natural stones.

Further investigations revealed, however, that these were nothing more than stones that were cut from the bottom tip of synthetic boules. It is generally assumed that this portion of a synthetic boule is discarded as waste. However, in an attempt to secure a quantity of these tips for examination, it was learned that many cutters in this country have channelled these boule tips to foreign cutters—particularly in the Orient—and have obtained prices for this material in excess of that usually received for flawless synthetic corundum. Apparently a large quantity of this material has been cut and returned to the trade, presumably as natural ruby. Since

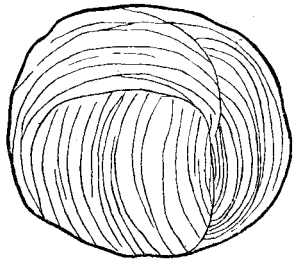

Fig. 1

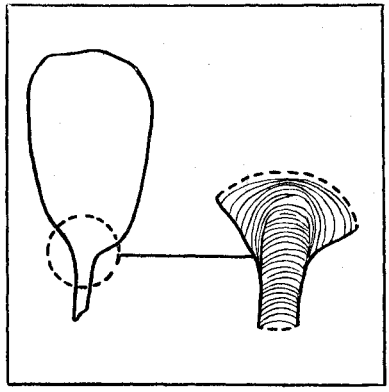

Fig. 2

they are highly flawed to the unaided eye, they could easily pass undetected in a parcel of natural stones.

The presence of intersecting curved striae is easily accounted for when considering the nature of the seed material used to start the boule. The majority of the stones that have been examined at the G.I.A. laboratory were taken from boules that had been started from oriented colourless rods—obviously, then, of fairly recent manufacture. A typical side view of the relationship of the growth lines in the rod to the surrounding material, and the corresponding area from which these stones were cut, is illustrated in Fig. 2.

Depending on the exact nature of the seed, and the orientation of the cut stone in relation to the original boule, the striation in these stones may appear through the table as intersecting striae,

oval-shaped striae, or completely circular and tightly curved striae. Furthermore, depending on the colour, or lack of colour, of the "seed," these stones sometimes display rather patchy colour distribution.

Fig. 3 pictures a cross section of a boule tip showing the concentration of bubbles and curved striae present in the rod, and a similar concentration of bubbles and striae to the right, showing the general pattern of growth of the boule from the rod.

Fig. 4 shows a different boule tip in which the top of the rod seed is well outlined. The surrounding boule is lacking in both bubbles and noticeable striae.

Fig. 5 shows half of another boule tip, with the direction of observation being made parallel to the rod seed. In this particular case the rod is visible as a colourless, flawless centre surrounded by the highly flawed and striated red synthetic corundum.

Fig. 6 reveals another characteristic—highly concentrated and elongated bubbles spreading out in a fan-shape from the centre of the rod. It should be noted that in nearly all cases where elongated bubbles are found in synthetics they are laying perpendicular to the growth lines. This is also shown in Figs. 3, 4 and 5. This characteristic would not be expected in a stone composed of sintered fragments, or one grown by melting fragments together.

Intersecting striae as well as the typical bubbles occur in stones cut from this material. Since a synthetic boule could just as easily be started from a natural seed or a fragment of another synthetic boule, the characteristics mentioned do not necessarily cover all that could be expected from stones made in this manner.

A second type of material presented to this laboratory as reconstructed ruby consisted of small "shoe button-shaped" boules of about three eighths inch in diameter. One of these boules is shown beside a typical modern synthetic boule in Fig. 7. They had been taken from a larger group of similar boules that had been in a jeweller's stock for many years, and were referred to on the invoice as "reconstructed rubies." The surface of these boules exhibit small, slightly raised circular areas which indicate that the boule was built up by a succession of deposits at different parts of the surface.

However, a cross section indicates a fairly even placement of striae beginning from the nucleus and accumulating to the outer edge. A small button on the bottom of the boule had been fused

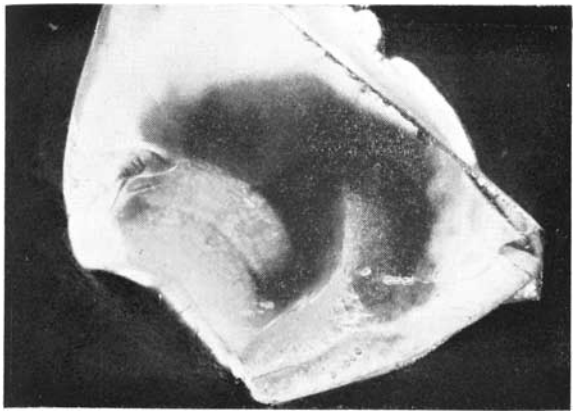

Fig. 3

Fig. 4

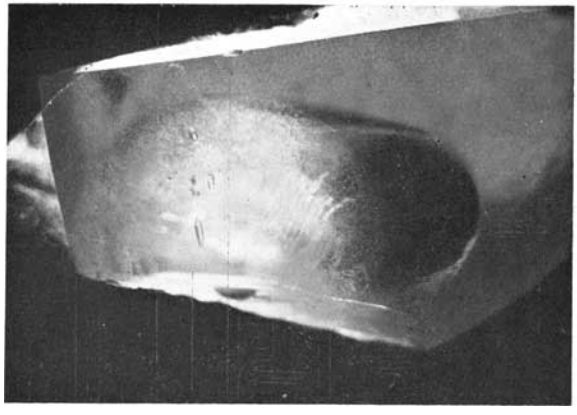

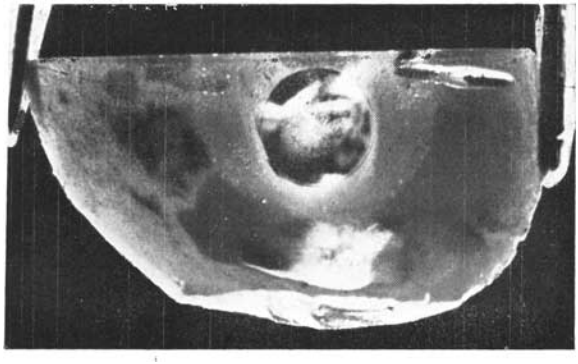

Fig. 5

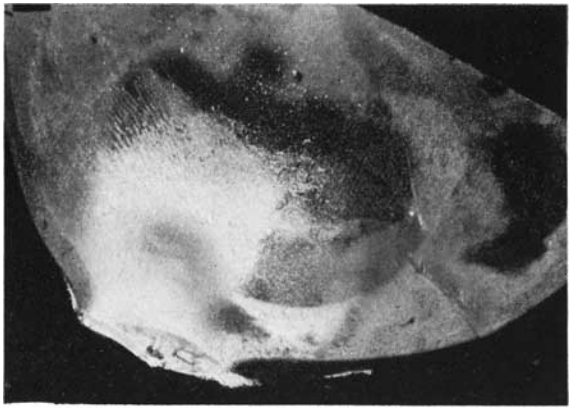

Fig. 6

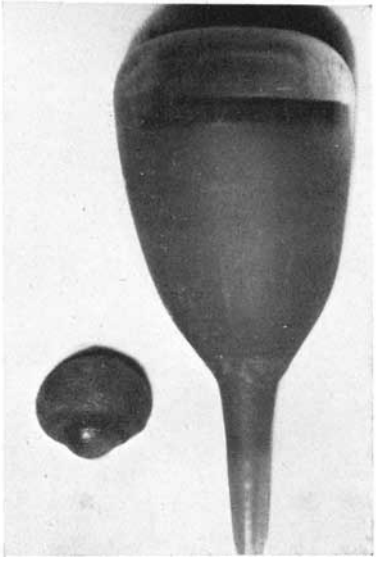

Fig. 7

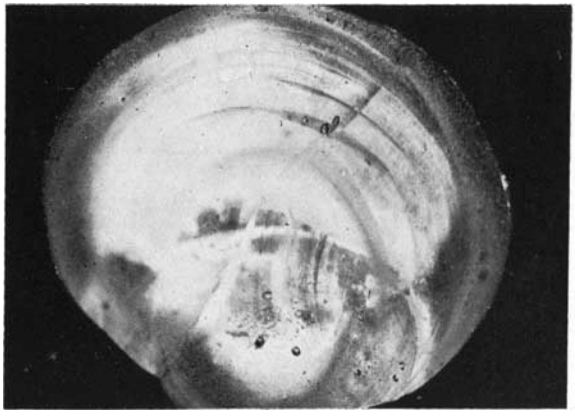

Fig. 8

over and, as such, did not indicate that it had been attached to anything during the growing process. Considering the nature of the striations which are indicated in Fig. 8, the boule could have been attached during the initial growing formation but if so the bottom portion was fused over and rounded upon completion of the boule. The seed or nucleus from which these were started was obviously a piece of corundum formed previously by the same method.

Although these boules correspond exactly to the description of some of the first reconstructed boules, they display absolutely no inclusions which in any way resemble or indicate that natural ruby was used. Also, since they were obviously grown from powder using a piece of similar material as a seed and possess striae, bubbles, and slightly uneven colour banding resembling closely the characteristics to be found in the boule tips, it is concluded that these are nothing more than synthetic boules grown prior to the commercial application of the modern Verneuil process.

Fig. 9 shows a different focus on the same cross section revealing the numerous bubbles also present in the seed area.

In conclusion, it may be said that the presence of any great quantity of truly reconstructed rubies in the trade is still rather doubtful, and that the majority of stones which have been so identified are probably synthetics of early manufacture. Obviously, ruby fragments which are bonded with quartz fragments that in turn would become amorphous upon solidification, would show characteristics quite unlike anything described above, and could be identified by hardness tests and lack of continuity in crystallo-

Fig. 9

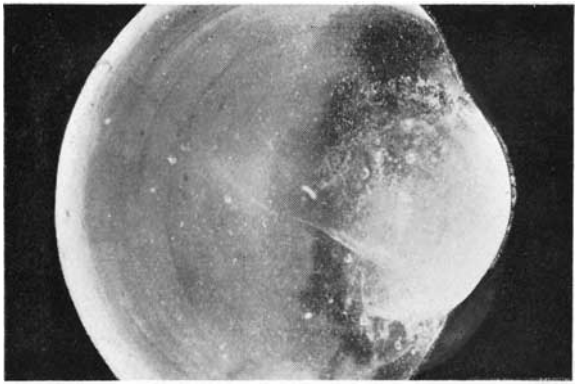

graphic orientation of the fragments. Also, any stone composed of sintered natural fragments will not display curved growth lines for the individual fragments as such lines can only result from artificial growth in which the material is completely melted and grown by accumulation.

Of course, as pointed out in previous publications,[2] a molten mass of natural ruby, while in a viscous state, could develop swirl lines which could be irregular and even intersecting, but there would be nothing in this type of growth to cause the development of elongated gas bubbles that would be perpendicular to the swirl lines. This is a characteristic of many stones which have been identified as reconstructed. Of course, this is not meant to imply that no reconstructed boules have been found. On the contrary, a few such boules have been reported in which some of the natural ruby from which they were grown is still intact.

However, none of the stones submitted to the laboratory as reconstructed have displayed characteristics that would indicate natural origin. Since it is now known that the characteristics of the reconstructed stone as outlined in present gemmological texts are to be found in synthetic stones, it seems only reasonable that—to avoid further confusion regarding stones cut from boule tips and similar appearing synthetics—the use of the term " reconstructed " should be confined only to stones which consist of sintered natural fragments and which, in turn, display inclusions characteristic of natural rubies.

[2] Gems and Gemology, Summer 1949, pages 184–190.

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ABSOLUTE and RELATIVE REFRACTIVE INDEX

by F. Hessling

POSSIBLY, more often than not, many who take up Gemmology have not the advantage of previous study in that branch of science known as Optics. They soon learn, either from the usual books on Gemmology or in classes, the rules and laws which cover incidence, refraction, total reflection and critical angles, all of which come under the sub-division of Optics termed "Geometrical Optics."

It is easy to grasp Snell's law—incidentally brought to its present form by Descartes—that, in its simplest form, the R.I. of a medium is the ratio of the Sines of the Incident and Refracted ray angles, or :—

$\frac{\text{Sin } i}{\text{Sin } r}$ = R.I. = a constant for any two stated media, the ray passing from the optically rare medium to the optically denser.

The diagrams or sketches in books illustrating Snell's law usually show the ray as travelling in air and incident on the medium under test into which it is refracted, i.e., from a rare to a denser medium.

Necessarily, for the purpose of having a comparative basis for gems and materials, air—it really should be a vacuum—is given the R.I. value of 1.0, and the many tabulated R.I. of gems, etc., are always on this basis. Strictly speaking, they should be termed "Absolute Refractive Indices."

Diagrams given show the reversibility of a ray, i.e., from a dense to a rare medium, and this rare medium is usually taken as air, to illustrate the "limiting angle" to refraction known as the "critical angle," beyond which "total reflection" at once commences in the denser medium in accordance with the law of reflection.

It is very easy to show that the reciprocal of a R.I. is the sine of the critical angle, and from this is strongly emphasized the principle (1) "The greater the R.I. of the denser medium, the smaller is the critical angle" or limit of refractive zone, thereby implying the reflected zone or angle is correspondingly greater.

It is this "demarcation boundary"—the critical angle—dividing the reflected (illuminated) and the refraction (unilluminated) zones which results in the "shadow edge" readings on a refractometer scale. Gemmological books emphasize this and, while they do sometimes make a more-or-less incidental reference that the rays are from a dense medium (refractometer table) to a rarer medium (stone under test), the significance of which is often missed by a student, they do not point out that the above principle (1) is "completely reversed" in a refractometer. Nothing to do with the reversing or erecting prism for the eyepiece.

The basic principle in refractometers is that of "Relative Refractive Indices" not Absolute, and this results in "The greater the R.I. of a medium under test, the greater is the critical angle and therefore the smaller is the zone of total reflection"—quite opposite to what one might have unthinkingly expected. This is shown in the normal use of refractometers in that the higher the R.I. of a medium under test (a gemstone) the less is the illuminated part of the scale.

This results from the fact that for absolute R.I. the basic unchanging medium of the two media in use is air—rarer than the test piece—whereas for relative R.I., as in a refractometer, the unchanging basic medium is the refractometer table (hemisphere or prism) which is the denser of the two media.

Without having grasped this fact it can be exceedingly puzzling to reconcile an accurate geometrical layout of the angular path of a ray of light for absolute R.I. of a gemstone to that very different layout of the angular path for the same gemstone through a refractometer (neglecting entirely any reversing prism), which is basically relative refraction.

It is quite simple to evaluate relative refraction. It is the simple ratio of absolute R.I. of refractometer table—not often given clearly—to the absolute R.I. of the stone under test.

E.g. : Abs. R.I. of table say 1.90 ;
,, ,, ,, Almandine 1.79 ;
1.90 : 1.79 = Relative R.I. 1.06.

As the reciprocal of this R.I. = Sin. critical angle or angle of total reflection, then

$$\frac{1}{1.06} = \frac{1.79}{1.90} = .9421 = \text{Sine of critical angle } 25'.$$

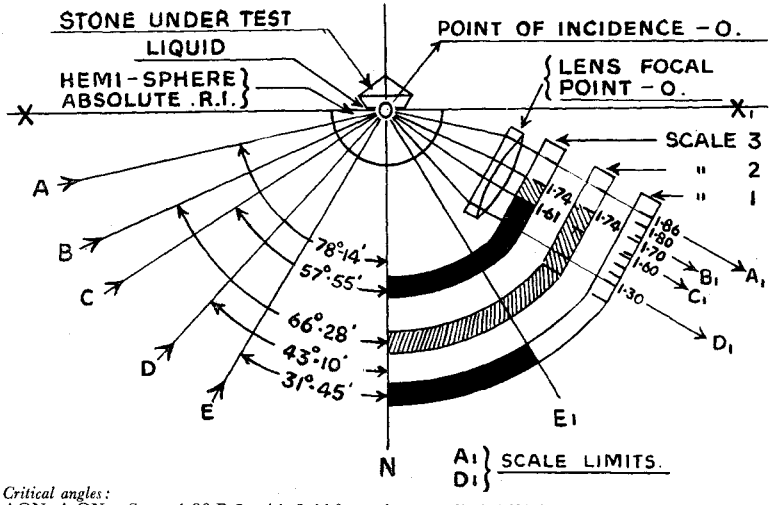

Critical angles:
AON, A_1ON, Stone 1.86 R.I. with fluid for scale upper limit 78°14'.
DON, D_1ON, assume media 1.3 R.I. arbitrary for scale lower limit 43°10'. This computed. Water nearest 1.33 R.I. EON, NOE_1 table/air alone 31°45' (Absolute R.I.)
BON, NOB_1 Fluid alone 1.74 R.I. 66°28'. CON, NOC_1 Fluid 1.74, stone 1.61 57°55'.
Scale readings:
No. 1 Ray E. No shadow edge. Only zone NOE_1 dark. Reflected zone EOX_1 covers full scale. No reading.
No. 2 " B. Faint shadow to 1.74. R.I. of fluid.
No. 3 " C. Scale dark to 1.61, faint shadow to 1.74.
Note. For above Critical angle AON, A_1ON, the fluid must be higher than 1.86 R.I.

The difference between Absolute and Relative refraction for the same material can be enormous. The saving feature is that while a refractometer functions on relative refractivity, the scale is graduated in terms of absolute R.I.

Again, while absolute R.I. tables of gemstones and other materials must be accepted as unchangeable—air always being the one unchanging medium—tables of relative R.I. of media would vary all depending on the R.I. of the media used for refractometer hemispheres or prisms, and these do vary quite considerably in different makes of refractometers.

As an example of the differences between absolute and relative R.I. the stones below are cited :—

Assume a refractometer table of R.I. 1.90.

	Absolute R.I.		Actual Relative R.I.	
	R.I.	Crit. angle	R.I.	Crit. angle
Quartz	1.548 (average)	40° 14′	1.23	54° 34′
Almandine	1.79	33° 58′	1.06	70° 25′

The drawing further illustrates the principle outlined above.

The Craft of
DIAMOND POLISHING

by O. Holstein

THE " Craft of the diamond polisher " was originally written for the use of the practical man, and was meant to be a help to the apprentice and master. Although necessarily the stress is laid on the practical aspect it may contribute to solving some problems of the gemmologist who for the first time tries to understand the intricacies of diamond polishing.

The Diamond Polisher

Skilled labour is essential for the rational working of the diamond because of its value, its hardness and its crystallization. We speak of sawing (cleaving), bruting and polishing, all three branches of diamond working needing special skill, and the application in all three occupations necessitates three or four years' training. Only years of intensive training will result in the necessary skill, accuracy and sharp eyesight.

The technique of all stages of polishing of diamond, as in the case of no other gem, is dependent on the gem's crystallization, i.e., the structure.

As we know, the diamond is the hardest available material. All other gems which are valued because of their hardness can be ground accurately with diamond. Of course the crystallization of the stones must be taken into account but as far as the actual grinding is concerned there are no difficulties if diamond powder is used as an abrasive. This is quite different in the case of diamond itself. The hardest material can only be treated with the hardest available matter, i.e., itself. The possibility is given, but is dependent on the natural structure of the crystal and intimate knowledge of it.

Ideally the diamond is perfectly crystallized as an octahedron. Eight equilateral triangles, which themselves may have slight pyramidal elevations, form the outer limits of the crystals, to make a pyramidal octahedron (trisoctahedron). In this crystal one can imagine three equal crystal axes intersecting at right angles, thus

grouping the diamond with the regular crystal system (cubic). Apart from the described ideal form, the diamond is found in many various habits. It is advisable to imagine these habits in the ideal octahedron form in order to arrive at the most effective way of polishing. The structure lines are easily visible and discernable guides to the way of polishing. Others may speak of growth stripes, of zonal structural phenomena, but the diamond worker, be he sawyer, bruter or polisher, is not concerned with them. He only knows one designation, the growth (Wuchs, waas), an international name of the trade.

The diamond is cleaved in the direction of the structure lines, the cleavage plane being parallel to an octahedral plane. In many cases sawing is preferred ; it is only possible in the direction of the axis (parallel to cube or dodecahedron planes). Polishing is, of course, also dependent on the growth, the most suitable direction being at right angles to the growth lines ; as the polishing also produces marks, these polishing marks should be at right angles to the growth lines.

Fig. 1 shows an octahedron face, or to be more exact an octahedron pyramid (three faces of a trisoctahedron).

One of the eight crystal faces, an octahedron face,

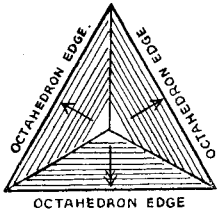

Fig. 1

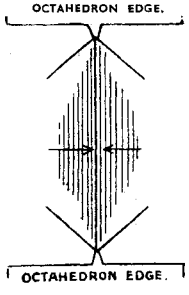

Fig. 2

The thin lines show the growth. The most advantageous polishing direction is indicated by the arrows from the pyramidal apex down to the octahedron edge. There are three possibilities which would result in three facets. But only one facet is required ; this is stipulated by the facet arrangement of the desired cut. This ideal habit is not often found in nature ; one of the three parts comprising the octahedron face is most probably prominent and occupies most of the space required for the facet. We polish, therefore, in the direction indicated by the majority of growth

lines and simultaneously grind over the two other growth lines in order to obtain the one facet. It is obvious that the polishing of these two other growth directions does not proceed as smoothly as polishing in the beginning—it is much slower because the polishing direction is not the most favourable one. Because of this fact it is often said (even in textbooks) that the diamond is harder in certain spots. The suggested explanation casts doubts on this assertion. The polishing is slower in parts where we do not utilize the most favourable direction. The stone itself has no discernable hardness differences on account of structure differences.

It is well-known to all polishers that there are stones which are easier or more difficult to polish but this refers to the whole stone or only to its skin but not to certain parts of it. But even in the case of difficult polishing we cannot talk of " harder " or " softer " but have to use the expression " tough."

Fig. 2 shows an octahedron edge (thin lines show the growth). The most favourable directions for polishing are again shown by the black arrows. We can only use one facet on the edge for reasons already given and we have to consider the growth and polish it in the most advantageous direction. In this direction we have to grind the complete desired facet although the polishing will interfere with the growth of the other parts, and thus proceed, of course, at a slower rate.

The other drawings deal almost exclusively with the most perfect cut of the diamond, the brilliant cut ; also with fancy cuts and with the eight-cut and the 16/16. The cut of the diamond roses, called roses for short (usually cleavage pieces) is orientated according to the shown structure of the trisoctahedron; it is outmoded by the eight cut.

Most of the illustrations explain the structure and completion of the brilliant cut ; most diamonds are cut according to these rules. The preliminary to the brilliant cut is the eight cut. The table must be ground first, it is not only the largest of all facets but (this is most important) rules the whole rhythm of the cut.

The fundamental requirement of polishing is to utilize the given raw material most advantageously, i.e., to produce the largest possible percentage (in weight) of cut stone. Accordingly the table must be placed very carefully. There are only three possibilities

The FOUR-POINT
All corners run in or out. The four-points of crown or pavilion run in similar fashion.

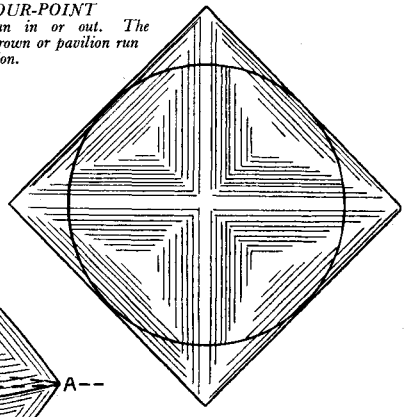

The DIAMOND.

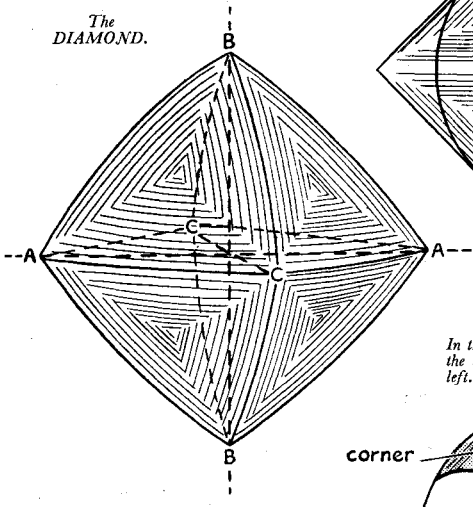

The FOUR-POINT
In the arrangement below of the table the largest main facet must be to the left.

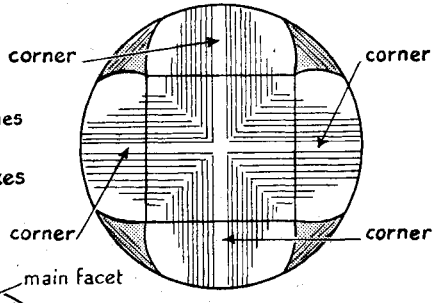

thin lines = growth lines

A-A
B-B } crystal axes
C-C

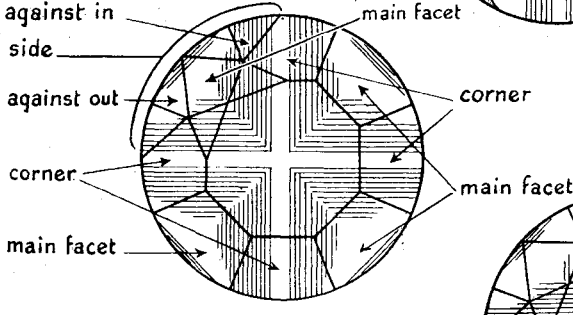

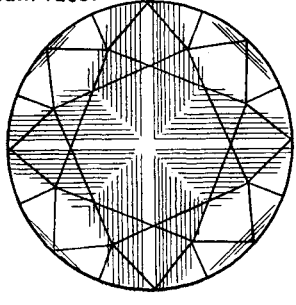

The FOUR-POINT
(Crown) *Either grind all main facets (eight cut, this is the best way) or grind one side after the other. Main facets run against in or against out, and also off.*

(Right) *The four-points of crown or pavilion run in similar fashion.*

In the illustrations the grinding directions refer to the growth lines and not to the individual facets.

The FOUR-POINT
(Pavilion)

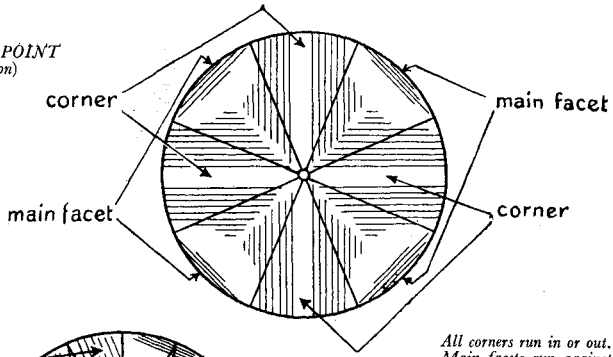

All corners run in or out. Main facets run against in or against out, on pavilion frequently off, this may be seen from the red growth lines.

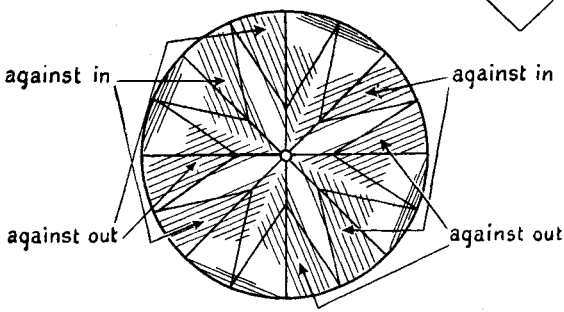

The four-point of crown and pavilion run in similar fashion.

The TWO-POINT

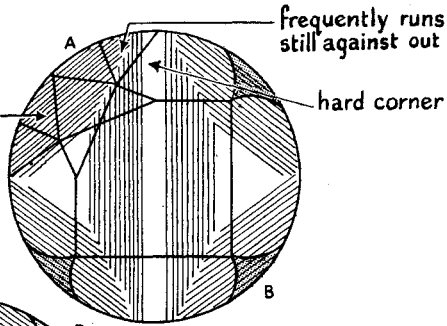

Main facet runs off in or against in, table facet against in, girdle facet off in or against in, on hard corner also against out.

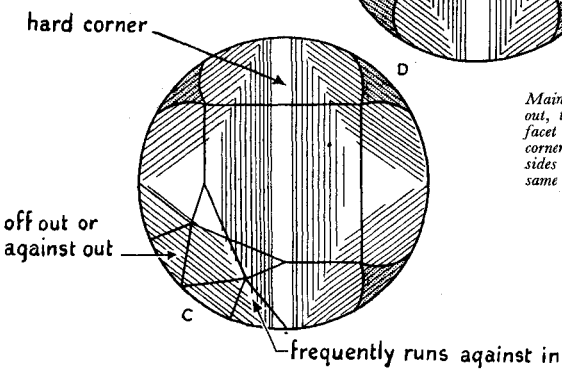

Main facet runs off out or against out, table facet against out, girdle facet off out or aganist out, on hard corner also against in. The opposite sides A and B, C and D run in the same way.

which depend on the crystallization (growth) because the growth governs always the possibilities of arranging the facets. In its own rhythm the geometric-symmetrical arrangement of the facets must harmonize with the growth, even if the outer shape of the rough diamonds deviates from the ideal octahedron.

(*a*) The table of closed (round) goods must be placed in the same plane as those of sawn stones where it coincides with the sawing plane. In this position it runs parallel to two of the crystal axes and intersects the third at right angles (cube plane). In this case we speak technically of the four point. The word " point " is derived from the Dutch word " punt " and means the protruding apex (head). (Sometimes the designation one point is used instead of four point.) Looking down on to the four point we notice four corners as the name implies. Most stones are cut according to the rules of the four point. Apart from the closed and cleaved goods nearly all sawn stones belong to the four points.

(*b*) The rough stone is so flat that it can be advantageously cut only by placing the table on to a flat octahedron edge (dodecahedron plane). We speak of the two point. Looking down on to the table two protruding corners are seen. Two points are nearly always closed goods, though occasionally also cleaved stones.

(*c*) The most suitable octahedron face is chosen for the table. We call this three point. The three corners of the triangular octahedron face determine the position of the table and the size of the brilliant. The three point is nearly always a closed stone, rarely a cleaved stone. Frequently it happens that the three point is not a single crystal but consists of two crystals. These are joined on their octahedral planes and may simulate a single crystal. This is the much dreaded naat stone feared by polishers who are not thoroughly skilled. The well-versed polisher knows that the twinning plane must coincide with the girdle and that shifting must be avoided in all circumstances. If those basic laws are observed the naat stone (macle) can be polished as easily as any other diamond. The three point when a naat stone deviates from the rule. The direction of attack of the scaife is the same in the pavilion as in the crown.

The protruding corners are removed by the bruter before polishing. The stone is bruted mostly to a round form on special machines. The bruting must be carried out with great care, some

spots of the original rough stone will always remain visible so that the growth is still discernable. These growth lines and the position of the bruted parts allow the really skilled polisher to determine whether he deals with a four, three or two point. And this again tells him exactly in which direction (plane) he must polish.

The directions of grinding or polishing refer to the position of the facet if the scaife in front of the polisher rotates from left to right (anticlockwise). If the girdle faces the rotating scaife, this spot is accordingly called " against." For the same reason the opposite position is called " off " or " running off." In the " in " and " out " positions the grinding direction runs parallel with the girdle ; in the first case the girdle faces the polisher and in the latter case the grinding spindle. Between these positions we have four additional positions, " off-in," " off-out," " against-in " and " against-out." " Off-in " lies between " off " and " in," " off-

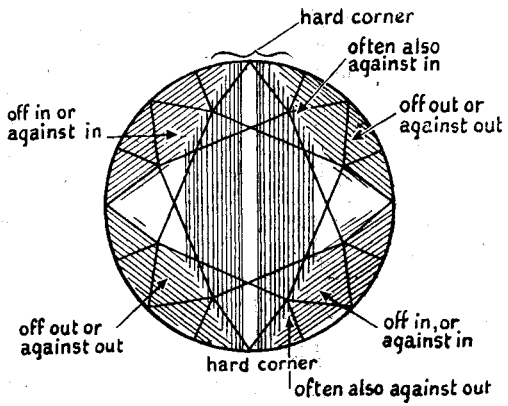

The TWO-POINT

The two-point of crown or pavilion runs in the same fashion.

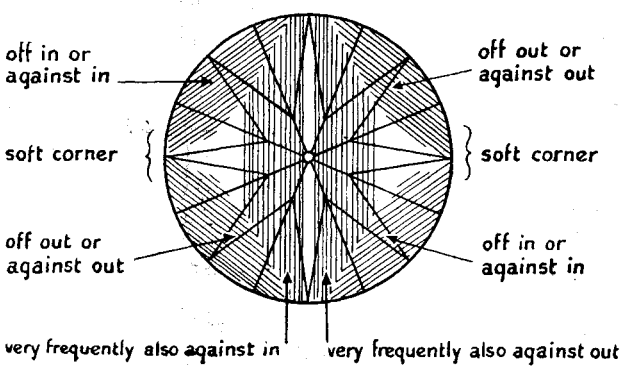

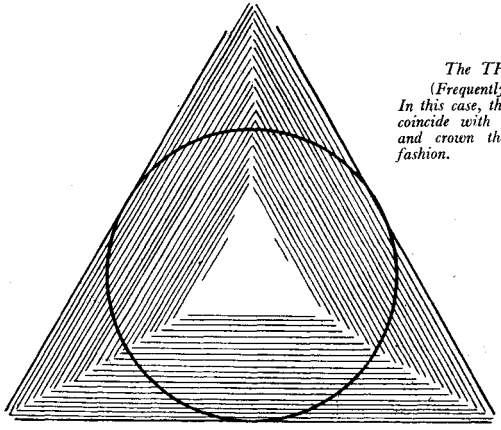

The THREE-POINT
(Frequently twin or "naat")
In this case, the twinning plane must coincide with the girdle ; pavilion and crown then run in the same fashion.

(Crown) *Table runs usually off. Hard Corner : off in or against in or off out or against out. Soft Corner : Off or against.*

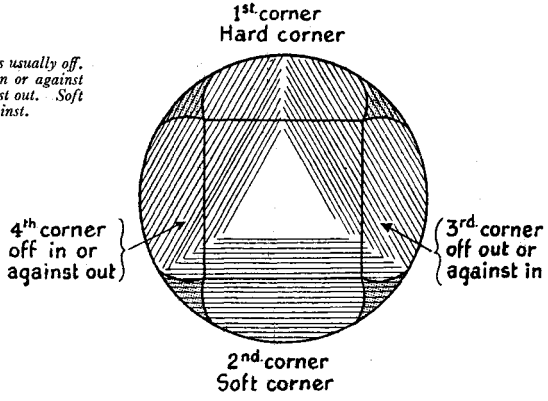

out " between " off " and " out," " against-in " between " against " and " in," and " against-out " between " against " and " out." These designations are well chosen because they indicate the positions clearly, though some others use such terms as " left in," " left out " and so on. There occur frequently slight deviations from the mentioned positions but it would not be advisable to introduce additional designations as they would only confuse.

The diamond polisher cannot work automatically without thinking because he must constantly consider the deviation in the polishing direction on account of the growth. The dop which holds the stone is not rigidly attached to the tang because of these deviations. A copper stalk which can be easily bent connects dop and tang and allows the polisher sufficient adjustment.

In the illustration the designations "hard corner" and "soft corner" have been used. These do not refer to the hardness—they are conventional expressions, and the stone is not harder in these spots than anywhere else. However, in these spots several growth lines meet as can be seen from the thin lines. If the polisher cannot imagine the structure of the stone which he is polishing, he will only find after many trials and errors the correct grinding direction for the facet on this particular spot. Sometimes he may not find the direction at all, and the inexperienced polisher may then encounter what is for him literally a "hard corner."

The "fire," the liveliness of the polished diamond, especially of the brilliant cut depends partly on the relative dimensions of crown and pavilion; on the angle between the facets and a plane through the girdle which runs also parallel to the table, and on the size of the table itself.

The BRILLIANT and its Dimensions

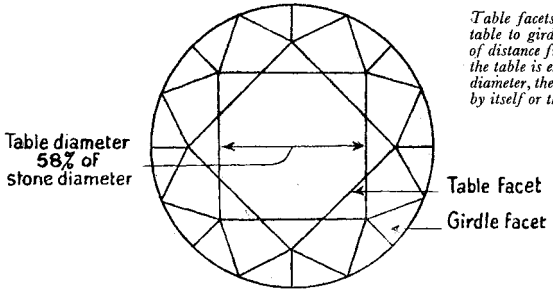

Table facets 2/5 of distance from table to girdle. Girdle facets 3/5 of distance from table to girdle. If the table is exactly 3/5 of the girdle diameter, the arrangement works out by itself or the stone is wrongly cut.

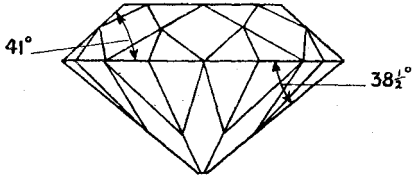

The total height is 6/10 of the diameter, larger stones are a little flatter, down to 58% of the diameter. The crown comprises 1/3 and the pavilion, 2/3 of the total height. This ratio must be strictly adhered to. The thickness of the girdle does not increase with the size of the stone, so that larger stones are somewhat flatter if the interfacial angles are the same.

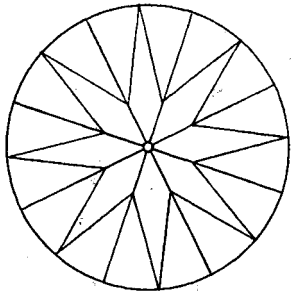

Pavilion.
Girdle facets 2/3 to 3/4 of the distance from girdle to cutlet exact octagon.

Illustrations on page 22 indicate all that is necessary for the diamond polisher to know. Although made for the practical polisher they consider also the purely scientific calculations of the light refraction and reflection of the brilliant.

Refraction forms the basis of the scientific calculation relating to the light rays which enter the stone. The fire and the liveliness of the stone depend to a large extent on the amount of light which leaves the stone and meets the eye. Practical experience and science have determined the relative dimensions of the brilliant and the interfacial angles of the facets in such a way that the largest amount of light leaves the stone and meets the observer. Thus the optimum " fire " and the greatest liveliness of the stone are guaranteed.

When second-hand diamonds or badly cut stones are repolished the polishing marks on the facets give a clear indication whether it is a two- three or four-point stone. For instance, if only on two opposite large facets the polishing lines run parallel with the girdle, the stone is a two point, and so on. In any case, the experienced polisher who understands the principles of diamond polishing will always know how to proceed.

LETTER TO EDITOR

Dear Sir,

In his article in the Journal for October 1952 (Vol III, pp 320 et seq.) Mr. Norman H. Day referred to the peculiar ripple-markings of amethyst and Dr. Spencer's description of them as " thumb-prints ", quoting his article on "Quartz" in the Encyclopardia Britannica, 14th ed., (1929). Dr. Spencer's article first appeared in the 11th (1910) edition of the E.B, with a cross-reference to the article on "Amethyst" by the late F. W. Rudler (formerly curator of the Geological Museum), from which the following quotation may be of interest.

" Amethyst is composed of an irregular superposition of alternate lamellæ of right-handed and left-handed quartz . . . In consequence of this composite formation, amethyst is apt to break with a rippled fracture, or to show " thumb-markings ", and the intersection of two sets of curved ripples may produce in the fractured surface a pattern something like " engine-turning ". Some mineralogists, following Sir D. Brewster, apply the name of amethyst to all quartz which exhibits this structure, regardless of its colour."

Yours faithfully,

J. R. H. CHISHOLM.

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NOTAE—UT INFRA

by D. S. M. Field, A.G.A.

IN addition to the scapolite reported in the last issue, two other deposits of interesting Canadian gem minerals came to light during 1952.

Near the village of Tory Hill, Monmouth County, Ontario, a mineral collector reportedly uncovered a large pocket of dark brown to black sphene crystals of large size. The crystals were found in a fissure vein of which the middle portion had been blasted out more than twenty-five years ago by prospectors in search of economic minerals. It is the collector's opinion that many more large crystals exist in the portions of the vein left intact, and work is now in progress on the deposit.

The writer has two fragments chipped from Canadian sphene crystals, and these appear to be of fine gem quality—perfectly transparent and with very pronounced adamantine lustre. One of the fragments is rich golden brown and the other is almandine red in colour.

Many of the so-called " black " crystals found in Canada are of very large size, and might yield quite attractive gems if the flawless portions were reduced to cutting size. It is quite evident that the richly coloured thin fragments mentioned above were removed from crystals that appeared black or brownish black in their natural state.

* * *

For many years, small deposits of kyanite of little commercial importance have been known to exist in Canada. Indeed, collectors have cut and polished the occasional piece of gem quality material—carefully selected from the relatively large impure masses of crystals of industrial grade.

The possibility of securing larger and better crystals of the unusual gemstone was recently considerably heightened by the discovery of what has been termed " huge deposits " near Mattawa, in the eastern part of Ontario.

M. F. Goudge, Chief of the Federal Industrial Minerals Division, The Department of Mines, stated that the highly prized mineral was uncovered after a Department engineer came across traces of the kyanite while examining a rock sample submitted

by a geologist prospecting for graphite. It has been estimated that the deposits run into " millions of tons."

Kyanite, an aluminium silicate, is a relatively scarce, heat-resistant mineral that, when powdered, is used industrially in bricks and concrete lining furnaces and various types of thermal apparatus. As a strategic mineral, it is indispensable as a coating for jet-engine exhausts.

It is expected that when the new deposits are fully developed they will enable Canada to cut down on expensive imports of the mineral, which she currently gets from India and other foreign sources.

Extensive mining will commence as soon as the Department completes preliminary research work on economical extraction methods.

As a gemstone, kyanite is unusual for two reasons : it is chemically the same as two other rare gemstones, andalusite and fibrolite, the formula for all three being Al_2SiO_5 : and it is unique among minerals in having a hardness that varies from 4, longitudinally, to 7, across the crystal. The colour of the finest specimens is bright sapphire blue.

* * *

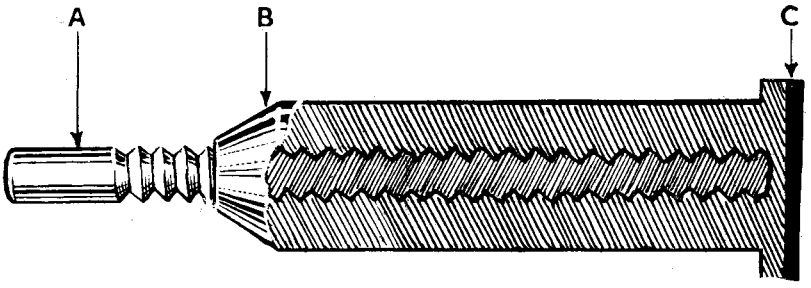

The accompanying figure is a schematic drawing of a retardation screw designed by the writer to permit free focusing of the microscope in either direction without risk of damage to the objective lenses or stone under test.

The accessory consists of a two-inch shaft (A), $\frac{1}{8}''$ in diameter, coarsely threaded from its tip to within $\frac{1}{4}''$ of the top, and a similarly threaded milled cap-stop (B) $1\frac{1}{2}''$ long and $\frac{3}{8}''$ in diameter.

The retardation screw is readily attached to any standard microscope, without disfiguration, by the simple process of slipping

the upper end into a shallow ($\frac{1}{4}''$ deep) hole—drilled just in front of the lower end of the rack of the coarse adjustment.

The screw, when in place, acts as an adjustable stop, preventing the lowering of the body tube below the required focus.

Before examining a parcel of stones, it is only necessary to set the cap-stop so that the tip of the objective lens is arrested before it can strike the highest point of the deepest cut stone in the parcel. (Or, if immersion liquid is used, the surface of the liquid). The examiner is then completely free to focus upwards or downwards, without frequent sidewise observations or fear of doing injury to either stone or glass.

The lower surface of the cap-stop should be cushioned with black suede leather or some similar soft lint-free material, to prevent marking the microscope stage.

* * *

The editors of *Life* have published a short description* of an ultrasonic carving and drilling machine for hard materials that has been developed by an American firm† in Long Island City, New York.

Known as the *Cavitron*, the apparatus ingeniously utilizes ultrasonic vibrations in combination with ordinary abrasives to push soft steel, brass, etc., through such relatively hard materials as glass and corundum.

Vibrating at the rate of 27,000 times per second, the tip of the cutting tool is in effect a miniature trip hammer that, pounding the hard abrasive against the material, chips off microscopic particles at a high rate of speed. The shape of the cutting bit is of little importance. Indeed, accompanying photographs show an ordinary corkscrew winding its way through a large solid block of glass, and metal rings and rods sunk into a large piece of synthetic ruby.

The Cavitron is said to cut more rapidly and cheaply than other known apparatus ; and since the machine can cut cavities of intricate shapes as readily as the conventional drill can drill a straight drill hole, it should find wide application in industry and the arts.

Already the machine is in experimental use by manufacturers of delicately carved jewels and radio and aircraft parts.

* *Life*, Nov. 3, 1952—P. 97 et seq.

† The Cavitron Equipment Corporation

COLOUR FILTER EXPERIMENTS

by L. C. Trumper, B.Sc., F.G.A.

Blue Stones

SUCCESS in the development of a filter capable of identifying ruby and of separating this stone with reasonable certainty from any other red stone, encouraged me to find out if a filter could be developed or devised for the rapid identification of blue sapphires or their separation from other stones of similar appearance including paste.

First of all, I searched carefully through my collection of gemstones and from it selected a batch of stones, all of which could be mistaken for blue sapphire, particularly if seen by themselves.

The stones selected were as follows :—

A Burma sapphire of the finest deep cornflower blue colour, a Kashmir sapphire with that distinctive rich deep blue glow, another Burma sapphire of rather more royal blue colour, a deep blue benitoite, two deep blue spinels of rich colour, one having a slight tinge of green, three cobalt blue paste stones, a deep blue tourmaline, very close to blue sapphire in general appearance, an Indicolite tourmaline having a slightly greenish tinge and a blue garnet-topped doublet.

These stones were then arranged upon the tray of the expermental filter viewing box as already fully described in the Journal of Gemmology for October 1951, Volume 3, No. 4, page 153.

As before, filter after filter was then tried and whenever any appreciable reaction was observed in any of the stones under examination, this was carefully noted and the following records were accumulated :—

Filter (Wratten)	Observations
RU64 (Ruby with Wratten Filter No. 64)	Sapphires remained unaltered but one blue spinel appeared more greenish.
3 Aero 1	Sky blue tourmaline and the Indicolite tourmaline became distinctly green.

FILTER (Wratten)	OBSERVATIONS
No. 8 K 2.	The tourmalines showed distinctly green as also did one of the cobalt pastes.
12 Minus blue.	All stones greenish except the benitoite which showed somewhat greyish.
22 E 2.	Tourmalines greenish, the cobalt pastes slightly greenish, remainder all brownish.
30 Rose Bengal.	All stones violet except the tourmalines which remain greenish. The blue sapphires however show a much more pronounced violet colour.
32 A Minus green 3.	Benitoite mauve, the remainder deep sapphire blue in colour.
46 Blue.	Spinels very slightly greenish ; remainder blue.
89 A Signalling red, dark.	One cobalt paste becomes colourless, the other stones remain dark.
97 Dichroic Filter.	One paste showed distinctly red, the others pinkish and the remainder blue.

Combinations of various filters were then tried, careful observations were again made and the following results were obtained :—

30 Rose Bengal with 3 Aero 1 superimposed.	Sapphires violet/purple, tourmalines green, remainder blackish yellow to brown.
30 Rose Bengal and 22 E 2 superimposed on the left eye and 31 Minus green 1 and 3 Aero 1 superimposed on the right eye.	The combined result was that sapphires showed a tinge of violet alone—other stones tourmalines and pastes greenish, remainder dirty brownish.
30 Rose Bengal and 85 very pale yellow superimposed.	Sapphires violetish, rest brown or greenish except a garnet-topped doublet which was also violet-coloured as well as one paste.
68 Fast green blue shade with 22 E 2 superimposed.	Similar to the Chelsea Filter in its general effect. Tourmalines green,

Filter (Wratten)	Observations
	one paste distinctly red, the other pastes reddish ; other stones black, spinel reddish and the garnet-topped doublet reddish.
30 and 11 X 1.	The garnet-topped doublet looked greenish ; the rest dark brownish.
30 and 13 X 2.	Very similar to above.
30 and 102 Photo cell compensating.	The garnet-topped doublet greenish, sapphires and spinels brownish to black, tourmalines greenish. Separation of garnet doublet better than with 30 and 11 X 1.
30 Rose Bengal and 7 K 1½	Sapphires tinged with violet, tourmalines greenish, garnet doublet bluish, pastes bluish to black.
30 Rose Bengal, 64 and K 1.	The nett result of these filters was similar to white light in appearance, the combined filter passing narrow balanced lines throughout the spectrum—of no help here.

From these experiments, it seemed that the best line of approach to a final filter was to try and bring out the predominant violet tinge present in the sapphire, which colour is less dominant in the other stones under examination.

An attempt was made to obtain from Oberstein filters of synthetic blue sapphire to try both alone and with other filters superimposed but it was not found possible to obtain satisfactory depth of colour in the synthetic material obtained from that source though it must be stated that even using the material on edge to secure the maximum depth, no very startling results were secured.

A small number of Ilford Filters were tried in addition to the entire Wratten range of filters together with a number of Omag filters.

The combination of filters which on the whole seemed to be most promising were the 30 Rose Bengal together with the No. 85 Yellowish filter superimposed.

Using this filter, considerable care is necessary and as much experience as possible, for the changes in some cases are very

difficult to detect. It must also be fully appreciated that many good sapphires of deep colour even Burma ones are frequently too dark to enable the filters to bring out sufficient colour for identification purposes.

The colour changes with this 30 and 85 Filter are that sapphires appear violet or violetish if they are not too dark. Garnet-topped doublets and most blue pastes do so also, but they can be eliminated with a preliminary run over with the Chelsea filter in which they show reddish. Similarly many if not most blue spinels show a dirty reddish appearance under the Chelsea filter. Tourmaline appears greenish.

Pale Blue Stones

Further experiments were then conducted on a selection of pale to very pale blue stones. The following were chosen from among my collection for this purpose :—

Aquamarine, pale blue topaz, blue apatite from Burma, Euclase, blue beryl from Madagascar, Tourmaline of sky blue colour, pale blue Zircon, pale blue Spinel, pale blue Fluor and another shade of blue spinel.

These stones when together look so much alike that picking out any particular stone, except possibly the tourmaline, became little short of guesswork.

The following filters were tried singly and the results are recorded, as before, as being those which gave a reasonably distinct colour change :—

Filter	Observations
Chelsea Filter.	Again, this filter is most useful for a preliminary survey. The aquamarine and blue beryl at once take on that distinctive apple-green colour. The euclase, particularly if of greenish tinge, showed reddish and the blue fluor pinkish ; the spinel tended towards a dark dirty pinkish colour and both it and the tourmaline appeared much darker. The blue apatite had a slightly greenish blue.
4 Kodak colour filter.	Tourmaline distinctly emerald-green.
5 Aero 2.	Tourmaline distinctly green.

Filter	Observations
16 Flavazine T.	Spinel brownish, tourmaline green, fluor pinkish, remainder pale green.
21 Monobromofluorescein.	Very similar to above.
32 A Minus green 3.	Tourmaline peacock blue, rest pale blue.
49 a C 4 light.	Spinel and tourmaline dark green ; rest paler blue.
65 Minus red 3.	Tourmaline and spinel slaty grey ; rest colourless.
97 Dichroic filter.	Zircon, topaz, fluor, euclase more or less colourless. Aquamarine and beryl and tourmaline peacock blue ; spinel brownish, apatite bluish.

Again, combinations of filters were then tried and any useful observations recorded as below :—

Filters	Observations
30 Rose Bengal and 85 Yellowish.	Tourmaline dark green, spinel dark brownish, pale blue fluor pinkish; remainder appear as if they were colourless.
34 D (Light) and 33 Xylene red.	Tourmaline deep royal blue, remainder greyish or just tinged violetish or colourless.
30 Rose Bengal and 34 A.	Almost identical results to the above.
40 Cine Green and 34 A.	Aquamarine, blue beryl and tourmaline appeared bright peacock blue, fluor pink, euclase pink, apatite greyish blue, zircon colourless, topaz greyish to colourless, spinel dark neutral tint or reddish.
68 Fast green blue and 22 E 2.	This Filter is very similar in its reactions to the Chelsea Filter, but is more sensitive with pale shades, giving deeper colour changes. It has, however, a residual flesh tint which can be confusing unless care is taken. The aquamarine and blue beryl showed a distinct deep apple-green, zircon and topaz colourless, spinel

showed a deep reddish tinge, euclase and fluor distinctly red, tourmaline dark green, apatite greyish green and iolite purplish blue. Very pale blue spinel shows pale plum red or purplish. Mauve spinel distinctly reddish.

Further consideration was then given to the whole problem of blue stones, whether pale or similar to blue sapphire, whether of light or dark shade and the conclusion reached was that from the experiments so far conducted, the best selection for both light and deep blue stones for addition as a separate disc to the Interchangable filter viewing Box as described on page 156 of Volume 3 of the Journal previously referred to, were the four pairs of filters, being one pair each of the filters set out below together with a note of the principal reactions :—

Filter	Observations
1. Chelsea Filter.	Aquamarine and blue beryl appeared distinct apple green. Garnet-topped doublets and some paste appeared reddish ; spinel dirty pink or reddish; euclase and fluor pinkish.
2. 68 Fast Green blue and 22 E 2.	Similar to the above, but more sensitive in the paler shades. The filter has a residual flesh tint and the use of a colourless neutral stone such as a Quartz as a control is recommended.
3. 30 Rose Bengal and 85 Yellowish.	Sapphires appeared violet-coloured ; blue fluor pinkish.
4. 30 Rose Bengal and 34 A.	Tourmaline appeared a deep sapphire blue.

By means of these filters, reasonably certain differentiation can be secured with practice, but their principal use lies more in the rapidity with which a parcel of stones can be examined and stones which show a radical colour change can be quickly extracted for more critical examination.

Again if the colour change is not what was anticipated one is at once put upon one's guard and a possible blunder prevented.

Further experiments will be made as time permits.

Gemmological Abstracts

CREMER (E.). *Die Deutsche Edelstein-und Diamantenindustrie in Zahlen.* German precious stone and diamond industry. Gold und Silber 5, 1952 (No. 9/10), pp. 10, 11.

New statistical material from 1949 onwards is available for the Idar-Oberstein district only. Therefore, the author has based his investigations on the year 1937 when employment was considered normal in the whole cutting industry. In spite of the time lapse and of war and post-war influences, the figures convey a valid message, especially as war damage to cutting plants was not significant. The total export of precious stones, pearls, synthetics, technical stones and diamond contract work amounted to two million £ sterling. From a total of 1902 firms employing 8,876 workers (70% of the capacity), the biggest group consisted of 722 diamond polishing plants employing 6,484 workers (80% of the capacity). Firms employing less than five workers were in the majority in all groups, amounting to

86% of the precious stone cutting shops,
96% of the agate cutting shops,
92% of the engraving shops, and
52% of the diamond polishing shops.

Over 50 workers were employed in one precious stone cutting factory, in one agate cutting factory, and in 11 diamond polishing factories. The important centres were Idar-Oberstein with 91% of the precious stone cutters and 39% of the diamond polishers ; Hanau with 29% of the diamond polishers ; and the Palatinate with 31% of the diamond workers whose orders came mostly from Idar-Oberstein and Hanau.

E.S.

ANON. *Diamond hunting in the jungle.* Gemmologist. Vol. XXI, No. 254, pp. 158–163. Sept. 1952.

An account of the prospecting for diamonds in the jungle of Ouganbui-Chari, French Equatorial Africa. Primitive apparatus is used for the recovery of diamonds which are in the sub-soil of ancient river beds several feet below the underbush. 135,000 carats of diamonds were mined during 1950. 4 illus.

R. W.

PAYNE (C. J.). *Sinhalite—a new mineral and gemstone.* Gemmologist, Vol. XXI, No. 255, pp. 177–181. Oct. 1952.

An account of the identification of the gem mineral which was for many years considered to be an iron-rich peridot. A table is given of the physical and optical constants of 24 sinhalites examined by the workers who identified the mineral (Dr. Claringbull *et al*). Little further information than given by Anderson in Volume III, No. 8, of the Journ. Gemmology.

R. W.

GORDIENKO (M.). *Polishing precious stones in the U.S.S.R.* Gemmologist, Vol. XXI, No. 255, pp. 181–182. Oct. 1952. (*Reprinted from the Diamond Worker*).

The author is the Chief engineer of the Moscow Jewellery and Diamond Polishing Works. Stone polishing in Russia dates back to the 17th century. Some 1500 skilled lapidaries were employed in the Urals during the 17th–18th centuries and during the latter part of this period a school was opened in order to train staff. Up till 1924 ordinary hand or treadle wheels were operated. Mechanisation started then and is now almost universal except for important stones which are still cut on the old type wheels in order to save weight. The lapidary's work is regarded as of great importance in the U.S.S.R., and the vocational schools in Leningrad and Sverdlovsk have special departments where young stone polishers are trained, and in addition, because Soviet industries are badly in need of lapidaries, youngsters are trained individually in the factories. Women are also employed in diamond cutting.

R. W.

ROBB (C. J.). *Irish jade.* Gemmologist, Vol. XXI, No. 255, p. 195. October 1952.

The existence of ancient Irish jewellery set with jade and the finding of jade celts supposes that jade had been found in Ireland. While tremolite is found in some of the metamorphic rocks, a source of jade has not yet been found.

R. W.

FRONDEL (C.). *Effect of heat on the colour of beryl.* Gemmologist, Vol. XXI, No. 256, pp. 197–200. November, 1952.

Observations on the colour change in the species beryl upon heat treatment, and a report on heating experiments carried out

at Harvard University, Cambridge, Mass., U.S.A. Controlled heating at temperatures between 100° and 1025° C. on some 23 beryls of different colours and from different localities were carried out. Parallel experiments on a number of beryls of various shades of green heated to 405° C. were carried out in order to corelate the depth of the original colour to the depth of the induced colour. Emerald was found to be stable up to 1025° C. (the limiting temperature used in the experiments). Manganese coloured raspberry-red beryl from Utah was also found to be stable up to this temperature. Morganite was found to bleach slightly at 440° C. and to rapidly decolour at 495° C. Golden beryl becomes completely colourless after 10 hours heating at 250° C. and fairly rapidly at 300° C. Greenish-yellow, olive green and yellowish-green beryls lose their yellow component between 250° C. and 280° C., leaving a clear green coloured stone which on further heating to about 300° C. turns blue, an effect common to all green beryls tested. The blue colour, which is proportional to the depth of the original green colour, appearing between the temperatures of 280° to 300° C., and takes place in a few minutes when the temperature is over 400° C The blue colour is then stable to 1025° C., the highest temperature used in the experiments. X-ray experiments on unheated and heated beryls, using a tube with a copper target and running at 40kV and 15mA, produced no change of colour. A green beryl irradiated with deuterons from a cyclotron became turbid through cracks developing owing to the high temperature generated during the experiment. A number of theories on the coloration of beryls are given. 12 references.

W.B.

Zeitschrift der Deutschen Gesellschaft fur Edelsteinkunde. Autumn, 1952, No. 1.

The official journal of the newly formed Gemmological Institute at Idar-Oberstein, edited by Prof. K. Schlossmacher.

SALLER (X.). *Zuchtperlen mit Glaskern.* Cultured pearls with a glass core. Zeitschr. Deutsch. Gessell. f. Edelsteinkunde. Autumn, 1952, No. 1, pp. 17–18.

Report on alleged discovery of pair of (Australian) cultured pearls with glass core.

E.S.

Notices of Books

PHYSICAL GEMMOLOGY. Walton (Sir James). 304 pp., 400 illus. Sir Isaac Pitman & Sons Ltd., London, 1952. Price 30s.

The modern concepts of physical science demand an understanding of the structure of the atom. Walton realized this and commenced his book with a detailed description of the past and present atomic theories. The atomic and molecular packing and its relation to crystal structure is clearly discussed and elaborated by some details of the methods of X-ray crystal analysis.

The chapter on crystallography is particularly notable in that it caters for the student gemmologist who may not be well versed in mathematics. Cleraly expressed text and line drawings tell all that the gemmologist needs to know of this subject. A short concise chapter on geology, usually omitted from gemstone literature, fills a valuable niche.

The chapter on *The microscopic characters of minerals* starts with a short discourse on the use of the compound microscope. This is followed by very full description of the various inclusions seen in natural, artificial and imitation gemstones, and illustrated by over 120 pen and ink sketches. The usual theories of light are given as an introduction to the chapter on the optical characters of minerals. An unexpected, but useful, contribution are notes on the path of light rays from curved mirrors and through lenses. The varieties of refraction are explained and the various methods employed for the measurement of refractive index discussed. This is followed by an explanation of diffraction and polarization of light and the use of the polarising microscope.

Colour is wisely given a chapter to itself, for colour is so important in gemstones and in gemstone testing. The causes of colour are discussed, with particular emphasis on Weyl's theory that the cause is due to unsaturated fields of electrical or chemical force. The chapter continues with an explanation of dichroism and the dichroscope, the spectroscope and their types, and the kinds of spectra. The absorption spectra of gemstones are treated at length in the text and are well illustrated by line drawings. The employment of the polarising microscope in interpreting the sign of birefringent stones by analysing the interference effects in convergent polarised light is discussed, and the chapter concludes with some short notes on luminescent phenomena.

The problems of specific gravity are discussed and the various methods used are explained fully ; included are notes on the special apparatus devised by the author of the book. Hardness, cohesion, fracture and cleavage are well explained and the chapter concludes with notes on magnetic, electrical and radio-active characters.

The volume contains no descriptions of the gem materials, an omission in keeping with the title of the book. It is surprising to find that the last chapter is devoted to the fashioning of gem materials. It is a well written chapter but seems " lost " and outside the scope of the book and could have been omitted without detriment.

There are a few errors which could be corrected in future editions, but they are of small consequence. Some confusion seems to be shown in the notes on dispersion; high birefringence gives two separate dispersions but is not essential to produce " fire," anyway both diamond and blende are singly refractive. Under allochromatic coloration ; the inclusion of the manganese and copper minerals, rhodonite and rhodochroisite and malachite, is surely incorrect. They too, with peridot, are included under the idiochromatic group on the preceding page. Although it is quite true to say that the dispersion of a prism spectroscope is more drawn out at the violet end, it is a moot point as to whether such a widening assists observation at that end. The bands or lines are themselves spread out and are thus more diffuse and are seen less sharply. The great number of line drawings which illustrate the book are beautifully clear. Some criticism may, perhaps, be levelled at the perspective used in drawing some of the crystals which tend to a distorted form.

The volume has an appendix listing books for further reading and is completed with a good index. The type selected makes for clear and easy reading and the printing is done on good paper. The book is attractively and durably bound in grey linen. The volume is a valuable contribution to gemmology.

R. W.

SOUTH AFRICAN DIAMOND MINES REVISITED

WHOEVER is interested in diamonds from a technical point of view, may feel that he cannot obtain accurate enough information through reading books, seeing films and talking to people, but that he may have to go personally to those distant parts of the globe, where this particular mineral is found. Mr. P. Grodzinski, Head of the Industrial Diamond Information Bureau was fortunate enough to make this journey for the second time in five years, and the following account is based on this journey to the world's most important diamond producing centres. Here are some of his impressions, gained when visiting the lands of diamonds, which he gave to members at a meeting held on Thursday, 20th November, 1952.

1. *The Premier Mines.* During the first visit he had to walk underground down an inclined haulage way until about the bottom of the Big Hole, which is almost 600 ft. below the surface. At that time there existed practically no recovery plants and it was not yet decided in which way the mine should be operated and what plants would have to be set up. To-day the situation has changed completely. The Premier Mine is not only the largest, but also the most modern diamond mine in the world. Its plants can treat four million tons per year and the present rate of production is over one million carat of diamond annually from which about 80% are industrial. Before the Premier Mine was closed down in 1932, having been in operation since 1902, it had been worked to a depth of 610 ft. by opencast mining methods. The Kimberlite pipe is 3000 ft. long and 1500 ft. wide, surrounded by a red micro-granite called felsite. The present underground mining is of the most interesting type and all mining engineers are full of praise for the ingenious methods which are being applied. A cut 200 ft. deep and 24 ft. wide was made across the full length of the pipe. Horizontal gangways in 50 ft. vertical distance are driven towards the slot and upholes are driven fanwise by rotary machines equipped with sintered carbide drill bits. The distance between every ring is 6 ft. and the rock is directly blasted into the slot. Working is in retreat so that no risks of accident exist.

The blueground of this mine is quite strong and has been exposed to the weathering, therefore relatively wide gangways can be built without timber support. The broken ground is driven off through cones at the bottom of the slot and passed through finger raises and an orepass to the 890 ft. level where the ground is transferred by 8-ton self-tipping cars into another orepass feeding the main haulage on the 1060 ft. level. Here the ground is loaded through compressed air operated loading boxes into trains of 180 cubic ft. or trucks drawn by electric locomotives to the main shaft, about 1200 ft. from the periphery of the pipe. The cars are automatically tipped at the ramps. The 8 in. oversize material is fed into an underground jaw crusher. The smaller than 6 in. production joins the undersize. A single 2500-h.p. Ward Leonard hoist brings two 12-ton skips from a depth of 1350 ft. in 52 secs. With an operation time of 20 hours per day 12,800 tons are brought to the surface. The treatment plant uses the most recent technical developments such as heavy media separation and vibrating grease tables as well as an electrostatic separator. Formally the yield was 17 ct. per 100 loads but with the present plants the yield is much higher. The new methods have reduced native labour by 57% and European labour by 11% for the same tonnage.

2. *Kimberley District.* During the first visit only two diamond mines were operating : the Bultfontein mine and the Dutoitspan mine. The situation has changed in so far as now the Dutoitspan mine and the Wesselton mine are operating whilst the Bultfontein mine is being refitted and exploration work is going on in other mines such as the De Beers mine, the Kooffiefontein and Jagersfontein mines. All these mines have before worked opencast but have now passed over to underground operation. As a matter of fact, with minor variations, the mining system is in general the same. Unlike the Kimberley and the Premier mine the blueground of Kimberley is relatively brittle and the underground gangways have to be kept relatively small and wooden supports are necessary. In addition, the blueground disintegrates rapidly when coming into contact with water and all drilling of blueground in the Kimberley mines, including long diamond drill holes, has to be done dry with suitable dust extractors. When exposed to air for longer time the blueground disintegrates rapidly and this was used for the very first extraction methods by placing the blueground containing the

diamonds on open fields ; the diamonds were picked out later by hand. With these primitive methods carried out till the end of the last century probably only a fraction of the diamonds were recovered and in future one point of the development programme will be to rework these " tailings."

The mining methods used are the following : sublevels are driven 25 to 50 ft. apart and on each level a slot or chamber 10 to 14 ft. wide and extending vertically to the level above is cut from one side of the pipe to the other. When such a slot or chamber has been completed, another is cut parallel to it, leaving a pillar 6 to 10 ft. wide between the two. This crushes down fairly quickly due to the weight of the broken ground above. Loading of the broken ground is by hand from tunnels of a centre distance of about 22 ft. 6 ins. running at right angles to the chamber lines into trucks which are pushed by natives. The ore passes are usually in country rock. One of the reasons for using small trucks is obviously the fragile nature of the blueground and, of course, also the cheap native labour abundantly available when the mining system was planned. The broken ground from a number of levels is brought to a collecting level below where endless rope haulage or more recently, conveyor belts, bring the blueground to the main shaft bin. The main hoisting shaft is set at a distance from the pipe in the country rock. 6000 loads (4800 tons) are brought up per 8-hour shift. On the surface the oversize material passes over sorting belts to the jaw crushers.

The material broken to a size less than 1 in. is fed directly into rotary pans with revolving radial rakes. A so-called mud puddle of specific gravity 1.8 separates diamonds and heavy mineral from lighter Kimberlite gangue. Tailings from the pans go through rolls with a $\frac{3}{8}$ in. gap and then to secondary or fine pans through $\frac{3}{8}$ in. screens, the oversize being returned to the coarser pans. Concentrates from both the fine and coarse pans are taken in trucks drawn by locomotives to the somewhat distant pulsator plant. Here further concentration is obtained through pulsating jigs ; the final concentrate is then passed over side-shaking grease tables. The pulsating jigs consist of a pulsating screen of about $\frac{3}{8}$ in. openings over which a bed of coarse gravel about 4 in. thickness is placed. The small size gravel is placed over these jigs, whereby the lighter material is carried away with the water, whereas the

heavier material, i.e., diamonds and accompanying minerals are brought to the grease tables covered with a thick layer of petroleum jelly (vaseline), and are periodically cleaned. The diamond being water repellant adheres whereas the other minerals pass over the tables. Periodically grease and diamonds adhering to it are scraped off. The grease is boiled off and the larger concentrates are hand-sorted. This technique established in about 1908 is now being modified. It is intended to eliminate the pulsator plant and to concentrate the material in a small heavy media separation plant and pass the concentrates over vibrating grease tables. This new type of grease table has already been installed at the Premier mine. They consist of small steps only about 6 in. wide and the concentrates pass over them extremely quickly.

Ultimately finer diamonds will be recovered by electrostatic separation. When this is achieved the pulsator plant will be used for reclaiming diamonds from the tailings. Actually it is already partly used for the purpose with good results.

The greatest attraction of Kimberley is the so-called Big Hole. The old mine which was worked opencast until the 90's of last century became too dangerous and a vertical shaft was driven down. The mine was operated successfully until 1908 when a big fire broke out after which the mine was filled up with water and had to be given up. The total depth of the hole is 1000 ft. and it is filled up to a 845 ft. level with water. It is a custom that a native boy throws a boulder down and one hears it splashing into the water. It is a pitiful thought that Kimberley and its surroundings suffer usually from a drought whilst plenty of water is collected in the Big Hole, the water level increasing there per year by about 2 ft. Probably pumping out of the water would not be an economic proposition owing to the lack of fuel in this district.

The other big attraction is the Consolidated Building, i.e., the building where the diamond sorting is done. It occurred that the sorting in Kimberley seemed to be a much easier task than elsewhere as here it is so very much brighter and the sun shines more brilliantly. Interesting collections of diamonds, in particular rare shapes are shown at the mine's sorting office ; pieces of blue-ground are on display in which relatively large diamonds are embedded.

Much related to the mines are the De Beers dog kennels where well-trained Alsatian dogs are kept, who watch the mining grounds during the night. It is worth while to see a performance of these extremely well-trained dogs jumping through rings 9 ft. apart and climbing up a vertical wall 10 ft. high. Hitherto no intruders have dared to cross the path of these dogs. A visit to the native compound is well worth the time, if one wants to gain an impression of their living conditions.

3. *Alluvial Diggings.* Probably the most romantic aspect of diamond mining are the alluvial diggings. Two years ago De Beers Consolidated Mines opened a large area for individual diggers at the Noiitgedacht Farm about 18 miles north of Kimberley. The director of the alluvial diggings, Col. Ormiston, allowed Mr. Grodzinski to accompany him on one of his visits to this property. 13½ miles were covered on an absolutely straight macadam road. Then suddenly the road turned to the right, directly into the " field," on a path which one could hardly call a road. It was winding through the bush and the car rocked in all directions. They came to a fence and a kind of door with a very long inscription forbidding the entrance and threatening trespassers with fines. Mr. Grodzinski passed some herds of cows and ultimately saw big water reservoirs on steel structures from which tanks on motor cars or donkey carts were filled with water. In the distance was a camp of native huts of a most shabby nature. Eventually some corrugated steel sheds were reached. These were the De Beers offices at Noiitgedacht. De Beers offices acquired the ground many years ago. The farmer before in possession carried out some diamond diggings and the efforts of his works, changing the grassland into molehills of red earth could still be seen. The main difficulty was lack of water and he could not exploit his property neither for diamonds nor agricultural purposes. Now the water so essential for the separation of diamonds from gangue is brought from the Vaal river, about 4½ miles away (also a place of alluvial diggings by a pipe line up to the farm. The diggers obtain the water at a price of 4d. per 60 gallons and they go very carefully about with it. Most of them separate diamonds from gravel only occasionally.

The digger is allowed to put a claim for 44 by 45 ft. down at any place of the farm given free for the digging. There is no surveying of the area and even the roads used can be suddenly obstructed

by a claim. The claim is marked by a small sheet of metal 2 by 4 in. long on to which the name of the digger is written and this is fixed to a steel post which is pushed into the soil. For his claim the digger has to pay to De Beers, 5s. per month, and he can acquire up to three claims and can work for himself or with his family or employees, i.e. natives. He can use no equipment except shovel and pit axe or perhaps a lever crane, but no bulldozer or other kind of modern excavating machine. The diamonds which are found on these claims have at first to be certified by the claims inspector then they can be sold to free diamond buyers who come each Friday and occupy tiny huts provided by the company. From the proceeds of all the sales of diamonds, the company gets 10%. It is curious that a company so deeply interested in diamonds does not send any buyers to the farm and only quite occasionally diamonds found on the diggings are bought by De Beers.

The buyers appear to work for foreign firms and at the time of the present visit one of them was arrested, being accused of illicit diamond buying. The methods of excavation of diamonds are quite similar. Usually only 2.5 ft. of the rock is removed but occasionally gravel is found down to 15 ft. in the bedrock and diamond diggers follow down to this depth. Thinking they come into fissures or pot holes of old river beds, diamonds are suspected here. The method of separating is practically always the same primitive one. The sieving jigs called "Baby" separates the coarse material from the fine and the latter is immediately discarded. Then the material is fed into a rotary pan formerly driven by hand with cranks and now quite universally a small Diesel engine is used for rotating it. In this pan the heavier material goes through the centre and is discharged. The material is placed on a round sieve and shaken by hand, an operation usually performed by the digger himself. The last operation is emptying this sieve on a stand covered with sackcloth. With one movement the contents of the sieve are emptied and owing to the swinging movement the diamonds are kept in the centre.

A number of other diggers were visited, successful and unsuccessful ones. A retired government claim inspector had native diggers dig up to 15 ft. depth in small holes but was not successful. He asked for new claims in the recently opened annexe. The farm was recently favoured with quite phenomenal findings. One man

found a 511 ct. stone for which he received £18,300. The life on the farm seems nothing less than comfortable. The diggers either live in tents, converted trucks, corrugated steel huts or caravans.

The diggers are very law-abiding To deal with diamonds or to possess polished diamonds one must be a South African licensed diamond dealer or cutter. One can see big brass plates of a prescribed size, about 4 in. high by 2 ft. long on all offices and undertakings connected with diamonds. Even the diamond research laboratories had asked one of their senior staff to become a licensed diamond cutter.

The life of the diamond diggers is very dull, only occasionally does it take a romantic and exciting aspect. There is no great hope in diamond digging. No new diggers are accepted and all those people who were digging in the mining districts of Berkley West, were diggers for a minimum period of 10 years or were already holding diggers certificates prior to the 1st April 1940. That means that no newcomers are accepted. All the diggers to whom I spoke were at least between 55 and 60 years of age. For this reason alone, the diamond digging may finish one day. Why did the De Beers open this farm for alluvial diggings about 2 years ago ? One reason is certainly a political one, i.e., they want to satisfy the demand of the diamond diggers. But might not the diamond diggers support another political party than De Beers ? The management realizes the bad conditions the diggers are living in. But the example shows they sometimes obtain up to £10,000 but still continue to live in a little tent. The field could be much better explored with modern equipment such as bulldozers, the use of which is not permitted to the diggers. But again the company would not dream of exploring the field in this way. Therefore, they must be in some way in favour of the digging and believe in romantic adventure as 80 years ago their forefathers did.

ASSOCIATION NOTICES

FORMATION OF BRANCHES

Midlands

A large number of Fellows and Members of the Association met at the Auctioneers' Institute, Birmingham, on 30th September, 1952, for the inauguration of the Midlands Branch of the Association. Mr. N. A. Harper, who had been invited by the Council to take the preliminary steps, welcomed members, particularly the President, Chairman and Secretary of the Association and Mr. O. Fahy, who qualified in the first examination which was held in 1913, and gave a brief outline of events that had led to the formation of the first Branch of the Association.

The President of the Association, Dr. G. F. Herbert Smith, in addressing the meeting, said that he regarded the occasion as an important event, and that he had good reason to believe that this feeling was shared by the Council of the Association. He gave details of the early work and struggles of the Association in the efforts made to stress the importance of gemmological study for the jewellery trade.

Mr. Trevor P. Solomon was elected Chairman of the Branch and Mr. J. Best, Honorary Secretary. As the result of a ballot the following were elected to serve on the organizing committee : Miss P. E. Cutts and Messrs. A. D. Conway, O. Fahy, N. A. Harper and D. N. King.

The new chairman was introduced by Mr. F. H. Knowles-Brown, Chairman of the Association and, in taking the Chair, Mr. Solomon said that it was gratifying that Birmingham had been chosen as the first centre for a Branch of the Association. They had heard that the original suggestion was for a Branch to be formed in Edinburgh, and it was gratifying that circumstances had enabled the Midland Branch to become number one branch. There was no doubt that the gemmologist was becoming more necessary nowadays, and could perform, many useful services. The new Branch was catering for the whole of the Midlands—it could be of considerable benefit to local members.

The Branch by-laws were notified and future meetings discussed. Dr. G. F. Herbert Smith and Mr. F. H. Knowles-Brown were thanked for their attendance and the help that they had given to the formation of the Branch.

West of Scotland

At a meeting in Glasgow on October 9, it was decided unanimously to form a branch of the Gemmological Association of Great Britain, to be known as the West of Scotland Branch.

Mr. S. D. Wood, who presided, said that it had been decided to form a local group and to endeavour to have it linked up in some way with the Gemmological Association. Since then he had been in touch with the Secretary of the

Gemmological Association, who had favoured the idea and had sent him a copy of the suggested rules for the working of such a branch. Membership would be open to subscribing Fellows, Associates, Probationary and Ordinary Members of the Association. If the branch wished representation on the Council of the Association, the procedure would be to nominate someone when vacancies occurred.

It was unanimously agreed to adopt the suggested rules and thereafter it was agreed, after a vote, that Mr. F. Bryan be chairman of the branch, with Mr. S. D. Wood as Hon. Secretary, and Messrs. J. D. S. Wade, J. Gillougley, E. W. McDonald, R. W. Dickson and Mrs. W. M. Revie (Ayr) as committee members. The annual general meeting would be in April. It was agreed to hold monthly meetings throughout the winter, one meeting to be held in conjunction with the newly-formed branch in Edinburgh.

Mr. Wood felt that if they were to stage an exhibition of gems in Glasgow in 1953, they would receive help from the parent body. A similar exhibition in Edinburgh had attracted over a thousand visitors. The more people they interested in gemmology the better. In addition, such an exhibition might be the means of bringing in more students to the gemmology classes held at Stow College.

East of Scotland

The East of Scotland Branch of the Association was formally constituted at the Heriot-Watt College, Edinburgh, on Wednesday, 22nd October, 1952. Mr. David L. Meek and Mr. D. J. Ewing were elected Chairman and Honorary Secretary respectively. Miss Thea McDonald and Messrs. Adam Forsyth, George Winnert, Robert Buckle and S. B. Dyce were elected to the committee. It is hoped that the Chairman of the Branch will be drawn from past Presidents of the Edinburgh and East of Scotland Association of Goldsmiths. The principal of the Heriot-Watt College has kindly given permission for major meetings of the Branch to be held at the College, and this will undoubtedly strengthen the link between the College and the jewellery trade in the East of Scotland area. During the first year of the Branch it is proposed not to hold more than four meetings. Although the third Branch to be formally constituted the idea of the formation of local gemmological groups or branches first came from Edinburgh.

It is proposed to hold joint meetings with the West of Scotland Branch from time to time.

Membership of branches is open to subscribing Fellows, Ordinary and Probationary Members in the district, and application to be included in the register of members should be made in the first instance to the Secretary of the Association at head office. No subscription is payable for branch membership.

COUNCIL MEETING

A meeting of the Council of the Association was held at 19/35 Gutter Lane, London, E.C.2, on Wednesday, 22nd October, 1952. Mr. F. H. Knowles-Brown presided.

The following were elected to membership :

FELLOWS

D.1951

Craik, Eric David, Edinburgh.

Tillander, Alexander Bertel, Stockholm.

D.1952

Allen, Herbert, Newbridge.

Boxall, William John, Edinburgh.

Cannon, John, Gerrards Cross.
Cuss, Francis Charles, London.
Davies, George Henry, Birmingham.
Davies, John William, Loughton.
Evans, Freda Margaret, London.
Flood, Frank, London.
Johnson, Douglas Robert, Toronto.
Jones, Albert Edward, London.
McRae, Arthur John, Glasgow.
Hval, Jens Olav, Oslo.
McKay, Jane, Glasgow.
Parsons, Charles Jay, El Cajon.
Paterson, William, Edinburgh.
Payne, Leslie, Bournemouth.
Pollington, Kenneth Ian, Welling.
Pye, David Trann, Methil.
Rice, Jean Mary, Birmingham.
Roos, Leo A., Lucerne.
Rudelsheim, Henri Salomon, Amsterdam.
Scott, Maxine O., San Diego.
Short, Elsie Andrina, Twickenham.
Smith, Jack Edwin, Reigate.
Spence, Christopher Roy, London.
Svensson, Kurt Wilhelm, Lidingö.
Velden, J. van der, Amsterdam.
Vos, Dirk, The Hague.
Whelan, Kenneth James, Hainault.

ORDINARY

Henderson, Matthew M., Dundee.
Inches, Ian Hamilton, Edinburgh.
Mearns, Moureen Ann, Brisbane.
Robertson, George, Edinburgh.
Rouse, Aubrey William, Sydney.

PROBATIONARY

Ashley, Elsie, Newcastle.
Bache, Samuel, Old Hill.
Bender, Claus, Hamburg.
Clutterbuck, Marie Elizabeth, Birmingham.
Collyer, Rodney Frederick, Birmingham.
Forsey, John Norman, Sutton Coldfield.
Gance, Aryeh, London.
Kell, Ronald George, London.
Lipman, Maurice, Johannesburg.
Murray, Kenneth Granville, Sutton Coldfield.
Penfold, Victor Sydney, London.
Waites, Leslie Phillip, Birmingham.
Walsh, John Frederick, Birmingham.
Whitehead, Jack, Dudley.
Wilson, Malcolm Edward, Birmingham.
Woolley, Trevor William, Birmingham.

Fellows, 30. Ordinary, 5. Probationary, 16.

The style of the names of the newly formed Branches and financial arrangements were approved.

The Chairman congratulated the President on the appearance of the twelfth edition of his standard book "Gemstones" and the Vice-Chairman on his recently published "Physical Gemmology."

RAYNER PRIZES

As the special Rayner refractometer, which is intended to be a permanent prize in connexion with the award of the Tully medal, will not be ready for this year, Messrs. Rayner & Keeler have kindly placed a voucher worth £20 at the disposal of the 1952 recipient of the medal for the purpose of gem testing instruments. The same arrangement will apply this year, if the medal is awarded.

TALKS BY FELLOWS

Blythe, G. : "Gems." Women's Institute, Hullbridge, Essex, 20th October; St. Luke's Women's Fellowship, Southend, 21st October.

Solomon, S. T. : "Gemstones." Mary Tavy Women's Institute, 11th December.

Hamer, E. : " Gemstones." Preston Branch of the British Horological Institute, 12th November.

Penny, W. J. : " Jewellery." Chepstow Women's Institute, 21st October.

Webster, R. : " Gems and the Jeweller." Bristol and West of England Branch of the National Association of Goldsmiths, 13th November ; South Devon Branch of the National Association of Goldsmiths, 13th October.

Morgan, D. J. : " Precious Stones." Corby 25 Club, 22nd October.

Caudell, P. M. : " Gem Testing." London Area Association of Dispensing Opticians (Junior section), 6th October.

Leak, F : " Pearls." Young People's Fellowship, Tyndale Baptist Church, Clifton, 5th November. " Science of Jewellery." Toc H Women's Association, Winscombe, Som., 19th November.

Maton, E. W. : " Gemstones." Rotary Club of Bridgend, 1st December.

Parry, Mrs. G. : " Diamonds and other precious stones." S.W. and Monmouth Branch of the British Horological Institute, 18th November.

GEMMOLOGY IN LIVERPOOL

Classes in gemmology were commenced at the College of Art, Hope Street, Liverpool, in September last. Mr. Nigel Kennedy, F.G.A., is the instructor.

PRESENTATION OF AWARDS

Many members of the Gemmological Association came together again on October 20th for the reunion and the presentation of prizes gained in the earlier examinations. They met at the Goldsmiths' Hall and the President, Dr. G. F. Herbert Smith, thanked the Worshipful Company of Goldsmiths for their hospitality, and the encouragement they had always given the Association.

It was clear that Members could not always come to London for meetings, yet it was desirable if the Association was to flourish that those composing it should meet from time to time. He had been privileged to be at the new Midlands branch, centred at Birmingham. From what he had seen of the energy and zeal of the officers and members of that branch he was sure it would have a flourishing career. Since then two further branches had been formed, one in Edinburgh and one in Glasgow, covering the east and the west of Scotland. He looked forward to the time when the whole of Britain would be covered by branches of the Association.

The meeting represented the climax of the Association's academic year. Many of those who had sat for the examinations in June were there to receive tangible evidence of success. He understood that this year there had been a larger proportion of failures than usual. To those who had failed he said they should not be discouraged. There were two things to remember. One was that there was no royal road to learning. It meant study and unremitting toil to gain an adequate knowledge of a new subject. The other was that having had a first experience of an examination the entrant knew what was expected.

The Diploma commanded a very high prestige here and in all parts of the world. It commanded it entirely because its standard was adequate.

They were fortunate, continued the President, that they had Dr. W. Campbell Smith to present the Diplomas. He was in charge of the great national collection of minerals, rocks and meteorites at the British Museum (Natural History) that started as a private collection.

Dr. Campbell Smith then distributed the awards, congratulated those who had gained Diplomas and especially those who had gained them with distinction. He also congratulated the winner of the Rayner Prize in the Preliminary and Mr. Siedle of Ceylon who had won the Tully Medal, which thus went for the first time to an Asiatic country. It was fitting that this gemmological student should come from an island famous for its gems and whose ancient name was enshrined in the name of a new mineral sinhalite. He was pleased that a representative of the Singhalese Government here was able to be present to receive the award.

He recalled that in 1947 the Council of the Association had honoured him by electing him an honorary Fellow. But his connection with gemmology went back a lot farther. He had received his introduction to the subject when he first went to the Natural History Museum in 1910 from Dr. Herbert Smith. Those were the days when the pioneer work was starting and the study of gems was being made by several people here, one of the most active being Dr. Herbert Smith. One could not be in the Department of Mineralogy without being made aware of the great interest that was taken in the subject. Soon the proof sheets of Dr. Herbert Smith's book on gem stones began to come through. He had to read them and naturally went on to read the book.

He was glad to see that evening that Dr. Herbert Smith was on one side of him and Sir James Walton on the other. Dr. Herbert Smith was the direct successor of Sir Henry Miers, the first President of the Association, who had come to the Museum in 1882 just after it had moved from Bloomsbury to South Kensington. He lectured on the subject in 1895. The Natural History Museum had been fortunate in having in the last seventy years, four men who had taken a great interest in gemmology and they had acquired some notable stones through their activities. In the work that had been done they had always received valuable help from the Hatton Garden Laboratory. Accurate observation had led to the discovery of new minerals and such work might still be done by members of the Association. A new field was opening out in the fascinating study of inclusions in gem stones for which the tool was X-rays. Much remained to be discovered about gem stones and minerals and crystals.

Sir James Walton proposed a vote of thanks to Dr. Campbell Smith and said that gemmology had reached and passed an important milestone in that it was regarded as part of the great branch of the science of mineralogy.

More and more was being found out about gem stones and this knowledge was helping the trade. Some gem merchants might not make sufficient use of the scientific facts and aids that were available and jewellers could make use more in their display of the science of gems. It would have a great public appeal. The more one knew about the subject, the more interesting it became. And interest made for a happy and contented life.

WEST OF SCOTLAND BRANCH

The inaugural meeting of the West of Scotland Branch of the Gemmological Association was held in Glasgow at the Y.M.C.A. Club on the 24th November, 1952. Mr. Fred Bryan, F.G.A. presided.

Dr. G. F. Herbert Smith, President of the Association, who was the principal guest speaker, spoke of how he first became interested in the science of gemmology and recalled his experiences from then up to the present day. Other guest speakers were Dr. Helen Currie, of the Glasgow University Hunterian Museum and Dr. S. M. K. Henderson, Director of Museums, Glasgow Art Gallery and Museum. Dr. Currie explained the work of a Curator, with advice on methods of arranging and cataloguing a collection and Dr. Henderson discussed the work of the Art Galleries and the services rendered by his department to students and the public. He expressed his willingness to assist the Branch in connexion with a proposed gemmological exhibition to be held in 1953, probably in June.

Other guests of the Branch included Mr. D. Meek and Mr. D. Ewing, Chairman and Secretary respectively of the East of Scotland Branch of the Association, and Mr. W. Aitcheson, Vice-Chairmen of the Scottish Association of Jewellers. Mr. D. Ewing, speaking on behalf of the East of Scotland Branch, extended best wishes for the success of the Branch organizer in the West of Scotland and which had commenced its activities so successfully.

The next meeting of the Branch was convened for 4th December in order to consider proposals for the 1953 exhibition.

GLASGOW EXHIBITION

The West of Scotland Branch of the Association hopes to arrange a Gemmological Exhibition during June 1953 at the Glasgow Art Gallery & Museum. The convenor of the exhibition, Mr. S. D. Wood, 50 Talbot Drive, Glasgow, W.3, would be glad to hear from readers who would be prepared to loan interesting exhibits.

EARLY POLISHING OF DIAMONDS AND GEMSTONES

A paper "Early polishing of diamonds and gemstones" in particular in England, will be presented by P. Grodzinski to the Newcomen Society on February 11th, 1953. The lecture will take place in the Lecture Room of the Science Museum, South Kensington, London, S.W.7, at 5.30 p.m.

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Walton Polariscope	6	6	0
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Specific gravity testing set	12	0	0
Methylene Iodide, S.G. 3.32, Nd 1.742	0	6	0
Monobromonaphthalene, S.G. 1.49, Nd 1.66	0	2	4
Bromoform, S.G. 2.86, Nd 1.59	0	2	0
Clerici Solution, S.G. 4.33 at 40 C.	1	4	0
(prices per ounce, bottles 8d.)			
Hardness pencils, Mohs' 6-10, per set	2	0	0
Hardness pencils, Mohs' 1-10, per set	3	0	0
Ultra Violet Lamp, complete with transformer, reflector and Test Cabinet	22	12	0
Woods glass, 2″ × 2″	0	5	0
Spectroscope, pocket, diffraction grating with fixed slit	2	5	0
Spectroscope, „ „ „ „ adjustable slit ...	5	17	6
Spectroscope, d.v. prism	8	15	0
Spectroscope, „ „ with wave length scale	17	0	0
Spectroscope stone holding attachment	0	12	6
Spectroscope cylindrical lens attachment	2	0	0
Spectroscope table stand	2	2	6
Spectrum recording stamp	0	15	0
Lamp, Sodium, complete with stand and control gear	13	5	0
Lamp, High Intensity, on stand with transformer, for microscope, spectroscope, refractometer	7	7	0
Diamond Balance, pocket	20	0	0
Stone Holder, three spring prong	0	9	0
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Practical Gemmology, *by R. Webster.* 15/-

Gemmologist's Compendium, *by R. Webster.* 15/-

Jade of the Maori, *by Elsie Ruff.* 10/-

Easy Guide to Stones in Jewellery, *by G. N. Sprague.* 5/- (postage 6d.)

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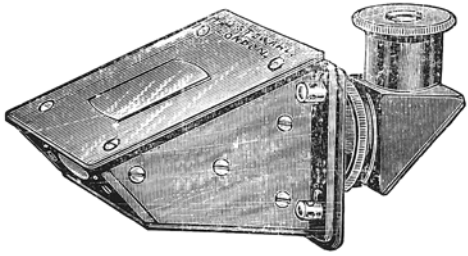

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THE JOURNAL OF GEMMOLOGY
AND PROCEEDINGS OF THE GEMMOLOGICAL ASSOCIATION OF GREAT BRITAIN

Vol. IV No. 2 APRIL 1953

VERDITE

by ROBERT WEBSTER, F.G.A

IN the useful and informative article on the employment of onyx marbles as the material for the production of small objects of art and utility, such as cigarette and clock cases, published in the Watchmaker, Jeweller and Silversmith for October 1952,[1] the use of *verdite* as an inlay is mentioned. References in the literature to this attractive green material give no data of value for testing. It is hoped that the following notes will, in part, supply some of these deficiencies.

The first account of verdite that I can trace is that written by Kunz,[2] who writes :—" During 1907 there was found on the south bank of the Nord Kaap river in South Africa, two miles above Kaap station, a stone of deep green colour. It has a hardness of 3 and is susceptible to a high polish. The colour is a rich chrome green and the stone contains a chrome muscovite and some argillaceous material. Occasionally it has yellow or red spots. The stone is obtained in blocks weighing 1 ton or more and is now sold in England at the price of £18 to £40 per ton (*1907-8*). The name verdite has been suggested for it."

Apart from references in Herbert Smith's " Gemstones "[3] where it is stated that the material is also known as " Transvaal-jade " and " African-jade " ; and in Schlossmacher's edition of

Bauer's " Edelsteinkunde,"[4] little has been written about this material in the literature on gemstones. A good account is given, without data, in the handbook of the South African Department of Mines.[5] This more modern work states :—" Verdite ; a variety of serpentine known locally as verdite has been worked for a number of years near Nord Kaap in the Barberton district, some 185 miles East by North of Johannesburg and 136 miles from the port of Lourenco Marques in Portuguese territory. It is an extremely beautiful stone of brilliant dark green colour. It has been used for all manner of small ornaments as well as for interior decorative architectural purposes. It occurs discontinuously in narrow bands in the Jamestown intrusive rocks. Sometimes it is intergrown with grey talc. The true verdite is soft and easily worked but it varies greatly in quality. It is sometimes intergrown with hard corundum-bearing rock of equally good colour but which is very difficult to work. The stone is obtainable only in comparatively small sizes, but pieces varying in weight from 25 lbs. to 100 lbs. or 200 lbs. and in exceptional cases up to 500 lbs. have been recovered. Pieces down to 4 square inches being saleable. It has been used in the interior decoration of prominent buildings such as the Bank of England and South Africa House in London."

The reference to the material being a serpentine calls for some comment. Bauer and Herbert Smith do not mention the term serpentine in their references to this material, whereas DuToit[6] states :—" The beautiful green variety of serpentine cut under the name of ' verdite ' is mined in Barberton " ; and Watson[7] notes that verdite is " an example of Sericite, a fibrous aggregate of Muscovite belonging to the Mica group of rocks, which occurs in the Barberton series of Swaziland " and that it " is deeply stained with green, owing probably to the presence of copper. It also possesses a silky lustre, a characteristic which has given rise to the name Sericite (from σηρικος, silky). It takes a fairly good polish, and is known commercially as Green Verdite Marble." It must be pointed out that the specimen Watson refers to, in the Sedgwick Museum at Cambridge, is not from the Transvaal, but from the Piggs Peak Mines, Swaziland, and may be quite different from the original verdite of the Barberton district, Transvaal.

In order to obtain a more satisfactory understanding of the nature of the substance, Dr. W. Campbell Smith, the then Keeper

of Minerals in the British Museum (Natural History), was approached. His reply is reproduced below.

" I have examined thin sections of our specimens of verdite, checked up on the X-ray photograph and spectograph taken in 1937, and had the density determined.

As far as thin sections show the rock consists of minute flakes and radiating groups of flakes of muscovite. The green colour is barely perceptible in thin section. I failed to detect any clay. The pale-yellow flecks are pseudomorphs of some mineral, but I cannot guess at its nature. The material of these patches is mostly opaque, but associated with it is a highly refracting birefringent mineral which may be epidote.

The X-ray photograph taken by Bannister showed muscovite and the spectrograph indicated chromium and a trace of copper, hence his identification of the main constituent as muscovite (var : fuchsite). The density is 2.82 as determined by Mr. S. E. Ellis.

As far as our evidence goes the rock can be described as a massive muscovite-rock coloured green by the chromiferous variety, fuchsite. Density 2.82. The description given in Mineral Industry for 1907, vol. 16, p. 108, is, " . . . contains a chrome-muscovite and some argillaceous material ; occasionally has yellow or red spots." That description, and Herbert Smith's in Gemstones, seems to be fairly satisfactory, but I have not proved the presence or absence of clay. I should ignore J. Watson's description ; except for the stress laid on colouring by copper his agrees with mine, i.e. is a massive muscovite-rock."

In order to obtain data of specific gravity, determinations of 23 specimens were recorded, and these are shown in the following table.

No.	*Weight.*	*Density.*	*Determined by.*
1.	7.30 carats	2.81	A. E. Farn.
2.	17.77 carats	2.82	R. Webster.
3.	?	2.82	S. E. Ellis.
4.	Large rough piece.	2.83	Chelsea students.
5.	4.95 carats	2.84	R. Webster.
6.	1.641 grams	2.840	,,
7.	1.6125 grams	2.841	,,

No.	*Weight.*	*Density*	*Determined by.*
8.	166.39 grams	2.86	R. Webster
9.	11.640 grams*	2.85	,,
10.	20.698 grams*	2.87	,,
11.	1.225 grams	2.902	,,
12.	1.457 grams	2.903	,,
13.	1.448 grams	2.904	,,
14.	1.571 grams	2.906	,,
15.	1.204 grams	2.907	,,
16.	1.117 grams	2.908	,,
17.	1.496 grams.	2.911	,,
18.	1.231 grams	2.912	,,
19.	0.968 gram	2.915	,,
20.	1.940 grams	2.921	,,
21.	1.203 grams	2.925	,,
22.	1.661 grams	2.953	,,
23.	1.876 grams	2.956	,,

* No. 8 was later sawn into two pieces and determinations made on each of the two pieces. No. 9 and 10 are the determinations on the two pieces.

The wide variation in density found is what would be expected in the case of a material which is essentially a rock and not a homogeneous mineral. The refractive index approximates to 1.58, but only a vague shadow edge can be seen on the refractometer. As a matter of interest the constants for muscovite mica are, according to values given in Larsen and Berman (1934), p. 237, refractive indices α 1.558–1.579 ; β 1.593–1.611 ; γ 1.598–1.615 ; and specific gravity 2.86–2.89. Examination by reflected light, and by transmitted light through fairly thin plates, showed the absorption spectrum to consist of three lines in the red, with the strongest near 7000 Å and a vague band in the blue about 4550 Å. The material does not luminesce when in the beam of an ultra-violet lamp, or under X-rays.

Perusal of the literature has shown that there are at least three other green materials of somewhat similar characters. Watson[8] mentions a fuchsite-schist from Shrewsbury, Vermont in the United States. Known as the Green Marble of Shrewsbury, it is a chrome-mica-schist found on the western slopes of the Green Mountain Range where the deposit, of Lower Cambrian age,[9] is

about 100 feet thick. The material when polished displays a brilliant dark emerald-green colour, varied with veins and patches of a lighter green colour. It is reported[10] that an attractive ornamental stone of serpentinised dolomite very beautifully coloured in wavy streaks of dark and light green and brown, and veined with white, is being obtained on the farm Bergendal near Belfast in the Transvaal. Kunz[11] refers to a deep green chromiferous syenite found at the jadeite mine at Bhamo, Burma, to which material he suggested the name "jadeolite." No opportunity has been found to examine these materials.

From the information obtained, the characters of verdite may be given as under.

VERDITE.

Composition.	A massive muscovite-rock coloured green by fuchsite.
Density.	2.80 to 2.96.
Refractive index.	About 1.58.
Hardness.	3 (Mohs's scale).
Absorption spectrum.	Three lines in the deep red and a vague line in the blue.
Luminescence.	None.

In conclusion I have to thank Dr. W. Campbell Smith for his ready help ; Mr. A. E. Farn for collecting a number of the specimens worked upon, and Messrs. Grant, of Torquay (per Miss J. Banister) for presenting the specimen No. 8.

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LIQUID INCLUSIONS in GEMS

In 1835 the English physicist, Sir David Brewster, distinguished two types of liquid inclusions. This was referred to by Dr. E. Gübelin in his article (Journal Gemmology, January 1946, page 24), and the full text of Sir David Brewster's letter to Sir Walter Scott, in which he detailed his observations is given below.

GRAND as the chemical operations are which are going on in the great laboratory of Nature, and alarming as their effects appear when they are displayed in the terrors of the earthquake and the volcano, yet they are not more wonderful to the philosopher than the minute though analogous operations which are often at work near our own persons, unseen and unheeded. It is not merely in the bowels of the earth that highly-expansive elements are imprisoned and restrained, and occasionally called into tremendous action by the excitation of heat and other causes. Fluids and vapours of similar character exist in the very gems and precious stones which science has contributed to luxury and to the arts.

In examining with the microscope the structure of mineral bodies, I discovered in the interior of many of the gems thousands of cavities of various forms and sizes. Some had the shape of hollow and regularly-formed crystals : others possessed the most irregular outline, and consisted of many cavities and branches united without order, but all communicating with each other. These cavities sometimes occurred singly, but most frequently in groups forming strata of cavities, at one time perfectly flat and at another time curved. Several such strata were often found in the same specimen, sometimes parallel to each other, at other times inclined, and forming all varieties of angles with the faces of the original crystal.

These cavities, which occurred in sapphire, chrysoberyl, topaz, beryl, quartz, amethyst, peridot, and other substances, were sometimes sufficiently large to be distinctly seen by the naked eye, but most frequently they were so small as to require a high magnifying power to be well seen, and often they were so exceedingly minute that the highest magnifying powers were unable to exhibit their outline.

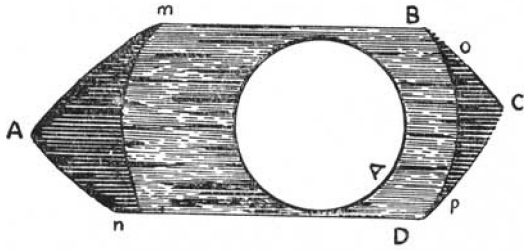

Fig. 1. The highly expansible fluid in the cavity of a gemstone. At low temperatures there is always a vacuity like an air bubble.

The greater number of these cavities, whether large or small, contain two new fluids different from any hitherto known, and possessing remarkable physical properties. These two fluids are in general perfectly transparent and colourless, and they exist in the same cavity in actual contact, without mixing together in the slightest degree. One of them expands thirty times more than water ; and at a temperature of about 80 deg. F. it expands so as to fill up the vacuity in the cavity. This will be understood from the above Fig. 1, where ABCD is the cavity, mnpo the highly expansible fluid in which at low temperatures there is always a vacuity V, like an air-bubble in common fluids, and Amn, Cop the second fluid occupying the angles A and C. When heat such

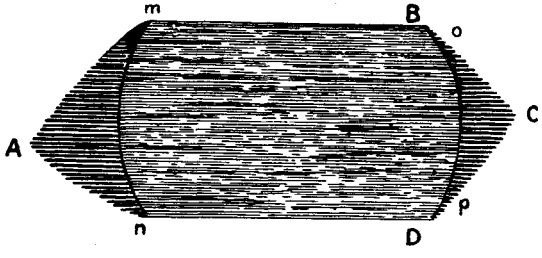

Fig. 2. When the specimen was heated the vacuity gradually contracted in size and wholly vanished at a temperature of about 80 degrees F.

as that of the hand is applied to the specimen, the vacuity V gradually contracts in size, and wholly vanishes at a temperature of about 80 deg., as shown in Fig. 2. The fluids are shaded, as in these two figures, when they are seen by light reflected from their surfaces.

When cavities are large, as in Fig. 3, compared with the quantity of expansible fluid m n o p, the heat converts the fluid into vapour, an effect which is shown by the circular cavity V becoming larger and larger till it fills the whole space mnop.

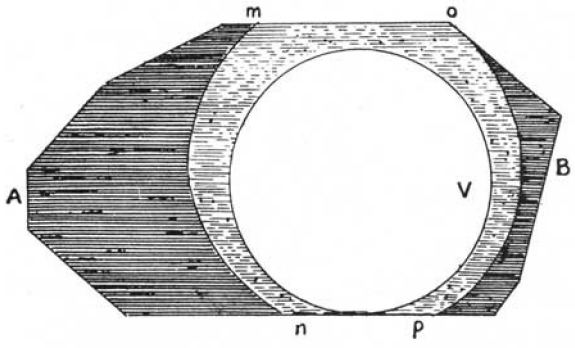

Fig. 3. In a large cavity containing a small quantity of expansible fluid the heat converts the fluid into vapour until it finally fills the whole space.

When any of these cavities, whether they are filled with fluid or with vapour, is allowed to cool, the vacuity V re-appears at a certain temperature. In the fluid cavities the fluid contracts, and the small vacuity appears, which grows larger and larger till it resumes its original size. When the cavities are large several small vacuities make their appearance and gradually unite into one, though they sometimes remain separate. In deep cavities a very remarkable phenomenon accompanies the reappearance of the vacuity. At the instant that the fluid has acquired the temperature at which it quits the sides of the cavity, an effervescence or rapid ebullition takes place, and the transparent cavity is for a moment opaque, with an infinite number of minute vacuities, which instantly unite into one that goes on enlarging as the temperature diminishes. In the vapour cavities the vapour is reconverted by the cold into fluid, and the vacuity V, Fig. 3, gradually contracts till all the vapour has been precipitated. It is curious to observe, when a great number of cavities are seen at once in the field of the microscope, that the vacuities all disappear and reappear at the same instant.

While all these changes are going on in the expansible fluid the other denser fluid as A and C, Figs. 1, 2, remains unchanged either in its form or magnitude. On this account I experienced considerable difficulty in proving that it was a fluid. The improbability of two fluids existing in a transparent state in absolute contact, without mixing in the slightest degree, or acting upon each other, induced many persons to whom I showed the phenomenon to consider the lines mnop, Figs. 1, 2, as a partition in the cavity, or the spaces Amn, Cop, either as filled with solid matter, or as

corners into which the expanding fluid would not penetrate. The regular curvature, however, of the boundary line mnop, and other facts, rendered these suppositions untenable.

This difficulty was at last entirely removed by the discovery of a cavity of the form shown in Fig. 4, below, when A, B and C are three portions of the expansible fluid separated by the interposition of the second fluid D E F. The first portion A of the expansible

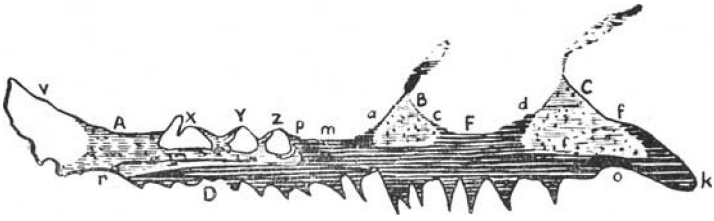

Fig. 4. Three portions, A, B, C, of the expansible fluid separated by the interposition of a second fluid.

fluid had four vacuities V, X, Y, Z, while the other two portions, B, C, had no vacuity. In order to determine if the vacuities of the portions B, C, had passed over to A, I took an accurate drawing of the appearances at a temperature of 50 deg. as shown in the figure, and I watched the changes which took place in raising the temperature to 83 deg. The portion A gradually expanded itself till it filled up all the four vacuities V, X, Y and Z ; but as the portions B, C, had no vacuities, they could expand themselves only by pushing back the supposed second fluid E E F. This effect actually took place. The dense fluid quitted the side of the cavity at F. The two portions B, C, of the expansible fluid instantly united, and the dense fluid having retreated to the limit m n o, its other limit advanced to p q r, thus proving it to be a real fluid. This experiment, which I have often shown to others, involves one of those rare combinations of circumstances which nature sometimes presents to us in order to illustrate her most mysterious operations. Had the portions B, C, been accompanied, as is usual, with their vacuities, the interposed fluid would have remained immovable between the two equal and opposite expansions ; but owing to the accidental circumstance of these vacuities having passed over into the other branch A of the cavity, the fluid yielded to the difference of the expansive forces between which it lay, and thus exhibited its fluid character to the eye.

When we examine these cavities narrowly, we find that they are actually little laboratories, in which chemical operations are constantly going on, and beautiful optical phenomena continually

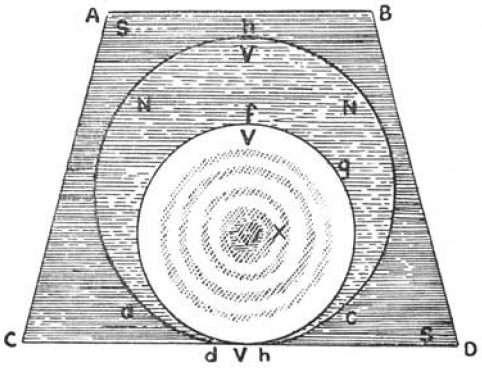

Fig. 5. When the temperature is perfectly uniform, the vapour rings are stationary. The first ring produced has swollen out to meet the first ring at the margin of the fluid.

displaying themselves. Let ABDC, in Fig. 5, be the summit of a crystallized cavity in topaz, S S, representing the dense, N N, the expansive fluid, bounded by a circular line abcd, and V V, the vacuity in the new fluid, bounded by the circle efgh. If the face ABDC, is placed under a compound microscope, so that light may be reflected at an angle less than that of total reflection, and if the observer now looks through the microscope, the temperature of the room being 50 deg., he will see the second fluid S S, shining with a very feeble reflected light, the dense fluid N N, with a light perceptibly brighter, and the vacuity V V, with a light of considerable brilliancy. The boundaries abcd, efgh, are marked by a well-defined outline, and also by the concentric coloured rings of thin plates produced by the extreme thinness of each of the fluids at their edges.

If the temperature of the room is raised slowly to 58 deg., a brown spot will appear at x in the centre of the vacuity V V. This spot indicates the commencement of evaporation from the expansible fluid below, and arises from the partial precipitation of the vapour in the roof of the cavity. As the heat increases, the brown spot enlarges and becomes very dark. It is then succeeded by a white spot, and one or more coloured rings rise in the centre of the vacuity. The vapour then seems to form a drop and all the rings disappear by retiring to the centre, but only to reappear with

new lustre. During the application of heat, the circle efgh, contracts and dilates like the pupil of the eye. When the vaporization is so feeble as to produce only a single ring of one or two tints of the second order, they vanish instantly by breathing upon the crystal, but when the slight heat of the breath reaches the fluid, it throws off fresh vapour, and the rings again appear.

If a drop of ether is put upon the crystal when the rings are in a state of rapid play, the cold produced by its evaporation causes them to disappear, till the temperature again rises. When the temperature is perfectly uniform, the rings are stationary, as shown between V and V in Fig. 5 ; and it is interesting to observe the first ring produced by the vapour swelling out to meet the first ring at the margin of the fluid, and sometimes coming so near it that the darkest parts of both form a broad black band. As the heat increases, the vacuity V V, diminishes, and disappears at 79 deg., exhibiting many curious phenomena which we have not room to describe.

Having fallen upon a method of opening the cavities, and looking at the fluids, I was able to examine their properties with more attention. When the expansible fluid first rises from the cavity upon the surface of the topaz, it neither remains still like the fixed oils, nor disappears like evaporable fluids. Under the influence, no doubt, of heat and moisture it is in a state of constant motion, now spreading itself on a thin plate over a large surface, and now contracting itself into a deeper and much less extended drop. These contractions and extensions are marked by very beautiful optical phenomena. When the fluid has stretched itself out into a thin plate, it ceases to reflect light like the thinnest part of the soap-bubble, and when it is again accumulated into a thicker drop, it is covered with the coloured rings of thin plates.

Effect of Hand Humidity

After performing these motions, which sometimes last for ten minutes, the fluid suddenly disappears, and leaves behind it a sort of granular residue. When examining this with a single microscope, it again started into a fluid state, and extended and contracted itself as before. This was owing to the humidity of the hand which held the microscope, and I have been able to restore by moisture the fluidity of these grains twenty days after they were

formed from the fluid. This portion was shown to the Reverend Dr. Fleming, who remarked that, had he observed it accidentally, he would have ascribed its apparent vitality to the movements of some of the animals of the genus Planaria.

After the cavity has remained open for a day or two, the dense fluid comes out and quickly hardens into a transparent and yellowish resinous-looking substance, which absorbs moisture, though with less avidity than the other. It is not volatilized by heat, and is insoluble in water and alcohol. It readily dissolves, however, with effervescence in the sulphuric, nitric, and muriatic acids. The residue of the expansible fluid is volatilized by heat, and is dissolved but without effervescence, in the above-mentioned acids. The refractive power of the dense fluid is about 1.295, and of the expansible one 1.131.

The particles of the dense fluid have a very powerful attraction for each other and for the mineral which contains them, while those of the expansible fluid have a very slight attraction for one another, and also for the substance of the mineral. Hence, the two fluids never mix, the dense fluid being attracted to the angles of angular cavities, or filling the narrow necks by which two cavities communicate. The expansible fluid, on the other hand, fills the wide parts of the cavities, and in deep and round cavities it lies above the dense fluid.

When the dense fluid occupies the necks which join two cavities, it performs the singular function of a fluid valve, opening and shutting itself according to the expansions or contractions of the other fluid. The fluid valves thus exhibited in action may suggest some useful hints to the mechanic and the philosopher, while they afford ground of curious speculation in reference to the functions of animal and vegetable bodies. In the larger organizations of ordinary animals, where gravity must in general, overpower, or at least modify, the influence of capillary attraction, such a mechanism is neither necessary nor appropriate ; but, in the lesser functions of the same animals, and in almost all the microscopic structures of the lower world, where the force of gravity is entirely subjected to the more powerful energy of capillary forces, it is extremely probable that the mechanism of immiscible fluids and fluid valves is generally adopted.

In several cavities in minerals I have found crystallized and other bodies, sometimes transparent crystals, sometimes black

spicular crystals, and sometimes black spheres, all of which are movable within the cavity. In some cavities the two new fluids occur in an indurated state, and others I have found to be lined with a powdery matter. This last class of cavities occurred in topaz, and they were distinguished from all others by the extraordinary beauty and symmetry of their form. One of these cavities represented a finely-ornamented sceptre, and, what is still more singular, the different parts of which it is composed lay in different planes.

Explosion Experiences

When the gem which contains the highly-expansive fluid is strong, and the cavity not near the surface, heat may be applied to it without danger ; but in the course of my experiments on this subject, the mineral has often burst with a tremendous explosion, and in one case wounded me on the brow. An accident of the same kind occurred to a gentleman, who put a crystal into his mouth for the purpose of expanding the fluid. The specimen burst with great force and cut his mouth, and the fluid which was discharged from the cavity had a very disagreeable taste.

In the gems which are peculiarly appropriated for female ornaments, cavities containing the expansible fluid frequently occur, and if these cavities should happen to be very near the surface or the edge of the stone, the fever heat of the body might be sufficient to burst them with an alarming and even dangerous explosion. I have never heard of any such accident having occurred ; but if it has, or if it ever shall occur, and if its naturally marvellous character shall be heightened by any calamitous results, the phenomena described in the preceding pages will strip it of its wonder.

A SPECIFIC GRAVITY VOLUMETER

by S. J. Everett and Sir James Walton

IN March 1950 one of us (J.W.) published an account of a balance which would give a direct reading of the specific gravity of a mineral.* At that time it was pointed out that the instrumental readings were not very reliable for small specimens having a weight of less than one carat.

Since then attempts have been made to devise an instrument which would give reliable results for small specimens. In a well-equipped laboratory very accurate results can be obtained by the use of heavy fluids but a considerable number of these fluids is required to cover a wide range and if great accuracy is required, as in the case of a rare or new mineral, a fluid has to be carefully mixed of such a density that the specimen is accurately suspended within it. The specific gravity of the fluid has then to be determined by the rather prolonged and tedious use of a pycnometer. Moreover a sufficiently large battery of fluids is not easily portable and the individual fluids have to be rather frequently controlled to make certain that their densities have remained constant. For accurate work corrections have also to be made for the temperature of the fluid. The method therefore has drawbacks for use in the field and for those who have no well-equipped laboratories.

It is a somewhat curious fact that although the basic formula for obtaining the specific gravity is Sp. gr. $= \frac{W}{V}$ in nearly all the other methods the volume is not directly estimated but is calculated from an estimate of the weight of fluid displaced by the specimen. It is true that with relatively large specimens the density may be estimated by dropping them into fluid contained in a graduated cylinder and observing the rise in the level of the fluid. The cylinder has, however, to be wide enough to admit the specimen and the scale cannot therefore be sufficiently delicate to give more than approximate results.

* "A New Type of Specific Gravity Balance." Mineralogical Magazine. Sept., 1950. Vol. xxix, No. 210, pp. 200–205.

The fact that capillary tubes are widely used in pathological and bacteriological laboratories to give very accurate determinations of the volume of small quantities of fluid led to the view that some adaptation of this method might be used to determine the volume of relatively small mineral specimens.

The first model made consisted of a syringe on the piston stem of which (Fig. 1) a screw thread had been cut and a knurled nut fitted to it. It was found however that most syringes on the market had much too inaccurately fitting a piston so that with only slight pressure the fluid readily passed from one side of the piston to the other. One of us (S.E.) was producing, however, syringes

From James Walton's "Physical Gemmology" by kind permission of Sir Isaac Pitman and Son, Ltd.

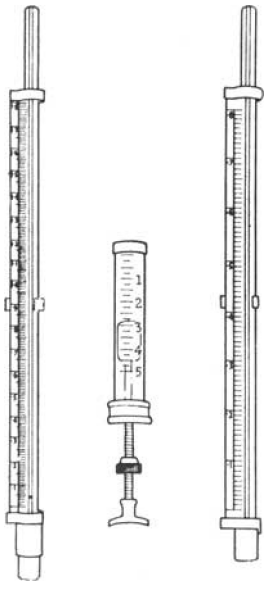

Fig. 1
Specific Gravity Syringe.

Tube 1.5*mm. diameter.*

Tube 1*mm. diameter.*

for other purposes which had pistons fitting so accurately that this difficulty was entirely overcome. The needle fitting was removed from such a syringe and into it was fitted one of two glass capillary tubes about 25 cms. long having a lumen of 1 and 1.5mm., which was fixed in a perspex support having a flat surface to take a scale and a carefully turned lower end with a taper of 1° so as to fit firmly and snugly into the cylinder. In use the syringe was half filled with any fluid, the syringe held vertically, the piston fully retracted, the capillary tube unit inserted and the piston advanced

until the fluid passed a little above the zero mark. On slowly screwing up the knurled nut the fluid could be easily and evenly withdrawn to the zero mark. The screw was left untouched, the piston fully withdrawn, the capillary tube unit extracted, the specimen inserted, the capillary tube unit replaced and the piston pushed up until its progress was stopped by the nut, i.e., it was in the identical position it occupied before the specimen was inserted. The volume of the fluid was however increased in amount by the volume of the inserted mineral and hence rose higher up in the capillary tube. The scale having been carefully calibrated this increase of volume was at once visible.

In practice the model gave satisfactory results if care was used to insert the capillary unit always with the same pressure but if greater pressure was used it was found that the perspex plug was sufficiently compressible to give an increased reading of several divisions on the scale. It was therefore unsuited for general use where varying pressure might be exerted by individual observers.

After considerable thought and experiment we have produced the present model which is free from this drawback and after very careful testing has been found to give accurate and reliable results.

It consists of a very carefully and accurately ground glass cylinder, the lower end of which is closed. It is mounted in a small wooden stand and about one half way up a horizontal line is inscribed (Fig. 2A). Into this passes a piston (B) equally accurately ground and fitting so perfectly that although sliding easily there is no leak of fluid around it. Through it passes the capillary tube (C), the lower opening being bevelled so that no air bubble collects there. Over the capillary tube and the upper end of the piston a brass tube (D) 4 cms. long and having an external screw with 24 threads to the inch is fixed with Canada balsam. Over this is fitted another brass tube (E) with a similar screw cut on its inner surface and having a knurled band so that it can be easily rotated. When the piston is inserted this outer tube rests on the glass cylinder and so determines the depth to which the piston can be inserted. To the upper end of the inner fixed screw is soldered a flat brass strip to hold the scale (F) and on it are soldered three semicircular brass bands (G) which closely embrace and hold tight the capillary tube.

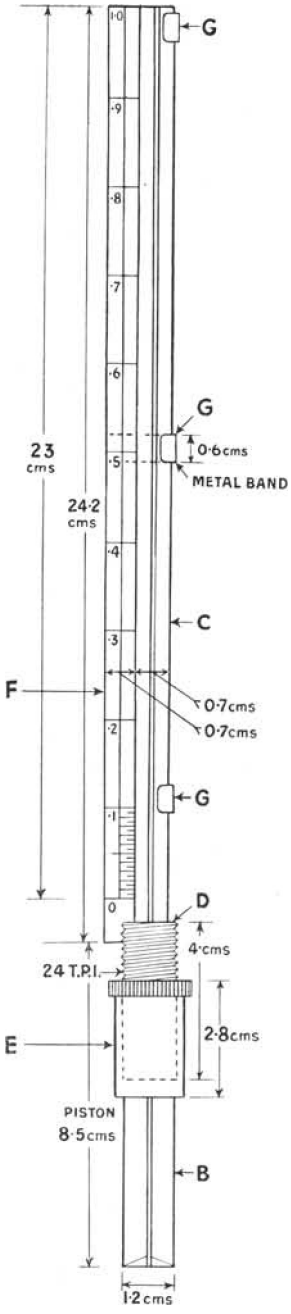

In use the cylinder is fitted with fluid up to the horizontal mark. Any fluid could be used for the volume is measured directly and is not estimated from the weight of fluid displaced. The ordinary commercial methylated spirit is found to be very satisfactory for it cleans and does not stain the glass surfaces and since it has a low viscosity and surface tension the common problem of getting rid of air bubbles attached to the specimen does not seem to exist.

The outer screw is screwed down so that the piston when inserted remains about $\frac{1}{4}$in. above the level of the fluid. The outer screw is then slowly screwed upwards and the piston slowly descends and as it does so the fluid rises in the capillary tube. Its movement can be most easily regulated and its upper level is set at the zero

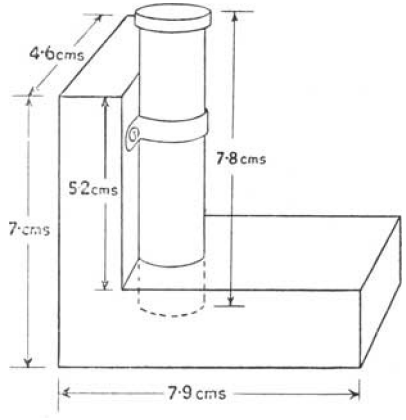

Fig. 2a.

mark on the scale. During this process the scale must be held with the left hand while the screw is rotated with the right so that the capillary tube and piston do not rotate with the screw. When the fluid is exactly at the zero mark the piston is slowly and carefully withdrawn by holding the scale. Care must be taken that the piston is drawn vertically upwards and not rotated lest the outer screw move on the inner. (In a future model the two will be fixed with a small screw).

The specimen, the weight of which has been carefully taken, is dropped into the cylinder and the piston replaced. It will fall until its progress is stopped by the tube E in exactly the same position it occupied before withdrawal but now the fluid in the tube will reach a higher level and the height of this above the zero mark will give the volume of the specimen. The weight divided by the volume will of course give the specific gravity.

The gramme as a unit of weight for all gemstones and most small mineral specimens is too large and the metric carat has been universally adopted. This is $\frac{1}{5}$ of a gramme and the volume of this weight of distilled water at 4°C is $\frac{1}{5}$ of a millilitre, that is 200 cubic mms. Unfortunately there is no name for this volume which we have therefore designated as a water carat. The capillary tube in this model is of such a length that it has a volume of exactly one water carat, and hence would record the volume of any specimen whose weight is identical with its specific gravity, but since with such a weight the fluid would be right at the top of the tube it is wise to limit the use of the instrument to specimens of a weight slightly below that of their density. The tube could, of course, be made of any length provided that the large sub-divisions have a volume of exactly 0.1 of a water carat. The large sub-divisions are again divided into tenths each giving 0.01 of a water carat, and these again into two so that of the smallest divisions register 0.005.

The calibration of the scale has to be very carefully carried out. If a small piece of a mineral of a known and constant density, such as quartz with a sp. gr. of 2.651 be taken and carefully weighed, its weight divided by its sp. gr. will give its volume and the position of the level of the fluid in the capillary tube given by this mineral when the instrument is used in the usual way will show

this volume. From this the volume of the whole length of the tube can be deduced. For greater accuracy the positions of the volumes of several specimens, say four of pure quartz of sp. gr. 2.651 and two of corundum of sp. gr. 4, are marked and the volume of the whole length of the tube estimated in each case. If they differ in the slightest degree an average is taken. Having obtained the volume in water carats of the whole length of the tube, the length of 0.1 carat is easily estimated, and this divided into ten equal parts.

There are two precautions that have to be taken. When the piston is first inserted it and the wall of the cylinder are dry. When the piston is withdrawn it wets the side of the cylinder with a thin film, but so delicate is the instrument that when the piston is reinserted the fluid column will be slightly lower in this model, about 0.02 of a water carat, but this film does not allow leakage for if the piston is inserted and the screw screwed up until the fluid reaches the upper end of the scale it will remain fixed and not fall as it would if there were any leakage. To overcome the faulty reading of this wetting it is wise with the first wetting to set the fluid at a given level, say 0.1, to withdraw the piston and then reinsert. If the reading is now lower, say 0.08, to reset it lower the column until it is at zero, when the piston can be removed and the specimen inserted in the usual way.

The second precaution is against allowing any wetting of the upper border of the cylinder from the lower end of the piston when it is withdrawn. This can be prevented by making the withdrawal vertically upwards. If it should accidentally wet the upper margin of the cylinder, the piston should be replaced and reset before the specimen is inserted.

The instrument is very delicate and accurate but if great accuracy is required, as in the determination of a new mineral, several determinations should be made and if there is any variation, they should be continued until three or four consecutive readings are identical, thus tending to eliminate human error.

With a little practice the investigations can be made very rapidly and the method has the great benefit that since the volume itself is measured no irksome corrections have to be made for

variations in the specific gravity of the fluid due either to its nature or its temperature. It is also very compact and portable and thus should be useful in field work.

The instrument is being manufactured by Mr. S. J. Everett of S. and R. J. Everett & Co. Ltd., at the Invicta Works, 939 London Road, Thornton Heath.

LETTER TO THE EDITOR

An Interesting Experiment

DEAR SIR,

While reading the chapter on single and double refraction from Mr. B. W. Anderson's " Gem-Testing," I thought of trying the following experiment.

I placed one polaroid above the sub-stage condenser, and below the stage of my Beck microscope. The other polaroid was placed within the eyepiece. Now, I placed a ruby red glass (1 inch by 1 inch) on the stage, when the polaroids were not crossed. On this red glass was placed a very thin and small crystal of Calcite, on which the eyepiece was focused, so that the Calcite crystal stood out sharply against the red background of the glass slide. The whole system was illuminated by a 15 watt. lamp in a dark room.

The polaroid in the eyepiece was gradually rotated in a circular motion. On doing so, the red glass background began to darken gradually, until it completely vanished and became " invisible " when the polaroids were in the crossed position. Now the Calcite crystal glowed, like a red hot coal, against a totally dark background. On further turning the eyepiece, the " status quo ante " was gradually restored.

By a little trial and error one can find the most suitable orientation for the Calcite crystal to show this effect to its best advantage. The crystal may even be permanently mounted on the red glass. Glass of any other colour may be used, but red gives the most impressive effect.

Yours faithfully,

India. V. R. KIBE, B.Sc., LL.B., F.G.A.

Gemmological Abstracts

ANON. *Ivory—an ancient gem material.* Gemmologist, Vol. XXI, No. 256, pp. 201–202. November, 1952.

A short article listing the properties of ivory and some simulating materials. Apparently culled from the earlier works of R. Webster. 2 illustrations. W.B.

SCHLOSSMACHER (K.). *Die Unterscheidung von echten Perlen und Zuchtperlen mit der Rontgenschattenbildermethode.* Differentiation between genuine and cultured pearls by X-ray radiography. Zeit. Deutsh. Gesell. f. Edelsteinkunde, Autumn, 1952, No. 1, pp. 14–17.

A brief survey of the usual methods of testing. An X-ray apparatus has been installed at the Institute at Idar-Oberstein. E.S.

——— *Synthetische Diamenten.* Synthetic diamonds. Ibid. pp. 19–20.

Short notes on official inquiry regarding experiments of Dr. H. Meincke and the Bell Telephone Corporation announcement of production of synthetic diamond in form of glossy hard balls through heating polyvinylbenzol to 1050° C. E.S.

CHUDOBA (K.). *Durch Chrom verursachte Edelsteinfarben.* Gem colours caused through chromium. Ibid. pp. 9–13.

Chromium is the pigment in several important gems. The relevant composition is frequently chromium oxide (Cr_2O_3), itself deep green and forming rhombohedral or hexagonal crystals. Traces of 0.11% to 0.19% of Cr_2O_3 cause the colour in emerald (ideally 3 $BeO.Al_2O_3$ 6 SiO_2) when some Al. ions (ion radius Al^{3+}=O.57Å) are replaced by Cr. ions (ion radius Cr^{3+}=O.64Å). Uvarovite garnet (3 $CaO.Cr_2O_3$. 3 SiO_2) contains 6.2-30.6% Cr_2O_3 (mostly about 25%). The ideal Uvarovite would contain 32.5% Cr_2O_3 but a part of this is replaced by Al_2O_3 and in rarer cases by Fe_2O_3 (Ion radius Fe^{3+}=0.67). The striking difference in Cr_2O_3 content of Emerald and Uvarovite is due to the different

capacity of the two crystal lattices when incorporating foreign ions through isomorphic replacement. Up to 1.5% of Cr_2O_3 causes green colour in demantoid (3 $CaO.F_2O_3$. 3 SiO_2) but red colour in pyrope garnet (3 $MgO.Al_2O_3$. 3 SiO_3). A similar phenomenon is observed in synthetic corundum where up to 8 atom per cent. chromium cause red colour and bigger quantities (up to 30%) green colour. The red corundums become green on heating and revert to red when cooling ; the green corundums turn red on cooling (minus 150° C) and revert to green at higher temperature. It is assumed that the green colour is caused by chromium-chromium contact in the lattice, giving the chromium partly a metallic structure. Chromium is also the pigment in red spinel ($Mg.O.Al_2O_3$). In synthetic spinel, too, red or green colour is produced by isomorphic replacement of Al_2O_3 through Cr_2O_3 the critical limit being 15 atom per cent. of chromium.

E.S.

Cox (H. H., Jr.). *Jet—the Black Beauty Gem.* Lapidary Journal. Dec., 1952, pp. 334–342, 2 illus.

Jet is used in costume jewellery and commands high prices. There is a strong possibility that much of it is not jet at all, some so-called jet being coarse grade glass. The article tells how to cut and polish jet without machinery ; files, paring knife and a jeweller's saw are the principal tools used. A.G.

Day (N. H.). *A visit to a French artificiat pearl factory.* Gemmologist. Vol. XXII, No. 258, pp. 15–16. January, 1953.

A note of a visit to " La perle du lac " imitation pearl factory at St. Gingolph on Lake Geneva. Scales of the bleak taken from the waters of the lake are employed. The scales are scraped off, washed in ammonia, and treated with other chemicals before suspension in a solution of amyl alcohol and ether. The beads are dipped in this solution, which is apparently bonded in a special enamel, to give the coating. Up to 17 dips are given to best quality pearls. Coloured pearls are made by using a dye for the third dip and completing with two further dips in standard solution.

R.W.

WEBSTER (R.). *Operculum.* Gemmologist, Vol. XXII, No. 259, pp. 31–33. February, 1953.

A reprint of an earlier article (1938) on the operculum of the topshell which has been used in jewellery. The origin of these pieces, the localities where the shells abound, the appearance of the opercula and the chemical and physical properties are given. An additional note to the earlier write-up refers to an article published during the last war, on the finding of these opercula by the fighting forces operating among the Pacific islands. 1 illus.

P.B.

ANDERSON (B. W.). *Two new gemstones : Taaffeite and Sinhalite.* Gems and Gemology, Vol. VII, No. 6, pp. 171–175. Summer, 1952.

A full description, with history, of the finding of the two new species. A list of their properties is given. The subject has previously been reported in Journ. Gemmology (*Vol. III, p. 77–80 taaffeite ; pp. 315–321, sinhalite*).

R.W.

SWINDLER (K.). *Engraved gems through 6,000 years of popularity.* Gems and Gemology, Vol. VII, Nos. 6 and 7, pp. 176–185 (Summer, 1952) and 213–222 (Fall, 1952).

A very full exposition of the history of engraved gems from the earliest times. Egyptian, Greek and Roman carved gems are discussed. Mention is made of the materials used (including shell cameos). The second part details the gems of the Middle ages to those of to-day. A note is given on the tools used in gem engraving. 17 illus.

R.W.

WEBSTER (R.). *Some unusual composite stones.* Gems and Gemology, Vol. VII, No. 6, pp. 186–187. Summer, 1952.

Tells of two types of composite stones which were somewhat unusual. Three were quartz soudée type—one the ordinary green emerald imitation and the other two similarly had a rock crystal crown and base but were of unusual colour. One had an " alexandrite-like " colour change, and the other was sapphire blue in daylight and purple under artificial light. The other three stones were composed of a rock crystal crown with a coloured glass base. Their colours were sapphire blue, purple and yellow and the glass bases had refractive indices of 1.51 and the density was respectively 2.61 ; 2.56 ; and 2.55. P.B.

HARRISON (A. R.). *Occurrence—mining and recovery of diamonds. Part II.* Gems and Gemology, Vol. VII, No. 6, pp. 188–190. Summer, 1952.

A further instalment of the series on the world occurrence of diamond. The localities dealt with are the Gold Coast ; French West Africa ; the alluvial deposits in South Africa and those of South West Africa. The production and mining methods of each of these localities are discussed. It is mentioned that the South West African deposits, and in fact most alluvial deposits, are not water-repellent because the diamonds are coated with a microscopic film of salts and it is necessary to first " condition " the diamonds by immersing and light milling the concentrate in a dilute solution of whale acid, or fish oil, and caustic soda before grease table recovery. The story that diamonds can easily be picked up on the beaches of South West Africa is shown to be false. A table is given of the relative yield of various diamond mines.

R.W.

SMALL (J.). *Weight estimation of cabochons.* Gems and Gemology. Vol. VII, No. 6, pp. 191–194. Summer, 1952.

By the use of a millimetre screw gauge or a dial gauge, such as the Leveridge or similar type, and employing the formula weight equals length in mm. multiplied by width in mm. x depth in mm. x .0026 x specific gravity of the stone, it is possible to arrive at an estimated weight with a low probability of error. The method may be simplified by the use of a graph (an example being shown). Working examples given and the derivation of the formula fully explained.

R.W.

PLATO (W.). *Oriented lines in synthetic corundum.* Gems and Gemology, Vol. VII, No. 7, pp. 223–224. Fall, 1953.

The existence of zonal lines in synthetic corundums is discussed. These are not " twinning lines." They are best seen in parallel polarised light when viewed down the optic axis—the direction being first found by the use of convergent polarized light. These lines, which show angles of 60° or 120°, are only with difficulty seen at any time and only along this one direction. They are suggested as an added sign of synthesis in difficult stones, as they differ from the effect seen in natural stones.

R.W.

BENSON (L. B.). *Los Angeles collector owns large specimen of new gem mineral.* Gemological digests. Gems and Gemology, Vol. VII, No. 7, p. 225. Fall, 1953.

A 158 carat sinhalite is reported to be in the possession of Los Angeles collector W. E. Phillips. The stone was originally purchased as a tourmaline, but its identity was questioned by Dr. George Switzer—possibly this stone is the one which initiated the work which produced evidence of the existence of the new gem species. Full data and photograph of the stone are included.

R.W.

TRUMPER (L. C.). *Iolite.* Gemmologist, Vol. XXI, No. 257, pp. 217–218. December 1952.

A discussion of the properties of three specimens of iolite in the author's collection, and on iolite generally. No new data produced. The author's measurement of the double refraction is given as 0.011, which he points out is slightly higher than the values 0.008 to 0.010 usually given in gemstone literature.

R.W.

ANON. *Joseph Strasser.* Gemmologist, Vol. XXI, No. 257, p. 224. December, 1952.

A story of the inventor of the brilliant lead glass known as "strass." It further tells that the inventor's daughter married John Dolland, the well-known English optician. *In a letter to the Editor, M. D. S. Lewis criticises many of the statements made in this article see p. 18, Vol. XXI, No. 258. January, 1953. This letter suggests that Strass (G. F.) is the rightful inventor of "strass."*

R.W.

KISCH (T. B.). *Suoth Africa's first diamonds.* Gemmologist, Vol. XXI, No. 257, pp. 226–232. December, 1952. (*Reprinted from OPTIMA*). Second instalment Vol. XXII, No. 258, pp. 9–13. January, 1953.

An original story of the early days of the South African diamond discoveries. It is taken from hitherto unpublished notes of Kisch, one of the forgotten pioneers of pre-Kimberley days. The introduction is by E. Rosenthal who obtained the papers. 2 maps, 1 illus.

R.W.

WEBSTER (R.). *Fish scales or silver ?* Gemmologist, Vol. XXII, No. 258, pp. 1–4. January, 1953.

An article printed in a trade journal of the paints industry casts doubt as to the truth that fish scales are used in the production of pearl essence, and suggests that finely divided silver is employed. Webster attempts to clarify the position by giving as full as possible the history of the use of pearl essence (guanine scales), and by the results of some experiments carried out to detect silver in pearl coatings. The results were negative for silver.

P.B.

PARKINSON (K.). *Ceylon : The island of gems.* Gemmologist, Vol. XXII, No. 258, pp. 5–6. January, 1953.

Further notes on the mining and marketing of gems in Ceylon. The method of bidding by code with the fingers while the hands are covered by a handkerchief is mentioned. Three per cent. commission is deducted by the buyer to be generally distributed one half to his mosque and one half to those who attend the sale—including lookers on. Of the 97% left 20% goes to the landowner ; 8% to the licensee and the remainder divided between the miners and labourers.

R.W.

ANON. *The beauty of star stones.* Gemmologist, Vol. XXII, No. 259, pp. 34–37. February, 1953.

A short article outlining the reasons for the effect known as chatoyancy and that known as asterism. Notes are given on the types of stones in which the effect may be seen. Chrysoberyl, corundum, garnet, quartz, beryl, tiger's eye, scapolite, calcite and tourmaline are mentioned. A silicified hematite from Minnesota, called locally *binghamite*, seems not to have penetrated gem literature.

P.B.

GRODZINSKI (P.). *A statue with diamond eyes.* Gemmologist, Vol. XXII, No. 259, pp. 24–25. February, 1953.

A small statuette in the British Museum is credited to the first century B.C. or A.D. Doubt is cast on the authenticity of the diamonds set in the eyes as being contemporary with the figure itself. Results of an investigation and general deductions seem to prove that the diamonds were inserted later. Illustrated.

R.W.

HEYNE (K. N.) and NICOL (H. Q.). *Japanese Gem Cutting Industry.* Lapidary Journal, February, 1953, pp. 420–432, 5 photos.

The centre of this industry is Kofu, comprising about 150 cottage establishments. The Kofu industry is concerned with cutting and carving of mass-production items, primarily from rock crystal, coloured stones being cut but rarely. As a result of employing much juvenile labour, the average age of workpeople employed is about 30. The various processes used in cutting rock crystal, amethyst, rose quartz and agate are adequately described. Most of the rough material is imported from Brazil, and the industry, which produces among other things the well-known crystal spheres, is aiming to capture the market which Chinese jade formerly occupied. The industry has its own research laboratory maintained by the local government.

A.G.

GÜBELIN (E. J.). *More notes of synthetic red spinel.* Gems and Gemology. Vol. VII. No. 8. pp. 236-247. Winter 1952-53.

The author states that synthetic red spinel is now commercially possible and may have to be reckoned with in the near future. Six specimens of this new synthetic, which are made by the Verneuil flame fusion process, were examined and the results fully reported. The colour is purple-red to ruby-red and approximates to that of ruby rather than to natural red spinel. X-ray Debye-Scherrer diagrams showed the stones to be identical with natural spinel, and to have unit cell $A_w = 8.084 \pm 0.001$ Å (natural spinel $8.086 \pm 0{,}001$ Å). The specific gravity was found to be 3.579-3.598 (3.595 in table); the refractive index 1.7191 to 1.7198, and the absorption spectrum to conform to natural red spinel. The fluorescence was found to be a dull red under short wave ultra-violet light and a bright red under the long wave radiation. The fluorescence spectrum exhibited a single broad red band (6850 to 6900Å) rather than the group of lines seen in natural red spinels. The composition of the stones is equi-molecular unlike the normal synthetic spinel with MgO: $3.5\ Al_2O_3$. The included gas bubbles take the shape more commonly seen in synthetic corundum and curved striae are present. Between crossed nicols anomalous double refraction may be seen, or in clear stones, complete extinction. 12 illus. 2 tables.

R.W.

BOOK REVIEWS

LANG (H.). *Das kleine Buch der Edelsteine.* Little book on precious stones. Coloured pictures by H. Lang, comments by F. Schnack. List of tables, 40 pp. Insel-Book No. 54. Published by Inselverlag, Leipzig, Germany.

The booklet consists essentially of 24 handsomely executed coloured tables, with a carefully prepared descriptive list of the depicted individual precious stones in the rough and cut. Ten pages commenting on the magic and the power of precious stones are hardly of interest to the gemmologist but may appeal to the romantic lover of folk-lore and the student of superstitions.

E.S.

GÜBELIN (E. J.). *Inclusions as a means of gemstone identification.* pp. 220. 258 illustrations with coloured frontispiece. Gemological Institute of America. Los Angeles, Calif. Dollars 6.75.

The many varied patterns, often so beautiful, seen in the interior of gemstones through the magnifying eye of the microscope, have always been a source of wonder to the gemmologist. That these patterns tell more than just that the stone is either natural, synthetic, or just a glass, has long been known in a scrappy sort of way : scrappy that is, because those workers who have interested themselves in such studies have published them in divers journals, and no full correlation has been made.

Dr. Gübelin, in " Inclusions as a means of gemstone identification " has in one volume told the major part of the story. A story mainly of his own observations, his own painstaking work which he clearly has enjoyed doing. The result is a book the like of which there is none other.

In his introduction, the author mentions and honours the workers who have gone over some of the ground before him, like Michel who at one time was his tutor. The importance of these inclusions in minerals as indication of the condition of the surrounding magma at the time of the host minerals formation is stressed. The value of the modern gemmological microscope with ordinary or dark ground illumination is discussed and also what is meant by the term " inclusion." The time of formation of the inclusions in relation to the host are explained when pre-existing ; contemporary and post-formed inclusions are discussed.

" Solid inclusions " are discussed in the first chapter. The various types of such inclusions are given and also is the method of identifying them. The next chapter is given over to " Liquid and gaseous inclusions " which include not only liquid-filled cavities but also the gas bubbles seen in synthetic stones and pastes. The difference in relief shown by these two types of inclusions are explained. Cracks, fissures and such growth phenomena as twinning and zoning complete the series on inclusion types.

The chapter on inclusions seen in synthetic stones is most complete. An interesting feature is the illustration—by line drawing—of the cause of the larger bright centre seen in bubbles in paste than seen in the case of bubbles in synthetic stones. Mention is made of a synthetic star corundum in which the star is produced by ruling fine lines on the base of the cabochon and then backing with foil. The following two chapters discuss the reconstructed ruby ; inclusions in glass and in doublets. The reviewer takes exception to the comment that goldstone is glass in which copper crystals or filings have been added in large quantities. The real fact is that copper is not added, but copper compounds are incorporated in the melt which subsequently crystallize as triangular (or hexagonal) platy crystals in the glass.

The following several chapters deal with the inclusions seen in diamond, in which the controversy of its genesis is commented upon. The inclusions in ruby are discussed from the angle of the different types seen in stones from such localities as Burma, Siam and Ceylon. Sapphire is similarly treated, stones from Cashmere, Ceylon, Burma, Siam and Montana are discussed. It is noted that Australian sapphires are omitted.

A very full exposition is given of the inclusions seen in natural emerald, with particular attention to the stones from the major localities : Colombia, Brazil, Russia, India and South Africa. The synthetic emerald having been fully dealt with in the chapter on synthetics. Discussion of the inclusions seen in aquamarine ; the garnets ; topaz ; tourmaline ; quartz ; peridot ; moonstone ; andalusite ; kyanite ; zircon and fluorspar complete the species covered. The final chapter gives the author's concluding remarks.

Such a subject would be lost if in script only and without some pictorial representation. The reader is treated to over 250 of Dr. Gübelin's incomparable photomicrographs, which alone are worth the price of the book.

There are very few errors in the printing, which is in an exceptionally clear fount. The illustrations appear to have been printed slightly too heavily and have masked the fine detail of some of the photographs. Incidentally, the picture of crystals of Ceylon sapphire (Fig. 19) on page 134 has crept in again as " emerald inclusions " (Fig. 5) page 148 ; and Figures 3 and 4 seem to have been transposed. The paper used is of a durable nature, but it is considered that the use of an art paper and half-tones might well have reproduced the pictures better. The book has no index (there is, of course, a table of contents at the beginning), the volume being concluded with an extremely comprehensive bibliography.

No discerning gemmologist can afford to be without a copy of this important work. R.W.

CHUDOBA (K. F.) and GÜBELIN (E. J.). *Schmuck- und edelsteinkundliches Taschenbuch.* (Gemmological Pocket Book.) Published by Bonner Universitaets-Buchdruckerei, Gebr. Scheur G.m.b.H. Germany 1953. 158 pp., 150 illustr., 27 tables, 2 colour plates.

This well-produced publication by two outstanding gemmologists corresponds largely to Webster's " Gemmologists' Compendium " and like it will be an invaluable help to gemmologists, jewellers, goldsmiths, collectors and those dealers and cutters who have more than a commercial interest in precious stones. The " glossary " is sub-divided in several respects. The glossary proper is preceded by two alphabetical lists of the names of gems and gem materials, with clear indications of internationally and nationally permissible denominations. The most important materials are marked in heavy type. The etymological derivations are given in most instances thus adding to interest and understanding. The second name-list groups the gem families together and confronts usual, correct and wrong designations. Four appendices to the glossary deal with styles of gem cutting, formation cycles of gem materials, geological terminology, and occurrence of the economically important precious stones. These sub-divisions, though no doubt increasing the clarity of presentation, can be irritating to the casual user of the " pocket book," because, for instance, he will not find the occurance of Diamond under " D " in the glossary, but only in the fourth appendix to it. The remarks introducing the tables in the section on " constants and data " are masterly, short and precise. Under the optical properties twenty-seven

diagrams of absorption spectra are given, paying tribute to the work of British gemmologists under B. W. Anderson. Two tables list precious stones which display fluorescence and those which do not respond under ultra-violet light (over 2000 Å). Diamond, for instance, is listed in both tables. The first table seems to suggest, that there is a connection between the colour of diamond in ordinary light and that displayed in fluorescence and phosphorescence. No such connection could be established in tests made in this country. An important section of the pocket book deals on 24 pages with inclusions, roughly half of this section being devoted to general considerations, the rest to diagnostical characteristics of individual species. The text together with 124 excellent photomicrographs in a separate appendix forms a concise and most valuable entity which is far more than a mere introduction into the exciting art of determining precious stones by the fingerprints of nature.

A summary of relevant physical properties of the most important gem materials is given in three tables. The first table, a most useful arrangement, corresponds roughly to the summary in Kraus and Slawson's " Gems and Gem Materials." The two other tables list the stones in colour groups with their density and Mohs hardness values. A small chapter describes Schlossmacher's precious stone microscope, a horizontally arranged polarizing microscope allowing rotation of the stone under observation in a liquid containing cell. Surprisingly, reference to the dispersion of gemstones has been omitted and it is also regrettable that the authors have given so much space to obsolete misleading names of gems.

Very interesting graphs showing the spread of colour, density and refractive indices in the individual species conclude the pocket book. The colour plates are excellently executed.

Any book relying mainly on tables to present its information suffers necessarily from inherent disadvantages. Apart from this reservation, however, the publication is extremely clear and useful and will soon be one of the most important and handy aids for the German speaking practical gemmologist.

W.S.

GEM MINERALS of the BRITISH ISLES

by Nigel W. Kennedy

BRITAIN is not and never has been a producer of gemstones in any large quantity or of high value commercially, nor is there any indication that the United Kingdom will make any really significant contribution to the gem markets of the world. In spite of this it is not generally realized that many representatives of gem species in many colour varieties are to be found in Britain.

Most text books which go so far as to mention the presence of gem material give a strong impression that it is of inferior grade or microscopic size, of interest only to the student of geology or mineralogy.

By a dispensation of Providence, which has resulted in the accumulation of a very complete sequence of geological formations between John o' Groats and Land's End, Britian is actually a rich hunting ground for the mineralogist, and strong evidence has been advanced that the rocks of which part of the Hebrides are formed were a part of the original crust of the earth, dating back possibly some two thousand million years ago. In view of this it is not so surprising that such a variety of minerals is to be found in so small an area, but what may surprise most of us is the fact that many gem minerals previously believed only to exist in minute form and dismal tones, are now known to occur in gem quality of cuttable size and often of fine colour.

Unfortunately no concise record of the occurrence of gem material in the British Isles as a whole, and particularly of the region covered by England, Wales, and Ireland, appears to have been written up to the present time, probably because comparatively few geologists have been sufficiently interested in gemstones. This is not so in the case of Scotland, where the Scottish Geological Survey seems to have taken the trouble to indicate the occurrence of gem material on many of their maps.

The reason for this, as will shortly be seen, is probably that Scotland as a whole is more prolific in gem material than the other countries in the Union. Of course many articles on gemstones have been published in the literature of various scientific organizations from time to time, but an enormous amount of research would be required to trace and correlate them into a single account.

In the case of Scotland, at least three competent authorities have been inspired to write detailed accounts of the occurrence of gem minerals, and the subject has been very ably dealt with by Heddle in " Mineralogy of Scotland," 2 vols. (1901) ; Smith, in " Semi-precious Stones of Carrick " (1910) ; and more recently by MacCallien in his " Scottish Gem Stones " (1937), and it seems likely that these will be followed by other equally interesting works.

I felt rather handicapped owing to this lack of data on gem minerals other than Scottish, and have tried to fill the gap by a careful inspection of the splendid collections on view at South Kensington. My notes must be necessarily incomplete as, while I have been able to examine the whole collection in the Geological Survey Museum, only about half of its collection is as yet displayed in the Natural History Museum, but even as it stands, the list I have been able to compile is a very interesting one and includes many unusual minerals.

Perhaps at this point I should recall that gem material may be classified according to two entirely different modes of origin, namely those which are purely mineral, and form the greater portion, and those produced by the agency of living matter, animal and vegetable. Both may be modified or completely changed in composition, form and properties, the fresh re-arrangement being due to the effect of pressure and heat, usually in the presence of water ; that is, by dynamic and hydro-thermal metamorphism. Intrusion of molten mineral material in each case also alters the nature of the rocks in immediate contact with the intrusion, resulting in the production of many new minerals often of gemmological value and interest.

Organic Materials

Since the number of *organic* minerals and other material used as gems, is relatively small, we can dispose of this section before proceeding to the more detailed discussion of gem minerals.

In the organic section we include pearls, corals, incised shells, mother-of-pearl, polished sections of calcitized ammonites and belemnites, fossil bones and teeth, fossil sponges, petrified (silicified, jasperized, and opalized) wood and bone, as well as amber, jet, and surely, bog-oak. We should also remember the many beautiful marbles quarried in many parts of the United Kingdom, including

White from Antrim ; Purbeck Marbles ; Coralline Marbles from Ludlow ; Oölitic Limestones from Bristol ; as well as shelly, ammonite, and crinoidal limestones from many other localities. British Marbles are found in an astonishing variety of colours—white, cream, yellow, grey, pink, greenish, brown, and black and compare favourably with any foreign marbles, as may be verified by anyone who visits the Geological Survey Museum.

British waters are no longer warm enough for either the pearl oyster or coral polyp, although some corals are found in the south, but the quite lovely Fresh Water Pearl secreted by the mussel, which still persists in some of our rivers and lakes, in spite of pollution, may be found in Western Scotland, North-west England, North Wales and Ireland.

Amber is still washed up on the East Coast, particularly after storms, and is of course, the resinous secretion of coniferous trees which in bygone days flourished in the forests of the wide Rhine Valley which owing to depression of the continental shelf is now inundated by the waters of the voracious North Sea. The fossilized teeth of sharks and wolves, and other creatures were used by our pre-historic predecessors as gemstones and are often found in burial sites. In medieval times they were frequently mounted as charms and amulets and worn in rings to ward off the Evil Eye, not as *teeth*, but in the belief (real or simulated) that they were gems secreted in the brains of reptiles, and known variously as " Toad Stones " and " Lizard Stones " and referred to as such by Shakespeare. Several examples of such rings are displayed in the jewellery section of the Victoria and Albert Museum. Belemnites are slender pointed cylindrical objects also sometimes polished and worn as charms from an early age, in the belief that they were darts or thunderbolts dropped by mythical beings during thunderstorms, and believed to be endowed with occult powers. They are really the casts of the bony guard, or pragmacone, and ink-bag of the cuttle-fish (or sepia, squid or octopus) which at one time inhabited the waters of former seas that covered Britain.

Ammonites are species of shell-fish of the nautilus family, that is, coiled in a flat spiral like the horns of Ammon, or of a ram, and are found in large quantities in some limestone formations. Ancestors of present species have left their casts in some limestones bearing their name, in which calcite and quartz have sometimes crystallized in these shells, which when cut and polished form

interesting mineral discs which when small enough were sometimes used as jewellery in Victorian times.

Jet, the precise origin of which is still a matter of conjecture, has been esteemed as an article of jewellery in Britain since prehistoric days, and beads and other artefacts in jet are found in many burial sites throughout the United Kingdom. Whitby has long been the centre of the Jet industry, which in Victorian days was very prosperous, but the discovery of ebonite, which may simulate jet closely, enabled the mass production of spurious moulded and cut trinkets and other objects to flood the market. During the recent War the industry revived somewhat owing to a demand from Americans in Britain, but now few persons are actually engaged in this craft.

The above seems to cover the organic minerals found in Britain and fabricated as gemstones, and we are now free to review the features of the inorganic minerals of gemmological interest which also occur here.

MINERALS

The gem minerals differ from each other very considerably, not merely by reason of variation in composition, but also owing to their very different circumstances of origin. Probably most gemstones are either primary accessory minerals, that is, were evolved during the formation of the granitic rock in which they are found associated with much larger proportions of the essential mineral constituents, or as secondary minerals in sedimentary and other formations penetrated by igneous intrusions, or were formed by the slow percolation of saturated mineral waters or gases.

For example, when molten material is intruded into limestone, it is converted into crystalline *marble* (Calcite or Dolomite) and in the presence of clays and other minerals, a re-arrangement takes place and *contact* minerals of an entirely different kind are produced in the area of metamorphism surrounding the intrusion. These include Corundum, Garnet, Spinel, Idocrase, Kyanite, Staurolite, Cordierite, Andalusite, Chiastolite and others. Minerals such as Azurite and Malachite, Barytes, and Blue John (Fluorite) which are stalagmitic in form, are of course, the result of percolation of saturated mineral solutions.

After reading " Scottish Gem Stones " one might expect that the rest of Britain would be equally rich in gem material, but this is not the case, and a study of a geological map of the British Isles

helps to explain why. It is seen that while Scotland consists almost entirely of ancient formations exposed at the surface, and extensively folded and intruded by igneous masses, and was the scene of most violent volcanic activity in past ages, we find that except for the north-west, Wales, and south-west, the remainder of Britain is covered by later formations which are only penetrated in a few isolated areas by ingeous intrusions, as at The Wrekin, in Shropshire, or Charnwood Forest, Leicestershire. Hence any minerals which may have been formed in the older rocks are likely to be buried beneath thousands of feet of later accumulations.

SCOTLAND.

Intense folding, like that which runs diagonally from N.E. to S.W. of Scotland, producing parallel mountain ranges and long narrow lochs and fiords, such as Loch Ness, are conducive to the formation of stress minerals like Garnet, Kyanite, Staurolite, Cordierite, which are alteration products, as are the gneisses in which they arise. These minerals are in fact found in quantity, but not always in gem quality; for example Cordierite is anything but perfect as found.

No doubt the most famous gemstones of Scottish origin are those of the quartz family, particularly from the Cairn Gorm area of the Grampians, namely, Rock Crystal (found all over Scotland), brown quartz, or Cairngorm, Citrine, Smoky Quartz or Morion, and Amethyst, which at one time were to be picked up easily on the hillsides. Formerly Scottish gems were obtainable at quite low cost, mined and cut in Scotland, but during the War American troops became more familiar with these stones whose beauty appealed to them so much that supplies appear to have been dried up, and the cost has soared.

Sections cut from many Scottish rocks show the presence of many interesting gem minerals, such as Olivine, Sphene, Enstatite, which give their names to rock types, but they are usually of small dimensions unsuitable for cutting. Many of them have, however, been found of cuttable size.

A few visits to our local museums will reveal the fact that British minerals are to be found in an astonishing variety of lovely stones in many colour variations and forms, comparable with anything from abroad ; some indeed possess an almost incredible loveliness of form and colour. Among such minerals one might

mention Goëthite its truly amazing variations in form, texture, colour and lustre ; Azurite and Violane of exquisite deep blue ; and purple Riebeckite. Yet although we are so fortunate as to have such a galaxy of magnificent specimens at hand to study, it is clear from such writers as Heddle, that these celebrated collections have in most cases still to be enriched by unusual colour varieties of relatively common minerals from Scotland, in shades one has never imagined.

For example blue Quartz, and really red Quartz, and even green Quartz ; and red and yellow Prehnite, as well as the elusive green Topaz of which no one seems to have a cut specimen.

IRELAND

There seems to be even less information available in literature in relation to the occurrence of gem minerals in Ireland, yet, the few specimens to be seen in our museums at South Kensington indicate that Ireland could contribute her quota of beautiful minerals but so far I have not had any opportunity to visit any Irish museums.

Probably the best known examples come from the Mourne mountains of County Down, where blue and green Beryl, and blue Topaz are found in the local granite, and similar crystals also come from County Donegal. Colourless Analsime and Kyanite are found in the Giant's Causeway, at Antrim, while brown Idocrase is found in County Donegal. Ireland also produces the well-known " Sceptre " crystals of quartz (rock crystal) which are found near Dublin, and some of the most beautiful marbles, in many shades, are quarried in many parts of the country. Bog-oak, which may be included as a gem material if jet is admitted, is produced in many parts of Ireland and fashioned into many cunning little trinkets, often beautifully carved. Fresh water pearls are still to be found in the mussel shells in many Irish rivers, and I have a fine specimen in pink, white and pale blue, which was recently found near Dublin.

WALES

This principality is certainly the richest source of native Gold in Britain, and in addition, quite a number of gem minerals are found there, probably more than have actually been recorded.

ENGLAND

A glance at a summary of minerals from English localities tells us that they may be roughly divided into two main areas, namely,

Cumberland, Durham, Westmorland, with North Lancashire and Yorkshire as one, and Devon and Cornwall as the other : few gem minerals are found in most other localities, in which, however, many delightful ornamental and building stones abound in many shades of colour.

A complete list of English gem minerals would probably show that most of them occur in Devon and Cornwall. Turquoise is not a mineral that one would expect to find in England, but it has definitely been located by Sir Arthur Russell in a vein near St. Austell recently. It is interesting that both Rhodonite and Rhodochrösite, as well as Phenakite, are found in the Duchy, and our London museums contain many lovely specimens of unusual minerals from this area which are or could be cut as gemstones, and whose colour and lustre are of a high order. Cassiterite is of course relatively common as a mineral but gem quality is very rare and cut specimens quite exceptional.

I am sure that a question that most of us would like to be answered is not merely what gem minerals have so far been located in the British Isles, but also where are they situated, and in what quantity and grade, and what is the possibility of tapping such resources as may be present ? Unfortunately I am not yet able to answer these queries, but I do sincerely trust that the day is not far distant when more information of a practical nature will be available.

In America where anything which takes on with the public does so with great enthusiasm, I am informed that the energetic Rock Hounds now number over three million, and it is clear that through their activities many new localities have been discovered in which beautiful and often new minerals are found. If they are controlled and guided by experts in their perambulations this should be a good thing, and I should like to see it followed here, but otherwise great crowds of people armed with picks and hammers may do untold damage and ruin valuable and interesting specimens which should be placed in museums for all to see.

I have been able to see several collections in Scotland recently and hope to do some considerable research there in the hope of unearthing many of the specimens described by Heddle in his amazing monograph of 1900. Unfortunately interesting specimens are not always clearly labelled in museums and it is therefore

difficult to trace many minerals. Also, some collections are still in a state of flux owing to taking over new galleries, but I have seen enough to believe that Heddle and other writers were justified in their descriptions of Scottish minerals, and I have made a short summary of the gem minerals included in his list.

Space does not permit more than brief references to some of the outstanding examples of gem minerals described by Heddle, and which excite one's imagination with anticipation, but I will quote a few :—

QUARTZ

" *Hyaline Quartz.*" A variety of Cairngorm, of a claret colour, but surpassing it in brilliancy, colour and pelucidity." Occurrence, Ben Lawers, Perthshire ; Lock Eck, Argyll.

Amethyst. " Occurs in Inverness in crystals usually capped, being alternately purple and colourless." Amethyst, with *red* quartz found at Scurdy Ness, Fifeshire. Amethyst associated with *blue* Barytes at Kintel, Forfar, etc.

He mentions that crystalline varieties of quartz occur in various colour varieties, as well as Rock Crystal with a general distribution, and cites Rose (Pink) Quartz (which is most unusual as a crystal), Scarlet, Red, Dark Red, Yellow, Brown-red and Purple Quartz, and also speaks of massive Quartz in blue, yellow, rose, yellowish-green, and green.

CHALCEDONY

Occurs in many forms all over Scotland, and includes Prase (leek-green), Blood stone, Cornelian (red, and yellowish) and Blue Chalcedony.

AGATES

There is a large collection of Scottish Agates in the Royal Scottish Museum at Edinburgh, in which many hundreds of specimens are exhibited in groups from respective areas, and it is clear that in many cases they form definite locality types by which many could be identified. They are usually very beautiful and some possess the most amazing groups of colour bands ; which make them worthy of comparison with the finest artificially-coloured stones from Idar-Oberstein. Here is a description of several which should excuse my enthusiasm :—

Blue, from Luthrie, Heather Hill, et cetera. Brilliant ink-blue and white, and wax yellow, from Blue Hole, Usan. Lilac, flesh-red, rose, grey, with blue chalcedony, often with layers of

Girasol opal, found at Agate Knowe, Perthshire. Dark blue, brown, black, white, grey and lavender, with violet chalcedony, cornelian, and vermilion jasper, from Midlothian. The most beautiful Scottish Agates are stated to occur at Agate Knowe, Tinkle Top, Perthshire.

OTHER MINERALS

As a gemmologist possibly I should not associate any particular colour with any specific mineral of gem interest, but I certainly had some rather fixed conceptions regarding some mineral species. For example, Kyanite and Prehnite, the former being named after its predominant blue colour, sometimes it is true, rather blue-green, but Heddle states that " Scottish Kyanite may be green, red, yellow, or colourless, most usually blue, and is found in association with Tourmaline at Unst, Shetland, and with Garnet at Glen Clovas, Forfarshire. Prehnite I have always thought of as a dirty-greenish mineral occurring rather sparingly in some lavas as a secondary zeolitic mineral, but Heddle writes of it as being found in white, dark green, pale green, brown, bright yellow, orange, and sometimes pink, as at Edinburgh. Likewise I had not realized that pink Fluorite was found to any extent outside Switzerland and France, yet apparently it is relatively common in occurrence in Scotland.

Microcline is another " surprise " mineral and is most familiar to us as a blue-green mineral found at Pike's Peak, Colorado.

In his description of this mineral Heddle scarcely mentions the occurrence of green or blue-green, but he has located red and brick-red Microcline at Cape Wrath and Shetlands respectively, and brown in the Hebrides, with purple at Tiree ; grey to cherry-red occurs in Nairnshire, and white to blue in Harris, blue also occurring (with Garnet, Tourmaline, Beryl and Orthoclase) at Struy Bridge, Ross.

Garnet. This seems to be very abundant, and has been found in fine gem quality, Pyrope having been worked as " Elie Ruby " at Elie Ness, Fife. Almandine occurs in many places, as well as Hessonite and Grossular, and an interesting reference is made to " Water Garnet," a colourless variety found in Aberdeen and Banff.

Beryl is found in blue, yellow, white and nearly colourless, and in Banffshire is usually banded in pink, white, green and colourless.

Topaz. In Aberdeenshire this mineral occurs in pale blue, red-brown, amber, and green, in crystals sometimes a pound in weight, and in banded crystals of many colours. Colourless Topaz also found in Bute and Argyll, sometimes honey-yellow.

Corundum is recorded by Heddle as occurring in pale and dark blue *asteriated* small crystals at Clova, Aberdeen.

Tourmaline he also mentions as being found in indigo-blue and brownish green at Kirkcudbright as well as black at Ross, and among other gem stones found in Scotland he records " perfectly transparent ruby red Zircon crystals from Ben Hope " as well as colourless from Ross ; yellow-brown from Fife ; pink from the Hebrides, and blue-black from Inverness. He also remarks that " Large numbers of fine spinel crystals were collected by Teall and presented to Edinburgh Museum."

In addition to the foregoing gem minerals Heddle also alludes to the occurrence of Nephrite, pale green stones, in Shetland, the Hebrides, and Banff and other places. Staurolite is stated to occur in orange-yellow crystals " as large as in Brittany " in Inverness, while Enstatite occurs at Banff " In large lustrous pale green crystals." Sphene of yellow colour associated with Fluorite, and Datolite with green Prehnite, Scapolite (Wehnerite) and Idocrase are also recorded.

This gives some conception of the gem mineral interest of the Scottish area, but it is one thing to know that something exists, and quite another matter to locate it and determine in what quantity and quality it occurs, and its general availability.

Since commencing my investigations I have been able to pay several visits to Scotland and have located many of the museum specimens referred to above, and indeed have handled some of them by courtesy of the museum authorities, but owing to the usual changes of staff and in display of specimens, I have not succeeded in tracing many interesting stones. The several museums in Scotland amply repay a visit, and the staffs are very helpful and interested in genuine students. The Royal Scottish Museum, Edinburgh, houses a very fine selection of Scottish and other gem minerals, including many cut stones, and its collection of Scottish Agates from various localities, consisting of many hundreds of polished stones, gives some idea of their beauty and variety, and it is clear that local differences sometimes provide a clue to identity, the collections being conveniently arranged in batches from definite

areas. It is a very lovely display.

Some of the gem minerals of Scotland are of very ancient formation, and time and the effect of dynamic metamorphism have in many instances altered the type of mineral, so that some are crushed and contorted beyond recognition and useless as gems. It is of interest, however, that they do occur, for in other places they may have been preserved for us. Corundum was recorded by Heddle in 1901, but since then it has been confirmed at Ardnamurchan Point, and on the Ross of Mull, by MacCallien, who states that blue crystals occur at Carsdig Bay, some over half-inch across, and deep blue crystals 2-3 mm. are found at Glebe Hill. I have handled these—about 2 cubic inches of them, and found them to be a lovely deep violet-blue. The occurrence appears to resemble that of Kashmir and Burma, where dykes penetrate limestone.

There is surprisingly little information as to activity in the working of gems in Scotland, and I was only able to learn that at present only one craftsman is actually engaged in cutting even in Edinburgh, where there is a constant demand for Scottish Gemstones (mainly cairngorms) by tourists. A shop in Oban has a good display of mounted stones, which from their general appearance seem to be genuine Scottish stones, slightly cloudy. The same shop has trinkets made from Iona Stone, guaranteed to be produced at that place, and I was informed that a lapidary still carries on at Arran, where Topaz, Beryl and other stones are sometimes found. I was told that during the recent War Mica was mined in a remote place in the West of Scotland, and that large crystals of Beryl had been discovered there, but no one had been interested between 1940-46. My informant was hoping to visit the locality this summer and to find beryls 12″ long, and according to him the quarry is situated some 2,000 feet up a remote mountain. The spot cannot be reached by road or rail, and it is only possible to take a bi-weekly steamer, or charter a private motorboat, and a week's stay is unavoidable. Few people realize that some spots in Scotland are very inaccessible owing to intervening mountain ranges, and that, for example, the Mull of Galloway is about 75 miles from the nearest railway station at Oban. Roads are good in most places, but in others local traffic does not justify them, and the gradients are often high, so that sea transport is usual in such cases. This has doubtless much in connection with lack of precise data on occurrence of gem and other minerals in Scotland.

Another important feature has to be constantly born in mind, and that is the psychology of salesmanship in relation to gemstones. In Cornwall, and many other places, gemstones are known to occur on the beaches and other places, tourists find odd stones and take them to local " lapidaries " and are told that the stones can be polished for them in a few weeks. In due course the mounted stones are received and in an attractive form, but in actual fact the originals may have been worthless and uncuttable—but what finder is prepared to believe it ? There was a constant trade in such goods between Idar-Oberstein and Cornwall and Scotland before the War, and this may be revived in due course. In Victorian days Elie Ness, Fifeshire, was the centre where " Elie Rubies " were found and became very popular. They are quite pretty Pyropes, and entered into the making of Scottish jewellery, but I cannot discover as yet whether there is now any trade in this stone.

I am still carrying on my researches into the question of gem resources of the British Isles and hope in due course to prove that under present conditions we have sufficient material to provide tourists and others with interesting specimens of British Gemstones at a remunerative rate. The general information that I have so far been able to collect on the subject seems to indicate that I am not wasting my time, and I trust that my gemmological and mineralogical colleagues will find similar interest in this record.

LOCATION OF GEMSTONE MINERALS

APPENDIX

The following is not a complete list of all gem minerals discovered in Britain, and those mentioned are in many instances found in other localities, but the purpose of this list is to indicate the great variety and wide distribution of the minerals included.

SCOTLAND

Beryl	Colourless, yellow, green, blue	Banff, Montrose, Arran, &c.
Corundum	Deep blue, and asterias	Mull
Garnet	Colourless, Almandine, Pyrope, Hessonite, Grossular	Banff, Montrose, &c.
Heulandite	Red	Dumbarton
Jasper	Red, orange, mottled	Montrose, &c.
Kyanite	Colourless, red yellow, green and blue	Eigg, Unst, Forfar, &c.
Idocrase	Brown	Banff
Opal	Girasol	Argyll
Piedmontite	Red	Glencoe

SCOTLAND (*continued*)

Prehnite	Green, red, yellow	Dumbarton, Edinburgh, &c.
Quartz	Rock Crystal, red, citrine, green, Amethyst, blue, Morion, Cairngorm Rose and Milky, and asteriated	Wide spread occurrence
Topaz	Colourless, blue, red, yellow, green	Banff, &c.
Tourmaline	Black, indigo-blue, pink, &c.	Ross, Kirkcudbright, &c.
Zircon	Red, colourless, red-brown, pink and black	In many areas
Agates	Chalcedony (black, grey, blue, brown, yellow) Mochas	Many places

Serpentine, Nephrite, Apatite, Andalusite, Sillimanite, Staurolite, Spinel, Cordierite, Sphene, Scapolite, Epidote, Enstatite, Olivine, Microcline, Obsidian.

IRELAND

Idocrase, Analcime, Obsidian and Kyanite, are found at the Giant's Causeway, Antrim ; Blue Topaz, and Blue Beryl, located in the Mourne Mountains, County Down ; Green Beryl, County Donegal. Rock Crystal from County Down; Gold—County Wicklow ; Irish Marbles of great beauty are quarried at Galway, County Down, County Kilkenny, &c. Fresh water Pearls are still found in river mussels.

Isle of Man : Agates, Cornelian and Onyx from Peel.

WALES

Yellow Fluorite and Yellow Calcite obtained in Flint, also Blende ; Brookite from Tremadoc ; Marcasite occurs at Cardigan, and Milky Quartz on Snowdon. Gold has been mined in Cardigan, Caernarvon, Flint and Merioneth.

ENGLAND.

Cumberland : Yellow and Green—Carrock Fell ; Barytes, Rich yellow, Frizington, Blue, Mowbray Mine ; Calcite, Green—Alston Moor ; Purple—Patterdale. Scheelite—Carrock Fell ; Smithsonite, Alston Moor ; Fluorite—Various colour varieties ; Blende, Haematite, Pyrites, Gold (Keswick), Smoky Quartz, &c.

Durham : Calcite and Fluorite in various colours.

Westmorland : Fluorite found in many colour varieties, also Grossular Garnet. Fresh water pearls in Derwentwater.

Cornwall : Apatite, Axinite, Goëthite, and Rhodonite, &c., from St. Just. Azurite, Olivenite, Phenakite, Malachite from Redruth ; Epidote, Serpentine, and Datolite from The Lizard ; Epidote and Chrysocolla, Pink and Black Tourmaline from Luxulian. Turquoise from St. Austell, and Rhodochrösite from Wheel Coates St. Agnes. Rock Crystal, Blende, Cassiterite, Rutile, Haematite, Barytes, Grossular Garnet are found in various localities, and Gold in some.

Devonshire : Blue Apatite and Tourmaline come from Bovey Tracey ; Colophone (Garnet) from Okehampton, and Scheelite from Marytavey, while Axinite and other minerals, including Gold ore, have been found in other places.

Derbyshire : The most famous mineral from this area is of course Blue John, a stalagmite variety of purple Fluorite, found at Castleton, and Satin Spar

(Gypsum, or Alabaster) and Heavy Spar, stalagmitic, are also occurrent in this country.

Extract from list of Minerals occurring in Scotland, according to Heddle.

ORES.

Gold	Cassiterite	Haematite	Pyrites
Blende	Marcasite	Magnetite	Rutile
Chromite			

GEM MINERALS, &c.

Acmite	Analcime	Andalusite	Apatite
Axinite	Azurite	Aventurine	Apophyllite
Agates	Barytes	Beryl	Chalcedony
Chrysocolla	Corundum (Sapphire)	Datolite	Delessite
Diamond (?)	Epidote	Enstatite	Fluorite
Forsterite (Olivine)	Fibrolite	Garnet (Various)	Goëthite
Heulandite	Iölite (Dichröite	Kyanite (Disthene)	(*Linarite*)
Labradorite	Cordierite)	Malachite	Microcline
Orthoclase	Opal	Oligoclase	Nephrite
Prehnite	Quartz	(*Riebeckite*)	Rhodonite (?)
Sodalite	Sphene	Spodumene	Scapolite
Staurolite	Sillimanite	Spinel	(Wernerite)
Serpentine	Thompsonite	Tourmaline	(*Vivianite*)
Topaz	Zircon	Zöisite	Mochas
Girasol	Crocidolite	Jasper	
Amber	Jet	Fresh water pearls.	

Other Minerals occurring in Britain

Obsidian is found in the Giant's Causeway according to Hatch. Brookite has been located at Tremadoc, North Wales, while rich yellow crystals of Barytes come from Frizington Mine, Cumberland. Analcime is also found at the Giant's Causeway. Yellowish, Green and Purple Calcite are found in Derbyshire, Cumberland and at Patterdale, respectively. The rocks of St. Just and Redruth, Cornwall, are rich in many unusual minerals as well as ores, and amongst these we find Azurite, Axinite, Cassiterite, Blende, coloured varieties of Fluor, dark green Goëthite, Olivenite, Phenakite, blue Chalcedony, Turquoise, Vivianite, Rubellite and others. Idocrase and Kyanite as well as blue Beryl, and Topaz, are also found in good form and quality at times, in Ireland.

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Semi-precious Stones of Carrick. James Smith. (Dalry, 1910).
Scottish Gemstones. W. T. MacCallien (Glasgow, 1937).
Petrology for Students. Harker.
Introduction to Petrology. Hatch.
Catalogue of Gemstone Collection. Geological Survey Museum, S. Kensington.
Guide to Mineral Gallery. Natural History Museum, S. Kensington.
Mineralogy. Rutley.
Geological Maps of the Ordnance Survey.

ASSOCIATION NOTICES

GEMMOLOGICAL ASSOCIATION OF AUSTRALIA

The following are the Members who have qualified for Fellowship in the 1952 Examinations.

The first three positions in Australia were filled by :—

1. I. L. Thomas (Victorian Branch)
2. R. Dove (New South Wales Branch)
3. S. E. Terrill (West Australian Branch)
   R. H. Hocking (New South Wales Branch)

The best student in each State was :—

New South Wales	*Victoria*	*Western Australia*
R. Dove	I. L. Thomas	S. E. Terrill

South Australia	*Queensland*
O. J. Cowlishaw	W. J. R. Frost

The Australian Prize has been awarded to I. L. Thomas of Victoria, and the Stevenson Award for the South Australia student to W. J. R. Frost.

The complete results are as follows :—

Out of 62 candidates who sat for the examination, 46 qualified.

	NEW SOUTH WALES	
I. P. J. Bloom.	Dolores Johnson.	K. Ramsden.
R. Dove.	K. J. Mansergh.	J. L. Shaw.
G. Freiberg.	H. G. Milham.	Livia Viola.
R. H. Hocking.	Julia Myers.	
	VICTORIA	
W. Bennett.	H. Crawcour.	B. Schillmoller.
B. Bowles.	J. R. Holdsworth.	I. L. Thomas.
W. Brown.	P. G. Hoskings.	K. P. Vanderkelen.
K. Chiffins.	C. Manning.	M. Walker.
D. Cook.	D. O. McRae.	
	QUEENSLAND	
O. J. Cowlishaw.	W. R. G. Knowles.	D. A. Robinson.
K. Halliday.	W. von Ploennies.	O. R. C. Runge.
	SOUTH AUSTRALIA	
I. P. Campbell.	G. T. Chambers.	W. J. R. Frost.
	WESTERN AUSTRALIA	
C. Brown.	R. Harper.	M. Pound.
I. R. Campbell.	L. C. Hedge.	S. E. Terrill.
R. Campbell.	A. V. Kerr.	Lindsay Wilson.
E. Dunkerton.	R. Levinson.	John D. Wyatt.

BRANCH MEETINGS

East of Scotland

A meeting of the East of Scotland Branch of the Association was held on Wednesday, 28th January, 1953, at the Heriot Watt College, Edinburgh. Mr. David L. Meek presided. The principal speaker of the evening was Professor W. H. J. Childs, Ph.D., D.Sc., F.Inst.P., F.R.C.E., whose subject was "Physics of Colour." Guests of the Association at the meeting, and at an informal dinner later, included Mr. Ian Reid, President of the Edinburgh and East of Scotland Goldsmiths' Association and Mr. S. Wood, Honorary Secretary of the West of Scotland Branch.

West of Scotland Branch

A meeting of the Branch was held on February 5th at the Y.M.C.A. Club.

The speaker for the evening was Mr. J. M. B. McWilliam, F.G.A., who opened a discussion on the Valuation of Jewellery.

Mr. McWilliam gave an outline of his methods in dealing with valuations and then invited questions and discussion. Later he gave a demonstration in the use of the American Leveridge Gauge.

COUNCIL MEETING

A meeting of the Council was held at 19/25 Gutter Lane, London, E.C.2, on Wednesday, 4th February, 1953, at 4.30 p.m. Mr. F. H. Knowles-Brown (Chairman) presided.

The Honorary Treasurer submitted the audited accounts for the year ended 31st December, 1952, which were approved for presentation to the twenty-third annual general meeting to be held on 1st April at Goldsmiths' Hall. The Council gave consideration to the future finances of the Association and decided that, with effect from 1st January, 1954, the Fellowship subscription, which had remained unchanged since 1947 in spite of increased costs of postage, stationery and the publication of the Journal, should be thirty shillings a year. Even at the new rate the subscription payable will be much lower than that asked by associations of comparable status. The rate of subscription could well be levied at two guineas, but the Council considered that this would be imposing too heavy a burden upon the younger members of the Association. It was further decided that Probationary Membership should be limited to persons under twenty-five years of age (for the previous maximum period of three years) and that the future annual subscription should be fifteen shillings. A small increase in the cost of the correspondence courses was also authorised.

The following were elected to membership :

FELLOWS

Ann Kochel, Alpine.

Kenneth John Lardeur, London.

ORDINARY

William Arden Crosbee, Birmingham.

Sydney J. M. Latimer, Edinburgh.

Margaret Middleton, Birmingham.

William J. Webb, Leamington Spa.

Robert A. G. Struthers, Portobello.

PROBATIONARY

Trevor Martin Brook, Lincoln.
Beatrice B. Brooks, Birmingham.
Eric William Brooks, Wallasey.
Josephus L. G. Candel, Groningen.
Arthur Dennis Collinge, Birkenhead.
Joseph Dean, Newport.
Walter R. Dibben, Birkenhead.
Eric B. Forrest, Edinburgh.
Robert Cecil Fox, London.
Elmer Grey, London.
Ronald Albert Hall, Lingfield.
John Hart, Glasgow.
Scott, C. Henderson, Dundee.
Allan W. Henn, Bridgnorth.
Frederick E. J. Hewitt, Ormskirk.
Ann Holmes, Edinburgh.
Anthony L. Kemp, Bristol.
David G. Lennie, West Kilbride.

PROBATIONARY

Eric Levy, Glasgow.
Frederick E. Martin, Edinburgh.
Shirley J. Messenger, St. Albans.
Niven T. P. Mitchell, Clarkston.
Daniel McAllister, Glasgow.
Barbara J. Nilsen, Birkenhead.
George Paterson, Glasgow.
Ivan Alan Piper, Mitcham.
Eileen Bridget Pyne, South Woodford
Raphael I. Roth, London.
Moira E. Samson, Glasgow.
Noel J. Sutton, London.
Alan E. Taylor, Wallasey.
Edna May Taylor, Birmingham.
Ronald Frank Tugwell, Thornton Heath.
Sidney F. Watts, Birmingham.
Frederick A. Welch, Bebington.
Colin S. Wickens, London.

The Council made the following nominations for Officers for the ensuing year :—President, Dr. G. F. Herbert Smith ; Chairman, Mr. F. H. Knowles-Brown ; Vice-Chairman, Sir James Walton ; Honorary Treasurer, Mr. F. E. Lawson Clarke. It was reported that according to the Articles of Association Messrs. A. R. Popley, W. Stern and R. Webster retired from the Council and were eligible to seek re-election.

MEMBERSHIP

FELLOWS transferred from Probationary membership :

Austin, Leslie Frank, London.
Boudreau, Guy Armand, Canada.
Caudell, Peter Miller, London.
Chisholm, Marie-Louise Ann, Leverstock Green.
Crouchley, David, London.
Denham, Francis John, Harrow.
Drury, Ernest George Henry, Rio de Janeiro, Brazil.
Edwards, John, Manchester.
Fifield, Lawrence John, St. Albans.
Light, Donald Ashton, Sutton Coldfield.
Mason, Stanley, Harrogate.
Siedle, Louis Cochrane, Colombo, Ceylon.
Silver, Bernard, London.
Yaghobi, Hadi, London.

CORRECTION

In Vol. 4, No. 1, in Mr. F. Hessling's article " Absolute and Relative refractive index " an error occurred in the last line at the foot of p. 12. It should have read " Sine of critical angle 70° 25′ ". In the illustration the hemisphere absolute R.I. is 1.90.

INDUSTRIAL DIAMOND BUREAU LIBRARY

The Industrial Diamond Information Bureau, 32–34 Holborn Viaduct, London, E.C.1, established in 1943, has collected from its initiation a large

amount of publications falling into the fields of diamond occurrence and mining, diamond tools, diamond polishing, gemstones, crystallography and all related mechanical, physical and technological sciences. It was felt that this library could be more usefully employed internally, as well as externally, if a classified list of these publications were available. This has been done in this List which is classified according to the Universal Decimal Classification (UDC).

Whilst the group headings correspond to the abridged English edition of the UDC the titles are occasionally shortened and some special groups are formed referring to special subjects not yet covered by the UDC. In two appendices in numerical order, Reports of Investigations and Information Circulars of the U.S. Bureau of Mines are listed, and Government Reports on foreign industries published after the war. The present List includes all accessions up to September 1952. Further accessions are listed in the monthly *Bibliography of Industrial Diamond Applications* issued by the same Bureau.

It is intended to publish annual supplements towards the end of each succeeding year. Publications contained in this List could be made available in general on loan for a period of 14 days, in England. The list comprises 214 pages and about 4,000 titles. A limited number of copies is for free distribution and applications should be sent as soon as possible.

TALKS BY MEMBERS

Cutts (Miss P. E.) : "Jewellery and Gemstones." Ladies' Circle, Walsall, 14th January, 1953.

Anderson (B. W.) : "Gem-testing without Instruments." Midlands Branch of the Gemmological Association, Birmingham, 13th February, 1953.

Webster (R.) : "Luminescence—its practical application in Gemmology." Members' meeting, London, 26th February, 1953.

Leak, F. E. : "Pearls." Victoria Park Contact Club, Bedminster, Bristol, 6th January. *ibid.* St. John's Fellowship, Fishponds, Bristol, 13th January. "The Science of Jewellery." Science Society of Sidcot School, Winscombe, Som. 27th January.

Armstrong, A. H. G. : "Gemstones of the Bible." Women's Guild of St. Andrew's Church, Stirling, 10th February.

Penney, W. J. : "Gemstones." Matheron Women's Institute, 18th February, 1953.

Blythe, G. : "Gems and Jewellery." Southend Business Men's Club, 19th February, 1953.

Parkinson, K. : "Gemmology." East Riding Branch of the National Association of Goldsmiths. Illustrated by films, 4th March, 1953.

Warren, F. W. : "Coronation Use of Crown Jewels." Bristol, West Young Conservatives, 25th February, also to Colston Girls' School, Old Girls' Society, 6th March, and Bristol Rotary Club, 30th March.

Parry, Mrs. G. I. : "Gemstones." The Llandaff Citizens' Association, 13th February. Ibid. The University Women, Cardiff, 13th March.

Rossiter, J. R. : "Gemstones," Catholic Women's League, Weston-super-Mare, 23rd March.

LUMINESCENCE IN THE SERVICE OF GEMMOLOGY

Mr. Robert Webster gave a talk to members of the Association at Goldsmiths' Hall, London, on Thursday, 26th February, 1953. Over 100 Fellows and Members were present. A summary of Mr. Webster's talk, which was profusely demonstrated, is set out below.

One normally couples light with incandescence, the burning faggot, the oil lamp, the gas flame and the white-hot filament of the electric lamp, all depend upon extreme heat for their luminosity. Luminescence is a light that is cold.

This light, which in general has only a weak intensity, may be induced by several different means. Cold light is not new, for the luminescence of living things has charmed and mystified mankind from the earliest times. This *bioluminescence*, as it is called, is common in sea organisms and is responsible for the so-called " phosphorescence " of the sea. Saprophytic bacteria are the cause of the " phosphorescence " of decomposing fish and meat, a light which so astonished Robert Boyle in 1672. Among terrestrial manifestations, the glow-worm and the firefly are powerful illustrations. Indeed in these insects we can approach our own sphere of interest, for in some parts of the world these luminous insects are used for adornment. For those who fear the broadening horizons of gemmology they may take heart that there is not the slightest intention of including entymology in the syllabus. Bioluminescence is actually a modification of *chemiluminescence* which is exemplified by the luminous glow given off by slowly oxidising phosphorus ; being due in the case of fireflies by oxidisation of the chemical compound *luciferin* activated by the enzyme *lucifrase*.

The luminescent glows which I want to stress are those due to *photoluminescence*, which depend upon the absorption of energy by a substance from some part of the electro-magnetic spectrum. This absorption of energy may then be re-emitted by the substance, but the re-emission is, according to Stokes, generally of a longer wavelength. Thus in the case of the absorption in the yellow green of ruby any re-emission should occur in the orange, red or infra-red regions, and this is known to occur. Accepting Stoke's Law as a generalization, it would therefore require absorption in the violet and ultra-violet in order to produce re-emision in the visible region—that is for it to be seen as light.

It may be well to consider the electro-magnetic spectrum. The waves above the visible red do not interest us to-night. The visible rays—those between 7000 and 4000Å are those which affect the eye and are seen as light, and those between 4000 and 3000 are termed the near (or long) ultra-violet rays ; those between 3000 and reaching down to about 100Å are the far (or short) ultra-violet rays, the lower end of these rays overlap the longer X-rays which have a mean of 1Å.

In modern terminology when the re-emitted luminescence is in the visible region and only occurs when the exciting radiations are impinging the substance, the glow is termed *fluorescence*. Should the glow persist after the exciting radiations are turned off, this after-glow, which can be of quite long duration, is termed *phosphorescence*. These phenomena may be briefly explained by a simple diagram. What happens is that the energy absorbed raises an electron—those unit charges of negative electricity which are planetary around the nucleus of all atoms—

from a stable orbit (the ground state) to one of higher energy level (the excited state) from which it returns immediately giving up its extra energy in the form of light—this is fluorescence.

In the case of phosphorescence some of the excited electrons do not immediately return to ground level but pass into a "metastable" level of somewhat smaller energy where it is trapped until further energy is imparted to it from the surrounding medium in order to bring it back to excited state from where it can return to ground level with emission of light. Pure substances rarely luminesce, but the inclusion of a trace of some other substance may cause it to do so. The main substance is termed the "*phosphor*" and the impurity the "*activator*."

There are two other types of luminescence which may be shown although they have little application to our science. *Thermoluminescence* is produced when certain substances are heated below incandescence. *Triboluminescence* is produced by rubbing or scratching. The reasons for these types of luminescence are not fully understood, but it has been suggested that the substance has somehow been pre-charged (pre-excited).

Fluorescence can also be excited by corpuscular bombardment. The most important is *cathodoluminescence*, which is generated by cathode rays (better known as the electron stream). Crookes showed this phenomena in the case of minerals including diamond and work on rubies was carried out by Coolidge during the '30s. The elaborate apparatus required precludes much work on these lines.

Of greater practical importance to the gemmologist are the glows induced by ultra-violet light and by X-rays. I will at once mention that the three types of radiation—long, short ultra-violet light, and X-rays may not give comparable results, and indeed it is my special point to-night to try to bring this out. Any source of radiation rich in ultra-violet light will produce fluorescence in a suitable substance, but to observe the glows darkness is necessary. As most of the sources give out visible light a suitable filter to cut these out but allow the ultra-violet rays to pass is necessary. Such a filter is Wood's glass, which passes the long-wave ultra-violet only. For the short-wave ultra-violet a special type of glass is used (one is known as OX7). This filter passes the short wave band down to about 2200Å, but it also passes much of the long wave band and some visible light, hence, as I shall explain later it is better used with certain types of ultra-violet sources.

The sun is rich in ultra-violet rays, but the earth's atmosphere absorbs all radiation below 3000A. Arc lamps with special carbons are excellent but are awkward to operate. A photoflood lamp in a suitable housing with filter is a cheap source for elementary long-wave work. The mercury vapour lamps are the best all round source. The high pressure lamp which has the best emission at 3560Å, with a suitable (Wood's glass) filter, is the best for long-wave ultra-violet light. The low pressure lamp being best for short-wave ultra-violet, owing to the best emission being at 2537Å (the resonance line). This, and the fact that the low pressure tube gives out far less visible light explains the better performance for short-wave ultra-violet. A new type of germicidal lamp is now being tried out. This lamp is rich in the 2537Å line and may be a useful and inexpensive addition to the gemmologist's equipment.

The generation of X-rays, produced when a greatly accelerated electron beam is made to strike a metal target, required expensive apparatus, but the rays can be more diagonistic than ultra-violet.

Luminescent phenomena have, since the last decade of the Victorian era, affected the world's of science, of industry and of art—in peace and in war. The existence of X-rays was detected by the fluorescence they caused on a mineral salt, and it is interesting to recall that Lenard, who was experimenting at the same time as Röntgen, employed a fluorescence screen made up of an organic salt which did not fluoresce under X-rays. Owing to this he may well have lost the honour of the discovery of X-rays. Advertising, decorative illumination and the stage have all turned to fluorescence for effect and novelty. Cathodoluminescence helped to give us radar in our greatest hour of need—and in peace, television. The chemist finds fluorescence of value in acidity and alkalinity and in the new study of chromatography. The circulation of percolation of fluorescent liquids along canals or fissures have use to the engineer, the geologist and the medical man. The modern fluorescent lighting depends upon the use of a low power mercury arc inducing fluorescence in powders deposited along the inside of the tube. However fascinating they are, we must not dwell too much on effects outside our own province.

Luminescent phenomena as an aid to gem testing have not been taken as seriously as well they might. A vast number of recordings have been published during the past 100 years, but their correllation does not seem to have been carried out with any completeness. A full record, and comparison, of the luminescent characters of all gemstones under the three main wavebands does not appear to have been made. The position is rather like the early days of mineralogy, when only about half the constants of the world's minerals were known. During the past years the staff of the Hatton Garden laboratory have collected a vast number of observations on the luminescent phenomena of gem materials under both wave bands in the ultra-violet and under X-rays. Some attempt has been made to correlate these and it is hoped that this compilation will be published soon.

This work, which cannot be said to have produced any surprising results, has often supplied added confirmation when the other work of testing has not been wholly conclusive. To-night I propose to mention a few important cases and some of which bring out special factors.

The fluorescence of diamond is probably due to a lattice defect rather than to activation by a foreign substance, and thus may be considered as one of the rarer group of so-called " intrinsic " phosphors. From the gemmological point of view, Anderson has given the best report on diamond fluorescence under long-wave ultra-violet light. This worker suggests that there are three groups :— blue fluorescing, green fluorescing and yellow fluorescing, groups which he coupled up with their absorption spectra. The most usual ultra-violet fluorescence of diamond is a violet blue and under X-rays a chalky white. Further the fluorescence spectrum is discrete which gives an added value to the test. As a matter of interest it has been found that diamond powder contaminated with carborundum may be investigated by ultra-violet light. The powder is spread on a slide and observed microscopically with the aid of a beam of ultra-violet light impinging on the powder.

The crimson fluorescence of chromium activated minerals, so well seen in ruby, red spinel, alexandrite and to a lesser extent in many other minerals, is particularly interesting in the case of ruby—and emerald. Both natural and synthetic ruby fluoresces under all radiations. Owing to the iron content of Siam rubies, iron being a great poisoner of fluorescence, such stones only weakly fluoresce and this lack of response has been suggested as a diagnostic test for provinence ; this is not thought by us to be wholly satisfactory. What is more useful is the fact that all the normal colours of synthetic rubies, when irradiated with X-rays show a perceptible afterglow (phosphorescence) while, again possibly through the iron which taints natural stones, natural rubies do not behave like this. There is one exception to this rule, that is in the case of the so-called " garnet colour " synthetic corundum which also does not show the afterglow. This is possibly due to over saturation with chromium. It could be noted that the ultra-violet lamp will give a quick initial separation of rubies and spinels from a parcel of mixed rough.

Despite their chromium content emeralds are feebly responsive to all the radiations. It has been suggested that the synthetic emerald can be detected by its more pronounced glow under the lamp but this has been found not to be so valuable as thought. Even the colour filter may be more useful in that direction. A method advocated to pick up weak red fluorescence is that employing crossed filters ; a bright source of light is masked by a round flask—which acts as a condenser—filled with a saturated solution of copper sulphate. This gives a blue light with no red so that if the specimen be bathed in this light and looked at with a red filter which passes no blue, any red fluorescence will be seen against a black background. This is also useful for the synthetic emerald. Some natural emeralds are known to fluoresce strongly—especially those from Chivor—so the test is not conclusive.

Despite some claims to the contrary the distinction of the synthetic blue sapphire from the natural counterpart does not seem to be possible by luminescent phenomena. On the contrary in the case of the yellow sapphire distinction is possible (with the aid of the spectroscope) ; for, Ceylon yellow sapphires show a strong apricot coloured glow under ultra-violet rays but show no 4500Å absorption band. The Siam and Australian yellow sapphires show no fluorescence but do show strongly the 4500 complex. The synthetic yellow sapphire shows neither. It is in the case of the Ceylon yellow sapphire that another factor comes in—that of photocoloration—for the pale yellow stones become a deep topaz colour after a few minutes irradiation by X-rays. This colour is not permanent, although it may keep for years if kept from light, it fades after about 3½ hours exposure to sunlight, or fairly quickly at a temperature of about 230 deg. C. Yellow sapphire is not the only stone which will colour under X-radiation. Kunzite is very spectacular in this for the " rayed " stones are green in colour in marked contrast to the lilac-pink of the untreated stones. Mostly the colour assumed by treated stones is a brownish shade. Colourless spinel is interesting in that the stones fluoresce either a strong apple-green or a bluish colour under X-rays and turn brown. They phosphoresce for quite a long time. After the glow has appeared to die out the stones are still brownish in colour and if they are dropped into boiling water they immediately glow again and partially lose their colour—completely if sufficient heat is applied.

Although initially used to detect cultured pearls ultra-violet rays are not sufficiently valuable. However under X-rays cultured pearls show a dull greenish-yellow fluorescence which seems absent from the oriental pearls. This can only be an indication as freshwater and some Australian pearls behave similarly. During the course of the experiments it was found that the massive grossular garnet, the so-called " Transvaal jade " showed an orange fluorescence under X-rays and hence can easily be distinguished from the true jades.

In the case of green fluorescing materials the use of the spectroscope will show whether the fluorescence spectrum is discrete or otherwise. A discrete spectrum indicating uranium and a continuous spectrum possibly manganese, which may give added information of a useful nature.

I hope to have shown to you to-night something of the reasons causing fluorescence ; something of the apparatus used for the the production of these fascinating effects and, albeit briefly, something of the use which may be made of these radiations in gemtesting. It is hoped that the publication of the corellated results of our observations during the past few years will materially assist the worker, but much work is still to be done in directions indicated by workers in other sciences.

Mr. Webster carried out several demonstrations during his talk and acknowledged the help received from the firms who made the following lamps available :—Hanovia long wave (Model 11), Hanovia short wave Chromatolite, American short-wave Mineralite, Bevis Smith Photo-flood lamp, Philips Black lamp, Philips germicidal lamp with filter supplied by Rayners. The Chelsea Polytechnic (Physics and Chemical Dept.), Messrs. Rayner and Keeler, and Messrs. H. Lee and A. Ramsay also provided material towards the lecture.

GEM TESTING WITHOUT INSTRUMENTS

Upwards of 70 Fellows and Members of the Birmingham branch of the Gemmological Association were present to hear a lecture by Mr. B. W. Anderson on " Gem Testing Without Instruments " at the Imperial Hotel, Birmingham, on 13th February.

Mr. T. P. Solomon, F.G.A., who was in the chair, introduced Mr. Anderson as one of the foremost gemmologists in Europe, already known to many of the audience for his book on gem testing and through his articles in the trade press.

Mr. Anderson said that gemmology might be considered a small subject, but that really it was a very large one, touching on many other sciences. " Some people," he said, " think that after a two years' course in gemmology, that they have ' done it.' But I have been at it now for 27 years, and I am sure I am nowhere near the end of it."

About 15 years ago, said Mr. Anderson, he knew a very able gemmologist who passed his examinations with distinction, but, in his business as a dealer, remained rather contemptuous of gemmology as taught at the schools, maintaining that the average student was lost when faced with an unknown stone, unless he could run to his instruments.

Mr. Anderson said that he recognised a certain amount of truth in this reproach, and had, since that time, sought to train his own eye to recognise stones without any instrument beyond a lens, and to encourage this kind of observation at least amongst the Post-Diploma students at Chelsea Polytechnic.

Every jeweller, he said, should carry with him a good pocket lens, magnifying 8 or 10 times. " If you took this out at a showing, people would not think you eccentric ; but if you whipped out a refractometer they might think it a bit peculiar."

Mr. Anderson then came to the main purpose of his talk, which was to run through some of the main properties of gemstones and show how, in many cases these could be assessed merely by careful inspection and by knowing just what to look for, with sufficient accuracy to identify the stone concerned.

First, he said, came *colour*. Despite the fact that many scientists disagreed with him, he was certain that a great deal of information could be gained from the colour of a stone. To take one example, the red of ruby was *not* the same as the red of spinel, and in testing thousands of calibré rubies under the microscope, an occasional red spinel was easily spotted by its colour, before completing the test by other means.

Next came the *distribution of colour*, which was often characteristic, as in tourmaline, amethyst, and sapphire. *Dichroism*, which was usually only thought of in connection with the dichroscope, could usually be detected in stones such as tourmaline, ruby, sapphire, and aquamarine, simply by turning the stone and noting the change in colour. A piece of polaroid would help greatly here, however.

The lecturer next mentioned *refractive index*, and said that, together with hardness, this played an important part in the *lustre* of a stone, which was one of its distinctive features. Stones of high refractive index looked shallower when viewed through the table facet than stones of similar cut but with lower index of refraction. One could note the difference here, for instance, between diamond and synthetic colourless spinel or sapphire. The adamantine lustre of diamond, so unlike that of any other gem, was due to its combination of hardness and very high refractivity.

The hardness of a cut stone, Mr. Anderson said, could often be assessed by the appearance of its edges and corners. Pastes could be detected with a lens by the blunt, moulded look of their facet edges. Chrysoberyl catseyes could be distinguished from even good quartz catseyes by their brighter lustre.

Next on the list came *double refraction*—a very important property in stone identification. The effect could be detected simply by holding a stone close to the eye and viewing some distant light-source through one of the small prisms formed by the facets. By this means, some idea of the dispersion of the stone could be gauged also by the extent of the spread of rainbow colours seen through the stone prism.

Mr. Anderson himself, however, preferred direct observation of the " doubling " of the facet edges of a doubly refractive stone when viewed through the front with a good lens. One had, of course, to turn the stone to find the position where the effect was strongest, and with practice, by taking into account the size of the stone, one could arrive at a pretty fair estimate of the extent of the double refraction. Zircon was one of the easiest stones to practise on, and could nearly always be recognised by its strong double refraction.

The lecturer showed slides showing the " doubling " to be seen of the back facets of tourmaline, zircon and synthetic rutile. He also demonstrated how one could check on the double refraction of a crystal ball by holding the corner of

a card immediately behind the ball and viewing the card through the ball. If the ball were really crystal, the card had a ghostly double edge, whereas in the glass imitations of crystal balls which were far less valuable, no doubling could be detected.

Mr. Anderson then mentioned *inclusions* in stones. In certain species such as demantoid garnet, with its radiating fibres of byssolite, the inclusions were nearly always distinctive. This was also true of Burma rubies. In many other cases long experience and perhaps a microscope would be needed to come to any safe conclusions. *Surface markings* were also very important. Among these might be mentioned the " naturals " left on parts of the girdle of many faceted diamonds, the " fire marks " so typically seen on both natural and synthetic corundum—though more noticeable in synthetics—the structures of pink pearl, coral, and imitation pearls. Also the brassy specks of pyrites in genuine lapis lazuli, compared with the patches of quartz in the stained jasper known as " Swiss Lapis."

The lecturer went on to deal briefly with *cleavage cracks* and nicks as an occasional aid to identification in such stones as topaz and diamond and fluorspar, and with chatoyant and star-stone effects and with interference colours as seen in opal.

He said that the *density* of a stone could be roughly assessed by its " heft " when balanced in the hand. Though difficult to get any accuracy in this way, one should be able to distinguish, say, between aquamarine and blue topaz, or between yellow topaz and quartz.

Thermal conductivity, went on the lecturer, was the scientific basis for coldness to the touch. Crystals were better conductors than glass—hence the well-known " coldness " of a crystalling stone compared with a paste when touched with the tip of the tongue. Plastics and amber, of course, would feel " warmer " still.

Finally, said Mr. Anderson, the *size* of a stone should be taken into account when judging its nature. " It is common sense to realise that large Burma rubies priced at £30 are just not knocking around these days," he added.

At the end of his lecture, Mr. Anderson described a very simple immersion method by which the refractive index of stones could be judged with fair accuracy, and showed slides of photographs taken by one variation of this method.

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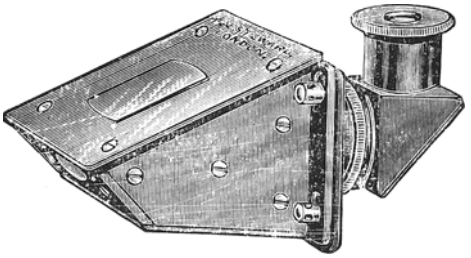

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Vol. IV No. 3 JULY 1953

IMMERSION CONTRAST SIMPLIFIED

by B. W. ANDERSON, B.Sc., F.G.A.

IN the "Journal" for April, 1952, I described an easy photographic method whereby the refractive index of faceted gemstones could be closely estimated and their size, shape, and facet distribution permanently recorded, without the use of a camera. Briefly, the process consisted in immersing the stones in a glass cell containing a suitable liquid, then, in the dark, sliding under the cell a sheet of printing paper or flat film, and exposing for a few seconds to light from an overhead lamp. After development, the contact print so produced showed very clear, indeed one might say spectacular, differences in the appearance of the stones according to their refractive indices in relation to that of the liquid.

This method gives results which are æsthetically pleasing* and of practical value in certain circumstances. But, being a photographic process, a heavily darkened room if not an actual "dark-room" is required, and moreover even the simplest processes of development and printing are bound to consume both time and money, each of which are usually in short supply. It therefore seemed worth while to find some convenient means of making the

process a visual one where desired. Simply by placing the immersion cell containing the stones on a ground-glass sheet and holding this above eye level under a hanging lamp one is able to see what the photographic emulsion recorded in the method outlined above ; but this is at best an awkward, and at worst a dangerous attitude to adopt, as a tilt of the cell may easily result in drops of noxious liquid falling into the eyes.

This difficulty can easily be overcome by placing a pocket mirror, tilted at 45°, under the cell and its ground-glass support. The following arrangement enables this to be done with comfort and security. Two cubic blocks are constructed from wood or cardboard, and a third, wedge-shaped piece, which in section forms a right-angled triangle, is placed between the cubes to form a support for the mirror. The sheet of ground-glass acts as a bridge between the two cubic blocks, and the immersion cell is placed in the centre of this bridge. It only remains to arrange for a suitable overhead lamp directly above the cell, and to place the blocks, etc., on some form of raised platform (a pile of books will serve as a temporary expedient) on a bench or table to enable the effects in the mirror to be observed without discomfort.

The actual dimensions of the blocks, etc., is largely a matter of choice, but the writer has found that blocks of about 3½-inch edges are suitable, the wedge-shaped centre piece being about 3 inches broad with two of its sides 3½ inches in length and the sloping side nearly 5 inches long, to satisfy Pythagoras.

In case this description is not sufficiently clear, a diagramatic sketch of the arrangement is given in Fig. 1. A finely-ground glass sheet, costing a shilling in quarter-plate size, can be bought at any photographic suppliers, and a mirror (about 3½ × 2½ ins.) from a chemist or Woolworth store. Having satisfied himself of the usefulness of the set-up, an enthusiast may care to construct something more handsome and permanent from wood. The writer happened to have at hand an old " dissecting microscope " stand consisting of a bevelled block of wood with a glass stage fitted with a sloping mirror below which answered the purpose of this immersion process admirably.

In place of a hanging lamp, a beam of more or less parallel light from a low-voltage microscope lamp can be used, or, in emer-

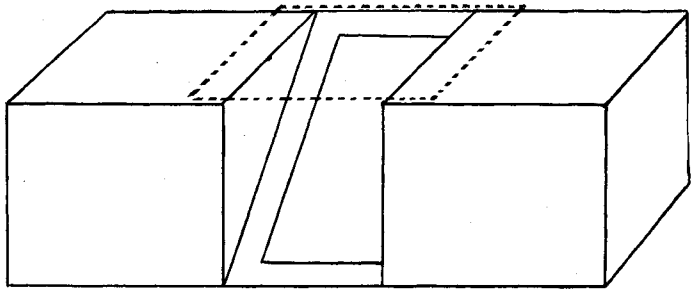

Fig. 1. Diagrammatic sketch showing two cardboard cubes and wedge-shaped support for mirror, as recommended for study of immersion contrast effects. The dotted line indicates the position of the ground-glass "bridge" on which the immersion cell containing the stones is to be placed.

gency, light from a pocket torch, if the room be suitably darkened. The results observed should be very similar to the contact photographs, with the added beauty of colour. Typical photographs were reproduced in my former article, but another is shown here in Fig. 2, to refresh the reader's memory.

Results of almost equal practical value, though less spectacular, can be obtained by even simpler means. If a sheet of white paper (filter paper serves admirably) be placed under a glass immersion cell containing faceted stones and the appearance of the stones critically noted when placed under a good light, the effects of dark borders and bright facet edges for stones of higher index than the liquid and bright borders and dark facets edges for those with lower index can be seen quite clearly. This simplest-of-all immersion technique was used by the writer with complete success in the course of a recent routine test of some parcels of small colourless baguettes, ostensibly diamond, but actually a mixture of synthetic white sapphires and spinels. When these were immersed in a glass cell containing methylene iodide, which has a refractive index almost exactly mid-way between the two species, it was remarkable how clearly the spinels could be separated from the corundums by their appearance as they lay in the cell on a sheet of filter paper with an ordinary bench lamp above and slightly to one side. The tiny facets of these stones made refractometer readings hardly possible, so that the method was here of real value, especially as the con-

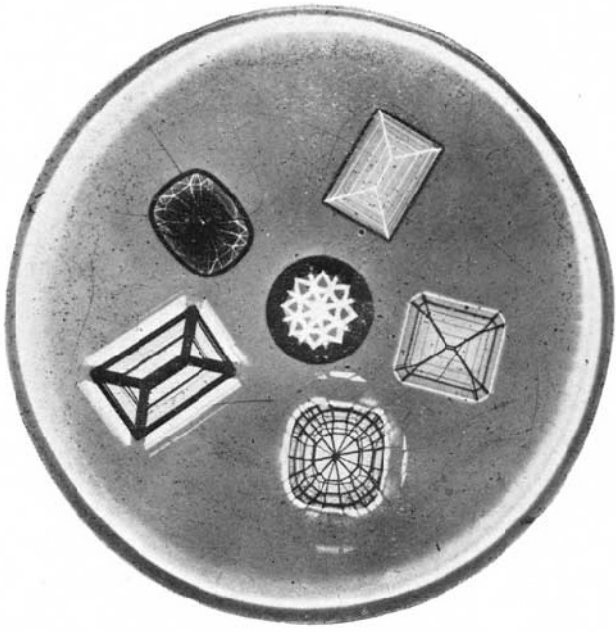

Fig. 2. Immersion contact photograph showing quartz, topaz, spodumene, spinel, chrysoberyl, and (centre) zircon, immersed in monobromonaphthalene.

signment consisted of more than a hundred stones. For purposes of record, an immersion contact photograph was taken of one of these parcels, and an enlargement of this is shown in Fig. 3. It will be seen how clearly the three synthetic spinels which were present stand out by comparison with the corundums. A difference exists here between what the eye sees and what the film records, since for the slow fine-grained emulsion used, blue and violet were the operative colours, and for these wavelengths methylene iodide, with its high dispersion, has a refractive index much nearer corundum than spinel—hence the greater contrast shown by the latter in the photograph. More than that : for blue-violet light the refractive index of methylene iodide is actually *higher* than that of corundum, as revealed by the faint pale borders and dark facet edges of the sapphires. To the *eye*, the reverse effect was visible.

This example underlines the great usefulness of the method

in detecting any " odd men out " in a parcel of stones which are meant to be all of one kind. It functions in this way very much

Fig. 3. Enlarged immersion contact photograph of synthetic corundum (faint outlines), and synthetic spinels (three stones with bolder outlines) immersed in methylene iodide. "Line" film used, 3 seconds exposure.

as heavy liquids do in the density field, and, like the latter, it gives the most clear-cut separation where the liquid is so chosen as to be intermediate in properties between the species concerned. Differences in immersion contrast have of course been utilised for years in a general way : what seems to have been hitherto unnoticed is the ease with which one can diagnose whether specimens have an index higher or lower than that of the immersion medium, and approximately how much higher or lower.

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* In a private letter, Mr. E. J. Burbage, F.G.A., revealed to me that he had taken contact prints of gemstones for decorative purposes many years ago. As they had no scientific purpose in view, these photographs were never published.

JADE

A PROBLEM IN NOMENCLATURE

by Sir Charles Hardinge, Bart.

I BOUGHT my first piece of jade in 1918 to celebrate the end of the war and was not long in finding out that few people knew much about it and that not many of these knew very much. The first person I got to know who was of any real help in acquiring knowledge was that very delightful man, the late Mr. Stephen Winkworth, who very kindly lent me his copy of "Jade," by Dr. B. Laufer, published about 6 years before. When I came to p. 22, and read foot-note 2, I found something I could not follow, I mentioned it to Mr. Winkworth: after some consideration he agreed with me. Other things and the fact that I did not then know any one else whose opinion was worth much, left the matter pigeon-holed until in April, 1950, Mr. S. H. Hansford very kindly presented me with a copy of his book, "Chinese Jade Carving." When I read the paragraph which begins at the bottom of page 1, I saw Mr. Hansford took the same view that I had 30 years earlier. I have often intended mentioning the subject to him but somehow it has always escaped me when I saw him. Quite recently I have been trying to get out a list of all authentic localities in which both varieties of jade have been found, crude and unworked (not necessarily "in situ"), and this has brought back to me very insistently that I should like to clear up the suspicion I have had for so long, one way or the other.

About the middle of the sixteenth century the first jade to be brought to Europe in any quantity arrived from the Spanish possessions in America, Raleigh is said to have acquired some from the Spaniards and to have been the first to bring it to England. It came as worked objects. The natives of the countries these objects came from called the mineral they were made of *Chalchihuitl* (*a*). We called it Jade and Nephrite.

Mineral (*a*) is *Chalchihuitl*, *Jade*, *Nephrite*, *Fei-ts'ui*, *Jadeite*. Mineral (*b*), referred to later, is *Yu*, and what the Maoris call *Pounamu*. There is no convenient or kennel name for it for Europeans and English-speaking peoples; it is described as either

(1) Felted or interlocked fibrous Actinolite, if it contains iron, or
(2) Felted or interlocked fibrous Tremolite if it contains no iron.

Dr. Laufer thinks *Jade* (*a*) was so called because the Spaniards called it " *Hijada*," and that it was also called *Nephrite* (*a*) because the natives of the countries the objects came from thought it possessed amuletic properties against diseases of the kidneys, both quite satisfying reasons. He discards a suggestion that *Jade* was derived from a Turkish word. Mr. Hansford spells the Spanish word " *Ijada*," and adds an alternative " *Rinones*." Miss Elsie Ruff in her book " Jade of the Maori " on p. 17 mentions " *Hijada*," " *Ijada*," and adds " *Yjada*," and " *Ijar*." She also makes another suggestion, that *Jade* is derived from the Latin word " *Ilia* " which means the flank, the fleshy or muscular part of the side of an animal between the ribs and the hip. " *Ilium* " is the upper part of the hip-bone—the flank-bone. Miss Ruff also says the Romans and the Spaniards both thought it had curative powers for colic. A medical friend of mine tells me you can only have colic in the kidneys if there is a stone in them and he thinks a derivation for the word *Nephrite* (*a*) from either " *Ilia* " or " *Ilium* " would be very far fetched, and nothing like as appropriate as the derivation which satisfies both Dr. Laufer and Mr. Hansford, and also I expect Miss Ruff. He agreed with me when I suggested that if Colic was responsible for naming the mineral that some such name as " *Abdomenite* " would be much more satisfying. For approximately 200 years, all, or practically all, the objects made from this mineral which came to Europe, came from the Spanish possessions in America.

About the middle of the 18th century, 200 years after the first importations from America to Europe, objects began to come from China which *were thought* to be made of the same mineral. The Chinese called it " *Yu* " (*b*). The Chinese had obtained probably all their Yu from the K'un-lun Mountains in Chinese Turkestan, about 1,800 miles in a straight line from Pekin, a very difficult and arduous journey. About the middle of the 19th century they also got some Yu from Siberia. They have been working this mineral for approximately 2,000 years. Naturally as it *was thought* to be the same mineral, these objects imported from China were also called both *Jade* (*a*) and *Nephrite* (*a*).

At about the same time, the middle of the 18th century, the

Chinese obtained a mineral from Burma, which they at first *thought* to be Yu, but from practical experience in working it they very soon found it was not real *Yu* (*b*) and they called it *Fei-ts'ui* (*a*). We are told at first they did not much care for it, but that it soon became more costly than *Yu* (*b*). It is from *Fei-ts'ui* that so many of the wonderful 18th century and later Chinese works of art are made. After the sacking of the Emperor of China's palace, some of these beautiful objects came to Europe and a French scientist, Damour, in 1863 found that many of these objects were not made from the same mineral as the Chinese had used for all their earlier objects *Yu* (which the Chinese had found out about 100 years earlier from practical experience) but that they were made from the same mineral (*a*) as the objects which had come from the Spanish possessions in America 300 years earlier (*a*) and which we had for 300 years called *Jade* (*a*) and *Nephrite* (*a*), he called it *Jadeite*, so it now had three names for Europeans and English-speaking peoples.

It seems to me that as there are so many Jadeologists to-day that any fact connected with either mineral would be of some interest to quite a number of people even if their primary interest was not perhaps mineralogical. I am not concerned in the very least about any confusion that may arise if my submission is correct, a fact is a fact, and if I am correct any confusion there may be started 90 years ago owing to a slip-up on the part of a mineralogist. Surely there is no reason for any mineralogist to-day to blush for a slip-up on the part of a professional ancestor three or four generations ago, it provides yet another example of the wonderful foresight of the Author of the ten commandments when he laid down :— " and visit the sins of the fathers upon the children unto the third and fourth generation." That any confusion will be caused is extremely unlikely I should imagine. I have only raised the matter in the hope of getting a definite decision one way or the other.

B. W. Anderson *writes* :—

Readers of Sir Charles Hardinge's interesting article may well be feeling somewhat confused in the matter of jade nomenclature, so perhaps I may be permitted to add a few words of reassurance.

The fact he has seized upon, and which most of us had admittedly not recognised, is that the terms jade and nephrite

were originally applied to the mineral we now call jadeite, as it was this material which formed the bulk of the jade objects which entered Europe after the Spanish conquests in South America. This is perfectly true, and certainly brings to notice a peculiarly twisted history in the nomenclature of jade. Bowenite properly plays its part also, since it was identified as nephrite by Bowen in 1822, and not recognised as a hard form of serpentine till years later.

But the really important issue does not belong to the past but to the present. What matters is, have we now got names for both these jade minerals which we can use without fear of confusion ? Terms, that is, acceptable and understood by mineralogists, jade collectors, and in fact by all those with a real interest in such matters. The answer is, yes, we have names, both scientific and general, which are quite well understood.

First, there is the general term *Jade*, which is an umbrella name under which, by common, if reluctant, consent, only two species are allowed to shelter. One of these, a calcium and magnesium silicate with density near 3.0, belongs to the great amphibole group of rock-forming minerals, of which hornblende is the most prominent member : the other is a sodium aluminium silicate with density near 3.3, which belongs to the equally important pyroxene group of minerals, of which augite is the type representative. The mineralogist places the amphibole jade in the tremolite-actinolite series, according to its iron content : the gemmologist is accustomed to call it nephrite, while the jeweller is apt to distinguish it as " New Zealand " jade, regardless of its actual origin. As for the pyroxene jade, the mineralogist recognises the term " jadeite " as the name of a definite mineral species (it has no other mineral name). The gemmologist, of course, follows suit, while the jeweller either just calls it " jade," since it is *the* jade of modern commerce, or, with his usual rather vague sense of locality, he may use the term " Chinese " jade.

The point I want to make is that, *whichever* of these terms is used, the meaning is clear, even where they are logically, historically, or geographically incorrect : and *clarity of meaning is the one really important thing about a name.*

After all, a tangled and twisted history is nothing exceptional amongst the names of gems. Even to-day, such names as olivine, jacinth and chrysolite mean different things to different people ;

the sapphire and diamond of the Bible were not the sapphire and diamond of to-day ; while when it comes to the use of " topaz " there is still a cleavage of opinion between the gemmologist and the jeweller.

Thus with jade, though it shares with alabaster the disadvantage of being too general a term, we may consider ourselves lucky to have an adequate number of more specific names, each of which is, in daily practice, unequivocal.

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Ex " A New English Dictionary on Historical Principles." Oxford 1901.

Jade, also Jadde. (F. le Jade (1667 in Hatz-Darm) for l'ejade (Voiture, 1633)). It. iada (Florio 1598) ad Sp. ijada in piedra de ijada or yjada (monardes, 1569) lit. " Colic stone " f. ijada, yjada, " the small ribs, the collike, the flanke " (Minsheu), the synonym Nephrite f. Gr. *Nephroi* kidneys, reins.

1569, Monardes Cosas de las Indias (heading) De la Piedra de la yjada.

1595. Raleigh discovered Guiana, 24, " a kinde of greene stones which the Spaniards call Piedras Hijadas, *and we use for spleenestones.*" See later Ref. ex Hakluyt's Voyages.

1598. Florio, Iada, " a kinde of precious stone like an emeraud."

1633. Voiture, Wks. Let. to Mdle Paulet, 1665, 47. " Ainsi pour ce coup, l'Ejade a eu pour vous un effect que vous n'attendez pas d'elle."

1657. J. D(avies) tr. Voiture's lett. XXIV, 37, " So that this time L'Ejade hath had for you an effect which you expected not from it." Ibid. XLII. – 79. " I perceive there must be found out for me some more substantial remedies than the Ejade." (mispr.) Ejacle.

Ex Bishop — " Investigations and Studies in Jade." I., p. 1.

" There is no word of *Jade* in European literature before the discovery of America by Columbus in 1492. The earlier Spanish navigators brought back specimens of green stones which were highly valued by the natives of Central and South America and were worn by them as badges of rank or as amulets against certain diseases. For this last reason it was given the name of piedra de hijada " Hypochondriac, or colic stones," which first occurs in the workes of Monardes, a physician of Seville, in 1565. He also alludes to its synonym piedra de los rinones or kidney-stone, and to its reputed value in renal diseases. Hence the name of nephrite from Nephros, the kidney, and that of Lapis Nephriticus which is so frequently used by the older writers."

Ex " History of the Conquest of Mexico." By Prescott, Vol. II, p. 63.

" Both cloak and sandals were sprinkled with pearls and precious stones among which the emerald and the chalchihuitl—a green stone of higher estimation than any other among the Aztecs—were conspicuous."

Ex Hakluyt's Voyages. Everyman Library Ed., Vol. VII, p. 296.

" These Amazons have likewise a great store of these plates of golde, which they recover by exchange chiefly for a kinde of greene stones, which the Spaniards call Piedras hijadas, *and we use for spleene stones :* and for the disease of the stone we also esteeme them. Of these I saw divers in Guiana : and commonly every king or casique hath one, which their wives for the most part weare ; and they esteeme them as great Jewels."

p. 302. " The Spaniards ledde him in a chaine seventeene dayes, and made him their guide from place to place betweene his countrey and Emeria, the province of Carapana aforessyd, and he was at last redeemed for an hundred plates of golde, and divers stones called Piedras Hijadas, or Spleene-stones."

pp. 333, 334. Same repeated again.

The above from a Report from Sir Walter Raleigh to Sir Charles Howard and Sir Robert Cecyll, of H.M.'s Privie Council.

These two from a Report by Laurance Keymis, gentleman, to Sir W. Raleigh.

p. 380. " Farther this old man showed mee, whence most of their golde commeth, which is formed in so many fashions : whence their Spleene-stones, and others of all sorts are to be had in plentie."

p. 386. " To such as shall be willing to adventure in search of them, I could propose some hope of golde mines, and certaine assurance of peeces of golde, of Spleene-stones, Kidney-stones, and others of better estimate."

The above was in the 16th century.

A GEMMOLOGIST VISITS the ROYAL ONTARIO MUSEUM

by D. S. M. Field, A.G.A.

RANKING among the great museums of the world, the magnificent Royal Ontario Museum buildings contain many unique examples of gemstones, and ornamental minerals in infinite variety. Indeed, nowhere else in the world are Canadian gemstones so well represented ; and for anyone accustomed to thinking of Canada purely as a source of economic minerals, a visit to the collections of Canadian gemstones holds many delightful surprises.

One of the most striking " gems " in the collection is not a precious stone at all, but it deserves special mention on account of its amazing size and symmetrical perfection. It is a section of a huge crystal of muscovite mica that measures nearly six feet in diameter and is almost completely free of inherent flaws and surface imperfections. The crystal from which the section was removed was found near Eau Claire, Ontario.

When it is remembered that single crystals a foot in diameter have fetched as much as seventy-five thousand dollars, the value of the Eau Claire mica crystal may be more readily appreciated.

Nevertheless, and notwithstanding the economic and scientific importance of the mineral collections housed by the R.O.M., it is the gemstones that are of paramount interest to the gemmologist.

It is difficult, however, to single out any particular specimen as the best one of the lot. Nearly all of them are most interesting and beautiful, although it must be said that the lighting arrangements leave much to be desired.

Upon entering the main gallery, one is at once impressed with the great size of the rough specimens. Indeed, many of the larger ones are individually displayed in large glass cases with a capacity of forty cubic feet or more. There are huge groups of rock crystal and fluorite—the latter from British mines; and blocks of amethyst, from Uruguay, measuring a yard or more in diameter, are in various sections of the hall. Indeed, a whole cave of enormous crystals of pink calcite—the whole measuring at least fifteen feet in depth—has been transported from Sterlingbush, New York.

In all, there are twelve cases of cut gemstones. These include spheres of cairngorm and chatoyant rose quartz, white scapolite cat's-eyes, star sapphires and star rubies, and opals of singular beauty and pattern. One cut specimen of black opal, cut in the form of a large marquise cabochon, is perhaps the most beautiful specimen of Australian opal.

Two cases are devoted to Canadian gemstones. One of these contains a sixteen-piece group of figurines, trays and strings of beads cut from sodalite ; while another case contains beads and cabochons of peristerite, collinsite, amazonite, and the rarer mineral cancrinite—which derives its name from the late Count Cancrin, of the Imperial Russian Court.

The green amazonite from Ontario is particularly beautiful ; but the faceted gems hint that Canada may someday become an important source of many familiar and rare gem varieties.

Of the faceted gems, iolite, aquamarine, almandine, rock crystal, diopside, sphene, zircon and vesuvianite (idocrase) are comparable to the best from other countries ; and this same obtains in the case of the cabochon stones. The latter class includes gold quartz, mordenite, agate, apatite, amber, banded jaspilite, labradorite, sphalerite, chlorastrolite, thomsonite and prehnite. A transparent orange-coloured cassiterite is among the rare gemstones on display.

The tenth case of cut gemstones contains a most interesting and unusual collection of stones cut by oriental lapidaries ; and the contrast is great between the symmetry of these and the modern well-proportioned stones produced in Europe and North America.

The last two cases are devoted to displays of synthetic corundum and spinel. These are well arranged, but one questions the wisdom of using misleading trade names in a scientific exhibit—particularly when such are used without qualification or species name, except at the foot of the case. For instance, a lovely blue coloured synthetic spinel group is labelled " kyanite," and the terms " topaz," " aquamarine," etc., are much in evidence.

Huge crystals of Canadian apatite, zircon, sphene, etc., are to be noted in some wall cases ; others show series of specimens to illustrate genesis, molecular structure and crystal habit. The student will find the beginners' collections, arranged to illustrate terminology of descriptive mineralogy, of great value ; while the advanced scholar will appreciate the systematic collections.

JADE in the MEXICAN ART EXHIBITION

by Elsie Ruff, F.G.A.

SOME standard must long have existed to give significance to the word *jade*—or the word's equivalent. Perhaps colour came first, followed by diaphaneity. Later, with the experience of cutting and polishing, toughness would be an essential. The mistakes of early peoples were probably no greater than those of to-day, for the word is still bandied about. Yet some norm was established. Had it been possible to prove that jade was in fact more than one species, the information could hardly have received more than passing attention. And regardless of the term used. It might be Chalchihuitl or Yü or Pounamu or, as we are told the Eskimos called it, Singok.

Jade labels in the recent exhibition of Mexican Art at the Tate Gallery could have been catalogued by the original artist. There is doubt whether some pieces were jade at all. It must be conceded they were jade-like. A few were labelled *jadeite*, confusing enough to the public. An enquiry disclosed that one might accept *jadeite* as tested material. *Jade* appeared where pieces may or may not have been tested. And that, in any case, all Mexican jade was almost certainly jadeite. Curiously enough, at the time, it seemed to have no more significance than we suppose it had to early man. Perhaps it was the atmosphere, or the appreciative visitors, or that you caught the spirit of those unknown artists. At any rate one found oneself questioning, why all the pother ? Why indeed ? It is not a question of something real as against something counterfeit, like gold and gold-plated. It is solid throughout. Nor is it based on wearability or longevity.

When we really get down to the nomenclature of jade and its varieties—and it is imminent—it would seem that we must first establish what we are after. Are we after the original substance known to man as jade—the material he dug out of the earth or

chanced upon in boulder form or collected from some clear river that almost certainly tricked him on colour ? Or are we after the early primitive expert's jade—the man who had learned to appreciate and carve it and leave his imprint upon it, for subsequent generations to worry over his meaning ? Original material will be hard to prove. Popular material a much simpler matter. Or are we going to accept the terms of one particular race ? Or are we going to ignore the background ?

Despite labels, the Mexican jade was very instructive. There was too, for those deeply interested in this subject, the pleasure of seeing some piece heretofore known only by illustration. Several pieces were familiar in this way. And since the museum of Mexico City is outside the ken of most of us, one's mind flashed back to illustrations in current books on Mexican art or to a famous illustrated journal. It was more than seeing the original of a great canvas most of us anticipate. Here was a change of dimension.

We are told that Mexico allowed these national treasures out of her country only with reluctance. Yet the British Museum was able to contribute in no small measure.

The story of Mexican jade has not yet been written. Indeed, Mexico itself is only just beginning to unfold. Matured Mexicologists are still hesitant about precise dates for the various cultures.

Unlike the Maori of New Zealand, who made no attempt to reproduce in jade the human face or figure—with the one exception of his Tiki—the early Mexican appears to have been intent on this very subject. Someone has suggested that this Mexican must have been somewhat of a world traveller, since he has produced an international gallery of types. The exhibition was proof of it, both in pottery and jade. There was Mongolian, Negroid, Norse. Did not Montezuma believe that Cortés represented the great white god of their mythology ? (Pacific Island people welcomed Captain Cook for the same reason). The ancient Mexican artist must have recognised that his country was made up of many types, layer upon layer of culture. Yet chalchihuitl persisted, not only as a medium but as the country's most precious material.

To jadeologists—to use a recently coined word—this is the most startling of all facts about jade. Not that it should have been dis-

covered, and used, perhaps simultaneously by several peoples, but that for so many races it represented *the most precious material.* And this material is still precious. Most of us to-day might prefer to discover diamonds or radium, but the motive behind our discovery would be totally different.

The exhibition of Mexican art was an innovation for this country. Only once before was ancient Mexico represented in this way, and that as far back as 1824. It was understandable therefore that the Presss made much of it. Frequent among the criticisms were the words grotesque and gruesome. Yet right throughout the Pacific, and indeed the Far East, this same style exists side by side with the gentler issues. Surely modern expressions repeat it, except that we interpret it in terms of the subconscious mind. Maybe these early peoples had no such term. They merely recognised that they felt this way—at times. A jade plaque might look out at you with an expression of derision. Derision is still a human characteristic though we do not carve it into our precious materials. Critics complained of human skulls carved out of fine substances. (The British Museum's Aztec rock crystal skull was an outstanding contribution.) But the skull and cross-bones has long been a motif in the white man's world. It played a part in World War II. Death cults have had several periods of popularity in Europe. Liquidations, whether you call the motive political or religious, leave no room for criticism of the odd human sacrifice in Mexico, frequently tendered rather than extorted.

In the Mexican jade and jewellery world there would seem to be evidence of Chinese influence. (Some suggest that it may be the other way round.) Since the general public is more knowledgeable on the subject of Chinese jade, one heard comments regarding this similarity. Yet other influences were apparent, Egyptian for one. The discovery of a tomb in Monte Albán, Oaxaca, disclosed work of the Mixtec culture (A.D. 800–1521)—a people greatly influenced by the preceding Toltecs—that not only established them as great goldsmiths but exhibited a style we have learned to associate with Egypt. There was a magnificent necklace, for example, in gold, turquoise, mother-of-pearl, and pearls, comprising no fewer than twenty-three rows, the fringe made up of small gold bells. Jade from this tomb alone was note-

worthy. There was a necklace of eighty-eight beads in various shapes. Another, with some of the jade a rich emerald green, of sixty beads. Both necklets would be wearable to-day. There was a pale jade necklet made up of three rectangular beads and six spherical ones. Another of seventy-seven beads in two rows with a pendant representing a human head. There was a white jade circular pectoral in the form of a monster's head. From this same tomb were jade pendants, jade earrings, one circular and almost the size of a bangle, another flower shaped. There was a lip-plug (for the lower lip) composed of a green jade and gold eagle head. Very interesting were three all-jade rings. One, a simple band (wedding ring style), each side finely grooved. Another, engraved. A third, of emerald green jade with the finger bone still attached to it. The rings were sizes that approximate to-day's finger. And all this from one tomb that may have ante-dated the Spanish Conquest by perhaps 700 years.

The jade and jewellery from another tomb, discovered on the Isthmus of Tehuantepec during 1952 has evidently not yet reached the exhibition stage. This story reads, for all the world, like a mummified Egyptian pharaoh with a Chinese bias. Yet it was no other than an exalted Mayan leader of the Palenque civilization. It is well worth quoting :

> " In the red-painted cavity below lay the all but pulverized skeleton of a middle-aged man. His fine cloth raiment was in tatters, but his burial jewellery made as rich a display as it had when he was interred 13 centuries ago. A jade diadem covered his skull, and chunky jade earrings lay where his ears had been. A jade mask with inlaid emerald eyes covered his face. Inside the mouth was a jade bead, and a long jade necklace hung over a beaded breast plate. At his crumbling collarbone he wore a pearl as large as a walnut. His right hand held a large jade cube, his left a jade sphere. Jade ornaments stood by his feet, and nearby were two jade idols."

The discoverer, Mexican archæologist Alberto Ruz Luhillier, does not attribute any of this to Egyptian influence. We are not told whether he gives credit to China, though his statement that it is no more than coincidental resemblance, proving only that wherever

man lived human culture followed similar patterns, would seem to deny this also.

The Mexican exhibition unfolded with an astonishing display of earthenware figurines, male and female. These were dated 1500—100 B.C. and were headed archaic. In it was no jade, though jade figurines were a feature of a later culture. Next came the Olmec culture, 500—100 B.C., which may be likened to the Han Dynasty of China, so high was its level of artistic creation. It is catalogued as " one of the riddles of Mexico." And it is rich in jade. One piece, probably less known than most, was lent by a private owner in New York. It is that of a standing human figure, $8\frac{11}{16}$-in. by $3\frac{1}{8}$-in., holding an infant to its body. One leg is broken off at the knee. Here were many representations of what appears to be the deformed head, not unlike cranial deformations we occasionally see to-day. The facial expressions on these heads vary from the sort of twisted-mind type to that of poised intelligence. It is believed that babies' heads were bandaged to produce this high cylindrical form, which was apparently desirable. But the human figure was everywhere in jade. There were squatting figures, recumbent figures (many with feline mouths), human masks, a wonderful head of an old man ($2\frac{3}{4}$-in. by $\frac{15}{16}$-in.), a jade head with gold encrusted eyes, cross-legged figures, seated figures, dwarfish bodies. And expressions both grotesque and joyous. We were told that the grotesque was largely the work of priests or priestly influence. Left to themselves, like most human beings, the ancient Mexican was not bereft of the joy of living.

Within these same cultures were, of course, beautiful jade axes. A large grey-green axe, from Vera Cruz, measured $8\frac{11}{16}$-in. by $3\frac{15}{16}$-in. Another, almost identical in size, came from Tabasco and was of pale green jade, beautifully polished. Both were Olmec.

Jade was sometimes combined with gold, sometimes with rock-crystal, often both. Rock-crystal seems to have been popular, perhaps second only to turquoise. And turquoise ran a close second to jade. Only one piece could I discover that bore any resemblance to the Maori's Tiki. This was a jadeite plaque from the British Museum, $5\frac{1}{2}$-in. in height and carved in relief. It was listed under

Small Male Nude Figure Olmec Culture. $4\frac{3}{4}$-in. Grey-green jade. Cerro de las Mesas (Vera Cruz).

Exhibited at the Exhibition of Mexican Art, London, 1953.

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the Maya culture of the Old Empire (A.D. 317–987). The bat was apparently a symbol in the Mexican world as it was with the Maori and the Chinese. One large pectoral, finely carved and realistic, was made up of jade, mother-of-pearl, and slate. It represented the Bat God with jade lips in the shape of a flower. Eyes and teeth were encrusted with mother-of-pearl.

The impact of Mexico—experienced in the hushed atmosphere of the Tate Gallery—was a strange one. It can hardly be described as stimulating. Yet it was unquestionably exciting. For the gemmologist it was another chapter on jade. One can do no better than quote the words of Dürer, with which Dr. S. Linné of the Stockholm museum concludes his article in the fine catalogue of Mexican Art issued by the Arts Council of Great Britain. The words come from Dürer's diary, after he had seen the collection of Mexican work sent to Charles V in Brussels during 1520. This great artist, incidentally the son of a goldsmith, was then in his maturity. He wrote : " Never in my life have I seen anything which so made my heart leap in me . . ."

Gemmological Abstracts

ANON. *Staatsexamen in Edelsteinkunde.* State examination in gemmology. Zeitschr.d.deutsch.Gesellsch.f.Edelsteinkunde, Vol. 1, No. 2, 1952–53, pp. 1–4.

An examination in gemmology has been introduced in Western Germany, corresponding roughly to the Diploma of the Gemmological Association in this country, but the " State-examination " of the State Institute for Gemmology at Idar-Oberstein is of a more official nature than the Diploma. Rules of examination and syllabus are given. First successful candidate was Mr. R. Wacker-Wakelin, F.G.A., of Birmingham. E.S.

CHUDOBA (K. F.). *Grundlagen und Probleme der Diamantsynthese.* Basis and problems of the diamond synthesis. Zeitschr.d. deutsch.Gesell.f.Edelsteinkunde. Vol. 1, No. 2, 1952–53, pp. 4–9.

Survey of literature on diamond synthesis. The author reaches the conclusion that in spite of many investigations, the knowledge gathered so far is but little and success not very near. E.S.

ANON. *Die Bonner Diamantsynthese.* The Bonn Diamond Synthesis. Zeitschr.d.deutsch.Gesellsch.f.Edelsteinkunde, Vol. 1, No. 2, 1952–53, pp. 9–10.

Indictment is expected soon in the Bonn case of fraudulent " diamond synthesis." No boart was produced any more when the experiments were transferred from the laboratory of the " inventor " to the Mineralogical Institute of the University of Bonn. E.S.

PLATO (W.). *Orientierte Streifung in synthetischen Korunden.* Orientated straight lines in synthetic corundum. Zeitschr.d. deutsch.Gesellsch.f.Edelsteinkunde, Vol. 1, No. 2, 1952–53, pp. 10–13.

The article refers to straight line and shadow effect observed when synthetic corundum is viewed between crossed nicols in parallel light in a direction along the optic axis. Characteristic photomicrograph is reproduced. E.S.

SCHMIDT (P.). *Onyx, der Stein der Bibel.* Onyx, the gem stone of the bible. Zeitschr.d.deutsch.Gesellsch.f.Edelsteinkunde, Vol. 1, No. 2, 1952–53, pp. 15–18.

Interesting article tracing facts and legend about onyx in biblical times and antiquity. Oldest Babylonian cylinder seals date from the 5th millenium B.C. E.S.

OLSON (E. E.). *History of diamonds in Wisconsin.* Gems and Gemology, Vol. VII, No. 9, pp. 284–285. Spring 1953.

Some twenty diamonds found in isolated areas in Wisconsin. They were found in the terminal moraines of the great glacial ice sheet, and are supposed to have been carried down from the Hudson Bay area by the Laurentian glacier some 25,000 years ago. Earliest report of a diamond find was in 1876, when a crystal of 16¼ carat was discovered near Eagle in Waukesha County during well drilling operations. The stone was bought by a Col. Boynton who bought it for one dollar as a " topaz," and subsequently sold it to Tiffany & Co. for 850 dollars. Col. Boynton subsequently " salted " the area with diamond crystals and floated a company. The fraud did not last long after the " salted " crystals were found to be South African stones. The largest diamond found in Wisconsin weighed 21½ carats and is known as the Therese diamond. R.W.

ANON. *Diamond polishing.* Practical Mechanics, Vol. XX, No. 231 pp. 232–234. March 1953.

A short but comprehensive survey of the polishing of diamonds for jewellery written for the non-technical reader. Reference is made to the close limits of work carried out by the diamond cutter using his eye alone. The actual process of diamond cutting has varied little in the past 400 years. Explanation is given of cleaving; sawing ; cutting (grinding or bruting) and polishing. Note is made of the experience necessary in order to find the " grain " of the diamond before polishing a facet, and the arrangement of

putting on the facets. The process of polishing is described very fully—the actual operations carried out by the polisher giving quite a personal touch. It is interesting to note that the lap is called a *schijf* (pronounced *sky-ve*). This is an unusual spelling and maybe a variation of the Dutch *schyf*. A very readable and informative popular article. 5 illus. R.W.

ANON. *Chinese jade grinding.* Gemmologist, Vol. XXII, No. 260, p. 50.

A short note on the method used in jade grinding during the Ming Dynasty. A two foot cast iron wheel rotated in a vertical plane on a horizontal shaft which was driven by two ropes wound round (in opposite ways) at each end. These ropes were fixed to two pedals and operation produced a backwards and forwards motion. Wet sand and water was used as a grinding and cooling medium. 1 illus. R.W.

ANDERSON (B. W.). *Crossed filters for the study of fluorescence.* Gemmologist. Vol. XXII, No. 260, pp. 39–45. March 1953.

A report on experiments on the employment of complementary filters, as used initially by G. G. Stokes, in the detection of fluorescence of chromium coloured gem minerals. A strong source of light (a projection lamp) is filtered with a 600 ml. round flask containing a saturated solution of copper sulphate. The specimen is then placed in this beam of blue light passed by the filter and observed through a red filter (ruby glass) which passes only those rays which are absorbed by the copper sulphate solution. Whereupon the specimen, if it shows a red fluorescence, will appear a glowing red against a black background. Stones examined by this technique included ruby ; red spinel ; emerald ; topaz ; alexandrite. Extensions of the method included observation of the fluorescence spectra, by viewing the red glow with a hand spectroscope in place of the red filter. By using an ammoniacal copper sulphate solution, which cuts out the yellow rays and much of the green, and employing a yellow viewing filter (Ilford 109), the green fluorescence of certain diamonds ; uranium activated glass and scapolite ; and manganese activated willemite and synthetic green spinels ; and the reddish-yellow glow of Ceylon yellow sapphires may be easily observed. 1 illus. R.W.

FOSHAG (W. F.). *Mexican opal.* Gems & Gemology. Vol. VII, No. 9, pp. 278–282. Spring 1953.

An excellent account of the history and the mining of the opals from Mexico. The author does not agree with the oft repeated statement that Mexican opals are unstable and quick to dry and crack. Fine quality stones are rare and much inferior material is sold giving a poor reputation to Mexican opals. The only Mexican opal available to-day is that from Queretaro—first discovered in 1855. Zimapan is not now a supplier. Mexican opals are the wine-yellow to cherry-red fire opals ; the limped opals with fine play of colour (water opals ?) and milk opals (lechsos). Mexican names are given, and markets and methods of marketing explained. Fakes, such as " replicas " in which two pieces of glass are joined together by an iridescent film—and even automobile tail-light glass have been foisted on to the unwary tourist. Full details of geologic occurrence and the minor localities are given. 2 illus. R.W.

CAUDELL (P. M.) ; WEBSTER (R.). *An inexpensive short-wave ultra-violet fluorescent lamp.* Gemmologist, Vol. XXII, No. 261, pp. 60–62. April 1953.

Describes the employment of a Phillips TUV germicidal lamp, which operates directly off the house mains (200–250 volts), in conjunction with a Chance OX7 filter, to give 2537 A ultra-violet light. The characteristics of the lamp and the filter are given. 4 illus. P.B.

CUSTERS (J. F. H.). *La Belle Helene—a type II diamond.* Gems and Gemology, Vol. VII, No. 9, pp. 275–277 and 287. Spring 1953.

An account of the 160 carat diamond crystal found in March 1953 near the mouth of the Orange river in South West Africa. The stone is said to be a rare type II diamond. Differences between type II and type I diamonds are said to be as follows : Type II diamonds are laminated, type I not. Type II diamonds are transparent in the ultra-violet down to about 2250 Å, whereas type I only to about 3000 Å. Type II do not fluoresce under long-wave

ultra-violet light, type I do fluoresce—mostly blue. There are differences in the infra-red part of the spectrum, and they have different counting properties (for alpha particles and gamma rays). It is mentioned that there may be two classes of type II diamonds (Type IIa and Type IIb). They show different phosphorescence when irradiated with short-wave ultra-violet light and their electrical conductivity differs. Type IIa does not phosphoresce nor conduct electricity. Type IIb phosphoresces a strong bluish colour and can carry a strong electric current when under a potential difference of 100 volts. La Belle Helene was type IIa. 3 illus.

R.W.

FIRSOFF (V. A.). *A gemmologist in the Highlands.* Gemmologist, Vol. XXII, No. 261, pp. 64–67. April 1953.

A description of the author's visit to the Highlands of Scotland and of his search for gem minerals. Venus hairstone, milky quartz, rose quartz, cairngorms and citrines may be found on Creag na Caillich. Almandine garnets, staurolite, epidote, kyanite are mentioned. Pearl bearing mussels are said to be found in Dochart and Fillan Water. R.W.

RUZICKE (P.); STEPANEK (J.), trans. HRASE (J.). *The genesis of diamonds.* Gemmologist, Vol. XXII, No. 261, pp. 57–59. April 1953.

Description of an investigation on the surface structure of diamonds as shown by the electron microscope. From these investigations it is inferred that diamonds with plane octahedral faces grow in sheets of atomic layers by direct attachment of carbon atoms diffused in the magma. In most diamonds it appears that a fog-like emulsion of minute drops of molten carbon was found in the magma. Rounded diamonds, it is suggested, crystallize in a great drop of liquid carbon which developed from the carbon " fog " and became the sole crystallizing centre. The surface of the drop of carbon protected the stone from gross impurities except for colouring matter dissolved in the liquid carbon. Boart and carbonado contain many impurities owing to each minute drop of carbon having formed an independent crystallizing centre. Tetragons (and trigons ?) it is suggested are due to a minute impurity,

perhaps only a single foreign atom, becoming attached to the growing face and disturbing the growth at that part. 2 illus.

P.B.

WEBSTER (R.). *Gemstones and jewellery.* The Police Journal, Vol. XXVI : No. 1, January/March, pp. 69–80 ; No. 2, April/June, pp. 150–159.

Written as a guide for the Police Officer. A comprehensive article giving the main facts concerning the more important gemstones, and the most common fakes. Some easy methods of identification are given ; the more common styles of cutting and information on the precious metals used in jewellery. An indication as to how jewellery may be best described ; literature to refer to ; where to obtain the testing apparatus and liquids referred to, and where and who to approach for expert technical advice. 17 illus.

P.B.

ANDERSON (B. W.). *Simple immersion techniques to determine the refractive index of faceted gemstones.* Gems and Gemology, Vol. VII, No. 8, pp. 231–235. Winter 1952/3.

A rewrite, with notes on additional techniques, of the immersion contact photographic methods, reported in the Journ. Gemmology for April 1952. Stones immersed in a cell of liquid of known refractive index and the cell and stones placed on a bare photographic film (or contact printing paper) and exposed to a point source light, show, on development, by their outline whether they have higher or lower refractive index than the liquid that they are immersed in. Stones of greater refractive index than the liquid show a dark border with bright facet edges on a print of the film. Stones with lower refractive index show a bright border and dark facet edges. The author points out that it is not necessary to photograph the effect, for it can be seen visually if the cell be rested on a ground glass sheet supported at each end by blocks so that a mirror arranged at 45 degrees is below the cell. On looking into the mirror the bottom of the cell is seen with the stones in the liquid. A suitable single point light source is arranged over the cell and the bright or dark borders and facet edges can then be seen comfortably in the mirror. Approximate refractive indices can be found by observing the effect in liquids of differing refractive index. A list of suitable liquids is given. 4 illus. R.W.

BOOK REVIEWS

EVANS (JOAN). *A History of Jewellery*, 1100–1870. Faber & Faber, London. 10 colour plates, 176 pp., 48 line drawings, 5 gns.

This is a detailed account of fashions in jewellery from the twelfth to nineteenth century. The illustrations are particularly valuable and Dr. Evans' book should give much pleasure and reward to those interested in jewellery and the influences that affected design in each century. Various important pieces are described in detail and attention has been given to portraits of well-known persons wearing jewels of a particular period. Dr. Evan's belief that the history of jewellery has reached its conclusion comes as a surprise and an art which is of such importance as to merit the scholarly book which has been produced is not likely to end. The book itself is an inspiration and although at first sight the price seems high, it is a book which will be sought by the collector, jeweller and designer and possibly become a standard work on the history of jewellery in Western Europe for the period covered. A.G.

GRODZINSKI (P.). *Diamond Technology*. 784 pp., 486 illus. N.A.G. Press, Ltd., London. 52s. 6d.

This is a second and extensively revised and enlarged edition of the author's *Diamond and Gem Stone Production*, which was published in 1942. It is divided into two parts (*a*) General Manufacturing Methods and (*b*) Special Manufacturing Methods, though there is some unavoidable overlapping. The author has made a special study of the harder natural and synthetic substances used in industry, and has made this new book a standard work. The first ten chapters will have a special appeal to all gemmologists interested in the cutting and polishing of diamond, for the subject is thoroughly discussed. The remainder of the book is for the engineer interested in watch and instrument jewels, the classification of industrial diamonds and processes connected with grinding and lapping of sintered carbides. There is a chapter dealing with the production of quartz and other optical crystals. The author has avoided writing in too technical a language and at the same time avoided incompleteness. The numerous line drawings are extremely valuable, but a few of the reproductions of photomicrographs lack clarity, though this is a minor criticism of a book which should be of great interest to cutter, polisher, student and all concerned with diamond technology. A welcome innovation is the absence of trade advertisements. S.P.

GEMMOLOGICAL EXHIBITION GLASGOW

by S. D. Wood, F.G.A.

WHAT more opportune time to stage a Gem Exhibition than during a Coronation period ? At a time such as this, when popular interest is centred on our Royal Family, the pomp and splendour of pageantry, and, indeed, in all things appertaining to this great historical occasion, jewels are very much to the fore.

Let us put the Calendar back twelve months to an evening when what was to be a branch of the Gemmological Association of Gt. Britain was in its embryo stage. A group of enthusiastic Fellows resident in the West of Scotland gathered to discuss the prospect of forming a local group in order to retain the interest of students graduating from the Gemmology Classes. One suggestion made that evening was that a Gemmological Exhibition be staged as part of the group's programme. Four months later, this same group unanimously decided to become the West of Scotland Branch of the G.A., and before the Meeting closed, the interim Secretary was instructed to investigate the possibilities of an Exhibition to be held during the Autumn of 1953. An approach was made to the Director of the Kelvingrove Museum, with the hope that he might see fit to allow the Association to use a tiny corner of his large domain for its modest effort. This hope was more than fulfilled, for the Director, Dr. Stewart Henderson foresaw possibilities in such an Exhibition if held in conjunction with the Coronation festivities. And so, overnight, a modest ambition became a large scale project.

The Exhibition opened on 30th May in the presence of six hundred visitors. Councillor James Ritchie, Convenor of the Glasgow Art Gallery and Museum Committee, introduced Professor T. Neville George, D.Sc., PhD., Professor of Geology and Dean of the Faculty of Glasgow University, who opened the Exhibition. In his introduction, Councillor Ritchie intimated that Professor George had been elected Chairman of the Geology Section for the next meeting of the British Association for the advancement of Science, and he felt he was expressing the feeling of all those

Opening Ceremony

concerned in this Exhibition, when he said they were honoured by his presence on this occasion.

Mr. A. Ross Popley, representing the Council of the Gemmological Association, expressed his pleasure at being present on this opening day and would take back with him to his colleagues in London a report on this excellent display.

The opening ceremony concluded with a vote of thanks from Mr. Fred Bryan, Chairman of the West of Scotland Branch. In particular, he mentioned Dr. Henderson for having given such a splendid opportunity to the Association and for the wholehearted co-operation received from him and his Curator Mr. Charles Palmar, not forgetting the office staff and technicians who had rendered valuable assistance.

The Museum, situated on the fringe of Kelvingrove Park and with the River Kelvin flowing nearby (these names perpetuating the name of the great Lord Kelvin), is surrounded by other cultural institutions—the University and the Anderson School of Medicine.

It has its own Association numbering 2,500 members, its schools service, and is the largest local-government-controlled Museum in the United Kingdom.

And, what of the Exhibition itself? What was its main objective? Mainly, its objective was to create an interest in gems and gemmology amongst the citizens of the Glasgow area who, as past records show, seem to have an almost insatiable thirst for knowledge. Owing to the long term of the Exhibition, the hours clashing with the normal business hours of the members, it was quite impossible to arrange for stewards to be in attendance at all times. Nor was it practicable, when stewards were on duty, to carry out demonstrations of gem testing, because of the large numbers of visitors. The members responsible for the various cases set up their exhibits in such a fashion, with cards suitably printed with explanations, illustrations, diagrams and models so that even the merest tyro could follow and understand what was on view. Care and attention was also paid to "window dressing," for to the uninitiated, this does help to appreciate the natural beauty of gemstones. This was particularly noticeable in the real and cultured pearl cases where the pearls were tastefully laid out in shells on a blue velvet background.

The Diamond Section consisted of the three cases. The first dealt with the evolution of diamond from a 20-carat crystal embedded in blue ground, through the various stages of cutting and polishing, illustrated by means of models, to the fully faceted brilliant. The second case held the revolving cone on which were mounted models of some of the famous diamonds including the Cullinan and Kohinoor. The third case included brilliant and baguette cut diamonds, a group of coloured specimens, industrial diamonds, etc., against a background of photographs depicting mining scenes. After viewing this section, visitors were better able to understand the work performed by Mr. Joseph Maman, who gave daily demonstrations of diamond polishing. His work proved a most attractive feature.

Local interest was well provided for in several of the cases. Most interesting, possibly, were the enlarged photographs of the only acknowledged synthetic diamonds ever produced. This scientific "feat" was performed by J. B. Hannay, the Glasgow chemist in 1876 and the diamonds presented to the British Museum in 1878.

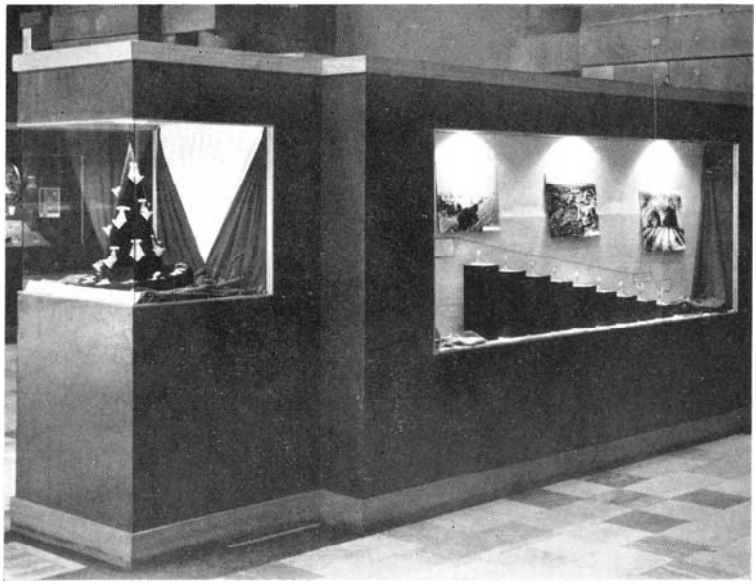

Diamond Exhibit

The Jade Exhibit with its contrasting pieces—the primitive weapons, tools and ornaments of the Maoris against a suite of jade jewellery in modern style—attracted much attention. Crossing to the West Wall of the Hall, the first case was the Ansell Collection, which included the famous Ansell Corundums reputed to be the finest collection of its kind in existence. Also included in this collection was a varied selection of spinels and zircons.

The next case told the story of the gems originating in Ceylon—that veritable jewel box. Displayed in proper sequence was the illam as scraped out of the dried up river beds, the dullam after the first process of washing, and the stages of sorting, cutting and polishing to the finished beautiful gem stone.

The Zircon Story followed along the same lines, with a series of photographs forming an attractive background. Here it was brought to the notice of the layman that the attractive colourless, blue and golden-yellow zircons are in reality the brown variety which has been heat treated.

Other items of local interest included massive specimens of various types of quartz found in Scotland—jasper, bloodstone and

agates ; also amethyst, citrine, garnet and beryl. Interspersed with these were mounted pieces in gold and silver in the shape of brooches, plaid brooches and a suite consisting of necklet, brooch and earrings.

Other cases emphasized that there are a great number of gem stones which are not generally known, and have, in most cases a strong resemblance in appearance to the more common gemstones. This was emphasized in an exhibition of four stones, identical in colour—zircon, beryl, chrysoberyl and peridot. Other

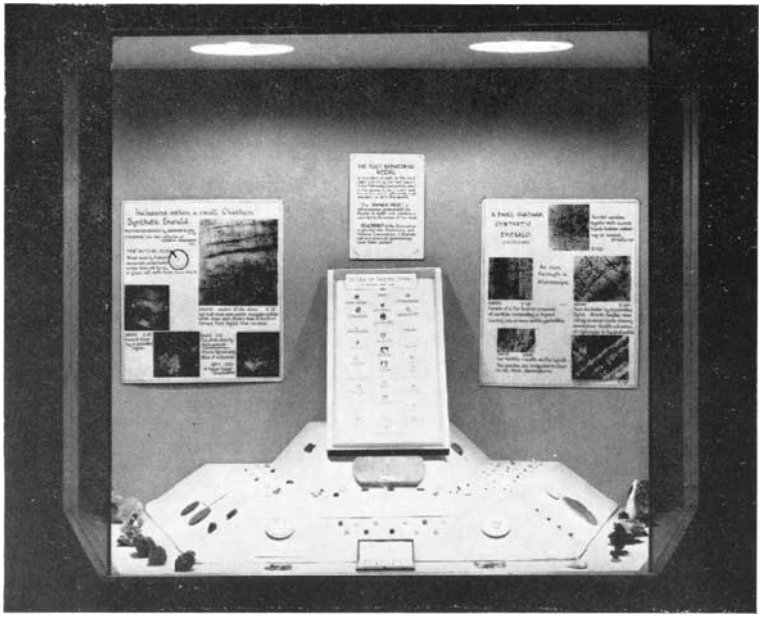

Rarer varieties of gem material

specimens shown were indicolite, azurite, brazilianite, kornerupine, sinhalite sphene and other rare and lesser known gems.

A pleasing and amusing exhibit was a world map, fronted by a panel of 16 press button switches, each bearing the name of a gem, and visitors were able to locate the world occurrence of the principal stones.

Of particular interest to the student was the series of 15 photomicrographs showing inclusions in natural gems and their counter-

parts. This exhibit was specially prepared for the occasion by the members of the East of Scotland Branch of the Association.

In the instrument section were practically all the aids used by the gemmologist in testing, together with explanatory cards, diagrams and models to help those whose knowledge of the subject is limited. The highlight of the section was undoubtedly the case set up with materials which respond to ultra-violet light. This was a piece of very fine equipment which not only delighted the public, but created tremendous interest amongst those acquainted with apparatus of this nature.

The West of Scotland Branch have achieved something of which they have a right to be proud and have undoubtedly created an interest in a comparatively unknown science in these parts.

NEW DIAMOND GAUGE

The new Diamond Gauge which has recently been produced by Messrs. Rayner and Keeler should be of great use to the jeweller as it provides a quick and accurate means of ascertaining the weight of diamonds. There is no other diamond gauge on the British market at the moment. The Leveridge gauge, which costs over £20, and the Moe gauge are unable to be imported.

The Rayner simple caliper takes readings down to 1/10th of a millimeter and the book of tables provided, which is really the most important part of the apparatus, is correct and satisfactory.

The cost of the gauge is 37s. 6d., or with a lens attachment 45s., postage and packing 6d. extra. The lens attachment instead of assisting tends to hinder reading of the scale.

It is a pity that a few extra shillings were not spent on the finish of the gauge and in giving greater clarity to the calibrated scale. Otherwise the gauge is a suitable and satisfactory instrument for the estimation of the weight of diamonds, and we understand it has been rapidly taken up by the jewellery trade.

FURTHER COLOUR FILTER EXPERIMENTS

by L. C. Trumper, B.Sc., F.G.A.

I HAVE made use of the method of feeding stencils successively to the print roll of an addressograph, to feed the large number of colour filters which I now have to a newly designed experimental filter viewing box, in such a way, that without removing my eyes from the viewing position, I can feed in two batches of 25 some 50 filters successively at one loading to a position in front of my right eye, and thereafter these are automatically ejected and restacked in the same order in which they were first loaded into the Feed rack.

Provision has also been made for from one to three filters to be placed additionally over the eye piece so that combinations of up to four filters can be achieved.

In this way with any one filter in the fixed position all other filters can be rapidly passed through and on selecting a suitable combination of two in this way they can if necessary be placed on the eye piece and the remainder passed through again and so further combinations investigated.

In addition to this by suitable fittings which can be rapidly fixed in position, one of the standard filter discs containing four pairs of filters as already described in this Journal, Vol. III, p. 156 (1951), can be inserted in the viewing box and used either alone or indeed superimposed on any of the other filters or combinations of filters.

Finally to provide for future possibilities, three sets of illuminants, all separately switched, are arranged in their lamp houses so that either may be selected to illuminate the box and stones under observation.

One light provides ordinary artificial light for the Chelsea filter, the discs of filters and for general purposes. A lever enables this source to be filtered by the complementary blue filter 45a for fluorescence test of rubies and spinels in conjunction with the Complementary filter 25A. (Vol. III, p. 163). A second illuminant is filtered through the Wratten Photometric filter No. 80 which thus provides an illuminant close to daylight for general

observation. The third illuminant is at present a spare for further development.

The construction of the viewing box is largely based on the experience gained with the earlier models, some useful modifications have however been made. The distance from the observing eyes to the stones under test has been increased, with particular advantage to older gemmologists, by 3 inches, by increasing the height of the box 2 inches and the height of the shaped viewing shield by 1 inch. At the same time the width of the viewing shield has been increased by $\frac{3}{4}$ inch to allow for the insertion of a normal face even if wearing glasses of normal overall width.

A slight increase in the depth of the box also allows more room for the viewing section and its fittings which is also removable without the necessity of unscrewing any screws. This is an advantage as it enables the half dozen or more filters which remain in the slide after the last filter has been introduced by the feeder, to be removed quickly.

The rack on the right can be loaded with up to 50 filters which are then fed by the slider one by one into the feed slide by the simple action of moving the slider from right to left, and then back again. Each movement feeds one filter into the slide, the next movement feeds another which at the same time pushes the previous one along ahead of it and so on.

There are three points to be noted should any other gemmologist contemplate making up a similar system. The first and most important, however obvious it may appear to be, is that of filter size standardisation. It does not matter what size but they simply must be all the same. In my case I fortunately adapted a standard right from the very first gelatine filter that I purchased—a filter size of $1\frac{1}{2}$-in. square, bound between cover slips $1\frac{5}{8}$-in. square. There usually is a reason for most things and my reason was a simple one—I happened to have by me a very considerable number of lantern slide cover glasses of convenient thickness (about 20 to the inch), these cut across with a diamond both ways yielded four squares of $1\frac{5}{8}$-in

Lantern slide binding strips were used to bind the gelatine filters between two cover glasses, but the width was first reduced to approximately $\frac{5}{16}$-in. The fourth edge was bound with white strips cut from gummed labels so that the identification of the filter could be written in Indian ink.

The finished thickness of the filter is about $\frac{1}{10}$-in., and when not in use they are stored in grooved boxes as shown—the grooves being $\frac{1}{8}$-in. wide and an $\frac{1}{8}$-in. deep and each box accommodates about 100 filters.

The second point is that the slider must be so made that at the extremity of its travel to the left, the end of it is some multiple of the width of a filter from the end of the filter in its exactly correct place under the viewing eye whether arranged for the left or right eye.

Clearly unless this is so, the slider movement will not feed the filters uniformly to the eye piece.

When using the slide for the purpose of rapidly changing the filters only one eye can be used and the other eye piece is blanked off by inserting a black square of wood or other opaque substance.

The third point is that after the filters have passed across the eye piece, the length of the slide, if necessary as in my case, by the use of an extension piece must be such that the completion of the movement of the slider just ejects the filter clear of the slide so that it can drop into the collecting rack which they do in the same order as placed in the feed rack.

Whereas the feed rack could be any height to hold almost any number of filters, experiment has shown that there is a practical limit to the depth of the collecting rack.

It was found that with anything over 3 inches deep, the weight of the filter was enough to cause it to turn either partly over or with increased depth right over.

The shorter collecting rack is however an advantage, for whereas the feed rack can be loaded with filters a few at a time until a stack of 50 or more are in readiness, the collecting rack is more conveniently emptied 20 or 25 at a time, as lifting out any greater number only results in the stack collapsing and the filters falling about all over the place.

I have also used a simple device with which to lift the stack quickly from the collecting rack.

The feed rack, slide and collecting rack must be accurately aligned and the dimensions of the slide as regards width and depth should allow for easy movement without any danger of a filter binding through slight inequality of the glass covers.

THE IMPROVED EXPERIMENTAL FILTER VIEWING BOX

A Box of Wratten and Ilford filters
B Slide for large illuminant filter
C Dummy filters to eject last seven filters from slide
D Blanks for eyepieces
E Rotating disc of four pairs of filters
F Adaptor to convert to rotating filter disc
G Drawer for gemstones
H Small illuminant slide to take standard size filters
I Collecting tray for ejected filters
J Lamp house for filtered illuminant
K Lever to actuate Blue complementary filter Wratten 45a
L General purpose illuminant lamp house
M Lamp house providing daylight compensated filtered light
N Feed tray with stack of filters ready for a test run
O Slider to feed filters into slide
P Main switch
Q Slotted viewing shield into which disc is slid and held by a pin around which it rotates
Ei Box for filter discs

NOTE.—The three selector switches will be seen on the front of the box and also a filter can be seen emerging from the slide and about to be dropped into the collecting tray I.

The drawer is of adequate size for placing the stones upon for examination and the whole of the inside of the box is painted with a special flat white paint that does not yellow with age, as so many white paints do. It was specially supplied by Hadfields of Mitcham, Surrey. Special Dead Flat White, Number 605278.

The outside of the box has been carefully varnished with several coats. Incidentally the wood used is a ¼-in. threeply with the outer faces cedar wood or mahogany and the inner ply a softer wood and a much wider ply which takes both panel pins and small brass screws without any tendency to split.

The lamp houses have been constructed from household tins of convenient size so that a 75-watt bulb will fit inside and provision has been made for ventilation which should be light tight at the top of each lamp house.

This is the lid end of a tin (a Cadbury Cocoa tin into which a 75-watt Osram bulb will just go), which is removable to enable a bulb to be changed or inserted and carries a standard bulb holder.

The end of the tin which goes into the viewing box has of course been cut away with tin snips.

For rapid identification the lamphouses have been cellulosed respectively red, white and blue and the colours of the push button switches correspond.

The filters over the light sources whether permanent or swinging into position must be light tight, this being achieved by means of a black velvet lining to the filter holder.

For hot air to escape, it must first be able to get in, so a number of holes have been drilled in the base a couple of inches underneath so that light cannot enter and the base itself is about ¼-in. clear of the bench being supported on four rubber buffers.

The push button switches are used to select the desired light source, but for general switching on and off a more robust tumbler switch at the right hand side conveniently placed below the slider is provided and this is in series with each of the push switches which are themselves in parallel.

A convenient length of flex with the usual adaptor is provided for connection with the gemmological switchboard described in the Gemmologist, Vol. 21.

The writer has a separate source of ultra-violet light with its own light tight viewing box, but if desired the central lamp with its

ventilating lid could be removed and the viewing box then placed under the " black bulb " of the lamp for testing fluorescence through the filters.

The interesting article in the Gemmologist for March, 1953, by B. W. Anderson on complementary filters, or crossed filters as he prefers to call them, for the purpose of producing fluorescence in many gemstones, particularly the red stones and in emerald, alexandrite, etc., and for their spectroscopic study, has since prompted me to make a further improvement to the box.

The left hand or red coloured lamphouse has been fitted with a slide so that from the left hand side a carrier can be inserted which carries the standard size $1\frac{5}{8}$-in. filter. In this way filters can be rapidly introduced beneath the illuminant and the box flooded with the resultant filtered light.

Filters can be quite rapidly changed for experimental purposes and in addition a further slide carrier has been made to take the largest possible filter (approx. $2\frac{1}{2}$-in. square) for regular use after the required filter has been selected from the experimental set.

By the use of this refinement, it will be possible to work out the most useful set of " crossed filters."

Use of the complementary filters Wratten 44a and No. 25 has already been referred to. At the viewing end, Ilford 204 and 205 is equally effective for ruby and red spinel but Ilford 205 is not so effective with emerald. Ilford 608 gives similar results and the Non-Photographic Kodak filter NP.562 will also serve.

The filter at the blue end over the lamp has yet to be experimented with and that is where the carrier and slide will come in. It is of course desirable that as far as possible the filter selected should be reasonably stable and heat resisting as unlike the other filter, it has to stand up to the heat and intense light of the lamp. In this connection Wratten 44a is reasonably stable and heat resistent and has been selected already for those reasons.

Since carrying out the experiments which were the subject of my article in the Journal for January 1953, Vol. 4, No. 1, pages 27 to 32, I have been able to considerably extend my collection of Filters by obtaining the complete set of Ilford filters amounting to about seventy filters, which in no case exactly correspond to any in the Kodak range of Wratten filters. A further dozen or so Kodak Wratten filters have also been added. In addition I have

also obtained a set of about thirty Kodak " Non-photographic " filters. These have been specially made for industrial purposes.

These are generally denser than the Wratten range and are for the most part made to pass a narrow wavelength band only. The available range covers the entire spectrum. These filters are more expensive and are only obtainable as coated glass filters. They can however be obtained cut to any size, so that I was able to obtain a set cut to $1\frac{5}{8}$-in. square and which I then protected by binding a cover glass to the coated side.

It is sometimes difficult to detect which side has the gelatine coating. If in any doubt, a useful check is to gently breathe on what you believe to be the glass side. If your judgment is correct, it will mist over, whereas the coated side will not do so.

Four of the slides proved to be too thick to pass through the instrument but these can of course be readily inserted over the eyepieces.

With the addition of nearly a hundred new filters, it was considered desirable to try further combinations of filters with the blue stones.

The following were a few of the more interesting results obtained with the pale blue stones from hundreds of tests :—

Filters	*Observations*
Wratten 68, 22 & 29F	Beryl, Aquamarine, Tourmaline and Apatite appear black, Topaz and Zircon grey, Euclase and Fluor colourless.
30 Rose Bengal and 203	Tourmaline green, rest colourless.
30 Rose Bengal and 105	Tourmaline green, other colourless but Euclase and Fluor pinkish.
30 Rose Bengal with 302 Minus Red	Aquamarine, Beryl and Apatite blue, Tourmaline a greenish blue, Zircon mauve, Topaz greyish, Euclase and Fluor pink.
Non-photographic 558/C/4	Euclase bright red, Tourmaline deep violet, Fluor pinkish, Beryl bluish, Apatite blackish, Topaz greyish, Zircon greyish.
Ilford 110, 23, E2	Tourmaline green, rest greyish.
302 Minus Red, 23 E2	Similar to Chelsea Filter.

Filters	*Observations*
105 and 302 Minus Red	Fluor and Euclase pink, Zircon colourless, Topaz pale blue, Tourmaline, Beryl, Aquamarine, Apatite peacock blue.
Non-photographic 552/5 and Ilford 501, Micro 6	Aquamarine, Blue Beryl, Blue Apatite and Tourmaline a bright Peacock blue, Zircon grey/colourless, Euclase and Fluor pinkish, Topaz colourless. (Better than 558/C/4 and very similar to the filters 30 and 34a already selected).

So far for pale blue stones, I have been unable to improve on the filters already selected. A further attempt was then made with blue stones of a deeper blue that could easily be confused with blue sapphires, namely two blue tourmalines, two blue spinels, three cobalt blue pastes, a blue garnet topped doublet, a benitoite, a royal blue kyanite and a royal blue iolite.

Many hundreds of tests were then made of which the following are a few of the more interesting results :—

Filters	*Observations*
207 Infra red	All black except the cobalt pastes which were reddish to bright red.
Ilford 111	Both tourmalines green, the pastes slightly greenish, rest black.
NP.549, Ilford 111	Pastes and the garnet topped doublet bright red, rest black or greenish.
NP.549, Ilford 110	Pastes and garnet topped doublet bright red, tourmalines bright dark green, rest black. (Better as background is nearly white).
12 Minus blue	Pastes green or greenish, tourmalines green, rest colourless.

Again it is felt that so far, the filters for the examination of blue stones have not been improved upon, but nevertheless the above examples will show the kind of results that can be obtained and may serve as a guide to other workers.

In conclusion it may be said that colour filters however well they may be selected can never replace the accepted methods of gemstone identification but they form an additional interest and a very quick method of initially checking a parcel of stones and of segregating doubtful specimens.

G. F. HERBERT SMITH, C.B.E., D.Sc., M.A.

1872 — 1953

ASSOCIATION NOTICES

DR. G. F. HERBERT SMITH

— AN APPRECIATION

To everyone who knew him well, the sudden death of Dr. Herbert Smith on 20th April came as a great shock. True, the evidence of the calendar was there to prove that he was over eighty years of age ; but, until the last few weeks of illness, he was so cheerful, so active, so mentally alert, that one somehow did not think of him as an old man, whose going might soon be reasonably expected.

For more than forty years he had rendered brilliant service to the cause of gemmology in this country, and the influence of his work here had spread throughout the world. To realise how great that service was is difficult for anyone who is not himself of that older generation.

His book, " Gemstones," first published by Methuen in 1912, and now in its twelfth edition, had achieved classic status almost from the outset, and, though popular in its appeal, set a standard of scholarship and accuracy that is unlikely ever to be excelled. The refractometer which bears his name is another enduring monument to his fame. It was the first efficient instrument to enable the jeweller to measure the refractive indices of mounted stones, and was a leading factor in establishing gemmology as an exact science.

By the high standards he insisted upon as an examiner, he ensured that the Diploma of the N.A.G., and later of the Gemmological Association, was a distinction with an enviable reputation at home and abroad. Moreover, it was mainly due to his tactful, authoritative, and persistent advocacy that the metric carat was officially adopted in this country in 1914, superseding the old " English " carat with its incredibly clumsy fractions as a medium for trade in precious stones.

When the Gemmological Association at length became a separate entity it was Herbert Smith's influence which enabled us to claim in succession such illustrious scientists as Sir Henry Miers and Sir William Bragg as Presidents of the Association. That he himself should then become our President was supremely fitting. It is good to know that he appreciated the honour keenly. On the title

page of " Gemstones," after the author's name, there is no parade of distinctions to which he was entitled (D.Sc., M.A., C.B.E.) but simply the phrase " President of the Gemmological Association of Great Britain." He never considered his office to be a mere sinecure, and was a constant attender at the Council meetings of the Association and at its major public gatherings. For many years he made it a practice to visit the Gemmology classes at Chelsea Polytechnic and deliver a short informal address of welcome and encouragement to students attending their first classes there.

He never courted publicity : his manner and appearance were, in fact, somewhat forbidding. But he was a loyal and generous friend to those who were not deterred by this lack of superficial cordiality. He had a keen sense of humour and an unusual fund of true humility which made him not too proud to accept correction and advice from his juniors when he realised that this was well founded.

While his book and his refractometer remain as tangible memorials to the name of Herbert Smith, of little less importance are those intangible qualities of integrity and respect for truth which his influence and character caused to be built in to the very fabric of the Gemmological Association of Great Britain.

Dr. Herbert Smith was born in 1872. He was the elder son of the Rev. George Smith, head master of Edgbaston Proprietary School, and of Doncaster School. He was educated at Winchester and New College, Oxford, where, as a scholar of the college, he read mathematics and physics. He studied crystallography under Professor P. Groth at Munich and later took up an appointment at the British Museum (Natural History), as an assistant in the department of Mineralogy. Later, in 1931, he became Secretary of the Museum and subsequently Keeper of Minerals (1935) until his retirement in 1937. He wrote many important papers on mineralogy and crystallography and, apart from his well-known refractometer, designed the three-circle goniometer.

He was a Fellow of the Royal Astronomical Society and of the Geological Society for many years, and a life member of the Mineralogical Society of Great Britain.

Apart from his keen interest in the Gemmological Association, Dr. Herbert Smith was Honorary Secretary of the Society for the Promotion of Nature Reserves and of the Nature Reserves Investigation Committee. He was also chairman of the Wild Plants Conservation Board and a member of the executive committee of the Council for the Preservation of Rural England. Outside scientific fields Herbert Smith had many activities, which included work for the Society of Civil Servants and the Civil Service Arts Council. He was also a member of the Council of the Royal Albert Hall.

Dr. Herbert Smith bequeathed his scientific books to the Association and the oil painting of himself, which was presented to him by the Association on the occasion of his retiring as senior examiner.

B.W.A.

TWENTY-THIRD ANNUAL MEETING

A tribute to the memory of Queen Mary was paid at the opening of the twenty-third annual general meeting of the Gemmological Association held at Goldsmiths' Hall on 1st April.

The Chairman, Mr. F. H. Knowles-Brown, who presided in the absence of the President, Dr. G. F. Herbert Smith, recalled that Queen Mary had always shown great interest in the association's work and given it her support in recent years. Members stood in silence as a token of respect to her late Majesty.

Mr. F. E. Lawson Clarke, the Honorary Treasurer, presenting the accounts, said there was a small surplus. It was, however, considered necessary to increase the Fellowship subscriptions from one guinea to 30s. 0d. next year. The present rate had been maintained since 1947.

Mr. Knowles-Brown in reviewing the events of the year said the most important happenings had been the establishing of branches. For some years it had been felt that this was desirable, because it gave an opportunity for those who could not get to London to meet together and further the work of the association. Three branches had been formed, two in Scotland and one in the Midlands. Already a great deal of work had been done. At a recent Birmingham meeting of the Midlands branch the attendance was seventy, which showed the extraordinarily good support. He thanked those who had helped to get the branches going.

Dr. Gübelin's lecture on diamonds had been notable and a twelfth edition of Dr. Herbert Smith's book had been issued with new material, together with a new publication from their vice-chairman, Sir James Walton.

The report and accounts were adopted.

The officers of the association were re-elected and it was agreed to send a letter to the president, Dr. G. F. Herbert Smith, hoping that he would soon be recovered from his illness.

Mr. F. Ullmann congratulated the Vice-Chairman on his book which was so helpful to students.

The retiring council members were re-elected and the Chairman in thanking all council members for their help said there had been a very good attendance at the council meetings.

Mr. G. Myers suggested that a lapel badge should be available for members who wished to wear it. Some members, he said, had expressed the view that such a badge was superfluous, but he thought it was needed for the reason that some Fellows like himself were behind the counter. Other assistants who were not gemmologists sometimes gave information to the public that was inaccurate. He had heard members of the public told that there was no difference between a diamond and a zircon except price. If an assistant were to wear a badge the public would notice it and have confidence in it, or, receiving inaccurate information, could take up the matter. Horologists wore a badge showing their proficiency. A badge would give a better understanding between the laymen-customer and the gemmologist.

Mr. Fishberg supported the idea and said he had taken the liberty of having a badge made for display which had been used in the retail business. It had been noted by the public, who had thus learned about the association.

Mr. F. Ullmann expressed opposition to the wearing of badges, saying it would lower the status of the association. Professional men, doctors, lawyers and so on, did not wear badges. If a man knew his subject, this was apparent to all. Mr. S. Redknap pointed out that it was a fallacy to think that examinations alone made an expert. He knew many people in the trade who had not passed examinations but who had forgotten more than he would ever know. Experience was necessary in the making of a gemmologist. Theory was not all.

The Chairman said the question had been raised before. The matter would be considered by the council if the meeting wished it.

Sir James Walton referring to the point made about the professions, said that the public could look up the qualifications of a doctor or surgeon in a reference book. Gemmologists had no such directory. He hoped to see a trend towards all people in the trade becoming qualified members of the association until any who were not would be working under a handicap.

On a vote being taken on whether the council should consider the introduction of lapel badges, it was heavily defeated.

MR. S. F. BONES

The death occurred in London in May of Stanley Frederick Bones, who was Honorary Treasurer of the Association from 1947 until his resignation on account of health in 1951. He obtained his Fellowship Diploma in 1946 and, after his election to membership gave much time to serving the Association.

NETHERLANDS GEMMOLOGICAL ASSOCIATION

At the annual general meeting of the Netherlands Gemmological Association (Nederlandsch Genootschap voor Edelsteenkunde) held in Amsterdam on 4th May, the following Officers were elected :—President : Ing. J. Hammes, F.G.A. ; Treasurer : D. Dresme, Jr., F.G.A. ; Secretary : D. Vos, F.G.A. Messrs. A. Bonebakker, F.G.A. and A. Schaap, F.G.A. were elected to serve on the Council of the Association.

TALKS BY MEMBERS

Parkinson, K. : " The testing and discrimination of precious stones." Sheffield and District Branch of the British Horological Institute, 27th May, 1953.

Meader, N. A. : " Famous gems of the Crown Regalia." Boscombe and Southbourne Rotary Club, 21st May ; *ibid.*, Bournemouth Seroptimist Club, 8th June, 1953.

Leak, F. : " The Coronation Jewels," Canadian Club of Bristol, 11th June ; *ibid.* Patient's Staff, Bristol Mental Hospital, 25th June.

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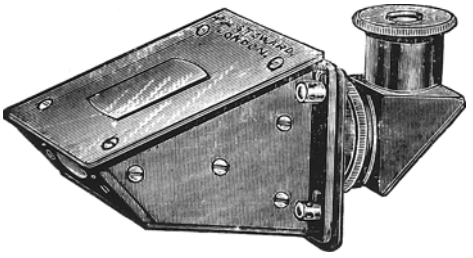

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AND PROCEEDINGS OF THE GEMMOLOGICAL ASSOCIATION OF GREAT BRITAIN

Vol. IV No. 4 OCTOBER 1953

FORENSIC GEMMOLOGY

by ROBERT WEBSTER, F.G.A.

ARISING from a discussion with a detective officer of the Metropolitan Police Headquarters, New Scotland Yard, it has been the writer's privilege to publish in a semi-official journal circulating among Police Forces throughout the British Empire[1], an article giving elementary information on gemstones and jewellery for the guidance of Police Officers. That this compilation was well received is evident by its re-publication in the *International Criminal Police Review*—the Official Journal of the International Criminal Police Commission (INTERPOL), whose headquarters are in Paris, this Journal being circulated to the Chiefs of Police in almost every country in the world.

The concluding paragraphs of this article were set out to show where any police officer could obtain advice on jewellery and gemstones. It is the intention now to suggest how any gemmologist called upon to assist the police, and who is willing to do so—as one should be if circumstances permit—may best perform the required services. To this end some idea will be given of the usual requirements of an investigating officer; the necessary testing required for given cases—both hypothetical and actual—and some details of Court procedure should the gemmologist agree to attend as an " expert witness."

Cases involving fraud are those most likely to come the way of the gemmologist. Such cases mostly comprise the simulation of diamond by white zircon, synthetic white spinel, or similarly made corundum, and other colourless stones—even pastes. The question " synthetic *versus* natural " seems to be a subject rarely investigated in the criminal courts—more often such a problem is dealt with before the civil court. However, the procedures in either court are fundamentally similar.

Questions involving jewellery in charges of theft may sometimes occur in which the gemmologist may be able to assist. Such matters may well involve considerable gemmological skill. Even the most serious charge in the criminal calendar may require the service of a technical gemmologist. This was manifest in the report of one such case which will be briefly referred to in this article. It is these last two types of cases which produce the most interesting work; sometimes even needing experiment.

For the purposes of description let a relatively simple case of fraud be taken; say a zircon ring fraudulently sold as a diamond ring. Such a description may well be divided into three main sections: the initial visit and discussion with the police officer in charge of the case; the testing and reporting and lastly the actual giving of evidence before the court.

A police officer having charged a person—in this case possibly with a charge of " stealing by means of a trick," or " obtaining a sum of money by false pretences," then has to prepare his case. He, or she, for there may well be a woman detective on the case, must not only produce his witness or witnesses to prove the actual commission of the crime, and give evidence of arrest; but must also find a suitable " expert witness " to testify to the stone, or stones; the nature of the mount; the value of the ring as it is and also its probable value should it have been set with real diamonds.

Finding a suitable and willing expert to give such evidence is one of the headaches of the detective officer, for his only hope is to approach any local jewellers for assistance. In doing this he may spend much valuable time finding someone who is suitable and willing to attend the court hearing. In this connection it is much more satisfactory to the officer if his witness has " status," and that is where a Fellow of the Gemmological Association is more acceptable than an ordinary jeweller. To this end the Gemmological

Association may give on request the names and addresses of all qualified gemmologists in a given area to any police officer needing such services.

It will be wise to mention at this stage the *snag* which causes most annoyance to a witness. That is the time wasted hanging about the court before being called to give evidence. This is in no way the fault of the detective dealing with the case, for he is answerable to the court and must produce his witnesses when called upon to do so. It is not always possible to state with any accuracy the time a witness will be required, hence, witnesses are required to attend in good time. Further, the defence may ask for further time to prepare the case, and this the magistrate usually gives, even if all the prosecution witnesses have been assembled. A remand for another day thus makes an abortive attendance for those witnesses. These are matters over which the police have no control. In recent years, however, the judge usually dismisses from the case all expert witnesses as soon as they have finished their evidence. This is a favourable and understanding turn from the old times when witnesses were not allowed to leave until the close of the case. The writer has purposely placed emphasis on these snags because it is better to be warned than to *moan* afterwards. With the modern judicial efficiency it is rare for an expert witness to be at the court for more than one day—only half a day is more usual. It is wise to remember that any attendance at court is not wasted, for the crook fraternity are detrimental to your own business. It is for your ultimate benefit, and for your colleagues in the jewellery trade, that you should assist the forces of law and order whatever be the slight inconvenience involved.

The first point to consider if asked to assist the police is whether the time can be afforded. If you cannot do the job then tell the officer directly, but do, if possible, advise him where next to try. If you are prepared to assist, then get a clear idea of the officer's need and further, get from him the full facts of the case as far as it is known. The writer states this advisedly, for you with your general and technical knowledge may be able to suggest points which have not been realized by the officer, who may well be unversed in gemstones and jewellery.

Having in mind the full picture, the necessary testing is next carried out. The gemstones will usually present no difficulty, but

the metal of the mount is more of a problem because to obtain an accurate determination of the metal and its quality would need an assay, which is outside the scope of a jeweller/gemmologist. It is a good plan, therefore, that the officer be informed that your decision is based on tests by acids, and, thus, can only be approximate.

It is suggested that on completion of the testing a full personal report be written out. This report should be signed by you and given to the detective. The report, of which you should keep a copy, should contain: a good description of the piece or pieces of jewellery; the nature of the stones and the metal of the mount, with, on your own copy, notes of the tests performed in all cases; your estimate of the value of the jewellery—each individual piece separate—and your estimate of the probable value if the stones had been real diamonds.

It is at this stage, *i.e.*, before the "signed statement" is made, that some consideration be given to the presentation of your evidence. In a simple straightforward case, where oral statements in the witness box are all that would be required, nothing further need be done than that which has been outlined. Depending on the nature and seriousness of the case, it may be felt that pictorial illustrations may be of assistance to the court in emphasizing the points you need to bring out. Should you decide to put in pictorial evidence, then prepare these ready for the first hearing (at the lower court), where they will be put in as exhibits.

Should pictorial illustrations *not* be prepared for the lower court and the case goes to the Assizes or Sessions (higher court), then, if it is considered better to supply pictures and this is done, such exhibits will need to be put in as additional evidence. Such an arrangement is not favoured by either the court or by the police authorities. It is for this reason that it has been stressed that the full facts—the strengths and weaknesses of the case—are obtained from the police officer in the first place. The employment of photography or drawings as an aid to presentation will be discussed later.

For completeness a few notes on court precedure could with advantage be given—mainly for those readers who have not had the necessity of attending a court hearing. Firstly, it should be noted that a witness attending court must remain out of the court

during the hearing of his case until called upon to give his own evidence, after which he remains in court until the end of the case; unless, as pointed out earlier, the judge allows the witness to leave. On being called into the court to the witness box, the usher, or sometimes the Clerk of the Court, will instruct you to read the oath, the wording of which may not be quite the same in all courts. Following the taking of the oath the Clerk will state your name, address and other particulars and ask you whether they are correct. The examination will then be taken over by the prosecuting solicitor (or barrister if in a higher court) who will ask you such questions which should bring forth answers from you which are the means of proving his case against the accused. In the hypothetical case of the zircon ring the questions may well be quite simple, such as: What are the stones in the ring? What is the metal used in the mount? What is your estimate of the value of the ring? What would be the value of the ring if the stones were genuine diamonds? Quite often, and sometimes by the judge himself, you may be asked to explain what a zircon is and how it compares with a real diamond. In cases heard before a jury the judge often puts such questions in order that the " twelve good men and true " should be in full possession of all the facts. Such questions should present no difficulty to a trained gemmologist. Indeed, it is for this very reason that the police authorities prefer a qualified gemmologist to a non-technical jeweller, who, maybe, knows the value of jewellery well, but is often hazy over the nature of the stones used as" fakes." To report, as one so-called expert did recently (if the press report be true) that the stones in a ring were " white spinels " known as " jargoons," lays a witness wide open to discredit from a knowledgeable defending lawyer. It is he who cross-examines after the prosecuting lawyer and his questions aim at bringing out any point which will favour the accused.

All the evidence given at the first hearing, *i.e.*, at the lower court, is taken down in writing by the Clerk of the Court. If the case is sent for trial—to the Assizes or Sessions—then the witness signs this written copy of his evidence, and he is then " bound over " in a sum of money to attend the hearing at the higher court. This is one of the " snags " in acting as an expert witness, for no exact information is forthcoming as to when the higher court will hear the case, and, moreover, the higher court may be held at a place

some distance away, which again wastes time in travel. Unfortunately these difficulties cannot be wholly avoided, but at the present time everything possible is done by the authorities to minimise time wastage.

Suggestions for the initial preparation of the evidence may be best demonstrated by assuming definite types of cases and discussing various methods which may well assist in driving home the points it is desired to bring out. By discussing a number of different cases it should be possible to apply these as a " framework " for any given problem.

Let the simple zircon ring case be the one to start with. The initial testing, from a gemmological point of view, would be to prove the stones to be zircons, by, it is suggested, the double refraction and the absorption spectrum. What can be done by way of identifying the metal of the mount and making the necessary valuations will complete the data required. In the matter of the presentation of the evidence, anything which will implement the spoken word would be an advantage, and in this respect photography can be an invaluable silent witness.

A photomicrograph of the doubling of the back facets seen in the actual stones in the jewellery—even the effect seen in one stone of the piece—will do much to assist the court, with, of course, verbal explanation that the doubling effect cannot be seen in diamond.

The question of the best type of photograph for this presentation may conveniently be discussed. The usual type of photomicrograph showing the doubling of the back edges of a stone due to double refraction illustrated in text books, may not be the best. Such a picture is shown in Figure 1. Although such a picture could be used, if it is possible to employ a sufficiently low power so as to show the full outline of the stone the impression will be clearer to the court and especially to a jury. Figure 2 illustrates this point. While contact prints might be acceptable (if the size of the negative be suitable), it is manifestly far better to have enlargements made —postcard size or 6 ins. by 4 ins. would be suitable. Initially three copies are needed, one for the prosecution and one for the defence, and a copy for you to hold as a control. If the case goes for trial before a jury a further six copies would probably be required—it is usual to have one copy between each two jurymen. Another copy to hand to the judge might well be desirable, or you

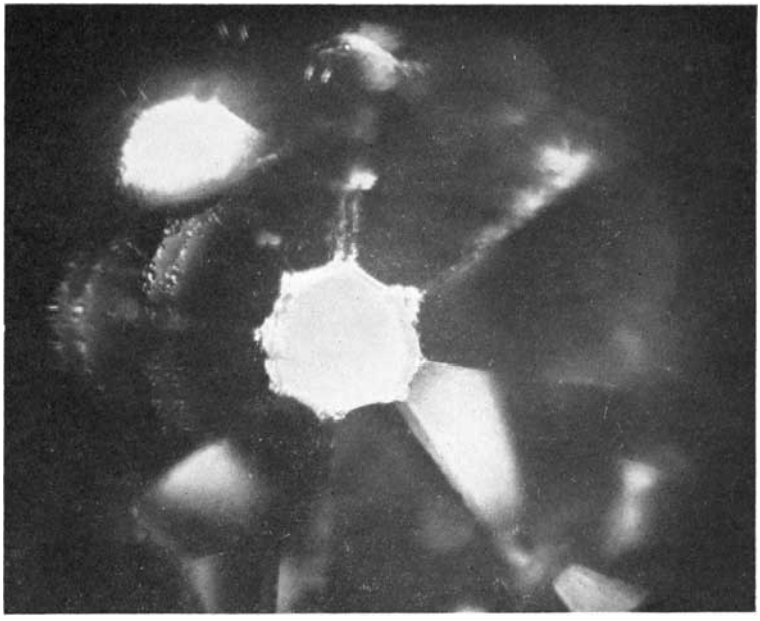

Fig. 1. *The usual type of text-book illustration of the doubling of the back facets of a zircon showing "paper worn" edges.*

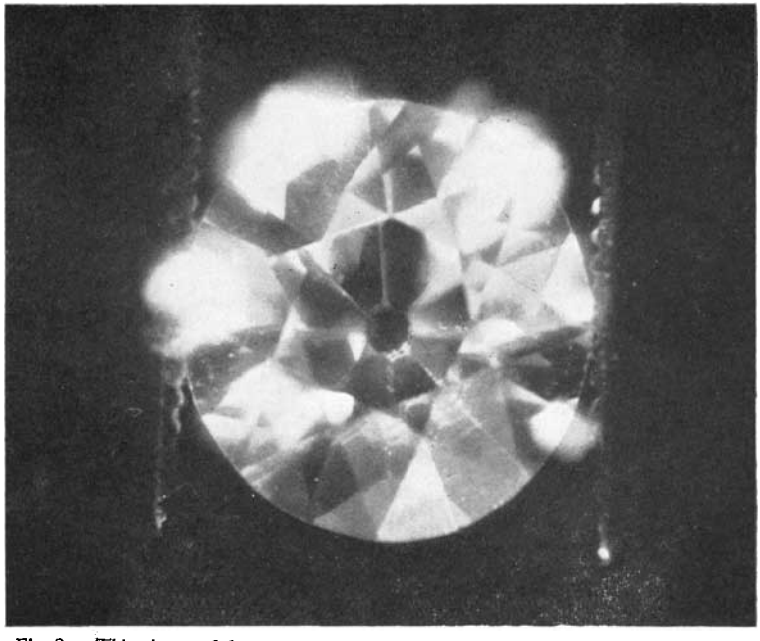

Fig. 2. *This picture of the same zircon as pictured in Fig.* 1, *has the advantage of showing the full outline of the stone. Such a picture is better understood by a lay person.*

could hand him your own " control " copy. Anyway, the cost of all photography is a charge on the expense sheet. It is not suggested that it is necessary to go to the extent of photography in every simple case. The detective officer will tell you how strong or weak in evidence his case is.

An elegant variation of the pictorial exhibit was used by Anderson nearly twenty years ago (Rex *v.* Rice). In this the marked difference between the degree of transparency to X-rays of diamond and white zircon was employed. Figure 3, which are prints of the actual radiographs taken at the time, show the effect. The lower picture was the one used in evidence in order to show that there was indeed a diamond in the single stone ring, for should the top picture have been used alone there would have been no reply to the defending lawyer's assertion that there was never a diamond in the ring. The contention that X-radiography is completely outside the scope of the average gemmologist has been proved false by Vincent[2], who obtained the services of a dentist in possession of an X-ray machine. Quite a number of dentists have such apparatus and would be willing to take the necessary X-ray picture. Or, in serious cases, the police would doubtless contact a hospital and obtain their assistance in taking a radiograph.

If the subject of the fraud is either a synthetic white sapphire or a synthetic white spinel, a " relief " picture comparing the degree of relief of the synthetics with that of diamond when immersed in a highly refractive liquid may be prepared. Such a picture is shown in Figure 4. The same effect may be shown with pastes.

A short discussion on the murder case referred to earlier (Rex *v.* Heath) will illustrate several points. In this case a solid glass imitation pearl bead was found in the jacket pocket of the accused, and the problem was to prove, as far as proof was possible, that the pearl could have come from a necklet, the broken remains of which were found near the body of the second victim. This pearl was sent to the Laboratory of the London Chamber of Commerce, with several of the pearls found by the body, for the experts there to see what comparison could be made.

The problem was not easy, for there was little in the way of published data on imitation pearls to go on. After an accurate weighing of the pearl found in the accused's pocket—for control purposes—an accurate density was taken by suspension in a bromoform

Fig. 3. *X-ray comparison photograph of zircon rings (in 3 cases with one stone deficient) showing the opacity of the zircons and the transparency of diamond to the rays. The lower picture was taken with a shorter exposure in order to prove that there was a stone in the diamond ring.*

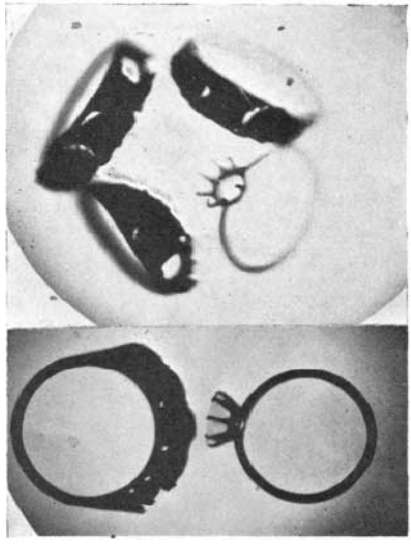

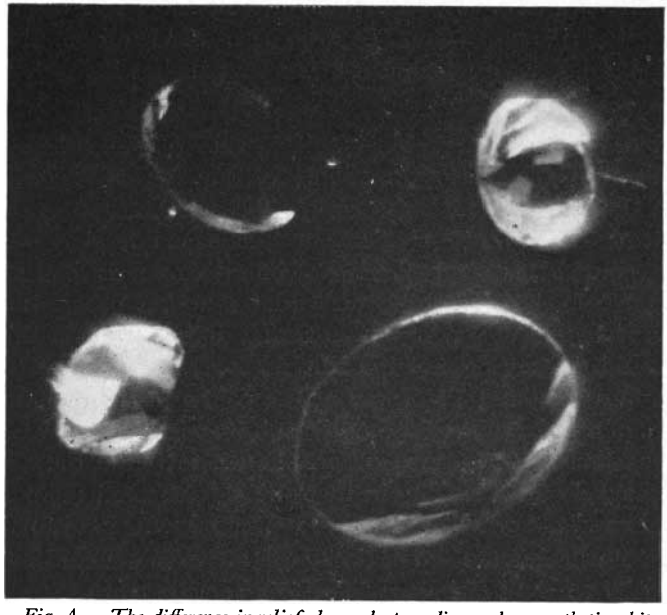

Fig. 4. *The difference in relief shown by two diamonds, a synthetic white sapphire (smaller stone) and a synthetic white sapphire (larger stone) when immersed in lighter petrol. Petrol was used instead of monobromonaphthalene as in the latter liquid the stones could scarcely be seen in a photograph.*

mixture and compared with the density of pearls from the broken necklace. The densities were not only found to be exactly similar, but were significantly lower in density than the values found for imitation pearls of that type by the writer some time earlier[3]. This, and the fact that the pearls were new, judged by the fact that the pearl essence coating near the string canal was not worn to any extent, suggested that the usual type of glass employed to make beads for imitation pearls was not used. This, it was considered, may be due to the fact that the manufacture of the "alabaster glass" normally used had not then been restarted after cessation during the war. Enquiries proved this premise to be correct, and to verify how common these low density pearls were a great number of pearls were examined for their density—the result of this minor research was published for record[4]. Comparison of the size of the string hole and the colour and texture of the "pearl essence" skin was made. The several chemical spot tests for the nature of the bonding of the guanine crystals in the essence forming the skin, reported in this journal[5], were not avail- at the time and were not used. One of the peculiarities of this case was that the one pearl found in the pocket of Heath could not in anyway be destroyed because it was essential that it be produced in evidence as an exhibit.

Another police investigation involving solid glass bead imitation pearls was mentioned to the writer by Mr. Lewis Nickolls, the present Director of the Metropolitan Police Forensic Laboratory at New Scotland Yard. In this case, the accused, charged with larceny, contended that the string of imitation pearls found in his possession belonged to his daughter and were not proceeds of the larceny. Mr. Nickolls was able to take a different line in this case as he could destroy part of the exhibit. His method was to take spectrograms of the glass of one of the pearls in the necklet, and the glass of a pearl taken from necklets in the stock from where the theft was presumed to have occurred. In this case the spectrograms showed dissimilarities, in that one glass showed the presence of arsenic and the other did not. The accused was acquitted. This instance illustrates the impartiality of an expert witness—he is there solely to assist the court in arriving at the truth.

Pearls are not as a rule suitable for pictorial representation, but cultured pearls may radiograph well enough to show with sufficient

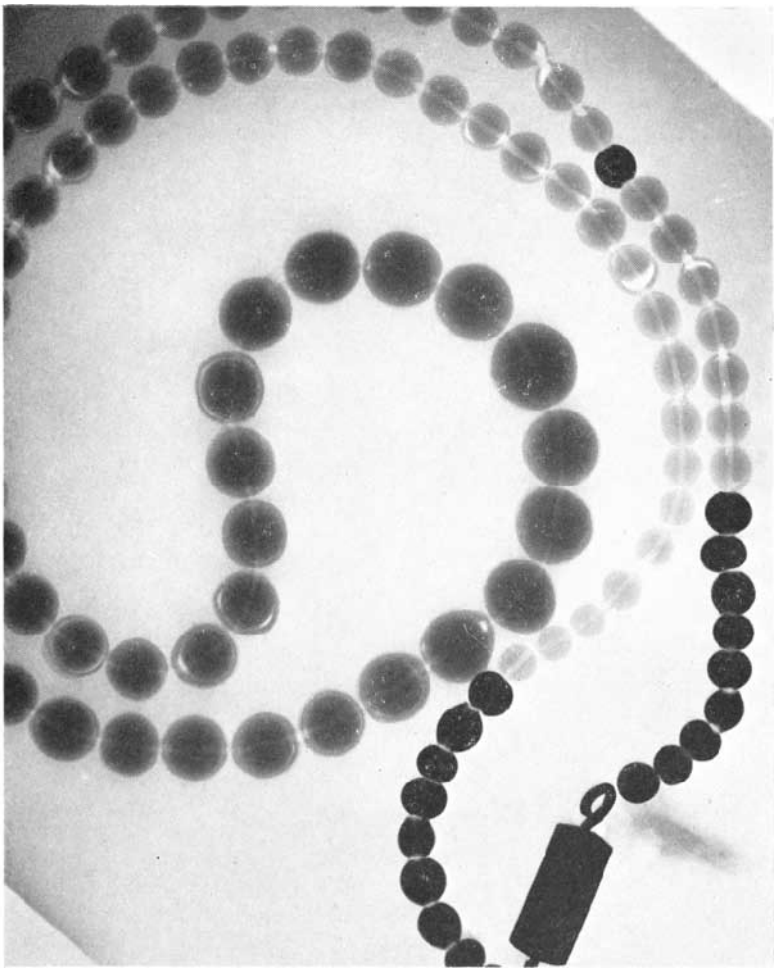

Fig. 5. Imitation beads in a cultured pearl necklet are shown up by their great opacity to X-rays. There are nine imitations at each end of the necklet and a stranger in the body of the necklet.

detail the bead nucleus to be of value as cogent evidence. The inclusion of imitation pearls in a necklet also show by their opacity to the rays, in comparison to the other pearls, that they are "foreign" to the necklet (Fig. 5). Synthetic stones and garnet topped doublets may also be suitable subjects for photographic presentation of evidence. It may be as well to remind the reader

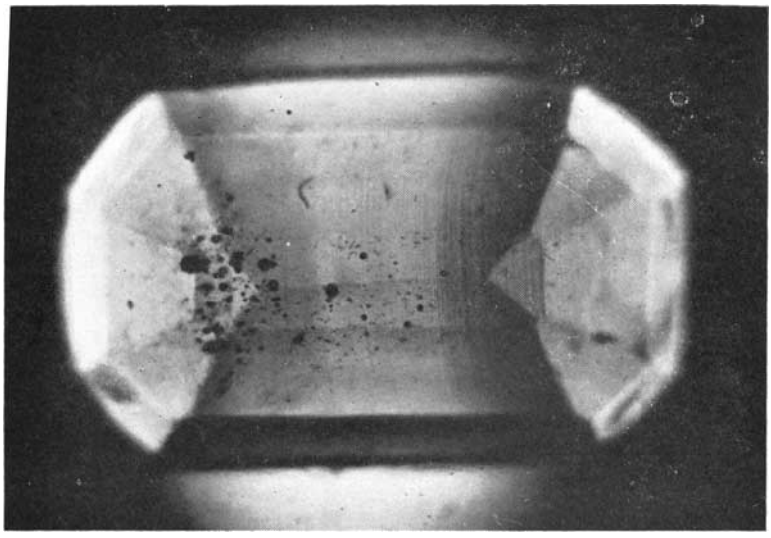

Fig. 6. Enlarged photomicrograph showing the curved lines and gas bubbles in a synthetic ruby. Note that the full outline of the stone is pictured.

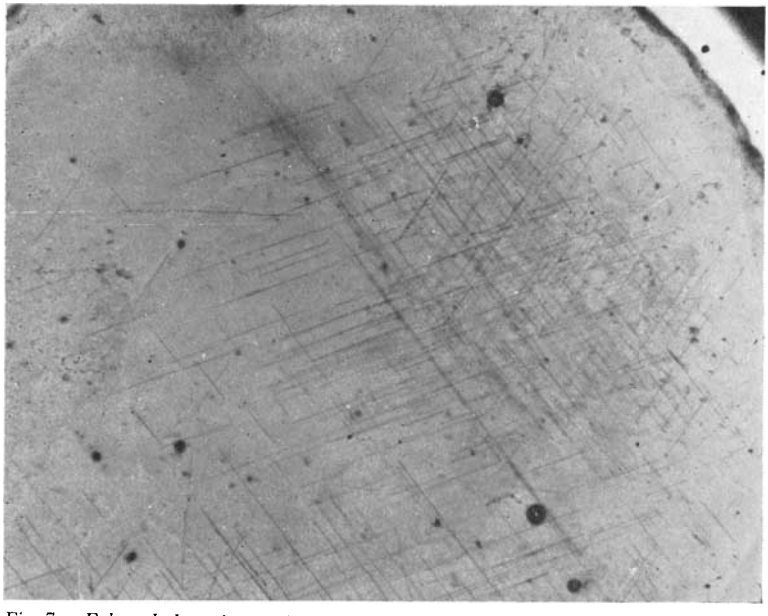

Fig. 7. Enlarged photomicrograph of a garnet-topped doublet. In this case the full outline of the stone is not shown, but there is sufficient to enable the layman to understand the description given by the witness.

that such pictures are to be shown to lay persons, and if the full outline of the stone can be got on to the picture it will be much more readily understood (Figures 6 and 7).

In a comparatively recent trial (Regina *v.* Hewett), the accused being charged with burglary and/or receiving stolen property, the prosecution sought to prove, as part of their case, that some small diamonds found in Hewett's possession had been forced out of a brooch which was part of the property stolen. In order to make clear to the jury the reasons for assuming that the stones had indeed been forced out of jewellery, the writer, who gave expert evidence in the case, prepared a photomicrograph showing the broken edges of two of the stones. The photograph was taken by reflected light, the stones resting on a piece of black paper—initial magnification being 10.5x and then enlarged 1.5 times giving a final magnification of approx. 16x. This was quite easy as only the broken girdle of the stones needed to be in focus (Fig. 8).

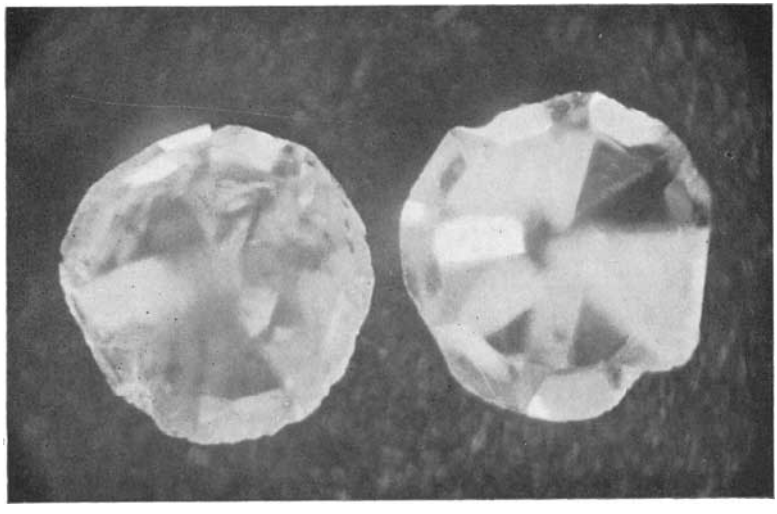

Fig. 8. *This photomicrograph showing two small diamonds (there were* 23 *diamonds weighing together* 0.53 *carat involved in the case) was taken in order to demonstrate the submission that the stones had been clumsily forced out of their setting.*

The photography so far discussed has been that used in conjunction with a microscope. Such type of work is best carried out by a gemmologist who understands the techniques of examining the internal features of gemstones. If it should be necessary to

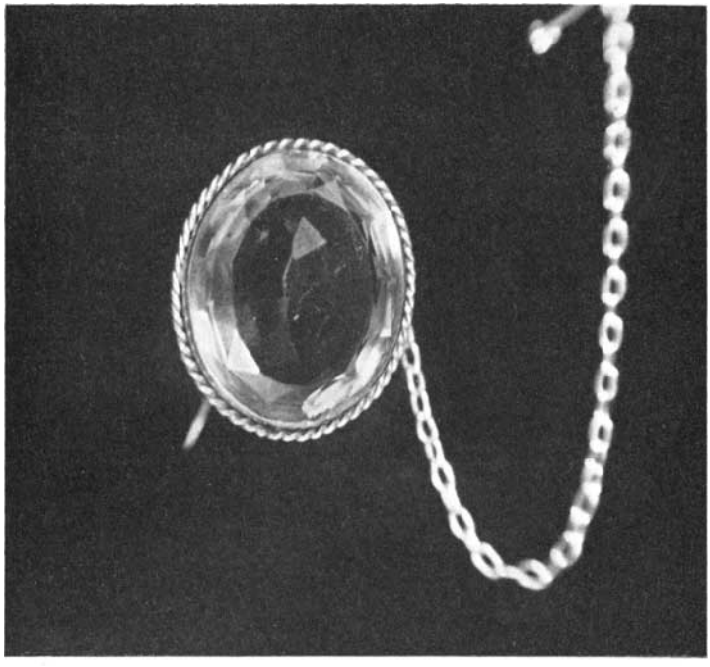

Fig. 9. An experimental picture of a single stone citrine brooch. This was taken with a small reflex camera, over the ordinary lens of which was held a short focus lens. This supplementary lens was an ordinary convex lens and failed to give sharp definition at the edge of the field, as is shown by the imperfect focus of the safety chain.

photograph pieces of jewellery in order to show the positions of stones or damage to the setting, the problem is rather one for a professional photographer, who should be told what prominent features to bring out. There is of course no reason why a keen amateur photographer should not be successful in producing what is necessary. Figure 9 shows what can be done by an amateur. Radley[5] recommends that in the photography of gemstones it is best to paint the stones thinly with a white water-paint, the solid edges and angles having the paint removed from them—this is to eliminate interference by reflections. It is suggested that the stone be placed on black velvet and photographed from above using low magnification, up to five diameters if the stone be small. A camera with double extension bellows in conjunction with a short focus lens is most convenient. To avoid the multiple reflections from

the stones in a piece of jewellery an indirect method of lighting has been evolved. The jewellery is placed on black velvet and completely surrounded with a cylinder of white paper. A concentric ring of lights around the paper gives an even diffuse glow over the whole piece which is then photographed from above.

Photography has been stressed advisedly for it is probably the best means of illustration. This does not imply, however, that practical demonstrations may not be of as great a value providing that they are not too elaborate—over elaboration would probably confuse the issue. A density test might conceivably be shown in court, or an experiment on painting the back facets of diamonds in order to improve their colour. At least two cases of experimental painting of diamonds has been carried out for the court, but whether actually in the courtroom or not is not clear. According to Press reports, in one such case the " expert " was reported to have stated that the stone had been painted with " luminous paint." It is rather difficult to reconcile that with colour correction.

In more serious cases it may be well to remember that when first examining jewellery, especially rings, that evidence may be concealed within the recesses of the setting. Obviously any investigation along these lines must be the work of the professional forensic scientist. Do, however, enquire about this factor before cleaning the filth from such settings in order to complete your own work. Failure to do so may destroy what may have been vital evidence.

At various times much has been made of the idea of " fingerprinting " gems and jewellery. In certain countries, particularly France and the U.S.A., certificates have been issued giving details of size and shape, weight, surface and internal imperfections, etc., with the view of future identification in mind. Although this problem is essentially bound up with forensic gemmology, the subject is too broad to include in this article without making it unduly long. It is hoped that a fuller discussion of this particular aspect may be given in a future issue of this Journal.

The writer has endeavoured to describe, within the limits of an article, the essentials, as far as gemmology is concerned, of police investigation and court procedure. Before closing it may be wise, if loose stones are the subject, to take into court a suitable pair

of stone tweezers—or better, spring tongs, in order to hold the stone safely. A lens should, of course, always be to hand. Finally, it must be stressed that your evidence is impartial, and your evidence can only be true evidence if it is your own work. Do every test and weighing yourself.

Acknowledgement is made to Detective-Inspector R. E. Phillips of the Criminal Investigation Department of the Metropolitan Police, New Scotland Yard, for his helpful suggestions.

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EXPERIMENTS with a POCKET MAGNET

by B. W. ANDERSON, B.Sc., F.G.A.

IN manuals of petrographic methods, such as the well-known books by Johannsen and by Milner, the magnetic properties of minerals are treated as a matter of considerable importance, and practical instructions are given for the separation of mineral grains into different categories by means of an electro-magnet. A much briefer treatment of magnetic methods is given in works on mineralogy, while in gemmological text-books, though some attention is usually given to the electrical properties of stones, the subject of magnetism is completely ignored.

In recounting the results of some very elementary experiments on gemstones with a small pocket magnet I make no claim to have added a testing method of any real importance to the ever-increasing list. But I do hope to show that magnetic tests on gemstones are quite easy to carry out ; that quite a large number of gemstones show some response to even a small magnet ; and that magnetic tests may in some circumstances yield information about the composition of an incompletely determined stone which cannot be gained by any other means of comparable simplicity.

A large electro-magnet, consisting of cores of soft iron surrounded by wire coils carrying an electric current, is capable of exciting a tremendous magnetic pull, influencing even substances not commonly classed as magnetic. Compared with this, the power of a pocket " permanent " magnet of the usual horseshoe type is very small. In fact until recently little magnets of this kind were thought only suitable for such puny and menial tasks as recovering pins, needles, small nuts or bolts from inaccessible places.

For the last ten years or more, however, the power of permanent magnets has been enormously increased thanks to the development of new alloys containing aluminium, nickel and cobalt, capable of acquiring and retaining a much higher degree of magnetism

than the tungsten steel formerly employed. It was with a small horseshoe " Eclipse " magnet of this improved type that most of the experiments described below were carried out. This was bought during the war for a shilling. To-day its price has risen to 2s. 3d. but is still not unreasonable considering its powers. Though it is little more than an inch in length and weighs only one ounce it is capable of lifting an iron weight of 2 lbs.

Some months ago, when using a George & Becker aperiodic balance for a hydrostatic density determination, it struck me how easy it should be on such an instrument to assess the magnetic " pull " exerted on a specimen simply by noting its loss in weight when attracted by a magnet held closely above it. The aperiodic type of balance is ideal for the purpose in hand since the degree of magnetic attraction exerted on a stone can be followed as it takes place, and the maximum measured in less than a minute. A similar assessment could probably be obtained on a standard balance but would take more time and patience. If any object weighing less than 300 mg. (= 1½ carat) is placed on the pan the balance, owing to an air-damping device, assumes a steady position of tilt, and the weight can be read off directly on a scale which is a projection of a transparent graticule attached to the pointer of the balance. For ranges of 300 mg., then, no weights need be added. There are, in addition, metal ring weights of 300, 600 and 900 mg. which can be dropped into position at the turn of a knob. Thus, only beyond 1,200 mg. (= 6 cts.) need the balance case be opened and external weights added. In no case do weights below 1 gram have to be handled, as the final fractional weights are always provided for by the rings and the graticule scale.

The metal of the balance pan was found to exert a slight magnetic pull, and to avoid any effect due to this a large cork of known weight was placed on the pan and the stone to be tested placed on this as a pedestal. Having weighed the cork and stone in the usual manner these were left on poise and the magnet held immediately above the stone and lowered slowly and steadily. When the poles have approached to within ¼-inch or so of the upper surface of the specimen, if the latter has any magnetic susceptibility the scale will begin to record a marked loss in weight. *The minimum weight which could be " held " by the magnet was taken as the required reading* and the difference between this and the true

weight recorded. If (as often happens) the magnet actually touches the stone the reaction on the scale is of course immediately noticeable as a sudden move *away* from the required minimum. The only way a lower minimum than the true one can be obtained is by reading the end of the swing when the balance beam is moving rapidly ; hence the insistence that the weight should be " held " by the magnet, if only for a few seconds. The most powerful pull was found to be exerted when the magnet straddled the stone as it rested on its table facet. The mean of at least three readings was always taken, and, considering the rough and ready nature of the process, results were remarkably consistent for any one specimen. The variation was usually not more than ± 5%. Each measurement takes less than a minute but the intense concentration needed to maintain the magnet steadily in the optimum position and at the same time read the scale almost inevitably entails holding one's breath. In any case, to avoid the effects of gusty breathing on the balance during a weighing it was found wise to close the glass front of the balance and thrust the left hand holding the magnet through the side door of the case. To ensure steadiness the arm can be supported by leaning the elbow on the table or shelf on which the balance rests. Enough has now been said about the technique employed. Other investigators are almost certain to modify it to suit their own particular needs and their particular type of balance.

Turning now to the results so far obtained. It is natural to expect that compounds containing a considerable quantity of iron, which is the magnetic element *par excellence*, would be the most likely to yield positive results. Broadly speaking this is true, but the mere percentage of iron present in a mineral does not necessarily give a clue as to its magnetic susceptibility : the nature of the other elements present and the structure of the crystal play an important part. Iron pyrites, for instance, with formula FeS_2, contains 46.6% of iron, and yet it is hardly magnetic at all—nor is marcasite, of similar composition. Almandine and even peridot, containing far less iron, are perceptibly attracted by the magnet. What surprised me most, however, were the strong magnetic effects shown by the gem minerals containing manganese. This element seemed to produce an effect quite as vigorous as iron, though nothing I have so far seen in the literature suggests that this is the case.

Here, for instance, is a list compiled by Doelter, who was one of the early workers on the subject ; the minerals being given in order of decreasing magnetism :

Native iron	Tourmaline
Magnetite	Bronzite
Pyrrhotite	Idocrase
Ilmenite	Staurolite
Haematite	Actinolite
Chromite	Olivine
Siderite	Pyrite
Almandine	Biotite
Limonite	Chlorite
Iron Augite	Rutile
Iron spinel	Diopside
Hornblende	Dolomite
Epidote	Feldspars

Apart from the omission of the distinctly magnetic andradite garnet and the absence of manganese minerals, my own results agree fairly well with Doelter's order. Magnetite, famous of old as " lodestone," the material for the first crude compasses, is unique among minerals in being not merely passively but actively magnetic; that is, its molecular constitution enables it to retain the magnetism derived by induction from the earth's own magnetic field. Readers may have seen a Museum exhibit in which a large lump of this iron-grey mineral is festooned with nails held in place by its magnetic power.

Of the gem minerals, haematite (100% Fe_2O_3), the two iron garnets, almandine (43% FeO) and andradite (31% Fe_2O_3), the manganese garnet, spessartite (43% MnO) and the manganese carbonate and silicate rhodochrosite (62% MnO) and rhodonite (54% MnO), are those which show the strongest magnetic susceptibility. The figures just given for the percentage of the magnetic oxide present in each are of course only to be taken as a rough guide, particularly in the garnets, where isomorphous replacement is so common that each variety shows some admixture with the others.

Having measured the magnetic loss in milligrams for each stone tested, it seemed reasonable to reduce these figures to a common basis by expressing the magnetic susceptibility in terms of " loss in milligrams per 1,000 " or in other words loss in milligrams

per gram. Obviously a small stone showing, say, 50 mg. magnetic loss was far more magnetic than another stone ten times its size which showed the same loss under the magnet. In the course of scores of measurements made, however, it soon became very apparent that the size (and to some extent the shape) of the specimen in relation to the magnet played a very important role in the results obtained. Using the small 1 oz. " Eclipse " magnet, stones of any one species gave the largest figures in milligrams per thousand if they were of small size. Such a stone would presumably be " saturated " with the magnetic lines of force, while with a big stone much of the material would be outside the strongest field of attraction. When weights of stones are plotted graphically against magnetic loss per gram the result for any one species is a shallow curve. Since in practice one cannot expect to work with stones which are all of the same size and shape, I sought for some way of expressing the experimental results which would give more or less consistent figures for each species, regardless of their dimensions. Having to resort to such an expedient is of course one of the penalties involved in not dealing in fundamental units but only in phenomena having a rough dependence on such units. As an analogy one might compare it with trying to assess the dispersion of different gemstones by measuring the length of the spectrum thrown on the wall when the stone was held in sunlight rather than by the fundamental method of measuring the difference between the refractive indices for two definite wavelengths.

Be that as it may, the entirely empirical formula

$$\frac{\text{Magnetic loss} \times 100}{\sqrt{\text{weight in mg.}}}$$

was found to " iron out " irregularities due to size to a considerable extent, and the figures obtained from this formula are therefore to some degree useful as a rough indication of the relative magnetic susceptibility of the different minerals tested. Some figures obtained with peridots of different sizes will illustrate this point. All the stones were of similar colour and provenance and could be presumed to contain almost identical amounts of iron (about 10% of ferrous oxide). The variation found in the values for magnetic loss in milligrams per thousand can thus be assumed to be not intrinsic but a function of the size of the stones.

Weight	Mag. Loss	Loss per 1,000	Loss × 100/$\sqrt{\text{weight}}$
328	11	33	59
669	17	25½	63
898	22	24½	73
1945	33	17	75
2702	34	12½	65
3569	41	11½	68

The gradual diminution in values of " loss per 1,000 mg." in inverse ratio to the weight of the specimen is obvious from the above table, whereas the figures in the last column, though by no means constant, do at least achieve a certain consistency. Square roots are admittedly tedious things to calculate, but are very quickly obtained by halving the logarithm of the number concerned or more quickly still with the aid of a slide rule. I must confess to having used a 10″ slide rule myself for all calculations connected with this paper : the errors inherent in the method are in any case so large that careful calculations would be a waste of time.

Much more experiment needs to be done, and indeed will be done as time permits ; but as the result of the tests so far carried out the following categories for gem materials showing appreciable magnetism can be suggested. The figures obtained by the empirical formula given above are appended in each case. It must be emphasized that the actual figures are only valid for a magnet of the size and strength used for these experiments : but the *relative* values should be similar whatever magnet was employed.

Strongly magnetic ...	Almandine*	290 — 410
	Spessartite	250 — 360
	Rhodochrosite ...	270 ±
	Rhodonite	280 — 370
	Haematite	220 — 310
Moderately magnetic	Demantoid	120 — 200
	Epidote	100 ±
	Pleonaste	80 — 130
	Peridot	50 — 75
	Pyrope*	40 — 75
	Dark green tourmaline	50 — 70
	Hessonite	40 ±
	Indicolite	40 ±

Weakly magnetic ...	Brown sinhalite	...	15 ±
	Green tourmaline	...	10 — 20

* The term "alamandine" in the above table is confined to stones with refractive index 1·79 and over, while by "pyrope" is meant those with index below 1·75. Intermediate members of the series (pyrandines) give intermediate magnetic values.

As remarked at the beginning of this article, no claim is made that magnetic measurements on gemstones will prove to have any great importance, but the following distinctions, at least, are some of those which could be made by a careful worker with no apparatus beyond a good balance and a small " Eclipse " magnet. In each case the more magnetic material is mentioned first.

Demantoid	from	Green zircon, sphene or diamond.
Pyrope	,,	Ruby or spinel.
Haematite	,,	Black pearl or black diamond.
Spessartite	,,	Hessonite or zircon.
Rhodonite or Rhodochrosite	,,	Thulite.
Brown peridot	,,	Sinhalite.
Stainless steel	,,	Marcasite (pyrites).

Some experiments have been carried out with larger magnets made by the " Eclipse " firm in Sheffield, but it was thought better to confine my remarks to the small magnet as this is the only one readily obtainable at most hardware stores, is cheap, easily carried in the pocket, and does its work very well. Even on an ordinary balance, provided the pans are non-magnetic, a marked diminution in weight can be easily noted when the magnet is caused to approach a magnetic stone closely when the balance is in poise, while if no balance is available a magnetic stone suspended on a thread will move perceptibly out of the plumb position at the near approach of a strong magnet.

I have to thank those of my colleagues and friends who have taken an interest in this work, and who have made several ingenious suggestions for better methods of magnetic measurement than the one I have described. These will, I hope, be given a trial in due course.

Gemmological Abstracts

SCHLOSSMACHER (K.). *Smaragd und Rubin—warum so selten?* Emerald and ruby—why so rare ? Zeitschr.d.Deutsch.Gesell.f.Edelsteinkunde, Summer 1953, No. 4, pp. 9-14.

The colouring in emerald as well as ruby is chromium, which occurs only once in the evolution of the rock and mineral forming processes and then only as chromite ($FeO.Cr_2O_3$). Chromite deposits are connected with the gabbros, *i.e.*, rocks which contain little silica, and which constitute about five per cent. of the earth's crust. The gabbros (and the chromium) originate in the " Sima " (silicon-magnesium magma). The corundums and beryls on the other hand belong to the " Sial " (silicon aluminium magma) which forms 95 per cent. of the earth's crust. Ruby and emerald are formations of the pneumatolitic phase of Sial magma solidification, emerald especially belonging to the pegmatitic and hydrothermal phase. Only where the rising sial magmas and solutions broke through chromite deposits in sima rocks could the chromium be dissolved and carried away to become the pigments of emeralds and rubies in rare instances and few localities. E.S.

CHUDOBA (K. F.). *Zur Farbe und Farbänderung von Diamant.* On the colour and (artificial) colour change of diamond. Zeitschr.d.Deutsch.Gesell.f.Edelsteinkunde. Summer 1953. No. 4, pp. 3-7.

X-Rays do not effect colourless diamonds, but yellow diamonds may acquire a purer yellow colour, green Brazilian stones may become bluish green or pure green, and brown diamonds may acquire a violet hue. Cathode rays hardly affect diamonds, only some colourless stones become slightly bluish. Remarkable is the influence of radium rays, especially alpha rays, which cause a deep (yellowish) green colour. Beta and gamma rays alone do not have this effect. Treated stones are radioactive. The green colour becomes paler or disappears when heat is applied. Lindt and Bardwell's tests (1923) are mentioned but not the earlier investigations of Sir William Crookes (*Diamonds*, Harper, London, 1909).

Deuteron bombardment by means of the cyclotron causes an olive green or turbid grey-green colour within three to eight minutes. Long and intensive bombardment causes a deep brown colour. After treatment the stones remain radioactive for less than an hour only. Heat application does not affect the green colour of bombarded (or natural) stones. Deuteron bombarded stones display a sharp demarcation between the green surface layer and the rest of the stone, creating the impression of well-made doublets. H. Berman's (1950) and F. H. Pough's (1951) investigations are mentioned. E.S.

SCHLOSSMACHER (K.). *Die Bonner Diamantsynthese.* The Bonn Diamond Synthesis. Zeitchr.d.Deutsch.Gesell.f.Edelsteinkunde, Summer 1953, No. 4, pp. 7-8. (Journ. Gemmology, Vol. IV, No. 3).

In the Bonn trial the "diamond maker" H. Meincke was sentenced to three years in prison, his wife to fifteen months, his brother to seven months, and his niece to three months. Meincke admitted having smuggled natural boart into the raw material. Investors lost half a million D-Mark. E.S.

ANON. *Die Quartzlampe in der Edelsteinbestimmung.* The Mercury Vapour Lamp in Gem Determination. Zeitschr.d.Deutsch. Gesell.f.Edelsteinkunde, Summer 1953, No. 4, pp. 16-20.

Description of new lamp model PL 342 by Quarzlampemgesellschaft m.b.H. Hanau. The price is about £9 in Germany. Transformer (from 220 v. A.C.) and lamp itself are housed in a tube of about 14 ins. length and 2 ins. diameter. A wooden handle and stand allow easy manipulation. The glass filter (about $2\frac{3}{4}$ ins. x $1\frac{3}{4}$ ins.) passes mainly wave lengths between 3,500 and 4,000Å. Also mentioned is the lamp described by H. Lee in the June 1953, *Gemmologist* for the shorter wave range around 2,500Å. The theory of luminescence and phosphorescence is shortly discussed. E.S.

GOEBELER (H.). *Lupenreinheit und Farbbestimmung bei Brillianten.* Purity and Colour Determination of Brilliants. Zeitschr.d. Deutsch.Gesell.f.Edelsteinkunde, Summer 1953, No. 4, pp. 20-22.

The purity is determined with an eye-glass (loupe) of 10x

magnification. The colour is graded according to the following scale:

Jager	finest blue white
River	blue white
Top Wesselton ...	fine white
Wesselton	white
Top crystal ...	very, very light yellowish
Crystal	very light yellowish
Top Cape	light yellowish
Cape	yellowish
Yellow	yellow

The " Colorimeter " and " Diamolite " of the Gemological Institute of America, and Dr. Gübelin's Coloriscope are mentioned. E.S.

WELLS (R. A.). " *Three-phase* " *inclusion in Synthetic Emerald.* Gemmologist, Vol. XXII, No. 263, p. 107, June 1953. Also described in Gems and Gemology, Vol. VII, No. 9, p. 283, Spring 1953.

A trapezoidal formation in an inclusion which also contains a bubble is remarked upon as either being a " three-phase " inclusion, or could be mistaken for one. One illustration. R.W.

ANDERSON (B. W.). *A New Test for Synthetic Emerald.* Gemmologist, Vol. XXII, No. 264, pp. 115-117, July 1953.

Synthetic emeralds were found by the author to be more transparent to ultra-violet light than stones of natural origin. Natural stones were found to absorb in the ultra-violet at about 3,000Å, while the synthetic stones are transparent down to 2,300Å. Experiments were carried out by the employment of a copper arc and a quartz spectrograph. It was further established that the effect could be observed directly by the use of a Philips TUV 7 watt lamp in conjunction with a Beck direct vision ultra-violet spectroscope. One illustration. R.W.

TRUMPER, (L. C.). *Viewing Boxes for Ultra-Violet Light or Chelsea Filter.* Gemmologist, Vol. XXII, No. 264, pp. 127-8, July 1953.

Descriptions of suitable viewing boxes for the easy observation of fluorescence (and colour filter effects). The ultra-violet viewing boxes are designed for use with the Hanovia " Detectolite " and the other for the Philips TUV 7 watt tube—both, therefore, for short wave ultra-violet. Two illustrations. R.W.

CHUDOBA (K. F.). *Zur Kennzeichnung der Synthetischen Smaragde.* The Determination of Synthetic Emeralds. Zeitschr.d. Deutsch.Gesell.f.Edelsteinkunde, No. 3, pp. 8-11, Spring 1953.

Survey of differences between synthetic and natural emeralds. Bibl. of seven items. E.S.

WILD (K. E.). *Das Achatschleifereigewerbe an der oberen Nahe.* The Agate Cutting Trade on the Upper River Nahe. Zeitschr.d. Deutsch.Gesell.f.Edelsteinkunde, No. 3, pp. 18-21, Spring 1953.

Historical review on the development of the German agate cutting industry. E.S.

STEIN (R.). *Drehapparat zur Untersuchung von Edelsteinen mit dem Vertikalen Mikroskop.* Adjustable Gem Holder for Investigation with the Vertical Microscope. Zeitschr.d.Deutsch.Gesell. f.Edelsteinkunde, No. 3, pp. 22-23, Spring 1953.

Description of a holder allowing sensitive adjustment of the object in an immersion cell. E.S.

WEBSTER (R.). *Gemstone Luminescence.* Gemmologist, Vol. XXII, Nos. 262-3-4, pp. 77-80; 98-103; 123-126, May/June/July 1953.

A series of articles (to be continued) on the luminescence of gemstones under long and short wave ultra-violet light, and under X-Rays. The first two instalments deal with the types of luminescence; the theory of photoluminescence; some historical notes, and the types of apparatus used in the production of ultra-violet light and X-Rays. The third instalment commences the record of the luminescent glows observed in gem materials by the author, and this is alphabetically arranged. Six illustrations. P.B.

ANDERSON (B. W.); Payne (C. J.). *The Density of Pearls and Cultured Pearls.* Gemmologist, Vol. XXII, No. 262, pp. 81-86, May 1953.

A reprint of an article published exactly fourteen years ago. It is the record of a vast amount of work on a considerable number of pearls. It was the outcome of some similar work carried out by Kerr in the United States. The densities were ascertained by employing suitably diluted bromoform solutions, and the experiments confirmed Kerr's original announcement that most cultured pearls sank in a solution made up to freely suspend a small rhomb of calcite (which has a density of 2.72). The statistical results of

the research are shown by two graphs and a table. A further table records the densities found for individual pearls. P.B.

LEE (H.). *A Pocket Lamp for Short Wave Ultra-Violet.* Gemmologist, Vol. XXII, No. 263, pp. 104-106, June 1953.

Describes the construction of a suitable aluminium lamp housing for the Philips TUV 7 watt germicidal lamp in conjunction with a Chance OX7 filter. The lamp described is portable and may be used either as a microscope lamp, to illuminate specimens on a table, or simply as a portable hand lamp. Full constructional details are given. One illustration. R.W.

GRODZINSKI (P.). *The History of Diamond Polishing.* Indust. Diamond Review, 1953, Special Suppl. No. 1, pp. 1-13. 22 figs.

Notes on early history with picture reproductions. Earliest account of methods used appears to have been made by Benvenuto Cellini. The claim that L. van Berquem of Bruges invented diamond cutting in 1476 is not substantiated. (A. SELWYN, *Retail Jewellers' Handbook*, 1945, p. 210, also held that the claim was invalid, citing the investigations of Henri Polak). The development of diamond cutting in the Netherlands and in England is commented upon. S.P.

JARMAN (R.). *They Spot Fake Jewels.* Saturday Evening Post. Commencing on page 28, June 27th, 1953.

A colourful popular article on gemstones and jewellers with particular emphasis on the formation and work of the Gemological Institute of America. Abundantly leavened with anecdotes, an article has been produced which is most readable. Journalistic enthusiasm had led the author to imply that the American jeweller was unable to value his merchandise correctly before the formation of the Gemological Institute of America. For the enlightenment of our American friends the value of the Black Prince's " ruby " lies in its history; exception, too, can be taken at the passage which states " recent scientific tests, however, showed that it was not a ruby at all, but a spinel of comparatively little value." The stone has been known to be a spinel from quite early times, certainly it was so known in the year 1653, for it was in the list of the regalia ordered by Cromwell to be destroyed or sold, and was correctly described as "1 Ballas ruby." An entertaining article which is useful propanganda for the gemmologist. Five coloured plates. R.W.

EPPLER (W. F.). *Further Observations on Synthetic Red Spinel.* Gems and Gemology, Vol. VII, No. 10, p. 306, Summer 1953.

Discusses the theory of growth striae in synthetic stones grown by the flame fusion method with respect to the facility of their crystallization. Dr. E. J. Gübelin, in an earlier article on synthetic red spinel, inferred that the strong striae seen in the stones he examined was due to difficult crystallization. This, Dr. Eppler does not accept and gives his reasons for not doing so. An appended table compares the succession of synthetic corundums and spinels according to the increasing facility of crystallization as suggested by Dr. Gübelin and by the author. R.W.

RUZ LHUILLIER (A.) *Gems of Ancient Mexico.* Gems and Gemology, Vol. VII, No. 10, pp. 291-302, Summer 1953.

Tells of the archæological finds of carved stones and jewellery in Mexico. Particular mentioned is made of the objects from Monte Alban; the find in Cerro de la Mesas on the coast of Vera Cruz; and the extensive finds at Palenque. The jade of Mexican archæological finds is jadeite, but is less transparent and more mottled than the Chinese jade (Burmese?). It is not known with certainty where the jadeite originated; there are no known deposits in Mexico. The use of gold, silver and copper appeared in Mexico only some three centuries before the Spanish Conquest. Much information on the materials used by the Ancient Mexicans. Seventeen illustrations. R.W.

WARWICK (J. E.). *The Thrill of Finding Opal.* Gemmologist, Vol. XXII, No. 263, pp. 110-112, June 1953. (Extracted from the Lapidary Journal).

The story of a visit made by the author to the Australian opal fields. Much anecdote but a good description of the country rock and the methods used in the mining of the gem. R.W.

CHUDOBA (K. F.). *Zur Formveredlung von Diamant.* On Improving the Diamond Shape. Gold Und Silber, Vol. 6, No. 4, pp. 12-14, April/May 1953.

Short historical review of the development of diamond polishing from the old "table cut" via "single cut," "double cut" (Mazarin) and "triple cut" (Peruzzi) to the modern American cut brilliant. E.S.

ANON. *Steinschneidekunst.* The Art of Gem Engraving. Gold Und Silver, Vol. 6, No. 4, p. 15, April/May 1953.

Zeitschr.d.deutsch.Gesell.f.Edelsteinkunde, No. 3, pp. 6-8, Spring 1953.

Report of the exhibition of cameos and intaglios by the (German) Association of Goldsmiths at Beckum in March 1953.

E.S.

BOOK REVIEW

BRADFORD (ERNLE). *Four centuries of European Jewellery.* Country Life, Ltd. London, 226 pp., 48 illus. Two guineas.

Antique jewellery has been largely neglected by writers on antiques—fortunately, perhaps, for there are many pitfalls for the unwary, and all too often the expert himself has to shrug and say that such a piece is "evidently South German, possibly 16th century . . ." Compared with silver or porcelain or furniture, little jewellery has survived the great melting pots of four centuries of European upheaval, and the few relics are scattered far and wide in the museums and art galleries and libraries of the Continent. In his recently published book Ernle Bradford has skilfully traced the history of jewellery styles from the Renaissance to the present day, weaving into his pattern a picture of jewellery against a background of social customs and changing fashions. To his credit he has done what few writers on the antique ever do—he has remembered that the student of antique jewellery wants to know how a piece is made, and he has been at pains to explain techniques—of setting, casting, ornamenting, and so on.

The book falls into two distinct sections—the history of jewellery and the materials of jewellery, and one is tempted to suggest that it might have made a little lighter reading if the methods and materials had been worked into the historical section—with perhaps some illustrations of contemporary craftsmen at work. But, despite this, for it is a book to be dipped into and digested slowly, Mr. Bradford has achieved a useful and comprehensive textbook. He has sorted out and illustrated the changes in jewellery fashions during four hundred years, and has not forgotten that to-day craftsmanship and techniques still play an important part in jewellery design. This is, indeed, the first book on the history of jewellery that treats of anything after the end of the last century. It is good to feel that the achievements of to-day, are recorded.

J.B.

TRANSPARENCY of GEMSTONES
to SHORT WAVE
ULTRA-VIOLET LIGHT

by NORMAN H. DAY, F.G.A.

I HAVE used a Trumper Viewing Cabinet for some months—the model[1] which, besides the half watt lamp for use with the Chelsea filters or crossed filters, incorporates a Philips TUV 7 watt short wave tube with an OX7 filter. This lamp, which gives a strong emmission at 2537 Å, has been fully described by P. M. Caudell and R. Webster[2].

With a suitable holder it is possible to use a microscope objective and eyepiece, to obtain an enlarged view of the fluorescing materials. I suggested to Mr. L. Trumper that the fluorescence of inclusions within gemstones might be of some diagnostic value. This raised the problem as to which stones were transparent to the rays of this lamp so that the inclusions could be excited. Search through the published literature failed to reveal any tables relative to gem materials, not even for long wave ultra-violet light of the wavelengths between 3000 Å and 4000 Å. The only tables relative to invisible light, are those of X-rays in the *Gemmologists' Compendium.* Since the beginning of this quest, Mr. B. W. Anderson has published[3] the results of his investigations with the quartz spectrograph of the transparency of natural and synthetic emerald and other beryls to the shorter waves of the ultra-violet light.

I have been using Mr. Anderson's shadowgraph immersion method[4] to record the size and cut of gemstones; and because photographic emulsions are in general very actinic to ultra-violet light, it seems feasible to adopt this method to obtain the information required provided that cells and suitable liquids transparent to the short ultra-violet light could be obtained. It appeared essential to cut out internal reflections because the collection of specimens which it was proposed to use are mostly of a small size.

L. Trumper has since overcome this difficulty by constructing a supplementary device incorporating a fluorescent screen and mirrors (see second paper).

It proved fortunate that the thin-bottomed cell obtained some months ago especially for normal immersion work should be made of Pyrex glass. This cell has a diameter of 40 m/m., is 15 m/m. high and has a base 2 m/m. thick. The makers, Messrs. Tintometer Ltd., explained that it is only practical to use this type of material when making a fused cell with a thin base. To test the transparency of the cell to short ultra-violet light, it was placed on a small piece of Ilford Contact Hard No. 3 printing paper and placed in the drawer of the cabinet, the room was reasonably darkened out and an olive safelight was in use. The ultra-violet lamp was switched on for five seconds and subsequent development of the paper in Ilford P.F.P. developer and fixing in an acid hypo bath, gave a negative that proved the cell to be practically transparent to this light.

Referring to literature on the use of ultra-violet light with the microscope, Johnson and Martin[5] suggest a mixture of glycerine (R.I. I.49), cane sugar (R.I. I.45) and water (R.I. I.33) to obtain a suitable mounting fluid. Kodak[6] have a table which shows that cedarwood oil (R.I. I.51), sandalwood oil (R.I. I.51) and balsam (R.I. I.52) are semi-transparent to the long ultra-violet wavelengths but are opaque to short ultra-violet.

Test negatives were made; filling the cell half full with series of liquids; the method already described was used, with the same exposure of five seconds.

Water	transparent	Clove Oil	opaque
Glycerine ...	nearly transparent	Methylene Iodide	opaque
Bromoform...	semi-transparent	Monobromonaphthalene...	opaque
Toluol... ...	nearly opaque		

A five seconds exposure of a 1.5 m/m. thick glass microscope slide showed it to be opaque, while a fourfold exposure of twenty seconds showed that quite sufficient light to make it appear transparent passed through ; therefore, in using this photographic method, due consideration of the exposure time and the thickness of the subject must be made. The human eye, in observing a fluorescent screen, judges the amount of brightness momentarily visible, whereas the photographic emulsion adds together the actinic value of the light for the whole period of the exposure.

Furthermore, the prolonged exposure allows residual light which passes through the OX7 filter to have its effect upon the emulsion.

This residual light arises from the other less powerful isolated spectral emission lines of the mercury vapour which the filter allows to pass. Some of this is visible as violet light when the direct light of the lamp is observed through the filter. (It is important to use some form of protection to the eyes in doing this for any length of time.

For the first trial with stones a green fluor and a white opal which is yellow to transmitted light were immersed in water. A five second exposure was made. The negative showed the opal to be opaque while the fluor proved to be transparent, with an interesting cut " pattern " and a Becke line edging. Changing to glycerine (same exposure) the fluor gave a negative which showed some fuzziness due to the fluorescence of the fluor and showed shadows of some cleavage inclusions.

Using a group of quartz in glycerine with an exposure of five seconds, a negative (Fig. 1A) and the subsequent print (Fig. 1B) were made; the stone at the top of this picture is rock crystal, the centre chalcedony, to the left a pale amethyst, to the right a cairngorm and at the bottom a dark amethyst. It is apparent that, whereas the rock crystal and the chalcedony are transparent, the cairngorm is opaque, and the amethysts become more opaque with the increase in the depth of colour. It is interesting to note that the rock crystal is more transparent than the glycerine.

Prints made from paper negatives are not so sharp as those made from plates or films. These prints were made on Ilford Bromide normal paper. Using bromoform, a series of the natural corundums were used, because of the semi-transparent nature of this liquid —the longer exposure of twenty seconds was given. This negative (Fig. 2A) and print (Fig. 2B). The print shows (left to right) top row, pink sapphire followed by three rubies; centre row, white sapphire, violet sapphire, green sapphire, yellow (pale) sapphire and star ruby; bottom row, pale blue sapphire, light blue sapphire, dark blue sapphire and dark blue sapphire colour mostly in the culet.

At a later date some Reflex Contact document paper was obtained. A small piece was placed in the cabinet and several stones placed on it table facet downwards, and an exposure of ten seconds made. This paper is much slower, more contrasty and its paper base much thinner than the paper used previously, though the development and subsequent processing is similar.

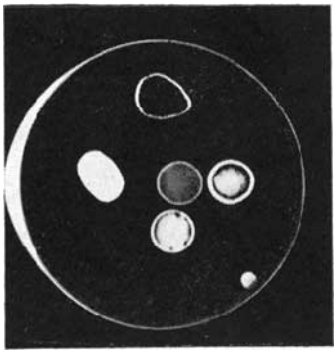

Fig. Ia.
NEGATIVE. Series of Quartz, in Glycerine.

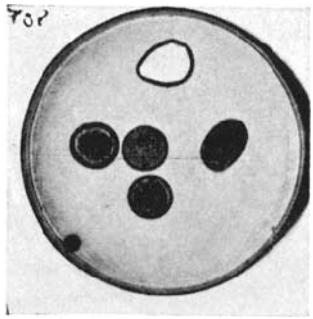

Fig. Ib. POSITIVE.
Top.—Rock Crystal. Centre.—Chalcedony. Right.—Cairngorm. Left.—Light amethyst. Bottom. —Dark amethyst.

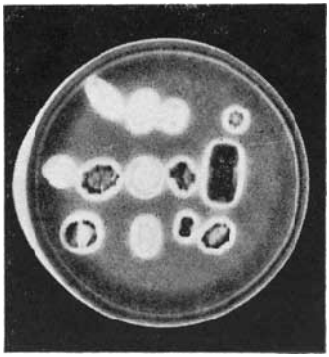

Fig. IIa.
NEGATIVE. Series of natural corundums in bromoform.

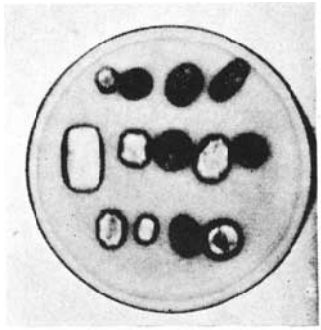

Fig. IIb. POSITIVE. (Left to right)
Top row.—Pink sapphire, three rubies. Centre row.—White sapphire, violet sapphire, green sapphire, yellow sapphire and star ruby. Bottom row.—Pale blue sapphire, medium blue sapphire, dark blue sapphire and dark blue, colour in culet sapphire.

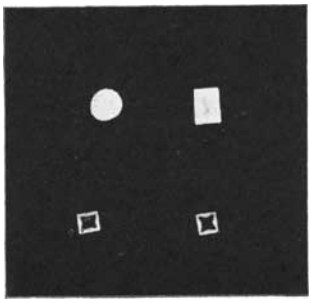

Fig. III.
NEGATIVE. Two top stones natural emeralds, the lower two stones synthetic Chatham emeralds.

So long as judgment is made on that part of the paper covered by the table facet only, it is quite easy to see which are transparent, (black on the negative) and those which are opaque (white on the negative). Figs. 3 to 4 inclusive show a series of negatives made by this method.

Using this shadow method, mass tests were quickly made; the immersion method being used in doubtful cases. With so many results it was necessary to record them on some form of chart; primarily a list of species with some grouping as to colour, Mr. Anderson[3] having shown that amongst the beryls transparency to short ultra-violet light varies with colour, and the prints (Fig. 1B and Fig. 2B) shows that this also occurs with the quartz and natural corundum species.

On this chart white stones are considered as colourless unless to transmitted light they show a body colour as do most white opals, which may show orange, yellow or green.

Reviewing this series of tests, the following conclusions can be made:

all colourless and pink stones are transparent, even water opal;

all colours of topaz are transparent;

all colours of synthetic spinel and corundum are transparent;

peridots and all varieties of the garnet species are opaque;

all green stones are opaque, synthetic emerald being the exception;

all yellow stones are opaque, the exceptions being topaz, natural sapphires and some chrysoberyls;

deep coloured natural blue and green sapphires and rubies are opaque.

Results for alexandrites are so far inconclusive; of the two specimens so far tried, one is transparent and the other semi-transparent; also, of the eleven andalusites tried, one appears semi-transparent.

Glass pastes require much more investigation and cannot be said to be in general opaque; one series of pink pastes are semi-transparent, while a pale blue paste with a cobalt absorption spectrum and which fluoresces a light blue appears extremely transparent. It is interesting that while the half pearls tested were quite opaque, a aragonite crystal is transparent. Iceland spar is transparent—this may prove useful for later experiments in the study of the directional transparency of crystals to short ultra-violet light.

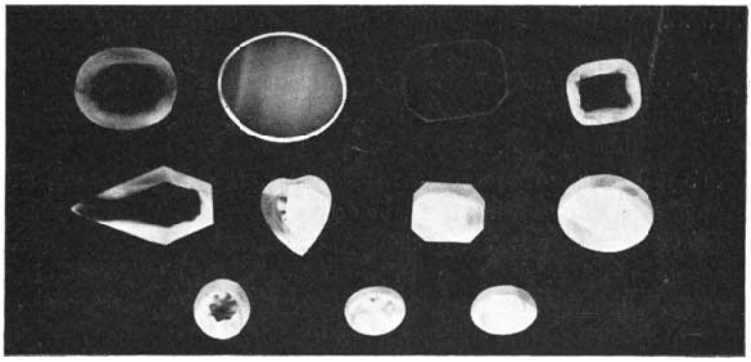

Fig. IV. NEGATIVE. Quartz Species. (Left to Right).
Top row.—Rock Crystal, Chalcedony, Rose Quartz, Lt. Smoky Quartz.
Centre row.—Pale Citrine, Citrine, Lt. Cairngorm, Cairngorm.
Bottom row.—Lt. Amethyst, medium Amethyst and dark Amethyst.

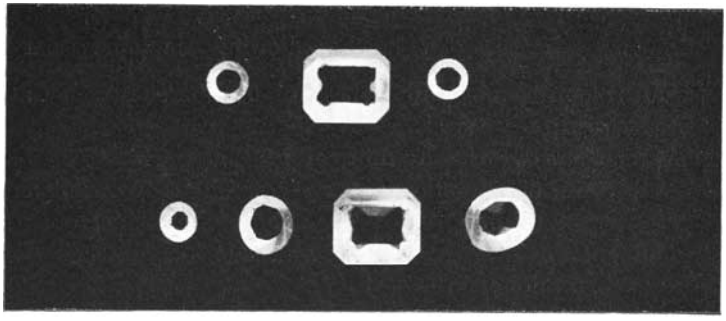

Fig. V. NEGATIVE. (Left to Right).
Top row.—White, Lt. blue and dk. blue, synthetic spinel.
Bottom row.—White, red, dk. blue and alexandrite-type synthetic sapphire.

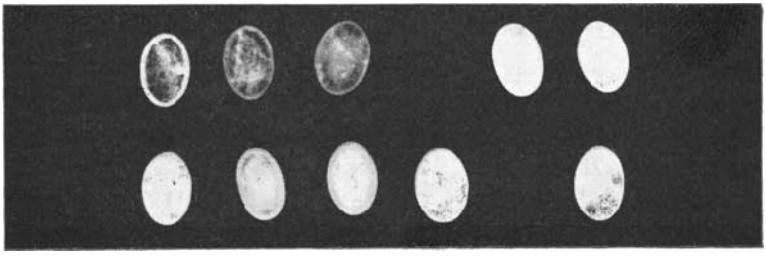

Fig. VI. NEGATIVE. Jadeites.
Top row.—Translucent white, translucent grey, translucent pink, orange and red brown.
Lower row.—Four shades of green and one black.

Fig. 3 shows a negative showing the important difference between the natural (top) and Chatham synthetic (bottom) emeralds.

Though some gemmologists may possess a TUV 7 watt short wave tube with an OX7 filter, they may not have a dark room and " wet " photographic facilities. Therefore, I have tried out some P.O.P. printing out paper. With this the negative image is visible without development, though it is not permanent. This paper was over twenty-five years old and is not now manufactured.

Bromide paper can be used in a like manner if sufficient exposure is given.

The emeralds to be tested are placed table facet downwards on a piece of bromide paper in a light-tight cabinet, so that the paper is within one inch of the filter. After an exposure of fifty minutes it will be found that the paper has turned a medium grey except under the table facets of the natural stones; the synthetics will show a light outline of the table facet due to internal reflection preventing the light reaching the edge, but the centre of the table facet will be dark, due to the rays passing through the stone. These negatives cannot be processed but they will not fade quickly unless they are exposed to a strong light or sunlight. Bromide paper used in this way can be handled in subdued natural light or ordinary artificial light. It should be noted that once paper is exposed to light other than a safelight, it cannot be used at a later date for normal photographic work.

I am indebted to Mr. P. Hoskins for the loan of several specimens which made it possible to study the effect of colour differences in several species.

TRANSPARENCY to ULTRA-VIOLET LIGHT

by L. C. Trumper, B.Sc., F.G.A.

THE inexpensive short wave ultra-violet lamp, Mr. Robert Webster's interesting notes in the Gemmologist on Gemstone Luminescence and Mr. B. W. Anderson's article "A New Test for Synthetic Emerald " in the same journal for July, open up new fields of enquiry.

Few can have spectrographic equipment at their disposal, so it is to be hoped that Mr. Anderson and others will provide us from time to time with spectrograms of the other gemstones showing their transparency to ultra-violet light. Meantime, Mr. Norman

Day, F.G.A., of Salisbury, and I thought that some method of assessing transparency to ultra-violet light, open to the gemmologist with more modest equipment, would be very useful and might moreover provide interesting results. Day has thought out a very interesting procedure which seems to give excellent results (see first paper). I had simultaneously, the same week-end, thought out another method which may give useful and rapid visual results and as this seems to provide a very simple way of providing approximate results, the method involved is set out here.

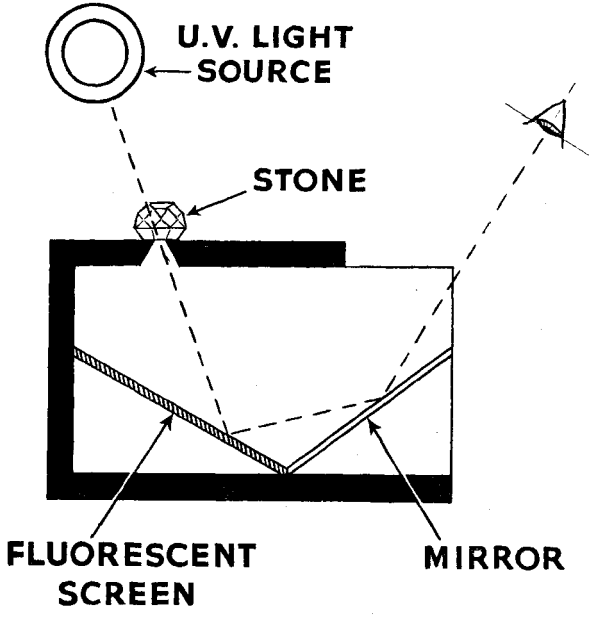

Gemmologists will be familiar already with the light-tight viewing boxes lined with black velveteen, which I consider to be a virtual necessity for the satisfactory study of luminescence. Anyone handy with a fretsaw and a few simple tools can make a viewing box for a few shillings. Anyone not so handy, I do strongly advise to have one or more built by the local carpenter or handyman. A point worth noting is that there is a great advantage in having the drawer and more especially the front of the drawer deep enough. Not only to take large specimens, but also to take the stage described below and which has to go in and out when the drawer is opened

and shut without fouling the upper portion of the front of the viewing box. It should be at least $3\frac{1}{2}$ ins. deep and perhaps 4 ins. would be better. It will be seen from the diagram that the device consists of a small stage $2\frac{1}{2}$ ins. x 4 ins. in which a very small hole $\frac{1}{8}$ins. diameter and a larger hole, say, $\frac{1}{4}$ ins. diameter has been drilled and bevelled with a countersink bit from underneath. This stage rests on three sides $2\frac{1}{4}$ ins. high and within is a fluorescent screen set at an angle of 30 degrees and a mirror set at an angle of 45 degrees. When this is inserted in the drawer of the viewing box, the angle of incidence of the ultra-violet light from the lamp is such that the spot (in actual fact with the short wave lamp, a horizontal bar of light) is seen in the mirror on the fluorescent screen suitably in the centre from the viewing position. At the same time, the fluorescent screen cannot be illuminated by any direct light from the lamp. The device is inserted in the drawer of the short wave ultra-violet light viewing box, the stone under examination is placed over the hole and with the drawer closed, the lamp is then switched on. If the stone is opaque to the radiation, no fluorescence is seen; if transparent, however, then a bar of light is seen on the fluorescent screen. If semi-transparent then the glow on the screen is blurred or slight, and so on.

So far time has permitted only a small number of observations to be made, but colourless quartz, as was to be expected, showed full transparency and a bright fluorescence on the screen. Amethyst, on the other hand, and citrine were opaque. Colourless topaz was transparent; a piece of ordinary slip glass was almost opaque. A synthetic alexandrite was opaque; on the other hand a natural pale pink spinel was moderately transparent and glowed with a reddish fluorescence at the same time.

It would appear, therefore, that the test could be useful in many cases and would, for example, quickly differentiate between diamond and paste. It is fully effective with transparent colourless stones, but with coloured stones it may be necessary to concentrate the rays with a quartz lens which at the moment I do not possess.

A word or two about the fluorescent screen. This can quite readily be made in one or two ways. Any fluorescent material that is sensitive to both long and short ultra-violet wave will do, but clearly it must be a material with the brightest possible fluorescence. Barium platino cyanide is the best, but is expensive. A good second

is potassium uranium sulphate which fluoresces the typical bright uranium green. A screen is prepared by gluing a small piece of white card on the base of the screen. Covering the exposed surface with gum or Durofix and carefully shaking the powder over it as evenly as possible from a pepper pot, afterwards tapping the surplus off. It is a good idea to have a practice run once or twice before putting the gum on, collecting the powder carefully on a large piece of white paper. To prevent reflections the stage and box should be painted dead black.

REFERENCES

1. Trumper (L. C.). *Viewing Boxes for Ultra-Violet or Chelsea Filter.* Gemmologist, July, 1953.
2. Caudell (P. M.) and Webster (R.). *An Inexpensive Short-Wave Ultra-Violet Fluorescent Lamp.* Gemmologist, April, 1953.
3. Anderson (B. W.). *A New Test for Synthetic Emerald.* Gemmologist, July, 1953.
4. Anderson (B. W.). *Immersion Contact Photography.* Journ. Gemmology, April, 1952.
5. Martin (L. C.) and Johnson (B. K.). *Practical Microscopy.* Blackie & Son, 1946.
6. *Photomicrography.* Eastman Kodak Company, New York, 1944.

   See also

   Wild (G. O.) and Biegel (H.). *Absorption of Sapphire in the Ultra-Violet Region.* Gemmologist, Oct., 1947.

   Anderson (B. W.) and Payne (C. J.) *Absorption of Visible and Ultra-Violet Light in Natural and Artificial Corundum.* ibid. Oct., 1948.

SYNTHETIC EMERALDS

There has recently been exhibited in the United States, at the Smithsonian Institute, a synthetic emerald crystal weighing 1,014 carats. It was made specially for the Institute, and must be regarded as exceptional, as it is of good quality. A larger crystal, of inferior quality has been shown at the Harvard Museum. This weighed 1,275 carats. The production of synthetic emeralds of fine quality and size suitable for mounting in jewellery is increasing.

PEARL FISHING CONTROL

The Commonwealth Government of Australia has broken off the negotiations with Japan which have been proceeding since April in an effort to find agreement on conditions under which the Japanese may fish for pearl shell in waters off the north coast of Australia. Australia is now to proclaim sovereignty over the whole continental shelf, reaching in places beyond 200 miles off the coast instead of the internationally recognized three-mile limit.

Having assumed in this area powers not recognized under international law but claimed also by the United States, the Government will enforce licensing and control measures over all pearlers of whatever nationality.

ASSOCIATION NOTICES

COUNCIL MEETING

A meeting of the Council was held at 19-25 Gutter Lane, London, on Tuesday, 25th August, 1953, at 4.30 p.m. Mr. F. H. Knowles-Brown presided

The following were elected to membership:

FELLOWS

Mary Adene Harrison, Lichfield D.1951
Albert Edward Shipton, Birmingham D.1932

PROBATIONARY

Michael Anthony Bates, Colombo, Ceylon
Peter Benton, Brighton.
Arthur Edmund Charles, London.
Neville Deane, Wednesbury.
Reginald George Golby, Birmingham.
Bapusaheb Shamrao Mahajan, Fort Bombay, India.
George Morton, Edinburgh.
Bernhard Muscat, Johannesburg, S. Africa.
Roger Arthur Pyatt, Orpington.
Philip Seager, Glasgow.
Mrs. G. Spiro-Haccou, Djakarta, Indonesia.

ORDINARY

Harold Charles Abbott, Auckland, New Zealand.
Doris Disby, Birmingham.
Isidore Abraham Drapkin, Birmingham
Frederick A. Ferraro, London.
S. Lorne Fear, Toronto, Canada.
Richard Homer, Birmingham.
Leonard Nathan, Birmingham.
Major Cyril Albert Reynolds, Wembley.
Commander Gerald Scott, Birmingham.
Harold G. Tandy, Birmingham.
Frederick William Thorn, Coventry.
John Harland Waller-Davies, Seaford.

It was decided to hold the presentation of awards gained in this year's examination at Goldsmiths' Hall, London, on 7th October, at 7.15 p.m., and that prior to this there should be held a Reunion of Members.

The Council with deep gratitude, heard of the various bequests to the Association made by the late President, Dr. G. F. Herbert Smith.

A report on the recent and highly successful gemmological exhibition held in Glasgow during June was received, and the Council placed on record its appreciation of the great efforts made by members of the West of Scotland Branch of the Association in contributing to the success of the Exhibition. The Council also recorded its appreciation of the part played by the Glasgow Art Gallery and Museum.

The results of the 1953 examinations, which were considered by the Council, are recorded separately in these notices.

RESEARCH DIPLOMA

The Council of the Association has awarded a Research Diploma to George Frank Leechman (Diploma 1938) for his thesis on the origin of the colours in precious opal. The topic selected was a very difficult one and Mr. Leechman's paper presented a very creditable performance.

This is the third occasion a Research Diploma has been awarded, the others being 1945 Mr. M. D. S. Lewis, and 1946 Mr. R. Webster.

OBITUARIES

David Lawrence Meek. We regret to announce the death of one of Edinburgh's jewellers, Mr. David L. Meek. He was the first Chairman of the recently formed Edinburgh and East of Scotland Branch of the Association and a past President of the Edinburgh and East of Scotland Goldsmiths', Silversmiths' and Watchmakers' Association. He represented the third generation of his firm, Messrs. J. and D. Meek of Bank Street.

Rose Rachael Meisl, of London. The death has occurred, after a serious illness, of Mrs. R. Meisl. She gained her Fellowship in 1947. The Vice-Chairman represented the Association at the funeral service.

SWISS GEMMOLOGICAL ASSOCIATION

In May, the Swiss Gemmological Association held a General Meeting in Germany. Three days were devoted to visiting the Idar Oberstein exhibition of precious stones, the Gemmological Institute, plants for polishing coloured stones, agate cutting shops, stores of imported agate, a local agate quarry, and an engraver's shop. Relevant historical, scientific and economic papers were read. The first contact between the members of the Swiss and German Gemmological Associations seems quite promising. It is intended to arrange exhibitions of Idar-Oberstein products (cut and rough) at the three or four biggest Swiss towns whose jewellers will take advantage of this by decorating their windows accordingly. Similar exhibitions are planned, with the help of the Swiss Association, for France, Holland and Belgium.

TALKS BY MEMBERS

Anderson, B. W. : "The use of the refractometer." Netherlands Gemmological Association, Amsterdam, 8th October, 1953.

Mrs. K. G. Warren : "Gemstones." Christ Church Young Peoples' Fellowship, Bromley, 16th October ; *ibid.*, Town's Women's Guild, Bromley, 4th November.

LETTER TO THE EDITOR

DEAR SIR,

May I, through the courtesy of your columns, express the gratitude of the Executive Committee and Members of the West of Scotland Branch of the Gemmological Association to all the following persons, companies and organisations for the assistance and advice afforded the Branch in the staging of its first Gem Exhibition in Glasgow during the month of June.

The Director, Royal Scottish Museum, Edinburgh, The Director, Birmingham Museum, The Director, Kilmarnock Museum, Messrs. Norman H. Day, A. Herriot, Kenneth Parkinson, A. R. Popley, R. Webster, K. A. Webster,

the Agent General for Queensland, Agent General for South Australia, British Museum (Natural History), East of Scotland Branch of the Gemmological Association, Dr. Norman Holgate, Midlands Branch of the Gemmological Association, Messrs. Rayner & Keeler Ltd., Muir & Sons, Diamond Trading Company Ltd., J. H. Steward Ltd., Impregnated Diamond Products Ltd., A. Bernard (Gems) Ltd., Gregory Bottley & Co., George Tarratt Ltd., Salford Electrical Instruments Ltd., Geo. Lindley & Co. (London) Ltd.

We are especially indebted to Messrs. J. & C. Ginder Ltd., for their part in arranging the diamond polishing demonstration and for the handsome donation towards the expense involved.

Finally, we would like to acknowledge the assistance and guidance afforded us by the Secretary of the parent body.

Yours faithfully,

S. D. WOOD, Exhibition Convenor.

1953 EXAMINATION RESULTS

In the 1953 examinations of the Gemmological Association the high number of candidates, which has been characteristic of post-war years, was maintained. For the Diploma examination eighty-six candidates sat in Great Britain and sixteen at overseas centres, while in the Preliminary examination the home and overseas entries were one hundred and five and twenty-eight respectively.

The Tully Medal has been awarded to Mr. J. B. Kemp, of Bristol, and the Rayner Prizeman is Mr. N. Deane, of Wednesbury.

The following is a list of successful candidates, arranged alphabetically :

Diploma

Qualified with Distinction

John Brian Kemp, Bristol (Tully Medal)
Trevor Martin Brook, Lincoln
Robert Cecil Fox, Seven Kings.
Ronald Albert Hall, Lingfield.
Anthony Lionel Wickenden Kemp, Bristol.
Bertram Krashes, Levittown.
Jeanne Gladys Marie Martin, San Diego.
Raphael Isaac Roth, London.
Colin Sidney Wickens, London.

Qualified

Samuel Bache, Old Hill.
John Thomas Baker, Bristol.
Hermann Bank, Idar-Oberstein.
Walter Bowen, Birmingham.
Alfred John Brack, London.
Helen Mary Lufkin Charles, London.
Rodney Frederick Collyer, Birmingham.
Anthony Warren Davis, Potters Bar.
John Norman Forsey, Sutton Coldfield.
John Galloway, Edinburgh.
Adrienne Mary Grahame-Ballin, St. Albans.
David John LeGrew Harrison, Amersham.
John Francis Hodges, Chester.
Roger Ward Jones, Cirencester.
Vincent George Jones, Sutton.
Graham Edward Keay, London.
Michael John Kutner, Wembley.
Norman Alfred Lambert, London.
Marjorie Betty Leak, Bristol.
Peter Francis Leese, Northwood.
David Gemmell Lennie, West Kilbride.
Brenda Elizabeth Lewis, Bristol.
Eric Lewis, Woking.
Leonard George Noye, Rushmere.
Richard James Neville Oliver, Eastleigh.
Dermot Stephen Rogers, Belmont.
William Sena, Singapore.

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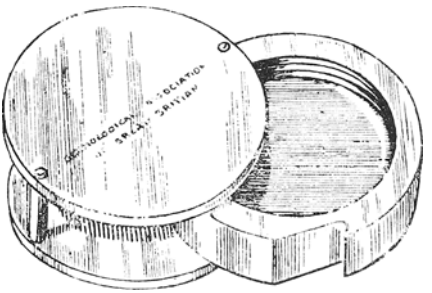

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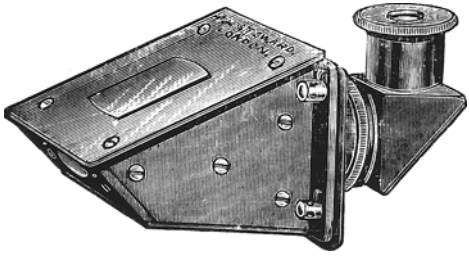

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Vol. IV No. 5 JANUARY 1954

BLACK CORAL

by ROBERT WEBSTER, F.G.A.

MANY text books refer to a true black coral which has been prized by the Chinese and Indian peoples but which does not appear as a medium for personal adornment in Western countries. There has recently come into the possession of the Gemmological Association a branch, some 10 inches long, of this black coral, and it has been the writer's privilege to be allowed to examine the specimen.

Black coral, the axial skeleton of the antipathes, is a coral of many genera, only one of which does not produce a black axial skeleton. Antipathes, one of the sub-class *Zoantharia* of the *Anthozoa*, are flower-like animals termed *polyps* belonging to the phylum *Coelenterata*. According to Sedgwick[1] the antipathidae are colonial zoantharia having six tentacles and six primary mesenteries and generally have a usually branched axial, hollow, horny skeletal rod containing an epithelial sheath ; this is the coenosarc which secretes the material which builds up the skeletal rod. Walton[2] has discussed the formation of coral most fully in his informative article on precious coral and repetition will not be necessary.

The antipathidae have a wide distribution and grow to a considerable height and thickness in tropic waters. The black coral fished for commerce is known as " Akabar " or " King's coral " and is taken from the waters of the Indian Ocean and the Persian Gulf. Halford Watkins[3] mentions a black coral akin to

the Indian Ocean material which is found in the Mediterranean and is termed " Giogetto."

In outward appearance the branch examined is a slightly curved rod with a single side appendage due to the cutting off of a side branch. The surface was shiny black and the cut ends showed that the rod had a central cavity—indeed the " rod " is a tube. The solid part showed the structure to be spiral, just like a rolled up paper tube.

For the purposes of examination two sections were cut off from one end of the branch. The cut end showed the material to

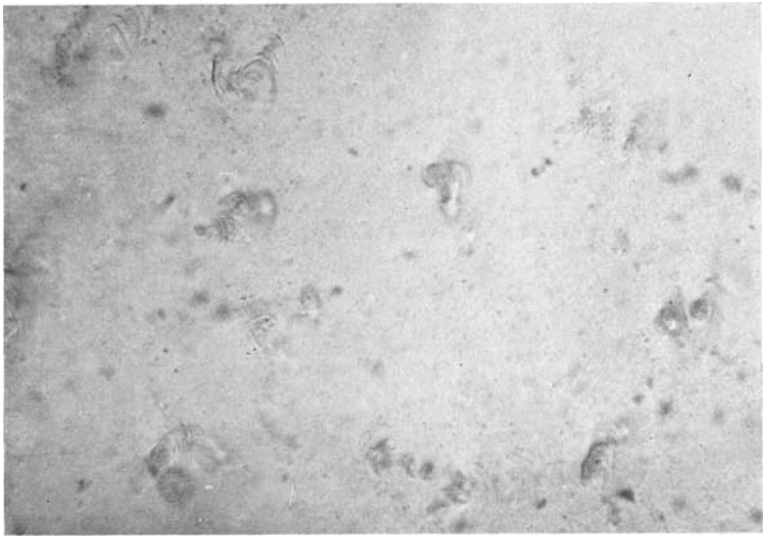

Fig. 1. *Longtitudinal section of black coral. Approx.* 80 ×.

be brownish in colour—a similar effect is seen in the case of jet. The density was found to be 1.32 for one piece and 1.35 for the other. This implies that the material is not horn (keratin) but conchiolin ; for the densities found agree with the value for conchiolin found by the writer[4] some years ago. The density for horn is 1.29 and varies very little from that value. A polished flat was put on one piece of the black coral and this surface gave a clear shadow edge on the refractometer of 1.56. There was no effervescence, even with the dust from the sawing process, when treated with acid. This indicates that there was no carbonate in the composition.

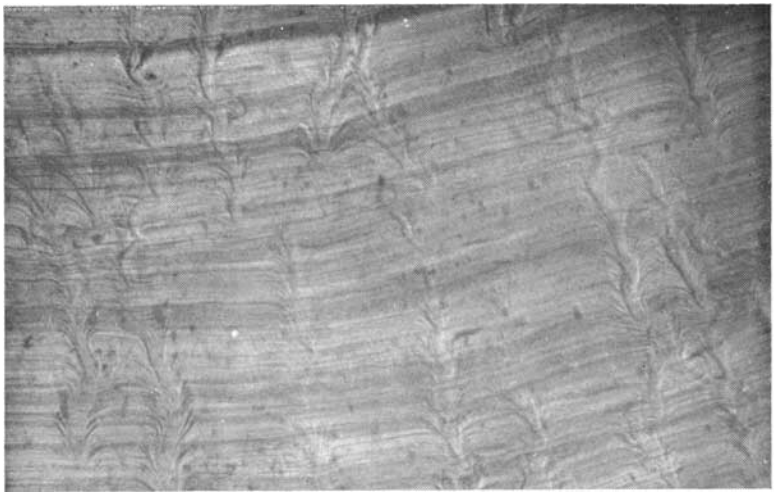

Fig. 2. *Transverse section of black coral. Approx.* 50 ×.

In order to examine the structure two thin sections were made; one transverse to the axis and the other parallel to it. Microscopical examination of the longitudinal section showed a field interspersed with " knots " as in a piece of wood, and indeed was reminiscent of " bird's-eye maple " (Fig. 1). Between crossed nicols the field showed strong polarization colours indicating anomalous double refraction, the strain patches being most pronounced around the localities of the " knots." The transverse section showed, with very low power magnification, banding or striae conforming to the spiral arrangement noticed in the macro section, and under higher power a finer arrangement of the striae could be seen. Over the whole of this field were observed feathery radial channels (Fig. 2). This section again showed strong anomalous double refraction when observed between crossed nicols, the strain patches being related to the channels. It is presumed that these " knots " and " channels " are remains of points of attachment of the polyps to the coenosarc and represent differential deposition of the conchiolin-forming secretion.

1. Sedgwick, A. *A student's textbook of zoology.* London 1898.
2. Walton, J. *Coral.* Gemmologist, Vol. XVII, No. 202, pp. 107–118. May 1948.
3. Halford-Watkins, J. F. *Coral ; its occurrence and collection.* Gemmologist, Vol. XIII, No. 153, pp. 39–41 and No. 154, pp. 47–49 and 55. April and May 1944.
4. Webster, R. *Operculum.* Gemmologist, Vol. VIII, No. 88, pp. 49–51, November 1938.

The ORIGIN of the COLOUR in PRECIOUS OPAL

by G. F. LEECHMAN, F.G.A.

SUPERFICIAL examination of precious opal emphasizes the presence of structural peculiarities which emit bright colours. Formerly these were thought to be due to thin cracks which had been refilled, but recent research appears to indicate that they originate in incipient lattice structures which have developed in the natural silica gel.

It is frequently said that opal is amorphous but this very broad statement is clearly not strictly correct. Some common opal may be completely without regular internal structure, although it has been shown by X-ray analysis that it normally contains crystallites of cristobalite and silica threads are probably present also, according to Sosman. Precious opal obviously contains many areas with visible orderly arrangement in the form of parallel threads or fibres, sometimes almost acicular. Between these two extremes is a comparatively seldom seen but nevertheless very revealing series of intermediate stages which clearly shows the gradual development of regular structures in the mass.

Several months spent recently on the opal fields have enabled the writer to collect a wide variety of specimens in which support for this suggestion is definite while evidence to the contrary is not to be found. Pieces of common opal which have obviously been cracked and subsequently flooded with a siliceous sol have often been carefully examined, but here no trace of the colour-effect is discernible. Many other pieces which bear no sign of any break carry indications of colour in various degrees. Finally, examples of the colloidal nature of the mineral are of course plentiful.

In this short summary it will be advisable to touch only on the more important points, omitting much detail and elaboration of many statements, so as to offer simply a straightforward and logical exposition of the method of attack and the progress made.

In order to discuss the subject satisfactorily some initial points, namely, the nature of colloids, the hypothetical cracks and the importance of the quality of the colour must be dealt with after which we may consider the theoretical aspect from the chemical, mineralogical and physical point of view. Practical work consists in a study of relative reactions in the laboratory, investigation of the geological field and associated minerals and the examination of many specimens both in the hand and under the microscope.

Colloidal solutions—or more properly " sols "—were formerly said to be those which on evaporation produce not a crystalline substance such as quartz or calcite but an amorphous jelly (or " gel "). A more modern and accurate definition is that the colloidal form is a state of sub-division of matter in which the particle size lies between that of the true solutions (less than 10^{-6} mm) and that of coarse suspensions (more than 10^{-4} mm). Many usually crystalline minerals may, under suitable conditions, be deposited in the colloidal state, i.e., having large non-crystallizing particles. Thus silica occurs both as quartz and as natural silica gel (as well as in many other forms) and calcium carbonate may be found as aragonite or as the sol from which the pearl oyster produces its nacre. The geologist and mineralogist frequently encounter colloidal forms but to some gemmologists they may be a new departure—amber, meerschaum and paste may be cited as familiar examples. In connection with the present subject ferric hydroxide and aluminium hydroxide are of importance as likely to influence the formation of sporadic structure in the colloid.

In 1801 l'Abbé Haüy, who has been termed the father of crystallography, suggested that opal colours appeared to be due to the presence of numbers of small cracks which had presumably developed in the mass when it was drying and shrinking. In spite of very strong evidence to the contrary this hypothesis has been repeated many times since. Only forty years later Sir David Brewster found it untenable and thirty years after that Behrens put forward the lamellar theory as preferable to that of Haüy. We are then in good company in doubting this suggestion and indeed superficial examination is sufficient to demonstrate its unlikely nature. If these areas were once cracks they do not resemble the conchoidal fracture of opal, concave with irregular borders and

curved shell-like markings ; the cracks would presumably vary in size and direction, might be a potential source of weakness and perhaps entrap air bubbles. Instead we see nearly flat patches, with edges frequently straight for short distances ; frequently they have strong parallel equidistant striations. Their thickness is never great, they are usually similarly oriented ; they very seldom show on a cleft surface and fluid inclusions are not often found. According to the present suggestion it may be advanced that most of these attributes could reasonably be assigned to a lattice formation :—planar, with striations and rectilineal boundaries they are thin, parallel and regular in structure.

To the casual observer there is usually but little difference between the quality of the colour of thin plates and the quality of prismatic colours, but to the practised, interested eye, this difference in tone is obvious—as different as the rainbow is from oil on a rainy puddle. The colours of Newton's rings (which we see for example in iris quartz, cracked glass or dragon-flies' wings) are produced by the cancellation of certain wavelengths, leaving all the others in the spectrum operative ; thus if yellow were obliterated we should see a mixture of all those remaining—red, orange, green, blue and violet—a rather unpleasant tone, far from monochromatic and very deficient in brightness, since all the yellow is damped out. Such peculiar shades are typical of interference colours but are never seen in precious opal (or in the spectroscope, diffraction grating or blue butterflies' wings). Here the white light is analysed by differential refraction and dispersion and becomes monochromatic. Its prismatic nature may be demonstrated with the sodium light, but it is the quality of the colour which indicates to the student whether the hue is pure or not, composed of but one wavelength or of many, whether it is like a single clear piano note or a dissonance. It may be possible to obtain a piece of opal which is obviously cracked so that a comparison may be made between the appearance of the actual crack and those areas which emit the usual colour effect. The argument in favour of incipient lattices is very strong.

Chemically opal is hydrated silica SiO_2nH_2O. Commercially it is sold as silica gel and, being very porous, is valuable as an absorbent, hence the percentage of included water varies. It is manufactured by treating a soluble silicate with an acid,

$$Na_2SiO_3 + 2HCl = 2NaCl + H_2SiO_3 \text{ (silicic acid).}$$

The silicic acid is then heated sufficiently to drive off the combined water. Experimentally silica gel is prepared in the same way. A few drops of water-glass suitably diluted are treated with a dilute acid (or a saline solution) when a sol or a gel of greater or less mobility will be formed.

Sosman in his monumental work on " The Properties of Silica " points out that threads formed of SiO_4 tetrahedra may commence to form even in gaseous silica above 1800°C—this implies an orderly arrangement of molecules in a gas. Below 1700°C the silica, now a liquid, may be compared to a mass of moving wires or, as he puts it, wriggling worms ; at lower temperatures a pad of twisted wires, i.e., silica glass. If the decrease of temperature is slow enough however, the threads will tend to pack as closely as possible, that is, they will ultimately lie straight and parallel, side by side, ionic linkage giving first quartzine, then cristobalite, tridymite and finally quartz. It seems reasonable to assume that when silica is produced in an aqueous solution a similar series of events occurs, the SiO_4 tetrahedra linking up into chains (Si_2O_6 as in diopside) or silica rings as in beryl $Be_3Al_2(Si_6O_{18})$.

This is well set out in Rutley—49th edition, page 140, where further steps are described. The chains may be linked side by side as in the amphiboles and pyroxenes (nephrite and jadeite) and a sheet structure develops when the SiO_4 tetrahedra are joined by three of their corners, extending indefinitely in a two-dimensional network only the thickness of $1\frac{1}{2}$ molecules. These sheets may be arranged in pairs, as in the micas. A three-dimensional framework is formed when each tetrahedron is connected up at all four corners producing a solid crystal as in quartz SiO_2 or felspar $KAlSi_3O_8$. Thus we see that before a three-dimensional crystal lattice is formed the sheet structure may be assumed and before that, the fibrous or chain formation. These appear to be connected with the striations and sheet structures we see in precious opal. It may be suggested that when a gel forms very slowly the chains of silica tetrahedra moving under the impact of other molecules are sometimes able to orient themselves into parallel positions and link up to form sheets, but that when solidification is rapid this is not possible and common opal almost devoid of structure is the result.

In the laboratory variations in the concentration of the reagents will be found of importance, as also will the resulting pH

values. Here a universal liquid indicator is useful and it will be found that when a very light gel breaks down and accumulates at the bottom of the tube this precipitate is basic, the liquor above being acidic while higher it may again be basic. Thus we may have a test tube showing a clear transparent liquid between two less fluid areas, the amorphous gel lying below and more opaque silicic acid with sodium hydroxide encrustations above. In this clear acidic area after some 30 to 48 hours diaphanous films will develop as tenuous flexible sheets suspended at random in the liquor. These films appear to be related to those which under other conditions produce the opal effect. They are the result of polymerization, the linking together of molecules, a secondary continuation of the process which developed the gel, now disrupted and lying at the bottom of the test tube. Here it undergoes syneresis (or contraction and an increase of rigidity) and some of the dispersion medium (mono-silicic acid) is now gradually expressed, it having remained in the porous gel after it had set. It carries molecules which are still in a lesser degree subject to polymerization and this now slowly takes place so that layer lattices and lamellæ build up in the clear area. That a similar process takes place under natural conditions is clearly indicated by an examination of many opal specimens collected in the field.

There are three types of opal field in Australia, but probably more than 98 per cent of the supply comes from the sedimentary sandstones of Cretaceous age. The remainder, either volcanic or else boulder opal, is negligible yet any explanation of the cause of the colour effect must take these two varieties into consideration as being equally important with the sandstone opal. This is found in extremely flat country only very occasionally varied by small isolated flat-topped hills and ridges which sometimes carry deposits of opal in the clay beds between the strata. These elevations are generally ascribed to differential erosion, due to increased hardness which has been caused by a local increase in silicification. The cap rock of indurated sandstone protects the softer beds below, and it is said that capillarity has drawn the soluble silica to the surface where it has remained, the lower layers being thus depleted. However there are several difficulties to be surmounted before this can be completely accepted and an alternative suggestion is that deep-seated increases of temperature

in Miocene times have resulted in hydro-thermal activity. Thus hot mineralized springs appear to have developed locally carrying silica which has seeped into the surrounding porous rocks both at the surface and lower in the workings.

Rapidly sketching the geological history, we had a wide inland sea (usually shallow but once or twice it became fairly deep), dividing the continent almost completely from north to south. Clay was deposited and to-day we find in it cretaceous fossil shells, bones and so on, sometimes opalized. The sea dried out into lagoons and salt pans, traces of which still remain and a long quiet period ensued, the Eocene, lasting several millions of years. This was followed by the Oligocene and then the Miocene, during which there was some renewal of tectonic activity. It was during this period that the silica deposits are considered to have invaded the Cretaceous sandstone beds, filling the seams and crevices, the cavities where plant remains and even fish had once been, then through the centuries gradually drying and hardening into opal. An essential feature of this is the wide extension of thick horizontal beds of originally porous argillaceous sandstone which has been saturated with siliceous solutions and consequently hardened, rendering the strata quite impervious and thus preventing any but the minimum evaporation from below them. On account of this a sol which contained much water or silicic acid as the dispersion phase would be able to gel only extremely slowly, the large polymerized molecules would be free to move and would do so until each had settled into a secure position from which it could not readily be dislodged by the impact of other molecules.

The opal is usually found dispersed in clay between the thick sheets of sandstone, but it may also occur in the rock above or below the layer of " opal-dirt." This clay appears to be of an estuarine origin and it is here that most of the fossils are found, giving some picture of the conditions at the time it was deposited.

Copi, or gypsum, is fairly common with ferric oxide and psilomelane but few other minerals are to be found although the former presence of saline solutions is strongly indicated when a sample of clay or of sandstone is washed. Small sheets of ferric oxide occur and red staining of the country rock by the hydroxide is quite common, being welcomed as indicative of precious opal. Aluminium silicate and hydroxide are of course present in the clay.

Except for the gypsum and salts all the minerals mentioned are in the colloidal form and were presumably originally present in the solutions which later formed the sol and finally the gel. This would give a silica gel with some impurities, which would have to be accommodated in the mass. As gelation proceeds some of the accessory minerals appear to segregate themselves and incipient crystal lattices form. How far this is successful would decide whether the result is to be merely common colourless opal, i.e., " potch," or gem quality material or else that intermediate product known to the miners as " potch and colour." Large quantities of unsaleable quality may be obtained, either discarded on the dumps or from the polishers and although of no value commercially, yet for the student here is obviously the key to the problem of the origin of colour. Whether examined as a hand specimen, with a small magnifying glass or under the microscope, a wealth of evidence is obtained which points conclusively to the colloidal origin of the mineral which yet occasionally undoubtedly shows obvious structure in the form of *small striated blocs* which actually flicker with colour on the surface of some specimens.

In order to appreciate the value of such evidence it is advantageous to look through great numbers of pieces, noting their implications carefully. In the larger lumps we see that the material is certainly solidified from a fairly mobile gel which has formed or been deposited in the seams and interstices of the beds of clay and sandstone. Various kinds of potch are noticeable, from the heavy almost opaque basic type to the clear water-white acidic hyalite. Sometimes cells or bands of the latter are included in the former, which normally lies in the lower part of the cavity. With a hand glass we may note the clear acidic areas where the colour occurs and examples may be found which show all five stages of colour formation. Specimens occasionally come to hand where small discrete sheets of colour, well isolated from their neighbours, may be observed without difficulty and their exact form and nature discussed. Rarely are to be seen pieces of opal which reveal on a fractured surface the striated bloc or film-pack structures previously referred to. Under the microscope these are quite obviously of a crystalline nature. Finally one may take a small fragment of colourful opal, crush it to the size of coarse sand grains and study these by transverse illumination—the typical shape of the particles approximates to a rectangular block in which

packs of films may sometimes be seen while by polarized light areas will be found which are not amorphous but definitely regular in structure.

Assuming then that we have shown from direct evidence that such regularity exists, the question arises as to how such comparatively coarse formations can be connected with the colour-effect. The lengths of the waves of visible light lie between 3600 A.U. and 7600 A.U., the waves being far too long to be affected by the primary lattice spacing of crystalline silica which is about 8 A.U. We are, however, not working on crystalline silica but on the colloidal form which has had ample opportunity to polymerize and many years in which to bring the long chain molecules into ideal positions. When the primary silicic acid gel is first formed it has a molecular weight of 60 to 100, but this immediately begins to increase and the process continues until, under satisfactory conditions, the molecular weight may be more than 10,000 and the length of the giant molecules up to 30,000 A.U. or more. Here we have passed beyond the domain of visible light and we see that colloidal silica may normally reach this stage. We may well suggest that the coarse macro-structures of film-pack form which are clearly visible in occasional specimens imply without a doubt that finer micro-structures may be present which could monitor the light, provided the lines on their surfaces are regular, parallel and equally spaced, as they must be. (Spencer, *Key to Precious Stones*, 1936, p. 222).

Sheet structure is typical of the micas, feldspars and clays, which are, speaking generally, aluminium silicates, that is, silica with some silicon ions replaced by those of aluminium (and other metals, such as iron). These are not truly isomorphous since the aluminium ion is much larger than the silicon and so causes some interference with the regularity. The ambidextral rotation of the crystallization of quartz must be taken into account also, and the subsequent twinning (see Journ. Gemmology, Jan. '53, p. 23). All these factors must influence the lattice spacing, which appears to be of special importance in the highest quality gem material. In this we see the ultimate stage in the production of colour, the development of which must now be shortly considered.

The first visible trace of colour is to be found in those specimens of hyalite which have faint *indefinite misty patches* of pale blue. These hazy parts have no obvious outlines ; the blue appears to be

diffracted from minute silica particles sparingly dispersed through the gel. This material, while very common on the field is entirely valueless and is therefore seldom seen elsewhere.

With increased deposition of silica we get more plentiful and larger particles regularly spaced, thus we find *definite blue clouds* with obvious outlines and fixed positions. This second stage blue is rather darker and the specimens in general not so transparent. Further development in this direction may lead to opaque potch.

The third stage shows the silica particles building up coloured *diaphanous films*. Good specimens may be obtained occasionally in amber potch, which corresponds very closely to Mexican opal, but they are not common. Here we see suspended in the clear gel very obvious films, usually almost flat, with rectilinear outlines and smooth coloured surfaces, one colour all over. In different directions they are of different hues, and as the position alters the shade may change from one prismatic colour to the next. They are definitely monochromatic and mixed tones such as mauves, greys, browns or crimsons have not been seen. This type of stone also is seldom handled by lapidaries or jewellers as it is of no interest to the average customer, but Mexican opal sometimes shows the effect.

When these *films become more heavily developed* they are usually fibrous or striated and then constitute the fourth stage. Here they are frequently rather irregular at the edges and sometimes appear to be fractured through the surface, but they are more numerous and brilliant, the stones being quite saleable. The fibres are sometimes so definite as to resemble acicular crystals and under the microscope by reflected light they are completely opaque. A surprising change is revealed however on switching to substage illumination as they then disappear entirely, the area where they were being completely translucent ; however, in polarized light some indication of their presence is usually discernible.

Finally we come to the ultimate development, where the display of colour is at a maximum. Considering the brilliancy in particular we cannot deny that it surpasses that of any other coloured gem-stone and in fact approaches in strength total internal reflection or that

of a backed paste. It seems incredible that such a thin translucent film could produce such a brilliant result, but let us consider the effect of one film forming behind another, with others similarly placed behind them, the spacing being such as not to interfere with the wavelength. Light entering laterally into a pack of parallel equidistant transparent films will be brighter, transmitted frontally, than light reflected under similar conditions from one plane only since the supporting films, being suitably spaced, will reflect a further proportion of light which would otherwise be lost.

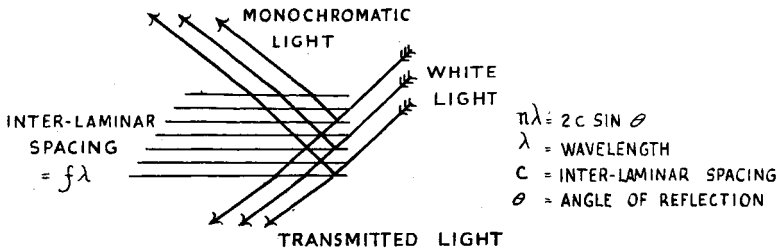

It is concluded that this resonance effect, illustrated in the diagram, is the governing factor in the production of the unusually brilliant and highly monochromatic colours of precious opal.

Summarizing briefly we may say that previous explanations of the effect appear unsatisfactory in the light of modern knowledge. Opal was formerly considered to be typically amorphous until X-ray investigation proved the contrary. Chemically it is natural silica gel and it may be produced by simple reactions. Consideration of these and of the actual opal fields raises the suggestion that delayed polymerization and protracted evaporation favour the development of incipient crystal lattices in the gel and specimens showing well-developed film-packs on the surface have been obtained. Since these macro-formations can be verified the finer micro-structures may be accepted as proved. When the lattice spacing is of a suitable order a series of films, although translucent in one direction, can reflect in the other pure colours of great brilliancy.

In volcanic opal and in the boulder variety the mode of origin is different but the same requirements for the production of colour have been met. Where a hot solution of silica has been trapped in the cavities of igneous rocks or where it has penetrated the cracks of ironstone boulders embedded in clay, the solidification will still be extremely slow and undisturbed. There is still the freedom from crystalline salts which might interfere and provided the pH values and the temperature are satisfactory a suitable crystal lattice should form. Perhaps unfortunately it is but seldom that all the highly critical conditions are satisfied and it may be said that good quality gem material in large pieces does not normally occur.

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(*Continued from page 211*).

shame the few cabochon bronzites and mediocre faceted greenish-brown stones I have previously seen. A rich, reddish-brown in colour these gems can be regarded as something new for the collector. Although these reached me from Ceylon they came originally from India.

Among stones for which there is no definite place of origin are several worthy of mention. One was a very fine rose pink scapolite cat's-eye. Another, a green tourmaline with a brilliant but unusually narrow chatoyant streak. A couple of cabochon cut dioptases and a bead of the rare Canadian mineral chlorastrolite complete my list.

SOME NOTES on UNUSUAL GEMS

by R. K. MITCHELL, F.G.A.

SEVERAL unusual stones have come my way in the past few months which have for the most part emanated from Ceylon —a seemingly never-ending source of the unexpected. I now list them briefly for the sake of placing them on record.

Firstly a large grey aventurine quartz, cut en cabochon, showed a faint but unmistakable six-rayed star. This is abnormal since it is usually considered that aventurine occurs only in massive quartz and not in the single crystals which would give the necessary orientation to the structure causing the star.

Another specimen was a small well-formed group of blue spinel crystals showing the very rare dodecahedral form dominating the more usual octahedron. The Natural History Museum had nothing like it so I parted with it to them.

A dark green glass with a four-rayed star and beautifully oriented inclusions is probably unique. Analysis shows that this contains lead and is therefore almost certainly artificial. I feel it may be a Ceylon " pit " glass of great antiquity which has reached an unusal state of devitrification. Work on this is still going on and further details may be published later.

A 60 carat water-worn sinhalite has also come to light. This definitely came from Ratnapura but more exact details are not available. It does serve, however, to give further proof of the origin of this newly recognized species.

Several iolites of good and medium quality have also reached me. Some years ago a 90 carat piece of rough passed through my hands. I have never seen another piece anything like it and still regret letting it go. This piece is now a prize exhibit in an American museum.

Perhaps the most interesting of all is a small parcel of *brown* gem-quality enstatite. The material is very strongly dichroic and has an extraordinarily rich absorption spectrum. It puts to

(*Continued on page 210*).

Gemmological Abstracts

POUGH (F. H.). *Gem collection of the American Museum of Natural History, New York City.* Gems and Gemology, Vol. VII, No. 11, pp. 323–334 and 351, Fall 1953.

A very full report on the gemstones in the New York Museum, of which the author was formerly curator. The collection owes much of its present magnificence to such well-known personalities as G. F. Kunz and J. Pierpont Morgan among others. The diamond display shows coloured diamonds and crystals which have been found in Wisconsin and Alabama. The corundum group includes among other large stones, a 100 carat orange Ceylon sapphire and the famed 100 carat De Long star ruby. The "Star of India," a blue star sapphire of 563 carats, is the world's largest star sapphire. The beryl collection includes the Schettler emerald, an 88 carat Indian engraved tablet, and a number of large size aquamarines reaching up to 400 carats in weight. These include some fine fancy coloured beryls, morganites and yellows. The notable topazes are the 144 facet egg-shaped blue Brazilian topaz weighing 1463 carats ; a 241 carat pale orange-brown Burma stone and a 70 carat spinel-red stone. Full description is given of the spinels, the garnets and the tourmalines, the latter having particular emphasis on those from Pala, California. The 208 carat cut blue zircon is said to be the largest stone of this type in the world. A clear green 6 carat zircon from Minas Gerais, Brazil, illustrates a new locality for zircon. The most notable peridot is an 82.5 carat Burma stone, and in chrysoberyls a 47.8 carat cat's-eye. The alexandrites are good but not large. The cases following, after a fine show of opals, consist of the rarer stones which include some exceptional kunzites and the largest known hiddenite. Unlike our National Museums the collection displays pearls. These are mainly freshwater, clam and conch pearls, but a selection of Japanese cultured pearls are also shown. Coral is also shown. The exhibit is finished with a case of the synthetic stones. 1 illus.

R.W.

FOSHAG (W. F.). *A visit to Idar-Oberstein.* Gems and Gemology, Vol. VII, No. 11, pp. 339–342, Fall 1953.

A historical survey of the gem cutting centre of the twin towns

on the Nahe river. Comparison is made of the new and the old methods and the machinery used. Personalities are mentioned. 4 illus.

R.W.

WALSH (A.). *Electron micrograph of a diamond.* Gemmologist, Vol. XXII, No. 267, p. 180, October 1953.

Using negative formvar replica process followed by gold palladium shadowing, electron micrographs at 40,000x magnification have been produced of the surface of a polished diamond. Information on sub-microscopic pits and polishing marks have been obtained. 1 illus.

R.W.

LEWIS (M. D. S.). *The History of Paste.* Gemmologist, Vol. XXII, No. 268, pp. 193–197, November 1953.

As its title suggests the article is a historical account of the use of paste (glass) as material for ornamentation. For perhaps 1,500 years glass was a material of great rarity and often worth more than precious metals. Glass was probably first produced in Egypt some thousands of years ago and for ornamental purposes. During the period up to the Middle Ages coloured glass was supreme (around the 14th century the re-discovery of the use of manganese for decolourizing glass allowed the production of colourless stones) and cabochon styles used. 1 illus.

R.W.

WEBSTER (R.). *Inclusions in yellow chrysoberyl.* Gems and Gemology, Vol. VII, No. 11, pp. 343–346, Fall 1953.

Reference is made to a " bladed " or " stepped " series of planes seen in yellow chrysoberyl. These are suggested as being parallel to the brachydome faces of the crystal. Other inclusions seen in chrysoberyl are referred to. 8 illus.

P.B.

WEBSTER (R.). *Gemstone luminescence.* Gemmologist, Vol. XXII, Nos. 265/6/7, pp. 139–143/161–164/188–191, August/September/October 1953.

(See Journ. Gemmology, Vol. IV, No. 4, p. 179). Continuation of the alphabetical series of the luminescence of gemstones, from Brazilianite to Paste.

P.B.

COGGIN BROWN (J.). *Emeralds in India.* Gemmologist, Vol. XXII, Nos. 265/6, pp. 133–136 and 165–168, August and September 1953.

A historical report on the occurrence of emerald in India. Udaipur emeralds found in 1943 when prospecting for mica and beryl for war purposes. Dr. Coggin Brown was formerly with the Indian Geological Survey and has full knowledge of Indian geology. 2 illus.

R.W.

MITCHELL (R. K.). *A new variety of gem enstatite.* Gemmologist, Vol. XXII, No. 265, p. 145, August 1953.

The report of a new variety of gem enstatite (or bronzite). Refractive indices given are 1.669 and 1.680 with a density of 3.33. Pleochroic colours are dark reddish-brown, pale reddish-brown and brownish-green. Spectrum shows the 5060 line very strongly with fainter supporting bands and others in the green and blue and violet. A micaceous cleavage is said to make cutting difficult.

R.W.

ANDERSON (B. W.). *The spectroscope and its applications to gemmology.* Gemmologist, Vol. XXII, Nos. 266/7/8, pp. 153–158/173–176/198–201, Sept./Oct./Nov. 1953. (To be continued).

The introduction to a comprehensive article on the absorption spectra of gemstones. These first three instalments give a historical account of the discovery of the solar spectrum by Newton in 1666, the work of Fraunhofer, Zantedeschi, who seems to be the first to use a collimating lens, Foucault, Fox Talbot, Swan and others. The important work of Bunsen and Kirchhoff is discussed and the discovery of the two new elements caesium and rubidium by these workers with the aid of the spectroscope is told. The employment of the diffraction grating by Ångström and his use of the ten millionth of a millimetre scale—known as the Ångström unit, and the diffraction gratings made by Rowlands and used by him to produce his *New Tables of Standard Wavelengths* are discussed. It is remarked that the absorption spectra may bear no apparent relationship to the emission lines of an element. Brewster and Stokes were the first to record absorption spectra of solids, and Church in the case of gemstones. The early work of Becquerel on the luminescence spectra is mentioned and also the work of

Herschel in discovering that the spectrum extends into the infra-red. In the ultra-violet similar discovery was the work of Ritter. This was further elaborated by later workers. 6 illus.

Rare gem found near Broken Hill. Commonwealth Jeweller and Watchmaker, Vol. XXXVIII, No. 4, pp. 145, Oct., 1953.

A report of the finding of small specimens of gem quality titanite near Broken Hill. Two gems are stated to have been cut. A.G.

SCHLOSSMACHER (K.). *Die Seltenheit des Saphirs.* The rarity of the sapphire. Zeitschr.d.Deutsch.Gesell.f.Edelsteinkunde, Autumn 1953, No. 5. pp. 8–11.

The colouring pigment in sapphire is iron and titanium, which two elements are found both in Sial and Sima rocks. Good quality stones are mostly found in pegmatites. E.S.

SCHMIDT (PH.). *Magie der Edelsteine.* Magic of the gems. Zeitschr.d.Deutsch.Gesell.f.Edelsteinkunde, Autumn 1953, No. 5, 13–16.

Review of magical powers attributed to gems during the ages. Far East, Middle East and old Roman jewellery is discussed. E.S.

SCHÜTT (E.). *Die Bestimmung hochlichtbrechender Steine.* Determination of stones of high refractive index. Zeitschr.d.Deutsch. Gesell.f.Edelsteinkunde, Autumn, 1953, No. 5, 17–20.

Stones of higher R.I. than 1.81 and the use of Clerici solution undiscussed. E.S.

KRACEK (F. C.), NEUVONEN (K. J.), and BURLEY (G.). *A thermodynamic study of the stability of jadeite.* Journ. Washington Acad. Sci., 1951, Vol. XLI, pp. 373–383. 1 fig.

This paper is interesting to the gemmologist insofar as it again emphasizes that all attempts to produce jadeite have failed as yet. There is the suggestion that jadeite might be formed at an atmospheric pressure around 25°C. S.P.

ADAMS (L. H.). *A note on the stability of jadeite.* Amer. Journ. Sci., 1953, Vol. CCLI, pp. 299–308. 1 fig.

Thermodynamical equations are formulated to arrive at the pressure-temperature range for the formation of jadeite. There is a break-down to glass, nepheline and albite at temperatures above 800°C. There was no definite result to the experiments recorded. S.P.

BOOK REVIEW

FISCHER (W.). *Praktische Edelsteinkunde.* Practical Gemmology. (Opuscula Mineralogica et Geologica, Vol. III). Published by Gustav Feller—Nottulnm Kettwig/Ruhr, Germany, 1953, 187 pp., 48 illus. Price £1 10s.

This publication is an important contribution to the much neglected branch of gemmology concerning itself with the fashioning of gems from the rough. In its special part the book deals with 68 gem species and in most cases valuable hints are given regarding grinding and polishing means and lap materials. To the amateur lapidary this section will be of the greatest value and the apprenticed lapidary too will make good use of this information which the author was in a particularly favourable position to compile, because he is the present director of the Trade School for Diamond Polishers, Lapidaries and Goldsmiths at Idar-Oberstein. In the preceding general part the author tries to satisfy the more scientific interest of a necessarily different group of readers, because it seems inconceivable for instance that his pupils will master the intricacies of crystal structure and crystallography. The more advanced student, on the other hand, will detect in this part several inaccuracies, simplifications, omissions and a general lack of references which may be due to the fact that the author seems to rely in the first instance on compiling material, but did not apparently refer to some of the most important contemporary works. His bibliography includes some English and American authors, but—B. W. Anderson, R. Webster, K. F. Chudoba and E. J. Gübelin are not mentioned. A modern book on practical gemmology omitting some of to-day's leading gemmologists is incomplete.

One particular item belonging to both the general and special parts is the interesting relationship between the crystal lattice of the diamond and its preferred grinding directions. Whilst the theoretical relationship is made perfectly clear (for instance in Table 1 and the appendix), the fact is not mentioned that of two, three, or four preferred directions in the three main crystal planes, there is frequently only one best grinding direction in a (main) plane, which is used in practice. This curious fact has already been described by Eppler and implicitly also by Holstein. In spite of this and similar flaws the book is a very valuable contribution to gemmology. W.S.

SIMPLE PHOTOMICROGRAPHY

by J. R. H. & P. M. H. Chisholm.

DR. GÜBELIN[1] has amply demonstrated what beautiful and informative results may be obtained by photomicrography of gemstone inclusions and Messrs. Vincent,[2] Day[3] and Trumper[4] have shown how satisfactory results may be obtained without either complicated or expensive apparatus. It is the purpose of this article to dispel any lingering doubts that may remain in the minds of some gemmologists that photomicrography is beyond them. In truth there is no cause for alarm either in the difficulty of the procedure or in the expense of the necessary apparatus, since photomicrographs may be taken easily with apparatus which can easily be improvised.

By Anderson's[5] fascinating " immersion contact " technique the " interior decoration " of gemstones may be recorded photographically without the use of either a camera or a microscope, but for photomicrography a microscope is essential. The only other essentials are a light-source, a photographic emulsion, whether on a plate or a film, and some means whereby the plate or film may be held above the microscope so that (1) it is exposed to no light except that passing through the optical system of the microscope and to that only for the time required and (2) it receives sharply focussed the image of the object projected by the microscope.

The requirement of a microscope should present no difficulty. A gemmologist without a microscope is inconceivable and any microscope suitable for examining gemstone inclusions is also suitable for putting them on permanent record by means of photomicrography. The light-source is satisfactorily provided by any ordinary electric microscope-lamp, although, particularly for large and dark-coloured stones or high magnifications, a more powerful bulb may be desirable to avoid unduly long exposures. The plate or film is easy to obtain and not expensive, so the only possible cause of difficulty or expense must lie in the provision of the required plate- (or film-) holder.

The requirements in respect or the plate- (or film-) holder are twofold. The plate or film must be (1) capable of being fixed rigidly in focus and (2) protected from all unwanted light. The first requirement may easily be met by using laboratory retort stands (Vincent), making a simple wooden or metal stand (Day, Trumper), or adapting a photographic vertical enlarger (Trumper). Our very simple and easily made wooden stand is described below. The second requirement can obviously be met by using a camera—" any camera," as Trumper is no doubt correct in saying, although some cameras are much better for the purpose than others.

Vincent obtained satisfactory results using a box camera and roll film, but found it necessary to add a tube containing a series of supplementary spectacle lenses ; and Trumper illustrated the use of a folding roll-film camera. It is generally, however, not so easy to obtain exact focus of the image on the emulsion in the ordinary roll-film camera, as it is with a plate camera having a ground glass focussing screen and it is not every gemmologist who owns a plate camera or wishes to buy one (although old ones, eminently suitable for this purpose, may be picked up quite cheaply).

For the gemmologist who has no easily adaptable camera, Day suggested a method, whereby, instead of the plate or film being housed in a camera to exclude unwanted light, all the light was shut in by a container allowing none to escape except through the optical system of the microscope. This involved a complete light-tight boxing-in of both the light-source and the microscope itself, causing some inconvenience in handling the object under examination and in adjusting the focus of the microscope. Moreover a light-tight box to include light-source and microscope, having cloth-covered openings to allow the hands access to manipulate the contents, is a more complicated piece of apparatus than the situation requires.

Since we had neither a camera specially constructed for photomicrography nor a plate camera with a focussing screen, we considered that rather than try to adapt a roll-film camera or follow Day's example it would be easier to make a plate camera for ourselves of the most elementary sort, and experience has convinced us that this is indeed the simplest and easiest solution of the problem.

Fig. 1.

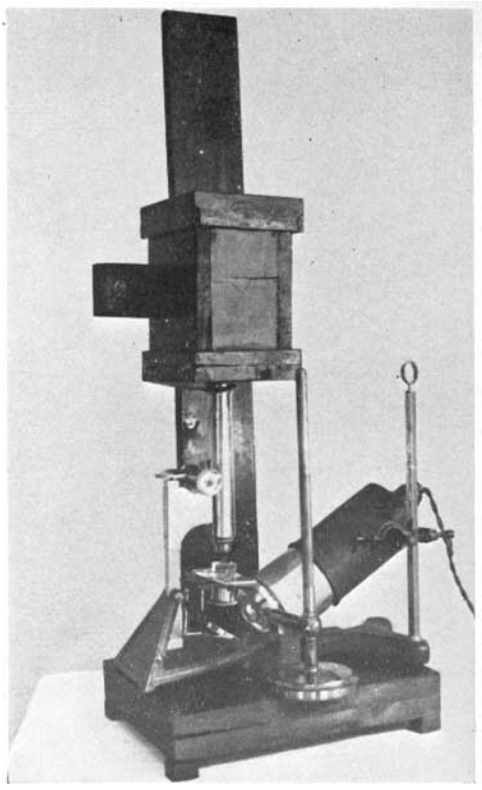

To make a folding roll-film camera would no doubt be a job to daunt even a more than competent handyman. But the camera required for our purpose is merely a light-proof box with (1) a lid under which the plate can rest horizontally and (2) a small hole (about $\frac{1}{2}''$ diameter) in the bottom : no lens is required and no shutter either. Our apparatus, which was made entirely from pieces of $\frac{5}{8}''$ and $\frac{7}{8}''$ floor-boarding (because we happened to have some), is described below, not as an example to be copied, but merely to show how simply apparatus which will work can be made. Actually, although the stand needs to be made of something substantial to ensure rigidity, a neater job might have been made of the " camera " if we had had some 3-ply : alternatively anyone

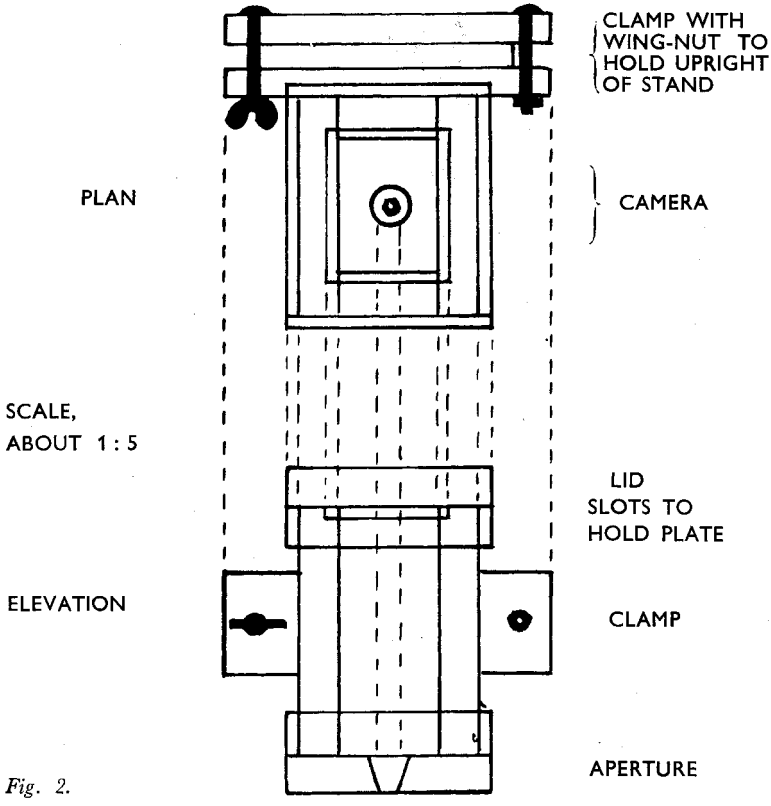

Fig. 2.

at all handy with a soldering iron could make an excellent camera for this purpose out of an old biscuit tin : or even more simply a stout cardboard box could be used.

Our apparatus complete with lamp and old Beck microscope is illustrated in Figure 1. The stand is made of a $''$ × $3\frac{3}{4}''$ × $30''$ upright screwed firmly to a base of two pieces of plank of $\frac{7}{8}''$ × $9''$ × $12''$ also firmly screwed together. The construction of the camera and the clamp holding it on the upright is shown in Figure 2. The clamp may be loosened by the wing nut to allow movement of the camera to any desired position on the upright. The camera is simply nailed together. No dove-tailing is needed and if necessary adhesive tape or paint run into the joints ensures light-tightness.

The first photomicrographs taken with this apparatus were of a hair, a drop of blood and a biological slide. They were successful but are not shown here. The first photograph of a gemstone was of an amethyst and the result is shown in Figure 3, which for a first attempt we considered encouraging. Incidentally, it shows that we had not yet learnt to arrange the stone to the best advantage so as to keep the maximum amount of its contents within the limits of the objective's depth of focus ; the inclusions observed were mostly in one plane, but, since that plane was not quite normal to the optical axis of the microscope, the two sides were respectively too close to and too distant from the objective and only a band across the middle of the picture is properly in focus. In our next photograph (Figure 4) this fault was eliminated.

Not all our photographs were taken using the same microscope. We also brought into service an old Wenham binocular, using of course the straight up ocular only, with the prism withdrawn from the optical system. This also proved satisfactory (see Figure 5), but having a 10″ tube increased the size of the image on the plate and therefore required rather longer exposures. Kodak 0250 orthochromatic quarter-plates were used.

The procedure with our apparatus differed little from that described by Day. The stone is placed on the microscope stage—either immersed in liquid in a cell or supported by plasticene on a slide—and the particular phenomenon to be recorded is brought into focus in the usual way. The " camera," with the back off and the ground glass plate in position (ground side down), is lowered until it is almost touching the eyepiece of the microscope and is then fixed, taking care that the image on the ground glass plate is properly centred and focussed : this may involve some slight adjustment of focus of the microscope. The light is then switched off—apart from a safelight, the actual " photography " must take place in the dark, as with Day's method, since the "camera" has no shutter—the sensitive plate unwrapped and substituted (emulsion side down) for the ground glass plate, the back replaced on the " camera " and the microscope lamp switched on for the desired exposure time. The plate is then removed—still in the dark—and either developed straight away or rewrapped for development subsequently.

Fig. 3.

Amethyst (cut stone).

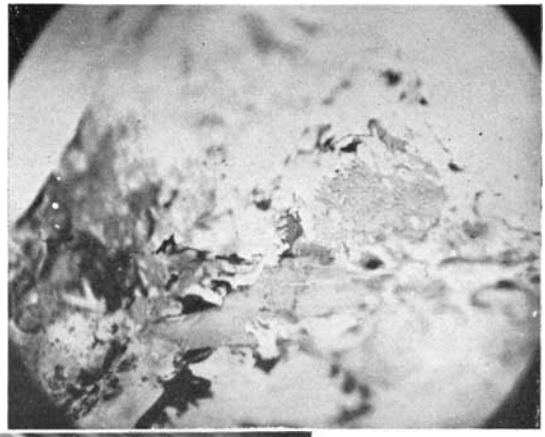

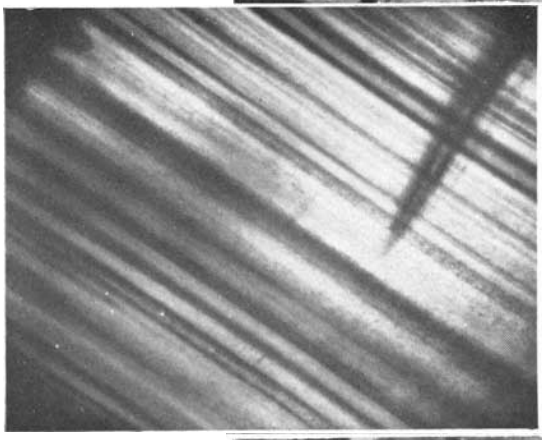

Fig. 4.

Blue-green Sapphire crystal.

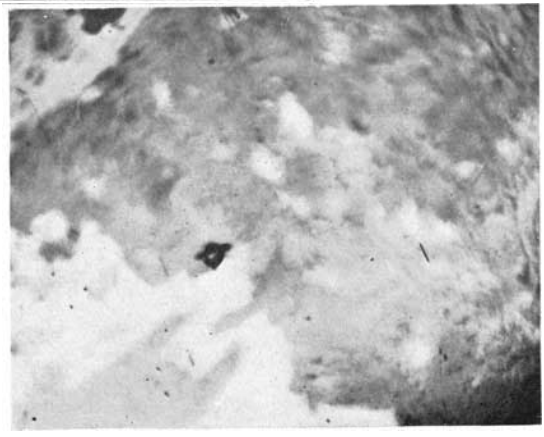

Fig. 5.

Alamandine cabochon.

Day has described the method for ascertaining the correct exposure time by a test plate and has also described the developing, but suggests it may be desirable to hand over the printing to a professional photographer. This, however, appears to be a needless confession of weakness, as the printing processes present no more difficulty than the developing and can best be carried out by the man who knows the particular results he wishes to obtain. It is surprising what different details can be brought out from the same negative by the use of different grades of printing paper (Kodak supply four contrast grades—soft, normal, hard and extra hard—and Ilford five—ultra hard in addition to the other four). For instance, Figure 4 lacked sufficient definition until printed upon Ilford ultra hard paper; in another case (not shown) the stone-edgd, visible when printed on Kodak normal, vanished on ultra hard.

In our work of collaboration P.M.H.R. made the apparatus and was responsible for the photography, while J.R.H. was principally concerned with manipulating the stones and the microscope and writing this article. As a child has been defined by Parliament[6] as " a person under the age of 14 years " and P.M.H.R. made the apparatus and took the first photographs within two months of his 14th birthday, we have grounds for asserting that it is so easy a child could do it.

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ASSOCIATION NOTICES

COUNCIL MEETING

A meeting of the Council was held at the Medical Society of London on Wednesday, 2nd December. Mr. F. H. Knowles-Brown presided. The following were elected to membership :

FELLOWS

Hermann Bank, Jun., Idar-Oberstein
Walter W. Bowen, Birmingham
Anthony W. Davis, Potters Bar.
John F. Hodges, Chester.
Roger W. Jones, Cirencester.
Vincent G. Jones, Sutton.
John B. Kemp, Bristol.
Norman A. Lambert, London.
Brenda E. Lewis (Miss), Bristol.
Jeanne G. M. Martin (Mrs.), San Diego
Leonard G. Noye, Ipswich.
Richard J. N. Oliver, Eastleigh.
Geoffrey H. Parsons, Bristol.
Anthony I. Stanton, London.
Roger I. Thomson, London.
Derek Walden, Enfield.
Leslie N. Wells, Oldham.
Helge R. Westgaard, Oslo.

Transfer from Probationary to Fellowship

Trevor M. Brook, Lincoln.
Robert C. Fox, Ilford.
Ronald A. Hall, Lingfield.
Anthony L. Kemp, Bristol.
Raphael I. Roth, London.
Colin S. Wickens, London.
Samuel Bache, Old Hill.
Alfred J. Brack, London.
Rodney F. Collyer, Birmingham.
John N. Forsey, Sutton Coldfield.
John Galloway, Edinburgh.
Graham E. Keay, London.
Michael J. Kutner, Wembley.
Peter F. Leese, Northwood.
David G. Lennie, West Kilbride.
Eric Lewis, Woking.
Dermot S. Rogers, Belmont.
William Sena, Singapore.
Gunnar B. Sunde, Oslo.
Ronald F. Tugwell, Thornton Heath.
Leslie P. Waites, Birmingham.
Peter J. Watson, London.
Harold J. Wheelock, Birmingham.
Beatrice M. Wood (Miss), London.

PROBATIONARY

Iris Chadwick (Miss), London.

ORDINARY

David Cameron, Edinburgh.
Vincent A. Davidson, Walsall.
Nellie E. Deane (Mrs.), Wednesbury.
Frank E. Goldie, Birmingham.
Bjarne A. Jensen, Bergen.
Patrick J. Laird, Omagh, N.I.
Atluri R. Sastry, Vijayawada, India.
Gordon M. Shaw, Edinburgh.

The Council amended By-law ten so as to prohibit the reproduction of the Seal of the Association in any form without consent of the Council.

BRANCH MEETINGS

Midland Branch

A meeting of the Branch was held on 13th November, when a gemmological competition was arranged. Meetings arranged for 1954 include : 22nd January (Imperial Hotel) ; 12th March and 14th May.

At the annual meeting held on 24th September Mr. Trevor Solomon was re-elected as Chairman, and Miss P. Cutts and Messrs. Harper, Perry, Conway and Leng elected to serve as the Committee. Mr. D. King was elected Honorary Secretary.

West of Scotland

At the extra-ordinary general meeting held on 23rd September, Mr. S. D. Wood was re-elected as Secretary of the Branch and Mrs. J. McKay and Messrs. J. Gillougley, I. McKenzie, E. McDonald and G. S. Wade, were elected Committee members. Mr. F. Bryan was re-elected as Chairman for a second year at the annual meeting held earlier in the month.

East of Scotland

Mr. G. Winnert has been elected Honorary Secretary of the East of Scotland Branch of the Association in place of Mr. D. J. Ewing. Mr. Ewing, who serves on the Council, has handed over in order to avoid filling two offices.

A competition between the East and West of Scotland Branches was held in Edinburgh on 26th November, and it proved highly successful. The specimens for the competition were provided by Head Office.

TALKS BY MEMBERS

Blythe, G. A. : "Gemstones," Young Wives' Association, Southend, 8th October ; North Country Club, Southend, 15th October, 1953.

Solomon, S. T. : "Gemstones," Townswomen's Guild, Plymouth, 12th January, 1954.

Webster, R. : "Gemmology," De la Beche Club, Royal School of Mines, Imperial College, South Kensington, 12th October, 1953 ; "The story of the synthetic gemstone," Chelsea Polytechnic Geological Society, Chelsea Polytechnic, 2nd December, 1953.

Melrose, R. A.: "Gems," Newcastle-upon-Tyne Branch of the British Horological Institute, November, 1953.

Leak, F. E.: "The Science of Jewellery" to the inmates of H.M. Prison, Falfied (the famous "Prison without Bars") November, 1953; "The Science of Jewellery" St. Dunstan's Church Fellowship, Bedminster Down, Bristol, November, 1953 ; "Diamonds," Victoria Park Methodist Church, Contact Club, Bristol, 3, January, 1954.

NATURAL HISTORY MUSEUM APPOINTMENT

The principal trustees of the British Museum have appointed Dr. G. F. Claringbull to the Keepership of the Department of Mineralogy in the British Museum (Natural History) in succession to Dr. F. A. Bannister, who has retired.

Dr. Claringbull, who joined the department of Mineralogy in 1935, has been an examiner in gemmology for the Association since 1938, succeeding Mr. A. H. Ward, and has also served on the Council since that time. He became General Secretary of the Mineralogical Society of Great Britain also in 1938. Dr. Claringbull has the best wishes of members on his new appointment.

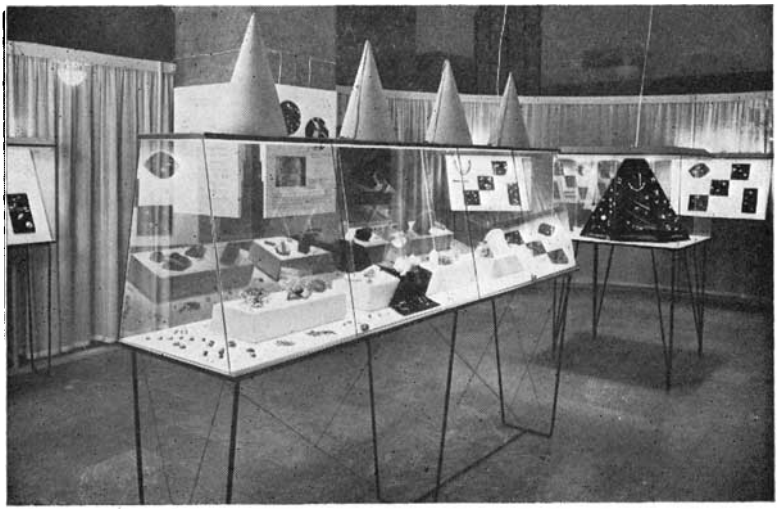

Sveriges Forening Exhibition 1953

SWEDISH GEM EXHIBITION

The Sveriges Forening Gemmologiska recently held a jewellery and gemstone Exhibition in Stockholm. For a first venture it was a great success and it is reported that nearly 50,000 visitors attended during the week that it was open.

Emphasis was placed on fine quality jewellery and, apart from outstanding pieces set with diamonds, rubies, sapphires and emeralds, there were many examples of the use of aquamarine, topaz and lesser known stones of equal beauty.

The Association reports that they have gained much goodwill for their organization, both in the trade and with the public.

The Exhibition was held in the Showrooms of Aktiebolaget Nordiska Kompaniet.

MEMBERS' MEETING

A meeting of members was held in the hall of the Medical Society of London on 2nd December. The Chairman, Mr. F. H. Knowles-Brown, presided over an " Any Questions " programme, which, for the Association, was in the nature of an experiment.

Mr. B. W. Anderson, Mr. R. K. Mitchell and Mr. A. Ross Popley comprised the Panel.

Question : What is the cause of some cultured pearls turning black after being in use for some time ?

Mr. Anderson replied that this question had often cropped up in the laboratory. There was a large number of such queries in 1947, and in the past year. It seemed that such queries occurred at times when there was a great deal of sunshine. It was wondered whether it was due to light on shop windows where the pearls were displayed, or on the necklaces while they were worn, causing some

photo-chemical action. Unfortunately, research was limited because they had not been allowed to cut the pearls. But during the past year a Fellow of the Association had made available some pearls on which experiments were conducted. X-rays showed nothing. It was found that the colouring was not, as was suspected, in the layer between the nucleus and the outside of the pearl ; it was in the outer nacre. Mr. Webster had been able to effect a partial remedy by treatment of the pearls with hydrogen peroxide, but whether this was a permanent improvement or not was not known. The full scientific answer to the problem was not yet known. This explanation brought some questions from a member of the panel, Mr. Mitchell, who was told that the blackening was, in fact, an ugly grey colour ; there was no evidence of shrinkage ; some had, and some had not, been in wear. It was suggested during the discussion that due to the porous nature of the pearls something might have been picked up from a wearer's perspiration. The hydrogen peroxide treatment was certainly rather drastic. It was better to scrape the pearls.

Mr. Kaye then asked : On heating, certain minerals have changed colour due to atomic structure of the gemstones ; what happened if gemstones were brought down to a very low temperature—would the slowing of atomic movement cause changes ?

The experts agreed that there was no reliable information on this, but it was interesting to cogitate on the matter. There was no facility, so far, for subjecting the gems to extremely low temperatures, though it was known that this would have to be done extremely carefully. One speaker said he had had a large emerald with him in the East for some time, during which it was subjected to about 50 degrees of frost without colour change. Mr. Ross Popley advanced the view that probably any colour change brought about by artificially low temperature would not be permanent.

Heat Treatment of Stones

Question : Is it possible to restore the colour to zircons which have faded in sunlight ? Mr. Ross Popley : It is possible to restore blue stones to their colour, and even to improve the colour, with stones which have faded, either in the window, or in wear. He added that the heating had to be most carefully controlled, and had to take place in a non-oxidising flame, followed by very slow cooling. Subject to these conditions they had obtained about 90 per cent success ; but experience was necessary.

Mr. Mitchell, in a supplementary, wondered how many times this restorative could be applied to one stone. The stone reaching this country was a product of heat. He was of the opinion that there would come a time when that could no longer be done in the laboratory.

Mr. Anderson replied that in some cases the first treatment was permanent, but in some cases, such as zircon, it was " re-altered " ad infinitum. Usually, a proper treatment was permanent, however.

Mr. Ross Popley, during discussion, said that stones would fade with the heat of rhodium plating (only about 180 deg. F.), and it was much more difficult to restore such a stone than one that had been subjected to sunlight. Mr. Anderson did not think, in answer to further questioning, that it was possible to improve

opals ; he had not tried to, but the cause of colour in opals was such that it was highly unlikely that colour could be improved by heating.

During exchanges concerning cracks in stones which had been repaired with oil, Mr. Ross-Popley said it had happened that some stones treated in white oil had lost a great deal of colour.

Mr. Anderson said he had normally considered loss of colour in zircon to be due to ultra-violet light, but it might possibly be due to heating to comparatively low temperatures. Mr. Ross Popley said that sometimes stones had lost colour while in the safe.

Synthetics

Mr. Ullman asked why, since synthetic and natural sapphires came from the same chemical elements, the synthetics rarely showed a line at 4,500 under the spectroscope ? Mr. Anderson said this had always worried them because they used that waveband considerably in testing sapphires. They knew iron was used in the making of synthetic sapphires, but it apparently evaporates during manufacture, having contributed to the colour formation, since it melts at a temperature lower than the titanium oxide.

Mr. Kent asked : If droplets of alumina crystallize immediately, why could long bubbles form which seemed to be at right angles to the formation of the boule ? Mr. Mitchell questioned whether the droplets did crystallize immediately (" how does it keep its shape ? " was interjected from the back of the hall). The surface of the boule was kept at a high temperature and he rather doubted whether droplets did crystallize at once. Mr. Anderson supplemented by saying the surface layers of the boule were in a fluid condition and it was a very gradual business, getting the right temperature on the surface to give a single crystal instead of the poly-crystalline mass. He thought the bubble was gas (hydrogen), rising to the surface and as more layers were applied the hydrogen was still trying to force its way to the surface, like a death watch beetle coming to the surface of a wooden beam.

The panel did not accept the accounts published from time to time of Indian lapidaries making stones, from a formula handed down from generation to generation, from powder remaining after the cutting of other stones. Mr. Anderson said that none such had reached the laboratory. Another speaker aid from what he knew of Indian lapidaries he marvelled that there should be any powder available. Re-heating would only produce a sort of glass—it might be quite hard. Dr. Gübelin had recently received samples of rubies with instructions on how to make them. Beryl glass had been seen but it was quite unlike crystalline beryl.

The indiscriminate use of the word " rhinestone " was deplored and the panel were amused by a reference in a national newspaper to " rhinestone pearls." There was general agreement to the suggestion that the word " rhinestone " had been taken up by the dressmakers and exploited. The omnibus use of the term was deprecated.

The meeting was also informed that the name was given years ago to attractive quartz pebbles won from the bed of the river Rhine (Rheinkieser).

Inclusions

Miss E. Ruff said the gemmologist waxed ecstatic about inclusions while the public was reared on the desirability of clear stones. Had anyone bridged the gap ? Mr. Anderson said that Dr. Gübelin showed the public, if they were interested, how one stone cost £50 and another £200 and attempted to explain how one has a number of inclusions which were very beautiful—though they do cause a " spotty " appearance. It would be a good thing if the public were to appreciate that inclusions could be signs of genuineness of the stone. There should be no objection to blemishes as long as they did not disfigure the stone. Mr. Mitchell stressed the importance of this when there was, in fact, a great shortage of clear stones. He thought it was mainly in diamonds and limpid stones that people desired a clear stone.

Another question asked whether the public was really interested in the lesser known stones. The theory was advanced that one of the troubles was lack of knowledge and interest by the jeweller. Some years ago one man in London had tried to popularize these other stones—but he had not made a great fortune out of it. Unfortunately the public were inclined to buy stones, not for their beauty so much as for investment purposes. Given more trade education the public could be sold these stones, one speaker considered. The colours, of course, were not so sharply perfect in these lesser-known stones.

Discussion then turned to the unfortunate aspects of referring to stones by their districts of origin—some districts were literally " damned " in the public eye, while others had a name which was absolute magic—like Kashmir. This was quite indefensible.

Can poor quality stones be improved by skinning ? another questioner wanted to know. Mr. Ross Popley answered that if the colour went through the stone it could be, but if the stone was stained one might be much worse off after skinning it.

In a discussion on detecting real stones and those which had been stained it was suggested that the answer lay mainly in experience, and comparison with as many other stones of known quality as possible. Sometimes it was a useful hint to beware of the stone which appeared to be " too good." Natural colouring was by no means always so equally distributed.

Coloured stones also showed the colour running into cracks and so on. But the most important point was a comparison which was as thorough as possible.

Cyclotron treated stones

Further questions on colouring showed that bombardment of a stone other than by radium gave no radio-activity a few hours after it had been carried out, although the radio-activity was considerable at the time of the work. One should, therefore, examine the fluorescence and colour distribution. Sometimes the bombarded stone showed a little " umbrella " at the base, or a girdle having a run of dark colour.

Laboratory proof of this treatment, it was again stressed, was not easy to produce. In the diamond it was very difficult to find out the colour distribution because of the extremely high refractive index, even in highly refractive oil. A

speaker from the body of the hall answered another question by saying he had often seen parti-coloured diamonds ; points often appeared darker. The parti-colouring was usually patchy, and most often seen by the observer in industrial diamonds. One often had layers which could be seen after cleaning. The thickness of a " skin " on a diamond varied widely from the thinnest film to one or two millimetres.

Reverting to bombardment of stones it was stated that cyclotron-treated diamonds could usually be polished back to their original state, but the effect of neutron bombardment was carried right through the stone.

Asked whether the lapidary could tell the difference, on the wheel, between real and synthetic stones (sapphires), Mr. Ross Popley said in about nine cases out of ten the answer was affirmative, because of the different " feel " of the stones on the wheel. He and other speakers, however, went on to reveal that there were startling (and often worrying), exceptions. A ruby mistaken for a garnet was one case instanced. It was dangerous to rely entirely upon the touch, however skilled that touch might be.

Mr. Anderson dealt at length with a questioner who asked why various text-books gave different figures (e.g. specific gravities), for the same stones. He said that there had been an unfortunate tendency for many authors to accept without study the figures of others, but that—often in earlier books—one found variations which were more acceptable than agreed figures because they were based upon actual tests made with gems from a given district. He did not think any examiner would penalise a student for giving a figure which lay within the acknowledged range, provided this figure was arrived at by reliable means. Quartz, of course, was very constant—fortunately—but this did not apply to other gemstones.

The Chairman then called the meeting to a close with some reluctance as it was evident that all had enjoyed the very interesting evening at which much useful information had been imparted.

It was agreed by the general wish of those present that a further session of this kind should be included in the Association's 1954 programme.

Change of Address

The Laboratory of the Diamond, Pearl and Precious Stone Section of the London Chamber of Commerce is moving to 15 Hatton Garden, London, E.C.1. on 1st February, 1954. Articles or stones for testing through the Association should continue to be sent to 19/25 Gutter Lane, London, E.C.2.

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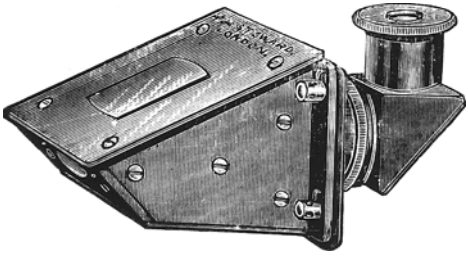

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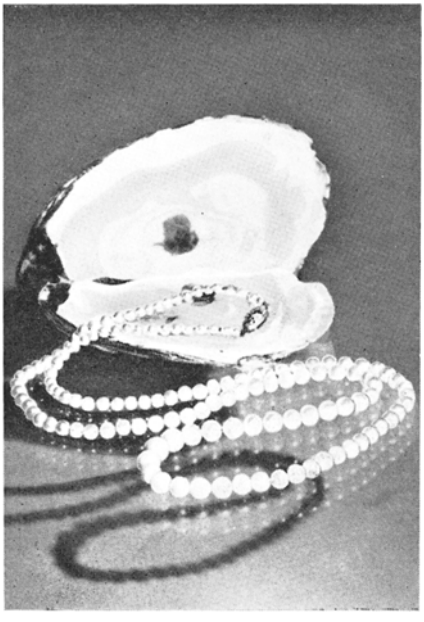

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Vol. IV No. 6 APRIL 1954

"FINGERPRINTING" GEMSTONES and JEWELLERY

by ROBERT WEBSTER, F.G.A.

IN an earlier article(1) the writer referred to "fingerprinting" gemstones and jewellery, that is the recording of various features whereby at some future date the stone or jewel may be re-identified. This, if not quite comparable, is at least analogous to the well-known " fingerprint " identification employed by the Police Authorities in the case of criminals. The value of such an identity service to the police and insurance companies is undeniable, and the same may be said too in respect of those rare cases of dispute with a customer.

Identification services are not new, and in this short article something will be told of the various methods which have been suggested and adopted, and some further ideas based upon modern technical developments. All schemes depend upon the recording of features characteristic of the stone or piece of jewellery ; however, the methods usually employed suffer from the disadvantage that the expenditure of considerable time is necessary in order to prepare the required data, much of which is rendered useless if the stone be recut or even repolished, or the piece of jewellery broken up.

What may well be the commonest " identity certificate " is the jeweller's stock book. Such a book can vary from records containing entries of a most perfunctory nature to one in which the descriptions are full of detail, and often with the notes on important pieces completed with coloured drawings or with photographs. Such books are a veritable mine of information.

In the case of unset gemstones the methods employed depend upon the exact determination of the weight ; the dimensions, usually in millimetres ; the errors, if any, in the junctions of the facet edges, and any inclusions which may be seen under moderate power microscopical examination. For mounted jewellery a similar technique would be followed, noting any irregularities in the setting, and, should the piece contain an important stone, or stones, each would be treated separately, even if they have to be unset for the purpose.

The method used by the well-known jewellers Cartier has been reported in literature[2, 3] and explains a general scheme. The Cartier method entails careful photography of the stone after the main peculiarities, both external and internal, have been examined and noted, the general practice being to photograph the stone actual size and to take three pictures, a top or front view, a back view, and a side view. Figure 1 illustrates such a set of photographs. Enlargements are made if more precise information is needed as to the position of flaws and surface markings. Copies of the pictures are appended to the record containing the other information, a chart being included upon which the special features noted about the stone are made clear diagrammatically. The internal imperfections are photographed in the normal way by the use of a microscope and immersion of the stone in a highly refractive oil. Not only are important stones recorded in this way but every piece of new jewellery made by the firm is photographed. Even in the remaking of a customer's old piece of jewellery to a modern design, photographs are taken of the piece as it originally was and of the new piece when made up, a chart being drawn up accounting for every stone in the original piece and its position in the new jewel.

For many years the Paris laboratory, the Service Public du Controle de la Chambre de Commerce de Paris, has issued certificates of identity for gemstones. As a matter of interest the London

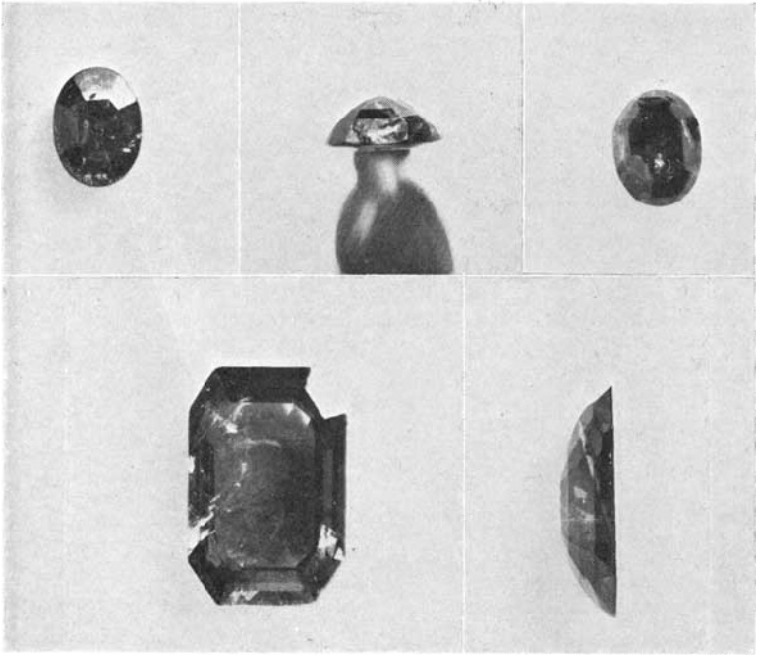

FIG. 1.

Identification photographs of gemstones as prepared by CARTIERS *for identification purposes.*

(Courtesy of Cartiers Ltd.)

laboratory, the Laboratory of the Diamond, Pearl and Precious Stone Trade Section of the London Chamber of Commerce, has not officially carried out work of this kind, but would readily do so if there were a demand for such a service.

The identity certification carried out by the French laboratory consists mainly of a series of photographs. Profile photographs of the stone are taken and a transparent positive accompanies the certificate which is handed to the owner. Figure 2 shows such a picture. Other photographs are taken, such as natural size pictures showing the inclusions (Figure 3), an enlargement showing the imperfections of the rear facet edges (Figure 4), and an enlarged photograph of the inclusions. These pictures are kept in the laboratory file with the report on the stone and are thus ready for future reference.

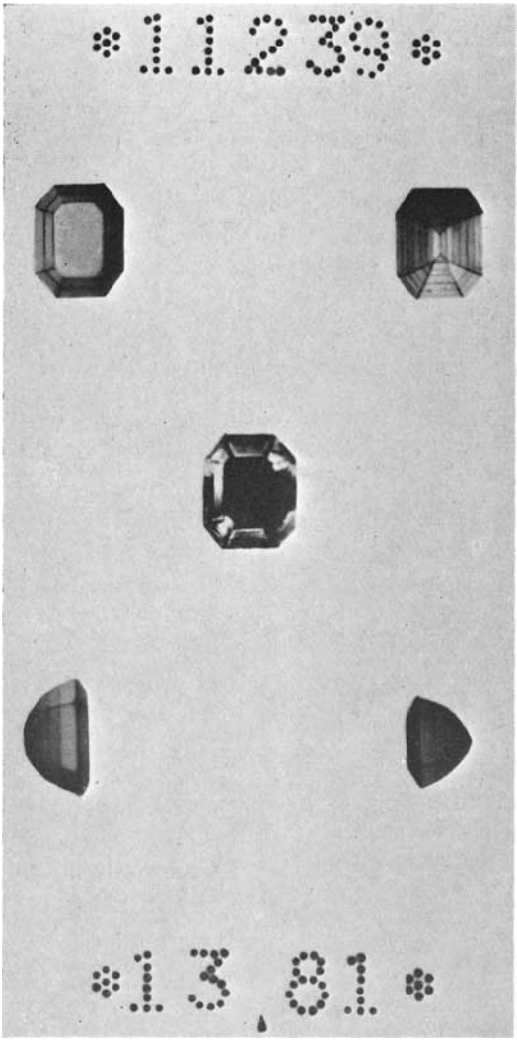

FIG. 2

External identification picture of an emerald weighing 13·81 *carats. This is a reproduction of the transparant positive which is given to the customer by the Paris Laboratory. Actual size.*

What is probably the most ingenious system for an identity service for gemstones is that devised by Aldrich and Davey of California, U.S.A.(4) The scheme involves the itemization of the salient features ; colour, outline, style of cutting, errors of facet junctions and internal imperfections. These features are entered on an index card by a system of code letters and numbers,

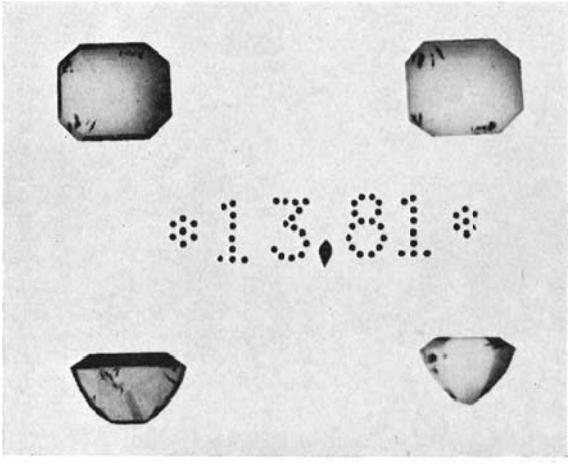

FIG. 3

Internal identification picture of the same emerald as Fig. 2. This is kept in the file at the Paris Laboratory. Enlarged magnified pictures are also kept. Actual size.

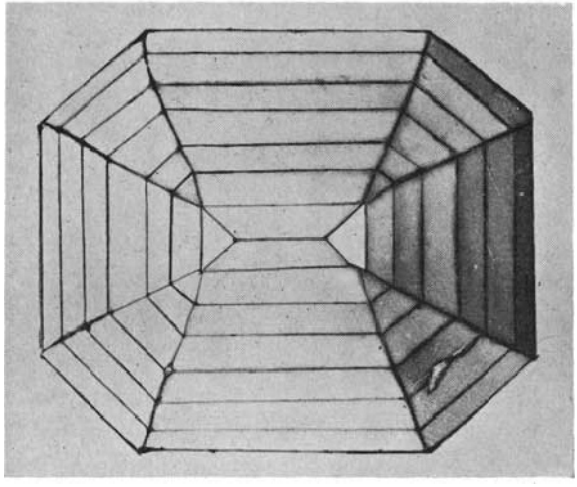

FIG. 4

Enlargement to show the imperfections of the facet edges of the same emerald as shown in Figs. 2 and 3. Paris Laboratory picture.

which are recorded as symbols, some of which are fractions. A full description of the method needs a long article and cannot be given here. It is the writer's opinion that, unless for very exceptional stones, the system proposed is far too time-consuming and is commercially unworkable. The idea behind the codifying of the features shown by the stone is that such codings may be telegraphed. One interesting and useful idea incorporated in this scheme is that the inclusions may be listed and oriented by a system of triangulation at a given magnification. A communi-

cation from the Director of the New York Laboratory, the Gem Trade Laboratory of the Gemological Institute of America, tells that he, assisted by Mrs. E. Miles, tried out the Aldrich & Davey system and found it far too complicated and that it could be made meaningless by slight repolishing.

The Gem Trade Laboratory at New York has not been called upon to issue identity certificates as such, although a certain amount of work in the plotting of inclusions for members and students has been carried out. This is done in duplicate on a diagram and is mainly for the purpose of arriving at a perfection grade for diamonds. The scheme employed by Tiffany's of New York merits comment. A special camera devised by Bruce D. Eytinge is used ; this produces a spot reflection pattern on a photographic film of the reflections from the facets of the stone of a narrow beam of light. The Eytinge camera and the method of its employment have been reported upon in the pages of this journal(5). It is understood that all stones above a certain weight are so photographed by Tiffany's. A similar scheme had earlier been suggested by the Dutch worker Bolman.

Basicly the requirements of an identity certificate for a gemstone are as follows :—

1. An identification certificate certifying the nature and accurate weight of the stone ; *e.g.*, a general certificate as issued by the London Chamber of Commerce laboratory.
2. Accurate measurements of the diameter in round stones, the length and width in oblong or oval stones, and in all cases the maximum depth. These measurements should preferably be made in millimetres and can conveniently be carried out by the use of a micrometer screw gauge or a suitably calibrated caliper stone-gauge.
3. Any irregularities in the cutting of the junctions of the facet edges, which may be denoted by coding, or may be better recorded photographically. Ordinary straight photography of the stone, with subsequent enlargement, is the method employed in the Paris laboratory. In such a process the facet edges of the stone may need to be inked in order to show up clearly. What may well be a simpler and less time-consuming method would be to employ the immersion-contact photographic technique reported upon by Anderson(6). This

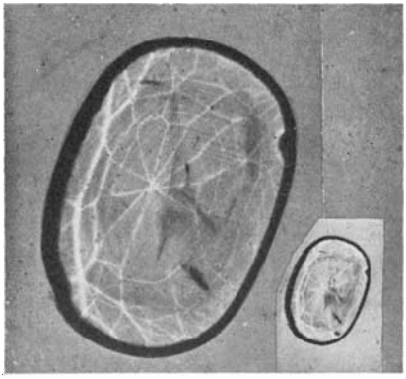

Fig. 5

Immersion contact pictures (actual size and enlargement) of a sapphire, showing the facet edges and inclusions.

method, however, would be unsuitable for those stones of high refractive index, such as diamond. Using an immersion liquid having a refractive index approximate to, but not too near, that of the stone, the facet edges will show up clear and distinct. True, the rear facet edges show up best in such a picture, but these alone will in general supply sufficient evidence. A film should be used in preference to a direct print made on ordinary "gaslight" or bromide paper, as from a film any number of prints can later be made should the identity data require to be circulated. An advantage of this method is that not only can enlargements be made, which are very necessary in order to see clearly the defects in cutting, but a contact print will show the stone actual size, and, further, such contact pictures, and enlargements from them, may well show the major internal imperfections also. Figure 5 illustrates these points.

4. The recording of any inclusions. These will best be dealt with by photomicrography. The magnification of the picture should be given, and, if possible, the relation of the inclusions to the facet edges should be recorded. If three inclusions can be arranged so as to photograph in one plane, the distances between these can be measured by the use of an eye-piece micrometer (Figure 6). On the finished print, or on an enlargement of it, lines could be drawn from the centre of one inclusion to the centres of the other two and by the use of these lines the angles between the inclusions may be measured with a protractor. This would provide valuable additional data.

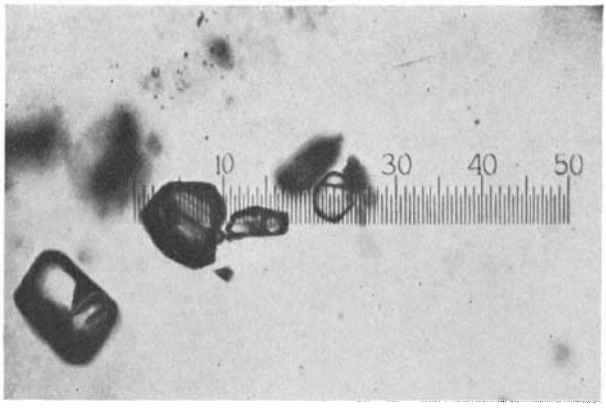

FIG. 6.
Inclusions in a Burma ruby, as seen with micrometer eyepiece scale superimposed. As the two large inclusions superimposed on the left hand end of the scale cover 17 *full divisions and as each of these divisions equals* 35·5*mμ.* (*Thousandths of a millimetre*) (*calculated from stage micrometer*), *then the inclusions are together* 603·5*mμ. or* 603·5/1000*mm.*

In the case of pieces of jewellery set with many cut stones of small and moderate sizes, the methods outlined would prove far too time-consuming and be uneconomic. The jewel, except for any important stone or stones would, need to be considered as one piece.

Much valuable jewellery to-day is set with a great number of round and baguette diamonds, either alone or in conjunction with rubies, sapphires, emeralds or other coloured stones. The writer suggests that advantage might be taken of the differential luminescent response to long-wave ultra-violet light. Diamonds, unlike most other luminescent gemstones, show a great variation in the intensity (and even colour) of the fluorescent glow. This glow can be photographed by straight photography providing that a suitable ultra-violet absorbing filter be placed over the camera lens. Such filters are Kodak "Wratten" 2B or Ilford "Q." According to O. Bloch(7) ordinary, non-colour-sensitive plates are best for this work.

Experiments carried out by the Raman School at Bangalore, India(8), have shown that longer exposures will cause the more weakly fluorescent diamonds to affect the photographic plate, for, unlike the human eye, the photographic emulsion builds up an image with increased exposure to light.

FIG. 7

Diamond double-clip taken in ordinary light. Actual size.

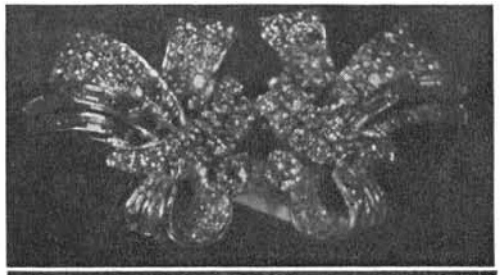

FIG. 8

Photographs of the fluorescence of the diamonds in a double clip brooch.

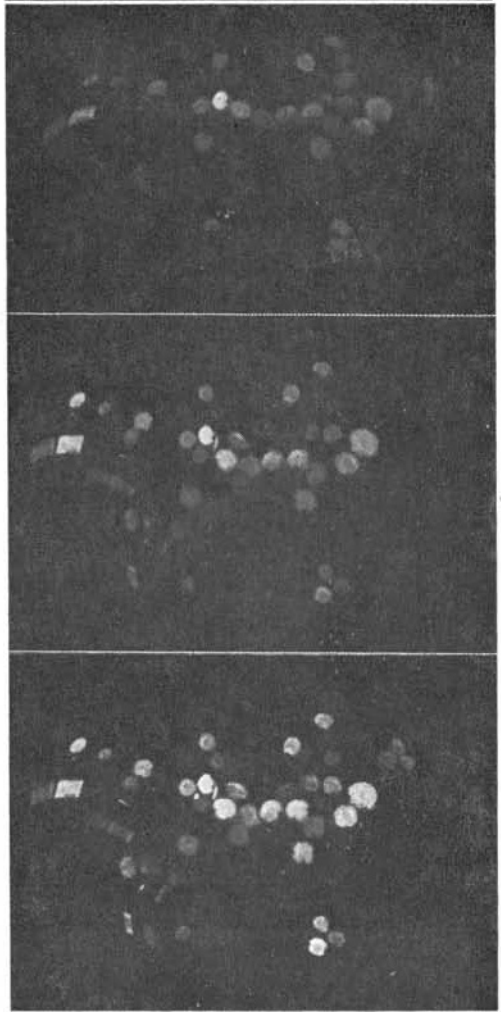

$2\frac{1}{2}$ *seconds exposure*

10 *seconds exposure*

40 *seconds exposure*

Taken on Ilford "Selochrome" with Kodak "Wratten 28" filter over camera lens. Actual size.

Fluorescence photographs of a diamond double-clip brooch containing one hundred and twenty-two diamonds, ninety-two being brilliants and thirty baguettes, were taken. Figure 7 shows the brooch actual size photographed in ordinary light. Figure 8 shows three different lengths of exposure of fluorescence photographs of the glowing diamonds when in a beam of long-wave ultra-violet light. Short-wave ultra-violet light will produce similar results, but in the case of diamonds the glows are not usually so strong and the time of exposure may need to be longer. Experience alone will tell what exposure is necessary, but it is usually quite short considering that the photography is carried out in darkness, the only light being from the glowing stones. If fluorescence photographs are incorporated in an identity certificate it is important that the photographic conditions are included, for, if the production of comparison photographs is required at a later date, a similar ultra-violet source and similar films (or plates) must be employed, and also similar exposures must be given.

Even one picture, such as the third (longest) exposure shown in Figure 8, may be all that is necessary, as it is extremely unlikely, indeed it would be practically impossible, to fabricate a facsimile piece of jewellery having diamonds emitting a similar intensity of response to ultra-violet light in similar positions in the jewel. As explained, further confirmation could be obtained by the method of differential exposures ; this latter fluorescence photography may well have a great value in the identity certification of large single diamonds.

No piece of jewellery has the metalwork made precisely accurate ; the holes for the stones rarely have their internal edges completely symmetrical, and these defects may be shown up by an enlargement of a direct x-radiograph, or even by the enlargement of a contact photograph. Figure 9 shows such an enlarged x-ray photograph, which would give considerable assistance in the future identification of the piece.

In the case of the identity of pearl necklets reference must be made to the Herz-Matrix system[9]. In this system each single pearl in the necklet is classified as under :—

(*a*) The weight of the pearl in grains.
(*b*) The colour.
(*c*) The shape.

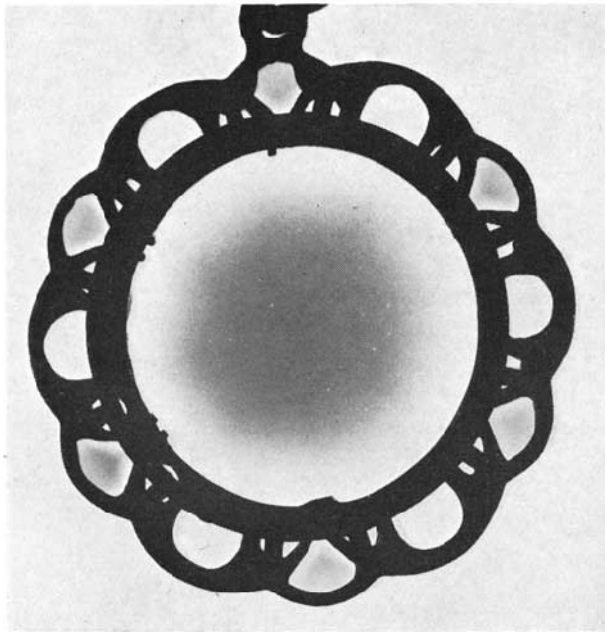

FIG. 9

A direct X-ray photograph of a euclase and diamond pendant showing the irregularities in the metal work. Enlargement is approximately three times natural size.

(*d*) The measurement of the outer layer.
(*e*) The measurement of the second layer.
(*f*) Internal faults seen in the interior of the pearl.

The data for the last three items in the classification are obtained by the use of the " Perlometer," a special microscope for the examination of pearls devised by Dr. H. Michel and Prof. G. Riedl of Vienna. The French " endoscope " could be similarly employed. The data so obtained are entered on a suitable record card but the recording method is time-consuming, and it is suggested that for practical purposes the usual trade " pearl statement " used in conjunction with a direct x-ray picture (skiagram) would give sufficient data to furnish an identity certificate.

In penning these notes the writer is sensibly cognizant of the fact that recutting or slightly repolishing a cut stone would

invalidate many of the diagnostic features, and that the breaking up of a piece of jewellery would completely destroy the identity of the jewel, if such a piece of jewellery had been considered only in its entirety. Recutting or repolishing a gemstone is rarely attempted by the thief, although it may be carried out by the "fence." In any case the job has usually to be carried out by a third party who may well be a dangerous witness should the police authorities become interested in individuals. While recutting or repolishing will alter the exact weight and size (very slightly in the case of repolishing) and possibly alter the irregularities of the facet edges, the internal features and the fluorescence will not alter.

If the jewellery is broken up, then, apparently, every detail is lost. This may not be wholly so. There have been cases where the thief has broken up the jewellery and sold the metal but has not had time or for other reasons has been unable to dispose of the stones (or conversely, the metal). In such cases knowledge of the weight of the metal, or of the stones, both of which would be known by the maker if a satisfactory stock book was extant, and knowledge of the fluorescent characters of any diamonds in the piece, if known, would be invaluable when the question of guilt and the question of ownership are debated.

No one method will give a completely satisfactory answer to the problem of the production of a perfect identity certificate. The procedure adopted must vary according to the nature of the subject, but must contain as many details as are possible to describe accurately. The fact that a perfect identity certificate may be an impossibility does not imply that any certificate containing some data is of no value ; such a document has infinitely greater value than nothing at all.

In conclusion it is the writer's duty to tender thanks to those who have assisted so greatly in the preparation of this article, particularly to Mlle. Dina Level of the Paris Laboratory ; Mr. Lovibond of Messrs. Cartier Ltd. ; Mr. G. Robert Crowningshield of the New York Laboratory ; Messrs. H. Landsberg (per Miss G. Landsberg) for the loan of the diamond clip used in the fluorescence photography; and to Mr. B. W. Anderson for the loan of the euclase pendant which is the subject of Figure 9, and for critically reading through the draft copy.

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TWO UNUSUAL PEARLS

Photographs (actual size) of two irregular-shaped pearls submitted by J. N. Dave, F.G.A. India. The pearl in the shape of a cross weighs 27.8 grains, and the crescent-shaped one, mounted on a plasticine cone, weighs 50 gains and has a silvery lustre.

GEMSTONE MYSTERIES

by NIGEL W. KENNEDY, F.R.S.A., F.G.A.

MOST people possessing an average knowledge, or ignorance, of the characteristics of gemstones, are surprised to learn that garnet is ever known in any other colour than red or purple, and that diamond occurs in most colours or tints. They are equally surprised to find that in this country it is unusual to see really blue-white diamonds for sale because we cannot usually afford to buy them. The gemmologist on the other hand, is aware that garnet, for example, exists in many colour varieties ; red, purplish, red-brown, orange-brown, orange, yellow, green, and black, but many of these varieties are much less common than one might believe from the descriptions in text books referring to them.

Amphigene, which is an interesting mineral existing in two forms, is also known as white garnet, although it is not strictly a garnet, and is not commonly met with. What has never yet been discovered is a *blue* variety of garnet, which seems rather strange, and this fact gave rise to the attractive title of a mystery story " The Blue Carbuncle " written some years ago. Amphigene, also known to the mineralogist as leucite, is not usually found in gem quality, and indeed the writer has been informed that it does not exist as a gemstone, but D. S. M. Field records it as occurring in Ontario, and that it has been cut locally as a gemstone.

Another member of the garnet family that seems to be less common than one might have supposed, is the humble pyrope, which is often confused with almandine. The true pyrope when compared with almandine, is seen to be quite a different colour, and its characteristic fiery red, from which its name is derived, does not really resemble the more subdued crimson or purple almandine. Other collectors have told me that they had some difficulty in obtaining a specimen of true pyrope, the reason being, of course, that the two minerals merge imperceptibly into each other, according to the preponderance of the MgO or FeO molecule, and the refractive index is controlled by the chemical composition, so that while a pure pyrope should have a R.I. of 1·74, and almandine up to possibly 1·82 a stone giving a reading

of 1·76 may be either mineral, and since the absorption spectrum of almandine is so strong and the spectroscopic test so delicate, the pyrope spectrum is often masked. This also applies to spessartites, which may contain sufficient of the almandine molecule to mask its own spectrum completely. An opportunity of examining a large number of garnets, particularly spessartites, has not yet been possible, but the writer is assured that the above observations are factual.

These varieties are a few of a small group of gemstones that may not be considered very rare, but which appear to be elusive. Some text books infer that they are commonly met with, but general experience does not support this. The following observations refer to gem minerals that I have so far found difficult to obtain, or which have not yet been traced. Readers may like to compare these remarks with their own experience.

A stone that is referred to almost casually in several text books and other sources of information, but which is not included in any collection so far seen, is the green variety of the mineral topaz. Church(1) definitely lists it among the colour varieties of topaz, and Herbert Smith(2) has suggested that its apparent rarity may be due to its similarity to aquamarine of nearly the same tint. As a gemstone green topaz is not recognized in the trade, and is therefore unsaleable, and hence might be included with green aquamarines either from ignorance or choice. The celebrated Scottish mineralogist Heddle(3) lists green topaz as a Scottish mineral that occurs in the Grampians and elsewhere, which definitely settles any question as to its existence. Text books do not suggest that blue topaz is a rare stone, yet the fact is that it is seldom seen, and brown topaz also appears to be a rare colour variety.

Odontolite is another gemstone which seems rather shy of appearing in public, although it has been stated that much of the turquoise in circulation some years ago was in fact bone-turquoise, a variety of fossil bone or ivory, stained naturally or artificially by copper compounds. Not much has been encountered by gemmologists of considerable experience. A small turquoise recently examined exhibited very strong fluorescence under ultra-violet light and it was thought that this might indicate an osseous or dentine origin, but on examination it was found to be natural

turquoise and the suggestion has been made that the fluorescence might have been due to the use of some detergent in cleaning it, which has not yet been verified.

Among other stones that have been difficult to trace, was the variety of opal referred to as " girasol," and sometimes mentioned in gemstone literature. For example, Heddle has stated that girasol forms one of the layers, together with cacholong, in some of the beautiful Scottish agates found in Montrose and other localities. I could never find a specimen in any collection, nor discover anyone who possessed one or could define it with any certainty. Most references failed to describe the mineral, which was stated to be obtained from Queretaro. However, I recently came across the following which may be of interest to other collectors who have had the same difficulty. This occurs in a little-known and interesting text book, "Manual of Precious Stones and Antique Gems" by Hodder M. Westropp (London, 1874)(4). " Fire Opal—Is a rich hyacinth-red variety of opal from Mexico. It is called ' Girasol ' or sun opal."

Hyalite is another uncommon variety of opal, rarely seen even in collections. I was offered some minute specimens—little lenticular objects which I spurned, in the belief that they were inferior, but I soon realized that it is unusual to find this mineral in anything but small specimens.

A gem of considerable rarity, but frequently referred to in text books, principally owing to its famous dichroism, is alexandrite, which is very seldom seen now.

It may not be out of place to mention simulations of alexandrite which are met with under the classification of " synthetic alexandrites " but which are almost invariably synthetic corundum, of a purple-greenish colour, fairly strong dichroism, and which do not actually resemble genuine alexandrite. The other " simulation " apparently sometimes occurring in trade under the same name (that is, " synthetic alexandrite ") is actually synthetic spinel. Only one specimen has ever been seen by me, and this was a sickly yellowish-green colour which was even less like any true Alexandrite, and could not possibly be confused with it.

Most text books give the impression that both orange and green spinel are relatively common ; in fact, the impression was gained that the green mineral chlorospinel was quite commonly encountered, and that the orange-red " rubicelle," to use its

obsolete name, was plentiful. This does not appear to be the case, as Mr. K. Parkinson states that during his last visit to Ceylon he was only offered two green spinels, and upon examination both were found to be synthetic. Yellow spinel—except as a synthetic—is also most rare, while the colourless variety is seldom found in nature.

The rather attractive yellow variety of beryl, known as " heliodor," is another stone that does not seem to be very common, possibly because it may be confused with other similar minerals. For some years it was lacking from my collection until a friend sent me several, when I remembered another collector who had mentioned some difficulty in securing a specimen. When I offered him one he asked if I had any objection to his testing the gem, and he explained that in the course of several years he had been sent at least a dozen different minerals under the name of " heliodor " by reputable firms who had themselves accepted the stones from their dealers without question, but that they all proved to be citrines, yellow corundum, topaz—but not beryl, and he was very glad to find a genuine heliodor at last. This emphasizes the fact that large firms obtain supplies from dealers who in turn receive them in good faith without test as being the minerals described, and that all too frequently it has been the practice to identify such stones by sight and general experience alone.

" Transvaal jade " is yet another stone which is mentioned quite casually in text books as of sufficiently common occurrence to be confused with jade and nephrite, yet there is reason to believe that it is very local in occurrence (as a massive variety of green grossular garnet) and even in South Africa it is not commonly seen. I have only seen one specimen myself, of a very pleasing green shade, and texture not unlike jade.

Microcline is another unusual gemstone, though more common than " transvaal jade," but the only variety seen is a bluish-green, in the form of polished cabochons ; the other colours of this mineral—red, yellow and blue—are probably very scarce and have not yet been seen by me.

Kyanite is also most unusual as a cut stone, probably because while the blue variety is moderately plentiful in the massive form, gem quality is rare, and only small cut stones are usually possible.

Green aventurine quartz makes attractive gems which are sometimes available in various forms, but the red variety is much

less common, although spurious paste " imitations " appear from time to time, and their bright red colour and sparkling spangles of brass make them very garish and vulgar. The name is often spelled " avanturine ". " Aventurine feldspar " (sunstone) is also far from common, and makes quite attractive cabochons, but is seldom met with.

The various naturally-occurring forms of silica produce a much greater variety of minerals in sundry colours, than any other mineral, as quartz, chalcedony (including the agates and mochas, etc.,) and the opals which will compare in beauty with any other representative of the Mineral Kingdom. Some of these are very plentiful while others are relatively uncommon, or even very rare. For example, morion, the nearly-black form of smoky quartz, does not appear to be common as a cut stone, even in Scotland. The deep brown, or honey coloured semi-transparent varieties which merge into cairngorm are much more usual. There is also a steel-blue-black variety of amethyst-morion, something like blue diamond, of which I have only one specimen and have seen few.

In the gemstone collection of the Geological Survey Museum at South Kensington there are two large and magnificent specimens of heat-treated quartz, which have a fine red-orange-brown colour and are transparent and free from flaw. This appears to be a most unusual and lovely colour and so far any similar stones have not been traced. Red quartz is also quite a rarity, and I have yet to see one either as a mineral or faceted stone ; this is, of course, referring to the transparent mineral mentioned by Heddle as apparently of usual occurrence in various parts of Scotland, notably the Grampians, and not to the rich red, opaque ferruginous quartz which is found in perfect crystal form at Santander in Spain, and which I have never seen cut as a gem.

Pink or rose quartz, which is sometimes of quite a deep shade, does not appear to be very commonly encountered, particularly as a gem. It is among the minerals found in Scotland, and listed by Heddle and others. Most text books state that rose quartz always occurs in the massive form, and never as isolated crystals. This is not strictly accurate since I am happy in the possession of a fine crystal. Blue quartz is yet another mysterious mineral, and in fact it is apparently found in two quite different varieties, namely the substitution product after the mineral crocidolite, in which asbestos fibres are replaced by quartz, with retention of the original

blue colouration, and which has been named " sapphirine quartz." A very fine specimen as a trap-cut gem is to be seen in the entrance hall of the Natural History Museum, South Kensington. I have never seen the other variety, which I understand is more like blue topaz in appearance, but the following description by Westropp[4] seems to refer to this variety : " Blue Crystal—Water-worn pebbles, of a beautiful blue colour, are found in France in the stream of Rioupezzouliou, near Expilly, in Auvergne ; they have been called saphirs de France, or saphirs de Puy-en-Velai."

Two other minerals have proved difficult to find, although not usually described as particularly rare, namely, colourless tourmaline and the dark blue variety of tourmaline, sometimes called indicolite. I have examined many specimens submitted for approval, and found that the " colourless " examples were invariably of a green or pink tint. What can one make of the people who submit deep blue-green tourmaline (not green-blue) of the colour formerly known to the trade by the now obsolete name of " brazilian emerald " and which cannot, by any stretch of imagination, be described as blue ? Some have even insisted that such stones were blue, and that they were definitely indicolite, and that the green tint (if seen) is purely a matter of opinion. In one parcel some fifty " indicolites " of 3 to 4 carat were received, but examination showed that only one was blue, the remainder being blue-green, and easily distinguished at a glance.

The reader is reminded that the observations made in this article are all in good faith, but are the result, in general, of my own personal experience, and that, through not being actually engaged in the gem trade, I have lacked the opportunity of examining vast numbers of stones, which some dealers and others have had, and that many stones might otherwise have been found more easily. On the other hand, other collectors, including many in the trade, have experienced much the same difficulty, and in actual fact, I have often had the pleasure of locating unusual specimens for fellow-collectors of wider experience.

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TWO DANISH GEMMOLOGISTS

by O. DRAGSTED, F.G.A.

CALLING a seventeenth century scientist a gemmologist is admittedly an anachronism.

The word "gemmology" was coined just over 140 years ago and covers a specialized science extracted from mineralogy, crystallography, natural history, optics, physics, geography, etc., whereas a scientist in the seventeenth century did not study within such narrow limits; he was a person of great and varied learning, a polyhistor. He might very well be a mathematician, astronomer, surgeon and theologian in one person. So was the case with Rasmus Bartholin and Nicolaus Steno. They touched upon many scientific subjects, which were to receive, later on, the suffix "-logy" and thus be established as separate branches of science.

RASMUS BARTHOLIN (1625 Roskilde-1698 Copenhagen) belonged to a family which has bred many outstanding scientists. He obtained his master's degree at Copenhagen University and studied several years in Leyden at the famous new university where so many prominent scholars met at that time. He was here given the task to publish van Schooten's lectures on Descartes. He was most fascinated by the great French savant, whose important results in mathematics and geometry as well as his philosophy influenced Bartholin's future works. In Paris Bartholin studied mathematics and became friends with de Beaune; in Padua he won the degree of Medical Doctor; and he also studied in England, after which he was made professor of mathematics and extraordinary professor of medicine in Copenhagen in 1657; later on he became rector magnificus several times and for 18 years he was Justice of the Supreme Court.

His greatest scientific achievement was the discovery of double refraction in Iceland Spar; in his own words the spar was *dis-*

diaclastic—gem students are happy that this term soon became obsolete. In 1669 he published " Experimenta crystalli Islandici disdiaclastici " (in 1922 appeared in Leipzig a German translation entitled " Erasmus Bartholinus : Versuche mit dem doppelbrechenden isländischen Kristallen "). He gives a very good description of the crystals and the results of each of his experiments, and as a good pupil of Descartes he accepts nothing which he has not seen with his own eyes ; he availed himself of Descartes' explanations about the behaviour of light, but he failed to find out the laws governing birefringence, and so did Newton. But Huyghens who had hesitated to publish his wave theory now became convinced that his own explanation was the right one, and so he ventured to publish this most valuable contribution to the understanding of the movements of light.

NICOLAUS STENO (1638 Copenhagen-1686 Schwerin, buried in Florence) was the son of a well-to-do Copenhagen goldsmith, Sten Pedersen ; latinized his name was Nicolaus Stenonis, but most authors call him Steno.

Steno was a most remarkable spirit : an anatomist famous for his demonstrations and discoveries (" ductus Stenonis " from ear to throat ; functions of tears, lachrymal gland and canal) ; a geologist with a very sharp eye and power of deduction ; and a searching theologian who eventually after deep consideration was converted to the Catholic faith and ended his days as bishop much too early because of a too ascetic life.

He studied in Copenhagen and Leyden, and stupid nepotism hindered his being made a professor at the Copenhagen University. Instead he went to the Medici Court in Tuscany. His main work was " De solido intra solidum naturaliter contento dissertationis prodromus," which was published (with many printing errors) in Florence, 1669, and (in a much better edition) in Leyden, 1679 ; an English translation appeared in London, 1671, of which the only copy known is in the British Museum.

In this " prodrome," or preliminary treatise, on solid bodies which are naturally embedded in other solid bodies, he is the first one to point out that the soil or crust consists of different layers ; what is now dry land was at one time the bottom of the

sea. He proves this through the existence of fossils, shells, etc. He was led into these thoughts while dissecting a shark; the teeth were strikingly alike some funny "sea tongues" or "glossopetrae" in the cliffs of Malta. So he set to study the soil of Tuscany and found sufficient evidence to support his theory of geological periods. In his book he also describes various crystal forms, and his strict mathematical way of thinking together with his power of imagination made him throw overboard the old theory that crystals absorb food from the ground through their interior body. They consist of imperceptibly small particles and grow in liquids by the outward addition of further particles. He also saw that the angles of the same crystals must be the same from whatever locality they came. And he maintained that if a "dissolving liquid" could be found, rock crystal could be dissolved into a liquid and again made to crystallize.

Later generations have called him the father of geology, and in 1881 a congress of geologists in Bologna undertook to erect a monument for him; over one thousand scientists sent in contributions, and a cenotaph was raised near his tomb. The short treatise he published because the Grand Duke who supported him was impatient. But Steno did write a more complete treatise, which he handed over to one of his pupils. This manuscript is not known and has no doubt been lost.

Gemmological Abstracts

DAKE (H. C.). *Opal in Oregon.* Mineralogist (Oregon), pp. 68–74, February, 1954.

Short account of the occurrence of precious opal in Lake County, Oregon. The opal field has been known for forty years, but few gems of commercial value have been found, though there is much common material. S.P.

JEANNELLE (H. F.). *The gems of Madagascar.* Mineralogist (Oregon), pp. 85–90, February, 1954.

A commentary on the most important gems of Madagascar by a resident mineralogist. Nearly all the gems occur in the granite pegmatites in various parts of the island, and a feature is the occurrence of gems in colours that are unique. It is suggested that some of the rare colours are due to long exposure to the gamma radiations of associated uranium minerals. The problem is complex and when commenting upon a black beryl, found in contact with radio-active euxenite and fergusonite, and a blue beryl, with numerous euxenite inclusions, the author suggests that there may be some other cause, and investigation is being made into the cause of colour in Madagascar gems. S.P.

COX (H. H. JR.). *Noble Coral, Gem of the Mediterranean.* The Lapidary Journal, Vol. 7, No. 6, pp. 494-502, February, 1954.

This interesting article is mainly devoted to the fashioning of coral to form ornaments and gems and thus, as is to be expected, is chiefly concerned with the red coral *Corallium rubrum*, the white and often beautiful corals of the East being only just mentioned.

It opens with a brief account of the historical uses of and the old mythical beliefs in coral. The old view is given that coral is the hard skeletal structure of certain marine polyps, whereas it is now known that it is secreted by the living basal disc, containing freely communicating tubes which also communicate with the central cavity or exterior of each living polyp so that the whole colony forms a single living organism. The whole of the basal disc is known as the coenosarc and it alone forms the coral which is

therefore a steadily increasing base upon which the polyps grow rather than a skeleton. In the red *Corallium rubrum* the coenosarc is arranged as a tube secreting coral on its inner surface and covered by the minute (1/20th-1/10th inch) polyps on its outer surface. Some of the lateral polyps may take on the function of increased coral formation and so give rise to lateral branches. A good account follows of the composition but in the description of the appearance no note is made of the parallel, longitudinal bands of darker colour which is the main distinction from imitations.

A description is given of the sites of production, the methods of obtaining, and the older and modern markets for the material, the latter being mainly around the Mediterranean and in India.

The most detailed and helpful account is that of the fashioning of the material, and stress is laid upon the brittleness of coral so that great care must be taken in sawing lest a valuable piece be shattered. For this portion alone the article will well repay careful perusal by every amateur or professional worker in coral.

J.W.

Edelsteine aus Idar-Oberstein. Precious stones from Idar-Oberstein. Published by the Idar-Oberstein Chamber of Commerce, under the direction of Dr. W. Holstein, Jr., text by Prof. Schlossmacher. 50 pp., 1 map, 1 comprehensive table, numerous photographs, several coloured illustrations and 2 colour plates.

This very attractive booklet is profusely illustrated, some of these illustrations being coloured and fairly representative. The text deals in popular fashion with the more important groups of gems and synthetics and there is also a short chapter on pearls. The map shows the origin of gems, the table gives name, chemical composition, crystal structure, hardness, spec. gravity, refractive index, colour, other optical properties and origin. Astrology and magic have not entirely been discarded which may have been thought to be pardonable in a propaganda booklet of this kind. A very pleasing publication.

W.S.

GÜBELIN (E. J.). *Synthetischer roter Spinell.* Synthetic red spinel. Zeitschr.d.Deutsch.Gesell.f.Edelsteinkunde, 1953/54, No. 6, pp. 4–9.

The author was perturbed by finding ruby-red polished spinel, submitted for examination, which had been cut from boules. Two years ago he published the reasons why to his mind a red synthetic spinel was not a commercial proposition (Gems and Gemology, Summer 1950, p. 307). In the Winter 1950 number (p.362) of the same paper Crowningshield and Holmes reported on a synthetic spinel octahedron grown on a palladium disc. These publications and private correspondence with Mr. B. W. Anderson led to successful experiments, gratifying no doubt to the scientist in every gemmologist but not quite so desirable in commercial respects. Altogether six specimens were available. The best example of an attractive ruby red hue was brilliant cut and displayed a very lively fire. All specimens looked more like genuine rubies of poor to fine hue than natural red spinels, especially as the yellow tint of the natural stone was missing. The chemical composition is $MgO.Al_2O_3$ (Ratio 1 : 1 as in genuine spinel and in contrast to the ratio 1 : 3 . 5 in other synthetic spinels). X-ray diffraction powder diagrams were identical for both synthetic and natural materials, *i.e.*, the lattice constants were the same. Specific gravity and refractive index were practically the same. Observation with the spectroscope of the fluorescent lines, however, allowed differentiation ; the synthetic material behaving more like ruby than natural spinel (broad band from 6,850Å to 6,900Å flanked by two weaker narrow lines). Microscopic investigation showed gas bubbles similar to those in synthetic corundum and somewhat surprisingly also the curved lines of corundum. They also lacked dichroism and extinction between crossed nicols allowed differentiation in this case. W.S.

CHUDOBA (K. F.). *Aus der Schmucksteinwelt der U.S.A.* Gems of the U.S.A. Zeitschr.d.Deutsch.Gesell.f.Edelsteinkunde, 1953/54, No. 6, pp. 14–19.

The article deals with " gems " like Shattuckite, Howlite, Variscite, Utahite, Augelite, Chlorastrolite, Thomsonite, Rhodonite, Smithsonite, Benitoite and Andalusite. Of Canadian and Brazilian origin are mentioned Peristerite, Sodalite, Cancrinite, Labradorite, Scapolite and Brazilianite. In most cases chemical composition, constants and other properties and derivation of the name are given. W.S.

LAIR (P. H.). *Yours for greater brilliance.* The Lapidary Journal, Vol. 7, No. 6, pp. 512–526, February, 1954. (8 Figs.).

A popular article in forceful language stressing the evident point that the brilliance of a brilliant cut gem is produced by the rays leaving the crown as opposed to the rays merely reflected internally. Dispersion is left out of the discussion deliberately and double refraction is not mentioned. For tourmaline, diamonds, zircon and quartz the author has computed angles between (1) main crown facets and girdle plane, and (2) main pavilion facets and girdle plane, which deviate considerably from those of the conventional or the ideal cut. The author must have been trapped by a table of ideal angles in which crown and pavilion angles have been interchanged. In all the cited cases the conventional crown angles are erroneously stated to be bigger than the pavilion angles ; and the author's computations led to similarly strange results. For brilliant cut tourmalines, zircons and quartzes he suggests bigger angles between crown facets and girdle plane than between pavilion facet and girdle. For diamond he calculates a crown-girdle angle of 32 degrees and a pavilion girdle angle of 37 as compared with the " ideal " 38 and 41 degrees. It is not stated whether the new theory has been put to a practical test. W.S.

Edelsteinausstellung 1954 *in der Schweiz.* Gem exhibition 1954 in Switzerland. Zeitschr.d.Deutsch.Gesell.f.Edelsteinkunde, 1953/54, No. 6, p. 3.

The Swiss Gemmological Association and the German Association for Gemmology are planning four exhibitions during summer 1954. The first exhibition will be held at Zürich from beginning of May to mid-July under the motto " The World of Gems." Berne is chosen for the second exhibition in September and Basle for the third in October. Geneva, too, will have its exhibition. In every case the town authority will be the exhibitor. W.S.

SCHMIDT (PH.). *Magie der Edelsteine.* Magic of the gems. Zeitschr. d.Deutsch.Gesell.f.Edelsteinkunde, 1953/54, No. 6, pp. 10–13. Cont. from 1953, No. 5, pp. 13–16, abstr. Journ. Gemmology, 1954, No. 4, p. 215.

Mentions shortly the " stone of the month," and a few historically well-known stones, *i.e.*, Hope diamond, Koh-i-Nur, Orlow. W.S.

The Diamond Tool Industry in 1953. 7 x 9½ in., 8 pp. Issued by the Industrial Diamond Information Bureau, 32-34 Holborn Viaduct, London, E.C.1.

This report, the ninth in succession, summarizes the main developments during the year 1953. The following fields are reviewed : diamond as a material, properties of diamond, synthesis of diamond, hardness and microhardness, surface finish, fine boring and fine turning, truing of grinding wheels, diamond powders, impregnated diamond tools, sintered carbide grinding, glass grinding and stone working, rock drilling, wire drawing, diamond use and salvage, new machining methods, and jewel bearing production. With each section references are given to literature, a total of 155 references being quoted. This year's report refers in particular to new developments in hardness and microhardness testing, diamond powders, impregnated diamond tools, and diamond use and salvage. The report will be of interest to all those engaged in the use and production of diamond tools. This summary is mainly based on a monthly bibliography that has been published for 10 years by the same organization. Copies of this bibliography can be obtained, free of charge, by those interested in the diamond and diamond tools. P.G.

WEAVIND (R. G.). *A process for recovering alluvial diamonds.* Gems and Gemology, Vol. VII, No. 12, pp. 365–366, Winter 1953/54.

Alluvial diamonds, unlike those found in the kimberlite pipes, do not, in many cases, stick to grease, hence the alluvial stones are not so susceptible to recovery by the normal sloping grease tables. This is due to the surfaces being wettable owing to the attraction of water soluble salts with which they have come in contact. This is overcome by treatment of the concentrate with a water solution of oleic acid and the employment of a special rubber " grease belt " which travels across a flat table from two rotating drums. R.W.

ELLISON (J. G.). *Testing drilled pearls with ultra-violet light.* Gems and Gemology, Vol. VII, No. 12, p. 367, Winter 1953/4.

It is suggested that by the aid of a beam of ultra-violet light (wavelength not given) projected down the string canal of the pearl,

any luminescence of the layers can be observed by a microscope. By observing the sides of the drill hole it may be apparent that the different layers show different degrees of fluorescent glow. The sharp division between layers would appear at one part only in the case of the cultured pearl. R.W.

WEBSTER (R.). *Gemstone luminescence.* Gemmologist, Vol. XXII, No. 269, pp. 229–231, Dec., 1953, Vol. XXIII, Nos. 270/1, pp. 17–19 and 29–31, Jan./Feb., 1954.

Continuation of the alphabetical series on the luminescent characters of gemstones. The instalments cover the gems from *pearl* to *spodumene*, and include references to the rare species *petalite*, *pollucite*, *scapolite*, and the important species *quartz*, and, natural and synthetic *spinel*. The *kunzite* variety of spodumene shows a photocoloration to green after x-ray bombardment. P.B.

KAPLAN (G. R.). *Procedures for cutting and grading of diamonds.* Gems and Gemology, Vol. VII, No. 12, pp. 355–360. Winter, 1953/4.

A general survey of diamond cutting, with particular stress on cleaving and sawing. The first process in cleaving is to make a V-shaped groove in the correct direction by using successively sharper diamond splinters. A steel wedge is then placed in the groove so that it rests half way down the groove. A tap on this wedge will cause downward and spreading forces which split the diamond along the cleavage direction. Twinned stones cannot be satisfactorily sawed and are better cleaved through the twin plane. Some shapes of crystals are more efficiently cleaved than sawed. " 10 commandments " are given as being necessary for the best production of a cut diamond. Notes are given on the colour grading of diamonds with particular emphasis on the American " colorimeter " and the American Gem Society standards. 7 Figures. R.W.

ELLISON (J. G.). *An unusual characteristic of gemstones.* Gems and Gemology, Vol. VII, No. 12, pp. 368–369, Winter, 1953/4.

Some experiments on the " feel " of gemstones. Large stones were tested by rubbing the table facet with the finger ; smaller stones by rolling between thumb and forefinger. A list is given of this effect of some 36 stones, but only two classifications are given—smooth and sticky. R.W.

DEANE (N.). *Adventures in lapidary work.* Gemmologist, Vol. XXIII, Nos. 270/1, pp. 1–5 and 32–36, Jan/Feb., 1954.

A series of articles (to be continued) on the experiences of an amateur lapidary in the cutting and polishing of gemstones. The author discusses saws and sawing (slitting) ; and the grinding and polishing of cabochons. Tells of the various types of saws and laps the author has tried ; how he has made dop sticks and what cement was most useful. 7 illus. R.W.

ANDERSON (B. W.). *The spectroscope and its applications to gemmology.* Gemmologist, Vol. XXII, No. 269, pp. 218–222, Dec., 1953. Vol. XXIII, Nos. 270/1, pp. 6–9 and 24–28, Jan./Feb., 1954.

The continuation of a valuable series. The historical introduction is concluded with reference to the employment of the spectroscope in astronomy. The Doppler-Fizeau principle is discussed, and the work of Hartley and De Gramont in the identification of the " persistent lines." The theory of spectra is discussed by a short historical survey of the work of the physicists. Emission spectra and their production and the methods of spectrum analysis by their aid are fully described as far as " flame spectra " and the use of the table spectrometer in conjunction with an arc source allows. A graphical method of calibrating the spectral lines seen in a table spectrometer is given. 3 illus. R.W.

LEECHMAN (G. F.). *Thoughts on cause of colour in precious opal.* Gems and Gemology, Vol. VII, No. 12, pp. 361–364, Winter, 1953/4.

A resumé of research work carried out by the author. This work has been reported more fully in the pages of this journal. (Journ. Gemmology, Vol. IV, No. 5, pp. 200–210, Jan., 1954.) R.W.

BULLOCK (H.). *The Great Koh-i-Nur diamond.* Gemmologist, Vol. XXIII, No. 270, pp. 10–13, January, 1954.

A short history of the " Mountain of Light " diamond written by one who has made Indian history his particular study. The stone, said to have been found at Golconda, which was a fortress and is a ruined city, may well have come from the alluvial earth along the banks of the Kristna river. Date of finding of the stone not certain. History of the stone from the time of Tavernier in the 17th century is given. 3 illus. P.B.

LINHOLM (A. A. L.). *Recovery of alluvial diamonds by electro-static separation.* Gems and Gemology, Vol. VII, No. 12, pp. 374–375, Winter, 1953/4.

An account of a method of separating diamonds smaller than 3 mm. from the diamond concentrate by an electrostatic process. The method depends upon the fact that diamonds are very poor conductors of electricity whereas the great majority of the gravel particles are better conductors. The electrostatic separator consists essentially of an earthed electrode and a charged electrode placed opposite each other and fairly close together. A high tension field is maintained between the two electrodes, the charged electrode being of positive polarity. The gravel conductors being relatively good conductors allow their charge to leak away to earth as they pass over the earthed electrode of the separator. In this way they acquire negative potential and are, therefore, attracted towards the positive high tension electrode. The induced charge on the surface of the non-conductive diamonds cannot leak away quickly enough and they retain their positive charge and are, therefore, repelled from the high tension electrode; thus the two groups are separated. R.W.

HUNGERFORD (T. A. G.). *Pearl oyster under the microscope.* Gemmologist. Vol. XXII, No. 269, pp. 213–217, December, 1953.

A general account of the Field Station of the Fisheries Division of the Commonwealth Scientific and Industrial Research Division based on Thursday Island in the Torres Straits. Six varieties of pearl shell are found in the straits, but gold- and silver-lipped shell are the only marketable varieties. Shell and not pearls forms the major commerce. The scientific investigations carried out at the Field Station consist of observations and the recording of the growth of the oyster at all stages of its life, and, in particular, observations of the sexing. It is reported that in the first year of maturity, when the oyster is from 2 to 3 years old, 95% mature as males, but in the next year 50% of these change to females. The reason for this is not known, nor is the actual method of reproduction. The work of the Station entails, also, the investigation of the possibility of using Torres Strait oysters for the production of cultured pearls. 5 illus. R.W.

BOOK REVIEW

POUGH (F. H.). *A Field Guide to Rocks and Minerals.* Houghton Mifflin Company, Boston, 1953, 333 pp. Many illustrations in colour and black and white.

If one scans the shelves in the " Natural History " section of any large bookshop, one will have no difficulty in finding well-illustrated books on wild birds, butterflies, flowers, mammals, fish, trees, and so on, but never a similar type of handbook for the mineral collector. To be sure, there are several good text-books on mineralogy, but none of them are at all suitable for carrying with one in the field as an aid to the identification of minerals on the spot.

This new little book by Dr. F. H. Pough fills this curious gap in the literature for the non-technical enthusiast exceedingly well. It is written by an American, and primarily therefore for Americans, but its usefulness is none the less universal. So far as the reviewer is aware, nothing at all like the " Field Guide " has before been attempted except for one little German book, Börner's " Was ist das für ein Stein," which was published just before the War. Dr. Pough's book is much more informative and truly scientific, and of far more value for the collector.

There are seventy pages of introductory matter. In this, practical advice is given about the simple apparatus and techniques recommended for collecting and testing minerals, in which the neglected art of blowpiping is given a prominent position. The main forms of rocks are described, the physical and crystallographical (but not the optical) properties of minerals are explained, and notes given on their chemical classification, following the order used by the editors of the new edition of Dana's " System." The remainder of the book consists of brief descriptions of all the common minerals and a few of the interesting rarer ones. The descriptions are greatly aided by numerous plates, on which are reproduced no fewer than 254 photographs of typical mineral specimens, 72 of which are given in colour. Opposite each plate is a series of well-chosen and well-executed drawings of the most important crystal habits of the relevant minerals, with a page reference to the text description. In the same way there is a

page reference to the appropriate plate at the head of each mineral description. This cross-referencing is very necessary, as the text and plates are often far apart. The book concludes with a brief glossary and bibliography, and there is an excellent index. This is emphatically not just a pretty picture-book but a working manual by a mineralogist who has a number of qualifications for the task of making a book of this kind. As curator for many years, he had access to the magnificent mineral collection in the American Museum of Natural History, from which most of the specimens photographed were taken. He has travelled widely throughout the world in search of minerals, and is personally acquainted with most of the famous localities, and finally he has first-hand experience of testing minerals by the methods he advocates here, as well as by the more erudite laboratory methods of which no mention is made in this book.

The text abounds in useful practical tips, which make interesting and rewarding reading even for those who have already a considerable knowledge of minerals. Knowing the popularity of ultra-violet lamps amongst amateur mineral collectors in the States, Dr. Pough makes frequent reference to fluorescent effects, but suggests that these can sometimes be far more diagnostic if one takes the precaution to roast the specimen first : a very useful hint. The gemmologist in search of a wider knowledge of minerals will regret the entire lack of optical data and also of determinative tables. But these are quite deliberately omitted by the author for reasons which seemed to him sound in a book of this particular kind—a field guide for beginners.

To anyone interested in collecting minerals from mine, tip-heap or quarry in this or any other country the " Field Guide " would be more helpful than any other book to take along. For those of more sedentary habits who dwell in cities, the book would serve as a valuable companion to walks round a museum collection. The author is sincerely to be congratulated on a really good job of work.

B.W.A.

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A list of books on gemmological subjects which have been published between 1850 and 1953. It is not exhaustive, and does not include articles which have appeared in journals or which have been reprinted as pamphlets.

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ASSOCIATION NOTICES

THE NEW PRESIDENT

Sir Lawrence Bragg, F.R.S., who has been elected as President of the Association in succession to the late Dr. G. F. Herbert Smith, is an eminent man of science, and the son of an equally famous scientist, Sir William Bragg, who was President of the Association from 1937–1942.

The new President has recently taken up his appointment as Director of the Michael Faraday Research Laboratory of the Royal Institution, a post also held by his father. The Directorship carries with it great prestige in the scientific world and provides unique opportunities for research work. Since 1938 Sir Lawrence had been Cavendish Professor of Physics at Cambridge University. Previously he had been Professor of Physics at Manchester University, Director of the National Physical Laboratory, and a Fellow and Lecturer at Trinity College, Cambridge. He is President of the Institute of Physics and a past-President of the International Union of Crystallography.

With his father he wrote *X-rays and crystal structures,* and is himself the author of *The Crystalline State* and *The Atomic Structure of Minerals.*

The Council are grateful that Sir Lawrence has honoured the Association by becoming its fourth President.

GEMMOLOGICAL ASSOCIATION OF AUSTRALIA

The following are Members who have qualified for Fellowship in the 1953 Examination.

The first three positions in Australia were filled by :—

1. R. N. Brown (South Australia).
2. A. Milston (New South Wales)
   G. L. Berkman (New South Wales)

The best Student in each State was :—

New South Wales	*South Australia*	*Victoria*
A. Milston G. L. Berkman	R. N. Brown	H. Blanchard

Western Australia	*Queensland*
B. Sturmer	J. B. Cameron

The Australian Prize goes to R. N. Brown of South Australia and the Stevenson Award for the South Australian Student goes to M. G. Soph.

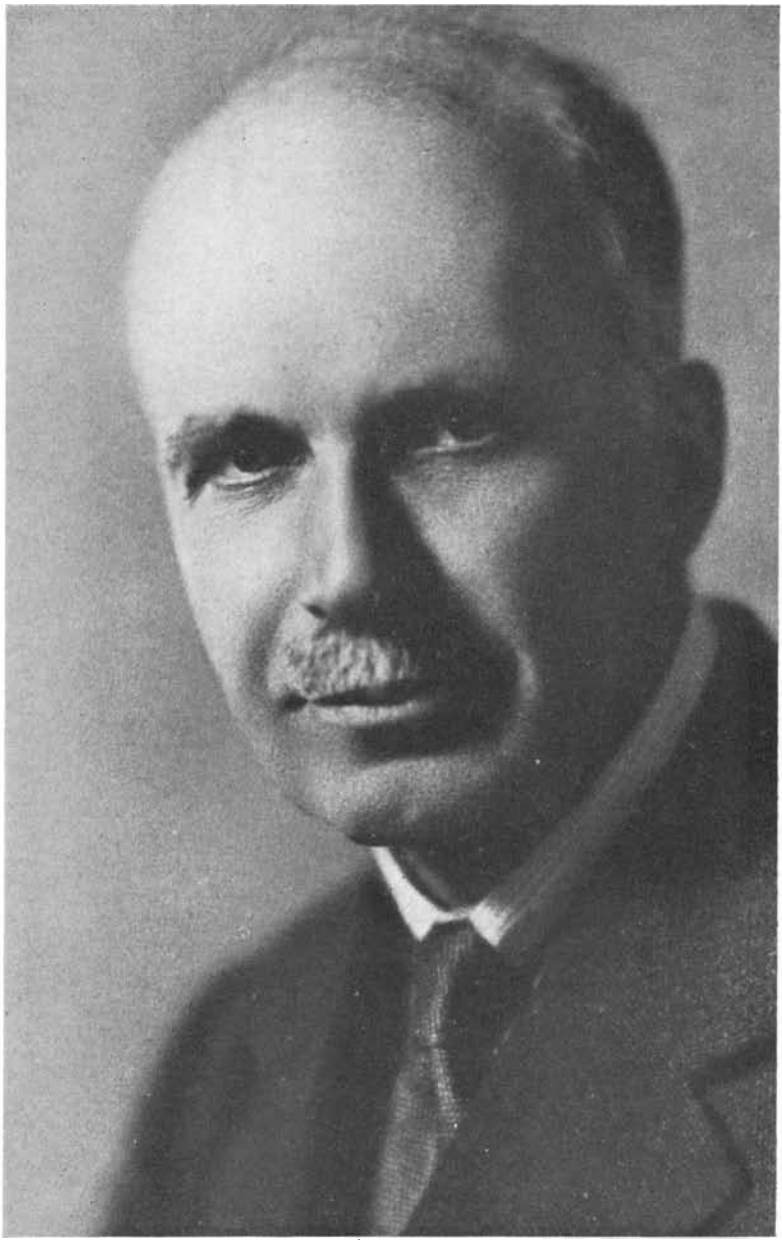

SIR LAWRENCE BRAGG, F.R.S.

The Association's New President

Of the 53 Students who sat for the Examination, 37 were successful and the complete list is given hereunder :—

NEW SOUTH WALES

M. B. Austin.	P. S. Marcus.	J. F. Schofield.
G. L. Berkman.	A. Milston.	E. G. Sherman.
M. Gayst (Miss).	L. Mulveney (Miss).	M. Smith.
J. D. Henderson.	K. A. Robertson.	J. G. Thomas.
R. B. Manzo.	R. Sawyer.	C. Totterdell.

SOUTH AUSTRALIA

R. N. Brown.	O. W. Kahl.	M. G. Soph.
J. W. Callery.	I. W. Offe.	A. J. White.

VICTORIA

S. Auchterlowrie.	D. Coleman.	B. J. McConnell.
H. Blanchard.	B. East-Almond.	J. Williams (Mrs.).
	H. E. Williams.	

WESTERN AUSTRALIA

J. Anderson.	J. A. Campbell.	W. A. Jones.
B. Sturmer.		E. White.

QUEENSLAND

D. Bell	W. Bishop.	A. J. Byrne.
	J. B. Cameron.	

TALKS BY MEMBERS

Dembo, Victor A. : " Gemstones." North Staffordshire Branch of the Geological Association, Newcastle-under-Lyme, 3rd February, 1954.

Blythe, Gordon A. : " Gemstones." Leigh-on-Sea Rotary Club, 25th January, 1954 ; Young Wives' Club, Leigh, 2nd Febuary ; Young Conservatives, Southend West, 3rd February ; Young Wives' Club, Thorpe Bay, 11th February.

Warren, Frank W. : " Gemstones." Whiteladies Road Contact Club, 15th January, 1954, also to Soroptimist Club, Bristol, 15th February, 1954.

Webster, R. : " Gem materials in watch and clockmaking." British Horological Institute, London, 28th January, 1954.

Gilmer, Charles T. : " Jewellery " and " Historic Gems in the Crown Jewels."

Melrose, R. A. : " Gemstones." Rotary Club of Blyth, Northumberland, 4th February and 4th March, 1954.

Anderson, B. W. : " Gemstones and how to recognize them." Cardiff Naturalists' Society, 18th March, 1954.

COUNCIL MEETINGS

At a meeting of the Council held at 19/25 Gutter Lane, London, E.C.2, on Tuesday, 19th January, 1954, the following were elected to membership :—

FELLOW : Baker, John T. Bristol (D. 1953).

PROBATIONARY : Pearce, Anne M. Old Windsor.

ORDINARY : Harper, John S. Birmingham.
Walker, Professor Frederick. Cape Town, S. Africa.
Wines, Elizabeth D. London.

The Council made the following nominations for Officers for the forthcoming year:—President: Sir Lawrence Bragg, F.R.S.; Chairman: Mr. F. H. Knowles-Brown; Vice-Chairman: Sir James Walton; Treasurer: Mr. F. E. Lawson-Clarke. The Council nominated Miss E. Ruff and Mr. R. K. Mitchell for re-election and Mr. T. H. Bevis-Smith for election to the Council. The Council also considered examination arrangements for 1954.

MEMBERS' MEETINGS

A meeting of members was held at the British Council Cinema, London, W.1, on Thursday, 28th January, 1954, when three films were shown including "In the land of diamonds" and "Light control through polarization."

On 3rd March members met at Goldsmiths' Hall, London, E.C.2, and displayed gems from their own collections.

EXAMINATIONS IN GEMMOLOGY

The 1954 examinations in gemmology of the Gemmological Association will be held as follows:—

Preliminary Papers—	London, Provinces and Overseas: Wednesday, 9th June.
Diploma Theoretical Papers—	London, Provinces and Overseas: Thursday, 10th June.
Diploma Practical Papers—	London and Overseas: Friday, 11th June; Birmingham: Friday, 4th June; Edinburgh: Thursday, 27th May; Plymouth: Friday, 4th June.

MEMBERS' MEETING

Members who were attracted to the first social meeting and individual display of gems of interest, which was held at the Goldsmiths' Hall on March 3rd, found the visit well worth while. The experiment of inviting members to show some of the special items in their collections met with an excellent response, especially as judged by the rarity of some of the stones.

Four members had responded to the invitation to "exhibit." Sir James Walton, the Vice-Chairman, Mr. B. W. Anderson, Mr. Keith Mitchell and Mr. F. Ullmann. And although not by design, the aspects of gemmology that were demonstrated by each of their collections were entirely different and illustrated its many sided appeal.

It might be said that the star stone shown by Mr. Mitchell was the "star" of the evening, for it appears fairly certain that it represents a mineral which in this form has not been described before. The stone came from Ceylon, having been cut because of its natural asterism and being sent to Mr. Mitchell by Mr. F. L. D. Ekanayake, a keen collector whose gemmological knowledge enabled him to recognise the interesting features of the gem. Of a greyish-green colour, the cabachon cut and polished stone was investigated at the Hatton Garden Laboratory where the first findings suggested that it was glass and because of the lead content noted, that it was artificial glass. As a result of this the stone was sent to the well known School of Glass Technology at Sheffield University

for further examination. The University confirmed that the constants found were correct but they further discovered the presence of thorium as a major constituent and that the stone was rather strongly radio-active.

It seems certain that this lead content is an end-product of the disintegration of the radio-active thorium and it is now considered that the stone is a natural mineral of the "metamict" type. Calculations based on its radio-activity suggest that this has been going on for a thousand million years.

Mr. Mitchell also showed some other unusual stones. There was a pair of pale yellow transparent plagioclase feldspars from Utah, U.S.A. They had the constants and composition of labradorite and could be regarded as a new form of that stone. There was a parti-coloured zircon, orange and green.

Sir James Walton brought along a selection of carved stones which he described and suggested that some of the carvings were difficult to explain. One, for instance, showed the figure of a male, wearing only a Greek helmet and with the right leg ending in an uncarved stump. He thought that this, like another carved stone, might have come from the tomb of some Egyptian mummy because of the traces of black patches of material that might be bitumen.

Mr. B. W. Anderson presented another aspect of gemmology with a collection that showed macro-inclusions in quartz. He told how he had bought them some years ago from the family of a Victorian collector whose notes upon them showed how much easier it may have been in one way to be a collector in those days. Thus he had recorded that the price of 3s. 6d. which he had paid for one fine specimen was "very expensive."

A good example of an included moving bubble a quarter of an inch across and preserved for millions of years in its hermetically sealed cavity could be easily seen in one specimen. Other examples had crystals of rutile, tourmaline and pyrites in them. Asbestos material which was on the way to becoming a quartz catseye could be seen on another, while there was a large ghost crystal of quartz with an inner crystal of milky opaqueness which contrasted with the later clear growth. Other specimens had crystals both inside and outside.

Mr. F. Ullmann had among his stones a fine specimen of phenakite from Russia, a parti-coloured quartz, sphene and a dark green garnet. An unusually large specimen of black coral, exhibited by the Secretary and recently described in the "Journal" by Mr. Robert Webster, was another choice specimen which interested the members who had braved the downpour of rain.

OBITUARY

It is with regret that we have to record the death on 20th March of Mr. Arthur Tremayne, aged 74. He was the Editor of the *Gemmologist, Industrial Diamond Review, Horological Journal* and *Goldsmiths' Journal*, and also Governing Director of N.A.G. Press Ltd.

Mr. Tremayne, in 1909, included the study of gemmology in the course for retail jewellers, which he was conducting at that time, and he carried on with this until a special gemmology correspondence course was prepared by Mr. I. Jardine. It was at a meeting of the Gemmological Committee of the National Association of Goldsmiths in May, 1931, that approval was given to Mr. Tremayne's proposal for the formation of a Gemmological Association.

The Herbert Smith Refractometer

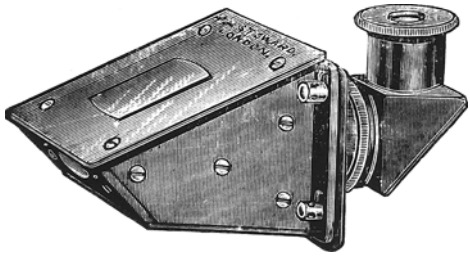

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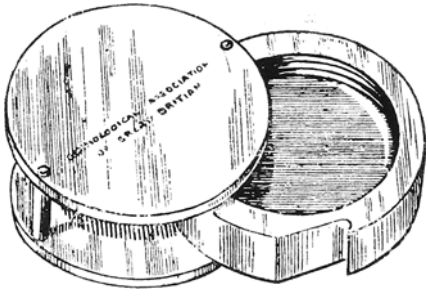

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NOTES on DISCOLORATION of PEARLS

by H. LEE and R. WEBSTER.

DURING the latter part of 1949 three cultured pearl necklets in which some of the pearls had assumed a dark colour were examined. These three necklets, which came from different sources (firms), were all of poor quality and were somewhat baroque. The blackening seemed to be concentrated and to show most conspicuously at the " pips " in the baroque pearls. The effect tended to agree with the surmise that it is the organic constituent of the pearl which is involved in the change.

The reason for the change in colour in these pearls seemed obscure, but, as nothing could be done with the pearls themselves (for they were not our property) little in the way of experiment could be carried out. X-radiographs were taken but these gave no help except that heavy pigmenting elements did not appear to be present. There was much theorizing and a small quantity of mother-of-pearl was demineralized by acid and the conchiolin recovered with a view to conducting experiments. At this stage, as there had been no further enquiries, the " urge " ceased and no experiments were carried out, the notes recorded being filed.

Last year the question again arose when a similarly discoloured necklet was passed to one of us. Preliminary examination by X-radiography again gave no indication of any unusual character, and, on request, permission was granted for some of the discoloured

pearls to be removed for experiment. Our original notes were withdrawn from the file and our previous theories re-examined and those more tenable considered in greater detail. Where possible experimentation was carried out.

The investigation, of which this is a record, had two aims in mind: to endeavour to ascertain the reason for the blackening, and to see what could be done in the way of bleaching such discoloured pearls.

Various lines of enquiry were considered, one of the earliest being the likelihood of some chemical action on the conchiolin of the pearl caused, perhaps, by cosmetics, scents, or by caustic alkalies in soaps and modern detergents. Except in one case, which will be discussed later, it was difficult to see how such substances could cause this change of colour. However, two tests were made on these lines ; two white cultured pearls were placed in separate tubes and covered respectively by Eau de Cologne and a strong solution of " Tide." They were left in these tubes for one month and then removed and dried. Examination showed no obvious change, nor had they changed when they were re-examined six months later.

Another supposition was that some form of radiation had caused a photochemical action in the conchiolin, possibly due to strong sunlight. Our earlier notes recorded that the summer of 1949 was very sunny. On enquiry we were informed that the necklet received last year had started to discolour after being in a shop window facing south, and, although not in direct sunlight, did have sunlight reflected on to it from the pavement. It is well-known that shop-window casements do become exceedingly hot and could be expected to dry out the moisture content of pearls—some 4 to 5 per cent in natural pearl. Alexander[1] has pointed out that in the case of genuine pearls desiccation of the water content does occur normally over a period of time, and this writer states that if the loss is continually maintained over some years damage to the pearls could result. It is not stated what external effect would be likely to be produced—whether discoloration or only cracking—on the drying out of the pearls.

Bolman[2] also suggests that decay of pearls is due to desiccation of the conchiolin, and he further mentions that the cracks may be made less obvious by filling with warm oil rubbed in after the pearls have been cleaned, a method of repair termed *decraqueler*.

That sunlight alone was the cause of the blackening did not

seem to be a likely one, for, if such was the case, then it would be expected that quite a number of complaints would be forthcoming, about both genuine and cultured necklets. However, an elementary experiment was carried out. Two cultured pearls were placed in corked specimen tubes and exposed in a sunny position. Unfortunately one of the tubes blew off the window ledge where it had been placed and was lost. The other showed no effect from the sunlight irradiation through the glass of the tube.

The question of the heating effect was tested by placing cultured pearls in long test tubes which were then placed in oil and water baths. In the first experiment the bath contained liquid paraffin which gives a heat of over 200°C. The initial test was unsatisfactory for the test tube containing the pearl was rested on the bottom of the beaker containing the oil, and, probably through local overheating, the pearl inconveniently exploded leaving powder and flakes of pearl at the bottom of the test tube. A second try was carried out, with the difference that the test tube was held off the bottom of the beaker by the aid of a retort stand. The pearl was seen to discolour to a light brown shade at about 200°C. A similar experiment using boiling water as the bath produced no effect on a cultured pearl after ninety minutes heating.

A further experiment consisted of heating a cultured pearl immersed in olive oil to about 200°C. At this temperature the pearl was found to have turned to a chocolate brown. This emphasizes the danger of heating in oil to repair cracked pearls. It is not the first time that a pearl merchant has suffered monetary loss through the overheating of pearls in oil.

These experiments have shown that the heat in a shop-window casement is unlikely to be the single cause of the discoloration of pearls, and, further, the colour assumed by the heated pearls is brown and not black.

It cannot be recalled that a natural pearl necklet has darkened in a similar manner to that shown by the cultured pearl necklets in question. Another aspect is, therefore, the trace of a manganese compound which, according to Alexander[3], is present in the fresh-water mother-of-pearl normally used as a nucleus. Manganese may under different conditions act as a reducing agent, or as an oxidizing agent, and this may have some bearing on the change of colour in the conchiolin of the pearl. The writers have not been able to devise a suitable experiment to test this theory.

The theory that the discoloured pearls were pearls which had been previously treated in some way, either to enhance the growth of the nacreous layer or to bleach the pearls, seemed a possibility. In this connection it was thought, maybe, that, during the war and until 1951, when the embargo on the import of cultured pearls was lifted, a quantity of dark pearls had been bleached by some means and then marketed ; later an unknown reaction took place had caused the pearls to revert to their original dark colour. In view of the sparsity of material available for experiment nothing was done to test this. Indeed, without some idea of how the treatment was carried out no particular line of testing could be decided upon. However, examination of the literature did disclose some interesting possibilities and these will now be discussed.

It is well known that sulphur compounds will react with certain metals to produce dark-coloured sulphides, and this appeared to be a profitable line of enquiry. Pearl consists of a mineral part—calcium carbonate in the form of crystallites of aragonite ; and an organic part—a scleroprotein of keratin type known as conchiolin. The formula for conchiolin as given by Herbert Smith[4] is $C_{30}H_{48}N_2O_{11}$, and by Hackh's Chemical Dictionary[5] as $C_{30}H_{48}O_{11}N_9$. It is suggested that this difference in the formulae may be due to a typographical error. In the first formula the nitrogen content is about 5 per cent and in the second about 24 per cent, a difference not likely to be an experimental error in analysis. Thus, except for calcium, no metals or sulphur are normally present, therefore, if a sulphide theory is to stand, the action must be ascribed to one or more trace element. Sulphur is often a constituent of protein, in some cases, as in hair, it can reach as much as 8 per cent, and it needs only a trace of sulphur to produce highly coloured metallic sulphides. Experiment showed that hydrogen sulphide (H_2S) is given off by dried conchiolin when it is decomposed by heat, but not until decomposition takes place. Alternatively the sulphur could arrive from an outside source, and in this connection depilatories which contain sulphur could conceivably be an activator.

With regard to the metal, the most common sulphide of a black colour is that of lead ; but the sulphides of silver, nickel, mercury, ferrous iron, cobalt, and copper are black. To test the validity of the sulphide theory one of the original darkened pearls, after being bleached (*vide infra*), was placed in contact with

a pad of filter paper kept moistened with a 5 per cent solution of sodium sulphide. After a day or so a darkening to a silver-grey colour occurred. Another of these darkened pearls was ground with a flat so as to expose the core and the ground surface examined microscopically. The darkening was seen to be just a skin effect on the nacreous outer layer. On immersing this pearl in the sodium sulphide solution the pearl quickly darkened and in a few days assumed a gunmetal colour. Other cultured pearls, a core from a cultured pearl, and some nacreous skin from a broken cultured pearl did not show any discoloration after similar treatment. From these experiments it seems most probable that the cause of the blackening is due to a metallic sulphide and that it can only occur in certain types of cultured pearls.

What metallic trace elements can be found in pearl ? Cahn, in his report,[6] mentions that Dr. T. Kosaki, of the Kyoto University Physics Department, believes that the colour in pearls depends upon some metal porphyrin in their composition. Kosaki states that pink pearls contain lead porphyrin. (The pink colour mentioned is so minute and subtle as to be distinguished only by experienced persons. The pink pearl mentioned, therefore, does not imply the non-nacreous conch pearl from the *Strombus gigas*, but the nacreous pearl from the *Pinctada martensii*). A spectrum plate, however, failed to show any trace of lead in the darkened pearl, hence the presence of another metal must be assumed. The spectrum plate was a comparison one using :—(1) copper arc alone ; (2) the pearl plus the copper ; (3) the copper arc with lead acetate giving the lead lines for comparison. It was not possible to isolate any other distinctive lines of elements owing to the comparatively low dispersion of the spectograph used. We are, therefore, unable to come to complete finality.

The immediate question from a trade point of view was whether the colour of such darkened pearls could be in anyway corrected. Reference to the literature describes many methods for bleaching pearls, some of which appear to be fraught with danger. Kunz and Stevenson[7] state : " Yellowish pearls are sometimes bleached by means of strong bleaching substances, such as chlorine or other powerful reagents, which although they may whiten the pearl, cause it to become very friable, as the animal substance becomes more brittle." Bolman[8] refers to the bleaching of pearls by immersion in phosphoric acid followed by cleaning in hydrogen peroxide.

In the Cahn report[9] mention is made that in artificial staining the cultured pearls are first bleached in a solution of hydrogen peroxide for several hours. In the same report (page 34) reference is made to the colour of black pearls as being apparently due to the presence of organic matter between the pearl layers, but that the identity of the material is not yet known, but there is some evidence to indicate that the dark colours may be related to the black secretion of the cells of the mantle edge. It is further stated that these dark pearls can be converted artificially into pink pearls by injecting hydrogen peroxide under pressure into the pigmented layer. This may have some bearing on the subject discussed.

In order to test the bleaching properties of hydrogen peroxide one of the darkened pearls from the necklet was immersed in a 10-volume solution of hydrogen peroxide for a fortnight. On removal from the solution the pearl was found to have been bleached to a good white colour. This pearl was then placed in a packet with another darkened pearl for comparison. Eight months later the pearl was found to be still a good white colour and showed no sign of reversion to a darker hue.

Further experiments were carried out on these lines using the conchiolin from the demineralized mother-of-pearl prepared in 1949. A small quantity of the dried material was separated into three portions and each placed in a specimen tube. One was left plain as a control ; one was covered with distilled water, and the third covered with 10-volume hydrogen peroxide solution. In each case the tubes were corked. These were inspected after one month and the liquids decanted off. The conchiolin which had been placed in water was found to be slightly lighter in shade (a nut-brown colour) than the control specimen. The material taken from the hydrogen peroxide solution had bleached to a pale yellow colour. Inspection of the dried samples eight months later showed that the sample from the water immersion had darkened to the same colour as the control sample, while that which had been in the peroxide was still a light yellow colour.

The theory of bleaching is somewhat involved and the writers can do little better than to refer to the work of Redgrove and Bari-Woollss[10] on the bleaching of hair, which is also a keratin type protein. These authors explain that the cause of colour of substances seem to depend upon the presence in their molecules of certain (usually unstable) groupings of atoms. Any chemical

change undergone by such a substance is liable to upset the grouping and thus to destroy the colour. Thus oxidizing, or reducing, agents may cause a chemical alteration which will turn a dark-coloured compound into one which is light in colour. In the case of hydrogen peroxide (H_2O_2) the reaction is an oxidizing one. The extra oxygen atom in this compound is loosely coupled and will readily part from its fellows leaving the stable compound H_2O which is water. Further the free oxygen atom is in the highly active "nascent" condition when it will readily react with other compounds, and particularly those containing carbon, i.e. organic compounds, bringing them to an oxidized condition or to a higher state of oxidation, and often to a compound having a lighter colour. This is the probable action in the bleaching of conchiolin by hydrogen peroxide.

To sum up : the cause of the darkening of the pearls is so completely involved with the structure of the organic compound that it is difficult to make clear cut decisions. So little work has been done on the chemical nature of conchiolin, and indeed, no structural formula for this material appears to be available. Such a formula would be essential for a full understanding of the chemical changes which could occur in organic substances. The following suggestions could reasonably be applied as tentative solutions to the problem ; but they must remain as suggestions until more work is carried out on conchiolin. It is hoped that at some future date one of us may be able to deal with the problem of the structure of conchiolin. The tentative suggestions are as follows :—

1. REARRANGEMENT OF THE LINKAGES BETWEEN THE VARIOUS GROUPS MAKING UP THE COMPLEX MOLECULE OF CONCHIOLIN.
   Most likely they would not be reversible and generally speaking oxidizing agents would favour double bonds and deeper coloration.

2. TRACE METALS IN NUCLEUS.
   Would probably produce only slight but very distinct colour difference in original pearl, as in the case of the grey and pink pearls mentioned. May be rendered active later by irradiation, fumes, etc.

3. TRACE METALS AS IMPURITIES.

   (*a*) *Purely adventitious. May occur in certain areas of water but not in others. May occur as pathogenic or post-mortem condition. Probably in heavy basic molecule.*

(*b*) *By adsorption as such or as trace metals entering as solution into the tissues by osmosis from sea (fresh) water and becoming fixed, say as sulphides or sulphates. Here again light coloration would occur and this would be reversible. S. darker* $\rightleftharpoons$ *O lighter.*

As far as can be told in this short space of time the bleaching was found to be fairly stable.

Acknowledgement is made to S. T. Solomon who donated the pearls which were the subject of the experiments, and to B. W. Anderson for assistance and advice.

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A NEW IMITATION of LAPIS LAZULI

by B. W. ANDERSON, B.Sc., F.G.A.

THE stained jasper popularly called " Swiss lapis " has for many years held the field as the only plausible imitation of the ultramarine-coloured rock known as lapis lazuli. Gemmologists will be interested to learn of an entirely new form of " ersatz " material which has recently been manufactured in Germany, a few sample specimens of which have reached this country from Idar-Oberstein.

In appearance this closely resembles fine quality lapis, though its colour contains more red, just as " Swiss lapis " contains more green, than the genuine material. It is indeed a typical cobalt blue—a fact which is indicated by the brilliant red appearance under the Chelsea filter and confirmed by examination with a hand spectroscope of the light reflected from a specimen.

When examined under a lens in a good light the imitation reveals a granular structure in which the grains are roughly circular in outline, thus differing from the patchiness seen in much true lapis. The small brassy specks of iron pyrites so typical of the natural gemstone were not to be seen in the imitation ; but the importance of this must not be too much stressed, since it is rumoured that the ingenious manufacturers of the new substance are experimenting with the incorporation of brassy grains to add to its verisimilitude—moreover there are specimens of fine lapis which reveal no pyrites.

The new material is exceedingly hard (approximately 8 on Mohs's scale), and this and the refractive index of 1.725 gives a strong hint that it is some form of artificial spinel. The density is lower than would be expected on this supposition, being 3.518 to 3.524 for the three specimens tested, but this can be accounted for if the material is a sintered product and not a single crystal. This is strongly suggested by its granular appearance and confirmed by the completely random scatter of Laue spots when an X-ray beam is passed through it on to a photographic film. Dr. G. F. Claringbull has kindly taken a powder photograph of the substance and has found its lattice constant to be 8.065 ($\pm$.005) which is near that for natural spinel (8.09).

As stated above, the sintered spinel shows a cobalt spectrum, but the distribution and relative strength of the bands are not quite the same as with blue spinel made by the Verneuil process. In particular, the band centred near 5800A, which in Verneuil synthetics is the prominent middle member of the predominant three bands of the spectrum, is here very weak, while a band at 4800A, which is hardly noticeable in the Verneuil stones is quite strong and clear. The full (reflection) spectrum is as follows :

6500A	broad and strong
5800	weak and vague
5320	very broad and moderately strong
4800	narrower ; moderately strong
4520	weak.

By condensing light from a 500 watt lamp it is possible to transmit a little light through a few millimetres of the new material, the residual rays having a reddish purple colour. This presented a remarkable sight through the spectroscope, showing a brilliant narrow transmission band in the red, centred at about 7050A, and a broader transmission region in the blue-violet ; almost all the remainder of the spectrum was absorbed. In a paper by Tromnau[1] on synthetic spinels coloured by cobalt, absorption curves are shown of these which reveal a similar state of affairs ; there is little absorption at the violet end up to about 5000A, then a steep climb in absorption to a maximum near 5850, declining steeply again until near 7000A there is a high degree of transmission.

To sum up : the new imitation lapis is an artificial sintered spinel material coloured by cobalt, having a refractive index near 1.725, density 3.52, and hardness 8. These compare with 1.50, 2.8, and 6 for true lapis. It resembles Afghanistan lapis lazuli rather closely, though rather more purple in tint. Careful examination reveals a distinctive granular structure. Its discrimination is quite simple, since its properties are entirely different from those of true lapis. Readings on the refractometer are not clear-cut, but quite good enough to prevent confusion with any other substance. The quickest test is provided by observing its brilliant red appearance under the Chelsea filter, or by examining its absorption spectrum by reflected light. Genuine lapis lazuli has no distinctive absorption bands and no marked colour-change under the filter.

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SOME INCLUSIONS in APATITES

by E. RUTLAND, Ph.D., F.G.A.

IT would be presumptuous to attempt to list in one article all the inclusions in apatite. There are too many places and varieties in which this entirely fascinating species is found. Only some of the typical or specially striking forms encountered are described and illustrated. Since words are an inadequate medium when dealing with inclusions some photomicrographs are reproduced, with apologies for their technique. Perhaps we may hope that this and other lesser gem species will receive their due attention in Dr. E. Gübelin's next book.

These notes owe their origin to a comment by Mr. B. W. Anderson on the curious bubble-like cavities he observed in some blue apatite. This stone, of which good specimens come from the ruby mines at Mogok, Burma, is already famous for its dichroism and its rare earth spectrum and figures 1–5 are based on it. The " bubbles " are of various kinds but all appear to be negative crystals and most of them contain liquids or liquids and gas.

The most common inclusions, typical of blue apatite, are clouds of small round bubble-like cavities, about 0.05–0.10 mm in diameter. Similar rounded negative crystals occur in layers or small groups in other minerals, but the dense clouds in Mogok apatite are not often found elsewhere. They are shown in Fig. 1 and it will be seen that sometimes two " bubbles " seem to have merged. Another curious excrescence which is often met with is illustrated in Fig. 2—a long thin channel extending straight from a rounded cavity. Such fine channels also occur on their own and, when they are dense and oriented, they give rise to a somewhat coarse type of cat's-eye. A photomicrograph of the latter is given in Fig. 5. It will be seen that the channels do not in all cases run parallel. It would be interesting to know if any star apatites have been encountered. It should, of course, be quite possible, though they would necessarily be of poor colour. But it may be that the channels run so predominantly parallel to the *c* axis that no stars are formed.

An even more extraordinary and quite specific type of cavity is that shown in Fig. 3. It is considerably larger, as a rule, than the " cloud " type and, unlike it, it only occurs singly or in small

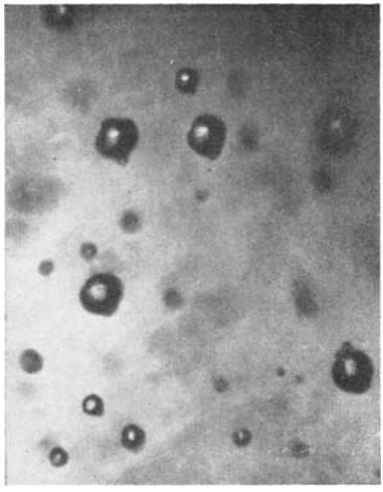

FIG. 1. *Blue Apatite. Cloud of small " bubbles."*

FIG. 2. *Blue Apatite. Small " bubbles " with one long cavity.*

FIG. 3. *Two-phase inclusion in blue Apatite. Large cavities.*

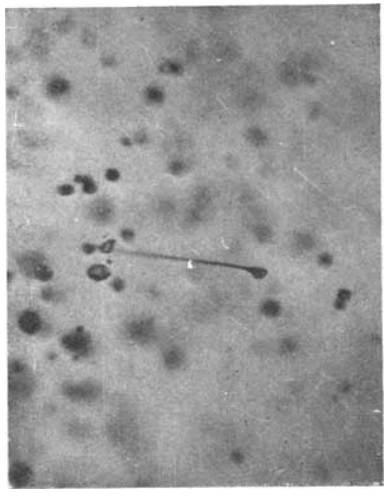

FIG. 4. *Blue Apatite. Dark blue inclusion.*

FIG. 5. *Fine channels in blue Apatite cat's-eye.*

FIG. 8. *Purple Apatite cavity.*

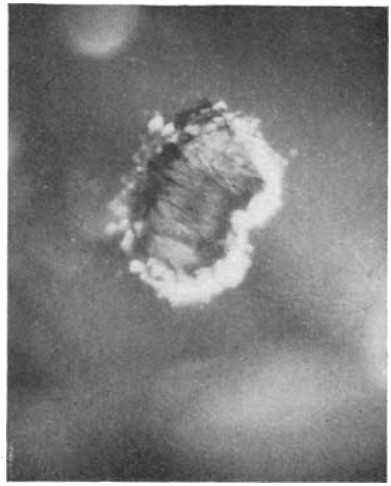

groups, though it may be interspersed with a " cloud." The most unusual shape of these large cavities (up to $\frac{1}{2}$ mm) is due to the corrugation of their walls with numerous crystal faces, some of which protrude into the solid stone, so that the cavity is surrounded by little pointers and pinnacles. Though they appear rounded, all these cavities have a crystalline form and some have been found as well-formed hexagonal prisms. One rounded cavity had a whole satellite system of minor hexagons attached to it by fine channels. Nearly all have two-phase contents, the gas bubbles sometimes being very large.

A rare but striking inclusion is coloured a rich blue (Fig. 4). It is a cavity intermediate in size between the two types described and also often shows crystal faces. The cause of the blue colour has not yet been determined. Specimens have been sent to Dr. Gübelin and to the Chamber of Commerce Laboratory and their findings are expected with much interest.* The blue inclusions are not dichroic. They are of a deeper blue even than the extraordinary ray but the colour sometimes does not extend over the entire inclusion. In some such cases the demarcation between the coloured and uncoloured parts is so sharp as to suggest a blue liquid and a gas bubble but in one case the inside of a cavity could be examined through the uncoloured part and it gave the appearance of being empty, with the colour coating the walls only.

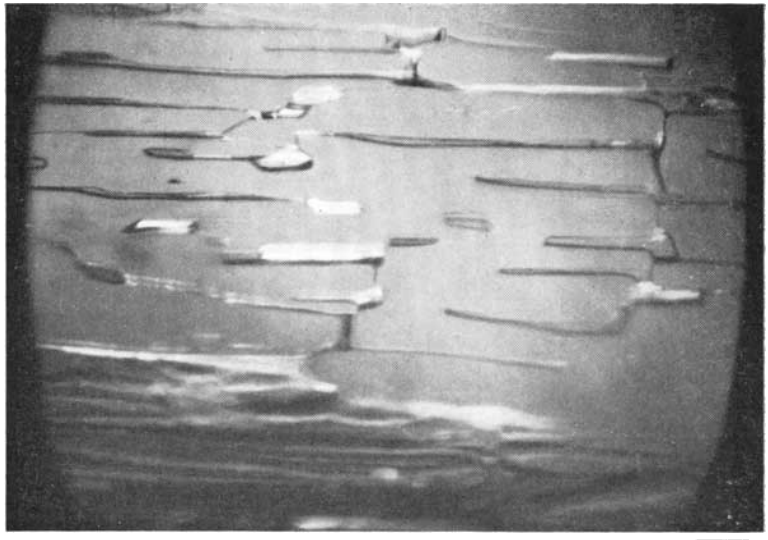

FIG. 6. *Yellow Apatite. Large channels.*

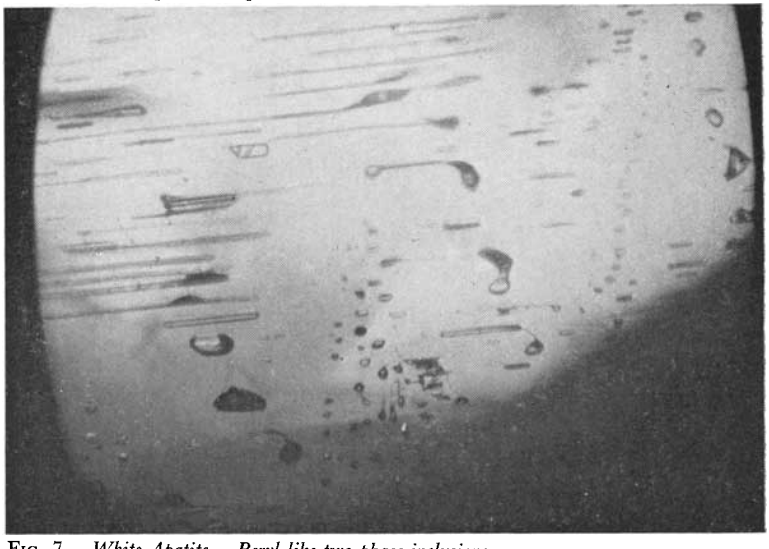

FIG. 7. *White Apatite. Beryl-like two-phase inclusions.*

Yellow apatite from Durango in Mexico, with the powerful didymium absorption spectrum, is perhaps the commonest variety. There is an abundance of beautifully clean material and it may be that only the cleanest pieces are cut, since inclusions of any diagnostic

value are uncommon. The only characteristic inclusions met with are illustrated in Figs. 6 and 7. The area reproduced in Fig. 6 measured about 2 mm square, so the branching and parallel channels shown are quite large. They are also very reminiscent of the " fingerprint " channels found in several other minerals. The other inclusions are strongly similar to those found in certain beryls—flattened angular cavities and two-phase contents.

Single stones of two other varieties have been examined with negative results. A white apatite from Japan was perfectly clean apart from a few tiny phenocrysts. A green apatite from Canada was also clean and contained only a fracture feather, such as might be seen in almost any stone. There was no sign of " healing." The third variety, however, produced the most bizarre inclusion of all and it is shown in Fig. 8. It comes from a purple stone from Maine, and, as there were three similar structures in the same stone, it may be found in others from that locality. The largest of the inclusions was over 0.7 mm in diameter and all three had an apparently helical structure. There is some kinship to the large cavities in the Burma stones and these inclusions also appear to be negative crystals, without any liquid, however. The search for inclusions is full of fascination and surprises.

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*In a subsequent private communication Dr. Gubelin stated : " Those blue inclusions are very puzzling. In the polarizing microscope they definitely look like solid inclusions, while under the stereoscope with dark field illumination, they rather give the impression of cavities coloured with a blue sublimation of their walls. One particularly interesting inclusion may be described as a cubic crystal within a stumped hexagonal negative crystal. In its interior there appeared to be a blue patch in the shape of a cube. This may speak for the inclusion being a rock salt crystal with a blue cubic patch caused by excess of sodium—a well-known feature of rock salt. At this state of my observations my examination had to end."

Dr. Gübelin then goes on to say that he is having a thin section prepared to determine whether the inclusions are cavities or solids, and if the latter, whether or not they are salt crystals. He says that salt crystals could quite possibly occur in the internal paragenesis of apatite.

FURTHER NOTES on the CAUSE of COLOURS in PRECIOUS OPAL

by G. F. LEECHMAN, F.G.A.

A VERY valuable contribution to this subject has recently been made by that eminent scientist Sir C. V. Raman, head of the Raman Research Institute, Bangalore, India. Dr. Raman has been working on the colour of gem stones for a number of years and it is to be regretted that his name does not figure more frequently in the relative literature. The value of his work is well illustrated in his presidential address to the Indian Academy of Sciences at its 19th annual meeting held at Ahmedabad, India, on 27th December, 1953. In his address Dr. Raman advanced as a reasonable hypothesis that iridescent opal consists of alternate layers of two crystalline modifications of silica of slightly different refractive indices, namely low tridymite and high cristobalite. This conclusion, he said, is established by comparative study of diffraction haloes and spectra, microscopical examination in reflected light and X-ray diffraction of hyalite and of gem opal. His investigations (in which A. Jayaraman collaborated) clearly show the existence of the film-pack structure referred to in the writer's previous contribution (Journ. Gemmology, Jan., 1954). The excellent photos reproduced in the report (Memoirs of the Raman Institute, Bangalore, No. 42) bring out both the series of similar parallel films and also the equidistant spacing of the lattice structure. Spectrographs reproduced in the report establish the fact that the colours are not produced by " interference " (as the term is commonly used) but by prismatic reflection and refraction of the incident light, while X-ray photos taken with cameras of very high resolving powers showed at first glance a similarity between opal, hyalite, vitreous silica, silica glass from Libya and silica-gel, though careful scrutiny showed significant differences.

In this connection it may be not out of place to enquire the exact meaning of the term hyalite, as used by Dr. Raman. He accepts hyalite as cryptocrystalline and sometimes iridescent, while agate and chalcedony, he says, are shown by X-ray studies to consist of crystallites of quartz. According to some writers, agate

consists of alternate bands of opal and quartz, which may be separated by crushing the specimen and dissolving out the opal in an alkaline solution, such as sodium hydroxide, when the residue will be found to contain crystals of quartz. Chalcedony has been considered as a form of fibrous silica related to the chatoyant quartz and to silica threads, or quartzine, as described by Sosman. Hyalite, as commonly understood, is a clear glassy silica, amorphous, similar to common opal but much more transparent. Should it show definite iridescence, it becomes water opal. If hyalite and common opal are cryptocrystalline, as Dr. Raman submits, is one justified in describing them as amorphous ?

Perhaps the answer to this question may be found with the help of colloids, a word which will be found, surely, more frequently in gemmology and mineralogy as the ubiquity of the colloidal state of matter is more fully realized. Many minerals which are to be found in crystalline form also occur in a colloidal state, and it may be that most forms which are described as mamillary, reniform, botryoidal, nodular, radiating or pisolithic are deposits from colloidal solutions or sols, where the groups of molecules (giant molecules or polymerized molecules) form particles too irregular to build up a true crystal structure; thus on solidification they settle out as a shapeless mass with, at first, but little coherence, that is, as a jelly or gel. This subsequently hardens into a mass which usually has curved surfaces, such as haematite, malachite, pitchblende, flint, much pyrites and some zeolites. In the case of opal it has been considered that the primary molecules of silicon tetraoxide (SiO_4)—produced in the sol perhaps by the action of a dilute acid incursion into a solution of a silicate—rapidly polymerize into silica threads or chains, having no regular orientation, but which on solidification produce what has been termed (by American investigators working on commercial silica gel) a " brush heap structure " —the sort of arrangement which twigs would take up when brushed into a heap. This constitutes, if opaque, common opal, and, if transparent or semi-transparent, hyalite. Under ideal conditions incipient crystal lattices in the form of parallel lamellae or film-packs are able to develop and thus produce iridescent opal.

The presence of two modifications does not appear to be necessary to the hypothesis, but Dr. Raman has shown the probability of their existence, and, indeed, previous research workers

(Dwyer and Mellor, Levin and Ott, inter alios) have formed the opinion that cristobalite is commonly present in opal, although tridymite does not appear to have been found. However, the President's inference, in an earlier paper, that the X-ray pattern of hyalite is a superposition of the patterns of high- and low-cristobalite is now admitted to be untenable to the conclusion that tridymite must be accepted, according to his evidence.

In a memorandum recently received, Dr. S. C. Robinson of the Geological Survey of Canada, a specialist in X-ray crystallography, says: "In studies of pitchblende deposits I have been impressed by the occurrence, in the same vein, of cryptocrystalline, colloform pitchblende and of euhedral discrete crystals of pitchblende. If the cryptocrystalline variety is attributed to coagulation from a sol, followed by ageing with increase in size of individual crystallites (this material yields sharp X-ray patterns, indicating that crystallites are greater than 1000A in diameter), then it must be assumed that the euhedral crystals (which are up to 0.2 mm on the cube edge) have grown from true solutions, which may well have been the liquid phase of the sol." This is an opinion with which the present writer warmly agrees.

A similar sequence has been observed experimentally, i.e. first a primary gelation, followed after syneresis and the consequent expulsion of some of the liquid phase—which lies as a clear liquor above the gel—by a slow crystallization. Not all the monosilicic acid polymerizes to form polysilicic acid, later becoming silica, but some remains in the interstices of the gel, is subsequently expelled by contraction and, since it contains simple molecules, regular crystallization can occur.

Geologically, siliceous solutions fill the joints, cracks and bedding planes of the wide-spread sandstone country. After the first precipitation of silica in the cavity a clear liquid rises above it and it is in this that colours may later develop. It has occurred to the present writer that the aspect of the terrain of the Libyan Desert is reminiscent of the Australian opal country and that possibly the silica glass brought from that area by Dr. L. J. Spencer may have been formed by a somewhat similar process.

It may be emphasized that this address provides conclusive evidence of regular internal structure, and that the photographs

reproduced are very illuminating. It is perhaps a pity that the degree of magnification is not given or the measurements referred to quoted fully.

The paper is extremely valuable to the student of opal and of crystallization colour theory in general, a branch of gemmology which is calling for research. The writer personally wishes he had known earlier of the work being done in Bangalore—some of the more abtruse problems would then have proved less difficult.

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RANDOM NOTES

by J. R. H. CHISHOLM, M.A., F.G.A.

READING articles in the *Journal of Gemmology*—or other papers on subjects of similar interest—is conducive of two quite distinct kinds of mental reaction. Primarily the process is one of assimilation of fresh mental pabulum, consisting maybe of facts observed and recorded for the first time, facts newly interpreted or novelly presented, recently evolved techniques or methods of procedure—the discovery of taaffeite, perhaps, or the " distant vision " technique. But there is also a secondary effect following the primary assimilation : the new matter is turned over and over in the mind, stimulated thereby to question, to argue, to check, to compare, to carry the matter perhaps a stage further. The paragraphs which follow are the products of this metaphorical chewing of the mental cud.

* * *

I found Mr. Leechman's[1] exposition of the cause of colour in opal full of interest. Spencer[2] has written :

> " the . . . colours shown by precious opal must clearly be due to . . . interference of light in thin films. Many explanations of the nature of these films have been offered, but their true nature still remains unknown. Here is an interesting problem for some keen admirer of opals."

This is one of the problems which Mr. Leechman has tackled. I take his " incipient lattice structure " to mean the same as " incipient crystallization " and his theory of opal structure to amount to this, that, owing to the opal " sol " having " gelled " while on the point of (and partially in the act of) crystallization, it has " set " in a state partly amorphous and partly consisting of giant polymerized chain and ring molecules of silica—if I may so call it, a thing of threads and patches—and thus in the case of " precious " opal it contains numerous parallel plates of regularly spaced atoms dispersed among the randomly arranged majority of atoms composing the generally amorphous structure of the surrounding gel. If I understand him aright, I imagine he would envisage these crystal plates, being in the nature of or composed of giant polymerized silica molecules, as of considerable size (relative to the atom) in two dimensions but with a thickness of no very

great number of atoms. But, while supplying this explanation of the lamellar structure, Mr. Leechman firmly denies the attribution of the colours to interference. He points out the monochromatic nature of the colour flashes and finds the cause of the brilliancy and of the monochromatic nature of these flashes in the spacing of the plates at such distances that the reflected rays do not interfere but on the contrary reinforce one another.

When Mr. Leechman was writing he was evidently unaware of the illuminating recent work on the same subject of Sir C. V. Raman and A. Jayaraman,[3] although he refers to their earlier work on iris quartz. The two papers first recording the new work on this problem of colour in opal are so important, that as they have not up to now been noticed in this *Journal*, I may be excused for quoting from them somewhat freely.

Undertaking the investigation " with the aim of elucidating the origin of the characteristic iridescence of precious opal," Raman and Jayaraman first conducted a series of experiments with four pieces of hyalite (or, as I should describe them, three water opals and one fire opal), using both optical and X-ray diffraction pattern methods, and concluded :

> " A study of the optical behaviour of iridescent opal indicates very clearly that the silica present in the material has a regularly stratified structure in which the alternate layers differ in refractive index, such difference being small but the same throughout the stratifications. A critical examination of the X-ray diffraction patterns of cryptocrystalline hyalites exhibiting optical phenomena identical with or analogous to those of precious opal confirms this finding and enables the two species of silica present in association with each other and giving rise to these phenomena to be identified respectively with high and low cristobalite."

Further studies were then carried out with gem opals as well as hyalite using X-ray cameras of higher resolving powers, and the resulting photographs were precisely measured. In the result they found that their identification of low cristobalite was incorrect but were

> " enabled . . . to reach the definite conclusion that the *two modifications of silica present in hyalite are respectively low-tridymite and high-cristobalite.* X-ray studies have also been made . . .

with common opal which occurs in massive form with a waxy lustre. These have led to a similar conclusion regarding the nature of the latter material.

The X-ray patterns of gem opals are diffuse, thereby making it less easy than in the case of the cryptocrystalline materials hyalite and common opal to identify the nature of the atomic groupings which appear in the alternating layers of its lamellar structure. Nevertheless, a careful examination of the patterns leaves little room for doubt that, as in the case of the iridescent hyalite, we are concerned with two modifications of silica present side by side in it, one of them having a structure resembling that of low-tridymite and the other that of high-cristobalite. Comparative studies of the optical behaviour of hyalite and of gem-opal . . . confirm this finding and establish this as the origin of the iridescence exhibited by these materials."

Although high-cristobalite usually becomes unstable and reverts to low-cristobalite under 300°C they consider it reasonable to assume that its association with low-tridymite, itself normally stable at ordinary temperatures, gives it the necessary stability.

" Since the two materials have the same chemical composition and nearly the same density, and since their structures have the silicon-oxygen tetrahedra as a common factor, there is no . . . difficulty in making such an assumption. Since the two structures are not identical, the materials would naturally tend to segregate and form layers so disposed with respect to each other as to present the maximum possible degree of continuity in the chains of valence bonds between the silicon and oxygen atoms extending through the material. Since the structure of low-tridymite is pseudo-hexagonal while that of high-cristobalite is cubic, geometric patterns in which the two structures alternate may be expected to arise, as is indeed actually observed in opal."

Mr. Leechman's references to the monochromatic nature of the colour flashes and to visible straight-line patterns are confirmed.

" Spectroscopic examination reveals that the internal reflections and the corresponding extinctions in the transmitted light are highly monochromatic. . . . When a gem-opal is examined through a microscope which has arrangements for illuminating the object from above the stage and viewing it by the

internally reflected light, the lamellar structure . . . becomes immediately evident. In not a few cases, geometric patterns of a very striking character are observed."

It is, moreover, made clear that " precious " opal is not amorphous. Common opal and hyalite, like agate and chalcedony, are shown to be cryptocrystalline and gem-opal to be minutely so.

" . . . the X-ray data point clearly to the conclusion that the structure of gem-opal is essentially the same as that of hyalite, except that the crystallites are now much smaller, thereby tending to make the material simulate a vitreous solid."

Thus all forms of opal, from common opal through hyalite to " precious " or gem-opal, have a similar structure and composition, the differences in optical behaviour being due to the diminishing size of the constituent crystallites and the increasing proximity of the laminae as the material becomes more " precious."

" It is clear from the facts that the optical effects exhibited by transparent hyalite and by iridescent opal form a continuous sequence in which there are three stages. In the first stage, the stratifications are too widely spaced to result in internal reflections, but give rise to diffraction haloes or diffraction spectra in forward directions. In the second stage, the stratifications are too closely spaced to give diffraction effects in forward directions, but result in reflections backwards towards the source. Finally, we have a third stage when the stratifications are too closely spaced to give any effects at all, unless the wave-length of the light is sufficiently small. In the cryptocrystalline hyalites, we would naturally expect the first stage to be commonest, and the second stage less common. In the gem-opals, on the other hand, where the material is approaching the vitreous condition, the stratifications may be expected to be much finer and the third stage therefore attained, unless the wave-length of the light is chosen sufficiently small. We do indeed have opals which exhibit a bright yellow or red iridescence. But those with a green, blue or violet iridescence are commoner, indicating that the more closely-spaced stratifications are favoured."

Confirmation that this is the true cause of the monochromatic colour flashes of gem-opal is found in the theory of the reflection of light in a regularly stratified medium which

" has been elaborately discussed . . . by G. N. Ramachandran.[4]

As has been shown by him, the degree of monochromatism of the reflections by such a medium cannot be indefinitely increased by increasing the number of its stratifications, their spectral width having a minimum limiting value which depends only on the reflecting power of an individual stratification. If such reflecting power be large, the monochromatism would necessarily be very imperfect ; *per contra*, if high monochromatism is actually observed, it indicates that the reflecting power of an individual lamination is small. These conclusions have an important application to the case of opal. They indicate that the difference in refractive indices of the alternate layers of the stratifications in opal is quite small. Further, such variation is strictly periodic and of the same magnitude throughout an individual set of stratifications."

While the last word may not have been said on the subject (in fact Mr. Leechman has some further observations elsewhere in this issue), Sir C. V. Raman claims[5] that the problem has at last been definitely solved and, so far as I can judge, it looks as if this old question of the cause of the play of colour in opal has indeed been finally answered.

* * *

Mr. N. Kennedy's " Gemstone Mysteries "[6] proved particularly evocative and set me thinking on the unfortunate lack of precision of some of the words we use.

For the identification of " girasol " with fire opal he need not have looked further than Herbert Smith's last edition[7] or the Oxford English Dictionary, and in deference to these two authorities we may think that this represents the orthodox modern English usage. But that is not the end of the matter, for the O.E.D.'s definition of " girasol(e) " as " a variety of opal which reflects a reddish glow in a bright light ; called also fire opal " is not very apt for the typical Mexican fire opal and some of the examples it quotes are quite clearly not what we now call fire opal or even not opal at all. Thus Cotgrave[8] in 1611 described " girasole " as " a precious stone, of the kind of the opals, that yields an eye-like luster, which way soever you turne it, unless it be towards the sunne ; for then it casts forth beames like the sunne," while in 1796 the mineralogist Richard Kirwan[9] wrote, " To this family (oriental sapphire) we may also annex the stone called Girasole."

And there is worse to come. If the Danas (father and son)[10] are reliable guides, then in America girasol for a hundred years has meant an opal " bluish white, translucent, with reddish reflections in a bright light " (which might be the same as Cotgrave and the O.E.D. intended), and finally Shipley[11] says that girasol is a name that has been applied to moonstone, to fire opal, to an almost transparent opal with a bluish floating light, to an opal with blue to white body colour and a red play of colour as well, and to many other stones, quoting Bauer – Spencer.[12]

The moral seems to be that the meaning of girasol in any author's works should be regarded as doubtful unless he obligingly describes it for us or at least provides sufficient clues to enable us to make a reasonably confident guess : and indeed this cautious approach is advisable in respect of all gemstone nomenclature, especially in the older literature on the subject. With regard to Heddle's statement of the occurrence of girasol in Scottish agates, quoted by Mr. Kennedy,[6] I would suggest that he probably used the word in the same sense as his fellow-mineralogists, the Danas, and that anyone searching Scotland for anything like true Mexican fire opal is doomed to disappointment.

* * *

When Mr. Kennedy[6] wrote of the " famous dichroism " of alexandrite, simulated (not very effectively) by synthetic corundum and synthetic spinel, he was clearly not referring to its pronounced pheochroism, due to differential absorption of light in the three principal optical directions, but to its capacity to look two different colours, green and red respectively, when viewed in natural and artificial light—a capacity which I am surprised to learn is apparently shared by a certain rare variety of tourmaline known in America as " chameleonite."[11] Science appears to have no special term to describe this latter type of " two-colouredness " or dichroism, and, unless we are to court confusion by earmarking " dichromism " or " dichromatism " for this meaning, it might be better to invent a word and call it " alexandrescence " (since " alexandritescence " comes awkwardly off the tongue).

Of course, all coloured objects possess this quality of alexandrescence in some degree : it is only the absolutely colourless—black—that shows no change of colour however much changed is

the wave-length or combination of wave-lengths of the light in which it is seen. The phenomenon, however, only becomes noticeable—and therefore notable—when the different colours are seen in types of light, such as sunlight and electric light, which are commonly encountered. Not all alexandrites appear red in all forms of artificial illumination : the change to red in this case depends upon the degree of richness in long and poverty in short wave-lengths of the particular illuminant used relatively to sunlight, and alexandrite owes its fame to the fact that all the light-sources hitherto common in domestic use, from the candle to the incandescent-filament electric bulb, have been comparatively deficient at the blue end of the spectrum. May it not then be that the introduction of new forms of illumination (fluorescent lighting, etc.) may extend the practical importance of alexandrescence, and other gems also may become notable for this type of colour-change ? I do not, of course, suggest that a ruby turning black in sodium-lighting is likely to make it popular—but there may be forms of lighting already with us or yet to come which will become common in places where ladies are wont to wear their finery and which will cause attractive colour-changes in gemstones hitherto unsuspected of any capability of alexandrescence.

* * *

I have some doubt whether Westropp's " blue crystal . . . found in France . . . near Expilly . . . called saphirs de France, or saphirs de Puy-en-Velai," quoted by Mr. Kennedy,[6] was indeed blue quartz, since Dieulafait[13] also refers to the " saphir de Puy " from Expilly (" sa couleur varie du bleu le plus foncé au bleu le plus pâle ; parfois elle passe au bleu rougeâtre et même au vert jaunâtre ") and states categorically that it is corundum. He does mention a blue quartz, however, called " saphir d'eau " (a name also used for iolite)—" il existe des saphirs d'eau qui sont des quartz presque purs "—whose colour " d'un blanc clair mêlé de bleu céleste constitue une nuance mixte, montrant . . . une différence complète avec la magnifique couleur bleu du saphir d'Orient." He calls it " une pierre à peu près sans valeur."

* * *

Mr. O. Dragsted[14] deserves our gratitude for recalling the gemmologist's debt to the seventeenth century scientists, Bartholin and Steno. There can be no objection to describing a man as a

gemmologist merely because he lived and died before the word was coined, but it is not a title that should be given to all those who have made to the general body of scientific thought contributions which have subsequently been useful in the study of gemmology. I feel that " gemmologist " is a name which should be reserved for those who, whatever their other interests, have devoted particular attention to the study of gemstones and all that pertains to them. This may deprive the ranks of the gemmologists of some of the great names of science, from Archimedes onwards, but although it has only been named in comparatively recent times and its emergence as a separate branch of learning has been a gradual development, due to the ever-widening horizons of knowledge and the increased specialization consequent thereon, our branch of science nevertheless has had its devotees from times of respectable antiquity—at least from the time of Theophrastus (c.372—287 B.C.), whom we may perhaps call the father of gemmology. And who knows how many centuries, how many millennia, before Theophrastus, there were gemmologists—in the civilizations of Egypt, Mesopotamia, Crete, and even earlier in the mists of stone-age pre-history—men who have left no written record, but who in their lives strove to attain beauty and extend the bounds of knowledge through the understanding use of gems ? *Vixere fortes ante Agamemnona. . . .*

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PREMIER MINE DIAMOND

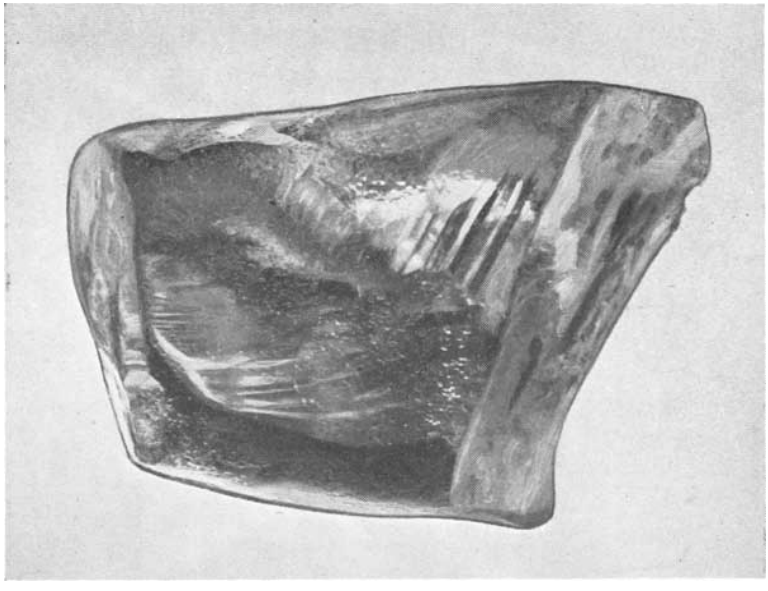

(*Photograph by courtesy of De Beers Consolidated Mines*)

A large diamond, weighing 426½ carats, was recently found in the Premier Diamond Mine at Cullinan, South Africa. Its size may be compared with the half crown. It is reported to be bluish-white and of good quality and Dr. J. F. Custers, who has examined the stone, mentioned in his talk to members in June that it was a Type IIb stone. The new diamond is one of the largest found though the Cullinan (3106 carats), Excelsior (995.2 carats), Jubilee (650.8 carats) and (allegedly) the Koh-i-noor (800 carats) exceeded it.

QUEEN MARY'S COLLECTION

by ELSIE RUFF, F.G.A.

WHEN Queen Mary visited the Gemmological Association's Exhibitions, she came, not as a gemmologist, as a collector. Nor was she a collector of gemstones. Her beginning as a collector, we are told, goes back to early childhood. Whereas some children assemble stamps, Queen Mary, then Princess May, was in a better position and her taste ran to *objets d'art.* Along with her other treasures to be seen at the Victoria and Albert Museum is her jade. Nevertheless, snuff boxes were snuff boxes, independent of gemstones. (Many boxes so catalogued were not either created for snuff.) Among her Fabergé treasures, the same spirit prevailed. Fabergé made his material fit his design. He might use metal or he might use gemstone material. The gemstones themselves were chosen for their decorative features.

Gemmology in its widest sense must embrace gemstones and gem materials (sometimes termed ornamental stones) in whatever form. While gemmology is necessarily allied to jewellery, it still has a relationship to bric-à-brac generally. Yet within this framework, the gemmologist stands at the opposite end to Fabergé, say. He was the jeweller-craftsman-designer fitting his medium to his design. The gemmologist proper fits his design to his gemstone.

The current collection at the Victoria and Albert Museum, therefore, has much to interest the gemmologist. He might begin by sighing for the wonderful materials common so short a time ago. Rhodonite, for example, approaches jade in its adaptability. Fine pieces of lapis lazuli tell one and all that to restrict it to the odd signet is a grave omission. Pieces of lapis lazuli in the collection have been combined with mother-of-pearl and also with green jade. A case of jades, from greenish white to wonderful dark greens, once decorated Queen Mary's dining room. And a separate case of jewelled jade places this Indian period somewhere between Fabergé (as the ultimate exponent) and the gemmologist proper. There is a large jade bowl that, unfortunately, stands on a green leather-

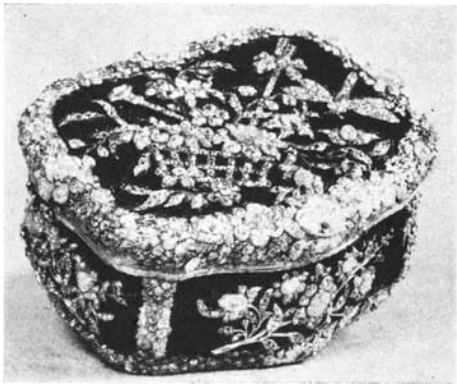

FIG. 1. *A German box of bloodstone mounted with gold and diamonds, formerly part of the Russian crown jewels. Dated about 1770.*

topped table, to the benefit of neither. There are beautiful examples of tortoiseshell and of ivory. There is serpentine, malachite, and moss agate. There is rock-crystal, often wedded to enamel. There is a bloodstone box heavily decorated with diamonds, part of the Russian Crown Jewels, and a diamond encrusted horse. And there are the consoling rubies and emeralds and sapphires and, of course, pearls. These earlier designers had the world of gems to choose from apparently and could do so with neither apology nor explanation. The modern cigarette case has never replaced the snuff box. When snuff went out of fashion, the gap must have been enormous—more so perhaps than one might contemplate should present propaganda add up to a non-smoking generation.

To men of the Fabergé calibre, there would seem to be no class-consciousness among gemstones at all. He needed red—very well, rubies if possible, but, rather than a line of unmatching corundums, garnets will do equally well. Fabergé was the supreme toy-maker perhaps, and Queen Mary was interested in toys. Her doll's house, now at Windsor, is an outcome of this interest. The modern world has little time for jewelled toys. Maybe, something between the Fabergé baubles and the realistic designs of to-day is needed. Salvador Dali has been cited as an adventurer in this field. From the gemmologist's point of view, it seems all to the good, for he appears to stand at the cross roads of Design and Gems.

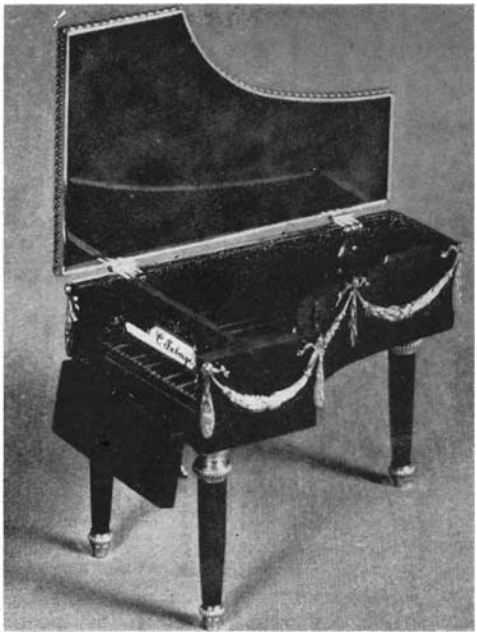

FIG. 2. *From Queen Mary's Fabergé masterpieces, a nephrite and gold miniature piano.*

No matter how one approaches this collection, it is almost impossible to view it as a collection. Rather is it an expression of a personality. And that gives it warmth. Queen Mary was no slave to any particular period, though the *Regency* undoubtedly captured her imagination early in life. Hers was a collection of things that she loved and wanted to live with. She had obviously concerned herself little with standards. The treasures at the Victoria and Albert Museum give the visitor contact, not necessarily with the collection, with the collector.

Many a gemmologist will see this exhibition. He will likely begin with the egg[1]—the first centre case as one enters the main hall—and almost certainly return to it. There he will also see a miniature grand piano in Siberian nephrite, which at least announces that the jade craftsman is still with us, as well as a rather vulgar rose quartz Buddha. Illustrated, Fabergé's Easter egg of 1914 conveys little. It depends on light and colour. As an example of the jeweller's craft it is, surely, exceptional. It might be described

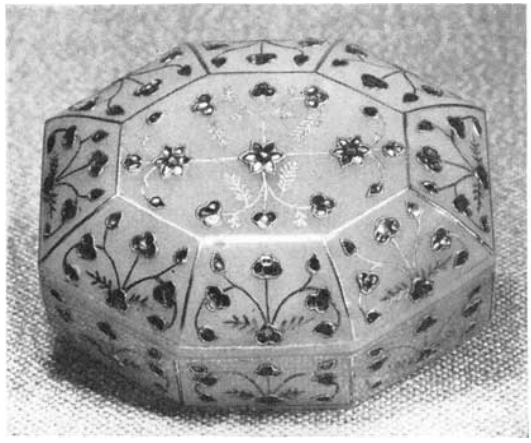

FIG. 3. *An 18th-century Indian box from Jaipur of white jade mounted with gold and rubies.*

as a jewelled cobweb styled into an egg. And this exquisiteness in platinum and gold and opaque white enamel would hardly count were it not for the minute gemstones and pearls. Whatever the individual part played by Fabergé in this creation (he employed something like 700 craftsmen) it must have afforded him intense satisfaction to sign his name to it. As it transpired, it was more than a personal signature—it was the signature of an era. Perhaps this too might be said of Queen Mary's collection.

1. Not one of the four eggs exhibited in London at the end of 1949.

Dr. J. F. H. CUSTERS' talk on

RECENT RESEARCH on DIAMONDS including ARTIFICIAL COLORATION

NEW facts about diamonds were revealed by Dr. J. F. H. Custers, Director of Research of the Diamond Research Laboratory, Johannesburg, at a talk he gave to members of the Gemmological Association at the Medical Society of London headquarters on 3rd June.

Earlier knowledge, said Dr. Custers, has made it clear that there are two types of diamonds, commonly known as Type I and the rarer Type II. The actual differences in structure are not fully understood, but there are clear differences in properties, notably in transparency in the ultra-violet range. It has been suggested by later research that there are even more types and the matter has become a little more complicated since it was discovered at the Johannesburg laboratory that there is a further sub-division of Type II into " a's " and " b's." Type IIb is characterized by being strongly phosphorescent when suitably treated. In the laboratory a large stone of 426½ carats showed remarkable phosphorescent effects when excited by short wave ultra-violet light.

Type IIb is a very good conductor of electricity. Diamonds are, of course, normally good insulators, but a Type IIb of one-sixth inch diameter would pass a few milli-amps when 100 volts was applied to it. This current would increase to about five amperes in a few minutes. It is very surprising to find that a diamond would conduct such a current, said Dr. Custers.

He then went on to explain this by pointing out that there are two forms of conductivity. Electricity could be carried by the atoms themselves or the electrons could move. This type of diamond evidently started off by having the current carried by the electrons and as the electrons got more excited and raised the temperature amid the imperfect lattice construction of the diamond additional

electrons got liberated to allow still more current to be carried. As a result the diamond became red hot and would oxidize if the current was left to run long enough.

The properties of these diamonds may open new fields for their use. For example, in a vacuum they might be used as semi-conductors at a high temperature. Such semi-conductors are becoming increasingly important nowadays. Germanium is one of them and it is used as a transistor device. It might be possible to use diamonds for such a purpose. Some of the British universities are working on these matters and Dr. Custer's own laboratory keeps in touch with them. Not only might the Type IIb diamond be used as a transistor, but " b " types are good counters of gamma rays. A Geiger instrument is usually employed for this, consisting of a gas-filled tube through which a wire runs. The electrons of the gamma rays pass through the diamond and liberate other electrons in the lattice and the movement is amplified and counted or heard.

The diamond is a crystal, said Dr. Custers, being one form of carbon. Graphite or charcoal are the common modifications. Graphite is the more stable. This is why high temperatures could transform diamond into graphite, but the transformation could not be done the other way because of the high pressures required. Even with 16,000 atmospheres of pressure it would take millions of years. High pressures have been obtained and in the United States they have attained 250,000 atmospheres but only for a fraction of a second. That, of course, is not long enough, even at an absolute temperature of 2,000 degrees.

The first part of the talk was concluded by Dr. Custers giving an explanation of how the phosphorescence could be kept " stored " for several weeks by maintaining the diamond at a temperature near absolute zero. If heated quickly then, the phosphorescence would come as a blue light so intense that one could almost see print by it.

In the question time that followed one member asked whether the flow of current is in one direction. " This has not been established," answered Dr. Custers. A second question was whether differences in colour or purity were a mark of the different types of diamond. There are two schools of thought on this, said Dr. Custers, and they are still trying to find out. Fluorescent stones

always had the same spectrum. If it was a matter of impurities, Dr. Custers said he could not understand why the diamonds should have the same spectra, but he thought it was a matter of structure and lattice defects.

Mr. B. W. Anderson, Director of the London Chamber of Commerce Diamond and Precious Stone Laboratory asked several questions, and the lecturer in reply said that Type IIb diamonds also re-acted to X-rays. There was no record of one type being transformed into the other by any kind of treatment.

Dr. Custers then spoke of the coloration and reaction of diamonds to atomic treatment. About three years ago it was found that a diamond put in an atomic pile turned green. There are three types of atomic radiation to which diamonds might be exposed—alpha particles, beta particles and gamma rays. Diamonds with the same green colour that is given by alpha particles are also found in gold mines in South Africa, though there is a difference between the two. The whole diamond is made green when exposed in a pile, whereas with those in the mines there is only a superficial skin effect.

Neutrons, being uncharged particles of similar mass to a proton (hydrogen nucleus) are able to run through the lattice atoms of the diamond and displace the atomic nuclei. At the same time the electrons are displaced, thus altering the absorption of light. Colour varies from light green to bottle green and if the diamond is kept in the pile long enough it turns black.

If the atoms of the neutron irradiated green diamonds have the chance to move again by heat treatment they do so and the diamond might turn from deep green to amber or light yellow, but the original colour is never restored. Some permanent damage has been done. That damage is called radiation damage. A green diamond is not of great interest in the diamond world, but the making of a blue diamond is quite another matter. Two years ago it was found that this could be done. To do so neutrons were not used as projectiles, but electrons. The neutrons damaged the lattice fairly severely, but the electron is lighter and did not cause so much damage. Electrons do not penetrate so far unless they are speeded up when damage could be more severe and the green colour again obtained. The coloration is only about one-fiftieth

of an inch deep in a brilliant, but with the naked eye it could not easily be ascertained whether the blue-white colour was natural or not. However, all natural blue-white diamonds are Type IIb, and no exceptions have been found. These are conductors of electricity and so it is possible to apply this test. It has also been found they have a different factor of light absorption. The artificially coloured ones absorb light more weakly in the red end of the spectrum. The blue-white colour can be corrected slightly by heat treatment afterwards.

Only a few days ago, said Dr. Custers, he had heard the first results of colouring diamonds by the use of gamma rays. Radiation had been carried out for about 1,000 hours. The gamma rays are not very readily absorbed by a diamond, but they liberate the electrons that surround the carbon nuclei in the diamond, thus allowing movement. As a result the whole diamond is coloured blue instead of a surface area. One difficulty is to find gamma rays of the right energy. Radio-active cobalt is one answer to this. Gamma rays are promising, but they are rather expensive.

There are still many problems to be solved and riddles to be answered so far as the diamond crystal is concerned, Dr. Custers said in conclusion of his talk. In his laboratory they are trying to find out more and better uses for industrial diamonds. The gem side does not interest them so much, but the matter of coloration is of such importance that it cannot be ignored.

At the beginning of the meeting the Chairman, Mr. F. H. Knowles-Brown had expressed the Association's gratitude to Dr. Custers for so kindly consenting to give a talk to members during an extremely brief and busy visit to Britain. Mr. B. W. Anderson, in moving a vote of thanks to Dr. Custers, said that although there were many minerals which had many problems to solve, diamond could still be regarded as the most puzzling and fascinating of them all and he expressed the indebtedness of members to Dr. Custers for such an interesting talk.

AUSTRALIAN PEARL FISHING EXPERIMENT

A BOLD experiment to save Australia's rich pearling industry began in April when the Intergovernmental Committee for European Migration (ICEM) transported a ten-man crew of Greek sponge fishers from Athens to Darwin, Australia, the world's largest pearl-beds, sprawled under the waters off the north-west coast of Australia.

The crew, recruited from among the fishermen of Kalymnos, a barren rock island in the South Aegean Sea, includes three divers, three tenders, three crew members and an engineer.

Darwin's pearlers will keep a close watch on the Greek sponge divers, their last hope to get the industry back on its feet. Australia's pearling fleet once numbered 300 luggers and employed 2,000 Asiatics. The war brought an abrupt end to that because the Japanese had dominated the industry before the war.

Only Japanese divers were able to go to the depths required, sometimes as much as 20 fathoms. Since the war, the Government has tried to utilize white divers, but with no marked success. Even the Malays were able to descend only or 12 to 14 fathoms. Last year, Australia was forced to re-admit 35 Japanese divers to Western Australia, despite the political implications of such a move. Divers from Koepang and Thursday Island were able to win barely enough shell to keep the industry alive.

Shell has become a great dollar earner for Australia and is now priced at the unprecedented figure of £700 Australian the ton. In addition to its commercial importance, a successful pearling industry would mean the maintenance of population in the continent's exposed northwest flank.

The Australian Northwest, a territory of some 530,000 square miles, holds fewer than 7,000 white persons. Much of this land is given over to enormous cattle and sheep stations but the potential economic wealth of this undeveloped region lies underground. There are valuable deposits of tin, lead, copper and iron, as well as of rarer metals. There have been rich strikes of uranium and oil. To hold on to this rich, unsettled land, Australia knows she must populate it.

Last year, the Commonwealth Government proclaimed its jurisdiction over the waters of the continental shelf, including the pearl-beds, long a fishing ground for Japanese pearl luggers. The Government is now backing up its claim with the importation of the Greek diving crew. If the experiment is successful, other sponge fishermen from Kalymnos are expected to follow.

For the people of Kalymnos, the Australian test may be the answer to their own difficulties. The 15,000 Greeks who make the rock island their home have only one source of income—sponges. For centuries, the hardy islanders have wrested their living from the bed of the Mediterranean.

For more than two years, however, the financial advantages of sponge-fishing have dropped so disastrously that the islanders have been forced to serious consideration of mass emigration. According to Anton Mavrikakis, mayor of the island, 500 of his people stand ready to quit Kalymnos.

Last September, an unofficial Australian emissary, Mr. Eugene Gorman, visited the Greek island, after conversation with ICEM officials in Geneva, to take a first-hand look at the Greek sponge divers. He asked two questions : Can Kalymnians dive as well as the Japanese ? Do Kalymnians know anything about shell-fishing ? He found that the island divers can go down as far as 35 fathoms, and that the adaptation to shell-fishing should not be difficult for sponge-divers.

Gorman warned the islanders that life in the Australian Northwest will be lonely and harsh. The people of Kalymnos already knows what that means. Their home is a bleak, yellowish-grey mass of rock. Even in springtime, it is hard to find a green patch anywhere on its dry, barren hills or cliffs. On feast days, many of the families have little more than bread, tomatoes and a few olives.

If the plan for Kalymnos wins final approval, the Intergovernmental Committee for European Migration will prepare the islanders for emigration, give them basic English courses, and arrange their transport to Australia.

Gemmological Abstracts

CUSTERS (J. F. H.). *Artificial coloration of diamonds.* Optima, Vol. 3, No. 4, pp. 8–12, December, 1953. Reprinted Gemmologist (1st instalment), pp. 81–85, No. 274, Vol. XXIII, May, 1954.

Written in non-technical language this article reports on the change of colour that diamond may assume after bombardment by particles of atomic size. The Rutherford-Bohr conception of the atom prefaces the note on the two best known ways in which radiation can interact with atoms. These are interaction with the outer electrons and interaction with the nucleus itself. The latter type of interaction did not have any importance until the invention of the cyclotron in 1925, and later that of the nuclear reactor, or as it is better known, the atomic pile. The writer explains the " radiation damage " as a displacement of the atoms in the crystal pattern which can drastically change the thermal and electrical properties, and also the absorption of light, hence change of colour can occur. A clear explanation is given why neutrons are more efficient than other particles, such as protons and electrons, for the penetration of atomic nuclei. A note is given on what is known about the colouring agents of natural fancy diamonds, which may be due to trace elements or to structural defects in the crystal lattice. Diamonds bombarded in an atomic pile turned bottle green if the dose of radiation was light, but if heavy the induced colour was so intense that the stone became black. On heating these irradiated stones the colour turned to deep amber to light yellow shades depending on the time and temperature of the heating. The discovery by R. A. Dugdale that diamonds could be turned blue by bombardment with high speed electrons from a Van de Graaff generator is commented upon. The colour of these " blued " stones is said to be only skin deep and of a shade different from the blue of natural stones. It is suggested that the natural blue diamonds form a new structural type which the author proposes to call Type IIB. All natural blue diamonds have been found to be of the rarer Type II. The article closes with the statement that the artificially blued diamonds can be readily recognized as man-made coloration, and that the market value of a diamond will not be

enhanced by artificial coloration. The light absorption of the artificially blued diamonds is said to differ from the natural blue stones, and it might be possible to devise a suitable light filter which will distinguish the natural colour from that artificially produced, the colour of which is said to be less stable than that of the natural blue. An informative and important article. 6 illus. (one in colour). R.W.

KLEEB (A. A.). *Watch jewels of the past.* Gems and Gemology. Vol. VIII, No. 1, pp. 3–15, Spring, 1954.

Tells of the first use of watch jewels and of the authors examination of the bearing jewels in a number of antique watches. Chrysoberyl and quartz were found to be quite common in these old watches ; beryl, ruby, sapphire, natural spinel, garnet and diamond (as end stones) were also found. Cornelian had been used for clock pallets and another clock had the bearings made of ivory. One watch was found to have " fake " bearings of red glass. 11 illus. R.W.

ANDERSON (B. W.) ; PAYNE (C. J.). *The spectroscope and its applications to gemmology.* Gemmologist, Vol. XXIII, Nos. 272–3–4, pp. 48–52, 72–76, 87–90, March, April, May, 1954.

Three further instalments of the most useful series in which description and methods of use of the quartz spectrograph are given, and also absorption spectra and the methods of observing them are discussed. A short but adequate survey of the quartz spectrograph is given ; the characteristics of the small, medium, and large instruments being covered. The methods employed in taking spectrograms with such apparatus and the methods of " reading " them are explained. After a short history of the early work carried out on the absorption spectra of minerals and gems there is a full description of the types of spectroscopes that can be best employed in observing the absorption spectra of gemstones. The best type of lighting to use and the various set-ups which aid satisfactory observation of the distinctive absorption bands and lines. 4 illus. R.W.

DEANE (N.). *Adventures in lapidary work.* Gemmologist, Vol. XXIII, No. 272, pp. 41-46, March, 1954.

The third instalment of this series deals with the writer's early trials and difficulties in obtaining suitable spindles to run his

apparatus. The making of jamb pegs and dop sticks is discussed. The author's early attempts at faceting are told and a discussion on polishing powders follows. Remarks are made on the difficulty of getting suitable rough material in this country. 4 illus.

R.W.

WEBSTER (R.). *Gemstone luminescence.* Gemmologist, Vol. XXIII, Nos. 272–3–4, pp. 58–60, 77–78, 98–100, March, April, May, 1954.

The concluding three instalments of this series comprise the luminescent characters of spodumene to zoisite. Appendices giving tables of the more pronounced luminescences, grouped in colours, for the three wave-bands covered by the series, i.e. long-wave ultra-violet light, short-wave ultra-violet light and x-rays. The series ends with a short glossary of terms. P.B.

CROWNINGSHIELD (R.). *Simple means to distinguish yellow chrysoberyl and yellow sapphire.* Gems and Gemology, Vol. VIII, No. 1, p. 31, Spring, 1954.

It is reported that a simple test for the distinction of yellow chrysoberyl from yellow sapphire by the refractometer is to employ a drop of methylene iodide as the contact liquid in place of the normal 1.81 liquid. Under such conditions if the stone be a chrysoberyl a portion of the spectral edge will be seen in the blue-violet, but if a yellow sapphire no spectral colours will be seen. The writer points out that if monochromatic light or a spectroscope be available these more orthodox tests would be better used.

R.W.

LEWIS (M. D. S.). *The history of paste.* Gemmologist, Vol. XXIII, Nos. 272 and 274, pp. 53–57, 91–94, March and May, 1954. (See Journ. Gemmology Abstracts, Vol. IV, No. 5, p. 213, Jan., 1954). The continuation of the article on the history of the making of paste stones).

These instalments discuss the use of glass imitation gemstones from the 15th century on. It is said that the prohibition in 1615 of the use of timber as fuel in English glass houses led to the change in process which gave the lustrous English flint glass. As the use of coal as a fuel necessitated the employment of covered glass pots

and hence a flux to lower the melting point, lead oxide in some quantity was added to the glass metal. The story of Stras, the Paris chemist-jeweller, is told with regard to the production of the heavy lead-glass pastes which go by the name of " strass." The article concludes with some details of the use of paste in jewellery and the design of jewellery in the 18th and 19th centuries. A note is given on the foiling of stones. The prevalent idea that modern jewellery is cast in a mould while antique jewellery was always " hand-made " is refuted by the writer, who avers that much antique jewellery was cast. 3 illus. R.W.

RAMAN (C. V.) and JAYARAMAN (A.). *The structure and optical behaviour of iridescent opal.* Gems and Gemology, Vol. VIII, No. 1, pp. 21–26, Spring, 1954. (Condensed and reprinted from The Indian Academy of Sciences Proceedings, Vol. XXXVIII, Section A, No. 5, from which quotations are given on pp. 292-296 of this issue of the *Journal*).

Gem opal shows an orange-red light by transmitted light and this may be reflected from the rear surface and enhance the beauty of the gem by contrast with the blues and greens of the " play of colour." Spectroscopic examination shows that the internal reflections and the corresponding extinctions in the transmitted light are highly monochromatic. This infers regularly stratified layers in great number. The lamellar structure can be observed by microscopic examination employing overhead illumination. It is suggested that this lamellar structure consists of alternate layers of two crystalline modifications of silica of slightly different R.I. This hypothesis is supported by X-ray diffraction patterns; and the iridescence is due to alternate layers of high cristobalite and low tridymite. 4 illus. R.W.

PAYNE (C. J.). *The Rotagem.* Gemmologist, Vol. XXIII, No. 273, pp. 47–48, April, 1954.

Describes an ingenious accessory, devised by D. S. M. Field of Canada, to fix on a Rayner refractometer in place of the cover, in order to hold and rotate the stone on the dense glass without damage and with greater ease than when the stone is held in the fingers. 1 illus. P.B.

ROBB (C. J.). *Imitating rubies in* 1699. Gemmologist, Vol. XXIII, No. 272, p. 57, March, 1954.

A note taken from an old manuscript which gives a formula for making imitation rubies. As the description tells of taking four ounces of natural crystal to which is added various other substances and the whole heated in a glass-house furnace, will the result be glass or " reconstructed ruby " ? P.B.

SCHLOSSMACHER (K.). *Die Entstehung der Edelsteine.* The formation of precious stones. Zeitschrift d.Deutsch.Gesell.f.Edelsteinkunde, Spring, 1954, No. 7, pp. 3–7.

Our direct observations are confined to the outer boundaries of the silicate shell (lithosphere) which reaches a depth of about 750 miles. Most rock-forming minerals (feldspars, micas, augites, hornblende, olivine, etc.) and many precious stones are silicates. Under the silicate shell lies the sulphide-oxide shell (750–1800 miles), which consists of metal-sulphur and oxygen compounds, and under this the iron-nickel core.

The eruptive cycle and the eruptive rocks are most important for the study of gem deposits and a differentiation is made between rock magma, extrusive rocks and intrusive rocks. The rock magma congeals in three phases. During the (first) intramagmatic phase some minerals crystallize and form rocks (for instance granites, diorites, gabbros). Precious stones of this phase are the diamond, some garnets, peridot and labradorite. The (second) pegmatitic-pneumatolytic phase starts when the pressure of the remaining solution grows to such an extent that part of it is pressed into the surrounding rocks. Of the intrusive rocks which are formed, the pegmatites are of the greatest importance as gem deposits. Pegmatitic minerals are tourmaline, topaz, most beryls including aquamarine, chrysoberyl, euclase, phenakite, etc. When magma is pressed into fissures surrounding rocks dissolve and recrystallize. This process is called contact metamorphosis, and deposits of ruby, many sapphires, emerald and nephrite are of this kind. This pneumatolytic part of the second phase owes its name to the volatile components which are prominent. Contact minerals are not only formed around intrusive rocks, but also around solidifying rock magma. During the (third) hydrothermal phase aqueous solutions from the magma penetrate into the surrounding rocks, fill

fissures and cause hydrothermal contact phenomena. Hot springs are solutions of this kind which reach the earth's surface. Many gems of the quartz group belong to this phase.

The three phases take place within the earth's crust and are called intrusive. When the magma penetrates to the earth's surface, they are called extrusive phenomena. These are of less importance for gemmology, only opal and agate being formed in this way from hot aqueous solutions.

The sedimentary cycle is of no importance for the formation of gems, except perhaps for amber and jet. However, many gems are found in secondary or tertiary deposits in sediments and sedimentary rocks.

Crystalline schists are formed from existing eruptive and sedimentary rocks through pressure, high temperature and solution. If the pressure was exerted in one direction only, a scaly habit resulted. Some rocks belonging to this group are gneiss, mica, serpentine and marble ; gem stones of this group are some garnets, nephrite and jadeite, which were formed at the same time through contact metamorphosis.

The cycle of weathering does not lead in general to the formation of new gem stones. Only turquoise, chrysoprase, malachite and azurite are products of weathering. However, weathering is of great importance for the formation of alluvial gem deposits.

E.S.

SCHLOSSMACHER (K.). *Eine neue Lapis-Imitation.* A new lapis imitation. Zeitschrift d . Deutsch . Gesell . f . Edelsteinkunde, Spring, 1954, No. 7, pp. 8–9.

Description of a new imitation lapis-lazuli. The colour is that of finest Afghanistan lapis. The hardness is over 8 Mohs's scale. The main constituent of the imitation is a colourless singly refractive mass of R.I. 1.72 and S.G. 3.6 pointing to a spinel-like composition. The second constituent is the pigment, perhaps a cobalt compound, appearing under the microscope as very small grain of nearly black colour. The greater hardness, R.I. and S.G. as well as the higher lustre and the lack of pyrites inclusions allow differentiation from genuine lapis lazuli. (A more detailed analysis of the new imitation is given on p. 281 of this issue of the Journal). E.S.

ANON. *Prasiolit—ein grün gebrannter Quartz.* Prasiolite, a green fired quartz. Zeitschrift d.Deutsch.Gesell.f.Edelsteinkunde, Spring, 1954, No. 7, p. 10.

Allegedly green quartz, completely transparent, was first discovered when amethyst rejects from Minas Gerais, near Montezuma, were accidently burned in a camp fire. To-day the material is selected and carefully fired in Rio de Janeiro and marketed in New York as " prasiolite." The crystals which are found in geodes within a particular vein, are small, at the utmost four inches long. Of interest is the elongation of the crystals in contrast to amethyst pyramids. The colour is pale, an outer zone of about ¼ to 1 inch is colourless. The crystal faces are green and covered with iron oxides. Only 4 per cent of the material are of the best colour. The stones resemble green beryls ; more rarely green tourmalines ; and especially liked is the peridot colour. The price corresponds to that of calibrated amethysts. A sufficient quantity to be of importance for the Christmas sales, 1954, is said to be available.

E.S.

REITENBACH (A.). *Aus dem Achatbergbau Idar-Obersteins.* On agate mining at Idar-Oberstein. Zeitschrift d.Deutsch.Gesell.f.Edelsteinkunde, Spring, 1954, No. 7, pp. 13–17.

Historical aspects and speculations concerning early agate mining in the Idar-Oberstein district. W.S.

VARIOUS AUTHORS. *Ädler Stenar.* Precious Stones. C. G. Hallbergs Guldmedsaktiebolag, Stockholm, 1953, pp. 51.

This is a very attractive propaganda brochure designed to stimulate interest in precious stones and jewellery. On twelve pages Dr. T. Lenk reports on the Swedish crown jewels, depicting characteristic examples in excellent reproductions. A fine colour plate shows the famous and magnificent crown made in 1561 by Cornelius ver Weiden for King Erik XIV. W. Deines reports shortly on the cutting of diamonds and precious stones and in another article gives a concise glossary of the most important gem species. This part of the brochure is most effectively illustrated by two colour plates by W. Wild. B. Tillberg devotes a few pages to precious stones in history and literature. Other articles deal

with folklore, famous diamonds and modern jewellery. This booklet is extremely well laid out, very pleasing in appearance and therefore should appeal not only to the gemmologist, but also to the connoisseur and potential buyer. W.S.

GRINSTEAD (L. R.) and DAKE (H. C.). *Methods of collecting specimens.* Mineralogist (Oregon), June/August, 1954, pp. 227 - 248.

A short account dealing with various ways of collecting specimens. S.P.

HALPERN (J. M.). *Arctic jade.* Rocks and Minerals, N.Y., 1953, Vol. 28, pp. 237 - 242, 1 fig., 1 map.

A short account of jade (nephrite and jadeite) occurring in the Arctic regions of Alaska and Canada. Occurrence is mainly in boulder form and there is a good deposit in Alaska, in the river Shungnak area. The article includes information on the use of jade by the Esquimo during several centuries. S.P.

FRONDEL (CLIFFORD). *Commercial synthesis of star sapphires and star rubies.* Trans. Amer. Inst. Mining Metall. Eng., 1954 (Jan.), pp. 78 - 80, 4 figs.

Short notes on the production of star stones. By the use of the Verneuil process boules are produced with the addition of ·06 - 2% Titanium to form a solid solution in Al_2O_3 at about 2000°C. Strain is removed by annealing at about 1900°C. and a solution of TiO_2 is caused by heating in an oxidizing atmosphere at 1100 - 1500°C. The rutile needles are perpendicular to the *c*-axis of the crystal. For sapphire ferric iron (0·3%) and for ruby chromium (1·4%), are added. S.P.

BOOK REVIEWS

SCHLOSSMACHER (PROF. DR. K.). *Edelsteine und Perlen.* Schweizerbart'sche Verlagsbuchhandlung, Stuttgart, 1954. pp. 280, illustrated.

More than thirty years have passed since Prof. Schlossmacher successfully completed the tremendous task of revising Bauer's great " Edelsteinkunde "—the first edition of which was translated into English by Dr. L. J. Spencer and is now a collector's item. Had the war not intervened it is possible that another new edition of " Bauer-Schlossmacher " would have appeared or be in preparation, but unfortunately present-day conditions and costs do not make so ambitious a work a practicable venture on the part of the publisher.

Schlossmacher's new book, *Edelsteine und Perlen,* is intended by the author to act in some measure as a small substitute for a revised version of the " Edelsteinkunde." He describes it as " ein Buch der Mitte "—a book, that is, not intended for the pure scientist on the one hand nor for those who read only illustrated papers on the other, but for the intelligent jeweller, dealer, or lapidary, and for the interested amateur of gems.

In this the author succeeds very well, the book being readable as well as informative. The opening sections on gemstones as minerals, the nature of their occurrence in the rocks, and their chemical compositions, are excellently done. After that, the book seems for a while curiously empty and lacking in " meat." This is partly because the author is afraid of giving too much detailed information of the sort one is accustomed to find in the average text-book, on crystal form, physical and optical properties, and the methods of measuring these.

But when one passes on to the descriptions of individual gem species which occupy some 60 per cent of the book it begins to come to life, and one finds that a surprising amount of information has been packed in under the smooth unbroken surface of the prose. Careful reading, indeed, reveals much matter which will be useful even to the advanced gemmologist. The description of inclusions found in corundum and beryl from the different localities, for instance, is unusually good and detailed. It is a pity that only one plate containing six photomicrographs is shown to supplement these descriptions. The author is a good photographer, and it

would have been worth while to include several more such black-and-white plates rather than to go to the expense of preparing the two coloured plates of rough and cut stones, which are poor in quality and unlikely even to help in selling the book (which is, one suspects, sometimes the raison-d'être of such plates) since they are tucked away at the extreme end of the volume.

The book makes no attempt to be comprehensive. Fourteen of the non-commercial gemstones are described in a brief section (there are no numbered chapters) at the close of which 45 undescribed species are listed in alphabetical order. Several of these rejected gems might, one feels, have been allowed a description in preference to some of the favoured fourteen. The reviewer, for instance, would consider diopside, kornerupine, phenakite, sinhalite and sphene more worthy of inclusion than (natural) rutile, kyanite, dioptase, epidote and chrysocolla. But such a choice must of course be coloured by local trade conditions and sources of supply.

For those who wish to know the constants of these and other stones there are tables at the end of the book giving the refractive indices, density, and hardness of practically all the materials cut as gems. Surprisingly, these tables are taken (with acknowledgement) en bloc from R. T. Liddicoat's " Handbook of Gem Identification." One would have expected that a man of Prof. Schlossmacher's experience and opportunities would have been able to provide figures derived from his own experience. Liddicoat's values, as one would hope, are for the most part very well chosen ; but 2.99 would have been a better density figure than 2.94 for brazilianite and 3.34 instead of 3.40 for peridot. Since the density of pure corundum and for pure quartz have been well established at 3.99 and 2.65 respectively, these also might have been correctly given.

The refractive indices of yellow or pink topaz, which are practically the only types used in jewellery, are 1.630 and 1.638 for the lowest and highest rays, and it would have been better to quote these in the table than the figures 1.619 and 1.627, which are the arithmetic mean between these and the lower figures found in colourless types, and are seldom found in any individual stone.

As the title of the book suggests, there is quite a long section on pearl and cultured pearl, and on the chief methods for distinguishing between them. The book concludes with rather brief accounts

of synthetic and imitation stones, and a description of cutting styles and methods.

The book is pleasantly bound and clearly printed on good paper : as already stated, it contains much useful information, but this is rather difficult to find. In a work which is so poorly sign-posted in the matter of chapters and sub-headings, a fuller index would have been helpful to the reader who wishes to use it for reference and not for bedside reading.

B. W. A.

BARTLETT (NORMAN). *The Pearl Seekers.* Andrew Melrose, London. pp. 312, illus. 15, and end-paper maps.

An authentic story of the Australasian pearling industry told as the result of investigating present and past conditions. The book is full of tales of the adventures of many of the early pearl fishers, and its appeal to the gemmologist who is seeking new information about the pearl itself is somewhat limited. The author vividly describes a typical day of pearl seeking and emphasizes the hard work and anxieties connected with the industry. He also discusses the economical and labour problems that confront the Australian fishers to-day, including that of making satisfactory arrangements with the Japanese over fishing rights.

Four types of shell maintain Australia's shelling industry : *Pinctada maxima, Pinctada margaritifera, Pinctada radiata* and a non-pearl-bearing *Trochus* (*Rochia*) *Nilotious*, which is used for poorer-quality buttons. The better pearls are found in *P. maxima*, which inhabits deeper and therefore more difficult-to-fish water. Maturity of the oyster is at two years and it may live until it is ten years old. *P. margaritifera* lives in shallower waters. It is the shell of the oysters, rather than the pearls that they may produce, that is the important part of the industry.

The Australians are interested in pearl culture in the Torres Straits area, but the author states that the Japanese are producing glass beads coated with iridescent essence at a value almost equal to the export trade in cultured pearls and they claim that " only experts can distinguish these pearls from real or cultured pearls." This new trend has apparently dislodged K. Mikimoto from his hitherto unchallenged eminence in the pearl industry.

Mr. Bartlett's book is most readable and, although it is filled with drama and adventure, it is undoubtedly a gemmologist's

divertissement and should take its place on the bookshelves along with Murphy's " They Struck Opal," Rosenthal's " Here are Diamonds," and Rainier's " Green Fire."

S.P.

TERTSCH (H.). *Die stereographische Projektion in der Kristallkunde.* Wiesbaden (Verlag für angewandte Wissenschaften) 1954. iv + 122 pp., 71 figs.

The stereographic projection is an indispensible aid in the detailed study of crystals, both for crystallographic computations and in the treatment of the physical properties. This detailed little treatise is reproduced from typewritten copy by a photolithographic process which has successfully reproduced some very complicated diagrams, though a larger scale might have been chosen with advantage. Little is said of the history of the projection ; after brief mention of earlier works the author provides a very detailed explanation of the construction and application of the S.P. under chapter headings : I.—Elements and chief properties of the S.P. (10 pp.). II.—Basic properties of the S.P. (14 pp.). III.—Graphical crystal computations by the S.P. (34 pp.). IV.—Crystal drawing by means of the S.P. (44 pp.). V.—Application of the S.P. in crystallographical research (13 pp.).

The first chapters give very full details of the constructions so widely used in crystallography. The last discusses the use of S.P. in crystal optics, recognition of the crystal system, computation of extinction angles, axial angles, and universal stage procedures (in a very brief outline with references to Berek, Reinhard, etc.).

A.F.H.

ASSOCIATION NOTICES

COUNCIL MEETING

A meeting of the Council of the Association was held at 19/25 Gutter Lane, London, E.C.2, on Wednesday, 26th May, 1954, at 4.30 p.m. Mr. F. H. Knowles-Brown presided.

The following were elected to membership :—

FELLOWSHIP : Laurence F. Dunne. Northampton (D.1929).

PROBATIONARY : Bernard R. Worth. Leicester.

ORDINARY : Dennis Bradshaw. London.
Alexander M. Ramsay. Glasgow.
Howard M. Vaughan. Ross-on-Wye.
Richard D. Buttermore. U.S.A.

The Council received details of the plan of the major trade organizations occupying offices in 19/25 Gutter Lane to move to other offices during 1955, and they accepted proposals of the National Association of Goldsmiths concerning accommodation for the Association.

A matter discussed at length by the Council was the varying and often disappointing standard of education of some of the students attending gemmological classes. In some cases it was felt that the student attended because his employer had told him to and that a reason for a promising student suddenly to become disappointing was concerned with deferment of National Service. As the classes in gemmology came under the jurisdiction of local education authorities the matter could not be dealt with by the Association.

Arrangements were made for the presentation of awards gained in the 1954 examinations to be held on 20th October.

The Council also heard of the bequest to the Association of the collection of gemstones of the late Mrs. Rose Meisl, F.G.A. It was her wish that the Association should have her collection and the Council, in recording their deep gratitude for the gift, decided to maintain the stones as the "Rose Meisl Collection" and use them for educational work.

TALKS BY MEMBERS

Penn, L. : "Pearls." Birmingham Microscopical Society, 6th January.

Blythe, G. : "Gemstones." Young Wives Group, Thorpe Bay, 11th February : Southend Inner Wheel, 5th April.

Leak, F. E. : "The science of jewellery." Knowle West Contact Club, 23rd February ; Bristol International Club, 10th March ; Westbury Park Townswomen's Club, Bristol, 13th April.

McKenzie, I. : " Identification of gems." W. of Scotland Branch of the British Horological Institute, Glasgow, 24th February.

Anderson, B. W. : " Gem testing without instruments." Bristol and West of England Jewellers' Association, 8th April.

Warren, Kathleen : " Gemstones." Orpington Young Conservatives, 26th April.

Webster, R. : " Precious Stones." Hillingdon Young Conservatives, Uxbridge, 13th May.

OVERSEAS VISITOR

In April the Association received a visit from Barnett C. Helzberg, Chairman of the Board of Directors of the Diamond Council of America. He is also a member of the Council of the American National Retail Jewellers' Association and the Jewellery Industry Council.

NATURAL HISTORY MUSEUM

The staff of the Mineral Department of the British Museum (Natural History) will be giving talks in the Mineral Gallery of the Museum each Saturday, at 3.15 p.m. Some of the talks already given have included " Minerals and metals of the Ancients," " Gem minerals " and " Building stones," and members of the Association who are able to visit the Museum on a Saturday afternoon will find other talks of equal interest.

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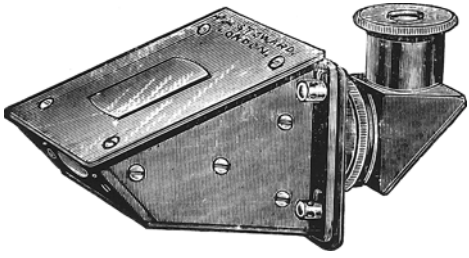

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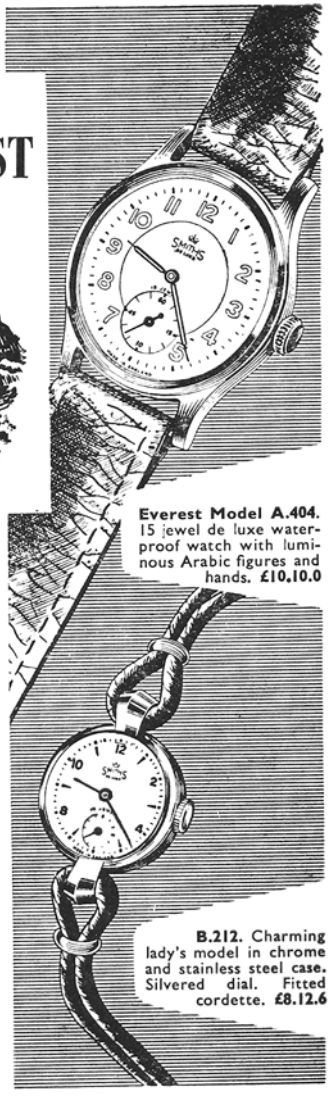

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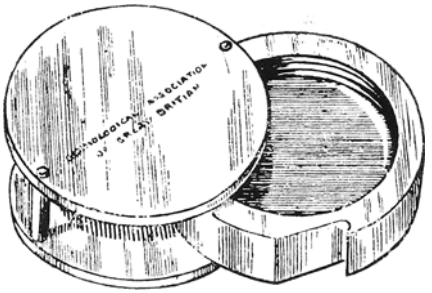

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THE JOURNAL OF GEMMOLOGY
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Vol. IV No. 8 OCTOBER 1954

SOME UNUSUAL STRUCTURES in PEARLS and CULTURED PEARLS

by ROBERT WEBSTER, F.G.A.

MODERN techniques employing the revealing eye of the X-ray beam have opened up a new era in pearl testing, and during the past decade many peculiar structures in pearls have been observed by X-ray photography, some of which may well be of interest to readers of the *Journal of Gemmology*.

It may be an advantage to preface these notes with a short explanation of the principles of direct X-radiography. Quite soon after Röntgen made his classic discovery of X-rays it was observed that the degree of transparency of a substance to the rays was, broadly speaking, in inverse ratio to the atomic density of the substance. Therefore, a body having a structure made up of different substances may show different intensities of shadow to the rays and thus so affects a photographic film, or a fluorescent screen, as to make the structures visible.

From the foregoing it will quite easily be understood that the bony structures of the animal frame will be readily revealed by the greater density of shadow given by the bones, containing the heavier atoms of calcium (atomic weight 40) and phosphorus (atomic weight 30), as against that of the flesh which is made up of the light atoms, carbon, nitrogen, oxygen and hydrogen (with atomic weights of 12, 14, 16, and 1 respectively). This is illustrated by the radiograph of part of a human hand. Fig. 1.

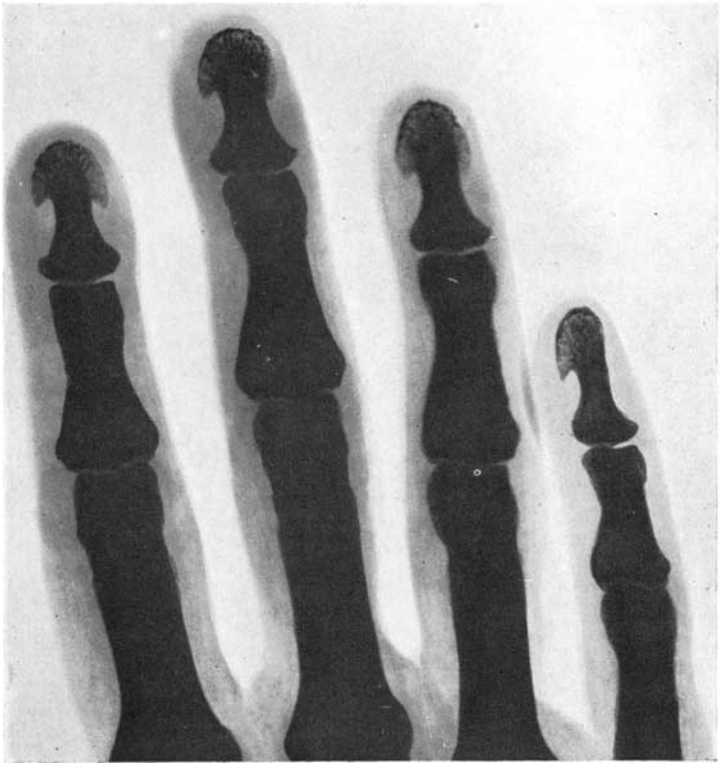

Fig. 1. *X-ray picture of a human hand showing the greater opacity of the bones to the rays than is the case with the flesh.*

The radiography of pearls is based upon the same principle of differential X-ray transparency, but owing to the very fine structures usually involved, special techniques are necessary. Gemmologists know that a genuine pearl consists of a mineral part, calcium carbonate ($CaCO_3$), usually in the form of pseudo-hexagonal twinned crystallites of aragonite arranged in concentric layers with their vertical axes radial to the centre, cemented with an organic substance called conchiolin. Therefore the analogy of bone and flesh again becomes evident. The conchiolin, however, need not be sufficiently concentrated to show up boldly like the picture of flesh and bone. It is much more likely to show up as fine line structures where the organic matter has been relatively more thickly deposited between the layers of the crystallites. The

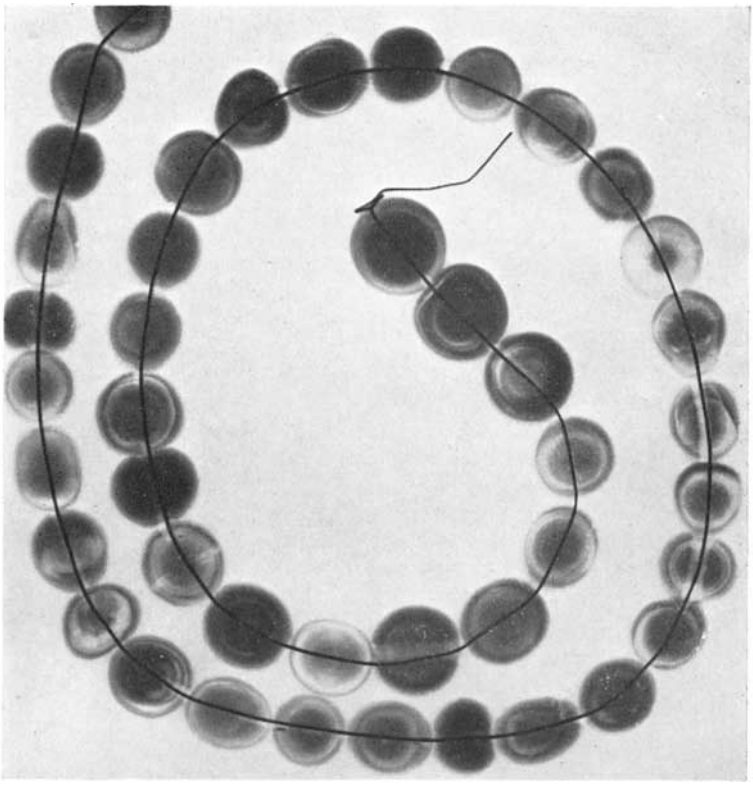

Fig. 2. Radiograph of a number of genuine pearls ; some of which show the " tree ring " effect.

X-ray picture may then show black lines as arcs or even complete circles, the latter producing a " tree-ring " effect. Most oriental pearls will show very little or nothing at all, although a conchiolin-rich centre is sometimes seen and indicates a natural pearl. Some of the structures seen in natural pearl are illustrated in Figure 2, which is a radiograph of some pearls showing much structure, an effect which is not often seen.

The finer structures seen in the X-ray photographs of genuine pearls rarely bear reproduction for illustrations. In every case of identification it is the film that is studied and even then must be examined closely in order to discern these fine structures which indicate the natural origin of the pearl. It must be mentioned at

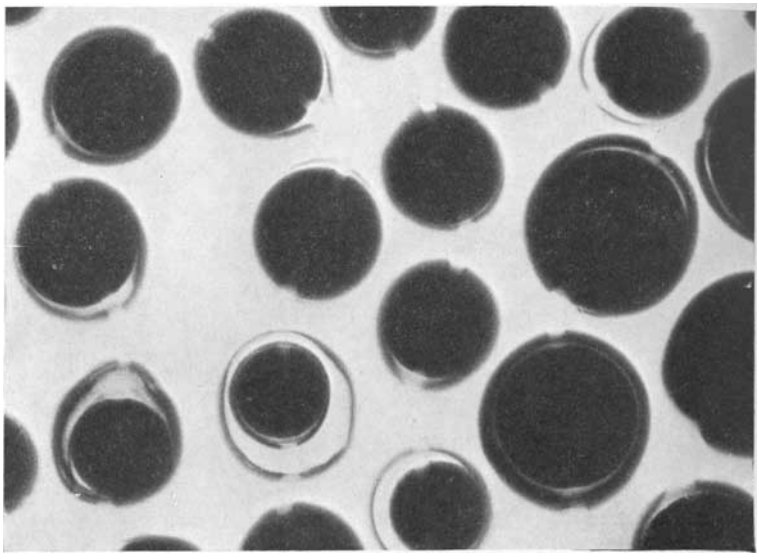

Fig. 3. Radiograph of cultured pearls showing the bead nucleus outlined by the conchiolin layer (white in this positive print but would show dark in the negative). One pearl appears to have had a cultured pearl used as nucleus.

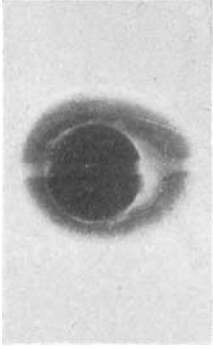

Fig. 4. Radiograph of a drop-shaped cultured pearl showing an excess of conchiolin at one end thus producing the pear shape, the bead nucleus being spherical.

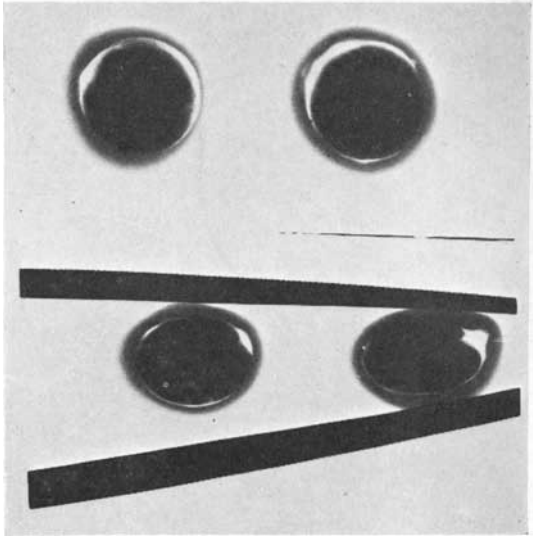

Fig. 5. Button-shaped cultured pearls with oval-shaped nuclei. Radiograph by Robert Crowningshield of New York.

this stage that all the illustrations are positive prints, and are also (except Figure 1) enlargements of the original film. Thus the white parts in the illustration will be black in the original negative—the blackening showing where the X-ray beam has been more easily able to penetrate. That is where the conchiolin patches lie.

In the case of cultured pearls with their relatively large mother-of-pearl nucleus, the bead centre often shows a slightly greater opacity to X-rays than the outer nacreous layer, and, further, shows no structure, except, when the position of the straight layers is parallel to the X-ray beam, when some differential absorption of the beam produces a weak but distinct banded appearance to the opacity of the bead nucleus.

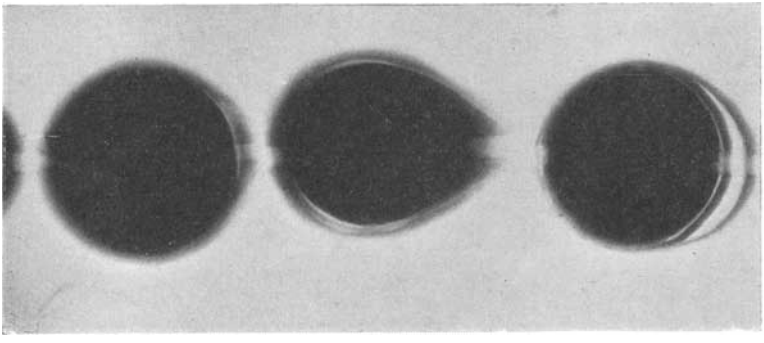

Fig. 6. A drop-shaped cultured pearl with a pear-shaped bead nucleus. The pearls on each side are normal cultured pearls with spherical beads.

What is usual in cultured pearls is to find that the bead is surrounded by a relatively thick layer of conchiolin. It is as though the oyster objected to the job of coating a large insertion and secreted conchiolin first and then completed the surface with pearly nacre. Figure 3 shows this effect well, but many cultured pearls show only a fine line encircling the bead—or sometimes the nature of the pearl may be seen only by the slight difference in the transradiability of the nucleus and the outer nacre. Often, especially with baroque pearls, the conchiolin deposit is considerable and irregularly arranged, an effect seen in some of the pearls shown in Figure 10. This is true also in the case of cultured drop-shaped pearls, which usually owe their shape to a patch of conchiolin producing the " pip " at one end (Figure 4).

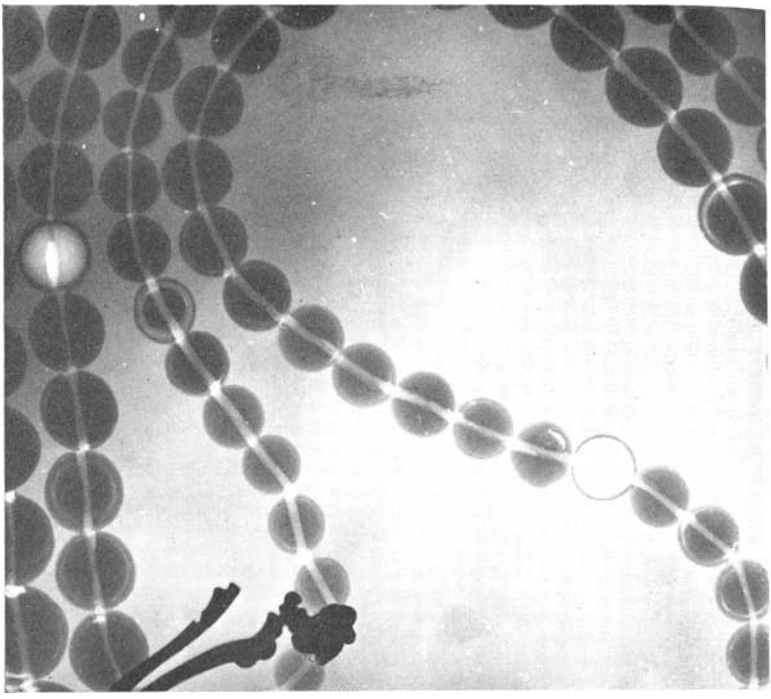

Fig. 7. The two cultured pearls with light coloured centres were found to have nuclei made of steatite (soapstone).

It is not, however, the intention here to discuss the techniques of pearl X-radiography, but merely to illustrate some of the more unusual structures met with in the course of routine testing.

In general the bead nucleus inserted into the Japanese pearl oyster (*Pinctada martensi*) is a spherical bead, but this need not be so, and some cultured pearls may show nuclei of different shapes. These are rare, for it is understood that the oyster does not take kindly to a nucleus of any shape other than spherical. It is said that nuclei of other shapes produce a greater mortality in the animals making the controlled production of pearls of other shapes than round to be less commercially practical, so that they are rarely used. That drop and button-shaped cultured pearls often occur adventitiously is well known, but these have round mother-of-pearl beads as cores and the resultant shape is due to vagaries of deposition of the conchiolin and nacre produced by the animal.

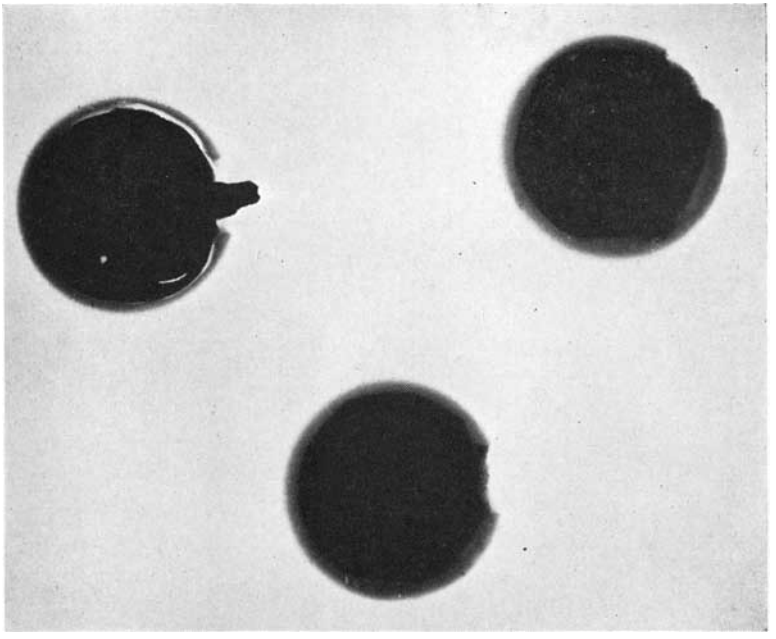

Fig. 8. Three cultured pearls which had their centres filled with cement.

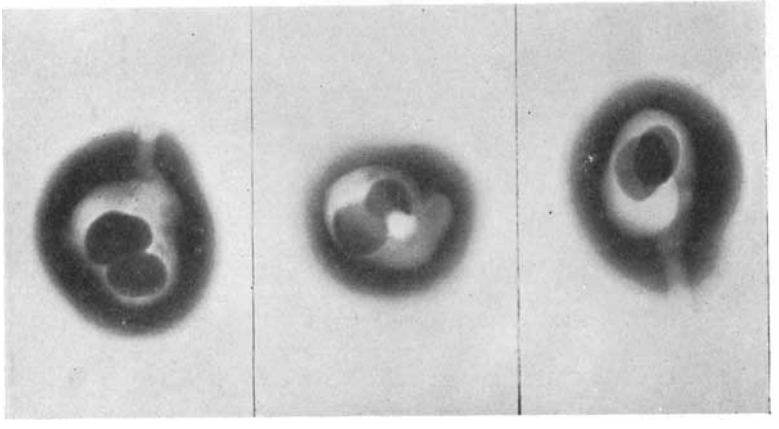

Fig. 9. A cultured pearl with "twin" nuclei. The pearl has been radiographed in three different directions.

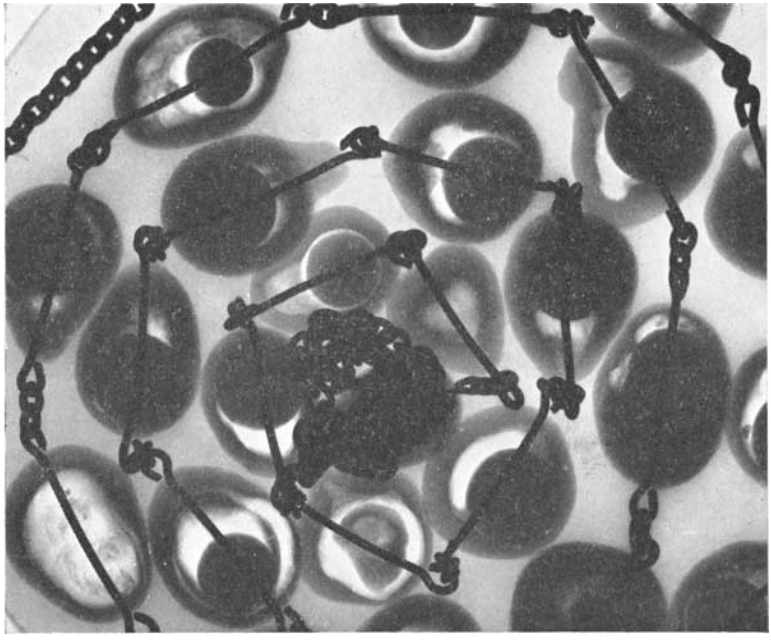

Fig. 10. *Radiograph of a very baroque necklet showing some pearls without nuclei. These pearls are probably from the fresh water pearl clam (Hyriopsis schlegeli) of Japan. The nucleated pearls may probably be also from the same animal.*

The writer has not happened upon an *oval* bead nucleus (used to produce button-shaped pearls) but is indebted to Mr. Robert Crowningshield of the Gem Trade Laboratory at New York for the illustration of a pair of such pearls (Figure 5). Mr. Crowningshield reports having met several pearls with such oval nuclei. Recently a case where the nucleus was pear-shaped was observed (Figure 6). Proof that this pearl was indeed a cultured pearl was made by the lauegram method. Laboratory records show that once before such a drop-shaped nucleus had been encountered, but in this case the direct picture did not show the outline at all well.

Several other cases of unusual nuclei in cultured pearls have been shown by direct X-radiography. Particularly interesting are the two pearls shown with white centres (black on the film) in the illustration of part of a cultured pearl necklet in Figure 7. As permission was given for these pearls to be removed and examined the nature of the nucleus could be determined. They were found

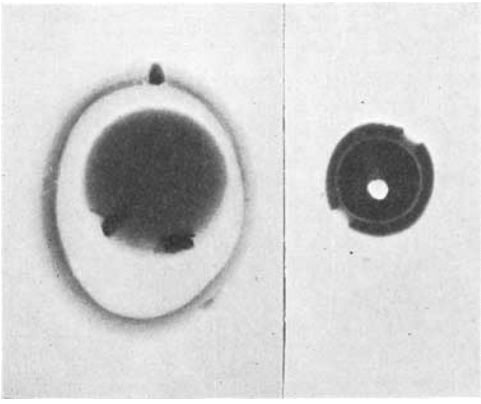

Fig. 11. *Cultured pearls in which the bead nucleus had become loose and had rotated.*

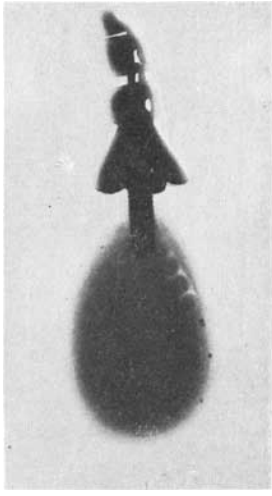

Fig. 12. *A genuine drop pearl with secondary drilling filled up with several seed pearls.*

to be banded steatite (soapstone). This effect has been seen since, a necklet subsequently tested showing a similar transparent-centred lone pearl. No opportunity was given to test this bead, which may even be one with a plastic core, it not being unreasonable to suppose that such a type of core could have been tried out experimentally.

Figure 8 shows three cultured pearls—at least they had nacreous skins—in which the inside was filled with some form of cement. Figure 9 shows three different views of a cultured pearl with irregular " twin " nuclei. The mate of this pearl was a perfectly good baroque cultured pearl with spherical nucleus.

The necklet illustrated in Figure 10 shows various types of baroque pearls including some without a nucleus. These latter pearls are thought to be some experimental non-nucleated pearls cultured from the freshwater pearl clam (*Hyriopsis schlegeli*) which lives at the south-eastern edge of the Biwa-Ko in Shiga Prefecture, Japan. The other pearls showing bead nuclei may also be from the same animal, for it is known that experiments with nucleated pearls were also carried out using the *Hyriopsis schlegeli*.

It is often noticed that the bead nucleus of a cultured pearl becomes loose and is able to rotate within the nacreous shell.

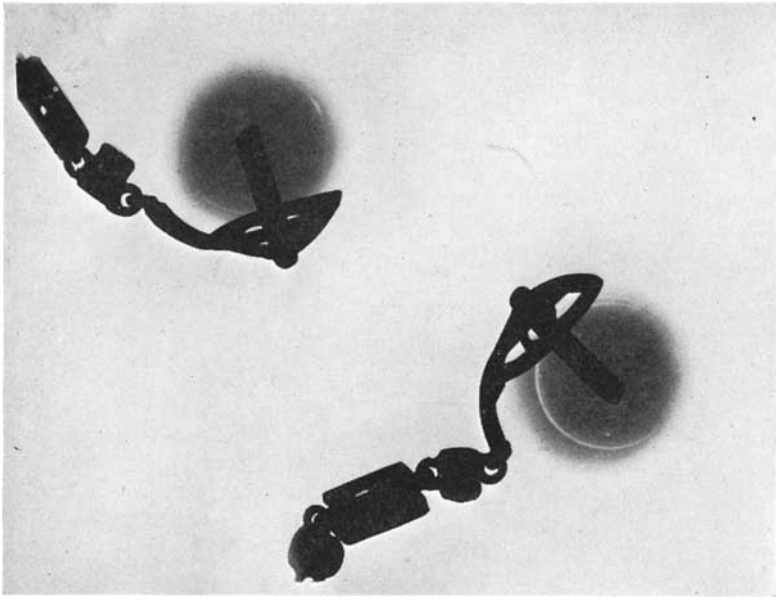

Fig. 13. One of this pair of pearls was seen to be clearly genuine from the negative. The other seemed to be just as clearly cultured. Both pearls were found to be natural by the lauegram method.

Figure 11 shows two examples of this effect, in one of which metal pins are evident.

Figure 12 shows a genuine drop-shaped pearl which has been "Chinese drilled," or drilled to relieve stress in a cracked pearl. In this case the secondary drilling has been filled up with four or five seed pearls.

Finally, reference must be made to the danger of direct X-radiography as a testing tool. The method requires experience in mastering the techniques necessary to produce a good negative, but considerably more in the interpretation of the negative itself. Figure 13 illustrates this point well, for on inspection of the negative it seemed clear that one of the pearls was genuine but that the other was cultured. The arcs and rings in the one pearl (much more clearly seen in the negative than in the positive reproduction) left no doubt as to its genuineness. The other pearl, however, showed only the one ring and there seemed little doubt that it was cultured. Lauegrams of the pearls, however, showed *both* to be natural pearls.

THREE GEMSTONES from BURMA

by B. W. ANDERSON, B.Sc., F.G.A., and C. J. PAYNE, B.Sc., F.G.A.

EARLY in May some unusual cut stones were submitted to the writers by Mr. A. D. C. Pain who has great interests in Burma. These stones all came from the well known stone tract at Mogok. The most impressive stone was a golden-orange sphene weighing 22·265 carats. A chip of this stone was first submitted which showed a small biaxial figure with great colour dispersion and very faintly the didymium lines in the yellow of the spectrum; very large birefringence seen through the polished facet and a vague reading on the refractometer at 1·91 all went to prove it to be a sphene. The large stone showed the didymium lines more strongly, and is the largest cut sphene ever seen in the Laboratory and very much larger than anything from the usual source in the Alps. It is unfortunately too full of vague lines and other inclusions of a powdery nature, which detract a little from the brilliance expected in a sphene. However, for sheer size it is a most remarkable stone. The density of the chip was 3·542 and the density of the large stone was identical.

Another unusual stone was a deep violet scapolite, weighing 4·083 carats. This stone had the following properties : ω 1·5487 ε 1·5398 ω—ε 0·0089 *d* 2·602. Pink and white scapolites were known from Mogok but this was an unusual colour. All Mogok scapolites are low type. Scapolite is the name for a series of silicates somewhat comparable to the plagioclase feldspars. They are tetragonal crystals of a lower class having only a horizontal plane and 4-fold axis of symmetry, their compositions vary from marialite $Na_4Cl\ Si_9\ Al_3\ O_{24}$ through dipyre and mizzonite to meionite $Ca_4\ CO_3\ Si_6\ Al_6\ O_{24}$, marialite and meionite being the end members of the series. The crystals are of course uniaxial and negative. This deep violet stone is on the borderline between marialite and dipyre, with about 80 per cent. marialite and 20 per cent. meionite. Most Burma stones that the writers have seen were of dipyre type.

The last stone was a grey blue star spinel of 18·24 cts. with a density of 3·591. Star spinels are rare and this was an unusually large specimen. The nature of the asterism is similar to that in the better known cubic mineral almandine garnet, alternating 4-ray and 6-ray stars all round the stone.

JADE STORY—EUROPEAN

by ELSIE RUFF, F.G.A.

TO begin an investigation of jade by writing of the ant seems irrelevant. Yet it is related to the subject in that it leads us to what might be called *The birth of the tool.* Maurice Maeterlinck's famous *Life of the Ant* contains a description of the Weaver ant's method of building a nest. The author sums up :

" Here, then, we have the first example, in the animal world, of the employment of a tool. We shall find no other example among the insects, nor even among the mammals, which occupy the highest positions in the hierarchy of living creatures. It is true that an ape has sometimes been seen to make use of a stick in order to rake in a banana or a nut which was not within reach of his hand ; but the action seems so precarious and uncertain, and inspired by such incoherent and fortuitous impulses, that it cannot be compared with the deliberate use of the distaff and shuttle."

Fossil amber from the Baltic area has provided abundant material for a study of ant life, in a period when the ant was already " civilized." This means, as Maeterlinck points out, that they existed in the Oligocene and the Miocene periods (20–35 million years ago and 1–20 million years ago respectively), long before the appearance of man. It was not till Pliocene times, approximately a million years ago, that we find man with crude flint implements. And many thousands of years elapsed before he used jade as his tool. There is no indication that jade was used for any other reason before this. Furthermore, it is quite evident that this jade implement was the highest achievement in Stone Age tools. It was the tool of experiment and experience. For efficiency it was second to none.

No wonder man valued early jade. Men are still proud of their tools, often to the point of veneration. In the Stone Ages a fine tool must have meant even more to individual man. For one reason, it could not be reproduced quickly. Time added to its preciousness, physical and psychological. Without it man could not live and remain *man*—evolving. Is it any wonder, therefore, that with the beginning of religious theories and superstitions specially fine jade implements were reserved for ceremonial occasions and became significant in various ways ? Sir James

Frazer (*The Golden Bough*) felt there were strong grounds for thinking that, in the evolution of thought, magic preceded religion. Certainly one can agree with him that precious stones were used as amulets long before they were worn as mere ornaments.

We find jade tools in Europe as early as 23,000 B.C. Swiss Lake Dwellers have left us ample evidence in beautifully finished artifacts. A lake community, built on piles, with a drawbridge that could be lifted at will, gives one a clear picture of early dwellers anxious about physical security. Pile dwellers are still extant, in various parts of the world, though the need for this type of protection has long since vanished. Early Swiss settlements were the dwellings of people using stone, bone and wood for their implements. Later communities added bronze. And, still later, iron.

Nor were these settlements isolated. The Lake of Neuchâtel accounted for fifty. Lake Constance for more than thirty. We may read that the settlement of Morges, in the Lake of Geneva, was exposed to view during the drought of 1921. Sutz, one of the largest settlements in the Lake of Bienne, extended to more than six acres, and its bridge, connecting with the shore, was nearly one hundred yards long and more than forty feet wide. From Lake Constance alone a thousand jade implements have been recorded, the station of Maurach having supplied nearly five hundred—not to mention chips and sawn fragments that inevitably surround the neolithic workshop.

We are entitled to believe that the period of man's use of jade in neolithic Europe was a long and well developed one. It was a period covering something like 20,000 years. Dr. Sydney H. Ball (*Roman Book on Precious Stones*) recorded that, in north-west Italy, neolithic people were using axes of both jadeite and nephrite as late as 2500 to 1500 B.C. and that Pliny's *Ceraunia* must have included just such axes.

In modern times, these jade implements first came to light during the 19th century and this led, naturally, to a great deal of speculation regarding their mineral origin. Many then believed that this jade came from the East, that is, China or perhaps Burma. It was suggested that a gradual emigration, involving generations, took place somewhere in the East, where jade was commonly used, and that some of these jade possessions accompanied the migratory people. (A similar theory was advanced regarding the migration

of the Maoris to New Zealand, though in this instance not to account for the presence of jade in the country).

In Dr. Keller's *Lake Dwellings of Switzerland*, published in English during 1878, we may read, on page 451 :

" Several nephrites and jadeites, one of which is in the shape of a long chisel four inches in length, were found in the Settlement of Gerlafinger (or Gérofin) in the Lake of Bienne. According to Professor Fischer of Freiburg (Baden) the density is 3.01. It is the most important of all the specimens of nephrite yet found in our lake dwellings, in fact its beautiful greenish-blue tint, with scattered reddish-yellow spots, make it look very like the Siberian nephrite of Bantongol. Professor Fischer has a fragment which was brought direct from that country. Now, the fact that the isolated block of nephrite found at Schwernsal, in the early part of this century, is perfectly identical with the nephrite of Siberia, may possibly furnish us with some data to the route which was followed by the first inhabitants of this country."

Others who studied the question believed that sooner or later a European locality would come to light. Since two occurrences of nephrite were later discovered, this theory has proved partially correct. Yet the source of jadeite remains a mystery. In a footnote to the volume quoted above (p. 61) Professor von Fellenburg, reading a paper at Bern in 1865, said : " . . . the question yet to be decided is, whether the nephrite found in our lake dwellings may not also have been of Swiss origin, like the celts more commonly found with it, made of serpentine and siliceous schist, for the serpentine and chloritic schist which occur in New Zealand nephrite districts, are found also in Switzerland . . . and very possibly also may show segregations of nephrite."

Nor were these jade implements confined to Switzerland and northern Italy. They have been discovered all over Europe, in particular Brittany. A very interesting paper, part of which follows, appeared in the Journal of the Anthropological Institute during 1930 (Vol. 60). It was entitled " On the use of Greenstone (Jadeite, Callais, etc.) in the megalithic culture of Brittany," by C. Daryll Forde : " In Spain and Portugal the megalith builders made extensive use of various green stones as a material for polished stone axes and necklace beads. North of the Iberian peninsula these elements of material culture thin out. In parts of the peninsula of Brittany, however, green stone beads and axes are again

abundant. They are found especially in a dense megalithic concentration which rivals Iberia in the magnificence of its tombs. Green stone axes, generally said to be of jadeite, have been found occasionally in the megalithic areas of France, in the Massif Central, in the Western Pyrenees and the tombs of the Marne. But they are reported in far greater number from the Breton peninsula. . . . The Breton green stone axes are often distinct both in form and size from the numerous tools of fibrolite and other substances which were in daily use among the megalithic builders. They are frequently bored with great care for suspension by a thong, and were sometimes deliberately broken when placed in the tombs. They show no sign of use as implements. These qualities justify us in regarding them as special productions for use in tomb ritual, and I shall therefore refer to them as ceremonial axes. . . . Ring discs of jadeite and other stones are associated with the ceremonial axes. . . . Damour examined specimens of Breton and other 'jadeite' axes. Of the French axes he says : 'We must regard the material of the axes as very rarely of an absolute purity. In many of the specimens it constitutes not a single species, but rather a mixture of various elements in which jadeite would appear to enter in a varying proportion. The mixed substance may belong to the minerals of the epidote group, or to the isomorphic pyroxenes of jadeite of approximately the same density' . . . The greater number of the Breton axes that have been mineralogically examined are of jadeite or its variety chloromelanite. . . . Occasionally axes of true jade (nephrite) are also claimed. . . . Green stones, generally identified as jadeite, were also used in the early cultures of Northern and Central Italy. They are frequent in the 'neolithic' caves of Liguria . . . it is clear that in Italy, as in Western Europe, the early civilized communities were expert practical mineralogists. The jadeite and the chloromelanite of the axes of North Italy are almost certainly of local raw material, for Franchi was able to show that the jadeite pebbles, long known in Piedmont, were derived from outcrops to be found, *in situ*, in the Ligurian Appennines and parts of Western Switzerland. . . ." In 1879 Dr. Heinrich Schliemann was unearthing the old walled city of Hissarlik and there thirteen nephrite implements—one white—varying in specific gravity from 2.91 to 2.99 came to light.[1] Professor Maskelyne, to whom

1. It is interesting to note that in his *Ilios, City and Country of the Trojans*, Dr. Schliemann, along with others of this period, refers always to jadeite and jade (nephrite).

Dr. Schliemann applied for these determinations, wrote that, among the thirteen Hissarlik jade implements, " . . . is the first . . . I have seen of true white jade as the material of a stone implement, and that too in association with the regular green jade."

Since Professor Maskelyne's remarks are so interesting, it seems right to quote him further, and at some length. " The presence of white jade," he goes on, " is interesting as pointing to the locality whence it came ; its association with its green brother is interesting as helping to confirm this indication. In fact, it is a very great probability that the Kuen-lun mountains produced the mineral of which these implements are made, and that they came from Khotan by the process of primeval barter, that must have nursed a trade capable of moving onwards over the ' roof of the world ' perhaps, or less probably by Cashmere, Afghanistan, and Persia, into the heart of Europe. If the Pamir and the Hindoo Kush was the route, this primitive stream of commerce may have flowed along the course of the Oxus before that great artery of carrying power had become diverted by the geological upheaval of Northern Persia from its old course to the Caspian. I have always wondered why jade ceased to be a prized material and an article of commerce as soon as civilization laid hold of our race. The Assyrians and the Egyptians hardly, if the latter at all, knew jade. Yet jade implements have been dug up in Mesopotamia of primeval type, and the commerce that transported these implements in far distant times bore them as far as Brittany. The Assyrians and the Egyptians, like all other peoples, have valued green stones. Green jasper and Amazon stone, and even Plasma, were known and appreciated ; why not then jade also ? My answer would be, that they could not get it. Unlike the Chinese, who have always kept it in honour because they have it at their gate, the Mesopotamian and Egyptian artists did not know jade, or only knew it as coming accidentally to hand, perhaps as a material of a prehistoric weapon. We need to know more than we do of the prehistoric movements of the human race, to be able to say whether the region of the Pamir and of Eastern Turkestan was once more densely peopled, was in fact more habitable, than to-day is the case ; but I am strongly inclined to believe that a geological change is at the bottom of the disappearance of jade from among the valued materials of the archaic, the ancient, and the medieval ages, down to within three hundred or four hundred years of this time. If

the upheaval of the regions, along which this commerce flowed, has rendered them less habitable, has planted deserts where once men dwelt with flocks, has made regions of ice where once winter was endurable — has, finally, diverted from its course a great river, that bore a commerce or at least fertilized the route of a commerce — there may be an explanation of the drying up of the stream of that commerce itself.

The Hissarlik locality for such an interesting find of so many and such beautiful jade implements has an interest also in this, that the geographical importance of the Hellespont, as the Bridge from Asia to Europe, seems to have brought to that spot the opportunity of selection and an abundance of material. I am writing to you perhaps some dreams more dreamy, you will think, than any of the dreams I wrote of in my first page. At any rate, while you are giving realistic life to the ancient tale of Troy, strive to do something, too, for this more venerable witness to the brotherhood and the intercommunication of the human race in the age rather of Kronos than of Zeus. Was it the jade-stone that Kronos swallowed?"

The author himself now writes : " Professor Fischer is amazed at hearing that among my thirteen Hissarlik jade axes there is a white one, for he had as yet only seen axes of green jade ; he knows rare white jade abundantly from Turkestan (at least, yellowish, greyish, and greenish white), besides perfectly white from China ; but no trace of axes was discovered by the travellers of his acquaintance who explored the jade quarries of Turkestan. (Footnote : This white jade axe . . . was found at a depth of 6½ feet below the surface, and must therefore belong to the latest prehistoric city of Hissarlik ; for in the subsequent settlement, which from the pottery I hold to be an ancient Lydian one, I never found stone implements.) The Siberian jade has a bright grass-green colour ; the New Zealand jade for the most part a more dark green colour. There is besides a very dark green jade in Asia, which must be native somewhere in Asia (perhaps in Turkestan), and of which Timur's[1] tombstone in Samarkand is made. Professor Fischer received fragments of the latter from the late Professor Barbot de Marny of St. Petersburg, who knocked them off with his own hand in the mosque, of course at the danger of his life. Professor Fischer says in conclusion that my thirteen Hissarlik jade axes come from the farthest eastern

1. Commonly known as Tamerlane by many European travellers. Up to the 20th century the tomb was described as of *jasper*.

point at which polished jade axes have been found, and expresses the wish that before the end of his life the fortune might be allotted to him of finding out what people brought them to Europe."

Isolated finds of raw jade have been legion. One reported piece of unworked jade in Europe goes back to 1815. Later in the century, Professor A. Damour, who gave the name to jadeite, recorded a pebble or boulder and a piece of crude jadeite from Italy.

During the discussions of the last century it was pointed out that, in the early days of the Swiss Lake Dwellers, Europe was occupied by a race of Turanian[2] aborigines and that it remained for the Aryans to introduce iron and finally to dominate the older race. We have no idea what this early European called his jade. He probably said no more than " pass me the axe." What we do know is that the jade comprised two varieties, jadeite and nephrite. In other words, our jade of to-day.

It was hardly possible, in those early days, for jade to be substituted. No other substance yielded so fine an edge—little short of good steel—or proved so tough in use. If he did not know, through fashioning, that he was dealing with a substitute, early man would be quickly aware of it in use. There could be no compromise until his need was ceremonial or amuletic or ornamental, and even then, since jade, if available, was not exactly scarce, it is very unlikely. Again, the early cutter could hardly have been deceived.

The study of jade teaches us much about man. Indeed, it is linked with him. To study jade is to study man. Jade is, as Professor Maskelyne put it, a "venerable witness." This study has helped to establish that early man travelled much more than we once gave him credit for. He migrated more, probably for a variety of reasons. In fact, the history of man is the history of his migrations. To some extent, this accounts for the fact that jade implements, *par excellence*, were in use literally all over the world. Another theory must also be considered, nevertheless. (And it may be that both are correct.) Given similar circumstances and similar needs, man arrives at similar conclusions. Human thought travels along much the same groove. (One may experiment with this for oneself, remembering that it is not always easy to be sure one acts *originally*, for memory plays tricks).

2. An obscure term thought to be of great antiquity.

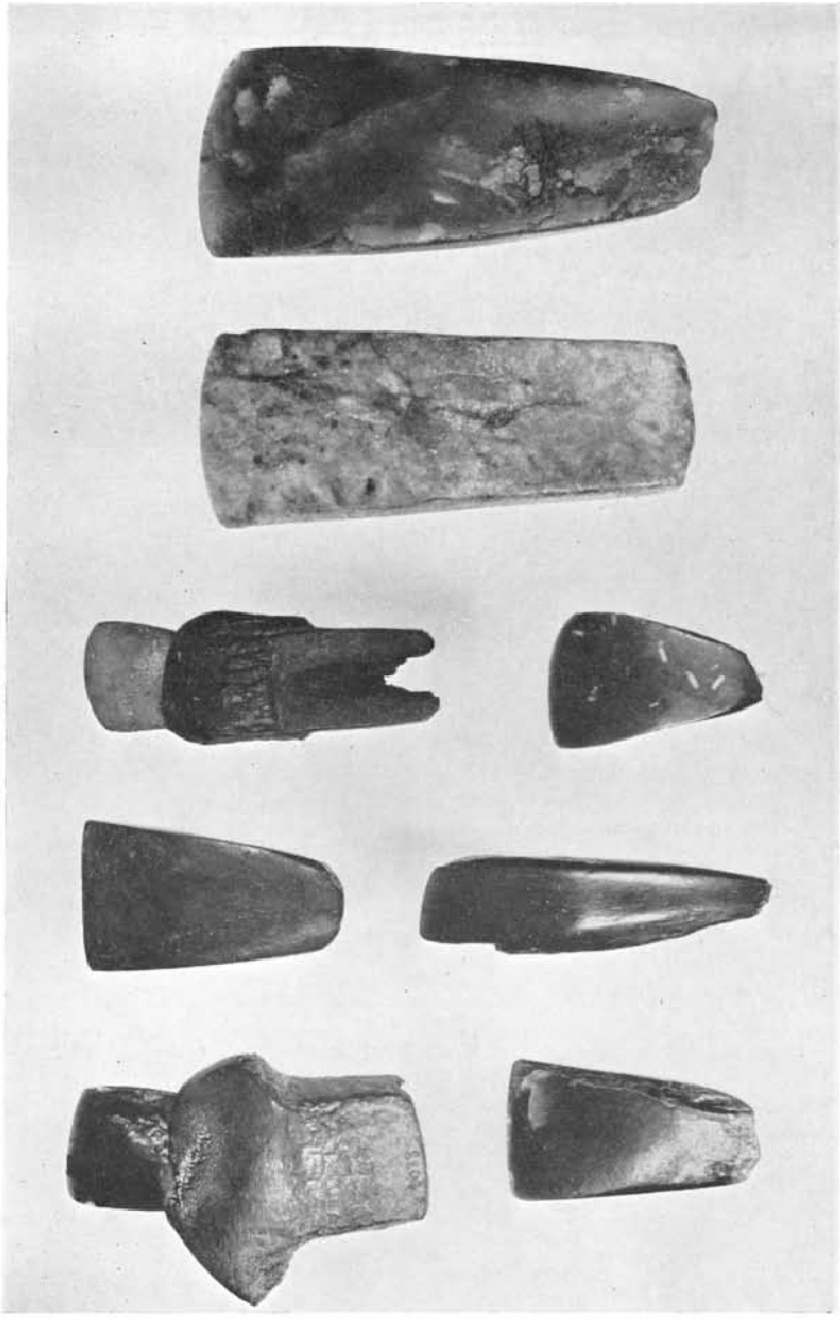

Photograph by courtesy of Swiss National Museum.

Apart from our knowledge that the Swiss Lake Dweller used jade—some of the hatchets were expertly fitted with horn handles comparable with our modern carving knives—and that he used, apparently indiscriminately, the two varieties, it has been shown that jadeite was much more prolific on some lakes while nephrite was prolific on others. Nephrite implements have been most commonly found in the lakes of East Switzerland, Lake Constance for example. Jadeite prevailed in the West—Neuchâtel and so on. In France, away from lake dwellings, jadeite predominated. Out of thirteen prehistoric implements tested from this country only one was of nephrite. These facts were established towards the end of the last century. Yet it did not mean that both types of jade were not often found together. During 1892 two small pebbles of nephrite from the Lake of Neuchâtel were tested for specific gravity, giving a reading of 3.02. Two more pebbles from the same shores gave specific gravity results as 3.42 and 3.36, and of these the following chemical compositions were published :

Specific Gravity			3.42	3.36
SiO_2	...	...	52.42	50.30
Al_2O_3	...	...	26.00	25.68
FeO	...	...	2.02	2.79
CaO	...	...	9.05	11.00
MgO	...	...	3.56	4.45
Fe_2O	...	...	7.44	6.30
H_2O	...	...	0.20	0.40
			100.69	100.92

Regardless of the term in use, whether by historians or contemporary gemmologists, our quest for jade would appear to stem from the jade of neolithic man, that is, man of the advanced Stone Age. And European neolithic jade is the oldest jade we know. The discovery of jade weapons and implements in the Cave of Mentone, and other such deposits of Western Europe, started off a series of enquiries in the last century that came to be known as *The Jade Question.*

The first recorded discovery of nephrite *in situ* was made by Hermann Traube of Breslau in 1884. Here in Silicia, Germany, near Jordansmühl, he came upon material he might easily have over-

looked, and which he first thought to be a hard serpentine. On chemical analysis it proved to be nephrite. In 1886 he found a further nephrite occurrence in the same country, this time at the well-known arsenical pyrites mines near Reichenstein. Later, in 1899, an American gemmologist, Dr. George F. Kunz, discovered, at Jordansmühl, one of the largest, if not the largest, boulders of nephrite yet to be quarried. It weighed 4718 pounds and is now in the American Museum of Natural History, New York City. Almost as satisfactory as the discovery of these occurrences was evidence that the deposits had been worked in prehistoric times.

It is interesting to read Max Bauer's account in his book *Edelsteinkunde*, published in Leipzig in 1896 and translated in 1904 by Dr. L. J. Spencer: " The occurrence of nephrite *in situ* in Germany, is limited to Silesia. . . . One of these (occurrences) is Jordansmühl in the Zobten mountains : here nephrite, usually of a dark green colour, forms a layer of considerable extent, and in places over a foot in thickness, between granulite and serpentine. The mineral occurs at the same place as rounded nodules, the largest of which measure 5 cm. across and in veins in the serpentine; the nephrite of which the axes found at Gnichwitz, two hours journey from Jordansmühl, are made, is very similar in character to the rough material found in the locality. The other locality in Silesia, at which nephrite is found, is Reichenstein, a famous mining centre. The material found here is compact, of a light greyish-green colour, sometimes tinged with red, and is indistinctly schistose ; it occurs in layers, the thickest of which are 7 cm. across, interlaced with a diopside-rock in the Prince adit."

Despite the enthusiasm that these occurrences developed, nothing further has come to light, and the jadeite of Europe is still a mystery. In the Journal of the Anthropological Institute of 1891, it was said that the missing factor in the jade problem was our ignorance—a statement applicable nevertheless to most studies—and that the last word had not yet been said on this subject. More than half a century has elapsed and we are no nearer a jadeite solution. Far from the last word having been said, we are still groping around to complete the first chapter of this story. And thousands of words on the subject of jade have appeared during the past five decades. Many occurrences of nephrite have been recorded in Scotland, not one of which has been established.

The favourite, involving the ancient little island of Iona, in the Hebrides, has been well publicized and definitely exploded. As far back as 1899, the following appeared in the Journal of the Anthropological Institute (Vol. XX) :

" Mr. Walhouse said that some years ago he noticed a letter in the *Times* in which the writer stated that, when visiting Iona, he had bought some pretty green pebbles from children who were offering them for sale on the beach, and some time after he had shown them to a Chinese gentleman of some learning, who pronounced them to be real jade. Mr. Walhouse said he had been to Iona himself some years before this letter in the *Times* and had bought some of these pebbles, two of which he produced. Mr. Rudler however pronounced them to be only serpentinous marble, or ophicalcite, a mixture of serpentine and limestone."

Mention has also been made of nephrite occurrences in Ireland though nothing that could give serious credence to this assertion has yet transpired. Some claims go back as far as the seventh century, when an Archbishop of Armagh is said to have had his mitre set with " three Gadde[1] stones of green mined in Tirone." That a neolithic people used jade in Ireland is by no means improbable. Lake Dwellings existed in that country and, to quote *Lake Dwellings in Switzerland* once more (page 493) : " . . . we believe the builders of the lake dwellings were a branch of the Celtic population of Switzerland, but that the earlier settlements belonged to the prehistoric period, and had already fallen into decay before the Celts took their place in the history of Europe."

Just as fossil amber has been invaluable in the study of ant life, so is it not without significance in the study of jade. Swiss Lake Dwellers traded in amber and this amber almost certainly came originally from as far away as the German coast. Assuming that the Silician nephrite occurrences were known in those days, the distance could hardly have presented great difficulty. We may learn that these early people were a " pastoral people, and possessed the most important animals, such as the dog, the cow, the sheep, the goat, and the horse. All these animals have their origin, not in Europe, but in Asia. . . ."

1. The term *Gadde* in 7th century Ireland must be discredited when applied to jade, as will be shown later.

2. Said to be the oldest existing Treatise on Stones.

Since Jordansmühl and Reichenstein have long remained just place names to the average gemmologist, the above map gives the position of these two small places — approximately 47 kilos apart — in relation to a large centre, viz. Breslau. Jordansmühl is about 31½ kilos from Breslau.
For this information we are indebted to Sir Charles Hardinge, Bart., who has made a study of the district from two sheets of an old and out-of-date German Ordnance Map.

In a fragmentary treatise *On Stones* that has come down to us, written by Theophrastus in 315 B.C.,[2] we are told that the Swiss Lake Dwellers and early peoples had solved the secret of striking fire with pyrites. The Reichenstein nephrite occurrence was discovered in the arsenical pyrites mines. If these ancient peoples obtained their pyrites from this mine, they almost certainly secured nephrite from the same source.

Gemmological Abstracts

SCHMIDT (PH.). *Jade—ein Edelstein in der Kultur der Jahrtausende. Jade—a gem in the culture of millenniums.* Zeitschr.d.Deutsch. Gesell.f.Edelsteinkunde, No. 8, 1954, pp. 11–15.

The archeologist Dr. Alberto Ruz Luhillier found in the grave of a Maya prince in the ruined city of Palenque on Tehuantepec inside a pyramid the skeleton of a middle-aged man. The head was covered with a jade diadem, and there were also jade ear-rings. The face was covered with a jade mask. Both hands held jade objects, which were also laying loosely about, especially small jade idols of the Maya sun god. During the whole history of man jade, especially nephrite because of its hardness, is of great importance. For a time it was assumed erroneously that prehistoric nephrite from Asia, specially China, was brought to Europe and the rest of the world. In 4000 and 5000 B.C. nephrite was used in Egypt for knives, saws, hammers, etc. Many of these prehistoric tools were found in other parts of the world, i.e. America, Australia and central Africa. In Europe these prehistoric articles made from nephrite were found in southern Italy, France, Austria, Switzerland and Germany. The material corresponds with European occurrences. To-day jade is found in Turkestan, Siberia, India, China and New Zealand. The Maoris use jade for ancestral masks. In Troja articles of gold, ivory, amber and nephrite were found. Although nephrite was used universally for arms and ornaments, it was valued most in China. In the seventh century B.C. " Yu " the gem of gems was described by Kvan-Yhung, the Chinese philosopher. The insignia of the Chinese emperors were jade and the emperors of the Tchou dynasty (122–249 B.C.) drank jade in water. Many jade articles were carved as symbols. Most precious stones were supposed to have some magical power in the antique, and nephrite was supposed to heal illnesses affecting the eye, stomach and especially the kidneys. It was also used as protection during child-birth. Even to-day jade is a talisman in Turkey against the " evil look," in India against lightning. It is worn as birthstone (Cancer) and as talisman by gamblers and racing motorists. Apart from its use as seals and ring stones,

New Zealand nephrite (green stone) is worked into amulets for the Maoris not only locally but on a bigger scale at Idar-Oberstein. The survey is a valuable historical account with many literary references. E.S.

BAMBAUER (H. U.), SCHMITT (K. H.). *Ein neues Lapis-Lazuli-farbiges synthetisches Produkt. A new lapis-lazuli coloured synthetic product.* Gold und Silber, No. 7/8, 1954, pp. 13–14. (See Journ. Gemmology, 1954, Vol. IV, No. 7, p. 281.)

Examination with the polarizing microscope of thin sections and powder specimens showed that the new Idar-Oberstein made material which appeared uniformly blue to the eye consisted of an aggregate of roundish grains which were optically isotropic and of a diameter of 0.07–0·6 mm. (0·003 to 0·024 inch). The nature of numerous apparently colourless roundish inclusions in the grains was not determined. The R.I. was $1{\cdot}716 \pm 0{\cdot}003$, the S.G. was $3{\cdot}58 \pm 0{\cdot}01$ (sic !) and the hardness around 8 Mohs' scale. The constants pointed to a spinel-like crystal compound. The material was soluble in pyrosulphate of potassium and the qualitative analysis had the following result :

Al_2O_3	...	79·52%
MgO	...	19·03%
CoO	...	1·53%
		100·08%

corresponding to a Mol. ratio of 0·63 MgO : 1·00 Al_2O_3, if the 1·53% CoO are added to the MgO. From these values a formula could be compounded as follows :

$$Mg_{1{\cdot}96}\ Co_{0{\cdot}09}\ Al_{6{\cdot}35}\ O_{12{\cdot}00}$$

If it was assumed that the material belonged to an isomorphous series the hypothetical end members of which were $3(MgO.Al_2O_3)$ and 4(Gamma Al_2O_3) (i.e. $Mg_3AL_6O_{12}$ and gamma Al_8O_{12}) ; it could be seen that the Mol. ratio $(R'''', R'')_{8{\cdot}40}O_{12{\cdot}00}$ pointed to a position of the material roughly in the centre of the series, but nearer the gamma Al_2O_3. The blue colour was caused by the presence of CoO. X-ray diffraction methods were used to determine the lattice constant a_0 $8{\cdot}042 \pm 0{\cdot}002$ Å. It could be shown in a diagram that this value fell on the straight line connecting the values for the end members of the isomorphous series, namely

a_0 8·09 Å for $Mg.Al_2O_3$ and a_0 7·88 Å for gamma Al_2O_3. The name given to the new material, i.e. " lapis-lazuli coloured synthetic spinel " is thus correctly chosen. W.S.

SALLER (X.). *Neuigkeiten vom Zuchtperlenmarket. News from the market in cultured pearls.* Zeitschr.d.Deutsch.Gesell.f.Edelsteinkunde, No. 8, 1954, pp. 4–6.

Newly imported pearls from Japan are most difficult to determine. Two grey baroque pearls were examined ; they were 10·5 × 9·5 mm. and weighed 8·93 cts. That they were cultured could perhaps be suspected from a small truncated conical protrusion, the top of which curved inwards in the manner of a crater and the surrounding of which was slightly pale. Also under the microscope, one could not find any definite indications. Cultured pearls usually adopt the shape of the piece which is inserted into the mollusc and covered by it. If this foreign body is round, the pearl will also be round, if irregular the pearl will be irregular or baroque. If the bead, however, is round and the pearl yet grows irregular, the reason remains obscure even if one cuts open the pearl. The two examined baroque pearls were abnormal. The reproduced X-ray radiography showed that they were cultured, The inserted round bead took up one-third only of the total volume and one-third only of the skin was attached to the nucleus. Two X-ray diffraction patterns taken at right angles to each other revealed the true nature without any doubt. When one pearl was opened it was found that the space between the skin and the bead was only partly filled with conchiolin. E.S.

SCHIEBEL (W.). *Farbskala für den Edelsteinhandel. Colour scale for the gem trade.* Zeitschr.d.Deutsch.Gesell.f.Edelsteinkun de No. 8, 1954, pp. 10–11.

The precise determination of the colour of a precious stone is most difficult, as there is no possibility of comparison in nature or technical and commercial literature. A suitable scale is wanted. In order to obtain a colour scale for himself the author obtained a series of synthetic stones of various shades. He points out that in other industries colour scales are existent, for instance in the paint and sugar industries. He suggests a scale made of glass specimens, each colour numbered, and distributed to all jewellers, workshops, factories, wholesalers and others. E.S.

ALTMANN (J. D.). *Spotlight on Australian Opals.* Lapidary Journ., Pt. 1, Vol. 8 (3), pp. 266–273.

A short account of the Australian opal fields and mining and business methods. There is a useful summary of definitions of opal and mining expressions. S.P.

RUTLAND (E. H.). *Vest-pocket polariscope.* Gemmologist, Vol. XXIII, No. 275, pp. 103–4. June, 1954.

Describes a small polariscope employing polaroid discs. It is no larger in size than a pocket loupe, and the design is based upon that of the usual folding magnifying glass. The stone is held in a " cell " which fits into the body of the instrument and is held firmly, but at the same time allowing rotation, by the pivoted top cover containing the upper polaroid disc. Instructions on how to use, and the use of, the polariscope are given, and some facts on the " extinctions " observed with doubly refractive stones and the anomalous effects seen in synthetic stones and pastes due to strain. 1 illus. R.W.

TRUMPER (L. C.). *Distinguishing kornerupine from enstatite.* Gemmologist, Vol. XXIII, No. 276, pp. 125–127. July, 1954.

A comparison of the properties of the two minerals named, with particular reference to the brownish-red enstatite reported upon earlier by R. K. Mitchell. (*Journ. Gemmology Abs., Vol. IV, No.* 5, *p.* 214). 1 illus. R.W.

WILD (G. O.). *Punched card system for gems.* Gemmologist, Vol. XXIII, No. 276, pp. 133–134. July, 1954.

Describes a system for the quick identification of gems from their observed characters ; i.e. refraction, colour, specific gravity, birefringence, dichroism, hardness, transparency, etc., by the " business efficiency " punched card system. For ordinary trade gemstones some 150 cards need to be prepared and some 300 needed to cover all gem materials. There is a slip in the illustration in that carbon tetrachloride is referred to as having an R.I. of 1·62 (CCl_4 has *n* 1·46). 1 illus. R.W.

CUSTERS (F. F. H.) ; DYER (H. B.). *Discrimination between natural blue diamonds and diamonds coloured blue artificially.* Gems and Gemology, Vol. VIII, No. 2, pp. 35–37. Summer, 1954.

Natural blue diamonds are found in few mines, the Premier mine of South Africa being the most important. Diamonds may

be artificially coloured by bombarding them with atomic particles either in or outside the atomic nucleus, which have been given high speeds ; e.g., neutrons from a nuclear reactor, protons and deuterons by cyclotron, and the electron most commonly by a Van de Graaf generator, which may also be used to accelerate protons and deuterons. High speed particles striking a diamond may eject atoms from the lattice site to an interstitial position. Such a displacement is known as radiation damage and can cause absorption of light by electronic transitions previously forbidden in the undamaged lattice. Pile-irradiated diamonds turn green and other colours have been reported after deuteron bombardment. Blue diamonds, nearly indistinguishable by eye from natural blue diamonds, have only a superficial colouration (depth of penetration of the electron is stated to be only 0·5 mm), but owing to reflection and refraction in a brilliant-cut stone this effect is not seen. All natural blue diamonds were found to be electrically conductive and this is considered to be the property of a special type of diamond classified as Type IIb. Blue diamonds owing their colour to bombardment are either Type I or Type IIa and are non-conductive. Simple conductivity experiments suggested as means of identification of artificially coloured blue diamonds. Type I diamonds are transparent down to 3000A only and Types IIa and IIb down to 2250A. Type IIa after " blueing " by bombardment then show clearly observable absorption at 2700A. It is suggested that a suitable filter which is selectively transparent at about 2700A, a photoelectric cell sensitive to that waveband, or a substance which will fluoresce in that range, may be suitable as detectors. It has been established that natural blue diamonds show a very strong absorption in the infra-red (from about 1 to 2 microns), whereas neither Type I nor Type IIa absorb appreciably in this part of the spectrum. It is suggested that a suitable filter in conjunction with a suitable infra-red detector might be used for distinction. All these devices are still in the laboratory stage but may admit of simplification for general use. R.W.

SINKANKAS (J.). *The gem and ornamental stone market of Hong Kong to-day.* Gems & Gemology, Vol. VIII, No. 2, pp. 47–53. Summer, 1954.

A survey of the present conditions in the jewellery and ornamental stone trade in the British Crown Colony of Hong Kong,

which is adjacent to Communist China. "Soochow jade" is a fine quality translucent serpentine. Two distinct classes of carved work are noticed—the old work of painstaking care and design, and the newer work of poor artistic merit but with slick finish. Some descriptions are given of the articles fashioned in the various quartz minerals, in amber, turquoise, serpentine, fluorite, beryl, lapis lazuli, tourmaline, malachite, corundum and some others. Jades are discussed and such discussion will be carried further in the next instalment.

R.W.

ANDERSON (B. W.) ; PAYNE (C. J.). *The spectroscope and its applications to gemmology.* Gemmologist, Vol. XXIII, Nos. 275/6/7, pp. 110–113 ; 119–123 ; 142–147. (Parts 10–11–12), June/July/August, 1954.

The series continues with a discussion on the colouring agents which are the cause of the colour in gem materials. The reason why some agents produce colours in some cases and not in others is said to be not properly understood. The elements with atomic numbers 22 to 29 (the so-called "transition elements") are the most common colouring agents. The position of the absorption bands of a given element varies considerably according to the species of the host mineral. Only in idiochromatic minerals can the absorption spectrum be said to characterize the entire species. A chromium spectrum may be said to betoken a mineral containing aluminium, and the didymium rare earth spectrum to be indicative of a calcium mineral. Titanium and nickel do not seem to produce definite absorption bands. The chromium spectrum in general is described. The brighter greens and reds seen in chromium-coloured minerals, as against the duller shades of the iron-coloured greens and reds, are ascribed to the fact that the absorption regions in the chrome-coloured minerals are sharply defined while those of iron are more diffused by weaker absorption over areas where general transmission occurs. The chromium absorption spectrum consists of broad absorption regions in the green and in the violet, and many fine lines in the orange and blue. Mention is made of the reason for these fine lines and there is a discussion on the reversibility of certain of these lines in the red part of the spectrum producing "fluorescence" lines. The stones showing Cr spectra are ruby, red spinel, pyrope garnet, alexandrite, emerald, topaz, jadeite,

nephrite, demantoid and uvarovite garnets, diopside, enstatite, euclase, kyanite, hiddenite, aventurine quartz, stained green chalcedony and glass. Part 11 (No. 276) gives the historical outline of the earlier work carried out on the chromium spectrum of ruby, and a full table is given of the lines seen in a ruby spectrum. There is a distinct difference between the absorption spectrum of extra-ordinary and ordinary rays in ruby, which is said to be most marked by the alteration in width of the broad absorption in the yellow-green. The absorption in the violet extends well into the near ultra-violet, followed by a further region of transparency to about 3000A in natural stones and not before 2700A in the synthetic ruby. The copper sulphate filter method is recommended for examination of the fluorescence lines. Part 12 (No. 277) details the absorption and fluorescence spectrum of red spinel. The spectrum of this gemstone does not show clearly lines in the blue, nor " hair lines " in the red. Identification is by a group of fluted or " organ pipe " fluorescence lines diminishing in strength from the centre outwards. Best observed by the copper sulphate filter placed before the strong light source. Distinction between the spectrum of red spinel and pyrope garnet mentioned. Reference is made to the absorption and fluorescence spectra of the rare synthetic red spinels. Some blue types of synthetic spinels (blue zircon and aquamarine colours) show a ruby-like fluorescence spectrum but with the main emission line some 20/30 angstroms below the corresponding line in ruby. 3 illus. R.W.

MEHTA (M. G.). *Diamond polishing in India.* Gemmologist, Vol. XXIII, No. 277, pp. 139–141. August, 1954.

A description of a Bombay diamond polishing works. Workers are all said to belong to the Patel tribe from Surat and Navasari to the north of Bombay. Only differences from the operations as performed in Western diamond polishing works are that the stones are bruted all over, which is said to leave much less work to be done by the crossworker, who also completes the brillianteering. The native workers sit " tailor-fashion " on the floor so that all work benches are low. Bruting is done in a different manner from recognized Western practice, the bruted stone being held in a vertical and stationary holder fixed to a pivoted bar controlled by a cross bar ; the other diamond being fixed to a wooden arm which may be swung across the stone to be bruted. The cast iron scaifes are

spun by electric motors, and are 14 ins. in diameter. The Indian polisher works from the inside to the outside of the scaife—the reverse way to that employed in Western countries. The diamond powder employed is obtained from the bruting operation, the powder and olive oil being applied to the whole of the scaife and during the operation paraffin is continuously applied by means of a wooden stick. 3 illus. R.W.

BARBER (R. J.). *The nature of jade.* Gems & Gemology, Vol. VIII, No. 2, pp. 38–46. Summer, 1954.

This is apparently the first instalment of a monograph on jade. Some consideration of the derivation of the term jade is made ; the legends and superstitions and some notes on the archaeological finds in this material are given. The naming of nephrite by Werner, and the finding by Damour that some jade was a different mineral—to which he gave the name jadeite—is mentioned. Both nephrite and jadeite are discussed from the point of view of the colour and its cause. " Imperial jade " is by Ridgway colour standards a " veridian green " rather than an " emerald green." It is suggested that mauve jadeite is coloured by manganese or vanadium, and the bluish green-grey material by vanadium and beryllium. The tomato-red coloured jadeite is said to owe its colour to the oxidation of iron with a little vanadium. Nephrite is softer but tougher than jadeite. Nephrite is infusible at moderate heat while jadeite fuses readily to transparent bubbly globules. Densities given are 3·33 to 3·50 for jadeite and 2·91 to 3·01 for nephrite. Both minerals are said to be products of deep-seated disturbances of original rocks, but the chemical and physical influences which have combined to produce them, and explanations of their modes of origin, are somewhat controversial. Sources of both jades are given and historical surveys of the original finds give added interest. 5 illus. R.W.

WEBSTER (R.). *Inclusions in a Madagascan yellow beryl.* Gems & Gemology, Vol. VIII, No. 2, pp. 60–62. Summer, 1954.

Four types of inclusions were noticed in this yellow beryl from Madagascar. They are :—tabular hexagonal green platelets; cavities showing crystal form with either eroded surfaces or a crystalline deposit on their inner surfaces, and containing a bubble with an included second bubble which disappeared on warming ;

cavities which seemed to be filled with a solid substance as through the liquid had crystallized out, some of which had " tails " and appeared like " mice " ; and tubes parallel to the vertical crystal axis were observed. The density was 2·71 and the refractive indices ω 1·581 ε 1·575 ; ω—ε 0·006. The dichroic colours were : for the ordinary ray a light pinkish brown, and for the extraordinary ray yellow. The absorption spectrum showed two vague bands in the blue at about 4500A and 4200A. There was no fluorescence and no radioactivity. 6 illus. **P.B.**

HARDY (E.). *Australia's " permanent interest " in pearling industry.* Gemmologist, Vol. XXIII, No. 277, pp. 155/6. August, 1954.

A general report on the Australian pearling industry. Japanese now allowed to fish in the Arafura Sea under certain limiting conditions. Bulk of Australian pearl shell goes to the United States of America where it is mainly used for the manufacture of pearl buttons. The manufactures are carried out in the States of Pennsylvania, Maryland, New Jersey, New York, and to a small extent in Iowa. Shell fished from the seas of Micronesia are mainly black-lip, gold-lip and trochus. Because of their larger size the shells of these are used as " blanks " for artificial pearl formation. Gold-lip and silver-lip oysters are employed to produce cultured pearls in the Micronesian islands (Palau, etc.), and these fisheries are American sponsored. It is stated that the nacre is laid down more rapidly and the production of pearls can be produced by these species in two years rather than the three to five years required by the Japanese pearl oyster (*pinctada martensi*). Some notes are given on pearl culture in general, and on the other localities of pearl-bearing mollusca. R.W

DEANE (N.). *Adventures in lapidary work.* Gemmologist, Vol. XXIII, Nos. 275-6-7, pp. 114–118 ; 128–132 ; 150–153. June, July and August, 1954.

The series (Parts 4, 5 and 6) continues with the telling of the difficulties of purchasing rough material, mention being made of the snags in buying opal. Australian garnet was found to cut into rather dark stones and the Australian sapphires obtained by the writer were rather unattractive. Tiger's-eye cuts well but is rather tough to saw and care is needed to orient the stone correctly

for the eye to develop. Green tourmaline from South West Africa was found to be dark and some experiments in lightening the colour by heat-treatment are mentioned. There was some betterment of the colour but cracks were apt to develop when the stones were heat-treated. Some Madagascan green tourmalines similarly heated did not lighten in colour and cracked so badly as to be ruined. A supply of rough from Ceylon was found to be of variable quality—the best stones probably being kept for cutting in Ceylon—and much of the parcel from this locality was incorrectly named. A surprise was the finding of a kornerupine. Some experiments on the heat-treatment of Ceylon zircons are described. The writer's first attempts at cutting facets and the apparatus used are fully described. Experiences with quartz, beryl, spinel, topaz, spodumene, enstatite and euclase are referred to and some notes on the order in which the facets are cut are given. The final instalment refers to the cutting of fancy shapes and the difficulties experienced with such species as apatite, brazilianite and fluorite. 11 illus. R.W.

BREEBAART (A. J.). *Two-phase inclusions in a yellow-green synthetic spinel.* Gems & Gemology, Vol. VIII, No. 2, pp. 56–57. Summer, 1954.

A report of two yellow-green synthetic spinels which showed two-phase inclusions arranged in a curved zone. Some of the cavities had straight and angular sides and may be negative crystals. Two photomicrographs are shown but the magnification of these is not given. One of the stones is in the possession of the Gemmological Association of Great Britain. R.W.

ANON. *Edelsteinkurse in Idar-Oberstein. Courses in gemmology at Idar-Oberstein.* Zeitschr.d.Deutsch.Gesell.f.Edelsteinkunde, No. 8, 1954, pp. 3–4.

In preliminary courses of one week precious stones and pearls are discussed. Students can see gems at permanent exhibition and belonging to firms. Methods of determination are explained and exercised. Diamond polishing factories, shops for grinding and engraving agate and coloured stones are visited. Apart from these courses there are correspondence courses and courses lasting a fortnight for advanced students entering the German examination in gemmology. E.S.

LENZEN (G.). *Die Entstehung orientierter Einlagerungen in Edelsteinen (Ursache der Asterien bei Sternrubinen und Sternsaphiren). The formation of orientated inclusions in precious stones (The cause of asterism in star rubies and star sapphires).* Zeitschr.d.Deutsch. Gesell.f.Edelsteinkunde, No. 8, 1954, pp. 7–10.

When a substance is made to crystallize on a crystal face of a completely different substance, the " guest crystal " will grow according to its own laws, but the direction of growth will be determined by the lattice symmetry of the " host " crystal ; i.e. the guest crystal will grow in certain directions which are " electrostatically agreeable." This has been shown experimentally by Willems. The orientation of the guest crystal will be such that the greatest possible number of " ion to ion " connections between the substances is achieved. As two different lattices are concerned, the distance between the ions of each substance is an important factor. If the host crystal keeps on growing, once crystals of another substance have formed on one of its faces, it will surround the guest crystals which become thus orientated inclusions (so-called contemporary orientated inclusions). These are of particular interest in the determination of minerals with the microscope ; well-known examples are rutile needles in corundum and the acicular hornblende crystals in garnet. The length of the unit cell of rutile in direction of the C-axis is 2·95 Å. The dimension of the corundum unit cell in the direction of the three auxiliary (hexagonal) axes is 4·75 Å. As the rutile needles are arranged in the (three) directions of the host's auxiliary axes, it can be seen that 5 rutile ions (14·75Å) correspond with three corundum ions (14·25Å). A similar relation can be shown in respect of the direction of the auxiliary (tetragonal) axes of the rutile needles and the rhombohedral faces of the corundum. The threefold symmetry of the rutile inclusions in ruby becomes visible in sections at right angles to the C-axis of the ruby, and the inclusions on account of light reflection, are the cause of asterism in cabochon-cut stones. The rays of the star are arranged at right angles to the directions of the needles. Whereas asterism in ruby can be explained in this way, no final explanation can be offered in the case of genuine star sapphires. In synthetic sapphire asterism is induced by orientated acicular rutile inclusions. In natural stones, however, one of the causes at least is " silk," i.e. a system of very narrow straight hollow channels, arranged at right angles to the C-axis and intersecting again at angles of

60 deg. and 120 deg. respectively. The origin of these channels is not certain. Some workers suggest " twinning," but possibly they are negative crystals, originally filled with rutile, which was absorbed when the host crystal (sapphire) formed around it. This assumption is supported by the zonal colour distribution, as titanium and iron are the colouring matter in sapphire.

W.S.

ANON. *Die Edelsteinausstellung in Zürich " Mensch und Edelstein." The gem exhibition at Zürich " Man and Precious stone."* Zeitschr. d.Deutsch.Gesell.f.Edelsteinkunde, No. 8, 1954, pp. 2–3.

Through combined efforts of Swiss jewellers and goldsmiths and the German (Idar-Oberstein) precious stone industry the Zürich exhibition has been a great success with over 25,000 visitors till end of July. The same exhibition was held at Berne during August and later in Basle. E.S.

REITENBACH (A.). *Ueberwundene Berufskrankheiten im Edelsteinschleifergewerbe. Conquered occupational diseases in the gem cutting industry.* Zeitschr.d.Deutsch.Gesell.f.Edelsteinkunde, No. 8, 1954, pp. 15–18.

No occupational diseases are existent to-day, but a detailed report, dated 1899, by the medical officer of the Idar-Oberstein district at that time is reproduced in full. It described silicosis (although the name is not mentioned) with following tuberculosis of the lungs and the digestive organs, and suggested as main preventive measure the general use of a new chair which was about to be introduced at the time. The chair allowed the agate polisher to sit in front of the big sandstone wheel with the head well above the dangerous grinding dust. He could still exert enough pressure on the workpiece. Previously he had to lie in a horizontal position with the chest compressed on a support and inhaling of dust could not be prevented in spite of wet grinding.

W.S.

COLOUR FILTER TESTS —GREEN STONES

by L. C. Trumper, B.Sc., F.G.A.

IT is considered most unlikely that any filter for the rapid examination of green gemstones can be any great improvement on the well known and most valuable Chelsea filter, obtainable from the Gemmological Association of Great Britain.

On the other hand it was felt that the series of experiments conducted on colour filters and reported on in the *Journal*, Vol. 3, pages 140/163, and Vol. 4, pages 27/32, would not be complete unless all the other colours of gemstones had been systematically worked through. For this purpose the Viewing Box[1] for the rapid examination of selected gemstones described was again used, providing for the same automatic feed of the Wratten, Ilford, and other filters of which the author now has more than 200 different standardized filters.

For the present examination of green gemstones, the following were selected :—

Chatham Synthetic Emerald
Muzo Colombian Emerald, ·63 cts.
Demantoid Garnets from the Urals
Blue Green Tourmaline, 2·13 cts.
Bluish Green Tourmaline, 1·475 cts.
Middle Green Tourmaline
Yellowish Green Prehnite
Green Beryl X1
Green Aquamarine, 3·178 cts.
Oil Green Peridot, 3·47 cts.
Green Sapphire, 2·83 cts.
Green Sapphire, 3·5 cts.
Green Stained Chalcedony
Green Andalusite
Green Smithsonite
Emerald Green Fluor
Bluish Green Fluor, 7·38 cts.
Middle Green Zircon, 1·32 cts.
Yellow Green Zircon, 2·73 cts.
Yellowish Green Zircon, 4.34 cts.
Green Chrysoberyl, 4·34 cts.
Alexandrite from Ceylon, ·50 cts.
Dioptase, 8·84 cts.
Enstatite, ·27 cts.
Diopside, 7·25 cts.
Chrysoprase, 19·4 cts.
Malachite

Visual examination of these twenty-seven selected green stones was a feast for the eye, as can be imagined. How relatively simple it is to compare stones when they are side by side, how difficult when they are not.

Unquestionably the emerald still stood out above the rest, yet it had to be admitted that it was quite closely followed, by first a superb emerald-green fluor bead, and secondly by a demantoid garnet from the Urals. Curiously enough this garnet exhibits no fire whatever, due partly, it is believed, to the poor cut and partly because of masking by the heavy inclusions of asbestos fibres, so typical of the demantoid garnet, and this stone could be mistaken for emerald with the greatest of ease. A further stone which would simulate emerald very easily is a green stained chalcedony.

By coincidence a green sapphire and a green zircon, both of intense slightly brownish green looked to the eye exactly the same. The typically oil green peridot stood out quite easily from the remainder, as also did the malachite cabochon and the dioptase cabochon. The chrysoprase and smithsonite could most easily be confused, the colour and general appearance being almost the same. The bluish green tourmalines could be picked out by comparison with the others.

Examination with an electric torch with an exceedingly narrow beam at once disclosed the raspberry red tint of the alexandrite and moving it about attracted attention to the demantoid by the considerable amount of fire thus disclosed.

Examination with a lens showed inclusions in the two demantoid garnets, and double refraction in perhaps one of the three zircons, the other two being of the low type.

Examination with the dichroscope disclosed that there would be no dichroism in the fluor, demantoid, low zircon, smithsonite or diopside.

Dichroism Observed

Enstatite	Green—yellowish green—brownish	(Distinct)
Chatham Emerald	Bluish green—yellowish green	(Moderate)
Colombian Emerald	Bluish green—yellowish green	(Distinct)
Stained Chalcedony	No dichroism.	

Green Aquamarine	Skyblue—Colourless ...	... (Very strong)
Green Sapphire	Greyish green—Green	... (Moderate)
Bluish Green Sapphire	Inky blue—Green ...	... (Strong)
Bluish Green Tourmaline	Almost none.	
Green Tourmaline	Bluish—Green ...	... (Distinct)
Alexandrite	Bluish emerald green—yellowish—Columbine red	(Very strong)

Turning now to examination with the colour filters at our disposal, below are given the reactions to the Chelsea filter, the Wratten 68/22 filter which closely resembles it, save that it tends to accentuate the colour change, particularly in the paler shades, in descending order of brilliance of the red colour change.

Then follow the reactions through the already standardized filters for the examination of blue and red stones, namely filters 30/34A, 30/85, 40A, and the ruby testing filter RU64 of which RU stands for an actual slice of synthetic ruby.

With the Wratten series of filters it seemed logical to first try the Minus Green 1 Filter No. 31, the Minus Green 2 Filter No. 32, and the Minus Green 3 Filter No. 33.

It may be noted that under Nos. 31, 32 and 33, the Enstatite and Peridot appeared strongly red unlike with any of the previous filters, and, of those stones previously red, the emerald becomes blue or bluish.

Examined between crossed filters only the Chatham synthetic emerald appeared distinctly red with the alexandrite and the Colombian emerald just perceptibly reddish and the prehnite very slightly tinged reddish.

Although there are clearly endless other possibilities, it is considered that the use of the Chelsea filter supplemented by the filters 30/34A and Rose Bengal 30 from the Wratten series and the Ilford Filters 502/302 could separate with a fair degree of accuracy all the transparent stones.

In the table below the gemstone is given in capitals or the colour at the point of final selection or elimination.

Chelsea Filter	Wratten 30/34A	Ilford 502/302	Wratten 30
Red	Red	Red	Red
Alexandrite	Alexandrite	Alexandrite	ALEXANDRITE
Chrysoberyl	Chrysoberyl	Chrysoberyl	ORANGE
Demantoid	Demantoid	Demantoid	GREEN
Prehnite	Prehnite	Prehnite	FLESH
Fluor	Fluor	MAUVE	MAUVE

Chelsea Filter	Wratten 30/34A	Ilford 502/302	Wratten 30
	Blackish		
Andalusite	Andalusite	BLACKISH	GREEN
Syn. emerald	Syn. emerald	Red	Blackish
Emerald	Emerald	Red	Blackish
Zircon	Zircon	RED	GREEN
Beryl	Beryl	MAUVE	Blackish
Green	Red		
Pale zircon	Pale zircon	RED	Green
Deep aquamarine	Deep aquamarine	BLUE	Yellow Green
Peridot	Peridot	BLACKISH	Yellow Green
Enstatite	Blackish	RED	Green
Stained chalcedony	Blackish	MAUVE	Bluish
Sapphire	Blackish	BLUE	Green
Tourmaline	VIOLET	Blue	Green
Diopside	Black	Black	BLACK

Of the opaque stones or translucent stones it is considered that malachite and dioptase would be recognized by their characteristic idiochromatic colour.

This also applies to chrysoprase though smithsonite is very close in appearance, but with the S.G. of the latter at 4·3 to 4·6 this gemstone feels perceptably heavier.

These stones together with diopside are green in the Chelsea filter, but blackish or bluish or greyish under all the other three.

It should of course be appreciated that the above results are based on tests with a limited number of gemstones of distinct green colour. Other green stones of a paler colour or of a more yellow green, may well give somewhat different results.

Nevertheless a selection by means of these filters would enable a separation to be made rapidly with a fair degree of accuracy.

Gemstone	Chelsea Filter	68/22 Filter	Filter 30/34A	Filter 30/85	Filter 40A	RU 64
Alexandrite	Blood red	Blood red	Bright red	Bright red	Blue green	Blue
Chatham synthetic emerald	Bright cherry red	Bright cherry red	Blackish	Blackish red	Green	Green
Demantoid garnet No. 34...	Bright red	Bright red	Red	Flesh	Green	Green
Colombian emerald ...	Bright red	Bright red	Blackish	Greenish	Blue green	Blue
Deep green chrysoberyl ...	Bright red	Blood red	Red	Pink	Green	Bluish green
Demantoid garnet No. 188	Red	Red	Red	Green	Blue Green	Green
Prehnite	Red	Red	Bright Red	Bright Pink	Grey	Pale blue
Emerald-green fluor ...	Reddish	Red	Red	Slightly reddish	Bluish	Blue
Deep green zircon... ...	Reddish	Reddish	Blackish	Deep green	Greyish yellow	Blackish
Bluish-green fluor	Pinkish	Reddish	Reddish	Grey	Grey	Pale blue
Green beryl	Trace of pink	Reddish	Blackish	Greyish	Blue	Blue
Green - stained chalcedony	Green unchanged	Pinkish	Blackish	Bluish grey	Blue	Blue
Pale green zircon ...	Green unchanged	Pinkish/flesh	Red	Pale green	Pale yellow	Brown
Deep green aquamarine ...	Apple green	Deep apple green	Reddish	Yellowish black	Blackish	Blue
Green tourmaline ...	Green unchanged	Green unchanged	Deep violet	Bluish green	Greyish/colourless	Blue/colourless
Bluish-green tourmaline	Green unchanged	Green unchanged	Deep violet	Bluish green	Greyish/colourless	Blue/colourless
Green sapphire	Green unchanged	Green unchanged	Reddish	Deep gold	Bluish grey	Blue
Deep green sapphire ...	Green unchanged	Green unchanged	Blackish	Blackish	Deep blue grey	Deep blue
Enstatite	Green unchanged	Green unchanged	Blackish	Green	Yellow green	Green
Dioptase	Green unchanged	Green unchanged	Blackish	Black	Deep blue	Deep bluish
Chrysoprase	Green unchanged	Green unchanged	Blackish	Greyish green	Grey	Bluish grey
Diopside	Green unchanged	Green unchanged	Blackish	Blackish	Blackish	Blackish
Smithsonite	Green unchanged	Green unchanged	Black	Greyish green	Grey	Bluish grey
Malachite	Green unchanged	Green unchanged	Blackish	Grey	Medium grey	Grey
Peridot	Green unchanged	Green unchanged	Reddish	Oil green	Pale gooseberry	Colourless
Green andalusite ...	Green unchanged	Green unchanged	Slightly reddish	Slightly reddish	Green	Green

	No. 31	No. 32	No. 33	Rose Bengal No. 30	Rose Bengal 30 and Minus Red 2 No. 43	Rose Bengal 30 Minus Red 30	502 302
Alexandrite	Red	Red	Orange red	Bright red	Red	Bright red	Red
Chatham synthetic emerald	Blackish	Bluish-black	Blue	Blackish	Red	Bright red	Red
Demantoid garnet No. 34	Red	Red	Orange red	Yellowish green	Red	Red	Red
Colombian emerald ...	Violetish	Blue/violet	Blue	Greenish	Purplish	Red	Red
Deep green chrysoberyl ...	Red	Red	Orange red	Orange	Red	Red	Red
Demantoid garnet No. 188	Red	Red	Dark green	Green	Red	Red	Red
Prehnite	Pink	Red	Pink	Red	Red	Red	Red
Emerald-green fluor ...	Dirty mauve	Dirty Bluish	Blue	Dirty Red	Mauve	Mauve	Mauve
Deep green zircon... ...	Red	Dirty red	Reddish	Green	Red	Red	Red
Bluish-green fluor	Mauve	Lilac/mauve	Mauve	Bluish mauve	Mauve	Mauve	Mauve
Green beryl	Blackish	Blackish	Bluish	Blue	Blue	Blue	Bluish
Green - stained chalcedony	Violetish	Blue	Blue	Greenish	Bluish	Mauve	Mauve
Pale green zircon ...	Reddish	Red	Orange red	Green	Red	Red	Red
Deep green aquamarine ...	Mauve	Blue	Blue	Yellowish green	Blue	Blue	Blue
Bluish-green tourmaline ...	Violet	Violet/blue	Violet/blue	Blue	Dark greenish blue	Blue	Blue
Green tourmaline	Green	Bluish	Bluish	Green	Dark green blue	Blue	Blue
Green sapphire	Red	Red	Red	Yellowish green	Golden green	Green	Blue
Deep green sapphire ...	Blackish	Blackish	Inky blue	Green	Dark blue	Blue	Dark blue
Enstatite	Red	Red	Bright orange red	Green	Green	Dark blue	Red
Dioptase	Deep blue	Dark blue	Blue	Dark blue	Dark blue	Blackish	Blackish
Chrysoprase	Grey blue	Grey blue	Grey blue	Grey green	Grey blue	Grey	Blue
Diopside	Blackish	Blackish	Blackish	Blackish	Blackish	Black	Blackish
Smithsonite	Grey blue	Grey blue	Grey blue	Grey green	Grey blue	Grey	Blue
Malachite	Deep blue	Dark blue	Dark blue	Dark blue grey	Lead grey	Black	Black
Peridot	Red	Red	Orange red	Green	Golden green	Yellow green	Reddish black
Deep green andalusite ...	Red	Dirty red	Blackish red	Green	Red glints	Red glints	Reddish black

BOOK REVIEW

First adventures in geology—the story of rock identification.

This attractive paper-covered book of some sixty pages has been prepared by the staff of the Gemological Institute of America, under the guidance of the Encyclopaedia Britannica, to form an instruction book to use with the " American Industry " educational hobby kits intended for the younger generation.

Just to whet the appetite, the introduction tells a story of an old prospector who finally, after many disappointments, makes a rich find of uranium ore. This is followed by the chapter " How to be a rock detective," and refers to the accessories supplied with the kit ; i.e. a geologist's hammer, a chisel for breaking rocks, a double-ended magnifying glass with two powers— × 4 and × 7, and a piece of copper and a piece of glass for making hardness tests. The kit contains also a notebook with printed and numbered information sheets and numbered gummed labels to stick on specimens. The kit is completed with 24 selected specimens of rocks and minerals which are unnamed—and of course this instruction book.

A chapter on " What to look for " gives the basic elements of mineral identification and is written in simple language. The difference between a rock and a mineral is explained, and the points to notice when examining a specimen. In this part ; colour, lustre, texture, shape (necessary in the case of crystals), cleavage and fracture, structure (and explanation of its difference from texture), weight (density by heft), and observation as to whether the specimen is likely to be one mineral or a combination of different minerals.

After a short description of the way and the nature of igneous ; sedimentary and metamorphic rocks, the reader is told to start elementary practical work by taking the card marked A from the kit, which contains 24 places each with a name on it, and the case of specimens. Reading on it is seen that a description is given of quartz ; from this description it is necessary to place the specimen on the appropriate position on the card—of course from what you have learnt you have to find the specimen of quartz from the unnamed specimens. The same procedure is to be adopted for the remaining 23 specimens from the information provided in the book. The specimens mentioned are : Basalt, Mica, Breccia, Anthracite coal, Bituminous coal, Conglomerate, Coquina (*fossil*

limestone), Feldspar, Gabbro, Gneiss, Granite, Hornblende, Limestone, Marble, Mica schist, Obsidian, Porphory, Pumice, Quartz, Quartzite, Sandstone, Serpentine, Shale and Slate.

Having thus sorted, or identified, the twenty-four specimens, second card, card B, is taken from the kit. The specimens are then re-sorted to four groups :—Four minerals, six igneous rocks, eight sedimentary rocks and six metamorphic rocks. Explanation of these various groups being given in the text, not only as a guide, but to give an understanding of the processes of rock formation.

The reader is then advised to go out and find and identify his own specimens from what the book and kit have taught him. The tools supplied with the kit are essentially there for the purpose of the latter " field " work. Many directions are given for rock hunting ; how to describe the specimens in the case book and the labelling of the actual specimens with the numbered labels. The determination of the specimens found by the process of elimination is described. (It is suggested that if no identification is made after all that can be done, the reader should approach a Curator of a Museum. Instructions for the formation of a collection and how to store a collection of rock and mineral specimens is given.

The concluding chapters deal with elementary general geology and of fossils and their use in the determination of the ages of rocks, and how rocks are formed. The chapter " Careers with rocks " describes some of the early geologists such as Agricola, Werner, Smith, Agassiz and J. W. Dana. The various branches of geology are described. As an example that of gemmology is fully described showing the advance of that particular science in the United States. The book is completed with a short pronouncing glossary. There is no index but one does not appear to be needed.

The book is leavened with well-selected photographs of crystals, minerals and rocks, quarries and mines as well as surface features. Some parts of the text are illustrated with black and white drawings to catch the juniors' eye. The coloured cover shows the Maroon Bell Peaks, West of Aspen, Colorado.

The admirable way the book is so arranged as to gradually enlarge on the subject and keep the reader's interest, and the clear way the text is expressed, makes this book a really good elementary textbook. There is much sound advice packed in little space ; all made intelligible to the immature mind of the school age boy.

R.W.

ASSOCIATION NOTICES

1954 EXAMINATION RESULTS

The 1954 examinations of the Gemmological Association of Great Britain were held in the United Kingdom and Overseas in June. World wide interest in the examinations, which have now been held since 1913, continues unabated and centres this year included :—London and provinces, Australia, Canada, Ceylon, Germany, Holland, Hong Kong, India, New Zealand, Norway, South Africa, Switzerland, and the U.S.A.

On the recommendation of the examiners the Tully Memorial Medal and a special prize of gem testing instruments (presented by Rayner and Keeler Ltd.) have been awarded to Neville Deane of Wednesbury for his work in the Diploma examination, and the Rayner Prize in the Preliminary examination to R. E. Muir of Wilmslow.

The following is a list of results arranged alphabetically :—

EXAMINATIONS 1954

DIPLOMA

Qualified with Distinction

Belcher, C. I., Johannesburg.
Bender, C., Cologne.
Bowden, F. A., Plymouth.
Deane, N., Wednesbury.
Furness, G. V. (Mrs.), Reading.
Lenzen, G. A. H., Hamburg.
Olsen, S. G., Bergen.
Solomon, J. P., Plymouth.
Stamness, J., Oslo.
Webb, M. H., Maidstone.
Wilson, M. E., Purley.
Wines, E. D. (Miss), London.
Zwaan, P. C., Leiden.

Qualified

Banister, H. J. (Miss), London.
Bolli, W., Lucerne.
Boxall, L. T., Richmond.
Burnett-Ham, D. (Miss), London.
Buttermore, R. D., Jnr., Parkersburg, U.S.A.
Campion, J. E., Plympton.
Chinn, A. B., London.
Goad, M. J., Sutton.
Harper, J. S., Birmingham.
Jackson, A. C., Greenford.
Kell, R. G., London.
Mahajan, B. S., Bombay.
Marsh, W., Edinburgh.
Shearman, J., Barnehurst.
Showers, A. St.G. F., Hove.
Sutton, N. J., London.
Walker, A. H., Bournemouth.
Watts, S. F., Birmingham.

Qualified

Alexander, F. E., Romford.
Allen, W. E., Newcastle-on-Tyne.
Ameringen L. J., van, London.
Anderson, J. E., Edinburgh.
Anfield, J., Edinburgh.
Bates, M. A., Ceylon.
Bell, N. F., Liverpool.
Bettis, V. A. (Miss), London.
Bialek, W., Birmingham.
Bodenham, J. E., Birmingham.
Bohe, E. R., San Diego.
Breeze, M. D., Leicester.
Brooks, E. W., Wallasey.
Brown, M. A. (Miss), Birmingham.
Bruder, E. R., Southwick.
Buttermore, R. D., Jnr., Parkersburg, U.S.A.
Cameron, J. S., Auckland, New Zealand.
Chadwick, I. (Miss), London.
Chandler, F. V., Northolt.
Clark, A. R., Glasgow.
Clark, J. A., Forfar.
Collier, P., Liverpool.
Collinge, A. D., Birkenhead.
Cooke, D. S., Melbourne.
Cooper, G. D., Colchester.
Crichton, J. M., London.
Davidson, V. A., Walsall.
Davies, B. P., Gerrards Cross.
Durricott, R. K. W., Bishops Briggs.
Dubois, J. W., Hong Kong.
Dungate, P. J., Loughton.
Fisher, P. J. (Miss), Birmingham.
Gill, M., Isle of Arran.
Grounds, W. J., Birmingham.
Hamilton, D. P., Glasgow.
Hart, J., Glasgow.
Hewitt, F. E. J., Ormskirk.
Hopewell, R. C., Grays.
Jansz, B. A., Ceylon.
Ineson, A., Wakefield.
Joseph, B. R., Birmingham.
Kahn, M. S., Welcom, S. Africa.
Kalleven Th. A., van, Arnhem.
Lenzen, G. A. H., Hamburg.
MacDonald, I. C., Glasgow.
Mahajan, B. S., Bombay.
Marsh, W., Edinburgh.
McGuigan, A. (Mrs.), Bearsden.
Mehra, P. N., Calcutta.
Messenger, S. J. (Miss), St. Albans.
Morrison, N. C., Inglewood, Calif.
Muir, R. E., Wilmslow.
Murray, K. G., Birmingham.
Nelson, P. K., New York.
Parkes, F. M. R., Brierley Hill.
Paterson, D. G., Edinburgh.
Pearce, A. M. (Miss), Old Windsor.
Phillips, W. H. M., Ross-on-Wye.
Price, J. S. (Miss), Birmingham.
Pyke, W., Birmingham.
Rankine, W. M. (Mrs.), Farnham.
Robertson, K. (Mrs.), Milngauie.
Rowe, G. P. (Miss), Abergavenny.
Sibley, A. J., West Wickham.
Silkebekken, M., Elverum.
Solomon, J. P., Plymouth.
Soukup, E. J., San Diego.
Spittle, T. R. (Miss), Birmingham.
Stern, E. (Mrs.), Wembley Park.
Sumner, R. A., London.
Tiessen, R. J., Hilversum.
Todd, G. E. (Miss), London.
Tyler, T. J., Edgware.
Urquhart, A. M., Edinburgh.
Vaughan, H. M., Ross-on-Wye.
Vince, J. O. E., Ipswich.
Walker, A. J., London.
Waller-Davies, J. M., Eastbourne.
Watts, M. (Miss), Pakenham.
Wells, R. A., Buffalo.
Whitley, P., London.
Worth, B. R., Leicester.
Zwaan, P. C., Leiden.

CHANGE OF ADDRESS

One of the earliest Fellows of the Association, Mr. Oscar D. Fahy, has recently moved from Vittoria Street to 64 Warstone Lane, Birmingham, 18.

OVERSEAS VISITORS

During September the Association was honoured by visits from Mr. Stanley Belcher, F.G.A., of Johannesburg, and Mr. H. St. C. Roberts, a Fellow of the Gemmological Association of Australia.

FORTHCOMING MEETINGS

October 20th, 1954. Reunion of Fellows and Members at Goldsmiths' Hall, Foster Lane, London, E.C.2, between 6 and 7 p.m. At 7.15 the awards gained in this year's examinations will be presented by Sir Lawrence Bragg, F.R.S., the President of the Association.

November 11th, 1954. Film evening for members, including showing of colour film " For Ever Diamond."

January 21st, 1954. An any questions evening to be held at the Medical Society of London's Hall, Chandos Street, W.1, at 7 p.m.

March 31st, 1954. Annual General Meeting.

DEPARTMENT OF MINERALOGY, BRITISH MUSEUM (NATURAL HISTORY)

Lectures in the Mineral Gallery on Saturdays at 3.15 p.m.

1954

Date	*Subject*	*Lecturer*
Oct. 23	Famous Diamonds	Miss Sweet
„ 30	How the ages of rocks are determined ...	Dr. Wiseman
Nov. 6	Gemstones	Dr. Claringbull
„ 13	Caves and cave deposits	Mr. Ellis
„ 20	Rocks of the Scottish Highlands	Mr. Francis
„ 27	Glass meteorites	Dr. Hey
Dec. 4	Gem minerals	Dr. Moss
„ 11	Physical properties in relation to crystal structure	Miss Shaw
„ 18	Sir Hans Sloane	Miss Sweet

This programme is subject to alteration without notice.

COUNCIL MEETING

A meeting of the Council of the Association was held on Tuesday, 24th August, 1954, at 19/25 Gutter Lane, London, E.C.2.

The report of the examiners on the 1954 examinations was received and approved. The Council considered it desirable to review the syllabus of examinations and it was agreed to hold a further meeting of the Council on 13th October to consider this and other examination matters.

Mr. Walter Hands, Birmingham, was elected an Ordinary Member of the Association.

The Council decided to send a message of congratulations to the National Association of Goldsmiths on the occasion of that organization's sixtieth anniversary.

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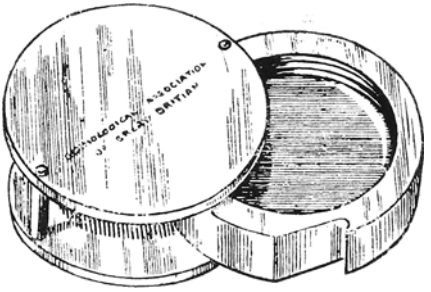

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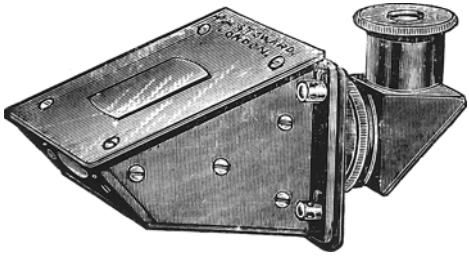

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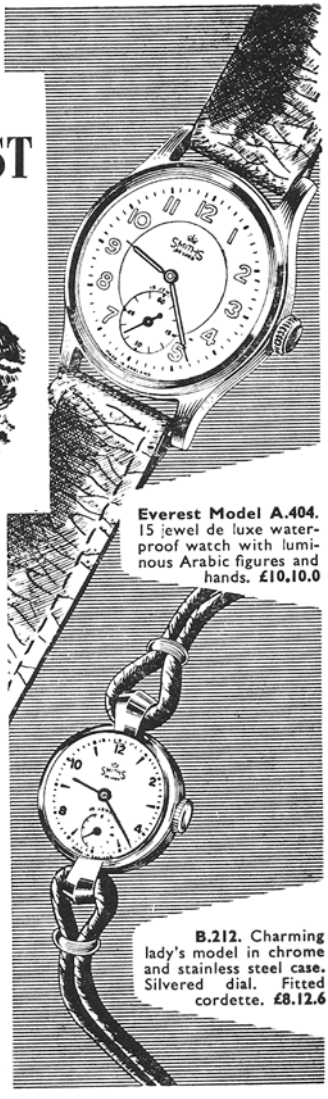

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THE JOURNAL OF GEMMOLOGY
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Vol. V No. 1 JANUARY 1955

NEW GEMMOLOGICAL MICROSCOPE

by E. H. RUTLAND, Ph.D., F.G.A.

OF the multitude of instruments now available for gem testing (and what a change there has been in the last ten years) the oldest of all, the microscope, undoubtedly remains the most essential, the most generally useful. It is unnecessary to labour this point to the expert, but to him who regards the microscope as the perquisite of scientists, it may be permissible to point out that it is the simplest, surest and quickest means of distinguishing pastes and synthetics (a growing problem) from natural stones ; indeed, it is the only test readily available for separating synthetic and natural ruby with certainty. To the expert a suitably equipped microscope can tell more about a gem than all the other instruments combined ; a fact which does not detract from their usefulness.

The evolution, for the first time in this country, of a microscope specially designed for the gemmologist and jeweller is therefore an event of some importance. There is already a great variety of microscopes on the market, some of which can be adapted very satisfactorily to gemmological work. The new instrument, however, combines all requisites for gem testing with sturdy construction and with a number of ingenious modern features which greatly simplify its use.

One such feature is the focusing system. There are three built-in objectives giving, with the ocular provided, 10 ×, 25 × and 60 × magnifications and all are completely parfocal. They can be changed by merely turning a large knob[2]. It is, therefore, possible to survey a large area rapidly and then to magnify anything unusual that is seen by a mere turn of the knob, with the assurance that the feature selected will be in focus without further adjustment.

1. Lever controlling spectroscope slit opening.
2. Change of magnification drum.
3. Spectroscope condenser.
4. Focusing knobs (2).
5. Knob for height control of dark-ground illumination.
6. Lamp holder securing screw.
7. Swing-in occluder to give dark-ground effect.
8. Dark-ground lever.
9. Swing-in polarizing filter.

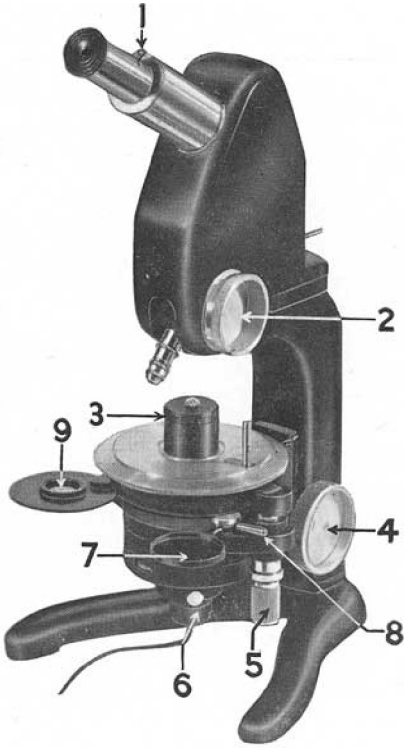

Focusing is further simplified by the low mounting of the focusing wheels on the stand[4]. This enables one to rest the whole arm on the bench while focusing and adds greatly to the smoothness of operation. The focusing wheel in fact moves the stage and not the body tube as in most microscopes. There is no fine adjustment, but in view of the large wheel employed and of the low magnifications used, this is no drawback.

The stage and sub-stage form a unit which contains quite a number of interesting features. Following modern trends, the lighting is built in. Expert microscopists may prefer the greater flexibility provided by independent lighting, but where speed and simplicity matter, it is a great boon to be able merely to switch on in the knowledge that the light will be in perfect adjustment and that this adjustment cannot be upset by a random movement of

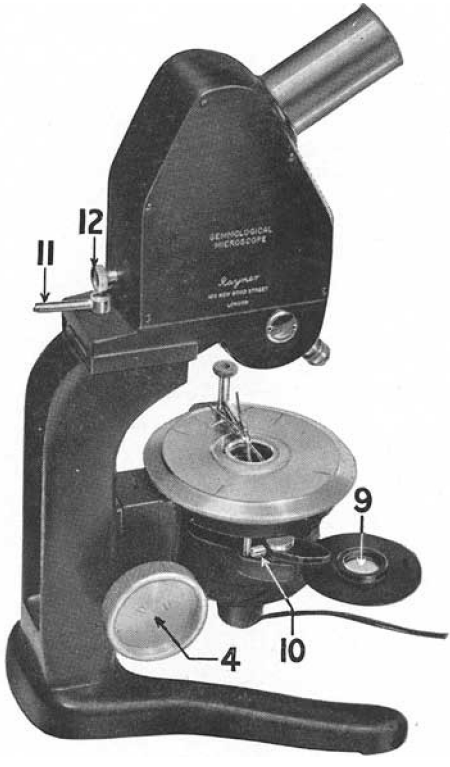

4. Focusing knobs (2).
9. Swing-in polarizing filter.
10. Polarizing filter lever.
11. Body-locking lever.
12. Push-pull analyser knob.

the instrument. The source of light is a 12W, 1A close coil lamp and is ample for most purposes. For normal working it needs to be dimmed by means of the rheostat provided, keeping full power for spectroscopy. A few of the spectroscopically more difficult stones may need stronger light than the instrument can give.

The substage condenser system is distinctly novel in that it employs both a condensing lens in front of the lamp for transmitted light and a mirror behind the lamp for dark-ground illumination.

The mirror is of paraboloid shape and produces a parallel beam of light upwards. This beam is then collected by another paraboloid mirror which deflects it at right angles and condenses it at a point just below the stage. This arrangement provides a most vivid form of dark-ground illumination. A glass cell is supplied that hangs by its rim below the level of the stage[16]. In this cell the specimen can be viewed either dry or in any of the usual immersion liquids. An ingenious stone holder is supplied that enables one to move the stone in any direction and hold it in any position. When dark-ground illumination is required a swivelling black disc[7] cuts off the direct light from the specimen and it now receives light only

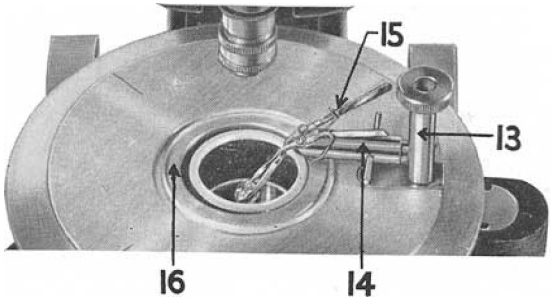

13. } Stone-holding attachment comprising : { Vertical post
14. } { Horizontal bracket
15. } { Tweezer
16. Dark-ground immersion cell.

from the top mirror, i.e. from all sides. A separate screw control[5] makes it possible to raise and lower the ring of light reaching the specimen in such a way that it traverses the stone from top to bottom.

Both dark-ground and direct-light illumination have their advocates among gemstone microscopists and each form has advantages for certain types of inclusion. On the new instrument one can switch from one to the other at the touch of a finger[8]—a pleasant experience when one is used to changing condensers.

Instead of the recessed immersion cell, the stage can be fitted with a frosted glass diffuser for normal working. This, too, should save many a small stone from losing itself in the inside of the

substage unit. For spectroscopy, the stage aperture can be closed with a condensing lens over which a black " pot " holds the stone in a small aperture at the focal point of all the light from underneath. Here an iris diaphragm would accommodate stones of all sizes but no doubt this would raise the cost. The pot is shown in position[3] in one of the illustrations.

The microscope is equipped with a rotating stage engraved with lines at 90°. The polarizer swivels[9] next to the dark-ground disc and the analyser works on a push-pull button[12] at the back of the instrument. Both are fitted with polaroid. The polarizing equipment provides the usual facilities for observing double refraction, dichroism, the spectra of individual rays, etc.

The inclined eyepiece is also in keeping with modern trends. The tube holding it will take a number of accessories : foremost among these is a new hand spectroscope. This slides right into the eyepiece tube and is shown in position in the illustration. It can of course also be used independently and gives as bright and clear a spectrum as any of the hand instruments on the market. It possesses the advantage that the slit can be adjusted by means of a small lever halfway along the spectroscope[1]. This is much more smooth in operation than the tiny screw with which such instruments are usually equipped. When in the eyepiece tube, the spectroscope is held in position with the red end of the spectrum on the left side.

The Rayner dichroscope can also be fitted to the eyepiece tube and used in conjunction with the microscope. Further fitments are understood to be in preparation, including a camera attachment.

It will have been observed that the optical constituents of this instrument are not of standard size and that the objectives and ocular are not interchangeable with other makes. This is because the instrument was designed as a whole and for use in gem testing primarily. It is a very good specialized tool for this particular purpose, rather than one that provides endless variety for the unspecialized microscopist. Messrs. Rayner, to whom gemmologists owe a great deal already, are to be congratulated on their enterprise, ingenuity and workmanship.

JADE STORY - EUROPEAN

(The second part of the Story of Jade in Europe)

by ELSIE RUFF, F.G.A.

THE Dark Ages of Jade might well describe one of the missing links in the story of jade.

If we take Dr. Sydney Ball's dates[1], we find remnants of the neolithic age in Europe around 1500 B.C. Up to this date it would appear that jade was highly valued and commonly used, at least among advanced stone-age peoples. Then we discover a gap. It is a wide gap, for it extends from this early date to the historical use of material undoubtedly referring to our present jade. In other words, we have jadeite and nephrite in what would appear to be constant use in Europe from the beginning of enlightenment to 1500 B.C. From this date we leap forward to the period of the Spaniards introducing the jade of South America, the jade of Sir Walter Raleigh. The jade of the Spaniards and that of Sir Walter Raleigh was principally jadeite. But to establish any type of jade in Europe is to wrestle with etymology.

We may read[2] " there is no word of jade in European literature before the discovery of America by Columbus in 1492." On his fourth and last voyage, during 1503, Columbus was in Jamaica. The Spaniards were in Mexico during 1519, but in 1511 they had contacted the Yucatans, nineteen years after the discovery of the continent by Columbus.

This may or may not mean that the author of the above statement, in 1906, had found mention of jade in Europe before the discovery of jade in South America by the Spaniards. In 1912 Dr. B. Laüfer (*Jade*) was writing : " Our word *jade* is but a recent introduction first brought to England by Sir Walter Raleigh (*c.* 1552-1618) who always uses the Spanish name for the stones in his books ; the word does not appear in our literature before this."

If Sir Walter used the Spanish term and, moreover, brought specimens of jade back with him, it is obvious that he too contacted Spanish culture somewhere in South America. He is alleged to have shown a piece of this jade to one of his friends and to have

commented that it was used in America for the treatment of renal diseases.

An official report by Sir Walter Raleigh on " The Discoverie of Guiana " mentions jade. It is referred to as the *spleene-stone*, and sometimes both *spleene-stone* and *kidney stone* are used, as though dealing with two separate stones. " . . . others of better estimate " suggests material more valuable than jade ; perhaps emeralds. Again, of the spleene-stone, he says : " . . . of these I saw divers in Guiana ; and commonly every king and casique hath one, which their wives for the most part weare ; and they esteem them as great Jewels." He wrote too : " A kinde of greene stones, which the Spaniards call *piedras hijadas* and we vse for spleene stones." (Whether he meant that the South Americans did not so use them is a moot point.)

There is little doubt that this jade, so venerated in South America and introduced into Europe under a Spanish name, was similar to the spleene-stone of England. In any case, it was close enough to bear comparison.

Since the Spanish invasion antedates the jade of Raleigh's time and the Spanish term was accepted, it would seem essential to put the enquiry back a few years. Certain it is that the Spaniards brought back enough of these stones to impress their fellow countrymen, in spite of the fact that the jade was often forced upon them by the Aztecs. Not always were these gifts accepted, for the Spaniards preferred gold and emeralds, which had a high monetary value in Europe. But the invaders were frequently treated as honoured guests. And they were guests in a luxury country. Nevertheless, it implied that while jade was less valuable in Spanish eyes, perhaps even of small degree, the newcomers were not unmindful of what was being offered. Whether the jade was accepted as a cure for kidney ailments is something not yet established. If not, then the Spaniards must have received these stones in the belief that they were in circulation as a cure for kidney diseases within their own country. It seems incredible that these (often uncouth) explorers would invent such a theory on the way home, for no particular reason—unless it was to establish that the stones were extremely valuable in the land of the Aztecs. To discover whether the Spaniards were hoodwinking the European world, it is necessary to discover whether such a belief existed anywhere.

The Monardes book, to be quoted later, appeared in the latter part of the 16th century and, quite apart from jade, is interesting in many ways. Not least is a letter written to the physician Monardes by a Spanish soldier in South America. He must have been a soldier of unusual capacities for he wrote the letter as a result of having read an early publication by Monardes. He stressed not only the intelligence of the people of the Indies and the wisdom of so much that they did, but also the indifference of the Spaniards who came to those parts, completely lacking in curiosity regarding the people they set out to subdue. Later in the volume, Monardes himself writes of stones " of a white couler " obtainable from certain large, strong fish common to the " Seas of the Indies," often weighing (the stones) more then " twoo pounds " and " hollowe in some parts, and verie white, thei are somewhat heavie. Of these stones they have in the Indias greate experience : givyng theim made in pouder unto those that dooth suffer the grief of the stone in the Kidneis . . . and to them that can not caste out the stone of the raines, and of the Bladder . . . This is a thyng emongest the Indians very plaine, and knowen ; and likewise emongest the Spaniards which doe dwell in these partes."

This information would suggest that kidney trouble was commonly treated by powdering a stone. And it would not be a long jump to use (perhaps by exalted personages) the most precious stone of all in this way, or to retain the stone and use it externally.

Montezuma said, when handing some of these jades to Cortez : " To this I will add a few *chalchihuis* (jades) of such enormous value that I would not consent to give them to anyone save to such a powerful emperor as yours ; each of these stones is worth two loads of gold." In similar vein, the Maori was to say, a few hundred years later : " Let the gold be worked by the white man. My only treasure is the *pounamu* " (jade). It has been said that when Montezuma played games of chance with Alvarado, one of the Spanish leaders, he was paid in chalchihuitl if he won and in his turn paid gold when he lost.

Before quoting Monardes, a writer who preceded him by a few years should be mentioned. He contributed little to the jade theme, but is undoubtedly of interest to the gemmologist. Conrad Gesner, or Konrad von Gesner (sometimes referred to as the

German Pliny), a professor at Zürich University, published in 1555 or 1565 (the year of his death)—there seems to be a difference of opinion with regard to the year of publication—a work entitled : *Book particularly on Stones and Gems. Their Forms and Similitudes. A Source of Aid and Pleasure, not only for doctors, but for all students of Natural History and Philology. Zürich.*

" *Various ornaments.* It is a habit to attach or wear on some part of the body ornaments for the sake of embellishment. People also attach to themselves ornaments in the hope of physical healing, as by amulets. Superstitious persons have produced all kinds of such for enjoyment or showing off. At this time, Gentiles of our very religion carry some, be it as ear-rings or armlets, be it that they use them in the form of beads for prayers out of piety. But we have not beads only but all kinds of figurings ; round, hollow, angular, rhombic. Amongst others one appears a mere exudation which I mention like Chalcedon, often named, and is found in the belly of a hen and partly consumed : in two of these pieces is a midget embodied as within the amber, in which often insects are embodied. I have been given pieces of Amber by friends in which parts of small insects are preserved. These round balls exist also in different materials, Jaspis, Chalcedon, as it is vulgarly called, Crystals, Amethyst, Silica precipitate, Coral, Amber, Jet, and as Galenus writes of the green stone of which this is the application : they suspend it from the neck that it touches the belly where the stomach lies. He simply says Gems with rings (of which we made mention before) of the round or the rectangular form. Besides stones, also gold and silver ornaments are suspended from the neck and worn in a different way. The Indians like to make from Beryls cylindric ornaments as Pliny states. I omit tambourine-shaped ornaments and ear-rings at this place. Also suspended pictures are worn as ornaments.

Green stone or gem which is utilized by the inhabitants of the India of the West. They fasten it on perforated lips, the thicker end inside the mouth and the rest hanging down in the front. You may therefore call it a mouth-ring, in the same way as with plants we have the expression ' Filipendulum.' One Ferrius from Piedmont has given me a stone for my documentation. He says in his letter to me, I send you a green coloured stone of a round shape, long like the middle finger of a man, fitted on both ends with a ring. This

stone the Nobles of Brazil carry when appearing in public, fastening it in their lips, which in their youth are perforated. They carry one or more according to rank and they are valued in accordance of what they show of their hanging ornaments."

The *green stone or gem* of the India of the West and of Brazil was almost certainly jade, though Gesner makes no statement regarding its species. In another place he refers to *belemnites*, certain dart-shaped fossils, used in Spain " against calculi in the kidneys." It was a substance that could be " burnt or indeed powdered and mixed with other things. Or prepared as a drink soaked in it. It also cleans the teeth when reduced to ash . . . "

Despite the interesting statement that Spain had its own curative for kidney diseases, Gesner does not appear to link up the disease in any way with his *green stone.*

This volume contains no less than thirty-four authorities (viz. earlier than 1565) consulted or quoted.

Monardes was the chronicler of the Spanish *piedra de ijada.* As a physician of Seville, he was writing of material interesting to medicine. It seems, in 1569, he was the first to use the term *piedra de ijada* in print. He is here quoted at length because his report is valuable. Apart from jade, both a South American wood and a root were used as cures for the same disease.

Joyfull News out of the Newe Founde Worlde, written in Spanish by Nicholas Monardes, Physician of Seville, and Englished by John Frampton, Merchant . . . London, 1577.

" . . . Of the Blood Stone and the Stone for the deseases of the Kidneis and Raines.

Thei doe bryng from the newe Spain, twoo stones of greate vertue, the one is called the Stone of the Blood, and the other is a Stone for the desease of the Stone in the Kidneis and Raines.

The Blood Stone is a kinde of Jasper of divers coullours redde, of the which stones the Indians doeth make certaine Hartes both greate and small . . .

The other Stone, whiche is for the desease of the stone in the Kidneis or Raines, the finest of them are like unto Plasma of Emeraldes, which is likened to greene with a Milkishe couller, the greatest is the beste ; thei bryng them made in divers forms and

fashions, for so the Indians had them in olde tyme, some like to fishes, other like to the heddes of birdes, other like to billes of Popagaies, other like to rounde Beadstones, but all pearsed through, for that the Indians did use to weare theim hangyng for the effecte of the griefe of the stone or stomache ; for in these twoo sickenesse it doeth marveilous effectes. The chief vertue that it hath, is in the paine of the stone in the Kidneis and Raines, and in expellyng of Sande and stone. In so muche that a gentleman whiche had one of them here, the best of them that I have seen, havyng put it to his arme, he dooeth make hym to expell and caste out muche sande, that many tymes he doeth take it awaie, for that he thinketh that it dooeth hurte hym for to put out so muche and in takyng it awaie, he comneth to caste away from hym, when he feeleth the paine of the stone, and puttyng hym to againe, it doeth take it awaie incontinente, with expellyng of muche Sande and smal stones. I have seen it carried to persones that have been grieved with greate griefe, and paines of the saied desease, and puttyng it to them, thei doe forthwith expell the sande and the little stones, and remain cleare thereof. This stone hath a propertie hidden, by the whiche meanes he doeth greate effectes, to preserve that thei fall not in to the paine of the saied desease, and after it is come it taketh it awaie, or diminisheth it. It doeth make the sande to bee expelled in great aboundance, and likewise stones. It taketh awaie the heate from the raines of the backe, it profiteth in griefes of the stomache, put to it : and above all it preserveth from the saied grief.

My Ladie, the Duchesse for that she had in shorte tyme three tymes, exceddyng paines of the stone, she made a bracelet of them, and she used to weare it at her arme, and sithence she put them to her arme, she never had more paines of the Stone, and so it hath happened to many other that had the like benefit, for the whiche thei are muche esteemed, and now thei bee not so sone had, as at the beginnyng : for that these stones onlely the gentlemen, and rich men have them, and with reason, because thei do suche marveilous effectes . . . "

This jade from the South American continent, which Monardes wrote *piedra de ijada*, was the *chalchihuitl* of the Aztecs. The Spanish rendering *piedra* (stone) *ijada* (sometimes spelt *yjada*[1] or *hijada*) flank or loins (kidney trouble producing tenderness or pain in the loins),

was alternatively written *piedra de los riñones* or *raines*, stone of the kidneys. (The Oxford Dictionary gives *reins*, archaic, the kidneys ; the loins.) Apart from archaic spellings, we have also to deal with the haphazard writings of earlier times. The Monardes extract, Englished, is an example of this.

Nevertheless, in 1569, we have an authoritative writer giving us *piedra de ijada*. In 1598—nearly thirty years later, yet time for Raleigh to have introduced his jade—an English writer, who was also a language expert in his day, gives us *iada*, using, it seems, the Italian rendering and describing the stone as " a kinde of precious stone like an emeraud." From this there would seem to be few obstacles for the establishment of our word *jade*. In 1777 it was spelt *jadde* by one[2] who wrote : " A piece of green nephritic stone, or jadde." As late as 1811, John Pinkerton (the man who coined the word *gemmology*) in his treatise on rocks (Vol. 1. p. 346) gives us " *Jad*—the *Giada* of the Italians. The Nephritic Stone." Here he remarks : " Werner and his disciples have continued the ancient name of nephrite to jad . . . and they divide it into two sub-species, the Oriental, which is brought from China and the East . . . and what they call Beilstein, or Axe-stone, because it is brought in the form of axes from South America, whence it might be strictly called occidental . . . Recent French writers have called it Felspath compact, Jadien, which, they add, is the Jad of the lapidaries, and the Nephrite of the Germans . . . " The French apparently spelt it *l'ejade* and later (changing its gender) *le jade*, so that had we collected the word direct from this source, as with so many of our words, the result could be the same.

We are told that the original Spanish *ijada* for flank or loins descends from the Latin *ilia* meaning loins. As a curative for colic there is an apparent error. Colic is described as a griping belly pain, and the Oxford Dictionary states that the Latin *ilia* for flanks has been confused with the Greek *eileos* for colic. Yet this connection with the word colic seems to have been common in Europe. It may be that pains in the loins as well as pains in the stomach were loosely described as colic. In certain instances kidney pains were interchangeable with the term colic by the same writer. Some Spanish dictionaries render the word *ijada* as both flank and colic. When one reads such statements, as late as the 18th century, that someone had died of a " dreadful cholic " one is left to imagine all

kinds of possibilities. Perhaps the following, written in 1775, is as good an explanation as any : " There is a great likeness of circumstances after colic and cardiac (of the heart) affections, nephritic pains come near and not the least sort which arises in the protruding gland, and the bile duct, or the tenacious back-holding, which originate from the stone in the kidney[1] . . . "

In 1632 a lady in Paris sent a jade bracelet to a friend in Madrid. The friend replied : " If the stone you have sent me does not break mine, it will at least make me bear my suffering patiently ; and it seems to me that I ought not to complain of my colic, since it has procured for me this happiness." If this passage has not suffered through translation, it would appear that the stone referred to was a kidney stone and the affliction described as colic, perhaps loosely meaning pain ; obviously not the belly pain of the dictionary. What appears most likely is that over a period most pains connected with the internal organs were loosely referred to as colic. A contemporary medical man has given some clue to this problem by stating that it is possible to have colic in the kidneys if there is a stone in them.

In 1633, Voiture, the poet, in a letter to Mlle. Paulet, wrote : " Ainsi pour ce coup, l'Ejade a eu pour vous un effet que vous n'attendez pas d'elle." Later, one of his letters appeared in English with the statement : " I perceive there must be found out for me some more substantial remedies than the Ejade."

The spleen stone as a remedy continues, at least, as late as 1725 when Sir Hans Sloane (also a physician and therefore interested in cures) was writing his *Natural History of Jamaica.* In it, (Part II. Book VIII) he makes two entries :

1. " *Jaspis e cinereo viridis.* (*Ash-Green Jasper*).

   This was of a more pale colour than the Spleen Stone, but green as it, having some paler veins in it, and being capable of as good a polish, but such a one as jasper takes, whence it is that I range it here. I found it amongst the pebbles and stones thrown up by the sea.

2. " *Jaspis Viridis. Spleen Stone.*

   This stone which is very hard, is frequently found on the shores of this island, amongst the stones or pebbles common

there. I have taken them up myself about Port Royal, and have had them cut in England, but they proved to be the same with that stone out of which the Indians make their hatchets, wherewith they served themselves in place of iron or steel tools, before the coming thither of Europeans. Of which hatchets I have found one in this island.

"This stone is opaque of a green colour, with some pale veins running through it very hard, and capable of a very good polish.

"They are cut into thin square pieces, and strings being tied to holes in their corners, they are fastened about the arm[1] and thought very much to help in the Stone and Hypochondriac affections. This opinion I take to be owing to a superstition of the Turks and Mohametans I have seen wearing sentences out of the Alcoran in Arabick, etc. wrote upon cornelians, etc. and loged in these grease stones which are hung about their necks or arms, to keep them from the power of the Devil or Diseases, etc.

"This is the Piedra de Hijada of the Spaniards, Pierre de Jade of the French authors, who magnify the virtues of it so as to make them incredible, nay M. Labat, a French late author, would make us believe it cures epileptic Fits. Sir Walter Raleigh first brought some of them to England, giving vast encomiums of them."

The spleen stone, referred to by Sir Walter Raleigh and, as we see, more than a hundred years later, by Sir Hans Sloane, whatever its species, was used curatively, as it was before the time of Raleigh's American expeditions. (The spleen, one of the ductless glands, has a connection with the kidneys that needs the explanation of a medical man to do it justice. The word has a connection also with irritability, a state of mind closely associated, one would suppose, with those suffering from kidney ailments.)

Sir Hans Sloane appears to have made his division on the strength of a slight difference in polish. There would seem to be no reason to assume that he was dealing with two distinct species. Both are *spleen stones*. Both are *Jaspis Viridis*. Yet, of the second

stone at least, he says it is the Spanish *Piedra de Hijada* and the French *jade*. Moreover it is also the ancient material of the Indians. Since the term jade was not then popular, and therefore little understood, this author uses the well-known *spleen stone*. *Jaspis*, a still older word, but obviously understood at that time, must be reserved for a later article.

As an example that the word *spleen*, as well as *colic*, covered a multitude of sins, the following is a quotation from the Appendix of Dr. Schliemann's *Ilios*[1], p. 724, Appendix V, Medical Practice in the Troad in 1879, by Professor Rudolf Virchow. " Tumours of the spleen are common among the people, and the term *spleen* (σπλήν) is generally employed to express the disease. Many apparently similar cases fall under the same term. Thus . . . one day a little boy was brought to me with a large echino-coccus, and my assurances that it was no " spleen " were hardly believed. A man whom I consoled with the assurance that his wife had no " spleen," but that she would present him with a child in a few months, was quite panic-stricken, for they had been married for seven years without having children . . . Another, who believed himself to be sick of the spleen, had a most developed purpura . . . "

The chart below is an attempt to clarify the development of the term *jade*.

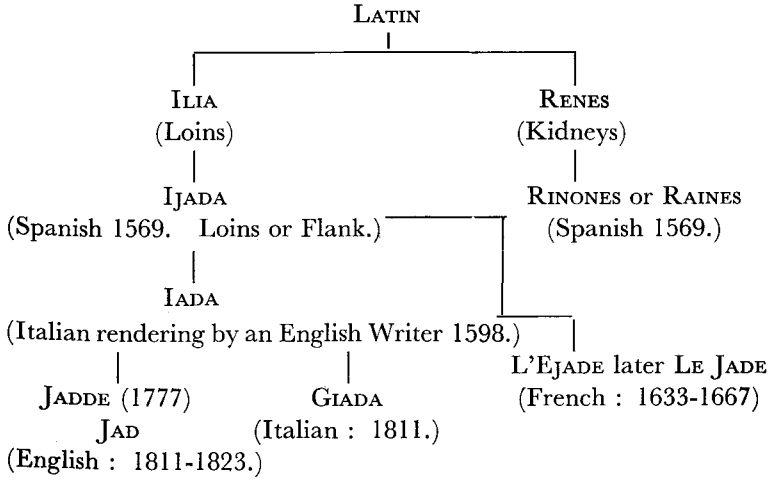

(A few years later Jade was spelt in the modern way.)

Although Monardes was writing in his own language as early as 1569 and it was Englished by John Frampton in 1577, most writers still employed the, then, more literary Latin. So that, instead of writing *piedra de ijada* or *piedra de los riñones* it would be written *Lapis Nephriticus*, again *lapis*, stone, *nephriticus*, kidneys. (From the Greek for kidney, *nephros*). It means therefore that while our word *jade* stems from Monardes (or evidence points that way, for the Spaniards in their heyday were asserting their nationalism) this new rendering was attached to material known generally as *lapis nephriticus*. That is, to all intents and purposes, it was one and the same material and accepted as such. We must remember too that the spleen stone was already familiar to Raleigh before the advent of *piedra de ijada*, so it seems likely that this spleen stone was also the established *lapis nephriticus*. *Lapis nephriticus* was the latin literary term that covered two[1] and perhaps many more local terms. When the writer, in 1777, wrote " nephritic stone or jadde " he established the connection clearly. Here therefore these terms part company, from the investigator's point of view. The search now is for *lapis nephriticus*.

REFERENCES

1. See *Journal of Gemmology*, Oct., 1954, page 337.

2. *Investigations and Studies in Jade.* Bishop.

3. i and j for long indicated the same sound. A sound for j seems to be the later one.

4. Georg Forster (1754–1794). *A Voyage Round the World*, 1, 161.

5. Johann Friedrik Cartheuser.

6. It is interesting to note that nearly always the *cure* was effected by the stone's contact with the arm.

7. *Journal of Gemmology*, Oct., 1954, p. 339.

8. The term *jadeite* does not concern us here. It is the word suggested by A. Damour, the well-known mineralogist, after extensive investigation, when he established that two distinct species had been covered by a single term. In a paper by F. W. Rudler, read before the Anthropological Institute of 1891, is the following : " He (Damour) therefore proposed to establish a new species under the name of JADEITE, retaining the old mineralogical term NEPHRITE for the typically Oriental jade."

THE FIRST HALF of the 19th CENTURY

by M. D. S. LEWIS, A.R.C.S., B.Sc., F.G.A., C.G.

IN some respects the years 1800-1850 form the most depressing period in the history of jewellery. Towards the close of the 18th century, design and workmanship had reached their apogee, yet in the short space of fifty years they were almost at their nadir. Nevertheless, the period is of considerable importance since the designation " antique " usually depends on some date associated with this era. In England an article tends to be regarded as such if over one hundred years old, whilst Americans mainly specify 1830 as the qualifying date. Within the half century originated many of those unlovely pieces, on the acquisition of which so many jewellers have expended so much time and treasure.

As far as Western European jewellery is concerned French and English influences predominated. The Italian school of Castellani, Novissimo and Giuliano, which attained such proficiency in filigree and enamel work flourished mainly after 1850. Towards mid-century Viennese jewellery had established a great reputation for fine workmanship and elegance of style, without, however, influencing the trend of fashion.

From the 17th century onwards, there have always been two main classes of jewellery. The "grand" jewellery worn principally in Court circles by the richest aristocracy and on the other hand the " popular " less expensive type of the " bourgeoisie." The former tends to be international showing no great variation from country to country and one must often look to the latter to discern national characteristics.

Three main currents compose the stream of jewellery from 1800-1850, merging, separating, crossing and re-crossing. First, a persistent recurrent return to Gothic and Mediaeval designs. Secondly, a striving after " naturalism "—the exact reproduction in jewellery of insects, boughs, sprays, etc. Often petty and banal in its effect, the full flowering of this tendency falls rather outside the period under review—not until the 1860's, when Massin, possibly the greatest of French jewellery designers, was producing

his superb sprays, prototypes of so many elegant patterns which have followed. Thirdly and probably most interesting to us, the typical gold and silver semi-precious* jewellery set with aquamarine, amethyst, topaz, and similar stones, which will always be associated with Victorian England.

The 18th century—age of elegance—came to an end, not in 1799, but with the French Revolution in 1793, when the guillotine claimed the heads which had borne the crowns, the aigrettes and the diadems with such charm and distinction. Every article of jewellery denoting wealth or aristocracy vanished from view, much of it for ever, and the only ornaments dared to be worn were emblems of Republicanism and Equality, such as medallions fashioned from stones of the Bastille and miniature guillotines.

An even worse blow to the art of jewellery, one from which it took nearly a century to recover, was the abolition in 1791 of the title " Master " of the Corporation of Parisian Jewellers. This privilege had imposed on the aspirant an obligation to produce entirely by himself an outstanding article of jewellery in the grand manner. The rigid but beneficial discipline of the 18th century Trade Guild gave way to supervision by the State with the result that apprentices had no longer to learn every aspect of their craft.

The beauty of 18th century jewellery was due, in part, to the fact that it was conceived as an artistic entity, executed throughout by one pair of hands. When later in the 19th century the Guilds were revived in a modified form, the age of specialization had been reached and jewellery manufacture was split into the two main (and often subconsciously opposed) processes of mounting and setting. The mounter produced the metal structure and having done so his interest in the article ceased. The setter received a mount in the design of which he had played no part ; his duty was merely to set securely the stones provided.

With a gradual subsidence of the Terror, the jewellery workshops began to re-open and in the absence of any special impetus, they resumed in the style which had been fashionable before the Revolution. This was the " style Pompadour," the antique classical fashion which had its origin in mid-eighteenth century, when the discovery of the ruins of Herculaneum and Pompeii had evoked an

* (The author prefers to use this term because he considers it suitable for describing these gems. Although much used in Victorian England, it is less used to-day.—EDITOR.)

intense interest in the culture of ancient Greece and Rome. Enthusiastically endorsed by Madame de Pompadour, beautiful and cultured mistress of Louis XV, it highlights a consistent feature of French jewellery—the influence of the Royal favourite. Diane de Poitiers, who fostered the 17th century vogue for black and white enamel, " La belle Ferronière " who originated the fashion of forehead ornaments, Madame de Sévigné, who gave her name to the series of bow brooches so popular in the 18th century, Madame de Pompadour, Madame du Barry, Marie-Antoinette, the Empress Josephine and lastly the Empress Eugénie—they all crowd into the long line of elegant queens, mistresses or friends, who in capturing the heart of the King, left also an indelible mark on the history of jewellery.

In England there is but one similar instance—Queen Elizabeth I. Her cameo portrait, the centre piece of so many 16th century jewels, is the outstanding feature of Elizabethan iconography, but this was a tribute to her imperial qualities, not to her beauty or leadership in the world of fashion.

In Paris at the turn of the century, the painter David, at the height of his fame and influence and dominating early 19th century French art, was the arch-exponent of the pseudo-classical style. What seemed right and proper, however, against the background of 18th century taste and discernment appears ludicrous in its excess amidst the ruins of the post-revolutionary era.

Women would dress as nymphs and Greek Goddesses wearing three bracelets on each arm, a large breast ornament, big round ear-rings and a multitude of rings in the Roman fashion. A celebrated Parisienne, Madame Tallien, clad in flesh-colour Greek tunic paraded in the Champs Elysées. A doctor wrote satirically, " Nothing is more agreeable than your modern costumes, your Greek tunics, which leave chest and arms uncovered ; nothing is more seductive to your admirers and above all more lucrative for us doctors." From the Journal de la Mésangère came the dolorous announcement that, " Madame X, young, pretty, amiable and rich, died on the 13th of this month for having wanted—contrary to the representations of her husband—to dress herself in the current fashion . . . Mme X is the victim of that deplorable mania for uncovering throat and arms like your Grecians. What is pleasing in Athens is fatal in Paris ; that is what the ladies forget."

Against such a background it was inevitable that the cameo—most classical of ornaments—should become the popular jewel. It was frequently mounted within a border of gold, ornamented by Greek-key motifs which conformed with the current style. Coral, too, now began its fifty years of popularity, perhaps because it was cheap and its employment in jewellery entailed little skill in mounting.

Around 1800 the growing stature of Napoleon began to dominate the Parisian scene. He loved spectacle and entertainment, whilst his Empress Josephine became one of the most extravagant purchasers of jewellery even in the opulent history of the French Court. In six years she was reputed thus to have spent over twenty-five million francs.

Marengo, Austerlitz, Jena, Wagram—a succession of brilliant victories made him the idol of Paris, initiator of a growing era of Court luxury in which he assumed the role of a new Caesar. In the Louvre, the colossal picture by David of his coronation in 1804 must rank as an outstanding historical record of contemporary jewellery. It shows, above all, the veritable passion for cameos which pervaded Paris at this time.

The Empress Josephine, as she kneels to receive her crown from the hands of Napoleon, wears a cameo bracelet over her gloved hand, in contrast to her other most magnificent jewellery. The Queen of Holland wore a belt ornamented by cameos and the two Duchesses in waiting wear diadems set with cameos. The crown of the Emperor was decorated by engraved hard stones and antique cameos.

Except for those pieces surviving from the 18th century, much Napoleonic Court jewellery was opulent and vulgar, mainly flat, lacking in artistry and with coarse heavy settings tending to magnify the size of the stones. Eagles, laurel leaves, imperial devices incorporating the initial " N " were frequent motifs. Bracelets were very popular and worn in pairs, one on each arm. The wearing of a single bracelet is a comparatively recent custom. Tiaras worn unbecomingly low on the forehead were almost *de rigueur*. The original " Laurel-Leaf " Tiara, copied so frequently, made its first appearance from the workshops of Nitot, Napoleon's own jeweller, an allusion, no doubt, to his client's military triumphs.

Outside Court circles it was a different story. The bourgeoisie wore little jewellery and that very modest and discreet. Portraits by well known artists, indicating their patrons were wealthy, show

little ornament. But in any event the era of Napoleonic luxury was short lived and with Waterloo rising menacingly above the horizon, we must now turn attention across the Channel.

From the Middle Ages to the end of the 18th century, English tastes had followed closely on those of France. In matters of jewellery, England had usually been content to seek guidance from Paris. There were minor exceptions of course, e.g. the manufacture of buckles, in which English makers were pre-eminent, but generally speaking the English fashion was somewhat of a tardy watered-down version of the French. The first half of the 19th century is unique, in that for the first time " le style anglais " was often preferred in France. The ravages of revolution and invasion, from which England remained happily free, could not fail to leave their mark on French art and industry. Throughout the Napoleonic wars England's mastery of the sea enabled her to import great quantities of semi-precious stones—amethysts, topazes, aquamarines—from South America and her early industrialization led her to devise inexpensive methods of manufacture. By the time France had recovered, England had (in certain directions) established a considerable lead, not lost until mid-century.

There is some evidence that the 19th century vogue for gold and semi-precious stone jewellery originated in England. In 1815 the Parisian jeweller, Odiot, sent his son to London to study the new industrial techniques in jewellery manufacture. Dr. Joan Evans attributes English origin to the fashion for " cannetille " in mounting amethysts, topazes, aquamarines and other gems. " Cannetille " is the name applied to those coiled wire pyramidal ornaments which together with matted and filigree wire work formed the standard motifs in so much semi-precious 19th century jewellery.

At first these ornaments were well and attractively made, often in three-colour gold and hand-fashioned mounts, but as the century progressed a growing army of Birmingham tool makers produced a vast number of cheap stampings in the form of standardized ornaments, galleries and collets which facilitated the mass production of the typical " Victorian " jewellery. On the Continent it never attained the popularity enjoyed in England, possibly on account of greater mechanical efficiency here or perhaps because of a higher standard of taste there.

To return to Paris of the Restoration (1815 to 1830), where a totally new order prevailed. Louis XVIII, old and fat, preferring

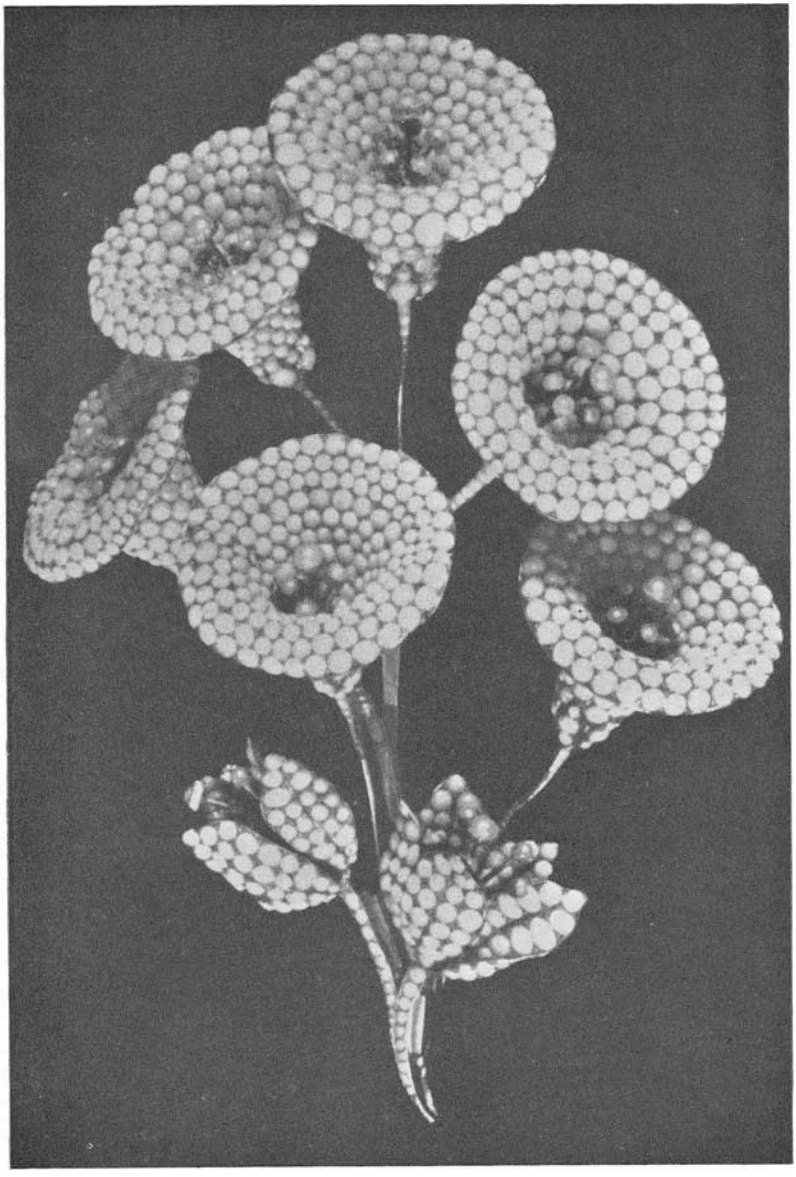

Convolvulus spray brooch closely set with turquoises French-Circa 1840.

(From the Victoria and Albert Museum, London Crown Copyright)

tranquillity to feasts, now ruled over a restored but impoverished aristocracy and the pendulum had swung to the other extreme. The classical style was dead, David had been banished and prudery pervaded womens attire. Every part of the female form was heavily veiled and a mediaeval Gothic fashion was now adopted. Receiving its initial impetus through the discovery of a new picture of Joan of Arc it was enthusiastically adopted by a Mademoiselle Mars, popular actress, and by la Duchesse de Berry, unchallenged leader of Parisian society. For formal occasions huge jewelled *ceintures* in the mediaeval manner were worn and in the lesser jewellery can now be detected the three principal 19th century characteristics to which earlier reference has been made—bias towards mediaeval and Gothic designs, naturalism and the combination of gold with semi-precious stones.

About 1820 the " Ear of Corn " began to enter jewellery design to remain steadily in favour for many years. In diamonds especially and often in turquoise and gold it seems to predominate in tiaras and sprays of the period. Butterflies were also much in evidence but one of the most characteristic features of early 19th century jewellery was the extraordinary popularity of the serpent. This reptile writhed its way into every article of jewellery—necklaces, belts, bracelets, rings, brooches and ear-rings. It coiled itself around stems of gold and silver fashioned to look like wood and very frequently was depicted, held at bay by a bird defending its nest. If no other role could be assigned, it justified its existence by suspending a heart from its mouth. Occasionally most immense technical skill would be lavished on these ornaments and some perfectly magnificent gold necklaces were made in snake form, in Paris around 1825, fully articulated and superbly enamelled in black and many other colours.

Cameos retained their popularity and were even copied in chocolate with white icing. Coral remained in favour, malachite is characteristic of the years 1820-1840, as were also *sautoirs* and suites of moss-agate. Chains were worn in large numbers to meet the new short-waisted style. The 18th century English fashion of faceted cut steel jewellery was much in evidence. Originally hand cut and polished it was at first surprisingly expensive. A bill rendered to the Empress Marie-Louise specifies 1724 francs for a suite of cut steel comb, chains, bracelets, etc. Even Napoleon's Empress had not disdained such non-precious jewellery. In 1819

a Frenchman—Frichot—discovered a mechanical method of manufacture, causing the price to drop sharply. It is interesting to note that by 1828 a French jeweller—Bernauda—was already using Platinum.

The perennial vogue for mourning jewellery remained strong. The woven hair jewellery, later wrought with such infinite skill by Victorian ladies, had originated much earlier but reached its apogee around 1840. In Paris black jewellery became almost a necessity when, in 1820, the Duc de Berry was assassinated and the city plunged into mourning. This was the heyday of " Berlin Iron-work " jewellery—long necklaces, bracelets and brooches of black cast iron links and medallions in not unattractive patterns. Originally made around 1804 in Germany where in the Napoleonic wars patriots surrendered their gold for the benefit of the Fatherland, the vogue spread to France and much so-called Berlin iron-work jewellery was actually made in Paris to meet the demand. Later, of course, Whitby entered the field and supplied jet jewellery to all parts of the world for half a century. In this it was helped by the long years of mourning observed in Queen Victoria's Court. The beginnings of the Whitby jet industry lie about 1809. By 1850 it was at its zenith and almost extinct by 1870.

The Restoration years had ushered in social changes of great significance in France—impoverishment of the nobility and rise of the commercial class. As in England, this was the seed from which grew the passion for cheap show of gold so characteristic of most of the Victorian era. Gold was the outward symbol of wealth ; the more the better. Wafer thin stampings, leaves springing from nowhere, scrolls and shells designed to give a pseudo-rocaille effect, flat strips of gold contorted into clumsy convolutions, the minimum of work, the maximum of show—these were the hall-mark of mid-19th century " popular " jewellery.

In 1830 with the accession of Louis-Philipe, a new tendency appeared in European art ; it was the beginning of the Romantic age with the pseudo-Gothic as its principal feature. In this, English influence was strong ; the spell of Byron and Scott had spread far beyond these shores into Europe. The fashion for Scotch jewellery, which flourished from 1830 onwards, was eagerly embraced in Paris. Queen Victoria's liking for everything Scottish was not without effect.

The few remaining vestiges of 18th century influence, e.g. very finely pavé-set small pearl and turquoise work on watch cases, now disappeared and generally speaking the period 1830-1848 is one of the least distinguished in jewellery history. There are few records of anything fine produced in the " Louis-Philipe" era; the word " ordinary " is probably the most flattering description which can be applied to the jewellery of this period.

Seed pearl work was very popular, reaching its zenith about 1837. Italian Mosaics and lava cameos depicting scenes of Italian archaeology made their appearance in gold mountings. The English were fast developing their zest for foreign travel and voyagers liked to bring home a souvenir of their continental holidays. This may also account for the continued popularity of coral, the liking for which remained strong until about 1845. Single bracelets replaced the pair always worn hitherto. Enormous buckles at the waist, charms and three similar brooches worn one above the other were very popular.

That most unbecoming of all ornaments—the Ferronière—remained consistently in vogue. This was a jewelled ornament worn on the forehead, in the manner adopted by the subject of Leonardo da Vinci's portrait, " La Belle Ferronière," in the Louvre. At one time this was mistakenly held to be the beautiful blacksmith's wife who became the mistress of King François I of France in his declining years. In a picture of one of Victoria's early courts, the Queen and many of the ladies are seen wearing ferronières.

Chrysoprase and ruby parures were popular about 1830. The typical Victorian pavé-set turquoise work in which small stones were set in rows of geometrical precision may be said to date from about 1835 though manufacture continued through the greater part of the century. Although the design of such pieces is often negligible, the quality of the setting cannot fail to arouse admiration and they constitute one of the minor triumphs of 19th century technique. The strange desire to imitate wood in silver and gold with faithful detail had originated quite early in the century but was now at its strongest. Victorian brooches fashioned like branches of a tree are very characteristic of the period. A more pleasing note is struck by the " Pampille " style of about 1840—cascades of diamond collets, etc. hanging gracefully from a floral ornament. Often such pieces had translucent green enamelled leaves.

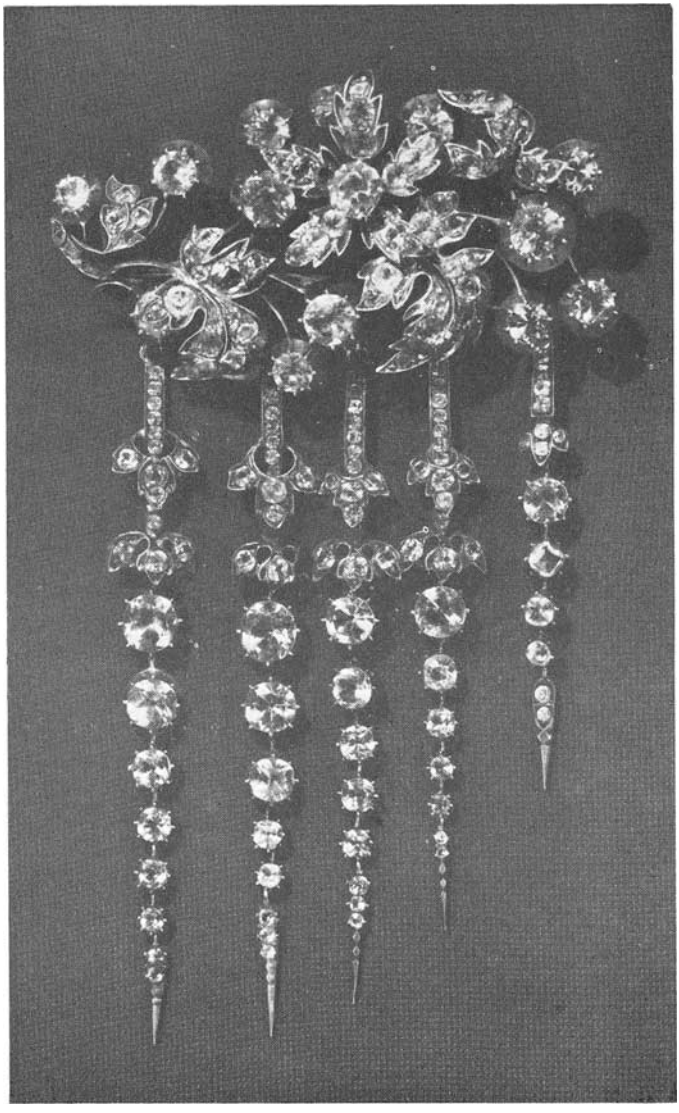

Ornament in the "pampille" style, very typical of French jewellery - cira 1840.
(Courtesy Frederick D Meller, London)

Meanwhile a new school of French jewellers was maturing. Led at first by Fauconnier who inaugurated a campaign against

" the English style " its most outstanding product was François Froment-Meurice who dominated European jewellery for some years. He revelled in the pseudo-Renaissance style of sculptured figures, knights in armour, mythical beings, lords and ladies in mediaeval costume. He was the arch-exponent of the Romantic and, as an obituary tribute reveals, also of the Naturalistic style. He did not make much jewellery himself but was a good organizer and businessman and although he probably produced a few " grand " pieces his principal achievement lay in the " pseudo-Gothic " style. He loved the human figure and his chef-d'oeuvre is the Gothic Bracelet depicting scenes from the life of St. Louis, which was particularly acclaimed at the Great Exhibition of 1851. He died suddenly in 1855 at the early age of 53 amidst a chorus of regrets. With typical Gallic fervour Théophile Gautier wrote—" It would be a lengthy task to recount the numerous works which have earned for Froment-Meurice the reputation which he leaves . . . He knew how infinitely to vary the fantastic creations of the world of ornament, where the female springs from the calyx of a flower, where the chimera ends in foliage, where the salamander writhes in a fire of rubies, where the enamelled lizard glides under emerald foliage . . . He would place waves of pearl, coral and mother of pearl under mermaids of silver with hair of green gold ; under the feet of terrestrial nymphs he would put a ground of diamonds, topazes and precious stones. He would combine grape-gatherers of ivory with vine branches of metal and set them in his snuff-boxes . . . He made his " boutique " a glittering Aladdin's cave, the treasure of the Calif Haroun al Raschid, the Wells of Aboulcasem or the Green Vaults of Dresden."

In spite of such enthusiasm the dust of time has settled heavily on Froment-Meurice and his work. Little seems to have survived and if it had, it is very doubtful whether, in spite of greater " antiquity," his jewels would attain the popularity of those by his successors, e.g. Giuliano or Fabergé. Deeply steeped in " Gothicism " the majority of his pieces would lack feminine appeal. The splendid original jewels of Gothic and Renaissance times are one thing ; the pale imitations of 1850 France are quite a different matter. In any case mediaeval and Renaissance jewellery was worn as much, if not more, by men, than by women and as Mr. Clifford Smith remarks, " Ladies have seldom a taste for archaeology." Froment-Meurice was a product of his age—the

mediocre era of Louis-Philipe—at whose simple and inelegant court the Queen Amelia never even wore the Crown jewels.

Other prominent jewellers of the period were Christofle, specializing in filigree work, and Dafrique who received technical advice from Gay-Lussac, one of the fathers of modern chemistry. Dafrique was expert in enamel work and revived the quite attractive idea of ornamenting cameos with miniature jewels, e.g. a tiny necklace around the throat of a negress, carved in two colour agate.

The Revolution of 1848 dealt another blow to French jewellery and several jewellers—Marchand, Morel, and others left Paris to work in London. It was not long, however, before the characteristic French resilience re-asserted itself and at the Great Exhibition of 1851 French jewellery exhibits secured sixty per cent of the awards.

This brings us almost to the end of the period under review, but a brief glance of what lay beyond may perhaps be permitted. A period of great brilliance and prosperity lay ahead for French jewellery in the second half of the 19th century. The new Emperor, Louis Napoleon, was determined to give Paris unchallenged leadership in fashion and elegance. In this, he was ably assisted by his beautiful wife Eugénie, who, from the moment she emerged as Empress on the steps of Notre Dame after their wedding, " fairer and more dazzling than the sun," exerted a profound influence on all aspects of fashion. She was a great lover of jewellery—particularly emeralds. She knew when to wear it and when not. Winterhalter's superbly graceful picture of 1855 shows her seated among the ladies of her court, they, all bedecked with jewellery whilst she, the centre-piece, wears no ornament whatever ; beauty unadorned sufficing. The Parisian stage was to be filled by a host of accomplished designers and craftsmen—Lemonnier, Mellerio, Falize, Massin, Viennot, Fontenay, and others. All this, however, belongs to another chapter and a later period. The truest evaluation of the years 1800-1850 is probably to be found in Mr. Clifford Smith's words, " The whole period (19th century) was an eclectic one and the majority of its productions, the result of nothing less than aimless hesitation and fruitless endeavour to revive the forms of the past, display at least doubtful taste."

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Gemmological Abstracts

BURBAGE (E. J.). *Dichroscope exhibited at Haslemere educational museum in England.* Gems & Gemology, Vol. VIII, No. 3, pp. 89-91. Fall 1954.

Describes an ingenious piece of apparatus constructed for exhibitional purposes to illustrate the effect of dichroism to the lay mind. The apparatus consists of a circular opaque disc having a thin radial or diametrical slit containing a strip of polaroid. A dichroic mineral placed behind the disc will show, for slow rotation of the disc, the two dichroic colours separately seen at positions every 90°. On speeding up the disc persistence of vision will ensure that a coloured figure will be produced in the form of a Greek cross. In the actual piece of apparatus the disc was rotated at speed, by a circumferential drive from a small A.C. mains driven motor, for it was rightly considered that more interest would be aroused by a demonstration involving movement. The dichroic plate used, in order to get a uniform field, was not a mineral, but a synthetic red dichroic filter, which showed red and colourless, to which an Ilford medium green filter was bound up, so as to complete the Greek cross. The assemblage was completed by a lamp, a ground glass screen and a low power lens, the whole being cased in a wooden cabinet which embodied the necessary electrical switches and connections.

5 illus. R.W.

SINKANKAS (J.). *The gem and ornamental stone market in Hong Kong to-day.* Gems & Gemology, Vol. VIII, No. 3, pp. 84-87 and 92. Fall 1954. (*Journ. Gemmology Abs.*, Vol. IV, No. 8, 1954, p. 353.)

The second and concluding instalment of this article.

Nephrite is the jade used from the earliest days of Chinese carving. Whitish shades commonly used which necessitate dependence upon excellence of form and deeply incised patterns. As outsides of boulders usually have weathered brownish-red skin this is commonly used to produce colour effects. An intense yellowish-green nephrite is most prized. A dark green nephrite with a

blackish cast and somewhat fibrous is used for the largest carvings. It is called " Jasper jade." The Chinese take the view that inferior jade-like minerals are jades in infant stages. " Soochow jade " (a serpentine) is called " New jade " as are other finely granular minerals. " Jasper jade " the name given to dark green varieties of nephrite are considered mere adolescents compared to the final product—*old* jade—the fine grained lighter hued nephrite. Jadeite carvings often lack artistic merit. White jadeite is often seen as eggshell carvings. Coloured variations more common, but jadeite is less reverenced than is nephrite. The wooden bases used to support carvings are accorded the same care and treatment as is the carved piece itself, and the packaging is always in silk covered wooden boxes in which the piece is placed upon recessed cushions. This differs from the Japanese method of packing in which the boxes are without lining. As the result of the Communist domination of the Chinese mainland much wealth has filtered into Hong Kong in the form of all kinds of Chinese art. Some carving is still going on in Communist China. There are no import or export taxes upon gemstones and carvings by the Government of the Crown Colony, yet prices are high and wages are steadily rising. Quoted cost of production compare closely with Japanese and Idar-Oberstein productions. Hong Kong is still a buyers' market but is rapidly reaching a point where its products will no longer be competitive. R.W.

COPELAND (F. O.). *An interesting discussion of an ancient art.* Gems & Gemology, Vol. VIII, No. 3, pp. 93-95. Fall 1954.

Tells the story of one of the few remaining gem engravers in North America, and possibly the only one in Canada. Apprenticed in London (England) the engraver tells the story of the dying industry—dying because no fresh apprentices are coming along to train for the exacting work. Notes on black onyx, the tools used and how the work is done are mentioned in this article written in popular style. R.W.

ANDERSON (B. W.). *A new substitute for lapis lazuli.* Gems & Gemology, Vol. VIII, No. 3, pp. 88-89. Fall 1954.

A further report on the new lapis-coloured sintered synthetic spinel, which was reported in the *Journal of Gemmology* for July (Vol. IV, No. 7, 1954, p. 281). New information is that some

specimens of the material are now supplied with specks of " pyrites " which are in fact real gold. Also that the pieces so far seen are cut as seal stones in cut-corner rectangles or as ovals. R.W.

SCHLOSSMACHER (K.). *trans. by* EHRMANN (M. L.). *The origin of gemstones.* Gems & Gemology, Vol. VIII, No. 3, pp. 81-83 and 92. Fall 1954.

A general survey of the origin of gem minerals. Largely a repetition of an article which has appeared in Zeitschr.d.Deutsch.-Gesell.f.Edelsteinkunde. (*Journ. Gemmology Abs.*, Vol.IV, No. 7, p. 315.) R.W.

SHAUB (B. M.). *Notes on the fracturing around zircon and other gemstone inclusions.* Gems & Gemology, Vol. VIII, No. 3, pp. 78-80. Fall 1954.

The author discusses the cause of the so-called " zircon, pleochroic or radio-haloes." The appearance of the haloes is first discussed, and followed by the author's theories. This theory is that the inclusions are usually unstable and revert to an isotropic and amorphous structure (metamict ?), with decrease in density and increase of volume which induces a pressure on the host mineral which cause the cracks (haloes) ; the colour of the cracks being due to alteration products, probably iron, working in along them. The risk of breakage of gems containing zircon haloes is suggested. R.W.

BARBER (R. J.). *The nature of jade* (*Part II*). Gems & Gemology, Vol. VIII, No. 3, pp. 67-77. Fall 1954. (*Journ. Gemmology Abs.*, Vol. IV, No. 8, 1954, p. 355.)

The second and final instalment of a monograph on jade. This second instalment discusses extensively the geology and mineralogy of the jadeite deposits of Upper Burma. During the rainy season mining is done along the high-bench conglomerate resulting from extensive surface erosion during Tertiary times. This conglomerate contains jadeite boulders. Flood waters of the watershed cut through these beds further sorting the jadeite boulders along the river beds. When rains cease the bedrock outcrops are mined. The succession of rocks, from the surface downwards, at the Tawmaw Dwingyi mines are tabled, and the names given by the Burmese traders to the different types of jadeite are given. Nearly all Burmese jadeite eventually reaches China, either legitimately or otherwise. Of scientific interest is the finding

of a small body of jadeite in Nagata province, Japan. The "Oceanic jade," the worked pieces found in many islands of the Pacific, is said to be serpentine and not nephrite. The nephrite found in the South Island of New Zealand is well discussed. The Maori names for the different types are given, as also the geology and mineralogy of the area where the nephrite is found. There is a small find of nephrite reported from the island of Celebes. The sources of jade in the Americas are given, with the historical accounts of the finding of nephrite in Alaska, in British Columbia, Wyoming and California entertainingly written. The problem of the source of the jadeite used for the artifacts found in Central America is discussed. Analyses of these jadeite pieces, which spread from Mexico to as far south as the Amazon, show that they differ from the Burmese jadeite, and that these archeological jades form three distinct groups—the Mexican, the Guatemalan and the Costa Rican. The writer considers that the material used was locally found and gives his reason for so doing. The article ends with a short summary.

8 illus. R.W.

ANON. *Diamonds.* Imperial Institute Commodity Leaflet (*New series*), No. 19.

A four page brochure giving bare facts about diamonds, diamond recovery, marketing and uses. The world yearly output of diamonds is about 18 million carats and the Commonwealth produces about one third of this. The value of the diamonds produced in the Commonwealth for 1952 is tabled. Foreign sources are given. The cause of the South African pipes, and the method of mining for the diamonds which they contain, are told by prose and picture. In the section on alluvial deposits mention is made of the Orangemouth deposits where the diamonds have been washed back from the sea on to the beaches and covered by sand to a depth of some seventy feet. After their long immersion the diamonds had become salt-coated so that they have lost their affinity for grease and require to be reconditioned by treating with fish-oil and caustic soda, or the smaller particle concentrate is treated by electro-magnetic separation. The methods and the styles used in fashioning are given. The last page tells the story of the use of diamonds in industry. The price is 4d. per copy.

11 illus. R.W.

MARCHER (G. H.). *Detection faceted glass gemstones.* Mineralogist (Oregon), Vol. XXII, No. 11, pp. 421-424, November '54.

An article, intended for the amateur, giving those characteristics of glass gems which may be observed by the use of a lens, a pocket knife or a hardness point of apatite. Points to notice are itemized and reasons are given for the causes of such characteristics.

The glass melt, " metal " as it is termed, is stirred with long poles which causes air to be entrapped. Because the air always tends to expand during the heating of the " metal," the bubbles shape themselves into spherical forms. Only synthetic stones show bubbles with spherical forms. Cavities in natural stones are always irregular. Imperfect mixing of the " metal " causes layers of different optical density and show up as irregularly curved lines termed " striae." In the synthetic stones such " striae " would be regularly curved and concentric ; and in genuine stones similar lines would be straight.

Glass gems are made by pressing the molten glass in brass or steel moulds. On cooling the facet edges harden first and the centre of the facets later, these then tend to shrink producing a depressed centre or shrivelling of the centre surface. Cheap grades are left like this, or they may have the table polished on a tin lap, or in better qualities the other crown facets may also be " tin cut." Most frequently the back facets are left just as they come from the mould and definitely indicate the once molten condition. Natural and synthetic stones must always have ground and polished facets, and cannot have shrivelled facets. The girdles of glass imitations will often show where the glass has been squeezed out between the two halves of the mould. In cheap stones this is merely chipped off leaving a glassy edge, or if a better grade may be " fire polished " after being ground off vertically. This effect is not seen in genuine stones.

The body colour of glass imitation stones is always " too good." Idealized colours should always arouse suspicion. Most gemstones, except diamond, zircon, sphene and demantoid, show little prismatic " fire," while the paste gems often show a good degree of dispersion. Hardness testing, using a penknife or a piece of apatite on an inconspicuous corner of the stone is recommended. A note is given on some special glasses, particularly the harder (6½ Mohs) " hard mass." These stones have little dispersion and are limited to imitations of sapphire and emeralds, but the blue

colour is, since the advent of the synthetic sapphire, not often seen, but " hard mass " emeralds are still sold. Such stones are finished all over. It is suggested that a collection of gemstones should be accompanied by an assortment of glass gemstones for comparison.

R.W.

SWITZER (G.). *29th annual report on the Diamond Industry*, 1953. Jewelers' Circular-Keystone, 10 pp.

The report mentions briefly the technological work of J. F. H. Custers and work of the Diamond Research Laboratory of Johannesburg. Artificial coloration of diamonds, improved means of recovering small diamonds and abrasion hardness of diamonds were some of the problems investigated.

Sales of gem and industrial diamonds during 1953 totalled £63,000,000 (£72,000,000 in 1952). World production was approximately 12,100,000 carats, the highest in history. The Belgian Congo continues to be the world's largest producer of diamonds in terms of quantity, although second to South Africa in value. Most of the Belgian Congo output is of industrial use only.

S.P.

DAKE (H. C.). *White jade mined.* Mineralogist (Oregon), Vol. XXII, 10 October, 1954, p. 338.

A report of an occurrence of white jadeite at Clear Spring Mine, in the jadeite area of San Benito County, California. S.P.

ALTMAN (J. D.) *Spotlight on Australian Opals.* Lapidary Journal, Vol. 8, 4 October, 1954, pp. 304-312. (*Journ. Gemmology Abs.*, Vol. IV, No. 8, 1954.)

The second part of a short review of Australian opal fields, the problems of mining and future prospects for the industry. After sixty years of opal production no advance in mining technique has been made, and tools similar to those used in the early days are still the main implements. The scarcity of rough opal has caused many to leave the opal fields for more lucrative work, even though there is a great demand for good quality stones. The author suggests that the economic prosperity of Australia has greatly influenced opal production, and that a big immigration programme might help in attracting new adventurers in the opal fields.

S.P.

———*Australian Opal production.* Mineralogist (Oregon), Vol. XXII (10), October, 1954, p. 346.

A very condensed account of information that has been stated by the author elsewhere. S.P.

BROSE (H. W.). *A short history of faceting.* Lapidary Journal, Vol. 8 (4), October, 1954, pp. 314-322; Vol. 8 (5), pp. 446-452.

Greater use of the many works which the author has undoubtedly consulted would have made this brief history of even more value. The faceting of gems is traced to a much earlier period than the often accepted fifteenth century, and the story of Louis de Berquen of Bruges placed in its proper order of events. The author suggests the early 1300's as the probable time of the introduction of facet cutting in Europe, and gives 1870 as the time of its introduction into America, and there it did not become general until the amateur lapidary took it up. S.P.

WEBSTER (R.). *Stichtite—a mineral new to gemmology.* Gemmologist, Vol. XXIII, No. 280, pp. 211-212, November 1954.

The article is actually a report of the Geologist's Association annual meeting and exhibition, held at Chelsea Polytechnic. Among the exhibits were specimens of stichtite both rough and cut as cabochons. Stichtite is an alteration product of serpentine and was first found at Dundas, Tasmania. Other sources are Algeria, the Black Lake district of Quebec and from Rhodesia or Transvaal. The material shown was said to have come from Rhodesia. The material made attractive lilac-coloured cabochons somewhat like lepidolite but without the micaceous spangles of the lithia mica. The data (taken from literature) are given as hardness 1·7, density 2·16 and refractive indices 1·542 for the ordinary ray and 1·516 for the extraordinary ray. The negative birefringence is 0·026. The rough material appears to be somewhat fibrous and of hexagonal symmetry of crystallization. Some luminescent properties are given. The article describes other exhibits, particularly some new gemstones in the collection of the Geological Survey Museum which were on show at the meeting. P.B.

WEBSTER (R.). *Imitation turquoise from the U.S.A.* Gemmologist, Vol. XXIII, No. 279, pp. 190-192, October 1954.

Reports the result of an investigation into the characters of an imitation turquoise presumably made in the United States of

America. Some other data on other imitations of turquoise is given. The U.S.A. specimen was found to have a hardness of $2\frac{3}{4}$, a density of 1·85 and a refractive index of 1·56. The specimen is a good turquoise colour and "veined" convincingly. Chemical tests showed the presence of copper, phosphate and possibly some aluminium. Calcium was not present. No decisive absorption was observed. Luminescent characters are given. Other turquoise imitations mentioned are a "reconstructed turquoise" made from finely powdered ivory stained with copper stain and bonded with cement. "Viennese turquoise" is said to have a density of 2·4 rising to 2·7 after thorough soaking in water ; and an R.I. of 1·45. Other imitations mentioned are stained chalcedony and coloured plastics.

1 illus. P.B.

Meldinger fra Norges Gemmologiske) Selskap. (Journal of the Norwegian Gemmological Association. Vol. 1, No. 1, 1954.

The first issue of a small periodical for members of the Norwegian Association. The main items are abstracts from other gemmological journals. No doubt this new publication will increase in size and make a useful contribution to gemmological literature. S.P.

WESTGAARD (H. R.). *A pocket dichroscope.* Gemmologist, Vol. XXIII, No. 278, p. 169, September 1954.

Describes a method of making a pocket dichroscope using a piece of polaroid so divided as to produce two half circles, each with its vibration directions at 90° to each other. These two half circles are bonded between glass circles and mounted in a pocket lens type holder, which may also incorporate a Chelsea colour filter, and also if desired a 10 × lens. *The use of pieces of polaroid suitably oriented had been suggested by Thibault as early as* 1939.

2 illus. P.B.

LEE (H.). *Tests on the bonding of artificial turquoise.* Gemmologist, Vol. XXIII, No. 280, pp. 199-200, November 1954.

The writer has made a more critical examination of the bonding material of the American imitation turquoise reported on by R. Webster. Lee's findings are that the bonding material is a styrenated alkyd. Notes are given on a quick chemical test for such material. The role of the phosphoric acid radicle is discussed.

It may be present as an inorganic phosphate in the general make up or could be used as a catalyst to accelerate polymerization of the bonding material. P.B.

FELDHAUS (F. M.). *Imitation emerald problems in the 16th century.* Gemmologist, Vol. XXIII, No. 278, pp. 174-176, September 1954.

From 1475 the main trades of the medieval town of Nuremburg were controlled by the so-called Ragsamt, which could be likened to the English City Guilds. Some notes made by the clerks of the Ragsamt, and still available, form the basis of the article. The bureau's function was to investigate complaints which, if substantiated, were passed to the police for action. The notes show to what extent control was enforced during these times on gemstones and jewellery. Many of the notes refer to the use of false emeralds and the penalties exacted for using them. Real emeralds were called "smarallen." An idea of the police methods of the time, which closely resemble present day methods, is illustrated by a note of 1581. A thief stole precious stones and jewellery from Steyr Castle. A messenger brought the information to the Magistrate at Nuremburg who had a search made for the stolen goods in the town and he circulated a description of the stolen goods among the artisans (jewellers?) and issued a detailed description of the thief. R.W.

ANON. *Suggestions for a new brilliant cut.* Gemmologist, Vol. XXIII, No. 279, pp. 177-179, October 1954.

Prof. R. L. Parker has critically reviewed the various brilliant cuts and has calculated a new brilliant cut, differing only in the angles and size ratios from other brilliant cuts, and not in a different distribution and number of the facets, as in the King and Magna cuts. The Parker cut has a lower crown in relation to the depth of the pavilion. In percentages of the girdle diameter the height of the upper part is 10·5 ; the height of the lower part is 43·4 ; the total height 53·9 and the table diameter is 55·9. The angle between the plane of the girdle and the crown facets is 25·5°, and between the girdle plane and the pavilion facets 40·9°. A table is given comparing the Parker cut with the Ideal cut of W. F. Eppler, the Tolkowsky cut and the Practical cut of Eppler.

1 table, 1 illus. R.W.

fully considered. Recently a ruby-red synthetic spinel and a schillerized spinel imitating moonstone have been produced. Synthetic sintered spinel coloured by cobalt imitates lapis-lazuli. Data on synthetic spinels are given. Centres of production are named and the series concludes with consideration of synthetic spinel, but no note is mentioned of synthetic strontium titanate.
13 illus. P.B.

HOPKINS (I.). *Gemmologist in Paris.* Gemmologist, Vol. XXVII, No. 328, pp. 211–213, November, 1958.

Discusses a visit to the Paris Mineral Gallery of the Jardin des Plantes and the Mineral Gallery of the Natural History Museum. Many of the beautiful specimens and objects of art seen in these galleries are mentioned.
2 illus. R.W.

POUGH (F. H.). *Hydrothermal ruby crystals.* Gemmologist, Vol. XXVII, No. 327, pp. 179–184. October, 1958.

The article gives a report on the growing by hydrothermal means of crystals of synthetic ruby by workers at the Bell Telephone Laboratories. The method of growth is similar to that used in the synthetical production of quartz crystals by using an autoclave. In the case of the ruby synthesis modifications were made in the autoclave in order to compensate for the higher temperatures and increased pressures (in excess of 30,000 pounds per square inch), and the more corrosive solutions used. The factors needed to give good results are mentioned. The nutrient is a hydrated alumina compound. The seed plates are round discs of Verneuil synthetic ruby cut so that their flat surfaces lie at right angles to the " c " axis, or with the " c " axis at such an angle that the growing crystal would have a rhombohedral face vertical as the crystal grows in the bomb. Pure nutrient produces in an iron autoclave greenish-coloured corundum crystals from iron contamination. The use of a silver lining to the autoclave allows colourless crystals to grow and by the addition of 1/10th of a gramme of sodium chromate to a litre of circulating solution ruby is formed. It is said that these crystals are grown for academic reasons and not for commercial exploitation.
3 illus. R.W.

stone and the spectroscope to cut off the ordinary ray so that the extraordinary ray can be seen alone. The strength of the absorption spectrum depends upon the amount of chromic oxide present, and is strong in the chrome-rich synthetic emerald. Green beryls do not show the chromium lines and therefore the presence of such lines entitle a stone to be called an emerald. The strength of the absorption spectrum will also give a clue to the depth of colour of emeralds " improved " by backing with green-coloured foil.

Other green stones which owe their colour (in part) to chromium and show a chromium spectrum are green fluorspar and certain heat-treated indicolites (tourmalines) and jadeite. Soudé emeralds (quartz and spinel) do not show a chromium spectrum but some green glass imitations do show a "woolly" spectrum, but too indistinct to cause confusion. Some notes on the residual colour seen through the Chelsea colour filter are given.

In alexandrite the three optical directions give different absorption spectra, but only the fast ray (lowest index ; red or purple coloured ray), and the slow ray (green colour with highest R.I.) need concern the worker. The intermediate " beta " refractive index (orange) has too weak an absorption effect to influence the spectrum. The spectrum of the green (slow) ray shows the 6805A doublet and the 6785A line to be most prominent, and other lines at 6650A, 6550A, 6490A, and 6450A are also seen in the red. The broad central absorption approximates from 6400A to 5550A and appears to have two narrower concentrations of absorption within it. There is a complete absorption of the blue and violet as far as 4700A. In the red (fast) ray the doublet is weaker and the 6875A line is now the stronger member, and only two of the lines—at 6550A and 6450A—are seen in the red. The broad absorption band has shifted to 6050A-5400A, accounting for the change of colour, and there is a clear-cut line in the blue at 4720A sometimes accompanied by a weaker line at 4680A. The general absorption of the blue and violet has receded a little to 4600A. The absorption spectrum is stronger for the stones from the Urals than for those emanating from Ceylon. A warning is given that a chromium rich alexandrite can show a spectrum reminiscent of that of a good Siam ruby, and a mistake can be made if the stone has not been first seen in daylight. The fluorescence effects of alexandrite as seen by the " crossed filter " method are also mentioned.

8 illus. R.W.

ANON. *The colourful career of John Mawe.* Gemmologist, Vol. XXIII, No. 278, pp. 157-158, September 1954.

John Mawe, a Derbyshire man, was a mineral and gemstone dealer and collector, who, in 1823, had a shop at 149 Strand. He travelled extensively and suffered many privations, especially in South America where he caught yellow fever and was also thrown into jail. He was a member of the Mineralogical Societies of London and Jena and was a prolific writer. His books include : *The Mineralogy of Derbyshire*, published when he was 38, *Travels in the interior of Brazil* ; *Familiar Lessons in Mineralogy and Geology* ; *Instructions for the management of the blow-pipe, chemical tests, etc.* ; *A descriptive catalogue of minerals* ; *A treatise on diamonds and precious stones* ; *A description of the lapidary's portable apparatus for cutting, setting and polishing crystal, jasper, agate, chalcedony and precious stones*, and also two books on conchology. R.W.

MITCHELL (R. K.). *Some further notes on hypersthene-enstatite.* Gemmologist, Vol. XXIII, No. 280, pp. 195-6, November 1954.

The similarity between the hypersthene-enstatite and brown kornerupine is discussed, with particular attention to the absorption spectra shown by the two stones. It is suggested that the 5060A line seen in the enstatite is not seen in kornerupine. The question of the twinning, previously mentioned by L. C. Trumper, is also discussed. R.W.

GEOBELER (H.). *Eine kleine Betrachtung zur Atomphysik anlasslich unserer Besichtigung des Max-Planck-Instituts in Mainz. Notes on atomic physics on the occasion of a visit to the Max-Planck Institute at Mainz.* Zeitschr.d.Deutsch.Gesell.f.Edelsteinkunde, No. 9, 1954, pp. 5-7.

A brief restatement of events leading to our present knowledge of atomic physics. At the end of the article there is mention of the potential impact of nuclear physics on gemmology. The cyclotron allows acceleration of alpha particles, protons and deuterons, with a present maximum energy of 400 million electron-volts. Diamonds bombarded in this way turn green after 5-8 minutes and are strongly radio-active for about one hour. Further bombardment causes a deep brown colour. E.S.

BAMBAUER (H. U.) : SCHMITT (K. H.). *Lapis-Lazuli-farbiger synthetischer Spinell. Lapis-lazuli coloured synthetic spinel.* Zeitschr.d.Deutsch.Gesell.f.Edelsteinkunde, No. 9, 1954, pp. 7-11.

This article is essentially the same as in Gold und Silber, No. 7-8, 1954, pp. 13-14, and abstracted in the *Journ. Gemmology*, Vol. IV, No. 8, pp. 349-350. E.S.

SCHÜTT (E.). *Die Theorie der Perlenuntersuchung mit Rontgenstrahlen. The theory behind the determination of pearls with X-rays.* Zeitschr.-d.Deutsch.Gesell.f.Edelsteinkunde, No. 9, 1954, pp. 11-16.

Cultured and genuine pearls consist mainly of crystallized calcium carbonate ($CaCO_3$), in the modification known as Aragonite. This is a rhombic crystal with a strong inclination for twinning, which at times can simulate hexagonal symmetry. Small crystals too which are not twinned, can show approximately a sixfold symmetry. Mother-of-pearl, as well as pearl itself, consists of innumerable minute scaly crystals which are orientated in a uniform fashion and cemented together by the organic conchiolin. In pearls, the tables of the crystals are all at right angles to the radii of the spherical pearl. A genuine pearl is thus built up of concentric shells. The author points out the differences between natural and cultured pearls and describes X-ray equipment used at the Idar-Oberstein Gemmological Institute and also the three methods employed.

(1) The fluorescence method is based on the fact that the beads in cultured pearls are mostly made of fresh-water mother-of-pearl, which has a greenish or bluish fluorescence (owing to its manganese content) when excited with X-rays. This fluorescence can be observed through a thin skin of a cultured pearl or through the hole of a drilled pearl. The human element in observation plays a large part in this method.

(2) X-ray radiography produces shadowgraphs which are in principle familiar from the medical application. During exposure the pearls are three-quarters immersed in carbon tetrachloride. The interpretation of the radiographs is sometimes difficult.

(3) X-ray diffraction allows definite determination. Genuine pearls always cause a " hexagonal " diffraction pattern

owing to the orientation of the aragonite scales. Cultured pearls may cause a similar pattern, when the layers of the mother-of-pearl are appropriately orientated in relation to the X-ray beam. When, however, the cultured pearl is then rotated through 90 deg., a four-fold symmetry will be revealed in the diffraction pattern. Thus a " hexagonal " pattern in the first instance calls always for a second exposure. The exposure time of 1 to 1½ hours for diffraction patterns has been reduced to 5 to 15 minutes by placing behind the film a foil (" Safirfolie," used in medical radiography) which emits blue and ultra-violet light when excited by X-rays. The additional light blackens the film from the back in those places which are already exposed to X-rays from the front. E.S.

BOOK REVIEWS

SELWYN (A.). *Retail Silversmith's Handbook.* 240 pp., 89 illus. (Heywood & Co. Ltd., 1954). 25s. net.

This companion volume to the late Arnold Selwyn's " Retail Jeweller's Handbook " should be welcomed by all engaged in the retail jewellery and silverware trades. It deals with silverware of all kinds, for the table, for personal use and presentation. It commences with chapters on these items and then deals with the metals used and the processes of manufacture.

It would have been helpful if the chapter order had been reversed, for the beginner is confronted with terms in the earlier sections, which are not explained until later in the book. This criticism apart, the book caters admirably for all interested in the craft of silversmithing, and the final chapters on the retailer's shop and his customers add emphasis to the title. S.P.

WALTON (J.). *A pocket chart of ornamental and gemstones.* Sir Isaac Pitman & Sons Ltd., 73 pp., December 1954, 12s. 6d.

Although this publication is referred to on the jacket cover as likely to be an assistance to jewellers, lapidaries, antiquarians and gemmologists, it is probably the latter, especially the gemmological student, who will find it of help in the course of studies or for subsequent work when more knowledge has been acquired.

The main basis of the chart is the grouping of the various gem species under their different colours, for as the author rightly contends, many engaged in the jewellery trade often rely on

identification by colour in the first instance. The stones in each group are then listed according to their refractive indices. Characteristics observed with a lens or microscope are amongst those recorded and have had to be made extremely brief. This is a pity, for the records, though helpful, are in some cases tantalizingly inadequate. One could have wished for the shapes of some of the " small crystals " and " crystal inclusions " to have been indicated. The filter used should have been indicated.

Absorption Spectra are recorded by lines or shadings and for the student gemmologist this method is generally to be preferred to the use of numerals.

The chart is really suitable for the pocket, a virtue which other books with similar claim have not possessed, and the data which the author has painstakingly collected should prove of help to the gemmologist who prefers his facts in condensed form. S.P.

MARYON (H.). *Metalwork and Enamelling.* 331 pp., 33 line drawings and other illustrations, 29 plates. Chapman and Hall Ltd., London, 1954. Price 36s.

This is the third (revised) edition of a valuable work which was first published in 1912. It is understandable that this standard work should have been reprinted. The scholarship and care in writing that characterized the first edition has been maintained and, in bringing it up to date, the author has been careful to emphasize that the methods described are those that have been used by himself and thoughtful enough to repeat the invitation of the first edition to those with other knowledge to communicate with him.

There is very little to criticize—the materials and tools used in soldering (there are comprehensive chapters), raising, chasing, spinning and casting of metals, polishing and enamelling, and the care and maintenance of tools are adequately considered. At the end there are various and very useful tables and standards. [In one of these the standard mark used by the London Assay Office for Britannia quality silver has incorrectly been given as " a lion's head erased and figure of Britannia," whereas London used the lion's head as its town mark for this quality.] The bibliography could have been added to, for there are several useful works unrecorded. These, however, are very minor points and this new publication should appeal to the craftsman, student, and all interested in goldsmiths' and silversmiths' work.

S.P.

INTRODUCTORY BIBLIOGRAPHY on OPAL

Mr. Frank Leechman, who was recently awarded a research diploma for his work in connexion with the cause of colour in opal, has prepared the following introductory bibliography on opal as an aid to others who may be interested in the literature on the subject.

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NEW METHOD of DETERMINING SPECIFIC GRAVITY

by J. HAMMES, F.G.A.

IN the gemmological literature, at least of the last seven years, I have found the following methods for the determination of the specific gravity of gemstones :

(*a*) direct measurement of weight and volume.

(*b*) measurement of the *volume* of displaced fluid.

(*c*) measurement of the *weight* of displaced fluid (hydrostatic weighing).

(*d*) the use of heavy liquids.

I am really convinced that we do not need more methods than the now existing ones and the intention of this article is by no means an attempt to fill a scientific hiatus. This new method came into my mind and I considered it useful to bring this method to the attention of gemmologists. This method has principally much resemblance to the well-known method of mixing two fluids till the gemstone remains just suspended in the liquid and determining the specific gravity of this liquid by means of the Westphal balance. But my method does not require the use of the expensive Westphal balance because I need only a pipette and a burette, two cheap articles.

The reader will know that the chemist determines the acidity of a solution usually in a volumetric way by titrating the solution with an alkaline solution of definite strength. He then always uses an indicator—for instance lacmoid, methyl orange or phenolphthalein —which indicator shows a change of colour at the right neutralization point. This first suggested the idea to me, that it must be possible to determine the specific gravity of a gemstone in a titrimetric way, using the gemstone itself as an indicator.

This titrimetric determination can be done for gemstones which have a specific gravity of 3·33 or lower in the following way.

Pipette (or, more accurately, measure off by means of a burette) 20 ml methylene iodide into a 50 ml Erlenmeyer conical flask and

add the gemstone to be tested. A burette is filled with toluene with a specific gravity of 0·8687. Now we add with the aid of this burette toluene drop by drop with constant shaking, until the gemstone passes from the floating to the suspended state. This end point of the titration can be determined with the exactness of one drop (that is 1/20 ml). After reading off the number of ml of toluene used we can look up in the diagram directly the specific gravity of the gemstone, exact to the second place of decimals.

Properly speaking I determine titrimetrically the volume-ratio of methylene iodide to toluene in the mixture, wherein the gemstone to be tested remains suspended and I read off the specific gravity of this mixture in the diagram. For I have calculated the line *a* in the diagram as the relation between the specific gravity of the gemstone and the number of ml to toluene used, so that after the titration I can read off directly the specific gravity of the gemstone on line *a*.

I have calculated line *a*, assuming a temperature of 15°C., and titrating with a quantity of 20 ml methylene iodide. Thus I used the formula :

$$Y = \frac{20 \times 3{\cdot}33 + X \times 0{\cdot}8687}{20 + X}$$

where :

Y = specific gravity of the gemstone.
X = number of ml toluene necessary to bring the stone to suspended position.
3·33 = spec. gravity of methylene iodide at 15°C.
0·8687 = spec. gravity of toluene at 15°C.

In order to avoid being able to use the 20 ml methylene iodide, which we need for the determination, only once, I have calculated and placed in the diagram other lines, starting from mixtures of methylene iodide and toluene with specific gravities of 3·1, 3·0, 2·9, etc. This I have done with the following purpose.

Say, we have done a titration and needed therefor 2 ml toluene. Then we read off on line *a* a specific gravity of the gemstone of 3·10. This figure is then also the specific gravity of the mixture after the titration. We can now use this mixture again as starting fluid for the determination of the specific gravity of a

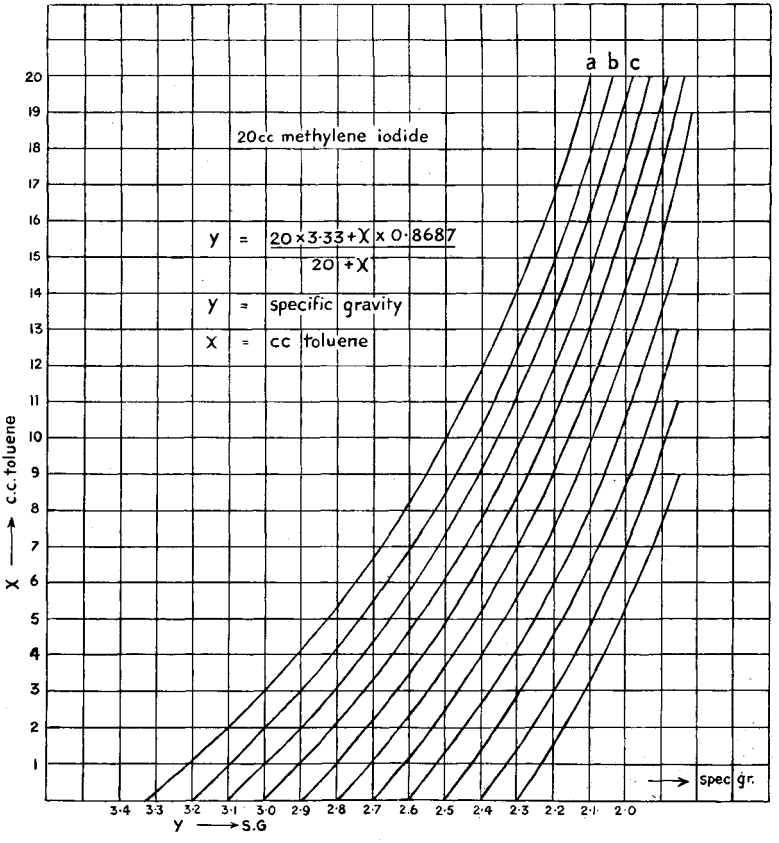

gemstone, which is 3·1 or lower. Only in this case we have to take our reading after the titration on line *c* of the diagram.

For the rest it is always easily possible to bring the used mixture to a higher strength by evaporation " au bain marie " or by fractional distillation, because of the great difference in boiling temperature of methylene iodide (180°C.) and toluene (111°C.).

As I already mentioned before, the line *a* is only right at a temperature of 15°C. Now Herbert Smith indicates in his handbook[1], mentioning the Westphal balance on page 114, that " the density of all liquids is somewhat seriously affected by changes in the

1 *Gemstones.* G. F. Herbert Smith, Methuen, 1952.

temperature." Therefore I have checked the influence of the temperature on the determination of the specific gravity with my method. Assuming that the temperature at which the determination will be done maximally will lie between 10° and 20°C., this problem is confined to the question what is the influence of 5°C. upwards or downwards.

Therefore I needed tables of specific gravity of methylene iodide and toluene at temperatures between 10° and 20°C. I found the table for toluene in Webster's *Gemmologists' Compendium*, page 223 :

Temp. C.	*Density of toluene*
10	0·8737
11	0·8727
12	0·8717
13	0·8707
14	0·8697
15	0·8687
16	0·8677
17	0·8667
18	0·8657
19	0·8647
20	0·8637

This table shows that the density of toluene regularly diminishes by 0·001 per degree Centigrade.

I quote the table for methylene iodide from Timmermans, *Physical chemical constants of pure organic compounds :*

Temp. C.	*Density of methylene iodide*
10	3·3478
11	3·3451
12	3·3425
13	3·3398
14	3·3372
15	3·3345
16	3·3328
17	3·3293
18	3·3265
19	3·3239
20	3 3212

Here also is a regular diminishing of the specific gravity of 0·0026 to 0·0027 per degree Centigrade. There is however in this table an irregularity at the temperatures 16° and 17°C. I suppose that at these temperatures a false determination has been done or there are some misprints in the table. In any case I must assume that the specific gravities in this table at 16° and 17°C. are wrong.

The right table must therefore be as follows :

Temp. C.	*Density of methylene iodide*
10	3·3478
11	3·3451
12	3·3425
13	3·3398
14	3·3372
15	3·3345
16	3·3319
17	3·3292
18	3·3266
19	3·3239
20	3·3212

so that the specific gravity regularly diminishes by 0·0026 to 0·0027 per degree Centigrade, as this regularity is normal for fluids.

With the help of these tables I have calculated at different temperatures the specific gravities of the liquid-mixtures, which are produced by mixing 20 ml methylene iodide with different quantities of toluene. The result is as follows :

ml toluene	*density of mixture*					
	10°C	11°C	12°C	13°C	14°C	15°C
1	3·2300	3·2274	3·2248	3·2222	3·2197	3·2171
2	3·1229	3·1203	3·1179	3·1153	3·1129	3·1103
3	3·0251	3·0226	3·0202	3·0177	3·0153	3·0129
4	2·9354	2·9330	2·9307	2·9283	2·9259	2·9235
5	2·8530	2·8506	2·8483	2·8460	2·8437	2·8413
6	2·7769	2·7745	2·7723	2·7700	2·7678	2·7655
7	2·7063	2·7041	2·7019	2·6997	2·6975	2·6952
8	2·6409	2·6387	2·6365	2·6343	2·6322	2·6300
9	2·5800	2·5778	2·5757	2·5735	2·5714	2·5693

10	2·5231	2·5210	2·5189	2·5168	2·5147	2·5126
11	2·4699	2·4678	2·4658	2·4637	2·4616	2·4595
12	2·4200	2·4179	2·4159	2·4139	2·4119	2·4098
13	2·3731	2·3711	2·3692	2·3671	2·3652	2·3631
14	2·3290	2·3271	2·3251	2·3231	2·3212	2·3192
15	2·2875	2·2855	2·2836	2·2816	2·2797	2·2777
16	2·2482	2·2463	2·2444	2·2424	2·2405	2·2386
17	2·2111	2·2091	2·2072	2·2053	2·2035	2·2016
18	2·1759	2·1739	2·1721	2·1702	2·1684	2·1665
19	2·1425	2·1406	2·1388	2·1369	2·1351	2·1332
20	2·1108	2·1089	2·1071	2·1052	2·1034	2·1016

ml toluene	*density of mixture*					
	15°C	16°C	17°C	18°C	19°C	20°C
1	3·2171	3·2146	3·2120	3·2093	3·2068	3·2042
2	3·1103	3·1079	3·1054	3·1026	3·1003	3·0978
3	3·0129	3·0105	3·0081	3·0055	3·0031	3·0007
4	2·9235	2·9212	2·9189	2·9164	2·9140	2·9116
5	2·8413	2·8391	2·8368	2·8343	2·8321	2·8297
6	2·7655	2·7632	2·7610	2·7586	2·7564	2·7541
7	2·6952	2·6930	2·6908	2·6885	2·6863	2·6841
8	2·6300	2·6278	2·6257	2·6234	2·6213	2·6191
9	2·5693	2·5671	2·5650	2·5628	2·5607	2·5585
10	2·5126	2·5105	2·5084	2·5062	2·5042	2·5020
11	2·4595	2·4575	2·4555	2·4533	2·4513	2·4492
12	2·4098	2·4078	2·4058	2·4037	2·4017	2·3996
13	2·3631	2·3612	2·3592	2·3571	2·3551	2·3531
14	2·3192	2·3172	2·3153	2·3132	2·3113	2·3093
15	2·2777	2·2758	2·2739	2·2719	2·2700	2·2680
16	2·2386	2·2367	2·2348	2·2328	2·2309	2·2290
17	2·2016	2·1997	2·1978	2·1959	2·1940	2·1921
18	2·1665	2·1647	2·1628	2·1609	2·1590	2·1571
19	2·1332	2·1314	2·1296	2·1276	2·1258	2·1240
20	2·1016	2·0998	2·0980	2·0961	2·0943	2·0924

This table proves that the influence of the temperature on the determination of specific gravity with the titrimetric method is much smaller than the remark of Herbert Smith would make us think. For this influence is at a difference of temperature of even 5°C. not more than 0·01 on the result.

From this we can conclude that we can determine the specific gravity of a gemstone with the titrimetric method easily exact to the second place of decimals.

I agree with Prof. Schlossmacher when he writes in his books, *Leitfaden für die exakte Edelsteinbestimmung*, on page 15, that in practice the determination of the first place of decimals will do for the discrimination of a gemstone, because firstly the specific gravity of a mineral is not fully constant but changes with the composition and inclusions, and secondly because to a certain specific gravity only a very limited number of gemstones can belong.

From this we can conclude that the only slight deviation that can be caused with this method by a little difference in temperature cannot be a reason to reject my method.

From the diagram it can be seen that the line is steeper the more ml toluene are added. Thus every next droplet gives a smaller diminution of the specific gravity. Here we have a difference with the titration of an acid with an alkaline solution. In that case we may start the titration by turning the tap of the burette on full and only just before the end of the titration we add droplets until the exact point of colour-change of the indicator. But with the titrimetric method of determining the specific gravity of gemstones we must just start with droplets of toluene, whereas on the contrary at the end of the titration one or two droplets more or less have not so great an influence on the result.

In the above-mentioned considerations I assumed that no contraction takes place by mixing methylene iodide and toluene. And that indeed will not be the case.

After writing this article I came upon a book, which is the latest publication about specific gravity determinations of minerals, namely E. M. Bonstedt-Kupletskaja, *Die Bestimmung des specifischen Gewichtes von Mineralien*, 1954. In this book many methods for the determination of the specific gravity of minerals are described, but the titrimetric method is not mentioned, so that I can assume that my method is a new one.

It is self-evident that checking the specific gravity of the fluids used is advisable. This can be done by pycnometer-method or by means of the Westphal balance. By titrimetric determination of a stone of known specific gravity (viz. quartz) the specific gravity of the fluids used can also be checked.

There is further a possibility of determining the specific gravity of stones with a specific gravity higher than 3·3 by this method. In this case we must combine the stone with a piece of plastic of known volume and weight[2]. We can for instance fasten the stone in a clamp of plastic and then determine the specific gravity of the combination. A short calculation is then necessary :

When :

V_c = volume of plastic clamp.
W_c = weight of plastic clamp.
V_s = volume of gemstone.
W_s = weight of gemstone.
S_s = specific gravity of gemstone.
S_t = specific gravity of fluid-mixture in which the combination remains suspended.

then we have the following formula :

$$S_t = \frac{W_c + W_s}{V_c + V_s}$$

hence

$$V_s = \frac{W_c + W_s - S_t . V_c}{S_t}$$

or

$$S_s = \frac{W_s}{V_s} = \frac{W_s . S_t}{W_c + W_s - S_t . V_c}$$

I do not pretend the titrimetric method for the determination of the specific gravity of gemstones is an improvement of one of the existing methods. It is only another and new method.

2. In 1889 Retgers applied hooks of glass to determine, with the method of heavy liquids, the specific gravity of minerals with s.q. higher than the fluid, but glass hooks are breakable and not elastic and plastic was not yet invented. (Bonstedt–Kupletskaja, p. 53).

ASSOCIATION NOTICES

PRESENTATION OF AWARDS

The recently elected President of the Association, Sir Lawrence Bragg, F.R.S. was welcomed by the Chairman and Vice-Chairman to the reunion of members, which preceded the presentation of awards, at Goldsmiths' Hall, Foster Lane, London, E.C.2, on 20th October. The reunion was attended by nearly a hundred members and subsequently, when they were joined by diploma winners and their friends, a large number assembled in the Livery Hall for the presentations.

Mr. F. H. Knowles-Brown, the Chairman, welcomed the members, especially those who were to receive diplomas. He hoped they had a sense of pride and achievement because the passing of the examination and winning a diploma was something of merit and note.

For over 40 years the Council had aimed to maintain the standard of examination and keep it at a high level. That was not always easy, but it was a policy which had been justified. Wherever one went it would be found that the diploma of the Association was held in very high regard. Mr. Knowles-Brown said he hoped also that they would regard their success as a milestone and not as an end. They would then derive a good deal of pleasure from what they learned by experience and further study.

He also welcomed Sir Lawrence Bragg who was a man of great international fame as a scientist, and a specialist in crystallography. They were honoured by his Presidency, which was almost a family affair, for his father, Sir William Bragg, was previously their President.

Sir Lawrence then presented the diplomas and prizes. He went on to thank the Association for asking him to be President. He appreciated the honour because his father had been President for five years—until his death in 1942—and another of his friends, under whom he learnt much, Sir Henry Miers, had also been President. He hoped that the winners of the awards would have a successful career in which they would use the knowledge they had obtained. Examinations might be loathsome things, even for the examiners, but there must be some form of assessing, some hurdle, some mark of distinction which measured attainment.

The President went on to speak of the advances that had been made in the study of crystals since the time when his father was President, and even earlier. This study had been begun by his father and himself about forty years ago. Then they studied the crystals of minerals which had been made in nature's workshop. The object then was to find out how the atoms were arranged and they worked from simple specimens. It was strange that only nature could make crystals of simple substances, which a chemist could not do. He could only give complicated structures. The simple ones seem the hardest of all to make. Later we looked

for more complicated crystals and found them in the silicates. As so often happened in research, looking for one thing another was found. They were trying to find the pattern of atoms by X-ray and discovered instead the key to the way in which the silicates—and that meant the greatest part of the earth's crust—were built up.

They had running through them a common plan. The mineralogist had divided them into certain families. They were all built into a geometrical plan and could be explained simply by geometry. How pleased the Greek philosophers would have been at this substantiation of their theories, commented Sir Lawrence. In this way they got towards the outline of a blueprint of structure, as it were. Once the key silicate structure had been worked out, one could see that the fact of the world cooling down had to produce rocksalt, mica, and so on.

The reason why they tried to analyse the structure was to gain an insight into why nature had built them up in this particular way to do the job they did.

In simple chemistry one did not have to worry about geometry, but in molecules with sixty atoms one way and forty the other, geometry was everything. With such knowledge one could also begin to understand the action of vitamins or poisons and how they were introduced into and altered the structure. Now, he thought, the secret had been gained of how to apply x-ray analysis to these large molecules. Their mere size gave certain advantages. Tricks could be played with them. They could, as it were, attach marker atoms that could move in and out of the crystals. Having once learned the trick of using mercury atoms as markers he thought that there would be a lot of other marker atoms that could be used, such as chlorine and iodine, that would reveal a lot.

Sir James Walton, the Vice-Chairman, thanked Sir Lawrence for his very interesting talk, and added his congratulations to the winners of awards.

HERBERT SMITH MEMORIAL LECTURE

To commemorate the introduction 50 years ago of a portable refractometer for the testing of faceted gemstones devised by the late Dr. G. F. Herbert Smith, the Association has arranged for a lecture to be given by Mr. B. W. Anderson, B.Sc., F.G.A. entitled " The refractometer and other methods of measuring the refractive indices of gemstones."

The lecture will be given at the Hall of the Medical Society of London, Chandos Place, London, W.1. on Wednesday, 30th March, 1955, at 7 p.m.

COUNCIL MEETINGS

At a meeting of the Council held at 19-25, Gutter Lane, London, E.C.2. on 12th October, 1954, the following elections to membership took place :—

Fellowship

Judith Banister, London ...	D.1954	Wilfred Marsh, London ...	D.1954
Werner Bolli, Lucerne ...	D.1954	Sigurd G. Olsen, Bergen ...	D.1954
Frederick A. Bowden, Plymouth	D.1954	Jack Shearman, Barnehurst	D.1954
Leslie T. Boxall, Richmond	D.1954	Arthur H. Walker, Bournemouth	D.1954
Alan C. Jackson, Greenford	D.1954	Malcolm H. Webb, Maidstone	D.1954
Jeffery P. Solomon, Plymouth	D.1954	Pieter C. Zwaan, Leiden ...	D.1954
Godehard A. H. Lenzen, Hamburg	D.1954		

FELLOWSHIP, TRANSFERRED FROM ORDINARY AND PROBATIONARY MEMBERSHIP

Neville Deane, Wednesbury D.1954
Claus Bender, Koln ... D.1954
Gwendoline V. Furness, Reading D.1954
Malcolm E. Wilson, Croydon D.1954
Elizabeth D. Wines, London D.1954
Dorothy Burnett-Ham, London D.1954
Richard D. Buttermore, Parkersburg D.1954
John E. Campion, Plympton D.1954
John S. Harper, Birmingham D.1954
Ronald G. Kell, London ... D.1954
Bapusaheb S. Mahajan, Bombay D.1954
Arthur St. G. Showers, Hong Kong D.1954
Noel J. Sutton, London ... D.1954
Sidney F. Watts, Birmingham D.1954

ORDINARY

Frank S. Azzopardi, Malta
Walter R. Burley, London
Jean W. Dubois, Hong Kong
Ronald E. Muir, Wilmslow
Frederick H. R. Parkes, Brierley Hill
Winifred M. Rankine, Farnham
William H. M. Phillips, Ross-on-Wye
John A. Clark, Forfar

PROBATIONARY

John S. Brown, Seaham
William J. Pearce, London
Anthony J. Sibley, West Wickham

The Council continued its discussions on matters arising from the examination results. The examiners emphasized that their aim was to endeavour to ascertain whether students had a real understanding of the subject and stressed that it was desirable to maintain the examinations at their present high level. The Chairman, in summing up the discussions, felt that the problems that had arisen were fundamentally concerned with teaching, a matter over which the Council did not have jurisdiction, apart from its own correspondence courses.

MEMBERS' MEETINGS

Midlands : The 3rd annual general meeting of the Midlands Branch of the Association was held in Birmingham on 30th September, 1954. The retiring Officers and committee were re-elected to serve for a further year. A gemmological exhibition in the autumn is to be the main feature of the Branch's programme this year, and it will be held under the auspices of the City of Birmingham Museum and Art Gallery Committee and the City Council.

East of Scotland : A meeting of the Branch was held on Thursday, 28th October, 1954, when a demonstration of the making of silverware was given in the workshops of Messrs. Hamilton & Inches, Jewellers & Silversmiths of Edinburgh.

London : A colour film " Diamond is forever," which deals with the mining and production of diamonds in South Africa, was shown to members in the London area on November 11th, 1954. The programme also included films on the precious metal, palladium, and horology.

GIFT TO ASSOCIATION

The Council of the Association is greatly indebted to the Gemological Institute of America for providing back number's of the Institute's quarterly publication " Gems & Gemology." The gift will enable the Association to maintain bound volumes of all issues.

OVERSEAS VISITORS

During November 1954, the Association were glad to see Hans van Starrex, of Ceylon, a Fellow who qualified in 1933. M. J. Porter, of India (Diploma 1947) on a visit to the U.K., has also called.

TALKS BY MEMBERS

BLYTHE, G. : *Gemstones*, Young Wives Guild, Leigh on Sea, 2nd November, 1954. LEAK, F. : *Diamonds*, Knowle West Men's Contact Club, Bristol, 12th October, 1954. *The Science of Jewellery*, Toc H Women's Association, Fishponds, Bristol, 2nd November, 1954. *Ibid*, Knowle Literary & Debating Society, Bristol, 8th November, 1954. *Pearls*, Bristol West of England Jewellers Association, 8th November, 1954. *The Science of Jewellery*, H.M. Prison, Falfield, 8th December, 1954.

ASSOCIATION REQUIREMENTS

The Association wishes to acquire the following books for its library :—

Eppler, W. F. Die Schmuck und Edelsteine. 1912.
Liesgang, R. E. Die Achate. 1915.
Cattelle, W. R. The Pearl. 1907.
Kunz, G. F. Rings for the fingers. 1917.
Cormack, M. B. First book of stones. New York.
Hershey, J. W. Book of diamonds. New York.
Krauss, F. Synthetische Edelsteine. 1929.
Wild, G. O. Praktekum der Edelsteinkunde. 1936.
Williams, G. F. Diamond mines of South Africa. 1906.

THE JOURNAL OF GEMMOLOGY
AND PROCEEDINGS OF THE GEMMOLOGICAL ASSOCIATION OF GREAT BRITAIN

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DIAMOND SYNTHESIS ACHIEVED

by B. W. ANDERSON, B.Sc., F.G.A.

DURING the past sixty years or so, the cry of "wolf! wolf!" has been heard so often that as each new story of "synthetic diamonds" came along it was greeted with little interest and with a shrug of disbelieving shoulders. But, in a quiet and unspectacular manner, scientists have been closing in on the problem. In the place of the patent recipes and hit-or-miss experiments of most of the older workers there have been careful calculations and controlled experiments based on a definite plan, and now at last the synthesis has been achieved. The wolf is not merely at the door but has come right inside, and will probably prove to be a fairly harmless sort of fellow after all.

The news was first published in America on February 14th, and on the following day some fifty journalists and scientific writers assembled in the General Electric Company's research centre at Schenectady, New York, and were shown specimens of the manufactured diamonds under the microscope and on lantern slides, and were given some details of the conditions under which the stones were produced.

The final success was achieved by two physicists, Dr. Francis Bundy and Dr. Tracy Hall, and a young physical chemist, Dr. Robert Wentfort. But, as in the conquest of Everest, credit belongs

not only to those who make the final assault but to the entire team—and, beyond that, to others before them who have planned and shown the way. Indeed, the process used by the General Electric research team may quite properly be called the "Bridgman" process, because it is the logical outcome of ideas promulgated and experiments carried out by Dr. Percy W. Bridgman, professor of physics at Harvard University, who, for more than twenty years has been famous for his work on the physics of high pressures.

In a paper published in 1947 (J. Chem. Phys., 1947, Vol. 15/2) Prof. Bridgman described experiments designed to establish the conditions under which the normal transition of diamond into graphite could be reversed.

The most accurate measurements for the heat of combustion of diamond and of graphite give the figures 94,490 and 94,040 calories respectively—that is, a difference of 450 calories in favour of diamond. This shows graphite to have the lower energy and therefore to be the more stable allotrope under normal conditions, and the figure of 450 calories is also the "heat of transformation" of graphite into diamond. Calculations based on these figures, using an elaborate equation due to Nernst, indicate that at 27° C. and a pressure of 15,000 atmospheres, diamond and graphite should be in equilibrium; while at 1,225° C. the pressure would have to be 40,000 atmospheres for equilibrium to be reached.

In the paper already cited, Bridgman relates how he was able to approach such colossal pressures experimentally, and to apply them at high temperatures to graphite, and to graphite seeded with diamond. He found that at 2,000° C., even under a pressure of 15,000 Kg/cm^2, diamonds were quickly and completely converted into graphite. At increased pressures the transition was less rapid, and at 30,000 Kg/cm^2— the highest pressure he could attain—there seemed to be no tendency for diamond to revert to graphite, so that the equilibrium conditions must have been very nearly satisfied at this point. Unfortunately for Bridgman, he was unable to continue these remarkable experiments further. It is difficult to the layman to appreciate the difficulties involved in attaining such enormous pressures, and in finding materials capable of withstanding them. The cost of researches of this nature is necessarily very great.

High temperatures are needed as well as high pressures because of the time factor involved. Diamond, although it is the

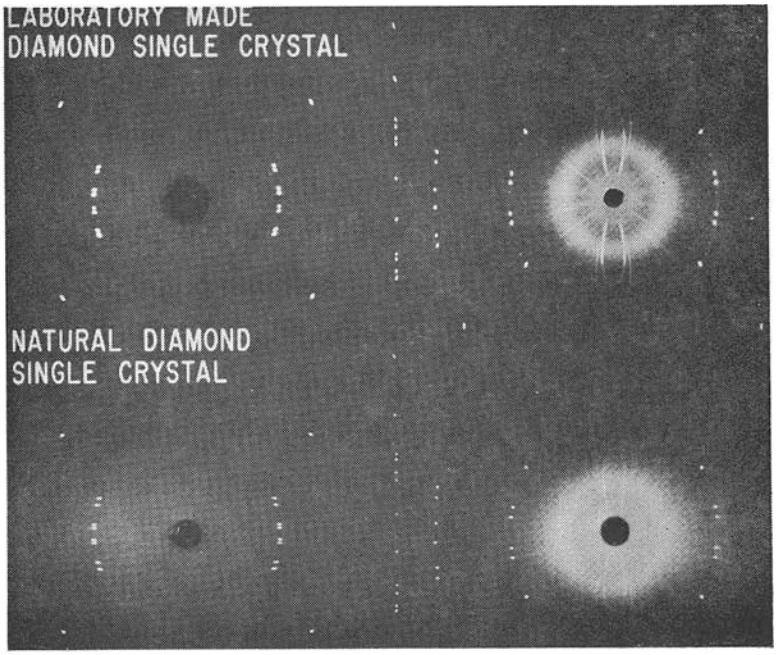

X-ray diffraction patterns of natural and man-made diamonds

(Photo by courtesy of General Electric Research Laboratory)

less stable allotrope of carbon under normal terrestrial conditions, is, as we know, stable enough to endure for millions of years without any trace of graphitization. Only at high temperatures is the change sufficiently rapid to be observed. Similar conditions apply to the conversion of graphite into diamond under high pressures. If sufficient pressure be applied to graphite, the conditions will, in theory, favour the formation of diamond; but unless the temperature is also high the transition will be almost infinitely slow.

The conditions under which an unspecified " carbonaceous compound " was converted into tiny crystals of diamond in the Schenectady laboratories are given as 1,500,000 pounds per square inch and over 5,000° Fahrenheit. Translated, this means rather more than 100,000 atmospheres at 2,775° C.—a far higher pressure and temperature than anything hitherto achieved in attempts to synthesize diamond (except perhaps instantaneously in explosions) but according well with those which one would expect to lead to

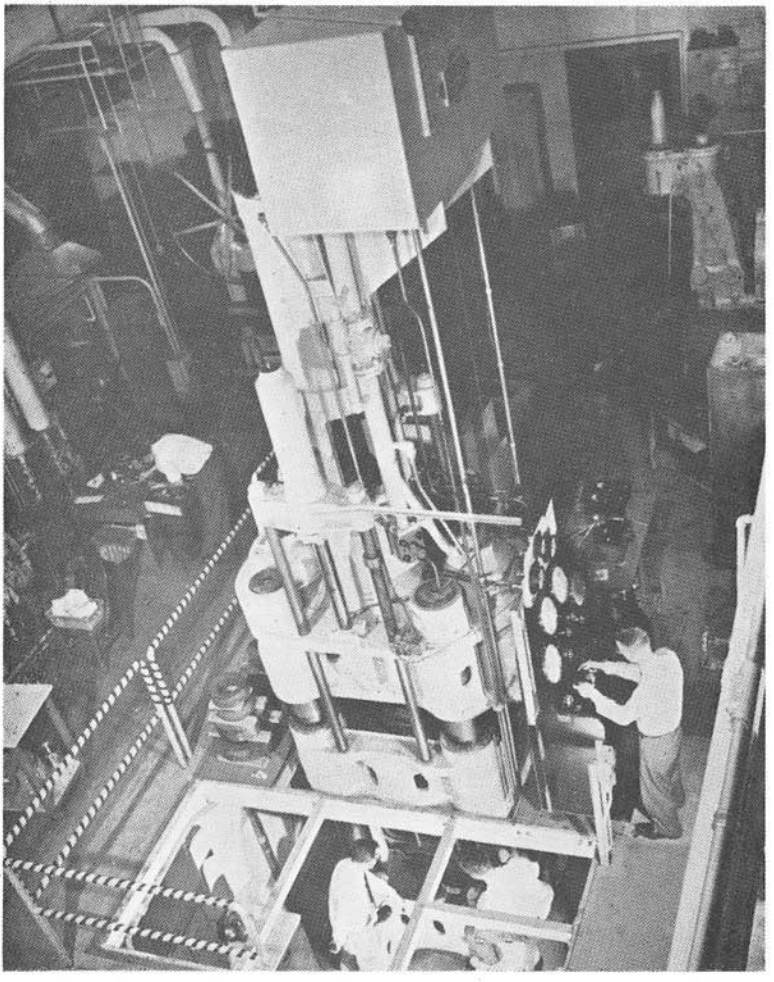

General Electric Research Laboratory's 1000-ton press for achieving high pressures. This is the apparatus in which man-made diamonds were first produced.

success from a consideration of the calculations and experiments mentioned above. As the basic pressure-producing apparatus a thousand-ton hydraulic press was used. The pressure chamber in which the diamonds were formed is reported to be very small—"about half the size of a rubber on a lead pencil." The first diamonds were produced last year, and the process has been

repeated many times with similar results—showing a "reproducibility" which was utterly lacking in all previous methods, which invariably gave null results when repeated by other investigators.

In the Bridgman process, some stones were formed in a few minutes, but the main batch was allowed to grow for sixteen hours and yielded blue, black, yellow, and colourless specimens of diamond. The largest crystal so far made had a maximum length of about 1·2 millimetres. A polycrystalline mass synthesized under more extreme conditions of temperature than the diamond just mentioned, weighed approximately 0·1 carat. This may seem small, but is quite large when compared with the specimens made by J. B. Hannay in 1880, which represent the only previous authenticated instance of artificial diamond production.

So far, at least, the news has been handled with commendable restraint and there has been no absurd panic to undermine the world confidence in the value of natural diamonds. This is as it should be. Some day, perhaps, the Bridgman process will have appreciable industrial importance. At present it can be hailed as a great technological triumph—the culmination of more than a century of scientific endeavour to achieve this end.

References.

This list of references has been reproduced with permission of the General Electric Company's Research Laboratory from their March, 1955, publication "Man-Made Diamonds," published by Research Information Services, Schenectady, New York.

Note.—References centring about the claims of Hannay and of Moissan, which are the major ones, are dealt with chronologically. Earlier references extending back to 1828 are considered in J. W. Mellor's "Comprehensive Treatise on Inorganic and Theoretical Chemistry," Volume V, Longmans Green and Co., 1924.

1. J. B. Hannay, *Proc. Roy. Soc.*, **30**, 188 (1880) or *Chem. News*, **41**, 106 (1880). Preliminary announcement of diamond synthesis by heating a mixture of hydrocarbons, bone oil, and lithium at red heat in a sealed wrought iron tube. A product identification including a density of 3.5 and a 97.85 per cent carbon content is given.

2. N. Story-Maskelyne, *The Times*, February 20 (1880), or *Chem. News*, **41**, 97 (1880). The British Museum on the basis of its own analysis labels as genuine diamonds received from Hannay and lauds him for his successful synthesis.

3. J. B. Hannay, *Proc. Roy. Soc.*, **30**, 450 (1880) or *Nature*, **22**, 255 (1880). A detailed account of the work announced in (1).

4. H. Moissan, *Comptes rendus*, **118**, 320 (1894) and **123**, 206, 210 (1896). Work summarized in "Fours Electrique," published in 1904; English translation, "The Electric Furnace" (Easton, Pa., 1920). Diamond is made by dissolving carbon in molten iron and quenching the solution to crystallize the carbon. The products have the optical properties of diamond and give some carbon dioxide on combustion.

5. J. B. Hannay, *Chem. News*, **86**, 173 (1902). Takes the Encyclopedia Britannica to task for calling his diamonds carborundum.

6. W. Crooks, *Diamonds* (London, 1909). Confirms Moissan's work.

7. O. Ruff, *Z. anorg. allgem. Chem.*, **99**, 73 (1917). Confirms Moissan's work.

8. C. A. Parsons, *Proc. Roy. Soc.*, **79**, 532 (1907) ; *J. Inst. Metals*, **20**, 5 (1918) ; *Phil. Trans., A*, **220**, 67 (1920). Confirms and extends Moissan's work, differing only on details and underlying causes. Reports failure with Hannay's method.

9. H. LeChatelier, *Leçons sur le carbone* (Paris, 1926), page 24. Expresses scepticism of the way in which the identification of supposed synthetic diamonds has been made.

10. C. H. Desch, *Nature*, **121**, 799 (1928). Summarizes new evidence submitted by Parsons to the Editor of *Nature*. Parsons' new work clearly and unequivocally demonstrates how he has been misled into regarding as diamond various transparent, singly refracting minerals (spinels) which are very resistant to chemical reagents and will not burn. Parsons repeats Moissan's work many times and obtains many particles which resemble diamond but will not burn. Unfortunately, none of Moissan's own products can be found for re-examination. Parsons also repeats the work of other investigators who have claimed to have made diamonds, but with negative results. It is Parsons' final conviction that neither he nor anyone else has ever succeeded in making diamond in the laboratory.

11. J. W. Hershey, *Trans. Kansas Acad. Sci.*, **31**, 52 (1929) and **40**, 109 (1937) ; *The Book of Diamonds*, Hearthside Press, 1940. Duplicates Moissan's work with production of even bigger diamonds. (No more has been heard from anyone concerning this claim.)

12. F. A. Bannister and K. Lonsdale, *Nature*, **151**, 334 (1943) ; *Mineral Mag.*, **26**, 309 (1943). The diamonds Hannay sent to the British Museum are shown by X-ray analysis to be true diamonds of a rare type. There is a great improbability that natural diamonds of such a rare type unrecognized at the time should be selected for fraudulent introduction either by dispirited workmen or by Hannay himself. These workers feel that Hannay has in fact succeeded in making diamonds.

13. C. H. Desch, *Nature*, **152**, 148 (1943). Reviews his previous article (10) and then summarizes Hannay's experiments. In view of the findings in reference (12) he feels that the whole question of man-made diamonds is re-opened and that perhaps diamond can be made under the conditions used by Hannay, Moissan, and Parsons.

14. Rayleigh, *Nature*, **152**, 597 (1943). Reports that his father has told him that a later paper submitted by Hannay to the Royal Society in about 1894 was rejected by a publication committee because there was distrust of his good faith. An offer of a demonstration was refused on the ground that no demonstration by Hannay himself would satisfy the sceptics. Rayleigh also points out two instances in which Hannay's work in other fields was branded by his contemporaries as being in bad faith. Rayleigh himself feels that one of these instances clearly shows that Hannay's critics had something more than prejudice to go on.

15. M. W. Travers, *Nature*, **152**, 726 (1943). Dismisses the foregoing incidents as an honest youthful mistake and repeats the praise and trust he accorded Hannay in an earlier memoir—*Chemisty and Industry*, **17**, 507 (1939).

16. J. W. French, *Nature*, **153**, 112 (1944). Reports that Hannay was not the type to fake a result but that he had indeed become concerned lest some practical joker had interfered with his experiments. French's father had been Hannay's partner.

17. K. Lonsdale, *Nature*, **153**, 669 (1944). Her work proves that the crystals in the British Museum were diamonds but not that Hannay made them. She feels that Hannay has a strong case and that his claim should be given the benefit of the doubt.

18. D. P. Mellor, *J. Chem. Phys.*, **15**, 525 (1947) ; *Research*, **2**, 314 (1949). Feels that Hannay has a very strong case but that its validity can finally be established only by a successful repetition of the work.

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ASTERISM in CORUNDUM

by ALICE SUMNER TAIT, M.Sc., F.G.A., C.G.

PRIOR to the last war the cause of asterism in corundum had not been definitely determined. There had been many suppositions and in most text books on minerals and gems asterism in corundum was described. Dana's Textbook of Mineralogy[1] states in the section on asterism that in corundum "it is explained by the presence of thin twinning lamellae symmetrically arranged," and in the section on corundum it says, "the cause is due to the presence of minute cylindrical cavities which lie parallel to the prism planes," while Kraus and Slawson[2] gives the explanation that in many cases this is due to regularly arranged inclusions of minute size. Dr. G. F. Herbert Smith[3] describes asterism in corundum in his latest edition as follows: "Its cause may be traced to a regular arrangement of bundles of lines within the structure which are at right angles to the principal crystallographic axes and are severally inclined to one another at 60°. The lines may be composed of included needles of rutile, tubular cavities, or even colloidal particles. The tendency to conform to the hexagonal arrangement is linked with the lamellar twinning characteristic of corundum."

It was these numerous and varying definitions and statements describing the cause of asterism in corundum that led me to take up the problem with the hope of finding more conclusive data concerning, not only the phenomenon of asterism, but the nature of the inclusions said to be the cause.

As early as 1878 the inclusions of corundum were observed and described. G. von Tschermak[4] found hair-like inclusions in ruby which he claimed were rutile. These lay parallel to the prism faces. In 1892 Prinz described the inclusions of corundum as gaseous, liquid and solid. In recent years Dr. Edward Gübelin[5] has done a great deal of research on inclusions in gemstones and has also described the inclusions of corundum as gaseous, liquid and solid, naming rutile and zircon as solid inclusions. He identifies included zircon in Ceylon sapphire by characteristic halos. In the Laboratory of the London Chamber of Commerce Messrs. B. W. Anderson, C. J. Payne and R. Webster have done much valuable work on inclusions corroborating Gübelin's findings.

Corundum belongs to the rhombohedral class of the hexagonal crystal system. It is commonly found in doubly terminated twelve-faced pyramids and hexagonal prisms with three rhombohedral faces above and three below, terminated in basal faces often triangularly marked due to the rhombohedral parting of polysynthetic twinning. The prisms often have a tendency to be barrel-shaped and are striated also with the rhombohedral twinning planes. The twinning habits of corundum are the repeated or polysynthetic twinning producing a laminated structure with basal parting (perfect 0001) and rhombohedral (1011), and penetration twins. The laminated structure of the polysynthetic twinning has given rise to one of the popular explanations of asterism and it is interesting to note that the authorities making the statement that asterism in corundum is due to the repeated twinning have offered no satisfactory scientific proof.

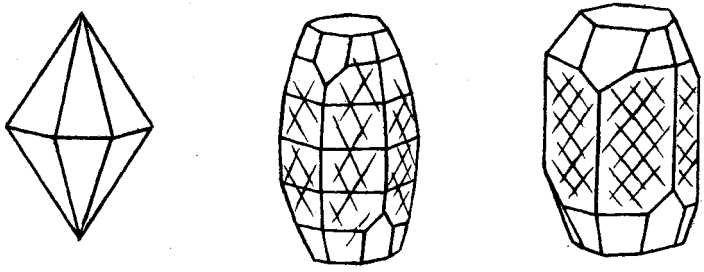

FIGS. 1, 2 & 3.

Figures 1, 2 and 3 illustrate the common crystal types of corundum with Fig. 2 showing the striations of the rhombohedral parting of the polysynthetic twinning.

The first problem was to get enough material from a variety of known sources. Fortunately a large quantity of material personally collected in Montana from Yogo Gulch in the Judith Basin, and from Sapphire Gulch near Philipsburg, plus a few North Carolina specimens, was available. The rest of the material was supplied by the late Albert Ramsey, an enthusiastic gem collector and dealer. He was most kind in supplying unlimited quantities of corundum from the gem gravels of the Ratnapura district of Ceylon; the Bo Pie district in Batambang, Siam; Mogok mines in Upper Burma; and from gravels near Anakie, Queensland, Australia. Mr. Ramsey not only allowed the study of pounds of

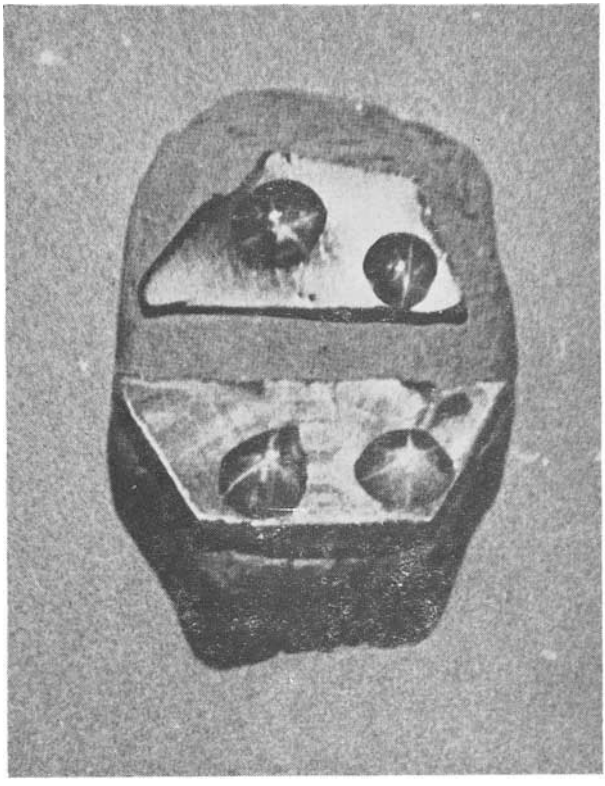

FIG. 4

material, and hundreds of cut stones, but he very kindly made thin sections to facilitate the study of the inclusions. These were cut in the basal plane of prisms enabling the author to examine the inclusions and their arrangement without distortion in both transmitted and reflected light and under high magnification.

As the problem was confined to the description of the phenomenon and the determination of its cause, inclusions other than those directly related to asterism were necessarily incidental, but it was impossible not to note that there were definitely the three types mentioned above.

Microscopic examination of star-stones and thin sections from star-producing corundum showed that the star was produced by the rod-like or needle-like inclusions which lay parallel to the prism faces of the hexagon and in the basal plane thus being severally

inclined to one another at 60°, and that when material containing an adequate number of these inclusions evenly distributed was cut cabochon with the principal axis of the stone (the axis at right angles to the base) parallel to the principal axis of the corundum crystal (the optic axis or c axis) a six-rayed star resulted.

Upon examination in transmitted light in thin section the inclusions were the red-brown colour of included rutile in quartz, and appeared to be the same mineral though finer than any the author had encountered in quartz. Under 900 x it was possible to see square cross-sections when viewed laterally. Conclusive proof that the inclusions caused the star of the material examined was the perfect stars seen in drops of water placed upon the thin sections of star bearing material (Mr. B. W. Anderson demonstrated this, and Fig. 4 shows these water-drop stars as seen in a beam of paralle light).

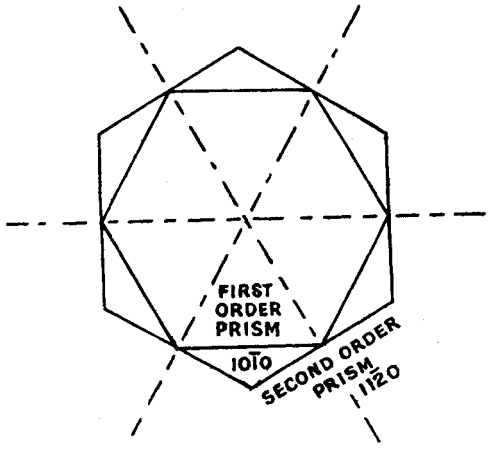

FIG. 5.

During this study a cause for twelve-rayed stars revealed itself, and can be seen by the photograph in Fig. 4 where the drop of water in the upper left-hand corner shows a ray normal to the prism face and not parallel to it. In examining star material on the lookout for a possible cause, it was found that much star material had at least some inclusions lying in the basal plane which were not parallel to the first order prism faces, but normal to them. It apparently is very rare to find material with sufficient concentrations normal to the prism faces to produce stars. Mr. Ramsey had a

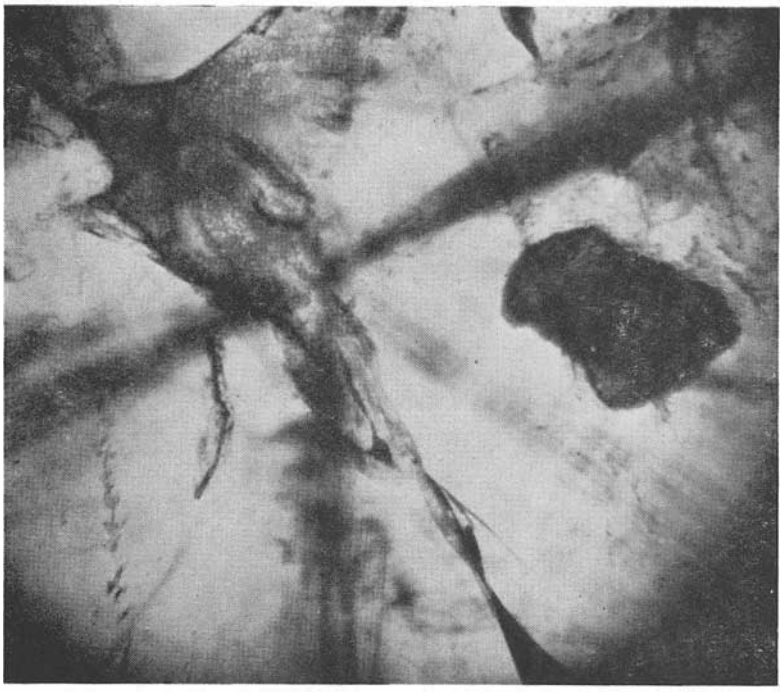

FIG. 6.

twenty carat star-stone that had two stars slightly off centre from each other which formed a twelve-rayed star. Examination of a cut stone precludes any accurate data resulting from optical examination due to distortion. But the fact remains that there are sections in which the inclusions lie normal to the prism faces and parallel to the second order prism $(11\bar{2}0)$, which are shown in Fig. 5 below and in the photograph (Fig. 6) where the concentrations of inclusions bisect the colour zones at right angles. The edge of the prism face can be seen dimly.

The next step was to determine the mineral species of the inclusions. Optical examination under the microscope up to 900 x added little as the inclusions were so fine. The Becke method to determine the refractive index of the included material was also impossible for the same reason. From the relative brightness of the light reflected from them it seemed very possible that they were considerably higher in refractive index than the material in

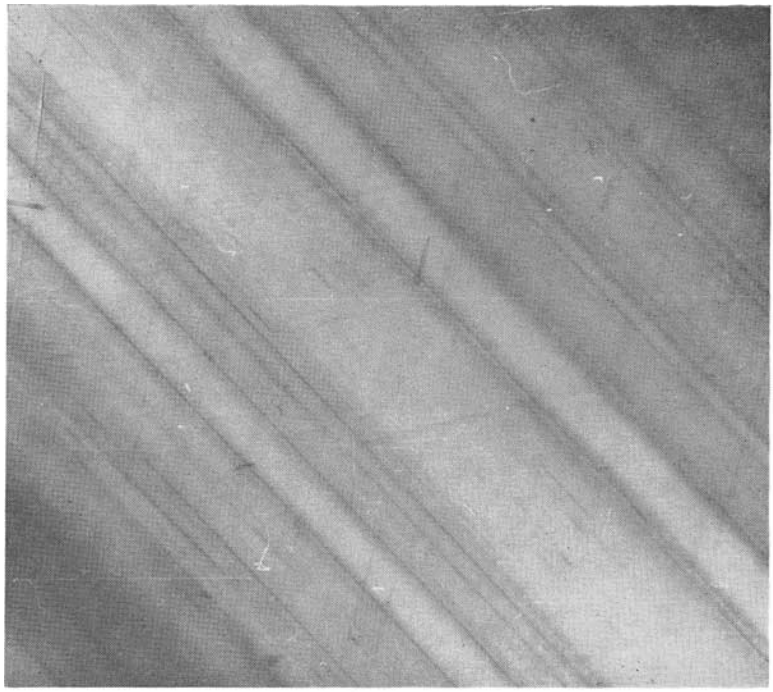

FIG. 7.

which they were included. Microscopic examination up to this point had given the following information: that the needle-like bundles or concentrations were the cause of the star, that they were in transmitted light red-brown in colour, and appeared to have square cross-sections. There was now one thing to do—find the chemical composition.

Micro-chemical analysis failed because the concentration of included material was too small. X-ray powder method also failed for the same reason. There was one course left, that of spectrographic analysis.

Insufficient experience with such a delicate test caused much time to be lost. Ultimately it was found that no mortar could be used to prepare the samples and that the apparatus used must be absolutely clean. (Not as easy to find as one would think.) A diamond point was used to scrape material from colourless corundum, inclusion - free under 20 x (solid inclusions), moderately

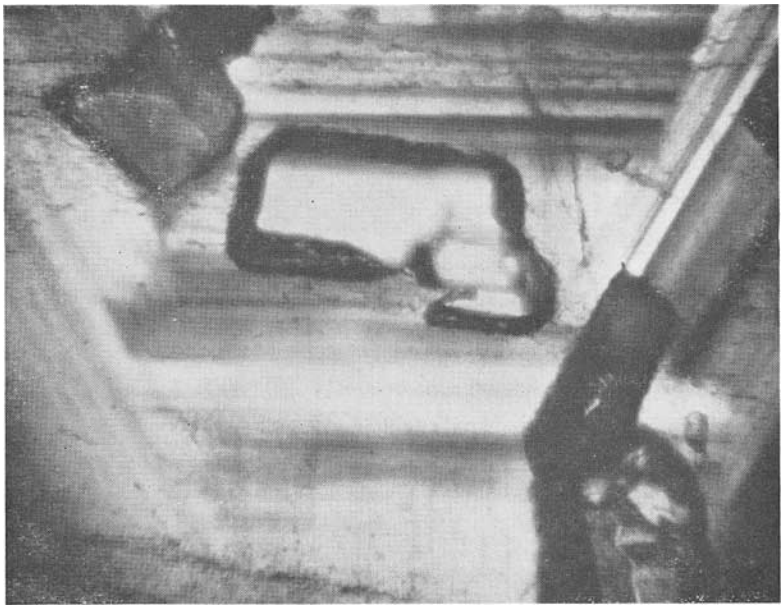

FIG. 8.

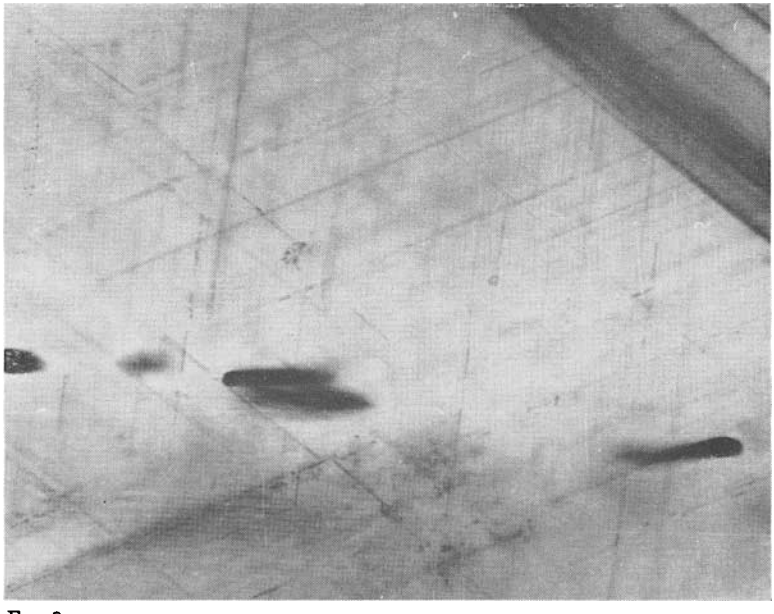

FIG. 9.

included material, and heavily included samples which had produced stars.

The following results were attained:—

Inclusion-free samples:

Al with a trace of Cr and Fe

Heavily included samples:

Al	
Ti	.001 %
Fe	.009 %
Cr.	trace

The results pointed to the possibility of the mineral being rutile, octahedrite or brookite. Octahedrite could be eliminated because of its crystal habit (octahedral or tabular) and brookite on the same grounds.

In summing up it was concluded that the cause of asterism in corundum is due to the symmetrical arrangement of included rutile needles which lie in the basal plane parallel to the prism faces of the hexagon.

Fig. 7 shows a micro-photo (300 x) of material which produced a cat's-eye effect rather than a star because the concentration of inclusions is one-directional. Fig. 8 shows material which would only produce one star because of the concentric arrangement of inclusions. This photograph also shows the inclusions lying normal to the prism faces too sparsely distributed to be seen in reflected light when the stone is cut. Fig. 9 is a perfect example of material which would produce a star cut anywhere providing the axis of the stone is parallel to that of the optic axis of the crystal. The dark bands are not inclusions, but colour zones.

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1. Dana's *A Textbook of Mineralogy*, revised W. E. Ford, 1932.
2. Kraus and Slawson, *Gems and gem materials*, 1941.
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5. E. Gübelin, *Inclusions as a means of gemstone identification*, G.I.A., Los Angeles. *Journ. Gemmology*, Vol. 1 (7), 1948 ; Vol. 2 (7), 1950.

INDIAN DIAMONDS

(Condensed from " Diamond Mining and recovery at the Majhgawan Mine in Panna, Vindhya Pradesh," by S. M. Mathur : Indian Minerals, Vol. VII, No. 1, pp. 34/42—January, 1953).

THE Panna diamond field has supported a widespread mining industry for several centuries. The gems have been obtained mainly from several conglomerate horizons in the Upper Vindhyans and from the gravels derived therefrom. Another source of these gems has been the Majhgawan deposit, situated about twelve miles South-west of Panna, where the diamonds have been recovered from a volcanic agglomerate tuff.

It was realized that the Majhgawan Deposit was not a conglomerate as early as the 18th century by Capt. J. Franklin[1] who stated that " the cavity of the chasm is filled with green mud," the habitat of the diamond " being in the green mud." These remarks lead K. P. Sinor to investigate the Majhgawan area whose examination revealed that it was a volcanic neck filled in with an agglomerate tuff. In 1930 he published a monograph on the Panna diamond pipe together with reports and analyses by foreign scientists.[2]

This mine is reported to have been flourishing as early as Akbar's reign in the 16th century. The first attempt to work it on modern lines appears to have been made nearly 65 years ago when a shaft was put down in this area. The results are not available now. Sinor put down a bore-hole through the agglomerate tuff during the late twenties and established the occurrence of this rock to a depth of 242 ft.

The Panna Diamond Mining Syndicate Ltd, the present leaseholders, reopened the mine in 1936. Until the Second World War the Syndicate sank five shafts, out of which two were not successful owing to caving in of the walls, the third was abandoned, and the fourth had to be closed during the last War. The remaining work also had to be considerably slowed down during this period and at one time almost no work was being done. The mines were rejuvenated in 1947. Systematic mining by mechanical methods has been undertaken and the hand washing of the ore has been replaced largely by machinery.

1. *Asiatic Researches*, Vol. XVIII, p. 111 (1829).
2. *The Diamond Mines of Panna State in Central India*, Bombay, 1930.

Doubts were expressed in certain quarters regarding the diamondiferous nature of the pipe rock, though the past records showed this tuff to be diamond bearing. Dr. A. E. Waters, Chief Geologist, and Mr. A. Royden Harrison, Mining Engineer, of the Anglo-American Corporation of South Africa Ltd, were invited in 1950 to carry out a detailed investigation. They took about 305 cu. ft of the tuff rock lying in the mines and washed it in an 8 ft washing pan, when nine diamonds weighing a total of 3.32 carats were obtained. Subsequent work also has amply proved the diamondiferous nature of the tuff. It is, however, to be expected that the entire ore-body may not be uniformly productive. The diamond content is likely to vary from place to place even as is the case with the pipes of the Kimberley area and there may also be barren patches in the ore-body.

The pits are situated within the confines of a volcanic neck which appears to have a pear-shaped outline on the surface. The maximum length of the pipe-mouth is about 1,600 ft and the width at the broadest is about 960 ft. The total area is approximately 112,500 sq. yds.

The diamondiferous ore in the pipe has been conveniently described as an "agglomerate tuff". In hand specimens it is dirty green in colour and its ground-mass is traversed by a closely-knit network of thin calcite stringers. Fragments of black shale (? porcellanite from the Semri Series), reddish sandstone and jaspers have been found occurring as xenoliths in the ground-mass. Under the microscope this green mass is seen to consist mainly of serpentine produced by the alteration of olivine, pseudomorphs after which are sometimes recognized in the slices. Grains of iron minerals and calcite are frequently seen distributed in the ground-mass. This rock bears superficial resemblance to certain types of South African "blue ground". Chemical and mineralogical examinations, however, show that it is not a true Kimberlite, which is a more complex rock than the Majhgawan tuff. Kimberlite, being rich in olivine, is a type of peridotite, but the Majhgawan tuff samples so far obtained are serpentine-rich. The tuff is an earthy-looking rock and has a tendency to crumble away in the presence of water. This property was utilized in the past by miners who left it exposed in the rain after which it could be easily treated for washing.

For a long time geologists considered that the original source of the diamonds in the Panna conglomerate were the dykes of the Bijawar age. But now that the true nature of the Majhgawan deposit is known to be diamondiferous volcanic pipe rock, it appears certain that the diamonds first crystallized in a formation of this type. The Majhgawan pipe is the only one so far discovered—and it is the only evidence of volcanic activity in the Vindhyans of this area—but it is quite possible that several others lie hidden under the younger rocks or alluvium, because it is rather difficult to believe that a single pipe of such a small surface area could supply gems in large quantities to widespread conglomerates found at different horizons.

The washing of the diamondiferous materials is still carried out by primitive manual methods elsewhere in the Panna diamond field. At the Majhgawan mine, however, a mechanical plant for the recovery of the gems was installed and has resulted in treatment of a much larger volume of ore. The diamonds are recovered by what is known as the " direct treatment process," because the ore is treated as soon as it comes from the mines without any intermediate preparation like exposing it to the weathering agencies for natural disintegration. This process in outline consists of breaking the ore by mechanical crushers, washing and concentration in a specially designed pan, classification of this concentrate through vibrating screens, and the final recovery of the diamonds on specially constructed grease tables. All the material from the grease tables is further checked by highly experienced hand sorters. At present the grease used is not proving very effective in holding the diamonds, but experiments are in progress to evolve a grease having suitable properties to which the Majhgawan diamonds would adhere. This is the reason why it is necessary to check all the concentrate by hand sorting. When dried by the natural heat of the sun, a team of nimble-fingered and sharp-eyed girls go through the concentrate. These girls have highly trained eyes and it is rare indeed for them to miss a diamond even if it be a dark coloured bort the size of a sand grain.

Since 1936 the production has deen fairly steady though not on a scale even remotely resembling the output of a similar mine in Africa. The figures available include the production both from the tuff proper and the overlying alluvium. It is not certain,

therefore, what is the actual yield from the pipe rock itself. It is essential to find out the actual weight of the diamonds won per unit[1] of ore in order to assess with a fair degree of accuracy the average diamond content of the ore and therefore the potential value of the property. Unfortunately no such data was collected in the past, but I am informed that this information is being now recorded.

The result of concentration by Waters and Royden Harrison has already been mentioned. It gives the yield at 15.2 carats per 100 loads.[2] As the test was an isolated one it is essential to emphasize that this figure should not be taken as an indication of the true value which can only be obtained by production figures collected over a fairly lengthy period.

1. The usual unit in diamond mining is a "load" which is equivalent to 0.8 short tons or 1600 pounds.
2. Extracted from a privately circulated Progress Report of the Panna Diamond Mining Syndicate Ltd. (1951).

NOTES from AMERICA

The appearance of almost colourless pieces of glass, brilliant cut, which have a refractive index of 1.785 and hardness of 5½, is reported by G. Robert Crowingshield in Vol. VI, No. 6, 1954, of the Gemological Institute of America's students publication. The material has been variously advertised as "new German synthetic" or "new synthetic from Japan". The dispersion of the glass is said to be high.

The G.I.A. also reports examination of material made from strontium titanite (*see Journ. Gemmology*, Vol. III (7), 1952). The material, which is singly refractive, has refractive index about 2.00 and a dispersion slightly greater than diamond. Although the material is soft, it is suggested that confusion with diamond might arise. The new product has not yet been marketed commercially.

RANDOM NOTES

by J. R. H. CHISHOLM, M.A., F.G.A.

ONE of the gemmologist's most satisfactory techniques, which he shares with the mineralogist and the petrographer, is the determination of specific gravity by means of heavy liquids, and the satisfaction which it gives is qualified only by the rather uncongenial nature of the liquids used for specific gravities over 3.33. For densities over that of methylene iodide the gemmologist usually relies upon Clerici solution, which by dilution with water covers the whole range from about 4.15 downwards but is unpleasant to handle (as well as being expensive). Johannsen[1] lists various liquids in this range together with their disadvantages, such as Klein's solution (aqueous solution of cadmium borotungstate —max. s.g. 3.55) and Rohrbach's solution (aqueous solution of barium mercuric iodide—max. s.g. 3.58), and there are a few other media mentioned in the literature with warnings of their high toxicity or other disagreeable attributes—such as molten silver thallium nitrate (Retgers's Salt[2]) and Clerici solution itself. A reference in the Industrial Diamond Review[3] to "antimony tribromide which melts at 96.6 deg. C. to give a liquid of sg. of about 3.6 and in a crude way can be used to separate alumina from diamond" therefore set me wondering whether this might not provide a useful aid for the gemmologist. I optimistically discounted the statement that "antimony tribromide is quite toxic and gives off toxic fumes at its melting point," in the light of the accompanying reference to "conflicting reports on the toxicity of methylene iodide," and decided to put the use of molten $SbBr_3$ for density-determination of gemstones to the test. In the result, I certainly cannot recommend its use, though it may be regarded as a possibility for some purposes, if no better medium is obtainable. Like Clerici solution, antimony tribromide is a Schedule I poison and its sole advantage over Clerici solution is that of price: it cannot be diluted with water and has other unamiable characteristics. These appear in the following account of my experiment in its use, which I append as a warning to any who may be similarly tempted to try it.

About 30 gms of antimony tribromide were placed in a test-tube held by means of a laboratory stand and clamp in a beaker of water, placed on a stand over a Bunsen burner. The height of the test-tube was so arranged that the surface-level of the water in the beaker was somewhat higher than the $SbBr_3$ in the test-tube; a second clamp held a thermometer in the water alongside the test-tube. The Bunsen burner was lit and the water gradually heated. When the heat of the water was between 92° and 93° C. the $SbBr_3$ began to melt and between 96° and 97° it melted completely to a clear pale-yellow liquid. Thereafter the water was kept at about 97° to 98°—just " off the boil ".

A topaz crystal was dropped into the liquid $SbBr_3$ and floated until, owing to the comparative cold of the stone, the liquid congealed on its surface and made it sink: after remaining at the bottom of the test-tube for some little time and re-heating, the $SbBr_3$ coating melted off and the topaz rose again to the surface.

Similarly a spinel crystal just floated, but an almandine cabochon sank straight to the bottom and remained there. In order to avoid what had happened to the topaz, the spinel and the almandine were both first heated in the Bunsen flame. The almandine, which had been chosen for the experiment because it was cracked and chipped, split into two pieces in the heat of the flame. It was also necessary to heat the corn-tongs in the flame before using them to take the stone out of the liquid, because otherwise the liquid congealed on the tongs in thick " gloves " (like the " Persian slippers " of Socrates's flea[4]) and made them unusable. (The " gloves " could be broken off with a knife or, more easily, melted off in the flame).

On removing the stone from the liquid it was found to be covered with a thin film of antimony tribromide, which of course immediately congealed. An attempt to remove this with boiling water failed, because, as I ought to have foreseen, the $SbBr_3$ reacted with the water to form a greyish-white coating of antimony oxybromide ($SbBr_3 + H_2O \rightarrow SbOBr + 2HBr$), which could, however, though with some difficulty, be rubbed or scraped off. More effective cleaning methods were to melt off the film of antimony

tribromide in the Bunsen flame—a procedure not without its attendant risk, for the almandine unfortunately disintegrated still further—or to wash it off in a hot solution of common salt: the salt prevents hydrolysis of the bromide, or at least forms a water-soluble complex with the oxybromide and so enables the stone to be washed clean.

As it was by then clear that antimony tribromide could not be regarded seriously as a rival to Clerici solution, it did not seem worthwhile to proceed further or to attempt to define its density more precisely.

* * *

Historical accuracy requires a correction of the statement made in this *Journal*[5] (following Dr. Gubelin[6]) that it was in 1835 that Sir David Brewster distinguished two types of liquid inclusions detailing his observations in a letter to Sir Walter Scott. Scott died on 21st September, 1832. On 24th April, 1832 Brewster had finished writing his " Letters on Natural Magic addressed to Sir Water Scott, Bart ", which were subsequently published in 1834 as Vol. XXXIII of the " The Family Library ". " My dear Sir Walter," Brewster wrote in the first of these "Letters", "as it was at your suggestion that I undertook to draw up a popular account of those prodigies of the material world which have received the appelation of *Natural Magic*, I have availed myself of the privilege of introducing it under the shelter of your name." The passage on inclusions reproduced in this *Journal*[5] is an excerpt from Letter XIII. It did not represent new work even in 1832, but was a much abbreviated and popularized account of investigations begun in 1818, of which a detailed record was embodied in a paper read before the Royal Society of Edinburgh in 1823, followed by a further paper in 1826, both being published in that Society's Transactions.[7] It is interesting to observe that among the many beautifully engraved illustrations of inclusions which accompanied the original papers—of which only a few were rather poorly reproduced in 1834—there is one of a three-phase inclusion (two liquids, a bubble and a cubic crystal) and two of two immiscible liquids with a cubic crystal—all three being in topazes—but reference to the included cubes (" small squares . . . within the cavities, which seem to be filled

up with crystallized matter") is made only in a footnote[8], and, although there is a description elsewhere of three-phase inclusions in quartz[9] containing "spherical groups of whitish crystals," Brewster had evidently not observed three-phase inclusions in emerald, since of emerald and beryl he wrote: "The degree of foulness which is so common in these gems arises generally from strata of cavities containing a single fluid and an air-bubble, which does not perceptibly decrease with a temperature of 150°."[10] It is also interesting to note that in his investigations into the nature of inclusions Brewster for the most part used only techniques available to the gemmologist: except by an occasional accident, like my own with the almandine, he seldom destroyed the objects of his research. "Though I have employed only the microscope, and the agency of heat and light," he wrote[11], "I have been led to results of considerable . . . interest. This physical method of determining the properties of minute quantities of matter, though often very difficult and sometimes perplexing in its manipulations, carries with it a degree of evidence not inferior to that of chemical analysis; while it possesses the advantage of examining the substance in its original and unchanged condition, and may be applied, in many cases, where the chemist cannot avail himself of any of the resources of his art."

* * *

On the subject of inclusions I have recently been reading F. G. Smith's *Historical Development of Inclusion Thermometry*[12] borrowed, through my County Library, from the Library of the Science Museum. It is divided into three sections; the first 85 pages record the published data on the subject in chronological order from 1818 to 1953, after which follows a 25-page critical summary of the present state of knowledge and the remaining 36 pages contain a bibliography in two parts, the first classified by authors' names and the second by subjects. The survey covers a period of 135 years—among the earliest workers in this field being Sir Humphrey Davy[13] and Sir David Brewster[7]—and includes a reference to Dr. Gubelin's article in this *Journal* in 1948.[14] Mr. Smith's book is of course in no way comparable with Dr. Gubelin's *Inclusions as a Means of Gemstone Identification*[15]; it deals with inclusions

in other minerals as well as gem-minerals and its purpose is not the diagnosis of different species but the determination of the temperature and pressure of formation: it is nevertheless full of interest to the gemmologist.

We are all familiar with " flies in amber ", but to me it was new that " sometimes quartz has been found enclosing undoubted fossils. A good example of well-formed, doubly-terminated crystals enclosing stromatoporoid fossils was described and illustrated by Erdmannsdorffer "[16]; and how delightful it is even to read of " a clear quartz crystal containing a liquid inclusion with a bubble and a movable crystal of gold."[17]

* * *

In South Africa diamond and pyrope garnet are found together, as in Brazil are diamond and quartz: South African diamonds frequently contain included garnets, and quartz is found as an inclusion in Brazilian diamonds. Diamonds themselves occur as inclusions in other diamonds and it would be interesting to know whether diamond inclusions have ever been found in pyrope or quartz—or in any other mineral. One would hardly think that included diamonds, if they in fact occur, could escape attention, since they would obviously present something of a problem to the lapidary. Yet, if they do not in fact occur, what can be the reason? The answer may provide a further clue to the still unknown origin of diamond. Dr. Gubelin appears to be in two minds on the question whether diamond inclusions in other minerals exist or not, since on page 91 of his book[15], he wrote, " Included diamond crystals . . . will be found only in diamond," while on page 173 we find, " It is to be expected that many garnets from South African diamond deposits will contain diamond inclusions, with the reverse being true also since during the secondary phase both gems were formed at the same time in these deposits."

* * *

The diamond pipe mines of South Africa are, of course, well known and provide an indication of the primary source of diamond so far as that continent is concerned. North America is not usually thought of as a diamond-producing area, but in fact it

is a producer on a modest scale, and there too a diamond pipe was discovered at Murfreesboro, Arkansas, in 1906; while the Australian diamond fields presumably also owe their origin to similar sources, a diamantiferous pipe having been found at Ruby Hill, near Bingara, N.S.W.[18] Until recently however there was no evidence to show whether the primary sources of Brazilian and Indian diamonds could also be ascribed to volcanic pipe rocks: it remained an open question whether all diamonds (other than those comparatively few of meteoric origin) had reached the surface of the earth by means of volcanic pipes, having been formed in the depths of the earth, or whether some had been so formed and transported while others had been formed elsewhere and otherwise transported. The question perhaps still remains open, and no pipes have yet been discovered in Brazil, but the clue to the primary source of Indian diamonds may now reasonably be concluded also to be found in volcanic pipes. In 1950 this *Journal*[19] reported the discovery of a diamond-bearing pipe near Panna in Central India, although another report[20] appeared to indicate that the pipe was barren of diamonds—as many kimberlite pipes in South Africa are said to be. Since then little further information has appeared in this country, but a full account of the Majhgawan Mine in Panna, which is indeed a volcanic diamantiferous pipe was published in India in 1953.[21]

In addition to its scientific interest the Majhgawan pipe is of course of commercial significance. In the *Times* of 20th September, 1954 the following report from Delhi appeared:—

> "Three Russian technicians have arrived here as the advance party of a construction team employed to instal machinery for a diamond mine in Vindhya Pradesh, the *Statesman* reported this morning.
>
> The company, the Panna Diamond Mining Syndicate, is said to have negotiated a contract with the Russian embassy here which has been accepted by the Indian Government. The machinery is to be ready for operation by 1956 and will be used to develop a newly discovered mine called the Majgawan pipe. Indian and foreign experts are reported to have said

that the Panna region should be a rich source of high-quality diamonds."

It would appear therefore that the Russians have been quick to seize the opportunity of "getting in on the ground floor" in respect of this new source of one of the few raw materials in which the U.S.S.R. and its satellites are notably deficient.[22] I am informed on good authority that the present output is 3,000 carats per annum and the pipe contains on the average two carats per 10 cubic yards, the output being industrial diamonds.

* * *

Those who are lucky enough to attend Mr. Anderson's "school" at Chelsea know that scientists may be divided into the "splitters" and the "lumpers". The "splitters" are those who are ever on the lookout for some small difference to reveal a new species, always trying to sub-divide into smaller and more exclusive categories; they may sometimes be suspected of an inability to see the wood for the trees. The "lumpers" on the other hand see resemblances in the most dissimilar objects, and like to classify in large and comprehensive families. The splitters love to discover, for instance, a new type of garnet—to distinguish a "spandite" or to differentiate a "rhodolite" from a "pyrandine"—while the lumpers delight in welcoming a new mineral as a member of an old family—seeing taaffeite ($BeMgAl_4O_8$) as an intermediate member of a group which also includes chrysoberyl ($BeAl_2O_4$) and spinel ($MgAl_2O_4$).

In 1934 the splitters got to work on diamond. In a classic paper[23] Robertson Fox and Martin split the diamond into two, designated respectively Type 1 and Type 2, with the following distinguishing features:—

Type 1: Band at 8μ, complete absorption at λ 3000, less isotropic optically, lamellar structure not typical;

Type 2: No band at 8μ, complete absorption at λ 2250, more isotropic optically, typical lamellar or mosaic structure.

Just ten years later Sir C. V. Raman replied for the lumpers.[24] He propounded the theory, supported by much practical evidence[25], that there are four ideal structural types of diamond—TdI and TdII (tetrahedral positive and negative), OhI and OhII (octahedral)—which in practice commonly occur intermixed in various proportions and manners, as by interpenetrative twinning of the positive and negative tetrahedral structures on a microscopic or ultra-microscopic scale, lamellar twinning of the octahedral structures, intertwinning of the tetrahedral and octahedral structures or dispersion of one structure in another in microscopically or ultra-microscopically small volume-elements. Type I and Type 2 then fitted easily into this grouping as members respectively of the tetrahedral and octahedral structure-groups.

Now, another ten years on, Dr. J. F. H. Custers, after referring to Raman's work on the subject only to say that perhaps it had not received the attention it deserved, has told us[26] of the discovery of another new type, so that Type 2 has itself been split into Type 2a and Type 2b. It appears at least possible that this new Type 2b is only another small sub-group whose characteristics (electrical conductivity, phosphorescence when activated by short-wave ultra-violet) are peculiar to a particular range of combination (whether in manner or proportion) of Raman's structure groups.

And what of Raman's latest work? Is he going over to the splitters? I think not. For although he and his associates are satisfied that amethyst (unlike rock crystal) is optically biaxial and crystallographically monoclinic[27], he insists on its close relationship to colourless quartz, finding that the change of structure from trigonal (colourless quartz) to monoclinic (amethyst) occurs during the growth of the crystal from material containing ferric impurities and is consequential on the progressive elimination of those impurities, which are finally deposited as a dome of discrete particles on the boundary between the amethyst and the colourless quartz.[28]

Monoclinic amethyst will take some getting used to; but so science progresses. The answer that received no marks in last year's Preliminary Examination may help to win next year's Tully Medal.

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AN UNCOMMON GEMSTONE

by SIR JAMES WALTON, K.C.V.O., F.G.A.

IN working as curator through the specimens in the Gemmological Association's collection there has recently come to light a very beautiful specimen which, although well known to mineralogists, appears to be, in this country, uncommon as a gemstone. It is the only specimen of its sort in the museum and not only have I no example in my own collection but I am unacquainted with one in any other private collection. It is not mentioned in Herbert Smith's treatise nor in the works of Anderson or Spencer.

Webster, however, mentions it in the glossary of his compendium and it is briefly described by Kraus and Slawson and their remarks are quoted in Shipley's Dictionary of Gems and Gemology.

It is a variety of feldspar known as peristerite. Dana, Ford and Read (Rutley's Mineralogy) describe it as being a variety of pure albite, although the latter states that albite rocks may contain up to 10% of anorthite. The present specimen certainly has all the physical characters of pure albite. It apparently occurs in very varied geological formations, in the alkaline igneous rocks, syenite and diorite, and in the feldspathic lavas, in the more acid rocks such as granite, in the metamorphic gneiss and schists, in pegmatite veins, and is also deposited in veins and rock cavities from superheated aqueous solutions.

Kraus and Slawson state that attractive varieties occur in Ontario, Quebec and Madagascar while Dana, Ford state that it occurs in Bathurst, Lanark Co., Ontario. It is probably because of its site of origin that greater attention has been given to it in American rather than British text books of gemmology. Unfortunately the full details of origin of the present specimen have been lost, the notes simply stating that it came from Ontario, Canada.

Most of the above authorities lay stress upon the fact that peristerite shows a play of colours resembling that of labradorite but this stone is a mixture of albite (30%-50%) and anorthite. In the present specimen there is a beautiful schiller resembling "moonstone", but again this name is usually given to an intergrowth of orthoclase and albite.

The specimen under discussion is an oblong rectangular cut stone with slightly rounded edges. It measures 18 × 12 × 8

mm. and weighs 18·7 carats. It is opaque and milk white but in certain lights has a definite pink tinge. Perhaps its chief characteristic is that it has a most beautiful pearl-like iridescence much resembling that shown by the feathers on the breast and neck of a pigeon, in fact Dana Ford state that the name comes from the Greek περιδτερά (a pigeon). In addition there is, on movement, a beautiful bright blue schiller more vivid and to my mind considerably surpassing that of most moonstones.

With the naked eye and more plainly with the lens there are seen multiple parallel laminae and also fine glittering specks, which may be of quartz, for Rutley states that this variety often contains disseminated grains of quartz.

Under the microscope the specimen is too thick and opaque to observe the structure and for a similar reason, although the lamination is almost certainly due to polysynthetic twinning according to the albite law on (010), the vibration directions cannot be determined between crossed nicols, although under these conditions the specimen remains light in all directions on rotation showing that it is composed of multiple minute crystals rather than of a single one.

There is no dichroism and under the Chelsea filter the stone remains white; with reflected light no absorption bands can be seen in the spectrum.

The refractive indices are α 1·525 and γ 1·536. Attempts to obtain β (which for albite should be 1·529) by the method of double reading were unsuccessful but these two readings with a birefringence of ·011 are characteristic of pure albite and differ considerably from the other feldspars (see Dana Ford & Herbert Smith). It has a fair polish and lustre. The specific gravity is 2·62 and the hardness 6·5.

Here, then, is a beautiful mineral capable of being formed into most attractive gemstones and worthy of a much greater interest by jewellers than appears to be shown. It is white and at best only translucent, but its pink tinge, its pearly opalescence and its lovely blue schiller are a delight to the eye. Mounted singly in a brooch, a pin, in earrings, or with others to form a necklace or bracelet it should form attractive jewellery. It is true that it is relatively soft, but at 6·5 it is as hard as other gems used for a similar purpose, e.g. garnet and nephrite, and harder than many others, e.g. turquoise,opal, scapolite and lapis lazuli, so that with moderate care it should maintain its lustre and polish.

Gemmological Abstracts

SUTHERLAND (G.B.B.M.), Blackwell (D. E.) and Simeral (W. G.). *The problem of the two types of Diamond.* Nature, Vol. 174, pp. 901-904, 1954.

Prof. Sutherland and Dr. Blackwell are already well known for their researches on diamond, and this is an important summary of their most recent work. It is now twenty years since Robertson, Fox and Martin first reported the existence of two types of diamond, showing marked differences in their absorptive properties in the infra-red and ultra-violet regions. Further differences were subsequently noted by other workers, and a summary of the main features of the two types can be given as follows:—

Physical property.	*Type I.*	*Type II.*
Infra-red absorption.	Bands at 4-5. Absorption 8-10.	Bands at 4-5. None between 8-10.
Ultra-violet absorption.	Complete beyond 3000A.	Transparent to 2250A.
X-ray diffraction.	Shows " extra " spots and streaks.	Normal.
Photo-conductivity.	Poor.	Good.
Birefringence.	Present.	Absent.

Since that time, the distinctions between Type I, to which almost all gem diamonds belong, and the rarer Type II stones, has been found to be far less clear-cut than was originally thought to be the case. Type I diamonds vary widely in the strength of their absorption in the 8-10 region, and Raman and his co-workers have found that strongly blue-fluorescent diamonds are transparent to well below the 3000A limit. A similar gradation has been found in the intensity of the extra spots in the X-ray diffraction patterns, and Grenville-Wells, who listed various physical properties of thirty-eight diamonds found four stones which exhibited anomalous X-ray streaks were transparent beyond 2400A.

It thus seems necessary to speak not merely of Type I stones but of extreme Type I, medium Type I, and weak Type I. Type II stones can also be sub-divided in accordance with differences in the 3-5 region absorption, according to Blackwell and Sutherland, while Custers recently suggested a division into Type IIa and Type IIb on the basis of luminescence and photo-conductivity. To complicate matters still further, the factors causing the X-ray variations are not necessarily the same as those causing differences in absorption. The present authors have therefore coined the symbols IS and IIS to indicate diamonds which are Type I or II so far as their spectroscopic properties are concerned, and IX and IIX for those in which it is the X-ray evidence that is being considered.

A study of the ultra-violet absorption of highly-branched saturated hydrocarbons (in particular that of adamantane, $C_{10}H_{16}$, which has a structure very similar to diamond in its distribution of bonds) shows that a cut-off at about 2200A is to be expected. In this respect Type II diamonds can be said to have perfectly normal ultra-violet absorption. Similarly, calculation of the fundamental frequency spectrum of the diamond lattice, combinations of which may be expected to give rise to infra-red absorption bands between 3500 cm.$^{-1}$ and 1800 cm.$^{-1}$ which are in fact to be found in IIS diamonds again show type II diamonds to be completely normal in their behaviour.

The surprising conclusion is thus reached that it is Type I diamonds that are abnormal and Type II which approximate to the ideal diamond from the crystallographic point of view.

It is suggested that "impurity centres" exist in Type I diamonds which account for their anomalous absorptive properties. These centres may consist of foreign atoms, missing carbon atoms, or carbon atoms which are not in the same electronic state as the majority of carbon atoms in the diamond lattice. Since most Type II diamonds are manifestly inferior in appearance to Type I stones, to which most gem diamonds belong, it would almost seem as though a large single crystal having the ideal Bragg structure is unstable and requires certain impurity centres to be incorporated to give stability. Such effects are by no means unknown in crystals of other substances. B.W.A.

COOMBS (D. S.) *Ferriferous orthoclase from Madagascar.* Mineralogical Magazine, Vol. 30, pp. 409-427, 1954.

The paper is chiefly concerned with the optic axial angles and the optic axial planes found in Madagascan yellow orthoclase, which vary in a puzzling manner apparently little related to the iron content. Of more interest to the gemmologist are the refractive index data for these gem-quality feldspars which are given for analysed specimens in Dr. Coombs' paper. Some of these are arranged below, and show very well the gradual rise in the indices with the tenor of Fe_2O_3.

Fe_2O_3%	α	β	γ	γ-α
0.62	1.5194	1.5237	1.5241	0.0047
0.9	1.521	1.5255	1.5255	0.0045
1.25	1.522	1.5265	1.5265	0.0045
1.45	1.523	1.5275	1.5277	0.0047
2.0	1.5245	1.529	1.5295	0.0050
2.56	1.5265	1.531	1.5315	0.0050
3.25	1.526	1.530	1.531	0.005

The optic axial plane was found to be perpendicular to the (010) plane in the first two and the fourth specimen in the above list, and parallel to (010) in the remainder. No density figures are given in the paper. B.W.A.

WEBSTER (R.). *Glass imitation gemstones.* Gemmologist, Vol. XXIV No. 282, pp. 8-9, January, 1955.

A short discussion on the range of refractive indices for glass imitation gemstones of different colours. An appended table shows the distribution of colour and refractive index of some three hundred specimens. Most colourless glass stones had refractive indices between 1.60 and 1.65: most reds between 1.60 to 1.70: dark blues between 1.60 to 1.65: pale blues 1.50 to 1.54: purple and violet colours between 1.50 to 1.60: greens 1.60 to 1.70: yellow and brown colours between 1.48 and 1.54: black glass between 1.60 and 1.65. Only four glass imitation stones have been reported as having refractive indices greater than 1.70. The Author advises caution in accepting the table, except as a guide, owing to the relatively small number of determinations.

P.B.

MARCHER (G. H.). *Detection of faceted glass gemstones.* Gemmologist, Vol. XXIII, No. 281, pp. 229-232, December, 1954.

A reprint of an article first published in the *Mineralogist.* (*Journ. Gemmology Abstracts*, Vol. V. No. 1, p. 34, January, 1955).

R.W.

PAYNE (C. J.). *Kornerupine.* Gemmologist, Vol. XXIII, No. 281, pp. 215-219, December, 1954.

Discussion of the localities in which kornerupine has been found: some notes on the properties of the species, and short biographical notes on J. Lorenzen, who first published a paper on the mineral, and on A. N. Kornerup, after whom the mineral is named. Kornerupine was first described from the locality at Fiskernaes in Greenland in 1884. In 1886 a new mineral named *prismatine* found in Saxony was proved to be kornerupine. A further source of the mineral was found, in 1912, at Betroka, Madagascar, and later, in 1922, another find was made at Itrongay in the same island, the stones from Madagascar being sage green in colour. About 1936 a number of browny-green stones from the illam of Ceylon were identified as kornerupine. A very opaque grey variety of kornerupine has been reported from Port Shepstone, Natal. Although an unidentified emerald-green stone was known about 1937, the occurrence of the emerald-green kornerupine, of which the earlier unidentified stone was a specimen, from the Mogok district of Burma, was not clearly known until the collector A. C. D. Pain produced another such stone in 1952. In 1949 two varieties, one dark green and the other yellow or greenish-yellow, were found in the Province of Quebec. The characters of kornerupine are given in the text and in a very full table.

R.W.

ANON. *Electro-static separation.* Gemmologist, Vol. XXIII, No. 281, p. 232, December, 1954.

Abstract of a report on a new process to recover diamonds that are too small to be separated satisfactorily by grease belts. First installed at the central recovery plant of the Consolidated Diamond Mines of South West Africa Ltd, in November, 1952. Following initial difficulties satisfactory results now obtained. Electrostatic separation depends upon the differential electro-conductivity

of the various particles of the mixture. Diamonds are poor conductors but most of the gangue minerals are better. The separator consists essentially of an earthed electrode and a positively charged electrode, placed opposite and fairly close to one another. A high tension electrical field is maintained between the two electrodes. When a diamondiferous gravity-concentrate is passed through the high-tension field all particles obtain an induced charge. The particles of gravel, being relatively good conductors, allow their charge to leak away to earth as they pass over the grounded electrode. Thus, they acquire the negative earth potential and are attracted towards the positive electrode. As diamonds are poor conductors the induced charge on their surface does not leak away to earth and are therefore repelled by the positive electrode. Thus a separation is achieved, but this is not quite complete. Diamond recovery is said to be as high as 99%.

R.W.

SMITH (R. J.). *Jade artifacts of Puerto Rico.* The Mineralogist (Oregon), January, 1955.

This is an interesting article describing two jade artifacts discovered on the small island of Puerto Rico which is at the eastern end of the Great Antilles group—part of the Commonwealth of the U.S.A.—and was visited by the author. These artifacts he establishes as jadeite and makes reference to the other jadeite localities of the world. The author lists China, Tibet, Burma, Costa Rica, and California, though only the third and fifth have been established. No known occurrence of jadeite has yet been confirmed in either China or Tibet. A known occurrence in Costa Rica would be welcomed by all interested in The Jade Question. The author's statement that " the Maori tribes of New Zealand are making axes from nephrite rocks today " is without foundation.

E.R.

ANON. *Adaptor for use with Rayner refractometer.* Gemmologist, Vol. XXIV, No. 283, p. 28, February, 1955.

A useful refractometer stand consisting of a base plate and two inclined wing slides with concave surfaces, devised by T. P. Solomon. The intention, for which the piece of apparatus seems most suitable, is to facilitate the control of bracelets, etc., which

tend to slip off the refractometer when the stones are being tested. The modification is similar to the hand rests often incorporated in the stage of dissecting microscopes.

1 illus. R.W.

ANDERSON (B. W.); PAYNE (C. J.). *The spectroscope and its applications to gemmology.* Gemmologist, Vol. XXIII, No. 281, pp. 222-225, December, 1954; Vol. XXIV, Nos. 28/23, pp. 5-8 and 31-33, January and February, 1955 (Parts 16, 17 and 18.)

The continuation of the series (Part 16) discusses the absorption spectrum of jadeite, Jadeite shows, in the case of the green-coloured material, fine lines in the red due to chromium, but the species as a whole has a more distinctive absorption band in the violet region (4375A) due to iron. It is intended that this will be further discussed when stones showing spectra due to iron are dealt with. The chromium lines seen in green jadeite consist of one centred near 6915A, which is possibly an unresolved doublet, a weaker line at 6550A and a vague band at 6300A and increase in strength with Cr content. These bands have a certain similarity to the bands seen in emerald in showing transparency patches alongside them. The prominent iron band at 4375A is masked if the chromium content is strong, but in practically all other specimens of jadeite is intense and diagnostic. This band in the violet is present in the yellow and green spodumene—an allied pyroxene mineral—but the appearance of spodumene is so different from that of jadeite that no confusion is possible. The absorption spectrum of nephrite is discussed. Some nephrite contains traces of chromium but any trace of this in the spectrum is vague and weak, and, despite the iron coloration, nephrite does not show the 4375A line seen in jadeite. Comments are made on the chromium-rich type of jadeite, possibly the so-called " Yunnan Jade." A summary of the jade spectra is given, which mentions also that jadeite, unlike emerald, does not show red under the colour filter, and reiterates the usefulness of employing a copper sulphate filter before the bright light source as an aid to observing the absorption spectra. Part 17 describes the spectrum of demantoid garnet. The name of this gemstone and the misnomers which have been applied to it are discussed. The " horsetail " inclusions of fine asbestos fibres in

demantoid are mentioned as an aid to identification. Demantoid garnet shows an intense absorption band at the beginning of the violet with its centre about 4430A which in the pale greenish specimens is sharply delineated and not very broad, but in the finer green specimens the chromium absorption is superimposed on that due to iron and a general absorption of the violet occurs so that the 4430A line may appear simply as a cut-off. The copper sulphate filter and the widening of the slit of the spectroscope will assist visibility of the band in the violet. In the richer chromium types the lines in the red are seen, but are not so clearly seen as in emerald and alexandrite. These lines in the red are at 6930A, 6400A and 6220A, the last two some 100A broad, and one in the deep red which has not, as yet, been possible to measure. Weak bands have also been measured in the blue part of the spectrum at 4850A and 4640A. Demantoid garnet shows pinkish through the colour filter. The comparison with gems similar in appearance to demantoid is discussed. These are green zircon, green sphene, green diamond, peridot, green sapphire, chrysoberyl, andalusite, enstatite, and emerald. Part 18 discusses the chromium spectra of such minerals as hiddenite, euclase, kyanite, enstatite, chrome diopside, the peridot from Hawaii, stained chalcedony, green glass, green aventurine quartz, variscite and scapolite. It is remarked that the prescence of a chromium spectrum is presumptive evidence that the mineral concerned contains aluminium.

2 illus. R.W.

PARKINSON (K.). *The open polariscope in gemmology.* Gemmologist, Vol. XXIV, No. 282, pp. 1-4, January, 1955.

Describes a polariscopic apparatus which is not combined with a microscope (an American instrument is illustrated). The vibration directions of nicols and polaroid plates are discussed in relation to the " crossed position." The comments on the effects seen when the analyser is rotated are not very clearly expressed ; the "crossed position" occurs at every 180° of rotation, that is twice in a full circle—not 90° as printed. The effects seen with doubly refractive stones and crypto-crystalline material and anomalous double refraction are discussed. The employment of such a polariscope to detect dichroism is touched upon. Methods

for observing the interference figures are discussed. In view of the the fact that the open polariscope does not have a condenser, it is suggested that a drop of highly refractive liquid placed on the surface of a facet which is normal to the optic axis will assist in obtaining the interference figure.

2 illus. R.W.

PARSONS (C. J.). *How to make a quartz wedge.* Gemmologist, Vol. XXIV, No. 283, pp. 21-28, February, 1955.

A continuation of the series on the polariscope by K. Parkinson, with this part written by a second author. A list of minerals with overlapping constants, in which case the determination of the optic sign will assist identification, is given. The method of making the quartz wedge is discussed, mention is made of the lapidary apparatus needed, and what can be improvised. The correct orienting of the optical directions of the rough quartz in preparation for the slicing is given. The way to grind to wedge shape and the way the wedge is finally mounted and is marked to show the Z (slow) direction are told.

4 illus. R.W.

ROSENBLOOM (W. E.). *Paua Shell—The Marine Opal.* Lapidary Journal, Vol. 8 (6), 1955, pp. 498-508.

Paua is a Maori name for a mollusc occurring around the coasts of New Zealand and Pacific waters. The Maoris used the shell as working tools, for hunting and fishing purposes and for ornamentation, such as inlaying of eyes for *tikis*. Little of the shell is dived for today and the only worthwhile material has to be obtained from a live mollusc. Iridescence or play of colours is apparently on inner surface of shell and greatly enhanced when polished, and the author regards it as superior to that of the *abalone* shell. Details are given for removal of outer limey deposit and for cutting and grinding the shell into suitable shapes for use in jewellery and ornamental articles.

S.P.

BOOK REVIEWS

HANSFORD (HOWARD S.). *A Glossary of Chinese Art and Archaelogy.* The China Society, London, 1954. 104 pp. 15/-.

Mr. Hansford, who is lecturer in Chinese Art and Archaeology at the Courtauld Institute of Art, has already earned the gratitude of all students of jade by his book, "Chinese Jade Carving," published in 1950. This gave a scholarly and up-to-date account of the nature and origins of jadeite and nephrite, and of the tools and techniques whereby the Chinese artist-craftsmen have fashioned these obdurate materials into objects of enduring beauty from the earliest days until recent times.

The small book now under review is much less general in its appeal. It is designed to fill a very special need—a need felt by the author himself many years ago when he was resident in China and studying those subjects in which he is now an acknowledged authority. It is addressed (to use the author's own words) " both to readers of Chinese who require precise definitions of technical and conventional terms met with in current writings on art and archaeology, and also to those already familiar with Chinese arts, crafts and antiquities, who have embarked on a study of the written language."

The glossary is divided into six separate headings: metals, gems, and gem-stones, sculpture in stone, painting, ceramics, and " miscellaneous." The last term covers such materials as lacquer, ivory, wood, glass, etc. Near the end of the book there are several pages of beautifully-executed line drawings depicting ritual bronzes and weapons. typical ceramic shapes and ritual jades. These are numbered and are referred to in the text, but a key adjoining the illustrations themselves might usefully have been provided.

The Chinese language is not rich in specific names for minerals, and two pages suffice to cover the Chinese names for gemstones. Under this general heading, however, there are other pages dealing with the lapidary's craft and various aspects of jade. Some of the names for gems are hardly inspired—Lu pao shih for emerald and hung pao shih for ruby, for instance, literally mean nothing more than "green precious stone" and " red precious stone " respectively. Others, such as ch'a ching—" tea crystal "—for cairngorm and tan-pai shih—" white-of-egg stone," for (common) opal—are delight-

fully apt. The term for diamond, chin-kang shih, or "gold-steel stone," may seem puzzling until expanded into " a stone which is as precious as gold and as hard as steel."

In the text, the Chinese characters for all the terms are given first, followed by the romanised version. It would have assisted the complete beginner in Chinese if a literal translation of the multi-syllable expressions could also have been appended. The book concludes with an index of the romanized version of all the terms given in the text.

The " Glossary " is admittedly a book for the specialist, but serious students of Chinese art and archaeology will undoubtedly welcome its appearance. Parallel works on architecture and calligraphy are planned by Mr. Hansford for future publication by the China Society.

B.W.A.

ANON. *The polarizing microscope.* Handbook (Publication No. M7000Z), Cooke, Troughton & Simms, Ltd, York.

This extremely well-written handbook is for use in conjunction with a miniature film on the subject, which is distributed by the well-known microscope manufacturers, Messrs Cooke, Troughton & Simms, of Haxby Road, York. The booklet, which is Part I (Part II it is understood will be in colour and will be issued later), deals with all aspects of the polarizing microscope and polarized light. The difference in visibility of the structure of transparent and opaque substances as seen through the microscope in ordinary light and in polarized light is dealt with. A clear dissertation is made on the nature of ordinary and polarized light and its production by Nicol prism and by artificial polarizing filters, and on the action of the Bertrand lens. Pleochroism and the behaviour of light in anisotropic substances are clearly explained with reference to the "parallelogram of forces" of the vibration directions. The Becke line method for the determination of refractive index and for the determination of birefringence is interestingly told, as is the " path difference " or " retardation " of the two vibration directions. The determination of the extinction angle is referred to and the use and action of the quartz wedge are discussed. Much valuable information in small space. No less than 63 illustrations help to make the text understandable.

R.W.

STRONTIUM TITANATE

A new synthetic gemstone

by DAN E. MAYERS

EVER since the introduction of synthetic rutile some years ago there have been rumours of a newer and whiter synthetic stone, but until very recently samples of it did not come upon the market. Recently the writer obtained a sample of the new material and had some stones cut from it; in addition a prism was made for the precise determination of refractive index measurements.

The new material is said by the producer to be composed of strontium titanate, $SrTiO_3$. It is entirely white, without any trace of the slightly yellowish rutile colour, and, most important of all, is isometric, hence there is none of the characteristic doubling of the back facets of cut stones as in the case of uniaxial rutile. Perhaps it is owing to this comparatively simple isometric structure that the material shows virtually none of the strain, layer structure, or other optical inhomogeneities which invariably occur in rutile.

The index of refraction and dispersion of strontium titanate very closely approximate to those of diamond, as can be seen from the following table of optical constants, for whose measurement I am much indebted to Dr. G. Calsow, of Carl Zeiss:—

Measurements made upon a prism of $34°9'\ 7.3'' \pm 2''$.

n_C—$2.40647 \pm 5 \times 10^{-5}$ Mean Dispersion, $n_F - n_C = 0.10104$

n_D—2.42513

n_d—2.42603 Abbe Number, $v_D = \frac{nd-1}{nF-nC} = 14.1$

n_e—2.45187

n_F—2.50751

n_g—2.58613 Dispersive Power $= 1/v_D$—0.0709

n_h—2.66692

From the purely commercial standpoint, and leaving gemmology aside, the striking thing about this material is the fact that it does, for the first time in man's long struggle in this direction, closely resemble the diamond. Cut strontium titanate shows the characteristic lustre, fire, and transparency of the diamond; the

play of colours is a trifle more pronounced than in the diamond but by no means as much as in the case of rutile.

The stone is not yet on the market commercially and distribution plans are far from settled; it is to be hoped that the experience gained by gem dealers in connexion with the sale of rutile will enable them to avoid some of the errors in distributing strontium titanate which marred the sale of rutile, particularly as strontium titanate is slightly softer than rutile and even less suitable for use as a ring stone.

Note by B. W. Anderson

I was naturally very interested to see the two small cut specimens of strontium titanate which Mr. Meyers handed to me in order that a density determination might be made. Hydrostatic weighing in ethylene dibromide gave the high density value 5·13. The stones only weighed 1·35 cts and 0·68 cts respectively, so that no great accuracy can be claimed for this result, which may need slight modification when larger pieces are available for experiment.

The refractive index figures obtained for Mr. Mayers by Dr. Calsow are obviously highly accurate, but it is a pity that wavelength figures were not quoted in addition to the Fraunhofer letters. In British works of reference, for instance " e " is not given, and if this is taken to mean Fraunhofer's E line = 5270 A this does not lie conformably with the curve formed by the other figures stated when the dispersion is plotted graphically.

Mr. Mayers' statement that the *dispersion* of strontium titanate closely approximates that of diamond is obviously a slip of the pen, since the C–F figure of 0·101 given in his table is about four times the corresponding value for diamond, and the greater degree of fire shown by the new material is sufficiently obvious to the eye.

COLOURED MINERALS and the DICHROSCOPE

by NIGEL W. KENNEDY, F.R.S.A., F.G.A.

HUMAN ingenuity in the exploitation of natural phenomena in the service of mankind has produced many optical instruments of particular interest to the gemmologist, but not every student of gemmology is able to make the best use of them.

Among these are two in the use of which few students are really proficient; these are the Chelsea filter and the dichroscope. It is probable that variation in eyesight is partly responsible, as in my own case, since with the filter I can rarely distinguish any other tone than black or brown of varying intensity. How I envy observers like Mr. L. C. Trumper whose keen colour sensitivity detects tone differences which are completely concealed from me.

This is due partially to a form of colour-blindness, but many other students admit their inability to see most of the characteristic appearances which should be observed. It is probable that this is largely due to inexperience, and the form and intensity of the light source is of great importance, particularly as a standard of comparison between stones examined at different times. Although I suffer from a defective colour-sense, this refers mainly to tones of red under adverse conditions. Under suitable illumination I can detect very slight differences between shades and tones.

These observations apply equally to the dichroscope, or rather, to the use of the various patterns of the instrument now available, of which some are simpler and easier to use than others.

In principle the instrument is easy to manipulate, but in actual practice this is not usually so. The normal instrument is a tube with the usual shaped calcite rhomb, and optically ground glass ends. With this type the user must support a stone in some way in order to examine it, and this introduces undesirable variations in technique, which easily lead to varied results. To avoid this some dichroscopes have a support or holder for the stone, or in one

instance, a rotatable table. These are intended to simplify operation and to eliminate errors that may occur by incorrect manipulation. The table model seems ideal—yet I am not the only user who sometimes removes the instrument in order to make an observation.

It is fairly obvious on consideration, that in order to make any accurate comparison between one stone and another, the conditions of examination should so far as possible be identical—lighting, distance from light, and uniformity in the angle of vision, not to omit the essential factor that it is best to use artificial light, since this eliminates any possibility of taking one observation in daylight and another in artificial light. Unless and until one is very skilled in this technique it is certainly advisable to record observations for future reference and comparison. In practice, when handling large numbers of stones, this may be virtually impossible, but as a principle it should be adhered to by the careful worker, and always with unusual stones.

It is not always realized that blue sky is quite distinctly dichroic, and this can upset observations quite considerably. It is rather disconcerting to discover, for the first time, that apparently white light may be and in fact, often is, distinctly polarized, so that instead of seeing a pair of evenly illuminated white squares in the instrument, one sees a white and pale blue square at times. If the reader has never examined blue sky through a dichroscope, it will be interesting to do so. Observations should be made from two points (a) back to the sun on a bright day, and (b) at right-angles to the direction of sunlight. The difference is, of course, due to the polarizing effect of minute crystals of ice high up in the sky, and the blue colour of the sky is directly due to this cause. When one rises high above the clouds on a bright day, the sun is a brilliant object set in a sky of velvety blue-black, studded with myriads of stars.

With due care, this effect is not present when using artificial light, but it is well, in recording observations (especially in the case of some unusual effect), to record the light in which it was made. Observations of quite common stones may differ quite considerably when taken by different forms of illumination.

The student may also be loosely aware that there is a polarizing angle for light incident to a reflecting surface, as in the case of the

sun's rays on water, and that therefore, one should be prepared to see this effect in the dichroscope, and to avoid it.

Some instruments are provided with a rotating table for the stone, and this has a semi-polished black surface, which under suitable conditions may slightly polarize light falling on it and reflected into the aperture, resulting in quite different tints being seen. This has puzzled observers, and has assisted in promoting a feeling of distrust for the instrument, as the reason for the differences noted was quite unsuspected.

Another similar effect which also puzzled me has been traced to total reflection from the inner surface of one of the glass ends cemented to the calcite rhomb in the instrument, and seen when, by accident, a stone is viewed in a direction oblique to the optical axis of the instrument.

Once these simple difficulties have been realized and avoided, the observer can make better use of the instrument, and will understand how essential it is that observations should be made so far as possible under identical conditions.

Before proceeding to a discussion of the use of the dichroscope, and of the method of recording phenomena observed, it may not be out of place to run briefly through the theory of the optical behaviour of matter which is transparent to light having wavelengths within the limits of the visible spectrum. In this connexion one is, of course, thinking in terms of composite (white) light, transmitted through material possessing the property of selective absorption, transmitting or reflecting vibrations which are interpreted by our sensory system in terms of colour.

A beam of composite light traversing an isotropic medium, that is, amorphous material such as glass, or anything crystallizing in the cubic (isometric) system, travels with equal velocity in all directions because it meets with equal retardation. If the two surfaces of the material traversed by the beam are parallel, the angle of incidence, or entry, and the angle of exit will be the same, and the emergent beam will take a path parallel with the incident beam, still maintaining its identity as white light. Such material is, of course, singly refractive.

On the other hand, a similar beam traversing anisotropic material—that is, material crystallizing in any other system than

the cubic system—is split up on entering into two rays vibrating in planes at right angles to each other which emerge as separate rays, such material being doubly refractive. The refractive index of each ray has a maximum and minimum value, according to the direction of propagation, and in some directions the rays have equal velocity and the same refractive index. Such a direction is referred to as an optic axis, and uniaxial crystals (the dimetric systems comprising the tetragonal and hexagonal) possess *one* optic axis, while the biaxial crystals (crystallizing in the trimetric systems, namely, orthorhombic, monoclinic, and triclinic) have *two* optic axes. In dimetric (uniaxial) systems, the two rays are known respectively as the ordinary ray (denoted by the letter " o " or Greek letter "ω"), and the extraordinary ray (denoted by the letter " e " or Greek letter "ε") because of their optical behaviour. The ordinary ray has a constant refractive index, while the extraordinary ray has a variable index according to its direction.

A beam of white light transmitted in the direction of an optic axis suffers equal retardation, has uniform velocity, and therefore, has one index of refraction, that is to say, in such a direction all minerals are singly refractive.

In uniaxial crystals the optic axis corresponds with the principal or "c" crystallographic axis, hence basal sections in dimetric (uniaxial) minerals are isotropic. It must be remembered that optic axes are purely directional and in biaxial (trimetric) minerals the concept of the optic axes becomes increasingly complicated as one proceeds from orthorhombic minerals to crystals of the monoclinic and triclinic systems. In fact, even H. G. Smith([1]) states in referring to this " The symmetry of the triclinic system being so low, it would be profitless to attempt a statement of optic orientation."

Light is transmitted through biaxial (trimetric) crystals by rays having maximum (gamma ray) and minimum (alpha ray) indices of refraction, with a third ray (beta) having an intermediate velocity and refractive index. Light travelling through such media is split into two rays vibrating at right-angles to each other, and travelling in pairs according to the direction of propagation, namely, as alpha-beta, alpha-gamma, or beta-gamma, and in intermediate directions.

The colour of minerals by reflected or transmitted light, is due to the selective absorption of certain rays by the material, while the

unabsorbed rays travel on to the eye. The effect, in the case of coloured glass, and other amorphous material, and substances crystallizing in the cubic system, is to transmit the same colour uniformly in all directions, as one would expect.

In the case of coloured varieties of anisotropic minerals, the pairs of rays into which composite light is resolved, differ in wavelength, and are differently absorbed during transmission. As a result the transmitted colour as interpreted by the eye may be a combination of differently absorbed wavelengths, and in some striking examples, a purple stone, for example, viewed at different angles, is seen by the unaided eye to be both red and blue, producing the effect known as dichroism. An example of this effect is seen in the lovely so-called " Alexandrine " sapphires from Ceylon, which display this optical effect most strikingly. In the case of biaxial minerals, in which the colour differs according to which of three directions light is transmitted in, possibly the most beautiful example of this effect is the lovely kunzite, or lilac spodumene, which is lilac in one direction, pale pink in another, and pale blue in a third. In light-hued stones the effect may be clearly seen, but in others the strong body colour may mask the effect.

By the use of suitable rhombs from the colourless and very strongly doubly-refractive mineral calcite, or "Iceland Spar", a complete separation of the two polarized rays may be achieved and compared in the dichroscope, by which a beam of composite light after traversing a transparent medium is doubly refracted, producing two adjacent square images of the aperture, which may thus be easily compared. Coloured isotropic material will, of course, produce two images of identical tint and intensity, when examined by light transmitted in any direction, and similar images will be seen when any doubly refractive mineral is examined in the direction of an optic axis.

All coloured glasses, being amorphous in nature, are optically isotropic, and in most cases their optical behaviour is normal, but there is one special type of glass which behaves rather differently when examined by the dichroscope. The only example I have encountered so far was in the form of small cut pastes in ear drops, made possibly forty years ago, and believed to have been of German origin, and sold as " Rhinestones." These have no connexion with, or resemblance to, the cheap paste trinkets of garish colours and cut,

coming from the United States of America just now, but to quite a different type of paste. I have not yet discovered the origin of the name " Rhinestone " nor whether, in fact, similar stones were ever found in the Rhine, and this would be interesting information. These little stones of about 1.5 ct are semi-transparent, and in one direction they appear to be pinkish, while in another the colour is brown. When examined by the dichroscope, two squares of the same colour are seen, but from another angle the transmitted light produces a pair of images of a different colour, thus differing from normal isotropic material, which gives identical colours in all directions. This phenomenon is known as dichromatism, and is not to be confused with dichroism; and is characteristic of a number of organic substances.

Solutions of some organic dyes may exhibit this effect to a remarkable extent. By transmitted light across the solution the colour reaching the eye may be a bright red, but when looking down at the surface of the liquid the reflected light may be blue owing to differential absorption.

Since the power of selective absorption varies in different directions in doubly refractive minerals, when coloured varieties of these crystals are viewed through a dichroscope by transmitted light in any direction except that of an optic axis, a pair of differently coloured images is usually seen. Not all doubly refractive coloured minerals display this phenomenon to any marked extent, for example some quite strongly coloured varieties of quartz and zircon; but conversely, pale varieties of some minerals show remarkable dichroism, for example, Burmese blue apatite. Maxixe beryl, brown tourmaline, ruby, and andalusite are a few examples of gems showing strong and delightful dichroism.

If observations should be made when by accident a strong light illuminates the stone at right angles to the axis of the instrument, the interior of the stone may be flooded by light of quite a different wave-length, resulting in the formation of images quite different from those normally transmitted. This effect is seen when examining a fairly large specimen in different directions in strong sunlight. This is why it is so essential to standardize the method of observation, in order that a direct comparison may be made between two specimens, even after an interval of time between

observations. If, for any reason, an examination should be made under other than normal conditions, the fact should be recorded for future reference.

It seems to me that in order to use the dichroscope to the best advantage, the student should be encouraged to use the instrument intelligently, and to record the results of his observations in his note book in a carefully tabulated manner. This would be facilitated if it were possible to obtain special pages, say quarto size, on which were printed pairs of blank frames representing the pairs of images seen in the instrument, which could be suitable coloured by the observer. I think that these frames should be printed in groups, each occupying a line across the folio.

The first should consist of, say, four pairs arranged horizontally, and the next, of four pairs, the first being horizontal, the next oblique, the third vertical, and the fourth horizontal. This arrangement should be repeated down the folio, space being left between each group for abbreviated notes. These should state the source of light, for example, a 40 w. " Pearl " electric light, at a distance of 8 ins. The vibration directions of the rays should be indicated where known. A system of shading lines could be used in place of colour if desired, although colour is more desirable.

I feel that it would be well worth while to study coloured minerals in the manner suggested, and the keen gemmologist will not find it a waste of time to keep a record of observations on various coloured media by means of the dichroscope. Much of the trouble in keeping such records would be in having to rule a large number of neat frames, but I believe that, subject to the demand arising, these ruled folios would soon be available to the student.

Reference.

1. H. G. Smith, *Minerals and the Microscope*, Thomas Murby, London, 4th edition, 1949.

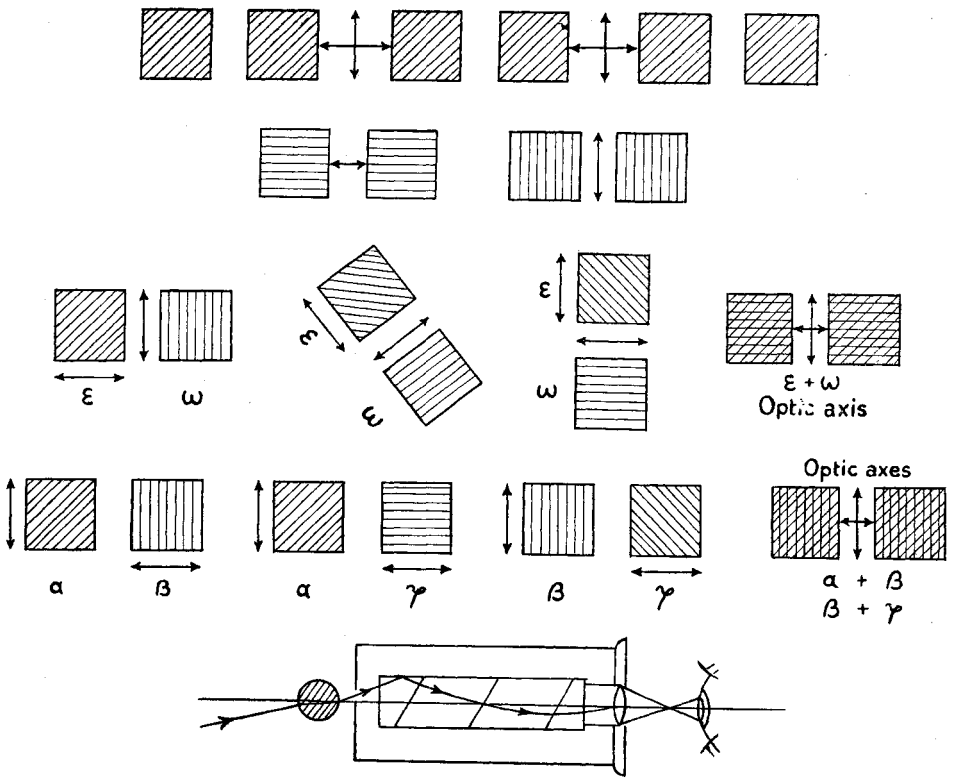

FIG. 1

ASSOCIATION NOTICES

CHANGE OF ADDRESS OF ASSOCIATION OFFICES

After 29th April, 1955, the address of the Association's registered offices will be SAINT DUNSTAN'S HOUSE, CAREY LANE, LONDON, E.C.2. Telephone : Monarch 5025/26.

Carey Lane runs at right angles to Gutter Lane, so that visitors to the new offices should easily find the new building. The Association occupies offices on the second floor, and members are invited to call whenever they are in the district.

A GEMMOLOGICAL BRAINS TRUST

Three experts in gemmology, Mr. Robert Webster, Mr. Fred Ullman and Mr. D. G. Kent, faced other experts in the same subject at the Association " Any Questions? " meeting on January 21, 1955, when it may be said that both sides gave a very good account of themselves. Questioners and the questioned were good, with interesting information being suggested, asked for and obtained.

In the absence of the Chairman owing to illness, the Secretary, Mr. G. F. Andrews, took the Chair.

The first question came from Mr. A. E. Farn who wanted to know why chrysoberyl and spinel were so little used in jewellery. Mr. Ullman responded with the reason that they were rare stones and from the public point of view their colour was on the dull side compared with sapphire or ruby, and Mr. Kent considered that the synthetic spinel out-classed the natural. Mr. Webster added that the yellow chrysoberyl had been fashionable in Victorian days. It might come back as the amethyst was coming back.

Dr. E. H. Rutland wanted to know how rare was really good spinel, say of a red colour, to which Mr. Ullman admitted that such stones were rarely seen in parcels today.

Entertaining discussion followed the additional query from Mr. A. E. Farn as to whether it was correct to term a stone colourless or white.

Mr. Ullman plumped for " colourless " as the more correct because white suggested a " colour " and Mr. Webster agreed, saying that to him white meant a milk-like colour that could be applied, for instance, to ivory or jade. He admitted that some people might say that as black was the absence of colour, so its opposite should be white, though in fact that represented all the colours of the spectrum.

Opposition came from Dr. Rutland who said the term " colourless " involved the denigration of good stones, and the Chairman asked how a colourless diamond could be called blue-white? Mr. Ullman said that diamond experts would say that the blue was due to fluorescence and was not a physical property of the stone.

Mr. M. D. S. Lewis asked if the interior of good paste had ever been found featureless and without " swirl " marks?

Mr. Webster said this was so as far as ordinary magnification was concerned. The more modern lead glass seemed less liable to interior imperfections than the old glass though they might show up under high magnification of eighty or more. Dr. W. Stern volunteered the theory that present methods of manufacture got rid of the bubbles, possibly by supersonic means.

Still on the topic of interior features, Mr. Lewis wanted to know if their absence suggested a natural or synthetic stone. Mr. Webster said such a stone was more likely to be natural Most of the synthetic corundums showed features, though the yellow was remarkably clean. Spinels were another matter. Sometimes these were clean when synthetic. The worst thing they could encounter was the natural stone which sometimes turned up and showed no features.

Mr. B. W. Anderson asked the panel what was the most difficult gemmological problem that they had encountered.

Mr. Ullman said it was the identification of natural or synthetic sapphire which required laboratory experience and professional skill in certain cases. Mr. Kent quoted the identification of danburite crystals or coloured tourmaline with an .030 double refraction, and Mr. Webster said he considered the hardest stone to distinguish was turquoise.

Another question of nomenclature was introduced by Mr. Farn who asked whether the panel favoured the changing of the description quartz-topaz which was well understood by the trade.

Mr. Ullman said it would be a good thing if the trade did accept and call things by their correct descriptions and he was supported by Mr. Webster who pointed out that at one time there was ruby-spinel, though he added that the term " ruby glass " was still used by the glass trade. However, that was a colour adjective and topaz might be used in the same way. The Chairman pointed out that since the Merchandise Marks Act, 1953 the description of a quartz as a quartz-topaz might make a dealer liable to prosecution. It was no defence, as had already been laid down in the Courts, to say that this was an established trade practice. Mr. J. R. H. Chisholm agreed and Mr. Anderson thought that the trade used the name because it sounded better. It would have to go in the cause of honesty. These terms were losing ground and eventually one name should stand for one stone.

Another question that was cleared up was why the jeweller's loupe was so-called. It was agreed that this came from the French word meaning magnifying-glass and was sometimes wrongly applied to the watch lens more commonly used by the jeweller.

Mr. Anderson propounded a question that rather stumped the panel when he asked if there are any blue cobalt minerals and if not, why not? Mr. Webster admitted that all the natural ones he knew were pink. He could not say why but Mr. H. Lee came forward with the suggestion that it was perhaps due to the relative speed of their formation.

An interesting discussion followed on the fate of the diamonds that were in the fire that followed the recent air crash at Prestwick. Mr. S. F. Redknap said he had heard that some of the diamonds had fused. Was there anything that could be done to make them commercially usable?

Mr. Webster said that he had heard from someone who had been engaged in the search for them that they were quite unusable. The stones were cracked and pitted. Most of the stones were in the rough state and the crystals had apparently corroded and fused as if something outside had pressed into them, that was how it had been described—it was almost as if they has been made plastic and then something pressed against them.

There were several questions concerning modern paste stones. Mention was made of an American paste with a refractive index of over 1.7 and a hardness of about six and there was a discussion about " case-hardened " paste from France. Other speakers thought these stones were of equal hardness throughout being toughened possibly as a result of an annealing process.

COUNCIL MEETING

At a meeting of the Council of the Association held at 19/25, Gutter Lane, London, E.C.2, Sir James Walton presided in place of the Chairman, Mr. F. H. Knowles-Brown, who was indisposed.

The following were elected to membership:—

FELLOWSHIP.

C. I. Belcher, Johannesburg.
S. S. Bradbury, London.
A. B. Chinn, Jersey.
J. Stamnaess, Oslo.

ORDINARY.

L. J. van Ameringen, London.
G. M. Beauchamp, Bournemouth.
R. E. H. Jeffreys, London.
E. J. Soukup, San Diego.

The Council heard with regret that Mr. Knowles-Brown wished to resign as Chairman because of ill-health and other reasons. The Council made the following nominations for submission to the Twenty-fourth annual general meeting:—Chairman, Sir James Walton, K.C.V.O., F.G.A.; Vice-Chairman, Mr. Norman Harper (Birmingham); Treasurer, Mr. F. E. Lawson Clarke (London). The Council further decided to nominate the retiring Chairman for election to the Council.

It was reported that Messrs. R. K. Mitchell and E. H. Rutland retired from the Council, in accordance with the Articles of Association, and, being eligible, were willing to offer themselves for re-election.

The question of including more work on diamond in the practical examination was considered, and deferred to a subsequent meeting.

Messrs. Watson, Collin & Co. were willing to continue as Auditors to the Association.

HERBERT SMITH LECTURES.

The Council agreed to establish annual lectures, to be known as the Herbert Smith Lectures, as a suitable means of commemorating the great services to gemmology of the late President. It was further agreed that these lectures should be given in March of each year.

TALKS BY MEMBERS

PARRY, Mrs. G. I.: " Precious stones." Cardiff and District Branch of Federation of Soroptimists Clubs, 24th November, 1954 ; *id.* S. Wales Domestic Science Teachers' Association, 9th December, 1954.

BLYTHE, G.: " Gemstones." Crowstone Young Wives' Group, Westcliff-on-Sea, Essex, 28th January, 1955 ; *id.* Benfleet Young Wives' Group, Essex, 1st February, 1955.

SOLOMON, S. T. : "Gemstones." Plymouth City Townswomen's Guild, 21st March, 1955.

LEAK, F. E. : " The Science of Gemmology." Redfield Youth Centre, Bristol, 12th January, 1955.

id. Wives' Comradeship, Tyndall's Baptist Church, Clifton, Bristol, 17th February, 1955.

id. Men's Contact Club, Westbury-on-Trym Baptist Church, Bristol, 18th February, 1955.

id. Companion's Club, St. Mary's Church, Stoke Bishop, Bristol, 26th February, 1955.

id. Townswomen's Guild, Warmley, Glos., 1st April, 1955.

LETTERS TO THE EDITOR

DEAR SIR,

However well-equipped laboratory a gemmologist may have, he sometimes finds it that a method without use of apparatus is a boon. When accurate statements are not necessary and only qualitative proofs are enough, the following method will be found very suitable.

Hold the table-facet of the stone to be tested just near your eye and look through the stone at a lighted clear-glass electric bulb. There will be as many images of the bulb as there are back facets on the stone, and there will be some spectrum in some images. But besides these two common sights, there will be a very interesting thing seen if the vision is fixed on one of the many images. Within the image of the bulb there will be a double image of the incandescent filament. The double image will be distinctly a little apart from each other even in stones like quartz, emerald, corundum, topaz, whose double refraction is low, even though the stone is small—say one carat size. But if the stone is deep-cut and large the doubling is enhanced. In stones like tourmaline, peridot, zircon, the doubling is larger and larger respectively, and the filaments appear far apart from each other.

By practice at home on stones of the gemmologist's collection, the amount of separation of filament-images of individual species can be ascertained.

Stones which do not produce such effects are diamond, spinel, garnet and a few uncommon stones. Paste also does not produce such effect, but it can be easily identified by feeling its low thermal conductivity. A spinel cannot be mistaken for ruby, neither garnet, however fine it may be. Diamond cannot be mistaken for any other stone.

A large faceted bead from a rosary, suspected to be of glass by a devout owner, on account of low price he had paid, was thus tested. Other beads were similarly tested and the rosary was confidently declared to be of rock-crystal,

and about four pounds in value. The owner had paid four shillings, for which only glass rosaries are obtainable. The devotee was so pleased. So the feel for heat, colour of the stone and qualitative double refraction by this method will enable a person to identify many stones without much eye-strain and from an easy chair.

Yours faithfully,
J. N. DAVE (India).

DEAR SIR,

A passage in Sir Mortimer Wheeler's "Rome Beyond the Imperial Frontiers" has somewhat puzzled me, and I wonder if any of your readers have an explanation to offer.

Speaking of trade from the Red Sea to India, he quotes from the Periplus of the Erythraean Sea, a geographical treatise of the first century A.D. written in (poor) Greek by a Roman subject living in Egypt. The treatise mentions the pearling industry of the Persian Gulf, but says that the pearls from there were "inferior to those of India".

If this was so, when did the Indian fisheries along the Malabar coast cease to be of importance, and when did the Persian fisheries first come to be recognized as producing the orient pearl?

Yours faithfully,
JUDITH BANISTER.

London, S.W.15.

ANNUAL MEETING

The 25th Annual General Meeting of the Association was significant for the retirement of Mr. F. H. Knowles-Brown, who has been the Chairman for many years and to whom a presentation was made, and the announcement that an exhibition would be held in Birmingham by the Midlands branch in October.

Mr. Knowles-Brown opened the meeting at the Goldsmiths' Hall on February 24th by welcoming the Chairman of the Midlands branch, Mr. Trevor Solomon, and the Secretary, Mr. King. He said he always felt that annual general meetings, although composed of business, were an important matter in the life of an Association and he was glad that so many had attended despite the bad weather.

Mr. F. E. Lawson Clarke presented the accounts. There was a balance of £380, partly due to the increased subscriptions now payable. These would be needed this year when the Association moved into its new premises. The income tax was up by £264 and there had been a reduction in certain expenses. He thanked the National Association of Goldsmiths for their financial support and the help they had given during the year.

Mr. Knowles-Brown in dealing with the report of the year spoke of the activities of the branches. It had always been an anxiety ot the Council to know what could be done for members who could not easily get to London for meetings. The activities of the local branches gave an opportunity and the Midlands branch had been particularly active.

The annual report and audited accounts for the year ended 31st December, 1954, were adopted.

Sir Lawrence Bragg, F.R.S., was elected President of the Association. In announcing the election, the Chairman said that it was a great honour to have Sir Lawrence accept office again.

Mr. Knowles-Brown said that since the Association was incorporated he had had the honour of being Chairman. It had been a very great pleasure to serve in that capacity but the time had come for him to hand over the office. It had been a pleasure for several reasons. First, the enthusiasm of all the members and he would like to thank them for their support. Secondly, there was the Council over which he had presided. Its members were regular in their attendance and sensible and wise in their deliberations. Thirdly, their secretary and the staff had also always been of the utmost assistance.

" It is therefore a bitter thing to say ' goodbye ',," said Mr. Knowles-Brown, " as Chairman, but I can come to the sweet part in announcing that my Vice-Chairman, Sir James Walton, has consented to accept the position. You know of his enthusiasm and I know that I can hand over to him with complete confidence that he will spare no effort in the interests of the Association."

Sir James Walton in accepting the appointment said he had worked with Mr. Knowles-Brown for some time and knew of no better Chairman and he hoped he would receive his help as a member of the Council.

Mr. A. Ross Popley said they regarded Mr. Knowles-Brown as a treasured friend. He had been their Chairman since 1946 and had served on the Council since 1936. He had been a member of the Association for much longer.

As a member of the Council, said Mr. Popley, he had great pleasure in presenting Mr. Knowles-Brown with this gift from his fellow Councillors—a specially bound volume of Kenneth Snowman's book " The Art of Carl Fabergé " —as a tribute to the way he had guided and helped them through the years.

After Mr. Knowles-Brown had returned thanks for this—and later obtained in it the signatures of the Councillors—the meeting went on to elect Mr. Norman Harper of Birmingham as Vice-Chairman, and Mr. Lawson Clarke as honorary treasurer. Mr. Knowles-Brown was also elected to the Council.

Mr. J. Saunders then asked if there were going to be any special events during the year and Mr. T. Solomon said the Midlands branch would hold an exhibition at the Birmingham Museum and Art Gallery on October 11th. It would be opened by the Lord Mayor and continue for a period of three weeks. Mr. Solomon added that he hoped he would be able to get the support of all fellow members in the way of loan specimens.

NEW HOME FOR GEMOLOGICAL INSTITUTE OF AMERICA

Construction is under way on new quarters for the Gemological Institute of America in Los Angeles. The G.I.A. has been serving jewellers throughout the United States, Canada and many other nations for nearly 25 years. Although it maintains the Gem Trade Laboratory and classrooms in New York City and gives classes in Chicago and other cities, the Institute's headquarters have been in Los Angeles from its inception in 1931.

The G.I.A. outgrew its present quarters several years ago and the new structure has been in planning stages during that time. Since 1931 the Institute has grown enormously and shortly after the war the rapid growth of the organisation forced the Institute to use all of the space in the building and to go elsewhere for both office and classroom space.

The new building will have approximately twice as much space for the Institute with room for construction of additional space as required. The site chosen for the new Institute is considerably farther from the centre of the city than the original locations in the Wilshire district.

At the 1954 meeting of the Board of Governors it was decided to choose and purchase a site for the new building and to select an outstanding architect to design facilities which would meet all the unusual requirements of the Gemological Institute. The architect chosen was the famous Richard J. Neutra, author of " Survival through Design " and books on the subject of modern architecture in several languages. The new Institute will be constructed along the modern lines for which Neutra is famous. The building is built in an " L " around a patio facing a parking lot behind the building.

With the building programme under way, the Institute will be able to celebrate its 25th year by moving into a new structure planned specifically for its use.

GIFTS TO THE ASSOCIATION

The Council acknowledges with gratitude the following gifts :—

Die Achate by R. E. Liesgang, for the library, presented by Mr. T. Stern.

A brown diamond crystal, for the gem collection, given by Mr. J. H. Underdown.

MEMBERS' MEETINGS

MIDANDS :

A talk on spinels was given to members of the Midlands Branch of the Association at the Auctioneers' Institute at Birmingham, on 4th February, 1955. The Chairman, Mr. Trevor Solomon, read the paper on behalf of Mr. Neville Deane, F.G.A.

* * *

On March 4th the Midlands Branch held a further meeting at the Auctioneers' Institute and heard Mr. F. E. Goldie talk about " Preparations for an Exhibition ". Mr. Goldie told of a private exhibition he had recently organized and of his experiences in gathering together a unique collection of gemstones. A fine group of Cameos was displayed by the speaker.

* * *

A meeting of the Midlands Branch was also held on 1st April, and details will be recorded in the next issue of the *Journal of Gemmology*.

Mr. Neville Deane's talk given on the 4th February to the Midlands Branch is here recorded:

SPINELS are gem stones which somehow contrive to become overlooked both by gemmologists, jewellers and the general public. It is most unusual to see any piece of jewellery marked as containing spinels, and I have spoken to working jewellers and gem setters who never seem to have heard of the gems.

This paper is not intended to be exhaustive, nor am I an expert on spinels, but is written in the hope that some interesting comments may be contributed by fellow-members to add to the general knowledge.

Spinels may be conveniently divided into natural and synthetic spinels, and first the natural spinels will be dealt with.

Natural gem spinels are mainly considered to be a compound of one molecule of magnesium oxide with one molecule of aluminium oxide, but spinels in general are an isomorphous class of minerals in the same way as garnets, i.e., there can be a replacement of the magnesium oxide or the aluminium oxide by another and similar oxide without altering the crystalline form. Within the gem classification we have a replacement by zinc oxide, producing gahnospinel which has the same crystalline form but higher refractive index and specific gravity. Also some of the magnesia may be replaced by ferrous oxide or manganese oxide, and some of the alumina by chromic oxide or ferric oxide, which replacements have important effects on the colour of the stone. In fact so rarely is colourless natural spinel found, that it may be considered that practically all natural spinels are mixtures and not chemically pure magnesia and alumina.

Obviously excess of admixed elements such as iron may take the spinel out of the gem class, as for example the iron rich Pleonaste or Ceylonite, which become practically opaque, although since they take quite a good polish they may be used for some ornamental purposes.

One of the most interesting of the spinel family which is not of gem quality is an iron ore, magnetite, which occurs in Norway and Sweden and when found in suitable specimens in mediaeval times was known as the Lodestone, used for an early form of compass.

In this mineral, the magnesium oxide has been replaced by ferrous oxide, and the aluminium oxide has been replaced by ferric oxide, so that only one metallic element is present. It is however a typical spinel and occurs as octahedra. When the ferric oxide is partially or wholly replaced by chromic oxide, the mineral becomes chromite, an important ore of chromium and again a spinel. There are also various other mineralogical names according to the replacing elements and the degree of replacement, such as hercynite which is ferrous oxide and aluminium oxide, franklinite which is zinc and manganese oxide combined with ferric oxide, and so on.

If, however, the magnesium oxide is replaced by beryllium oxide as in chrysoberyl, and partially in taaffeite, the crystal is no longer of the cubic or isometric system, but becomes orthorhombic in the case of chrysoberyl and hexagonal in the case of taafeite and so these minerals are not true spinels although they are related to them by composition.

Spinels seem to be regarded as rather common stones, somewhat in the same class as amethysts and citrines, but actually the sources of supply are quite limited, being mainly from the Ceylon gem gravels, as more or less water-worn pebbles, or from Burma where they are found in conjunction with rubies often as quite good octahedra. A few originate in Siam. A former source, although probably not available at present, was Afghanistan and another minor source was the U.S.A., in New York State and Montana.

The distribution is therefore very limited indeed and this is what might be expected from their composition, which is wholly basic, containing no silica and therefore most unlikely to be found in the more acid rocks containing much silica. In fact the most usual sources of gem spinels are crystalline limestones, that is, limestones which have been exposed to heat under the earth thus allowing the constituent parts to crystallize or the gravels which have resulted from their decomposition. Spinel also occurs in some basic and ultra-basic igneous rocks.

Spinel belongs to the cubic system, and the most common form is the octahedron, very similar to the diamond, but the shapes are much deformed, and in many cases it would be hard to identify the spinel by its crystalline form. It is in fact rather a matter for

surprise that the Singalese can so often accurately pick out the spinels from the gravel, rather than that they sometimes make mistakes. I have myself found a couple of small purple corundums amongst a parcel of small rough spinels, but these were quite indistinguishable until, after cutting, the usual method of polishing spinels with ruby powder on a tin lap made no impression on them and they were polished with diamond dust instead. After cutting and polishing they could of course, be readily detected by means of the refractive index.

Spinels occur in a variety of colours, but on the whole, the colours might be called "subdued". The richest colours are undoubtedly the brighter reds but these hardly reach the richness of colour of the best rubies, though they can equal or even surpass the colour of the pale Ceylon rubies or pink sapphires. As to other colours, there are rather cold blues, various mixtures of blue and red resulting in shades of purple and amethyst, greenish-blues and rather dark greens. Sometimes the colours are so dark that the rough stones might be considered black, and it is very difficult to know whether to cut them or not. Perhaps a hollow cabochon similar to a garnet might yield useful results, although personally I have not tried it as yet. There are reports of yellow and colourless spinels, but these are undoubtedly rare in spite of the fact that the chemical combination of pure magnesia and alumina is colourless. A pale lavender-colour is fairly common and the nearest to colourless that occurs freely. Various names have been used such as ruby-spinel, balas ruby, rubicelle, almandine spinel, sapphirine and chlorospinel, but they are better discarded.

A peculiar feature of the coloration is the appearance of two-coloured rough stones, i.e., a stone with a blue centre and a pinkish outside rim, or a dark greenish blue centre with a lighter blue rim or a pink rim. The appearance is fairly characteristic, not at all like the abrupt colour change in tourmaline, or the straight bars of colour in corundum, but a much more delicate effect, rather like an internal halo. Some of the rough stones shown display the effect in daylight although possibly not in artificial light. It is very difficult to capture the two colours in a cut stone as the lighter coloured outer rim is nearly always lost in cutting.

The different colours of the gem are ascribed to different metallic elements. Red is due to chromium, the yellowish-red

tints to iron, and manganese may be the cause of some of the violet colours; blue is ascribed to iron, whilst copper has been referred to, perhaps incorrectly, as the cause of some greens. Zinc in gahnospinels, which are blue, apparently does not affect the colour. Quite a number of varieties of stones may be improved by heat-treating which will often change an unpleasant colour to a more pleasant one or make a too dark tint to a more usable lighter tint, but so far I have not heard of, or found any way of changing the colour of spinel with the means at my disposal.

Spinels quite often exist as twinned crystals in a shape so characteristic that it is called the spinel twin, a form of contact twinning, and these twinned crystals are often flattened and might easily be mistaken for hexagonal ruby crystals, unless the presence of the re-entrant angles is noticed. The twin is formed as if the crystal had been cut in half parallel to a face of the octahedron and one half had been turned round 180°.

The spinels which come near to ruby in colour have been called " balas rubies " in the past, although it is a term which should be discarded. The name may be derived from Balascia, now Badakshan, in Afghanistan, from where good spinels were derived in mediaeval times. Two stones which are commonly called rubies, and are of great historic interest, are actually " Balas rubies " or spinels. One is the Black Prince's Ruby in the Imperial State Crown, of which the first mention is in 1367 when it formed part of the treasure of the King of Granada, was seized by Pedro, King of Castile and given by him to the Black Prince. Henry V wore the stone in his coroneted helmet at Agincourt. During the Commonwealth the Crown Jewels were ordered to be sold and included in the inventory was the Black Prince's Ruby valued at £4 only.

The stone eventually turned up again in Charles II's reign, since in his crown there is a position which because of its peculiar shape could only have been intended for the Black Prince's Ruby. This stone is of great antiquity. I learn that the exact weight is not known as it is mounted in a very old gold setting which is not to be removed from the stone, and therefore the stone and setting are mounted together in the Imperial State Crown. However the weight is computed at 170 carats. The stone is not faceted but polished in the rough octahedral shape, as can be seen in the

picture of the Imperial State Crown, and the shape is irregular, the length being nearly two inches. The colour is very rich.

The Timur Ruby is probably one of the largest spinels that is known and has engraved on it the names of Mogul and Persian Emperors. In 1912 it was in the possession of Queen Mary. The weight is 361 carats.

This splendid but rather dark red spinel, which also is not faceted, has a history dating back at least to 1398 when it came into the possession of Timur, or Tamerlane as he is more commonly known to Europeans, at the capture of Delhi. From him it passed into the possession of various Mogul and Persian Emperors, some of whom had their names engraved thereon ; some of these inscriptions were subsequently erased. Eventually it reached Lahore and remained there until the annexation of the Punjab in 1849, when together with the other State jewels it came into the possession of the East India Company. It was exhibited at the Great Exhibition in 1851. There does not seem to be any photograph or illustration of the Timur Ruby extant.

Probably in early days it was assumed that these stones were true rubies, but their real nature has been known for a very long time. It is evident therefore, that these representatives of the spinel family have had a long and honoured history. It is quite possible that some smaller cut spinels still may go under the description of rubies. Birmingham Art Gallery is said to have a good collection of spinels, but when I personally have visited the galleries they have not been on exhibition.

A striking justification of the science of gemmology was the detection of the spinel which was not a spinel by Count Taaffe of Ireland in November, 1945, reported in April, 1951. Whilst examining some spinels by means of a binocular microscope he noticed that one of a pale mauve colour showed a small but distinct doubling of the back facets. Since spinel belongs to the cubic system and has only single refraction, this, if correct, could only point to the stone being something other than a spinel, in spite of the constants of specific gravity and refractive index being within the spinel range. He sent the stone to the Laboratory at London, and it was in fact confirmed that the stone was doubly refractive and therefore was not a spinel, and the question was as to what it could be, as no known doubly refractive stone had these

constants. From a small portion taken from the pavilion it was found that by composition the stone, instead of being a magnesium aluminate, was in fact a magnesium beryllium aluminate and belonged to the hexagonal system.

So far, one other specimen has turned up and from careful measurements the birefringence has been established at .0041, which is small but distinct. The second stone was slightly deeper in colour than the first. I have seen this stone in the Minerals section of the British Museum (Natural History).

Naturally these discoveries led to a scrutiny of available spinels, and personally I examined my small stock by means of the microscope between crossed polaroids to try to find some double refraction. I did in fact find one which showed a slight lightening of the darkness on revolution of the stone, and in great hopes sent this to Mr. R. Webster to see what he had to say about it. He very kindly did examine it, but, alas, stated that the appearance between crossed polaroids was an anomalous double refraction caused by strain, due to included crystallites in the stone, so it was just a spinel and not a taaffeite.

However, one can always hope, and so I try to examine any spinels I acquire, particularly light coloured ones, and as far as possible any rough spinels, to see if by good chance a taaffeite should turn up. Since only two specimens are known—although doubtless there are others unknown—the value of the stones is problematical and could hardly be commercially assessed. One wonders what would be the value of the stones, if only two diamonds were known!

Spinel is a hard stone—hardness 8—about the same as topaz, and therefore a good wearing stone. It has something of a reputation for being brittle, although personally I have not found this to be pronounced. Spinel has no definite cleavage planes, and being singly refractive, it has no dichroism and the stones may be cut in any convenient direction without the careful orientation necessary in some varieties of stones. As regards cutting they are fairly easy and the stones can be rough-ground preferably on a diamond grinding wheel, with no risk of starting flaws on cleavage planes or through local overheating. The facets cut crisply and clean on a diamond-charged bronze lap, and may be polished readily on a pure tin lap with " ruby powder ," without much risk of scratches appearing. If these should occur on the larger or table facets, the

use of a lead-tin alloy lap—softer than pure tin—will usually solve the problem.

The specific gravity of gem-quality spinel is about 3.60, varying from 3.58 to 3.63 but in the types rich in zinc the specific gravity may reach 3.98, whilst in the opaque varieties such as ceylonite rich in iron, it may be 4.0 and in the mineral gahnite (zinc aluminate) it varies from 4.0 to 4.6.

The refractive index is also variable, being round about 1.72. The lowest R.I. is 1.715 and most natural gem spinels are below 1.72, but in red spinel the R.I. may rise to 1.735 according to chromium content and in blue spinel to 1.747 according to zinc content. Consequently the R.I. test will not show conclusively whether a spinel is natural or synthetic, although the majority of natural gem spinels are at or below 1.72 and synthetics above 1.72, but these figures are only a kind of guide and must be confirmed by other means.

Some red spinels exhibit fluorescence under ultra-violet light; the lighter reds show this effect to the best advantage. The darker and duller reds show more of a dull red fluorescence, disappearing as the purple-tinted stones are tested. The study of fluorescence has been dealt with very fully and ably recently in articles in the *Gemmologist* by Messrs. B. W. Anderson, C. J. Payne and R. Webster and is a very technical subject. Briefly, the fluorescence is due to five bright lines in the red portion of the spectrum of which the two strongest form a pair. Although the red fluorescence appears much the same as that of ruby to the unaided eye, the lines producing it are not of the same wave-length.

Spinels also exhibit absorption spectra, which vary, as might be expected, according to the colour. Red spinels which owe their colour to chromium show bands in the red portion and a blotting out of part of the green and yellow, but red spinels which owe their colour mainly to other elements than chromium do not fluoresce and do not show the bands in the red.

Blue spinel which contains iron, shows an absorption spectrum which may contain as many as ten bands, of which a strong band in the blue portion is very persistent and is visible in stones with only 2% of iron oxide.

Spinel has a colour dispersion of .020. This figure is not large and in natural coloured spinels has little visible effect, but in

synthetic colourless spinel it does make a very bright and lively stone (much more so than colourless corundum, which has a dispersion of .018) and coupled with the hardness makes a very useful stone for articles of jewellery for which the cost of diamonds would be prohibitive and yet which are required to be more permanent and also more valuable than paste jewellery.

Synthetic spinels, as is commonly known, are produced by the inverted blowpipe method (Verneuil method) and this material, besides being commercially useful, is of great scientific interest. In nature spinels consist of equal parts of magnesia and alumina, but the synthetic can contain one molecule of magnesia to four molecules of alumina. The effect of this change is to vary the specific gravity from 3.58 to 3.62 and the refractive index from 1.719 to 1.728.

Natural spinel belongs to the cubic system but corundum, consisting of alumina, belongs to the hexagonal system. It would appear therefore that synthetic spinels with 80% of alumina ought to be hexagonal rather than cubic, but in fact this is not so, and many boules show quite a pronounced square shape indicative of the cubic system. It has now been discovered that alumina can assume in a certain modification a cubic structure, but usually this is not stable at ordinary temperatures, whereas evidently when combined with 20% of magnesia it can so retain the cubic structure at ordinary temperatures. Obviously, however, the synthetic spinels do not quite belong to the same class as the natural spinels in spite of their seeming similarity of properties.

Synthetic spinels are not as a rule made in colours the same as the natural; in fact it is not easy to make a synthetic red spinel. I believe the usual colour obtained by the addition of chromium is a green rather than a red, and it is only comparatively recently that a pink or red colour has been achieved. The usual colours are colourless or white, blue in various different shades and greens of a rather dark tint. A yellow colour is also made.

The blue colours are due to the addition of cobalt. It was due to the attempt to colour synthetic corundum by means of cobalt to imitate sapphire, and the failure to obtain a good distribution of colour without the addition of magnesia to the alumina that the synthetic spinel was first made, since the addition of magnesia lowered the hardness from 9 to 8 and changed the crystalline

structure from hexagonal to cubic and the refraction from double to single refraction, i.e. the result was a spinel and not a sapphire.

Most of the blue colours are named as resembling aquamarine, of which they are a fair imitation. However, natural aquamarines are dichroic, the colours being blue and a greenish blue, whereas the synthetic blue spinel is not dichroic, and a packet of the natural stones has a subtly different appearance from a packet of synthetic stones. The darker blue colours have a very rich appearance, not like any natural stone. If they are sold for what they are, and the buyer knows the material and likes the appearance and the price; there is no harm in them. They are of course much harder and more durable than pastes, and therefore more suitable for use in jewellery, provided no attempt is made to sell them as natural gem stones.

The green colours that I have seen are not particularly meritorious, one being more of a dark green, sometimes referred to as tourmaline green. The other green is termed "emerald green", which can only be called very unconvincing.

The yellow colours may imitate chrysoberyl and the pinks may imitate topaz, tourmaline or rose-coloured beryl (morganite).

The absorption spectrum of the synthetic blue spinels is that due to cobalt, three heavy broad bands in the orange yellow and green, and these stones can be readily distinguished from aquamarines by examination through a Chelsea filter, under which the true aquamarines appear green, whereas synthetic blue spinels appear red in the darker colours to orange in the paler colours.

The appearance of the synthetic spinels under the long wave ultra-violet lamp is most interesting and attractive. Whereas the natural red spinels fluoresce red, the blue stones do not fluoresce, the presence of iron as colouring matter acting as an inhibitor of fluorescence. The blue synthetic stones fluoresce red of various tints since here the colouring matter is not iron but cobalt. The rather pale yellow synthetic fluoresces a very beautiful apple-green and the pale greens fluoresce darker green colours, again in distinction from the natural stones. In fact so beautiful are the fluorescent colours that synthetic spinels might well be used as " stage jewellery " for scenes where fluorescent effects are wanted; which the writer has seen in aquatic events.

So far no mention has been made of inclusions, and possibly these are not of so great importance as in some other stones.

Perhaps the most typical inclusions are small octahedral crystals. In the synthetic spinels, the inclusions, where present, are usually gas bubbles, but the stones are often extremely clean, and, whereas the presence of gas bubbles is an aid to identification, their absence may not indicate a natural stone.

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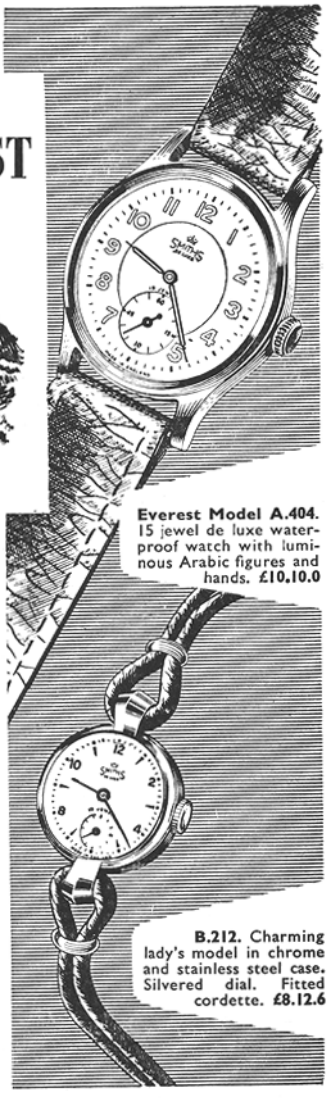

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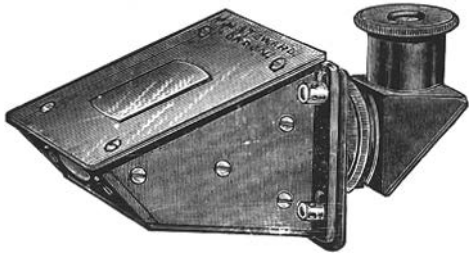

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A POCKET CHART OF ORNAMENTAL AND GEM STONES

By Sir James Walton, K.C.V.O., M.S., F.R.C.S., M.B., L.R.C.P., B.Sc., F.G.A., F.A.C.S. The ornamental and gem stones dealt with in this chart are grouped according to their colours, and within each colour group in order of their refractive indices. The other characters are then listed and any special properties of the stones are indicated in italics. This handy-sized chart, compiled by the author of "Physical Gemmology", will be of great assistance to all jewellers, antiquarians, lapidaries and gemologists. 12/6 net.

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THE JOURNAL OF GEMMOLOGY
AND PROCEEDINGS OF THE GEMMOLOGICAL ASSOCIATION OF GREAT BRITAIN

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Mr. CLAYTON'S DIAMOND

by

JESSIE M. SWEET, B.Sc., and A. A. MOSS, B.Sc., Ph.D., F.S.A.

IN the autumn of 1663 Robert Boyle heard that a certain Mr. Clayton, newly returned from Italy, possessed a diamond which became luminescent when rubbed in the dark. This information so intrigued him that he set off at once to find its owner. As Mr. Clayton was preparing to go out and the luminescent effects were not visible in broad daylight, Boyle borrowed the diamond for the night. He described it as " a Flat or Table Diamond, of about a third part of an Inch in length, and somewhat less in breadth, that it was a Dull Stone, and of a very bad Water, having in the Day time very little of the Vividness of ev'n ordinary Diamonds, and being Blemished with a whitish Cloud about the middle of it, which covered near a third part of the Stone." This rather unprepossessing gem was set in a ring.

In a long letter to Sir Robert Morray, F.R.S., which was also intended for the information of a certain Monsieur Zulichem, he gave an account of previous reports of luminescence in stones, most of which he regarded with scepticism. Many of them were referred to as " carbuncles " which in those days meant any red stone (ruby, spinel or garnet). The only one he examined was a vivid

ruby which was supposed to have this property, but nothing he did to it could induce it to shine in the dark.

He was so anxious to start his experiments with the diamond that he could not wait for the evening, but got into his four-poster bed straight away and drew the curtains, but no effect was observed until twilight. In the first place he was not absolutely convinced that the stone was a diamond, but after finding that it scratched both quartz and glass, he felt a little more confident about it. He also found that it had electric properties and would attract in the same way as amber or jet when rubbed, though after heating near a candle-flame it attracted nothing. But the real interest lay in its luminescence and this was not visible until the diamond was actually rubbed or heated, when, as he says, it shone in the dark like the scales of whiting or putrefied fish. He did realize, however, that the light was not caused by the destruction of matter as in organic bodies, but by a mechanical operation.

Boyle used various means to excite the diamond and increase its luminescence. He rubbed it with cloths of different colours (of which apparently black gave a poor result) and then with transparent horn, a white wooden box and white porcelain, all of which gave good results, but he would not deduce from that that the colour of the medium used had any influence. After rubbing it with a cloth he covered it with blue glass, but the luminescence was not sufficiently strong to penetrate it. He then held it near a candle-flame, but the effect was not good although he kept his eyes averted from the light. When pressed with a white glazed tile, it seemed to luminesce ; and it gave a vivid reaction when pressed with a steel bodkin, and eventually even with his finger. Finally he took it to bed with him and held it against his body, the warmth of which was sufficient to cause it to glow.

He then tried to quench the luminescence by immersing it in water and other liquids and also by covering it with saliva, in spite of which treatment it still shone. He thought that warm water excited it and that it glowed more brightly when removed, but he could not see the effect when immersed owing to the escape of air bubbles. He did, however, think that the rate of decay of the luminescence was thus accelerated and the visible luminescence would, in any case, appear to have been of short duration.

The results of these experiments were communicated to the Royal Society on 28th October, 1663, when the stone was exhibited, after which it was returned to Mr. Clayton, who presented it to Charles II. Boyle regretted that he was no longer able to demonstrate its properties to Sir Robert Morray or Monsieur Zulichem, but suggested that it might be possible for them to see it, "though it be now in the hands of a Prince that so highly deserves, by understanding them, the greatest Curiosities ; yet he vouchsafes you that access to him as keeps me from doubting, you may easily obtain leave to make further Tryals with it, of such a Monarch as ours, that is not more inquisitive himself than a favourer of them that are so." Eventually he discovered that several other diamonds exhibited a similar luminescence, but none so well as Mr. Clayton's.

We may infer from these observations that, during exposure to daylight, Mr. Clayton's diamond absorbed radiation which it could emit under the stimulus of heat, applied either by "affriction" (as Boyle called it) or by immersion in hot water—a phenomenon known as thermoluminescence. We have repeated these experiments of Boyle under more controlled conditions and the following is a brief account of the results obtained and the conclusions drawn.

Mr. Clayton's diamond not being available, it was first of all necessary to select a suitable diamond. Accordingly, since it seemed probable that a diamond that fluoresced strongly under ultra-violet light would be likely to exhibit thermoluminescence, a set of diamonds from the Belgian Congo, presented to the British Museum by Sir Ernest Oppenheimer, was placed under a high pressure mercury discharge tube, the radiation from which was caused to pass through a Wood's filter.[1] One of this set (B.M. 1946, 1a)—a rough spinel twin, which fluoresced (bluish-white) much more than the others, was chosen for the experiments. After exposure to ultra-violet light, the diamond was removed to a dark room, where for about 2 hours it was easily visible to an observer that had accustomed his eyes to the darkness. When it was no longer visible, the diamond was placed in a beaker of hot water (temperature between 70 and 80°C) and the diamond again glowed brightly. It has been customary to call the former phenomenon phosphorescence,[2] and the latter thermoluminescence. The two phenomena are in point of fact the same in that phosphorescence and thermoluminescence denote the flowing out of energy that has

been stored during the period of activation, the only difference between them being that in the former instance only is the rate of emission of light energy at room temperature sufficiently great to be detected by the eye. As the energy contained in the diamond decreases, the rate of emission of this energy also decreases (just as the rate of flow of liquid from a vessel decreases as the level of liquid in it falls), until this rate is too low to be visible. This emission of energy is still, however, taking place and, in the case of diamond, the rate can be increased by elevating the temperature, whereby the luminescence can once again be seen. It was further discovered that this low rate of light emission continued for several days : thus, the diamond, after exposure to ultra-violet light for 3 minutes, followed by 10 days in darkness, glowed quite brightly when placed in water at 70–80°C. The luminescence could, however, soon be thermally quenched and after maintaining the diamond at 100°C for a few minutes, visible luminescence at this temperature ceased.

Although these experiments show clearly that this diamond can absorb energy in the form of ultra-violet light and emit it later as visible light, they are not exactly analogous to those of Boyle, whose diamond was exposed only to daylight. The diamond, therefore, after heating at 100°C to remove the absorbed light-energy, was allowed to lie near a north window (the day was dull and rainy) for 4 hours. When it was placed in water at a temperature of 70–80°C it was observed to luminesce. It seemed probable that the source of luminescence of the diamond was the absorption of ultra-violet light, and this was confirmed in the following manner. The diamond was placed in a light-tight box and heated to 100°C as before. The box was removed to the dark room where the diamond was transferred to another box in which it could be illuminated through an ultra-violet filter.[3] This box was then placed near a window so that daylight could fall on the diamond and left for a day. When the diamond was examined in water at 70–80°C, it produced no visible luminescence.

Having shown that there was sufficient ultra-violet radiation in north daylight to activate the diamond, it was next necessary to find what wave-length of ultra-violet light was being absorbed. Accordingly it was decided to repeat the experiments using a tungsten filament lamp instead of daylight. This source of light was chosen for two reasons : firstly, it is known that the tungsten

filament lamp emits only a very small amount of ultra-violet light,[4] and secondly, it was an easy matter to determine the lower wave length limit of this ultra-violet light. It was in fact 3130 Å.[5] By illuminating the diamond with this filament lamp we were trying to ascertain whether there was sufficient energy in the very weak ultra-violet radiation between 3130 and 3910 Å,[6] to activate the diamond. The results of the experiments were the same as when daylight had been used. Finally the radiation from the tungsten filament lamp was caused to pass through the ultra-violet filter before striking the diamond. The results were the same as when daylight had been the source.

Diamonds are usually classified as type I and type II, a characteristic difference between the two types being that type II diamonds do not absorb ultra-violet light of wave lengths greater than about 2250 Å whereas type I diamonds absorb strongly below 3000 Å. It may be concluded from this that the diamond used in the above experiments should be a type I diamond, since, as we have shown, it is activated by, and presumably absorbs, wave lengths between 3130 and 3910 Å, and this was confirmed by examination of the spectrogram of an iron arc[7] taken with the diamond placed before the slit of the spectrograph which showed that the absorption of ultra-violet light by the diamond was strong below about 3000 Å and complete beyond 2940 Å.

We have shown that the active ultra-violet wave-lengths in the production of luminescence lie between about 3910 and 3130 Å, and it would appear probable that this band of wave-lengths would also be mainly responsible for the fluorescence. This was shown to be so in a qualitative manner by holding the diamond in the focal plane of the spectrograph, when illuminated by an iron arc, and moving it slowly from the visible to the ultra-violet end of the spectrum. The fluorescence was most intense in the region just below 3900 Å, and diminished as the diamond was moved to a position illuminated by ultra-violet light of wave-lengths less than 3000 Å, although fluorescence could just be detected at 2000 Å. It would seem, therefore, that although the absorption of ultra-violet light below 2940 Å is complete, the energy so absorbed is largely dissipated in other ways than by light emission.

A considerable amount of work has been done in an attempt to discover the cause of the different behaviour of the two types of

diamond, but it is not our purpose to discuss these here. It will suffice to say that, in general, fluorescent and luminescent diamonds are type I, if the absorption of ultra-violet light be accepted as the distinctive characteristic,[8] and, from the experiments we have carried out, some of these type I diamonds, to which category Mr. Clayton's diamond must also belong, are activated by absorption of long wave ultra-violet light (3910–3130 Å) of very low intensity, the energy so absorbed being slowly emitted over a period of several days, a fact that could be made visible, as Boyle demonstrated, by increasing this rate of emission by raising the temperature.

References.

1. This filter absorbs visible light, but allows ultra-violet light of wave lengths between about 4000 Å and 3000 Å (Å = Angstrom Unit = 10^{-8} centimetres) to pass.
2. Luminescence is a better term and will be used in this article.
3. An ultra-violet filter transmits visible light, but allows no ultra-violet light to pass. The filter used was found by experiment to absorb all wave lengths below 3910 Å.
4. 88% of the output is infra-red radiation.
5. The limits of this radiation were determined experimentally for a 150 watt (230 volts) lamp working at 230 volts exactly.
6. See footnote 3.
7. The iron arc is a strong emitter of short wave ultra-violet light.
8. Sir C. V. Raman, Proc. Ind. Acad. of Sci., A, 1944, **19**, 199.

SYNTHETIC DIAMONDS

Since the publication by the General Electric Company of America of the production of synthetic diamond, two other reports of manufacture have been received.

The Swedish A.S.E.A. works are stated to have produced synthetic diamond in February of 1953. Using a pressure of 80,000–90,000 atmospheres and temperatures up to 5,400°F. and on principles discovered by the Swedish scientist Baltzar von Platen, the company made 40 minute colourless or faintly greenish stones at that time. It is stated that stones up to a 2mm. size can now be made.

The N.V. Bronswerk laboratory, in the Netherlands, is also reported to have produced synthetic diamond, with results similar to those produced by G.E.C. (*Journ. Gemmology*, Vol. V (2), 1955). The first " fields of crystals " were produced in January, 1955.

NOTES on the OCCURENCE of TWO-PHASE INCLUSIONS in SYNTHETIC SPINEL

by Dr. J. W. BRINCK and Dr. P. C. ZWAAN, F.G.A.

IN " A letter to the Editor " of *Gems and Gemology* (Vol. VIII, 1954, No. 2) some synthetic spinels showing distinct two-phase inclusions were described by Aldert J. Breebaart, F.G.A., Nijmegen, Holland.

A short review of the contents of this letter is given here :—

The writer reports the occurrence of many inclusions with a distinct two-phase appearance in a yellow-green synthetic spinel. This spinel was part of a delivery of cut synthetic from Germany. The stone was sent to England for further examination. There the occurrence of two-phase inclusions of a hydrothermal type was stated ; the first phase being a liquid one, the second phase a vapour. These liquid and vapour phases of the inclusions might have been introduced in the stone during its growth in the Verneuil furnace. Here the water might have been formed under certain ideal circumstances occurring when the hydrogen and oxygen of the blowpipe fused at a ratio of 2 to 1. Due to the terrific heat in the furnace, this water would be evaporated immediately and perhaps it was included as vapour during the growing of the boule, and on cooling partly condensed into water in the thus formed cavities.

Seeing the photographs published in the article, we were convinced that the real character of the inclusions might be other than supposed. Some of the features displayed by the inclusions make it difficult to interpret these inclusions as of a hydrothermal type, containing water-vapour phases.

The hydrothermal type of inclusion is a very common one, reported and studied by many authors in different kinds of natural crystals. (G. A. Deicha, 1951, and E. Ingerson, 1947.)

Ingerson concluded there is a certain ratio between the volume of the liquid- and the vapour-phase (" bulle de retraite " of Deicha), controlled by the P/T ratio at time of forming.

Supposing the circumstances during the time of formation of the growing boule in the Verneuil furnace being about atmospheric pressure and rather high temperature ($> 200°$), the evaporated

water would have a very low density, resulting on cooling in a very small liquid phase and a corresponding rather large vapour phase.

Since the reverse is the case, as was shown by the photographs, this constitutes a strong argument against the hydrothermal character of the inclusions.

A second argument was indicated by the kind of differences of the refractive indices of the three phases (crystal and two-phase inclusions) in respect to each other. This, however, necessitated proof by microscopic examination of the stone itself.

Mr. A. J. Breebaart was so kind as to send us the described synthetic spinel to be re-examined together with some other synthetic spinels of the same delivery.

Description of the stone :

It is a brilliant cut stone weighing 2·10 carats with a yellow-green colour. The refractive index is 1·731 measured on the table. Its specific gravity has the average value 3·643. Under the Chelsea colour filter the stone has a greenish colour. Microscopic examination indicates curved structure lines and typical inclusions. In addition anomalous double refraction occurs.

Inclusions :

The inclusions of the synthetic spinel were found to be visible at low magnifications. They were studied by the writers at magnifications up to about 500 ×, by observation through the table.

There are one-phase inclusions in the spinel, showing a refractive index considerably different from that of the stone. Their morphology shows rounded form while sometimes elongated bodies meander through the spinel. They appear as black or nearly black inclusions and were identified as air bubbles, introduced in the stone during its growth in the Verneuil furnace. (Profiled air bubbles of Gübelin, 1953.)

Besides these air bubbles there are also many of the interesting inclusions, of the type described by A. J. Breebaart, being certainly two-phase inclusions.

They often show negative crystal faces. Needle-shaped forms predominate, but sometimes broad and flat forms occur. One of the two phases, filling most of the inclusion, shows by its transparency that it has a refractive index similar to that of the spinel, while the Becke line shows that it is slightly smaller.

The other phase observed in the inclusions consists of rather

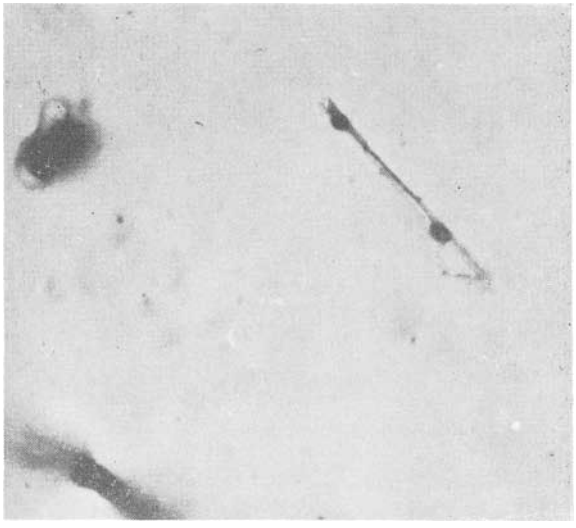

Two-phase inclusion, with negative crystal form Two bubbles of gascous phase in the same inclusion— different ratio between vitreous and gascous phase volume

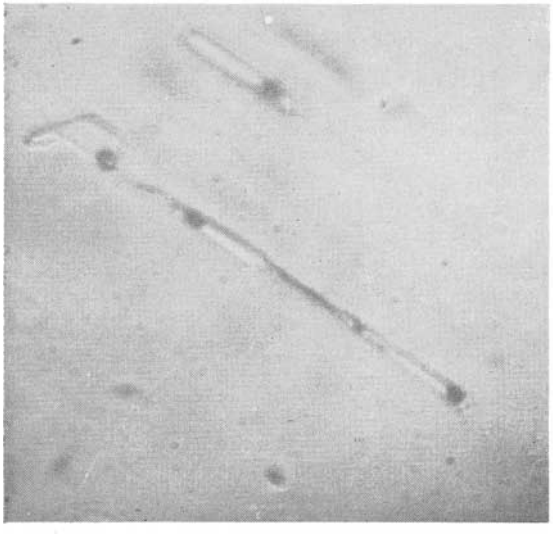

Two-phase inclusion with negative crystal form

small rounded bodies, with a much smaller refractive index than the spinel.

In many inclusions, mostly the smaller ones, there occurs only a single body of this second phase. In the bigger ones,

however, we see two and even more, of varying size.

None of the second phase bodies found in the inclusions show any Brownian movement. This proves they are in a fixed position, being controlled by the first phase of the inclusion.

The ratio between first and second phase in the inclusions, as was seen in many of them, is not always the same.

These observations render it impossible that the inclusions are of a hydrothermal character, but make it almost certain that the first phase in the inclusions is a vitreous one, whereas the second phase is a gaseous one, and is probably air.

The occurrence of vitreous inclusions in crystals (natural) was stated by H. Vogelsang (1867), and has been studied and proved recently by Dr. G. A. Deicha (1951).

Deicha describes quartzphenocrysts, having vitreous inclusions. These inclusions show beautiful negative hexagonal bipyramids, proving that at the time of formation the quartz was in the β-phase ($> 573°$). Natural spinel being isometric hexoctaedral shows isometric negative crystal forms, as was described by Dr. E. Gübelin (1953). The needle-shaped negative crystal forms point to some unknown crystal-phase of $MgAl_2O_4$ at the time of formation of the boule.

The same type of two-phase, vitreous inclusions was found in two other synthetic spinels of the same delivery. They are dark green stones, with many inclusions that appear as shadowy streaks to the naked eye.

At magnifications up to 500 ×, they show two types of inclusions The first type consists of profiled air bubbles. These inclusions are rather large compared to the inclusions of the second type, which are also less abundant.

They are of a vitreous two-phase type, being glass and probably air, as in the case of the stone described above.

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ORIENTING BLUE TOPAZ with ULTRA-VIOLET LIGHT

by HUGH LEIPER

OVER a considerable period of time, I have been faceting blue topaz, to me, a very fascinating and beautiful gem. But I must admit that many of my earlier attempts did not result in a finished gem of the depth of colour that the rough material seemed to promise.

This puzzled me a great deal. I sought accumulated examples of the gem rough from every available country of occurrence—Russia, Brazil, Australia, Ceylon, Nigeria and the United States ; particularly, in the latter case, from Mason County, Texas, which was fairly near my home and from which a wealth of varied material was available at the cost of many hours of back-weary digging.

By ordinary methods of orienting the preforms, I was able to secure, at times, a satisfactory flooding of the finished gem with the beautiful sky-blue for which this material is known. At other times, the finished gem would show this blue colour only when tilted to certain angles away from the perpendicular line of sight (to the table). I realized that something was definitely wrong with my method of orienting the preform but I was, at that time, guided only by such areas of strong colour as could be seen by ordinary daylight.

One evening while in my home workshop showing visitors some of the various fluorescent minerals I had accumulated, I happened to pass the short-wave ultra-violet light over a tray of large topaz crystals, some from Australia, the majority from the Texas area. My eye caught a *lemon-yellow* fluorescence from a large cleavage of Australian topaz. On closer examination, this showed as an " hour-glass " shaped area extending from two opposite corners of what had been a practically square crystal before it had been fractured and cleaved. After the visitors departed, I got out my entire collection of rough gem topaz, and went over it carefully.

I discovered that there were three distinct patterns of fluorescence present in this topaz rough.

Type 1

Zones of lemon-yellow parallel to the " C " axis of the crystal, but in hour-glass shape when viewed from the basal cleavage, and extending the length of the crystal. I have called this Type 1-A.

Zones of lemon-yellow parallel to the " C " axis, but lying parallel also to *four* of the eight *sides* of the crystal. I have called this Type 1-B.

Zones of lemon-yellow parallel to the larger of the terminations of the crystal ; generally two, in a few instances three, and rarely four zones being visible. These zones are not on the surface of the terminations but are generally found to be from 2mm. to as much as 8mm. below the surface, and are *joined* at the apex—a very important point. This type of zoning appears to be the most common of the three, and, since a great many of the water-worn pieces found are simply terminations which have been broken from their attachment, rolled and eroded until they have often entirely lost their former crystal form, the discovery is very helpful. I have called this Type 1-C.

Type 2

These specimens are perhaps the most spectacular when first viewed. They are suffused all over with a cloudy lemon-yellow glow, rather than having definite colour bands. They do not, however, yield the depth of colour when faceted that can be expected from zoned crystals properly oriented.

Type 3

When first examined these were not apparent. But, after all zoned specimens had been graded out, it then became evident that the remaining crystals were of two colours under ultra-violet light. One of these showed crystals of apparent deep indigo-blue, while the remainder were a much lighter blue in colour. Upon separating the two and later comparing them in daylight, it was found that the first (indigo-blue under U.V.) were homogeneous blue all over by daylight, while the lighter blue specimens (under U.V.) turned out to be the common white topaz. I have called the first Type 3-D, and the latter simply white topaz.

These simple methods of grading blue-zoned topaz will be of material assistance to faceters, both in the purchase of suitable gem

rough for faceting and in evaluating that which they may dig for themselves. Likewise it makes possible more accurate orienting of the colour zones in the preform and makes more certain the cutting of a finished gem that will take maximum advantage of the colour available in the material. (Be sure your rough is free of oil or detergents before examining under U.V. light. Work in complete darkness.)

My examination of topaz rough from various sources leads me to the following conclusions about topaz from various countries.

Russian topaz crystals that I have been able to examine appear to be uniformly of Type 3-D, homogeneous with colour distributed throughout. Some of the splendid examples of this topaz in our various museums, notably in the American Museum of Natural History in New York, the U.S. National Museum, Washington, and the Chicago Natural History Museum, show this quality of colour to perfection and there are few from other areas that can match them.

Brazilian crystals appear to be of both Type 2 and Type 3-D ; inclined to have numerous veils and feather-like inclusions. I have observed none of Type 1 in any of its zoned forms among the Brazilian material although my examination has not been thorough for want of sufficient material.

Australian topaz which I have been able to examine shows material of Types 1-A and 1-B, one example of Type 1-C, several of Type 3-D, also white topaz. It is probable that the missing Type 2 will likewise show up from this area upon examination of a larger selection of crystals.

Topaz crystals examined from Nigeria have shown themselves to be of Type 3-D and white topaz—no zoned specimens having come to my attention. They average very light blue to blue-white.

Such specimens as I have been able to examine from Ceylon have been native-cut small gems, and all those examined have been of Type 3-D or white topaz. The blue topaz from this area is usually of very light, blue-white colour, possibly due to the lack of orienting of the rough by the native cutter—a very common failing in all gems from this area where they seem to cut for weight alone.

Topaz of the blue variety has been known to occur in the United States in various localities—Maine, New Hampshire,

Massachussetts, Colorado, California and Texas. I have not been able to procure specimens from all of these areas yet, hence my own examinations of material have been largely confined to the Texas material, where all of the various types occur, with a marked predominance of the Type 1-A, 1-B and 1-C noted, also a large number of beautiful pieces of Type 3-D. The ratio of the " blues " of various types to white topaz in the Texas area seems to run almost 50-50. A very large percentage of the large crystals found are blue-zoned—relatively few large white topaz crystals showing up.

The drawings accompanying this article show the proper manner of orienting the preform to the prevailing type of colour in the topaz rough. Note that in Type 1-A, illustrated in Fig. 1, the transverse " hour-glass " blue zones, extending from two opposite corners, have been placed so that the zones are vertical to the table of the gem. A saw cut made with a very thin diamond saw first separated the crystal lengthwise parallel to the C axis.

The preform was then ground accurately to rectangular shape, the corners of the rectangle were ground off, and the immense table polished. After this the pavilion was cut into six steps, each pair of which was then skew-cut. The crown was cut into four steps and these pairs skewed, after which a fifth step, quite narrow, was cut around the edge of the table. The rough weighed approximately 700 carats. Sawing removed a piece of approximately 100 carats, with a sawing loss of approximately 23 carats. Out of the remaining 577 carat rough, a preform of approximately 410 carats was made and from this a finished gem of 333·5 carats resulted, a " save " of 57·8% of the rough. Several nice gems could be cut out of the 100 carat slice.

Fig. 3 shows how two or more preforms may be cut from a crystal having Type 1-B colour zoning. It often happens that a crystal will have both Type 1-B and Type 1-C zoning. In such a case it is wiser to make use of the termination for the larger gem with its Type 1-C zoning as this type has the zoning joined at the apex. This is then placed in the culet area of the pavilion so that no light may pass into the gem without being reflected through this portion of the culet. With Type 1-B, carefully notice that the colour zones that are parallel to the sides of the crystal are often not joined at the corners. There is, therefore, a small amount of area in the

FIG.1 TYPE A

TEXAS BLUE TOPAZ
700 CARATS

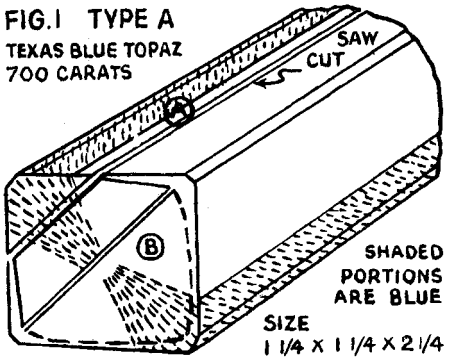

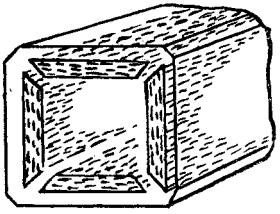

FIG. 2. SHOWING
TYPE.B. BLUE ZONES
PARALLEL TO C.AXIS

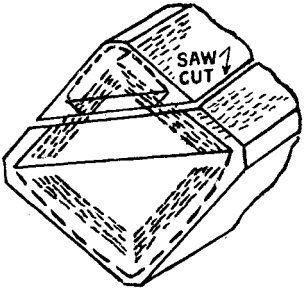

FIG.3 TYPE.B.
ORIENTING PREFORMS
TO TAKE ADVANTAGE OF
COLOUR ZONING.

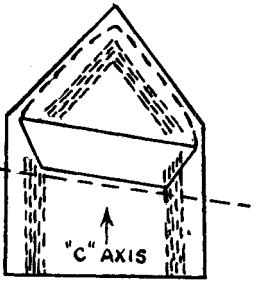

culet that will not be blue-zoned. By throwing the table cut slightly off to the left or right, it may be possible to place a portion of one of these blue zones into the culet area where it does its best work. A smaller gem or two can often be cut from the upper portion which is sawn off, provided it is cut deep enough.

Figure 4 illustrates a cross section through a terminated topaz crystal and the usual placement of the joined blue zones. This is an idealized drawing—your piece of gem rough may be, and probably will be, only the tip of a crystal, tumbled and water-worn almost completely out of shape. The terminal zoning under short-wave U.V. will, however, give an accurate clue to the grinding of the preform. Note carefully that the table must be placed at least 15 degrees off the plane of basal cleavage and, when polishing the table, it is best to polish " down-hill " away from rather than into the grain.

Other gems may be cut from the remainder of the crystal by placing the side-zoning in the greatest diameter of the girdle. Such preforms are cut parallel to the " C " axis or nearly so. By turning the table so that it comes from the interior portion of the material, it is sometimes possible to place the blue-zoned area well down in the culet area where it will do the most good in flooding the gem with colour.

All blue topaz should be cut with a fairly shallow crown, about 25% of the height, and the pavilion made as deep as the rough will allow if colour is to be enhanced. The final facets in the culet must never go below the critical angle for topaz, given as 39 degrees for this facet by some authorities, but my personal experience has shown that a final set of facets at 40·5° is much better and more brilliant.

Topaz that is of Type 3-D, homogeneous and apparently blue and uniform, can usually be cut in almost any direction that the rough will allow except, of course, the table must be at least 15 degrees off basal cleavage. I have tried as low as 5° and had real trouble.

In general, the apex of a crystal will yield an excellent brilliant with the smallest waste of rough, while a step cut gem may often be laid out best parallel to the " C " axis, or lengthwise to the crystal.

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JADE STORY — EUROPEAN

(*The third part of the Story of Jade in Europe*)

by ELSIE RUFF, F.G.A.

THE study of jade—in particular its symbolism and early use—has long been considered one for the specialist alone. And this particular specialist has hardly ranked as a gemmologist. Gemmology itself has had a tendency to shelve the jade question, again, regarding it as a subject for the specialist. Most gemstone textbooks deal with the material very perfunctorily. To study jade in its widest sense is to leave behind the field of the specialist. For the difficulty of digging in the jade hole is that it goes so deep, and has so many ramifications, it unavoidably cuts through into other holes.

To establish the term *lapis nephriticus* (see JOURNAL OF GEMMOLOGY January, 1955, p.16) is not difficult, but it will be obvious that the question is not a long one for etymology alone. Bright's disease is a disease of the kidneys, known as nephritis. The Spanish for *lapis nephriticus* is *piedra nefritica*—nephrite stone. A modern Spanish dictionary combines two terms *piedra nefritica o jade*. The French *pierre néphrétique* is of course the same thing. And the Latin *nephriticus* stems from the Greek, *nephros*, νεφρός, kidney There seems no doubt whatever that this word has always been associated with the kidney. More than one student has felt that the occurrence of nephrite boulders in kidney form might be responsible (long since) for this expression, but as the term could as aptly apply to boulders of other materials, similarly shaped, it would seem a suggestion we may confidently discard.

As it is not possible to quote every source, or even necessary or advisable from the point of this enquiry, we may confine ourselves to various authorities over the past few hundred years. What must come as a surprise to all researchers is the enormous amount of literature available on this subject (provided one is intent enough on the search) and the vast number of people concerned or intrigued with the story of jade.

The nineteenth century, which is late enough to begin the inquiry, was the era of *The Jade Question*. It was the century too, for

the discovery of the Jordansmühl and Reichenstein occurrences.[1] American gemmologists were now in the picture; men who have given their names to gemstones with which every gemmology student is familiar. It was the era of Dr. A. B. Meyer, of Dr. F. W. Rudler, of Mr. James Hilton, F.S.A.A., and of Jean Pierre Abel Rémusat, of whom we shall hear later. There was also Dr. Heinrich Fischer, who differed strongly with Dr. Meyer on the occurrence problem. There was Dr. Schliemann as we have seen[2], and a host of other authorities. Not least among them was A. Damour of Lyons, considered the leading mineralogist of his day, who investigated this subject extensively and was responsible for the segregation, in 1863, of the two distinct minerals—suggesting the term jadeite for the jade of the pyroxene group. This term was adopted, used, and more recently questioned. (We are told by Dr. Rudler (*Journal of the Anthropological Institute*, Vol. XX, 1891) that M. Damour felt the old mineralogical term nephrite should be confined to the strictly oriental jade.) There was also the American geologist, Mr. Pumpelly, who spent many years in the East and became an enthusiastic contributor to *The Jade Question.*

In 1879, before the discovery by Traube (see the JOURNAL OF GEMMOLOGY, October, 1954, p. 344) Dr. F. W. Rudler's article appeared in *The Popular Science Review* (Vol. 3). Dr. Rudler, who died in 1915, needs little introduction. He was Registrar of the Royal School of Mines and one of the founders of both the Ethnographical Society and the Anthropological Institute, apart from holding many other public offices. His article, entitled *On Jade and kindred stones*, is too long to quote in its entirety. The following extract will, however, express the author's approach to the subject.

" Much of the esteem," wrote Dr. Rudler, "which the ancients set upon precious stones was due, in like manner, to the superstitions by which such minerals were liberally surrounded. No doubt the properties which we prize at the present day—such as colour, brilliancy, and hardness—were equally prized in the remotest times at which precious stones were used; but above and beyond these obvious characters, overarching all these physical properties, there was the higher value derived from their metaphysical virtues. Some of these values were of a purely spiritual character, such as the power attributed to so many gems of dispelling vicious propensities and of inspiring purity of life in the

owners. Others, however, were of less subtle nature, and were in fact medicinal rather than metaphysical. In order to cure disease, it was in most cases considered sufficient simply to wear the stone, when its sympathy with the affected part brought its curative powers into play. But in other cases recourse was had to the grosser method of internally administering the powdered gem. These superstitions naturally led men to seek eagerly for stones so marvellously endowed, and thus our knowledge of such minerals and their mode of occurrence became widened. Such stones which were reputed to possess therapeutic virtue were carefully preserved and studied in their minutest details. Who indeed would not diligently seek and fondly cherish an object which was at once a personal ornament and a specific against disease?

Science is unquestionably the arch-foe to superstition; yet superstition, it must be conceded, has unwittingly rendered an occasional service to the cause of science. How ill, for instance, might it have fared to-day with the student of prehistoric archaeology if our ancestors had been free from any superstitious regard for those implements of stone—unknown alike in origin and use—which they occasionally brought to light with the help of spade and plough. As long as the flint arrow-head was regarded as a "fairy dart" or the stone axe as a "thunderbolt" it stood in little danger of being heedlessly destroyed; shielded by the supernatural origin to which it was referred, generation after generation, until, in these later days, it has come to grace the cabinet of an archaeologist. The time of real danger was not when there was too much superstition abroad, but when there was too little superstition, yet not sufficient science—when men had ceased to value a stone implement as a talisman, or amulet or charm, but were not sufficiently enlightened to recognize its true meaning and to value it on scientific grounds."

This clarity of thought—all the more remarkable when we consider the date—finds an echo in the words of a famous contemporary physicist: " Science has given back to the universe that quality of inexhaustible richness and unexpectedness and wonder which at one time it seemed to have taken away from it . . ."

During 1892, in the Journal of the Anthropological Institute, p. 319, Dr. A. B. Meyer was perpetuating an early blunder. He wrote: " The occurrence of raw jade in Silicia (Germany), viz., near Reichenstein, was already known to Linnaeus (*vide* the 12th

Latin edition of Gmelin, Nuremburg, 1777, Vol. 1, p. 458), and has only recently been rediscovered by H. Traube[3]." While it seems to have been established that the jade occurrences had been worked in pre-historic times, it has not been established that the Swedish Linnaeus ever knew of these occurrences. Gmelin was writing of *Lapis Nephriticus*, a term it transpires that in his day covered other substances, such as Steatite and Serpentine[a]. Hence Gmelin's occurrences for *lapis nephriticus* are invalid, or doubtful, from our point of view. Several countries he quotes have recently denied such occurrences, including Sweden itself[b].

In the second edition of the *Encyclopaedia Britannica* (1777), a date coinciding with Gmelin's work just quoted, the same confusion exists:—

"*Lapis Nephriticus*, SEE Steatites."[c] Yet, under NEPHRITIC STONE there is further doubt. This is described as a "soft, opaque stone not susceptible of a good polish; smooth, and as it were, unctuous to the touch; variegated with several colours of which green is the principal. It is found in Saxony, Switzerland, Spain, and Mexico; and from the imaginary virtues ascribed to it in nephritic disorders, has been ranked among the precious stones, but differs exceedingly from them in all its sensible qualities. Neumann finds fault with some authors for referring this stone to the jaspers, agates, or marbles, from all of which he says it widely differs: it wants the red specks of jasper, the hardness and compactness of the others, and all of them want its unctuosity or soapiness." Except for the occurrences, this description could refer to what we know to-day as nephrite, but later in the article doubt increases. "Dr. Lewis," it runs, "tells us that the nephritic stone is a species of indurated clays, called from their unctuosity, steatitae. With these it agrees not only with its obvious properties but likewise on burning hard, the peculiar character of the argillaceous earths. Its green colour seems to proceed from copper . . . . The nephritic stone is considerably the hardest of all the substances of this class." Again, the last sentence suggests that while the word nephrite or nephrite stone or nephritic stone includes these lesser minerals it also applies to the nephrite we accept to-day.

(*a*) Even up to recent years a form of serpentine has passed under the misnomer Jade.

(*b*) For this information we are largely indebted to Sir Charles Hardinge, Bart., who has taken the trouble to communicate with responsible people in the countries involved.

(*c*) Under this heading, the article reads : ". . . a name given by late authors to a substance called in English soap-earth, for making porcelain . . ."

Although the above quotation is a century earlier than the one we are at the moment examining, it is included here for obvious reasons. In the first edition of the *Encyclopaedia Britannica* there is no mention of jade.[a] That was in 1768. In the third edition, 1788, eleven years later than the one quoted above, there is an item headed JADE-STONE. Under this we read: "Jade-stone, Lapis Nephriticus, Jaspachates,[b] a genus of siliceous earths. It gives fire with steel, and is semi-transparent like flint . . . . A kind brought from the river of the Amazons in America is called CIRCONCISION STONE . . . . The jade stone is unctuous to the touch; . . . . Mr. Kirman seems to suggest that it contains a portion of argillaceous earth, or rather magnesia. The specific gravity is from 2·960 to 3·389; the texture is granular, with a greasy look, but exceedingly hard, being superior in this respect to quartz itself . . . . Mr. Saussure seems to have extracted iron from it. Sometimes it is met with of a whitish milky colour from China, but mostly of a deep or pale green from America. The common lapis nephriticus is grey, yellowish, or olive colour. It has its name from a superstition of its being capable of giving ease in nephritic pains by being applied externally to the loins. It may be distinguished from all other stones by its hardness, semi-pellucidity, and specific gravity."

To this excellent contribution, the name of the author has not, unfortunately, been attached. Credit should, however, go to the Swedish mineralogist, Axel Fredrik Cronstedt, a translation of whose work was published by J. H. de Magellan in 1788 (second edition). It was entitled *Essay towards a system of Mineralogy*. The *Encyclopaedia Britannica* version is an excerpt, almost word for word, from this work. As a contribution this is outstanding, if only for the great strides made in no more than eleven years and at a period nearly two hundred years ago. And more. It uses the word JADE as we today understand it. It included under this heading the term we are concerned with, *Lapis Nephriticus*. (The term Jaspachates, to be met with from time to time, here suggests jasper of an agate-like formation.) At this time there was no separation of nephrite and jadeite, consequently the CIRCONCISION STONE from the river Amazon was classed merely as jade. Yet the specific gravity tells us plainly that the two species were being

(*a*) Under Nephritis, medicines for dealing with diseases of the kidney include nephritic stone.

(*b*) Jaspachates or iaspachates was for a long a general name for agate. It is to be found as far back as Pliny.

examined. (Sp.G. for nephrite 2·90-3·03, for jadeite 3·33.[a]) Its hardness has obviously been confused with its toughness—a common error in early times and not unknown today. To the point of our enquiry, its curative properties for nephritic pains has also been recorded.

Little advancement on this contribution appears during the nineteenth century, as far as the *Encyclopaedia Britannica* is concerned. (And they have drawn on the experts of the day.) In 1801 there is the item: (4th edition). "Jade-stone or Lapis Nephriticus, a species of Mineral. See Mineralogical Index. *Genus V. Magnesian Species. Nephrite or Jade.*" The species is divided into two sub-species. 1. *Common Nephrite*, with a Sp. Gy. 2·97—4·38(!), of the following constituents:

Silica	47%
Magnesia	38%
Alumina	4%
Lime	2%
Oxide of Iron	9%
	100

"The repository of nephrite is unknown," the article goes on. "It was originally brought from the Levant, East Indies, and China. It is found also in the Alps, in Switzerland, and in Piedmont. The water-worn pebbles which are collected on the banks of Lake Geneva often contain this mineral. It is found also in a similar form at a particular place on the shores of Iona, one of the Hebrides in Scotland."[4]

"Oriental nephrite," is the final word on this section, "long known under the name of jade, is held in considerable estimation on account of its hardness and tenacity. It was employed by the Turks for the handles of knives and sabres, and frequently by others for various ornamental purposes. The property of curing diseases of the kidney is ascribed to this mineral by ancient authors, and hence the name Nephritic-stone or Nephrite."

The second sub-species in this article takes the heading of *Axe-stone*. "La Pierre des haches . . . Beilstein of the Germans. *Exter. Char.* This is also found massive, but most frequently in rounded pieces; lustre glimmering or weakly shining; fracture in

(*a*) B. W. Anderson.

large masses; slaty, in small splintery fragments in the form of plates. *Colour.* Deep meadow green, sometimes olive-green; translucent; semi-hard; not very brittle and more difficultly fusible than the preceding variety.

Localities, etc. The mineral is found in China, the East Indies, and South America, on the banks of the river Amazon. It is found also in some of the islands of the South Sea, as well as in Corsica, Switzerland, and Saxony.

Uses. Axe-stone is employed as hatchets and other cutting instruments, by the natives of the countries where iron is little known."

So satisfactory and up-to-date, apparently, was the above information that the next edition of the Encyclopaedia (the 5th, published in 1815) carried the article without alteration.

Until we come to the 8th edition (1853) there is little to record. Here JADE is classed as: "An ornamental stone of which there appear to be two varieties, common jade or nephrite, and saussurite, or jade tenace. Common jade is a silicate of magnesia, oxide of iron, and alumina. Its specific gravity varies from 2·9-3·0. Hardness 7·0. Its colour is leek-green, passing into grey. It is very tough and scarcely fusible before the blow-pipe. Nephrite was formerly worn as a charm, and was supposed to be a cure for diseases of the kidney, whence the name from νεφρός kidney. From its toughness it has been used for the blades of hatchets by the New Zealanders and other savage nations . . . In China the jade is of a whitish colour and is called YU . . . A great variety of jade ornaments from India and China appeared at the Great Exhibition of 1851 . . . Jade is polished like cornelian but it takes only a greasy, not a brilliant, polish. Saussurite is a double silicate of magnesia, lime, and oxide of iron, with a silicate of alumina. Specific gravity 3·2. Hardness 5·5. Its colour is greenish-white, or ash-grey; . . . it is extremely tough, and is fusible before the blow-pipe."

This article was written by Charles Taylor, D.D., Hon. LL.D. (Harvard), Master of St. John's College, Cambridge.

In 1875 the 9th edition of the *Encyclopaedia Britannica* arrived, with a long article on jade by F. W. R., the Dr. Rudler of an earlier quotation. Apart from his reference to Chinese jade "often described by early mineralogist as 'jaspis viridis'" (see JOURNAL OF GEMMOLOGY, January, 1955, p. 13) there is little we need quote here.

In the summary he gives a number of chemical analyses under no less than nine varieties, with the following Sp. Gy. constants:—

"White Jade. China. Damour. Sp. G.2·97.
White Jade. Turkestan. L. R. von Fellenberg.[5] Sp. G. 2·96.
Green Jade. New Zealand. L. R. von Fellenberg. Sp. G. 3·02.
Green Jade. Swiss Lake Dwellings. L. R. von Fellenberg. Sp. G. 3·02.
Oceanic Jade. Damour. Sp. G. 3·18.
Jadeite. China. Damour. Sp. G. 3·34.
Chloromelanite stone celt. Damour. Sp. G. 3·31.
Saussurite. Lake Geneva. T. Sterry Hunt[a]. Sp. G.3·30.
Fibrolite celt from Morbihan. Damour. Sp. G. 3·18."

As the 10th edition of the *Britannica* contains only supplementary volumes to the 9th edition and does not supersede it, we find no further information here. In the 11th edition (1910) Dr. Rudler again contributes at length, and in 1950, a supplement to the 14th edition, we have W. A. Wooster, Ph.D., Demonstrator in Mineralogy at the University of Cambridge, and Dr. G. F. Kunz, the late American gemmologist. These contributions are actual copies of the articles included in the 14th edition first published in 1929.

Another author who should certainly be included in the 19th century is the Frenchman, S. Blondell, whose publications, *Jade, Historical, Archaeological and Literary Study of the mineral called Yu by the Chinese*, first appeared in Paris during 1875—twelve years after Damour[b] had published the result of his investigations and had separated the two species.

M. Blondell, of whom we shall hear more later, points out that the separation of jade and jasper (perhaps more important than that of jade and nephrite) is somewhat modern, though this is by no means the first indication.

There are several outstanding contributors to *The Jade Question* during the 18th century. A. G. Werner, of Freiberg, locally known as the father of German geology, is credited with having

(*a*) Thomas Sterry Hunt, 1826–1892, American Geologist and Chemist.

(*b*) Dr. G. F. Kunz wrote, in 1903 (Jade—nephrite—German New Guinea, Silesia, and elsewhere) : "Dr. Meyer has published in all no fewer than 36 articles on the general subject, and, as is well known, has clearly shown that the subject is a chemical rather than an ethnological problem."

Englished *Lapis Nephriticus*, giving us NEPHRITE, in 1789. In 1779 Antoine Grimoald Monnet published *Nouveau Systeme de Mineralogie*. On p. 217, Part VIII, is a long paragraph on *Le Jade, ou pierre néphrétique*. (Again, two terms to describe the same material.) Here the author separates nephrite from chalcedony. He speaks of its " greasy " look, " like oil." He observes that jade is dearer than it is precious because of the superstition attributed to it, but adds that he has not observed sufficient varieties to establish the various qualities. He doubts whether M. de Bomare (see below) is qualified to establish the three types he suggests. Finally he mentions the " very coarse texture " of jade, noticeable in a fracture. And, like a well behaved scientist, he repeats that he will make no decisions.

Monsieur Wallerius (Johan Gotsch Wallerio) has been quoted as introducing nephrite, that is, the pierre néphrétique, into mineralogical nomenclature, yet there are several others of his century who have done more to classify nephrite. In his publication of 1772, Wallerius quotes various experiments made by various workers in this field with which he does or does not agree. That one experiment with *lapis nephriticus*, if powdered and mixed with water, " brought it back . . . . to the state of steatite." He writes: " I prefer to offer no comment." He does, nevertheless, classify it under the general heading of *jaspis*, greasy in appearance. And he lists (almost as Bomare, 10 years earlier):

" (a) *Lapis Nephriticus*—whitish. Faintly milk-white, at times quite transparent. China.

(b) *Lapis Nephriticus* of green undertone. " Lapis Divinus " (Holy stone) is less transparent. Oriental.

(c) *Lapis Nephriticus*, not transparent. Of green shade. Lapis Amazonicus. Colour similar to prasius (Prase). From America."

In the same year, viz., 1772, we have *Antiquitates Medicae Selectae* by Johann Ernst Immanuel Walch, published in Latin. This author mentions *Lapis Nephriticus* and the " very great powers " attributed to it by the doctors of old. Dealing with a number of stones and their cures he first observes, under the heading *Use of Stones in antique medicine:*

" As we have found, they made a special use of a certain kind of their erudition in their ponderous way. We must confess that we hold this as an unpleasant task. It must not have been easy for them to suggest that a stone could exert its high powers by its own

strength, even if it was reported that some stones had a healing power in their litholatry, which as a rule meant a sanitary cleaning of wounds and remaking of the wounded body and members . . ." He concludes, after much quoting: " Whatever it may be, and we do not want to deny it, the surgeons of old must in the presence of the suffering have used all their ingenuity, while having only less efficacious medicaments of inferior composition they contrived psychological means." (A refreshing observation made nearly two hundred years ago.)

A year earlier, in 1771, M. Bucquet had published, in French, *Introduction à l'étude des Corps Naturels tirés du Règne Minéral.* Of jade, he writes of its colour " green . . . . more or less dark, olive or brown," and of its greasy appearance, of its toughness, rendering it difficult to work. He separates it from the agates, as others have done, " because jade reddened in fire and thrown into water, does not break." In the fire " it loses its colour," a fact long known in China.

In 1762 appeared *Minéralogie ou Nouvelle Exposition du Règne Minéral.* By M. Valmont de Bomare. On the subject of *Jade ou Agate Verdâtre, ou Pierre Néphrétique*, he quotes a number of writers who " consider this stone differently. Be that as it may, after our experiments in the stone which they name today nephritique stone, we have arranged it in this order . . ." Bomare goes on to speak of the nephritique stone as " rough grained . . . compact . . . . oily to the sight and touch like the lard stone of China, of a green colour, or olive, or more or less milky . . . . difficult to polish highly, because of its extreme toughness . . . . it makes fire with steel . . . . one attributes to it many properties which are fictional, also they have decorated it with many different names . . ."

In his classification he gives:

" (1) White jade . . . . the true jade of the Orient, which is no onger known to be quarried.

(2) Jade . . . . a clear green . . . . excellently named *divine stone* or nephritique stone.

(3) Jade of a dark green . . . . its colour resembles a piece of dark emerald; it is called Stone of the Amazons.

Note 1.—The nephrite stone which many of these authors recognise to be the green jasper of the ancients . . . . its green comes from copper, one notices that that from China is of the same

species but more transparent and clearer; that from Saxe (Saxony) is opaque and dark."

He speaks further of the Indians and their art of cutting this stone " with holes sometimes six to seven inches long, and without any iron tools." Later, an apparent contradiction of his title, he says: " . . . . some workers admitting themselves that jade surpasses in toughness, the agate, the jasper, and the porphyry . . . . It is also this extreme toughness of the jade which has rendered it so precious and of such great esteem with the ancients . . . . It is highly esteemed for warming the kidney-stone, and for epilepsy, and often worn as an amulet on the collar or arm, on the kidneys, and on all afflicted parts." Later he quotes Voiture[6] in the 23rd of his letters to Mlle. Paulet, " the jade stone is a remedy in a country where there is not another . . . ."

Dezallier D'Argenville also wrote of the *néphrétique stone*, published in French during 1742. " . . . . a species of jade of a dark green; spotted black, sometimes yellow; this stone is tougher than ordinary jasper . . . . and does not polish perfectly, they believe it has the property to cure nephritique colic." And later: " The green and white jade which borders on the green, on the yellow, and sometimes in the blue, is often called Divine Stone and Nephritique, because it is imagined that worn over the kidneys it cures colic . . . ."

Finally, in 1704, we come to Langius or Christianus Joannes Lange. Here in the beginning of the eighteenth century we find one with an almost complete mastery over the subject, far more convincing than many who came after him in his own times, as well as those in the nineteenth century. He describes *Lapis Nephriticus* as: " A gem neither transparent nor opaque, nor green only, now mixed with colour, which means to say, showing from a green undertone, white or yellow, azure or black, in such a way that the green always predominates, somewhat greasy on the surface, as if dipped in oil, on which account it cannot be very well polished." " The rarest is white all over," he states. Under Etymology he writes: " The reason for its name originates from its effectiveness, in fact it is called NEPHRITICUS from the Greek word νεφρός which means a kidney, as in kidney pains it frees them in forcible style from the calculi and thus it originates the cure." It is noticeable here that he does not say whether or not he agrees with this *cure*. He merely states what is common in his day.

Lange then goes on to describe its differences compared with other stones. He writes of one who believed it to be a kind of dark smaragdus and of others who thought it to be a species of jaspis. "Nevertheless," he continues, "there are differences between the true jaspis and nephriticus. (1) Harder than jaspis if anything. (2) It does not show any red lines " (earlier he had spoken of the red spots of jaspis, referring doubtless to our bloodstone). " (3) It does not allow of any exact polishing by reason of its oiliness. (4) It shows two distinct colours but nearly always one of them is whitish green. We can therefore say that Laet is right. Nephriticus is a species of its own, neither prasius (prase) nor jaspis (jasper)." Later, he speaks of what is thought to be an artificial Nephriticus that comes from New Spain, viz., South America. Even here, Lange suspects, at any rate, that the species is different. And in the various beliefs of the Americans he quotes Monardes[7].

To gather up the evidence of these two important centuries (the 18th and 19th), it seems clear that the words JADE and NEPHRITE—or nephritic stone or *pierre néphrétique* or *lapis nephriticus*—were one and the same material. That the South American jade was included under this general heading(until Damour separated the species) is also clear, whether it was called CIRCONCISION STONE or Divine Stone. A single exception is the " artificial Nephriticus " of New Spain, that is, material differing from the known nephrite. It is generally understood also that this jade or nephrite was not jasper, though earlier believed to be so. Furthermore that the term *lapis nephriticus*, while it covered other substances such as steatite, confusing the occurrence issue, the gemstone material was still the major portion of such classifications. Finally, of great assistance in establishing *lapis nephriticus*, it is in every case used as a curative for nephritic disorders.

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2. *ibid.*, — p. 339.
3. *ibid.*, — p. 344.
4. *ibid.*, — p. 346.
5. *ibid.*, Vol. 5 (1), 1955, p. 13.
6. *ibid.*, — p. 338.
7. *ibid.*, — p. 13.

GEMSTONES in BIRMINGHAM MUSEUM

by VINCENT C. SMITH, F.G.S., E.M.A.

WITH Birmingham as one of the main centres of the jewellery trade, it has always been the policy of this Department to display a portion of the extensive series of gemstones in our possession.

However, additions in recent years to this collection have necessitated rearrangement of the existing exhibit and a new case has recently been put on display in the Geological Gallery of this Department.

It is hoped that this case will also be of interest to the general visitor and specialist. The range of stones is as comprehensive as we have been able to make it and practically every variety of Corundum, Spinel, Beryl, Topaz, Garnet, etc., is represented, together with the rarer gems like Spodumene and Iolite. There are also displayed stones which have been chosen for their educational value rather than their intrinsic worth and an example of this is the very fine Citrine weighing 1 lb. 12 ozs. avoirdupois, which forms a centre piece to a selection of the varieties of Quartz.

As the Geological section caters primarily for the mineralogist many stones not normally utilized by the jeweller are included. Fluorspar is a typical example, for although this mineral can be very beautiful when cut and polished, its softness and low refraction make it unsuitable for the trade ; nevertheless this type of specimen can often be of especial interest to the geologist.

Adjoining the gemstone case is a display of precious and semi-precious stones in their natural state, and it is hoped that this will be of interest to jewellers, augmented as it is by comprehensive reference collections of cut and uncut gems which are available to students and specialists on request.

The gemstones are mainly from the collection formed by the late Mr. A. S. Wainwright, a name well known to the trade in Birmingham, the late Mr. William Bragge, whose collection was purchased and presented to the Museum by the Rt. Hon. Joseph Chamberlain, and lastly the Bernard Senior Collection which was purchased by Ansell's Brewery and presented to this Museum and Art Gallery in 1928.

ANOTHER MINERAL in GEM QUALITY

by JACK E. SCHUNK, B.A., F.G.A., and NEVILLE DEANE, F.G.A.

THE discovery of another mineral in a form which will provide a cut gem is always an event, and this is a short account of such an occurrence.

Early in January, 1955, one of the authors (N. Deane) received a letter from the other from Brazil, stating that he was sending a piece of potentially useful material which might provide some entertainment. The sender stated that he thought he knew what it was, but left it to the recipient to discover. The colour varied from pale to rather less pale yellow, and he had about 100 grams of the material and thought he might be able to secure more of it.

When received the piece was about 16 carats in weight, light yellow, but obviously dichroic in two shades of yellow and, although it did not show an obvious crystal face, was rather flat and appeared to have one good cleavage and another less clear. It was quite transparent, and looked cuttable, although with new material there is always a risk that it will crack with the heat of dopping, or cleave when ground with abrasives.

As one face was almost flat, it was decided to grind and polish it, to determine the refractive index and also the density, but otherwise to leave it as it was. This was done and the selected face was not too difficult to polish.

Laboratory tests were carried out, although at this time there was a cold spell and the temperature of the toluene used in the S.G. test was only 8°C. and the lens of the refractometer had to be well wiped as it soon misted up by moisture in the breath. However, the density was determined as 3·03, and the R.I. as a minimum of 1·608 and a maximum of 1·637. The hardness was less than quartz and about 6. These constants did not agree with anything in the list of gemstones. It had been thought it might be

Brazilianite although its behaviour was different, and the only gemstone with somewhat similar constants appeared to be Nephrite and it was obviously not that. This was as far as the writer could go, and the specimen was sent to the Gem Testing Laboratory in London for examination.

By return of post, Mr. R. Webster wrote that he and Mr. B. W. Anderson had examined the material, and found it to be Amblygonite, composition $(LiNa)Al(PO_4)F,OH$, isomorphous with Montebrasite and having the constants S.G. 3·029, R.I. 1·609, 1·626, 1·637, and that according to the new edition of Dana one of the places in which it was found was Mogi das Cruzes, Sao Paulo, Brazil. The spectrum showed a very vague and unmeasurable band in the blue and a cut off in the violet. Fluorescence was weak, if any, under Long Wave ultra-violet, possibly a weak orange under short wave ultra-violet and a brightish bluish-green under X-rays, with no phosphorescence. Phosphate was determined by microchemical test and lithium by flame test, which also confirmed phosphate.

The rough material being a phosphate, similar to Brazilianite and apatite, it was thought possible that it might easily fracture with the thermal shock of " dopping " in the ordinary way, so it was decided to be careful and dop by the " under water " method in which stone, cement and dop stick are all put in water at room temperature, warmed till the cement softens, assembled and then removed from the water and cooled slowly.

But first the rough had to be sawn to shape, as, although it could be ground to shape, it was wished to reserve a projecting piece in case of further examination, and in the operation of cementing for sawing the indications were that the material would fracture with thermal shock. Sawing was easy, using a metal-bonded diamond saw. The material was moderately hard—about as hard as feldspar—and showed no signs of flaws appearing on cleavage planes (as does spodumene), although amblygonite is stated to have an excellent cleavage. Grinding to shape was also easy. There was a slight odour apparent when grinding, as there usually is with apatite, and no cleavage flaws developed. Cutting the facets on a diamond-charged bronze lap was also easy, although, as the material is softer than quartz, it is very easy to overcut a

facet. Polishing was moderately easy. A lap of 18% tin, 82% lead, was used, with " ruby powder," and gem polish came readily, but with a tendency to leave polish marks or very slight scratches rather than to leave an absolutely flawless mirror polish. The lustre is quite good for a stone softer than quartz and better than the writer (N.D.) has obtained on apatite. At the end, the finished stone was a step-cut, cut-corner rectangular shape of 4·6 carats, not completely flawless, but transparent and a nice bright stone of a pale yellow colour.

It is obvious that the material, being softer than quartz, and of a not uncommon colour amongst stones, is not likely to be amongst the most popular and useful stones as regards jewellery, but nevertheless if supplies of rough are made available, stones will undoubtedly be cut from it and amblygonite and its constants should be listed as one of the stones which may occasionally appear.

A second lot of amblygonite has now been received by one of the authors (J. E. Schunk) in Brazil. There was an equal amount of excitement on the examination of this second lot, the main reason being the presence of several pale blue and greenish specimens, and these are known colour-varieties of amblygonite. But on a more careful examination all of the blue and green pieces turned out to be beryl. The rest of the parcel was amblygonite. The colour, as compared to the first lot received, was much lighter, the majority of it being colourless or almost so. The quantity was as limited as it was in the first parcel. Almost every piece showed one excellent cleavage surface. The inclusions had a white mossy texture plus some of a bright green colour. No good crystal shapes were found although some pieces showed a flat moulded-glass appearance on one surface. Once it has been seen in its rough state it is fairly easy to separate from other gem materials. Brazilianite, which has a similar refractive index, almost always has numerous crystal faces present and has a more intense colour. Amblygonite is perhaps most similar to beryl, but the obvious cleavage surfaces plus strong birefringence eliminate beryl. In all specimens this strong birefringence, resulting in the doubling of inclusions and of opposite edges, is easily seen by the unaided eye.

The source of this new find is in the north-eastern part of the State of Minas Gerais, Brazil.

Gemmological Abstracts

ANON. *California Jade.* Mineralogist (Oregon), Vol. 23, 4, April, 1955, p. 178.

A further reference (*Journ. Gemmology Abs.*, Vol. V (1) 1955, p. 34) to the occurrence of green to white jadeite at Clear Creek, San Benito Co., California. According to a report of the U.S. Geological Survey, the jadeite is found in small veins cutting albite-glaucophane, acmite schist, and as larger lens-shaped pods with serpentine. The vein jadeite is associated with albite, analcite, natrolite and thomsonite. The white jadeite vein material is almost pure jadeite. The average specific gravity is 3·43, and chemical analysis of the green variety shows that it carries about 10% of the diopside molecule and 14% of the acmite molecule.

J.S.

PARSONS (C. J.). *How to use a quartz wedge.* Gemmologist, Vol. XXIV, No. 284, pp. 39–42, March, 1955.

This is part 3 of the series on the quartz wedge started by K. Parkinson and carried on by the above-named author. (*Journ. Gemmology Abs.*, Vol. V (2), 1955, pp. 94-95.) The method of obtaining an optic figure is briefly described. The use of a small drop of liquid on a plane facet of a stone is advocated in order to give the necessary curved surface for convergent rays. The spherical end of a small glass rod is mentioned as being suitable for a similar use. The different types of optic figures are given and determination of the *sign* by the use of the quartz wedge is fully discussed.

12 illus. R.W.

LEE (H.). *Further notes on American artificial turquoise.* Gemmologist, Vol. XXIV, No. 284, p. 56, March, 1955.

A short note on the examination of another specimen of the plastic bonded imitation turquoise (*Journ. Gemmology Abs.*, Vol.

V (1), p. 36). These are now known to be made by Harold Maryott, of Arizona, U.S.A. This improved version is slightly harder and the density is higher, being 2·39. The maker mentions that a newer plastic bonding will be used in later manufactures.

R.W.

NEUHAUS (A.). *Theoretical principles of diamond synthesis.* Gemmologist, Vol. XXIV, Nos. 284/5, pp. 47–48 / 72–73, March/April, 1955.

A technical article explaining the difficulties in the synthesis of diamond. Earlier attempts at diamond synthesis did not fully realize the high pressure needed, as deduced from the specific gravity of diamond. In Moissan's experiment a real high pressure was not possible and he took refuge in the expectation of a production as a metastable synthesis. The chance production by metastable formation is said to be remote and is fully discussed. The work of nucleation, undercooled viscous melts and the kinetic theories involved are discussed. The work of Bridgeman on high temperatures and pressures is mentioned, and the article concludes with a general summing up.

2 illus. R.W.

MCLEOD (H. L.). *More about Stichtite.* Gemmologist, Vol. XXIV, No. 285, p. 74, April, 1955.

Mention is made of the use of stichtite from Kaapsche Hoop Transvaal, South Africa, a source now said to be exhausted, for the production of cabochons.

R.W.

ANDERSON (B. W.) : PAYNE (C. J.). *The spectroscope and its applications to gemmology.* Gemmologist, Vol. XXIV, Nos. 284/5/6, pp. 43–46/68–71/92–95, Mar./Apl./May, 1955. (Parts 19, 20 and 21.)

Continuation of this important serial. Discussion is now made of those stones which owe their absorption spectra to iron. There

are two categories, the ferrous corresponding to FeO, almandine, peridot and blue spinel being examples, and ferric, corresponding to Fe_2O_3, illustrated by chrysoberyl, yellow orthoclase and green sapphire. Ferrous iron often replaces magnesium (even in almandine, which always contains a small quantity of Mg) and gives red or blue colours. The absorption spectrum of almandine was first noticed by Church, and this spectrum is the first discussed. This spectrum is characterized by three strong wide bands at 5760A, 5260A and 5050A, the last having a " core." A number of weaker bands are also present. All red garnets show the almandine spectrum to a greater or lesser degree, even hessonite (grossular), spessartite and pyropes, which usually have a trace of the almandine molecule. An almandine spectrum may be seen in the case of almandine-garnet-topped doublets and this may well deceive the unwary. The absorption spectrum of blue spinel is less easily recognized and may be confused with the cobalt spectrum of the synthetic blue spinel, but the strongest band in the natural stones is in the blue where there are no bands in the cobalt spectrum. This strong band is at 4580A and there is a weaker band at 4780A—these two making a distinctive pattern. There are other weak bands in the green, yellow and orange. The rare gem taaffeite is the only gemstone to have an absorption spectrum in a marked degree similar. Mention is made of the absorption spectra of green tourmaline and blue/green sapphire for comparison. The bright colour of the synthetic blue spinel as against the rather sad blue of the natural stones and the strong red of the synthetic as seen through the Chelsea colour filter (the natural blue spinel also shows a reddish colour through the filter but it is unlike the strong red of the synthetic) are diagnostic if the absorption spectrum is in doubt. The absorption spectra of peridot and sinhalite are discussed, reference being made to the similarity of composition and atomic structure of these two minerals. Peridot has three main bands in the blue centred at 4930A, 4730A and 4530A. The 4930A has a distinct narrow " core " at 4970A ; the 4730A is fairly narrow, while the 4530A is broader and less well-defined. There is some variation with optical direction, and the bands seen in the three optical directions are given. The bands for sinhalite are given as 5260A (weak and vague) ; 4930A (mod. strong and narrower) ; 4750A (mod. strong and narrow) ; 4630A (mod. strong and broader) ; 4520A (mod. and narrow) ; 4350 (strong

and as a cut-off). The extra band at 4630A in sinhalite may be used to distinguish from peridot.

5 illus. R.W.

WEBSTER (R.). *X-rays and their use in gemmology.* Gemmologist, Vol. XXIV, Nos. 285/6, pp. 63–67 / 87–91, April/May, 1955.

This new series commences with the historical aspects of the experiments which led to the discovery of X-rays by Rontgen in 1895. The effects seen when a high-tension electric current is discharged between electrodes at atmospheric pressure, and under reduced pressures, are described. The story of Rontgen's discovery is given, and the part played by Sir J. J. Thompson in identifying cathode rays as streams of electrons is referred to. The opacity of a substance to X-rays is a function of the atomic weight of that substance. Until the classic experiment of von Laue in 1912 proof of the nature of X-rays was in doubt. The story of this experiment, which gave experimental proof of the theory that X-rays were *light* of short wave-length, and that crystals have an orderly arrangement of their atoms, is told. The apparatus employed for the production of the necessary high-tension current is briefly mentioned. The earlier types of " gas tubes " used to produce X-rays, and the modern " hot-cathode " tube devised by Coolidge, which employs the " Edison effect," that is, the formation of electrons from a heated filament, are discussed.

8 illus. P.B.

WEBSTER (R.). *New Italian gem-testing laboratory.* Gemmologist, Vol. XXIV, No. 286, pp. 79-83, May, 1955.

Description, from photographs, of the new gem-testing laboratory opened in Florence. The laboratory is well equipped for pearl and gemstone testing, and has, unusual in such laboratories, a well-appointed chemical department. Apparatus for absorption spectroscopy not evident. The laboratory is operated by the Cassa di Risparmio di Firenze (Florence Savings Bank) and the local Chamber of Commerce.

3 illus. P.B.

GOODWIN (PETER). *Ten points about pearls.* Printed by the South China Morning Post Ltd., Hong Kong. 1955.

A well-printed, paper-covered booklet of eleven pages. The author states that the pages are written to help those who are interested in pearls. He discusses ten points :—shape, colour, blemishes, lustre, matching, graduation, drilling, clasp and threading, size and weight, and value and price. A test for the roundness of pearls is said to be the ability of a pearl to roll straight across a polished surface. Best colour is rosée, other colours being mentioned. Variations of colour are best seen when a necklet is coiled-up in the palm of the hand, a procedure better than observing on black velvet. One spot or blemish may not matter as the drill canal can be drilled through it, but 10% of the value may be lost by each other blemish. Lustre is defined as the natural polish of the pearl, and orient is said to be connected with the colour of the nacre lining the shell. The orient of cultured pearls is said to be stronger than natural pearls. Matching for colour and graduation are discussed. Holding a necklet out straight and shaking it gently will show any off-centre drilling by such pearls tending to rotate so that the heavier side turns to the bottom. A good clasp will never be found on an inferior necklet, and thus the nature of the clasp will indicate the quality of the necklet. A note is given on the stringing of necklets and why knotting between each pearl is important. Value and price, and size and weight, as expressed in the booklet, are at variance, for the unit weight given is the *momme*, the Japanese weight equal to 0·13 oz. avoir., a weight used for cultured pearls only, while in the chapter on value and price reference is made to the *base system* which is used for genuine pearls only. Indeed, in the introductory chapter the author states " these points are about cultured pearls only," but much of the text is more in keeping with advice about natural pearls, than the much less important cultured variety.

R.W.

ASSOCIATION NOTICES

SWISS GEMMOLOGICAL ASSOCIATION

The Swiss Gemmological Association held their Annual Instruction Course from 23rd to 25th May. The first day was devoted to the examinations and several members sat for the Diploma Examination and some for the Diamond Examination. These examinations are carried out in a similar way to the British and American gemmological examinations. The Diploma Examination consists of two different written examinations, which must be answered without the help of books and notes and within the period of two hours each. The Practical Examination consists of testing 24 stones within unlimited time. The Diamond Examination consists of a theoretical part—two hours answering questions without books and notes and two hours of more difficult questions with the help of books and notes. For the practical part of this examination five diamonds are submitted for grading (grading of colour, perfection of cut and transparency, as well as measuring depth, angles, diameter of girdle and table).

On the second day the Annual General Meeting was held, in the course of which the following members were awarded Diplomas :—

Mr. W. Frieden, Thun ; Mr. E. Frischknecht, St. Gallen ; Mr. A. Leicht, Geneva ; Mr. W. Meister, Zurich ; Mr. W. Ruckli, Lucerne ; Mr. E. Seiler, Jr., Basle ; Mr. R. Widmer, Aarau ; Mr. K. Zigerli, Berne ; Mr. J. Ryser, Biel (Bienne) ; Mr. H. Perrenoud, Lausanne.

The rest of the second day as well as the third day consisted of the real course, which this year was theoretical only.

The following lectures were given by the Association's Scientific Instructor, Dr. E. Gübelin, C.G., F.G.A. :—

Introduction to the general knowledge of inclusions ; specialized description of inclusions, particularly with regard to their diagnostic importance.

Diamond grading methods ; artificially coloured diamonds and their identification ; synthetic diamond.

Gem testing without instruments.

New gemstones (Taaffeite, Sinhalite, Amblygonite, Hypersthene-Bronzite, Stichtite, Augelite) ; new synthetic stones (synthetic rutile, synthetic strontium titanate, synthetic lapis-coloured spinel, synthetic red spinel).

Practical application of the immersion method.

Distinction between genuine and synthetic stones by means of transparency in short U.V. light.

The course was a complete success and the members went home with great enthusiasm and with the conviction that there is always something new to be learnt about gemstones.

COUNCIL MEETING

Sir James Walton, Chairman, presided at a meeting of the Council held at Saint Dunstan's House, Carey Lane, London, E.C.2, on Tuesday, 10th May, 1955.

The following were elected to ordinary membership :—

Michael D. G. Breeze, Leicester.
Markson A. Gam-Dede, New York.
Robert Klippel, Sherman Oaks, U.S.A.
Robert S. McGrath, Washington, U.S.A.
George F. de Menasce, London.
Enoch C. Parrott, Vancouver.
Xaver Saller, Munchen, Germany.

The Council discussed the inclusion of diamond in the diploma practical examination and possible damage to instruments, and complications that arise when mounted specimens for the examination are sent abroad.

Mr. J. R. H. Chisholm, M.A., F.G.A., was appointed by the Council as an examiner in gemmology to work with Dr. G. F. Claringbull and Mr. B. W. Anderson.

GIFTS TO THE ASSOCIATION

The Council of the Association is indebted to Mr. R. W. Hester, F.G.A., of Princes Risborough, for providing a new case for the Association's set of historical diamond models, and for a wooden case for sending the models by post.

The Council is also grateful to Mr. George Lindley, F.G.A., for a gift of a piece of coral, for display in the Association's new offices.

Mr. Antonio C. Bonanno, of Washington, D.C., U.S.A., has kindly presented the Association with eighteen American mineral specimens.

TALKS BY MEMBERS

ANDERSON, B. W. : *Herbert Smith Memorial Lecture.* The refractometer and other methods of measuring refractive indices. Association meeting, London, 30th March, 1955.

HESTER, R. W. : " Gemstones." " All Wives " Club, Halton Camp, Bucks. 1st February, 1955.

WEBSTER, R. : " Gemstones." Eastcote Branch, British Legion. 19th April, 1955.

" Some newer problems besetting the jeweller." Midlands Branch of the Gemmological Association. 6th May, 1955.

GEMOLOGICAL INSTITUTE OF AMERICA

At the annual meeting of the Board of Governors of the Gemological Institute of America, which met in Boston, on April 2nd, Dr. Edward H. Kraus, Dean Emeritus of the College of Literature, Science and the Arts, of the University of Michigan, was re-elected President of the Institute for the tenth consecutive year.

GEM EXHIBITION — 12th–30th OCTOBER, 1955

Organized by the Midlands Branch of the Gemmological Association of Great Britain and the City of Birmingham Art Gallery

A Series of PUBLIC LECTURES will be given at **6.30 p.m.** in the LECTURE THEATRE at the CITY of BIRMINGHAM ART GALLERY

THURSDAY, 13th October. HISTORICAL GEMSTONES.

Speaker : TREVOR P. SOLOMON, F.G.A., Chairman of the Midlands Branch of the Gemmological Association.

SATURDAY, 15th October. THE GEM DIAMOND

Speaker : NORMAN HARPER, F.R.G.S., F.G.A., Senior Lecturer in Gemmology at The City of Birmingham School for Jewellers and Silversmiths ; Vice-Chairman of the Gemmological Association of Great Britain.

MONDAY, 17th October. GEMSTONES — THEIR GEOLOGICAL BACKGROUND

Speaker : VINCENT SMITH, F.G.S., E.M.A., Assistant Keeper, Department of Natural History, Birmingham Art Gallery.

THURSDAY, 20th October. THE STORY OF GEM DISCOVERY.

Speaker : B. W. ANDERSON, B.Sc., F.G.A., Director of the Diamond, Pearl and Precious Stone Laboratory of The London Chamber of Commerce.

SATURDAY, 22nd October. THE ROMANCE OF THE PEARL

Speaker : ROBERT WEBSTER, F.G.A., Lecturer in Gemmology at the Chelsea Polytechnic ; Scientist at the London Chamber of Commerce Laboratory ; Author of " Practical Gemmology," etc.

MONDAY, 24th October. RUBY AND SAPPHIRE : GEMS OF THE ORIENT

Speaker : D. N. KING, F.G.A., Honorary Secretary of the Midlands Branch of the Gemmological Association of Great Britain.

THURSDAY, October 27th. GEMSTONES THROUGH X-RAY EYES

Speaker : G. F. CLARINGBULL, B.Sc., Ph.D., Keeper of Minerals at the British Museum (Natural History).

(*Admission Free*)

The Exhibition will be opened by the Lord Mayor of Birmingham on Wednesday, 12th October.

LETTER TO THE EDITOR

The Editor,
Journal of Gemmology.
DEAR SIR,

So long as the " orient pearl " has been known, its principal sources have been (and still are) the various colonies of *Margaritifera vulgaris* off the coasts of Arabia and India. In the first century A.D., Pliny brackets pearls from the Persian Gulf and from India as being of the highest value, while the author of the *Periplus* refers to the pearls of the Persian Gulf, India and the Red Sea. The Red Sea is no longer an important source of pearls, but although India (which for this purpose includes Ceylon) produces supplies of pearls only intermittently, it is still listed as a principal source (e.g. by Herbert Smith and R. Webster.) The Ceylon fishery of 1905 surpassed all records, and Miss Judith Banister will be able to find full information on the subject of her query in the *Book of the Pearl*, by G. F. Kunz and C. H. Stevenson (London, 1908).

By a curious coincidence, Miss Banister's letter[1] suggesting that the Indian fisheries had ceased to be of importance appeared at a time when after a lapse of some years another Indian fishery was actually in progress. It was advertised in time-honoured form in the personal column of *The Times* of 11th March last as follows :—

" *Indian Pearl Fishery*. A Pearl fishery will take place at Tuticorin, South India, on or about the 15th March, 1955—weather permitting. About 2½ crores of oysters will be fished. The fishery may last up to 30th April, 1955. The pearl oysters will be sold in public auction by the Madras Government at Tuticorin daily during the period of fishing. For further particulars apply to the Assistant Director of Fisheries, Tuticorin, South India."

Yours faithfully,

J. R. H. CHISHOLM.

1. Journ. Gemmology Vol. V, No. 2, 1955, p. 112

HERBERT SMITH MEMORIAL LECTURE

by B. W. ANDERSON, B.Sc., F.G.A.

The Refractometer and Other Refractive Index Methods

WHEN I was asked by the Gemmological Association to give the first Herbert Smith Memorial Lecture I accepted the offer without hesitation although I knew it would involve me in a good deal of work, since I welcomed the opportunity to pay tribute to a man who has done more than any other to further the cause of gemmology.

Though mineralogy was his profession, G. F. Herbert Smith, in the course of his long and active life, had many other interests and worked in many other fields. In each of these fields he has left friends who will gratefully remember his work. To us, as gemmologists, his name is held in honour for many reasons. We will remember his keen interest in our Association, of which he was President from 1942 until his death in April, 1953 ; we remember him as an examiner who initiated and maintained the high standard which has made the " F.G.A." the most coveted gemmological qualification in the world. But most of all we remember him as the designer of the first trustworthy jewellers' refractometer and as the author of a book on gemstones which, ever since its publication, has been the standard work on the subject in the English language.

Since it is exactly fifty years ago that the first model of the famous Herbert Smith refractometer appeared, it is appropriate that the refractometer and its use should be the main burden of this Memorial Lecture. The book " Gemstones " was first published in 1912. The refractometer, the book, and the classes which began as " Mineralogy for Jewellers " under Mr. I. G. Jardine at Chelsea Polytechnic just before the first World War, all worked together to create that British School for Gemmology of which we are so pardonably proud.

I must now, without further delay, come to grips with the main subject of my lecture—the origin, development and powers of the jewellers' refractometer. I will also touch briefly

on other methods of refractive index measurement which may be resorted to in cases where a refractometer, for one reason or another, cannot be used.

The Basis of the Refractometer

When a ray of light passes obliquely from one transparent substance to another of lower optical density, the ray is refracted away from the normal to the surface of contact. As the incident angle is increased, a critical point is reached where the refracted ray forms an angle of 90° with the normal. This is known as the *critical angle* between these two media, and rays of light impinging on the intersurface at angles greater than this are totally reflected. The size of this critical angle depends entirely upon the relative refractive indices of the two media. The British scientist W. H. Wollaston was the first to point out that if a standard block of dense glass were used as the medium of high index, the refractivity of substances of lower index could be assessed by measuring the critical angle between them and the block when placed in optical contact with it. On that principle, elaborate instruments designed to measure this critical angle with great accuracy, employing a prism, cylinder or hemisphere of very dense lead glass, were developed later in the nineteenth century. We are happy to have an Abbé Zeiss-Pulfrich refractometer of this kind in our Laboratory. In the hands of a trained scientist it is an invaluable instrument where there is a need for refractive index readings accurate to within one or two units in the fourth place of decimals—but it is quite unsuitable for the jeweller, besides being very expensive.

In 1885, Professor Bertrand designed a small and simple refractometer in which the sudden beginning of total reflection at the critical angle could be seen as a shadow-edge on a transparent scale. Several of these little Bertrand refractometers were amongst the equipment in the British Museum (Natural History) where Herbert Smith was working as an Assistant in the Mineral Department. He was often faced with the task of identifying specimens of gems submitted by members of the public, and there were moreover many unidentified or wrongly identified specimens of faceted stones in the Museum's own collection. It was thus that Herbert Smith felt acutely the need for a robust and simple refractometer of reasonable accuracy. He found that the Bertrand

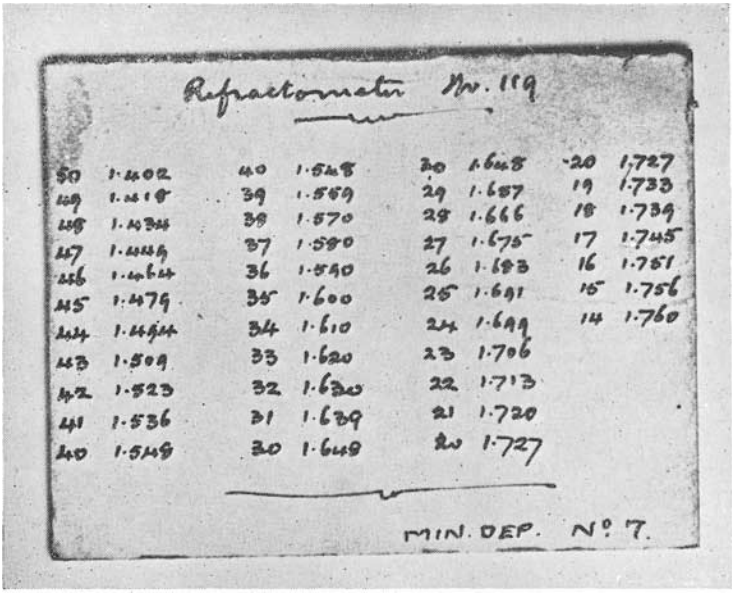

Herbert Smith's own calibrations for his first model (1905) refractometer.

instruments were incapable of giving reliable readings owing to a faulty optical system, in which the focal surface was not a plane. By introducing a correcting lens between the dense glass hemisphere and the scale and by other modifications he was able to rectify matters, and in 1905 the first Herbert Smith refractometer was born—being manufactured by J. H. Steward, the well known opticians in the Strand, London.

Though a great improvement over the Bertrand, the 1905 Herbert Smith refractometer had several faults. Large stones could not be accommodated, the scale was an arbitrary one, and had to be translated into terms of refractive index with the aid of a calibration card supplied with the instrument, and the highest index which could be read was 1·76, so that the instrument would not give refractive index readings for the important corundum gems, ruby and sapphire, nor for many of the garnets. The second model of the " Herbert Smith " was a great improvement, with a table capable of taking gems of any dimensions, and a scale calibrated directly in refractive indices and reading up to 1·775. This was in 1907 ; and in the same year Steward had the good

sense to publish a slim booklet " The Herbert Smith Refractometer and its Use," in the last few pages of which is given a masterly summary of the optical and other properties of thirty-four gemstones. In his preface, Herbert Smith remarks " I have paid particular attention to the usefulness of the instrument for the discrimination of faceted gemstones, because in not one of the many treatises on precious stones is enough prominence given to the extreme importance of the refractive indices as a discriminative test, and because no orderly arrangement of the requisite data is at present available." The refractive index figures given in this booklet were largely the results of his own observations, and have hardly been bettered since that time.

Herbert Smith must have enjoyed himself in those early years, in which he was prodigiously active in research and in the design of instruments. One version of a schoolboy's dream of heaven was to have the whole of the Crystal Palace to throw stones at, with Brighton beach handy for ammunition. In more adult terms, Herbert Smith had at his disposal the whole of the Museum's collection of gemstones to verify, and his own newly-designed instrument with which to undertake the job.

Later Refractometers

For nearly twenty years the Herbert Smith refractometer held the field unchallenged. Then, in 1926, the gemmologist and Bond Street Jeweller, B. J. Tully, whose name is commemorated in the " Tully Medal ", co-operated with the firm of Rayner and Keeler to produce an altogether larger instrument which in many ways was easier to use than the little Herbert Smith. The " Tully " is no longer being made, but for a time was very popular, with its large and easily-read erect scale, extending to 1·86 ; its rotating hemisphere, white reflector, and covering shield for the stone.

The range of this refractometer was potentially much greater than that of the earlier instrument, because a glass of index over 1·90 was employed—but the *effective* range was limited by refractive index of the contact liquid, which consisted of a saturated solution of sulphur in methylene iodide, having an index of approximately 1·78.

In an effort to raise this limit, C. J. Payne and I, working in the Precious Stone Laboratory of the London Chamber of Commerce,

sought out, and where necessary prepared, a number of organic fluids of high refractive index, some of which enabled us to take readings to the 1·86 limit of the Tully scale, though at the expense of tarnishing the chemically sensitive surface of the lead glass hemisphere. Our most successful non-harmful liquid was prepared by adding 18% of yellow crystalline tetraiodoethylene to sulphur-saturated methylene iodide, which gives a stable liquid of index 1·81, and is now issued as a standard refractometer liquid.

We then co-operated with Messrs. Rayner in attempting to increase the range of the refractometer by using minerals of high index in place of the usual lead glass. Two minerals with high single refraction suggested themselves : zinc blende (2·37) and diamond (2·42). It was when experimenting with blende that Rayners had the bright idea of employing a truncated prism of the material in place of the usual hemisphere, and the first " Rayner refractometer " was actually a blende model with a scale extending up to 2·20. With this little instrument, using a spontaneously inflammable mixture of phosphorus, sulphur and methylene iodide suggested by West, which has an index of 2·05, we were able to measure the refractive indices of a whole range of zircons in which we were at that time particularly interested. Soon afterwards, the generous gift of a diamond by the Diamond Trading Co. enabled Rayner to make for us the first diamond refractometer. Apart from the initial cost, diamond is of course the ideal material for a refractometer prism, with its optical purity, single refraction, and its superb surface which is virtually impervious to chemical or physical attack.

It is the lack of suitable contact fluids which now chiefly prevents the gemmologist from making high index readings. All those so far tested in the range 1·81 to 2·05 are in some way noxious. It has been suggested that firm contact of the stone being tested with a slightly curved refractometer surface may enable dry optical contact to be made, and obviate the use of any liquid.

In actual practice, it is far more important to have a refractometer that will give clear readings in the lower index ranges than to have one which is capable of very high readings. It is in the " one-fifties " and " one-sixties " that the stones most tricky to

identify occur, and that range is admirably covered by a special Rayner refractometer employing a prism of synthetic white spinel, which gives very clear readings even in white light—a point I shall refer to later. Of the gemstones with indices above 1·81, only zircon, diamond, demantoid, sphene, and an occasional almandine, are used in jewellery, and these can all be identified by means of the spectroscope or other simple tests, if not at sight.

I have so far been speaking as though every substance had only *one* refractive index, whereas in reality, as you know, even singly refracting substances have an infinite number of indices, according to the wavelength of the light employed. Yellow sodium light of mean wave-length 5893A is the universally accepted standard for refractive index measurements, and refractometer scales are designed to give accurate readings for this light. Sodium light can be cheaply produced by means of a gas or spirit flame in which an asbestos wick saturated with a sodium salt is inserted, though for those who can afford it a sodium discharge lamp is brighter and more convenient. Only in monochromatic light can the knife-sharp shadow-edges be obtained which are needed for a detailed study of the movements of shadow-edges in birefringent stones which I am going to describe presently. For routine identification purposes white light readings are often sufficient, particularly if they are sharpened by use of an orange colour-filter.

The ratio between the refractive index of the refractometer glass and the stone which is being tested, upon which the critical angle between the two depends, varies considerably with wavelength since the glass has a dispersion far higher than that of the stones which come within the refractometer range. The higher the dispersion of the stone or liquid tested the less is this variation of the critical angle. Thus the contact liquid, which has high dispersion, gives a relatively sharp, uncoloured edge in white light —and so does a lead paste—whereas a low-dispersion stone like quartz shows a broad fringe of colour. Here lies the advantage of the spinel refractometer : the spinel used has a dispersion very similar to those of the stones tested, so that sharp edges are the rule even in white light. Pastes are at once noticeable for their colour-fringed shadow edges, and so are contact liquids such as bromonaphthalene—a reversal of the effects seen on the normal refractometer. Careful observation of the sharpness or otherwise

of a shadow edge in white light will thus often reveal whether the substance tested has high or low dispersion—a piece of information which is occasionally of practical value.

Measurement of Birefringence

But it is with birefringent stones that the refractometer really comes into its own, as it gives information of the highest diagnostic value about the extent and nature of the double refraction, merely by rotating the facet which is in contact with the refractometer table. *The full amount of double refraction can be measured on any one facet*, a most important fact. All that is needed is to note the highest and lowest readings obtainable and subtract one from the other. A single invariable edge is sure evidence of an isotropic stone—either a cubic mineral or a non-crystalline material such as opal or glass. In uniaxial stones the shadow-edge due to the ordinary ray is invariable in position, while in general the edge due to the ordinary ray can be seen to move when the stone is turned. If the moving edge has the higher index, the stone is optically positive; if it has the lower index it is negative in sign. Where the optic axis lies in the plane of the facet used a single edge will be observed twice in a complete rotation, this being a sign that the axis is lying along the line running from the eyepiece to the observer. As the stone is turned from this position the extraordinary edge is seen to separate from the ordinary, and to reach a position of maximum birefringence before starting to close in again. This is often seen in specimens of green tourmaline and in aquamarine. When the table facet of a uniaxial stone is parallel to the basal plane of the original crystal (that is, at right angles to the optic axis) we see the strange effect of *two* invariable edges, since all the rays grazing along such a facet are travelling in a direction of maximum birefringence. Another case where two invariable edges are seen is in specimens of chalcedony, when two edges separated by about 0·007 units can be seen rather lower on the scale than for crystalline quartz. This is due to so-called " form birefringence " caused by fibres of quartz being set in an opaline matrix.

With biaxial stones the behaviour of shadow-edges is rather more complicated, though the simple rule that maximum index minus minimum index reading equals the full birefringence still

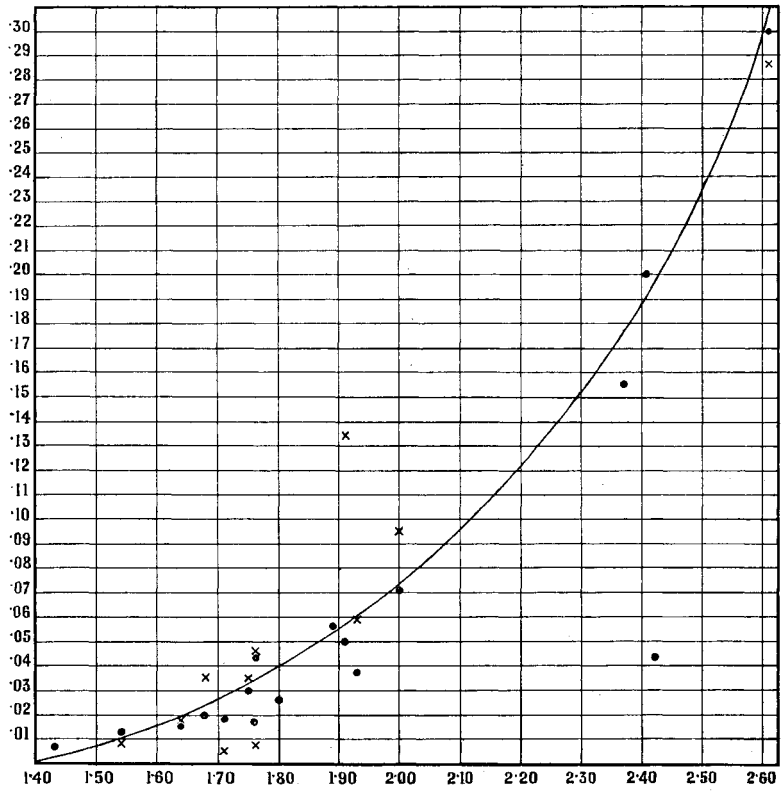

Diagram showing numerical relationship between dispersion (•) birefringence (X) and refractive index. The dispersion/refractive index relationship is fairly regular, with the exception of diamond, which has an unusually low dispersion for its index. The birefringence figures are numerically often similar to those for dispersion, but they bear no real relationship to the refractive index values

The values indicated are for :—Fluorspar, Quartz, Tourmaline, Peridot, Idocrase, Epidote, Corundum, Benitoite, Almandine, Demantoid, Slhene, Zircon, Cassiterite, Blende, Strontium Titanate, Diamond, Rutile.

happily holds good, and is the thing that matters most. In general *both* shadow-edges move, since both the rays are " extraordinary " in their behaviour. Rays vibrating parallel to one of three mutually perpendicular directions have critical values. The least and greatest of these, alpha and gamma, vibrate parallel to the lines bisecting the angles between the optic axes. Rays vibrating at right angles to the plane of the optic axes have an intermediate critical value, known as beta. When beta is closer to alpha than to gamma, the stone is called positive ; when it is nearer to gamma

the stone is negative. When the angle between the optic axes is small, either the lower or the upper edge will move very little, and it is then easy to see whether the stone is positive or negative by analogy with uniaxial stones. In special cases, where the facet tested happens to be cut at right angles to the vibration direction of one of the critical rays, this ray will be seen as an invariable edge when the stone is rotated. If the ray happens to be beta we have the intriguing sight of the moving edge crossing over the invariable beta position, giving at four points in a complete rotation a *single* edge. This of course is a sign that the rays are all running along one of the two optic axes in one direction or the other.

Thus we see that readings carefully taken on a refractometer give us much more information about the material we are testing than just its refractive index. We are enabled to place the stone in one of five optical categories—isotropic, uniaxial positive, uniaxial negative, biaxial positive, biaxial negative. If it falls within the last four groups we can obtain a figure for the birefringence, which is an enormously important piece of information. We also gain a fair idea of the degree of dispersion of the stone, and of the optical direction in which the stone was cut in relation to the original crystal.

Until recently, it was thought essential to have a flat facet available if a refractometer reading were to be expected. A valuable technique suggested some years ago by the American gemmologist Lester Benson now enables us to obtain refractive index readings on polished cabochon surfaces also, though these are not so critical as the readings obtained on flat surfaces, and the birefringence cannot usually be measured. In this " spot contact " or " distant vision " method the smallest possible drop of contact fluid is applied to the table of the refractometer and the cabochon surface makes a tiny disc of contact at this point which can be seen when the eye of the observer is withdrawn by about twelve inches from the refractometer eyepiece, while keeping the head in the line of sight. When the eye is slowly moved in an up and down direction this little disc can be seen to change from being dark in the low refractive index regions of the scale to light in the upper portions—this being a sign that total reflection has set in. The trick is to manoeuvre the eye into the exact position where the disc is bisected by the line of shadow and then to refocus the eye

by an effort of will in order to ascertain on what part of the scale this particular point falls. While performing this operation the gemmologist is apt to assume the attitude of a cobra about to strike. Auxiliary lenses may help to make the contact disc and the refractometer scale more easily focused at the same time, but with practice quite good results can be obtained without altering the standard refractometer eyepiece. The "distant vision" technique is also useful for obtaining readings on tiny faceted stones which give too faint an edge in the ordinary manner of observation.

There are other helpful tricks that can be used on occasion with the refractometer. Certain stones and many pastes seem reluctant to give a shadow edge. Sometimes this is due to a surface tarnish that can be removed by rubbing the surface on a cloth or leather, perhaps with addition of a little jeweller's rouge. But sometimes the trouble persists. My colleague C. J. Payne has found that one can often get "bright line" readings by grazing incidence in such awkward cases. All that one need do is to pull off the covering shield of the standard Rayner (which is designed to be removable), block the window through which light normally enters the instrument by means of a box of safety matches, which, on its side, is exactly the right height, and arrange one's desk or microscope lamp at a level slightly above that of the table of the refractometer. When the stone is turned, a bright line (or two bright lines in a birefringent stone) should be seen crossing the scale, which will otherwise be almost entirely dark. The effect is rather beautiful and the technique is worth trying out if only for this reason. It is as well to start with a step-cut stone since this style of cutting yields better results than others. In the case of a green tourmaline and an andalusite tested by this method recently it was amusing to notice the distinctly different colours of the two bright lines—an effect due to the strong dichroism of these minerals. One does not normally associate dichroic effects with the refractometer.

Other Methods

There are of course many other methods that can be used to determine the refractive indices of gemstones, and some of these

may have to be pressed into service where a refractometer cannot be applied or when no refractometer is available.

It has to be admitted that a microscope is an even greater essential to the gemmologist than a refractometer, since only with its aid can he distinguish with certainty between synthetic and natural stones. A young gemmologist who has spent his spare money on a microscope may not be able to afford the extra fifteen pounds or so needed for a refractometer, however much he would like to. It is worth his while, therefore, to gain some skill in using the microscope to measure the refractive index of stones. If the microscope has a fine adjustment which has marked on it a scale to show the number of rotations and parts of a rotation made when adjusting the focus, this can be used to take measurements by the " real and apparent depth " method, which was first suggested by the Duc de Chaulnes and brought to a high degree of accuracy by Sorby towards the end of the last century. In this, the stone can be supported by a small piece of wax or plasticine on a glass slide with its table facet uppermost and horizontal and its culet in contact with the slide. The microscope is focused accurately (using a fairly high-power objective, such as 8 or 16 mm.) on the surface of the table facet, and the reading A taken on the scale of the fine adjustment. The focus is then lowered until the culet appears sharply in focus : let this reading be called B. The slide is then moved a little way so that the stone is no longer under the objective, and the focus again lowered (using the fine adjustment, of course) until the surface of the slide is reached. Then the refractive index of the stone should be given by the formula A – C/A – B. This formula only holds true for isotropic stones and for the ordinary ray in uniaxial stones, and results are in any case not accurate to more than one or two units in the second place of decimals. There is no upper limit to the index that can be tested, however, and the method can form a useful check in the case of a dubious diamond. In this connection it is useful to remember that the extent of a flaw or the depth of an inclusion can be assessed by measuring the " apparent " depth under the microscope and then multiplying this by the refractive index of the stone. This may be useful information where recutting is contemplated.

The use of liquids of varying refractivity is a more generally

useful and flexible method of refractive index determination. It is well-known that when a transparent solid is immersed in a liquid of the same refractive index it becomes virtually invisible due to the lack of reflection and refraction at its surface. Ice in water is a homely example of this, and quartz in ethylene dibromide is one instance of it that can be easily demonstrated by the gemmologist. A trial of the degree of " relief " shown by an unknown stone when immersed in turn in liquids of different refractive index will often by itself give helpful information. A yellow topaz, for instance, in the ethylene dibromide mentioned above, which has an index of 1·54, will stand out quite clearly compared with the yellow quartz or citrine with which it is often confused. Where the stone is mounted and a density test precluded, simple immersion tests of this kind can be very useful.

Still without calling in any apparatus, we can do better than this rather vague observation of relief or lack of relief. If the stone or stones being tested be immersed in a glass dish of liquid and a sheet of white paper placed underneath, and closely observed under a single overhead light, each stone will show one of two effects: either it will be surrounded by a pale border and the junctions of its facets appear dark, in which case the stone has an index lower than that of the liquid; or the stone will be surrounded by a dark border and the facet edges appear white—in which case the stone has a higher index than that of the liquid. The breadth of the border and the thickness of the facet-edge line effect will give a very good idea how closely the liquid index and that of the stone are matching. If the stone has an identical index with the liquid for light of one wave-length it will still not be quite the same for other wave-lengths, as the dispersion of the liquid will be higher. Thus a very near match between stone and liquid is heralded by a coloured fringe to the stone. Using this simple immersion contrast technique with overhead light and white paper under the dish one can pick out with certainty and rapidity white synthetic sapphires which have become mixed in a parcel of synthetic white spinels by immersing them all in methylene iodide, or amethyst-coloured pastes which have been mixed with a parcel of genuine amethysts, by immersing them in ethylene dibromide—to mention two actual instances where I have used this technique with success quite recently. Records of such differences in con-

trast can be obtained by very simple photographic means, as I explained not long ago in the JOURNAL OF GEMMOLOGY.

As with all other tests, immersion methods are more easily carried out when the stones are unmounted, but they can none the less prove useful with mounted goods. A diamond eternity ring, for instance, is an awkward thing to test for "strangers" in the form of synthetic white sapphires or other substitutes, but by immersing the whole ring in methylene iodide and examining it under the microscope, diamonds stand out in bold relief and any substitutes are at once detectable.

Only a few well-chosen liquids need be kept in stock, and these will last for years if properly stoppered. In addition to the usual "stock" liquids of the gemmologist which would normally include ethylene dibromide (so useful for hydrostatic weighing) with its index of 1·54, bromoform (1·598), monobromonaphthalene (1·658) and methylene iodide (1·745) one can recommend chloro- bromo- and iodo-benzene, supplying liquids with indices respectively 1·525, 1·560 and 1·620, which fill in gaps between the others and are not unpleasant in use.

There is no time to deal with other refractive index methods such as the minimum deviation method, which was greatly favoured by Dr. Herbert Smith, as the full description of it in his book indicates. His chart relating prism angles, angles of minimum deviation, and refractive indices is a most ingenious piece of work. The method is a beautiful one and very accurate under ideal circumstances : it further enables an accurate measurement to be made of the dispersion of the stone tested. But the fact that a rather elaborate instrument, the table spectrometer, has to be used, that much skill and time must be spent over each determination, that only occasionally can a full measure of the birefringence be obtained, and that it is almost essential that the stone should be unmounted, puts the method out of court except for the laboratory worker or the dyed-in-the-wool enthusiast.

Mr. R. Webster's talk given on the 6th May to the Midlands Branch is here recorded:

AFTER being introduced by Mr. T. P. Solomon, the Chairman of the Midlands branch, Mr. Webster opened his talk with the explanation that, although the title of the talk was "Some newer gem problems," his remarks would deal with what is new in materials and techniques since the war, and he craved the patience of his audience if much of the things he would refer to was material which had already been published, but it was necessary to do so to complete the picture adequately.

Much had been made of the new gem minerals, and indeed, as no new gem minerals had been discovered since the finding of benitoite in 1907, the finding of three new gem minerals in the past decade was an achievement. The speaker referred to taaffeite, brazilianite and sinhalite and mentioned the latter as being unique in that it was known for 60 odd years under another name—brown peridot. These new minerals have little commercial importance.

It was in the realm of synthesis that the greater advances had been made since the war, and in the corundum gems the production of the synthetic star rubies and sapphires was an important advance. The star effect is formed by oriented rutile needles developed after secondary heating of the boule, which contained a small proportion of titanium dioxide as well as the alumina and the colouring oxide. The earlier specimens of these synthetics were comparatively clear, showing a good star which did not reach all the way down to the girdle of the stone, and they were easily detected by the curved lines and many gas bubbles. Later syntheses are much more opaque, making it difficult to see the curved lines, but they contain gas bubbles which can be seen with a microscope if a strong light be used, and moreover the base does not show the zonal structure so common in natural star stones, and the "star" and the colour are much too "good." Specimens of synthetic star corundums were exhibited, but to illustrate star stones further, Mr. Webster showed on the screen a coloured slide of an attractive young lady holding in her hand the three famous star corundums of natural origin which are the show pieces of the American Museum of Natural History, New York. These are the 100 carat De Long ruby and the 563 carat "Star of India," and with them the 117 carat

" Midnight Star." Among ordinary clear varieties of synthetic corundum, the speaker referred to some new shades of colour, including the pale pink sold as " Rose de France ", a much richer pink sold as " Rosaline," and two brown colours, " Palmyra topaz " and a darker shade known as " Madeira topaz."

The synthetic rutile resulted from experiments on the production of strategic minerals. Originally made in a yellowish white, yellow, orange, and blue, only the near-white shades are seen at all in jewellery. The blue colours were quickly taken off as they tended to chip badly. The strong double refraction and the exceptional " fire " allowed easy distinction. What is really new, said the speaker, is the strontium titanate. This stone has less " fire " than the rutile, is much whiter—so more the appearance of diamond—and is singly refracting. It has a similar refractive index to diamond but the density is high, being just over 5, and it is somewhat soft, about 6. Only two of these new stones have been seen in this country so far and these two stones have now left these shores and so cannot be exhibited.

The new synthetic spinel of lapis colour is made by sintering powdered synthetic spinel coloured with cobalt oxide. It was devised by a German dentist using sintering techniques common to his profession and some specimens are equipped with included specks of " pyrites " which are in fact particles of gold. Synthetic emerald, although rather a pre-war advance than a post-war, was mentioned, with a report that about 50,000 carats of rough crystals were grown per year, of which only ten per cent. were of gem quality and the best fetched some 120 dollars per carat (say about £40). The synthetic can be distinguished by several methods, all of which may need to be called into play to pin the stone down completely. One of the more important of these was the nature of the internal inclusions and to illustrate this coloured slides of inclusions in natural and synthetic emeralds were shown. Mr. Webster emphasized to his listeners that proficiency must be obtained in the use of the microscope and to drive this home mentioned that one should start young.

It was recalled that for many years the fact that certain gemstones could be turned to a different colour by heating them was well-known. This was particularly so with topaz, zircon and some

quartz, mainly amethyst to a yellow colour. The only new departure in this direction is that some amethyst from Montezuma, a place about 37 miles from Rio Pardo, in Minas Gerais, Brazil, will turn green on heating. The effect was found by a prospector who used some of the rough amethyst to build a fireplace and found after drawing the fire that the amethyst had turned green. These "greened amethysts" are now marketed under the name "prasiolita."

The speaker said that what was the most interesting development in coloration of gemstones was that by radiation and by bombardment with particles of subatomic size. Coloration by X-rays has produced spectacular effects, especially in the wishy-washy yellow sapphires from Ceylon, which develop a rich topaz colour in a few minutes in a strong X-ray beam, and kunzite which turns green. Except for the possibility of fraud in the case of yellow sapphires offered at a good price to a customer soon after radiation, the radiation coloration has little practical importance, for the stones fade quickly in about 3½ hours' exposure to sunlight or by heating to 230 degrees Centigrade. (In reply to a questioner it was suggested that if the stone be placed in boiling medicinal paraffin the necessary temperature would be obtained.)

With respect to bombardment with atomic particles, Mr. Webster said that this had the greatest importance in the case of gem diamonds. Coloration of diamond to green by emanations from radium compounds had been known since the experiments of Sir William Crookes in 1905, but as such "greened" diamonds themselves became radioactive they could easily be detected by the aid of an electroscope, a geiger counter, or the scintillations seen on a suitable fluorescent screen ; the best all round method, however, was to place the stone on a bare photographic film for a night, or even a few hours, when the radioactivity of the stone would cause it to take its own photograph, termed an autophotograph, and such a picture was thrown on the screen. (Fig. 1.)

Since the war much work has been done experimentally, and in some cases commercially, in the colouring of diamonds by bombarding them with particles of subatomic size, such as deuterons (the nuclei of heavy hydrogen), alpha particles (which are the nuclei of helium atoms), protons (the nuclear particle with unit

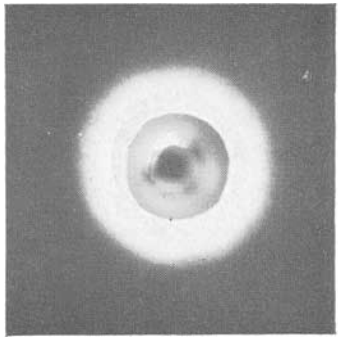

Fig. 1

An autoradiograph of a radium-treated diamond

positive charge), neutrons (the uncharged nuclear particles), and electrons (which are the unit of negative charge and are planetary around the nucleus of the atom). The apparatus used for this type of coloration is a cyclotron, and a picture of such a formidable piece of apparatus was shown on the screen. The stones thus treated are intensely radioactive when they come from the cyclotron, but this quickly dies although the induced colour remains, so radioactivity cannot be used to detect such stones as in the case of the radium-treated diamonds. The colour induced is, like the radium-treated stones, a green, but by heating, either on the apparatus by the heat generated during the process or subsequently, a brown colour is induced. Thus by keeping cool whilst being bombarded—and this is done by using water-cooled probes or by a jet of liquid helium impinging on to the stones—green colours are produced. By varying the heat and beam intensity a number of shades of green and brown can be produced. Coloured slides of bombarded diamonds were shown. Like the radium-treated stones the colour is usually only skin-deep, but more recent techniques have produced coloration throughout. Detection is not always possible, but many cyclotroned stones show a typical pattern around the culet, said to be due to the method of fastening the stones on to the holder of the apparatus. This pattern, called by the laboratory workers "The Umbrella," was shown by a slide (Fig. 2). "The

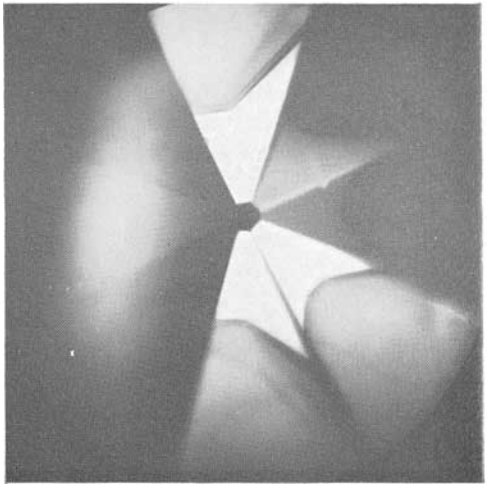

Fig. 2

The "umbrella" seen in some cyclotron-treated diamonds

Umbrella " is a sure sign of cyclotron coloration, but its absence does not imply that the stone is not artificially coloured. Indeed it is not always possible to be sure, although other signs may assist, including the response to ultra-violet light. As more of these stones become available for examination, they will give the laboratory staffs more and more data to build up the picture and eventually an answer to the problem may be provided.

Bombardment by neutrons from an atomic pile has been carried out experimentally. On removal from the pile the stones are practically black and need to be heat-treated in order to obtain a green or brown colour. Three specimens which had received treatment and subsequent heating in the pile BEPO at Harwell were on show.

Recent reports have stated that an aquamarine-blue colour can be induced in diamonds by bombardment with high-speed electrons from a Van de Graaff generator, a picture of one being shown on the screen. No " blued " diamonds have been available for examination, but, according to Dr. Custers, as the natural blue

diamonds are electroconducting and the "blued" stones are not, a method of distinction lies in that direction.

Mention was made of the new techniques worked out during the past decade. Methods of immersion contrast by direct observation, which Mr. B. W. Anderson had described to the Midlands branch at an earlier talk, were briefly mentioned and illustrated with slides. The use of the short-wave ultra-violet lamp as a useful tool for the discrimination of synthetic spinel was mentioned, slides being shown of a number of synthetic spinels in ordinary light and glowing under the short-wave lamp. The " crossed-filter " method for observing the fluorescence of chromium-coloured minerals and the use of the copper sulphate filter in absorption spectroscopy were discussed and beautifully illustrated by a couple of slides taken by Mr. Anderson, showing a powerful light with a round glass flask of copper sulphate solution before it and bathing a group of stones in the blue light. The second slide was taken through a red filter and showed the stones glowing red.

Mention was made of a number of cases of cultured pearls going a dirty black colour and the experiments to find out the cause. It was suggested that it was caused by a trace of metal impurity in the pearls becoming a dark sulphide by chemical change from noxious sulphide gases in the air coupled with the heat of some shop windows, a possible cause being sulphide vapours given off from the leather of jewellery cases in a hot shop window.

Some interesting inclusions in glass and natural stones, particularly " bubbles " in apatite, and crystal inclusions in glass, were shown by coloured slides.

The meeting closed with a word of thanks to the lecturer from Mr. Norman Harper, Vice-Chairman of the Gemmological Association, after which the audience spent some time examining the many specimens on show.

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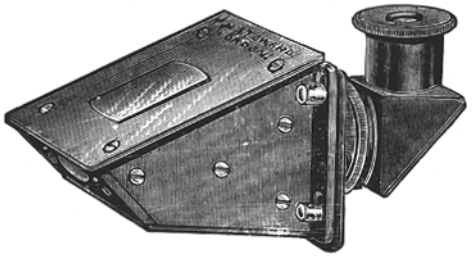

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The EMERALD

by

ROBERT WEBSTER, F.G.A.

THE loveliness of the emerald of perfection colour has been aptly described in those lines written by Herbert Smith ; " which in its verdant beauty recalls the exquisite lawns that grace the courts and quadrangles of our older seats of learning," and there are few other mineral species which have varieties exhibiting the nuances and the rich velvet-green of quality emeralds. It is a stone that was offered in Babylon, the earliest known gem market, nearly four thousands years before the Birth of Christ.

Ancient Lore

Dedicated by the ancients to the Goddess Venus, emerald is steeped in superstition and lore. Fittingly it is the birthstone for May, thus symbolizing the beauty and promise of nature in Spring ; emerald has been called the symbol of immortality, the conqueror of sin, the symbolization of faith—and faith in adversity—and of kindness and of goodness. Emerald by changing its colour has been said to reveal the inconstancy of lovers, and to have the power to render a man invisible so long as he be unwed.

The fable, told by Pliny, that the emerald is beneficial to the eyes, may not be so completely false, for the restfulness of green light is well known. It is said that the gem cutters of Europe are accustomed to keep an emerald on their work benches so that they may look at it to relax their nerves and so sooth their eyes after severe strain.

In the early days emeralds were a popular curative agent. At first they were employed externally, Hindu doctors treating numerous illnesses by applying the gem in divers ways ; and powdered emerald was used until comparatively recent times as a cure for fevers, for dysentery and for the bite of venomous animals. Aristotle tells that if an emerald be worn it will prevent epilepsy, and Caesar collected the stones because he believed that this was so.

Herbert Smith states that the name emerald is derived from a Persian word, later appearing in the Greek as *smaragdos* and Latinized as *smaragdus*. It is from this derivative that the altered forms *esmeraude*, *émeraude* and *esmeralde* were derived, the present form not making its appearance in English until the 16th century. The name *emerald* has always been used for a green-coloured mineral, but often not for the emerald we now know. Green sapphire, chrysocolla, lapis lazuli, malachite, green turquoise, green alabaster, glass, and even the copper ore known as bornite (peacock ore) have been graced by the name of emerald.

Nature of Emerald

What is emerald ? It is the grass-green variety of the mineral beryl, in which a silicate molecule combines with the light metals aluminium and beryllium. The formula for the mineral is $Be_3\ Al_2\ (SiO_3)_6$, but considerable replacement of the beryllia by the oxides of the alkali metals and the alumina by the oxides of chromium and iron occurs. Beryl is one of the few minerals containing the element beryllium, an element previously known as *glucinum* owing to the sweet taste of its salts. This element was first discovered by Vauquelin in 1798 but was not prepared in a pure state until 1828. The purified element was prepared by the chemist Wöhler, who one year earlier had made the first preparation of pure aluminium. To-day, beryl of non-gem quality is assiduously mined as a raw material for beryllium, which has now obtained importance as a strategic metal.

Beryl crystallizes in the hexagonal system of crystal architecture, and emerald itself usually takes the simple habit of a six-sided prism closed by flat ends—the basal pinacoids. The atomic structure is formed by $Si_6 O_{18}$ groupings as independent six-fold rings formed by six SiO_4 tetrahedral groups linking through oxygen atoms. These rings are further bonded with the fairly small aluminium and beryllium cations which serve to bind the *rings* tightly together, both laterally and vertically. This strength of bonding cancels out the possibility of prismatic cleavage and allows only an ill-defined and poor cleavage parallel to the basal plane. The crystals are quarried out of the rock in which they are embedded ; they do not project into cavities as is the case with topaz and quartz. They will be discussed further in this article in connexion with the different localities in which they are found.

Emerald owes its verdant green colour to a trace of chromic oxide (Cr_2O_3), although a trace of vanadium may have some influence on the shade of colour. It is interesting to note that chromic oxide gives to ruby its magnificent red colour. The mechanism of this change of colour is, according to Anderson, due to the difference in intensity and the wavelength position of the broad absorption band which is such a characteristic feature of the absorption spectra of chromium-coloured minerals. The sharp bright lines in the red shown by the fluorescence spectrum of emerald tend to prove the small-scale isomorphous replacement by the chromium ion, as they do in ruby. Traces of iron are usually present in emerald and these again may have some bearing on the final shade of colour, as indeed they may have on certain other properties. This included iron is thought to be the cause of the lack of transparency to ultra-violet light below 3000A, as against the greater transparency of the probably purer synthetic emerald, which is transparent down to about 2250A.

The hardness of emerald is given as about $7\frac{1}{2}$ on Mohs's scale, the density 2·70, and the refractive indices 1·57-1·58 with the small mean birefringence of 0·006. There are slight variations of these values for stones from different localities and these will be mentioned when each locality is discussed. The refraction is double and since the index for the extraordinary ray is less than for the ordinary ray the sign of the refraction is negative. The dichroism of emerald is distinct, with the "twin-colours" blue-green for the extraordinary ray and yellowish-green for the ordinary ray.

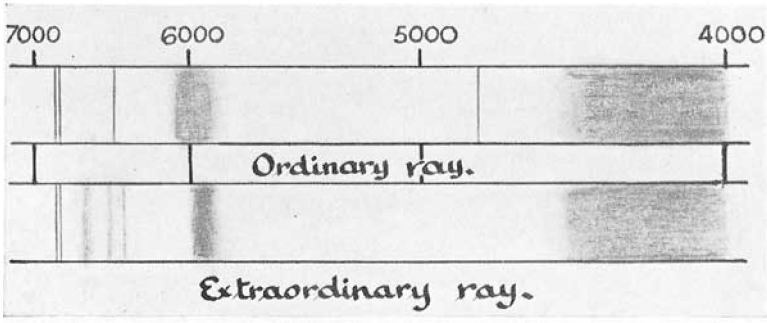

Absorption spectrum of the ordinary and extraordinary rays in emerald.

The absorption spectrum is that typical for chromium coloured minerals, showing fine lines in the red part of the spectrum, a weak diffuse central absorption with absorption of the violet, and rather weak lines in the blue. In emerald there is a distinct difference between the absorption spectrum for the ordinary ray and for the extraordinary ray. In that of the ordinary ray only two narrow lines can be seen in the red and they are of almost equal strength. These two lines consist of the main doublet (6830 and 6800A) and a clear cut line at 6370A, the central weak absorption patch covers from about 6250A to 5800A, and there is a narrow line in the blue at 4775A which may only be seen in very chrome-rich stones, when another line at 4725A may also be noticed. The absorption of the violet commences at about 4600A. In the spectrum of the extraordinary ray the doublet is rather stronger, particularly the 6830A line of the pair ; the 6370A line is missing and in its place are two rather diffuse lines at 6620 and 6460A, these being bordered on the short-wave side by characteristic transparency patches. The broad absorption region is now nearer to the red and is much weaker, and there are no lines in the blue.

Emerald, although a green stone, transmits a considerable quantity of the deep red, which is also a region of fluorescence, and it is this fluorescent red light which mainly gives the red colour seen when emeralds are viewed through the Chelsea colour-filter. Should this fluorescence be suppressed or dimmed by a fluorescence " poison," as by iron, such emeralds may not show red through the filter ; this may well be the reason for most South African and Indian emeralds remaining green when viewed through such a

filter. The majority of the emerald imitations and simulating minerals show green through the filter, but there are exceptions, such as the older type of soudé emerald, and certain varieties of natural minerals, particularly the emerald green fluorite, the demantoid garnet, and green zircons, which show reddish through the filter. Synthetic emeralds, owing to their chrome-richness and freedom from those impurities such as iron, show a fiery red appearance through the filter. Although this strong red residual colour can indicate a synthetic emerald it must not be taken too literally, for some natural emeralds from the Chivor mines of the Bogotá region of Colombia behave similarly.

Cutting

The cutting of emerald is usually performed on a copper lap charged with diamond dust and the polishing carried out on a similar lap with rottenstone as the agent. The best quality emeralds are almost universally fashioned in the trap-cut style with the corners truncated, giving an elongated octagonal outline, a style which has, owing to its common use for emerald, become known as the "emerald-cut." It is the style of cutting which, owing to its few plane facets, shows the saturated deep velvety-green of emerald to best advantage. Although the mixed-cut, with a brilliant-cut top and a step-cut pavilion, has been used for emerald, such a fashioning is rare and is said to give a glassy look. Poor quality

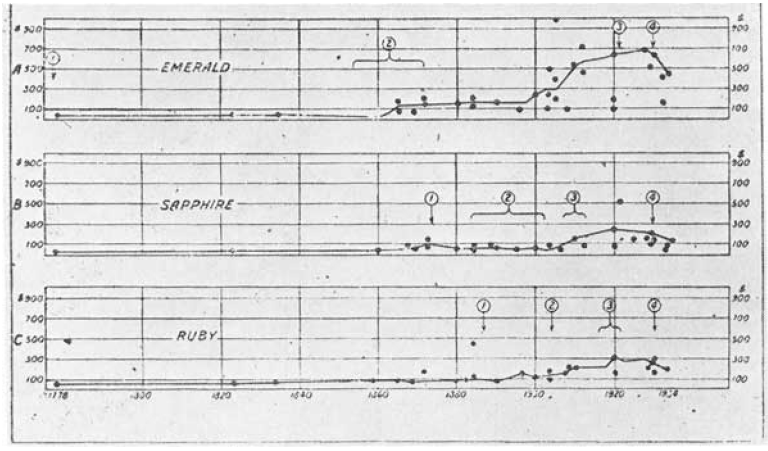

Price graph of emerald compared with ruby and sapphire, from the 18th to 20th century.

and badly flawed emeralds are cut *en cabochon* or as beads, and much Indian jewellery is set with such stones, which are usually poor quality emerald imported from Russia or the Transvaal. Native-cut stones are often " doctored " by boiling in fat which has been suitably coloured. Such " treated " emeralds tend to show spots at a later date, so if any suspicion is aroused it is best to soak the stones for some time in warm alcohol when some of the false material will dissolve out and reveal the trick, and, incidently, show the true colour of the stone.

An emerald cut with the table facet at right angles to the optic axis, that is at right angles to the length of the prism, will give a blue-green colour due to the ordinary ray. At right angles to this direction, that is with the table facet cut parallel to the prism (and of course the optic axis also) the colour is more yellowish-green due to about 50 per cent of the extraordinary ray. This latter colour is often more pleasing to many than the shade deeper in colour due to the ordinary ray.

Emeralds are often carved, especially if the material is of good colour but marred by many fissures and flaws. It is said that Cleopatra had her portrait engraved on many emeralds which were then made as gifts to her favourites. The five stones which Cortes presented to his bride, the niece of the Duke de Bejar, and by so doing mortally offended Queen Isabella, were said to have been worked into divers shapes—as a bell, a charm, a fish and a rose.

Large Stones

Emeralds, unlike large or historical diamonds, have rarely been honoured with individual names, steeped in history as many of them were. The only emerald which is at all well known by name is the Devonshire emerald, an uncut emerald crystal. This crystal, said to be from the Muzo mine in Colombia, is a fine green hexagonal crystal weighing 1,383·95 metric carats and was given to the sixth Duke of Devonshire by Dom Pedro the First, Emperor of Brazil, on coming to Europe after his abdication in 1831.

The English Crown Jewels contain many large and smaller emeralds, none of which have ever been graced with names. Outstanding amongst these gems is a large cabochon emerald in the front band of the Crown of India, and there is another trap-

cut emerald in the cross-paté at the top of the same crown. Another large emerald is set on one side of the cross surmounting the Orb.

Seen by many who visited the exhibition of the Art Treasures of Vienna was the world's costliest unguent jar cut from a single emerald. This masterpiece was fashioned by Dionysio Miseroni about 1642 for the Hapsburg family. It was said to have been cut from a Colombian crystal and it weighs 2,680 carats. An example of the use of the hexagonal form of an emerald crystal is the watch mounted in such a case found in the so-called " Cheapside hoard." This hoard was found when a workman crashed his pick through the chalk floor of a building at the corner of Cheapside and Friday Street in the City of London, and into the remains of a box containing some two hundred and thirty pieces of jewellery including the watch. The hoard in all probability constituted the stock-in-trade of a jeweller, for in the 17th century Cheapside was the home of many goldsmiths. The watch consists of a single hexagonal emerald, seven-eighths of an inch across and similarly deep, into which the watch movement is centrally inserted, and over the green enamelled dial is a thin emerald slab forming a protective cover for the hands of the watch. This particular piece is of interest as watches were not known to have been worn in England until after 1540 when Henry VIII presented Catherine Howard with a girdle watch set in a carved emerald.

In the Gellatly collection of the American National Museum is a large emerald cup with a curious history. It is the so-called " Emperor Jehangir " cup carved from a single Colombian emerald. The story is told that Jehangir, Conqueror of the World, enjoyed the drinking of wine to the full, and with his companions imbibed the liquor from high cups of gold. His favourite wife, Nur Jehan, chid him for using a cup no better than those of his subjects and presented him with the emerald cup. Jehangir, it is said, was much pleased until he noted the smaller capacity of the new cup.

Said to be one of the largest emeralds in the world is the Kakovin emerald. Iakov Ivanovich Kakovin was the Director of the Ekaterinburg Cutting Works and in 1934 received a large emerald weighing 2,226 grams from the mines at Sretensk. Kakovin became enamoured with this stone and several others and kept them in hiding, but he was detected in this and rather than suffer punishment committed suicide. On its way to the Court this stone was

again removed, by one Perovsky, a state official who collected beautiful stones. The Kakovin emerald later came into the hands of Prince Kochubey, whose heirs subsequently put the stone up for sale in Vienna. Having survived fire and robbery the emerald again returned to Russia, Czar Nicholas II having signed an edict which allowed the stone to be purchased for the Imperial State. In 1935 the emerald was transferred from Leningrad (the old St. Petersburg) to Moscow to leave there again for the safety of the Urals which gave it birth, during the period of the German invasion. Since victory the Kakovin emerald is again back in Moscow as one of the jewels of the Russian Diamond Treasury, which repository houses any number of fine emeralds including one of 250 carats, two dark green cabochons of 170 carats each and a plain stone bearing a Persian inscription weighing 153 carats. In all the emeralds of the Russian Treasury total 3,500 carats.

Another famous cup, the *sacro catino* or Holy Grail, in Genoa, was for centuries believed to be a single emerald of enormous size, although it was actually nothing more costly than green glass. The story is to the effect that the Genoese government being in financial distress offered the Grail to a wealthy Jew as a pledge for the loan of two million crowns. The Jew realizing that the cup was worthless resisted the proposal, but was forced to make the loan, although he protested that unfair advantage was being taken of the unpopularity of his race, since they could not find any Christian willing to advance the money. Some years afterwards the Government wished to redeem the priceless relic, but found that several persons claimed to have it in their possession. The Jew had turned his discomfort to profit, had had made imitations of the *sacro catino* and pawned each for a large sum, assuring each moneylender that the Government would redeem the pledge.

One of the most priceless pieces of emerald-set jewellery is said to be the " Crown of the Andes." The crown, stated to have been created in 1593, was sculptured from a solid block of pure gold, and encrusted with what is said to be the largest collection of fine emeralds in the world, and to be of inestimable value. Included in the galaxy of gems in this crown was said to be the Atahuallpa emerald, a 45 carat stone named after the last Inca of Peru. The crown was made for the statue of the Madonna in the Cathedral at Popayan, in which place full records of the history

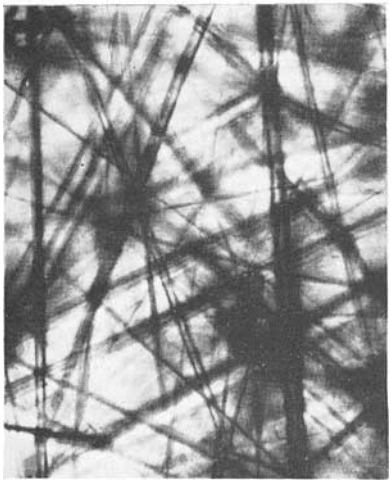

Grammatite (tremolite) inclusions in Habachthal emerald (photo. E. Gübelin).

Three-phase inclusions in an emerald from El Chivor Mine.

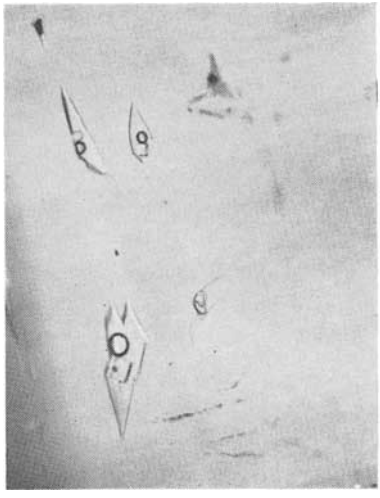

Included pyrites crystal in an emerald from El Chivor Mine.

Three-phase inclusions in an emerald from the Muzo Mine.

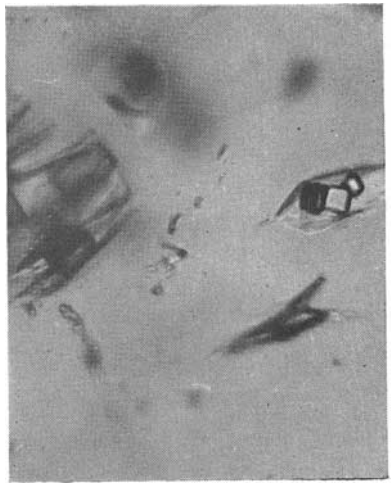

of the crown are documented. The crown had, during its long history, suffered capture by the English in 1650, who only held it for three days ; and again in 1812 the crown became a capital prize during the war and revolution in which Simon Bolivar freed the South American colonies from Spanish rule. In 1939 the crown was finally sold and it is understood broken up, its 453 emeralds weighing 1,521 carats being removed and sold separately but it was intended to preserve the gold crown itself in some museum.

Emerald, according to Ball, was for the period from 1567 until 1800 a depressed market owing to oversupply of the crystals from Colombia. Between 1852 and 1871 emeralds were very popular under the French Third Empire, and increased their popularity in the twentieth century, to a great extent because of the enthusiasm of the late Queen Mary. Despite two global wars and the production of the true synthetic emerald the popularity and value of good natural emeralds have remained undiminished.

Localities

(*a*) *Egypt*

Historically the earliest known locality for emerald was the group of mines by the Red Sea in Egypt, the so-called Cleopatra's emerald mines. These mines were probably worked some 2,000 years before the Birth of Christ and from them came most of the emeralds used in the ancient jewellery. The location of these mines was completely lost during the middle ages and not rediscovered until 1818 when Cailliaud, who had been sent by the Viceroy of Egypt to search for them, at last found the ancient workings. The mines are in the hillsides of Gebel Sikait and Gebel Zubara in Northern Etbai ; the hills lie parallel, and some 16 miles inland, from the Red Sea and about 100 miles north-east of Aswan, the ancient Syene. There are hundreds of shafts of the ancient workings, some of which had workings extending to a depth of some 800 feet, and in which tools and appliances dating back to the time of Sesostris (1650 B.C.) were found. Sporadic attempts have been made since the rediscovery to work the mines, but owing to the poor quality of the flawed crystals found in the micaceous and talcose schists which form the mother rock, the workings have been found unprofitable. Little data is available concerning the properties of these light-coloured and cloudy emeralds.

(*b*) *Austria*

Said to have been known since the time of the Romans there is an occurrence of emerald in a very inaccessible spot, some 7,500 feet above sea-level, on the east side of the Legbach ravine, a branch of the Habachthal, in Salzburg, Austria. The occurrence is of little importance, but mining by irregular methods has been carried on intermittently through the years, and in 1937 the mine was reopened on a small scale. Since World War II some crystals have been seen but whether these are from the 1937 working or from a resumption of mining since the war is not certain. The simple hexagonal crystals are found in a mica and chlorite schist, a type of mother rock similar to that of the Uralian source. Thus the inclusions seen in the Habachthal emeralds are in general similar in type to those seen in the Russian emeralds, namely actinolite rods and mica plates with rounded outline. The density of the Salzburg emeralds approximates to 2·74 and the indices of refraction are ω — 1·591 and ε — 1·584 showing a double refraction of 0·0068.

(*c*) *South America*

Who first discovered the lovely green crystals found in the Andes of Colombia, which give to this South American country the honour of being the source of the world's finest emeralds, will never be known. It is quite evident that the native Indians realized something of the value of the emeralds which they had used for barter with other neighbouring tribes, and which probably extended to those as far north as Mexico, and south to Bolivia and Peru. Despite three hundred years diligent search no other emerald bearing areas outside Colombia have been found in the Andean ranges, or in Central America or Mexico. The so-called "Peruvian" or "Mexican" emeralds were in all probability products of the ancient Colombian mines.

Europe first knew of the fabulous emeralds from South America when Pizarro ruthlessly conquered and despoiled Peru, taking from the Incas an immense quantity of emeralds, many of incredible size being sent to the Queen of Spain. Subsequently the old native workings in Colombia were found by the Spanish invaders and worked by them, sending the stones, both those mined and those stolen from the Indians, to Spain where they were later sent to Paris for sale.

The mines of Colombia are situated in the Cordillera Oriental, the eastern range of the Andes, and are principally in the Departments of Boyaca, and Cundinamarca and lie to the north of Bogotá, the Colombian capital. The only workings of importance are those of Muzo and Cosquez, and those of El Chivor, sometimes known as Somondoco, a word which means " God of the green stones." Some other small deposits are known, but, like those near Nemoncón, are of little more than scientific interest.

The first indication of the source of the South American emeralds came in 1537 when Gonzalo Jiménez de Quesada conquered Colombia, and was presented with nine green stones by the inhabitants of the town of Guachetá. Although the Indians carefully guarded the whereabouts of the mines, a youngster gave the invading forces the information that the emerald mines were at Somondoco, the mines now best known as El Chivor, so Chivor should be the first to be told of the famous South American emerald mines.

The Chibcha Indians of the high plateau of Colombia mined emeralds from Chivor (pronounced *she-vore*) before the Spanish conquest, the stones recovered being traded for gold from the Indian tribes across the Magdalena river. Some time after the Spanish subjugation of Colombia the conquistadores worked the mines of Somondoco. In 1592 Francisco Maldanaldo de Mendoza built an extensive viaduct, remnants of which still remain, in order to supply the water necessary to wash the mining debris away. Within one hundred years the mines were abandoned, either because of the lack of a successful yield or because of the discovery of the fruitful mines at Muzo some 150 miles to the north west. Chivor died out as a mine and the prolific growth of tropical vegetation effectively hid the workings for over 200 years.

After a long search the Somondoco/Chivor mines were rediscovered by Don Francisco Restrepo in 1896. Restrepo had nothing to go on except a note in a chronicle written by a friar on the Spanish Conquest, which said " The mines of Chivor are situated on the point of a ridge from which the llanos of the Orinoco can be seen." A company, The Chivor Emerald Mine Company, was formed by Restrepo, but, although the State tax was paid for twenty years, the mine was not successfully worked. The rights to the emerald mining at Chivor passed to a German commercial

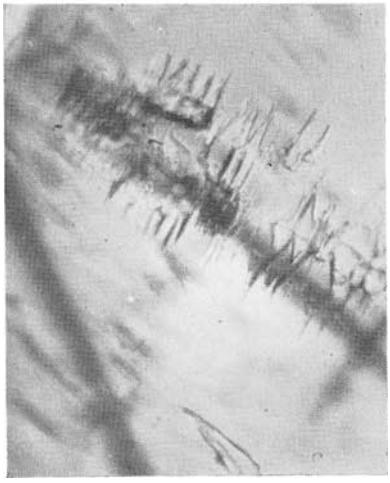

Spiky-edged cavities in an emerald from the Muzo mine.

Inclusions in a Brazilian emerald.

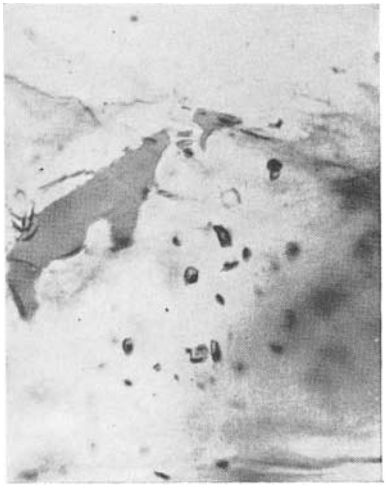

Large actinolite crystal in a Russian emerald.

Typical inclusions in a Russian emerald.

group just before the first world war, and they, after having the report of Prof. R. Scheibe, sent, during 1911 and 1912, Herr Fritz Klein to test the mine workings. The outbreak of war in 1914 stopped further exploitation by the company. In 1919 the mines passed to an American company—The Colombian Emerald Syndicate Ltd, which was in 1926 converted into the Colombia Emerald Development Corporation of New York, and in 1927 Major P. W. Rainier took over the management of the mine for the lessors, and in his book *Green Fire*, he tells entertainingly of the trials of mining Chivor. The mine had many vicissitudes with periods of inactivity and bursts of frenzied activity. The mine was being worked in 1937, but little is known concerning the war years, indeed there was little news at all until 1950 when R. W. Alderton became manager. At the end of 1951, owing to litigation and depredations by the local banditry, Chivor ceased working and was for all intents and purposes closed.

The emeralds of Chivor are found near the summit of the mountain overlooking the headwaters of the mighty Orinoco. When the Spaniards mined for emeralds they chose the western slopes, while the recent mining was carried out on the slopes facing the east. Until some six years ago when tunnel mining was commenced, the mining was of the traditional terrace-type, in which the emerald-bearing veins were exposed by digging horizontal terraces in step-like formation along gullies and washing the debris away with water released from a lake-like reservoir above the cuttings.

The emeralds are found in vein-shaped cracks some 20 centimetres wide and varying in length up to 70 metres. The crystals are usually in "strings" or in "nests" (pockets) containing anything from a few to over a hundred crystals. As the emerald pockets are approached there are showings of *moralla*, an uncrystallized form of green beryl, and this gives an indication that the miner may soon find a pocket of *canutillos*, the Colombian miners' name for good quality emerald crystals.

The crystals, usually of a good blue-green colour are unfortunately often shattered owing to the force of earlier geologic cataclysms. The crystals take the usual hexagonal prismatic form but often show small pyramidal faces. Often they are found loose in the pockets owing to their having been weathered out from the

Dark inclusions and mica plates in an emerald from Poona, Cue, W. Australia.

A mass of mica plates is a common inclusion in emeralds from the Transvaal.

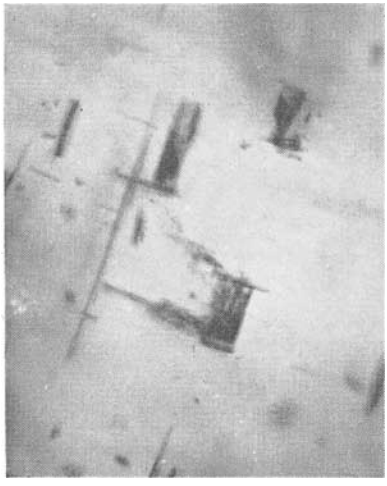

Comma-like inclusions in an Indian emerald.

The masses of inclusions in this Norwegian emerald make the stone turbid.

parent rock and such emerald crystals are covered with a tenacious coating of limonitic red iron oxide. This coating needs to be cleaned off by acid in order to see the quality of the emeralds, which are then sorted into five qualities or grades.

The emeralds of Chivor have a density of 2·69 and refractive indices of ω — 1·577 and ε — 1·571, with a birefringence of 0·006. Chivor stones usually show a fairly strong red under the colour-filter and a red fluorescence when bathed in ultra-violet light and therefore behave somewhat like the synthetic stones. The inclusions seen in Chivor emeralds are the three-phase types common to South African emeralds, but most typical of Chivor stones are inclusions of well-formed crystals of pyrites.

The world's most beautiful emeralds are said to come from the mine at Muzo, which, with the mine at Cosquez, is operated by the Colombian Government ; the stones recovered are deposited in the Banca de la Republica for marketing. They are sold as the market warrants, and when the stock of emeralds in the bank is surplus to market needs the mines are shut down ; therefore the actual mining is carried on very sporadically.

The geology of the area is fundamentally similar to that of Chivor, but the emerald-bearing veins, containing calcite, quartz, dolomite, and pyrites, run through a black carbonaceous limestone and shale which form the country rock. The crystals, embedded in the vein material, have the simple forms of the hexagonal prism closed with basal pinacoids. The Spaniards mined Muzo by driving adits, but the method of terracing and washing away the debris is now employed.

The yellowish-green stones from the Muzo district have a warm velvety appearance which is most prized. The density of the emeralds from Muzo is generally slightly higher than for the Chivor stones, the values of the constants being for the density 2·71 and the indices of refraction, for the ordinary ray 1·584 and for the extraordinary ray 1·578, the double refraction being 0·006. Muzo stones usually show the typical three-phase inclusions of a bubble of gas in a liquid and a cubic crystal, which is probably sodium chloride (common salt), contained in a flat cavity having spiky or jagged outlines with tail-like appendages. Pyrites crystals, so common in Chivor stones, are not seen as an inclusion in the

emeralds from Muzo and Cosquez, but occasionally there are seen in Muzo emeralds yellowish-brown prismatic crystals of the rare-earth mineral called *parisite*, a fluo-carbonate of the cerium metals, a species whose type-locality is the emerald mines of Muzo.

It has been said that the emeralds of Cosquez were the best quality, but other reports suggest that the Cosquez stones are more comparable to those of Chivor and are poorer in colour than the Muzo emeralds. Little is known of Cosquez ; the last news heard of it was that in 1951 Russell W. Anderton was negotiating for the lease of the mine from the Colombian Government ; what transpired and whether the mine is now being worked are not certain.

Early in 1934 a law was passed in Colombia requiring all persons engaged in cutting or selling emeralds to register with the Government. Emeralds being found in the possession of unregistered persons became liable to forfeiture. A report of 1951 states that it is illegal to transport rough emerald anywhere in Colombia without their first having been appraised and sealed by the officials of the Ministry of Mines, export being permitted on a reintegration basis with the official *peso* valued at approximately two to an American dollar.

The belief in mediaeval times that there was a fabulous source of emeralds in Brazil contributed in no small degree to the opening up of the interior of this vast country. The first expedition set of in 1554 under the leadership of one Bruzo Espinoso and a Jesuit priest. This expedition, and also a second under Martin Carvalho in 1567, failed to find the source of the coveted gem. The name of Sebastiao Fernandes Tourinho brings interest to the stories of the searches for emerald in Brazil, for he made three journeys into the interior, the first in 1555 and the third and most important in 1572. Taking his followers into the " barbarous forests of the Rio Doce," he eventually reached the watershed dividing the rivers flowing east from the tributaries of the Jequitinhonha and the Arassuahy. There he was said to have found many stones of divers colours, and finally emeralds themselves. On his return to Porto Seguro the stones were sent to Portugal where they were pronounced to be " emeralds from the surface baked by the sun, and stones that the earth had rejected as refuse." It was suggested that better stones would be found by " digging deeper."

This " digging deeper " suggestion led to more expeditions which were in the main organized by the Governor of Bahia. In 1574 Antonio Dias Adorno left with 650 followers and many slaves but failed to find anything but " baked emeralds." Twelve years later Martin Cao searched along the Rio Doce das Esmeraldas but found no emeralds, although he made a name for himself by his inhuman treatment of the Indians he took as slaves. Marcos de Azeredo Coutinho took out an expedition in 1612 and he did find green stones reported to be emeralds by Portugal. Coutinho died without revealing the secret of the locality. Five more expeditions, two led by the sons of Coutinho, failed to find the emerald area ; but a sixth, under Fernao Dias Paes Leme from Sao Paulo, did, in 1674, find Coutinho's locality of the green stones. Leme died before suffering the disappointment of finding that the stones never were emeralds, but only green tourmalines. The last expedition was organized in 1713, but its only claim to success was the discovery of the alluvial gold of the Rio das Contas.

Eventually the source of the Brazilian emerald was found at Brumadinho in Bahia, and emeralds were later located in the Rio Doce area ; so were Coutinho's emeralds genuine or were they misidentified in Portugal ? More recently deposits of emeralds have been found at Conquista in Bahia and at Itaberai in Goyaz and Ferros in Minas Gerais. In 1913 a find was made at Bom Jesus dos Meiros in Bahia, where the crystals were found in cavities in an altered marble capping a mountain. The crystals, often much flawed, are hexagonal prisms with basal pinacoids, with the edges truncated with small pyramidal faces. The yield is small and the mining primitive.

The density of the Brazilian emerald is 2·69 and the refractive indices are ω — 1·571 and ε — 1·566, with a birefringence of 0·005. Brazilian emerald, which appeared on the market about 1900, is a pale yellowish-green and so resembles ordinary green beryl that at first they were rejected as imitations. The stones are fairly free from inclusions, which further tends to give the impression that the stones are just green beryl rather than true emerald, but the existence of a chromium absorption spectrum effectively proves that the stones are true emeralds. When internal features can be seen in the Brazilian stones they are usually two-phase inclusions or tubes, or both.

(*d*) *Russia*

The source of the Uralian emerald was found quite accidentally when a peasant, in 1830, noticed some green stones at the foot of a tree torn out by a storm. After the discovery large Government mines were sunk in the dense forest amid marshes some 70 kilometres north east of the town of Sverdlovsk, which in the heyday of the Russian Empire was known as Ekaterinburg. The mines are on the Asiatic side of the Ural Mountains and on the Takovaya river. The crystals, generally large and cloudy and of poor colour, although smaller ones of good colour form valuable stones, are found in a mica schist which is interfoliated with talc and chlorite schists. The crystals are found in this locality in association with the other beryllium minerals *chrysoberyl* and *phenacite*, and with common beryl.

Russian emeralds have a density rather higher than the emeralds from the sources previously discussed, being 2·74, and the refractive indices are 1·588 for the ordinary ray and 1·581 for the extraordinary, the double refraction being 0·007. The characteristic inclusions seen in Siberian emeralds are mica plates and actinolite needles in single individuals or as dishevelled groups. Three-phase inclusions are said to have been observed in Siberian emeralds, but in these emeralds the solid phase is rhombic in form. Such inclusions are not commonly observed. For a number of years during the inter-war period the mines were worked by an American company, but how they are operated to-day is another secret hidden behind the Iron Curtain.

(*e*) *Australia*

The first discovery of emerald in Australia was in 1890 when W. A. Porter, while prospecting for tin, found green crystals in a dyke off-shoot from a greisen granite where it had taken on the form of pegmatite. The locality is some nine miles north by east of Emmaville in New South Wales. Prof. David inspected the site in 1891 and found the crystals to have a density of 2·67 and to be inter-crystallized with topaz, frequently penetrating fluorite as delicately accicular prisms, or sometimes embedded in a kaolinized rock and occasionally surrounded by mispickel. In that year a crystal weighing 23 carats was found completely embedded in mispickel. In 1891 and 1892 the mine was worked by the Emerald Proprietary Mines, who mined some 25,000 carats of emerald each

year. Since then the mines have closed down and have only been worked sporadically by prospectors.

A tin prospector named Ryan, found in 1909, in a biotite schist and in pegmatite dykes, another source of emerald at Poona, a place some 40 miles north-west of Cue in Western Australia. In 1912 the State Mining Engineer made an independent discovery in the area. He secured several promising stones that were cut in Sydney and in London, where Mr. E. Hopkins reported very favourably upon them. In the same year J. Pearl opened up one of the deposits but found it nearly worthless, although two fine stones were sent to Paris for cutting, one of which weighed 5 carats and was sold for £100 to the Montana Sapphire Syndicate, who resold it for £170. This Montana Sapphire Syndicate then took over the mine and spent £5,000 on equipment but the outbreak of the first World War stopped the project. After the 1914-1918 war the mines at Poona remained more or less dormant until the Star Emerald Syndicate commenced development. Little is heard of this now.

The Poona emeralds are associated with quartz, albite, oligoclase, topaz, tourmaline and fluorite, and with the micas—biotite, muscovite, lepidolite and zinnwaldite. The stones are mostly pale in colour and badly flawed, but there are some which are a fine colour, including one found by H. Mandelstam embedded in a small quartz leader in the dark biotite schist. Batchelor reports one fine stone of thirty carats from the same locality.

A few small crystals of emerald were found in the Wodgina district of Western Australia which reached some 10 mm. in length but were too turbid and flawed to be worth cutting. In South Australia a few poor emeralds have been found near Mt. Crawford near Williamstown, where they occur with aquamarine and heliodor in pegmatite. The occurrence at Mt. Remarkable in the same State, mentioned by Bauer, seems debatable, for there appear to be no records in the publications of the South Australian Department of Mines.

(*f*) *Africa*

In the year 1927 beryl crystals, many of which had the colour and other qualities of true emerald, were found some 12 miles east-north-east of Gravelotte station in the Leydsdorp

district of the Letaba area of north-eastern Transvaal. The deposits are associated with acid pegmatite intrusions in biotite, chlorite and actinolite schists belonging to the Swaziland system. The gemmy crystals occur almost invariably in the biotite schists at or near contact with the pegmatite bodies. Associated with the emeralds are such minerals as quartz, apatite, schorl, molybdenite, pyrite and feldspar.

The crystals have the usual prismatic form and range in size up to two inches or more in length, but most often are variable in colour, cloudy, cracked and flawed. Some clear pieces, however, have been sold for £100 per carat for cut stones. The flawed material has usually been cut into cabochons.

In 1929 some five companies operated in the area, including the Beryl Mining Company's " Somerset Mine " which was worked by a shaft and by open cast mining. This mine was installed with mechanical treatment plant capable of treating up to 200 tons of emerald-bearing schist per day. This recovery plant employed a modified form of tube mill to separate the emerald crystals from the enveloping mica schist. During the period before the second global war the only consistent producers were the Somerset mine and a mine operated by Cobra Emeralds Ltd., and in 1930 some 12 pounds weight of emerald crystals were being sent to London cutters each week.

During the slump of 1930 and 1931 most of the workings were abandoned, or at least ceased working, and this included the Somerset mine. In 1934 increased demand opened a new interest, but the only consistent producer was the Cobra Emerald Company. Mining during the war years for all intents and purposes ceased, except perhaps for the winning of crude beryl for beryllium. After the war the mines restarted to some extent but productivity has been marred by the trade boycott with India, which took much of the poorer flawed material for cutting into cabochons and used it in native jewellery.

At one time an emerald cutting project was started in Johannesburg but the endeavour did not bear fruit. In 1947 there was talk of reopening the Somerset mine by the Beryl Mining Comany, which, it seems, is still in existence, as is the Cobra Emerald Mining Company with its New Chivor mine. Other groups are also registered, including the operator of the Green Pigeon Emerald Mine.

South African emeralds have a somewhat higher refractive index than most other emeralds. Typical values are 1·593 for the ordinary ray and 1·586 for the extraordinary, the birefringence being 0·007 ; and the density is near 2·75. The inclusions are typically brownish mica plates and if these are profuse they tend to make the stones dark or even brownish. The South African emeralds rarely show red through the Chelsea colour-filter and hence have at times been rejected as imitations.

(*g*) *India*

The emerald has been held in high esteem in India from ancient times, but until the find in 1943, a source of true emerald in India was not known. A number of references exist about Indian emerald resources, but despite careful investigation no proof of an emerald locality in India was forthcoming. The locality called " Canjargum " or " Cangagam " given as a source of Indian emeralds seems to refer to the aquamarine mines of Padyur near Kangayam in the Coimbatore district of Madras. It is interesting to note that some small green rolled pebbles, which the natives regarded as emeralds, have been found at Ajmere, Rajasthan, which is perhaps better known as the old State of Rajputana. Although these stones were officially understood to be ordinary green beryls, in the light of the 1943 discovery there must always be a doubt whether or not emerald has been mined in days long past.

Even if emerald was mined in India in past days it would not account for the vast quantities of emerald used in native jewellery for some 1,500 years. J. Coggin Brown refers to old Sanskrit writings which tell of emeralds from " a mountain situated on the edge of the desert near the sea coast," a description which would well apply to the mines of Gebel Sikait and Gebel Zubara alongside the Red Sea. In more recent times the emeralds from the mines in Siberia were the source of the emeralds used in Indian jewellery, and in the 19th century much emerald of the poorer quality was exported to Asiatic countries from the stone markets of London and Paris. Much of the emerald mined in the Transvaal was sent to India, but since the trade boycott between the two countries the sale of South African rough has stopped, with the consequential pile up of emerald stocks in the Transvaal while new markets are sought.

The finding of emerald in the Arawalli mountain range of Rajasthan in 1943 was the result of the war-time search for beryl and mica as strategic minerals. During the search some small green crystals were found in the Kaliguman area of Udiapur, and these were identified as emeralds. A mining lease over the Kaliguman area was granted by the Udiapur authorities, then the independent State of Rajputana, to Sir Bhagchand Soni and his partner Seth Banjilal Thulia, the latter an emerald merchant of Jaipur. The first mining efforts in 1945 met with immediate success and crystals up to four inches in length were recovered. The emeralds are found in bands of biotite (mica) schist. Further searches followed this first successful attempt at emerald mining in India and other finds have been made both in Udiapur and Ajmere-Merwara. In 1947 quarrying was begun at the Rajgarh mine some 15 miles south of Ajmere, in which the emeralds are found in a soft talcose-biotite schist. Another source is near Bhilwara.

The Indian emeralds vary greatly in quality ; the stones from the Rajgarh mine, and other sources in Ajmere-Merwara, have, in general, a better quality than those from the Kaliguman mines, although good stones of large size have been recovered from the first discovered locality. The density of Indian emeralds is commonly 2·73 to 2·74 and the refractive indices are ω —1·593, ε—1·585, the double refraction being 0·007. The inclusions seen in Indian emeralds are typically characteristic and are of a type not reported from the stones of any other locality. These inclusions consist of two sets usually running at right angles to each other. Oriented parallel to the vertical axis of the crystal are oblong cavities containing a liquid and a bubble of gas. These cavities are characterized by having a shorter columnar projection on the edge of one end, giving them the appearance of "commas." Gübelin has shown that these cavities are groups of negative hexagonal crystals, one being remarkably longer than the others. The second type of inclusion Gübelin found to be biotite tablets oriented parallel to the basal plane. Like the South African emeralds the Indian stones may not exhibit a red residual colour through the colour-filter. The Indian stones are marketed mainly in Jaipur.

(*h*) *Norway*

Emeralds have been found at Eidsvoll, at the southern end of Mjøsa lake some 35 miles north-north-east of the capital, Oslo.

The crystals are found embedded in granite, and are nearly always turbid. The density of a specimen of Norwegian emerald, cabochon cut, of good colour but very turbid, was found to be 2·68. The dichroism of this specimen was found to be distinct and the absorption spectrum strong, and under the filter the stone showed a bright red. Observation by microscope of the internal features of this stone showed that it was filled with masses of inclusions, mostly "mossy" in character, but combined with a vast number of interconnecting cavities rather like vesicles. To these masses of inclusions is due the turbidity of the stone, which would preclude such a stone being successfully cut with facets, although as a cabochon it was quite attractive.

(*i*) *North America*

Occasional crystals of emerald have been reported from Stony Point, Alexander Co., North Carolina, at Haddam, Connecticut, and at Topsham in Main and New Hampshire, all localities in the United States of America. They have local significance only. Reports of occurrences of emerald in the Harrach and Bouman rivers of Algeria, and also *in situ* in the neighbourhood, are not, as far as is known to the writer, fully substantiated and the mineral may be simply green tourmaline.

Imitation and Synthesis of Emerald

Such a prized gemstone as emerald invited imitation, simulation and synthesis.

Emerald, unlike corundum and spinel, on fusing forms a glass and does not recrystallize ; therefore, the Verneuil method of flame fusion by blowpipe cannot be employed in synthesizing beryl. In general crystallization can occur in three main ways ; from a fusion, by sublimation, or from a saturated solution, and, although the details of the modern synthesis of emerald are not fully known, it is clear that the solution method is the one employed.

The earliest well-recorded attempts at the synthesis of emerald were the experiments carried out by Ebelman, one time Director of the Sèvres Porcelain factory, who, in 1848, obtained microscopic crystals of emerald by heating powdered emerald with boric acid, a form of reconstruction rather than one of synthesis. Other workers employing similar methods but different formulae also

Small twisted veil-like feathers and general turbidity in a synthetic emerald made by Prof. Nacken.

Inclusions in German synthetic emerald (Igmerald) showing twisted veil-like structure and a number of two-phase inclusions.

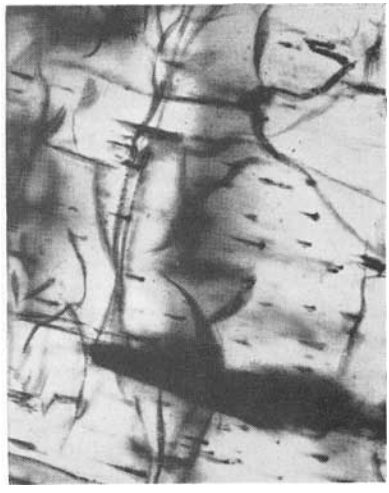

Twisted veil-like feathers in an American synthetic emerald.

Differential transparency of synthetic and natural emeralds to short-wave ultra-violet light.

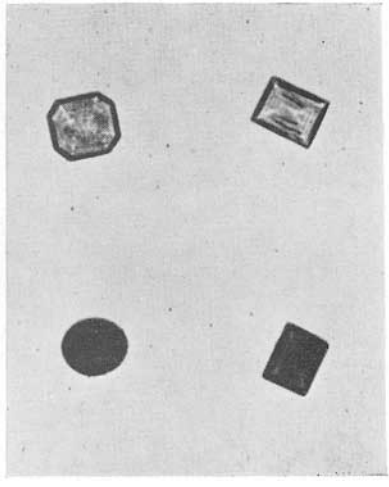

obtained limited success. Although only of academic interest, as the resultant crystals were far too small to be cut into gemstones, the experiments of P. G. Hautefeuille and A. Perrey in 1888 deserve mention. In their most successful experiment a mixture of alumina, beryllia and silica (with a trace of chromic oxide) in the correct proportions for beryl was placed in a platinum crucible and the mixture covered with a layer of lithium molybdate. The charged crucible was then placed in an autoclave and the temperature raised to a dull red heat for some twenty-four hours, after which the temperature was raised to 800°C. and kept at that value for fifteen days. The fused mass when cooled was broken up and digested in dilute hydrochloric acid. It was discovered during these experiments that if the temperature was allowed to rise above 800°C. the beryllium silicate mineral known as phenacite (Be_2SiO_4) was formed ; and it was further found that if the experiment was conducted at a temperature of 750°C., the crystals were short tabular hexagonal prisms and at the higher temperature of 800°C. their habit was prismatic, the length being some one and a half times that of the diameter across the prism. These workers also found that the colouring oxide was wholly taken up by the crystals if it was only a thousandth part of the mixture, but if as much as three thousandth parts were employed much of the oxide remained in the gangue material.

In 1912 Prof. Nacken, then of Frankfurt University, commenced experiments on the problem of synthesizing emerald and other minerals usually classed as extremely insoluble in water. Nacken's first experiments were to attempt the synthesizing of such minerals by crystallizing them from water or dilute aqueous solution in the neighbourhood of the critical temperature. The critical temperature being that temperature, characteristic for each gas, above which it is no longer possible to liquify it by compression. In 1928 Nacken succeeded in synthesizing a number of minerals including emerald crystals up to 1 carat in weight.

The method Nacken used was to grow on a " seed " crystal larger crystals, making use of the fact that the solubility of these minerals in water becomes appreciable at high temperatures and pressures. The technique used was crystallizing from a solution by sealing up the requisite raw materials in an autoclave (an autoclave, or " bomb," is a thick-walled vessel with a tightly fitting lid, in which substances may be heated above 100°C. by superheated

steam) which was heated to the critical temperature of water. The thick-walled steel autoclaves used consisted of a cylindrical vessel with a capacity of about thirty cubic centimetres, closed at one end with an internal screw plug. The vessel was lined with silver and the seed crystal was suspended from a silver wire attached to the plug. The solvent, which was water containing traces of a weak alkali, occupied about twenty per cent of the volume at room temperature. The raw material, consisting of a mixture of beryllium oxide, alumina and silica in the correct proportions, was placed in the autoclave, which was then closed and the temperature raised to about 370°-400°C. and was kept at that temperature for a few days. Under these conditions the water is in the neighbourhood of the critical point and completely fills the vessel. The largest crystals made were up to 1 cm. in length and 2 to 3 mm. in width.

About 1934 the results of an emerald synthesis by H. Espig and E. Jaeger at the North Bitterfeld factory of the German dyestuff combine I. G. Farbenindustrie, were announced, and groups of such crystals were exhibited at the Paris Exhibition about 1936, and a few cut stones were circulated, mainly in scientific circles. These true synthetic emeralds were called *Igmerald* from I.G. and emerald, but these synthetic stones never became a problem for the jeweller. The nature of the process, said to be slow and expensive, was not divulged, but was assumed to be hydrothermal and a modification of Nacken's method. With the rise of Hitlerism and the outbreak of the Second World War nothing further was heard of these synthetic emeralds, and since the cessation of hostilities, with the Bitterfeld factory in that part of Germany in Soviet hands, the term *igmerald* has become just a name in gemmological history.

Quite independent of the European synthesis, Carroll F. Chatham commenced experiments earlier than 1930 on the synthesis of emerald at his laboratory in San Francisco, California, in the United States. Not beset with the ravages of war these experiments were continued and to-day a commercial production is maintained with ever-increasing quantity, quality and size of crystals. It is said that to-day some 50,000 carats of rough crystals are produced annually of which less than 10 per cent is of gem quality and the top quality sells for 120 dollars per carat (about £40).

That Chatham's method employed in growing the crystals is hydrothermal there is little doubt; indeed in the brochure issued by Chatham it is stated, " The general method of *culturing* emeralds is similar to the recent hydrothermal quartz process, simulating superheated springs under tremendous pressure several miles below the surface of the earth. By using the very small building rocks of nature, each emerald—large or small—is slowly grown in an artificial mine under ideal conditions for at least a year."

While no sound information is available of Chatham's process, much can be learnt from the report of the synthesis of quartz which has been freely published. There are two methods, both of which employ an autoclave. In one method, the so-called *temperature-gradient method*, proved more successful. In this method with silica glass, as a source material, above it. The contained alkaline water is kept at a constant temperature of 360°C., and in this condition the vitreous silica glass kept at saturation and the " seed " at supersaturation, with consequential deposition of silica on the seed as quartz, growing it to a larger crystal. The method, however, was found to have defects, and a second method, the *temperature-gradient method* to be more successful. In this method the "seed" is again suspended in an alkaline solution in the bomb, with crushed quartz at the bottom as the source material. The temperature at the bottom of the autoclave is 400°C and at the top 360°C. Thus the saturated hot liquid as it rises becomes supersaturated at the cooler top and deposits the quartz on the " seed." It is presumably some such method as these which Chatham employs, indeed he states so, and owing to the use of a seed he prefers to call his emeralds *cultured* rather than *synthetic*, but " synthetic emeralds " will be the term used for these " man-made " emeralds by all gemmologists.

The characters of these synthetic emeralds, so near in appearance and even in inclusions, to the natural stones, do, however, show features by which they can be distinguished from natural stones. They are usually of a saturated colour, and, like natural emeralds, are sorted into five grades of quality. The density of the synthetic emerald is perceptibly lower than for the natural stones, being near to 2·66, which is only just above that of quartz. Thus, in a bromoform/monobromonaphthalene mixture in which quartz just floats, a synthetic emerald will either just float or be freely suspended, while natural emeralds will sink decisively. This is the

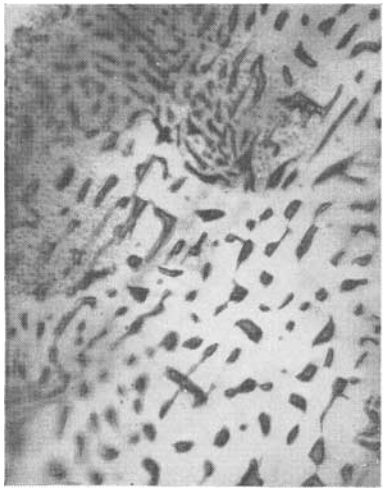

Magnified view of part of a veil-like feather in an American synthetic emerald.

Feathers in parallel arrangement common in synthetic emeralds.

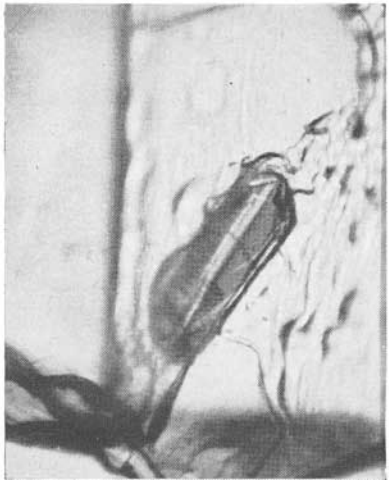

Phenacite crystal in an American synthetic emerald.

Anomalous double refraction shown by a synthetic emerald when examined between crossed nicols.

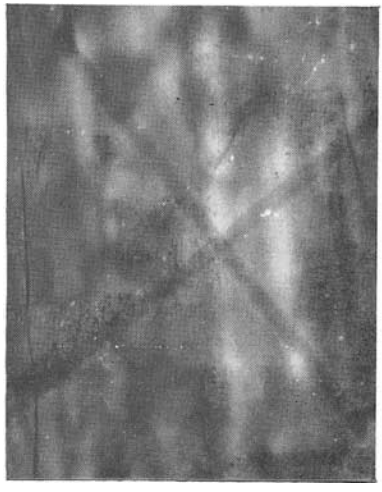

position as it is known at the moment, but future syntheses may not be so helpful in this way, and the gemmologist must forever be on his guard.

The refractive indices for the synthetic emerald are also lower, being, as far as all the specimens so-far examined have shown, 1·564 for the ordinary ray and 1·561 for the extraordinary ray, thus, the birefringence is as low as 0·003. Therefore, a low refractometer reading would betoken a synthetic and indicate that such a stone should be further examined.

When viewed through the Chelsea colour-filter, synthetic emeralds show a strong red residual colour, but again this can only be indicative, for some natural emeralds, particularly those from El Chivor, may show as strong a red. This warning also applies to the fluorescent red glow shown by synthetic emeralds when they are bathed in invisible ultra-violet light, of which the short-wave lamp (2537A) may supply the more diagnostic radiation. Indeed, by the use of this lamp the greater transparency to ultra-violet light of the synthetic emerald to that of the natural stone may be demonstrated, or even used as a test. Possibly owing to the trace of iron in natural stones they cut off radiations below about approximately 3100A, while the synthetic stones are transparent down to 2300A.

The inclusions so-far observed in synthetic emeralds are usually diagnostic, provided that the stone is not clean ; and clean stones are far from common. Grown in a more natural way, the characteristic signs shown by corundums and spinels made by the flame-fusion process of curved lines and included gas bubbles are not present in synthetic emerald, and the inclusions seen in the latter stones are most " natural-looking " feathers. These consist mainly of two-phase inclusions in the form of "curtain-like" feathers, which, when profuse, make the stone appear cloudy. These feathers are sometimes arranged in parallel bands. Straight and angular zoning is common, and in the lower grades of quality dark masses of inclusions mar the beauty of the stone. Phenacite crystals, as well may be expected from their similarity of chemical composition, are sometimes found as inclusions in synthetic emeralds.

Chatham, in his advertising brochure, says " The synthetic crystals are free from impurities and strain so can be raised to an incipient white heat while a natural stone is destroyed far below

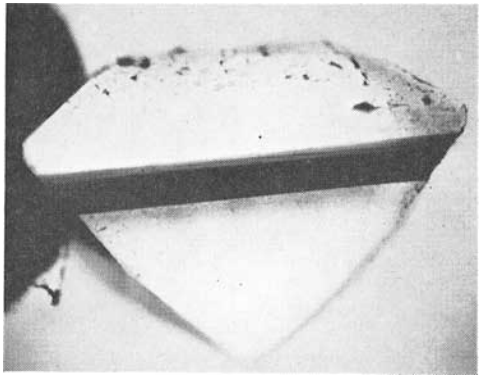

A soudé emerald when immersed in liquid and held sideways will show the clear top and base, with the colour layer distinct.

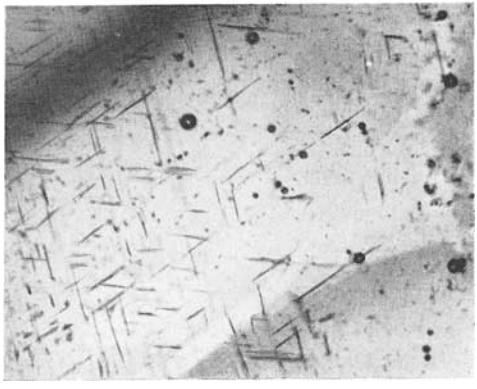

Microscopic examination of a garnet-topped doublet usually shows a layer of bubbles in one plane and natural inclusions in the garnet top.

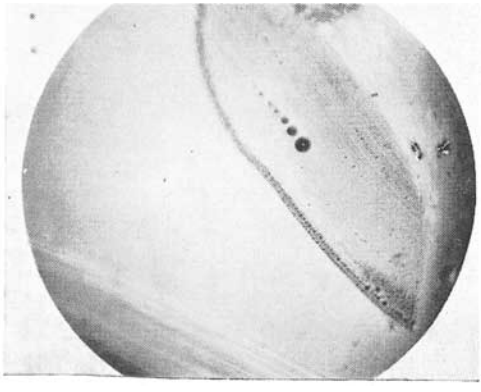

Swirl bubbles in paste.

the visible temperature range." Experiment has shown that natural emeralds do fracture and cloud at a lower temperature than the synthetic, but the absence of strain is rather denied by the effect shown when synthetic emeralds are examined between crossed nicols, the stripy nature of the anomalous double refraction belying the absence of strain.

Pale natural emeralds are sometimes painted on the back with a green pigment in order to enhance the colour. This, when the stones are set with open backs, is easily detected and easily removed. When, however, the stones are set in closed settings the problem is not so easy and examination by microscope may be necessary in order to see the patchiness of the blobs of colour below the stone ; or the strength of the absorption spectrum may indicate the true colour of such backed stones. Pale emeralds, or even rock crystal, are set in a closed setting containing a suitably coloured foil. It has been pointed out by M. D. S. Lewis that such a green foil may cause the stones to appear red when viewed through the colour-filter owing to selective reflection of light. The spectroscope will assist in such cases.

It is not easy to assess when the so-called soudé emeralds were first produced, but from perusal of literature it seems that the earlier types must have been marketed at the turn of the century. These earlier soudé emeralds were constructed of two pieces of rock crystal, selected often because they had natural feathers, or two pieces of nearly colourless beryl have been similarly used, cemented together with a thin layer of green-coloured gelatine between them. From this composite piece of material a stone is cut so that the green layer lies along the plane of the girdle. Most effective as these stones are, the quartz types are quickly unmasked by a refractometer reading, or either type by the aid of a spectroscope. Two characteristics of this earlier type of soudé emerald are that the gelatine layer caused the stone to show red through the colour-filter, and, further, that the green colour tended to deteriorate and turn yellow.

A newer and better type of soudé emerald later came on the market, which it is believed was devised by d'Horne. Fundamentally the stone is the same as the older type—the two pieces of rock crystal with the green-coloured layer between ; but it is this green layer which supplies the difference. In this later type the residual colour seen through the filter is green and the colour is stable. The

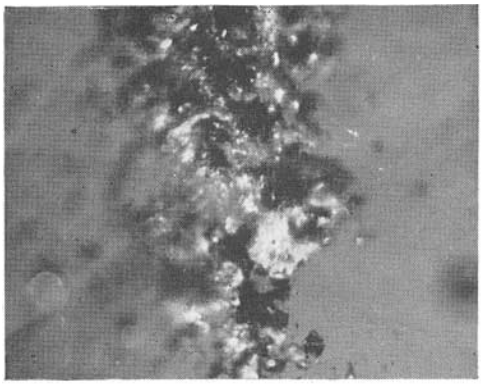

A glass imitation emerald showing masses of solid matter giving the stone a superficial natural appearance.

density of these pieces, however, is higher than what one would expect knowing that the bulk of the material is rock crystal (2·65) for the values obtained are about 2·8. The earlier type with gelatine filter does give values at 2·65. This high density implies a colouring agent with a heavy atom, but the actual nature of the colouring material and the method of bonding of the two pieces of quartz has not yet been satisfactorily determined—no information seems to be available from the maker. That copper is present has been proved, but so far the rest is conjecture. The best theory is that it is a metallo-organic compound colouring a sintered layer between the two quartz halves.

It is interesting to note that neither the synthetic corundum nor similarly produced spinel have ever been made in an emerald-green colour. Maybe this fact (and perhaps because it could be produced cheaper) led to the production in 1951 of a type of soudé emerald in which the quartz (top and base) is replaced by synthetic white spinel. These emerald doublets, or *soudé sur spinelle* as they are called, will give the refractometer reading for synthetic spinel (1·728), and again the density is slightly higher than for synthetic spinel, because of the nature of the green layer which seems to be the same as for the quartz type, the density varying between 3·66 to 3·69 (syn. spinel 3·63). The stones do not show red through the filter and an extra test is the whiteish glow seen from the white spinel when the stones are bathed in short-wave ultra-violet light—the quartz types being inert under the lamp, while true emeralds show a reddish tinge under short-wave ultra-violet.

The writer cannot recall hearing of a true emerald doublet made from two pieces of real emerald. Commonly found, however, are the garnet-topped doublets made by fusing a slice of red garnet to a base of green glass and then cutting the composite piece so that the harder garnet forms the crown of the stone. Tricky as these stones are when set in closed back settings, they are given away by the colour not being just right for emerald and often slight reddish gleams proclaim the fake. Technical detection is by the refractometer reading for garnet, usually about 1·79, and by the layer of bubbles in one plane due to the melting of the glass when the two pieces were fused together and by the crystal inclusions which may often be seen in the garnet top.

Earlier in this article it has been mentioned that emerald will not fuse and recrystallize like corundum and spinel but simply solidify as a glass—a beryl glass. It is recorded that over 70 years ago Greville Williams fused emeralds and found that the density decreased from 2·70 to 2·40, and the same worker prepared beryl glasses by fusing together a mixture of the same composition as beryl, colouring them by the addition of various metallic oxides—green with chromic oxide, blue with cobalt oxide and pink with didymium oxide. These beryl glasses had a density of 2·42. Beryl glasses, usually of a blue or green colour, have been met with in jewellery, but are rare. It has been found that such stones have a density between 2·39 and 2·49, but are generally about 2·42 ; the refractive index is near 1·52, and they have a hardness near to 7 on Mohs's scale. They contain usually a profusion of gas bubbles. Quite recently the writer examined five so-called " synthetic emeralds " supposedly obtained from Spain. These stones had every indication of being just beryl glasses. Their hardness was 6¼ on Mohs's scale ; the index of refraction of four of the stones, two dark green and two yellowish green, was 1·53, and of the fifth, a bluish green stone, 1·521. The density of the four stones with same R.I. was 2·39 and of the odd one out 2·37.

Glass imitations of emerald can be very effective, of good colour and appearance, and they are often embellished with " flaws " and " feathers " produced by layers of bubbles or by included extraneous matter. The so-called Ferrer's emerald is a glass which usually has a density about 2·69 and an index of refraction of 1·63, and is made specially as an emerald imitation. No emerald imitation in glass need present difficulty, for rarely is its refractive

index near to that of true emerald, and, further, it is isotropic and can only show one shadow edge. It is non-dichroic, and even if the colouring is by a chromium compound, the characteristic absorption spectrum of emerald is lacking. Of other counterfeits of emerald mention may be made of the so-called "Indian emeralds," which are simply green-dyed crackled quartz.

In conclusion the writer tenders his thanks to all those who have assisted in this compilation by giving of their own personal information and other help. Among these many helpers especial thanks are due to Prof. Rex T. Prider and Mr. Allan Wilson of the University of Western Australia, for the information on Australian emeralds and the gift of specimens of Cue emeralds ; Mr. Simpson of the Dept. of Mines, South Africa House, London ; Mr. Hans Myhre for the opportunity of examining the Norwegian emerald ; Mr. W. C. Buckingham for information on imitations ; and Dr. E. Gübelin for the photograph of the inclusions in Habachthal emerald.

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Intensely green and blue diamonds are rare, and it is often wrongly assumed that all such diamonds are artificially coloured. The artificial coloration can usually be determined. Diamonds have been coloured green by embedding them in radium salt. Such stones are radio-active on the surface; this causes the stone to fog photographic paper when placed on it for about 8–12 hours. Those diamonds which are coloured by bombardment with deuterons, protons and alpha particles are only radioactive for about one hour after treatment. Such stones usually have a very distinct parting line between the coloured portion of the stone and the uncoloured one; this can be observed particularly well if the stone is immersed in a highly refractive liquid, e.g. methylene iodide. Neutron bombardment often colours the complete stone, so that no dividing line can be observed. Martin L. Ehrmann (1950) once examined a 14-carat green diamond. After eight months it could only be said that the stone had not obtained its green colour by radio-active treatment, but no guarantee could be given that the stone was naturally green. F. H. Pough and A. A. Schulke (1951) observed a concentration of colour near the surface when a stone had been coloured by cyclotrons. M. L. Ehrmann saw tiny black specks on the surface as if the stone had been burned there. When recut, the cutting may go deeper than the layer affected by deuterons, so that the stone loses its green colour and regains its former shade. J. F. H. Custers and H. D. Deyer observed that artificially blue-coloured diamonds are coloured only to a depth of 0·5 mm. In a brilliant-cut stone it is difficult to see this. At a voltage of 125 and at 0·1 mA. naturally blue diamonds of about 1 carat became red hot; with larger stones a higher voltage was necessary; artificially coloured blue diamonds, however, did not conduct electricity, and did not turn red. There is also a difference in the transmission of infra-red and ultra-violet light which can be shown with selective filters.

E.S.

SALLER (X.). *Süsswasser-Zuchtperlen aus Japan.* Cultured fresh water pearls from Japan. Zeitschr. d. Deutsch. Ges. f. Edelsteinkunde, No. 12, pp 6–8, 1955.

This variety of cultured pearls owes its importance to the fact that the pearls—like the genuine ones—do not have an inner mother-of-pearl bead or another distinguishable core. The fresh water mussel *Hyriopsis Schlegeli*, locally called " Ikochogai," is greenish-black from the outside. The inner side of the shell is covered with a mother-of-pearl layer of very fine colour and good lustre. This mollusc slowly reaches a size of about 9½ by 5 inches and may be about 2½ inches thick. It lends itself well, therefore, to the production of big pearls. After six to seven years, when it has reached a size of about 5 inches, it is ready for the " operation." The locality is " Biwa-Ko " (Lake Biwa), the biggest fresh water lake in Japan. (The shape of the lake corresponds roughly to that of a " biwa," a Japanese string instrument.) The lake is about 40 miles long and 12½ miles wide at the widest part. In the north it is about 300 feet deep. The southern third is narrow and only about 16 feet deep. Here, in the Hirako Reservoir, with its rocky, sandy and muddy ground, the living conditions are well suited for the mollusc. It lives on (vegetable) phyton-plankton, although the water contains 60 per cent animal and only 40 per cent vegetable plankton. Early experiments after the first world war were abortive, mainly because the majority of the mussels died, when beads were inserted. This led eventually to the application of a new method. A mussel is carefully opened and its mantle separated from the shell with a spatula. From this mantle, i.e. from the side nearest to the shell, about half the thickness is cut out with sharp scissors and divided into strips of about 1½ by ¼ inch. (The deeply coloured mantle rim must not be used.) The strips are cleaned and divided again into squares of about $\frac{5}{32}$ inch. These squares of mantle tissue are then placed into another mussel which has been carefully opened and is held in a special frame. About three or four tissue squares are inserted from one side, preferably into the sex glands. Then the mussel is turned round, and three to four other tissue squares are pressed into position. Thus, each mollusc contains six to ten " scions." In contrast to the " surgical " operation with marine pearl oysters, the " grafting " of mussels consists of simply pressing into position the tissue squares, which form into (and take over the functions of) pearl sacs. Nearly every tissue square

develops into a pearl, i.e. in each surviving mussel an average of eight pearls will be found. In 1946, only 2,000 out of 50,000 mussels survived; in 1948, the technique had been improved already to such an extent, that 40,000 out of 50,000 mussels survived the operation. The pearls are reported to be of very fine colour and of good lustre; the shapes, however, leave much room for improvement. The author leaves no doubt that the new pearl ought to be called " cultured." The difficulty of determining its nature will be shown in a forthcoming article.

W.S.

SCHMIDT (P.). *Turmalin— der Proteus unter den Edelsteinen.* Tourmaline— the Proteus of the gem world. Zeitschr. d. Deutsch. Ges. f. Edelsteinkunde, No. 10, pp. 9–11, 1954/5.

Tourmaline is not one of the more precious gems, but just as Proteus, the Greek God of the Seas, was capable of changing his appearance, so tourmaline is found in many varieties. The stone was not known in ancient times. In 1703 children of an Amsterdam merchant played with his wares, which he obtained from Ceylon. The children noticed that under the lowering sun the stones attracted small particles of ash, paper, straw, and thus the stone was called " aschentrekker," i.e. attracter of ashes. It is found to-day in Madagascar, Ceylon, Burma, S.W. Africa, California, the American States of Maine and Connecticut, and chiefly in Brazil, where it is wrongly called " Brazilian emerald." There are brief notes about the physical characteristics. Because of its electrical properties it is used for the measurement of radium emanation. In submarines it is used to show small differences in pressure.

E.S.

ROULET (R.). *Die Perlenfischerei in der Lüneburger Heide.* Pearl fishing in the heath of Luneberg. Zeitschr. d. Deutsch. Ges. f. Edelsteinkunde, No. 11, pp. 16–19, 1955.

Fresh-water pearls were found in mussels in the rivers of the Lüneberg Heath in the middle ages, and used by monks for embroidery, etc. During the latter part of the middle ages, the Dukes of Lower Saxony took over the monopoly, but poaching was very common, and thus most of the mussels were exterminated.

E.S.

MEYROWITZ (R.). *A compilation and classification of immersion media of high refractive index.* Amer. Min., Vol. 40, pp. 398–409, 1955.

In this useful paper Meyrowitz brings together the multifarious media of high refractive index which have been proposed from time to time for use as immersion or contact liquids. The substances are classified by Meyrowitz into four groups: 1. Pure Liquids, 2. Liquid solutions, 3. Pure solids, 4. Mixed solids.

The list of pure liquids is a short one, consisting of methylene iodide (1·74), phenyl-iodoarsine (1·85) and selenium monobromide, for which Borgström in 1929 claimed an index of 2·1, but which Anderson and Payne (1934) found when fresh to give a value of 1·96, which rises on exposure to air due to decomposition and self-saturation with selenium.

The solutions and mixtures are too numerous to quote in a brief abstract. Meyrowitz himself has proposed new liquids with arsenic trichloride as a basis, giving an index value of 2·07 for a mixture of arsenic tribromide, arsenic trisulphide, and sulphur (presumably fused together). Most of the liquids mentioned in the paper are obnoxious in one way or another, if not positively dangerous in use. Up to the present, it appears that the solution of sulphur and tetraiodoethylene in methylene iodide (proposed by Anderson and Payne in 1934), which has a refractive index of 1·81, is still the highest index liquid which does not seriously damage the soft lead glass of the standard refractometers. With diamond or blende refractometers the matter is different, and some of the unholy mixtures proposed in this paper may be worth a trial. The paper concludes with 85 references to the relevant literature.

B.W.A.

CUSTERS (J. F. H.). *Large type II diamonds.* Nature, Vol. 176, p. 360, 1955.

In a recent article in *Nature* by Sutherland, Blackwell and Simeral (see abstract in this Journal, Vol. V., p. 88, 1955) the authors stated " . . . in our experience all large diamonds of gem-stone quality are always type I diamonds." Commenting on this sweeping statement, Dr. Custers states that in actual fact the four largest and finest diamonds examined since 1951 in the Diamond Research Laboratory in Johannesburg were all of type II. These stones weighed 34½, 66, 160 and 426½ carats, respectively. All four were pure white in colour, showed laminations, and were transparent

to short-wave ultra-violet light. None of the diamonds showed fluorescence under long-wave ultra-violet rays, but two of them showed the green-blue phosphorescence after irradiation with short-wave ultra-violet and the semi-conductor properties which Custers associates with his type IIb diamonds (see this Journal, Vol. IV, p. 300, 1954). Custers further expresses the opinion that nearly all the larger gem diamonds belong to the type II category, and also remarks that the Premier Mine produces a higher percentage of type II stones than any other mine. With this in mind, it would be interesting to test one of the minor stones cut from the Cullinan, which was also recovered from the Premier mine.

It would seem that the legend that type II diamonds are exceedingly rare is gradually breaking down. Of four " portrait stone " diamonds from different sources tested by the abstractor, three were transparent to short-wave ultra-violet light, and come into the type II category.

B.W.A.

SCHALLER (W. I.): HILDEBRAND (F. A.). *A second occurrence of the mineral sinhalite.* Amer. Min., Vol. 40, p. 453–457, 1955.

In 1932 Larsen and Schaller wrote an account of an occurrence of the rare mineral serendibite in Warren County, New York State. The mineral occurs in thin layers of a contact zone between limestone and an intrusive granite, and is of hydrothermal contact-metamorphic origin. Among the associated minerals were diopside and two undetermined species which the authors designated " mineral A " and " mineral B." Mineral A remains unidentified. Mineral B has now proved to be sinhalite, as shown by comparison of X-ray powder photographs made from fragments of material remaining from the former investigation with those published by Claringbull and Hey for sinhalite in 1952. This announcement does not mean that a new source of gem-quality sinhalite is now available, but it is extremely interesting scientifically, as it indicates a probable origin for the sinhalite found in the gem gravels of Ceylon. Serendibite is known to occur near Ambakotte, Ceylon, in contact zones between limestone and a granulite, accompanied by blue spinel, apatite, scapolite, and diopside. It is suggested that re-examination of specimens of serendibite from Ceylon might reveal the presence of sinhalite *in situ* as an associated mineral

B.W.A.

SHAUB (B. M.). *Recent discovery of fine gem tourmalines in Maine.* Gems and Gemology, Vol. VIII, No. 5, pp. 131–136, Spring, 1955.

Tourmaline was first found in Maine at Paris, at the locality now known as Mount Mica. A relatively small quantity of gem crystals from this locality is now available. It is mentioned that practically the only area which has produced gem tourmalines is a narrow zone near the south-west border of the State of Maine, extending from Auburn to Andover and west to New Hampshire. The recent discovery reported is from a location in the town of Norway where a number of trial pits were sunk for the recovery of mica. During these trial borings a pocket of gem-bearing material was located. This material was removed and by softening with water a number of tourmaline crystals were recovered. There were about 14,000 carats of crystals found, many of which had been broken across the prism by natural forces before mining operations opened the pocket. Of this quantity of crystals about 8,000 carats will produce gems, and 4,000 carats of bluish indicolite may cut into cabochons. Many crystals were terminated with etched and dull faces. Most of the material is bluish-green in colour, the few pieces of pink coloured material not being suitable for gems. Much information is given on the associated minerals.

4 illus. R.W.

SHAUB (B. M.). *Recent discoveries of topaz.* Gemmologist, Vol. XXIV, No. 288, pp. 124-127, July, 1955.

Tells the story of some recent finds of topaz crystals from microlitic crystal-lined cavities and fissures in a medium- to coarse-grained granite. The locality of the find is near Conway in New Hampshire, U.S.A., not far from the borders of Maine. The crystals, varying in colour from white to weak brown-yellow, are found in association with crystals of reddish microcline, smoky quartz, albite and fluorite. The article, further, gives a report of the tourmaline find in the town of Norway in Maine. (*See abstract from Gems and Gemology above.*)

3 illus. R.W.

ELLISON (J. G.). *Advantages in recutting star stones.* Gems and Gemology, Vol. VIII, No. 5, pp. 151—153, Spring, 1955.

Discusses the value of recutting badly shaped, off-centred,

and too heavily based star stones. Seven reasons are given for the advantage of recutting, the cost of so doing being negligible compared to the increased value of the stone.
5 illus. R.W.

RICHARDSON (H. L.). *The art of gem engraving.* Gems and Gemology, Vol. VIII, No. 5, pp. 137–144, Spring, 1955.

Gem carving or engraving is said to date from approximately 3800 B.C. and the earliest were copies of the sacred scarabs made in steatite, carnelian, chalcedony etc. Later early engraved gems served the purposes of seals and were used as personal marks before the invention of writing. Some engraved gems were simply amulets, and some were family seals handed down from generation to generation and were the forerunners of the family crest. The designs used on ancient seals depicted every phase of life. Cylinder seals were used in Ancient Egypt, Babylonia and Assyria. Three-sided seals from the Minoan culture of Crete were made of steatite. Earliest known engraved portrait stone is about 1500 B.C. Cameo carving attained its greatest splendour at the beginning of the Roman Empire. The history of cameos, and of the methods used in cutting them from mediaeval times till the present time is told. Shell cameos are cut from the Bull's Mouth shell found in the East Indian seas. The article closes with the story of the engraving of a monogram on a flat diamond.
9 illus. R.W.

MITCHELL (R. K.). "*Bloodshot*" *iolite.* Gemmologist, Vol. XXIV, No. 287, pp. 110–112, June, 1955.

Reports the characters of two unusual iolites which exhibited a red colour. The colour was found to be due to countless minute ultra-thin hexagonal plates of an included blood-red mineral, which, it is suggested, may be hematite or goethite, the former being the most probable. Fuller examination showed that there were two types of inclusions in the matrix of normal iolite; they are the hexagonal plates already mentioned, and short needle-like forms at right angles to the plates. The plate-like habit of the hexagonal type of inclusion gave, owing to their thinness, a pseudo dichroic effect. Mention is also made of the colourless labradorite feldspar found in Utah.
2 illus. R.W.

WEBSTER (R.). *X-Rays and their use in gemmology.* Gemmologist. Vol. XXIV, Nos. 287/8/9, pp. 106–109; 131–135; 148–151, June/July/August, 1955.

The series continues with notes on modern X-ray tubes, and gives elementary theory of the production of X-rays. X-rays are produced by the rapid deceleration of a fast electron stream colliding with the target. This produces a continuous or as it is called "white" radiation. When the energy of the bombarding electrons is powerful enough to ionize the target material, radiation of discrete wavelengths is produced. This gives a " line " spectrum known as the " characteristic radiation." The production of monochromatic X-rays is briefly touched on. X-rays are employed in gem testing in three main ways; by the luminescence induced by the rays; by the variable transparency of different materials to the rays, and thirdly, by the diffraction of the rays from the atomic planes of the material. The luminescence of gem materials under X-ray bombardment is only touched upon in the article as the subject has been well covered in an earlier series (*Gemstone luminescence*) by the same author. Differential transparency, or radiability, is a function of the atomic weight of the element or elements forming the substance. The use of this differential transparency is discussed in relation to diamond doublets and gemstones with greatly differing transparency to the rays, and to the direct radiographic (skiagram) method of testing pearls. The techniques needed in such a method of pearl testing are explained. The diffraction methods are discussed, with particular attention to the lauegram method of pearl testing. The " powder " method is briefly explained, and the modification of the Sach's back reflection method devised by Holmes and Switzer is mentioned. The article closes with a warning that some gemstones tend to turn to a different colour after extensive bombardment by X-rays.

15 illus. P.B.

SMALL (J.). *Weight estimation of pearls.* Gems and Gemology, Vol. VIII, No. 4, pp. 99–105, Winter, 1954/5.

A set of tables for the weight estimation of pearls according to diameter in millimetres. The formula employed for working out the tables is given. The table gives the weights for pearls from 1 mm. diameter to 17·7 mm. diameter. The weights being given in " pearl grains," " mommes," " carats " and " grams." Owing

to an error in the computation of the " momme " (given as 1 momme equals 0·0132 ounces instead of 0·132 ounces) the " momme " column is incorrect by one place of decimals, the decimal point needing to be moved one place to the left. This error is corrected by an announcement on page 157 in the succeeding issue. A graph is also incorporated.

R.W.

LIDDICOAT (R. T.): CROWINGSHIELD (G. R.). *Strontium titanate.* Gems and Gemology, Vol. VIII, No. 5, p. 148, Spring, 1955.

A report on the new synthetic strontium titanate. Not a synthetic equivalent to any mineral in nature; closest in minerals is *perovskite* ($CaTiO_3$). Strontium titanate, a product of the Verneuil furnace, has a hardness of 6; a refractive index of approximately 2·409; a dispersion (N_F—N_C) of 0·108. The specific gravity is approximately 5·13. The material is opaque to X-rays and displays no fluorescence. The critical angle is 24° 32″, and the melting point of the material is 2080°C. The stones are to be marketed under the name " Starilian."

R.W.

LEECHMAN (G. F.). *Lattice structure in precious opal.* Gems and Gemology, Vol. VII, No. 5, pp. 154–155, Spring, 1955.

Refers to the work of C. V. Raman on the colour of opal. Common opal is said to be completely amorphous, but precious opal, from X-ray investigations, contains tridymite and cristobalite, and may be said to consist of amorphous hyalite containing random blocks of crystal lattices formed of parallel laminae, presumably with the structure of cristobalite. Mention is made of the regular structures induced in colloid gels under certain conditions and of the nearly monochromatic nature of the light reflected from such structures—having what is called a " film pack " structure.

R.W.

RAMAN (C. V.): JAYARAMAN (A.). *X-ray study of fibrous quartz, chalcedony, iridescent agate.* Gems and Gemology, Vol. VIII, No. 4, pp. 106–107, and 125, Winter, 1954/5.

An abstract made of three articles appearing in the " Proceedings of the Indian Academy of Sciences " Vol. XXXVIII, Nos. 4 and 10; and Vol. XL, No. 3. Mineralogists designate a mineral as fibrous when it consists of visibly distinct rods or threads,

irrespective of whether these are separable from each other. Quartz pseudomorphs of fibrous minerals also have fibrous structure. Microscopical investigation in polarized light shows the quartz fibres to be parallel to the " c " axis and such fibrous quartz may be described as polycrystalline quartz with a strongly preferred orientation for the crystallographic " c " axis. In chalcedony the crystallites of quartz have been found by X-rays to have the " a " axis parallel to the fibre length. Lamellar structure is said to be due to variations of the " c " axes of the crystallites in the successive layers which are perpendicular to the length of the fibres. With the rarer iridescent agate it is stated the crystallites of quartz form fibres elongated in the direction of the " a " axis, while their " c " axes lie in the planes of banding but are oriented in a periodic manner in these planes so as to build up a structure which functions as a diffraction grating. It is known that quartz exhibits a type of twinning in which the " c " axis in the two components of the twin are nearly at a right angle to each other. It is inferred that the fibres of quartz in iridescent agate may be described as polysynthetic twins in which the alternate elements are related to each other presumably in the same manner as the twins referred to.

R.W.

WEBSTER (R.). *Stichtite—an ornamental stone.* Gems and Gemology, Vol. VIII, No. 5, pp. 149—150, and 156, Spring, 1955.

Describes, and gives the history of the finding at different localities, of the mineral stichtite. The mineral has been cut *en cabochon* and has been suggested as usable for inlay work as a contrasting coloured material in ornamental stonework. The material is found massive in matted aggregates of plates or scales. The hardness is between 1½ to 2; the refractive index approximately 1·53, and the density was found to vary from 2·15 to 2·22 (determined on specimens from Transvaal). The rose-coloured mineral is a hydrated carbonate-hydroxide of magnesium and chromium. The material shows no luminescence and the absorption spectrum is of chromium type.

1 illus. P.B.

GOODWIN (PETER). *Points on judging jade.* Printed by the South China Morning Post Ltd., Hong Kong.

A companion booklet to *Ten points about pearls* by the same author (*reviewed in Journal of Gemmology, July*, 1955). The points indicated include " Is it jade ? "—which mentions seven other materials imitating jade, namely glass, plastics, green-stained chalcedony, the so-called " New Jade," verdite, New Zealand jade and Yunnan jade. The texture of jade—and it is clear that the author is writing about jadeite, so often called " Chinese jade "—is discussed. Emphasis is placed on the " dimpling " seen on the surface of polished jade, and this is described as being due to a difference in hardness in the composition of the stone, which, according to the author, is composed of two minerals rather coarsely mixed together. The surfaces of glass and plastics are said to be usually quite smooth and regular. The extremely low hardness of plastics appears to have been overlooked. Point 3 deals with the substitutes, or at least three of them; New Zealand jade and Yunnan jade are mentioned as varieties of jade from the mineralogist's point of view, and these do not show the dimpled structure and their colour is much less pleasing. The so-called " New Jade " is described as having " a sickly yellow-green colour, is quite translucent and looks like good quality candle grease of a fancy shade . . . it hardly seems to have been worked by hand but gives the appearance of having been moulded." This material is said to be seldom used for jewellery but mainly as carved figures. It would be interesting to know what this " New Jade " really is. Point 4 describes other green stones, and these are confined to chalcedony and, strangely, verdite. The chalcedony is said to be stained a very bright green and sold always as jewellery and never as carved ornaments. Verdite, of which the author admits having seen only one piece—a necklace—in the Far East, is well described as to its appearance and its low hardness is remarked upon. Malachite is also described and prase and chrysoprase are mentioned. This is followed by a short summing-up. The value of jade pieces is then discussed with respect to quality, weight and spread, and the final point discusses the value of the setting. The concluding pages, give a general summary. The booklet, consisting of sixteen pages, is well printed on pale green paper and has an imitation snake-skin cover of similar hue.

R.W.

ANDERSON (B. W.): PAYNE (C. J.). *The spectroscope and its application to gemmology.* Gemmologist, Vol. XXIV, Nos. 287/8/9, pp. 102–105; 128–130; 143–146, June/July/August, 1955.

These three instalments (Parts 23, 24 and 25) of this important series continue with the stones which owe their colouring to ferrous iron. In the description given of the absorption bands of enstatite and diopside a discussion is made of the chemical affinities of enstatite, bronzite and hypersthene; and also of diopside. The absorption spectrum of enstatite is characterized by a single sharp line in the blue-green at 5060A. There are a number of weaker and vaguer bands to be seen in favourable specimens, and these are tabled. Comparison of the 5060A line is made with other lines near this wavelength in other minerals coloured by ferrous iron. The 5040A line seen in some diamonds is very similar in appearance to the enstatite line but seems to be due to a totally different cause. Diopside shows bands and lines at 5470, 5080, 5050 and 4900A, of which the narrow lines at 5080 and 5050A are alone prominent. In the case of the chrome diopsides the " chromium lines " in the red are seen, with the doublet at 6900A fairly strong. The ordinary dull green diopsides show feeble absorption spectra which have small diagnostic value. The absorption spectrum of kornerupine is weak and varies somewhat for the gamma ray and beta ray—the bands in these two cases being tabled. The only bands at all prominent are 4460A band in the green ray and the 5030A band in the yellowish-brown ray. The attractive green kornerupines from Burma show no definite absorption spectra. In axinite the bands are in general weak, but there is a narrow line at 4150A which is fairly strong. The influence of iron and manganese in the coloration of green and pink tourmalines is discussed in relation to the ferrous iron coloration of the green and blue-green tourmalines. In this connection the work of the Bradleys on the X-ray crystallography and absorption curves of tourmaline is mentioned. The absorption spectrum of green tourmaline shows the red absorbed up to 6400A, and in some cases even further; the yellow-green freely transmitted except for a faint absorption region near 5600A. In the blue-green coloured stones a typical ferrous iron band at 4980A with a weaker band at 4680A. In some specimens of green tourmaline, particularly in the blue-green coloured stones, a strong band may be seen in the violet at 4150A, which may be present in the dark green or the brownish-green tourmalines but masked by

the strong absorption in that region. The strong pleochroism of iolite is discussed, the different coloured rays being linked up with the optical directions, before the absorption spectrum of this stone is described. The absorption spectrum of iolite is not spectacular and consists of a number of weak bands, the most prominent being at 6450, 5930, 5850, 5350 (most clearly seen in the yellow ray), 4920, 4560, 4360, and 4260A. The bands at 6450A and the one at 4260A are best seen in the yellow ray for the absorption of the red and the blue-violet mask them in other rays.
7 illus. R.W.

REICHEL (F.). *Neuer Aufschwung der japanischen Perlenindustrie.* Increase in the Japanese pearl industry. Gold und Silber, No. 1, p. 13, 1955.

In November, 1954, the Japanese pearl industry opened a new centre at Kobe, through which 80 per cent of the Japanese sales are made. There is a shortage of large pearls, as for financial reasons pearls which are only one year old are put on the market. Investments are asked for, to produce more mature pearls. Export maximum prices are to be fixed and low quality goods excluded. From January, 1952, to August, 1952, the U.S.A. bought Japanese pearls to the value of Mill.$2·2, partially for re-export. Japanese pearl fishers are prevented from working nearer than 10 miles to the Australian coast.

E.S.

MARTIN (J. G. M.). *Kokichi Mikimoto—a tribute.* Gems and Gemology, Vol. VIII, No. 4, pp. 108–122, Winter 1954/5.

A short appreciation of Kokichi Mikimoto who died earlier in the year. The article is built up mainly from extracts from the Cahn report (*Journ. Gemmology*, Vol. III, No. 8, pp. 337–8, 1952), and as such is sound and provides a valuable abridged version of this important American Government Publication.
7 illus. R.W.

ASSOCIATION NOTICES

OBITUARY

SIR JAMES WALTON

The Association records with deep regret that Sir James Walton, K.C.V.O., M.S., F.R.C.S., F.G.A., the Chairman of the Association, died at his home in Mayfield, Sussex on August 27th, 1955, at the age of 73. Sir James was a distinguished surgeon who made the study of gemmology his hobby. He was extra surgeon to Her Majesty the Queen and had been surgeon to King George V, King George VI, and to the Royal Household. From his student days he was intimately connected with the London Hospital and became senior surgeon. He held other appointments in the medical world, including the presidency of the Association of Surgeons, the Medical Society of London, and the Vice-Presidency of the Royal College of Surgeons.

He had a brilliant career obtaining his B.Sc., M.B. and M.R.C.P. degrees rapidly, and in 1907 became a Fellow of the Royal College of Surgeons. He obtained the M.S. degree in 1909. He was created K.C.V.O. in 1935. Other honours that came to him were Chevalier of the Legion d'Honneur and honorary fellowship of the American College of Surgeons.

When he was nearing retirement as a surgeon he was attracted to the study of gemstones, and in 1945 qualified in the Association's diploma examination with distinction. His hobby absorbed much of his time and he became Curator of the Association's gem collection in 1947. In 1951 he was elected Vice-Chairman and in February of this year he became Chairman. In addition to important medical books, Sir James wrote *Physical Gemmology*, published in 1952, and a *Pocket chart of ornamental and gem stones* (1954). The National Association of Goldsmiths were greatly honoured when Sir James accepted an invitation to become President of that organization, and he served in office from 1953 until his death. He was a distinguished and lovable gentleman and he will be sadly missed.

MEMORIAL SERVICE

A service in memory of Sir James was held at St. Philip's Church, Stepney Way, London, on Tuesday, 13th September. The Queen was represented by Sir Arthur Porritt, Serjeant-Surgeon to Her Majesty. Members of the Association present included Mr. F. H. Knowles-Brown, Dr. E. H. Rutland, Mr. J. R. Chisholm, Mr. J. H. Saunders, Dr. W. Stern, Mr. T. Stern, Mr. G. F. Andrews, Mr. A. R. Popley, Mr. B. W. Anderson, Sir Cyril Dyson (National Association of Goldsmiths) and Lady Dyson, and Mr. I. Tarratt and Mr. J. Holgate, members of the Council of the National Association were also present.

B. W. ANDERSON writes

One of the earliest of many treasured memories of Sir James Walton is so typical of him that it is worth recounting. It was June, 1945; I was invigilating the practical examination of the Gemmological Association at Chelsea Polytechnic, and Sir James was one of the entrants. Coming up to the table where the heavy liquids were assembled, Sir James dropped the stone he was testing first into one liquid and then another, handling the tongs with a surgeon's sure precision (in contrast to the nervous fumblings of the younger students) and meticulously wiping clean the specimen and tongs between each operation. He caught my glance of amused admiration, and as he passed by me whispered enthusiastically, " I say, Anderson, this *is* fun ! "

Yes, gemmology *was* fun to Sir James, and continued fun, to the end. *Serious* fun, of course. He was the eternal student, and took the keenest delight in all the impedimenta connected with his hobby. His notebooks were a pleasure to behold: page after page packed with his characterful and very legible hand, and illustrated by careful diagrams and drawings.

In the post-diploma class at Chelsea, Sir James was for many years the most distinguished member of a memorable " front bench " of enthusiasts. On these occasions his attaché case revealed itself as a portable laboratory from which issued microscope, polariscope, heavy liquids (the latter mounted cunningly on gimbals, so as to remain upright when the case was being carried) . . . and an old Herbert Smith refractometer, to which he was greatly attached.

From time to time he could be persuaded to give lectures himself to the class on subjects on which he had read and thought extensively, such as the structure of the atom, jade and the jade-like minerals, or the internal structures of quartz. He was a delightful and polished lecturer. Invariably he had been at great pains to prepare his verbal and illustrative material to the last detail. The exposition was clear and orderly, yet there was no rigid adherence to notes to mar the interest.

His book, " Physical Gemmology," which was derived from his own carefully compiled notebooks, was, for all its minor faults, original in conception and a distinctive addition to our literature, which, one must admit, tends to become rather hidebound.

Sir James's ingenious mind and craftsman's hands resulted in the production of many gadgets, models, and intruments, some of which are now being manufactured by Rayner on a commercial scale.

He served the Gemmological Association well in many capacities—as councillor, curator, Vice-Chairman, and (all too briefly) as Chairman. All who knew him held him in high affection and esteem. His simple, natural friendliness, complete lack of snobbery or " side," his courtesy and kindness, his generosity and humour, all combined to make a most lovable personality. He will indeed be profoundly missed by all of those who were fortunate enough to have been his friends.

COUNCIL MEETING

A meeting of the Council of the Association was held at Saint Dunstan's House, Carey Lane, London, E.C.2, on Tuesday, 23rd August, 1955. Mr. Norman Harper, Vice-Chairman, presided.

The Council heard with deep regret that the Chairman, Sir James Walton, was gravely ill and that he would be unable to attend any further meetings.

The results of the 1955 examinations were presented to the Council, together with the report of the examiners. In general the standard in the examinations was higher than in 1954. (A list of successful candidates is given in these Notices.) The Worshipful Company of Goldsmiths had kindly given permission for the presentation of awards to be held in the Livery Hall on 9th November.

The following were elected to Ordinary Membership:—

Benjamin A. Clay, Halesowen.
John Morgan-Smith, London.
John G. Thomas, Carlton, Australia.
Brian Simpson, Swansea.

TALKS BY MEMBERS

CAFFELL, E. W. : "Gemstones." Westfield and Kingfield Women's Institute, Surrey, 1st September, 1955.

EWING, D. J. : "An introduction to gemmology." Dunfermline Naturalist Society, 10th October, 1955.

MELROSE, R. A. : "Gemstones." Rotary Club, Seaham, 30th August, 1955.

MELROSE, R. A. : "Gemstones." Inner Wheel, Blyth, 6th July, 1955 ; *id.* Rotary Club, South Shields, 14th July, 1955.

WEBSTER, R. : "The use of the microscope in gem testing." Central School of Arts and Crafts, London, 15th June, 1955.

1955 EXAMINATION RESULTS

The 1955 examinations in gemmology, held by the Gemmological Association of Great Britain, were again marked by a large number of entries. One hundred and forty-eight candidates entered for the preliminary examination, of whom one hundred qualified, and fifty-four out of eighty-three candidates qualified in the diploma examination. Last year's Rayner Prizeman, Mr. R. E. Muir of Wilmslow, Cheshire, has been awarded the Tully Medal. The Rayner Prizeman is Mr. M. S. D'Arcy of Peterborough, for the knowledge of the subject shown in his papers.

The following is a list of successful candidates, arranged alphabetically:—

DIPLOMA

Qualified with distinction

F. E. Alexander, Romford.
W. Bialek, Birmingham.
C. Bonanno, Washington, D.C.
S. C. Henderson, Dundee.
R. Klippel, Sherman Oaks, Calif.
R. E. Muir, Wilmslow.
F. H. R. Parkes, Brierley Hill.
A. J. Sibley, West Wickham.
Miss G. E. Todd, London.

Qualified

J. Anfield, Edinburgh.
A. J. R. Bennett, Cheltenham.
F. Brinks, Leiden.
J. S. Cameron, Auckland.
Miss J. R. Chalmers, London.
A. R. Clark, Glasgow.
J. A. Clark, Forfar.
P. Collier, Liverpool.
E. Colman, Leamington Spa.
P. G. Cooper, London.
J. M. Crichton, London.
Miss G. Cross, Birmingham.
B. P. Davies, Gerrards Cross.
J. W. Dubois, Hong Kong.
P. J. Dungate, Loughton.
D. S. M. Field, Toronto.
Mrs. A. H. Greenhill, Belerno.
J. Hart, Glasgow.
A. D. Havenhill, Fresno, Calif.
F. Hessling, Birmingham.
Miss D. M. Janes, Margate.
M. Lipman, Johannesburg.
R. S. B. Lyon, Edinburgh.
I. Macdonald, Glasgow.
A. E. Middlesmiss, London.
N. C. Morrison, Jnr., Ingleswood, Calif.
M. J. O'Hara, Sydney.
D. G., Paterson, Edinburgh.
W. Pyke, Wolverhampton.
Miss E. B. Pyne, South Woodford.
Mrs. W. M. Rankine, Farnham.
B. Roulet, Basle.
A. Schilling, Stuttgart.
E. J. Soukup, San Diego, Calif.
Miss T. R. Spittle, Birmingham.
Mrs. E. Stern, London.
W. H. Summers, Burnham.
L. J. Van Ameringen, Leiden.
H. M. Vaughan, Ross-on-Wye.
J. O. E. Vince, Ipswich.
A. J. Walker, London.
R. A. Wells, New York.
D. K. Williams, Holland, U.S.A.
B. R. Worth, Leicester.
D. Wright, Weston-super-Mare.

PRELIMINARY

Qualified

Agnes C. Allison, Glasgow.
James Allison, Glasgow.
Ian J. Allum, Wellington.
Sture Andersson, Uppsala.
Kenneth A. Banks, Manchester.
Alan J. R. Bennett, Cheltenham.
Dennis C. Bentley, Epsom.
Charles E. Beresford, Birmingham.
Kjell Berggren, Angelholm.
Antonio C. Bonanno, Washington.
William G. Bone, London.
H. G. Bonning, Tonsberg.
James G. Boyd, Cambuslang.
F. Brinks, Leiden.
Cote Carlebjork, Enkoping.
Norman Catherall, Wallasey.
Sylvia D. M. Chiles, Coulsdon.
David R. Clarke, Sutton Coldfield.
Edwin W. Clifford, Cassington.
Walter G. Cook, Liverpool.
Michael S. D'Arcy, Whittlesey.
Kurt Decker, Lidingo.
J. C. Ebbestael, Oslo.
Carl-Eric Eriksson, Harnosand.
J. Felin, Oslo.
William F. Ferguson, Alexandria.
J. Flapper, Arnhem.
Kenneth W. Fortune, London.
M. A. Gam-Dede, New York.
Charles D. Goodwin, Trentham.
Davina E. Gordon, Ruislip.
Anthony C. Hackett, West Ewell.
David E. Haigh, Lincoln.
Peggy I. R. Hall, Edinburgh.
John S. Harris, Glasgow.
Asher D. Havenhill, Fresno, Calif.
August F. E. Herr, London.
John M. M. Hirshman, Plymouth.
Edwin S. Hodgson, Darlington.
Kenneth Hoskyns, Birmingham.
George F. Humphreys, London.
Roy E. H. Jeffreys, London.

Archibald V. King, Edinburgh.
Peter N. Kingwill, London.
Ronald M. Kirk, Rutherglen.
Robert Klippel, Sherman Oaks, Calif.
Geoffrey W. Laney, Walton-on-Thames.
A. L. Larsen, Drammen.
Angus D. Lauder, Edinburgh.
Hugh Leiper, Austin, U.S.A.
Emily C. Lewis, London.
William Longbottom, Hull.
Hector M. MacLeod, Glasgow.
Patrick R. Mallory, Bath.
John A. Maxwell, London.
C. S. Mendis, Colombo.
Frank Molyneaux, London.
John Morgan-Smith, London.
William A. Muir, Wilmslow.
John Mulvey, Glasgow.
Bernard Muscat, Johannesburg.
Barbara J. Nilson, Birkenhead.
M. J. O'Hara, Sydney.
Anthony T. Ould, Plymouth.
Edna P. Padbury, Birmingham.
Norman H. E. Parker, London.
E. C. Parrott, Washington.
Sarah A. Peplow, Stourbridge.
Alan W. Peters, Birmingham.
Brian L. Peters, Camberley.
Walter Petersson, Linkoping.
Frants Pettersen, Oslo.
Elsie Pitcher, Birmingham.
Frederick D. W. Pollard, London.
Kenneth Ratcliffe, Buxton.
Adi Redman, Johannesburg.
Bernard Roulet, Sweden.
Harry P. Samuel, Birmingham.
J. J. Schoo, Arnhem.
Achim Schilling, Stuttgart.
Brian L. Selwood, Bushey.
Walter Semple, Baillieston.
Julian S. Sherrard, London.
Brian Simpson, Swansea.
Cora A. Smith, Grays.
C. W. Smith, Baltimore.
Lawson B. Smith, Birmingham.
Alan W. Y. Stewart, Hampton-in-Arden.
George W. Stewart, Glasgow.
Graham C. W. Street, Sutton.
Antony K. Swann, Sutton Coldfield.
Elizabeth Tapper, Birmingham.
Brian G. Toms, Plymouth.
Leslie H. Tye, Bromley.
John T. Tyerman, Harrogate.
Milos Vainer, London.
Yngue Wahlberg, Gavle.
Arthur G. Wardell, Edinburgh.
Gunnar Werner, Goteborg.
Donald K. Williams, Holland, U.S.A.

BRITISH MUSEUM (NATURAL HISTORY) LECTURES

LECTURES IN THE MINERAL GALLERY, BRITISH MUSEUM (NATURAL HISTORY) ON SATURDAYS AT 3 P.M.

Oct.	22nd	Lead and its minerals	Dr. M. H. Hey
	29th	Chalcedony	Dr. A. A. Moss
Nov.	5th	How to find minerals in Britain	Miss J. M. Sweet
	12th	Submarine volcanoes—methods of detection	Dr. J. D. H. Wiseman
	19th	Uranium minerals	Dr. G. F. Claringbull
	26th	Rocks from the Antarctic	Mr. S. E. Ellis
Dec.	3rd	Geological thermometers	Dr. G. H. Francis
	10th	Silicate minerals	Dr. A. A. Moss
	17th	The great Siberian meteorite	Dr. M. H. Hey

(*This programme is subject to alteration without notice*)

CURATOR

The Council of the Association has appointed Mr. G. M. Sprague, F.G.A., to be Curator of the Association gem collection in place of the late Sir James Walton.

DIAMOND CORPORATION GIFT TO THE GEMOLOGICAL INSTITUTE OF AMERICA

The Gemological Institute of America is proud to announce that the Diamond Corporation has just presented to the Institute the Oppenheimer Student Collection of over 1,500 carats of rough diamonds. This generous gift was authorized for educational purposes by Sir Ernest Oppenheimer, Chairman of the Board of the Diamond Corporation, Ltd., of London and the Union of South Africa. The Collection has an importance to jewelers throughout the industry for it will be used for the expansion of the Institute's diamond grading and evaluation training.

Included in the Collection is a wide range of shapes, sizes and qualities, representing colors from collection to eighth (color grades employed by the Diamond Trading Company), clarity grades from glassies to fifth spotted, and crystal shapes from symmetrical octahedra to distorted macles. Individual crystals range in weight from over 23 carats to stones several to the carat. Among the stones included are macles of 23·06, 22·23, 19·48 and 15·68 carats and octahedra of 15·99, 13·14, 10·50 and 10·43 carats, as well as several others from 6 to 9 carats each. There are several hundred carats of bort crystals.

The Collection was first loaned to the Institute a number of years ago for demonstration purposes. By giving the Collection to the G.I.A., the Diamond Corporation has made it possible to have some of the stones cut to increase the number of diamonds available for class appraisal work. This will provide over two hundred additional stones in sizes from about ·20 to 2·50 carats. This cutting will be done according to specifications drawn up to duplicate the general range of cutting proportions and qualities now represented in the stones offered to the retailer by all types of diamond sources. In other words, various makes from ideal to spread, to those with symmetry faults, poor angles, and various other proportion and finish irregularities, will be represented so that Diamond Evaluation and regular Resident Class students will appraise a complete cross section of what is available in the market.

According to Richard T. Liddicoat, Jr., Director of the Institute, "This forward-looking and generous act by the Diamond Corporation will make it possible for the Institute to increase the number of its popular Diamond Evaluation Classes and to make them available in more cities throughout the country. We can only regard this gift of the Oppenheimer Student Collection as an endorsement of the effectiveness of the G.I.A. diamond training program."

LETTER TO THE EDITOR

DEAR SIR,

I read with great interest Mr. J. R. H. Chisholm's notes in *Journal of Gemmology* 1955, Vol. V (2) pp. 77-79 (Apr.) with regard to the determination of specific gravity using heavy liquids. He reported on some tests with antimony tribromide which were originally suggested by J. Swimmer in *Ind. Diamond Rev.*, 1953, Vol. XIII, p. 255. Antimony tribromide which melts at 96·6 deg. C. and gives a liquid of about 3·6 was suggested for separating alumina from diamond. Ultimately its use for determining the specific gravity of a topaz crystal did not prove successful. Mr. J. Swimmer of National Biochemical Co., to whom Mr. Chisholm's notes were submitted, commented on this :

" As far as I can see everything Mr. Chisholm says about the use of antimony tribromide is true and it really is not suitable for use by the gemmologist. Also, as stated in my original article, it is not especially suitable for work with diamond powders but it will work where Clerici solution fails, owing to the fact that Clerici aqueous solution does not wet fine diamond and its common contaminants properly for separation work. Antimony tribromide's low price is another key factor in its use for routine work. Also the tendency to solidify is an advantage for powder separation because after the separation has been made hot and the mass allowed to solidify the sink and float can be separated by cutting the solid bar in two for removal of the respective fractions. Benzene (benzol) can be used to remove the last traces of antimony tribromide after most of it has been removed by heat. Most of these pros and cons on antimony tribromide are academic because it is of limited usefulness at best and we do not use it.

We recommend our MI-GEE methylene iodide being from $\frac{1}{2}$ to $\frac{1}{4}$ as toxic as carbon tetrachloride.

We also have a heavy liquid which is tailored for work with diamond powders being of 3·6 gravity at room temperatures of 70 deg. F. It is a solution of chemicals in methylene iodide of our own manufacture and the subject of patent applications. It is very useful for diamond powder work and may not be too good for gemmology but has more merit there than antimony tribromide. Its improved wetting power of minerals over aqueous solutions leads us to believe that it will have definite fields of usefulness."

I hope that this detailed explanation will clarify the position.

London. P. GRODZINSKI.

JOURNAL OF GEMMOLOGY

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Vol. 1, Nos. 1, 2, 3, 4, 5 and 6.

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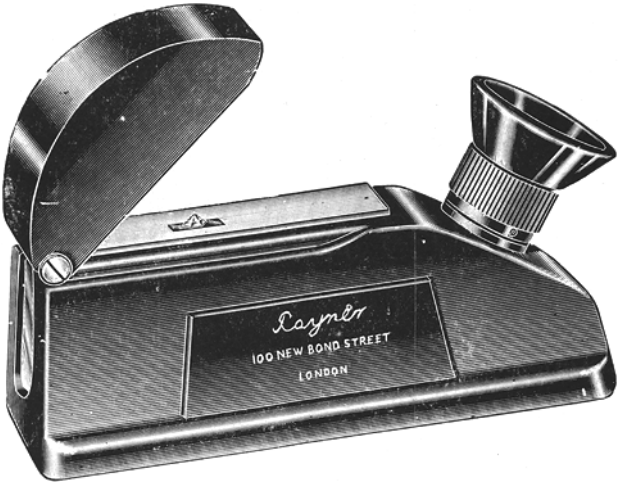

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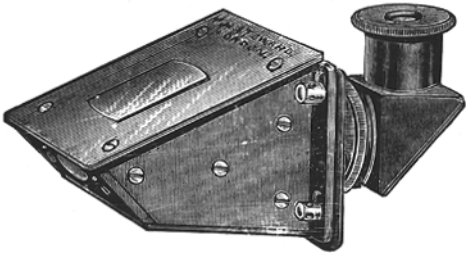

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THE JOURNAL OF GEMMOLOGY
AND PROCEEDINGS OF THE GEMMOLOGICAL ASSOCIATION OF GREAT BRITAIN

Vol. V No. 5 JANUARY 1956

DETAILS OF HARDNESS

by W. F. EPPLER

GENERALLY speaking, the hardness of gem-stones is defined by Mohs's scale of hardness, which was established in 1822. Testing, according to this scale, is made by scratching one stone with another. By this means the resistance, which a stone in question shows against the penetration of a corner or a point of another stone is ascertained and this scratching procedure is, in practice, sufficiently exact to determine the hardness of stones. The resistance against scratching, i.e. the scratching-hardness, is similar to the grinding-hardness, for grinding can be regarded as a kind of repeated scratching. Therefore, it is easy to understand that testing by grinding gives similar results for hardness as when using Mohs's scale. This was known as long ago as 1896, when Rosiwal published his results on grinding-hardness. His method was afterwards improved by other workers, and particularly the work of Tertsch on calcite may be mentioned. An example of the usefulness of this method is seen in Fig. 1 (the values of the grinding-hardness on the cleavage plane of calcite). It exhibits the well known fact that along the shorter diagonal of this plane the hardness is greater from north to south than in the inverse direction from south to north. The most recent investigations on grinding-hardness are those of Grodzinski and collaborators, about two

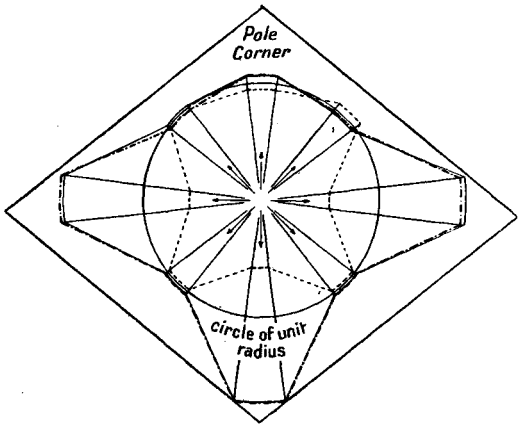

Hardness differences in the cleavage plan of calcite.

------ 'reduced weight loss' for area of 1 sq.cm.

——— 'relative hardness'

-·-·-·- 'relative hardness', ideal mean value based on symmetry.

Fig. 1

years ago. He used small rotating discs, charged with diamond, with which were produced grooves on the polished surface of the specimen. The length of the grooves gives the measure for the hardness. With this method the dependence of the grinding-hardness upon the crystallographic direction can be proved, particularly with diamond.

Now, if we look a little closer at the scratching method we find that by using a sclerometer (Fig. 2) this kind of hardness testing can be done accurately. This instrument was designed by Martens (1912). A diamond point with an angle of 90° is charged with a weight, so that the point rests with a certain pressure on the specimen. Then the stone is drawn beneath the point, and the resulting scratch or groove is measured with a microscope. The definition for the hardness is the weight which produces a groove with a width of 10 microns.

Later, this instrument was improved by Zeiss with an instrument called "Diritest." It is very useful, as it is practically a microscope, the objective of which can be exchanged for a diamond point.

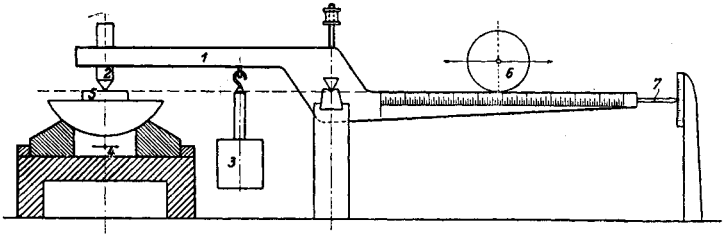

Fig. 2

If we examine a scratch, or a groove made by scratching, we learn that this groove is not only set in appearance by simply removing a certain part of the surface of the stone, but also by another phenomenon, plasticity. This is shown by Fig. 3, which

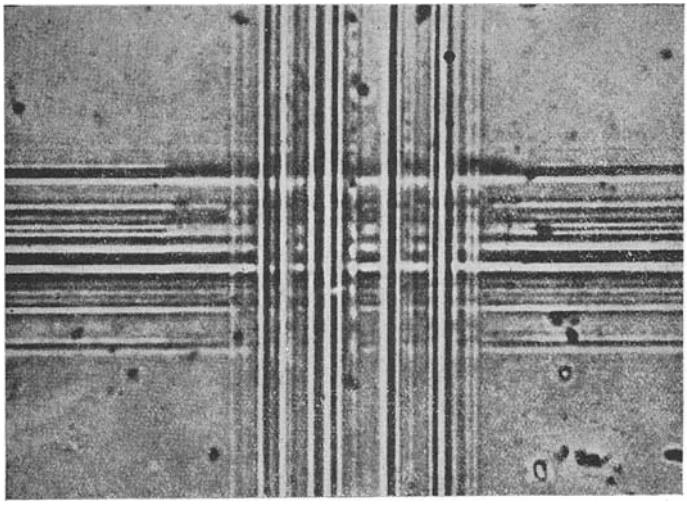

Fig. 3

depicts the surface of a piece of glass with intersecting scratches. This experiment was carried out by Smekal, some twenty-five years ago. He first scratched some parallel lines in the glass, which in the illustration are those running from west to east. Then he produced another series of scratches, running from north to south. It can be observed that the second series of scratches closes parts of the first series, where they intersect.

This seems only to be possible when the pressure, which is necessary to produce a scratch, causes parts of the surface-layers of the glass to be liquefied, or, as the *terminus technicus* says, to be plastified. As glass belongs, without any doubt, to the brittle bodies—just like the gemstones—we have to consider that gemstones also have this property.

These facts indicate that plasticity will influence that particular property of gemstones which we are accustomed to call hardness. The extent of this influence is not exactly known in every case. And as there are additional factors, which must be held in mind, the problem of hardness seems to be somewhat complicated—and it is very complicated indeed.

In Fig. 4 an attempt is shown to bring the basic factors of plasticity, elasticity, brittleness, and toughness in connection with the hardness, which, by the way, is sometimes also called strength. It is not possible fully to agree with such a simplifying construction. Softness can be stated as a very low hardness ; and plasticity only makes its appearance when the elasticity is exceeded by a mechanically produced stress or strain.

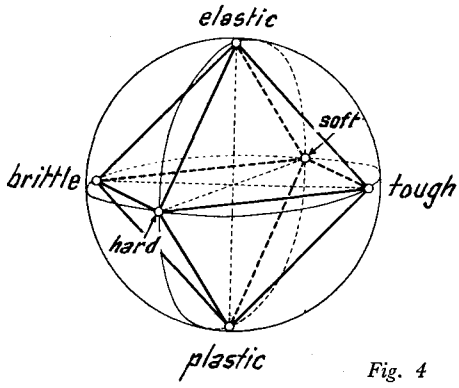

Fig. 4

To sum up : hardness is, in practice, a very useful property and the components which build up this property are related to each other and influence each other in a very complicated manner. A correct definition of hardness is, however, most difficult to devise.

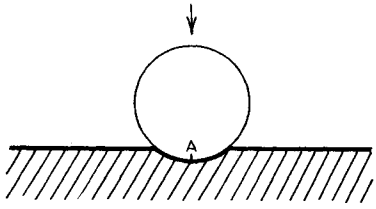

Hardness according to Hertz

H_h = normal pressure on A at limit of elastic deformation (kg/sqmm)

Fig. 5

Methods for testing hardness. Discussion here is confined to so-called brittle bodies, to which belong gemstones. The testing methods have to be divided into two categories—those which are called static, and those which are called dynamical methods.

Hertz (1882), an ingenious worker, proposed that if a ball be pressed on the flat surface of a brittle material, then a pressure will be reached under which the elasticity of the material is just exceeded and a first crack appears. This pressure in kg/sq.mm. shall be equal to the hardness of the material under test. To-day, we know that this definition describes the elasticity only.

Next must be mentioned indentation methods. The principle of these is that if a mechanically produced pressure forces an indenter to work on the flat surface of a specimen, then the surface receives at first an indentation, which corresponds with the elasticity of the specimen. By removing the indenter the surface recovers and the indentation disappears. But, if the pressure is increased to such an extent that the limit of elasticity is exceeded, then the plastic properties of the material will become apparent. This means that the material will flow and show a lasting deformation in the shape of the indenter. How great this plastic deformation or indentation will be depends on the form of the indenter, on the applied pressure, and on the material under test (Fig. 5). While the hardness, according to Hertz, gives an idea on the elastic property, all indentation methods give as a result figures for the resistance against the plastic deformation of a material in question.

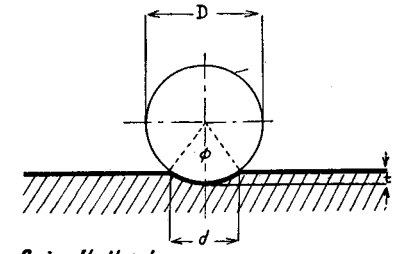

Fig. 6

Brinell Hardness

$$H_B = \frac{P}{O}\ kg/mm^2$$

$$H_B = \frac{}{\frac{\pi}{2} D \left(D - \sqrt{D^2 - d^2}\right)}$$

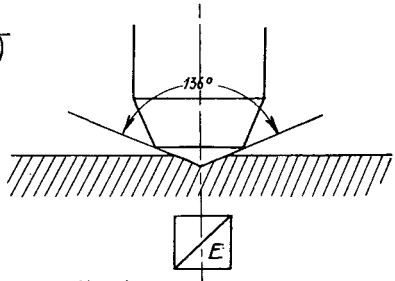

Fig. 7

Vickers Hardness

$$H_V = \frac{P}{O}$$

$$H_V = \frac{P\ 1.8544}{E^2}\ kg/mm^2$$

Fig. 6 shows the principle of the well-known Brinell-hardness method, which was developed in 1900. This also uses a ball, but the pressure used is so great that a permanent indentation is produced. This pressure, measured in kg. over the surface of the spherical indentation, gives the Brinell-hardness in Kg/sq. mm. The values differ with the diameter of the ball. In spite of that, this method is widely used in testing the hardness of metals and alloys. For gem-stones it is not so useful, as their brittle material is so easily destroyed at its surface. The same applies to the cone-indenter of Ludwik. Here a cone is used with an opening angle of 90°. Better known is the so-called Rockwell-hardness, which also uses a cone, but with this method, the depth of indentation is measured, after a primary pressure is increased by a certain amount.

What is recognized as the best method for the hardness testing of gemstones by the indentation process is measurement by the Vickers-hardness (1922), Fig. 7. Here the indenter is a diamond

pyramid, the opposite planes of which include an angle of 136°. The indentation has the form of a similar, but negative pyramid, which can easily be measured. The hardness is found by $\frac{P}{O}$, where " P " means the applied pressure in kilograms and " O " the surface of the indentation in sq. mm. As the surface can easily be calculated, when the diagonal " E " of the square base of the indentation is known, we find for Vickers-hardness $\frac{P \times 1{\cdot}8544}{E^2}$ with the dimensions of kg per sq. mm.

Many instruments are used for the measurement of Vickers-hardness. One type is very useful as it enables the Brinell, Rockwell, and Vickers-hardness as well to be ascertained. The specimen is placed on the table which then is screwed upwards, until it rests against the lower end of a holder, which looks like an inverted cap. Then the inner mechanism is set in action by one of the two handles at the right of the instrument. By this the diamond pyramid is lowered from above and produces an indentation with a previously chosen pressure. Then with the other handle, the diamond pyramid is withdrawn and exchanged for an objective of an opaque illuminator type. By this means an enlarged picture of the indentation is projected on the round screen, where it can be measured with a special rule.

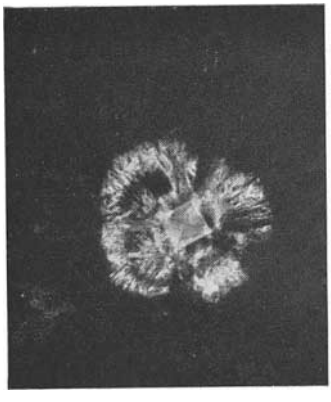

Fig. 8

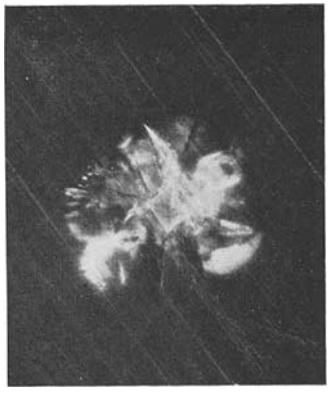

Fig. 9

Fig. 8 shows the indentation with a pressure of 2 kg. on synthetic-spinel, which was improved in hardness by heat-treatment. Besides the indentation itself there are cracks or fissures (which originated from the formation of the negative pyramid). Fig. 9 gives the indentation of a synthetic, colourless corundum, again with shear-cracks around the negative pyramid. In contra-distinction to this are the indentations which were produced on agate (Fig. 10). Here the edges of the base square are curved towards the centre. This fact indicates that the agate has not only a great toughness, but also a considerable elasticity. Incidentally, the reason for the toughness and great elasticity of agate is to be found in its structure. A thin section of this material (Fig. 11) exhibits the fibrous structure of its components. These fibres consist of elongated quartz crystals, similar to the form of a cigar. They are oriented perpendicularly to the layers of the agate. The spaces between the " cigars " are filled with opal, the non-crystallized form of silica. This arrangement produces the particular properties of agate.

It has been mentioned that with the measurement of the Vickers-hardness shear-cracks could be observed. In Fig. 12 these particular cracks are seen as a drawing. If a square is drawn which includes the possible area of those cracks, by using the formula given in the illustration, an expression for the shear-strength can be found. This newly developed measurement of the shear-

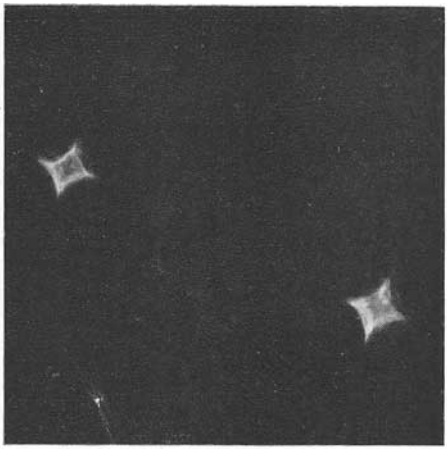

Fig. 10
Indentations produced on agate.

strength has been found to be very useful in finding, for example, the best colour for jewel bearings of synthetic corundum. A similar indentation method to the Vickers is that of Knoop (1939). Here, the indenter has the form of an elongated pyramid. Consequently, it produces an indentation of a lozenge- or rhomb- shape in which the length is seven times the width and thirty times the depth. The latest development is the so-called " double-cone-

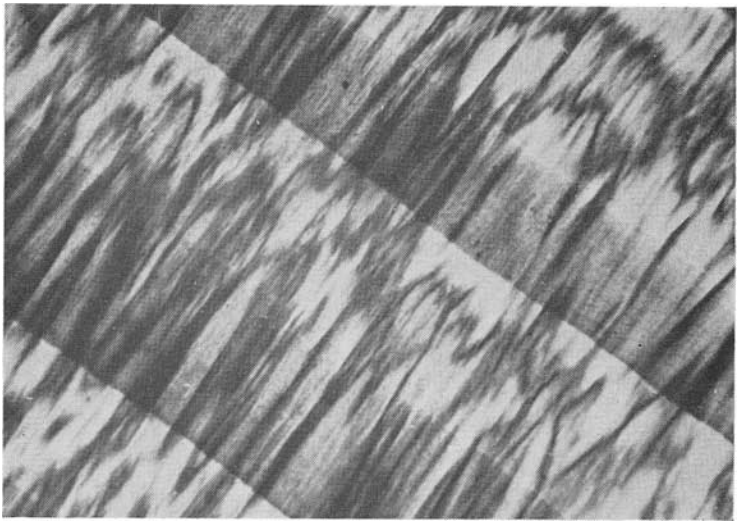

Fig. 11

indenter," which was introduced by Grodzinski. In 1941, the Zeiss-factory in Jena developed a new kind of Vickers-indenter, which allowed determination of the hardness of very small specimens. This instrument was called a " Micro-Hardness Tester." It consists of an objective, which bears in the middle of its front lens a small diamond pyramid or a small Vickers indenter. This instrument allows the application of loads up to 100 gram. which can easily be realized by using this objective in a special microscope. The loads or the applied pressure can be controlled and observed during the pressure by the means of a scale within the objective, and this scale is visible in the eye-piece of the microscope. This instrument is of great value in testing ores or alloys.

These indentation methods are statical. Of the dynamical methods we have already considered two—scratching and grinding. Besides these there exist numerous other dynamical methods, which are mostly and properly developed for the testing of metals. But, two of them are interesting enough to be mentioned—pendulum hardness and the impact abrasion hardness methods.

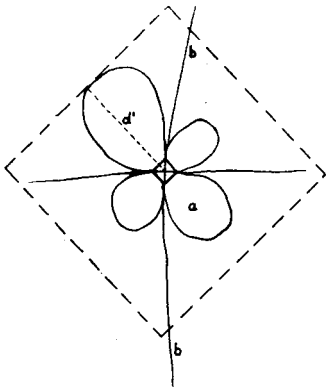

Fig. 12
Vickers-hardness shear-cracks, shown as on drawing

$$Hv = \frac{P}{l} = \frac{P \cdot 1{,}8544}{d^2} \quad kg/mm^2$$

$$Sv = \frac{P}{O'} = \frac{P}{4d'^2} \quad kg/mm^2$$

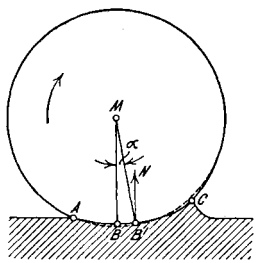

Fig. 13

The pendulum hardness method was first applied by Herbert in 1923. He used a pendulum which is so constructed that its centre of gravity lies just a little below the moving support, so that it can swing easily. The support itself consists of a steel ball of about one millimetre in diameter. This is placed on the specimen to be tested and the pendulum set in oscillation. The oscillations are reduced by the friction of the ball support, and this reduction gives a measurement for the hardness of the specimen. Fig. 13 demonstrates the indentation in the surface of a metal and indicates how the oscillations are reduced. At present this method is not used on brittle materials, such as gemstones. It might be worth while, as it seems that many interesting results could be obtained with this somewhat unusual method.

The second dynamical method is the impact abrasion hardness. It was first applied by Ridgway and collaborators in 1933. This is based on the technique of sand-blasting. Compressed air is forced into an injector, by which the sand is transported upwards in a combined nozzle under which rests the specimen under test. This is sand-blasted for a certain time and afterwards its loss of weight is determined. The surplus sand falls down in a funnel, from which it is used again. The whole is placed in a housing of sheet-iron which carries a window and an exhaust, to remove dust. This device is very simple indeed, if one knows all the tricks which make the difference between success and failure. This method was used to find out whether or not it was possible to harden agate, as this stone is widely used as bearings in instruments and particularly in balances. It was imagined that such a hardening could be done, if transformation of the component of the agate, which consists of opal, into crystallized quartz, could be achieved. This could be possible by a heat treatment within a reasonable range of temperature. It failed ; not because the method of sand-blasting was not good enough, but because the impact abrasion hardness of agate is more than three times higher than that of the crystallized quartz. This was not known in advance, but was ascertained later, as is shown in Fig. 14. At a little over 200°C the impact abrasion hardness drops until it reaches a constant low value, which is identical with the hardness of quartz. Here, for the first time the elastic properties of a material were found to have a considerable influence on the hardness and particularly on the values of the impact abrasion hardness.

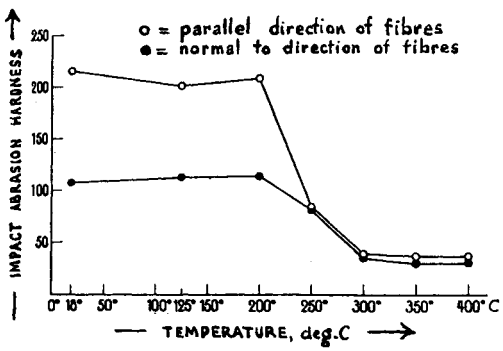

Fig. 14

Next this very sensitive method was used to test the hardness of synthetic corundum, that is in the directions parallel and perpendicular to the c-axis and after heat-treatment as well. Even a heat-treatment of 24 hours at 1,200°C has no measurable influence on the hardness of this material.

Hardness according to Mohs	Relative grinding hardness according to Rosiwal (Quartz = 100)	Relative impact abrasion hardness (Quartz = 100)
1	0·03	6·2
2	1·04	6·2
3	3·75	10·1
4	4·17	9·9
5	5·42	5·0
6	31	46
7	100	100
8	146	81
9	833	594
10	117,000	109,000

Fig. 15

It is very interesting to compare the impact abrasion hardness with other methods of hardness testing. Fig. 15 shows the relation with grinding-hardness, all numbers correlated on quartz equal to 100. Both kinds of hardness follow Mohs's scale, but with a much more increasing rate. Of particular interest is the fact that impact abrasion hardness number 8, measured on topaz, appears to be distinctly lower than number 7, measured on quartz. Here again the influence of elastic properties may be responsible for such extraordinary findings.

To emphasize that such seldom used practices as impact abrasion hardness can be very useful, Fig. 16 shows the result of an investigation on the hardening of synthetic spinel. Synthetic spinel can only be produced commercially if it contains an excess of alumina in the form of gamma-corundum. It was shown by Rinne, as early as 1928, that, by heat-treatment the additional alumina can be precipitated within the spinel. He also demonstrated that the precipitation of micro-crystalline alpha-corundum produces an asterism, which, by the way, is too poor to be of any value. It was considered that by such a precipitation the hardness of the synthetic spinel itself could be increased. During our investigations it was noted that the sand-blasting method, which provides the impact

abrasion hardness, is able to disclose very small differences in hardness. There is a large increase in the impact abrasion hardness by heat-treatment, also for the normally produced synthetic spinel with a ratio of 1 magnesium oxide to 3·5 aluminum oxide. It was further ascertained that the addition of more alumina could not increase the hardness to an appreciable extent.

Fig. 17 exhibits the very fine differentiations in the effect of sand-blasting. It was wondered what would happen if blasting was extended over several hours instead of minutes. The picture shows the surface of a synthetic corundum which formerly was flat and even. After extremely long sand-blasting grooves were found which seemed to be the softer parts of the stone. But, besides this, harder parts which indicated a greater resistance against the sand-blasting and which formed ridges were noticed. These chains of ridges are nearly parallel to each other. And it is thought that they follow in orientation the edge of the trigonal rhombohedron, which is the ruling crystal-form of synthetic corundum. Before the ridges is a plane, geographically speaking, with some small elevations. The altitude of the elevations over this area was found to be 150 microns. The indentation hardness of the ridges and hollows was measured and the hardness of the plane area and the bottom

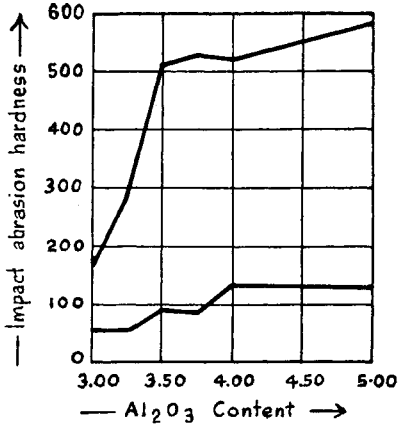

upper line : after heat treatment.
lower line : before heat treatment.

Fig. 16

Results of an investigation on the hardening of a synthetic spinel

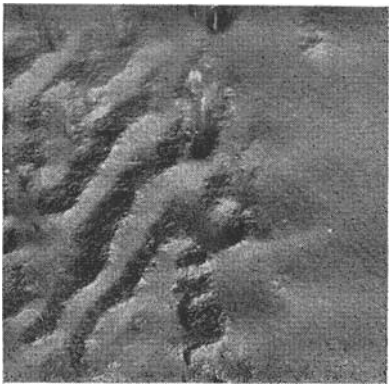

Fig. 17

Five differentiations in the effect of sand-blasting surface of a synthetic corundum.

of the " valleys " were found to be identical. The top of the ridges, however, had a Vickers-hardness which was 220 kg/sq. mm. higher. This shows astonishingly great differences in the hardness of synthetic corundum in a single crystal.

This experiment was possible because the impact abrasion method is very sensitive, and a further contribution to the fact that the ideal crystal only exists in the imagination was gained and that the so-called " real " or " realistic " crystal with its deformed or disturbed lattice-structure, is that which is both offered by nature and likewise found in artificially-made crystals.

BIRMINGHAM GEMMOLOGICAL EXHIBITION

THE gemmological exhibition organized by the City of Birmingham Museum and Art Gallery and the Midlands Branch of the Association was opened by the Lord Mayor of Birmingham (Alderman A. Lummis Gibson) on Wednesday, 12th October. Mr. Trevor P. Solomon, Chairman of the Midlands Branch, who thanked the Lord Mayor, was supported by Sir Cyril Dyson, Chairman of the National Association of Goldsmiths. Great credit is due to the organizers, particularly Mr. Solomon, Mr. D. N. King, the Branch Secretary, and Mr. N. A. Harper, Vice-Chairman of the Association, for staging such a splendid exhibition. Attendance for the period 12th–30th October was 50,400. Those responsible for the exhibition produced a display gems, both unmounted and in jewellery, which was every bit as fine as the exhibitions staged previously in London and Glasgow.

Many of the exhibits were obtained from private collectors, museums and associations. Her Majesty the Queen lent an opal

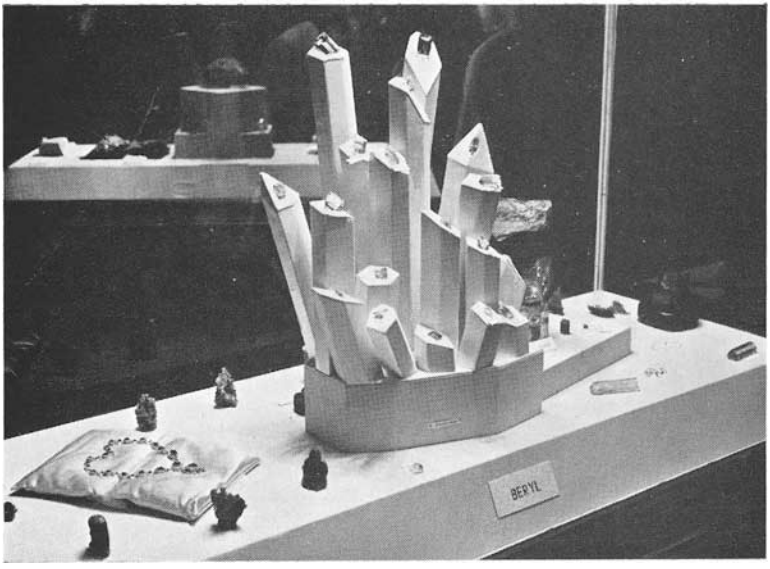

and diamond suite which contained the Andamooka opal, a present to her from the people of South Australia, and the Duke of Devonshire loaned the famous Devonshire emerald, an uncut crystal of 1,383 carats. Many of the show-cases were devoted to single gem species and outstanding of these were those of diamond, beryl (this case contained a huge aquamarine crystal weighing 28,504 carats) and opal, and the case of lesser known gems, such as hiddenite, sphene, euclase, and a specimen of taaffeite.

Mounted specimens were displayed side by side with the cut and uncut gems and an extremely fine emerald necklace was outstanding. A few pieces of Carl Fabergé emphasized the genius of the jeweller, and many carved ornaments of jadeite, nephrite, coral, quartz and amber were a delight.

On the whole it was the unmounted stones, which were in a majority, that impressed most visitors and the way in which they were presented was most rewarding to those that had painstakingly gathered the many gems together during the past twelve months. The diamond exhibit alone was valued at more than £100,000, and there were some excellent stones, including one valued at £16,500.

The greater part of the exhibition was arranged in show-cases grouped round Sir Jacob Epstein's statue of Lucifer, while cases containing miniature models of diamond-cutting apparatus and gem-testing instruments were in an adjacent room. A special feature was periodic demonstrations of gem-cutting, given by Neville Deane, F.G.A.

The organizers had catered for every interest—lovely gems to delight and interest the non-technical to fluorescent gems and cyclotron-bombarded diamonds for the initiated.

To assist those who were interested and to form a permanent guide to gemmology a fifty page booklet—*An introduction to gemstones* —was issued with a front cover of gems in colour. (See p. 270.)

Once again members of the Association, by much hard work, had been able to demonstrate the loveliness of gemstones, and it will be a long time before another exhibition is staged that will be as successful as that arranged by the Midlands Branch.

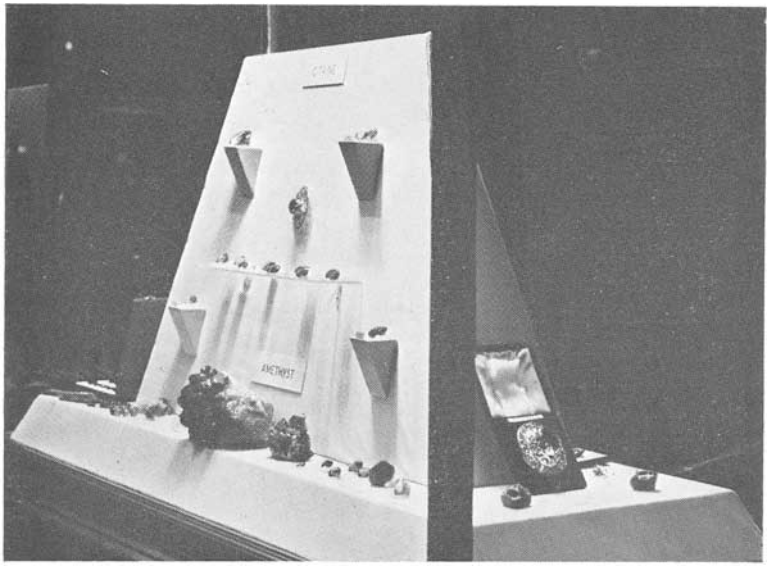

Gemmological Abstracts

SWITZER (G.). *Diamond Industry 1954.* Jeweler's Circular—Keystone, 15 pp., 1 map.

Total diamond production in 1954, at 20,440,000 carats, was once again a world record. 16,840,000 carats were of industrial grade and 3,600,000 of gem quality. The U.S.A. consumes about three-fourths of world production. This annual report (the thirtieth) contains the usual information about cutting, mining, technology, and there is reference to synthetic diamond.

S.P.

BROSE (H. W.). *Civilizations and Gems of America* (Part One). Lapidary Journal, Vol. IX, No. 4, p. 354, October, 1955.

One can forgive the author if there is little information on gems. In the search for gems it is easy to get lost—among people. Perhaps it is that gem research provides a more human approach, compared with the strict historian or pre-historian.

That the question of " civilization . . . is open to argument " regarding the races of America before the white man appeared, is surely wrong. So much has been uncovered in recent years that it might be difficult for the white man, fully conversant with facts, to feel superior. While scientists are unrolling the carpet one way, archaeologists are unrolling it the other, with comparable speed.

The author writes of two schools of thought on the origin of early American peoples. He might have added a third, for it claims a substantial proportion. This is the theory of *two distinct migrations.* Of these invaders, one group came from Asia, via the Bering Strait, still obvious by the Mongolian features of the Eskimoes and northern Indians, and one from the north and east coasts of South and Central America respectively. This race is believed to have involved the Atlanteans, as the author suggests. According to Plato the final sinking of this continent took place between 9,000–10,000 B.C. But there were earlier catastrophies. It is suggested that parts were submerged long before, sending its

colonizers all over the known world with tales of a terrible flood that lives on in the Bible story, and in many an unwritten literature of races unacquainted with the Old Testament.

Some experts attribute the Crô-Magnon or Aurignacian race of Europe—described by Sir Arthur Keith as one of the finest types, mentally and physically, the world has ever known—to this very race. They appeared in Europe at the end of the last Ice Age, about 25,000 years ago. Other off-shoots or developments of this sunken continent are supposed to have lived on in races that to-day we know quite a lot about. The outstanding civilization, in this respect, is Egypt. As the author says of the American races, they did not develop their culture *after* arrival. The Egyptologist, Walter Bryan Emery, gives an example of a ready-made civilization. Mesopotamia, he says, started from simple things, with its lowest levels of crude implements used by near-savages and its upper strata gradually improving. When the " Egyptians " took over the Nile, they found the established culture neolithic, of a fairly high grade, but not a civilized grade. They came with a written language and papyrus to write on.

The author gives the first cities of the Incas as 500 to 600 B.C. Obviously these were no early Americans. The Incas merely took over what was already there, mostly stone colossi.

Brose comments upon the poorly polished gems in this period, that is, around 500 B.C. and later, and suggests that polishing was a lost art. Among non-metal people the art of polishing was very high indeed. The beautiful jade cylinder from Guiana in the British Museum is an example of the lapidary's art in this part of the world. And fine jade polishing has lived on, not only among the cultured Chinese but in the neolithic Maori.

E.R.

HASTIE (R.). *My Trip to Jade Mountain in Alaska.* Lapidary Journal, Vol. IX, No. 4, p. 296, October, 1955.

Perhaps no one could have been more helpful to the author on this subject than the man he sought—James Kraft. Mr. Kraft, like many another anxious to locate the Jade Mountain of early maps, some years ago went to the length of backing an old native of those parts whose story he believed. Fortunately, Mr. Hastie was able to make the greater part of the journey by air. With a confederate and his two-seater plane, the rest was all but easy. Even before

they arrived at the base of Jade Mountain the author discovered boulders of jade released from the earth in the process of gold-mining. Although some of this jade was of inferior quality, other boulders were good, ranging in colour from dark green, mottled with black spots, to a light grey. Further away they came upon an old prospector who had spent thirty years mining gold and had built himself a jade-cutting machine, using water power and a cutting wheel of 24 inches. Later, the explorer located Jade Mountain from the air, with its " large amount of green serpentine " covering it. Eskimoes had said that, on a sunny day, the reflection from this deposit made it easy to identify. Landing so as to minimize walking, the two men covered " approximately seven miles, across the tundra and up Jade Mountain." On the way, after crossing Jade Creek, they came upon the finest jade of their trip, some of it of gem quality, with variegated greens and free from the black spots of the earlier finds. Other explorers too had been impressed, for here were cabins and a diamond-cutting saw, with power provided by a gasoline engine. The equipment must have travelled by barge up the Kobuk river, " and then pulled on a drag across the tundra to its location."

The top of Jade Mountain reads a little like a fairy-tale. Tremendous boulders of jade were lying everywhere " as though a giant had dropped them indiscriminately." Some weighed approximately 20 tons, and more. Most fantastic perhaps was that a complete area had been staked out as a claim. To-day, with all the jade resources of Alaska to draw on, the author sought a boulder that might prove worthy of time, trouble and cost. The selected one, to quote again " had a smooth, rust-coloured rind with green showing at several spots." The problem to-day is not only one of cutting and polishing, with labour at a premium, but transportation.

E.R.

SWITZER (G.). *Star spinel showing four six-rayed stars.* Gems and Gemology. Vol. VIII, No. 6, pp. 163–164 and 190. Summer, 1955.

The description of an unusual phenomenal stone from the Ratnapura district of Ceylon. Identification of the stone was made by the X-ray powder diffraction method. The stone is black in colour and the specific gravity was found to be 3·550. No measure-

ment of refractive index could be given as the stone is cut as a double cabochon ; measures 12 × 14 mm. and weighs 11·80 carats. When viewed from the top it shows a sharp well-centred six-ray star and when viewed from various directions nearly parallel to the girdle, three additional six-ray stars are distinctly visible, being placed around and slightly above the girdle at 120° to one another. Each of the three girdle stars has one ray in common with the main star. The stone is a single crystal and is not twinned. The crystallographic relations—the stars are said to be due to inclusions oriented to the edges of the octahedral faces—are fully discussed. The stone is said to be unique as all known star spinels have four-rayed stars due to inclusions parallel to the edges of the cube faces.
4 illus. R.W.

BENSON (L. B.). *Why make appraisals ?* Gems and Gemology. Vol. VIII, pp. 172–190. Summer, 1955.

A very full discussion on the carrying out of the work of jewellery appraisals and on appraisal policies as they relate to the retail trade in the United States of America. Five reasons are given showing why firms tend to refuse this type of work, and the writer suggests that these reasons need not be valid. The ambiguity of the term value ; the question of the competitor ; misrepresentation, and the attitude of the customer is discussed. The necessary requirements of an appraisal service are given and the basis for the fee to be charged is discussed. It is brought to notice that insurance coverage includes payment for damage as well as for loss, and most appraisal forms do not give enough information for the insurance company to determine the extent of damage. The types of forms used for reporting the appraisal as used by many firms are considered in detail and suggestions for improvement made. An article of use to jewellers and gemmologists.
6 illus. R.W.

WALTON (J.). *The formation of quartz and chalcedony.* Gemmologist. Vol. XXIV, Nos. 288/289/290/291, pp. 119–123 ; 139–142 ; 164–169 ; 191–194. July/Aug./Sept./Oct., 1955.

Silicon, while not occurring in the free state, forms 28% of the earth's lithosphere. Combined with oxygen the silicon may then occur as free quartz, which, while containing no hydrogen,

acts like an acid. Rocks are classified according to the amount of free silica present in them. The outer layers of the lithosphere—Sial and Sima—are referred to, and the rocks and their classification discussed. A large proportion of the free quartz occurs massive and in veins, crystals not occurring until there is space for their free growth. The formation of pegmatites is discussed and the order in which minerals crystallize out in them and in veins is given. Weathering may expose the crystal containing cavities and the crystals subsequently breaking down and finally becoming water-worn pebbles forming the alluvial gravels. A general discussion on the formation of geodes is made. Rose quartz is usually found massive and localities for this material are given. Aventurine quartz is mentioned as a quartzite containing inclusions of fuchsite or hematite. Quartz cat's-eyes and tiger's eyes are mentioned in the closing remarks on crystal quartz. Crypto-crystalline quartz is made up of multiple sub-microscopic crystals. Prase may be rock crystal coloured green by many actinolite fibres. The term chalcedony is used for the whole crypto-crystalline quartz group, and for the uniformly greyish-green translucent variety ; it is suggested that the name chalcedony be reserved for the variety and the group designated as crypto-crystalline quartz. The group is said to be concretionary in origin, to contain small amounts of hydrated silica in the amorphous form opal, and to have been deposited from concentrated hydro-thermal solutions. The formations produced and the varieties are mentioned, the latter being due to impurities and colouring material from the mother rock. Most, including jasper, show in varying degree a banded structure, but the author puts forward a theory that chalcedony and cornelian be not so and deduces this from the effect seen when a polished slice is rotated in transmitted light. It is inferred that these roughly hexagonal areas seen under such conditions are due to growth in concentric layers from widely separated nuclei which eventually meet one another and produce this pseudo-hexagonal mosaic effect. This effect is not seen in chrysoprase or chalcedony which has been stained. The colour of cornelian is ascribed to dark brown grains of hematite surrounded by red circles which are aurioles of greater iron pigmentation to the diffused iron which has coloured the main mass. The banded formation of agate is made up of layers of varying porosity. An elaborate survey is made of the theories of the formation of agate geodes, and included

in this are the so-called " Thunder eggs." Green moss-agate may be derived from included twisted fibres of green asbestos, and prase is suggested as a closely packed form of this type of green moss-agate. Many moss-agates owe their " moss " to granular inclusions, and bloodstones may be a similar closely packed effect with the addition of flakes of, possibly, the mineral chlorite. The series closes with a short note on jasper.

21 illus. R.W.

SHERMAN (E. G.). *Gem of all gems—the opal.* Gemmologist. Vol. XXIV, Nos. 290/291/292, pp. 159–163 ; 183–186 ; 208–211. Sept./Oct./Nov., 1955.

An outline of the opal and its mining in Australia written by a miner and dealer in this gem. The opening paragraph deals with the romanticism of opal. The Hungarian occurrences are mentioned as being found as deposits of little veins in a hard white rock. Australian opal is found in flat desert country with scant vegetation. There is little in the way of geological structure to guide the prospector ; and occasional " floater "—a piece of surface opal—may give an indication, but this may have been washed down for miles away and the indication be therefore spurious. Claims, 150 by 150 feet, are staked and miners need a licence, commonly called a " Miner's right " in order to work the claim. The opal is usually found some 15 to 85 feet below the surface and mining is by shaft, dug until the opal stratum "band" is reached. The sandstone of the district overlies a floor of clay, but between this lies a highly ferruginous and siliceous stratum varying from a film to two inches thick which is known as the " casing." The base of the sandstone for a thickness of two to eighteen inches is somewhat ferruginous and hardened and this is generally called the " band." Opal is found in the clay, the " casing," the " band " and in the main mass of the sandstone. Horizontal tunnels are driven along the " band " from the bottom of the shaft and the earth so removed is brought up in cowhide buckets and spread along the top of the shaft. Illumination is provided by candles or by carbide lamps. There are four types of opal—*boulder* opal, *sandstone* opal, *seam* opal and *black* opal. Boulder opal was first discovered in Central Queensland in 1875. This variety occurs in thin veins ramifying through hard

jaspideous greasy and brown boulders varying in size from a man's fist to a man's body and occurs at varying depth. The cost of carting big boulders is heavy and they are usually broken up by the use of a tomahawk. The seams are thin but the colour brilliant and this opal is said to be harder than some other varieties. *Sandstone boulder* and *Vowah nuts* are sub-varieties of boulder opal, the vowah nuts occurring in a unique formation not far from Vowah Homestead ; they are the size of walnuts or large almonds and are found in a regular band about one foot thick around the floor of the mine. These contain opal either as a central kernel or as a thin jacket running between the outer coating and a deep chocolate-brown ironstone centre. Occasionally little veins of opal traverse the centre but never run to the outer edge. Sandstone opal was found in 1889 in Central Queensland. It is a variety forming " pipes " with a thickness varying from that of a needle to an inch or more running through the free sandstone. Seam opal was discovered in 1890 at White Cliffs in New South Wales. It is found in flat cakes with a thickness from that of a wafer to that of a dog biscuit and comes clean out of the ground without any adhering matrix. In vertical seams it is thicker and extends below the " band " but often the major portion is common opal, called " potch," with noble opal as thin bands in it. Black opal was found in 1903 at Lightning Ridge in New South Wales and is mined to a depth of 120 feet in places. This opal is found in the grey clay below a steel-like band, commonly called " shincracker," owing to the way the pick flys off it, and which lies below the sandstone. The opal is located in small pockets of small " nobbies " as they are called locally, and are said to be pseudomorphs of corals and sponges. The important cut and named opals are discussed and the story told of the unscrupulous people known as " night-ratters " who work another's shaft during the night. The seam opal at Coober Pedy in South Australia was discovered in 1915 in a part still rather inaccessible. The opal is found in slides and verticals and is a rich but small field although two years ago only seven old men were working there. In 1930 opal was found at Andamooka, also in South Australia. The opal here, which is harder than most other types, is found in shallow workings in a small area. This opal does not tend to crack like much which comes from the damp clay. Some black opal is found at Andamooka. An article with much information and illustrative of mining conditions. R.W.

KENNEDY (N.). *The classification and storage of gemstone specimens.* Gemmologist. Vol. XXIV, No. 291, pp. 186/7. October, 1955.

Describes the use of stone papers of different colours as an aid to storing a gem collection ; with particular reference to the control of stones for teaching purposes, different colours of paper being used for stones classified as having particular properties, e.g., dichroism, fluorescence, etc.

R.W.

ANDERSON (B. W.) ; PAYNE (C. J.). *The spectroscope and its applications to gemmology.* Vol. XXIV, Nos. 290/291/292, pp. 171–174 ; 195–197 ; 204–206. Sept./Oct./Nov., 1955.

This series continues with the consideration of the absorption spectra of idocrase, actinolite and serpentine, minerals in which the spectra are due to ferrous iron, and are three materials which simulate the jades. Nephrite is a convenient term for the massive amphibole of the tremolite-actinolite series, " Mutton fat " nephrite being nearly iron free tremolite while the commoner green nephrite is nearer to actinolite in composition. The strongest and most constant band in the absorption spectrum of idocrase is centred in the blue at 4620A and was first noted by Henry Becquerel in 1889. The band is characteristic of the extraordinary ray only. In brown idocrase this band may be masked by the strong general absorption in the blue-violet. In the green types it is broad and clearly seen and, although narrower, is seen in the massive green variety called *californite.* Other bands are seen in idocrase at 5280A (narrow) and a broad band at 4870A, but these are relatively weak. In some Laurentian (Canada) brown idocrase the rare-earth spectrum of didymium consisting of fine lines in the yellow and green may be seen. In actinolite the bands are weak. There is a vague band in the yellow and two faint and narrow bands at 5100A and 4950A, the latter sometimes being seen in " mutton fat " nephrite which also shows another band near 4600A. Most of the serpentines show a typically ferrous iron band at the junction of the green and blue at about 4920 to 4980A and another at 4650A. The bowenite variety has vague bands at 4970A and at 4640A which have little diagnostic value. The williamsite variety has a vague band near

5400A and a narrow band at 4500A. The serpentinous calcite known as Connemara marble shows the 4650A strongly but is usually masked by the general absorption at this region. There is a weak band at 4950A. Pseudophite, the so-called " Styrian jade," is mentioned as having a line at 4980A. A specimen of antigorite, another variety of serpentine, showed lines near 5400A and others in the blue. It is noted that the region near 5000A is a key position for spectra due to ferrous iron. The absorption spectra of gemstones which owe their colour to ferric iron have their maximum at a shorter wavelength, at about 4500A. Sapphire is the most important, and in the green sapphire there are three evenly-spaced absorption bands centred at 4710A, 4600A and 4500A, the last being the strongest and almost merges into the next strongest at 4600A. Australian blue sapphires have a similar spectrum. Burma, Kashmir, Siam and Montana blue sapphires show the 4500 line clearly while in Ceylon sapphires it is extremely weak. The use of a copper sulphate filter allows the line to be more clearly seen. In deep coloured blue sapphires a vague absorption may be seen centred at 5850A. Yellow sapphires show a similar spectrum ; in the case of Australian, Siam and Montana stones the lines are distinct but in Ceylon stones very weak. There are diagnostic bands in the ultra-violet in natural blue, green and yellow sapphires. The synthetic blue, green and yellow sapphires show no bands and this aids distinction. In yellow chrysoberyl there is a strong band centred at 4440A which may be distinguished from the sapphire bands by its single composition. In some deep yellow chrysoberyls there are faint narrow bands at 5050 and 4850A. In brown chrysoberyls the 4440A band is masked by the general absorption of the blue-violet, but in the honey-yellow and greenish-brown catseyes it may be seen and aids distinction from quartz catseyes. The absorption spectrum of aquamarine cannot usually be seen unless the stone is fairly large when a moderately strong line at 4270A and a feeble line at 4560A may be seen, with a line at 5370 which is narrow and clear. This line, and the others, are seen most clearly in the extraordinary ray and a polaroid employed to separate this ray will assist observation of the 5370A line, which can also be observed in colourless and yellow beryls. The beryl from the Maxixe mine in Minas Gerais, Brazil, shows an unusual spectrum consisting of a strong narrow band at 6950A and another at 6940A with weaker bands in the orange and yellow and a weak vague band in the

green at 5500A. Maxixe beryl has a high density (2·80) and refractive indices of 1·584–1·592, but the material is not used for jewellery to any extent for the colour is said to fade. Yellow orthoclase feldspar from Madagascar shows a weak diffuse band at 4480A and a stronger diffuse band at 4200A and in the ultra-violet there is a strong band at 3750A. The pyroxene minerals yellow spodumene and jadeite have precisely similar spectra to each other as far as the lines in blue due to ferric iron are concerned (as mentioned earlier in the series the green jadeite shows lines in the red due to chromium). These ferric iron lines consist of a strong band at 4370A and a weaker " echo " at 4330A, these being the same for yellow spodumene and for jadeite. Kunzite does not show these lines. The 4370A line in jadeite is diagnostic, but may need a fairly open slit to the spectroscope for it to be seen, and the use of a copper sulphate filter to cut out the red, yellow and bright green part of the spectrum will facilitate the observation of this line.

6 illus. R.W.

BOOK REVIEWS

MONNICKENDAM (A.). *The magic of diamonds.* Hammond, Hammond & Co., London, 1955. 192 pp., 28 plates, 16 line drawings. 18s.

Although at first sight this book seems expensive it is a well-written account of personal experiences in many years of diamond trading and cutting. There is comment about famous stones and old aspects of diamond history are embellished by the author's own experiences or observations. Mr. Monnickendam suggests that a stone once shown to him by an Indian Prince was most likely the Orloff, re-cut. Portraits of Boer farmers winning diamonds in the early days and the rivalry between Rhodes and Barnato are vividly depicted. As is to be expected from a master diamond cutter the technical section of this book is excellent and as good as anything that has yet appeared for the general reader. The control of diamond mining and distribution are re-stated and the book ends with a brief reference to the production of synthetic diamond and the prospect that such production is likely to be restricted to industrial needs.

S.P.

TOLANSKY (S.). *Microstructures of diamond surfaces.* N.A.G. Press, London, 1955. 67 pp., 143 plates. 40s.

The author has specialized on the microphotographical structure of the surfaces of diamonds for many years and this book is, to a large extent, an up-to-date record of his work. The text has been restricted to emphasize the numerous pictures. The optical techniques used in the study of diamond surfaces, the nature of trigons and etched surfaces are chapters of considerable interest. Discussing diamond polishing Professor Tolansky suggests that a Beilby layer does not form when diamonds are polished and interferometric observations support this view. Although it is claimed that the book is written for the general reader, the specialist is most likely to read and understand its valuable technical contents.

A.G.

HARPER (NORMAN). *An introduction to gemstones.* City of Birmingham Museum and Art Gallery, 1955. 50 pp. 2s. 6d.

Written with the intention of supplying the need for an inexpensive book suitable for the lay person visiting the gem exhibition held under the auspices of the Midlands branch of the Gemmological Association and the authorities of the City of Birmingham Art Gallery and Museum, " An introduction to gemstones " is a short but surprisingly complete " text-book."

The fifty-page paper-covered book has the cover showing eleven gemstones in full colour printed on a grey background.

The frontispiece is that familiar illustration of the " big hole " of the Kimberley diamond mine. The caption says 3,601 feet deep. This is the depth of the shaft mine and not that of the open working which is illustrated and which is only somewhat over one thousand feet in depth.

The preface tells the reasons for the publication of this book and mentions some of the important exhibits shown in the exhibition, and also something of the valuable collection of gemstones in the Natural History Department of the Museum itself which includes the Ansell collection of sapphires and spinels.

The general survey given at the commencement of the text is a masterpiece of lucid coverage leading up to sections dealing with the physical and optical properties, preceded with a section on elementary crystallography, the crystal systems being well

described with the aid of line drawings. There is a short section on the chemistry of gemstones and a very full one on specific gravity where the direct weighing method of density determination is described with examples, heavy liquid methods also being told. The factors depending upon cohesion are mentioned followed by the section on optical properties, in which the behaviour of light rays in different media is told and this leads up to considerations of the refractometer and its use. Colour phenomena are covered by references to dispersion, pleochroism and absorption spectra. At first sight a section on electrical and luminescent phenomena appeared to be superfluous in such a book until it was recalled that a fluorescence exhibit was incorporated in the gem exhibition.

Glass imitation gemstones are well explained, some notes on their distinctive characters being given and the metallic oxides used to give the various colours to glass are tabled. The artificial formation (synthesis) of gemstones is entertainingly told, and includes notes on the synthesis of diamond which has so recently broken on the world of gemmology. Verneuil's process for the production of synthetic corundum and spinel is clearly explained, synthetic (alexandrite colour) corundum and synthetic star stones being mentioned and also the uses that are now made of such synthetically produced material in industry. The synthetic emerald, and synthetic quartz, are dismissed in just over four lines. Artificial coloration by heating, by staining and by bombardment with particles of atomic size are discussed. A general survey of precious stone cutting is given, the styles of cutting being well illustrated by line drawings. A note is given on the units of weight employed for gemstones and some of the factors in gemstone valuation.

Thumbnail sketches are given of the more prominent gemstones ; these being diamond, corundum, beryl, topaz, spinel and garnet, tourmaline, olivine, chrysoberyl, zircon, opal and quartz, and finally " Chinese jade." The text for each stone adopts the usual style—the composition and constants, a general note, varieties, if any, the style of cutting used and the localities where found. A number of the rarer stones are dealt with in tabular form at the end of the book, which closes with a short bibliography.

There are few errors in this work, and none serious. The gemmologist might disagree with the values of density and refractive index given for topaz, 3·53 and 1·62–1·63, which are values very

rarely found in actual practice, there being two distinct divisions of the topaz family with slightly different values. The term " blue white " for perfection diamond might have been omitted in view of the proposed discontinuation of this term. For a similar reason the term chrysolite might have been with advantage left out. Are quartz cat's-eyes wrongly described as cat's-eyes ? Surely cat's-eye is the term for an optical effect and not the name for a gemstone, whether it be the prized chrysoberyl or the more lowly quartz—or tourmaline for that matter. It would have taken only a few more words to give the colours of aventurine quartz, the "aventurescence" of which is not always due to mica. That the nephrite jade mineral is " Chinese jade " would not be acceptable in trade circles, which term only the material from Burma " Chinese jade," i.e., jadeite. Sphene, despite mention in the text, is omitted from the table of rarer stones. The absence of a full point after *alum* in the chemical composition of oligoclase and labradorite feldspar tends to infer that the mineral contains a double sulphate (alum). There is no sulphur in feldspar.

The book is printed on good quality paper, and a very clear type is used which makes for easy reading. The text is considerably enhanced by the line drawings so very well done by Jean Rice. At two shillings and sixpence " An introduction to gemstones " makes a really cheap authoritative book.

R.W.

SINKANKAS (J.). *Gem cutting.* D. van Norstrand Co., N.J., U.S.A. 397 pp., profusely illustrated. $8.95.

A comprehensive book dealing with all aspects of gem cutting and written primarily for the amateur who wishes to become a proficient worker. The author has been at pains to study the literature on the subject and has added to the knowledge gained therefrom his practical experience. The book is divided into three sections, the first dealing with equipment, its uses and limitations ; the second part of the book discusses faceting, bead making, drilling and sphere cutting, and cabochon work ; and the final section tells how to collect gem materials and gives other information of use to the enthusiastic gem cutter in North America. The title is the same as that used by J. D. Willems in 1948.

S.P.

MIDDERIGH-BOKHORST (B.). *Glans en Gloed uit donkere diepten.* (Lustre and fire out of dark depths.) Levensverzekeringmaatschappijen, Nillijm/Arnhem. 88 pp., numerous illus., colour, and line drawings.

This book, the production of which was financed by a Netherlands Life Assurance Company, is outstanding in its presentation—and inexpensive, for it sells at about five shillings. It has been written to interest young and old alike in the world of gems, and it succeeds admirably, for history, romance and scientific data have been carefully written. There are numerous illustrations, in colour, of gems and gem minerals, which are extremely well done and which contribute greatly to the book's value. Proceeds from sales are being given to institutes which aid crippled children.

S.P.

PERIÓDICO DA ASSOCIAÇÃO BRASILEIRA DE GEMOLOGIA. Ano. 1, No. 1, 1955.

The first number of the official journal of newly formed *Associação Brasileira de Gemologia.* Illustrations in line are good but some photographs of mineral crystals suffer in the quality or the age of the blocks and details are sometimes lost in an inky blurr. Papers are in Portugese and of an introductory nature. They include : Gemmology—Science and Art ; The Large Brazilian Diamonds: Structural Imperfections and irregularities in Gems: Ideal dimensions and angles for stone cutting ; Colour of precious stones. Official notices give particulars of the Brazilian Association formed under the auspices of the Department of Mineralogy and Petrology at the University of São Paulo in July, 1955, Pro. R. Saldanha as President. Courses of instruction are planned.

At the present official rate of exchange the annual subscription for associates is in the region of £20, but it is noteworthy that this fee exchanged at the free market rate would be no more than £5. A further example of the peculiar exchange conditions is in the price of an ordinary dichroscope, advertised as a " Magic eye," and costing at the official rate roughly £35, and at the free rate about £9.

JADE STORY—EUROPEAN

(*The fourth part of the Story of Jade in Europe*)

by ELSIE RUFF, F.G.A.

IN leaving behind the 18th century, we by no means divorce ourselves from *The Jade Question*, though at that period the question had not been isolated. Travelling back in time, we find the first contributor of note to be Robert Boyle, a natural philosopher. In 1672 he published an essay entitled *Origine and Virtues of Gems*. Robert Boyle was a Fellow of the Royal Society, a linguist, and one of the leading scientists of the day. On p. 115 of this essay, we read :

" And from the greater or less plenty, and natural activity of the impregnating particles in this or that gem, may possibly be deduced the difference in colour of some, and in virtue of other stones of the same denomination, of which we have in a learned writer or two, eminent examples gives us of the great virtue of some, and the inefficiency of other, that experience has discovered among those stones that go under the title of *Lapis Nephriticus*."

And on p. 132 : " As I remember, that an ingenious Physician told me of a Spleene Stone, as they call them, in the hands of an acquaintance of his (where I might have seen it if my occasions had permitted) amounting to about four score pounds weight."

Further, p. 175 : " That sometimes stones that are thought without scruple to be of the same kind as hath been particularly observed by Learned men of the *Lapis Nephriticus*, are of such different qualifications, that some of them have very considerable Remedies in cases where others prove almost utterly ineffectual. And I have observed also, though very rarely, that a Medical Stone may have virtues that are taught to be the properties of stones of another kind."

Here we have an Englishman (an Irishman to be exact) using two well-known terms for the same material. His words suggest that Spleene Stone was rather the prerogative of the medical man, since to him it was mainly a medical stone, and that *Lapis Nephriticus* was the correct or scientific term. Only 77 years separated

Raleigh's publication, in 1595, from this work of Robert Boyle, and Raleigh himself was recognizing the jade of South America as the Spleene Stone of England. (See *Journ. Gemmology*, Vol. V., No. 1, 1955, p. 7.)

Lapis Nephriticus (as well as Achate[1]) is mentioned in 1632 and in 1661, both works by Joannes Jonstonus, and here referred to as a product of New Spain. The author writes of the tremendous healing powers of this material which, he says, are both natural (physical) and psychological. It has been proved, he affirms, by many effective cures.

More than 200 years earlier than Monsieur Blondell, who pointed to the separation of jade and jasper as " somewhat modern " (see *Journ. Gemmology*, Vol. V. No. 3, 1955, p. 148), Ulissi Aldrovandi in a posthumous publication of 1642, was writing of this very difference. Nevertheless his rendering of the term *Lapis Nephriticus* is not clear, though undoubtedly he uses it in part to cover both nephrite and jadeite. As Aldrovandi died in 1605, the year he founded the University library of Bologna (the beginning of the museum of Bologna is also attributed to Aldrovandi's collection) this must have been written about fifty years earlier, viz., towards the end of the 16th century. In a still later publication, we find : " . . . As *Heliotropius*[2] is counted a jasper, so is *Lapis Nephriticus*, but it differs in being very much harder, the surface is greasy and cannot be highly polished. It is used for health reasons as it is not elegant." This author quotes Boetius, who was looked upon as an authority in this century. Aldrovandi calls for respect, not only because he states that *Heliotropius* is a jasper but because, knowing that *Lapis Nephriticus* was also considered a jasper, he nevertheless sees differences between the two. While we know that there is little between the hardness of nephrite and that of jasper, the toughness of nephrite must have led, often, to Aldrovandi's conclusion.

In 1636 R. P. Bernhardus Caesius was writing of *Lapis Nephriticus*, of its recent arrival from New Spain, and of its value in

1. Agate. According to *Gemstones* (G. F. Herbert Smith) this name is derived from the river Achates, in Sicily, where it was found at the time of Theophrastus. (See *Journ. of Gemmology*, Vol. IV, No. 8. p. 347.)

2. Bloodstone.

expelling calculi. Here, too, was another writer to refer to the difference between jade and jasper and also the fact that jade was recognized by various names such as *lapis nephriticus*, *pierre néphrétique*, and *piedra de ijada*. Furthermore, he identifies the various occurrences which, in the light of present day knowledge, were not incorrect. The only doubtful one he lists is India. For the remainder he gives China, Burma, Mexico, and Central America.

An important contributor in the 17th century was Joannes de Laet. There are three editions of this author's work. The first, in Latin, was published in Antwerp in 1633. It was called *Novae Hispaniae* (New Spain). On p. 324 is the following :

" Let us speak a little on gems . . . a species of Jaspis with points (punctulis) white, variegated, which are called IZTLIA YOTLI QUETZALIZTLI, or not transparent *Smaragdus*,[1] and which attached to the arm or the region of the reins[2] scatter the nephritic pains, break and expel the calculi and various things that pass from the body which obstruct the passage."

The next edition was in French and published in Leyden during 1640. In Volume V, Chapter IV, entitled : *De Quelques fleurs et herbes, animaux, et pierres précieuses de la Nouvelle Espagne* we read, p. 144 : " The Mexicans call EZTETL a stone which seems to be a kind of green *Iaspis* with certain spots of colour of blood ; they affirm that attached to the arm and neck it stops all flux of the blood by reason of that they have the habit of putting this, powdered, in the holes of the nose when they are bleeding too heavily. There is found another species of *Iaspis* spotted with small points (poincts) of white which they call IZTLIA YOTLI QUETZALIZLI or dark emerald, which attached to the arm or the right of the reins mitigate the pain nephritic (as they say) break down the stones and expel the matters altogether that block the passage. Compare what Monardes says on this point.

"There is still a third category, darker colour with no points and more uniform, which they call TLILAYOTIC, which they believe cures colic if applied to the navel. Finally, to mention all, there is another stone black, uniform and not polishable, which they say is very good for the ills of the matrix . . . see Monardes."

1. Emerald. 2. Kidneys.

This, as we see, is a development of the first edition, the opening sentence of which refers to the bloodstone ; information, apparently, which Laet collected from Monardes. The third edition, written in Latin, was printed in 1647. This was called *De Gemmis et Lapidibus*. Here Laet writes : " The stone which to-day is called *Nephriticus* for his most eminent virtue of being potent in the ejection of sandy grains from the reins, is called by the original inhabitants of New Spain IZTLIAYOTLI QUETZATLI because they considered it a species of darker Smaragdus, thus wrote Fr. Ximenes.

Small jadeite axe. Engraved on both sides with Gnostic inscription

Spaniards call it *Piedra de los Riñones*,[1] Italians *Osiada* from Sciatica, as its carriage is said to cure this, the French call it *Siadre*, a corruption of the Italian word according to Boetius. To which, we add, in the same New Spain is found another stone which the Spaniards call *Piedra de Hyada* ; which the Italians call *Osiada* and the French *Siadre*. It seems that Boetius deals with two stones which are different. Thus Fr. Ximenes describes this *nephriticus* in the other chapter, where he comes to it.

1. See *Journ. Gemmology* Vol. V., No. 1, 1955, p. 10.

"There is another species, green *Iaspis*, much different from the proceeding called TLILAYOTIC by the natives and different in weight, colour, form and qualities from the previous. The Germans call it *Nephriticum*, *Kallesznin*n (Pliny calls it *Callais*[1] *Callaias*) Belgians one *Kalzbee*, bad form of the name *Callais* as one would say ; as they have nothing in common. Some classify the green *Iaspis* . . . some older experts judge it to be still another kind of green *Iaspis ;* this, however, is not likely so, because it is harder. Still further from the truth are those who compare it with *Prasius*. I classify it as a species in its own right, contrary to the old experts, potent in virtue as I know, also very hard, more like the darker species of *Smaragdus* which has been described as pure green. Neither is this gem very dark nor transparent, but only half way in both considerations and it has this special property that it never can be properly polished and that the surface is always somewhat oily and fatty. . . . The one Monardes exalts is even more green. A third which is mentioned by Fr. Ximenes, *smaragdus* green of the darker kind has, however, points either of white or of ash-grey. The fourth is of a yellow green like honey with a fatty surface. The fifth is a mixture of divers colours, green, yellow, white, and black. . . . Sixth, mentioned by Boetius, dark green, opaque as somewhat with black intermingled ; this like *Ophite*[2] has also some black spots. Very hard, distinguished by some lines and placed by Pliny in Cyprus, as reported by Augerius Clutius who had some amongst his Nephrites, some of which he has shown me, but of whose genuineness I have some doubt. It is admitted that Boetius classifies it amongst the Crystals, but I observed the white cloud independent of the green.

"Besides these there is also found the honey-coloured variety mostly found in America on the brinks of the Amazon river and other rivers, which in this part flow into the ocean, many and most in New Spain from where many stones came to Spain and the rest of Europe. They are partly in massive blocks, thus Boetius writes that he has seen in the gem collection of the Emperor Rudolph II (1552–1612) a piece of the value of 1600 thalers of which was cut a cup of large size. I remember having seen in *Anglia* a block the

1. Here it is thought that Pliny refers to our turquoise.

2. Serpentine.

size of a man's head which had originated from America, i.e. the Amazon river, it was a milky green. He who had brought it valued it at £50 (quinquaginta libris sterlingensibus) . . . . Original inhabitants of Guiana work large pieces and use some of pyramid form for ornaments of the lower lip. These Gesner calls *Oripendula.* Monardes writes of the virtues of this stone saying that the Indians have a habit of wearing them attached against the kidney and stomach pains thus to expel calculi and renal impediments. They praise them as cures for Nephritic diseases. I know a nobleman owning one beyond compare, this attached to the arm expelled so many stones that he feared it to be too excessive, he took it off from time to time. . . . Dulcissa Bejar suffered three times from nephritis in a short interval, she made herself an armlet of this stone which she wore perpetually, her pain ceased and has not returned for ten years, many others felt the same effect, therefore these stones have a high value, not only as they are difficult to get but also on account of their miraculous quality. . . . Ximenes, who wrote in his commentary in New Spain itself and edited in a Mexican town, presents and recognizes one green like *Iasper* but variegated with white spots. Boetius lauds the stone, Nobleman Nicolai Dammani possesses one dark green with small black spots. Others speak highly about others. I can in consequence of certain experiments which were made on my wife, affirm that an oblong stone I have in my possession, at the same time a flat and separately thick stone of faint honey colour with an oily surface, I can attest that worn in the hollow of her arm my wife experienced the same effects which Monardes attributes to the stone of his noble friend. I have also another stone armlet of a dark green stone with nearly black points which also my wife has worn often. I know of many which underwent great dangers in this Amazon river, but there these stones did not always show such results. Therefore it should be investigated on what part of the body it should be attached to obtain the best results. Shall it be in the arm-hole or on the part where the doctors measure the pulse, it seemed to me the most useful. But others favour the place of the reins or where the pain is felt. I believe it is best to experiment and act accordingly."

In this third edition we see the author's indebtedness, which he acknowledges, to Gesner and to Monardes. Indeed, it is questionable whether he knew the nobleman of whom he writes, or whether

he is not here quoting Monardes. Since there are nearly eighty years between the two publications, it could hardly be that this gentleman was known to both. Dulcissa Bejar was, it seems, Monardes' *Ladie, the Duchesse,* though Bejar appears to have been of American-Indian birth.

Although it is obvious that Laet has tried to classify the various stones, his efforts afford little help to the 20th century investigator, particularly as there is much confusion of terms. Between the second and third editions Laet must have given this subject a good deal of thought, to say nothing of experiments. In the third edition he writes (in Latin) of *Nephriticus.* Earlier, this same stone was, to him (and to many another), a jasper. Material of the necessary green and transparency was classified as an emerald, that is, *smaragdus*—an error that may still occur, so like an emerald are fine pieces of jadeite. Quite clearly Laet separates bloodstone and jasper. And he is also definite that *Nephriticus* is not prase.

Perhaps the outstanding contribution of Laet is that he appears to be separating two species. The jade coming from the New World, or New Spain as it was then called, was, it is thought, jadeite. Was he separating this from the jade of Europe, with which he was familiar, a jade that was likely nephrite ? Or was it the jade of Turkestan, also nephrite ? Lange (see *Journ. Gemmology*, Vol. V, No. 2, July, 1955, p. 152), in 1704, clarifies this for us with the statement that " Laet is right. *Nephriticus* is a species of its own, neither Prase nor Jasper." To add to our confusion of this New World jade, turquoise seems to have come under the same heading as jade, that is, *chalchihuitl*, and was regarded as a close second in preciousness. It is likely too that, used ornamentally, when the softer substance would not be so easily distinguished, turquoise often passed for jade. Frequently the turquoise is more truly green than blue, particularly after it has been worn or used for some time.

We come now to another publication of some importance, its date 1628. Here is Bartholinus of Malmoe, or Caspar Berthelsen, who was born in Malmoe, Sweden, in 1585, and died a year after *A Small Essay in four parts* was published. One of his sons, Erasmus (1625–1698), is of interest to gemmologists as the discoverer of

double refraction in Iceland Spar. It seems that Bartholinus was a physician (as most of the scientists of that day were), a linguist and a traveller. From the section of his work called *De Lapide Nephritico* we learn that in Spain it was called *Jgiada* (still another spelling), and in Belgium *Calsvee* which is probably the *Kalzbee* of Laet. In Chapter III we are told that *Lapis Nephriticus* is often found in conjunction with *Jaspis* and *Prassius*, though more frequently alone. Cups, he says, are made of it and sometimes thought to be green *smaragdus* or *callais* " on account of the soft green tint." In quoting Pliny, via Caesalpinus,[1] and one Encellius, it is most difficult to determine whether the author and Pliny mean exactly the same thing. Nevertheless, he does say that the hardness of *Lapis Nephriticus* exceeds that of jasper. (His description of the way in which this material is found is a direct copy of Pliny's *Callaina*, which we believe is our turquoise. This is corroborated in a later chapter of Pliny where the reference is to *Callais* or *Callaina*.) A statement of interest to us is that Bartholinus quotes the authority of Boetius for the occurrence of *nephriticus* in Spain and Bohemia, but adds : " This is little believed by mineralogists, they attribute it to the finding of *smaragdus*, *prassius*, or *Jaspis*." Since no source of nephrite has been found, up to this date, in Spain, we must laud the author for disagreeing with a much-quoted contemporary.

Throughout these times there would seem to be an enormous number of people not above counterfeiting *Lapis Nephriticus* or passing other substances off as such. The curative properties would, of course, make this well worth while. So here, in Chapter 5, we read : " Notwithstanding what has already been stated, it will not be difficult to differentiate between *Nephriticus* and other stones. The diagnosis is so much easier when the similar close species are present. Let us not be imposed on by fakers of Gemstones. There are indeed some or other dealers who sell adulterated stones as *Nephriticus*. Take for instance the merchants of Frankfurt who sold false stones to the Magnates in the form of bracelets and girdles, as stated by Clutius, substituting similar (looking) stones for *nephriticus*. Such are : 1. *Jaspis* ; 2. *Callaitidus* ; 3. *Smaragdus* ;

1. Andreas Caesalpinus (1519–1603) was a distinguished Italian botanist and physician to Pope Clement VIII.

4. *Prassius* ; 5. *Smaragdus-Prassius* (most likely prase, which was sometimes called Mother-of-Emerald)[2] ; 6. *Heliotropius* ; 7. *Malachitus* ; 8. *Ophitus* ; 9. A very low-grade *Nephriticus* as they call it from the West Indies, nearly black,[3] and opaque, less hard than the oriental *nephriticus*. The power of this *nephriticus* is not established. The inhabitants of those parts use it for wedges in their wood-work, and as hammer-heads, weapons in battle, and for the execution of offenders. This is a list of real Gemstones and near species, with the exception of No. 9."

A study of this list leaves one full of admiration. Not only did it state the case for that period, that is in 1628, but the list could take its place in a modern text-book. There was no doubt, it would seem, in the mind of Bartholinus about *lapis nephriticus*. Nor did he ignore the curative side. In Chapter XI of this work, the author writes of " the derision of Erastus, Gesner, and others who condemn and deride the use of amulets completely. Trallianus perhaps upholds them when he says Galenus teaches such use notwithstanding that he has started by mistrusting them." " Not only," he continues, " does he (Galenus) speak of what he heard, but he speaks of his own experiments. Erastus attacks him on the score of amulets. . . . Whatever is pointed out we know that there cannot be any effect. If applied for as long a time as you like, the illness is not affected. . . . It is sensible to help the evacuation, which is stated before to be done by the application of *lapis nephriticus*."

This statement is not the contradiction it first appears to be. The following paragraph explains the author's meaning, in which he is differentiating between a remedial stone and those believed to promote virtue and so forth :

" I well know what by some is attributed to the stone, things which are unobtainable by the simple means of nature can be obtained by invisible influences in affections of the eyes, provoking adultery, which is attributed to the *smaragdus*, to bestow eloquence, make poor, render beloved of all, make rich, fortunate, victorious,

2. G. F. Herbert Smith gives " Prase, or mother-of-emerald, which at one time was supposed to be the mother-rock of emerald, is a quartz, coloured leek-green by actinolite fibres in the interior."

3. Probably chloromelanite.

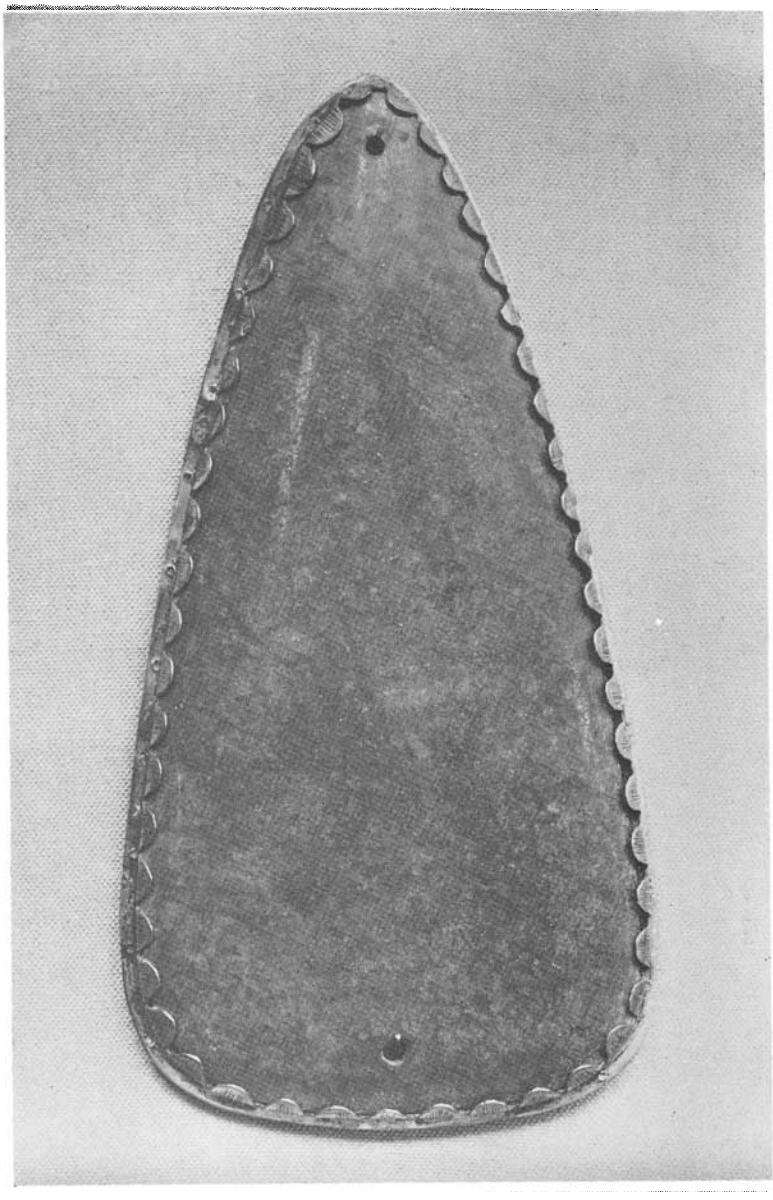

Jadeite axe, mounted in silver, and perforated for attachment to a belt. Believed to have been worn in Scotland as late as early 19th cent. as a protection against kidney diseases

and all kinds of things. *Adamentis* is described as giving faithfulness, victory, courage, the smoothing of wrath, conjugal affection, reconciliation. Thus far goes human madness, that we read that some precious stone confers the favours of the Deity, or drives out demons. It is enough in mending bodily ailments to follow the natural processes. We do not put our faith in the superstitious use of Gems."

It is not always easy to remember the limits of 17th century literature, living as we do in an age of ever-increasing printed matter. Since too most of the available literature was in Latin, reading was necessarily restricted to classical scholars. Nevertheless it did mean that these scholars were acquainted with, perhaps, *all* the available literature. And this state of affairs had further merit in that a variety of interpretations and points of view have come down to us. Furthermore it preserved the authorities of antiquity, providing us with opportunities for checking the accuracy of the older manuscripts. Thus we see how Pliny was quoted, how Monardes and Gesner were quoted—to name only three.

All this is particularly noticeable in one Cluyt (Outiger) who wrote under the Latin name of Augerus Clutius. His first work, which included an *Essay on Calsue or Nephritic Stone* was published in Rostock, Germany, during 1627. He writes : " The stone *Nephriticus*, by some called Calsue, comes to us from New Spain, a province of America. It is not dissimilar to *Prasius*, always green with a shade of yellow, *prasius*-like or leek-green wax : various shadings appear at times but it remains steady regarding the basic colour and hardness. Besides this the stone is bright and of high clarity . . . Dr. Bernard Paludanus, a famous and excellent expert, Curator of all natural and medical matters, kept with him a piece of *Nephriticus* the size of a Reichs thaler which he employed together with some of his friends making use of it as an example. It was handed to Mrs. Elisabeth Parvia and Mr. Egberris Enchusiensis, in which cases it worked happily, which benevolent action Monardes attributes to Calsue."[1] Here again we read of the Dulcissa Bejar quoted by Laet, in this case called Princess Bejarise, of the West Indies. " Thus also several others in West India found the same help with the greatest improvement in their health, which is a proof of the potential value of the stone. Therefore, the Indians

1. The word *Calsue* does not appear in the English translation of Monardes' work.

hold the stone in high esteem, which results in the fact that the stone is only rarely obtainable ; as the kings, princes, and inhabitants conceal the provenance of the *Calsue*, they hold it for their ornaments and not only conserve them as treasure but also on account of the magnificent and incredible effect. Thus Monardes even secured it very rarely." Speaking of the Emperor Rudolph, he writes : " He made an ample collection of gems to a great extent from the cold German and Bohemian mountains, mainly *jaspis*, both transparent and dark of similar value to the oriental prase and heliotrope from India, going for the most beautiful specimens and craftsmanship. There are also in *Gallia* persons of high standing who prefer the green *Calsue* to all other stones especially the one similar to the transparent prase. . . . Many places have had the advantage of being indicated as the home of this stone and have been recognized by the experts as true *Nephriticus*. . . . Mons. S. Annae collected a species of serpentine stone similar to our ORIENTAL species, however less hard and easily breakable, which is helpful in colic complaint and cures stomach colds, if heated, applied to the body : thus he applies it and sells it for this purpose. This species has not been found in the river Amazon." Helpful here is a statement about the word *Calsue*, which we now meet for the first time, and which, according to this writer, is interchangeable with the Nephritic Stone. " *Calsue* is a species of dark dross-like colour and much darker is not highly estimated. However, it is frequently used by the people of the isthmus (presumably the isthmus of N. and S. America) because it can be easily divided into small entities. Hendius, in Theatre Orbis, mentions this stone for its elegance, and it is in artistic ways incrusted in wood on the weapons of these people with which they execute men condemned to death, and which they use in battle. This gem, as I remember when I was young, had some spots, but it cannot be compared with the ORIENTAL kind. In some parts of the river a superior species is found and highly valued by the local inhabitants, it is of a feeble white colour with minute spots or lines, it is used for handles of knives or daggers. It is perforated and often round as if made to be slung to the body. This stone is not unreasonably compared to the so-called stone of the Nile which is found in the bottom of the river Nile notwithstanding that it is also found in India and Attica,[1] so

1. A district of ancient Greece.

says Andrea Caesalpinus, Book 2, cap. 26, and if I remember right this is the stone CALLAIS which name has been changed into *Calsue*. It is affirmed that this stone in the past has been found in nests of birds[2] and is known in ancient times as Melancoryphos." Cluyt wrote further of " *lapides Nephritici* of all sizes and forms worked into shapes and fashioned, imported from BOTH INDIES. Also brought from Germany, made into figurations with or without acknowledged designs, prepared for special applications in a variety of forms. . . . Some are shaped in the form of a heart beautifully chiselled of the size of a thaler, with name inscribed with inscriptions in Arabic[3] characters telling of the power and strength of the *Calsue*. However, they are not seldom without such inscription, pieces of idols, if larger, in the form of a barefoot boy or the form of an arm. Not less frequent are those in the form of a belly, or the reins, they have a certain use. . . . We do not speak of the heliotrope as it is a species of stone dissimilar to ours . . . so many authors have written about it, as well in general of medical plants, stones, and the varieties of such materials and effects." " As I have some vacant space," the author sums up, " here is a note on Anselmus Boetius de Boodt. As heliotrope is cited amongst *jaspis* so also *Nephriticus*. As *jaspis* appears in various colours, so *Lapides nephritici*. The difference between *jaspis* and *nephriticus* can be stated. *Nephriticus* is harder, never red in itself. Then it cannot be quite polished. The surface feels fatty as if of oil. It seldom has two colours, whatever the shade, the ground colour is always milky-green, of equal import. If not thinner than a little finger it is darkly translucent. It is called by the Italians *Osiada* from sciatica, which it is considered to heal if carried. Belgians call it *Kalsuee*, Germans *Kalsbee*, Gauls say *Siada* from the Italians."

One's first impulse is to disqualify Cluyt, but as we begin to study him we find him interesting and often correct. The biggest hurdle to surmount would appear to be the word *Calsue*, adding still another spoke to the umbrella of jade. This word, he tells us, comes from *Callais*, a word we have met earlier. The *Callais* of

2. This information is to be found in Pliny.

3. It will be recalled (*Journ. Gemmology, Vol. V, No.* 1) that Sir Hans Sloane mentions the same thing in 1725 of material he saw in Jamaica.

Pliny would appear to refer to our turquoise or turquoise matrix. Yet, as mentioned earlier, in South America the turquoise was known by the same word that was used for jade—Chalchihuitl. Certainly the turquoise is not hard enough to be used as a weapon, the weapons of South America cited by Cluyt. Weapons of the New World, as elsewhere, were frequently of jade. And the colour of this *Calsue* suggests that chloromelanite, the dark variety of jadeite, is being described. It is easy to see where the Belgian *Kalsuee* and the German *Kalsbee* are developments of *Calsue*. Yet the Italian *Osiada* is closer to *iada*, the jade of Italy. (See *Journ. Gemmology* Vol.V, No.1, 1955, p.15.) In the list of Bartholinus, quoted above, number 9 refers to " very low-grade *nephriticus* . . . nearly black, and opaque, less hard " and this was the weapon and the implement of the inhabitants of the Indies. There would seem to be hardly a doubt that this was also Cluyt's *Calsue*.

A few years earlier, in 1623, was Laurembergius (Guilielmus, the Elder). Here is another medical man and his work takes the form of what might be a modern journal. He writes of his " deplorable state of health " in 1609, when he was at the beginning of his 63rd year (rather an old man in those days). And he describes his " nephritic pains " which, he says, he had " never sensed before." Over a period of thirty-six weeks the author is naturally concerned with a cure, giving a list of herbal medicines. He adds, p. 11 : " Let me in the same respect mention the gem called in Spain *Igiada* . . . Somebody treated this way for calculi was cured, but as at the same time other medicaments were given it is doubtful if the healing can be attributed to the gem. . . ."

Around the turn of the 17th century, there were two authors of the same name. One was Christophile de la Costa, writing of the medicines of the American Indians. This work, published in French during the year 1619, was called *Histoire des Drogues, Espiceries*. Here again we find a repetition of Monardes, including La Duchesse de Bejar (a compromise in titles, it seems). The second author, a Spaniard, José de Acosta (*c.*1539-1600) was more original. As a Jesuit he was sent to Peru in 1571. It is claimed that his was the first book to be published in Peru, and that as early as 1590. It is interesting also that an English translation was evidently so desirable that one appeared in 1604, fourteen years later. In

Chapter XIV, headed *Of Emeralds*, it is almost certain that, in part at least, the reference is to jade :

" The Kings of Mexico did much esteem them, some did use to pierce their nostrils, and hang therein an excellent emerald, and they hung them on the visages of their idolls. . . . The emeralds grow in stones like unto cristall. I have seen them on the same stone, fashioned like a vein, and they seem by little and little to thicken and refine. I have seen some that were halfe white and halfe greene ; others all white, and some greene and very perfite. I have seen some of the bignesse of a nut and there have been some greater found."

This excerpt is particularly valuable, not only because it brings us closer to Monardes (separated by no more than 21 years) but because it was written and published on the spot.

Between the last two authors was another writer whom Laet frequently quotes and moreover informs us that he wrote in New Spain and edited in Mexico. His name was Francisco Hernandez or Ximenes, and his work, in four books, was published in 1615. This author refers to *Piedra de los Rinones* and also *Piedra de Hijada*, treating them as different stones. Of *Piedra de Hijada* he says : " It is a kind of green *Jaspis*, although much rarer. . . . For use it is made into several shapes and cut according to the affected parts into flat pieces like plates, or round pieces like a ball, and attached to the hands or as often as not to the part of the body where there is pain. It cures the ills of colic, and the reins, ejecting the troublesome bodies from the affected place ; it is very often attached to the wrist." Nevertheless, this author is far from clear. Later he writes, presumably of the same stone : " It is often taken for another stone of the same species on account of its very clear green similar to *jaspis* or the inferior emeralds. . . ." And, just as we distrust Ximinez' differentiation, so he distrusts the Indians " because they are always on the war-path and have no time to distinguish much between one stone and another." The important point for us here is that the same stone was used for the same cures and this was written and published, seemingly, in Mexico. Even so, at this date, the *cure* could have been introduced or created by the Spaniards.

When we come to de Boodt—Anselmus Boetius—in 1609, we are studying a much quoted writer. Boetius was a physician to the Emperor Rudolph, as we have read, and he classifies *Lapis Nephriticus* as a jasper, and describes the stone as not very beautiful but useful in kidney disorders. Once more Monardes is quoted and occurrences given as Spain, Bohemia, and New Spain. We have seen how Bartholinus disagreed with this statement as far as it concerned Spain and Bohemia. A much later author, Charles William King, M.A.[1] in 1867, said : " . . . even the practical de Boot was evidently a firm believer in *Lapis Nephriticus* and the prices quoted by him testify to the general faith in its medicinal virtue, a piece no larger than a half thaler selling at one hundred crowns. . . . De Boot again mentions (under *Smaragdo-prasius*) that the West Indians, the Caribs, wrought this particular stone, which some held to be the only genuine Nephrite, into a cylinder. . . . He also asserts a very singular thing, that the true nephrite was then found in Spain and also in Bohemia, a fact that he adds was but little known, because the ignorant lapidaries mistook it for smaragdoprase, or the green jasper." In King's earlier book[2] published in 1865, he writes : " Supported by the authority of Galen its (achates) efficacy was undisputed even in 1609. De Boot testifies that in his own practice he had observed effects scarcely credible from the application of the Red Jasper in cases of haemorrhage, and mentions the prevailing belief that a Green Jasper engraved with the figure of a scorpion, when the sun was entering the sign, was a sure preservative against the formation of the stone in the bladder." Here De Boodt was obviously referring to the bloodstone, in the first example, about which there seems to be no problem, and his green jasper was almost certainly his *Lapis Nephriticus.*

According to Thomas Wilson, in his comprehensive paper *Jade in America,* 1900, Boetius followed the opinions of his predecessors in the first two editions, but in the third, published in 1647 (nearly 40 years later than the first edition), he recognizes and reports the different minerals, describing jade under the heading *Lapis Nephriticus* " a greenish stone mixed with milky veins or splotches brought a few years ago from New Spain."

1. King (C. W.) : *The Natural History of Gems and Decorative Stones.*
2. *The Natural History of Precious Stones, Gems, and Precious Metals—Ancient and Modern.*

There was, as we have seen, a great interest in jade during this century, not least the urgency to separate Jade from Jasper, suggesting it had long been confused. (And was to continue so, for something like 200 years.) Nevertheless, our search has taken us no further back than the beginning of the 17th century. Yet it is apparent that the writers of this era do not appear to be coining a new term for a new stone (or perhaps one should say, identifying a new stone), or translating the Spanish of Monardes into Latin. All authorities go back to Monardes as the final and perhaps the first word, so that any literature of the 16th century or earlier that may come to light, using the term *lapis nephriticus*, will add much to this research.

A very early source quoted for the establishment of the term *lapis nephriticus* is that of a poem attributed to Orpheus. Orpheus, a Greek poet, is believed to have lived around the period of Homer. Poems attributed to him were much quoted and in circulation during the early part of the Christian era. One, entitled *Lithika*, or *Lithica*, was published in the 4th or 5th century. Yet evidence for the word nephrite is slim. The following extract, from two verses of this poem, is given by Charles William King[1] :

> " Take in thy pious hand the Crystal bright,
> Transparent image of the Eternal Light,
> Yet though of fire the source, strange be it told,
> Snatch from the flame the stone—'tis icy cold !
> Girt round his loins with this, the sufferer gains
> A sure-relief from all nephritic pains.
>
> Hence to me the *Nebrite*, a gem divine,
> A gift to mortals from the god of wine.
> The potent *Nebrite* heals the venomed smart,
> To wives it also binds their spouses' heart.
> Hence were thy priceless virtues to me shown
> Against the deadly asp, life-saving stone ! "

The first verse of this quotation refers to crystal, which was not, necessarily, the rock-crystal of to-day. Yet the evidence is not negligible, mainly because nephritic pains (a common ailment in early times, it seems) were treated in the same manner as in later

1. King (C. W.), *The Natural History of Precious Stones, Gems, and Precious Metals, etc.*

times. In the second part of the quotation we come across a word very like nephrite and later perhaps mistaken for it. According to Pliny, *Nebritis* was a stone sacred to Bacchus, commonly identified as the God of Wine. He tells us too that the stone receives its name from *nebris*, a Greek word referring to the skin of a fawn or deer as worn by the Bacchanals during their celebrations. A glance at the second verse of the above poem confirms this. In John Florio's Italian/English Dictionary " A Worlde of Wordes," which was printed in London during 1598, is *Nebrite*, " a kinde of precious stone." He also gives us *Nephrite*, an ache in the raines of the bache. Also the stone or grauell in the raines." It is well, however, to remember that not only were words frequently mis-spelt in early times but the same substance might be known under a variety of spellings. This applied even to proper names. Sir Walter Raleigh, a person famous enough to have an established spelling, is found to have had no fewer than five ways of spelling his surname. Although the second verse does not connect *nebrite* with nephritic symptoms, the species of this gemstone is not established. Pliny's translators believe it to be either agate or jasper, particularly the mottled variety similar to an animal's skin. But Pliny further states, after *nebris*, " There is also another stone of this kind that is black." Was he too referring to chloromelanite ? And was the mottled stone nephrite or jadeite ?

The oldest existing treatise on stones was written by Theophrastus, a native of Eresus in Lesbos, around 315 B.C. (*Journ. Gemmology*, Vol. IV, No. 8, 1954, p. 347). Unfortunately only a fragment of this remains. It was translated by John Hill and two editions published, one in 1746 and the other in 1774. It seems fitting, therefore, in our search for *Lapis Nephriticus*, to hesitate here. Dealing with the word *Prasius* the translator writes that it " more properly belongs to *Lapis Nephriticus*." Theophrastus was writing of *Prasius*, Root-of-the-Emerald. It has also been termed mother-of-emerald, as mentioned earlier in this article. The basis of both these terms is thought to be the mother rock of the true emerald. On the other hand Prase is leek-green in hue, and its Greek name πράόμον means a leek. So it is just possible that Theophrastus was not writing of the leek-green prase, but of an *emerald*-green stone.

TORONTO'S PUBLIC SERVICE GEMMOLOGICAL LABORATORY

by DEAN S. M. FIELD, F.G.A.

ESTABLISHED several years ago for the purpose of furnishing accurate scientific gemstone identifications and appraisals for insurance companies, trust companies and the jewellery trade, Toronto's Gem Lab has lately revised its policy and now functions as a public service institution staffed by three gemmologists representing both the British and American schools.

From a simple oak-topped desk with three or four basic testing instruments, the Gem Lab has grown, in the space of a very few years, to a modern, scientifically lighted laboratory equipped with more than twenty instruments—several of which are of unique design and usage.

Being the only public service laboratory of its kind in Canada unconnected with the retail jewellery trade or with a pawnbroking establishment, the Canadian public is showing great confidence in the work being carried out within its walls, and the number of persons visiting the premises continues to grow. Indeed, a second laboratory to accommodate the public is now in the blue-print stage; and this will house not only duplicates of many of the essential instruments now in daily use, but also X-ray equipment for gemstones and pearls, a full range of chemicals, and equipment for the restoration of the beauty of stained and soiled porous gems, such as turquoise and pearls. To date, only the excellent modern laboratory of Mappin's Limited, in Montreal, has X-ray equipment for the examination of pearls and crystals.

At first viewed with suspicion by jewellers of the " old school," more and more reputable tradesmen are availing themselves of the services the Gem Lab offers ; realizing—what every gemmologist knows—that unscientific gem testing methods are no longer proof against the new synthetics and clever counterfeits now in the market, nor general appearance always a reliable guide.

Too, where proof of value for money received is urgently needed, the Canadian jeweller needs no longer to depend upon the ethics of a competitor or the honesty of a pawnbroker to effect a sale to a Doubting Thomas. If a jeweller is giving honest value,

the Gem Lab will support his claim, and even issue a certificate to that effect ; for in this laboratory jewellery is not bought or sold, and opinions are wholly objective.

Since a great number of jewellery estates of Central and Western Canada now pass through the Toronto Laboratory for checking, it is not surprising that some interesting and unusual specimens have come to light ; and these, like all other items examined, are microfilmed and the details recorded on a special certificate for future reference in case of loss or theft. Among the loose gems that fall into this category, perhaps the most exceptional specimen, in recent months, was a large deep green peridot measuring 30·1 × 30·6 × 16·5 mm. This stone is, without doubt, one of the largest and finest gems of its kind in the world. Flawless to the unaided eye, and of very fine colour, a myriad of tiny included crystals were noted under the dark-field binocular microscope, giving the appearance of rounded particles in colloidal suspension. The peridot is emerald-cut, almost square in outline, and weighs 108·2 metric carats. Research has shown that only two peridots surpass it in weight, one being the huge gem in the Smithsonian Institution in Washington, D.C., and the other the 192·75 carat flawed stone said to be in the Diamond Treasury in Moscow.

Another but lesser gem—a 1·97 carat diamond—provided a pleasant surprise when placed under long wave ultra-violet light. It was a modern-cut brilliant of good white colour that fluoresced bright apple-green. Closer examination revealed that that portion near the culet fluoresced bright yellow while the remainder fluoresced light blue. This resulted in the strong apple-green blend mentioned above, when the stone was viewed from the front, in its setting.

Yet a third stone proved to be of more than usual interest. This was a fairly large antique brilliant-cut gem of lively appearance and resembling pink tourmaline or rubellite. A check on the refractometer gave a reading of 1·62 – 1·64 uniaxial negative. This seemed to be conclusive proof that the stone was indeed tourmaline. Subsequent checking with the microscope (a fast rule in the Gem Lab) revealed it to be a composite stone : lead glass at the back and with a pink tourmaline crown. This is the only example of its kind to come to the writer's notice, and points to the need for several tests before making a positive decision.

ASSOCIATION NOTICES

COUNCIL MEETING

A meeting of the Council of the Association was held at Saint Dunstan's House, Carey Lane, London, E.C.2, on Wednesday, 16th November, 1955. Dr. G. F. Claringbull presided.

The Council elected Mr. F. H. Knowles-Brown to act as Chairman of the Association until the next annual general meeting.

The following elections to membership took place :—

Fellowship

Anfield, John, Edinburgh
Bennett, Alan J., Cheltenham
Bialek, Walter, Birmingham
Bonanno, Antonio C., Washington, U.S.A.
Brinks, Feye, Leiden, Holland
Cameron, James S., Auckland, N.Z.
Chalmers, June R., London
Clark, Alastair R., Glasgow
Collier, Philip, Liverpool
Colman, Eric, Leamington Spa
Cooper, Paul O., London
Cross, Grace, Birmingham
Davies, Brian P., Gerrards Cross
Dungate, Peter J., Loughton
Havenhill, Asher D., Fresno, U.S.A.
Janes, Doris M., Margate
MacDonald, Ian C., Glasgow
Middlemiss, Albert E., London
Morrison, Neil C., Jnr., Inglewood, U.S.A.
O'Hara, Malcolm J., Sydney, Australia
Paterson, Douglas G., Edinburgh
Pyke, William, Wolverhampton
Schilling, Achim T., Stuttgart, Germany
Stern, Evelyn, Wembley Park
Summers, William H., Burnham
Todd, Evelyn, London
Williams, Donald K., Holland, U.S.A.
Wright, David, Weston-super-Mare
Wells, Robert A., New York, U.S.A.

Fellowship, Transferred from Ordinary and Probationary Membership

Clark, John A., Forfar
Dubois, Jean W., Hong Kong
Greenhill, Ann H., Belerno, Scotland
Hart, John, Glasgow
Henderson, Scott C., Dundee
Hessling, Frederick, Birmingham
Klippel, Robert, Sherman Oaks, U.S.A.
Lipman, Maurice, Johannesburg, S.A.
Muir, Ronald E., Wilmslow
Parkes, Frederick H. R., Lowestoft
Pyne, Eileen B., South Woodford
Rankine, Winifred M., Farnham
Sibley, Anthony J., West Wickham
Soukup, Edward J., San Diego, U.S.A.
Van Ameringen, Louis J., London
Vaughan, Howard M., Ross-on-Wye
Wells, Robert A., New York, U.S.A.
Worth, Bernard, Leicester

Transferred from Associateship to Fellowship

Field, Dean S. M., Toronto, Canada

ORDINARY

Chittock, Arthur, Blackpool
Clifford, Edwin W., Cassington
Diss, Geoffrey D., Barrow-in-Furness
Fox, Hobart D., Austin, U.S.A.
Grimsdell, John L., London
Humphreys, George F., London
Janison, Murray E., Brooklyn, U.S.A.
Leiper, Hugh, Austin, U.S.A.
Longbottom, William, Hull
Mendis, Clement S., Colombo, Ceylon
Metherell, Anthony W., London
Muir, William A., Wilmslow
Parker, Norman H., London
Rossiter, Bernard M., East Barnet
Schoo, Johan J., Arnhem, Holland
Sibley, Leslie P., West Wickham
Smith, Lawson B., Birmingham
Vainer, Milos, London
Weller, George T., Tunbridge Wells

PROBATIONARY

Banks, Kenneth A., Manchester
Clarke, David R., Sutton Coldfield
Craven, Barrie R., Leeds
Hodgson, Edwin S., Darlington
Peters, Brian L., Camberley
Pringle, David A., London
Smith, Cora A., Grays
Street, Graham C. W., Sutton
Cassarino, Joseph A., New York, U.S.A.

A sub-committee was appointed to consider services available to members and to make recommendations.

MIDLANDS BRANCH

At the annual meeting of the Midlands Branch of the Association, held at the Auctioneers' Institute, Birmingham, on 4th November, 1955, Mr. T. Solomon was re-elected to act as Chairman of the Branch for a fourth term. Mr. A. E. Shipton was elected Secretary of the Branch in the place of Mr. D. King, who had resigned for personal reasons. The following were elected to serve on the Committee :—Miss J. Rice and Messrs. A. Conway, G. Davis, B. Leng and D. King.

The meeting discussed the results of the recent exhibition (reported on p. 257) and approved votes of thanks to all who had contributed to its success. The official attendance figure, for the three weeks that the exhibition was open, was 50,400, by far the largest number that have visited a gemmological exhibition held in the United Kingdom.

MEMBERS' MEETINGS

14TH OCTOBER : E. Gubelin, Ph.D., F.G.A., C.G.—" Some notes on gemstone inclusions," given at the Medical Society of London Hall, W.1.

9TH NOVEMBER : Reunion and presentation of awards, Goldsmiths' Hall, London, E.C.2.

16TH NOVEMBER : Film evening, British Council Cinema, London, W.1. Films shown : Mi Vida and Diamond Coast.

The lectures given in connection with the Birmingham gemmological exhibition were recorded on p. 164 of Vol. V, No. 3, of the Journal.

TALKS BY MEMBERS

LEAK, F. E. : " The Science of jewellery," Redland (Bristol) Townswomen's Guild, 6th September, 1955 ; " Pearls," H.M. Prison, Falfield, Glos., 12th October, 1955 ; " The Science of jewellery," Toc H, Durdham Down Branch, Bristol, 28th October, 1955.

PARRY, MRS. G. : " Gemstones," Inner Wheel of Caerphilly, 7th November, 1955.

MELROSE, R. A. : " Gemmology," Rotary Club, Newcastle-on-Tyne West, 14th November, 1955.

STOLLERY, E. : " Gemstones," Inverness Technical Society, 19th October, 1955.

GIFT TO THE ASSOCIATION

The Council of the Association has received the gift of a monochromatic light unit from Mr. K. Decker of Sweden. The lamp, which gives monochromatic light at 5893A is housed in a solid metal casing, chromium plated inside to give good light reflection.

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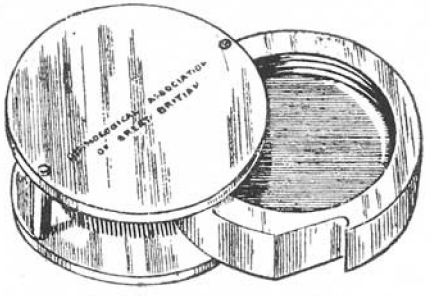

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THE JOURNAL OF GEMMOLOGY
AND PROCEEDINGS OF THE GEMMOLOGICAL ASSOCIATION OF GREAT BRITAIN

Vol. V No. 6 APRIL 1956

MORE NOTES ON IMMERSION CONTACT PHOTOGRAPHY

by B. W. ANDERSON, B.Sc., F.G.A.

FOUR years have elapsed since the first account was given in this Journal of " Immersion contact photography." [1] This very simple yet effective photographic technique involved the use of no camera, nor indeed of any apparatus beyond a glass cell and a few immersion fluids. It was found that when transparent gems were placed in liquid in a glass cell, and light from an overhead source was passed through them on to a sheet of printing paper or slow film, the contrast occasioned by the difference between the refractive index of the stones and that of the fluid was demonstrated in a spectacular manner when the photographic image was developed.

Stones with an index higher than that of the liquid displayed (in the *negative* picture) a white marginal rim, while the facet edges were marked with dark lines. If the index of the stone was lower than that of the fluid the effects were reversed. Moreover, the width of the marginal border and of the lines caused by the facet edges gave a clear indication of how nearly the index of the stone approached that of the liquid.

A positive print from one such photograph which had been taken on slow film (Fig. 1) will remind readers of the striking effects produced. The stones in this case were immersed in bromonaphthalene. A key to the stones is given in the rough sketch shown as Fig. 1a. Though for sodium light the liquid has a refractive index near 1·66, for the violet light which is chiefly operative with this unsensitized emulsion it is nearer 1·70. Hence the spodumene, for instance, is shown, by its narrow white border, to have an index slightly lower than that for the liquid.

Another immersion contact photograph having some interest is reproduced in Fig. 2. This was taken to confirm a suspicion that some of the beads in a tourmaline necklet were in fact aquamarine. The necklet was immersed in a cell of bromobenzene (1·56 for sodium light) and a contact photograph taken on Ilford " line " film by exposing for 15 seconds under an enlarger lamp stopped down to f/16. An enlarger is very convenient for the job, if available, as the stones in the cell can be arranged as one wishes in the light passing through the orange filter below the projection lens before swinging this on one side to make the actual exposure. It can be seen from the positive print reproduced that the tourmalines, having a higher index than the bromobenzene, all display a strong dark rim, where the aquamarines hardly show any border, since their index almost exactly matches that of the liquid for violet light. No fewer than five aquamarine " intruders " can be clearly seen in the photograph—a result not easily obtained by more orthodox methods.

As reported in a second article,[2] a convenient means has been found for making these immersion contrast effects visible without resorting to any kind of photographic process. In the present note I wish to report on recent developments in the original photographic technique which have potential practical value in gem testing.

In the original paper it had already been mentioned that major inclusions, zoning and other structures in stones were clearly visible in contact photographs if the immersion fluid had an index near that of the stone. Also, it was pointed out that this provided a convenient record of the shape, size, and facet disposition of the stones so photographed.

Some months ago, a reputedly genuine sapphire was sent from overseas for test in the Laboratory. A brief inspection under the

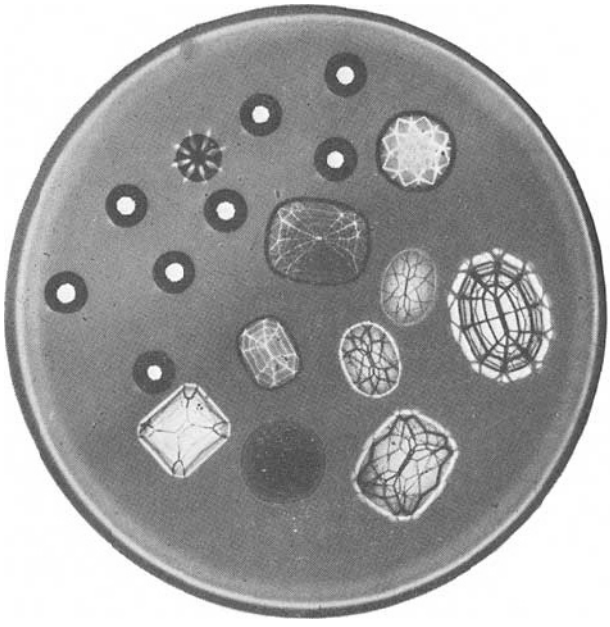

Fig. 1

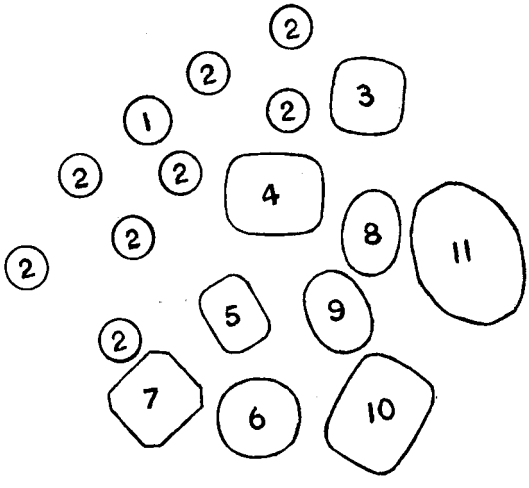

1. *Synthetic rutile*
2. *White Zircon*
3. *White sapphire*
4. *Golden chrysoberyl*
5. *Pink spinel*
6. *Brown sinhalite*
7. *Green spodumene*
8. *Phenakite*
9. *Hambergite*
10. *Tourmaline*
11. *Citrine*

Fig. 1a.

microscope sufficed to show the presence of numerous bubbles, and there was no shadow of doubt that the stone was a Verneuil synthetic. Curved bands of colour could also be seen when the stone was tilted slightly from the horizontal position. In view of a possible dispute about the identity of the stone after it had left our hands, it was thought wise to take an immersion contact photograph of the specimen immersed in a cell of methylene iodide.

The exposure was carried out under an enlarger lamp, using a narrow beam as described above. When the resultant photograph was examined with a lens, it was noted with some surprise and (one must admit) excitement, that a clearly-defined series of curved lines could be seen traversing the entire stone. This was remarkable for two reasons : firstly, because no curved striae of any kind could be seen in the stone itself when examined with lens or microscope in this orientation (resting on its table facet), and secondly, though curved swathes of colour could be seen when the stone was tilted (as mentioned above) these were the ordinary broad bands familiar in synthetic blue sapphire, and not the closely-spaced striae revealed in the photograph, which were almost like the " gramophone lines " one sees in synthetic ruby. They were, in fact, too closely spaced to be visible with the naked eye.

Encouraged by this result, another trial was later made with a large synthetic sapphire mounted in a ring in which, owing to the setting and the orientation of the stone, it was extremely difficult to see curved bands of any kind—and these were needed as proof, since the stone was remarkably free from bubbles. An immersion contact photograph in methylene iodide again rendered visible the " invisible " structure lines, and again as closely-spaced striae. An enlargement from this film is reproduced in Fig. 3. The only slightly curved striae may be discerned in the centre of the mounted stone, parallel to the length of the specimen. This negative was over-exposed and prints thus show poor contrast. The far more spectacular striae in an " alexandrite " type synthetic corundum, as revealed by the same technique, are shown in Fig. 4—again enlarged from a " line " film negative. One has to admit that in this case the lines were also visible under lens or microscope in this direction.

The powers of the method were further explored, and its crowning triumph in revealing invisible features came when it

Fig. 2.

enabled faint but indubitable growth-lines to be seen in two samples of *colourless* synthetic sapphire. Failure must be admitted, however, in the case of several yellow synthetics in which the same technique was followed.

Close inspection of some of the negatives showing the curved striae has revealed a series of faint *straight* lines intersecting the growth lines at a steep angle. The straight lines are strictly parallel to one another, and may be of the same nature as the straight lines parallel to rhombohedral planes, ascribable probably to twinning, which can sometimes be seen in synthetic corundum when viewed in directions nearly parallel to the trigonal axis—preferably between crossed polars. This is one of many points which require further investigation.

Experiment showed that for the curved striae to reveal themselves in these contact photographs the liquid must be very nearly the same refractive index as the stone. Thus attempts with synthetic sapphires immersed in bromonaphthalene were unsuccessful. A narrow beam of light is also advantageous, but in the absence of an enlarger something quite simple could probably be rigged—a focusing torch would probably prove quite effective. Given these not very onerous conditions we obviously have here a valuable accessory means of proving stones to be synthetic which are reluctant to yield this information under the microscope.

Since boules are commonly split before stones are cut from them, it is fairly certain that large synthetics at least will be cut with their table facet nearly parallel to the length of the boule—which means to say that the curved striae, which are always parallel to the cap of the original boule, will be viewed in an advantageous direction at right angles to the table facet, or very nearly so. It is undoubtedly

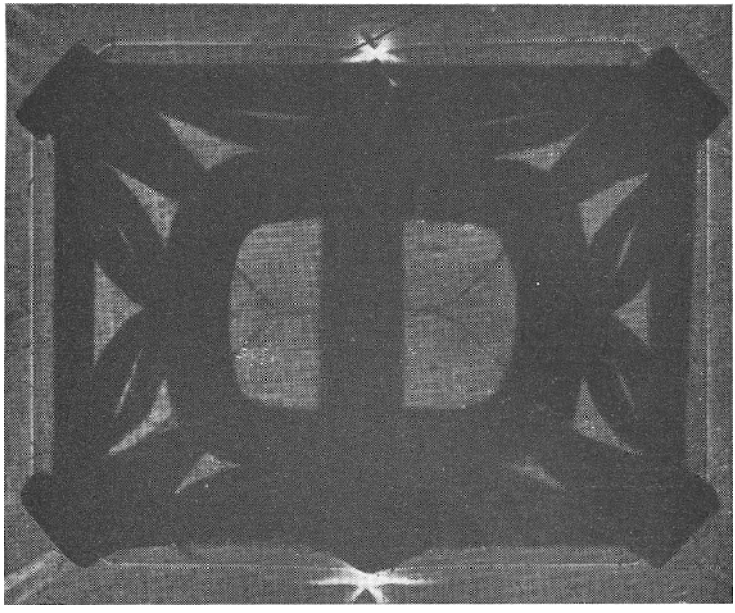

Fig. 3. Synthetic sapphire in ring immersed in methylene iodide.

this fact that makes the striae show up in these photographs, which are all taken with the stone resting on its table.

Transparency Tests

Before closing this article, it is perhaps permissible to remind readers of another interesting development of immersion contact photography, which merits further exploration, and that is, the differences in transparency for various wavelengths of light which such photographs can be made to reveal. In Fig. 1, for instance, the brown sinhalite (numbered 6) is seen to be nearly opaque to the operative violet light, and the golden chrysoberyl (numbered 4) very nearly so. Similarly, the green tourmalines in the necklace shown in Fig. 2 appear notably dark in the contact photograph, being almost opaque to violet light.

Obviously, by using panchromatic film and a series of good colour filters, much information concerning the colour absorption of the various stones could be obtained, and incidentally concerning their dispersion, compared with the known dispersion of the liquid used.

Experiments of this kind, however, would no longer be very simple, and would have small value in practical testing. But transparency tests extended into the ultra-violet can be of real

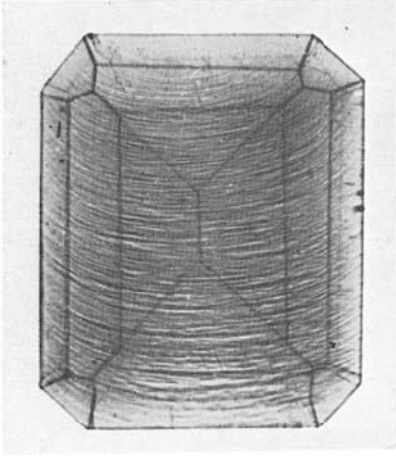

Fig. 4.

Synthetic "alexandrite type" sapphire, immersed in methylene iodide.

diagnostic importance in distinguishing between synthetic and natural emerald, and between synthetic or natural red, pink, yellow or colourless corundums. In each case it has been found that the synthetic stone is notably more transparent to ultra-violet light than the natural[3]. In these latter traces of iron probably act as the absorbing factor.

We have to thank Mr. Norman Day[4] for the brilliant suggestion (backed by a series of fruitful experiments) that immersion contact photographs taken with one of the inexpensive short-wave mercury lamps first introduced to gemmologists by Caudell and Webster[5] could be made to reveal these differences in ultra-violet transparency very clearly. Ordinary printing-paper (e.g. Velox) was found preferable to the faster bromide paper for such experiments, as it is less sensitive to the residual violet light passed by the OX7 glass filter of this lamp. Exposures must be short and are rather critical. It is almost essential when testing an unknown stone by this method to include known natural and synthetic stones on the same photograph for comparison.

Day used a dish made from thin pyrex glass, which is silica-rich and thus fairly transparent to ultra-violet rays. The difficulty of dish transparency can be side-stepped, the writer found, by putting the stones directly on the paper, immersed in water in any convenient dish (such as a developing dish). A parcel of some hundreds of calibre rubies, for instance, could be checked by this means to give a guide as to whether any synthetics were present. Glycerine is also transparent a long way down into the ultra-violet, and could be used in place of water provided the paper were well rinsed before development. Its higher index of refraction (1·47) would allow more light to pass into the stones than when they are immersed in water (1·33).

No satisfactory comprehensive papers can be found in the literature dealing with the ultra-violet transparency of minerals. Of the two references known to me, the first is a paper by Miller published in 1862 (Phil. Trans.). In this, which, it will be realized, dates from a time when the spectroscope was in its very early stages, no wavelengths are given ; simply the relative lengths of the spectra of light transmitted through his rocksalt spectrometer with quartz lens camera. This paper is chiefly interesting in that, of the three

diamonds tested by Miller, two were clearly of the rarer type II variety.

The second reference is to a paper by Absolom (Phil. Mag., 1917) in which wavelengths are given of the last line transmitted from a copper arc when passed through various minerals.

Looking at these and other known data the general conclusion can be drawn that substances, whether liquid or solid, of low refractive index and dispersion are relatively transparent to ultra-violet light (water, glycerine, rock salt, fluorspar, quartz). But this generalization refers only to the true ultimate absorption of the substance and can be profoundly modified by the presence of absorbing impurities, such as iron. Hence the variations between synthetic and natural stones and the relative opacity of amethyst and citrine compared with rock crystal, which was noted by Mr. Day.

It has been found that differences between type I and type II diamond are clearly shown by this method, and the fact that strontium titanate with its high dispersion is more absorbent of near

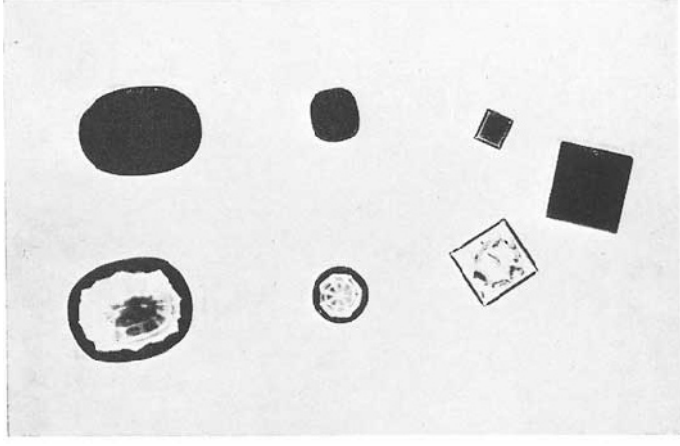

Fig. 5.

Top row (from left) : Yellow sapphire, type I diamond and two natural emeralds.

Bottom row : Synthetic yellow sapphire, type II diamond, synthetic emerald.

ultra-violet light than diamond with its relatively low dispersion may provide a useful test for distinguishing the two when mounting precludes a density test.

Fig. 5 shows an example of an ultra-violet contact photograph in which the stones were immersed in water and rested directly on line film.

Enough perhaps has been said to indicate the rich potentialities of immersion contact photography in practical gem-testing, over and above its original use in demonstrating differences in refractive index. Much work remains to be done—and will be done, as opportunity permits.

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   Anderson (B. W.). *A New Test for Synthetic Emerald.* Ibid., July, 1953.
4. Day (N. H.). *Transparency of Gemstones to Ultra-violet Light.* Journ. Gemmology, October, 1953.
5. Caudell (P. M.) and Webster (R.). *An Inexpensive Short-wave Ultra-violet Fluorescent Lamp.* Gemmologist, April, 1953.

COBRA EMERALD MINE REOPENED

The Cobra Emerald Mine, situated in the Gravelotte district of the Northern Transvaal, has been reopened recently and production commenced.

Before the last war, the Cobra Emerald Mine was a consistent producer of the best qualities and quantities of Emeralds mined in South Africa ; the highest output, recorded in 1937, was 154·081 carats.

The Cobra Emerald Mine is presently owned and operated by African Gem Company, P.O. Box 9112, Johannesburg.

DOUBLING OF THE BACK FACETS IN DIAMOND

by R. KEITH MITCHELL, F.G.A.

THE photograph reproduced in Figure 1 is of an interesting stone lent to me recently by Mr. John Croydon of Ipswich. The stone was not easy to photograph and for the sake of clarity I have drawn the effect seen, in diagram form, in Figure 2. In spite of the extraordinarily pronounced " doubling " of the culet and back facets to be seen in these two illustrations the stone is in fact a diamond.

Such " doubly-refracting " diamonds have been encountered from time to time and may even have lead to their being dismissed as white zircon. But apart from possible anomalous patches due to strain, such stones are just as isotropic as any other diamond. The " doubling " effect is an optical illusion entirely due to reflection. This, in turn, is due to the unusually bad cutting of the stone.

In the present stone the pavilion facets are inclined to each other at an angle of approximately 80°. They are, therefore, as shown in Figure 3, steep enough to allow totally reflected images of opposing edges of the culet to be seen through the front of the gem. The effect is enhanced by the fact that the pavilion facet edges are not diametrically opposite each other, so further reflections give the impression that these edges are also doubled.

Examined with a x10 lens the stone gives a very passable impression of being strongly birefringent, but closer inspection shows that something is not as it should be. Firstly a double image of the culet in a birefringent stone will show one image laterally displaced in respect of the other in one direction only. Here the " displacement " consists of a second and larger culet image outside the first one. Also the space between the two images is mirror-like in appearance (total reflection) while if this were genuine doubling both images would be transparent. It will also be noticed that the doubled pavilion facet edges diverge and that in one case an edge is actually seen in triplicate. None of these things could happen in the genuinely birefringent stone.

Having established these points of variance the question then became one of proving that the effect was due to simple reflection.

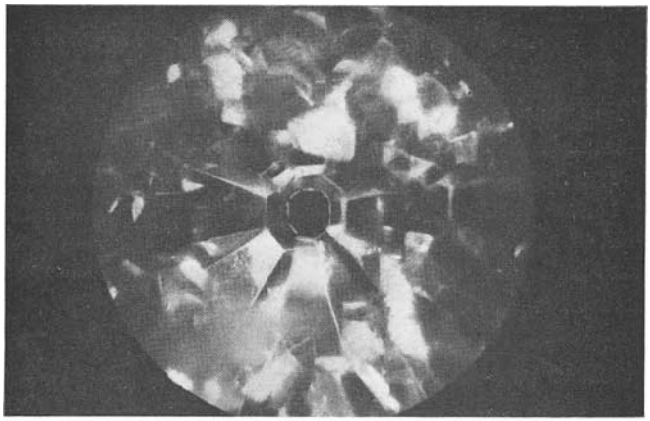

Fig. 1.

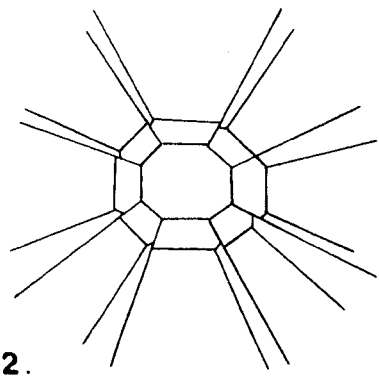

FIG. 2.

DIAGRAMATIC DRAWING OF "DOUBLING" SEEN IN FIGURE 1.

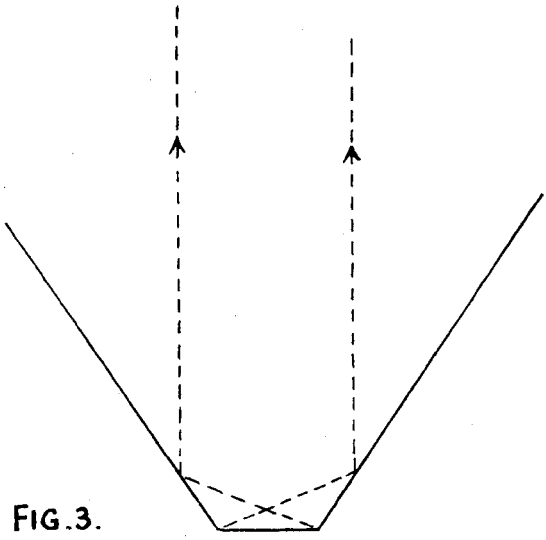

FIG. 3.

DIAGRAM SHOWING HOW STEEP ANGLED PAVILION PERMITS CULET REFLECTIONS TO BE SEEN THROUGH TABLE OF STONE

This did not seem easy until the thought occurred to put a minute dot of ink on one culet edge. This was done and its reflection was seen in the second image but on the opposite side of the stone. The matter was proven.

It may be asked—Why does this happen only in occasional stones ? The answer is simple enough—it is just a matter of cut. In a correctly cut stone the pavilion facets converge at about 100°. At this angle any reflected images of the culet edges would pass out of the side facets of the crown and no complete culet image could be seen through the table. It is possible in many instances, even in modern stones, to see reflections of opposed pavilion facet edges, but, without the " double " culet, the eye sees no significance in this fact.

I am grateful to Mr. Croydon for the loan of this stone and permission to write about it and to Mr. Robert Webster for help in the rather difficult matter of producing an acceptable print from my rather inexpert photo-micrograph negative.

DIAMOND SELLING PRACTICES IN AMERICA*

by RICHARD T. LIDDICOAT, Jnr.

FOR the past three to four years the Gemological Institute of America has been engaged in an analysis of the diamond marketing structure from the point of sale of rough by the Diamond Trading Company to its purchase by the retail jeweller.

This investigation was initiated to provide a means of appraising exactly the effect of make on price.

The need for such a study was pointed to by some of the diamond-selling methods employed by many jewellers. Specifically we wondered if some of the best-trained jewellers weren't being persuaded unwisely to muzzle some of their most effective weapons : i.e., those based on their superior knowledge of diamonds. Out of this study came our new diamond correspondence course, the diamond evaluation class, and a number of convictions regarding the sale of diamonds at retail.

Many signs point to the conclusion that interest in diamonds is high—but few jewellers seem to take utmost advantage of this interest to increase their sales to a maximum. Diamond sales seem at best to represent a small part of their potential.

Every jeweller must believe that diamonds bring pleasure and beauty into their owners' lives. Therefore, the jeweller who sells a diamond to a person who wouldn't otherwise buy one is performing a valuable service.

In certain respects fine jewellers seem to have oriented their diamond selling more to what other jewellers will think than to serving the public taste.

This is demonstrated by the manner in which diamonds are offered and the jeweller's interpretation of grading standards. First let us examine the methods by which diamonds are sold by many jewellers and the direction of recent trends in this field.

There are still many jewellers who offer basically one grade only. They may obtain a heavily flawed stone, if requested, or have

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a price line which is offered almost reluctantly—but basically they contend that they offer one grade.

This grade may be called top colour, flawless ; " blue-white, perfect " ; " the finest money can buy " ; " a good value " ; or " the famous Jones & Jones quality."

Firms handling one grade only meet price competition either by more effective selling or by hedging their established standards for that grade. Standards are hedged through forcing the grader to be less particular on colour or clarity or to buy spread stones. If these stores sell more effectively, they could be adding sales without the handicap of having only one price to offer in each size. If they hedge, the reputation of the firm is threatened, if and when qualities sold as the finest are demonstrated by competitors to be misrepresented.

If its grade is really top quality in all respects, the firm earns a reputation for high prices. A single grade at highest to fairly high quality gives the fake discount man and the high-markup house a beautiful screen behind which to operate. Perhaps the fact that so many jewellers have offered diamonds in only one grade is responsible for the common question, " What is a one-carat diamond worth ? "

Thus the single-grade diamond house is condemned if it maintains the standards it claims and condemned if it doesn't. In the face of this, it is amazing that so many fine firms have continued to emphasize one grade only.

To better their competitive position, other firms have added an extra grade or more to be able to offer lower prices. In our opinion, this is a step in the right direction. The question that arises immediately is how far a fine firm should go.

A satisfactory solution is one which preserves the reputation of the firm and keeps inventory within sensible bounds. A thorough analysis of the reputation question suggests a review of the development and meaning of diamond quality standards.

Inclusions not visible to the unaided eye and poor proportions are not considered important by jewellers in many countries. Many years ago jewellers in the U.S.A. and Canada started using watchmaker's loupes to examine diamonds. Gradually more powerful ones were used. This trend to more careful grading was

culminated in the Jewelery Trade Practice Rules of the Federal Trade Commission and the American Gem Society Rulings. Such standards are wonderful if they are interpreted in the way they were intended ; that is, that no stone should be sold when described by the highest quality terms unless it meets these certain standards. However, it does not mean anything less is undesirable, which is the interpretation applied to quality terms by many ethical jewellers.

Diamond grades and diamond standards from the customer's angle are much different than from the jeweller's. What does the term perfect or flawless mean to a layman ? When it is understood what is involved, how many would choose a larger stone for the same money ?

The Gemological Institute's imperfection system employs a standard nomenclature ; flawless ; very, very slightly imperfect ; very slightly imperfect ; and imperfect ; with each grade below flawless divided into two categories for pricing purposes.

In this system flaws are not visible to the unaided eye in any grade above SI_2, and even then are difficult to see. In fact, stones of that grade contain no visible flaws face up in the mounting. An SI_2 of the finest colour and make has a value between 50% and 60% of a flawless stone of the same colour and make.

Unless the flaws are cleavages they do little if any harm to the stone. To the customer, inclusions which make a stone unique and reduce its price could well add to its desirability if presented positively. The fact that a flaw is shown to him under magnification surely adds to his confidence. In fact, the sceptic may well prefer the inclusion he has seen to the one he fears is there in the stone represented to him as flawless. In any event, confidence is inspired by the fact that inclusions present are pointed out. When flaws are invisible and have no effect on beauty, what is their importance to the layman who wants a larger stone than he could afford in a flawless, top-colour stone of fine make ? The perfect and flawless standards were written to protect him from misrepresentation—not to force him to buy only flawless or perfect goods.

In colour standards, a somewhat similar situation exists. How far down the colour scale must one go before colour is visible face up ? Of course, the size of the stone governs to a degree the point at which colour becomes visible.

In the diamond-colour picture, grading terminology and colour scales tend to present a somewhat misleading picture, in that grades at the very top of any scale differ in transparency rather than in colour. On the American Gem Society's Colorimeter Scale, it takes a keen eye to detect any colour whatsoever above 1·5, even under the controlled conditions afforded by the Diamondlite. It takes a keen eye to note colour in a 2·5 face up in a mounting. On the Institute's letter colour scale, this would be about I, and roughly a top crystal in the old terminology. The lowest colour not visible face up in a mounting will usually cost about 80% to 85% of an otherwise similar stone of top colour.

This discussion so far assumes that yellow is considered ugly by the average customer. Some layman like topaz and golden sapphire colours and would like a yellow diamond unless told that a yellow stone is inferior. Yellow quartz is one of the more popular stones with the buying public, indicating that many people find yellow an attractive colour. When he consistently directs customers away from yellow colours in diamonds, the jeweller is stressing rarity rather than what to someone else is beauty. In view of all this, how vital to the potential owner are the jeweller's quality standards in clarity and colour ?

How many jewellers who handle genuine stones are interested in wearing or owning synthetics ? Very, very few. Yet how often have layman friends said to you, " why buy a real stone when the synthetic is hard to tell from the real and a lot cheaper ? "

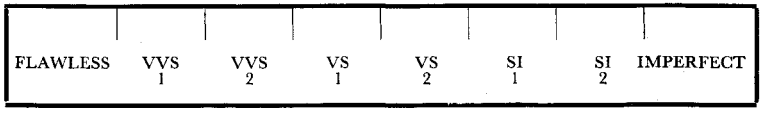

Fig. 1
A Clarity Yardstick.

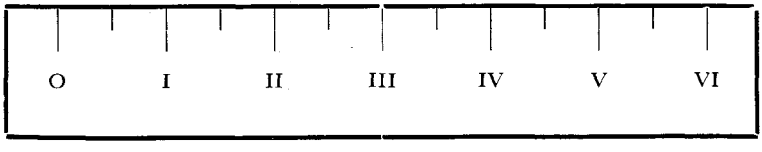

Fig. 2
The American Gem Society's Colour Yardstick.

If some customers feel this way how can they appreciate the jeweller's feeling about such intangibles as River versus a Wesselton—or even a Top Cape ? If anything, this lack of appreciation of differences not visible to the unaided eye is most common in the well-educated and wealthy groups the prestige jeweller is seeking to sell.

Oddly, many jewellers lay great stress on clarity and colour in grades the layman cannot distinguish ; yet make, the easily distinguishable characteristic of diamonds, is often disregarded. Make should be stressed and minimum acceptable standards for his finest quality set by the jeweller.

The American-cut proportions were worked out and offered originally as the compromise, giving maximum fire consistent with maximum brilliancy at a decent weight yield from the octahedral crystal. Considerable departures from the highest clarity standard—flawless—and the highest colour can be made without change in a diamond's appearance. However, more than slight deviation from either the proportions or the angles of the American-cut affects the stone's beauty. Although price reductions of up to 50% are possible with make discrepancies alone, it seems to be the last quality factor which should be lowered to meet price competition.

However, if size is the only concern of an individual, make quality reductions added to those in colour and clarity give the jeweller a wide range of sizes to offer at a given price. The trained jeweller can select make deviations, such as the thin crown and spread table with correct pavilion, so that at least the brilliancy remains high in the quality which offers maximum size for money spent.

Taking these prices versus quality standards into consideration, how can the over-all diamond situation be improved ?

It will never improve until fine jewellers take a realistic attitude in offering diamonds to the public. The real potential has never been reached in selling diamonds. True, more engaged couples declare their intentions with diamond than at any time in the past, but this represents a small part of what is possible.

If jewellers make it clear that a customer can have a stone which he would like at a price he can afford, much as he can when purchasing the items which compete for the consumer's money, half the battle is won.

The average person knows nothing about diamond quality. To the layman, the size of the price ticket is what determines quality. Anything which clarifies diamond grading without befuddling is sure to aid the ethical jeweller. Unless the trained man takes advantage of his training to help his customer, he fails to perform a duty and fails at the same time to make the customer aware of the real advantages to him of the jeweller's knowledge. It is constantly amazing how fearful many fine jewellers are of giving customers any information whatsoever—this is to prevent boredom, they say. Yet a short exposition of how to grade diamonds and the care used is often the one item that brings customers.

Figure 3 demonstrates graphically how a customer who has been given a very brief account of the three C's* and how diamonds are graded may be shown how he may choose quality desired at the price he wishes to pay.

CLARITY AND CUTTING GRADES

AGS Colour Grades →		**0.-1·4**	**1.9-2·4**	**2.4-2·8**	**3.5-4·0**	**4.5-5·0**
Flawless	Fine Cut	$1000	910	860	670	390
	Good Cut	925	840	795	630	360
	Fair Cut	800	730	690	535	310
	Poor Cut	615	560	530	410	240
$V.V.S_2$	Fine Cut	820	750	710	550	330
	Good Cut	760	695	655	510	305
	Fair Cut	655	600	570	440	265
	Poor Cut	505	460	435	340	260
$V.S_2$	Fine Cut	670	640	590	450	280
	Good Cut	620	590	545	415	260
	Fair Cut	535	510	470	360	225
	Poor Cut	410	395	360	275	170
$S.I_2$	Fine Cut	550	510	480	380	230
	Good Cut	510	470	445	350	210
	Fair Cut	440	410	385	305	185
	Poor Cut	340	315	295	235	140
		Colourless			Colour visible Face-up	

Fig. 3

Assuming a Retail Value of $1000.00 *for a Diamond which is Flawless, of Finest Colour, and Cut to the Standards of the American Cut, the other Figures show comparable Retail Values depending on Quality. In no Imperfection Grade listed would a flaw be visible to the unaided eye when the Diamond is mounted. Note that there are Gaps between both the Colour and Imperfection Grades Shown. Fair and Poor Cuts represent Degrees of Spreading.*

* The term " 3 C's " is employed by American jewellers to indicate Colour, Clarity or imperfection and Cutting grades of relative quality.

One simple way to convey a complex story without boring the listener is by diagram. By showing the yardstick by which each quality factor is judged and his careful grading methods, the jeweller establishes himself as an expert and gives the layman a better idea of what is important in buying a diamond. A diagram such as that shown in Figure 3 may be used to demonstrate the range of possibilities in quality and size variation at a given price. It is clear that the price of a stone with the finest make can drop over 50% with reductions in colour and clarity grades insufficient to affect the appearance of the mounted stone. Few customers understand this. If clarified by diagram, the customer's choice may be different and it is sure to be made with greater assurance. A simple, logical presentation establishes the confidence that produces immediate sales or brings " lookers " back.

When a jeweller handles one grade only, X money buys one size only. That size may seem too small. The same problem exists when only two or three qualities are handled. Why not increase the size range by adding grades ? Some jewellers say, " We will never reduce our standards." In effect this is saying, " We will continue pushing our own ideas and tastes on our customers." In other words, such a jeweller uses his training and the keen eye he has developed with years of practice to force on his customer a more expensive stone because it has a quality requiring the jeweller's training and keen eye to appreciate. Is this realistic or is it fair to the average customer ?

What seems to stand between such jewellers and offering any or all grades is pride. This is often prompted by a natural unwillingness to give outside appraisers grounds on which to criticize merchandise. How can a firm's reputation be impugned if the customer has been told in detail exactly what he is getting and the same information appears on the sales slip ? If a customer wants a 1-carat stone in a platinum mounting and wants to pay no more than $500, what valid reason is there for not supplying such a stone ?

When asked this question, some jewellers say, " Even if I tell him what it is, he may tell his wife or another jeweller it is blue-white and perfect." Often firms which sell nothing but flawless, fine-coloured diamonds cut to exacting standards have their

merchandise criticized by the unethical. Unwarranted criticism of others' merchandise of prices is one of the banes of the jewellery industry. However, no need nor desire for another's appraisal exists if your customer has been given a clear story of the quality of the merchandise (and if the grading is listed on the sales slip).

Maintaining high standards can be done regardless of the qualities which are sold. To the layman, standards have to do with business ethics ; in other words, the manner in which merchandise is presented and represented. This has nothing to do with specialization, which is the true nature of a one-quality policy.

So long as goods are represented honestly and each grade is listed on the sales slip, why not offer the customer the stone that will give him the most satisfaction ? The average customer will take more pride in a stone 30% or 40% larger for the same price if he cannot see a quality difference. It seems somewhat more important to satisfy customers than to try to silence appraisers.

One other argument against many grades is more logical. It refers to firms which have difficulty selling their top merchandise and who feel that adding grades will reduce their average sale.

It should be emphasized that adding grades is not suggested only as an answer to price competition—these suggestions are offered in the belief that they will increase customer confidence as well as satisfaction and increase the diamond sales potential. If grades are added and the result is nothing more than a lower average sale, the diamond salesmen are not selling effectively or qualities and grading are not explained effectively.

A jeweller has been highly successful in maintaining sales of his finest quality while stepping up the sale of some-what lower-priced goods. His simple system makes clear graphically where every stone falls on each scale. This is carried out on price tags by a colour code. This system makes the finest seem most desirable and keeps the jeweller constantly in an open-to-buy condition in many sizes of his top quality while increasing the sale of lower priced goods as well. This firm handles a range permitting stones to be offered as low as half the price of their finest, while keeping make fine and colour high. With little effect on appearance, a considerably wider range is possible and seems desirable.

To summarize : We at the Gemological Institute are convinced that the full potential of diamond sales possibilities has not approached realization. We feel that one reason is that some of the quality standards imposed by many fine jewellers are unappreciated by the average person. As a result, for those who can neither appreciate nor afford the finest in a good size, prices are much higher than they need to be. Why force such people into unethical establishments by failing to offer what they want at a price within their reach ? By giving the customer a clear picture of just what is available to him for the amount he can spend, and showing him that a stone of a size of which he will be proud is well within his budget, the jeweller can increase his diamond sales tremendously.

By offering a wide range of qualities and prices and letting the public know about it, the legitimate jeweller removes the protective screen behind which the long-markup man and so-called discount man operate.

Why continue to force on the customer an appreciation of quality gained only through long training and experience, when that appreciation of the very finest quality is not shared by the average customer ? Why rob that customer of the pleasure of owning a diamond or reduce his pride of possession by selling a smaller stone than the size he would enjoy most ?

One of the factors tending to affect diamond sales is the public's limited knowledge of the product. The trained progressive jeweller is in a position to dispel that fear without either boring his prospective customer or using a technical approach.

The greater knowledge possessed by gemologists means diamonds can be presented to customers more excitingly and displays and advertising can be better planned to attract favourable attention to diamonds—that is how diamond knowledge best serves the jeweller.

It is the retailer's function to *serve* the public to the best of his ability, but not to use his ability to convince customers that what they want is not the best for them. The trained jeweller who will merchandise diamonds realistically will increase customer satisfaction, as well as his success in business.

Gemmological Abstracts

FRANCO (R. R.). *A côr das pedras preciosas.* Gemologia, Ano. 1, No. 1, pp. 23-27.

Deals in general terms with intrinsic colour in precious stones, explaining briefly allochromatism, idiochromatism, heat treatment and so on. Gems listed under their colouring elements and again under colour headings. It is to be noted that although Peridot appears in the text, its place under " Gemas Verdes " (Green Gems) is taken by " crisólita "—a confusing usage. Mention is made of the local practice of selling greenish, heat-treated quartz as Brazilianite, to the detriment of the true mineral of that name.

R.K.M.

MOREIRA (P. S.). *Os grandes diamantes Brasilieros.* Gemologia, Ano. 1, No. 1, pp. 5-12.

An account of large diamonds found in Brazil. Some 28 are listed with details of weight and provenance. A final table lists the 60 largest stones found in all parts of the World. It is significant that 23 of these are Brazilian, some ten of which, including the Presidente Vargas 726·28 cts., the Darcy Vargas 460 cts., the Coromandel 6º 400·65 cts., have been found in the last twenty years.

1 Illus. R.K.M.

GRODZINSKI (P.). *Gemstones in early Indian writings.* Gemmologist. Vol. XXV, No. 295, pp. 28-30. February, 1956.

The literature of the Middle Ages provides some curious writings on gemstones. Dr. Grodzinski's article is built up from extracts from the French work *Les lapidaires Indiens* by L. Finot. It mainly deals with the legends about diamond.

R.W.

SINKANKAS (J.). *Some freaks and rarities among gemstones.* Gems and Gemology. Vol. VIII, No. 7, pp. 197-202 and 229. Fall, 1955.

Details some unusual specimens and varieties of gemstones. These include a golden beryl crystal from Madagascar which produced a number of chatoyant cabochons, one of 44 carats. One of these was subsequently heat-treated to give an aquamarine colour. Another beryl crystal of full blue colour from Brazil is discussed. This showed a cat's-eye effect. Morganite cat's-eyes are discussed. Star beryls from an unknown locality in Brazil are mentioned and the nature of the inclusions producing the star effect referred to. Enstatite-hypersthene from India is another stone mentioned and sphalerite (zinc blende) from a number of sources is discussed in respect to the difficulty in polishing. A notable specimen of near-colourless material (cleiophane) from New Jersey was fashioned into a trap-cut stone of 10 carats ; it looked like a slightly greenish diamond. Small stones have been cut from the clear pink-coloured tremolite called *hexagonite.* Hexagonite appears to be a name new to English gemmology. Greenish-blue boracite from Germany, orange-brown calcite from Baja (Lower) California, Mexico, and colourless magnesite from Bahia, Brazil, have been faceted into stones.

R.W.

LEA (I.). *Notes on microscopic crystals included in some minerals.* Gems and Gemology. Vol. VIII, No. 7, pp. 203-207 and 218. Fall, 1955.

The article is a verbatim reprint of two of three papers written for the Proceedings of the Academy of Natural Sciences of Philadelphia by Isaac Lea in 1869. These papers probably represent the earliest work done in the United States on gemstone inclusions. Most of the inclusions referred to are needles in garnets, star garnets, sapphires and star corundums, and in red spinels (spinelle ruby). The second paper records the inclusions seen in fourteen individual specimens and other observations on some rubies and sapphires. Of historical value only.

1 illus. R.W

GÜBELIN (E.). *Amblygonite—new gem.* Gems and Gemology. Vol. VIII, No. 7, pp. 208-214. Fall, 1955.

During 1953 some pale yellow crystals were found in a drawer of an old museum, and these were identified by Dr. A. Schroder of the University of Hamburg as amblygonite. The present article is an exposition of the characters of this lithium aluminium fluo-hydroxy-phosphate mineral. The colour, the symmetry and habit of the crystals are given. There is one direction of cleavage parallel to the basal plane. Amblygonite belongs to an isomorphous series in which the refractive index diminishes and the density increases with increasing amount of fluorine. The gem material, which has a hardness of 6, is however fairly constant with refractive indices of 1·61 and 1·64 (birefringence is 0·026) and the density 3·01 to 3·03. The axial angle is given and compared with that of spodumene. A table of the constants found from individual stones is given. The inclusions are cloud-like and in parallel formation, the parallel bands running either parallel to each other or intersecting each other, and they consist of a multitude of tiny cracks mixed with impure matter. Under long-wave ultra-violet a faint greenish-yellow fluorescence has been noted. X-ray powder photographs were made using Cu-K radiation in a 114mm. diameter Debye-Scherrer camera. A table of the lines and their intensities is appended. There is no information concerning localities.
6 illus. R.W.

WATABA (N.). *Electron microscopic observations of aragonite crystals on cultured pearls.* Gems and Gemology. Vol. VIII, No. 7, pp. 215-218. Fall, 1955.

The article is a reprint of a report of the Faculty of Fisheries, Prefectorial University of Mie, Japan, Vol. 1, No. 3, pp. 449-454. The author had previously made a study of the surface crystals of cultured pearls and had distinguished three types of surface pattern : volute, parallel and irregular, caused by different modes of aggregation of aragonite crystals. As the crystals are so small, about 2·5 μ in diameter, they could not be well examined by an optical microscope and the electron microscope was employed in the later investigations. Three pearls were examined, one of each type. The method used was to clean the pearl surface with alcohol

and then place it on a polymerizing methylmethachryl on a glass slide. After polymerization the pearl was removed leaving an imprint on the plastic surface. This was then plated with a thin membrane of aluminium, and this replica of the pearl's surface in aluminium was electron micrographed at 50kV, giving a magnification of ×2000. The results obtained with these three pearls is given and the data obtained discussed. A concluding summary is appended in which the author gives his theory of pearl formation as the nacreous layer of pearls is formed by repeated crystallization, partial dissolution and recrystallization.
6 illus. R.W.

BROWN (J. C.). *Kollur : Reputed home of the Koh-i-nur.* Gemmologist. Vol. XXIV, Nos. 292/3, pp. 199-203 ; 222-225. November/December, 1955.

A critical review of the history of the Koh-i-nur diamond which now rests in the front of the Queen Mother's crown. Some writers relate the name Koh-i-nur to the place Kollur where many large diamonds had been found. The history of the stone since it came into the possession of Nadir Shah in 1739 has been well told in Major General Sitwell's recent work *The Crown Jewels and other regalia in the Tower of London*, but before this time the history is controversial—there being two major contentions, one, based on their weights, is that the Koh-i-nur and Baber's diamond were identical, and the other is that the Koh-i-nur is part of the Great Mogul diamond remarked upon by Tavernier. The history of Baber ; notes on Tavernier's travels, and other records are marshalled in order to give the reader some idea of the difficulties in deciding the origin of the famous diamond. The visit of Tavernier to the Indian mines and his description of them, the diamonds found there and the methods of mining are given. It is said that despite his claim Tavernier was not the first European to visit the mines. The *rati*, the seed of the *Abrus precatorius*, is the weight used for jewels in Northern India, but the *mangelin*, the seed of *Adenanthera pavonia* (calculated to be 1·45 metric carats), is used in Golconda and Southern India. The geological features of the area are briefly touched upon.
12 references. 4 illus. R.W.

AMRINGE (E. V. VAN). *Crocidolite and Tiger's eye.* Gemmologist. Vol. XXIV, No. 293, pp. 230-232. December, 1955. (Abstracted from the Mineralogist for September, 1954.)

Asbestos is discussed as a mineral ; the varieties are named (chrysotile misspelled as chrysolite), and the commercial significance of the mineral remarked upon. Particular attention given to the crocidolite variety. The Griqualand West, Northern Cape Colony deposits are discussed geologically and with reference to the mining. The pseudomorphs of the mineral found at Naauwpoort in the Hay district near Prieska, are a soft oxidized variety of golden yellow colour called *griqualandite* and the hard siliceous variety of golden yellow through yellowish-brown to a red colour ; the material so well known as Tiger's eye. When less altered, somewhat softer and of a blue colour, it is known as Hawk's eye. Sixty years ago the material fetched 22s. 6d. per carat; it is now one of the cheapest of attractive gemstones. The material is cut as cabochons and as cameos and intaglios. An interesting stone resembling cat's eye is prepared from tiger's eye by treating the rough material with hydrochloric acid. R.W.

ANON. *A pearl fishery will take place.* Gemmologist. Vol. XXV, No. 294, pp. 1-3. January, 1956.

After a lapse of 28 years a pearl fishery took place in the Gulf of Manaar last year. Some notes on Tuticorin and the fisheries is given. The pearl producing oyster is the *Margaritifera vulgaris.* The Indian pearl banks, or paars, extend over a distance of 100 miles from Cape Comorin to Rameswaram. There are three divisions ; the southern from Cape Comorin to Manapad, the central from Manapad to Vaipar, and the northern from Vaipar to Rameswaram. The central division, the Tuticorin division, being the most productive. The paars fished last year were the Tholayiram, Kuthadiyar, Vadaombathur and Saithombathur.
3 illus. R.W.

GÜBELIN (E.). *Further notes on gemstone inclusions.* Gemmologist. Vol. XXV, No. 295, pp. 21-24. February, 1956.

A report on the lecture given by Dr. E. Gübelin to the Gemmological Association in October, 1955.
12 illus. R.W.

GRODZINSKI (P.). *Engraving on diamond.* Gemmologist. Vol. XXIV, No. 293, pp. 219-221. December, 1955.

The article traces something of the history of engraving on diamond and mentions some of the engraved diamonds recorded in literature, with special reference to an engraved diamond showing the head of the Dutch Queen Fredrica.
10 references. 1 illus. R.W.

ANDERTON (R.). *The new Gachala emerald mine in Colombia.* Gems and Gemology. Vol. VIII, No. 7, pp. 195/6. Fall, 1955.

Said to have been accidentally discovered during 1954 in the Province of Cundinmarca, Colombia, is a new emerald mine, Las Vegas de San Juan, or as locally known, the Gachala, which lies some five miles from Chivor. An estimated million dollars worth of emeralds was taken out by contraband miners during the first six months. Since then the Government has prevented further mining and a legal concession has been applied for, but banditry is still rife. The deposits have been considered to have been thrown down from higher levels of the mountain, and no crystals in matrix (Gangas) have been found. Simple shovel and bar mining of the soft sand and gravels is the method used for recovery of the emeralds, which are said to be of better quality than those of Chivor, and indeed nearer to those of Muzo. The inclusions or *jardin* tend to settle at the bottom of the crystals and make for cleaner and clearer stones. Chivor is said not now to be worked and Muzo is about to operate on a limited scale. Cosquez has not been operated for many years. The outlook for greater emerald production is poor.
1 illus. R.W.

ANDERSON (B. W.) : PAYNE (C. J.). *The spectroscope and its applications to gemmology.* Gemmologist. Vols. XXIV and XXV, Nos. 293/4/5, pp. 226-228 ; 4-6 ; 25-27. December, 1955, January/February, 1956.

This research series continues with the completion of the absorption spectra due to iron in the ferric state. Andradite garnet, of which demantoid is the gemmologically important variety, has earlier been discussed in view of the chromium absorption spectra in

the deeper green colours of this gem. The absorption bands in demantoid due to ferric iron are mentioned as being the most diagnostic, especially in the paler greens and yellowish-green types where the violet end of the spectrum is not absorbed by the chromium spectrum as is the case with the deeper green coloured material. The strongest of the iron bands in demantoid is a narrow and intense line at 4430A in the blue-violet absorption and thus appear to sharply edge the violet producing a cut-off effect. Other weaker lines in demantoid are at 4850 and 4640A. The absorption spectrum of epidote was first observed by H. Becquerel in 1889, who found it to vary with direction. The main band in epidote is near 4550A, but is only clearly seen in pale and transparent specimens, for in the darker varieties the general absorption in the violet, common with brownish stones, tends to mask this band. A general summing up is given of the gems which owe their absorption spectra to ferric iron. Absorption spectra due to manganese are confined to three natural gem materials ; rhodonite, rhodochrosite and spessartite garnet. The absorption spectra in the case of these three minerals, as observed on transparent specimens, are as follows : rhodonite shows bands at 5480, 5030, 4550A, with weaker bands at 4120 and 4080A. Rhodochrosite shows bands at 5510, 4545, and 4100A, while spessartite shows bands at 4950, 4890, 4620, 4320, 4240 and 4120A. The wavelength 4120A appears to be a key position for bands due to manganese. In the yellow-green synthetic spinel bands due to manganese are present at 4485 and 4230A, and these are sometimes seen in conjunction with the cobalt spectrum in the paler blue synthetic spinels made to imitate the blue zircon and the aquamarine. It is inferred that the manganese is incorporated in these cases in order to give a greenish cast to the stones. Comment is made on the assertion of the Bradleys that manganese is the colouring agent in the red and pink tourmalines, and the absorption spectrum of these varieties of tourmaline is discussed in relation to this theory. The absorption spectrum of the red and pink tourmalines is given as a broad absorption in the green, centred at 5250A, within the long wavelength end of which is seen a very distinctive narrow line at 5370A, and in addition two lines in the blue at 4580 and 4500A. The writers, dealing with coloration by cobalt, explain that cobalt in natural minerals gives a red colour, but in glass and synthetic spinel a blue colour is induced by cobalt compounds. This is

explained by reference to the theory of Hantzsch, who established that red and pink colours are found where the cobalt ion is surrounded by six oxygens, while blue colours are produced when the ions are surrounded by only four oxygens. The absorption spectra of cobalt-coloured materials of a blue colour consist of three strong bands in the orange, yellow and green. These bands may vary slightly in position and in width in different materials, the most important examples being that in synthetic blue spinel the bands are centred at 6300, 5800 and 5380A, while in blue glass the bands are centred at 6560, 5900 and 5380A, and, moreover, in the case of synthetic blue spinel the centre band is the broadest, whilst in blue glass it is the narrowest of the three. In cobalt-coloured plastics the bands, although similar in disposition, have their centres again slightly different. The writers express disagreement with the theory given by Wherry that cobalt is the cause of the colour in natural blue spinel. It is noted that the appearance of the cobalt spectrum in a stone is proof that the stone is an imitation or manufactured stone. A sharp line at 4750A is seen in the vanadium-coloured synthetic sapphire which is made to imitate the alexandrite. This line at 4750A is due to vanadium and is characteristic for this alexandrite imitation, and is another example of the absorption spectrum giving a nearly positive answer to the nature of a stone. Mention is made, however, that there has been a case of a natural sapphire exhibiting this vanadium line at 4750A.
7 illus. R.W.

ANON. *The story of Verneuil.* Gemmologist. Vols. XXIV and XXV, Nos. 293/4/5, pp. 228-229 ; 13-16 ; 31-34. December, 1955, and January/February, 1956.

Based on a lecture given in Paris by Professor Lafuma on the history of the origins of synthetic gems and the man who contributed so much to their development. Many scientists tackled the problems of the synthesis of ruby during the nineteenth century, but Verneuil alone had the merit of perfecting the method of its production. Auguste Verneuil was born at Dunkirk in 1856 and started researches on the problems of ruby synthesis in Frémy's laboratory in the Museum of Natural History in 1873. In 1905 he was appointed professor at the Conservatoire of Arts and Crafts. Reference is made to Gaudin's experiments in 1837 and to

Ebelmen's work on ruby in 1847, when he was professor of the Conservatoire and Verneuil's predecessor in the chair. The experiments of Frémy and Feil are fully told, as are the later experiments carried out by Frémy in conjunction with Verneuil. Reasons are given for Gaudin's lack of success. The conditions needed in order to produce transparent ruby crystallized by fusion are, according to Verneuil, to carry out the fusion in the part of the flame richest in hydrogen and carbon, to produce the increase of the mass of corundum by superposed layers from bottom to top, and lastly to obtain fusion in such conditions as to limit the contact of the melted material to an extremely small surface. A description of the inverted furnace devised by Verneuil is given and the method of the working of such a furnace is explained. In this type of furnace the conditions postulated by Verneuil are achieved. The paragraphs on the properties of the rubies made by this process may, in the light of more recent knowledge, be contestable. These very valuable notes culled from the Paris lecture are followed by a short review of the synthetic stone industry of France and Switzerland. In this survey some notes are given on garnet-topped doublets which were first made by a French firm in the Jura, and were called *doublée* stones. It is stated also that the same firm elaborated a process of making a vein in an emerald-coloured glass in order to imitate the natural stone. The discoveries of Verneuil gave birth to the industrial production of synthetics around Saint-Claude and Septmoncel in the Jura. A historical survey of the industry in France and Switzerland is given, in which the world crisis of 1929 is said to have nearly killed the industry. The story of the Djéva factory at Monthey in Switzerland is told and the article closes with contemporary reports on the Verneuil experiments published in the Horological Journal for 1890 and 1891.
2 illus. R.W.

ANON. *Cyclotron-coloured diamonds.* Diamond News and S. African Watchmaker and Jeweller. Jan., 1956, p. 5.

A report that cyclotron-coloured diamonds are available in several shades of green and gold, though rare in commerce at the moment because of the skill required in producing them. The colour change is permanent. S.P.

ASSOCIATION NOTICES

COUNCIL MEETING

Mr. F. H. Knowles-Brown, Chairman, presided at a meeting of the Council held at Saint Dunstan's House, Carey Lane, London, E.C.2, on Thursday, 19th January, 1956.

The following were elected to membership :—

FELLOWSHIP

Lyon, Rodger S. B., Dundee
Roulet, Bernard, Geneva, Switzerland

PROBATIONARY

Cox, Karl J., Hounslow
Gard, Alan M., London
White-Hide, Richard G., Wadhurst

ORDINARY

Albert, Gilbert, Geneva, Switzerland
Campbell, (Mrs.) Elizabeth, Washington, U.S.A.
Hopkins (Miss) Iris P., London
Jank, Robert A., Boscombe
Molyneux, Frank, London
Semple, Walter, Baillieston
Smyth, John C., Baltimore, U.S.A.
Thurm, Rudolf, Benghazi, Libya

TALKS BY FELLOWS

STOLLERY, E. : "Agate Collecting," Rotary Club of Inverness, 14th December, 1955.

A. L. KEMP : "Gemstones," Farnham Round Table, 17th January, 1956.

T. LEWIS ELLIS : "Dumb Jewels." Hove Rotary Club, Tuesday, 31st January.

WOOD, S. D. "Diamonds." King's Park Parish Church Literary and Debating Society, 14th February, and Kelvingrove Museum and Art Gallery Association, 22nd February.

SIMPSON, B. "Gemstones and their geological aspect." Mid-Glamorgan Scientific Society, 1st February ; "Gemstones." Young People's Guild, Mumbles, Swansea, 13th February, 1956 ; "The geological aspect of gemstones." Geological Society of the University of Exeter, 9th March, 1956.

BLYTHE, G. "Gemstones." Women's Gas Federation, Southend-on-Sea, 12th March, 1956.

138,484 PEARLS TESTED

The Laboratory of the Diamond, Pearl and Precious Stone Trade Section of the London Chamber of Commerce had a busy year in 1955, and in particular received for testing no fewer than 138,484 pearls. This was a considerably greater number than in the previous year, mainly because a merchant from Pakistan submitted a very large consignment to the laboratory. It is a remarkable tribute to the reputation of the laboratory, that these pearls should have been brought to London for testing in preference to any other centre.

TRIBUTE TO DR. E. H. KRAUS

Dr. Edward Henry Kraus, who is well known to English-speaking gemmologists as senior author of the best American text on gemstones and as President of the Gemological Institute of America, celebrated his eightieth birthday on December 1st last. Among his other distinctions, Kraus is Professor Emeritus of Crystallography and Mineralogy, and Dean Emeritus of the College of Literature, Science and the Arts of the University of Michigan—to which University he first came as assistant professor of mineralogy as long ago as 1904. He has been the author of several text-books on crystallography and mineralogy, and of nearly 100 papers on these subjects. He also earned himself a high reputation as a teacher and an administrator.

" Gems and Gem Materials," which first appeared in 1925, was written in collaboration with E. F. Holden. After the tragic death of the younger author, C. B. Slawson filled his place. The fifth edition of " Kraus and Slawson," an attractive and well-illustrated text, appeared in 1947. Dr. Kraus's career—and the part he has played in American Gemmology—is in many respects parallel to that of Dr. G. F. Herbert Smith in this country.

The entire Nov.–Dec. number of the " American Mineralogist " is dedicated to Kraus in honour of his 80th birthday. The papers in this issue are mostly purely mineralogical, but there are one or two contributions which should interest gemmologists, even if all except one of them make stiff reading. The exception is a paper by Richard T. Liddicoat (Director of the G.I.A.) on " Techniques employed in the identification of gemstones." This gives a very able summary of present-day practice in gem determination in the U.S.A., and reveals notable divergences between the methods favoured in America and those used in Britain.

According to Liddicoat, the three most important gem-testing instruments are the refractometer, a simple polariscope, and a binocular microscope equipped with dark-ground illumination. The spectroscope is not even mentioned. This in European eyes throws the article out of balance. Thus, we find two pages in this nine-page article devoted to a description of various methods by which interference figures can be viewed and studied in faceted stones. Though this is well worth reading for its own sake, the information derived from interference figures (optical nature and sign) can almost always be more quickly derived from careful refractometer readings, as Liddicoat himself explains in an excellent summary of the significance of shadow-edge movements which he gives on a later page. The spectroscope, on the other hand, provides evidence (often conclusive) on the identity of gem varieties which is quite independent of results obtained with any other instruments, and often provides a safe short-cut in awkward cases. Mr. Liddicoat's article concludes with an explanation (compressed in masterly fashion) of pearl-testing by means of X-radiography, and succeeds in making the often exceedingly tricky separation of cultured from natural pearls seem a very simple matter. There are points in Liddicoat's exposition which are open to question. For instance the remark that " the rather narrow gap between the melting point at about 2100°C and boiling point about 100° higher makes synthetic corundum difficult to produce by the Verneuil process without gas bubbles." This seems to imply that the bubbles in synthetic

corundum are or were filled by vaporized alumina instead of hydrogen as generally accepted.

One of the most interesting of the other papers is " Chalchihuitl—a study in jade," by Dr. W. F. Foshag. Foshag identifies the Aztec gemstone chalchihuitl with jadeite or closely allied minerals, and gives news of a recently discovered occurrence of jadeite in the Montagua valley of Guatemala, close to the serpentine area of the Sierra de las Minas. There is considerable evidence that this was a source for some of the jade artifacts used by Mayan and other ancient Meso-American cultures. It is unfortunate that Dr. Foshag's earlier and fuller accounts of this important new find of jadeite are not available to the English reader. As in other occurrences of jadeite, it is associated with serpentine, and often contains abundant albite. There are other serpentine areas in Guatemala and Mexico which may contain jadeite deposits.

Other papers in the Kraus issue of the " Amer. Min." include a study of pleochroism in synthetic ruby by Denning and Mandarino and of piezobirefringence in diamond by E. Poindexter. In the first of these, the absorption of the ordinary and extraordinary rays in a synthetic ruby sphere of 9·52 mm. diameter was quantitatively measured for various wavelengths of light. From these measurements, " biabsorption " curves, analogous to birefringence curves, were prepared. An apparent anomaly was that for light of 4860A the biabsorption parallel to the c-axis was not zero as theory demands for a uniaxial substance.

In Poindexter's research on the piezobirefringence of diamond, a parallelopiped of the mineral was subjected to considerable stresses between crossed polars, and the relative retardation produced by each known stress was observed. Diamond was found to be nearly isotropic in its effects, and to recover immediately without deformation upon the removal of loads, however great. It behaves as a negative uniaxial crystal when compressed on the cube or octahedron faces, and as negative biaxial when compressed in any other direction. There is much interesting but difficult theoretical discussion in the course of this important paper.

A shorter but valuable contribution on the same subject is given by Slawson and Denning later in the journal.

One other paper in this fine number may be briefly mentioned—one on " coesite " or silica-C by L. S. Ramsdell. Coesite is a high pressure form of silica which is not found in nature. The material was in the form of very small colourless transparent crystals, some of which showed simple monoclinic forms resembling gypsum. Though monoclinic, silica-C is dimensionally hexagonal, with the a and c axes equal and the monoclinic angle = 120°—an interesting state of affairs. The density of coesite is given as 3·01. The number of formula weights in the unit cell obstinately works out at about 17 instead of the 18 or 16 demanded by theory. It is suspected there may be deviations from the strict stoichiometric ratio of silicon to oxygen to account for this discrepancy.

B.W.A.

JADE STORY

The two illustrations used in Jade Story—European in Vol. V, No. 5, January, 1956, were reproduced by permission of the Trustees of the British Museum.

GEMMOLOGY AT HASLEMERE

The Haslemere Educational Museum, which enjoys a more-than-local fame for its excellent work in promoting natural history studies, has always regarded geology and mineralogy as within its sphere of interest. Under the energetic direction of Mr. John Clegg, the present curator, the displays of ornamental and economic minerals were supplemented by temporary loan exhibitions of gemstones in 1951 and 1954 and it has now been possible to arrange a small, but representative collection of gemstones for permanent public display. A Fellow of the Gemmological Association, Mr. E. J. Burbage, has been associated with Mr. Clegg in this project. Collectors may be interested in the Haslemere solution of how to display one's specimens without incurring the expense of calling in a jewellery case-maker : following a suggestion by Mr. A. Ross Popley, the display pads were made of dental plaster, moulded to take the stones, and surfaced by spraying with " Modelcraft " shredded rayon fibre. The construction of the pads, and other fittings and electrical wiring was carried out by Mr. H. Burbage.

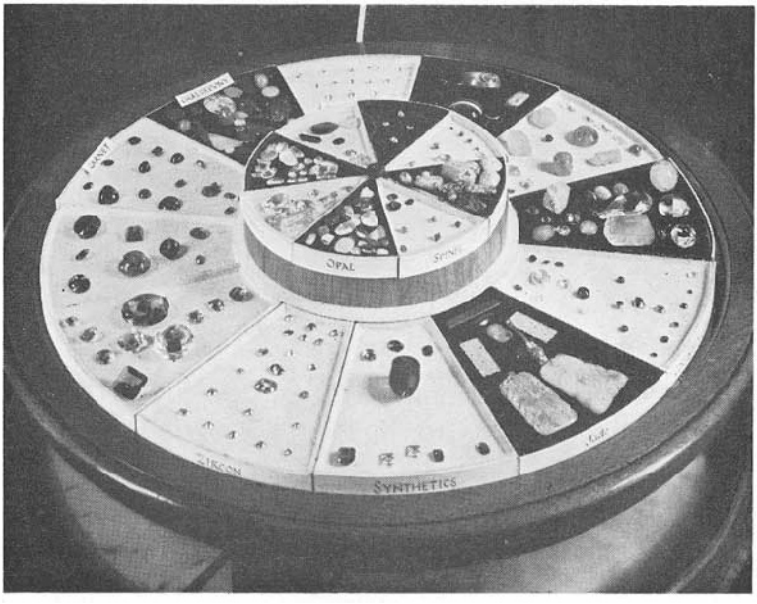

ANNUAL MEETING

At the 26th annual general meeting of the Association held on 1st March, 1956, at Goldsmiths' Hall, Foster Lane, London, E.C.2, the following Officers were re-elected :— President : Sir Lawrence Bragg, F.R.S. ; Chairman : Mr. F. H. Knowles-Brown ; Vice-Chairman : Mr. N. A. Harper ; Treasurer : Mr. Lawson Clarke. Messrs. R. Webster and W. Stern were re-elected to serve on the Council. Messrs. Watson Collin & Co. continue as auditors to the Association.

MEMBERS' MEETINGS

Midlands : A meeting of the Branch was held at the Chartered Auctioneers' and Estate Agents' Institute, Birmingham, on Friday, 2nd March, 1956. Mr. E. R. Kempson, of Messrs. Johnson, Matthey & Co. Ltd. gave a talk on " Gold for industry and the goldsmith."

The Herbert Smith Lecture for 1956 was given by Dr. Frederick Pough, lately Curator of Minerals in the American Museum of Natural History, on Wednesday, 28th March, at the British Council Cinema, London, W.1. Dr. Pough's lecture will be given in the next issue of the Journal.

London : Members of the Association met at Saint Dunstan's House, London, E.C.2, for another "Any Questions" evening on Wednesday, 1st February, 1956.

A report follows of a members' meeting held at Saint Dunstan's House on 1st February, 1956, on the occasion of an annual " Any Questions " evening. The Secretary, Mr. G. F. Andrews, presided, and the panel consisted of Mr. A. E. Farn and Mr. T. H. Bevis-Smith.

The first question sought to know whether it was a lack of culture to describe synthetic emeralds as " cultured." The panel agreed that it was " uncultured " so to describe them, and there was support from members, though some disagreed. One thought that it was a word that should be reserved for pearls—or mushrooms. Elsewhere in the audience it was considered that " cultured " was only a selling word and that synthetic emeralds were correctly described as being synthetic.

The second question produced the reply that wearers of pearls should have them cleaned and re-strung regularly. Another point was that certain cosmetics had a bad effect upon pearls, because of their sulphide content.

One of the problems regarding the identification of such items as topaz and quartz was that sometimes they "turned up," as one speaker put it, "not in their normal guise." An example of difficult pieces to identify was a recent instance of a pre-Georgian piece containing table-cut diamonds which had none of the normal appearance of diamonds. The Siam ruby was often very well imitated by garnets. One member of the panel said he recalled a case of a stone replacement which became necessary ; the customer insisted that the stones in the piece were rubies and the speaker was equally confident that they were garnets. The stones were, in fact, rubies, but this fact had to be proved with the aid of instruments.

Another questioner wanted to know whether the panel deemed the Chelsea filter more likely to inform than to mislead the "average jeweller." The first speaker considered that it was a great help to the jeweller but was best used to confirm an opinion already formed. In the early days the filter was considered an "absolute guide" to emerald—but nowadays one had had second thoughts on this. Another speaker considered that, perhaps, even yet the "average jeweller" had not much idea of gemmology. The filter "was not gospel", one had to bear in mind that, for instance, green zircon showed red under the filter. Fluor and other stones also showed red under it. The consensus of opinion was that in the right (i.e. fairly experienced) hands the filter was a very useful thing.

Another questioner had submitted : "What power lens would the team recommend to the student of gemmology, and what magnifications of the microscope ?"

The first speaker to answer this said that for the lens he felt that $\times 10$, which he had used for many years, was suitable. As far as the microscope was concerned a power of $\times 38$ up to $\times 99$ or $\times 100$ was ample. Of late years this speaker had preferred to use a binocular microscope whenever such was available.

The second speaker recommended a lens of from $\times 8$ to $\times 12$ according to the eyesight of the user, provided the lens was a good one with a flat field. He used $\times 25$ most of the time on a microscope and sometimes up to $\times 60$. Any higher magnification than this, in the speaker's view, would lead to the enlargement of error if an error were being obtained ; that is, unless one were going in for

the study of inclusions and so on. It was agreed among speakers in the body of the hall that × 10 was an accepted standard in the U.S.A. for the " clean " diamond.

There was some discussion of the point that sometimes customers were invited to use the lens, and most people present thought that it was not good practice to allow the customer to use the lens ; the client did not know what he was looking at (or for), and might well be disappointed when he had no reason to be.

The Trade as a Career

There was a deal of discussion on a question from the body of the meeting asking whether the panel would suggest the following of the jewellery trade by a school-leaver.

Among the points made by various speakers, the one which brought the largest measure of audible agreement was that it depended upon which part of the trade the lad should be encouraged to join. The feeling was that the man at the bench was the first to suffer if trade slumped, and the last to recover when it improved. One speaker recalled having, before the war, taken home 3s. 6d. for a week's work—because there had just not been anything for him to do.

The job needed a great measure of skill and concentration and this speaker felt that the appropriate reward was not there. As far as the man in the front shop was concerned—well, he had not done that job, so he did not feel competent to comment.

Earlier, it had been said that the jewellery trade covered jewellery, silver and horology. The lad could obtain a very fine apprenticeship in the trade and could then specialize in one of these three lines.

A speaker, who declared from the body of the hall that he was not in the trade, said that he was dismayed to hear the comments concerning the lot of the craftsman. He instanced other industries, such as milling, where young men could compete for quite valuable scholarships which would enable them to visit other countries, including the U.S.A., to see what was done in these countries to make the industry more efficient, and, generally, the young folk had a great opportunity to acquire a sound knowledge of their trade. He warned the jewellers in forthright fashion that if they did not organize themselves to make the technician's job attractive

and really give the thing proper attention they would soon find themselves without craftsmen in these days of competition for the best skilled people.

Another contributor said that it was too bad about the people in Hatton Garden ; if they made £50,000 last year and only £49,000 this year they had lost £1,000 ! He recounted the story of the shopkeeper adjacent to the Garden who told him he was very sorry for these people in the jewellery trade. Many of them had had to part with one of their three motor-cars—and he always kept some loose change in his pocket so that he could slip them something to help them along . . . A sally which was enjoyed by the gentlemen from Hatton Garden who were present at the meeting.

A Choice of Words

As is to be expected at a meeting of this kind, there are " hardy annuals " among the questions. One of them is why the trade continues to encourage the use of the terms " precious " and " semi-precious."

The general merriment from the previous question and answer having subsided, it soon became apparent that there were two schools of thought on this topic, at least. One school felt that it did not really matter very much because we all knew what was meant. Another school—shall we call them the purists ?—felt that the word semi-precious was ridiculous. It was also suggested that we should refer to all stones as gemstones (though some thought this signified uncut stones) ; others felt that they should be collectively and equally referred to as gems.

One speaker confessed that he had almost given up trying, after many years, to influence the people in his firm to abandon the " semi-precious " term. It was also remarked that anything worth £30 a carat was not justifiably referred to as " semi-precious." The view was also expressed that all stones considered worth mounting in jewellery were entitled to be regarded as precious.

In connection with another question speakers gave the view that the term " golden quartz " was better than citrine. The majority of jewellers, thought this speaker, would continue to call it topaz and sell it as such. The meeting was reminded that the recently passed Merchandise Act barred such a description and it

was thought that an action might well lie where such a misleading description was used. In a supplementary, a questioner asked when was the term topaz given to fluosilicate of aluminium. From the body of the hall came the answer that, as far as the speaker was able to ascertain, the Latin *topazus* was used by Pliny for the green stone we now call peridot. After the Middle Ages the term had been used for yellow stones down to about the Renaissance, when there was a distinction between yellow stones in that some were found to be harder. This speaker thought that the term topaz for a yellow stone ante-dated citrine by about 200 or 300 years.

The panel was asked what it considered were the ethics in regard to the mixing of natural and artificial stones and misnomers on the one hand and on the other hand keeping them distinct in displays, as was enforced on the Continent, where separate windows as well as separate displays were compulsory.

There was again considerable discussion of the point and it seemed that one or two points were agreed to by the great majority. The first was that it was bad practice to mix real and other stones in the same piece of jewellery. Next, the method of display rather turned upon the amount of window space the jeweller had available. One bad practice, it was considered, was to exhibit a piece in the window without a price. People would look at it and hurry away ; they felt that as it was not priced it was probably expensive and they did not want to be humiliated by going into the shop and having to walk out again without buying anything.

It was better to give attention to the grouping of pieces on their various pads in the window, and probably the best thing to do in a limited space was to head the pad with a generic description of the stones present in the pieces on the pad, and to mark the price of the items. There was no great measure of difference between the big shops in London and in Paris as far as normal practice was concerned ; the difficulties began with the man who had a small amount of window space.

The panel was next asked what were its members' most intriguing stones which had had to be tested.

The first answer to this was that it was awkward to think of something at such short notice but that day the speaker had had in for test a red stone on a bar brooch surrounded by colourless

table-cut stones. He had been fortunate in having seen this particular piece before. The first time it had come in he had been convinced that this 8-carat stone was probably a garnet or a natural spinel—or, failing that, a glass. He had applied the spectroscope and could not recognize anything at all ; he had wanted to try to recognize it without the refractometer. Finally, he had taken its refractive indices—and had been very much surprised. It was, in fact, quite a nice red topaz.

Another speaker referred to what he called his " most embarrassing stone." About a month before, he had been brought for examination a gipsy ring with a 2½-carat diamond. It did not look quite right and he had thought it was a doublet. Finally, examination proved that it was a diamond doublet, with glass.

A question of considerable interest elicited the information that the questioner had heard of something which, so far, had not come to the attention of the panel. It appears that in U.S.A. there is a new method of determining the age of minerals to within plus or minus 50,000,000 years. The process uses potassium 40 over argon and by this means it had been established that the oldest piece of rock so far discovered was one showing an age of 2,900 million years. There was a piece in Canada which very nearly approached this age.

The question was asked whether gemmology was a science ; was the governing council turning to the scientific attitude and was the trade no longer possessing an effective voice in stating its requirements? The consensus of opinion among panel members seemed to be as follows—gemmology is an art which in these modern times calls upon the aid of many sciences. It would be a bad thing for a gemmologist in touch with the public to set himself up as a scientist, because he would only frighten his customers away. Fellows of the Association, it was considered, were artists with scientific training rather than scientists. As far as the trade's voice was concerned, there were ample opportunities at annual general meetings and other occasions to make itself heard.

Subject to a few slight revisions this report is reprinted, with permission, from the *Jeweller and Metalworker.*

GIFTS TO THE ASSOCIATION

The Council of the Association has received, with deep appreciation, the following gifts :—

From Mr. Anthony Walton, a case of gem-testing instruments and crystal models and other gemmological items from the collection of his father, the late Sir James Walton, K.C.V.O.

From Miss Maxine Scott, F.G.A., a copy of " Gem Cutting," a lapidary's manual by John Sinkankas, autographed and dedicated to the Association by the author.

From Mr. Malcolm Gardner, a copy of "Adventure in Diamonds" by D. E. Walker.

From Mr. B. W. Anderson, a copy of his book "Gem Testing" translated into German under the title of " Praktische Edelsteinprüfung " by Prof. W. F. Eppler.

OBITUARY

The Council of the Association has recorded with deep regret the death of Ernest Arthur Dodd, T.D., Vice-President of the Association, aged 89. A director of P. G. Dodd & Son, Ltd., Jewellers, of Cornhill, London, he was Chairman of the Association before its Incorporation from 1935 until 1942, and was a past-President and past-Chairman of the National Association of Goldsmiths, and past-Chairman of the Pearl and Precious Stone Trade Section of the London Chamber of Commerce.

A memorial service, at which the Association was represented, was held at St. Michael's, Cornhill, on Wednesday, 11th April, 1956.

THE JOURNAL OF GEMMOLOGY
AND PROCEEDINGS OF THE GEMMOLOGICAL ASSOCIATION OF GREAT BRITAIN

Vol. V No. 7 JULY 1956

IDENTIFICATION OF DIAMONDS BY THEIR FLUORESCENCE

by W. F. COTTY

FLUORESCENCE is a property of diamonds which has been studied scientifically by a number of research workers but, so far, it has received little attention from the diamond trade itself. This is rather surprising, because fluorescence offers the dealer an invaluable tool for identifying his diamonds, especially if the stones in question have a distinctive colour of fluorescence. If he knew the fluorescent properties of his stones he could, at any time, recognize them instantly, or conversely he would be warned immediately of the loss of any of them.

Experiments have shown that the majority of gem diamonds fluoresce to some degree under the rays from an ultra-violet lamp fitted with a Wood's filter. The apparatus required to view this phenomenon is a specially prepared black box in which the ultra-violet lamp is mounted. (Such equipment is available commercially for the outlay of a few pounds.) In general, diamonds fluoresce in many colours, notably blue, green and yellow, while those of white and bright yellow are sometimes found. On the other hand, there are diamonds which do not fluoresce at all and are almost invisible in ultra-violet light. As a matter of interest to the scientifically minded readers, diamonds which fluoresce

belong to the group which scientists call Type I, while the rare Type II specimens are found among the non-fluorescent diamonds.

From the results of the academic work done in laboratories we know that fluorescence in diamonds is due to the internal structure of the crystal. In the author's experience 80–90% of all gem diamonds show some sort of fluorescence, and, because this property depends on the crystal's structure, many shades of the different fluorescent colours can be distinguished.

If, for example, we took a parcel of rough and uncut melee (Fig. 1) and sorted it in the normal way into, say, two qualities of good colour and a lot of yellow stones, he would be a clever man indeed who could select a number of diamonds from each group, then return them to their original groups and later pick out the same diamonds with any degree of accuracy. If, instead of the rough melee, we used well matched cut stones the task would be infinitely more difficult. Therefore, we may say that by using ordinary methods we reach the limit of identification for any diamond after we have recorded its physical properties of shape, quality, colour and weight. And any of these, except the colour, may be changed subsequently by cutting and polishing.

Now if we examined the same parcel under ultra-violet light (Fig. 2) an entirely new field is open to us. Since the fluorescence is determined by the internal structure of the diamond and as no two individual diamonds—as distinct from pieces of the same stone—have an identical number of chemical impurities or lattice defects, what may appear to be a perfectly matched pair of diamonds in ordinary light, may well show very different fluorescent characteristics. It needs but little practice to grade a parcel of diamonds into the three common fluorescent colours of blue, green and yellow, and, as one gains experience, to subdivide each of these colours into three shades, say, pale, medium and bright. This gives us a choice of nine fluorescent colours. If we took a photograph in colour of the diamonds fluorescing we would have a permanent record of them. Add to this the stones' physical properties and we have as good an identity card as one is likely to get—a diamond passport as it were.

If necessary, we could go one step further and add the diamond's " finger prints " to its passport by including a graph of its absorption properties in the ultra-violet or infra-red regions of

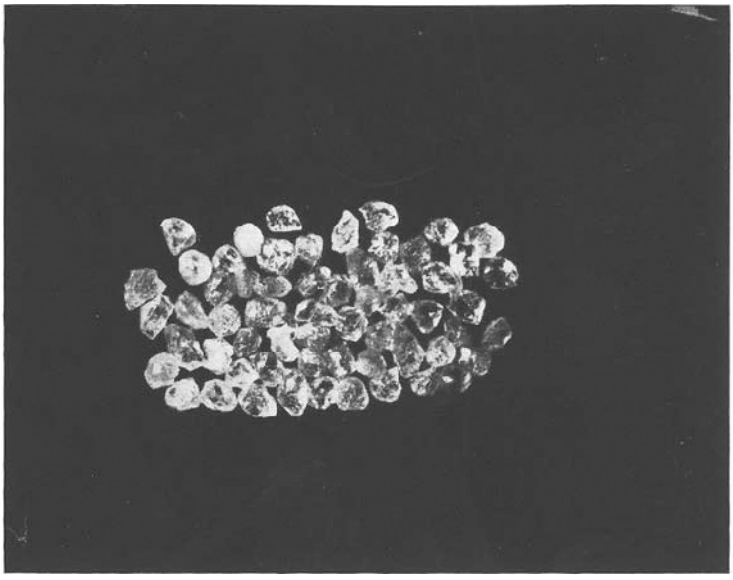

Fig. 1

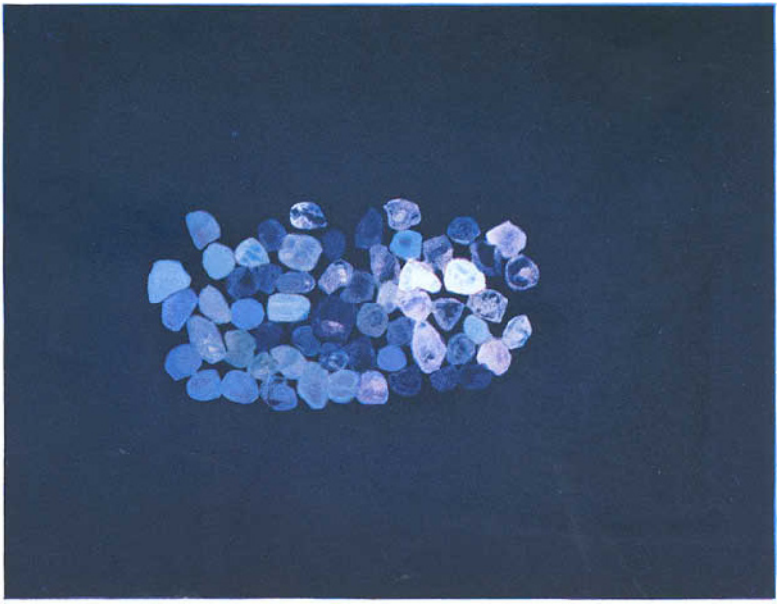

Fig. 2

the spectrum. The graph actually records the variations in the structure of the crystal so one would expect every diamond to give a different trace. Experiments have confirmed this. To illustrate the wide variations which sometimes occur we have included Fig. 3, which shows the graphs traced out in the infra-red region of the spectrum by (*a*) Type I diamond and (*b*) Type II.

In the discussion so far we have dealt only with loose diamonds, but the fluorescent method may be equally useful for identifying pieces of diamond jewellery. In all probability the diamonds in a cluster would fluoresce different colours and if the jewellery were photographed in colour while fluorescing we could record the details permanently. Should the jewellery ever get lost, identification on recovery would be helped considerably by a picture such as this. We believe that this photographic record used in conjunction with those specifications already in common use would make most pieces of diamond jewellery practically unique for purposes of identification.

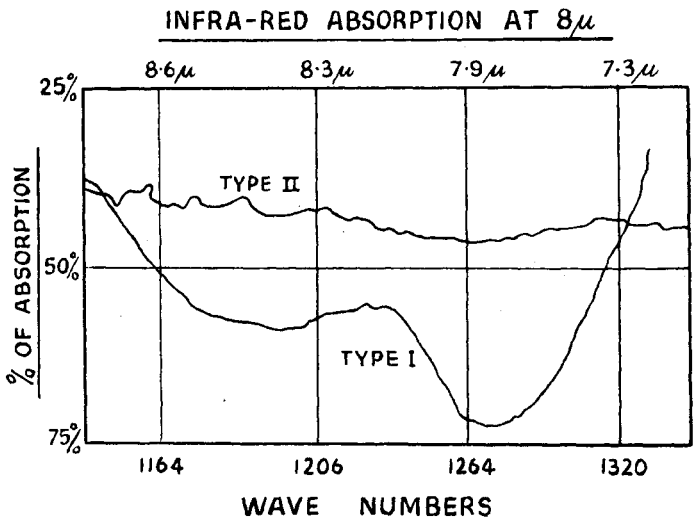

Fig. 3

EMERALD FROM HABACHTAL

by E. J. GÜBELIN, Ph.D., C.G., F.G.A.

THE emerald deposit of Habachtal, in Austria, is discussed in some detail in this paper not only because it is the only source of emeralds on the continent of Europe and among the oldest known to man but because to date practically no authoritative literature on the deposit exists in the English language. [10, 11] The initial aim of this study, however, was to discover whether the emeralds from the relatively unknown but nevertheless very interesting deposit in the Habachtal area differed by any local characteristics from emeralds from other sources.

History

The occurrence of emeralds in the Salzburg Alps was already known to the Romans who did not actually exploit the mine but found emeralds among the rocks and gravel in the Habach Valley while prospecting for ores. There is evidence that the Archbishop of Salzburg had the mine worked for emeralds, from which old Salzburg families still retain cut specimens, in the Middle Ages. But the fate of the mine was subject to frequent changes throughout the centuries ; legal as well as illegal prospectors challenged their luck ; but at no time did the " Mountain of Green Jewels," as it was called by the native mountaineers, yield its treasures generously. In a Mining Chronicle published in 1727 the emerald of Habachtal is mentioned among " ores, rocks and stones " of the Duchy of Bavaria, to which the area belonged in the 18th century. The Empress Maria Theresa owned an inkpot, the size of a big man's fist and sculptured from a Habach emerald, which is now exhibited at the Museum of Art in Vienna. J. Frischholz[1] described the emerald deposit thoroughly in 1821. But there was no organized exploitation until a jeweller from Vienna started regular mining in 1860, yet with no profitable success. At the beginning of this century an English Company was founded which intensified the operations. Although no statistics are available, the locality is credited with having yielded good returns. In 1906 the operation was ceased ; the mine fell into decay and was not repaired until after World War I, when Austrian

Fig. 1
Col. Hans Zieger and one of his miners sorting "emerald-rock" before the entrance to the mine.
(Photo H. Zieger)

Fig. 2.
The couloir of the Legbach with the entrance to the mine in its northern slope (on the left side of the picture at an altitude of 2,100 m.).
(Photo H. Zieger)

prospectors resumed mining. In 1936, after the mine had been lying idle for many years, a Swiss company (Schaffhauser Smaragd A.G.) bought it and promoted the exploitation with great energy and generosity. A fifth gallery was driven 110 yards into the mountain. All of these five drifts lay in the emerald-bearing layers. That period is said to be one of the most prosperous —and, among others, one find was made that was valued at 20,000 gold crowns. The Nazis hindered further operations of the Swiss company but continued themselves until the mine was confiscated as German property by the Allies after World War II. It was later released as property of the Salzkammergut, the Government of which let it out on lease to an old prospector, Col. Hans Zieger, who worked the deposit on a small private basis (Fig. 1) with a few employees until his recent death. The cold and rainy summers of the last three years did not favour exploitation. One reason for the continued failures may be due to the fact that the source lies at an altitude of 2,100 m. in the inhospitable area of the Gross Venediger, where for three-quarters of each year there is severe wintry weather. Frequent rock-slides, thunderstorms, avalanches, etc., render approach and access to the mine extremely hazardous (Fig. 2), and life in the simple rest camp is most primitive. At present the deposit is worked chiefly by a few solitary prospectors who hold licences. They are adventurers who attempt to make their fortune at the price of hard labour and privation. The output is not rich, although recently a few respectably large specimens have been recovered (Nos. 1 to 5 of Table 1). Further and systematic prospecting may yield gratifying results to a company with sufficient resources and a generous licence to enable them to undertake the extensive mining necessary to investigate the occurrence.

Locality

The Habachtal—the name is a distortion of " Valley of the Hay Brook "—is the most picturesque of several valleys descending from the main ridge of the Gross Venediger in the Hohen Tauern towards the north-west. The Hay Brook (Habach) is the outlet of the Habach Glacier and one of the southern tributaries of the Salzbach, which it joins near the hamlet of Habach (a local stop of the Pinzgau train). Pinzgau itself may be reached by train from Salzburg via Zell-am-See (Fig. 3). The Habach Valley

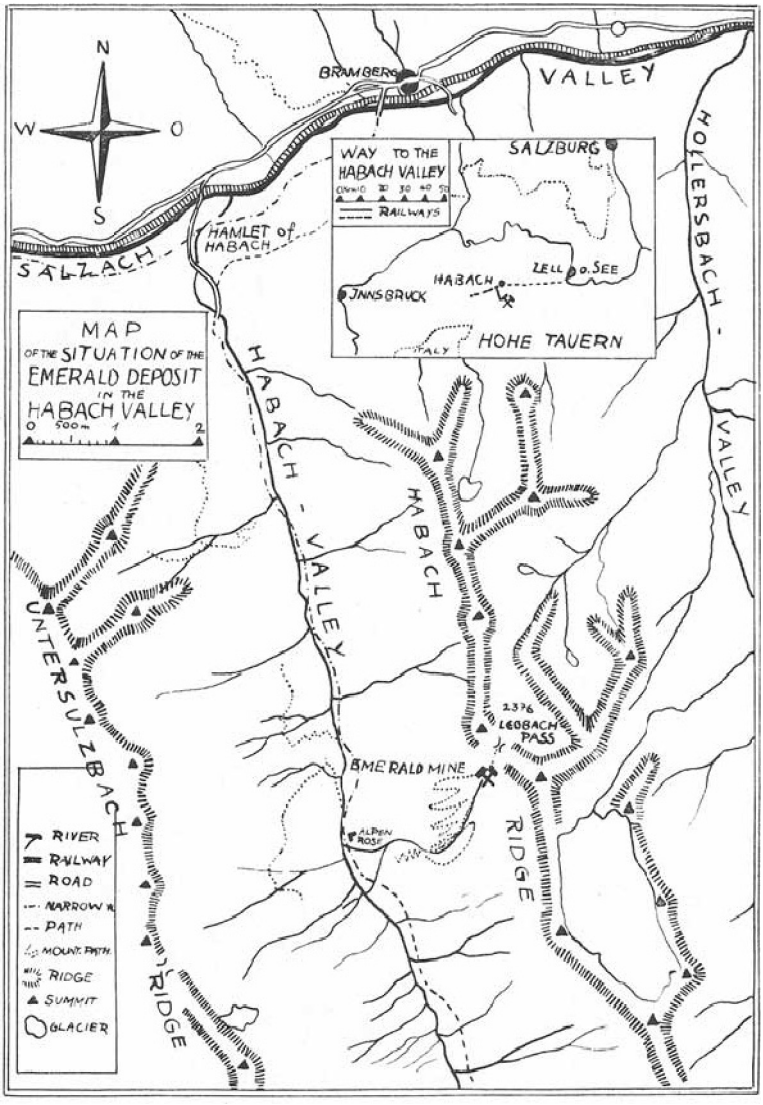

Fig. 3. Map showing the situation of the Habach Valley and the emerald deposit in the Legbach couloir. (R. Bolsche (Lit. 7).)

has the characteristic shape of a former bed of a long glacier nose. After the first ascent which leads through a narrow V-shaped gorge, cut through the rocks by the melted waters of the glacier, the valley opens, revealing a U-shaped profile, and presenting a beautiful view of the majestic scenery of the snow-capped peaks of the Hohen Tauern. After seven hours of rigorous hiking one reaches the mine which is situated on the western slope of the Habach ridge that forms the side of the Habach Valley on the east. A narrow stony pass called Legbach Scharte (2,375 m.) (Fig. 4) leads into the neighbouring valley to the east—the Hollersbachtal. The emerald deposit is situated a little below this pass in the topmost part of the Legbachrinne. (Fig. 5.)

Geology

This couloir, which is a geotechnical depression, is situated in the actual contact-zone of the two main bodies of rock forming the Hohen Tauern—the central gneiss on the northern side and the schists on the southern side. Originally this contact was an injection-contact, and the emerald deposit owes its formation to the intrusion of residual solutions from the granitic magma of the central gneiss.

The local geological conditions are such a classical example of the alteration of old neighbouring rocks by the intrusion of eruptive (igneous) rocks—so-called contact metamorphosis—that it may be instructive to give a more detailed description of this deposit.

The gneiss originated from granite which solidified from molten masses in the depths of the earth. In the course of, and through the formation of the mountains it was mauled and assumed a schistous character and thus turned into so-called gneiss. Its colour is pale grey-white and its composition of grains of quartz, feldspar and mica may be seen with the naked eye. The disintegration of this gneiss is already quite remarkable.

The amphibolite on the southern side is a schistous dark rock which, contrary to the gneiss, consists of such tiny mineral-components that even with a loupe they cannot be distinguished. Under the microscope thin sections disclose hornblende (amphibole)—the main component besides feldspar, zoisite, epidote and

Fig. 4.
Topmost part of the Legbach couloir and Legbach Pass.
(Photo R. Bölsche)

Fig. 5.
Col. H. Zieger and one of his miners before the entrance to the mine.
(Photo H. Zieger)

others. The hornblende is responsible for the dark-green hue of the amphibolite-schist. This amphibolite is a so-called crystalline schist which was re-formed in the depth of the earth's crust out of some other rocks as a result of pressure and high temperature. Later this amphibolite happened to get in contact with the molten masses, out of which the granite (gneiss) was formed through the process of cooling off and solidifying. The couloir of the Legbachrinne is one section of the zone where contact took place. Along this contact-zone the glowing hot molten mass of granite affected the amphibolite and, through the reaction of these two rocks, new rocks and minerals were formed. The contact-rocks and contact-minerals of this schist pod are of various kinds. The emerald mother-rocks and the emerald itself—being the most precious product of this contact-metamorphosis—belong to them.

One interesting species of rock is the " migmatite " (mixed rock) which clearly shows some effect of the intrusion process. It was formed by an intermixture of the molten mass of granite with the amphibolite. The migmatites form layers—dark amphibolite layers interchanging with layers of light-coloured granite. The fact that these layers are often bent and folded is evidence that during the intrusion of the granite into the amphibolite the mountains went through a phase of formation. Another most conspicuous kind of rock is a bright, white talc schist which appears above the emerald mine. This rock is soft and greasy to the touch and in many places it is interspersed with glittering specks of brass-yellow cubes of pyrite. The same pyrite inclusions may also be found interstratified in a further altered rock of this intrusion zone—the aplite, which is almost white and consists of minute grains. This is a gangue which was formed by the molten mass of granite penetrating into clefts of the adjacent rock. The most beautiful rock of this contact metamorphosis is a sort of tremolite-rock, bearing long, slender, bright dark green tremolite crystals in a white ground-mass. The serpentine rock belongs to the gabbro group and owes its formation to a metamorphosis from peridotite.

In connexion with the present study, still another altered rock of this contact zone is of eminent interest—it is the strongly schistose, dark brownish to brownish-green biotite schist which is the actual emerald-bearing bed of the whole complicated metamorphic

schist pod and the mother-rock of the Habach emerald. The biotite appears in all colours from deepest black and green through brown to almost colourless transparent plates. The biotite schists often form veins within the amphiboles, yet emeralds and white translucent beryls may occur only in a few places and only within hanging aplites or where strongly dispersed with aplitic veins. The best specimens, clear and with few or no cracks, are found in the softest, talc-like parts of the biotite schist where the emerald crystals could develop undisturbed. Also in tremolite schists, talc schists, and very rarely in actinolite schists, have emeralds been found, but only in closest relationship to biotite schists.

Microscopic and chemical examination revealed that the distribution of rock, the variety of minerals, and the transportation of material during the formation of the deposit show greatest similarity to those larger and richer emerald mines in the eastern Siberian Urals. In the Habach Valley the central gneiss must have brought all the minerals. Free silica and potash must have reacted with ingredients of the melanocrate basic rock pods, MgO, FeO and CaO forming great masses of biotite schists along with tremolite, actinolite and chlorite. It is interesting to note that here in the Habach Valley below the Legbach Pass the same arrangement and succession of mixture-rocks may be observed as described by Fersmann for the emerald deposits in the region of the Tokowaya in the Urals, namely :

(*a*) Aplite (present in Ural pegmatite)

(*b*) Biotite schists

(*c*) Tremolite, actinolite and chlorite schists

(*d*) Talc.

According to Fersmann these are the rocks of the emerald series and all four of them are in close contact with each other.[3, 4, 5]

Colour

The majority of beryls (which never occur as massive pieces, but always as well-developed euhedral crystals) are green, while only a small part shows true emerald green colour. Most are pale sea-green, grey-green, and sometimes parti-coloured—white and green. White and yellowish varieties are rather rare. The green hue of well-coloured emeralds from the Habach Valley is extremely

beautiful. Some jewellers consider it the finest velvety emeral green that exists. Indeed, the highly-prized green of the fine emeralds occurs more often in the Habach emeralds than i emeralds from Muzo, El Chivor, Tokowaya, Transvaal or Indi Same as in all emeralds, the green hue is caused by an intermol cular impurity of chromium oxide, of which H. Leitmeier in h chemical analysis found ·12 per cent to be present in pale an ·16 per cent in deep green emeralds. This again substantiat the contention that the percentage of the chromium content responsible for the shade of the emerald-green hue. Howeve the greatest number of these stones are unfortunately marred b numerous inclusions, hence the appearance and value of th otherwise beautiful Habach emerald are completely impaired.

Crystallization

The local influence as exerted on the development of th crystal habit is very obvious with emeralds from this source. A varieties of beryl in this Habach deposit developed the sam habit. The emerald from the Habach Valley has poorer crysta

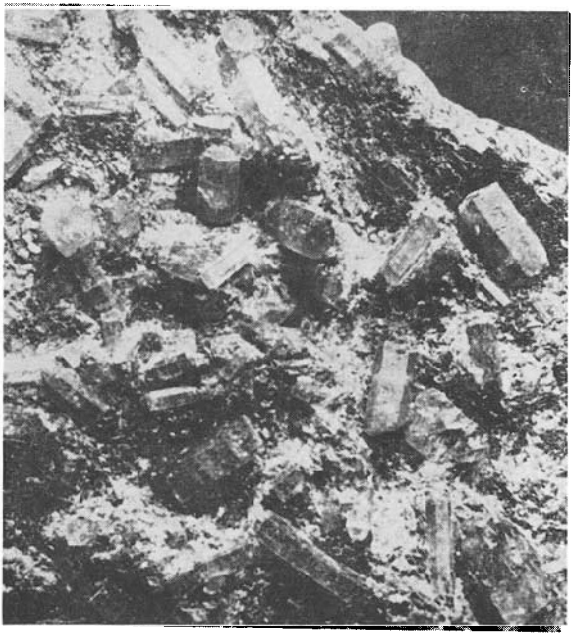

Fig. 6.
Habach emeralds i situ.
(*Photo R. Bölsche*

faces than the emeralds from all the other sources. Without exception only the prism face (1010) and the base (0001) are developed, though the latter is usually absent. In the biotite schist the emeralds lie partly parallel, and partly oblique to the schist plane (Fig. 6). In the latter case they are often developed as tablets in that two opposite prism faces dominate, although they may sometimes recede so that the crystals assume a rhombic habit.

Chemical Composition

H. Leitmeier carried out numerous analyses with abundant material, the purest of which gave the following values :

	per cent
BeO	12·28
MgO	1·82
CaO	·71
Al_2O_3, Fe_2O_3, Cr_2O_3	18·20
SiO_2	63·24
H_2O	3·03
	99·28 per cent

If when considering theories of crystal structures the calculation was based upon RO only for the value of BeO, and R_2O_3 only for Al_2O_3, the chemical analysis would concur well with the formula, which would allow one to assume that by far the majority of the other elements do not act as atomic replacements. One would obtain :

$$R_2O_3 : 3{\cdot}1\ RO : 6{\cdot}2\ SiO_2\ (1\ H_2O) = Al_2O_3.\ 3BeO{\cdot}6SiO_2 = Be_3Al_2Si_6O_{18}$$

The chemical composition, just the same as the particular geological circumstances of the deposit, offers instructive information on the formation of the emerald. Beryllium, which occurs in the composition as BeO, is a chemical element which originates from the granite ; the amphibolites do not carry any beryllium. The colour pigment chromium, present as Cr_2O_3, was offered by the serpentine rock, which as a member of the gabbro-group brought that valuable element into the process of contact metamorphosis.

Physical Properties

The determination of the specific gravity was carried out by the hydrostatic method with a semi-automatic Mettler balance with immersion of the stones in ethylenedibromide. It proved rather difficult to obtain constant density values for all the material tested, the reason for this being partly the enormous quantity of impurities which are so densely enclosed by almost all Habach emeralds. However, this variation in values should be attributed to the variation in chemical composition rather than to mere inclusions and due mainly to the impurity of ferric iron (Fe_2O_3), which forms a structural impurity by isomorphous replacement. The density was found to vary from 2·72 to 2·76 with an average value of 2·74.

All the refractive indices given were measured with an Abbé-Pulfrich refractometer and, despite small facets on the smaller stones, reliable values could be read in all directions. It was interesting to observe that dark specimens showed higher indices while the birefringence remained quite constant for all stones tested. Chromium content seems to have a greater influence on this variation than the amount of iron. The following average values may be established :

$$\omega = 1{\cdot}591 \quad \varepsilon = 1{\cdot}584 \quad \Delta = 0{\cdot}007$$

No optical anomalies were observed.

Keen gemmologists may be interested in receiving more detailed information on the findings with individual specimens (vide special Table No. 1).

The average data from Table No. 1 may be compared with indications published by other authors.

In order to reveal how individual and of what local importance these values of the Habach Emerald are, especially with a view to clearly recognizing them and distinguishing them from emeralds of other localities, the data become particularly instructive when compared with the average constants of emeralds from other sources.

The dichroic colours vary slightly according to the specimen's body colour but may generally be described as yellow-green for ω and bluish green for ε in dark stones. The dichroism is never strong.

Table No. 1

Habachtal Emerald		Refractive Indices			Specific Gravity	Dichroism	Absorption	Chelsea Filter	Fluorescence			Inclusions
		ω	ε	Δ					Stokes' Fluoroscope	U-V long 3650A	U-V short 2537A	
15·35 ct	No. 1	1·59505	1·5880	·00705	2·7470	yellowish green blue green	normal: 6830, 6800, 6620, 6460, 6370, 6300–5800	red	distinct, pale red	inert	inert	Tremolites
11·79 ct	No. 2	1·5925	1·5856	·0069	2·7395	yellowish green bluish green	normal	red	distinct, red	inert	inert	Biotite, Microlites & Secondary liquid Inclusions
10·82 ct	No. 3	1·5901	1·5831	·0070	2·7536	greenish yellow bluish green	normal	red	distinct, red	inert	inert	Tremolites
6·06 ct	No. 4	1·5922	1·5853	·0069	2·7522	yellow green bluish green	normal	red	distinct, red	inert	inert	Numerous Inclusions, parallel fine fissures
4·77 ct	No. 5	1·5970	1·5901	·0069	2·7460	yellow green bluish green	normal	red	distinct, pale red	inert	inert	Numerous Inclusions, polysynthetic layers parallel to basis
·69 ct	No. 6	1·5919	1·58466	·00724	2·7670	yellowish green bluish blue green	very strong, all lines are broad bands	red	weak, red	inert	weak, red along girdle	Tremolites
·26 ct	No. 7	1·5901	1·5831	·0070	2·7401	yellowish green bluish blue green	normal	pink	strong, red	inert	inert	All of them contain many Inclusions, especially Biotite, Fissures, Tremolites, Apatites, other Microlites and secondary Inclusions
·60 ct	No. 8	1·5880	1·58094	·00706	2·7309	yellowish green bluish blue green	normal	pink	strong, red	inert	inert	
·44 ct	No. 9	1·58514	1·57815	·00699	2·7203	yellowish green bluish blue green	normal	pink	strong red	strong, red	inert	
·54 ct	No. 10	1·5871	1·58002	·00708	2·7266	yellowish green bluish blue green	normal	pink	strong red	strong, red	inert	
·62 ct	No. 11	1·5892	1·5821	·0071	2·7337	yellowish green bluish blue green	normal	pink	strong red	inert	inert	

TABLE No. 2

Authors		Refractive Indices			Spec. Gravity
		ω	ε	Δ	
H. Leitmeier	No. 5	1·5819	1·5769	·005	2·703 Lit. 2
,,	No. 7	1·5790	1·5740	·005	2·704
R. Böse	No. 30	1·5907	1·5839	·00681	2·740 Lit. 9
W. F. Eppler		1·5907	1·5839	·00681	2·740 Lit. 8
R. Webster		1·591	1·584	·0068	2·740 Lit. 10
E. Gübelin		1·591	1·584	·007	2·740

The absorption spectrum appears to be normal with slight changes in the strength and width of the absorption lines and bands, and all of the following were observed :—6830, 6800, 6620, 6460 and 6370A.

Through the Chelsea Filter the Habach emeralds appear pink—a very pale pink in transmitted light but pronounced pink in reflected light.

The high iron content in the majority of the Habach emeralds acts as a strong inhibitor of fluorescence in ultra-violet light (both long and short waves). Only along the girdles of some thin slabs

TABLE No. 3

Locality	Refractive Indices			Spec. Gravity
	ω	ε	Δ	
1. Transvaal	1·595	1·585	·007	2·72 —2·78
2. Indian	1·595	1·585	·007	2·725—2·745
3. Habachtal	1·591	1·584	·007	2·72 —2·76
4. Eidsvold	1·5908	1·5838	·007	2·759
5. Siberian	1·588	1·579	·006/·007	2·72 —2·74
6. Columbian	1·584	1·569	·005/·006	2·69 —2·71
7. Brazilian	1·582	1·565	·004/·006	2·67 —2·70
8. Synthetic	1·566	1·563	·003/·004	2·645—2·665

or stones of low specific gravity can reddish fluorescence be observed. On the other hand, the fluorescence is quite distinct between the crossed filters of Stokes' Fluoroscope and varies from red for dark stones to pink for paler ones.

Inhomogeneities and Inclusions

The dense cloudiness of the interior which makes most Habach emeralds so turbid to the naked eye reveals itself to be a multitude of fascinating inclusions which are very characteristic of this locality. Cleavage parallel to the base is quite remarkable. Specimens without any cleavage cracks, or indications thereof, are quite rare. As a matter of fact this easy cleavage is perhaps the most serious drawback of Habach emeralds in that the crystals very often not only break readily under the slightest pressure (even when carefully removed from their mother-rocks), but also frequently contain a succession of numerous cleavage cracks. Open cleavage cracks, into which biotite has intruded, appear quite often. In addition, numerous fissures and fracture cracks may occur which usually traverse the crystals with striking regularity and at angles deviating from 10° to 20° from the basal plane. Together with the cleavage cracks they often form a lozenge-shaped grill pattern. As long as the crystal still lies in its mother-rock it may be observed that many of these cracks run parallel to the exfoliation of the surrounding schists.

Apart from these cleavage and fracture cracks which still persist, the stones show proof of successful healing activity during their growth, since they are often densely interspersed with healed fissures. This proves that in the course of crystal formation we may conclude that some mechanical forces must have caused fractures, and while the beryl formation continued the cracks filled with healing substance out of the mother liquor. Very often this healing liquid lacks pigment, resulting in a thin colourless layer within the otherwise green emerald. This observation may allow the assumption that the Cr_2O_3 was exhausted during the early phase of beryl formation which resulted in emerald, whereas in a later phase only colourless beryls were able to grow. These healing fissures are the cause of the numerous liquid feathers which form irregular, wavy, conchoidal planes traversing the crystals in all directions.

Fig. 7. Liquid and solid inclusions. 75 ×.

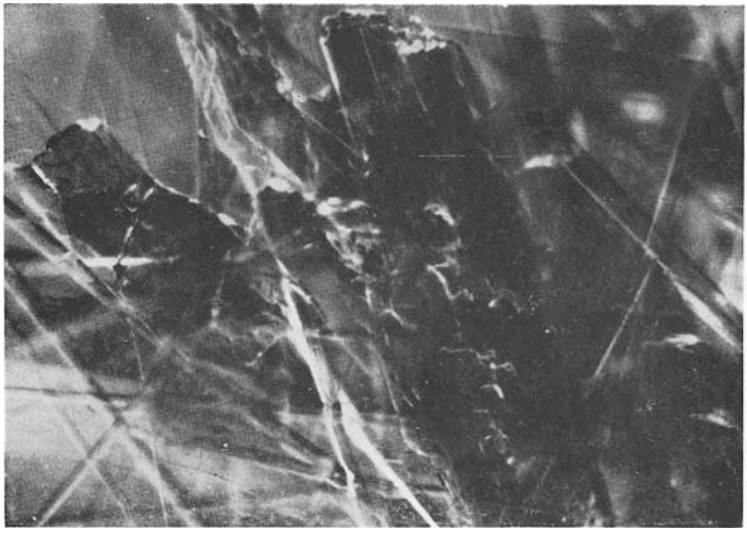

Fig. 8. Long and stout stalks of apatite enclosed among slender tremolite rods. 80 ×.

Since most of the minerals of the rocks in the " emerald series " were formed almost simultaneously we may expect to encounter most of the externally paragenetic minerals again in the internal endogenesis of the Habach emeralds. Thus we find biotite, tremolite, tourmaline, apatite, epidote, sphene and rutile in evidence (Figs. 7 and 8). Biotite is by far the most frequent mineral inclusion, often penetrating the emerald through its surface, i.e. from the mother-rock extending through the host—partly irregular and partly along cracks. Sometimes these cracks, accompanied by biotites, run parallel to the exfoliation of the former matrix through the emerald—oblique according to the relative position of the crystal in the schistose rock (Fig. 9). In many emeralds there are clusters of biotite " books " which are nothing else but tiny enclosures of the mica component of the mother-rock. Then again, biotite laminae are strewn singly throughout the crystal (Fig. 10) or filed into parallel or irregular rows. This biotite is either brown (in all shades) or completely colourless in thin leaves or, again, sometimes light to dark green in accordance with the rock in which the host emerald was formed. Also, the biotite is not always fresh and well-preserved but quite often surrounded by a brown coating of hydrate of iron oxide or strongly resorbed. Sometimes biotite seems to have disappeared so that only the residual ferrite substance may be seen. The biotite inclusions are almost always accompanied by liquid inclusions—either irregular cavities or negative crystals very often forming two-phase inclusions and frequently so tiny and so numerous as to form feathers. They are the type which is most common in beryls and they are mainly responsible for the turbid appearance—hence the mediocre quality of the Habach emeralds of the biotite schist. Very few have the deep rich green transparency so highly valued by jewellers.

The emeralds from the tremolite rocks are considerably clearer and most beautiful, although their colour may not be as fine but rather a cold bluish-green. They are, on the other hand, less frequently and less densely marred with cracks and yet they are normally teeming with thin tremolite needles (Fig. 11) or broad blades. They may either traverse the entire host crystal (Fig. 12) or end within its body with broken stumps (Fig. 13) or with euhedral heads. They are usually evenly distributed through the emerald or congregate in clusters and bundles and are not always straight but often bent (though rarely crushed) (Fig.

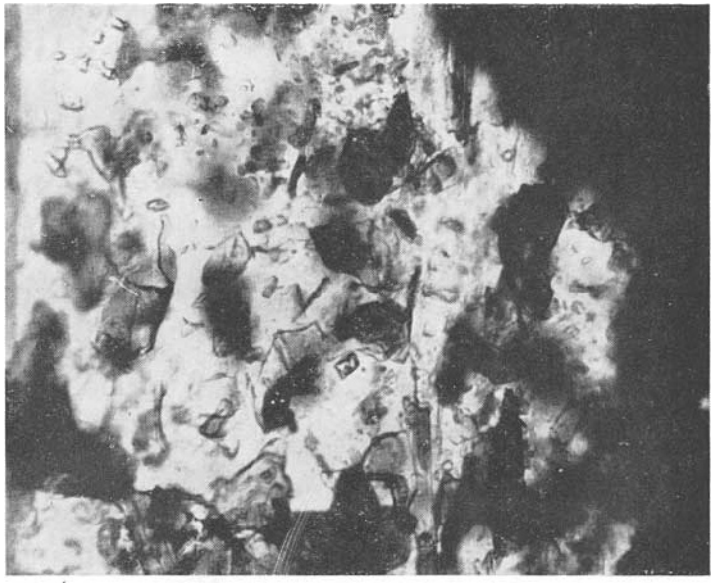

Fig. 9. Broken or resorbed biotite platelets. 75 ×.

Fig. 10. Individual flakes of biotite. 80 ×.

14). Their colour is always green but varies from pale to dark shades. The phenomenological picture of these tremolite inclusions is absolutely unique and most characteristic for Habach emeralds, particularly to the jeweller since most cut specimens originate from the tremolite rocks which produce the clearer emeralds. This type of inclusion cannot be easily confused with those in emeralds from other sources, not even with Ural emeralds although these are characterized by actinolite inclusions which admittedly show some resemblance to tremolite. Rutile inclusions are quite rare, but sometimes occur in dense masses within a single crystal. The clearest of all are the bluish emeralds from the baryte-mica rocks. They contain none of the above-described mineral inclusions and usually have very few cracks.

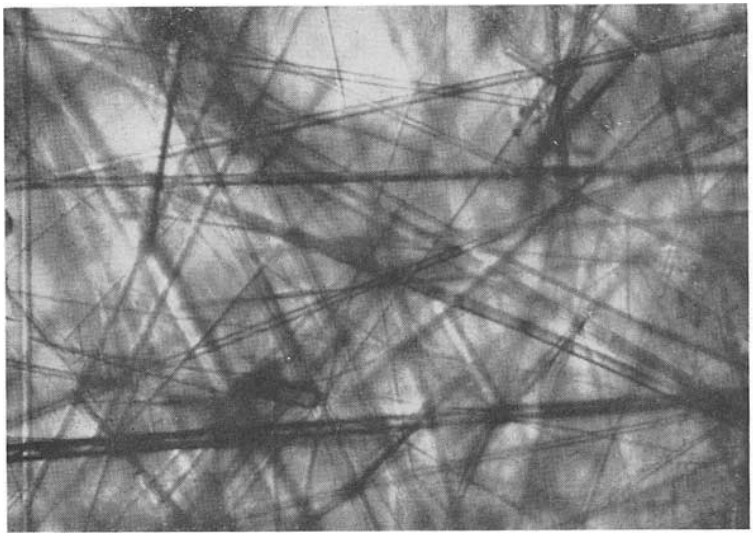

Fig. 11. Long slender needles of tremolite. 75 ×.

SUMMARY

Detailed investigation of the deposit demonstrated it to be a classical example of emerald for formation in biotite schist and revealed close relationship to the deposits in Siberia, India and Transvaal. As regards physical properties, the emerald from Habachtal ranks well with emeralds of similar occurrence and even excels by its phenomenological physiognomy of internal paragenesis.

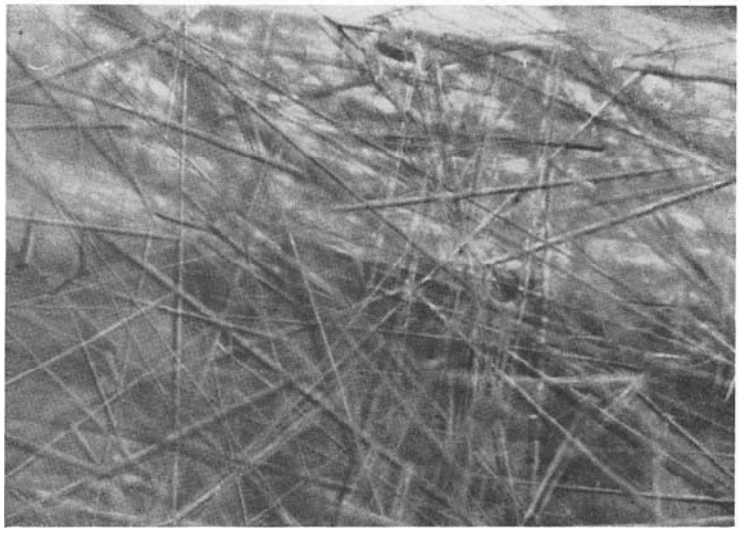

Fig. 12. Habach emerald dense with tremolite needles. 40 ×.

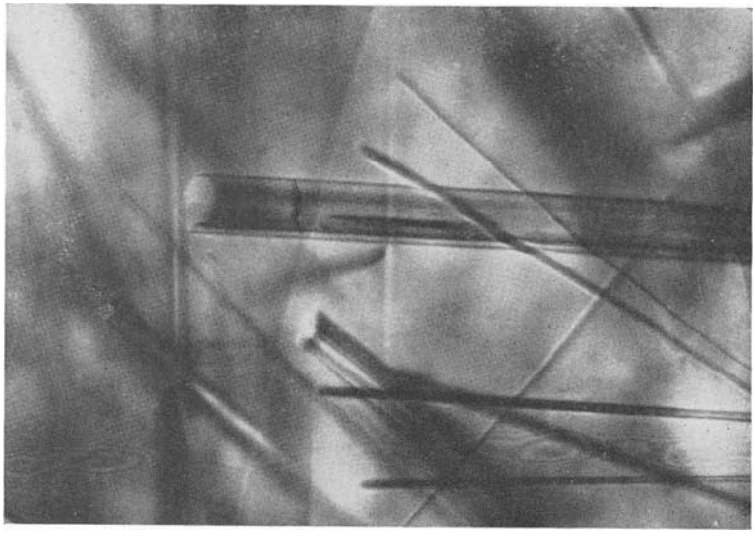

Fig. 13. Tremolite rods partly with euhedral partly with broken ends. 125 ×.

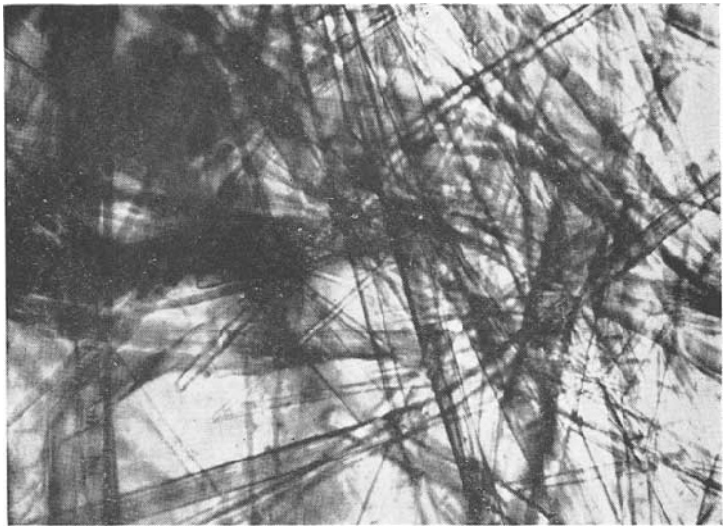

Fig. 14. Some of the tremolite needles were bent or broken as they were embedded by the growing emerald. 75 ×.

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OBSERVATIONS ON THE ORIGIN OF OPAL FIELDS

by G. F. LEECHMAN, F.G.A.

THE importance of some knowledge of geology and mineralogy to the student of gemmology is perhaps not always sufficiently appreciated. Gemmology is undeniably a particular section of the study of minerals and some knowledge of it is more than merely advisable for those who would claim to be specialists. Further, a knowledge of the foundations renders the subject of still greater interest. For instance, gem quality corundum occurs as isolated crystals in crystalline limestone, while other corundum occurs in igneous rocks. If we find this contrast rather intriguing, in order to read it up satisfactorily we should be able to realize what is implied by crystalline limestones and what by an igneous rock. Geology is an absorbing subject which, like our museums, has for too long been wrongly suspected of a musty dusty atmosphere of fossils and skeletons. The student who visits the Scottish Highlands, the Cornish cliffs or any field between them will find in fact that it is far from dull. During a recent trip into the centre of Australia the writer was deeply impressed by the advantages of following such a policy. The feeling was that, having some knowledge of the geological history and formation of each area, and some appreciation of the normal origin of the various minerals observed to be " out of their natural surroundings," some activity must have taken place in the past which had been associated with the formation of precious opal, some unusual activity which had not been thoroughly investigated, so far as was known.

The route from Adelaide was by train to Port Augusta and on to Pimba, thence to Andamooka by lorry and then back via Pimba and Kingoonya (both on the Transcontinental Railway) in a jeep to Coober Pedy ; thence by car to Alice Springs and returning by air to Adelaide. Thus we flew back over much of the country which had been traversed by road and so were able to correlate

observations made on the surface with views over larger tracts of the terrain from the air.

Once a week from Pimba the lorry carrying goods and the mail and perhaps a passenger or two in the cab or on the back makes its way over the 70 miles of soft sandy cart-track to Arcoona and Andamooka sheep stations and 30 miles north to Andamooka opal fields. The road is impossible if wet. We left at 9 a.m. with three and a half tons and five passengers aboard and arrived nine hours later, just before dark—we got bogged nine times and dug ourselves out eight. The last time a jeep from Andamooka station came and pulled us out. They had been worried by our lateness and came to see where we were. During all those descents to solid ground there was ample opportunity to note that all the surface stones (gibbers they call them, with the " g " soft) were of coarse angular greyish sandstone quartzite, obviously derived from the weathering of the bare rock immediately underneath them. (This is very ancient, Cambrian or older, has almost no soil and very sparse vegetation. The erosion is almost entirely aeolian—it very seldom rains. But as we approached Andamooka opal field gibbers were partly replaced by different materials, rounded quartzites of fine grained purple sandstones, pieces of milky quartz, chalcedonic veinstones, agates, limonite and even some silicified siderite—iron carbonate. These were definitely out of place and unexpected, and the question naturally arose how did they get there and why had the agency which brought them to Andamooka not deposited them equally over the plain ? They were not artifically dumped for road making (there is none on that route) and they were too water-worn to be glacial erratics. Some explanation was called for. Another point was that driving over the very extensive peneplain extending all the way from the railway line no valleys or water courses were seen—merely slight undulations and occasional groups of sand hills which slowly creep about over the almost flat surface, driven by the prevailing winds : but a few miles south of the opal field we found ourselves close to a steep and deep dry gully, exceptionally large in view of the very limited basin it drained. At Andamooka a number of these well-developed valleys ran together to form Opal Creek. This and the one previously mentioned both run into Tea Tree Creek which leads to Lake Torrens about eight miles to the east. There is, of course, seldom any water in these creeks or indeed in the lake, which

is a dry flat of saline deposits some hundred and twelve feet above sea level. Andamooka draws its drinking water from three wells sunk in the bed of the creek.

The little village has perhaps a hundred inhabitants, not including a large number of aboriginals who have a permanent camp a mile or two away. There are some fifty to sixty dwellings, some very nicely built of wood and white clay, others entirely of earth and stone. There is a wireless telephone, post office, store and school with five pupils. About twenty to thirty men are gouging regularly, but the production of opal, especially of good quality, is very low. The shafts are sunk in the hill sides down some twenty to forty feet through sandstones and thick beds of white gypsite, a mixture of sand, clay and gypsum. Thick seams of gypsum are often found, also, usually 6 to 8 inches across, filled with shining fibrous crystals of pure satin spar. Below the gypsum we usually find the opal level (although sometimes opal occurs in and through the crystals). It consists of a thick seam (12 inches to 18 inches) of siliceous mud in which are the so-called painted boulders. These are of the same material as the fine grained purple sandstone quartzite pebbles previously described, but they frequently carry precious opal either in cracks which penetrate them or as a coating perhaps $\frac{1}{8}$ inch thick which partially surrounds them. Precious opal is also occasionally found in separate nodules and in seams in the clay or even in the country rock; a great deal of useless inferior opal (potch) also occurs, as well as ferruginous veins and staining and quantities of iron hydroxides either as muds or nodules.

It seems that one should not simply accept these deposits without any thought as to how they came to accumulate there. The usual explanation is that they are derived from the decomposition by weathering of the superlatant strata. However, in those areas in which opal fields are found these upper strata are invariably sandstones from Cretaceous beds. Being sand they have already suffered very extensive weathering and decomposition and one would hardly expect them to produce large amounts of calcium sulphate, ferruginous muds or soluble silica (the sand, being a marine deposit, is obviously insoluble under surface conditions). The deposits could perhaps be fluvial, in which case they should occur in many old river beds and estuaries, or alternatively they might be derived from deep-seated hydrothermal activity.

Two miles south of Andamooka is an extensive fault, running east and west for at least ten miles. The crush zones associated with faults frequently form reservoirs or aquifers which, on pressure, supply springs and these are normally mineralized as the waters, superheated under the great pressure at depth, dissolve or carry in suspension various constituents of the rocks. Studying the creeks in the area it was noted that they each became suddenly deeper and wider approximately on the fault line. If springs were responsible the coincidence in the positions of the watercourses and their large width and scour would be explained, as also would the type of minerals found and the waterworn pebbles first noted among the typical gibbers.

We went on to Coober Pedy by jeep—it was an ancient jeep with no speedometer, which made navigation a thing of guess and gain, no oil gauge, no brakes (except switching off the engine) and particularly no springs. The distance is about 370 miles with some 6,000 corrugations to each. We went via Pimba and Kingoonya.

Coober Pedy is several degrees more primitive than Andamooka. There are only three houses or buildings and the other habitations are dug-outs which reminded me of the trenches in 1916, the year in which the field was opened. There is a post office and store, but no school. There are perhaps twenty-five miners and production is far from large. The water supply is held in a large circular concrete reservoir, the result of communal effort years ago ; it is over 100 feet in diameter and more than 10 deep and when full it is said to contain enough water to last ten years. It is covered to lessen evaporation and wire-netted to prevent kangaroos, dingoes or other livestock from getting drowned in it.

The road from the south over which we travelled is marked on the maps as " very rough and hazardous. Travellers to Alice Springs are advised to rail their cars." It runs across an endless peneplain, an extension of the Nullabor (Treeless) Plain very similar to that south of Andamooka, but of Cretaceous Age, with much loose sand, less gibbers and practically no vegetation. Approaching Coober Pedy we see two buildings, nothing else. One is the post-office with its store ; across the road is the boarding-house and its store. Here the road takes a hair-pin bend round the post office to avoid going over the cliff—and then continues on to Alice Springs. The cliff is the steep edge of the peneplain. To the east the flat

" low level " spreads out 150 miles towards Lake Eyre, which is 39 feet below sea level—the scarp between the two levels stretches roughly north and south from the junction of the Todd and Hale Rivers in 25 degrees south latitude to Lake Torrens in 31 degrees south—a distance of over 350 miles.

The scenery at Coober Pedy, typical of that all along the scarp, which parallels a major continental fault, is most impressive. Standing on the low level flats and facing north, on the left and behind is the steep slope while in front and on the right are a number of isolated conical hills and flat-topped ridges and mesas of a particular form, their sides being always of a gradient of nearly 30 degrees, similar to that of the scarp, and their height being constant at about 80 feet. Thus the individual hills are invariably strictly conical, the ridges appearing to be a sequence of such conical hills close together. These outlines are seen over many miles. They have admittedly been formerly part of the peneplain whose elevation they equal, the constant (aerial) erosion having attacked the formation from the side and driven back the talus slope while the mesas and buttes emerged.

One of these hills was particularly striking and known to the aboriginals as the " Sacred Mount," probably because they held corroborees there. It is a perfect cone, its peak pure white against the blue sky and its lower flanks a light sandy shade. At its foot on one side is a dry water course with a number of small green trees and bushes, the only ones in sight. Their roots were evidently in touch with some deep source of moisture. On its southern slope we found quantities of stone artifacts and many discarded fragments of spear heads and scrapers. It was evidently the site of an ancient armament factory. Further up specimens of jasper were found, some roughly worked—white (porcelanite), yellow (siderite silicified), brown (kidney ore), bright red (haematite) and dark purplish brown (manganese)—all of which appeared to be silicified muds. In addition there was a small seam outcrop of limonite and many crystals of gypsum—a collection sufficient to make anyone pause and ponder. Most interesting, however, was the material from which most of the artifacts were worked—a homogeneous fine-grained light grey quartzite. It gave out a pleasant musical clink, and could be flaked to a smooth fine finish with hard and sharp edges and point. What mineral was this

and where did it come from ? The answer was found on the top of the hill, on the tops of the ridges and, but only in patches, on the original peneplain—large rounded water-worn and wind-eroded boulders of grey mudstone quartzite, commonly known as Grey Billy, a name probably given by the old Cornish miners to whom a " billy " or " bully " is a large smooth stone. Here and there, accumulated on the flat surface, are groups of these boulders, sometimes bound into a conglomerate by a bond of friable brown mud which is easily, and often has been, washed away by what little rain does fall. These form a siliceous capping which may partly protect the surface from pluvial erosion, but not the sides, which are exposed to the strong desert winds. Thus the escarpment is steadily cut back until here and there the outlines of more resistant masses appear. In time the cliff becomes embayed as the harder parts emerge and stand out like headlands on a sea coast. Steadily the process continues until they become peninsulars and eventually isolated conical island peaks standing apart out on the low level desert plain.

Sometimes the upper beds of the Cretaceous sandstone, the surface of the peneplain, are heavily cemented by soluble silica, forming an almost impenetrable cap-rock (but even that gets undermined over the less resistant sectors). Thus wherever the rises show patches of white gypsite, whether protected above only by grey billy boulders or by extensive indurated sandstone slabs, there the peninsulars which ultimately become outlying conical hills seem to develop. Completely unprotected from the wind they endure its attack over very long periods while in the same amount of time the slope with its talus has retreated perhaps two or three miles, sometimes more. Obviously these hills are much more resistant, better equipped to withstand erosion and an explanation must be sought which will conform with this feature. It seems that any explanation which treats the peneplain as a homogeneous formation will be unable to account for such local variations but if we suggest that concealed in it are extinct springs, their sites hardened by silicification yet marked only by a group of boulders, a scree of pebbles different from the normal gibbers, or gullies unusually large, we are able to explain the embayment of the scarp and the subsequent development of the promontories and isolated peaks. Where a line of springs marked a fault, there we might

suggest a ridge or small plateau would take shape. Such an explanation seems to meet satisfactorily every question advanced.

The underground workings at Coober Pedy are similar to those at Andamooka and the typical heavy deposits of gypsum are seen, the beds of siliceous earths and the quartzite pebbles and jaspers. Ferric compounds are perhaps not so plentiful but there is more manganese. In general, the area has all the appearance of a hydro-thermal region, which has become extinct probably on account of a decrease in the rainfall.

For most of the journey to Alice Springs the countryside was much the same as it had been south of Coober Pedy—the same undulating stony tableland covered with sparse vegetation and loose iron-stained sand a few inches deep. For miles and miles there was almost nothing to be seen, not even trees. The track runs across bare open country unfenced and without a dwelling of any kind. On the run we saw only four houses in three hundred miles. However there were often hills in the far distance and we drove across a number of wadis, their beds strewn with waterworn pebbles of various kinds and stained white in places from the gypsum in the surface sand. Here and there we passed likely looking opal country marked by patches of white earth in contrast to the usual grey or reddish sand, and often in their vicinity a light covering of nodular limonite or martite spread over the hill side. Several such places were carefully noted and subsequent enquiries have verified the existence of potch or opal having been found there.

A hundred miles south of Alice Springs the country begins to get much more interesting. The wide Fincke River bed lined with splendid trees was crossed and the finger post—" a thousand miles to Darwin and 1,000 miles to Adelaide "—passed. Hills and mountains converge on the track until the scenery is awe-inspiring and beautiful. Henbury cattle station, famous for its meteorite craters, was seen, also the road out to Hermannsburg mission in the McDonald Ranges, while the great Ayers Rock lay off to the West of our route.

We were now completely out of the opal country, which is away to the East, over the great artesian basin which lies beneath the massive sandstones deposited in the inland seas of Cretaceous times. Subsequently these strata rose as an unbroken shield over

1,000 miles across. This uplift was associated with faulting, especially on the western and southern edges where the opal fields of White Cliffs, Andamooka and Coober Pedy are found. Lightning Ridge is not precisely on the edge, but some 50 miles north of it, while the Queensland fields lie in a belt down the centre of the dome as if a line of weakness were there. This faulting and consequent pressure resulted, presumably, in hydro thermal springs, which, rising towards the surface, found themselves blanketed by substantial beds of lightly consolidated sand and shales. Through this they were able to penetrate with three results. Firstly, the superheated waters would be able to enlarge their channels by removing the sandstone lining them, thus scouring out considerable cavities. Secondly, the mineralized waters would seep horizontally into the beds surrounding the springs and thus produce an enriched cemented mass. Thirdly, the siliceous waters emerging on the surface of the peneplain would, to some extent, spread out over it, depositing siliceous sinter and mineral muds and permeating the upper strata, resulting in a highly silicified indurated capping and later carving gullies in the otherwise almost level country. Such springs might flow for many centuries depositing at different times volumes of gypsum, soluble silica, ferric and similar hydroxides derived from decomposition of the deeper rocks.

In many cases, when after a long period a spring commences to recede, and while the temperature is still high at depth, intermittent ejection in the form of geysers may take place when siliceous grey mud-stones and boulders, vein-quartz fragments and various quartzites may be ejected to accumulate around the orifice. As activity decreases further the vent is likely to become choked since ejected material falls back and is cemented together into a concrete-like mass (found in the opal workings) forming an immovable plug. Under pressure, still spasmodically exerted from below, the saturated waters seek a new outlet but the sandstone above is already silicified into an impermeable capping. The waters are thus forcibly injected along the lines of least resistance, through the shaley bedding planes between the massive blocks, where further deposition will take place. The spring continues to die away, the deposits slowly consolidate, silica gel forms from the sol and in time hardens to opal in various forms, as found lying in the different levels.

This appears to be the " unusual activity " referred to earlier in these notes. Stated thus, as briefly as was possible, it will be seen to account for the phenomena observed, the minerals seen, the resistant isolated hills and ridges, the enlarged gullies and the harder masses in the cretaceous beds revealed as they emerge from the retreating scarp. The heavily cemented plug would prove extremely durable and maintain the altitude of the conical hills.

Much of the evidence available has not been included. A number of very pertinent mineral specimens were collected and many photos taken of relevant topography.

We reached " The Alice " in bright sunlight and found it really delightful. It is prosperous, well organized and attractive. The water supply is unlimited, being derived from springs beneath the well-timbered alluvial flat which the river has formed among the outstanding McDonald Ranges of ancient well-weathered and craggy rocks.

We flew back to Adelaide over some likely looking country and dry Lake Eyre, touching down at Oodnadatta. *En route* white-topped hills were noted here and there and carefully recorded, especially those with dark aureoles, presumably of ferruginous nodules. Just North of Oodnadatta one particularly favourable spot was seen. It appeared to have all the brand marks of an opaliferous area. Weeks later, back in Sydney, the writer, visiting the technical museum, saw a deeply glowing opal—from Oodnadatta.

Gemmological Abstracts

CHUDOBA (K. F.). *Zur Synthese und Bezeichnung der "Chatham" Smaragde.* (On the synthesis and name of the Chatham emeralds.) Deutsche Goldschmiedezeitung, Vol. 54, 1956, No. 2, p. 64.

D. E. Mayers has stated his opinion (Gemmologist 290, 1955) that Chatham emeralds were not synthetic, and suggested the name "cultured emerald," as they were not produced by the Verneuil process, but a hydrothermal method. Chudoba disagrees and objects to a hydrothermally produced stone being called anything but synthetic.

E.S.

SCHLOSSMACHER (K.). *Das Einschlussbild der Edelsteine.* (Picture of inclusions in gems.) Deutsche Goldschmiedezeitung, Vol. 54, 1956, No. 3, p. 106.

This article deals with the "picture of inclusions" by which the author means the appearance of the whole field of view, not just of individual inclusions. He draws a comparison between a flower (corresponding to the inclusion) and the impression of the whole garden (being the picture). Examples are Burma rubies, where the rutile needles, intersecting at 60 degrees, give a picture of the stone. Ceylon rubies and Ceylon sapphires also have rutile needles, but these present a completely different "picture," as the long, thick, straight needles are more loosely arranged. Zircon is a characteristic inclusion material in many Ceylon stones. Ceylon corundums often contain veils of liquid inclusions. These are also seen in Siam sapphires, which often contain "flying saucers," black hexagonal minerals resting on a thin, flat, round "saucer."

E.S.

STOKES (R. B.). *The Australian Opal Fields.* Mineralogist (Oregon) May, 1956, p. 231.

A brief restatement of the occurrence, mining of opal and types of opal by a mining engineer who has visited the Australian opal fields.

S.P.

BAIER (E.). *Benennung und Wertung in Wissenschaft und Prax* Terminology and value in science and practice. Zeitschr d. Deutsch. Ges. f. Edelsteinkunde, No. 15, 1956, pp. 7-12.

This valuable contribution by Prof. Baier illuminates tl difficulties which arise in the " applied science " of gemmolog In scientific definitions there is no room for valuations li " precious " or " semi-precious." Gemmologists, however, mu adapt their terminology to the demand of industry and trade.

In chemistry, synthesis is the formation of a compound fro its elements or simpler compounds. It does not seem justifie therefore, to use the word " synthesis " for the preparation of crystallized material from a suitable melt. In spite of this, it h become usual in mineralogy to call a laboratory-made mine " synthetic " if it corresponds to the natural mineral in compositi and crystal structure. The gemmologist must not be blamed f following this lead, although the genetic " artificial " would ha been at least as clear.

Gemmology is trying to bridge two attitudes. On one si there are producers, manufacturers and buyers of gems with th sense of the beautiful, durable, genuine and their ideas of prop ganda, presentation and value, and on the other side the scienti whose object it is to devise a classification comprising all materi of the earth's crust, without expressing any opinion on value. It useful to illuminate these different attitudes in order to facilita fruitful discussion. W.

WILD (K. E.). *Die Anfänge der Schmucksteinschleiferei im Mittelalt* The beginnings of the gem cutting industry in medieval tim Zeitschr. d. Deutsch. Ges. f. Edelsteinkunde, No. 15, 19 pp. 12-19.

An interesting contribution to the history of gem cuttir The author reports that the first lapidary shops in the Idar-Ob stein district were mentioned in the 16th century and thus contr dicts the theory that they are of Roman origin. Bibliography 19 items. W.

PLATE (W.). *Edelsteinkunde als Unterrichtsfach.* Gemmology as subject for teaching. Deutsche Goldschmiedezeitung, V 54, 1956, No. 5, pp. 209-210.

The Technical College of the Precious Metal Trade Schwäbisch Gmünd is a compulsory school for goldsmiths' a

setters' apprentices. Two hours weekly are devoted to gemmology. So long as there were fewer than 12 pupils, one hour was spent on theory and one hour on the practical use of instruments. Now, with about 60-70 pupils, the weekly hour devoted to theory has been maintained, but the practical exercises are limited to two-day courses each for 12 pupils at the end of the term.

W.S.

CHUDOBA (K. F.). *Künstlich "grüne Diamanten" durch Elementarteilchen-Beschuss.* Green diamonds through atomic particle bombardment. Deutsche Goldschmiedezeitung, Vol. 54, 1956, No. 4, pp. 152-153.

A review of the present state of knowledge. Diamonds can be artificially coloured by exposing them to a bombardment of atomic particles which have been charged in a cyclotron with several million electron-volts. Diamonds coloured in this fashion show a clear demarcation line between the green outer layer and the undisturbed core, if deuterons or alpha particles are applied. The demarcation line can be observed easily when the stone is immersed in a liquid of high refractive index, for instance methylene iodide. If the diamonds are subjected to a neutron bombardment, the whole stone may be uniformly coloured green. A reliable method of differentiation between natural green and artificially coloured diamonds has not yet been established. It is relevant that the American Atomic Energy Commission stipulates that diamonds coloured in their reactors may be sold only as artificially coloured diamonds.

W.S.

ANON. *The opal deposits of Queensland to-day.* Gemmologist. Vol. XXV, Nos. 226-7, pp. 57-8 and 75-6. March-April, 1956.

A factual write-up of the appearance of the Queensland opal fields to-day by a prospector who first visited them in 1899. The writer tells of the country west of Hughenden and beyond the rail station of Winton into the opal country. Visits were paid to the Fermoy opal field, the Don field and the field at Opalton and those about the Moyne river. The opal surrounded by ironstone nodules known as "Yowah" nuts is mentioned. Gypsum is a common associate in the opal-bearing ground. Notes and anecdotes on the flora and fauna of the district enliven the article.

2 illus. R.W.

SINKANKAS (J.). *Some freaks and rarities among gemstones.* Gems and Gemology. Vol. VIII, No. 8, pp. 237-241 and 254. Winter, 1955-56.

The second instalment of this article describes the transparent rhodonite from the John Reed mine at Alicante, Lake Co., Colorado. The tourmalines from Maine and California are said to suffer from spontaneous rupture and fissuring, especially in the case of the parti-coloured crystals in which the colour is parallel to the length of the crystal. Some conjectural reasons for this are expounded. A cat's-eye nephrite from the Kobuk river (Alaska) is mentioned as well as the brownish-yellow idocrase from Laurel, Quebec, Canada. A light olive-green diopside from near Richvilla, De Kalb Township, St. Lawrence Co., New York ; leucite from the Alban Hills, Italy, and the transparent datolite from Westfield, Massachusetts, and from the New Jersey Quarries are mentioned. The kyanite from Sultan Hamed, Kenya, and from Brazil, and the green kyanite crystals from Yancey Co., North Carolina, are also discussed. The article closes with a description of the co-called " Television stone," which is a fibrous massive ulexite (a monoclinic hydrous borate of sodium and calcium) found in California. It was found that when a thick section of the material was cut at right angles to the fibres, these were so straight and reflective that newsprint placed against one polished face appeared like magic on the other, even with an intervening distance of an inch of material. The fibrous mineral is ordinarily used, despite its softness (1 on Mohs's scale) for the production of cat's-eyes. It is suggested that a similar " television effect " might be possible with the gypsum satinspar found in England. R.W.

WEBSTER (R.). *Fire pearl.* Gemmologist. Vol. XXV, No. 298, pp. 88-92, May, 1956.

Billitonites, glassy pebbles ascribed to a meteoric origin, have long been known. This article tells the story of attempts to popularize stones cut from such pebbles through the medium of sensational journalese. The physical and optical data obtained from two specimens of this material are recorded. The density was found to be 2·455 and 2·442 and the refractive index 1·51. The pebbles are round to oval in shape, of a dark greenish-black colour, and have a wrinkled exterior surface. A composition of billitonite (taken from literature) is given and the internal structure is reported

as containing round bubbles typical of bottle glass. The structure is unlike moldavite. The origin is said to be problematical.
1 illus. P.B.

ANDERSON (B. W.) : PAYNE (C. J.). *The spectroscope and its applications to gemmology.* Gemmologist. Vol. XXV, Nos. 296-7-8, pp. 41-43, 61-66, 81-84. March-April-May, 1956.

The absorption spectra due to copper are discussed. Copper in the divalent state gives a blue colour, while with monovalent copper the medium coloured is most often red. The absorption spectrum of cuprite (ruby copper) shows a continuous absorption from the orange at 6300A to the ultra-violet, producing a " colour filter " passing the red only. It is suggested that the deep " copper ruby " glasses owe their colour to minute crystals of elementary copper. Cuprous copper compounds on the other hand effectively absorb the red and pass the blue and violet, e.g. copper sulphate. Azurite and malachite are said to owe their different colours to a variation in the content of hydroxyl ions. These two copper carbonate minerals are too opaque to transmit enough light for spectrum observations to be made, and by reflected light no bands have been observed. Turquoise alone exhibits bands due to copper which are of a diagnostic nature. There are three bands in turquoise, a vague band centred at 4600A, a sharper and more prominent band at 4320A, and another, which is too far into the obscurity of the violet to be visible except by photographic methods, at 4200A. The 4600 and 4320A bands are visible by scattered light and these are important as turqouise is simulated by so many natural and artificial substances. The absorption spectrum of zircon is fully discussed. The history of its first observance by Church in 1866, and Sorby's similar discovery of the bands which he inferred as due to a new element which he named *jargonium* (this he later realized was incorrect and that the lines were due to uranous oxide) is interestingly told. The absorption spectrum of zircon consists of a number of dark lines throughout the spectrum and full tables of these are given. The most important is the strong and persistent line at 6535A. In Ceylon zircons about 14 bands may be seen ; in Burma zircons as many as 41 lines have been counted in one stone. The brown crystals from Indo-China show scarcely anything but the heat-treated material derived from them, the colourless, blue and orange zircons used in jewellery, always show the 6535A line and other lines, particularly one at 6605A.

Red-coloured zircons are usually devoid of absorption lines. Low-type zircons, the type broken down by radio-activity (called metamict zircons) exhibit only a woolly band centered at 6535A. Two rare variations of the zircon spectrum are reported, both of which are metamict types of zircon. One of these shows three broad strong bands in the red and centred at 6535, 6690 and 6865A, and these three bands are present in conjunction with many other bands similar to normal type zircon spectra. The refractive index and density of one such stone was found to be 1·792-1·796 and 3·965 and the colour was a dull green. Another variation in the spectrum of a low-type zircon was shown by three cases where bands at 6550 (vague), a strong band at 5200A and another at 4560A were seen. In each of these three stones the refractive index and density was 1·82 and 3·98 respectively. No birefringence was seen. The writers then deal with spectra due to rare earths. There are three groups of rare earths, the cerium group, the terbium group and the yttrium group. The compounds of these rare earths are so similar chemically that they are difficult to separate from one another. The reason for this has been found to be due to the difference in the electronic distribution of such elements from that of the elements more commonly known. In the case of the rare earths the electronic difference from one element to the next in the series involves the " filling-up " of a deeper lying electron shell, the N shell, and not to the " filling-up " of the outer shell of electrons as is normal. To this is also due the sharpness of the absorption lines, and the fluorescence lines, in the spectrum of such elements. The wavelengths of the lines are very little affected by the host crystal as these deeper electrons are screened by the shells of outer electrons, and thus electron shifts in the N orbits are relatively undisturbed. The spectrum due to didymium is described as not being that of a single element but a combination of two elements—neodymium and praseodymium—which are always in association with each other and thus give a combined spectrum which is always referred to as the didymium spectrum. This didymium spectrum consists of a group of closely spaced fine lines in the yellow at 5975, 5855, 5825, 5772 and 5742A, with another group in the green at 5335, 5295, 5265, 5250 and 5210A. This is the absorption spectrum seen so strongly in the yellow apatite, and it is seen, albeit very weakly, in other minerals having calcium in their make-up, such as danburite, sphene, fluorspar, idocrase, calcite and scheelite. Warn-

ing is given that many Crooke's glass spectacles show a vague didymium spectrum and this should be taken into account if such spectacles are worn during the examination of the absorption spectrum of any stone. The observance of a didymium spectrum in emerald which contains an inclusion of the rare mineral parisite is noted.

8 illus. R.W.

BROSE (H. W.). *Civilizations and Gems of America* (Part Two). Lapidary Journal, Vol. IX, No. 5, p. 456, December, 1955.

While the first part of this article (*Journ. Gemmology Abs.*, Vol. V, No. 5, 1956) covered the title ground more or less generally, part two deals with the particular. The author shatters the illusion —if indeed it still is an illusion—that the early American colonies were largely made up of British people. Here again a new country was being traded for beads, and the Island of Manhattan, on which New York now stands, cost the Dutch $24.00—in beads. The early story of any new country is a story of survival—agriculture, fishing, hunting, home industries, begetting children, primary education, and so on. An interest in jewellery, and therefore gemstones, is a much later trend. Ornamentation means at least some leisure—not only to create it but to wear it. Yet in a country of such virility as the U.S.A. this developed with surprising rapidity. Not much later than a hundred years after the first settlers, there were already goldsmiths and silversmiths, and the famous revolutionary leader, Paul Revere, was a first class goldsmith. This, however, was merely the eastern side of the U.S.A. Those who went west, and the trek seems to have been continual, with appalling hardships, were still confronted with the primal urges. They had to hunt for food and later grow it. The gold rush, comprising people of all nationalities and classes, was still later. Somewhere out of this medley, Mr. Brose tells us, the prospector developed, and drawing largely on his own experience the author gives us a thumb-nail sketch of many unusual characters. There was the cook, or chef, who, with two fat ponies, headed for the mountains every spring. For diversion he read geology and " polished an enormous garnet, larger than a hen's egg." There was the man who first discovered and operated a sapphire mine. There was the engineer who found a magnificent opal (one-third matrix) weighing almost ten ounces. There

was the Shakespearean scholar who "hunted opals in Mexico, topaz in Texas, diamonds in Arkansas, sapphires in Montana, and beryl in Colorado." There was the man who had worked in the Chivor mines and owned an exceptionally beautiful emerald crystal. And so on and on. The gemstones of Brazil alone must be a very long story, too long to condense into a short article. Later, the author deals, almost affectionately, with the gemstones in each of the States ; not the spectacular variety of South America but those that must interest every gemmologist. Nature seems to have a strange way with gemstones. She is either prolific or she yields sparingly, almost grudgingly. We are reminded by the author that he writes of the south-west some forty-years ago though with renewed acquaintance between the years of 1948 and 1952. Prospectors are a vanishing breed. Without question they were colourful. And the author's nostalgic note is understandable. E.R.

PAYNE (C. J.). *An alexandrite crystal from Burma.* Gemmologist. Vol. XXV, No. 296, pp. 39-40. March, 1956.

The report of an alexandrite crystal which was found in the Mogok Stone Tract of Upper Burma, a locality not considered as a usual source of alexandrite. The crystallography and physical data are given. The refractive indices were found to be : for the gamma ray 1·7548, for beta 1·7484 and for alpha 1·7463 giving a birefringence of 0·0085 and biaxial positive in sign. The density proved to be 3·706 and the pleochroic colours : gamma (z) blue-green, beta (y) green and alpha (x) purple, the latter deeper in colour when viewed with artificial light and weak when in daylight. A full list of the absorption bands is given and the inclusions were found to be reminiscent of those seen in Burma ruby. 3 illus. R.W.

VERMA (R. K.) : SIRKAR (G. N.) : CHATTERJEE (S.). *An automatic Verneuil furnace.* Gemmologist. Vol. XXV, No. 296, pp. 52-56. March, 1956. Extracted from Journ. Sci. and Industrial Research (India), Vol. 13, No. 11, November, 1954.

Describes a Verneuil inverted oxy-hydrogen furnace of usual construction except for the addition of an automatic drive to control the height of the boule in the flame, and the gas and powder feeds. The apparatus was primarily designed to produce rod-type boules

of various synthetic minerals, such as the tungstates of calcium and cadmium, used for the detection of nuclear radiations. Synthetic gemstone production may also be carried out on such apparatus (which is covered by patents). The gas supply is controlled by needle valves and capillary tubes, and the powder supply by a relaxation oscillator (10, 20, 30 and 40 times per minute) operating an electro-magnetic relay on the tapping hammer. The raising or lowering of the boule support is by an electric motor through reduction gearing and this is controlled by a photo-electric cell, which " sees " the luminous tip of the boule and keeps it in the hottest part of the flame.
5 illus. R.W.

MITCHELL (K.). *Some unusual inclusions.* Gemmologist, Vol. XXV, No. 297, pp. 59-60. April, 1956.

The article describes a pink synthetic spinel with " hose " type inclusions and tells of the sale of the stone as a natural pink sapphire. The note closes with the report of a dark grey scapolite cat's-eye. The refractive indices of this stone were measured as 1·548-1·568, and the density to be 2·638.
3 illus. R.W.

LEA (I.). *Further notes on " inclusions " in gemstones, etc.* Gems and Gemmology. Vol. VIII, pp. 231-236 and 254. Winter, 1955/56.

A further verbatim reprint of one of three papers written in 1869 (*see Abstracts Journ. Gemmology.* Vol. V, No. 6, p. 320). The inclusions noted and drawn by this nineteenth century worker are reported—in particular the two- and three-phase inclusions seen in emerald and quartz. The inclusions, or lack of them, observed in calcite, fluorite, apatite, the feldspars, tourmaline, cyanite, quartz, topaz, beryl, garnet, zircon, chrysoberyl, iolite, peridot, spinel, turquoise, opal, lapis lazuli, and corundum are discussed.
1 illus. R.W.

SLAWSON (C. B.) : BASTOS (F. M.). *The gemstones of Minas Gerais, Brazil.* Gems and Gemology. Vol. VIII, No. 8, pp. 227-229 and 253-254. Winter, 1955-56.

An account of the gemstone industry of the State of Minas Gerais, Brazil. Few cutters were employed prior to the second World War, but, during the hostilities, owing to the virtual closing

down of the European cutting of gemstones, a cutting industry grew up in Belo Horizonte, Teofilo Ontoni and Rio, some 450 cutters being employed in these three places. The dyeing and cutting of black onyx, which was shipped north from near Soledade, Rio Grande do Sul, was mainly carried out at Belo Horizonte, but this activity practically ceased after the war ended. Refugee cutters from Europe aided this expansion, although their value was more as middlemen on the commercial side than actual cutting. After the war came the demand for strategic minerals to be found in the pegmatites and alluvials, such as industrial diamonds, rock crystal quartz, high quality sheet mica, cassiterite, scheelite and industrial beryl, and these endeavours opened up new sources of gem minerals. The Marta Roche aquamarine, weighing 74·8 lbs. was found in 1954 in alluvial diggings whilst searching for rock crystal for the electronics industry. The crystal, named after a young Brazilian woman who had obtained second place in an international beauty competition of that year, yielded 60 to 70 per cent of cuttable material of extremely good colour. The Brazilian cutting is good, but does not equal pre-war Idar-Oberstein standards. The cut is often for weight to the detriment of brilliancy. The cutting is done on laps of tin and lead solder with carborundum as an abrasive, and polishing is with tripoli on a lead coated cast iron lap. The laps are often allowed to become slightly concave resulting in the facets being to some extent convex, which is again somewhat detrimental to the make of the stone. Comparison is made of the attitude of customers in the United States and those in Brazil, the latter appreciating fine colour the better. This is specially so in the case of aquamarines. 1 table. R.W.

HEGEL (O.), SCHLOSSMACHER (K.). *Das Einschlussbild der Edeltopase.* Inclusions in precious topaz. Zeitschr. d. Deutsch. Ges. f. Edelsteinkunde, No. 14, 1955/56, pp. 12–16.

Many stones were examined and the pink variety was found to have most inclusions. E. Gübelin mentions that topaz has many liquid inclusions, frequently containing two liquids which do not mix. This was found to be so. These inclusions can be very small, can form feathers ; there are also large inclusions, irregularly bound, always flat. E.S.

GÜBELIN (E.). *Einteilung der farbigen Edelsteine nach Ursache der Farbe.* Sub-dividing coloured precious stones according to the cause of their colour. Zeitschr. d. Deutsch. Ges. f. Edelsteinkunde, No. 13, 1955, pp. 7–8.

Short survey of idiochromatic and allochromatic stones. Allochromatic stones can be subdivided into those stones where the colour is caused by a "colouring" molecule, for inst. Cr_2O_3 in Al_2O_3, and those where the colour is caused by colloidal or otherwise microscopically fine particles, which are either regularly arranged in the stones, or can be irregular or arranged in zones.

E.S.

GÜBELIN (E.). *Absorptionsspektren von Edelsteinen.* Absorption spectra of precious stones. Zeitschr. d. Deutsch. Ges. f. Edelsteinkunde, No. 13, 1955, pp. 9–13.

This table deals with the absorption spectra of (*a*) zircon, (*b*) gems coloured with Cr_2O_3, (*c*) gems coloured with iron, (*d*) caused by manganese, (*e*) caused by other pigments, (*f*) structurally caused spectra, (*g*) didymium lines, (*h*) synthetic stones and (*i*) glasses.

SCHLOSSMACHER (K.). *Die Einschluesse.* Inclusions. Zeitschr. d. Deutsch. Ges. f. Edelsteinkunde, No. 13, 1955, pp. 13–17.

A short survey covering nimeral inclusions as well as gas bubbles feathers, etc. E.S.

BOOK REVIEW

CHUDOBA (K. F.) ; GÜBELIN (E. J.). *Echt oder Synthetisch* ? Grundlagen und Methoden zur Unterscheidung natürlicher Edelsteine von synthetischen Steinen. (Genuine or synthetic ? Basic theory and methods of differentiating between natural precious stones and synthetic stones.) 156 pp., 117 illustrations, 11 tables, 1 colour plate. Rühle-Diebener Verlag K. G., Stuttgart, 1956.

The reader who expects a most valuable contribution by two top-ranking gemmologists will not be disappointed. Much has been written before on the synthetic gem-stones and their determination, but a concise compilation of facts had been missing so far. The authors have succeeded admirably in showing how a century of scientific work formed the basis of modern methods of gem-material production. The Verneuil process and hydrothermal methods are dealt with adequately. The history of

diamond synthesis, given in nine pages, shows how another method has been added, namely direct transformation of one modification (graphite) into another (diamond) at high temperatures and extremely high pressure.

It may perhaps be suggested that in future editions of the book not only the names of previous workers are given, but that their papers are listed in the bibliography at the end of the book. On page 26 credit for the development of a lapis-lazuli coloured synthetic spinel is given to a Dr. Jaeger, whereas at Idar-Oberstein the synthetic is called " Grasmück lapis " after its inventor, a local dentist.

Roughly half of the book is devoted to the differentiation between genuine and synthetic stones, and all known scientific methods are described meticulously. The initiated will welcome in particular the tables listing the characteristics of genuine and synthetic stones and their behaviour when examined in different ways, for instance under filters, U.V. light, X-rays, etc. Dr. Gübelin's competence in pointing out the difference revealed in microscopic inspection of inclusions in synthetic and genuine stones is well known. His photomicrographs are a source of joy, even if reproduced in black and white. It is inherent in the method, that inclusions reveal frequently not only the genuineness of a stone, but also the locality where it comes from. An exact determination of this kind is highly satisfying. It should not be overlooked, however, that those who deal in gems are frequently in a position to see the " occurrence " at the first glance. Among the hints given, the colour of synthetic and precious stones in ordinary daylight should not be forgotten. For instance, the difference in appearance between a Burma and a Siam ruby may be due to inclusions, but iron containing feathers in Siam rubies may give them also the less desirable brownish hue which the " connoisseur " spots at once.

The authors considered natural and cultured pearls outside the scope of their book. Although the methods of determination are completely different from those relating to synthetic stones, it is to be hoped that the title of the book does not stand in the authors' way, should they feel that the book could be usefully enlarged in this direction.

The book is a most useful and enjoyable help to the gemmologist in a field which is perhaps the most important in practice.

W.S.

ASSOCIATION NOTICES

VICE-PRESIDENCY

Dr. Edward H. Kraus, President of the Gemological Institute of America and Dean Emeritus of the College of Literature, Science and the Arts of the University of Michigan, has honoured the Association by accepting the Council's invitation to become Vice-President of the Association. Recently Dr. Kraus was re-elected as President of the Gemological Institute of America for the eleventh year. Over the years he has done much to further the cause of gemmology, and is a co-author of *Gems and gem materials*, firstly with Dr. E. F. Holden, and subsequently with Dr. C. B. Slawson.

GIFTS TO THE ASSOCIATION

The Council of the Association is indebted to Mr. R. Webster for a copy of Tutton's " Crystals " and various specimens of gem material which have been polished by " tumbling."

The Council is also grateful to Dr. E. Gübelin for a copy of " Echt oder Synthetisch ? " by K. Chudoba and E. Gübelin.

GEMOLOGICAL INSTITUTE OF AMERICA

New Building

A combined dedication of its new building in the Brentwood area of Los Angeles and the 26th annual meeting of the Board of Governors made 27th February a significant day for the Gemological Institute of America.

The ceremony was held in the spacious new classrooms, with Jerome B. Wiss, Chairman of the Board, introducing H. Paul Juergens of Chicago as Master of Ceremonies. The programme took its keynote from the rededication of plaques in recognition of Beatrice and Robert M. Shipley, founders of the Institute in 1931 ; the late Godfrey Eacret, sponsor of the Institute's first laboratory facilities ; and Edward Wigglesworth, Ph.D., Director of the G.I.A. Eastern Laboratory in Boston until his death in 1945.

A crucifix carved from wood from the Mount of Olives, with a figure made from early American silver, was presented to the Institute by Mr. Loud as a symbol of the faith in ideals which is reflected in the sound growth of the Institute. Mr. Loud felt that the wood from Jerusalem, the Holy City to Catholic, Protestant and Jew alike, represented religious faith, and the early American silver from various times of crisis in our past represented faith in the democratic way of life ; that together they made an appropriate symbol of faith by which to guide the future of the Institute.

Richard T. Liddicoat, Jr., Executive Director, rededicated the aims of the Institute to the principles on which it was founded ; viz., the training of personnel for the jewellery profession and the maintenance of high standards for all phases

of the industry, through knowledge. He outlined some of the projects which are now nearing completion, including the two new courses to be announced within the next few months, as well as the future objectives contemplated by the G.I.A. staff.

Dr. Edward H. Kraus, Dean Emeritus of the College of Literature, Science and the Arts of the University of Michigan, was re-elected President of the Institute for the eleventh consecutive year.

Diamonds for Institute

In 1955 G.I.A. announced the generous gift of over 1,500 carats of rough diamonds made to the Institute by the Diamond Corporation, through the generosity of Sir Ernest Oppenheimer. This important acquisition, the Sir Ernest Oppenheimer Student Collection, contained many crystals in a range of qualities which if cut would provide for the Institute an excellent group of stones for Diamond Evaluation and other Resident classes.

Upon learning of the acquisition of the stones, the firm of Lazare Kaplan & Sons, New York City, immediately offered to cut a large number of these stones for the Institute without charge. The Kaplan firm, which has already cut about fifty stones, followed to the letter the G.I.A. request to cut the stones in a manner which would yield a cross section of the types of makes and finishes commonly encountered in the industry to-day. Thus the generosity of the Kaplan firm, following that of the Diamond Corporation and Sir Ernest Oppenheimer, has provided the jewellery industry of America with a large number of stones which are ideally suited to the diamond evaluation instruction offered to the trade by the Gemological Institute.

TALKS BY MEMBERS

BLYTHE, G. A. : " Gemstones," Ladies' Circle, Southend-on-Sea, 18th May.

EWING, D. J. : " Gemmology as applied to Police inquiries," Police Training College, Edinburgh, 9th April.

GALE, H. C. : " Modern Jewellery Design," Chapelfields Townswomen's Guild, Coventry, 15th September, 1955 ; St. Mary Magdelen's Young Women's Guild, Coventry, 23rd November, 1955 ; Stoke Heath Townswomen's Guild, Coventry, 21st January, 1956.

MELROSE, R. A. : " Gemstones," Heaton Rotary Club, Northumberland, 24th April, 1956.

COUNCIL MEETING

A meeting of the Council of the Association was held at Saint Dunstan's House, Carey Lane, London, E.C.2, on Tuesday, 8th May, 1956. Mr. F. H. Knowles-Brown, Chairman, presided.

The Council decided to invite Dr. Edward H. Kraus, President of the Gemological Institute of America, to become Vice-President of the Association.

The following were elected to membership :—

FELLOWSHIP

Hartland, Edward, London D.1949

Spittle, Theresa R. (Miss), Birmingham D.1955

PROBATIONARY

Blignaut, Adi (Mrs.), Johannesburg, S. Africa
McCann, Brian J., Whitecraigs
Sherrard, Julian S., London

ORDINARY

Asscher, Joseph (Jr.), Amsterdam, Holland
Baily, Hugh G., Sutton Coldfield
Flapper, Jan, Arnhem, Holland
Hewlett, Jack W., London
Inglis, Alexander, Dunfermline
Lawrie, William H., Killin
MacLeod, Hector M., Glasgow
Marks, Percy G., Sydney, Australia
Padbury, Edna P. (Miss), Birmingham
Thirlwell, Arthur P., Great Malvern
Walsh, Harvey L., Arlington, U.S.A.

Arrangements were made for the presentation of the awards gained in the 1956 examinations to be presented by Mr. B. W. Anderson at Goldsmiths' Hall, London, on Wednesday, 3rd October, and for a Conversazione to be held at the same place on 28th November.

Bye-law 5 (*e*) was amended so as to read: " The President, Vice-Presidents and Honorary Fellows shall not be called upon to pay an annual subscription."

The Council also decided to acknowledge as being competent the gemmological examinations and title of the Swiss Gemmological Association.

HERBERT SMITH LECTURE

The growing shortage in the world of real gemstones might well cause British jewellers to take an increasing interest in synthetic stones and this factor might lead to a " realistic attitude " being taken towards them. This was a belief expressed by Dr. Frederick Pough, when he gave the annual Herbert Smith Memorial Lecture before the Gemmological Association of Great Britain on 28th March.

Dr. Pough, who received a most enthusiastic welcome, was lately curator of minerals at the U.S. Museum of Natural History and is also the author of the extremely popular book, " A Field Guide to Rocks and Minerals."

Earlier in his talk, Dr. Pough referred to the remarkable ability of oxygen to bring about changes in a synthetic gemstone boule. In the production of synthetic titania the work started with the production of a boule which was almost black in colour. Yet, during a period of only about eight hours, the gas could penetrate this boule and give it an off-white colour ; this meant that the oxygen succeeded in penetrating, during this short time, about half an inch of solid material.

The speaker also gave an interesting commentary upon preferences in stones. Long ago, those who had the handling of them were unable to cut them and so produce sparkling gems. Preference, therefore, ran to the most opaque stones (a factor which is easily confirmed by the reader who cares to examine the gems in museums). This aspect of the subject was illustrated by lantern slides of outstanding character, as were the later parts of the lecture. Of course, the glass imitations of jewels made with comparative ease in days gone by were by no means durable, but obviously the jeweller's main requirement to-day was durability of high order. Early in the development of the craft there had been attempts made

to melt aluminium oxide, but it was found extremely difficult to achieve the temperatures and pressures necessary. The achievement of glass-like synthetics was made possible only in the last century with the development of the Verneuil process.

It had never been practicable to melt down either ruby or sapphire material in order to produce a number of inexpensive gems. Those rubies and sapphires produced from boules, however, were the same as natural stones save in respect of the inclusions, which could be observed with a magnifying glass. Even to-day, there were great difficulties met with in the production of these stones and great quantities of rejected material might still be found at manufacturers' premises, due to upsetting factors which had obtruded themselves during the growth of the boules. All these failures, or " accidents," increased production costs.

There was no doubt that the synthetic industry in the United States had grown up of necessity during the war years, when the U.S. was cut off from European supplies. By the time supplies were resumed, the manufacturers had made considerable progress and were producing types of stones not made in Europe. The rod-shaped sapphire, which was free from wastage, was a good example. This formation resulted from a supersaturation of the boule with titanium oxide. The boule is heat-treated at just below the melting point of titanium oxide. Of the star forms, rubies were larger and generally more successful than sapphires. The American Museum of Natural History possessed the largest example of such stones which the speaker had seen. This, dubbed the " Turkey Egg," weighed 109 carats. There was a hint for those whose tasks included the separation of synthetics from real star stones. If one observed the back of a synthetic, one found that it was smooth and partly polished.

There had also been star stones made in Germany, but in the U.S. this achievement ran up against patent difficulies. The patent specification granted was such that even if a different technique were used the final product must not be the same. The German stones were, in the experience of the speaker, more milky than the American, and the star formation was not so distinct.

Another German achievement was that of a dentist who had synthesized a lapis lazuli type of gem from sintered spinel. The appearance was assisted by the making of little pits in the stone and filling these with gold.

In the U.S. there had been very great progress made in the past 17 or so years. The speaker instanced a West Coast producer who, before World War Two, was synthesizing emeralds. At that time this particular producer was managing to bring his stones up to the order of about one-tenth ct. Shortly after the war he had managed to bring the size of stone up from four to five carats ; but so far he had not been able to exceed this limit significantly while still producing clean stones. All these stones were started as crystals. There was no patent on the process, but the secret had been well kept. The lecturer gave the view that these stones were probably started from seed crystals in a high temperature, high pressure " bomb," with a growing time which might be as long as between six and 36 months. The largest stones so far produced were little more than " stunt " pieces ; they were rather liable to break down.

Another process using the high temperature, high pressure " bomb " was rather off the jewellery line—the production of quartz for the radio industry. This process started with slices of natural quartz, and American workers had soon found out the importance of proper orientation of the quartz slices, a factor which had been overlooked in the past by German scientists on a similar line of country. Effective rate of growth of quartz crystal was stated to be in the region of 1 lb. per diem. Synthetically produced quartz had a small crystalline formation and research workers were still unable to find the factor which, in nature, led to large-diameter crystals. There was also a considerable amount of work done in connection with the growth of the so-called " rose-quartz "—a substance which came under fire at the recent panel session of the Gemmological Association. So far, attempts to synthesize this material resulted in non-transparent samples. Amethyst production had met with a similar fate. Synthetic mica had been produced and this material had a higher temperature tolerance than did the natural substance.

Dr. Pough turned his attention to some of the raw materials used in synthesis and after a discussion of halogen compounds dealt with silicon carbide. He stated that stones made from this material were extremely attractive with an appearance similar to that of cyclotroned diamonds. This material, like titania, would seem to have great possibilities in the realms of synthetic gem production. Using titania (found in nature as black rutile), stones of many attractive colours had been made, and some large sizes achieved. Indeed, stones weighing up to 200 ct. had been manufactured. Most trade interest centred upon white stones produced from this material, but gold, blue, red, and purple were among the colours achieved.

Finally—and, doubtless, as many of his hearers hoped—Dr. Pough referred to the synthetic diamonds which had been produced by the General Electric Co., in U.S.A. These were not, he asserted, of gem quality. They were at first manufactured in pressures of 1,500,000 p.s.i., but this had now been stepped-up to 2,500,000 p.s.i. at temperatures around 5,000 deg. F. So far, the largest synthetic diamond made was of about one-hundredth of a carat. The press was about two storeys high, yet the actual chamber in which the stone was formed was about the size of an india-rubber. He understood that success was now being achieved consistently, with about 80 per cent of the raw material used being converted into diamond material. Production had now emerged from the experimental orbit and had been taken over by a manufacturing department. No one had so far seen one of the end-products outside the G.E.C. organization so that he was not aware of the differences between the synthetic and natural diamonds. (This report, with slight revision, is reprinted with permission from the *Jeweller and Metalworker*.)

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FURTHER NOTES ON SYNTHETIC RED SPINEL

By W. F. EPPLER

MUCH has been written about synthetic red spinel,[1] yet there are still no red-coloured synthetic spinels on the market. Recently another piece of a red synthetic was obtained. At the first glance it was thought that it might be synthetic corundum, but it proved to be synthetic spinel. It is possible that it might have originated in a Swiss factory. The broken piece of approximately 25 carats showed the external features of a boule from the Verneuil type. The specific gravity was determined at $d = 3{\cdot}599 \pm 0{\cdot}001$ and the single refraction $n_D = 1{\cdot}720$ on the refractometer. Compared with the values of natural spinel (3·60 and 1·717) there are no great differences. Therefore it can be assumed that the composition of this synthetic red spinel will be characterized by the ratio $MgO : Al_2O_3 = 1 : 1$, as with natural spinel.

Examination under the microscope confirmed the findings of the internal features which have been described by E. Gübelin for other synthetic red spinels. In Fig. 1a we see curved lines, which indicate growth by the Verneuil process. The lines, particularly on the left side of the figure, are not strictly parallel but appear

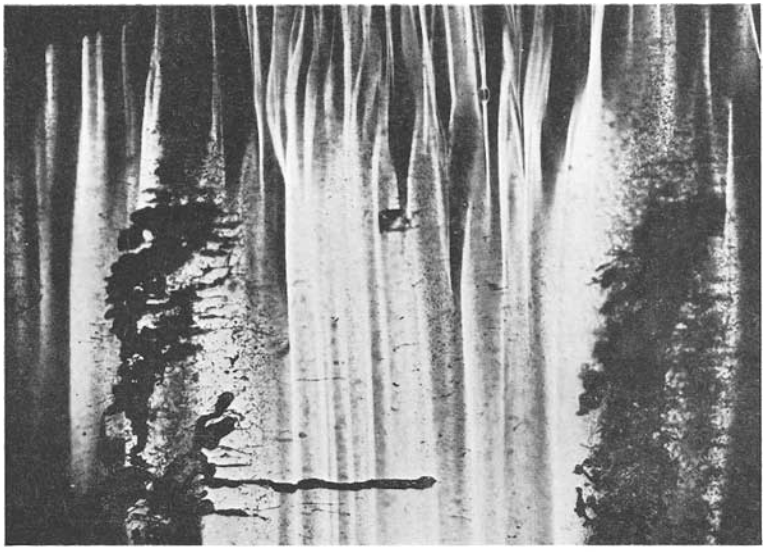

Fig. 1a and 1b. Synthetic red spinel, showing curved growing lines and gaseous inclusions. 15 ×.

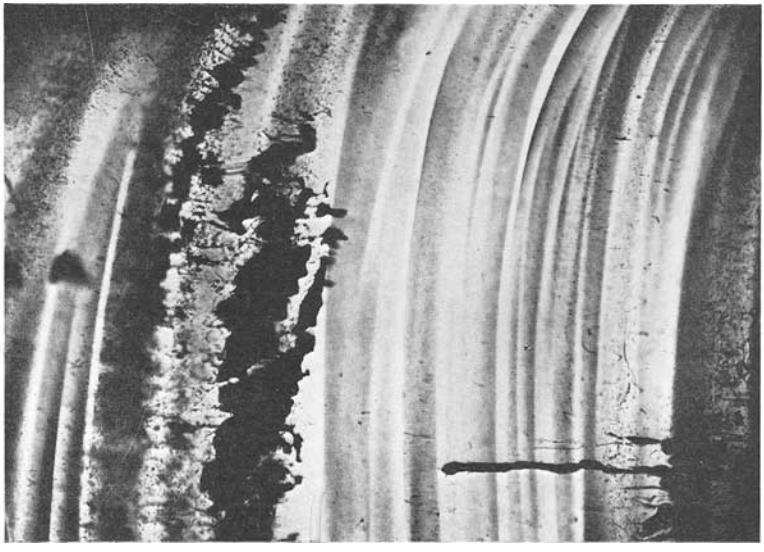

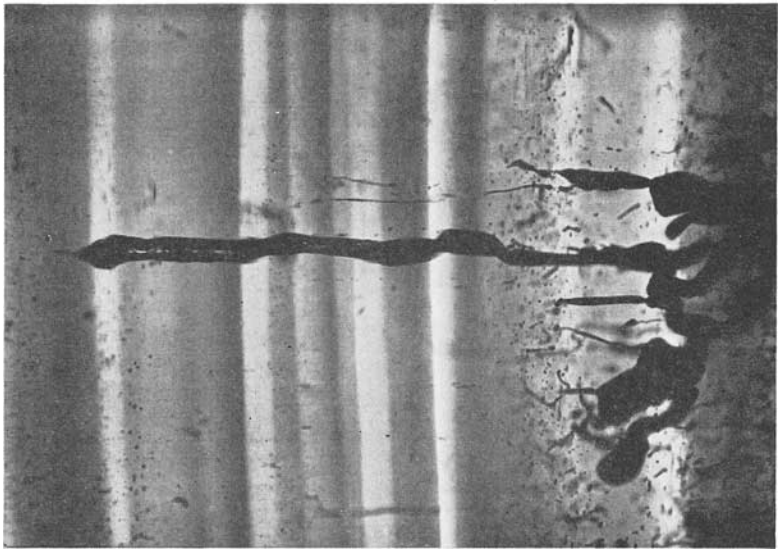

Fig. 2. Part of Fig. 1. 40 ×.

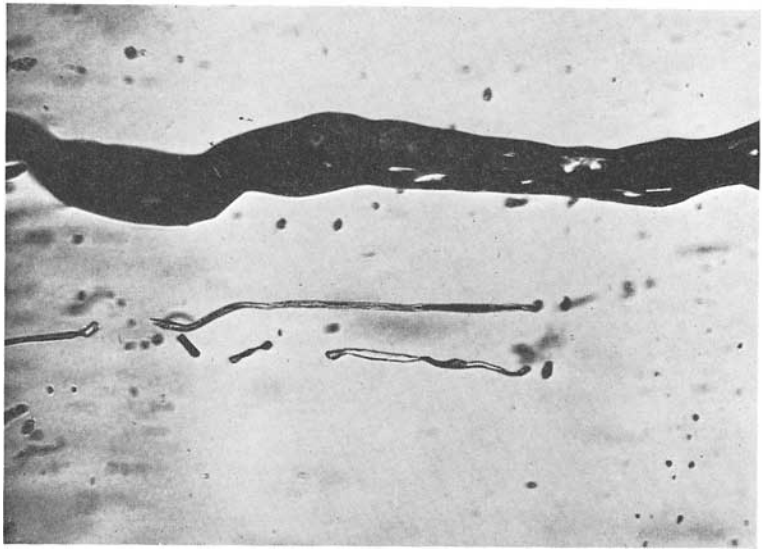

Fig. 3. Part of Fig. 2 ; tube-like two-phase inclusions. 100 ×.

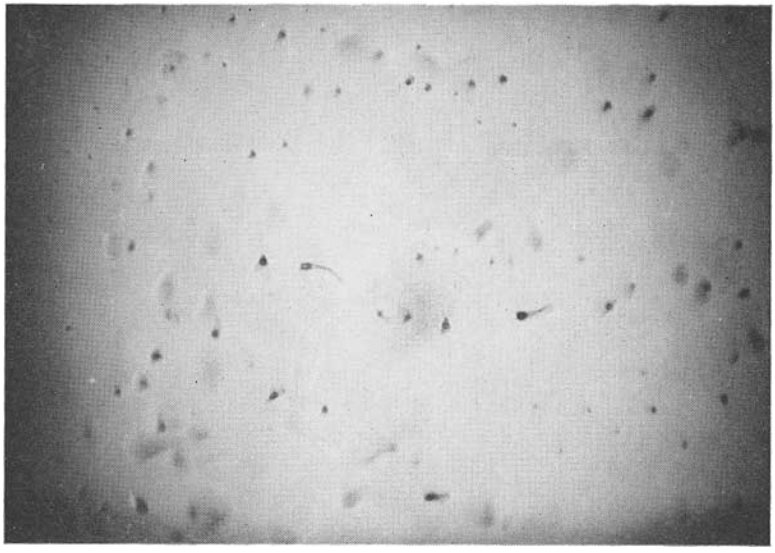

Fig. 4. Synthetic red spinel ; triangular and tadpole-shaped two-phase inclusions. 120 × .

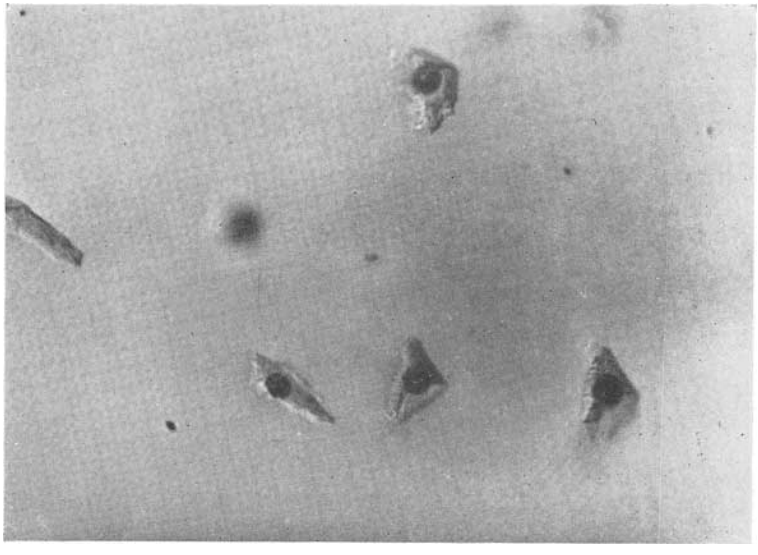

Fig. 5. Part of Fig. 4. 610 × .

distorted or disturbed. This is due, probably, to some kind of irregularity during the growing process. Fig. 1b shows the curved growth lines on the right edge of the specimen. The black spots are gaseous inclusions, very irregularly developed in the form of round-shaped cavities and hose-like channels. The long tube of Figs. 1a and 1b is shown again in Fig. 2, at a somewhat greater enlargement. Here we can observe that it is accompanied by thinner tube-like inclusions which are nearly parallel to the big one. In Fig. 3 these thin tubes appear again at higher magnification, as two-phase inclusions. It is very likely that the dark part of the small tubes is gaseous, that is hydrogen, and the bright one liquid, that is water.

Fig. 3 also exhibits a number of small black spots, which must be considered as gas bubbles (all pictures were taken in transmitted light). A somewhat greater enlargement of these is shown in Fig. 4. Here we easily recognize that the " dark spots " are two-phase inclusions, most of them in triangular forms and some almost a tadpole shape.

Fig. 5 again shows these two-phase inclusions. They represent negative crystals with a filling of hydrogen and water. Similar two-phase inclusions are known within the commercially produced synthetic spinels with the usual ratio of $MgO : Al_2O_3 = 1 : 3{\cdot}5$; but here the forms are different.

REFERENCES

(1) Gübelin (E. J.). *Are Synthetic Red Spinels Available ?* Gems and Gemology, Summer, 1950, 307-309; Crowningshield (G.R.) and Holmes (R. J.). *Synthetic Red Spinel*, Gems and Gemology, Winter, 1950-51, 362-367 ; Gübelin (E. J.). *More News of Synthetic Red Spinel.* Gems and Gemology, Winter 1953, 236-247.

Gemmological Abstracts

BANK (H.). *Reiseeindrücke von Brasiliens Edelsteinlagerstätten.* (A traveller's impression of Brazilian Gem Deposits.) Zeitschr. d. Deutsch. Gesellschaft f. Edelsteinkunde, No. 16, 1956, pp. 3–8. A continuation of an article in Zeitschr. d. Deutsch. Gesellschaft f. Edelsteinkunde, No. 14.

The article lists and describes localities in Brazil where beryls (aquamarines and " Brazilian emeralds "), tourmalines, amethysts, citrines and agates are found. The author, who is connected with the Idar-Oberstein industry, stresses the importance of geological and mineralogical training for prospectors as opposed to the " mere chance " method. W.S.

BOLSCHE (R.). *Ueber das Smaragdvorkommen im Habachtal.* (On the emerald occurrence in the Habach valley.) Zeitschr.d. Deutsch. Gesellschaft f. Edelsteinkunde, No. 16, 1956, pp. 19–23.

Two sketches (maps) give a clear impression of the geographical conditions. Of special interest are the profile sections showing the altitudes of the occurrences. Previous literature is mentioned. The author describes the way to and the position of old galleries. (To be continued.) W.S.

PLATE (W.). *Die synthetischen Steine.* (The synthetic stones.) Gold und Silber, Vol. 9, No. 8, 1956 (August), pp. 22–24.

A popular review of the history of synthetics and a description of the Verneuil process lead to the listing of the characteristics of synthetic corundum (also star corundum), spinel and rutile. The author stresses the necessity of careful microscopic investigation to differentiate between genuine and synthetic corundum ; the use of a hand lens is not mentioned. Synthetic emerald is to be discussed in a future article. W.S.

BANK (H.). *Reiseeindrücke von Brasiliens Edelsteinlagerstätten.* Impressions from a journey to Brazil's precious stone mines Zeitschr. d. Deutsch. Ges. f. Edelsteinkunde, No. 14, 1955/56, pp. 2–9.

The article starts with a general geological survey and points out that in most cases the gems in Brazil are not mined systematically.

Often a stone is found by coincidence, then a " run " sets in and many people come to try their luck, mostly to give it up again. The zone of Teofilo-Ottoni is described in some detail. There one finds aquamarines, and tourmalines, various beryls, i.e. white, green, yellow and also pink morganite. Occasionally one finds chrysoberyls and chrysoberyl cat's-eyes. Andalusite, brazilianite and spodumene are also found. The next place the author visited was Santa Maria de Itabira, well known for its intensely blue aquamarines. Also some emeralds have been found there. In Rodrigue Silvas and Dom Bosco precious topaz of good quality used to be found together with euclase. At the time of the author's visit, these mines were not worked. Caetite-Brumado-Brejinho (state of Bahia) is well known for amethysts, which are found with quartz. (To be continued.) E.S.

ARENA (P.). *Os Satelites do Diamante.* The subsidiary minerals of diamond. Gemologia (Brazil), No. 3, pp. 1–8.

Brazilian diamonds are found in secondary deposits of gravel (cascalho). This diamantiferous material consists of some fifty or more different minerals, many of them in gem varieties, the waterworn pebbles being often sufficiently characteristic in appearance to have acquired picturesque names among the native miners.

The deposits have from time to time yielded important specimens of gem andalusite, chrysoberyl, epidote, euclase, spinel, spessartite, topaz and tourmaline. The writer describes stones in some detail, often in colours which are not necessarily found in these localities. Some surprising finds are reported, such as specimens of alexandrite, a cymophane of 400 carats, and an 80 carat red spinel. Both sapphires and rubies have been found but apparently not in cuttable sizes.

2 illus. R.K.M.

LOEB (M.). *Algunas notas sôbre clivagem.* Some notes on cleavage. Gemologia (Brazil), No. 2, pp. 13–18.

A summary of the best known facts of the difficult subject of cleavage. The property is classified under system headings and under method of production : pressure—gypsum ; impact—calcite ; thermal shock—quartz. It is further defined under (1) the face to which it is parallel, (2) facility of production, (3) nature of the resultant surface. Parting is mentioned in connexion with twin planes and also with zoned structures and with

layers of inclusions. The last two are less usually recognized causes.

Several possible conditions required for cleavage in different minerals are given. Mention is made of an apparent connexion between rate of growth and cleavage, but the writer does not appear to have made it clear that he means the relative rate of growth between the different faces of one crystal and not the rate of growth of the whole crystal.

2 illus. R.K.M.

ANDERSON, (B. W.) ; PAYNE (C. J.). *The spectroscope and its applications to gemmology.* Gemmologist, Vol. XXV, Nos. 299/300/301, pp. 101–104 ; 115–119 ; 143–144. June/July/August, 1956.

This very complete research paper continues with further discussion of the spectra of rare-earth-containing gemstones. Reiteration of the reasons for the fine-line nature of rare-earth absorption spectra are made, and the minerals which give a didymium absorption spectrum noted. These are yellow apatite, which shows the strongest didymium spectrum, danburite, sphene, idocrase, scheelite and fluor in which the strength is very weak. In the case of the didymium spectrum any difference in the measurement of the lines with the different species is too small to be observable with the standard spectroscopes used. The spectrum of blue apatite, ascribed to unknown rare-earths, is seen in the ordinary ray of the mineral, and consists of a band of moderate strength at 6310A (in the orange) with weaker bands at 6220 and 5250A ; a strong narrow band at 5110A at the end of the green ; a broad weak band at 5070A followed by a strong broader band at 4900A, with, finally, a vague weak band at 4640A. Although the refractive indices of the yellow (Mexican) apatite are much the same as for the blue variety (Burma) the density of the yellow stones is 3·213, which is slightly higher than for the blue which approximates to 3·184, suggesting some difference in composition. Mention is made of the bands seen in the blue beryl from the Maxixe mine of Minas Gerais, Brazil, which may be ascribed to uranous uranium. The bright green andalusite, probably from Brazil, shows a rare-earth absorption spectrum of bands in the green. This spectrum shows a graded absorption band ending in a knife edge at 5535A followed by lines at 5505, 5475, 5180 and 4950A. There is also

a band at 4550 in the rather strongly absorbed blue-violet part of the spectrum and there is sometimes a narrow band at 4360A.

This series (Part 35) continues with the absorption spectrum of diamond. Diamond absorption spectra are ascribed to structural irregularities and are in two main groups. The main line in the " Cape " series of stones is at 4155A and varies in intensity with the strength of the yellowish colour. With this 4155A line are secondary and weaker lines at 4785, 4650, 4520, 4350 and 4230A. Such stones show a blue fluorescence. Brown-coloured diamonds and other tinted diamonds which show a green fluorescence show lines at 5040, which may be strong, and weaker lines at 4370 and 4080A. Stones exhibiting both series of absorption spectra and a combined fluorescence are not uncommon. The 5040A line has been observed in some but not all bombarded diamonds. Experiments by R. A. Dugdale on neutron-irradiated diamonds have shown that controlled heating of such stones at 350 degrees C. brings out the 5040A line and a green fluorescence which disappears on heating to over 400 degrees C. The authors continue with notes on the miscellaneous spectra and mention the bands seen in zinc blende (sphalerite). They are a strong band, which is fairly narrow, at 6650A, another at 6510A and a broader band, which is not very easily seen, at 6920A. Sodalite shows a rather strong and broad band at 6800A with weaker bands at 5950 and 5400A. The cause of these bands is not known. Fibrolite shows bands at 4410, 4100 and 4620A, the 4100A band being the strongest.

4 illus. R.W.

WEAVIND (R. G.). *Simplified manufacture of diamond tools.* Gems and Gemology, Vol. VIII, No. 10, pp. 310–319, Summer, 1956. (Reprinted from OPTIMA of March, 1956.)

A survey of the uses of industrial diamonds in precision engineering is first given. Reference is made to the work of the Diamond Research Laboratory (South Africa) in investigating the possibilities of simplifying manufacturing procedures by the development of semi-automatic machinery for shaping industrial diamonds and to the institution of training courses for factory workers with little or no knowledge of diamond, so that they can quickly learn how to make and service diamond tools. The cleaving and sawing directions of octahedral and dodecahedral crystals

are explained in the text and by illustrations. One of the semi-mechanical tangs developed by the Research Laboratory is fully explained.
11 illus. R.W.

BROWN (J. COGGIN). *Sapphires of India and Kashmir.* Gemmologist, Vol. XXV, Nos. 298/299/300, pp. 77–80 ; 97–100 ; 129–132, May/June/July, 1956.

Indian jewellers divided precious stones into two main groups, the great gems—*Maharatani*—into which they placed diamond, pearl, ruby, sapphire and emerald, and the secondary gems called *Uparatnani*. The blue sapphire (*nilamani*) was divided into two varieties, the rare and more precious being called *indranila*, and the poorer quality *mahanila*. The Indians knew that the ruby and sapphire answered the same physical tests and that no other stone except diamond would scratch them. The unpredictable effect of heat on sapphires was also known. Earliest Sanskrit writings gave only Ceylon as a sapphire source, but later Kalinga and Kalpur were mentioned. The first was identified as lying between the Mahanadi and Godavari rivers in the north-east of the Indian Peninsula, while the latter formed part of Central India. No sapphires are found there to-day. Kashmir sapphires are not mentioned in ancient writings. The Kashmir stones were first found in 1880 in the Zangskar Range, near Sumjum in Southern Kashmir. The history of the mines from their discovery, due to a landslide in 1880, to the present day is given. At an elevation of some 15,000 feet the mine was difficult to work and with the attacks by bands of robbers the mine was abandoned in 1887. In 1888 some 23,000 carats of sapphires were obtained from the detritus of the old mine. No systematic mining was carried out until 1906 when a lease was granted to the Kashmir Mining Company, but the endeavour lasted only till 1908. The mines were practically dormant until 1924 when the Himalayan geologist Pandit Labhu Ram Badyal discovered new sources from which a licensed prospector in 1926 removed a hundredweight and a half of sapphire crystals, but his licence was revoked owing to the irregularity of his working. The sapphires were obtained from lenticles of tough china clay associated with a little tourmaline and garnet. Some remarks on the geology of the region are given. The sapphire crystals are bipyramidal with no prism faces and the faces of the

pyramids are horizontally striated. Kashmire sapphire is not prone to " parting." Some crystals show an unusual feature in that in cavities in the centre of the crystal lie crystals of dark brown tourmaline. The crystals of sapphire are usually coated with a white skin which needs to be washed off before the colour of the crystal can be seen. Parti-coloration is common. Experimental working of the mine was carried out in 1927 and, after a scheme of development made in 1928, private enterprise worked the mines in succession from 1933 to 1951. The mining area is now said to be worked out but further deposits may be found. Mention is made of a source of sapphire crystals on the moraine of a glacier on the southern ascent of the Hagshu-la pass at 16,600 feet.
3 illus. R.W.

ANON. *Extension of Diamond Coast.* Gemmologist, Vol. XXV, No. 299, p. 107, June, 1956.

In 1909 diamonds were discovered on the coastal lands of what was then German South West Africa, and in recent years the area has been extended southwards along the coast almost to the mouth of the Orange River. The diamond-bearing gravels vary in thickness from practically nothing to about four feet and are covered by sand and conglomerate which may reach thirty feet in depth. This overburden is removed by mechanical excavation and then the diamondiferous gravel removed, the bedrock being scraped and brushed so that no loss occurs. Land Rovers have replaced horses for transport. No information is given as to the methods used in the recovery of the diamond from the gravel. The mines are operated by The Consolidated Diamond Mines of South West Africa, who recovered some thirteen million pounds worth of diamonds in 1955, of which 95 per cent were gem quality.
1 illus. R.W.

GÜBELIN (E. J.). *The emerald from Habachtal.* Gems and Gemology, Vol. VIII, No. 10, pp. 295–309. Summer, 1956.

A comprehensive survey of the Habachtal emerald mine and the characters of the crystals from this locality. The script closely parallels the author's article on the same subject published in Volume V, No. 7, of JOURNAL OF GEMMOLOGY, except that many of the illustrations are different.
14 illus. R.W.

WEBSTER (R.). *Nigerian topaz.* Gems & Gemology, Vol. VIII, No. 10, pp. 291–294. Summer, 1956.

A description of the topaz found around the tin-mining area of the Bauchi district of Nigeria. Crystals are colourless or with a pale greenish or bluish shade. They have a short prismatic habit with two prominent dome faces forming a chisel-shaped termination. Most are singly terminated with the basal cleavage at the end where they have been detached from the rock, but some doubly terminated crystals have been encountered. Most of the topaz found in Nigeria is in the form of rolled pebbles. Three refractive indices and ten determinations of specific gravity are given. The refractive indices agree to the values 1·61–1·62—with a birefringence of 0·10—and the density varies from 3·549 to 3·572. Thus Nigerian topazes are of the fluorine-rich type. The inclusions are described as being two-phase cavities, sometimes with two immiscible liquids and irregular cavities. In one case cubic crystals, which may be fluorite, were seen. The luminescence observed with long and short-wave ultra-violet light, and X-rays, is given. The effects are said to be weak. The story is told of some pebbles which had been sold as blue topaz, but which on investigation proved to have the colour on the surface due to an external application of indigo dye.

5 illus. P.B.

FARN (A. E.) : WEBSTER (R.). *Massive pink grossular garnet.* Gemmologist, Vol. XXV, No. 300, pp. 122–124. July, 1946.

Describes a pink and greyish massive grossular garnet probably from the same locality as the massive green variety miscalled "Transvaal Jade." The material has a density of approximately 3·4 and shows on the refractometer a vague refractive index of 1·72. Like the green variety the pink material shows an orange fluorescence when irradiated with X-rays. The material is said to be a nearly pure grossular with a trace of zoisite, and the colour is understood to be due to manganese.

1 illus. P.B.

MARCHER (G. H.). *Redondo "moonstones."* Gemmologist, Vol. XXV, No. 229, pp. 108–109, June, 1956.

Tells of the milky chalcedonies found on the beach at Redono, California, in the early part of the century, and of the commercialization of them by the local lapidaries. Cut chalcedony from Germany

were sold as Redono stones, and the knowledge of this did much to destroy the interest of the public in the beach chalcedonies, the choicest of which are clouded with a pretty translucent mottled appearance, rather like the fair-weather clouds known as mackerel sky.

R.W.

MacLeod (Helen). *The adulteration of turquoise.* Gemmologist, Vol. XXV, No. 229, p. 110. June, 1956.

Turquoise is reported to have its colour " improved " by oiling or dyeing. Recent " waxing " methods, involving the boiling of turquoise in paraffin, is said to give a false polish to chalky material. Much turquoise is fashioned by the " tumbling " process producing baroque shapes. Some " waxed " material may have been strengthened with colourless plastic, such as leucite (perspex), in order to withstand the tumbling operation. The colour of turquoise is often intensified to a shade which is " too good " ; and " matrix " may be imitated. It is suggested that turquoise powder formed into a paste and bonded in plastic has been used to produce " turquoise." An alternative suggestion is that the powder of chrysocolla may be used instead of powdered turquoise. Another type of turquoise imitation may be produced by using a type of Portland cement coloured by powdered chrysocolla. Rough seam turquoise can usually be considered genuine.

R.W.

Anon. *Hardness numbers of minerals.* Gemmologist, Vol. XXV, No. 301, pp. 149–150. August, 1956.

A table showing for comparison the hardness numbers of some forty gemstones and minerals as found by the Knoop and Vickers systems. Mohs's scale numbers are not included.

Robb (C. J.). *Ecclesiastical and Classical pearls.* Gemmologist, Vol. XXV, No. 301, p. 151. August, 1956.

A note on the origin of the name *pearl ;* on its use in church ornaments and classical anecdotes. Some Irish book shrines were set with Irish river pearls.

R.W.

JADE STORY — EUROPEAN

(The fifth part of the Story of Jade in Europe)

By ELSIE RUFF, F.G.A.

" THE term jade has been supplied to nearly all greenish, translucent stones which are susceptible of being wrought into ornamental objects and for which there was no other well defined name . . . therefore I venture to recommend that *Jade* be used as a generic term. . . . Jade is either a generic term or it is nothing. If it is not used generically, it must be dropped. . . ." Dr. Thomas Wilson, Curator of Prehistoric Archaeology (U.S. National Museum) made this statement during 1900 in his paper *Jade in America.* And the statement is still tenable, except that to-day we confine the word *Jade* to two distinct minerals, jadeite and nephrite. Though suspected on more than one occasion these two minerals were not scientifically separated until 1863, by Damour. Since chloromelanite is a jadeite containing iron which renders it a very dark green—at times almost amounting to black—there is no problem concerning this word. The Latin term for nephrite, *lapis nephriticus*, was used largely as Dr. Wilson defined the word *jade*, roughly between the period of Monardes and Damour.

Nevertheless, these terms, perfectly clear to us to-day, represented only a small part of the jade terminology. To attempt a list is to discover that it is almost inexhaustible. There are many lists of jade-like stones or stones imitating jade, but the following collection covers the names most commonly used for the substances mentioned by Thomas Wilson in the paragraph above :

Agate Verdâtre.
Amazon Stone or Stone of the Amazons, or *Lapis Amazonicus.*
Chalchihuitl.
Circoncision Stone.
Divine Stone or *Lapis Divinus.*
Fibrolite.
Green-stone.
Jaspachates.
Jasper or *Jaspe* or *Jaspis* or *Jaspis Viridis.*
Kidney-stone.

La Pierre des haches.
Oceanic Jade.
Piedra de los riñones or *raines.*
Piedra ijada or *yjada* or *hijada.*
Pierre néphrétique, also spelt *pierre néphritique.*
Pounamu.
Prase or *prasius.*
Saussurite or jade tenace.
Smaragdus.
Spleen stone or spleene-stone.
Steatite.
Yü.

This list, formidable at first sight, may be quickly reduced. *Yü*, *Chalchihuitl*, and *Pounamu*, representative of countries, that is, China, South America, and New Zealand respectively, may be dismissed. In no way do they confuse the European issue. The Spanish equivalent of *lapis nephriticus* has already been discussed.[1] Amazon stone refers, as the name indicates, to the jade, or jade-like stones, coming from the precincts of the Amazon river in South America. Divine stone covers the same substance, though not necessarily from the Amazon river area. It is a translation resulting from the miraculous qualities attributed to this stone.[2] Circoncision stone again refers to similar material and was so-called because used in this rite, as indeed a stone is still sometimes used. These three terms, all referring to South American jade, will come up for discussion at a later date. Jaspachates has been mentioned earlier.[3] Saussurite, or what seems to be an older term, jade tenace,[4] was named after the Frenchman H. B. de Saussure, and is material familiar to every gemmologist as decomposed feldspar. Also well known is prase corresponding to the Latin *prasius*. *Smaragdus* was the Latin term for emerald.[5] Fibrolite and Steatite may also be dismissed. Most gemmology text-books define these minerals. Greenstone, a very loose term, is discussed at length in *Jade of the Maori*. It is a word, surely, never intended to be other than an initial description, that is, some kind of green stone. Captain Cook, in his journals dealing with the discovery of New Zealand during the second half of the 18th century, makes this crystal clear. " Many of the Indians," that is, Maoris, he wrote, " wear pieces of greenstone round their necks which are transparent,

and resemble an emerald. These being examined appeared to be a species of the nephritic stone." (This statement alone should rank him among the early gemmologists.) From time to time one finds the word greenstone used in the same way in connexion with South American material.

From this long list, therefore, we are left with Agate Verdâtre, Spleen-stone, Kidney-stone, and Jasper, with its foreign equivalents. Here Agate Verdâtre presents no difficulty. It is a French term literally meaning greenish-agate. Agates are always banded, with curved layers, and because of this they are not easily confused. If the term covered what we now know as jade, as it seems to have done, it was very loosely applied. Jade may be mottled, or speckled, but is never banded in the way that agate is. Spleen-stone and kidney-stone may be grouped together. One was a curative for spleen trouble, the other for kidney disorders. As mentioned in an earlier article, the connexion between these two states is so subtle that either term might be used for a disturbance or trouble in that area. There have always been fashions in diseases or, for want of more knowledge, certain symptoms have frequently been grouped under a few fashionable headings. Which of these two terms is the older is difficult to say. In 1734, E. Milward, an M.D., published a work entitled *Trallianus Reviviscens* (revised). It was a small volume in the form of a letter to Sir Hans Sloane, for whom the author had a great regard. Trallianus, or Alexander of Tralles, was a Greek physician of the 6th century B.C. He travelled widely —through his own country, through Spain, Gaul, and so on. The Greek text of his work *Βιβλια Ιατρικά* was printed in Paris during 1548 and his *De Lumbricis* at Venice in 1570. Milward wrote : " He is excellent in distinguishing the *stone* from the *Colick*, which have so near an affinity in their signs to each other, that they often-times impose upon the unwary practitioner." After suggesting various medicines in such cases, he goes on : " . . . and it is very observable, that he mentions a large cupping-glass to be applied to the Region of the Navel, which, he says, will dissipate the pain with such amazing expedition, as to make the bystanders believe the cure has been performed by *Art Magic* or something supernatural." Here we have an acknowledgment between one medical man and another of this constant interchange of *stone* and *colic* over a very long period.

The only disputable term that emerges from this long list is, as we see, the word Jasper, or the French *jaspe*, or the Latin *jaspis*. Or there is *jaspis viridis*, as used by Sir Hans Sloane and others. In this case the term would seem to differentiate between green or greenish jasper and jasper (or jade) of other colours. Certainly the term jasper sometimes covered the material we know to-day as such. It also covered other substances.[6] Without question it covered jade, often describing it as a kind of jasper, as we might say that jadeite is a kind of jade. Was this too a generic term ? Was this the jade of the ancients, the term largely displaced when *lapis nephriticus* came into use ? It is possible, though unlikely, that a well known mineral may not be mentioned for a number of centuries, perhaps due to a lessening popularity, and bearing in mind the limited (and even more limited as we dig back) literature of the times. It is possible too that this paucity of the written language is the explanation. The Chinese were the first printers, printing from movable type in the years 1041 to 1049 by one Pi Shéng. The European invention, which is believed to be completely independent of the Chinese discovery, took place around 1440 A.D. It was not really before the 16th century that knowledge was able to circulate more freely among those who could read, when a printed book was more available than a hand-written copy. Hand-written copies were either the work of individual scholars or were sponsored by influential men of the day. In either case the book was precious. This means that Monardes' book might never have had a chance of circulating, except among the few, had the information it contained come a century earlier. And the chances of an English translation would have been more limited still. Another point emerges here, which has a bearing on man's very early use of jade. This is the fact of rare independent invention. Four hundred years separated the two printing inventions, and about 1,500 years of European development was to elapse, before the printing press. Scholars there have always been, in plenty, but up to the advent of the printing press no one had thought up a way of making knowledge as easily available as it later became.

The question that comes to mind as a result of all this is, if jasper was not a generic term, could the substance we know as jasper to-day be mistaken for jade ? A few lines from modern authorities

describing this material will answer the question :

> " *Jasper* is an impure variety of quartz. It is compact, and being very hard it takes a fine polish. It occurs in many colours—dark green, brown, yellow and sometimes blue and black. . . . Unlike chalcedony it is opaque, and does not possess a splintery fracture. The term jasper is now restricted to opaque stones, but the ancient *jaspis* or *ἴασπις* was at least partially translucent, and probably included some chalcedony and chrysoprase. . . ."[7]

> " Jasper consists of a compact aggregate of finely granular quartz mixed with impurities in large amount which act as the colouring matter. There may be a wide range of bright colours, and the material takes a good polish. It is often rather of the nature of a metamorphic rock formed by the baking of mudstone and shale."[8]

(Here this is the whole of the quotation.)

> " Jasper is a chalcedony coloured blood-red by iron oxide, while bloodstone is a green chalcedony spotted with jasper."[9]

(There is no mention here of green jasper.)

These three excerpts, taken at random, suggest that, whatever the ancients thought of jasper, the modern world has very little interest. The most obvious point of differentiation between jade and jasper is of course its polish. The description of a greasy or wax-like polish immediately releases jade from any confusion with modern jasper since, as the first two quotations point out, jasper takes a fine polish.

Sir James Walton,[10] writing of jasper, says : "The very impure form *jasper* which contains up to 20% of impurities occurs like agate in many different colours, e.g., red, brown, green, bluish or black. . . . Unlike agate, all the varieties are opaque." The Rev. C. W. King[11] wrote : " Thus it appears that the ancient idea of the *Jaspis* was exactly the opposite to the modern of the Jasper, the latter being our term for a class always opaque." Right up to recent years the separation of jasper from jade was causing concern. G. F. Kunz[12] wrote : " The real separation of jasper and jade seems to have occurred about the end of the 16th century." But, as we have seen, in the 17th century there was still a great urgency to do just this and evidently the term jasper had such a foothold that it continued to be confused right up to the 19th. And as late as

the 19th century the jade tomb of Tamerlane or Timur in Samarkand was described as jasper. (*Journ. Gemmology*, Vol. IV, No. 8.) Why ? Because custom and habit die hard and those who called it jasper were really thinking in terms of jade and not the compact quartz material just defined.

Valmont de Bomare, in 1762, made a note at the base of his very able list. (The list occurs in the *Journ. Gemmology*, Vol. V, No. 3.) " The nephrite stone which many of these authors recognize to be the green jasper of the ancients. . . ." Ancients, to this author, would surely mean some period ante-Monardes. Biron (quoted earlier), in 1703, said that it was not easy to distinguish jasper from nephrite, especially as many of the nephritic stones were of various colours. He cites yellow, white, and black. Sydney H. Ball[13] wrote : " Our word jasper comes to us through the Latin from the Greek, the word being evidently of oriental, but otherwise unknown, origin." Schliemann, in his *Ilios*, tells us that *jaspis* is of Semitic origin.

In the Archaeological Journal for 1888, Vol. XLV, pages 187-205, is an interesting contribution by James Hilton. It is called *Remarks on Jade*. He writes : " The word ' jade ' is regarded as a corruption of an old Spanish expression, signifying the supposed medicinal properties of the stone we are now considering. The Spanish appellation seems to have been a corruption of the Chinese name passing through a Dutch pronunciation of it . . . until we get 'jade' as the English word, which I find in use in 1730 to indicate the mineral substance ; but certainly the word in our language had a very different signification 200 years ago." In 1883 appeared *The Middle Kingdom* by Samuel Wells Williams. On p. 308 we find : " . . . Jade has long been known in Europe as a variety of Jasper, its separation from that stone into a species by itself being of comparatively recent origin. Since the third edition of Boetius in 1647, the two minerals have been regarded as entirely distinct." In the 9th edition of the Encyclopaedia Britannica, published in 1881, F. W. Rudler was writing : " In Turkestan jade was known as YASHM or YESHM and a word which appears in Arabic as YESHB is said to be cognate with ἴασπις or jasper. Indeed, by early mineralogists the jade was often described as ' jasper viridis.' "

A letter to *The Times* dated 15th January, 1880, was written by F. Max Müller. It ran : " Throughout the thousands of years

of human history until the discovery of New Zealand, the only known worked mines of pure jade were on the river Kara-kash in the Kuen Luen Mountains. . . . Jade is found, however rarely, among the ornaments of Roman ladies. . . . As the enquirer advances into the domain of history, jade advances with him. But the secret of its presence in Assyrian and Greek and Roman palaces is no more plainly solved than among stone pile hovels. The ancients, though they esteemed it very precious, had not even a distinct name for it. They called it *jasper*, though jasper it clearly is not. The Middle Ages of Europe valued the stone, but had no more understanding of the process by which it came into their hands than Greeks and Romans. India itself, while it made much account of it, received it as something strange and mysterious . . . there can be little doubt that *ijada* is derived from the latin *ilia* . . . it can only be an accidental coincidence if there existed in Sanskrit Buddhist texts the word *yeda* as a name of a material out of which ornaments were made." (The word *yeda*, referred to by several writers, should be mentioned here to include all the evidence. Another rendering seems to have been *Yada-stone*, coming from Central Asia and thought to have powers of producing rain—which they no doubt badly needed. Again, from further west in Asia, the *bejadah* was another stone said to have been mined there.)

One of the ablest contributors to the Jade Question was Jean Pierre Abel-Rémusat during the 19th century. We benefit by his translation from the Chinese of *A History of the town of Khotan in Chinese Turkestan.* In this we find *Researches on the mineral substance called by the Chinese Pierre de IU (YU) and on the jasper of the Ancients.*

Monsieur Rémusat goes into great details describing the various gem substances and their names in this part of China. And further, he shows that jade, known as *kash* (see river) to the natives of Eastern Turkestan and the Western Mongols, was the *Yeshm* of the Persians and peoples of Western Asia. This word, he tells us, written *Yeshb* in Arabia, is synonymous with the Hebrew *Yeschfe* (Exodus XXVIII, 20), from which were derived the Greek ἴασπις, the Latin *jaspis*, and the French *jaspe*. He refers also to Pliny's green jasper that resembled an emerald (certainly no modern jasper does) and was worn as an amulet throughout the East. This, he suggests, was probably jade.

Dr. Rudler writes of Rémusat : " He describes with great erudition the meaning of the word, and refers it to great antiquity. In the province of Yunnan, a particular kind of jade, to be hereafter noticed, is known as FEI-TSUI, while in Turkestan the jade-stone is called YASCHEM, a word which is also found in the form of YESCHL, and is said to be cognate with *ἰαοῆις*, and therefore our jasper."[14]

In 1783-88 appeared five volumes, published in Paris, by Le Clerc (Georges Louis), Count de Buffon. It was called *Histoire Naturelle des Mineraux.* On page 44 is the sub-title *Jaspe* : " . . . It is found in many parts of the Grande Indies, also in China. Jasper is much sought after in China . . . where they make vases of it . . . and different forms of jewellery. This jasper is named THUSF in the country. One distinguishes two species—the one that is precious is a heavy and large pebble which is fished in the river Kotan, near the royal city (town) of Kashgar. The other . . . is taken from quarries to be cut in pieces about two inches large . . . they have seen the same in somewhat large quantity and of many different colours in the high mountains of America (contrary to the minerals of New Spain, they praise a species of jasper which the Mexicans call EXTETL, the colour of grass with spots of blood. . . . A third is named TLIAYCTLIC, the colour more obscure and without spots, but more presentable, which, applied to the navel, cures the most painful colic, this is likely jade, which they name Nephritique stone)."

Here is another author who, to some extent, has drawn on the early writers, perhaps Laet. Still another kind he mentions is IZTLLIA, YOTLI, QUATZALITZLI. Nevertheless, his interpretation of what to-day we spell Yü is interesting and THUSF (pronounced) is not so wide of the mark.

In an entry of Captain Cook's Journal, on his first voyage to New Zealand, Maori jade is referred to as *jasper*, and in the same paragraph the axes made of this very material as *Green Talk* (Talc). Here is material, without any question nephrite, referred to as two distinct substances. Thus, in 1768, to Captain Cook, an intelligent and competent man, jade or *pounamu* or nephritic stone was jasper. (He was evidently misled by the axes he saw, some of which are very dark and therefore unlike the semi-translucent or translucent ornamental Maori jades.)

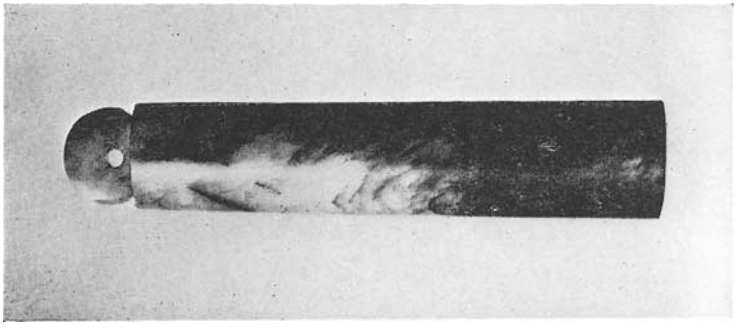

Sir Hans Sloane, Bart., a President of the College of Physicians and a President of the Royal Society, seems to pass in and out of these pages with great regularity. And deserves to do so. Part of his jade collection may be studied to-day in the British Museum (Natural History). Among the identified specimens of nephrite (tremolite) are a " loving-cup " from Surat, Bombay, India ; a mirror and a bowl, both probably Chinese ; a beautiful thumb ring in whitish-green nephrite, side by side with a jasper thumb ring with a white band (an excellent comparison to prove that these two substances *could* be mistaken) ; a small double box in leek-green nephrite, probably Chinese ; and not least in importance, the greyish veined pendant of jade from Guiana, South America, illustrated here. It is tubular and beautifully polished. This cylinder comes from the locality mentioned by Sir Walter Raleigh in 1596. It arrived in the British Museum in 1753 with the general collection of Sir Hans Sloane. Sir Hans Sloane's own entry (No. 223) describes it : "A pale nephritic stone from Guiana with a hole in it to hang to the body by a string for the cure of diseases." The shape of these tubular ornaments was well known. We may recall that Gesner wrote : " . . . The Indians like to make from Beryls cylindric ornaments as Pliny states."

Langius (or Lange) who, in 1704, contributed so ably to the jade subject had also something to say of the substance called Jasper. Under the heading *Lapis Nephriticus* was a sub-title : *A Species of Jasper.* " Now by reason of the varying colours which are mixed with green in this stone, some affirm, and not without some justification, that it belongs to the family of *Jaspis*, as in fact it is possible to be compared with it in the way it is coloured, and so it is

found, nature made it in this way. See Boot de Gemmis, p. 259. . ." Lange also introduces the first reference thus far for the *Internal Use* of this material, and writes : " Internal use is made of powder or pills. However, this refers mostly to stones of this species which are administered not so much as a remedy but to fill the patient with some hope, which has an incomparable effect. In this instance the stone which is as green as *jaspis* and marked with white spots, has the greatest appeal. If, however, this has not the desired effect we must consult Laet and find a more efficacious stone."

The very fact that Lange must go back some fifty years for a medical remedy is further indication not only that authorities were fewer, but that the written word was scarce in the 17th century.

Regnum Minerale . . . Metallorum, Lapidum, etc., appeared in 1686, by Emanuel the Elder, or Koenig. He too had a few words to say of *Jaspis*. " *Jaspis* has a variety of colours as well as many species, among which are *Heliotropius, Lapis Nephriticus*, and Malachite. *Lapis Nephriticus* is most often green and if we may say so, oily, and it does not vary in colour as *jaspis* does. Thus also the best informed say that green has an apparently black base and is not transparent. Its power is proved very great to liquidate *calculus* ; if applied to the region of the loins it has effect inside the body where the *calculi* are gathered. If the effect is lacking it is introduced into the body by mixing it with the food. See Wormius and Boyleus (Robert Boyle). The channels and openings of the body are so affected that the obstacles in the circulation are ejected, especially if it penetrates into the spaces of the kidneys." Here we find another internal use, 18 years earlier than Lange.

In the Journal of the Geological Society of London, Vol. XXX, p. 568, Dr. F. Stoliczka writes, in 1874, of a translation in two large folio volumes of a work by J. Nieuhof, published in 1673. This describes the Chinese Yü and the conditions of its occurrence in the mountains of ' Caskar.' It runs : " The translator applies to it the names used by traders, *jasper*, and *marble* : he does not use the word ' jade ' which probably was not then known. He says, however, that the stone was ' no jasper '." Another writer who should be recorded is Thomas Nicols. In 1652 he published *Arcula Gemmea* or *A Cabinet of Jewels*, in London. As an example of further confusion in nomenclature he writes of the " Emerauld "

(p. 93) and says that it is called " Green Stone, Emerauld and Smaragde." The " Praſsius, Smaragdite, and Chryfoprasius " he apparently links together, saying ; " . . . the transparency of it is through a cloud : it is sometimes found to have reddish, whitish, or blackish specks of colour, by reason of its growing to a Jasper, or Crystall, or to some other jewell." To add further to the confusion he continues, p. 98 : " They are found both in the East and West Indies and in Europe, and in Germanie, and these are fairer than the Orientall ones, but somewhat softer. They are found in Bohemia. . . . It is said to be of the nature of the Smaragde or Emerauld, but of somewhat more remiſſe (remiss) power and faculties." On p. 101 he writes of the Smaragdo-Prasius and gives to this the curative properties that have all along been associated with *lapis nephriticus*. Of jasper the author seems very sure. He refers it to Holy Writ and says it is diaphanous and perfectly transparent. He quotes others liking it to an emerald. Yet of *Lapis Nephriticus* he says it is a hard semi-transparent " gemme of a white greenish colour," and gives as his authority Boetius. He goes on : " Anselmus Boetius and others reckon both the Heliotrope, and also this stone (that is, *Lapis Nephriticus*) amongst the Jaspers. . . . They are sometimes found growing to a Jasper and Prassius. . . . They are found in Spain and New Spain." There were, doubtless, so many of these stones in Spain, as a result of South American interests, that it was generally believed they were a product of Spain itself. John Wittich, Bericht von Wunderbaren bezoardischen Steinin, in 1587, wrote of " kidney-stones " (griesstein) that could be purchased for sufficient money from the Portuguese in Antwerp.

Francis Bacon also mentions these stones from the Indies. His *Sylva* or *A Naturall Historie* was published in London in 1627, a year after his death. In it he writes : " . . . It is likewise Received that a kinde *stone*, which they bring out of the West Indies, hath a peculiar force to move Gravell, and to dissolve the *stone*. In so much as laid but on the wrest (wrist), it hath so forcibly sent down Gravell as they have been glad to remove it ; It was so violent." Here again we see that a famous writer and thinker is indebted to Monardes. Perhaps in those days acknowledgement was neither given nor expected.

Father Benedict Goez was another valuable contributor to the jade story. After a great deal of time spent in Turkestan

he was able to give a first-hand picture of conditions there. Quoting Goez from Williams's *The Middle Kingdom* we read : " There is no article more valuable than the lumps of a certain transparent kind of marble, which was, from poverty of language, usually called Jasper . . . Out of this marble they fashioned a variety of articles. . . . These marbles (with which the Empire is now overflowing) are called IUCE. There are two kinds of it, the first and more valuable is got out of the river Khotan, almost in the same way in which divers fish for gems, and this is usually extracted in pieces about as big as large flints. The other inferior kind is excavated from the mountains." Benedict Goez, or Goes, who reached Yarkand in November, 1603, found himself marooned there for many months. IUCE or, since I and J were one in those days, JUCE, is another rendering of what this material sounded like to European ears, the modern way of expressing it being Yü.[15]

In 1570, that is between the two Spanish versions of Monardes, Joannes Ferrandus, a senior medical practitioner, published, in Paris, a Latin volume called *De Nephrises*. He does not mention *piedra de ijada*, nor does he use the term *lapis nephriticus*. But he does write of jasper, and quotes Galenus. On p. 100 he says : " The Jasper which is called *Judaicus* is a greenish jasper. It has a more efficacious faculty for dissolving the kidney stones on account of which the Moderns call it Tricholiton." This reference is a particularly valuable one, for here we have jasper, described by a medical man, in use as a medical stone for the alleviation of nephritic pains during the period of Monardes. Surely this suggests that the Spaniards who brought jade stones back from South America were introducing no new-fangled ideas, whether or not the natives of that country used the stones in the same way. It would seem that up to this time jade, or what the Spaniards knew as jasper in Europe, was a curative for kidney disorders. A further point of interest is the word *Judaicus*, which we come across for the first time. The word is an adjective meaning *Jewish*, and scholars are agreed that the word jasper has a semitic origin.

Georg Fabricius (1516-1571), the German poet, historian, and archaeologist, was writing in 1565 of Galenus, the much-quoted medical authority (130-200 A.D.) : " Galenus confirms these to be of medical use," he says, in reference to jaspers, " which a certain king has had made from *jaspis* in such a way as to have it attached

to his neck that he made it touch his stomach ; he affirms to have witnessed with his own eyes a form of dragon : the king Nechepsus had ordered it to be sculptured as told by Galenus."

Another writer, the Father of mineralogy, frequently quoted in gemmological literature, was Georgius Agricola (1494-1555). His publications covered several large volumes and appeared in the 16th century. One, in 1556, an enormous work, was entitled *De Re Metallica*. Here *jaspis* is translated (in the English version by Mr. and Mrs. Herbert Hoover of the U.S.A.) as part coloured quartz and part jade, meaning, it would seem, that the term covered both jasper (quartz) and jade. In *De Natura Fossilum*, a later edition of which appeared in Basel in 1646, the author uses the term jasper to cover various minerals, as well as a variety coming from abroad which, he says, is " like to grey fat, or greenish, sprinkled with milky " and " like grey-green fat." Gesner also mentions jasper, as well as jaspachates " which combined seemed to have health-giving utility."

Printed in London during 1555 was *The Decades of the Newe Worlde of West Indes*. In this volume several books were combined and published and edited by Richard Eden. Part of it is attributed to Peter Martyr of Angleria.[16] On p. 115 one reads : " . . . Especially one Gonzalus Fernandus Ouiedus beinge one of the maiestrates appointed in that office which the Spanyardes caule Veedor, who hath also hitherto entered further into the lande than any other. He affirmeth that he chaunced uppon the fragmente of a saphire bigger than the egge of a goose. And that in certeyne hylles where he travelled with thirtie men, he founde many of the precious stones cauled smaragdus, calcidones, and Jaſpers . . ." And on p. 163, amongst the presents sent to the King of Spain was " gold and silver jewellery with cleare redde stones, and yet no rubyes, a hundrethe fouve coze (fourscore ?) and three greene stones, and yet no emeralds. Nevertheless, these are in lyke estimation with them as the other are with us." (Almost certainly these green stones were jades, though the Spaniards would have preferred to find emeralds.) This again seems to be confirmed on p. 237 : " *Of Smaragdes or Emeraldes*. Smaragdes growe in the countrey of Babilon. . . . They growe also in other partes of India. They are stones of fayre greene colour, and are lyght and tender. Of these stones, many are conterfecte. . . . There is lykewyse founde an

other kynde of smaragdes, whiche are greene stones, but not so much esteemed. Nevertheless, the Indians reverence these to set them forth with other precious stones. They leave not any greene coloure uppon the touche " (touchstone).

This book was published before Monardes' venture. There is no mention here of *lapis nephriticus*, nor of any medicinal qualities attached to the stones. Richard Eden himself identified the green stones as emeralds, or something similar. He writes also of jaspers.

In Zelia Nuttall's paper, read before the Anthropological Society of Washington in 1901, she quotes the famous Friar Bernardino de Sahagun, in his Book XI (1530 A.D.), Chapter VIII: " There is another stone belonging to the species of *chalchihuitl*, which is called *tlilaiotic*, and is a mixture of black and green. Besides the above mentioned stones there are other jasper stones of many colours. . . . Some of these are white as well as green and are therefore called iztaczhalchihuitl " (literally " white *chalchihuitl* "). *Chalchihuitl* was not jasper. That we know. Yet here was the Friar calling it jasper. And white jasper ! Had he lived one or two hundred years later he would probably have referred to this substance as *lapis nephriticus*, and a few generations later still as jade.

Another author familiar to most gemmologists is Camillus Leonardus. His work, originally published in 1502, was dedicated to Caesar Borgia. The English translation, which appeared in 1750, has the attractive title *The Mirror of Stones*, or *Speculum Lapidum*. Leonardus was also a physician, and of some eminence in the ancient city of Pifaro in Italy. On page 18 of this work we read : " Neither shall we depart from the authority of that consummate Philosopher Albertus Magnus in his Book of Minerals who holds that stones are of double kind, and faith . . . and others, with a dry aqueous, but more of the Terrene, as Marble, Jasper, and the like." And on page 112 : " Ja*ſ*per, Iaspis as it is in the Greek, and in Latin, Green, varied into so many colours that seventeen species have been discovered by the Learned, and by some more. For in these times Germany is so fruitful of Ja*ſ*pers, and produces such a variety." Further Leonardus says that the green (jasper) with the red is best of all and that its principal virtue is to stop the flux of blood. Clearly here the bloodstone is intended. Apart from the seventeen species of Jasper he also mentions twelve species of smaragdus.

Fifteenth to sixteenth century Europe must have been simply humming with activity. There was the printing machine in 1440. There was the discovery of America by Columbus in 1492. In 1503 Columbus was in Jamaica and in Yucatan in 1511. The Spaniards were in Mexico in 1519. Gesner's book came out in 1565 and 22 years later Monardes was writing, for the first time as far as we know, of *piedra de ijada.* In 1595, Sir Walter Raleigh wrote in *Discovery of Guiana :* " After the death of this Morequito, the soldiers of Borreo spoiled his territory, and took divers prisoners ; amongst others they took the uncle of Morequito, called Topiawari, who is now king of Arromaic (whose son I brought with me into England) and is a man of great understanding and policy . . . the Spaniards led him on a chain seventeen days and made him their guide from place to place. . . . He was at last redeemed for 100 plates of gold and divers stones called *piedras hijadas* or spleen stones." And later : " After we had fed and drew ourselves back to our boats upon the river, and there came to us all such kind of vitual as the place yielded . . . and of these stones which we call spleen stones."

This account, which is quoted by Thomas Wilson in his paper (mentioned earlier) is followed by an observation by the author : " That Sir Walter Raleigh could, in 1595, find on the east coast of South America, and far in the interior of the valley of the Amazon, sufficient evidence of jade implements or objects to cause him to notice them. . . ."

It was in the early part of the sixteenth century that the loot from South America began to arrive in Spain. Most of it was intended for the Monarch of that country. We have read that Cortes received, on behalf of his king, jades presented by Montezuma. There are many extant lists of this spoil. One, entitled : *Historia General y Natural de las Indias* is the work of Gonzalo Fernandez de Oviedo y Valdes, and was finally published in Madrid during 1851. Another was called : *Report of the Jewels, Shields, and Clothing* sent to the Emperor Charles V by Don Fernando Cortes and the Town Council of Vera Cruz. Much of this valuable material was gold. There were many emeralds. There was also *chalchihuitl,* or *chalchihuitl* and gold. Sometimes the word greenstone appeared on the inventories, doubtless because those responsible knew that the stones were not emeralds but could not otherwise determine their

species. There were other reports also, including letters to Cortes between 1519 and 1526. These were translated by J. Bayard Morris in 1928. We know that much of the spoil never reached its destination. Recent diving discoveries from a submerged wreckage off the coast of Bermuda established a Spanish galleon with just such loot. While no jade was apparent, there was a good deal of gold and a beautiful cross of cabochon emeralds. This galleon has been dated late sixteenth century and the Christian cross tells us that Europeans were then well settled in the New World. What has happened to the spoil that arrived is anybody's guess. Since jade cannot easily be destroyed, or melted down, like gold, for commercial purposes, it must be assumed that most of it is irretrievably lost or that it has passed into private hands where it remains unidentified.

More than a century earlier, Geoffrey Chaucer (c. 1340-1400) was providing a clue for the twentieth century to the value placed on jasper. He wrote :

> " What is bettre than gold ? Jaspre.
> What is bettre than Jaspre ? Wisdom.
> What is bettre than Wisdom ? Womman.
> And what is bettre than a good Womman ?
> No — thing."

We may compare this with Montezuma's " . . . each of these stones (viz. *chalchihuitl*) is worth two loads of gold " early in the sixteenth century. And the Maori's (nineteenth century) : " Let the gold be worked by the white man. My only treasure is the *pounamu* " (jade). The Maori did not suddenly adopt this scale of values. He had adhered to it ever since his arrival in New Zealand, and we know not how long before, since he arrived there with jade in his canoes. The great migration to New Zealand was a fourteenth century venture, but it has been established that there were earlier arrivals.

Chaucer was speaking for the fourteenth century, and he was not positing news. He was making a statement that was apparently acceptable to his times. (As a point of interest the Sloane collection, referred to above, contains a broken pebble of brown jasper from Egypt, with a supposed likeness to Chaucer on both its parts.)

Montezuma was speaking for the early sixteenth century and we know not how many hundreds of years before that.

Another writer of the fourteenth century was Mandeville, or Sir John Mandeville as he is sometimes referred to. Mandeville's *Travels* was printed by Wynkyn de Worde, who followed Caxton in the English printing business. (He is credited with helping himself liberally first from the Journal of Friar Odoric (c.1286-1331), a Fransciscan missionary who was sent to the East, and secondly from the travels of Marco Polo.) Whatever we think of Mandeville, he has an interest for us here in that he did not use the term *lapis nephriticus*, when referring to jade, but jasper.

Certainly our greatest witness on the subject of jade in the Middle Ages is Marco Polo, and his *Travels*, easily available, are so readable.

Marco Polo, born in Venice in 1234 A.D., set out with his father and uncle in 1271, together with two preaching friars who, long before they had reached their destination, regretted the undertaking and turned back. The Polos journeyed together for three and a half years. They arrived at the court of *Kubla Khan*, as this monarch has since been popularized, in 1275. The court was then at Shangtu, near Pekin. The Polos did not set out for home, we are told, till 1292. Father and son sailed from a Chinese port for Persia and this voyage alone accupied roughly two years. From thence the travellers rode through Persia, arriving back in Venice in the year 1295. Later, as a prisoner of war in Genoa, Marco Polo is believed to have dictated his now famous book to a fellow prisoner. Allowing for the lapse of time and Marco Polo's memory, as well as the customary embellishing, and also allowing for any mistakes or elaborations that his fellow prisoner might have made, so much of the information has since been corroborated by later travellers that his contribution to the jade question can hardly be lauded enough.[17] Writing of Peyn, he says :

" Peyn is a province of five days' journey in extent, in the direction of east-north-east." This is believed to refer to places situated on the eastern side of Khotan, in the neighbourhood of the great sandy desert. " It is under the dominion of the grand Khan, and contains many cities and strong places, the principal one of which is likewise named Peyn. Through this flows a river, and in its bed are found many of those stones called chalcedonies and jasper. . . . All the before-mentioned provinces, that is to say, Kashcar, Khotan, Peyn, and as far as the desert of Lop, are within

the limits of Turkestan." A footnote here reads : " . . . the Bukhar or Bucharian, although much mixed with Persian words, is one of these dialects—which consequently reaches to the borders of the great desert of Kobi." And a further footnote in this edition runs : " The jasper, or a hard kind of stone resembling jasper, is noticed by several writers as the production of this part of Tartary ; and Goez speaks of its being procured from the bed of the river Khoten, which may probably be the same stream that afterwards runs to Peyn." Further in the text itself we read : " Charchan is also a province of Turkistan, lying in an east-north-east direction (from Peyn). In former times it was flourishing and productive. . . . Through this province run several large streams in which also are found chalcedonies and jaspers, which are carried for sale to Cathy, and such is their abundance that they form a considerable article of commerce."

It will be noticed that the material Marco Polo saw mined and " fished " was not called jade or anything like it. Nor, as a member of the Latin race, does he call it *lapis nephriticus*, which he could so easily have done had he been familiar with the term. He interpreted it as we should do to-day, that is, according to the stones he knew. And, from his observations, they were either chalcedony or jasper or both. Since we know that he was seeing the jade mines of Khotan, there is hardly a doubt that most of what he saw, certainly the " considerable article of commerce " was jade. He was no mineralogist nor, for that matter, a scientific observer. He was simply a traveller and explorer, and as such seems to have been very well received. The outstanding evidence of all this is that jade, recognized by thirteenth century Marco Polo, was jasper to thirteenth century Europe. And this was approximately three hundred years before South American jade began to arrive in Europe.

During Marco Polo's period, Albertus Magnus (c.1206-1280), Bishop of Ratisbon, was wielding great influence in his time. His *De Mineralibus* was published in 1262. In 1525 a small book entitled *The boke of Secretes of Albertus Magnus, of the vertues of herbes, ſtones, and certaine beaſtes* " was translated into English and printed in London. Although he segregates the various stones for their " vertues " we learn nothing helpful concerning jasper. Since, however, he was an accepted authority for hundreds of years, it is necessary to record him here.

Another contributor who writes of a stone we believe to be our jade was the Gallic poet Marbodus, who died about the year 1123 A.D. He was Bishop of Rennes between the years 1067 and 1101, and is frequently quoted by Mediaeval writers. Lange (1704) quotes him, saying that Marbodus writes : " It is the best of the translucent green stones and that it is more efficacious, as have been proved." Cluyt (1627) wrote : " Marbodus, an old Gallic poet, gives tribute to this green and clean stone and chants of it : ' Best in green and lighting colour, And proved as great and beneficial.' " Here again we find that Marbodus drew largely on Pliny for his information, writing of " seventeen varieties of jasper."

While it was virtually impossible to record all the references to *lapis nephriticus* for the second half of this millennium, so it is well-nigh impossible to record all references to jasper for the first half of the millennium. And while *lapis nephriticus*, as its name implies, was established as a curative for kidney disorders, we cannot make this claim for jasper, though it was certainly a medical stone of importance. The evidence that it was a " cure " for kidney troubles specifically is slender. Nevertheless, it exists. In trying to clarify this subject it is sometimes necessary to forget species, or the scientific side, and concentrate on the medical stone. That is, jade became *lapis nephriticus* only if it effected a " cure " for kidney ailments. To choose such a " cure " one selected a green or greenish or yellowish-green or greyish stone—the known colours. Later, when these stones were better recognized, it was observed to have a greasy polish. These two points, perhaps plus its tough qualities, gave it species. Yet, if a stone did not work—so great was the faith —it was considered not to be the real thing. In other words, it was largely a medicine and not a gemstone. And so, on the look-out for a kidney cure, someone might pick up a stone resembling jade, such as a cloudy emerald, and if this " worked " then *that* was *lapis nephriticus*.

Perhaps the so-called Dark Ages is a difficult period for gemmological research, partly because of the scarcity of the written work and partly because much that we enjoy to-day was lying fallow. Nevertheless we are just beginning to catch up with the idea that there was a great concentration of learning and knowledge and accomplishment that was quietly kept alive. And the outstanding evidence, such as Marco Polo's and others, seems to leave little

doubt that jade was always around, always valued, and for the most part living under the generic term, jasper.

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2 C. Biron, who published a small book in French during 1703 dealing with the Indies, writes of the Divine Stone that it was a new species of *Pierre Néfrétique* and that the name *Divine* was given because of its " virtues." In particular he mentions its curative properties as it affected *les reins*.
3 *Journ. Gemmology*, Vol. V, No. 3.
4 There seems little doubt that this word has reference to *Tenacity*.
5 *Journ. Gemmology*, Vol. V, No. 5.
6 C. Biron, mentioned earlier, writes of jasper in use as an amulet in the Indies, but not in connexion with kidney trouble ; his description of it strongly suggests bloodstone, and not jade.
7 W. A. Wooster.
8 L. J. Spencer.
9 G. F. Herbert Smith.
10 *Gemmologist*, October, 1955.
11 King, C. W. *Natural History, Ancient and Modern, of Precious Stones and of the Precious Metals.*
12 G. F. Kunz. Investigations and studies in Jade. Vol. I, 1906.
13 *Roman Book on Precious Stones, p.289*
14 There are so many renderings of this old word that it is difficult to be exact. Rémusat later spells it Yeschife, including an i. The Bible gives Yâshéphch and there is an Arabic rendering Jashaph.
15 The modern use of i and j, as well as u and v was not firmly established till the first half of the 17th century.
16 According to Dr. G. F. Kunz (*Investigations and Studies in Jade*, 1906) Columbus returned to Europe with a battle-axe with which Peter Martyr experimented. Tried on a piece of iron, it was found to cut into the metal without injury to the stone.
17 Columbus is said to have possessed a Latin copy of Marco Polo's book and made his own notes in it.

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ASSOCIATION NOTICES

SILVER JUBILEE OF ASSOCIATION

Although the genesis of the educational scheme initiated by the National Association of Goldsmiths in 1908, culminated in the formation of the Gemmological Association of Great Britain, it was not until May, 1931, that the idea of a separate organization for gemmology was suggested. A resolution from the gemmological committee of the National Association was approved in June of the same year and formal inauguration took place at the annual distribution of awards in October, under the title Gemmological Association.

In 1938 greater precision was given to the title by the adoption of the form : Gemmological Association of Great Britain. A short history of the Association, covering the period 1908–1955, was issued to members earlier in this year. The Association can look back with pride and satisfaction at many years of valuable educational work.

GIFTS TO ASSOCIATION

The Council of the Association has received with gratitude the following gifts : 1·75-carat synthetic emerald from J. B. Ipekdjian & Co. Ltd. ; specimen of uncut prehnite from R. Webster, Esq.

BRITISH MUSEUM (NATURAL HISTORY) LECTURES

Lectures in the MINERAL GALLERY on Saturdays at 3 p.m.

1956

Oct.	27th	How is a mineral species defined ? ...	Dr. M. H. Hey
Nov.	3rd	Sulphide minerals	Dr. A. A. Moss
	10th	Minerals of Wales	Miss J. M. Sweet
	17th	Cosmic dust—is it a cause of climatic change ?	Dr. J. D. H. Wiseman
	24th	Identifying minerals by X-rays ...	Dr. G. F. Claringbull
Dec.	1st	Ornamental stones of the British Isles...	Mr. S. E. Ellis
	8th	Preparing pure samples of minerals...	Mr. P. G. Embrey
	15th	Geology of the Antarctic	Dr. G. H. Francis
	22nd	Meteorites (I)	Dr. M. H. Hey
	29th	What are crystals ?	Dr. A. A. Moss

THIS PROGRAMME IS SUBJECT TO ALTERATION

LETTERS TO THE EDITOR

DEAR SIR,

Some few weeks ago, whilst preparing a modest gemmological display to be given in conjunction with a short talk, I happened on a device that might be of some practical help to fellow workers. Having had previous experience of the nervous strain of demonstrating the use of a spectroscope to the general public, when mounted in the " normal " way on top of a simple microscope, I tried to find a safer solution, and hit on one of those childishly simple things that are so absurdly logical we wonder why they have not been standard practice for some time.

The technique is as follows :—

Hold the spectroscope with the aperture uppermost, and lay the stone to be tested over the slit in such a way that it covers most of the opening ; now take a short piece of colourless transparent adhesive tape, and run this over the stone, pressing the ends against the " squared " portions of the spectroscope. When carefully done, the focusing and adjusting of the aperture is not interfered with in the slightest, and with the stone securely held one can pass the instrument round a group of novices with the utmost confidence, asking them merely to look through it at a strong light source.

This is a very great help at demonstrations, but to my surprise I have since found that it yields most excellent results in every-day testing, the light loss being extremely small. It has the added value that no equipment need be used apart from a strong light and the spectroscope.

Yours faithfully,

R. MUIR.

DEAR SIR,

Fiji is where most of the " black " pearls are found and when I was there recently I tried to obtain information about them. Pearl divers to whom I spoke could not explain very much and I had not time to seek other information. The area, apparently the only one, is in the Yasawa group, which lies 40 miles north-west of the main island of Vitu Levu. I was told that the shells are not stained black and there is no mud to stain either shell or pearls ; the dark shade seems to come partly from an excess of conchiolin in the structure of the pearl. It may be that the shells, although not dark inside, also have excess conchiolin outside, which gives them greater protection from erosion.

The origin of the area is " recent volcanic " and I thought that perhaps there might be a deposit of some mineral on the rocky sea-bed, but I cannot suggest any which might account for the colour of the " black " pearls, or that fraction of it which is not the result of excess conchiolin.

The sands all round Fiji are black with mica, magnetite, etc., but this applies to many parts of the Pacific where there are recent volcanoes. The problem is—why do they occur more in that area than others ?

Yours faithfully,

FRANK LEECHMAN.

1956 EXAMINATIONS IN GEMMOLOGY

The 1956 examinations of the Gemmological Association of Great Britain were held in the first week of June and examination centres included London, Birmingham, Leeds, Liverpool, Edinburgh, Glasgow, Plymouth, Oslo, Lucerne, Pforzheim, Washington, D.C., Colombo, Melbourne, Los Angeles, Zeist, Sydney, New York, Auckland, Toronto, Austin, Johannesburg.

Ninety candidates qualified in the preliminary examination and 61 in the Diploma. The Tully Memorial Medal has been awarded for the first time to an Australian candidate.

The following is a list of successful candidates, arranged alphabetically :

Diploma

Distinction and Tully Medal

Marks, Percy George, Sydney.

Qualified with distinction

Brewer, George Paul Richard, Aldershot.
Chiles, Sylvia Doris Marion, Warlingham.
Gordon, Davina Beryl, Ruislip.
Longbottom, William, Hull.
Mason, Cyril Thomas, London.
Morgan-Smith, John William, London.
Muir, William Arthur, Wilmslow.
Vainer, Milos, London.

Qualified

Andersen, Arne Thorvald, Tönsberg.
Banks, Kenneth Arthur, Manchester.
Bates, Michael Anthony, Croydon.
Batt, Keith Michael, Torquay.
Bentley, Dennis Cyril, Epsom.
Bochatay, Albano, Geneva.
Bohe, Edward R., San Diego.
Bone, William George, London.
Boyd, James Gourlay, Cambuslang.
Breeze, Michael Dennis Clithero, Leicester.
Brooks, Beatrice Briercliffe, Bristol.
Burley, Walter Robert, London.
Clifford, Edwin William, Cassington.
Downing, Richard Allen, London.
Ebbestad, Jens Christian, Oslo.
Ekanayake, Brian Edmund Rodney, Colombo.
Felin, Juul, Oslo.
Ferguson, William Fleming, Alexandria.
Fortune, Kenneth William, London.
Gam-Dede, Markson Ayebatekeyo, New York.
Grounds, Walter Joseph, Birmingham.
Harris, John Smith, Glasgow.
Hewitt, Frederick Edward John, Ormskirk.
Hodgson, Edwin Stanley, Darlington.
Hopewell, Ronald Cooper, Grays.
Hoskyns, Kenneth, Birmingham.
Jeffreys, Roy Ernest Henry, London.
Kingwill, Peter Newton, London.
Kirk, Ronald MacDonald, Glasgow.
Laney, Geoffrey William, Hersham.
Leiper, Hugh, Austin.
Lewis, Emily Catherine, London.
Maxwell, John Anthony, London.
McGuigan, Alix, Bearsden.
Mendis, Clement Stephen, Colombo.
Messenger, Shirley Joan, St. Albans.
Molyneux, Frank, London.
Muscat, Bernhard, Johannesburg.
Oftedahl, Christoffer, Stabekk.
Padbury, Edna Phyllis, Birmingham.
Peplow, Sarah Alison, Stourbridge.
Peters, Brian Leonard, Camberley.
Phillips, William Howard Merrick, Ross-on-Wye.
Pollard, Frederick David William, London.

Qualified

Schoo, Johan Juliaan, Jr., Arnhem.
Selwood, Brian Leslie, Watford.
Sherrard, Julian Sigismund, London.
Sidaway, John Terence, Torquay.
Smith, Cora Ann, Grays.
Smyth, John Calvin, Baltimore.
Toms, Brian Geoffrey, Plymouth.
Tye, Leslie Herbert, Bromley.

PRELIMINARY

Rayner Prize

Jank, Robert Alexander, Boscombe.

Qualified

Anderson, Vernon David, Glasgow.
Armbrecht, Bertram John, London.
Baily, Hugh Graeme, Sutton Coldfield.
Blackmore, Howard Loftus, Caterham.
Blanshard, Christine Janet, Croydon.
Boermans, L. Th. M., Venlo.
Botting, Anthony John, Gravesend.
Brewer, George Richard Paul, Aldershot.
Campbell, Elizabeth W., Washington.
Cassarino, Joseph Anthony, New York.
Chittock, Arthur, Blackpool.
Clay, John Jeremy, Leicester.
Cooper, Colin L., Neuchatel.
Cope, John Richard, Honiton.
Crosthwaite, Norman McLaren S., Giffnock.
Davies, Margaret Valerie, Coventry.
De Silva, Lindamulage J. C., Moratuwa.
Diss, Geoffrey Dixon, Barrow-in-Furness.
Ditchburn, Michael, Birmingham.
Downing, Richard Allen, London.
Drapkin, Clive Magnus, Birmingham.
Etelman, Sol J., Stamford.
Fernando, Kurukula Suriya, Colombo.
Francis, Barry Peter, London.
Galtung, Johan D., Oslo.
Gaudernack, Lilly, Sandvika.
Gaudernack, Rolf, Sandvika.
Gerritsen, G. H. T., Arnhem.
Gillow, Harold, London.
Grimsdell, John Leslie, London.
Grude, Rolf K., Oslo.
Gundersen, Henrik O., Jr., Larvik.
Hadjizade, Ahron, London.
Hatcher, June Ann, Birmingham.
Henn, Elizabeth Rosemary, Dudley.
Hermitage, Wendy Barbara, London.
Hill, Reginald, Solihull.
Hill, Stanley George, Birkenhead.
Hinton, Vera Georgina, Staines.
Holland, Norman Alfred, Birmingham.
Hopkins, Iris, London.
Hutchins, Brian Percival, Hornchurch.
Janison, Murray E., Brooklyn.
Jones, Wilfred Russell, Auckland.
Kent, Muriel Constance, Folkestone.
Kelly, William Henry, Glasgow.
Laidlaw, Thomas Alfred J., Edinburgh.
Lauvland, Karl, London.
Leake, Douglas Michael, Nuneaton.
Lode, Georg, Egersünd.
Mackenzie, Enid Lily, Glasgow.
Marks, Percy George, Sydney.
McGrath, Robert Sterling, M.D., Washington, D.C.
McKay, Robin Ian, Thames Ditton.
Meanwell, Brian Sydney, Birmingham.
Mitchell, Peter John, London.
Neale, Alan, Berkhamsted.
Neerbye, Rolf, Gjerpen.
Oftedahl, Christoffer, Stabekk.
Parkhouse, John Richard, Maidenhead.
Pedersen, Erik M., Oslo.
Petterson, Björn W., Norway.
Phillips, Alan Lewis, Bardsey.
Phillips, Denis, Leeds.
Roach, John George, Hockley.
Rose, Jack Arthur, Newcastle-on-Tyne.
Ros, David Douglas, Ripon.
Safiyulla, Mohamed Thahir, Colombo.

Siebenberg, Paul, Birmingham.
Skrede, Agnar, Oslo.
Smith, Clifford James, Birmingham.
Smyth, John Calvin, Baltimore.
Snow, Keith Michael, Chelsea.
Solman, Barbara, Worcester Park.
Strange, Peter John, London.
Taylor, Donald Herbert, Ipswich.
Tipping, John Richard, Edinburgh.
Walsh, Harvey L., Arlington.
Warburton, Frederick W., Toronto.
Weatherill, John, Cardiff.
Weaver, Gerald Owen, London.
Weiss, Kurt, London.
Weller, George Thomas, Tunbridge Wells.
Weller, Raymond John Howard, Croydon.
West, Gordon Francis, Mitcham.
White-Hide, Richard George, Wadhurst.
Vane, Frederick James, Croydon.
Ystad, Per T., Potsgrunn.
Zibung, Ali, Lucerne.

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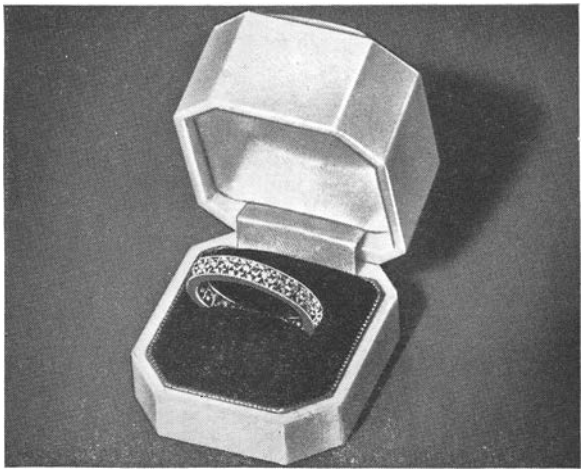

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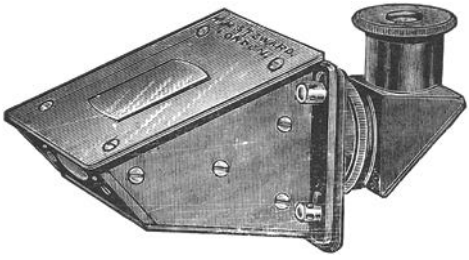

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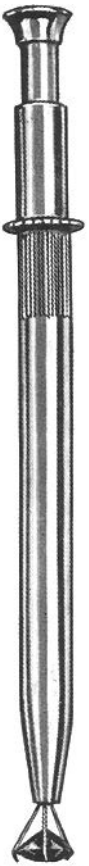

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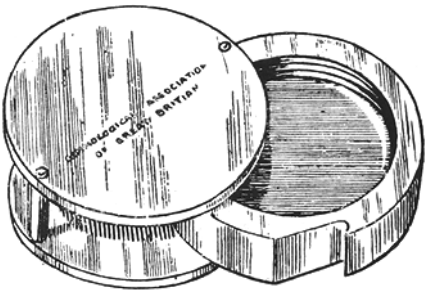

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A CONTRIBUTION TO THE GENEALOGY OF INCLUSIONS

by E. J. GÜBELIN, Ph.D., C.G. F.G.A.

QUITE apart from the tendency to take the subject of inclusions out of the sphere of imperfections and accentuating their aesthetic value, particular emphasis was hitherto put on the description of the phenomenological appearance in order to set forth their diagnostic and practical importance. Under this aspect a classification of inclusions was established which agreed best with their importance as a means of identification, and occasional discussion of the genesis of inclusions was only interwoven for the purpose of incidentally shedding light on the origin of gemstones themselves.

A new phase may now begin by concentrating more intensified research on the formation of the inclusions themselves, and some important steps have already been taken. The problem offers enormous difficulties and various explanations as well as experiments which were considered to reveal the truth had subsequently to be given up. It may, therefore, be comprehensible that in spite of the great number of studies on inclusions, the question of the formation of inclusions and the morphology of the phenomena have,

with a few exceptions, been hitherto neglected. Thus the morphology of inclusions, which is an essential factor for diagnosing gemstones, will in future be increased to a valuable extent by the genealogy of inclusions.

Under the aspect of the genetic characteristics of all types of inclusions—solid, liquid and gaseous—which might be united in a system, one could divide them into two main classes :—

(a) Primary Inclusions,
and (b) Secondary Inclusions.

Both classes may again be sub-divided into two groups :—

Primary Inclusions into (aa) Autogenetic Inclusions,
(ab) Xenogenetic Inclusions.
Secondary Inclusions into (ba) Healing Fissures (Secondary Liquid Inclusions),
(bb) Inclusions formed by exsolution.

(aa) Autogenetic Inclusions

Autogenetic inclusions are such formations as originate from the mother liquor, e.g. glass (Fig. 1) or magma for pyrogenetic minerals, and are caused by peculiarities of the crystal growth, especially through skeleton-like (Fig. 2), step-like (Fig. 3), " druse "-like development ; therefore they are always related to real crystal faces, and the so-called " phantoms " (Fig. 4) form a typical example of this kind. All such marks of inhomogeneous, disturbed or irregular process of formation can hardly be considered true inclusions but may much more adequately be called "inhomogeneities." They are usually affected by the conditions of growth and are consequently either irregular or subjected to the law of periodicity. It has been found that inclusions arrange themselves on the faces which have a stronger bond, i.e., the greater speed of growth, and primary inclusions are never found outside these faces and directions. Hence primary inclusions never form intersecting planes or feathers ; yet, since they follow crystal faces, they may meet at angles and create the impression of crossing. These inclusions either occur on faces of the growing crystal or in a plane which was developed as a trace of the movement of an edge, or in a row or string (Fig. 5) upon which (acting as a rail of the movement) the crystal point had moved along. Thanks to the complete wetting of the crystal face with mother liquor, the autogenetic inhomogeneities either reveal the shape of an exact replica of the crystal, or they

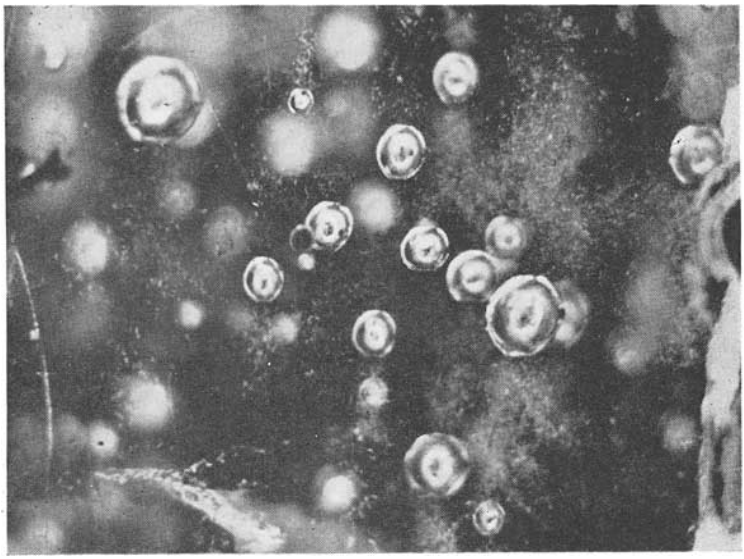

Fig. 1. Glass " bubbles " in peridot. 80 ×.

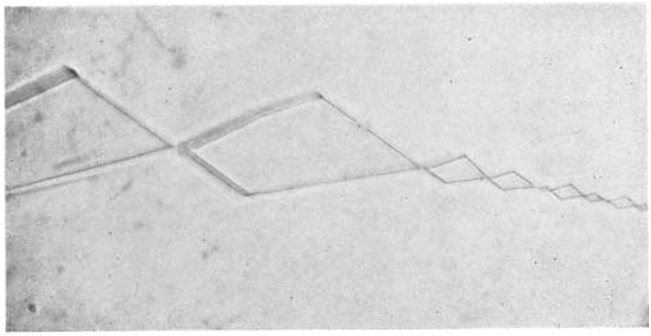

Fig. 2. Autogenetic inhomogeneity as a result of skeleton growth in topaz (Lit. 3). (Photo by K. Schlossmacher.)

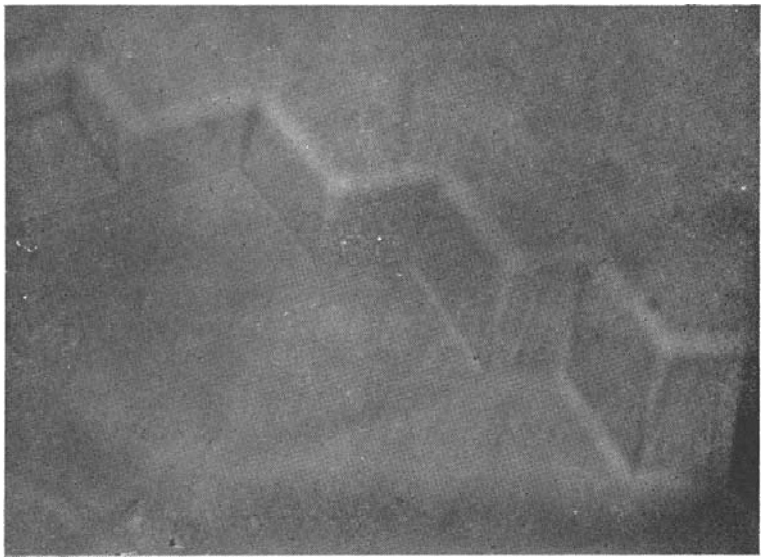

Fig. 3. Step-like markings as a result of irregular growth. (Lit. 6.) Photo by R. Webster.

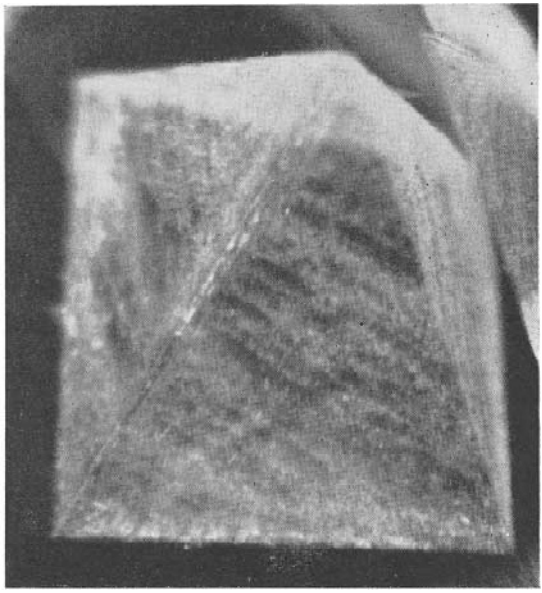

Fig. 4. Octahedral phantom in diamond. 80 ×.

form an accessory sculpture of the face as it was at the moment of being embedded (Fig. 6). In cross-sections one can see the well-known picture of zonal arrangement (Fig. 7), or radial orientation (trace of the edges) (Fig. 8).

(ab) Xenogenetic Inclusions

Xenogenetic inclusions are any foreign substances enclosed in a mineral regardless of their phase of matter at the moment of being trapped, i.e., solid, liquid or gaseous. Contrary to many autogenetic inclusions, xenogenetic inclusions are true enclosures (inclusions)—foreign substances enclosed in the host mineral. If a foreign matter happened to drop, or rest, or grow on a face of a crystal in *statu nascendi*, it was mechanically enclosed (Fig. 9) and if foreign inclusions densely cover crystal faces, sometimes even in succession, conclusions may readily be derived about the host crystal's habit at previous stages (Fig. 10). Here xenogenetic inclusions have some similarity to the " phantom " formed by autogenetic inclusions. Xenogenetic liquid inclusions are also formed by drops of foreign liquid which did not mix with the mother liquor. Since they did not at all or only partially wet the surface of the growing crystal, they assumed the shape of a drop, which usually became slightly deformed after the growth direction of the growing host. Such slightly deformed drops may often be encountered in quartz (Fig. 11), Ceylon sapphire (Fig. 12), emerald and other minerals, and in the laboratory they can readily be caused in alum crystals by adding olive oil to the aluminous solution. Since the formation of primary inclusions stands in direct relation to the phases of growth of the host crystal, autogenetic and xenogenetic inclusions prefer to arrange themselves according to crystallographic directions. They are normally found in zonal orientation.

(ba) Secondary Liquid Inclusions

The difficulty of explaining the appearance of certain liquid inclusions through primary formation leads to the idea of secondary liquid inclusions. Considering the powerful strain of mechanical pressure on account of geotectonic upheaval, it is not far fetched to assume that in the course of such disturbances crystals fractured along irregular directions, or were affected by some shifting force developing planes and fissures of translation, and that liquid could infiltrate into the cavities of the damaged crystal along fine fissures,

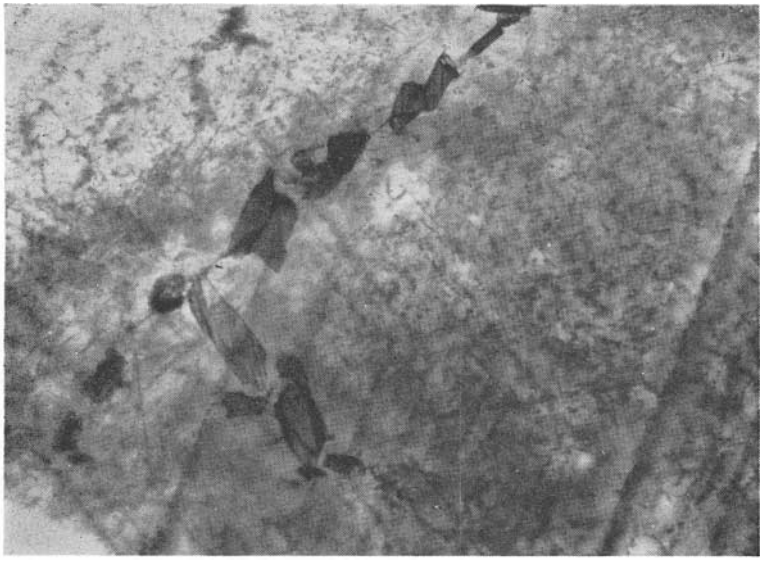

Fig. 5. Sphene crystals tracing crystallographic directions in spinel. 75 ×.

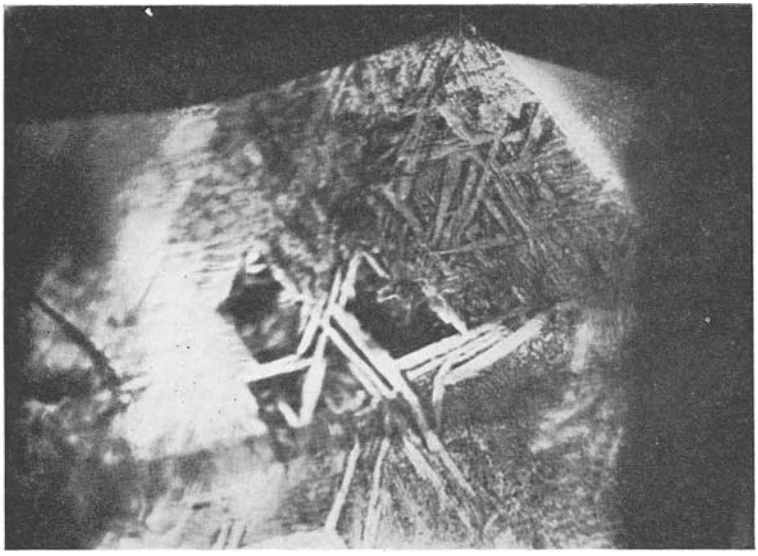

Fig. 6. Sublimation of alien matter on previous crystal face of a ruby. 75 ×.

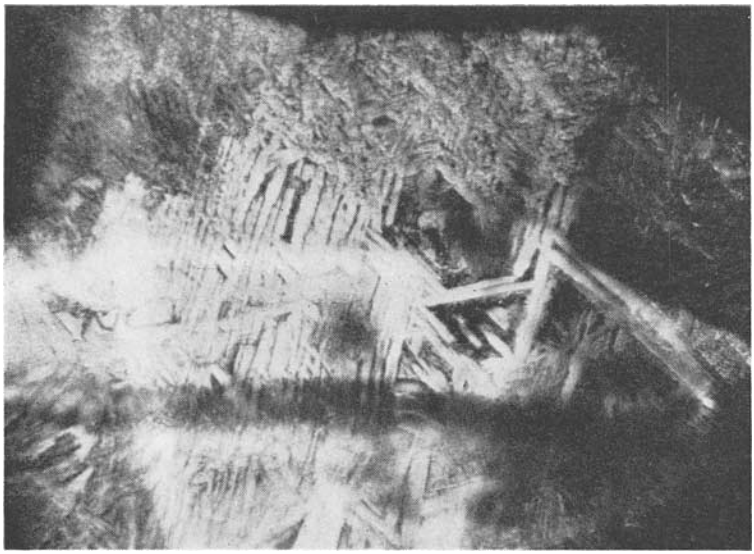

Fig. 6a. Sublimation of alien matter on previous crystal face of a ruby. 75 ×.

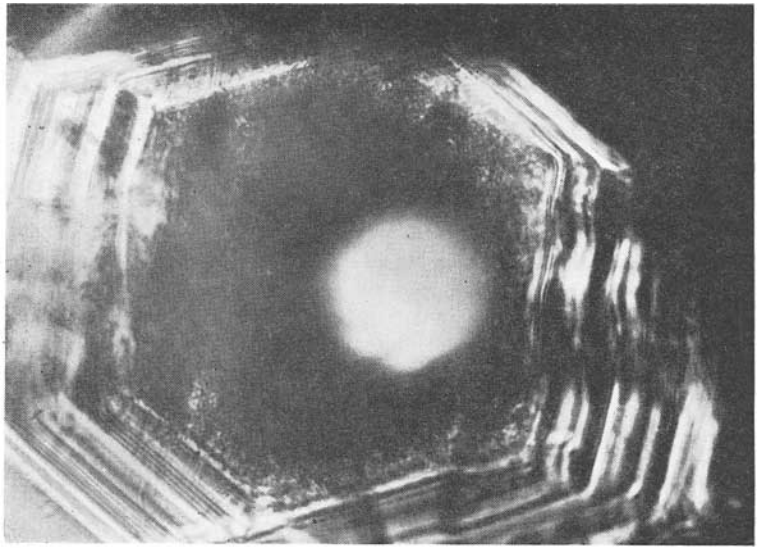

Fig. 7. Strongly marked zonal structure in ruby. 25 ×.

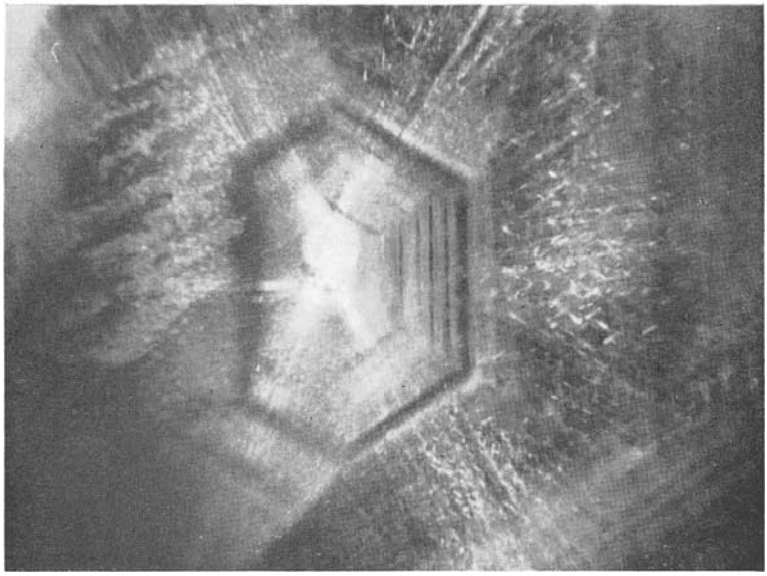

Fig. 8. Zonal structure with radial sub-structure of rutile needles in a sapphire. 15 ×.

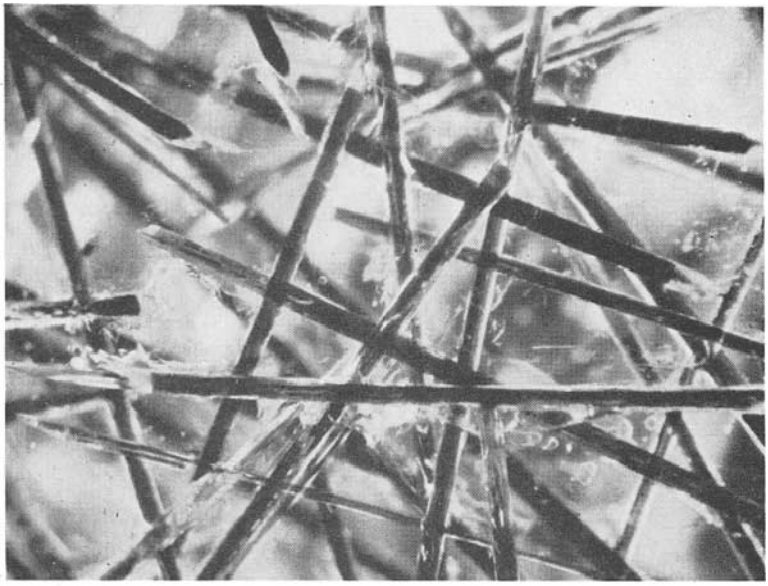

Fig. 9. Tourmaline rod-crystals in quartz. 20 ×

which later on closed up in growing and then healed up. Cracks resulting from change of temperature, contraction, or alteration may have caused the same defect. The whole procedure can only be imagined if it happened as long as the mineral was still in direct contact with its mother liquor, which contained and supplied the remedial ingredients necessary and responsible for the process of closing up. These healing fissures have always special characteristics and display the very typical pattern of liquid inclusions. They traverse the mineral along irregular directions, rarely following crystallographic orientation, and very often intersecting each other (contrary to primary liquid inclusions, which never cross each other). Under the microscope these " feathers " appear to consist of minute liquid drops, all more or less densely arranged in one compact form and of most fanciful shapes. Their geometrical outlines vary in accordance with their location within the fissure and also according to the host crystal which imposes directional growth power on the formation of these inclusions, e.g. in isometric crystals following the contours of the principal faces (Fig. 13), in orthorhombic crystals forming rectangular shapes or lozenges, in hexagonal gems manifesting the main crystallographic directions (Fig. 14), etc. In the narrower part of the wedge-like fissure they are particularly affected by crystallographic influence (Fig. 15), whereas towards the open end of the crack the droplets may change into irregular (Fig. 16), distorted, hose-like, twisted and most bizarre shapes (Fig. 17). The fissures, easily recognizable by the enclosed liquid drops, frequently come to an abrupt end within the crystal along a convex or irregular line (Fig. 18). Here the liquid inclusions are very tiny, increasing in size towards the surface, and they may attain remarkable dimensions sometimes, yet in all cases they are extremely flat.

George Laemmlein (Lit. 1) was successful in carrying out several ingenious experiments in that he partly split crystals of rock salt and nitre (Saltpetre) by pressing the sharp point of a knife against the surface, thus producing an artificial crack. He then allowed solutions of NaCl and KNO_4, respectively, to soak into the fissure which, because of capillary power, filled immediately. After a short while he could observe how dendritic crystals started to grow from the innermost edge of the fissure and how the orientating influence of crystallographic power exerted itself on the dendritic crystals (Fig. 19) and forced them to grow along the directions of

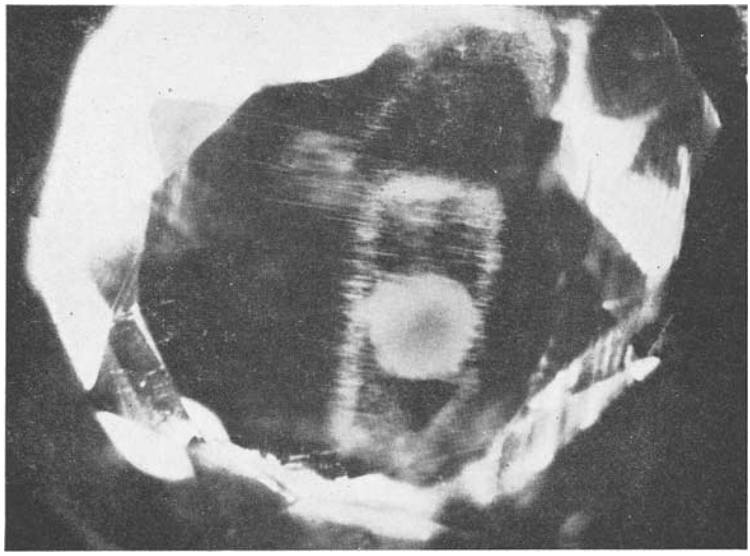

Fig. 10. " Phantom "-like arrangement of " silk " marking previous phase of growth of ruby crystal. 25 ×.

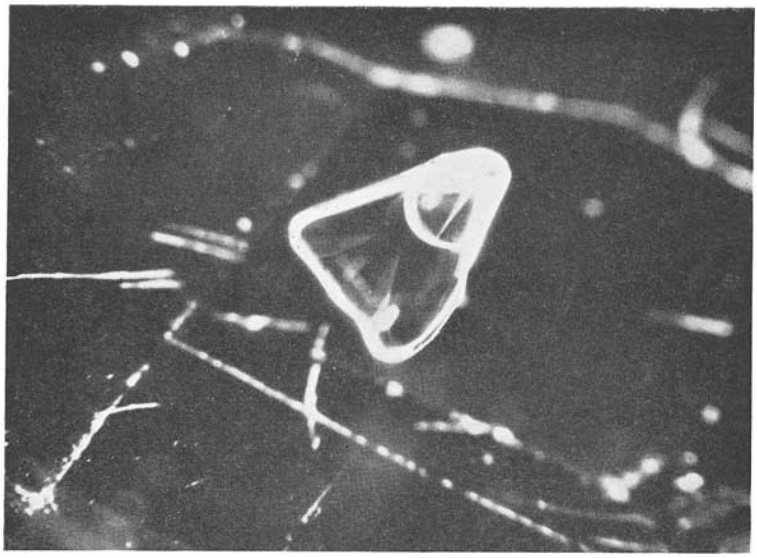

Fig. 11. Cavity filled with liquid and libella in amethyst. 15 ×.

Fig. 12. Stocking-shaped liquid inclusions of primary origin in sapphire from Ceylon. 30 ×.

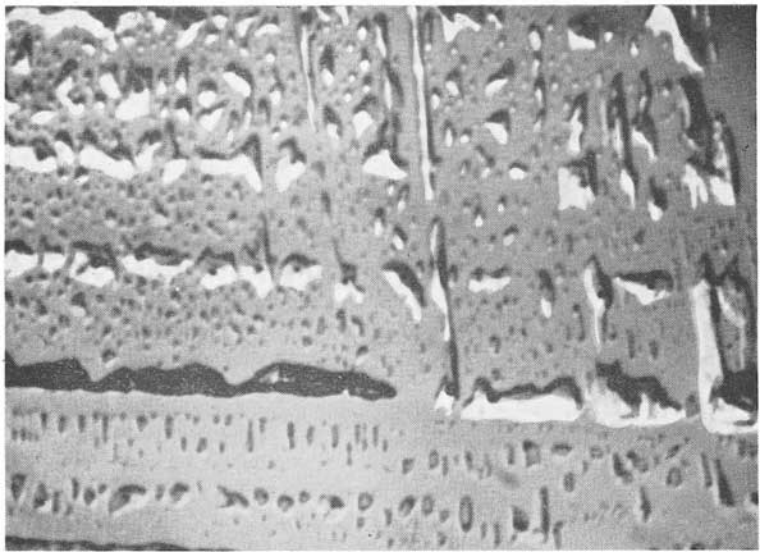

Fig. 13. Fluorspar : healed fissure, liquid drops being affected by directional crystallographic power. 75 ×.

main growth of the host crystal (octahedron and principal rhombohedron respectively). This is easy to understand if we consider that the growth of the dendritic crystals takes its course within the walls of a homogeneous substance and begins where these walls are closest together. Branches of crystals developed in directions of first, second and third rank and met at last, leaving residual drops of the healing solution (artificial mother liquor) between themselves. In accordance with the conditions and depending on the quantity of healing material, the droplets were smaller or larger, sparsely or more densely distributed. It proved especially instructive to observe that these liquid residuals of enclosed mother liquor did not immediately assume a definite shape, but altered their form continuously in an attempt to decrease their surface energy with unchanged volume. Long channels, large films and hose-like drops revealed a tendency to shrink into numerous small, compact, negative crystals of cubic, octahedral or rhombohedral shape respectively, thus assuming the stable form of liquid inclusions. Many of the inclusions created by this process of healing showed convex contours (modelled by growth) at the beginning, which altered in the course of the distribution of the material into liquid inclusions with concave relief (modelled by dissolution). After a few days the healing process was completed. Comparison between the artificially healed fissures and the natural ones showed entire conformity and led to the conviction that similar healing processes on a much more gigantic scale must occur in all mineral deposits which have undergone mechanical disturbances. Experiments similar to those described were also performed with alum crystals, which disclosed a novelty in that in crystals already containing layers of feathers of primary liquid inclusions the fractures paralleled those layers, so that the layer of secondary inclusions was superimposed upon the layer of primary inclusions. Similar occurrences may also be often met with in natural gems (Fig. 20).

Through these experiments and the observations they rendered possible the intrinsic character of the mechanism of the formation of secondary liquid inclusions and their virtue have been recognized, while their characteristic patterns may be described as follows :—

1. Coincidence of layers of secondary liquid inclusions with fractures, cleavage cracks, translation cracks and contraction cracks simultaneously traversing the elements of crystal growth, such

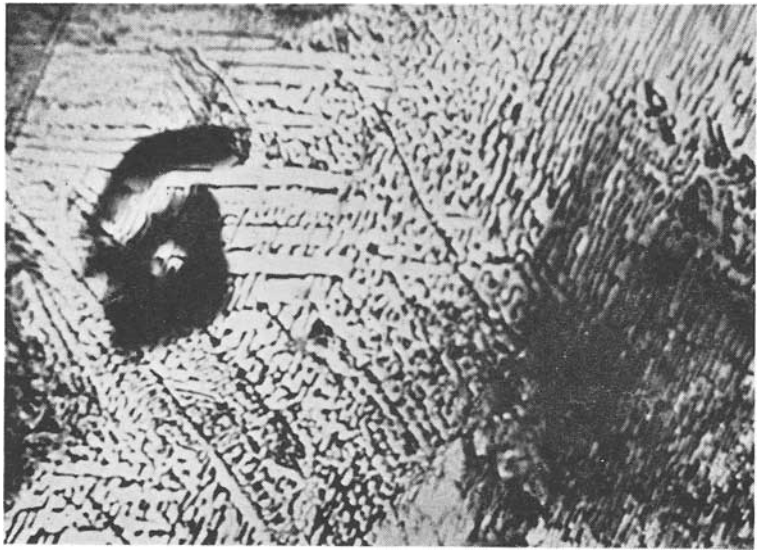

Fig. 14. Ruby : healed fissure, the liquid drops of which are oriented according to crystallographic directions. 40 ×.

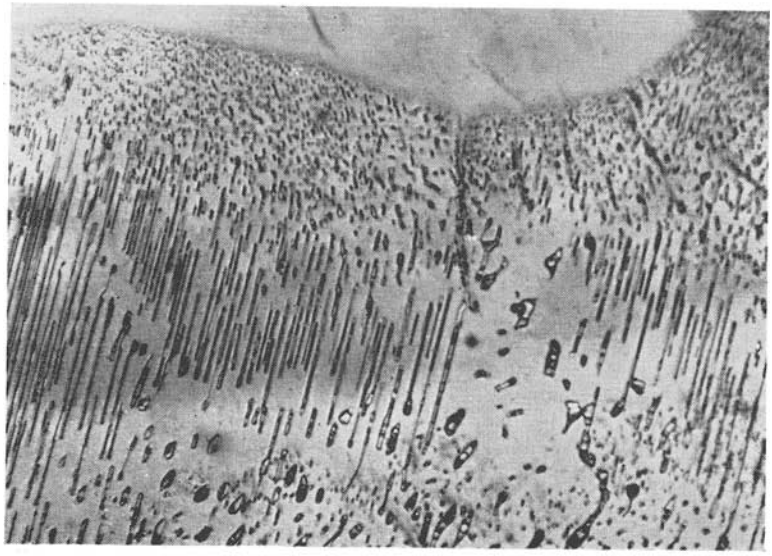

Fig. 15. Healed fissure in Burma sapphire. 75 ×.

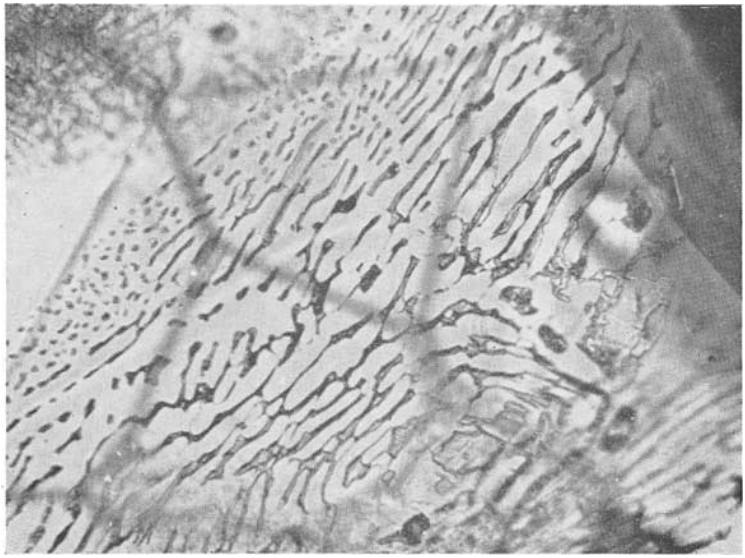

Fig. 16. Healed fissure with irregular liquid drops in Burma ruby. 50 ×.

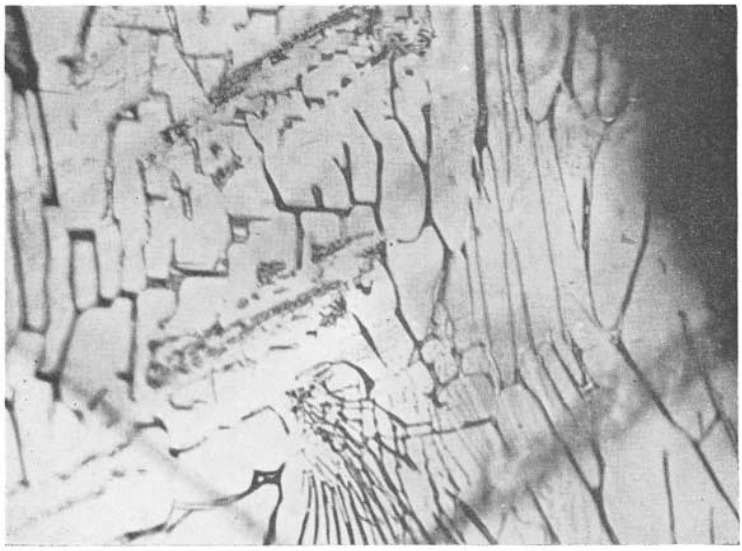

Fig. 17. Irregular shapes of residual liquid drops in healed fissure in sapphire. 75 ×.

as zonal colouring and zonal arrangement of primary inclusions, polysynthetic lamellae, etc. (Fig. 21).

2. Layers of secondary liquid inclusions are not only flat (cleavage, translation and contraction planes), but may also be curved, corrugated or conchoidal fractures (Fig. 22).
3. The healing fissures may run parallel to a layer of primary inclusions and through the process of healing the secondary inclusions are superimposed on the primary ones (Fig. 23).
4. Layers of secondary liquid inclusions must not necessarily traverse the whole crystal but may end within the host (Fig. 24). Such healed up fissures are usually wedge-shaped and the dimensions of the liquid inclusions increase from the interior towards the external opening of the fissure (Fig. 15).
5. With regard to their extent, secondary liquid inclusions may attain considerable dimensions, while their thickness is limited by the walls of the crack and in most cases is film thin (Fig. 25).

For all the past years whenever I studied inclusions in gemstones I tried to find the individual characteristics described above in order to separate the inclusions into those of primary and secondary origin. It was thus noticed that secondary inclusions—healed and unhealed ones—may occur in any gemstone ; especially in those of hydrothermal formation and those partly in relation with pneumatolytical processes.

We may now examine some typical primary and secondary inclusions (healing fissures) in gemstones :—

Diamond. In diamond the primary inclusions are much more common than secondary inclusions. Phantom-like clouds (Fig. 26) and marks of growth-phases (Fig. 27) are autogenetic inhomogeneities ; enclosed diamonds and trapped fragments of matrix are also of autogenetic origin, while all those numerous well-known foreign enclosures, such as zircon, graphite, garnet, olivine, quartz and hematite, are xenogenetic (Fig. 28). Among the thousands of diamonds I have tested, I have never found any with definite secondary liquid inclusions, although a great many of them contained cleavage (Fig. 29), or fracture cracks, or fissures by tension or contraction (Fig. 30), many of which were certainly of secondary origin, yet all these flaws appeared to be dry and unhealed. The fact that diamonds are devoid of secondary liquid inclusions may offer a valuable contribution towards an explanation of the genesis

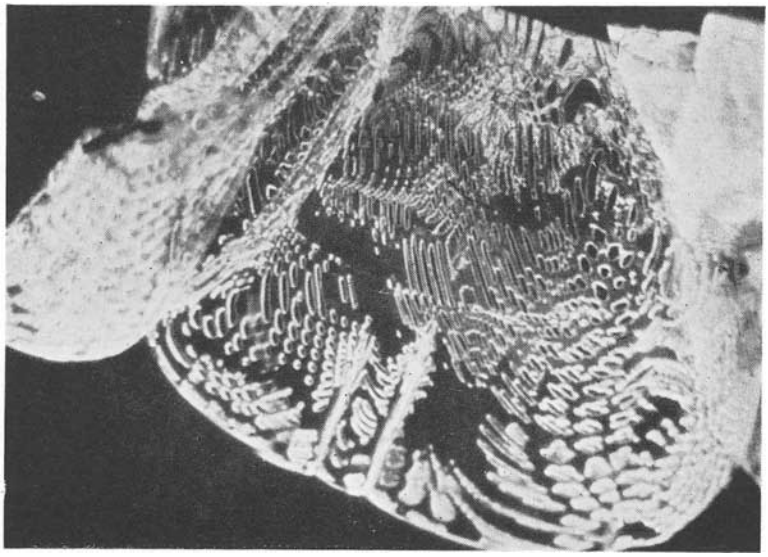

Fig. 18. Healed fissure with individual drops in green beryl. 40 ×.

Fig. 19. Solar pattern of re-crystallization centres in healed fissures in Burma sapphire. 75 ×.

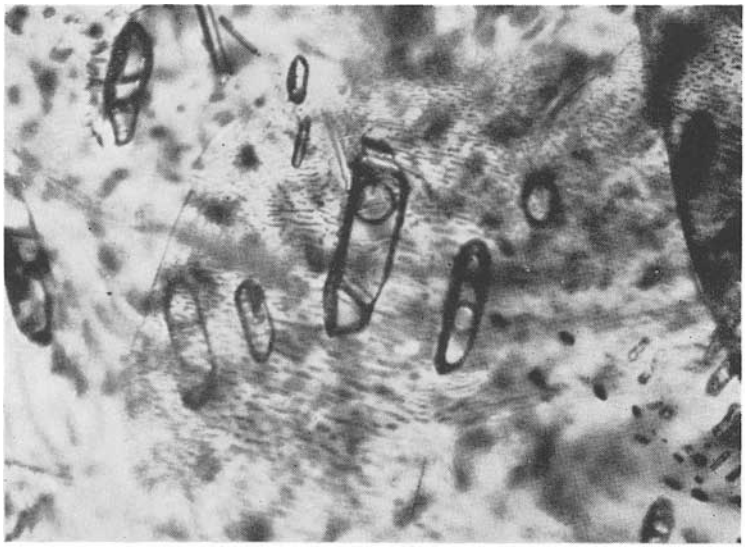

Fig. 20. Primary autogenetic liquid enclosures overlying secondary liquid inclusion in ruby from Ceylon. 125 ×.

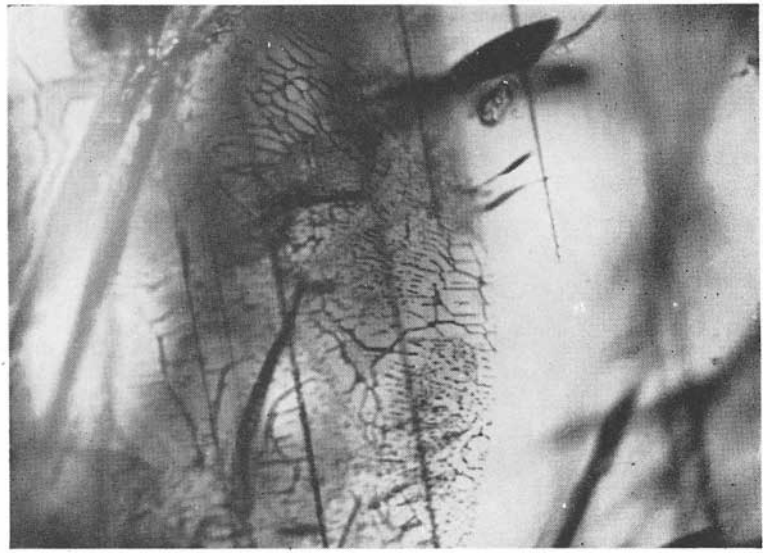

Fig. 21. Network of residual liquid drops of a healed fissure traversing several twin lamellae in Siam ruby. 75 ×.

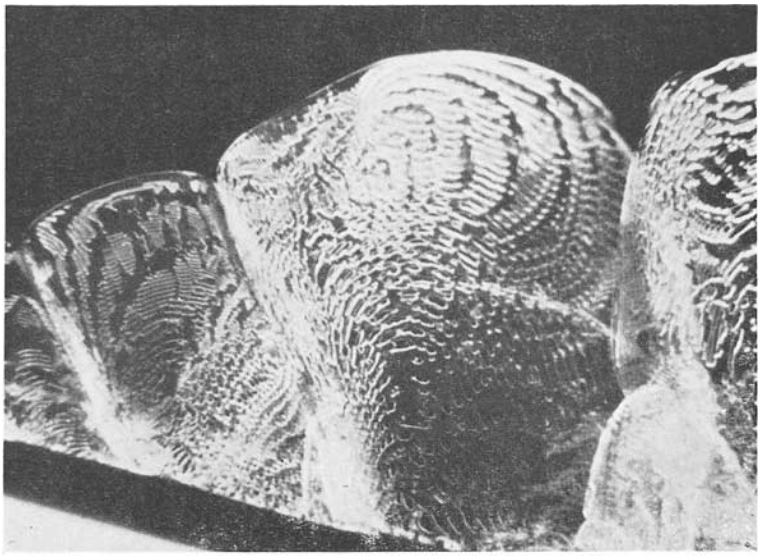

Fig. 22. Succession of various conchoidal healed cracks in green beryl. 30 ×.

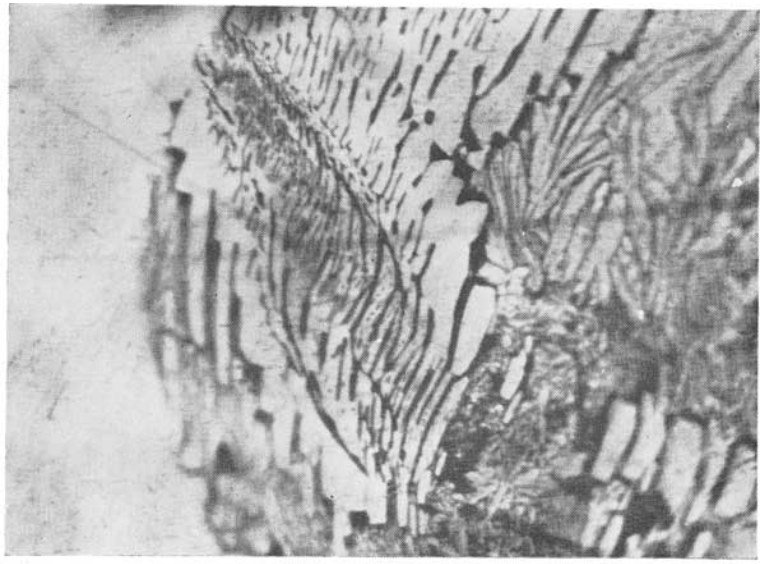

Fig. 22a. Curved and corrugated liquid feather in a Ceylon sapphire. 75 ×.

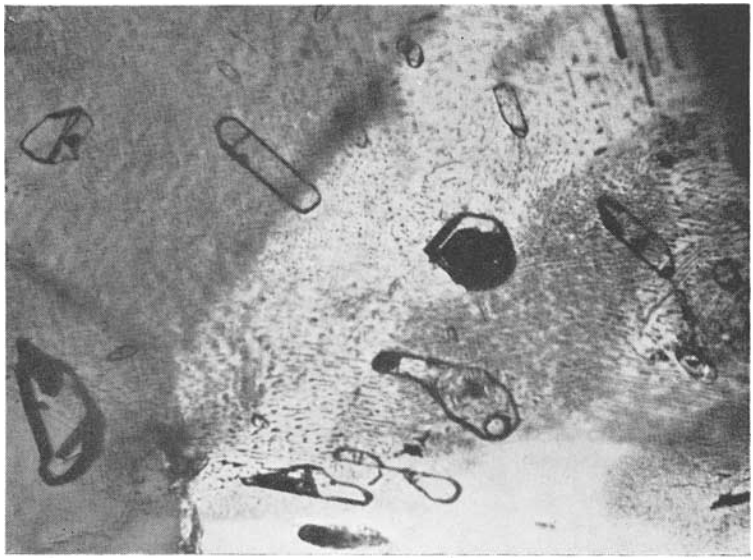

Fig. 23. Primary liquid drops overlying secondary liquid inclusion. 75 ×.

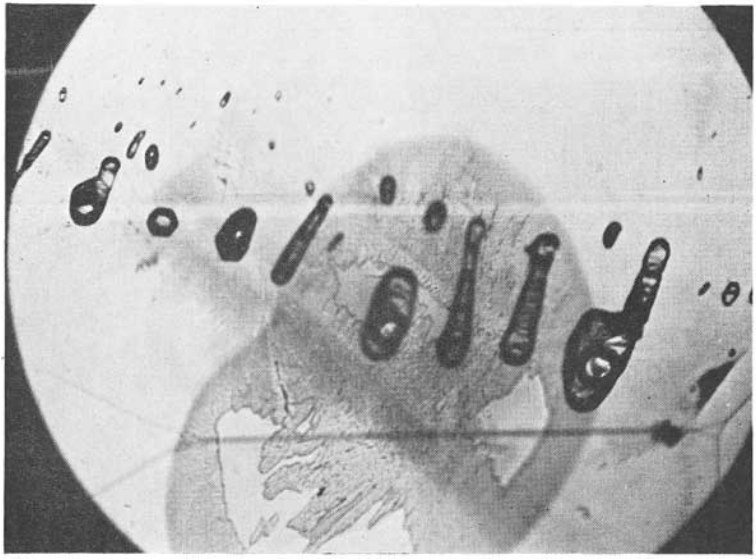

Fig. 23a. Primary liquid drops overlying secondary liquid inclusion. 75 ×.

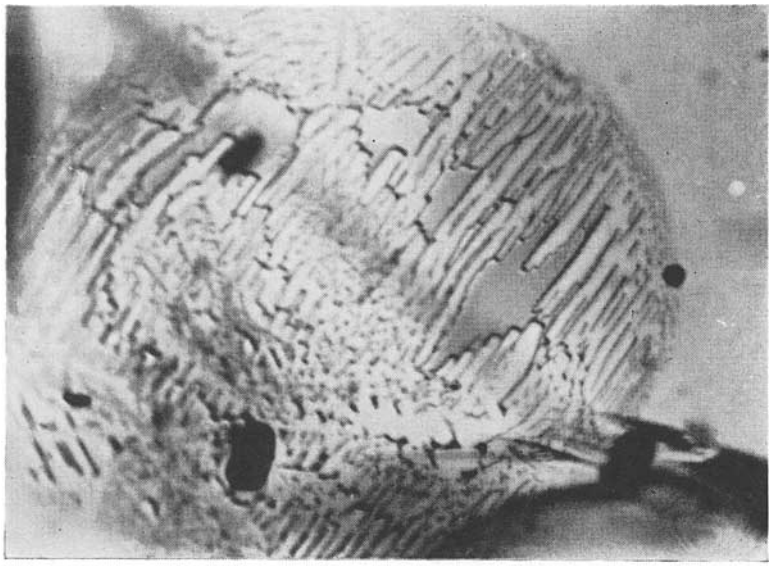

Fig. 24. Healed crack with circular circumference in Ceylon ruby. 125 ×.

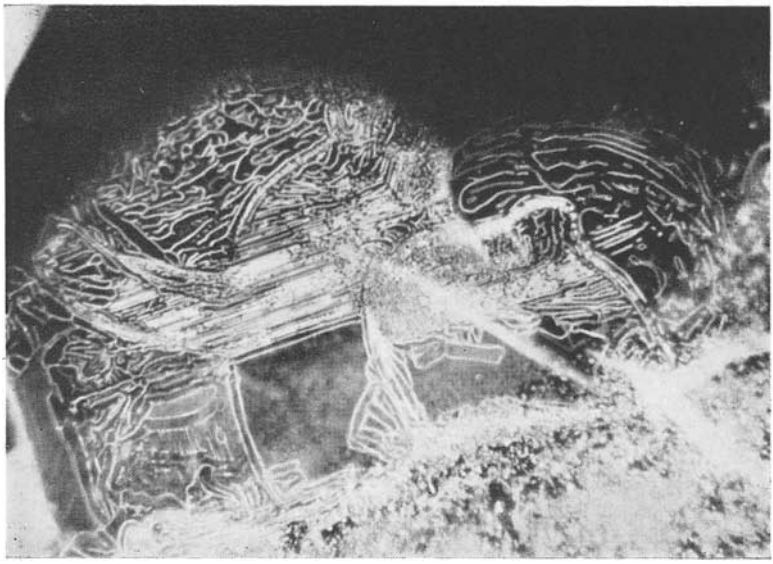

Fig. 25. Extremely thin healed fissure in zircon from Mongka. 80 ×.

of diamond, indicating that the diamond had been formed way down in the " sima " before it was lifted up by the kimberlite magma into the earth's crust, where it was often broken when the blue and yellow ground solidified, or that the diamond was formed in that gaseous carbon crystallized by avoiding the liquid phase (pneumatolytic genesis).

Corundum. With respect to inclusions corundum grants a profusion of interesting material. All genetic kinds of inclusions may frequently be found within one and the same stone. Zonal structure, phantoms, negative crystals filled with mother liquor and opaque grains of corundum such as in Siam rubies and Montana sapphires are autogenetic inclusions (Fig. 31). Xenogenetic inclusions are represented by the great number of foreign minerals, such as zircon, spinel, garnet, ores, rutile, etc. Those well-known liquid feathers which seem to occur at random and often intersect primary inclusions are in most cases healing fissures clearly marked by the residual drops of mother liquor trapped within the healed portions (Fig. 32). They characterize themselves by all the aforementioned features. Healing fissures usually run in irregular directions (Fig. 33), but may, however, sometimes parallel crystallographic orientations (Fig. 34), such as the basis or parting planes, and sometimes traverse same (Fig. 35), or they may be found lying across one lamella which was broken during its growth, subsequently healed and then acted as a seed of a polysynthetically twinned corundum crystal (Fig. 36), and occasionally their shape may portray the hexagonal habit of the host (Fig. 37). Whether the secondary liquid inclusions, that is, the cracks into which the mother liquor subsequently infused, occurred as a result of mechanical strain or in the course of a crystallographic alteration (altering from the α modification into the γ modification) will have to be investigated by further studies, the results of which may give the answer to an unsolved genetic problem about corundum.

Beryl. Many of the heretofore described inclusions in emerald, which often designate the host gem's nature or source, such as pyrite in El Chivor emerald, calcite, coaly substance or parisite in Muzo emerald, actinolite in Ural emerald, tremolite in Habach emerald, are primary inclusions of xenogenetic origin.

In beryl from all deposits, secondary liquid inclusions are found in great quantities and all observations made hitherto have shown that, in general, healing fissures lie parallel to the basal plane or to

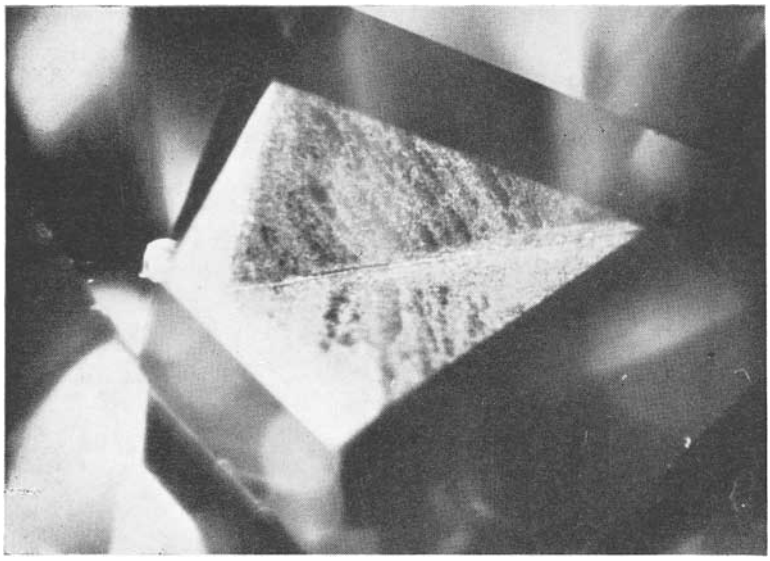

Fig. 26. Autogenetic inhomogeneity forming a " phantom " in a diamond. 20 ×.

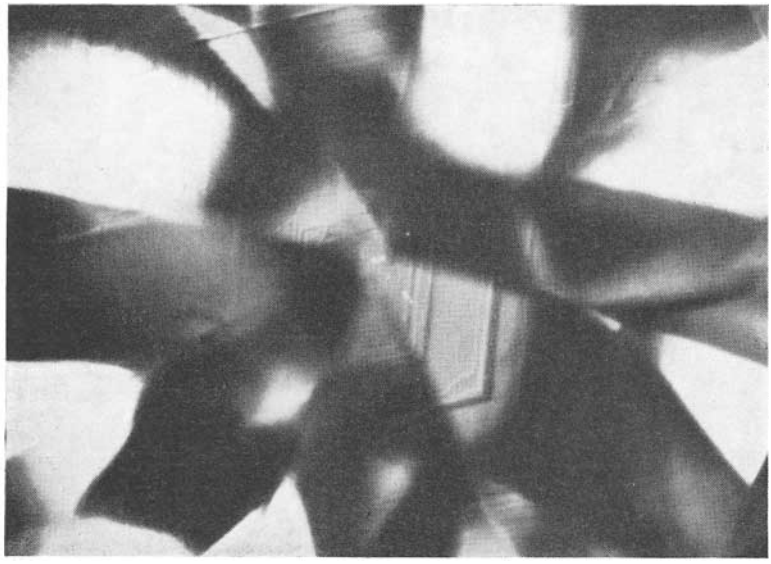

Fig. 27. **Marks of growth phases in a diamond. 40 ×.**

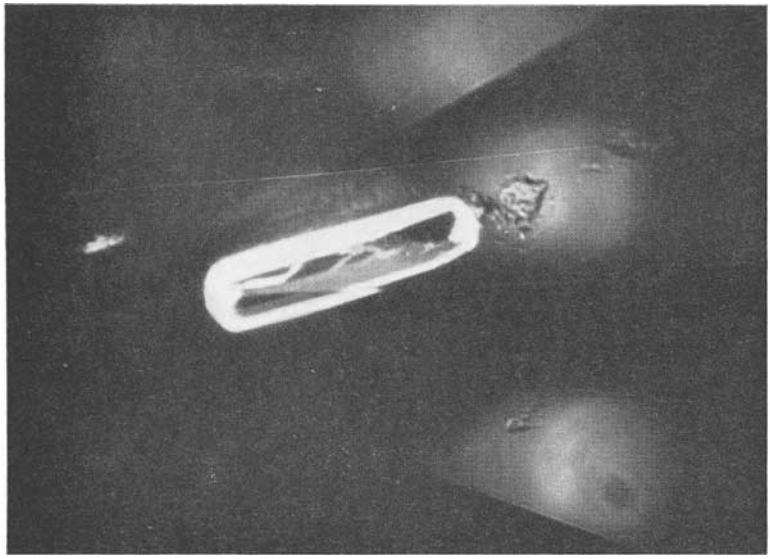

Fig. 28. Euhedral olivine-crystal in a diamond. 120 ×.

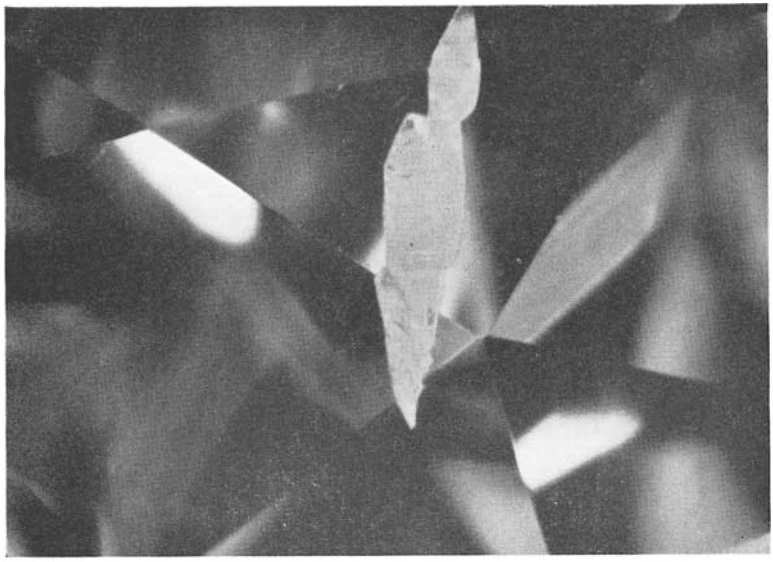

Fig. 29. Cleavage crack in a brilliant-cut diamond. 40 ×.

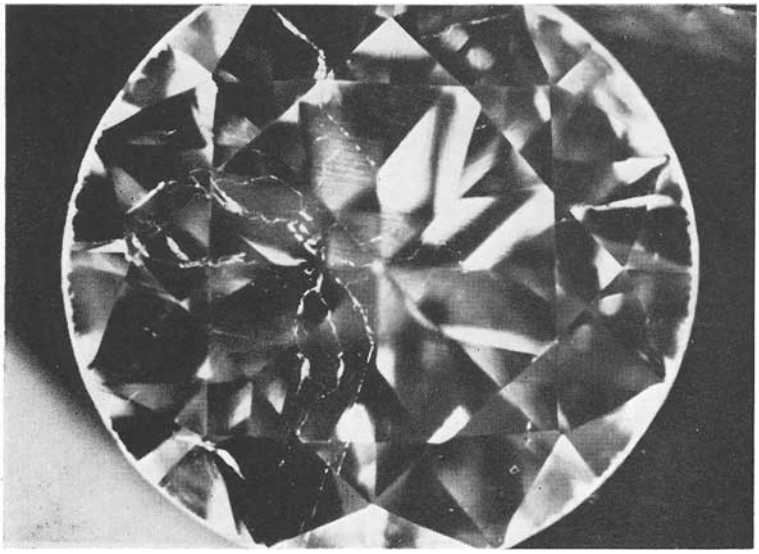

Fig. 30. Cracks by tension or contraction in a brilliant-cut diamond. 20 ×.

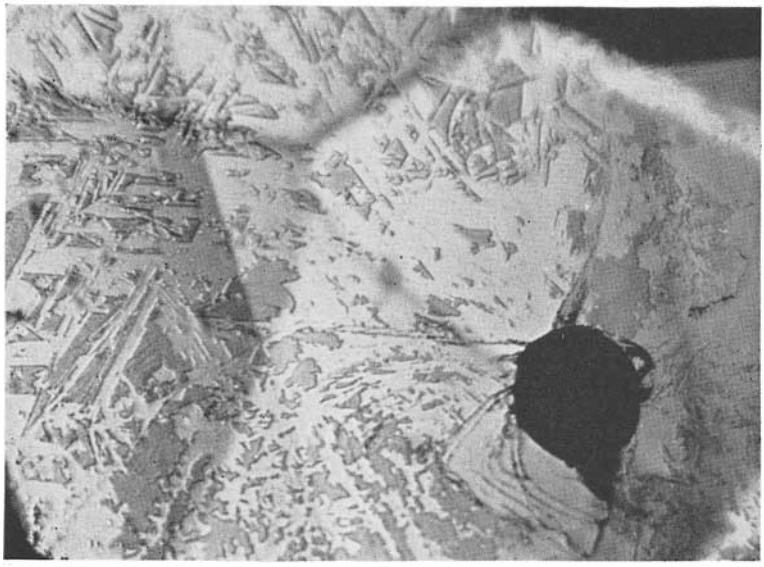

Fig. 31. Opaque crystal of primary origin with crystallization halo. 75 ×.

the prism $(10\bar{1}0)$, but may also be found to form accidental undulating planes. Healing fissures parallel to the basis may betray themselves by the tell-tale pattern of the liquid drops which often fill part of the stone's centre only and do not extend into the homogeneous coat which wrapped the broken core after it had become healed (Fig. 38). This proves that in the course of crystal formation we may conclude that some mechanical forces must have caused fractures and, while the beryl formation ceased, the cracks filled with healing substance out of the mother liquor ; the outer coat, however, grew afterwards without further disturbance. This phenomenon is frequently met with in emeralds from Habachtal.

But there is a further type of secondary liquid inclusion which contains a libella and almost always a well-shaped cubic crystal, or slightly distorted crystal, of NaCl (rock salt)—the well-known three-phase inclusions in emerald from Colombia (Fig. 39). Their form is most individual and distinctly different from other secondary liquid inclusions and so also is their content.

Though they seem to prefer orientation parallel to the prism, they are very frequently assembled in irregularly curved or undulatory layers. Comparison with the comma-like two-phase inclusions in Indian emerald reveals most beautifully the well-defined distinction between primary autogenetic and secondary liquid inclusions (Fig. 40 and Fig. 41). Such a remarkable difference in the character of the arrangement, shape and content of the two types of inclusions could never be explained by simultaneous formation with regard to the growing phases of the host minerals. It is interesting to know that exactly the same type of secondary three-phase inclusion is also found in fluorspar from South Africa and in quartz from various sources. Contrary to the primary inhomogeneities (negative crystals that are evenly developed in all directions) these secondary liquid inclusions predominantly spread in the plane of development (healed fissure), while their expansion perpendicular to this plane is confined by the walls of the fissure, that is, mostly extremely thin.

In aquamarines healed cracks are generally found to lie either parallel to the basal plane or the prism, but both differ entirely in character. While those parallel to the basis are made visible by the typical character of the droplet pattern (Fig. 42), those following

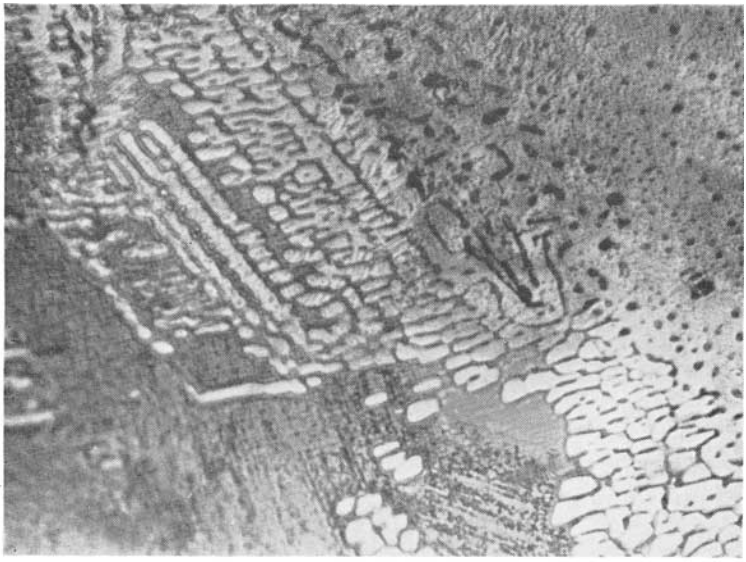

Fig. 32. Interesting pattern of a healed fissure in a Siam sapphire. 125 ×.

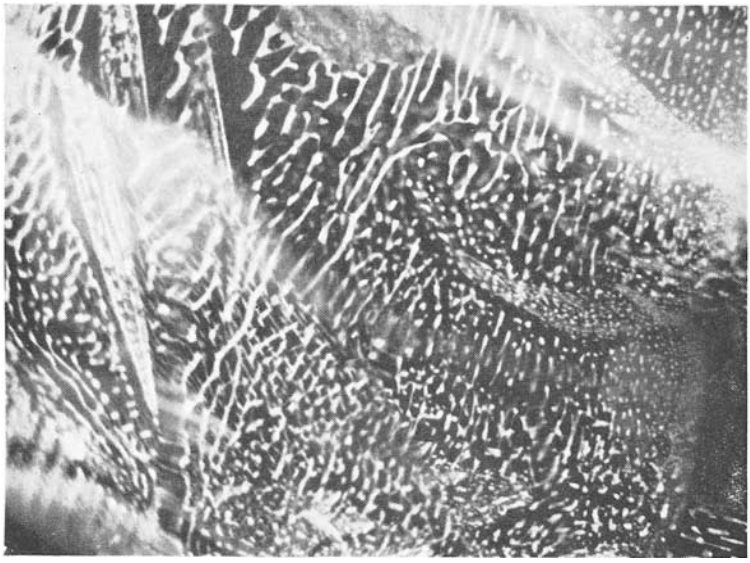

Fig. 33. Various healing fissures of typical design running in different directions in a sapphire. 40 ×.

the prism consist of extended parallel liquid filled tubes. With the latter it would be rather difficult to distinguish them from the very similar type of primary autogenetic liquid filled straight capillaries which were formed by the skeleton growth of aquamarines (Fig. 43), were it not for the tell-tale pattern of healed fissures consisting of long, extended yet interrupted, irregularly shaped tubes surrounded by a collar of tiny liquid drops in the thinner part of the wedging fissure from where the remedial action began (Fig. 44).

Quartz. Quartzes from many different sources, particularly those from the Alps and from Russian deposits, are pregnant with a treasury of secondary liquid inclusions worthy of investigation. Primary liquid enclosures are mainly confined to cairngorm, smoky quartz, amethyst and rock crystals from Carrara, Brazil, and Herkeimer, N.Y., and usually consist of euhedral negative crystals occurring singly or in masses and are of the autogenetic type (Fig. 45). They are filled with liquid usually confirmed by a libella and sometimes washing round some ore crystals. Another type of rather frequent primary inclusions in quartz is formed by glass drops. I have mentioned these two types of primary inclusions in quartz because they occur very often in relation with secondary inclusions. Quartz offers the most classical examples of "phantoms," which often depict a complete *curriculum vitae* through all the phases of growth by an unbroken succession of " phantoms " from the minutest embryo up to the fully grown finished crystal. Undulating veils of intersecting and overlapping secondary liquid inclusions with myriads of drops traverse these gems giving lively evidence of the manifold phases of turmoil they must have gone through.

As stated above, the three-phase inclusion containing a cubic crystal of rock-salt is also one of the striking types of healing features in quartz.

Apart from these healed fissures there is still another type of secondary inclusion or rather a secondary inhomogeneity, which is the result of some shifting actions causing cracks of translation, which if they did not fill with healing liquid remained dry and appear as those intriguing cracks with " tiger-stripes " (Fig. 46). In A. E. Fersman's opinion (Lit. 2) cracks and fractures in pyrogenetic quartz were not caused by mechanical strain but rather on account of crystallographic alteration which was an inversion of

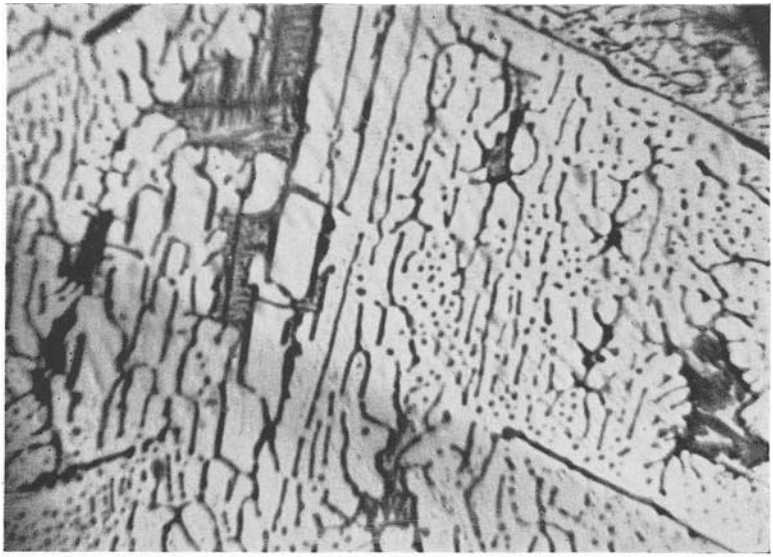

Fig. 34. The individual drops of this healed crack in a sapphire are strongly influenced by the directional crystallographic power of the host. 120 ×.

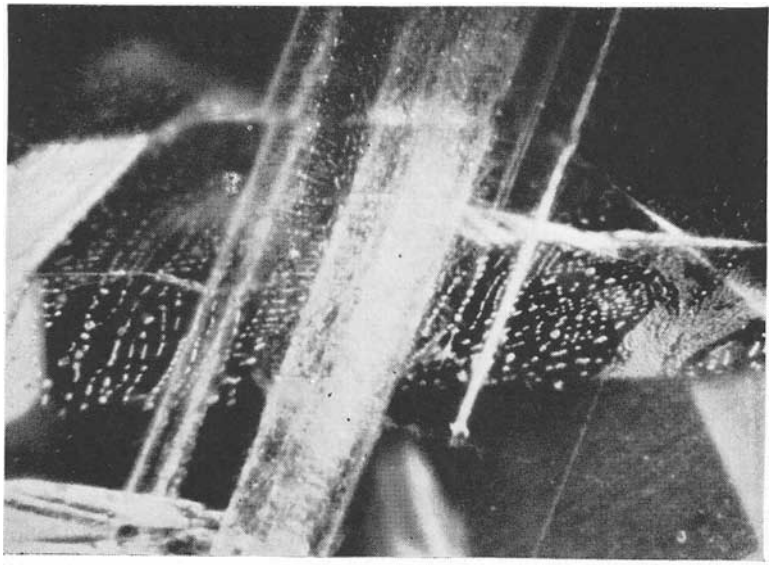

Fig. 35. Healed fissure traversing polysynthetic twin lamella in a sapphire. 40 ×.

the hexagonal α-quartz into the trigonal modification of β-quartz caused by continuous sinking of the temperature of the magma down to 575°C. The fissures of translation and the fractures run parallel to one prism and rarely along the rhombohedron. If in the course of postvolcanic processes a hydrothermal phase follows, the permeating solutions will infuse the previously formed dry fissures and heal them up. Through this process β-quartz will precipitate.

Topaz. In topaz just as in the gems dealt with before, inclusions are of primary and secondary origin and may be clearly distinguished. Among the primary autogenetic inclusions we know the typical negative crystals (Fig. 47) occurring individually or arranged in planes and recently we were informed about interesting growth marks in topaz manifesting irregular faces of growth (Lit. 3) (Fig. 2). Hornblende blades, asbestos fibres, hematite and many other foreign minerals are xenogenetic inclusions. Secondary inclusions are often bound to the various types of cracks as well as to planes which are weakened by primary inclusions. Consequently, secondary liquid inclusions may occur in flat, curved or wavy planes, or in layers superimposed upon primary inclusions. Sometimes a primary cavity may have become filled with liquid of secondary origin, or large primary inclusions may be embedded in a thin film of secondary inclusions spread over the same plane and following the direction of the basal cleavage (Fig. 48 and Fig. 49).

Fluorite. Fluorspar offers the most characteristic example of secondary liquid inclusions (healed fissures) strongly affected by directional crystallographic power. Residual liquid drops are usually extended according to crystallographic directions (orientations) and groups of parallel liquid inclusions follow either octahedral or cubic directions, often intersecting each other (Fig. 50). In other specimens a multiple dendritic pattern manifests healed fissures such as depicted in Fig. 51. They seem to have exerted a much more powerful healing effect on the damaged fluorspar than a third type of secondary liquid inclusions—the so-called three-phase inclusions containing liquid, a gas-bubble (libella) and a cube of NaCl (Fig. 52).

Primary autogenetic inhomogeneities are formed by those negative cubic bisphenoids filled with liquid, which are so specific a mark of this gemstone. Primary xenogenetic inclusions may also consist of various internally paragenetic minerals.

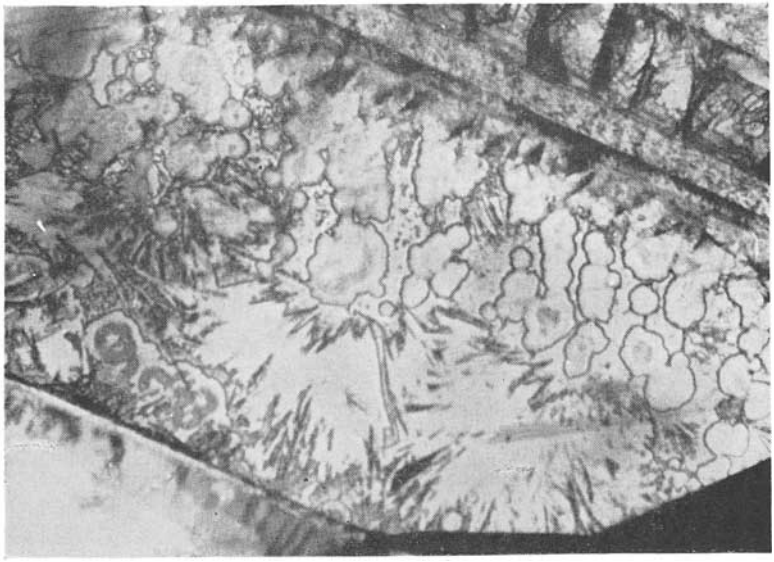

Fig. 36. Healed fissure limited to one twin lamella in a sapphire. 120 ×.

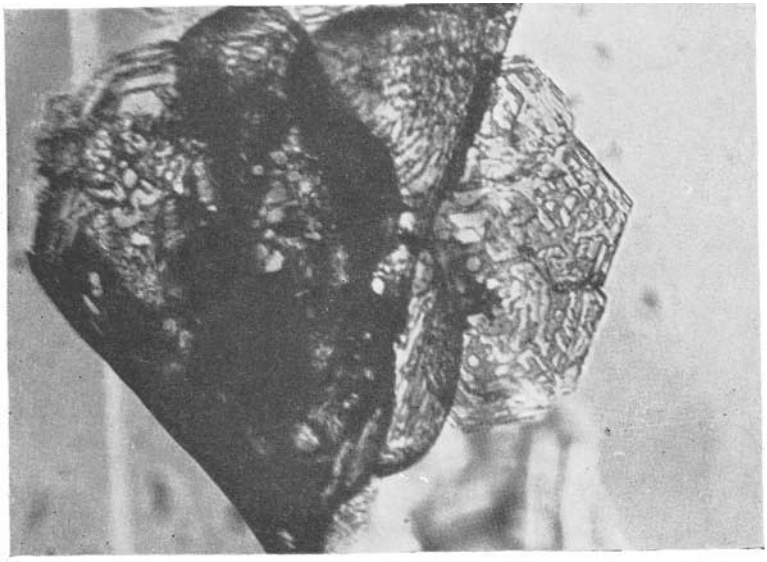

Fig. 37. Multifold healed crack with hexagonal outlines in a Montana sapphire. 120 ×.

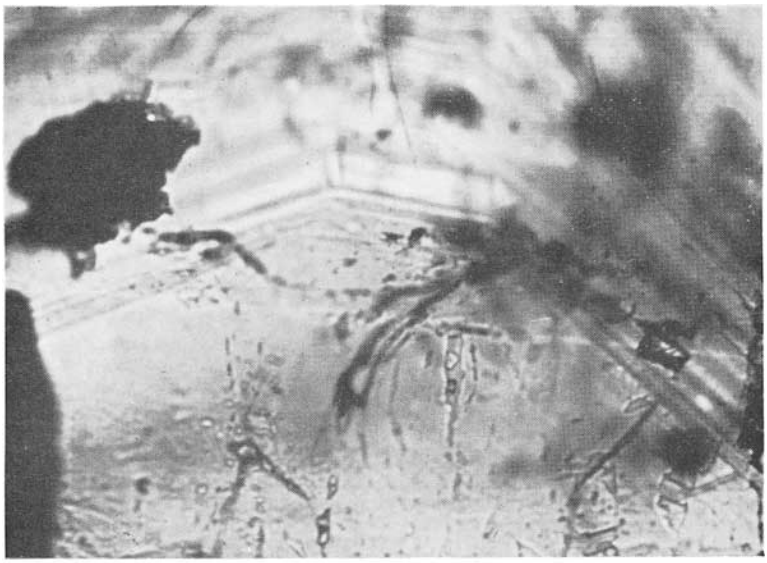

Fig. 38. Emerald with healed crack parallel to basis enclosed by homogeneous coat which is of a later phase. 40 ×.

Fig. 39. Secondary liquid inclusions of the three-phase type parallel to one prism in an emerald from Colombia. 40 ×.

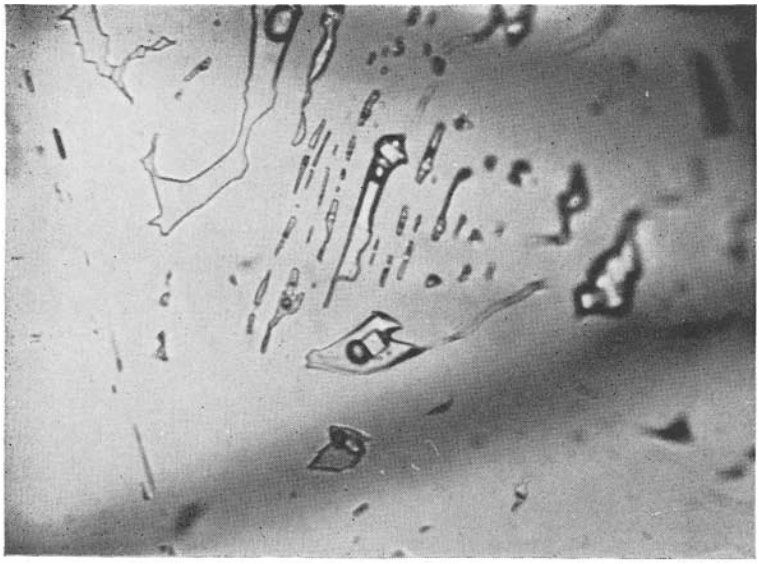

Fig. 40. Secondary liquid inclusions with a cube of NaCl, being residual drops in a healed fissure in emerald from Colombia. 120 ×.

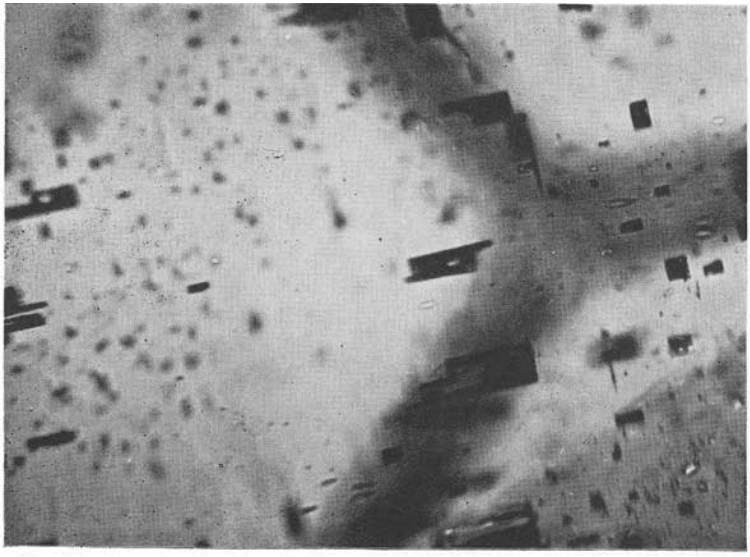

Fig. 41. Primary liquid inclusions of the two-phase type characteristic of Indian emerald. 75 ×

(bb) INCLUSIONS FORMED BY EXSOLUTION

It was extremely difficult to understand the occurrence and genesis of some solid inclusions, which always consisted of foreign microlites usually very densely filling the host gem, until the synthesis of star corundum densely permeated with rutile needles shed light on the problem. It then became known, and was understood, that their formation was due to an " un-mixing " of one component at lowered temperature of a mixed crystal that had been homogeneous at high temperature.

For the sake of those readers who may not be sufficiently acquainted with the theory of isomorphism in modern mineralogy, a brief explanation of the process and definition of the theory is given.

We know that several gemstones belong to the so-called isomorphous series and isomorphism is obvious in all those cases in which elements can easily form with each other isomorphous, mixed crystals in all proportions of mixing, such as albite and anorthite in plagioclase, forsterite and fayalite in olivine, enstatite and hypersthene in orthorhombic pyroxenes, etc. This relationship is thus expressed that in chemical stoichiometric compounds the replaceable atoms, called " diadochic " atoms, are put in parenthesis and separated by a comma, e.g., olivine mixtures $(Mg,Fe)_2SiO_4$, spinel group $(Mg,Fe)Al_2O_4$, etc.

If the isomorphism is less pronounced, then interruptions (miscibility gaps) occur in the isomorphous mixture series, and only a smaller and variable part of one component may be replaced by the other one. The grossular members $[Ca_3Al_2(SiO_4)_3]$ and almandine members $[Fe_3Al_2(SiO_4)_3]$ of the garnet family offer a good example in that the compounds of Mg,Fe″ and Mn″ on one hand and of Al and Fe‴ on the other hand are unlimitedly mixable.

A further group, however, does not seem to permit the least isomorphous mixture. For instance, NaCl and KCl crystallize isometric holohedral, they cleave isometrically, yet they do not mix at all at room temperature, because the radii of Na(·98Å) and K(1·34Å) differ too much. If the chemical compounds are complex, mixtures may readily occur even with relatively great differences of dimensions (mass-isomorphism). Thus in apatite Cl (radius 1·81) and F (radius 1·33) may replace each other.

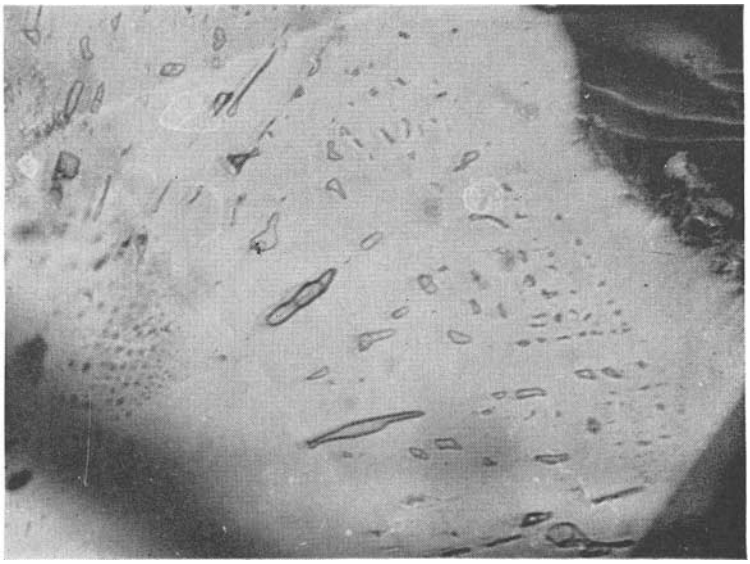

Fig. 42. Secondary liquid drops parallel to basis in aquamarine. 75 ×.

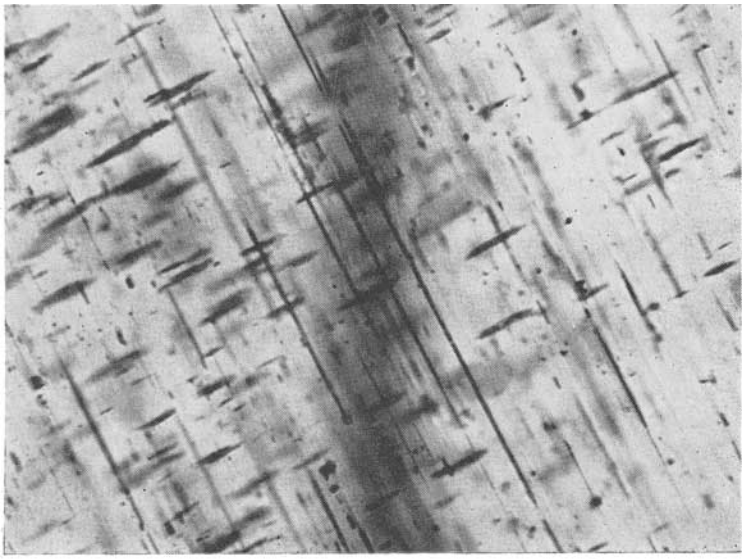

Fig. 43. Primary liquid-filled tubes running parallel to the c-axis in aquamarine. 75 ×.

Minerals of similar development and of different chemical composition are mutually isomorphous if their formulae are analogous both as to the total number of atoms and to the number of positive and negative ions.

The unit cells must be nearly identical and the positive as well as the negative ions within the cells must occupy analogous positions.

The identity of the elements comprises conformity of their radii as well as of their polarizing properties within certain limits. Complete isomorphism therefore postulates that the crystals with " diadochic " atoms belong to the same class of symmetry and even to the same space group. We thus see that in a certain type of crystal structure, particles of the same co-ordinative behaviour and similar space requirements can substitute for one another. This behaviour is called diadochic. This substitution may, under certain conditions of formation, take place either to a limited or unlimited extent.

In the above, only the isomorphism of elements with identical valency has been considered, but it happens very often that elements of different valency substitute for one another, this being made possible by their having similar space requirements and the same co-ordinative properties. Since the structure must remain unchanged, the deficiency or excess of valency produced by such a substitution must be compensated by substitutions producing the reverse effect. This is called coupled atomic substitution.

Pressure and temperature affect the length of the radii of ions and the polarizing properties, the latter being more strongly influenced by temperature. (Generally the degree of isomorphism increases with rising temperature.) There are many examples of substances which mix more readily at high temperature than at low. As mentioned above NaCl and KCl do not mix at all at room temperature, yet readily form mixed crystals near their melting point. Diopside $CaMg(SiO_3)_2$ for instance and clino-enstatite $MgSiO_3$ do not mix in rocks, which solidified at relatively low temperature, yet mix readily and unrestrictedly if they crystallize from dry fusions. Such conditions of isomorphism have been observed with many minerals. The constituents mix together and melt into mixed crystals at high temperatures, but they refuse so to react at low temperature. In this case, as in many others, mixed crystals which formed at high temperature separate from

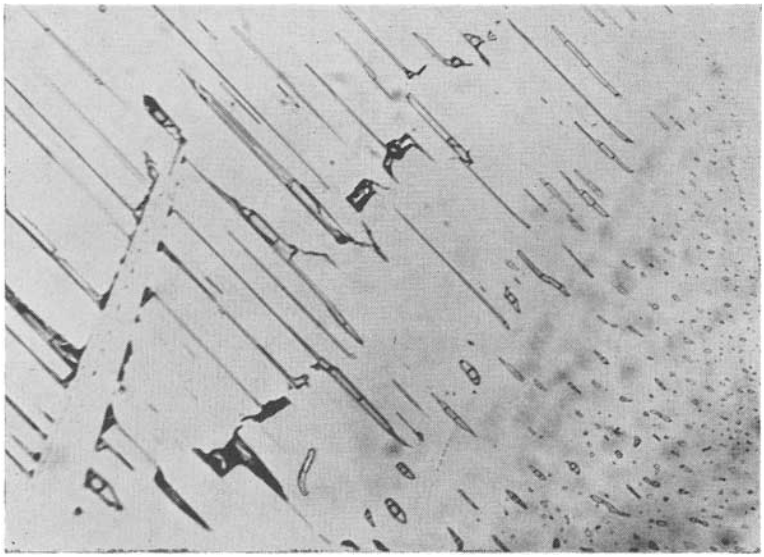

Fig. 44. Secondary inclusions parallel to one prism. The healing action began in the region of the tiniest droplets. The directional power of the growing crystal is well marked by the elongation of the liquid inclusions. 75 ×.

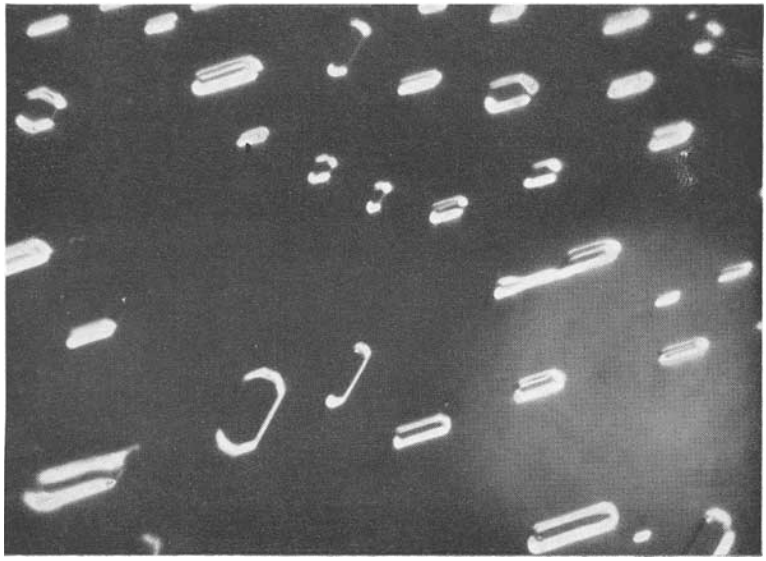

Fig. 45. Negative crystals in an amethyst. 80 ×.

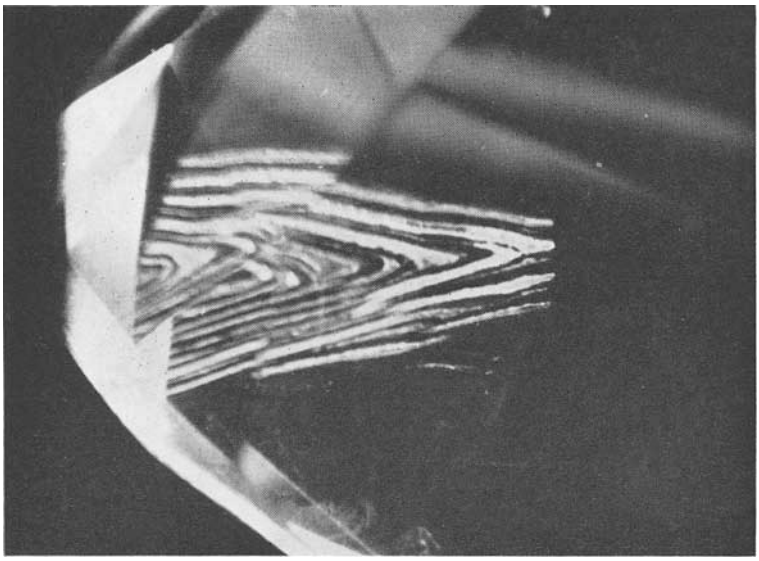

Fig. 46. Translation crack marked by " tiger stripes " in a citrine. 20 ×.

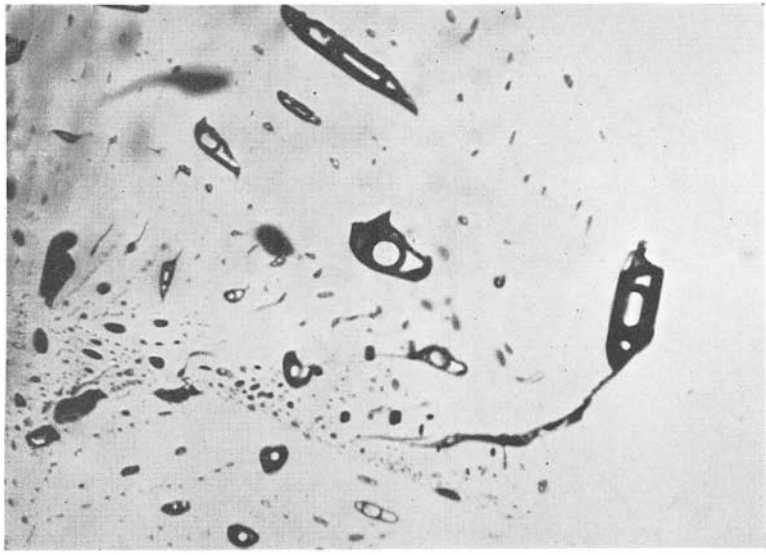

Fig. 47. Negative crystals being of primary origin in a topaz. 30 ×.

each other in the solid state, because cooling causes elements, which are no longer able to substitute for the main atoms, to leave the mixed structure and form another new species within the originally homogeneous mixed crystal, i.e., they un-mix at lower temperatures. This process of separation is called exsolution. The mixture crystal of NaCl and KCl fused together at high temperature becomes labile at room temperature and un-mixes, turning into a turbid porcelain-like product. In silicates formed at high temperatures some Ti is often found to have replaced other elements (e.g. Mg, Fe, Al) having kz 6 in respect to O (see footnote*). At low temperatures it often forms TiO_2 by un-mixing. Crystallizations of rutile needles are then to be found in the originally homogeneous mineral (e.g. almandine). Similarly, some silicates in which Al has kz 4 in respect to O tend, on cooling, to separate in the form of hematite (Fe_2O_3) (e.g. peristerite, scapolite).

The application of this particular peculiarity of isomorphism with interruptions of mixture leading to exsolution made possible the synthesis of star corundum by the Linde Air Corporation and Wiedes Carbid Werke and the " un-mixing " of corundum microlites in synthetic spinel (Fig. 53) by W. F. Eppler. The latter and the author have been carrying out some work of research, investigating properties in natural gemstones with the aim of creating a better understanding of the relationship between certain intermixed compounds in these gems and their inclusions. These studies are not yet terminated, but will be published as soon as definite conclusions are possible.

Since the shedding out of the excessive constituent which had been primarily incorporated in the melt, from which the mixture crystal was formed, occurred in the course of the subsequent process of cooling off, the inclusions formed thereby may also be classed as secondary inclusions. The size of the un-mixed microlites is usually minute but their number is legion, hence they are often responsible for a certain turbidity or certain optical phenomena such as spangled glitter, aventurescence, asterism, play of iridescent colours or complete alteration of colour. The emigration of the excess component, however, does not always take place over vast areas within the host-component, but covers sometimes small patches only (Fig. 54) Since the dimensions (the radii of the ions) and

* kz symbolizes co-ordination number of ions, e.g., SiO_2 or SiO_4 in which the kz of Si in respect to O is 2 or 4.

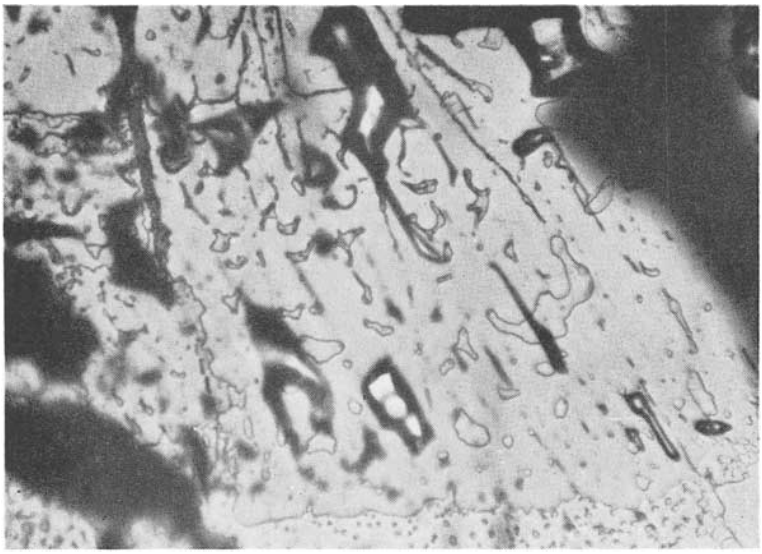

Fig. 48. Primary and secondary liquid inclusions in a topaz. 75 ×.

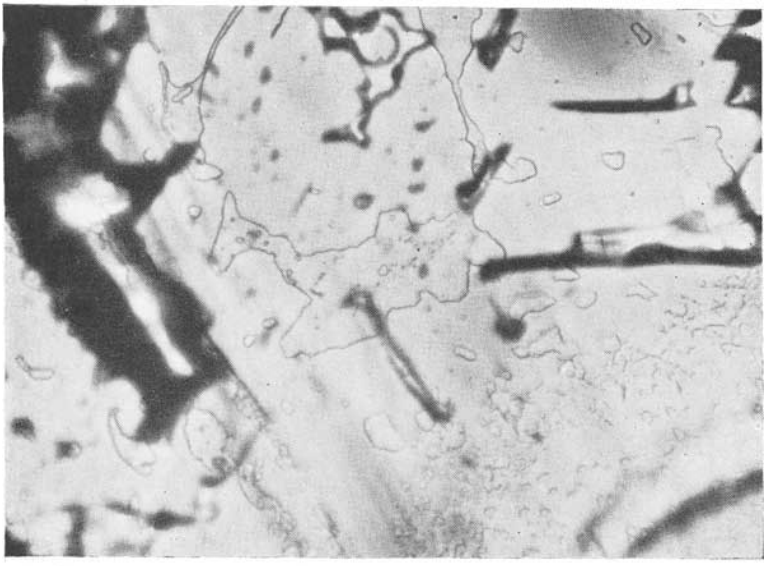

Fig. 49. Healed fissure with very flat residual drops in a topaz. 120 ×.

the distances (space requirements of the ions) of the constituent elements are the fundamental law of isomorphism, the solid inclusions formed by exsolution parallel themselves according to the crystallographic directions.

From the mineralogical point of view the feldspar family is the most important group of reciprocal isomorphism and exsolution. The examples are extraordinarily numerous, so that their products by exsolution expressly received the name of perthite. The spangled effect of aventurine feldspar (sunstone) is due to platy goethite crystals, and the often greenish-black metallic appearance of peristerite is caused by platelets of hematite ; the origin of both types of inclusions is due to an un-mixing of an originally homogeneous feldspar that contained some iron oxide in solid solution. Separation of components within labradorite is also responsible for its play of iridescence. The subtle bluish adularescence of the moonstones from Ceylon is partly due to un-mixed albite molecules. In moonstone—a very pure variety of orthoclase—the grade of milky haziness depends on the portion of expelled albite (Na), and exsolution is often impossible either on account of lack of sufficient intermixed albite or because of very quick cooling off. Slow cooling off favours exsolution, while sudden chilling prevents this and forms a clearly transparent mixture crystal. The waterclear moonstones from Burma were either chilled off very quickly or they did not contain the albite molecules necessary for perthitic exsolution.

For the gemmologist corundum forms the most valuable example of a gemstone being greatly affected by the results of exsolution. By far the majority of the well-known acicular rutile crystals owe their existence to this process of internal separation from the alumina component of the original mixture. Under certain circumstances certain crystallographic planes may be favoured by heavier concentration, and thus twinned rutile needles may un-mix in sagenite pattern. It is then not always easy to distinguish the origin of rutile needles either from exsolution or from sagenite-like adsorption. The latter forms flat layers which may repeat while the former usually distributes the inclusions all through the host, playing an important role as the cause of asterism, although concentration along zones may often be preferred. Another constituent readily mixing and un-mixing with corundum is ilmenite, which also is a frequent inclusion in corundum.

There exists such intimate correlation of isomorphism between

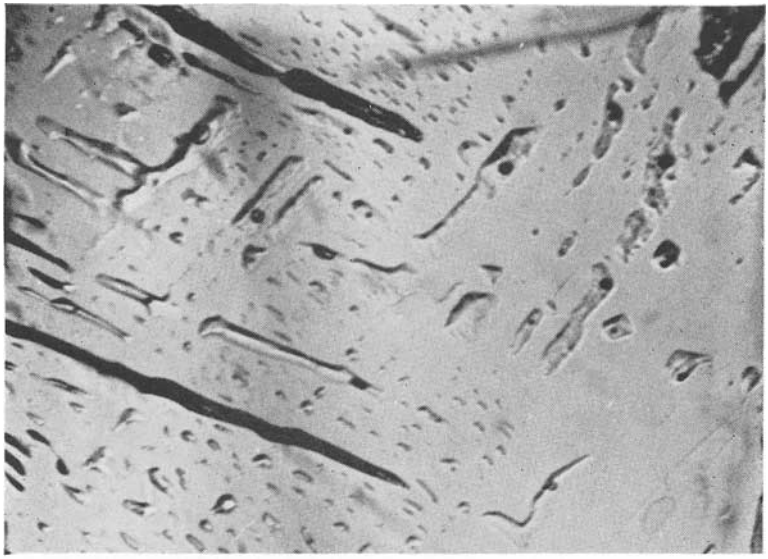

Fig. 50. Fluorspar. The residual liquid drops of this healed fissure reveal directional crystallographic power. 75 ×.

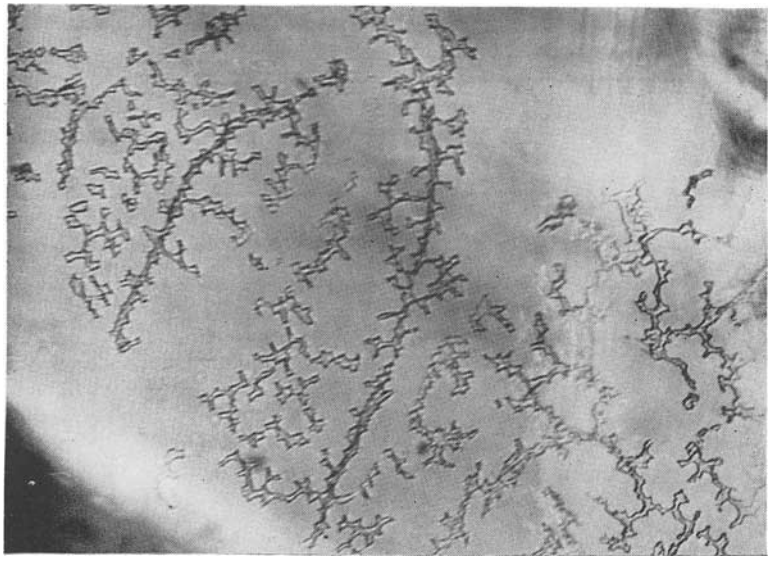

Fig. 51. Almost completely healed fissure with but a few residual dentritic liquid inclusions in fluorspar. 125 ×.

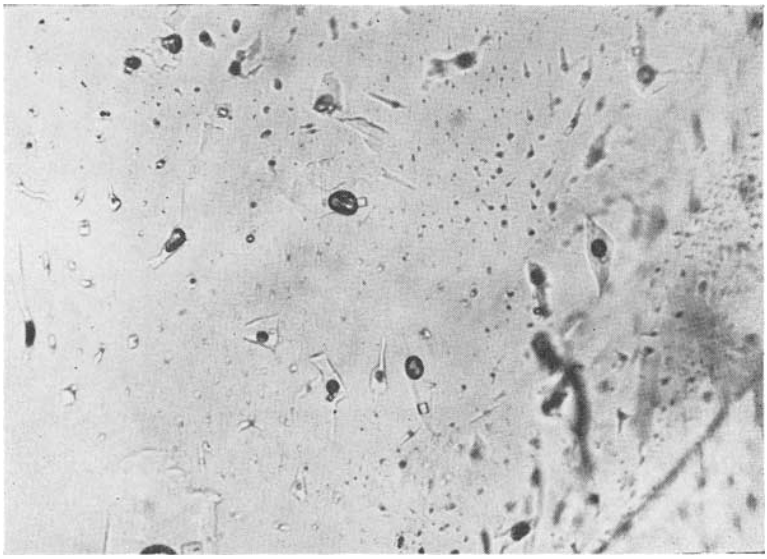

Fig. 52. Fluorspar. Secondary liquid inclusions of the three-phase type with a cubic rock-salt crystal and a libella. 75 ×.

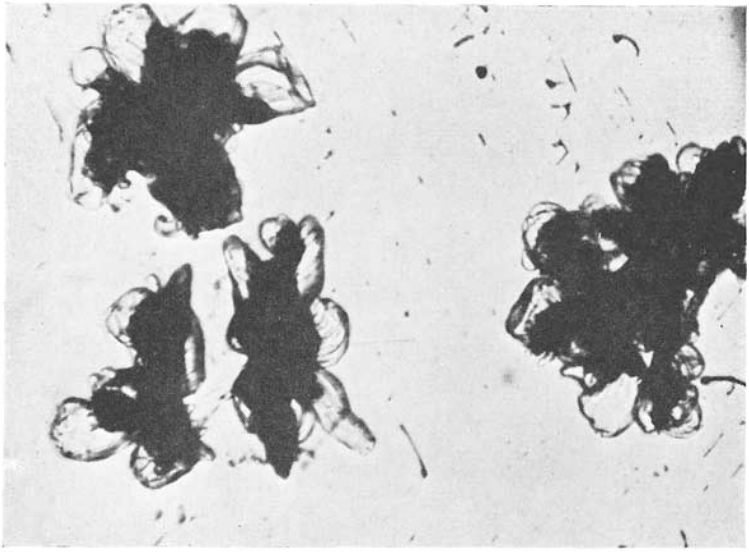

Fig. 53. Clusters of corundum crystals caused through exsolution in a synthetic spinel. 75 ×.

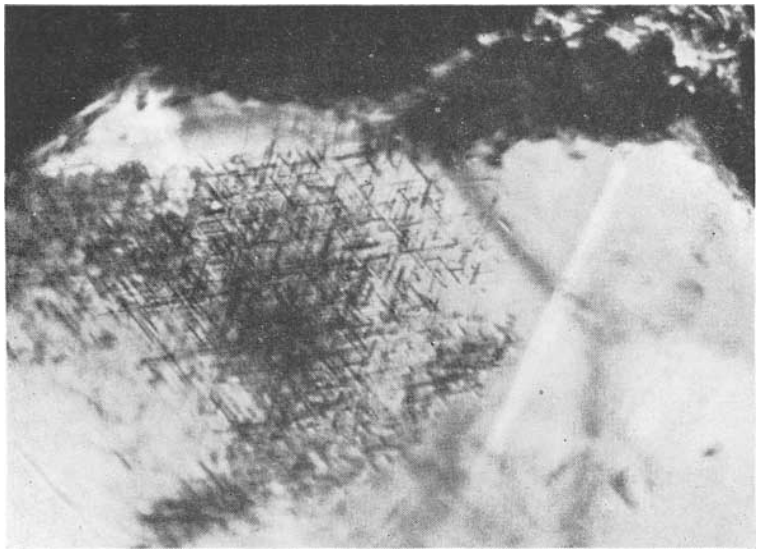

Fig. 54. One of those characteristic patches of rutile needles in a Burma ruby. 75 ×.

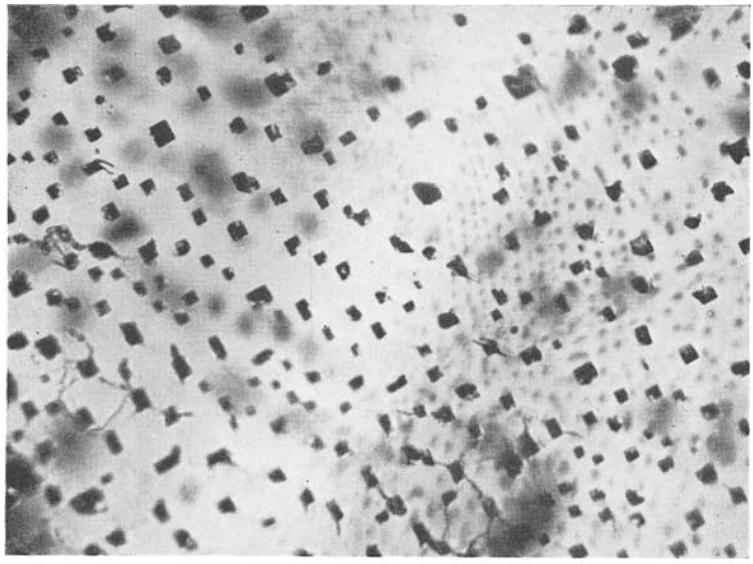

Fig. 55. Uncountable magnetite octahedra formed by un-mixing of one of the diadochic elements in spinel. 50 ×.

the members of the spinel-magnetite group that not only all grades of reciprocal isomorphism but also of exsolution take place, the manifestation of which is manifold. The black tell-tale octahedral (Fig. 55) microlites distributed in small groups, or over wide planes in spinel, are magnetite crystals " exuded " by exsolution. These spinels seem to have had abundant time for cooling off slowly in order to allow the separation of the phases. To the same cause of origin have also to be ascribed those myriads of minute, acicular, sphene crystals (Fig. 56) which often cause asterism in spinels. Their phenomenological appearance differs very distinctly from those sphene wedges (Fig. 57) which grew in sagenite-like arrangement on previous crystal faces and became thus entrapped in the spinel, being primary xenogenetic inclusions. However, under certain circumstances large sphene crystals may sometimes un-mix along definite crystallographic directions and then cover certain privileged crystal planes manifesting also a sagenite-like pattern.

A characteristic result of exsolution consists in the dense repletion of cordierite with goethite (lepidocrocite) platelets (Fig. 58) recently described by R. K. Mitchell (Lit. 4), while the white, blotty agglomerates of opaque white crystals also observed in iolite by E. H. Rutland (Lit. 5) are rather the result of alteration into pinite or mica by the introduction of alkaline.

The bronzy colour and metallic iridescence of bronzite is due to ilmenite tablets that completely fill the body of the host crystal, thanks to subsequent separation of phases of an originally homogeneous mixture crystal.

In many peridots, which to the naked eye appear somewhat hazy or brownish, the uncountable numbers of ultra-tiny fayalite crystals (Fig. 59) are also the characteristic result of exsolution, i.e. they are secondary solid inclusions which owe their presence to the slow cooling off and the separation of the constituent rich in iron from a previously isomorphous and homogeneous mixture crystal.

The whirl-like appearance of hessonite (Fig. 60), which belongs to an isomorphous series of garnets (andradite and uvarovite) that may mix unrestrictedly, is an indication of the internal strain and initial dilapidation in the smallest areas as a result of incomplete exsolution. Through quick cooling off (temperature that sank too quickly) the separation of phases microscopically visible was inhibited although in view of the equal proportion of both ions the chemical conditions ought to have exacted exsolution.

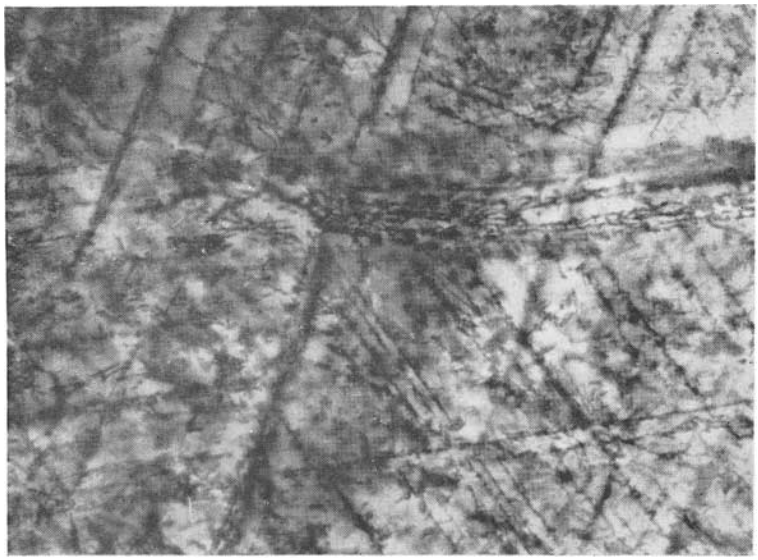

Fig. 56. Star spinel : dense and partly oriented repletion of tiny sphene needles caused by exsolution. 75 ×.

Fig. 57. Sagenite-like deposition of sphene crystals on a previous crystal face in a star spinel. 75 ×.

Fig. 58. Myriads of tiny platelets of lepidocrocite in a cordierite from Ceylon. 125 ×.

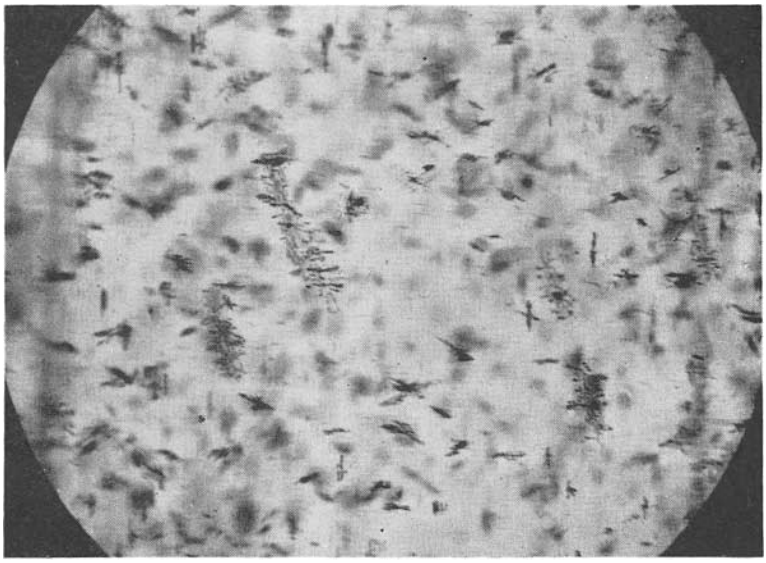

Fig. 59. Through the action of exsolution legion of microscopic fayalite crystals were formed within a peridot. 50 ×.

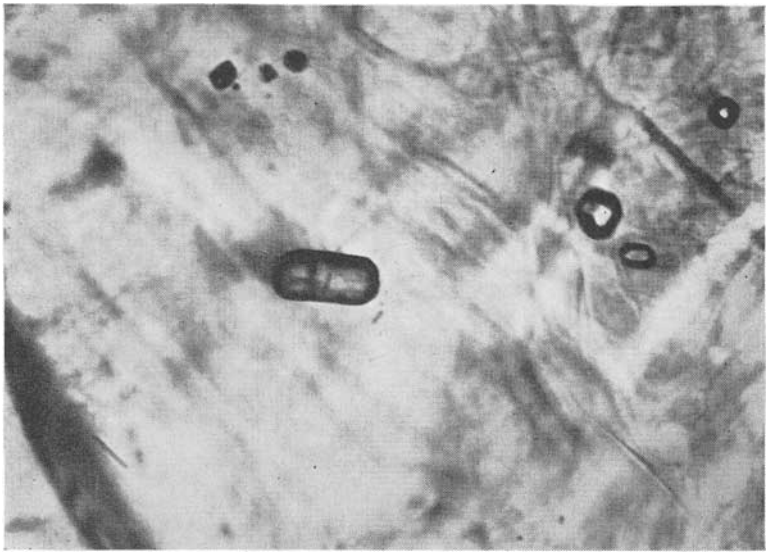

Fig. 60. Typical swirl-marks in hessonite as a result of incomplete un-mixing. 75 ×.

As can be seen from the above explanations, a new classification for gemstone inclusions has been established, distinguishing between primary and secondary inclusions. Primary inclusions can be divided into autogenetic and xenogenetic inclusions and examples are mentioned. The secondary inclusions are those which were formed during a secondary phase, or after completion of the crystal growth. Most liquid secondary inclusions are healing fissures which are either completely or partly healed cracks, or were still in the state of healing when the gem was extracted from the mother earth. Solid secondary inclusions are frequently formed by the process of exsolution, which has also been briefly explained. Further studies must confirm the correctness of this classification and it is hoped that future investigations will yield increasing and valuable knowledge on the genesis of inclusions and their hosts.

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Lit. 1. George Laemmlein. *Sekundaere Fluessigkeitseinschluesse in Mineralien*, Z.f.Krist.Bd. 71, Heft 3, p. 237 ff.

Lit. 2. A. E. Fersmann. *Sur la Nature des Cristaux de Quartz des Rochers Porphyriques.* Bulletin acad. St. Petersbourg, Serie 6, Vol. 7, 1913.

Lit. 3. K. Schlossmacher. *Das Einschlussbild der Edeltopase*—Christa Hegel and K. Schlossmacher, in Zeitschrift der Deutschen Gesellschaft für Edelsteinkunde, Heft 14, Winter 1955/1956.

Lit. 4. R. K. Mitchell. "*Bloodshot*" *Iolite*, in The Gemmologist 1955, p. 110.

Lit. 5. E. H. Rutland. *Inclusions in Iolite* (Letter to the Editor), in The Gemmologist, 1953, p. 51.

Lit. 6. R. Webster. *Inclusions in Yellow Chrysoberyl*, in Gems and Gemology, Fall 1953, p. 343.

ASSOCIATION NOTICES

GIFTS TO THE ASSOCIATION

The Council of the Association acknowledges with gratitude the following gifts : from Mr. A. J. Breebaart, F.G.A., of Nijmegen, Netherlands, a cabochon cut synthetic spinel with the appearance of moonstone ; *Das Reich der gesteine*, by Karl Kruger (anonymously) ; and from Mr. R. Webster, Encyclopedia of Gems by H. E. Briggs, Introductory Gemology, by V. Hinton and the donor, and a specimen of Aragonite (var. Flosferri) from the Organ Mts., New Mexico.

PRESENTATION OF AWARDS

The presentation of the awards gained in the 1956 examinations in gemmology took place at Goldsmiths' Hall, Foster Lane, London, E.C.2, on 3rd October. The Chairman of the Association, Mr. F. H. Knowles-Brown, presided and welcomed members and their friends. He specially welcomed Mr. Malcolm Stevenson of Adelaide, Australia. Mr. Stevenson was a Fellow of the Association and had been active in the formation of the Gemmological Association of Australia in 1947, and was now President of the South Australian Branch of that organization.

Mr. B. W. Anderson presented the prizes to the successful candidates and asked Mr. Stevenson to accept the Tully Medal on behalf of Mr. Percy George Marks, of Sydney, Australia. It was the first occasion that the Association's highest award had been won by an Australian.

Mr. Stevenson, in accepting the award, spoke briefly of the work of the Australian Association and said that he would convey greetings to the members of his organization from the British gemmologists.

The Vice-Chairman, Mr. Norman Harper, thanked Mr. Anderson for presenting the awards.

Afterwards members and visitors inspected an exhibition of silver work that had been arranged in an adjacent room by the Worshipful Company of Goldsmiths.

A list of successful candidates was given in the October, 1956, issue of the *Journal* (Vol. 5, No. 8).

MIDLANDS BRANCH

The fourth annual general meeting of the Midlands Branch of the Association was held on 4th October, 1956, at the Auctioneers' and Estate Agents' Institute, Birmingham.

Mr. Trevor Solomon was elected to serve as Chairman for a fifth year and Mr. A. E. Shipton was re-elected as Secretary. The following were elected to the Committee : Miss J. Rice, Miss E. Padbury, Mr. D. King, Mr. B. Leng, Mr. W. Bowen.

A presentation was made to Mr. Norman Harper by the students of the Branch, on the occasion of his resignation as senior lecturer in gemmology at the Birmingham Jewellers' School.

TALKS BY MEMBERS

KING, R. F.: "Fakes and Mistakes," to Nottingham Business and Professional Women's Association, 12th December, 1956.

MELROSE, R. A. : "Diamonds and Diamond Cutting," Durham Rotary Club, 26th September, 1956 ; "Colour and Gem Stones," Newcastle-upon-Tyne Inner Wheel, 1st October, 1956 ; "The Story of Diamonds," Houghton-le-Spring Rotary Club, 3rd October, 1956.

WARREN, KATHLEEN G. : "Gemstones," to Baptist Women's Fellowship, Bromley, 12th October, 1956.

WEBB, MALCOLM H. : "Gems," to Rochester Church Women's Guild, 6th November, 1956,

MEMBERS' MEETINGS

A meeting of members will be held at Saint Dunstan's House, London, E.C.2, on Friday, 1st February, 1957, at 6.45 p.m., for an "Any Questions" evening.

The twenty-seventh Annual General Meeting of the Association will be held at Goldsmiths' Hall, Foster Lane, London, E.C.2, on Friday, 15th March, 1957, at 6.30 p.m.

The President of the Association, Sir Lawrence Bragg, F.R.S., has kindly consented to give the Herbert Smith Memorial Lecture at the Royal Institution on Wednesday, 3rd April, 1957. Sir Lawrence will be speaking about the atomic patterns of gemstones and other minerals.

BRITISH MUSEUM (NATURAL HISTORY)

Lectures in the MINERAL GALLERY on Saturdays at 3 p.m.

JAN.	26th	Gemstones made by man	Dr. G. F. Claringbull
FEB.	2nd	Minerals in everyday life	Mr. P. G. Embrey
	9th	Compressed rocks	Dr. G. H. Francis
	16th	Meteorites III : Glass meteorites ...	Dr. M. H. Hey
	23rd	What are crystals ?	Dr. A. A. Moss
MAR.	2nd	How to take care of minerals ...	Miss J. M. Sweet
	9th	Radioactivity of the deep-sea... ...	Dr. J. D. H. Wiseman
	16th	Diamond and graphite	Dr. A. A. Moss
	23rd	Magnetic minerals and rock magnetism	Dr. G. F. Claringbull
	30th	How crystals grow	Mr. P. G. Embrey
APR.	6th	Baked rocks	Dr. G. H. Francis
	13th	Meteorite craters	Dr. M. H. Hey
	20th	Mineral fakes	Miss J. M. Sweet
	27th	The structure of silicate minerals ...	Dr. A. A. Moss

THIS PROGRAMME IS SUBJECT TO ALTERATION

COUNCIL MEETING

At a meeting of the Council of the Association held at Saint Dunstan's House, Carey Lane, London, E.C.2, on 30th October, 1956, the following were elected to membership :

FELLOWSHIP

Anderson, Arne T., Tonsberg, Norway.
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Messenger, Shirley J., St. Albans
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Morgan-Smith, John, London
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Muscat, Bernhard, Johannesburg, S.A.
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Peters, Brian L., Camberley
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Stanoyev, William N., Regina, Canada

PROBATIONARY MEMBERSHIP

Horton, Anthony, London
Hatcher, June Ann, Birmingham

CONVERSAZIONE AND EXHIBITION

Well over 200 members and their friends attended a Conversazione, held at Goldsmiths' Hall on 28th November, 1956.

It was a most successful evening and in addition to demonstrations a small exhibition had been arranged. A central feature showed literature, minerals, gems and instruments associated with the gemmological organizations in Australia, Brazil, Germany, Great Britain, Norway, Switzerland and the United States of America.

Mr. B. W. Anderson demonstrated the immersion contact of gemstones by using the comparative refractive index of stones in a fluid of known refractive index. Another impressive demonstration was arranged by Messrs. H. Lee and D. Hill who showed samples of the materials used by nature in the formation of minerals. A skilful synthesis of what happened in nature was demonstrated alongside. A display of apparatus and photographs telling of the synthesizing of quartz, rutile, corundum and spinel was arranged by the Research Laboratories of the General Electric Company Limited. Some twenty minerals were displayed under ultra-violet light and visitors were invited to identify the specimens and their provenance.

Around the hall were show cases of various rough and cut gems and gem minerals and a display of photographs from some of the larger exhibitions arranged by the Association. Of interest, too, was a Bill of Lading, dated 1756, for the shipment of corals to Fort St. George, and the oil portrait painting of the late Dr. G. F. Herbert Smith.

The Council of the Association is indebted to many people for the success of the evening and, apart from those who kindly arranged demonstrations and displays, acknowledges the help given by Messrs. Rayner & Keeler, Ltd., Drewell & Bradshaw, Ltd., W. Stern, E. H. Rutland, B. Silver, A. E. Farn, Mrs. T. H. Bevis-Smith and the Gemological Institute of America. The Council is specially grateful to Miss E. Ruff, Mr. T. H. Bevis-Smith and Mr. R. Webster, who comprised a Committee which arranged the whole programme and staged most of the exhibits, and to the Wardens of the Worshipful Company of Goldsmiths for kindly placing the Livery Hall and other rooms at the disposal of the Association.

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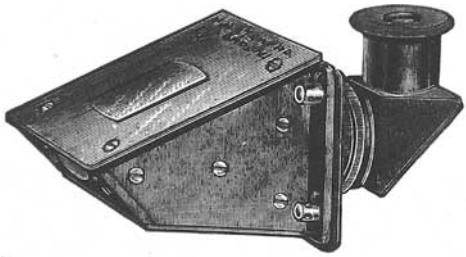

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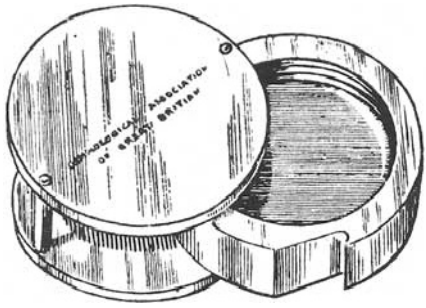

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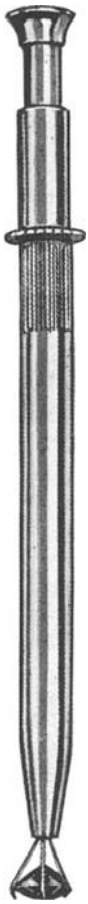

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No. 1
January, 1957

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Vol. VI No. 2 April, 1957

THE JOURNAL OF GEMMOLOGY

and

PROCEEDINGS OF THE
GEMMOLOGICAL
ASSOCIATION
OF GREAT BRITAIN

GEMMOLOGICAL ASSOCIATION
OF GREAT BRITAIN
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THE JOURNAL OF GEMMOLOGY
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Vol. VI No. 2 APRIL 1957

CHROMIUM AS COLOURING AGENT IN PRECIOUS STONES

by K. F. CHUDOBA

COLOUR is the most obvious of the physical properties of precious stones. In many cases it is of significant importance not only for their recognition and determination, but also for value.

The pleasure given by a coloured stone is frequently connected with the problem of the cause of its colour. Mostly it is difficult to find a well-founded answer because the merely visual appearance of a peculiar colour may depend on a variety of different factors.

Naturally progress in science will have its effect on the understanding of the causes of colour in general and of chromium as colouring agent of precious stones in particular. The latter problem will be discussed shortly in this paper.

Of general importance is the fact that most precious stones are colourless when they are chemically pure. Their coloured varieties contain small quantities or even only traces of additional elements which are of no importance whatever for the chemical composition of the precious stone. The significance of these " impurities " was at first completely unknown. When, however, always the same

trace elements turned up in certain colour varieties, it became highly probable that these colours owed their existence to the "added impurities." This supposition was proved to be correct, especially when different coloured stones were synthesized. In these syntheses, the typical colour could be obtained by adding those trace elements which were found in the corresponding natural crystals.

The clearest case of a connexion between a colour and a trace element exists for the element chromium, which was discovered in the year 1797 by L. N. Vauquelin in the mineral crocoite—$PbCrO_4$. It became likely that chromium was a colouring agent, when M. H. Klaproth in the year 1802 determined analytically 0·30% Cr_2O_3 in Muzo emerald. In due course the number of precious stones presumably coloured by chromium grew considerably. Contributory causes of the discoveries were improvements in chemical analysis and especially the development of different spectroscopical methods, which show the presence of even very small elements of a trace elements.

Surprising is the fact that precious stones coloured by chromium may be either red or green as shown in the following table.

TABLE I

PRECIOUS STONES COLOURED BY CHROMIUM

Precious stone	*Chemical composition*	*Cr_2O_3 content*
A. RED GROUP		
Ruby { natural, synthetic }	$(Al\ cr)_2O_3$	mostly trace; up to 2%
Red Spinel { natural, synthetic }	$Mg(Al\ cr)_2O_4$	mostly trace; up to 2%
Pyrope	$Mg_3(Al\ cr)_2Si_3O_{12}$	0·25–3·00%
Pink Topaz	$(Al\ cr)_2SiO_4(OH\ F)_2$	trace
B. GREEN GROUP		
Emerald { natural, synthetic }	$Be_3(Al\ cr)_2Si_6O_{18}$	traces to 0·30%; up to 1%
Spinel, synthetic	$Mg(Al\ cr)_2O_4$ + gamma Al_2O_3	up to 1%
Alexandrite	$Be(Al\ cr)_2O_4$	trace to 0·34%
Hiddenite	$Li(Al\ cr)\ Si_2O_3$	trace to 0·2%
Demantoid	$Ca_3(Fe\ Al\ cr)_2Si_3O_{12}$	up to 1·36%
Euclase	$Be(Al\ cr)SiO_4OH$	trace
Chrome diopside	$(Mg\ cr)CaSi_2O_6$	up to 2·12%
Chrome enstatite	$(Mg\ cr)SiO_3$	up to 0·95%
Chrome vesuvianite	$Ca_{10}(Mg\ Fe\ Fe)_2(Al\ cr)_4Si_9O_4(OH)_4$	trace
Jadeite	$Na(Al\ cr)Si_2O_6$	trace to ~ 0·01%

Some of the precious stones mentioned in Table 1 contain not only traces of chromium, but appreciable quantities. The table corresponds roughly with a survey by E. J. Gubelin[1] based on extensive investigations by B. W. Anderson and C. J. Payne.[2] In some instances the correct name of the precious stone depends on the identifiable presence of chromium. A green beryl which does not contain a trace of chromium is not considered to be an emerald. An example is the green gem beryl of Vinnietharra, Western Australia. Alexandrite, too, deserves its name only if the colouring agent is chromium. The same is true in the case of hiddenite and pyrope.

The most conclusive proof that chromium as a colouring agent produces red as well as green gem varieties is the fact that both synthetic ruby and synthetic emerald owe their typical colour to a corresponding addition of chromium. The content of the colouring element, however, is considerably higher in the synthetics than in natural ruby or emerald, as can be seen in Table 1.

Further proof for the colouring effect of chromium is the relation between chromium content and colour intensity. With increasing chromium content the colour of some precious stones becomes appreciably deeper.

Stones not listed in Table I may occasionally also contain chromium, such as the deep olive-green peridot (Hawaii, 0·14% Cr_2O_3) ; the brownish-green sphene of some occurrences in Finland and California (0·01 to 0·64%) ; the dark to black-green tourmaline from the chromium iron deposits of the Urals (occasionally several per cent Cr_2O_3) ; the delicate green nephrite, especially fine qualities (traces of Cr_2O_3). These stones, however, are of a green or greenish colour also if no chromium content can be determined. This shows, as has been recognized for a long time, that not only chromium but other elements as well can cause green tints. Bivalent iron is considered the main colouring agent in green beryls, tourmalines and peridots, whereas combined addition of bivalent and trivalent iron (Fe^{II} and Fe^{III}) is supposed to produce the colour in aquamarine and green apatite. Nickel is the colouring agent in green chrysoprase.

In this connexion the question arises : What importance should be attributed to the chromium if other colouring agents are present as well? Spectroscopically several trace elements are usually found in one precious stone. Previous investigations are not always

convincing. Georg O. Wild and R. Klemm[3] found that chromium and vanadium together are probably responsible for the yellow green colour of hiddenite. Esther W. Claffy[4] doubts whether the addition of vanadium has an influence on the colour of chromium-tinted hiddenite. Controversies of this kind are quite frequent because a definite proof, through synthesis for example, is lacking. Even synthesis does not remove all doubts because to the eye the same colour can be produced in a synthetic stone by adding different metal oxides to the colourless crystal material. Thus the usual aquamarine-coloured spinel owes its colour to an addition of chromium and cobalt oxides. A second, rarer variety of visually the same colour is made by the addition of cobalt and titanium oxides.[5]

Of interest also is the question whether diamond is coloured by chromium, which has been found several times as trace element in this precious stone by Frank G. Chesley.[6] From this paper Table II has been extracted :

TABLE II

Diamond occurrence	*Cr content*	*Colour*
Angola	little	colourless
	trace	white
Congo	very little	pale yellowish
Brazil	trace	very pale yellowish

A relation between colour and chromium content cannot be deduced from these sparse indications. For diamond, only iron and titanium are likely to have a recognizable effect on the colour. In any case, the presence of a certain element, such as chromium, is in itself no cogent reason to consider it to be the cause of the colour in precious stones.

So far it has become obvious that the colouring effect of chromium in precious stones is of " bichromatic " nature, i.e. chromium causes either a green or a red colour in allochromatic stones (as opposed to idiochromatic stones, which owe their colour to the substance of the stone itself, for instance malachite). Emerald-green and ruby-red are the outstanding colour tints. An exception seems to be the chromium-containing disthene (kyanite), which according to several statements is blue.

The presence of chromium as colouring agent in several precious stones leads logically to two essential questions : (1) How is the chromium disposed in the lattice of the host crystal ?

(2) Why does chromium cause either a red or a green colour—what is the cause of the bichromatic effect of chromium on the colourless substance of precious stones ?

In answering the first question, it seems of importance to point out that microscopic and ultra-microscopic investigations show that chromium-coloured stones appear to be completely homogeneous, i.e. quite uniform. Neither pigments nor other colloidally distributed colouring matter can be observed. Chromium must have been received sub-microscopically by the precious stone, in a way that led to a homogeneous solid solution.

This solid solution must be of a special kind because precious stones are crystals with a regular inner architecture. The building blocks fall with their effective centres forming a regular pattern in the three dimensions called a lattice, which can be expressed by shape and size of a single unit cell (see Fig. 1).[7]

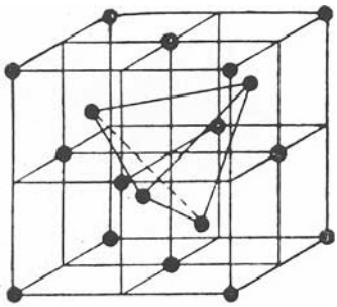

Fig. 1. Unit cell of diamond

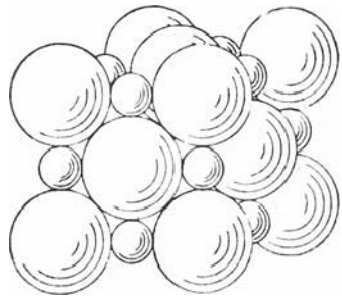

Fig. 2. Arrangement of ionic spheres in sodium chloride crystal (big spheres, chlorine ; small spheres, sodium)

In a lattice it is essential that the individual building blocks—being point charges—comprise an " electric field," which as a first assumption is considered to be spherical. These spherical fields are of different dimensions for different atoms and ions and can be expressed by the so-called atomic and ionic radii (Fig. 2). In this connexion the fact is of fundamental importance that a chemical building block of a lattice can be replaced by others, if they correspond closely in shape and size. Just as clay bricks in a wall can

be replaced by glass bricks of the same size and shape, is it possible to replace chemical building blocks in precious stones by very similar ones, provided there is an inner regular array of the building blocks, i.e. provided the stone is in its crystalline state?

A replacement of an element by one of similar shape (isomorphous replacement) is possible if in the first instance the ionic radii are practically of the same size. In this connexion the simplified assumption of ionic spheres building up a chemical composition is of some importance.

A search for an element in chromium-coloured precious stones which in accordance with its ionic radius can be replaced by chromium ions reveals that only aluminium ions fulfil this condition. (In the case of ruby, aluminium only is available.) Chromium and aluminium ionic radii have only approximately the same size, namely $Al^{3+} = 0{\cdot}57$Å, $Cr^{3+} = 0{\cdot}64$Å. Not all precious stones, however, in which chromium has been detected, contain aluminium which could be replaced by colour-giving chromium. In Table 1 chrome diopside and chrome enstatite are mentioned, which do not contain aluminium. Sphene, too, which may contain chromium, is free of aluminium. Which element in the crystal lattice of these precious stones can be replaced by chromium? The element magnesium must not be overlooked. Its ionic radius has been determined to be 0·65Å and thus corresponds nearly exactly with that of chromium. It is true that magnesium has a positive bivalency (chromium is trivalent), but this is not a determining factor. The univalent sodium, too, with an ionic radius of 0·97Å is very often isomorphously replaced in various minerals by the bivalent calcium with an ionic radius of 0·99Å. An analogy is therefore given, even if on a different valency level, for chromium and magnesium. The latter element is an essential component of both chrome diopside and chrome enstatite. In sphene, titanium plays an important role. An isomorphous replacement of the tetrad titanium with an ionic radius of 0·68Å by the chromium ion (radius 0·64Å) is not only possible but practically certain. These examples show that the colouring agent chromium cannot replace Al only in a solid solution, but also the elements Mg and Ti. If not only precious stones were dealt with, but minerals in general, other elements would have to be mentioned which are replaced isomorphously by chromium.

A few explanations are given to answer the second question : Why does chromium as colouring agent cause either a red or a green colour ?

A red colour caused by chromium seems peculiar, because chromium oxide (Cr_2O_3) is green, just as most precious stones or minerals which are coloured by it. Why colourless matter should turn red through addition of a little deep-green chromium oxide is still an unsolved problem. Some explanations and interpretations do, however, exist.

It seems proved and often confirmed that the *quantity* of the colouring chromium may be decisive for the red or green colour of the precious stone. Thus it is known that the chromium in ruby powder causes occasionally a green zone near the lower part of the boule around the supporting clay rod of the furnace. On top of the green zone a pale pink sinter cone rises from which grows the deep red ruby. The green parts have an exceptionally high chromium content. According to E. Thilo[8] mixed crystals of Al_2O_3 and Cr_2O_3 are red up to a chromium content of 8%. With increasing chromium content they become at first reddish-grey, then red-green and finally from 30 atoms per cent of chromium onwards pure green.

This result is of importance. It means that a ruby-red boule can be expected only up to an addition of 8 atoms per cent of chromium to Al_2O_3.

The mixed crystals of spinel, too, have according to Thilo and collaborators[9] a red colour if small quantities of chromium are added and a green colour if greater amounts are present. In this case ($Mg\ Al_2O_4 + Cr_2O_3$) the dividing line red/green lies at about 15 atoms per cent of chromium. It must be mentioned, however, that special observations were made on synthetic spinel produced by the Verneuil process. It is important that red spinels are obtained only when chromium oxide as a colouring agent is added to an equimolecular mixture of MgO and Al_2O_3 (Ratio 1 : 1). Investigations of F. Rinne[10] show, however, that all synthetic spinels are mixed crystals of $Mg\ Al_2O_4$ of the cubic, unstable, gamma modification with a surplus of Al_2O_3 in relation to MgO (Ratio 5 : 1). It must be noticed that with these synthetic mixed crystals an addition of Cr_2O_3 produces never red but always green boules. Only above 1075°C., when the gamma modification

Al_2O_3 is transformed into the trigonal alpha Al_2O_3 modification, does the colour change from green to red.

A colour change through heating is also observed in ruby which becomes green between 300 and 600°C. On cooling it reverts to its original red colour. By a reverse process, at lower temperatures, green mixed crystals adopt a colour similar to ruby. With rising temperature they revert to the original green tint.

How can these observations be explained ? A conclusion reached by Thilo is worth noting. Up to an addition of 8 atoms per cent Cr in the (Al_2O_3—Cr_2O_3) mixed crystals, the chromium is screened off by the oxygen and aluminium ions of the corundum lattice in such a way that the chromium ions cannot contact each other. They remain genuine trivalent ions, and these cause the red colour in ruby. Above 8 atoms per cent chromium, there occur not only a " lattice expansion " but according to Thilo also contacts of chromium with chromium within the lattice, causing in parts a metallic bond (?). This would then result in a green colour. These explanations help also in the understanding of the red-green and green-red colour-changes through heating or cooling. Normally the chromium ions in rubies are in fixed positions and separated from each other. With rising temperatures the chromium ions become mobile. Thus, at least in parts, ions with metallic bonds are formed. These cause the green colour. On the other hand, green corundums are supposed to possess at room temperature freely moving metallic chromium ions, which become immobile and fixed at lower temperatures. Thus corundums originally green can become ruby-red. With rising temperature the original state is reached and the colour reverts to green.

The theories discussed seem clear and plausible, but reservations must be put forward. The normal colour of the Cr^{3+}ion is not red, as stated by Thilo, but green. The red colour may be caused by the character of the crystal field, the relative strength of which depends on the atomic distance (i.e. on lattice expansion and contraction). This opinion is based on theoretical and experimental investigations of W. Feitknecht.[11] He showed that a colour-change from red to blue was due to a transformation from a co-ordination number of 6 to a co-ordination number of 4 Co (II) which caused a contraction of the atomic distance Co – O in the lattice, a deformation of the ions, etc. Similar colour-changes were demonstrated by O. Schmitz-Du Mont[12] when the crystal field

was weakened through an expansion of the spinel lattice (i.e. the atomic distance Co – O). In this case Al was successfully replaced by Ga. It seems reasonable therefore to attribute the peculiar colour-change of several chromium-containing precious stones during heating or cooling to a weakening or strengthening of the crystal field through lattice expansion or contraction.

The available experimental results are sparse, but they make the conclusions indicated at least probable.

The lattice expansion from pure corundum ($a_{hex} = 4{\cdot}76$Å) to green corundum with 30 atoms per cent chromium content ($a_{hex} = 4{\cdot}78$Å) can be measured, although the difference of 0·02Å is quite small.

In the case of the synthetic spinels, which according to Thilo showed a red/green dividing line at 15 atoms per cent chromium, no statements about changes in the lattice were made in the paper. For synthetic " boules," however, it is of importance that a change in the lattice is caused by a surplus of Al^{3+} replacing Mg^{2+}. Thus Rinne determined for $MgO{\cdot}Al_2O_3$ a lattice distance of a_w 8·02Å. The same distance for $MgO{\cdot}3Al_2O_3$ was 7·96Å. This lattice contraction seems to lead to changes in the relative strength of the crystal field and thus is connected with the red/green colour-change.

The lattice changes for the colour varieties (of garnet), namely pyrope, demantoid and uvarovite (Table III) can be shown more clearly. The chemical analogy (with the above phenomena) is striking, especially in the cases of pyrope and demantoid.

TABLE III

Colour variety	*Chemical composition*	*Cr_2O_3 content*	*Colour*	*a_w*
Pyrope	$Mg_3(Al\ Fe\ cr)_2Si_3O_{12}$	0·25–3%	red	11·51Å
Demantoid	$Ca_3(Fe\ Al\ cr)_2Si_3O_{12}$	up to 1·3%	green	?
Uvarovite	$Ca_3(cr\ Al)_2Si_3O_{12}$	6·5–27·5%	emerald-green	11·95Å

In these two colour varieties the chromium content is about the same, and the Fe_2O_3 contents too agree remarkably well according to chemical analyses. The only difference seems to point to the R^{II} element, being magnesium in the case of pyrope, and calcium in the cases of demantoid and uvarovite. The big lattice expansion of 0·44Å (from 11·51 to 11·95Å, Table III) is surely caused by the difference in size of the ionic radii of Mg^{2+} (0·65 – 0·78Å) and Ca^{2+} (0·99 or 1·06Å) and not through the replacement of Al^{3+} by Cr^{3+}. Thus an indirect change of the atomic distance is caused and

with it a difference in the relative strength of the crystal field for the Al^{3+} or Cr^{3+} ions respectively. These differences seem to be connected with the colours in the various garnets.

SYNOPSIS

All chromatic precious stones with chromium as colouring agent (Table 1) are predominantly green, otherwise red. It is not certain yet what role can be attributed to chromium if other colouring elements are present as well in precious stones. This applies to diamond as well (Table II). Speculations on the cause of the red or green colour in chromium-coloured precious stones are based in the first instance on observations relating to ruby and red spinel. Both precious stones change from red to green with increasing chromium content and also with increased temperature. Synthetic spinels (boules), however, are red only when the ratio $MgO : Al_2O_3$ is equimolecular. A surplus of Al_2O_3 causes a green colour.

According to Thilo this phenomenon is due to an exchange effect between the Cr^3 ions, because the Cr^3 ion is in undisturbed (crystal) state only if the colour appears to be red.

Based on the papers of Feinknecht and Schmitz-Du Mont, the conclusion is reached that the bichromatic (red/green) effect of chromium as a colouring agent is connected probably in the first instance with the relative strength of the crystal field. Speculations in this direction deal especially with the colour varieties of garnet—pyrope and demantoid (and uvarovite).

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ARKANSAS DIAMONDS

By HUGH LEIPER, F.G.A.

EARLY in March, 1956, an accomplished amateur gem-cutter, Mrs. A. L. Parker, of Dallas, Texas, U.S.A., set out by car in the company of Dwight Halstead and his wife for a rock hunting expedition into East Texas. Along the way, Mr. Halstead, whose profession is the manufacture of commercial diamond tools, talked about the diamonds he had previously found at the peridotite dike near Murfreesboro, Arkansas—nineteen in all at that time. As the trip progressed toward their original " petrified-wood " destination, they were also getting closer to the diamond area. However, the fascination of finding a genuine diamond is something that gets in the blood, and when the party reached a crossroad point in the East Texas pines, where a right turn would take them on to the " petrified-wood " area, or a turn to the left and many more miles of driving would take them to Arkansas—the lure of the diamond won. Mrs. Parker had never been to the location before, so looked forward to the new experience.

Early the next morning, the party reached the so-called " Crater of Diamonds," as the 72 acres of diamond-bearing earth have been named by the operators, The Diamond Preserve of the United States, Inc. For a fee of $1·50 they were permitted to enter the sketchily-fenced area. According to the rules, they could dig with anything they could carry by hand, and were entitled to keep any gem of 5 carats or less which they might find. If a stone larger than 5 carats should be found, a royalty of one-fourth of its appraised value would be payable to the owners of the property. The " finds " had been averaging about twenty to thirty a month, all of small sizes—fractional carat to 1·87 cts. As a tourist attraction, even with the lure of finding a diamond, the " Crater " wasn't exactly making anyone wealthy. Hundreds came, and went away —with nothing.

Walking into the sun, so that the slanting rays might be reflected into their eyes from any scintillating pebble ahead of them, the three members of the party went their own way over the partly-ploughed and often-picked-over pasture. Some time went by without anything being found, and finally Mrs. Parker turned back toward where a thermos-bottle of coffee had been left at the foot of a tree. Hardly had she started, when a glint of light from some

white-coated object approximately 25 feet away caught her eye. Without undue excitement she advanced and picked the object up. Then it dawned on her that she was holding in her hand a large flat oddly-shaped piece which had all the ear-marks of a diamond. She had seen the smaller crystals Mr. Halstead had found on previous trips. She also had enough experience with gems from her own hobby-work with them to appreciate what a diamond should look like in the rough. But this piece she held in her hand was over one and one-half inches long and approximately seven-sixteenth inch wide, by about one-fourth inch deep.

She returned to her companions with her prize, and then the excitement began, for they assured her it was indeed a diamond. When cleaned of the superficial coating and weighed, it tipped the scale at 15·31 carats, but what was even more important, it was pronounced a water-white diamond of finest clarity and quality—probably the finest ever found on the North American continent.

After the stone had been exhibited in Little Rock, state capital of Arkansas, and named " The Star of Arkansas " by Governor Faubus, it was taken to Dallas, Texas, where it was shown in the uncut state in the window of a leading jeweller of the city. It was then forwarded to New York, where it was entrusted to Mr. Harold Branch, president of the firm of Schenck & Van Haelen, for cutting. This firm had made a speciality of Arkansas diamonds, having to its credit the cutting of the " Uncle Sam," an original 40·23 carat stone found at the Murfreesboro mine in 1924, which yielded a pinkish stone of 14·24 carats, emerald-cut. They had also cut the 20·25 ct stone, an octahedron, found in 1921, which was cleaved and made into two fine gems.

It was determined that the gem was a single crystal entity, though of very unusual shape ; that it had some very unusual markings on its surface and that it was of unusual hardness. It was not fluorescent. Dr. Ralph J. Holmes, of Columbia University, is preparing a report on the stone's structure and markings. The electron micrographs (Figs. 3 and 4) show the unique " squid-like " markings revealed by magnification at 6,700 and 10,200 diameters.

It was decided to fashion the gem into a marquise-shape. Attempts at bruting it into this outline soon showed difficulties, for " nats " or super-hard spots caused the carbonado or tool-diamond that was used to bring about the reduction to shape

to erode at a ratio of 8 carats to one of weight lost by the gemstone. For days it seemed that little or no progress was being made, but eventually it yielded to the cutter's persistence and was shaped to form. From that point on, the diamond " cut itself " with little further trouble. Divisions of twelve rather than eight facets were used, and due to the unusual shallowness of the stone as found, additional small facets in the culet area were found necessary.

The finished gem preserved the original dimensions of the crystal remarkably, and is 1½ inch by 7/16 inch in size, and has the spread and appearance of a 15-carat gem. The finished weight is 8·27 carats. The gem is so brilliant that it is very hard to make out the outline of the table, and there is no dead spot, as might be expected in so shallow a stone. The " Star of Arkansas " is truly a thing of beauty. The owner does not intend to have it mounted but prefers that it remain as an exhibition piece, and it is expected that it will be sent to various places in the United States for showing in jeweller's windows as an example of a quality all-American diamond. No attempt of any kind will be made to commercialize the owner's good fortune in finding such a gem, variously valued at from $25,000 upward.

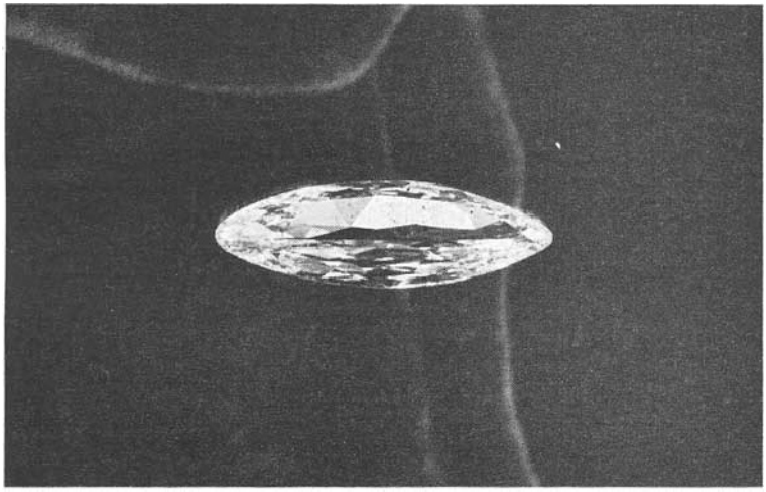

Fig. 1. The finished gem, " Star of Arkansas," 8·27 carat marquise-cut diamond, measuring 1½ inches × 7/16 inches.

(Photo, Courtesy Clint Grant, Dallas, Texas)

From the time just about fifty years before Mrs. Parker made her find at Murfreesboro, when John Wesley Huddleston, an Arkansas farmer, turned over the first crystal with his plough in the gravelly foothills of the Ouachita Mountain area of South-western Arkansas, the field has seen a kaleidoscopic turn-over of owners ; court proceedings over who owned what ; feuding and even the simultaneous burning of three separate recovery plants on various parts of the property ; mismanagement and what has been labelled outright looting from within and without. Approximately 10,000 diamonds have been registered with the state authorities for tax purposes in these fifty years since its discovery in 1906, but it is probable that five times that many diamonds have actually come out of the ground there.

The first finder, Huddleston, sent his shining pebble to Chas. S. Stifft Co. in Little Rock, for identification and was not disappointed. A local banker joined Mr. Stifft in forming the Arkansas Diamond Co. and they bought out Huddleston's 160 acres for $36,000, but the new company lacked capital properly to pursue mining and drifted along for some years. Then the banker, Sam W. Reyburn, was able to attract additional capital. The company was then reincorporated as The Arkansas Diamond Corporation of Virginia. More modern recovery equipment was procured for washing and separating the gem gravel, and a plant was built. However, operations were not a success financially, as although a considerable number of diamonds were recovered pilferage was high. The area was not tightly fenced, and it is no secret that local residents of the area could and did make a tidy income from marketing their own chance finds. The engineer in charge had no previous diamond experience, but the owners attempted to remedy their poor start by sending him to South Africa to try to learn more about the art of recovering diamonds—and keeping them. However, shortly after his return, the big plant was shut down, never to run again. It was later burned to the ground at night under suspicious circumstances.

Meanwhile, two other segments of the diamond-bearing kimberlite were under the ownership of M. M. Mauney, who leased a portion of this land to Austin Millar and his son Howard.

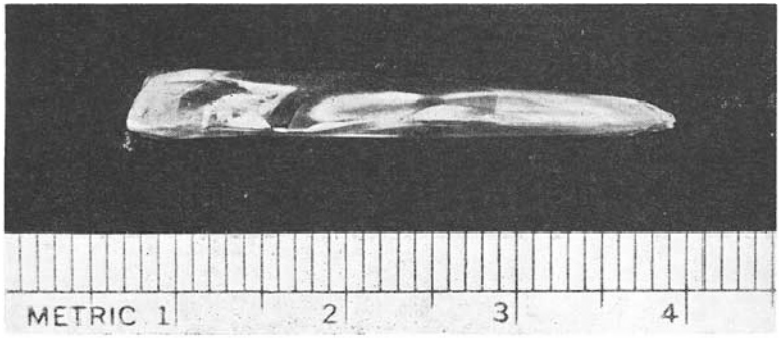

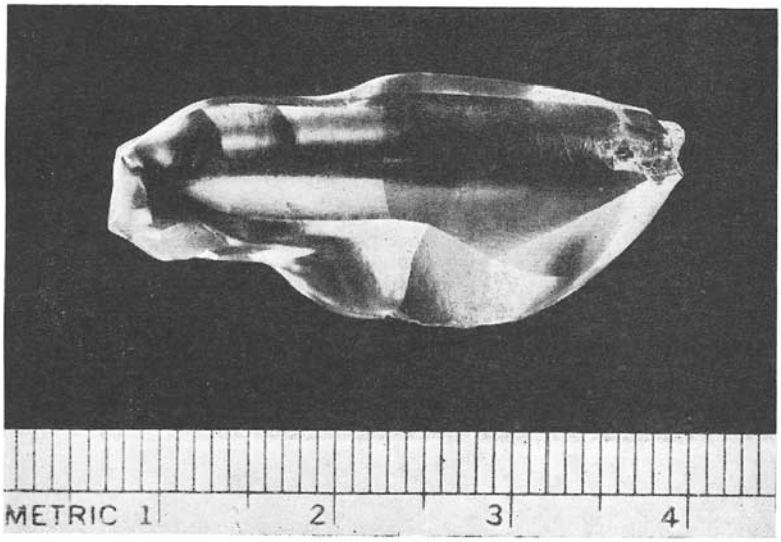

Fig. 2 and 3. Frontal and edgewise view. "The Star of Arkansas," 15·31 carat diamond crystal found at the "Crater of Diamonds," Murfreesboro, Ark., by Mrs. A. L. Parker of Dallas, Texas. Photographs by Dr. Ralph J. Holmes, Columbia University, New York.

The Millars knew how to extract diamonds successfully, but they did not get on well with the Mauneys, and disagreement ensued, with court battle after battle. Then the Millars bought a portion of the property themselves, and attempted to run this ore through the mill they had erected on the leased Mauney ground. More litigation and even shooting resulted. Attorneys were the only persons who profited.

Finally, the Arkansas Diamond Corporation of Virginia sold out to a promoter, Ray Blick, for $175,000 in 1941, but it later developed that most of this money had been put up by a Logansport, Indiana, manufacturer, the late Charles Wilkinson, whose widow, Mrs. Ethel Wilkinson, now owns the larger portion of the property.

During World War II, the increased demand for industrial diamonds and the threat of interruption in production in portions of Africa, caused the Bureau of Mines of the United States Government to institute a small pilot plant study of the Murfreesboro area under a competent geologist. Begun in 1943 and completed in 1944, this sampling effort was completed in report form in 1947, but was not published until 1948, as Bulletin 808, Bureau of Mines. The results were extremely discouraging as the average findings of 0·03 carats per cubic yard did not seem to warrant commercial operations. There have been many interpretations and much criticism of the report, some believing that the samplings were not taken from true diamond-bearing kimberlite areas, or some in ground that had already been worked over. Others contend that nothing except superficial sampling has ever been undertaken, with the deepest shaft having penetrated only 136 feet. Suffice it to say that there is still room for considerable difference of opinion as to the possible future of the Murfreesboro area as a diamond producer of consequence.

Glenn L. Martin, an aircraft manufacturer who had become interested in diamonds, formed a corporation which leased the Williamson property, and purchased the remainder of the Mauney slice for $250,000. A recovery plant was set up and operations with surface earth-moving equipment were started in 1948, under the supervision of a former building contractor and liquor-store proprietor with no diamond-recovery experience. The work continued for about a year, but on tallying up the results of the expenditure of some $700,000, Mr. Martin was faced with a total find of 246·15 carats which were registered with the State of Arkansas.

Local residents, who had seen almost everything, realized that they had now seen the outstanding experience with the mine.

The facts are that even now, with tourists only scratching at the worked and re-worked surface, the annual recovery is almost as much as that yielded by the massive Martin machinery.

The Arkansas Diamond Area

The Arkansas diamond area, known as the Prairie Creek Area of Pike County, Arkansas, lies just below the confluence of Prairie Creek with the Little Missouri River. The property consists of 929 acres, more or less, lying North of the Little Missouri River and east of Prairie Creek. It covers parts of Sections 20, 21, 28 and 29, Township 8 south, range 25 west. The deposit itself has the shape of a rough equilateral triangle with well-rounded corners. The diameter is approximately 1,800 feet and the depth unknown. It covers slightly more than 72 acres. Before the area was mined, the surface was fairly level from east to west, but rose approximately 50 feet in a distance of 1,500 feet from

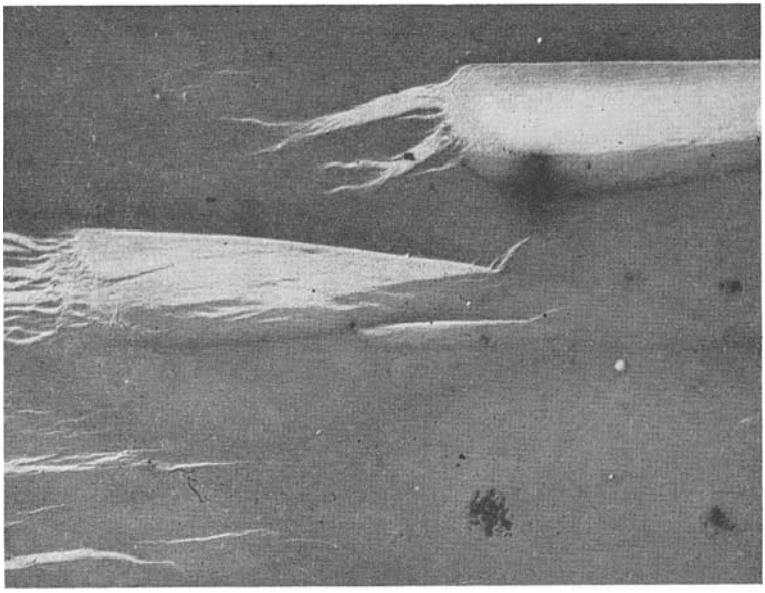

Fig. 4. Electron Micrograph by Dr. Ralph J. Holmes, Columbia University, New York, magnification 6,700 diameters, showing unusual " squid-like " markings on the surface of " The Star of Arkansas," 15·31 carat diamond found at the " Crater of Diamonds," Murfreesboro, Ark.

south to north. Present irregular contours and gullies are the result of former mining operations.

It is probable that the peridotite was intruded from a great depth, penetrating deep-seated sedimentary beds, including the Carboniferous and a portion of the Lower Cretaceous. After the intrusion of the peridotite, it seems apparent that explosions took place which ejected portions of the intruded mass and carried with them some deep-seated shale and sandstone. This ejected material probably formed a crater with sloping sides and also eventually re-cemented into a peridotite breccia. This brecciated area occurs in a roughly eliptical area covering about 28 acres on the east and south sides of the pipe. The old mine pit, covering about 15 acres, lies within this area. Several small dikes, from two inches to a foot wide, run in many directions. These contain barite, quartz and an asbestos-like material. Some garnets are found, as well as iron minerals, magnetite, perovskite, siderite and unaltered olivine. It is in this peridotite breccia that most of the diamonds are found. The tuffs and fine grained breccias are composed essentially of chlorite with phlogopite and serpentine. The colour is light blue. No diamonds have been reported found in them. There is one reported instance of a diamond having been found in the unaltered hypabyssal peridotite.

Other Occurrences of Diamond in North America

All other finds of diamonds in North America, other than those at the Arkansas mine, are the result of chance, are always in alluvial formations or as a by-product of placer-mining.

A broad belt of Northern border states, which were covered with glacial debris of the Ice Age, has produced an occasional find from creek gravels or while digging wells. These have been noted principally from Wisconsin, where several sizeable stones, notably two of approximately 19 and 13 carats, were brought up from wells ; others from Illinois, Michigan and Indiana.

In 1928, the " Punch Jones " diamond was found at Peterstown, W. Virginia, by a farm boy seeking water at a spring. This weighed 34·46 carats. Earlier in 1855, a negro workman digging an excavation in a street at Manchester, Virginia, came up with an octahedron of 23·75 carats which, however, was not of fine quality. Still another chance find was that of Mrs. Pellie Howard

of Searcy, Ark. While chopping cotton in a field with her father as a young girl, she picked up a shiny pebble and kept it for twenty-one years before realizing that she might have something valuable. Finally, in 1946, it was sent to Tiffany & Co., in New York and was declared to be a 27·21 carat diamond. This area is 150 miles from the Murfreesboro diamond pipe.

Early placer-mining operations in North Carolina turned up numerous small diamonds in the area of Burke, Rutherford, Lincoln and Mecklenburg Counties in the South-western portion of the state, and one instance in Franklin County, farther to the east. The first stone found was in 1843, and this was the first instance of a diamond being found in North America, so far as is known. A yellowish-white crystal found at Dysartville, McDowell Co., N.C., in 1886 weighed 4 1/3 carats, and is now a part of the Morgan Collection in the American Museum of Natural History, New York.

The gold-rush to California and other Western States in 1849, took with it placer-miners from the North Carolina and Georgia goldfields, who had likewise gotten to know what diamonds looked like in their sluice boxes. Hence, it was to be expected that a number of gem diamonds were found in California and Oregon gold operations during this period, but more certain that sizeable numbers were crushed in stamp mills breaking up the conglomerate ores—indeed, fragments of diamond embedded in the stamps have been noted.

The U.S. National Museum (Smithsonian), Washington, D.C., houses the Col. Washington A. Roebling collection of native American diamonds, which is regarded as the finest in the country. Not previously mentioned, it includes a solitary white octahedron from Huntsville, Texas.

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STRUCTURE & INCLUSIONS OF SYNTHETIC STAR-STONES

By A. J. BREEBAART, F.G.A., G.G.

THE microscopic study of the synthetic star-corundums, which are at present on the market, reveals some interesting features. The star-stones from the Linde Air Company, which appeared first, are first considered. It is known that the rough material is produced by the Verneuil process thus resulting in an ordinary boule, but to the chemical compounds is added a certain amount of titanium oxide. When the boule is taken from the furnace, it has to undergo a kind of annealing in order to make the added titanium oxide crystallize as oriented needles, because it is the presence of these needles which gives rise to the asterism.

It is quite reasonable that, these stones being products of boule-production, we shall meet the same kind of inclusions as in the ordinary synthetic rubies and sapphires. There are some distinct differences however. In the first place, naturally, there is the presence of the very fine oriented rutile needles ; these needles are short and thickly packed, whereas sometimes coarser crystals of (probably) rutile are seen. Air bubbles are almost always present in the form of clouds of tiny pin-points, but their general appearance is different from that in ordinary corundum. The bubbles are spherical and very small, and they are not so thickly packed as is generally the case in ordinary corundum. Lastly there is the presence of curved striae, which especially in the case of star-ruby is quite interesting. In ordinary synthetic ruby the striations are usually very fine and invisible to the naked eye, while in the star rubies these growth lines are easily visible, because they are comparatively widely separated.

The monopoly of synthetic star-stones, however, is no longer in the hands of the U.S.A. only, because star-stones of German manufacture are reaching the market in growing quantities. Although their method of production is not known to the writer, there must be some definite differences, compared with the American procedure, because the internal features of these stones are quite different. Naturally the oriented rutile needles are present too, but they are longer and coarser than in the American stones.

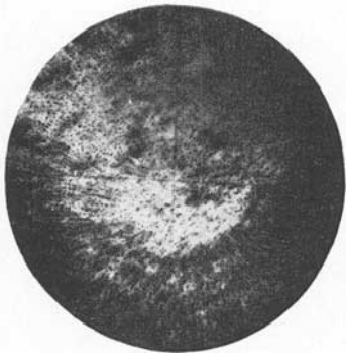

German Star Sapphire. 48 ×.
Air bubbles radiating from centre of stone.

Synth. American Star Ruby. 48 ×.
(dark field)
Curved striae with oriented straight bands meeting at an angle.

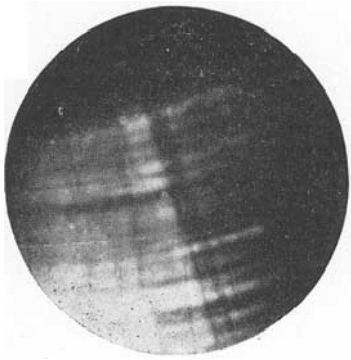

American Star Ruby. 48 ×.
(dark field)
Widely spread curved striae. Straight line running across probably twinning plane.

American Star Ruby. 48 ×.
Very fine rutile needles and tiny air bubbles. Lines visible probably internal fractures.

Air bubbles are present and their distribution in the stone is quite peculiar. In the German star-sapphires they are present as tiny pin-points throughout the whole stone, and it seems that they are in some way oriented, because they seem to be radiating out of the centre of the stone towards the girdle. In the star-rubies air bubbles are seen in a great many forms, from tiny pin-points to tadpole-shaped forms, whilst their orientation is circular. In both rubies and sapphires widely separated, probably rutile, needles

can be seen near the girdle of the stones, meeting at an angle corresponding with the angle between the crystal faces of the hexagonal system.

The position of these different inclusions is in layers, because when looking through a stone with the microscope, one, for instance, first has rutile needles in focus and on focusing down the air bubbles become visible.

There is a circular space in the stones, surrounded by air bubbles. This space is completely transparent and continues until about half way through the stone, where the rutile needles occur. Typical of the German stones is also the absence of curved striae. On the contrary growthlines will be seen, which are perfectly round and oriented as concentric bands. These bands are always visible and a round dark spot surrounded by concentric bands is an indication that the stone is of German origin.

COLOUR CHANGES IN IRRADIATED GEMSTONES

By E. BURBAGE, F.G.A., and THOROLD G. JONES, F.G.A.

WHEN, less than twelve years ago, the news of Hiroshima stunned the world, few could have guessed that the power hidden within the atom would soon be harnessed to the most various and unlikely tasks, from the re-creation of the primitive tulip for the plant geneticist, to the non-destructive analysis of the feldspars. Naturally, such projects as the preparation of tracer-isotopes for use in medicine have understandably received first priority treatment but it has recently become possible to find room and time for other researches of scientific and technical interest. One venture of interest to mineralogists, and in particular to gemmologists, has been the irradiation of coloured stones, and although very considerably more work is needed before anything like a survey of the field can be presented, it may be of interest to record a few notes by way of a preliminary report on work in progress.

The group of stones to be described have been shown, first at Harwell during Open Week last summer, and to the public for a period of about two months during the winter at the Educational Museum at Haslemere. At the instance of the Harwell Metallurgy Division, a range of pairs of stones was assembled, one member of each pair being irradiated by neutron bombardment for periods of three or of six days, and they were displayed for study and exhibition purposes with their untreated counterparts for comparison.

The following results were noted :—

Synthetic Corundum

Here, the most striking change was induced in a colourless boule which became brown in colour. There was strong dichroism, which was accentuated when the light transmitted through the boule was coloured by a cyan photographic filter. Viewed in a Stokes " crossed filters " apparatus, the irradiated boule fluoresced strongly, even though the apparatus, employing " narrow-cut " cyan and red filters, normally yields less brilliant results than the conventional copper-sulphate-solution set-up. It has been noted by B. W. Anderson[1] that some colourless boules fluoresce to some extent in such an apparatus, due to the presence of chromium impurities in the alumina, and it seems probable that the greatly enhanced fluorescence in the irradiated boule results from this cause. It is only fair to record that G.E.C., the synthesizers of the boule in question, claim an exceptional purity for the alumina in such colourless material but, as has been noted by Anderson, de Boisbaudron, as far back as 1886, showed that the presence of 1 part of chromic oxide in 10,000 of calcined alumina was sufficient to cause luminescence, and impurities on such a minute scale are perhaps within the tolerance limits in commercial chemical engineering.

A synthetic ruby boule became darker with some corresponding increase in dichroism, Here, the fluorescence in the Stokes apparatus was less than in its untreated counterpart. A pink synthetic sapphire originally strongly dichroic in yellow and pink, became brown, resembling a golden zircon in colour with little change in dichroism, but its Stokes apparatus fluorescence was diminished. Two blue

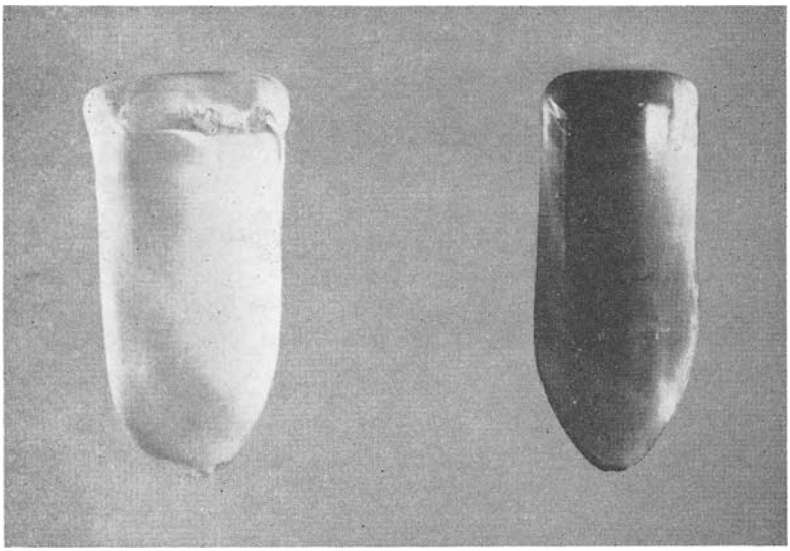

Boules of White Sapphire before and after irradiation.

synthetic sapphires, both treated for six days, produced quite dissimilar results ; one became dark brown, with no appreciable dichroism, but the other stone, initially darker, became greenish-blue with very strong " directional " dichroism visible without instruments. A colour-changing so-called " alexandrite " type synthetic became a garnet-red, dichroic in yellow and red, and lost its colour-temperature sensitivity.

Natural Corundum

Colour changes in natural corundums were less pronounced than in synthetics, a ruby showing no appreciable change, and a sapphire slight darkening.

Synthetic Spinel

A blue synthetic spinel, of colour simulating that of blue zircon, lost colour to become pale greyish-brown, with a more subdued red colour under the Chelsea filter, and a pale-blue synthetic spinel developed a more " steely " blue.

Quartz

A cairngorm showed slight, and an amethyst considerable, darkening. Rose quartz also darkened.

Topaz

A pink topaz reverted to an " unfired " sherry-brown colour, and a pale yellow topaz acquired a rather darker and greenish hue, and the dichroism was correspondingly accentuated (pink and very pale green).

Zircon

Both blue and golden stones had the shorter period of irradiation (three days), and were very greatly changed in colour, no doubt by reason of their rare-earth impurities. All assumed a very deep reddish-brown, almost black, appearance, and even on immersion in monobromonaphthalene they were almost opaque to transmitted light excepting at the girdle, where it was possible to check that they were still anisotropic, but non-dichroic. In the immersion cell, it was noted that, in one stone, the coloration followed a linear banded pattern similar to that common in cairngorm.

Garnets

The garnets were not greatly changed ; rhodolite seemed unchanged, the colour deepened a little in almandine, and the emerald-green of demantoid was debased to a " peridot " green.

Miscellaneous

Brown tourmaline became greenish-brown, and kunzite a sherry-brown, dichroic in pink and brown. Peridot became a brownish-green, golden beryl assumed a deeper colour, and orthoclase turned sherry-brown with some dichroism in two hues of brown. Colourless periclase produced the most aesthetically satisfactory colour-change by turning a " blue chalcedony " blue.

REFERENCE

1. Anderson. " Crossed Filters for the Study of Fluorescence," Gemmologist XXII, 39-45, 1953.

FURTHER COLOUR FILTER TESTS

YELLOW AND ORANGE GEMSTONES

by L. C. TRUMPER, B.Sc., F.G.A.

THE separation of gemstones by colour filters has already been discussed at length and red, blue and green gemstones dealt with in this respect in the Journ. of Gemmology, Vol. III, p. 149 ; Vol. IV, pp. 27, 139, 360. Yellow gemstones would not appear to offer very much scope for separation by means of combinations of colour filters, being the purest in colour of any. Orange-coloured gems alone seemed likely to hold out much prospect of giving useful results. It was felt, however, that the series would not be complete without an attempt at least being made to search for possible filters.

The following gemstones were selected :

1. *Scarlet-orange to orange-yellow*

Gemstone	*Colour*
Fire Opal from Mexico	Indian orange, colour 713 Wilson colour chart. SO 14, 12° Villalobos.
Spessartite	Mars orange, o13 Wilson colour chart. SO 15, 12° Villalobos.
Spessartite	Burnt orange, o14 Wilson colour chart. SSO 8, 9° Villalobos.
Hessonite	SO 12, 12° Villalobos. Burnt orange. Wilson, BCC 58, Rust.
Fire Opal	O 17, 11° Villalobos.
Topaz	O 18, 8° Villalobos.
Zircon	OOY 17, 12° Villalobos. Yellow ochre o7/1 Wilson.
Zircon	OOY 16, 8° Villalobos.
Zinc Blende	OOY 15, 12° Villalobos. Tangerine o9 Wilson.
Topaz	OOY 19, 9° Villalobos.
Topaz	OOY 18, 6° Villalobos.
Golden Beryl (Heliodor)	OY 17, 12° Villalobos ; Old Gold BCC 115.
Citrine	OOY 15, 11° Villalobos.
Idocrase	OOY 14, 11° Villalobos.

2. *Yellow orange to yellow.* (*YYO–Y*)

Fluor	YYO 18, 12° Villalobos. Empire yellow 603/1. Wilson. BCC 114, Gold.
Heliodor	OY 19, 12° Villalobos.
Sapphire	OY 19, 12° Villalobos
Sphene	YYO 15, 9° Villalobos.
Tourmaline	Y 17, 11° Villalobos. Canary yellow 2/2 Wilson.
Chrysoberyl	YYO 18, 8° Villalobos.
Sapphire	Y 19, 5° Villalobos.
Zircon	Y 19, 9° Villalobos.
Tourmaline	Y 17, 10° Canary yellow Villalobos. 2/2 Wilson.
Smithsonite	Y 18, 12° Villalobos. Primrose 601/1 Wilson.

Scapolite	Y 18, 3° Villalobos.
Beryl	Y 19, 9° Villalobos.
Y. orthoclase from Madagascar	Y 18, 4° Villalobos.

3. *Greenish yellow.* (*YY*2)

Yellow Spodumene ...	YYL 19, 3° Villalobos.
Brazilianite	YYL 19, 9° Villalobos. Chartreuse green, Wilson 663/3.
Chrysoberyl	YYL 17, 11° Villalobos. Chartreuse green, Wilson 663/1.
Apatite	YYL 18, 3° Villalobos.

The Villalobos colour atlas comprises 7,279 colours : three simple hues—green, ultramarine and scarlet; six transitive double hues—emerald, cobalt, violet, ruby, orange and lime green ; then twelve sets of intercalary hues of the first rank and a further twelve of the second rank.

Thus between green and ultramarine there are the following hues : green, green green emerald, green emerald, emerald emerald green, emerald, emerald emerald turquoise, emerald turquoise, turquoise turquoise emerald, turquoise, turquoise turquoise cobalt, turquoise cobalt, cobalt cobalt turquoise, cobalt, cobalt cobalt ultramarine, cobalt ultramarine, ultramarine ultramarine cobalt, ultramarine.

Each of the thirty-eight simple, main double, transitive or intercalary hues are then shown expressed in twenty gradations of light to dark (or lightness value) and each gradation is shown in each of twelve degrees of chromaticity. Thus each plate of 191 colours ranges from white through 19 neutrals to black, from palest through 19 light values to darkest, from palest to white and from darkest to black, and so on. A scarlet-orange colour of medium chromaticity and lightness would be designated—SO 11, 6°.

Examination with the Chelsea Filter

It had already been established that of all yellow or orange stones examined, yellow beryl alone shows apple-green. This was confirmed, no other yellow gemstone showing green at all. Golden-yellow beryl or heliodor appeared colourless to yellow.

Yellow Idocrase (Xanthite) showed blackish, deep golden-yellow beryl and yellow zinc blende showed very pale cobalt blue, but these under the 502/302 filter showed deep red, and the yellow beryl blue. As before the 68/22 filter emphasized the apple-green colour. The remainder exhibited no colour-change worth recording, though the zircons showed pink and the hessonite, spessartite,

fire opal deep red. With the 502/302 filter yellow beryl showed blue, idocrase deep blue green, remainder red or reddish.

Examination with Colour Discs

Careful examination with the colour discs already established for the examination of red, blue and green gemstones showed no notable colour-changes apart from those observed with the Chelsea filter and filters closely allied to it.

Examination with the Ilford series of colour filters

Examination with 110 Micro 4—minus blue, showed that spessartite, fire opal, hessonite garnet and a deep orange zircon remained distinctly orange. Smithsonite, fluor, pale yellow beryl, brazilianite, yellow apatite, orthoclase, chrysoberyl and a pale yellow ziron showed practically colourless. The remainder showed varying traces of yellow or brown.

210 Orange, showed spessartite, hessonite and fire opal orange, the yellow-brown idocrase slightly greenish-yellow and the remaining stones practically colourless. 111 Orange yellow and 108 Micro 9, pale yellow, gave results very similar to 110 Micro 4—minus blue. With 302 minus red, all showed green from light to very dark in shade. With 406 Astra, the deep orange fire opal alone showed distinctly orange.

Examination with the Wratten series of colour filters

With the filter NP 549-very deep green, the spessartite, fire opal, idocrase and hessonite only showed deep red. With 23E E Red, spessartite, fire opal and hessonite alone showed orange, the rest colourless.

Conclusions

In dealing with a bright and pure colour, it was not anticipated that much success would be achieved in a search for filters that would produce distinct colour changes. Research into the problem indeed shows that on sight alone it is impossible to identify with certainty any yellow gemstone except perhaps yellow sphene and the deeper orange-coloured fire opals.

The Filter NP 549 is useful in confirming the separation of spessartite, fire opal and hessonite, and the Chelsea filter in detecting yellow beryl. Beyond that it is not possible to go at present.

Gemmological Abstracts

DE SOUZA (J. E.). *Notas sobre Espodumenios Brasileiros.* (Notes on Brazilian spodumene.) Gemologia, No. 4, 1956, pp. 12–22 (11 figs. and 4 photomicrographs).

A profusely illustrated account of spodumene in all its varieties. The author appears to have worked at length on the morphological aspects of several crystals and provides drawings and photographs of the fine natural etching of the crystal faces. The symmetry of the etch figures reflects that of the face on which they occur. Brazilian occurrences are given in some detail and at least one locality is claimed for hiddenite. This is evidently the pale green spodumene and should not be confused with the emerald-green tone hiddenite from N. Carolina—one of the rarest of gems. Apparently the Brazilian " hiddenite " can be deepened to a blue-green colour by exposure to X-rays. R.K.M.

WEBSTER (R.). *A Esmeralda* (The emerald). Gemologia, No. 5, 1956, pp. 8–32 and No. 6, 1956, pp. 3–14.

A translation of the paper which appeared in the Journ. Gemmology, Vol. 5, No. 4, 1955. R.K.M.

CAMPOS (J. E. de S.). *Sobre un cristal de Berilo do estado de Espirito Santo.* (Aquamarine from the Espirito district.) Gemologia, No. 5, 1956, pp. 1–7.

A description of a blue-green aquamarine crystal from the Espirito Santo district of Brazil. No indication of size is given but it is this crystal which is the source of many line drawings both on the cover of the publication and in the text of the article. The author claims that some of its inclusions are very similar to those attributed by Roulet (Zeit. d. Deutsch. Gesell. f. Edelsteinkunde 1955) to Indian emeralds, while others are like those seen by Webster (Journ. Gemmology, Vol. 5, No. 4, 1955) in Siberian emeralds. Minerals included in the crystal are phlogopite, rutile, pyrites and, in three-phase cavities, calcite. Some three-phase inclusions show two non-miscible liquids as well as the gaseous and solid phases. R.K.M.
2 figs.

ZWAAN (P. C.). *Some unusual gemstones in the collection of the Rijksmuseum van Geologie en Mineralogie of Leiden.* Leidse Geol. Med., vol. 20, 1955, pp. 225–237. 6 illus.

The unusual gems described include spessartite, kornerupine, diopside, bronzite, apatite, andalusite and scapolite. The data obtained during identification are compared with results of various authors. Reference is also made to the immersion contact photograph method described by Anderson (Journ. Gemmology, Vol. 3, No. 6, 1952, pp. 219–225). The illustrations are all photomicrographs of inclusions, except one of immersion contact photography. S.P.

CHUDOBA (K. F.). *Zur Kenntniss des Mondsteins.* (Knowledge of moonstone.) Deut. Golds. Zeitg. Vol. 54 (1956), No. 9, pp. 419–420.

A general article about the nature of moonstones, with reference to the causes of opalescence. Sir C. V. Raman thought this property to be due to a diffusion of light on tiny crystallites. There are no outstanding substitutes for moonstone, white chalcedony and heated amethyst being the nearest in appearance. Moonstones are found in Burma, Tanganyika, Madagascar and Brazil, but the most important source is still Ceylon. The importance of these occurrences steadily dwindles. The stones are usually cut en cabochon in Ceylon and re-cut and polished in Idar-Oberstein. E.S.

SCHMIDT (Ph.). *Amethyst, de Adelige in der quarzfamilie.* (Amethyst, the aristocrat of the quartz family.) Zeitschr. d. deutsch. Gesell. f. Edelsteinkunde, No. 17, 1956, pp. 5–8.

A review of the qualities of amethyst known to us, and as they were known to the Egyptians, Greeks and Romans. The name probably came from the greek *amethustos*—wine-coloured, although it was thought for a long time to come from *a methuo*—not to be drunk, and was therefore worn as a charm against drunkenness. E.S.

LEUVEN (E. P.). *Garnet of many varieties.* Mineralogist (Oregon), Vol. 25, No. 1, 1957, pp. 16–20.

A list of the varieties of garnet; out-moded names have been included and it is unfortunate that their obsolescence has not been indicated. S.P.

GRODZINSKI (P.). *On the history of the rose cut.* Gemmologist, Vol. XXV, No. 302, pp. 167–8, Sept., 1956.

The author has endeavoured to trace the inventor of the rose-cut, and, from documents in the Nuremburg archives, has discovered the invention to be due to Heinrich Hahn in 1591. Other information on the history of the rose-cut in the 17th and 18th centuries is included.

1 illus. R.W.

COUSEN (T. W.). *Mexican fire opal.* Gemmologist, Vol. XXV, No. 303, pp. 182–186, Oct., 1956. (Reprinted from Gems & Minerals.)

The centre of the opal mining of Mexico is at Queretaro, the mines being situated in a radius of some thirty miles around. The percentage of high grade opal found is small. The methods used by the miners for selling the recovered opal are entertainingly told. The material is precious enough to be sold by the carat and gram. The various types of opal are described and the Mexican names for these are given. Opal tends to crack on drying out, but this can sometimes be corrected by periodic soaking of the gem in water. Some of the methods used for cutting are described. The local lapidaries also cut amethyst from Guerrero.

6 illus. P.B.

CUSTERS (J. F. H.). *Colours in diamonds.* Gemmologist, Vol. XXV, No. 303, pp. 188–190, Oct., 1956. (Extracted from Optima of June, 1956.)

Colour depends firstly upon three factors ; the source of light, the object that reflects or transmits the light, and the eye and brain, in conjunction, which interpret the colour characteristics, that is the hue, the saturation and the intensity. Each of these effects is described. The difficulty met with in the colour grading of diamonds by colorimeter or by absorption spectrophotometry is discussed. The advantage and limitations of the eye grading of diamonds in a folded white paper are mentioned. Some notes on the theories of the cause of colour in diamonds are given. Type I diamonds are said to contain more impurities than the Type II. Diamonds coloured artificially by atomic bombardment owe their colour to radiation damage.

R.W.

SWITZER (G.). *The Diamond industry*, 1955. Jewelers' Circular-Keystone, Philadelphia.

The 31st report on the diamond industry. In 1955 production was again the highest on record, although accurate figures were not available for all countries. 21,540,000 metric carats (including 17,500,000 m.c. of industrial stones) were produced compared with 20,440,000 m.c. for 1954. Sales of gem and industrial stones also set a new record at approximately £77,000,000.

S.P.

FAIRBANKS (E. F.). *A study of the polished surface.* Mineralogist (Oregon), Vol. 24, No. 9, pp. 327–332.

An interesting article on research carried out on polishing agents and surfaces. Arising from Beilby's contention that during polishing a melted or softened solid is spread over a surface to form the Beilby layer, experiments were made using abrasives with higher melting points than that of the mineral being polished. Zinc oxide with hardness 4 will polish quartz. The melting point of zinc oxide at above 1,800°C is higher than that of quartz. Zirconium carbide with melting point of 3,532°C was used by Kaplan to polish diamond (m.p. about 3,500°C). Surface temperature at points of contact during polishing may be high enough to cause melting of a metal or mineral. The point is made that the criterion to apply to efficient polishing should be speed whereby a true specular surface is developed. On this basis diamond dust for diamond polishing is unsatisfactory ; tin oxide less efficient than zinc oxide for quartz ; and cerium oxide unsatisfactory for many types of glass. S.P.

RUTLAND (E. H.). *An unusual brown beryl.* Gemmologist, Vol. XXV, No. 304, pp. 191–2, Nov., 1956.

A report on an asteriated brown beryl from Gov. Valdares, Minas Gerais. The inclusions consist of oriented rutile needles, which produce the weak star, and coarser agglomerates and flat partly resolved black inclusions parallel to the basal plane. The inclusions produce the brown hue and where the stone is relatively clean the colour is that of a pale green aquamarine. The stones show a strong schiller which tends to mask the asterism. This schiller is said to be due to the layered structure of the stone, the layers being parallel to the basal plane, and these layers act as

reflectors, as the image of a light source is clearly mirrored at the centre of the star, rather like the rose-quartz star doublet. The stone resembles bronzite but has an index of refraction near 1·59 and a density of 2·712. No characteristic spectrum was observed and there was no luminescence.
4 illus. P.B.

ANON. *Diamonds and pearls.* Kodak View, No. 3, 1956, pp. 19–22.

A general survey of the photographic techniques used in the London Chamber of Commerce Laboratory in Hatton Garden. The X-ray photographic techniques employed in pearl testing are described both in the text and by illustrations. The types of films used for such testing are mentioned. The use of fluorescence photography as a method of identity certification in the case of multi-stone diamond jewellery is shown pictorially and described in the text, as is the taking of photomicrographs for such purposes, and for illustrating purposes, and by the use of colour film, for transparencies for projection purposes. The ultra-violet transparency method for the detection of synthetic emeralds is referred to as well as the autoradiographic method used for the detection of radium-treated diamonds. An interesting and informative article enhanced by many illustrations, two of which are in colour and show a number of minerals in ordinary white light and when fluorescing under ultra-violet light. The typographical inclusion of the word "synthetic" before diamonds when the radium-treated stones are mentioned mars an otherwise excellent article.
13 illus., 2 in colour. P.B.

WEBSTER (R.). "*Fingerprinting diamonds.*" National Jeweler, Vol. 51, No. 11, pp. 72–73 and 156, November, 1956. New York.

The differential fluorescence of diamonds is suggested as being a means of identifying jewellery set with many diamonds. Fluorescence photographs showing the differential intensity of the glows may be used as a permanent record. The employment of colour photography is considered to be too time-consuming and expensive for commercial purposes. The method advocated is to take a straight photograph of the piece of jewellery and then a second picture of the fluorescent glows induced by ultra-violet light. Long-wave ultra-violet is used, as the short-wave lamp passes

too much visible light and does not give such a clear fluorescent picture. The fluorescence picture is taken with the room lights turned off, and an ultra-violet absorbing filter is needed over the camera lens for this picture, as the photographic emulsion is responsive to ultra-violet light.
7 illus. P.B.

GÜBELIN (E.). *Inclusions in synthetic spinels.* Gemmologist, Vol. XXV, Nos. 302/3, pp. 153–157 ; 173–176, Sept./Oct., 1956.

A survey of the " bubbles " and " inclusions " seen in synthetic spinels of recent manufacture. Most synthetic spinels are comparatively clean, and some may show very small bubbles of pin-point size, which are sparse and rarely in clouds. The red synthetic spinel is an exception in that it usually shows many bubbles which lie in broad parallel bands similarly to the effect seen in some synthetic rubies (note: red synthetic spinel is not marketed). The cavities found in synthetic spinels of other colours are described and the reasons for their formation explained. These are bubbles which have elongated into hose-like or worm-like forms, which may run parallel, criss-cross, or anastomose, and may appear like natural " feathers." Low pressure of the blowpipe gases may cause speeding up of the growth of the boule and produce gaps in the lattice, giving rise to types of negative crystals parallel to the length of the boule. These may take fantastic rounded forms, termed " profilated bubbles." Shred-like formations are occasionally found and are said to be empty or gas-filled cavities formed through the rapid growth. Curved banding is rare in synthetic spinel but this has been occasionally seen. Typical cracks following definite crystallographic planes and other cracks and whorls are said to be due to strain, the strain exemplified by the anomalous double-refraction seen between crossed nicols. One manifestation of these cracks assumes a hexagonal outline and can be somewhat confusing. Two-phase inclusions have been observed in some synthetic spinels. The original theory that they contain water in the liquid and gaseous condition has been questioned from recent investigations. The newer theory is that the two phases of matter are a solid one (a glass) and a gas, which is probably air. Crystals of alumina brought into formation by a process of ex-solution form a disturbing kind of inclusion.
19 illus. R.W.

ANDERSON (B. W.) : PAYNE (C. J.). *The spectroscope and its applications to gemmology.* Gemmologist, Vol. XXV, Nos. 302/3/4/5, pp. 158–162 ; 177–179 ; 193–198 ; 211–216, Sept./Oct./Nov./Dec., 1956. Vol. XXIV, No. 306, pp. 13-14, Jan., 1957.

Parts 37 to 40 of this serialization on the absorption spectra of gemstones deal, firstly, with those of synthetic gemstones. The spectroscope will give no help in the separation of ruby and pink sapphire from the natural stones of these colours. The 4500Å line seen in the natural blue sapphire is absent in synthetic blue corundum. It is mentioned that a vague band may be seen about 4550Å in synthetic blue sapphire, which, although near that of the band in natural sapphire, is a vague blur of considerable width quite unlike the sharp nature of the band in natural blue sapphire. Such a vague band may also be visible in the yellow synthetic sapphire, and the newer brown types show an absorption from this 4550Å line onwards. Synthetic green sapphires do not show a characteristic spectrum but the " alexandrite " type shows a line at 4750Å due to vanadium. The blue shades of synthetic spinel (" aquamarine," " zircon " blues and deep blue) show, with varying intensity, the three-band spectrum of cobalt centred at 6350, 5800 and 5400Å. These bands may be also observed by reflected light in the synthetic sintered blue spinel made to imitate lapis lazuli. Many synthetic blue spinels show a bright line spectrum at 6870Å which, except for position, resembles the fluorescent line of ruby, and not the " organ pipe " fluorescence lines seen in the natural red spinel. The yellowish-green spinels which owe their hue to manganese show a strong band at 4230Å and a broader and weaker band at 4480Å. These manganese bands may in some cases be in association with the cobalt bands. Synthetic emerald shows, except perhaps for intensity, the same spectrum as natural emerald. Synthetic rutile shows a strong band at 4230Å and no bands have been observed in the new strontium titanate. The part on the absorption spectra of glasses mentions the blue, pink, orange, red and " canary " yellow and green glasses. In most blue glass the colour is due to cobalt, the spectrum being similar to that of the synthetic blue spinels, except that the outer bands are at a greater distance from the centre band, which is the narrowest (in the synthetic spinel it is the band in the green which is the narrowest). Vague blurred chromium lines may be found in some green pastes. Pink glasses are sometimes coloured with didymium

and then show the typical groups of lines in the yellow, such as are seen in yellow apatite. Most red pastes are coloured by selenium in conjunction with cadmium sulphide and the spectrum exhibits a broad band in the green. Orange glasses show a cut-off near 5900Å and beyond ; to some extent this spectrum resembles that of fire opal, but the refractive index of these orange-coloured pastes is higher than that of fire opal. The uranium-coloured " canary " yellow or green glasses show no useful bands, although some vague bands may be seen with difficulty in the blue and violet. The fluorescence spectra of certain gems and minerals are remarked upon with particular reference to the chromium-coloured minerals. The rare earth fluorescence spectra are discussed, zircon being the most important gemstone in this group. The important subject of the luminescent spectra of diamond is also discussed within the limits of the scope of the article. Luminescence of diamonds is described under three groups, blue-fluorescent, yellow-fluorescent and green-fluorescent stones, and the spectral characteristics of these three groups are discussed. Blue-fluorescent diamonds show yellow phosphorescence with a strength proportional to the intensity of the blue fluorescence. Part 40 gives a summary of the absorption spectra discussed in the series, the relative reliability and practical importance of each spectrum being marked by the system of " stars." The classification of this summary is based on colour grouping. The series has an index.

2 illus. R.W.

MEHTA (M. G.). *Last remaining descendant of ancient Indian diamond artisans.* Gemmologist, Vol. XXV, No. 304, pp. 205–208, Nov., 1956.

The cleaving of diamonds was not known before the 16th century in Europe but the art was known in India many centuries before that time. The large plate-shaped diamonds found in old Indian jewellery supply the proof of the age-old cleaving of diamonds in India. The Indian names for these types of flat stones of old India are given, and the story is told of a living Indian cleaver, a descendant of those of ancient India. The methods used by this worker are described.

6 illus. P.B.

ANON. *Agate colouring by heat treatment.* Gemmologist. Vol. XXV, No. 304, pp. 208–209, Nov., 1956.

Agate will not always stain easily ; it may take the colour only in patches or even only on the surface. Brazilian agate is the more easily coloured material. It is suggested that agate should be cut into sections with the microcrystallites in parallel orientation with the layers. Inorganic mineral salts, which have smaller-sized molecules, would penetrate the agate better than the organic colouring agents (sugar, honey and aniline dyes) with their larger-sized molecules. Oil and petroleum used in the sawing process may prevent subsequent absorption of the dyes unless completely removed. G. O. Wild suggests that a preliminary heating between 200 and 300 degrees C. alters the structure of the agate and makes for easier colouring. P.B.

HANSON (L.) *Sillimanite.* Lapidary Journal, Vol. 10, No. 4, 1956, pp. 294–298 ; Reprinted Gemmologist, Vol. XXVI, No. 307, pp. 23–25, February, 1957.

A report on the sillimanite (fibrolite) from the Clearwater River Valley, Idaho. The material is white to blue in colour with often patches of black, brown or yellow. It is fibrous and produces a cat's-eye effect when cut cabochon. The hardness is said to be 7 to 7½, although some pieces are said to exceed 8. The black to yellow patches of colour turn to a pale salmon-pink or red when heated, but the blue colour does not alter. At Dent, Idaho, some fifty miles upstream, there is a further deposit of water-worn material and nearby is a source *in situ.* Gem quality sillimanite is found in Burma, Ceylon and Brazil.

R.W.

MEINKE (H.). *Crystals produced in a carbon arc.* Gemmologist, Vol. XXVI, No. 307, pp. 33-38, February, 1957.

The author, the central figure of the Bonn diamond synthesis affair, discusses the growing of crystals by the use of a carbon arc in a gaseous atmosphere in a special pressure chamber, the temperature being in the region of 6000°K. The " mushroom " formed is said to consist of pure and transparent graphite crystals, which, although not properly identified, are not silicon carbide. The arrangement of the furnace is described and reasons for the

non-burning of the graphite when oxygen is the gas used in the furnace are given. The gases used were oxygen, argon, nitrogen and air. Much technical data is given.
6 illus, 2 tables. R.W.

ANON. *What atomic irradiation can do to precious stones ; "Bombarded" and normal gems compared.* Illustrated London News, Vol. 230, No. 6142, Supplement page 4, 23rd February, 1957.

A coloured plate showing a number of stones from the collection of Thorold Jones which illustrates the colour before irradiation and after treatment in an atomic pile. Mention is made that colour changes normally disappear when the stones are heated to 500°C. It is not considered that the sale of coloured diamonds will be seriously affected by stones colour-changed by irradiation. The stones illustrated in the plate are synthetic corundums and spinels of various colours, natural sapphire and natural blue zircon.

R.W.

DÉRIBÉRÉ (M.). translated by CHISHOLM (J. R. H.). *Luminescence of minerals : Luminescence of diamond.* Gemmologist, Vol. XXV, No. 304, pp. 200-204, November, 1956, and Vol. XXVI, No. 306, pp. 4-6, January, 1957.

The luminescent effects seen in a number of minerals, including some which are gem minerals, are mentioned. Fluorescence, phosphorescence, radio-luminescence, cathodo-luminescence, tribo-luminescence and thermo-luminescence are discussed. Much is told of the luminescence of diamond. Under some radiations certain diamond crystals exhibited different strengths, and even shades of colour, of the glows on the various crystal faces ; the cube face showing the brightest luminescence. A diamond activated by contact of long duration with radium bromide, showed, when heated, a clear thermoluminescence. Under long-wave ultra-violet light the luminescence is less constant and it is suggested that this effect might, providing previous knowledge be known, provide a check on a piece of diamond jewellery should it be stolen and recovered and have subsequently to be re-identified. Some of the applications of luminescence in mining and mineralogy, and in industry, are given.

R.W.

BREEBART (A. J.). *A simple, but effective, dark-field illuminator.* Gemmologist, Vol. XXVI, No. 307, pp. 21-22, February, 1957.

Instructions for the construction of a simple home-made dark-field illuminator for the microscope stage. The materials needed consist of a tin lid, a bicycle lamp reflector with lamp holder for a low-voltage lamp to be fed from a step-down transformer, a metal disc and the necessary screws, nuts and electric wire. The stone is held in spring tweezers mounted on a pivot.
1 illus. R.W.

ANON. *Modern Chinese carving in ivory and jade.* Gemmologist, Vol. XXVI, No. 306, pp. 8-13, January, 1957.

A report on the exhibit of Chinese craftsmanship which was shown by the Chinese Peoples Government at the Handicrafts exhibition held at Olympia in West London. Carved ivory and jade pieces shown were said to have been carved within the last ten years. The main centres for this craft are the towns of Shanghai and Peking (mostly jade) and Canton (principally ivory). Craftsmen in China are now said to number 100,000 and they work in communities. Their products are marketed through a Government organization. Traditional methods are used in carving and the craftsmen tend to specialization. Coral, turquoise, emerald, serpentine, rock crystal, agate, rose quartz and soapstone are also carved.
4 illus. R.W.

CROCKER (R. C.). *The Yogo Sapphire mine.* Gems and Gemology, Vol. VIII, No. 11, pp. 323-330, Fall, 1956.

A comprehensive article on the Yogo sapphire mine at the foot of the Little Belt Mountains, Montana. The location of the mines and the flora and geology of the locality are given. The sapphire was first discovered at Yogo Gulch in 1894 by prospectors searching for placer gold. The history of the mining area from the early 1890s to the current year is fully told. Yogo sapphires have a metallic lustre and vary in colour from a pale steel-blue to a cornflower blue. The crystals are small in size.
5 illus. R.W.

COLEMAN (R. G.). *Jadeite from San Benito Co., California.* Gems and Gemology, Vol. VIII, No. 11, pp. 331-334, Fall, 1956.

A factual report on the jadeite found along Clear Creek in San Benito County. The mineral jadeite is compared with nephrite, and mention is made that only three other localities for jadeite have been previously known: they are Upper Burma ; Kataki, Niigata Prefecture, Japan, and near Manzanal in the Motagua valley of Guatemala. Jadeite was first reported from California in 1939 but the Clear Creek boulders were not discovered until 1950. The geology and the mineralogy of the material is given. It is a very pure jadeite in white and dark green colour but does not compare favourably with the jade from Burma. The optical properties of the white material are given as α 1·654, β 1·657, γ 1·666, and the density is stated to be 3·34. The dark green material polishes better than the white material.
3 illus. and 1 table. R.W.

SPAULDING (D. L.). *The ruby mines of Mogok, Burma.* Gems and Gemology, Vol. VIII, No. 11, pp. 335-342, Fall, 1956.

The writer visited Mogok and the Stone Tract during the Fall of 1955 and this article is a very full account of the area as it is since Burma was given her freedom by the British in 1948. Present conditions of travel are told and the state of Mogok itself. The native method of mining is mentioned. The gem minerals found in the tract are listed. " Ruby rough " consisting of skillfully tumbled synthetic corundum is reported. Native cutting methods are explained and the method of bargaining for stones by holding hands under a cloth is described. Conditions in Burma are hazardous and the State holds an uncertain future, but the finest rubies are found at Mogok.
11 illus. R.W.

ANON. *Irradiated gemstones : Colour changes by irradiation.* Gemmologist. Vol. XXV, No. 305, pp. 217–220. December, 1956.

The first of these articles describes the display of various gemstones in conjunction with similar stones which had been irradiated in an atomic pile at Harwell. This display had been on show at an " open day " at Harwell and then at the Haslemere

Educational Museum. The species of the stones irradiated are given in the caption to one of the illustrations, and it is told that most of the irradiated stones assumed a darker and muddier colour. A specimen of colourless periclase did, however, turn to a much more attractive deep blue. The second article makes an attempt to explain the cause of colour and what happens on irradiation. Idiochromatism and allochromatism, parti-coloration, pleochroism and sheen are referred to. The staining of black onyx to a black colour by sugar and sulphuric acid, and the pinking of topaz by heating are mentioned. The effect of heat and radiation in altering the colour of gemstones is referred to and the reasons described by illustrations. Ion vacancies in the lattice, the missing ions of which may be present interstitially producing Frenkel defects, or on the surface giving Schottky defects, are alluded to, and colour may be caused by incident radiation ionizing other atoms and ions which become trapped in the vacant sites giving rise to absorption of light. The higher energy of neutrons and high energy electrons may in addition cause ions to become displaced in the lattice.

4 illus. R.W.

CHALMERS (R. O.). *Some aspects of New South Wales gemstones.* Journ. and Proc. of Royal Society of New South Wales, Vol. LXXXIX, pp. 90-108, Sydney, 1956. Reprinted as *Gemstones of New South Wales.* Gems and Gemology, Vol. VIII, No. 11, pp. 343-349, Fall, 1956.

This article is the report of the Clarke Memorial Lecture delivered by the author to the Royal Society of New South Wales on 16th June, 1955. It deals with diamond, opal, sapphire, ruby and spinel, beryl and emerald, topaz, zircon and garnet, quartz, turquoise, titanite (sphene) and prehnite, each section being fully dealt with both historically and scientifically. The writer concludes with some notes on the economic significance of the gemstones in the State of New South Wales. Considerable information is given on the localities of the various gem minerals mentioned, and these are supplemented by line maps. This very important paper is completed with a good list of references.

4 maps (not in Gems and Gemology reprint). R.W.

EPPLER (W. E.). *Ueber die Färbbarkeit des Achates.* (Colouring Agate.) Deutsche Goldschmiedezeitung, Vol. 54, No. 11, 1956, p. 551.

Agate consists of SiO_2, or more correctly of two types of SiO_2, namely crystallized quartz and opal, which can have a larger or smaller water content. The colouring property of agate depends on the water content of the opal, which can be as high as 10%. The greater the water content, the easier it is to colour the agate. The colouring is also influenced by the structure of the crystalline SiO_2. The closer knit the fabric, the less room there is for the water-carrying opal, and therefore the more difficult it is to colour the stone. The theory is proved by the specific gravities which are

rock crystal = 2·651
technical agate = 2·600 ± 0·002
coloured gem agate = 2·594 ± 0·002

E.S.

GRODZINSKI (P.). *Edelsteine in der alten indischen Literatur.* (Gems in old Indian literature.) Gold und Silber, Vol. 9, No. 12, 1956, pp. 21–22 (also in Gemmologist, Vol. XXV, No. 295, pp. 28–30, February, 1956).

An extract of information about diamonds as compiled by L. Finot in Paris in 1896 collected from old Indian writings. The colour of the diamond was thought to be determined by the caste to which it belonged and was dedicated to one particular god, and accordingly certain virtues belonged to the stone, i.e. riches or glories. The form of the stone is discussed and a list of stones is given which can be used to imitate diamonds.

E.S.

KLÜPPELBERG (E.). *Eine neue Darstellungsweise der Schleifrichtungen am Diamanten.* (A new method of demonstrating the grinding direction of diamonds.) Deutsche Goldschmiede-Zeitung, Vol. 54, No. 12 (Dec.), 1956, pp. 607–608 ; Vol. 55, No. 1, 1957, pp. 15–17.

The article is an extract from a book by the author on the " Grinding of the brilliant " which will be published soon. It describes a new method developed and tried out by the author at the Industrial Trade School in Idar-Oberstein. Previously drawings showed the grinding directions by indicating the natural

growth lines and the direction of the grinding marks on the facets. The new method brings these indications in relation to the direction of the scaife rotation and the position of the tongue which holds the diamond. Thus the apprentice can visualize more readily the connexion between the drawing used as a visual aid at school and the actual work he is asked to perform in the shop. The direction of lap rotation is indicated by thick parallel arrows from the right. The axis of the tongue is at right angles to this direction and is indicated on the drawing by showing part of the tongue. The eight " compass directions " (in — out — against, etc.) of the tongue are shown by a circle with four black and four white octants. Within this circle a rotatable disc is placed, which shows the facets of the brilliant or eightcut together with the superimposed growth marks of the 2, 3 or 4 point. This drawing then shows to the apprentice the position of the stone as he sees it when he actually looks onto the stone " in the tongue," i.e. when the tongue is removed from the scaife for inspection.

W.S.

FREY (E.). *Edelsteine in Süd-Afrika.* (Gems in South Africa.) Deutsche Goldschmiede-Zeitung. Vol. 55, No. 1, 1957, pp. 18–120.

A general survey of gems found in South Africa. The author does not believe in the stability of diamond value as allegedly (*a*) the price is kept artificially high and (*b*) the synthetic stones are going to oust them from their leading position. South-West Africa, the former German colony, the author alleges to have been searched most thoroughly. In this part one finds beryls, tourmalines, topazes, malachites, azurites and other minerals. In Namaqualand, south of the river Oranje, one finds diamonds, rock crystals, amazonites, malachites, beryls (no emeralds) and spodumenes. A sketch of this region is included. In West Griqualand amethysts, garnets, jaspers, and tiger's-eyes are found. Transvaal is very rich, where apart from gems one finds gold, iron, chromium, platinum, asbestos, coal, tin and mica. The gems include diamond, rock-crystal, agate, haematite, emerald and tourmaline. This district (Letaba) was also the site of the recent find of the largest emerald (24,000 cts.).

E.S.

CHUDOBA (K. F.). *Neue Diamantfunde : in der ostsibirischen Sovietrepublik Jakutien.* (New diamond finds in the east Siberian Soviet republic of Jakuta.) Deutsche Goldschmiede-Zeitung, Vol. 55, No. 1, 1957, pp. 20–21.

Short survey about properties, occurrence and synthesis of diamonds. In Jakuta no systematic production of diamonds has yet begun. Up to now diamonds of 4–6, occasionally 11 cts., were found, also one of 32 cts. Nothing is known of the quality.

E.S.

QUICK (L.). *Story of Benitoite.* Lapidary Journal, Vol. 10, No. 6, Feb., 1957, pp. 510–518.

A useful account of benitoite. Discovered in 1906, this rare gem occurs in the unusual form of a ditrigonal bipyramid of the hexagonal system at a mine near Santa Rita Peak, San Diego County. Much good material was destroyed early on by attempts to hammer crystals from parent rock—a natrolite dike in serpentine, associated with neptunite. Later it was found possible to dissolve the matrix with hydrochloric acid. Many crystals are flawed and unsuitable for cutting and it is rare to find a faceted stone of more than about a fifth of a carat. A stone of seven carats is in the Smithsonian Institution, Washington.

S.P.

SCHIEBEL (W.). *Gewichtsformel fuer regelmaessig geschliffene Steine* und *Perlen, insbesondere fuer dem Diamant-Vollbrillant.* Weight formulae for pearls and cut stones especially the full cut brilliant. Zeitschr. d. deutsch. Gesellsch. f. Edelsteinkunde, No. 18, Winter 1956/57, pp. 16-22.

From the weight given in Diebener's tables for a brilliant of 10mm. diameter the author determines the factor 0.003449 with which the cube of the diameter has to be multiplied to obtain the weight in carats. Based on the ideal relationship between girdle diameter—table diameter, total height, height of crown and pavillion, for the fine cut brilliant (without girdle height) a long table has been evolved giving all these data (in reasonable small steps) for brilliants from 0·003 to 20·000 cts. In a log log diagram with the weight in carats as one co-ordinate and the girdle diameter as the other, all other dimensions of the brilliant are represented by parallel straight lines. Facts are also given to determine the weights of different pearl varieties from the diameter. W.S.

KLUEPPELBERG (E.). *Beobachtungen an Gaseinschlüssen in Glas und synthetischen Steinen.* Observing gaseous inclusions in glass and synthetic stones. Deutsche Goldschmiede-Zeitung Vol. 54, No. 10, 1956, pp. 496–498.

The appearance of gas bubbles under the microscope in transmitted and reflected light is discussed. In transmitted light the bubble appears as a dark rim with a bright centre. This bright centre is due to the light beam which is deviated less than 8 deg. (for glass with a R.I. of about 1·5). Photomicrographs show bubbles with a dark spot in the bright centre due to indian ink marks at the under side of the glass specimen. In a very small bubble the bright centre is hardly discernible. Interesting mathematical explanations by Eppler relating to the light path are given. In reflected light (incident at 70-80 deg.) the bubble appears three-dimensional. 8 photomicrographs, 2 line drawings. W.S.

PENSE (J.). *Achate unter dem Elektronenmikroskop.* Agates under the electronmicroscope. Zeitschr. d. deutsch. Gesellsch. f. Edelsteinkunde, No. 18, Winter, 1956/57, pp. 7-9.

Two electron photomicrographs show an etched agate specimen at 3200 × and 15000 × magnification. According to the author's interpretation, a network of coarser and finer fibres was seen. The fibres are supposed to be crystallized chalcedony and the spaces between the fibres presumably opal. Whether the opal plays any part in the artificial colouring of agate remains to be investigated within a research programme to be carried out by the Mineralogical and Petrological Institute of the University Mainz. W.S.

BÖLSCHE (R.). Ueber das Smaragdvorkommen im Habachtal. Occurrences of emeralds in the Habach valley. Zeitschr. d. deutsch. Gesellsch. f. Edelsteinkunde, No. 18, Winter, 1956/57, pp. 10–14. Conclusion. See Journ. Gemmology, Vol. 5, No. 8, 1956, p. 394.

By carefully removing surrounding matrix the author found small emerald crystals in helical arrangement indicating that these emeralds were formed in plutonic penetration channels. Investigation also showed a multitude of small crystals in random orientation more or less within a plane.
3 illus. W.S.

CHUDOBA (K.). *Lapislazulifarbiger synthetischer Spinell = Sinterspinell.* Lapis-lazuli-coloured synthetic spinel = sinter spinel. Zeitschr. d. deutsch. Gesellsch. f. Edelsteinkunde, No. 18, Winter, 1956/57, pp. 15-16.

Prof. Chudoba draws attention to different nomenclature by the manufacturer (Degussa) of the sintered spinel. The white " sintered " material which is also called " Degussit " is used for fine ceramic products. The lapis-lazuli-coloured " synthetic " spinel is used as gem material for adornment. The author suggests it should be correctly called lapis-lazuli-coloured sinter spinel (as opposed to synthetic spinel). W.S.

GOEBELER (H.). *Bestimmung von gelben ind farblosen synthetischen Korunden.* Determination of yellow and colourless synthetic corundums. Zeitsch. d. deutsch Gesellsch. f. Edelsteinkunde, No. 18, Winter, 1956/57, p. 23.

Summing up of known methods. Fluorescence observed under ultra-violet light (wavelength around 3650Å) was allegedly different from that reported by B. W. Anderson, namely :

natural yellow corundum : weak green,
yellow corundum (Ceylon) : orange to apricot yellow
natural colourless corundum : very weak orange to yellow,
synthetic yellow corundum : carmine red,
synthetic colourless corundum : weak ; dim green.

W.S.

GRENVILLE-WELLS (J.). *Harder than diamond ?* New Scientist, No. 15, Feb., 1957, pp. 16-18.

A short account of the G.E.C. experiment in making a compressed form of boron nitride, which has been named borazon. Under pressure boron nitride (white graphite) changed from a hexagonal to a cubic form, the crystals produced being sand grain size. Borazon withstands a temperature of 1,800°C, while diamond " burns up " in air at 800°C. Optical properties are not yet known but borazon crystals are claimed to be harder than diamond, though it has not been stated whether the new material will scratch the synthetic diamond produced by G.E.C. in 1955. Hardness probably lies somewhere between the two. Cleavage, differential hardness and toughness will be important in assessing the usefulness of borazon relative to diamond. Its high temperature resistance is already notable. S.P.

ASSOCIATION NOTICES

ANNUAL MEETING

The 27th annual general meeting of the Association was held at Goldsmiths' Hall, London, E.C.2, on Friday, 15th March, 1957. Mr. F. H. Knowles-Brown, Chairman of the Council, presided.

The audited accounts and report of the Council for the year ended 31st December, 1956, were adopted. Sir Lawrence Bragg, F.R.S., was re-elected as President and the retiring Chairman, Vice-Chairman and Treasurer were also re-elected. Miss E. Ruff and Mr. T. H. Bevis-Smith were re-elected to serve on the Council, and Mr. D. J. Ewing elected to serve in the place of Mr. R. K. Mitchell.

Messrs. Watson Collin & Company continue as auditors to the Association.

In his report the chairman mentioned the 1956 Herbert Smith Memorial Lecture, which had been given by Dr. F. Pough. He did not know whether or not that speaker had had "his tongue in his cheek" when he had said that a time might come when, owing to the shortage of gems, synthetics might be of far greater value and interest than at the present time. Mr. Knowles-Brown commented that that may seem far-fetched but that a famine of gemstones might not occur because there was a dearth of them in the earth. They had entered the Plastic Age. It had come upon us without our realizing it. Veneers had been produced upon plastics in such a way that the veneer was better than the genuine article. This was a factor that they were not realizing at the moment. They were also entering another age—the Synthetic Age. Human nature did not keep pace with scientific research ; he could remember the time when there were no cinemas, no gramophone disc records, no telephones, nor aircraft, and only a few motor cars ; he could also remember when men were happy ! All the things we had now in this modern world had appeared in the speaker's own lifetime. He could not be expected to understand it all. Progress was being made faster and even the younger men in the audience would not be able to keep pace with it. There were things which were a complete mystery to him and yet schoolboys understood and accepted them.

Diamond had now been produced by man; now it seemed that the position of the diamond as the hardest thing on earth was being disputed. Years ago, corundum had been synthesized, but the identification of the synthetic had been a comparatively easy matter. To-day's condition and those of the future would call for a far greater technological understanding and for the use of much more complex and expensive equipment. Gemmologists would have to change their approach to their study of gems. They must be more prepared to identify these synthetics.

The chairman also spoke of the keen and useful work of the Midlands section, represented at the meeting by the Association's vice-chairman, Mr. Norman Harper.

COUNCIL MEETING

A meeting of the Council of the Association was held at Saint Dunstan's House, Carey Lane, London, E.C.2, on Friday, 1st February, 1957. Mr. F. H. Knowles-Brown presided.

The following were elected to membership :—

FELLOWSHIP

Bentley, Dennis C., Epsom. D.1956
Maxwell, John A., London. D.1956

PROBATIONARY

Callaghan, David J., London
Francis, Barry P., London
Hope, Kenneth, London

ORDINARY

Bettis, Violet A., Reading
Cavenago-Bignami, Prof. Speranza Milan (Italy)
Dickenson, William N., Godstone
Hadjizade, Ahron, London
Harland, Ian P., Newcastle-on-Tyne
Kent, Muriel C., Folkestone
Langton, Edward G., London
Rose, William E., Southwater
Staley, Harry F., Birmingham
Warburton, Frederick W., Toronto
Weaver, Gerald O., London (Canada)

DEPARTMENT OF MINERALOGY—BRITISH MUSEUM (NATURAL HISTORY)

Lectures in the Mineral Gallery on Saturdays at 3.0 p.m.

1957

MAY	11th	How new minerals are found ...	Dr. G. F. Claringbull
	18th	Natural glasses	Mr. S. E. Ellis
	25th	The alteration of minerals	Mr. P. G. Embrey
JUNE	8th	Colour in minerals	Dr. M. H. Hey
	15th	Amber	Dr. A. A. Moss
	22nd	Crystal architecture	Dr. G. F. Claringbull
JULY	6th	The story of garnets	Dr. G. H. Francis
	20th	Mineral associations	Mr. P. G. Embrey
	27th	British gemstones	Miss J. M. Sweet

This programme is subject to alteration

TALKS BY MEMBERS

BLYTHE, G. A. : " Gemstones," Women's Fellowship, St. Aidens Church, Belfairs, Leigh, 19th February, 1957.

" Gemstones," Young Conservatives' Association, Prittlewell, 26th February, 1957.

DUNCAN, JAMES M. : " Gemstones," Paisley Naturalists' Society, 11th January, 1957.

FORSEY, PATRICIA : " Gemstones," Auxiliary Missionary Group, Runnymede United Church, Toronto, 28th January, 1956.

JOHNSON, T. J. : " Gemstones," St. Oswald's Church Young Wives' Association, Croxley Green, 11th March, 1957.

WEBB, MALCOLM H. : " Gemstones," 2nd April, 1957, to Church Guild, Maidstone.

WEBSTER, R. : " Modern synthetic stones and fakes," Tunbridge Wells, Tonbridge and District Branch, N.A.G., 8th January, 1957.

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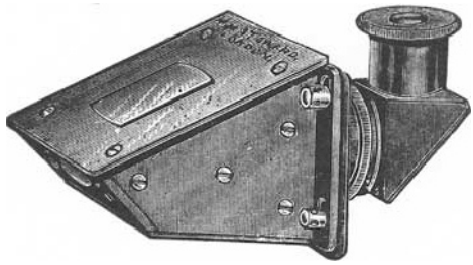

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THE JOURNAL OF GEMMOLOGY

and

PROCEEDINGS OF THE
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RUBY AND SAPPHIRE

by ROBERT WEBSTER, F.G.A.

IT is often difficult for the uninitiated to realize that ruby, with its red colour, and the blue sapphire are one and the same mineral—corundum, and that an impure form of the same mineral is abrasive emery. Both ruby and sapphire have been coveted as gems over the centuries, even when fine quality specimens were more plentiful than they are to-day.

LEGEND

The legend and lore of ruby and sapphire are quaint. The lucky owner of a fine ruby was said to be assured of a life lived in peace and concord with all men—neither his land nor his rank would be taken from him, and his house and garden would be saved from damage by tempests.

Ruby has been claimed to be the most precious of the twelve stones God created when he created all creatures, and this " Lord of Gems " was placed on Aaron's neck by Christ's command. The high esteem placed on ruby is further indicated by the names applied to ruby in Sanskrit. These were *ratnaraj*, which may be translated as " King of Precious Stones " and *ratnanâyaka*—" Leader

of Precious Stones." The Hindoo peoples described the glowing hue of the ruby as an inextinguishable fire which burned within the stone, and asserted that this inner fire could not be hidden and would shine through the clothing or through any material wrapped round the stone. If placed in water the inner heat was communicated to it causing the liquid to boil.

Ruby was said to preserve the mental and bodily health of the wearer, for it removed evil thoughts, and, although considered to be associated with passion, it was also thought to control amorous desires, to dispel pestilential vapours and to reconcile disputes.

Some Indian beliefs were that he who made offerings of rubies to the images or gods in the worship of Krishna would be reborn as a powerful emperor ; or if with a small ruby he would be reborn a king. Rubies, and other red stones whose colour suggests that of blood, were thought to be a remedy for haemorrhage and inflammatory diseases. Such stones were believed to confer invulnerability from wounds, but the Burmese said that it was not alone sufficient to wear the stones, but that they must be inserted into the flesh and thus become, so to speak, part of the wearer's body. Those who in this way bear a ruby about with them believe they cannot be wounded by spear, sword or gun. Ruby is the natal stone for the month of July.

The gem of the soul, and of autumn, sapphire, the natal stone for September, was said to preserve the wearer from envy and to attract divine favour. Fraud was banished from its presence and necromancers honoured it more than any other stone, for it enabled them to hear and understand the obscurest oracles. The ancients thought sapphire to be endowed with the power to influence spirits, to be a charm against unchastity and capable of making peace between foes and protecting its owner against captivity. The Sinhalese respect the star-sapphire as protection against witchcraft.

Tradition is that the law given to Moses on the Mount was engraved on tablets of sapphire, but from Pliny's description the tablets were more probably made from the stone we now know as lapis-lazuli. The religious significance of sapphire was further enhanced in the 12th century, when the Bishop of Rennes lavished encomiums upon the sapphire and began the use of this stone in ecclesiastical rings.

The names ruby and sapphire mean red and blue respectively; the first is derived from the Latin *ruber* and the second from *sapphirus*, the latter being derived from a Greek word of similar spelling. Similar words are found in Persian and Hebrew, and the primary derivation, though uncertain, may have been Sanskrit.

Properties

The mineral corundum, of which ruby and sapphire are the most highly prized varieties, is simply a crystallized form of aluminium oxide (Al_2O_3), and if pure is colourless. Like so many other things in nature a very small trace of impurity will alter a comparatively uninteresting material to one of striking beauty and increased value. A small trace of chromic oxide is the cause of the blood-red colour of perfection ruby, and the oxides of titanium and iron give to corundum the rich blue which alone can be seen in the lovely sapphire.

Corundum crystallizes in the rhombohedral division of the hexagonal system of crystal architecture, but the habit varies greatly, not only by locality, but by variety, ruby crystals usually showing

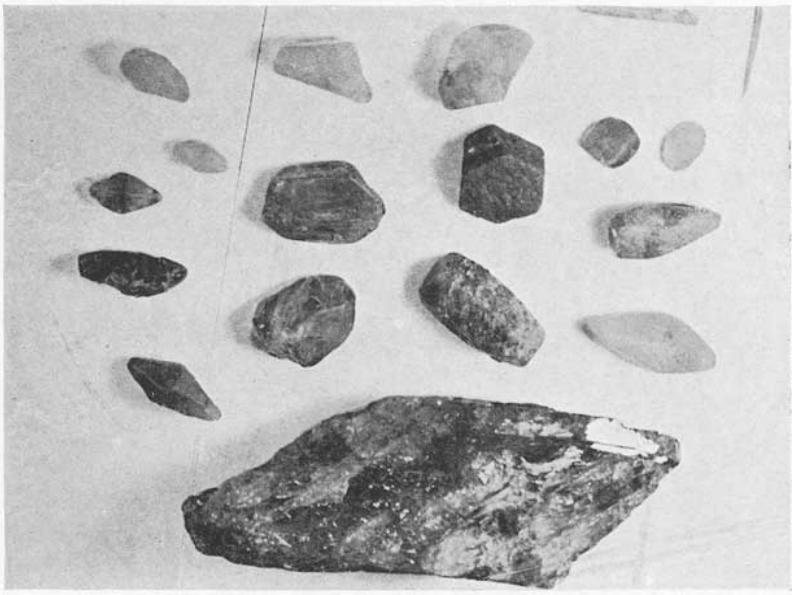

Group of corundum crystals.

a different habit from that of sapphire. Ruby from Burma usually takes the form of a hexagonal prism terminated at both ends by a basal plane at right angles to the faces of the prism, with more or less well-developed rhombohedral faces at alternate corners. These rhombohedral faces may be partly or entirely absent, specially in the large, and usually opaque, crystals from Tanganyika and Madagascar. In many crystals the prisms are very much flattened and although they may be of large diameter, are relatively thin, and such crystals often present a stepped or platy appearance, as though the crystal were composed of a number of thin plates, each a little smaller in certain directions, superimposed on each other. The basal planes of many of the crystals are traversed in three directions by fine parallel striations, which take the form of hair-like lines crossing each other at an angle of 120° and dividing the area up into small equilateral triangles.

Sapphire, and in some cases ruby, usually takes the form of a hexagonal bipyramid of twelve triangular faces, six above and six below, meeting at a girdle. This general habit may occur in

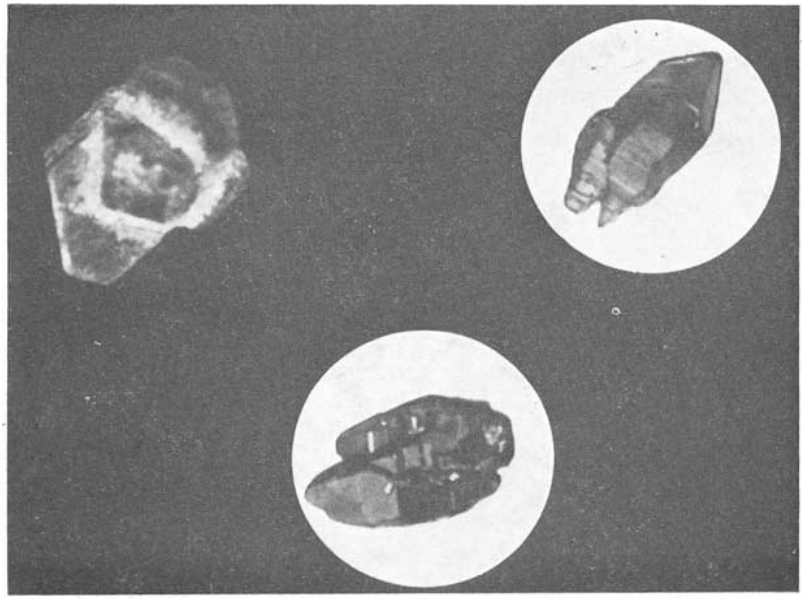

Corundum crystals.
Top left, ruby from Tanganyika. Top right and centre, sapphire from Ceylon.

different combinations of three bipyramids of different inclinations, with sometimes the girdle formed by a narrow hexagonal prism, and the ends of the crystal are often capped by the flat basal face. These forms are aptly described as having a " barrel-shaped " habit. The hexagonal bipyramid habit is common in the sapphire from Ceylon, and in this form the faces are often deeply striated horizontally, due to repeated oscillation between different pyramids. The sapphires from Montana on the other hand tend to take a rhombohedral and tabular habit.

Ruby may vary from the very palest shade of pink, through all shades of red to a very deep crimson, sometimes known in the gem trade as " black." The sapphire may likewise vary from nearly colourless through all shades of blue to a very dark indigo which to the eye appears black. Gem corundum may, indeed, have any colour, such as violet, green, brown, yellow and colourless, which, however, in natural stones is never completely water-white. The pink corundum may be considered as a pale ruby, but there is a decided difference in tint between a pink sapphire—all coloured corundums other than blue and red being termed sapphire with the colour as prefix—and a pale ruby, and this difference the experienced eye can detect. An attractive, although somewhat rare, shade in corundum, is an orange-red colour from Ceylon. This stone has been called *padparadscha* from the Sinhalese word meaning lotus colour, though some authorities contend that there is no need for such a term.

The trace of chromium oxide (Cr_2O_3), which causes the colour of ruby, enters the crystal lattice as a small scale isomorphous replacement. The amount, about 0·4% of chromium oxide, determines the depth of colour, but the presence of iron in the ferric state also modifies the tint, giving to Siam rubies that brownish tinge which is so typical of stones from Thailand. The most highly prized shade of colour for ruby is the so-called " pigeon's blood," a red slightly inclining to purple. There seems little doubt that titanium oxide and iron oxide are the cause of the blue colour in sapphire, although it is considered by some authorities that a trace of chromic oxide can take part in the coloration. This theory gains some credence because a greenish-blue glass can be obtained by the use of the oxides of chromium and iron. There is some reason for assuming that two types of coloration may be

encountered in blue sapphire, for some blue sapphires lose colour on heating and some do not. Titanium and iron are known to be present in sapphire in the form of ilmenite ($TiFeO_3$), and this compound is not isomorphous with alumina, and the ultra-microscope has revealed that the colouring agents are in the form of colloidal particles. This also provides an explanation of the irregular distribution of colour in sapphire. The production of a blue colour in synthetic sapphire by the addition of the oxides of iron and titanium gives added confirmation of the Fe/Ti coloration. There is, however, an added complexity in that the synthetic blue sapphire shows no iron band in its absorption spectrum. Iron is included in the powder used to make sapphire but it tends to volatilize in the heat of the oxy-hydrogen blowpipe flame. The part that iron plays in the coloration is therefore not clearly defined, and, further, benitoite, a barium titano-silicate, a mineral which has a colour so like sapphire, appears to have the coloration due to titania alone, for analyses (by Blasdale) give no iron, and absence of iron is further indicated by the typical fluorescence shown by benitoite under short-wave ultra-violet light.

The density of the purest corundum, that is the colourless sapphire synthetically produced, is 3·989, and the refractive indices for such pure material are ω 1·7687 and ε 1·7606, giving a birefringence of 0·0081 which is negative in sign. The density of ruby and sapphire approximates to 3·997 and there is little variation for specimens of different localities, although the iron-rich types from Australia may go up to about 4·00. The refractive indices do not vary much from the values given for the pure material—slightly higher in most cases—but only in the iron-rich green sapphires do the values reach as high as 1·77-1·78. The hardness of corundum is 9 on Mohs's scale and is the standard for this number. The lustre is vitreous to nearly adamantine and the velvety lustre of perfection sapphires is said to be due to the colloidal nature of the colouring.

The fracture of corundum is conchoidal to uneven and stones need to be handled with some care for they are brittle and if dropped on to a hard surface or given a sharp blow tend to develop internal flaws and cracks. There is no true cleavage in corundum, but there is a false cleavage, or parting, parallel to the basal plane, and two less distinct partings parallel to the prism and rhombohedral faces.

Some authorities contend that these partings are really true cleavages, and other theories are that they are due to pressure and lamellar twinning on these faces, or to weakness caused by incipient decomposition along these planes.

The dispersion of ruby and sapphire is only 0·018, between the B and G lines, hence corundums have little " fire," the beauty of the stones being in their colour nuances only. The dichroism is moderate in most coloured corundums, except in the yellow stones where it is rarely seen. The most attractive colour in both ruby and sapphire is that of the ordinary ray. These are a deep blue colour in sapphires and a deep purplish-red in ruby. In order that a stone may show the best colour it is necessary for the stone to be cut with the table facet at right angles to the vertical crystal axis.

The absorption spectrum of ruby is characterized by fine lines in the red, the strongest being a close doublet with wavelengths at 6942 and 6928Å. Other weaker lines are at 6680 and 6592Å which are more in the orange part of the spectrum. There is a broad absorption band which cuts out the yellow and green light, and another band cuts out the violet end. Therefore the blue light is transmitted and in this " window " there are three narrow lines, a close doublet with wavelengths of 4765 and 4750Å and another line at 4685Å. The doublet in the red, with a mean of 6935Å, is characterized by its reversibility, for under certain conditions it will show as a bright line. This fluorescence line, as it is called—and indeed the fluorescent effects of ruby are due to it—is best seen when light is scattered from the surface, and this is spectacularly seen if a flask of saturated copper sulphate solution be placed in front of the incident light. Then the bright lines are well seen on a black background. This fluorescence line indicates that the chromium, which is the cause of the absorption spectrum, is incorporated in the crystal lattice.

The absorption spectrum of sapphire shows bands due to iron in the ferric state, and the spectrum shows considerable difference in intensity with a decrease of iron content. In the iron-rich green, greenish-blue and greenish-yellow stones there are three evenly spaced absorption bands in the blue region. These are centred at 4710, 4600 and 4500Å, of which the 4500Å band is the strongest and most persistent. This 4500Å band is sometimes so

wide that it merges with the 4600Å band giving a two band aspect to the spectrum. With decrease of iron content these bands, usually known as the 4500 complex, decrease in intensity until in the case of the rich blue sapphires only the 4500Å line may be seen and that often only with difficulty, even with the aid of the copper sulphate filter before the light source, which filters out the brighter light from the longer wave end of the spectrum. Many Ceylon sapphires show the bright red fluorescent line at 6935Å, due to a trace of ruby, and the 4500Å sapphire line is only seen in them with great difficulty.

The other colours of sapphire have an absorption spectrum reminiscent of the colour nearest to it, such as the pink and violet sapphires which show the spectrum of ruby, although the lines in the blue may be much weaker. Colourless and brown sapphires do not exhibit an absorption spectrum which can be observed in the spectroscope. Unlike stones from other localities, the yellow sapphires from Ceylon do not show the 4500Å complex, iron apparently not being the colouring agent in this case. The absence of iron is borne out by the unusual fluorescence shown by this variety of sapphire. In one case only, that of an orange-red stone from Burma, has a line at 4750Å been seen. This line, which is attributed to vanadium, is diagnostic for the synthetic sapphire coloured to imitate the alexandrite.

The luminescence of the chromium-coloured corundums, ruby, pink and violet sapphires, shows when bombarded with long- or short-wave ultra-violet radiations, or X-rays, a strong crimson light. This is due to excitation of the chromium ion, the glow being due mainly to the intense emission from the doublet at 6935A. This red glow can be seen spectacularly when viewed between " crossed filters "—that is, by placing the stone in a beam of blue light which has been passed by a copper sulphate filter and viewing the stone through a filter which passes only the red rays. The stone then appears glowing red on a black background. This is because blue light will also excite the chromium ion. If this fluorescence light be examined with a spectroscope the bright lines are the same as seen in the absorption spectrum. This discrete spectrum only occurs when electronic shifts, to which the luminescence is due, are sufficiently screened by an outer electron shell so as not to be too greatly interfered with by the surrounding atomic field. This

effect appears to occur only with chromium, rare earths, and diamond ; in the latter case, however, the mechanism is somewhat different. When rubies are viewed through the Chelsea colour filter this fluorescent red may be seen and this is a convenient method to adopt when picking out rubies from a mixed parcel of rubies and garnets, the latter not fluorescing.

The fluorescence of ruby has been suggested as a test for distinguishing between rubies from Burma and those from Siam—and for distinguishing synthetic stones from natural rubies. Experiment has shown that it is impossible to pick out the synthetics with any degree of certainty from a mixed parcel of synthetic and Burma stones. Owing to the damping of the fluorescence by iron content, rubies from Siam show a much weaker fluorescent glow than those from Burma, which glow brightly. This effect has been suggested, and used, as a distinction between the two sources of ruby. While this usually operates in typical cases it is apt to fail in precisely those cases where it is most needed, such as in the case of a deep-coloured Burma ruby and an exceptionally fine Siam stone. It should be mentioned at this stage that the gem trade refers as Burma rubies to stones of a typical red colour, and as Siam rubies to all those stones which are darker, or show a slight brownish or violet tinge, and do not approach the " ideal " red. Ceylon rubies to the trade are those lighter coloured rubies approaching the pink sapphire. True localities may not necessarily be meant, although the designation may be correct in eighty per cent of the cases.

In the case of the blue sapphires the luminescent glow is practically non-existent. An exception, however, is the Ceylon sapphires which contain a trace of chromium. These show a red or orange glow under long-wave ultra-violet light. Under short-wave ultra-violet light some blue sapphires show a weak blue glow, an interesting observation in view of the bright blue glow shown by the titanium mineral—benitoite—under the short-wave lamp, while it is practically inert under the long-wave rays. Most sapphires are inert under X-rays, except the Ceylon, Montana and some Indian (Kashmir) stones which may show a dull red or yellowish-orange glow. It has been reported that under bombardment by cathode rays (fast moving electrons) Kashmir sapphires show a greenish-blue glow, Burma stones a strong dark purple, Siam stones a weak dull red, and sapphires from Ceylon a vivid red fluorescence.

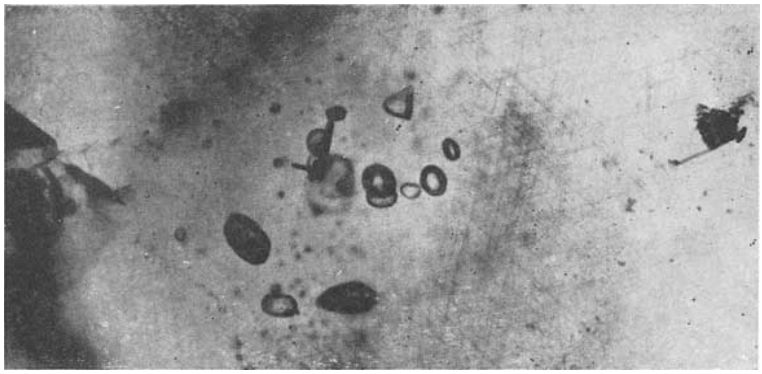

Inclusions and silk in a Burma ruby.

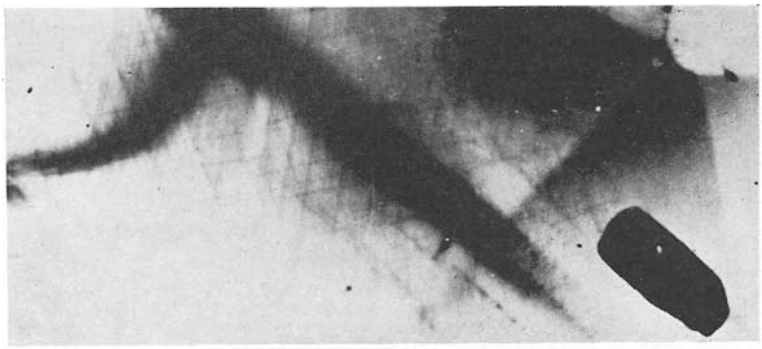

Large crystal and silk in a Burma ruby.

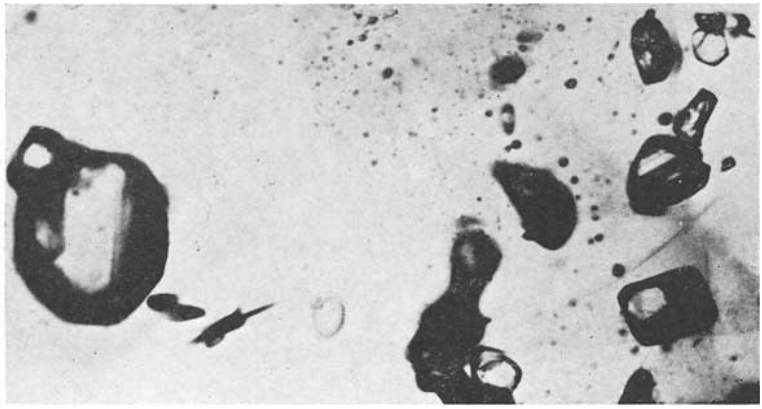

Inclusions in a Burma ruby.

The iron-rich green and yellow sapphires show no luminescence under any of the aforementioned radiations, but the yellow stones from Ceylon show a strong apricot-yellow glow under ultra-violet light and X-rays. The cause of this particular luminescence does not appear to be known. Such stones when bombarded by X-rays turn to a rich topaz-colour, however weakly yellow they were originally. This colour is not permanent for the colour reverts on exposure to about 3½ hours sunlight or quickly when the stone is heated to a temperature of about 230°C. Colourless sapphires may also suffer this change of hue by X-ray bombardment, but the shade of yellow attained is usually lighter ; and further some blue sapphires will change to a dirty amber colour.

Much work has been carried out, particularly by E. Gübelin in Switzerland, on the nature of the inclusions in corundum, with a view to identifying the locality from which the stone emanates. It is the writer's opinion that while in some cases the evidence so obtained is sufficient to give an indication, in many cases there are insufficient grounds to formulate a satisfactory conclusion, and, apart from other factors, this is the primary reason why most gem-testing laboratories refuse to certify the locality of a stone.

Burma stones, especially rubies, show a system of short rutile needles arranged in three directions parallel to the faces of the hexagonal prism, that is crossing each other at angles of 60° and 120°, and these lie in planes at right angles to the principal axis of the crystal. To these needles, which may in some cases have decomposed leaving canal-like cavities, is due the shimmering whitish sheen popularly known as " silk." Stones from Burma may show included well-formed crystals of rutile, octahedra of spinel and mica platelets. Rounded crystals of corundum, zircon and garnet make up the general picture of corundums from this source. The rich bright red colour of Burma rubies is often to be seen in swirls, rather like the effect seen when treacle is stirred, hence this colour swirling is sometimes known as " treacle."

Siam stones usually show " feathers " consisting of large loop-like systems of a reticulation of fine canals which often enclose swarms of hexagonal shaped " slabs." Quite commonly these " feather " systems contain a conspicuous black inclusion. Siam stones often contain tubes or tube-like liquid inclusions in cross-joined parallel arrangement producing a script-like design. Other

common features are flat cavities of brownish colour and twin planes, the latter often in two sets at approximately right angles producing a checkered design. These are more pronounced when the stone is viewed between crossed nicols.

Corundums from Ceylon show rutile needles which are characterized by being longer and more widely spaced than in the stones from Burma. They often traverse the whole stone. Very characteristic of Ceylon stones are inclusions of zircon crystals, each of which is surrounded by a " halo " of brown colour due to stresses caused in the host mineral. The well-defined " feathers " seen in stones from this island consist of large networks of irregular liquid-filled cavities. Clearly defined colour-zoning is common in Ceylon stones.

The sapphires from Kashmir owe their attractive milky or hazy appearance to a fine veil-like formation of hazy lines oriented at 120° to each other. The " feathers " in such stones usually

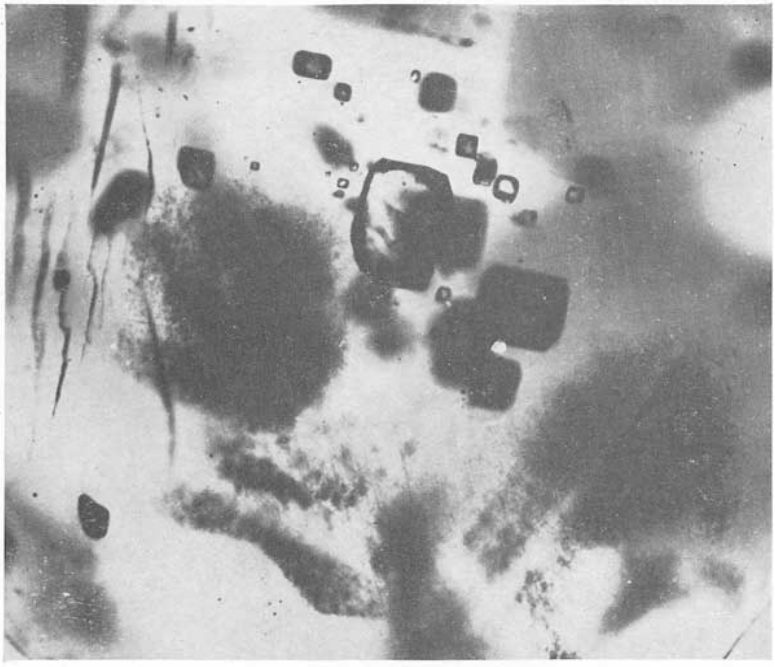

Zonal silk and large crystals in a Burma ruby.

consist of thin films of yellow or brown colour with the edges terminated by an irregular system of liquid-filled canals. The stones from Montana, U.S.A., contain negative crystals surrounded by, or in near proximity to, extremely flat liquid films. Typical inclusions in such stones are long rods or tubes with projections making them appear rather like feather quills. The many accessory minerals seen in corundums from oriental localities do not appear in Montana stones. In Australian stones the " feathers " are liquid-filled cavities and dark flat cavities, and zonal structure is most pronounced.

Bound up with the internal features of corundums are the star-stones, or asterias, which to many have such a fascinating appeal. Much consideration has been given to the reasons for the production of the star-like effect seen in these attractive stones, and the theories have been summed-up, and added proof deduced by the work of Alice S. Tait. The " silk " which has been previously mentioned may so impregnate the stone that the tubes or fine needle-like crystals running in three directions parallel to each pair of prism faces completely fill the crystal. If a stone be cut in the

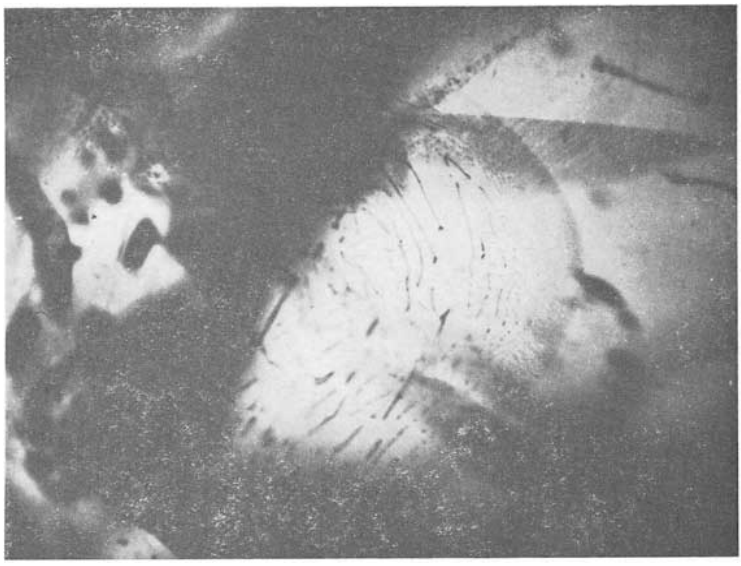

Feathers in a Ceylon sapphire.

cabochon form from such material, so that the base of the cabochon is at right angles to the vertical crystal axis, that is parallel to the basal plane, three rays of white light cross the stone at right angles to the direction of the needles, thus producing a six-pointed star. This light is by reflection from the fibres and is termed epiasterism. If only one set of needles be present, as occasionally may happen, just one ray of light will be seen in a suitably cut stone, therefore under these conditions a corundum cat's-eye will be produced. Rarely, a six-rayed (12 pointed) star is seen in asteriated corundums. This effect is understood to be due to oriented needles not only conforming to the prism faces of the first order prism, but to the addition of a second set of three parallel to the faces of the second order prism which lie at 60° from those of the first order. Thus, there will be not only the three rays of light from the needles parallel to the first order prism faces, but a second set of three rays due to the needles parallel to the faces of the second order, thus producing a six-rayed, or twelve-pointed, star. Tait has found, from the shape of the needles and by spectroscopic examination of the material of the needles, that they are rutile crystals. It

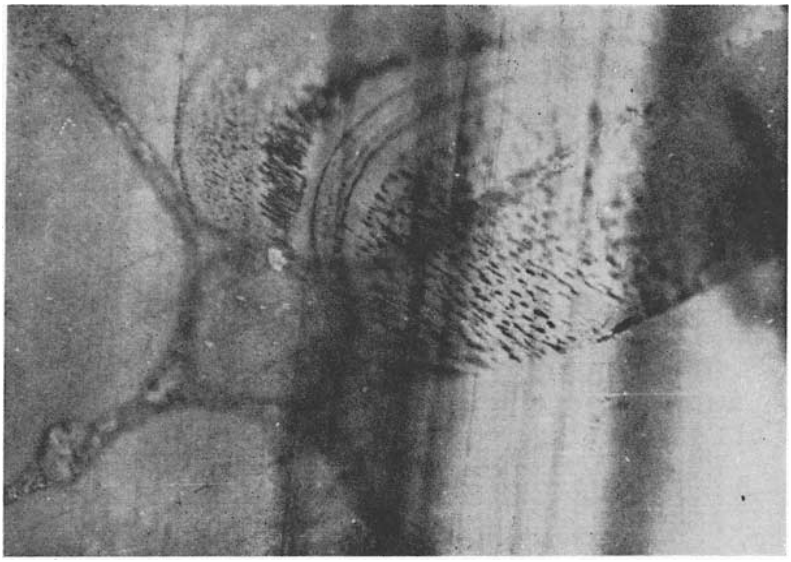

Feather and zoned silk in a Burma ruby.

should be mentioned that in order to see the star effect (called *asterism*) to the best advantage, the stone should be viewed by light reflected from a single overhead light ; a room with a multiple number of lights destroys the effect. Star-stones may be of any colour, but the red-coloured material (star-ruby) is the most prized, and the fine blue (star-sapphire) next in value, but much depends upon the brightness and symmetry of the star and the body colour of the stone. Pink, violet and brown colours are common, but a stone with a nearly black body colour makes a most lovely asteria.

There are few true rubies with an individuality, and except for the Chhatrapati Manick so charmingly described by V. Clarke, the 43 carat " Peace ruby " a crystal found in 1919, another crystal, but not of true gem quality, the 167 carat Edwardes ruby in the British Museum (Natural History), and the 100 carat De Long star ruby in the American Museum of Natural History, there are no rubies to which names have been applied. The historical " Black Prince's ruby," which graces the front of the Imperial

Inclusions in a Siam ruby.

State Crown, and the "Timur ruby" which is also part of the Crown Jewels, are both red spinels.

Among sapphires there are a number of fine stones, among them the St. Edward's sapphire and the Stuart, or Charles II's sapphire, both of which are companions to the Black Prince's ruby in the Imperial State Crown. The American gem dealer, Harry Winston, has, or had, in his possession several lovely large sapphires, one the so-called Catherine the Great's sapphire and another gorgeous stone weighing 337·10 carats. In the American Museum of Natural History is a 536 carat star sapphire known as the Star of India and a smaller black star called the Midnight Star, weighing 116 carats. That sapphires can attain a large size is amply illustrated by the work of Norman Maness, who spent 1,800 hours carving a 2,302 carat sapphire into the form of the head of Abraham Lincoln.

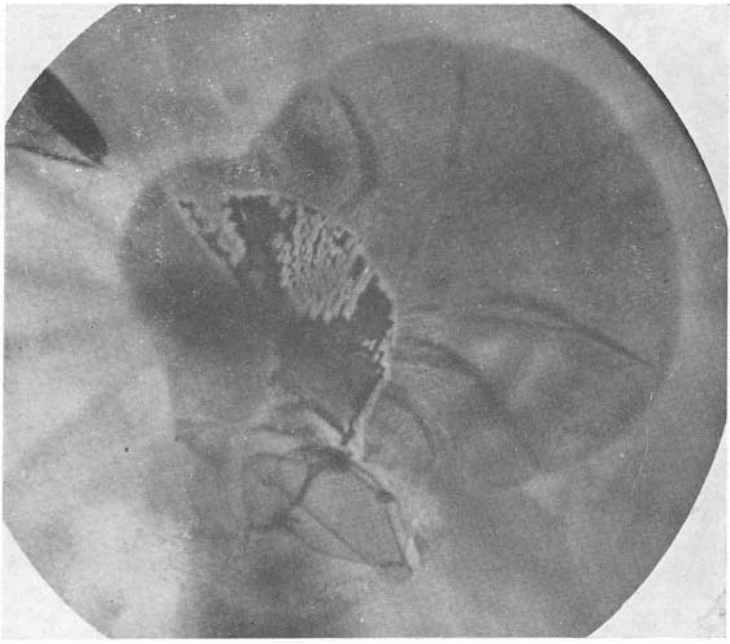

Large feather in a sapphire.

BURMA

The most famous locality, and maybe the only locality for fine rubies, and much fine sapphire, is the district around Mogok in Upper Burma. This so-called Mogok Stone Tract is an area of some 400 square miles, but the area now being spasmodically worked is some 25 miles from the town of Mogok itself.

When the Burma ruby mines were first discovered is quite unknown. The earliest that is heard of them is in a Burmese legend of untold age, which relates of an inaccessible fever-stricken valley in the Chinese Country, into which human beings could not descend, but into which lumps of raw meat were flung from the surrounding hills, to be retrieved by the vultures, and from which the adhering rubies were picked off. This legend corresponds with the writings of Marco Polo (1254-1323), and he must have picked this up during his wanderings in Cathay (China). On this legend is based the story of " Sinbad the Sailor." A further proof of the great age of the mines is the comparative abundance of prehistoric implements both of stone and bronze age found amongst the detritus of the mining.

The first real record of the mines is that early Burmese history records that they were taken over from the Chinese in 1637, in exchange for Mong Mit (Momeit) and that mines were then in full operation in the valley. The country, covered with dense forest, was so notoriously unhealthy that there was a shortage of labour, and to alleviate this King Bodawgyi sent thousands of captives from Manipur to work in the mines. This was about 1780, and subsequently the place became the place of exile for those who had incurred the king's displeasure. Shortly afterwards the district was placed in charge of Governors or So-Thuygis (So's) who allowed mining on payment of a tax, with a stipulation that all stones mined of an individual value of two thousand rupees and over were the property of the king without payment. This went on for some years and the So's enriched themselves greatly by oppressing the miners and forcing them to sell their stones for little or nothing to themselves. As they held absolute powers of life and death, the So's were very well placed to terrorize the unfortunate miners. Things went from bad to worse, and the miners deserted their villages and left the district.

King Mindoon Min then took over the district and control of the mines but made such a bad job that in 1863 another Governor

was appointed with the responsibility of collecting a tax of some £5,000 a year from the miners, to be paid directly to the king, beside what the So could collect for himself. Under this arrangement matters became much worse and a rebellion took place, the whole Stone Tract being beset by gangs of fierce robbers, and practically deserted by peaceful miners. As the king was getting no revenue he made mining free to everybody, and the miner had the right to sell all stones under 2,000 rupees in value—the king taking all stones above this value—to anyone within the Stone Tract, but not outside of it. All stones not sold in the Stone Tract had to be sent under seal to a central ruby mart in Mandalay. Here they were offered for sale, and if sold the purchaser paid 10% and the owner 5% on the price by way of tax. If no sale took place the owner paid 10% on the valuation and was then free to sell the stones anywhere. This restored prosperity for a time, but abuses again became apparent, mainly on account of the king's demand for more revenue, not only from the mines but from the Governors, which

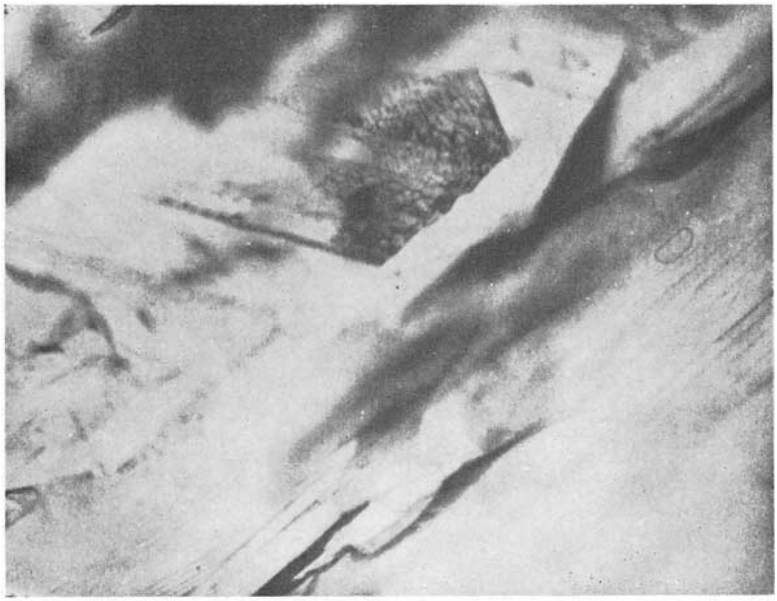

Inclusions in a Siam ruby.

they obtained by again oppressing the miners and swindling the traders who came to the mines to buy. These demands for more money grew apace and in 1885 King Thebaw appointed a Governor whose business it was to find no less a sum than £16,000 per annum. This was the last straw, and the district again entered a state of chaos. The villages were raided daily by gangs of robbers forcing the villagers to go about in armed bands for self-protection. The road from Mogok to the river was infested with robbers, three local bandits establishing a convoy system down the road, demanding as much as ten rupees a head for a safe passage ; if travellers did not pay they were simply robbed or murdered. At this time King Thebaw was negotiating with a French syndicate for a lease of the mines, and this was one of the deciding factors which led to the annexation of Upper Burma by the British in 1886.

After the annexation, Streeter, the Bond Street jeweller, who was said to have been negotiating with Thebaw, obtained a concession from the British Government to work the mines. The

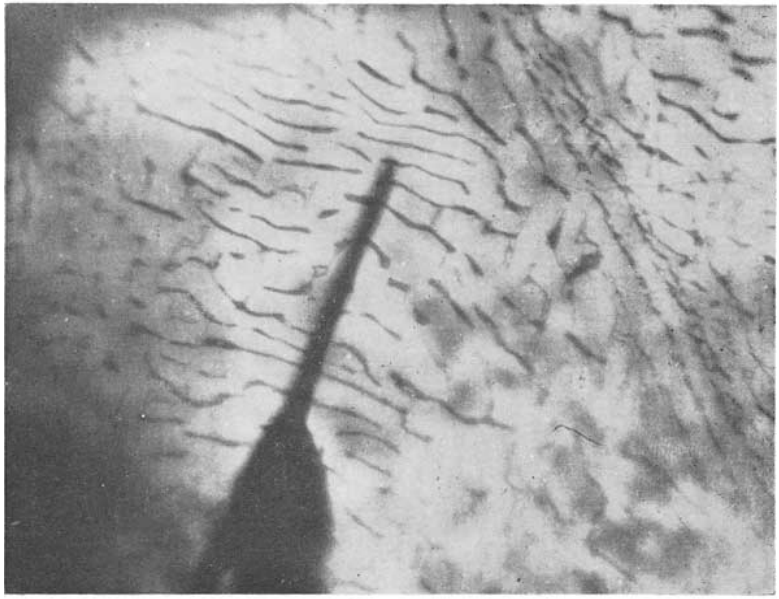

Liquid-filled feather in a Ceylon sapphire.

Burma Ruby Mines Limited was immediately floated and the issue was over-subscribed in a few minutes and double the amount, £300,000, could have been easily raised.

The British Government's annual rental for the mines was fixed at the tremendous sum of £30,000 plus 30% of any profits, in return for which the Company were to have the right to work any unoccupied land with the use of machinery. The native miners were to be allowed to continue working by purely native methods, on payment to the Company of 30% of the value of their declared finds. It was thus considered that the Company would have a monopoly of rubies and would be able to control the price of them. This was a mistaken idea as was soon evident ; for the native miner naturally concealed the greater part of his finds and produced absurdly small parcels for valuation. The smuggling of the concealed stones was a simple matter and quite impossible to check, and these stones coming on the market stopped any regulation of the price of rubies. Subsequently new arrangements were made whereby the native miner paid a fixed monthly fee of twenty rupees a month for each workman he employed. This fee went to the Government but was collected by the Company, who received 10% of the total for their services. The annual rent for the mines was reduced by 50%, and was subsequently abolished altogether in view of the open market created by the native miners selling their stones.

At the beginning the Company's engineers were confronted with a task of great magnitude. The ruby bearing alluvials were found to lie deep down under heavily water-logged valleys, and a considerable portion of the ruby-bearing ground was under the town of Mogok itself. This entailed purchasing the buildings and re-erecting the town on another site. Heavy machinery and pumping plant had to be brought for sixty miles over a rough mule-track through dense fever-stricken jungle infested with wild animals, from tiger to elephant, and passing over mountains five thousand feet high. It took over a year to make a road passable by very light bullock carts, which took three weeks to make the journey and could not travel at all for seven months of the year. Rinderpest was a scourge, and machinery lay abandoned on the roadside for months owing to lack of transport. These difficulties were eventually overcome and a good road constructed. At the

mines a 400 kilowatt hydro-electric power station was opened, a low-level drainage tunnel constructed for a mile through a mountain range at a cost of £40,000 and five large washing mills, each dealing with some thousands of tons of earth per day, put into operation. Subsequently, three more mills were erected eight miles away near Kyatpyin, and the mines entered on a period of prosperity.

The mines were worked by the open-cast method, there being no underground working at all. The first process was to take all the earth from grass level to bedrock and truck it away to large washing mills by hand labour and rope haulages. This method was subsequently superseded by a system of washing the earth down by large jets of water (monitor jets) under high pressure and passing the earth through a series of sluice-boxes, to which it was elevated by large gravel pumps, which made a great saving in mining costs.

All went well with the mines and the Company was paying dividends until 1908, when the synthetic ruby was placed on the market, causing an immediate panic and making rubies difficult to sell. At the same time America was passing through a depression and the prices of fine rubies fell, while the depreciation in lower grades was much greater. It was the beginning of the end for the company, although all through the lean years of the First World War Burma Ruby Mines Limited struggled on. The company fought a losing fight until 1925, when it went into voluntary liquidation, only to struggle on further until 1931, when it finally surrendered its lease to the Government.

On the cessation of activities by the Burma Ruby Mines Limited the mining was carried on by native miners working by their primitive method. Up to the commencement of World War II these miners paid a monthly fee of ten rupees per workman to the Government, but for an enhanced fee were allowed to use water and explosives. In order to obtain a licence to mine in Burma it is necessary that one's name should be on a very arbitrary list of Registered Miners, but those on the list are often willing to lend their names to the less fortunate for a consideration. A licensee usually employs three workmen, who receive as payment 50% of the total profits of the mine for the month to share between them. Every market day they draw a very small advance for the purchase of food, and if the month's work shows a loss that amount is wiped

out, and they receive no further payment. If the mine shows a profit this sum is deducted from the 50% of the total profits of the mine.

In the dry season these men mine by sinking a shaft on to the layer of *byon* (the name applied to the gem-bearing alluvial gravel) ; if there is little or no subsoil water these pits are merely small round holes just large enough to allow a man to descend into them. They are sunk very rapidly and contain no timbering. The pits are called *twinlon* and are usually from twenty to forty feet deep. After this depth they are often unsafe, but in very favourable ground may go down to one hundred feet. At this depth a second shaft is sunk parallel to the first, and is connected with it by openings at intervals for the purposes of ventilation.

One workman simply squats at the bottom of the shaft and loosens the earth with a tiny spade, and then presses it into a small bamboo basket with his hands. This basket is hauled to the surface by the second workman by means of a balance crane constructed of three bamboos, and a basket of heavy stones, or other weight

Twinlon workings, Mogok Stone Tract.

known as a *maungdaing*. Light is reflected to the workman below by means of a piece of tin set at an angle above the hole. Until the *byon* is reached the earth removed is thrown away, after which side tunnels are driven by two workmen along the *byon* in every direction for about forty feet. Every scrap of *byon* is carefully removed from the entire area. The tunnels are allowed to fall in when finished with, but are consolidated so as to provide support for the top whilst the other galleries are being driven.

If the ground contains water a *twinlon* would not stand so a square pit known as *lebin* is put down. This has sides two foot each way and is lightly timbered with brushwood and leaves held in place by thin sticks to keep the wet earth in place. Such pits may go down for over two hundred feet. Larger pits with sides of four and a half feet are known as *kobin*, while still larger ones with sides of twenty to thirty feet are known as *imbye*. These large heavily timbered pits need a number of men to operate them and are expensive to work.

Water is removed from the wet pits by bailing with fuel-oil cans tied to the *maungdaing* or by the use of an ingenious bamboo

Washing the byon, Mogok Stone Tract.

pump, which is best explained by reference to the illustration. Effective down to a depth of twenty feet, the pumps are arranged in relays for greater depths.

In the rainy season when the pits cannot be worked the hillside deposits are tackled. The miner makes a cutting into the hillside washing the loose earth away by means of sprays of water falling from bamboo pipes placed at a height above the working. The light earth is allowed to wash away to waste while the heavier sands and gravels are led away to narrow water courses, where the heavier portion, containing the gems, is trapped in holes made in the channels and is sorted by hand. This method of mining is known as *hmyawdwin* and may be of any size from an insignificant cut to an enormous opening. The water to work the mines is often brought from long distances by channels cut in the rock, and even through tunnels, being carried over valleys on high bamboo aqueducts in bamboo mats luted with clay.

The deposits in the interior of the hills are contained in the cracks and crevices in the rocks, which often open out into large caverns of great beauty. These caverns are reached by long tortuous passages, so small that a man can scarcely worm his way along them, and such mines are called *loodwins* or *loos*. Some of the finest stones are found in such *loos*.

The local streams are worked for the gems by rudely damming them with logs and brush wood and the gravel held up by this being dredged out by hand and small baskets. The return from this source is usually poor.

The *byon* removed from the mines is placed in a pear-shaped washing place called a *yebangwet* and is then broken up with water by men using hoses. The slurry formed is allowed to fall into a channel from the narrow end of the *yebangwet* where the heavy gravels are trapped in a series of holes dug in the floor of the channel. This heavy concentrate is removed and more highly concentrated by hand in small round bamboo trays. This residue is then sorted by hand for the gems.

In all the streams poor women armed with round bamboo trays may be seen scraping up the gravel from the bed, and sorting it for rubies. This is a hereditary right for women only and is known as *kanase*. It is free of all fee and licence and the

women must not be interfered with. Usually their finds are small.

What goes on in Burma to-day is to some extent conjecture, for the Mogok Stone Tract became part of the battleground of the 14th army and the Japanese invader. Burma is now no longer a British possession and it is not known what fine sapphires and rubies now emanate from Burma.

The Burmese ruby occurs embedded in a mother rock of white dolomitic granular limestone, or marble. This is a common rock of the district and is said to be originally a sedimentary limestone, which has suffered metamorphism by contact with intrusions of igneous rock causing the calcium carbonate to recrystallize out as marble, and its contained impurities to crystallize out as other minerals including corundum. The sapphire from the Burmese locality is, however, not found *in situ* in the marble, but in a feldspathic rock. It is in the alluvial deposits derived from the weathering of the parent rocks that the gem corundums are mostly found ; this is the *byon.* Rubies predominate around Mogok, whilst sapphires are more common at a site some eight miles away, near the village of Kathe, which is some 100 feet higher than the Mogok valley. At Bernardmyo, at an elevation of some 300 feet above Mogok, rather dark-coloured stones are found in a hard black iron-cemented conglomerate.

Siam

The next most important occurrence for rubies and sapphires is Siam, where the rubies are rather a brownish-red and somewhat dark in colour, while the sapphires are of excellent quality. The main occurrence covers a considerable area in the neighbourhood of Chantabun, where rubies predominate, and Battambang, important for sapphires, and the deposits spread over the border at Phailin in Cambodia. The stones are found in a coarse yellow or brown sand, overlaying a bed of clay or basaltic rock. The beds are mostly within six to eight feet or less from the surface, but some of the mines are over twenty feet deep. The Siam deposits have only been worked to any extent in comparatively modern times and at one period were worked under a concession by an English company. The mining is by native methods and the miners are mostly Burmese.

KASHMIR

Sapphires of a magnificent colour, possessing a fine milky lustre, often of a fine cornflower-blue with a slight milky appearance, are found in the Zanskar district of Kashmir. The mines are near the village of Soomjam (Sumsan) in the Pader District. The deposits were said to have been first discovered by an avalanche laying them bare in 1881, but there is reason to believe that the local inhabitants knew of them much earlier. The deposits lie in a small valley about half a mile long by a quarter wide in the Kanskar Range of the north-western Himalayas. The valley, on a tributary of the Chenab, lies approximately midway between Srinagar and Jammu at an elevation of 14,950 feet, and except for a few months of the year is under deep snow. The stones occur in a pegmatite vein in association with tourmaline, garnet, kyanite and euclase. The pegmatite veins penetrate lenses of actinolite-tremolite rock in crystalline limestone ; the sapphires are often found in pockets of kaolin derived from the pegmatite. When first discovered the sapphires were extracted from the face of a precipice at the head of the valley, and it was not until some years afterwards that the whole floor of the valley was found to be covered with a thin layer of white pegmatite overlain by a few feet of ordinary earth which carried sapphires in immense quantities. Mainly due to the severity of the climatic conditions the work was carried on in a desultory way until 1924, when the mines were re-opened after the deposits came under the notice of the Kashmir Mineral Survey. The crystals are well-formed and often of large size when found in the rock, but the stones found in the valley are water-worn and rarely show crystal form. The crystals are said frequently to enclose green tourmaline. Cut stones, which make excellent night stones, often contain " silk," and according to some reports also contain inclusions of green mica. Little is known of the mining methods. The mining must be primitive, for the stones are picked out by hand, a very crude form of ground sluice being used.

CEYLON

In the south-west part of the island of Ceylon are found corundums of many colours—blues (usually rather pale), violet, yellow, white, green and pink, which often attains a quality comparable, to that of ruby and is, if a rich enough rose-red, called a Ceylon ruby. Star-stones, too, are plentiful in this island but as a rule

have not a colour which can be said to be fine. Pit-mining is carried on in Ceylon in a similar manner to the Burmese system. The miner searches for the small and scattered localities by observing the surface for signs of rolled pebbles. These localities are often in the rice paddies, and having found what he hopes will be a good spot, the miner sinks a pit which goes down, maybe, fifty feet to reach the gem-bearing strata known as *illam*, which is a blue and yellow mud. Sometimes the gems are found embedded in boulders of semi-decomposed gneissic rock. If the miner is not successful with his first pit he must fill it in and start another somewhere else. If he strikes gem gravel, then it is brought to the surface and panned by the use of a finely woven basket. The gravel is washed by placing it in the bottom of the basket and being broken up by water, the light mud separating off through the fine meshes of the basket and the heavy concentrate sinking to the bottom. This is then searched for gems, which are subsequently sold by auction. Much of the gem material won from the *illam* is cut and polished by native craftsmen on the island. Squatting outside his cottage, or in a back alley, the cutter fashions the corundum gems on a small wooden wheel mounted at the end of a horizontal shaft which is rotated by a drawstring bow which he saws back and forth. For polishing, a chamois leather pad is fixed over the vertical lap, and the stone is usually held in the hand while being cut and polished. The Sinhalese cutter aims at getting the most weight out of a stone, so that the proportions are wrong by European standards, the base being overweight and often not symmetrical. Much blue sapphire from Ceylon is parti-coloured and the wily native cutters cut such stones with the blue colour at the bottom of the pavilion, so that by total internal reflection the stone when viewed from the top appears a good blue colour ; such stones looked at sideways are found to be colourless at the top and the patch of blue near the culet. Some blue sapphires from the island contain a trace of ruby (chromium) and although they are a good blue colour in daylight they tend to turn purple when seen in artificial light. In common with many stones of other species that are found in Ceylon the corundums from this locality often show as inclusions small crystals of zircon surrounded with circular dark areas where stresses from the zircon have affected the surrounding host mineral. These inclusions are usually known as " zircon haloes."

Australia

Corundum, mainly blue, green and yellow colours, but some ruby, is found in Queensland and New South Wales, Australia. The Queensland sapphire fields are located around Anakie and extend for some two hundred square miles. Ruby Vale is a prominent locality for Queensland corundum and at Willows, some 212 miles west of Rockhampton, a 28 pennyweight yellow sapphire was found in 1946. The Anakie deposits, discovered in 1870, are along the banks of creeks and not in the beds of the present streams, the stones being found in a clayey, or loose and friable, alluvium. Owing to the arid nature of the area, sluice-boxes are not often used and the mining is carried on by hand-picking and by the use of hand-sieves. The New South Wales deposits, which are centred around Inverell, west of the New England Range, lie in the north-east part of the state. The sapphires are found in an alluvial deposit of recent age, and here the mining is carried on by dredging and the sapphires reclaimed by the use of sluice-boxes and pulsators. Australian sapphires are usually rather dark blue and somewhat inky, the yellows are of an attractive greenish-yellow, and Australia produces probably the best of the green stones. The greenish tinge of the stones is due to iron, and this is shown by the strong 4500Å complex seen in the absorption spectrum, by the slightly higher constants and by the lack of luminescence when under a beam of ultra-violet light. Australian corundums usually show dark "feathers," but also show strong colour-zoning. Some sapphire is found, too, in the north east part of the island of Tasmania.

U.S.A.

The only important locality for gem corundum in the United States is in Montana, where it is found as water-worn pebbles in the gravel bars of the Missouri river, and at Yogo Gulch, near Utica, where flat gemmy crystals, pale in colour but with a curious metallic lustre, are found in nearly vertical and much weathered dark-coloured fine-grained igneous dykes. The crystals are small and only furnish stones suitable for calibre work, or for instrument jewels. The blue stones have a decided greenish tint and a bright metallic lustre ; ruby is not common, and the same may be said for star-stones. Montana sapphires make attractive night stones. Small rubies of fair quality have been found in Macon County, North

Carolina, the stones being found in the sands of Cowee Creek. Blue sapphire is said to occur in Colorado and Idaho.

Other Occurrences

Corundum is of wide-spread occurrence, but the above-mentioned occurrences are the important gem localities. There are a few minor sources of gem material which have little commercial significance. There is a small deposit of ruby at Jagdalak in Afghanistan, some thirty miles east of Kabul, and small corundums of various colours are found in the Somabula Forest in Southern Rhodesia. About 1952 a number of large ruby crystals of excellent colour but rather opaque were found by A. G. Clough in the Matabatu Mountains of the Northern Province of Tanganyika Territory. The short prismatic ruby crystals are found, sometimes as aggregates, in a bright apple-green zoisite rock. At the same period, possibly found in the local alluvium, were small water-worn pieces of ruby which were transparent enough to cut ; and some of these

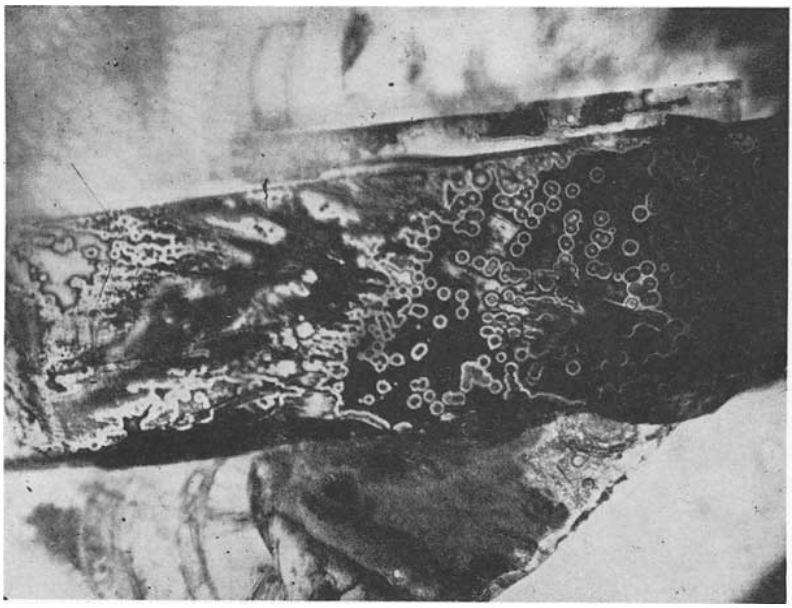

Feather or flaw in a Burma ruby which has " boiled out " owing to overheating by a blowpipe flame.

stones were cut and, it is believed, marketed. These cut specimens were a rich colour, as good as much Burma material, but the stones were not so transparent and were extremely chrome-rich. Similar red crystals are found in Madagascar at Gogogogo, east of the Linta River in the south western part of the island. The matrix here is said to be a green mica schist. Sapphire is also reported to have been found in Madagascar. Gemmy corundum has been mentioned as occurring in Czechoslovakia, the U.S.S.R. (Ural Mountains), Rumania and Borneo, and as a matter of interest, small blue sapphires, of no use for gems, are found embedded in the rocks of the Isle of Mull, Scotland.

Rubies and sapphires may be faceted in many different styles; mostly the mixed-cut is used, the brilliant-cut crown being backed with a step-cut pavilion. For fine stones the step- or trap-cut is often employed, and if the material be poor in quality or much flawed it may be cut into beads or even carved. Star-stones are cut cabochon in order to exhibit the attractive optical effect of asterism. Pale stones are often mounted with a closed setting and the back of the stone sometimes foiled with a suitable colour. Bingley states that it was formerly the practice, in the case of blue sapphires, to place under the stone the blue part of a peacock's feather instead of foil.

Synthetic Corundum

Ruby has a value so high that it was one of the first stones to warrant experiments in an endeavour to make the stone synthetically. These experiments leading to successful synthesis were essentially a French endeavour, and to-day there is an industry in France and neighbouring Latin-speaking countries.

The first experiments were carried out by Marc A. A. Gaudin, who, whilst at the Bureau of Longitude, was the first to melt quartz and produce silica glass by the aid of the oxy-hydrogen blowpipe. Gaudin, using a similar technique, attempted to make rubies by fusing a mixture of alum and a little potassium chromate, but although crystals of corundum were formed, they were opaque on cooling and did not take the colour as expected. In 1847 Ebelmen, using borax and boracic acid as a type of flux, made ruby from alumina and chrome oxide. These crystals were in the form of thin hexagonal lamellae.

In 1885, or perhaps three years earlier, a number of rubies came upon the gem market and at first were accepted as genuine. Soon their natural origin was questioned, and it transpired that the stones had been made by the direct fusion of small fragments of well-coloured natural ruby. These so-called "reconstructed rubies" were said to have been made by an enterprising priest in a small village near Geneva and were known as " Geneva rubies."

The trouble that these stones caused at the time is well illustrated by the abridged abstract from a trade paper of 1890 :— " A Berlin jeweller has just been the victim of a curious hoax. He recently received a circular from a Zürich firm offering rubies at remarkably cheap rates, and thereupon entered into negotiation for the purchase of some. He bought 25 rubies, for which he paid 4,500 marks (£225) receiving a guarantee from the firm that the stones were genuine. Shortly after, the jeweller heard that false rubies were being manufactured so cleverly as to deceive connoisseurs, and, becoming alarmed, sent those he had purchased to Paris to be examined by the Syndicate of Dealers in Precious Stones, who are considered unimpeachable authorities. They reported that the stones were not imitation, but were real rubies, which were small, and consequently of small value, fastened together so cleverly as to render detection difficult. The jeweller then wrote to Zürich requesting that the firm take back the stones. This they refused to do, on the ground that their guarantee only ensured the genuineness of the gems and contained no mention of their size."

In 1895 the French chemist Michaud developed a technique employing the fusion, or rather sintering, of poor quality Siamese rubies in a platinum crucible under an oxy-hydrogen blowpipe, adding bichromate of potash to enhance the colour. As the process became well known and other people commenced making them—even in London's Hatton Garden—the price dropped so that manufacture became uneconomic, and with the introduction of Verneuil's method of synthesis these " reconstructed rubies " were no longer made. These crucible-made stones, with their fine cracks and other imperfections, which often appear like " silk," have an appearance nearer to that of natural ruby than the much cleaner modern synthetic stone.

During the time that the reconstructed ruby held sway the French chemists had not been idle. In 1877 E. Frémy, in partner-

ship with C. Feil, worked on the problem of ruby synthesis and successfully produced ruby and other colours of corundum. This synthesis was reported in the French journal *Comptes Rendus*, and an abstract was made in the *Mineralogical Magazine*. The abstract makes most interesting reading:—" Frémy and Feil have lately succeeded in preparing artificially variously coloured crystallized corundum and emerald (? green corundum) of such a size and transparency as to be suitable for the purposes of the jeweller and watchmaker. Several methods of preparation have been adopted, but that which is said to give the best results is to dissolve alumina in oxide of lead at high temperature in an earthernware crucible. After the solution is complete, the temperature is maintained for about twenty days. The silex of the crucible is gradually dissolved and by replacing the alumina causes it to crystallize out very slowly. The remarkable success obtained is mainly due to the Authors having used as much as twenty to thirty kilograms and having command of large furnaces. The various coloured specimens of corundum have the same specific gravity, hardness and crystalline form as the natural mineral. The artificial ruby was coloured, as is the natural, by oxide of chromium ; but the artificial sapphire was coloured by oxide of cobalt and they probably differ from the natural. Very blue sapphire does not give a spectrum at all like that due to cobalt. The true nature of the colouring substance is somewhat doubtful."

Later another young French chemist, by name Auguste Verneuil, a name which has since become a byword in gemstone synthesis, joined as Frémy's partner in place of Feil. Their work progressed, and it is noteworthy to recall that in a trade journal of 1890 mention was made of the synthesis in these words :— " More valuable than mere theory was the fact that these chemists exhibited, for the benefit of the Paris Academy of Sciences, some hundreds of the specimens of the glittering red crystals they had succeeded in producing—the only regrettable part of the business is that owing to the high price of the chemicals required and the difficulty of manipulation, the artificial rubies cannot be produced at a price cheaper than the natural precious stones." Some of these small rubies were used as watch jewels and a few were cut as small gemstones. A year later Moissan, of diamond fame, published particulars of a process of fusing alumina in his electric furnace.

The crucible method of making ruby was never a success commercially, but Verneuil had learned much from the experiments which had gone before, particularly that the fusion must be carried out in the hottest part of the flame richest in hydrogen, but not hot enough to cause boiling ; he had also learnt to produce the mass of corundum by superimposed layers from bottom to top and lastly to limit the contact of the melted product to an extremely small surface. In 1891 Verneuil had deposited with the Paris Academy of Sciences a sealed account of a new and revolutionary process for ruby synthesis, and this he published freely to the world in November, 1902.

The Verneuil inverted furnace consists of two iron tubes, A and B in figure. Tube A is widened into a circular chamber at the top, the lower and thinner end passing down the centre of the tube B, into which it is tightly screwed so as to form a gas-tight joint. Both tubes are constricted to nozzles at the lower ends, that of A being situated close to, but inside and above that of B. Pure oxygen under pressure is admitted to tube A through the pipe O. Within the upper chamber of A is placed a small basket or canister with a base of fine wire mesh (30 to 80 mesh have been reported as having been used) C, which is rigidly fixed to a metal rod passing upwards through a block of resilient rubber D contained in a cylinder which forms part of the chamber lid. In some cases a phosphor-bronze diaphram is employed instead of the rubber. At the top of the rod is placed an adjustable cam-shaped head F, which may be adjusted to regulate the force with which the small hammer E will strike it. This hammer, which is operated either by an electro-magnet or a cam rotating on a shaft (not shown in the drawing) may also be regulated to give a regular series of gentle taps. Hydrogen under pressure is admitted to the tube B by means of the pipe H. This meets and mixes with the oxygen at the orifice, where it is ignited. Owing to the intense heat generated, some 2,000°C, it is necessary to protect the pipes against fusion and this is done by placing around them a water jacket G with cold water continually running in at I′ and out at I″. Below the orifice is placed a fireclay support J (usually known as the " candle ") carried on an iron rod connected to a stand K fixed to the bench or floor, and provided with screw and sliding adjustments not shown in the drawing, whereby J may be centred below the orifice of the burner, and may be raised or lowered as

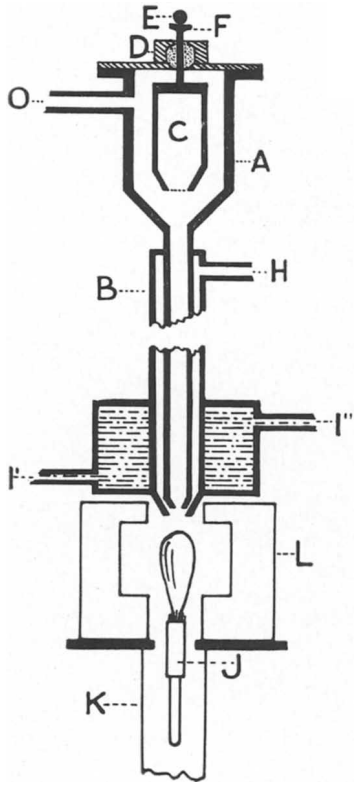

A & B. *Iron Tubes.*
C. *Mesh basket.*
D. *Rubber block.*
E. *Hammer.*
F. *Cam-shaped head.*
H. *Hydrogen-pipe.*
I' & I'' *Coldwater inlet and outlet to water jacket.*
J. *Fireclay support.*
K. *Stand.*
O. *Oxygen pipe.*

Verneuil inverted furnace.

the *boule* grows. *Boule* is the name given to the pear-shaped single crystal which forms. This name is derived from the French word for ball, for the small specimens first grown by Verneuil were ball-shaped. To protect the growing *boule* from cold draughts and to maintain a regular temperature around it, a divided fireclay chamber L is provided, in front of which is held a red screen, so that the growth of the *boule* can be watched.

In the manufacture of synthetic stones by the Verneuil " flame fusion " method, as it is called, the gases and chemicals used must be of exceptional purity and have certain physical attributes. To-day most of the factories manufacture their own gases and chemical powders. To make the corundum gems—the ruby, colourless, blue and variously coloured sapphires—it is necessary

to prepare a fine powder of alumina as the feed powder. This is done by calcining crystals of ammonium alum in silica trays in a muffle furnace at 1100°C for two hours. During decomposition the noxious gases generated are carried off by high chimneys and the charge swells up spectacularly to a meringue-like cake. This is an anhydrous (water-free) alumina in the so-called " gamma " form, and these cakes are then broken down to a fine powder by a tumbling process.

If ruby is required this snow-white powder has added to it about 8% of chromic oxide before calcining. It is then placed in the basket C at the top of the blowpipe. The hydrogen gas is turned on and lit at the nozzle ; then the oxygen is admitted, which with the already ignited hydrogen forms the intensely hot oxy-hydrogen flame. The hammer H is then started, at a rate which may be fairly fast—at some 80 per minute—causing a release of a sprinkling of the alumina powder at every tap—and this travels down the oxygen stream and fuses as it passes through the hottest part of the inverted flame, the melting point of alumina being 2050°C.

The molten powder is caught on the top of the ceramic " candle " J, which is about $\frac{1}{4}$ to 1 inch in diameter and is situated in the cooler part of the furnace. This fused alumina solidifies on the " candle " in the form of a small cone consisting of a number of small crystals of corundum. The tip of this cone remaining in the hotter part of the flame remains molten. By manipulation of the speed of tapping down of the powder and the amount delivered at each tap, which is controlled by alteration of the distance of the hammer from the top of the peg, and the gas supply, the single central part grows upwards, stalagmitic fashion, and opens out to mushroom shape, after which the speed of tapping is reduced in order to keep the *boule* diameter to about $\frac{3}{4}$ inch. This rate of tapping (for ruby) is about 20 per minute.

When the *boule* reaches a suitable size, about $2\frac{1}{2}$ inches (60mm.) in length for ruby, and weighing 150 to 200 carats, the gas supply is cut off and the *boule*, a single crystal of alpha alumina, is allowed to cool on the furnace and when cool it is broken away from the " candle " and fritted cone of crystal aggregates. The stem of the *boule* is nipped with a pair of pliers, or given a slight tap with a hammer, when it splits longitudinally into two nearly equal halves, the flat faces of which are essentially plane.

Different manufacturers employ slightly different techniques, but the essentials are the same and little difference can be seen between these modern blowpipes and Verneuil's original. Even the arrangement of the banks of furnaces is similar. Quite recently an electrically driven slow-motion drive has been incorporated to lower the *boule* automatically during growth, this being carried out by periodic operation of a hand wheel in manually operated blowpipes. Further, the rate of tapping has been automatically controlled in these modern blowpipes by the use of photo-electric cells and electronic circuits.

It is interesting to recall that a French chemist, who had learned Verneuil's process before leaving Europe, started making synthetic rubies at the small lumber town of Hoquiam, Washington, the capital for the project being supplied by two wealthy lumbermen, Polson and Ninemire. Small *boules* were said to have been produced but the location was too far away from jewel markets, and the material was poor and liable to " crack-up," so the venture died. There does seem to be doubt, however, whether the process used was that of " flame fusion " by the inverted oxy-hydrogen blowpipe, or that of reconstruction by crucible.

Without colouring oxide the pure alumina powder will give clear water-white sapphire *boules*, and stones cut from them are the well known synthetic white sapphires. By the addition of other oxides many different colours are made.

About 1907 attempts had been made to produce blue sapphire by the blowpipe method. The true nature of blue colouring in natural sapphire was still in doubt, and the logical use of cobalt oxide as a colouring agent was made. The *boules* produced from this alumina-cobalt oxide were found to be very patchy in colour, and at best the colour was a poor imitation of the rich blue of natural sapphire. In order to overcome this patchy colour the experimenters added magnesium oxide to act as a flux, and by this method did produce a blue boule of uniform colour, but still of a hue unlike that of sapphire. These stones were cut and marketed under the fanciful name of " Hope Sapphire." Examination of these stones showed that they had the characters of spinel and not those of corundum. It was this " accident " which led to the production twenty years later of the synthetic spinel in so many lovely shades of colour.

When scientific investigation had clearly shown that the cause of the colour in natural sapphire was due to a trace of titanium and iron, these oxides were used in the production of the synthetic blue sapphire with great success.

To-day synthetic corundum is manufactured in a great number of colours and shades of colour. A dark red is made to imitate the garnet and a light red or pink gives the synthetic pink sapphire. A deep pink-coloured material is termed " Rosaline," and a lovely lilac pink is the " Rose de France." An attractive orange colour is known as " Padparadscha," and this stone, presumably made to imitate the rare natural orange sapphire in the deeper shades does very much resemble fire opal of rich colour. At least two shades of yellow are produced, termed " Topaz colour " and " Danburite colour," but these stones also, of course, simulate the true yellow sapphire found in nature. Recently two rather attractive brown shades have been marketed under the names " Palmyra topaz " and " Madeira topaz." A good green which is like the natural green sapphire and a light green, which may imitate the peridot and is called " Amaryl," have been made. The true amethyst—the violet quartz—is imitated by a synthetically produced violet sapphire. And finally, although there seems no end to the shades of colour that the technician can produce, there is the synthetic corundum made so that in daylight it appears green, and in artificial light a red colour, presumably made to imitate the alexandrite chrysoberyl.

Up to 1947 any star-sapphire or ruby was bound to be genuine and it was confidently expected that such stones would never be produced synthetically. In that year the jewellery trade learned that such stones had been made. By the introduction of a percentage of titanium oxide into the feed powder, followed by heat treatment, synthetic asteriated corundum, both in red (ruby) and blue (sapphire) was produced. Many different colours of these synthetic star-stones have been produced but so far only the two colours mentioned have been marketed. The stones are made by adding to the gamma alumina powder, plus the necessary colouring oxides, not more than 0·3%, or less than 0·1% of titanium oxide (TiO_2). The *boules* formed from this feed powder are subsequently subjected to a temperature above 1,100°C, which precipitates needles of a titanium compound, most probably rutile, along the prominent crystal planes—that is, parallel to the faces of the

hexagonal prism, which is the fundamental crystal form, even if it is rarely shown by the *boule* itself.

These synthetic star-stones, which were an American innovation, had the artificial " silk " confined to the outside of the boule and cabochon cut stones show concentrations of " silk " at the upper 2/3rds or 3/4ths of the stone, the rest being clear and showing all the characteristics of the normal synthetic corundum. It is due to this partial " silk " that the early synthetic star-corundums showed the arms of the star to only about 3/4ths of the way down the sides of the cabochon. Such stars are altogether too bright and the stones too strong in colour to make them really deceptive to the experienced eye. The more modern American synthetic asterias are much more opaque and although they make beautiful stones they still look unreal. A Bavarian firm has produced similar star-stones in synthetic corundum, which are much more like the natural stones and in which the star is more diffuse. All these synthetic asterias, however, show a " ground

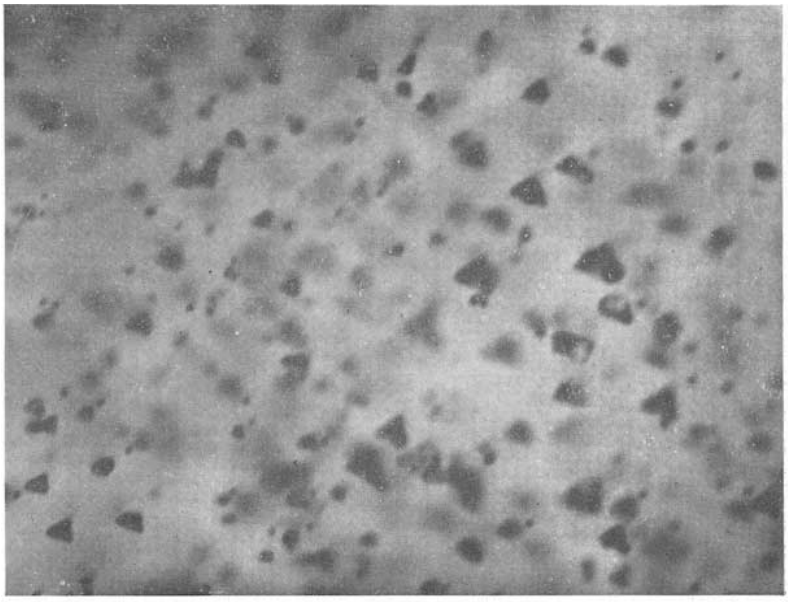

Triangular-shaped two-phase cavities in a synthetic star-ruby. (Other parts of the stone showed many bubbles.)

glass " surface at the back, unlike the zonal structure shown by the natural star-corundums.

The physical and optical characters of the synthetic corundums are those of the natural stones, so neither density nor refractive index measurements will give evidence of their synthetic nature. Owing to their mode of formation being so different the structure differs from that of natural stones in a number of respects, and these are sufficient to distinguish between them. Synthetic corundum, owing to the shape of the top of the *boule* and the discontinuous nature of the feed powder—necessary in order that each increment of fused powder will have time to crystallize, and crystallize in conformity with the layers below it—shows, if coloured, curved structure lines, or bands when examined under the microscope. In the case of ruby, and some other colours including the " alexandrite " colour, these lines are fine and closely spaced and have been likened to the lines on a gramophone record. With blue sapphire these curved structure lines are wider and more widely spaced ; they take on the form of bands rather than lines. The synthetic corundums show included gas bubbles, either as clouds of small bubbles (which look like a mass of dots), round bubbles (often with a tail like tadpoles), or bubbles of flask-shaped or bomb-like outline. When large enough these bubbles show, when examined by a microscope, a bright centre with a dark outline. Often some of the feed-powder does not get completely fused whilst passing through the blowpipe flame and these angular-shaped dark pieces may appear to be natural, but they are never alone and the other features will assist a diagnosis.

In the case of synthetic blue sapphire the 4500Å absorption line is not present, due it is thought to the evaporation of the iron by the heat of the blowpipe flame. Therefore the presence of this absorption line, or the group of three forming the 4500Å complex, will prove a stone to be genuine. Further, the spectroscope will prove the nature of the synthetic sapphire made to imitate the alexandrite, for a narrow line in the blue at 4750Å, with absence of lines in the red, is markedly different from the absorption spectrum of the true alexandrite.

Owing, it is considered, to the purity of the synthetic corundums, more especially in that they contain no iron compound (and iron is universally found in natural gems), the synthetic corundums transmit ultra-violet light much more freely and further down

in the range than natural stones. Natural stones cut the transmission at about 2900Å, whilst the synthetics pass the "light" down to about 2200Å. Thus, if a synthetic corundum be placed with a natural ruby or sapphire on a piece of photographic contact paper immersed in water in an open-topped cell and the stones given a short irradiation from a short-wave ultra-violet lamp (2537Å), the paper under the synthetic stone will darken more than where the synthetic stone has rested ; this, of course, shows on development of the paper. Recently Anderson has shown that by employing the immersion contact method of refractive index estimation fine curved structure lines have been revealed in synthetic corundums of blue and other colours. and that this method has revealed lines which were not observed by the usual microscopic examination.

IMITATIONS

Apart from some natural stones, which may have a colour not unlike natural corundums, and which reveal themselves by normal

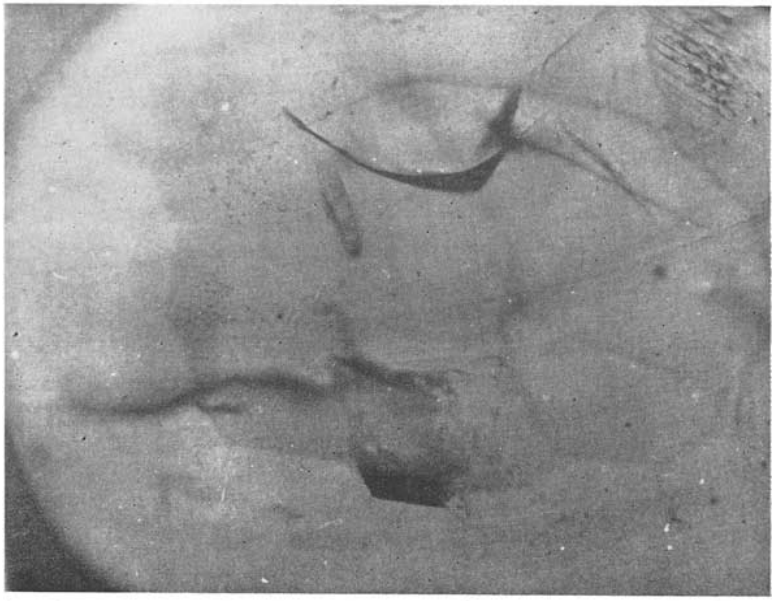

Deceptive crack-like markings (probably induced) in a synthetic ruby.

gemmological tests, the only common imitations are pastes of similar colour and garnet-topped doublets. Red pastes usually show an absorption spectrum which has a broad band cutting out the yellow and green, but, unlike ruby, they do not show the lines in the red and blue parts of the spectrum which are due to chromium; likewise the red garnet-topped doublets will exhibit a similar spectrum (due to the glass base) upon which is superimposed a weak almandine garnet spectrum. Neither of these show a " fluorescent effect " when viewed through the Chelsea colour-filter, nor will

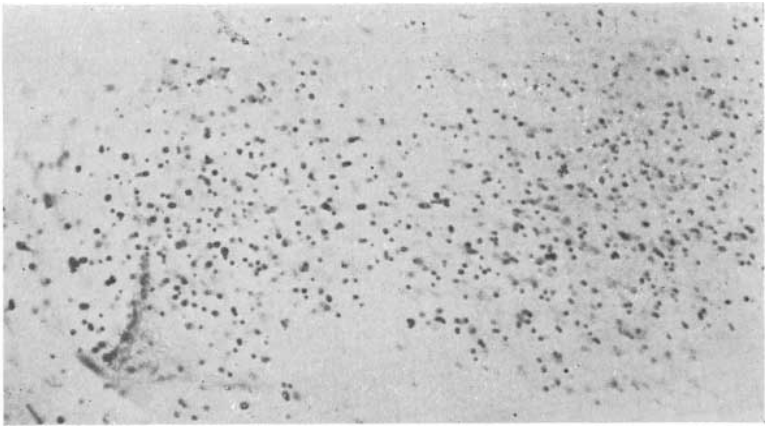

Bubble cloud in a synthetic sapphire.

Bubble cloud and deceptive solid inclusions (probably alumina) in a synthetic ruby.

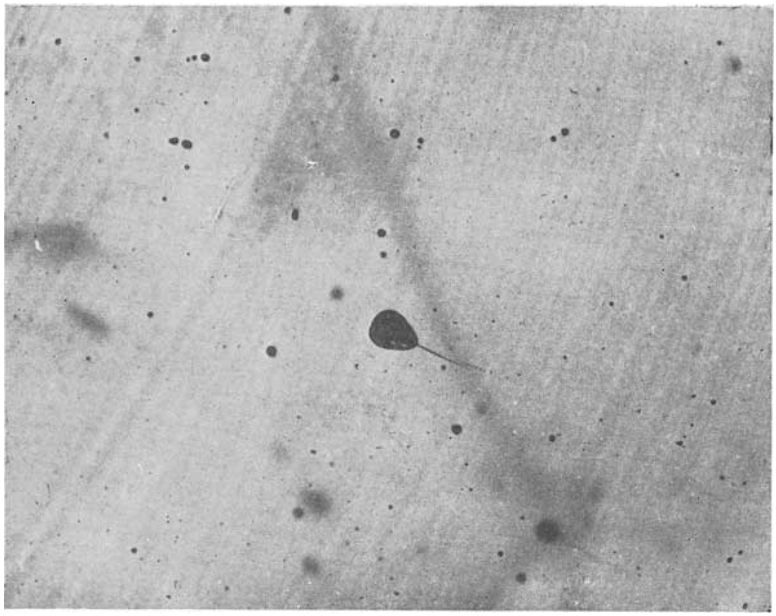

Curved (gramophone record type) lines and tadpole-shaped bubble in a synthetic ruby.

the crimson fluorescent glow shown by natural or synthetic ruby when bathed in either range of ultra-violet light be present with pastes or garnet-topped doublets. Most blue pastes show the cobalt spectrum of three broad bands in the orange, yellow and green of the spectrum, and no line at 4500Å ; further, such stones show a strong red when viewed through the Chelsea colour-filter. Some paler blue pastes, however, owe their colour to copper and do not show a characteristic spectrum or a red colour through the filter, so in this case reliance must be placed on the refractive index, lack of dichroism and the microscope.

The star-stone is, however, imitated by a special type of doublet—the star rose-quartz doublet. When a polished slice of a certain type of rose-quartz, which is cut at right angles to the optic axis of the quartz, is viewed from a single light source transmitted through it a bright star of light is seen. This is *diasterism* and the effect is used in the imitation of star corundums. A cabochon of rose-quartz cut with the base at right angles to the optic axis of the quartz is backed with a reflecting film or mirror, which has been

suitably tinted, usually blue. This mirror on the base reflects the frontal light back through the stone making apparent the star effect due to diasterism and altering the pink colour of the rose-quartz to a bluish shade (only blue shades have been seen on the market). Such imitations, unlike the natural and synthetic star-corundums, in which the star is due to *epiasterism*, show an image of the light source at the crossing of the three rays forming the six-pointed star, and on moving the stone nearer to the light this image enlarges—no further test is needed. Another fake asteria consists of a cabochon of synthetic corundum, or even glass, on the flat base of which fine lines are engraved running in three directions at 120°. These imitations are not common and are only passably effective, distinction being easy when the base is examined by a lens.

It is in the species corundum, gemstones as highly prized as the regal diamond and the lovely emerald, that the truth is evident

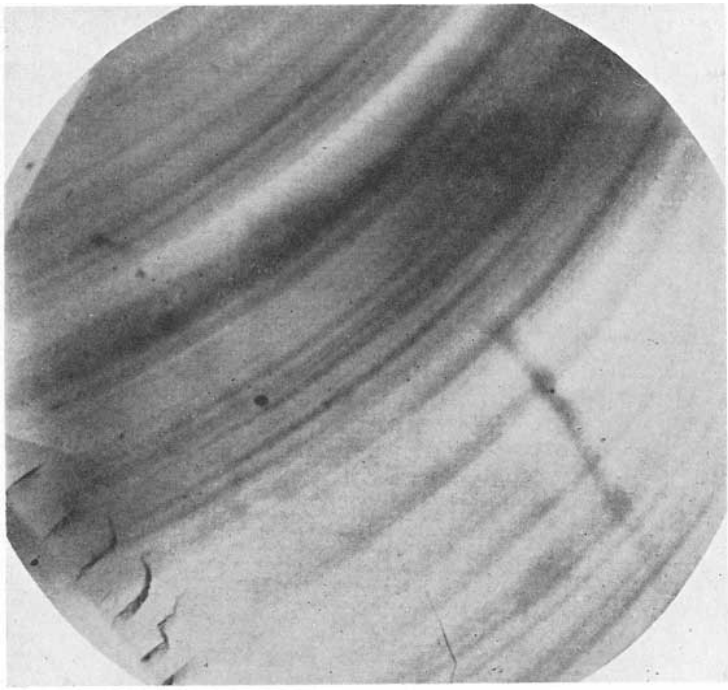

Curved colour bands in a synthetic blue sapphire.

that synthesis can never completely undermine the true value of a stone which has had its genesis in nature.

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NETHERLANDS RESEARCH INSTITUTE

On 26th April, 1957, the University of Leiden and the Netherlands Gold and Silver Federation established the Stichtung Ned. Institut v. Wetensch. Onderzoek van Edelstein en Perlen (Institute for the scientific research of gemstones and pearls).

The laboratory of the Institute is in the National Museum of Geology and Mineralogy at Leiden and the director of the Museum, Prof. I. M. van der Vlerk, is ex-officio president of the Institute. Members of the committee are: Ing. J. Hammes, F.G.A., secretary-treasurer, Prof. B. G. Escher, Prof. W. P. de Roever, As. Bonebakker, F.G.A., and J. J. Schoo, F.G.A. The director of the laboratory is Dr. P. C. Zwaan, who is also a Fellow of the Gemmological Association.

ASSOCIATION NOTICES

THIRD HERBERT SMITH MEMORIAL LECTURE

The third Herbert Smith Memorial Lecture was given at the Royal Institution, London, on Wednesday, 3rd April, 1957, by the President of the Association, Sir Lawrence Bragg, F.R.S. The title of the lecture was " The atomic structure of gem-stones and other minerals," and Sir Lawrence entertained over one hundred members and friends with an intensely interesting illustrated talk.

B. W. ANDERSON *writes* :—

Those Fellows of the Gemmological Association who, on April 3rd, attended the third Herbert Smith Memorial Lecture must surely have felt a sense of privilege as they took their seats in the famous lecture theatre in the Royal Institution to hear their President, Sir Lawrence Bragg, F.R.S., deliver his address. Sir Lawrence, with his father Sir William Bragg, was amongst the foremost pioneers in investigating the atomic structure of minerals by means of X-rays in the years immediately following Laue's famous experiment in 1912. In particular, he and his school of X-ray crystallographers in Manchester were chiefly responsible for elucidating the structures of the silicates, those chemically complex substances which embrace so many of the best-known gemstones.

In his lecture, Sir Lawrence, using simple language and many amusing analogies and metaphors, was able to show how this apparently hopelessly complex series of compounds can be grouped and classified on the basis of their structure into quite a few fundamental types of crystal.

The lecturer began by recalling " The Ethics of the Dust "—a book written for young people by John Ruskin in the middle of last century (1866). In this book Ruskin tells his young audience how, had they eyes which could see the infinitely small, they would realize that when they walk along a muddy road they are walking on " gems "—tiny crystals, in each of which the atoms were arranged in a beautiful pattern. Thus Ruskin, writing nearly fifty years before X-rays had revealed for us the structure of crystals, had, with a poet's imagination, understood their fundamental nature. The mineral world, said Sir Lawrence, showed order and perfection, in contrast to the animal and vegetable world, which showed disorder and untidiness, and added " order and perfection spell death : disorder and muddle spell life."

The lecturer stressed that a mineral must be exceedingly stable to last for many millions of years. He went on to explain the fundamental principles underlying the structure of minerals. In these the bonds between the atoms were mainly ionic—a result of the tendency of some metallic atoms to part with a loosely-held electron, becoming thereby an electropositive ion, while other elements tended to pick up an extra electron, becoming an electronegative ion. The erratic orbits of these loosely-held electrons were shown to the audience in the form of models based on atomic structures as first conceived by the genius of the Danish physicist Niels Bohr.

The overriding importance of the relatively large electronegative ions in minerals was explained to the audience : in particular oxygen—the tiny metallic ions often fitting into interstices in an almost close-packed oxygen lattice. When one reviewed the relative abundance of elements in the earth's crust it was remarkable to find that 98% of the total could be accounted for by eight elements only, in the order oxygen, silicon, aluminium, iron, calcium, sodium, potassium and magnesium. Oxygen and silicon (the essential elements in the formation of the silicates) between them accounted for nearly three-quarters of the whole. Even such " common " elements as copper and sulphur dwindled into insignificance by comparison.

The main bulk of minerals were silicates, the structure and stability of which depended essentially upon the intensely strong silicon-oxygen tetrahedron, in which silicon at the centre was equally surrounded by four oxygen ions. This can be linked with other such units in four different ways, making four great groups of minerals. In a group containing olivine (peridot) chrysoberyl, topaz, and the garnets, the SiO_4 tetrahedra were not directly linked to one another. In another group, which included beryl, the tetrahedra were linked by sharing one of the four oxygens, forming rings. In the great amphibole and pyroxene families (which include the jade minerals) there were chains of SiO_4 tetrahedra in which two of the oxygens were shared. Yet another group comprised the micas, chlorites and serpentines, in which there were endless sheets of linked tetrahedra, giving rise to the flaky structure of mica and similar minerals. To another group belonged the feldspars and the crystalline forms of silica itself.

By the aid of slides and models Sir Lawrence made these structures plain. Of the beryl structure, he related how, after he had just worked it out, he showed it to his wife, who was so charmed with the beauty of the pattern that she embroidred it on the front of her nightdress. Later, it was used as a decorative theme in the Festival of Britain, and was adapted by a Nottingham lace manufacturer.

The lecturer made the interesting point that the commonest minerals were those of lowest density (quartz and the feldspars), as though they had floated to the surface of the magma sea. Of the main groups, the olivine group was the densest.

In addition to the tetrahedra of silica Sir Lawrence showed the role in pattern making of the octahedral unit of alumina. He spoke of these two units as being analogous to the plain and purl of the knitter, from which basic stitches such an amazing variety of pattern could be formed.

Towards the close of his lecture Sir Lawrence had something to say on colour. He showed an amusing slide in which the elements in ascending atomic order were competing for seats (=electron shells) in a theatre. After one row of good seats had been completed (representing the rare gas structure) the next element had the " choice " of inferior side seats in an inner shell of electrons or central seats in the next row, further from the " stage " (=nucleus). It was transition elements of this kind (chromium, iron, etc.) which usually gave rise to colour ; electrons being moved by the light from one place to another.

Some words on hardness followed, in which the importance of highly charged ions with small cations was mentioned. The idea of hardness inevitably makes one think of diamond, and Sir Lawrence's last slide showed the structure of that extraordinary mineral (which was one of the first to be elucidated by him and his

father). So exceptional was the nature of the diamond, said the lecturer, that it could hardly be classed as a mineral at all !

In accordance with the lecturer's wish and the traditions of the Royal Institution there was no formal introduction to the lecture, and no vote of thanks at the close. The gratitude and enthusiasm of the audience was, however, well expressed by the prolonged applause which greeted Sir Lawrence at the end of his masterly address.

WEST OF SCOTLAND BRANCH

At the fourth annual general meeting of the West of Scotland Branch of the Association the following Officers were elected—Chairman : Mr. Douglas Wade, Secretary : Mr. C. Wade. Mrs. McGregor and Messrs. E. Macdonald and R. Dickson were elected to serve on the Standing Committee.

MIDLANDS BRANCH

The May meeting of the Midlands Branch was held on the 10th of the month, when Mr. Ivan Shortt, J.P., a Guardian of the Assay Office in Birmingham, gave a talk on " Antique and modern silver and plate."

COUNCIL MEETING

A meeting of the Council of the Association was held at Saint Dunstan's House, London, E.C.2, on Wednesday, 12th June, 1957. Mr. F. H. Knowles-Brown presided.

The following were elected to membership :

FELLOWSHIP

Argent, George, Vancouver, Canada

PROBATIONARY

Drapkin, Clive M. Birmingham
Kothari, Ramesh R., Madras, India
Milito, John T., London
Phillips, Alan L., Leeds
Weatherill, John, Cardiff

ORDINARY

Brown, Thomas C., Tarkwa, Ghana
Dholakia, Anilkumar B., Bombay, India
Fuhrbach, John R., Amarillo, Texas, U.S.A.
Jones, James R., Mortdale, Australia
Jones, Wilfred R., Auckland, New Zealand
Marais, Hoffman, Johannesburg, S. Africa
Moloo Brothers & Co. Ltd., Zanzibar
Monath, Henry, Newcastle-on-Tyne
Nei-Chong, Li, London
Olkowski, Leonard J., London
Parekh, Pravin H., Bombay, India
Patrick, John T., Christchurch, New Zealand
Phillips, Dennis, Leeds
Phillips, Frank C., Bristol
Ryan, Pat, Albrook, Canal Zone

CURATOR :

Mr. Robert Webster was elected as Curator in place of Mr. G. M. Sprague, who wished to resign for personal reasons. The Council recorded their appreciation of Mr. Sprague's services to the Association.

RESEARCH DIPLOMA

The Council, upon the recommendation of the examiners, decided to award a research diploma to Edward Gübelin, Ph.D., F.G.A., C.G., for his work in connexion with the inclusions that occur in gemstones.

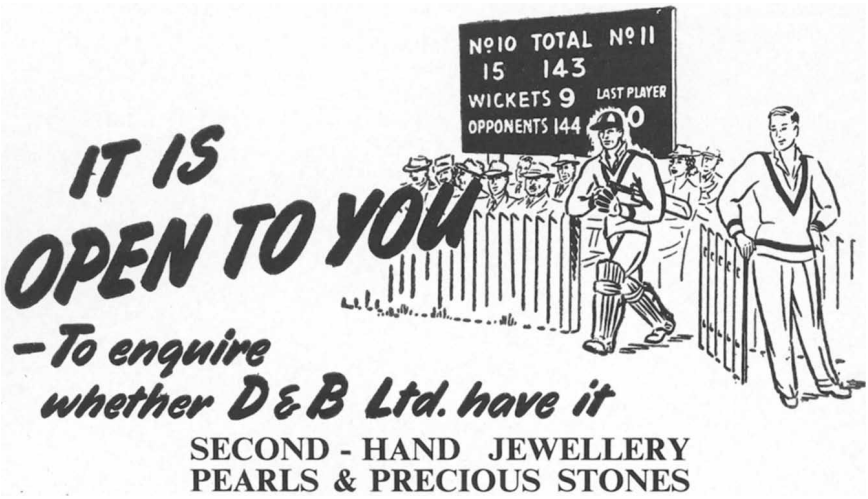

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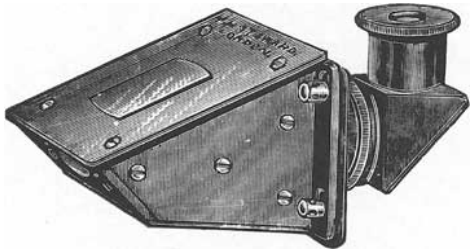

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No. 3
July, 1957

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THE JOURNAL OF GEMMOLOGY

and

PROCEEDINGS OF THE
GEMMOLOGICAL
ASSOCIATION
OF GREAT BRITAIN

GEMMOLOGICAL ASSOCIATION
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Vol. VI No. 4 OCTOBER 1957

APPLICATION OF PHASE CONTRAST MICROSCOPY IN GEMMOLOGY

By E. J. GÜBELIN, Ph.D., C.G., F.G.A.

THE present article deals with a new accessory to the microscope—the so-called phase contrast equipment, which renders heterogeneous objects richer in contrast and facilitates their examination. The Phase Contrast Method was discovered in 1932 by the Dutch scientist, F. Zernike,* and its further development lead to its adaptation to the polarizing microscope ; the construction of an easily manipulated attachment makes it now possible to employ this method in combination with the conventional microscopic methods also used in gemmology. The Phase Contrast Method is frequently a source of new knowledge and results mostly in greater contrast in brightness between inclusions and inhomogeneities on one side and the host substance on the other, or between individual particles, even if they are of the same substance (=mosaic structure). This new method can, therefore, be used to good advantage in connexion with better examination of details of the interior of gemstones and for research work.

Every microscopist knows from experience that in the transmitted light of bright field illumination microscopic images are often unsatisfactory, because their details are frequently drowned by

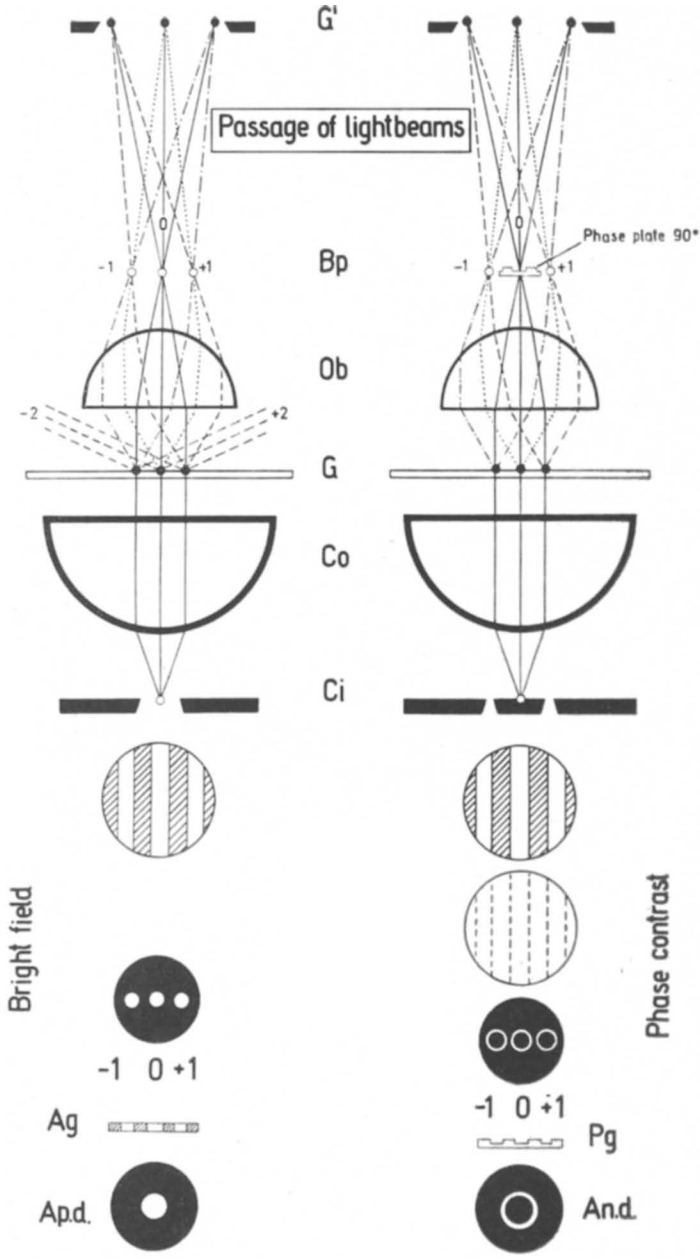
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Fig. 1

the bright light. This handicap can be overcome by increasing the contrast through shutting the condenser diaphragm. Yet this makeshift does not wholly meet the requirements, as the resolving power of the objective is diminished, the microscopic image is darkened and diffraction phenomena may lead to a wrong interpretation of the picture. A considerable intensification of contrast is, however, often ensured by dark field illumination, which makes inhomogeneities and inclusions stand out brightly against a dark background. Yet this method suffers also from the disadvantages that merely the edges of the details are shown, that it gives negative images of the details of the structure, and that with sudden changes of optical continuity certain details are eclipsed, which render examination of the subtlest details impossible.

The new Phase Contrast method enables an increased contrast in details to be observed. The mode of operation of the phase contrast can only be understood if the essential procedures producing the image in the microscope are realized and understood as explained by E. Abbe.

According to the laws of geometrical optics, the objective (Ob in Fig. 1) produces a magnified image of the object G at G′. This image is observed through the eye-piece, which again works as a magnifying glass. It was, therefore, formerly believed that even the smallest details of a microscopic object could be made visible by increasing the magnifying power of the ocular and objective. Abbe has, however, refuted that opinion by pointing out that the formation of the image can only be understood if the nature of light is considered as an undulatory motion (physical

FIG. 1. FORMATION OF THE IMAGE IN THE MICROSCOPE

Ci = Condenser iris
Left : circular = bright field = Ap.d.
Right : annular = phase contrast = An.d.
Co = Condenser
G = Microscopic object (=grating)
Ag = Amplitude grating (corresponds to object of different colours)
Pg = Phase grating (corresponds to completely colourless transparent, non-absorbing object)
Bp = Back focal plane of the objective.
—1 ; 0 ; +1 = Maxima of the diffraction spectrum
(These are the aperture images of the condenser iris Ci formed by the condenser and the object ; O=virtual or direct image ; —1 and +1 = the secondary images diffracted by the structure details of the object (on the left they are circular, on the right annular). In the path of rays for bright field illumination two further diffraction maxima —2 and +2 have been sketched, which, however, do not reach the objective and hence do not contribute to the formation of the image at G′. In the path of rays on the right side the light waves passing the maximum O are displaced in their phase for as much as a quarter wavelength by the phase plate 90°.
G′ = Microscopic image of object G caused by the objective Ob and formed by the interference of light waves coming from the aperture images. The second circular plane (disc) drawn a little lower on the right top side represents schematically the image hardly visible of the phase grating, which is produced if the phase contrast equipment is not used.

optics). Those straight rays which seem to emanate from a source of light according to the laws of geometrical optics, in reality only indicate the directions in which the undulation progresses. If such an undulatory motion strikes upon the fine structures of a microscopic object, the impinging light becomes partly diffracted in such a manner that every structure may be considered as a new source of illumination. This plays a vital role in connexion with the formation of the image in the microscope, and, in order to illustrate it, Abbe used an artificial object—a microscopic grating with parallel striae. A beam of light coming from the aperture of the condenser Ci and passing through that grating is split up into numerous diffraction beams, which appear through the objective Ob in its focal plane Bp as so-called diffraction images of the light source (often also called aperture images because the aperture Ci of the condenser functions as image frame of the light source). The whole of these diffraction images at Bp is usually described as a diffraction spectrum. Besides the direct and brightest aperture image O—the maximum of O-order—the diffraction images ± 1, ± 2, etc., are visible, but their brightness diminishes proportionally as the distance from the optical axis of the microscope is increased. All these diffraction images caused by the microscopic grating may be considered as new light sources, the undulatory motions of which influence one another, i.e., increase one another (thus producing greater brightness) or, vice versa, weaken one another (thus causing less brightness or even complete darkness). At G′—the image of the objective—the mutual interference of the light waves radiating from the diffraction images is of such a nature as to form an image which corresponds more or less accurately with the object G. An image completely corresponding to the details of the object can only be produced if all the light beams diffracted by the structure of the object reach the objective lenses, thus participating in the formation of the image. Under such circumstances the microscope has only to make the details appear so large that they can be recognized.

The grating used by Abbe, which consists of parallel absorbing striae with transparent intervals, reduces the amplitudes resulting from interference of the various diffraction images in the image plane G′, which are caused by the light waves coming from such objects. Thus the microscopic image of the object is formed,

being composed of brightness differences and becoming perceptible to the eye as well as the photographic film. Such a grating is called an "amplitude grating" and the corresponding microscopic objects "amplitude objects."

If instead of an object another, also very fine, grating is used which, however, does not consist of absorbing striae, but of completely transparent ones alternately at different heights, the means hitherto known fail to give an efficient microscopic image. Such a grating takes the place of entirely transparent thin microscopic objects. Its structures do not transform the amplitudes of the light but affect only the state of vibration (=phase) of the diffracted beams; that is, they cause a change of the phase. Contrary to the amplitude grating, which produces brightness differences through interferences of light waves with transformed amplitudes, the image of the phase grating must remain uniformly bright, i.e., the structure of the grating must stay invisible, for neither the eye nor the photo-plate can register minute phase differences. Such transparent objects are called "phase objects."

Actually the microscopic objects occurring normally are hardly ever amplitude objects, or phase objects, in the true sense of the above description. Thus, an absorbing structure differs in most cases somewhat in its refractive power from its surroundings while an element causing phase difference often causes simultaneously a slight absorption. Consequently, the microscopic image of a phase object does not, as a rule, appear uniformly bright but allows some faint, usually very indistinct, structures of the object to be observed. Evidently the actual conditions are such that in the microscopic objects generally examined, either the absorbing effect prevails, or that altering the phase. Therefore, with the new conceptions of amplitude object and phase object, an appropriate distinction has been established.

As explained above, light waves leaving a phase grating cannot be equally constituted with regard to their state of vibration (=phase) as the light waves coming from an amplitude grating. The difference lies in the fact that with an amplitude grating these light waves show similar phases everywhere, but different amplitudes, while with the phase grating they show similar amplitudes everywhere, but different phases. Exact investigations and calculations carried out by F. Zernike proved that the reason for the almost

completely contrastless image of the phase grating must be traced back to the fact that the light waves issuing from the diffracted aperture images ± 1, ± 2, ± 3, etc., in the image plane G′ merely show vibrations which are displaced in their phase by a quarter wavelength against those vibrations which originate from the direct aperture image O. The image of the phase grating must, therefore, be equally rich in contrast as the one of the amplitude grating, if it is possible to reverse the phase-shift mentioned. This is possible, indeed, if according to Zernike's suggestion a thin, transparent, so-called " phase plate," which displaces by 90° the phase of the light passing through, i.e., a quarter wavelength, is put into the back focal plane of the objective (at Bp)—there, where the direct image O of the light source is formed. Through this " artificial " intervention in the diffraction spectrum the phase differences caused by the phase grating are, to a certain extent, converted into amplitude differences, through which process details of the phase object, otherwise hardly visible, show up with remarkable contrast.

It proved difficult to apply the normal phase contrast equipment for gemmological microscopy, because, according to the principle of the method, it was built with objectives of very high magnifying power and, therefore, had an extremely short focal depth only. Consequently, the Phase Contrast Method could be used only for very thin or flat objects, and inhomogeneities or inclusions lying deep in a gemstone could not be " reached." A special equipment was then developed by the Zeiss-Winkel optical plant in Göttingen, thanks to the personal interest which Dr. H. Piller gave to this gemmological requirement. The gemmological phase contrast equipment now consists of (1) a special adjustable collector-lens which is placed into the foot of the microscope, (2) three special achromatic objectives—Ph_1 6.3/0.16, Ph_1 10/0.25, Ph_2 25/0.45. They differ from ordinary objectives in that they contain an annular phase plate, so that they produce the phase contrast, but they can also be used for bright field observations as well as dark field observations, which facilitates manipulation and comparison considerably. They have a long focal distance, which is essential for gemmological microscopy. (3) For small magnifications a special tube-like condenser, housing a phase annulus, was developed, which is placed on to the collecting lens. This condenser may be replaced by (4) a disc-shaped substage condenser with revolving disc. The latter bears various phase annuli corresponding to the phase

FIG. 2. GEMMOLOGICAL PHASE CONTRAST EQUIPMENT

1. Adjustable collecting lens
2. 3 Phase contrast objectives
3. Tube-shaped condenser with phase annulus
4. Disc condenser
5. Auxiliary Microscope
6. Filter.

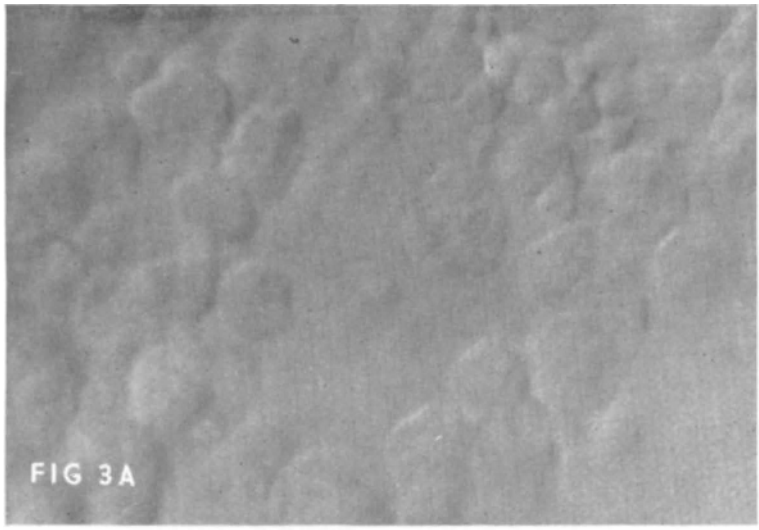

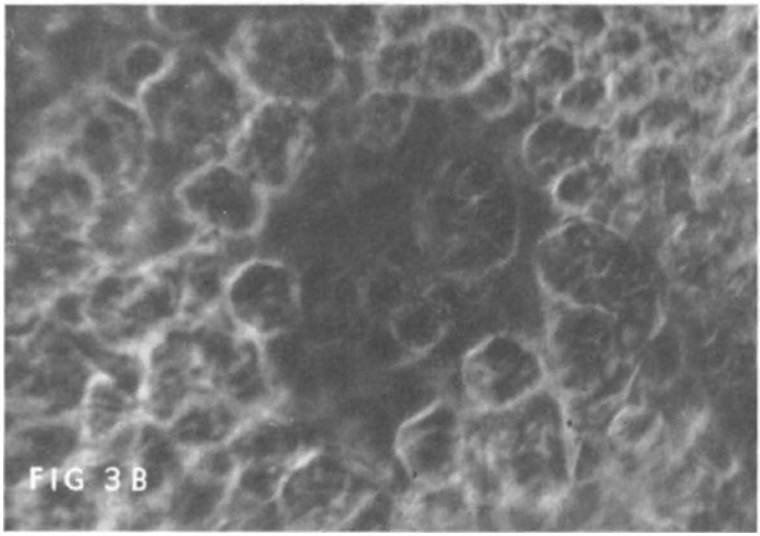

BRIGHT FIELD.—Photo ocular 10x. Achromatic objective 6.3/0.16 Huygens. Neutral filter, condenser iris closed to half and extra-focal position of tube. Mag. 63x.

PHASE CONTRAST.—Photo ocular 10x. Achromatic objective Ph_1 6.3/0.16. Mag. 63x.

Ex-solution of calcite in an emerald from Muzo, Colombia. The phase contrast picture not only emphasizes the contrast between unmixed calcite particles and the host substance but also reveals structure details within the calcite grains.

objectives of higher magnifying powers : Ph_2 25/0.45, Ph_3 40/0.65, Ph_4 90/1.25 (Fig. 2). For extraordinary phase contrast effects dark field illumination may also be adopted. (5) By means of an auxiliary microscope placed into the slot of the eye-piece, the image of the phase annulus and the annular image of the phase plate can be focused and brought into perfect concurrence (Fig. 2). For carrying out the experiments leading to the results described here, the gemmological phase contrast equipment was used in connexion with the binocular polarizing microscope by Zeiss-Winkel.

Completely transparent details of a phase object (e.g. inhomogeneities and inclusions in a gemstone) differ solely from their surroundings by their thickness or refractive power. In such an object portions of higher refractive index will appear darker than their surroundings in the phase contrast image†. However, this phenomenon occurs in only a distinct manner if the details that are to be rendered visible have but small phase differences, that is, if they are sufficiently thin and their refractive index differs but slightly from the host substance. Under such conditions the microscopic phase contrast image shows all the details of the structure of the object with a wealth of contrast and with more faithful reproduction than any other microscopic method known heretofore.

Discussion of Illustrations

Fig. 3 to Fig. 8 manifest excellent examples of the application and importance of the Phase Contrast Method in gemmological microscopy. They represent but a small selection of the very great number of photomicrographs taken during the experiments, which lasted three years, in probing the various possibilities of the Phase Contrast Method for gemmological purposes. The illustrations are arranged in pairs in order to facilitate comparison and to emphasize the great difference of contrast between bright field and phase contrast. The pictures of each pair represent exactly the analogous area within the same stone and are shown with the same degree of magnification. For obtaining the greatest possible contrast effect in bright field, everything within the possibilities of orthodox polarizing microscopy was done, such as closing the

† This particular appearance of the phase contrast image is called positive phase contrast—contrary to the negative phase contrast, which shows when applying a phase plate of phase retarding effect (instead of a phase accelerating effect) and causes the same portions to appear brighter than the background.

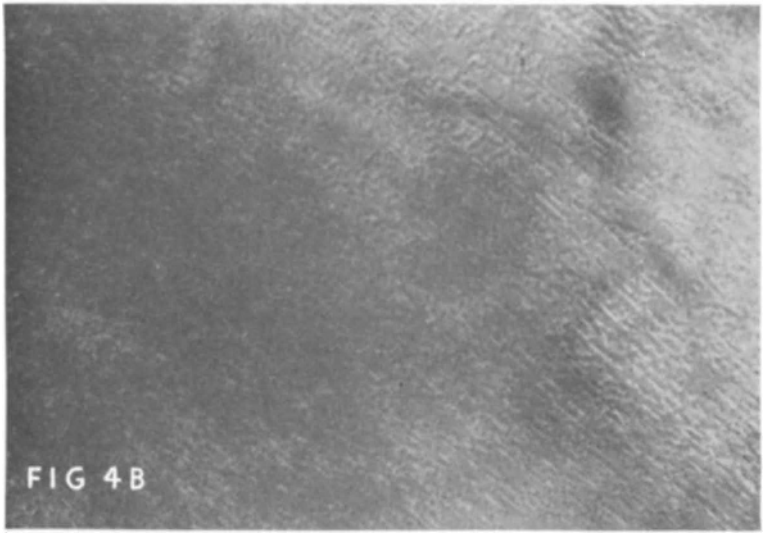

BRIGHT FIELD.—Photo ocular 10x. Achromatic objective 6.3/0.16 Huygens. Contrast filter. Mag. 63x.

PHASE CONTRAST.—Photo ocular 10x. Achromatic objective Ph_1 6.3/0.16. Mag. 63x.

Very fine sub-structure in an iolite from Ceylon caused by alteration into pinite. These two pictures clearly manifest the great difference of contrast between normal bright field which reveals nothing and the phase contrast which offers interesting information

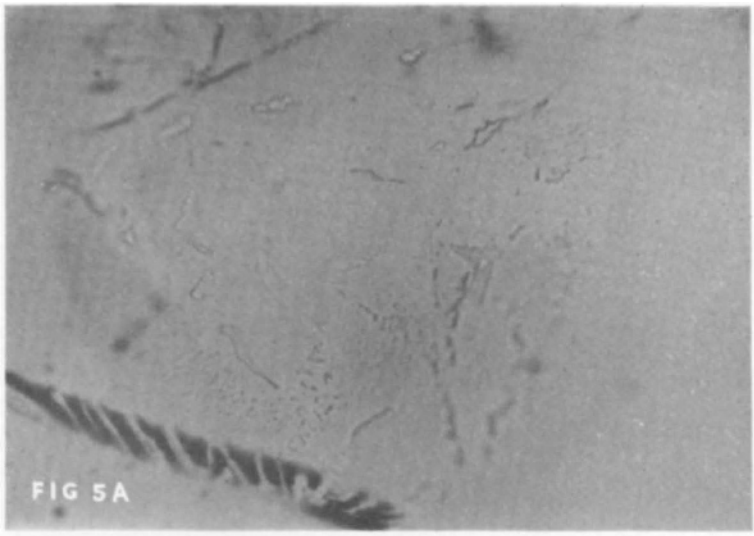

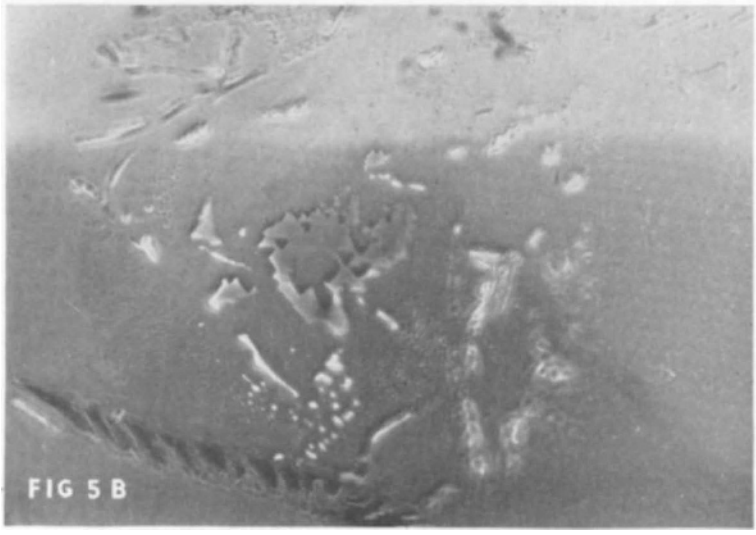

BRIGHT FIELD.—Photo ocular 10x. Achromatic objective 10/0.25 Huygens. Condenser iris closed to 1/3 of object aperture. Mag. 100x.

PHASE CONTRAST.—Photo ocular 10x. Achromatic objective Ph_2 10/0.25. Mag. 100x.

Residual drops of the remedying liquid in a healed fissure in a Burma sapphire. The phase contrast picture manifests conclusive details very distinctly where there is hardly anything visible in the bright field.

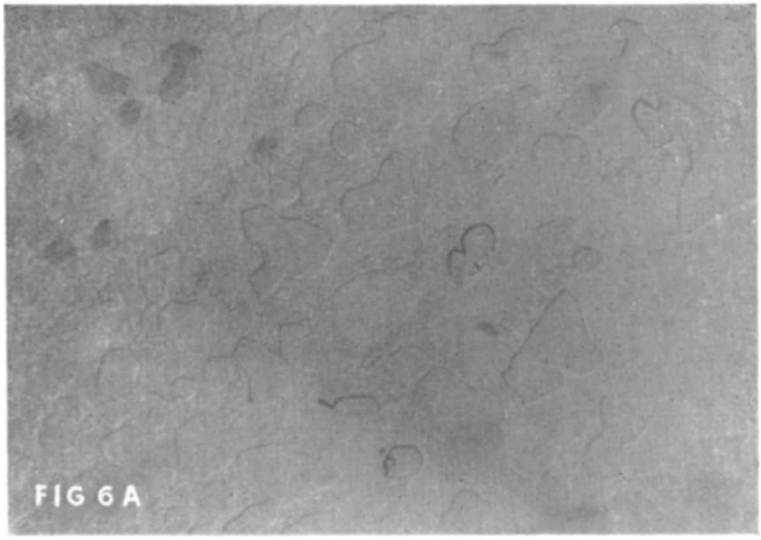

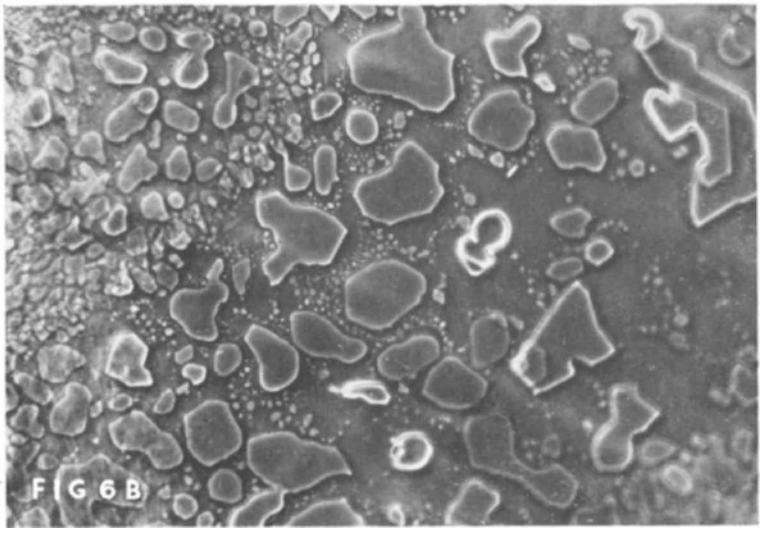

BRIGHT FIELD.—Photo ocular 10x. Achromatic objective 10/0.25 Huygens. Condenser iris closed to 1/3 of object aperture. Mag. 100x.

PHASE CONTRAST.—Photo ocular 10x. Achromatic objective Ph_2 10/0.25. Mag. 100x.

Partly healed crack in a yellow beryl from Madagascar with legion of extremely flat liquid drops left over from the exhausted healing liquor. This is a typical example of phase contrast being used for bringing out details.

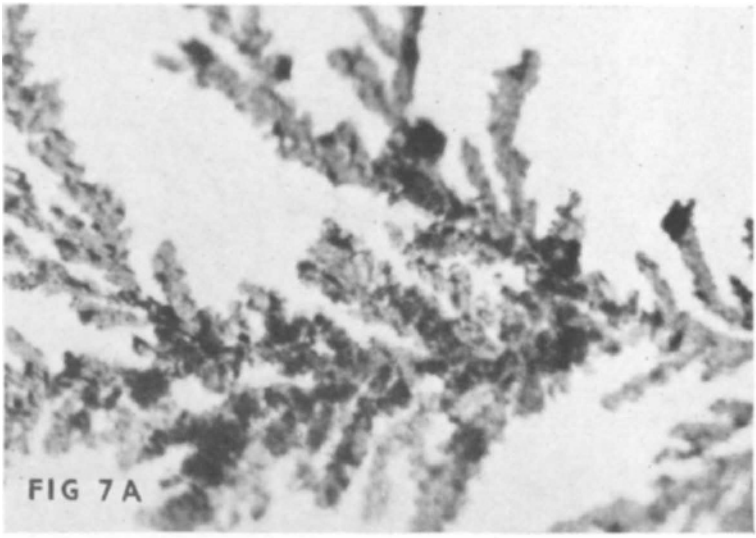

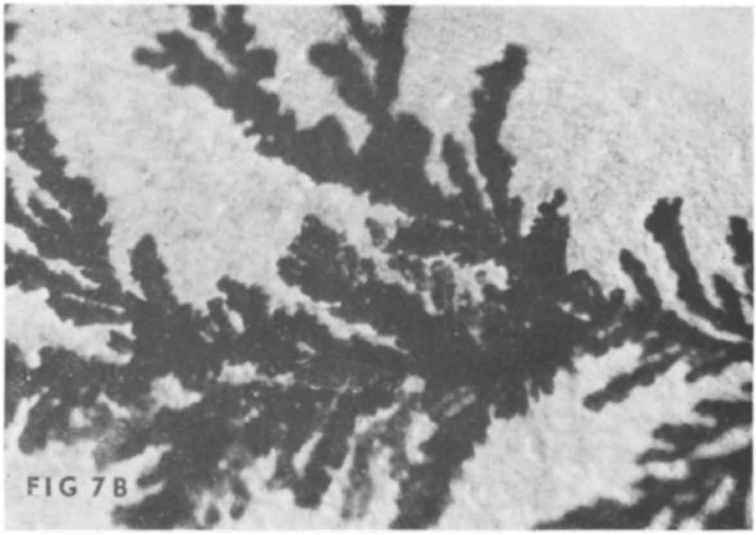

BRIGHT FIELD.—Photo ocular 10x. Achromatic objective 6.3/0.16 Huygens. Neutral filter. Mag. 63x.

PHASE CONTRAST.—Photo ocular 10x. Achromatic objective Ph_1 6.3/0.16. Mag. 63x.

Dendritic formation of manganese oxide in rose quartz. The bright field picture does not reveal in any way the intrusion of this foreign matter, while the phase contrast makes it apparent that the dendritic formation developed in a crack and, therefore, is of secondary origin.

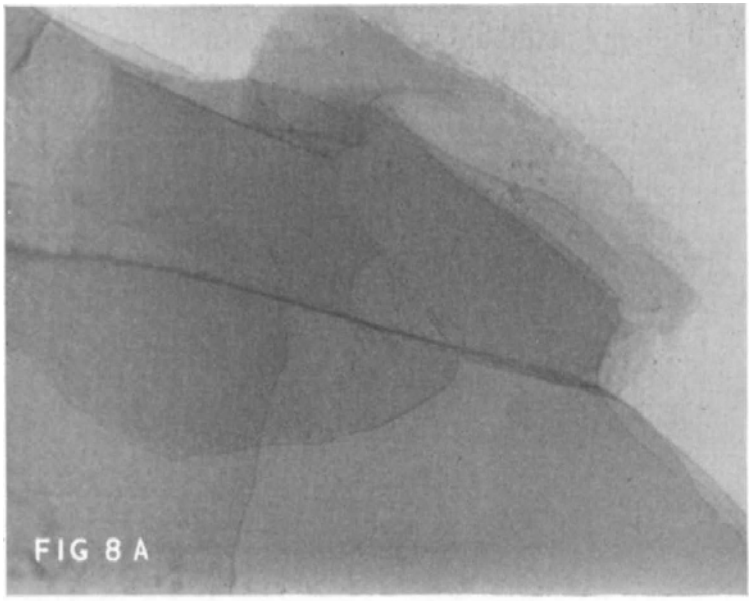

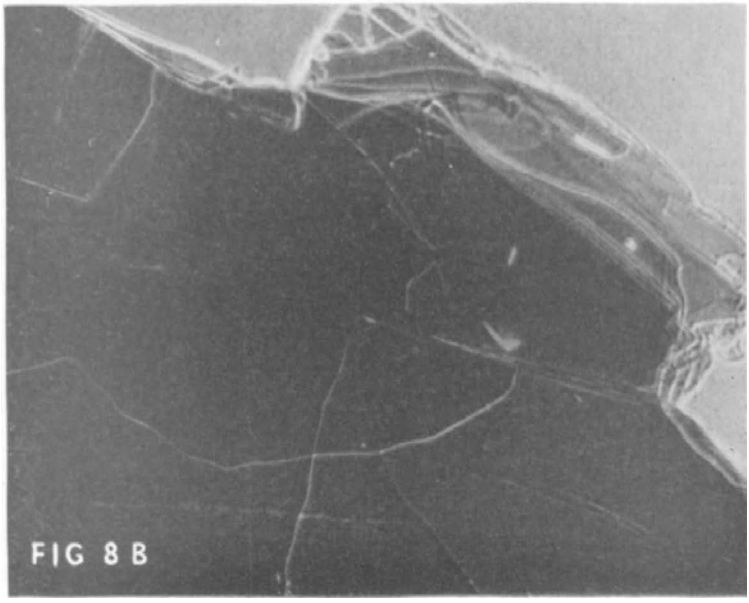

BRIGHT FIELD.—Photo ocular 10x. Achromatic objective pol. 6.3/0.16 Huygens. Neutral filter and condenser iris half closed. Mag. 63x.

PHASE CONTRAST.—Photo ocular 10x. Achromatic objective Ph_1 6.3/0.16. Mag. 63x.

Muscovite flake in a yellow beryl from Madagascar. This is a typical example of how the Phase Contrast Method is advantageously employed to emphasize details of a very flat solid inclusion with but slightly different refractive index, of which the bright field would yield but very scanty information. This proves that with phase contrast extremely minute differences of refractive index (in this case as small as $\Delta = .03 \pm .005$) show up very distinctly, while in bright field they remain invisible.

condenser diaphragm, raising or lowering the tube, using singly polarized light, or using filters. All these experiments showed that within certain limits and for certain purposes the Phase Contrast Method could very well be applied for gemmological investigation, particularly for studying structural peculiarities, such as inhomogeneities, the results of incomplete exsolution, alterations, and partly or completely healed cracks. Among the true inclusions, those with a slight difference of refractive index from the host gem, or those which are extremely thin and transparent, become strikingly visible through the phase contrast. However, the visibility of all those well-known " orthodox " inclusions which have often been described, such as foreign ores and crystals, or negative crystals, two-phase and three-phase inclusions, liquid feathers and so on, is not greatly improved by using the Phase Contrast Method. The Phase Contrast Method, which represents one of the greatest improvements in modern microscopy, opens a new and fascinating field of research in the enchanting wonderland of inclusions in gemstones and a considerable amount of valuable information will be gained. Such inclusions and inhomogeneities as illustrated, and many others, can hardly be seen, let alone be properly studied, in bright field illumination.

I am greatly indebted to Dr. H. Piller for his interest and important help in devising and constructing a gemmological phase contrast equipment.

* LITERATURE.—For those who are interested in studying more about the Phase Contrast Method or its various possibilities of application, ample information may be obtained from the " List of Literature Dealing with Phase Contrast Microscopy," Series ZW115-S issued by R. Winkel G.m.b.H., Göttingen.

MEASURING DICHROISM—SOME EXPERIMENTS

By E. J. BURBAGE, F.G.A., and THOROLD JONES, F.G.A.

NOTHING is inviolate from the earnest Ph.D. researcher, and probably at least one thesis is already gathering dust in the archives of some State University in Arkansas or Florida attempting a critical appraisal of Chesterton's use of paradox, and this monograph can scarcely fail to have spotlighted into major place the Inversion Type, in which G.K.C. takes a well-known proverb or cliché, and, standing it on its head, shows it to be still valid, and even more illuminating. Thus, from the gnomic but unexciting platitude so drearily familiar in one's schooldays, Chesterton produced the profound truth that, " if a thing is worth doing at all, it's worth doing badly." An aphorism worthy of employment as a touchstone for any venture which one contemplates ! So, having regard to the paucity of objective quantitative information about pleochroism in gemstones, we considered it worth while to make some tentative enquiries into this field, even though the results now presented do not pretend to be other than a first approximation only.

In our view, the dichroscope has never attained the position among gemmological instruments to which its potentialities entitle it. It is not expensive, is fairly robust, has a reasonably wide scope, and does not require any very exacting degree of expertise for its employment.

In mineralogical literature, any data relevant to the measured degree of dichroism in a gemstone have usually been implicit in an investigation of the absorption shown by a crystalline plate for various wavelengths. From a pair of transmission curves, obtained when employing polarized light sources of vibration directions mutually at right-angles, a measure of the degree of pleochroism may be calculated. Slawson and Thibault's paper on tourmaline may be quoted as an investigation of this type.[1] Ideally, such an enquiry is best served by using a spectrophotometer, of which the sensitivity can be very great, approaching that of the human eye, but few gemmologists are likely to have access to such an expensive, elaborate, and bulky piece of apparatus, and, in addition, the cutting of sections from rough material is not an activity upon

which the average gemmologist is likely to embark very readily.

A modification of the dichroscope for approximately measuring the strength of dichroism in a cut gemstone seemed therefore to be indicated. The calcite dichroscope, the instrument devised by Haidinger over a century ago,[2] and used by de Sénarmont in his researches in pleochroism,[3] is still unrivalled for spotting small differences in dichroic colours, but it is not suitable for alteration to enable measurements to be made. It is reasonably easy to mock-up a dichroscope using polaroid, and variants on such home-made instruments have been devised, described, and shown by Anderson,[4] Thibault,[5] Dollar and others. Such instruments consist essentially of two optically-at-right-angles polaroid strips laid side by side, and some kind of lens for viewing. Having decided to employ this type of instrument, it was then necessary to consider what measurement conventions should be employed, and what means could be used to obtain the requisite data.

A scheme for matching by colour was clearly impracticable, for it would require optical engineering of considerable complexity, and would raise questions of colorimetry and subjective colour vision whose resolution would be outside the scope of the non-specialist. A translation into linear terms, so to speak, by using monochromatic light seemed the most hopeful approach, when the measurements would be of absorptions for selected wave-lengths. A further simplification, admissible in view of the approximate, rather than critically accurate, standards envisaged, would be to employ " narrow-cut " photographic filters. For measuring transmission densities, it was decided to match these against superimposed polaroids, using the trigonometrical relationship between angle-from-extinction-position and absorption, by which, if the light-transmission in the " parallel " position is taken as unity, then at angle θ from extinction it is $\sin^2\theta$. This was effected by using two semicircular discs of polaroid in place of the two strips customarily employed in polaroid dichroscopes. The central area of the polaroid composite was used in displaying the dichroism, and the periphery, separated by an intermediate narrow metal wall, functioned as the " stator " of the photometer. Capping this end of the dichroscope were a metal fitment, embodying a moving " finger " of polaroid functioning as the " rotor " of the photometer, and a dial graduated to enable angular rotations from extinction positions to be measured.

For the narrow-cut filters, the Ilford " Spectrum " range, numbers 600 to 608, was decided upon. These are composite filters giving narrow transmission bands, and their ranges and the relevant data for polaroid are shown in the diagram. Naturally, the limited transmission ranges of these filters mean that they are very dark in colour, and one has to employ a correspondingly bright light source—the Osram " Silverlight " 150 Watt lamp being found very suitable. Also, to increase transmission and to eliminate light reflections, an immersion-cell was used.

The diagram illustrates how these Ilford filters slice up the visible spectrum into convenient ranges, although these overlap to variable extents, are not all symmetrically disposed about a central axis, and have varying amplitudes. It would be interesting to find their cumulative effect when used in parallel (so to speak) in some such apparatus as the calico-printer's Mutachrome, but the result would almost certainly approximate to daylight or to tungsten-light only by the most careful differential light-control by the iris diaphragms. As a corollary it will be seen that one cannot emulate Hurter and Driffield and their successors in photometry by attaching significance to comparative values of transmissions or densities for various regions of the spectrum, although this limitation does not invalidate the measurement of dichroism. In other words, if, for two filters, absorption values derived by the sine-squared rule are x_1, x_2, and y_1, y_2, the ratios between x_1 and x_2 and between y_1 and y_2 will provide quantitative measurements

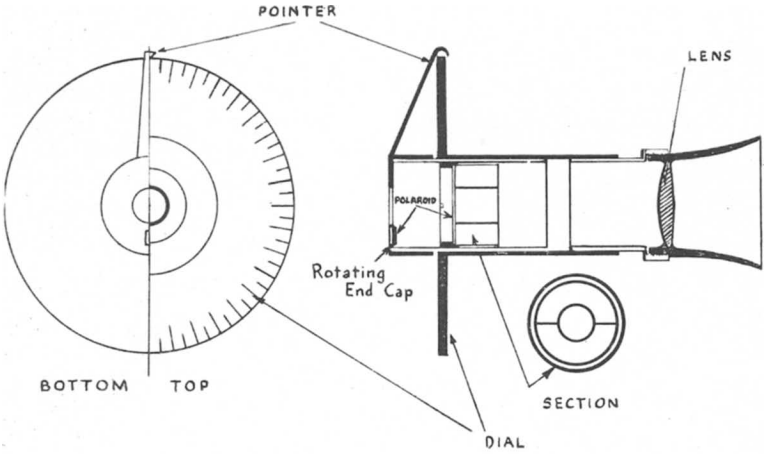

of the dichroism for the two regions of the spectrum, although the significance of the ratios between x_1 and y_1, and x_2 and y_2 will be vitiated by the quiddities of the filters employed

If we were attempting something more definitive on the subject of dichroism than these notes, and were gifted with the linguistic panache of a J. J. Sylvester, we might attempt new and more precise terms for the various types of dichroism. Whilst, over here, we do not normally follow the U.S.A.'s practice of classing the behaviour of herepathite and similar compounds as examples of dichroism, a pedant might with some logic object to a degree of imprecision in our own usage in this matter, in that the cases where two different colours are shown is not large, and very often the "twin-colours" are saturated and unsaturated versions of the same colour. The distinction between "true" and "saturation" dichroism was reflected in our results, where we found that in the latter type, a filter of different colour was necessary to exhibit a difference in absorption. It is easy to see why this should be so—in a gem such as blue zircon, dichroic in blue and nearly colourless, a blue filter will transmit blue without change, and will convert the colourless sector to a matching blue.

Few can afford to commission a lapidary to refashion gem material in better conformity with the principal optical directions,

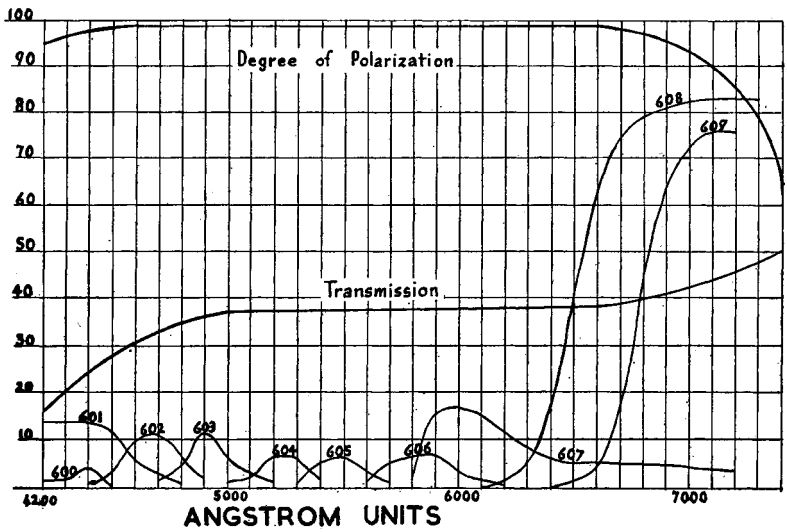

and as our material consisted chiefly of cut stones, we confined our enquiries to those stones which as far as we could judge displayed maximum dichroism when placed table downwards in the immersion cell. Even in these selected stones, it is possible that by experiment or calculation, rotation to positions yielding still more intense dichroism might have been possible, but apart from practical difficulties, this procedure did not seem worth-while for the majority of gemstones showing dichroism. The interrelationship between the dichrometric ratios (if one may so style them) is of greater interest than their actual values, which will in any event depend upon the depth of colour of the gemstone, and generally this will still be discoverable at positions not too far removed from that giving maximum dichroism. This will be true for all uniaxial and probably for many biaxial media, but trichroic biaxial media form a special group, where one would expect the absorption curves to ring the changes in infinite permutations between three limits. To deal adequately with the trichroism of faceted gemstones, one would need to employ some form of universal stage. Trichroic media are not common, and the best-known example among the gemstones, iolite, is very fully documented in " the literature," having engaged the attention of the scientific world for well over a century—certainly since 1819, when we find Brewster somewhat rashly venturing a statement in the Philosophical Transactions[7] that, as far as he knew, dichroism had never been observed in any other minerals than iolite and mica ! A less incurious inquirer, Haidinger, dealt very competently with iolite in his 1845 paper,[2] and some very thorough and careful work was described by Camichel in 1895.[6] Coming nearer our own day, some of us will recall that the late W. T. Gordon of King's College, London, was sufficiently interested in the mineral to have a cube fashioned from it, such that each pair of faces transmitted a different colour. Hence, we felt justified in turning a blind eye to the trichroics, whose only important gemstone member is this interesting but well-documented mineral.

This is a large and fascinating subject, and we have considered only a few aspects of it, although even our limited researches have inclined us to echo de Sénarmont's typically Gallic comment, " Si j'ai fini par entrevoir un fil conducteur dans ce dèdale, ce n'est qu' après de longs efforts." Even so, our stumblings around the maze have certainly proved of interest to ourselves, and if they

result in any small measure in the rescue of the sadly under-rated dichroscope from unmerited neglect, they will have been repaid.

It is outside the scope of the present paper to list the " dichrometric ratios " of the dichroic gemstones, and in any event we have as yet far too little data to attempt to do so. It is interesting, however, to consider the order of magnitude of the ratios of one or two stones which we have measured. A synthetic ruby showed no dichroism for filters Nos. 600 and 601 (deep violet and violet) slight dichroism, too small to measure, for 602 and 603 (blue and blue-green), 604 (green) gave ratio 1·84, 605 (yellow-green) 15·4, 606 (yellow) 3·46. We found 607, the orange filter, insufficiently localized in the spectrum to be of much general use, and, like Camichel in 1895, we found it quite impossible to work with red light, and hence the filters of this colour proved of little avail. For a natural pink sapphire we found a localization of the dichroism in the yellow-green and yellow regions, where filters 605 and 606 gave ratios $3\frac{3}{4}$ and $3\frac{1}{4}$ respectively. If one of the sectors proved too light or too dark to measure, no calculations were of course possible, even though the other was measurable. This we found less satisfactory than when both sectors proved simultaneously intractable, one giving full transmission, the other nil, when an infinity ratio could be recorded. This result we obtained for a green tourmaline for filters 600, 601 and 602 ; for 603 a calculable value of 25 was obtained.

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Gemmological Abstracts

CLARINGBULL (G. F.), HEY (M. H.) and PAYNE (C. J.). *Painite, a new mineral from Mogok, Burma.* Min. Mag., Vol. XXXI, No. 236, March, 1957, pp. 420–425.

A singly-terminated transparent, deep garnet-red crystal originally weighing 1·7gm. from a gem gravel from Mogok, Burma, proves to be a new mineral having Al_2O_3 76·2, SiO_2 5·6, B_2O_3 2·2, CaO 15·7, H_2O 0·7, Fe_2O_3 and MnO traces, total 100·4. Sp. gr. 4·01 ; ω 1·8159, ε 1·7875 ; H7½. The hexagonal unit cell has *a* 8·75, *c* 8·50Å., space group $P6_3$, $P6_3/m$ or $P6_322$, and contains approximately 38 O. The name *painite* is proposed in honour of A. C. D. Pain, Esq., who recognized the unusual nature of the crystal.

5 figs. W.S.

KLUPPELBERG (E.). *Beobachtungen an Gaseienschlussen in Glas und synthetischen Steinen.* Observing gaseous inclusions in glass and synthetic stones. Deutsche Goldschmiede-Zeitung, Vol. 55, No. 3, 1957, pp. 107–109. (See Journ. Gemmology, Vol. VI, No. 2, 1957, p. 97.)

A continuation of a previous article. In this part the inclusions in natural and synthetic crystals are discussed with special mention of inclusions in synthetic spinels, which are shown in carefully selected and well-produced microphotographs.

W.S.

CHUDOBA (K. F.). *Zur Bezeichnung synthetischer Smaragde.* On the nomenclature of synthetic emeralds. Deutsche Goldschmiede-Zeitung, Vol. 55, 1957, No. 3, pp. 109–110.

A further discouragement of terms like " cultured," or " cultivated " used instead of the correct designation of *synthetic emerald.*

W.S.

—— *Borazon—ein synthetischer Hartstoff.* Borazon—a synthetic hard material. Deutsche Goldschmiede-Zeitung, Vol. 55, 1957, No. 3, pp. 110 -111 (March).

An article of February 13th, 1957, in the *New York Herald*

Tribune is abstracted. It contains the first report on " borazon," the new synthetic developed by R. H. Wentorf, of the General Electric Company. Dr. Wentorf scratched a diamond with borazon, and also demonstrated that diamond was hard enough to scratch borazon. The author (Chudoba) speculates on the chemical composition of borazon, which he thinks is a high pressure modification of BN (having a lattice similar to graphite). Owing to its heat resistance, which is claimed to be greater than that of diamond, the new synthetic material may be of potential importance in industry, once it can be produced in quantity at an economical price.

W.S.

EHRMANN (M.). *Gem mining in Burma.* Gems and Gemology, Vol. IX, No. 1, pp. 3–30. Spring, 1957.

A concise survey of the Mogok Stone Tract as it is to-day. A full account is given of the geography of the Union of Burma and in particular the Mogok Valley. The Burmese people, their dress and their homes are described. Reference is made to the geology of the Mogok area and the methods used in the winning of the gemstones are described in detail. The gemstones found in the Mogok Stone Tract apart from ruby, sapphire and spinel, are peridot, beryl, danburite, scapolite, zircon, fibrolite, topaz, orthoclase, kornerupine, sphene, diopside, iolite, chrysoberyl, apatite, albite and amethyst. The topaz and quartz crystals are found in Sakhangy, 12 miles south-west of Mogok, and the peridots from Pyaung Gaung, which is eight miles north-west of the town of Mogok. The history of Mogok in particular is entertainingly written. There is a good account of the jadeite mines near Myitkyina, which includes the history, geology and geography. The location of the amber mines and the occurrence and mining of amber are described, and the article concludes with a section on the gem trading of India and Burma.

23 illus. R.W.

BURGOON (J. R.). *Diamond mining in Arkansas.* Gems and Gemology, Vol. VIII, No. 12, pp. 355–362. Winter, 1956-7.

Diamonds have been found in almost every State of the United States. The suggested source is the James Bay area of Canada and the diamonds are supposed to have been carried south by ice

flows. The Arkansas mine, in Pike County, was found in 1906. It differs from the other sources of diamond in the United States in that this is a pipe mine similar to the diamond-bearing pipes of South Africa. The Arkansas area was first geologically prospected in 1842 and later in 1889 and in both times no diamonds were found and the general view of the geologists was that the pipe was barren. In 1906 John Huddleston took an option on the site of the earlier geological survey and did find diamond, but in very small quantity. Huddleston sold the mine to a group of businessmen who formed the Arkansas Diamond Company. The mine was worked intermittently with the aid of machinery but was not successful and was closed in 1931. The mine was restarted under another company in 1936 but again did not prosper. The mine was sold to the Diamond Corporation of America who put in fresh machinery. The venture was a failure. The mine area is now a tourist attraction and " rockhound " hunting ground. An interesting account with many anecdotes.

5 illus. R.W.

ANON. *Amsterdam " Diamond City."* Netherlands Ind. and Comm., Vol. XI, No. 130, pp. 16–18. May, 1957.

A short history of Amsterdam as a diamond cutting centre and market during the past three centuries. The commencement of the expulsion of Jews from Portugal and Spain in the sixteenth century, and of the Protestants from France led to the settlement of diamond merchants and cutters in Amsterdam. In the early days diamonds came from India and Borneo. Then in 1727 the Amsterdam merchants were granted a monopoly of the diamonds from Brazil. The Brazilian stones were said to be harder to cut than the Indian stones, and a new technique of cleaving was developed to deal with them. The various wars from the Napoleonic to the Franco-German of 1870 caused depression in the industry, but these soon righted themselves. After the 1870 war the diamond supply came from the new South African mines. The Boer War caused disaster to the Dutch cutters, as did the First World War. Neither of these killed the industry, and it soon revived. The German occupation during the Second World War caused damage, not only through the denying of supplies, but through the damage to equipment, and, what was more

serious, the loss of life owing to the purges against the Jews, many of whom were diamond merchants and cutters. Despite this severe damage the Dutch diamond industry has again recovered, although new cutters have had to be trained and new premises built. A section is given to the industrial uses of diamond and on the properties of diamond. The glass factory at Leerdam still practices engraving on glass by diamond tools.

5 illus. R.W.

FEHR (F. L.). *Amsterdam, Diamond City.* The Netherlands Ind. and Comm., Vol. XI, No. 130, p. 13. May, 1957.

The last two years of the diamond industry of the Netherlands have been a period of comparative boom, profits, however, being less than those made by other manufacturers in different industries. The piece-work form of payment and new production methods have brought about increased production of fashioned diamonds. The damage caused by the German occupation has now been mostly repaired. A short introduction is given for the Diamond Exhibition, which was held in the Apollohal in June and July.

R.W.

LABOYRIE (J. B.). *The selection of diamonds.* The Netherlands Ind. and Comm., Vol. XI, No. 130, p. 14, May, 1957. (*Extracted Gemmologist, Vol. XXVI, No. 311, p. 116. June, 1957*).

The appreciation of diamonds is influenced by four items, colour, cleanliness, size and shape, and for polished diamonds a fifth requirement is necessary, that of grade of manufacture. In general, cuttable rough diamonds are more expensive than the industrial rough, and in normal circumstances there is a well defined borderline between the two. When the demand for industrials is great, the lower range of cuttables (gem grades) may be bought for industrial purposes, and at higher prices than they would fetch as cuttables. Conversely, when there is a demand for a cheap polished product, the manufacturer starts to buy certain industrials that are still serviceable for cutting, again at a higher price than they would fetch as industrials. Such use of industrials for cutting disturbed the Dutch market in 1956, but has tended to disappear this year.

1 illus. R.W.

WEBSTER (R.). *Strain " knots " in synthetic spinel.* Gemmologist, Vol. XXVI, No. 311, pp. 99–100. June, 1957.

The strain patterns seen in synthetic spinels when viewed between crossed nicols are considered. They are patterns which may be likened to the " zircon halos " seen in many stones from Ceylon, but are only observed in polarized light. The " knots " have been seen in all colours of synthetic spinel, but appear to be more profuse in the yellow-green-coloured materials. The points of disturbance can only be vaguely seen in ordinary light, and no reason is given as to the cause of the " knots."

2 illus. P.B.

MEINCKE (H.). *Control tests of synthetic crystals by the use of isotopes.* Gemmologist, Vol. XXVI, No. 308, pp. 46–51. March, 1957.

Describes the use of non-radioactive isotopes (mainly C^{13}) as a means of characterizing a substance under test and to study their influence on its chemical or other change. From the experiments the conclusions were drawn that considerable admixture of isotopes causes changes in the properties not only of the original material but also of the resulting crystal deposit, so that they no longer correspond to those of the natural material. This fact precludes the use of non-radioactive isotopes for control purposes during changes in substances.

R.W.

ROBB (C. J.). *The jewel cure.* Gemmologist, Vol. XXVI, No. 308, p. 45. March, 1957.

Tells the story of some Irish jewels, which, legend has it, could cure divers illnesses. Generally agates, the two of which most is written are the " Imokilly jewel " and the *Cloch Omra.*

P.B.

WEBSTER (R.). *The pearl.* Gemmologist, Vol. XXVI, Nos. 310–311–312, pp. 78–85, 102–109, 126–128. May–June–July, 1957.

A general article detailing the formation and character of pearl and the location and methods of fishing in the various pearling waters. Mention is made of conch pearls and those obtained from molluscs which live in fresh water. The colours of pearls, their shapes and their preparation for marketing, are referred to,

and the " base " method for the calculation of the price of pearls is explained. Some notes are given on the " doctoring " of pearls by " skinning " and staining and some hints on the care of pearls.
11 illus. P.B.

ANON. *Diamonds within diamonds.* Gemmologist, Vol. XXVI, No. 310, pp. 92–93. May, 1957. (*Extracted from OPTIMA*).

Observations on a diamond inclusion in another diamond. Polarized light shows strain patterns of anomalous double refraction, and thus indicates that the included diamond does not fit perfectly and sets up strain in the host crystal. Such an effect accounts for the occasional shattering of a diamond a short time after leaving the mine, probably owing to the support of the containing rock being removed, or when being cut.
1 illus. R.W.

MARLE (F.). *Une émeraude synthétique.* (A synthetic emerald.) Revue Française des Bijoutiers Horlogers Exportation, Vol. III, No. 71, pp. 45–50. 1957.

An incomplete report of the growing of emerald crystals at the Centre National d'Etude de Télécommunications in Paris. A young scientist, during experimental work on crystal growth, produced emerald using advanced techniques based on the experiments of Hautefeuille and Perrey. Rather vague details of the apparatus used are given, and although a fusion method is indicated it is not conclusively explained whether that is the method used or a hydrothermal one.

R.W.

BERRY (R. B.). *Changing the colour of quartz.* Gemmologist, Vol. XXVI, No. 310, pp. 90–91. May, 1957. (*Extracted from Gems and Minerals*).

Records the results of several experiments in the irradiation of quartz in an atomic pile. Fifty brilliant-cut stones (colour not stated but presumed colourless) were given three weeks treatment in a pile. When removed thirty stones had turned black, fifteen to a smoky hue and five to a beautiful citrine yellow. Subsequent heat treatment at 400°F showed the smoky-hued specimens to give a blue luminescence, after which they reverted to become as clear as before irradiation. The citrine-coloured stones did not revert, and all but five of the black stones behaved similarly to the

smoky-coloured stones in that they turned clear after a short blue luminescence. The five exceptions turned to a citrine colour, and these yellow-coloured stones showed no tendency to revert after prolonged exposure to solar radiation. No amethyst colour was reported to have been produced. Some speculations given as to the cause of colour in amethyst and smoky quartz.

R.W.

HALFORD WATKINS (J. F.). *Reasons for chatoyancy and asterism.* Gemmologist, Vol. XXVI, No. 309, pp. 69–75. April, 1957.

Originally published in the Gemmologist for August, 1932, as "Chatoyant phenomena," the article gives a general survey of the legends and the physical causes of asterism and chatoyancy. The article was written before the production of the synthetic star-corundum and is hence somewhat out of date. There is much good information and advice given in the article.

6 illus. R.W.

TRUMPER (L. C.). *Mounting a collection of gemstones.* Gemmologist, Vol. XXVI, No. 312, pp. 120–121. July, 1957.

Some ideas for the mounting of gemstones for display, either by the means of metal pins with adjustable claws or by specially shaped perspex fittings mounted on stems.

4 illus. R.W.

MELROSE (H.). *Spanish Armada pearls.* Gemmologist, Vol. XXVI, No. 312, pp. 117–119. July, 1957.

The story of four pearls (from the photograph they are apparently blister pearls), which have been named the O'Donnell pearls. The shells are approximately 13/16th of an inch in diameter and are said to be identical in formation with a mollusc of oyster type (*Pteria phalaenocea*) which were believed to have become extinct some 35 million years ago. Their presumed history since the days of the Spanish Armada is given.

1 illus. R.W.

LEIPER (H.). *Orienting blue topaz with ultra-violet light.* Gemmologist, Vol. XXVI, No. 312, pp. 133–136. July, 1957.

A reprint of an article published in Gems and Minerals, and also reprinted in JOURN. GEMMOLOGY, Vol. V., No. 3, pp. 135–140. July, 1955.

4 illus. R.W.

TRUMPER (L. C.). *The measurement of fluorescent spectra.* Gemmologist, Vol. XXVI, No. 312, pp. 122–123. July, 1957.

Describes a fitting to take a direct-vision prism spectroscope with wavelength scale, so that the fluorescence spectra can be measured—the scale of the instrument being illuminated by a secondary low-power light source incorporated in the fitting.
2 illus. R.W.

SINKANKAS (J.). *Recent gem mining at Ramona, San Diego County, California.* Gems and Gemology, Vol. VIII, No. 12, pp. 367–373. Winter, 1956–57.

A general review of the gem-bearing pegmatites near Ramona, San Diego Co., California. The area was first thoroughly explored in 1903. Dark green tourmaline, blue, greenish and colourless topazes, morganite beryl, smoky quartz and orange spessartite are mined from this locality. The fine orange spessartite from this area was first found in 1955 in the Little Three mine, one of the seven mines in the area, the others being the A.B.C., Black Panther, Lookout, Hercules, Spaulding and Surprise. Notes on the geography and geology of this area are given.
1 map. R.W.

POUGH (F. H.). *Greened amethyst.* Gemmologist, Vol. XXVI, No. 311, pp. 110–116. June, 1957.

A full description of the heat-treated amethyst which turns a green colour. There is a note on the " burnt amethyst " of " topaz " colour. Occasionally green quartz had been encountered on the market, but the origin was unknown. The discovery of the greening amethyst was accidental. The material amenable to such treatment is said to come from one locality only, that of Montezuma about 37 miles from the Rio Pardo in the State of Minas Gerais, Brazil. The deposit is a vertical vein which was originally worked by trench mining—shaft mining now being used. The amethyst is found in pockets and the individual crystals are more prismatic than ordinarily for amethyst. The colour is of moderate intensity violet and the crystal faces are dull and iron-stained. The heat-treatment is carried out at Rio de Janeiro and the resultant greened amethyst is sold under the name " prasiolita " or " prasiolite."
5 illus. R.W.

PELTON (C. R.). *A study of chalcedony.* Amer. Journ. Sci., 1956, Vol. 254, pp. 32–50.

The author suggests that chalcedony is microcrystalline quartz with submicroscopic pores. The quartz crystallites are somewhat misoriented from fibre to fibre which gives rise to local strain. Water may occur in the pores and optical evidence of strain, etch tests, absorption spectra and heating tests is given. The characteristic brown colour of chalcedony is ascribed to the scattering of light from the submicroscopic pores. S.P.

LEONARDOS (O. H.). *Ocorrencias de andalusita no Brasil.* Gemologia, No. 7, 1957, pp. 10–14.

This paper is of particular interest and ranks with earlier articles as an authoritative account of the occurrence of this rare gem mineral in that country. Principal localities are Minas Novas, Araçuai and Espírito Santo. Apparently crystals of any size are rare, the majority being from 3mm. to 10mm. in length and up to 5mm. broad. The shape of the crystal often compels the cutter to sacrifice the red colour for size and most stones are apparently trap cut, green in colour with some red flashes from the end facets only. Small uncuttable sizes seem to be reasonably common, but anything of good size is very exceptional.

1 Fig. R.K.M.

DE FREITAS (R. O.). *O Zircao na Gemologia.* Gemologia, No. 8, 1957, pp. 1–7.

This paper is chiefly of note for its account of Brazillian sources of gem quality zircon, particularly as Brazil is not generally thought of as a country producing this species.

For those who think of Zircon crystals in terms of simple tetragonal prisms (110) and pyramids (111) the illustrations of habit will come as something of a shock. All six drawings show the second order prism (100) well developed in addition to the normal forms, and four of them show the (311) pyramid, a steep form sometimes known as a zirconoid but not often seen. The last drawing shows the second order prism combined with the first order pyramid to produce a 12 sided crystal closely resembling the cubic rhombdodecahedron.

Generally the mineral appears to be abundant but not in gem quality or sizes.

6 Figs. R.K.M.

HARDY (E.). *Culture pearls.* Gemmologist, Vol. XXVI, No. 307, pp. 26–27. February, 1957.

A general article on the proposal to culture pearls in Malayan waters near Penang and Singapore. The formation of a cultured pearl fishery in Brecknock Harbour, Western Australia, using the large Australian pearl oyster *Pinctada maxima*, is also reported.

R.W.

ASSCHER (J.). *Locating imperfections in diamond.* Gemmologist, Vol. XXVI, No. 310, pp. 86–88. May, 1957.

Before fashioning a stone from a diamond crystal it is necessary to examine it thoroughly for internal imperfections in order to get the best cut-stone from the rough. Windows are polished on the crystal to see inside the stone. The article tells the use of a modified Rayner gemmological microscope for determining the position of imperfections in the crystal. The microscope is fitted with a large measuring drum on the focusing adjustment and a measuring stage. The scheme of operation is shown, and the use of polarized light to locate " inclusions " which are not observable in ordinary light is referred to.

3 illus. R.W.

ANON. *Brief notes about the colourful history of some famous diamonds.* Netherlands Ind. and Comm., Vol. XI, No. 130, pp. 18–21.

Thumbnail histories are given of twenty-nine famous diamonds. Six illustrations are included which have no relation to the text.

R.W.

WEBSTER (R.). *Tumbled gems.* Gemmologist, Vol. XXVI, No. 309, pp. 61–63. April, 1957.

A short description of the tumbling method for the production of baroque gems by churning in a slowly rotating barrel with abrasive and, subsequently, polishing agents.

4 illus. P.B.

CORRECTION. In the abstract of QUICK (L.). *Story of Benitoite.* (Journ. Gemmology, Vol. VI, No. 2, 1957, p. 96), the occurrence of benitoite should have been given as Santa Rita Peak, San Benito County, and not San Diego County.

S.P.

The summer issue of the *Zeitschrift der Deutschen Gesellschaft für Edelsteinkunde* contains a series of articles specially written by international gemmologists to celebrate the seventieth birthday of Professor Karl Schlossmacher, who was born on 10th July, 1887. This special number of the Journal edited by Professor K. F. Chudoba is a welcome and valuable contribution to gemmological literature, and summaries of the articles are given below.

ANDERSON (B. W.). *Refractive index data for some useful immersion liquids.*

When taking " immersion contact " photographs of gemstones, it is noticeable that the relation between the stone and the liquid varies appreciably according to the wavelength of the light used for the experiment. This, of course, is due to the well-known fact that the dispersion of liquids is higher than that of crystals of comparable refracting power.

A fairly precise knowledge of the dispersion of liquids used for this or for any other immersion method is thus essential if accurate work is to be attempted, unless one is content to use sodium light and a very large number of different liquids. Since it is not easy to find the necessary data in the literature, it was thought worth-while to make a series of measurements on some of the liquids most often used by gemmologists. The four liquids, methylene iodide, monobromonaphthalene, bromoform, and bromobenzene, are readily obtainable, and cover almost completely the range in refractive index from 1·80 to 1·56, if different wavelengths are used.

The liquids were placed in a hollow 60° glass prism, and the positions of minimum deviation for prominent lines in the mercury spectrum were measured on a table spectrometer, and the appropriate refractive indices calculated by the usual formula. The mercury lines cover the spectrum well, and mercury lamps are available to most gemmologists, being used extensively for fluorescence work. Colour filters can also be readily obtained whereby at least three well-spaced mercury lines can be isolated in turn, thus yielding three sources of monochromatic light.

In this paper, dispersion curves of the four liquids in question are reproduced, and examples are shown of immersion contrast photographs taken in yellow and in violet light, which serve to illustrate the effects of dispersion.

BIEGEL (K. H.). *Über künstliche Farbveränderungen von Edel- und Schmucksteinen.* (Artificial coloration of precious stones.)

A brief summary of the methods of artificial alteration of precious stone colours mostly applied by stone-cutters and dealers. Distinction is made between real improvements of stones and impregnation with colouring matter. The possibility of introducing colouring metal ions into crystals by electric current especially at elevated temperatures is briefly discussed in connexion with a report on experiments with quartz crystals.

BÖLSCHE (R.). *Neue Beobachtungen am Habachtal-Smaragd.* (New observations on Habachtal emerald.)

In a small aggregate of emerald crystals of varying colour and development from Habachtal (Austria), the presence of " bleischweif " (thinly laminated galena) between the crystals and on their surfaces could be detected. The influence of the " bleischweif " on the formation of the crystals is considered. The zonal striations in one emerald are described.

FISCHER (W.). *Zur Entwicklung der Idar-Obersteiner Edelsteinindustrie nach dem Kreige.* (Post-war development of Idar-Oberstein gem industry.)

The post-war development of the gem and diamond industry at Idar-Oberstein is discussed on the basis of statistical data available from the school for lapidary apprentices. The proportion of apprentices among the lapidary employees is relatively high, if one considers the average of a little more than two employees per workshop. Proposals for a modification of the training are made for those lapidaries working exclusively on synthetic gems. Possibilities for further development are seen in the processing of gems and diamonds for technical purposes and in the increasing economic importance of gem amateurs, especially in North America, who are getting interested more and more in gems which have not yet been worked in Idar-Oberstein on an appreciable scale. Comments are given on the reports of F. H. Pough on the situation of the Idar-Oberstein lapidary industry published after his recent visit there. The share of the practical work in the schools done by apprentices with special reference to the attainments and precision of the work and to the progress of the artistic achievements at Idar-Oberstein, which was greatly emphasized by F. H. Pough, is discussed. The article is supplemented by results of final exams of apprentices in the gem and lapidary industry.

GOEBELER (H.). *Steinschneidekunst.* (Art of gem engraving.)

The terms intaglio and cameo are defined as carved gems with incised and raised engraving respectively. The carving may be done either by simple manual tools, or by rotary tools (drilling and grinding). The material for engraved gems is chiefly yielded by the minerals of the quartz group. Hematite was used for the ancient mid-eastern seal-cylinders. Engravings on emerald, beryl, garnet, peridot and topaz have been rare. Through all ages glass (paste) has been a material for imitating gems. For these glass-pastes a mould of an intaglio or a cameo was impressed on plastic clay to cast the glass, which, after cooling, was brought to its final shape by finishing with tools.

The oldest engravings on gems originated from about 5000 to 3000 B.C. The Hittites, Egyptians, Assyrians, Persians and the ancient Greeks are worth mentioning for their art of carving gems. Remarkable works were accomplished by Greek artists for members of the Roman noble class during the time of the early emperors. Famous examples are the Gemma Augustea (Vienna) and a sardonyx representing the triumph of Germanicus (Paris). Since the time of Constantine the Great engravings on gems representing religious subjects were made in Byzantium. There are only very few carved gems preserved dating from the medieval ages. Our knowledge of ancient glyptography is based on the collections of the important museums and on the abundance of gems in pieces of medieval jewellery.

Towards the middle of the 19th century a rapid decline of glyptography began and the interest in carved gems was lost. Nowadays the art is mastered only by a small number of artists. A revival of glyptography would certainly add an element of special delicacy to the pictorial arts of to-day.

GÜBELIN (E.) *Das Phasenkontrast-Verfahren nach Zernike zur Untersuchung von Inhomogenitäten in Edelsteinen.* (Phase contrast microscopy for observation of gemstone inclusions.)

This paper emphasizes the great advantage of the phase contrast method of F. Zernike over the orthodox operations used previously for improving the contrast in bright field and the adaptation of dark field illumination. The principle of the phase-contrast method is explained and schematically depicted by a simplified diagram. Thanks to the development of a special phase contrast

equipment for " bulky " objects the application of the phase contrast method has become possible for gemmological microscopy.

The new method offers interesting possibilities for investigating the interior of gemstones, particularly with regard to inhomogeneities caused by ex-solution, alteration and strain. It also reveals ultra-thin, transparent and colourless inclusions of very slight refractive difference and it discloses the state of healed fissures not visible under ordinary light conditions. Eight examples are shown and explained by means of photomicrographs. Thus the phase contrast method promises to become a source of new and interesting knowledge in gemmological microscopy.

KRAUS (E. H.). *The Development of gemology in the United States and Canada.*

Although some excellent books on gems had been published and courses on gems had been introduced at several institutions of higher education, it was not until about 1930 that a real interest in gemology began to be developed in the United States and Canada.

LIDDICOAT, JR. (R. T.). *Beauty versus excess weight.*

Whilst the diamond cutter usually cuts to the ideal pavilion angles at least, the lapidary often seems to have but one goal : to retain as much weight as possible. This preoccupation with maximum weight retention is difficult to understand. If proportions were given more careful attention, many more people would be attracted to coloured stones.

LIETZ (J.). *Neue Untersuchungen über die Bestrahlungsfärbung von Zirkon.* (New investigations on the radiation colouring of zircon.)

The coloration of colourless zircon from Mongka, Indochina, by UV-radiation is investigated in the visible and ultra-violet part of the spectrum. The absorption was measured at —173°C, and the crystal irradiated at 20°C as well as at —173°C. The absorption spectrum consists of single bands at 1·60, 2·10, 2·60, 3·30, 4·00 and 4·50 eVolt. The first bands to appear at low temperature are those of greater wave-lengths. These diminish with rising temperature and new bands of shorter wave-lengths are produced.

PAYNE (C. J.). *Painite : A new mineral which can be cut as a gemstone.* This new mineral is referred to in an abstract on p. 172

PLATO (W.). *Ringstein-Prüfapparat.* (Testing of mounted stones.) Illustrated description of an apparatus facilitating microscopical study of mounted gems both by parallel and convergent illumination.

POUGH (F. H.). *The Coloration of gemstones by electron bombardment.* Colorations induced in various mineral substances, including a large number of gemstones, by an accelerator-produced electron beam are described and classified. They are distinguishable in degrees of permanence, with diamonds falling in a special class, because, once induced, their discolorations cannot be removed, only altered. The coloration of all other minerals is variable. Some may be changed to a colour which is apparently permanent, except to significant heat, and in others the colour change is only temporary, even though the specimens may not be exposed to light. A last group, so far limited to one mineral (wernerite), appears to lose the induced coloration spontaneously, even though the stones are kept in darkness.

One result of this study, which is a part of a continuing series of experiments with various particle sources, is the recognition that in most cases, the coloration—no matter whether induced by protons, deuterons, neutrons, alpha-, beta-, or gamma-particles, X-rays or electrons—is always the same for any mineral (again excepting diamond). This suggests that atomic spacing and lattice defects are almost entirely responsible for the hues produced, rather than any impurity accidently present. There are however, many discrepancies remaining to be explained, such as the failure of some amethyst to turn smoky like other quartzes, the difference between topazes of various origins, and the inconsistencies in spodumene responses. The explanations proposed by physicists, who so far have worked with only the simplest structures, are found to be inadequate even for their minerals, and do not begin to approach an explanation of the colorations which take place in the truly complex silicate structures.

ROSCH (S.). *Das Grune Gewölbe in Dresden.* (The green vault in Dresden.)

The author's own observations on the treasures in the famous green vault of Dresden. The contents of the vault are described

in greater detail than in the official catalogue published in 1921 and the hope is expressed that the treasures will one day be returned to Germany.

SCHIEBEL (W.). *Interferenzerscheinungen bei Spannungsdoppelbrechung.* (Interference patterns caused by anomalous double refraction.)

The article deals with the strain birefringence in transparent gem-stones and glass imitations by coloured interference phenomena. Certain crystal plates may be used for this purpose between crossed polarizers. The phenomena observed in instances of synthetic spinel and in glass imitations are described. The resulting pictures, which are rather complicated, are interpreted in terms of differences in velocities of light.

SCHMIDT (P. S. J.). " *Das Steinbuch des Aristoteles.*" (The gem book of Aristotle.)

It is a salient feature of the history of mineralogy that the ancient Greeks did not pay much attention to gems. Among the papers by Aristotle there is none dealing with stones. The so-called " Lapidary of Aristotle " certainly is spurious. A critical study of its contents reveals that Aristotle's authorship is out of the question. His pupil Theophrastus, however, gives an idea of what a lapidary would be.

SCHRÖDER (A.). *Zur Optik und Dichte der Edelturmaline.* (Optics and density of tourmaline.)

Some 40 different flawless tourmaline gems have been investigated. All of the stones were cut and faceted. Special regard was given to the correlation between the specific gravity and the refractive index of the ordinary ray for yellow sodium light. The resulting points plotted on a graph were arranged in a continuous curve which could be used in determining other stones of the species.

SCHUTT (E.). *Ist bei der mikroskopischen Echtheitsprüfung eine Immersionsflussigkeit notwendig ?* (Does microscopical observation need immersion liquids ?)

A technique permitting the microscopic study of gems without immersion liquids is described and recommended as a method for testing gems. Studies of inclusions in emerald and gems of the

corundum group are given as examples, and possible errors arising from the use of immersion liquids are explained. Such mistakes are avoided in the new method without immersion liquids.

Another technique for the microscopic study of gems using reflected light is described in detail. It is stated that this method should be most suitable in routine work for jewellers and goldsmiths.

WEBSTER (R.). *Short-wave ultra-violet light as a gemmological tool.*

Observations on the luminescent behaviour of gems have been recorded since 1903, and much more advanced work was carried out by later workers, particularly by H. Michel of Vienna. Ultra-violet radiations are stated as lying between 4000Å and 150Å ; the range between 4000Å and 3000Å is termed the long-wave band and between 3000Å and 2000Å the short-wave band, as below 2000Å the rays cannot be usefully employed. Earlier workers used a high-pressure mercury arc with a Wood's glass filter, which passed the strong emission line at 3650Å. The short-wave ultra-violet lamp uses a low-pressure mercury arc in conjunction with a special glass envelope and filter, allowing the strong resonance line of mercury at 2537 Å to pass out, while to some extent absorbing the visible glow and the long-wave ultra-violet radiation. The short-wave lamp was not used much before 1942, when it was extensively employed in the mining of scheelite and willemite. After the war the use of the short-wave lamp was considered as an additional gem-testing instrument, where it is particularly useful for those stones which do not respond to the long-wave lamp but fluoresce under short-waves—for instance, benitoite and synthetic spinel. The lamp is useful in identifying certain types of doublets, and, by a photographic method, for determining the greater transparency to ultra-violet light of synthetic emerald in comparison with natural emerald, which may be used as a means of identification.

NEUHAUS (A.), and SCHILLY (W.). *Über Absorptionsspektren und Koordination einiger chromhaltiger Minerale und Edelsteine.* (Absorption spectra and co-ordination in certain chromium-bearing minerals and gemstones.)

On the basis of a new theoretical approach to the absorption spectra of the coloured complexes of the transition metals (Ti to Ni) made by Hartmann, and on the basis of the great advances made in

the field of crystal growth and electronic spectrometry, it appeared useful to consider once again the old problem of the " dilute " allochromatic colouring of minerals and to attempt to arrive at an understanding of the causes.

This is demonstrated in a short systematic discussion, using crystals coloured by chromium ($Cr^{\cdots}$). In conformity with both theory and experiment on chromium-coloured crystals, and irrespective of the colour shown (red, violet, or green), absorption curves were found to follow the same general shape and pattern.

Thus, curves showed two very prominent absorption-maxima (i.e. absorption bans) of medium intensity in the visible spectrum, which were located :

1. For green crystals of the " emerald " type, at 5,400 to 5,700Å and 3,900 to 4,150Å, respectively, including natural and synthetic emerald, uvarovite, smaragdite, fuchsite, chrome-diopside, synthetic chrome-rich spinels, alexandrite and chrome-mullite.

2. For crystals of the " ruby " type, at 6,000 to 6,320Å and 4,200 to 4,350Å respectively, including natural and synthetic ruby, natural and synthetic normal spinel (i.e. without surplus alumina), zinc-spinel and chrome-alum.

This uniformity of the absorption curves is conditioned by (*a*) the symmetry of the co-ordination-polyhedra around the chromium ion, (*b*) by the influence of the polarization changes between the respective central ions and " Liganden," and (*c*) by the distance between the latter. In accordance with this, green-coloured crystals occur when, in addition to aluminium and chromium ions, another strongly polarizing ion exists in the lattice, as for instance, silicon in the silicate minerals, while on the other hand red-coloured crystals occur when there is an absence of such strong central ions, which contra-polarize the chromium-oxygen polyhedra, or when these polyhedra are indirectly pressed together by the expansion of the terahedral gaps, as for instance in magnesium and zinc spinels. This leads one to the opinion that the red/green colour effect of the chromic ion is not due to two different types of co-ordination as postulated by Thilo, but to two different states of the chromic ions : the normal state, as in the silicates, and a forced metastable state, as in ruby and normal spinels.

In the light of such an interpretation, as can easily be seen from a study of the genesis of these crystals, it is now possible to understand better than ever before, not only the colour differences, but also many other characteristics of chrome-rich crystals. Thus we can understand better the " thermochromatology " (change of colour on heating) as a direct function of genesis, since heating means expansion of the polyhedra, leading to the emerald (green) type, while cooling means a return to the compressed, metastable ruby type. It also gives some explanation of the double refraction due to strain and the " hardening " (lattice compression) of chrome-rich synthetic rubies.

ASSOCIATION NOTICES

EXAMINATION RESULTS

In the 1957 examinations in gemmology 130 candidates presented themselves for the preliminary and 100 for the diploma examination. Upon the recommendation of the examiners an award of the Tully Memorial medal was not made.

The following is a list of successful candidates, arranged alphabetically :—

Diploma

Qualified with distinction

Blackmore, Howard Loftus, Caterham.
Hinton, Vera Georgina (Mrs.), Staines.
Hopkins, Iris Patience Letitia (Miss), London.
Jank, Robert Alexander, Boscombe.
Weller, Christine Janet (Mrs.), Croydon.
Weller, Raymond John Howard, Croydon.

Qualified

Armbrecht, Bertram John, London.
Cassarino, Joseph A., Rochester, N.Y.
Cook, Walter George, Liverpool.
Cooper, Colin Lester, Lucerne, Switzerland.
Cope, John Richard, Plumtree.
Diss, Geoffrey Dixon, Barrow-in-Furness.
Drapkin, Clive Magnus, Birmingham.
Flapper, Jan, Arnhem, Holland.
Gaudernack, Rolf, Oslo, Norway.
Grimsdell, John Leslie, London.
Hadjizade, Ahron, London.
Hatcher, June Ann (Miss), Birmingham.
Hirschsohn, Clive Louis Richard, Cape Town, S. Africa.
Holland, Norman Alfred, Birmingham.
Jones, Wilfred Russell, Auckland, N. Zealand.
Kelly, William Henry, Glasgow.
Lauder, Angus Davidson, Edinburgh.
Lauvland, Karl, London.
Leake, Douglas Michael, Nuneaton.
MacLeod, Hector MacDougal, Glasgow.
McKay, Robin Ian, Thames Ditton.
Meanwell, Brian Sydney, Birmingham.
Mitchell, Peter John, London.
Pedersen, Erik Martinius, Lillehammer, Norway.
Seager, Philip, Abingdon.
Seneviratne, Dayatissa, London.
Skrede, Agnar, Boerüm, Norway.
Solman, Barbara (Mrs.), Worcester Park.
Strange, Peter John, London.
Warrender, John Stanley, Sutton.
Weatherill, John, Cardiff.
Weaver, Gerald Owen, London.
Weiss, Kurt, London.
Ystad, Per Thomas, Porsgrunn, Norway.

Rayner Prize

Steadman, Ivor Noel, Huntingdon.

Preliminary

Ainsworth, Michael Barlow, Blackburn.
Aldridge, Patrick Edward, London.
Armstead, John Miller, London.
Atkinson, James Cockburn, Whitley Bay.
Barker, John William, Plymouth.
Barrett, John, Ayios Nikolaos, Cyprus.
Beeson, John David, London
Biddulph, Brian, Leicester.
Buckler, Albert Norman, London.
Cairns, Jean Mary (Mrs.), Birmingham.
Callaghan, David John, London.
Canning, Thomas Alfonso, Edinburgh
Clarke, Eric Michel, London.
Claudi, Fredrik, Oslo, Norway.
Coakley, Brian, Manchester.
Cook, Anthony Jean, Birmingham.
Cook, Peter Bryan, Birmingham.
Cooke, Barrie Ellis, Birmingham.
Copeland, Margaret Edith (Miss), Sutton Coldfield.
Crawford, Andrew, Birmingham.
Donaldson, Robert Gordon, London.
Eakins, Harry, Liverpool.
Falconer, Richard Arthur, New Malden.
Ferguson, Charles Thomas, Smethwick.
Fitzpatrick, Norman Reginald, Glasgow.
Fowler, Margaret Anne (Miss), Birmingham.
Gibbs, John Alfred Robert, Birmingham.
Hall, Edwin Frank, Birmingham.
Hayman, Harry Miller, New Westminster, B.C., Canada.
Hellman, Frank Viktor, Oslo, Norway.
Hirschsohn, Clive Louis Richard, Cape Town, S. Africa.
Hope, Kenneth, London.
Hopper, Peter John, Edinburgh.
Huddy, George, Liskeard.
Hysingjord, Jens, Oslo, Norway.
Kothari, Ramesh Rasiklal, Madras, India.
van Laarhoven, Andréas Martinus, Nairobi, Kenya.
McKechnie, Thomas McLean, Glasgow.
Milito, John T., London.
Mooney, Eugene, Edinburgh.
Moss, Graham, Patrick, London.
Mowbray, Terence, London.
Du Naier, Sidney W. Long Island City, N.Y.
Patrick, John Thomas, Christchurch, New Zealand.
Peplow, William R. H., Stourbridge.
Phillips, Roy Edmund, Sutton.
Picken, Joy Florence (Miss), Bromsgrove.
Plews, William Archibald, Edinburgh.
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Sando, Kolbjörn, Eyvind, Rjukan, Norway.
Seneviratne, Dayatissa, London.
Seneviratne, Seetha, London.
Silva, Sena de, Colombo, Ceylon.

Skinner, Ramon, London.
Smith, Charles, Peebles.
Smith, David John, Brighton.
Smith, Winifred Joan Russell (Miss) Edinburgh.
Spencer, Alan, Liverpool.
Stacey, Frank Roland, Kenton.
Taylor, Joseph, Newcastle-upon-Tyne.
Thomson, Patrick Norman, Port Elizabeth, S. Africa.
Tungate, James Brian, London.
Turney, Eric Robert, London.
Wall, John Sydney, London.
Walton, Joseph Howard, Cirencester.
West, Peter John, Romford.
Whyte, Archibald Gilroy, Midlothian.
van Zeijst, Anton Herman Maria. Groningen, Holland.

TALKS BY MEMBERS

PARRY, G. (MRS.). "Gemstones," Swansea Branch of the British Horological Institute, 13th March.

MESSENGER, S. (MISS). "Precious stones and some superstitions." Young Women's Fellowship, St. Albans, 2nd October.

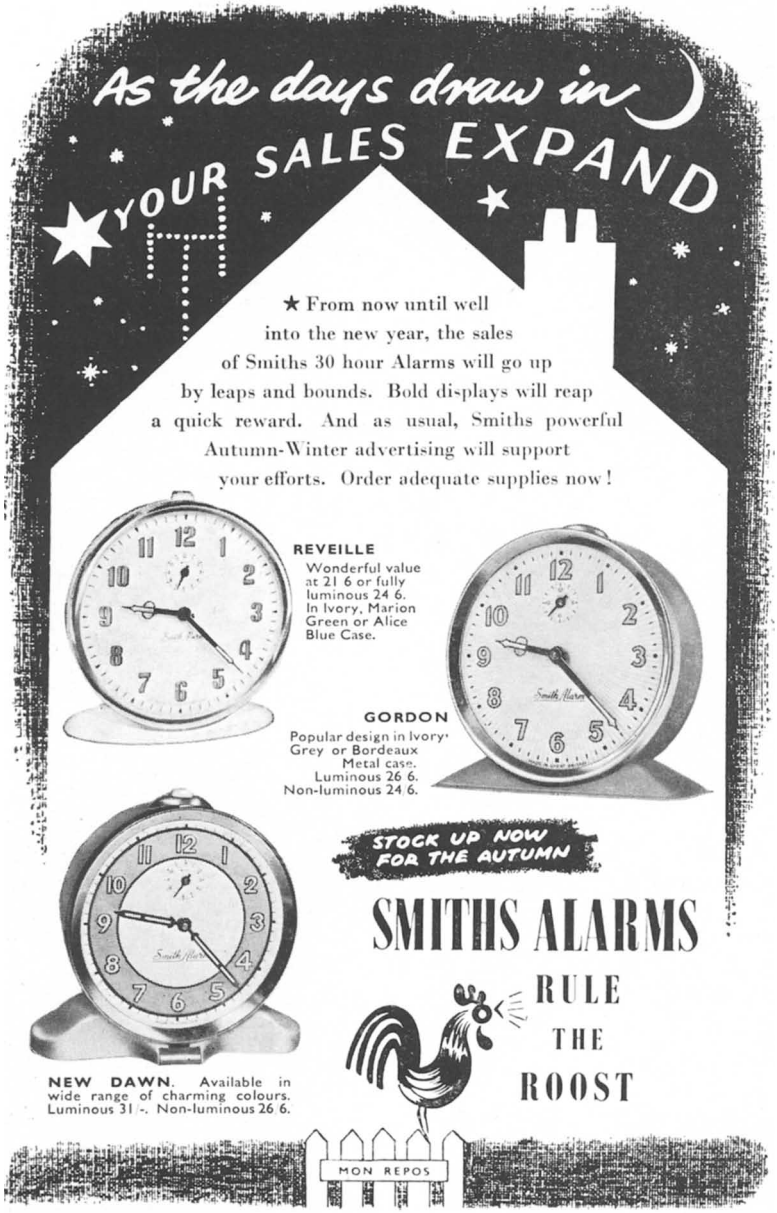

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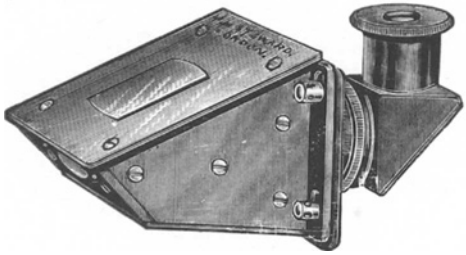

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THE JOURNAL OF GEMMOLOGY

and

PROCEEDINGS OF THE
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NOTES ON ASTERISM
IN CORUNDUM, ROSE QUARTZ AND ALMANDINE GARNET AND CHATOYANCY IN BERYL

By W. F. EPPLER

1. Causes of Asterism and Chatoyancy

There recently appeared in *The Gemmologist* an article by J. H. Halford-Watkins about the " Reasons for Chatoyancy and Asterism."[1] This article was originally published in the same journal in 1932. The author pointed out that asterism in corundum (star-sapphire and star-ruby) was due to the presence of fibres. This fibrous structure, or silk, follows the prism faces of the corundum crystal and is likewise parallel to the basal plane. The fibres are, the author suggests, most probably minute tubes or cavities which took their origin from the radioactivity in the matrix. Similar fibres, he suggests, may be the cause of chatoyancy in chrysoberyl.

This theory was formerly accepted by many writers. In opposition to it are the results of the careful investigations of Alice Sumner Tait,[2] published in The Journal of Gemmology in 1955.

This author concluded that :

> " The cause of asterism in corundum is due to the symmetrical arrangement of included rutile needles, which lie in the basal plane parallel to the prism faces of the hexagon."

This statement confirms the observations of Tschermak,[3] who as early as 1878 found hair-like rutile needles in ruby. At the same time it confirms and completes the information given by G. F. Herbert Smith,[4] who speaks of " included needles of rutile, tubular cavities, or even colloidal particles " as the cause of asterism in corundum.

In seeking an explanation for the causes of asterism, if we imagine that a polished stone has, for instance, the form of a rectangular prism, then we have on the top plane the conditions shown in the figure (Fig. 1). But if we imagine further that the long edge of the top plane is replaced by a facet, then, with the same direction of the incoming light, the reflected light will be distributed. It is evident that the newly polished facet causes the reflected light to travel along a somewhat different direction. The more the newly applied facet is inclined downwards, the greater this deviation from the original direction of the reflected light becomes.

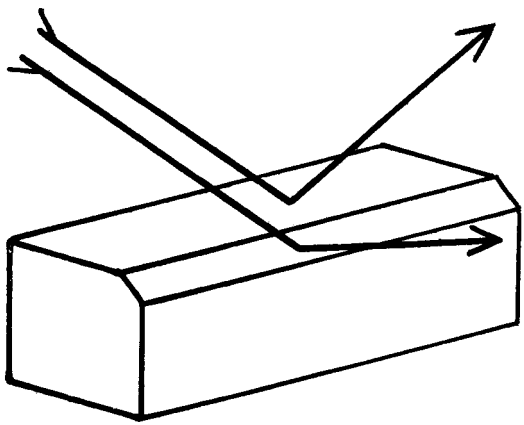

Fig. 1.

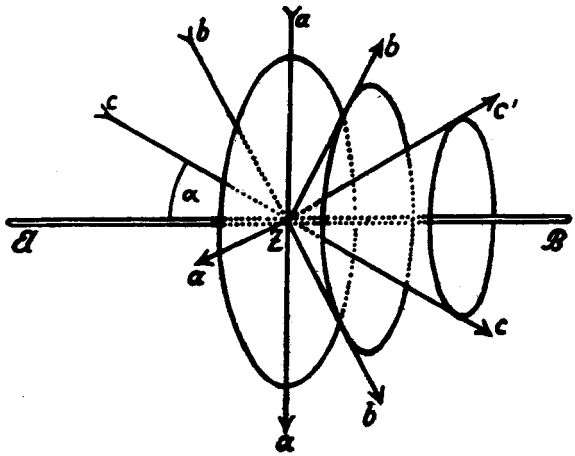

Fig. 2. Rays of light distributed over surface of cone. From " Brillanten und Perlen " by W. Maier, Stuttgart 1949

If there is not only one facet on the prism edge but an endless number of facets covering all the prism edges, then an endless number of reflections will be seen in different directions. In this case, the original prism has changed into a cylinder with the cross-section of a circle.

If this reflecting cylinder is extremely thin, so that it corresponds in size with the rutile needles in corundum, then the rays of reflected light will be distributed over the surface of a cone (Fig. 2). The axis of the cone coincides with the cylinder, and the opening angle of the cone is twice as great as the angle which the incident light forms with the cylinder. The greater this angle, the greater is the opening angle of the cone of reflection. These facts have been recognized and published by Kaemmerer[5] in 1915. This author also found that the effect of diffraction is present as well when a number of rod-like cylinders have the same parallel orientation. But this does not complicate the matter, as the diffraction is masked by the effect of reflection, which therefore remains as the only cause of asterism and chatoyancy.

The needle-like inclusions of rutile in corundum can be compared with very fine and very thin cylinders. Each cylinder, or rutile needle, produces its own cone of reflection, if a ray of light falls upon it. In corundum the included rutile needles form a

pattern which is strictly orientated in accordance with the hexagonal (or trigonal) symmetry of the host crystal. This means that the needles lie in the basal plane and are parallel to the faces of the hexagonal prism of the first order. If we polish the flat basal plane of a corundum crystal, then the rutile needles are situated within this plane and they form at the same time a pattern of intersecting lines at angles of 60°. But even if this basal plane is perfectly polished, asterism cannot be observed in reflected light. The only effect is a sheen or a schiller, seen six times during one full rotation. The reason for this effect is that the multitude of parallel rutile needles produces a multitude of parallel cones of reflection. On a flat surface such as the polished basal plane of a corundum crystal mentioned above, we best observe the reflection if the source of light, the length of the rutile needles, and our own eye are in one plane. This happens with the hexagonal arrangement of the needles six times during one revolution. As the flatness of the polished surface allows the incident light to be reflected on all needles of the same orientation simultaneously, we can only observe a very small part of each conical reflection. The cone of reflection in full cannot come into operation in this case.

The effect is different if the flat basal plane is replaced by a convex surface. If we regard the curved surface as having the form of a half-cylinder, so that the long axis of this half-cylinder coincides with the length of one bundle of the included needles, and a beam of light falls upon the cylindrical surface, we again observe the reflection best when the source of light, the length of the needles, and our eye are in one plane. This time the conical reflection causes a regularly distributed schiller over the entire surface of the curvature, on its top as well as on the sides.

If we now cut away and polish both upper ends of the half-cylinder so that the cylindrical surface is gradually replaced by a spherical one, then the formerly widespread reflection diminishes until it is limited to a fine, circle-like reflective zone. At the same time the half-cylinder has changed into a hemisphere, and the circle-like reflection runs over the spherical surface of the stone in the direction perpendicular to the length of the included rutile needles.

Thus, the conical reflection of light on very thin included rutile needles, which are orientated to each other, causes a reflection also on a curved or spherical surface. It produces not only a

reflection on the top of the curvature, but, so to say, also " sideways "—that is, on the flanks of the curvature. Secondly, the spherical surface of a stone selects for the eye under the proper conditions only a circle-like reflection. This particular line of reflection runs, as is quite obvious, perpendicular to the length of the included needles.

In the case of corundum the needles lie in three directions which include angles of 60°. The needles of each direction produce a circle-like zone of reflection, if the stone is properly cut. As these three reflecting zones intersect each other on the apex of the convex surface of the stone, we receive the impression of a six-rayed star.

An impressive demonstration of asterism can be given by a ball of suitable material, such as rose-quartz or synthetic star-corundum. If such a ball is viewed in reflected parallel light, we observe round the ball three complete circles, which intersect each other at two opposite points. If we look at one of these points, we receive the impression of a six-rayed star. The two opposite points of intersection mark the spots where the main- or c-axis leaves the stone.

Chatoyancy therefore is clearly due to the conical reflection of light on very fine and very thin and elongated inclusions which are orientated parallel to each other and which follow only one direction. If cut in a convex form or as a cabochon, the conical reflection produces a single line of reflection which runs perpendicular to the length of the elongated inclusions.

Only such stones exhibit asterism, or a star effect, as contain elongated inclusions of a symmetrical orientation. The inclusions must be thin enough to produce the conical reflection of light in a similar way to its manner of production on very thin cylinders.

The cat's-eye effect, or chatoyancy, is caused by such inclusions, which are orientated in only one direction.

As the symmetrical orientation of the inclusions is due to the symmetry of the host crystal, stones must be cut according to this symmetry to show asterism or chatoyancy respectively.

A star-effect can be artificially produced, if cylinder-like grooves are scratched on the back of a transparent stone. The scratches act in the same way as cylinders and produce a conical reflection of light. From this particular reflection the spherical cabochon selects for the observing eye the circles of reflection which form the star (Fig. 3).

2. Origin of the Inclusions which produce Asterism or Chatoyancy

Corundum. In corundum the regularly included needles of rutile cause the asterism of star-sapphire and star-ruby. A relatively dense accumulation of acicular crystals is necessary to generate the star-effect. Less dense patches of rutile needles, commonly known as " silk," cannot produce a perfect star.

An indication of the origin of the rutile needles in natural star-corundum is given by synthetic star-stones. According to the process used by the Linde Company in Chicago, which is disclosed in U.S. Patent 2,488,507 of 15th November, 1949, the synthetic star-stones are manufactured by the exsolution of titanium dioxide within the crystal of synthetic corundum. The powder used for making blue or red synthetic star-corundum does not contain more than 0·3 per cent of titanium dioxide. The resulting boules are transparent and look the same as ordinary boules of the same colour. This indicates that the titanium dioxide forms with the corundum a synthetic " mixed-crystal." During subsequent heat-treatment the dissolved titanium dioxide slowly crystallizes in the form of rutile needles, a process which is generally known as " exsolution." These newly formed rutile crystals occupy

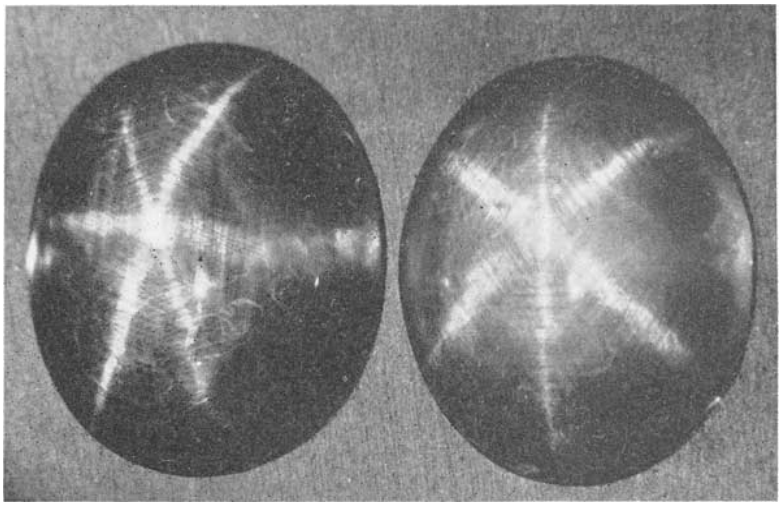

Fig. 3. Star-effect produced by scratching cylinder-like grooves on back of synthetic spinel.

preferred spaces within the lattice of the synthetic corundum crystal and consequently they are arranged in the same symmetrical order as in natural corundum. The heat-treatment is accomplished at temperatures within the range of 1,100 to 1,500°C which are maintained for a period of over 72 hours.

It is very unlikely that the natural star-corundum crystals have been treated in the same way. Most probably, the temperature was not so extremely high, but the pressure, which in the earth's crust can reach considerable amounts, acted in a favourable sense. It seems, therefore, that in natural star-corundums also the rutile needles originated from exsolution.

Fig. 4 shows the well known pattern of rutile in a star-sapphire from Ceylon. On one side of the picture they are enriched by zones parallel to the first order prism $(10\bar{1}0)$.

A very rare star-stone is the twelve-rayed star sapphire. The star is apparently composed of two six-rayed stars, the second of which is turned against the first one at an angle of approximately 30°. This results in a similar arrangement of the two systems of rutile needles. While the first system is orientated in the usual manner, the second system of needles follows the hexagonal bipyramid of the second order $(22\bar{4}3)$. It is most probable that this explanation is correct. Another explanation could be that the second system of needles follows the second order prism (1120) ; but in that case the points of intersection of both systems must be in coincidence, which they are not.

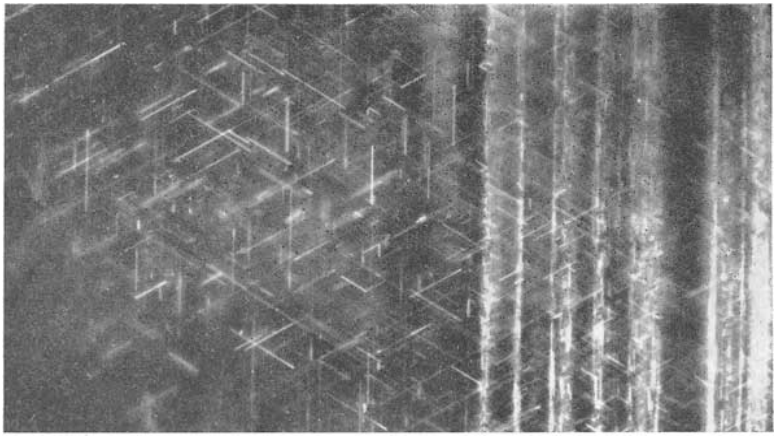

Fig. 4. Rutile pattern in Ceylon star-sapphire.

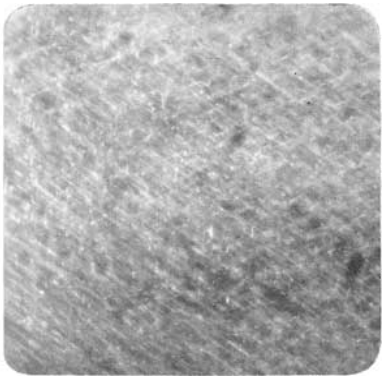

Fig. 5 (left). Long and relatively thin rutile needles in a Linde star-sapphire.

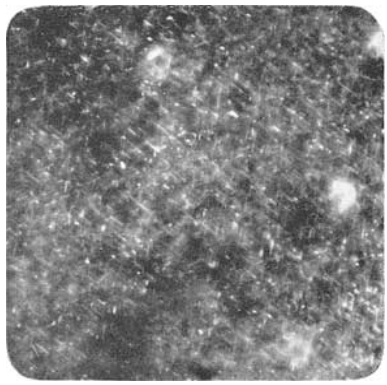

Fig. 6. (right) Short and relatively thick rutile needles in a German star-sapphire.

Differences between the American and the German synthetic star-corundums are seen in figures 5, 6 and 7. The Linde boules for star-stones are manufactured with a high growing speed. Large boules are produced, from which several stones can be cut. The German boules are slowly grown, and rather reminiscent in shape of the " shoe-button " reconstructed rubies of which descriptions were published some years ago.

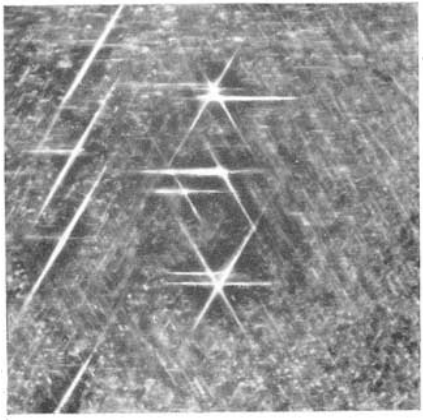

Fig. 7. Short and relatively thick needles of rutile in a synthetic star-sapphire (German) ; also areas of highly concentrated rutile needles which follow plane of first order prism ($10\bar{1}0$).

The difference in the rate of growth influences the shape of the rutile needles. In a synthetic star-sapphire from Linde, the needles are long and relatively thin, whereas in the German blue stone short and relatively thick needles can be observed. Similar differences exist between the two kinds of synthetic star-rubies. The needles of the Linde stones are long and those of German production are short. Besides this the German star-stones of red colour exhibit areas of highly concentrated rutile needles, which areas follow the planes of the first order prism $(10\bar{1}0)$.

The difference in shape of the needles influences the star-effect. The long and thin needles of the Linde stones are responsible for a striking, narrowly developed star. The short and thicker needles of the German stone produce on the other hand a wider star, similar to that in the natural star-corundums.

Besides the difference in the rate of growth the two kinds of synthetics differ in that the Americans do not appear to have made use of so-called crystallizers, which, on the other hand, are added by the German manufacturers. This is shown by the different shapes of the included gas bubbles. Fig. 8 shows, at high magnification, the round bubbles in a Linde stone ; Fig. 9 demonstrates the non-spherical bubbles in the German product. The bubbles in the Linde star are spherical and the German star contains non-spherical bubbles of a more triangular shape.

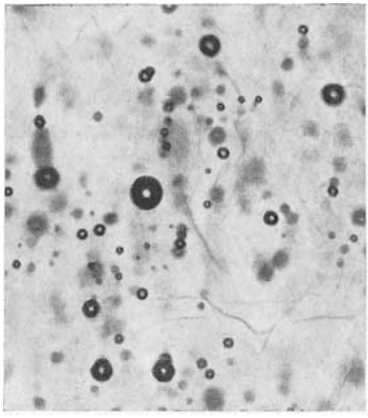

Fig. 8.

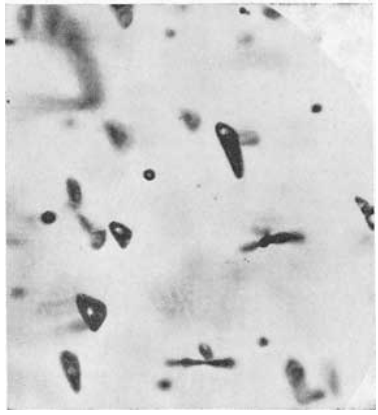

Fig. 9.

These pictures are taken parallel to the c-axis. In observing in other directions, for example perpendicularly to a plane of the rhombohedron, the so-called " bubbles " in the German synthetic star-corundum are seen as two-phase inclusions or as negative crystals in the form of a rhombohedron (Figs. 10 and 11).

A last and very characteristic difference between the two kinds of synthetics is shown by the so-called " Sandmeier-Plato striation." Fig. 12 shows the quickly grown and " empty " Linde stone and Fig. 13 exhibits this particular pattern in the slowly produced German stone.

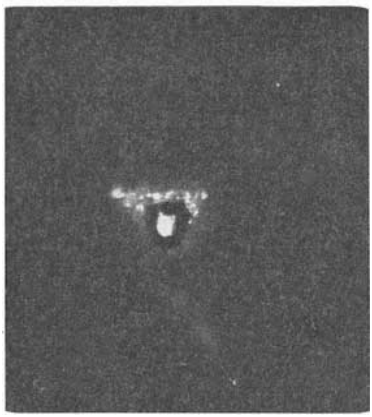

Fig. 10. So-called " bubble " in a German synthetic star-stone seen as a two-phase inclusion.

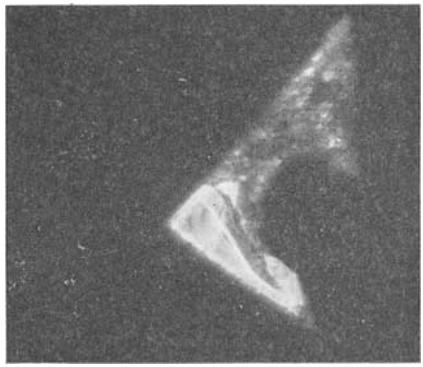

Fig. 11. A similar inclusion seen as a negative crystal in the form of a rhombohedron (greatly enlarged).

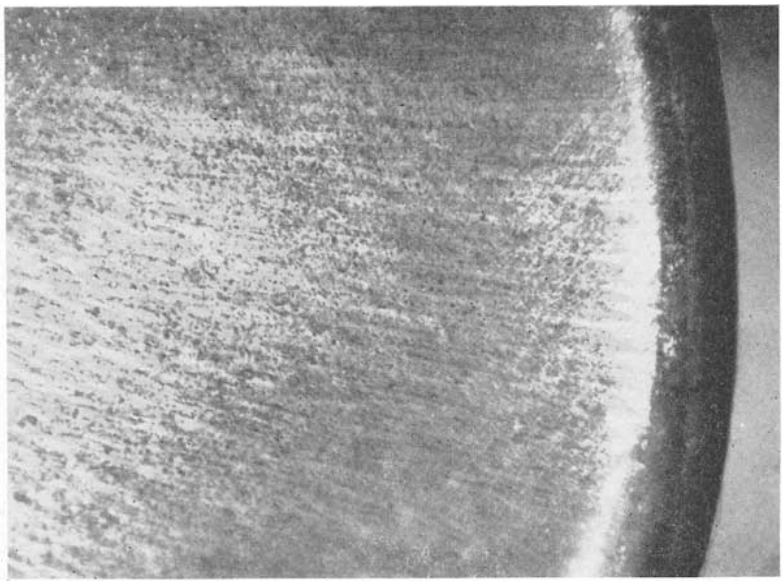

Fig. 12. Sandmeier-Plato striation (American synthetic star-stone).

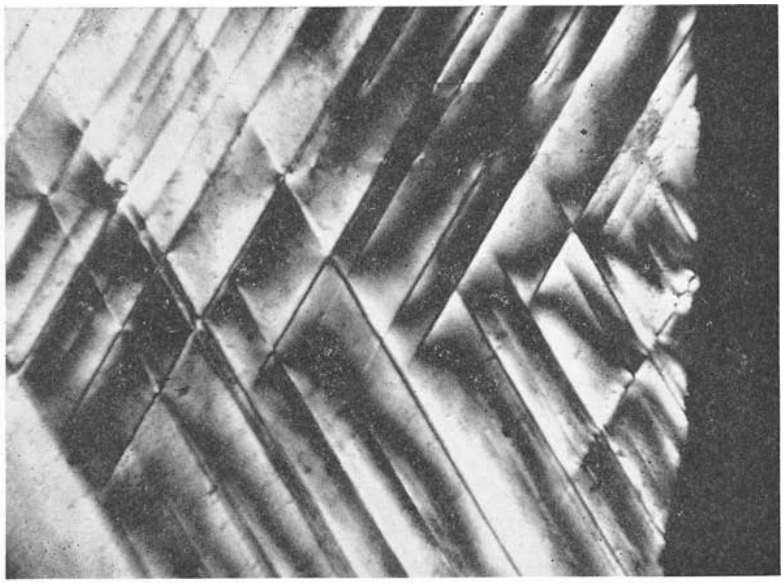

Fig. 13. Sandmeier-Plato striation (German synthetic star-stone).

Rose quartz. Asterism is commonly present in rose quartz, and the imitation of star-sapphire by a doublet of rose quartz with a backing of blue material has been described by B. W. Anderson.[6] But the origin of the asterism in this stone has long been unknown.

It was recently found by J. von Vultée that asterism in rose quartz is caused by rutile needles. He crushed a rose quartz showing asterism and treated the powder with fluoric acid to remove the quartz particles. The residue proved to be pure titanium dioxide. Fig. 14 shows, under the electron microscope, long needles with a rectangular cross-section, which consequently are crystals of rutile, and von Vultée easily found the rutile needles under the ordinary microscope.

Of great interest are two new discoveries, made by him. He found that there exist no less than thirteen different ways in which the rutile is orientated within the rose quartz crystal. According to him, the needles are not only parallel to the main axis and to the lateral axes, but they are also parallel to the intermediate axes and parallel to the edges of several rhombohedrons. This multitude of possibilities gives the explanation for some additional effects of reflected light on a ball of rose quartz. The effects consist of some circular lines weaker than the three main lines of reflection and in so-called " light knots." Both effects can easily be seen under suitable illumination.

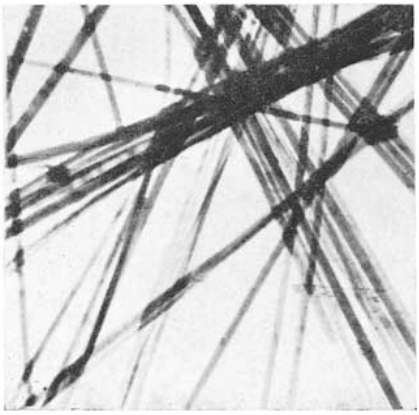

Fig. 14. Residue of titanium oxide (rutile) after crushing rose-quartz.

From J. von Vultée's " Uber orientierte Verwachsungen von Rutil in Quarz," Neues Jahrb. f. Mineral.

The second result found by this author is the discovery of two new twinning laws of rutile, which must be added to the two already known. In some gemstones with needle-like inclusions of rutile, such as corundum, those needles seem to be inclined at one end or even appear to bend. The inclination caused by bending has 169° as a mean value. The continued bending of the needles, which is so difficult to explain in this and other gem material, is regarded by him as a consequence of the simultaneous growth of quartz and rutile. He writes (in translation) :

> " Either these bent needles follow a curvature which is constant over the whole length of the needles, or they are perfectly straight and only bend at one end. I assume that in this case the seed of the rutile originally was attached to the quartz in an orientated manner and that, by some mechanical or other means, the growing seed was bent and diverted from the originally prescribed direction of growth. This seems to be possible because of the elasticity of the extremely thin needles. In the bent and diverted position they have been imbedded in the growing quartz crystal."

From this it may be concluded that in the case of rose quartz the rutile needles are not secondary, but primary, or perhaps syngenetic, inclusions. The thickness of the rutile needles in rose-quartz has been measured from 0·01 to 0·2 micron and in very clear and intensively coloured pieces from 0·05 to 0·07 micron.

Almandine garnet. The asterism of almandine has been described by R. Brauns[8] in 1907. Brauns presumes that the asterism in almandine is caused by the reflection of light on needles of an asbestos-like augite, and he states that the needles are orientated parallel to the edges of the dodecahedron. They cause a four-rayed star on a cabochon or fourteen points of intersection on a ball. E. J. Gübelin[9] determined the nature of the needles as hornblende. As the almandines have been weathered out mostly from hornblende schists this determination seems to be correct. Fig. 15 shows the orientated hornblende needles and reveals other tubular inclusions, the nature of which is not yet known.

It seems to be obvious that the hornblende needles originated from a process of exsolution, details of which cannot even be guessed. Only a hint may exist in the fact that garnets like almandine

belong to the " old " crystals ; that is, they mostly occur in old crystalline schists which have been situated under great pressure during long geological periods. It may be that the pressure to which these garnets were formerly subjected is one of the main reasons for the exsolution of the hornblende.

Beryl. E. H. Rutland[10] reported about a brown beryl with asterism in 1956. The colour of this particular stone was not

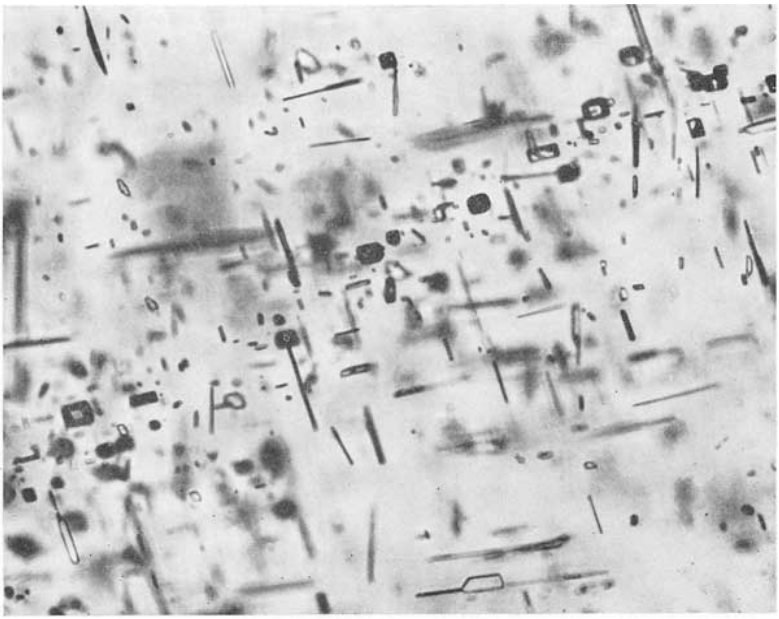

Fig. 15. Hornblende needles in almandine garnet.

attractive and the star very poor. According to Rutland the stone came from Minas Gerais (Gov. Valadares), Brazil ; its dark brown colour was due to rutile needles, and coarser agglomerates presumably also consisted of titanium dioxide ; flat and black inclusions, parallel to the basal plane, might perhaps be muscovite.

By chemical and spectrographical analysis, made at Munich University, it was found that the characteristic inclusions of this particular beryl displaying asterism were not rutile, but ilmenite ($FeTiO_3$ trigonal). Microscopic examination of the stone revealed

very interesting features. A photomicrograph (taken perpendicularly to the c-axis) showed a multitude of straight lines, which run parallel to the basal plane. When the stone was turned at about 45° a marked dichroism was seen. In Fig. 16 some straight lines are to be seen, which are strictly parallel to the c-axis, while others show a small deviation from this direction. With higher magnification (Fig. 17), thread-like inclusions of solid material can be observed, the nature of which is still unknown. In Fig. 18, taken at even higher magnification (420 ×), the straight lines parallel to the basal plane reveal flake-like patches which are seen sideways. Perpendicular to them crosses a thread with various branches.

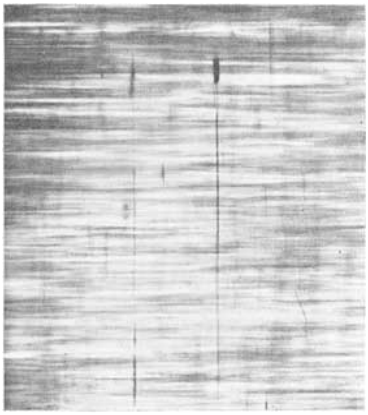

Fig. 16. Multitude of straight lines in beryl showing asterism, parallel to c-axis.

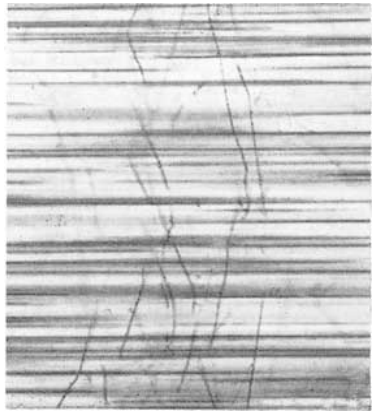

Fig. 17. Thread-like inclusions of solid material, the nature of which is still unknown.

In making observations parallel to the c-axis the patches were recognized as very fine crystallizations of ilmenite. They could be called " skeletons " of ilmenite, which, as shown in Figs. 19 and 20 are orientated according to the hexagonal symmetry of the host crystal. In reflected light (Fig. 21), a coarser and finer network of ilmenite is shown which must be regarded as the cause of asterism. These shapes do not represent the ideal form for a perfect conical reflection. Therefore it follows that the asterism of this beryl is very weak and poorly developed. The patches or separations of ilmenite are very thin and from their shape and distribution it is safe to conclude that they originated from a process of exsolution.

Asterism in spinel and chatoyancy in various gem minerals will be discussed in a subsequent paper.

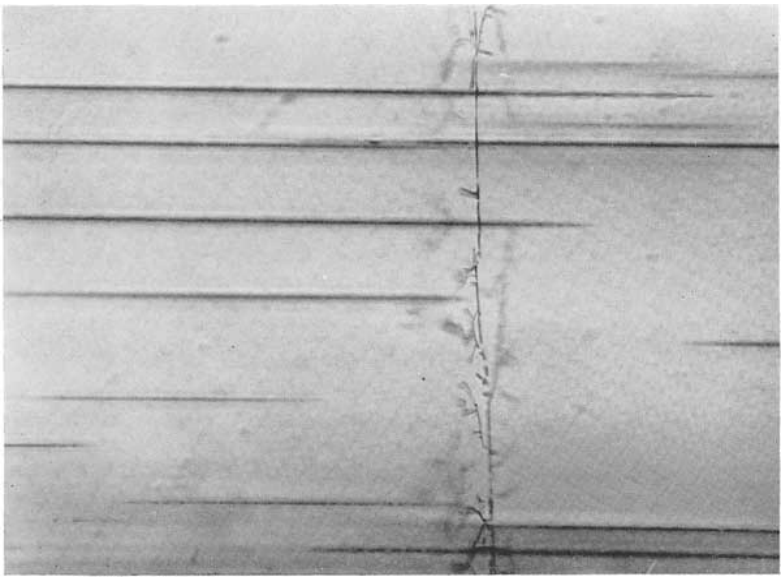

Fig. 18. Straight lines parallel to basal plane are seen, under high magnification, to reveal flake-like patches. Perpendicular to them crosses a thread with various branches.

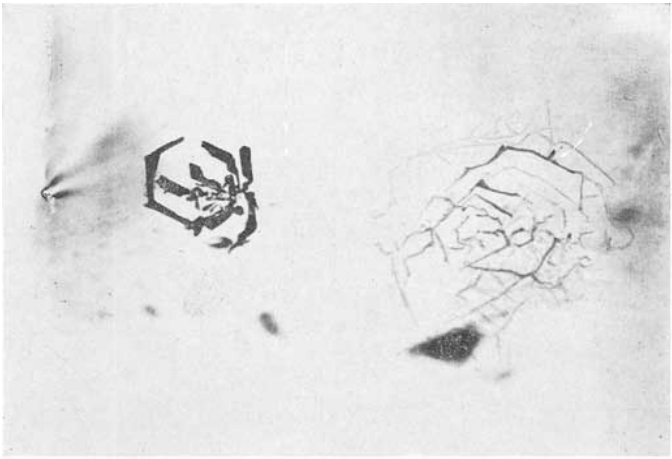

Fig. 19. Skeleton of ilmenite, orientated according to hexagonal symmetry of host crystal.

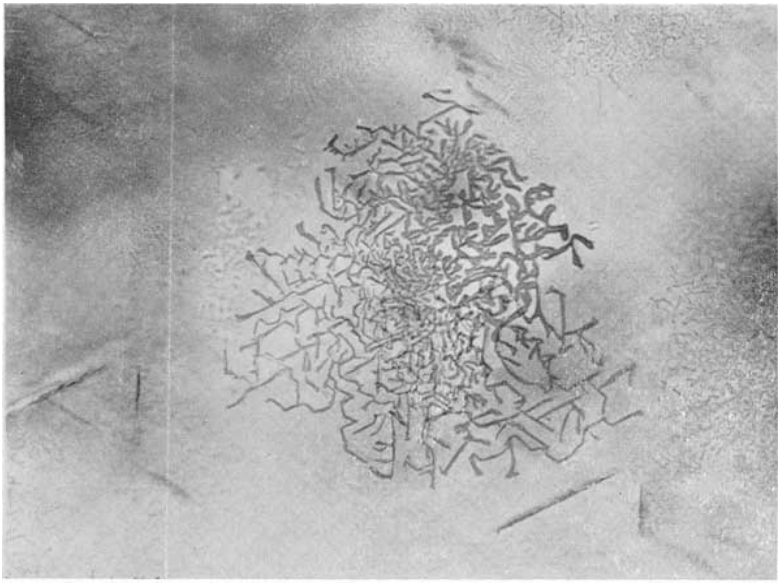

Fig. 20. Skeleton of ilmenite, orientated according to hexagonal symmetry of host crytal.

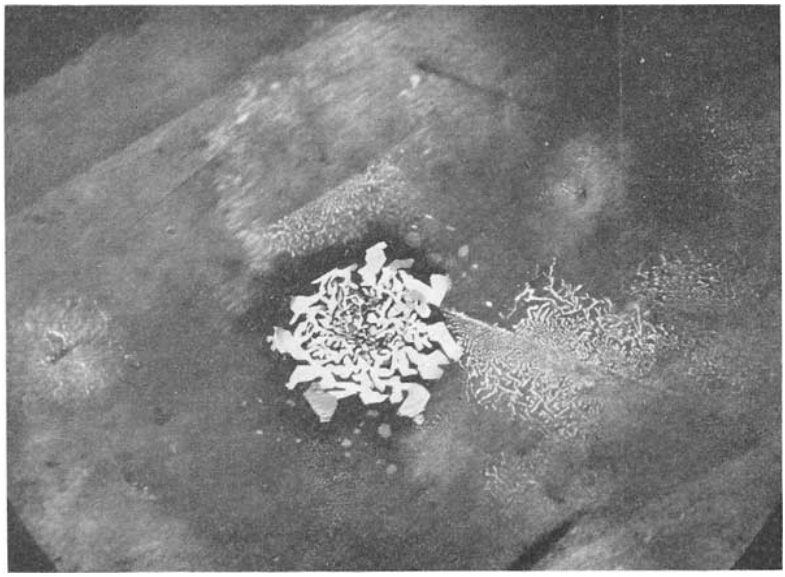

Fig. 21. A coarser and finer network of ilmenite, which is regarded as the cause of asterism, seen in reflected light.

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10. E. H. Rutland. *An Unusual Brown Beryl*, Gemmologist, Vol. XXV, No. 304, November, 1956, pp. 191-192.

SYNTHETIC MOONSTONE - COLOURED SPINEL

By ALDERT J. BREEBAART, F.G.A. C.G.

A FEW months ago the first samples of a moonstone-imitation in synthetic spinel came into my hands. These stones, which were cabochon cut, had a colour which ranged from nearly colourless to bluish, and their transparency varied from nearly transparent to translucent, all stones possessing a kind of sheen upon rotation, comparable with that of genuine moonstone.

The refractive index appeared to be the same as for the common synthetic spinel at 1·728. The specific gravity was slightly higher, however, six stones giving 3·639, 3·653, 3·641, 3·665, 3·658 and 3·660. These variations in values are probably an indication of a partial conversion to corundum, caused by the crystallization of excess aluminina. Under short-wave ultra-violet light the stones show a strong greenish fluorescence, the same as seen in the other synthetic spinels ; spectroscopic examination did not reveal any typical bands.

Besides the bluish or silvery sheen, most of the stones possess a weakly developed irregular star by reflected light and some stones have distinct chatoyancy.

To find the cause of these optical effects, the stones were examined under the microscope. Air bubbles were found in several stones in the same irregular forms and patterns as seen in the other synthetic spinels. One tiny circular cloud of irregular air bubbles, all in one plane, with directly above it a " feather " of two-phase inclusions, as described in one of the earlier issues of this journal by I. P. Zwaan, was noted.

Some stones contained bigger, separate bubbles with definite hexagonal habit or termination and clearly visible surface striations, either parallel or six-sided hexagonal. Strain knots also were present in some stones.

The patchy appearance of synthetic spinel between crossed nicols is quite interesting in these stones. It is completely different, showing colours in yellow, blue and green, and the typical brushes of

anomalous double refraction are absent upon rotation. The colours seen are probably caused by interference of microscopically small fractures which run through the stone. Its appearance makes one think of a fibrous structure, the fibres sometimes running almost parallel and sometimes radiating out from different centres in the stone. The presence of these microscopic fractures may also be the explanation of the effect that the stone remains comparatively bright upon rotation between crossed nicols. The moonstone star and cat's-eye effects of these stones must also derive their origin from the reflection of light from these fractures.

The manufacturer of these stones informed me that the ordinary spinel boules underwent a heat-treatment in order to produce the moonstone-effect, but further information was not given

1. J. W. Brinck and P. C. Zwaan, *Notes on the Occurrence of Two-phase Inclusions in Synthetic Spinel*, Journ. Gemmology, 1955, **5**, 131-4.

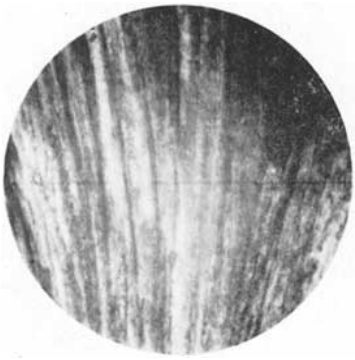

Synthetic moonstone-coloured spinel possessing weak asterism 32x. Structure picture between crossed nicols.

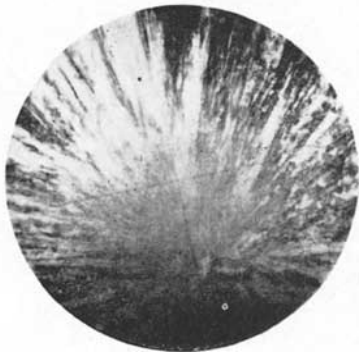

Synthetic moonstone-coloured spinel possessing chatoyancy. 32x. Structure picture between crossed nicols.

Gemmological Abstracts

WEBSTER (R.). *Emerald.* Meldinger f. Norges Gemologiske Selskap. Vol. 1, No. 5, 1957, pp. 3-17.

The second part of an article on emerald, reprinted, with illustrations, from the *Journ. Gemmology.*

P.B.

ANDERTON (R.). *Diamond possibilities in Colombia.* Gems and Gemology, Vol. IX, No. 2, p. 63. Summer, 1957.

Old records of Bogota tell of diamonds given to Philip of Spain and that they were found at a secret mine past Tequandama Falls some twenty miles outside Bogota. It may be that " pipes " exist below the " Llanos " behind the town of Bogota. A large diamond was said to have been found in blue sands on the " Llanos " side of the Andes. The district is thought to be a difficult one for the purposes of prospecting for possible " pipes."

R.W.

—— *Emerald outlook in Colombia.* Gems and Gemology, Vol. IX, No. 2, pp. 60-61. Summer, 1957.

The author refers to the regulations on emerald mining and marketing proposed by the Colombian Ministry of Mines. It is suggested that *moralla*, the low grade emerald crystals, can only be cut on a business-like basis by shipping to India, where cutting costs are low. The Chivor mine, operating under a receivership for creditors, has installed its first automatic compressor. Emerald of fine quality has been found at Buena Vista opposite Chivor and may be mined commercially. The Muzo mine has been plagued, owing to the wet season, with landslides, but the crystals mined are of increasing size and quality. Cosquez is still not operative, while the Gachala mines are under heavy guard against illicit mining by *contrabandistas*, although fine rough from an undisclosed source is currently being cut at Bogota. Prices for fine-quality cut stones are still high. Eleven applications for new emerald locations are on the file of the Mining Ministry.

R.W.

LIDDICOAT (R. T.). *Are present diamond rulings adequate ?* Gems and Gemology, Vol. IX, No. 2, pp. 38-42. Summer, 1957.

A general discussion on the Federal Trade Commission and the American Gem Society rulings on diamond grading. The question " What is a blemish ? " is discussed as well as the factors depending on the " make " of the stone. Colour is said to be more difficult to assess. The value of the American colorimeter is mentioned as being useful in this connexion. There is an excellent photograph of a " natural " seen on the girdle of a diamond.
2 illus. R.W.

BENSON (L. B.). *Diamond substitutes.* Gems and Gemology, Vol. IX, No. 2, pp. 56-59 and 62. Summer, 1957.

Adapted from a lecture given to the American Gem Society Conclave the article fully discusses the stones which can simulate diamond. Strontium titanate is said to have a hardness of 5 to 5½ rather than the published value of 6 to 6½. The names " Starilian," " Fabulite " and " Ultamite " have been used for this material. Some twenty " fancy " names have been used in the marketing of synthetic rutile. The doubling of the rear facets of synthetic rutile, the dispersion and other factors are mentioned as indications of these fakes of diamond. Synthetic sapphire and spinel are considered and mention is made that trap cut diamonds do not show their " fire " to the full, hence the lack of " fire " in the trap cut spinels is not so evident. Colourless zircon, glass, and composite stones are discussed and the article is completed with a table of the diamond substitutes with their characters.

R.W.

CROWNINGSHIELD (G. R.). *An introduction to spectroscopy in gem-testing.* Gems and Gemology, Vol. IX, No. 2, pp. 46-55 and 62. Summer, 1957.

A general survey of the absorbtion spectra of gemstones and the instruments and methods to use for making satisfactory observations. Some historical notes are given and 27 drawings of spectra are incorporated in the text. A line at 5960Å seen in yellow diamonds may be an indication that they have had their colour altered by bombardment with atomic particles.

R.W.

ELLISON (J.). *Formulas for the weight estimation of colored faceted stones.* Gems and Gemology, Vol. IX, No. 2, pp. 43-45. Summer, 1957.

A series of formulae devised to cover the various shapes of coloured faceted stones of various species by taking into account the dimensions of the stone and its density with a multiplying factor. A page of illustrations is appended as a guide to the percentage to add or subtract from the calculated weight when the stones have thick girdles or flat or lumpy crowns or pavilions.

R.W.

CROWNINGSHIELD (G. R.). *New or unusual gem materials encountered in the Institute's Gem Trade Laboratories.* Gems and Gemology, Vol. IX, No. 2, pp. 35-37 and 61-62. Summer, 1957.

The article tells of some of the unusual minerals which have been examined during routine work at the laboratories of the Gemological Institute of America. Specimens mentioned are sodalite from Canada—it is remarked that sodalite can at times contain pyrites like lapis lazuli—and some tumbled stones which were found to consist of an intermixture of green nephrite, pink thulite and greyish-brown zoisite. Some "jade" beads were a combination of white albite feldspar and green actinolite, while another necklet consisted of approximately equal numbers of albite and matching white prehnite beads and was offered as "Japanese jade." Another "jade" was found to be a breccia of true jadeite in kaolin. Ruby in green zoisite from the Kenya-Tanganyika border produced attractive cabochons. Faintly chatoyant sillimanite from Idaho is challenged as not being a gem material despite the publicity to that effect. "Television stone" (ulexite) had on examination a hardness greater than 2 and a density near 2·00, which are values greater than published. Synthetic sintered spinel imitating lapis lazuli and a schillerized synthetic spinel imitating moonstone are mentioned, as are some specimens of synthetic red spinel. Three dark green stones with refractive index of 1·805 and a density of 4·44 are mentioned as being gahnospinels (? gahnite). Heat-crackled synthetic ruby and similarly treated green glass are mentioned as being troublesome to the jeweller. Tests for the recently produced dyed jadeite and the jadeite triplet are mentioned. Highly refractive glasses as paste imitation gemstones are discussed. Criticism of the emerald colour

filter as a test for emerald is made but its value in the testing of synthetic blue spinels is noted. Some pale beryls painted with a coloured plastic coating and some soudé-type emeralds (emerald triplets) show red through the colour filter.

R.W.

LEECHMAN (G. F.). *True story of White Cliffs.* Mineralogist, Vol. 25, No. 10, pp. 339-343. Oct., 1957.

The story of the discovery of the opal deposits of White Cliffs and of the activities of the early miners. In 1897 there was a population of some 3,500 and to-day about forty. The two illustrations show the opal fields of Coober Pedy, South Australia, and of Lightning Ridge, New South Wales.
2 illus. R.W.

DAKE (H. C.). *More on dyed jade.* Mineralogist, Vol. 25, No. 10, pp. 349-352. Oct., 1957.

Light grey translucent jadeite is dyed lettuce-green, apple-green or emerald-green. The cabochons are first shaped leaving the back rough. Minute holes are drilled from the back and the cabochons are then boiled in a dyestuff derived from vegetation, one report stating that the dye comes from Japan. When the colour has sufficiently penetrated into the material the back is ground off to remove the holes and to round the base slightly. The treated material is highly polished. The dyed jadeite fades on exposure to strong sunlight. The dyeing techniques are said to have been originally developed in Pekin but now may be carried out elsewhere and even in the United States. Some of the material has been sold under the name "Korean jade," which suggests that it may have been smuggled from Red China to the United States zone of Korea. The vegetable dye used can be removed by soaking in chemicals. It is suggested that if jadeite is so porous as to take stain it should be possible to use more stable coloration by the use of nickel, chromium or copper compounds, and it is hinted that such colouring agents may have already been used.

R.W.

ANDERSON (B. W.). *Stained jade : a warning.* Gemmologist. Vol. XXVI, No. 314, pp. 155-157. Sept., 1957.

Examination of specimens of jadeite, received from the Far East, which had been artificially stained to an excellent green

colour. That jadeite was susceptible to dye was not previously suspected. The dye is concentrated along cracks in the stone and in some cases is quite evident. The stained jadeite shows pink through the Chelsea colour-filter, but the spectroscope is the best test as the absorption spectrum shows a rather broad woolly band near 6500Å with a weaker band near 6000Å. The narrow 4370Å line of jadeite could, in one specimen, be seen in the gloom of the blue-violet. Another and more convincing-looking faked green jade cabochon is filled with a closely fitting inner cabochon of similar material, the base being finished off with a third piece of jadeite. The dyestuff, a blue dye and a yellow dye mixed together, fills the interspace between the hollow cabochon and the " plug " and the baseplate, the three pieces being held together with resin. The triplet also shows pink through the colour-filter and the absorption spectrum is similar to the above mentioned stained jade except that the bands are at 6300Å and 5800Å respectively. The density of one of these triplets was found to be 3·27.
1 illus. R.W.

LEECHMAN (F.). *The origin of the Roman opal.* Gemmologist, Vol. XXVI, No. 315, pp. 175-177. Oct., 1957.

After an introduction to opal and mention of the more common localities where precious opal is found, notes are given on the eastern European mines from which opal obtained found in Roman times. The workings are near Czerwenitza on the River Pruth. There is little evidence that opal was known, at least in Europe, before Roman times, and the reasons for this assertion are fully given.

R.W.

JANK (R. A.). *A superior method of testing for dichroism.* Gemmologist, Vol. XXVI, No. 315, pp. 185-186. Oct., 1957.

A scheme whereby two pieces of polaroid with opposite optical directions are mounted on an annular cardboard ring cut to fit loosely on the diaphram of a microscope ocular. The advantages of this dichroscopic ocular are enumerated, a particular point being that the specimen is under microscopic magnification and is evenly illuminated with light. The specimen may also be immersed in liquid whilst the dichroism is observed.
1 illus. R.W.

SPENCE (G. H.). *Emerald Mining in Colombia.* Mineralogist, Vol. 25, No. 11, pp. 387-391.

An account of the author's own observations since 1952. Basic methods of mining have changed little since days of Spanish workings. Much of the material mined is fragmentary and opaque. The geology of the emerald-bearing district is briefly mentioned.

S.P.

STEINWEHR (H. E. v.). *Eien neue Türkis-Imitation.* A new turquoise imitation. Zeitschr. d. Deutsch. Gesellt. f. Edelsteinkunde, No. 21, 1957, pp. 3-4.

A new material was found on the German market, looking like turquoise, but specific gravity, refractive index and X-ray powder diagram were different from the natural product. The material was found to consist of Al $(OH)_3$ and a copper phosphate $Cu_3(PO_4)_2.3H_2O$.

E.S.

HAUSMANN (P. A.). *Untersuchungen mit Phosphor-32 an Achaten.* Experiments with Phosphorus 32 on agates. Zeitschr. d. Deutsch. Gesellt. f. Edelsteinkunde, No. 21, 1957, pp. 4-9.

The problem was to colour agate so that the polisher could easily distinguish between " hard, medium and soft parts," Various experiments were made, using phosphorus 32 to enter the agate material. When agate was coloured it used to be assumed that the irregular absorption of colouring matter by the agate was due to the varying porosity of the material ; it is now shown that the construction of the molecular chains is the reason for the varying absorption.

4 illus.

E.S.

MOHAMED (Y. a H.). *Achat und Onyx von Yemen.* Agate and Onyx from the Yemen. Zeitschr. d. Deutsch. Gesellt. f. Edelsteinkunde, No. 21, 1957, pp. 9-14.

Survey of occurrences of agate and onyx in the Yemen, with bibliography.

E.S.

LEHFELDT (W.). *Das Ultraschallverfahren in der Edelsteinindustrie.* The ultrasonic method in the gem-cutting industry. Zeitsch. d. Deutsch. Gesellt. f. Edelsteinkunde, No. 21, 1957, pp. 19-24.

Untrasonic sawing, drilling and cutting of gem stones is being used more and more, in the case of hard materials. The principle

of the method is explained in detail with illustrations. Speeds are given in cub. mm./minutes, and are for instance, for ruby 15, agate and oynx 25-30, spinel 30-35. There is a short bibliography.

E.S.

SCHIEBEL (W.). *Ultraschall-Verfahren zur Bearbeitung von Edelsteinen.* Ultrasonic methods for working of gemstones. Zeitschr. d. Deutsch. Gesellt. f. Edelsteinkunde, No. 19, 1957, pp. 7-11.

This method is now in general use for hard stones such as diamonds, especially when holes with small diameter have to be drilled. As the cutting and drilling can be controlled easily, this method is also used for engraving stones on a mass-production basis. It should also be possible to produce cabochons and faceted stones by this method. E.S.

SCHLOSSMACHER (K.). *Echte perlen mit echtem Kern.* Real Pearls with real neuclus. Zeitschr. d. Deutsch. Gesellt. f. Edelsteinkunde, No. 19, 1957, pp. 22-23.

The Institute at Idar-Obserstein was given a broken real pearl, which inside had a neuclus of pearl, which also was real. Although composed like a cultured pearl, tests proved this to be a real pearl.

E.S.

—— *Susswasserperlen im Rontgenbild.* River pearls under X-rays. Zeitschr. d. Deutsch. Gesellt. f. Edelsteinkunde, No. 19, 1957, pp. 23-24.

By combining X-rays and X-rays shadowgraphs it is possible to determine river pearls and to differentiate between sea-water pearls as well as cultured pearls. E.S.

BATCHELOR (H. H.). *Very little mining at Lightning Ridge.* Gemmologist, Vol. XXVI, No. 315, pp. 187-188. Oct., 1957.

The author tells something of the present conditions in the mining fields of New South Wales and Queensland. Some sapphire mining is being carried on at Ruby Vale but little work is done at the Lightning Ridge opal fields.

P.B.

WEBSTER (R.). *Cultured pearls.* Gemmologist, Vol. XXVI, Nos. 312, 313, 314, pp. 129-132 : 147-152 : 158-163. Jul./Aug./Sept., 1957.

The coating of objects placed between the shell and the mantle by nacre-producing molluscs has been known from the 13th century. The experiments of Carl Linné in the 18th century are mentioned. K. Mikimoto produced the cultured half-pearl (cultured blister pearl) by cementing a mother-of-pearl bead to the shell of the pearl oyster and then removing it after the animal had coated it with nacre. Mikimoto patented and commercialized the process. The mystery of who discovered the method or methods for the production of whole cultured pearls is discussed. The localities where pearls are cultured and the types of oysters used are mentioned. There is a full description of the cultivation of the oysters and the subsequent operations to produce the cultured pearl by nucleus insertion. Experiments with plastic beads as nuclei showed them to be unsuitable, but " marble " has been used. The cultured pearls recovered are counted, sized and graded. The methods used in drilling the beads are explained. The pearls are strung as graduated necklaces in Japan and are sold by the *momme* (1 momme equals 18·75 carats). The base method of price calculation is not used for cultured pearls. A note is given on non-nucleated cultured pearls. Some notes on the detection by eye of cultured pearls is given and hints on the care of cultured pearls. The dyeing of cultured pearls to a black or a rosée colour is mentioned.

6 illus. P.B.

SCHWARTZ (J.). *Collecting crystals.* Gemmologist, Vol. XXVI, No. 314, pp. 173-174. Sept., 1957.

Hints on the care of crystal specimens during transport and in storing. Methods of cleaning crystals by boiling in acids are given, and the labelling and systematic arrangement of a collection are discussed.

R.W.

SIR JAMES WALTON MEMORIAL LIBRARY

The library, which was established in memory of Sir James Walton, K.C.V.O., F.R.C.S., F.G.A., by the National Association of Goldsmiths and the Gemmological Association, has now been completed, and its main sections are shown in the photographs. In addition to books on jewellery, gemmology, gold and silverware and horology, the library contains gemstones and gem minerals.

The National Association of Goldsmiths has contributed substantially to the formation of the library and various members of that organization also made generous contributions. Donations that have been kindly sent by companies to the Gemmological Association are recorded on page 245.

It is one of the most comprehensive private libraries on the subjects mentioned. There are some gaps, however, and the Council of the Association would be most grateful for any contributions of books, gemstones or gem minerals or donations.

Final section of the library.

First section of library, completed in 1956.

Further aspect of final section of library,
with oil painting of the late Dr. G. F. Herbert Smith, C.B.E.

Nephrite plaque with inscription " In memory of Sir James Walton, K.C.V.O., F.R.C.S., F.G.A." and drawers containing models made by Sir James.

JADE STORY—EUROPEAN

(The sixth part of the Story of Jade in Europe)

By ELSIE RUFF, F.G.A.

IN search of jade we have travelled backwards, from the known to the known, perhaps along the line of effect to cause. Here it seems necessary to generalize, and in doing so we find the mainspring of knowledge established in the Roman Empire during the height of her power, and thence on to her decline. In other words our search for jade, or jasper, in Europe, is now largely a search in the Roman world or a world deeply influenced by Rome. We are roughly half-way between the neolithic use of jade in north-west Italy—referred to in the first article of this series—and our own times.

Because specialization belongs to this age, it is difficult to pin-point usage and authority in earlier days. In any case, authority tapers. Terms are vague and spelling is elastic—almost one might say up to recent times. Dates have therefore a different implication. The whole tempo of life was, of course, slower. There is no moral involved here. It is fact. Legends, too, might be particularly popular at some known period, and the period may date them, but in actual fact the birth of a legend may be ante-dated by hundreds of years. Works by the poet Orpheus have been confused in this way. He has been quoted as a possible authority for the use of the word *nephrite* during the fourth to fifth centuries.[1] Nevertheless he seems to have lived around the period of Homer. He wrote of other gemstones, fortunately, including jasper, and here we are on safer ground :

> " . . . Who'er the polished grass-green Jasper wears
> His parched glebe they'll satiate with rain,
> And send fat showers to soak the thirsty plain."

C. W. King[2] says :

> " . . . hence, Orpheus terms it ' the Jasper ' colour of spring."

A modern author, Lyn Thorndike, who has contributed two extremely interesting volumes on *The History of Magic and Experimental Science* (1923), has something to say about this poet :

" Among poems of some length extant under Orpheus' name and the one of most interest to us is the *Lithica*, where in 770 lines the virtues of some 30 gems are set forth with considerable allusion to magic . . . The date of the poem is now generally fixed in the fourth century of our era. . . .The *crystal* wins favourable answers from the gods to prayers, kindles fire, if held over sticks, yet remains cold ; as a ligature benefits kidney trouble. . . . "

The story of Tristan or Tristram and Iseult is an example of a legend used in many countries. Tristan himself was one of the most famous of mediaeval heroes. He is found in the Arthurian legend. One scholar maintains that the story had its roots in an unknown Anglo-Norman poet. Be that as it may, our interest here is in a ring set with a green jasper, not because it represented great wealth but because it was valuable in a much deeper sense.

" And friend " the story runs, " I have here a ring of green jasper. Take it for love of me, and put it on your finger ; then if someone come saying he is from you, I will not trust him at all till he show me this ring, but once I have seen it, there is no power or royal ban that can prevent me from doing what you bid—wisdom or folly."

There can hardly be a greater example of human loyalty than this or greater motive attributed to a particular stone. And here was the " jasper " of Marco Polo,[3] seen in the mines of Turkestan. It is the " better than gold " of Chaucer a little more than a hundred years later, quoted in the same JOURNAL.

From the evidence examined thus far jade appears to have fraternized with both the ornamental and the medical. Sometimes it was medical only. As late as 1811, John Pinkerton, writing of *Jad*—the *Giada* of the Italians, said :

" . . . the nephritic stone was supposed when worn, to cure diseases of the reins or lumbago, according to others the stone or gravel, in which sense it is used by modern physicians."

If physicians were using jade as a curative at the beginning of the nineteenth century, in this country, the illustration in VOL. V of this JOURNAL[4] suggests that such pendants must have been approved " medicine " in the medical world. Almost a hundred years later, there is still evidence of its association, medically. Thomas Wilson, in what is now regarded as a famous paper on jade (liberally quoted in these articles) writes of a call he made at the French National Library in Paris during 1900, and of being corrected for enquiring for certain books on jade in the mineral department when he should have consulted the medical section.

This twentieth century custom of filing information on jade in the medical section must have gone on for hundreds of years, in France at least. A work was published in Paris during 1694, written by Monsieur Pomet, Chief Druggist to the French King, and entitled *A Compleat History of Drugs.* It is doubly interesting to us because the translation was dedicated to a famous Englishman who passes in and out of these pages. We read :

" Done into English from the Original. London, 1712. Dedicated to the Truly Ingenious and Learned Dr. Sloane, Physician extraordinary to Her Most Sacred Majesty, Secretary to the Royal Society, and Fellow of the College of Physicians, London."

" P. 405. 9 :

" Of the Jafper. There being various sorts of Jafpers, fuch as the Green, the Purple, Cérulean, Aurora, or Crystal like. I shall speak only of that which is sold in the shops, which is the Green Jafper ; and if it had not been of some small use in Medicine, I should not have spoken of it.

" *Jaspis*, the jafper, is a fine, hard, smooth resplendent, precious Stone, which differs little from the Agate, only that it is not so hard and pure . . . "

" 10. Of the Jade Stone :

" The jade is a greenish Stone, inclinable to grey, extremely hard and very rare. This Stone is little used in Physick, it being difficult to cut . . . The Oriental is the finest Jade. Jade is a very hard Stone, of a greenish grey Colour ; the finest comes from the East Indies . . . Some pretend that applied to the Region of the Kidnies, they are proper to bring away Stone and Gravel, but I can give no credit to such remedies."

" 11. Of the Nephritick Stone :

" The Nephritick Stone is a greyish Stone, with a little Mixture of Blue in it, so that it is usually of a bluish colour, being fat and oily like Venetian Talck. This stone is much valued by certain Perfons for the Cure of Gravel, which makes it so scarce ; and so much enquired after, because of its Virtues, which it performs by hanging about the Thigh of those who are troubled by the Stone or Gravel in the Kidnies, from whence it is called *Nephritick Stone* . . . The true *Nephritick Stone* comes from *New Spain* ; and whoever would know further of it may read Mr. Worms, who has writ a large Description of it, too long to be inserted here . . . It is found in New-Spain, sometimes with Jafper, and sometimes alone. Some reckon it among the kinds of Jafpers, making no great Difference, but only that it is harder . . . they are likewise gathered in Bohemia, and several Parts of Spain, but these are not so much esteemed as what comes from America.

" This Stone has the Property to ease the Stone Colick, to break the Stone in the Reins, and expell Gravel by Urine, being hung about the Neck Thigh and Arm. Some prescribe it to be taken inwardly from four to fifteen grains. Of the latter years there is brought into Use for the same Diseases,

a brown, smooth, shining Stone, which they call from its great Virtues, the *Divine Stone* ; this breaks the Stone in the Kidnies, and forces it away by Urine ; they tye it in their Cloaths about the Back."

Thanks to our earlier reading, this book on drugs makes sense. Running over the above list it is possible to feel that the author might be writing of one material only, and that material nephrite ; though his jasper that " differs a little from agate," and the various colours, quoted in the first sentence, are not clear. Here, too, is a prescription for internal treatment, mentioned a little later by Lange (1704) and a little earlier by Emanuel the Elder,[5] in 1686. A further point here is the term Oriental jade as opposed to the jade of New Spain.

An earlier link in connexion with cures displaces an oft-quoted authority for the coining of the word *nephrite* itself. Always this not-so-clever title (being a simple matter to adapt from *nephriticus*) has gone to the credit of A. G. Werner of Freiberg,[6] in 1789 (though two other writers have been cited, one in 1762 and the other 1760). The honour probably belongs to Cleandro Arnobio in his *Tesoro delle Gioie*, published in Venice in 1602—over a hundred and eighty years earlier than Werner. Arnobio writes, page 109 :

" The stone of the flanks (or hips)—kidney stone—named Nephite, the finest specimens included in emeralds. Its shades incline to the green, with a milk-white undertone. It is worn in various forms coming from the use the Red Indians carried it for, according to the part of the body it was intended to cure for flank trouble or stomach pains."

Quoting Monardes he writes that the gem was called NEFRITE and named for the flank—kidney stone. On page 110 he says again it is useful for stomach trouble and quotes two experiments. Further, that the Spaniards called it Stone of the *Iada* and the Greek NEPHITE.

" It is found in many shades, mostly a white-green—and also where the white dominates. It is never transparent."

Later in the volume he writes of various stones " carried in Italy on account of their medical appropriateness, notably the Gioia NEPHITE."

The Italian use of what is quoted as the Spanish term *iada* corroborates the Italian/English dictionary *Worlde of Words*[7] printed in 1598, just twenty-nine years after Monardes. The 1611 edition of this publication, greatly enlarged and improved, makes

little distinction between the two terms that concern us here. *Iada* or *Jada* is a " kinde of pretious ftone like an emeraud," while *Iaspe* or *Jaspe* is " a pretious Stone called a iasper ftone." Certainly the word *iada* would not have appeared in a dictionary of 1598 had it not been already established.

Arnobio is valuable evidence, not only because we find our word Nephrite (though spelt *nephite* and *nefrite*) in earlier use than heretofore believed but because the writer was familiar with Monardes, who had written *piedra de ijada* in 1569, and also because even as early as 1602 people were in the habit of carrying nephrites in Italy on account of their belief in the medical efficacy of the stones. He knew too that the custom of the Red Indians was similar.

In *The Magic of Jewels and Charms* (1915) G. F. Kunz quotes Arnobio as having received a specimen of American jadeite prior to 1602 and having shown this to one Signor Michele Mercate[8] " a man well versed in medicine and in the knowledge of minerals and herbs " and that he immediately recognized and called the specimen *nephrite* from its virtues, saying that he had found it useful in aiding parturition. Later the specimen was shown to a pharmaceutist who declared that he had used the stone but did not know its name. A much earlier writer (1098-1179) invests the jasper with the same virtue, i.e. as an aid to child-birth.

Unless communications were much more rapid than we have reason to suppose, it must be obvious that before 1600 nephrite was known in Italy, not only by name but for the cures it was supposed to effect. Had this not been so, the material, as well as the custom, must have been adopted in less than thirty years. Even the fact that a specimen of American jade had come to hand does not detract from its common use among the Italian people.

An even greater interest for us here is suggested by a further excerpt from Dr. Kunz's book. He writes :

> " Proceeding to dilate upon the many virtues of this stone, Cleandro quotes Aldobrando, ' a physician, physicist, and philosopher of Bologna ' who described it as having usually a purple shade, almost like porphyry, with various figures of herbs, flowers, knots, and Arabic characters in yellow colour. There were, however, according to the same authority, some of the darker hue, with protuberances and bands of yellow, and also black spots, as though the stone were a section of the spleen. In another variety in the midst of the purple colour might be seen a yellow stain with pittings and hollows : this was thought to figure a section of the liver. spattered with bile, and such stones were employed with good effect to cure those suffering

with bilious disorders. To discharge the bile a dose of four grains was administered, the powdered stone being thoroughly dissolved in wine. Still another kind of a reddish hue like coagulated blood, full of pittings and veinings, was thought to be more especially as a remedy for disorders of the blood and for checking hemorrhages."

Many stones may perhaps be confused in this quotation but almost certainly jade was among them, and the " physician, physicist, and philosopher of Bologna " was most likely Ulissi Aldrovandi of Bologna who used the term *lapis nephriticus* in his own writings[9] around this period. Aldrovandi was no mean scientist either, as the earlier reference substantiates. It would seem therefore that both the term *lapis nephriticus* and *nephrite* originated in Italy.

A further point of interest is that Arnobio gives a dose of 4 grains as a cure for bile while Monsieur Pomet, about a hundred years later, safeguards himself with a suggested 4-15 grains ; albeit for a slightly different disorder. Here too may be an answer to an oft-repeated question : Why were certain stones considered suitable as cures for certain diseases ? Either the *appearance* of the stone suggested a part of the body in need of aid or suggested the aspect of the disease in the body.

Gemstones were sometimes used as charms for purposes other than medical or moral. In Elizabethan times, for instance, there was a charm to find stolen goods :[10]

" *To know where a thinge is that is stolen.*

Take virgine waxe and write upon yt ' Jasper + Melchior + Balthasar ' and put yt under his head to whome the good partayneth, and he shall knowe in his sleape wher the thinge is become."

There is really more than meets the eye in this belief. It is linked, psychologically, with " sleeping on a problem " when answers present themselves on waking, as many know from their own experience.

Although the terminology of Gesner (1516-1565) was not very helpful, from our point of view, he was undoubtedly a very great authority in his day. In the Proceedings of the Free Museum of Science and Art, University of Pennsylvania (May, 1897-1900) is an article by Professor P. Brown. He writes :

" Thus we find in Gesner that amulets of green ' jasper ' mottled with white were reputed to have extraordinary powers in protecting the wearer from death by poisoning, and he states that this use was universal thoughout the East. Even in the time of Pliny this use seems to have been common."

It could be that Gesner was not going to be bothered with any newfangled title such as *Piedra de Ijada.* He was, after all, a contemporary of Monardes and as such was entitled to some degree of scorn. Certainly he stuck to the old term *jasper.* Kunz, in the above volume wrote :

> " Gesner states that he saw in the possession of a writer of Lausanne a green jasper, bearing the image of a dragon with rays, similar to the gem described by Galen."

A name well known in the gem world is that of John Trevisa, a mediaeval writer frequently quoted. As a native of Cornwall he brings a rather more local flavour to the jade problem. John Trevisa, or John of Trevisa, was born around A.D. 1322. His literary work consisted mostly of translations from Latin into English and although it is claimed that he produced very little original work, his value as a translator, particularly into the language of this country at that time, has earned for him the title of " Father of English Prose." Caxton printed some of his work and, later, Wynkyn de Worde. Besides being a scholar, John Trevisa was also a traveller. One of his most important translations was *De Proprietatibus Rerum,* written by Bartholomaeus Anglicus (de Glanville) another Englishman. Bartholomaeus, who joined the Fransciscan order in France, produced an encyclopaedia around A.D. 1250, which became famous largely because it mirrored the life of the day. Shakespeare is said to have been familiar with this work. Doubtless it was one of the books to be consulted for that period, and around the thirteenth and fourteenth centuries books were being hired in Paris. (Was this the forerunner of our lending libraries ?) Trevisa's translation appeared in 1398 (or 1387, for controversy exists here also). In Chapter 53 is a heading : *De Lapidibus Preciosis,* with something to say about jasper :

> " Jasper is a precious stone and is greene like to *smaragdus ;* but it is more dim of colour. And there be 17 kinds thereof as Isidora saith. *Jaspis* when greene is called *Gemma Prassiua* (*Prassius*) and though the chief colour be greene, yet it hath many colours . . . *Jaspis* is more beauteous in Silver than in gold . . . and men say it is a stone of wonder virtue . . . And best *Jaspis* is found in the mountains of Licia."

Many Virtues are attributed to this stone and it is suggested that it is helpful also if taken in powdered form dissolved in milk.

Isidore, Archbishop of Seville, quoted above, was another of the early encyclopaedists, and a name to appear in print for hun-

dreds of years. A translation of his work *An Encyclopedist of the Dark Ages*[11] was made as recently as 1912, in New York. In Book XVI of this work is a section *On Stones and Metals* and the stones are classified according to colour. On green gems :

> " Certain believe that the jasper gives both attractiveness and safety to its wearers, but to believe this is a sign not of faith but of superstition."

Isidore's period was A.D. *c.* 570-636 and a footnote to this volume states that Pliny's *Natural History* was the chief source of writers of these times and that an epitome or an epitome of an epitome was made by Solinus in the third century and that Isidore is supposed to have used both the epitome and the original as well as an unknown work. The authority of the Roman Pliny was the chief source for writers on gemstones for hundreds of years. The tragedy is that so little of Pliny's own authorities is extant.

Julius Solinus was a Roman of the third century A.D. A translation of his work appeared in London in 1587. Here we find the " native soil of the Emerald " " . . . the land of the Arymafpes" (Scythians) and a statement that the emeralds of Scythia are better than those of Egypt, Chalcedon or Media, and " maketh it to be liked above all others." Later we read, in an interesting paragraph easily linked with Pliny :

> " . . . for in the inner parts of Germanie is found a stone called *Callais*, which men prefer before the precious stones of Arabia : for it passeth them in beauty. The Arabians say it is not found anywhere but in the nests of birds which they call MELANCORYPHES which no man believeth forasmuch as they are found in the regions of Germanie among stones, although very rarely. In respect of the estimation and value of the Emerawd, it is of colour a faint greene. . . . "

There are frequent early references to green stones emanating from " Germanie," which is not surprising since gem cutting was an industry in that part of the world in Roman times.

Numerous references to jasper exist, both ornamental and medical. The word is frequently found in Roman writings. The difficulty is to determine whether the word *jasper* referred to jade or to other substances, that might too include jade, or even to the jasper of to-day. It could hardly be that jade was not in the picture at all when so many descriptions of jasper clearly describe jade. Virgil wrote of " yellowish jasper." These stones were set into a sword " all sparkling like stars " suggesting that the stones were

neither jade nor jasper, for though our own jasper takes a good polish it can hardly be said to sparkle. Such references abound. C. W. King[12] wrote that :

> " no stone held so high rank in the alexipharmaca of both ancient and mediaeval physicians as the Jasper."

He said also :

> " Fine specimens of jasper continued to be prized under the Empire, in spite of the then comparative abundance of the true emerald. Thus Juvenal excuses the host's watchfulness over the ' sharp nails ' of this needy guest when he handles his jewelled cup, on this plea : ' *Da veniam : praeclara illic laudatur iaspis.*' " (Freely translated : Pardon me : the praised (valued/ prized) jasper is there.) E.R.

King adds :

> " Similarly, Martial, after making his exquisite look over and bargain for all the most expensive articles in the Septa, or Grand Bazaar—slave boys, ivory ear-rings, antique bronzes, old plate, crystal and murrhine vases—ends with ' Sardonychas veros mensa quaesivit in omni, Et pretium magnis fecit iaspibibus.' Freely translated : He looked for real precious stones at every table and declared them worth great jaspers. (Supposing that jasper was as good as money.) E.R. This verdant colour furnished the idea to King Polemo for the pretty epigram (X750) ' If you saw on the land these cows and this jasper, you would declare that the first were breathing creatures, the last a field of growing grass'. "

Germanicus, the Roman commander, is reputed to have been highly superstitious (along with his contemporaries) and always to have slept with a talisman beneath his pillow. The talisman was of green jasper engraved with a figure of the Goddess Hecate, who presided over magic arts and spells. After a life fraught almost daily with danger, Germanicus came to a tragic end. It was then discovered that his talisman had disappeared.

It seems incredible that a part of the world could ever have revered what we now term jasper. In *Quartz Family Minerals*[13] (p. 145) we have an informative description of jasper :

> " Jasper includes, in a general way, nearly all varieties of impure, opaque, coloured, amorphous quartz. Under the microscope it is essentially a very fibrous quartz—a characteristic in which it differs from all other varieties . . . In colour, jasper may be red, yellow, brown, green, bluish or black. These different colours are due to the inclusion of different impurities, such as clay, iron in varying stages of oxidation, or organic matter, and possibly admixtures of other minerals in minute quantities. From time immemorial, the jaspers have enjoyed wide popularity as gem stones. They take a splendid, glossy polish, wear well, are attractive in appearance . . . jasper is not translucent, unless cut into very thin sections."

In other words, jasper covers a range of colour not unassociated with jade itself and certainly not at variance with some of the old lists, yet by no stretch of the imagination could its polish, which everyone agrees is glossy, be mistaken for the greasy wax-like finish of jade. In 1865 C. W. King[14] was writing :

> " The modern jasper, distinguished from the modern agate as being quite opaque, and containing more iron, was certainly the stone known to the ancients as the Achates."

Undoubtedly a small piece of jasper, here and there, might be generally acclaimed beautiful and of specimen status, but one does not need to search for beauty in jade, whatever its shade or size. In early days, as now, emerald green was the most admired green. Writing of *Callaina*, Pliny said :

> " The best of them have just the colour of *Smaragdus*, a thing that proves that the most pleasing property in them is one that belongs of right to another stone."

How often we meet this, and not alone in the world of gems. We love something mainly because it is like something else that we love. So the modern taste in jade, said always to be the emerald green, is by no means original. It seems to have been in demand at all periods.

Vessel in nephrite, probably early 17th century, believed to be work from the Imperial Court Workshop of Rudolph II, in Prague.

What we do know is that Rome not only imported the luxuries of the world—for she was in a position to do so, rather as the U.S.A. is to-day—but she was also a clearing house for these luxuries, and gemstones were luxuries as well as talismans, and necessities in the medical sense. Sir Mortimer Wheeler has unearthed numerous instances of a thriving trade between Rome and India, and the frequent arrivals of Indian missions at the court of the Roman Emperor suggests that the exchange was of mutual advantage and desirable. During the fifteenth and sixteenth and even seventeenth centuries Europe found another continent eminently to her interest, but in the Roman day there was a vast country to fascinate Europe and that country was India. Pliny makes frequent mention of it.

A writer of the third century A.D. (though the date is contested) was Dionysius, the Geographer. It is believed that this author of blank verse (translated from the Greek in 1789 in London) was an Alexandrian. He writes of Eastern India, ancient and modern :

> " The Indians, dwelling near the western Sun,
> These are distinguished by their tawny skins
> . . . .
>
> Of these some search with Care the hidden Gold,
> Digging the Sand with Spades for that Intent :
> . . . .
>
> Some trace adjoining to the Torrent's Streams,
> Or the blue Berrill, or the Adamant
> Transparent, or the Jasper green to Sight,
> Or the bright Topaz of a clearer Blue
> Fair flowing Indus, whence the Land takes Name,
> The Indian Realms the Ganges cuts in two."

Yet another around this period was Epiphanius, who wrote of gems. Epiphanius was bishop of Salamis (called Constantia after A.D. 395) in Cyprus. He was born in Palestine of Christian parents around A.D. 315 and died in 403. In 367 he became bishop of Salamis. One of his few works was on the *Twelve Stones*, and he attributed the jasper to Peter the Apostle. On page 113 of this volume is the heading : " The Gem Jasper " (*Iaspini*) :

> " The jasper is a green gem whose appearance is similar to that of the emerald. It is found in the immediate neighbourhood of the river T'ermagondos and near Iamant'isa—not that which is in Cyprus, for in the nature there are many places which they call Amat'usion."
> (Footnote : T'ermagondos = Thermondontis. Iamant'isa = Amathunta.)
> " Its appearance is green in colour, like the emerald but to a slight

extent like that of the bnobi (a reference to obscurity) and from within it emits a green colour like that of copper rust."

C. W. King translates the last paragraph as follows :

" . . . the Emerald, like which it is green, but duller and more obscure, and having its substance green inside resembling verdigris."

Epiphanius continues :

" Those make much use of it who adorn their person, as is stated in the fables. . . . "

On p. 136 he writes :

" The sixth gem is the jasper (*Iaspini*) on which is inscribed the name of Naphtali (Nep't'alem) who was next in birth . . . Many are the kinds of this gem, nor is it found in one place, but in many quarters . . . jasper . . . is in appearance like to the hue of the emerald, and secondly its colour resembles that of the sea . . . As I have said before about this stone, it is a revelation, as it were, which comes in a dream. It is found in the regions of Phrygia, as it were, in a nest like a trough of clay."

One of the most quoted writers of the Middle Ages (and later) was Galen, sometimes spelt Gallen, or given the Latin renderings, Claudus Galeni or Claudius Galenus. Galen was a Greek Physician who lived around A.D. 130-200. He wrote a great deal on medical matters and as a medical authority was second in importance only to Hippocrates. One of his works *Natural Faculties* was translated into English in 1586 and printed in London. In search of knowledge Galen is said to have roamed through Greece, Cilicia,* Phoenicia, Palestine, Crete, Cyprus and finally Alexandria where he visited the famous medical school. Eventually he settled in Rome and on one occasion when he left the city for Pergamum was recalled by the emperor Marcus Aurelius. We are told that Latin translations of his works were studied in European medical schools until the beginning of the nineteenth century. According to Gesner, Galen is reported to have worn a jasper on his finger and to have asserted that hanging from the neck jasper influenced the stomach. C. W. King quotes the " sober Galen " as follows :

" The green jasper benefits the chest and the mouth of the stomach if tied upon it. Some set it in a ring and engrave upon it a serpent with a radiated head, just as King Nechepsos prescribes in his thirteenth book. Of this gem I have had ample experience having made a necklace of such stones, and hung it round the neck, descending so low that the stones might touch the mouth of the stomach, and they proved to be of no less service than if they had been engraved in the manner prescribed by King Nechepsos."

*Then a Roman province in Asia Minor.

Thomas Wilson does not share King's opinion that by jasper Galen meant Plasma.[15] Wilson believed that Galen, writing of green jasper, referred to jade. He said, " Galen, who speaks of green jasper (subsequently identified as jade) as having certain medicinal qualities," and he quotes Galen's words, " Jaspis virens, nempe, stomachum adhalaesu (or adhaesu) ventrisque es colores mitigat." Freely translated, the first part of the sentence runs, " The green jasper indeed calms the stomach by its clinging (power) . . . " The rest of the sentence is not clear. Wilson continues

> " The name *jaspis*, and the phrase " jaspis virens, viridis ' seem to have been continued with the inclusion of jade from the time of Galen and Actius through Orpheus, Argonautica (Hymni et Libellus de lapidibus), (A.D. 500-600), Albertus Magnus (A.D. 1205-1280), Marco Polo (A.D. 1271-1323) and others too . . . "

In Revelations of St. John the Divine, written in A.D. 96, just 17 years after the death of Pliny, there are references to jasper. It seems fitting to record them here :

Chapter 4, v. 3 :

> " And he that sat was to look upon like a Jasper and a sardine stone : and there was a rainbow round about the throne, in sight like unto an emerald".

Chapter 21, v. 11 :

> " Having the glory of God : and her light was like unto a stone most precious, even like a jasper stone, clear as crystal."

Chapter 21, v. 18-20 :

> " And the building of the wall of it was of jasper and the city was pure gold, like unto clear glass. And the foundations of the wall of the city were garnished with all manner of precious stones. The first foundation was jasper ; the second, sapphire ; the third, a chalcedony ; the fourth, an emerald ; the fifth, sardonyx ; the sixth, sardius ; the seventh, chrysolyte ; the eighth, beryl ; the ninth, a topaz ; the tenth, a chrysopraseus ; the eleventh, a jacinth ; the twelth, an amethyst."

Contemporary with Pliny was Dioscorides of Anazarba in Cilicia. He too has been frequently quoted. Lange mentions him as giving the synonym *Gemma Calsnee*. Gesner wrote of his medical knowledge. His great work, compiled in the first century A.D., was later illustrated by a Byzantine in A.D. 512 and Englished in 1655 by John Goodyer, though not then printed. This book had to wait for our own age for the privilege of print; in 1933 it was

edited by Robert T. Gunther. It seems better to quote him here, before Pliny, because just as *ijada* stems from Monardes, jasper must halt with Pliny. In Book V, No. 160, p. 655, we read :

> " *Iaspis*. Lithos. Jasper. *Lapis Iaspis*, some of it like ye Emerald, and some like Christall resembling phlegm, some like ye air and some (is called) Capnia, as we should say, besmoked, and some also having white middling partitions, and glittering, called Assyrius. And some is called Terebinthizusa being in colour like *Calais*. But all are said to be Amulets being hanged about one, and to speed deliverance, being tied to ye thigh."

Pliny the Elder was born in A.D. 23 and died in the eruption of Vesuvius in 79. It has been claimed that his work was more read than any other during the Middle Ages, with the single exception of the Bible. Perhaps at this time his authority has never been higher, for, with the discovery of the Dead Sea Scrolls and the subsequent ruins of the monastery connected with the scrolls, scholars have turned to Pliny for a description of this organization and its location.

Since the word jade (or nephrite), in any of its forms, was not then born, and since, despite its Latin, the term *lapis nephriticus* can be traced no earlier than the end of the sixteenth century A.D., it remains to discover what this famous Roman called jade. Pliny has several references to *Jaspis*. He also has a chapter on *Beryls : Eight Varieties of them*. Not only has jade been likened to the emerald in modern times, it has been a favourite description by almost everyone writing on the subject. And it is an apt description, since it is possible for a fine piece of green jade to be mistaken, on sight, for an emerald. Even Captain Cook likened the Maori jade to the emerald, as did Florio in his dictionary some 200 years earlier than Cook.

Pliny[16] writes :

> " Beryls, it is thought, are of the same nature as the *smaragdus*, or at least closely analogous. India produces them, and they are rarely to be found elsewhere. The lapidaries cut all beryls of an hexagonal form ; because the colour, which is deadened by a dull uniformity of surface, is heightened by the reflection resulting from the angles."

Two interesting points emerge here. First, the term beryl is a species in itself and includes the emerald, and Pliny was familiar with this. Secondly, the emerald occurs naturally in hexagonal crystals, so it is possible that Pliny thought this the work of man rather than of nature.

" The most esteemed beryls," he goes on, " are those which in colour resemble the pure green of the sea ; the chrysoberyl being next in value, a stone of a somewhat paler colour, but approaching a golden tint." After describing various other varieties he says : "The people of India are marvellously fond of beryls of an elongated form, and say that these are the only precious stones they prefer wearing without the addition of gold . . . They prefer too, cutting the beryls in a cylindrical form, instead of setting them as precious stones . . . " (Gesner mentions this also.)

Our next reference to *Iaspis* (Chapter 37) is entitled : *Iaspis : Fourteen varieties of it.* (These are the famous fourteen varieties so frequently quoted by later writers.) " *Iaspis* too is green, and often transparent ; a stone which, if surpassed by many others, still retains the renown which it acquired in former times. Many countries produce this stone: that of India is like *smaragdus* in colour; that of Cyprus is hard, and of a full sea-green." (Another rendering of this passage, given by Dr. Ball in his *Roman Book*, page 162, is : " The *jaspis* of Cyprus is very hard and of a greasy grey colour, between white and green.") " That of Persia," Pliny continues, " is sky-blue, whence its name ' aerizusa.' "

If jasper (or jade) could have been confused in certain instances with one of Pliny's beryls, here little doubt remains that one, at least, of his jaspers is our jade. The sky-blue of the Persian stones was undoubtedly our turquoise. The various colours he mentions later, under this same *Iaspis* heading, differ little from those quoted in the French book on Drugs. He also says that there is a *jaspis* that resembles *sarda* in appearance, probably referring to red jasper. Again jasper here seems to be a generic term like jade. " One great defect in them," he goes on, " is a subdued lustre, and a want of refulgence when viewed from a distance. . . . Throughout the East, it is a custom, it is said, to wear *iaspis* by way of amulet. The variety of this stone which resembles *smaragdus* in colour is often found with a white line running transversely through the middle." (The confusion here could be with cat's-eye though a natural white line is not unknown in nephrite. Dioscorides mentions this, above.) " Here, too, I may take the opportunity of exposing the falsehoods of the magicians who pretend that this stone is beneficial for persons when speaking in public." This may be a falsehood in one sense but for another reason it was

common among the Maoris (who were great orators) and the Chinese.

Although it is certain that Pliny's jasper included our jade —for what could be more convincing than the " renown of former times," the " greasy-grey colour, between white and green," the " subdued lustre and want of refulgence," the amuletic properties and the use of it in oratory ?—it is not possible to discover, via Pliny, that " jasper " was a cure specifically for kidney ailments. Moreover, Pliny throws little light on this subject. The nearest is his chapter on : *Precious stones which derive their names from various parts of the human body.* " . . . Adadunephros, adaduphthalmos, and adadudactylos, meaning ' kidney of Adad,' ' eye of Adad ' and ' finger of Adad ' respectively, and Adad was a god of the Syrians." A footnote here explains : " An ancient king of Syria, worshipped by the people of that country and the inhabitants of Phrygia. According to Macrobius,[17] the Assyrians worshipped Jupiter and the Sun under that name."

Despite the fact that these stones were called after various parts of the body, we are not told whether it was so because of the *shape* in which such stones were discovered or sometime discovered or whether it was similarity of colour or markings to the various parts of the body, or, as was the case quoted above, because the stones gave an appearance of a diseased part of the body and were believed to have curative properties on this account. Another authority, Ignatius Donnelly in *Atlantis,* gives some information on the word Adon which is probably related to Adad.

> " Adon was one of the names of the Supreme God of the Phoenicians ; from it was derived the Greek god Ad-onis . . . just as in the Bible we have allusions to the " Sons of Adad ' who were the first metallurgists."

In his *Roman Book* S. H. Ball seems certain that Pliny's *jaspis* in part referred to jade, particularly the variety emanating from India, or more likely by way of India ; though he was doubtful about Adadunephros. He also felt that Pliny's *Ceraunia* may have included some of the jade axes used by neolithic people in north-West Italy.

Perhaps Pliny's most interesting contribution, from our point of view, is his reference to *Callaina:*

> " . . . the stone known as *callaina* and of pale green colour. It is found in the countries that lie at the back of India, among the Phycari, namely, who inhabit Mount Caucasus, the Sacae, and the Dahae . . . it is

only amid frozen and inaccessible rocks that it is found, protruding from the surface . . . not as though it formed an integral part of it . . . People so habituated as they are to riding on horseback, cannot find the energy and dexterity requisite for climbing the rocks to obtain the stones . . . It is with this stone that the people pay their tribute, and this the rich look upon as their most graceful ornament for the neck."

A footnote here says that Isidorus, Archbishop of Seville, see above—B. XVI, ch. 17—claims they wore the ornament in their ears. Pliny goes on : " . . . The best of them have just the colour of *Smaragdus* . . . The finest of them lose their colour in contact with oil, ungents, or undiluted wine even . . . "

Pliny's *Callaina* possibly covered two species, (1) turquoise, often of a pale green, and (2) jade. It is even possible that this occurrence refers, in part, to the northern slopes of the K'un Lun Mountains in Sinkiang. Certainly jade was used there as tribute. The term Caucasus was a geographical one with extremely elastic frontiers. The *Sacae*, mentioned by Pliny, occupied territory north of Kashmir, which in ancient times was part of the Persian empire. The *Dahae* were rather more to the west. Though turquoise is never a true emerald green, grease and oil and indeed the atmosphere may render it a definite green in time.

The word *Callaina* is yet another term persisting over the years and evidence suggests that it covered jade or turquoise or more likely the two materials. Solinus speaks of the stone *Callais* being found in the inner parts of " Germanie " and tells us that it was precious. Was this the nephrite of Silicia ? It was quite common to lump turquoise and jade under the same heading, as was the case in South America where it was called *chalchihuitl*—perhaps because of the greenness of turquoise after exposure. In the first article of this series C. Daryll Forde, describing the megalithic culture of Brittany, includes Jadeite and *Callais* under a *Greenstone* heading. Joannes de Laet, in his third edition, printed in 1647, wrote : " There is another species, green *Iaspis* . . . The Germans call it *Nephriticum*, *Kallesznin*n (Pliny calls it *Callais Callaias*), Belgians one Kalzbee, bad form of the name *Callais* one would say " (yet, of course, very close to the German word) " . . . Still further from the truth are those who compare it with *Prasius*." Cluyt, writing in 1627 said : " The stone *Nephriticus*, by some called Calsue." Cluyt tells us too that the word comes from *Callais*.

No chart is needed to clarify the word *jasper*. It seems always to have been with us, serene and uncomplicated, at least back to Roman times. No deviation of spelling is apparent. Perhaps it was that the word itself is so simple it could hardly be misspelt. An English/Welsh dictionary defines it : Jasper—*maen jaspis*. (*Maen*—stone). Here jade is defined Jâd, also Jaden. The question of the Semitic origin of the word jasper must await a later article. In the list of words[18] covering material we know as jade (at various periods of history) it will be recalled that jasper was included as :

Jaspis and *Jaspis Viridis*—Latin version (or slight variations of this, meaning always green or greenish).

Jasper—Anglicized version. *Jaspe*—French version.

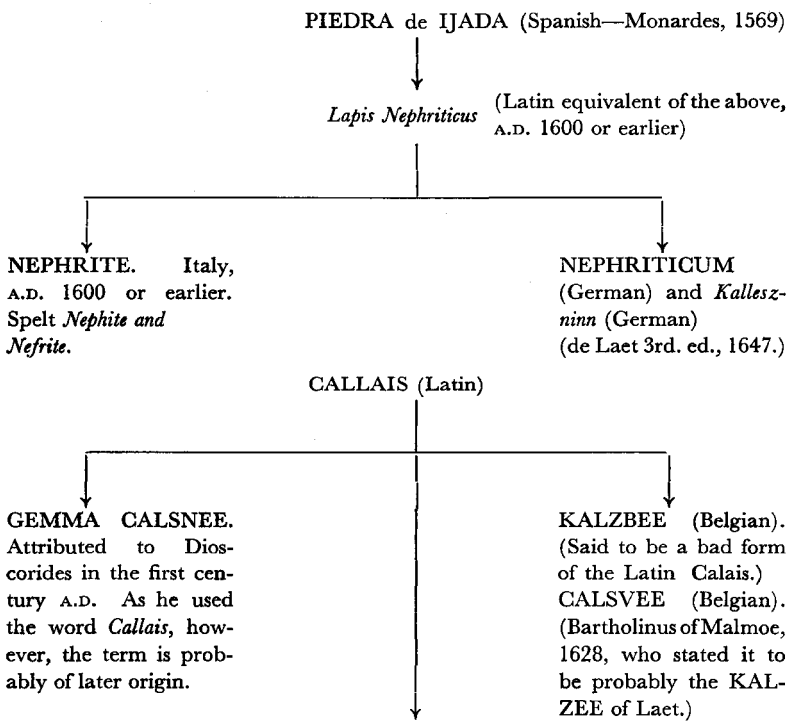

In search of jade, therefore, it seems imperative that we not only accept many of the references under the *jasper* heading as our modern jade but also accept *Callais* which, though sometimes referring to turquoise, also indicated jade.

It would appear that the Germans knew that *Nephriticum* and *Kalleszinn* were one and the same, perhaps the second word being a local form of the first.

The word *Callais* or Callaite is to be found in almost every modern summary of mineral terms and goes back, as we have seen, to Pliny.

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4. Journ. Gemmology, January, 1956, pp. 283.
5. Journ. Gemmology, October, 1956, p. 411.
6. Journ. Gemmology, July, 1955, pp. 148-149.
7. Florio's *Worlde of Words*, Italian/English dictionary, 1598. See Journ. Gemmology, January, 1955, p. 15.
8. Signor Michele Mercate was the author of *De Gli Obeliscgh di Roma*, published in Rome during 1589.
9. Journ. Gemmology, January, 1956, p. 275.
10. George Gordon Coulton. *Social Life in Britain from the Conquest to the Reformation.* 1918, p. 527.
11. By Ernest Brehaut.
12. C. W. King. *Natural History of Precious Stones and Gems.* 1865, p. 209.
13. Dake, Fleener and Wilson. *Quartz Family Minerals.* N.Y., 1938.
14. C. W. King. *Natural History of Precious Stones and Gems.* 1865, p. 206.
15. Certainly our modern Prase and Plasma could be confused with our modern Jasper and perhaps often is. To quote *Gemstones*, G. F. Herbert Smith (5th edition) p. 240 : " Prase, or mother-of-emerald, which was at one time supposed to be the mother-rock of emerald, is a quartz coloured leek-green by actinolite fibres in the interior." And on p. 247 : " It is a dull leek-green in hue, . . . the name comes from πράσον a leek. Plasma, which may have the same derivation, is a bright leek-green." *Quartz Family Minerals* classifies Plasma as a much coarser variety of Quartz than Prase " approaching jasper in texture and appearance . . . The name Plasma means *image* and refers to the use of the stone in olden times for seals and signets . . . "
16. The Natural History of Pliny. Bostock & Riley, London, 1857.
17. Macrobius. Roman grammarian and philosopher, flourished during 395-423.
18. Journ. Gemmology, October, 1956, pp. 402-403.

GEMMOLOGICAL NOTES

Capt. John Sinkankas reports the finding of hambergite crystals in the dumps of the Little Three Mine at Ramona, San Diego County, California. Apparently hambergite occurred in the pegmatite of this mine as an isolated cluster upon the floor of a pocket associated with quartz and clevelandite. The material looks like shards of microcline and orthoclase feldspar and this no doubt accounts for its being overlooked by collectors who have visited the dumps in search of tourmaline, quartz and topaz. These splinters form during late stages of hydrothermal activity and appear to represent the failure of pocket walls under considerable pressure developed inside the openings. Quartz and feldspar are therefore often found as broken pieces, recrystallized upon all surfaces. Superficially, the hambergites appear like some of these shreds and bits. Capt. Sinkankas has kindly sent some samples of the new find to the Association.

ASSOCIATION NOTICES

GIFTS TO THE ASSOCIATION

The Council of the Association has recorded with gratitude donations from the Worshipful Company of Goldsmiths, the Diamond Trading Co. Ltd., the Mond Nickel Company and various members towards the cost of providing the final section of the Sir James Walton Library. This library was jointly established by the National Association of Goldsmiths and the Gemmological Association in memory of Sir James who was President and Chairman of both organizations respectively at the time of his death. (See page 223.)

The Council has also recorded with gratitude the following gifts :

Four rose-quartz, showing asterism, from Starstones, Limited, London.

Samples of hambergite found at the Little Three Mine, Ramona, San Diego Co., U.S.A., from Capt. John Sinkankas, U.S.N., C.G., Arlington, U.S.A.

A fine specimen of corundum (ruby) from a recently discovered locality in Southern Norway, from Hans Myhre, F.G.A., of Oslo.

A sample of realgar glass, from D. S. M. Field, F.G.A., Toronto.

A book on diamonds and their occurrence in the U.S.S.R., published in Moscow, 1957, kindly presented by D. Seneviratne, F.G.A.

Three models in quartz of famous diamonds, from T. Stern, London.

TALKS BY MEMBERS

KENT, D. G. " Gemstones," Deptford Round Table, 9th October, 1957.

KENNEDY, N. " Illumination in relation to gemstones," Illuminating Engineering Society (Liverpool Centre), 19th November, 1957.

WEBB, MALCOLM H. " Gemstones," Tovil Community Club, Maidstone, 12th December, 1957.

JONES, THORLD G. " Gemstones," Institute of Metals, Oxford, 3rd December, 1957.

MELROSE, R. A. " Diamonds and their history," Hexham Inner Wheel, 29th October, and Newcastle Business and Professional Women's Club, 14th November, 1957.

NEW AUSTRALIAN SECRETARY

Mr. F. Leechman, F.G.A., has recently taken up his duties as Federal Secretary of the Gemmological Association of Australia. In the 1930's he took up lapidary work in Cornwall, and studied geology, mineralogy and gemmology. He obtained his Diploma in 1937, and was awarded the Association's Research Diploma in 1953, for his study into the cause of colour in precious opals. He became a member of the Australian Association in 1949, and with his appointment as Federal Secretary has also become the New South Wales State Secretary.

MIDLANDS BRANCH

At the annual general meeting of the Midlands Branch of the Association, held at the Auctioneers' and Estate Agents' Institute, Birmingham, on 21st October, 1957, Mr. Trevor Solomon was re-elected as Chairman for the sixth year. Mr. A. E. Shipton was re-elected as Honorary Secretary and the following were elected to serve on the Committee : Miss J. Rice and Messrs. B. Leng, W. Bowen, B. Clay and J. Harper.

The second annual dinner of the Branch was held at the Imperial Hotel, Birmingham, on Friday, 1st November. Mr. Trevor Solomon presided and principal guests included Mr. F. H. Knowles-Brown, Chairman of the Association, the Secretary and the Librarian, and Mr. David Wright, President of the British Jewellers' Association.

On 29th November, 1957, Mr. W. Bowen gave a talk to the Midlands Branch members of the Association on the " First 5,000 years of personal adornment."

The Midlands Branch are to be congratulated on a fine year's work maintaining enthusiasm for gemmological study in their area.

PRESENTATION OF AWARDS

The 1957 presentation of awards took place at Goldsmiths' Hall, London, on 10th October. Diploma winners from Norway and Cape Town were among those who attended. The diplomas were presented by Dr. G. F. Claringbull, Keeper of Minerals at the Natural History Museum and one of the examiners. Mr. F. H. Knowles-Brown was in the chair. He said that it was almost exactly 50 years ago that the idea of the Gemmological Association was born, largely the conception of the late Samuel Barnett. He felt that Mr. Barnett would have been proud to see the growth of the Association : his son was present that evening.

Mr. Knowles-Brown then welcomed the friends and relations of the successful candidates who had come to see them get the rewards for their achievements : it was an achievement, for if the examinations weren't difficult, the diploma wouldn't be worth getting. Once it was desirable to obtain the Fellowship of the Association, now it was almost essential. He was proud of the high regard in which the Association and its examinations were held overseas, and to pass was to enter a world-wide fellowship. So much was happening in the world of to-day that there was an essential need to keep abreast of new developments in manufacture and synthesis, and for this reason he was particularly pleased that Dr. Claringbull had agreed to present the awards.

Dr. Claringbull made some illuminating remarks about how to pass—and fail—the gemmological examinations. The examiners made things hard for the candidate : they intended to. This year, 40 per cent of candidates passed, but that was a good figure compared with passes in other professional examinations, and was certainly reasonable when one considered that the Gemmological Association set no educational standard ; university candidates, for example, were weeded out year by year, so that the finalists numbered fewer failures among them since the less studious had fallen by the wayside.

Dr. Claringbull said he felt the Association were right not to restrict entry to the examinations ; he was not so sure about the fact that one could sit for the

examination without attending any course. Certainly, all candidates needed a good working knowledge of the practical side of gemmology, the recognition of stones and the use of instruments, for failure to pass the practical examination, which accounted for about a third of the failures, meant failure altogether. It was as well, too, for candidates to have some contact with instructors and other students—the same question could appear in both the preliminary and the diploma papers, but as an examiner he would expect very different answers from the candidates.

Looking back on 20 summers of examination-correcting, Dr. Claringbull said that he divided failures into two kinds—honest failures, who just didn't know and let it go at that, and dishonest failures, who seemed to think the examiner so naïve that he would accept their writing around a subject without ever answering a question. He said he could not understand how jewellers could possibly sit for an examination without thinking about time, and dividing up the number of questions (and marks) sensibly over the period allowed. It was no use doing one question brilliantly and no other, if there were four questions to be answered.

Dr. Claringbull ended by saying how much he appreciated the good fellowship of members of the Gemmological Association. Gemmology was a very small part of mineralogy, but gemmologists had made some very definite contributions to the parent science. He couldn't help being interested in gemstones, and he was sometimes gratified to see, especially in little jeweller's shops, displays of gemstones all labelled. Too often, fine and even rare stones were shown in jewellers' windows without a label of any sort.

Mr. B. W. Anderson, who is a co-examiner in gemmology with Dr. Claringbull, thanked him for his talk, which was straight to the point and would be of great help to prospective candidates. He said that we often tended to forget that gemmology was a part of mineralogy, and, even if the gemmologist did sometimes help the mineralogist, the gemmologist had a debt he should not forget to the research workers in minerals. On behalf of all gemmologists, he was proud that in the Department of Mineralogy they had someone interested in their subject who was so willing to help and encourage them.

The Chairman expressed the thanks of the Association to the Worshipful Company of Goldsmiths for so kindly making the Livery Hall available for the presentation.

FORTHCOMING MEETINGS

Annual General Meeting, 13th March, 1958, at Saint Dunstan's House, Carey Lane, London, E.C.2, at 6.15 p.m.

The Herbert Smith Memorial Lecture will be given by Professor S. Tolansky, F.R.S. at the Science Museum Lecture Theatre on Wednesday, 2nd April, 1958, at 7 p.m.

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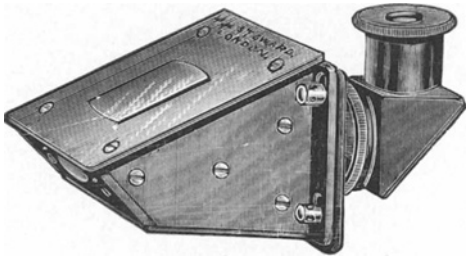

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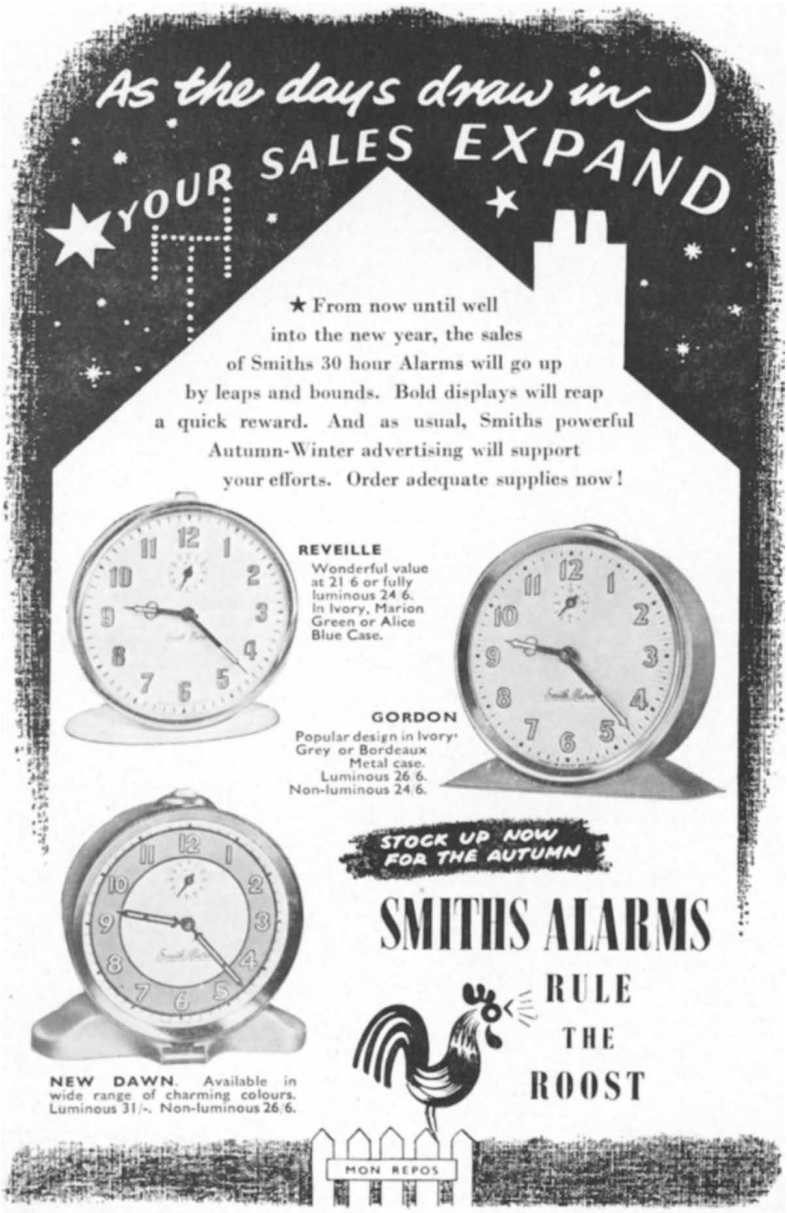

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January, 1958

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THE JOURNAL OF GEMMOLOGY

and

PROCEEDINGS OF THE
GEMMOLOGICAL
ASSOCIATION
OF GREAT BRITAIN

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Vol. VI No. 6 APRIL 1958

CULTURING PEARLS IN EARLS COURT

By FLORENCE M. VAUGHAN

A PASSION for miscellaneous and ill-regulated reading has its unexpected rewards, and one such recently presented itself to the writer from the unlikely pages of Lloyd Sanders's " Old Kew, Chiswick and Kensington " (1910). Writing of the transition of Earls Court during the eighteenth century from a small village in rural surroundings to a suburb of Kensington, the author notes that an early settler was John Hunter, the eminent surgeon, who in 1764 built a house there, in a sizeable piece of ground, where he kept a menagerie of an unusual and varied sort, including buffaloes and leopards. He had a pond in the grounds, ornamented with skulls (a nice 18th century Gothick—Castle of Otranto—touch, that !), and in it Sanders tells us that he experimented with the artificial formation of pearls in oysters.

Now, Lloyd Sanders's book is a vast *olla podrida* of anecdotal gossip about his three parishes, and its range is so extensive that one would expect it to be largely a surface gathering, so to speak, from

readily accessible primary sources such as Lysons, Leigh Hunt and Faulkner. However, this does not seem to be the case with the statement about Hunter's work on pearls, since a reasonably thorough search through books about and by Hunter yielded only one reference to the subject, from the four-volume edition of Hunter's works, published by James F. Palmer in 1835. In volume I, page 105, the following tantalizingly short reference occurs :—

" Hunter, it would seem, was busied in trying to make pearls by introducing extraneous substances into oysters as nuclei for them to form. What success he had does not appear, and indeed the following letter of his to his friend Sir J. Bankes gives us all the information we possess regarding the inquiry.

Dear Sir Joseph, *1787*

I have these two days been draining the pond or rather fishing for pearls, the success of which you will see by the specimens. Those I had made the experiments on were dead but there is one recent. I have a few alive that I mean to put under experiment but I shall open the shell and put in the extraneous body. If any other method suggests itself to you be so good as to inform me. *J.H.*"

From this disappointingly vague letter, one is left in doubt as to Hunter's intentions in these experiments, whether to anticipate Mikimoto by culturing true pearls, or to rest content with the more modest objective of producing " japs." One would have thought that the chances would be nil of an oyster surviving sufficiently long in an Earls Court pond to cover an extraneous body, even if the pond water were laced with mineral salts to assist the process. Moreover, those were pre-Lister days, and one suspects that even Hunter's genius in the fields of surgery and anatomy could scarcely have compensated for an unawareness of the importance of asepsis.

NOTES ON ASTERISM
IN SPINEL AND CHATOYANCY IN CHRYSOBERYL, QUARTZ, TOURMALINE, ZIRCON AND SCAPOLITE

By W. F. EPPLER

In Vol. VI, No. 5 of the Journal, Professor Eppler discussed the causes of asterism and chatoyancy, and gave notes on asterism in corundum, rose quartz, almandine garnet and beryl.

THE nature of the star-producing inclusions within the spinel is not yet known in all cases. Probably needle-like crystals of rutile are responsible for this rare phenomenon, as in some spinels from Ceylon such crystals have been found (Fig. 1). They are strictly orientated and follow the edges of the octahedron. They are no doubt rutile, which has been crystallized by a process of exsolution.

Star-spinels are very rare. Anderson and Payne[1] described a grey-blue spinel with asterism from Burma in 1954 and a year later G. Switzer[2] reported an unusual black star-spinel from Ceylon. He found that the asterism was caused by needle-like inclusions which were parallel to the edges of the octahedron.

Another possible cause of asterism in spinel from Ceylon is the presence of doubly refractive crystal fibres. Sometimes they occur singly in the shape of a little rod, which may be either straight or bent, sometimes they are accumulated in very impressive bunches (Fig. 2). It is certain that these crystal fibres are not rutile, as the

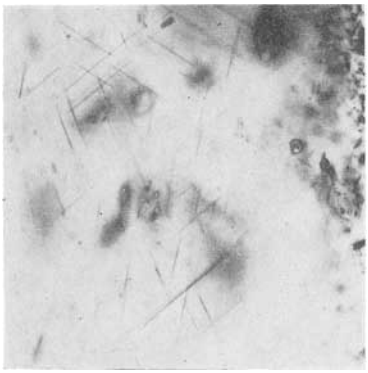

FIG. 1. *Inclusions of oriented rutile needles in a red spinel from Ceylon.* 120 ×.

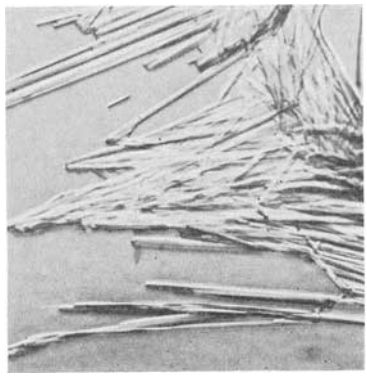

FIG. 2. *Doubly refractive crystal fibres in a red spinel from Ceylon.* 240 ×.

refractive index is lower than that of spinel. The material at my disposal has not been suitable enough to come to a definite decision as to their identity.

In E. J. Gübelin's paper, " A Contribution to the Genealogy of Inclusions "[3] it was pointed out that sphene crystals often cause asterism in spinel. Figs. 3, 4, 5 and 6 show some photomicrographs with sphene in a spinel from Ceylon. These crystals are too scarcely distributed to produce any kind of asterism. The sphenes are orientated parallel to the octahedral growing plane of the spinel. These sphenes are primary inclusions of xenogenetic origin. This can be seen in Fig. 4, where parts of the formerly complete crystals have been dissolved by the surrounding spinel. Also the arrangement of sphene crystals, as in Fig. 5, shows a characteristic group

FIG. 3. 90 ×

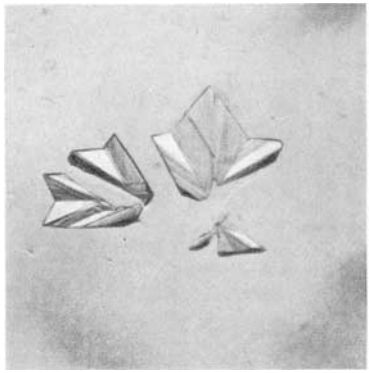

FIG. 4. 240 ×

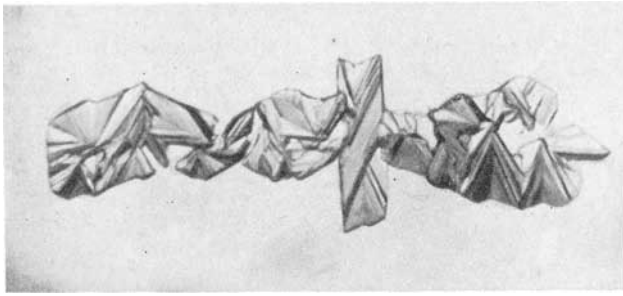

FIG. 5. 200 ×.

FIGS. 3–5. *Primary inclusions of orientated sphene crystals in a mauve-coloured spinel from Ceylon.*

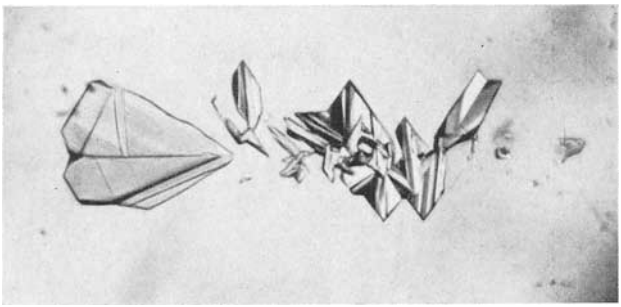

FIG. 6.
Sphene crystals in spinel from Ceylon. 220 ×.

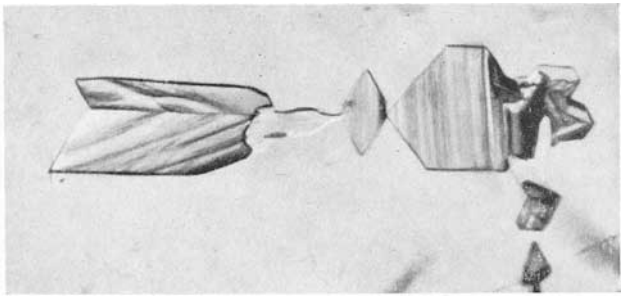

FIG. 7.
Sphene crystals in spinel from Ceylon. 240 ×.

of crystals, which formerly have been " freely " grown on the underlying octahedral plane of the spinel. Afterwards, this group has been " entrapped " by the further growing spinel crystal. These are not forms which indicate an exsolution (Fig. 6).

Another proof of the primary origin of the sphene is indicated in Fig. 7. Here, greater parts of the left-hand crystal have been dissolved by the surrounding spinel, which, owing to this newly " digested " material, shows in the places formerly occupied by the sphene a slightly higher refractive index. This is by no means in contradiction to the results of Gübelin. He also observed in spinel sphene crystals which have the form of minute needles and which have been caused by exsolution. It is obvious that the needle-like sphene crystals produce a better star in spinel than the larger crystals.

Spinels from Burma have inclusions (Fig. 8) which are very different from those in spinel from Ceylon. The large, nearly black, crystal inclusions are birefringent and have a hexagonal symmetry. They are not yet identified. The very fine, dust-like particles, which seem to have been concentrated near the larger

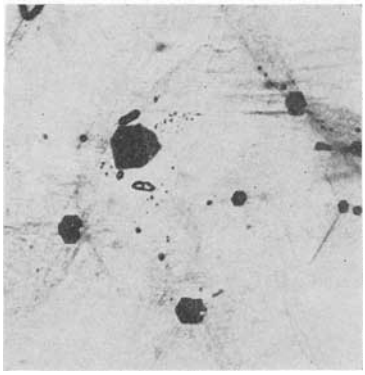

FIG. 8. 80 ×.

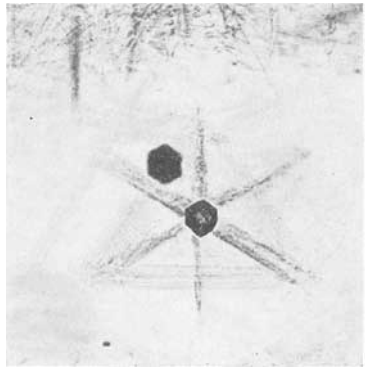

FIG. 9. 120 ×.

FIGS. 8 and 9. *Red spinel from Burma with inclusions of dark crystals of hexagonal shape, surrounded by tiny rutile crystals.*

crystals, are most probably rutile. Fig. 9 shows a strange pattern. It consists of a six-rayed star arrangement, which seems to superpose the triangular plane of an octahedron, and in the centre of the image is one of the large crystal inclusions. A possible explanation is that the large dark crystal is a primary inclusion. This crystal caused in one way or another a stress or a strain on its surroundings in the spinel crystal. Within this little zone of disturbance the exsolution of the rutile seeds started—so slowly that every newly formed crystal had time enough to take its pre-determined place within the possibilities of the spinel lattice. These small particles formed a pattern, which is in full coincidence with the symmetry of the spinel, from which they have been discharged. The pattern indicates further the main directions and places with a maximum amount of strain. Even at a higher magnification the dust-like particles remain so small that no further details can be recognized. The main indication why they are most probably rutile is the typical brownish colour, which is so characteristic for small rutile inclusions.

Even if they do not cause any kind of asterism, Burma spinels are of interest. Fig. 10 shows long and straight liquid inclusions, following crystallographic directions. Fig. 11 shows another part of these channel-like inclusions, which in some places are broadened to a band. Fig. 12 exhibits a part of such a band at very high magnification (1,500 : 1), revealing an accumulation of orientated and very small droplets.

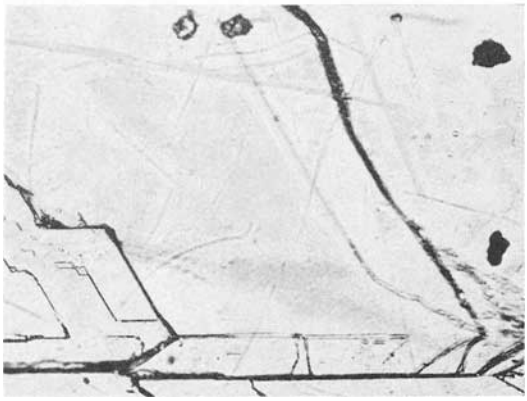

FIGS. 10 and 11. *Channel and band-like liquid inclusions in a red spinel of Burma.* 120 ×.

FIG. 10.

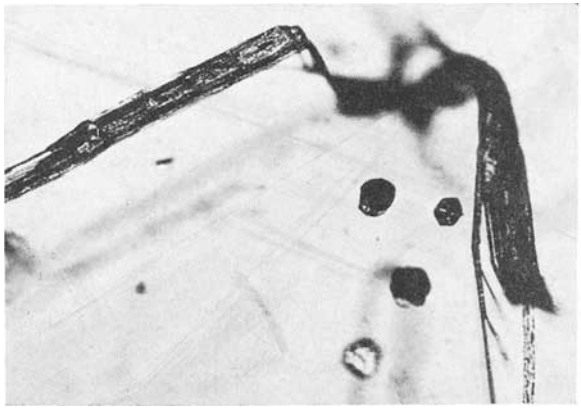

FIG. 11.

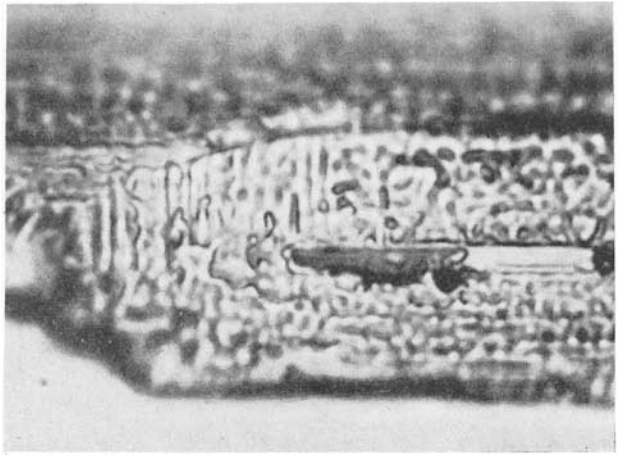

FIG. 12. *High magnification of broad channel from Fig.* 11. 1500 ×.

Some inclusions in a spinel from Burma are most puzzling (Fig. 13). They are singly refractive fibres with a refractive index near that of spinel ($<1{\cdot}717$). They are not dirt particles on the surface or in a fissure—they are unknown things embedded as inclusions in a natural, untreated spinel from Burma.

Synthetic Spinel. Examination of the possibilities of manufacturing synthetic spinel star-stones brought no practical results. As long ago as 1928, F. Rinne[4] published his paper showing that an asterism could be caused by the exsolution of the excess of alumina in synthetic spinels. He found that heat-treated synthetic spinel of the usual composition separated a part of the excess alumina by exsolution. This alumina, he suggested, adopted the gamma form alumina, an interpretation which was revised recently by Jagodzinski. This author found an intermediate phase, consisting of a magnesium-aluminate ($MgO.Al_{20}O_{39}$) of monoclinic symmetry. In any case flakes of an alumina composition are originated, which are parallel to the planes of the deltoid-icositetrahedron (311). These act as " asterites " ; but because of the unfavourable form of the flakes and the little difference of their refraction compared with the surrounding spinel, the asterism caused by them is very poor and of no commercial value.

Rinne found that exsolution in a commercial synthetic spinel starts in preferred zones of the boule. The zones are symmetrical

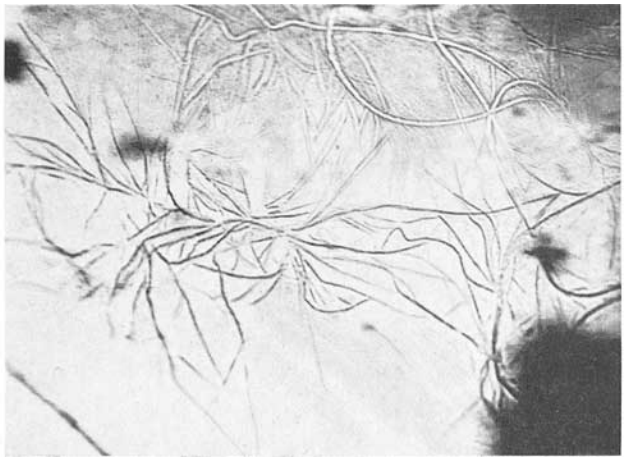

FIG. 13. *Unidentified inclusion in red spinel from Burma.* 120 ×.

to the geometric axis of the boule, and they indicate the areas of internal stress. The exsolution is caused by a heat-treatment, and the resulting separations (Fig. 14) are relatively coarse and somewhat irregularly distributed, but they follow the symmetry of the spinel crystal and, when properly cut, exhibit asterism. If, in a synthetic spinel, the excess of alumina is considerably increased, a particular kind of exsolution commences during the formation of the boule (Fig. 15), but the asterism caused by these flakes or little plates is very weak and not effective.

Synthetic spinel can be induced during its growth to develop long hoses of gas instead of round-shaped bubbles. The hoses include right angles, according to the cubic symmetry of the spinel. If a cabochon is cut from a boule containing these long gas hoses in a suitable manner, the hose-like inclusions act as " cylinders " and produce a four-rayed star. This experiment however has only academic interest.

Chrysoberyl cat's-eye. In literature, the chatoyancy of the chrysoberyl cat's-eye is always attributed to a multitude of microscopic channels, which are arranged parallel to the c-axis and which are said to be usually hollow. In opposition to this widely spread

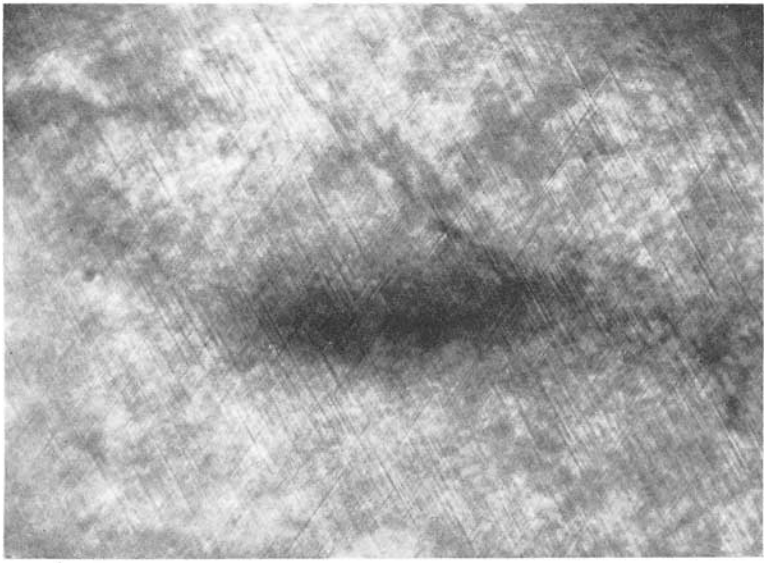

FIG. 14. *Orientated plates in a synthetic spinel.* 110 ×.

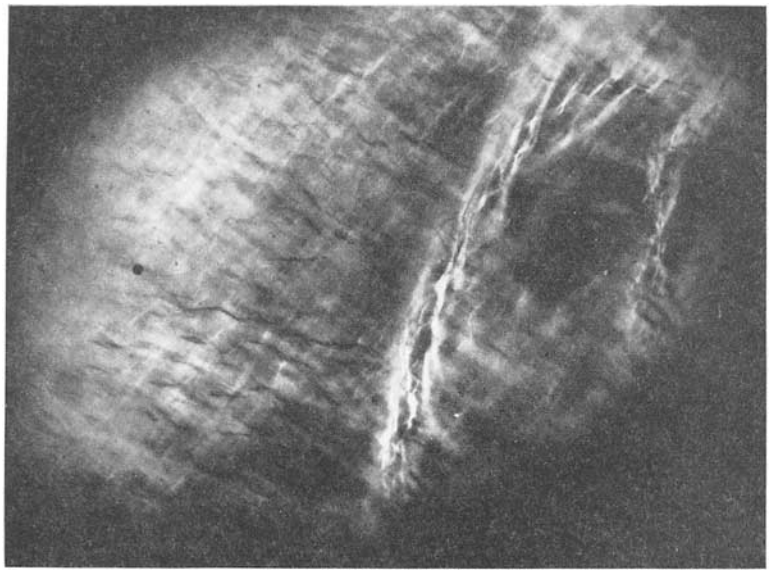

FIG. 15. *Orientated plates in a synthetic spinel with considerably increased excess of alumina.* 38 ×.

opinion, in a chrysoberyl from Ceylon with a fine and sharply developed cat's-eye effect (Fig. 16) a multitude of relatively short needles, all following the c-axis of the host crystal (Fig. 17) were observed. The needles had a higher refractive index than that of the chrysoberyl (mean value 1·748), and besides this, they were doubly refractive. These needles could not be recognized, nor could any evidence be found for their origin. Probably they may have been produced by a process of exsolution.

Quartz cat's-eye. This well known gem owes its chatoyancy to a multitude of fibres of the mineral asbestos or amianthus, which is a hornblende. The fibres are orientated parallel to the c-axis of the embedding quartz (Fig. 18). It is most probable that they are primary inclusions.

Tourmaline cat's-eye. As with chrysoberyl cat's-eye, the literature states also in the case of the tourmaline cat's-eye that its chatoyancy is caused by hollow channels, following the c-axis of the host crystal. Fig. 19 is from a good rose-coloured tourmaline with a strong line of reflection. The stone is supposed to come from California. The picture (E. Gübelin) was taken in reflected

FIG. 16.

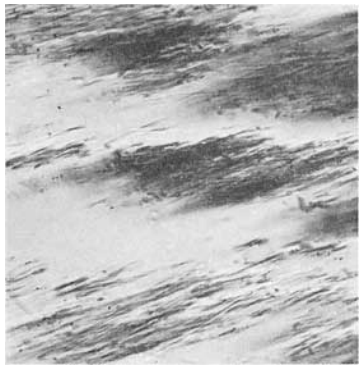

FIG. 17.

FIGS. 16 and 17. *Chrysoberyl cat's-eye with small needles (doubly refractive) parallel the c-axis.* 120 ×.

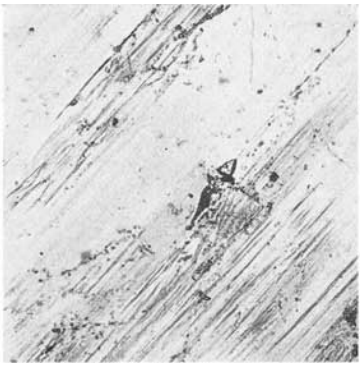

FIG. 18. *Quartz cat's-eye with orientated fibres of asbestos.* 120 ×.

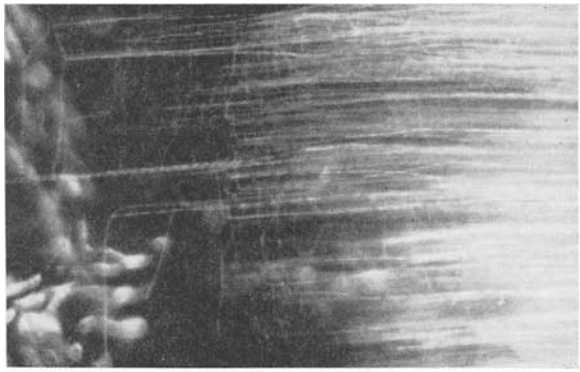

FIG. 19. *Rose-coloured tourmaline cat's-eye with crystal fibres (Photo : E. Gübelin).* 80 ×.

light. Apparently it confirms the ruling opinion that these inclusions are hollow channels, particularly with regard to the curved and twisted ends of these "channels." Some further photomicrographs of my own taken from the same stone in transmitted light (Figs. 20 and 21) reveal that these fibres are crystals. They have a brown colouring and are doubly refractive. The refractive index is greater than that of tourmaline (1·63 as a mean value).

The form of the fibres gives the impression of extremely elongated crystal fibres. Similar to the explanation given for the origin of curved rutile needles in rose quartz by von Vultée, it can be assumed that in this case also the fibres and the tourmaline originated simultaneously. Consequently, the fibres are primary inclusions of syngenetic or xenogenetic origin.

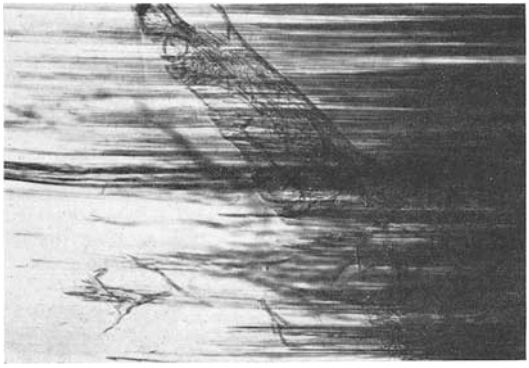

FIGS. 20 and 21.
Rose-coloured tourmaline cat's-eye with crystal fibres.

FIG. 20. 120 ×.

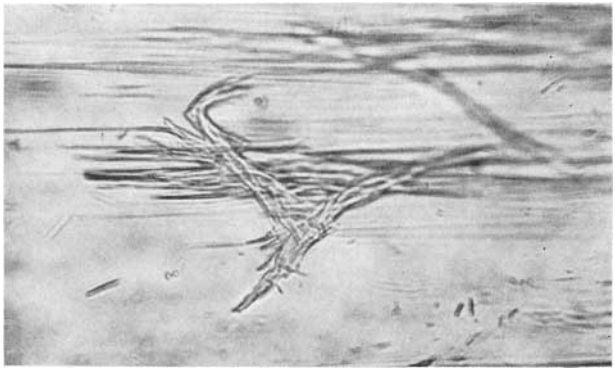

FIG. 21. 420 ×.

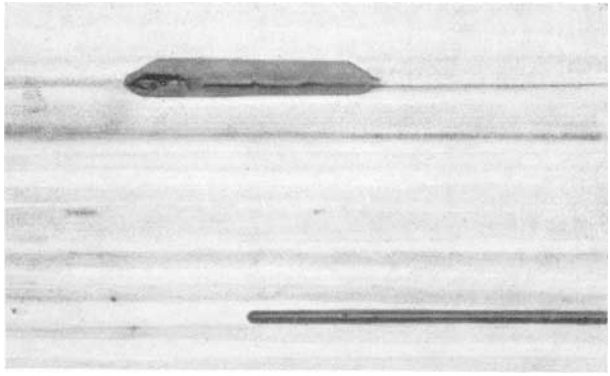

FIG. 22. *Scapolite with chatoyancy, Madagascar ; liquid-filled channels parallel c-axis and a patch of specular iron (on top).* 340 ×.

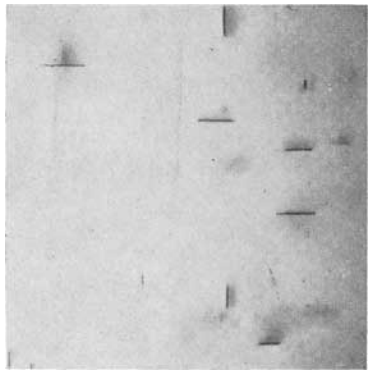

FIG. 23. *Scapolite with chatoyancy with newly-formed " blades," caused by exsolution* 240 ×.

Zircon cat's-eye. Zircon sometimes shows chatoyancy. This was first described by R. Brauns.[5] He found in a green zircon from Ceylon a great number of inclusions, which proved to be minute crystals, situated parallel to the c-axis of the zircon. The nature of the inclusions was not determined.

Scapolite. Recently some fine crystals of scapolite came from Madagascar to Europe. Their colour ranges from a dark to a bright grey and is not so brilliant as Brazilian stones. Some of them have a very fine cat's-eye effect, the cause of which is hollow channels, liquid-filled channels (Fig. 22), and long needles of doubly refractive crystals, all following the main- or the c-axis of the scapolite. Sometimes, patches of specular iron can be observed, which also follow the general orientation.

The spacing of the channels and the needles observed on the basal plane reveal their minute size in diameter. Besides this, straight lines (Fig. 23) on the basal plane indicate that another kind of inclusion in the form of blades follows the channels and needles in orientation.

Fig. 24 shows the blades sideways, that is perpendicular to the c-axis. It is certain that, besides the channels and the needles, these blades likewise influence the chatoyancy of the stone. They represent a wonderful example of exsolution, for which the scapolite seems to be predestinated by virtue of its chemical composition. Scapolite is an isomorphous mixture of the minerals marialite and meionite. Both minerals have a complicated chemical composition and as marialite contains sodium and meionite calcium, it may be supposed that the molecule of meionite with its contents of calcium undergoes exsolution more easily than its partner (Fig. 25).

Marialite : $2\ NaCl\ .\ 3\ Na_2O\ .\ 3\ Al_2O_3\ .\ 18\ SiO_2$

Meionite : $CaCO_3\ .\ 6\ CaO\ .\ 6\ Al_2O_3\ .\ 12\ SiO_2$ (sometimes with a certain content of SO_4)

	Marialite	*Meionite*
n_ω	1·539	1·596
n_ε	1·537	1·557
neg. D.R. ...	0·002	0·039

Tiger's-eye. Fig. 26 shows the reason for the chatoyancy of the tiger's-eye—long and slightly curved fibres of a hornblende asbestos. These are primary inclusions.

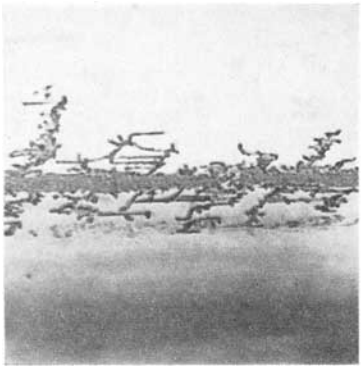

FIG. 24. *Blades in Fig. 23 shown perpendicularly to c-axis.*

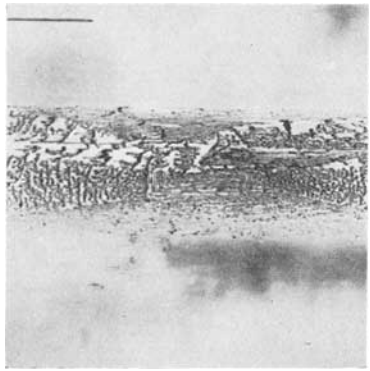

FIG. 25. *Scapolite with chatoyancy with newly-formed "blades," caused by exsolution.* 120 ×.

FIG. 26. *Tiger's-eye ; long and slightly curved fibres of hornblende asbestos.* 70 ×.

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3. E. J. Gübelin. *A Contribution to the Genealogy of Inclusions.* Journal of Gemmology, Vol. VI, No. 1, January, 1957, p. 44.

4. F. Rinne. *Morphologische und physikalisch-chemische Untersuchungen an synthetischen Spinellen usw.* Neues Jahrbuch für Mineralogie etc., BB LVIII, Abt. A, 43-108.

5. R. Brauns. *Lichtschein bei Granat, Zirkon und Saphir.* Neues Jahrbuch für Mineralogie, etc., 1907, Bd. 1, 13-20.

ACKNOWLEDGMENTS

The author is indebted to Dr. E. Gübelin, of Lucerne, for permission to publish the photograph of Fig. 19 in this issue of the Journal and Fig. 15 on p. 208 of Vol. VI, No. 5.

The two synthetic spinels illustrated on p. 200 of Vol. VI, No. 5, are the property of Dr. Gübelin, and it was he who produced the star-effect by scratching cylinder-like grooves on the back of the stones.

Gemmological Abstracts

GÜBELIN (E.). *Einschlusse in Diamanten.* Inclusions in diamonds. Gold und Silber, No. 11, pp. 27–30. 1957.

Inclusions generally recognized as diamond inclusions are carbon spots, feathers and cracks. The term " carbon spots " covers all inclusions of mineral in the diamond, and generally this could be graphite or haematite, magnetite or ilmenite or one of a number of colourless or coloured materials. Inclusions in diamonds, as in other stones, can be solid, liquid and gaseous. This article deals mainly with " carbon spots." Examinations have shown that many of the solid inclusions in diamonds were present as primary crystals in the magma. Apart from foreign minerals, diamond crystals are often found as inclusions in the diamond. Such an inclusion is usually of the rounded octahedral form, but twin crystals have also been found. The included diamonds vary in colour, but are usually darker than the mother crystal. Zircon must also be mentioned as an important inclusion of diamond. Diamonds which have solid inclusions have the tendency to break easily. This is especially so when zircon is the included material, as this has a higher heat expansion coefficient. When the diamond is warmed on the grinding wheel, this might cause the stone to break. South African diamonds often have garnet inclusions. Quartz is found in Brazilian, but never in South African, diamonds. The article ends with a short description of liquid and gaseous inclusions in diamonds, mentioning cracks and feathers.
7 illus. E.S.

PLATE (W.). *Der Diamant und seine Syntheses.* The diamond and its synthesis. Gold und Silber, No. 12, pp. 26–28. 1958.

Survey of the development of diamond synthesis. The diamond lattice is described and compared with the lattice of graphite. Early attempts at synthesis, i.e. Moissan, Parsons, G. Friedel and von Berthelot are mentioned and synthesis by the G.E.C. described.

E.S.

BÖLSCHE (R.). *Neues von Smaragdvorkommen im Habachtal.* News of the emerald finds in Habach valley. Zeitschr. d. deutsch. Gesellsch. f. Edelsteinkunde, No. 22, pp. 19–22. 1957/58.

The Habach valley in Austria has been known as a source of emerald since the Middle Ages. This is a short review. Apparently some crystals have been found recently, the largest weighing 180 cts. and being $4\frac{1}{2}$ cm. long; this stone should yield 8–10 emeralds of a total weight of 35cts.

E.S.

EPPLER. (W. F.). *Synthetischer Sternsaphir und synthetischer Sternrubin.* Synthetic star-sapphire and synthetic star-ruby. Zeitschr. d. deutsch. Gesellsch. f. Edelsteinkunde, No. 22, pp. 5–7. 1957/58.

In natural star-sapphires and rubies the star is formed by reflection of the light caused by very fine rutile needles, intersecting at 60°. When producing synthetic star-corundums, rutile needles have to be grown into the stone. The including of rutile needles is not very easy. Apart from the colouring materials, which are metallic oxides, TiO_2 is added to the boule. This forms a mixed crystal with the Al_2O_3 when heated, but later the rutile needles crystallize out again and are orientated in the same way as natural needles. This method was used separately in America (Linde Air Products) and in Germany, but various differences can be seen. In the American synthetic star-sapphire the needles are very long and thin, while the German rutile inclusions are shorter and thicker. Another difference is shown by the air bubbles, which are round in the American stone, and irregular, often triangular, in the German star-sapphire.
3 illus. E.S.

BAMBAUER (H. U.), BANK (H.). *Amblygonit und Brazilianit—Möglichkeiten ihrer Unterscheidung.* Amblygonite and brazilianite, possibilities of differentiation. Zeitschr. d. deutsch. Gesellsch. f. Edelsteinkunde, No. 22, pp. 8–10. 1957/58.

Refractive index seems to be similar for both stones (1·599-1·607, 1·619-1·632). The densities differ only very slightly (2·99 and 3·00). The authors suggest chemical analyses and radiography for differentiating between rough stones. In the case of cut stones

the relation between refractive index, density and the optic axial angle have to be examined.
1 diagram. E.S.

RÖRIG (H.). *Lapis-lazuli und ultramarin.* Lapis-lazuli and ultramarine blue. Zeitschr. d. deutsch. Gesellsch. f. Edelsteinkunde, No. 22, pp. 10–16. 1957/58.

Historical survey of the use of the colour and of lapis-lazuli. E.S.

DYER (H. B.) *Artificial coloration of diamond.* Gemmologist, Vol. XXVI, No. 316, pp. 193–199. November, 1957.

The assessment of colour by the eye and its limitations are discussed. The operation and function of a spectrophotometer are simply explained. Diamond is essentially colourless and any colour is due either to the presence of minute amounts of foreign atoms or to a local disarray of the carbon atoms. Artificial coloration is said to be due to the latter cause. Diamonds may be artificially coloured by bombarding them with suitable high-energy particles. The types of such particles, their characteristics and how they may be accelerated are discussed. The mechanism of colouring diamond by irradiation is explained by reference to the blueing of diamond by electron bombardment. A " blued " diamond shows a complicated system of absorption lines in the orange-red region of the visible spectrum. (Note—this is shown only by a photospectrometer and is not visible in an ordinary hand spectroscope.) A simple ultra-violet device is said to have been produced to enable distinction to be made between natural blue diamonds and those artificially coloured, but no details are given. A very full explanation of the irradiation process which alters the colour of diamonds is given. About one-tenth of the incident high-energy electrons make effective elastic collisions with carbon atoms transferring just sufficient energy to eject them from normal positions to interstitial positions leaving a vacant site behind. It is believed that the four atoms surrounding each vacant site give rise to the absorption. The effect of subsequent heating is explained, as are also the processes in the case of neutron bombarded diamonds. The cause of the colour in natural blue diamonds is discussed. A trace of manganese is said to be the cause of the colour of pink diamonds.
10 illus. R.W.

SINKANKAS (J.). *Recent gem mining at Pala, San Diego Co., California.* Gems and Gemology, Vol. IX, No. 3, pp. 80–87 and 95. Fall, 1957.

The history, geography and geology of the Pala district is given. A number of the mines are individually considered. In the Katerina mine much spodumene is found in association with pale straw-yellow quartz. Spodumene in the variety kunzite and crystals with a definitely bluish shade, as well as material of a peculiar greenish colour resembling aquamarine, are found in the Vanderberg mine. Kunzite from Pala fades on exposure to sunlight. The future prospects of the Pala group of mines are forecast.

4 illus. R.W.

SINKANKAS (J.). *" Green " amethyst from Four Peaks, Arizona.* Gems and Gemology, Vol. IX, No. 3, pp. 89–95. Fall, 1957.

Reports of a source of amethyst which, like the material from Montezuma, Brazil, turns to a green colour on heating. The " greening " of the amethyst from Four Peaks was an accidental discovery. A store of amethyst rough was burnt down and the crystals were then found to have assumed a green colour. Some notes on the geology and geography of the area are given. The amethyst deposits are crystal-lined geodes and the crystals have a habit similar to those found at Thunder Bay, Lake Superior. The distribution of colour and the twinning of the crystals are discussed. Heating experiments, by D. B. Stewart, are fully recorded.

2 illus. R.W.

GÜBELIN (E. J.). *The phase contrast method.* Gems and Gemology, Vol. IX, No. 3, pp. 67–79. Fall, 1957.

An article on phase contrast microscopy similar to that published in the Journ. Gemmology, Vol. VI, No. 4.

14 illus. R.W.

WEBSTER (R.). *The detection of cultured pearls.* Gemmologist, Vol. XXVI, Nos. 315 and 316, pp. 178–184 ; 200–207. October/November, 1957.

A comprehensive survey of the history and methods used in detecting cultured pearls. The use of density methods, the principles of the lucidoscope, pearl compass and the pearl microscope

are discussed and illustrated. The endoscope, its use and limitations are described, as are the spot diffraction X-ray method, direct method and fluorescence of pearls under X-rays.
16 illus. P.B.

WEBSTER (R.). *Imitation pearls.* Gemmologist, Vol. XXVI, No. 317, pp. 213–217. December, 1957.

Imitation pearls were first produced by Jonquin of Paris, who noticed the lustrous nature of fish scales and used them in making a pearl essence. The preparation of the hollow glass bead type of imitation pearl is explained. The nature of the fish scales and the modern methods for their production are discussed. The solid glass bead type of imitation pearl is also explained. A special type of glass is usually used for making the beads, but plastics, mother-of-pearl and vegetable ivory have been used.
2 illus. P.B.

WEBSTER (R.). *Coral, shell and operculum.* Gemmologist, Vol. XXVI, No. 318, pp. 7–15, January, 1958.

The coral polyp is described and the method of growth of the calcareous framework which supplies the precious coral explained. The locations of the fisheries, the methods of fishing and the varieties of coral are mentioned. The fishing and the use of mother-of-pearl from the pearl oyster and from the haliotidae are discussed. The Helmet shell and the Queen conch are used for cutting cameos. The thick columns of the Top Shells are used for beads and the dividing septa of the pearly nautilus provide a mother-of-pearl suitable for inlay, while the central whorl of the same shell gives the so-called *coque de perle.*
9 illus. P.B.

BARTA (C.). *Why synthetic corundum boules split.* Gemmologist, Vol. XXVI, No. 317, pp. 219–224. December, 1957.

Natural corundum is the alpha modification of alumina produced by complex metamorphism of rock masses. The history of the early experiments in the synthesizing of ruby is told. The estimated production of synthetic corundum in 1952 is said to be about 550 million carats. The splitting of corundum boules, which is not connected with the parting of corundum, occurs with boules over 4 mm. in diameter. The causes of the splitting can be

influenced at certain stages, i.e. during production processes, following production (by removing internal stresses), and during mechanical machining. Discussions of these factors and the formation of rhombohedral cracking are given.
6 illus. R.W.

CORRECTION. In the abstract Coleman (R. G.). *Jadeite from San Benito Co., California.* (Journ. Gemmology, Vol. VI, No. 2, p. 92, 1957), the density should have been given as 3·43 and not 3·34 as printed.

BOOK REVIEW

PARSONS (C. J.) : SOUKUP (E. J.). *Gem Materials Data Book*, Gems and Minerals, Mentone, California, 1957. 36 pages.

This work endeavours to provide all the pertinent data needed by the gemmologist for the identification of gem materials.

The contents consist of an introduction and a master data-list of some 450 entries, followed by a number of gem identification talbes and a list of the false names applied to gems.

In their introduction the authors state that the data have been compiled from all reliable sources and from their own observations. It is further stated that these gem tables mark the first time an attempt has been made to compile all the pertinent information covering gem characteristics into one comprehensive body of data. This may be true for North America but it is certainly not so for Europe, for similarly designed tables, comprehensive at the time of their publication, have been known since 1937. Indeed the " pocket book " by Sir James Walton published in 1954 has also been translated and published in the German language.

Certain data have been omitted from the tables for one of the following reasons: (1) not available, and (2) of no interest to gemmology. In view of this it seems strange that there is only one reference to absorption spectra, but on the other hand measurements are given in a number of cases of the angular size of 2V, a constant which is difficult to measure, and which in the majority of cases is of far less value in gem distinction than absorption spectra.

The excellent main table, which by the use of a code of abbreviations, lists the colours, transparency, lustre, refractive index, birefringence, crystal system, optical characters and sign, dispersion, pleochroism, specific gravity, hardness, cleavage, fracture, characteristic inclusions, habit, and any special tests, is most complete. The purist may well question the right of some of the mineral species listed to be gemstones, but as some collectors cut anything, however unsuitable, as gems, the authors no doubt felt their inclusion justified.

The refractive index and density values appear to have been culled mostly from data published in mineralogical textbooks. Such values, while fairly satisfactory in most cases, are not wholly reliable when values for the *varieties* of gem materials are needed. This is exemplified in the case of the entry for beryl, where the values of refractive indices as given are not common to all varieties. Further, the higher values mentioned for aquamarine are much more commonly encountered in the pink and white beryls. Similarly, the green corundum often has higher indices of refraction than the other colour-varieties of sapphire.

The reference to synthetic corundum having an absorption spectrum with wider absorption bands than the natural stone is unhelpful for, apart from any consideration of the validity of the assertion, it is not stated what these absorption bands are or in what varieties they may be present. There are some minor inaccuracies.

The *Gem Materials Data Book* is a valuable contribution which has the advantage of carrying information on the more unusual types of gem materials. The book has a bright-yellow stiff paper cover and is rather large in size (12 by 9 inches). Opening like a reporter's note-book, it is more suitable for desk use and is not a pocket volume like the earlier English books of similar type.

R.W.

THE DESIGN AND CONSTRUCTION OF A GEMMOLOGICAL SPECTROSCOPE

By L. C. TRUMPER, B.Sc., F.G.A.

General and Introductory

The gemmologist's enthusiasm is continually being re-kindled not only by the arrival of some new species or variety, but also by some hitherto unsuspected property or reaction. The study of the absorption spectra of gemstones—pioneered by Anderson and Payne in this country—is full of interest and excitement as well as being a valuable method of distinguishing various species, and the recognition of its importance in discriminative gemmology is now beginning to spread in the U.S.A. also. It has, however, appeared to me that the equipment available to meet the gemmologist's requirements in this field falls far short of what is needed and that suitable equipment ought to be specially designed to meet the growing demands of those engaged in this interesting branch of gemmology.

Present Practice

In his *Gem Testing*,[1] and more recently in *The Gemmologist*,[2] Anderson has rightly pointed out that an enormous amount can be done with the simplest of spectroscopes and the minimum of illumination. He has also shown how a more advanced instrument with more powerful illumination will bring still greater rewards.

Anderson has advocated the use of a 500 watt projection lamp (alternatively a 250 watt or 300 watt lamp) inside an asbestos-lined plywood box, with suitably arranged ventilation louvres permitting ample ventilation but arranged to trap the unwanted light. He has pointed out that projection lamps and suitable holders or adaptors can be obtained from any good photographic establishment—standard fittings with E.S. holders being available to fit or for the conversion of optical lanterns. He has explained in detail how the microscope may be used to collect the powerful beam of light on the substage mirror and thus direct it through the microscope condenser—the gemstone being held either in some form of tongs just above it or face down on a microscope slide. A low-power objective collects the resultant transmitted light after passing through the stone under observation, and, the micro-

scope eye-piece having been removed, the spectroscope is held in the hand just above the tube thus flooded with light.

An alternative method has been described by D. J. Ewing.[3] He uses a car head-lamp in the base of a large cocoa tin, fitted with a diaphragm containing a condensing lens above the lamp ; the light is thus directed on to a small hole in the top of the lid of the tin, upon which is placed the gemstone to be examined. The spectroscope is again held in the hand with the slit about an inch above the stone.

An entirely different procedure, devised by R. Keith Mitchell,[4] makes use of reflected light. The spectroscope is placed in the cradle of a small stand at an angle of 45°, the slit directed at a small turntable with a matt black surface upon which the gemstone is placed table facet downwards. The turntable enables the stone to be rotated in the beam of light which is directed downwards through the stone on to the table facet and internally reflected up to the slit of the spectroscope. This method is useful with pale stones, as the path of the light through the stone is doubled, but it is a difficult technique to master in practice, and frankly I admit that I have had very little success with it.

In 1951, E. Gübelin[5] exhibited at the Gemmological Association's Exhibition in London the only spectroscope hitherto constructed solely for the gemmologist. A very compact instrument, it had built-in illumination, an illuminated wavelength-scale, tongs for holding the stone and other refinements. The cost at the time was understood to be in the region of £85 and this high cost has doubtless discouraged its commercial production.*

Some Improvements

Like many other gemmologists, I had hitherto followed Anderson's suggestions, using the lamp house and condenser of a " Russian Iron " Optical (or magic) Lantern fitted with a 250 watt projection lamp with Edison screw holder as the source of illumination and my Watson microscope to condense the light further on to the stage, racking up the microscope tube with the eye-piece removed and holding the spectroscope above it. I did, however, achieve two improvements. Firstly, the fitting of a mechanical stage greatly facilitates the movement to and fro and up

* In 1953 E. Gübelin improved his spectroscope by adding a polaroid filter and a diaphragm to exclude supplementary light. The instrument now has a prism system which enables an undisturbed spectrum from the light source to be compared with the spectrum under test. A monochromator aids measurement of position of absorption lines.—*Editor.*

and down of the stone under observation, and, secondly, I designed[6] a simple holder† for the spectroscope, which could be inserted into the top of the microscope tube and could thus not only hold the spectroscope steady, but also leave both hands free for adjustments.

In considering what improvements to gemmological spectroscopic equipment could be carried out I realized that one source of inconvenience was the continual " one-eyed " viewing. Having an admirable binocular prismatic microscope at a reasonable price, why not a binocular spectroscope ? I decided to put this latter problem to the test by borrowing an identical spectroscope and, by a system of iron stands and clamps, synchronizing both spectroscopes on to a gemstone. This proved my point, namely, that it was three times as restful to look with both eyes at rest at a spectrum, and that much easier to see a faint line, instead of half the time imagining one and probably seeing one in a different place each time one looked.

Obviously synchronizing a pair of spectroscopes was not a very practical way of setting about it, but as a result, I submitted to a firm of instrument makers the following suggested design, making use of a single wavelength spectroscope and a half silvered prism to divide the light between the two eyes. In this way there is no loss of light and comfort can be achieved. I argued that, given greater comfort, one could obviously get more accurate results and more pleasure out of spectroscopic examinations. It remains to be seen whether an adaptor is made to secure binocular viewing. I can see no reason why it should not and no reason why it could not be arranged as an extra to fit any type of spectroscope that may be designed.

Further Improvements Desired

The next point considered was the need for a direct-viewing prism spectroscope with a really accurate wavelength scale. The Beck instrument No. 2522, good as it is, has its limitations. My own experience is that it can be adjusted to be sufficiently accurate between say 4300Å and 6000Å, but above that the accuracy falls off rapidly. I can see no reason why with a little modification of the design the same type of instrument could not be made both more accurate and more reliable. I am quite sure that there is a large potential demand among gemmologists throughout the world for such an instrument.

† Now marketed by R. & J. Beck Ltd.

That there is a demand for a lighting unit suitable for spectroscopy appears to have been recognized and it is understood that work on the design of such a unit is proceeding. The desirability of incorporating a blue filter equivalent to that provided by a concentrated solution of copper sulphate needs little emphasis nor does the desirability of eliminating if possible the immense amount of heat produced by the powerful light-source.

In any design, the aim should be for the examination to be conducted sitting down comfortably at a bench or table, at normal table height, with the eyepiece of the instrument (or the optical centre of the instrument) inclined at an angle of approximately 60°.

To the above suggestions might be added provision for inserting a series of colour filters for the selection of different parts of the spectrum and provision for the illuminant to be transmitted through or on to the specimen.

One last suggestion considered was the desirability of drawing out the red end of the spectrum to try and emulate the even distribution of the grating spectroscope.

The Projected Design

My object was to build a table model with inclined viewing, complete as a unit and ready to switch on instantly, incorporating the source of illumination, wavelength spectroscope, illumination for the wavelength scale, interchangeable spectrum filters, provision for holding the stone and a heat resisting filter. Having had something of the sort in my mind for a long time, I had been gradually collecting the components together and with most of them to hand, made a start on the construction. The first essential was to plan and construct the body of the instrument to the minimum possible dimensions. To do this it was first of all necessary to know the focal lengths of the condensing lenses upon which the basic measurements throughout depended. Having by me an old lantern, I decided to make use of the condenser, the lenses of which were about 10 cm in diameter.

Using a small electric lamp as a source of light and a scale set alongside to make a crude " Optical Bench," I measured the focal lengths of the lenses separately and together using a ground glass screen (a piece of white card does just as well) to receive the image. One lens had a focal length of approximately 9·5 cm and the other of 13·5 cm.

Construction of the Gem Spectroscope

Upon this basis the box to form the body was constructed, but alas, although I had the 250 watt projector lamp by me, I had taken a chance on the height of the E.S. adaptor and when this arrived found that I had not allowed enough height. I felt, however, that I had by this time got too far with the rest, so decided to get over the problem by using an E.S. batten holder instead of the adaptor, which was adjustable for height, focus and laterally, to insert this " through " the base to gain head room (i.e. to lower the height of the filament) and to rely on accurate measurements to get the focus correct from the start, taking up any adjustment in the final positioning of the condenser. I did, however, make some slight provision for raising or lowering the filament and, most important in case of a replacement of the projector lamp, provision for rotating the holder so as to orientate correctly the filament and mirror which is integral with the lamp.

The Heat Absorbing Filter

The next item to consider was a heat-absorbing filter not only to prevent the uncomfortable heat, but also to avoid damage to the specimen and, equally important, damage to any filters being used. There is, however, the added point that the lower the temperature of the specimen the denser the absorption lines become. One filter tried had to be rejected as it failed to transmit the blue and violet part of the spectrum, but the ON20 filter made by Chance Brothers Limited proved satisfactory. Chance Brothers Limited claim[7] that it is the most efficient heat absorbing filter obtainable, the infra-red being almost completely absorbed, and the small percentage of heat transmitted coming entirely from the visible radiation.

ON20 is nearly colourless and, therefore, does not affect colour values. This point I have checked by examination with the spectroscope. No apparent absorption takes place beyond a very slight reduction in the intensity of the light. Chance Brothers point out that a theoretically perfect filter would still transmit 7 per cent of the heat energy falling on it. ON20 comes close to the ideal in that it transmits 9·5 per cent for a 3 mm thick filter and at this optimum thickness it transmits 84 per cent of the light. They point out that the best position for the filter is between

the lamp and the condenser, it being important that a free flow of air can pass both surfaces.

As the filter absorbs the heat it naturally becomes very hot and for this reason the mount should be loose and even illumination of the whole area of the filter is important. Round filters are preferable to square ones, and large filters with very powerful sources should be cut into strips. The makers add that a 2″ disc can be mounted with reasonable safety within 3″ of the filament of a 1,000 watt lamp. Finally they issue a warning that the special glass used in its manufacture is sensitive to attack by moisture and should be kept in a dry place and preferably unwrapped.

Spectrum-Isolating Filters

I next turned my attention to the provision of a set of filters to isolate different parts of the spectrum and came to the conclusion that the position first selected, that is, between the condenser and the Abbé condenser, was undesirable in that it would be subjecting the filters to the almost unrestricted and concentrated output of the lamp as far as the light was concerned as well as the residual heat not absorbed by the ON20 filter. I, therefore, re-designed the unit, arranging for a disc consisting of eight filters and one blank to be rotated in the beam of light after passing through the specimen and the microscope objective and before it reached the slit of the spectroscope. Before adopting this procedure, I tested the result of inserting colour filters between the spectrum and the objective and between the eyepiece of the spectroscope and the eye. As had been anticipated the actual position made no difference to the results reaching the eye.

Ilford Limited of Ilford, Essex, manufacture two sets of spectrum filters for purposes just such as this and I decided to use the " Bright Spectrum Series," though for reasons which will become evident later it would be quite easy to have a second disc of the much deeper and narrower series.

The Spectrum Filter Disc

The disc of spectrum filters was constructed by cutting out three circles simultaneously, two of them in $\frac{1}{4}$″ plywood and one in $\frac{1}{16}$″ plywood. Holes $\frac{7}{8}$″ in diameter were then cut, accurately spaced, again simultaneously in all three circles ; the holes in the $\frac{1}{16}$″ circle, subsequently being enlarged to just over 1″ diameter. This circle acts as a spacer between the other two. The $\frac{1}{16}$″

thick circle was then carefully placed over one of the others and the spectrum filters, carefully cut to size, were then sealed between two microscope cover slips with Canada Balsam. When all had set, the top circle was screwed on, the whole painted matt black and the filter numbers then punched in, using a template to ensure accuracy. Finally, the edges of the filter disc were milled and each sector opposite a filter was painted with the corresponding filter colour for rapid identification.

The Pre-filter Section

Gemmologists will be familiar with the advantages of filtering the light from the projector lamp with a blue filter so as to eliminate from the gemstone under examination all traces of orange and red light.

Under these conditions, the fluorescent lines in ruby, spinel[8] and certain other more rare examples stand out in brilliant red against an otherwise dark background in that portion of the spectrum. The fluorescence is induced by the blue light transmitted. The method usually adopted is to make up a chemical flask of copper sulphate solution, using this to filter and concentrate the light. Copper cuts out every trace of red and infra-red light.

It was clearly desirable to use a more permanent and compact method in the gem spectroscope. Unfortunately, the vast number of aniline dye filters all pass the infra-red and nearly all pass a proportion of light in the far red. I was, however, able to obtain a small quantity of a special celluloid filter, the transmission and absorption of which were equivalent to a two-inch thickness of copper sulphate solution.

The pre-filter section of the gem spectroscope is fitted with guides each side $2\frac{1}{4}''$ apart. The pre-filter unit is constructed as a self-contained piece of equipment which slides between these guides into the spectroscope, accurately locating the filters carried by it.

The unit consists of a container $2\frac{1}{8}'' \times 4\frac{1}{16}'' \times$ approximately $7''$ high. Internally it is divided by a set of guides into three sections. In each section a slide or filter carrier is arranged so that the pre-filters lie below the beam from the projector lamp and openings in the slide-carriers and container allow the beam to pass through unimpeded. The filters, each 5·8 cm wide and 4·2 cm high, can be brought into position, in the path of the beam

SPECTROSCOPE SYSTEM AND ELECTRICAL LAYOUT

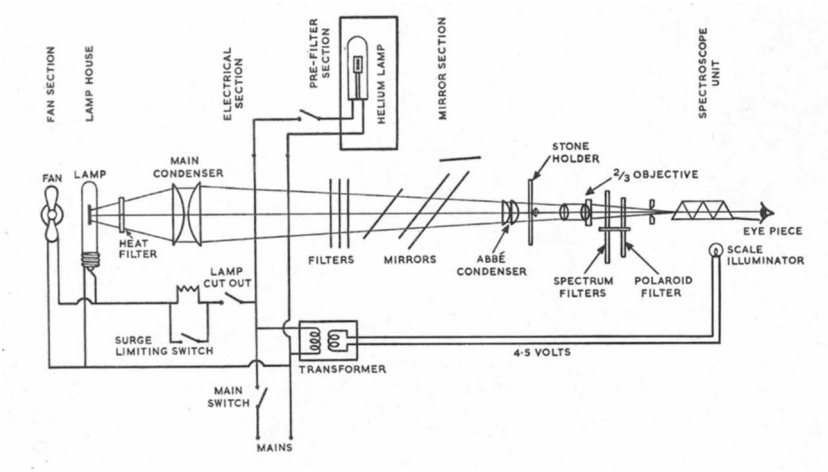

of light, by lifting with the knob provided through a distance of 4·6 cm. In this position all extraneous light is masked by the filter carrier and container and only filtered light reaches the gemstone and spectroscope. The pre-filter unit is fitted with two blue filters, each the equivalent of 2″ of copper sulphate solution and cutting out all transmission above 5,600Å, and the third carrier has been fitted with a yellow filter which cuts out all transmission below 5,000Å. One, two or all three filters can be in use at a time. A blank is available to slide into the pre-filter section grooves when the pre-filters are not required, though the pre-filter unit can remain in position as it does not impede the beam of light.

A further means of distinguishing rapidly between ruby and pyrope garnet is provided by bringing all three filters into position and the spectrum filter 625, when light in the green between 5,200Å and 5,400Å only is transmitted. With pyrope there will be some transmission, with ruby practically none at all. Alternatively, with the pre-filters in operation only, with ruby the green transmission some 200Å in width is to the left of the transmitted band

and with pyrope to the right (this is with the violet end of the spectrum to the left as in the Beck instrument). If a known specimen is placed in the adjoining hole in the stone holder disc and the disc moved quickly from one stone to the other, the difference if any is at once apparent, as the narrow band of visible light jumps from left to right.

The Periscope Attachment

Having built in the prism spectroscope to receive light, either transmitted or indirect, from the projector lamp alone and from a point immediately over the Abbé condenser only, it became necessary to devise a means whereby light from an entirely outside source, whether Fraunhofer lines, mercury vapour, sodium light, etc., could be examined without dismantling or disturbing any part of the gem spectroscope.

This was readily achieved by designing and constructing a simple periscope attachment, to the same general dimensions as the pre-filter unit and which could be inserted into the pre-filter section in its place. The mirrors are so placed that light grazing the top of the spectroscope is directed to the Abbé condenser by way of the deflexion mirror. A further mirror hinged to a base board which can be placed on the top of the spectroscope unit in front of the top periscope mirror can be arranged to collect light from any position and pass it to the periscope.

Examination in Polarized Light

It is well known that in many doubly refracting stones the spectrum of the ordinary ray differs substantially from that of the extraordinary ray, though for most practical purposes the combined spectrum of the two is sufficient. It was nevertheless decided to incorporate a polaroid filter in the unit, so that the light could be polarized before reaching the slit of the spectroscope.

This was done by sealing a 4″ disc of polaroid between two $\frac{1}{16}$″ thick circular discs of perspex, cementing them all together with Durofix. The disc is pivoted at the centre and placed immediately above the disc of spectrum filters.

So that the polaroid disc can be put out of action when not required a hole $\frac{7}{8}$″ diameter in line with the blank on the spectrum filter disc was cut out of it and a peg normally holds it stationary in this position. A small rectangular hole was also cut out to expose the spectrum filter numbers beneath. Irrespective of the

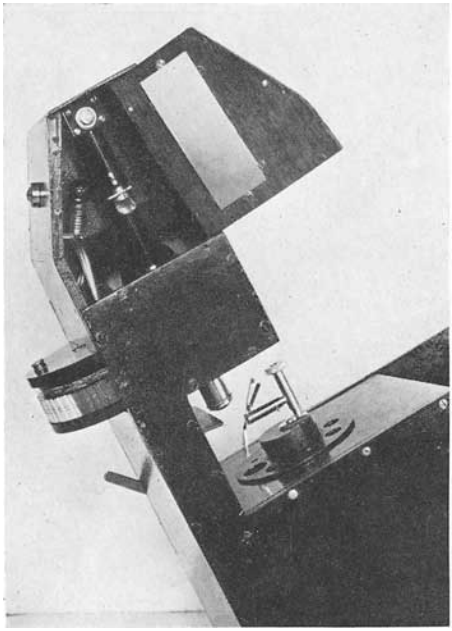

Head of spectroscope housing filter, polaroid discs, deflecting mirrors, ⅔″ objective, stone-holder, disc of stops and spectroscope.

orientation of the gemstone under observation, rotation of the polaroid disc will bring first one ray and then the other into action when suitably rotated. The spectrum filters can be used simultaneously if so desired.

The Projector Lamp

In a leaflet accompanying their Osram Projector Lamps, the General Electric Co. Ltd.[9] point out that the filament, which is accurately located, operates at a very high temperature. The voltage applied to the lamp should not exceed that marked on the lamp, as for each 1 per cent rise in voltage the life of the lamp is reduced by 12 per cent. Most important of all, the lamp must be positioned as directed and for most lamps this position is vertical with the cap down. Cooling may be either forced or by convection, but an unobstructed flow of air past the lamp is essential. The equipment should be moved as little as possible particularly when the lamp is alight.

Surge-Limiting Resistor

A heavy surge takes place when a lamp is switched on and protection for the lamp against this heavy surge can be secured by a surge-limiting resistor connected in series with the lamp. The resistor can be short-circuited within a few seconds of switching on.

A resistor limiting the starting current to about three times the normal running current may be calculated from the formula

$$R = \frac{V^2}{3W}$$

where R = Resistance of the resistor in ohms
V = Voltage of lamp (i.e. of the supply)
W = The projector lamp voltage.

Thus for 230 volts and 250 watts a resistor of 70 ohms would be required and for 250 volts and 250 watts, of 82 ohms ; a 230 volt 500 watt lamp would need a surge limiting resistor of 35 ohms.

It was subsequently confirmed experimentally that a suitable surge limiting resistor for 230 volts, 250 watts was a 110 volts, 100 watt lamp.

The Blower or Cooling Unit

The lamp-house had been very carefully lined inside with asbestos of appreciable thickness—about $\frac{3}{8}''$. The asbestos not only surrounded the projector lamp but also extended forward to cover the main $3\frac{1}{2}''$ condenser and also the surge limiting resistor. Asbestos may be fire-proof—being a mineral substance—but experience has shown that it is a poor insulator against heat and in spite of the provision of twelve half-inch holes in the base and nine above the lamp with complete freedom of air-circulation, it was found that the outer casing soon became very hot, scorching the polish.

The fitting of a blower was thus considered a necessity if the spectroscope was going to be run for more than a few minutes at a time, as well as a further insurance against the premature breakdown of the projector lamp.

A blower was accordingly obtained from " The Educational Foundation for Visual Aids "[10] and the model suitable for up to 300 Watt projector bulbs was found to be ideal for the purpose. It would undoubtedly be quite suitable for 500 watt projector bulbs. It is supplied complete with a simple chassis, nuts and screws and a set of four small rubber buffers.

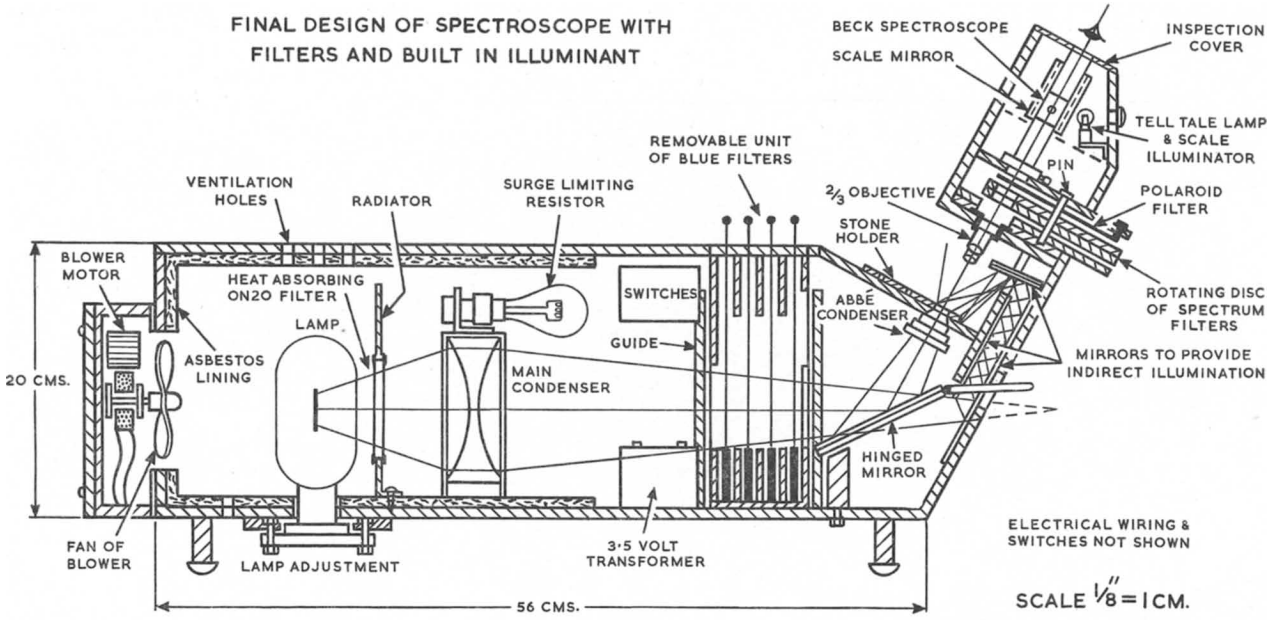
FINAL DESIGN OF SPECTROSCOPE WITH
FILTERS AND BUILT IN ILLUMINANT
BECK SPECTROSCOPE
SCALE MIRROR
INSPECTION COVER
TELL TALE LAMP & SCALE ILLUMINATOR
PIN
POLAROID FILTER
REMOVABLE UNIT OF BLUE FILTERS
VENTILATION HOLES
RADIATOR
SURGE LIMITING RESISTOR
2/3 OBJECTIVE
STONE HOLDER
BLOWER MOTOR
HEAT ABSORBING ON20 FILTER
SWITCHES
ABBÉ CONDENSER
ROTATING DISC OF SPECTRUM FILTERS
LAMP
GUIDE
ASBESTOS LINING
MAIN CONDENSER
MIRRORS TO PROVIDE INDIRECT ILLUMINATION
20 CMS.
HINGED MIRROR
FAN OF BLOWER
LAMP ADJUSTMENT
3·5 VOLT TRANSFORMER
ELECTRICAL WIRING & SWITCHES NOT SHOWN
56 CMS.
SCALE 1/8" = 1 CM.

SECTION

A further piece of good fortune was that the blower was a perfect match in size for the unit as already constructed. Some consideration was given to the best place to fit it—the possible alternatives being at the end, on either side or even on the top. The best position would have been underneath, but this was ruled out as it would have entailed raising the whole unit by another $1\frac{1}{2}''$. The remaining logical position was as low down as possible at the front end, so that the air introduced could circulate around the base of the lamp and then upwards, as well as blowing at and through the radiator cooling the heat-absorbing filter. This was decided upon, the end of the unit removed without disturbing anything else and a 10 cm diameter hole was cut with a fretsaw through both $\frac{1}{4}''$ plywood and $\frac{3}{8}''$ asbestos sheet. It was then arranged that the blades of the fan of the blower unit should operate exactly within this hole to secure the maximum introduction of air into the unit.

To carry the blower, a framing was constructed around the hole, the sides of which were provided with louvres, the base being left open, but the top covered. An end cover was then constructed and the motor was attached to this cover on a frame so that it was accurately aligned with the hole in the end of the spectroscope unit. To mount the motor, the portions carrying special mounting slots in the chassis were cut off with a hacksaw, and these two metal plates were accurately screwed to the framing, taking care to see that there was clearance for the inside bearing of the fan between it and the end cover. The small rubber buffers were inserted in the slots and the screws on the motor then inserted through the holes and bolted finger tight. This provides the necessary resilience and freedom from noise and vibration.

The assembly completed, the wires of the motor were then connected in parallel with the projector lamp. This has the added advantage, that in addition to coming on and off with the projector lamp, which is of paramount importance to prevent too rapid cooling, it also runs at half speed when the resistor is in circuit and automatically runs at full speed when the projector lamp is fully on and the resistor cut out. The final result is admirable, there is a most excellent circulation of air, indeed air is blown out of every ventilating hole at considerable pressure and also finds its way throughout the unit, freely emerging out of the mirror opening above the stone holder and objective.

It is also quite quiet in operation, vibrationless, and does not distract from any observations being made.

Provision for Indirect Illumination

It will also be apparent from the design adopted, that by means of the system of mirrors built into the spectroscope section of the body, the light beam could be cut off from the Abbé condenser, by swinging the mirror upwards by pulling a short lever projecting through the back of the instrument, and thus allowing the converging beam of light to pass on to the back mirror and by repeated reflections to pass up the body, emerging through the aperture above the table by being reflected again down on to the table below the objective ; thus providing indirect lighting for the observation of opaque specimens, and for the observation of the fluorescent lines in ruby and red spinel. The correct angle for the top mirror is important ; luckily I got it right the first time, and on test was delighted to observe the strong rectangle of light on the table on pulling the lever.

Absolute accuracy of the position of the hinges of the mirror deflecting the convergent beam of light from the condenser to the Abbé condenser is essential so that the correct angle and position is taken up by the mirror when at rest. The underside of the Abbé condenser must be above the horizontal optical centre by an amount exceeding half the beam width at that point, plus the overall thickness of the mirror. The hinge must be accurately sited in the same plane as the mirror when at the correct angle of reflection, which is 30° for the comfortable viewing inclination of 60° from the horizontal. An adjustable stop was fitted in the base of the unit to ensure final accuracy of the angle of reflection.

Similarly correct alignment of Abbé condenser, objective, spectroscope and filter mount is vital. This gave some trouble to begin with, leading to a masking of part of the spectrum band. By trial and error, however, this was overcome and the use of a $\frac{2}{3}''$ objective was found to give the brightest spectrum. The distance of 4·3 cm between Abbé condenser and $\frac{2}{3}''$ objective and of 5·5 cm from objective mount (8·5 cm from objective lens) and slit of spectroscope have been shown experimentally to be sound and practical.

The use of a 4″ condenser close to the projector lamp increased by about thirteen times the illumination over normal procedure of using the sub-stage mirror of a microscope.

The Electrical Section

A bell transformer giving an output of 4, 6 or 8 volts was wired to the switch, in parallel with the projector lamp and the output led by a twin wire up the body of the stand to illuminate the scale of the spectroscope and the tell-tale light at the rear of the unit.

The 4·5 volt miniature bulb being at the rear of the spectroscope and about half way down the body, a strip mirror was fitted to the inspection cover at the right hand side of the upper part of the body. A small mirror of tinfoil had already been attached to the short tube carrying the wavelength scale set at an angle of 45° and by trial and error this was soon positioned to pick up the reflected light from about the miniature bulb and at a total light distance of about 4″ the degree of illumination was found to be just about that required. Most of the wiring is carried out within the body of the instrument. Where it became necessary to go outside, this was done beneath the base and the exposed wires covered by a conduit screwed to the underside of the base for protection. An additional 2 amp. switch plug has been fitted inside the unit for the purpose of providing a 230 volt supply for subsidiary equipment, including a helium, neon or argon lamp for adjusting the wavelength scale of the spectroscope. A short length of flex ending in a bayonet holder emerges through a hole in the base. Construction of the base unit being completed, the whole was painted matt black and then French-polished. The completed unit stands on three short legs with rubber feet.

The best position for the gemstone under observation was found to be as close to the Abbé condenser as possible. The sloping table in this respect is a disadvantage, so it was decided to design and construct a small rotating disc containing a series of holes (or stops) of different diameters to accommodate different-sized stones up to the maximum aperture of the Abbé condenser. Further, it was decided to provide half-way round each hole at a distance of from 2 mm to 4 mm a low rim, or its equivalent, to keep the gemstone in place and prevent it from slipping down.

Provision of a stone holder of the small tweezer variety was also allowed for so that the gemstone might be orientated in any way required. This was fixed on to a circular pedestal capable of rotation, fitted over another $\frac{1}{16}$″ thick disc containing a similar series of eight different-sized stops, so that the appropriate size of

stop could be selected. Correct orientation of the stone has to be achieved before inserting in the tweezers, as the Rayner type of mount[11] has no universal movements but only a limited amount of movement from side to side or to and fro or up and down.

Adjustment of the Wavelength Scale

Since the success of the spectroscope is greatly enhanced by the provision of a wavelength scale and since the scale on the Beck instrument is not accurate throughout, it is clearly important to take the greatest possible care in adjusting it to get the greatest degree of accuracy possible. To facilitate this, the instrument has been provided with a simple fitting, holding a neon or argon or helium glow-lamp immediately below the $\frac{2}{3}''$ objective, automatically centred by means of the spigot or pivot upon which the stone-holder disc rotates. The lamp is conveniently plugged into the 2 amp. switch plug referred to above, after first unscrewing the projector lamp or fitting a switch to cut it out of action. These lamps have a metal plate with a slit in it, arranged to concentrate the light in a small area.

Actually the 5 watt neon type of indicator or night-light lamp costing only a few shillings, does almost as well, but takes up rather more room. Helium is probably the most useful for calibration purposes as the lines are easy to see and are well separated through the spectrum. The sodium lamp used with the refractometer can easily be brought into use with a mirror, as can also the mercury lines from a fluorescent tube, should this form of lighting be available. Less easily, reference can also be made to the Fraunhofer lines of the solar spectrum.

Wavelength Reading Comparison Periscope

Notwithstanding having made the most careful setting of the wavelength scale, it is still difficult to obtain accurate readings due to a tendancy of the scale to float laterally as the eye, placed close to the eyepiece, is moved from side to side. The internal design of the No. 2522 spectroscope[12] requires that the rays forming the spectral image shall traverse the main dispersing prism which has an inclined exit face. The image-forming rays of the reference scale emanating from the side tube are brought coincident with the main tube by reflection off this inclined prism face.

Both sets of rays are, therefore, independent until superimposed in this way and are capable of being focused individually to suit each other and the observer's vision. This is accomplished by sliding either the slit assembly or the scale mount in the two tubes of the spectroscope body. If parallax exists between the spectrum and the scale, it can be eliminated by re-focusing either one or both of the two units. It may be possible that readings in the blue region require a different setting from those in the red region of the spectrum, but exact coincidence between the two images should be possible by careful adjustment of the focus. It was felt desirable to devise some means whereby the eye could take up a constant position when taking wavelength readings for record purposes, where a great degree of accuracy was desirable.

I decided to overcome the problem by making a further periscope attachment, in which the lower mirror occupied only half of the available space, the other half being open, front and back, so as to allow half of the beam from the projector lamp to pass through the Abbé condenser. Sodium light was then picked up, via any suitable mirror or direct from a sodium lamp, by the top periscope mirror, whilst the gemstone spectrum was examined in the usual way.

In this manner the bright yellow sodium emission doublet was superimposed upon the gemstone absorption spectrum ; the eye moved from side to side until the sodium line was synchronized accurately on the 5890/5896 mark on the scale and then, keeping the eye absolutely steady in this position, the desired wavelength reading was taken. This procedure was then repeated for each measurement required. In the same way, a standard line could easily be used from an alternative source, such as a mercury vapour lamp (fluorescent type) or a helium lamp.

Possible Modifications

It will be appreciated that this prototype although planned and designed as far as was foreseeable at the time, was frequently modified in the light of experience as construction and testing proceeded. In building further models, certain further modifications mostly of a minor character could be made in the light of the knowledge gained in the prototypes constructed and subsequent operation.

1. The external switches would be less obtrusive if they were of flush or panel mounting type.
2. So accurate is the construction of the modern projector lamp that the facilities for adjustment incorporated in the prototype could be dispensed with.
3. The housing around the eyepiece of the spectroscope, could be more drastically bevelled to the front and rear. It could indeed be bevelled on the side away from the scale attachment, which if on the left-hand side as in the prototype would slightly facilitate viewing with the right eye—but this would be at the expense of loss of symmetry and is not really necessary.
4. Some increase in the height of the projector lamp filament above the base—i.e. if the batten holder was fitted inside the base, instead of through it—could be obtained without increasing the overall height of the unit, by inclining or tilting downwards the whole optical train slightly, instead of having it truly horizontal as in the prototype.
5. It would probably be better, however, to gain the additional height inside the lamp house by (in effect) lowering the base and reducing the height of the legs or indeed dispensing with them entirely by not only mounting the batten holder inside, but also arranging the whole of the wiring inside also.

   In other words, the unit would remain exactly as the prototype except that the base would be lowered by some 4 cm and thus the overall height of the lamp house, etc., section would become 24 cm instead of 20 cm as shown in the drawing.
6. For comfortable viewing with the unit on a bench or table of normal 30″ height, the overall height of the eyepeice above the table or bench should not exceed 38 cm or 15 inches with the viewing section inclined at 30° from the vertical (60° from the horizontal).
7. It would be quite a simple matter to arrange for the adjustment of the width of the slit to be made from outside the unit. It is, however, a simple matter to remove the inspection cover to make this adjustment which rarely needs alteration once made.

8. As an alternative, the spectroscope could be fitted with a right-angled prism to swing over half of the slit, so that a further beam of light could be picked up to enable a comparison spectrum to be produced exactly adjacent to the main spectrum. To enable this to be done, a small window would be needed in the side of the unit, in line with the right-angle prism. An emission spectrum can readily be superimposed upon the absorption spectrum as already described.

Conclusion

The constructional details of the gem spectroscope have been given to encourage any gemmologist who is handy with a few simple tools, to build one for himself. Starting from scratch, it took five months of almost every available moment of spare time to build it. Nevertheless the instrument has more than fulfilled expectations and it has already been of the greatest help in making spectroscopic examinations quickly and at a moment's notice.

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10. Educational Foundation for Visual Aids. Blower Unit suitable for 250 Watt Projector lamps.
11. Rayner & Keeler Limited. Spectroscopes and Gem-Testing Instruments.
12. R. & J. Beck Limited. Spectroscopes.

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Beck milled screw.
Ilford spectrum filters.
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110 Volt 100 Watt resistor lamp.
Brass holder with $\frac{1}{2}''$ flange.
Bakelite lamp-holder.
Edison screw lamp-holder.
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One 2 amp switch plug.
Blower unit.
16 C.P. screws $\frac{1}{2}'' \times 4$.
140 Brass screws $\frac{1}{8}'' \times 4$.
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Four Bakelite knobs.
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Abbé condenser.
ON20 Heat absorbing filter 2″.
G.E.C. bell transformer.
Miniature bulb.
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Polaroid filter.
Rayner stone-holder.
Blue filters.
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20 $\frac{7}{8}''$ microscope cover slips.
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ASSOCIATION NOTICES

COUNCIL MEETING

A meeting of the Council was held at Saint Dunstan's House, Carey Lane, London, E.C.2, on Thursday, 6th February, 1958. Mr. Norman Harper, Vice-Chairman, presided.

The following were elected to membership :—

FELLOWSHIP

Vince, John O., Ipswich. D.1955
Weller, Christine J. (Mrs.), Croydon D.1957
Weller, Raymond J., Croydon D.1957

PROBATIONARY

Edwin, Wilfred, Sumatra, Indonesia
Pragnell, John W., Bournemouth
Robins, Alan P., London
Turner, Bernard A., Nelson
Yates, Roy F., Manchester

ORDINARY

Bennett, Bradley F., London
de Silva, L. J. C. F., Colombo, Ceylon
Dietz, Robert S., London
Fernando, K. S. L. T., Colombo, Ceylon
Gray, Eleonora (Miss), Paris, France
Hinton, Vera G. (Mrs.), Staines
Laarhoven, Andreas M. van, Nairobi, Kenya
Massey, Derek W., Wolverhampton
Medley, Harold, Kingsworthy, Hants.
Mendelsohn, Michael, Cape Town, S. Africa
Parson, Chhagan L., Bangkok, Thailand
Powell, Colin V., Cheltenham
Rawlinson, William, Rhos-on-Sea
Rowan, Cyril, Wellington, New Zealand

Examinations.—The Council received details of the arrangements that had been made to hold the 1958 examinations at Goldsmiths' Hall.

Provident Scheme.—Approval was given to a proposal for enabling members of the Association to join the scheme arranged between the National Association of Goldsmiths and the British United Provident Association whereby private patient facilities could be obtained in the cause of illness or accident rates available under group schemes.

MEMBERS' MEETINGS

Members who met at Goldsmiths' Hall, London, on 23rd January, 1958, heard talks and saw demonstrations by two Fellows of the Association : Mr. L. C. Trumper and Mr. T. G. Jones. The Secretary, Mr. G. F. Andrews, was in the Chair.

Mr. Trumper said that he was indebted to a great many people for help with the equipment he had produced. There were articles from the pens of Messrs. Anderson and Payne which had prompted him to take an interest in the subject

and when Dr. Gübelin had produced a self-contained spectroscope the speaker and a friend had made some sketches of this equipment. He had also had some correspondence with Mr. Caudell, of Rayners, and, finally, had decided to build a spectroscope embodying the features he felt were required.

In the ordinary way the spectroscope required a powerful light-source and a " certain number of gadgets " to be set up in order to take a reading. He had come to the conclusion that " standing on a box and hovering above the instrument," trying to spot a line and then losing one's place when one stood up again was not very convenient. So he had decided to build an instrument with everything rigid. He had tried to incorporate other people's ideas and to put everything together.

Mr. Trumper's instrument is described on pp. 271-289.

In discussing the irradiation of gemstones Mr. Thorold Jones explained that nuclear scientists had been interested in the properties of diamonds for quite a number of reasons. The trade's interest was obviously that the irradiation of stones might make them more valuable.

A few stones had been irradiated, but with somewhat inconclusive results. The audience would know that these stones were not enhanced in appearance or value by irradiation. White stones subjected to irradiation sometimes gave attractive blue or blue-green results, but most had a green character. A certain amount of adjustment to the lattice took place through subsequent heat treatment. Some stones had as a result assumed quite pretty colours, mainly corn, gold and yellow. There was still much to learn about the mechanics of the colour-changes.

The speaker had had a small diamond put into the Bepo unit, where it was left for some weeks at a very high flux. This stone had turned black and has so far defied all efforts to restore its colour. Two other stones subjected to bombardment in the accelerator had come out respectively blue and, with the stone irradiated by neutrons, green. These experiments had not been carried out very accurately so the information was rather sketchy.

Irradiation could consist of X-rays, gamma rays, electrons, or neutrons, the latter being the source of big bangs and electrical power. The power acted upon things in the most extraordinary ways. The types of irradiation most commonly used were gamma rays, alpha particles, and neutrons.

Mr. Jones then explained the principle of the Bepo reactor and discussed its construction and use.

Both speakers interested members with demonstrations. Mr. Trumper showed what results could be obtained with his spectroscope and Mr. Jones displayed two cases of gemstones showing the effects of irradiation, together with instruments measuring their radioactivity.

Mr. B. W. Anderson proposed a vote of thanks to the two Fellows.

SYNTHETIC MOONSTONE-COLOURED SPINEL

The captions to the illustrations on p. 214 of Vol. VI, No. 5, were unfortunately transposed (*v.* Synthetic moonstone-coloured spinel by A. J. Breebaart, F.G.A., C.G.).

THE PRESIDENT SPEAKS ON GEMSTONES

The Director of the Davy Faraday Research Laboratory, Professor Sir Lawrence Bragg, O.B.E., M.C., M.A., D.Sc., F.R.S., who honours the Association by being its President, spoke on " Gemstones " at the 31st of January Friday Evening Discourse of the Royal Institution. The Friday Evening Discourses are only one of the many activities of the Royal Institution and are in fact social evenings arranged for the members and their ladies and friends ; the speaker, a notable person in the world of philosophy, discoursing on a subject of his particular interest. The talk, semi-popular in style, is given in the historic lecture hall of the Institution in Albemarle Street.

Sir Lawrence commenced his discourse by paying tribute to Dr. G. F. Claringbull, who had been so helpful in assisting in the preparation of the evening's lecture. Credits, too, were given to those who had arranged the exhibits shown in the library before (and after) the talk. In this connexion thanks were given to the Officers of the British Museum (Natural History), the Gemmological Association, the Diamond Trading Company, Messrs. Asprey Ltd., and the Director of the London Chamber of Commerce Laboratory (Mr. B. W. Anderson) and his assistant, Mr. R. Webster. Sir Lawrence also tendered thanks to Mr. Ginder for the loan of a large diamond which was to be used in the lecture demonstration.

Diamond, corundum, beryl, topaz, spinel, tourmaline, garnet, chrysoberyl, zircon and olivine, or, as it is known better in the jewellery trade, peridot, were discussed, and reference was also made to amethyst, citrine and rock crystal. All the major gemstones, except perhaps peridot, had a hardness greater than quartz and were thus able to resist the abrasive action of the quartz particles in the atmosphere. The superior hardness of diamond was explained by the close bonding of the atoms and was illustrated by the use of an atomic structure model.

The high index of refraction of diamond was the main cause of the superb brilliancy of a well-cut diamond, for in such a case the light rays entering the front were returned out again through the front of the stone. This total internal reflection of light was demonstrated by the use of a glass tank containing a fluorescent liquid, the beam of light projected through it being reflected internally at the critical angle for the liquid and air—this critical angle, in the case of diamond, being nearly a quarter of a right angle. The lecturer further illustrated the effect of this return of light in diamond, and the lack of it in a " glass imitation diamond," by an elegant experiment. A diamond and a glass imitation were placed table facet down on diaphrams.. The stones were illuminated from below and the effect projected on to the screen, no light coming through the diamond but a considerable amount through the " paste " stone. The " fire " of a diamond was also discussed and demonstrated by projected diagrams.

Sir Lawrence referred to the synthesis of diamonds by the General Electric Company of America and on the screen were shown (in colour) some of these diamonds and the apparatus used to make them. Some specimens of synthetic diamond were then placed under the epidiascope and by the comparison with the operator's hand their small size could be estimated.

By reference to atomic models the formation of gem crystals was explained

as being due to the electronic attraction of positively charged oxygen atoms of relatively large size to small metallic ions with a strong negative charge.

A slide showing the various colours assumed by ruby and sapphire illustrated the coloration by trace-elements and reference to chromium as a colouring agent. Chromium normally gives a green colour but the speaker pointed out that in ruby the ions are in a state of strain, in fact they are " pinched so badly that they turn red." The effects of the selective absorption of light and colour induced by fluorescence were remarked upon. Two pairs of pink-coloured socks were used to demonstrate the effects of selective absorption and coloration by fluorescence, one of the pair of socks being fluorescent and glowing when placed in front of an ultra-violet lamp. Sir Lawrence remarked that fluorescent socks were a new idea, but ruby had the idea all through the ages.

The audience, which had been issued with pieces of cardboard, each framing a circle of polaroid split into two half circles mounted one above the other with their vibration directions at right angles to one another, was then told about the effects of the polarization of light and of dichroism. By the use of the polaroid gadgets polarization by reflection and the dichroism of gemstones were ably demonstrated, and included in these demonstrations was the effect of bad colour in a ruby cut in the wrong optical direction.

The cause of the star effect in star stones was shown to the assembly by an amusing experiment. A sheet of glass was lightly covered with vaseline and strokes with a whitewash brush were made in three directions at 60° to each other. When the sheet was held up with a light behind it, a six-pointed star was clearly seen.

The epidiascope was then used to throw on to the screen a number of boxes of cut stones of various species, species which the lecturer then dealt with in some detail. Referring to the misuse of the name topaz for the yellow quartz, Sir Lawrence mentioned an incident which occurred in Scotland. Seeing a lovely yellow quartz crystal he inquired about it and was categorically told that it was topaz. He queried this and was promptly informed that of course it was topaz and that the interfacial angles were correct for topaz, and further he was told that if he did not understand about the angles the vendor would be willing to lend him a book on the subject.

The difference in the density of topaz and yellow quartz was demonstrated and at the same time a crystal of brown topaz was placed on a retort stand over a lighted bunsen burner. At the end of the talk this crystal was removed and allowed to cool, when it was seen to have assumed a pinkish colour, thus illustrating the " pinking " of topaz. The use of a plate of tourmaline as a producer of polarized light and its early use for that purpose in the tourmaline tongs were also demonstrated.

Double refraction and its effect of doubling of the rear facet edges in the case of such stones as zircon and peridot were shown, but the most impressive demonstration of the doubling effect was produced when a notice was flashed on the screen telling the audience that there would be refreshments available after the discourse. Over this notice was placed a rhomb of iceland spar and the wording then appeared doubled. Finally a polaroid sheet was arranged over the rhomb of calcite and the writing became single again.

Sir Lawrence was applauded for the excellent discourse he had given and then the gathering, which must have numbered about five hundred, left the lecture hall for refreshments and to inspect the exhibits arranged in the imposing library of the Royal Institution.

These exhibits covered a wide field of gemmological endeavour. The Gemmological Association displayed a number of specimen gemstones from their collection. The Diamond Trading Company had on show a magnificent octahedral crystal of diamond weighing 167½ carats besides a suite of plastic models illustrating the stages of the cutting of a brilliant. The British Museum (Natural History) exhibited a number of specimen crystals of gem minerals, among which were a large aquamarine from Brazil, corundum crystals in matrix from Norway and emerald crystals in matrix from the famed Muzo mine in Colombia. Topazes from Russia and Brazil, spinels from Burma, opal from South Australia, kunzite from California, garnet from Italy, and sapphire from Ceylon, were some of the lovely minerals displayed.

One of the London Chamber of Commerce Laboratory displays, under the care of Mr. Anderson, comprised a very full suite of gem-testing equipment, to which could be added the show by Rayner and Keeler Ltd., who exhibited their new Asscher diamond microscope. Mr. Anderson had on display and demonstrated the immersion contact method of refractive index determination, the spectroscope set-up for observation of absorption spectra and the crossed-filter experiment. Mr. Webster at another table showed and demonstrated the use of ultra-violet light of both operable wavelengths, the two lamps for which were kindly loaned by Hanovia Ltd. This demonstration covered the use of the differential response of diamond as a means for the preparation of identity certificates. Coloured transparencies of gemstone inclusions set up in an illuminating frame, loaned by Kodak Ltd., and a case of tumbled stones flanked Mr. Anderson's exhibit.

The display which undoubtedly attracted most attention from the ladies present was a show of mounted jewellery by Asprey Ltd. In a well-lit showcase were suites of jewellery in diamonds and coloured stones of modern design, garnet-set jewellery of the Victorian era and many specimen coloured stones mounted in brooches and pendants. A rose-quartz dish and a seal with a red jasper handle showed beauty in another guise. In another showcase was a large piece of rock containing ruby crystals from the new source in Tanganyika, and alongside the wall an illuminated case contained a working model illustrating *Bragg's Law*, the law worked out by Sir Lawrence himself.

GIFTS TO THE ASSOCIATION

The Council of the Association is most grateful for the following gifts :—

Jade Miscellany by Una Pope-Hennesy, from P. J. Leese, F.G.A.

The Romance of the Jewel by Francis Stopford, from R. K. Mitchell, F.G.A.

Three models of famous diamonds, in case, from E. Burbage, F.G.A.

TALKS BY MEMBERS

R. J. N. OLIVER. " Gemstones," Liverpool " 41 " Club, 6th December, 1957.

KENNEDY, N. W. " Woman and Gemstones," 14th January, to Soroptimist Club, Wallasey.

EWING, D. " Gemmology as applied to Police enquiries," Edinburgh C.I.D., 26th March, 1958.

WEBSTER, R. " Pearls," Tunbridge Wells and Tonbridge Branch of the National Association of Goldsmiths, 25th February, 1958.

WARREN, MRS. K. G. " Gemstones," Business and Professional Women's Club of Bromley and Beckenham, 17th March, 1958.

JARVIS, C. A. " Gemstones," High Road Young Wives, Ilford, 25th March, 1958.

DUNCAN, J. " Gemstones," Townswomen's Guild, Netherlee, Glasgow, 11th March, 1958.

ANNUAL GENERAL MEETING

The 28th Annual General Meeting of the Association was held at Saint Dunstan's House, Carey Lane, London, E.C.2, on Thursday, 13th March, 1958, at 6.15 p.m. The Vice-Chairman, Mr. N. A. Harper, presided in the absence of the Chairman, who was indisposed.

The Treasurer, Mr. Lawson Clarke, presented the accounts and thanked the National Association of Goldsmiths for their assistance throughout the year. The Secretary read a message from the Chairman who wrote :

" The Association has had another active year and, in particular, it will be noted that our Midlands and West of Scotland branches have been going ahead with a steadily expanding programme. This, I think, you must regard with satisfaction.

" I would like particularly to thank those who have contributed to the success of the Association's year now under review. We are indebted to the examiners for their painstaking work and for maintaining the high standard in our examinations, which enjoy such a world-wide reputation. In addition I would like to thank Mr. Robert Webster for all that he has done in connexion with the practical examination arrangements in London. Our own *Journal of Gemmology* increased in circulation during the year, and we are grateful to those who contributed to its success. I would like to add a special word of thanks to Mr. J. R. Chisholm in this connexion. I am grateful to the members of the Council and to all those who have supported meetings in various parts of the country.

" ' The evil that men do lives after them—the good is oft interred with their bones.' Shakespeare's philosophy was rarely at fault, and here he qualifies with ' oft ' the burying of his good deeds with the man. For it is not always so, and we, in the Gemmological Association, have two names we try to keep fresh in our minds . . . those of Dr. Herbert Smith and Sir James Walton. But we remember them for somewhat different reasons. Dr. Herbert Smith was the expert who, by his energies and research, advanced the study of gemmology. He left his own memorial in his book (which is still a standard work on the subject) and we remember him each year when the Herbert Smith Memorial Lecture is given. Sir James Walton was quite a different personality. In fairness he would not be

called a brilliant gemmologist. His greatest assets were his sincerity and integrity, and it is these aspects of him that we remember most. For this purpose the National Association and our own organization created the Sir James Walton Memorial Library. The N.A.G. provided the major portion and the final section, a contribution from our own organization, was completed at the end of last year. The library will serve a valuable purpose and I hope that it will keep alive that extraordinary enthusiasm that Sir James brought to bear on the activities of the Association. Very few in the Association can hope to emulate Dr. Herbert Smith —though I am glad to say that we are fortunate in having some who will leave as deep an impression on the subject as he did ; but there is not one of us who cannot be quickened by the memory of Sir James and spurred into activity. There is always much to be done for the Association by the enthusiast."

The annual report and audited accounts for the year ended 31st December, 1957, were adopted.

The following officers were re-elected:—*President:* Sir Lawrence Bragg, F.R.S. ; *Chairman:* Mr. F. H. Knowles-Brown; *Vice-Chairman:* Mr. N. A. Harper; *Treasurer:* Mr. Lawson Clarke. The Vice-Chairman said that the Association was greatly honoured by Sir Lawrence continuing in office.

Miss Iris Hopkins was elected to the Council and Messrs. W. C. Buckingham, A. R. Popley and E. H. Rutland were re-elected. Messrs. Watson, Collin & Co. continued as auditors to the Association.

Professor Cavenago-Bignami, of Milan, sent a telegram conveying good wishes to members attending the meeting.

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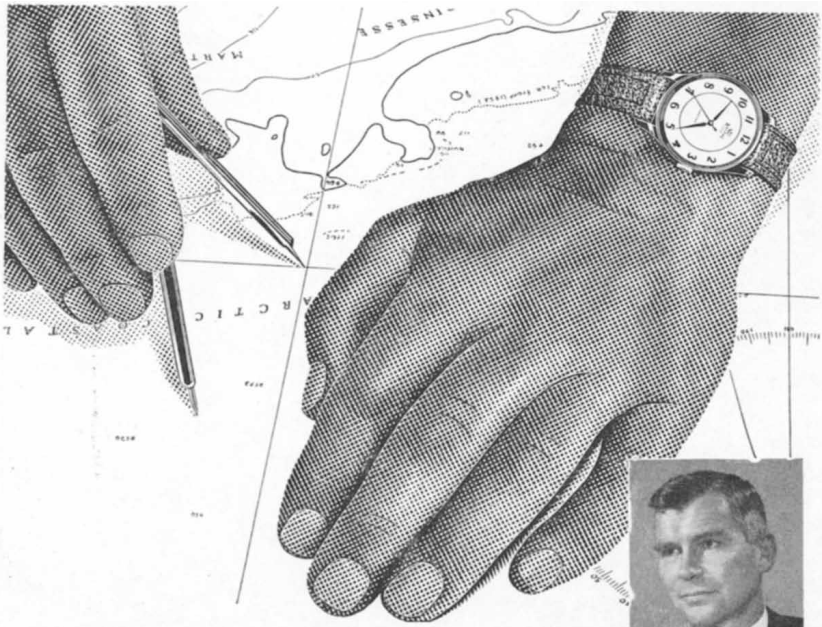

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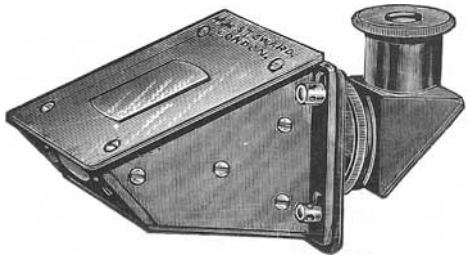

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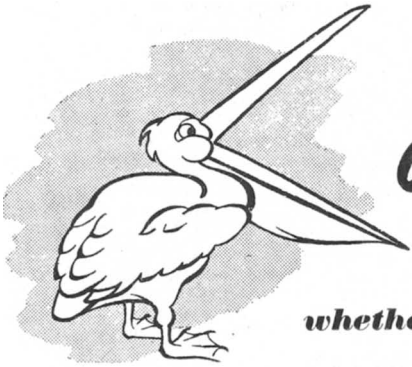

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MARBLES AND OTHER ORNAMENTAL STONES

By ROBERT WEBSTER, F.G.A.

NAMED from the Latin word *marmor* (a shining stone), marble may be said to cover a considerable number of rock-like formations ; indeed all marbles are typically rocks. What is marble ? To the geologist marble is usually defined as a crystalline aggregate of calcite, often with a saccharoidal texture. From the point of view of the ornamental stonemasons—or shall it be said the commercial view—marble is widely interpreted and may be said to include all ornamental stones harder than gypsum, and indeed, in popular parlance the massive form of gypsum known as alabaster is thought of as marble.

For the purpose of this study the subject of marbles is divided into the true marbles—the often colourful compact limestones, and the stalagmitic calcites, miscalled the " onyxes." The quartzites, porphyries, alabasters and some other types of rocks, so like marble and therefore termed marble in commercial parlance, also demand inclusion. The pale coloured " onyxes," as used in decorative wares, are often relieved by inlaying with a " marble " of contrasting colour. Many of these are well-known minerals which, from the earliest of civilizations to the present-day, have been the sign of magnificence and regal splendour.

The True Marbles

Marbles, as the geologist knows them, the true marbles, are the product of the alteration of an existing calcareous rock by the agency of heat and, maybe, pressure, which occurred through geologic upheavals in past ages. Such geological alteration of existing rocks is termed *metamorphism*, and a rock altered by such a process is called a *metamorphic rock*. There are a number of different types of metamorphism but the type which produces the true marbles is that known as *contact metamorphism*. Such an effect occurs when a mass of igneous rock at a high temperature intrudes into an existing rock formation, the heat of the slowly cooling intrusive rock causing the surrounding country rock to alter. The extent of the alteration away from the margin of contact may be anything from several inches to many miles, the size and completeness of this *metamorphic aureole*, as it is often called, depending upon the size and temperature of the intrusion, the rate of cooling and the nature of the rocks. True marbles are the result of contact metamorphism of pre-existing pure or impure limestone rocks.

When the country rock is a very pure limestone the only change which can be produced is recrystallization, since the action of heat on calcium carbonate is a reversible one and soon stops unless one of the products of dissociation is removed as fast as it is formed. Heating pure limestone ($CaCO_3$), a rock which has been laid down as a sediment, produces quicklime (CaO) and carbon dioxide (CO_2), but under the deep-seated conditions of contact metamorphism the carbon dioxide is not dissipated and the quicklime and carbon dioxide recombine. The rock recrystallizes out as an interlocking mosaic of calcite crystals, in fact a pure white granular marble.

It is by such a cause that the white statuary marbles have been formed. Such a white marble is the *Marmor Pentelicum*, or Pentelikon marble, which is quarried on Mount Pentelicus some eight miles north-east of Athens. Another of the Greek white sub-translucent statuary marbles was mined—it is said as early as the sixth century B.C.—on the Island of Paros in the Aegean Sea.

What are probably the most important of the white marbles are those found in the Apuan Alps around Carrara in Tuscany, Italy. The purest white marble from this locality is quarried on Monte Altissimo about eight miles from Serravezza. This mountain rises to a height of 5440 feet and its precipitous crags are practically

pure white marble. When the marbles of the Apuan Alps are less pure they become clouded with greyish veins, and such a marble is often called " Sicilian marble," a misnomer originally adopted in England. Various reasons have been put forward to explain the use of this name, one of which is that the first cargo came over in a ship called " Sicilia " and this gave the name to the marble. Others assert that the vessel carrying the first cargo was damaged by a storm and put into a Sicilian port for repairs, and when the ship finally reached England it was thought that the cargo had come from Sicily. A third suggestion takes the view that the first cargo of these marbles came from Italy when Napoleonic rule prevailed and export of Italian goods to Great Britain was prohibited, and to overcome the difficulty the traders resorted to false Customs declarations and used as the country of origin the island of Sicily.

Hundreds of marble quarries are dotted about the twenty-five miles between Pisa and Spezia on the west coast of Northern Italy. These quarries, generally in groups, are mainly in the valleys of Rayaccione and Sagro near Carrara, and also around Massa and Serravezza.

The limestones which have suffered metamorphism may have contained impurities and such impure rocks will produce attractively coloured marbles. A marble rock may be shattered by subsequent earth movements and the fissures so produced in the marble may be reconsolidated by other, often coloured, mineralization, thus producing the beautiful veined marbles. If the fissures are very numerous and are filled with secondary minerals of many colours the product is then a *variegated marble.*

A marble which suffers great stresses subsequent to its formation may break up into angular fragments which are subsequently recemented together by infiltration or by pressure. Such a rock is a *brecciated marble* and can be very attractive.

Limestones which contain siliceous or clay (aluminous) impurities may, under the influence of contact metamorphism, cause the lime (CaO) to unite with the foreign material with the elimination of carbon dioxide. Such a change might, if silica be present, result in the formation of the simple lime-silicate, wollastonite. Such a change may be illustrated by the following chemical equation :—

$$CaCO_3 + SiO_2 = CaSiO_3 + CO_2$$

Should the silica be insufficient to decompose all the lime, a *wollastonite marble* results. This is a marble which has little interest as an ornamental stone, but the chemical changes occurring in its production will serve as an example of the changes which can occur in the metamorphism of rocks.

Many limestones contain more or less magnesia without being dolomite (calcium magnesium carbonate), and on contact metamorphism the magnesia reacts with any silica and alumina present to form amphiboles and pyroxenes. The changes which occur in pure or nearly pure dolomitic rocks under low-pressure contact metamorphism are governed by the greater reactivity of the magnesia part than the calcite part and result in the dissociation of the magnesium carbonate with crystallization of calcite. The following equation will explain this *dedolomitization effect*, as it is termed :—

$$\underset{\text{(dolomite)}}{CaMg(CO_3)_2} = \underset{\text{(Calcite)}}{CaCO_3} + \underset{\text{(Periclase)}}{MgO} + \underset{\text{(Carbon dioxide)}}{CO_2}$$

The magnesia (periclase) formed is highly hygroscopic and undergoes hydration, forming brucite ($Mg(OH)_2$; the resulting rock being a mixture of brucite and calcite may be classed as a *brucite marble*, and such a rock is found in the Austrian Tyrol.

When silica is present in a dolomitic rock, various silicates of lime and magnesia are formed. Should there be only a little silica, so that the bases are in excess, the silica combines with the magnesia to form an orthosilicate of the olivine group—forsterite (Mg_2SiO_4)—while the lime molecule forms calcite :—

$$2CaMg(CO_3)_2 + SiO_2 = 2CaCO_3 + Mg_2SiO_4 + 2CO_2.$$

Thus a *forsterite marble* is produced. If the silica be in excess the lime molecule enters the silicate forming diopside, $CaMgSi_2O_6$, or tremolite, $CaMg_3Si_4O_{12}$. Since the original rock may contain calcite as well as dolomite the resulting rock is a crystalline aggregate of diopside or tremolite and is thus a *diopside marble* or a *tremolite marble.*

These magnesium silicates, which frequently contain traces of iron, become readily altered by later chemical action into green serpentine. The resulting serpentinous marbles are known as *ophicalcite*, and examples of such rocks are the well-known Connemara marble or Irish green marble, which is found in County Galway, Ireland. Iona stone, found near the Bay of Port-na-Carrack on the

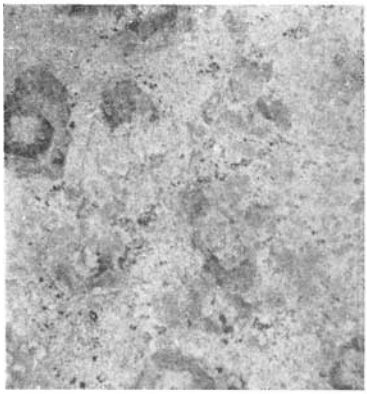

Xalostocite, a marble containing pink crystals of grossular garnet.

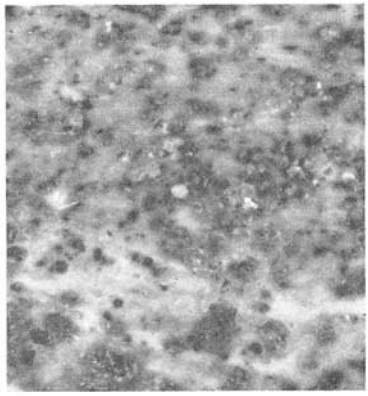

Tiree marble, a marble having green diopside crystals in a pink ground-mass.

small Inner Hebridean island of Iona, is a similar serpentine marble, and another source of ophicalcite is at Glen Tilt in Perthshire, Scotland.

The metamorphism of impure limestones may produce a marble which has comparatively large euhedral crystals embedded in the calcite groundmass. The gemmologist knows well that the ruby found at the Mogok Stone Tract of Upper Burma has crystallized in white marble, and, indeed the white marble which is obtained from the Sagyin quarries, thirty miles north of Mandalay, occasionally has rubies embedded in it. In Xalostoc, Morelos, Mexico, is found an ornamental marble which consists of large crystals of pink grossular garnet in a creamy-white marble. This marble is called *xalostocite* (after the locality) or *landerite* (after Carlos F. de Landers) or *roselite* (after the colour). A similar material is said to have been found at Jaurez, Lower California. The so-called *Tiree marble*, which is found on the small island of Tiree, which lies off the island of Mull, Argyllshire, on the west Scottish coast, is another such marble which contains visible crystals, in this case crystals of diopside in a pink ground-mass.

The names applied to the various types of marble are legion and there would be little value in repeating what may well be local quarry names. In general there are two main types of nomenclature, one consisting of the name of the quarry and the other referring in some manner to the colour of the marble, and these may often be combined. Thus, *Cipollino* is the name given to

marbles which have alternate bands of white and green. The name is particularly applied to the marble from the quarries on the Greek island of Euboea (Negroponte), a marble which was known as the "Marble of Carystus." The modern name, cipollino, relates to the well-defined layers resembling an onion (cipolla). The name *Pavonazzo* which is given to a group of white or pale yellow marbles traversed with coloured veins, is said to have originated from the supposed resemblance between the colour of the purple veins and the plumage of a peacock (pavone).

When the marble is brecciated the name *Breccia*, or *Breche*, may be incorporated in the title, and *Griottes* are red marbles whose colour resembles that of the Griotte cherry. To illustrate the impossibility of attempting to identify a marble by the name alone, the so-called "Molina rosa," a reddish marble from the Garfagnana quarries of Tuscany, owes its name to the Spanish marble quarried near the town of Molina.

The second type of marble to consider is the massive crystalline calcium carbonate deposits which form from waters charged with calcium bicarbonate. These are the so-called *travertines* and *stalagmitic marbles*. Although calcium carbonate is almost insoluble in pure water, when the water contains carbon dioxide, as all natural waters do, the calcium carbonate from the limestone rocks, over which the water flows, will be acted upon, producing the more water-soluble calcium bicarbonate, as expressed in the following equation :—

$$CaCO_3 + H_2O + CO_2 = H_2Ca(CO_3)_2.$$

Pressure increases—and heat, by driving off the carbon dioxide, decreases—the solubility of the carbonate. On decrease of pressure, or on heating the water, or by its evaporation—all processes which lead to the loss of the gas carbon dioxide—this will result in the precipitation of crystalline calcium carbonate producing beds of travertine or stalagtites and stalagmites, which in general have a layered structure. This physico-chemical description of the deposition may not, however, tell all the story, for organisms such as algae and bacteria may assist in the deposition, and it is not always possible to separate the purely inorganic deposition from the biochemical processes.

The travertines and stalagmitic calcites are often banded and they are commercially known as the "Onyx marbles" or "Oriental alabaster," both terms which are misnomers ; for the true onyx

is a banded chalcedony (agate), while the name *alabaster*, in correct mineralogical nomenclature, means a massive gypsum—a hydrous calcium sulphate. The origin of the use of these mineralogically incorrect names is a matter of conjecture. It seems clear that the name *alabaster* was applied to the stalagmitic marbles in Biblical times, and also that at different times the material was successively known as " Oriental alabaster " and then " Alabaster onyx," while more recently the term " Onyx marble " was mostly used.

There seems some doubt of the origin of the name *Alabaster*, for some writers assert that the name was derived from the town of Alabastron in Egypt, where the stone was first quarried and worked. Alternatively the name may well have received its genesis from the use made of this type of marble in making the slender narrow-necked vase or cruse without handles, called *alabastron*.

Normally the ground colour of these " onyx marbles " is white, but invariably they are veined by coloured fissures or tinted in areas by the infiltration of metallic oxides. It is owing to their translucency and their soft delicate bands of colour in amber, orange and green, that these stalagmitic calcites have won such esteem with the makers of small *objects d'art* and at the present time are popular for fine quality clock cases, when the soft effect of the marble is offset by inlaying with other minerals having a stronger or more contrasting colour.

Deposits of " onyx marble " are widely distributed in almost every region of the world, but it is only in a few places that the deposits are of sufficient importance to be commercially worked. The most abundant supply of the marble comes from Algeria, where it is found in quantity in the provinces of Oran and Constantine. The major quarries are close to Bon-Hanifa, a village about ten miles north-east of the modern town of Mascara. Bon-Hanifa lies near to the ancient Roman town of Aquæ Sirenses, which was noted for its hot springs, and it may well be that the deposits originated from these springs. The Constantine deposits lie about ten miles from Constantine, the capital of the department of the same name, and much of the marble from this locality is bright red in colour. On the Moroccan side of the border with Algeria is another deposit of stalagmitic marble, which may be considered an offshoot of the Algerian deposits. Like the Oran marble the colour of Moroccan marble is normally white with coloured veins, but

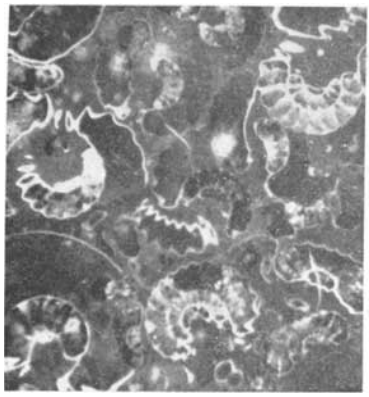

" *Fossil marble.*" *A fossil limestone containing ammonite shells.*

Brecciated agate.

material of a blue, grey or pink colour mixed with green, as well as a bright red, is found.

Another North African deposit is that of Egypt, where stalagmitic marble, in early times known as " Egyptian alabaster," was found near the town of Alabastron, and was extensively used in Egypt from the First Dynasty. The Egyptian material, a translucent light amber-coloured rock marked with wavy bands, was formerly worked over a large area of the Nile Valley, but the little material quarried in recent years is obtained from workings on the lower flanks of the Asyut mountains, some twenty miles from the town of Asyut. During the nineteenth century some stalagmitic marble was obtained from the caves near Beni Suef in the Nile Valley, and material from this deposit was used for embellishing the famous " alabaster " mosque at Cairo.

About three hundred miles south of San Diego lie the Pedrara quarries of Lower California, Mexico, where a deposit of stalagmitic marble is exposed on the surface or is not more than eight or ten feet below. After being mined, this white or green translucent rock, veined with dark orange, amber or brown and known as " Pedrara onyx," is sent to Santa Caterina which is the nearest port. Other sources of " onyx marble " in Mexico are in the States of Puebla and Oaxaco. " Mexican onyx," as the marble is commonly called, is in America sometimes called *Tecali marble*, a name given to it by the Aztecs, the ancient inhabitants of Mexico, who deemed the stone too sacred for it to be used by the common

people. The marble was almost solely devoted to the ornamentation of religious buildings or the making of sacrificial vessels. Indeed, Tecali is but a corruption of the Aztec name *Teocall* given by Mexican Indians to their temples. It is from the Mexican localities that most of the " onyx marbles " used in England for the modern marble clock-cases, cigarette boxes and other small ornamental pieces comes.

The commercially used, and in England comparatively well-known, term " Brazilian onyx " is a misnomer, for the material to which it is applied is found in the province of San Luis in the Argentine Republic. The marble from San Luis differs little in appearance from that found in Mexico. A similar marble is found and mined in Yavapai Co., Arizona, in the southern part of the United States. This marble, which is commercially called " Yava onyx," is found in irregular and somewhat lenticular layers from one inch to two feet in thickness interbedded with a coarse breccia formed of schistose and dioritic fragments in a sandy and calcareous matrix. Near Lehi, some twenty miles from Salt Lake City in Utah, occurs a vein of highly translucent stalagmitic marble of a bright lemon-yellow colour traversed with orange-coloured sinuous veins. This " Utah onyx," as it is called, is not an important source of marble.

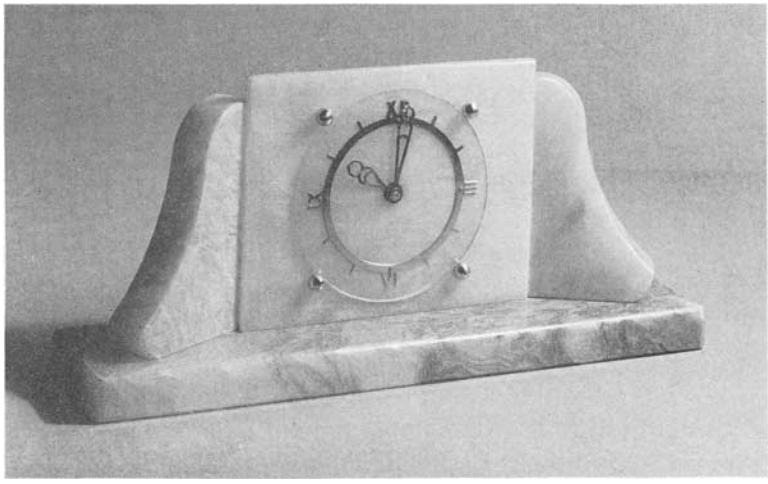

Clock in alabaster.

" Onyx marble " is found near Laasee in the valley of the Vintschgau. This slightly translucent marble with orange-coloured veins is known as " Tyrolese onyx " and is mainly worked in Vienna. The *Stalagmite de Bédat* is found in the Department of Hautes-Pyrénées, where it is obtained from the roof and walls of caverns and grottos on the banks of the river Ariège, which rises near Andorra and flows northwards through the Departments of Ariège and Haute-Garonne. Another deposit is found at Manère, in the French Department of Pyrénées-Orientales.

Gibraltar stone is a stalagmitic deposit found in the caves which abound in the limestone rocks which form the Rock of Gibraltar. The material is a translucent travertine with brown and amber-coloured sinuous veins. The marble is mainly used for the production of small ornamental objects for sale to tourists. " Java onyx " is a stalagmitic marble, usually dull white in colour or variegated with amber-coloured wavy banding. The rock, which is found around the town of Kediri (Wadjak), which lies some sixty miles south-east of Surabaja (Surabaya) in the Toeloeng Agoeng district of Java, has not the translucency met with in stalagmitic marbles from other localities.

A crystalline marble, which consists of fibrous crystals of calcite, is known as *satin-spar* (cf., gypsum). The material is found in veins and the fibrous crystals stretch across the vein from side to side. When polished with a flat surface the material shows a silky lustre and the " marble " has been used as an inlay and for bead necklaces. Calcite satin-spar, which occurs in England at

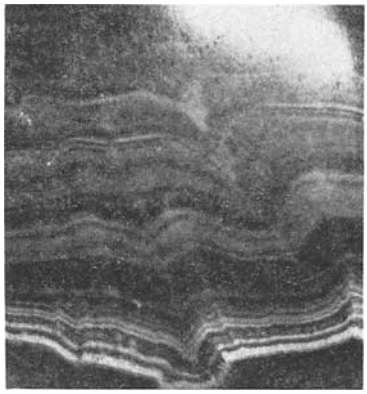

A polished flat cabochon of Gibraltar Stone.

Alston Moor in veins one to four inches in thickness, in Scotland at Glen Tilt, Perthshire, and in several states of North America, is now rather scarce.

Some few years ago there were marketed, under the fanciful misnomers " Imperial Mexican Jade " or just " Mexican Jade," carved and fashioned pieces of a green material which was subsequently identified as calcite (marble). It was further suggested that the colour of these pieces was due to artificial staining.

LIMESTONES

Many architectural marbles—and some of these are used for small ornamental pieces—are simply limestones which owe their attraction to colour and to the patterning caused by included fossils. Unlike the marbles already mentioned, limestones are sedimentary rocks consisting mainly of calcium carbonate with varying amounts of impurities to which their colour may be due. They are sometimes laid down in layers, producing stratified rocks, although the stratification may be of any thickness from paper thin to layers so thick that no layering can be seen in pieces of average size. Indeed, in certain limestones stratification is entirely absent.

The deposition of lime rocks may occur through physico-chemical conditions, by the loss of carbon dioxide from bicarbonate-rich water, as has been explained for the formation of stalagmitic marbles. Such occurrences may also happen with organic formation, which illustrates the difficulty, if not impossibility, of truly deciding the group to which a marble belongs.

Most limestones owe their origin to organic processes and these may be either biochemical or biomechanical. In the first of these it is the vital activities of the organisms which promote a chemical condition favouring precipitation of lime ; the bacterial limestones are of this type. Biomechanical deposits are due to the rock being formed from the detrital accumulation of organic materials, as in the case of coral, encrinital and shelly limestones. The grain-size of such mechanically formed rocks depends upon the initial sizes of the component organisms or upon the size of the fragments into which they naturally break. Such limestones may be heterogeneous in composition, consisting of a great variety of organic fragments embedded in a calcareous mud due to their comminution, one group of organisms often predominating to give character to the rock. Such rocks are the " Fossil marbles."

Probably the most common marble is the so-called " Black marble," which was so often used for casing clocks in the late Victorian and Edwardian periods, and the use of which did not entirely disappear until just before the beginning of the Second World War. These black marbles, often veined with white, are mostly obtained from the Lower Carboniferous series which lie in the Provinces of Hainault and Namur of Belgium. These marbles, known as the " Noir Belge " (Belgian black), are found along the Sambre and Meuse rivers. The more important quarries are those of Basècles, a small town close to the French frontier about thirteen miles south-east of Tournai. The other main quarries run parallel to the left bank of the river Meuse a little to the north of the towns of Mazy and Golzinnes, near Charleroi. Much black marble is found in the Departments of Nord and Pas de Calais in Northern France. That from the first-mentioned locality is known as " Grande Antique " and that from the Pas de Calais is called " Noir Français." Other black marbles of note—for there are quite a number of localities which provide such marbles—are the " Irish Black " found in County Carlow, Ireland.

Many of the compact limestones are brightly coloured in reds, browns, yellows and greens of varying tones and may be in variegated colours. However, neither monochrome photography nor the written word can adequately describe the multitude of effects shown by such " marbles." There are so many of these marbles, often named from local quarries, that an attempt to name them would be confusing and have little value.

The " fossil marbles," owing to their obvious characteristics, do allow some grouping and description. The fossils visible in limestones may be either shelly (mainly the shells of the mollusca), coralline (various corals), or encrinital (containing the remains of crinoids, or, as they are sometimes known, *sea lilies*). Of the first type the best known is the " Purbeck marble." This is a light blue-grey to reddish-brown marble made up of countless fossil shells of fresh water snails (*Paludina carinifera*), hence the " marble " is sometimes known as *Paludina limestone*. The quarries supplying this marble stretch westwards from the Dorset town of Swanage as far as Kingston, four or five miles distant. A similar " marble " is found near East Grinstead and Netherfield, near Battle, in Sussex. It is known as the " Petworth marble " or " Bethersden marble," depending upon the locality where it has been obtained,

" Purbeck marble," a " fossil marble " from Dorset. A limestone containing masses of freshwater snail shells.

A small ashtray turned from reddish-brown " encrinital marble."

and, although resembling the " Purbeck marble," the fossil shells are those of *Paludina fluviorum*, which is a larger species. A striking " fossil marble " is that which contains fossil ammonites in a dark brown ground-mass. The Irish " black marble "—the Kilkenny black " fossil marble "—is picked out by white circles which are abundant brachiopod shells.

A most beautiful " fossil marble " is the so-called " fire marble," known also as *lumachella*, *lumachelle* or *lumachello*, a word which means " little snail," This somewhat rare " marble," which has been cut for the tops of snuff boxes and other ornamental articles, is a dark brown " marble " marked throughout with small whitish shells, possibly ammonites, which in certain parts exhibit iridescent colours rather like opal, and indeed the " marble " may be mistaken for opal in matrix. The " marble " is found in veins forming the roof of the lead mines at Bleiberg in Carinthia, Austria, and also in Astrakhan, Russia.

Fossil coral limestones produce intriguing " marbles " and the fossils form diverse patterns. Such is the " red Ogwell marble," which contains the coral known as *favosites*. The so-called *Petoskey stone* from Michigan in the United States is a fossil coral limestone.

The encrinital limestones are usually fawn to reddish-brown in colour and are prettily marked by the broken stems of the crinoids (sea lilies). Such marbles are abundant in the Derbyshire quarries.

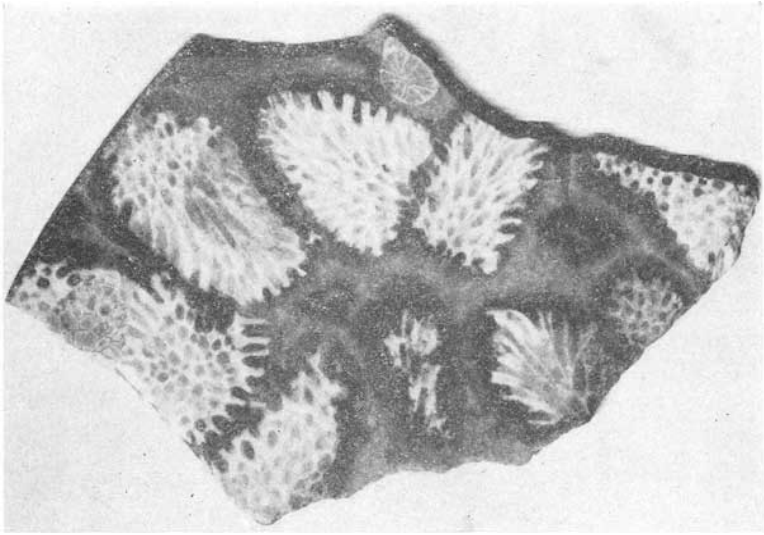

"*Fossil marble.*" *A limestone containing the fossil coral* Favosites cervicornis, *from Torquay, Devon.*

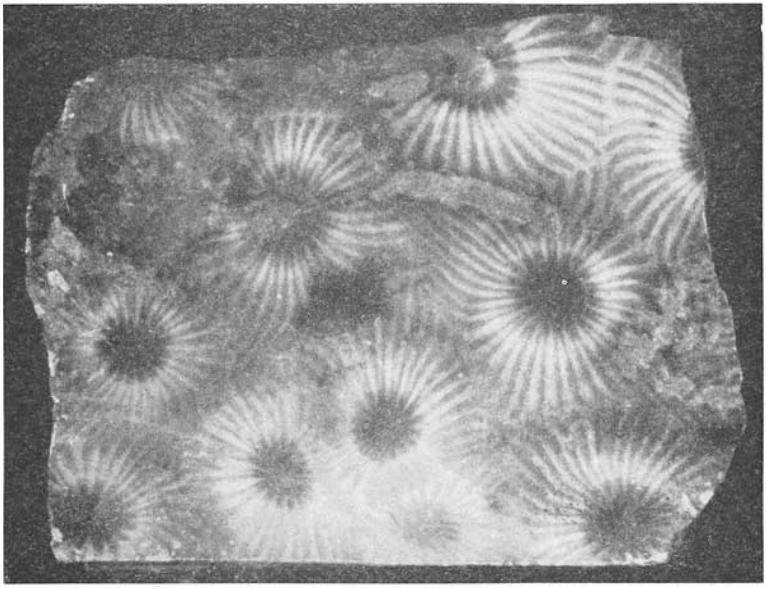

"*Fossil marble.*" *A fossil coral limestone. The coral is* Thamnastræa.

The so-called " Hopton Wood marble " from Middleton and the " Bird's-eye marble " from Ashford are Derbyshire encrinital " marbles," and many such " fossil marbles " are found elsewhere.

The " landscape," or " Cotham, marble " is a light fawn-coloured rock, having dark brown, nearly black, dendritic markings throughout, which are said to have been caused by the infiltration of ores of manganese and iron into the soft calcareous mud from which the rock originated. These dendritic or arborescent (tree-like) markings frequently show patterns on the polished surface of the rock which simulate trees and other vegetation. The "marble " is somewhat scarce and specimens are mostly reserved for museums. The " marble " is found near the base of the White Lias of the Rhaetic beds and is mined at Cotham, a district north of Bristol.

" Florence marble," or, as it is better known, " Ruin marble," is a calcareous marl of greyish-green colour which has suffered fracture in straight angular pieces. A polished slice of the "marble" shows, owing to infiltration of iron oxide, yellowish sections, and the general picture appears like a panorama of ruined buildings, and when viewed at a distance appears like a drawing in bistre. It is a common occurrence in the Val d'Arno near Florence in Italy.

PROCESSES OF MANUFACTURE

The working of " marble " may best be described by telling how " onyx marble " articles are manufactured. The large blocks of " marble," often six or more feet long and weighing two to four tons, are first " slabbed." This is carried out by using a battery of thin soft iron blades some four inches in width, which are held in an iron frame suspended above the block of stone. The saw, which has the blades set about three-quarters of an inch apart, is swung to and fro in a flat arc, and is gradually lowered so as to cut through the stone, which it does at the rate of about one inch in an hour. The cutting action is obtained by the use of carborundum powder, sand and water, which is continually sprayed over the saws and stone.

The slabs are then examined for cracks and " sugary " veins, areas which do not take a good polish, by splashing with water, which shows up the flaws. The clean areas are then marked and cut out by thin carborundum wheels (between one-eighth to one-quarter of an inch in thickness), which are lubricated by a slow stream of water.

These good slabs are then marked out by the aid of templates to the size and shape required for the article to be made. The piece is roughly ground to shape on a rotating wheel, and then to a more accurate outline on another and smoother wheel.

The processes so far described apply to the thin slabs required for the manufacture of cigarette boxes and some clock cases. When the piece is for ashtrays and larger objects with curved surfaces a suitably sized piece of marble is turned on a lathe, using high-speed steel turning tools to cut the marble. The rough turning is followed by a fine grinding, using a mixture of carborundum and snakestone which smooths away the rough marks made by the grinding.

The initial polishing is carried out on a lathe running at high speed, using spirits of salts (hydrochloric acid) and putty powder (tin oxide) as polishing media. In the case of flat pieces this initial polishing is carried out after any necessary milling of grooves to take hinges or inlays, but, instead of using a lathe, the polishing is carried out on a large horizontal felt lap dressed with putty powder and salt of sorrel (an acid potassium oxalate). The final polishing is done by hand, using a felt-covered board impregnated with putty powder and salt of sorrel, which gives to the marble a fine glass-like gloss.

The hardness of pure crystals of calcite is 3, calcite being the standard 3 for Mohs's scale, but owing to the admixture of impurities marble may in some cases be slightly harder. The purest true

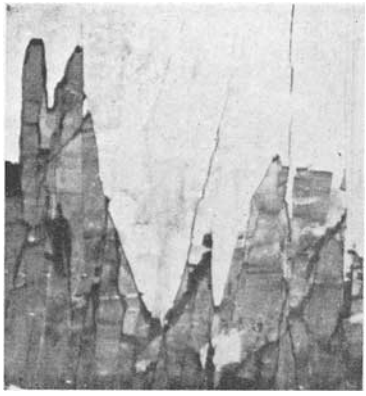

"*Ruin marble.*"

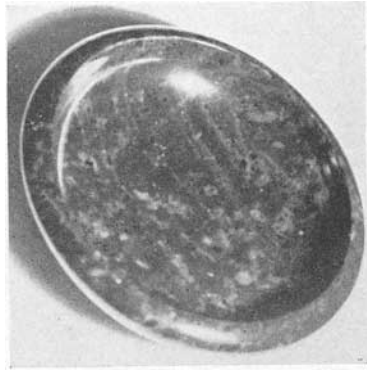

A brownish-red serpentine ashtray. Lizard, Cornwall.

marbles, such as the white statuary marbles from Carrara, break with a sugary (saccharoidal) surface, while the fracture in limestones is usually much smoother. The refractive indices of calcite are 1·658 for the ordinary ray and 1·486 for the extraordinary ray, but in the compact and granular marbles the most pronounced edge seen on the refractometer is that of the extraordinary ray at 1·48, which can sometimes be seen to move upward on rotation of the specimen, but the ordinary ray is seen with difficulty, if at all, much depending on the granular size of the calcite crystals. The limestones generally show an indistinct edge at about 1·50.

The density of pure calcite is 2·71, but in marbles and limestones there may be, and usually is, a lowering of the density due to the granular nature of the crystal aggregates, or the density may be raised owing to the inclusion of other minerals. The range of density for marbles (and limestones) varies from 2·58 to 2·75.

The absorption spectra of marbles are too vague to be of value in identification, nor does the fluorescence under ultra-violet light help. The luminescent glows exhibited under either wave-band of ultra-violet light, if any fluorescence is shown at all, are patchy, some of the veined material showing up the veins as a whitish glow. Some of the travertines, including Gibraltar Stone, show a bright greenish-yellow glow and a strong phosphorescence under both wavelengths of ultra-violet light. Under X-ray stimulation most true marbles and many limestones show the typical orange glow shown by calcite. As calcite is a carbonate, a spot of acid placed on marble will produce an effervescence. This effervescence is a sure test for marble against some other, but not all, marble-like rocks.

Alabaster

The marble-like massive variety of the mineral gypsum, *alabaster*, a hydrous calcium sulphate ($CaSO_4 2H_2O$), was known from the days of the Phoenicians, the Assyrians and the Egyptians. These peoples made all kinds of beautiful vases and amphorae, and were the first to find out and use its translucent beauty as a medium for direct and indirect lighting. The delicately wrought alabaster vases that were found in the tomb of Tutank-amen were used to illuminate the temples in the land of the Pharoahs.

The purest form of alabaster is white and translucent, but the material is often associated with a trace of ferric oxide, which

produces light-brown and orange-coloured bands and veins, or with other impurities which colour the stone in yellows, browns and black in veins or patches. The softness of the rock, especially when freshly quarried, enables it to be easily carved. Alabaster can be scratched by a finger nail, but to a slight extent the mineral hardens after exposure to the air and then will take a good polish. Moreover, alabaster is sufficiently porous to allow it to be stained and artificial coloration is often carried out.

The formation of alabaster is usually by the evaporation of an enclosed sea-basin, or occasionally the mineral may be deposited from desert lakes. Gypsum is frequently formed in mineral veins where sulphuric acid, derived from the oxidation of pyrites and other sulphides, has acted upon limestone.

Massive gypsum is of world-wide occurrence, but in relatively few localities are quarries worked for ornamental alabaster One of the most important localities is at Castellina in the district of

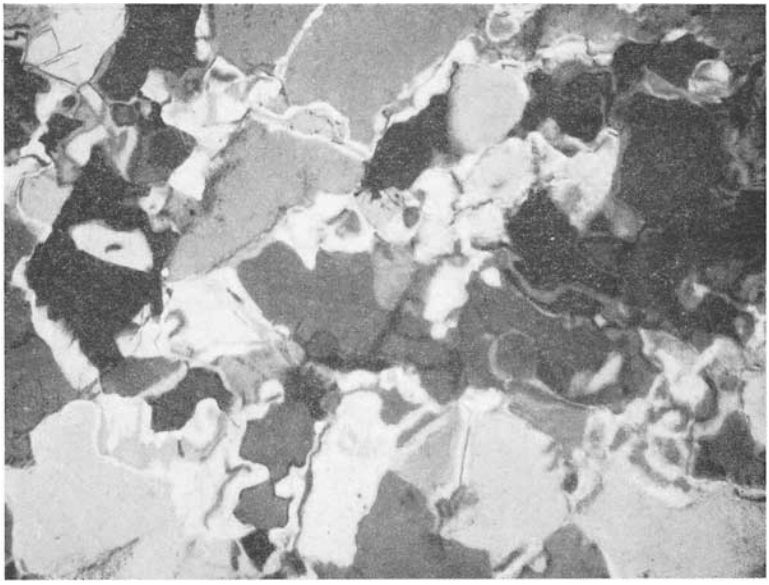

A thin section of quartzite as seen between crossed nicols. The different optical directions of the various quartz grains are shown in this monochrome photograph by the tones of grey.

Volterra, about twenty-five miles north-west of Pisa in Tuscany, Italy. The alabaster of the Volterra district is found in nodular masses embedded in limestone interstratified with marls. The mineral is mainly worked by mining through underground galleries.

The carving of the Tuscan alabaster is carried out not only at Florence and Pisa, but in other cities of Central Italy, and the industry dates from Etruscan times. Some of the pure white alabaster from Tuscany, after carving, is treated by immersion in cold water which is then slowly raised to boiling point. The stone is allowed to cool very gradually and is afterwards thoroughly dried. This treatment is said to make the alabaster scarcely distinguishable from white marble.

The most important quarries for ornamental alabaster in England are in Derbyshire and Staffordshire. The Derbyshire alabaster is found in the south-eastern part of the county, in the neighbourhood of Chellaston, where the mineral is found in thick nodular beds or " floors " and in small lenticular masses termed " cakes." These deposits, which were known prior to the fourteenth century, are close to the surface and are worked by open pit mining. The major Staffordshire quarries are at Fauld near Hanbury, and near Weston, which lies close to the Derbyshire border. There are occasional thin bands of fine granular gypsum of a pinkish colour found along the coastal plain of Glamorgan in South Wales. It is known as pink Welsh Alabaster but is not commercially important.

The fibrous crystalline variety of alabaster which fills veins in rock formations with parallel fibrous crystals stretching across the vein from side to side is called *satin spar*, but it is softer than the similar calcite type of deposit to which the same name is applied. Gypsum satin spar is found at Matlock, Derbyshire, and at Newark, Nottinghamshire.

Alabaster is fashioned, not only for the bowls of indirect ceiling lighting fittings, but for attractive " marble " powder bowls, ashtrays, cigarette boxes, letter weights, pen stands, book ends and other *objets d'art.* The pure white Tuscan material is often carved into figurines having a religious significance.

The hardness of gypsum is given as $1\frac{1}{2}$ to 2 on Mohs's scale, but most alabaster is found to be slightly harder than 2. The fractured surface is more finely granular than the saccharoidal fracture of true marble. Alabaster may vary from material that is highly

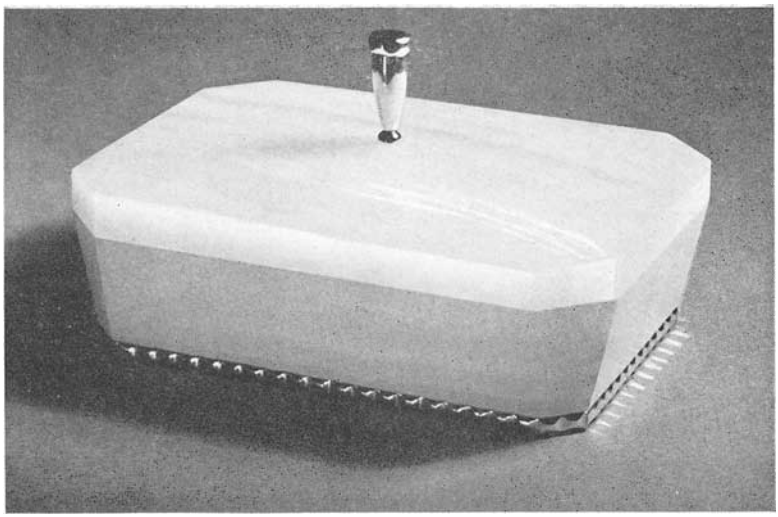

" Onyx " box with metal-gilt base and lid attachment.

translucent to that which is practically opaque, and the lustre is glistening. The refractive indices of gypsum are 1·52 – 1·53, and in the case of the massive variety—alabaster—a shadow edge about this value is moderately clearly seen on the refractometer scale. The density of alabaster lies between 2·30 and 2·33. There is no absorption spectrum of value to be seen in alabaster, and the luminescence under ultra-violet light, usually a brownish shade, gives little aid in distinction. Under X-rays the material is inert.

The Porphyries

Types of igneous rock which show comparatively large and well-formed crystals embedded in a ground-mass of much finer texture are the porphyries. The cause of the porphyritic structure is considered to be a two-stage crystallization, or solidification, of the igneous magma at the time of its intrusion into the surrounding rock or extrusion on to the earth's surface, when the magma contained already-formed crystals enclosed in the molten liquid which subsequently solidified as a fine-grained ground-mass.

Porphyritic structure is common in rocks and it might well be expected that a wide range of such a type of rock could be used as an ornamental " marble." This does not seem to be the case

and only two porphyries have an interest in this work. Moreover, they are interesting for historical reasons rather than as ornamental stones of modern application.

The first of these is the green porphyry found in the Province of Laconia in Greece, a rock with an olive-green ground-mass and light green feldspar crystals sprinkled abundantly through it. The green colour is due to included epidote and chlorite throughout the rock, a rock known in classical times, when, as Pliny records, it was known as *Marmor Lacedæmonium Viride.* It was later known as *Perfido serpentino,* but the rock is not a serpentine. The quarries yielding this rock lie between the towns of Sparta and Marathonisi.

The other, and perhaps more important, porphyry is the famous red porphyry of Egypt, which was known in classical times as *Porphyrites leptosephos* or later as *Perfido Rosso Antico.* This rock has a dark red ground-mass, the colour being due to included piedmontite, a manganese mineral. In this ground-mass is an abundance of small white and light pink feldspar crystals. The rock is quarried from a dyke some eighty to ninety feet in thickness on the Jebel Dhokan mountain, which lies some twenty-five miles inland from the junction of the Red Sea with the Gulf of Suez and about fifty miles eastwards from the Nile. It is doubtful whether the rock was known to the Egyptians ; it was most probably discovered by the Romans in the reign of Claudius, who took it to Rome where it was called *Lapis porphyrites,* and later " The Stone of Rome." During the Roman occupation of Egypt thousands of workmen were employed in the quarries and the stone was transported to the Nile *en route* for the Imperial City of Rome. There may be seen in the British Museum a carved head of the Emperor Hadrian in Egyptian red porphyry. It is said that the carving of this head was carried out by using copper tools fed with sand and emery ; it is presumed to have been made in Egypt near the time of Hadrian's visit to that country about A.D. 130.

Serpentine

Gemmologists meet serpentine in two main forms, the hard massive variety known as *bowenite,* and the " serpentine marble " which occurs in rock masses mixed with other minerals. It is this second type which demands inclusion as a " marble," but bowenite is now so often used for carvings that some mention of this variety is necessary. The origin of the name *serpentine* is in

some doubt. One explanation suggests that the name arose from the ancient view that the mineral was a cure for a serpent's bite ; another, perhaps better, derives the name from the resemblance of the dark-green mottled variety to the skin of a serpent.

Serpentine is a hydrated silicate of magnesium, $H_4Mg_3Si_2O_9$, and crystallizes in the monoclinic system, but the mineral is always massive and is never encountered as crystals. Much has been written on the origin of serpentine and, indeed, there are a number of different geological processes which may produce the mineral by alteration of basic rocks of igneous origin or metamorphic pyroxenes. One of these processes, dedolomitization, has been referred to earlier in this article. Serpentine is soft, about $2\frac{1}{2}$ on Mohs's scale, except in the variety bowenite which reaches 4 or more. The rock-like types may vary also in their hardness owing to the admixture of other minerals.

Most of the bowenite variety of serpentine used so much to-day for carvings and other articles of virtu is a translucent yellowish-green material, which often contains whitish cloudy patches. The density is 2·58 and the mean refractive index—all that is likely to be seen on a refractometer—is 1·52. The absorption spectrum shows bands at 4970Å and 4640Å, but they have little diagnostic value. There is, owing to the iron content which in part gives the green colour to serpentine, little, if any, luminescence under any excitation (X-rays or ultra-violet light).

There is a translucent deep green variety of bowenite found in the South Island, New Zealand, which was used by the Maories, but little dark green bowenite is encountered to-day, nor is the rather coarser dark green bowenite from the Delaware river, Pennsylvania, and Smithfield, Rhode Island, seemingly used. As a matter of interest the density of a Maori ear-pendant in dark translucent green bowenite serpentine was determined as 2·617.

Much light yellowish-green bowenite, in the form of carved figurines, has been exported from China to the Western World under the misnomer " New Jade." It is possible that this material has emanated from Tuoyuan in Hunan province. Bowenite, known to the Persians as *sang-i-yashm*, is found in Afghanistan, and this material is utilized at Bhera in the Shahpur district of the Punjab for the manufacture of dagger hilts, knife handles, caskets, amulets and other articles. Afghan bowenite appears to occur in rock masses at the head of one of the mountain gorges that run

down from the Safed Koh into the valley of the Kabul river.

The most notable source of the " serpentine marble " in classical times was the brecciated serpentine quarried at Casambala, a few miles north-east of Larissa in Thessaly, and known as *verde antico*, or as it was known to the Romans as *lapis Atracius*, for the quarries were near the ancient town of Atrax. It has been reported that the quarries were destroyed by the Germans. Some authorities class the *verde antique* with the ophicalcites. Much fine serpentine is found near Genoa and Levanto in Liguria, and near Prato in Tuscany. These Italian serpentines vary from green to brownish red in colour and often the material is veined with white steatite.

In England the best known " serpentine marble " is that found on the southern promontory of the Lizard peninsula, Cornwall. The Cornish serpentines, of which the major quarries are at Kennack Cove, Kynance Cove, Spernic Cove and Carleon Cove, vary considerably in colour and texture and may be green-veined or spotted with red, brown, or white ; while others may be red or purple to nearly black and relieved by coloured veining. The Lizard serpentine is usually fashioned locally into small wares suitable for the tourist. " Serpentine marble " is found at Rhoscolyn, Holy Island, which lies off Anglesey, Wales. It is known locally as " Mona marble." Another source is at Portsoy, Banffshire, Scotland.

" Serpentine marble " is also found at St. Paul in the French Basses-Alpes and south of Innsbruck in the Austrian Tyrol and at Hof Garstein in the province of Salzburg.

The density of the " serpentine marbles " varies somewhat, as might be expected in such an impure rock as serpentine. The values between 2·5 and 2·6 are those most commonly found in serpentine and in a few cases only have densities been recorded outside this range. The other properties agree, in general, with those given for the bowenite variety, except for the hardness.

A variety of aluminous serpentine is *pseudophite*, or, as it is often miscalled, " Styrian Jade "—a material which has been used to fashion small bowls and ornamental pieces. The material is found at Bernstein, Burgenland, Austria, about 57 miles south of Vienna on the borders of Styria and Austria, a place which, before the Versailles Treaty, was in Hungary. Another material of similar appearance is found at Gurtipohl near St. Gallenkirch, Montafon Valley, Vorarlberg, a province of Austria which lies

between the Tyrol and Lichtenstein. This material is worked as an ornamental stone under the name " miskeyite." Pseudophite is soft, with a hardness of $2\frac{1}{2}$ on Mohs's scale ; the refractive index is about 1·57 and the density 2·69.

QUARTZITE

Just as limestone metamorphoses by heat and pressure into marble so does sandstone recrystallize into a granular mass of quartz crystals. This quartz rock is known as *quartzite*, and such material has been used for carvings and small objects. Often this quartzite rock contains small crystals of mica, or an iron mineral may outline the quartz granules or be scattered as inclusions throughout the rock. In such a manner is produced the well-known aventurine quartzes. When the inclusions are the green chrome mica, called *fuchsite*, the green aventurine quartz is produced, a rock which is often used for beads and other small articles of jewellery, and which is sometimes miscalled " Indian jade." A variety of green aventurine quartz, which is so impregnated with fuchsite mica that it is practically opaque and is often banded with lighter and darker green zones, may be readily mistaken for the green copper mineral, malachite.

The iron-coloured types of aventurine quartz vary from a creamy white to a reddish brown in colour, and a grey quartzite with mica inclusions is known. The creamy white to brown

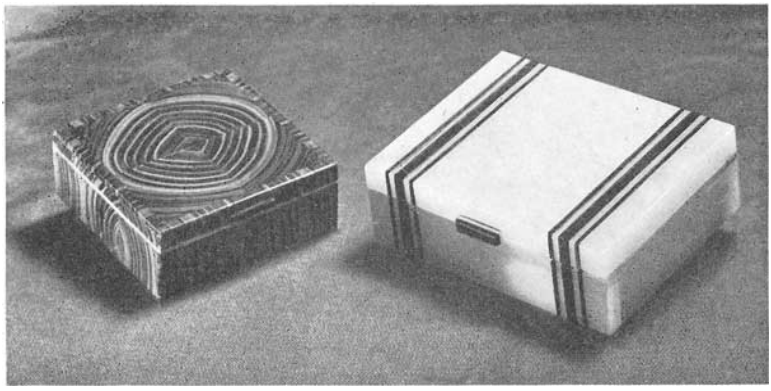

The box on the right is "Onyx" inlaid with malachite. On the left is a box in agate.

aventurine quartz is obtained from Siberia. The beautiful Murchison vase in the Geological Survey Museum at South Kensington is such an aventurine quartz ; the rock from which it is carved came from the Korgon Mountains in the Tomsk division, U.S.S.R. A fine reddish-brown type of aventurine quartz is found at Cap de Gata, near Almeria on the south coast of Spain, and a grey variety comes from Chile.

The green variety of aventurine quartz is mostly found in India, where the rock is obtained from a number of localities. A rich bluish-green aventurine is found near Belvadi in the Hassan district of Mysore, and about three miles north-west, at Sindagere, occurs a banded variety. Other sources in India are in the Coimbatore and Nellore districts of Madras, where, in the latter locality, is found a large-grained quartzite of a delicate pale aquamarine-green colour, banded with deep purple. A vase cut from a nearly pure mica rock of green colour was found at Mohenjo-Daro and was dated not later than 2750 B.C. Some green aventurine quartz is found in Siberia.

The refractive indices of quartzite correspond to those of crystal quartz, but owing to the confused mass of disoriented crystals with which the mineral is composed, a refractometer reading may not be clearer than a vague shadow edge at 1·55. The density, owing to the admixture of other minerals and to the facts that it is not completely homogeneous and may be slightly porous, may be as low as 2·64 and as high as 2·69. The green aventurine quartz shows a red residual colour under the Chelsea colour-filter and this may be used to distinguish it from malachite.

Two other siliceous rocks may be mentioned at this stage. These are the *agate breccia*, in which broken angular fragments of agate have become cemented together by secondary silica, and a conglomerate in which siliceous pebbles have similarly been recemented ; such a conglomerate is the *Hertfordshire pudding-stone.*

The modern tendency to inlay the " onyx marbles " with a mineral of contrasting colour calls for some reference to be made to these colourful minerals.

MALACHITE

The lovely green colour of malachite with its agate-like bandings makes an ideal foil for the creamy-white " onyx marble," and this mineral is extensively used as an inlay in " onyx " clock cases and cigarette boxes.

Essentially a hydrated copper carbonate, $Cu_2(OH)_2CO_3$, malachite is formed by the dissolving of copper ores and subsequent deposition in rock cavities and veins as botryoidal, reniform or stalagmitic masses. These masses are composed of closely packed slender monoclinic crystals in divergent arrangement which produces the botryoidal forms and the circular banding shown by many polished pieces. The hardness of malachite is low, about 4 on Mohs's scale, and the massive material fractures rather easily, although with care it can be turned on a lathe.

The density of the ornamental material—malachite may also be found as an incrustation on other copper minerals—has a mean value of 3·8 but varies somewhat according to the compactness of the crystal aggregates. The refractive indices of the crystals are $\alpha = 1{\cdot}655$, $\beta = 1{\cdot}875$ and $\gamma = 1{\cdot}909$, but all that can be seen on the refractometer scale is an indistinct edge at about 1·65. Malachite is a carbonate mineral and will therefore effervesce when touched with a spot of acid ; it has no distinctive absorption spectrum and does not luminesce under ultra-violet light or X-rays.

Compact malachite, which is now becoming quite scarce, in earlier days came mostly from the copper mines around the Ural Mountains, notably near Nizhne Tagilsk, Perm, Siberia, U.S.S.R. Malachite suitable for cutting is obtained from Queensland, New South Wales, and from the Burra Burra mine, which lies about one hundred miles north-east of Adelaide, South Australia. The

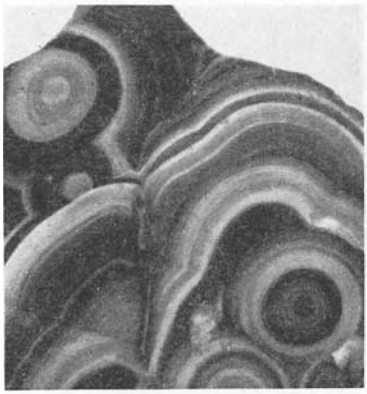

A polished slab of malachite.

Rhodochrosite, showing the banded structure

mines of the Northern Rhodesian copper belt supply malachite, some of which is characterized by the banding being in slender parallel pencil-like lines instead of in curved or wavy forms.

Malachite is often found in intimate association with the other copper carbonate, the deep blue *azurite*. When so associated the two minerals are occasionally cut together to give a banded green and blue material. Such a combination of the two copper carbonates is termed *azur malachite*.

Verdite

Less commonly known than some other ornamental materials, *verdite*, so named from its colour, a deep green which is often speckled with yellow or red spots, was first found during 1907 on the south bank of the Nord Kaap river in the Barberton district of Transvaal, South Africa.

Verdite is essentially a rock and may be referred to as a massive muscovite rock coloured green by the chromiferous mica, fuchsite. The material, although rather soft (3 on Mohs's scale), does take a good polish. The density varies from 2·80 to 2·99 and the refractive index is near 1·58. The absorption spectrum shows three lines in the deep red and a vague line in the blue, a spectrum typically that of a chromium-coloured mineral. Verdite does not luminesce either under ultra-violet light or X-rays.

A similar material has been reported from the Piggs Peak mines, Swaziland, South Africa, and from the western slopes of the Green Mountain range near Shrewsbury, Vermont, U.S.A. This latter material is known as the " green marble of Shrewsbury."

Lapis Lazuli

The beautiful blue stone called *lapis lazuli* has been known from ancient times. The material owes its name, as do several other blue minerals, to the Persian word *lazhward*, which means blue. The colour of lapis lazuli varies from a blue tending to greenish, to a rich purple-blue, the perfection colour being a dark blue of extraordinary depth and intensity. Owing to the inclusion of iron pyrites most specimens show bright brassy specks, which, if not too prominent, are valued as a sign that the mineral is genuine. (This may not be such a sure sign as was previously thought, for it has been reported from America that pyrites has been seen in the blue sodalite from Canada). In olden days the stone was known as

sapphirus, a name which is now applied to blue corundum. That *sapphirus* of classical times referred to lapis lazuli is well shown by Pliny—" In the blue sapphire shine golden specks ; it is like a serene sky adorned with stars, on account of the golden points "—an apt description of lapis lazuli.

Unlike nearly all other gem materials lapis lazuli is a complex aggregate of several minerals, particularly *hauynite* (to which lapis lazuli owes to some extent its beautiful colour), *sodalite* (of which more will be said later), and *noselite*. *Lazurite*, an isomorphous combination of hauynite and sodalite, is also present. In mineralogical works lapis lazuli is often known as lazurite. These four minerals, all belonging to the cubic system, are members of the group of rock-forming minerals known as felspathoids, which are produced when the silica content of the rock is insufficient to complete the formation of true feldspar. There are always present in lapis lazuli both calcite, which produces the whitish parts of the poorer quality material, and, as previously mentioned, iron pyrites. Small amounts of diopside, augite, mica and hornblende are generally present. Lapis lazuli is therefore a rock and not a true mineral.

The indefinite nature of the composition naturally affects the physical properties of lapis lazuli. The refractive index is generally somewhat vague, but a fairly definite shadow edge can be seen on the refractometer at about 1·50. Earlier text books gave the density of lapis lazuli as 2·38 to 2·45, values determined a century ago on small fragments of rather pure material. The commercial type of lapis has a density near to 2·8, but may be anything between 2·7 to 2·9, or over if much pyrites be present. The hardness is $5\frac{1}{2}$. The material is decomposed by hydrochloric acid, giving off the obnoxious smell of hydrogen sulphide. The luminescence of lapis lazuli is not very diagnostic and is limited to orange or copper-coloured patchy glows, usually stronger in the Chilean material than in that from Afghanistan.

The most famous locality for lapis lazuli is in the Badakshan district in the mountainous north-eastern part of Afghanistan, the mines of which have been intermittently worked for six thousand years. They were visited and described by Marco Polo in 1271, but owing to their inaccessibility and remoteness little is known of them. They are near a place called Firgamu on the upper reaches of the Kokcha river, which is a tributary of the Oxus, the rock being

found in a black and white limestone. What are probably the same mines, or another part of them, were described by A. E. Fersman, who visited them in 1930 as one of an expedition to find the " lazurit " which legend said existed in the Pamirs. The party found the way exceedingly difficult, and after reaching some 11,500 feet had to leave the horses and continue on foot along one of the rivers which had the name Liadjuar-Dar , which means " River of Lazurite." On reaching 16,500 feet the party found a great glacier-field covered by immense stones which had fallen from the adjacent steep wall of marble and gneiss. In this snow-white marble were veins and nests of lazurite (lapis lazuli), some bright blue, some delicate blue with beautiful passages into violet and green tints. That the natives knew of this place was given credence when one of the guides said that he had heard of it from his father and that he, with others, tried to reach the place but all contracted mountain sickness and turned back.

The mining of these Afghanistan mines is primitively carried out by heating and quenching the rock in order to obtain pieces of a size, about 10 lbs. each, convenient for bringing out of the inhospitable locality. A quantity of this material reaches Northern India and is made up into jewellery at Lahore.

Amidst the wild Sayan Mountains light blue boulders of lapis lazuli are found in the Slyudanka rivulet which flows into the southern end of Lake Baikal bordering on Mongolia. A paler coloured lapis lazuli is mined in the Chilean Andes, the most important localities being at Ovalle Cordillera, Coquimbo Province, and further north near Antofagasta. On Italian Mountain, high in the Sawatch Range of the Colorado Rockies, lapis lazuli is found in stringers in a limestone rock. This source was discovered in 1939 but has only been worked spasmodically owing to the short season, high altitude and the necessity of removing badly fractured overburden for safety. This material is almost black to an intense blue in colour, contains narrow veins and spots of calcite and is heavily charged with pyrites. The density varies from 2·82 to 2·85. An occurrence of lapis lazuli has been found near the summit of Ontario Peak in the San Gabriel Mountains, Bernardino Co., California, which lies about 40 miles west of Los Angeles. Lapis lazuli is also found in the Mogok Stone Tract, Upper Burma, and some poor quality material has been obtained from Baffin Island, north of the Labrador Peninsula.

SODALITE

Best known to gemmologists as one of the components of the richly-prized lapis lazuli, sodalite became of importance as an ornamental mineral on the discovery in Canada, about 1905, of masses of a rich blue colour.

In composition sodalite is a sodium aluminium silicate with sodium chloride, $3NaAlSiO_4NaCl$. The hardness of the mineral is $5\frac{1}{2}$ to 6 on Mohs's scale and the density varies from 2·15 to 2·35, the massive blue material usually having a value near 2·28. The refractive index, a single index for the mineral is cubic in crystallization, is 1·48.

Blue sodalite has been found in the Langesunde Fiord district of Southern Norway, at Litchfield and West Gardiner, Kennebec, Maine, and at Salem, Essex County, Massachusetts in the U.S.A. The mineral is found, also, in the State of Rajasthan (Rajputana), India. The major commercial source of sodalite is the massive blue material, often speckled with bright red, pink or orange spots, found near Bancroft in the township of Dungannon, Hastings Co., Ontario, where it occurs in segregations in a belt of nepheline-syenite. Other Canadian localities are in the counties of Peterborough and Haliburton, Ontario, and in the rocks of Mount Royal in the City of Montreal in the Province of Quebec.

The Canadian sodalite never reaches the beautiful rich blue of lapis lazuli, the colour being more of a Royal blue. In recent times the material, now often used as an inlay with " onyx marble," has been called *Canadian Bluestone*, or just *Bluestone*.

RHODONITE

A beautiful rose-red translucent marble-like mineral is the massive variety of rhodonite, which in composition is a silicate of manganese, $MnSiO_3$. The material is often veined with black patches and streaks, where part of the manganese oxide has been further oxidized by weathering. Although rhodonite has a wide occurrence, the major localities for the massive material are in the Sverdlovsk district (formerly Ekaterinburg) of the Ural Mountains of Russia Other deposits are in the Vremland district of Sweden, a number of localities in the United States, in Mexico, and in the Broken Hill district of New South Wales, Australia. A small quantity of colourful rhodonite is found in Cornwall, England.

Rhodonite takes a good polish ; the hardness is about 6 on Mohs's scale and the density for the massive material used for

ornamental work lies between 3·6 and 3·7. With such material only a vague shadow-edge near 1·73 can be seen on the refractometer. There is no luminescence shown by the material and the absorption spectrum is not sufficiently distinctive to use for certain identification. Rhodonite so often contains some manganese carbonate that it will effervesce with warm acid, thus this test for the distinction of rhodonite—the silicate—from the manganese carbonate—rhodochrosite—will not be completely satisfactory.

RHODOCHROSITE

The massive rhodochrosite (for the mineral is also found as crystals and granular) usually has a paler and more delicate rose-red colour than rhodonite. Rhodochrosite, the manganese carbonate, $MnCO_3$, is characterized by the lovely pink shade of colour, variegated and in bands. The material may be likened in its banding, but not in colour, to the green malachite ; indeed, as in malachite, the banding is due to stalagmitic formation, the prismatic rhombohedral crystals tending to a radial arrangement.

Although rhodochrosite is found in many different localities, only a few supply the compact material usable as an ornamental stone. The use of rhodochrosite as an ornamental mineral may be said to have begun just before the Second World War, when a quantity of this veined rose-coloured stone came from Argentina. The deposit from which it came was stated to have been found in a long disused mine. The mine, situated on a mountain fissure, at a high altitude, was thought to have been worked by the Incas for silver and copper during the thirteenth century. It was owing to this connexion that the name " Rosinca " was given to the stone. Colorado, Montana and other States of the North American continent are sources of the mineral. Roumania, Hungary and Freiberg, in Saxony, are other localities, but these are unimportant as sources of supply.

The hardness of rhodochrosite is near 4 on Mohs's scale ; the density lies between 3·45 and 3·60 (although higher values have been recorded—possibly for the purer crystals) The refractive indices are 1·820 for the ordinary ray and 1·600 for the extraordinary ray, the large double refraction being characteristic of a carbonate mineral. The fact that ornamental rhodochrosite is a crystalline aggregate precludes the large double refraction being of value, for only a diffuse shadow-edge will be seen on the refractometer. The

absorption spectrum of the mineral shows a band at 5510Å (and other vaguer lines), but they scarcely assist identification. Under the stimulation of ultra-violet light a dull red glow was observed in samples of the mineral from Argentina and from Colorado. The material effervesces with acid, but, as mentioned under rhodonite, the test is not conclusive.

THULITE

The massive pink variety of zoisite known as thulite, after Thule, the ancient name for Norway, is occasionally used as an ornamental stone. The mineral has a pleasing pink colour which is often variegated with white areas, but thulite is less common than many other ornamental minerals used as inlays with " onyx marbles."

Zoisite is a hydrous calcium-aluminium silicate, $Ca_2Al_3(SiO_4)_3(OH)$, and crystallizes in the orthorhombic system. Thulite has a hardness of 6 on Mohs's scale and the material has a density which does not vary greatly from 3·10. The refractive index, at least as far as concerns the vague shadow-edge that can be seen on a refractometer scale, is near 1·70. There is no typical absorption spectrum, and, except in the type from North Carolina, which is said to glow orange-yellow under long-wave ultra-violet light, thulite does not fluoresce, although a weak rose-coloured glow with slight phosphorescence may be seen with X-rays.

Thulite is found in the parish of Souland in Telemark, in Trondhjeim and near Arendal, Norway. Other localities are in the Zillertal, Tyrol and Mitchell Co., North Carolina, U.S.A.

Mention may be made that the massive granular green zoisite in which the magnificent, but opaque, ruby crystals from Tanganyika are found, has been cut complete with the included rubies as a bowl.

FLUORITE (FLUORSPAR)

Apart from its occasional use as an inlay, massive fluorspar, particularly the *blue-john* variety, has been worked in its entirety. The most important is *Derbyshire spar*, or, as it is more popularly called, *blue-john*, a mineral which has been used since Roman times for making vases and other decorative objects. Prettily patterned in curved bands of blue, violet and purple, the last often so deep in colour as to appear black, on a reddish or a colourless ground, blue-john is unique in having only one source of supply, that is at

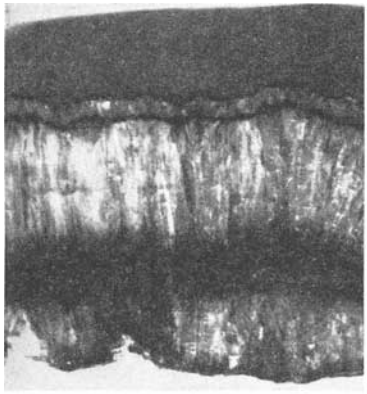

A polished slice of blue-john.

Treak Cliff, an outlier of the Mam Tor range near Castleton, in the Kinderscout district of Derbyshire—a source which is now said to be exhausted. The blue-john mine was driven for lead ore and consists of a number of workings opening out of a fine range of caverns, where often the beautiful fluorite is not at first seen owing to the complete covering of the rock face by stalagmitic formations. The mineral is in nodular masses and veins in oolitic limestone (aggregates of little spherical deposits of carbonate of lime which have formed as concentric crusts around nuclei—sometimes a grain of sand or a minute organism), and tends to be botryoidal in form and shows when broken the typical radial and banded structure.

The amethystine colour of blue-john has been variously said to be due to traces of manganese, impurities of a vegetable origin and/or crude petroleum, and also to a physical disarrangement of the crystal lattice, possibly from radio-active emanations. The most usual explanation given to account for the colour is that a pulsating flow of hydrocarbon-rich liquid during the crystallization of the fluorite caused the banded colour.

The fashioning of small objects of blue-john is carried out by first rough grinding the piece of rock to the requisite shape by the use of a foot lathe, a method which gives complete control through varying speeds. The roughly shaped piece is then finely surfaced with a Water-of-Ayr stone, after which crocus powder (a coarse-grained iron oxide, a coarse rouge) is used on a revolving felt pad to smooth the surfaces and put on a semi-polish The final glazed polish is put on by using putty powder (tin oxide) in conjunction

with a power-driven lathe. For larger pieces, owing to the fact that the rock is chiefly composed of an aggregate of friable crystals, it is necessary to " bond " them after the piece has been cut to a suitable shape by a copper disc charged with emery or carborundum powder. The sawn piece is therefore heated in a natural resin which runs between the cracks of the aggregate of crystals, effectively " bonding " them. The bonding process needs to be repeated continuously as the work of turning on the lathe is carried out. This turning is done with high-speed steel tools.

While not exhibiting the beautiful bands of colour shown by blue-john, several other types of massive fluorspar have been used for carving and inlays. One variety is nearly colourless but veined with yellowish-brown markings, and another type has a strong violet-blue colour in which the aggregate nature of the crystals forming the piece can be clearly seen. Massive fluorite of a full yellow colour is the so-called *Ashover spar* obtained from the Ashover quarries, Derbyshire, and a massive green fluorspar also has a vogue for carved pieces.

A table lamp in massive green fluorspar.
Photo : B. W. Anderson.

Fluorspar is crystallized calcium fluoride (CaF_2), which has, for crystals, a density of 3·18, but the massive types, owing to contamination with impurities and the crystalline aggregate nature, may vary in density between 3·00 and 3·25. The refractive index is 1·434, there being only one index since the mineral is of cubic crystallization. The absorption spectrum of fluorspar is in general too vague and indecisive to be of value as a test, and, unlike most crystallized fluospar, blue-john does not luminesce ; nor to any extent do the other massive types. The hardness of fluospar is 4.

Lepidolite

The massive fine-grained granular lepidolite, or *Lithia mica* as it is well known, has been polished into slabs when the mineral is of a rich rose-red to lilac-red colour. It could make excellent inlay material. The hardness of the massive lepidolite is about 3½ on Mohs's scale and the density, according to most authorities, varies from 2·8 to 3·3. A determination on an actual piece of the massive material gave a value of 2·82. There is no distinctive absorption spectrum and no luminescence with lepidolite. Massive lepidolite is found in the Ural Mountains of Russia, in Madagascar, and in California, Maine and Connecticut, U.S.A.

Feldspar

The variety of oligoclase feldspar known as *sunstone* or *aventurine feldspar* was first described from the southern coast of Norway, where it is found at Tvedestrand and Hitero. The material contains microscopically thin platy crystals of hematite which reflect the light as sparkling red-gold rays. Oligoclase is an intermediate member of the series of triclinic feldspars known as the plagioclases, the end members of which are albite ($NaAlSi_3O_8$) and anorthite ($CaAl_2Si_2O_8$). The hardness of the mineral approximates to 6 on Mohs's scale and any fracture is overshadowed by the two directions of easy cleavage—a dangerous weakness in fashioned material. The density of sunstone is 2·64, and the refractive indices are 1·535–1·544, but only a vague reading may be seen on the refractometer. Apart from the Norwegian source, where the mineral occurs as irregular masses in veins of white quartz traversing gneiss, the other localities for sunstone are at Verkhne Udinsk on the Selenga river near Lake Baikal, U.S.S.R., and at Mineral Hill, Delaware Co., Pennsylvania, U.S.A.

The greyish feldspar known as *labradorite* shows the most brilliant interference colours in sweeping flashes of blue, green, gold, red and orange and shows them best when in plates of fair size with flat polished surfaces. Labradorite is nearer the anorthite end of the plagioclase series, hence the refractive indices are higher than for sunstone, the values being 1·56–1·57, and the density is 2·69. There is no significant absorption spectrum nor is there any luminescence. The coast of Labrador, Canada, is the source of most ornamental labradorite. Canada also provides another ornamental feldspar, *peristerite*, a pale flesh-pink feldspar with an attractive pale-blue flash. Peristerite is a variety of albite and in this case the constants will be lower. The density is 2·62 and the refractive indices 1·53–1·54.

There is no end to the number of rocks and minerals that could be utilized for ornamental purposes, but those which have been mentioned are undoubtedly the more important. One more " marble " may be mentioned, particularly as from its appearance it might be thought to be a " fossil marble." This rock is the orbicular diorite of Corsica (*corsite* or *napoleonite*). The orbicular structure shows orbs and spheroids composed of the same minerals as the parent rock arranged in light and dark concentric layers with a radial or tangential arrangement. The structure is believed to be due to crystallization around solid fragments in varying conditions of temperature, pressure or condition of volatiles in solution. Liesegang, in 1913, ascribed the structure to rhythmic supersaturation and precipitation in a crystallizing magma. Orbicular diorite has been used for the bodies of large ornamental vases.

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ASSOCIATION NOTICES

HERBERT SMITH MEMORIAL LECTURE

THE fourth Herbert Smith Memorial Lecture was given by Professor S. Tolansky, F.R.S., in the lecture theatre of the Science Museum, South Kensington, London, on 2nd April, 1958. This lecture has become one of the annual highlights of gemmology. Professor Tolansky chose as the title of his talk " Studies on the surfaces of diamonds " and though he did not delve farther into the diamond than a few atoms' depth below the surface, depth of interest was unfathomed. For the trigons and etch-marks on the surface of every diamond—and Professor Tolansky has proved by his searching photographic methods that every octahedral face of diamond bears these marks and pits—made an entrancing subject that turned an hour, seemingly, into little more than a minute. The chairman, Mr. Knowles-Brown, introduced the speaker.

Professor Tolansky has been working on diamond for some ten years, and in the course of his researches he has developed special recording instruments. Many years ago, he was handed a fine diamond on which, said the owner, he defied him to find any trigons. Professor Tolansky set to work. On one side, true, there were only about a million, on the other about a million and a half. So shaken was the owner, that he thereupon gave Professor Tolansky the diamond.

Professor Tolansky's work has been concerned entirely with the surface of the stone, and he has christened his study " microtopography." He showed the close relationship between this work and that of the geographer by a series of photographs of the contours of the diamond's surface. The technique he uses is one of multiple beam interference, based on the theory of Newton's Rings, which gives a contour map of the surface, and by means of which extremely

minute variations in the surface can be measured. Silver is evaporated on to the surface of the diamond and on to the lens being used for detection and by this means the masses of trigons can be detected—looking like a thousand wigwams, but in truth only a few atoms deep. Professor Tolansky's technique of crossed fringes gives very sharp definition of the surface variations, and he believes trigons, which are found only on the octahedral faces, to be growth marks. Diamond, he considers, grows in sheets travelling in three directions at 60 degrees to one another. If the process is stopped, one is bound, therefore, to get an equilateral triangle, a trigon. For this reason, too, all the trigons are orientated in the same way.

Etch pits, on the other hand, are not quite rectilinear, and are not orientated in the same way. Professor Tolansky contends that it is very easy to etch diamond, at the very critical temperature of 475 to 500°C. An etched octahedral face will show trigons with their points to the side, etch pits parallel to the side ; etch pits will eat into one another, though they are still extremely shallow, and will form a pattern of blocks, each at an angle of 60 degrees, that looks like " the Manhattan skyline."

The etching of cleavage planes produced a most interesting effect. By etching matched faces of a cleaved diamond, the one part showed an exact 1 : 1 correspondence with the other part. This showed, therefore, that etching revealed something of the molecular growth of diamond, the etching preferentially attacking slight flaws or weaknesses in the planes of growth. If the surface was cracked, Professor Tolansky likewise found that the diamond took the etching preferentially. Diamond cracked far more easily than most scientists thought, and, in conjunction with the late Dr. Grodzinski, he had found that a hemisphere of diamond pressed into the surface of another diamond would crack with as little as 10 to 15 lb. load. He had been able to watch these cracks grow, and to photograph them. They were shallow, with the inside of the crack flat, bounded by two sharp " hills," perhaps either plastic flow, though the crack was produced at room temperature, or elastic. Multiple cracks showed the tiny heights to be jagged. On the dodecahedral faces, the cracks tended to be distorted, but on cubic faces there was a tendency towards squareness, even though the pressure was exerted by a round ball.

Ring-cracks found on diamond were probably due, believed Professor Tolansky, to the crushing machine, for diamond did not

seem to be so hard that minute surface variations could not be caused quite easily. Etching brought out these ring-cracks, the hot oxygen eating into them. Etching was produced in nature providing the critical temperature and oxidation conditions were present.

Professor Tolansky, answering a number of questions from members of the audience, said that he would not commit himself about the genesis of diamond, but he believed that it was laid down in sheets, judging from the cleavage and etch patterns he had observed. The significance of trigons seemed to be that there was no sign of a spiral growth in the diamond crystal. Asked by Mr. B. W. Anderson if he had any evidence of change of habit during the growth of the crystal, Professor Tolansky said that he had not, but that some diamonds showed a change from Type I to Type II cleavage, that is, from irregular cleavage to smooth, almost perfect cleavage.

The meeting concluded with a vote of thanks from the vice-chairman, Mr. Norman Harper.

EXAMINATIONS IN GEMMOLOGY

The 1958 examinations of the Association were held at the end of May in the United Kingdom and various oversea centres including the U.S.A., Canada, the Netherlands, Norway, Australia, Southern Rhodesia, India, Ceylon, Switzerland, New Zealand, Thailand, South Africa, Hong Kong, Indonesia.

The Council of the Association is grateful to the gemmological organizations, universities, colleges and other educational authorities who kindly assisted in the proctoring of the examinations. In all 143 candidates sat for the preliminary examination and 100 for the diploma.

BRANCH MEETINGS

West of Scotland. The guest speaker at a meeting arranged by the West of Scotland Branch on 8th May was Mr. B. W. Anderson, B.Sc., F.G.A., who gave a talk on synthetic gemstones and their detection.

A successful summer outing was also arranged by the Branch on 8th June, when mineral localities in East of Scotland were visited.

The fifth annual meeting of the West of Scotland Branch was held at the Royal Hotel, Glasgow, on 5th May, 1958.

The Chairman, in reporting upon the work of the year, thanked those members who had contributed to the success of the branch.

The retiring office bearers, Mr. J. D. S. Wade, Chairman, and Mr. C. D. Wade, Secretary, were re-elected. Messrs. S. Ramsay, E. Macdonald and W. Ferguson were elected to serve on the committee.

Midlands. On 4th May members of the Midlands Branch visited the blue-john mines at Castleton and Chatsworth House, home of the Duke of Devonshire.

GIFTS TO THE ASSOCIATION

The following gifts to the Sir James Walton Memorial Library are gratefully acknowledged by the Council :

A fine copy of the first edition of Max Bauer's *Edelsteinkunde*, from Mr. T. Stern.

A selection of mineralogical books, from Mr. R. Webster.

Samples of emerald and beryl from the Belingwe district of Southern Rhodesia, from Mr. Lewis Jason.

Two note-books of the late B. J. Tully and other books, from Mrs. F. L. Tully.

Synthetic emerald crystals made by Professor Nacker in 1926, emerald-coloured tourmaline from Usakos, S.W. Africa, and an emerald-green glass from Czecho-Slovakia, from Mr. George Wild.

COUNCIL MEETING

A meeting of the Council was held at Saint Dunstan's House, Carey Lane, London, E.C.2, on 17th June, 1958. Mr. F. H. Knowles-Brown presided.

The Council decided that, as from 1st January, 1959, the Fellowship and Ordinary Membership subscriptions should be £2 2s. 0d.

A report on the holding of the London section of the examinations at Goldsmith's Hall was considered and the Council recorded their indebtedness to the Goldsmiths' Company for so kindly making the Livery Hall available. The Council also recorded their appreciation of the work of Mr. R. Webster in connexion with the examinations.

The following were elected to membership :—

Fellowship

Crichton, John M., London D.1955
Harkins, Thomas, Glasgow D.1949
Lauvland, Karl, Norway D.1957
Swettenham, George W., Cranham D.1951

Probationary

de Lema, Audrey (Mrs.), Medellin Colombia
Mowbray, Terence W., London
Tungate, James B., London

Ordinary

Britchfield, Charles F., Gravesend
Brown, John C., Broxbourne
Cheng, Cho-Cheong, Hong Kong
Etienne, Lorette (Mrs.), Bangkok Thailand
Gryska, Stephen, Worksop
Hiralal, Manu M., London
Millar, Hugh H., Detroit, Mich., U.S.A.
Relwani, Arjan C., Calcutta India
Schoppy, John D., Ventnor City New Jersey, U.S.A.
Smith, Charles W., Baltimore, Maryland, U.S.A.
Thomson, Patrick N., London
Tolat, Fulchand C., London

Removal from Register

The Council authorized the removal from the Register of the following :

Fellows

Gale, Herbert C. Pyke, William Stockwell, James C. Yaghobi, Hadi

Ordinary Member

Law, Leslie

Elections to membership at the October, 1957, meeting of the Council were:—

Fellowship

Armbrecht, Bertram J., London D.1957
Blackmore, Howard L., Caterham D.1957
Cook, Walter G., Liverpool D.1957
Cooper, Colin Lester, Cape Town, S. Africa D.1957
Cope, John R., Nottingham D.1957
Gaudernack, Rolf, Oslo, Norway D.1957
Holland, Norman A., Birmingham D.1957
Kelly, William H., Glasgow D.1957
Lauder, Angus D., Edinburgh D.1957
Leake, Douglas M., Nuneaton D.1957
McKay, Robin I., Thames Ditton D.1957
Meanwell, Brian S., Birmingham D.1957
Pedersen, Erik M., Lillehammer, Norway D.1957
Strange, Peter J., London D.1957
Warrender, John S., Sutton D.1957
Weiss, Kurt, London D.1957
Ystad, Per T., Porsgrunn, Norway D.1957

Transfer from Probationary Membership to Fellowship

Weatherill, John, Cardiff D.1957
Hatcher, June A. (Miss), Birmingham D.1957
Drapkin, Clive M., Birmingham D.1957
Cassarino, Joseph A., New York, U.S.A. D.1957

Transfer from Ordinary Membership to Fellowship

Weaver, Gerald, O. London D.1957
Diss, Geoffrey D., Barrow-in-Furness D.1957
Flapper, Jan, Arnhem, Holland D.1957
Grimsdell, John L., London D.1957
Hadjizade, Ahron, London D.1957
Jones, Wilfred R., Auckland, New Zealand D.1957
Solman, Barbara (Mrs.), Worcester Park D.1957
Macleod, Hector M., Glasgow D.1957
Seager, Philip, Abingdon D.1957
Seneviratne, D., London D.1957
Hopkins, Iris P. (Miss) London D.1957
Jank, Robert A., Boscombe D.1957

Probationary

Coakley, Brian, Manchester
Rushworth, Jack, Halifax

Ordinary

Baeta, Carlos, Lisbon, Portugal
Baldinger, Kurk, Cape Town, S. Africa
Barwell, Alfred H., London
Biggers, Willard B., London
Bruford, Alan P. W., London
Carr, Arthur G., Rio de Janeiro, Brazil
Crawford, Andrew, Birmingham
Delario, Anthony J., Paterson, N.J., U.S.A.
Hamilton, Douglas P., Glasgow
Norris, Aubrey, Maidenhead
Rafee, M. A., Karachi, Pakistan
Rose, Jack A., Newcastle-upon-Tyne
Safiyulla, M. T., Colombo, Ceylon
Stern, Hermann, London
Suresh, Choksi, London
Welford, Dorothy A. (Mrs.), Winchester
Wells, Charles L., Jr., Jacksonville, Florida, U.S.A.

ITALIAN GEMMOLOGICAL LABORATORY

The British Consul in Turin and the First Secretary (Commercial) of the British Embassy in Rome recently paid a visit to the gemmological laboratory at Valenza which is run by Professor Speranza Cavenago-Bignami, a member of the Association.

TALKS BY MEMBERS

LEIPER, H. : " The fascination of faceting," California Federation of Mineralogical Societies, San Bernardino, Cal., 21st June, 1958. Mr. Leiper, a Fellow of the Association, is now associate editor of the Lapidary Journal, Del Mar, California.

MELROSE, R. A. : " Diamond and diamond cutting," North Shields Rotary Club, 18th February ; " Synthetic Gemstones," Newcastle-upon-Tyne Hadrian Round Table, 26th February ; " Art of the Jeweller," Association of Home Economists, 7th March ; " Gemstones," Tynemouth Business and Professional Women's Clubs, 2nd April ; " Story of Diamonds," Chester le Street Business and Professional Women's Club, 15th April ; " Antique and Modern Silver-ware," Newcastle Business and Professional Women's Club, 30th April ; " Precious Stones," Ashington Business and Professional Women's Club, 27th May ; " Gemstones," Newcastle-upon-Tyne Round Table, 1st July.

OLIVER, R. J. N. : " Gemstones," to Liverpool Round Table No. 8, 4th June, 1958.

FORTHCOMING MEETINGS

The 1958 presentation of awards will be held in London on Tuesday, 11th November, at 7 p.m.

CORRECTION OF MEMBERSHIP REGISTER

Mrs. Vera Hinton, F.G.A. was elected to Fellowship on 6th February, 1958, and not as an ordinary member (Vol. VI, No. 6, p. 290

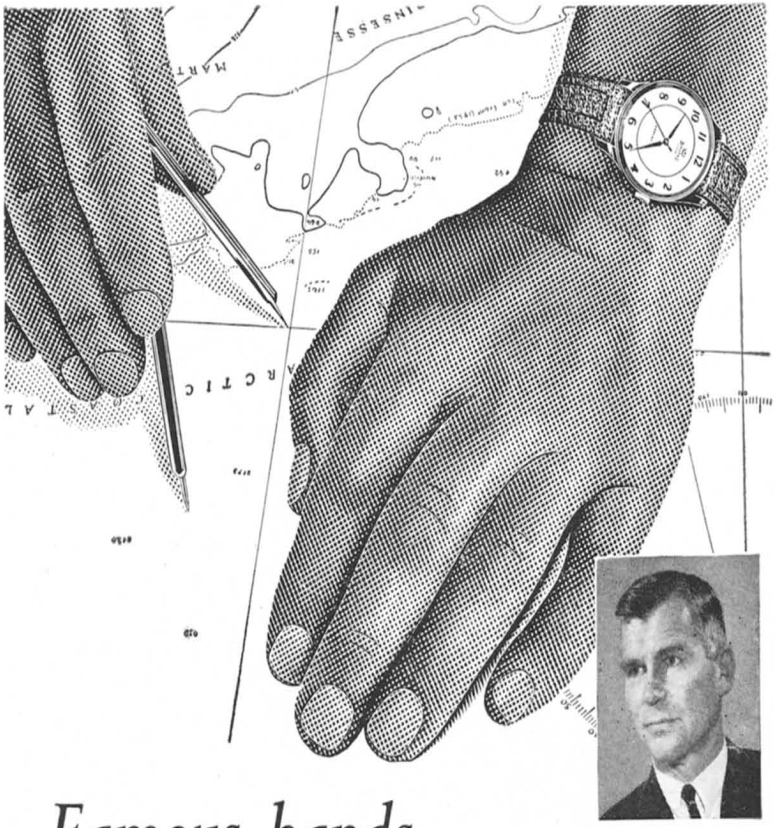

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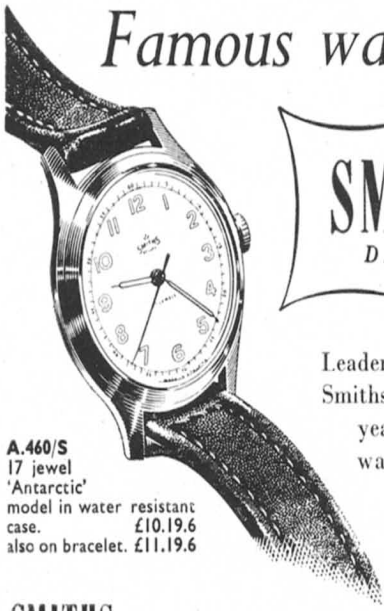

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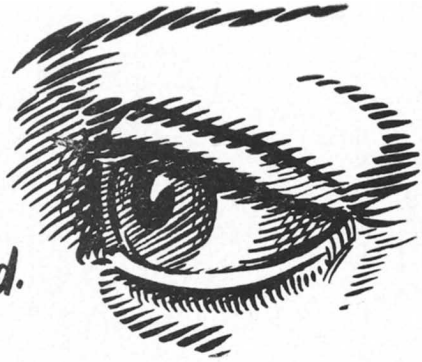

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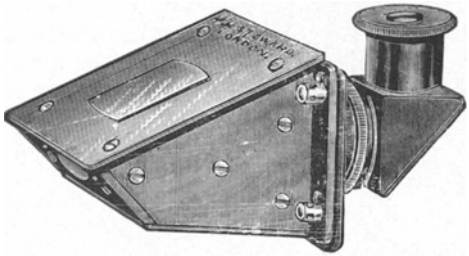

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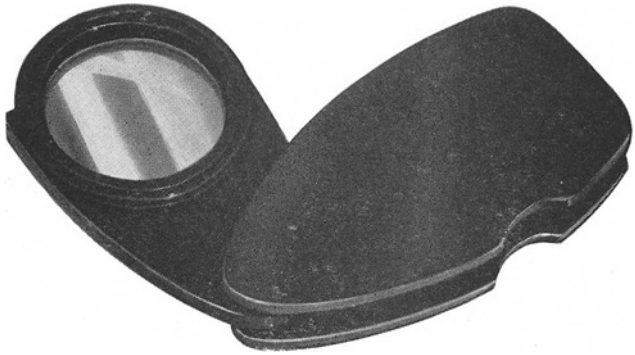

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Vol. VI
No. 7
July, 1958

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THE JOURNAL OF GEMMOLOGY

and

PROCEEDINGS OF THE GEMMOLOGICAL ASSOCIATION OF GREAT BRITAIN

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OF GREAT BRITAIN
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INCLUSIONS IN SANDAWANA EMERALDS

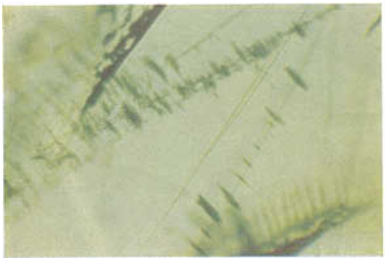

Lines of parallel fissures.

Typical "splashes."

Tremolite fibres.

Tremolite fibres.

Flat liquid film.

Brownish garnet with halo.

THE JOURNAL OF GEMMOLOGY
AND PROCEEDINGS OF THE GEMMOLOGICAL ASSOCIATION OF GREAT BRITAIN

Vol. VI No. 8 OCTOBER 1958

EMERALDS FROM SANDAWANA

By E. J. GÜBELIN, Ph.D., C.G., F.G.A.

IT is most pleasant and gratifying that even in this atomic age of sophistication and technique, which seems to foresee everything by means of reason and computation, the realm of gemstones has not lost its nimbus of romance and adventure and that now and then new gems or new gem localities are found.

In October, 1956, the prospectors, Laurence Contat and Cornelius Oosthuizen, who had been attracted by the advantageous offers made to prospectors by the Rhodesian Government, happened to investigate the rocks near the valley of Sandawana in the Belingwe district of Southern Rhodesia together with their " prospecting boys" —native helpers—trained to look for unusual rock yields. Having a good knowledge of geology, Contat and Oosthuizen decided to concentrate on a small area showing the most favourable conditions for the occurrence of large pegmatites. They were not disappointed. Within ten days after their arrival they discovered the first emeralds and they ordered their boys to fan out in a more intensified search, but it was seven months before they struck the second deposit—a rich one this time.

The first samples were taken to Mr. A. E. Phaup of the Geological Survey Office at Gwelo, who confirmed the gem's nature.

The Department of Mines was then informed, but the Southern Rhodesian Government was not very much interested in this find until they heard that Contat and Oosthuizen had sent emeralds worth about US$15,000 to New York. An ordinance was then passed in February, 1958, by which all precious stones in Rhodesia were subject to the same control regulations as those in South Africa. At first the rumours mentioned a diamond find, but when the law was gazetted on 25th April, 1958, it was known everywhere that emeralds had been found.

The writer was then asked to investigate these newly found emeralds in order to find out their local peculiarities and other typical characteristics that would distinguish them from emeralds from the already known sources which have been thoroughly examined and are known to well-informed gemmologists. An initial lot of 92 stones was submitted to him and it appeared appropriate to carry out an extensive study so that comparison could be made between these new emeralds and those of other provenance with the hope of ascertaining some locally typical features which might differentiate them from others.

Occurrence

The emerald occurrence of Sandawana is in very isolated country on the south side of the Mweza Range of mountains and so far only little geological and petrological investigation has been carried out. The position is roughly longitude 29° 56′ east and latitude 20° 55′ south. The Mweza Range is composed of very old pre-Cambrian rocks extending for some 45 miles (72 km.) east-north-east in a huge area of granitic rocks that are also of pre-Cambrian age. The range is two to three miles wide (3 to 5 km.) and rises about 500-800 ft. (150 to 200 m.) above the surrounding country.

The metamorphic rocks forming the range belong to the Bulawayan System of Southern Rhodesia and are probably 2,700 to 3,100 million years old. They have been tightly folded into a complex structure with a general direction east-north-east and very steep, almost perpendicular. On the flanks of the range the rocks are basaltic lavas and dolerites that have been metamorphosed into greenstones and epidiorites composed of amphiboles (chiefly hornblende), sodic feldspar and clinozoisite. The core of the range is a variety of banded sedimentary rocks that have been meta-

morphosed and now contain micas, almandine garnet and various amphiboles, including grunerite. They consist of banded iron-stones, phyllites, sericite-quartz schists and quartzites. Very long, narrow sills of peridotites were intruded into these older rocks and have been altered into serpentine and related rocks.

The rocks forming the range were folded, metamorphosed and intruded by granitic rocks at the end of the Bulawayan times and again at the end of Shamvian times about 2,650 million years ago. A batholitic mass of granitic rocks extends for over 20 miles (32 km.) in all directions from the range and small stocks were intruded into the schists of the range and the gneissic granite contact around it. The emeralds have been found associated with the pegmatite dykes in the tremolite schists. The majority of the dykes probably belong to the end of the Shamvian System and contain beryl, lepidolite, petalite, spodumene and tantalum-niobium minerals. The intrusion of the granitic magma into the tremolite schists caused contact metamorphosis of the two rocks through which new minerals were formed, the most valuable of which is the emerald. It is most instructive to study the formation of emerald as shown by this particular deposit, which seems to have much in common with the emerald-bearing rocks at Tokowaya (Ural), Transvaal, Ajmer in India and the Habachtal in Austria. There, same as here, the circumstances of formation and the chemical composition of the various rocks explain the formation of the emerald. The beryllium is an element that emerges from the granite. The tremolite schists do not carry any beryllium. The granite has also brought free silica, while chromium, which acts as a pigment, under favourable conditions accompanies basic rocks of the gabbro group, which are poor in silica ; it is present in minute quantities in the altered serpentine rocks and was carried up from great depths by the peridotite. In the course of the numerous successive intrusions, alterations and re-formations, the chromium got into the process of contact-metamorphosis, thus becoming responsible for the superb colour of the Sandawana emeralds.

Appearance

Up to the day of writing these notes, no clearly and well developed crystals could be obtained from the new mine, but a report from Sandawana mentioned that well developed, euhedral crystals are extremely rare and that most of the crystals found are

so thickly encrusted with limonite that no clear crystal faces nor their combinations could be observed, let alone measured. Therefore, the present examination of Sandawana emeralds could not include a study of the crystal habit and its possible local peculiarities. Of the 92 cut specimens received for carrying out the study, all displayed a superb verdant emerald green with a brightening yellow glint that renders the stones very vivid. To the naked eye the gems appear amazingly clean and only in a few specimens denser concentrations of inclusions altered the colour into a more bluish green hue.

Unfortunately the majority of the rough material is so badly broken or occurring as small crystals only, that most of the Sandawana emeralds reaching the market of cut gems will be below 1/4 carat in weight, although larger gems may appear as the exploitation of the vast deposit progresses. The largest Sandawana emerald obtained to date weighs 1·56 carat as a cut gem. It is, however, welcome news to the jeweller that even small calibre sizes, weighing only a few points, retain the unrivalled beauty of colour, which seems to be the outstanding virtue of the Sandawana emeralds.

Chemical Composition

A small amount of rough material made it possible to analyse the chemical composition, which was determined jointly by a chemical as well as a spectrographic analysis. On account of the tiny quantity at the writer's disposal, the three main components had to be determined with a piece weighing as little as 50 mg., which somewhat impaired the accuracy to be expected. (It may be mentioned that even with normal quantities of 0·5-1·0 gm. the analysis of beryl is no easy task.) The chemical analysis supplemented by the spectrographic examination gave the following result :—

SiO_2	65%	(67%)
Al_2O_3	14·2	(19%)
BeO	13·6	(14%)
Cr_2O_3	0·5	
Fe_2O_3	0·5	
MgO	3·0	
Na_2O	2·0	
Li_2O	0·15	
Total	99%	

TABLE I

Sandawana Emerald	*Refractive Indices*			*Specific Gravity*	*Absorption*	*Dichroism*	*Chelsea Filter*	*Fluorescence*			*Inclusions*
	ω	ε	Δ					*u-v 3650*	*u-v 2537*	*Stokes' Fluoroscope*	
No. 1	1·5949	1·5880	·0069	2·7496	Blurred lines at 6830, 6800 6620, 6375	Bluish green Yellowish green	Very faint red	Inert	Inert	Glowing pale red	System of fissures similar to Fig. 6.
No. 2	1·5955	1·5884	·0071	2·7414	Normal	,,	,,	,,	,,	,,	Two tremolite needles
No. 3	1·5948	1·5877	·0071	2·7525	,,	,,	,,	,,	,,	,,	System of fissures and tremolite needle piercing fissures. Fig. 6.
No. 4	1·5940	1·5871	·0069	2·7623	,,	,,	,,	,,	,,	,,	Sheaths of bent tremolite needles. Fig. 2.
No. 5	1·5925	1·5856	·0069	2·7570	,,	,,	,,	,,	,,	,,	clean
No. 6	1·5934	1·5864	·0070	2·7470	,,	,,	,,	,,	,,	,,	Tremolite needles long and short. Fig. 3.
No. 7	1·5877	1·5806	·0071	2·7525	,,	,,	,,	,,	,,	,,	Healing fissures. Fig. 7
No. 8	1·5935	1·5864	·0071	2·7684	6460 only	,,	,,	,,	,,	,,	Splashes and patches. Figs. 4 and 5.
No. 9	1·5913	1·5843	·0070	2·7436	Normal	,,	,,	,,	,,	,,	Curiously disturbed structure. Fig. 6
No. 10	1·5932	1·5861	·0071	2·7558	,,	,,	,,	,,	,,	,,	Single, short tremolite needles, bundles of long tremolite needles. Fig. 1.

The figures in parenthesis represent the theoretical values based on the formula :—

$Be_3Al_2Si_6O_{18}$
SiO_2 was determined by evaporating twice with HCl
Al_2O_3 was precipated as oxychinolate from an acetic solution
BeO was separated by means of NH_3 with pH 8-9

Cr, Fe, Mg, Na and Li were ascertained by means of a Jarrell-Ash Ebert plane grating spectrograph with direct current carbon arc and anodic irritation. The spectral lines used were: Cr 5204, Fe 4325, Mg 5167, Na 5688, Li 6103. The accuracy is 10-20 per cent of the result obtained. It is interesting that a relatively remarkable quantity of lithium is present, the percentage of which amounts to ·15 per cent.

PHYSICAL PROPERTIES

Of the 92 cut gems submitted, ten specimens of outstanding quality were selected, so that the greatest possible constancy of data was guaranteed. Table I shows the individual data obtained and comparison with the individual figures shows how minute the variations are.

The refractive indices were determined with an Abbé-Pulfrich total reflectometer which enables four decimals to be read. The readings are collected in Table I and it may be noticed that they vary individually between the extreme values of 1·5877-1·5949 for ω and from 1·5806 to 1·5884 for ε with a slightly varying birefringence from ·0069 to ·0071.

With the intention of receiving even more reliable constants and simultaneously measuring the dispersion, the optical properties of a small, clear crystal prism were measured by means of the method of minimum deviation. A one-circle goniometer was set up in combination with a monochromator. The crystal prism was extraordinarily euhedral and displayed very flat and smooth prism faces, so that values of high accuracy could be expected. First the medium birefringence was determined from a series of measurements which showed little variation only and the arithmetical average was found to be ·0071. Then the mean value of the various individual measurements of ω and ε was determined for each of the five wave-lengths that had been used and these values were then balanced with the average birefringent constant. This procedure resulted in the optical data compiled in Table II (the figures have been rounded off to the third decimal).

TABLE II

Line	*B*	*D*	*E*	*F*	—	*Dispersion*
Wavelength	687	589	527	486	455	687–455
$\varepsilon = n\alpha$	1·583	1·586	1·589	1·592	1·594	·011
$\omega = n\gamma$	1·590	1·593	1·596	1·599	1·601	·011
Δ	0·007	0·007	0·007	0·007	0·007	

None of these average figures differs by more than $\pm$·0002 from those actually measured. Hence the variation is very small. Perhaps one ought to have reckoned not only with a dispersion of the refractive indices (n), but also of the birefringence (Δ). However, since no systematic alteration of the Δ-values according to the wave-lengths could be observed, an effect of this kind (if any at all) may be too small to be noticed. Consequently, it may be assumed that the adjustment of the birefringence to ·0071 over the whole spectrum will hardly cause any mistake. Thus the most reliable figures for the optical data of emeralds from Sandawana can be given as :—

$$n_\omega = 1{\cdot}593 \; ; \quad n_\varepsilon = 1{\cdot}586 \; ; \quad \Delta = {\cdot}007$$

From Table II the reader may also derive that the relative dispersion B-F of this new emerald amounts to ·009. Comparison with Table I shows a rather good concurrence of these R.I. values with those of specimens Nos. 5, 6, 8 and 10. For further comparison emerald No. 5 was also examined by the method of minimum deviation and a similarly good agreement was obtained as the following figures were measured for the D-line :—

$$n_\omega = 1{\cdot}592 \; ; \quad n_\varepsilon = 1{\cdot}586 \; ; \quad \Delta = {\cdot}006$$

with a relative dispersion B-F of ·0085. At this place it may be interesting to compare the optical values of the Sandawana emeralds with those of other important sources as registered by Ph. Vogel, who probably carried out the most thorough study on the optical properties of emeralds from the main sources known then. In Table III the refractive indices of the Rhodesian Stones are the highest for all wavelengths. The emeralds from the Habachtal, the Ural, Transvaal, Colombia and Brazil follow with degrading values. The same diminution occurs with the birefringence. While the progress of the dispersion remains identical through all

the wave-lengths for the emeralds from different sources, the numerical amount of the relative dispersion (B-F) varies in being similar for emeralds from Rhodesia, Colombia, Brazil and the Habachtal on one side and for those from the Ural and Transvaal on the other.

TABLE III

Locality		*Refractive Indices*				*Dispersion* $B-F$	*Birefringence* Δ_D
		n_B	n_D	n_E	n_F		
Sandawana	ω	1·590	1·593	1·596	1·599	·009	·007
	ε	1·583	1·586	1·589	1·592	·009	—
Habachtal	ω	1·5859	1·5893	1·5925	1·5954	·0095	·0066
	ε	1·5794	1·5827	1·5856	1·5885	·0091	—
Ural	ω	1·5846	1·5881	1·5915	1·5946	·0100	·0066
	ε	1·5783	1·5815	1·5845	1·5880	·0097	—
South Africa	ω	1·5814	1·5850	1·5884	1·5914	·0100	·0063
	ε	1·5752	1·5787	1·5820	1·5846	·0094	—
Colombia	ω	1·5730	1·5762	1·5797	1·5825	·0095	·0056
	ε	1·5675	1·5706	1·5739	1·5767	·0092	—
Brazil	ω	1·5677	1·5712	1·5742	1·5772	·0095	·0049
	ε	1·5628	1·5663	1·5693	1·5720	·0092	—

With regard to the other optical properties, the Sandawana emeralds do not seem to show any anomaly or local peculiarity but appear to behave very similarly to their relatives from other deposits. Dichroism is distinct—displaying yellow-green for ω and bluish-green for ε. When viewed through the Chelsea colour filter the gems appear very weak red.

In the absorption spectrum the normal absorption lines show clearly at 6830, 6800, 6620, 6460, and 6370Å, as well as the characteristic band extending from 6300-5800Å with its absorption maximum near 6125Å, while the minimum is in the region of 5050Å. The absorption lines at 6370 and 6460Å usually just form the stronger border lines of the band extending between them. In one stone only the line at 6460Å was observed.

Although Sandawana emeralds do not react in the least when excited with u.v. light of short or long waves, it may easily be noticed that the stones are remarkably less transparent in short u.v. rays,

and indeed examination with the u.v. absorption spectroscope revealed that they transmitted u.v.-light only down to 3200Å where complete absorption set in with a sharp cut off. As far as this phenomenon is concerned Sandawana emeralds behave like those from India. In the Stokes' fluoroscope (two-filter method) all specimens tested displayed a distinct fluorescence of glowing pale red colour.

The figures of the specific gravity were ascertained by means of the hydrostatic method, immersing the stones in ethylene dibromide and weighing very carefully with a semi-automatic Mettler balance Although all the stones examined were rather small, the remarkable freedom from any influential amount of inclusions ensured a rather good consistency of constants between the extreme values of 2·744 and 2·768 with a mean figure of 2·756. Thus the specific gravity of Sandawana emeralds ranks among the highest density figures known for emeralds and stands in conformity with the high refractive indices and great birefringence.

Internal Characteristics

All the properties described above, though ranging among the highest ones for emeralds—are not sufficiently individual to serve

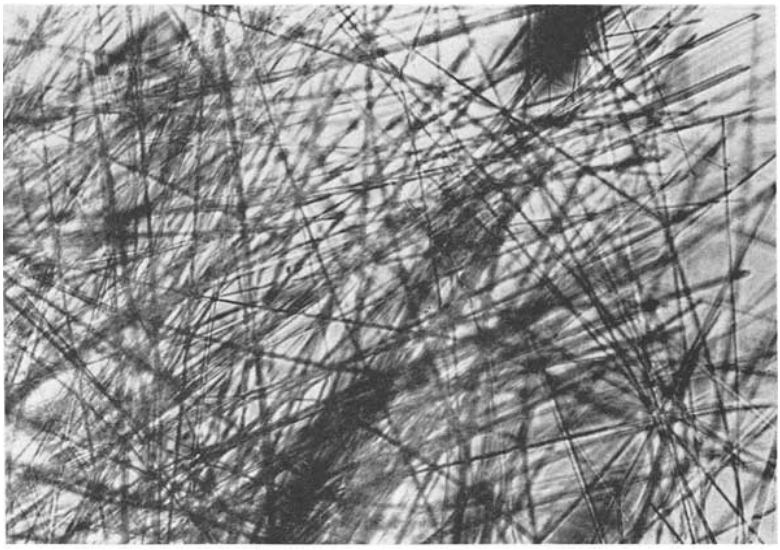

Fig. 1. *Dense accumulation of fine tremolite needles.* 125 ×.

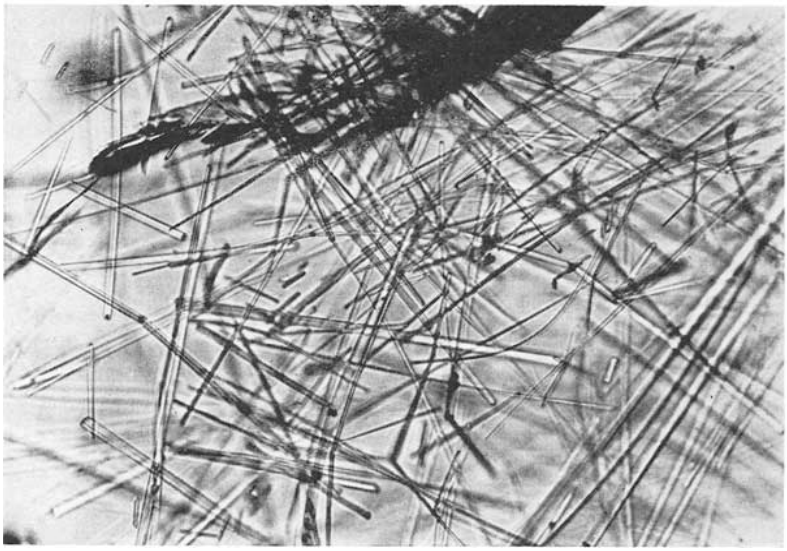

FIG. 2. *Long and short acicular rods of tremolite.* 125 ×.

as marks of identification of Sandawana emeralds or to distinguish them clearly from those of other localities. The constants of emeralds overlap in border cases, rendering it impossible to determine the origin of a given specimen, were it not for the unique internal birth-marks which in most cases point infallibly to the place of formation.

It was mentioned before that the Sandawana emeralds resulted from contact-metamorphosis between granitic magma and tremolite schists, and, as a matter of fact, acicular tremolite inclusions yield the most characteristic feature of their internal paragenesis. The gems of inferior quality teem with dense masses of short and long slender needles (Fig. 1), while in those of good quality the tremolites occur either as short pins lying criss-cross, or as very fine long fibres assembled as dense bundles or masses without any definite orientation at all (Fig. 2). Sometimes the short pins are brownish but usually all the tremolite needles are bluish-green, throwing upon the host emeralds a slight bluish cast when present in great quantities. Quite often these fibres are curved and sometimes they run through several disc-like cleavage fissures, leaving the impression of tiny flakes being threaded on silk.

The phenomenological picture of these tremolite inclusions

resembles somewhat that shown by the emeralds from the actinolite schists in the Habachtal, and to those seeing it for the first time it may be most confusing. In Sandawana emeralds, however, the tremolite fibres are much finer, the occurrence of dense masses is rare and there are always short pins present (Fig. 3). Indeed, in the Rhodesian stones the tremolite fibres rather form bundles and are usually so fine that they may be compared with the well-known byssolite fibres in demantoid.

Already considerably more vivid and beautiful by nature than the emeralds from the Habachtal, the Sandawana emerald will always excel by its superior splendour and greater transparency since the tremolite needles as well as other inclusions are much rarer. The deposit in the Habachtal is almost exhausted and has never thrown many stones of good quality on the gem market, so that in future emeralds containing tremolite needles may with the greatest safety be considered as Sandawana emeralds because no other important emerald source is known to have its precious products teeming with tremolite fibres.

The tremolite needles are usually associated with other endogenetic minerals of minor importance. The most frequent and

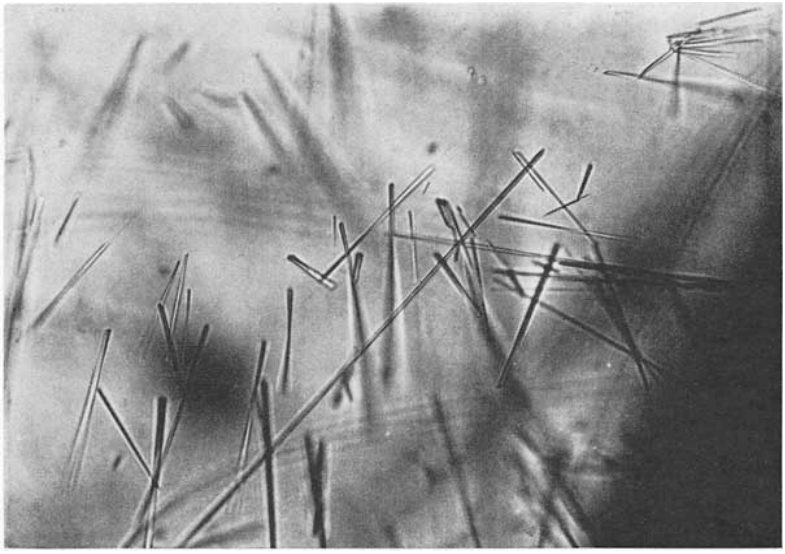

FIG. 3. *Tremolite needles of varying lengths.* 125 ×.

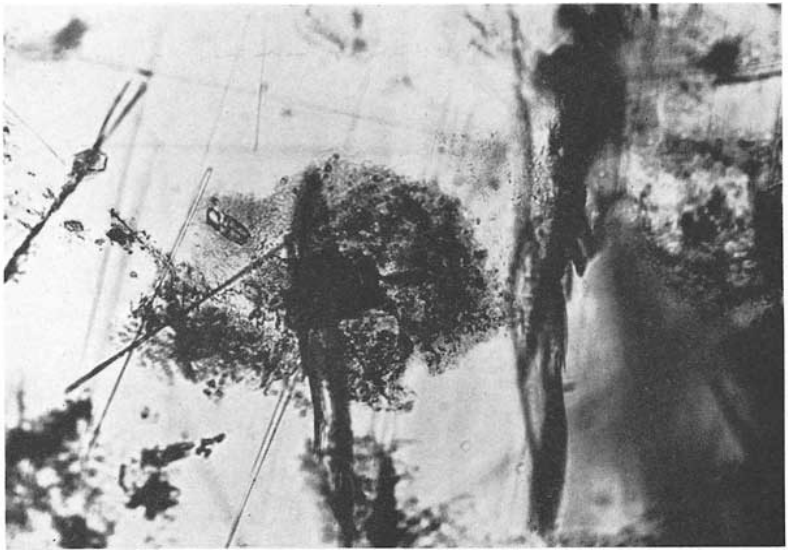

FIG. 4. *Strongly resorbed garnet crystal surrounded by a brownish, dusty halo.* 125 ×.

FIG. 5. *Numerous " splashes " consisting of ultra-minute liquid drops, sometimes forming a halo around a resorbed garnet.* 75 ×.

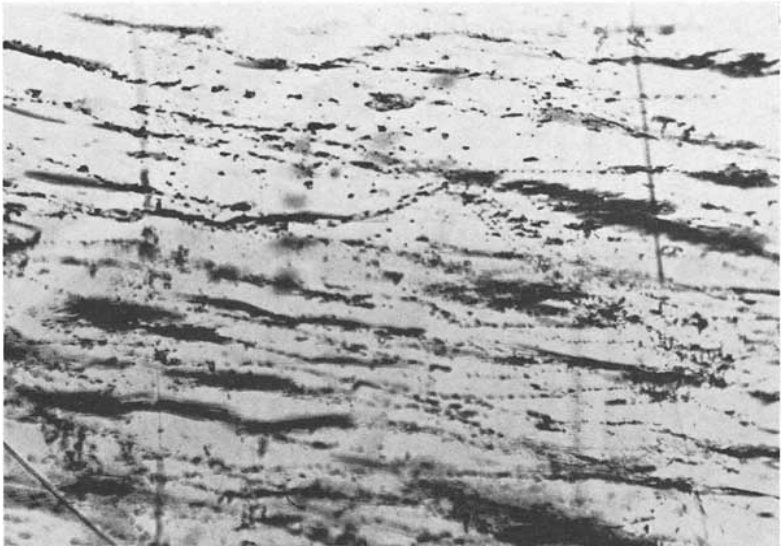

FIG. 6. *Parallel pattern of "shadows" caused by a system of fissures running parallel to the basal plane.* 125 ×.

typical companion is a brown, limonitized garnet which usually sits in cracks near the surface of the host gem (Fig. 4). The cracks are in most cases filled with limonite, which is quite common and also coats the surface of the emeralds. In association with garnets it often forms brownish, patchy halos, which also seem to be a local characteristic, yet considerably rarer than the tremolite needles. Apart from these, other rare inclusions consist of hematite tablets, decomposed plagioclase feldspar and dots of magnetite. Anthophyllite is present in the wall rock neighbouring the emerald-bearing matrix, so that it is possible for anthophyllite needles to occur as inclusions, but none have so far been seen in the gems tested.

Yet the interior of the Sandawana emeralds is not only typified by solid inclusions—two most individual kinds of inhomogeneities add to its character. One gives the impression of being splashes of a dust-like appearance, oriented parallel to the C-axis. Normally they seem to be green but sometimes they may be limonitized and then assume a brownish tint (Fig. 5). Occasionally it is impossible to distinguish these splashes from the brownish halos surrounding the garnet inclusions. Just as strange as these are sheets consisting of irregular, interrupted lines and strokes running

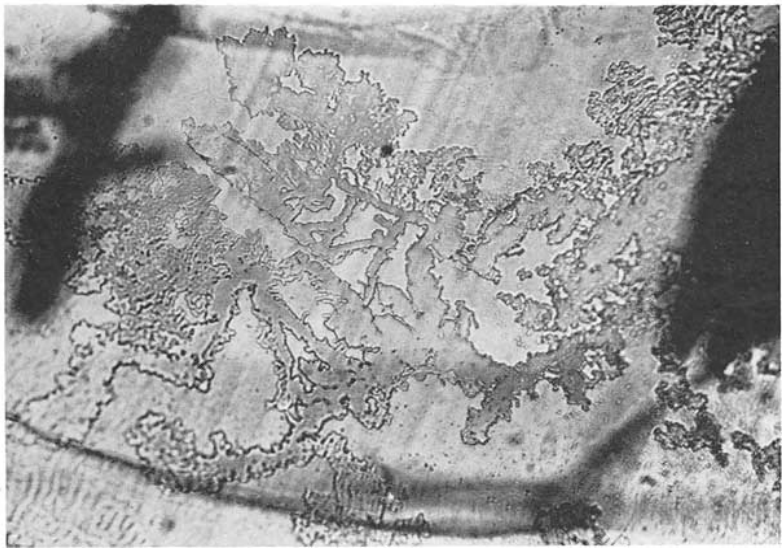

FIG. 7. *Interesting design of a film of residual liquid in a healing crack.* 125 ×. Photographed with phase contrast photo ocular 12·5 ×. Achromatic objective Ph_2 10/0·25.

more or less parallel (Fig. 6). They represent systems of very fine cleavage fissures lying parallel to the basal plane. Although resulting from exactly the same cause of origin—a deficiency of cohesion between the sheets of $(SiO_3)_6$ rings—as those well known and characteristic planes of disc-like fissures which are so abundant in emeralds from the Urals, the pattern of these cleavage fissures is distinctly different and should not lead to confusion. In Russian emeralds they appear like silvery fish-scales lying in flat or curved layers, while in the Rhodesian stones they resemble irregular strokes with a brush.

One specimen displayed beautiful, lace-like patterns of liquid films which have remained " undigested " in healing fissures (Fig. 7). One single occurrence of such formations does not justify a generalization of the observation and, indeed, it may not be a typically local feature, but it should be noted and may serve as a valuable reference for future investigations of Sandawana emeralds.

It will be interesting for the reader to get acquainted with Sandawana emeralds ; he will not find it difficult to recognize their

locally typical inclusions and to distinguish them from the emeralds of other occurrences.

The author wishes to express his gratitude to Mr. A. E. Phaup of the Geological Survey Office at Gwelo for his explanations of the geological conditions, to Prof. R. L. Parker for the determination of the R.I.'s by the minimum deviation method, and to Dr. M. Weibel for the chemical analysis.

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ASCERTAINING THE NATURE AND EXTENT OF DAMAGE OR INHERENT FLAWS IN GEMSTONES

By G. ROBERT CROWNINGSHIELD

THE Gem Trade Laboratories of the Gemological Institute of America are frequently called on to render opinions regarding the nature of cracks and flaws in many varieties of stones. Most often, the question is whether a crack is inherent, partly inherent and extended, or due to damage that occurred after the stone was polished. It is my purpose here to set forth the methods used by the staff of the laboratories in arriving at an opinion based on careful microscopic observations.

It is common knowledge that insurance companies do not require very much information about jewellery before issuing policies and collecting premiums. Most jewellers have experienced cases where this practice has been troublesome, if not embarrassing.

Few jewellers make a detailed diagram of inherent flaws in stones they sell or appraise, other than perhaps in diamonds, since insurance companies do not demand it. Therefore, stones with inherent fractures are frequently insured that may later be mistaken for damage, causing an unnecessary and time-consuming settlement.

Let us reconstruct a hypothetical case in which an insured customer first believes he has damaged a stone. One day the insured trips and falls and believes that he has struck his star-sapphire on the concrete floor. His first thought, after seeing that no bones are broken, is to inspect his star-sapphire. For the first time the stone is examined carefully, perhaps with strong transmitted light. Sure enough, there is a crack ! The insurance company and an adjuster are notified, and he sees the crack. The jeweller is notified. He inspects the stone with his loupe and admits that he sees a crack too. All too often the insurance company pays off, but not before considerable time and effort have been expended.

Much too frequently the supposed damage is an inherent fracture or even a characteristic fingerprint inclusion or repeated twinning, especially in star-sapphires and some star-rubies. This could have been proved by the proper use of a microscope and direct reflected light.

How is this done ? If the flaws (cracks) come to the surface and were present at the time of last polishing, the act of polishing invariably leaves tell-tale evidence. This is usually in the form of polishing drag marks originating from the trailing edge of the crack. Bits of the leading edge break off and score the polished surface for varying distances from the crack. If the polishing direction happens to parallel the crack, these polishing drag marks will not be evident, of course. Instead, there may be undercutting along the crack, although in this case, especially in diamonds, there may be no visible evidence.

To observe both the polishing drag marks and the undercutting, a source of light other than the dark field of the Diamondscope or Gemolite is needed. In some cases, the ordinary overhead light attachment of the latter instrument is sufficient. With diamond, however, a more distant source of light is usually necessary. The light should be direct, not diffused. In addition, the magnifications needed are 60 × and 120 ×, the higher power principally for diamonds. With 120 ×, polishing lines can frequently be detected on all facets of a diamond, but not with equal ease. Occasionally, an extraordinarily well polished diamond may show no polishing marks even under 120 ×. But this same diamond with an inherent crack may show the polishing drag marks mentioned above.

Another clue that may be helpful in determining whether a crack is inherent or due to damage is the presence of foreign material within the crack. Considerable caution must be exercised here, because what may appear as a stain may be a brownish nondescript interference of light caused by air in the crack, possible in both old and new cracks. Of course, if the crack can be proved to terminate or originate in a definite fingerprint inclusion, then it must be concluded that at least part of the effect seen is inherent.

A frequent cause for concern and trouble is the fact that many coloured stones, particularly flawed specimens of emerald, star-sapphire and ruby, are oiled to help conceal the inherent fractures and flaws. It is shocking to learn that some merchants actually believe that this oiling is necessary in order to replace the " natural oil " of the stone lost in lapping ! This fraudulent practice is engaged in quite openly ; in fact, members of the staff have observed emeralds soaking in oil in sunny windows of firms that otherwise have fairly good reputations. The oils used vary considerably : from 3-in-1 penetrating oil to whale oil and even mineral oil. An

oil that will " set " upon standing is preferred, since subsequent changes are slower in coming about.

Unfortunately, the presence of penetrating oils cannot always be detected, although gentle warming of a suspected stone may produce an oozing of the oil from the cracks. At the Laboratory in New York we have seen star-rubies " weep " red oil and emeralds " weep " green oil. After several years, depending on the treatment the stones received meanwhile, the oil tends to dry out and cracks become more visible. For this reason, oiled stones more frequently appear in necklaces and pins than in rings.

The retailer who sells oiled stones is more than likely not aware of the oil. Hence, when the customer complains in a year or two that the stones are cracked (and she can usually recall some occasion when the piece was dropped or some other occurrence to which she can lay the blame) the jeweller goes along with the story. A microscopic examination of the surface termination of the cracks may not reveal any evidence of damage whatsoever, but instead, prove that the cracks were present at last polishing. This unfortunate situation has arisen more than once at the New York Laboratory involving firms of the highest integrity.

Most insurance policies insuring for damage (all-risk policies) do not allow for ordinary wear and tear nor for inherent weakness. The possibility that an inherent slight fracture or cleavage may extend due to wear and tear, a blow, temperature change, pressure from uneven prong tension, etc., always exists. After all, a crack in a stone can be seen only when air is allowed to enter and form a reflecting or interference plane. It is conceivable that many cracks are actually much larger than assumed, even when observed under the most favourable microscopic conditions. It requires only an extremely slight change of the thickness of the crack to allow air to enter and thus allow the crack to be seen.

Not all suspected damage is actually inherent, of course. One of the indications of actual damage is one or more chips from which fresh cracks radiate indicating a blow, cracks that do not show polishing drag marks or undercutting. Another indication is a raised flake at the point of intersection of two fresh cracks or under a prong. The raised condition indicates that it could not have left the polishing wheel in that condition. One unexpected incident that gave us a clue that the sapphires in a bracelet had been mistreated, probably by heat during manufacture, was the presence in two of

the stones of " exploded " negative crystals that had pushed the surface up, much as a mushroom pushes up the ground above it.

Much disagreement about damage in diamonds originates from a lack of ability to recognize *naturals*. Some crystal surfaces actually form re-entrant angles and may appear very much as a chip. We have encountered several brilliants that have turned in their settings and thus exposed *naturals* that were originally hidden by the prongs. A study of the surface under high magnification may reveal the difference between the natural surface and the fresh cleavage or cleavage-fracture combination that is characteristic of broken diamonds. At times, it has been the experience of the Laboratory that no conclusion can be reached, since a *natural* with octahedral orientation can be confused with a cleavage nick, which, of course, has the same orientation.

A further word about the set-up necessary for observing drag marks, particularly in diamonds, is in order. As expressed above, high magnification is frequently required to observe drag marks in diamond. When observing the surface of the stone in search of drag marks originating at the crack, one may see no evidence of them for much of the distance along the crack. The polishing marks may be seen to cross the crack unmodified by the crack. However, at slight zig-zags in the crack one may see drag marks. The presence of even one distinct polishing line originating at the crack is considered proof of the existence of the crack before last polishing.

Note that I have used the phrase " last polishing." This wording is used because the presence of polishing drag marks, or even some of the other clues discussed, do not necessarily prove inherence of the crack in the original crystal. We have seen cabochon sapphires in which there was evidence that the stones had been polished in their settings; whether this was an attempt to remove a setter's slip or not is unknown. Another case involved an emerald that had been broken in setting and then had been removed and repolished without the owner's permission. Since all cracks had polishing drag marks, it could not be determined which were due to recent damage and which were inherent.

May I suggest that readers practice with some star-sapphires, which are rarely without some inherent fractures. One can gain much information about the nature of undercutting and polishing drag marks from these stones. Note that cabochons are polished in

many directions, unlike faceted stones, particularly diamonds, in which the polishing marks are usually all in one direction. In cabochons, since the inherent cracks are almost certainly crossed by one or more of the directions, drag marks will almost certainly be seen. An exception to the rule might be stones that have been repolished in this country by certain very meticulous lapidaries who specialize in this work.

When observing star-sapphires and rubies it is well to become acquainted with the appearance of repeated twinning. The recently imported very dark purple-red star-rubies from India are almost invariably twinned in a rhombohedral direction, a condition which may give rise to three series of parallel lines around a " bulls'-eye " centre zone. Of course, the zoning may not be well developed in all three directions. In black star-sapphires note the almost universal development of the basal repeated twinning planes, which may show up as bright " fractures " parallel to the girdle of the stone. These kinds of twinning in corundum are frequently mistaken for damage.

When repeated twinning in corundum is recognized, the alert jeweller will bear it in mind when setting, sizing or otherwise subjecting the stone to any forces. We once encountered a very large star-sapphire that had been split neatly into three sections because it had not been removed from the setting. The ring had been slipped over a steel mandril while the jeweller attempted to enlarge the shank by hammering ! To be sure, the stone had possessed well developed rhombohedral twinning.

One final observation comes to mind. Much of the actual damage in both diamonds and coloured stones has been observed in stones with " knife-edge " girdles. Although the tendency in diamond-cutting is toward too thick a girdle instead of too thin, because of the factor of weight recovery from the rough, a sufficient number of thin-girdled stones are encountered to make it imperative for the jeweller to consider rejecting these stones or using safe mountings. After all, the consumer frequently believes a diamond cannot break because it is the hardest thing in the world. Since not all consumers can be educated to the *truth*, it is well that he not learn the truth on his own stone !

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SYNTHETIC EMERALD

By W. F. EPPLER

An important series of articles, *Synthetischer Smaragd*, has been abstracted from the Deutsche Goldschmiede-Zeitung, 1958, Vol. 56, Nos. 4-7. The illustrations accompanying the abstract appear by the courtesy of the Deutsche Goldschmiede-Zeitung.

Nacken Synthetic Stones

Apart from the scientific interest in the work of Hautefeuille and Perry (*Comptes rendus*, 1888, 22, 237, and 1889, 107, 786), the first successful synthesis of emerald was that of E. Nacken around 1928 (G. van Praagh, Synthetic Emeralds, *Science News*, 3, 1947). The second process was developed by I. G. Farbenindustrie, Bitterfeld, Germany, in 1930 and improved around 1935, when the stones, named Igmerald, were first marketed (E. Schiebold, Comparison between natural and synthetic emerald crystals, *Zeitschr.f.Kristallographie*, A 92, 435-473). The third variety of synthetic emeralds was produced some years later by C. F. Chatham, San Francisco. These stones appeared on the market in 1941 and have been regularly produced since 1951. To-day they are the only synthetic emeralds of commercial importance. This series of articles is a report on extensive microscopical investigations showing interesting differences as well as connexions between synthetic emeralds produced by the three methods. The first instalment is concerned with Nacken's synthesis and photomicrographs show inclusions of this particular variety of synthetic emeralds. The production of synthetic emerald crystals is described briefly and the author warns that this description might be a misleading analogy to Nacken's synthesis of quartz. " Tie-pin " inclusions seem to be present in all the Nacken synthetic emeralds and only in them. Tiny emerald crystals formed between stages of growth of the host crystal form the heads of the " tie-pins." The pin itself is a tapering hollow tube arranged parallel to the *c*-axis. Other typical inclusions are very small phenakite crystals, which are smaller than the more developed phenakite crystal inclusions in the Igmerald and Chatham emeralds. In common with all other synthetic emeralds, the Nacken stones show the typical twisted veil-like feathers which are not found in natural emeralds.

Igmerald

After a short description of the production method (diffusion melt), the differences and similarities of Igmerald and other synthetic and genuine emeralds, as revealed under the microscope, are enumerated. Igmerald, like other synthetic emeralds, shows twisted veil-like feathers, but they are somewhat coarser and bigger than those of the Nacken synthetics. Both Igmerald and the Chatham synthetic stones show phenakite crystal inclusions due to a local deficiency of aluminium oxide in the melt (solution). Emerald is a beryllium aluminium silicate and phenakite a beryllium silicate. Typical of Igmerald are small synthetic emerald inclusions and spotted areas, which are liquid inclusions with very small doubly refractive particles (probably phenakite).

Chatham's Synthetic Emerald

Although this is the only synthetic emerald which is produced and marketed regularly at present, no reliable information has been published about its production method. Microscopical examination, however, shows so many inclusions similar to those of Igmerald that it would be surprising if Chatham's method varies fundamentally from that of the former I.G.Farbenindustrie. Naturally, this does not exclude the possibility of certain variations regarding concentration, temperature during formation, purity of the raw material, and possibly use of different crystallizers. This is indicated by small differences between the inclusions of the two varieties of the synthetic emerald. On the other hand the similarity of the inclusions is so striking that the probability is that both methods are identical. This means that Chatham's synthetic emeralds like Igmeralds are almost certainly made by the same melt-diffusion method.

The following descriptions of inclusions show these similarities and at the same time point to the small differences between the two varieties.

Veil-like liquid inclusions occur in all three varieties of synthetic emerald. These veils show greater similarities with those of Igmerald than those of Nacken's product. The veils of Chatham's synthetic emerald show certain peculiarities. These are occasional long-drawn two-phase inclusions.

A further peculiarity is shown in Fig. 1. These liquid inclusions form a regular pattern similar to that shown in Igmerald

(Fig. 2). In Chatham's product, however, the inclusions are connected with each other, whereas they remain individuals in the Igmerald. If one studies the angles of the pattern, those of 120° stand out and correspond to the angles of the hexagonal prism. It can be assumed, therefore, that most probably these inclusions are former crystals which have been resorbed. At first they were attached to the basic plane of the seed crystal. Their former liquid inclusions, which were concentrated near the outer zones, are still indicating their former position and size.

Still greater conformity with the Igmerald is shown in Figs. 3 and 4. The formation of these inclusions has not yet been explained. In both varieties the inclusions are arranged parallel to the basic plane of the host crystal ; different only is the agglomoration of small phenakite crystals which surround the described inclusions in Chatham synthetics. The phenakite crystals are characterized by their double refraction and their barely indicated hexagonal forms.

A further similarity with Igmerald, which approaches conformity, is shown in Fig. 5. These angular and interconnected liquid inclusions in Chatham synthetics resemble largely a veil form in Igmerald shown in Fig. 6. Different, however, are solid doubly refractive inclusions within the liquid inclusions of the Chatham emerald. These are presumably phenakite crystals due to a surplus of the phenakite component in the raw material, or, amounting to the same thing, to a slightly smaller percentage of the aluminium oxide which facilitates formation of the phenakite.

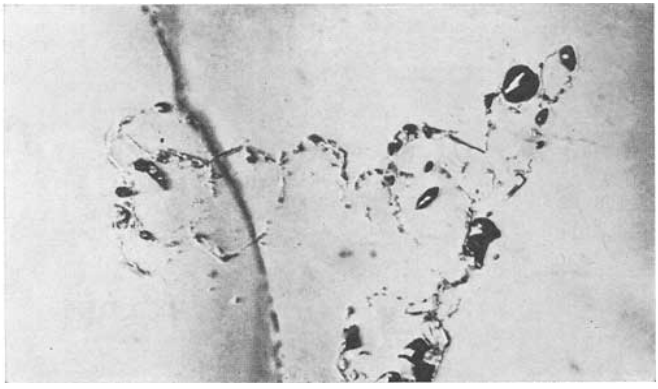

FIG. 1. *Pattern of liquid inclusions in Chatham synthetic emerald parallel to basal plane of host crystal.* 120 ×

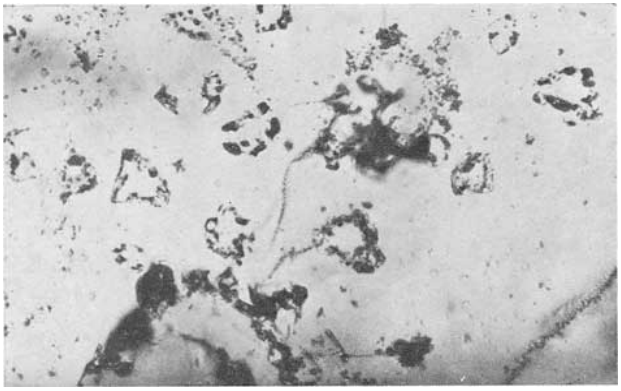

FIG. 2. *Irregularly arranged liquid inclusions in Igmerald, parallel to basal plane of host crystal.* 120 ×

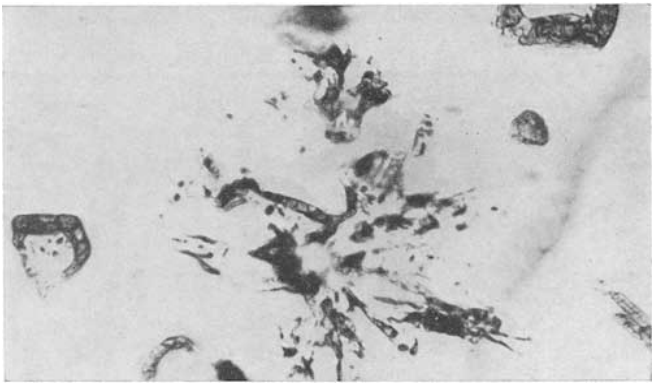

FIG. 3. *Chatham's synthetic emerald. Irregularly arranged liquid inclusions, parallel to basic-plane of host crystal ; to the left and right agglomeration of small phenakite crystals.* 120 ×

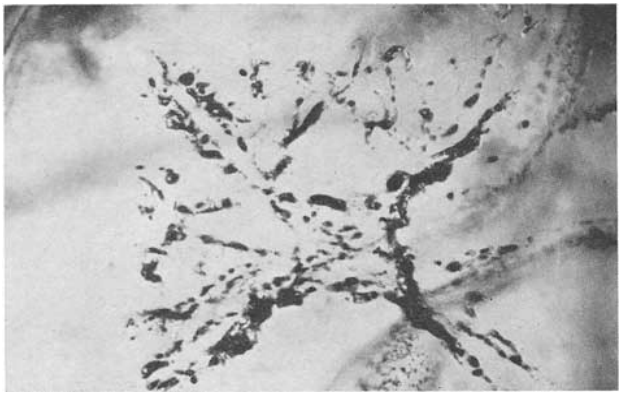

FIG. 4. *Igmerald. Irregularly arranged liquid inclusions, partly two-phase inclusions parallel basic plane of host crystal.* 120 ×

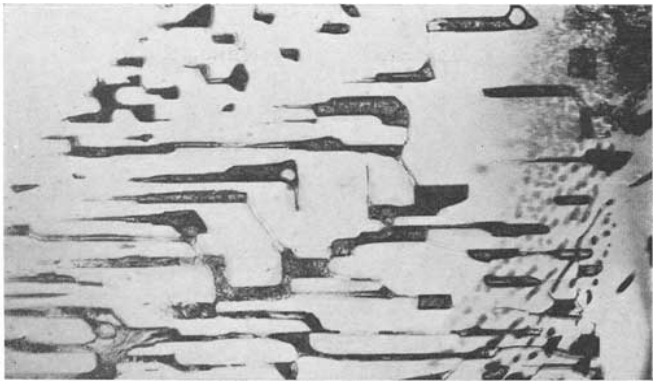

FIG. 5. *Chatham's synthetic emerald. Part of inter-connected veil of liquid inclusions. Some inclusions contain solid doubly refractive matter, presumably phenakite.* 120 ×

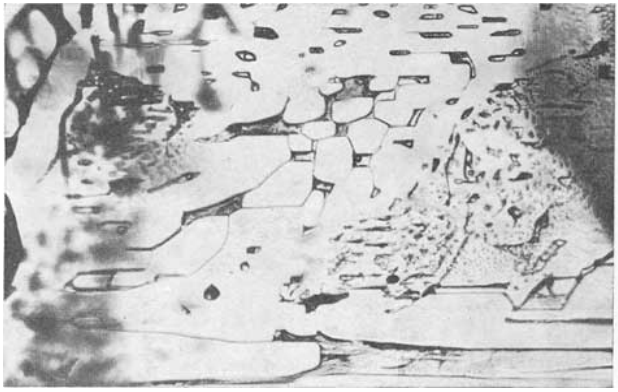

FIG. 6. *Igmerald. Veil of liquid inclusions, partly interconnected.* 120 ×

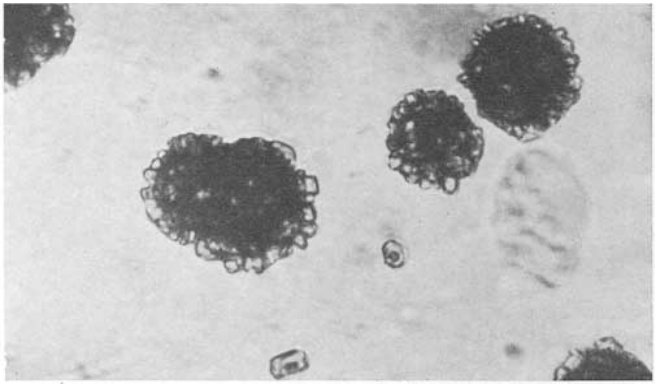

FIG. 7. *Chatham's synthetic emerald. Rounded groups of phenakite crystals.* 320 ×

Among the liquid inclusions of Chatham synthetic emeralds occur occasionally long drawn ones parallel to the *c*-axis of the host crystal. They may form veils or occur individually. Frequently they are three-phase inclusions, the solid matter presumably being phenakite. The two other varieties of synthetic emerald do not show these inclusions, which differ also from the tubular two-phase inclusions in Nacken's product. In Chatham's synthetic emerald, phenakite crystals are mostly arranged in small groups of rounded patterns (Fig. 7) which resemble phenakite inclusions in Igmerald (Fig. 8) in spite of their different size. Other phenakite

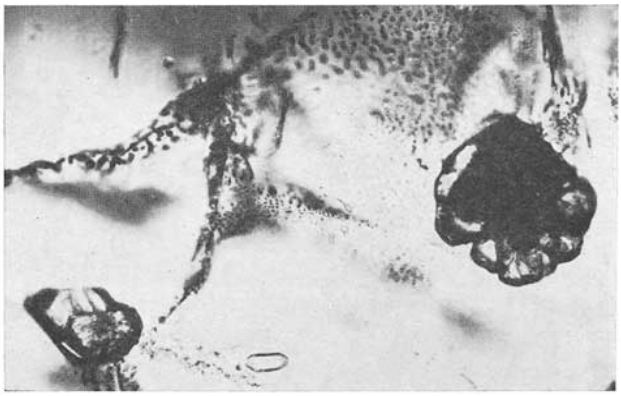

FIG. 8. *Igmerald. 2 inclusions of phenakite crystal groups and strongly twisted veils of liquid inclusion.* 120 ×

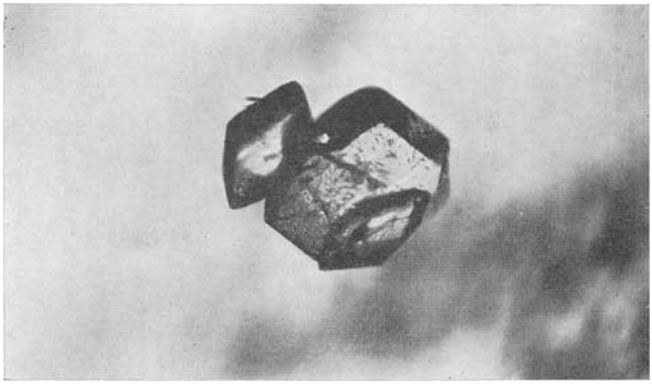

FIG. 9. *Chatham's synthetic emerald. Inclusion group of phenakite crystals.* 120 ×

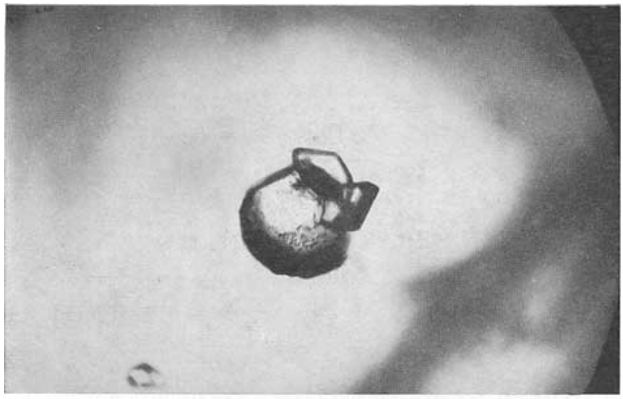

FIG. 10. *Igmerald. Typical inclusion, phenakite crystal group.* 90 ×

FIG. 11. *Chatham's synthetic emerald. Inclusion of phenakite crystal of prismatic shape.* 120 ×

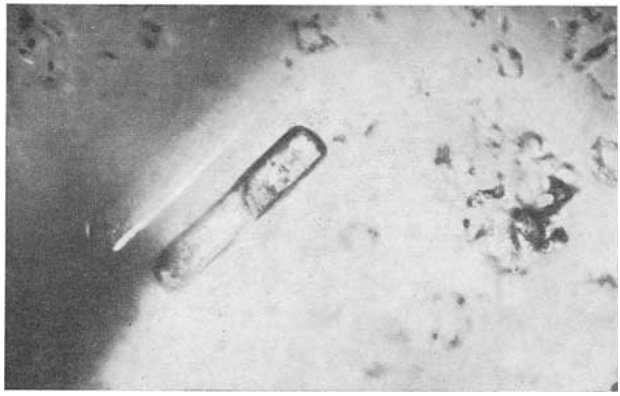

FIG. 12. *Igmerald. Phenakite inclusion of prismatic habit. To the left weak reflection of prism caused by polished facet.* 120 ×

inclusions show typical habits (Fig. 9) similar to those encountered in Igmerald (Fig. 10).

Finally, phenakite crystals in Chatham synthetics were also observed in the shape of elongated prisms (Fig. 11) comparable with the inclusions shown in Igmerald in Fig. 12.

Summary

All three varieties of synthetic emerald (Nacken's, Chatham's, and Igmerald) have typical veil-like inclusions consisting of small and very small liquid droplets. No satisfactory explanation has yet been found regarding the formation of these veil forms, and the following theory is offered for discussion.

Experiments with easily crystallizing substances have shown phenomena which can only be called " healing cracks." It has been observed that these " healing cracks " developed during the growth of the crystal without any outside influence. Often they were started by a growth disturbance the cause of which has not yet been found. An example is shown in Figs. 13 and 14. Alum was crystallized from aqueous solution at room temperature. After removing the crystal from the mother liquor it showed on an octahedral plane a growth disturbance consisting of a rough spot on and under the surface from which emanated a crack which was in the process of healing. During the growth of the alum crystal the crack must have developed and it must have been subject to a healing process. The crack could be healed completely

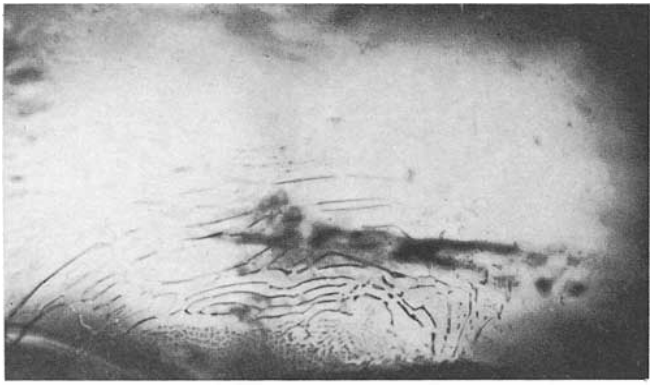

Fig. 13. *Alum crystal. A healing crack emanates from the growth disturbance. The healing crack developed during growth of the crystal, but is not oriented. It can be compared with secondary healing cracks in many precious stones.* 50 ×

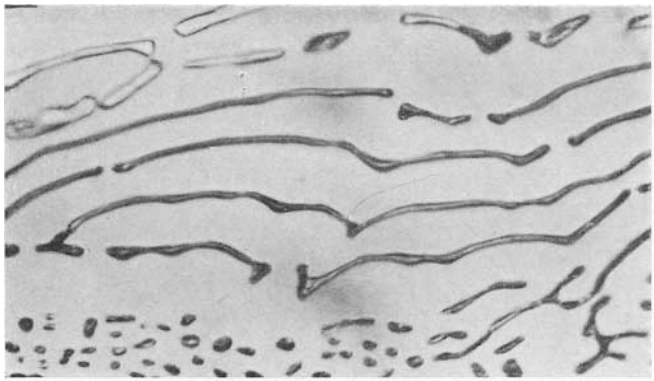

FIG. 14. *Alum crystal ; healing crack, section of Fig.* 13. 240 ×

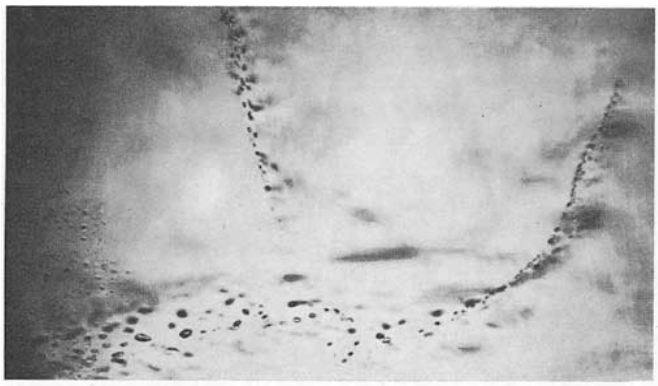

FIG. 15. *Crystal of magnesium aluminium sulphate. Two strongly twisted healing cracks.* 90 ×

when the crystal was re-placed in the mother liquor. Artificially inflicted cracks could be healed in the same way. Experiments with magnesium-aluminium sulphate produced healing cracks (Fig. 15) which showed a certain similarity with those in synthetic emeralds. It seems likely, therefore, that the typical veils in synthetic emeralds also represent healing cracks. The author deals with a few points which could be raised against the validity of his theory and concludes the series of articles by illustrations showing the similarities and differences between Chatham's synthetic emerald and Igmerald.

Summarizing, the author states that Nacken's synthetic emeralds were most probably produced by a hydro-thermal method; Igmeralds by a melt-diffusion method. It seems by a conformity of inclusions that Chatham's synthetic emeralds are produced by a similar method to Igmeralds, although small specific differences exist. All three varieties show the typical veil-like feathers. The author thanks Messrs. B. W. Anderson, H. Espig and E. Gübelin for the loan of specimens.

W.S.

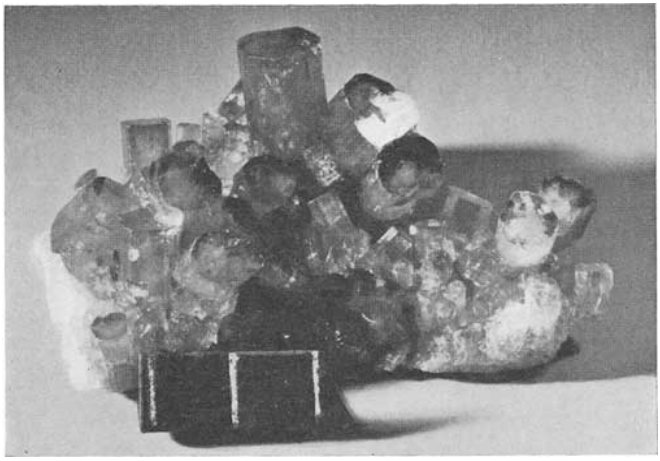

FIG. 16. *Group of synthetic emerald crystals (Chatham) formed by uncontrolled growth. The group shows that the crystals grew (downwards) from pieces of quartz which floated on the molten mass. From this it appears that the production of synthetic emerald by Chatham is very similar to that of the earlier German synthetic, the so-called Igmerald.*

NOTE ON THE HOPE DIAMOND

For the second time in less than ten years, the Hope Diamond has been shown at the Canadian National Exhibition, in Toronto, Canada. The largest blue diamond in the world, the Hope was closely examined by Mr. Dean S. M. Field, F.G.A., Director of the Gem. Lab. Research Division of H. Forth & Company Limited, Toronto.

Mr. Field describes the Hope Diamond as follows :

It is quite unlike the glass replicae commonly displayed by jewellers and in museums. The shape is more oval than anything else, one side being slightly shorter than the other, indicating that it may have been cut from a larger pear-shape stone. The colour is slate grey-blue and bears no resemblance whatsoever to a sapphire. The only other gems that might resemble it in colour are the blue-grey spinels from Ceylon.

The diamond was measured in the vaults of the Imperial Bank of Canada's Head Office, and the dimensions were found to be approximately : length, 25 mm ; width, 22 mm ; depth, 14 mm. No flaws nor inclusions were visible under a ten-power glass, but several of the facets were not quite symmetrical in relation to the others.

Rather surprisingly, Mr. Field found that the diamond had a faceted girdle, a feature not supposed to have been developed when the Hope Diamond was cut in its present form.

The culet is small in relation to the size of the stone, which is shallow and appears to be much heavier than it really is. Nevertheless, the brilliancy is good for a coloured diamond, and the cutting, generally, is much more modern than one might expect in such an old stone.

The diamond is now owned by Mr. Harry Winston, well-known New York diamond broker, who acquired it from the estate of the late Evelyn Walsh MacLean, of Washington.

Gemmological Abstracts

BARRON (E. M.). *The gem minerals of Mexico.* Lapidary Journ., XII, 1, pp. 4-16, 1958.

A concise account of the gem localities of Mexico and useful notes about marketing. Banded and other agates are discussed in detail and there is a reference to a location of fine danburite at San Luis Potosi. Gems found in the country, apart from the well known opal and agates, include garnet, topaz, apatite, orthoclase, and amethyst. Gem-grade tourmaline has also been found, but the locality is not disclosed.

S.P.

WILSON (G.). *Nephrite jade discovered in Wisconsin.* Lapidary Journ., XII, 1, p. 76, 1958.

A report of an occurrence of nephrite in Marathon County, Wisconsin, in an area of primarily dolomitic rocks. A near white sample gave a specific gravity of 2·96, with refractive index of 1·62.

S.P.

CARRARO (F. L.). *A Identificação das Gemas Preciosas pela Difração de Raies-X.* Identification of precious gems by X-ray diffraction. Gemologia 9, pp. 1-4, 2 illus., 1957.

A brief account of X-ray diffraction identification as applied to mineral specimens, including the latest apparatus whereby the diffracted rays are fed via a geiger counter to an automatic register which delivers the result in graph form for easy and rapid identification.

R.K.M.

UNTERMAN (J.). *Os Filtros de Luz na Identificação de Gemas.* Light filters in gem identification. Gemologia 9, pp. 17-24, 1957.

A discourse on the use of light filters in gemmology, describing the beryloscope and the Chelsea Filter ; with a list of residual colours under the latter, reprinted from Webster's Gemmologists, Compendium. The writer goes on to describe a series of 12 filters

known as ABG filters (after the Assoc. Brasiliera de Gemologia) which he has compiled. These are mainly intended for use in identifying emerald, Chatham synthetic emeralds and synthetic blue spinels and apparently they do these jobs with varying efficiency. The most interesting appears to be ABG12, which is a very dark filter absorbing all visible light up to 7500Å. Used with a very strong light source green stones placed on a white background are visible as black outlines, with the sole exception of the Chatham synthetic emerald which fluoresces and appears almost invisible against the background.

R.K.M.

MENDES (J. C.). *Pérolas : Gemas de Origem Biológica.* Pearls : gems of biological origin. Gemologia 10, pp. 1-8, 4 illus., 1957.

A general account of the pearl, its cultivated form and its imitations. The writer includes a schematic diagram of a cross section of a pearl which perpetuates a misconception of the structure of oriental pearls. The section shows the pearl with concentric regions of nucleus, conchiolin, prismatic layer and nacreous layer. This sequence is true of mother-of-pearl, if we omit the nucleus, but it conveys a false picture of the pearl, which is almost entirely nacreous material with a fine interlacing of conchiolin acting as a " mortar " between the nacreous crystals.

R.K.M.

GÜBELIN (E.). *Diamant, Echt Oder Synthetisch ?* Diamond, Natural or Synthetic ? pp. 14, 5 illus.

A pamphlet printed in German and French for Swiss readers. It is written as an answer to possible loss of faith in natural gem diamond following the announcement of the production of the American synthetic. Gübelin points out that the material produced by G.E.C. is of minute size and contains many flaws and impurities ; that it is being primarily produced for its industrial abrasive value rather than as a forerunner to production of synthetic gem diamond. Even if the obviously immense problems which prevent the making of large single crystals of gem quality were ever surmounted, the synthetic origin of the resultant gem would be detected.

R.K.M.

SLAWSON (C. B.). *Hardness of synthetic diamonds.* Amer. Min., Vol. 42, pp. 299-300, 1957.

The cutting and polishing by a fine powder of synthetic diamond of a natural diamond close to the octahedron face is described. A facet was cut within 1° 23′ of parallelism with the octahedron and it is concluded that there is no difference in the actual hardness of natural and synthetic diamonds.

G.A.

WYART (J.) and ŠĆAVNIČAR (S.). *Synthèse hydrothermale du beryl.* (Hydrothermal synthesis of beryl). Bull. Soc. franç. Minér. Crist., Vol. 80, pp. 395-396, 1957.

Notes of the hydrothermal synthesis of beryl. A mixture of SiO, AlO and BeCO, with addition of water, was used with a pressure varying from 400 to 1500 bars. Beryl in the form of fine white powder appeared at 400°C. and at 600°C transparent crystals were obtained showing form, together with small amounts of phenacite and chrysoberyl. When a small amount of chromium replaces part of the Al of the starting material, phenacite, quartz, chromium oxide and faintly green beryl are obtained. This green colour may be due to inclusions of chromium oxide or to replacement of Al by Cr in the beryl structure.

G.A.

SCHALLER (W. T.) and HILDEBRAND (F. A.). *A second occurrence of the mineral sinhalite.* Amer. Min., Vol. 40, pp. 453-457, 1955.

A contact metamorphosed limestone in Warren County, New York, was found to contain sinhalite.

G.A.

WEBSTER (R.). *Amber, Jet and Ivory.* Gemmologist, Vol. XXVII, No. 321, pp. 65–72. April, 1958.

The continuation of the series on organic gems. The inclusion of flies in amber is discussed and the types of amber imitations which may be encounted are mentioned. A description of jet including its properties and he localities where it is found are given. The imitations of jet are mentioned. Ivory from the elephant and the mammoth is discussed. The nature of ivory and the types of elephant ivory are mentioned.

6 illus. P.B.

ANDERSON (B. W.). *More news of man-made diamonds.* Gemmologist, Vol. XXVII, No. 321, pp. 59–61. April, 1958.

Dr. Grenville-Wells and Prof. K. Lonsdale of University College have examined by rotation X-ray photography specimens of synthetic diamonds made by The General Electric Company of Schenectady. The photographs showed a comparatively strong reflection from " 200 " planes hitherto not seen in natural diamonds. This and other irregular features are explained as each man-made diamond consists of a matrix of normal diamond with a lattice constant of 3·567Å within which occur islands of a different face-centred cubic structure with spacing 3·54Å lying closely parallel with the diamond matrix. An analysis of some G.E.C. diamonds by Messrs. Johnson Matthey showed traces of Si, Al, Fe, Mn, Mg, Na, K, Ti, Ca, Cr, Cu, and B, with also significant quantities of nickel to which the extra spots on the rotation X-ray photograph are ascribed. Examination of samples of these synthetic diamonds by the author (B.W.A.) shows that the grit-like particles are mostly aggregates of tiny diamond crystals. They are mostly interpenetrant octahedra or in parallel growth. Cube forms were not infrequent and these faces are remarkable for their smoothness. Flattened " hopper " crystals are particularly noticeable. Fluorescence is hardly observable, but a few showed the typical blue, green or yellow glow. Some of the particles were found to be magnetic.

1 illus. R.W.

REEVE (V. J.). *Gem hunting in Australia.* Gemmologist, Vol. XXVII, No. 321, pp. 62–63. April, 1958.

A report on a visit to Lightning Ridge and other areas where gems are found. A visit to the Turon goldfield is described and some of the activities of the Lapidary Club of New South Wales are mentioned.

R.W.

MAHAJAN (B. S.). *Birthstones—an Indian interpretation.* Gemmologist, Vol. XXVII, No. 319, pp. 21-23. Feb., 1958.

The article tells of Indian beliefs of astrology and astral medicine, and the ancient beliefs in the medicinal qualities of gems, The Indian aspect of birthstones is discussed.

R.W.

EPPLER (W. E.). *Particularidades sobre durezea.* (Details of hardness.) Gemologia, No. 12, pp. 1–14. 1958.

A translation of the article which appeared in Journ. Gemmology, Vol. 5, No. 5, 1956.

R.K.M.

KELLER (J. E.). *The lapidary of the learned king.* Gems and Gemology. Vol. IX, No. 4, pp. 105-110 and 118-121. Winter 1957/58.

In the Escurial near Madrid the library contains a book known as the *Lapidario* said to have been written by Alphonso X el Sabio (the Learned). This article describes the book and comments on the caligraphy and the illumination. Mention is made of the difficult times which occurred in Spain during the period in which it was written and subsequent happenings at the Escurial. Three hundred and sixty gems are listed, many of which are described as having fantastic and extraordinary properties. Much of the book relates to the older conceptions and fables of gemstones, especially the medico-mysticism and the lore of precious stones. 4 illus.

R.W.

CROWNINGSHIELD (G. R.). *Spectroscopic recognition of yellow bombarded diamonds and bibliography of diamond treatment.* Gems and Gemology, Vol. IX, No. 4, pp. 99–104 and 117. Winter, 1957/8.

Colours of bombarded diamonds which are commercially available are various tones and intensities of yellowish-green to bluish-green, brown to orange-brown, and yellow to brownish-yellow. Blue and greenish-blue stones have been reported and a few brownish-red tones have been seen but are not available commercially. Unless green *naturals* are present on a dark green diamond (an indication of green-skinned stones from Venezuela or Bahia) few dealers accept as natural any dark green stones. Radium treatment is suspected if the stones show blackish surface discoloration and if they " take their own picture " when exposed to a photographic film for 12 to 36 hours. Cyclotroned stones, which have only surface coloration, show, if the top of the stone has been treated, dark bands in the crown facet reflections; or, if the bottom of the stone has been treated, a star-shaped zone of colour will be seen at the culet. Pile treatment by neutrons causes through-

out coloration of the stone and no visual features are apparent. The yellow and brownish-yellow diamonds which owe their colour to pile treatment and subsequent heat treatment but show no signs of irradiation are a greater danger and pose problems in identification. The darker the original colour of the " dark Cape," the darker the result of treatment. A fine white stone will take the best colour, whether green or yellow. The diamond trade has not yet reached the point where the artificial coloration is accepted, like that of citrine, aquamarine or zircon. Extensive study of the absorption spectra and fluorescence has been carried out and some correlation made. The "Cape" spectrum, the brown diamond spectrum and the luminescence shown by each of these groups are referred to. The finding of an absorption line at 5920Å in a bright yellow diamond and the subsequent recognition of this line in nearly every yellow to golden yellow treated diamond and in some of the brown treated stones are reported. Observation on some twenty stones before and after pile treatment showed that the bombardment and subsequent heating had induced the 5920Å line as well as, in some cases, the 5040Å line. It is remarked that treated diamonds tend towards a brownish-yellow and not towards a greenish-yellow, and that 1950 is set as the arbitrary date after which any yellow diamond is suspect. An important article which ends with a useful bibliography.
4 illus. R.W.

CUSTERS (J. F. H.). *Minor elements in diamonds and their effect on diamond colours.* Gems and Gemology, Vol. IX, No. 4, pp. 111–114. Winter, 1957/8.

Diamond colours resulting from the presence of minor elements are highly stable even at temperatures up to 500°C. Heating a diamond to this temperature will verify if the colour, if present at all, was introduced after the diamond was crystallized. Two types of diamond colours are known to change on moderate heating. One is introduced artificially either by bombardment with neutrons from a nuclear reactor or electrons from a high-voltage electron-source or by irradiation with sufficiently energetic gamma rays. The resulting colour is green, blue and greenish-blue respectively. The other type is the natural green diamond frequently found in Sierra Leone. All these diamonds turn to a light brown or yellow on heating to 450°C. Such coloration is due to a fraction

of the carbon atoms being displaced from their original position. This is the so-called " radiation damage." Experiments on the absorption spectra of coloured diamonds by light absorption curves using an absorption spectrophotometer are reported. The results obtained by the author, and by other workers are mentioned. It is established that the colour of pink and mauve diamonds is most probably due to one element, namely manganese. An absorption band with a maximum at 5500Å was found in all pink and mauve diamonds, and some brown diamonds also show this band. Manganese was found as a minor element contained in diamond, with silicon, calcium, magnesium and aluminium. In the mauve and pink diamonds it is suggested that it is the manganic ion which is responsible for the colour. Nearly all semi-conducting diamonds are steel blue in colour, but a few pale brown stones were also found to be semi-conducting. Much technical information given.
1 illus. R.W.

SHIPLEY (R. M.). *Electronic colorimeter for diamonds.* Gems and Gemology, Vol. IX, No. 5, pp. 136–143. Spring, 1958.

A full description of an electronic colorimeter built specially for the colour-grading of diamonds. The use of an optical colorimeter, its defects and limitations are commented upon. The design construction and working of the latest electronic colorimeter are described. The colour assessment is made numerically on a meter by electronic means. The limits of accuracy of the machine are given.
1 illus., 4 graphs. R.W.

WEBSTER (R.). *Ivory, bone and horns ; vegetable ivory and tortoiseshell.* Gemmologist, Vol. XXVII, Nos. 322 and 323, pp. 91–98. May and June, 1958.

The continuation of a series. Mammoth, hippopotamus and walrus ivories are discussed. The " horn" of the rhinoceros is not ivory but a packed mass of hairs, and has a low density of 1·29. The structure of teeth is commented upon and the detection of ivory by examination of the peelings is described. The nature of the vegetable ivories, their structure and testing factors are given. Tortoiseshell is obtained from a turtle. The properties of the material and its imitations are discussed.
12 illus. P.B.

STEIGER (A. J.). *Russian diamonds.* Gemmologist, Vol. XXVII, No. 323, pp. 108–111. June, 1958.

The Russian diamond area of the Siberian taiga forests is situated on what is termed the Siberia plateau and extends over 1,000 miles from Krasnoyarsk to Yakutsk between the Lena and Yenisol rivers. The geology is said to resemble that of the South African and Indian regions. The right bank of the Vilyui, a tributary of the Lena, is the centre of the richest find—a diamond pipe. Some history of the geological endeavours leading to the finding of diamonds is given. The first diamonds were found in 1947 in the Upper reaches of the Nizhnaya Tunguska river. The finding of pyropes in 1953 in the region of the Upper Markhi river led to the finding of the kimberlite pipe. A new design X-ray separator working on the principle of the X-ray luminescence of diamond crystals is used to separate the diamonds from the run-of-the-mine rock.

1 illus. R.W.

ANDERSON (B. W.). *Synthetic gemstones and their detection.* Gemmologist, Vol. XXVII, No. 322, pp. 79–85. May, 1958.

A report of a lecture given to the West of Scotland branch of the Gemmological Association. Reconstructed rubies were remarked upon and synthetics and the difficulties which may be encountered in their detection discussed. The use of the spectroscope as an aid to the detection of some synthetics explained. Various other " special " synthetics, such as the synthetic star stones and the new red synthetic spinels, are mentioned. Some remarks on the synthetic emerald and on other synthetics were made by the lecturer.

6 illus. R.W.

BOWDEN (F. P.). *Polishing diamond.* Gemmologist, Vol. XXVII, No. 322, pp. 86–90. May, 1958. Extracted from *Adhesion and friction,* Endeavour, January, 1957.

An elegant article explaining experiments carried out on high-speed polishing. The diamonds are rubbed against a rotating metal ball held and rotated in a vacuum by magnetic means. Polishing does not occur at speeds over 250 metres per second for at high speeds the high temperature caused by the friction causes softening and melting of the ball, or metal lap, to take place without

abrasion of the diamond, whereas at speeds just below this, diamond is polished, even on the octahedral faces which are difficult to polish by conventional means.
6 illus. R.W.

WEBSTER (R.). *A new imitation turquoise from Germany.* Gems and Gemology, Vol. IX, No. 4, pp. 115–117. Winter 1957/8.

A further report on imitation turquoise made in Germany (*cf.* Steinwehr, Journ. Gemmology, Vol. VI, No. 5, p. 220.) A short review of older turquoise imitations is given and the new material is compared with the so-called "Viennese turquoise," and with the American plastic-bonded types of imitation turquoise. The new material has a hardness of $3\frac{3}{4}$ (Mohs's scale) ; the refractive index is near 1·55 and the density about 2·4. Like some of the other turquoise imitations a spot of hydrochloric acid turns yellow when placed on the surface of the specimen, a test which if carried out on the base or an inconspicuous part of the stone leaves little or no damage. The new imitation does not show the turquoise spectrum and under the long-wave ultra-violet lamp a bluish glow pin-pointed with bright blue spots is seen.

P.B.

BATCHELOR (H. H.). *Gem fields of Australia are finished.* Gemmologist, Vol. XXVII, No. 325, pp. 153–154. August, 1958.

Owing to the drought and lack of water most of the miners have left Lightning Ridge and it is said that the black opal is a thing of the past. All the opal fields are deserted except Coober Pedy and Andamooka where a few old pensioners are scratching over the old workings. The sapphire fields are said to be worked out except Willows where a couple of prospectors are getting some small yellows and greens. A few diamonds are found in nearly all States, the largest a 12 carat black crystal. The only minerals sought after are silver, lead and uranium. Gemstones are not in demand in Australia, the people being quite satisfied with synthetics. R.W.

VAN LEUVEN (E. P.). *The virtues of bloodstone.* Gemmologist, Vol. XXVII, No. 325, pp. 155–156. August, 1958.

An article recounting the legends and the supposed medicinal properties of the quartz mineral called bloodstone or heliotrope.

R.W.

WEBSTER (R.). *Coral, shell and operculum.* Gemmologist, Vol. XXVII, No. 319, pp. 28–29. Feb., 1958.

The continuation of the series reported in Abstracts, Journ. Gemmology, page 268, April, 1958. The objects known as " shell " or " Chinese cat's-eyes " are discussed. Correctly termed operculum, the pieces have no optical chatoyancy but have eye-like markings. The pieces are the lid or door which shuts in certain shellfish when they retire into their shell. Most of these objects come from the snail-like animal *Turbo petholatus.* The density of such pieces lies between 2·70 and 2·76 and the hardness is 3½. They are found in the Pacific Ocean along the shores of many of the islands. Fossil ammonites are mentioned as having been mounted in jewellery.

2 illus. P.B.

MAYERS (D. E.). *The Sandawana emerald discovery.* Gemmologist, Vol. XXVII, No. 320, pp. 39–40. March, 1958.

The report of a discovery of emerald in Southern Rhodesia. The deposit was found by two field geologists, who promptly reported their find to the Southern Rhodesian Government. The emeralds occur in schist, bordering a pegmatite; The occurrence resembles that of the Gravelotte emeralds of Northern Transvaal. The crystals are not impressive, are distributed over a large area and the bulk of the stones are worthless for gem purposes.At one spot they occur in superb quality and are of a deep green colour. Fine stones have been cut from the good quality rough, but as the material is badly flawed only calibre sizes under a quarter of a carat can be obtained as cut stones.

R.W.

MUIR (R. E.). *Is it a diamond ?* Gemmologist, Vol. XXVII, No. 321, p. 77. April, 1938.

A report on the appearance of, and the response by jewellers to, a three-stone ring set with strontium titanates. Most jewellers considered it to be a " deceit," but not in all cases were the stones spotted as not being diamonds. Those who thought it wrong could not name the stones. It is suggested that price will keep the synthetic strontium titanate from the hands of the unscrupulous.

R.W.

WEBSTER (R.). *Amber and jet.* Gemmologist, Vol. XXVII, No. 320, pp. 50–55. March, 1958.

A full description of the various ambers and the localities where they are found is given. Mention is made of the varieties and the commercial classification. " Sun spangled " amber and the inclusion of insects in amber are discussed. The various imitations and their detection completes the article.

P.B.

BROWN (J. C.). *Sapphires of Burma.* Gemmologist, Vol. XXVII, Nos. 318/319/320, pp. 1–6, 24–27, 41–44. Jan./Feb./Mar., 1958.

A very complete survey of the occurrence and recovery of the sapphires found in Burma. Burma sapphires were for long unjustly classed as inferior to those from Thailand, Cambodia, Ceylon and Kashmir. The history of the negotiations with Streeter, after the annexation of Burma by the British forces in 1886, which formed the basis of the ruby regulations and the formation of the Burma Ruby Mines Ltd. Comment is made on an unsatisfactory clause in the agreement with the company. The recovery of the gems during the 37 years the Burma Ruby Mines Ltd. were in existence is discussed, and the value, weight and percentages of the rubies, sapphires and spinels mined are given. The company went into voluntary liquidation in 1925 but a skeleton staff carried on small scale mining until 1931 when the Government of Burma assumed supervision of the industry. The method of licensing by the Burma Government and the financial return to the Government from the different methods of licensing are mentioned. This state of affairs ended when the Japanese erupted into Burma and mining was not recommenced (and then only on a small scale) until 1945, this post-war mining being hampered by the insurrection and political unrest and difficulties of communication. The weight and value of the rubies, sapphires and spinels officially recovered in Burma for the ten years 1945 to 1955 is told. The grading of Burmese sapphires into six groups, excluding the star-sapphires and the fancy-coloured sapphires is explained. Yellow, purple and colourless corundums are fairly common while violet and deep amethyst are rare and green sapphires almost unknown. An " alexandrite "-coloured sapphire exhibiting a change of colour has been reported. The ethnographical connexion of the Bur-

mans with the Shan States of Siam is discussed, and reference made to the trading of Burmese sapphires to Bankok in Siam giving the impression that stones emanating from Burma were Siamese sapphires. The mines of the Phailin deposits were discovered by the Shans from Burma and were mined by them. Some notes on the history of the mining sapphires from Siam and Cambodia are given. The blood-red colour of Mogok rubies is described as the colour of a living pigeon's eye. Comparison is given of the colour of the blue sapphire from Siam as against that of the stones from Burma. The writer mentions that the provenance of a stone may not always be possible to determine. The chief mining centres for Burma sapphires are at Kathe, Kyaungdwin and Gwebin.
4 illus. R.W.

EHRMANN (M. L.). *A new look in jade.* Gems and Gemology, Vol. IX, No. 5, pp. 134–135 and 158. Spring, 1958.

A factual report on the staining of jade. Whitish-grey jadeite cabochons are heated over a charcoal burner until they turn to a glossy opaque finish. After cooling the stone is placed in a dye solution for a short time (48 hours in practice) after which they are rinsed in alcohol and dried on a towel. Two acid-based dyes are used, a yellow and a blue, which are mixed in pure alcohol. The stones are finished by placing in melted wax, after which they are thoroughly dried. A salt-based dyestuff with distilled vinegar will also produce the desired colour. The formation of jade triplets is also discussed. In these the centre piece of jadeite is coloured with a jelly-like dye and this is inserted into the hollow top and the bottom piece is then glued on.
1 illus. R.W.

WEBSTER (R.). *Imitation pearls—their manufacture and properties.* Gems and Gemology, Vol. IX. No. 5, pp. 144–147. Spring, 1958.

A reprint of an article published in the Gemmologist and recorded in Journ. Gemmology (Abstracts), Vol. VI, No. 6, page 268.
2 illus. P.B.

NAUTIYAL (S. P.) : MUKHERJEE (B.). *Absorption spectrum and colour of blue sapphire.* Gemmologist, Vol. XXVII, No. 324, pp. 119–121. July, 1958.

Discusses the absorption spectrum and fluorescence of blue sapphire. Comments on the finding of two absorption bands in

the ultra-violet at 3750 and 3880Å, but makes no mention that these bands had been previously recorded by Anderson. Spectrographic analysis made on sapphires from Burma and Ceylon. The criticisms made of earlier workers in the field of fluorescence do not agree with the text of the actual articles.
1 diagram. P.B.

SCHLOSSMACHER (K.). *Neue Instrumente zur Edelsteinuntersuchung.* New instruments for the determination of precious stones. Zeitschr. d. Deutsch. Ges. f. Edelsteinkunde, No. 23, pp. 10–13, 1958.

The following instruments developed by E. Gübelin are described : (*a*) the precision stone spectroscope, a complete unit with light source of varying intensity, universals pecimen holder, wave-length scale and eye piece with rotating disc to bring one of several lenses in position to suit the eyes of the user, (*b*) the gemmolux, an adjustable light source of many uses for the gemmologist, (*c*) the gemmoscope, a binocular microscope with polarizing equipment, adjustable light source, specimen holder and provision for the attachment of the " perloscope " which allows examination of drilled and half-drilled pearls, (*d*) the fluoroscope, making use of a copper sulphate solution filter (Stoke's principle), (*e*) hardness plates.

W.S.

MEDENBACH (K.). *Ein Mikroskop zur Untersuchung von Edelsteinen und Lagersteinen.* A microscope for the examination of precious stones and jewel bearings. Zeitschr. d. Deutsch. Ges. f. Edelsteinkunde, No. 23, pp. 13–17, 1958.

An inverted microscope with polarizing equipment by Leitz, of Leica fame, is described (magnification 15 × to 250 ×). The microscope developed by Dr. Waldmann, Basel, is particularly useful in the determination of the crystal orientation of jewel bearings. (Wear properties depend on correct orientation.)

W.S.

POUGH (F. H.). *Now, " cultured rubies."* Jewelers' Circular, Keystone, p. 56, July, 1958.

A short account of the production of synthetic corundum by a technique similar to that used for production of synthetic quartz

and emerald. The corundum is grown from a seed of synthetic corundum produced by the Verneuil method. Colourless corundum and ruby have been produced but the crystals are small. Larger crystals are possible but at the moment the experiment is of scientific rather than commercial interest.

The article refers to an argument put forward that the word " synthetic " is insufficient to describe some materials produced by man. The suggestion is made that there is need for etymological distinction between substances formed by two wholly different techniques. This seems quite unnecessary, for a ruby produced by the Verneuil method or from a seed in an autoclave is a *synthetic* to any clear thinking gemmologist.

S.P.

The Australian Gemmologist. A journal of gemstones, jewellery and minerals produced for the Gemmological Association of Australia. No. 1 of Vol. 1 appeared in July, 1958.

WIRTH (A. A.). *Gem inclusions through a* ×10 *loupe.* Australian Gemmologist, 1, 1, pp. 10-12, 1958.

A short survey of the inclusions in the principal gemstones which may be recognized with a 10 × pocket lens.

S.P.

TOLANSKY (S.) : HOWES (V. R.). *Induction of ring cracks on diamond surfaces.* Proc. Phys. Soc., Vol. 70B, pp. 521-526, 1957.

Further work on the production of percussion marks on diamond surfaces has shown that softer materials can be used to produce pressure crack figures : tungsten carbide and sapphire balls have produced cracking on an octahedral face of diamond. The full development of a pressure crack is traced : three distinct types of cracking are associated with each percussion mark and the mechanism of each is discussed in terms of cleavage, crystallographic shatter and cracks due to shock-wave propagation.

R.A.H.

EMARA (S. H.) : TOLANSKY (S.). *The microstructure of dodecahedral faces of diamond.* Proc. Roy. Soc., Vol. 239, A, pp. 289-295, 1957.

Multiple-beam interferometry and the light-profile microscope

have been used to study the microtopography of the faces of six dodecahedral diamonds. These faces show either striations or oriented network patterns, both being caused by narrow shallow ruts often less than 50Å deep. These ruts are compared with the results of etching and it is considered that dodecahedral faces are more subject to natural solution processes than are octahedral faces.

R.A.H.

BOOK REVIEWS

SMITH (G. F. H.). *Gemstones.* Revised by F. Coles Phillips. 13th edition, 560 pp., 28 plates (4 in colour) and 138 text illustrations. Methuen & Co., Ltd. London, 1958. 50s.

Gemmologists throughout the world will be glad to know that, five years after its author's death, a new and revised edition of Dr. Herbert Smith's *Gemstones* has made its appearance.

The work of revision was entrusted to Dr. F. Coles Phillips, Reader in petrography in the University of Bristol, and author of the best modern book on crystallography. The choice has proved to be a very happy one. No small part of the book's standing as a classic has lain in the scholarly, authoritative and academic vein in which it was written, and it would have been a great mistake for revision to be carried out by someone with an entirely different style and cast of mind. Passages of Dr. Phillip's own writing differ from those of the original author in being more succinct and more easily comprehended, but the general flavour and feel of the book has not been marred in any way.

Before new matter could be added to the book an essential and rather drastic job of pruning had to be undertaken. The best issue of *Gemstones* before the present (13th) edition was the 9th edition, which appeared in 1940. In this, the author, by a great effort continuing over several years, had almost entirely rewritten the former relatively slight text, and expanded it into a formidable volume containing over 200,000 words. In a subsequent revision (1949) the book became unbalanced ; far too much space being devoted, for instance, to crystal morphology at one end of the book and to ivory at the other, while the gemmologist's most essential tool, the microscope, was still only accorded incidental mention.

Dr. Phillips has succeeded in improving the balance very effectively. Discussion of crystal morphology has been reduced to an essential minimum ; long and stringent mathematical proofs of certain formulae have been omitted or simplified ; ivory now has a suitably modest place amongst the borderline materials of gemmology and, on the positive side, a new chapter has been added, describing with admirable clarity the functions of the polarizing microscope and its application to gemmology. It is worth noting, perhaps, that Dr. Phillips has plumped boldly for *seven* crystal systems in accordance with current British practice. This is certainly more logical than making the trigonal system an appendage of the hexagonal, since with seven systems each can be related to unique features in their axes of symmetry. Thus, the triclinic system can be said to include all crystals possessing no axes of symmetry ; the monoclinic system includes all crystals possessing a single digonal axis, the trigonal system includes all crystals possessing a single trigonal axis, the hexagonal system includes all crystals which possess a single hexagonal axis . . . and so on, as shown on p. 34 of the book.

The descriptive part of *Gemstones* was always its strongest feature, and Dr. Phillips has wisely made few alterations here, except by the inclusion of newly-discovered gem materials such as sinhalite and painite, and a re-arrangement of the less important gems in alphabetical order for ease of reference.

The bibliography has also been brought up-to-date and re-arranged under such headings as " Early works," " General," " Identification," " Diamond," etc., which will probably prove useful to those in search of special information though lacking in the sheer chronological sweep of Herbert Smith's earlier arrangement. The index, too, has come in for some welcome pruning, page references being limited to those which are really useful, often with bold type to indicate the most important reference.

The whole lay-out of the book is clean and attractive, and the publishers, Dr. Coles Phillips, and his advisers are to be congratulated on producing a worthy successor to the previous editions of this famous and essential classic.

B.W.A

SCHLEGEL (DOROTHY M.). *Gem Stones of the United States.* U.S. Geological Survey Bulletin 1042G. pp. 50.

A small paper-covered book issued by the U.S. Geological Survey. The great value of the work lies in the exhaustive list of gem localities given in the second part of the book. This occupies 17 pages and lists more than one thousand gem mineral occurrences in over 650 localities under State and County headings.

The fact that the book is apparently written largely for a lay public and is about American sources only is probably responsible for the omission of refractive indices from the descriptive section, and for the relegation of zircon, peridot and spinel to " also-ran " positions in a list at the end of the book, entitled " Other Gem Stones of the United States." The book is primarily for home consumption. It is none the less a contribution to world gemmological literature out of all proportion to its size.

R.K.M.

WILLIAMSON (G.). *Sky smuggler.* Robert Hale Ltd., London, 1958. 16s.

Describes many exploits of smuggling and the way H.M. Customs and Excise authorities have adapted their methods to compete with the difficulties encountered with the introduction of air travel. Diamonds and watches account for a large part of smuggled articles and there are many references to the various ruses and tricks attempted by would-be smugglers.

H.W.

AN INEXPENSIVE ULTRA-VIOLET LAMP

By RUDOLF THURM

In order to obtain an effective ultra-violet light lamp at moderate cost, I purchased a Phillips fluorescent tube and a Chance OX7 filter. The lamp was placed into a pupil's pencil box, backed with an aluminium foil from a cigarette box to act as a reflector. The lid of the box had to be cut out slightly to enable it to slide over the lamp socket. A pocket knife did all the cutting necessary.

The illustrations show some results that have been obtained with the pencil-box ultra-violet light lamp. The fluorescence of the synthetic red corundum appears rather weak in the illustration because the film used was more sensitive to blue light.

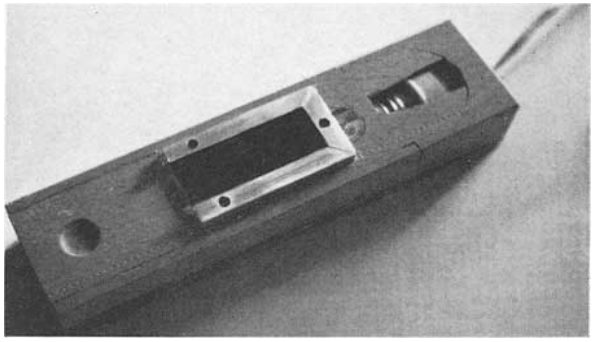

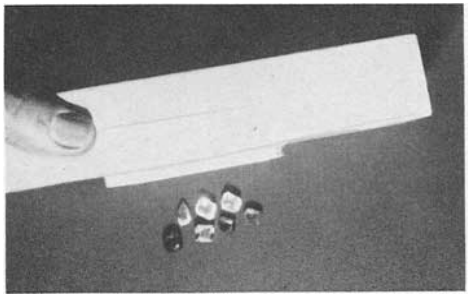

Left to right Top line

Aquamarine

Synth. aquamarine-coloured spinel

Synth. peridot coloured spinel

Bottom line

Green tourmaline

Synth. green-tourmaline-coloured spinel

Red garnet

Synth. ruby-coloured corundum

ASSOCIATION NOTICES

EXAMINATION RESULTS

In the 1958 examinations in gemmology 138 candidates presented themselves for the preliminary and 100 for the diploma examination. Upon the recommendation of the examiners the Tully Memorial medal was awarded to John G. Roach of Birkenhead.

The following is a list of successful candidates, arranged alphabetically :—

DIPLOMA

Tully Medallist : Roach, John G., Birkenhead, Cheshire.

Qualified with Distinction

Coakley, Brian, Manchester.
Donaldson, Robert G., London.
Fuhrbach, John R.,
Amarillo, Texas, U.S.A.
Roots, Jack L., Rainham.
Rushworth, Jack, Halifax.
Tungate, James B., London.

Qualified

Ainsworth, Michael B., Blackburn.
Aldridge, Patrick E., London.
Armstead, John M., London.
Atkinson, James C., Whitley Bay.
Baglee, Gordon, Whitley Bay.
Biggers, Willard B., London.
Black, Vete G.,
Spring Valley, Calif., U.S.A.
Boyd, Russell T. F., Toronto, Canada.
Callaghan, David J., London.
Clarke, Eric M., London.
Clay, John J., Leicester.
Cook, Peter B., Birmingham.
Cooke, Barrie E., Birmingham.
Delario, Anthony J.,
Paterson, N.Y., U.S.A.

De Silva, Lindamulage J. C. F.,
Colombo, Ceylon.
Eakins, Harry, Liverpool.
Falconer, Richard A., New Malden.
Ferguson, Charles T., Smethwick.
Francis, Barry P., London.
Greene, Patrick, London.
Gunning, Jack W., Toronto, Canada.
Henn, Elizabeth R. (Miss), Farmcote.
Hermitage, Wendy B. (Miss), London
Hill, Stanley G., Birkenhead.
Hopper, Peter J., Boston.
Huddy, George, Liskeard.
Jones, James R.,
Mortdale, N.S.W., Australia.
Lema, Audry Hayes de (Mrs.),
Colombia, South America.
Mackenzie, Enid L. Dowell (Miss),
Glasgow.
Mooney, Eugene, Edinburgh.
Ould, Thomas A., Plymouth.
Peplow, William R. H., Stourbridge.
Petterson, Bjorn W., Oslo, Norway.
Phillips, Dennis, Leeds.
Plews, William A., Edinburgh.
Reeves, Roger C., Chatham.
Reynolds, Helen M. (Miss), Ludlow.
Ritchie, Arnold J., Toronto, Canada.
Sando, Kolbjörn, E., Oslo, Norway.
Skinner, Ramon, London.
Smith, Clifford J., Walsall.
Smith, David J., Brighton.
Steadman, Ivor N., Huntingdon.
Stitt, John, Toronto, Canada.
Taylor, Joseph N.,
Newcastle upon Tyne.
Walton, Joseph H., Cirencester.
Warburton, Frederick W.,
Toronto, Canada.
Weller, George T., Tunbridge Wells.
White-Hide, Richard G., Wadhurst.
Whyte, Archibald G., Edinburgh.
Wille, Robert F., Toronto, Canada.

Rayner Prize : Mendelsohn, Michael, Cape Town, South Africa.

Allden, Arthur G., London.
Allemann, Susanne (Miss),
Basel, Switzerland.
Bacon, Frank H., Kempston.
Battersby, Keith W., London.
Bergan, Kjartan E., Oslo, Norway.
Betts, Geoffrey N., Birmingham.
Biggers, Willard B., London.
Black, Vete G.,
Spring Valley, Calif., U.S.A.
Boyd, Russell T. E., Toronto, Canada
Britchfield, Charles F. J., Gravesend.
Brodtkorb, Anne K. (Miss),
Hokksund, Norway.
Brousseau, Murray P., Toronto,
Canada.
Buitenen, A. Th. Cr. v.,
S-Hertogenbosch, Holland.
Clark, Alexander, Ruislip.
Conyers, Barry, London.
Dalrymple, Angus, Canvey Island.
Delario, Anthony J.,
Paterson, N.Y., U.S.A.
Durrant, Anthony W., Ipswich.
Edminson, Dennis F.,
Toronto, Canada.
Edwin, Wilfred, Medan, Sumatra.
Engstrom, Hans, W. E., London.
Etienne, Lorette (Mrs.),
Bangkok, Thailand.
Feer, Beatrice D. (Miss),
Geneva, Switzerland.
Fuhrbach, John R.,
Amarillo, Texas, U.S.A.
Fernando, W. B. C.,
Mount Lavinia, Ceylon.
Fjeld, Per G., Oslo, Norway.
Griffiths, William H., Birmingham.
Gryska, Stephen, Worksop.
Gulliksen, Gunnar B., Oslo, Norway.
Gunning, Jack W., Toronto, Canada.
Hickman, John T., Bristol.

Jarvis, John C., Calcutta, India.
Jones, James R.,
Mortdale, N.S.W., Australia.
Just, Turid, Oslo, Norway.
Kay, Jonathan G. D., Woolton.
Langton, Edward G., London.
Lax, Edgar, London.
Leek, Stanley H., Toronto, Canada.
Lema, Audrey Hayes de (Mrs.),
Colombia, South America.
McCulloch, Robert, Glasgow.
Malm, Knut, Oslo, Norway.
Marshal, Michael, Cottingham.
Maund, Anne A. (Miss), London.
May, Peter G., Leicester.
Morrell, Anthony, Knaresborough.
Neil, Peter B., Glasgow.
Parker, George E., Birmingham.
Patience, Kenneth, Norwich.
Pattni, Pravinkumar, Birmingham.
Pilot, Lawrence M., London.
Ponka, Bernard, Birmingham.
Pragnell, John W., Bournemouth.
Raven, Robert H., Chelmsford.
Relwani, Arjan C., Calcutta, India.
Ritchie, Arnold J., Toronto, Canada.
Schoien, Magnus, Skien, Norway.
Shapland, Roger S. C.,
Cookham Dean, Berks.
Shotton, John J., London.
Smith, James S. A., Glasgow.
Solomons, Alexander, Guildford.
Stitt, John, Toronto, Canada.
Stocker, Philip Leslie, London.
Turner, Bernard A., Nelson.
Turner, Stanley, London.
Vlerk, Hendrik T. van der,
Schiedam, Holland.
Wheeler, Alfred, Aylesbury.
Whitehead, Helen B. (Mrs.),
Edinburgh.
Whitehead, Henry J., Edinburgh.
Wille, Robert F., Toronto, Canada.
Winter, Elspeth W. (Miss), Guiseley.
Yates, Roy Frank, Manchester.
Zegerius, Harry, Amsterdam, Holland.

TALKS BY MEMBERS

LONGBOTTOM, W. : " Gemstones," to Yorkshire Federation of Women's Institutes, Hull, 9th September, 1958.

NORWEGIAN GEMMOLOGICAL ASSOCIATION

The offices of President and Secretary of the Norwegian Association have changed as the result of the election of the Secretary, Mr. Gunnar Sunde, F.G.A., as President and Mr. Hans Myhre, F.G.A., as Secretary. Mr. Myhre had been President of the Association for the past four years.

The Norwegian Association has been successful in arranging a radio series on " Our precious stones." Several members have given talks on gems, pearls and testing, each broadcast taking about twenty minutes.

MEMBERS' MEETINGS

The meeting of members held at the Medical Society of London's Hall on Tuesday, 14th October, 1958, will be reported in the next issue of the journal.

A reunion of Fellows and Members will be held in the Goldsmiths' Hall, London, E.C.2, on 11th November, 1958, between 6 and 7 p.m. The presentation of awards gained in this year's examinations will be at 7.15 p.m. Dr. F. C. Phillips, Reader in Petrology at the Bristol University, who has recently revised the thirteenth edition of G. F. Herbert Smith's *Gemstones* has kindly consented to present the awards.

GEMMOLOGICAL ASSOCIATION OF AUSTRALIA

In July the Australian Association produced the first issue of its own journal, the " Australian Gemmologist." It will be abstracted in this Journal. The Council of the Association has sent its congratulations and good wishes to its sister organization upon its enterprise.

GIFTS TO THE ASSOCIATION

The Council of the Association acknowledges with gratitude the following gifts :—

The recognition of minerals by C. G. Moor, from Mr. R. Webster. A collection of synthetic emeralds made by Prof. Nacken, from Mr. G. Wild.

An anonymous donation of £5 for the Sir James Walton Memorial Library.

GEMSTONES AND GEOLOGY

Tutor : M. J. Frost, B.Sc., F.G.A.A., Research Fellow in Geology, University of Birmingham.

The department of extra-mural studies, University of Birmingham, has arranged a course on gemstones and geology. The course emphasis will be on the geological aspects of gemmology. It is not intended to be a vocational course. The classification, properties and occurrence of gemstones will be covered in the lectures and an approach will be made to gemstone prospecting and gem determination. Special attention will be given to the study of inclusions in both synthetic and natural gemstones as a clue to their mode of origin.

The practical work will introduce the study of natural, treated, and man-made gemstones. Participants will have the opportunity of using most of the instruments used in gemstone determination and of examining many of the

more important gemstones, cut and uncut, as well as the rocks in which they are found.

Enrolments will be limited to ten. Applications must be made before the commencement of the course, accompanied by a statement of previous experience in geology.

Eleven meetings ; Mondays, 6.45–8.45 p.m., beginning October 6th. At the Department of Geology, the University, Edgbaston, Birmingham. Fee 10s.

ASSOCIATION SUBSCRIPTIONS AND INCOME TAX

The Commissioners of Inland Revenue have approved the Gemmological Association of Great Britain for the purposes of Section 16, Finance Act, 1958, and that the whole of the annual subscription paid by a member who qualifies for relief under that Section will be allowable as a deduction from his emoluments assessable to income tax under Schedule E.

The circumstances and manner in which members may make claims to income tax relief are described in the following paragraphs.

Commencing with the year 5th April, 1959, a member who is an office holder or employee is entitled to a deduction from the amount of his emoluments assessable to income tax under Schedule E of the whole of his annual subscription to the society *provided that*—

(*a*) the subscription is defrayed out of the emoluments of the office or employment, *and*,

(*b*) the activities of the society so far as they are directed to all or any of the following objects :—

(i) the advancement or spreading of knowledge (whether generally or among persons belonging to the same or similar professions or occupying the same or similar positions) ;

(ii) the maintenance or improvement of standards of conduct and competence among the members of any profession ;

(iii) the indemnification or protection of members of any profession against claims in respect of liabilities incurred by them in the exercise of their profession ;

are relevant to the office or employment, that is to say, the performance of the duties of the office or employment is directly affected by the knowledge concerned or involves the exercise of the profession concerned.

A member of the Association who is entitled to the relief should apply to his tax office as soon as possible *after 31st October, 1958*, for form P 358 on which to make a claim for adjustment of his pay as you earn coding.

SMITHSONIAN INSTITUTION

At the end of July the Smithsonian Institution, Washington, D.C., opened an exhibition hall in the modernized Institution which contains a most extensive collection of gems. Among the exhibits are a 316 carat star-sapphire, a 66 carat alexandrite and a 310 carat peridot. The new hall is called the hall of " Gems and Minerals " and contains examples of all the principal species of minerals. Featured among them is a large greenish specimen of smithsonite, a carbonate of zinc named after its discoverer, James Smithson, the Englishman who founded the Smithsonian Institution.

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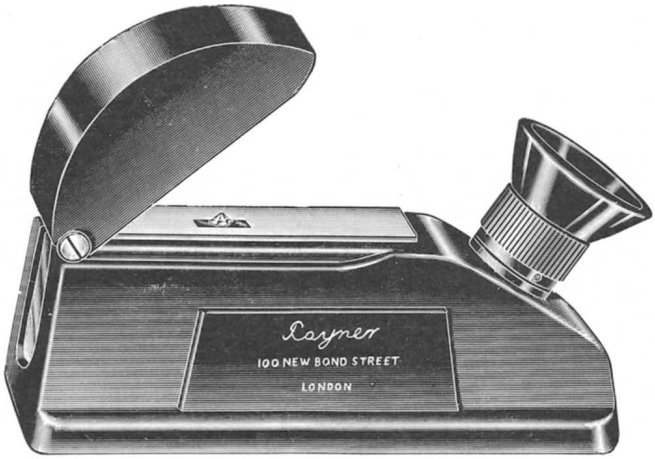

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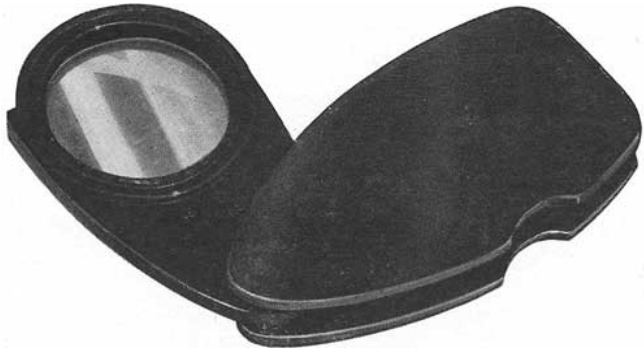

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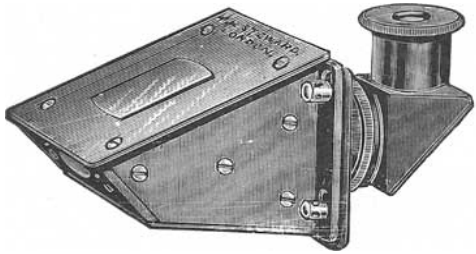

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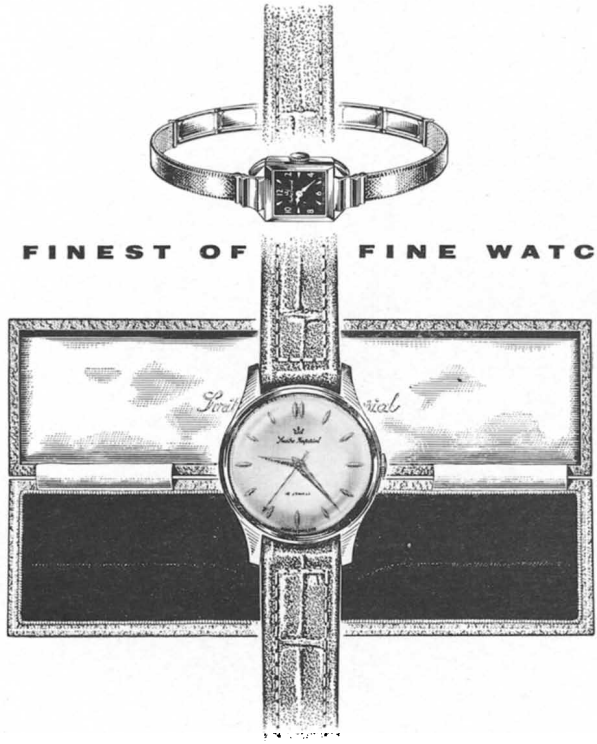

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PROPERTIES AND CLASSIFICATION OF INDIVIDUAL GARNETS

By. B. W. ANDERSON, B.Sc., F.G.A.

THOUGH we are accustomed to think of the garnets as providing perfect examples of an isomorphous group of minerals, it has been shown that not all of the six recognized garnet molecules are completely intermiscible. They fall, in fact, into two sub-groups to which Winchell has given the "portmanteau" names Pyralspite (pyrope, almandine, spessartite) and Ugrandite (uvarovite, grossular, andradite). Within each group, continuous replacement of one molecule by another is possible, but *between* the groups replacement is seldom found to exceed some 20 per cent. A reason for this may perhaps lie in the cell dimensions, since pyrope and almandine, for instance, have a value of near 11·5Å for the length of the unit cube, and spessartite only a little larger (11·6), whereas with grossular and andradite the cell is distinctly larger (11·9 and 12·0Å, respectively).

PYRALSPITE

In the " pyralspite " group the following are the values calculated (originally by W. E. Ford in 1915, and since modified by Fleischer) for the pure molecules.

Garnet	*Composition*	*Density*	*Ref. index*
Pyrope	$Mg_3Al_2Si_3O_{12}$	3·51	1·705
Almandine	$Fe_3Al_2Si_3O_{12}$	4·32	1·83
Spessartite	$Mn_3Al_2Si_3O_{12}$	4·18	1·80

In the pyrope-almandine series, to which almost all the red garnets belong, the above figures do not correspond with any stones found in nature, and quoting these figures in books as though they were testing constants has often given rise to confusion. It is important from the practical point of view to know the limits of refractive index and density actually found. The beginner, for instance, may find himself unsure from the constants he has determined for an isotropic red stone whether he is dealing with a " low " pyrope or a " high " spinel. The writer at one time went into this question in some detail, and found that, though there were a few rare cases where chrome-rich spinels might have a higher refractive index (up to 1·734) than the lowest figure for pyrope (1·730), there still existed a gap between the densities even in these extreme cases : the spinel having the exceptional index of 1·734 had, for instance, a density of 3·611, while the pyrope with the record low figure of 1·730 for its refractive index was found to have a density of 3·650. Were these the only tests, of course, confusion might occasionally arise, but differences in the absorption spectra of the two species, the fact that pyrope is inert under ultra-violet light while spinel is fluorescent, and the distinctive inclusions of each, should enable the gemmologist to be on quite safe ground, and the resort to analysis, which has been advocated, quite unnecessary.

Figures may here be quoted for some of the " low " pyropes encountered by the writer. Two rose-red specimens from an unspecified Australian source had a density 3·670 and refractive index 1·733; another stone, from an unknown source, had density 3·669 and an index of 1·732, while a specimen from Arizona had a density just below 3·65 and refractive index 1·732. These figures are exceptional, not normal. The majority of pyropes used in jewellery, from Bohemia, Kimberley or Arizona, have densities near 3·70 and refractive indices from 1·742 to 1·750. The *dispersion* of pyrope was found to be appreciably lower than the figures given

in standard texts : it was in fact little higher than for spinel, being 0·021 to 0·022 for the B-G range.

It may be said, then, that pyropes in nature never contain less than 20 per cent almandine, in addition to a few per cent of grossular and of uvarovite—the latter representing the chromium to which the fine red colour of pyrope is mainly due.

Turning to gem almandines, the highest figures so far measured have been density 4·245 and refractive index 1·814, corresponding to a composition of approximately 88 per cent almandine and 12 per cent pyrope if other molecules are ignored. Other high almandines measured include one with density 4·190 and refractive index 1·811, and another with density 4·161 and refractive index 1·809. More common figures are d = 4·06 and R.I. 1·795, d = 4·004 and R.I. 1·785.

In between the undoubted pyropes and undoubted almandines are many garnets from Ceylon and elsewhere having approximately equal amounts of each, with smaller percentages of other garnet molecules. Constants for two such garnets may be given merely as examples : one had a density of 3·93 and refractive index 1·772, the other had d = 3·83 and R.I. 1·758. For such stones the name *pyrandine* was suggested by the writer some years ago, to avoid the cumbersome description " almandine-pyrope." One must admit that in the trade the term " garnet " alone is sufficient for any stones belonging to this series, but gemmologists prefer to be more specific.

One intermediate type which finds mention in most books on gems has been given the name rhodolite on account of its rose-red colour. Specimens from the well-known source, Corundum Hill, near Franklin, N. Carolina, had a bulk density (that is, the average of several small specimens) of 3·860 : one refractive index was 1·7585 and another 1·7570 for sodium light, and each had a B-G dispersion of 0·0227. The first specimens of rhodolite described were from Mason's Branch, Macon county, N. Carolina (Hidden and Pratt, 1898) and had a density of 3·838. Analysis showed the presence of 57 per cent pyrope and 35 per cent almandine, with traces of andradite and grossular.

Rhodolite is not really a suitable name for all pyrandine garnets, partly because it is tied to a certain shade of red and partly because

the name itself is too easily confused with the manganese silicate mineral rhodonite.

Less familiar amongst the gemstone garnets are those belonging to the almandine-spessartite series, but such mixed manganese garnets are by no means rare, and in such cases the question of correct nomenclature assumes considerable importance. Spessartite at its best is a very beautiful stone, and highly valued by collectors. Its characteristic tint is a subtle shade of orange to which the epithet " aurora-red " has been given. This is often modified or even obscured by the presence of almandine, and it then becomes a difficult question to know at what point the more favourable " selling name " of spessartite must be abandoned.

A recent example of this was a garnet from Brazil occurring in large irregular dodecahedral crystals showing a curious layered growth-structure already observed in other undoubted spessartite crystals both from Brazil and Norway. The colour, though very deep, had perceptibly a spessartite tinge by transmitted light: the absorption spectrum, though difficult to observe because of the strong general absorption, showed spessartite bands as well as those of almandine : and the inclusions (scattered liquid films) were more like those associated with spessartite than with any almandine. The density (4·245) and refractive index (1·815) were, however, virtually those of a high almandine (see above). The case seemed sufficiently intriguing to warrant the expense of a complete professional analysis. This was carried out by Messrs. Johnson, Matthey & Co., and established the presence of 44 per cent spessartite and 53 per cent almandine, with 1·5 per cent grossular but no magnesium (pyrope). The full analysis, on 5·65 grams of material, dried at 100°C., was as follows :—

Silica (SiO_2)	35·02
Alumina (Al_2O_3)	21·22
Ferrous oxide (FeO)	23·12
Manganous Oxide (MnO) ...	18·92
Lime (CaO)	0·57
Magnesia (MgO)	nil
Oxygen and loss	1·15
	100·00

It is obvious from the above analysis that there is no single name that can be given to such a garnet. For similar manganese-rich garnets described in the literature the term " mangan-almandine " has often been used. For gemmologists, the name " spessandine " might usefully be coined for such half-way specimens, by analogy with " pyrandine " in the almandine-pyrope series. Manganese-pyropes do not seem to occur.

The constants of almandine and spessartite are too close to serve as a reliable guide in assessing the relative amounts of each that are present in a given case. *Knowing the result* of an analysis it is easy to justify the constants with reference to the theoretical figures—but working the other way round is by no means so certain. Since chemical analysis is seldom possible in dealing with gem material, one has to rely on colour, absorption bands, and inclusions in addition to the density and refractive index in an attempt to place the garnet in its correct category. The absorption spectrum of almandine (due to FeO) is of course very well known. Of the three most prominent bands, centred in the yellow (5760Å), green (5270) and blue-green (5050), the latter is the most persistent and can be seen as a fairly narrow line when quite small amounts of almandine are present. The spessartite bands (due to MnO) are confined to the blue and violet and, as with all manganese spectra, increase in strength towards the ultra-violet. A vague band at 4880Å is followed by a rather stronger band at 4620, while a powerful band at 4320 often completes the picture, since (as in all orange stones) there is strong general absorption of the violet. In pale yellow spessartites two other strong narrow bands may be seen at 4240 and 4120Å, while photographs have revealed two further powerful bands in the near ultra-violet. It is worth noting that almandine has a weak band at 4620Å, identical in position with one of the spessartite bands. If the much more powerful 5050 almandine band is missing or faint, however, a band at 4620, when seen, can only be due to spessartite.

Both almandine and spessartite are quite strongly magnetic, as can be demonstrated when a specimen of either is in equipoise on an aperiodic balance and approached by a pocket magnet, when the loss in weight gives a roughly quantitative value for the strength of the magnetic effect. Using the empirical formula Loss $\times 100/\sqrt{}$ weight, the values for gem almandines were found to

range from 290-410, and for spessartites 250-360. In the literature almandine is said to fuse to a black magnetic globule and spessartite to a black non-magnetic globule. Experiment did not confirm this, though admittedly the almandine glass globule was the more magnetic—sufficiently so to be actually lifted by a small " Eclipse " magnet, whereas the spessartite bead (fused from a piece of orange-yellow rough showing no almandine bands) gave a magnetic value 260 on the above formula, and was sufficiently attracted to move when placed on a polished surface and closely approached by the magnet. While on this subject, magnetic values for the other garnets may be quoted : they are, pyrope 40-75 ; hessonite 40 ; demantoid 120-220, using a small horseshoe " Ellipse " magnet.

The constants of some of the gem quality spessartites we have measured may be given to provide some idea of their usual range. A dark orange specimen from Norway, kindly given to the writer by Mr. Hans Myhre, had density 4·157, refractive index 1·793. This contained appreciable almandine. A purer orange specimen from Arassuahy in Brazil had density 4·160 and refractive index 1·8003. A beautiful orange-yellow crystal from the Gold Coast gave a density 4·196—no refractive index being obtainable. Another "aurora red" specimen from Brazil, showing the 5050 almandine band, had density 4·185 and refractive index 1·800.

Ugrandite

The theoretical properties of the three remaining garnets, grouped together by Winchell as " Ugrandite," have been calculated as follows :—

	Composition	*Density*	*Ref. index*
Uvarovite	$Ca_3Cr_2Si_3O_{12}$	3·78	1·86
Grossular	$Ca_3Al_2Si_3O_{12}$	3·53	1·735
Andradite	$Ca_3Fe_2Si_3O_{12}$	3·83	1·895

In this group, problems of the kind discussed above do not arise. Uvarovite can be discounted as a gem species, despite its

lovely chromium-green colour, since specimens really suitable for cutting have not yet been found, while grossular and andradite of gem quality have remarkably consistent properties and appearance, which differ greatly from each other. Hessonite, the form of grossular most used in jewellery, has a density ranging from 3·60 to 3·65, and refractive index near 1·743. Its properties are close to those of pyrope, but its characteristic orange-brown hue and granular and treacly internal structures prevent any confusion. The massive green, or sometimes pink, form of grossular, which is used as an effective substitute for jade, has lower properties than the above (d 3·48, R.I. 1·72) and shows a marked orange fluorescence under X-rays.

The magnificent green garnet, demantoid, is an almost pure andradite, coloured by chromium in addition to its intrinsic yellow colour due to ferric iron. Its density never varies far from 3·85, nor its refractive index far from 1·89—approaching closely the theoretical figures for pure andradite. Its high dispersion of 0·057 for the B-G range is twice as great as that of other garnets, and considerably higher than for diamond. Though its refractive index is beyond the range of the normal refractometer, its well-known " horsetail " inclusions of asbestos fibres (seen, curiously enough, in stones from the Belgian Congo as well as in the familiar specimens from the Ural Mountains), its fire, and its intense absorption band at 4430Å, all render it easy to identify.

Nowadays it is hardly necessary to caution gemmologists against the terms " hyacinth " or " jacinth " for hessonite or against " olivine " for demantoid. Even when these names are correctly applied to flame coloured zircon and to peridot, respectively, they are best avoided, as they engender confusion.

Apart from the attempt to provide a brief survey of the properties of the individual garnets which we meet with in jewellery, the chief purpose of this paper has been to draw attention to the difficult problem the gemmologist may sometimes be faced with in attempting to give a correct and at the same time acceptable trade name to certain garnets, not only of the commonly-occurring pyrope-almandine series, but also of the rarer almandine-spessartite series, in which latter case it must be realized that the value of the stone may be considerably influenced by the name chosen.

Gemmological Abstracts

CHAMPION (F. C.). *Diamonds.* Science Progress, Vol. 45, No. 179, pp. 447-461. July, 1957.

A general review of the physical properties of diamonds is given with theoretical interpretations of their optical absorption, photo-conductivity and luminescence in terms of their structural defects. Radiation damage can change the atomic structure of diamonds and introduce defects at will into the specimens and a detailed study of the results of such experiments is presented.

R.A.H.

DAVIDSON (C. F.). *The diamond fields of Yakutia.* Mining Mag., Vol. 97, No. 6, pp. 329-338. December, 1957.

A review of the recent descriptions, in Russian, of the newly discovered diamond fields in the basin of the River Vilyui and nearby areas in the north-west of the Yakutia A.S.S.R. in central Siberia. Both placer deposits and kimberlite pipes have been found : one of the latter is the " Mir " intrusion near the town of Suntar, and here the kimberlite is overlain by residual clays and gravels carrying 2 carats of diamonds per cubic metre. The largest diamond so far reported is a stone of 32·5 carats from the Mir pipe, but the most characteristic feature both of the pipes and alluvial deposits is the predominance of extremely small diamonds. Most of the diamonds are colourless, the rare coloured examples having lemon-yellow to deep orange-yellow tints : these yellow stones have an octahedral habit and are commonly covered by triangular etch figures. In ultra-violet light most stones fluoresce in bluish and greenish tones, the quality of this fluorescence varying with the crystal habit. Inclusions of graphite and other minerals are noted.

R.A.H.

CHAMPION (F. C.). *Some physical properties of diamonds.* Advances in Physics (Suppl. to Phil. Mag.), Vol. 5, pp. 383-411, 5 figs. October, 1956.

Following an outline of the theory of the properties of pure diamond and a consideration of the physical behaviour of actual diamonds the applications of the defect theory are considered. The seven possible defects are dislocations and mosaicity, single vacant sites, aggregates of vacant sites, single interstitial carbon atoms, aggregates of interstitial carbon atoms, substitutional foreign atoms, and interstitial foreign atoms. The problems of diamond growth, their infra-red absorption spectrum, and the behaviour of some diamonds as conductors are discussed.

R.A.H.

DYER (H. B.) and MATTHEWS (I. G.). *The fluorescence of diamond.* Proc. Roy. Soc., Ser. A, Vol. 243, No. 1234, pp. 320-335. January, 1958.

The 3650Å group of Hg lines has been found to excite fluorescence in all the type I and type IIa diamonds examined, but type IIb specimens gave no emission with this wavelength. The fluorescence spectra usually contain one or more " systems " of lines, each system consisting of a main principal line accompanied by a banded ancillary structure : these are compared with features found in absorption spectra. The effect of irradiation and of subsequent heat treatment on the fluorescence spectrum is described. The nature of the centres responsible for the fluorescence is discussed.

R.A.H.

COULSON (C. A.) and KEARSLEY (M. J.). *Colour centres in irradiated diamonds.* I. Proc. Roy. Soc., Ser. A, Vol. 241, pp. 433-454. September, 1957.

A theoretical calculation of the energy levels, and hence absorption spectrum, of an isolated vacancy in an otherwise perfect diamond lattice has been made, and the concept of a defect molecule is introduced. The results suggest that the observed band at 2·0 eV causing irradiated diamonds to appear blue is due to spin and orbitally allowed electronic transitions in the neighbourhood of isolated neutral vacancies.

R.A.H.

KOHN (J. A.). *Twinning in diamond-type structures : high-order twinning in silicon.* Amer. Min., Vol. 41, pp. 778-784. 1956.

Relative orientations of four components in part of a silicon crystal pulled from a melt have been determined from a Laue photograph. They form a non-parallel twin complex (111), and the high order twin joins represent substantial structural discontinuities. These results are of significance for twinning in diamond.

J.Z.

SLAWSON (C. B.) and DENNING (R. M.). *Stress and double refraction in diamond.* Amer. Min., Vol. 40, pp. 1135-1139. 1955.

Compressional stress was applied across a pair of octahedral faces of a normally isotropic diamond while the specimen was viewed between crossed polaroids in sodium light. The strain birefringence produced was shown by the interference patterns (curves of equal path difference), which were similar to those produced by glass under similar conditions. Considerable birefringence can be produced by small stresses so that in naturally occurring slightly birefringent diamonds, strains (if uniformly distributed) are relatively small and probably unimportant by comparison with those suffered in subsequent industrial use.

J.Z.

DA SILVA (R. R.). *Oleos Vegetais Como Líquidos de Imersão.* Vegetable oils used as immersion liquids. Gemologia, No. 12, pp. 21-24.

A list of 25 " easily obtainable " vegetable oils covering the R.I. range from 1·447 to 1·660 for use in immersion refractive index work. Apparently the liquids more normally used are difficult to obtain in Brazil, hence the suggestion that babassu oil, tomato seed oil, oiticaca oil among many others, are more easily obtained. Of the oils listed, 19 cover the range from 1·447 to 1·484, while the range from 1·500 to 1·600 includes only six of the oils. The advantages of these comparatively non-volatile liquids over such substances as chloroform, carbon tetrachloride and other rapidly evaporating liquids are emphasized.

R.K.M.

GUIMARÃES (A. P.). *O Carbonado.* Gemologia, No. 11, pp. 9–16, 1958.

An account of the cryptocrystalline type of industrial diamond found in Brazil and known as carbonado. A general account of the material, its relationship to boart and to gem diamond and particular reference to the uses to which this valuable material is put.

R.K.M.

CAMPOS (J. E. de S.). *Asterismo.* Gemologia, No. 11, pp. 17-23, 1958.

A summary of the writings of various workers on the subject of asterism in corundum and other stones. The writer discusses epiasterism and diasterism and refers to various text-books and to the detailed paper by Alice Sumner Tait (Journ. of Gemmology, Vol. 5, No. 2, 1955) which attributes the cause of asterism in corundum to oriented acicular crystals of rutile.

The writer concludes by posing further questions which he contends are not yet answered. Among them the cause of asterism in stones showing zoned growth but no rutile needles ; in stones in which the rutile needles are not regularly oriented ; and the cause of asterism produced by artificial corrosion and diasterism in minerals having no oriented inclusions. He also asks whether it is reflection or diffraction at the rutile needles which produces the effect.

4 illus. R.K.M.

MARTIN (J. G. M.). *Historical Himalaya mine resumes production.* Gems and Gemology, Vol. IX, No. 6, pp. 163-173. Summer, 1958.

A million and a half dollars worth of gem tourmaline, apart from other gem minerals, was produced by the gem mines of southern California between 1902 and 1912. The Himalaya mine was the most productive, mainly tourmaline and beryl, and much of the production was exported to China for carving. The mine, owing to the cessation of export to China and lack of outlet for its produce, was virtually abandoned in 1914, and subsequently was only culled by rockhounds. In 1952 the mine was sold and this amateur gem collecting ceased. The mining property is situated on Gem Hill at an altitude of 3,800 feet and about 4½ miles north-west of Mesa

Grande store between San Luis Rey River and the Mesa Grande Creek. Ralph R. Potter who purchased the mine in 1952 commenced reconstruction of the buildings and roads, and commenced exploratory mining. This early endeavour had many misfortunes. However, in 1957 a new tunnel was driven towards the old mining area and many small pockets of tourmaline were found. This tourmaline was of various colours, principally green, red and yellow. The associated minerals are pink beryl, albite, cleavelandite, lepidolite, apatite, muscovite, allanite (radioactive), microcline and stibiotantalite. A report of a visit to this mine by the author and G. Robert Crowningshield is mentioned. Notes on the marketing of the mine's produce and further notes on the early history of the mines are given.

9 illus. R.W.

SEMANADA (M. K. J.). *Gem mining in Ceylon.* Australian Gemmologist, Vol. 1, No. 2, pp. 11–13. August, 1958. (*Abstracted from an article in The Eastern Jeweller and Watchmaker*).

Gems are among Ceylon's oldest exports. The gems found in Ceylon are listed. In the days of the Sinhalese kings the right of digging was a royal prerogative, but this was abolished by the British and changed to a licensing system. Three methods of mining, surface-placer, pit-gemming and river-gemming, are discussed and information on the cutting and marketing of the gems given.

2 illus. R.W.

MCCONAHAY (W. C.). *Clarity.* Gems and Gemology, Vol. IX, No. 6, pp. 174-179 and 190. Summer, 1958.

The article outlines a suggestion that the usual method of grading diamonds tends to negative thinking and the author proposes another approach which avoids the issue and can yet be ethical. The author does not claim that he has solved the problem but rather to have posed a question.

WEBSTER (R.). *The Tradehall Museum at Idar-Oberstein.* Gemmologist, Vol. XXVII, No. 329, pp. 224–225. Dec., 1958.

Describes the gemstone and ornamental stone exhibits in the Gewerbehall at Idar-Oberstein. The exhibits are changed at times but when visited by the author had a general arrangement according to continents. P.B.

SCHLOSSMACHER (K.). *Fabulite—a new gem substitute.* Australian Gemmologist, Vol. 1, No. 2, pp. 8–9. August, 1958. (*Translated from the German by J. T. Altmann.*)

Fabulite—strontium titanate—is made by the American National Lead Company and in composition is near that of the natural mineral *perovskite.* The synthetic strontium titanate is made on the Verneuil-type furnace, and, like rutile, leaves the furnace black in colour and needs some hours' treatment by heating in oxygen before becoming colourless. Fabulite is cubic and the material has a refractive index of 2·40 to 2·42 and a dispersion of 0·20 to 0·22. The density is 5·13 and the hardness 6½. Some comparisons with diamond and synthetic rutile are made.

R.W.

ANON. *Australia's first pearl culture venture.* Australian Gemmologist, Vol. 1, No. 3, pp. 15–19. September, 1958.

Following a survey by a Japanese technician a site was chosen in Brecknock Harbour, North-West Australia, and operations commenced for the cultivation of spherical and half pearls in the shellfish *Pinctada maxima.* A small bay in Brecknock Harbour, recently named Kuri Bay, is the location of this first Australian culture farm. This place is approximately 200 nautical miles north-east of Broome which is the supply town for the settlement. The first harvest was expected in 1958. The half (blister) pearls are cultured by cementing a stone nucleus of half spherical shape to the shell itself underneath the mantle. This is covered with nacre by the natural processes of the oyster. The nacre covered blister is harvested by cutting out with a hollow drill. The unfinished half pearls are freighted to Japan for removal of the stone nucleus and the polishing of the inside surface of the shell of nacre which is refilled with a hemispherical piece of mother-of-pearl which is set in with a special white gum under temperature. The rear part of the pearl is completed by a backing of mother-of-pearl, which is usually finished oversize so that the jeweller can grind down to suit his needs. A description of the nature of the farm locality is given but no information is imparted concerning whole-cultured pearls. (*Samples of the first harvest of whole-cultured pearls from this locality were on show at the 1958 Jewellery Exhibition at the Royal Albert Hall, London.*—EDITOR.)

2 illus. R.W.

LEEPER (R.). *The development of the diamond industry.* Gemmologist, Vol. XXVII, No. 329, pp. 234–238. December, 1958. (*Reprinted from OPTIMA.*)

A general survey of the diamond industry from the South African diamond discoveries to the present day. The expansion of the diamond cutting industry is discussed. It was in India that diamond cutting originated and it was the Indian lapidary who adopted the basic principle that a diamond should be used to cut a diamond. Later the cutting of diamonds became centred mainly in Amsterdam and Antwerp. During the 1939-1945 war the diamond cutters of the Low Countries went to England and the United States and during the war New York became the diamond cutting centre of the world. In recent years Amsterdam as a centre has declined and the industry has developed to some importance in Israel. An estimate of the number of diamond workers in each different country for 1955 is given. There is a note on the sales organization and on the synthesis of diamond. The Russian diamond fields are mentioned.

R.W.

ANON. *Diamond find in Basutoland.* Gemmologist, Vol. XXVII, No. 326, p. 174. September, 1958.

A further report on the diamond locality in the Makhotlong area of Basutoland which lies some 9,000 feet up in a valley surrounded by mountains. The first finds were small industrial stones, but some small gem diamonds have been recovered. The mining concessions are that 60 per cent shall go to the Treasury of the Paramount chief.

R.W.

SMITH (A.). *Freshwater pearling in Scotland.* Gemmologist, Vol. XXVII, Nos. 325 and 326, pp. 139–143 and 162–168. August/September, 1958.

British pearls were known to the Romans and in the 10th century pearls from Central Europe, France, Ireland and Scotland were highly prized, and in the 14th century France forbade the mounting of Scotch pearls in conjunction with oriental pearls except in ecclesiastical jewellery. A number of references to the use of Scotch pearls from the 16th century onwards. The natural formation of pearls is discussed. Scotch pearls are found in the mussel (*Unio margaritifera*). There is no true pearl industry in

Scotland, although at times some commercialization has been attempted. The fishing is by vagrant and casual enthusiasts. The appearance of the pearl mussel is shown by illustrations and the habits of the animal are discussed. Fishing for the molluscs is carried out by wading into the water and searching the river bed through a glass-bottomed bucket. It is not a shell-shaped object that has to be looked for, but a narrow dark streak with a fleshy grey strip along the middle about the width of a pencil, for it is only the thin syphon end of the mussel which is seen, for the animal is mostly submerged in the pebbly gravel and mud. Sudden heat and high temperature, and obnoxious gases from decaying vegetation, is fatal to them, but they seem to be immune to cold. Scotch pearl mussels are not attached to rocks by threads as in sea mussels, but live a free existence. The mussels are fished by pressing a forked stick over the shell and jerking it sharply to detach it from its hold. Misshapen specimens are most likely to contain pearls, and many of the larger pearls come from small or short-shelled animals. A clear quiet-loving water is best for mussel growth. The streams of Aberdeenshire and Perthshire were formerly the most productive of pearls. Over-fishing and pollution is the cause of the present scarcity. It is common practice to roll the pearls in olive oil or glycerine to import added lustre to them before sale. American fresh-water pearls have been sold as Scotch pearls, but do not have the lustre, but Irish fresh-water pearls are similar in lustre to those from Scotland. Some comments on the doctoring and cleaning of pearls are given and a note of the exceptional specimens found in Scottish waters is made.
4 illus. R.W.

WEBSTER (R.). *Synthetic gemstones.* Gemmologist, Vol. XXVII, pp. 124–129, 146–152, 170–173, 187–190. 1958.

A survey of the synthesis of gemstones including the history of the experiments which lead to the production of synthetic diamond and borazon by the G.E. Company of America. Experiments by Verneuil produced ruby and sapphire and, accidentally, spinel. A table of colours of synthetic corundum and spinel shows a great range. Various differences in internal structure, as a means of identification, are mentioned. The absorption spectra of synthetic corundums and the differential transparency to ultra-violet light of natural and synthetic stones are

fully considered. Recently a ruby-red synthetic spinel and a schillerized spinel imitating moonstone have been produced. Synthetic sintered spinel coloured by cobalt imitates lapis-lazuli. Data on synthetic spinels are given. Centres of production are named and the series concludes with consideration of synthetic spinel, but no note is mentioned of synthetic strontium titanate.
13 illus. P.B.

HOPKINS (I.). *Gemmologist in Paris.* Gemmologist, Vol. XXVII, No. 328, pp. 211–213, November, 1958.

Discusses a visit to the Paris Mineral Gallery of the Jardin des Plantes and the Mineral Gallery of the Natural History Museum. Many of the beautiful specimens and objects of art seen in these galleries are mentioned.
2 illus. R.W.

POUGH (F. H.). *Hydrothermal ruby crystals.* Gemmologist, Vol. XXVII, No. 327, pp. 179–184. October, 1958.

The article gives a report on the growing by hydrothermal means of crystals of synthetic ruby by workers at the Bell Telephone Laboratories. The method of growth is similar to that used in the synthetical production of quartz crystals by using an autoclave. In the case of the ruby synthesis modifications were made in the autoclave in order to compensate for the higher temperatures and increased pressures (in excess of 30,000 pounds per square inch), and the more corrosive solutions used. The factors needed to give good results are mentioned. The nutrient is a hydrated alumina compound. The seed plates are round discs of Verneuil synthetic ruby cut so that their flat surfaces lie at right angles to the " c " axis, or with the " c " axis at such an angle that the growing crystal would have a rhombohedral face vertical as the crystal grows in the bomb. Pure nutrient produces in an iron autoclave greenish-coloured corundum crystals from iron contamination. The use of a silver lining to the autoclave allows colourless crystals to grow and by the addition of 1/10th of a gramme of sodium chromate to a litre of circulating solution ruby is formed. It is said that these crystals are grown for academic reasons and not for commercial exploitation.
3 illus. R.W.

BOOK REVIEW

ANDERSON (B. W.). *Gem testing* (6th edn.). Heywood & Co., London, 1958. 42s.

In the seven years since the last edition of Mr. Basil Anderson's *Gem Testing*, gemmology, like so many sciences to-day, seems to have moved faster than usual. There have been developments of new synthetic materials, there have been advances in methods of detection, there has even been the identification of a new gem mineral, sinhalite, previously thought to be brown peridot. *Gem Testing* has always, since the first edition of 1942, proved to be of especial help in practical day to day gemmology. The book is arranged to be of greatest use to the student and the jeweller who is setting out to identify a gemstone; it is a book to augment knowledge and to remind one of salient points about gemstones. The new edition retains the old order with some enlargement and rearrangement of certain chapters—notably descriptions of the immersion contact photography techniques developed by the author, and a new section on fluorescence as an aid to identification. The chapter on the use of the spectroscope has been entirely renovated, and comes equipped with a series of black and white half-tone illustrations of absorption spectra of gemstones that are far easier to comprehend than the table of absorption bands in the previous edition. The new issue has lost the coloured frontispiece of absorption spectra, but the coloured plate showing jade-like minerals that replaces it is not over-helpful and certainly not clearly captioned. The publishers have been at some pains to increase the number of text illustrations, but it is a pity that the thinner paper used has tended to diminish their impact, especially those of inclusions which play so important a part in the determination of the new synthetics. Four large photomicrographs of typical inclusions in synthetic emeralds are, however, a useful guide, and a new section deals with synthetic strontium titanate—now being marketed under the name of Fabulite. Both this and, incidentally, sinhalite, are omitted from the index which ends this admirable and most practical aid to memory for the jeweller-gemmologist.

J.B.

JADE STORY—AMERICAN

By ELSIE RUFF, F.G.A.

THE discovery of America has always been associated with Christopher Columbus, yet the name of Amerigo Vespucci (1451-1512), a Florentine merchant-adventurer, has been perpetuated by a whole continent. Both men, acquaintances if not friends, must have known that the Vikings sailed up the St. Lawrence river nearly five hundred years earlier. Columbus, we are informed, was greatly interested in Marco Polo's *Travels*, a copy of which he is said to have owned, and was also influenced by legends and stories of the sea and an ancient document that had come into his hands. Since he was searching for a passage to the East—the East of Marco Polo—it is accepted that he died believing he had touched the Orient. We are therefore left with such terms as *Indian* in reference to native peoples of the American continent, confusing enough to every young school-child. A further proof of this geographical error is the name given to the islands off the east coast of the continent, the West Indies. It seems ironical, after all the suffering, time and effort involved, that it was left for man to create this passage in the form of the Panama Canal. Sir Walter Raleigh played an early part in America, as we all know, and had a hand in potatoes, tobacco, gallantry, scribbling with diamonds on panes of glass, and, to the point of this story, jade.

There is not the slightest evidence that jade played any part in the motive that led to the New World's discovery—as we believe it did in the discovery of New Zealand by the Maoris—nor even that it was suspected, except perhaps as one of the many wonderful products of the Orient. In actuality, the Spaniards, who followed closely on the heels of Columbus (a Genoese), were primarily interested in gold, as was Sir Walter Raleigh. Perhaps it is not too much to say that just as the adventurers of to-day are fired with the conquest of Outer Space, the fifteenth century explorers—a century of explorers if ever there was one—were fired with the discovery of unknown lands that would at least prove the world a globe. Yet jade met these explorers of America at every turn ; not the raw jade that the Maoris knew in New Zealand, but wrought jade,

often of great beauty. The jade or *chalchihuitl** of America (there are various spellings in old records, depending on the European rendering of the pronounced word and, perhaps, to some extent at least, on the accent of the particular area) was, too, forced upon their observation, since it was the most prized native possession. In any gesture of hospitality or good will this native substance was the medium, rather to the astonishment of the Spanish who expected to be rewarded with gold—and, at a later period, emeralds. Yet the Spaniards called this jade *jasper*, the term used by Marco Polo some two centuries earlier, for *jade* as a word was not then in use. Jasper, too, though always in the background, as the study of European jade has proved, did not at that time hold pride of place in European jewels. Sometimes this *chalchihuitl* was of so fine a colour that it was labelled *emerald* and various qualifying adjectives came into use such as *baja esmeralda*, meaning an inferior kind of emerald. In many of the inventories produced by the Spaniards these green (or greenish) stones were merely labelled *green-stones*, suggesting that the quality of this *jasper* was so much finer than commonly seen in Europe (where jasper was a generic term, anyway) that there was some doubt of the stone's identity—a doubt that yet at times forbade the use of the term *emerald*.

To the gemmologist, the discovery of America was the discovery of American jade, and just as the European term was also a generic one, so did *chalchihuitl* appear to be. The word was defined by Molina (*Vocabulario Mexicano*) in 1571 as an inferior kind of emerald. On the other hand emerald proper was called *quetzalitztli*, that is, *quetzal*, the bird known to science as *trogon resplendens*, and *itztli*, stone. The word *chalchihuitl* undoubtedly covered turquoise, in certain areas at least, amazon-stone, and some emeralds. The very fact that much of this jade work has been claimed the equal, technically and aesthetically, of the best in China, repudiates any suggestion that these people were merely natives on a stone-age level. Yet it was a stone-age jade—that is, the jade was worked with stone-age tools, as was the jade of the Maori. (Metals were nevertheless known and used about three centuries before the advent of Europeans.)

* ch as in church, al as in alcohol, chi as in chick, h mute, ui as in wit, tl as in cuttlefish.
In some instances this word has been treated as singular, the final "l" dropped for the plural and the Spanish "es" added.
For this pronunciation I am indebted to Mr. C. A. Burland, F.R.A.I.

Although Columbus sighted the mainland of South America during his third voyage, in 1498 (according to some reports Amerigo was there in 1497), he did not set foot on the soil. What he had noted, and thought to be another island, was the peninsula of Paria, the north-eastern extremity of what is now Venezuela. But on his two earlier voyages, and on his fourth and last one, he spent much time in the various islands of the West Indies. From then on it was merely a matter of time before Europeans were flocking to the New World. In 1513, Vasco Nunez de Balboa took formal possession of the Pacific Ocean (no less) for the Spanish crown on the Peninsula of Nicoya. In 1517, Francisco Hernandez de Cordova discovered the east coast of Yucatan and " the remains of a high aboriginal civilization which had already entered upon decline. There were deserted cities falling into ruins and others, like Chichen-itza . . . which were still inhabited by remnants of their former Maya populations." Hernando Cortés was busy, between 1519 and 1521, overthrowing the Aztec empire with its base in Mexico City. His first landing, on Good Friday, 1519, was in the harbour which he named Vera Cruz, later to become the most important port of the republic. The chronicler, Bernal Diaz del Castillo,[1] wrote of this landing and of the first messengers sent by the celebrated emperor Montezuma with "four *chalchihuitls*, a species of green stone of uncommon value, which is held in higher estimation with them than the *smaragdus* " (emerald). In another place he says that each *chalchihuitl* was held in higher regard than a great cargo of gold.

To understand the high development of American jade it is necessary, at least, to glance at its background. The *Edinburgh Review* of 1867, in a series of articles on *The Archaeology of North America* by several competent writers, gives us a brief picture : " From Guatemala to Upper Canada and from the Atlantic to the Pacific ocean, the surface is strewn with stupendous ruins of pyramidal temples and tumuli, entrenched camps and fortifications, walled towns and villages, amphitheatres and pictorial grottos, embankments and bridges, towers and obelisks, wells and aqueducts, high roads and causeways, gardens and artificial meadows ; the greater part of which was designed, constructed and maintained by numerous intelligent and skilful races of men who have long since disappeared from the several scenes of their labour, bequeath-

ing to posterity no written or even solitary traditional memorial of themselves or even of their ancestors . . . 'When I beheld the delicious scenery around me,' exclaimed that honest old soldier Bernal Diaz, 'I thought we had been transported by magic to the terrestrial paradise. . . . Some of our men who had visited both Rome and Constantinople declared that they had not seen anything comparable in those cities for convenient and regular distribution or for number of people' . . . "

Perhaps one of the most astounding things of the New World colonization was the early appearance of the printing press. This was only possible, surely, because one culture was superimposing itself upon that of another. The first press was set up in Mexico around 1538 (official dates differ), hardly a hundred years after the printing press appeared in Europe and about twenty since the arrival of Europeans in the New World. We are privileged therefore in having vivid accounts of those early days. In an imaginary dialogue printed in Mexico during 1554 is a description of the city itself. " How the view of this great street delights the mind and refreshes the eyes ! How wide and ample it is, how straight, how level, all paved with stones, lest in winter the feet be mired. Along its centre, for ornament and use, flows water in its channel, open to the sky, that it may give the greater pleasure. All the houses on both sides are splendid and costly, such as befit the richest and most noble citizens. . . . "

Continuing this American scene at the time of the early Spaniards, which was a geographical concentration on the narrow neck of land from Mexico to Peru (known as Middle America) plus the contiguous islands, we have, nevertheless, a picture also of the Amazon country to the south by C. W. King in his book *Antique Gems*, published in 1872. King is here quoting from Wallace's *Amazon :*

" I now saw several of the men with their most peculiar and valued ornament, a cylindrical, opaque, white stone looking like marble, but which is merely quartz imperfectly crystallized.† These stones are from 4″ to 8″ long and about 1″ in diameter. They are ground round and flat at the ends, a work of great labour, and are each pierced with a hole at one end, through which a string is

† *See* Journ. Gemmology, p. 410, Oct., 1956.

Jade ornaments from Old Mexico. (Bernal Diaz tells that a jade as big as a man's thumb could be exchanged for a man's load of gold.)

Jade pendant, Mexico. (Part of Sloane Collection.) Photos by courtesy of the British Museum.

inserted to support it round the neck. It appears almost incredible that they should make this hole in so hard a substance without any iron instrument for the purpose. What they are said to use is the pointed flexible leaf shoot of the large plaintain, triturating with fine sand and a little water, and I have no doubt it is, as it is said to be, a labour of years. Yet it must take a much longer time to pierce that which the Tushatia (chief) wears as an emblem of his authority, for it is generally of the largest size and is worn transversely across his breast, for which purpose the hole is bored lengthways, from one end to the other, an operation, I was informed, that sometimes occupied two lives. The stones themselves are procured from a great distance up river, probably from near its source at the base of the Andes ; they are therefore highly valued and it is seldom that the owner can be induced to part with them. The chiefs scarcely ever." (One is reminded here of Captain Cook's almost identical words in another part of the world in reference to native jade.)

A fascinating account of the early contact that the Spaniards effected with Mexico, is contained in Bernal Diaz' report, published in 1632.[2] He writes of the fabulous Montezuma possessing everything he could desire, largely acquired by force from those who would not willingly part with their riches. Foremost among these luxuries was *chalchihuitl*, nevertheless Montezuma was ready and willing to pay tribute to the Spaniards' " Great Emperor." This tribute covered gold, silver, cloth and *chalchihuitl*. The only stipulation was that the Spaniards absented themselves from Mexico. On one occasion Montezuma ordered his governors to barter gold for some green beads of the Spaniards, in the belief that these beads were of *chalchihuitl*. It would seem that of this substance the ancient Mexicans could never get enough. Diaz writes of the skilled workmen employed by Montezuma such as lapidaries and " workers in gold and silver and all hollow work, which even the great goldsmiths in Spain were forced to admire. Then for working precious stones and *chalchihuites* which are like emeralds, there were other great artists." Later in the narrative we find Diaz on the march again and arriving at another town where they were received and given something to eat ". . . but not much, unless we paid them with some pieces of gold and *chalchihuites* which some of us carried with us, and they gave us nothing without payment."

We have, too, a description of Montezuma when first interviewed by Cortés, his mantle thickly studded with *chalchihuitls* and pearls. " Out of this same gem (i.e. *chalchihuitl*) was carved the elaborate clasp fastening the monarch's imperial robe ; for green was the colour appropriated to royalty in ancient Mexico." Diaz seems to have contented himself with four pieces of *chalchihuitl* alone out of all the treasure he apparently could have had, and found later that he had made a wise choice ; for at that stage Cortés had been forced to evacuate Mexico and those who had burdened themselves with nuggets of gold perished in their attempts to ford the beaches.

Prescott, in his *Conquest of Mexico* (Vol. III, p. 323), writes of the gifts Cortés made to his youthful bride which " excited the admiration and envy of the fairer part of the court. This was five emeralds of wonderful size and brilliancy. These jewels had been cut by the Aztecs into the shapes of flowers, fishes, and other fanciful forms, with an exquisite style of workmanship, which enhanced their original value. They were probably part of the treasure of the unfortunate Montezuma, and being easily portable may have escaped the general wreck of the *noche triste*." One has only to read Monardes (Journ. Gemmology, Vol. V, Jan., 1955, p. 10) to question whether these jewels were in fact emeralds.

One of the earliest chroniclers of this part of the world was the Franciscan monk Bernardino de Sahagun,[3] who was in Mexico as early as 1529. He it was who described *chalchihuitl* as " the Mexican or *Nahutl* name for it which appears to have been applied to any greenish, partially transparent stone, capable of receiving a handsome polish." He too submits it was a " jasper of very green colour, or a common emerald." Writing in 1530, he quotes a native father addressing his daughter upon reaching the age of discretion : " Although you are but a little damsel you are as precious as a *chalchihuitl*." This simple statement reveals much. It shows us how close in thought and symbol these ancient Mexicans were to the early Chinese, who never ceased to liken loveliness of character and preciousness generally to jade. Similarly it establishes an immediate link with the Maoris. It tells us too that despite the tribal customs which Europeans professed to be appalled by (and which were those of a nation in decline) these people did not treat their girl children cursorily. " The little damsel " was obviously precious to her father. Dr. Alberto Ruz (Lhuiller) writing in 1953[4]

says, on the other hand, that " My Jade " was the sweetest term of endearment a mother could address to her son. Sahagun writes too of four Mexican gods who were patrons of the lapidaries. These gods were honoured as the inventors of the art of working stones and *chalchihuites*, which work included drilling and polishing. The same recorder gives us also some valuable information on the classification of this stone. " Among the jaspers," he says, " is a variety in colour, white, mixed with green, and for this reason called *iztac chalchihuitl* (*iztac* signifies white ; i.e. white-*chalchihuitl*) Another variety has veins of clear green or blue, with other colours interspersed with white. . . . And there is yet another kind of green stone which resembles the *chalchihuites*, and called *xoxouhquitecpatl* (from *xoxouhqui*, *cosa verde*, something green, and *tecelic*, stone ; i.e. green-stone). It is known to the lapidaries as *tecelic*, for the reason that it is very easy to work, and has spots of clear blue. The wrought and curious stones which the natives wear attached to their wrists, whether of crystal or other precious stones, they call *chopilotl*—a designation that is given to any stone curiously worked or very beautiful."

Writing of the emerald (whatever Sahagun meant by the word) he says : " The emerald which the Mexicans call *quetzalitztli* is precious, of great value, and is so called because by the word *quetzalli* they mean to say a very green plume, and by *itztli*, flint (or stone). It is smooth, without spot ; and these peculiarities belong to the good emerald ; namely it is deep green with a polished surface, without stain, transparent, and at the same time lustrous. There is another kind of stone which is called *quetzalchalchivitl*, so called because it is very green and resembles the *chalchivitl* ; the best of these are of deep green, transparent, and without spot ; those which are of inferior quality have veins and spots intermingled. The Mexicans work these stones into various shapes ; some are round and pierced, others are long, cylindrical and pierced ; others triangular, hexagonal or square. There are still others called *chalchivites*, which are green (but not transparent), mixed with white ; they are much used by the chiefs, who wear them fastened to their wrists by cords, as a sign of rank. The lower orders (*maceguales*) are not allowed to wear them. . . . There is yet another stone called *tlilaiotic*, a kind of *chalchihuitl*, in colour black and green mixed. . . . "

Sahagun describes also the ornaments of the Mexican lords used in their festivals : " . . . a head-dress called *quetzalalpitoai*, consisting of two tassels of rich plumes, set in gold, and worn suspended from the hair at the crown of the head, and hanging down on each side towards the shoulders. They also wear rings of gold around their arms and in their ears, and round their wrists a broad band of black leather, and suspended to this a large bead of *chalchihuitl* or other precious stone. They also wear a chin ornament (*barbote*) of *chalchihuitl* set in gold, fixed in the beard. Some of these *barbotes* are large crystals, with blue feathers put in them, which give them the appearance of sapphires. There are many other varieties of precious stones which they use for *barbotes*. They have their lower lips slit, and wear these ornaments in the openings, where they appear as if coming out of the flesh ; and they wear in the same way semi-lunes of gold. The noses of the great lords are also pierced, and in the openings they wear fine turquoises or other precious stones, one on each side. They wear strings of precious stones around their necks, sustaining a gold medal set with pearls, and having in its centre a smooth precious stone."

In another part of this work we get even further details of jade. The *Quetzal chalchihuitl* was precious *chalchihuitl*, white, without much transparency and a slight greenish tinge, " somewhat like jasper," *Tlilavotic chalchihuitl*, which means literally of a blackish-watery colour, had shades of green and black intermingled and was partially transparent. *Tolteca-iztli*, literally " Toltec knife " or Toltec Obsidian was a clear, translucent green and very beautiful, we are told.

" The ancient Mexicans, according to Sahagun," says a modern journal,[5] " called their most precious green jade *quetzal chalchihuitl*, on account of the resemblance in colour to the gorgeous metallic-green plumage of the *quetzal* bird ; the Chinese, by a curious coincidence, no doubt accidental, derive the name *feia-ts' ui* from a kingfisher, the peacock-green plumes of which they often use inlaid in jewellery. In fact, all the jade objects that have been discovered in Mexico and Central America are made of jadeite."

From Viscount Kingsborough's *Antiquities of Mexico*, published in 1848,[6] we have : " The following is a literal translation of the greater portion of the 21st chapter of the sixth book of Sahagun's *History of New Spain*. ' Those who lived a life of perfection in

Small jade figures found in Honduras, in the museum of the American Indian Heye Foundation (Photo by courtesy of the Museum).

this world uttered them, and those who conform to them are indeed like precious *chalchihuites* and costly sapphires in the eyes of the Lord. The *chalchihuitl* was a sort of green jasper highly prized by the ancient Mexicans. It deserves to be remarked that the jasper and the sapphire were stones on which the Jews set extreme value and they are frequently referred to in the Old Testament for a similie. . . . This similie is borrowed from a curious belief of the Mexicans tha precious stones always emitted fine vapour at sunrise."

The late F. W. Foshag, a modern authority on the jade of the Americas, left us a concise picture of early days :[7] " When the Spanish explorers of the early sixteenth century reached the coast of Mexico, they found a light-green stone in use among the inhabitants of the region, which the indigenous lapidaries fashioned into ornaments and figurines. The early chroniclers, impressed by the vivid green colour of the stone, and by the great value placed upon it by the natives, referred it to the emerald. This is not surprising since they had no previous experience with a stone of this nature, and the superior quality of the emeralds recovered as loot from the Incas of Peru, and later from the mines of Colombia, was not yet

known to them. The Aztecs of Mexico, who particularly esteemed the stone and demanded it in tribute from their vassals, called it *chalchihuitl* and restricted its use to the emperor and nobles. . . . Within fifty years after the conquest of Mexico, the supply of jade for amulet use became practically exhausted, because the stones in the possession of the nobles were by then already sold (see Monardes) and the knowledge and appreciation of this gem in its original home was soon forgotten. . . Among the Aztecs *chalchihuitl* was the most precious of substances. . .. The greatest virtues were comparable to this stone. . . . Sahagun was the first to refer to " esmeralda " in Mexico, but no occurrence of emerald is known in Meso-America, and no emeralds have been found in archaeological sites north of Panama. It is suggested here that this stone is the finest quality of jade, similar to the Chinese *fei-ts'ui* jade, emerald-green in colour, flawless, and almost transparent. This opinion is supported by Monardes, who states the finer qualities of ' piedra de yjada,' that is *chalchihuitl*, resemble emerald."

Juan de Torquemada[8] tells us that when a great dignitary died in Mexico his corpse was richly decorated for burial with gold and plumes of feathers, and they put in his mouth a fine stone resembling an emerald, which they call *chalchihuitl*, and which they say they place as a heart. The stone, according to another chronicler, " if laid upon the tongue of the deceased, will help the soul to pass the seven ordeals before reaching *Quetzalcoatl* in Heaven."

The American *Journal of Science* for March, 1858, says : " Torquemada makes frequent mention of *chalchihuitl* and regarded it as a species of emerald. He states that the Mexicans gave the name of *chalchihuilt* to Cortés, intending thus to show their respect, ' for *chalchihuitl* is the colour of the emerald, and emeralds were held in high esteem.' Offerings of this stone were made by the Indians in the temple of the goddess Matlalcueye. . . . The Indians state that the art of cutting and polishing *chalchihuitl* was taught to them by their god Quetzalcohual."

Torquemada also wrote of the goddess of water who bore the name of Chalchihuitlicue, the woman of *chalchihuites*, and that the name of *Chalchiuhapan* was often applied to the city of Tlaxcala, from a beautiful fountain of water found near it " the colour of

which was between blue and green." Quetzalcoatl, the lawgiver, high-priest and instructor of the Mexicans in the arts, was said to have taught, amongst other things, the art of working metals, and " en especial el arte de labrar piedra preciosas, que son *Chalchihuites* que son piedras verdes, que extimaban en mucho precio." According to certain traditions, this authority also claims that Quetzalcoatl himself was begotten by one of these stones, which the goddess Chimalma placed in her bosom. *Chalchihuites* were offered to the goddess Metlalcueye together with the plumes of the Quetzal.. . . .

Another chronicler, Villaguitierre,[9] in his account of the conquest of the Itzaes of Yucatan, speakes of idols in their temples " of precious jasper, green, red, and other colours." In describing the great temple of Tayassal, he mentions particularly an idol which was found in it, " a span long, of rough emerald (*esmeralda bruta*), which the infidels called ' the god of Battles,' and which the conquering general, Ursua, took as part of his share of the spoil. . . . "

Fuentes y Guyman[10] was another to contribute a history of Guatemala, never to be published. He wrote of the Indians of Quiché wearing " head-dresses of rich feathers and brilliant stones, *chalchihuites*, which were very large and of great weight, under which they danced without wearying."

A further historian, though of slightly later date, was Herrera. His *General History of America*[11] was translated and published in London during 1725. In Volume One he reports the voyage of Alonzo de Ojeda in 1498 (though 1499 seems to be the official date) and of the natives of the east coast of South America. " All their wealth consisted of feathers, of several colours, and sometimes beads made of fish bone and of white and green stone, which they wore at their ears and lips. They neither sought nor valued gold, pearls, or other precious things."

In the Tribute Roll of the ancient Mexican Empire, the *Codex Mendoza*, we find the tax levy from each district and city given in detail. Strings of *chalchihuitl* are mentioned, evidently referring to rounded pieces used as beads and obtained from the sands and streams. From one district alone were large pieces demanded, perhaps again depending on what was available.

Thomas Wilson's famous *Jade in America* paper (1900) provides interesting information about this tribute roll. He tells us of the last years of Montezuma's reign concerning these tributes. Tribute

was paid in tithes and " the roll represents every imaginable object in use by the natives. The sum total estimated in, or reduced to Mexican money, was 13,158,522 dollars. I have examined the list in search of objects of jade and turquoise." Wilson goes into details of objects in these substances, examining the roll both in Spanish and that published in the native hieroglyphics " and rendered in colour." These substances he was able to separate, in that the various items were labelled *blue* or *green*. " An examination and comparison of the respective figure with their different colours all satisfactorily explain the differences between the two minerals according to the native understanding. Whatever their names, the natives must have known the difference between jade and turquoise, and while *chalchihuitl* represents jade, it did not to them represent turquoise. There are four plates in the Tribute-roll which contain this hieroglyphic, signifying in each place *chalchihuitl*, that is to say, jade. The resumé of the tribute shows 20 pieces valued . . . at 254 dollars. I consider this a demonstration that a string of beads, four long and three round, was the native hieroglyphic for *chalchihuitl*, and was jadeite, or, rather, Mexican jade."

The late G. F. Kunz, an archaeologist as well as a gemmologist, contributed a picture of the period of the Conquest as a result of his own researches, published in 1915 in his book *The Magic of Jewels and Charms*. He writes : " In the native language of Mexico and Central America, the name *chalchihuitl* most frequently denotes jadeite, but it appears sometimes as the so-called Amazon-stone from the region of the Amazon river, and even occasionally to Turquoise. Thus the talismanic value of the *chalchihuitl* seems to have depended rather upon its hue and its rarity than upon its mineralogical character ; indeed among primitive peoples stones of the same or closely similar colour, although of a different composition, often bore the same name, and were conceived to have the same virtues, whether talismanic or therapeutic." Later he writes : " Among eight green stone objects sent to the writer at one time as jadeite, four were jadeite, one was laminated serpentine, another a greenish quartz, and two a mixture of white feldspar and green hornblende. In a string of beads were four pieces of jadeite, but all the others were, as are the jadeite beads, in the form of rounded pebbles, drilled from both sides, and there were nearly a dozen different substances in this string. The fact that these jadeite beads were strung in with the others, apparently without any order

except that they were graded to taper towards each end, points very strongly to the conclusion that they were found with the other pebbles in a brook and, being of the correct size, had been drilled the same as the others, although very much greater in hardness. . . . Among other green stones used by the ancient Mexicans were green jasper, green plasma, serpentine, a fine-graded green shale, and the Tecali marble, which was often of such a rich green colour that at a glance it might have been mistaken for jadeite." In another place Kunz advanced the suggestion that the term *chalchihuitl* covered turquoise in the north (New Mexico) and jade in the south (Old Mexico).

F. W. Rudler, quoted at length in the J. of G., July, 1955, page 142, in his series of European jade, asks : " And what, after all, was this extraordinary stone—so wondrously endowed and so highly prized ? This is a question which, in spite of all that has been written on the subject, has not yet, and perhaps never will, be answered with scientific accuracy. Some have described the *chalchihuitl* as a coarse emerald, others a turquoise, others as a jasper, and some finally as jade. Probably the term comprized a number of distinct minerals, having in common a green or greenish-blue colour, and including the jade-stone." This article appeared in 1879 and is interesting in view of present knowledge.

The late George C. Vaillant,[12] who contributed so much to our information on Mexico, and indeed died in the field, wrote, in 1939, the following : " Art is a common denominator in all types of human culture. . . . The tendency of our artists and designers to draw inspiration from the arts of other peoples in other climes and other times may be due in part to this communal poverty in artistic expression and in part to the specialization implicit in a highly skilled profession . . . The jades from southern Mexico rival in sheer intrinsic value of colour and design the long admired art of China. Yet there is no doubt of the independent evolution of these two arts."

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ASSOCIATION NOTICES

GIFTS TO THE ASSOCIATION

The Council of the Association is grateful for a gift of books from Mrs. F. L. Tully.

MEMBERS' MEETINGS

At a meeting of members held on the 14th October in the Medical Society of London Hall, the Secretary of the Association presided in place of the Chairman, who was indisposed. The subject of the evening was " Emeralds," and in introducing it the Secretary said : " Recently, in America, sapphire has been produced hydrothermally, but the experiment was academic and unlikely to have any commercial significance. It has been suggested that gemmologists should look for a new word to describe man-made stones which have not been produced by the accepted process of synthesis. But if one consults a dictionary it is found that there is really no need to coin a new word merely to describe another process of production. The term ' synthetic ' is well understood by gemmologists, jewellers and public alike and I do not think that we need confuse the matter by thinking up a new word. Whether it is rubber, oil, sapphire or emerald, the word ' synthetic ' can suffice for the product of the laboratory."

Mr. Keith Mitchell demonstrated the crossed filter technique in distinguishing synthetic emerald. The stone is illuminated by a powerful source of light. Using an infra-red filter, synthetic emerald will emit strong fluorescence, natural emerald much less strong fluorescence. A further application of this method was examination of the stone in light transmitted through a copper sulphate solution, and viewing it through two filters. The natural emerald (except, occasionally, for a fine glow from Colombian emeralds) was blacked out completely, whereas synthetic emeralds still betrayed fluorescence. Using crossed polaroids, a spectacular effect was obtained, with synthetics showing a brilliant red, and at most the faintest of glows, but usually complete blackness, from the natural emeralds.

Mr. B. W. Anderson offered a note on the transparency of natural and synthetic emerald—an extension of earlier work on the corundums. Using a laboratory quartz spectroscope transmitting down to about 2,000 Ångström units, ordinary film and a copper arc, he had discovered that natural emeralds all showed absorption in the 3,000Å region, while synthetic emeralds were exceedingly transparent, down to about 2,300Å or 2,200Å. This was due to traces of impurities in natural emerald, notably iron. Using water for immersion, Mr. Anderson then demonstrated the method and produced on the spot a photograph proving the greater transparency of the synthetics.

The Secretary then showed members slides produced by Dr. E. Gübelin and Professor W. Eppler showing the characteristic inclusions in synthetic emerald—

notably the veil-like two-phase inclusions which were a useful diagnostic aid in determining synthetic emerald. It had been suggested that these inclusions were healed fissures due to the fast growth of the synthetic stone. Other inclusions were groups of phenakite crystals. Mr. Andrews then showed slides of typical inclusions in the emeralds recently mined in Rhodesia—most typical were dense masses of tremolite crystals.

The Council of the Association is indebted to Messrs. Charles Mathews & Son and Messrs. George Lindley & Co. Ltd., for the loan of Colombian and Sandawana emeralds respectively, to Messrs. Rayner and Mr. Theo Stern for examples of synthetic emerald and Dr. E. Gübelin and Professor W. Eppler for photomicrographs.

COUNCIL MEETING

A meeting of the Council was held at Saint Dunstans House on 11th November 1958. Mr. N. A. Harper presided in the absence of the Chairman.

The following were elected to membership :—

Fellows

Ainsworth, Michael B., Blackburn
Aldridge, Patrick E., London
Atkinson, James C., Whitley Bay
Baglee, Gordon, Whitley Bay
Black, Vete George, Spring Valley, California, U.S.A.
Bowden, Aubrey, Plymouth
Boyd, Russell T. F., Toronto, Canada
Brandsma, A. H., Maastricht, Holland
Clarke, Eric M., London
Cooke, Barrie E., Birmingham
Eakins, Harry, Liverpool
Falconer, Richard A., New Malden
Ferguson, Charles Thomas, Smethwick
Greene, Patrick, London
Gunning, Jack W., Toronto, Canada
Hermitage, Wendy B. (Miss), London
Hill, Stanley G., Birkenhead
Huddy, George, Liskeard
Mackenzie, Enid L. D.(Miss), Glasgow
Ould, Thomas A., Plymouth
Peplow, William R. H., Stourbridge
Petterson, Bjørn W., Oslo, Norway
Reeves, Roger C., Chatham
Reynolds, Helen M. (Miss), Ludlow
Ritchie, Arnold J., Toronto, Canada
Roach, John G., Birkenhead
Roots, Jack L., Rainham
Skinner, Ramon, Borough Green
Smith, David J., Hove
Steadman, Ivor Noel, Huntingdon
Stitt, John, Toronto
Stol, Dirk, Amersfoort, Holland
Taylor, Joseph N., Newcastle
Walton, Joseph H., Cirencester
Wille, Robert F., Toronto, Canada

Ordinary

Anderson, Thomas M., Epsom
Benthall, Richard P., Calcutta, India
Brousseau, Murray P., Toronto, Canada
Charles, Russell J., Camp Hill, Pa., U.S.A.
Curmi, G. T., Valetta, Malta
Engstrom, Hans W. E., London
Flower, John C., Cleveland, U.S.A.
Hickman, John T., Bristol
Hool, R. H., Rotterdam, Holland
Keiser, Paul J., Detroit, U.S.A.
Law, Leslie, London
Jones, Mayhew Pettus, Tenn., U.S.A.
Meadows, Everard C., Purley
Overdorff, Frank C., Johnstown, U.S.A.
Parsons, Elizabeth M. (Miss), Leicester
Phillips, Roy E., Sutton
Riddell, Eileen Rose (Miss), Armagh, N.I.
Sellers, Thomas L., Margarita, Canal Zone
Smith, Denis E., Derby

The following were transferred from Ordinary and Probationary Membership to Fellowship :—

Biggers, Willard B., London
Callaghan, David J., London
Coakley, Brian, Manchester
Delario, Anthony J., Paterson, N.Y., U.S.A.
De Silva, Lindamulage, J. C. F., Colombo, Ceylon
Donaldson, Robert G., London
Francis, Barry P., London
Fuhrbach, John R., Amarillo, U.S.A.
Jones, James R., Mortdale, N.S.W., Australia
Lema, Audrey Hayes de (Mrs.), Colombia, South America
Phillips, Dennis, Leeds
Rushworth, Jack, Halifax
Smith, Clifford J., Walsall
Tungate, James B., London
Warburton, Frederick W., Toronto, Canada
Weller, George T., Tunbridge Wells
White-Hide, Richard G., Wadhurst

In connexion with applications from India concerning membership and the holding of examinations it was decided that the rules should not be altered to meet special circumstances.

With new methods of producing synthetic and imitation stones there was a possibility that present instruction might not be able to be confined to the present two-year period and the Council decided to review the syllabus of examinations with a view to keeping it within reasonable limits.

MIDLANDS BRANCH

At the sixth annual meeting of the Midlands Branch of the Association, held in Birmingham on 24th October, 1958, the following were elected to office: Chairman, Mr. T. P. Solomon, for the sixth year; Vice-Chairman, Mr. A. E. Shipton; and Mr. J. R. Shaw, Secretary, who succeeds Mr. A. E. Shipton. Miss J. Rice and Messrs. A. E. Shipton, J. Hoskyns, B. Clay and J. Harper were elected to serve on the Committee.

The Branch have decided to commission a Chairman's Badge of Office. The following meetings have been arranged—Friday, 30th January, 1959, Dr. H. Proctor on " X-rays." Friday, 17th April, Mr. B. W. Anderson on " Recent developments in synthetic gemstones." Both meetings will be held at the Auctioneers' Institute, Birmingham. The Branch will hold a dinner at the Medical Institute, Five Ways, on Saturday, 7th March, 1959.

WEST OF SCOTLAND BRANCH

A dinner was held by the Branch on 4th December, 1958.

HERBERT SMITH MEMORIAL LECTURE

This year's lecture will be given by Dr. D. K. Hill, of the British Glass Industry Research Association, at the Science Museum, London, S.W.7 on Wednesday, 15th April, at 7 p.m.

The twenty-ninth Annual General Meeting of the Association will be held at Saint Dunstan's House, London, E.C.2, on Friday, 1st May, 1959, at 6.15 p.m.

TALKS BY MEMBERS

GILLOUGLEY, J.: "Facts about diamonds," Paisley Business and Professional Women's Club, 24th November, 1958.

CAIRNCROSS, A. D.: "Gemstones," Inchture W.R.I., 10th September., N.U.R. Women's Guild, 29th October, and Murthly W.R.I., 18th November; "Pearls," Institute of Bankers in Perth, 16th October, and Perth and District Jewellers, 26th November, 1958.

FORSEY (Mrs. Patricia): Dunnville Quarter Club, Ontario; "Gemstones," 18th September; "History of a diamond," 30th October; "Coloured gems and pearls," 11th December, 1958.

1959 EXAMINATIONS

The 1959 examinations of the Association will be held as follows :—

Preliminary : Wednesday, 3rd May.
London, provinces and overseas.

Diploma : Thursday, 4th May (theoretical).
Friday, 5th May (practical).
London and overseas.

U.K. provincial centres to be arranged.

Completed entry forms must be received no later than 2nd April, 1959, and entries cannot be accepted after that date.

INCOME TAX AND SUBSCRIPTIONS

Members are referred to page 394 of the October, 1958, issue of the Journal (Vol. VI, No. 8) whereon is set out procedure for claiming the whole of the amount of subscription as a deduction for income tax purposes by those who qualify for tax relief.

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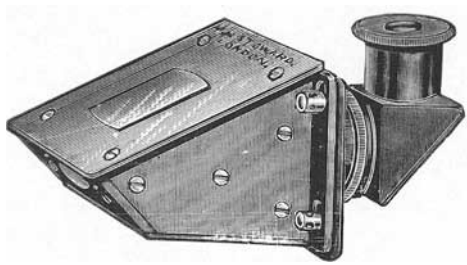

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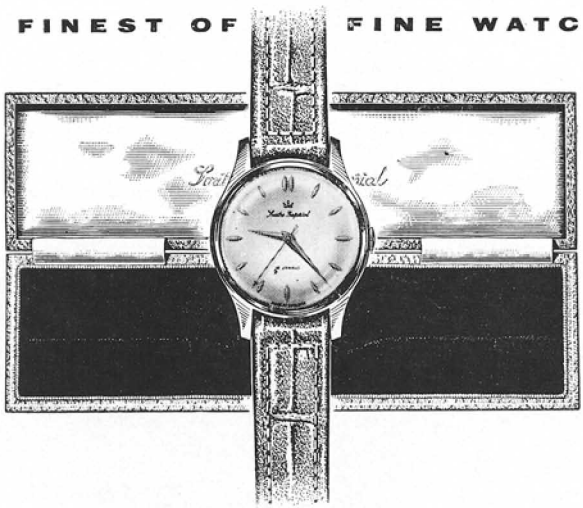

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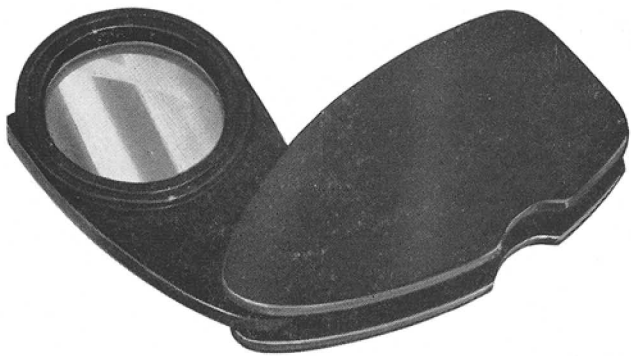

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No. 1
January, 1959

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THE JOURNAL OF GEMMOLOGY

and

PROCEEDINGS OF THE
GEMMOLOGICAL
ASSOCIATION
OF GREAT BRITAIN

GEMMOLOGICAL ASSOCIATION
OF GREAT BRITAIN
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THE JOURNAL OF GEMMOLOGY
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Vol. VII No. 2 APRIL 1959

SPINEL OR STANDARD REFRACTOMETER

By A. E. FARN, F.G.A.

MOST gemmologists at some stage in their lives think of purchasing a refractometer, either for business reasons or gemmological interest. Since the jewellery trade and its offshoot gemmology depend entirely upon commerce for their very existence, it is necessary to consider financial outlay in terms of value for money and profit.

What is the best buy for a gemmologist, dealer or retail jeweller ? The greatest proportion of gemmological trade is transacted in the following gemstones : emerald, ruby, sapphire, topaz, aquamarine, garnets, quartz (varieties), alexandrite, cat's-eye, tourmaline, peridot, zircon, etc.

In every branch of the trade there are two questions concerning goods—" What is it ? " and " How much ? " These may seem elementary observations to experts, but the average jewellery dealer and trader often needs a quick check on goods.

It is advisable to have the following apparatus : a spinel refractometer, a spectroscope, colour-filter and lens, plus basic S.G. liquids with suspended indicators.

Now if the standard (soft glass prism) refractometer is used frequently (however carefully maintained) it will soon need repolishing and adjusting—no small item of money compared to its initial cost. If the prism is scratched badly by quick checking of mounted jewellery it becomes practically useless for all the time it is left in such a state and all the time it is away being repaired. Nothing is more frustrating than expensive items of apparatus which cannot be used.

The spinel refractometer (how much we all owe to Anderson and Payne is seldom appreciated), however, will stand up to quite a lot of hard work, and the contact liquid (methylene iodide) has the advantage of not corroding, if it is inadvertently (and it often is) left on the instrument. Most gemstones tested, which require the use of a refractometer, from a jeweller's point of view, are topaz or quartz, aquamarine or synthetic spinel, natural or synthetic emerald. In these latter cases the spinel refractometer is supreme, far surpassing in results the standard model. Tourmaline is easily identified on the spinel refractometer and although peridot cannot be fully read, its easily observed double refraction (by lens) and absorption spectrum avoid the use of the standard refractometer. By the time most people have read this article some will have thought of a reason or stone which has not been mentioned, but by and large it is possible to avoid the use of the standard refractometer.

Above all, the spinel refractometer has the advantage of needing no sodium light or monochromatic filter eyepiece.

So far, the most usual stones needing to be tested for trade purposes have been mentioned. The spinel model is even more useful from a rarity point of view, since it has a more easily read scale.

Briefly to sum up, all those stones which cannot be tested on the spinel refractometer can be tested by means other than the standard refractometer. Here are some stones which cannot be tested on the spinel refractometer and some which cannot be tested on either standard or spinel model :

Blue spinel will have octahedral inclusions and a typical absorption spectrum distinct from sapphire or synthetic spinel.

Red and pink spinel—octahedral inclusions and chromium fluted spectrum.

Synthetic spinel, blue—red under Chelsea filter, with a cobalt spectrum.

Synthetic spinel, red—(so far small stones)—bubbles, curved lines and chromium spectrum.

Synthetic spinel, colourless—bubbles, singly refracting (no known colourless natural spinels of such " whiteness ").

Chrysoberyl, yellow and green—absorption spectrum.

Alexandrite —daylight green, chromium spectrum, inclusions.

Cat's-eye —S.G., absorption spectrum.

Corundum—refractometer will not distinguish between synthetic and natural ; therefore other tests for inclusions and spectrum necessary. The synthetic sapphire imitating alexandrite has a daylight colour of no known stone, as well as a vanadium spectrum and curved structure lines.

Garnets—all reds show typical absorption spectra.
Brown or orange hessonites have typical diopside inclusions.
Spessartite has a manganese spectrum.
Demantoid has asbestos fibres and absorption spectrum in deep blue.

Zircon—strong double refraction easily seen by lens, and heft.

Sphene—double refraction, dichroism.

Synthetic rutile—double refraction, dispersion and heft.

Strontium titanate—single refraction, soft, dispersion.

An analysis of the tests involving the use of the spinel refractometer, Chelsea filter, lens and spectroscope brings forcibly to mind the terrific amount of work and the debt gemmologists owe to the work put into the perfection of the Anderson-Payne spinel refractometer, the tremendous lists of absorption spectra observations and the colour filter—all devised and offered gratis by those two eminent gemmologists. I had not fully realized before just how much they had done.

THE ORIGIN OF HEALING FISSURES IN GEMSTONES

By W. F. EPPLER

HEALING fissures as inclusions in gemstones are well known and have often been described. In spite of this, the question of their origin has not yet been answered. A most valuable hint can be found in papers published by American authors about liquid inclusions in some minerals of the pegmatite series. Here, the aim of numerous investigations was to find out whether or not the liquid inclusions could be used as a "geologic thermometer." In this sense researches have been made to prove whether those particular inclusions could supply the desired information about the temperature at which the minerals of the pegmatites, and consequently the pegmatites of certain localities itself, have been formed.

As some of the pegmatite minerals belong to the best known gemstones and as, on the other hand, a great number of liquid inclusions are combined with healing fissures within these stones, the results which were found are important enough to be quoted.

E. N. Cameron, R. B. Rowe, and P. L. Weis[1] give the following explanation :

> " The implication is, that the secondary inclusions (the ' healed fractures ') are formed from solutions of the same general composition as the apparently primary (liquid) inclusions and probably they are developed only a short time after the host crystals ; *i.e. within the period of pegmatite formation.*"*

A confirmation of these observations is found by P. L. Weis.[2] He obtained the same results during his studies of the fluid inclusions in beryl, quartz, tourmaline, and spodumene.

The observations of these authors indicate that healing fissures are mostly originated during the growth of the host crystal. This point of view could be confirmed in many cases. In other cases it seemed to be likely that the formation of healing fissures took place after the growing period of the host crystal, i.e. during a later time, when the crystal was still *in situ* within the mother rock, or weathered out from it and embedded in a second or third deposit. For these

* The terms in parentheses and the italics have been added for the purpose of this article.

reasons it is useful to distinguish between " early " (or " subsequent" instead of secondary) and " late " healing fissures, as both types can be easily recognized. Such a differentiation could also avoid the more common term " secondary " healing fissures, which has already caused some misunderstanding.

The proposed classification has the following meaning : " Early " (or subsequent) healing fissures originated during the growth of the host crystal ; they are of syngenetic origin. " Late " healing fissures are formed after the growth of the host crystal ended ; they are of epigenetic origin.

During the study of a great number of healing fissures in numerous gemstones it was observed that the main reason for their " early " or syngenetic origin was undoubtedly *a great growing rate* of the brittle host crystal. It seems to be obvious that a rapid growth of a crystal, practically in all cases, is combined with the effect of a strain or a stress, which in its turn produces cracks in preferred directions or at random. It is also not difficult to understand that such syngenetic fissures immediately after their formation had to undergo a healing procedure, which lasted so long as the host crystal itself could continue to grow. Preferred directions are those of the cleavage planes of the including crystal, and these are indeed more often than expected the places of healed or partly healed cracks.

Another cause which could be found, is the presence of primary crystal inclusions. Such a foreign material could produce cleavage cracks (early) or tension fractures (early and late), and both kinds healed according to the ruling circumstances.

Finally a mere shear tension, which could easily occur for different reasons, has been the cause of cracks which subsequently healed into different kinds. It has been found that these particular healing fissures are formed either by a rapid growth of the host crystal (early) or that they are favoured by the existence of a cleavage (early and late), or by other reasons of geologic events (mostly late).

In order to obtain a general view of the complex features of the healing fissures and the different causes of their origin, the following scheme is suggested :

Originated by	*Examples*	*Time of Origin*
I. Rapid growth of the host crystal	Synth. emerald, pegmatite minerals like quartz, beryl, topaz, tourmaline, etc.	early
II. Incipient cleavage	Topaz, fluorite, scapolite, zircon	early and late
III. Primary crystal inclusions which cause		
(*a*) cleavage cracks	Snow-flake inclusions in aquamarine	early
(*b*) tension cracks	Tourmaline, aquamarine, garnet	early and late
IV. Shear tension which causes tension cracks in the host crystal A shear tension can arise by (I) and it can cause (II)	Aquamarine, garnet, zircon, and numerous others	early (and late)

Convincing examples for a rapid growth of a crystal causing healing fissures were found by the crystallization of ammonia-alum ($Al(NH_4)(SO_4)_2 \cdot 12\,H_2O$). In applying a greater growing rate, clusters of very small alum crystals are deposited on an already present crystal plane. As can be seen in Fig. 1, tiny and unoriented crystals form a stripe, running from left to right. It caused within the bearing crystal, fissures in different directions, from which fissures one happened to be nearly parallel to the growing plane (111) of the host crystal, so that it can easily be observed.

In another case (Fig. 2), such a smaller cluster produced cracks in different directions which had already started to heal. This early healing process could be accomplished by bringing the host crystal back in the mother-liquor for a longer time (Figs. 3-5).

A great growing rate is also most probably responsible for the cause of those curious veil-like twisted " feathers " which are so typical of synthetic emeralds. It has been explained elsewhere[3] that these feathers are true healing fissures (Figs. 6 and 7). There

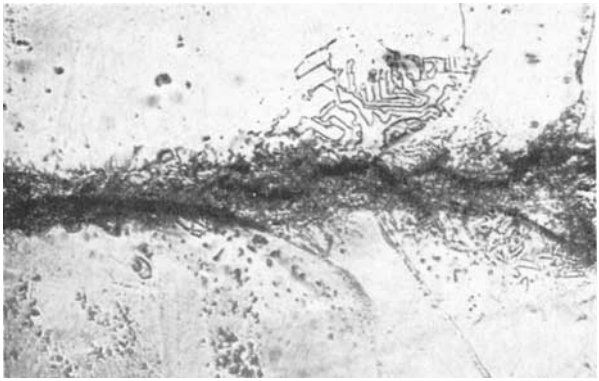

FIG. 1

The surface (111) of an ammonia-alum crystal. It bears a broader stripe of clusters, consisting of tiny, unorientated alum crystals, and caused by a great growing rate. The clusters caused tension cracks within the bearing alum crystal. One of these cracks shows the typical features of a healing fissure. 120 ×

FIG. 2

Octahedron plane of an alum crystal. A system of healing fissures starts from a cluster of tiny, rapidly deposited alum crystals. 120 ×

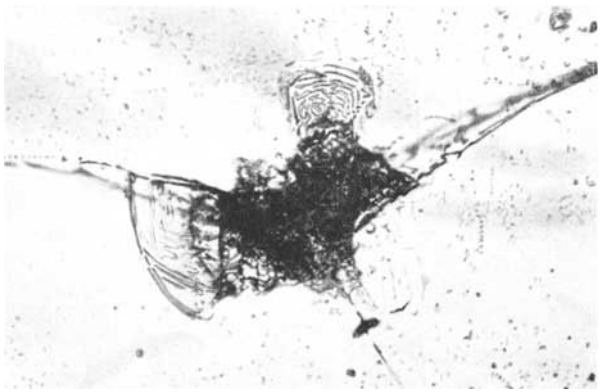

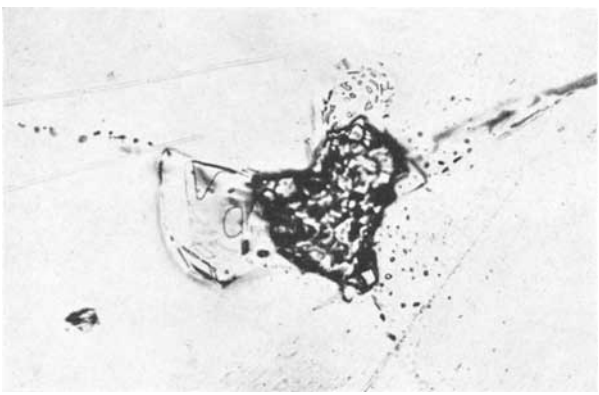

FIG. 3

Same as Fig. 2 after 6 hours in the mother liquor. 120 ×

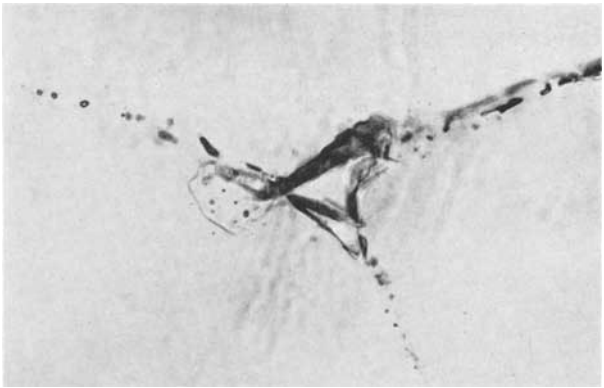

FIG. 4

Same as Fig. 2 after 4 days in the mother liquor. 120 ×

FIG. 5

Same as Fig. 2 after 12 days in the mother liquor. 120 ×

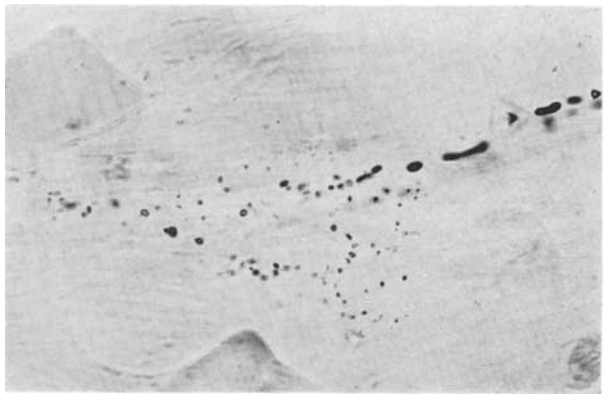

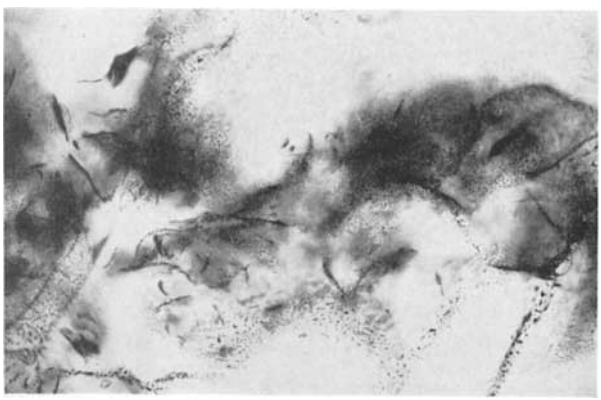

FIG. 6

Synthetic emerald (Chatham). Typical veil-like "feathers" which are true healing fissures. 40 ×

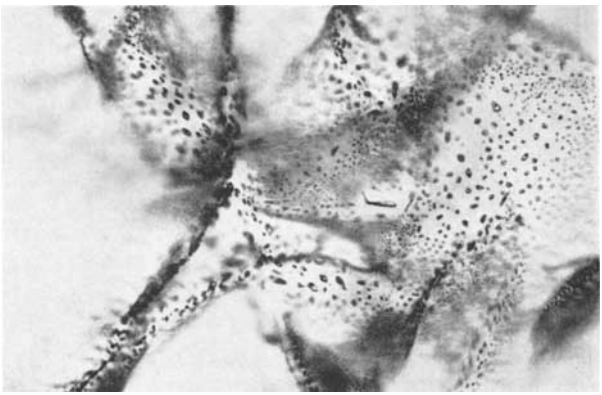

FIG. 7

Synthetic emerald (Igmerald). Healing fissures. 120 ×

FIG. 8

Blue topaz, showing a set of syngenetic (early) healing fissures, intersecting each other and consisting of liquid inclusions at random orientation. 85 ×

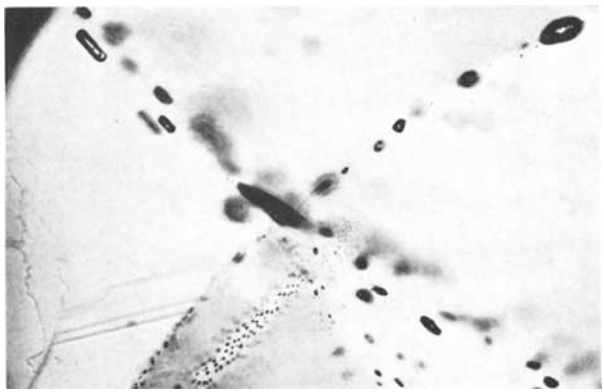

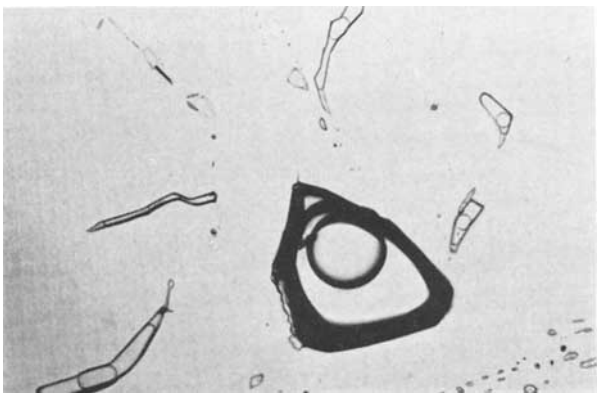

FIG. 9

Blue topaz with a large liquid inclusion of primary origin (with broad dark rim), surrounded by syngenetic (early) smaller liquid inclusions, indicating a healing fissure. The system of inclusions is strictly parallel to the basal cleavage plane of the host crystal. 105 ×

may also exist other reasons for the formation of the cracks, like shear-tension, caused by a great gradient of temperature during the synthesis, but it seems to be certain that the relatively rapid growth of the synthetic emerald crystals was one of the main factors which caused these partly healed cracks. It must be kept in mind, moreover, that the synthetic emerald has a similar brittleness to the natural one, so that cracks can easily be formed for various reasons.

It has already been mentioned that the origin of healing fissures is a very complex matter. In the following, details are given for a number of gemstones showing healing fissures, and an explanation of the origin of the more or less healed cracks has been attempted in each case.

Topaz. This gemstone exhibits two kinds of healing fissures, one of them, shown in Fig. 8, is characterized by liquid inclusions which follow curved planes and at random orientation. The fissures may intersect each other. It can be assumed that this type of healing fissure is caused by a rapid growth of the host crystal and that the fractures are of syngenetic (early) origin.

The other kind is shown in Fig. 9. Around a broadly rimmed liquid inclusion of primary origin, smaller liquid inclusions are arranged which follow strictly the basal cleavage plane of the host crystal. They represent a nearly healed fissure which formerly had been formed along the cleavage plane of the topaz and which is also of syngenetic origin.

Scapolite cat's-eye. The tetragonal crystals of scapolite exhibit a perfect cleavage parallel to the prism face (100) and a less perfect one parallel (110). According to Fig. 10, the residues of a healing fissure follow the direction of the perfect cleavage. They form three-phase inclusions in which the liquid phase consists of carbonic acid. The solid material is represented by doubly refractive, colourless crystals of not yet known composition. It has to be assumed that these crystals are primary and, furthermore, that they caused a cleavage crack which started to heal during the growing period of the scapolite crystal. This healing fissure is of typical syngenetic origin. The marked striation of the inclusions indicates that the healing process preferred crystallographic orientated directions. The lines, which form the striation, are repeated edges between the tetragonal prism and the bi-pyramid.

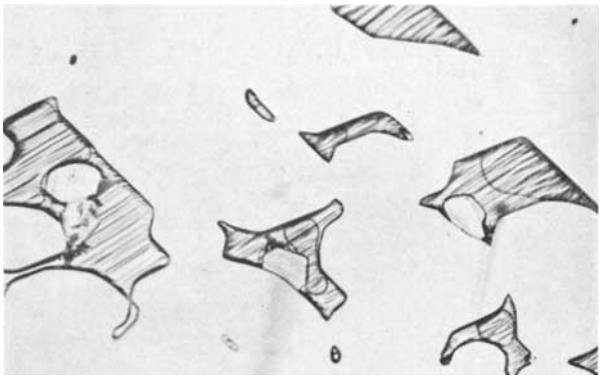

FIG. 10

Scapolite cat's-eye, showing a healing fissure in the direction of the perfect cleavage along the prism face (100). 120 ×

FIG. 11

Fluorspar with syngenetic (early) healing fissure parallel to the cleavage plane (111). 70 ×

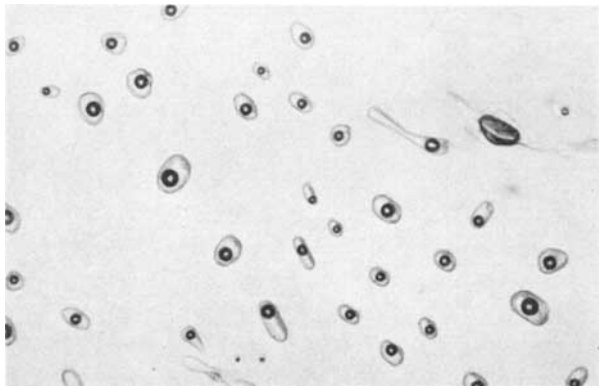

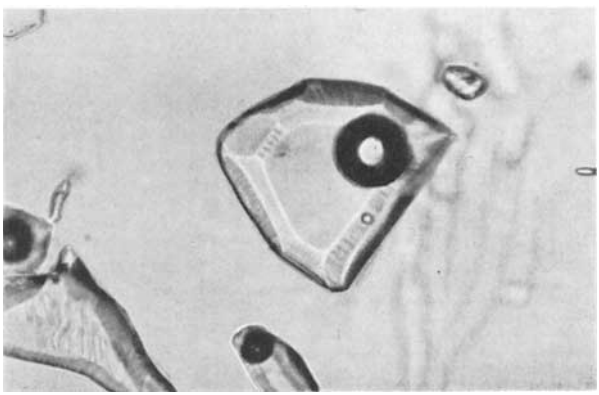

FIG. 12

Fluorspar. A single liquid inclusion of a healing fissure parallel (111), showing the crystal planes of the octahedron (111), the cube (100), and of the dodecahedron (101). 200 ×

Fluorspar. The healing fissures in the cubic fluorite often follow the octahedron plane (111), which is the direction of perfect cleavage in this crystal. Fig. 11 shows such a cleavage crack which has been healed to a certain degree. In spite of the cause of the cleavage not being known, we have to consider this particular healing fissure as of syngenetic (early) origin. The single droplets represent the residues or the " undigestible remnants " of the former filling of the cleavage fissure which could not be resorbed by the host crystal. It is worth noting that the droplets are limited by crystal planes which, as shown in Fig. 12, belong to the octahedron (111), to the cube (100), and to the dodecahedron (101).

These inclusions are not to be mistaken for the primary liquid inclusions in fluorite which firstly have been described by E. Gübelin.[4] They are claimed to be negative tetrahedrons (or bisphenoids), filled with a liquid and showing a libella. It is easy to agree with their primary origin, but for their shape it is preferable to consider them as the threefold corner of a cube, which is more in conformity with the cubic symmetry of the host crystal.

Quartz. Most of the healing fissures in quartz, particularly in rock crystal and in amethyst, follow curved planes and at random. In some cases, interesting features can be observed, and to these belong those cracks which form the so-called " tiger pattern." Without any doubt, they are partly healed fissures. On the other hand, they are composed of two components (Fig. 13), namely of liquid inclusions and of negative crystals. Both kinds of inclusion are arranged in distinct directions, whereas the liquid inclusions at the same time have an orientation according to the basic rhombohedron. It is presumed that the negative crystals are of primary origin and that they caused " subsequently " a fissure which in its turn entrapped during the healing process the liquid inclusions. This example, therefore, is a combination of primary inclusions (negative crystals) and of syngenetic liquid inclusions, the latter owing their typical shape to certain circumstances such as a rapid healing process.

Another peculiarity is the strict orientation of liquid inclusions of a syngenetic healed crack in combination with other liquid inclusions which seem to be unorientated. Fig. 14 shows such a combination in a rock crystal with a faint brownish hue. The fissure itself is slightly curved and has no orientation within the host

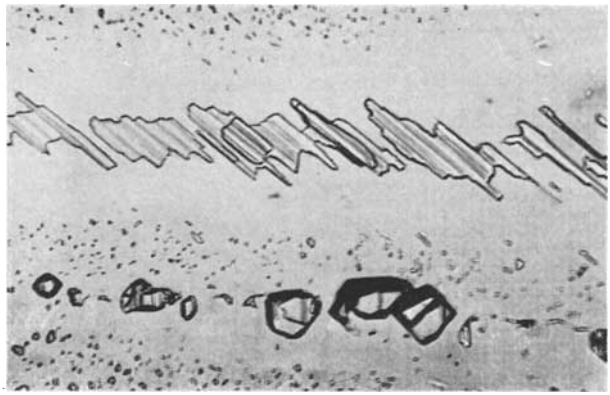

FIG. 13

Amethyst. Part of a so-called "tiger pattern." The rows of liquid inclusions alternate with other rows of negative crystals (with dark borderlines). 105 ×

FIG. 14

Rock crystal with parts of a syngenetic (early) healing fissure. 40 ×

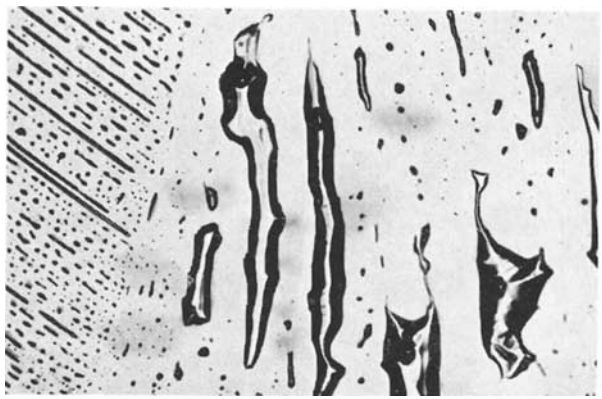

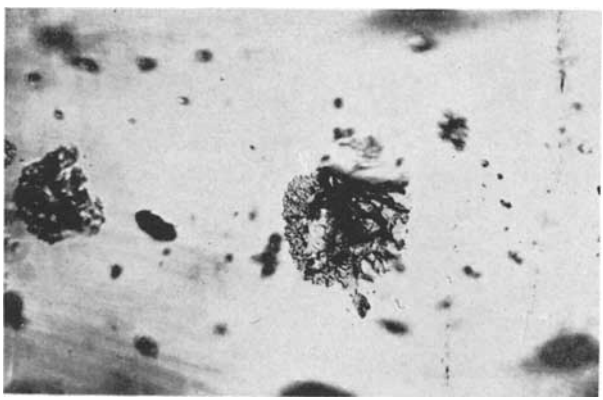

FIG. 15

Andalusite. A primary crystal inclusion (black centre) has caused a crack parallel to the cleavage plane (110) of the host crystal. The syngenetic (early) healing process left very small droplets within the area of the former crack. 105 ×

crystal. It is not possible to give an explanation for such a differentiation which, by the way, can be observed similarly in some aquamarines.

Andalusite, a rarely used gemstone, sometimes exhibits healing fissures which cover only a small and limited area. In Fig. 15, a doubly refractive crystal of primary origin caused a tension crack, which followed the direction of the cleavage parallel to the prism plane (110). The crack underwent a healing process and can now be recognized by the field of very small droplets, which surround the primary crystal inclusion nearly like a halo. This particular kind of healing fissure can be found in other gemstones. It is a typical example of early origin.

Orthoclase feldspar. A significant property of this monoclinic gemstone is the perfect cleavage along the basal plane (001) and the prism face (010) of the crystals, and both planes include an angle of 90°. In some of these stones from Madagascar, primary inclusions of dark and birefrigent crystals could be observed which had caused cracks parallel to both cleavages. The early-produced cracks healed (syngenetic), and they exhibit the picture of typical healing fissures (Fig. 16).

Spinel. Even in a crystal like spinel, which does not belong to the pegmatitic series, healing fissures can be observed occasionally. Such a healed fracture is shown in Fig. 17. It is of syngenetic origin and it follows approximately the octahedron plane (111).

Tourmaline. Healing fissures in tourmaline are well known. As described by E. Gübelin[4], they mostly consist of " thread-like capillaries of most irregular arrangement." The discoverer (Gübelin) termed them " trichites " and mentioned them to be " ultrafine tubes which are filled with a liquid." It is no doubt that these typical " trichites " are the remnants of former healing fissures of early formation.

Besides this, other inclusions in tourmaline can be observed which, so far, also seem to be of diagnostic value. In Fig. 18, liquid inclusions of characteristic triangular forms are arranged parallel to each other, following at the same time the basal plane (0001) of the host crystal. They must be considered as the " undigestible residues " of a syngenetic healing fissure, showing now the faces of the trigonal pyramid $(10\bar{1}1)$. On the right of

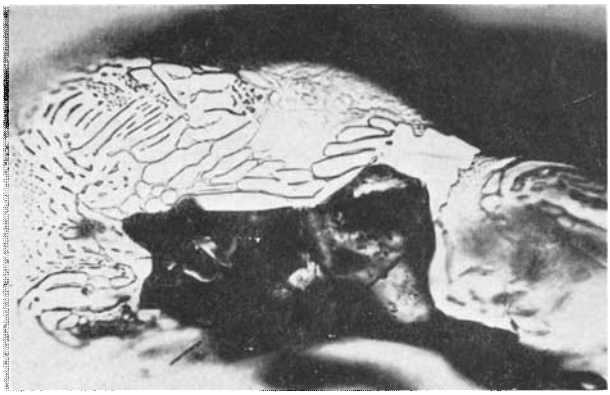

FIG. 16

Yellow orthoclase feldspar from Madagascar. A birefringent primary crystal inclusion caused two cleavage cracks which healed. One of them, seen here, exhibits the typical features of a healing fissure, particularly on its left side, where it shows a thinning like a wedge. The broad black rim near the top of the picture is the second crack, perpendicular to the first one, and out of focus. 105 ×

FIG. 17

Red spinel. A small healing fissure (centre), starting from a large crystal inclusion (below, black) and consisting of a pattern of little droplets. 105 ×

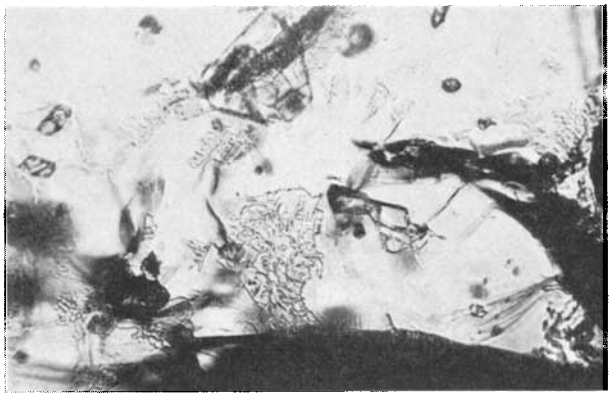

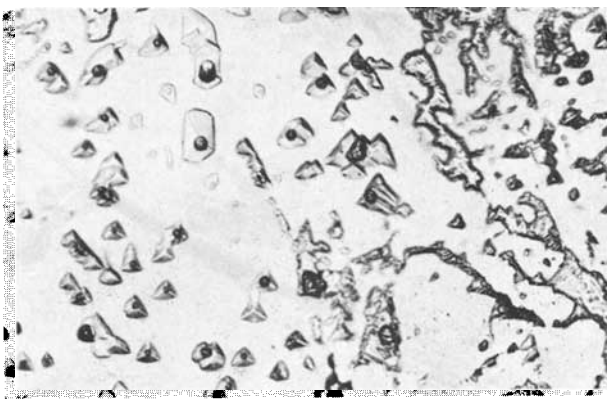

FIG. 18

Green tourmaline, California. A syngenetic (early) healing fissure parallel to the basal plane of the host crystal with liquid inclusions, forming trigonal pyramids and broader patches. 105 ×

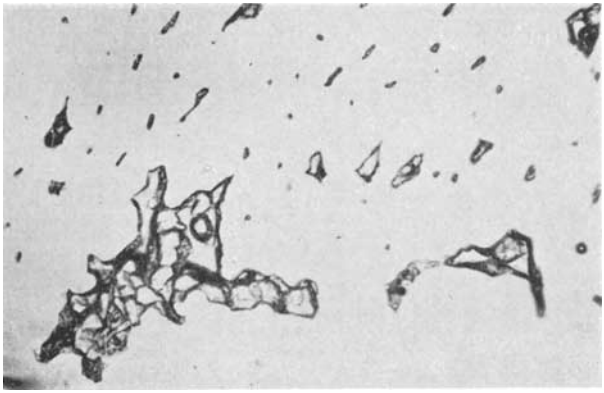

FIG. 19

Rose coloured tourmaline, California. A syngenetic healing fissure parallel to the basal plane of the host crystal, showing liquid inclusions in various phases of resorption. 105 ×

FIG. 20

Rose coloured tourmaline, California, with an epigenetic (late) healing fissure. 40 ×

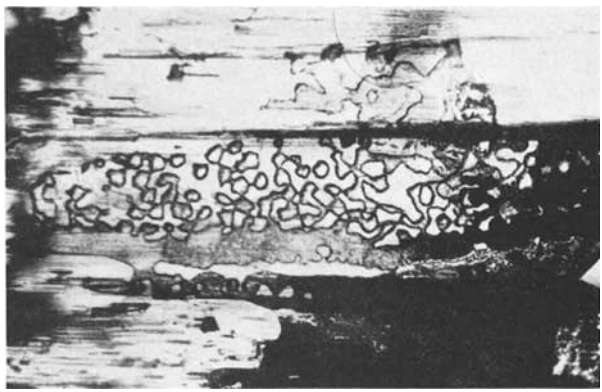

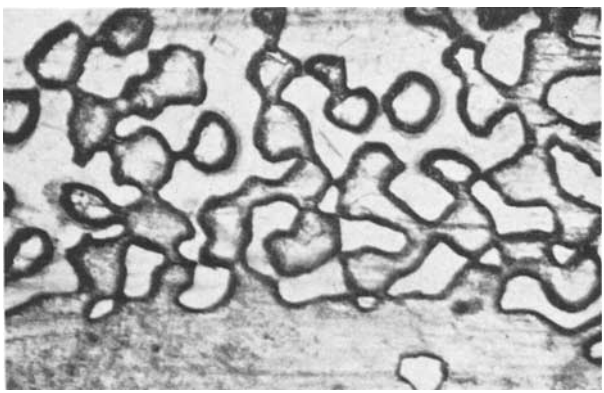

FIG. 21

Same as Fig. 20. 120 ×

Fig. 18, the liquid inclusions form broader and coarser patches which indicate that here the resorption (or the healing process) could not go so far as on the left side of the picture.

Confirmation for the correct characterizing of these inclusions is given by Fig. 19. Here, the healing fissure is nearly completely healed, particularly in the upper half of the picture. Only very thin capillaries and small droplets of liquid inclusions remain in the presence of a former healing crack, while the coarser patches in the lower part of the picture confirm the syngenetic origin.

In the same rose-coloured tourmaline, a typical epigenetic, partly healed crack of very late origin could be observed (Fig. 20). The filling of this fracture is of red-brown colour and does not contain any liquid. At higher magnification (Fig. 21), the first impression, as if grains are distributed throughout the fissure, is confirmed by the observation that a healing process has started, producing particles of greyish colour with a broad, dark rim. This particular filling must have happened long after the time when this tourmaline had left its mother-rock.

Beryl, a typical pegmatitic mineral, exhibits a great number of healing fissures, the origin of which is mostly syngenetic and not so often epigenetic. In many cases, an orientation of the healing cracks can be observed with respect to the host crystal. To these belong the best known three-phase inclusions, which are so typical of the Colombian emerald. They must be considered as parts of healing fissures which, with some deviations, follow generally the basal plane of the emerald. This is a direction in which the beryl has a weak or indistinct cleavage.

In *aquamarine*, three types of healing fissures could be observed, namely those

(*a*) parallel to the main or c-axis of the host crystal,

(*b*) parallel to the basal plane, and

(*c*) at random orientation.

Examples for (*a*) are given in Figs. 22 and 23. Both pictures show typical healing fissures of early origin. They consist of liquid inclusions, which during the resorption or during the healing process developed elongated forms parallel to the direction of the c-axis of the host crystal. It is interesting to mention that these pictures furnish more than one hint for the healing process itself. Without

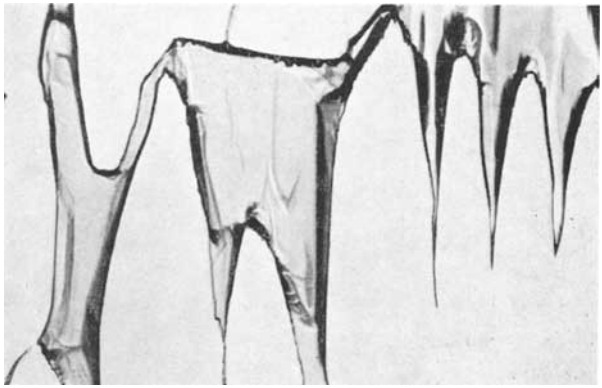

FIG. 22

Aquamarine. Strongly resorbed liquid inclusions of a healing fissure parallel to the c-axis. 105 ×

FIG. 23

Aquamarine. Part of the same healing fissure as Fig. 22. 105 ×
(*In Fig. 22 the direction of the c-axis is from top to bottom; in Fig. 23 it is from left to right.*)

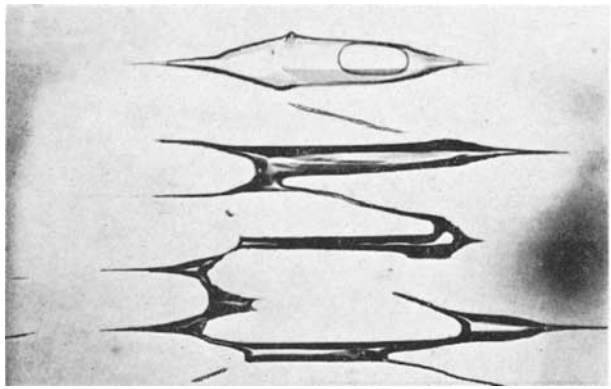

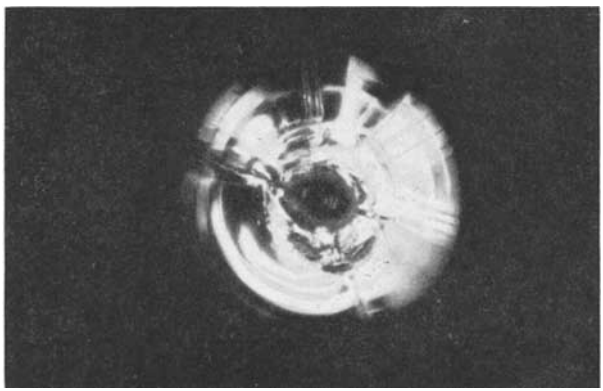

FIG. 24

Aquamarine. A circular crack along the cleavage plane (0001), caused by a crystal inclusion (centre); reflected light. 100 ×

any doubt, the first thing that happened was the origination of a crack, most probably caused by rapid growing of the aquamarine. The second step must have been the filling of the fissure with material, that surrounded the host crystal and which we are accustomed to call " mother-liquor." The following step will have been the deposition of aquamarine substance on the inner walls of the crack, and this happened in a preferred direction, namely in the main growing direction of beryl, the c-axis.

It is not difficult to imagine that this particular step, the real healing process, is also responsible for the fact that some of the mother-liquor has been entrapped within the healing fissure. In the following period, conditions must have been in existence which enabled the aquamarine crystal to resorb such parts of the entrapped mother liquor, as could further build up the crystal edifice, or as could occupy intermediate places within the crystal lattice. The latter process would be a true resorption. In any event, there remained a residue of non-suitable material which, with regard to the healing fissures, mostly consists of a liquid.

(*b*) Wonderful examples of healing fissures parallel to the basal plane of the aquamarine crystal are the so-called " snow flake" inclusions. Details about these inclusions of such peculiar beauty have recently been published elsewhere.[5] It could be found that the cause of each of these " snow flakes " is a primary embedded crystal inclusion which produced already during the growing period of the aquamarine a little crack in its host crystal. Mostly the crack has a circular shape, and it is always parallel to the basal plane as the direction of a weak cleavage in aquamarine. This crack started to heal immediately after its origin. Now, this healing fissure consists of six-sided droplets which are arranged round the primary crystal inclusion according to the symmetry of the host crystal. Again, the liquid inclusions are the " indigestible remainders " of the former filling of the crack, and they represent a very early (syngenetic) originated healing fissure.

A convincing example for the correct explanation given for the origin of the "snow flakes " was found in another aquamarine, probably from Brazil. Here, a crystal inclusion, possibly ilmenite, had caused by one reason or the other a circular crack along the cleavage direction (basal plane) of the host crystal. In reflected light (Fig. 24), the crystal in the centre is hardly to be seen ; but

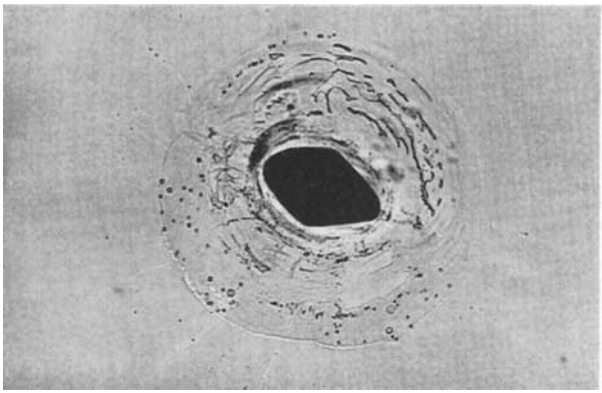

FIG. 25

Aquamarine. The same crack as in Fig. 24 in transmitted light, revealing the cleavage crack as a typical healing fissure. 120 ×

FIG. 26

Aquamarine. The same healing fissure as in Fig. 24 and 25 in transmitted light with crossed polarizers. The dark cross and the four bright fields respectively indicate in this direction (// c-axis) of single refraction the presence of a distinct tension in the host crystal, caused by the solid crystal in the centre. 120 ×

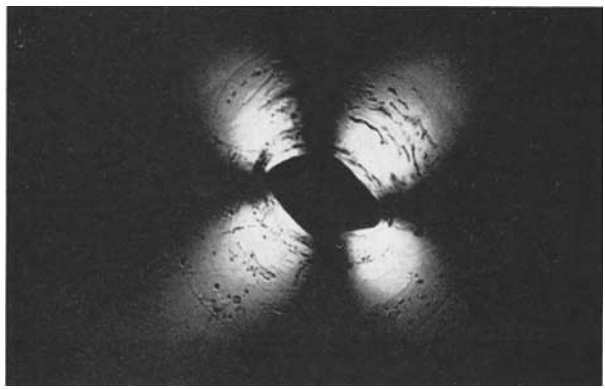

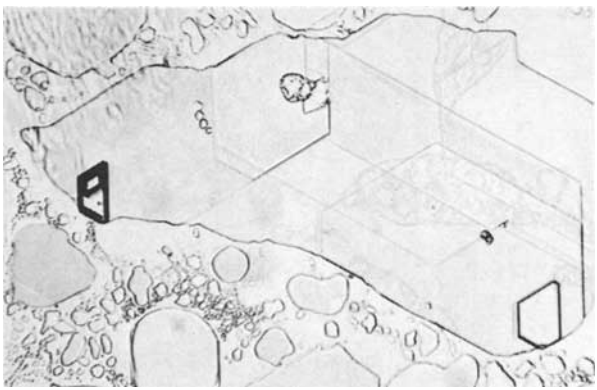

FIG. 27

Aquamarine. Films of syngenetic (early) liquid inclusions parallel to the basal plane of the host crystal. 100 ×

the cleavage crack itself acts in some way like a mirror. In transmitted light (Fig. 25), at a somewhat greater enlargement than Fig. 24, the crack reveals itself as a typical healing fissure with liquid inclusions, forming a kind of halo around the primary crystal in its centre. In polarized light, the expected darkness in this direction is not uniformly present, but only in the area of a cross, the branches of which indicate the directions of vibration of the combined set of polarizers (Fig. 26). The four bright fields mark a strongly developed tension, which covers the area of this particular healing fissure, and which is caused by the central crystal. It is amazing that the tension still exists in spite of the already started healing process. Regarding the time of its origin, it is certain that this healing fissure was formed during the growing period of the aquamarine (syngenetic), but also that by some unknown reason, the healing process itself went on at a relatively slow rate. Therefore, this inclusion could be termed an " under-developed snow flake."

Another kind of syngenetic inclusion parallel to the basal plane of the aquamarine is represented by very thin films of liquid inclusions (Fig. 27). They occur in different sizes showing rounded forms, or they are limited by straight lines, indicating the first order prism. The relatively large inclusion in Fig. 27 seems to be separated by some thin lines in several parts. In reality, these are only border lines of areas of different thickness of the same film inclusion. The films are so thin, that in transmitted light they have only a faint contrast against the surrounding host crystal, and therefore can easily be overlooked. In reflected light, however, they show the rainbow- (true interference-) colours, which vary throughout the entire visible spectrum according to the thickness of the liquid inclusions or parts of it.

Finely healing fissures of epigenetic (late) origin parallel to the basal plane of the aquamarine could be observed (Fig. 28). Here, a cleavage crack is partly filled with dark brownish crystal needles in a dendritic-like arrangement. From this it is assumed that the origin of the crack and its filling lies in a relatively late period, i.e. after the growing of the host crystal.

The needles are arranged in groups and in straight or bended directions. They strictly follow the directions of the hexagonal symmetry of the aquamarine. Although they resemble ilmenite crystals in colour, which often can be found in aquamarine, it seems to be unlikely that they are identical with this mineral.

FIG. 28

Aquamarine. An epigenetic healing fissure parallel to the basal plane of the host crystal, showing dendritic-like arranged crystal needles of unknown nature. 100 ×

FIG. 29

Aquamarine. A syngenetic healing fissure with coarser liquid inclusions, overlying a smaller healed crack. 40 ×

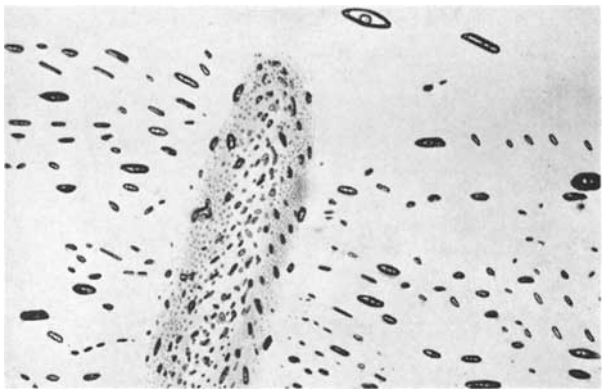

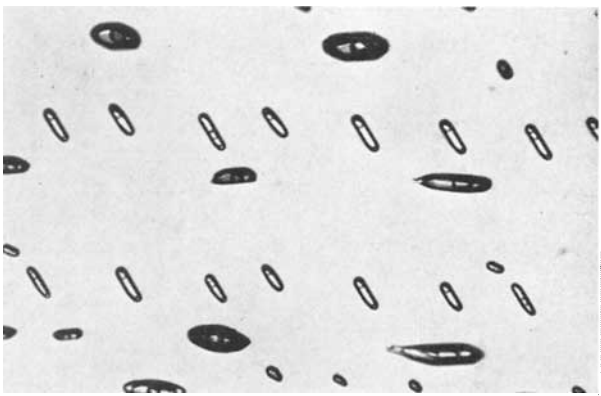

FIG. 30

Aquamarine. Part of the healing fissure of Fig. 29. 110 ×

(*c*) Healing fissures at random orientation are most common in aquamarine. It seems to be certain that in most cases they have been formed by a relatively rapid growth of the host crystal, and therefore they are mostly of very early origin.

In Fig. 29, parts of such a broadly extended healing fissure can be seen, consisting of coarse liquid inclusions and overlying a smaller healed crack with the typical wedge-shaped borders. On the right of the picture, some of the inclusions seem to follow preferred directions. Under higher magnification the arrangement of the liquid inclusions reveals an orientation which corresponds with the symmetry of the host crystal (Fig. 30). In some way, it is a temptation to consider these inclusions as of primary origin. But this would not be correct, as the healing fissure itself is unorientated and shows typical curvatures. It can only be concluded that the healing process started early and lasted long enough to bring the unused material, the liquid inclusions, in directions which are suitable for the symmetry of the aquamarine.

Another kind of unorientated healing fissure in aquamarine is shown in Fig. 31. Here, the elongated hose-like liquid inclusions form a pattern which seems to be identical with the features of a conchoidal fracture. In another picture of the same aquamarine (Fig. 32), the resemblance with a conchoidal fracture is even more distinct. Most probably, the liquid inclusions of Fig. 31 and 32 represent a healing fissure which was formed after the growth of the aquamarine had ended, while the crystal was still in contact with the mother liquor. Perhaps we have in this case a transition from the syngenetic to the epigenetic origin of healing fissures.

A good example of an epigenetic healing fissure of random orientation in aquamarine is given in Fig. 33. It represents the filling of a flat crack with conchoidal markings. The filling consists of ramified liquid inclusions and a solid material of brown colour in different shades. The bright areas indicate the places of an advanced healing.

Zircon. Healing fissures in zircon from Mogok or Ceylon exhibit a pattern of elongated liquid inclusions which show by their rectangular arrangement an adaption to the tetragonal symmetry of the host crystal. In most of the cases they are nearly parallel to the first order prism (110) and follow the direction of the main or c-axis. They are of syngenetic origin.

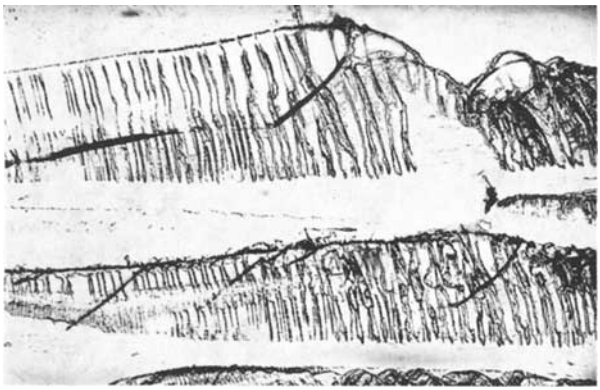

FIG. 31

Aquamarine. Unorientated healing fissures with the features of conchoidal fracture. 105 ×

FIG. 32

Aquamarine. Feather-like border of an unorientated healing fissure consisting of liquid inclusions. 105 ×

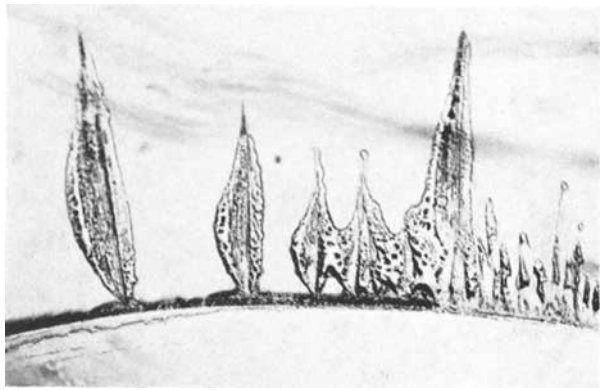

FIG. 33

Aquamarine. An unorientated healing fissure of epigenetic origin. 35 ×

FIG. 34

Brown zircon from Madagascar. An epigenetic healing fissure, containing tiny droplets and some crystals (left). 120 ×

FIG. 35

Same as Fig. 34, but crossed Nicols. 120 ×

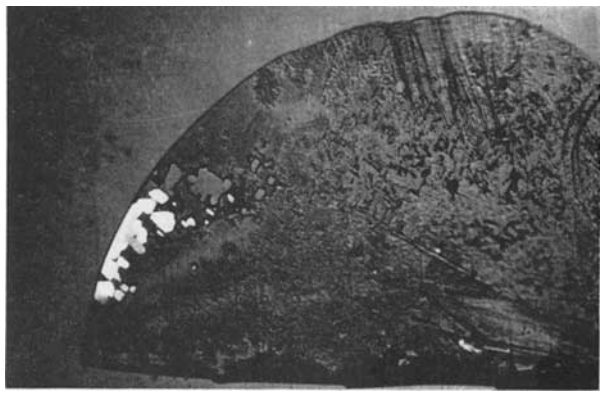

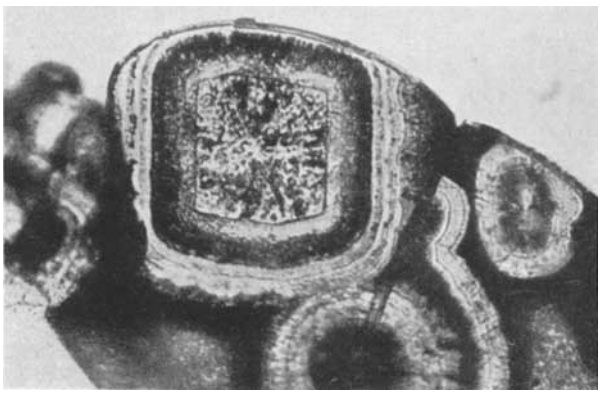

FIG. 36

Brown zircon from Madagascar. An epigenetic healing fissure, consisting of solid material. 420 ×

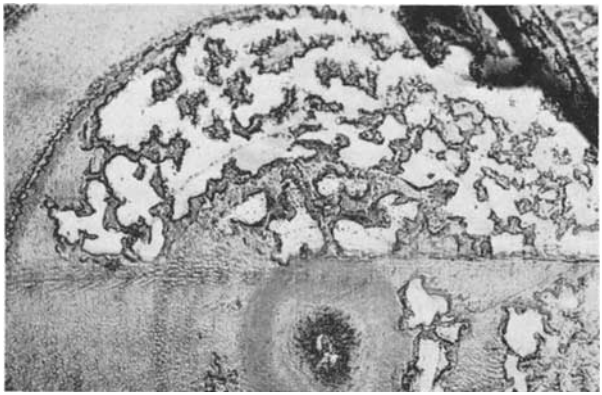

FIG. 37

Brownish zircon from Madagascar with epigenetic healing fissures, containing disc-like aggregationen of iron oxide. Here parts of such a deep red coloured disk have been resorbed by the host crystal, forming a peculiar pattern. 120 ×

FIG. 38

Brownish zircon, same healing fissure as Fig. 37. Between the red disks are colourless crystal needles, mostly radiating from one centre. 120 ×

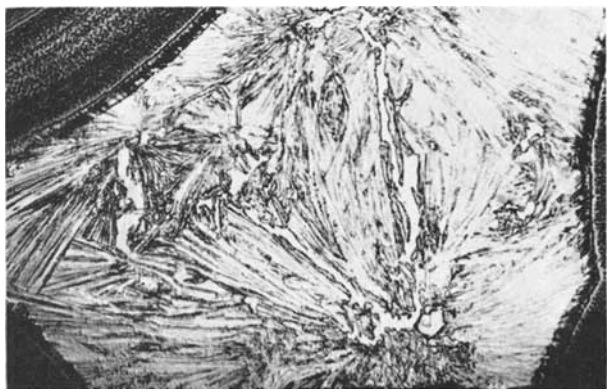

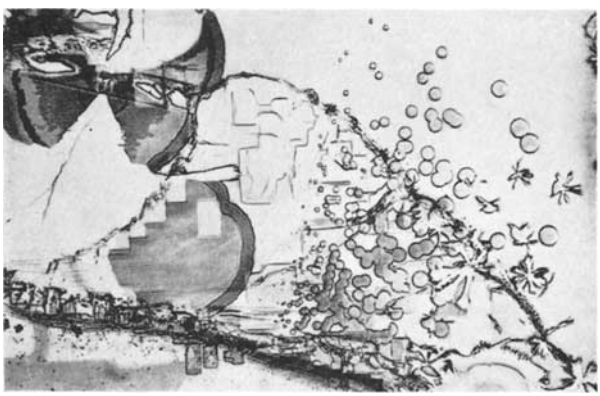

FIG. 39

Brownish zircon from Madagascar. A healed cleavage crack (epigenetic), with strangely formed deposits of iron oxide. 105 ×

Recently, some brownish-coloured zircons from Madagascar arrived in Europe. The stones contain healing fissures of extraordinary shapes, which so far have not been described elsewhere.

One of the Madagascar stones contained a healing fissure which is shown in Fig. 34. It consists of tiny droplets, forming a shagreen texture, and some crystals near the left edge. The crystals are doubly refractive (Fig. 35), but otherwise nothing is yet known about their nature. The shapes of the fissure and of the tiny droplets indicate that most probably its origin is epigenetic. This seems to be confirmed by another part of the same crack, which exhibits an unusual pattern (Fig. 36). It consists of solid material, the nature of which could not yet be determined in spite of the application of high enlargement. There is no doubt that this particular filled or healed crack is of epigenetic origin.

Another brownish-coloured zircon from Madagascar showed healing fissures parallel to the main cleavage plane, the first order prism (110) of the host crystal. The filling of the cleavage crack proved its epigenetic (late) origin. It consisted of iron oxide forming greater and smaller discs of deep red colour. Some of these beautiful looking formations have been submitted to a resorption process which produced peculiar patterns (Fig. 37). The spaces between the discs are occupied by crystal needles, mostly starting from one centre (Fig. 38). These singly refractive needles are typical of a rapid crystallization, and this indicates, together with the aggregation of iron oxide, a very late origin of the healing fissure.

Other zircons from the same source contain similar epigenetic healed cleavage cracks which are puzzling by their strange appearance. Fig. 39 and 40 give only a small selection of the manifold formations of the deposition of heterogeneous material and its partial resorption within an ordinary cleavage crack.

Garnet. Healing fissures in garnets are encountered only occasionally. In almandine garnet very early fissures could be observed (Fig. 41) which without any doubt have been submitted to a long-lasting healing process. This conclusion seems to be correct because the healed crack mostly consists of doubly refractive crystal inclusions which, moreover, are arranged in certain crystallographic directions.

FIG. 40

Same healing fissure as Fig. 39, showing rectangular fields of resorption. 105 ×

FIG. 41

Almandine garnet. A very early healing fissure, mostly consisting of double refractive crystal inclusions. 110 ×

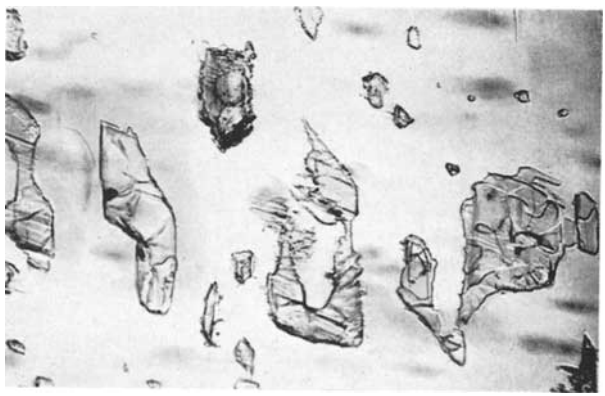

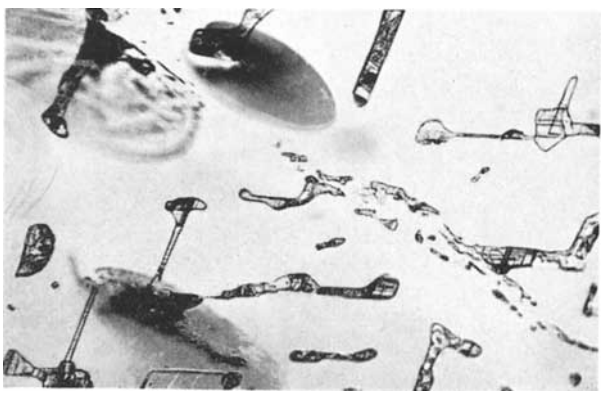

FIG. 42

Almandine garnet. An early healing fissure, the former liquid inclusions of which have been partly crystallized. 105 ×

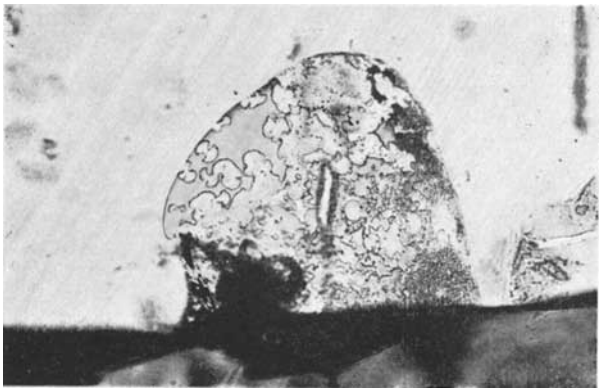

FIG. 43

Almandine garnet from East Africa with a typical healing fissure of late origin. 105 ×

FIG. 44

Almandine garnet from Madagascar. An inclusion of a slightly rounded zircon crystal. 110 ×

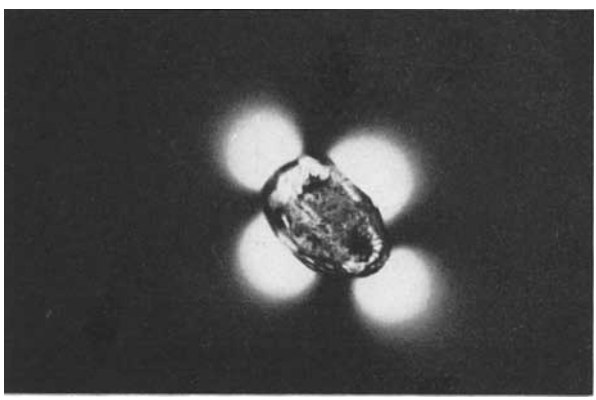

FIG. 45

Same as Fig. 44, polarized light. The four bright fields around the zircon indicate the area of a strong tension within the garnet. 110 ×

Another almandine (Fig. 42) showed a syngenetic healing fissure, the former liquid inclusions of which have been crystallized. They likewise follow preferred directions, which most probably are the edges of the dodecahedron. The newly formed crystals are birefringent. In some cases they have caused disc-like tension cracks, parallel to each other and to a crystal plane likewise, the indices of which could not be determined. Some of the discs show the characteristic brownish colour in transmitted light, which indicates that they are true cracks. Others exhibit the typical pattern of a beginning healing process. Examples of both kinds are to be seen in the upper left corner of Fig. 42. They are of epigenetic origin. The inclusions of this almandine show the rare phenomenon of both kinds of early and late healing fissures present in the one stone.

In an almandine from East Africa, a typical healing fissure of late origin could be observed (Fig. 43). It consists of very small liquid films with characteristic rounded forms.

Another example may be given of the strong tension which an included zircon causes on its host crystal. As is well known, inclusions of zircon in gemstones, as in garnet likewise, can cause cracks, which sometimes look like a halo around the included zircon. It is believed that these cracks are formed by the shear tension, which the zircon exerts on its host crystal. In an almandine from Madagascar, a slightly rounded zircon was found which had not yet caused such tension cracks in its host (Fig. 44). In polarized light, four bright fields around the zircon disclosed an area of strong tension within the garnet (Fig. 45). If this tension is by any reasons increased only a little, the well-known cracks are originated which afterwards may be submitted to a healing process. In this phase, Fig. 45 shows a not yet developed crack or an " unborn " healing fissure.

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1. E. N. Cameron, R. B. Rowe, and P. L. Weis. *Fluid Inclusions in Beryl and Quartz from Pegmatites of the Middletown District, Connecticut* ; American Mineralogist, 38, 1953, 218-262.
2. P. L. Weis. *Ibid*, 671-697.
3. W. F. Eppler. *Synthetischer Smaragd* ; Deutsche Goldschmiede-Zeitung 1958, 193-197, 249-251, 327-329, 381-385.
4. E. J. Gübelin. *Inclusions as a Means of Gemstone Identification* ; Gemological Institute of America, Los Angeles, 1953.
5. W. F. Eppler. " *Schneeflocken* " *im Aquamarin* ; Schweizer Goldschmied No. 6, 1958.

Gemmological Abstracts

ZWAAN (P. C.). *Remarks on inclusions in an aquamarine.* Proc. Kon. Ned. Akad. v. Wetensch., Vol. B 61, pp. 260-264. 1958.

A light bluish green aquamarine of unknown origin had ε 1·572, ω 1·578; weak pleochroism, ε bluish, ω yellowish; sp.gr. 2·693. A plane containing the c-axis has negative crystals and tubular and irregular inclusions. The negative crystals have two liquid phases and a vapour phase, and on heating to ~30°C. one liquid phase disappears; this is taken to be liquid CO_2. Part of the tubular inclusions are filled with a liquid and a vapour phase, the rest are hollow. Other planes of inclusions occur oriented parallel to (0001) and contain irregular droplike forms. All the inclusions are believed to be of secondary origin.

R.A.H.

WEBSTER (R.). *Synthesis of emerald.* Gemmologist, Vol. XXVII, No. 328, pp. 203–206. November, 1958.

The article gives the history of the attempts to synthesize emerald from the time of the experiments of J. J. Ebelmen in 1848 and P. G. Hautefeuille and A. Perrey in 1888, to those of R. Nacken in 1912 and onwards and H. Espig and E. Jaeger's manufacture of *igmerald*, to the present commercial production of Carroll F. Chatham. Some idea of the possible methods of production is given, and the physical and optical properties, types of inclusions and other factors are compared with those of natural emeralds. 6 illus.

P.B.

SCHLOSSMACHER (K.). *Fabulit—der neue Diamantersatz.* Fabulite—the new diamond substitute. Zeitschr. d. deutsch. Gesell. f. Edelsteinkunde, No. 24, pp. 10-12. 1958.

The article deals with (synthetic) strontium titanate and lists its physical properties in comparison with those of diamond. Previously published in the July number of the Deutsche Goldschmiedezeitung. An English text has appeared in the Australian Gemmologist, Vol. 1, No. 2, 1958.

W.S.

SCHLOSSMACHER (K.). *Die bisherigen Ergebnisse der Diamantschürfung im Gebiet Jakutsk.* Results of diamond mining in the Jakutsk area. Zeitschr. d. deutsch. Gesell. f. Edelsteinkunde, No. 24, pp. 12-15. 1958.

The article is based on information issued by the German authorities for Foreign Trade who abstracted the Russian publication " Woprossy Ekonomiki." Six diamond bearing districts were listed :

1. Malo-Botuobinsk on the Malo-Botuobujy river, a tributary of the Wiljuij (itself a tributary of the Lena river).
2. Daldyno-Alakitsk (not on the map published by USSR in 1955).
3. Sredne-Marchinsk on the river Marcha, a tributary of the Lena river.
4. Tjungsk on the river Tjung, a tributary of the Wiljuij.
5. Munsk, on the river Muna, a tributary of the Lena river.
6. Severo-Oleneksk on the river Olenek.

Prospecting seems to be advanced in the districts listed under 1 and 2. The mines are named " Mir " in district 1 and " Udatschnaja " in district 2. The two mines are likened to Premier and Jagersfontein. According to " Woprossy Ekonomiki " the production possibilities seem most promising in these districts.

W.S.

STEINERT (Dr.). *Die sowjetischen Diamanten.* Soviet diamonds. Zeitschr. d. deutsch. Gesell. f. Edelsteinkunde, No. 24, pp. 16-17. 1958.

Attention is drawn to a Moscow scientific publication of 158 pages by 14 authors on the diamonds of Siberia and a popular propaganda sheet printed in Germany and published there by the Russian Embassy. Reference to fluorescence of diamonds under X-rays (as opposed to ultra-violet light) in the latter publication seems spurious to Steinert.

W.S.

BLANK (H.). *Eine neue Quarzlampe für kurzwelliges UV-Licht.* A new quartz lamp for short wave UV light. Zeitschr. d. deutsch. Gesell. f. Edelsteinkunde, No. 25, pp. 10-12. 1958.

The author describes the " Blank's Gem-testing lamp " developed by him for gemmological purposes. The mercury discharge lamp has a wattage of about 94 mW at 2540Å and about 5mW at 3650Å. The effective rays therefore lie within the shorter

wave range. The mean life of the lamp is 5,000 hours. The luminescence of a number of precious stones is described.

W.S.

SCHLOSSMACHER (K.). *Fehlerprüfung von Brillianten.* Examining flaws in brilliants. Zeitschr. d. deutsch. Gesell. f. Edelsteinkunde, No. 24, pp. 20-22. 1958.

A new instrument, the " Brilliantendoskop " (!) is described. This is essentially a microscope arrangement allowing inspection and photographing inclusions at 10 × magnification. (A diamond dealer may fear that the requirements for a " loupe clean " diamond become too high.)

W.S.

SALLER (X.). *Das Färben von Perlen.* Dyeing of pearls. Zeitschr. d. deutsch. Gesell. f. Edelsteinkunde, No. 25, pp. 12-14. 1958.

Interesting article on pearls, their colour and processes of dyeing them. The organic conchiolin takes colour more readily than the mineral components (aragonite, calcite). The pearls are dyed cold or at a temperature of 50°C., the dye being dissolved in aqueous, alcoholic, acetone or similar solution. For dyeing with inorganic dyes certain metal chlorides are being used; these are mostly halogen compounds of strontium, barium or tin, which produce red, blue and blue-red hues. Organic dyes are rarely used, one of the few being that derived from the carcuma-root, which produces yellow. The most important dyes are the synthetic ones, with which the finest colour shades can be obtained. Alkaline and acid dyes can be used, the first being much quicker in use. A list of obtainable colours is added. The colour of the natural pearls is caused by chance similarly to the creation of the pearl itself.

W.S.

FLOOD (T. G.). *Die Zuchtperle—ein zweihundertjähriges Mysterium* The cultured pearl — a two hundred year old mystery. Zeitschr. d. deutsch. Gesell. f. Edelsteinkunde, No. 25, pp. 14-16. 1958.

An interesting historical article showing that round, cultured pearls were produced before Mikomoto's era by the Swedish scientist Carl von Linné, around 1761. Linnaeus's production method was bought by a Petter Bagge, whose grandson emigrated

to Leith in Scotland around 1820, where he died nine years later. The documents relating to the invention have since been lost.

W.S.

(Carl von Linné is usually known as Linnaeus in England—some of his cultured pearls are in the possession of the Linnean Society of London).

—— *Die neue Türkisimitation.* The new turquoise imitation. Zeitschr. d. deutsch. Gesell. f. Edelsteinkunde, No. 25, pp. 17-18. 1958.

A successful imitation of turquoise has been made consisting of aluminium hydroxide and aqueous copper phosphate. The specific gravity of the imitation is lower than that of genuine turquoise. Thoulet's solution discolours the imitation (brown); the natural stone is not affected by it.

W.S.

PENSE (J.). *Die Formbeständigkeit technischer Achate.* Stability of industrial agates. Zeitschr. d. deutsch. Gesell. f. Edelsteinkunde, No. 25, pp. 23-24. 1958.

Investigation with the Zeiss interference microscope showed that the surface of agate remained completely smooth and plane at temperatures between 0°C and 60°C, also edges were not bent. From 200°C bending could be observed, but this temperature is far above any encountered in a known application of agate. Further investigations may refer to thermal expansion, humidity absorption and other properties of agate.

W.S.

SCHLOSSMACHER (K.). *Die exakte Messung der Brilliantfarbe.* Exact determination of the colour of brilliants. Gold und Silber, No. 9, pp. 25-26. 1958.

The author describes the " electronic colorimeter " of the American Gem Society, in particular the Shipley diamond colorimeter, which contains the light-source, 2 colour-filters, the measuring instrument and a calculating machine. The instrument does not require great skill in handling and gives fairly consistent results.

W.S.

EPPLER (W. F.). *Flüssigkeiten in Edelsteinen.* Fluids in Precious Stones. Deutsche Goldschmiedezeitung, No. 9, pp. 489-490. 1958.

Description of a two-phase and a three-phase inclusion in colourless Siam sapphires. The gas bubble in the two-phase inclusion being CO_2 varies with the temperature and is shown in three different photomicrographs taken at different temperatures. The fourth photomicrograph shows nonmiscible liquids with libellae.

W.S.

GÜBELIN (E. J.). *Notes on the new emerald from Sandawana.* Gems and Gemology, Vol. IX, No. 7, pp. 195-203. Fall, 1958.

A concise report on the characters of the Sandawana emerald of Southern Rhodesia. The article is parallel to that published by the same author in the Journal of Gemmology, Vol. VI, No. 8, October 1958.

7 illus. R.W.

MAYERS (D. E.). *Sandawana emeralds—some commercial aspects.* Gems and Gemology, Vol. IX, No. 7, pp. 221-223. Fall, 1958.

Tells something of the finding of the emerald in Southern Rhodesia and of the methods of marketing the stones. Owing to the fractured nature of the crystals generally only calibre cut stones can be fashioned from the rough material.

R.W.

MAHAJAN (B. S.). *A study of style and fashion in Indian jewellery.* Gems and Gemology, Vol. IX, No. 7, pp. 204-220. Fall, 1958.

An article giving much interesting information on the designing, manufacture and marketing of jewellery in India. India has, from time immemorial, been known to the world as the land of fabulous gems, but jewels in India are prized not only for their beauty but for their investment value. The design and native use of necklaces, ear ornaments, nose rings, sari pins, bangles and rings are discussed. The introduction of a system of hallmarking gold and silver is proposed. A series of five double illustrations show models wearing jewellery with companion line-drawings showing suggested improvements in the style of jewellery worn.

11 illus. R.W.

BOOK REVIEW

SPERANZA CAVENAGO-BIGNAMI. *Gemmologia—Pietre Preziose e Perle* (Gemmology—Precious Stones and Pearls). Ulrico Hoepli, Milan, 1959, XXXIV and 1110 pp., 32 coloured plates, 850 illustrations, 67 tables. Price 15,000 Lire.

Written by the Director of the Italian State Gemmological Laboratory, this is a work conceived and carried out on a grand scale and achieves a very great degree of success, although it is not entirely free of the faults which are usual in such comprehensive works.

The book is divided into four main parts together with a bibliography and the indices. Part 1 is a discourse on the characteristics of minerals in crystals generally, Part 2 a detailed examination of each mineral in its aspect as a gemstone (including as well as the materials strictly belonging in this section, those organic substances, such as coral, amber and pearl that are used as well as the precious minerals for jewellery), Part 3 a description of the tests for precious stones, and Part 4 a number of tables repeating in a concise form for reference much of the information given at length in the preceding parts.

The mineralogical information given in Part 1 is a far fuller one than is customary in gemmological text-books, and perhaps demands a greater degree of scientific knowledge than would be expected of a student in this country, but the explanations are admirably clear and the illustrations of minerals both copious and effective. One fault, however, lies in the lack in many cases of captions to the illustrations, leaving their explanation to be sought in the text, perhaps at some distance.

The detailed descriptions of the stones given in the second part are well arranged with a table of principal characteristics of each stone at the head. It is perhaps of comparatively small importance in a book intended for use by Italians that the English equivalents of the Italian names for stones are often wrongly given ; this is especially true in the many cases where English usage is incorrectly made to follow the German, frequently resulting in out-of-date and inaccurate nomenclature. The references to English names and

to English gemmological practice generally are one of the weaknesses of the book, which does not appear to have been read in manuscript or proof by anyone with more than a slight knowledge of English or of English gemmology, and the derivation of one of the English names for nephrite (axestone) from actinolite (ἀκτίς - ray, λίθος - stone), one of the constituents of the tremolite-actinolite series to which nephrite belongs, instead of from the literal translation into English of the Maori word " punamu " is indicative of this, especially as the Maori word is given and correctly translated into Italian. It is, of course, possible that similar errors could be found relating to the French and German languages, but this reviewer's knowledge of gemmological practice in either country is insufficient for him to detect them. However, as has already been said, these faults are comparatively minor in a book intended for use by Italian students.

The arrangement of this section with the stones described in descending order of hardness has much to recommend it. In particular it has the advantage over the more usual alphabetical arrangement that the most important gemstones fall naturally in the beginning of the section (diamond first, followed by corundum), whereas most writers who use the alphabetical arrangement find it necessary to take at least diamond out of its proper place to deal with it first. The part of this section dealing with pearls, both natural and cultured, is particularly well carried out.

The third part, although entitled methods of testing precious stones and pearls, in fact covers a wider field than this would indicate, and gives a full description of the equipment and setting up of a precious stone laboratory. Part 4, tables, collects into convenient form for quick reference all the information which has been given in detail in Part 2. The main index is well arranged with the principal reference to any precious stone in bold type and is easy and convenient to use.

The production of the book is excellent and in general coloured plates attain the high standard which we have learned to expect from Italian printing, and considered generally this is a most valuable work for anyone whose knowledge of Italian is sufficient to enable him to use it successfully. Perhaps we may hope for an English edition to be published before long.

P.G.

AUSTRALIAN CULTURED BLISTER PEARLS

Further investigation of the large Australian pearls shown on the occasion of Mr. R. Webster's talk on pearls on Tuesday, the 27th of January (see p. 75), has demonstrated that the original bead nucleus cemented on to the pearl shell is a soft material and may be talc (soapstone). This bead, after the oyster has coated it with nacre, is removed from the shell with a hollow drill. These objects are then sent to Japan for a final finishing, which consists of the removal of the original nucleus, the polishing of the inside of the shell of nacre and the insertion of a smaller bead nucleus embedded in a white cement. The pearl is finished with a backing piece of mother-of-pearl. This is strikingly shown by the radiograph reproduced here. The lower picture shows the blister as removed from the shell and the upper shows the finished cultured blister pearl. The reason for the need to change the bead seems to be because the oyster first secretes a heavy layer of conchiolin over the nucleus before depositing nacre, and this shows through the translucent layers of nacre and gives a darkening effect to the colour of the pearl. By cleaning, and possibly tinting, the inner surface of the nacreous shell, the colour of the pearl is much improved and may even be enhanced by the white cement used to fix the new nucleus. This is no new departure, for some of the earliest patents of Mikimoto's were for such methods.

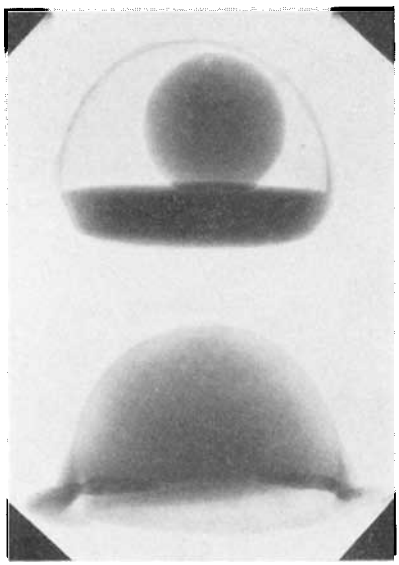

ASSOCIATION NOTICES

COUNCIL MEETING

A meeting of the Council of the Association was held at Saint Dunstan's House, Carey Lane, London, E.C.2, on 27th January, 1959. Dr. W. Stern presided.

The following were elected :—

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Zwirs, H. L., Curaçao, Netherlands Antilles D.1950

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Guest, George M., Leeds

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Hool, Rene H., Rotterdam, Holland
Owens, Carl P., Atlanta, Georgia, U.S.A.
Ronald, James (Dr.), Inverness
Scott, Cecil E. E., London, N.
Weatherhead, Albert V., Wellington, New Zealand
Wilson, Charles W., Chamblee, Georgia, U.S.A.
Kelley, William F., Lakewood, Ohio, U.S.A.

The Council agreed to make a contribution towards the cost of a badge of office for the Chairman of the Midlands Branch and recorded appreciation of the efforts of the Branch members in maintaining activities in the Midlands which were doing much to foster interest in gemmology. The income and expenditure account and balance sheet for the year ended 31st December, 1958, were approved for submission to the annual general meeting, which had been arranged to be held on 1st May next. The officers of the association were nominated for re-election.

TALKS BY MEMBERS

BLYTHE, G. : " Gemmology," Chalkwell Evening Townswomen's Guild, 26th January, 1959.

LIEPER, H. : " Gem pegmatites of San Diego County," Rotary Club, Del Mar, California, 16th October, 1958 ; " The titania gems," San Diego Mineral Society, 19th November, 1958 ; " The lapidary hobby," Fallbrook Gemological and Mineral Society, Fallbrook, California, 21st November, 1958.

JONES, T. : " Gemstones," Institute of Metals, Middlesbrough, 20th November, 1958.

WELLER, G. T. : " Pearls," Tunbridge Wells Congregational Church Youth Club, 28th January, 1959.

BLYTHE, G. : " Gems," Infantile Paralysis Fellowship, Southend, 4th February; Hockley Young Wives, 9th February; Westcliff Young Wives, 23rd February, 1959 ; "Gemmology," Southbourne Women's Conservatives, 4th March ; Rayleigh Rotary Club, 5th March, 1959.

DUNCAN, JAMES M. : " Precious Gems," to Glasgow and West of Scotland Building Societies Institute, 10th February, 1959.

WADE, D. : " Diamonds," Queen's Park Rotary Club, 4th February ; " Gemstones," Clan Donald Highlanders Institute, Glasgow, 20th February, 1959.

WARREN (Mrs. Kathleen) : "Gemstones," Beckenham Young Wives' Club, 10th February ; Beckenham Mothers' Union, 25th February ; Bromley Young Wives' Club, 3rd March ; Bromley Mothers' Union, 4th March, 1959.

BOWDEN, A. : "Gemstones," Hartley Town Women's Guild, Plymouth, 9th January ; Hessenford Women's Institute, 13th January ; R. N. Friendly Union & Sailors' Wives, *H.M.S. Raleigh*, 12th February ; Botus Fleming Women's Institute, Cornwall, 1st April; St. Ann's Chapel Women's Institute, Plymouth, 2nd April, 1959.

On Tuesday, 27th January, 1959, Mr. Robert Webster, F.G.A., gave a talk to members called " Pearls—ancient and modern " at the Goldsmiths' Hall, London. After references to the use of pearl in ancient times he surveyed the nature and occurrence of the pearl oysters, *pinctada vulgaris, p. maxima* and *p. martensii*, and the conch, clam and the pearl-bearing mussels. *Pinctada martensii* is used by the Japanese for pearl cultivation and the present-day method of inducing an oyster to produce a pearl is by inserting a small disc of the mantle from another oyster by means of a probe. A mother-of-pearl bead is then inserted after the piece of mantle, which grows round the bead nucleus and secretes nacre upon it. *Pinctada maxima*, in which Australian cultured pearls are grown, produces a larger cultured pearl. The first harvest of these was in 1958 and some specimens were exhibited by Mr. Webster.

Recently the Japanese have attempted the production of pearls without a nucleus, using the mussel *Hyriopsis schegeli* found in the inland lake Biwa Ko. The pearls produced are of fair colour but usually very baroque. Similar experiments have been tried in the new Australian fishery at Kuri Bay using the *maxima* oyster. The Japanese non-nucleated cultured pearls have been marketed in Arabian countries, but there does not appear to have been any marketing of the Australian product.

Coloured pearls are always prized; those with a yellow tint are appreciated by the dark-skinned beauties of Spain and Italy. Gunmetal-coloured bronze-coloured and black pearls have a charm of their own, and it is these blackish colours which may be artificially produced by staining with silver nitrate solution. It has been found by Anderson that natural black-coloured pearls show a dim glow when viewed in blue light through a red filter and that the artificially stained black pearls do not, and, further, owing to the opacity of the reduced silver, which gives

the colour to the pearl, to X-rays a radiograph may show the conchiolin layers as white lines on the negative instead as black lines.

Other materials than mother-of-pearl may be used for the nuclei, but these are rare. Glass is one, but a more uncommon type is talc, and sometimes freak nuclei are found.

The cultured blister pearls were spheres of mother-of-pearl cemented to the oyster shell between it and the mantle of the animal, which secretes the nacre and which after a time covers the bead with this pearly substance. These objects were removed from the shell and the non-nacreous back ground flat and then backed with a dome of mother-of-pearl. Such an object is illustrated in Herbert Smith's book, but X-ray photographs of such pearls show a rather different structure, in which the central bead is smaller than would be expected. It appears that the original bead is removed, the inside of the shell of nacre polished, and maybe tinted, and a smaller new bead cemented into the cavity by white cement. The pearl is finished with a backing piece cemented on. This, indeed, was an early patent of Mikimoto's and we are apt to think of such objects as old fashioned. This is not so, for in the new Australian fisheries this type of cultivation, as well as whole pearl cultivation, is now carried on, using the large *pinctada maxima*. These Australian blisters are removed from the shell by drilling out with a hollow drill and these unfinished objects are sent to Japan for the removal of the core, the polishing of the inside and the refilling with a new bead.

The most useful and accurate method for testing drilled pearls is by the Endoscope, which clearly detects by a narrow beam of light passed through a special needle whether the pearl is concentric to the centre or has a layered structure. When the pearl is undrilled recourse is made to X-rays, of which the Diffraction method, also called the Lauegram method, is the most conclusive. By passing a narrow beam of X-rays through the centre of the pearl it is possible to determine whether the pearl structure is radial or directional. Cultured pearls usually fluoresce weakly under the influence of X-rays, but this is not conclusive as most freshwater pearls and some Australian pearls may show this effect. A direct X-ray picture will in certain cases give considerable help, but in the case of pearl necklets is rarely fully conclusive.

The mineral matter of pearls is calcium carbonate in the form of aragonite. It is well known that carbonates effervesce with acid and in a minor way an acid perspiration will dissolve the mineral part of pearl, and this is shown by the barrel-shaped wear of the smaller pearls of a necklet, the pearls which are at the back and press upon the skin of the neck. Grease from cosmetics can have a deleterious effect on pearls, specially cultured pearls. Greasy substances avidly collect dirt, and this dirty grease may travel along the string canal and seep into the discontinuation layers, so prominent between the bead and the nacreous outer layers in cultured pearl. This dark grease shows through the translucent layers and the pearl appears a dark, blackish, very unattractive colour. If not too far damaged, these discoloured pearls may be " degreased " by careful treatment in an organic solvent. An unusual type of discoloration was found to be due to the darkening by sulphiding of some natural component in the make-up of cultured pearls.

Mr. Webster illustrated his talk by over fifty slides.

MIDLANDS BRANCH

X-rays were the subject of a well attended lecture given by Mr. Harry Proctor, surgeon at the Birmingham Accident Hospital, to members of the Midlands Branch of the Gemmological Association of Great Britain at the Auctioneers' Institute, St. Philips Place, Birmingham, on Friday, 30th January, 1959. Mr. Trevor Solomon, Chairman of the Midlands Branch, presided.

Mr. Proctor described some of the early developments leading up to the discovery of X-rays by Röntgen in 1895, and discussed the nature of X-rays following on to natural radioactive materials and the discovery of radium by Madame Curie. He referred to the uses of X-rays in medicine, both for the diagnosis and treatment of disease. The talk was illustrated throughout by slides showing the apparatus used in early experiments up to the more complicated modern X-ray tubes.

The dangers of over-exposure to X-rays was stressed, those by far the most dangerous to the public being given by machines used in some shoe shops. The X-rays from these machines, being "soft rays," are readily absorbed by the human body and if used too frequently could lead to serious consequences.

Mr. Proctor then described the importance of X-rays to the gemmologist, mentioning the powder X-ray photograph, the Switzer-Holmes X-ray diffraction camera and the use of X-rays to differentiate between real and cultured pearls.

He showed also, with some very interesting slides, how X-rays have played an important part in the studying of works of art.

The evening concluded with an examination of a modern X-ray machine, with cut away sections enabling the working parts to be seen. Some very fine X-ray photographs of flowers were also exhibited.

* * *

Members of the Midlands Branch held their annual dinner on Saturday, 7th March, 1959, at the Medical Institute, Edgbaston, Birmingham. Mr. Trevor Solomon, F.G.A., presided. Among the guests were Mr. John Croydon, F.G.A., Chairman of the National Association of Goldsmiths and Mrs. Croydon, Mr. R. Weston, President-Elect of the British Jewellers' Association, and Mr. K. Mindelsohn, B.A.

Speeches were few and brief and members and their guests enjoyed dancing after the dinner.

The Branch chairman wore the badge of office that had been designed by a member of the Branch, Miss J. Rice. The emblem of the Association, in enamel, is the principal motif of the badge.

Smiths Imperial

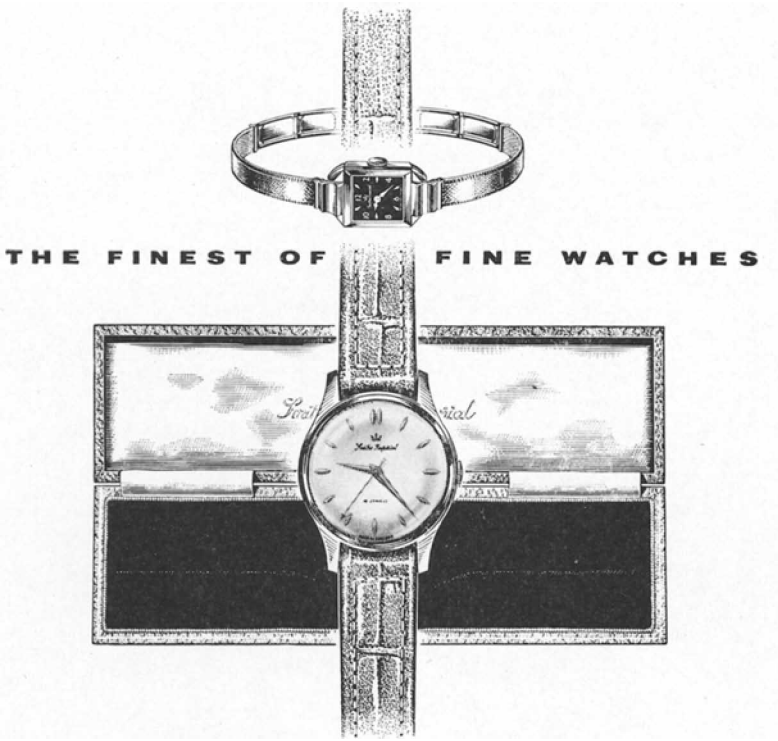

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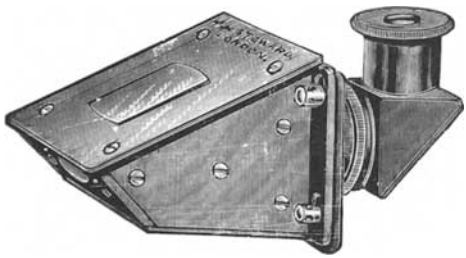

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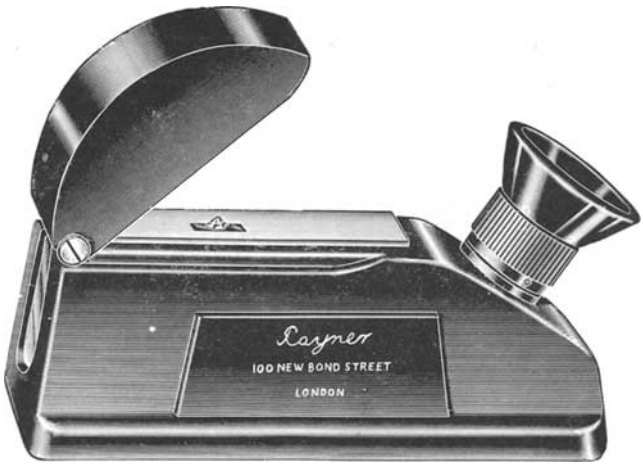

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April, 1959

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Vol. VII No. 3 JULY, 1959

THE JOURNAL OF GEMMOLOGY

and

PROCEEDINGS OF THE

GEMMOLOGICAL ASSOCIATION OF GREAT BRITAIN

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SOME DIAMOND PROBLEMS

By R. WEBSTER, F.G.A.

OF all the gems with which the jeweller trades, and which the public so greatly appreciate, diamond has supreme importance. It is the gemstone which forms the greater part of a jeweller's stock and is the stone which he understands best. Indeed, unless there is something unusual with regard to a specimen, diamond presents little trouble in identification. In this short article something will be told of those diamonds which show anomalous appearance and thus give rise to doubt.

A cut diamond owes its brilliance, fire and characteristic adamantine lustre to its high index of refraction (2·42), coupled with the exceptional hardness of the mineral, which surpasses all other natural and synthetic substances (except perhaps the synthetic compound borazon, boron nitride). This superior hardness, which allows a perfect polish, coupled with the high index of refraction, results in the brilliancy and lustre of the gem. The high refractive index of diamond means that the critical angle is small, when the second medium is air, and is about $24\frac{1}{2}°$ for yellow light. Hence, as shown by the diagram (Fig. 1), in a well-made brilliant-cut diamond practically all the incident light falling on the crown (top facets) of the diamond will be returned by total internal reflection and refracted out again through the front of the stone.

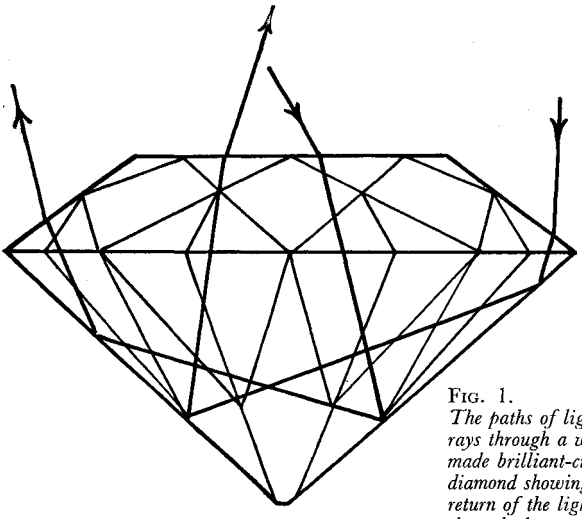

FIG. 1.
The paths of light rays through a well-made brilliant-cut diamond showing the return of the light out through the top facets.

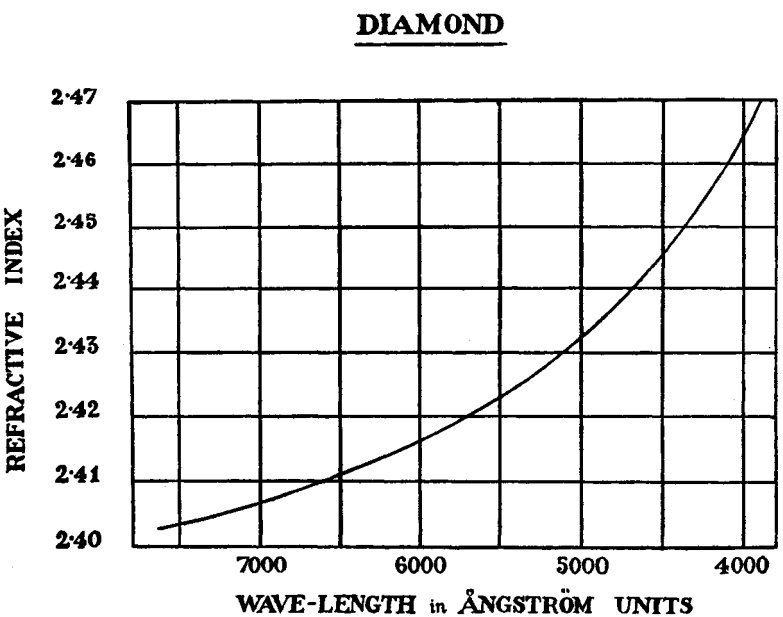

FIG. 2. *Curve showing the refractive index to wavelengths of light in respect of diamond.*
Taken from *Gemstones* by G. F. Herbert Smith, by courtesy Methuen & Co, Ltd.

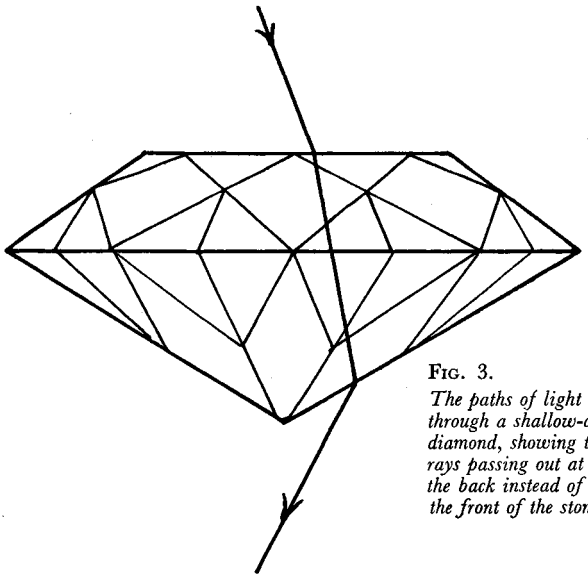

FIG. 3.
The paths of light through a shallow-cut diamond, showing the rays passing out at the back instead of the front of the stone.

Further, as the refractive index differs for light of different wavelengths (colours), as shown by the graph in Fig. 2, white light will be split up into its component colours, and, owing to the long path of the light rays passing through the stone twice, the rays will be all the more dispersed. It is this colour dispersion which constitutes the fire of a stone and this effect is well seen in diamond.

The more common causes of a diamond " looking wrong " are that the stone is cut with incorrect proportions or has an unusual tinge of colour. A diamond which is cut without sufficient depth for the spread of the stone gives a so-called " fish-eye " effect. Such diamonds are often called " laxey," a term probably derived from *lasques*, the name applied to the flat tablets into which many Indian diamonds were cut. Shallow-cut diamonds, owing to the angle of the crown and the rear facets not being at the correct inclination to totally reflect the rays out through the front, lose much of the light and the brilliancy suffers (Fig. 3). If a diamond is cut too thick the stone is said to be " lumpy," and again the optical effects are not at their optimum for the production of full brilliancy, although such stones do not appear to lose the diamond appearance so much as flat stones (Fig. 4). Such thick cutting, probably done to conserve weight in the finished stone, was common in earlier days and diamonds so cut are often called " Brazilian stones," for before 1866 most of the gem diamonds came from Brazil.

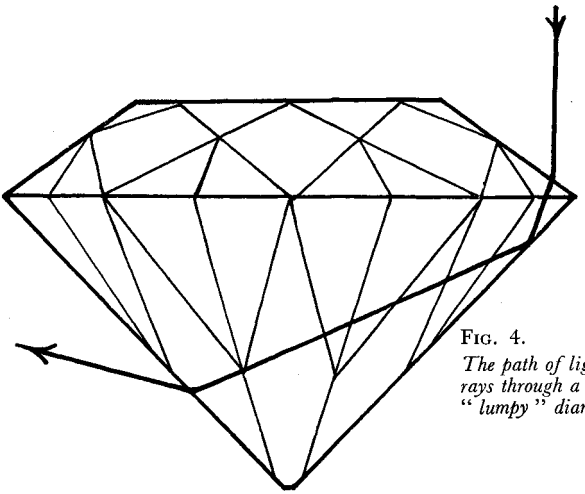

FIG. 4.
The path of light rays through a "lumpy" diamond.

A diamond full of dust-like inclusions may appear cloudy or milky and such stones may engender doubt. Further, a diamond which has been accidentally burnt will show a ground-glass effect on the surface of the facets, and when magnified this surface may be seen to be made up of pits, which take the form of the crystal face nearest to which the facet is parallel.

Colour in diamonds may be divided into two groups, diamonds which have a pronounced and pleasant colour, such as pink, blue, canary yellow, and green, termed fancy diamonds, and diamonds which have only a tinge of colour or an unpleasant brownish shade. In some cases these stones can look wrong, and this is especially so with those diamonds which have a peculiar blackish look. The causes of colour in diamond are not known with certainty. Except for the pink stones, in which the colour is said to be due to a trace of manganese, the colour in diamonds is thought to be due to lattice defects, and not to trace-impurities as in most other gemstones.

Quite often ill-made diamonds or those of unusual tint, which inspire doubt as to their being diamonds, may be confirmed as diamonds by the presence of *naturals* on the raw edge (the unpolished edge) of the girdle. These are traces of the original faces of the crystal and are often purposely left on by the cutter, either to enable him to recognize the grain of the stone, or to show the owner of the crystal that he has not cut away too much of the crystal in making the finished stone. Fig. 5 shows such a natural. Further,

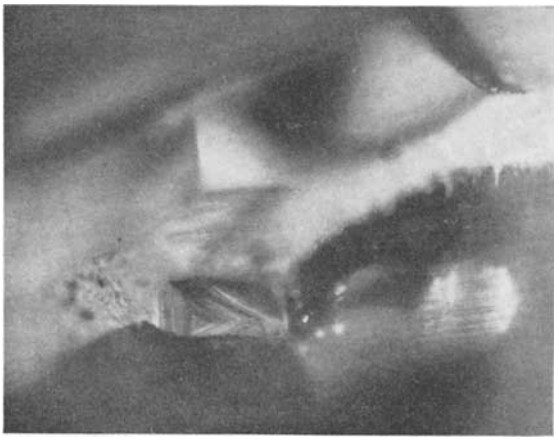

FIG. 5.
A " natural " on the edge of a brilliant cut diamond.

in the case of diamond a hardness test is applicable and is most useful. To do this the stone should be tested by applying the girdle of the stone to a piece of corundum (a piece of corundum boule or an old synthetic ruby or sapphire makes a good test plate) and examining the scratch mark, after rubbing any powder away, with a lens to see if the corundum has been scratched or not. A scratch on the corundum surface indicates that the stone tested is a diamond, except for the very rare case when a cut carborundum is encountered. A stone should not be tested by applying the test piece of corundum, for, if the stone does not happen to be a diamond, it will be badly marked.

Unpleasing brownish and yellowish diamonds are called " off-colour " stones and are less highly prized. It is such stones which are treated with dye to improve the colour for fraudulent purposes. Before 1890 yellowish Cape diamonds, which had been "whitened," were sold to Belgian and French diamond dealers at some 25 to 30 per cent above their market value. In 1891 M. Gilot (or Guillot) a French chemist, investigated this whitening of diamonds. Starting on the scientific principle that violet is the complementary colour of yellow, he bathed some yellowish diamonds in an alcoholic solution of violet aniline, to which were added a few grams of benzoin gum. This whitened the diamonds, but the treated stones lost their fire to a great extent. Gilot found, however, that if aniline solution was used alone, the brilliancy and fire were not impaired to a great extent.

Periodically " painted " stones treated with aniline dye solution—usually water coloured mauve with a copying-ink pencil —have been sold to unwary jewellers. As, usually, a water-soluble dye is used, a thorough washing of a suspected painted stone will remove the dye and reveal the true colour of the stone. There have been instances, however, where the dye has been more tenacious and has resisted ordinary washing. In such cases washing in alcohol, or in extreme cases with nitric acid (*aqua fortis*) with subsequent washing in water, will be necessary to remove the dye and show up the true colour of the diamond. Should a tinted lacquer, such as used for nail varnish, be used, acetone or amyl acetate might be the best solvent for the coating.

During the past twelve months a warning has been issued by the Jewellers' Vigilance Committee in the United States of America that diamonds have been whitened by a new coating process, which is only removable by treatment with strong acids. What method of coating is being used here to counteract the yellowish colour has not yet been disclosed. One could surmise that a sputtering technique resembling that used for coating stones to give a greater brilliancy, which is analogous to the "blooming" of camera and field-glass lenses, may be the method used.

Examination of the girdle of a suspected " painted " diamond by a hand lens may show up traces of the dye clinging to the unpolished edge and give away the faking. It should be realized that only off-coloured yellowish or maybe pale brownish diamonds will be colour-corrected by the use of violet dye. The painting of greyish stones by such a dye will be ineffective, for this colour correction is based upon the use of a complementary colour.

One of the more dangerous fakes of diamond is the diamond doublet. This composite stone is made with a crown of real diamond which is cemented on to a pavilion of some other inferior colourless material, which may be rock crystal, colourless topaz, synthetic white sapphire or spinel, or glass. Fig. 6 illustrates the construction of a diamond doublet. Diamond doublets, owing to the adamantine lustre of the diamond crown, might well be taken for a genuine diamond if only casual observation be made. However, identification is not difficult, for on looking into the stone it is seen to be lifeless and lacking in fire ; the optical effects appear wrong. Owing to the light rays striking the back facets at a smaller

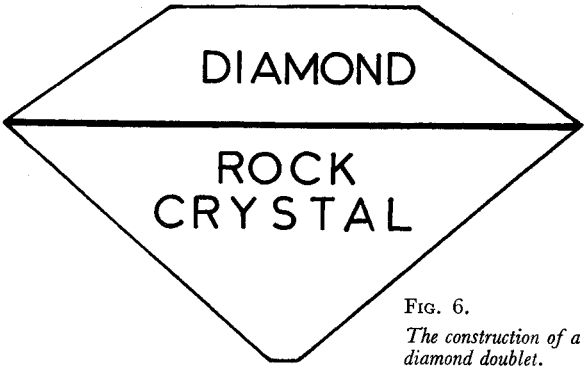

FIG. 6.
The construction of a diamond doublet.

The base need not be rock crystal but may be any inferior colourless stone.

angle than the critical angle for the medium—the critical angles for the inferior materials used for the base are greater than for diamond itself—much of the light will be refracted out through the back and not returned to the front by total internal reflection.

As the cement used to join the two pieces of material together in these diamond doublets, which is probably Canada balsam, deteriorates with age and forms white "feathery inclusions" in the cement layer, these, and "Newton's rings," circularly arranged coloured rings, due to air films between the cement and the stone, may be seen near the edge of the girdle.

What may be the best test is given by the reflection of the edge of the table facet on the cement layer, which shows up as a dark shadow edge when the top of the stone is inclined away from the observer and the stone is held between the source of light and the observer (Fig. 7). If the stone is unset, detection is easy, for not only may the line of joining be seen but a refractive index measurement may be made on the rear facets, which will at once tell the nature of the inferior base material of this composite stone.

The artificial coloration of diamond has attained some commercial importance, owing to the colouring effect produced when the stone is bombarded with particles of sub-atomic size. The production of a green colour in diamond by bombardment with radioactive particles from radium compounds has been known since early in the present century. With the advance of atomic science since the Second World War other methods of colouring diamonds

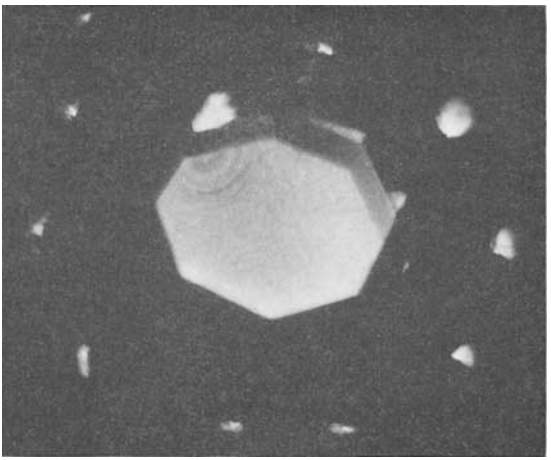

FIG. 7.
The shadow of the edge of the table facet on the cement layer, and Newton's rings, in a diamond doublet.

by particle-bombardment, using modern high-voltage particle-accelerators, have led to some commercialization of artificially coloured diamonds.

Sir William Crookes, as early as 1904, carried out a number of experiments on the action of radium on diamond and found that alpha-particles (i.e. Helium nuclei), which are emitted from radium, caused the diamonds gradually to change to a green colour. Crookes also found that such greened diamonds became radio-active, and that the radio-activity, like the colour, persisted for an indefinite number of years. He also found that vigorous chemical treatment had no effect, or only a temporary one, on the radio-activity and had none on the colour. Repolishing the stone did remove the colour, which is therefore only skin-deep.

S. C. Lind and D. C. Bardwell showed that heating such greened diamonds to a dull red heat (about 450°C) for several hours had the effect of destroying the colour and the radio-activity, and, further, they found that the gas radon (radium emanation) acted more quickly than the salts of radium itself in inducing a green colour in diamond.

Radium and radium compounds are expensive and are dangerous chemicals to handle, so that facilities for the green colouring of diamonds are not easily available. Still, there are a number of radium-greened diamonds known to be on the market. Their detection is, however, easy, for leaving the diamond in contact with a

bare photographic film or plate overnight in a light-tight box will cause a marked blackening of the emulsion on development of the film (or plate), the resultant autoradiograph showing the shape of the stone and a curious echo of the facet pattern beyond the borders of the stone (Fig. 8). Heavily treated diamonds may even glow in the dark, and scintillations may be seen when a radio-active diamond is placed on a zinc sulphide screen in a dark room, and the screen near the stone examined with a lens after the eye has become dark-adapted. These scintillations, each tiny splash of light representing the effects of one alpha-particle striking the screen, make a very beautiful and impressive sight. A radium-treated diamond will also discharge an electroscope in a few minutes, and this, except for a Geiger counter, provides the speediest and most sensitive test for such diamonds.

Experiments have shown that the radio-activity of a radium-greened diamond does not consist entirely of alpha-particles, but that the stones also emit some beta-particles (electrons). There is also the question of the physiological danger in wearing such a radium-treated diamond. Experiments using a Geiger counter have shown that the danger cannot be great, for the radiation given off was found to be no greater than that emitted by the radium on the dial of a luminous wrist watch.

The first of the post-war experiments in the artificial coloration of diamond was by the use of a cyclotron, and in the United States of America diamonds so treated have become an established feature in North American commerce. Cyclotroned diamonds are coloured by bombardment with fast moving protons (nucleus of the hydrogen

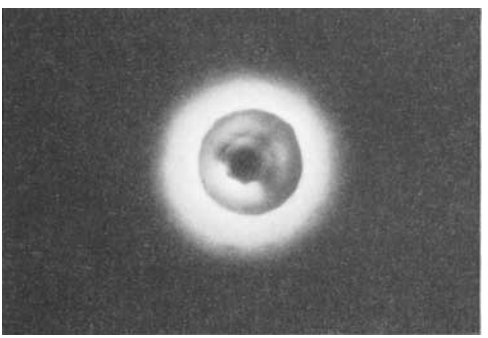

FIG. 8.
An autoradiograph of a radium-treated "greened" diamond.

atom with unit positive electrical charge), by deuterons (the nucleus of deuterium, the isotope of heavy hydrogen), and by alpha-particles. The colour produced is, like radium-treated diamonds, a green colour, or, if over-exposed, a black colour.

For treatment the diamonds are mounted on a long probe which is mounted in the vacuum chamber of the cyclotron (in some types of apparatus), or on special holders, usually made of aluminium, for those cyclotrons which can produce external beams. The heat generated when the atomic particles hit the target, in this case the diamonds and the holder, is intense and some means of cooling must be used. The probe or holder is usually water-cooled and further cooling is carried out by a jet of liquid helium. If the cooling is not efficient and the stone heats, the resulting colour produced in the diamond is brown and not green, and, further, cyclotroned-green diamonds may be turned to a golden-brown or to a yellow colour by subsequent heat treatment at about 800°C. In the short exposures used the coloration is only skin-deep and disappears on re-cutting. In all cases, whatever the type of particle used, bombarded diamonds are intensely radio-active for some hours after treatment, but this does not persist and dies out, and the stones cease to be radio-active. The colour, however, remains, and, as far as yet can be said, the colour is permanent.

A careful examination of cyclotroned stones will reveal a series of reflections of triangular cubist patterns that show varying intensity of green. A stone which has been treated through the table will, when examined with the pavilion up, show a dark ring around the girdle. A diamond treated through the pavilion will show a light ring around the girdle, and will show, when viewed through the table facet, a "watermark" rather like an opened umbrella surrounding the culet (Fig. 9). It is said that by irradiating the diamond through the side these tell-tale markings can be eliminated. In such a case the only distinction is by the unnatural green colour, which is rather a deep tourmaline green. With the brown colours, as G. R. Crowningshield has pointed out, there is always a narrow absorption line at 5920Å in the treated yellow and brown stones, whereas this line is absent in natural brown and yellow diamonds. It has been further reported that irradiated diamonds of a brownish-pink colour show absorption lines at 6370Å and a pair of lines at 6200 and 6100Å in conjunction with the 5920Å line.

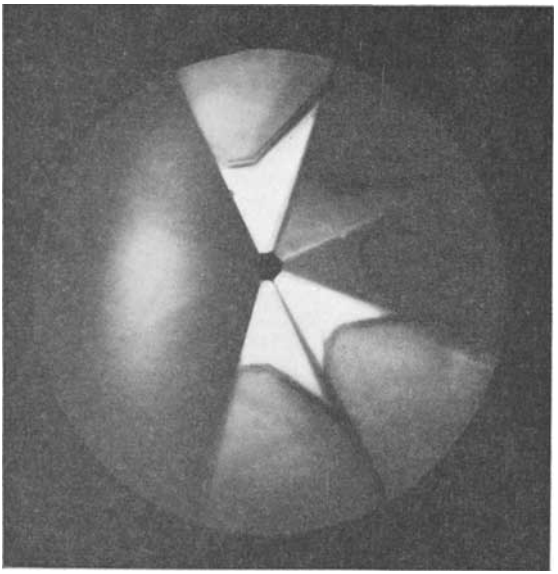

FIG. 9.
The " umbrella " seen around the culet in some cyclotroned diamonds.

A similar state of affairs occurs when the diamonds are treated in an atomic reactor (atomic pile) in which neutrons (the uncharged particles found in the nuclei of all atoms except those of hydrogen) are the particles used. The colours produced are, like those of cyclotronic coloration, green, brown and yellow, the brown and yellow colours being obtained after subsequent heat treatment. The diamonds when they come from the pile are green in colour and are intensely radio-active. The radio-activity quickly dies out, and by subsequent controlled heat treatment any of the colours named may be obtained. In pile-treated stones the coloration is throughout the stone and hence cannot be removed by polishing. There are no characteristic markings to be seen in pile-treated diamonds and with the green-coloured stones the unnatural colour is virtually the sole guide, but with the brown stones, and the yellows, the 5920Å absorption line is present and gives conclusive evidence of treatment.

By the use of fast-moving electrons from an accelerator, such as a Van de Graaf generator, diamonds have been coloured a pale aquamarine blue to a greenish-blue hue. Such stones are not easy to detect, but the treatment is not extensively carried out. It is

known that all natural blue diamonds are Type 2, a type which is transparent much further down in the ultra-violet than are the Cape stones, which are normally used for coloration experiments, and, further, the natural blue diamonds are electro-conducting. Therefore, if it can be proved that a blue diamond conducts electricity and is transparent to ultra-violet light to, say, 2200Å, then the stone can be taken as a naturally coloured one. Such determinations need laboratory apparatus and techniques. Bombardment with gamma rays will also produce a bluish-green colour, but this method is not commonly used.

All colourless stones might be said to simulate diamond, but to approach in any way the appearance of diamond such colourless stones must be somewhat similar in lustre and fire, and this limits the possibles to some half a dozen stones. The stone most commonly used to simulate gem diamond, fraudulently or otherwise, is the heat-treated colourless zircon. White zircon has a high index of refraction, a resinous-adamantine lustre and a dispersion (fire) nearly as great as that of diamond itself. Unlike diamond, zircon is a doubly-refractive mineral, and, further, is so strongly doubly-refractive that the rear facet edges as seen through the thickness of the stone appear doubled, an effect which can be clearly seen with a 10x lens (Fig. 10).

It must be realized, however, that zircon is a tetragonal mineral and thus has one optic axis, that is one direction along which light rays do not split into two rays. At a position at right angles to this direction of single refraction there is a direction where the full double refraction may be seen and hence the widest separation of the two images of the facet edges. Therefore, the doubling of the rear facet edges of a cut zircon may not necessarily be seen through the table facet, but may appear strongest when the stone is examined through the side. This doubly-refractive effect, which tends to give zircons a misty look, is so clearly evident that it seems inexplicable why such stones should ever be mistaken for diamonds. On the other hand, as pointed out by R. K. Mitchell, a spurious doubling of the back facets may sometimes appear in gem diamonds cut in the brilliant-cut style. This pseudo-doubling is due to a reflective effect in certain types of badly cut diamonds (Fig. 11).

The refractive indices of zircon (1·93–1·99) are too high to be measured on the normal refractometer, but complete identification

of white zircon can be easily accomplished by examination of the absorption spectrum, even if the stones are set. The fine line at 6535Å, the strongest and most persistent line seen in zircon spectra, is always present in white zircon, and other weaker lines may also be present with it.

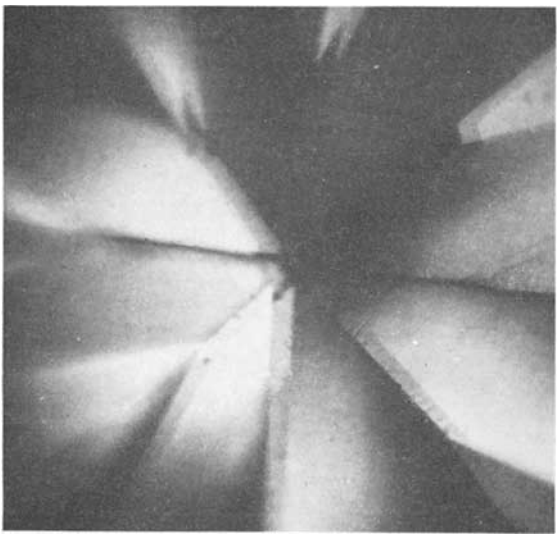

FIG. 10.
Doubling of the back facet edges, due to double refraction, seen in a white zircon.

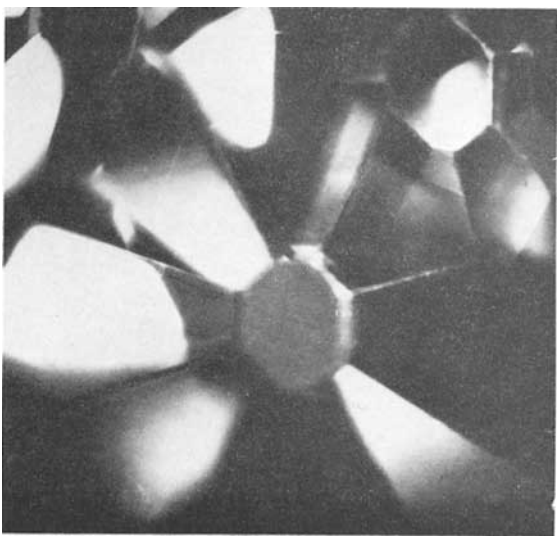

FIG. 11.
Pseudo-doubling of the facet edges seen in an ill-cut brilliant-cut diamond.

Natural white sapphires are not so often encountered, but the synthetic white sapphire is quite commonly met with in jewellery. When first produced, just before the First World War, synthetic white sapphire was shamefacedly sold as " synthetic or scientific diamonds." Synthetic white sapphire has too low an index of refraction and too vitreous a lustre effectively to imitate diamond and the stones have only a third the fire that is shown by diamond. Stones of this synthetic material of half a carat and over do not pose any difficulty in identification, despite the fact that the double refraction is insufficient to separate the two images of the rear facet edges except for the most practised eye. The index of refraction can be obtained by the use of a standard refractometer. It is when small stones are encountered, and synthetic white sapphire is fashioned into calibre and baguette-shaped stones of small size for use in multi-stone jewellery, that the position is not so easy and the stones more readily mistaken for diamonds. In such a case if the piece of jewellery can be immersed in a cell containing methylene iodide (R.I. 1·74), or α-monobromonaphthalene (R.I. 1·66), the relief will be high if the stones are diamonds and low if synthetic sapphires (or any other stones with similar refractive indices). (Fig. 12.)

Although it has a slightly lower index of refraction, 1·73 as against 1·77 for the synthetic sapphire, the colourless synthetic spinel has a particularly brilliant lustre and apparent fire, although the dispersion is only 0·020, which is less than half that of diamond. When the synthetic white spinels first came on the market about 1935 the stones were miscalled " Jourado diamonds," after the name of the dealer who was retailing the stones. Most of these stones were of large size, 6 carats and upwards, and mostly cut in the emerald-cut style, a style of fashioning which has a vogue for gem diamond. However, such a style of cutting does not bring out the best in diamond so that there is a nearer approximation in the appearance of the two stones. Thus, those who have had little experience with step-cut diamonds may be deceived by these synthetic stones.

Like the synthetic sapphire it is the small calibre and baguette synthetic spinels which can cause confusion. Such stones are considerably used in jewellery to-day, being sold for what they are. It is when such pieces come on the secondhand market that trouble could occur.

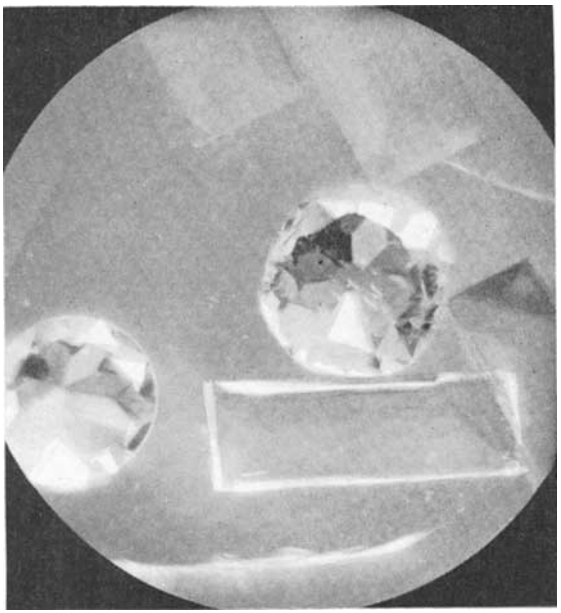

FIG. 12.
The strong relief of diamonds and the low relief shown by synthetic white sapphires and spinels when immersed in monobromonaphthalene.

As in the case of the very similar synthetic white sapphires the immersion test in liquids of high refraction will serve to separate them from diamonds, but not by this direct method from the synthetic white sapphires. These two species may, however, be separated by the contact immersion method devised by B. W. Anderson. In this method the stones, or piece of jewellery, are immersed in a cell filled with methylene iodide (n—1·74) which is illuminated by an overhead light and with a suitably placed reflecting mirror arranged so that the underside of the cell can be viewed. The synthetic white sapphires, which have a higher refractive index than the liquid in the cell, will show a dark border to the stone and the facet edges will show as white lines. In the case of the synthetic spinels the reverse will be seen, the edges of the stones being light and the facet edges dark (Fig. 13).

Short-wave ultra-violet light can assist in identifying diamond, synthetic white sapphire and synthetic white spinel. Under the short-wave lamp, with an emission at 2537Å, diamonds, which under the long-wave ultra-violet lamp (3650Å) generally glow with a violet or blue glow of varying intensity (sometimes with a yellow

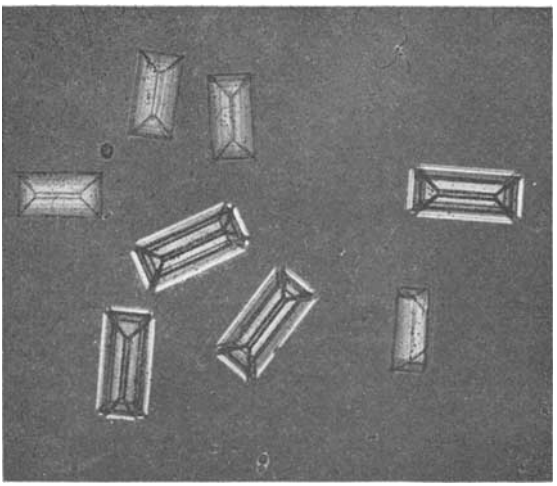

FIG. 13.
Contact immersion photograph of synthetic sapphire and synthetic spinel in methylene iodide.

or green glow), respond only weakly to the short-waves. Neither white synthetic sapphire nor spinel respond to the long-waves, but under the short-wave lamp the white spinels glow with a bluish-white light and the synthetic sapphires with a dull deep blue glow. Anomalies have been found, however, where in some cases the synthetic white sapphire has shown a glow rather similarly to the response given by the synthetic white spinel.

The research work carried out during the Second World War for materials of strategic importance resulted in the synthetical production of at least two new gemstones. The first of these is synthetic rutile, which has been produced in colours which are rarely, if ever, found in natural rutile.

Synthetic rutile, often known as Titania, has not been produced in a water-white colour—there is always a cast of yellow. Attempts have been made to improve the whiteness by surface sputtering with alumina, and these *sapphirized* stones are indeed much whiter in appearance, but the method does not seem to be extensively carried out. The most prominent characteristics of synthetic rutile are the strong double refraction and the exceptional fire. These adequately distinguish the stone from diamond. Synthetic rutile has a hardness of only 6½ on Mohs's scale, hence it would be scratched by quartz, or, better as a test, it will not scratch rock

crystal. The density is 4·25, which is greater than that of sapphire, so a synthetic rutile will not have the spread of a diamond for a given weight. The refractive indices are 2·61 and 2·90 for the two rays of this uniaxial mineral. Such indices are too high, indeed higher than that of diamond, for them to be measured on the standard refractometer, but the double refraction of 0·287, which surpasses all other diamond simulants in this respect, is readily visible even with the low power of a watchmaker's eyeglass.

The most striking aspect of synthetic rutile is the exceptional fire, 0·300 for the B to G interval, which is about six times that shown by diamond. The remarkable display of spectrum colours in this stone makes it look to some extent something like an opal. Synthetic rutile does not show a fluorescent glow under ultra-violet light, but does show an absorption band at 4250Å which cuts short the violet end of the spectrum.

Although it is the nearly colourless synthetic rutiles which are the types which may be said to simulate diamond, other colours have been produced. These are, particularly, a yellow and a golden-brown, but a red colour has been produced and so has a sapphire-blue coloured stone. The red coloured stones are not often encountered and the blue stones do not now seem to be made for they were found to have too great a tendency to chip at the facet edges.

Of more recent manufacture is strontium titanate, a synthetically produced material which has no counterpart in nature. This synthetic stone, which is known in the United States of America under the name of Fabulite, has what are probably the nearest characteristics to diamond. The colour is water-white and the stone is, like diamond, singly refracting, for the material is cubic in crystallization. Thus there can be no doubling of the back facet edges. The hardness, however, is low and is only 5½ on Mohs's scale, and the stone is rather brittle, which makes it prone to damage during the process of setting. The density is remarkably high at 5·13, so that, much more than rutile, the stone will have a small spread for a given weight. Indeed, such a stone which came into a dealer's hand was suspected by him because on weighing the stone he noted that it was far too small to be a diamond of that weight. The index of refraction is 2·41, and, hence, differs from diamond only in the third place of decimals.

It is the display of prismatic colours, that is the fire, which distinguishes strontium titanate from diamond, for if the stone is set in jewellery, then the high density will not assist in detection. Although strontium titanate has only four times as much fire as diamond (about 0·180 for the B to G interval), as against six times for rutile, the flashes of colour displayed by the stone are sufficient to tell that it is not a diamond. Again, like rutile, strontium titanate does not show luminescence under ultra-violet light, and, although with great difficulty seen, there is an absorption band in the extreme violet.

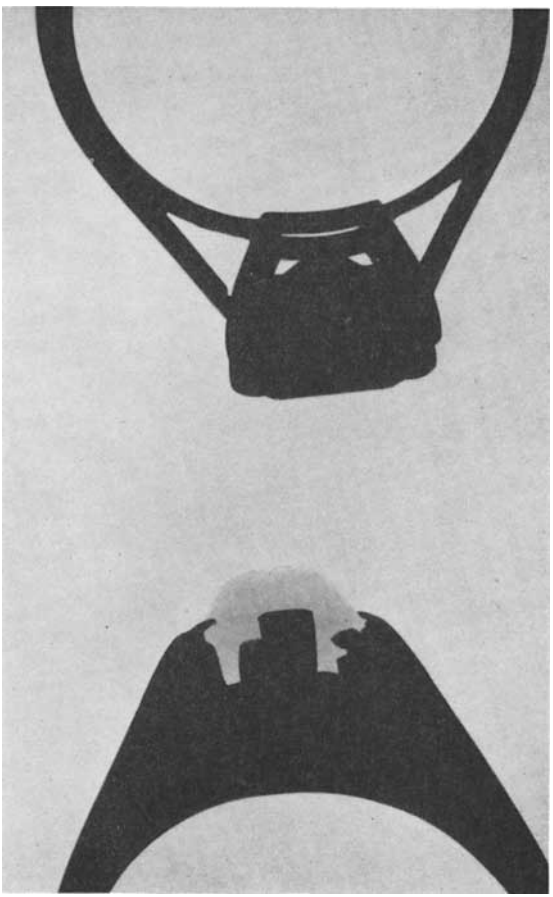

FIG. 14.

A diamond (lower ring) is transparent to X-rays while strontium titanate (upper ring) is opaque to the rays.

NOTE.—Rutile, zircon and synthetic white sapphire and spinel are also opaque to X-rays.

Like all the diamond simulants strontium titanate is much more opaque to X-rays than is diamond (Fig. 14). While such a test will prove whether a stone is a diamond or not, it will not distinguish the stone, nor, in general, is an X-ray machine readily available.

One characteristic of strontium titanate is the moulded look of the facet edges of a cut stone when it is examined by a lens. This effect tends to give the impression that the stone may be a paste of high dispersion, but even the more highly dispersive glasses do not seem to have the fire shown by strontium titanate. The low hardness of this gem has led to the suggestion that a needle point carefully pressed on to the surface will make a small mark and indicate the low hardness of the stone. Such a test if carried out needs to be most carefully controlled in order to prevent damage. Bearing in mind that this synthetic stone is far from inexpensive, such a test is better left undone.

It may seem impertinent to suggest that a glass imitation diamond could fool anyone, and nor it should with those who have had at least some experience of handling stones. However, with some of the brilliant and fiery pastes that are occasionally met with a cursory glance may not be enough, and this is specially so with small stones. A glass will always give a refractometer reading, so that a positive test can be applied here, except when the stone is *bloomed*, or the stones are small and inaccessible. The blooming may be removed by polishing the facet with a rouged leather to enable a refractometer reading to be obtained, and in the case of highly dispersive pastes, as pointed out by A. E. Farn, an Anderson/Payne spinel refractometer is the best instrument to use, for with these stones a pronounced spectrum edge forms the shadow-edge of the critical angle in the case of this instrument.

Small paste stones set in jewellery may need a different method of attack. Immersion contrast methods may be usefully used here, specially when all that is needed to be known is that the stones are not diamonds or are. Short-wave ultra-violet light will cause most glasses to glow with a deep blue or a whiteish-blue light which is not unlike the glows given by synthetic spinel.

There are a number of natural coloured stones of different species, which, owing to their high optical qualities, may resemble a coloured diamond. The first of these is sphene, the monoclinic silicate of titanium and calcium, which is usually yellow or brown-

ish-yellow in colour, but in rare cases may be green. Sphene has a density of 3·53, which is near to that of diamond. The refractive indices, which are round about 2, are too high to measure on the standard refractometer, and the stones have a sufficiently large double refraction for the rear facet edges to be clearly seen doubled when viewed through the thickness of the stone. The dispersion of 0·051 for the B to G interval, is greater than that of diamond, so sphene exhibits strong fire, but, as is the case in all coloured stones the fire is to some extent masked by the body colour. Sphenes have a hardness of only 5 on Mohs's scale and the lustre is decidedly resinous. The dichroism is fairly strong in this species and observation of this will immediately tell that the stone is not a diamond, nor a yellow zircon, which has so little dichroism as to be scarcely seen. Sphene may show, but very weakly, the group of fine lines in the yellow of the spectrum which are due to the rare-earth elements collectively known as didymium, and the mineral does not luminesce under ultra-violet light.

More important as an ore of tin, the naturally occurring crystalline oxide of tin, cassiterite, has, when found in transparent crystals, been cut as faceted stones. Brown in colour with a hardness of about 6½ on Mohs's scale, such stones have an adamantine lustre due to the high refractive index, which is not far removed from that of sphene. The double refraction is strong so that the back facet edges will be seen doubled. The fire is strong but is masked by the brown colour of the stone, and, unlike sphene, the dichroism is extremely weak. Cassiterite has a density of 6·8 which is so high that it clearly identifies it from any other stone by its heft, if the stone be unset. Cassiterite is rarely encountered except in the hands of collectors.

The green demantoid garnet, owing to its high optical properties, must be considered. The refractive index of this green garnet is 1·88, but the colour dispersion of 0·057 for the B to G interval exceeds that of diamond. Again the exceptional fire is masked by the body colour of the stone. The density of demantoid is 3·84, and like so many highly refractive minerals demantoid suffers from a low hardness, which in this case is 6½ on Mohs's scale. The most useful tests for demantoid as against diamond, apart from the hardness test, are the facts that demantoid shows a reddish hue under the Chelsea colour filter, and that invariably the stones contain inclusions of byssolite fibres in radial or horse-tail groups.

Zinc blende, which has a refractive index of 2·37, may be considered as a possible stone to be mistaken for diamond. It is, however, very unlikely that this could happen, for the resinous lustre, strong dodecahedral cleavage making it difficult to cut into faceted stones, and the extremely low hardness of $3\frac{1}{2}$ to 4 on Mohs's scale, go against it. True the colour dispersion of zinc blende is considerable, over three times that of diamond, but zinc blende makes a poor imitation of diamond. The density of this stone is 4·09, which is just a little higher than sapphire.

It has been reported that stones have been cut from the green crystals of silicon carbide (SiC), which is best known as the artificial abrasive carborundum. This material, of which there are several modifications, including a hexagonal and a cubic form, has a hardness of about $9\frac{1}{4}$ on Mohs's scale. The type from which the few stones have been cut is the more common hexagonal modification and this material has a refractive index of about 2·66 with a double refraction of 0·043. The dispersion is given as 0·103 (B to G ?) and the density is 3·17. From experiments on the carborundum abrasive powder it is known that the material exhibits a dull mustard-yellow glow when irradiated with long-wave ultra-violet light. As a diamond substitute it is unimportant, for it is doubtful whether there are many of these stones in existence.

Other colourless stones, such as rock crystal, white topaz, phenacite and white beryl, some of which have quite good brilliancy, lack the other optical characters which would allow them to vie with diamond.

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ARTIFICIAL COLORATION OF DIAMOND

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PRECIOUS OR SEMI-PRECIOUS

By A. E. FARN, F.G.A.

TRADE usage cannot be pleaded in defence of misnomers any more than sheer perpetuation of " understood " terms makes for clarity when gemmologists clash with " rule of thumb " jewellers. The latter it is true are conversant with gemstones by the constant handling of them, and if this knowledge can be combined with a true gemmological knowledge, then of course we have the ideal.

By precious stones it is assumed that diamond, ruby, sapphire and emerald are the imperative choice and until recently little else could challenge the field. However, since alexandrites obtain astronomical figures and even demantoid (still often miscalled olivine) fetches quite satisfactory prices, and black opal, topaz (not quartz) and especially chrysoberyl cat's-eye command high prices, it seems hardly logical to term them semi-precious.

So what are the semi-precious stones to be termed—and which are they ? Pale rubies from Burma can grade down to near colourless but still retain all the characteristic inclusions of Burma origin—silk, treacle and crystalline inclusions. These can hardly be termed precious, and to my mind are not even semi-precious. Similar cases occur with sapphires and emeralds. It is quite easy to buy very cheap but nevertheless genuine emerald and genuine sapphire ; although commercially they are rubbish, yet their name invokes the term precious.

So far all this is common knowledge and generally agreed, but in actual fact the term " semi-precious " means, I suppose, half precious and it is difficult to imagine how to explain this. It would be better to drop entirely the terms precious and semi-precious and treat all jewellery stones on a basis of expensive, rare and less expensive, and regard them all as important and stress their respective merits, i.e. colour, hardness, occurrence and suitability to each particular style of jewellery or type of article.

Necklaces of beads composed of golden quartz, tourmaline, garnet, jadeite, nephrite, rose-quartz or opal with matrix, can

be very durable and beautiful items. As such, though costing quite a bit more than paste or costume-type jewellery, they do represent much better value for money than either the poorest type of " precious " stone jewellery or the more expensive of the imitation jewellery. In fact we do not exert enough energy in putting over the lesser-known gemstones to the public. There are so many pretty and inexpensive stones available that it is time we educated the public into a true appreciation of something which is good, durable and attractive.

It is imperative, therefore, to drop the terms precious and semi-precious and to concentrate on true descriptions of goods. It is so much better to describe a stone as golden quartz than incorrectly as " topaz quartz " and have the customer find out later on that he hasn't a true topaz and thus leave a slightly nasty taste behind. If, however, an article is truly described, as it must be, and suitably praised with regard to its merits, it will always be a source of pleasure and have the merit of re-saleability, which is more than can be said for any form of imitation jewellery. (Although golden quartz has been quoted here, there are of course many more instances where misnomers are still perpetuated, which would be better discarded and the true gemstone accurately described.) Nothing is quite so poor-looking as an old and worn imitation pearl necklace or rubbed paste jewellery, whereas a good stone bead necklace can last for years and years and still command a fair price.

Having rather stressed the worn out appearance of secondhand imitation jewellery I am reminded of the humorous occasion when a dealer produced a pair of genuine lapis-lazuli ear-studs complete with minute traces of pyrites and complained that his customer said the brass was showing where the enamel had worn off ! !

Recently some jadeite was sold as such by a dealer who was somewhat concerned to find it was " Chinese Jade." So it seems there is room for teaching at all levels, " sublime and ridiculous," " precious and semi-precious."

X-RAY PICTURE OF AN ABALONE PEARL

Abalone pearls, which come from abalones or ear-shells (Haliotidae), with their striking iridescent colours of greens and blues are rarely met with set in jewellery. The X-ray examination of such a pearl, which was mounted as a pendant, gave interesting results. It was known that these pearls were hollow inside but details of the structure of the actual pearl substance were lacking. The X-ray picture reproduced below shows the structure of the abalone pearl to be convulated and layered.

In some abalones the quality of the nacre is outstanding and superior to that of many pearl-oysters. In general the pearls are of small size, the main interest being in the colour, usually green but sometimes blue and yellow, which they display.

The large colourful ear-shells are found in the American waters off California and Florida, and are there known as abalones. Paua shell, from the Maori, is the name given to similar shells from New Zealand and Australian waters. These shells are related to the smaller " ormers " fished around the Channel Islands. The hollow nature of these pearls gives them an extremely low density and this would serve to identify them if doubt existed as to their nature.

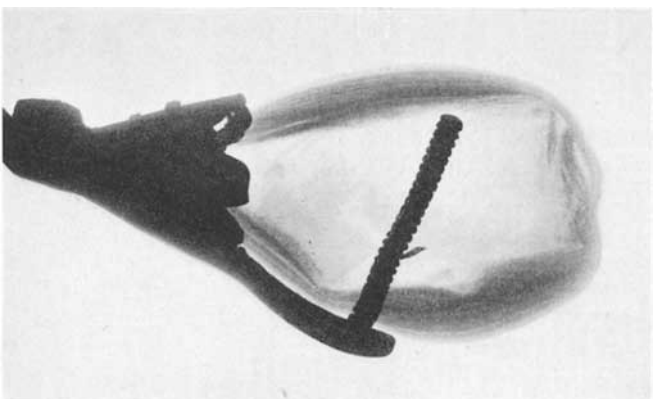

Photo : R. Webster

Gemmological Abstracts

RAAL (F. A.) *A new absorption band in diamond and its likely cause.* Proc. Phys. Soc., Vol. 71, pp. 846-847. May, 1958.

A new absorption band, very broad at room temperatures, is located at approximately 5500Å and cannot be resolved into component lines even at the temperature of liquid oxygen. It is found in all pink and mauve diamonds and its strength is correlated with the intensity of coloration of the diamond. Spectrographic analyses showed the presence of Mn, in addition to the Si, Al, Mg and Ca normally found in diamond, and the Mn was found to vary with the depth of colour. The new absorption band is thus correlated with the presence of Mn in these diamonds.

R.A.H.

STEPHEN (M. J.). *The infra-red spectrum of diamond.* Proc. Phys. Soc., Vol. 71, pp. 485-490. March, 1958.

The contribution of lattice vibrations to the infra-red spectrum of diamond in the 2 to 6μ region has been calculated from the vibrational frequency distribution where second nearest neighbour central forces are taken into account. Most of the details of the observed spectrum are reproduced in the calculated spectrum.

R.A.H.

WEBSTER (R.). *Pearls—ancient and modern.* Gemmologist, Vol. XXVIII, No. 331, pp. 21-29. February, 1959.

An article based on the talk given by the author to the Gemmological Association. The pearl oyster is discussed as is the early use of pearls for ornamentation. The conch, abalone and freshwater pearls are mentioned. The history and the methods of the cultivation of oysters and culturing pearls are given. The new Australian cultured pearls are discussed.

7 illus. P.B.

TOMBS (G. A.). *Synthetic diamonds through the microscope.* Australian Gemmologist, Vol. I, No. 6, p. 12. December, 1958.

Reports the examination of some American synthetic diamonds. The size of the crystals was approximately 300 to the carat and under twenty times magnification the crystals were seen to be of a typical rough diamond shape and to have the lustre of diamond. Under higher magnification (60 and 250 times) the pieces were seen to be aggregates of crystals, three or four crystals apparently fused together. Some crystals showed octahedral habit and some dodecahedral. The colour was mostly greyish.

R.W.

CROWNINGSHIELD (G. R.). *Highlights at the Gem Trade Laboratory in New York.* Gems and Gemology, Vol. IX, No. 8, pp. 227-229 and 254. Winter, 1958/9.

Some reports on exceptional items brought in for testing at the New York laboratory. These included an unusual greenish brown diamond containing black needles oriented in three directions; a gold tie-pin set with 24 yellow stones which were mostly zircons but included a brown sinhalite and a yellow kornerupine. More than a dozen sinhalites were tested during the past few months. The fluorescence test for emeralds is commented upon and the artificial coloration of turquoise discussed.

R.W.

JESSOP (J. E.). *Glittering oasis.* Gems and Gemology, Vol. IX, No. 8, pp. 232-239. Winter, 1958/9.

An account of the diamond mining along the south-west African seaboard by the Consolidated Diamond Mines of South-West Africa. The diamond fields extend 220 miles north from the Orange river and from 50 to 60 miles inland from the Atlantic. Great quantities of sand overlie the diamondiferous gravel and this is removed by earth-moving machines and bucket-wheel excavators. On the completion of the stripping of the overburden the diamond-bearing gravel is dug out and loaded into trucks and taken to the screening plants where only the gravel of a size known to contain the richest diamond concentration is saved. Final recovery is by heavy media separation and by electrostatic separation, for the

grease tables are not effective with the seashore diamonds. The uneven bedrock below the diamondiferous gravel is swept and shovelled to collect the last layers of gem gravel. Some notes are given on the town of Orangemund and of the social life there.
8 illus. R.W.

BENSON (L. B.). *Highlights of the Gem Trade laboratory in Los Angeles.* Gems and Gemology, Vol. IX, No. 8, pp. 230-231 and 254. Winter, 1958/9.

Reports on unusual pieces tested at this American laboratory. A dark green emerald, which was much lighter in colour when removed from the setting, was found to owe its deeper colour to the black enamelling carried out on the inside of the bezel of the setting. An 8 carat radium-treated yellowish-green diamond was reported upon. Discussion is made of the fact that a number of jewellers are unaware of the true nature of " Fabulite " (synthetic strontium titanate) and " Walderite," the name apparently given in the United States to synthetic white sapphire. A drop-shaped demantoid garnet of 9·73 carats was tested.

R.W.

ANON. *Smaragd — Synthese oder Kultur ?* Emeralds, synthetic or cultured ? Zeitschr.d.deutsch.Gesell.f.Edelsteinkunde, No. 26, pp. 21-22, 1958/1959.

Referring to the discussion as to whether an emerald, which has grown from solution, and not been produced in a Verneuil furnace, should be called synthetic or cultured, the Paris Chamber of Commerce has come to the conclusion that all stones which are not natural stones, should be called either imitation or synthetic.

E.S.

GÜBELIN (E.). *Synthetische Diamanten.* Synthetic diamonds. Gold und Silber, Vol. 12, No. 2, pp. 23-24, 1959.

Most synthetic diamonds are too small to be of interest to jewellers, also they are mostly not crystals, but aggregates. In one of three microphotographs the synthetic diamond chosen showed an octahedron broken from a crystalline mass. The centre of the octahedron face showed small porous holes, which indicate that the stone grew very quickly. Most of the small crystals are grey, yellow,

brown to green. Some are black. The powder produced from these crystals is grey to black. Indications of stress were seen under polarization which must be a disadvantage. The X-ray diffraction points are not as clear as in the natural mineral, which also indicates stress.

E.S.

EPPLER (W. F.). *Ein überzeugendes Beispiel für die Entstehung von Heilungsrissen in Edelsteinen.* An explicit example of the formation of healing cracks in gems. Deutsche Goldschmiedezeitung Vol. 57, No. 4, pp. 190-191, 1959.

Great speed of growth of the gem crystals is the main cause for the formation of healing cracks. This is the case in many natural gems (with the exception of diamonds) and in synthetic emeralds. In many instances the healing cracks, which are generally regarded as flaws, are very attractive as far as form and colour are concerned. Photomicrographs show the growth of a synthetic quartz crystal with healing cracks which form at the lower end of the crystal and decrease as the speed of growth is reduced.

E.S.

GÜBELIN (E.). *Noch einmal Zuchtperlen oder — Ehre, wem Ehre gebührt.* Once again cultured pearls or — honour to whom honour is due. Zeitsch.d.deutsch.Gesell.f.Edelsteinkunde, No. 26, pp. 20-21, 1958/59.

On the occasion of the 50th Jubilee of the cultured pearl and in addition to a report by T. G. Flood, Stockholm, on Carl von Linné, the author reminds us that Prof. Alverdes of Marburg succeeded in 1913 in inducing the formation of cultured pearls by injecting epithelium cell tissue into the inner part of the oyster mantle. In 1914 Alverdes sent his patent to Japan and seven years later the first cultured pearls appeared on the market.

W.S.

EPPLER (W. F.). *Die Sandmeier-Plato Streifung im synthetieschen Korund.* Sandmeier-Plato striation in synthetic corundum. Deutsche Goldschmiedezeitung, Vol. 57, No. 2, pp. 62-64, 1959.

Typical striation in synthetic corundum was first observed about 1920 by Sandmeier and confirmed by Plato. In 1952

Müller used them as a determining factor in distinguishing between natural and synthetic corundum. In 1958 these striations were used to distinguish between American and German synthetic star-rubies and sapphires. These striations were only to be observed in polarized light and then only in the direction of the optic c-axis. Sandmeier thought they were twin lamellae formations. The Sandmeier-Plato striations seem to consist of very thin lamellae. In etch tests, they are dissolved to a greater degree on the basal plane of the host crystal than in the surrounding synthetic corundum and therefore stand out in kind of " walls." The author assumes that the lamellae are arranged parallel to the prism face as twinning plane in such a way that the c-axes of both lamellae and host crystal are at right angles to each other. Optical confirmation is still outstanding. 8 figs.

E.S.

BRUSIUS (O.). *Opal — aktuelles über Bearbeitung und Verwendung.* Opal — facts about working it and using it. Deutsche Goldschmiedezeitung, Vol. 57, No. 2, pp. 67-69, 1959.

Working of opals is most difficult, and from the raw material one cannot definitely say whether finished gem is likely to be good. During working, opals crack easily. Sometimes cracks are seen in the stone, once it is set, but these can close again by themselves. The author warns against cutting opals too thinly.

E.S.

SCHLOSSMACHER (K.). *Brillianten mit Farbyerbesserungsüberzug.* Brilliants with colour-improving coats. Zeitschr.d.deutsch.Gesell. f.Edelsteinkunde, No. 26, pp. 22-23, 1958/59. Abstract from Gold und Silber.

Diamonds with this type of cover are increasingly in use in U.S.A. What the coat consists of is unknown, also how it is actually covered. The covering can be dissolved in a 20 per cent solution of sulphuric acid. Another way of showing whether a stone is so treated or not is by viewing the polishing marks under an interference microscope. The covered stones show completely even interference lines, the uncovered stones show these lines at both ends somewhat frayed.

E.S.

SALLER (X.). *Die Färnung von Perlen.* Colour of pearls. Deutsche Goldschmiedezeitung, Vol. 57, No. 4, pp. 201-202, 1959. Abstract from the Jahrbuch des Goldschmiedes, 1959.

Pearls are coloured or dyed, so as to improve poor natural colours or produce very rare beautiful ones. The colour-absorption of a pearl depends on its mother-of-pearl layer, the type with high lustre being less suitable than the matt variety. The organic conchiolin is coloured more slowly than the mineral parts, aragonite, calcite. The colouring is carried out cold or at 50°C, the dye being in aqueous, alcoholic or acetonic solution. The dyes themselves are inorganic, synthetic or natural materials. Metal chlorides are usually used in vapour form. Most important are the synthetic dyes; these are usually used in 1/3 solution at 50°C and kept in the solution till the wanted colour is effected.

E.S.

BOLSCHE (R.). *Neue Aquamarinefundstelle im Habachtal.* New aquamarine find in the Habach valley. Zeitschr.d.deutsch.Gesell. f.Edelsteinkunde, No. 26, pp. 19-20, 1958/59.

A few well-developed crystals of pencil size have been found.

E.S.

GÜBELIN (E.). *Das neue Smaragdvorkommen in Rhodesien.* The new emerald occurrence in Rhodesia. Zeitschr.d.deutsch.Gesellschaft.f.Edelsteinkunde, No. 26, pp. 4-15, 1958/59.

Survey of emeralds from Rhodesia. In 1958 the author was asked to examine these emeralds, and was given 92 stones. The occurrence is about 29° 56′ east and 20° 55′ south. Most of the material found is either broken up or very small, so that most Sanadawana emeralds, which are cut and of commercial interest are under $\frac{1}{4}$ ct. Most stones are of a beautiful colour. A chemical analysis found the stones to be : SiO_2—65%, Al_2O_3—14·2%, BeO—13·6%, Cr_2O_3—0·5%, Fe_2O_3—0·5%, MgO—3%, Na_2O—2·0%, Li_2O—0·15%. The refractive inditi were 1·5877 to 1·5949 (ord. ray) and 1·5806 to 1·5884 and the double refraction was between 0·0069 and 0·0071. Sp. gravity was from 2·744 to 2·768. Dispersion 0·009. Sandawana emeralds were formed by contact metamorphosis of a granite melt with tremolite; shaped tremolite inclusions are characteristic. In the stones of good quality the

needles are either small or very fine and long, in poorer quality stones there are masses of short or long needles. A table gives optical data of emeralds from various sources. (Journ. Gemmology, Vol. VI, p. 8, 1958).

E.S.

WIRTH (A. A.). *Prasiolite.* Australian Gemmologist, Vol. I, No. 5, pp. 6-8. November, 1958.

A general introduction to the heat-treated greened quartz from Montezuma, Minas Gerais, Brazil, to which the name prasiolite has been applied.

R.W.

MELLOR (D. P.). *A new method for producing synthetic ruby.* Australian Gemmologist, Vol. I, No. 5, pp. 10-11. November, 1958.

An account of the experiments carried out at the Bell Telephone Laboratories in the United States of America on the hydrothermal production of synthetic ruby crystals. (Abstract. Journ. Gemmology, Vol. VII, No. 1, p. 16. January, 1959).

R.W.

WIRTH (A. A.). *Introducing precious gemstones.* Australian Gemmologist, Vol. I, No. 7, pp. 17-19. January, 1959.

A discussion on the changing aspect of the cardinal virtues usually ascribed to gemstones in textbooks. Beauty, rarity, durability, fashion and value are commented upon. Some discussion on the use of the terms precious stones and ornamental stones.

R.W.

VOLL (R.). *Deutschland ist der Welt drittgrösster Verbraucher von Zuchtperlen.* Germany is the worlds third largest consumer of cultured pearls. Deutsche Goldschmiedezeitung, No. 9, pp. 496-497. 1958.

The article gives the Japanese export figures for 1957. An illustration shows the instruments used for the operation on the oysters; another illustration depicts the plastic containers now used to protect the oysters against certain parasites.

W.S.

ANDERSON (B. W.) : WEBSTER (R.). *Variations in the luminescence of emerald.* Gemmologist, Vol. XXVIII, No. 332, pp. 41-45. March, 1959.

A discussion on the fluorescent effects shown by synthetic and natural emeralds when various types of ultra-violet lamps are used to excite the glow. Comparison is made of the value of low-pressure short-wave ultra-violet radiating lamps giving an emission at 2537Å, the normal medium-pressure long-wave lamps fitted with a Wood's glass filter which have a maximum emission at 3650Å, and the American Burton and the English Longlamp types, these latter being a modification of the fluorescent tubes used in office and factory lighting. In these tubes the powder coating on the inside of the tubes is such that it emits light in the long-wave ultra-violet region and in the visible violet, the emission being from about 3100 to 4100Å. Such ultra-violet fluorescent lamps were found to be best for separating synthetic emerald from its natural counterpart.

5 illus. P.B.

ASSCHER (L.). *The rebirth of a diamond city—Amsterdam.* Gemmologist, Vol. XXVIII, No. 333, pp. 70-73. April, 1959. Reprinted from *Optima.*

An article on the history of Amsterdam as a diamond city. The effects caused by the various wars and setbacks since the 14th century are told. The article explains how the diamond industry of the city was reformed after the Second World War.

P.B.

BATCHELOR (H. H.). *Mining in Australia.* Gemmologist, Vol. XXVIII, No. 333, pp. 66-68. April, 1959.

Some notes on the present day mining in Queensland and New South Wales. Mainly opal, sapphire and diamond.

P.B.

ANON. *Falsified diamonds.* Gemmologist, Vol. XXVIII, No. 333, p. 69. April, 1959.

A note taken from a report published in the 1890's on the fraudulent whitening of diamonds by " painting " the rear facets with violet dye.

P.B.

WEBSTER (R.). *Quartz in many varieties.* Gemmologist, Vol. XXVIII, No. 333, pp. 61-65. April, 1959.

A review of many types of the crypto-crystalline chalcedonic varieties of quartz. Some notes on the staining of agate are given. Forms with dendritic inclusions and chalcedonic pseudomorphs after other materials discussed.
4 illus. P.B.

WEBSTER (R.). *Amethyst—the best of the quartz.* Gemmologist, Vol. XXVIII, No. 332, pp. 46-49. March, 1959.

A general article on the amethyst variety of quartz, including crystallization and geological occurrence. The suggested causes of the colour and the changes of colour on heating are discussed. When heated to between 400°C and 500°C usual colour change is to a brownish-yellow. Above 500°C stones become colourless. Amethyst so heated provides a simulation of moonstone. Some properties of the violet quartz and the inclusions noted are mentioned. A number of localities where amethyst is found are given.
P.B.

WEBSTER (R.). *Infra-red photography of gemstones.* Gemmologist. Vol. XXVIII, No. 330, pp. 1-5. January, 1959.

A report on the results of some experiments on the photography of gemstones using Gevaert infra-red 35mm film. Some information is given about infra-red rays, the response of photographic emulsions to infra-red light, and of the techniques used in the photography. The most striking results were shown by the photograph of synthetic and natural emerald. The infra-red photography of turquoise and various imitations of turquoise was found to give no difference in the effect shown by the real and the false.
4 illus. P.B,

ANON. *Improved diamonds—a U.S. warning.* Gemmologist, Vol. XXVIII, No. 330, p. 18. January, 1959.

Reports the coating of diamonds by a special technique to improve the colour of off-coloured diamonds. It is more permanent than the method of painting the back facets with aniline dye and the new coating needs acid to remove it.
R.W.

ASSOCIATION NOTICES

GIFTS TO THE ASSOCIATION

The Council of the Association gratefully acknowledges the following gifts:

A collection of 2″ × 2″ coloured slides of inclusions, synthetics, and cultured pearl, from Mr. R. Webster.

A copy of *The World of Jewel Stones*, from the author, Mr. M. Weinstein.

A collection of slides of inclusions in natural and synthetic emerald, from Professor W. F. Eppler.

Anon. Two artificial silica glass cat's-eyes.

29th ANNUAL GENERAL MEETING

The twenty-ninth Annual General Meeting of the Association was held at Saint Dunstan's House, Carey Lane, London, E.C.2, on Wednesday, 1st May, 1959. Mr. F. H. Knowles-Brown presided.

In his comments upon the work of the year the Chairman said the annual report showed a satisfactory year, with growing interest in the work of the association, growing circulation for the JOURNAL OF GEMMOLOGY and a satisfactory number of successful candidates for the diploma courses. During the year the second year course had been extensively revised, and Mrs. V. Hinton had been appointed an additional instructor. Students from all over the world had sat for the examinations, and the international character of the Association was emphasized by the co-operation with the associations in Australia and the United States. There had also been a large number of members' meetings held in London, Birmingham and the West of Scotland, and the branches were especially commended for the work their officers and committees had done in the interests of gemmology.

They were very pleased with the continued extension of the educational work and the examinations. The latter were being taken by students in many parts of the world. This cost money and created difficulties for the staff, but these considerations were insignificant compared with the satisfaction which the entrants gave everyone. It meant that the examination was valued and respected all over the world, and it was well worth the trouble of sending samples, arranging invigilation and so on.

Mr. Knowles-Brown felt that the factor which had built up the prestige of the examinations more than anything else was the sincerity behind them and the training course.

The chairman also wished them to know how sorry he was that, due to ill-health, he had had to be absent from a number of council and association meetings during the past year. He offered his thanks to Mr. Norman Harper and to the Secretary, Mr. G. F. Andrews, for taking his place on those occasions.

Mr. F. E. Lawson Clarke, Treasurer, presented the audited accounts and the annual report and accounts were adopted.

The following officers were re-elected :—

President : Sir Lawrence Bragg, F.R.S.
Chairman : Mr. F. H. Knowles-Brown.
Vice-Chairman : Mr. N. A. Harper.
Treasurer : Mr. F. E. Lawson Clarke.

Sir Lawrence sent his apologies for non-attendance, as the annual meeting of the Royal Institution was also being held at the same time.

Messrs. D. J. Ewing, W. Stern and R. Webster were re-elected to serve on the Council.

MIDLANDS BRANCH

Recent developments in synthetic gemstones formed the subject of a talk given by Mr. B. W. Anderson to members of the Midlands Branch of the G.A. at the Auctioneers' Institute, St. Philip's Place, Birmingham, on Friday, 17th April, 1959.

Mr. B. Shipton, Vice-Chairman of the Midlands Branch, presided in the absence of the Chairman, Mr. T. Solomon.

This meeting, the last of the present series, was attended by a record number of members and friends.

Mr. Anderson began his talk by outlining the types of stones made synthetically to-day, and by explaining how they originated. The first synthetic stones mentioned were reconstructed rubies, which made their first appearance in 1882 and were made by fusing together small chips of inferior natural ruby under the flame of an oxy-hydrogen blow-pipe.

From reconstructed rubies Mr. Anderson then described how stones were produced by Verneuil and how to-day the same principle is used to produce such modern synthetics as red spinels, rutiles and strontium titanates, as well as corundum.

Mr. Anderson then described the hydro-thermal process of synthesizing emeralds. He was most emphatic that these should be called " synthetic emeralds" and not just "Chatham emeralds," lest the public be confused into thinking they are real emeralds originating from a place called Chatham.

Synthetic diamonds were the next to come under consideration and Mr. Anderson said that he did not feel we need worry about synthetic diamonds so far as gem quality stones were concerned, at least not for a very long time.

The second part of the evening was devoted to the showing of slides which Mr. Anderson had brought along. These were microphotographs of both natural and synthetic stones showing the differences in their internal structures. Also shown were some microphotographs of synthetic diamonds.

The third part of the evening was devoted to a practical demonstration to show the differences in the transparency of natural and synthetic emeralds to ultra-violet light. The technique used was to place a piece of Velox photographic contact printing paper in a shallow dish, sensitive side upwards. The natural and synthetic emeralds were then placed on top of the paper and water was gently poured over the paper until the stones were completely covered, this whole opera-

tion being carried out in subdued lighting. The dish was then illuminated by light from a short-wave ultra-violet lamp of the American Mineralite type for three seconds at a distance of two feet. The paper was then removed and developed ; after a brief rinse it was handed round for all to see. The results were excellent and no difficulty was had in picking out the natural and synthetic stones.

The Annual General Meeting of the Midlands Branch will be held in Birmingham on Friday, 9th October, 1959.

WEST OF SCOTLAND BRANCH

The sixth annual meeting of the West of Scotland Branch of the Association was held in Glasgow on 17th April, 1959. Mr. Ian Mackenzie was elected Chairman and Mr. C. D. Wade was re-elected as Secretary. Messrs. E. McDonald, H. McDonald and J. McWilliam were elected to serve on the committee.

In presenting the annual report the retiring Chairman, Mr. J. D. S. Wade, welcomed new members and expressed satisfaction at a successful year's work.

Members of the branch held their annual summer outing on 7th June, when they went to Elie-Fife, in the ancient Kingdom of Fife.

TALKS BY MEMBERS

BLYTHE, G. : " Gems," Rotary Club of E. Ham, London, 14th April, " Gemstones," Senior Supervisors' Association, Marconi Ltd., Basildon, 28th April, 1959.

BOWDEN, A. : " Gemstones," St. German's Women's Institute, 6th May ; Stoke Townswomen's Guild, 12th May ; St. Dominic's Women's Institute, 13th May ; Callington Women's Institute, Cornwall, 24th June, 1959.

FORSEY, Mrs. P. : " Diamond," Dunnville Baptist Chapel Men's Club, Ontario, May, 1959.

PARRY, Mrs. G. I. : " Gemstones," Cardiff and District Hard-of-Hearing Club, 1st June, 1959 ; National Federation of Business and Professional Women's Clubs (Cardiff and District Branch), 4th June, 1959 ; National Federation of Women's Institutes (Dinas Powis Branch), 5th June, 1959.

THE LATE DR. L. J. SPENCER — A TRIBUTE

By B. W. ANDERSON

Dr. Leonard J. Spencer, F.R.S., Keeper of Minerals at the British Museum from 1927-1935, died on April 14th aged 88.

Dr. Spencer was one of the foremost mineralogists of his time, and his name was also well-known to gemmologists, since he was the translator (in collaboration with his wife) of Max Bauer's massive *Edelsteinkunde* and, much more recently, author of that lively little book *A Key to Precious Stones*.

Spencer's translation of Bauer's great classic appeared in 1904. Long out of print, it now ranks as a valuable collector's item, and is still the most extended treatise on gemstones in the English language. Prof. Schlossmacher, it may be remembered, prepared a revised German edition of Bauer's *Edelsteinkunde* in 1931.

A Key to Precious Stones, published by Blackie in 1936 and still available, is very different in its character and scope. It is perhaps the most readable text on the subject, and contains incidental information not found in other books, with touches of erudition unexpected in so advowedly " popular " a work. In this book the jeweller has to accept some hard knocks from Dr. Spencer on the subject of synthetic stones, as the following extract will indicate :—

" The operations of the chemist are strictly analogous to those of a gardener, but nobody would suggest that products of the latter are " artificial " cabbages or roses. They may be cultivated, like ' cultured ' pearls or gentlemen. Adjectives are apt to get a little mixed when applied to different nouns. We may talk of wild roses and tame rabbits, but not of wild rubies and tame rubies; of artificial rubies, but not of artificial babies. ' Artificial ' flowers and eyes are made artificially but are neither flowers nor eyes. . . . " and so on.

Though in his early years as a mineralogist Dr. Spencer carried out some original researches, and his scientific papers numbered over 100, it was as a curator and bibliographer that his chief services to mineralogy lay. No other man had so intimate and profound a knowledge of the relevant literature. His record with the *Mineralogical Magazine* (the Journal of the Mineralogical Society) was quite astonishing. He served as editor from 1901 until 1955, and when Mineralogical Abstracts were first incorporated with the Magazine in 1920, Spencer wrote the majority of the abstracts and he compiled all the indexes until 1955.

His reviews of books in the Magazine (Abstracts) were usually full and fair, but occasionally he succumbed to the temptation to be brief and rude.

Dr. Spencer took a special interest in meteorites, of which the Museum has a fine collection. It was this interest and the prospect of an unusual adventure which led him in 1934 to join an expedition to the Libyan Desert in search of the source of the extraordinary masses of yellowish silica glass which are to be found over a wide area on the surface of that sandy waste. He had some of this mysterious material cut as gems—though its cloudiness and insipid colour and lustre hardly justified this except as a collector's curiosity.

Spencer devoted almost all his waking hours to mineralogy, to the service of the Museum, the Mineralogical Society, and its Magazine, to their lasting benefit. As Editor of the Magazine for more than fifty years he must have attended far more Council meetings of the Society than anyone else in history, and for a similar period he also took a leading part in the discussions arising out of papers read at meetings of the " Min. Soc."

As with Dr. Johnson or G. K. Chesterton, Spencer was perhaps even more notable as a " character " than as a mineralogist or scholar. His personality and his pen both made their mark for more than half a century.

COUNCIL MEETING

A meeting of the Council of the Association was held at Saint Dunstan's House, London, E.C.2, on Wednesday, 10th June, 1959. Mr. F. H. Knowles-Brown presided.

The following were elected to membership :

FELLOWS

Berry, Harold W., Wellington, N. Zealand D.1935

Jeffery, Albert C., Newton Abbot D.1938

PROBATIONARY

Ellis, John R., Reading
Elout, Helene (Miss), Paris, France
Kothari, Udai C., Jaipur, India
Manley, John J., London
Schidlowski, Dietrich, Pretoria, S. Africa

ORDINARY

Aungchi, U., Rangoon, Burma
Beattie, Mary M. (Mrs.). Cleveland, Ohio, U.S.A.
Bloom, Geoffrey I., Cricklade
Bradley, C. Zeslawa (Miss), Nairobi, Kenya
Briggs, James R., Cromer
Grupe, William A., Los Angeles, U.S.A.
van Halem, Adrianus C., Singapore
Hollis, Jerome P., Hamilton, Bermuda
Hunter, John W., Glasgow
Nicholls, George W. A., Bromley, Kent
Smith, Reginald A., Benson, Oxford
Whitehead, Henry J., Edinburgh
Whitley, Peter, Rise Park, Essex

The 1959 presentation of awards and reunion of members was arranged for the evening of Tuesday, 17th November, at Goldsmiths' Hall, London.

Upon the recommendation of the examiners the Council awarded a research diploma to Mr. L. C. Trumper, B.Sc., F.G.A., for his thesis on the measurement of refractive index by reflection.

The Council revoked by-law 7, relating to the payment of life membership subscriptions.

Approval was given to a request from the Gemological Institute of America to use the filter in the Chelsea colour filter in their instruments. The Council also considered arranging visits for members to scientific and similar establishments.

183 entries for the preliminary and 70 for the diploma examinations for 1959 were reported.

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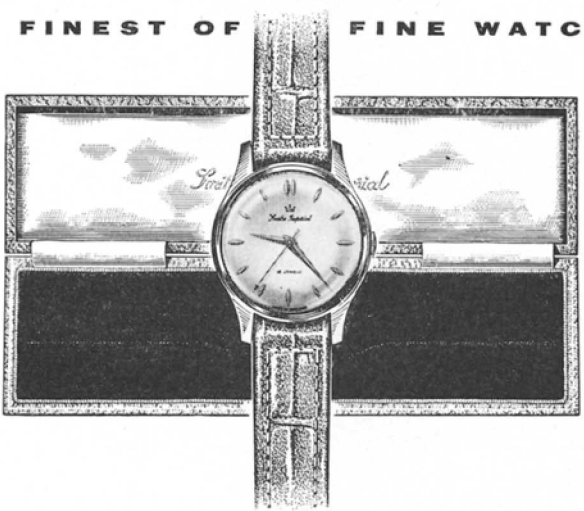

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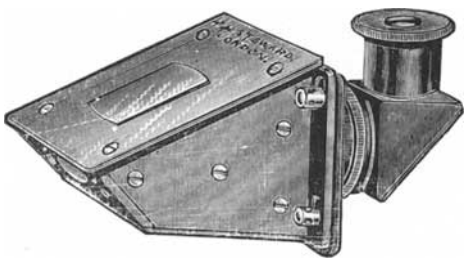

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Vol. VII
No. 3
July, 1959

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THE JOURNAL OF GEMMOLOGY

and

PROCEEDINGS OF THE
GEMMOLOGICAL
ASSOCIATION
OF GREAT BRITAIN

GEMMOLOGICAL ASSOCIATION
OF GREAT BRITAIN
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THE JOURNAL OF GEMMOLOGY
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Vol. VII No. 4 OCTOBER 1959

GEMMOLOGICAL NOTES

NEW SYNTHETIC EMERALD

K. SCHLOSSMACHER

A new synthetic emerald is making its appearance and is in all probability made in Germany. The microscope discloses an extremely great abundance of small, very much wrinkled and entangled feathers. According to the light-line and shadow-line the refraction of light is lower than benzyl benzolate. These synthetic stones can easily be distinguished from genuine emeralds by the characteristics above mentioned and from synthetic Chatham Emeralds by the shape of the wisps. They resemble most the " Igmerald " but their inclusion of feathers is denser than in the latter. Under long-wave U.V. light the fluorescence is a weak red, as with the " Igmerald," while the synthetic emeralds from America have a strong fluorescence. From these resemblances it is presumed that a fresh trial has been made of the " Igmerald process," but till now the stones are not up to the " Igmerald " in quality, as they are quite cloudy.

In the synthetic emeralds of the latest production from the Chatham Laboratory an improvement can be perceived, but the difference between them and genuine emeralds can still be as easily detected as before.

OPAL IMITATIONS

E. GÜBELIN

Recently two new types of opal imitation in the form of triplets have appeared on the market. These triplets are composed of a colourless cabochon quartz top backed by a very thin layer of white or black opal which is covered by another layer of opal of inferior quality, black glass or black onyx, joined together by a black cement. The cabochon-shaped upper part gives the refractive index for quartz, while the base shows a different R.I. according to the material used. The density is between 2·48 and 2·65 according to the composition of the triplet.

ARTIFICIALLY COLOURED CULTURED PEARLS

E. GÜBELIN

Messrs. Herbert A. Peisak Co. of New York are offering cultured pearls artificially coloured black, the beautiful colour of which can rival that of genuine black pearls. They display the same soft iridescence with black, green and purple interference colours. The nature of the colour-dye used has not been made known. On the other hand, the Gem Trade Laboratory has tested the durability of the artificial colouring with various reagents and gives the following report :—

" We have subjected the five treated black cultured pearls to a variety of reagents which might be encountered by a manufacturer and repairman as well as the customer.

It is our finding that exposure to the following did not affect the colour in any manner :

1. Ammonia, in the form of concentrated spirits as well as jewellers' cleaning solution.
2. Alcohol, denatured grain and Eau de Cologne.
3. Acetone, in the form of nail polish.
4. Acetic ether and nail polish remover.
5. Hot soapy water.
6. A detergent solution.
7. Boiling water for one half-minute.
8. Steam for 20 seconds.
9. Carbon tetrachloride.

Further, one pearl measuring 6·49mm. was immersed in concentrated hydrochloric acid until it was reduced to 6·25mm. in diameter (approximately 40 seconds). Although the surface lustre was destroyed as expected, the colour remained. It was found that under a blow-pipe the colour was unaffected up until the point where the nacre was destroyed and began flaking off. Removal of several layers disclosed that the colour remained beneath the destroyed layers. One pearl which was sectioned showed that the colour not only is concentrated through the entire nacreous coating but also appears in the mother-of-pearl nucleus in parallel bands."

The photograph shows that when looking sideways into a drill-hole of a pearl, which is illuminated over the top, the snow-white core contrasts strongly against the black nacreous layer.

KUNZITE

NEVILLE DEANE

The Pala-Chief Mine of San Diego County, California, has recently been re-opened and several pockets of the best faceting grade of kunzite have been found, and also other colours of gem spodumene, which are referred to as violet-blue and cornflower blue and also green. Two pieces of the kunzite colour which have come to hand have been of very good colour and very clear.

The deposit occurs as a decayed pegmatite dyke on a hill top and a mechanical hoe is used to remove unwanted material until a pocket is found, when further work is done by hand. It is said that so far about 4,000 grams have been found, and the price required for good material is high—for example a crystal of 113 grams of unusual blue colour was priced at $335 (£110).

Kunzite and gem-quality spodumene make very bright and lively stones, like the other lithium containing gems, but they are exceptionally difficult to saw, grind or cut, as they are very susceptible to cleaving with the slightest mechanical shock. Once the facets have been cut, polishing is relatively easy. There is, of course, a right way to cut them to show the best colour, but if the crystal is rather thin then they may have to be cut in the " wrong way," but with facets well sloped at the ends to show the colour in the end facets, even if the middle portion is not well coloured.

Although kunzites are obtained elsewhere—Madagascar for example—many of the crystals are very pale, and the re-opening of a mine giving good coloured and clear crystals is to be welcomed even though the cut stones are bound to be rather expensive.

" BLUE-WHITE "

JOHN PROBUS

Of 500 high grade diamonds recently examined by the Gemological Institute of America only one was found to have a trace of blue. Fewer than ten of the stones showed no trace of yellow.

In the United Kingdom there are jewellers who all too frequently use the term " blue-white." Perhaps they do not understand the significance of the term or, what is more likely, have not sufficiently studied the problems of diamond grading by colour.

There is a recommendation in the U.S. that the term " blue-white " should not be used in advertising. It is also not used in advertisement in the U.K. but the term does occur in sales talk. In view of the extreme rarity of a so-called " blue-white " diamond it is obvious that it is a term to be left severely alone by all but the specialists, who themselves are not as numerous as we are sometimes led to believe.

NON-NUCLEATED CULTURED PEARLS

R. WEBSTER

The commercialization of cultured pearls without a bead nucleus has now become of some importance to the jewellery trade all over the world. These non-nucleated cultured pearls are produced by inserting into the pearl-secreting mollusc a small portion of epithelial tissue (the mantle) and this acts as the irritant and the " core." Originally this method of production was confined to the freshwater mussel (*Hyriopsis schlegeli*), which is farmed in the Japanese freshwater

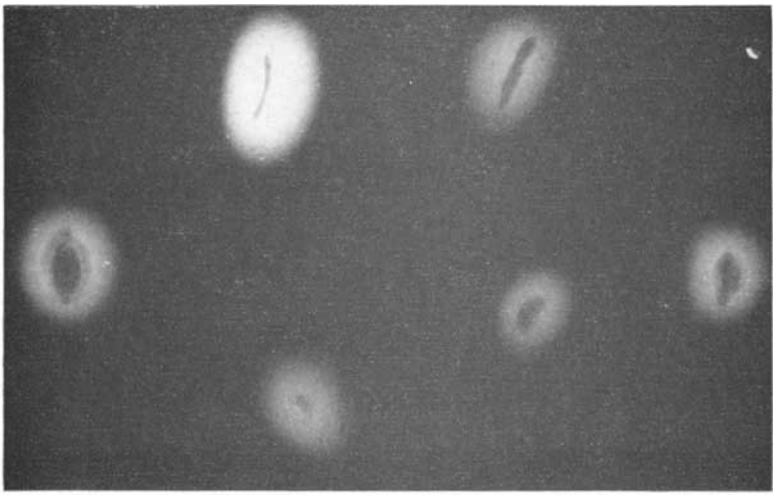

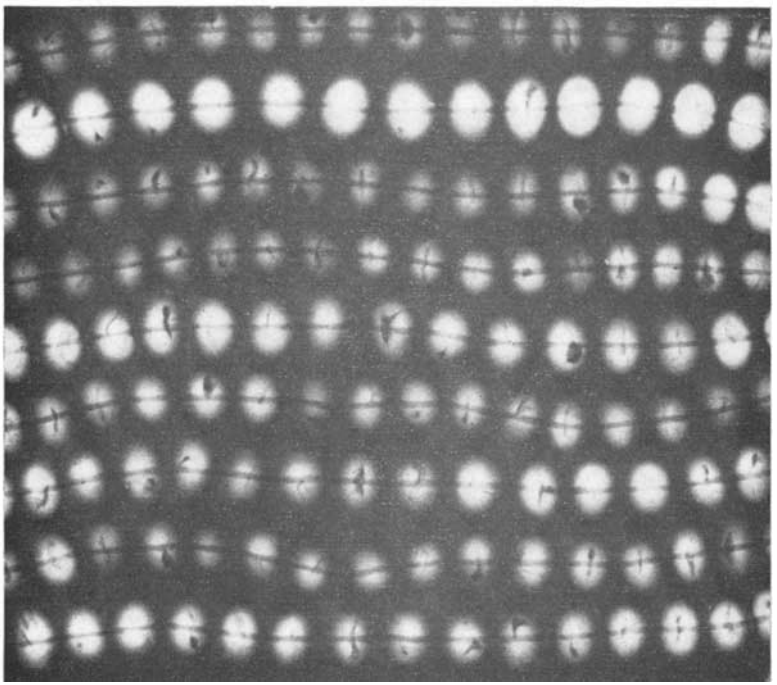

X-ray skiagrams of non-nucleated pearls.

lake Biwa-Ko in Shiga Province of Honshu. A similar method of production has more recently been carried out in Australian waters using the large oyster *Pinctada maxima.*

All these non-nucleated cultured pearls are somewhat baroque or oval in shape. The Japanese freshwater variety seem to have a brighter and more pleasing lustre than the whiter Australian non-nucleated cultured pearls, but the Japanese pearls are much smaller in size.

Both types can be identified by the characteristic structure seen from an X-ray skiagram, in which an irregular gap, sometimes in dumbell form, is seen in the pearls but not necessarily at the centre. This effect is shown in the pictures illustrating this note. X-ray diffraction patterns do not in these cases provide a diagnostic test. Further, it may be mentioned that the freshwater non-nucleated pearls from Japan fluoresce strongly under X-rays, but the sea-water Australian non-nucleated cultured pearls only do so weakly.

" THE EARTH BENEATH US "

A. E. FARN

A book published in 1955 entitled " The Earth Beneath Us," by H. H. Swinnerton, caught my eye the other day. I quite expected a treatise on soil condition and hoped for some helpful hints on how to treat a chalk garden or at least how to adapt a calcifuge.

To my intense interest I found a very readable book written round the subject of the earth on which we live. The book deals progressively with the earth's origin, facial features, volcanic activity, climatic patterns of the past, the setting of the stage of evolution and the coming of man. This may not seem truly gemmological but certainly it is an allied subject. Very interesting details of the cause and effect of volcanoes and their build up are given and especially interesting is the occurrence of " parasitic cones."

A fascinating description of the primeval liquid magma of the earth's core and a description of silica as a solid acid, tasteless and used as a constituent for Pyrex dishes, makes unusual reading, as does the account of the formation of quartz family gemstones. A clear picture is given of the formation of gemstones, which is not always so adequately dealt with by gemmologists since they are not themselves usually too well versed in geology. The chapters described as Pluto's Laboratory and Pluto's Treasury are fascinating accounts of gem formations.

Although primarily a geologist's book Professor Swinnerton's has considerable interest for gemmologists. A chapter entitled " Ships of Pearl " has a description of the pearly nautilus and its structure and its method of jet propulsion.

Many more chapters are devoted to various aspects of the earth's creation and evolution of man, but the book, which is simply expressed, has gemmological interest, and after perusing it one feels much more knowledgeable of facts, which previously had rather been slurred.

REVOLUTIONARY EXPERIMENTS IN COLOUR VISION

By B. W. ANDERSON, B.Sc., F.G.A.

COLOUR is of such prime importance to gemmologists that no apology is needed for including in this Journal some account of recent experiments in colour vision which seem to disrupt completely many general ideas on colour, which had appeared to rest on unassailable foundations.

For nearly three centuries our fundamental concepts of colour, at least in its physical aspects, have been based on the classic experiments of Newton, which were carried out for the most part in 1666, when he was a young man of twenty-four and, in his own words " . . . in the prime of my age for Inventions, and minded Mathematics and Philosophy more than at any time since." It will be remembered that by passing a narrow beam of sunlight (which had been allowed to penetrate into his darkened room through a quarter-inch hole in the shutter) through a large glass prism, Newton resolved or analysed the white light from the sun into the colours of the rainbow. These were seen as a 13-inch spectrum on a screen which was suitable placed to receive the rays after they had been variously refracted by the prism. In other experiments Newton proved that the spectrum colours could be re-combined by passing them through a second prism in reversed position to form a spot of white light, and that rays of any pure spectrum colour could not be further analysed into rays of different colour. By adding rays from one part of the spectrum to rays from another part, it was shown that a colour of intermediate hue in the spectral series (red, orange, yellow, green, blue, violet) could be produced. In modern parlance: by blending rays of two different wavelengths, the eye receives the colour-impression produced by rays of wavelength intermediate between the two.

Newton's experiments were logical and irrefutable, so far as they went, and on them were later built, by Young, Helmholtz, and others, theories of colour-vision which, with slight modifications or extensions, have held the field till the present day. According to Young's theory, formulated at the beginning of the nineteenth century, there are three kinds of receptor in the normal human retina: one type specially sensitive to red rays, another sensitive to green rays, and another sensitive to blue rays. Red, green and

blue were considered as " primary " colours, since most colours met with in nature can be closely matched by suitable mixing of red, green and blue coloured lights. For exact matching, a fourth colour such as yellow, has been found necessary.

The most promising experimental approach to this type of theory has been that of Professor Granit, of Sweden, who, by placing minute electrodes in contact with nerve fibres in the retina of an anaesthetized animal, was able to amplify the tiny changes in electrical potential which occurred when the nerve fibre was exposed to different kinds of light sufficiently to give audible clicks on a loudspeaker. In these experiments Granit found that there were as many as seven different types of photo-receptor in the retina of most animals, each of which gave a response to different, fairly narrow, regions of the spectrum. He also found receptors which gave a broad response, being stimulated by rays from most parts of the spectrum. Experiments of this kind have not been carried out on human eyes, but it seems reasonable to suppose that very similar effects would be obtained.

In cases of colour-blindness, some form of which is said to affect about eight per cent of the male population, it has been natural to suppose that certain of these colour-receptors are defective, rendering the subject insensitive to red or to green, etc.

Colorimetry, the quantitative measurement of colour, has been built up on the same general background of theory, descriptions of any given colour being given in terms of the proportions of three carefully chosen primary colours needed to reproduce or match the colour in question.

Though too briefly stated to be adequate, the above does, I believe, represent in outline the almost universally accepted ideas on colour and colour-vision at the present time, and, bearing this in mind, one can appreciate the revolution in thinking on the subject that will now be necessary as the result of a series of experiments carried out by Dr. E. H. Land and his associates in the United States. Dr. Land, as the inventor of " Polaroid," has already exercised a tremendous influence on optics and the optical industry: it is possible that the verdict of history will be that his recent discoveries in the field of colour vision are even more important.

Without further preamble, let me describe one of Land's experiments. Two black and white photographs of a group of differently coloured objects were taken through chosen yellow

filters, one of which transmitted yellow of rather longer wavelength than the other. From the negatives, two black-and-white transparencies were obtained, identical except in slight differences in the distribution of light and dark portions of the objects pictured. Next, the image of each of these transparencies was projected in such a manner that the two images were superimposed on the screen. If the projection was carried out through the same yellow filters which were used in taking the original black and white photographs, the astonishing fact was that, in place of a yellow picture as commonsense and normal scientific thinking would confidently expect, the image of the picture now appeared *fully coloured!* If the black-and-white slides were removed from the projectors, the two slightly different yellow beams combined to give a yellow spot on the screen as one would confidently expect. By what unexpected process can the two superimposed yellow images of the black and white transparencies yield to the eye the impression of colours, which one would have said could only be produced by rays of wavelengths quite different from those emitted by the twin projectors ?

The startling discrepancy between Land's results and those of innumerable previous workers in the field of colour-vision and colour-matching seems to be due to the fact that all former experiments have dealt with *spots* of light, or with pairs of spots, one being matched with another by varying the amounts of the (usually three) colours used in producing the second " spot." Land and his co-workers have been for the first time in history exploring colour vision under natural conditions in *complete images.* In a vast range of carefully thought-out experiments, carried out over a period of some five years, they have found that, in order to produce colour from black-and-white transparencies of coloured objects, one need only illuminate these transparencies with light of almost any pair of wavelengths (identical with those used in forming the transparencies) and superimpose them on the screen. For the sake of simplicity they have termed one of these the long-wave, or " long " record and the other the short-wave or " short " record. The colours in images so produced appear to depend, not upon the particular shade of the long or short wavelengths used, but from *the interplay of long and short wavelengths over the entire scene.*

In some of these experiments a full range of colours has been produced by using a red filter to provide the " long " record and

no filter (i.e. white light) to act as the " short " record. According to classical ideas and experiments one can obtain only different shades of pink by a combination of red and white light, and when two such beams of light from the projectors are combined on the screen pink is indeed produced. But as soon as the black-and-white transparencies are dropped each into its appropriate projector, the image on the screen is flooded with the colours originally present in the objects photographed. If the red filter is removed, the colour disappears and a black and white picture appears.

More stringent experiments were carried out in which different wavelengths of truly monochromatic light were employed in place of the relatively broad bands of wavelengths passed by filters. It was found that any pair of wavelengths that are sufficiently far apart will produce images under the conditions outlined above in which a range of colours is seen extending far beyond what one would expect from classical theory. As we have already noted, the wavelengths chosen can even approach so closely as to be of the same colour description (yellow). There does, however, seem to be a special spectral position at about wavelength 5880 Å on either side of which the " long " and " short " record must predominantly fall if full colour is to be produced. One wonders whether this is in any way linked with the known fact that in this region of the spectrum the human eye can best detect slight differences in hue when the wavelength is varied by small amounts.

The colours produced in these " two wavelengths only " experiments were admittedly not so bright and saturated as when a richer range of wavelengths was available: but that colours should be produced at all under the conditions is the outstanding and amazing fact that calls for entirely new thinking.

Only a few of Dr. Land's experiments have been outlined in this brief article. Many more are described and splendidly illustrated by diagrams and in coloured pictures in a paper entitled " Experiments in Colour Vision " by E. H. Land, which appeared in the " Scientific American " for May, 1959. This is very clearly written, and can be recommended to anyone who wishes to have a greater insight into these astonishing developments. A preliminary paper[1] had already been published by Land at the beginning of the year, but I first became aware of these new discoveries by reading an article " Seeing things in their true colours," which appeared in the " Science to-day " columns of the *Manchester Guardian* for

14th July. Copies of this excellent review of Land's work can probably be obtained by those interested from the offices of *The Guardian* (as the paper is now called) in Fleet Street.

Land seems to have shown remarkable restraint in withholding publication until he and his colleagues had investigated the new phenomena " in depth." These recent discoveries, his work on " Polaroid," and numerous less-known researches and inventions, seem to place him in a category almost as high in the field of physical optics as that occupied by his countryman R. W. Wood, who died about a year ago. Wood's book, " Physical Optics," is one of the most original and exciting of its kind ever written, even to one ill-versed in mathematics. One wishes that Dr. Land would also embody in book form his lifetime's experience in experimental optics. From what one remembers of the entertaining lecture he gave on polarized light at the Royal Institution in 1949, any book by him would be highly readable as well as richly informative.

It will be interesting to see how the new facts revealed by his work on colour vision gradually influence thinking, teaching, and writing on this important and intriguing subject.

1. Edwin H. Land, *Color Vision and the Natural Image, Part I,* National Academy of Sciences (U.S.A.), Vol. 45, p.115, 1959.

THE MEASUREMENT OF REFRACTIVE INDEX BY REFLECTION

By L. C. TRUMPER, B.Sc., F.G.A.

THE upper limit of the standard refractometer is 1·81. Using special liquids, all of which possess serious disadvantages, a slight increase in this upper limit can be obtained, but in general, other techniques need to be used, which either are time-consuming or require laboratory equipment beyond the ordinary gemmologist's means.

Many attempts have been made to devise simpler but effective means of measuring refractive index particularly in the higher ranges, as for example by the measurement of Brewster's angle.

When an unpolarized ray of light impinges on a plane surface, otherwise than at the normal or grazing incidence, the reflected light is partially polarized. Maximum polarization is obtained when the tangent of the angle of incidence is equal to the refractive index of the medium.

A practical method of carrying out this method on gemstones was described by B. W. Anderson in 1941,[1] but its accuracy is very much dependent on the acuteness of the observer.

Fresnel's Law

Alternative methods have been worked out, making use of Fresnel's law

$$\frac{(n-1)^2}{(n+1)^2} \times 100 = \text{the percentage of light reflected at normal incidence.}$$

These methods are based upon the measurement of absolute reflectivity.

Reflectivity can be measured either visually or photoelectrically. The latter method has been effectively used by Orcel (1927, 1928 and 1930), by Ehrenberg and Ramdohr (1934), Moses (1936) and Folinsbee (1949), and a method capable of giving measurements to within 1% has been described by S. H. U. Bowie.[2]

In this, a normal ore microscope is used with a tube iris diaphragm with a " cover-glass " type of reflector unit. The ocular is replaced by a selenium barrier-layer cell in a suitable holder and measurements are provided by a galvanometer of 450 ohms internal resistance. Stabilization of the light source is secured by supplying

a partially stabilized current from a constant voltage transformer to a heavy duty accumulator charger, which in turn keeps the battery charged. Comparisons are made against pyrites, which has proved a reliable and convenient standard with a reflectivity of 54·5.

A visual method has been described by A. F. Hallimond,[3] similarly using an ore microscope, in which reflection is first secured of the light source by means of a small mirror at an angle of 48½° and then from the surface of the medium under test contained in a cell at an angle of 7°. In both cases extinction is obtained by a microphotometer employing two fixed and one moving disc of polaroid.

Design of the Trumper Reflectometer

A reflectometer of original design, calibrated to provide a direct reading of refractive index has now been constructed with the special needs of the gemmologist in mind. Unlike the refractometer, it has unlimited range.

The principle upon which the instrument operates is extremely simple. By a system of totally reflecting prisms, an evenly illuminated ground glass screen, forming a circular spot which can be varied in size to suit the size of the table facet of the gemstone under test, is observed by one eye through two different paths simultaneously.

One path observes the full brightness of the spot, the other path observes the spot after reflection at the quasi-normal by the surface under test. The prisms are so orientated that the two spots appear close together side by side.

The brightness of the spot directly observed is reduced to match the lesser brightness of the reflected ray or spot by means of a carefully constructed annular neutral tint wedge. The amount of rotation required is calibrated with the help of a carefully constructed graph using well polished gemstones of known refractive indices, thus enabling the instrument to provide direct readings of refractive index between 1·40 and 3·20.

The observations are carried out in a light-tight box, so arranged that errors cannot arise through stray light. Supplementary neutral tint and colour filters are provided to vary the incident light and diaphragms to adjust the size of the images are incorporated.

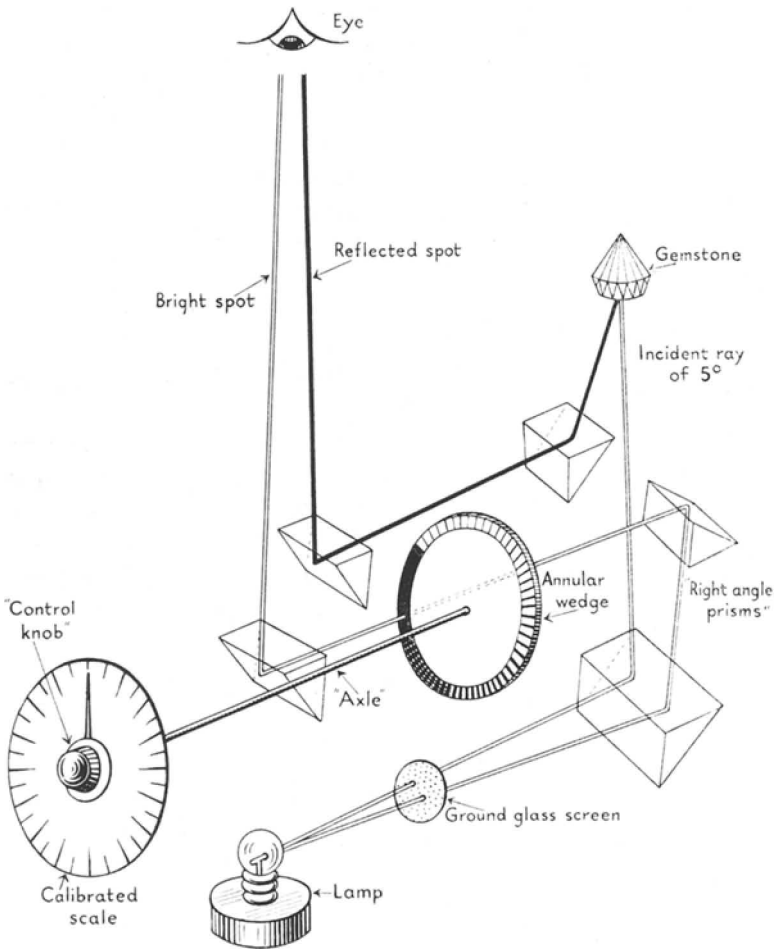

FIG. 1. "*Exploded*" *view of reflectometer showing the two alternative paths of light from the ground glass screen. Any variation in the intensity of the light is common to the two paths.*

An " exploded " view of the reflectometer (Fig. 1) shows the two alternative paths followed by the light from the ground glass screen to be followed.

It will be seen that the same optical principles are observed by both paths, that any variation in the intensity of the light is common to both paths and that the relative intensities of the two remain the same.

This has been proved experimentally, by using different intensities and by varying the neutral tint and other filters. The readings obtained remained the same, provided the observer exercised the same degree of care in making the observations.

Optical Principles Involved

The path followed by the ray of light reflected by the gemstone is longer than the path followed by the main ray.

Since the instrument has been calibrated thus, it makes no difference, but in any event it can be shown that an object (as opposed to a point of light) appears equally bright at all distances.

If S be the area of the small spot of the ground glass screen illuminated by the electric light bulb, d the distance to the eye and a the area of the pupil of the eye, then let Q be the quantity of light emitted per second.

Then the amount of light entering the pupil of the eye per second is $\frac{aQ}{4\pi d^2}$

The solid angle (cone of rays) at the eye is $\frac{S}{d^2}$

and the size of the image on the retina is proportional to this.

The brightness as seen by the eye is therefore proportional to

$$\frac{aQ}{4\pi d^2} \div \frac{S}{d^2} = \frac{aQ}{4\pi S}$$

This result is independent of d — the distance.

From the above it follows that if the areas of the circles of illuminated ground glass screen are different, then the quantity of light emitted to the pupil of the eye will also differ, although any part of the surface will be of the same brightness.

It is for this reason desirable to equalize the two light circles being compared in the instrument by the series of stops provided. Four different diaphragms are needed to accommodate different sizes of table facets with stops to correspond to the path of the main ray.

If a lens or mirror is used to form an image of the circle of illuminated ground glass screen, by the same reasoning as above, the brightness of the image will be $\frac{aQ'}{4\pi S'}$

Q' being the light emitted per second by the image and S' the area of the image.

If O is the object distance, I the image distance and R the radius of the lens, then $\frac{S'}{S} = \frac{I^2}{O^2}$

The solid angle subtended by the object to the lens is proportional to $\frac{R^2}{O^2}$ and by the image proportional to $\frac{R^2}{I^2}$

The light falling on the lens is proportional to $(R/O)^2Q$ and the light falling on the image proportional to $(R/I)^2Q'$

Then $(R/O)^2Q = (R/I)^2Q'$ or $\frac{Q}{O^2} = \frac{Q'}{I^2}$

Thus the brightness of the image $\frac{aQ'}{4\pi S'} = \frac{aQ}{4\pi S}$

which is the same as the brightness of the object.

It can be shown that the above is true also of mirrors and since the table facet of the gemstone is acting as a mirror, it may be argued that slight convexity or concavity of the facet will not affect the brightness of the image observed.

It has been shown experimentally that moderate convexity of the table facet has no effect on the accuracy of readings.

Reflectometer Readings Unaffected by Colour or Transparency

It is believed that reflection of light occurs at the point of change of refractive index, that is at or exceedingly close to the surface of the medium.

It has been experimentally determined that neither the colour of the gemstone nor its transparency has any effect on the readings

obtained by the reflectometer. For example, the extreme case of a jet black spinel, which was almost opaque, gave a normal spinel reading of 1·72. A completely opaque silver-grey haematite gave a reading of 3·1 and a translucent synthetic rutile a reading of 2·72.

The Beilby Layer

The results of progressively polishing calcite have been carefully observed and described by Sir George Beilby in a lecture in 1911 to the Institute of Metals.

The cleavage surfaces exhibit a high natural polish. When polished, however, he estimated that a mechanical disturbance penetrated to a depth of about one thousandth of a millimetre, causing furrows which were however healed over by a surface flow. At a depth of about one ten thousandth of a millimetre, these furrows were almost absent. In the surface layer of about one twenty thousandth of a millimetre there was no trace of broken material, the appearance was absolutely homogeneous, like a coating of varnish which is harder than the original surface.

All the evidence points to the fact that this surface flow occurs for a depth of about one thousandth of a millimetre and that the resulting surface is in a vitreous amorphous state. This layer is referred to as the Beilby layer and is probably produced on most gemstones. Diamond is an exception and in the case of corundum recrystallization occurs. Thus, if the gemstone is fully polished, the reflection may be not from the original gemstone surface but from the Beilby layer resulting therefrom, which is amorphous. The Beilby layer is too thin to have any effect on the refractive index readings of the ordinary refractometer. Nor does it appear to have any effect upon the measurements obtained in determining Brewster's angle, but in the case of reflectometer readings it may give a reading differing from the refractive index of the original gemstone material.

Where minerals are known in an amorphous state, the refractive index is usually lower than that for the crystalline material. Thus the refractive index of quartz is 1·547, but for amorphous silica it is 1·460. For high zircon, the mean index is 1·96, but for low or amorphous zircon it is 1·78.

It may well be, therefore, that in polished gemstones a reflectometer reading may result in a lower refractive index than has been established for the gemstone by normal methods, being the refractive index of the Beilby layer of the gemstone.

This may account for the fact that low readings have been obtained for blende. On the other hand, S. H. U. Bowie suggests that the reflectivity of blende depends upon the iron content.

Bireflection, Dispersion, and Dispersion of the Bireflection

The reflectivity of a transparent isotropic medium at normal incidence can be calculated from Fresnel's equation :

$$R = \frac{(n-1)^2}{(n+1)^2} \times 100$$

The reflectivity of diamond for sodium light is 17·2. That is, 17·2% of the incident light is reflected.

It follows that for anisotropic media there is bireflection and that the reflectivity depends upon the orientation of the surface from which the reflection is being obtained and there will be two principal directions which differ in their reflecting power.

An extreme example is provided by the mineral covelline for which variations in reflectivity of from 5 to 20 in orange light are quoted by S. H. U. Bowie.

The reflectivity also varies with the wavelength of the incident light, thus exhibiting dispersion. Diamond varying from 17·1 for green light to 17·3 for red (Bowie) and pyrites from 49 for violet light to 55 for red.

A. F. Hallimond records the following reflectances for pyrites:

Ang°	4700	4900	5200	5500	5800	6100	6500	6700
R ...	49·1	50·9	52·6	52·7	54·3	55·1	56·4	55

Similarly, whilst aluminium is not a good reflector of visible wavelengths, it is well known that it is a highly efficient reflector of short wave ultra violet wavelengths.

The reflectivity of the two principal directions in the surface of an anisotropic mineral also vary independently with the wavelength of the incident light, thus producing " dispersion of the bireflection."

The Lapidary

In cutting a gemstone, the object of the lapidary is to produce an attractive gemstone with the minimum loss of the rough material. He will grind and polish it to produce facets which by a high polish and reflection of light, bring out the inherent qualities of the stone to the best advantage.

Facets examined with a lens in oblique light may disclose :

(*a*) Scratches, roughness, polishing marks and furrows,

(*b*) A corrugated surface, due to the action of the polishing medium reacting differently to different areas of hardness,

(*c*) Concavity, due to the shape of the lap,

(*d*) Convexity, due to the movement of the stone as the lap rotates,

(*e*) A cylindrical curve due to lack of rotation of the stone or to a side to side movement,

(*f*) A combination of two or more or all of the above.

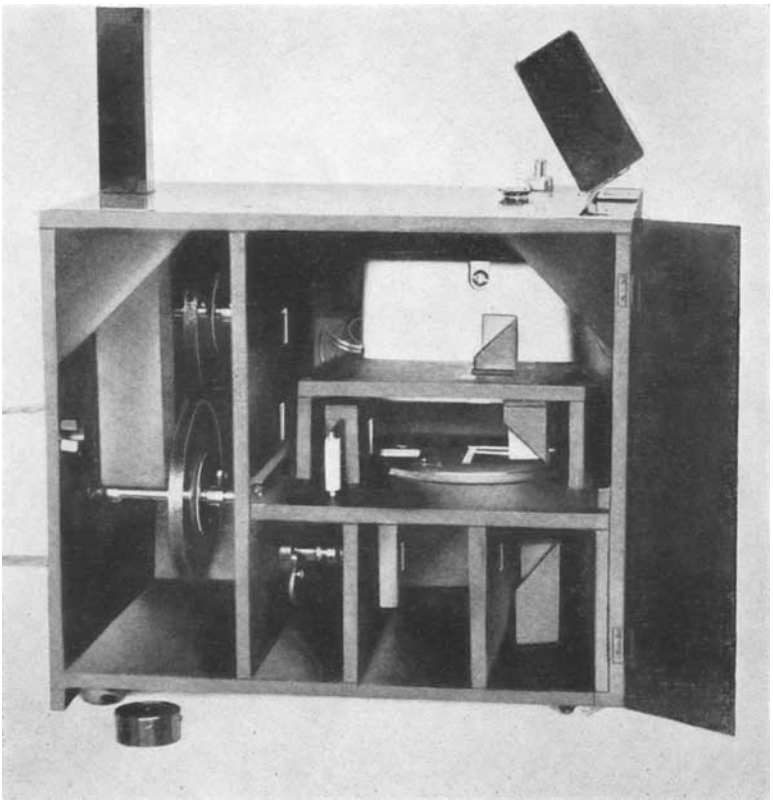

Interior of reflectometer showing prisms, filter disc, stops and wedges.

Assessment of a Gemstone's Suitability for Reflectometer Readings

The reflectometer depends on Fresnel's law of reflection of light and as a preliminary to any readings with the instrument, the gemstone must be submitted to a searching examination as to the suitability of its table facet.

Considerable research has shown that slight convexity or concavity does not affect the readings, but a high degree of polish and freedom from scratches is essential if accurate readings are to be obtained.

Many complicated instruments exist for the examination of plane surfaces, but a simple test for convexity may be made by observing Newton's rings. Press the table facet against the underside of a microscope slide glass and observe in oblique light. Coloured concentric rings will usually be observed. If few and widely separated, the facet will be almost optically plane. If close together a greater degree of convexity is indicated. Generally if rings are observed the gemstone will be sufficiently plane for a reflectometer test.

Using the facet as a small mirror, observe a distant object such as a blind cord against the light or a distant electric lamp filament. If the polish is poor, it will be blurred or distorted as the facet is gently moved from side to side. If well polished, the distant object will be sharp and the reflection good and free from ripples as the facet is moved too and fro.

If satisfied that the facet is suitable, it should be carefully cleaned and polished with a chamois leather or better still polished up on a felt lap charged with a little rouge or chromium oxide.

Conditions Necessary for Reflectometer Readings

Summing up, the conditions necessary for the examination of gemstones in the reflectometer are :

(1) A reasonably flat or plane table facet,

(2) A highly polished table facet free from scratches,

(3) Correct orientation to obtain maximum reflection and a circle of light in the eyepiece of the instrument,

(4) Equal and similar areas of light visible in the eyepiece for comparison,

(5) Comfortable conditions in which to make the observations and preferably in subdued general lighting,

(6) The observer completely relaxed and the eyes free from fatigue.

Conclusions

The reflectometer was specifically designed for the comparatively rapid examination of gemstones, particularly those with refractive index above 1·81, with the object of providing a direct reading without the use of expensive or complicated apparatus and to provide an instrument which would not get out of adjustment or be dependent on any standard that could deteriorate.

Provided the precautions outlined above are taken, the instrument is capable of providing refractive index readings within 0·02 if several careful readings are averaged.

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1. Anderson, B. W. *Gemmologist*, 1941, Vol. X, 115.
2. Bowie, S. H. U. *Min. Mag.*, June, 1957, Vol. XXI.
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Gemmological Abstracts

SEAL (M.). *The abrasion of diamond.* Proc. Roy. Soc. London, Ser. A, Vol. 248, pp. 379-393. November, 1958.

The rates of wear for diamond abraded with diamond powder vary by a factor of >500 for different crystallographic directions. The variation is related to a small directional variation in the coefficient of friction. The difference observed in behaviour at high and low sliding speeds is consistent with wear being due principally to a thermally activated chemical effect.

R.A.H.

WILKS (E. M.). *The cleavage surfaces of type I and type II diamonds.* Phil. Mag., Eighth Series, Vol. 3, pp. 1074-1080. October, 1958.

Microscopy and multiple-beam interferometry have been used to show that, in general, three are more cleavage lines on type I diamonds, and also a greater number of the so-called river systems. The results suggest that impurities within the lattice lead to a more broken substructure in the type I diamonds. Any birefringence does not appear to be related to the cleavage pattern : very few type II diamonds show evidence of a laminated structure.

R.A.H.

BOWDEN (F. P.) and SCOTT (H. G.). *The polishing, surface flow and wear of diamond and glass.* Proc. Roy. Soc. London, Ser. A, Vol. 248, pp. 368-378. November, 1958.

The wear of diamond sliding on glass is due partly to the degradation of diamond to amorphous carbon or graphite. This degradation appears to occur at interface temperatures lower than that required for obvious graphitization of diamond heated without rubbing.

R.A.H.

HALPERIN (A.). *An uncommon growth feature in diamond.* Phil. Mag., Eighth Series, Vol. 3, pp. 1057-1060. October, 1958.

Growth features which extend as terraces from the edges of growth sheets on {111} faces of a diamond are described. One of these features is very flat, probably down to atomic dimensions

over its whole area ($\frac{1}{3} \times \frac{1}{2}$ mm.). Its characteristics suggest that in the last stage of growth of a diamond, when trigons are formed on its surface, growth sheets become frozen and growth proceeds only to the fixed edges.

R.A.H.

LEONARDOS (O.H.). *Diamante e carbonado no Estado da Bahia.* Gemologia No. 14, pp. 1-20.

A reprint of a paper formerly published in Mineracao e Metalurgia. Discusses diamond and carbonado as found in the Brazilian State of Bahia. In his classification the author describes a type of industrial diamond between boart and carbonado, known as bala—being the ball-like radial crystalline stones—which he lists as the most valuable of the industrial types of diamond. Values quoted are those obtained by the garimpeiros (miners). The mine values for carbonado are compared with prices asked in London and New York and show a ratio of 1 to 5 or even 1 to 10. The paper describes the geology of the diamond area, methods of recovery, concessions and numbers of garimpeiros working—the latter being based on estimated pre-war figures.

R.K.M.

LEIPER (H.). *Kunzite strike at reopened California mine.* Lapidary Journ., p. 348, June 1959.

Gem-quality kunzite and fancy spodumene have been taken from the Pala Chief Mine since its recent reopening. This mine has produced the largest amount of gem spodumene of any mine in the world. Blue specimens of the gem have been found. Some pale green spodumene has also been obtained, which is not of sufficiently deep colour to merit the name hiddenite.

S.P.

JADE STORY—AMERICAN (2)

By ELSIE RUFF, F.G.A.

THE white man's arrival in America was to change, almost overnight, all that the American Indian knew as a way of life. There was no gradual transition, nor was the European entirely resented, or his culture always imposed by force. Records exist that prove the white man was sometimes welcome, for there was a strong belief in ancestors that were white, with beards, and legends promised their return. Also, the newcomer had merit. He brought iron tools and the wheel. And he brought horses.

Columbus undoubtedly had other ideas than just conquering a new world or linking up with an exotic one. Letters he left, still extant, proclaim him no chance adventurer. Already he had visited many countries, including Britain. Perhaps it is our loss that he was never to peep into the rich land of Mexico. Yet the most imaginative adventurer could hardly have anticipated the racial admixture of this new land, nor the diversity of its languages. J. W. Kraft (*Adventure in Jade*) wrote : " If you examine the Mexican pebbles at the great museum of Mexico City, you will observe a remarkable thing : the faces carved upon them seem to be an international gallery. Some of the faces appear Oriental, some Norse, some Negroid. The artists who worked in this jade must surely have been world travellers."

To study American jade is to study this racial admixture. There is little doubt that migrations of people, perhaps over a very long period, entered the New World from north-eastern Asia via the shallow Bering Strait. It is thought that many of them made use of a land bridge or perhaps ice-jams. Certainly the Mongoloid features of many Eskimoes and Indians to-day bear witness. It has been suggested that changes in climatic conditions were responsible for this move at an early stage. Even now Eskimoes on both sides of the strait are practically identical in customs, speech and general physique. N. C. Nelson, a leading authority on early man in America, believes that these people arrived somewhere between 5,000 and 10,000 years ago (others say 15,000), and that they were then enjoying a partially developed neolithic culture. He says too that the trend was to trek south where conditions of life and climate were more hospitable. This Asian immigrant appears to have been somewhat of a wanderer anyway, though many did settle

down to agriculture. Only the, then, impenetrable growth farther south imposed a slower pace. Nevertheless, this section of the American population merely accounts for one race. Undoubtedly there were aborigines, and unions between the two must have taken place which, together with the change of conditions and climate, modified the Mongolian characteristics. Yet neither of these races represented the highly developed civilization that the white man discovered. There are races, or at least one race, still to be accounted for.

In studying the Jade Question of America, it is logical to ask: Was jade stimulated by this Mongolian invasion, suggesting that it was part of their neolithic culture ? (And it is all too easy to connect the Mongols with China and jade.) The old theory that wrought jade discovered in America came from the Orient in the rough (a theory once advanced to account for European jade) has long been discarded. Or we may ask : Was jade a part of the life of the aborigines ? Or, was jade a part of the culture or cultures of those races not yet identified ? The answer could be that jade played a part in the life of all three. It is also possible that the study of jade may contribute to an ethnographical answer. A fact emerging from American excavations is, that the deeper the archaeologist digs, the finer the jade he discovers ; in this instance discrediting the evolutionary view as far as jade is concerned. Nor was this jade merely a question of lapidary technique. Pal Kelemen,[1] writing of pre-Columbian jades, said : " It is noticeable that the material used in the earlier centuries is of higher colour and finer quality than later, when during Aztec and Toltec supremacy the scarcity of the better type of jade apparently forced the artisans to reach for darker and coarser materials."

Since the subject of jade in America covers a vast territory, it will be necessary to approach the matter geographically, and to begin where Cortes began is to start with Mexico, essentially a transitional country. Mexico is sometimes described as *A Federal Republic of North America*, and sometimes referred to as part of Central America. Its official language, Spanish, is only one characteristic that has spilled over into California. Perhaps because Mexico is a contiguous neighbour of the U.S.A. we know more of this country than of those to the south. It has, too, a far greater population, Mexico City alone claiming over 4,000,000

souls. Certainly its people, originally *Nahau*-speaking, have been for us the most famous on the American continent.

When the Spaniards landed at Vera Cruz (the Indian name for which was Chalchicuela—cf. Chalchihuitl) the people of Mexico were called Aztecs. This is now so commonly known that we frequently associate the word with Mexico. At the helm of that day was Montezuma. The various descriptions of him suggest an embroidered eastern potentate. Nevertheless, Vaillant (*Aztecs of Mexico*) described him as " simply dressed but for the gold crown and jade earrings of his exalted office." However, he does not appear to have lacked sagacity, benignity, or any of the other distinguishing traits of statesmanship. The gemmologist can do nothing but salute him. For gem-splendour he was, surely, the American version of Henry VIII. Yet the Aztecs as a race were comparatively short-lived. They were preceded in the Valley of Mexico by a people of greater culture, a race that the Aztecs

themselves admired. They were called Toltecs, though for awhile this term was unacceptable (and still is in some quarters) to certain authorities who were inclined to assign the Toltec race to legend. It is to the Toltecs that the archaeological remains of ancient Mexico are now attributed, though at the time of the Aztec invasions they were a disintegrating people. Vaillant tells us that the Aztecs arrived from the north, first setting foot on Mexican soil in the eleventh century—about the time of the Norman invasion into this country. " In less than a hundred years," he wrote, " rising on the ruins of the older culture, they developed an extraordinary civilization." Although these Aztecs succeeded in spreading themselves pretty well over Mexico, there were states, Yucatan in particular, where the populace were neither Aztec nor Toltec. Seemingly they were older than both. They were called Mayas (pronounced My-ers), and although at some time during their

Symbol for chalchihuitl.

" Most precious heavenly jewel confined at the four directions."

Chalco is S.W. of Mexico City. Top part of the illustration represents capture of Chalco in reign of Aztec King Chimalpopocha 1400-1428.

Dark centre is green jade. set in red surrounded by white.

(FROM THE J. COOPER CLARK'S CODEX MENDOZA, BODLEIAN LIBRARY).

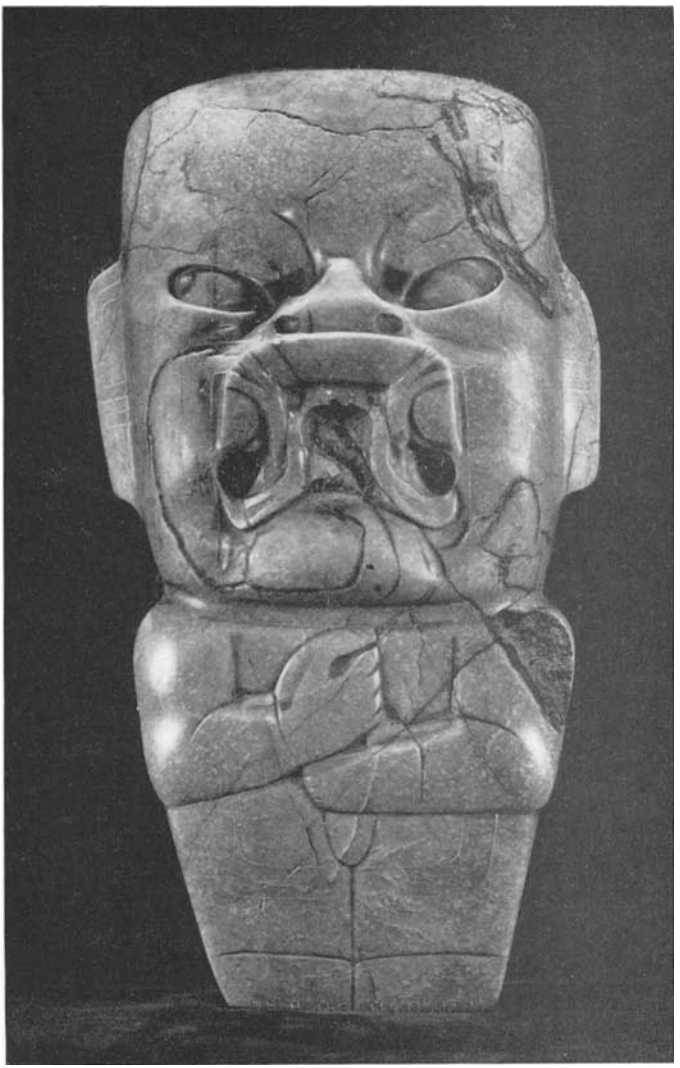

Mexican Kunz collection. Votive Adze of jadeite.

(Courtesy of American Museum of Natural History.)

history they must have been contemporary with the Toltecs, it is generally agred that they were a more ancient race.

For convenience of study the Maya history has been divided into two parts. The Maya Old Empire is roughly dated from the third to the seventh centuries A.D. The second Empire flourished from the eleventh to the fifteenth centuries A.D. These dates have been taken from inscriptions on important sites. S. K. Lothrop, of the American Indian Museum (Heye Foundation), writes : "At the close of the sixth century A.D. the Mayas abandoned their southern cities and embarked on a period of wandering, interrupted by temporary settlements. Finally, about the year A.D. 1000, the foundations of the great cities were laid and the Maya entered on a period usually called the Renaissance. All the Maya, however, did not move to Yucatan ; a large number settled in the highlands of Guatemala."

Of recent years the term pre-Maya has come into existence, and this race was certainly neither Mongoloid nor aboriginal. Legends say they were white, bearded and tall.

From his own studies Kraft (see above) believes that the order of values in the Aztec empire, as material for jewel and votive pieces, was first jade, then turquoise and finally gold. Edward Seler, of the University of Berlin, visited America in 1902 and later referred to the extraordinary value that jade possessed both to the Aztecs and the Mayas. He spoke of an ancient commercial road leading from the Highlands of Mexico to Tabasco and Yucatan, and to the Rio Montagua in Guatemala. " Along this road," he wrote, " there had grown up trading stations where the Mexicans met the Mayas and jade was an important article of traffic at these points." G. F. Kunz, quoting Seler, said : " . . . It is surprising how the Chinese, the Swiss lake-dwellers, and the ancient Mexicans, recognized correctly the water-worn iron-stained and apparently unrecognizable pebbles, as jade or jadeite, whether they were selected for an art object, a celt or tool, or for an ornament."

So important was jade to the Mexicans and their forbears that no book on the country itself or its history can ignore it. In 1947 a volume appeared entitled *Mexico South.* The author (M. Covarrubias) wrote: " While the Mexicans often placed jade beads in the mouths of corpses, the Chinese 2,400 years ago placed a cicada of jade in theirs. Although these parallels are most likely coincidental, it is hard to explain why both Chinese and Mexicans painted their

funeral jades with a coat of bright red cinnabar. Furthermore, the style of ornamentation of some of these jades is often strikingly similar, variations of the squared spiral motive . . . Jade was to the Mexicans, as well as to the Chinese, more than just a precious stone : it was worshipped as a symbol of everything that was divine and valuable. In Mexico the name chalchihuitl and the glyphs for jade were synonyms of ' jewel ' or ' precious '. (See sketch.) Jade was linked to rain, vegetation, life, and godliness. . . . Because of its rarity and great intrinsic value, it was reserved for the great. . . . The famous culture-hero of ancient Mexico was Topilzin Ce Acatl, in turn an incarnation of Quetzalcoatl* (a fair-faced, bearded god). He was the semi-divine sage, priest, and ruler responsible for all art and science of the Toltec nation, the Huang-Ti of America. Even his birth was miraculously achieved ; he was conceived years after his father's death, by means of a green jewel, a piece of jade that his mother had swallowed."

One of the earliest contributors to our knowledge of American jade was E. G. Squier. His famous paper, " Observations on a collection of chalchihuitls from Central America," was read in 1869, and, although nearly a hundred years old, is still quoted. Like everyone else who has handled these old documents he was endeavouring to sort out the various species included under a general heading. " The Mexicans," he wrote " nevertheless had true emeralds, of which we have left to us the most glowing descriptions. Gomara, a Spanish historian of the sixteenth century, describes particularly five large ones which Cortés took with him from Mexico to Spain at the time of his first visit, and which were regarded as among the finest in the world. They were valued at 100,000 ducats (approximately £45,000) and for one of them the Genoese merchants offered 40,000 ducats (approximately £18,000), with a view to selling it to the Grand Turk. Cortés had also the emerald vases, which the padre Mariana assures us, in the supplement of his *History of Spain*, were worth 300,000 ducats. They were reported to have been lost at sea. All these emeralds were cut in Mexico by Indian lapidaries under the orders of Cortés, and were most elaborately worked. One was wrought in the form of a little bell, with a fine pearl for a clapper, and had on its lip this inscription in Spanish . . . ' Blessed he who made thee ! ' The one valued most highly was in the shape of a cup, with a foot of gold. . . . Remarkable

* Quetzalcoatl — pronounced KAYT-ZAL-CO-AL.

as were these emeralds, Peter Martyr[2] mentions one, of which Cortés was robbed by the French pirates, that must have surpassed any of them in size and value. ' But what shall we speak of Iewelles and precious stones ? Omitting the rest, there was an Emerode like a Pyramis, the lowest part or the bottom thereof was almost as broad as the palm of a man's hand, such a one (as was reported to Caesar, and to us in the Kinges Senate) as never any human Eye behelde. The French Admirall is said to have gotten it of the Pyrattes at an incredible price.' (Decade VIII, c. 4) "

G. F. Kunz in *Gems and Precious Stones of Mexico* had something to say of these treasures sent to the King of Spain (also commented upon by a more modern authority).[3] " Many specimens of carved jade," he wrote, " were brought over early to Spain, but it is probable that the most remarkable were lost. Wonderful tales were told of the sacred articles of ' emerald ' belonging to Montezuma, including a goblet and a ' rose ' that were shipped by Cortés to the King of Spain ; among the choicest treasures of the conquest. Unfortunately the vessel that bore them foundered at sea, and these unique works were forever lost. It is impossible that they could really have been emerald, as that gem scarcely occurs in Mexico at all. They were probably chalchihuitls of peculiar richness of colour, and constituting doubtless both in workmanship and material the finest products of Aztec art. The most remarkable specimens now known of jadeite from Mexico are chiefly carved masks and pendants or celts and adzes, these latter often being carved and elaborately ornamented, showing that they are insignia of rank and not implements for use. Many of them retain on the back or sides portions of original rounded surfaces, proving that they were made from boulders. In several instances large pieces have been reduced by cutting out smaller portions from the back, leaving the carved surface uninjured—thus indicating increasing scarcity of high-priced material, which induced their removal of superfluous portions to make new objects, or perhaps some peculiar tradition or superstition, attributing special sacredness to pieces once belonging to some deceased chieftain, which might perpetuate to his successors by bestowing on them parts thereof, while the main original was buried with its possessor. . . . One of the most important recent discoveries of jadeite objects was made in the excavations at the Escallerillas in the City of Mexico, immediately at the back of the cathedral, which stands near or upon the site of the great ancient

temple. This excavation was carried on during the years 1900 and 1901, and brought to light at least 2,000 beads of jadeite, also jadeite tablets, many hundred copper objects, and a large and beautiful knife measuring 32″ in length. . . ."

Perhaps the most outstanding excavation of recent years was that made by Alberto Ruz, Director of Research at Palenque, in Chiapas, one of the states of Mexico. There he unearthed a tomb that could vie with the most lavish of Egyptian tombs and where the majority of the gems were jades. Jade idols ; jade ear plugs (a popular ornament in that part of the world) ; a diadem made of tiny discs of jade ; a mosaic mask of jade that covered the face of the deceased and is thought to represent his features ; jade tubes ; jade beads ; jade cut into spheres, cylinders, flowers, fruit ; a bracelet of 200 jade beads on each wrist ; and rings of jade on the fingers. There were, too, symbols of rank in jade, and a dark jade bead in the mouth of the corpse as part of the funeral rites of the Mayans. It was noticed also that this Mayan potentate or ruler or king was taller than the Mayans of to-day, supporting early traditions on this subject of ancestors. He may not, of course, have been a Mayan. A king he certainly was. His date, worked out from Mayan reckoning, is believed to be around the seventh century A.D. This pyramid tomb of a prince of Palenque has been named the Temple of Inscriptions.

Writing of the treasures of this temple in *Gems and Gemology* (Summer, 1953), Ruz says : " . . . As for the jewels which we discovered in the tomb of the Temple of Inscriptions, we can state to-day that in their work of precious stones, the Palenquans were, likewise, great and refined artists. We have the impression that there did not exist for them anything impossible to accomplish in architecture, sculpture, and lapidary art, since their ingeniousness and artistic feeling permitted them to overcome any difficulty. This is evidenced by the complex shape of the beads, produced from irregular fragments of jade, whose original conformation was made use of to transform into flowers, full blown or partly open or closed, and in lengthened or spherical beads. Other evidences were the beads with lengthwise perforations through which the threads of a necklace passed transversely. Another is the perfect adaptation of fragments for mosaic, for which they used bits of broken jewels. A large bead has been scooped out and provided with two plaques

for fastening it ; ear hoops were made of various constituents and skilfully fitted."

In the same journal Ruz writes of other important excavations, including that of Alfonso Caso in Monte Albán, State of Oaxaca, during 1932. Here the tomb rendered no less than 500 objects, many of gold, jade, turquoise and pearls. One extraordinary object was that of a rock-crystal goblet, and in this connexion Dr Ruz brings to notice, because of the rarity of such objects, that of the rock-crystal skull in the British Museum. Among the jade pieces, he tells us, were the handle of a fan in the shape of a serpent, the head of an eagle with eyes inlaid with gold, finger-rings, ear-rings, ear-hoops, and beads that once made up necklaces. Another important excavation mentioned was made in 1941 by Matthew Stirling in Cerro de las Mesa, on the coast of Vera Cruz. Here 782 pieces of jade were found in a variety of colours from milky-white to black, and also pale bluish. Writing in the National Geographic Magazine for 3rd September, 1941, Stirling says that " many of the figurines and objects of jade were as bright and shiny as on the day on which they were buried."

Stirling's words best portray his own finds : " There were two beautiful statuettes of blue translucent jade, four and five inches long, one realistic and in the round, the other flat and stylized. There was a splendid three-inch figure of a nude man, seated, with an extreme head deformation, carved out of green jade, a masterpiece of solid monumental sculpture. There was still another figurine in grey jade, covered with a coat of red cinnabar, and with a glimmering little disc of crystalline hematite stuck on its chest. It represents a plump girl wearing a skirt, with her hair hanging loose at the back and with bangs in front. Her face resembles those of the colossal heads and bears the same wistful smile that distinguished two of them. Also of the finest jade was a pair of green square ear-plugs engraved with eagles' heads, and a realistic replica in jade of a large clam shell, as well as a bulb-shaped object with a stem, a delicate copy of a stingaree's tail in clear blue jade, a paper-thin little mask of a duck's head, and a number of emerald green jade beads shaped like sections of bamboo. . . . Hundreds of jade axes, generally in groups of thirty-seven, were found buried at various places, undoubtedly offerings, carefully arranged in rows and in groups, apparently with a magic purpose in mind. . . ."

In his 1943 season of excavation, Stirling found Olmec figurines (Olmec culture approx. 500-100 B.C.) this time with eyes inlaid with hematite, more axes, and endless objects of jade, many made out of the precious emerald-green clear variety called in China (and in North America to-day) " jewel jade," and known previously to come only from Burma—now found in America for the first time. " Nothing like the discoveries of La Venta[4] have ever been made before, and the identity and cultural connexions of its inhabitants remain shrouded in mystery."

Squier describes one piece among the collection he examined as bearing a resemblance to the engraved Assyrian seals " or, as they are sometimes called, ' Chaldean ' cylinders. It is a perforated cylindrical piece of heavy, opaque stone, of a dark sea-green colour (nephrite ?), two inches long by an inch and one-tenth in diameter. In a kind of oval, or what Egyptian scholars would call a *cartouche*, is presented the profile of some divinity (the Maya god of death ?), with the eye closed and the tongue depending from the corner of the mouth. Something like claws, engraved on the projection of the cylinder, start out from the cartouche, on the left side. The whole is boldly and sharply cut, and highly polished. This relic was obtained from the island of Flores, the ancient Tayasal, in the lake of Itza or Peten, in Yucatan. Among the things found by the conqueror of the Itzaes, Ursua, in the temples which he destroyed on the island in 1697, he mentioned ' an idol of emerald a span long, which ' said the chronicler ' he appropriated to himself.' "

Dated 1901 is an account, of an exploratory nature, written in German by Teobart Maler and later translated. The author's own words (again) best tell the story : " We reached El Caso on 20th May. (1897.) Here too the river afforded a magnificent panorama. . . . Here the mineralogist can gather an interesting collection containing specimens of all that are buried in the heart of the most distant mountains of Chiapas and Guatemala. . . . Many species of stone are found here. I thought I recognized carnelian, syenite, jadeite, ophite, hematite, pure white marble of the finest grain, very pretty pieces of petrified wood, etc. These stones, the most of which are extremely hard, are of all colours, many are striped with several colours. . . . On the following day we undertook an exploration of the ruins of the Budsilhá, which according to our estimate must be six kilometres below La Mar. . . . On the summit of the rock standing alone not far from the waterfall, some monteros,

Tuxtla statuette, Tuxtla, Vera Cruz, Mexico. Height 6″; base $3\frac{7}{16}$″ by $3\frac{15}{16}$″. Jadeite-diopside.

(Courtesy of the Smithsonian Institution).

roaming about some years ago, found a small figure of hard green stone (jadeite), which subsequently through the instrumentality of Sr. Mejenes came into my possession at Tenosique. In ancient Mexico the manufacture of objects from hard stone was the work of skilled stone-cutters, and the profession descended from father to son. Certain villages were especially famed for such works in stone, which as articles of trade were carried far and wide. As such objects are indestructible they may belong to the most remote period and place—wherever they are found—and their origin can

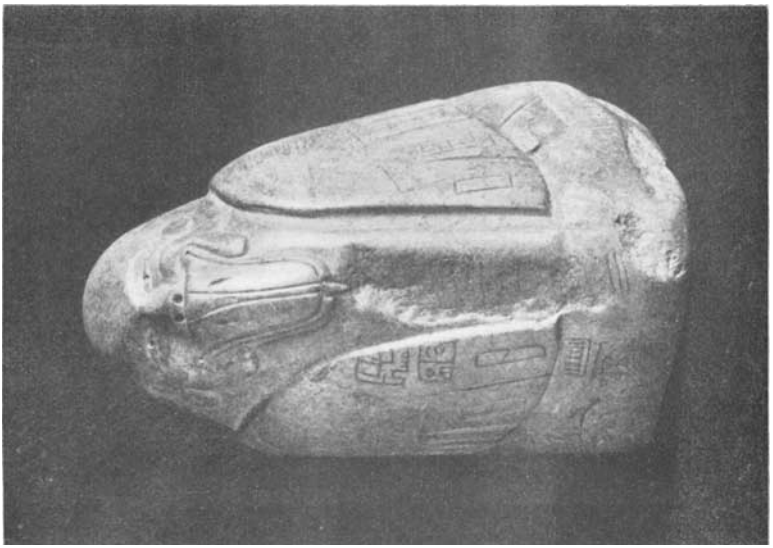

Further views of jadeite-diopside statuette, Tuxtla, Vera Cruz.

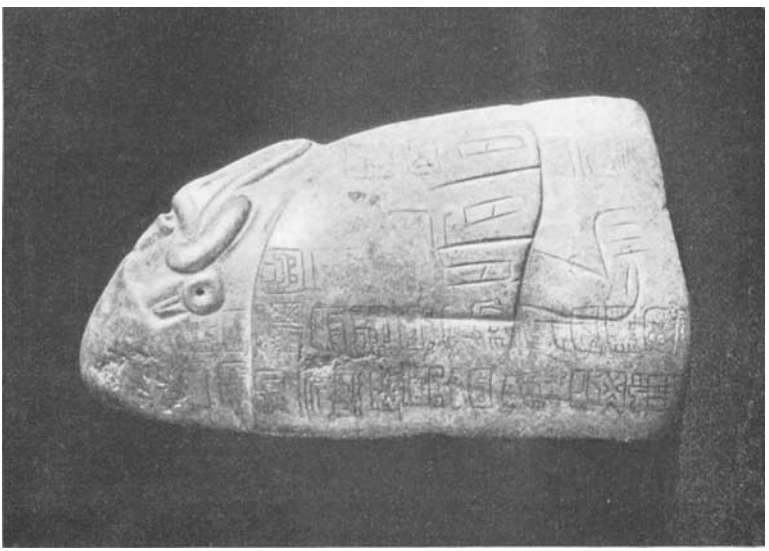

(Photographs by courtesy of the Smithsonian Institution).

be determined only by comparison. At first I was only able to recognize that the little figure from Budsilhá originated among a people having a head of pronounced oblong shape ; later it proved that the shape of the face, especially the mouth, is similar to that of the god from what was once the principal temple of San Lorenzo on the lower Lacuntun. The little jadeite figure is 14cm. long and represents a man standing erect with his left arm against his waist and his right arm across his abdomen. He wears a girdle (maxtli, mastli), the loop of which falls down in front. Small ornaments are delicately worked on the knees and breast. He has no head covering, and there are no discs attached to his ears. The small hole through the centre suggests that the figure may have been worn on a necklace or attached to some object." A little further on the author is describing the figure of Ketsalkoatl (Quetzalcoatl) " placed upon the step in a niche, sitting cross-legged in Asiatic fashion . . . the god had oblique eyes (that is, Chinese or Mongolian eyes). . . . It is undeniable that these images of gods in Zaxchilan and Piedras Negras, sitting cross-legged in their niches, and wearing serpent headdresses or turbans, are strongly suggestive of the Indo-Turanian representations of Buddha. At all events the oblique eyes indicate Turanian[5] origin, even if the historical reason why the principal god of the Maya-Toltec (Ketsalkoatl ?) displays Turanian type may not be clear to us. But where history is mute monuments are eloquent."

The ancient city of Teotihuacan about 30 miles north-east of Mexico City was an early Toltec capital, which the later Aztecs never apparently restored or used. Although Aztec influence extended from sea to sea, certain areas held their independence. Teotihuacan was conquered in 1429, yet appears to have held no importance in Aztec eyes. Research was carried on there recently by S. Linné of the Ethnographical Museum of Sweden and here he found the datable finds of the Aztec era scanty when compared with those of the older culture. A jade plaque discovered there, and now in Mexico, was studied exhaustively by Thomas Gann.[6] This plaque he described as consisting of two distinct laminae, " the curved surface being of bright apple green, the back of dull translucent blue with intrusive veins of green penetrating it obliquely. It is 14 cm. in length, 14 cm. in breadth at the widest part, weighs 1 lb. 4 oz. and is bored completely through its upper margin, probably for suspension. Apart from the fact that it is, both in

workmanship and quality of material," Gann wrote, " one of the most beautiful examples of jade ever found in America, this plaque is of extraordinary interest, as it proves conclusively the existence of intercommunication between Teotihuacan, the Toltec capital, and some Maya city of the Old Empire." Gann adds : " The design is typically and unmistakably Maya. . . . How this remarkable ornament, which among the Maya must have been regarded as the Koh-i-noor diamond is in the modern world, can have found its way across the long distance and through many hostile tribes separating the Toltec capital from the nearest Maya city, is one of the mysteries for which no solution is ever likely to be forthcoming."

Says another writer:[7] " Finely carved jades were undoubtedly regarded by the Mayas as objects of great value. They could be passed from generation to generation and could be traded in different parts. In most cases one cannot rely on the circumstances of their discovery to evince their origin and often the only clue is the style of the carving itself, at best an uncertain criterion, especially as conclusions must be based largely on analogy with arts of different technique. Fortunately a few jades were inscribed with dates, and when these dates can be related to inscriptions on monuments they sometimes furnish more reliable evidence than does either style or stratigraphy."

Undoubtedly the most famous jade piece thus far discovered in the Americas is the so-called Tuxtla statuette, reproduced here, and now in the U.S. National Museum in Washington, D.C. Most authorities agree that this masterpiece was the work of a pre-Maya race, suggesting that the date on the object had been added later, perhaps by the Mayas when the statuette was first discovered. Some have associated it with the enormous stone statues freely discussed in recent years. The Tuxtla statuette (pronounced Tushtla) is 6 inches high and $3\frac{7}{16}$ inches wide at the base It acquired its name from the place of its discovery around 1907, at San Andres Tuxtla, in the State of Vera Cruz, Mexico. It is the earliest dated Maya jade object found *outside* the region where Maya civilization was known to have flourished, which may be one reason for suspecting it to be pre-Maya, and contributes to the theory that, whatever this unknown race, it had spread itself over a wide territory. According to Gann (*An Unknown Land*, 1924) this statue bears a date in the early part of cycle 8 in Maya chronology, or about 100 B.C. He writes : " If that statuette was made where it

was found it would indicate that we must look for the birthplace of the Maya civilization in this region, rather than 200 miles to the south where it attained its highest development." If, therefore, this date is correct, it antedates the coming of Columbus by something like 1,600 years. We are told that the statuette represents a priest dressed in ceremonial bird costume, the whole a pale-green variety of jadeite. " In carving this figure," Gann continues, " the Maya artist—one with great ability and a feeling for realism rare in Maya art—has evidently been constrained to adapt his design to the shape of the boulder. Remains of the original water-worn surfaces are clearly visible on the front, on the left side, and on the back. . . . It is impossible as yet to read the Maya hieroglyphs that run vertically down the sides and back, but students of American archaeology now know very well the characters used by the Mayas to express numbers and dates, so that we can interpret the hieroglyphs that appear on the front of the image."

Henry S. Washington, a geophysicist, writing in 1926[8] said: " The material of the statuette is composed, obviously, of jade and the present study by optical and chemical methods shows that the material is not nephrite, as once thought, but a variety of jadeite. . . . Through the kindness and courtesy of Dr. W. H. Holmes, to whom I would express my sincere thanks, I was privileged to examine the figure in the geophysical laboratory and to remove enough material for chemical and optical studies. . . . The rounded conical image (flattened at the back) represents an oldish man, bald headed, with the beak of a duck-like bird masking the lower part of the face, and moustache-like features connecting the nostrils and folding down over the cheeks. If the carving represents a god, he must have been a beneficent one for there is a merry twinkle in his eyes and a suspicion of a smile behind the beak that are facial characteristics, widely different from the usually repellant features of gods as they are frequently depicted on the Mayan monument."

Among the earliest dated objects, after the Tuxtla statuette, is that known as the Leyden Plate, " one side of it inscribed in shallow lines, now much worn, the figure of a king or warrior, and upon the reverse a Maya inscription." It was found during the construction of a canal connecting the Rio San Francisco del Mar with the Rio Gracioza on the frontier of British Honduras and Guatemala in 1864. This also is of jadeite and etched upon it is an ancient date of Maya history—one interpretation is that of 320 of our times,

another as A.D. 61. Found at a very great depth, by a Dutch civil engineer named S. A. von Braam, it was given by him to the Ryks Museum in Leyden, Holland, and so acquired its name. About 8″ high, this celt-shaped plaque has been described as " very pale jade of fine quality."

Closely linked with the Leyden Plate is the Humboldt Celt, a votive adze presented to Humboldt by Del Rio in 1803 when he was making a tour of Mexico. Humboldt deposited this celt in the Royal Museum at Berlin without commenting upon it. Lord Kingsborough[9] gave it its first illustration in Vol. V of his collection. But not until 1875, when Professor Fischer of Freiberg, to quote his own words " succeeded in rediscovering the precious and forgotten relic on the dusty shelves of the Berlin Museum", was any particular notice taken of it. This piece is also of jadeite and is 16·5cm. in height. The connection between the Leyden Plate and the Humboldt Celt is that both stones are almost the same shade of green, the unity of colour being interrupted here and there by flakes of a bluish hue. Both stones show the outlines of what is known in archaeology as the celt, and exhibit on their surface carvings of beautiful execution. They appear equal in size, 222mm. in length and 80mm. in width, though the top of the Humboldt celt is broken off. If restored it is reckoned that the length of the celt would be probably 275mm. Philip J. J. Valentino[10] writes : " There are essential points of difference between the two specimens. The Humboldt jade has the full form of a celt, namely that of a wedge. It is bi-convex, with a thickness approximating to 34mm. The edge approaches the crescent form. The Leyden specimen, on the contrary, is almost flat and only shows the well-known celt form in its outlines, with an average thickness of 5mm. On closer examination a slight bevel will be noticed from the edges towards the axis, on both surfaces of the plate, exhibiting therefore rather a tendency to bi-concavity. . . . Let me at this time state the fact that by far the greatest number of *chalchihuites* gathered from the hands of natives at the time of the conquest, and in the course of the following centuries, have turned out to be falso-nephrites. Genuine nephrites must have been employed by the earliest generations for they are distributed only in ancient graves, or in the soil at a considerable depth, or at the foot of ruined buildings, of which the natives themselves attest that they did not know what kind of people built them. However, their cult, calendar, ceremonies, and

usages so acknowledged were derived from ancient times. Among their ceremonies, as we learn, the entombing of the deceased with a green stone on his tongue was considered a religious duty. A considerable number of *chalchihuites* must have therefore been annually consumed."

G. F. Kunz writes (*Gems and Precious Stones of North America*) that the Humboldt Celt has a thickness of $1\frac{2}{5}''$ and the Leyden Plate $1\frac{1}{5}''$. From the fact that the two, if placed together face to face, have exactly the same outline, it is highly probable that they were originally part of one and the same celt and it is quite possible that remaining parts may be found."

During 1862, one, Daniel Wilson, was writing of another axe that had an interest for Humboldt. He says : " Humboldt figures in his ' Vues des Cordilleres ' a hatchet made of compact feldspar passing into true jade, obtained by him from the professor of mineralogy in the School of Mines at Mexico, with its surfaces covered with graven figures or characters. In commenting on this interesting relic, M. Humboldt adds : ' Notwithstanding our long and frequent journeys in the Cordilleras of the two Americas we were not able to discover the jade *in situ* and this rock being so rare we are the more astonished at the great quantity of hatchets of jade which are found in turning up the soil in the localities formerly inhabited, extending from the Ohio to the mountains of Chili. Here also we have a glimpse of widespread ancient trade and barter carried on throughout the American continent in ancient times and of a wide intercourse embracing North and South America, that the investigators of the traces of a former civilization have been willing to recognize '."

Kunz described what he believed to be the largest jadeite adze yet to be found. It is now known as the Kunz adze and illustrated here. " On its face is figured a grotesque human figure, and for a hard material the workmanship is excellent. It is believed to have been found in Oaxaca, Mexico, and measures $10\frac{13}{16}$ inches in length, 6 inches in width, $4\frac{5}{8}$ inches in thickness, and weighs 229·3 Troy ounces. . . . The colour is light green with a tinge of blue, and streaks of an almost emerald green on the back. In style and ornamentation it very closely resembles a gigantic adze of granite . . . it has almost a counterpart in the green adventurine quartz adze now forming part of the Christy collection in the British Museum. . . . From all appearances this adze was shaped from a boulder, since

weathered surfaces, such as appear on all sides of it would be found only on an exposed fragment. . . . The lapidarian work on this piece is probably equal to anything that has been found, and the polishing is as fine as that of modern times." Kunz goes on : " The next most important specimen is a large jadeite celt described by A. B. Meyer[11] as belonging to the Royal Ethnological Museum at Dresden. This, however, weighs only 7 pounds and is wholly devoid of ornamentation."

Of Mayan Jades, Gann wrote: " From the earliest days of the Old Empire, a period going back at least fifteen centuries before the arrival of the Spaniards, green jade was regarded by the Maya of Central America as the most valuable of all the precious stones known to them. Both among the later Maya and the *Nahuatl* tribes, skilled lapidaries, whose occupation was hereditary, devoted their lives to fashioning it into such objects as ear plugs, gorgets, labrets, wristlets, anklets, and beads, many of them exquisitely engraved with human and animal figures, and far, to us naturally, the most interesting with hieroglyphic inscriptions, recording the contemporaneous dates of the objects upon which they were engraved." He observes : " The Leyden Plate was found in making an excavation for engineering purposes, and was not associated with any grave or ruin. How is such an extremely valuable object, as this must have been, come to have been lost by its owner nearly 2,000 years ago is difficult to imagine. Small and very valuable objects such as jade ornaments were probably carried for long distances in ancient times, either in the course of trade or as gifts from one ruler to another, and the probabilities are that places in which they are found are not usually their place of origin, and may not be within many hundred miles of the latter. The fact that two of the earliest known Maya dates are inscribed upon small objects, and not, as are the majority of the later ones, upon great monoliths, would tend to show that the invention of the Maya calendar and hieroglyphic systems antedated the custom of erecting stone monoliths at regular intervals, by a considerable period, though by how long our knowledge of the early history of the Maya is not at present sufficiently advanced to enable us to hazard a guess."

Gann goes on : " Carved Maya jade affords an extremely fascinating study for the archaeologist, as next to the great sculptured monoliths and the painted stucco walls, it formed probably

the chief channel through which the Maya artist found expression for his artistic conceptions. Bound down as the Maya were by religious conventions in painting, wood carving, and sculpture in stone, some of these jades compare favourably with the best Chinese and Japanese work, both in technical skill and in the beauty of the material used."

REFERENCES

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10. P. P. J. Valentino. *Two Mexican Chalchihuites*, Proc. of the American Antiquarian Soc., Oct., 1880-Oct., 1881, Vol. 1, p. 283-303.
11. *Journ. Gemmology*, July, 1955, pp. 142 and 143.

ASSOCIATION NOTICES

A book-plate has recently been designed for the Sir James Walton Memorial Library, which is administered by the Gemmological Association and the National Association of Goldsmiths.

The interest in this comprehensive trade library is quite remarkable and both organizations are grateful for various contributions that have been made of books, gems, minerals and donations. The book-plate was designed by Mr. C. Cullen.

TALKS BY MEMBERS

ATKINSON, J. C. : " Gemstones, synthetics and imitations," Newcastle West Rotary Club, 31st August, 1959.

BOWDEN, A. : " Gemstones," Cawsand, R.A.M.E. Women's Institute, Cornwall, 18th September.

WARREN, F. : " The story of diamond," Bedminster Rotary Club, August, 1959.

MEMBERS' REQUIREMENTS

Tourmaline tongs and quartz wedge. Ref. : 591.

GIFTS TO THE ASSOCIATION

The Council of the Association records with appreciation the following gifts :—

A collection of about 150 rough minerals, for teaching purposes, from John R. Fuhrbach, B.Sc., F.G.A., C.G. Texas.

A zircon crystal from C. V. Powell, Ltd., Cheltenham.

A number of books for the Sir James Walton Memorial Library from Professor W. F. Eppler including " The book of the pearl " by Kunz and Stevenson; " The production of precious stones in 1902, 1903, 1906-10, 1929, by various authors; " Queensland gems " by J. R. Sankey; " Gems and ornamental stones of California " by L. E. Aubury; History of the gems of N. Carolina " ; " Gems and precious stones of N. America " by G. King; " The diamond mines of S. Africa " by G. F. Williams," and various other texts.

EXAMINATIONS, 1959

The 1959 examinations attracted a large number of candidates and 183 sat for the preliminary and 60 for the diploma. Centres for the examinations were established in Australia, Canada, Ceylon, Finland, Germany, Holland, Kenya, New Zealand, Nigeria, Norway, South Africa, Southern Rhodesia, Switzerland, Thailand and the United States of America, apart from the United Kingdom.

Upon the recommendation of the examiners the Tully Memorial Medal has not been awarded. The Rayner prize has been awarded to Mr. P. W. T. Riley of Chester.

The following is a list of successful candidates, arranged alphabetically :—

Diploma

Qualified with Distinction

Blignaut, Adi, Johannesburg
Davis, George, Glasgow
Mendelsohn, Michael, Cape Town
Phillips, Alan L., Bardsey, Nr. Leeds
Shane, Leon, Toronto
Stocker, Philip L., London
van der Vlerk, Hendrik T., Schiedam, Holland

Qualified

Allden, Arthur G., London
Battersby, Keith W., London
Bergan, Kjartan E., Oslo
Betts, Geoffrey N., Birmingham
Britchfield, Charles F. J., Gravesend
Brousseau, Murray P., Toronto
Buckler, Albert N., London
Buitenen, A. Th. Chr. v., Jr., Holland
Bykersma, Barbara T., Toowoomba, Australia
Durrant, Anthony W., Ipswich
Engstrom, Hans W. E., London
Etienne, Lorette, Bangkok
Feer, Beatrice D., Geneva
Fitzpatrick, Noram R., Glasgow
Gaudernack, Lilly, Sandvika, Norway
Griffiths, William H., Birmingham
Gryska, Stephen, Worksop
Hall, Edwin F., Smethwick
Hope, Kenneth, London
Kay, Jonathan G. D., Liverpool
Kelley, William E., Lakewood, U.S.A.
Langton, Edward G., London
Marshall, Michael, Hull
Maund, Ann, London
Meadows, Everard C., Purley
Neil, Peter, Glasgow
Patience, Kenneth, Louth
Pilot, Lawrence M., London
Pragnell, John W., Bournemouth
Raven, Robert H., Chelmsford
Sack, Karl A., San Diego, U.S.A.
Schaffner-Allemann, Susanne, Basle
Schoien, Magnus, Skien, Norway
Seneviratne, Seetha, London
Shapland, Roger S. C., Cookham Dean
Sidoli, Jules, London
Smith, James S. A., Glasgow
Wall, John S., London
Whitehead, Henry J., Edinburgh
Weatherhead, Albert V., Wellington, N.Z.
Yates, Roy F., Manchester

Preliminary Qualified

Asmodt, Knut, Oslo
Abhyankar, Jagannath S., Bombay
Arend, Robert, Toronto
Beach, Michael L., Twickenham
Bearman, Janette O., Barking
Bills, Raymond F., Streetly
Burton, John R., London
Burwood, James R., Coventry
Bykersma, Barbara T., Toowoomba, Australia
Calderwood, Barbara J. R., Dalrn
Chalcroft, Pamela, Edinburgh

Charles, Russell J., Camp Hill, U.S.A.
Charles-Jones, Julia, London
Childs, Alan J., Hornchurch
Christophersen, Einar, Sandnes
Church, Bruce A., Wakefield
Collins, Christine D., Wolverhampton
Edge, William S., Glenelg
Elout, Helen, Holland
Erichsen, Bjørn T. N., Horten
Fernandez, Cyril W. A., Bombay
Finucane, Alfred D., London
Fisher, Leonard G., London
Fisher, Peter J., Cookstown, Co. Tyrone
Frith, Kathleen C., London
Gunnari, Tuula-Pia I., Helsinki
Gustafsson, Ethel K., Helsinki
Goward, David E., Matlock
Havem, Unni, Oslo
Heesom, Thomas H., Altrincham
Heikkila, Heikki S., Helsinki
Hinks, Peter J., London
Hool, Rene H., Rotterdam
Horrox, Conrad, Manchester
Hunter, John W., Glasgow
Hyman, Geoffrey M., St. Annes
Jackson, Jane K., Glasgow
Johnston, Suzanne S., Edinburgh
Johnstone, John M., Wirral
Juste, Robin L., South Brent
Kaksonen, Yrjo E., Helsinki
Kaskimies, Keijo L., Helsinki
Kelley, William E., Lakewood, Ohio
Kenworthy, Margaret, Bramhall
Kociumbas, Joseph, Toronto
Kothari, Udai C., Jaipur City
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Norman, Michael S. J., Bath
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Saller, Xaver, Munich
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Schidlowski, Dietrich, Pretoria
Schofield, John, Stalybridge
Scorer, Brian, London
Shane, Leon, Toronto
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Slack, Ernest H., Manchester
Snaddon, James, Sale
Springall, John E., London
Stuart, Donald R., Scarborough, Canada
Sundqvist, J. A. M., Helsinki
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Tannum, Brit, Fredrikstad, Norway
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CANADIAN GEMMOLOGICAL ASSOCIATION

The Canadian Gemmological Association was incorporated by Letters Patent, December 1958, with headquarters at Toronto, Canada. Meetings are held, bi-monthly, at the Westbury Hotel, Toronto, with members and their friends being notified about a week in advance of such meetings. The following is a list of the executive officers :

President : D. S. M. Field, F.G.A.
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The Advisory Board of the Canadian Gemmological Association comprises the following officers :

Dr. V. B. Meen, M.A., Ph.D., Royal Ontario Museum
Dr. W. M. Tovell, B.A., M.S., Ph.D., Royal Ontario Museum
Dr. D. H. Gorman, B.Sc., Ph.D., University of Toronto
H. M. Forth, Esq., G.G. (G.I.A.)
A. Lerman, Esq., F.G.A.
H. A. Creates, Esq., R.J. (A.G.S.)

The objects of the Canadian Gemmological Association parallel those of the Gemmological Association of Great Britain, and the rules and regulations governing procedure are also patterned after the Brit'sh Association. The chief

R. T. F. Boyd, D. S. M. Field, A. Ritchie, J. Stitt, J. Gunning, R. Wille.

function of the Canadian Gemmological Association is to maintain in Canada the high standards set by the accredited gemmological bodies in other countries.

No attempt is being made to set up Canadian courses of study in gemmology. Membership is open to all students and gemmologists who have achieved standing in organized courses offered by accredited gemmological bodies in Great Britain, the United States, Australia and Continental Europe.

MEMBERS' MEETINGS 1959-1960

October	22	Medical Society of London Hall, 7 p.m. Questions and discussion evening.
„	22	West of Scotland Branch—visit to Glasgow Police Museum.
November	17	Reunion of members (6 p.m.—7 p.m.) and presentation of awards (7.15 p.m.), Goldsmiths' Hall, London, E.C.2. Lady Walton has kindly consented to present the awards.
January	21	West of Scotland Branch—Mr. R. Webster on " Gemmological problems."
„	22	Midlands Branch Meeting.
February		New diamond film " Stars that shine for ever," British Council Cinema. Date to be arranged.
March	4	Midlands Branch Meeting.
April	12	Herbert Smith Memorial Lecture. Dr. A. F. Hallimond on " Polarization." Goldsmiths' Hall, London, E.C.2., 7 p.m.
„	21	West of Scotland Branch Annual Meeting.
„	29	Midlands Branch Meeting.
May	5	30th Annual General Meeting, Saint Dunstan's House, London, E.C.2, 6.45 p.m.
June	4	West of Scotland Branch summer outing.

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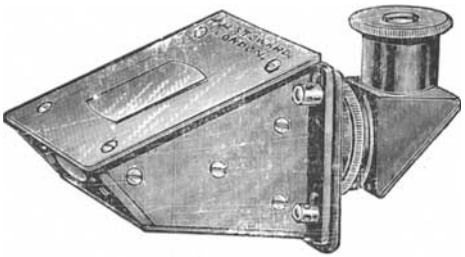

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THE JOURNAL OF GEMMOLOGY

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Vol. VII No. 5 JANUARY 1960

FACETED GEMSTONES

Cutting for Maximum Brilliance

By O. LeM. KNIGHT, B.E.(Syd.), A.M.I.E.(Aust.)

IT is surprising how little attention is paid by lapidaries to the optical properties of the gems they cut and polish, although these properties should determine the proportions of the finished gem.

Gemstones differ not only in their hardness and specific gravity, but also in their refractive index, critical angle, and degree of colour dispersion. These are the factors that must be taken into account when determining the proportions of any gem, if the maximum brilliance is to be obtained.

The early days of facet-cutting were marked by experimental attempts to find a type of cut that showed the gem to best advantage. This applied particularly to the diamond and resulted in the discovery by Peruzzi, at the end of the seventeenth century, of the " brilliant " form of cut. This first disclosed the real brilliance that could be achieved by " shaping " the diamond. Proceeding still by trial and error the proportions of the " brilliant-cut " were improved until, at the end of the nineteenth century, they were very close to the proportions that theory has since shown to be ideal.

It was not until 1918 that Tolkowski attempted to solve the problem theoretically for the diamond, and during the next twenty

years a number of distinguished scientists, notably in Germany, interested themselves in the ideal proportions for a " brilliant-cut " diamond and for gemstones of other refractive indices. Not only do their results agree in all essentials, but the correctness of the theoretical values has also been confirmed by measurement of a great number of gems, particularly diamonds, which have been graded by experts according to their degree of brilliance.

Whatever may be the practice in the diamond cutting industry the fact remains that for other classes of gems these theoretical studies have been largely ignored. Books on lapidary work rarely make reference to them, and when they do it is to dismiss them as the work of theorists who have never cut a gem in their lives. It appears to be the practice to emphasize that the practical cutter learns to treat each individual piece of rough on its merits. Curiously enough, this is frequently followed by a table of proportions recommended by the particular author. Even in courses on gemmology the significance of optical properties in relation to the cutting of gems appears to be rarely stressed. Gem material does not become a gem until it is cut and the gemmologist should be an authority not only on identification of gems but also on the correctness of their cut.

For the " brilliant " type of cut it has been proved that the theoretically ideal proportions result in maximum brilliance. For other types of cut the same general principles apply even though, as explained later, it is impossible to set down precise ideal proportions.

As the studies referred to are not readily available in English an endeavour will be made to explain the basis on which the ideal proportions have been calculated and to give a summary of the

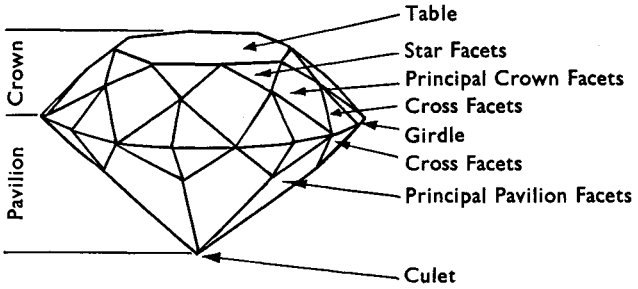

FIG. 1. *Brilliant-cut Gem.*

results. Fig. 1 shows a typical brilliant-cut gem with the terms usually applied to its various components.

In its completely general form the problem is perhaps unsolvable. It becomes necessary therefore to make two simplifying assumptions. These are that parallel light falls on the gem perpendicularly to the table and that light emerges from the gem also at right angles to the table. At first glance this may appear to be a very severe limitation on the lighting of a gem, but a little consideration will show that such is not the case.

When rays of light fall on a polished transparent surface from any direction, portion are reflected from the surface as lustre and portion are transmitted through the surface, the intensity proportions being determined by Fresnel's formulae. The rays that are transmitted through the surface of a gem fall first on the principal pavilion facets, and there they are either totally reflected on to the opposite pavilion facets or pass out in large measure through the back of the gem. Which of these two events happens depends on whether the light strikes the pavilion facet at an angle greater or less than the critical angle for the particular material. This is shown in Fig. 2, the angles being measured between the light ray and the normal to the surface on which the light falls.

The angle at which a ray of light meets the pavilion facet depends on the angle at which it is incident on the table, the refractive

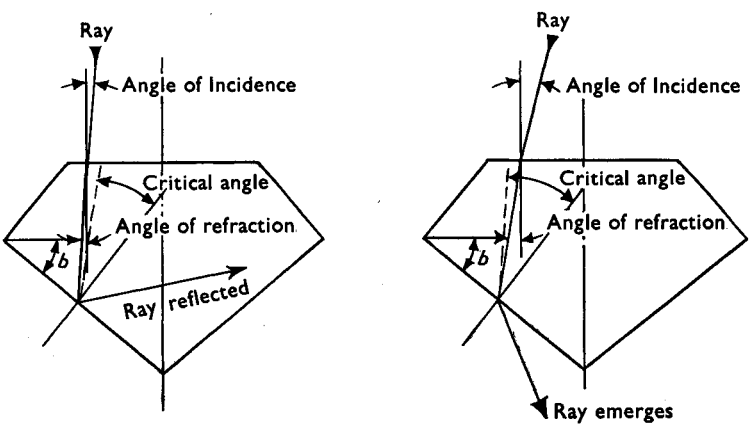

FIG. 2. *Conditions for reflection or emergence of light.*

index (n) of the gem, and the angle of inclination of the pavilion facet (b).

Light rays perpendicular to the table are not refracted on entering the gem, but inclined rays are refracted, the angle of refraction depending on the refractive index of the material. It can be shown that for gems of high refractive index light rays can be incident on the table at a comparatively large angle before being so refracted that they strike the pavilion facet at less than the critical angle. Gems of low refractive index, however, have such a large critical angle that practically all inclined rays on the table of a normally proportioned gem will strike the pavilion at an angle less than the critical angle and will pass through the facets instead of being totally reflected. Thus for diamond ($n = 2{\cdot}42$) the angle of incidence may be as high as $37\frac{1}{2}°$ before light is lost through the pavilion facets, whereas for topaz ($n = 1{\cdot}63$) the limiting angle of incidence is only about 2°.

Fig. 3 shows the effective cone of light for gems of varying refractive index, for a pavilion angle of 39°. All light entering the gem within this cone is totally internally reflected at both pavilion facets. From this it can be seen that with the exception of the diamond there is no great error in assuming that the only effective light falling on the gem is that at right angles to the table.

It can further be shown that if a gem is so proportioned that vertically incident light emerges vertically, then inclined incident light will also emerge in a direction parallel to its incidence ; i.e. towards the source of light.

Incidentally, this means that for the best effect a gem should be viewed from the direction in which it is illuminated. The import-

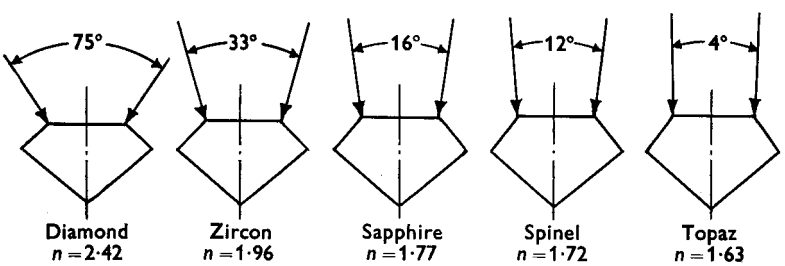

FIG. 3. *Effective cones of light for different values of* (n).

ance of this is not always realized when gems are being displayed ; nor is the fact that illumination should be from a point source and not from light diffused by opal globes or fluorescent tubes.

Having accepted the assumptions that the incident light is perpendicular to the table, and that its emergence from the gem is in a parallel direction, it is now possible to state the conditions to be fulfilled in order that a gem may have maximum brilliance. These are :

1. That the gem shall have around the table an even number of principal crown facets, and just as many principal pavilion facets, these being opposite to one another, i.e. lying in a common meridian.
2. That the angle of the pavilion facets (*b*) shall be such that the light incident on the table and principal crown facets is totally internally reflected by the pavilion facets.
3. That the light incident on one side of the table, from its centre to its edge, shall, after internal reflection, emerge from the full length of the principal crown facet on the opposite side of the table.
4. That the angle (*a*) of the principal crown facets shall be such that the internally reflected light strikes the facet at less than the critical angle, and, after refraction, emerges in a direction parallel to the light incident on the table.

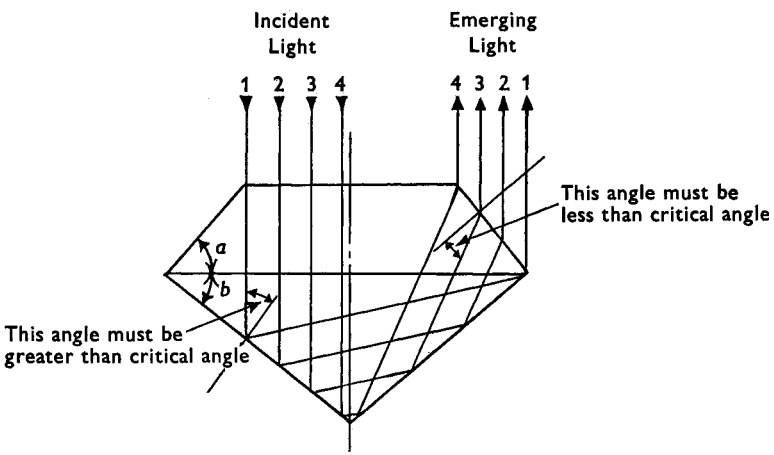

FIG. 4. *Conditions for total utilization of light.*

TABLE 1

THEORETICAL OPTIMUM PROPORTIONS FOR "BRILLIANT-CUT" GEMSTONES

GEM MATERIAL			ANGLES OF PRINCIPAL FACETS		PROPORTIONS OF GEM As a percentage of girdle diameter		
NAME	Refractive Index (n)	Critical Angle	Crown (a) Fig. 4	Pavilion (b) Fig. 4	Table Dia.	Height Crown	Height Pavilion
RUTILE	2·75	21°20′	38°56′	38°35′	·559	·179	·399
DIAMOND	2·42	24°26′	41°06′	38°42′	·561	·192	·40
CASSITERITE	2·04	29°20′	44°55′	38°48′	·571	·215	·402
SPHENE	1·96	30°41′	46°29′	38°51′	·574	·224	·403
ZIRCON	1·96	30°41′	46°29′	38°51′	·574	·224	·403
GARNET (ANDRADITE AND ALMANDINE)	1·89	31°57′	47°24′	38°53′	·577	·230	·403
GARNET (SPESSARTITE)	1·79	33°57′	49°10′	38°58′	·582	·244	·403
CORUNDUM	1·77	34°25′	49°45′	38°58′	·583	·247	·405
CHRYSOBERYL	1·75	34°53′	50°00′	38°59′	·583	·248	·405
GARNET (PYROPE AND HESSONITE)	1·745	34°57′	50°12′	39°00′	·584	·250	·405
SPINEL	1·717	35°39′	50°58′	39°01′	·586	·255	·406
OLIVINE	1·677	36°37′	51°42′	39°03′	·588	·261	·406
TOPAZ	1·634	37°44′	53°00′	39°06′	·591	·271	·406
TOURMALINE	1·631	37°52′	53°00′	39°06′	·591	·271	·406
BERYL	1·578	39°19′	(43°)	39°10′ (40°)	(·48)	(·24)	(·42)
QUARTZ	1·548	40°15′	(41°)	39°12′ (41°)	(·40)	(·26)	(·43)

Crown and pavilion angles, and heights are measured from the girdle plane. All proportions are referred to a girdle diameter of 1·0.

These conditions are illustrated in Fig. 4, which, for clarity, shows only the conditions for light incident on one side of the table. If this is repeated for the other side of the table it will be seen that all light falling on the table emerges through the crown facets. By reversing the arrows it can also be seen that vertical light falling on the principal crown facets will emerge through the table. Thus the whole of the crown is illuminated.

In 1926 S. Rosch determined, by graphical methods, the proportions and angles of the principal facets to fulfil the above conditions, and in the same year A. Johnsen arrived at identical proportions through strict mathematical analysis. Their work has since been confirmed and elaborated by other scientists and verified by practical cutting tests. Without going into the details of the somewhat involved calculations the results are tabulated in Table 1.

This table gives the actual calculated values for the refractive indices shown in Col. 2. However, the refractive index for any particular variety of gem is rarely constant, and, further, it is hardly possible to cut to an accuracy better than half a degree. For practical purposes, therefore, the angles given in the table may be rounded off to the nearest degree and the proportions to the second place of decimals without adversely affecting the result. Thus, for zircon, the angle of the pavilion facets may be taken as 39°, that of the principal crown facets as 46° and the crown and pavilion heights as ·22 and ·40, respectively, of the girdle diameter.

Three facts stand out very prominently in Table 1.

First.—The very slight difference in the calculated angles of the pavilion facets (*b*) and consequently in the height of the pavilion ; less than half a degree over the whole range. This arises from the fact that incident light perpendicular to the table is not refracted on entering the gem. It is reflected internally and therefore only subject to the law of reflection (angle of reflection equals angle of incidence).

Second.—The relatively large difference in the angles of the crown facets (*a*) and consequently in the proportions of the crown. This is due to the fact that light emerging from the crown facets

is highly refracted and the amount of refraction varies with the refractive index of the gem.

Third.—The fact that for gems having a refractive index below 1·58 the calculated angle for the pavilion facets is less than the critical angle of the gem. This means that a refractive index of 1·58 is the lowest for which a theoretically perfect brilliant-cut is possible.

In regard to the third point, which applies particularly to beryl and quartz, Table 1 gives (in brackets) proportions based on a pavilion angle 1° greater than the critical angle. This gives some cutting tolerance above the critical angle. If the pavilion angle is made much greater than this the brilliance of the gem is greatly reduced. Further, increased pavilion angles require considerably reduced crown angles to avoid loss of light through the pavilion facets. For example, if the angle of the pavilion facets for quartz is made 42°, the angle of the principal crown facets must be less than 35°, if vertically incident light on these facets is not to be so lost. So much for the principal facets which determine the proportions of the gem.

Secondary Facets

These comprise 8 star facets surrounding the table and 16 cross facets surrounding the girdle both on the crown and pavilion, and, excepting for gems of high dispersion, as diamond and zircon, the angles of these facets are not critical and have not received theoretical study. For gems of high dispersion, as Rosch has pointed out, the cross facets above the girdle contribute largely to the fire and their angles should be such that the internally reflected rays strike them at only slightly less than the critical angle. This ensures maximum colour dispersion. The cross facets below the girdle serve to reflect some of the light that falls obliquely on the table and meets the pavilion facets above and outside the area lying immediately beneath the table. One point should, however, not be overlooked. An examination of Fig. 4 shows that while vertically incident rays passing through the table fall only on that portion of the pavilion facet immediately beneath the table, the whole of the opposite pavilion facet is used for their reflection. For this reason care should be taken to see that the principal pavilion

facets are not unduly reduced by making the secondary facets too large.

Step-cut Gems

Some reference should be made to step-cut, or emerald-cut, gems, although these are not included in the theoretical studies referred to earlier. This type of cut is usually applied to coloured gems in which the absorption of light is appreciable, and their brilliance is thereby reduced. Their forms are too well known to need description and vary too greatly to permit the calculation of an " ideal " form. Some rules can, however, be laid down broadly to assist in obtaining maximum brilliance. In the first place no pavilion facet should ever be cut at less than the critical angle of the gem. If it is, a " window " will result ; that is, it will be possible to see right through the gem from the table. This is a particularly common fault in step-cut gems. The angle of the lowest row of pavilion facets can quite satisfactorily be made the same as the angles for pavilion facets given in Table 1. They should not, indeed, be more than a degree or two below these angles even for gems having a low critical angle, such as zircon.

The upper rows of pavilion facets are cut more steeply, but the increase in angle, particularly between the two lowest rows of facets, should not be unduly great. Steps increasing by 5° can be cut without difficulty and this should not be greatly exceeded for the lowest rows of facets. Certainly many step-cut gems are cut much more steeply than this with pleasing results. But although increased weight and greater depth of colour are thereby obtained it is at the cost of some loss of brilliance.

As the steepness of the pavilion facets is increased so must the height of the crown be reduced by decreasing the angle of the crown facets. If the bottom row of pavilion facets have an angle of 39° and the upper rows of pavilion facets increase in steepness by 5° for each row, then the total height of the gem will remain the same as in Table 1 and the angle of the crown facets will be reduced by about 10° as compared with the values shown in Table 1. As a general rule the width covered by the lowest pavilion facets should be approximately equal to the width of the table. A comparison

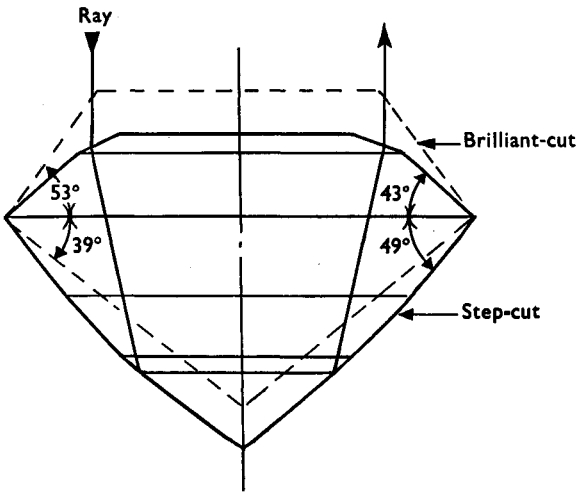

FIG. 5. *Comparison of step-cut and brilliant-cut topaz* ($n = 1{\cdot}63$).

of such a step-cut gem with an ideal brilliant-cut gem is shown in Fig. 5.

The narrow row of facets surrounding the table can be so cut that vertically incident light on a facet at one side of the table will have a symmetrical ray-path within the gem and will emerge vertically through the facet on the opposite side of the table. Such a ray is shown in Fig. 5. The angle of these facets depends on the angle of the lowest pavilion facet and on the refractive index of the gem. If the lowest pavilion facet has an angle of 39° the angle of the table facets will vary from 24° for zircon ($n = 1{\cdot}96$) through 27° for sapphire ($n = 1{\cdot}77$) to 29° for topaz ($n = 1{\cdot}63$). If the lowest pavilion facet has an angle of 38° then the angles of the table facets should be about 2° greater than these values.

It is frequently stated that stones of deep colour should be cut shallower than usual and that pale stones should have greater depth, in order to improve the colour. While the step-cut lends itself to such practices it is very questionable whether any improvement can be so gained. Any alteration to the tint, and it could only be slight, is more than offset by the loss of brilliance due to imperfect

reflection within the gem. Deep coloured rough, as for example deep blue sapphires, will only show the colour to advantage if cut into small gems of the correct proportions, preferably brilliant-cut ; while for pale coloured gems the combination of maximum brilliance and pale colour is always more attractive than a " dead " stone of slightly deeper colour.

Size and Number of Facets

It is sometimes asked whether the 58 facets (including table and culet) of the standard brilliant-cut (Fig. 1) should always be applied to a brilliant-cut gem regardless of size. Rosch and others have pointed out that for a diamond, or gem of high colour dispersion, the size of the facets has an important bearing on the " fire." For this reason alone large diamonds require more facets than do small ones. Rosch has suggested an upper limit of 3 millimetres and a lower limit of $\frac{1}{2}$ millimetre for the size of facets for the diamond. For a standard brilliant this would correspond to sizes from about 10 carats to 1/8 carat. For larger gems the number of facets should be increased, and for smaller gems some or all of the secondary facets may be omitted.

For coloured gems the conditions necessary for colour dispersion are not important and the standard brilliant-cut can be very beautiful for very much larger gems. For step-cut gems the number of " steps " both on crown and pavilion can be varied widely so long as the general rules set out earlier are observed.

In any case, and whatever the type of cut employed, the general principles outlined above should be followed. That is, that vertical light falling on the table should be totally internally reflected and should emerge from the crown facets (not through the table) at an angle as nearly perpendicular to the plane of the table as possible. If these conditions are fulfilled the maximum brilliance will be achieved.

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Gemmological Notes

JAPANESE CULTURED PEARLS

JOHN PROBUS

The Japanese cultured pearl fisheries have been badly hit by a hurricane. There is likely to be only about half of the normal production during 1960 and prices of cultured pearls have hardened.

CRYSTAL INCLUSION IN EMERALD

V. G. HINTON

A microscopic examination has been carried out on an emerald having interesting inclusions. The emerald was of poor quality, country of origin unknown, and of no commercial value. It was a very flat, square step-cut emerald of pale colour and when viewed with a hand lens showed a great many dark inclusions. On closer examination with a microscope these were found to be needle-like crystals, and when viewed with a white light appeared as yellow-brown fluorescing crystals. These were sharply defined, as shown in the attached photomicrograph. There appeared to be some form of growth on the surface of the crystals, but this may have been a dendritic overgrowth. There was no method available for identifying the crystal inclusions but their crystal form and physical properties suggested aragonite.

The crystal was the property of Mr. H. L. Blackmore, who gave permission to publish the photograph.

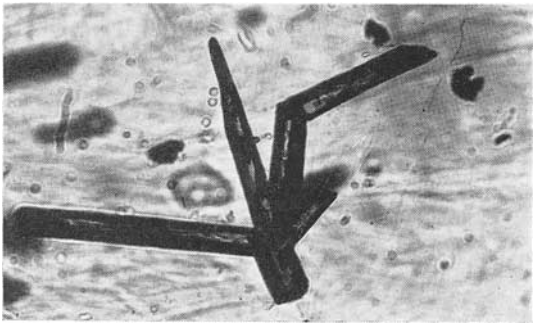

Crystal inclusion in Emerald

PLONK TESTING

A. E. FARN.

My fellow gemmologist and friend, Dr. E. H. Rutland, delights in, and is an expert at " Plonk Testing." To " plonk " (an unusual gemmological term meaning " to go off the deep end ") is to view a gemstone, usually *not* one of the better known gemstones, which has recently come to hand and to state categorically what the stone is—usually to the delight of the possessor since he is usually armed with details in advance.

A rule of thumb approach and a keen eye backed by knowledge of gemmology are the essentials to expertise. Possibly the hardest school is that which backs its judgment by placing not the stone upon the refractometer but its hand in its pocket.

Having attended many lectures and listened to much theory on the subject of gem testing and the rival and relative merits of certain instruments, I am reminded of certain examination questions phrased in the following style :—

" What do you consider the equipment necessary to furnish a model laboratory ? "

or " What are the most important or imperative instruments a gemmologist needs ? "

To answer such questions one usually has or shows a marked preference for certain instruments or gives obvious indications of techniques favoured by an instructor. Some people are keen on refractometer work, others specific gravity or the spectroscope, and some of course combine the use of each. There are some tests so rudimentary and positive that it is needless to go further, which of course admits a knowledge of gemmology.

Whilst testing by sight is not necessarily accurate, it is usually applied with a background of knowledge and reasoning. I should have stated earlier that perhaps a lens is permitted, but no more. An instance of such testing could be a completely colourless (or white) stone, whichever term is preferred, with one or two minute bubbles, no double refraction discernible but perhaps a slight " chatter-marking "—a sure sign of heating of corundum. Therefore the stone would be a synthetic corundum. This, of course, is a very obvious instance. There are, doubtless, countless others which will spring to mind. Most gemmologists, of course, test stones for enjoyment at leisure; professionals test against the clock and seldom

have much time to browse amongst the undoubted beauties of inclusions in Burma or Siam rubies. The latter, though less expensive commercially, are amongst the most beautiful stones from an inclusion point of view. Having tested some tens of thousands of stones I am afraid I do not linger too long in throes of delight on seeing either a Ceylon zircon spectrum or hessonite garnet inclusion. These are merely speedy recognition signs for testing.

Quite recently a parcel of 284 cts of mixed round stones of various colours, and approximately 3,500 stones came into my possession. My first reaction was to glance swiftly through the stones spread out on the table on a sheet of white paper and pick out any likely stones, i.e. those which " looked " interesting. Most seemed to me to be the product of Ceylon—later proved correct. Two stones only proved to be of a likely hue and appearance. The remainder I sorted by colour into piles of brown hessonite garnets, red/pink Ceylon garnets, pale blue, green and yellow Ceylon sapphires, and an intriguing assorted coloured section of zircons of every hue. The colourless portion, thank goodness, was very small —these are always a headache except in this instance.

Having decided the piles on colour, the next step was to check by spectroscope. Every pink/red garnet was swiftly pushed into a spot of light from an intensity lamp focused onto the table, and the garnets fed from left to right. With the spectroscope held in the right hand some 600 stones were accurately observed and dealt with in about two hours (having all the same spectrum helped a lot). The zircons came next and the same procedure took place, except that here some had a full Ceylon spectrum and some just a hint of the 6535Å line, some metamicts. Again this was a speedy test of approximately similar quantities and time. A point of interest here is that the quick focus spot method of scattered light will give a sharp absorption spectrum from a stone of less than one-tenth of a carat whereas by transmitted light through a microscope it would be flooded out and the eye would quickly become fatigued. The next parcel, possibly the largest in number, were those "plonked" as hessonites. Here there could be (I hoped) a Spessartite or two and the spectroscope came into play once again. None of the stones showed a spectrum, my eye being focused on the blue section end looking for a sign of manganese in the make-up of the stone. There was no need to take the R.I. of any of these stones since a quick check of samples by lens and use of corn tongs showed all had

the familiar diopside crystal inclusions—the characteristic sign of hessonite. After a time, when one has concentrated solely on one colour of gemstone, the eye becomes attuned and exceedingly quick to distinguish any unusual stone. These three groups had reduced the bulk by about 85%.

The next lot were the potential Ceylon sapphires. Knowledge of colour shades indicated no synthetics being present, since these latter stones are usually a finer colour than their natural counterparts.

Although the spectroscope was speedy in picking out green-blue sapphires, it only gave a hint of chromium being present in the pale shades of blue sapphires. This was interesting to note, since the evidence was also proved by the slight change from pale blue to pale lavender or pink when being transferred from daylight on the table to the artificial light on the focus from the intensity lamp. Although these stones were small, quite a fine bright fluorescent line could be picked up by eye on tilting the spectroscope to the left. This is a useful tip when " searching " for a spectrum, e.g. commercial quality Ceylon sapphires do not readily or easily show a 4500Å line, but tilting the spectroscope will often bring it into view. (In the latter case the spectroscope is tilted to the right). Having hinted perhaps that my tuition was carried out in an atmosphere partial to absorption spectroscopy, I must state the obvious and point out that for a gemmologist it is red on the left, blue on the right, when looking through a spectroscope. The pale blue and yellow sapphires together were checked by lens and tongs for chatter-marking and feathers, of which fortunately there was an abundance. Ceylon liquid feathers and two-phase inclusions are a joy in speedy establishment of origin.

The hard core of " seeded " stones now came to be tested. Several mauve/brown stones proved to have the refractive index of natural spinel, two other deep golden brown stones were chrysoberyl, whilst the remainder of colourless stones were quartz and topaz respectively. Considering its travels and origins I was lucky not to find a single paste or synthetic stone in the parcel.

SYNTHETIC EMERALD

D. WHEELER

There has been objection in the U.S.A. to the use of certain descriptions which have been used in promoting the sale of

" Chatham cultured emeralds." There has also been a denial of all the material allegations and the matter is now before the Federal Trade Commission. In many countries these laboratory-made stones have been described as synthetics and the jewellery trade has accepted this without question. Presumably the new hydrothermally produced rubies, from the same laboratory, will be affected in what they may be called by the Commission's future decision. There is good reason for calling these products synthetic, as, on the other hand, there is a reasonable case for calling them by a name which indicates the method by which they have been formed. The Vernuil synthetic is a flame-fusion product and the " cultured " stones are grown from a saturated solution, by what has been called a melt-diffusion process.

SYNTHETIC DIAMONDS

JOHN PROBUS

De Beers Consolidated Mines Ltd. have fairly quickly followed the General Electric Company of America in producing synthetic diamonds of industrial quality. Similar processes were used by both companies and other developments are expected from Holland and Sweden, where synthetic production has previously been announced. The latest report of the G.E.C. is that both the colour and shape of the crystals can be controlled. The scientist in charge of the De Beers production was Dr. J. H. Custers, Director of the De Beers Adamant Laboratory.

MORE RUBIES FROM THE LABORATORY

G. ANDREWS

Following the report in 1959 (Journal of Gemmology VII, 1, 16) of the production of hydrothermally produced corundum, C. F. Chatham has announced the making of ruby in his laboratory. The problem for gemmologists and jewellers is distinguishing these new products from the natural and first evidence indicates that it may be more difficult than differentiating between natural and laboratory-produced emerald. Curved growth lines are obviously absent and the new product contains various types of inclusions similar to those which occur in the natural stone, due no doubt to the crystals used as " seeds " for the new growth. The new stones fluoresce brightly but not all phosphoresce. The new product raises issues of considerable importance to the jewellery trade.

AN UNUSUAL STAR-BERYL

By W. F. EPPLER

BERYL with asterism must be very rare, as it is seldom seen among gemstones. The gemmological literature mentions only a few cases of beryl with this phenomenon. V. Goldschmidt[1] described a ball of a bluish and transparent beryl (aquamarine) from Brazil, with fine tubes parallel to the c-axis. Under proper illumination the tubes cause a complete circle of reflection round the ball, so that in this case a cat's-eye effect is exhibited.

On the other hand, Hauswaldt[2] demonstrated an impressive asterism on beryl in transmitted light, showing a sharp-lined, six-rayed star.

E. H. Rutland[3] described a dark brown beryl from the Gov. Valadares area of Minas Gerais, Brazil, which has a somewhat poorly developed star. It was found by the writer[4] that coarser and finer skeletons of orientated inclusions of ilmenite were responsible for this asterism.

An unusual star-beryl, owned by Mr. B. W. Anderson, represents a valuable rarity. It is of an agreeable greenish colour with a greyish tint, translucent to nearly opaque, and it exhibits a perfect star of the quality of a good rose-quartz asteria. Anderson found the S.G. to be 2·682 and the values for the R.I. with $n\omega = 1{\cdot}569$ and $n\varepsilon = 1{\cdot}564$. The size of the well cut stone was 93 carats.

(This had been the original weight, for Anderson generously agreed that from the convex back a slice could be sawn to obtain the material for further investigations. The operation did no harm to the beauty of the stone, even if it caused the loss of a number of carats).

A first look through the microscope revealed that the star-beryl itself is transparent. Only a multitude of crystal inclusions of different kinds reduces the transparency strongly. The inclusions are densely distributed throughout the entire stone (Fig. 1). They consist of opaque flakes and groups of transparent crystals. In reflected light (Fig. 2) it is easy to observe that the flakes are six-sided and that they are orientated parallel to the basal plane of the host crystal. By using a higher magnification (Fig. 3), they reveal a bronze-yellow colour. It was found that they consisted of pyrrhotite, FeS, including in themselves brighter spots of a brass to

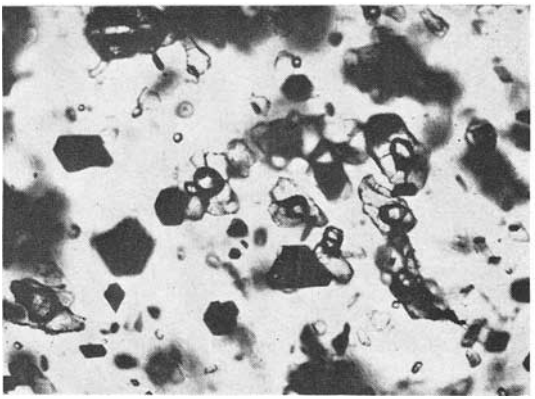

FIG. 1.
Star-beryl with inclusions of black flakes of hexagonal shape, and of transparent crystal groups. View perpendicular to the basal plane (0001); transmitted light, 50 ×

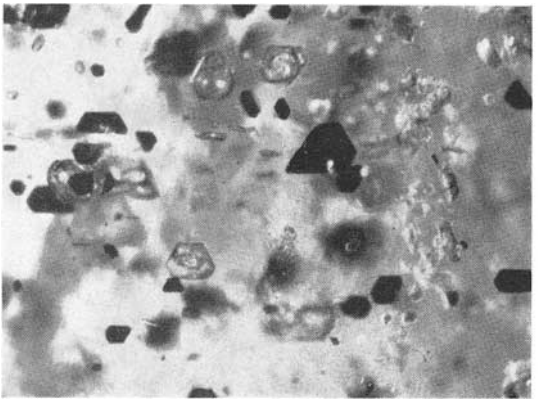

FIG. 2.
Same as Fig. 1, in reflected light, 65 ×

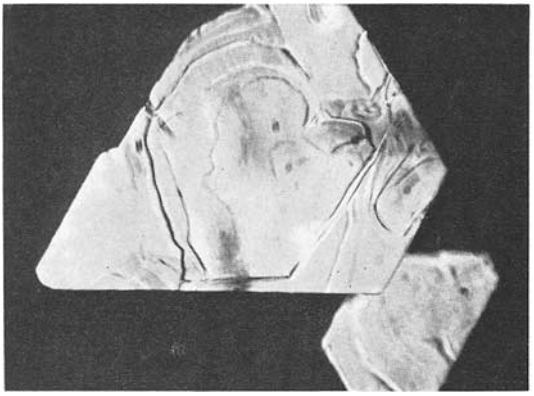

FIG. 3.
A tabular crystal of pyrrhotite as the cause of asterism in the star beryl, part of Fig. 2, reflected light, 220 ×

golden yellow colour of the tetragonal chalcopyrite, $CuFeS_2$. In Fig. 3, the small spots appear faintly on the left side and in the upper right corner of the big plate.

These very thin but strongly reflecting tabular crystals of pyrrhotite are the cause for the star-effect of the beryl. Their orientation parallel to the basal plane with their edges parallel to the first order prism of the host beryl makes it obvious that they originated by exsolution. They are, therefore, of secondary or epigenetic origin.

The transparent crystal groups, which have no particular orientation to the host crystal, do not contribute to the star-effect. They present difficulties with respect to their nature and origin. As it is shown in Fig. 4, each group consists of several individual crystals, which one kind differs considerably in R.I. from the other. To anticipate the results of testing, which will be explained later, the following seems to be very likely. The darker and mostly rounded crystals in the centre of each group have a higher R.I. than the including beryl. They proved to be epidote. They are overlying one or several fragment-like pieces of another crystal with a R.I. lower than beryl, and which could be determined as quartz. The pieces of quartz have different orientations. In each group they are closely put together and sealed or cemented by the over- (or under-) lying epidote crystal. Such a combination of two different kinds of crystals as inclusions in a third crystal is very strange and not yet known in any other gemstone.

Besides the flakes of pyrrhotite and the crystal groups of epidote and quartz, the star-beryl contains further inclusions of less frequent distribution. One of these is clusters of pyrite of which, unfortunately, no photomicrograph could be taken. Finally, acicularly developed crystals of apatite with the typical cleavage cracks could be observed, of which Fig. 5 represents an example.

The method of investigation, in this case, was absolutely unorthodox. From the slice of star-beryl, a piece of sufficient size was taken and crushed in a steel mortar by a few gentle blows. The fragments obtained by this brutal procedure varied in size, but they proved to be very useful. Fig. 6 and 7 show such a fragment of random orientation, embedded in bromoform and in benzylbenzoate respectively. Both pictures give a general view of the distribution and the arrangement of the dark-rimmed epidote and the brighter quartz likewise.

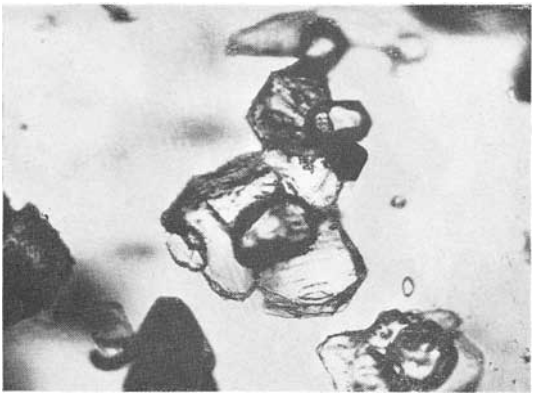

FIG. 4.
Groups of transparent crystal inclusions seen perpendicular to the basal plane of the star-beryl, 120 ×

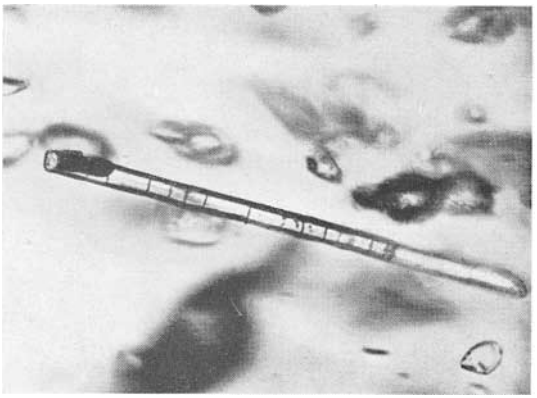

FIG. 5.
An unorientated apatite as an inclusion in the star-beryl. The lack of sharpness at the right end of the crystal is due to other overlying inclusions, 120 ×

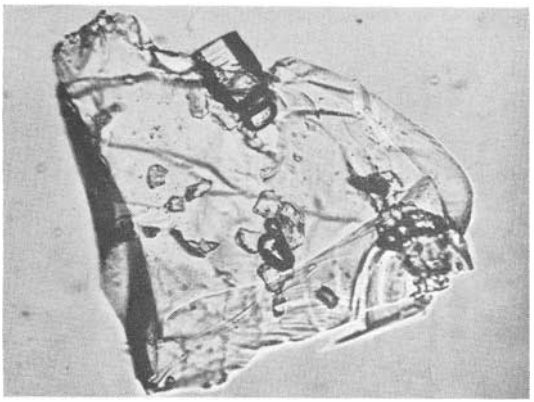

FIG. 6.
A fragment of star-beryl embedded in bromoform ($n = 1{\cdot}59$), 65 ×

Fig. 8 and 9 represent another fragment of the star-beryl in ordinary and in polarized light. The flakes of pyrrhotite appear as small but somewhat indistinct lines indicating that the fragment nearly follows the direction of the c-axis. Also in this direction, the distribution and the arrangement of the epidote-quartz inclusions are practically the same as in Fig. 6 and 7. From this can be concluded that the crystal groups do not prefer a particular orientation. A confirmation is offered by Fig. 10, which shows a fragment approximately parallel to the base-plane of the beryl. This orientation can be deduced from the inclusions of pyrrhotite, which appear in this position as six-sided plates. Also in this case, no preferred orientation of epidote and quartz can be observed.

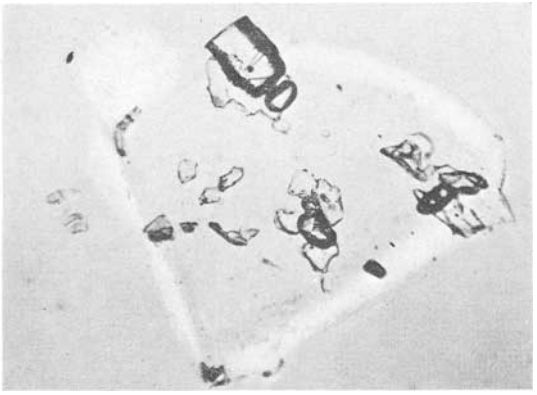

FIG. 7.
Same fragment of star-beryl embedded in benzylbenzoate B B E ($n = 1{\cdot}570$), 65 ×

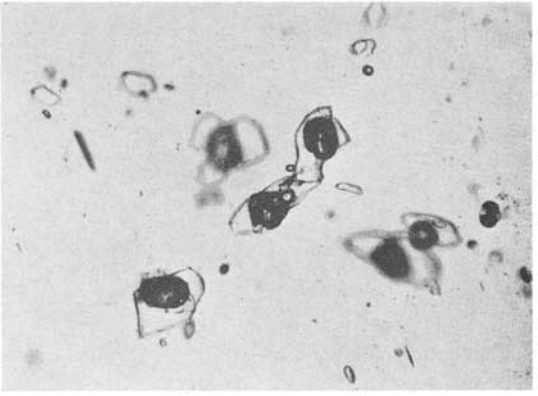

FIG. 8.
A fragment of star-beryl nearly parallel to the c-axis, embedded in BBE ($n = 1{\cdot}570$), 65 ×

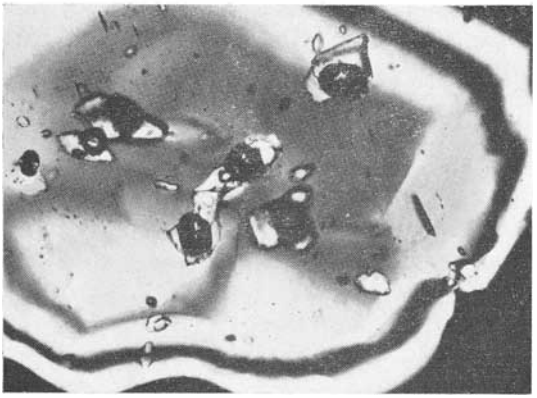

FIG. 9.
Same fragment of star-beryl embedded in BBE ($n = 1{\cdot}570$), in polarized light, 65 ×

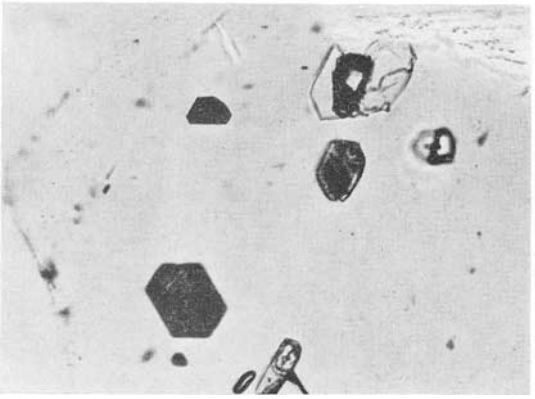

FIG. 10.
A fragment of star-beryl approximately parallel to the base plane, embedded in BBE ($n = 1{\cdot}570$), 120 ×

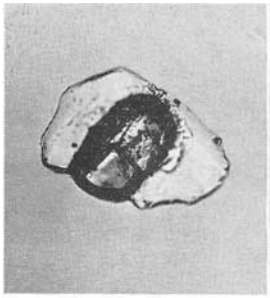

FIG. 11

FIG. 12

FIG. 11.
A crystal group consisting of two differently orientated quartz particles in contact with a rounded crystal of epidote ; separated from the star-beryl, embedded in BBE ($n = 1{\cdot}570$), 120 ×

FIG. 12.
An epidote crystal separated from the star-beryl, embedded in BBE ($n = 1{\cdot}570$), 65 ×

The smaller fragments of the crushed star-beryl have been carefully examined to find pieces of pyrrhotite, but without any success. It can only be assumed that the brittle and very thin plates of these crystals—they have a thickness of a few microns only—have been powdered into such small particles, that their size lies below the given possibilities of observation.

Other of the smaller fragments of the star-beryl proved to be epidote, quartz, apatite, and pyrite. Fig. 11 displays a crystal group, separated from the star-beryl by the crushing process. It consists of two pieces of quartz of different orientation, which have no crystal faces but look like broken chips with irregular borders. Their seam is covered by a rounded epidote crystal. Also single chips of quartz can be encountered in the star-beryl as well as in the powder obtained by crushing. The latter have been tested by the use of proper liquids which allowed to find the R.I. to be between 1·54 and 1·56 and the S.G. at 2·65. A comparison with similar chips obtained by crushing a natural quartz crystal had the same results.

It is extremely difficult to understand what might have been the cause of embedding chips of quartz in a beryl. Even more difficult is it to find an explanation for the fact that two or more quartz chips are in tight contact and, moreover, cemented by an epidote crystal which, on its part, looks as if it had been strongly water-worn. Only one fact seems to be certain, namely, that quartz chips and rounded epidote crystals are pre-existing inclusions, which had already passed an impetuous period of crystal life before they finally became entrapped within this particular star-beryl.

Among the smaller fragments of the powdered beryl, a certain number of epidote was present, with different shape and size. With the aid of the immersion method it was found that their R.I. is very closely near 1·74, and with the heavy liquid method resulted a value for the S.G. of approximately 3·4. Every crystal of this kind is doubly refractive, and has an angle of inclined extinction within the limits of 1° to nearly 3°. These figures are in conformity with those quoted for epidote by E. S. Larsen and H. Berman.[5] It seems somewhat puzzling that the enclosed and the separated crystals of epidote did not display even a shadow of the usually marked green colour. But the colour may change with the different contents of iron. On the other hand, the smallness of the crystals can make them appear to be colourless.

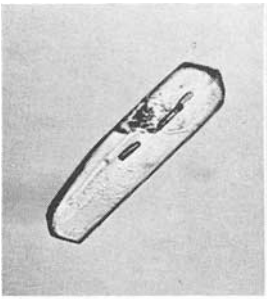

FIG. 13.
An epidote crystal separated from the star-beryl with elongated crystal inclusions ; embedded in alpha-bromonaphthalene (n = 1·659), 120 ×

FIG. 14.
Part of an epidote crystal with inclusions, separated from the star-beryl, embedded in BBE (n = 1·570), 65 ×

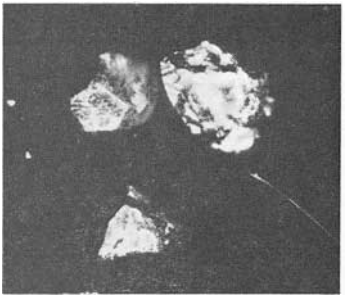

FIG. 15.
Exclusions of pyrite, obtained from the star-beryl. One of these particles exhibits a pentagon, 22 ×

Figs. 12-14 show three typical forms of epidote separated from the star-beryl. Fig. 12 shows a rounded crystal, with a marking of the spot where formerly two chips of quartz had formed a borderline. It is the broader black line in the middle of the crystal which indicates a still existing step. Besides this, the epidote contains some inclusions of an unknown nature.

The epidote in Fig. 13 is embedded in a liquid of higher refraction. • Therefore, elongated inclusions of doubly refractive crystals are visible, the R.I. of which is distinctly lower than that of the host crystal.

Among the crushed pieces, the apatite with its characteristic cleavage cracks was only met with in very small pieces. It could be found that the R.I. of such pieces is not far from 1·64, and the S.G. nearly coincides with the value of Thoulet's solution (3·17). These figures, in combination with the typical appearance of the material as an inclusion in the star-beryl (Fig. 5) are sufficient for its identification.

No photomicrograph could be taken of the clusters of pyrite which the star-beryl contains. But the "exclusions," which are

shown in Fig. 15 could be determined as pyrite. One of the particles exhibits a pentagon, the crystal face of the pentagonal dodecahedron (210). In this crystal form pyrites can be very often encountered.

Summary

The unusual star-beryl consists of transparent beryl, which contains a multitude of crystal inclusions. Because of this, the stone appears to be translucent to nearly opaque. The inclusions are : tabular and very thin pyrrhotite, FeS, which is the cause of a perfect star ; crystal groups consisting of a combination of quartz chips and rounded crystals of epidote (both kinds of materials also appear as independent inclusions) ; rod-like developed apatite and clusters of pyrite.

Acknowledgment

The author is indebted to Mr. B. W. Anderson for so generously allowing a slice to be taken from the star-beryl and to Prof. Dr.Ing. A. Maucher, Director of the Geological Institute, University of Munich, for the determination of the pyrrhotite and pyrite inclusions.

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Gemmological Abstracts

LEIPER (H.). *Botryoidal nephrite find in California.* Lapidary Journ., Aug. 1959, p. 394.

A conglomerate mass of serpentine, with botryoidal lumps of nephrite closely packed together throughout the piece, has been found in San Diego County, California. The nodules are complete in themselves and the colour of the jade is light to emerald green. When some of the nodules were sliced, the centre of the slabs were a white mutton fat, the outside a pleasing green. It has been suggested that the material is a pseudomorph after chalcedony nodules—the forms they take are identical. Very little is known about the causes of metamorphic changes affecting nephrite and its associated minerals.

S.P.

CROWNINGSHIELD (G. R.). *Highlights of the Gem Trade Laboratory in New York.* Gems and Gemology, Nos. 9 and 10, Vol. IX, pp. 268-270 and 286 ; 291-294, Spring and Summer, 1959.

Reports red and blue-green colours in irradiated diamonds. The red-coloured diamonds showed the absorption line at 5920Å and the blue-green stones a strong line at 4800Å and a weaker line at 4900Å. Many more yellow diamonds are now being tested in this laboratory. Some comments on other diamonds tested are given. A number of jade imitations sent in for identification included aventurine quartz, calcite, dyed serpentine, smithsonite and glass, also dyed jadeite. There is difficulty in identifying turquoise from the many simulants now produced. Comment is made on white coral and its simulation by pinkish conch shell and reference is made to a press report of a black coral from Hawaii. A yellow-green glass had a refractive index greater than 1·80 and a density of 5·40. A blue fluorescent diamond, which showed two bright fluorescent lines at 4350 and 4420Å, and a brown fluorescent diamond, which turned a green colour on exposure to sunlight but returned to brown after being returned to the dark for some time, were two unusual diamonds examined. Clam pearls are more

frequently encountered. A warning is given that a case is extant where a yellow sapphire had badly faded on exposure to strong sunlight and it is inferred that the stone had been treated with X-rays to improve the colour. Star-stones, with two sets of rays (one a twelve-rayed stone) showed each set of rays to have different colours, a blue and a yellow.
1 illus. R.W.

SINKANKAS (J.). *1800 sea-green carats.* Gems and Gemology, No. 10, Vol. IX, pp. 299-305, Summer, 1959.

An enormous mass of sea-green spodumene weighing 3675 carats was cut into an octagonal step-cut stone of 1804 carats. The dimensions of the stone when finished were $3\frac{7}{8}$ inches by $2\frac{1}{4}$ inches. Cutting involved the construction of special equipment.
3 illus. R.W.

LAMB (N. F.). *Determination of mounted stones.* Australian Gemmologist, No. 2, Vol. II, pp. 11 and 12, August, 1959.

Some notes on the methods which may be used to identify mounted stones (with particular reference to the identification of mounted stones in the practical examination of the Gemmological Association of Australia). The scheme suggested has good points, specially in that a careful examination by a lens should be the first to do, but later methods appear to suffer from the fact that the use of absorption spectroscopy is completely ignored. Its use would give conclusive results and save valuable time.

R.W.

GÜBELIN (E.). *New fakes to simulate black opal.* Gemmologist, No. 337, Vol. XXVIII, pp. 141-142, August, 1959.

Opal is imitated by an opalescent glass and by fusing together two plates of glass in such a way as to produce an interference effect. Opal doublets are made of a slice of real opal cemented on to a second piece of opal, or on to a black glass or black onyx. Two new types of opal composite stones are described, the first consisting of a colourless cabochon of quartz, which is backed by a thin layer of white or black opal and the whole completed with a backing of a piece of opal cemented with black cement. The refractive indices of the top are that of quartz (1·55) and the base will give a reading of 1·45, that of opal. One such composite stone gave a density of

2·48. A second type of opal triplet has similarly a rock crystal top with a thin slice of opal below, but in this case the base is finished with a base of black glass which has a refractive index of 1·49. The density of one such stone was found to be 2·62. In both cases the stones look " wrong " and the play of colour is seen to lie conspicuously deep below the cabochon surface. Unset, the stones show a pronounced line of joining of the component parts, but if set this is hidden and recourse may be made to the immersion of the whole jewel in water. When viewed sideways the colourless top of quartz is made clearly visible.

R.W.

METCALFE (B.). *Experiments on colouring diamonds by nuclear radiation.* Gemmologist, No. 338, Vol. XXVIII, pp. 161-164, September, 1959.

The author has been engaged in experiments in the bombarding of diamonds. Some of the history of earlier experiments on the colouring of diamonds by radium emanations is given. The article is mainly concerned with the types of treatment, colours produced, and something of the methods used in irradiating diamonds to-day. The cause of the colour-change produced in diamond by irradiation is due to the disturbance of the crystalline arrangement of the carbon atoms. The degree of this disturbance and the way in which the original lattice is distorted give rise to colour-centres which change the visible colour of the stone. Heat at various temperatures produces a partial annealing of the disturbed crystal structure and can change but not destroy the colour. Neutron, electron and proton bombardment and gamma-ray irradiation have been used in the experiments. In experiments using neutrons, with irradiations of 1, 2, 5 and 50 hours, the shorter exposures were found to give a green colour to diamonds, the depth of colour varying with the length of exposure. The long exposure (50 hours) produced a coal-black stone. It was found that a given intensity of colour at a given neutron flux was inversely proportional to the cube root of the weight of the stone. The colour produced is additive and in no way could the colour of an originally coloured stone (Cape stones) be reduced. Heating experiments on green irradiated stones showed them to turn to a yellow, amber, or cinnamon-yellow colour, and the depth of the yellow colour was relative to the depth of the induced green colour. Electron

bombardment by the use of a Van de Graaff generator was the subject of other experiments, and the methods and apparatus used to hold the stone in the electron beam are given. The colours produced by electron bombardment are light green to green-blue or blue-green, but the stones were found not to give identical results. A pale green colour was induced in one stone treated with protons. Gamma irradiation was carried out by using Cobalt 60 and a bluish-green colour was produced in the stones. A summary and a short list of references is given.
3 illus. R.W.

WEBSTER (R.). *The jades.* Gemmologist, Nos. 337 and 338, Vol. XXVIII, pp. 153-157 and 166-168, August/September, 1959.

Jade is the name applied to two minerals, nephrite and jadeite. The derivation of the names, characters and localities of the two minerals are discussed. Mention is made of the so-called " buried jades." Some notes are given on the fashioning of jade and on such minerals as simulate the true jades. These are bowenite serpentine, prehnite, massive grossular garnet, massive idocrase, microcline feldspar, smithsonite, chrysoprase and green aventurine quartz, saussurite, smaragdite, pseudophite, verdite and agalmatolite. A green material from New Guinea, called astridite, is composed of chrome-rich jadeite intergrown with picotite, quartz, opal and limonite, which has been derived from olivine rock. Jade is stained to an Imperial jade colour and to a strong mauve. Notes are given on the new jadeite triplets and the imitations of jade in glass and plastics.
2 illus. P.B.

HILL (D. K.). *Glass and Gemmology.* Gemmologist, No. 337, Vol. XXVIII, pp. 143-150, August, 1959.

An article based on the Gemmological Association's Herbert Smith Memorial Lecture of 1959. The nature of glass and the effect the differences between crystal and glass show to an X-ray beam are mentioned. It is a fundamental property of glass that it has no fixed melting point, thus it has a continuous viscosity temperature curve. Many glasses are deliberately prepared with inclusions ; such glasses are the opal glasses, aventurine glasses, etc. Orientation of the inclusions can only be made in one direction,

to produce satin and chatoyant glasses. The effect of the inclusion of colouring oxides in glasses, and manufacture of "dichroic glasses," which show different colours according to the nature of the light or when of different thicknesses. The methods used for the production of glass and glass wares are explained. The uses of glass in art and industry conclude the article.
3 illus. R.W.

TRUMPER (L. C.). *Zincite ; a rare gemstone.* Gemmologist, No. 334, Vol. XXVIII, pp. 81-83, May, 1959.

A report on the characters of a cut zincite. The stone, of a deep red colour, which weighed 1·528 carats, was found to have a density of 5·665. Using the differential reflectometer devised by the author, the refractive index of the stone was estimated to be between 2·00 and 2·10. No dichroism could be assessed owing to the masking effect of the deep red colour, and no fluorescence was observed, nor was any transparency to short-wave ultra-violet light found. The absorption spectrum showed an absorption of the blue-violet, the edge being at 5150Å, and there was a broad and deep absorption band between 5900 and 6300Å. The inclusions present were of two types, hair-like inclusions and clouds of small dot-like inclusions. The only source of gem zincite, an oxide of zinc (ZnO), is at Franklin Furnace, New Jersey, U.S.A.
2 illus. R.W.

HARDY (E.). *The Australian Pearl Shell Industry.* Gemmologist, No. 334, Vol. XXVIII, p. 98, May, 1959.

A short description of the present state of the pearl shell fishing industry of Northern Australia. The large *Pinctada maxima* is the oyster fished. Modern diving dress is used by the divers. When the diver finds a good patch of shell he is tempted to stay down too long with the likelihood of developing air bubbles in the blood-stream—"the bends." To avoid this a table of safe times and depths to work, based upon Royal Navy diving experience, is used as a guide. Most of the pearl shell is exported to the U.S.A., Germany, Britain and Italy. An expert of U.N.F.A.O. visited the Red Sea fisheries to instruct the native fishermen in the use of a newly invented Italian diving equipment of simple form.

R.W.

WALTER (D. R.). *Some notes on a recent West Australian mineral discovery.* Australian Gemmologist, No. 11, Vol. 1, pp. 16-17, May, 1959.

Describes the recently discovered " opalized tiger's-eye " found in the north of Western Australia. The material has been formed by the gradual replacement of asbestiform serpentine by compact opal, the fibrous structure being retained. The colour range of the material is from lemon yellow to yellow-green, grey-green, honey brown, and chocolate brown. A similar material is said to be found at Eyre's Peninsula in South Australia.

R.W.

BOOK REVIEWS

SINKANKAS, JOHN. *Gemstones of North America.* 675 pp., 176 illus. 112s. 6d. D. van Nostrand, New York and London, 1959.

Well known as the author of a standard work on gem cutting, Captain Sinkankas has written an excellent treatise on the gems and gem minerals of North America. Almost all of the book is given to descriptions of the gems and their localities. The properties of gems and their terminology are treated briefly and further reading suggested. In addition to the essential data on the chemical and physical properties of the individual species there is abundant information on locality occurrence, the author having visited and worked in several of the areas mentioned. Unnecessary mineralogical data are sensibly omitted. The arrangement of the book is in accordance with the abundance and rarity and commercial importance of the various species that are found.

The chapter on rarer and unusual gems contains several unfamiliar names and one day gemmologists will have to come to terms with the recording of minerals which have been faceted or cut en cabochon at the whim of the collector. There is a brief section on pearl and other organic gem materials.

International nomenclature is followed and the book is refreshingly free of the many fanciful names that are sometimes given to gems by American enthusiasts. The labelling of quartz with the name " topaz " is rightly condemned but the use of " Spanish topaz " or " Madeira topaz " for heat-treated amethyst does not earn similar disapproval. Chrysolite is named as a variety of olivine, a name which is discouraged in Europe.

There is a comprehensive geographical and locality index, a tabular review of the geology of gemstone deposits, notes on collections and the collecting of gems and a useful glossary. The bibliography is excellent with, as an unusual feature, the author's comments about each work mentioned. It is noteworthy that Captain Sinkankas considers that G. F. Herbert Smith's " Gemstones " is " the best general treatment of the subject of gemmology in the English language."

The author has received valuable assistance with the many photographs which are reproduced, but the handsome coloured illustrations (unfortunately too few) and numerous drawings are his own work. They are beautifully done.

Gemmologists in North America are fortunate in having such a competent book, which is accurate in detail and in which the clarity of the text makes it easy to read. Captain Sinkankas, who is serving with the U.S.A. Navy, has made hobbies of collecting and fashioning gems. His second major work has established him as a gemmological author of first rank.

S.P.

WEINSTEIN (MICHAEL). *The World of Jewel Stones.* Sheridan House Inc., New York. 50s.

Michael Weinstein is already known by name to many gemmologists as the author of a short book, "Precious and Semi-precious Stones," published by Pitman thirty years ago, which has since been through several editions. " The World of Jewel Stones " is a much more ambitious work, being a large and well-produced volume of more than 400 pages. It represents an attempt, as stated in the author's foreword, " . . . to give the reader some general information on all gemstones and also the more important materials (apart from metals) which may be seen in modern jewellery." Mr. Weinstein continues " . . . All too often a purely scientific approach to this subject is offered to the general reader, but here it is hoped that those interested will find sufficient information of both a practical and theoretical nature, presented in plain language, which can be pleasantly and profitably assimilated."

One may say that the author's aim has been fulfilled with a fair degree of success. Unfortunately, the publishers make far more pretentious claims for the book: " About once in a generation there

is written a definitive book on a great subject. This is the great book on gems and jewel stones for the present time." The book has far too many shortcomings, particularly on the technical side, to be worthy of the adjective " great."

On the purely descriptive side the book has much to commend it. The author has had a lifetime of experience in the precious stone trade, and he has obviously been at pains to cull from various sources information concerning the mining and recovery of gemstones, and the quantity and value of stones mined in historic and recent times. The book has none of those preliminary sections on the crystallography and physical properties of gems which are apt to alarm the non-scientific reader. After a brief chapter on " The Antiquity of Jewel Stones," the author leads straight on to a description of individual gemstones, beginning, as is usual, with the commercially most important stones, diamond, ruby, sapphire, and emerald. His descriptions of amber and jade are particularly good (as they were, one remembers, in his smaller book), and it will please the collector to find that he manages to give brief coverage to the rarer gems which are seldom if ever seen in jewellery.

With the " general reader " in view, one can understand the author's reluctance to introduce technical details into the descriptive part of the book, but one could wish that when these *are* included they had been made more accurate and truly informative. Too often a " half-baked " statement is made which will satisfy nobody and must certainly irritate the informed gemmologist or the student in search of information. For example, with obvious reference to Type I and Type II diamonds, Mr. Weinstein writes: " Actually, diamonds may be divided into two types, the one being a more perfect single crystal than the other. This is shown by the difference in cleavage; and also the one class is transparent while the other is opaque to certain ultra-violet and infra-red rays." This statement merely leaves a muddled impression: surely it would have been wiser either to omit all mention of these interesting variations in diamond, or to have been more explicit. Again, instead of a clear account of the important fluorescent behaviour of diamonds under ultra-violet light, which is so fascinating both to the layman and to the scientist, Weinstein writes (in his diamond chapter): " In a vacuum and exposed to a high tension current of electricity, diamonds phosphoresce in different colours . . . ."

giving the reader the impression that only in an elaborately equipped laboratory can the fluorescence colours shown by diamond be observed. In a later chapter, it is true, a paragraph is devoted to fluorescence effects under ultra-violet light; but this is summarized from the work of physicists who are unfamiliar with gemstones, with the result that such mis-statements as that aquamarine " gives a strong reaction " under the rays are included.

There is a carelessness, too, in the author's use of English. " Mitigates," for instance, is used more than once where " militates " is obviously intended, and such phrases as (pink beryl) . . " is the largest pink transparent stone found " and (aquamarine) . . . " which does not change in artificial light " abound.

In dealing with synthetic gemstones—a subject of great importance to the jeweller—the author is less than adequate. The sintered blue synthetic spinel which is used to simulate lapis lazuli, for example, is not mentioned, nor is strontium titanate, the most successful imitator of diamond. In mentioning synthetic rutile, Weinstein states that it cannot be confused with diamond on account of its low hardness and greater specific gravity, without mentioning the two characters which make this synthetic immediately recognizable—its outstanding dispersion, rendering it as full of colours as an opal, and its enormous double refraction, visible under even a low-power lens.

The technical chapters, particularly those entitled " The formation of gemstones and their general physical properties " and " The discrimination of gemstones," are the weakest in the book. Space is wasted on descriptions of laboratory apparatus such as the Bragg X-ray spectrometer, never used by gemmologists, and the Tully refractometer, which is obsolete, while directions for the use of simple and more practical instruments are not sufficiently exact or correct to enable the student or interested amateur to use them. The author's description of the table spectrometer (as a means for determining refractive indices) is quite extraordinarily muddled, while immersion methods for refractive index determination, which are often of essential importance to the gemmologist, are dismissed in one vague paragraph. There is also much overlapping, e.g. in the description of the refractometer and its use, between the two chapters mentioned, and a great deal of space could have been saved or more valuably used.

The last two chapters in the book, "Jewel stone weights and values" and "Prospecting and buying, judging for value," contain useful information derived from the author's own experience, of a kind not found elsewhere. The book concludes with a chronologically arranged bibliography, lists and tables, and an index.

There are a number of illustrations in colour and black-and-white. Most of the coloured plates (derived from drawings by two Dutch artists) depict cut gemstones and the rough crystals from which these are derived, in juxtaposition. This is basically a good idea, but the reproductions are unfortunately not clear enough to give the reader more than a very vague idea of the actual appearance of the stones concerned. The black-and-white plates are taken from excellent photographs.

Within the pages of "The World of Jewel Stones" there is enough good material to make a useful book for the general reader. It would, however, need drastic pruning and revision before it could honestly be recommended to the serious gemmologist.

B.W.A.

WILD (K. E.). *Zur Geschichte der Schmucksteinschleiferei im Gebiet der oberen Nahe und Saar.* History of the gem cutting mills of the Upper Nahe and Saar. 71 pages. Birkenfeld 1959.

One of a series of books published for local industries of the Birkenfeld region, this book deals with the gem cutting industry of the area of the Nahe, Saar, Mosel, Auerbach and Speyerbach rivers of the German Pfalz. The development and working of the gemstone-cutting from medieval times are discussed, but the post-war and present state of the gem-cutting industry of Idar-Oberstein does not seem to be covered. In 1905 there were 69 agate-cutting water-mills operating along the Idarbach, but in 1925 there were only 31 working. Five original manuscripts are printed, beginning with one concerning the mill at St. Arnual-Saarbrücken of 1478. Others concern the Guild of Agate-cutters of Oberstein of 1609 and an inventory relating to Johann Kraysens of Brebach, Saar, of 1628. The diary of Johann Hoffman, who with Mattes Krätsch, searched for coloured stones around the district of Baumholder during 1600, is given. There are extracts from Collini's study of the mineralogy of the Oberstein region, and of the finding and cutting of the agates found there. There are twenty illustrations, two maps and a bibliography of 33 references.

R.W.

SCHLOSSMACHER (K.). *Edelsteine und Perlen.* Precious Stones and Pearls. 2nd edition. E.Schweizerbart'sche Verlagsbuchhandlung, Stuttgart, 1959. 340 pages, 133 illustrations, two colour plates. DM30.

Since the first edition of Prof. Schlossmacher's book was published, five years ago, great developments have occurred in the field of gemmology. Synthetic diamonds—so far only industrial boart—and non-nucleated cultured pearls have appeared on the market ; synthetic corundum has been produced by hydrothermal methods. All these and other " advances " have been faithfully reported by the author, who is an eminent mineralogist and the director of the Gemmological Institute at Idar-Oberstein, one of the centres of the gem and diamond cutting industries. Practical gemmology uses many branches of science and in spite of international contacts and translations of books and articles, teaching and application is largely influenced by the background and the preferences of the outstanding personality in the Institutes of the different national centres. Thus a British gemmologist will miss in this book an adequate survey of the determination of gem species with the spectroscope ; or of the possibilities of immersion in suitable liquids to show differences in refractive indices. The author does not fail to observe the difference in refraction, but does not concede that it is possible to determine which substance has the higher or lower R.I. (p. 40).

The tables of physical constants are not based on own observations, but taken from R. T. Liddicoat.

The second edition is an appreciable improvement on the first. The general part is enlarged by 40 pages, the sections relating to reflection and refraction are much clearer and the determination of optical properties with the microscope is a masterly exposition. The special part of the book, too, has been enlarged by 20 pages to bring the survey up-to-date.

The fundamental difficulty of writing a book of the middle road, which serves all those connected with gemmology, consists in choosing the subjects which require explicit description and those which allow mere indications. On the whole the author's choice is excellent, but it is still to be hoped that he has not descarded the idea of revising Bauer, Schlossmacher's " Edelsteinkunde."

W.S.

ASSOCIATION NOTICES

GIFTS TO THE ASSOCIATION

The Council of the Association acknowledges with gratitude the following gifts :—

From William E. Kelley, F.G.A., Cleveland, Ohio, the sum of $25 for the Sir James Walton Memorial Library.

Various publications concerning jade, from Robert Webster, F.G.A.

Tavernier's Travels in India (two volumes) from R.J.S. Ltd., London.

A copy of *Os Grandes Diamantes Brasileiros* from the author, Esmeraldino Reis, Brazil.

A copy of Gemstones of North America by John Sinkankas, from the Officers of the Canadian Gemmological Association.

Various examples of faceted and cabochon gem material for students' study, from John R. Fuhrbach, Texas, U.S.A.

LIBRARY

The following books are required :—

GOURJON, M. *The Indian connoisseur ; or the nature of precious stones.* London, 1785.

BARBOT, C. *Guide pratique du joailler : ou traité complet des pierres précieuses.* Paris, 1858.

EPPLER, A. *Die Schmuck- und edelsteine.* Stuttgart, 1912.

EPPLER, A. and W. F. *Edelsteine und Schmucksteine.* Stuttgart, 1936.

MIKIMOTO, K. *The story of pearl.* Tokyo and London, 1920.

FRÉMY, E. *La synthèse du rubis.* Paris, 1891.

TRAILL, G. W. *Treatise on quartz and opal.* Edinburgh and London, 1867.

PRESENTATION OF AWARDS

Most of the London recipients of the diploma of the Gemmological Association, and a welcome number from Ipswich, Birmingham and other centres, even so far afield as Glasgow, came to Goldsmiths' Hall recently to receive their certificates from Lady Walton. Mr. Knowles-Brown was in the chair, and welcomed Lady Walton, the large gathering of Fellows and the new diploma holders and their friends. He said that he was old enough to look back on the progress that the Association had made in nearly half a century. His father, he recalled, held Diploma No. 9. Now the certificates were numbered in thousands, and membership extended throughout the world. He considered why the diploma

was held in such high esteem in the gemmological world, and felt that the Association's approach to training and examinations commanded respect by its maintaining of high standards. There was also something more—for the Gemmological Association endeavoured to keep one step in advance of events. Some years ago, the Secretary had issued a warning about the new synthetic emeralds of size being made in the United States. At that time, imports were severely restricted. Now the restrictions are off, and we have Chatham synthetic rubies as well—and the gemmologists of Britain are prepared for them. Research, too, was important, and vigilance, eternal vigilance, was more than ever a necessity in the present age of the synthetic gemstone. It was vital for the gemmologist to keep up to date, with reading and practice and discussion at meetings and lectures.

After she had presented the Rayner prize to Mr. P. W. T. Riley, of Chester, and diplomas to 25 new holders, Lady Walton said she had a word of encouragement for the less successful examiness. She told them not to be discouraged, but to fight their difficulties. She thought of gemmology as of especial importance nowadays as part of the whole science of the universe. It was an absorbing study, and she told how her late husband, Sir James, took up gemmology when he was more than 60 years old. He studied and persevered and eventually wrote a book about it, and became chairman of the Association. She said that the wonderful library, founded by the N.A.G. in association with the Gemmological Association, would have delighted Sir James, whose name it bears. She concluded with a word of gratitude to the hard-working instructors and examiners who needed so much patience and so much experience to pass on their knowledge.

Mr. Norman Harper thanked Lady Walton for so graciously presenting the awards. He said that the Association liked the diplomas to be presented by someone connected with the science, and Lady Walton had maintained her husband's interest in the Association. He presented on behalf of the Association, the framed original of the bookplate used in all the books in the Sir James Walton Memorial Library.

The meeting concluded with thanks from the chairman to the Prime Warden and Court of the Worshipful Company of Goldsmiths for permission to use their Livery Hall.

Before the presentation of awards there was a happy reunion of about one hundred members of the Association.

OBITUARY

The death has occurred of Joseph Azzopardi, F.G.A., the Association's first member in Malta. He was one time Consul for the Maltese goldsmiths and silversmiths and a keen supporter of the Association.

The Association also records with regret the death of Edward H. Howell, London (D.1923), and John W. Reynolds, London (D.1945).

Mr. Reynolds was one of the retail trade's well known silver buyers and he had been employed by Wilson & Gill, Ltd., of Regent Street, London, W.1, for forty years.

The death has also occurred of John Melson Peyton Biggs, Chairman and Managing Director of Carrington & Co. Ltd., Regent Street, London.

COUNCIL MEETING

A meeting of the Council of the Association was held on Tuesday, 17th November, 1959, at Saint Dunstan's House, Carey Lane, London, E.C. Mr. F. H. Knowles-Brown presided.

The Council received with regret the resignations, for personal reasons, of Miss Elsie Ruff and Mr. A. R. Popley, and recorded their appreciation of the work which they had done as members of the Council.

The Council formally received notification of the formation of the Canadian Gemmological Association and approved affiliation between that organization and the British Association.

The following were elected to Fellowship of the Association.

Battersby, Keith W., London
Betts, Geoffrey N., Birmingham
Buckler, Albert N., London
Buitenen, A. Th. C. v.,
s-Hertogenbosch, Holland
Davis, George, Glasgow
Diggan, Gerald, London
Durrant, Anthony W., Ipswich
Hall, Edwin F., Smethwick
Hedges, F. C., London
Kay, Jonathan G. D., Liverpool
Marshall, Michael, Hull
Neil, Peter B., Glasgow
Patience, Kenneth, Norwich
Pilot, Lawrence M., London
Plews, William A., Edinburgh
Raven, Robert H., Chelmsford
Sack, Karl A., San Diego, California,
U.S.A.
Schoien, Magnus, Skien, Norway
Seneviratne, Seetha, London
Shane, Leon, Toronto, Canada
Shapland, Roger S. C., Cookham
Dean
Smith, James S. A., Glasgow
van der Vlerk, Hendrik T.,
Schiedam, Holland
Wall, John S., London
Whyte, Archibald G., Edinburgh.

The following were transferred from Ordinary and Probationary Membership and elected to Fellowship.

Blignaut, Adi, Johannesburg, S. Africa
Mendelsohn, Michael, Cape Town, S. Africa
Phillips, Alan L., Bardsey, Nr. Leeds
Britchfield, Charles F. J., Gravesend
Brousseau, Murray P., Toronto, Canada
Engstrom, Hans W. E., London
Etienne, Lorette, Bangkok, Thailand
Gryska, Stephen, Worksop
Hope, Kenneth, London
Kelley, William E., Lakewood, U.S.A.
Langton, Edward G., London
Meadows, Everard C., Purley
Pragnell, John W., Bournemouth
Whitehead, Henry J., Edinburgh
Weatherhead, Albert V., Wellington, New Zealand
Yates, Roy F., Manchester

The following were elected to Ordinary and Probationary Membership.

Attygalle, Cyril E., Ratnapura, Ceylon
Beattie, Louise G., Bangkok, Thailand
Booley, Edward, Chatham
Budd, Douglas H., Kingston, Jamaica, W. Indies
Cohen, Adolphe, Nice, France
Cole, Kenneth C., Salisbury, S. Rhodesia
Dyball, Frank G., Coventry
Eggers, Jodie G., Karachi, Pakistan
Fisher, Peter J., Cookstown, Co. Tyrone
Geiger, Jacob C., Curacao, Netherlands Antilles
Guy, Frederick L., Hull
Hamblyn, James H., Wellington, N.Z.
Hyman, Geoffrey M., Blackpool
Ostwald, Joseph, Kalgoorlie, West Australia.
Pavitt, John A. L., Singapore
Schwartz, Jonathan P., New York, U.S.A.
van Halem, Adrianus C., Singapore
White, George A., Norwich

Catton, Cedric T., Ipswich
Childs, Allan J., Hornchurch
Church, Bruce A., Wakefield
Patni, Chandulal G., Nairobi, Kenya
Schidlowski, Dietrich, Pretoria, S. Africa
van Gurp, Fransiscus P. C., Curacao, Netherlands Antilles

MEMBERS' MEETINGS, 1960

February	10	New diamond film, "Stars that shine for ever," British Council Cinema.
March	4	Midlands Branch Meeting.
April	12	Herbert Smith Memorial Lecture. Dr. A. F. Hallimond on "Polarization." Goldsmiths' Hall, London, E.C.2, 7 p.m.
,,	21	West of Scotland Branch Annual Meeting.
,,	29	Midlands Branch Meeting.
May	5	30th Annual General Meeting, Saint Dunstan's House, London, E.C.2, 6.45 p.m.
June	4	West of Scotland Branch summer outing.

TALKS BY MEMBERS

BLYTHE, G. A. : "Gemstones," South Essex Natural History Society, 22nd October, 1959.

WELLER, G. T.: "Lesser known gems," Tunbridge Wells Toc H, 26th October, 1959.

WARREN, K. (Mrs.) : "Gemstones," Eltham Congregational Ladies' Friendship, 27th October, 1959.

FORSEY, PATRICIA (MRS.): "Gemstones," Women's Senior Auxiliary of Grace, United Church, Dunnville, Canada, October, 1959.

GILLOUGLEY, J. : "The diamond story," Sanderling Wives' Club, Royal Naval Air Station, Abbotswich, Paisley, 3rd November, 1959.

CAIRNCROSS, A. : "Gemstones," Dunbarney Men's Guild, 22nd October ; Dunning Parent Teacher Association, 7th December ; Scone New Church Women's Guild, Perthshire, 8th December, 1959.

AN EXHIBITION OF GEMSTONES AND JEWELLERY

City Museum and Art Gallery, Birmingham, from 17th February until 16th March, 1960. (Industrial section in the Museum of Science and Industry, Newhall Street).

Open daily from 10.30 a.m. until 6.30 p.m. and until 8 p.m. on Tuesdays, Thursdays and Saturdays. Sundays 2 p.m. until 5.30 p.m. Admission free.

This exhibition, the largest of its kind ever held in the provinces, will include a great many famous, historic and priceless pieces that are rarely seen and that never before have been gathered together for public display. Her Majesty the

Queen has graciously lent several magnificent jewels. Others have been borrowed from a number of private and public sources in order to create, with the aid of the City's own collections, a quite fabulous display that will not readily be seen again. All departments of the Museum and Art Gallery have contributed to the exhibition. In order of time the Department of Archaeology is showing jewellery dating from 2000 B.C. up to 1600 A.D. and from then until the end of the nineteenth century follow the displays by the Department of Art. Gemstones as such are the contribution of the Department of Natural History, and at the Museum of Science and Industry is an exposition of the modern industrial uses of diamond.

During the course of the exhibition, there will be films and demonstrations concerning gemstones and the making of jewellery, and on successive Thursday luncheon hours there will be talks on various aspects of the exhibition given by distinguished visitors. Dr. Joan Evans, the well-known authority on the design and history of jewellery, will open the exhibition at 5.30 p.m. on Tuesday, 16th February.

The Devonshire Emerald, a diamond necklace and wonderful natural crystals of aquamarine focus attention on the beryls, but bidding fair in rivalry are the rubies and sapphires, zircons and topaz, tourmalines and garnets. These, with the spinels and chrysoberyls and olivines, are stones in their profusion to admire. The quartz group contains beautiful chalcedonies, amethyst, citrines and rock crystal. There are ornamental stones, many of ancient usage, turquoise and lapis-lazuli, jasper and jade, the latter being a separate showing of magnificent oriental craftsmanship. The opals are well represented, and a concise natural history and display of the several kinds of pearls leads to a superb example of a necklet. One exhibit deals with birthstones for each month of the year, and another with rare and unusual gemstones that are but seldom seen.

Films in sound and colour about diamonds and the fabrication of jewellery will be shown during the luncheon hours of Mondays, Wednesdays and Fridays throughout the exhibition, and on these same days between 5 and 6.30 p.m. will be demonstrations of mounting and setting. Between 3 and 6 p.m. on alternative days there will be complementary demonstrations of stone cutting and polishing. In the Museum of Science and Industry, Newhall Street, there will be an exhibition concerning the industrial uses of diamond, principally the myriad needs and purposes of cutting, grinding and drilling most things from teeth and gramophone records to oil wells. This exhibition also will include practical demonstrations.

The ancient jewellery which will be shown at this exhibition ranges from Egyptian jewels and necklaces of 2000 B.C. to the rich Elizabethan Cheapside Hoard of about 1600 A.D. Primitive goldwork from America is also included. On the prehistoric side many of the major gold objects from Britain have been collected and will be shown together for the first time. These include the famous gold plates from barrows in Wiltshire.

Some magnificent examples of jewellery dating from the seventeenth to nineteenth century are also included.

One of the outstanding exhibits will be a Parure of jewels which belonged to the Empress Josephine and which were made for her in about 1805. An emphasis has been laid on quality of design from the seventeenth century to about 1914. It will be possible to follow most of the trends in jewellery in Europe during this period.

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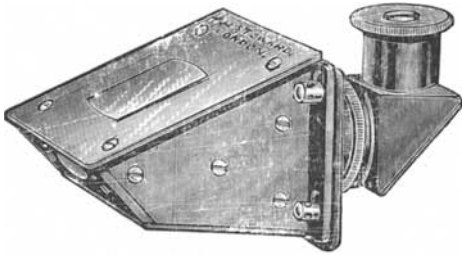

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Metalwork and enamelling by Maryon. A standard text for goldsmiths and silversmiths. 4th edition, revised, 1959. £2 . 5 . 0.

Retail jewellers' handbook by A. Selwyn. The course book of the National Association of Goldsmiths of Great Britain for retail sales assistants. £1 . 10 . 0.

Practical gemmology by R. Webster. A standard work for first year students of gemmology. 17s. 6d.

Engraving on precious metals by A. Brittain, S. Wolpert and P. Morton. Useful for all engaged or interested in the art. £1 . 15 . 0.

Retail silversmiths' handbook by A. Selwyn. A companion to the above-mentioned book by the same author. £1 . 5 . 0.

Gemstones of North America by J. Sinkankas. An authoritative and extremely well written work. £5 . 12 . 6.

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January, 1960

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THE JOURNAL OF GEMMOLOGY

and

PROCEEDINGS OF THE
GEMMOLOGICAL
ASSOCIATION
OF GREAT BRITAIN

GEMMOLOGICAL ASSOCIATION
OF GREAT BRITAIN
SAINT DUNSTAN'S HOUSE, CAREY LANE
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THE JOURNAL OF GEMMOLOGY
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SYNTHETIC OR ARTIFICIAL

By A. E. FARN, F.G.A.

MOST gem-enthusiasts have at some time or other either attended a gemmological exhibition, or proudly shown their own collection of gems to friends and relations—always to be asked the inevitable question, " how much are they worth ? " To the keen collector, this is an irritating question, since it indicates clearly where the interest lies and how the average person reacts to such terms as gemstones or jewellery. Seldom does one meet the true appreciation of beauty or rarity, but always the eternal " how much ? "

Unfortunately certain elements in our society readily apply their criminal psychology to this materialistic interest in valuables so quickly evinced by the more greedy or gullible section of the public. Thus, when a new material came on to the market and displayed tremendous fire and attraction for a price low in comparison to diamond, it afforded possibilities which the unscrupulous were not slow to realize. The new material's trade name of fabulite seemed coined specially for word play—fabulous for the credulous ! It was not until some fairly recent occasion that I was asked by a gem-dealer, who wanted to satisfy a customer's enquiry, whether it *was* intended to simulate diamond and if it was a synthetic stone.

Answering rather quickly without very serious thought, I replied that it certainly was not intended to simulate diamond but doubtless it could be so used. It was not synthetic diamond, since its formula was $SrTiO_3$, strontium titanate, but it could be

described as a synthetic stone. Since then I have had second thoughts. I began to wonder if it was correct to describe this product as synthetic, and without going into the various aspects and methods of manufacture of synthetics generally I wondered whether it was correct so to describe strontium titanate.

Being weak on etymology I could only have recourse to what I had been taught, and as far as I could remember a synthetic stone is a stone which has the same chemical composition, refractive indices and specific gravity as its natural counterpart.

If a synthetic ruby be analysed it would correspond with natural ruby and similarly in the case of sapphire. With synthetic spinel this is not quite the same, as here there is an excess of alumina in the composition and the properties are slightly higher in R.I. and S.G. than those of natural spinel. It would seem to be hair-splitting, but even synthetic spinel is not a true synthesis of natural spinel. It did not intend to propound this particular case, but it slipped in as a natural sequence.

What I really wanted to *focus* on is:—strontium titanate, is it a synthetic, since so far as is known there is no naturally occurring mineral ? Certainly it is an artifact as indeed are all synthetics, whether corundum, spinel, rutile or emerald. The Concise Oxford dictionary gives synthesis as " Combination, composition, putting together. Chemically:—artificial production of compounds from their constituents." Jarrolds' dictionary of difficult words gives synthesis as " Combination of parts into a uniform whole. Synthetic —pertaining to synthesis and adjectivally as artificial." Webster's Compendium carefully states, "Synthetic gems having similar chemical composition to natural corundum and spinel and which in physical and optical properties approximate to these gems are made in an oxy-coal gas furnace (Verneuil process)." Anderson's Gem Testing gives: " Synthetic stones, manufactured stones which have essentially the same composition, crystal structure and properties as the natural mineral they represent."

It would seem, therefore, that a concensus of opinion is against terming an artifact of no known natural counterpart as a Synthetic from a gemmological view. Incidentally, most so called synthetics which have a counterpart in nature are all certainly harder than fabulite, which has a softness too low to admit of normal jewellery usage. It would seem therefore that strontium titanate is in fact an artificial stone and should be so described.

STRONTIUM TITANATES EXAMINED UNDER A MICROSCOPE

HERBERT TILLANDER, F.G.A.

The microscope used was an ordinary binocular microtype instrument fitted with the American Gem Society's illuminator. The pictures were taken under dark-field illumination with a magnification of 10 × and 40 × using a Leica and Peruz 17 Din film.

Basil Anderson gives in his excellent book " Gem Testing " an excellent description of how to recognize this synthetic from both diamond and other substitutes. To those who have perhaps not the sensitive feeling of an expert the " false and over coloured appearance " shows immediately under the microscope. In fact it is amazing how, properly illuminated, practically every facet seems to have a different colour, which is never the case with diamond or other white brilliant-cut stones. This unfortunately could only be shown in a colour picture. But I found many other details during my inspection of twelve stones.

1. Focused on the surface the microscope reveals faint, but very distinct scratches on practically every facet. (*Fig.* 1.)

2. The culet in practically every stone examined under 40 × shows an irregular shape, which can also be recognized under 10 ×. (*Figs.* 2 *and* 3.) Very often it is also chipped (*Fig.* 3.) The reason is obvious, the stone is not hard enough for precise cutting.

3 In several stones the girdle was found to be so heavy and rounded in shape that it could be seen from above, looking straight down into the stone. In addition it is very often polished. (*Fig.* 4.)

4. Another expression of the inexact cutting can be seen by closely examining how the various facets on the crown meet (*Fig.* 5.) *Fig.* 6 shows how some facet edges may have quite a rounded appearance.

5. Finally I have produced pictures of the " centipede-like " inclusions, which indeed are very typical and could be found in all but two of the examined stones. (*Figs.* 7-8.) I have been unable so far to find any bubbles and other typical inclusions of ordinary synthetic stones produced in the Verneuil process.

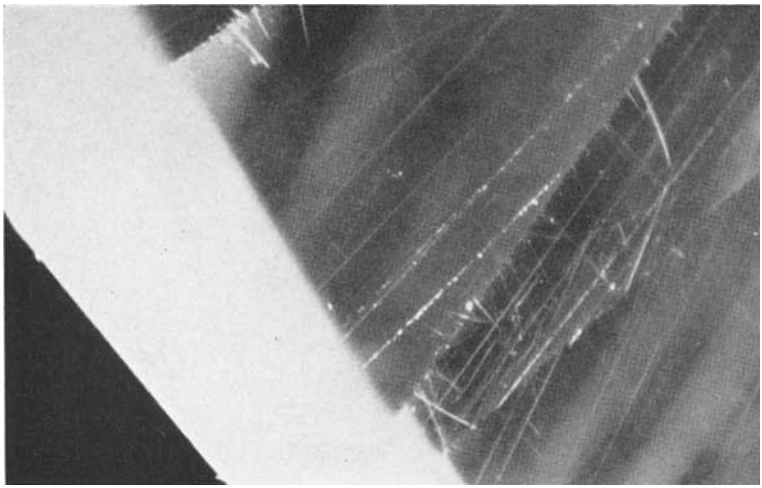

FIG. 1. *Faint scratches seen on most facets of strontium titanate*

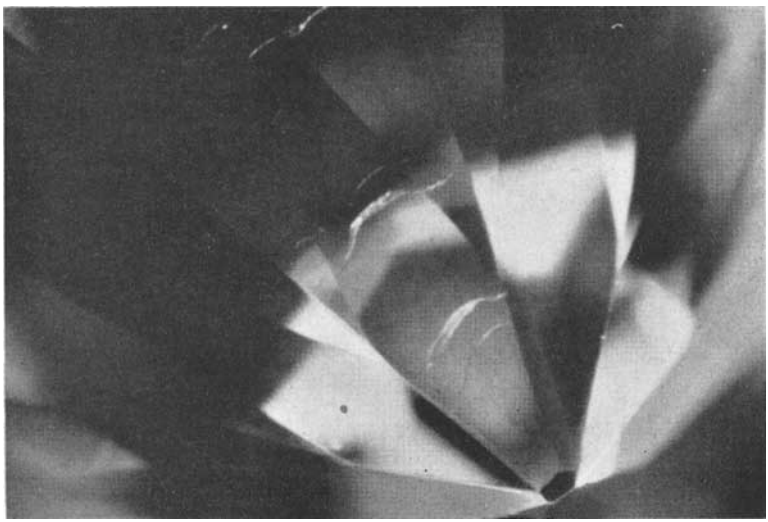

FIG. 2. *Irregularly shaped culet*

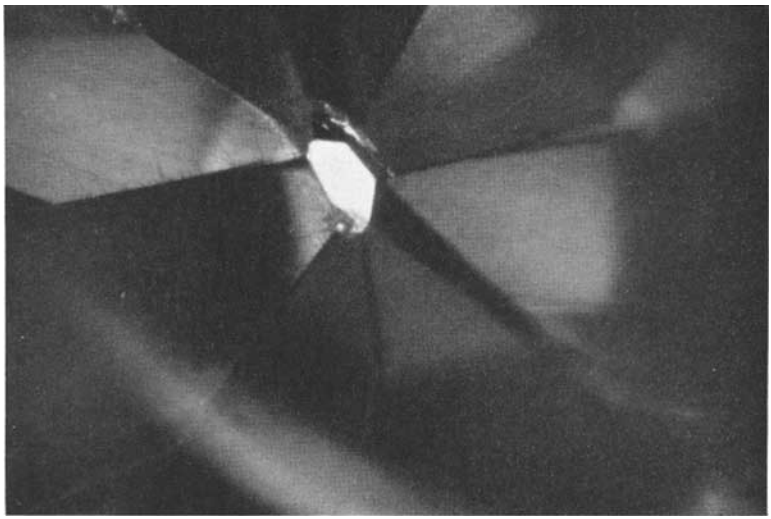

FIG. 3. *Irregularly shaped culet, showing chip marks*

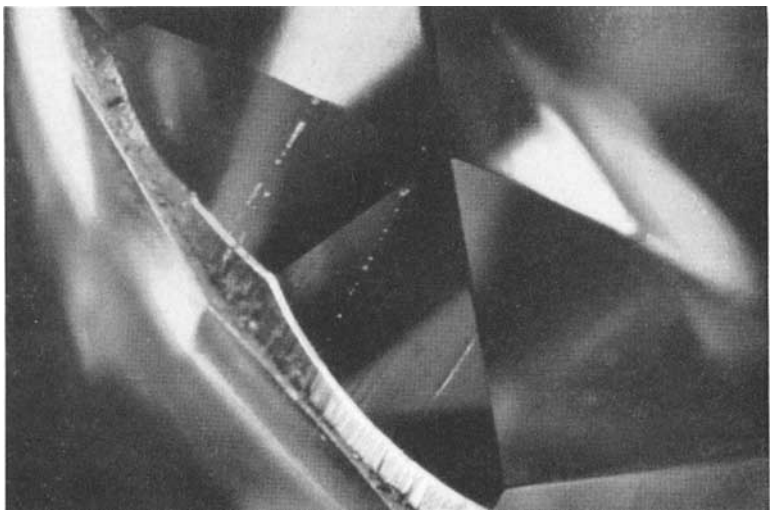

FIG. 4. *Heavy girdle, often visible when looking down into stone*

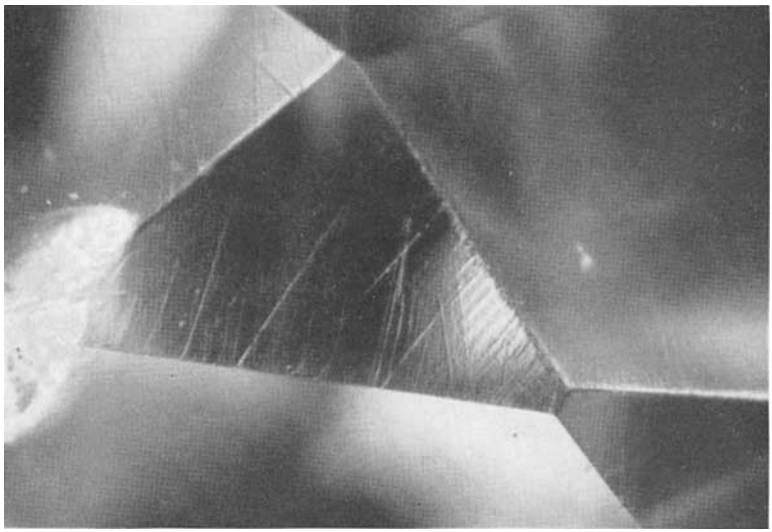

FIG. 5. *Irregular meeting of crown facets*

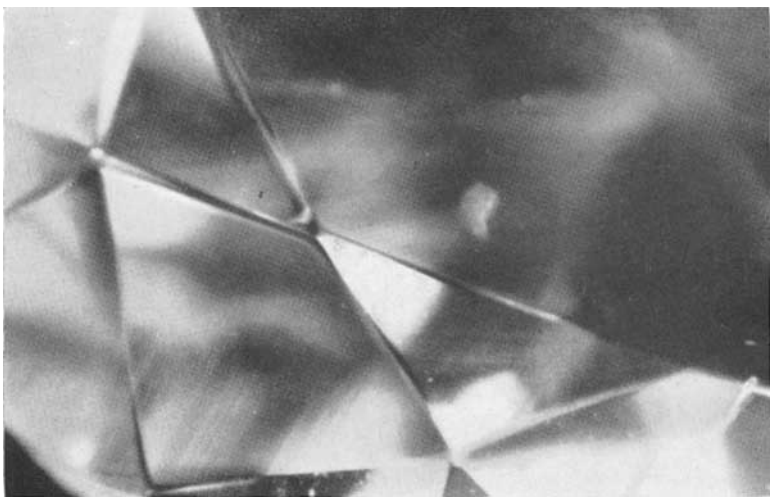

FIG. 6. *Almost rounded appearance of some facet edges*

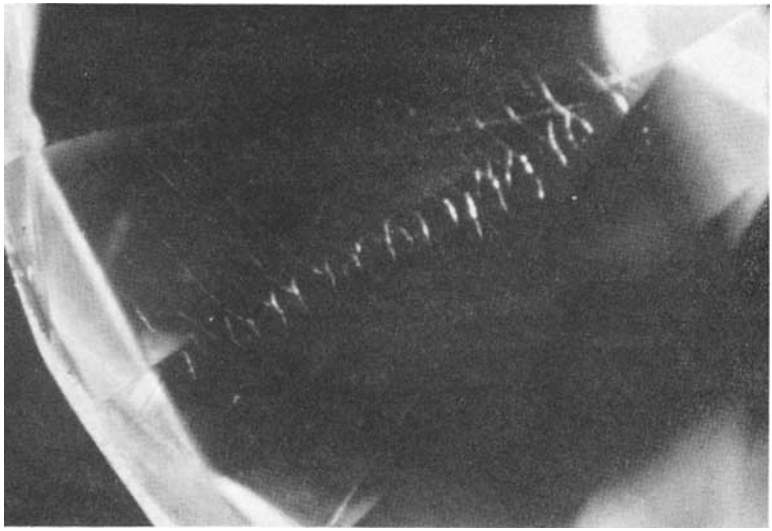

FIG. 7. *Characteristic "centipede" inclusion*

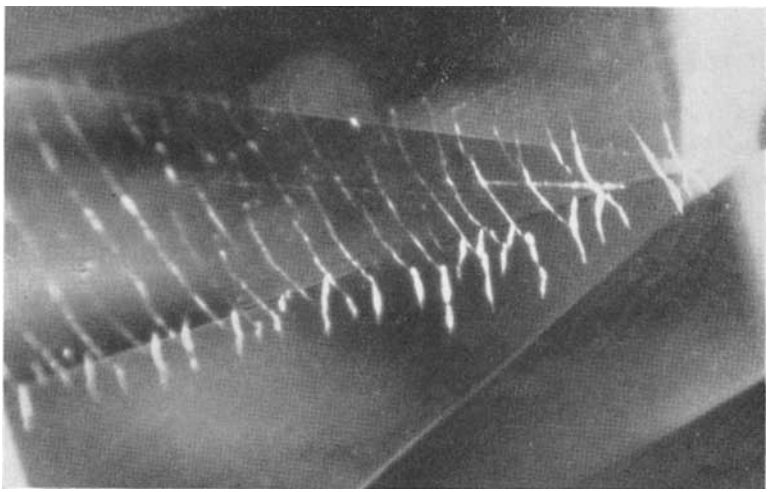

FIG. 8. *Development of "centipede" inclusion*

LUMINESCENCE OF A LARGE PINK DIAMOND

By B. W. ANDERSON

THE show-piece amongst a number of " highly important jewels " sold by auction at Sotheby's on 17th March, was undoubtedly a large pink diamond, cut as an oval brilliant. It was dramatically listed as " Lot 100," and it was sold for £46,000.

The stone weighs 34·64 carats, and it has a pleasing shade of pink—not unlike that of kunzite. One would expect a diamond of such exceptional size and colour to have a " history " and a name—but none seems to be forthcoming. It seems possible that it originally came from the old " Golconda " mines of India.

Messrs. Sotheby submitted the stone to the Laboratory for examination, and the following notes on its properties are published with their permission.

Though it is by now well established that the density of gem diamond lies within the narrow range 3·514 - 3·518, it was thought worth while to measure and record the density of so exceptional a stone. A careful hydrostatic determination was therefore made in ethylene dibromide, giving the figure 3·517.

The absorption spectrum of the diamond showed nothing notable : vague bands in the blue-green and in the middle of the blue were all that could be seen. It was in its luminescent properties that, to a scientist, the greatest glory of the stone was revealed. Under all forms of stimulating radiation (long and short wave ultra-violet light, X-rays, and even white light filtered through copper sulphate solution) the stone showed a strong orange-yellow or " apricot " fluorescent glow. After exposure to long ultra-violet or to X-rays there was also a persistent phosphorescence of the same colour. With X-rays this afterglow was remarkable in showing none of that immediate diminution when the rays were switched off which is almost universal in mineral phosphors, the glow only beginning to fade after an interval of a second or so.*

More interesting still was the emission spectrum revealed when the fluorescent light was examined through a hand spectroscope. A series of bright lines could be seen, extending towards the red end of the spectrum in diminishing strength from the end-member in the series, a clearly defined line in the yellow. The wavelength of this

* Subsequent experiments revealed that the stone has an ultra-violet transparency characteristic of Type II diamonds.

yellow line could be measured with considerable accuracy, using a Beck wavelength spectroscope, as 5750Å. The line is quite close to the mercury doublet at 5769 and 5790Å, which can be seen in the ordinary fluorescent lighting tubes used in the Laboratory, and these lines were used as a reliable standard for calibrating the spectroscope in this region. The other lines in the series were more diffuse and much weaker : the wavelength figures obtained for these, 5860, 5985, and 6185Å, must therefore be considered as only approximate. Undoubtedly at liquid air temperatures the definition of the whole series would be far sharper, and accurate values could then be obtained.

By a curious coincidence a smaller pink diamond in the same sale (but of different ownership) showed a precisely similar luminescence spectrum, though the phosphorescent glow was far less strong. This was a navette-shaped brilliant weighing 2·83 carats, listed as Lot 57. It might be thought that this was no coincidence, but merely an indication that all pink diamonds show this form of luminescence and emission spectrum. We have, over a period of years, recorded the luminescence of a number of pink diamonds from various sources, and none has displayed the same features.

J. F. H. Custers has suggested, on the basis of spectrographic analyses of diamonds of different colours, that manganese may be the cause of the colour in pink diamond. If this were so, one would expect greater consistency in the absorption and emission spectra of such stones. Admittedly, traces of manganese are held responsible for the vivid green fluorescence of willemite from Franklin Furnace and the pink fluorescence of aragonite from Girgenti, in which last the spectroscope reveals a short-lived orange as well as a longer-lasting green component. But neither of these show a line emission spectrum. Moreover, the series of lines observed in these two pink diamonds is very reminiscent of the series of emission lines seen in green-fluorescing and in blue-fluorescing diamonds. In each of these latter types there is a " key " wavelength at which a narrow band may be seen, either as an absorption or fluorescence line, and this is attended by weaker bands, not all of which are " reversible." In blue-fluorescing diamonds the key position is the 4155Å band (first observed by Walter in 1891) ; in green-fluorescing diamonds the key line is at 5040Å—first seen as a fluorescence line by Crookes (1879), together

with others at 5370 and 5130Å, and seen as an absorption line in 1935 by C. J. Payne. The existence of these two systems was worked out and recorded by the writer in 1943[1] and independently in 1944 by Anna Mani[2] (of the Raman school) in a much more elaborate paper.

Though yellow-fluorescing diamonds are also well-known, we have never previously seen any definite bands or lines in their emission spectra, though in some cases there seemed to be traces of a discrete structure. The emission lines in these pink diamonds seem thus, in the words of the old cliché, to " fill a long-felt want."

Though most strongly luminescent gem diamonds have a blue fluorescence there is probably always a yellow or green component in the emitted light, though it is usually masked by the stronger blue emission. This can easily be demonstrated (without using a spectroscope) by the use of suitable colour-filters, and by the fact that, at least when the stimulus is long-wave ultra-violet light, the yellow component is far more persistent than the blue and can be seen as a phosphorescent after-glow when the stone is removed from the exciting rays and observed in darkness.

E. Becquerel[3] discovered this interesting effect 100 years ago in the course of his brilliant investigations on luminescence. For this work he designed a phosphoroscope consisting of spinning slotted discs by means of which he was able to examine the spectra of light emitted by substances a fraction of a second after they had been exposed to the rays of the sun. He found that blue-luminescent diamonds appeared yellow unless the speed of the phosphoroscope was increased to a point where observations were being made at an interval of only 1/200 to 1/1000 second after the stone had been exposed to sunlight—though this brief persistence of the blue glow was not quite the same for all diamonds. The yellow component he found in general to persist for several minutes at least.

An interesting fact, established by the Raman school of workers,[4] is that the energy of the blue component, though apparently vanishing so quickly, is actually still held by the diamond, and can be seen as a bright blue thermoluminescence when the diamond is subsequently heated—even when the experiment is carried out some days after activation.

Reverting once more to the emission lines seen in Sotheby's large pink diamond—it is probable that the 5750Å line was seen among others by Crookes during his observations of the bright glow

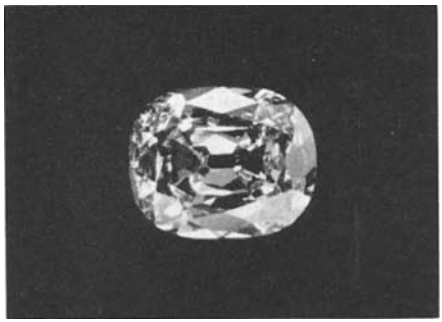

Photograph in natural size of pink diamond.

(Courtesy of Sotheby's, London)

emitted by diamonds under Cathode rays. In his little book " Diamonds " he states (p. 97) : " Diamonds which phosphoresce red generally show the sodium line on a continuous spectrum. In one Brazilian diamond phosphorescing a reddish-yellow colour I detected in its spectrum the citron line characteristic of yttrium."

Crookes was a pioneer with the spectroscope : he had discovered the new element thallium with its aid, and investigated the fluorescence spectra of the rare earths. He is hardly to be blamed for ascribing to definite elements any bright lines seen in the spectroscope when studying the light from his brightly glowing diamonds. The effects he noted, however, were far more probably due to structural peculiarities in the diamond itself.

Miss Mani, in the paper already cited, gives the wavelengths of several emission lines in the yellow and orange of green- or yellow-fluorescing diamonds—one of which she measured (from a photographic plate) as at wavelength 5758Å, and this may be the same line which we measured as at 5750Å in the two pink diamonds. Miss Mani describes this as part of the 5040 system, however, whereas certainly in the stones described above the 5750Å line was acting as the head and chief of its own system of lines. It was, moreover, far brighter and clearer than either the 4155 or 5040Å emission lines as seen in other diamonds, which under ordinary conditions are quite difficult even to discern.

Before concluding, reference should be made to an important paper on the fluorescence of diamond by Dyer and Matthews,[5] which the writer has only recently had the opportunity of seeing. Using 3650Å mercury light as the exciting radiation, these workers have found, in addition to the 4155 and 5040 series of lines, a system

of bands at the red end of the spectrum based on wavelength 6195, with other members at 6291, 6393 and 6494Å.

These emission " peaks," however, were not resolved at room temperatures, but were studied and measured at liquid-air temperatures, i.e. at 80K or – 195°C. The lines quoted were not associated with any corresponding absorption bands. They were found to accompany the blue- and green-fluorescing systems, and were too weak to influence appreciably the colour of the fluorescence.

Though a formidable corpus of research has been carried out on the physical properties of diamond, it is certain that much more remains to be discovered.

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2. Mani. *Proc. Ind. Acad. Sci.*, 1944.
3. Becquerel. *Ann. Chim. Phys.*, 1859.
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DIAMOND INCLUSION

R. WEBSTER

An interesting inclusion was noticed in the centre stone of a small diamond ring. The inclusion appeared to be isotropic between crossed nicols and has the appearance of being a cavity. There may be a libella in the centre of the central bar. The fluorescence of the stone under long-wave ultra-violet light is bright blue and the inclusion stands out dark.

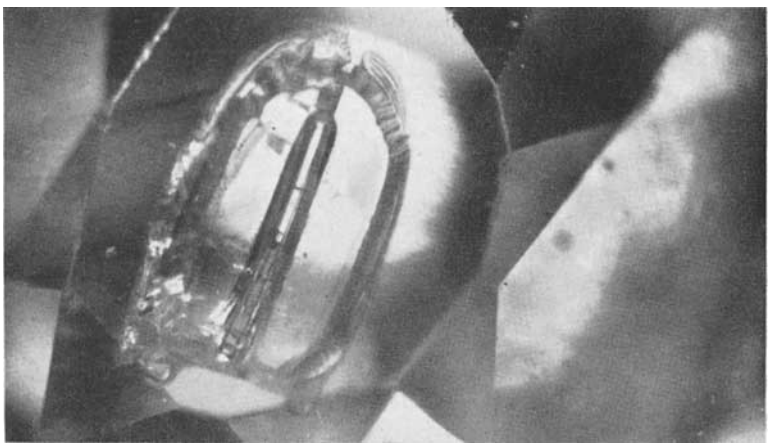

A BRAZILIAN EMERALD

(A contribution to the study of crystal growth)

By W. F. EPPLER

THE final size of crystals depends on several factors, the most important of which are concentration and composition of the mother solution (or melt) and pressure and temperature during crystallization. The time-factor, too, is of some importance, although it is often overrated.

The growth conditions may change during crystallization; the growing of crystals in nature, therefore, is frequently not a steady process, but often interrupted or subject to phases. One of many good examples is certain tourmaline crystals from California, U.S.A., which display, in cross section, a pink core surrounded by green outer layers. In this case an original pink tourmaline kept adding green layers through change of the pigment-content in the mother solution.

Another example, which is just as instructive, is a crystal of Brazilian emerald from Bom Jesus das Meiras, Bahia, Brazil. Its dimensions were $24 \times 6 \times 4$ mm (about $1 \times \frac{1}{4} \times \frac{1}{6}$ in.), and its weight about 7 cts. The cross section showed it to be free from inclusions apart from a narrow outer rim. Under the microscope, when the aperture was nearly closed and an intense light-beam produced, interesting growth phenomena became visible. These phenomena are shown in illustrations 1 and 2 and are summarized in a greatly simplified sketch (Fig. 3). The illustrations show how growth developed from an hexagonal nuclear crystal, which itself started growing from a minute germ crystal (not illustrated). Bordering the hexagonal nucleus is a rather homogeneous growth phase, namely the area enclosed by the heavily rimmed dodecagon. The weak white lines (broken lines in Fig. 3) from the nucleus to the heavy dark outlines indicate that during this growth phase there were present several pyramidal faces, which disappeared later. The dodecagon was produced by the combination of the faces of the second order prisms with those of the original first order prisms.

The following growth phase shows frequent changing in the preference for the prisms of the first or second order. During this phase " islands " were developed, which are orientated in accordance with the second order prisms and indicated by Fig. 3 in

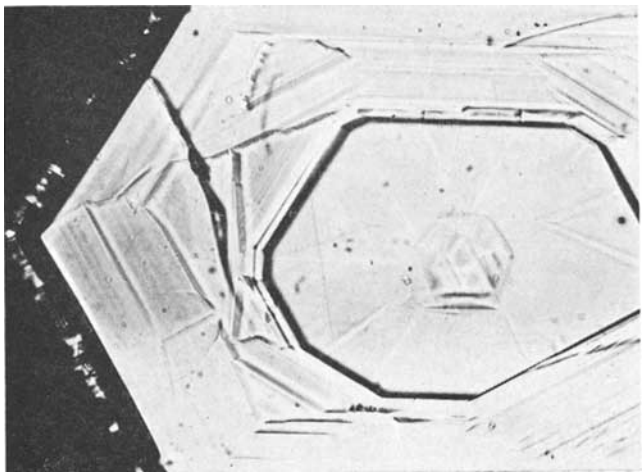

FIG. 1. *Brazilian emerald with different growth phases. Plane of slide parallel to crystal base.* 22 × *mag.*

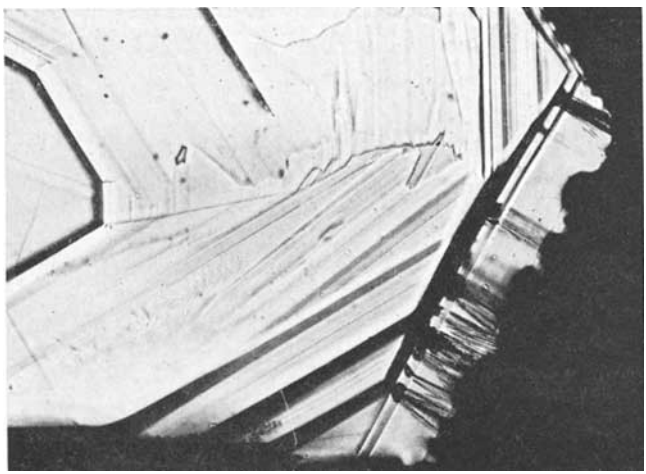

FIG. 2. *Brazilian emeralds with different growth phases. Plane of slide parallel to crystal base.* 22 × *mag.*

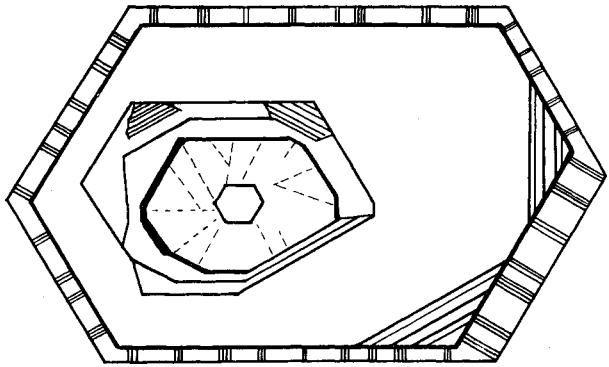

FIG. 3. *Diagram of some growth phases of the Brazilian emerald.*

corresponding hatching. Eventually the growth of this crystal ended in an hexagonal outline, the corresponding faces of which are parallel to the inner nuclear crystal and belong to the first order prism. During this last phase the crystals did not at all grow uniformly and without interruptions. This is indicated by the different fine lines, which in Fig. 1 and 2 belong to the different hexagonal bipyramids.

At normal illumination the emerald crystal appears completely uniform. This means that the individual " layers," which indicate growth-phases similar to rings in trees, vary only very little in their refractive index. These small variations in their turn are indications of a slight difference in the chemical composition of the individual layers. This shows conclusively that crystals grow in varying conditions. It can be assumed that the composition of the mother-solution changed slightly with time, or that material of differing chemical composition crystallized at different periods. It is difficult to find a definite reason for this. It may be that crystallization from the mother-solution caused a surplus of one or other component, which later was balanced by the addition of new mother-solution. It may also be possible that the mother-solution was added intermittently and that small variations in concentration caused these linear " growth striations." Finally, there is the possibility that the mother-solution was subject to certain currents, which could explain small changes in chemical composition and

also in concentration. Furthermore, if one takes into consideration that possibly pressure and temperature may have changed, it becomes apparent that in this case crystal growth appears to have been a very complicated process depending on many factors.

One further interesting phenomenon shown by this Brazilian emerald is in its outer growth layer. This is the layer which can be seen on the left hand side of Fig. 1 as a dark seam with a few light spots and on the right hand side of Fig. 2 running at an angle to the edges of the illustration. In Fig. 3 the layer is depicted by irregular hatching. This layer has brush-like inclusions arranged at right angles to the prism faces (Figs. 4 and 5). They consist of a broad and darker " foot " from which capillaries extend towards the outer prism face. The " foot " consists of a hollow containing a small quantity of liquid. The shape is irregular. The capillaries, which do not always run absolutely parallel to each other, are, on the other hand, completely filled with liquid. At times they were subject to resorption by the host crystal, as can be deduced from interruptions in some capillaries. This resorption or healing process is well illustrated in Fig. 5.

The only explanation for these peculiar inclusions seems to be that the growing of the crystal was disturbed shortly before the

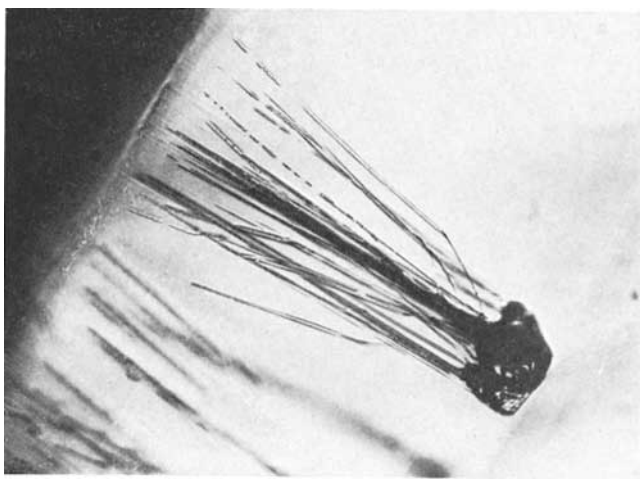

FIG. 4. *Brazilian emerald, brush-like liquid inclusions. Plane of slide parallel to crystal base.* 120 × *mag.*

FIG. 5. *Brazilian emerald. Brush-like liquid inclusions. Plane of slide parallel to crystal base.* 200 × *mag.*

layer was formed. The surface (prism face) of the emerald crystal at that stage served as a support for the " foot," which with further crystal growth developed into these brush-like formations. As these inclusions are distributed over the whole crystal, it is perhaps permissible to think of a " shock " during the growth of the crystal. Unfortunately there are no indications which would allow definite conclusions with regard to the nature of this disturbance or its cause.

Both phenomena, the intermittent growing of this Brazilian emerald crystal and the regionally limited presence of the unusual liquid inclusions, allow the conclusion that its genesis must have been full of incidents. If these phenomena should be present in other Brazilian emeralds of the same occurrence, especially the liquid inclusions on account of their peculiar shape and arrangement, they might be of value as typical characteristics.

Translated from Schweizer Goldschmied, L'Orfevre Suisse, 1960, vol. 49 (No. 1), pp. 23-27. The Association is indebted to the Schweizer Goldschmied for the illustrations.

SARKSTONE

By E. H. RUTLAND

In preparation for a recent holiday in the Channel island of Sark I decided to find out something about its geology, especially as I heard that amethyst was found there. My quest for rock specimens proved unavailing. Most surprisingly the Channel Islands are outside the area covered by the Geological Museum. I was referred to the Imperial Institute, but found nothing on display there either. An attendant tried to help by suggesting that if I would specify any particular stones I wished to see, a search would be made in the stores. However, I did not wish to put the staff to a lot of trouble with my amateurish inquiry and contented myself with reading Professor Wooldridge's most useful chapter in "The petrology of Sark," *Geological Magazine*, June, 1925.

Friends who knew the island well warned me not to expect much from the local variety of amethyst known as Sarkstone. This proved to be justified. No material that is even slightly attractive appears to have been found in recent years. There are two places where purplish quartzite is found. Both are on the south-east coast of " Little Sark," the southern part of the island. One of these is really only accessible from the sea, but I got to the other one, known as the " Pot." This is a typical " creux," a formation frequent in the Channel Islands.

Large caves washed out by the sea and often only accessible from it abound round Sark. They often extend up to 100 yards into the steep cliffs. Sometimes the roof at the back of the cave crumbles and caves in, leaving a roughly circular shaft up to 100 ft. high and with nearly vertical walls. Such is the Pot. Its floor is submerged at high tide but at low tide a broad archway connects it with the sea. The floor is strewn with boulders and pebbles, some of which are very attractive and include jaspers and chalcedonies of various kinds. Access to the Pot is by an easy path to its top rim but the descent into it calls for a scramble on all fours and not everyone will attempt it.

The Sarkstone is in a vein running vertically up the cliffside. Many veins of white quartzite permeate the rocks in this locality but only in the two places mentioned are purple pieces sometimes found. Most of the material in the Pot vein is stained brown with iron but

I hacked out some pebbles in which the brown colour had changed to a dark purplish red. This cryptocrystalline material was all I could see. There were some water-worn pebbles of it on the floor of the Pot, and I also picked up a drusy boulder containing white opaque crystals of milky quartz. From this it seems possible that crystalline amethyst may also occur, albeit not of any high degree of transparency.

Inquiry among residents and habitués of up to thirty years addiction to Sark produced the same answer : Nothing worth while had been found for a very long time. A local jeweller produced two brooches set with pale amethysts which were claimed to be of local origin. They were quite transparent but indistinguishable from any other amethyst. There were stories of necklets in the possession of old Sark families, but one got the impression that these were quite rare.

It was therefore somewhat disconcerting to see an entire jeweller's window in an adjacent island labelled SARKSTONE and displaying a large array of the most flashy violet paste. There were some large geodes of amethyst, presumably of South American origin, at the sides and a notice explaining that sarkstone owed its colour to manganese whilst amethyst owed it to iron. There was no explicit claim that the pastes were Sarkstone or that any of the material on display came from Sark, but such would certainly be the impression one would receive. A jeweller friend in London has in fact been shown a bracelet of these pastes by a customer who explained that they were Sarkstones. She seemed to think that they were natural. But then, I have met some people who thought that rhinestones were natural. Such are the dangers of proliferating the names of gemstones.

Gemmological Abstracts

SWITZER (G.). *34th Annual report on the diamond industry*, 1958. Jewelers' Circular—Keystone.

Dr. Switzer's admirable survey of the diamond industry in 1958 takes the usual pattern. World production of diamonds was the highest on record, most of the increase coming from the Belgian Congo. There was a decrease in sales, 6 per cent for gem diamonds and 33 per cent for industrials. By the end of the year demand had increased and was running at a satisfactory level.

S.P.

LEIPER (H.). *How to cut cat's-eye gems.* Lapidary Journ., 1959, 13, 604-616, 3 figs.

A general survey of the problems of fashioning gemstones which show chatoyancy. Apart from the usual gems, such as chrysoberyl, quartz, scapolite, there is reference to nephrite cat's-eyes, which are obtained from an Alaskan jade, ulexite, witherite, mesolite, and other less familiar species.

S.P.

ZAVERI (C. K.). *Gem mining in India.* Lapidary Journ., 1959, 13, 246-556, 618-628, 1 map, 1 illus.

Gemstone occurrence in India is mainly confined to the northern part. Only Madras and Mysore produce gems in any quantity in the southern states, where the mining is not so well organized and where much recovery is by hand-picking from the fields. The range of species which is found in the country is considerable, though there is need for the modernizing of mining methods.

S.P.

PENSE (J.). *Zum elektronenmikroskopischen Faserbau des Achates.* On the electron microscopical fibrous structure of agate. Zeitschr. d. Deutsch. Gesellschaft f. Edelsteinkunde, 1959, No. 27, Spring, pp. 3-4.

Electron-microscopical investigations (mag. 20,000 to 60,000 times) have shown that an individual fibre in agate consists of many quartz crystals arranged with the optical axis at right angles to the long axis of the fibre.

W.S.

BLANK (H.). *Ein neuer mondsteinartiger synthetischer Spinell.* A new moonstone-like synthetic spinel. Zeitschr. d. Deutsch. Gesellschaft f. Edelsteinkunde, 1959, No. 27, Spring, pp. 11-12.

This synthetic spinel, when cut cabochon, resembles a moonstone, but has a strange blue shiller and faint asterism not known in genuine moonstone. The back is flat and polished and has the steel-blue appearance of a bloomed lens. Under the microscope anomalous double refraction and gas bubbles could be detected. Refractive index, specific gravity and hardness are those of synthetic spinel. Under short-wave UV (2540 Å) the synthetic spinel fluoresced vividly yellow-green compared with a delicate pink of the moonstone. Under long-wave UV (3650 Å) the synthetic fluoresced reddish, whereas genuine moonstone showed hardly any fluorescence.

W.S.

ANACKER (H.). *Vorkommen und Entstehung der Achate im oberen Nahegebiet.* Occurrence and genesis of agates in the upper Nahe valley. Zeitschrift d. Deutsch. Gessellschaft f. Edelsteinkunde, 1959, Vol. 27, Spring, pp. 12-24, Vol. 28, Summer 1959, pp. 19-24.

Geological observations which may affect validity of theories relating to the genesis of agate.

W.S.

FUTERGENDLER (S. I.). *X-ray study of solid inclusions in diamonds.* Soviet Crystallography, 1958, Vol. 3, No. 4.

Garnet, olivine, diopside, chrome-spinel, and diamond were found as inclusions in diamond by X-ray methods. X-ray investigation of inclusions is claimed to be more reliable than a visual study under the microscope.

G.F.A.

SCHLOSSMACHER (K.). *Türkis, gefärbt und gehärtet.* Turquoise, dyed and hardened. Zeitschrift d. Deustch. Gesellschaft f. Edelsteinkunde, Vol. 29, Autumn 1959, pp. 11-16.

Inferior but genuine turquoise has been impregnated *in vacuo* with colourless plastics, the nature of which is a trade secret. Thus a darker, more pleasing colour is produced and a harder gem material results, which takes a better polish than the original poor material. The existing rules on nomenclature do not cover

the case and there were difficulties in preventing the use of the correct but insufficient label " treated " turquoise. The author insists that a correct description would be " dyed and hardened."

W.S.

JAKOB (E.). *Die Verbrennungstemperatur von Diamantpulver.* The combustion temperature of diamond powder. Zeitschrift d. Deutsch. Gesellschaft f. Edelsteinkunde, Vol. 29, Autumn 1959, pp. 16-18.

Five test series were carried out with diamond powder of 05; 1; 3; 5 and 10 micron grain size, showing that combustion (in air) started at temperatures of roughly 350°C (662°F) when the particles were smaller than 3 micron. With bigger particles the combustion started at 700°C (1292°F). The author does not refer to other workers in this field and does not mention that sintered and other diamond abrasive tools are frequently produced in reducing or neutral atmospheres.

W.S.

SCHLOSSMACHER (K.). *Fortschritte in der Diamantsynthese.* Progress in diamond synthesis. Zeitschr. d. deutsch. Gesell. f. Edelsteinkunde, No. 30, pp. 2-4. 1959/60.

Survey of the present position mentioning American, South African and Russian production.

W.S.

———. *Neues über Zuchtperlen und Blisterzuchtperlen.* News about cultured pearls and cultured blister pearls. Zeitschr. d. deutsch. Gesell. f. Edelsteinkunde, No. 30, pp. 9-10. 1959/60.

For the production of non-neucleated pearls in Lake Biwar the Japanese use the fresh-water mussel *Hyriopsis Schlegeli.* Most of the pearls are of baroque shape. Similar tests were carried out in the West Australian Pearl Farms near Brecknock Harbour using the oyster *pinctada.* The Pearls Pty. Ltd. in the same district has also developed a new method of producing blister pearls, making use of the oyster *Pinctada maxima.* The blister pearls are finished in Japan in the way the first Japan pearls were made.

W.S.

SCHMIDT (PH.). *Geheimnisvoller Jaspis.* Mysterious Jasper. Zeitschr. d. deutsch. Gesell. f. Edelsteinkunde, No. 30, pp. 10-12. 1959/60.

Article dealing with history and legend relating to jasper.

W.S.

———. *Zucht schwarzer perlen.* Production of black pearls. Gold und Silber, Vol. 13, No. 3, p. 21. March, 1960.

Recently a magnificent black pearl was produced artificially in Japan by exposing the interior of a white pearl to radio-active radiation. For the last two years Prof. Horiuchi of the Mie-University has experimented with the change of natural pearl colour. He found that a colour change was effected by bombarding with neutrons. Only the interior of the pearl became black, the outer pearl layer did not change its colour. The neucleus of a pearl contains small quantities of manganese, which become black if exposed to radiations for a long time, and light blue or grey at shorter exposures. The colour change of manganese is due to oxidising induced or accelerated by radiation. W. St.

Schlossmacher (K.). *Künstlich gefärbte Achatlagensteine.* Artificially dyed agate layer stones. Zeitschr. d. deutsch. Gesell. f. Edelsteinkunde, No. 30, pp. 20-22. 1959/60.

Layer agates are used mainly in the production of cameos. " Niccolos " are the conventional stones consisting of a dyed (usually black) lower layer and a thinner upper layer, usually white, which is worked upon by the engraver. (The white layer does not absorb pigment during the dyeing process.) The most prized layer agates are those in which the two layers meet in an even plane.

Two different methods are used to imitate natural (though dyed) layer agate : (*a*) doublets—nothing new is to be said about this imitation ; (*b*) artificially produced layer agates, usually called false layer agates. An agate suitable for dying and without any natural white layer is chosen and cut into a block of twice the thickness of a " niccolo." The top and bottom faces must run parallel to the natural striation of the stone. The block is stained in a solution of chlorate of cobalt and ammonium chloride until it is completely saturated. It is then soaked in hydrochloric acid until the chlorate of cobalt and the ammonium chloride have been removed to a depth of 1mm all round. After this treatment the block is heated in potash dye. The outer layer becomes white and the inner core remains black. The block is then sawn through the centre so that two imitation " niccolos " result. In cameos worked from this sort of material the white layer may become patchy after some time. The author is concerned with the correct nomenclature for this imitation. W.S.

SMITH (W. E.). *The origin of chert.* Gemmologist, Nos. 339-340, Vol. XXVIII, pp. 184-188 ; 210-214. October/November, 1959.

A definition is given of chert and its varieties, of which jasper is one. The sources of the silica in chert are given as (1) of organic origin (sponges and/or radiolaria), (2) inorganic origin (volcanic or silica gel on the sear floor) and (3) from transported silica. These three sources are not, however, independent of one another. The whole origin of chert is discussed.

R.W.

KNOWLTON (C. S.). *Gem materials in the Taj Mahal.* Gemmologist, No. 339, Vol. XXVIII, pp. 195-198. October, 1959.

Describes the gem minerals used in the decoration of the Taj Mahal and the Fort of Agra.

1 illus. R.W.

MITCHELL (R. K.). *The largest beryl crystal ?* Gemmologist, No. 341, Vol. XXVIII, p. 228. December, 1959.

Reports and describes the finding of a non-gem quality crystal of blue beryl which measured eight feet across the prism. The crystal was found on the Muine mine at Alta Ligonha, Mozambique.

1 illus. R.W.

ALEXANDER (A. E.). *The Chatham ruby makes its bow.* Gemmologist, No. 340, Vol. XXVIII, pp. 210-204. November, 1959.

The report of an investigation into the characters of the hydrothermally-produced synthetic ruby. There appear to be two types ; crystals of Burma colour and faceted stones, which have more the colour of Siam rubies. The crystals examined showed microscopic crystals with well defined crystal forms and " finger-prints " of a variety of size and form. Silk, colour zoning and uneven distribution of colour were also seen. In some of the crystals a few metallic particles of minute size were found and it is suggested that these may be caused by particles from the autoclave lining. The darker faceted stones showed wisp-like inclusions somewhat similar to those seen in the Chatham synthetic emerald and, further, these stones phosphoresced under X-rays whereas the crystals did not.

R.W.

MARTIN (P). *A musical instrument made of jade.* Gemmologist, No. 341, Vol. XXVIII, pp. 233-234. December, 1959.

Describes the set of chiming stones, called Ch'ing, used in Old China, often made of ornamental minerals of which jade was the best.

1 illus. R.W.

SMITH (W. E.). *The nature of chalcedony.* Gemmologist, No. 342, Vol. XXIX, pp. 5-7 and 16. January, 1960.

The characters of chalcedony, which have considerable gem importance, are discussed. The refractive index and the density of chalcedony are compared with those of quartz and opal. It is suggested, and reasons are given, that the description of chalcedony as being a form of silica distinct from quartz, or as an intimate mixture of colloidal silica (opal), is not tenable. It is now suggested that chalcedony does not contain opal but the lowering of the refractive index and density is due to minute spherical pores (crypto-pores) of about 0·1 microns in diameter, which are probably filled with dilute saline solution. Banded agates could owe their structure to rhythmic release of minute bubbles during crystallization of the silica gel, the bubbles containing dilute aqueous solution derived from the aqueous phase of the gel. This may also account for the different staining capacity of the bands.

R.W.

BENSUSAN (K. E.). *Lapidary trends in America.* Australian Gemmologist, No. 5, Vol. 2, pp. 9-12. November, 1959.

Amateur lapidary work in the United States commenced about 30 years ago, mainly through the activities of rockhounds who collected minerals in their various forms and took up cutting in order to bring out otherwise hidden beauty in rough material. Many rockhounds now collect with the sole idea of getting cutting material. The idea that one must start learning lapidary work by making polished flats and cabochons has now been dispelled, for those who prefer faceting may commence at once with the aid of precision machines which replace the old jam-peg. A scheme of preliminary teaching is given and the necessity of knowing the critical angle for the species is mentioned. The tumbling process is described. Six-sided drums are better for the grinding and round barrelled ones for the polishing process.

R.W.

ANON. *Gemmological exhibition in Brussels.* Gemmologist, No. 342, Vol. XXIX, pp. 1-4. January, 1960.

A report on the gemmological exhibition held at the Institut des Arts et Metiers in Brussels. Apart from the general display, demonstrations of diamond and gem cutting and of laboratory work were given. A series of lectures were also a feature. One of these was given by Thorold Jones, F.G.A., of Harwell, who spoke on irradiated gemstones. Comment is made that while the exhibition was well publicised on the Continent little or no publicity was made in the United Kingdom.

2 illus. R.W.

BENSON (L. B.). *Highlights at the gem trade laboratory in Los Angeles.* Gems and Gemology, No. 11, Vol. IX, pp. 336-340. Fall, 1959.

Reports a thin rose-cut diamond set in a gold and enamel ring with a depression under the stone, which is lined with metal foil moulded into facets of the same shape as the facets of the diamond. This gave considerable " life " to the stone. A black coral from Hawaii, which had an approximate refractive index of 1·56 and a density of 1·37, showed a radial structure and the material did not show fluorescence. An amber-like resin of rose-pink colour is another material referred to and it is said that this material responded to all the tests for amber, except specific gravity, but the facts are not given. Some notes are given on treated turquoise, and on the errors in the stencil gauges used for weight estimation of diamonds. A variable-speed spinner (0·3600 r.p.m.) in conjunction with a 100 watt zirconium arc lamp and an adjustable triplet lens is mentioned and is used for absorption spectroscopy.

6 illus. R.W.

CROWNINGSHIELD (G. R.). *Highlights at the gem trade laboratory in New York.* Gems and Gemology, No. 11, Vol. IX, pp. 341-343. Fall, 1959.

A badly worn cultured pearl necklet shows what can happen when care is not given to such necklets. The danger in using atomizers for perfume when wearing pearls is discussed. A transparent crystal of green jadeite in the mass of a piece of translucent jadeite is commented upon. Some notes are given on the so-called coque de perle and these are said to be distinguished from blister pearls by the transverse ridges seen on the surface. " French

river pearls " are the section of the lip of one valve of a salt water mollusc. A black opal, on being polished, lost its black colour and became ordinary white opal. It was thought that the original black colour was due to treatment by the introduction of carbonaceous deposits along minute cracks near the surface. A coated diamond is reported.

5 illus. R.W.

GÜBELIN (E. J.). *Leucite.* Gems and Gemology, No. 11, Vol. IX, pp. 333-334 and 350. Fall, 1959.

Describes the occurrence and provenance of the cubic mineral leucite. Transparent material of this species has been cut into faceted stones. Leucite is found in igneous rocks, particularly in young lavas, and hence crystals are found in areas of past or present volcanic activity, such as Italy, the Eifel district of the German Rhineland and in the United States of America. The hardness is said to range from $5\frac{1}{2}$ to 6 and the density, from the specimens examined, varied from 2·46 to 2·48. The mean refractive index, usually displaying a weak birefringence of not more than 0·001, was found to vary from 1·504 to 1·509. The dispersion is 0·008. Polysynthetic twinning is common. Considerable investigation has been made by the author on the inclusions seen in the specimens he has examined. From experiments entailing moderate heating the author has deduced that the crystals of leucite consist of orthorhombic twin lamellae.

R.W.

WEBSTER (R.). *The prized chrysoberyls.* Gemmologist, No. 339, Vol. XXVIII, pp. 190-194. October, 1959.

The mineral species chrysoberyl is discussed in general terms. The varieties, the physical constants, luminescent effects and the absorption spectra of the different varieties are mentioned. The reason for the colour change of the alexandrite variety is explained, and the types of inclusions seen in this species are noted. The cat's-eye effect is in chrysoberyl due to a multitude of relatively short needles parallel to the vertical axis of the crystal. Localities where found and the styles of cutting most commonly used for the species are given.

2 illus. P.B.

JADE STORY—AMERICAN (3)

By ELSIE RUFF

TWO factors have added very considerably to our knowledge of both Mexican and Central American jade—the Tribute Roll and the several inventories that captors drew up to accompany loot to their native land. The Tribute Roll was a document of the native American economy. Taxes were not paid in coins, they were paid in the valuable products of the day, such as gold, skins, plumage and precious stones. Foremost among these valuables was *chalchihuitl*, an Aztec word derived from *zali* (jewel) and zihuitl (green).

Our knowledge of the Tribute Roll is due largely to the research, and a subsequent paper, by Zelia Nuttall, a well-known archaeologist.[1] This work not only defines the districts which were expected to contribute jade but in many instances specifies the quantity and occasionally the form it should take, such as beads, pebbles, rolled pieces or single boulders. Occurrences must have been known to the Aztec Treasury, since it was useless to demand large pieces from an area where only an occasional pebble was found. This paper, written as long ago as 1901, may yet be used as a guide for occurrences of jade still eluding us. Boulders and rolled pieces were, of course, carried down by streams. But almost certainly the ancient Mexican and the Maya knew where to obtain the mineral *in situ*. Each Ruler or King seems to have been responsible for his own Tribute Roll and that of Montezuma gave a full list of the towns from which *chalchihuitl* was demanded. A copy of this document was despatched by Cortés to his king, Charles V. In Chiapas, a province of Mexico, Montezuma expected tribute from no less than nine towns, six of these towns lying near the Pacific coast and Guatemala. Yet an inland town, G. Kunz pointed out in *Gems and Precious Stones of Mexico*, not listed. in the Tribute Roll, bears the name of *Chalchihuitan*—" *the land of chalchihuitl.*" The result of this careful survey shows that the main contributors of *chalchihuitl* as tribute were located in several states of Mexico and in Guatemala. (Journ. Gemmology, 1959, VII, 4, 143.)

It was not until Francisco Hernandez de Córdova returned to Spain after his discovery of Yucatan that the Spaniards awoke to the fact of a New Spain rich indeed. Later, many cargoes of

valuables found their way to the home country—and many never reached it. Inventories were made, some of them extant, that tell of this rich loot.[2] The Spaniards were primarily interested in gold and emeralds, and under the heading *emeralds* were unquestionably many beautiful *chalchihuitls*. What has happened to them is anybody's guess. Some of these articles were definitely described as *chalchihuitl*, often combined with gold, or with other gems. Many such pieces were merely listed *Greenstone*, and since those responsible for the inventories were more likely to have recognized emeralds, with which they were familiar and certainly anxious for, it is likely that such pieces were also of *chalchihuitl*, perhaps of inferior quality or at least of a shade of green not commonly associated with emeralds. Articles of *chalchihuitl* were worked up into such trinkets as bells, trees, shells, beads, medals, hearts, collars, birds, cicadas, crabs, snakes, butterflies, heads of humans or near-humans, monsters; even rings set with *chalchihuitls* or other gems were sometimes included.

Marshall H. Saville writes:[3] " It has been demonstrated by the statements of Bernal Diaz[4] and especially by a study of the lists of the great Aztec loot, that by far the greater part of the gold treasure gathered by Montezuma for the invading Cortés and his fellow Spaniards went at once to the crucible to be melted into bars for immediate division. Of this the King of Spain received his royal fifth and certain other small proportion of the spoils, the greater part being retained by Cortés and his companions. Of all the priceless relics of ancient Mexico, such as gold, jewels, stone mosaics, and the unique feather mosaic-work, which were not destroyed but sent to Spain as treasure or curiosities, probably fewer than two score of these objects are to be found in Europe. During the passing of four centuries, the melting-pot, careless hands, and moths, have each contributed to carry to oblivion visual knowledge of these arts. Of the jewels of gold sent to Europe by Cortes and others . . . no specimens are extant . . . "

Among the ornamental jades of Mexico and Central America, it will be noticed that carved plaques and carved figurines, and of course beads, were perhaps the commonest forms, though ear-plugs (as they were called, though in no sense did they plug the ear) were also common. These ear-plugs were used, almost exclusively, by men. Since many of the carved pieces were pierced, it is obvious that they were intended for suspension as pendants. There

were also wristlets,[5] earrings, called by the Maya *orejeras*, and nose ornaments. Labrets or lip ornaments were sometimes so enormous that the distorted lip must have been as painful as the distorted ear lobe that had to be stretched to maintain the ear-plug. Finger rings were far less common and have been established mainly as a result of burial excavations. Cortés wrote of the market place where the jeweller displayed his wares of gold jewellery side by side with precious stones and *chalchihuitl*. Thomas Gann writing of *Mystery Cities* (p. 56), gives us a fascinating picture of a mound he excavated:

" The objects found on the summit of this mound are singularly suggestive: nodules of flint of various colours, nodules of jade, cores of obsidian, and the shells from which were derived the material for making beads, earrings, gorgets, and other ornaments, together with hammer stones, chisels, and a grinding stone for working these materials; in fact what amounts to the entire outfit of an Old Maya jeweller and lapidary, together with a number of his finished products in flint, obsidian, and ivory . . . We learn from Landa, a bishop of Yucatan, writing about the middle of the 16th century . . . that the Maya was accustomed to bury his dead with objects associated with the deceased in life . . . Now here we have what can be nothing else than the stock in trade of an ancient jeweller and I think the inference fairly obvious that the individual buried beneath, whether on the summit, or, as we shall ascertain later, in a chamber at the base, was a jeweller and worker in flints, ivory and precious stones. That he was a person of the first importance, is indicated by the size of the monument erected over him . . . " Gann continues: " . . . constructing a path from Succots to Benque Velgo along the western branch of the Mopan river, two very crude figurines of greenstone were discovered buried in the sand and gravel along what had originally been the bed of the river. Both these were typical specimens of archaic figurines, the prominent eyes surrounded by a ridge . . . But the archaic was a highland civilization which flourished from Mexico to the Andes some 2,000 years B.C.; how then do these specimens come to be embedded in the river-drift near Xumantunich ? This is one of the many mysteries of Central America . . . the area was also occupied by other branches of the Maya many centuries after that date."

Although jade was undoubtedly the most valuable and popular material for ornamental purposes, turquoise ranked a good second

(despite its less enduring qualities). Other gems admired and used were rock-crystal, jasper, serpentine, amber, onyx and agate. S. K. Lothrop wrote[6] in 1936: " . . . Middle American jewellery in aboriginal times was made principally of jade, of softer green stones, as well as jasper, crystal, and other rocks with distinctive

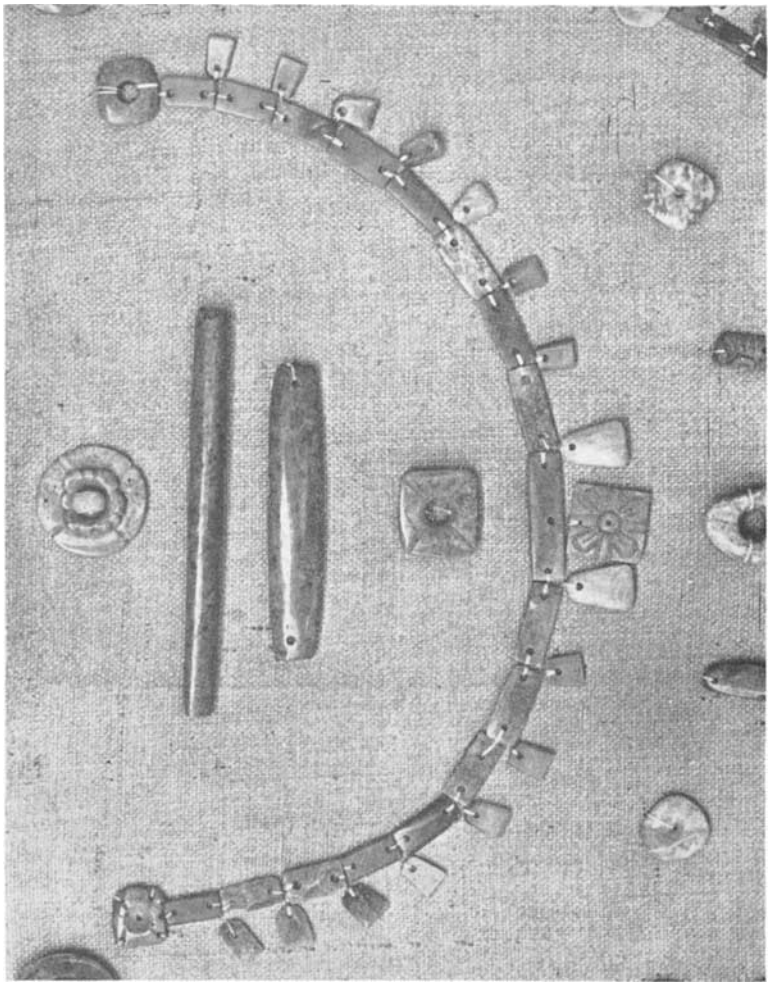

Jade ornaments from Zacualpa. The large tabular bead is 6·25″ long.

(Photo by courtesy of Peabody Museum, Harvard University).

colours. Jade seems to have been manufactured in several centres, of which the most important were in the State of Oaxaca . . . the north coast of Honduras, and the adjacent Bay Islands, and in the Nicoya region in Costa Rica. While artistically the finest individual specimens have been found sporadically, the great bulk of the recorded material comes from these regions. In spite of the importance of jade in the ceremonial life and artistic traditions of Middle America, no complete study of the subject has been made, and only a comparatively small number of specimens have been published . . . The Indian women of Santo Thomas Chichicastenago and other Quiché towns have, until recently, sewn silver coins on their blouses. In ancient times pieces of jade evidently were used for this purpose . . . The explanation for this may be that the Guatemalan highlands flank one of the great aboriginal trade routes of the New World, so that foreign ideas and commodities were more prevalent there than among the relatively isolated but highly specialized communities of Peten and Yucatan."

The accompanying photograph shows a collection of jade ornaments from Zacualpa, Guatemala, illustrating pieces of jade that were almost certainly sewn to garments as Lothrop points out. These ornaments are now in the Peabody Museum at Harvard University, U.S.A.

S. Linné, of the Ethnographical Museum of Sweden, writes: " Both ear-plugs and labrets show great uniformity over a large area of the country. No doubt they were products of the workshops of skilled specialists, and it should be possible to trace them back to certain centres of manufacture . . . Certain ceramic finds as well as objects of jadeite (discovered at Teotihuacan, the Toltec capital) have furnished ample evidence of far-flung trading connections . . ."

P. Keleman in *Jade and other semi-precious stones* wrote: " . . . Among the stones used in mediaeval America were jade, turquoise, rock-crystal and serpentine, as well as amber, onyx, jasper, and agate. Of these the jade work stands first in quantity and in its artistic quality. The finest carving however, is confined to the Mexican and Maya areas, where the styles are so frequently interrelated that they will be presented here as if from one vast region . . . Besides its rarity and beauty jade had a deep symbolic meaning for the Maya andMexican. The Maya word for it was *TUN*, the *Nahua* (or Aztec) name *CHALCHIHUITL*, " green stone "; an association with grass or herb, emphasizing the colour which is

the symbol of life itself . . . In the Tribute Roll towns were assessed for it . . . "

G. C. Vaillant[7] describes Tlalteloco, a communal centre, " as majestic as that of Tenochtitlan . . . The market place of Tlalteloco consisted of a large area of polished pavement, bordered by arcades which sheltered many of the merchants . . . Elsewhere was a row of vendors of implements and tools, such as obsidian blades . . . pottery . . . Jewellers displayed jade ornaments and gold worked into precious rings of filigree or massive beaten gorgets. It was the jade, however, which caught the envious eye and was produced with furtive circumspection as a material of great price."

A further ornamental use for jade (though it is just possible that it could have been a surgical one) was as a filling for teeth. Gann reports that small, round plugs of jade, gold, or obsidian were often let into the front teeth, apparently for aesthetic motives. A Field Expedition to British Honduras,[8] excavating Maya ruins in 1931, came across "remarkable examples of aboriginal dentistry. The most interesting is a set of teeth from the upper jaw of an ancient Maya, showing four incisors and two canines inlaid with jade discs and with their edges filed to form a decorative pattern. The teeth of the lower jaw are undecorated. The owner was in the early thirties at death, and lived about a thousand years ago. The jade discs are set in cavities drilled in the front teeth with hollow bones or bamboo drills and sand, or possibly with points of jade or some equally hard stone. The process must have been extremely painful and we have no means of knowing if any anaesthetic was employed, but it is possible that it was, for it is known that the Aztecs thus assuaged the sufferings of victims sacrified by fire. On the other hand it may be that the drilling was done as an ordeal cheerfully undergone by young warriors to demonstrate their bravery. Other persons of wealth and rank wore such ornaments, for jade was an article of rarity and high value among the Mayas. The second Marshall Field expedition to British Honduras discovered teeth decorated with discs of iron pyrites, which probably adorned persons of less wealth. The discs were held in place by fine cement, faint traces of which were found on one tooth. Inlaid teeth have been found in various parts of the Maya area. Materials employed in addition to jade and iron pyrites are turquoise, obsidian, and hematite. A second upper jaw was found by the expedition at the same ruins of San Jose. The teeth in this one have no inlay,

but the incisors and canines have been filed down to points, giving a serrated appearance . . . It is certain that the inlays and filing of teeth do not represent surgical dentistry, although false teeth have been found in Maya skulls in two instances . . . A thick incrustation of tartar showed that it had been inserted in the jaw during the life-time of the owner."

An excavation of the ruins of Copan, in Honduras, revealed that the majority of the skeletons not only were buried with jade beads in their mouths but had jade fillings in their teeth.

To quote Professor Saville[9] again: " Another custom which we have found in Esmeraldas, and which, as far as we are aware, is not present in any other part of South America, is the decoration of the teeth by the insertion of small perforations cut in the enamel of the front incisors. This custom of decorating the teeth was quite common in various parts of Mexico where different settings were used. In the Maya area as far south as Salvador, the object most often used for the inlay was jadeite . . . "

In the second article of this series it seemed wiser to approach the subject of Jade in America from a geographical angle, but by progressing in a southerly direction it is almost impossible to divide these areas, since cultures frequently overlap. Yet, in moving south, one deals mainly with the Maya, whose culture was well passed its prime when the European arrived. In a very primitive form, and in small pockets, this culture still exists. We are told that the Maya region included the states of Chiapas and Tabasco in Mexico itself; the peninsula of Yucatan; Guatemala; Spanish Honduras; British Honduras; Salvador; and part of Nicaragua. The length and breadth of this area was roughly 500 miles each way, with the first Mayan settlement approximately central. T. Gann writes (*History of the Maya*): " Almost every city developed along lines of its own . . . Palenque for its beautiful stucco moulding and engraved jades . . . engraved jades from Palenque are found as far west as Teotihuacan, near Mexico City, and as far north as Chichen-Itza." Dr. Gann speaks of the Mayas as " the least war-like nation ever existing " and writes of their first contact with the Spaniards in Yucatan in 1517.

Writing in *Gems and Gemology* in the Spring of 1952, Raymond Barber said: " The greatest number of authentic jade carvings have been found in the states of Guerrero, Oaxaca, Chiapas, Vera Cruz and Tabasco . . . this jade was held in the highest esteem

Jade Maya disc from British Honduras.

(British Museum photograph.)

by all the early peoples of Mexico—the Maya, Mixtic, Zapotec, Olmec, Toltec, and Aztec. The great quantities of jade artifacts that have been discovered in Maya ruins . . . probably were brought there from the mountains of Oaxaca in the west, or of Guatemala in the south, to be carved for use in religious ceremonies . . . "

We are indebted to a Spanish friar,[10] who spoke fluent Quiché, for preserving and translating a native MS. known as *The Popol Vuh* (" The book of our people "). In it we learn that when the relatives of the deceased were too poor to put a piece of jade in the mouth of the corpse, they used grains of maize. He tells us too that poor people who could not afford, or were not permitted, jade, had to be content with ear-plugs, and even beads, of pottery. " Nose ornaments of various types were used, the material being jade, amber, and in later times gold."

Maya jade carving

Olmec jade carving

(British Museum photographs).

During 1946 three men[11] were excavating at Kaminaljuyu in Guatemala. " . . . Great value was placed upon jade throughout MesoAmerica," they wrote, " particularly jade of brilliant colour. Nowhere, apparently, were lapidaries so preoccupied with this quality as at Kaminaljuyu. Whether for that reason the local craftsman traded for outstanding raw material, or whether, as we think more probable, ready access to sources of unusually good jade made them, so to speak, colour-conscious, the fact remains that specimens from the Esperaza tombs contain a larger proportion of beautiful stone than any other collection we have seen. Decoration was confined in almost every case to effects which could be produced by straight sawed lines and by circles and arcs of circles made with the hollow drill . . . The shape of any given piece was often dictated by that of the stone, but even more by the distribution of its colour."

In *Maya Jades* T. Gann tells us: " Probably the most spectacular and certainly the largest cache of Maya jades ever found was unearthed quite recently in the ruined city of Copan in the Republic of Honduras, by workmen digging out stone to build a house." He describes a jade pebble found here as: " bi-convex, 8″ long, and carved on one side, the rest of its surface showing distinct attrition by water. The material is of light yellowish-

green jade, and the sculpture is very typically early Maya . . . At the intersection of the limbs of the cross was found a very remarkable cache, containing an anthropomorphic figure in highly polished green jade, 7.5 inches high; eight pendants of highly polished apple-green, almost translucent jade, representing human heads; grotesque animals holding human heads in their mouths; two pairs of jade ear-plugs and two long tubular jade beads pierced through their long diameters for suspension; forty jade beads of various sizes . . . The jades were placed in the centre, around them were arranged the sea-shells, so as to form a covering . . . it is obvious that the anthropomorphic figure . . . though closely resembling that found in the dated vault is more archaic in style. It dates probably from about the middle of the third century A.D. Within this mound was found a human burial accompanied by objects of jade and flint . . . "

A research party[12] in 1945 discovered " the skeletons of six adults with . . . twenty-five complete pottery vessels, a marble bowl, and thirty-four jade specimens . . . Among the jade were tubular beads of fine quality jade, one a brilliant dark green with white streaks, one green with white mottling. Of the jade pendants, one was of a pale blue-green stone. And there were jade ear-plugs."

So many variations in the dates of early American objects exist that the matter has now assumed controversial proportions.

Maya jade carvings (Central Maya region)

(British Museum photograph.)

At first it was thought that the various finds were of extreme antiquity. Later the picture changed, and only a few hundred years separated much of the work with the European invasion. Some years ago a book appeared entitled *The Conquest of the Maya.*[13] A thoughtful reviewer observed: " There is another extraordinary point about this architecture (Mayan). It seems to have been an art which sprang full-fledged into its highest pitch of achievement. There is no development in it, no growth, no life. It is completely static, and always imitative, as if each successive generation copied what had gone before without the faintest notion of why they were piling one stone on another in a particular way. For example, they had unquestionably wonderful mathematicians who ' could calculate to a nicety immense passages of time ' and yet they never discovered the principle of the true arch, in which case each stone is self-supporting, nor could they draw a mathematical right-angle."

Only some four years ago an expedition discovered an Olmec ceremonial centre at La Venta. Here, in a marsh-surrounded island near the Tovala River, were found among the relics several fragments of charcoal, " presumably the remains of ceremonial fires. The carbon 14 content of the charcoal bits taken from La Venta's lowest level gave its average date as 814 B.C., with a maximum possible error of 134 years. Since they lived in a rainy region where only the toughest relics avoid disintegration, almost nothing would be known about the Olmecs if it had not been for their curious custom of carving in jade and hard stone and burying the carvings . . . They also carved monstrous human heads nine feet high with petulant baby faces. They floored their ceremonial rooms with clay tinted red with cinnabar . . . Dr. Robert Heizer, one of the leaders of the La Venta expedition, believes that the Olmecs' radio-carbon dates will ' force a total chronological re-assessment of early American history.' "

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ASSOCIATION NOTICES

GIFTS TO THE ASSOCIATION

The Council of the association has received the following gifts:

Samples of turquoise hardened with polyester synthetic resin and colloidal silica, and samples of the mineral before impregnation, from Harold Maryott, Arizona.

A small parcel of stones from Harold Cropp, London.

A large piece of nephrite, from Monterey County, California, from A. Ramsay, Glasgow.

A collection of Southern Rhodesian gem minerals from K. C. Cole, of Salisbury, S. Rhodesia.

A small parcel of cleaned spessartite garnet from Rutherford No. 2 mine, Keener Farm, near Amelia, Virginia, from Capt. John Sinkankas, U.S.A.

GEMOLOGICAL SOCIETY OF SAN DIEGO

The Gemological Society of San Diego has eight of its members who are Fellows of the Gemmological Association of Great Britain. This is the second largest group of F.G.A.s in any city outside the U.K., Toronto having thirteen. One of the objects of the San Diego group is to train speakers to go before other groups and speak on various aspects of gemmology.

The San Diego Society would welcome correspondence with any similar society and letters should be sent to the President, Edward R. Bohe, G.G., F.G.A., 3145 North Mountain View Drive, San Diego 16, California, U.S.A.

WEST OF SCOTLAND BRANCH

A talk was given by Mr. Robert Webster to the West of Scotland branch of the Gemmological Association at Glasgow last January in which some problems currently confronting the jeweller were discussed.

The difficulty of identifying strontium titanate, known in the gemstone market as FABULITE, when such stones are in a setting was demonstrated. It was pointed out that owing to their pronounced fire, low hardness and the peculiarity of the rounded facet edges (rather like those seen on paste stones), these stones would be obvious to the jeweller once he had seen samples. To this end a series of Fabulites in brilliant- and emerald-cut styles, and varying in weight from 14 carats to as small as 0.16 carat, were exhibited.

The new Australian whole cultured pearls and cultured blister pearls were discussed, and so were the non-nucleated cultured pearls from a freshwater lake in Japan and in the salt waters of north-west Australia.

The effect of wear and greasy cosmetics on cultured pearl necklets was referred to, and it was suggested that a customer should be told that periodical restringing

and cleaning should be carried out. It was explained that owing to the discontinuation layer between the core and the outer nacreous layer, greasy skin preparations, which so readily collect dirt, travel up between the core and nacreous outer skin and this dirty grease showing through the translucent layers of nacre impart an unpleasant dark colour to the pearls.

Mr. Webster also discussed the new hydrothermal rubies grown from " seeds " of small water-worn pieces of Burma ruby, which Carroll Chatham of California proposes to place on the market. Some information on the structures of these rubies was given and the question of the correct naming of this type of man-made ruby discussed. Rough Burma rubies used for " seeding " in the hydrothermal process, some hydrothermally grown crystals and stones cut from them were exhibited. The work being carried out investigating these hydrothermal rubies illustrates something of the research work carried out in the London Chamber of Commerce laboratory, an aspect of the laboratory's work which is not so apparent to the jeweller as the routine testing.

The imitation of turquoise and the bonding and hardening of this mineral by impregnation with plastic and colloidal silica were discussed and specimens shown. The coloration of diamond by bombardment with particles of atomic size, the staining of jadeite and jadeite triplets, and imitation hematite were also mentioned.

OBITUARY

Bernard Roulet, Zürich (D. 1955), after a motor accident.

Fred J. Waller, Southend (D.1932).

TALKS BY MEMBERS

WORTH, J. R.: " Diamonds," Leicester Round Table Club No. 39, 24th November 1959.

ATKINSON, J. C.: " Gemstones, synthetics and imitations," Morpeth Soroptimists, 26th January, 1960.

BLYTHE, G. A.: " Gemstones," Rayleigh Round Table, 18th January; Business and Professional Women's Club, Basildon, 2nd February; Rochford Young Farmers' Club, 3rd February, 1960 ; Benfleet Business Luncheon Club, 16th February, Eastwood Teenage Club, 4th April, 1960.

CAFFELL, ERNEST W.: " Gemstones," Hook and Chessington Branch of the Young Conservative Organization, Ace-of-Spades, Kingston-by-Pass, 15th February, 1960.

WARREN, K. (MRS.) : " Gemstones," Women Conservatives and Bromley Parish Church Women's Fellowship, 21st January; Dartford Business and Professional Women's Club, 2nd February; Young People's Fellowship, Christ Church, Bromley; 12th February; Crofton Townswomen's Guild, 25th February; Young Wives' Fellowship, St. George's, Bickley, 5th March; Mothers' Union, St. Augustine's, Bromley, 6th April.

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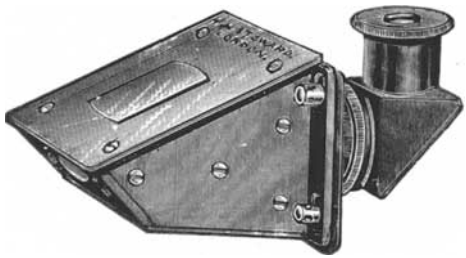

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Practical gemmology by R. Webster. A standard work for first year students of gemmology. 17s. 6d.

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IMITATION AND TREATED TURQUOISE

By H. LEE and R. WEBSTER

ARCHAEOLOGISTS tell us that the turquoise found in the Sinai peninsula was used for beads and jewellery in both the Old and Middle Kingdoms, and even as early as pre-dynastic times. It may well be expected then that imitation, as so often occurs, would follow, and indeed one form of imitation known as *faience* was also as old as the pre-dynastic times, say before 4777 B.C.

Faience, a glazed siliceous ware, was said to have been invented at Faenza, Italy, in the 13th century and is a glazed earthenware, of which Wedgewood ware is a modern example. The ancient faience of Egypt is somewhat different in that the broken surface shows it to consist of two or sometimes three layers. Always there is an inner core of fine gritty material, which may be powdered quartz, with an outer coating of coloured glaze, and, occasionally, there is a third middle layer between the core and the glaze. This when present is very marked owing to the differences in colour and density and was probably used to enhance the glaze.

Although primarily intended and used as a pigment, *frit* was composed of a crystalline compound of silica, copper and calcium. It was probably made by heating together silica, probably in the form of quartz pebbles, a copper compound which was generally malachite, and calcium carbonate and natron (a natural sodium carbonate), but there are variations of this. The date when this

material, called by Vitruvius *caeruleum*, and by Theophrastus *kyanos*, was first used is uncertain, but it has been found as early as the 4th dynasty (3998-3721 B.C.).

Glass has been reported prior to the 18th dynasty (1587-1328 B.C.). The glass of ancient Egypt—and Egypt is usually accorded the honour of the discovery of glass—is generally opaque, rarely transparent and always coloured. Copper compounds were usually the colouring agent in the Egyptian blue-coloured glass, but one specimen from the tomb of Tutankhamen (*circa*. 1350 B.C.), analysed by W. B. Pollard, was found to be coloured by cobalt. The finding of cobalt glass as early as the 14th century B.C. is of importance since no cobalt, or very little, is found in Egypt, and this pre-supposes some connexion with abroad — maybe Greece or Rome. The foregoing imitations have archaeological interest only.

Glass imitation gems were made in Roman times, the *gemmae vitreae* of Pliny, but turquoise was not the most popular stone in the period of the Roman Empire. Again in the Dark and Middle Ages, when the centre of the glass manufacture was Venice, and after 1291 at Murano, turquoise-coloured glasses again had no great vogue.

Some forms of blue enamel can imitate turquoise. The basis of all enamels is an easily fusible colourless silicate glass to which the colour and the desired degree of opaqueness are imparted by mixtures of metallic oxides. The molten mass, after cooling, is reduced to a fine powder and washed. The moist powder is then spread, usually with a spatula, upon the surface of the metal. The whole is then fired in a furnace till the enamel is melted, when it adheres to the metal. Enamel, which is really just an opacified glass, has been used from early times, both in the Near East, Europe and the Orient. Blue enamel is obvious for what it is by reason of its vitreous lustre, and because the coloured areas are not in settings.

Glass imitations of turquoise consist, usually, of an opaque white glass to which a trace of copper oxide, or oxide of cobalt, is included in order to produce the colour. Such imitations are often finished on the upper surface with a layer of clear glass. The density of glass imitation turquoises varies between rather wide limits according to the type of glass used. Most commonly the density falls within the range 2·80 to 3·30 ; likewise the refractive index varies between 1·55 and 1·60.

Turquoise imitations in glass quite often show, on examination with a hand lens, small pits on the surface, which are surface bubbles

cut across, or small bubbles just visible below the surface. The luminescence shown by glass " turquoises " when bathed in invisible ultra-violet light shows characteristic differences from the glows shown by true turquoise, and from many other types of imitation turquoises. Glass imitations do not conduct electricity, while much real turquoise and some other turquoise imitations often do.

Imitations of turquoise in coloured china (porcelain) are not common. Such material is characterized by its constant density of 2·3. Owing to the fact that most often these pieces are finished with a vitreous glaze the refractive index will be that of the glass finish.

The popularity of turquoise during the 18th and 19th centuries gave an impetus to its imitation and fake turquoises made of many different materials were produced during this period.

There should be discussed first, however, a number of natural minerals which simulate turquoise. Most are too rarely met with to need comment in this article but mention must be made of *lazulite* and *variscite*. Lazulite occurs as monoclinic crystals of a sky-blue colour or as finely granular masses known as *blue spar*. Such material is found in Salzburg, Switzerland, near Diamantina in Brazil, and as nodules at Death Valley, California, and at North Groton, New Hampshire, in the United States of America.

The chemical composition of lazulite is very similar to that of turquoise, being a hydrous aluminium phosphate, but containing in addition some iron and magnesium. The mineral forms an isomorphous series from the bright blue *lazulite*, $(Mg,Fe)Al_2(PO_4)_2(OH)_2$, to the darker *scorzalite*, $(Fe,Mg)Al_2(PO_4)_2(OH)_2$. Lazulite may be easily distinguished from turquoise by its higher density which approximates to 3·1, although the refractive index (1·61-1·64) overlaps that of true turquoise. The hardness is $5\frac{1}{2}$ on Mohs's scale, which is rather less than that for true turquoise. There is no copper present so that a test for copper giving a negative result will prove that a suspected piece is not turquoise. Lazulite does not show the turquoise absorption spectrum.

The mineral *variscite* is a hydrous aluminium phosphate, Al,PO_42H_2O, but by isomorphous replacement usually contains some iron, producing a series in which the pinkish or amethystine *strengite*, Fe,PO_42H_2O, is the iron end member. Variscite resembles turquoise but is usually greener in colour. The green nodules from

Fairfield, Utah, called *utalite*, and veins from Lucin in the same state of North America have both been used for jewellery purposes. Large masses and small nodules are found near Brisbane in Queensland, Australia, and other localities for variscite are Freiberg in Saxony, Pontevedra in Spain and Arkansas in the United States of America. Variscite has a slightly lower density than for normal turquoise, approximately 2·4, and has a refractive index near 1·57. There is no copper in its composition and the material does not show the turquoise absorption bands in the blue of the spectrum, but quite often lines in the red are seen, which may be due to chromium.

What is probably variscite of great transparency and fine colour is the mineral *callainite*, or *callais*, which was used in pre-historic times as a precious stone. It was found in an ancient Celtic grave at Mané-er-H'roek, near Locmariaquer in Brittany, France.

Although not strictly a mineral, the material called *odontolite*, or variously " Bone turquoise," " Tooth turquoise," " Occidental turquoise," " Turquoise de la nouvelle roche," or " Fossil turquoise," is the bones and teeth of certain extinct vertebrates, such as the mastodon and dinotherium, which have during the process of fossilization become impregnated with the mineral *vivianite*, a phosphate of iron, $Fe_3(PO_4)_2 8H_2O$, a mineral which is sometimes called " Blue iron earth " (*not to be confused with the glauconite sand, or " blue earth," of the Baltic amber deposits*). The material when taken out of the ground is a dingy greyish-blue in colour, but after moderate heating it changes to a fine deep sky blue. Some material is impregnated with a copper mineral instead of the iron *vivianite* producing a green odontolite, but such material does not seem to have been used in jewellery.

Odontolite varies in refractive index from 1·57 to 1·63 and has a density, for the gemmy material, just above 3·00. The hardness is 5 on Mohs's scale, and thus is softer than true turquoise. Owing to the carbonate content of the original bone or dentine the material " fizzes " when a spot of acid is placed upon it (do this on an inconspicuous part of the specimen, for the acid destroys the polish), and, further, in many cases the organic structure can be seen on the surface by magnification. Odontolite is found at a number of places but is especially abundant in the Miocene beds of Simorre, near Auch, in the Department of Gers in Southern France, a

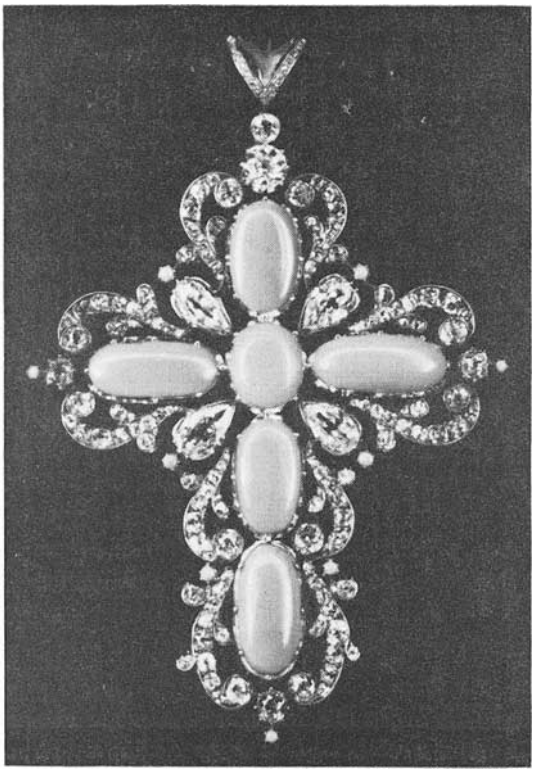

A charming diamond and odontolite cruciform pendant, the odontolites bordered by Diamond scroll work, the centre stone with a pear-shaped diamond set in each angle.

The property of Her Royal Highness the Duchess of Aosta, this piece has a long history. It was a presentation gift to the Princess Royal by the King of the Belgians, her sponsor, on the occasion of her Christening, 10th February, 1841. It belonged to Princess Charlotte of Wales. More recently it was given by Her Majesty the Empress Frederick to Her Royal Highness Princess Sophie of Prussia, on the occasion of her marriage, October 1889.

(Photograph by courtesy of Sotheby & Co.)

locality which was known before the French Revolution as Languedoc, and where for a time the deposits were systematically worked.

By calcining recent ivory and staining the resulting product by soaking it with copper sulphate solution an imitation odontolite is obtained. Such imitation odontolite has the density of ivory, that is near 1·80, so distinction is easy.

Imitation turquoises made of suitably stained chalcedony are not common, but such objects may occasionally be encountered. Stained chalcedony is much more translucent than turquoise and may be definitely identified by the typical density of 2·63 and the refractive index of 1·53. Another rare imitation is bone stained blue (or green), probably with phosphate of iron. Such material has the characters of bone, that is it has a refractive index of 1·55

and a density of just over 2·00. The bone structure is usually visible when the piece is examined with a hand lens. A " reconstructed turquoise " has been made from finely powdered ivory bonded with a copper stain and cement. Coloured clay is another fake turquoise.

Many attempts have been made to produce an imitation turquoise which would have a composition near to that of the genuine mineral. The first of these substances is that which was known as " Viennese turquoise," and, according to Koch-Dudich, was made by finely grinding and intimately mixing malachite, aluminium hydroxide and phosphoric acid. This was then heated to over 100°C and was then compressed into a compact mass using great force. Another type was said to have been made by pressing together a precipitate of aluminium phosphate coloured blue by copper oleate. There have been others, all of which were made on similar principles, but they have scant importance.

These " pressed " or " reconstituted " types of imitation turquoise, which have a hardness of 5 to 5½ on Mohs's scale, give, when a snap density is taken, a value near 2·4, but after soaking the value may rise to over 2·6. The refractive index of such imitation turquoise has been found to be remarkably low, about 1·45. Such imitations blacken or fuse to a black glass when heated and do not decrepitate as does true turquoise. Further they do not exhibit the turquoise absorption bands at 4300 and 4200Å. Such pressed imitations have been found to be moderately electro-conducting, although this is no test, for much real turquoise behaves similarly.

The easiest test for " reconstituted turquoise " is to place a spot of hydrochloric acid on an inconspicuous part of the specimen. The acid liquid will quickly turn to a yellow-green colour, which will stain a piece of filter paper (blotting paper) when the acid is soaked up by it. Such an effect does not occur with real turquoise and carefully applied the test does not damage the stone except for taking away the polish at the spot where the acid is applied.

Much of the turquoise matrix sold in the East is said to be a crude imitation consisting of some form of blue substance, often glass or china, which is embedded in a black mass resembling hard pitch. This may usually be detected by soaking the stone in methylated spirits, which dissolves the black substance and also by the fact that the matrix is black or nearly so, whereas limonite is

dark brown. M. Weinstein mentions a clever fake made from clay into which matrix has been introduced.

During 1957 a " synthetic turquoise " was sold to the gem cutters of Idar-Oberstein which was subsequently found to be a new type of imitation, an imitation which has a lovely blue colour, which is made more convincing by the addition of sinuous dark veins of " matrix." The production and marketing of this material makes an interesting story.

Since 1953 a young chemistry student from Bremen, who was studying in Hamburg, had been working on the production of an artificial turquoise and in 1957 he finally produced a suitable " turquoise." This material was sold to the Idar-Oberstein cutters, apparently as turquoise and without disclosing the man-made nature of the product. One report says that the Mineralogical Institute of the University of Hamburg, to whom samples had been sent for test, could not prove that it was manufactured. Further, it is said that solicitors were consulted, who were of the opinion that it would be correct to call the product turquoise without the qualification synthetic.

The buyers of this " turquoise " later became suspicious and samples reached Prof. K. Schlossmacher of the Idar laboratory, who,

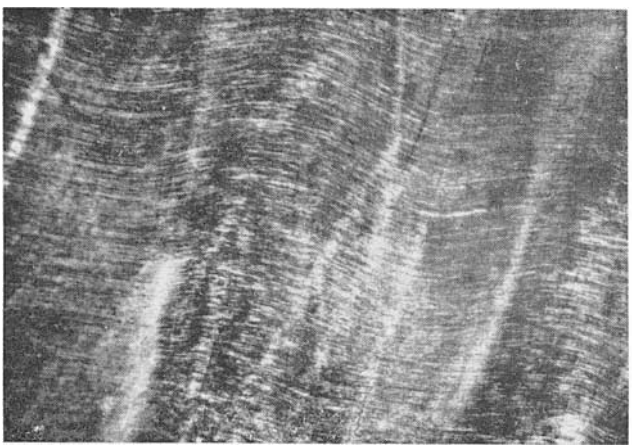

Wave-like structure of the canals as seen in a thinnish section of recent elephant ivory.

in view of the difference in density and refractive index thought the material was not turquoise and sent samples to the University of Mainz for confirmation. By X-ray powder photography and chemical analysis the material was found to be a mixture of *bayerite* and a copper phosphate—$Cu_3(PO_4)_2 3H_2O$—the " matrix " being probably an amorphous iron compound.

Bayerite is a by-product of the clay and aluminium industry, and is a material which has the same chemical composition as the mineral *hydrargillite* (*gibbsite*) an aluminium hydroxide with a formula usually given as $Al(OH)_3$. Bayerite is not identical with hydrargillite but gradually alters into it.

The Idar cutters made enquiries and found that the material was artificially produced. They then brought a charge against the student of "misusing gemmological terms." The student was found guilty and sentenced to eight months in jail, a sentence against which he lodged an appeal, the final result of which is not known to the authors.

Examination of a sample of the German material, which is now being marketed as a turquoise imitation under the trade name " Neolith," showed the material to have a hardness of about 3 on Mohs's scale, and a refractive index, so far as the vague reading could be determined, of about 1·55. Owing to the porous nature of the material the density determinations were unsatisfactory. A snap determination gave values as low as 2·33, but after allowing the pieces to soak for some time, values near 2·4 were obtained. Chemical tests proved the presence of phosphorus, aluminium and copper ; the test for iron by potassium ferrocyanide was considerably masked owing to the presence of much copper.

When heated this German material blackens but does not decrepitate like true turquoise. A thinnish section microscopically examined showed the material to have a granular structure as though a fine-grained powder had been consolidated by pressure. There is no convincing absorption spectrum to be seen, the turquoise bands at 4300 and 4200Å not being present. Under long-wave ultra-violet light (3650Å) this German imitation shows a bluish glow pin-pointed with bright blue spots, an effect which is also seen, but much less strongly, under the short-wave lamp (2537Å). A test for electro-conductivity showed that the blue material did not

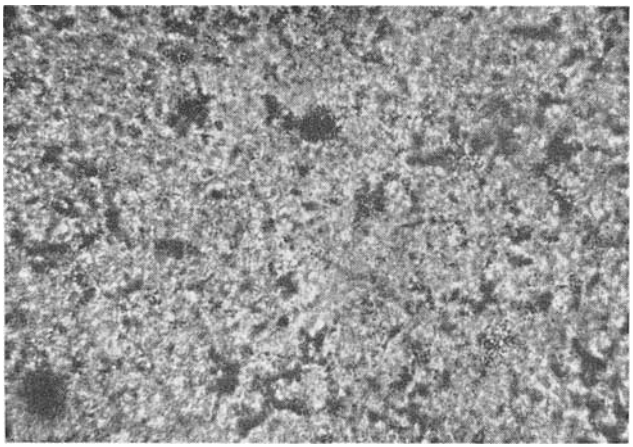

Thin section of American turquoise from Gleeson mine, Gleeson, Arizona, × 200 before enlargement of 1½ times.

conduct, but where a " vein " passed right through the piece the conduction was strong along this " vein of matrix."

K.Schlossmacher has suggested that a spot of Thoulet's solution (Sonstadt's solution)—a saturated solution of potassium mercuric iodide in water—which at one time had a vogue as a heavy liquid (density of 3·18), when placed on this German imitation will produce a brown stain and thus provide a test. It has been found that the hydrochloric acid spot test mentioned earlier as a test for the " Viennese turquoise " types of imitation also provides the answer here, the acid turning strong yellow-green. Hydrochloric acid is a much more easily obtained chemical than Thoulet's solution.

An imitation of turquoise which has a somewhat different mode of formation emanated from the United States of America about 1953. This material, which has a good blue colour, but is neither so fine nor does it take such a good polish as the German " Neolith," is " veined " with brown markings. The general appearance of this material seems to suggest that small nodules of a blue material have been bonded with some sort of cement—in fact it is bonded with a styrenated alkyd type of artificial resin. Examination with a lens showed the blue masses to consist of small white and blue grains

producing a fine mottling, and this granular structure was confirmed by microscopically examining a thinnish section.

This plastic bonded material has a hardness estimated at $2\frac{1}{4}$ on Mohs's scale and the density was found to be about 1·85. Later samples of this type of imitation were found to be harder and denser, the hardness reaching to $3\frac{1}{2}$ on Mohs's scale and the density to about 2·39. The refractive index, as far as could be observed from the vague shadow-edge seen on a refractometer, is 1·56. There are no absorption bands in the blue as are observed in true turquoise and under the long-wave ultra-violet lamp a bluish fluorescence was seen. In this type of imitation turquoise the hydrochloric acid spot test also gives a positive result which makes distinction easy.

Plastic bonding by similar means of real turquoise, particularly the pale chalky material from Arizona, is now carried out in order to " harden " the raw material so as to make it usable for the arts. This bonded, but unfinished, turquoise is in the main exported from the United States of America to Hong Kong, Tokio, Osaka, Bombay and Idar-Oberstein. The remainder is sold to cutters in the United States who provide calibre-cut stones for setting into machine-made Indian type jewellery. The small sized nuggets are made into costume jewellery, probably by first fashioning by the tumbling process. Some turquoise is treated specially for the Navajo and Pueblo Indians of the American south-west who use it to make their own jewellery and for the jewellery they sell to the tourists.

Specimens of plastic-bonded real turquoise were found to have a density which varied from 2·18 to 2·5 and had a hardness of about 3 on Mohs's scale. The refractive index, as far as could be measured on a contact refractometer, was about 1·61. The luminescent glow under ultra-violet light was weakly blue but this has little diagnostic value. Unlike the imitation turquoises discussed earlier, this material, a true turquoise, shows, albeit weakly, the two absorption bands in the blue-violet shown by real turquoise. The lower density will assist in identifying this type of bonded turquoise, but the most satisfactory test is to identify the plastic bonding by chemical means.

A newer departure consists of bonding the chalky Arizona turquoise with colloidal silica, a stable opalescent liquid consisting of an aqueous dispersion of SiO_2 with a density of 1·21. The type used is " Ludox " made by The Monsanto Chemical Company of

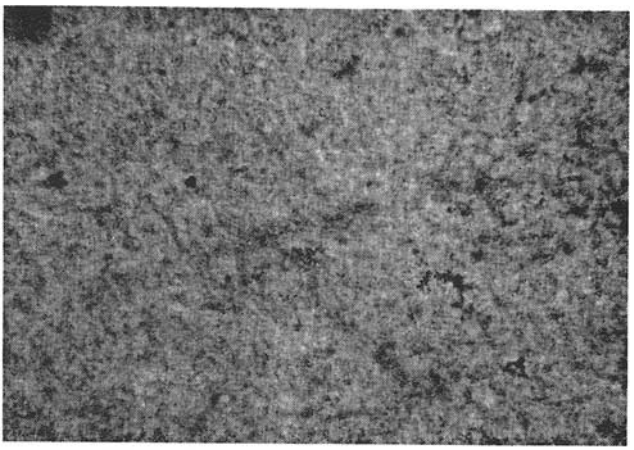

Thin section of silica-bonded American turquoise. × 200 and 1½ × enlargement.

St. Louis, Missouri. Such silica-bonded turquoise has a more natural, although on the whole a paler colour than the plastic-bonded types.

A sample of silica-bonded turquoise which consisted of a nodule with a botryoidal surface to which crystals of pyrites, and, maybe, quartz were adhering was examined. One end of the nodule was polished with a curved surface. For the purposes of this investigation this nodule was sawn into four pieces, and from one piece a thin section was made. The hardness was found to lie between 4 and 4½ on Mohs's scale and the density had a mean of 2·66. Two of the pieces had a density of 2·65 and two of 2·67. This result, in view of the bonding, is surprisingly high. The refractive index was found to approximate to 1·61, and the material shows weakly the two absorption bands of turquoise. Examination of the thin section showed the structure to agree with that shown by a thin section of turquoise from the Gleeson mine, Gleeson, Arizona.

The effective identification of silica-bonded turquoise seems to necessitate the determination of the silica-bonding, which is not an easy assignment, for silica is to some extent always present in natural turquoise and, indeed, appears to be very much in evidence in the raw Arizona turquoise.

The exact method used in impregnating turquoise with plastic or colloidal silica is not known. Much of the Arizona turquoise is sufficiently porous to allow impregnation by soaking in the liquid plastic. This plastic subsequently polymerizes ; the silica remains in the colloidal state. Alternatively the chalky turquoise could be reduced to powder and then formed into a paste with the plastic or silica which subsequently hardens. Such treatment does not give an increased hardness as such, but merely " bonds " the very friable and porous natural turquoise used. The bonding, too, may well be the cause of the darker and brighter colour of the finished material rather than this being effected by the addition of colouring agents.

Recently a number of carved figurines, up to twelve inches in height, which had apparently come most probably from China, have been seen. Two such pieces which have been examined gave inconclusive tests of the nature of any bonding. The general impression is that these pieces are rather soft and more easily powdered than the known bonded types worked upon. One specimen had " matrix veins " painted on, and the first impression was that the piece was a plaster imitation. It was later proved, by a phosphate reaction and by the weak turquoise absorption spectrum that could be observed in light reflected from its surface, that the figure contained turquoise. The density of this piece was found to be 2·1, but another figure of similar colour had a specific weight of 2·58, a value quite near to that of American turquoise. The inference is that the pieces are exceedingly lightly bonded turquoise —and may be Arizona material—the low density specimen with plastic and the heavier specimen with silica. However, at this stage we do not feel justified in publishing any other of our findings.

In connexion with bonding turquoise it is interesting to recall that F. B. Wade mentioned that a little after he had published an article " *On the cause of colour in precious stones* " in 1942, he was besought by a turquoise miner in Nevada to assist him in finding out how to prevent the fading of the somewhat porous turquoise he was then mining.

After some experimentation Wade gave the miner the following advice—to soak the pieces of porous turquoise in sodium silicate (water glass) for a greater or lesser time according to its degree of porosity, then to transfer the stones to some concentrated hydrochloric acid, and subsequently to wash them and soak them in a

The wavy structure as seen in this thin section of odontolite proves the organic nature of the substance (compare with the picture of ivory structure). This section was ground very thin and does not give the relief shown by the thicker section of ivory.

highly concentrated deep blue solution of cuprammonia sulphate (made by adding an excess of ammonium hydroxide to a saturated solution of copper sulphate). Experiment had shown the turquoise to become stained to a deep blue which on drying became less blue but still of excellent colour for the purpose. As the coloration was only " skin deep " the miner was advised first to cut and sand his stones before treatment and then to dry and polish them.

Incidently Wade advised the miner to claim (not to admit) that *his* turquoises had had the colour " stabilized " and that every stone was warranted not to fade for a year and that any which faded would be replaced without cost. Experience with such treated stones showed that the colour held. Was this the beginning of an idea for the bonding of turquoise ?

One of the greatest difficulties encountered in deciding whether a specimen is natural or one of the many imitations is due to the fact that the majority of the imitations most likely to be encountered are very similar in composition to the actual mineral. Many are in fact reconstructed from the pulverized mineral itself while others are composed of the identical components comprising the real mineral.

Turquoise is in fact an hydrated double phosphate of copper and aluminium—aluminium phosphate, copper phosphate, or aluminium hydroxide with a phosphate and an alternative copper

salt all occur in the more common simulants. Obviously chemical tests on these lines are anything but conclusive. Even if elaborate quantitative tests are carried out some of the imitations approach very nearly to the natural turquoise, which itself varies over quite appreciable amounts. One thing, however, entirely foreign to any natural turquoise, and inevitably present in any simulant is the material with which the components are bound together. More often than not the binder is organic in type, usually one of the synthetic plastics, though it may be entirely inorganic, as is the case with one of the latest simulants and which more nearly approaches the natural product in most chemical and physical properties.

A few simply applied chemical tests will not only give positive proof of the spurious nature of the specimen, if such is the case but, what is still more convincing, will enable the actual binding material used to be identified.

The first test which should invariably be applied is most simple, one indeed which can scarcely be considered a " chemical " test—merely the heating of a small fragment or some scrapings in a small narrow test tube—the use of a small narrow tube is emphasized, preferably about three inches long and a quarter of an inch in diameter. Heat gently at first, afterwards heating more strongly.

Turquoise gradually turns black, or at least brown, small droplets of water may be observed on the cooler part of the wall of the tube and if an appreciable sized particle has been taken decrepitation will most likely occur. Furthermore, what is very characteristic, it remains in quite discrete particles.

Simulants with inorganic binders behave very similarly, probably, however, not so evenly as the real stone. The colour change also is not so distinct and often returns to a somewhat lighter colour.

Simulants with organic binder. These behave in an entirely different manner. The substance blackens readily and at the same time usually becomes sticky. The degree to which this takes place is, however, dependent on the amount of binder present. In some very lightly bound simulants, which have been tested, the product is so lightly bound that this is not apparent. There is often an appearance of fusion; this however is not really correct—what does happen is that the binder fuses, turns black and conceals the minute particles of the inorganic constituents. Watched carefully several

other effects are noticed. A cloudiness of water droplets condenses on the wall of the tube. A yellowish liquid is often seen to condense on the cooler part of the tube and under suitable conditions with some binders a sublimate of feathery crystals form. Vapours are evolved which have characteristic odours. These vapours have also certain reactions to indicator papers and other chemicals. The significance of each of these observations is dealt with below.

These simple tests are as far as the reader may care to go and certainly, if carried out with care, do indicate the general class to which the binder in the specimen belongs ; but most convincing proof of all is to be able to name specifically the actual binder used.

More Exhaustive Chemical Tests

Inorganic binders. While quite a number of inorganic materials may be used to bind together the loose aggregate of crystalline material, actual crushed turquoise or appropriately coloured substitutes, up to date this field rather surprisingly appears to have been explored only to a very limited extent compared with the number of organic binding agents which have been tried. "Artificial stones " of quite fine texture and useful hardness have been known and used outside the gem trade for many years. These include sulphates, oxides and other compounds which, by partial hydration or the formation of oxy-salts such as oxychlorides, are self-setting and do constitute a further possible entry into the field of gem simulants. The contemporary inorganic simulant of turquoise is one bound with silica. While the identification of the forementioned types may require a fairly full routine chemical analysis, the description of which would be entirely out of place here, the latter lends itself to a simple test.

The silica is used in this process in the form of an aqueous dispersion and it follows that it is truly amorphous in character and binds much in the same way as the organic binders and not by crystallization. Silica occurring in natural turquoise is substantially crystalline, however fine the material may appear. A number of compounds of amorphous type, and amorphous silica in particular, possess the useful property of adsorbing on the surface other chemicals. If then we take a solution of a compound which is so balanced that any withdrawal of the constituent with which the compound forms a soluble complex results in precipitation we have

a very delicate test for any substance which acts as an adsorbent. Several such solutions may be used. One which is particularly useful is a solution of the red-brown silver chromate in ammonia. This results in a straw-coloured ammine which under normal conditions is quite stable. If it comes into contact with anything which takes up ammonia, the loss of ammonia from the solution results in the immediate precipitation of the red-brown silver chromate easily seen on the turquoise and forming a very sensitive test.

To prepare this solution silver chromate is first prepared by adding potassium dichromate solution to silver nitrate solution and thoroughly washing (preferably by decantation) the precipitated silver chromate. Distilled water should be used for this. Strong ammonia is then added drop by drop till the greater part of the solid is dissolved. It is most important that some of the silver chromate remains undissolved to ensure that there is no excess of ammonia. Stir the suspension thoroughly in order to make sure the excess of the chromate will not dissolve and allow to stand for at least one hour. Decant and filter off the clear liquid. The solution lasts quite well and if after some time there is some precipitate of chromate this does not interfere in any way. Just neglect it and use the clear solution. The test is carried out by placing a drop of the solution on an area of the stone, preferably a smooth surface but one which is not a " show " surface as the brown stain usually requires a certain amount of abrasion to remove entirely. The test can of course be applied to powder or scrapings.

Organic binders. These are many and the number is increasing rapidly. Binding materials of greater permanence and greater hardness are continually coming on to the market. So far as their identification is concerned from the gemmologist's aspect they have one thing in common; they all admit of easily carried out tests which give very characteristic and in many cases quite specific reactions. While it is not considered likely that the average reader will wish to attempt the identification of all the probable ones used, there are several which are frequently encountered, and the identification of these may be considered well worth-while, if only to be able to give a precise reply to the question " What is it ? "

It is important to note that before any further testing is carried out, particularly the specific tests, as many observations as can be

made by the simple heating in a dry test tube as mentioned above should be made, as this test alone may give the specific answer to the investigation and will almost certainly, if due attention is given, indicate the class to which the binder belongs. The following points should be noticed :—

Blackening. The " tarry " blackening of the organic constituent is entirely different from the darkening which occurs with the natural stone.

Watery condensation. The liquid droplets on the wall of the tube, while apparently similar to those evolved by the natural stone may prove to be either acid or alkaline to indicator paper. The inferences here are that if the liquid is neutral or slightly acid it has little significance. Minerals may have been used which give off acid vapours. If strongly acid they are probably due to either hydrochloric acid or acetic acid. Hydrochloric acid may be evolved from some artificial stones or from certain organic binders such as the vinyl or similar products, although we have not yet encountered these compounds in this connexion. Acetic acid may also be evolved from vinyl and similar compounds. The significance of an alkaline reaction will be explained in detail later.

Oily liquid condensation. Usually somewhat yellowish in colour and condensing some distance away from the watery material. Several tests should be applied to this. This is most probably the product of the decomposition or depolymerization of the plastic binder and very likely *styrene.* The irritating smell of this compound is quite characteristic and if the reader is not familiar with it he should heat a small fragment of polystyrene. He should then have no difficulty in deciding whether the original liquid is from *polystyrene* or not. This is a very suitable binder and a number of simulants have been met where this has been used. Another similar liquid has a rather sweetish smell, similar to some types of toffee. This is probably the decomposition product of an *alkyd* resin. The usual procedure adopted in this case is to heat this part of the tube again carefully, keeping the part of the tube further up as cool as possible, when quite often the crystalline component of the oily liquid will condense on the cooler part in feathery crystals. These crystals are phthalic anhydride—a decomposition product of an alkyd resin. This type of resin is very often used along with styrene. If the separation

suggested does not produce crystals the tests mentioned below under crystals should be carried out on the actual liquid.

Crystals. Under suitable conditions crystals will form on the cooler part of the tube without any further treatment. These usually take the form of feathery rosettes on the wall of the tube or occur in a form resembling cotton wool growing across the tube from the wall. These are practically specific for *alkyd resin.* That these crystals are in fact phthalic anhydride from an alkyd should be confirmed by one of the following tests. Phthalic anhydride condenses with either :

Resorcinol	to form		fluorescein
Thymol	,,	,,	thymol phthalein
Phenol	,,	,,	phenol phthalein.

The method is exactly the same in each case. The test is carried out on the crystals if present, or if not, on the liquid (see above) and is carried out *in situ.* A small quantity of one of the above is mixed with the crystals or oil, about twice as much should be taken and placed in contact. Mixing is carried out with a glass rod on the end of which is a drop of concentrated sulphuric acid. When thoroughly mixed this part of the tube is gently heated in the small flame of a bunsen burner or spirit lamp, which heating is most conveniently carried out by rotating the tube on the glass rod. When fusion is complete, marked in the case of resorcinal being used by the melt having a ruby red colour, the tube is allowed to cool off slightly and the melt rinsed out with water into a small beaker. The solution is now made alkaline by the addition of a few drops of caustic soda or sodium carbonate.

The *resorcinol* mix gives a strong green fluorescence (due to fluorescein).

The *thymol* mix turns a bright blue (sodium thymol phthalein).

The *phenol* mix turns a bright pink (phenol phthalein).

The change should be quite distinct, a light suggestion only of these changes should be ignored. A positive test in each case is quite specific.

Vapours. The vapour emitted from an artificial turquoise may be acid, neutral or alkaline. Those vapours which are alkaline are the only ones which need consideration at this stage. They all turn a

moistened neutral or red (acid) litmus paper blue and may be ammonia (obvious by smell), amine (characteristic fish-like odour) or melamine (intensely fish-like odour). The last two signify a ureaformaldehyde resin and melamine-formaldehyde polymer respectively. The writers have not encountered either of these resins as binders for artificial turquoise but they are possibilities. The phenol-formaldehyde resins are not dealt with under this heading as there is a very simple and specific test which is carried out on the original simulant.

Phenolic resins (Bakelite and others). If a small fragment or a few scrapings of one of these resins is boiled with a small quantity of distilled water in a micro-test tube sufficient phenolic material is leeched out to give a very positive reaction with 2·6 dibromoquinonechlorimide. This is used in the form of an aqueous suspension. Several drops of the yellow suspension are added to the extract from the resin and the mixture is gradually made alkaline with a very dilute solution of caustic soda. If phenol be present a deep blue colour develops.

The tests suggested above will serve to identify the binders most likely to be met with in artificial turquoise. They are all simple to carry out and do give positive reactions and call for little in the way of apparatus and chemicals.

List of the necessary materials

Micro-test tubes. $3'' \times \frac{1}{4}''$ diameter to $3'' \times \frac{3}{8}''$ diameter.

Narrow glass rod.

Small beaker (or wide neck bottle).

Litmus paper (red).

Feigl's solution (silver chromate in ammonia).

Resorcinol, *or* thymol, *or* phenol.

Caustic soda. Concentrated sulphuric acid.

2·6 dibromoquinonechlorimide.

Finally it is suggested that the reader unfamiliar with the odours of the products mentioned should do blank tests on fragments of the known resins.

With so many successful simulants of turquoise available it would seem unnecessary to produce a composite stone, but such an object has been reported by B. W. Anderson. This doublet was

said to consist of a front half of a low cabochon of suitably opacified and coloured glass cemented to a piece of blue-stained chalcedony which formed the back.

Other treatments of real turquoise are oiling or waxing, and dyeing. Much turquoise is of fine colour when it is taken from the mine but often tends to pale as soon as any contained moisture dries out. Wetting such a stone may temporarily deepen the colour but a better method is to soak the stone in wax or oil—petroleum jelly (Vaseline), melted paraffin wax or paraffin oil are substances which have been used. Such practices are said to be commercially acceptable, but some traders frown upon the practice. In the authors' opinion the danger in oiling turquoise lies in the likelihood of the oil getting contaminated or altering in character and then giving the stone a patchy murky yellowish-green appearance. E. Gübelin, in a private communication, mentions a turquoise which was badly stained from some grease or oil and with the exception of a tiny spot on the top which remained forget-me-not-blue, the whole stone had gained a murky complexion. To try and correct this bad discoloration Gübelin boiled the stone for two or three weeks in ether. This was done by placing the stone in a bulb-shaped phial filled with ether. The phial was closed by a rubber stopper into which a very long glass tube was inserted (air condensor). The boiling was carried out on a water bath whose temperature was kept constantly at approximately 40°C. This procedure extracted the grease from the turquoise and after two or three weeks the stone showed a yellowish-green colour which bleached well by bathing the stone in hydrogen peroxide, exposing this to the sun. After this treatment, lasting about a week, the turquoise had assumed its original beautiful forget-me-not blue.

Poor colour turquoises have had their colour " improved " by staining with Prussian blue. This treatment does not seem to penetrate far into the stone, like the copper coloration of Nevada turquoise, hence the colour wears and the stones become patchy. Ammonia is said to take away this stain as, of course, with any alkali.

A problem which faces the trade with these new types of bonded real turquoise is what to call them. " Reconstructed turquoise " or " Reconstituted turquoise " are scarcely true for they are not a true reconstruction, as is " Pressed amber " which contains no

foreign material in its make up. " Dyed and hardened turquoise " as suggested by K. Schlossmacher is again not really acceptable for there is no proof of any dyeing in much of this material. The writers suggest that the term " Bonded turquoise " is probably the best and truest description.

In conclusion we thank Mr. Harold Maryott of Miami, Arizona, for the gift of many of the specimens of both natural and bonded turquoise worked upon, and to the Officers of H.M. Geological Survey, in particular Mr. E. A. Jobbins, for carrying out the necessary slicing of the silica bonded nodule and preparing a thin section.

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TAKING CARE

By A. E. FARN

WAS it Marie Antoinette who said "Why don't they eat cake if there's no bread ?" Certainly a little cake now and again is welcome, but it is the regular plain food which is so essential to well ordered progress and steady building of sound economic structure, both dietary and physical. In similar vein does the professional gemmologist work.

Other people's jobs are far more interesting it seems than one's own, though in my case I must admit I find my own completely satisfying from an interest point of view. At one time of day I envisaged work as a professional gemmologist being a series of exciting rare stones, in fact all the interesting ones ending in " ite."

I'm afraid such is not the case. When something new occurs it is quite an occasion. Being a Hatton Garden worker necessitates a very down to earth contact with the commerce of the jewellery world (without whose existence gemmology would not survive) and the requirement is to know whether it is genuine or synthetic, real or cultured, followed by " how much ? " Routine testing means parcels of calibré rubies, sapphires, emeralds, single stone rings, brooches, pendant necklaces, and other items of jewellery, and the ordinary run of coloured gemstones including the precious and others of lesser cost. Seldom are diamonds tested. The emphasis recently has been on the more expensive stones, which are being artificially produced in extremely close characters to those of nature.

A purely routine test of a pearl brooch, set with two rubies and two emeralds, was left on my desk. A quick glance through the microscope established " silk," double refraction and " chatter " marks in both red stones to establish them as genuine rubies. Of the two green stones one had such obvious colouring spangles of faded blue that I thought it was painted on the back to influence a poor colour of mediocre emerald. I must add here that it was impossible in its setting to obtain a refractive index, but from observation a host of two-phase inclusions were readily apparent. The brooch was in very poor condition and an accidental touch caused the rectangular green stone to fall out and rather to my surprise I found

the " blue patches " were not staining but the gelatine colouring layer of a soudé emerald doublet, which had deteriorated and lost its green hue and changed to blue. Anyone, of course, could have quickly seen the obvious now that the stone was out of its setting.

The second stone was a little smaller and square in shape in a box-setting with crimped edges and once again I could not get a reading on a refractometer because of the setting. The stone turned red under the Chelsea filter ; its inclusions were twisted veil-like feathers of liquid drops. These feathers had a curled look about them and were in two directions almost at right angles to each other. Apart from the feathers a host of large two-phase inclusions were seen on a large scale and I thought the stone to be Colombian, though I was *not* happy about the feather structure, which looked similar to some I had seen in Igmerald and Chatham synthetic emerald. I decided to ask permission to have the stone taken out.

So far I had based my partial identification on the fact that the stone was red under the filter, had two-phase inclusions, and was green in colour. The feather particularly seemed suspicious to me. I hadn't seen any quite similar in any other type of Emerald whether Sandawana, Colombian, Habachtal, Indian or South African, but basically the two-phase inclusions suggested Colombian or Brazilian type.

However, since it is better to state facts I felt justified in having the stone taken out. I was surprised to be challenged on this necessity because I hadn't taken an absorption spectrum, but quite frankly I couldn't easily differentiate between absorption spectrum of synthetic or natural Emerald. However, it proves the necessity of taking all possible precautions and a spectrum revealed a broad absorption between 6020Å and 6060Å and no signs of chromium. Between crossed filters the stone was a very weak red or muddy pink, not by any means what one would expect from an emerald, except of the very lowest quality. Under the Chelsea filter the stone was a distinct red and this fact and the curled feather prompted me to think in terms of Chatham synthetic emerald. Fortunately we have varied types of ability at our beck and call and after the denouement of the spectroscope, a second opinion was very definitely for paste bubble layers and larger single bubbles. This of course prodded me to further intensive study of the internal inclusions of the stone, on which I had based my first conclusion. *Now* of course

FIG. 1. *Two-phase bubbles in beryl base seen through quartz top.*

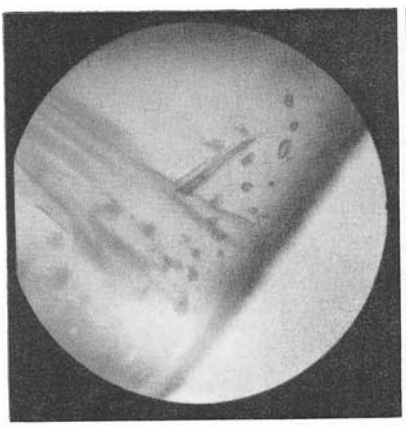

FIG. 2. *Demarcation line, liquid feather and two-phase inclusions.*

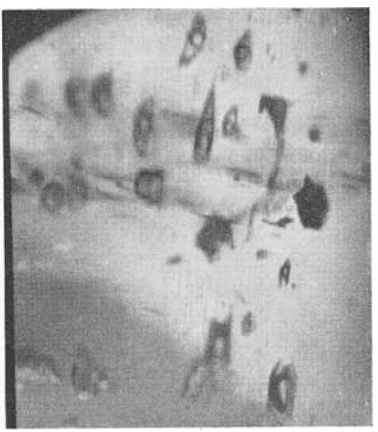

FIG. 3. *Groups of two- and three-phase inclusions in beryl base.*

the stone was carefully cleaned and to my intense relief I found the feather to be of natural origin, and the large bubbles to be indeed two-phase and natural. However, the cleaning had revealed very minute signs of a break in colour which was not a natural feature and at last the truth began slowly to filter through that this was an old-type soudé emerald of quartz construction (hence the two-phase inclusions and liquid feathers), with a colouring layer of some organic substance which did the trick of turning red under the Chelsea filter. There were no obvious signs of a junction or layer of opacified flattened bubbles often seen in ordinary soudé emeralds. In fact the routine test this time of ordinary gem-set jewellery proved to be not " a piece of cake " but certainly a change of diet. The stone weighed just the bare half carat. Having established that the stone was a quartz-topped doublet I immersed it in monobromo-napthalene and was surprised to find the top layer clear and transparent and the bottom layer full of feathers and two-phase inclusions. This surprised me since I thought that it should have been the other way round. By way of interest I placed the back of the stone on the refractometer and obtained a beryl reading. I checked all four sides of the back and reached the same conclusion each time. This was indeed a new thing to me. I suspended known quartz in a suitable liquid of carefully checked S.G. and placed the doublet in it and it sank slowly whilst the quartz indicator slowly rose—this was not a positive check so I put in a known soudé emerald of quartz top and bottom and this stone sank much more rapidly. Thinking perhaps that my beryl readings were due to rounded facets or parallax I decided to check the stone in nitrobenzene, which had an R.I. of 1·56. The stone showed quite a distinct difference in relief when viewed through the side with the layer vertical in the matching liquid. An immersion contact photograph using the technique perfected by B. W. Anderson seemed the next step and here I was assisted by R. Webster, who speedily produced the immersion contact photograph seen (Fig. 1). The inclusions showing junction and liquid feathers and two-phase inclusions (Figs. 2-3) were taken by R. K. Mitchell. To all these people I owe thanks for their very ready assistance.

THE OCULAR THERAPY OF STONES

By WILLIAM EMMOTT

Reproduced by courtesy of the author and the journal *The Optician*, April, 1960.

FROM earliest times stones of all kinds have been awarded a variety of attributes.

These have been mainly due either to the history of their formation or to folk-lore, and their value as therapeutic agents was praised by many ancient philosophers including Galen, Theophrastus and Pliny.

Shakespeare utilizes the science of gemmology very frequently to provide metaphors, but only once does he refer directly to any stone as possessing curative properties, and since pearls are encysted foreign bodies which have found their way into the oyster with consequent pain, this gem is entirely appropriate for a poetic description of tears.

For instance, one of the characters in *King John* says that :—

> " His grandam's wrongs, and not his mother's shames
> Draw those heaven-moving pearls from his poor eyes."

The emerald, the Indian agates and to a lesser degree the sapphire, share the magical quality of curing eye diseases on sight.

In his *Natural History*, Pliny has much praise for agates, the mere sight of which, he says, will cure eye diseases, inflamed eyes and eyelids, and headaches.

Looked at intently, the sapphire was supposed to be protection from eye diseases, but should there be a foreign body in the eye it was only necessary to place the stone on the eye. It was claimed that the power from the stone would then pass into the eye and loosen the foreign body.

" The deep-green emerald, in whose fresh regard weak sights their sickly radiance do amend "* was of the utmost importance in early pharmacies ; whether it was powdered and used internally, suspended over the affected part or worn as a charm, its efficiency was considered to be infallible.

The mere sight of it was said to strengthen the memory and restore failing vision, for which latter purpose engravers kept them on their benches to relieve the strain consequent upon the intricacy of their work.

* *A Lover's Complaint*—Shakespeare.

The Emperor Nero is traditionally supposed to have made constant use of an emerald for visual purposes, the exact nature of which is not known and which would depend on how the stone was cut. It is fairly certain, however, that this particular stone was chosen in preference to any other on account of its claimed therapeutic qualities.

The opal has suffered many vicissitudes as a popular gemstone. The Romans thought much of it both as an ornament and for its curative properties. It was claimed that it not only strengthened the sight and cured eye diseases but also was capable of rendering the wearer invisible. There are no specified methods of application extant, methods which would certainly have been mentioned by Pliny had such been the case. This omission and the claim that it makes the wearer invisible leads one to suppose that its properties were fabulous and not considered of any use in the early pharmacies.

Of the non-precious stones hæmatite and its varieties enjoyed a great popularity among ancient physicians as a remedy for eye diseases.

This stone, which is of blood-red colour on account of its probable high red peroxide of iron content, is described by one of the most ancient writers* as " all serviceable."

Galen thought much of it and a solution in water sufficed for bloodshot eyes and inflamed eyelids. Should there be tumours on the eyelids, solution in the white of an egg was required. In either case the application was made by pouring through a tube a few drops at a time into the eye. Should the case not respond readily, the solution was made thicker until a cure was effected.

A variety of hæmatite called schisto or splitstone when ground and mixed with woman's milk was said to be particularly useful for arresting discharge from eye corners and for reducing procidence of eyes.

Procidence is another term for prolapsus, a falling down from a normal position, and it is hardly likely that Pliny intended to mean a falling down of the eyeball itself but of either the lens or the iris.

As was the case with many stones used in ancient pharmacies, hæmatite acquired talismanic virtues in addition to those of medicine. For instance, Zachalias of Babylon, besides recommending it as

* Sotacus.

a cure for diseases of the eye and liver, strongly urged everyone presenting petitions addressed to Kings to ensure success by having a piece of this stone about his person.

Magical properties are also attributed to Gorgonia, Heliotropium and Median Stone. The former is a coral so named from the fact that though it is soft in the sea it gradually hardens on removal from water, and its virtue lies in its alleged ability to counteract the evil eye.

Heliotropium, found in Ethiopic Africa and Cyprus, is normally of a leek-green colour streaked with blood-red veins, but if placed in a vessel of water and exposed to the full sunlight it changes to a reflected colour as of blood.

Magicians said that if it was combined with the plant heliotropium and incantations were uttered the carrier would be rendered invisible.

Median stone is said to possess powers of good and evil according as it is used. Should it be dissolved in the milk of a woman who has borne a son and applied to the eyes, it will even restore sight to the blind, but should it be dissolved in water and the forehead bathed, the sight will be destroyed.

Pumice, now used either for removing stains or polishing, was employed in early pharmacy for the treatment, when combined with woman's milk, of eye ulcerations. It is somewhat difficult to understand how the abrasive nature of this stone can have any beneficial effect on the eye, and yet it was claimed that it had both a healing and a cleansing effect on ulcerations. It is, however, easier to appreciate the claim that applied in a powdered form it would produce new flesh on cicatrizations of the eye and remove all scars.

It would be very interesting to know the exact method of application, but unfortunately no details are extant.

A dangerous " cure " is to be found in Egyptian folk-medicine. It is the Kabbas stone, which usually forms part of a talismanic necklace. The stone was rubbed on a mother-of-pearl shell into which drops of water were allowed to fall. The liquid becomes whitish and was then used as an eye lotion for cases of purulent ophthalmia, with inevitable results of further damage to and often loss of the eyeball.

The continued and general use of this and similar " remedies " over a considerable period gives one a good idea as to the hold which superstition and folk-lore had on the minds of the people.

Although amber is fossilized resin and not in the literal sense a stone it was used and referred to in antiquity both as having been shed as tears by mythological figures and as a cure for sore eyes.

In Scandinavian mythology Freya is said to have shed tears of amber on the departing of Odin into the world, and Sophocles, the Greek poet, said that amber was produced in far eastern countries from the tears shed by birds in mourning for Meleager.*

Shakespeare, however, gets a little nearer to realities when, in one of Hamlet's speeches, he utilizes the original resinous quality of the " stone " to describe the discharge of mucous often seen in and around the eyes of elderly people. He says : " Slanders sir, for the satirical rogue says here that old men have grey beards, that their faces are wrinkled and their eyes purging thick amber and plum-tree gum."

So far as its medical properties are concerned, Callistratus describes it as being " good for any age whether taken in drink or attached to the body as an amulet. Worn upon the neck it is good for fevers and diseases of the throat and if it be beaten up with Attic honey it is beneficial for dim sight." Moslems also regarded it as beneficial for dim sight and sore, inflamed eyes, but it was necessary to reduce it to ashes before application.

Long before foreign-body spuds were invented, a favourite method of removing foreign bodies from the eye was to place small " eye stones " underneath the eyelid to induce a copious flow of tears. It was expected, as it would actually do in some cases, that the foreign body would move as a result. There is no evidence extant as to how far this method was successful or what the procedure was should the case be one where the body was firmly embedded in the cornea. It is fairly safe to assume, however, that anyone having to endure this "treatment" would be only too willing to say that " it was out " whether that was actually so or not !

* Pliny denounces this latter story as " one of the frivolities and falsehoods of the Greeks."

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Gemmological Abstracts

ANON. *More on Beilby.* The Mineralogist, 1960, 28, 4-5, pp. 90-92

A note on a paper published in the Australian Journal of Science. While this paper refers mainly to polished metal surfaces, it is applicable to gemstone surfaces. Hooke, Newton and Herschel all held that the asperities in a roughly ground surface are cut away during polishing leaving a series of fine grooves or " scratches." Rayleigh agreed that the asperities are worn down but thought that the material is removed in an almost molecular fashion.

In 1921 Beilby advanced the radical view that, instead of asperities being worn away, the depressions in the surface are filled in by material which is smeared across the surface, covering it with a layer which he thought was glass-like or amorphous in character. This has come to be known as the " Beilby " layer. The idea of the layer being truly amorphous has been modified slightly in more recent times, but the basic concept of a layer which is physically distinct from the substratum and which has lost its obvious crystalline properties is still retained.

Beilby did not propose any specific smearing mechanism, although he inferred that surface tension forces were responsible. A most plausible mechanism was afterwards advanced by Bowden and Hughes, which was based on observations that very high local temperatures can be attained when two solids rub past one another. They suggested that the asperities in the surface are melted when abrasive particles rub across them, the liquid so formed depositing in and filling adjoining depressions.

It was further proposed that, due to very rapid chilling, this molten material solidifies in an amorphous-like condition.

A paper by L. E. Samuels reviews work carried out at the New South Wales Branch of the Defence Standards Laboratories which strongly supports the earlier view that polishing is essentially a fine cutting process, and is believed to establish with reasonable certainty that the Beilby layer does not exist.

The new theory is that metallographic polishing occurs primarily by cutting, the individual abrasive particles acting in a

similar manner to a planing tool. Material is removed and scratches are produced ; the better the polish the finer the scratches. The surface is crystalline but deformed, the magnitude of deformation decreasing with increasing fineness of polish to a surprisingly low level in the case of the finest polishes. Moreover, the deformation decreases rapidly with the depth so that comparatively perfect material is exposed by a very light etch.

S.P.

SEAL (M.). *Graphitization of diamond.* Nature, 1960, Vol. 185, pp. 522-523.

The extra X-ray and electron diffraction spots in partially graphitized diamond previously attributed to an intermediate carbon structure are shown to be due to silicon carbide and other impurities.

R.A.H.

TOLANSKY (S.) and SUNAGAWA (I.). *Spiral and other growth forms of synthetic diamonds : a distinction between natural and synthetic diamonds.* Nature, 1959, Vol. 184, pp. 1526-1527, 6 figs.

Phase-contrast microscopy has shown that synthetic diamonds may have highly perfect cube faces or cube faces showing growth spirals : a dendritic habit has also been observed. Such observations have not been made on natural diamonds and may be characteristic of synthetic diamonds which are grown rapidly and which may contain metal carbide impurities.

R.A.H.

TOLANSKY (S.) and SUNAGAWA (I.). *Interferometric studies on synthetic diamonds.* Nature, 1960, Vol. 185, pp. 203-204, 8 figs.

Crystal defects or surface films lower the reflectivity of synthetic diamonds and increase the visibility of fringe systems obtained with double beam interferometry. The appearance of the crystal surfaces is described.

R.A.H.

WASKEY (F. H.). *Gemstones of Alaska.* Lapidary Journ., 1960, XIV, 1, pp. 16.

Gemstone collecting areas in Alaska have not been sufficiently prospected and the material so far found is unsuitable for faceting.

S.P.

BOVENKERK (H. P.), BUNDY (F. P.), HALL (H. T.), STRONG (H. M.) and WENTORF (R. H., Jr.). *Preparation of diamond.* Nature, 1959, Vol. 184, pp. 1094-1098, 11 figs.

Diamonds have been grown from carbon in the presence of catalysts at pressures ranging from 55-100 kilobars and at temperatures ranging from 1200°-2400°C. Catalysts include Cr, Mn, Ta and the group VIII metals or those of their compounds which will react to give free metal under the experimental conditions. The habit and colour of the diamonds produced varies with temperature of formation.

R.A.H.

BENSON (L. B.). *Highlights of the Gem Trade Lab. in Los Angeles.* Gems and Gemology, Vol. IX, No. 12, pp. 355-357 and 378. Winter 1959/60.

Among many interesting items referred to were a pair of "jade" birds which were found to be serpentine. A badly fashioned sapphire, probably cut from a distorted piece of rough, would have lost 50% of the weight if cut correctly. The question " Is it ruby or purple sapphire ? " is emphasized with a current example. Corundum, including brown coloured asteriated material, is reported to have been obtained from a Finnish deposit north of Inari, which lies near to the Arctic Circle. A large clear inclusion of possibly biotite gave an apparent double refraction to a spinel. An interesting pearl, which has a black spot and an encircling black band, is mentioned.

2 illus. R.W.

CROWNINGSHIELD (G. R.). *Highlights of the Gem Trade Lab. in New York.* Gems and Gemology, Vol. IX, No. 12, pp. 358-361 and 377. Winter 1959/60.

The destruction of the settings which entailed loss of the diamonds, probably by electrolytic action, when jewellery is left in a hypochlorite-type bleach, is reported upon. Doublets consisting of grey-blue synthetic tops and natural corundum bases are mentioned. The apparent change of colour of a pink diamond to brown after bombardment with X-rays is said to be due to continued phosphorescence. The original pink colour returns after gentle heating. The question of nomenclature when only part of the stone is of typical colour was illustrated by the case of a beryl figure

which was colourless with patches of blue. Could it be called aquamarine. Some discussion is made on this problem. The small relative size of the nucleus of a large Australian cultured pearl is commented on and some notes are given on the Japanese cultured pearls dyed roseé. Some baroque beads were found to be green plastic-coated beryl and these showed red under the emerald filter. Some notes on the coloration to an orange colour of brown zircons by X-radiation, and on the spectroscopic examination of blue diamonds, are also given.
3 illus. R.W.

ANON. *Pearl fishing beds in Ireland.* Gemmologist, Vol. XXIX, No. 345, pp. 64-65. April 1960.

A short note on the pearl fishing beds of the River Strule, which are said to be now practically exhausted. Fishing is carried out as in the Scotch pearl fishing by the use of a glass-bottomed bucket. Only amateurs fish to-day.

R.W.

DERBY (C. H.). *Opal.* Gems and Gemology, Vol. IX, Nos. 11 and 12, pp. 323-332 and 350 ; 362-370. Fall and Winter 1959/60.

The history, locations of the mines and the mining of opal are given. Particular mention is made of the South Australian deposits of Coober Pedy and Andamooka, which are now more important than the deposits at White Cliffs and Lightning Ridge in New South Wales. The geological features are given for both Coober Pedy and for Andamooka. Andamooka opal is darker than the opal found at Coober Pedy or White Cliffs and compares favourably with opal from Lightning Ridge.
14 illustrations and 5 maps. R.W.

POLLARD (E. R.) ; DIXON (C. G.) ; DUJARDIN (R. A.). *The "Pork-knockers" of British Guiana.* Gemmologist, Vol. XXIX, No. 343, pp. 30-36. February 1960.

Extracts from *Diamond Resources of British Guiana,* a publication of the British Guiana Geological Survey. Diamonds were first found in British Guiana in 1887 as a result of placer gold-mining around the Mazuruni, Cuyuni and other rivers. The diamonds are recovered from alluvial deposits derived from the sandstones of the Roraima formation. These deposits are discussed in detail. The

mining is carried out by prospectors called " pork-knockers." Notes are given on the methods of mining, on the production and on the prospects for the future.
1 illus. R.W.

MACINTOSH (E. K.). *Seeking gems in South Africa.* Gemmologist, Vol. XXIX, No. 344, pp. 48-49. March 1960.

The author of the article has found many gems in the Union of South Africa, Rhodesia and neighbouring areas. These include rose quartz in Namaqualand ; amethyst and amazonite from Kakamas, and jasper and tiger's-eye at Prieska and Griguatown. Agate, jasper and coloured quartz is found around Kimberley, as well as the Drakensberg range in Basutoland. Verdite and stichtite are found around Barberton. " Transvaal jade "—massive grossular garnet is found near the chrome mines near Rustenburg, and cornelian and jasper in Rhodesia.

R.W.

WELLER (G. T.). *A gypsum mine in Sussex.* Gemmologist, Vol. XXIX, No. 345, pp. 61-63. April 1960.

Describes the mining of gypsum near Mountfield in Sussex. The mineral is mined from the Purbeck Bed in the Upper Jurassic and includes the satin-spar variety.
3 illus. R.W

JANKS (R. A.). *Two gemmological gadgets.* Gemmologist, Vol. XXIX, No. 343, pp. 21-23. February 1960.

Describes a combined light source and stand for the Rayner refractometer, and a metal and glass pot to fit into the Rayner immersion cell in order to facilitate examination of stones in polarized light.
3 illus. R.W.

ALEXANDER (A. E.). *Dyed pearls.* Gemmologist, Vol. XXIX, No. 343, pp. 28-29. February 1960.

Pearls are usually dyed black by the use of silver nitrate. Mention is made of an optical system giving an intense beam of light of small area as a means of indicating whether a pearl has been dyed. The use of X-rays in the dyeing of pearls is mentioned.

R.W.

JONES (T.). *Irradiation of Pearls.* Gemmologist, Vol. XXIX, No. 343, p. 38. February 1960.

Brief details of experiments carried out with the coloration of natural and cultured pearls by irradiation with neutrons.

R.W.

HOLDSWORTH (J. R.). *Ruby.* Australian Gemmologist, Vol. 2, No. 8, pp. 5-8. February 1960.

A general article on the mining, characters and history of ruby, with notes on the synthetical product and on those stones which simulate ruby.

R.W.

F.T.C. CONSENT ORDER ON " CHATHAM EMERALDS "

The following companies and individuals have consented to a Federal Trade Commission order forbidding them to misrepresent that their " Chatham Emeralds," " Chatham Cultured Emeralds " or any other manufactured stones are natural stones: Carroll F. Chatham, trading as Chatham Research Laboratories; Anglomex, Inc., and Dan E. Mayers, its president and principal owner; Ipekdjian, Inc., and its wholly owned subsidiary, Cultured Gem Stones, Inc., and Adom and Georges Ipekdjian, their president-treasurer and vice-president respectively.

The order, agreed to by both respondents and F.T.C.'s Bureau of Litigation, was accepted in an initial decision which the Commission affirmed.

In its complaint of 13th October last, the F.T.C. said Mr. Chatham manufactures the stones and sells them to Anglomex, which in turn resells to the Ipekdjian concerns. The latter sells to jewellery retailers and to the public. All respondents co-operate in advertising and promoting the products. The complaint charged that these typical advertising claims were exaggerated, false, misleading and deceptive:

" Chatham Emeralds "

" Chatham Cultured Emeralds "

> " These stones are identical to natural emeralds in all of their properties: Chemically, physically, optically, with the same crystal faces, atomic arrangement, and even the same inclusions and ' gardens '."

The F.T.C.'s order provides that respondents must stop:

> Claiming that manufactured stones are cultured, natural stones, or identical to natural stones;
>
> Using the word " emerald " or the name of any other precious or semi-precious stone to describe such stones unless it is preceded by a word such as " synthetic " which clearly discloses the nature of the product and the fact that it is not a natural stone. This does not mean, however, that the manufacturing method or process used by Mr. Chatham must be disclosed.

The agreement is for settlement purposes only and does not constitute an admission by respondents that they have violated the law. It is understood that " Chatham Created Emeralds " may be used in future to describe the laboratory-produced stones.

ASSOCIATION NOTICES

COUNCIL MEETING

A meeting of the Council of the Association was held at Saint Dunstan's House, Carey Lane, London, E.C.2, on Wednesday, 16th March, 1960. Mr. F. H. Knowles-Brown presided.

The following were elected :—

Fellowship

Bergan, Kjartan E., Sandefjord, Norway. D.1959
Gaudernack, Lilly, Sandvika, Norway. D.1959
Sidoli, Julien, Milan, Italy. D.1959

Ordinary Membership

Arend, Robert, Richmond Hill, Ontario, Canada
Beresford, Charles E., Birmingham
Buzalewicz, Sobieslaw, Cracow, Poland
Engstrom, Lars G. H. Hagersten, Sweden
Glasgow, George H., Plockton
Green, Leslie, Rainhill, Nr. Liverpool
Ho, W. K., Rangoon, Burma
Jhaveri, Himatlal C., Bombay, India
Leek, Stanley H., Toronto, Canada
Lewis, Roy, Ottawa, Canada
Nolan, Constance J. C., Gomersal, Nr. Leeds
Podolsky, Paul, London
Rowley, Clement J., Sneyd Green
Szymczyk, Joseph, London
Wilson, William I. S., Loanhead

Probationary Membership

Cozens, Jonathan R., Taunton
Hill, Alan R. C., Salisbury, S. Rhodesia
Hodgkinson, John A. W., Aberdeen
Wolmark, David C., Ruislip

The audited accounts for the year ended 31st December, 1959, were approved for submission to the 30th Annual General Meeting. The Council nominated the Officers of the Association for re-election and Mr. T. H. Bevis-Smith for re-election and Messrs. C. T. Mason and E. Levett for election to the Council.

OBITUARY

The Council of the Association records with regret the death of John H. Stanley, F.G.A. Mr. Stanley was associated with Bristow J. Tully in the latter's gem business in New Bond Street, London, and between 1927 and 1942 was the official correspondence course instructor to the Association. He was most painstaking in his work and endeared himself to many students by his helpfulness and kindly words of encouragement. He was Treasurer of the Association from 1942

until 1947. Before his retirement from business he was with the City Jewellers, Gowland Brothers, of Cornhill, where he kept contact with the Association and continued his interest in music, for he was a competent violinist. John Stanley was one of the pioneer gemmologists who greatly helped the Association in its early days and he will be sadly missed.

MIDLANDS BRANCH

A film show for members of the Midlands Branch was held at the Auctioneers' Institute, St. Phillips Place, Birmingham, on Friday, 4th March, 1960.

Mr. B. Shipton, Vice-Chairman of the Midlands Branch, presided in the absence of the Chairman, Mr. T. Solomon.

The films shown, both dealing with cultured pearls, were " A Pearl is Born " and " Cultured Pearls."

Both films were excellently made and dealt with the whole operation from the raising of the oyster until its maturity, the insertion of the mother-of-pearl bead, and finally the reaping of the pearl harvest.

Members of the Midlands Branch held their second annual dinner and dance on Saturday, 26th March, 1960, at the Medical Institute, Edgbaston, Birmingham. Mr. T. P. Solomon, Chairman of the Midlands Branch presided. Among the guests were Mr. N. A. Harper, Vice-Chairman of the Gemmological Association and Mrs. Harper, Mr. R. Weston, President of the British Jewellers' Association and Mrs. Weston and Mr. R. Webster.

There were some very witty speeches by Mr. T. P. Solomon who proposed the toast of the Association, Mr. N. A. Harper who responded, Mr. A. E. Shipton who proposed the toast of the guests and Mr. R. Weston who responded. The evening was a great success with over a hundred members and guests present.

* * * *

The seventh annual general meeting of the Midlands Branch was held at the Chartered Auctioneers' and Estate Agents' Institute, Birmingham, on Friday, 29th April, 1960. Mr. Trevor Solomon presided.

The Secretary reported on a most successful year, which had included talks by Mr. B. W. Anderson, Dr. H. Proctor and the showing of various films. Mr. Solomon, who was vacating the chair after serving as chairman of the branch since its inauguration seven years ago, handed over office to Mr. A. E. Shipton, who had served the Branch as Secretary and Vice-Chairman. Mr. Shipton paid tribute to the long service which Mr. Solomon had given to the Branch. Mr. W. W. Bowen was elected Vice-Chairman and Mr. J. R. Shaw was re-elected as Secretary. The following members were elected, after ballot, to serve with the officers on the committee : Miss J. Rice, Mr. J. S. Harper, Mr. K. Hoskyns, Mr. T. P. Solomon, with Mr. N. A. Harper as an ex-officio member.

It was proposed that an outing to Berkeley Castle and the Servern Wildfowl Trust, Slimbridge, be organized during the summer.

After the meeting Mr. Solomon gave a talk on " Antique dealing," and spoke of his recollections of the trade and gave a broad outline of the principles governing the classification of various articles as antiques.

At the end of the meeting Mr. Solomon was presented with a rare book on diamonds.

WEST OF SCOTLAND BRANCH

The seventh annual meeting of the Association's West of Scotland Branch was held in Glasgow on 21st April. Mr. E. Macdonald presided in the absence of the chairman.

Mr. Ian Mackenzie, the chairman, was re-elected to office together with Mr. C. D. Wade, Secretary. Mr. A. McWilliam was nominated for co-option to the Council of the Association.

The annual summer outing of the Branch has been arranged for the week-end of 21st-23rd May. The place chosen to be visited is Strontian, Argyllshire.

TALKS BY MEMBERS

BROWN, A. J. Bayliss : " Gemstones," St. Andrews Church, Ilford, 19th April, 1960.

BAGLEE, G. : " Gemstones," Backworth Women's Institute, 6th April ; East Stanley Women's Institute, 12th April, 1960 ; " Gemstones," Good Companions Club, Newcastle-upon-Tyne, 4th May ; Chester-le-Street Business and Professional Women's Guild, 26th May, 1960 ; " Gemstones," Seaton Deleval Afternoon Tea Club, 7th June, 1960.

BLYTHE, G. : " Gems," Young Liberals of Eastwood, 5th April, 1960.

CAIRNCROSS, A. D. : " Gemstones," Dunbarney Men's Guild, 22nd October ; Trinity Church Women's Guilds, 3rd November ; Kinnoull Church Women's Guild, 3rd December ; Dunning Parent-Teachers' Assn., 7th December ; Scone New Church Women's Guild, 8th December ; Dundee and Angus Watchmakers' and Jewellers' Assn., 12th December, 1959 ; Letham Townswomen's Guild, 25th February ; Soroptimists' Club of Crieff, 3rd March ; Scone Old Church Women's Guild, 10th March ; Scone Old People's Welfare, 25th March ; Inverness Assn. of University Women, 19th March, 1960.

LAUVLAND, K. : " Jewellery and gemstones," Norwegian Y.W.C.A., London, 20th April, 1960.

LEIPNER, H. : " It isn't necessarily so," a talk based on errors and fallacies which have been perpetuated from author to author over the ages. Gemological Society of San Diego, California, 4th May, 1960.

SOLOMON, T. : " Gemstones," Handsworth Conservative Association, Birmingham, February, 1960.

WARREN, K. (Mrs.) : " Gemstones," Eltham Parish Church Women's Fellowship, 24th May ; Evening Townswomen's Guild, Crofton, 13th June, 1960.

WELLER, G. T. : " Diamonds," Rotary Club of Maidstone, 11th March ; Resident's Association, Tunbridge Wells, 18th March, 1960.

THE LAPIDARY JOURNAL

The *Lapidary Journal*, a leading American gem-cutting and jewellery-makers' magazine directed principally to the amateur hobbyist, has been sold by the founder Lelande Quick to Lee S. Packard, of San Diego, California, a printing firm executive.

Hugh Leiper, F.G.A., co-author of the recently published gem-cutting book *Gemcraft*, and for the past two years associate editor, has been appointed editor

of the Lapidary Journal. Mr. Leiper was formerly editor of the *Mineral Hobbyist* of Austin, Texas. He has published numerous papers on gem research, some in the *Journal of Gemmology*.

GIFTS TO THE ASSOCIATION

The Council of the Association is grateful for the following gifts to the Sir James Walton Memorial Library :—

Samples of rough gem material from John R. Fuhrbach, B.Sc., F.G.A., G.G., Amarillo, Texas, U.S.A.

Volumes of the Industrial Diamond Review from Robert Webster, F.G.A.

"Podstaroy Mineralogii," by A. G. Bietiechten, from S. Buzalewicz, Cracow.

A selection of books, including a complete set of the Industrial Diamond Review, from Mr. Robert Webster, London.

A copy of Robert de Berquen's *Les merveilles des Indes Orientales et Occidentales, ou nouveau traité des pierres precieuses et perles*, Paris, 1661.

ANNUAL MEETING

Mr. F. H. Knowles-Brown presided at the 30th Annual Meeting of the Association held at Saint Dunstan's House, Carey Lane, London, E.C.2, on 5th May, 1960.

Among those present was a member from Scandinavia, Mr. H. Tillander, one of Helsinki's foremost jewellers and a "leading light," so the Chairman called him, in the development of gemmology in Finland.

The Chairman, in moving the adoption of the annual reports and accounts, said there had been a steady increase in membership in the past year which in itself was an indication of the steady growth of the Association. The Tully Medal had not been awarded that year and the reason for this was that the standard set was high. The medal provided students with an object to aim at and the fact that it had not been awarded meant that no one had reached that level. It would have been easy to pick out the best man and give him the medal, but the examiners had not taken the easy way out and the Association as a whole could be grateful to them for this, for it kept the value of the Association's diploma very high and internationally valuable.

The Officers of the Association were re-elected as follows :—

President : Sir Lawrence Bragg, F.R.S.
Chairman : Mr. F. H. Knowles-Brown.
Vice-Chairman : Mr. N. A. Harper.
Treasurer : Mr. F. E. Lawson Clarke.

Mr. T. H. Bevis-Smith was re-elected and Mrs. E. Levett and C. T. Mason elected to serve on the Council.

This concluded the formal business of the meeting and Mr. Knowles-Brown then called upon Mr. Tillander to speak to members.

Mr. Tillander said that the gemmological movement in Finland had started quite recently, in fact about 18 months ago, but they had worked hard and made progress. They had a number of students sitting for the first time for the preliminary examination and about 12 would be sitting for the diploma this year. Naturally

they had had initial difficulties, particularly with translation, but these had now been largely overcome.

He went on to discuss a method which he had developed for the identification and evaluation of diamonds. He had found it very useful and he thought perhaps other retailers might be interested in it. Naturally people's judgment varied but he thought his system would give pretty accurate results. It was based on an American system though different from it in certain particulars.

He then showed a foolscap form divided into 20 sections. At the top of the page was a drawing of the stone, showing top, bottom and side view, upon which notes could be made concerning inclusions.

Below this was a ruled half-column lettered from F 1 to VS 2, SI to 4.P 12, and numbered 0-9 for purity. Zero stood for the stone which was absolutely flawless—very rare.

Section 3 dealt with the colour of the stone, using the normal colour-descriptive names, in accordance with U.S. custom. The fourth panel concerned the minimum and maximum diameter of the stone as measured by micrometer or gauge. Section 5 recorded depth and four panels, X.A.B. and C., could be marked according to the cut—X for excellent, A for good, etc.

The proportions of the stone were dealt with in the following sections and No. 9 showed the size of the table. Mr. Tillander said that this section had taken him some time to work out. He used an ordinary loup, using the picture to match up the stones.

Sections 10 and 11 noted, after examining a stone from the side, if the table was parallel with the girdle or not, also if the table was not in the centre. The twelfth panel noted the crown angle, whether perfect and within 33-35 degrees, or if too low as in the second drawing or too high as in the third. It was not altogether necessary to do this, but if a stone did not look right, a jeweller would want to find out why. Checking it in this way would give him the reason. The thirteenth panel dealt with variations in the culet. Section 14 concerned facets where grinding had varied and next came the thickness of the girdle, a matter which the Americans calculated most precisely in maintaining the weight of a stone in its cutting.

The first drawing in the sixteenth panel showed top and bottom facets meeting exactly, while the other two could be marked according to variations. Sections 17 and 18 dealt with the straightness of the girdle and variations in the size and shape of the base facets. Panel 19 applied to stones where little could be found that was wrong, but it might be noted that the pavilion facets varied or did not meet at the same points. Such points could be noted on the drawings. At the bottom of the page there was space for general remarks on the character of the cut, etc.

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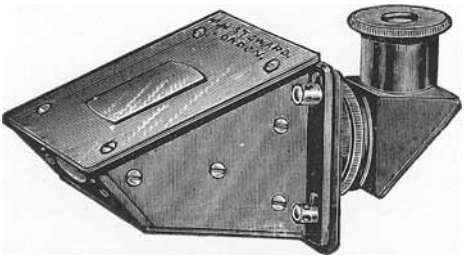

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No. 7
July, 1960

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THE JOURNAL OF GEMMOLOGY

and

PROCEEDINGS OF THE
GEMMOLOGICAL
ASSOCIATION
OF GREAT BRITAIN

GEMMOLOGICAL ASSOCIATION
OF GREAT BRITAIN
SAINT DUNSTAN'S HOUSE, CAREY LANE
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THE JOURNAL OF GEMMOLOGY
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Vol. VII No. 8 OCTOBER 1960

Gemmological Notes

Simple Method of Differentiating between Natural Blue Diamonds and Diamonds coloured blue artificially

J. F. H. Custers, H. B. Dyer and F. A. Raal

To-day diamonds can be coloured a distinct blue artificially by appropriate bombardment with electrons or gamma-rays of an energy of about 1 MeV.

This artificial colouration, which is offered as a facility in the United Kingdom and the U.S.A., has come to worry the ethical jeweller in that a diamond of somewhat inferior quality could be irradiated and sold by unscrupulous elements as a natural blue stone which, in comparison, is highly priced and sought after. An expert, after a lot of practice, might be able to discriminate between such diamonds, but he could not be absolutely sure just from visual inspection.

The ensuing method, which is an adaptation of one by Custers and Dyer[1], provides a simple and inexpensive way of ascertaining unambiguously whether a diamond is coloured blue naturally or artificially. The method, besides being quick, also has the advantage that a brilliant does not have to be demounted, but could be tested *in situ* in a ring.

The basis of the method[2] is that all natural blue diamonds are semi-conductors of electricity, i.e. they pass an electric current, however small, on the application of a voltage across them, whereas

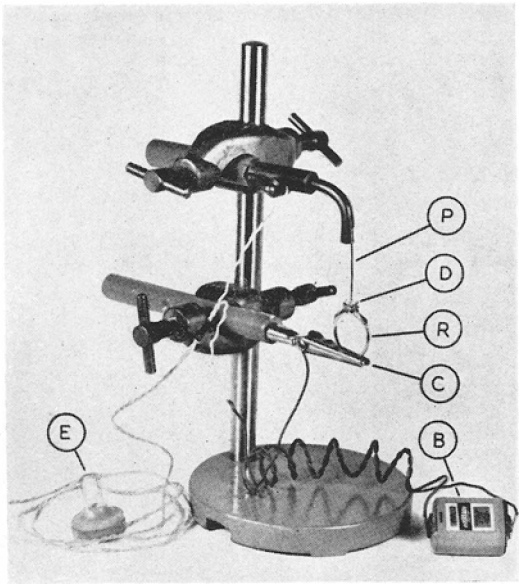

FIG. 1. *Simple Apparatus for testing whether a diamond is coloured blue naturally or artificially.*
E—earphone;
B—30 volt dry battery;
C—clip; R—ring;
D—diamond brilliant and P—insulated metal probe.

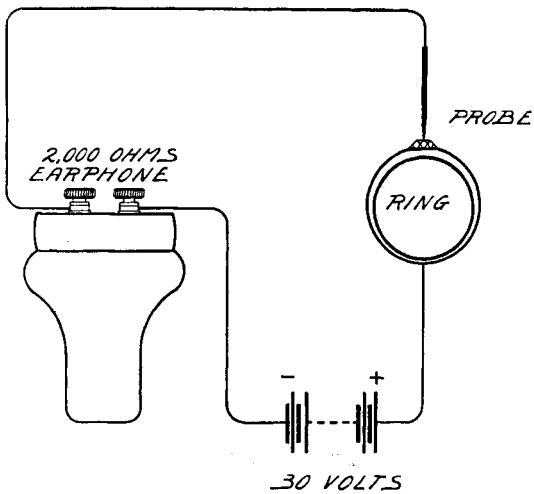

FIG. 2. *Schematic circuit diagram of the apparatus in Fig.* 1.

all other diamonds to our knowledge, are insulators and do not carry an electric current.

Earphones are very sensitive to the passage of minute electric currents as witnessed by their constant use in electrical conductivity experiments. Good earphones, of which there are many miniature versions on the market, and a power supply are, therefore, virtually all that are needed for the test.

Fig. 1 shows a diamond subjected to test and Fig. 2 depicts the electrical circuit of the set-up.

It is found that a 30-volt hearing-aid dry battery serves well as a power source, and that it is advisable to have a sharp-pointed probe to make contact with the table of the brilliant. In order to get maximum response from the earphone it is best to choose one having more or less the same electrical resistance as a natural blue diamond. The electrical resistance of these diamonds varies considerably from specimen to specimen and is, of course, also dependent on the size of the stone. However, a value of about 2,000 ohms is average and an earphone with this resistance has proved most satisfactory.

The procedure of testing is as follows.

The ring R, of which the brilliant has to be tested, is held in position by the clip C such that the probe P just touches the surface of the diamond D. On listening with the earphones E and moving the probe P around a bit on the surface of the diamond D a scratchy noise is heard when the diamond is a natural blue one. The noise heard can be likened to that of the " atmospherics " experienced with older radio sets. If the diamond is an artificially blue one no sound whatsoever will be detected.

Care should be taken for the probe not to come in contact with the metal of the ring as the electrical circuit would then be closed and could lead to erroneous interpretation.

Also, due to the nature of the semi-conductivity of natural blue diamonds, it is essential that the probe be connected to the negative pole of the dry battery as shown in Fig. 2.

A considerable number of natural blue and other diamonds have been tested in this way, and without fail one could discriminate between them.

REFERENCES

(1) Custers, J. F. H., and Dyer, H. B. *Gems & Gemology*, Vol. VIII, No. 2, 35, 1954.
(2) Custers, J. F. H. *Physica*, **18**, 489, 1952.

CUTTING A KUNZITE

NEVILLE DEANE.

Kunzite is a very beautiful gem-quality spodumene of an attractive lilac colour, varying from pale to much richer shades, and also tints more inclined to the blue side of lilac. That is, the stones are beautiful when they are cut, but unfortunately many of them fall by the wayside.

Kunzite is very dichroic. The crystals are usually thin, flat tabular pieces, and the best colour is obtained when the table facet is cut across the thin section. This limits the size of the stone very much, and usually Kunzites are cut with rather greater depth than most other stones, for this and other reasons.

The material is very cleavable, and is liable to cleave, when worked with abrasives having a " wedging " action, very much like a " book " of mica. If this does happen the stone is either completely spoiled, or becomes even thinner. Sawing a crystal is done with a very smooth diamond saw and more or less with hopes that no cleavages will develop. Unfortunately they quite often do and once started are liable to go further and further down the stone.

Madagascar kunzites seem to be particularly awkward, those from California less so, and the attractive green spodumenes from Brazil (not true hiddenites) are rather more accommodating.

Having sawn the crystal into suitable pieces for cutting stones, the best thing to do with them is to put them away for a day or so. It is not at all uncommon to leave apparently sound pieces over night only to find some of them showing cleavages in the morning so the best plan is to leave the pieces and not waste any more work.

In the ordinary way, the next job is to grind flat that surface which will be the table facet, on a lap. This is a tricky job, because the cleavages can start round the edges and extend right down the stone, so the only way is to play safe and use a very small grit and a soft lap, the safest being 600 grit on a lead lap. This is a job for patience, and quite often the surface becomes flat but has more or less an " etched " appearance. This does not matter as polishing will take care of that.

Next comes grinding roughly to shape, that is, shaping up the pavilion. The best advice in this connexion is not to attempt grinding at all. There may be a grinding wheel which is safe, but the writer has not found one yet, and kunzites are rather too expensive with which to do much experimenting. The green

spodumene from Brazil may sometimes, with the utmost caution and smooth even-running wheel, be trimmed up a little.

But the best way is to mount the stone on the dop stick, and using 600 grit and water, slowly wear the stone down to shape. Whilst a lead lap is safest, a harder lap can be used with care. The writer has used a steel lap with success, and found it preferable to use a harder lap with the fine 600 grit, than to use the lead lap with a coarser grit such as 320. The latter has caused trouble, particularly when the grinding of the stone gets down to size. Working seems a bit easier if done first on one side of the stone, then on the opposite, and then on the other two sides, then going back to the first side and so on, but nothing so far tried can really reduce the time taken and ensure safety to the stone.

Polishing is fairly easy. Of course the polishing powder—in this case ruby powder—is extremely fine, so there is not much risk of cleavage, and it is really quite a treat to see a dull and sometimes rather etched facet take on a brilliantly polished appearance. On one or two facets it may be necessary to finish off the polishing dry, instead of wet, but compared with the cutting of the facets, polishing is relatively easy.

At this stage, and quite often only at this stage, is it possible to see into the stone, and it is surprising how in many cases, an apparently clear crystal will show a few long straight crystal or tube-like inclusions. However only a few stones have no inclusions at all and the brightness of the finished stone hides small inclusions quite effectively. Undopping and cleaning present no particular difficulty and if all has gone well the result is an extremely attractive and unusual stone.

REGENCY TABLE (Period 1810–1820)

G. A. White.

During a recent geological field excursion to Derbyshire I had occasion to call at the offices of Derbyshire Stone Ltd., Bank House, Matlock, and there I saw a Regency Table which is a superb example of Derbyshire minerals.

This lovely table was for many years in the home of a Scottish nobleman. The wood, is principally Burr Elm, which is supported on a pillar of Egyptian porphyry.

The top consists of 124 polished sections, each 1½ inches square, of Blue John, Derbyshire spar, Hopton wood marbles, Fossil

marbles, Galena and non-ferrous minerals, the whole contained within Greek White Statuary inserts and surrounded by a polished frame of Ashford Black Marble which is etched to show Bacchus, grapes and vines.

A casual caller at the Derbyshire Stone Ltd. offices could not fail to be attracted by this colourful table but a geologist or gemmologist would find this a most fascinating exhibit.

THE STRANGE CASE OF W. J. LEWIS ABBOTT A. Stores

It is one of the inexplicable quirks of the literary world that the career of a solid, dull, Erastian, middle-of-the-road Bishop is more likely to be crowned by a definitive two-decker biography than is that of someone whose passage through life has followed a less predictable but more interesting orbit.

I was not therefore surprised to find how lamentably inadequate was the documentation of W. J. Lewis Abbott. This was the man who initiated the first classes in gemmology, yet his death went unrecorded in the gemmological journal of that time, and one gets the impression that no gemmologist has given him a thought ever since.

Outside gemmological circles, one meets with occasional references to Abbott as an archaeologist and geologist, references mostly of an unenthusiastic or even pejorative sort. The trouble is that so little data survive that it is difficult to attempt a balanced judgement on Abbott as a gemmologist, although he is better documented as an archaeologist. All that seems to be recalled about him is that he was a peppery, self-opinionated little man with eccentric notions on how to stock a retail jeweller's establishment, which may be true, but I am confident that there was more to Abbott than this unattractive façade and I feel that a reappraisal of the man is long overdue.

Personal facts are certainly scarce about Abbott. He was born in the eighteen-fifties and apparently worked at the bench at Benson's as a young man. He was a member of a group of amateur geologists and archaeologists which centred round Benjamin Harrison, the archaeologist-grocer of Ightham, near Sevenoaks, and showed an early interest in worked flints, especially in the Wealden area; an early paper, published in the 'eighties dealt

with the eoliths found in the Forest-Beds of Cromer in association with *Elephas meridionalis*, but most of his later published work relates to Sussex and Kent. In order to be near his archaeological " digs," he left Benson's and set up shop as a jeweller first in Sevenoaks and later in St. Leonards. He instituted classes in gemmology at the Polytechnic in Regent Street and lectured there during the 1900s, although unfortunately the Poly archives can provide nothing about this most interesting phase of his career. At his St. Leonard's shop gemstones jostled incongruously with worked flints, bones and so forth and, not surprisingly, his business suffered and friends had from time to time to come to his aid financially. The exciting days of the Piltdown Skull affair saw Abbott much in evidence, and he was accustomed to let it be thought that Dawson's " discovery " resulted largely from his suggestion and encouragement.

He died at St. Leonards in 1933 at the age of eighty.

Abbott's papers on archaeology are numerous and wide-ranging. H. G. Wells in his " Outline of History " (1920) paid tribute to his work on flint implements and, in an appreciation of his work published in *Nature* shortly after Abbott's death, it was stated that he " must always be held in esteem by archaeologists as a pioneer and substantial contributor by a long series of discoveries to the advancement of archaeological studies in Britain."

J. S. Weiner in " The Piltdown Forgery " (1955) delivers a distinctly less favourable judgement, quoting instances where Abbott's findings do not to-day find ready acceptance, and where some of his excavations are now regarded as not wholly satisfactory.

The changing climate of archaeological opinion, and the more exacting techniques of excavation are hazards which beset all archaeologists, and as they have occulted the reputations of Pitt-Rivers and Colt-Hoare, they will similarly dim those of our pollen-analysis and radio-carbon contemporaries in the process of time. This being so, Weiner's verdict seems an ungenerous one, glossing over Abbott's very positive achievements such as that which earned him the Lyell Award of the Geological Society, his discovery of a cache of vertebrate remains in the Shode Fissures near Ightham.

In contrast to the many papers by Abbott on geology and archaeology, published locally and in the journals of learned societies, and which are preserved in the libraries of the geological

and science museums, only one item of gemmological interest seems to have achieved publication, a rare little pamphlet called "Gemmographical Tables," of which a photostat was obtained for me through the good offices of Miss F. M. Vaughan, who ran a copy to earth in the library of the Natural History Museum. It is undated, but evidence suggests 1896 or thereabouts. It consists of " Tables of Specific Gravities, Hardness, Crystalline Forms, Cleavage, etc., Illustrations and Descriptions of Crystalline Forms of Gems, Names and Colors of Two Hundred Varieties, Twin Colors of Gems as seen in the Dichroscope. (Arranged in Tables to be removed and framed for constant reference where desired). By W. J. Lewis Abbott, F.G.S., etc., Lecturer on Gemmology at the Polytechnic Institute, Regent Street, W."

Many of us will recall having seen similar tables many years ago " framed for reference " in the grubby outer offices of Hatton Garden wholesalers, bearing the names of stone-dealers such as Claremonts, which may have been overprinted issues of Abbott's compilation.

A series of tables is necessarily impersonal in character, but nevertheless throws some light both on Abbott and on the state of gemmological knowledge half a century ago. The absence of any reference to refractive indices points to its compilation at a date before the marketing of Dr. Herbert Smith's handy little instrument and, although the present writer notes with approval that Abbott evidently set great store by the dichroscope, the exhaustive listing of the twin colours of (for instance) fourteen shades of colour in both ruby and sapphire seems excessive, whilst some of his findings seem gravely open to question, e.g. peridot (twin colours cited as brown-yellow and pea-green) and aquamarine (light sea-green and straw yellow). A typical Abbott touch is provided in the note on dichroic gems. " Daylight is best, but an opal covered light will answer, allowance being made for the Phenomenon of Noctichroism "—an example of his zeal for the creation of neologisms (Plateauliths, Mezzoliths, the technique of Lithoclasiology, etc.; —of these inventions, only Gemmology seems to have taken root.)

Of a monochroic gem he somewhat mystifyingly writes that it " presents a far lighter and clearer field and usually shows decomposition in one of the squares."

His list of 200 varieties is a fake, since if all the now obselete variant names and the minerals which cannot be accepted as

gemstones are thrown out, the number reduces to quite modest proportions.

My quest for Abbott has had much less success than that of Symons for that equally puzzling oddity, Baron Corvo, or (to vary the literary simile) after much Hunting for the Snark I still cannot determine whether or not he was a Boojum. Does he (after all) merit his present deflated reputation ? Not, I think, on his work on the Wealden Pleistocene, but Abbott as a gemmologist is still problematic. If only one knew a bit more about those classes at the Regent Street Polytechnic ! Was he (one wonders) a free agent or subservient to the control of some other department ? Did he lecture, or demonstrate, or set practical work, and, if so, with what equipment ? Was he, as Weiner surprisingly states " inspiring " ? (one would not have guessed it). Did he ever look over the wall (so to speak), and, straying from his syllabus, evince any awareness of matters outside his special interests ?

All such questions must necessarily remain unanswered, unless, by good fortune, there are any JOURNAL OF GEMMOLOGY readers who " sat under " Abbott in those days and can satisfy our curiosity.

" INMITES " IN MICA

E. H. RUTLAND

It is always pleasant to browse among minerals with a microscope. Even the dullest-looking stones can reveal breath-taking beauty of design, form and colour under the right lighting and magnification. One always finds out something new and is led on to further comparisons. When I sit down to have a good look at new specimens I am always prepared for surprises, even from familiar species. I was not prepared for this one :—

At the end of a viewing session I picked up a somewhat cloudy slab of muscovite mica that had come to me with a collection of minerals some ten years ago and which I had used for various jobs about the house. I wondered what caused the cloudiness. There were the usual fibrous inclusions of asbestos and also some curious articulated fibres which I had not seen before. But almost the first thing that came into the field of view, right in the middle of the slab, and about 1½ inches from the nearest edge, was an unmistakable insect ! There was no obvious means of entry, no obvious air space and no sign of strain in the mica. The insect was flattened

but preserved a trace of 3-dimensionality sufficient to necessitate focusing with the fine adjustment on different layers at 30 × enlargement. Further search revealed several more insects and parts of insects in this and another sheet of mica. Their size ranged from 1mm to 0.2mm.

Drs Evans and Speyer at the Natural History Museum kindly identified the insects as mites (Cheyletus) and thrips (Limothrips) of British species but also widely distributed round the world. They thought it likely that they crawled between the layers during storage in Britain. Clearly the mica must then have been agape, closing up again subsequently. Some of the edges of the slabs still show an earthy deposit. Apparently insects are sometimes found preserved in shale in the same way. What causes these spiders and insects to behave in such a flagrantly non-claustrophobic manner is difficult to guess at. However, these "inclusions" appear to be quite recent and not in the least comparable with the venerable flies in amber, which may be up to 50 million years old.

BOOK REVIEW

QUICK, LELAND and LEIPER, HUGH, F.G.A. *Gemcraft.* Chilton Co., Philadelphia, 181 pp., $7.50, and Pitman, London, 242 pp. 42s. 1960.

Copiously illustrated with step-by-step photographs, this book is a further addition to the excellent works on gem cutting that have been published in N. America in recent years. The book covers the equipment needed and describes how to saw, grind, sand, lap and polish many types of gemstones. The sculpturing of gemstones and mosaic and intarsia work are also described. There is a description of the properties and physical characteristics of gems and their imitations, though the book keeps away from gemmology as far as possible and limits itself in sensible and concisely expressed language to the creating of gem materials into gems and other useful objects. The bibliography is very helpful and lists works not only about gem cutting but on jewellery making, minerals and gemmology.

S.P.

HEALING FISSURES IN PERIDOT

By W. F. EPPLER

AMONG the inclusions which are typical for this lovely gemstone with three names (olivine, peridot, chrysolite), E. J. Gübelin* describes a particular feature as:

" An inclusion characteristic always of chrysolite consisting of a rounded but flat concentration of irregular cavities with a small brown to black inclusion in the center."

By testing a good coloured cabochon of medium size, the cavities were revealed as rounded to oval-shaped cleavage cracks parallel to the main cleavage plane (010) of the host peridot, as is demonstrated in Figs. 1 and 2. The cause of origin of the peculiar cleavages was found to be a dark primary crystal inclusion which has been already mentioned by Gübelin. In Fig. 2, the dark crystal is situated near the right border of the crack. In most cases, the cleavage crack started to heal after its origin, producing a charming and at the same time a typical pattern, as shown in Fig. 3. Here, the dark primary (heterogeneous) crystal inclusion centres an oval-shaped healing crack. Just below it is situated a small system of a similar healing fissure, the crystal inclusion of which is a little off

* E. J. Gubelin, Inclusions as a Means of Gemstone Identification, Gemological Institute of America, Los Angeles, 1953

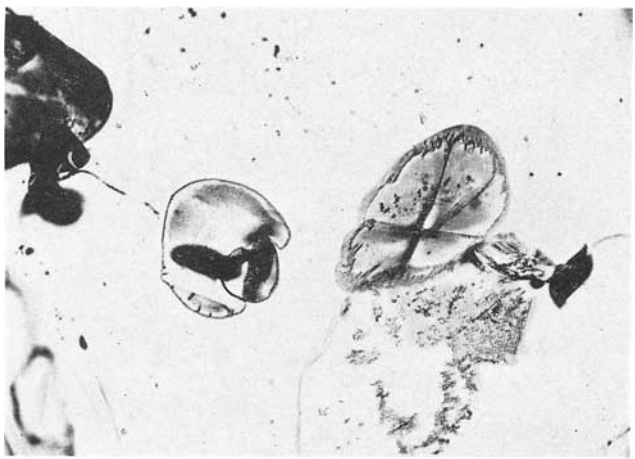

FIG. 1. *Healing fissures of typical shape parallel to the prism plane of a peridot. 22 ×.*

centre. By chance it was found that the primary crystal inclusion, which caused the origin of the disklike cracks, is a very dark red garnet. According to its colour, it belongs to the almandine series.

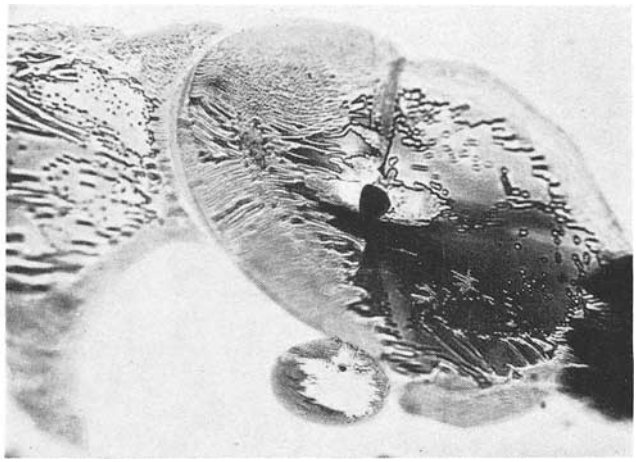

FIG. 2. *Cleavage crack in a peridot. Part of Fig. 1. 65 ×.*

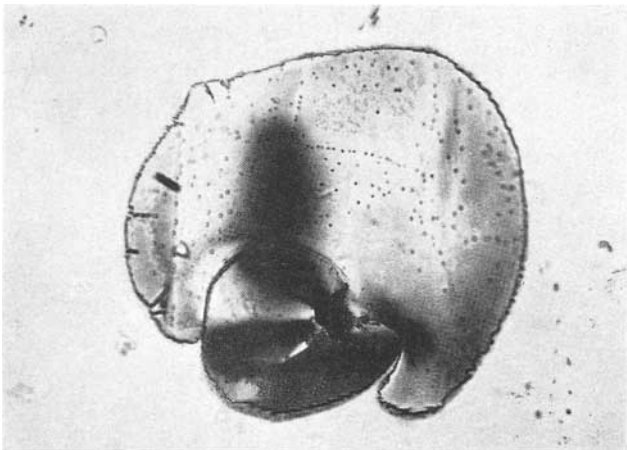

FIG. 3. *Typical healing fissure with a very dark almandine garnet in its centre. The system is parallel with the main cleavage plane (010) of the including peridot. 22 ×.*

HOW RARE ARE CHATOYANTS AND ASTERIAS ?

By NIGEL W. KENNEDY

THE very detailed article describing an unusual star-beryl recently examined by W. F. Eppler, which appeared in the issue of the Journal for January, 1960,[1] attracted my interest and attention, and has encouraged me to write some observations on the subject of chatoyancy and asterism in minerals, and on rarity of gems.

I have never posed as an authority upon this subject or any other in the field of gemmology, and the fact that I am not in the gem trade rather limits the number of specimens that pass through my hands. My ever-increasing collections of both minerals and cut stones, and my intense interest in other collections, private and public, have brought to my notice many unusual minerals including a wide range of chatoyants and asterias, a further acquaintance with which has convinced me that there is ample room and an urgent need, for an exhaustive work on the occurrence and characteristics of cat's-eyes and star-stones.

Some of the most enlightening articles in recent gemmological literature include a general survey of these phenomena by Alice S. Tait,[2] and two contributions by W. F. Eppler,[3, 4] and sundry odd references during the past ten years or so, yet to the seeker after useful information they are rather like the crumbs from the rich man's table.

What strikes me most forcibly is the use of the prefix " rare " in Eppler's observations on asterism, if not so much in reference to chatoyancy, and I am left with the impression that he believes both phenomena to be much less common than is, in fact, the case.

My interest in asterias was first awakened by the sight of two lovely examples on view at an early gemmological exhibition at Goldsmiths' Hall. Two superb gems, a star-sapphire and star-ruby of 8 or 10 carat each, and exhibiting perfect asterism, colour and translucency—two of the finest star gems ever to be allowed out of India.

Since that occasion, through the interest of so many friends, I have made acquaintance with many beautiful minerals that display chatoyancy or asterism, sometimes both, and my present gem collection includes some fifty cat's-eyes and about fifteen asterias.

In my experience these delightful optical effects are to be found to a greater or lesser extent in most gem minerals, although the phenomena may be of rare occurrence in a few species, and I know of only a few minerals (topaz, for example) in which I have so far never heard of their occurrence.

It seems to me that the average gem collector, or student of gemmology, lacks enthusiasm for the little-known chatoyants and asterias, probably because most gemmologists are in, or connected with, the jewellery trade, and liable to be biassed in favour of the few " trade stones " which consist of the better-known stones in popular favour. There are, in fact, too many jewellers who could not care less if no other species existed.

The lack of interest on the part of other and more broad-minded gemmologists may be accounted for if, as appears very probable, they interpret the terms " chatoyants and asterias " to refer to a very limited number of gems, namely chrysoberyl and quartz cat's-eyes, and tiger's-eye; and star-sapphire and ruby, with possibly star-garnet, which are all commonly known.

Another explanation for apparent lack of interest in the subject may be that the usual text-books are at fault (as in other instances I can recollect), in that they give the student quite an incorrect impression that these fascinating optical objects are very much rarer than they would actually appear to be.

I remember an anecdote that I attribute to a gemmologist it was never my good fortune to meet—Louis Kornitzer—but whose memoirs provide much profitable and amusing reading. He relates that on one occasion a friend said he had never seen a star-garnet. Kornitzer asked him if he had a stock of almandines at hand, and in due course they went through a selection by the light of a candle, and in a short time had easily found quite a number whose existence had not even been suspected by their owner.

The text-books tell the student that gemstones are rare because minerals of gem quality are only produced in nature's

laboratory if impurities and external influences can be avoided, otherwise impure minerals are formed which have no gem value. Two familiar examples are corundum and emerald, which as minerals are relatively common in a grade suitable for industrial purposes, usually as abrasives, but are impure and opaque, and useless as gems. In general, gem quality in a species is usually found rarely and only in certain areas.

In the case of chatoyants and asterias, perfect clarity is not usually essential, and some chatoyants may be quite opaque without loss of beauty, for example, crocidolite or sillimanite cat's-eye. Asterias are usually translucent and sometimes only faintly so but both effects are, after all, due to the presence of inclusions of various types, which, however, must be arranged in parallel bundles, or layers, or lines, orientated with perfect relation to crystallographic development of the host mineral.

In many instances such materials may be so commonly found as characteristic inclusions that they are of diagnostic importance, and if this simple fact is admitted (and I do no think anyone would deny it) then it must be clear that in species in which this is the rule, the possibility of such optical phenomena may be far from rare. My limited experience indicates that this is so.

Now to return to the original object of my observations, namely the able article by Professor Eppler. My comments are made merely as an attempt to unravel the skeins of what appears to be a well-established gemmological mystery. From the outset, I had the impression that the large star-beryl, was of special interest for several reasons: (*a*) because it was an asteria; (*b*) because in addition it was a star of the beryl species, which he evidently regards as rarer than most other asterias; and lastly (*c*) because the inclusions responsible for the asterism were not what one would have anticipated.

For reasons that follow I cannot understand either (*a*) or (*b*) but (*c*) is, of course, a very different matter, and Eppler's article is proof of the intensive nature of the research undertaken.

So far as I can see, asterism and chatoyancy in the beryl species is no novelty, but stones of large size may of course be rare. When the magnificent mineral and gem collection made by the celebrated mineralogist, the late Colonel de Vesignié, was split up on

his decease, and part brought for disposal to this country, I was fortunate to have an opportunity to acquire many rare gems I had never expected to possess, although I did find that some were incorrectly labelled. Among others was a star-aquamarine of 26 carats, dark blue, transparent and displaying an irregular 6-ray star. It was badly formed and will require re-cutting and centring, but is a fine stone.

Church includes one star-emerald in his catalogue of the Townshend Collection:[5] " Emerald. With six-rayed black star, sub-globular, with face and back centrally flattened, circular, ½-inch diameter, plain swing mount. (Hope catalogue, p. 46, No. 9), Plate II, fig. 24." The illustration is actually of a horrible looking object, but I assume the original is more impressive. So far I have never been able to locate the Townshend Collection in South Kensington and it is likely that the illumination will not be suitable for chatoyants and asterias.

I should imagine that star-emeralds *are* rare, and I have never seen one. I should add that I have no idea what is meant by the description " 6-rayed *black* star ".

Some years ago I acquired an aquamarine cat's-eye, of deep colour (blue), an oval three-quarters of an inch in length, with the eye lengthwise, and a lighter aquamarine 4-ray asteria five-eighths of an inch in diameter, with a definite but easily discerned star. Some time ago I received a half-inch diameter morganite (pink beryl) cat's-eye, cut from a piece of rough from Brazil. I also have a small milky-white cat's-eye beryl of unknown origin.

Until comparatively recently I had never heard of black star-beryl, but I understand that it is found in Brazil (?) and is sometimes offered for sale in mineralogical literature of the U.S.A.; and I have before me as I write an advertisement from a recent journal which includes the following gem items:—

" Black star and rose quartz in the rough,

Golden beryl cat's-eye and tiger-eye in the rough,

Morganite cat's-eye and aquamarine cat's-eye in the rough and the following polished cabochons:—

Star-moonstone—cat's-eye tourmaline and cat's-eye scapolite."

These items are not priced in the advertisement, but I have another which offers rough black star-beryl at 80c. per gramme. Incidentally, it is not clear to me whether the term " black star-beryl " indicates a black beryl asteria, or a black star in a beryl, similar to that described by Church in relation to the star-emerald he mentions.

This is something on which I should like to have further information.

It is clear to me that there must be a large amount of unpublished data in relation to this subject, particularly in the beryl species. It seems fairly certain that many chatoyants and asterias are known to occur in America, particularly North America. I have not read *Gem Collection of the American Museum of Natural History*,[6] nor have I read George F. Kunz's monograph on Gem Minerals of North America, now out of print.[7] I am hoping shortly to study John Sinkankas's recent work on the same subject[8] and feel sure that he will give much data in relation to asterism and chatoyancy, and having read so many of his recent articles on gem minerals[9] I am looking forward with great anticipation to reading his latest interesting contribution to gemmological literature.

With reference to other interesting examples of chatoyancy and asterism cited by W. F. Eppler in his valuable contributions on the subject (*Journ. Gemmology*, January,[3] and April,[4] 1958) I agree that star-spinels are very rare. I recollect having examined only one, some years ago, and one was described[10] in 1954.

Chatoyant zircon also appears to be rare, and the only specimens I have are grey stones which are faceted in a clumsy native manner, an extraordinary thing to do. I do not think that chatoyancy is rare in tourmalines, nor asterism in almandine and rose-quartz, but it seems odd that I have not seen any reference to a rose-quartz cat's-eye, nor asterism in tourmaline, optical effects governed by crystallographic development and the type of inclusion enclosed.

Although chrysoberyl cat's-eye is regarded as the most popular species (largely because the jeweller is not familiar with most other varieties), yellow scapolite cat's-eye appears to enjoy a deserved popularity when obtainable. I had not previously heard of the grey variety mentioned by Eppler.[10]

It is possible that some observations on the specimens forming my own collection of chatoyants and asterias might be of interest to fellow gemmologists and collectors and with this object in view I propose to resume the subject on a later occasion.

On further reference to available literature I found after writing the above observations, that I had overlooked a micro-photograph illustration to Eppler's contribution in the *Journal of Gemmology*, April, 1958, which shows a distinct 6-ray star in a spinel, consisting of dark inclusions forming the star, presumed to be caused by strain round an unidentified crystal.

Something of this nature might explain the black star-emerald mentioned by Church. I have also noticed, on again reading Sinkankas's article in *Gems and Gemology* (Fall, 1955), that he referred to a black star-beryl from Brazil as follows:—" . . . A most unusual beryl . . . which yielded star-stones when cut . . . like Australian star-sapphires, possessing the same dark-brown body colour and bronzy luster . . . " He found that asterism was due to abundant inclusions producing colour that varied from deep blue by transmitted light to bronzy black by reflected light. He hoped that more of this interesting mineral would become available, and since then his hope appears to have been realized.

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Gemmological Abstracts

HOLMES (R. J.) and CROWNINGSHIELD (G. R.). *A new emerald substitute.* Gems and Gemology, No. 1, Vol. X, pp. 11-22. Spring, 1960.

Fully reports the production by Johann Lechleitner in the Austrian Tyrol of a new type of synthetic emerald to which the name *Emerita* has been suggested. The details of the method used in the production have not been revealed. It is suggested that it is by hydro-thermal or by flux-fusion process. The seed used for the product is a faceted single-crystal piece of colourless or faintly coloured beryl. These shaped stones are approximately the size of the finished product and the synthetic emerald is deposited in crystallographic continuity on this faceted beryl. When the overgrowth is of sufficient thickness a stone, which only needs the facets to be polished, and is of good colour, is produced. The short time needed to produce a satisfactory overgrowth will influence the price of the stones which, presumably, will be cheaper than the Chatham synthetic emerald. The Authors had available a number of specimens, both rough and cut, of these synthetic stones for examination and they carried out a comprehensive and accurate study of them. They found the density to vary from 2·649 to 2·707 (average 2·684) and these values are compared with those for the Chatham synthetic emerald and of natural emeralds from various localities. The hardness, tenacity and fracture were found to be similar to the natural and earlier synthetic emeralds. The depth of colour depends upon the thickness of the overgrowth. The indices of refraction are higher than for other synthetics and were found to be 1·575-1·581 (the average of three determinations). The transparency was seen to be greater than most natural or synthetic emeralds and the absorption spectrum was that usual for emerald. The fluorescence under long-wave ultra-violet light is a visible reddish but less intense than that observed in the American synthetic emeralds. The surface markings seen in the rough stones are discussed. The internal structures were observed to be numerous parallel and sub-parallel short straight lines which are apparently minute parallel internal fractures in the synthetic overgrowth and may be attributed

to relief of strain. This defect is more pronounced in the ealier production and is expected to be less, or to be overcome, in later manufactures. X-ray powder diffraction patterns, both on the seed and the synthetic overgrowth, on Chatham synthetic and on natural emeralds, established the identity in structure. This important article concludes with a summary of properties.

7 illus. R.W.

CRIBB (H. G. S.). *Opal deposits and the Hayricks opal mine.* The Australian Gemmologist, No. 11, Vol. 2, pp. 7-16. May, 1960. (*Extracted from the Queensland Mining Journal of February, 1948*).

An introduction is given to the opal mining industry in Queensland. The opal deposits are some 250 miles in width and some 550 miles long in Western Queensland. The geology of the area and the occurrence of opal are covered in the survey. Particular information is given of the Hayricks opal mine, which lies near Quilpie. The various types and formations of opal are referred to. The mining methods and the production, and future prospects are discussed. An important article.

1 illus. R.W.

BENSON (L. B.). *Highlights of the Gem Trade Lab. in Los Angeles.* Gems and Gemology, No. 1, Vol. X, pp. 3-6 and 30. Spring, 1960.

Reports of a cabochon-cut star peridot with a 4-rayed star and an unusual synthetic sapphire in which a mass of gas bubbles were concentrated in the pavilion of the stone and the table of the stone had an etched or fused appearance, and there were twinning lines and distinct needle-like inclusions to be seen in this stone.

4 illus. R.W.

CROWNINGSHIELD (G. R.). *Highlights at the Gem Trade Lab. in New York.* Gems and Gemology, No. 1, Vol. X, pp. 7-10 and 31. Spring, 1960.

Refers to the danger of using anything but a black background to the stone when examining it for fluorescence effects under ultra-violet light. Discusses the second largest diamond found in the State of Arkansas in the past twenty years. This crystal weighs 6·43 carats and has a " Cape " colour. Reference is made to a

large cabochon sapphire in which was an included crystal of blue spinel. The Hope blue diamond was examined for electro-conductivity and was found to be electro-conductive. A number of unusual gemstones tested in the laboratory are mentioned.

5 illus. R.W.

GARTRELL (B.). *Sapphire mining in Australia.* The Gemmologist, No. 347, Vol. XXIX, pp. 103-108. June, 1960. (*Reprinted from The Australian Amateur Mineralogist.*)

A description of the Anakie sapphire fields of Central Queensland. Ruby Vale, Sapphire and The Willows are the mining towns. The flora and fauna, and the living conditions of the area are mentioned. The type of deposit and the associated minerals are referred to, and the methods of mining discussed. Famous sapphires found in the locality are mentioned.

3 illus. R.W.

BRUTON (E. M.). *Diamond mining in Guinea.* The Gemmologist, No. 348, Vol. XXIX, pp. 121-131. July, 1960.

Describes a visit paid by the author to the diamond fields of the newly formed Republic of Guinea, West Africa. The mines have been worked since 1936 and diamonds form 5% of the total exports of the Republic (in value). The diamond mines are in the forest area of Haute Guinée. The town of Kankan is the centre of the buyers' mart, where the sellers expect to be offered a price and not as normally price their stones. The weights are approximate. The mine visited was that of the Soguinex Co. There is also a French mining company and a native co-operative organization, and the history of this latter venture is fascinatingly told. The mine visited was at Banankoro and here the diamonds are found in the " pay gravel ", a yard thick. This is a whitish sand and is overlain by twenty feet of brick-red sandstone. Below the diamondiferous layer is the bed-rock of granite. The methods used in the mining of the diamonds are explained. Something of the French company and the native co-operative organization is told, and also notes are given on the living conditions in the area.

5 illus. R.W.

ANON. *Stone of the sun.* Gemmologist, No. 349, Vol. XXIX, pp. 157-159. August, 1960.

Discusses the greenish-yellow variety of beryl called *heliodor* which is found in the form of large crystals at Ameib, Rossing and Jackalswater some twenty miles north of Steinkopf in Namaqualand in south-west Africa. First found at Rossing mountain in 1912, there was a second discovery in 1925 and a third in 1938. The crystals are said to be radioactive. The article refers to the myth that heliodor came to the earth in a shower of meteorites and gives the reasons which led to this conjecture. The mines are now said to be worked out.

R.W.

WEBSTER (R.). *The many marbles.* Gemmologist, No. 346, Vol. XXIX, pp. 91-97. May, 1960.

A survey of the marbles used for ornamentation. It is a résumé of the author's work first published in this Journal. (*Journ. Gemmology, No.* 7, *Vol. VI, pp.* 297-333. 1958.)
5 illus. P.B.

WALTER (D. R.). *Kuri Bay.* Australian Gemmologist, No. 6, Vol. 2, p. 15. December, 1959.

Kuri Bay is about 200 miles north of Broome and is the location of the Australian cultured pearl industry, which is controlled by Pearls Pty Ltd., with whom is associated the Nippon Pearl Company of Tokyo.

R.W.

WEBSTER (R.). *Turquoise imitations.* Australian Gemmologist, No. 4, Vol. 2, pp. 5-7. October, 1959.

Discusses the recent advances in the imitation of turquoise and the impregnation of friable American turquoise in order to harden it. The imitations mentioned are stained chalcedony, opacified and coloured glass, " Viennese turquoise," the German product " neolith " and some others. Resin and silica-bonded true turquoise are mentioned and some methods whereby these simulants may be detected are given, except for the silica-bonded type which, up to the time of writing, the writer had not encountered.

P.B.

WEBSTER (R.). *Density determination by spring balance.* Gemmologist, No. 347, Vol. XXIX, pp. 101-102. June, 1960.

Reports some experiments for the determination of density of figurines and other pieces which are too large to be accommodated by the usual chemical balance. Two spring balances were used ; one giving a range of one gram to 100 grams, and the other one gram to 500 grams. The results obtained with the balances and the accuracy found are discussed.

P.B.

WEBSTER (R.). *Spinel suite.* Gemmologist, No. 340, Vol. XXVIII, pp. 206-209. November, 1959.

A general discussion on the gems of the spinel species.

1 illus. P.B.

LEECHMAN (F.). *A matter of names.* Gemmologist, No. 346, Vol. XXIX, pp. 81-83. May, 1960.

Discusses the use of names for the varieties of chalcedony and criticizes the use of certain names for various types of the silica group of gems. A table of the silica family is given but this does not completely agree with the facts.

R.W.

GRANTHAM (D. R.) and ALLEN (J. B.). *Kimberlite in Sierra Leone.* Overseas Geol. & Mineral Resources, 1960, Vol. 8, No. 1, pp. 5-25, 6 pls., 2 figs.

Diamonds occurring in alluvium have been traced to kimberlite dykes near Sefadu, Sierre Leone. A high proportion of the Sierra Leone diamonds is coated but every transition exists between clear and coated stones : the octahedron, with related modifications, is morphologically dominant in both clear and coated types. An abraded or water-worn appearance is common even on stones collected directly from the source kimberlite, and subsequent re-growth with clear diamond is often shown. These features imply a considerable fracturing at depth before crystallization of the diamonds was completed. There are several excellent photographs illustrating the morphology of the diamonds and their surface features.

R.A.H.

ASSOCIATION NOTICES

COUNCIL MEETING

A meeting of the Council of the Association was held at Saint Dunstan's House, Carey Lane, London, E.C.2, on Wednesday, 13th July, 1960. Mr. F. H. Knowles-Brown, who presided, welcomed Mr. C. T. Mason, O.B.E., F.R.I.C., M.A., and Mr. E. Levett to the Council.

The following were elected:—

FELLOWSHIP

Rae, John G., Weisdale, Shetland. D.1934

Rostron, Norman J., Chiswick, W.4. D.1948

ORDINARY MEMBERSHIP

Blyth, Elizabeth R., Nanaimo, Canada.
Edelstein, Albert, Toronto, Canada.
Eschenbacher, Joseph A., Minnesota, U.S.A.
Graham, Dennis, Middlesbrough
Johnstone, John McLeod, Wirral, Cheshire.
Lasagna, Stefano M., Genova, Italy.
Penny, Lional F., Hong Kong.
Rao, A. V. S. G., Gwalior, India.
Rudman, Philip, Royton, Oldham.
Sher, Bernard, Los Angeles, U.S.A.
Taylor, Arnold, Transvaal, S. Africa.
Tooley, Gordon K., Waynesville, U.S.A.
Walter, Dennis R., Woodville West, S. Australia.

PROBATIONARY MEMBERSHIP

Lodge, John W., Newcastle on Tyne.

The Council agreed to invite Mr. G. McWilliam, of the West of Scotland Branch to serve on the Council as a co-opted member.

Messrs. J. R. H. Chisholm, T. H. Bevis-Smith and R. Webster were appointed to review the syllabus of examinations and to make recommendations to the Council.

GIFTS TO THE ASSOCIATION

The Council of the Association is grateful for the following gifts to the Sir James Walton Memorial Library :—

Gemcraft : How to cut and polish gemstones by Leland Quick and Hugh Leiper, F.G.A., from Hugh Leiper, editor of the *Lapidary Journal.*

A collection of rough and cut gems from John R. Fuhrbach, B.Sc., F.G.A., C. G., Amarillo, Texas.

From S. Buzalewicz, Cracow, Poland, a copy of *Einführung in die Kristallographie,* by W. Kleber.

One half of a large garnet crystal from John R. Fuhrbach, B.Sc., F.G.A., of Amarillo, Texas, U.S.A. The crystal was found in Ontario, Canada, and measured 71·6 × 95·4 mm. before being divided.

Three books about Indian jewellery from H. C. Jhaveri, of Bombay, India.

The Ancient Indian methods of testing gems by A. V. G. Rao, from the author.

The Association is indebted to the *Jeweller and Metalworker* for the report of the 1960 annual meeting, which appeared in Vol. VII, No. 7.

TALKS BY MEMBERS

WELL, G. T. : " Diamonds ", Maidstone Rotary Club, 11th March ; Tunbridge Wells Resident's Association, 18th March, 1960.

LAUVLAND, K. : " Jewellery and gemstones ", Norwegian Y.W.C.A., London, 20th April, 1960.

BAGLEE, G. : " Pearls and opals ", South Shields Afternoon Tea Club, 20th July, 1960.

BLYTHE, G. A.: " Gemmology ", Royal College of Nursing, Westcliffe, 12th September, 1960.

EXAMINATIONS IN GEMMOLOGY, 1960

The 1960 examinations attracted a large number of candidates and 185 sat for the preliminary and 110 for the diploma. Centres for the examinations were established in Holland, Switzerland, Kenya, France, Finland, Canada, Ceylon, Poland, West Indies, Southern Rhodesia, Norway, Malta, Australia, India, Germany, South Africa, Hong Kong, New Zealand, Netherlands Antilles and the United States of America, apart from the United Kingdom.

Upon the recommendation of the examiners the Tully Memorial Medal has been awarded to Mr. H. S. Heikkilä of Helsinki, Finland. The Rayner prize has been awarded to Mr. D. Hayes of London.

The following is a list of successful candidates, arranged alphabetically :—

DIPLOMA

Qualified with Distinction

Arend, Robert, Richmond Hill, Canada
Edge, William Seebo, Glenelg, S. Australia
Goward, David Evans, Matlock
Gritzkewitz, Boris, Helsinki
Haigh, David Ernest, Lincoln
Heikkilä, Heikki Sakari, Helsinki
Hinks, Peter John, London
Hyman, Geoffrey Maurice, Blackpool
Orkomies, Lotta, Helsinki
Paronen, Tauno Kalevi, Helsinki
Riley, Philip William Temple, Chester
Rufli, Jean Claude, Idar-Oberstein
Saller, Xaver, Munich

Qualified

Beach, Michael Leonard, Twickenham
Boermans, L., Venlo, Holland
Burwood, James Raymond, Coventry
Chalcroft, Pamela, Edinburgh
Childs, Allan John, Hornchurch
Christophersen, Einar, Sandnes, Norway
Collins, Christine Deanne, Wolverhampton
Elout, Hélène, Wassenaar, Holland
Fisher, Peter Jack, Cookstown, N. Ireland
Hamara, Pauli Richard, Helsinki
Havem, Unni, Oslo, Norway
Hickman, John Thomas, Bristol
Jarvis, John Clifford, Calcutta
Kaskimies, Keijo Lauri Kalervo, Helsinki
Kraus, Pansy D., San Diego, U.S.A.

Qualified

Lee, Kenneth Arthur, London
Masters, Christopher Robin, Blackpool
May, Peter George, Coventry
McMillan, Archibald, Edinburgh
McTurk, George Leslie Cummings, Edinburgh
Mikkola, Toini, Helsinki
Mortimer, Frederick, Loughton
Norman, Michael Stephen John, Bath
Nyman, Yrjö Ilmari, Helsinki
Øiesvold, Arild, Aarnes, Norway
Øiesvold, Odd, Jessheim, Norway
Parker, George Edward, Birmingham
Parsons, Elizabeth Marian, Leicester
Patni, Chandulal Gordhandas, Nairobi, Kenya
Pettersson, Ulf Jarl, Helsinki
Ranta, Olavi, A., Helsinki
Riddell, Eileen Rose, Armagh, N. Ireland
Rowley, Clement John, Stoke-on-Trent
Sarin, Baldev Krishan, London
Scorer, Brian, London
Sharp, Charles Sidney, Toronto, Canada
Springall, John Edward, London
Stoodley, Simon Alan, Eastbourne
Sundgvist, Jalo Aavre Matti, Helsinki
Taylor, Peter Gordon, Hounslow
Turton, George Gerald, Bromsgrove
Waddington, Alfred M., Scarborough, Canada
Walker, George Eustace, Toronto, Canada
Wilding, Peter, Liverpool

Preliminary Qualified

Aarne, Eino Leo, Helsinki
Abdeen, Mohammed Maharoof Zainual, London
Agius, Frank J., Malta
Ainsworth, Kenneth John, Blackburn
Allen, Michael, Ilford
Aminoff, Benjamin David, London
Anderson, Thomas Mark, Epsom
Axon-Ryder, Albert Roy, Bolton
Badrutt, Retor T. P., Geneva
Beasley, Barbara Ann, Windsor
Billington, Ronald Bernard, Cheadle
Bishop, Trevor, London
Blades, Colin, Harrow
Borgen, Per Otto, Sarpsborg, Norway
Brooks, Raymond Eric, Wallasey
Budd, Douglas Harold, Jamaica, W.I.
Burke, Frieda J., Philadelphia, U.S.A.
Butler, William Charles Finlay, Paisley
Buzalewicz, Sobieslaw, Cracow, Poland
Catton, Cedric Trevor, Ipswich
Cole, Kenneth Charles, Salisbury, S. Rhodesia
Cooper, Harry Alan, Mansel Lacy, Hereford
Cooper, William Edgar, Manchester
Cox, Karl Johaan, Ghana, W. Africa
Cozens, Jonathan Roper, Taunton
Crew, Leonard Wilfred, Hong Kong
Deeks, Noel William, Luton
De Silva, Edward Herbert Leslie, Colombo
Devlin, Gilpatrick, London
Dunbar, George, Liverpool
Ellis, John Rodney, Reading
Flower, John C., Cleveland, U.S.A.
Foy, Cyril, Blackpool
Francis, Roger, Birmingham
Friedman, Franklin, Johannesburg
Gray, Eleonora, Paris
Green, Edward William, Toronto, Canada
Green, Leslie, Rainhill, Nr. Liverpool
Greeph, Mayer, Manchester
Gritzkewitz, Boris, Helsinki
Gunaratne, Herbert Stanley, Colombo
Gurp, P. C. van, Netherlands Antilles
Halpern, Carlos Eugénio Júdice, London
Hamera, Vaino Aleksanteri, Helsinki
Harrold, David John, Southend-on-Sea
Hayes, Denis, London
Heasman, David John Alfred, Colchester
Heenan, Gillian Ruth, Wirral
Heidelberger, Martin, Zurich, Switzerland
Henry, Paul Brooks, Scarborough, Canada
Hewson, Robin John, Egham
Hill, Dennis Alan, Glasgow
Hirshon, Gerald Martin, London
Hiscox, Sieglinde Elsa, Solihull
Hodgkinson, John Alan William, Aberdeen
Inglis, Andrew Ian, Edinburgh
Ismail, Omar Mohular, Colombo
Iverson, Anker, Trondheim, Norway
Jochems, Ellen Meta Margaret, Holland

Preliminary Qualified

Jones, David Winzer, Sanderstead
Joseph, Timothy Richard, Knowle
Keiser, Paul J., Detroit, U.S.A.
Ketelaar, J. G., Heemdtede, Holland
Kraus, Pansy D., San Diego, U.S.A.
Maki, Juho Kalervo, Helsinki
McCarty, Fay Veronica, Birmingham
McGoldrick, Bernard, Liverpool
Maunton, Frederick John, Bromley
Morris, Clive Raphael, London
Nilam, Mohamed Abusalam Mohamed, Colombo
Nuttall, John, Manchester
O'Connell, Sean, London
O'Neill, Marjorie, Henlow
Overvik, Eiliv, Namsos, Norway
Paronen, Tauno Kalevi, Helsinki
Pettersen, Egil Normann, Fredrikstad, Norway
Piirainen, Veikko Kalevi, Helsinki
Price, Denis Edward, Smethwick
Proctor, Hugh C., Don Mills, Canada
Ranta, Olavi A., Helsinki
Redding, Roland Edward, Southend-on-Sea
Rhodes, Douglas Brian, Preston
Rintala, Berit, Helsinki
Ritvanen, Martta Kyllikki, Helsinki
Rowe, Alan David, Worcester Park
Rouvier, Andre Edmond, London
Rufli, Jean Claude, Idar-Oberstein
Rybom, Lene, Fredrikstad, Norway
Sanford, Peter, Hatfield
Segal, Frank, Johannesburg
Sharp, Charles Sidney, Toronto, Canada
Siltanen, Jsmo Kalevi, Jyuaskyla, Finland
Silverberg, Lily, Pretoria, S. Africa
Sloman, Peter, Southend-on-Sea
Smith, Reginald Albert, Oxford
Stewart, Norman James Morton, Rochford
Stirton, Kenneth Geeki, Ripon
Stout, Cornelis Andries, Rotterdam
Sundgvist, Arvo J., Helsinki
Synan, Nartin Thomas, Slough
Szymczyk, Joseph, London
Velthuizen, S. P., Arnhem, Holland
Westergärd, Eila Margareta, Vaasa, Finland
White, John Anthony, Frome
Williams, Geoffrey Francis, London

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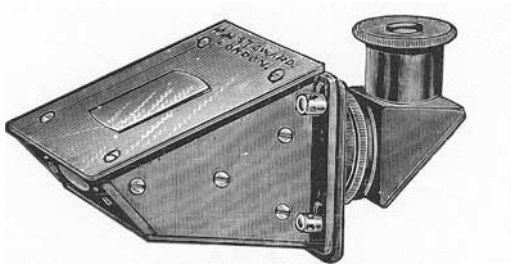

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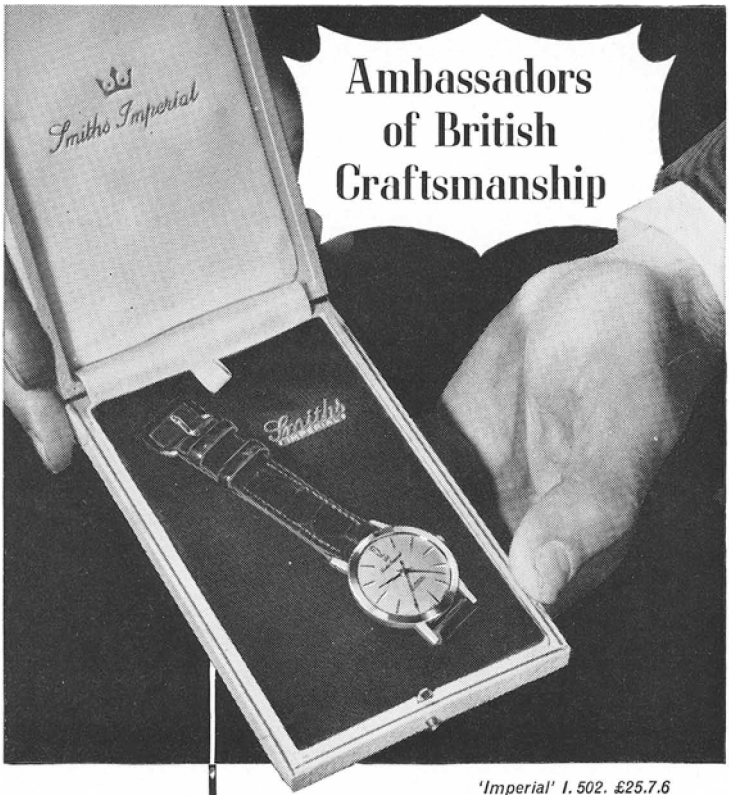

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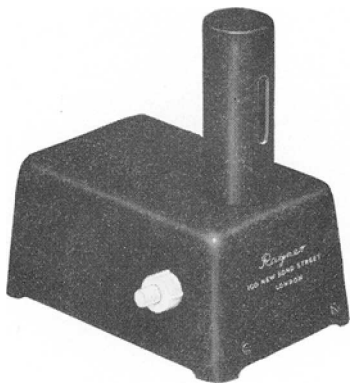

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INCLUSIONS IN DIAMOND

By W. F. EPPLER

THE two modifications in which carbon occurs, are diamond and graphite. Diamond as an inclusion in diamond has often been described. Graphite in diamond has also been mentioned many times.[1] But not every inclusion is a " carbon spot " of diamond or graphite. It is the high refractive index of diamond, from which results a small angle of total reflexion, which often causes a black appearance of the inclusions. Therefore, it is understandable that particles which look " as black as coal " are described by using the term " carbon spots ", even if they are quite a different material.

The mineralogical and gemmological literature mentions a great number of solid inclusions in diamond :

Particles of kimberlite, the mother rock of diamond
(a basic igneous rock, very rich in olivine)

Graphite	C	hex.
Garnet (pyrope)	$Mg_3Al_2(SiO_4)_3$	cub.
Magnetite	Fe_3O_4	cub.
Haematite	Fe_2O_3	trig.
Ilmenite	$FeTiO_3$	trig.
Chromediopside	$Ca(Mg, Fe, Cr)\ (Si_2O_6)$	mon.
Augite	$(Mg, Al, Fe, Ti)\ (Ca, Na)\ (Si, Al)_2O_6$	mon.
Enstatite	$Mg_2(SiO_6)$	orth.
Phlogopite	$K\ Mg_3(F, OH)_2\ (AlSi_3O_{10})$	mon.
Chromite	$FeO\ .\ Cr_2O_3$	cub.

Chlorite	Mg – Al – silicate	mon.
Pyrite	FeS_2	cub.
Olivine	$(Mg, Fe)_2SiO_4$	orth.
Quartz	SiO_2	trig.
Zircon	$ZrSiO_4$	tetr.
Diamond	C	cub.
Apatite	$Ca_5 (F, Cl) (PO_4)_3$	hex.

To the list, apatite must be added as it has been found recently. With every respect for the earnest ability of the authors, some doubt arises with regard to two of the crystal inclusions mentioned—graphite and quartz. It may be possible that a diamond crystal, which is embedded in another diamond, can be coated by a thin layer of graphite.[2] But, the independent occurrence of graphite in diamond is not yet confirmed with certainty. The original reports of graphite inclusions in diamond are dated back in literature for many decades, and no modern investigation has been made in this direction as, for example, by X-ray analysis.

The same argument must be taken into consideration with quartz. The mother-rock of diamond is a strongly basic (ultra basic) material from which no quartz crystals could be included by the diamond. The presence of quartz in diamonds from Brazil represents a particular kind of intergrowth between both minerals The only reference which could be found in literature is a communication of C. W. Correns[3] with the following conclusions (in translation) :

" The enclosures of quartz in (Brazilian) diamond consist of lamellae, mostly parallel to the octahedral plane and often limited by the same faces on their small sides.

" These quartz lamellae are not uniform crystals and, as could be found by X-rays, they have no orientation with the diamond or vice versa. From the border of the quartz enclosures it may be concluded that they must be of later origin than the diamond. It is shown that they can be regarded only as the fillings of etched cavities. Perhaps, these deeply trenched cavities originated from cleavage fissures, which have been caused by the tectonic movement of the mother-rock. Probably, these fissures have been gradually enlarged by the action of solutions of alkali carbonate or by overheated water. Both media are able to cause the sericitization of the rock and the recent formation of the quartz ".

Obviously, such diamond crystals with large intergrown quartz lamellae are not of gem quality, and they range among the boart of inferior quality.

Some of the solid inclusions which are listed above could be identified by testing industrial diamonds. Stones with interesting inclusions have been burnt subsequently by heating at 915°C for six hours. By this way, the crystal inclusions were separated and tested with conventional methods. Inclusions of diamond or graphite cannot be isolated by such a procedure as they are burnt and transformed into carbonic acid.

Garnet. In a small octahedron (Fig. 1), a red crystallized inclusion caused some perplexity by its form, which resembled the crystal habit of trigonal ruby (Fig. 2). The bewilderment was increased by its apparent anisotropic character which, as was found later, was due to the strongly developed tension—birefrigence of the host diamond. E. J. Gübelin took an interest in the problem. He found that the absorption lines, characteristic of ruby, were not present. Therefore he thought the interesting inclusion to be a garnet, which was confirmed after the separation (Fig. 3). This experiment was the cause of further investigations during which many garnets were found within diamonds. Sometimes, the garnet was found with its dodecahedron face parallel to the octahedral plane of the diamond, while in most of the cases no orientation of the garnets could be observed.

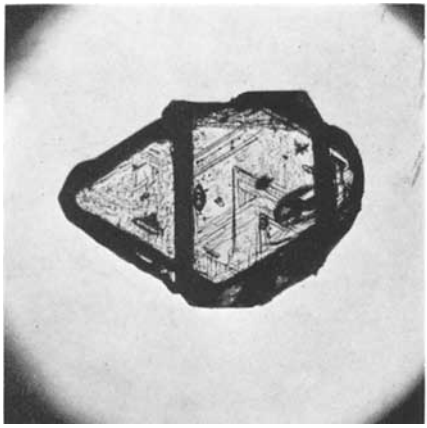

FIG. 1. *Garnet inclusion resembling crystal habit of trigonal ruby. 15 ×*

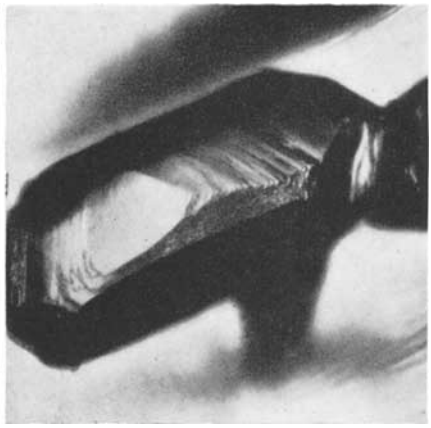

FIG. 2. *Garnet inclusion (see Fig. 1). 200 ×*

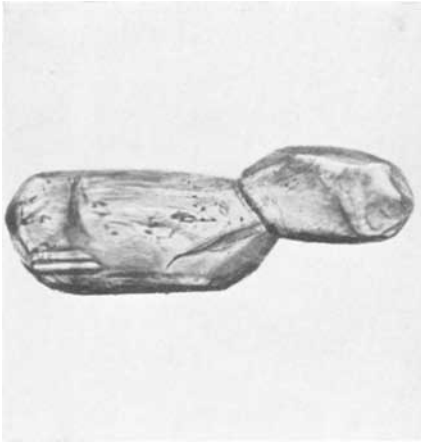

FIG. 3. *Garnet shown in Figs. 1 and 2 separated from host diamond. 120 ×*

FIG. 4. *Inclusion of Ilmenite. 65 ×*

S. I. Futergendler[2] found by X-ray analysis of garnet inclusions in diamond, that the lattice constants correspond to garnet of the almandine series, while judging by the refractive index, they approach pyrope most closely. Another property of many of the enclosed garnets is the fact that they are responsible for cleavage fissures parallel to the octahedron plane of the diamond. As can be seen in Figs. 1 and 2, little cleavage cracks surround the included heterogeneous crystal like a halo. In transmitted light they look like " carbon spots ".

Ilmenite. Fig. 4 shows an example of this interesting enclosed mineral. In transmitted and in reflected light, the ilmenite appeared black. Only the translucent thin edges exhibited a brownish colour, which is typical for this mineral. The orientation to the host crystal was deduced from the bright striation in Fig. 4, which indicates the direction of the octahedron edges : it is most probable that the basal plane of the ilmenite is parallel to the octahedron face of the diamond and, additionally, that a lateral axis of the ilmenite coincides with the direction of the octahedral edges of the diamond. Generally, inclusions of ilmenite in diamond seem to be relatively rare.

Olivine. R. S. Mitchell and A. A. Giardini[4] described oriented olivine inclusions in diamond. The orientation takes place in such

a way that the prism face (010) of the olivine is parallel to the octahedron plane (111) of the diamond. S. I. Futergendler[2] describes the enclosed olivines as transparent and colourless in the form of isometric or tabular crystals. Fig. 5 shows such an elongated olivine with a smaller one in a parallel position. Both are surrounded by little cleavage cracks. It is the same group of inclusions which can be seen on the left side of Fig. 1.

It has been found that the forms of the enclosed olivines vary considerably. While Fig. 5 shows olivine crystals of a similar elongated habit as indicated by Mitchell and Giardini, more rounded crystal forms can also often be observed (Figs. 6 and 7). The olivine on the right side of Fig. 6 is encircled by strongly developed cleavage cracks. They look black in transmitted and in reflected light. The dark spots on the left side of the picture are also cleavage cracks, running parallel to another plane of the same octahedron. They are caused by other inclusions.

Fig. 7 exhibits the separated olivine which, on its part, contains tiny inclusions of an unknown nature. The formerly colourless enclosure turned into a reddish-brown colour, which is due to the various contents of iron, a characteristic component part of olivine. The burning process of the diamond—to cause the separation—

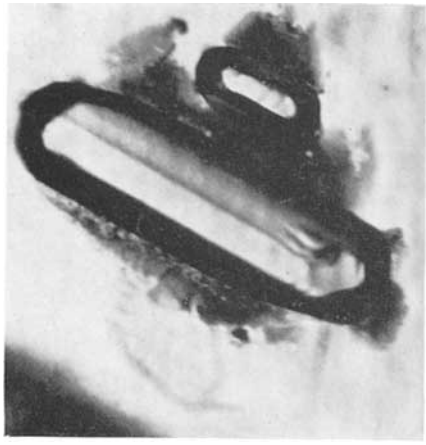

FIG. 5. *Elongated olivine inclusions in parallel position. 200 ×*

FIG. 6. *Olivine inclusion encircled by strongly developed cleavage cracks. 65 ×*

FIG. 7. *Olivine inclusion after separation (see Fig. 6) containing inclusions of an unknown nature. 120 ×*

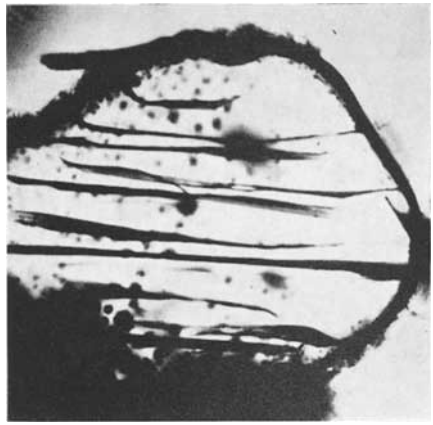

FIG. 8. *Tabular inclusions of olivine. 120 ×*

oxidized the iron content of the olivine and caused its change of colour.

Besides the elongated and rounded forms, tabular-developed crystals of olivine inclusions can be encountered, sometimes of surprising size. One of these is shown in Fig. 8 and 9. The dark rim of the olivine in Fig. 8 is due partly to the difference in the refractive indices between diamond and its enclosure. On the other hand, small cleavage fissures of opaque and black appearance broaden the border zone of the enclosed crystal. Fig. 9, a view of the separated olivine, exhibits the cracks which it had formerly. Its size is 0·6 mm, and its thickness only 0·03 mm. The refractive index was near 1·67, and the specific gravity was found to be approximately 3·27. Both values correspond with the properties of an olivine with a small iron content, so that the tablet appeared to be near to the forsterite member of the olivine group. A confirmation of the nature of this " exclusion " was obtained by an X-ray analysis made by H. Jagodzinski. Another tabular enclosure of olivine in diamond is shown in Fig. 10.

During the investigation of inclusions in diamond it was impressive to observe the great number of included olivines with widely varying sizes and forms. Olivine must be by far the most frequent heterogeneous crystal inclusion, whereas the complexity of

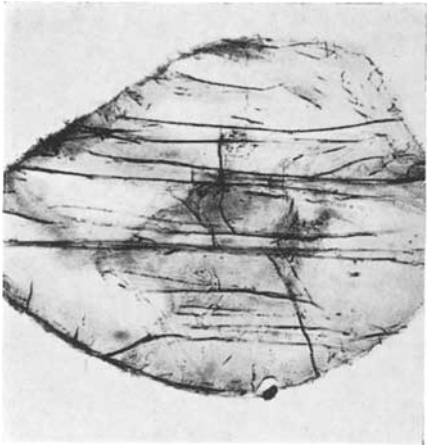

FIG. 9. *Olivine inclusion (Fig. 8) after separation, showing cracks. 120 ×*

FIG. 10. *Tabular inclusion of olivine in diamond. 65 ×*

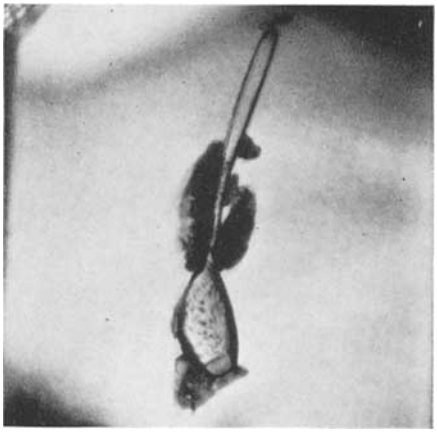

FIG. 11. *Olivine inclusion in diamond of unusual shape. 65 ×*

FIG. 12. *Apatite inclusion in diamond showing cleavage cracks. 220 ×*

its crystal habit may be the reason for its being confused with other crystals like quartz and zircon.

An extraordinarily formed olivine inclusion is shown in Fig. 11. This spoon-like formation is a single crystal of olivine, oriented to the host diamond. The dark areas near its narrowest part and at both ends are larger and smaller cleavage cracks in the diamond, which have been caused by the enclosure. The strange form of this particular olivine inclusion can perhaps be explained by the following hypothesis :—

Without any doubt, the genesis of diamond took place in a region of high pressure and high temperature. These conditions must have been above the stable state of the pre-existing olivine, so that its lattice suffered a breakdown, or the olivine crystal started to melt. In the situation of higher mobility, the liquified material, in some way or the other, followed the direction of decreasing pressure in the diamond, before it could solidify again. In the case of a greater difference of pressure, a certain flow could occur, as shown in Fig. 11. With less differences of pressure within the diamond, the olivine material became flattened or tabular, as demonstrated by Figs. 9-10. Such a hypothesis would mean that regular or euhedral inclusions of olivine crystals indicate little or no differences of pressure in the growing diamond.

Apatite. Although apatite is reported to be a primary constituent of kimberlite, the mother-rock of diamond, it had not yet been observed as an inclusion in diamond. It was fortunate, therefore, to find in a flattened octahedron of diamond a crystal of this species, unoriented to its host and characterized by its typical cleavage cracks (Fig. 12). The black parts, which, in the illustration, accompany the apatite, are cleavage fissures of the diamond, indicating the direction of its octahedral plane. The separation of this rarity failed in some way as, by reason of its marked cleavage, the apatite disintegrated during heating into tiny particles, from which the biggest, approximately 0·07 mm in diameter, was lost during immersion in alpha-bromonapthalene. It was just possible to find the refractive index of the splinter to be a little less than 1·6585 which is, together with the general appearance of the inclusion, sufficient to detect its nature (apatite has a mean refractive index of approximately 1·64). As this was the only apatite inclusion in a great number of diamonds under examination, it can be assumed that this particular kind of enclosure is very rare.

FIG. 13. *Gaseous inclusion in diamond.* 65 ×

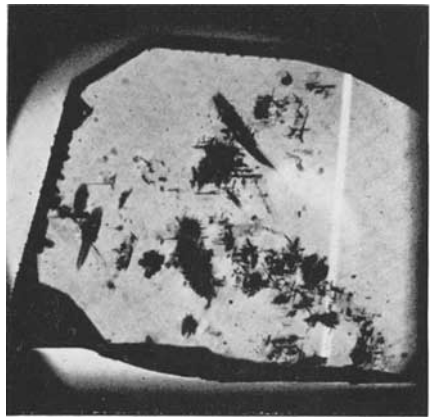

FIG. 14. *Cleavage cracks in diamond.* 22 ×

Gaseous inclusions in diamond are reported to form clouds of foggy patches which consist of minute gas-filled cavities (E. J. Gübelin[5]). Sometimes they indicate former growing planes of the host crystal. Fig. 13 shows an assembly of such gaseous inclusions. They are difficult to observe, as even with a high power magnification no particular details can be disclosed. The black inclusion on the left side of the picture represents a cleavage crack starting from a small crystal inclusion and following the direction of the octahedral plane of the diamond.

Cleavage cracks and fissures can be listed together with the gaseous inclusions as they contain air or gaseous carbonic acid. Most of the cracks must have been caused by tension of the diamond, as they follow the direction of cleavage along the octahedral plane. It is thought that formerly some of them have been considered as graphite, as they look black, especially in transmitted light. Fig. 14 gives a general view of several of those cleavage cracks. Some of them are broad patches, others appear in a needle-like form, and may be easily mistaken for solid material or crystallized needles. But they follow the plane of the octahedron of the diamond and its edges respectively.

Healing fissures in diamond are supposed to be present but not yet confirmed with certainty. It is necessary to observe the phenomenon with greatest care as otherwise some confusion may arise.

The cleavage crack in Fig. 15, which starts from an enclosed olivine crystal (right), is not a healing fissure in spite of the triangular etch figures (bright). Even the fissure in Fig. 16 is an ordinary cleavage crack. It reached to the outer surface of the diamond and was filled with a brownish material, imitating to some extend the pattern of a healing fissure.

With another cleavage crack parallel to the octahedral plane of a diamond (Fig. 17), it was not easy to make a decision whether it was a real healing fissure or not. Possibly the crack had absorbed some liquid, distributing the liquid material in tiny droplets over its area. It is very likely that such an interpretation is correct, as no signs of a healing process could be observed.

On the other hand, real healing fissures with all the significant peculiarities of the phenomenon can sometimes be encountered as inclusions in the diamond. Fig. 18 gives an example. A cleavage crack, parallel to the octahedral plane of a diamond, has been reduced to about one-third of its former extension by a healing process. Subjective examination under the microscope revealed the widespread healed area much better than a photograph. In spite of this, even Fig. 18 exhibits distinct differences in the texture of the healed and the unhealed part of the former cleavage crack.

Another healing fissure in a diamond developed similarly formed liquid inclusions (Fig. 19). They are well known in

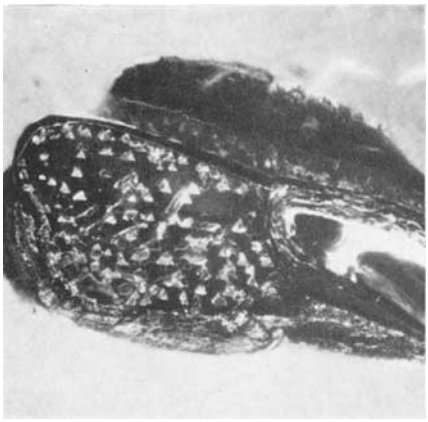

FIG. 15. *Cleavage crack in diamond starting from an enclosed Olivine crystal. 220 ×*

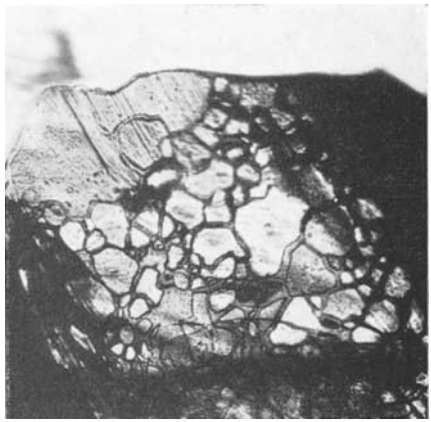

FIG. 16. *Cleavage crack in diamond. 120 ×*

corundum and in the gemstones of the pegmatite series. There is little doubt that the liquid consists of carbonic acid. Fig. 20 exhibits details of the interesting former cleavage crack. It must be emphasized that the elongated or hose-like liquid channels follow the directions of the octahedral edges of the host diamond. The borderline of the former crack forms nearly a semi-circle. (Fig. 19).

FIG. 17. *Cleavage crack parallel to the Octahedral plane of a diamond. 110 ×*

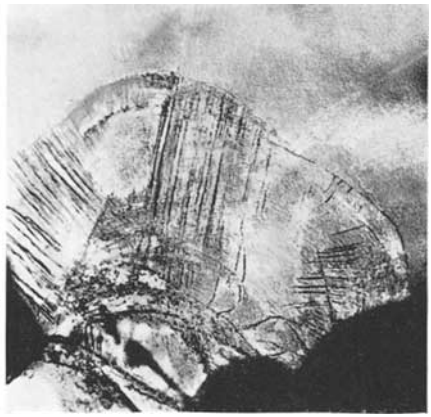

FIG. 18. *Healing fissure encountered in a diamond. 120 ×*

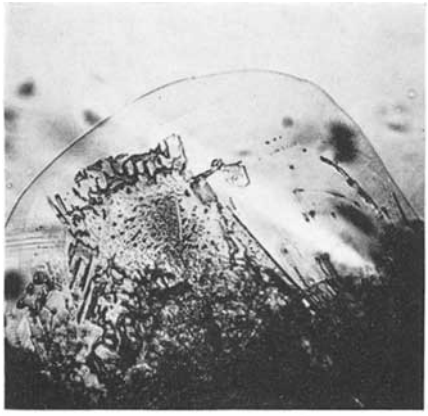

FIG. 19. *Healing fissure in a diamond. 65 ×*

FIG. 20. *Part of the healing fissure in Fig. 19 with inter communicating liquid inclusions. The hose-like liquid channels follow the octahedral edges of the diamond. 240 ×*

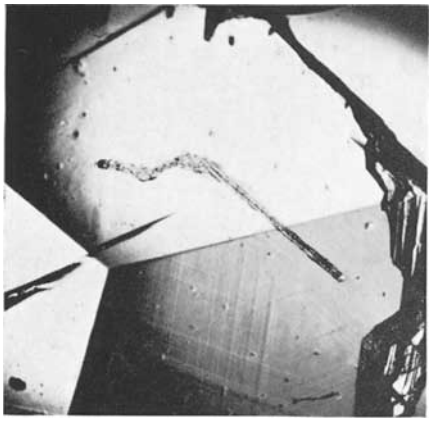

FIG. 21. *Worm-like inclusion in a diamond. 22 ×*

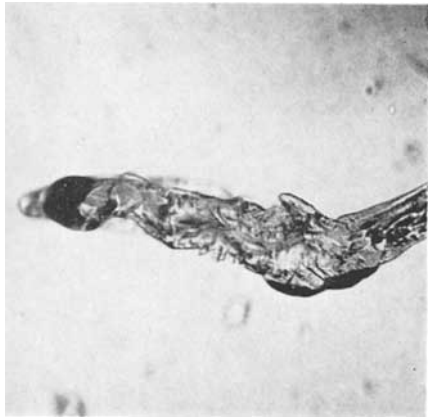

FIG. 22. *Enlargement of part of Fig. 21 showing gas bubble termination. 120 ×*

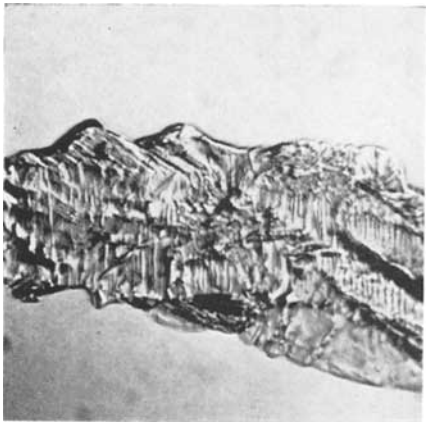

FIG. 23. *Middle part of hose-like inclusion (Fig. 21). 240 ×*

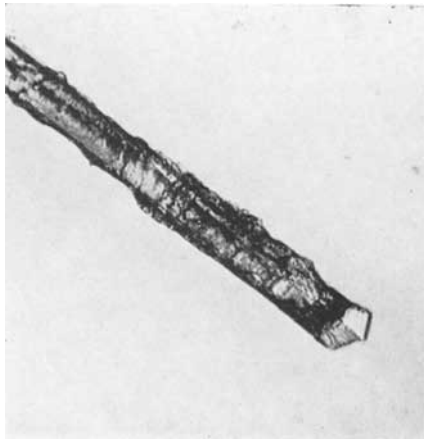

FIG. 24. *Octahedral termination of other end of hose-like inclusion (Fig. 21). 120 ×*

An unusual inclusion in diamond is shown in Fig. 21. Within a rose-cut stone, there was a worm-like enclosure, a longer part of which was rectilinear. By comparing its direction with the rough (or broken) girdle of the stone, which exhibited growing lines, and by using a higher magnification, a coincidence of this and other preferred directions with the edges of the octahedron was found (Fig. 22-24). Additionally, the left part of the " worm " ended in a gas bubble (Fig. 22), while the end of its right part exhibited two crystal faces which belong to an octahedron (Fig. 24). The middle part (Fig. 23) revealed a rough surface with marked lines. They coincided with the direction of the growing lines of an octahedron plane. It is not unlikely that this unusual formation represents a negative crystal, which is filled with a liquid (carbonic acid). The gas bubble as well as the transparency of the crystal are in conformity with such an explanation, while its isotropic character supports this explanation.

Summary. Garnet, ilmenite, olivine, apatite, gaseous inclusions, healing fissures, and an extraordinary negative crystal have been observed in diamonds. The solid inclusions have been tested after their separation from the host crystal. It is certain that a number of other crystal inclusions occur in diamond, as has been reported by some authors. During this study, however, no evidence could be found that graphite and quartz were present, a result which should not be overestimated as only industrial diamonds were examined, the exact occurrence of which was not known.

ACKNOWLEDGMENT

The author is indebted to Messrs. Ernst Winter & Sohn, Hamburg, for having supplied the suitable diamonds and to Prof. Dr. H. Jagodzinski, Max Planck Institut für Silikatforschung, Würzburg, for the X-ray analysis of an olivine inclusion. Most of the industrial diamonds were obtained by the courtesy of Messrs. Ernst Winter & Sohn, Hamburg.

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NEW STAR-STONES AND THEIR ANTECEDENTS

By FREDERICK H. POUGH

A DURABLE new " star-stone " for the jewellery trade is the latest comparatively inexpensive stone to be offered in the United States of America in the past year. Since American acceptance of star-sapphires and rubies has always been better than that of the rest of the world, it is not surprising that these stones are assembled in the U.S. and that the cutting is done abroad to obtain the precision, production and lower cost expected of German lapidaries. Basically the stone is a doublet, with in one case a cement that might justify the term triplet for the finished product. The top of the stone is transparent synthetic sapphire or spinel. The star appears to be produced by minute scratches that spread reflections into a bar.

Before describing the new stones, it might be interesting to follow the rise of star-stones to their current popularity. The stars that could be disclosed in natural sapphires and rubies by the combination of cabochon cutting and proper orientation were popularized on the American market many years ago by some of the more aggressive tradesmen. Slightly cloudy sapphires and rubies, which could have produced a star if properly cut had been faceted and sold in the past without any attempt being made to take advantage of the rutile " silk " ; allowing it, in fact, to be a detriment to the stone. Some of these early stones have been profitably recut into star-stones in the West. Usually they are stones with weak stars, but they are also often unusually deep in colour.

Once stars had become popular, there was naturally a desire on the part of artificers to provide more and cheaper stones for this market. Numerous attacks on the problem were made before Linde finally solved it for the better class market. Human nature, of course, still provided a reason for a cheaper solution, and the new stones will appeal to this regrettable character defect, and look much better than any previous aspirants. One of the earliest synthetic " star-sapphires " must have been intended for buyers who had heard the name but who had no conception of its appearance. It

was synthetic all right, and it showed a star. But the star was engraved on the back : a sort of upside-down intaglio. Similar stones were made of glass, with a star that was fixed and motionless on the back of the stone. From these imitations the " experts " then adduced an edict: that the star moved about, depending on the viewing angle, only in genuine stars. This test soon fell down, but surely no-one was ever deceived by the carved imitations: their only resemblance was verbal. They are said to have been made about 1930.

Shortly before the 1939 war a far better substitute was found : one that promptly gave the lie to the idea that a fixed star was a characteristic of all imitations. This material is now well known, and still being made, but is neither synthetic nor sapphire.

The presence of star-like reflections or dispersions of transmitted light was known to be an uncommon, but characteristic, property of a number of crystallized substances. Star-garnets, with 4 and 6-rayed stars, were found among the Indian carbuncles. Star-quartz, from pale rose to almost slightly grey, was every bit as pronounced in its stars as sapphire. Someone, probably in England, since the very first stones came from London to New York, got the brilliant idea of colouring the back to make the pale quartz opaque and coloured. These were quite effective, though few people were probably deceived by them. If the back could be seen, it was at once obvious that it was a painted or an enamelled back. Generally the colour on the back was the colour the stone showed, and when one looked sideways at the stars one could easily see the pale, nearly colourless nature of the star-material.

The star-quartz imitations had their limitations. The colouring material had a disconcerting habit of coming off after a time, not being as impervious to water and wear as one might wish. Then, too, some men's perpetual lifetime goal (to make something cheaper than the other fellow, with no heed to quality) achieved something like perfection by making the stars so frightfully bad that they lost all their appeal to buyers, who had earlier found some merit in the initial products when price was not quite so much of an object. They are still on the market but seldom seen in jewellery.

The lack of hardness, in comparison with real star-sapphires, was no great factor in leading the ingenious imitators to turn to corundum material as their next raw material for the star-imitations.

It is more likely that the colour, and possibly the name, suggested that the new imitations should be made from synthetic boule material. Someone got the idea of scratching the back of a ruby or sapphire cabochon with three sets of fine lines. A very bright light shining on the top of the stone showed a weak coloured star radiating from the centre of light reflected back from the bottom of the stone. To intensify this an attempt was made to mirror-plate it, or to cement a mirror surface to the bottom of the cabochons. It helped, but the housewife's dishwashing soon took it off and the sale of the stones collapsed. Another error was in cutting the stones in very high cabochons, which made them thick and dark, so that the star, at best, was very weak.

At about this time, or soon after the War, an American, Louis Moyd, had a bright idea that was inspired by a familiarity with a Canadian phlogopite (magnesium mica) which also showed a star by transmitted light (Fig. 1). As in the quartz and the corundum, it is caused by the presence of innumerable microscopic crystals, oriented by the mica into the same sort of three-rayed pattern as in the former two minerals, for its crystals, though monoclinic, are almost hexagonal in their symmetry (Fig. 2). A glass or ruby hemisphere, laid on a piece of phlogopite, focuses the light into a spot and reflects back to the viewer as a star. If the mica is really saturated with the inclusions, possibly rutile, possibly some other material, it becomes very bronzy and opaque. The best results

FIG. 1.

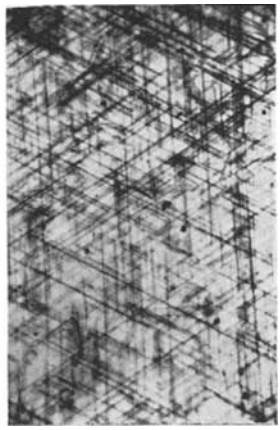

FIG. 2.

were found with this type of mica, but the star was not as brilliant as could be wished, little better than that of the scratched-back synthetics. At the time, too, no good cement was known and nothing could be found that would not separate after a time.

New cements, particularly the plastics known as the Epoxy resins, which have been introduced in the past few years, have made cemented stones more practical. Coming as two separate viscous liquids, they are mixed in equal proportions and allowed to set : a hardening process which can be hastened by mild heating. Once hardened they cannot be dissolved with any of the simple solvents and are little affected by water. They have greatly simplified some forms of jewellery making, for with " Epoxy " one does not have to drill tumbled stones for mounting : they are simply cemented into a cap.

Naturally this remarkable material revived an interest in the star-doublets, and two makers at least are now producing synthetic stones with stars. Though they sell for about the same price, one is very much better than the other in appearance (Fig. 3). It would be hard to guess about their respective durabilities. Their names are in need of some clarification, for while synthetic sapphire and ruby are the basis of some stones, synthetic spinel is also used, glass is seen occasionally, and not all of the stones are stars. If one puts a single set of scratches on the stone, then one gets a cat's-eye in place

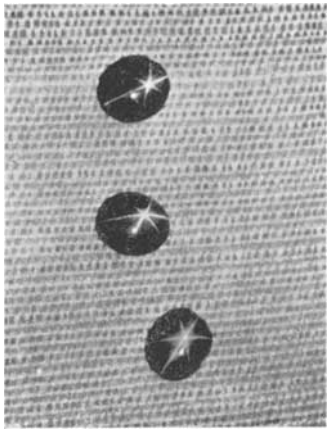

FIG. 3.

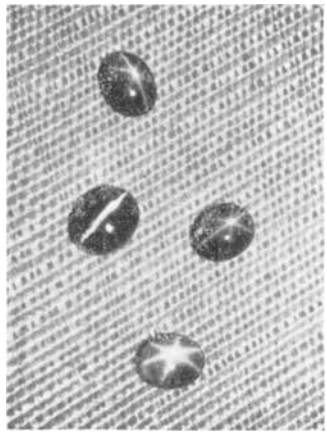

FIG. 4.

of the star. The manufacturer of the plastic-resin cemented stones makes cat's-eyes as well as stars. (Fig. 4.)

The star, or cat's-eye, can be made to appear in a stone in three different ways. The star-causing reflecting surfaces can be in the stone, as they are in natural star-stones. They can be scratched on the back of the stone, as they were in the first synthetic ruby imitations, or they can be on or in the backing material, as they were in the phlogopite-backed doublets.

The plastic-cemented doublets (double doublets one might say, since there are four layers) belong to the latter group. (Fig. 5.) The maker of these stones starts with low cabochons, one might almost call them " buff tops ", probably cut in Germany in calibrated sizes from any sort of material ; synthetic sapphire and ruby, synthetic spinel in blue or green, emerald-green glass and a sort of an opal glass. The " epoxy " cements this to a clear glass back, less than a millimetre in thickness. However, from the back this glass back seems first to have been scratched with one, or three, sets of scratches, and then plated with a mirror surface. The plating is so thin that the scratches show on the metallic surface.

This is a better product than any of the earlier substitutes because the top is thinner and paler than the first deep cabochons were, permitting brighter reflections. The colour is rich and approximately right (though the star is very highly coloured in comparison with the real or Linde stars). An epoxy cement can probably take any normal sort of abuse without separating. From the back one sees a silvery moonstone-like surface.

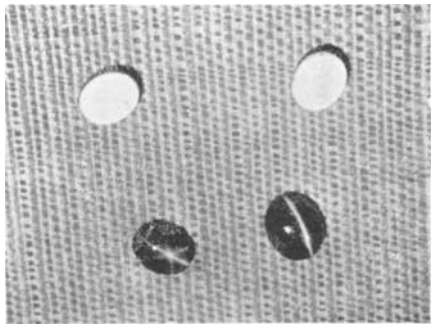

FIG. 5.

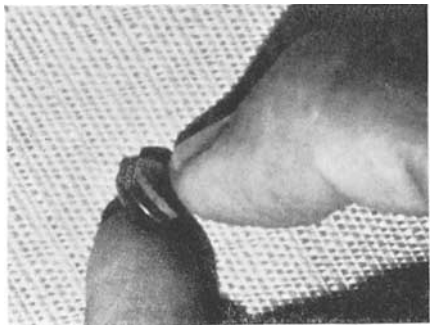

FIG. 6.

Over-heating could destroy these stones : the sort of heat that might be applied in careless sizing. Other than that they seem to be satisfactorily permanent, but one obviously cannot expect any plastic material to withstand really high, burning, temperatures. The glass backing too would be likely to crack in too much heat.

The second manufacturer of synthetic star-sapphire doublets doubtless produced a stone even less susceptible to disruption by heat. This doublet can only be described as soldered (a term with which the jeweller is familiar through the unsoldered " soldered emerald "). This new star stone is, literally, soldered together. (Fig. 6.) It is a triplet, the top layer is a buff-top, German-cut synthetic ruby or sapphire, just like the other. The back, which fits perfectly, is made of blue or red sintered corundum, an opaque deeply coloured material. In the case of the blue stones it looks just like the sintered synthetic spinel imitation of lapis-lazuli. X-ray tests indicate that it is a corundum, however, or at least the red material was.

The buff-tops, as imported, are polished all over. The first step is probably scratching the surface in a series of microscopic grooves, in the three different 60° directions. The greater hardness of the synthetic corundum may be in part responsible for the better appearance of these stones, creating on sapphire weaker and sharper scratches than are made on glass. The two halves, of almost equal thickness, must then be soldered together with some relatively low melting point metallic solder, which adheres strongly to the corundum. The solder provides the reflecting surface, holds

the two parts together and appears unaffected by most of the normal hazards. The stones were found to separate under extreme heat, an abuse to which they would never be subjected under normal conditions.

As loose stones there is no difficulty in recognition, and even in a mounting the sintered corundum back is quite unlike that of any natural stars : the colour is far too deep. Just why this material was used as a backing is not clear, except that possibly it was felt that a metal that would adhere to the corundum on one side might just as well be backed with equally durable material. Probably a metal plate would do as well.

The star is very fine, coloured of course, but sharp and bright. The finer, better defined lines that are made, presumably by rubbing the corundum on a coarse diamond dust studded surface in three precise directions, give a sharper star than that produced by the metal-plated scratches on glass. The soldered sandwich is probably slightly more durable under extreme conditions than the glass-backed stones, but the testing conditions are not likely to be encountered by either of the stars under normal wear and handling.

The new stars have considerable merit because of their beauty and their durability. One can also confidently predict a poor future, for their manufacture is too easy. Glass imitations which have had poor acceptance till now would soon ruin the appeal of the star-stones and cat's eyes once a good demand had been created by the more attractive synthetics.

I am indebted to the Wm. V. Schmidt Company and the International Gem Corporation for their co-operation in providing samples of the assembled synthetic sapphire-ruby-spinel stars for the illustrations and tests.

THE JAPANESE CULTURED PEARL INDUSTRY

By JUDITH BANISTER

FORTY years ago, the London gem market was startled and alarmed by the appearance of " pearls " from " a new fishery in Japan ". At first, it seemed feasible enough, for the pearl-bearing *pinctada martensi* is a native of southern Japanese waters, and in the north island, Hokkaido, the *unio margaritifera* still produces freshwater pearls. But it was quickly discovered that these new " pearls " were the result of man's interference with the abnormal ability of the oyster to produce nacreous substances. Mikimoto's persistent experiments to cultivate pearls had borne fruit. To-day, almost all the world's cultured pearls come from Japan, about 80 per cent of them from Ise Bay, in the Mie Prefecture, where Mikimoto lived and first produced his man-assisted pearls.

The history of cultured pearls, as most things Japanese, starts in China. There, it is said, the ancients used to insert small objects into living mussels so that they might be coated with the shimmering nacre. But it took centuries for the idea to cross the China Seas, and only at the end of the last century were the shellfish-abundant waters of Ago Bay exploited by men of Mikimoto's enquiring genius in order to copy the ancient Chinese skills. As long ago as 1893, Kokichi Mikimoto achieved the reasonably successful culture of semi-spherical pearls, but his new round ones in 1921 were an advance indeed. His " whole-wrapping method " entailed the destruction of one oyster, by removal of the nacre-producing mantle, so that another might be " injected " with a bead wrapped within this tissue and tied with fine silk. For this Mikimoto has generally, and justly, been acclaimed the father of the cultured pearl. But others were also at work, and at the National Institute for Pearl Research at Kashikojima, due credit is given to a gallery of gentlemen whose pioneer work helped to build up Japan's now vast cultured pearl industry.

Second to Mikimoto was his son-in-law, Tokichi Nishikawa, also known as " the cultured pearl man ". He, with his two assistants, Tsuguyo Fujita and Masaya Fujita, developed the " piece insertion method " that has revolutionized cultured pearl production. Others studied the best materials for the composition of the bead nucleus. In 1907, experiments were made with lead nuclei.

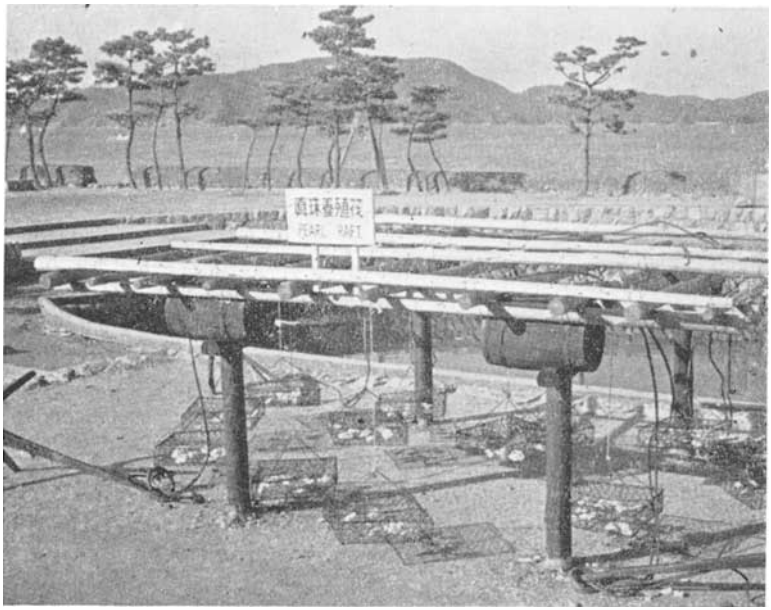

Section of one of the rafts, exhibited for tourists.

From 1907 to 1909 Tatsuhei Mise was using silver particles for insertion, and, indeed, is said to have produced round cultured pearls at the same time as Mikimoto. Nishikawa also used silver pellets, and other experiments were made with stone, marble and glass. But it was Kikutaro Konishi who established the use of Gamanose, clam shell from the Yangtse river, which, until China's doors were closed to trade, provided the best nucleus for the beads. To-day, Pig's Toe Shell from mussels in the Mississipi is used, and cut and ground into spheres in special rotating cast-iron discs. As the years went on, the size of the nucleus or nuclei inserted has been generally increased. About 1913, very tiny beads were used. To-day, large pearl oysters (*pinctada margaritifera*), inhabiting the warm southern waters off Australia, can take beads even up to 60 mm in diameter, though in Japan the *pinctada martensi* cannot really accommodate a bead larger than 12 mm.

Japanese pearl cultivation has become a highly skilled laboratory process. Dental instruments for the operational work were suggested many years ago by Mikimoto's dentist friend, Otokichi

Kuwabara, and certainly look more workmanlike than some of the earlier tools used. But there are still picturesque features at the pearl farms, most of which are situated in the wooded inlets of Ago Bay. The ama, or diving women, wearing long-sleeved white bathing dresses, still collect oysters from the rocks, remaining seemingly endless minutes beneath the surface. But there are fewer than there used to be, as most oysters used in pearl cultivation are raised from spat. The long serried rows of rafts which carry the cages of oysters give a strange Klee-like pattern to the waters of the Bay, their flatness relieved here and there by the little roofed pavilions where the cages are sorted out of the sun. But for the rest, pearl farming is a business, organized and tabulated, with profits and losses gauged by oyster mortality or health, by natural

Lifting oyster cages for cleaning.

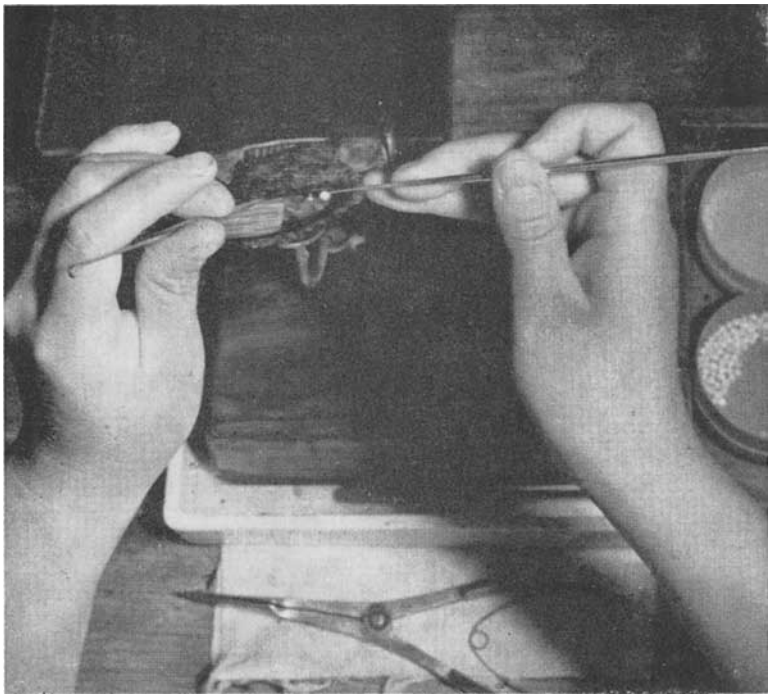

Insertion of mother-of-pearl bead.

enemies and by the luck of successful production of nacre within the host oyster.

Some idea of the size of the industry to-day can be gauged from the fact that one good operator can insert between 200 and 300 beads in her eight-hour day, and that on one farm alone approximately 50 million oysters are reared, so that some 20 million can be operated on every year.

The " piece insertion method " attributed to Nishikawa and the Fujita brothers has revolutionized cultured pearl production. Instead of destroying one oyster to operate on another, the mantle of a single oyster is cut into several dozen sections. The tissue is gently scraped—it will live for several hours in favourable conditions —and is cut into tiny rectangular slivers. The oysters on which the operations are to be made are kept in salt water. The operation is a quick and skilled one : the oyster is lifted out of the water, and a

wooden peg slipped in to keep the valves apart. A slender tool, like a gingevectomy knife, is used to make a tiny slit within the epithelium sac of the living oyster, a sliver of the grafting tissue inserted, and then a bead placed in exactly the same slit. Four or five small beads may be placed within a single oyster of about three years old. Another advantage of this piece method is that large beads can be inserted, whereas with Mikimoto's wrapped method the slit to be made would have been so large that the oyster would inevitably die.

The raising of oysters from spat helps to ensure a constant supply of healthy young oysters for the pearl operators. It is most important that the oysters should be healthy and strong, and though small nuclei can be successfully inserted when the oyster is only a year old, it is better to wait another year, and even better if the pearl cultivator can afford to wait until the oyster is three years old before the bead is inserted. The pearl oyster usually lives about 10 years but its pearl-bearing life is over by the time it is seven years old. In a good-sized oyster, as many as five or six small nuclei can be inserted, or two of 4 mm in diameter. A large nucleus does tend to weaken the host, and losses of oysters carrying large beads are legion. Careful study of the oyster has helped to cut the death rate, however. It was found that the Japanese pearl oyster hibernated during the four coldest months of the year and was therefore very weak during the immediate period afterwards, producing nacre of very poor quality then, even if it survived at all. So large nucleus insertions are now made in July and August, so that the oyster becomes accustomed to the bead within its mantle for 40 or 50 days before the winter sets in. So simple (though skilled) an operation has the insertion of small beads become that these can be inserted at any time of the year, with very little loss of life, providing always that the oyster is in a healthy condition and that health is maintained for the rest of its life. Health also, claim the Japanese, helps to promote a good layer of nacre on the beads. This layer is said to be at least 1 mm thick on 3 mm and 4 mm nuclei, and rather more on larger ones. A law of 1957, the Cultured Pearl Enterprise Law, was designed to regulate production and to prohibit the export of inferior quality pearls.

Immense precautions are taken to ensure the health and safety of the oysters. They are housed in wire cages suspended by ropes below the bamboo rafts—sometimes nylon mesh is used, but wire is

generally considered a better protection. Between 30 and 50 oysters are kept in each cage—the fewer the better, as more air and food can penetrate. The oysters are never artificially fed, but rely on the plankton that is carried by the tide. It is thought, however, that the oyster's food may affect the colour of the nacre, and experiments are being made to probe this theory. It has been found that suspension of the cages at various heights is better than placing them on the seabed, and careful readings are taken to ensure that the cages are suspended at the height most beneficial to the oyster. When the waters are too warm in summer, the cages are lowered ; in winter they may be raised or moved to more sheltered parts of the Bay, and again, during the rainy season, they must be moved to saltier depths as too much fresh water will suffocate the oysters. In emergencies, the ropes holding the cages must be cut, and then the ama will dive down later to retrieve them. The oysters are also regularly inspected to see that they have not been subject to disease, and they are scraped of marine growths, shells and other parasites

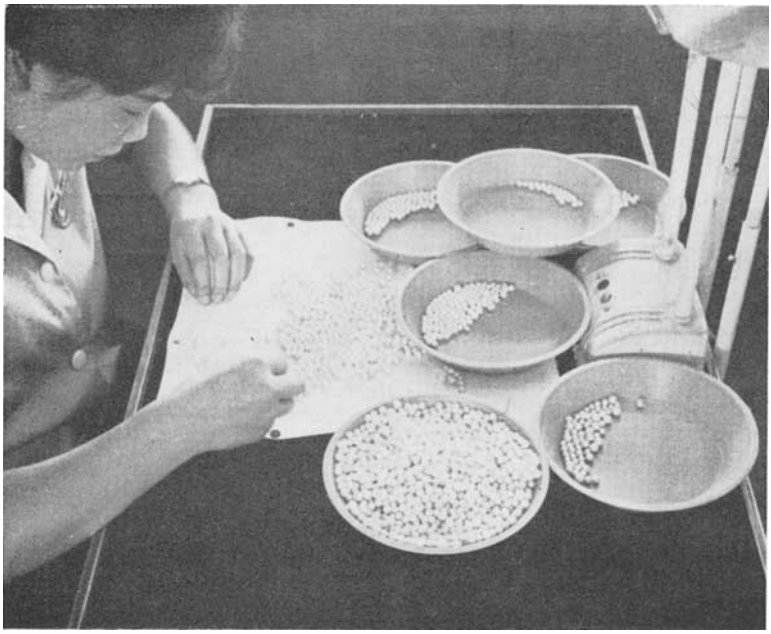

First sorting of cultured pearls.

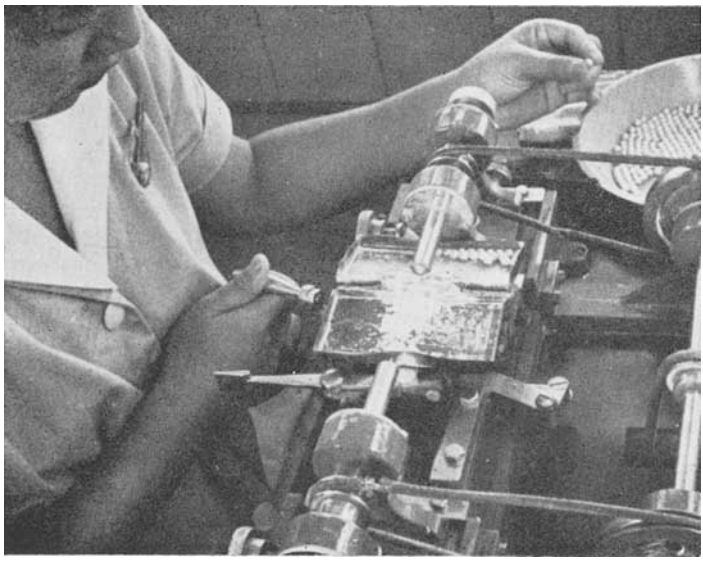

Drilling of cultured pearls.

about five times a year. Another precaution taken against wasted work is the X-raying of oysters every year ; by using weak X-rays it can quickly be detected whether the oyster has ejected the bead nucleus—a large percentage of larger beads are spat out by the oyster within the first year.

Besides watching for water and temperature changes, constant guard must be kept against the depredations of the oyster's enemies. Marauding fish that attack the oysters include the octopus and the starfish, both of which choke the oyster and then eat it. The sea-eel, globefish and the black snapper all prise open the shell as the oyster breathes and then eat the flesh, and barnacles, the hiro worm and other smaller oysters tend to batten on the shell and cause the oyster to suffer from malnutrition. Day and night watch is also kept on the rafts against human thieves, and to give ample warning of natural disasters.

The terror of the *akashio*, or red tide, that comes several times a year to the southern coasts of Japan is much less of a danger than

once it was, for early warning is usually given and the pearl cultivators have time to move the precious rafts and to scatter lime to eliminate the red tide. Hazards of wind and water are more difficult to contend with, and the typhoons that in summer sweep across the China Seas from the equatorial regions present an annual threat. The severe typhoon two years ago destroyed over a million oysters in Ago Bay and caused thousands of pounds worth of damage to the rafts and farm installations.

I was staying in Kashikojima on Ago Bay last May when the tidal wave set off by the Chilean earthquakes hit Japan. The waters surged into the Bay and receded, an almost silent dawn destruction that seemingly peaceful 23rd May. Raft was swept against raft, a tangle of bamboo spars, floats and cages. Pavilions were swept down, motor boats piled on the shore. At first the farmers feared that they had lost about a third of their oysters, but though damage was estimated at about 100 million Yen (£100,000), a large majority of the oysters were recovered by the diving girls.

But despite every precaution, there is at least a 10 per cent mortality of oysters every year, whether from disease, age or disaster. In addition, of course, there are large losses when the oysters are opened. A considerable number of cultured pearls are of qualities inferior to those laid down by Japanese law, and must be destroyed. However healthy the oyster, the pearl cultivator has no guarantee that the coating of nacre will be even, of good thickness or of an acceptable colour, and continued demand for large cultured pearls, especially from United States markets, means a higher death rate and a lower percentage of good cultured pearls.

Up to 5 mm in size, losses are less extensive, and about 15 to 20 per cent of oysters produce good quality cultured pearls of A grade. However, increase the size to 7 mm, and the yield will only be between 5 and 10 per cent, to 8 mm, and the yield is between 2 and 3 per cent, and to 10 mm, and it will be less than 1 per cent.

The first grading of the pearls is to separate gem quality from pebble. Badly shaped and lustreless pearls are rejected, to be used for throwing back into the seat at ceremonies, or to be skinned and the nucleus re-used for insertion. From the small percentage of good quality pearls recovered, there must be further grading according to colour and size. Some baroque shapes are accepted—

baroque cultured pearls are usually due to the nucleus having remained in the oyster too long. Occasionally, of course, natural pearls are also found in the shells, but on the whole the Japanese do not bother to distinguish between them. The operator can, of course, detect them when the shell is opened, because the natural pearl will lie along the outer membrane, and not within the mantle where it has been found the oyster will best produce the nacre to coat the inserted bead. Recent developments have also been made in Japan in the culture of pearls in freshwater mussels in Lake Biwa, near the old capital of Kyoto.

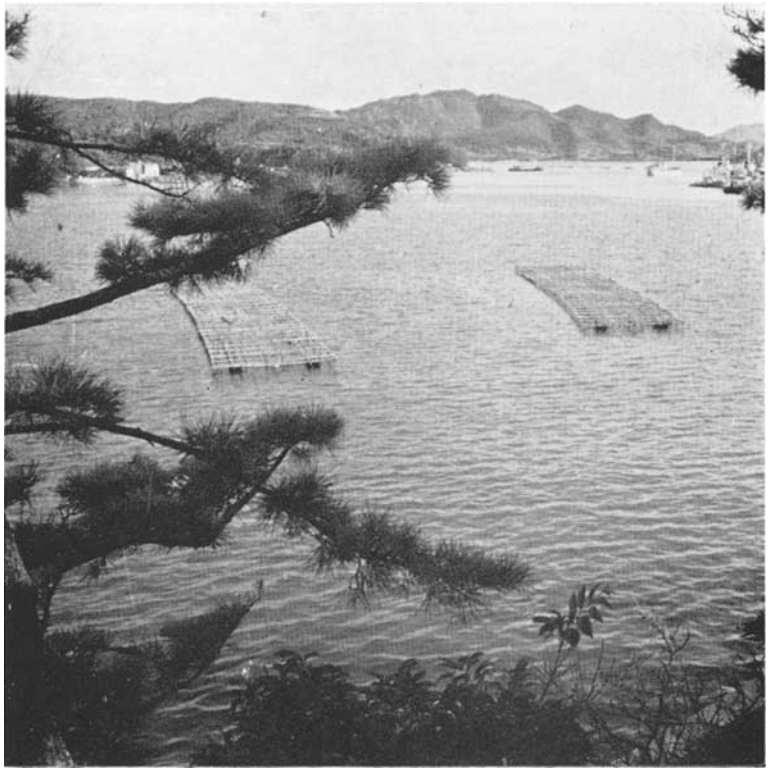

Pearl rafts in Ago Bay.

Gemmological Notes

ELUSIVE CHROMIUM

A. E. FARN

The abundance of minerals—metalliferous and gemmological—ensure that we have plenty of solid gold and real gemstone jewellery (although not all will stand up to etymological exactitude).

Nature, in scattering the earth prolifically with silica, corundum, carbon and beryl has been slightly less liberal in dosing her gems with chromic oxide—it makes such a difference ! It's like forgetting to put the salt in the potatoes—they are edible but do not whet the apetite.

The chromium content of the important gemstones is very critical indeed and it is necessary for optimum quality of colour and hue that it should be not too little, and not too much. Pale pink sapphires and pale emeralds obviously suffer from chromium starvation, whereas too dark and saturated green emeralds and almandine-red rubies have too much. These latter are often termed Siam stones when in fact they are chrome-rich Burma stones. On the other hand it is very difficult to take over from nature the dietary deficiencies of these important gemstones—even in their synthetic counterparts. Witness the all too familiar shocking raspberry-red of the synthetic ruby and the strong blue-green of the Chatham synthetic emerald, both cases of excess chromic oxide. In the case of the synthetic Verneuil ruby it is often the random cutting of the stone which causes it to " look " wrong, but it is a fact that it has a far stronger fluorescence under the ultra-violet lamp or X-ray set and a visible persistent phosphorescence sometimes easily seen to last a few minutes—all characteristic of an excess of chromium.

Even the correct or optimum amount of chromium in these important stones does not necessarily ensure that they will exhibit the ideal colour, because the presence of too much iron in the chemical composition of the stone has a quenching effect upon chromium and this causes the less commercially attractive colour of Siam rubies and *pro rata* affects the price per carat accordingly.

The most striking example of the importance of the balance of colour, sensitively displayed in a chromium-coloured gemstone, is that of a well cut Alexandrite. Here the price per carat rockets astronomically (not surprising in a Russian stone).

The reaction and excitement caused to even biased people such as Hatton Garden dealers in London are quite remarkable when the magic word alexandrite is mentioned. Although green chrysoberyl is a very pleasant stone and perhaps a little rare in occurrence of any sizeable pieces, it does not command prices per carat in any way comparable to its brother who was fortunate enough to inherit a trace of chromium.

Thus the small green stone becomes fabulous and sought after because it exhibits a colour-change effect when taken from daylight to artificial light and is the rarest of precious stones carat for carat of quality.

There are of course many brown-hued chrysoberyls which do in fact show some difference in tone of colour when taken from one light source to another—but it is the green/red colour change which is truly alexandrite. A true alexandrite must be therefore a stone which is green in daylight and a tone or hue of brown-red or pink-red in artificial light. It has chromium in its chemical composition, which can be seen clearly in the absorption spectrum when viewed by a spectroscope. This seems a hair-splitting test and a stone exhibiting a colour change from pale green or dark green to a hint of pink hue or deeper muddy colour can prove to have chromium in its physical make-up and must therefore be termed alexandrite. The limiting factor of its poor appearance and barely discerned colour change will be portrayed adequately in its price per carat, a most sensitive factor which has a very sobering effect on gemmological enthusiasm. Even so, the latter specimen still commands a price out of all contrast to its normal green type.

Fairly recently I had a parcel of alleged green chrysoberyls literally, metaphorically and almost physically thrust upon me—not by some philanthropic gemmophobe, but by a dealer, who, not desirous of my further education or commercial progress, was interested in the settlement of some previous transaction in which I was theoretically making a profit.

However, it is part of an education especially when transactions affect the pocket, so, in search of some good basic reason for a

come-back, I decided to examine and test the parcel. On sorting, I found that several (including the largest) were paste, some were peridot and one a peculiar hue of brown-green quartz—a very flat shallow oval stone. The remainder, by far and away the smallest stones, were green chrysoberyls. Later, when placed between crossed filters, one glowed a cheerful cherry-red and when checked by spectroscope gave a faint but distinct chromium spectrum and thus achieved a distinction in gemmology by qualifying for the term alexandrite, albeit a very wan specimen. Now, of course, the stone became reasonably interesting and although not destined for the highest American market will, it is hoped, fill a long felt want in someone's gemmological drawers.

UNUSUAL STRUCTURES IN A "PEARL" R. WEBSTER

A brownish non-nacreous spherical object recently examined was said to have been removed from a shell—from its description maybe one of the *Avicula*—which was fished in Greek waters.

The object, which presumably could be called a pearl, was calcareous and had a density of 2·53. When examined microscopically, using a very strong transmitted light, the colour was golden brown and a most intriguing internal structure was revealed. This structure was in the form of radiating prisms showing different shades of brown and the terminations were attractively marked with scales or striations. The monochrome picture fails to do justice to the beautiful view seen through the microscope.

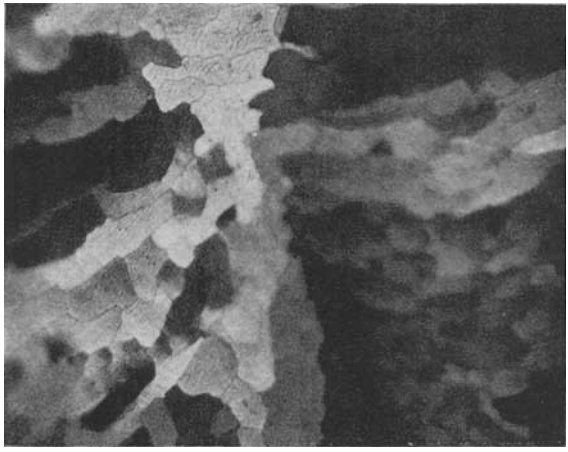

Gemmological Abstracts

ESPIG (H.). *Die Synthese des Smaragds.* The synthesis of emerald. Chem. Techn., Vol. 12, No. 6, June 1960, pp. 327-331.

Single crystals of synthetic emerald (Igmerald) which were suitable for cutting, were first made 30 years ago by I. G. Farben, Bitterfeld. The process was kept secret. This left room for the assumption that a hydrothermal method was used, especially as microscopical inclusions seemed to point in this direction.

Production has ceased since 1942 and the reasons for secrecy have disappeared. H. Espig has now disclosed an interesting mineral synthesis, which might lend itself also to other applications.

By melting the components BeO, Al_2O_3 and SiO_2 a glass results, due to the low crystallization speed of emerald. For this reason the use of Verneuil's process was ruled out. Instead the components had to be united by means of a flux. Hautefeuille and Perry found in 1877 that alkaline vanadates, tungstates and molybdates were suitable for the synthesis of silicates. In 1888 they reported a successful synthesis of emerald using lithium molybdate. They used a mixture of BeO, Al_2O_3 and SiO_2, in the ratio indicated by genuine emerald, and heated it with a five-fold amount of lithium molybdate for a fortnight at 800°C (1472°F) in a platinum vessel. A great many emerald crystals were obtained but only up to the size of 1 mm (0·040″).

These experiments were repeated and varied. Many seed crystals and mineralizers were tried. In Bitterfeld work had been carried out since 1911; the experiments of the author himself, which started in 1924, aimed at crystallizing emeralds from oversaturated solutions.

The first success was obtained when it was recognized that the process was not just a simple crystallization but a chemical reaction depending on the fact that emerald was formed in lithium molybdate and was less readily soluble than its components. Temperature and concentration were critical conditions. When these were given, the three components BeO, Al_2O_3 and SiO_2 crystallized from the solution. However, when the three components were evenly distributed, an oversaturated solution resulted and a great many

small crystals were obtained. The oversaturation, therefore, had to be reduced to a minimum by separating the components in the melt. To achieve this, BeO, Al_2O_3 were placed on the bottom of the platinum vessel. Next came the flux and on top of this a disc of molten quartz. The densities are such that the quartz floats on the melt, BeO and Al_2O_3 remaining on the bottom. Through diffusion and currents the oxides and their reaction products with the molybdate reached the zone near the quartz disc where SiO_2 dissolved in the melt. Crystallization began in a comparatively narrow zone as soon as the saturation point for emerald was surpassed. The emeralds grew in nice single crystals on the quartz disc. This arrangement allowed for the gradual joining of the components necessary when crystal material is grown which is not readily soluble. After having established the method in principle, optimum conditions with regard to raw material, temperature, concentration, influence of other substances and arrangement of apparatus had to be found in numerous tests. Growth of the emerald crystals on a quartz disc led to inclusions and fracture on separation. Therefore a platinum wire mesh was placed horizontally underneath the quartz disc. The seed crystals were floated under the platinum wire mesh. A vertical platinum cylinder in the centre allowed for feeding in the components BeO and Al_2O_3. All the quartz for a growth period of two to four weeks was added in one amount, the oxides BeO and Al_2O_3 in small portions every two days. Crystals of up to 1 cm size resulted, but they grew through the wire mesh. When the mesh was replaced by a holed platinum sheet (2mm holes), the emerald crystals were not attached any more. With sufficient supply of the oxides, emeralds with sharp edges and glossy prism faces and bases resulted. When the melt became deficient in oxides the emerald crystals began resolving. Pyramidal faces resulted, the edges became rounded and the surface matted with etch marks. Over-rapid growth led to needle structure at the base. Emerald formation started at 640 to 750°C. At 770 to 800°C the seed crystals grew best, at 800 to 850°C new crystals appeared and at 900°C emerald formation came to a halt, existing emerald crystals were resorbed and other crystals formed. These are listed by the author. Also listed are several of the mixtures of the initial melts. The finally established figures were (1) a minimum of 6·55% emerald ($BeO + Al_2O_3$) had to be contained in the melt to saturate it; (2) an additional feed of 0·25%, representing very

slight oversaturation, was required. Practical details were as follows:

A platinum vessel of about 7″ diameter and 3½″ in height was used; in it was suspended a horizontal circular holed platinum sheet to which the vertical feed tube was permanently attached. The distance of the circular disc from the bottom of the vessel was about 2″ (55-60mm). On the bottom of the vessel was placed the BeO–Al_2O_3 mixture in the theoretically indicated ratio, altogether 80 grammes including a few grammes of lithium chromate as colouring agent. Over this was the melt consisting of acidic lithium molybdate, which had been prepared by melting MoO_3 together with lithium carbonate and by pulverizing the cooled melt. The platinum vessel contained 2·8 kg of the melt. On top of the melt were placed 80 grammes of emerald seed crystals, which had been obtained in previous test runs. Next came the holed platinum disc and on top of that 250 grammes of quartz fragments from 8 to 10 mm thickness. The vessel was placed in an electric furnace, which had been heated to 800°C and this was kept at that temperature (+10°C) during the whole growth period of 20 days. Every two days $BeO + Al_2O_3$ was fed in through the platinum cylinder. This resulted in a weight increase of 20% of the seed crystals during the 20 days period. An improvement was achieved by using prismatic seed crystals. These were obtained by sawing off pyramidal ends with a diamond saw. Eventually 12 furnaces were in operation and single crystals of 2 cm (over ¾″) length were grown during a period of one year. Chromium oxide as colouring agents resulted in a bluish-green colour and other additions had to be found to produce the desired grass-green colour. The production in Bitterfeld came to an end in 1942. According to W. F. Eppler the inclusions in Chatham synthetic emeralds resemble those in Igmerald to such an extent that in all probability the production methods can be assumed to be similar.

The described method of synthesis was not entirely restricted to emerald. Other minerals—especially silicates—were produced, namely phenakite, willemite, zircon, garnet, titanite and rutile. 11 illus., 2 tables. W.S.

GROSS (H.). *Suesswasserperlen.* Fresh water pearls. Deutsche Goldschmiede-zeitung, Vol. 58, No. 5, 1960, pp. 260-261.

Short article describing fresh water pearls, especially those found in central Europe, i.e. Germany, Bohemia and Austria.

These pearls take 20 to 25 years to grow to a diameter of 4 mm and perhaps 40-50 years to grow to 6-7 mm. A photograph shows a pearl of 5·76 mm with 39 rings, i.e. of an age of about 39 years. With the increase of impurities in rivers the fresh water pearls also decrease. X-ray radiography and diffraction pattern show the difference between salt- and fresh-water pearls.

E.S.

HOHENESTER (G. W.). *Bernstein.* Amber. Deutsche Goldschmiede-zeitung, Vol. 58, No. 7, 1960, p. 371.

Five photographs showing insect inclusions in amber. There is a growing difficulty in finding amber with insect inclusions as most of the raw material comes from E. Germany. Only pieces free of insect inclusions seem to be exported.

E.S.

EPPLER (W. F.). *Wachstumserscheinungen am Aquamarin.* Growth phenomena in aquamarine. Deutsche Goldschmiede-zeitung, Vol. 58, No. 5, 1960, pp. 258-259.

Usually growth phenomena are shown by the external habit of a crystal. The internal growth phenomena are more difficult to observe. This article deals with the internal signs of growth phenomena in Brazilian aquamarine. There are often irregular lines in the stones, which look like swirl marks ; these lines were caused by periodic and irregular variations in the mother-solution. It could be seen that the aquamarine had grown from a small crystal via various intermediary stages to the final stone. Photographs illustrate various intermediary stages, i.e. intermediary crystals within the final aquamarine.

E.S.

EPPLER (W. F.) *Aetzroehren im Aquamarin.* Etch tubes in aquamarine. Deutsche Goldschmiede-zeitung, Vol. 58, No. 7, 1960, pp. 368-370.

Among the various inclusions in aquamarines, long thin tubes or channels are the most frequent. They are filled with either a liquid, a gas or with both. These tubes are always orientated in the same direction, parallel to the c-axis. It is probable that these tubes were produced by etching. The tubes can be of various thicknesses. Apart from the long, thin tubes, there are some shorter

tubes, also parallel to the c-axis. Their contents are usually one or more doubly refractive crystals, a liquid and a gas, i.e. they are typical three-phase inclusions. Sometimes resorption phenomena can be observed on these growth tubes.

E.S.

HEGEL (C.). *Einschluesse von Diamant in Diamant.* Inclusion of diamond in diamond. Zeitschr. d. deutsch. Gesell. f. Edelsteinkunde, 1960, No. 32, p. 23.

Photomicrograph of diamond octahedron in small brilliant.

E.S.

PICHL (M.). *Edelsteine in der Goldschmiedewerkstatt.* Gems in the workroom of a goldsmith. Zeitschr. d. deutsch. Gesell. f. Edelsteinkunde, 1960, No. 32, pp. 21-23.

Includes table of 46 gems and how they could be affected mechanically, chemically and by heat.

E.S.

SCHLOSSMACHER (K.). *Die Entstehung der Achate.* The formation of agates. Zeitschr. d. deutsch. Gesell. f. Edelsteinkunde, 1960, No. 32, pp. 16-20.

A new theory has been put forward by the Carnegie Institute in Washington. This suggests that magma from which stones solidify can in its liquid form house two types of melts at the same time. These two types do not mix, but one swims in droplet form in the other type, one being acid, the other alkaline. The basis put forward is that the lava from the eruption of a volcano is not homogeneous, but that these alkaline melts included drops of acid melt, forming a kind of suspension.

E.S.

MIRTSCHING (A.). *Die Diamantlagerstätten Ostsibiriens.* Diamond occurrences in east Siberia. Zietschr. d. deutsch. Gesell. Edelsteinkunde, 1960, No. 32, pp. 11-16.

The north-west part of the Republic of Jakutia in East Siberia seems to be one of the parts of the earth richest in diamonds. A map of the district is shown, with photographs of the general landscape and two of the stones produced.

E.S.

BENSON (L. B.). *Testing black pearls.* Gems and Gemology, No. 2, Vol. X, pp. 53-58. Summer 1960.

Two basic types of treatment are mentioned, surface and centre treatment. Some cultured pearls have their nuclei treated before insertion in the mollusc. Silver nitrate at one time extensively used and X-radiography may detect. Most natural black pearls fluoresce reddish to rays of approximately 4000Å—usually by the " crossed filter " technique. Dyed pearls do not fluoresce, but care must be taken as centre dyed pearls may fluoresce from the normal glow of the whitish nacreous outer layers. Coated pearls may be detected by using a small swab moistened with a 2% hydrochloric acid solution, which on being rubbed over the surface of a coated pearl will show on the cotton wool a slight brownish coloration. This test will also detect pink and bronze dyed pearls. Fluorescence experiments were carried out by using a 100-watt mercury spot lamp.

1 illus. R.W.

CROWINGSHIELD (G. R.). *Development and highlights at the Gem Trade Laboratory in New York.* Gems and Gemology, No. 2, Vol. X, pp. 59-63. Summer 1960.

Comments are made on some American misleading advertisements using the names " Diamond-ite ", " Trulite ", " Brillight " and " Vespa gem " for synthetic white sapphire, and giving incorrect hardness values for this material. Synthetic emeralds are reported which have inclusions of platinum and the author points out the danger that these metallic inclusions can influence the density. A number of unusual specimens tested in the New York laboratory are mentioned and these include a citrine-coloured soudé-type stone. The absorption spectrum of a brownish willemite is mentioned.

3 illus. R.W.

BENSON (L. B.). *Developments and highlights at the Gem Trade Laboratory in Los Angeles.* Gems and Gemology, No. 2, Vol. X, pp. 45-52. Summer 1960.

Three diamonds showing a bluish adularescent effect, said to be due to a combination of minute inclusions, and the fluorescence are reported. A diamond is mentioned which had an elongated internal fissure, upon the surfaces of which crystal growth marks could be seen. It is suggested that these marks indicated that the fissure is an

elongated negative crystal. Reference is made to a string of purple beads sold as " purple jade ", which proved to be dyed aventurine quartz. Other stones examined were a chatoyant golden-brown kornerupine and a blackish-green gahnite having a density of 4·50 and a refractive index of 1·79. A pearl-like formation of orange-brown colour, which was represented as a black pearl, showed that light was readily transmitted parallel to the prismatic crystals but was opaque at right angles to that direction. The object was thought to have been fashioned from a section of a large shell. There is a report of turquoise beads imported from Japan which had been treated with paraffin or other wax. The method is said not to be permanent. Another strand of turquoise beads (S.G. approx. 2·71) was too dense to be impregnated with wax, and a process involving etching the beads in presumably hydrofluoric acid had been used to impart myriad pits on the surface. The beads are then coated with blue-coloured epoxy resin. References are made to the new modified polaroid jewellers' camera, and to the Custers audio-electric-conduction apparatus and to the meter type devised by the Gemological Institute of America.
11 illus. R.W.

HOWE (E. L.). *North America's only diamond field.* Australian Gemmologist, No. 1, Vol. 3, pp. 16-17. July 1960.

A short article on the diamond field at Murfreesboro which was first found in 1906. It is now open to tourists.
1 illus. R.W.

ANDERSON (B. W.). *Gem testing by non-destructive testing methods.* Non-Destructive Testing, No. 2, Vol. 2, pp. 3-8. August 1960.

A general description is given of the methods of testing gem-stones and pearls. Gems are precious and any testing must be non-destructive. The use of the jeweller's refractometer is explained and also the method of refractive index estimation using immersion fluids (immersion contrast methods). The absorption and fluorescence spectra methods of gem testing are discussed. The use of the microscope in the detection of synthetic stones is explained. The article concludes with notes on density methods and the use of X-rays in the testing of stones and pearls.
11 illus. R.W.

SCHLOSSMACHER (K.). *Modern diamond grading.* Diamant, No. 23, July 1960. (Reprinted in Gemmologist, November 1960).

The grading of diamonds by colour is discussed and an International Colour Classification appended. It is pointed out that some names occasionally used by dealers are not mentioned. Some notion of percentage prices from Top Wesselton is given. Purity from inclusions and some of the typical inclusions seen in diamond are mentioned. An International scale of cleanness grading with some remarks on accuracy of cutting as a price factor are given.

R.W.

POUGH (F. H.). *The Spanish topaz mines.* Gemmologist, No. 351, Vol. XXIX, pp. 183-186. October 1960.

The Margarita mine near Vilas Buenas in north-western Spain was discovered about 100 years ago. This is the source of all the brownish-yellow quartz erroneously known as " Spanish topaz ". Some comments on the reason for this misnomer are given. The mine, which supplies rock crystal as well as citrine, is again being worked to some extent.

3 illus. R.W.

RAMSAY (A. M.). *Scottish gem localities.* Lapidary Journal, No. 4, Vol. 13. October 1959. (Reprinted in Gemmologist, November 1960).

An account of the gem minerals which have been found in Scotland. It is disputed whether diamond has ever been found in Scotland, despite the reports of finding isolated diamonds in Sutherlandshire. Pearls from Scotch rivers are mentioned and the sapphire from the island of Mull. Beryl, topaz, garnet and zircon are found in a number of counties but not necessarily of gem quality. Prehnite is recovered from Boylestone quarry, Barrhead, Renfrew and has been cut into cabochons. Thomsonite is found at the same locality. The chief gem minerals found in Scotland are those of the silica group. Rock crystal is common and there is much brown quartz (cairngorm). Amethyst is recovered from a number of localities. Agates are common and the places where they may be found are given. Jaspers, aventurines and bloodstones are also found in Scotland.

1 map. R.W.

CHALMERS (R. O.). *Kalgoorlie—El Dorado of the west.* Australian Gemmologist, No. 1, Vol. 3, pp. 5-9. July 1960. (Reprinted from the Australian Museum Magazine).

The story of the Kalgoorlie goldfield of Western Australia. The geology of the goldfield is discussed and the production figures given.

2 illus. R.W.

WIRTH (A. A.). *The noble opal of Australia.* Australian Gemmologist, No. 1, Vol. 3, pp. 6-7. July 1960.

A general article on what constitutes a fine quality opal.

R.W.

WEBSTER (R.). *Testing for electro-conductivity.* Gemmologist, No. 350, Vol. XXIX, pp. 161-169. September 1960.

Reports the results of experiments carried out on various types of detecting apparatus for the electro-conductivity of gem materials. A simple circuit consists of a source of current, two electrodes for the specimen to be tested and a detecting device. Various types and voltages of current were tried and the efficiency of meters, neon lamps and telephones was examined. A neon lamp screwdrived circuit tester was found to be very efficient. The results on a number of tests on gem materials are mentioned. Natural blue diamonds, but not irradiated blue diamonds, were found to be conductive. Other gem materials which experiment showed would conduct electricity were hematite, much chalcedony (but not jasper), pyrites, marcasite, pseudophite, synthetic blue rutile, verdite, some serpentine and most turquoise.

6 illus. P.B.

FRANCO (R. R.). *Pequeno glossario gemologico.* Gem glossary.

A glossary of 180 gem minerals in Portuguese.

S.P.

BYKERSMA (R.). *A trip to Rubyvale.* Australian Gemmologist, Vol. 3, p. 2, 1960.

A short account of a visit to the Anakie sapphire field, Queensland, Australia. S.P.

CAMPOS (J. E. de S.). *Safiras do Rio Coxim, Matto Grosso.* Gemmologia, 1960, No. 21, pp. 1-8.

An account of the sapphire crystals found in the Rio Coxim area of the Matto Grosso.

S.P.

RAO (A. B.) and SOUSA (M. S.). *Gahnita do nordeste e variedades de espinelio.* Gemmologia, 1960, No. 21, pp. 9-18.

This paper deals with the general classification of the spinel group. Chemical composition, physical and optical properties and X-ray data are enumerated, and occurrences in general, and localities in Brazil are cited.

Special reference is made to spinels occurring in Borborema pegmatites, where the presence of possible gahnite-hercynite spinels is noted. Theur properties are detailed, and X-ray powder patterns and spectrochemical data are given. Paragenetically they are in association with cassiterite deposits. These spinels are sporadic in occurrence and lack transparency.

S.P.

MCKAY (H. C.). *Elementary optics for the lapidary.* Lapidary Journal, 1960, Vol. XIV. No. 5.

A well-illustrated article which considers problems of reflection and refraction encountered by the lapidary.

S.P.

ASSOCIATION NOTICES

PRESENTATION OF AWARDS

There was an international flavour about the presentation of awards held in the Livery Hall of the Goldsmiths' Company on 15th November 1960. Not only had Dr. Edward Gübelin come from Lucerne to present the prizes, but also members from Germany and Ceylon. Altogether two hundred members and friends were present. Later in the evening they had Ceylon brought to them in " glorious colour " through the film made by Dr. Gübelin of the gem industry of the island.

Mr. Norman Harper, the Vice-Chairman, described the occasion as the crown of the year, yet marking only the beginning of the gemmologist's career. This was emphasized by the fact that during the evening they would also be presenting Research Diplomas for the first time.

Dr. Gübelin in presenting the prizes and diplomas also said that this was the evening to which many had been looking forward for two years. Their knowledge was wide. As gemmologists they were also acquainted with mineralogy and other aspects of the science of nature. The jeweller who was also a gemmologist had a most useful hobby. Yet gemmology was also an art. The splendour of gem stones and the pleasure that could be derived from their colours and vivid brilliance could enrich our lives. Some of them would want to know more about gem stones. Others would use their knowledge to help them in their careers. They all had a new talent of which they should make good use.

Mr. B. W. Anderson proposed a vote of thanks to Dr. Gübelin, which was enthusiastically given.

Mr. Harper, also thanking Dr. Gübelin, said he was glad that they could do this by giving him something in return, namely one of the Research Diplomas for his work on inclusions. His name would always be associated with this aspect of the subject and he led the world in this study, though he covered a much greater field.

There was to-day an even greater need for gemmologists. They had to keep the trade and true gem stones in the exalted position which they had occupied through the centuries.

Mr. Harper then presented the following research diplomas :—

1945 August — M. D. S. Lewis, B.Sc.
Some surface properties of gemstones.

1946 October — Robert Webster
An investigation into the properties of ivory : the materials used in its simulation, and the methods whereby they may be severally distinguished.

1953 August — G. Frank Leechman
The origin of the colours in precious opal.

1957 June — EDWARD GÜBELIN, Ph.D.

A contribution to the genealogy of gemstone inclusions.

1959 JUNE — LEONARD C. TRUMPER, B.Sc.

The measurement of refractive index by reflection.

Before the presentation there was a reunion of just over 100 members held in the Exhibition Room of Goldsmiths' Hall.

Dr. Gübelin's fascinating film about gem mining in Ceylon opened with a dinner party, at which various questions about gems were asked. Then a pearl drop at the end of an Indian lady's ear-ring faded into the island of Ceylon. Animated drawings showed the formation and occurrence of the gem gravels and, after a few scenes of the exotic plant life of the island, the two methods of obtaining stones from the gem gravels were shown. The primitive methods of cutting and polishing the gems and the method of selling the finished stone were most interesting. A cloth is placed over the hands of buyer and seller and by grasping one, two, three or four fingers, and by means of other signs, a bid for the stone is made and acceptance, strangely enough, is indicated by a shake of the head and not a nod. The onlookers to such a transaction receive one rupee each. At the end of the film the various gems which are found in Ceylon were shown, some of the most outstanding being ruby, sapphire, cat's-eyes, zircon and spinel.

Details of the making of a piece of jewellery were shown and at the end the film returns to the dinner party with a further display of articles of jewellery.

This excellent film is most suitable for showing to a lay audience, and it is hoped that the Association will have a version with English dialogue sometime during the year.

MIDLANDS BRANCH

Mr. Robert Webster gave a talk to members of the Midlands Branch on 11th October, 1960. His subject was " Diamonds and some of their problems ", and he dealt with the many problems that are met with in the jewellery trade. The meeting, which was attended by an unusually large audience, was an excellent start to the Midlands Branch winter programme.

On 25th November, Miss Judith Banister gave an illustrated talk about her recent visit to Japan and the cultured pearl fisheries there.

A visit to the Severn Wildfowl Trust at Slimbridge and to adjoining historic Berkeley Castle provided a pleasant ending to the Branch's summer programme. Slides of this outing were shown to members by Mr. Clay and Mr. Deane at the November meeting.

The Midlands Branch Annual Dinner and Dance will be held at the Medical Institute, Edgbaston, on 22nd March, 1961.

WEST OF SCOTLAND BRANCH

The first meeting of the winter season for the West of Scotland Branch was a film show, held on 20th October, 1960, when the films " Diamond Coast " and " Stars that shine forever " were shown to an audience of members and friends.

TALKS BY MEMBERS

WEBSTER, R. : " Diamonds and some of their problems ", Midlands Branch of the Gemmological Association, 11th October, 1960.

BLYTHE, G. A.: " Diamonds and their substitutes ", Inner Wheel Club, 3rd October; Marlborough Conservative Association, Southend-on-Sea, 13th October; Conservative H.Q., Southend, 16th November, and Southend Business Luncheon Club, 17th November, 1960.

BOWDEN, A. : " Gem Stones ", Plympton Townswomen's Guild, 11th October; Pelynt (Cornwall) Women's Institute, 13th October ; Plymouth Y.W.C.A. Luncheon Club, 2nd November ; R.N. Young Wives, H.M.S. *Thunderer* Plymouth, 22nd November, 1960.

CAFFELL, E. W.: " Gemstones ", Guild of St. Andrew and St. John, Cobham, 11th November; Bracknell Townswomen's Guild, Easthampstead Community Centre, Bracknell, Berks., 6th December, 1960.

VISITORS FROM AMERICA

A welcome visitor to the Association's offices in October last was Richard Liddicoat, Jr., Director of the Gemological Institute of America. His visit gave great pleasure and further cemented the friendship that has existed between the two organizations over the years.

Other welcome visitors were Dr. F. H. Pough, of New York, who kindly presented the Association with a new type of synthetic star-stone and Mr. W. E. Kelley, Lakeland, Ohio, who added to the Association's collection by a generous gift of various opal specimens found in the U.S.A.

GIFTS TO THE ASSOCIATION

The Finnish Gemmological Society has presented the Association with a collection of gems and gem minerals, all of which were found in Finland. The specimens were donated by various members of the Society and some were faceted by them. The Council of the Association is greatly indebted to the Finnish Gemmological Society for the presentation.

The Council also acknowledges the following gifts :—

From De Beers Consolidated Mines Limited a new film about diamonds entitled " The Eternal Gem ", a valuable addition to the Association's film collection.

Mr. J. R. Funrbach, B.Sc. has sent a further collection of gem minerals for student use and Mr. A. V. G. Rao, an article on the Panna Diamond Mining Industry.

Samples of Dallasite, a peculiarity of Vancouver Island, Canada, from Mrs. Rhoda Blyth.

From Mr. R. Webster, a large piece of lapis-lazuli.

Mr. W. E. Kelley, of Lakewood, Ohio, specimens of black opal from Humboldt County, Nevada, including a sample in vesicular basalt, various common opal specimens from the same county and specimens of silica glass " cat's-eyes ".

DIAMOND DICTIONARY

The Gemological Institute of America has just published a comprehensive, profusely illustrated dictionary of the diamond industry.

The Diamond Dictionary represents an effort by the teaching and research staff of the Institute to define every important term relating to the gem diamond. Unlike the usual brief definitions of a dictionary, however, most of the terms are given an expanded explanation and discussion, thus ensuring a full understanding of the subject. Important subjects such as grading and evaluation, market controls, fashioning and cutting styles, properties, mines and mining methods, and grading and testing equipment are explained in detail.

One of the many outstanding features of this 317-page book is the careful consideration that has been given to describing more than 250 of the world's large and notable diamonds, many of which are illustrated, a far greater number than have been treated in previous books. In addition, many industrial-diamond terms and foreign words and phrases are defined and discussed. There are numerous photographs and line drawings illustrating diamond imperfections and cutting discrepancies. It is the conviction of the authors that it will fulfil a long-felt need of jewellers and diamond men in all branches of the industry.

The book is priced at $8.75 (65/-) and may be ordered through the Association of Great Britain.

CORRESPONDENCE

DEAR SIR,

Mr. Stores in his " Strange Case of W. J. Lewis Abbott " in the October, 1960, issue of the *Journal of Gemmology*, asks for a few more details about this pioneer of gemmological training. He may be interested to learn that Mr. Abbott was writing regularly for the Watchmaker, Jeweller and Silversmith from 1890 onwards. The issue for 1st December, 1890, contained the following note :

" Mr. W. J. Lewis Abbott, who for some months past has been contributing a series of articles on gems to our paper, has begun a course of lectures on the science of gems at the Horological Institute, on alternate Tuesdays to last through the winter months. . . ." It was added that the hall was full for the first two lectures in November, and that many people " lingered " afterwards to ask questions and to see further demonstrations.

On 1st June, 1891, the name " W. J. Lewis Abbott, F.G.S." appears on the masthead of the W. J. & S. as editor, when he presumably officially took over from Mr. David Glasgow, whose untimely death at the age of 34 was reported in the same issue. Mr. Abbott continued as editor until 1897, and continued writing for the journal even after Mr. Augustus Steward became editor in that year.

Yours faithfully,

JUDITH BANISTER.

The Editor,
The Journal of Gemmology.

COUNCIL MEETING

A meeting of the Council of the Association was held at Saint Dunstan's House on Tuesday, 29th November, 1960. Mr. F. H. Knowles-Brown presided

and specially welcomed Mr. J. M. McWilliam, representing the West of Scotland Branch.

The following elections took place :—

Fellowship

Beach, Michael L., Twickenham
Burwood, James R., Coventry
Chalcroft, Pamela, Edinburgh
Christophersen, Einar E., Sandnes, Norway
Haigh, David E., Lincoln
Hamara, Pauli, Helsinki, Finland
Heikkila, Heikki S., Helsinki, Finland
Jarvis, John Clifford, Calcutta, India
Kaskimies, Keijo L. K., Helsinki-Munkkivuori
Kraus, Pansy D., San Diego, U.S.A.
Lee, Kenneth A., London
Masters, Christopher R., Blackpool
May, Peter G., Coventry
McMillan, Archibald, Edinburgh
McTurk, George L. C., Edinburgh
Mikkola, Toini A., Otaniemi, Finland
Mortimer, Frederick, Loughton
Norman, Michael S. J., Bath
Nyman, Yrjö, Helsinki, Finland
Øiesvold, Arild, Arnes, Norway
Øiesvold, Odd, Jessheim, Norway
Clay, John J., Leicester
Collins, Christine D., Wolverhampton
Cook, Peter B., Birmingham
Coward, David E., Matlock
Gritzkewitzh, Boris, Helsinki, Finland
Orkomies, Lotta, Roihuvuori, Finland
Parker, George E., Birmingham
Paronen, Tauno K., Helsinki, Finland
Pettersson, Ulf J., Helsinki, Finland
Ranta, Olavi A., Helsinki, Finland
Riley, Philip W. T., Chester
Rufli, Jean C., Stockholm
Scorer, Brian, London
Springall, John Edward, London
Stoodley, Simon A., Alton
Sundqvist, Jalo A. M., Helsinki, Finland
Taylor, Peter G., Hounslow
Turton, George G., Bromsgrove
Waddington, Alfred M., Scarborough, Canada
Wilding, Peter, Liverpool

Ordinary Membership

Bradley, Robert C. W., Didcot
Capps, A. E., Plymouth
Georgiadis, Jack C., London
Goldin, R., Johannesburg
Gould, Henriette, Johannesburg
Keller, Jean P., Lucerne
Kern, Edward E., West Hartford, U.S.A.
Liebman, Arnold, Johannesburg
Lister, John G. C., Uganda, E. Africa
Maunton, Frederick J., Bromley
McChlery, George M. A., Glasgow
Mullen, Joseph, Glasgow
O'Connell, Sean, London
Piper, Robert W., Guernsey
Preston, Iris W., Iver
Rose, Thomas D., Hove
Winner, Frank E., Warner Robins, U.S.A.

Probationary Membership

Angell, David J., Tonbridge
Butler, June I., Waltham Abbey
Butler, William C. F., Paisley
Jones, David W., Sanderstead
Lee, Raymond G., Torquay
Paterson, Andrew, Paisley

Cropp, Alan R., Cambridge
Dayal, J. P., Hong Kong
Halpern, Carlos J., Lisbon, Portugal
Heasman, David J. A., Colchester
Hill, George R., Salisbury
Ranger, Clive J., Bromley
Sealey, Roger M., Totton
Stanley, Edward, Manchester
White, John A., Frome

TRANSFERRED FROM ORDINARY AND PROBATIONARY MEMBERSHIP TO FELLOWSHIP

Burwood, James R., Coventry
Lee, Kenneth A., London
Masters, Christopher R., Blackpool

The Council gave consideration to a report of an examinations committee on proposed revision of the syllabus of examinations. The committee were requested to present a further report which would take into account the views expressed by members of the Council, instructors and examiners.

The Chairman recalled that recently the National Association of Goldsmiths had congratulated Mr. H. J. B. Wheeler upon completing twenty-five years with that organization. Mr. Wheeler had also served the Gemmological Association and its predecessor for a similar period and the Council placed on record their appreciation of Mr. Wheeler's long service.

HERBERT SMITH MEMORIAL LECTURE

The 1961 Herbert Smith Memorial Lecture will be given by Professor W. F. Eppler, of Munich, at Goldsmiths' Hall, Foster Lane, London, E.C.2, on Monday 24th April, at 7 p.m., instead of 12th April previously announced.

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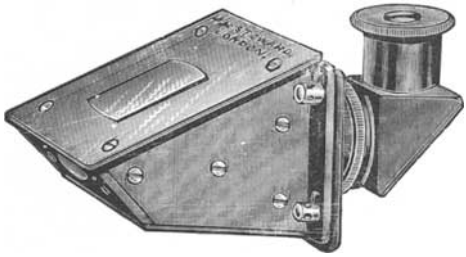

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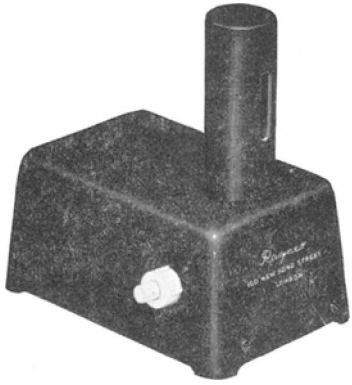

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Practical gemmology by R. Webster. A standard work for first year students of gemmology. 17s. 6d.

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HYDROTHERMAL RUBIES AND EMERALD-COATED BERYL

By E. GÜBELIN

TWO new forms of substitutes for gems have appeared on the gem market in the course of the last 15 months and only a few samples have as yet been submitted for investigation. These few, however, have offered ample possibilities for thorough examination and especially for the finding of characteristic means of distinction.

Hydrothermal Ruby

In the autumn of 1958 two American scientists, R. A. Laudise and A. A. Ballman,(1) of the Bell Telephone Laboratories, succeeded in producing synthetic ruby by the same hydrothermal process as was used for making synthetic quartz. At first this achievement was considered to be of mere scientific or technical interest, until Carroll Chatham announced similar progress in his laboratory in San Francisco and declared that he would soon develop the experimental stage into commercial production. He also claimed that the new production would provide stones that were more reminiscent of natural rubies. It is to be anticipated that these new synthetic rubies may be placed onto the market and one can but hope that they will not be sold with misleading names.

The apparatus used by Laudise and Ballman corresponds with that which Bell Telephone Laboratories are using for the synthesis of quartz—which has its ancestry in the method invented by Professor R. Nacken. However, the task is much more complex because the nutrient in the form of aluminium oxide complicates the problem on account of the various modifications (gibbsite [$Al(OH)_3$], boehmite [Al OOH], diaspore [Al OOH] and corundum [Al_2O_3]) in which it occurs. Many experiments were necessary in order to ascertain optimum conditions of the techniques. Solvent, nutrient, temperature, pressure and the additional foreign reagents, are only a few of the variable factors which may render the hydrothermal synthesis a hazardous gamble.

The autoclave consists of a welded steel cylinder closed with a threaded cap which could support pressures in excess of 30,000 pounds per square inch. In the cavity of this vessel a cylindrical silver tube is placed, within which the reaction takes place. The nutrient, consisting of poorly crystallized gibbsite [$Al(OH)_3$] or corundum [Al_2O_3] is concentrated at the bottom of the silver tube and the tube is filled with sodium carbonate. The seed crystals, which might be either natural or synthetic ruby, of desired orientation, are suspended from a silver frame in the upper part of the apparatus. This assembly is heated up to 400°C. from below by means of an electric heating plate. The top region remains cooler, thus leading to temperature conditions which cause circulating currents in the interior of the saturated alkaline solution. This is very similar to the water central heating system, raising the warmer solution from the area of the nutrient to the top of the bomb, while the cooler solution sinks to the bottom, where it is heated and made to ascend again. The precipitation of the reagent, that is to say the crystallization of alumina (corundum), takes place on these seed crystals, which grow analogous to any natural or synthetic crystals, forming in a solution in accordance with their typical crystal habit and developing all the faces characteristic of their particular species. Thus the nutrient, which is first an aluminium-hydroxide, transforms into alumina crystals during this process. One single run may take one or two months. It is interesting to learn that Verneuil synthetic rubies of the rod shape made by Linde Air Products may be used as seed crystals, if slabs are cut whose main face is oriented at right angles to the main crystal axis.

The crystals grow extremely slowly. Under favourable conditions the growth rate may vary from 2/1000 to 1/100 inch per day. The fastest-growing face is the basal plane, whereas flat plates seem to be the prevalent forms on which the prism faces are strongly reduced. Occasionally rhombohedral forms are also developed. The sizes of these hydrothermal rubies vary from $\frac{3}{4}$ to $1\frac{1}{4}$ inches. The colour depends upon the percentage content of chromium oxide. The best hue is obtained through the addition of one per cent of chromium, i.e., in that 1/10 g. sodium-chromate is added to one quarter gallon of solvent. The colour is also affected by the material of the interior wall of the autoclave, which makes the corundum crystals green if it is made of iron. Silver gives the best results.

I have recently had the opportunity of examining a few hydrothermal rubies claimed to be produced by Chatham, and since I believe that my observations are able to yield some clue as to an easy and reliable identification, I shall describe them hereafter. Determination of the physical data offers no diagnostic distinction, as all specimens tested revealed physical properties identical to those of natural rubies. The refractive indices were within the normal limits of 1·76–1·77 and the birefringence was constant with a value of −·008. In some instances these constants were difficult to identify, because the film-like artificial coating caused the shadow edges to be rather indistinct. The dichroism showed the well known twin colours of purple-red and yellowish-red, while the absorption spectrum displayed its characteristic sequence of four lines in the red (6942, 6928, 6680 and 6595 Å) and three lines in the blue region (4765, 4750 and 4685 Å) with a broad band between 6100 and 5500 Å. Short-wave radiation excited strong red fluorescence, whose hue was toned slightly differently depending upon the light source. The specific gravity varied between 3·9840 and 3·9882 only. Phosphorescence under x-rays was not distinct enough to serve as a criterion, but it might be evident if the seed consisted of synthetic ruby.

Under the microscope the stones were deceptive owing to the natural inclusions in the core. The latter formed the integral and main part of the stones' volume, for the former seed crystals of natural origin had been covered with a relatively thin synthetic

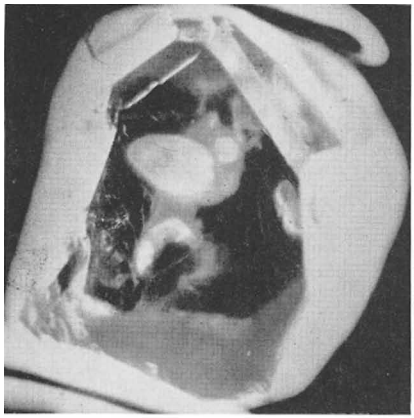

FIG. 1. *Ruby crystal with synthetic overgrowth displays typical habit and crystal faces of seed-crystal. Dark ground illumination. 20 ×.*

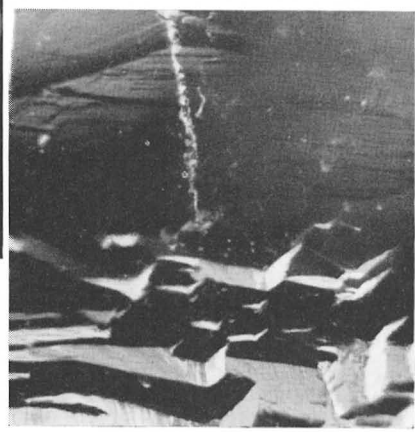

FIG. 2. *Rough surface markings of synthetic mantle indicating prism faces. Dark ground illumination. 80 ×.*

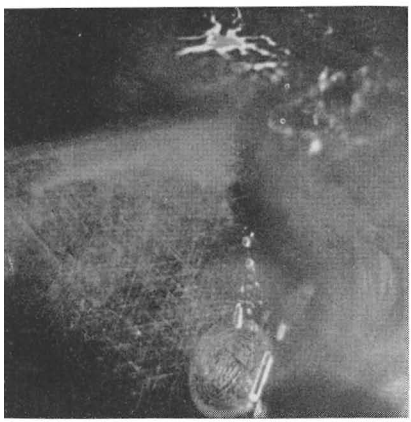

FIG. 3. *Typical "silk" consisting of acicular rutile inclusions, a circular liquid feather and a group of prismatic microlites in the natural ruby "seed". Dark ground illumination. 7 ×.*

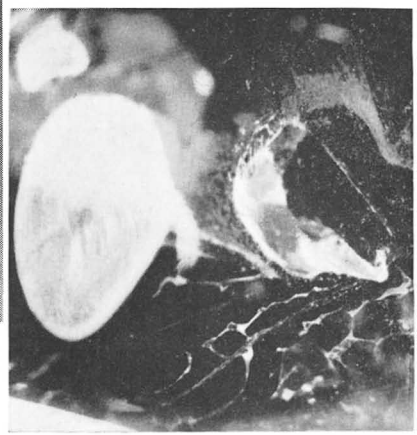

FIG. 4. *Natural inclusions in the ruby core. Dark ground illumination. 40 ×.*

coat. The specimens were rough crystals, and had they been or were they ever to be cut, then most or all of the coat would be abraded in the cutting process. The man-made surface layer had in all cases simulated the habit, shape, crystal faces, growth marks and external irregularities of the seed crystals. In distinct contrast from the hydrothermal rubies produced by Bell Telephone Laboratories, Chatham's samples were not flat, tabular crystals, but exhibited the typical truncated hexagonal prisms ending with rather small basal planes (Fig. 1). All specimens were strongly marked by typical growth features such as incipient development of the prism and the rhombohedron faces (Fig. 2).

Within the genuine core, various types of natural inclusions could be observed: for instance, rutile needles forming plane-like " silk " (Fig. 2) or whitish clouds or zones and solid mineral inclusions of the kind typical of Burma rubies, as well as liquid feathers and any other natural inhomogeneities (Fig. 4). The synthetic coating, however, could be discerned under very intense scrutinization because it teemed with minute gas-bubbles. These were either distributed singly or more often accumulated into lines, planes, clouds, or other odd shapes (Fig. 5 and Fig. 6). It was possible to notice that the formations were abruptly terminated

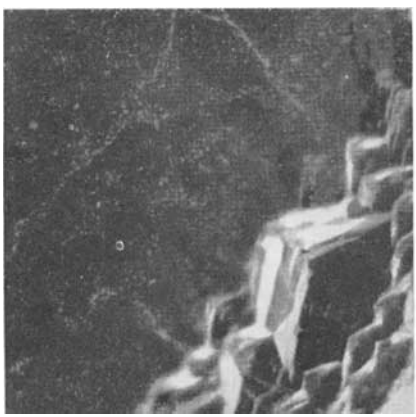

FIG. 5. *Lines and tiny clouds consisting of myriads of minute gas bubbles in the synthetic surface layer. Dark ground illumination. 80 ×.*

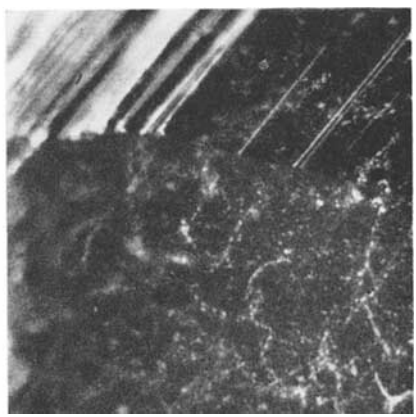

FIG. 6. *Characteristic shape of short curved lines of submicroscopic gas bubbles in the hydrothermal coating. Dark ground illumination. 80 ×.*

along the junction planes between seed crystal and unnatural layer. In one sample it could be seen how a natural feather of liquid inclusions ran across the core and was sharply cut off by the previous natural crystal face. This face was, however, overlaid and traversed by a loose cloud of gas bubbles in the artificial overgrowth. These features are extremely delicate, and it takes a sharp eye and a keen microscopist to discover them, but they offer sufficient proof to pronounce a decisive verdict.

Emerald-coated Beryl

The latest surprise in the field of gem substitutes is a product made at Innsbruck in Austria, the process of manufacture having been devised by Johann Lechleitner. The name of " Emerita " has been given to the material, based on the words " emerald " and " merit ". The idea of giving this new synthetic material a fancy name is, though debatable, not altogether out of the question: it would rank in the same category as other coined names for gem substitutes such as Simili, Strass, Igmerald and Fabulite. These have become known and accepted by the public as names for gem substitutes.

This new substitute is also composed of two parts, a genuine colourless or slightly coloured beryl functioning as a nucleus upon which a thin layer of synthetic emerald is deposited by a special process, the technical details of which have not yet been completely released. In a personal communication J. Lechleitner confirmed that his method of production is purely hydrothermal and completely different from C. Chatham's process, which depends upon the principle of the diffusion flux (similar to the method used by the German Dye Trust.)(7). He claimed his procedure to be an entirely new method which he had developed and which has proved to involve innumerable possibilities for alterations, which would allow the synthesis of a great number of minerals. The formation of emerald, however, is limited to the exact combination of very precise conditions, such as the mixture of the nutrient, composition of solvent, chemical component in the very zone of formation, temperature and temperature gradient as well as pressure. Unfortunately, J. Lechleitner would not disclose any further details.

The unusual feature of this process is that these synthetics are grown from a seed or core which is either cut as cabochon or faceted, and synthetic emerald in the form of a very thin coat is deposited on the cut beryl nucleus. Thus the synthetic stones, as they result from the production run, are either unpolished cabochon or faceted samples with a rough crystal surface. Both these parts, beryl nucleus and emerald mantle, are wholly crystalline and completely homogeneous, because the beryl core continues to grow synthetically as emerald. Consequently, both parts form one homogeneous monocrystal, absolutely analogous to those natural crystals, such as tourmaline, which consist of variously coloured growth states, and they exhibit all the properties characteristic of beryl and emerald respectively. This speeded-up method of producing a surface layer on beryl cores will obviously result in very thin overgrowths only. The unpolished specimens display all the external features and growth marks of genuine beryls, but they evidently differ considerably on the various facets owing to crystallographic orientation (Fig. 7). Needless to say all these emerald-coated specimens are

FIG. 7. *Growth markings in the hydrothermal emerald mantle on one of the pavilion facets. Dark ground illumination. 80 ×.*

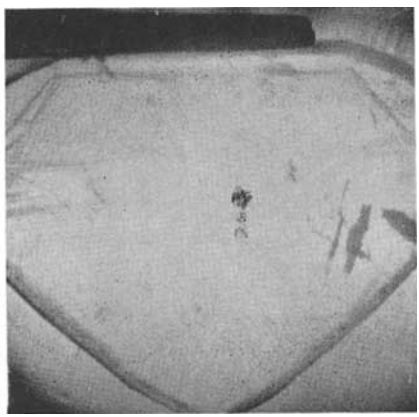

FIG. 8. *Lateral view manifests the dark "relief" of the synthetic emerald coating which envelops a colourless beryl seed. Bright field illumination. 10 ×.*

polished before they are offered to the trade. Lechleitner, with a sincere tendency to follow ethical sales principles, proposes to leave the pavilion facets unpolished so that these may serve as a mark of his product.

Also, due to varying growth speeds in accordance with crystallographic directions, the thickness of the synthetic overgrowth varies in different directions and therefore on different facets (Fig. 8). The intensity of the colour also depends upon the depth of the overgrown emerald layer, which usually gives the stone a cold bluish-green hue. In electric light the appearance is at its best, when the stone has an additional warm yellow tinge and vivid fire. As a tentative test I had a strongly coloured yellow heliodor and a well coloured aquamarine coated with synthetic emerald layer, but to my surprise no appreciable colour-difference resulted, although their transparency was slightly inferior to those specimens which embraced a pure and colourless beryl core.

Because of the excellent homogeneity of the product there is some difficulty in distinguishing it from a genuine gem. The refractometer would always only measure the refractive indices of the synthetic overgrowth, which correspond with those of the natural counterpart.

With specimens whose hydrothermal emerald film is very thin the shadow edges may appear rather blurred and render R.I. readings very difficult and inaccurate. In such stones interference colours can be observed if the stone be swivelled.

In contrast to " Igmerald " and Chatham's synthetic emeralds, this new material has no lower values, so that the very reliable immersion test in benzylbenzoate ($n_D = 1{\cdot}57$) cannot be applied here. On my specimens I measured 1·578 to 1·590 for ω and 1·571 to 1·583 for ε, with a constant value of ·007 for the birefringence. It will be interesting to learn what factor accounts for these surprisingly high figures, as other features of these substitutes seem to indicate that there is no interstitial content of trace elements in the lattice. On the other hand I found the specific gravity to yield normal figures between 2·676 and 2·713, while the beryl core of one sample, from which the synthetic layer had been polished off, gave a specific gravity of 2·672 only and R.I. of 1·564–1·570.

The dichroism is weak but equal to that of genuine and other synthetic emeralds, being yellowish-green for the ordinary and blue-green for the extraordinary ray, but the intensity of the twin colours changes with the depth of the coating. When I received the first specimens in March, 1960, I was astonished by the strong and very clear absorption spectrum, which showed all the typical chromium lines in the red region (6835, 6806, 6620, 6460 and 6370 Å). The luminescence, excited by short-wave irradiation, is of red colour, which is, however, less intensive than in synthetic emeralds of other productions.

The best and most reliable means of identification is secured by microscopic examination. Here again, exactly as with the hydrothermal ruby, one might be seriously confused by natural inclusions in the seed. These might consist of any of the usually occurring endogenetic formations, such as solid mineral inclusions, liquid feathers, two-phase and even three-phase inclusions of primary or secondary origin (Fig. 9). If any of these happened to reach the previous surface, these will show because of their sharply linear termination a little below the present surface. Errors might

FIG. 9. *Three-phase inclusions in natural nucleus superimposed by tell-tale straight lines and dust-like particles in the synthetic overgrowth. Dark ground illumination. 40 ×.*

FIG. 10. *Cracks (dark specks) in genuine beryl nucleus are mirrored in synthetic overgrowth if specimen is inclined and looked at through its body. Dark ground illumination. 40 ×.*

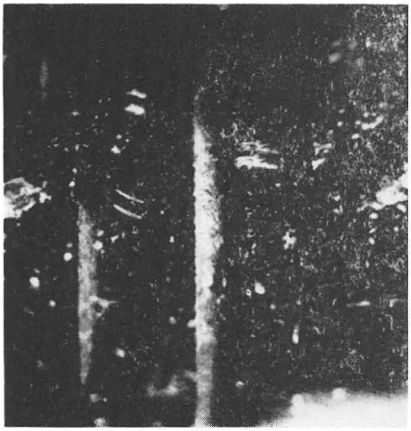

FIG. 11. *Mirror effect of impurities in the synthetic emerald layer if stone be appropriately tilted. Dark ground illumination. 40 ×.*

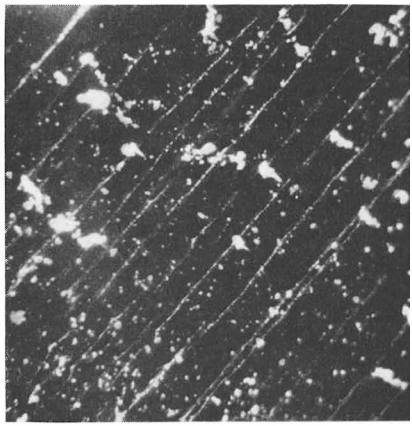

FIG. 12. *Straight lines and dust-like particles form a typical feature in the internal structure of the hydrothermal coating. Dark ground illumination. 40 ×.*

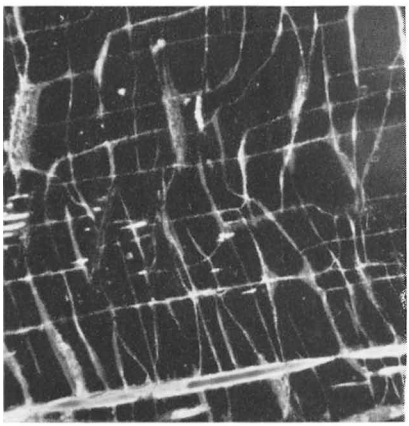

FIG. 13. *Net pattern produced by systems of parallel cracks running along the direction of the prism and parallel to the base. Dark ground illumination. 40 ×.*

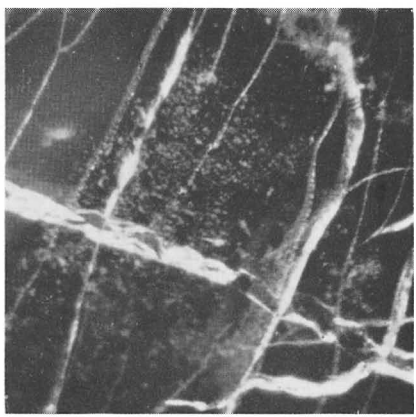

FIG. 14. *Looked at sideways the straight " lines " disclose themselves to be tension cracks. Dark ground illumination. 80 ×.*

easily occur if one had to discriminate between these emerald-coated beryls and emeralds from the new Gachala Mine in Colombia, whose bluish-green colour the new substitutes simulate rather well. If submersed in a suitable immersion liquid such as benzylbenzoate and examined sideways, it is usually possible to distinguish between the core and the dark green seam formed by the man-made mantle, which appears as a dark narrow border line (Fig. 8). In dark-field illumination, and if turned into an appropriate position, the junction plane often behaves like a mirror and it becomes possible to discern the beryl-nucleus from the surface layer. This occurs if the refractive indices between beryl body and hydrothermal mantle happen to differ slightly. Genuine inclusions in contact with the former surface of the seed may appear reflected in the synthetic mantle, or foreign particles and inclusions in the overgrowth are mirrored in the core (Figs. 10 and 11). In some specimens the junction plane seems to be covered with a " dusty powder ", which betrays the overgrown layer most conspicuously by its expansion over the flat surface of the nucleus. A most striking means of identification is provided by a system of straight parallel lines or by nets of crossing streaks in the mantle (Figs. 12 and 13). When the stone is tilted and examined obliquely these lines reveal

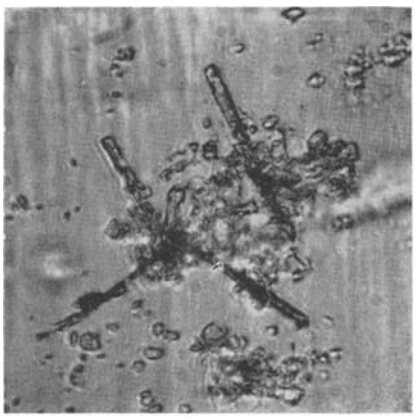

FIG. 15. *Radial arrangement of euclase or phenacite crystals surrounded by numerous tiny microlites of this alien crystal phase on the surface of the beryl seed. Bright field illumination. 500 ×.*

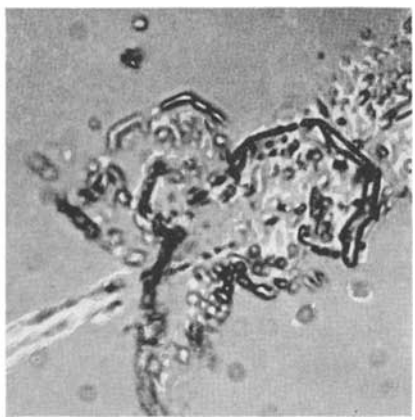

FIG. 16. *Skeleton of alien crystal depicting hexagonal outline and developed on surface of beryl core. Bright field illumination. 250 ×.*

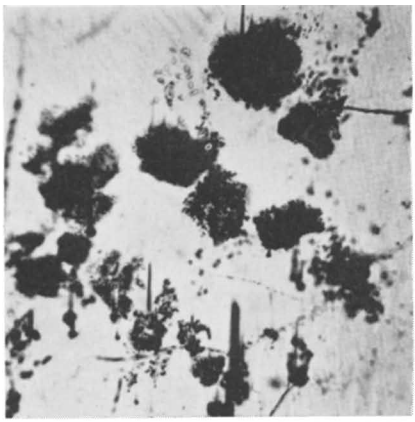

FIG. 17. *Ball-like aggregates of "foreign" crystals formed on junction plane between beryl nucleus and synthetic emerald overgrowth. Bright field illumination. 100 ×.*

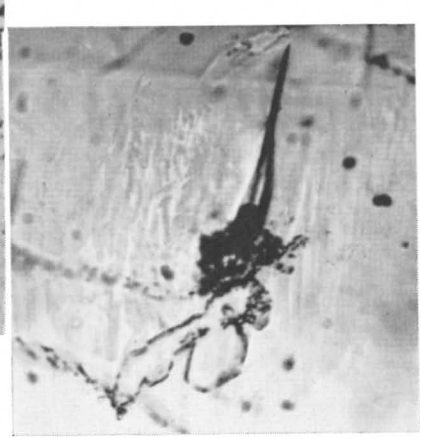

FIG. 18. *Growth funnel forming a two-phase inclusion above an agglomeration and a skeleton of alien crystal phase which acted as obstacle in the growth flux. Bright field illumination. 250 ×.*

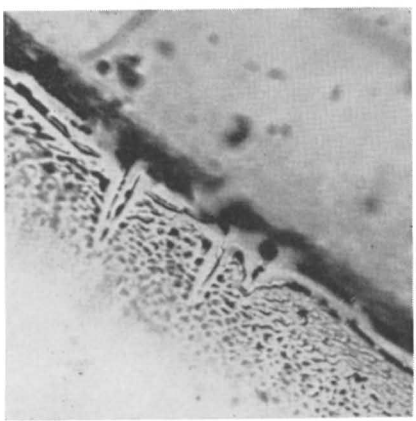

FIG. 19. *Partly healed fissure in the synthetic emerald coating being clearly marked by the "undigested" residual liquid drops. Phase contrast 250 ×.*

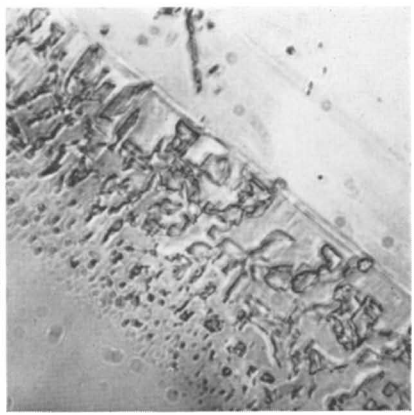

FIG. 20. *Liquid drops being the "undigested" residue of the hydrothermal solvent and being trapped in a healed fissure of the synthetic emerald layer. Phase contrast 500 ×.*

themselves to be cracks in the synthetic emerald-coating. Their breadth usually corresponds with the depth of the hydrothermal overgrowth (Fig. 14).

These are the impressions one may gain under a low-power lens. Strong magnification, however, may reveal the hydrothermal emerald coat to contain an abundance of most informative inclusions. What seemed to be dusty particles are in reality single crystals, crystal skeletons or tiny agglomerations of some alien phase (e.g. phenakite [Be_2 SiO_4] or euclase [Be (AL, OH) SiO_4]) or other related minerals, which may grow on the junction surface at the beginning of the operation before the favourable conditions for the formation of the emerald layer are reached (Figs. 15, 16, 17). They may be deliberately caused to develop or not, through a low temperature, a different temperature gradient or other reasons. In many cases larger individuals or aggregations of these foreign particles may act as obstacles in the growth flow of the nutrient and thus give rise to a lattice vacancy in the shape of a spike-like tube. This corresponds with a general tendency of the emerald structure to develop " growth-funnels " parallel to the c-axis. These acicular cavities form two-phase inclusions containing a

FIG. 21. *Characteristic appearance and distribution of residual liquid drops in one of these tell-tale healing fissures in the hydrothermal overgrowth. Phase contrast 100 ×.*

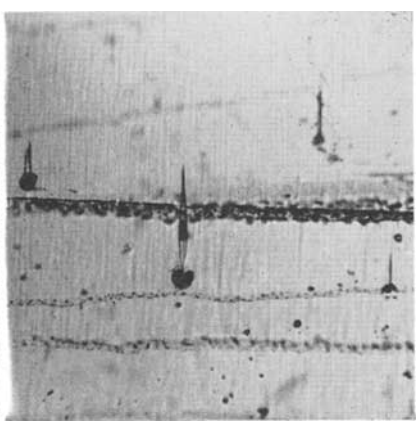

FIG. 22. *Straight healing fissure running parallel to the basal plane (0001) and several growth funnels lying in the direction of the c-axis. Phase contrast 100 ×.*

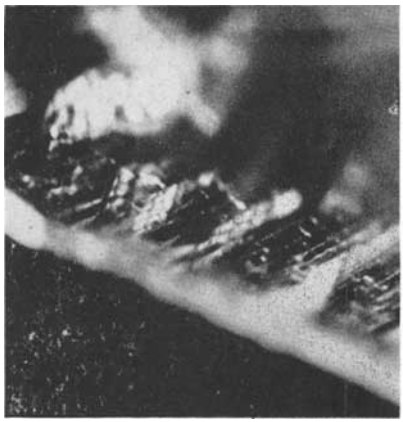

FIG. 23. *Some of the parallel straight fissures clearly manifest the thickness of the hydrothermal emerald mantle. Dark ground illumination. 40 ×.*

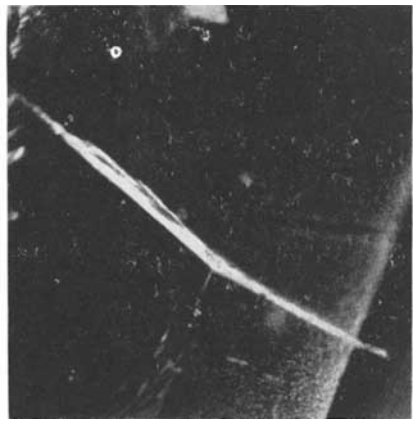

FIG. 24. *Dry crack running through synthetic emerald layer along undetermined direction. Dark ground illumination. 40 ×.*

watery fluid of the hydrothermal solvent and a bubble. The pointed end of their tapering shape indicates the direction of growth (Fig. 18). Likewise the lines mentioned above, which proved to be fractures in the synthetic emerald mantle, exhibit the characteristic appearance of healing cracks, which substantiate that they occurred while the stone was still suspended in the saturated hydrothermal solvent and the emerald layer still in its *statu nascendi*, so that the fissures could fill with mother-liquor and eventually heal (Fig. 19). The spotted pattern, which may be observed under small magnification, is caused by the " undigested " residual drops of the liquid which soaked into these cracks (Figs. 20 and 21). The fractures are likely to be caused by a slight atomic disarrangement between the surface lattice plane of the beryl-body and the superimposed emerald layer, which contains a small content of chromium-oxide. One set of these healing fissures developed along the growth directions and hence runs parallel to the two-phase inclusions formed by the dwindling growth-funnels, while the other system of cracks lies more or less perpendicular to the direction of principal growth, that is to say, in the basal plane (Fig. 12, 13 and 22). Such an arrangement of cracks causes a net-like pattern of streaks and lines in the artificial overgrowth, whose thickness

can readily be recognized by the breadth of these fissures, if the stone is properly inclined and the cracks examined sideways (Fig. 23). In many respects the endogenetic features of the synthetic emerald overgrowth resemble the internal structure of the synthetic emerald produced by R. Nacken[6] and therefore indicate an analogous mode of synthesis.

Knowing these tell-tale characteristics, the gemmologist should encounter no particular difficulty in identifying this new substitute, if the hydrothermal overgrowth displays any of the features described above. But here again, as in the case of the hydrothermal ruby, the microscopic examination must be carried out with the utmost care, otherwise one might easily be deceived by genuine inclusions and readily overlook the much more delicate, yet definitely conclusive, structural features in the man-made overgrowth.

Moreover one must remain aware of the fact that the hydrothermal process of producing crystalline material can easily be governed by deliberately altering the growth conditions. Thus the synthetic emerald mantle may develop absolutely pure and clear of any markings, and indeed Lechleitner has produced specimens whose hydrothermal emerald mantle was completely flawless while others were merely marked by a few irregular " dry " (not healed) cracks (Fig. 24). In these cases the lateral examination, displaying a dark green rim round a pale or colourless body, may yield the sole verdict.

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Gemmological Notes

JEWELLERY AND GEMMOLOGY

J. ROACH.

Nigel W. Kennedy's article, "How rare are Chatoyants and Asterias", which appeared in the Journal for October, 1960, raises two points of interest which prompt me to write about the difficulties facing gemmologists employed in the trade. On the one hand Mr. Kennedy feels that his not being employed in the trade limits the number of specimens coming to his notice; on the other hand he criticizes jewellers for their bias towards "trade" stones.

Regarding the first point, I have found, along with many other gemmologists, that there is no advantage in being a jeweller when it comes to handling the lesser known specimens, although one can become very proficient in handling the so-called "trade" stones. Despite the fact that these latter stones are the life-blood of gemmology, they play but a small part in our scientific studies.

Indeed, learning gemmology in the trade is fraught with trials and tribulations. Most employers, in these enlightened days, encourage their staffs to study the subject; but it is still far from easy for the young newcomer. The youngster finds he is speaking a different language—what to him are Citrines, Demantoids and Spinels are to others Topazes, Olivines and Balas Rubies. At the same time he is more than likely to meet opposition from senior personnel who themselves have never bothered to learn and are determined to prevent others from so doing.

It is no new experience for jewellers to be accused of bias towards certain stones and of not caring about the rest. I do not think, however, that our critics really appreciate the difficulties besetting the jewellery trade in this respect. Without the commerce of jewellery, gemmology would perish, as was pointed out by A. E. Farn (*Journ. Gemmology*, 1960, VII, No. 7).

Most gemmologists are keen; but if not kept in check keenness can run away with itself. After all, selling jewellery is a commercial enterprise, gemmology a science. On the whole most jewellers make money, while by common conception most scientists do not.

One must realize that as far as the jeweller is concerned, gemmology is a means to an end not an end in itself. The keen gemmologist will find that 90% or more of his gemmology is practised outside his place of business.

If any proof is required of the relatively small part played by gemmology in a jeweller's business, a reference to the Retail Jewellers' Handbook elicits the suggestion that one third of a jeweller's total sales should consist of gem-set and gold jewellery. When one realizes that probably 95% of public demand for gem jewellery consists of diamonds alone, one gets a realistic picture of the very small proportion left for the sale of other stones. Is it surprising that both manufacturers and retailers do not venture into the realms of star beryls, etc. ?

No, I am afraid that life in the jewellery trade does not consist of hours spent in testing and studying gemstones. Indeed, were it not for hours spent at home doing such things, many a gemmologist would not use an instrument for weeks on end, and when something unusual does turn up the day is truly an eventful one. Such a stone, incidentally, was the chatoyant topaz I was fortunate enough to come across some two years ago in an assorted parcel. This, sad to relate, was my last " big find ".

SOME NOMENCLATURE PROBLEMS

O. DRAGSTED.

Some time ago I was shown a necklace bought in the East as " Tibetan Jade ". It consisted of aventurine quartz beads. I looked up various dictionaries and textbooks on gemmology to find out whether aventurine quartz was known under this misleading trade-name, but in vain.

My next thought was, must this misnomer now necessarily be translated into many languages and included in all future dictionaries, mentioned in lists of improper names as a warning, and included in the tuition of students.

Would not this procedure mean that a rather isolated case of misrepresentation is vigorously spread out to a large number of people. Perhaps the result would be that some dealer after consulting a textbook on gemstones would tell his customer: " Strictly speaking this is a so-called aventurine quartz but it is much better known as ' Tibetan Jade '." And the lucky customer will show

her friends the fine " jade " from Tibet. In this way we might involuntarily set ablaze a misguiding torch which ought to be quenched.

How many gemmologists are not thinking of the forbidden words " Korean Jade " when encountering a serpentine figurine ? Because they are taught not to use this false name, they will always remember it.

The other day a woman showed me some Jutland amber which she had stained. There were several colours, and she remarked that the green dyed amber had now attained a jade-like appearance. I visualized a brand new trade name " Jutland Jade ", so I retorted " No jade ever had that poisonous hue " !

A jewellery manufacturer showed me a few years ago some gold ornaments set with what he termed " blue topazes ". They were small milky cabochons, and it demanded a great deal of imagination to see any tint of blue in them. They turned out to be quartz, and I must admire the logic of his suppliers:

" Burnt amethyst which has attained a yellow hue is marketed as ' topaz ', so burnt amethyst which has been burnt milky white (somehow resembling a poor quality of the otherwise bluish moonstone) must be marketed as ' blue topaz '." In Sweden this product has been called " månkristall ", a name which indicates that it belongs to the same family as rock crystal having at the same time some resemblance with moonstone.

I may mention a queer example showing how literature keeps alive a false name which might otherwise have been forgotten long ago. Revising a commercial vademecum I found under kyanite (disthene) a note that this stone had been known earlier as "simple sapphire ". It is perhaps now 200 years since kyanite was determined, so I chose to omit that it had ever been sold as sapphire. This information was new and interesting when published in 1808 by C. Prosper Brard in his " Traité des Pierres précieuses " as follows: " On avoit voulu les faire passer pour des saphirs . . . Ce fut M. Haüy qui s'apercut le premier que ces prétendus saphirs n'etoient que des disthènes ".

We are constantly teaching students that they must doubt the identity of any stone they get in their hands, because so many stones are sold under false names. Some misleading gemstone names are so widespread that we cannot omit them. But many others could

doubtlessly be excluded, especially those which correspond to mineralogical definitions.

So this tends to be an appeal towards our common aim of a clean nomenclature: Let us subdue the misnomers through our silence. Let us eliminate them from our gemmological books. Let us leave them to oblivion.

One might accuse us that through our silence we give consent to the falsities. *Qui tacet consentit.* I would rather say that our literature should contain nothing but the truth, so if a stone-name cannot be found there, it is suspect, and our silence would be an accusation. Said Cicero versus Catiline, " *Cum tacent clamant* ".

FASHION, TREND OR VOGUE

A. E. FARN.

Just after the war there was a great scarcity of everything—except demob suits. Suddenly there seemed to be a demand and very ready sale for cameos in jewellery. Every teenager, middleager, old ager and dowager had to have one. At first they were scarce and consequently high in price in comparison to the quality of workmanship. As time passed however there came a glut of cameos carved in stone, shell, plastics, china, plaster and coral, every conceivable medium was fully exploited to saturation point. Now that popular demand has ceased, the true level of merit and worth has caused fine pieces to assert themselves in a mediocre market. Most jewellers can remember the pre-war days when one steadily smashed up all old gold and silver objects which were bought for melting, especially all those (then) hideous Victorian bracelets, pendants and brooches which now have assumed considerable merit and there has been searching of trinket boxes to find these (now) sought after pieces. If one could foresee a trend, of course, one could make money. If one could really afford to sit on present day outmoded stock it would in time turn a full circle to sudden demand.

The change in demand for certain styles of jewellery is often sparked off by newspaper items, giving details of royalty, film stars and ballerinas, attending some function or other, wearing this and that garment with, for example (hopefully) a huge row of ivory beads, matching bangle and ear studs. A little later the fashion page of the dailies gives a write up on the new fashion which Miss someone or other (top model or near celebrity) features in so and so's dress

collection and a small blurb on recent well-to-do personages who also export this new fashion. The daily diary talking on events in town also lends a hand in this touch of Society news. Very soon the fashion descends to the lower ranks, which causes the local jeweller to gnash his teeth when he thinks of all those lovely ivory beads he so often refused to buy or was so pleased to sell at a give-away price, "Sic transit black Monday", but soon to his rescue come the fashion (imitation) jewellery sales; if the local girl cannot get ivory she is just as happy with (spare the term) simulated plastic ivory.

Speaking of the local girl, one of course realizes the tremendous potential the teenager exerts in spending power. They must be recognized and treated as to-morrow's mainstay.

To-morrow's mainstay or yesterday's white elephant, neither is of much financial solace unless one can turn it to account; this does not happen to the man who cannot afford to sit and wait.

For a short while jet seemed to enjoy a comeback, but once again the plastic imitation killed its real appreciation, since plastics are so easily moulded and are a much more malleable material and so cheap to produce.

Amber, too, has this plastic rival, though I find it hard to understand why so many huge necklaces of bakelite beads of perfect match, colour, transparency and beautiful graduation should cause any jeweller to ponder—are they amber ? Once again his teenage customer buys for colour and not for authenticity and his " contemporary " (a word meaning modern) jewellery sales increase and in fact to-day form a steady part of his regular trade. It is strange how even the word contemporary adds a hint of glamour to fashion, whereas " modern " doesn't sound half so genteel—a question of U and non-U in mundane eyes or ears.

Certain types of jewellery, which are rather specially created such as stone-set crosses, are a particular case in point. Since they originally had a particular denomination or type of person as their ultimate wearer they prove to be a very hard seller indeed upon the secondhand market. As time goes by, however, and the steady drop in the purchasing power of the pound continues, the break up value rises until, regrettable aesthetically but to the utmost satisfaction of the jeweller, the cross becomes an economic " breaker ".

One fashion which is slowly re-asserting itself is that of wearing a stick-pin. This in itself is a very welcome change especially as a

slight relief to the somewhat sombre garb of the more conservatively dressed male. Apart from dress relief it also allows the use of the drop-shape and slightly baroque pearl, the yellow diamond or pear-shaped ruby or sapphire, all of which lend their shape so well to stick-pin usage. Although it needs sales promotion, national press-coverage and snob-appeal to get people stick-pin minded, it would certainly help trade and would be a good idea to get the fashion launched. When one considers some of the audiences and committees of jewellery functions—the very heart of the gem trade—one is struck by the low sartorial standard of the assembled males and their lack of any normal items of jewellery—some in button cuffs and soft collars, some no cuff links at all—perhaps one stick-pin per 100 jewellers or jewellery-trade workers present. These people could, if they tried, help their own trade enormously by creating a fashion and thus a demand. A man need not be terribly well off to sport a slim silver cigarette case, plain or engine-turned cuff links and a stick-pin costing (if carefully purchased) not more than ten pounds. The stick-pin might, if carefully chosen, even advance in value as time goes by, which could thus become a good buy and a form of investment, whereas contemporary jewellery is merely a goodbye to one's money with an immediate heavy depreciation somewhat like leasehold property—a declining asset.

Coral, amber, jet, tortoiseshell, ivory, mother-of-pearl, scent bottles, chatelaines, card cases, fans, lorgnettes—all will have their turn—well not all.

LIGHTING SPECTROSCOPE

S. Buzalewiez.

The lighting spectroscope consists of two joined tubes: the spectroscope proper and an electrical battery lamp emitting focused light.

The cutting of stones is devised for the purpose of totally reflecting most rays of light falling onto, and passing into, the gem, and of returning them to the eye when viewing the gem from above, i.e., vertically to the table facet. Practically all the rays of light falling on the gem at right angles to the plane of the table facet, or slightly oblique from such direction, are totally reflected and the majority of all other rays falling on the gem (increasing as the refractive index of the stone decreases), not being totally internally reflected, pass through the gem and do not return to the viewing eye.

There are therefore two conditions of optimum observation of the light passed into a gem:—

1. Observation of the gem from above, perpendicularly to the table facet.
2. The lighting of the gem from above also as nearly as possible at right angles to the plane of its table facet.

These conditions are fulfilled by observation of a gem in the light passing from the spectroscope itself.

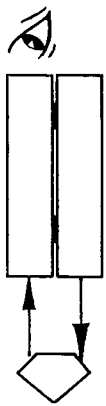

Spectroscope and electric battery lamp emitting focused light joined together to form the lighting spectroscope.

Being a pocket apparatus adapted to the observation of gems, both unset and set, by both transmitted and scattered light, the lighting spectroscope, in conjunction with a pocket atlas of absorption spectrum bands, can become a main gemmological instrument in commercial practice.

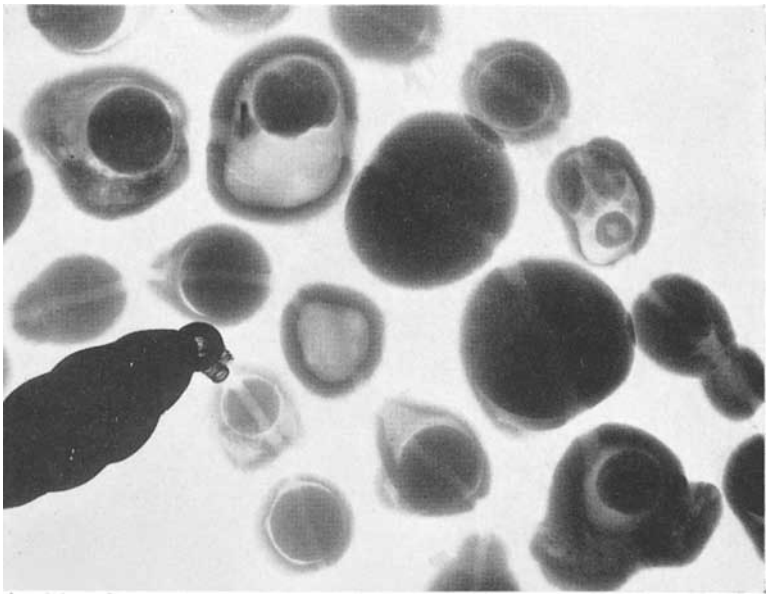

A striking photograph of part of a very baroque cultured pearl necklet showing two pearls with unusual structures. One pearl has three peculiar nuclei, and the other appears to be non-nucleated. The presence of such pearls in a cultured pearl necklet may be due, it is suggested, to the mother-of-pearl bead nuclei having been aborted, but the pieces of mantle tissue remained in the animal and had formed non-nucleated pearls. *Robert Webster.*

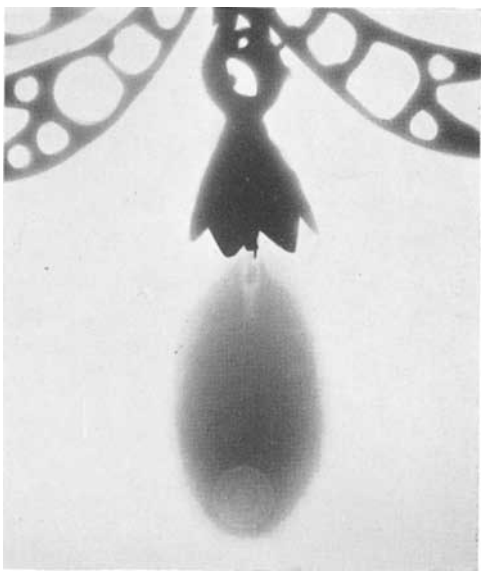

An agate-like nucleus in an unusual position at the extreme end of a natural elongated drop pearl.

B. W. Anderson.

GROWTH MARKS IN EMERALD

By W. F. Eppler

THE intermittent growing of beryl has already been demonstrated on a Brazilian emerald[1]. Emeralds from other localities exhibit similar features, an example of which is shown in Fig. 1. The striae of growth are parallel to the basal plane, and they are bordered by " steps ", which indicate the direction of steep hexagonal bipyramids. The layers indicate a fluctuation in the composition of the mother-solution. While this part of the stone is colourless, it is covered by a good emerald-green upper part (dark in Fig. 1), which has been grown later. The system exhibits an intermittent growth of the emerald, which has been caused by a considerable change of the components of the mother-liquor as well as their concentration.

In another emerald, a similar striation parallel to the basal plane can be observed (Fig. 2 and 3). The layers represent a

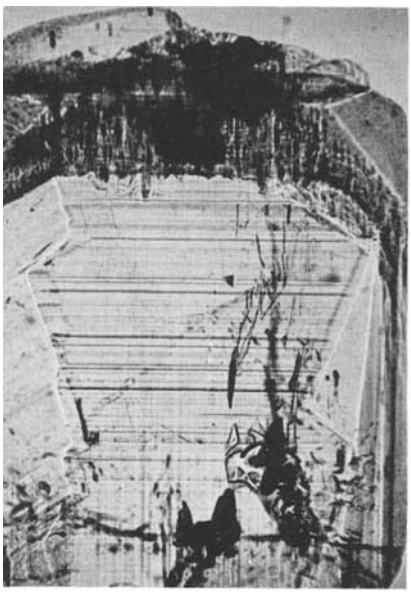

FIG. 1. *Emerald with a striation parallel to the basal plane. This part is colourless. Upper part (dark) exhibits a good emerald-green. View perpendicular to the c-axis.* 22 ×.

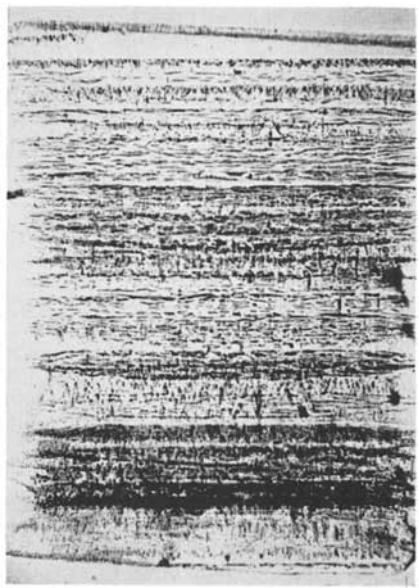

FIG. 2. *Emerald with a marked striation parallel to the basal plane. Dark green layers alternate with brighter or colourless ones.* 22 ×.

former frontier of growth, which has been advanced by a nutrient of an alternating composition. Thereby, darker green layers are followed by brighter ones, which sometimes appear to be nearly colourless. By using a higher magnification, traces of steep growth-pyramids can be observed, indicating differences in the former conditions of growth likewise (Fig. 3).

The marks of growth in emerald can best be observed by immersing the stone in benzylbenzoate, a liquid the refractive index of which ($n = 1{\cdot}570$) approaches very closely to that of genuine emeralds. Additionally it is useful to close the aperture nearly completely when observing the stone under the microscope. In realizing these conditions, very little differences in the refractive index can be detected, so that with this technique minute variations in the chemical composition of different parts of the same emerald can be revealed.

Other peculiarities of crystal growth in emerald are chips or splinters of beryl, or emerald respectively, which have been entrapped at random orientation (Fig. 4). They are easily overlooked as they have the same refractive index as the host crystal, but they are clearly seen when using polarized light (Fig. 5). Without any doubt, the splinter has been pre-existent with regard to the embedding emerald.

Sometimes, the splinters caused a disturbance at the growing emerald by which liquid-filled tubes have been originated. In

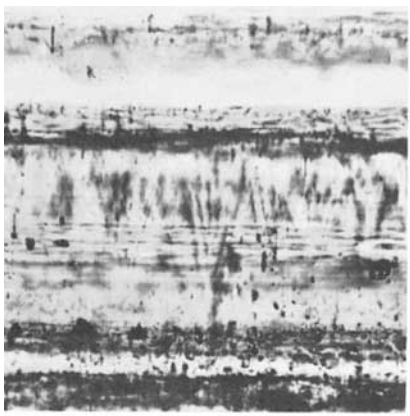

FIG. 3. *Emerald with steep growth-pyramids; part of Fig. 2. 65 ×.*

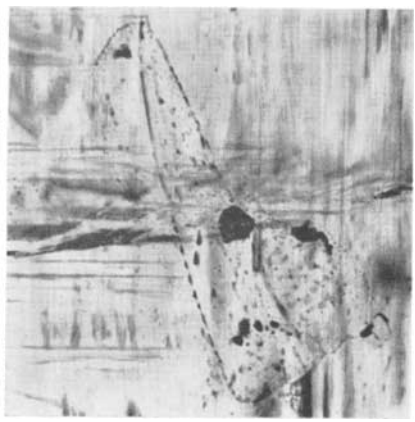

FIG. 4. *Emerald with an unorientated chip of another emerald. 65 ×.*

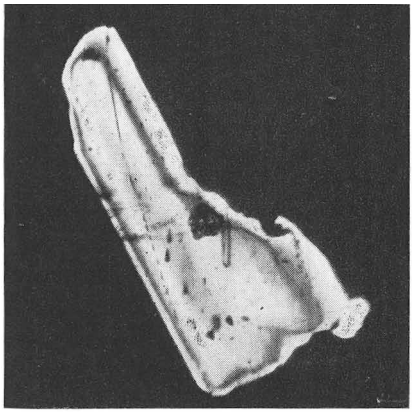

FIG. 5. *Emerald, same as Fig. 5, crossed polarizers. 65 ×.*

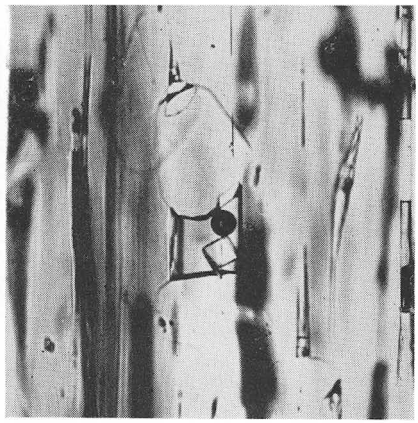

FIG. 6. *Emerald from Colombia. Two unorientated chips of a pre-existing emerald caused a liquid-filled tube with a libella and a cubic crystal. View perpendicular to the c-axis of the host crystal. 120 ×.*

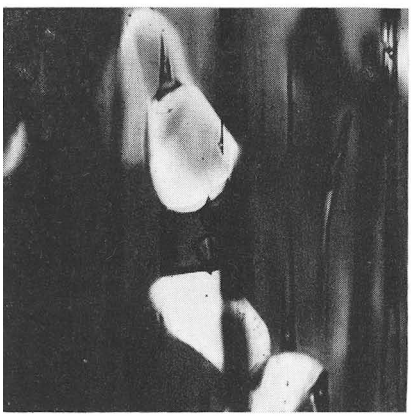

FIG. 7. *Emerald from Colombia; same as Fig. 6; polarized light. 120 ×.*

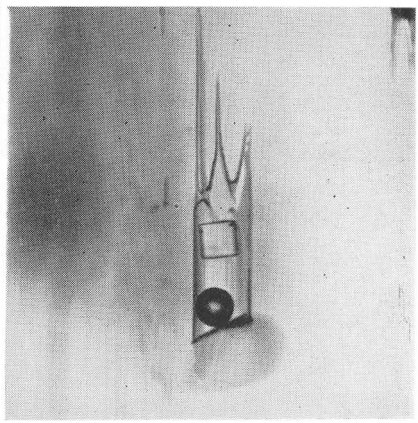

FIG. 8. *Emerald from Colombia. A heterogeneous splinter of emerald caused a three-phase inclusion with a pronged end. View perpendicular to the c-axis of the hosting crystal. 120 ×.*

Fig. 6 and 7, two chips are connected by a short tube representing a typical three-phase inclusion. It is evident that the chips were present while the emerald was still growing. When it reached with its surface the first chip (below), it not only surrounded the foreign particle but deposited behind it some of the material unsuitable for its own growing process. The same happened after having reached the second (upper) chip, as can be concluded from the tip-like little tube on its top, which is a smaller repetition of the three-phase inclusion. With regard to Fig. 6 and 7, such an explanation supposes a growth of the emerald crystal from below in an upward direction.

A similar case is shown in Fig. 8, where a pronged three-phase inclusion seems to bear a (shadow-like) splinter of a former emerald. In reality, the phenomenon originated during the growth of the crystal which took place (in Fig. 8) from above downwards. Such tubes caused by growth seem to be typical for emeralds from Colombia. They are characterized by sharp ends, indicating at the same time the direction of growth and the c-axis of the emerald. Mostly, they represent three-phase inclusions, the solid components of which are cubic crystals. In Fig. 9, the enclosed crystals exhibit other forms than the cube only, by which the speculations of their nature are multiplied.

These particular tubes, originated by the growth of the emerald from Colombia, have a counterpart in the three-phase inclusions which have been originated by the healing of fissures (Fig. 10). In most of the cases, they follow approximately the direction of the basal plane of the host crystal, and they are characterized by irregular forms. Occasionally, the inclusions contain several isotropic crystals, as is shown in the picture.

Among the marks of crystal growth, inclusions of calcite have been reported (E. J. Gübelin[2]). Fig. 11, taken from a Colombian emerald, exhibits a flattened three-phase inclusion. Its contours are not clearly visible as they are out of focus. In spite of this, the typical components of a three-phase inclusion are well illustrated: a rounded libella with a broad dark rim, indicating the presence of a liquid; very near to its right side a cubic crystal, partly covered by overlying other inclusions, and, which seems to happen very rarely, a well-developed rhombohedron of calcite (above the libella). It seems unusual that a calcite crystal forms a constituent of a three-phase inclusion in an emerald.

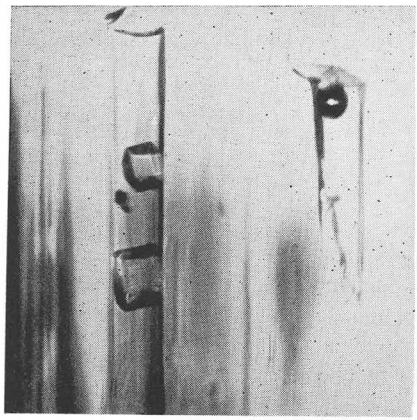

FIG. 9. *Emerald from Colombia. A tube parallel to the c-axis with two colourless crystal inclusions, exhibiting additional faces. 120 ×.*

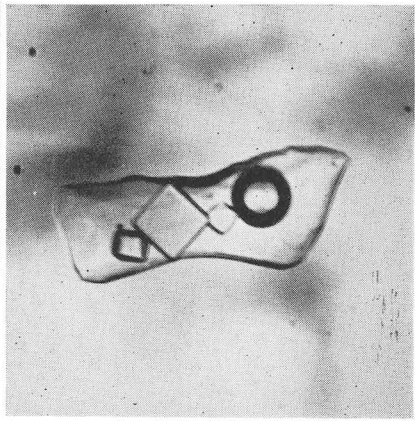

FIG. 10. *Emerald from Colombia. A three-phase inclusion of a healing fissure with several isotropic crystals. View approximately in the direction of the c-axis of the emerald. 220 ×.*

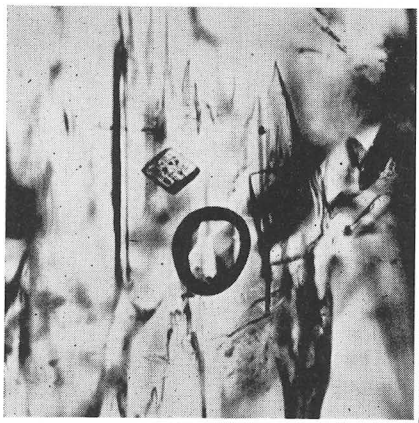

FIG. 11. *Emerald from Colombia. A calcite crystal (rhombohedron) as an unusual constituent of a three-phase inclusion. View perpendicular to the c-axis of the emerald. 120 ×.*

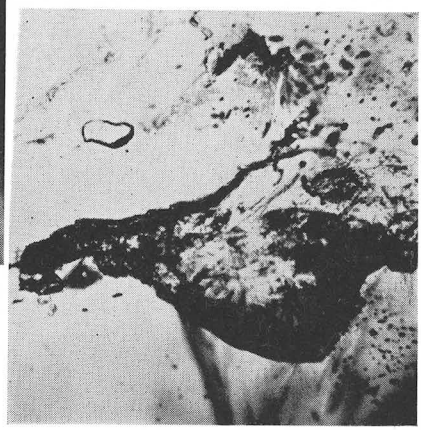

FIG. 12. *Emerald with rounded inclusions of petalite at random orientation. 65 ×.*

Crystal inclusions of petalite have been found in an emerald (Fig. 12). This mineral has been described recently as an inclusion in Brazilian aquamarine,[3] from which it could be separated and determined. The chemical composition of the monoclinic crystal ($Li_2O . Al_2O_3 . 8SiO_2$) is very similar to that of spodumene, from which it differs only by a higher content of silica. Larsen-Berman[4] quote the values for it as follows: $n_\alpha = 1{\cdot}504$; $n_\beta = 1{\cdot}510$; $n_\gamma = 1{\cdot}516$; $n_\gamma - n_\alpha = +0{\cdot}012$; inclined extinction $= -8°$; specific gravity $= 2{\cdot}4$; perfect cleavage parallel (001), less perfect parallel (201). It seems likely that the presence of petalite in a beryl or emerald is due to an excess of lithium and a shortage of beryllium in the mother-solution. If these conditions have only been temporary, the newly crystallized petalite could partly be dissolved by the growing emerald. For such reasons, the inclusions of petalite both in aquamarine and emerald have the appearance of remainders with rounded surfaces rather than of well-developed crystals.

Summarizing, significant marks of growth, detectable in emerald, are: straight layers of growth following preferred crystal planes; splinters or chips of pre-existing emerald which have been, for some reason or other, broken and embedded in newly grown emerald crystals as heterogeneous inclusions; three-phase inclusions in the form of tubes parallel to the c-axis caused directly by the process of growth; other three-phase inclusions characterizing healing fissures and being regarded as the " undigestable remainders " of the mother liquor; crystals of calcite; and partly dissolved crystals of petalite.

The emerald, without any doubt one of the most desired gem stones, reveals to the interested observer a multitude of pecularities, the evaluation of which imparts a comprehensive knowledge of crystal growth.

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3. Eppler, W. F. *Ungewöhnliche Kristall-Einschlüsse, Deutsche Goldschmiede-Zeitung, 1961, 1,13-15.*
4. Larsen, E. S. and Berman, H. *The Microscopic Determination of the Nonopaque Minerals*, Washington 1934.

ASSOCIATION NOTICES

GIFTS TO THE ASSOCIATION

The Council of the Association is grateful for a copy of *Kamienie Szlachetne* (Precious stones) by K. Maslankiewicz, from S. Buzalewicz of Warsaw.

A donation of £25 to the Sir James Walton Memorial Library from Lady Walton is also gratefully acknowledged.

MIDLANDS BRANCH

A meeting of the Midlands Branch of the Association was held at the Imperial Hotel, Birmingham, on 24th January, 1961. Mr. E. Shipton presided and the guest speaker was Mr. M. Bowen who gave a most interesting talk on personal adornment from the Roman era to the present day. Mr. Trevor Solomon warmly thanked Mr. Bowen for his erudite and fascinating talk.

MEMBERSHIP

At a meeting of the Council held on 29th November, 1960, Mr. Geoffrey Hyman, Blackpool, D.1960, was transferred from Probationary to Fellowship membership.

OBITUARY

The death has occurred of Mr. Leonard Nathan, Birmingham, an Ordinary member of the Association since 1953.

TALKS BY MEMBERS

BLYTHE, G. : " Gemstones," Priory Round Table, Southend, 16th January ; " Diamonds and their substitutes," South Essex Natural History Society, 19th January, 1961.

TODD, G. E. (Miss): " Gemstones ", Housewives' Club, Purley, 10th January, 1961.

JONES, T. G.: " Gemstones ", Institute of Physics, Bristol University, 9th December, 1960; Physical Society and The Institute of Physics, London, 13th January; Nuclear Research Centre, Harwell, 8th February, 1961.

WELL, G. T.: " Introduction to gemmology ", Eighteen plus Club, Sevenoaks, January, 1961.

GILLOUGLEY, J.: " Diamonds ", Scottish Women's Rural Institute (Brookfield Branch), 20th February, 1961.

PARRY, G. (Mrs.): " Gemstones ", Women's Institute, Llanbarry, Glamorgan, 7th March, 1961.

THOMAS-FERRAND, J. (Mrs.): " Birthstones of the month ", East Anglian Television. One talk each month until August.

CAIRNCROSS, A. "Gemstones", Letham Kirk Women's Guild, 23rd January; Perth Young Unionist Branch, 9th March; Laggan W.R.I., 14th March; Mortloch Church Women's Guild, 13th March, 1961.

COUNCIL MEETING

A meeting of the Council was held at Saint Dunstan's House, Carey Lane, London, E.C.2, on Wednesday, 15th March, 1961. Dr. W. Stern presided.

The following were elected:—

FELLOWSHIP

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PROBATIONARY MEMBERS

Harber, David A., Crawley
Hewson, Robin J., Egham
Penner, Ernest W., Islington, Canada
Grumser, Pierre, London

The Council gave approval to a revised syllabus of examinations, to be introduced for the 1962 examinations.

BELGIAN GEMMOLOGICAL SOCIETY

A Belgian Gemmological Society has recently been formed and the first President is Mr. F. Duyk and the Secretary is Mr. H. Mornard both of Brussels. Mr. van de Walle, of Bruges, is Treasurer. The Society has arranged courses in gemmology and holds examinations, and students are also encouraged to take the gemmological courses held in Idar-Oberstein. Arrangements have been made to exchange information with the Belgian Society.

WAVERLEY GOLD MEDAL ESSAY

The Journal *Research* is this year sponsoring The Waverley Gold Medal Essay Competition for the ninth year in succession. The Competition is designed to encourage the scientist in the laboratory and the engineer in the production plant to express his views and translate his work into an essay that will be readily understood by other scientists, directors of industrial firms and others interested in science and technology.

The **Waverley Gold Medal,** named after and bearing the coat of arms of the late Lord Waverley, together with **£100** will be awarded for the best essay of about 3,000 words describing a new project or practical development in pure or applied science, giving an outline of the scientific background, the experimental basis and the potential or actual application of the idea to industry or their importance to society.

A second prize of **£50** will be awarded and also a special prize of **£50** for the best entry from a competitor under the age of thirty on 31st July 1961.

The last date of entry is 31st July 1961

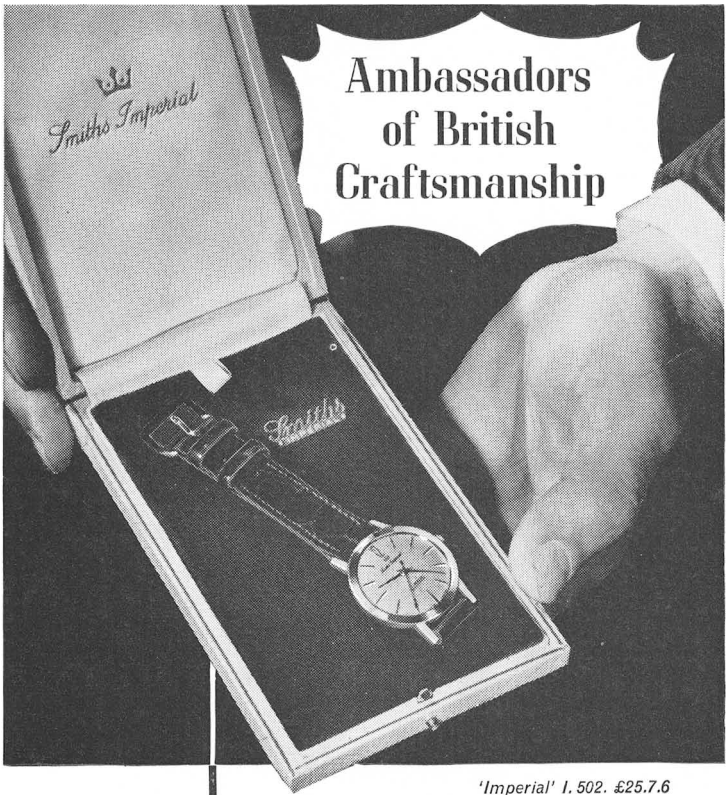

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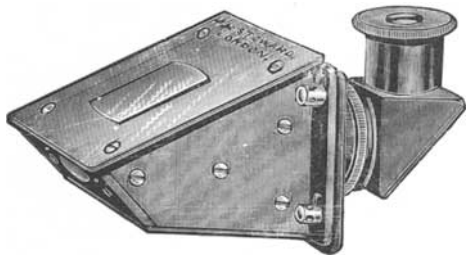

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Vol. VIII No.3 July, 1961

THE JOURNAL OF GEMMOLOGY

and

PROCEEDINGS OF THE

GEMMOLOGICAL ASSOCIATION OF GREAT BRITAIN

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COMMERCIAL COLORIMETRY OF GEMS

By SOBIESLAW BUZALEWICZ

The light, by which a stone is illuminated during observation, is a major factor in determining the colour of the stone.

The best illumination of a stone for the purpose of the determination of its colour is the natural daylight of the north sky covered with white clouds in the fore- and after-noon hours, i.e., sunlight reflected from the atmosphere and falling on the stone in a perfectly scattered form. An artificial light corresponding with the natural north-sky light is produced by the daylight lamp (pattern C CIE), which must be shapeless, exactly scattered and of the same strength as the natural light. The use of other light during the observation causes a change in the colour of the observed stone. A change in the colour of the stone is caused also by any change in the manner of the stone's illumination by the scattered light—for instance, by observation in directional light, whether parallel or convergent.

Any increasing or diminishing of the natural size of an observed stone image affects its colour. The colour of a stone, and especially of a transparent one, is a dimensional appearance, and therefore differs when observed in an image of a stone in the natural size, in an increased or in a diminished image. An increasing of the natural size of the stone image causes an apparent rarefaction of

the colour-substance of the stone, diminishes intensity of the colour, and increases its brightness until there is nearly complete disappearance of the colour. Diminishing the natural size of the examined image has the opposite effect: it apparently condenses the colour-substance of the stone, increases the intensity of the colour and diminishes its brightness. For this reason, observation of the colour should be made on the natural size of a stone image.

The manner of the holding of a stone on a white background also affects the observed colour of the stone. A stone lying immediately on a white surface is not lighted equally from all sides; the part of the surface, on which the stone lies, and which is darkened by the stone itself, is not a source of white light, and does not illuminate that side of the stone on which it makes contact with the surface. This side of the stone remains darker, consequently causing a change of the colour of the stone. To be illuminated equally from all sides, a stone must not lie immediately on the white background, but should be held a short distance away from the white surface by means of tongs in such a way that the background could be lighted over the entire surface and thus could be a source of the daylight illuminating the stone from every side. The tongs holding the stone must be thin and sufficiently long, so as not to disturb the illumination of the stone.

The colour of the environment affects the colour of the observed stone. A white background causes an apparent darkening of the observed colour of a stone. To avoid the influence of the colour induced by the white background on the colour of a stone, it is useful to make the colour-observation by means of a " contrast colorimeter ", which consists of an open conical tube, black inside and white outside.

The contrast colorimeter acts through its black inside neutralizing the influence of the white background on the colour of the observed stone; comparing the colour of an observed stone with the black and white environment, thus enabling expression of the brightness of the observed colour in the theoretical units of measurement; limiting the field of sight and eliminating disturbing optical impressions from without; concentrating attention exclusively on the observed object, thus emphasizing the details of the image. It does not increase the natural size of the observed object and does not change its colour.

The gem trade needs precise assessments of colour. General descriptions of colour which do not specify the conditions under which it is observed are ambiguous and imprecise and can cause misunderstandings and difficulties in the gem trade. The solution can be attained by an agreement on the conditions to be observed when measuring the stone's colour, which, if generally accepted, should be a uniform and precise measure. The proposed conditions could be " normal trade colour " observed in evenly scattered north sky light, illuminating a stone held above a white background, seen through the contrast colorimeter by an observer with normal colour vision.

DENSITY BY MENSURATION AND WEIGHING

Some of the most accurate density determinations ever made on solids were carried out by exact mensuration of cubes of pure quartz, followed by accurate weighing. This was done in Paris more than fifty years ago—and the resultant figure of 2·6506 at 0°C. is unlikely to be bettered.

But in ordinary gem-testing this method would be so time-consuming and of such doubtful accuracy that it hardly merits consideration in practical gemmology. Recently, however, a " turquoise " bead was submitted for test, and the fact that the diameter of the bead in millimeters was quoted accurately on the packet decided me to attempt the calculation on the weight/volume basis. The resulting density figure (2·30) was (more by luck than skill) surprisingly close to the value of 2·295 obtained later by hydrostatic weighing in ethylene dibromide.

The specimen showed a turquoise absorption spectrum; but the low density pointed to an admixture with some lighter material. Careful micro-chemical tests showed the presence of synthetic resin and the bead was thus proved to consist of a resin-bonded turquoise of the type described by R. Webster and H. Lee in their article in THE JOURNAL OF GEMMOLOGY, July 1960.

B.W.A.

THE "COLENSO" DIAMOND

by JESSIE M. SWEET, M.B.E., B.Sc., and A. G. COUPER

The "Colenso" (B.M.63153) is the largest diamond crystal in the Mineral Collection of the British Museum (Natural History). It is a pale-yellow octahedron with rounded edges (longest edge 2.5 cm., major axis 3.2 cm.) and triangular markings on its faces. It weights 133.1450 carats. Apart from the fact that it was presented by John Ruskin in 1887 in honour of his friend Bishop John William Colenso (1814-1883) of Natal, South Africa, very little was known of its history. Much poring over the works of Ruskin and the recent publications of his diaries gave very little more information although it was discovered that there are still at least two Ruskin Museums in the country in which quite a number of minerals are preserved. It was quite by chance that contact was made with Mr. R. G. Young and through him with an article in the *Strand* magazine for April, 1896[1] in which there are some notes on the history of the diamond. According to the story told there a storekeeper at the Cape in South Africa left his shop and went up country prospecting for diamonds. He invested £2,000 in a claim in which he had two partners. After some time, when the claim appeared to be valueless, two of the partners decided to give up and the third went on alone. The workings fell in on this unfortunate man and the other two, who were afraid of being accused of murder, went home. After some months the ex-storekeeper returned to give the body decent burial and found interred with it several loose diamonds of which the largest was the one now known as the "Colenso".[2] He brought this to England and sold it to R. C. Nockold of Soho—a well-known dealer in precious stones.[3]

John Ruskin, whose appreciation of natural crystals was great, was a constant visitor to Nockold's shop and was instantly apprised of the arrival of this specimen. He apparently received it on approval and sent the following letter to the Nockolds:

Brantwood, Coniston, Lancashire

"My dear Couple,—I had nearly congealed into a diamond myself with fright when I opened the box. I thought in your first letter that 130 (it was written like that) meant 13½ carats, or I

never should have asked for the loan ! I'm most thankful to have it, for it is safe here and is invaluable to me just now; but what on earth is the value of it ? I don't tell *anybody* I've got such a thing in the house.

" Ever gratefully and affectionately yours,

J. RUSKIN."

and later he asks:

" And now, please, will Mr. Nockold and you *advise* me whether to buy this diamond for Sheffield Museum or not ? "

He eventually bought it for £1,000 and he and his secretary, W. G. Collingwood, spent many weeks studying the diamond and many sketches and water-colours were made of it but unfortunately their present whereabouts is unknown.

Ruskin was the founder of the Guild of St. George which was largely financed by him and it was his original intention to present the diamond to its museum. It was at this stage called the " Guild " or " St. George's " diamond. However, he was on very friendly terms with Mr. (later Sir Lazarus) Fletcher, Keeper of Minerals in the British Museum (Natural History) and suggested that the Museum might like to have the diamond on loan. He was asked if he would like it to be called the " Ruskin " diamond but he replied:

" The Diamond is not to be called the Ruskin, nor the Catskin, nor the Yellowskin, diamond. (It is not worth a name at all, for it may be beaten any minute by a lucky Cape digger.)."[4]

In February, 1884, it was deposited in the Museum and exhibited at Professor Ruskin's own risk. In January, 1887, he decided to present it to the Museum on condition that it should always be exhibited with the following description:

" The Colenso Diamond, presented in 1887 by John Ruskin, in Honour of his Friend, the loyal and patiently adamantine First Bishop of Natal ". And that is how it became known as the " Colenso " diamond.

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1. W. G. FitzGerald. *The Romance of the Museums*, Strand Magazine, 1896, Vol. 11, p. 429.
2. According to A. Brink (25th June, 1912), chief valuer to the De Beers Consolidated Mines Co., Ltd., this stone, to judge from its characters came from one of the upper levels of the De Beers mine.
3. Mr. R. G. Young is a great-nephew of R. C. Nockold and was trained in his workshop.
4. Sandgate, 14th December, 1887. *The Works of John Ruskin* (Library edition) edited by E. T. Cook and Alexander Wedderburn, 1906, Vol. XXVI, p. lv.

A NEW PHOTOMETER

By E. J. BURBAGE and T. G. JONES

MESSRS. RAYNER'S excellent and comprehensive list of instruments might, to an outsider, seem to provide all that a gemmologist could possibly require, no matter how extensive his interests or unembarrassed his bank balance might be. Nevertheless, a sort of gemmological " do-it-yourself " virus seems endemic among the fraternity, or, to be completely fair to them, a situation frequently arises where an enquiry can only be satisfied by the construction of a device specially tailored for the occasion. An assemblage of such gadgets would, we conjecture, make a major display.

Our own latest effort at gadgetry has been suggested by the appearance on the market of a constructional kit for a photometer of a new sort. In photographic circles one had heard in recent years of new exposure meters of vastly increased sensitivity, utilizing a cadmium sulphide cell, and at the last Photokina such instruments aroused great interest. Like most Photokina innovations, the time-lag between first showing and availability on the English market

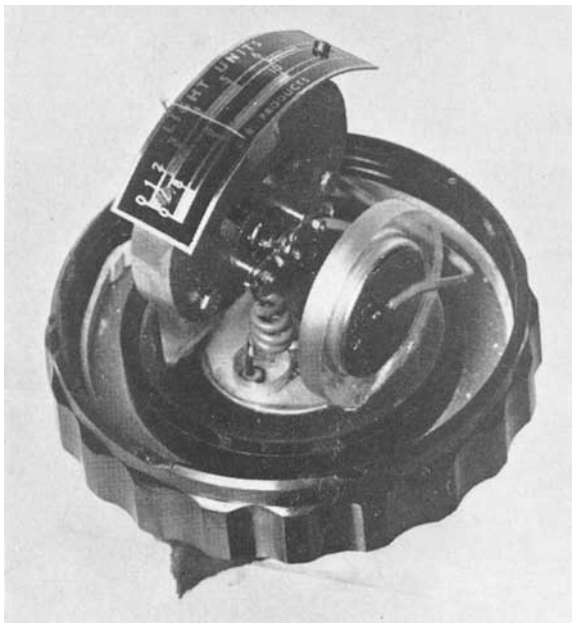

has been considerable, and so far only one quite expensive model has reached the English photographic dealers. However, an enterprising Bristol firm, G.R. Products, has recently had the sound idea of offering for sale the components for the amateur construction of such an instrument at a very reasonable figure, and, unlike most kits of this sort, one is not pinned down to a narrow predetermined constructional pattern, as no doubt the suppliers rightly foresaw that the instrument could find applications other than as a conventional exposure meter. Consequently, we were able to construct a housing to meet our own requirements with a cell at the base, the point being that one could conveniently read light values corresponding to a beam traversing an optical system or transmitted through a mineral, e.g., through a microscope or a gemstone in an immersion cell.

In photography it seems probable that meters of this sort will compete with others of the S.E.I. type in colour-printing laboratories, or in what one might loosely call " endoscopy " as for instance in photomicrography. In fact, a cadmium sulphide cell was used in an exposure meter designed for this purpose and shown at a Physical Society exhibition of a year or so back. In straightforward photography in poor lighting conditions it will probably be preferred to a visual meter, such as the Practos, by those who consider instruments of the latter type too " subjective ".

As a photometer, one would guess that the mineralogist could employ it in the comparitively new and somewhat esoteric business of " reflectance determinations ". Certainly it is of value to the gemmologist in the parallel situation where a comparison of transmitted beams needs to be made, as for instance in quantitative work on pleochroism. As assembled by ourselves, it is a simple matter to transmit a polarized beam through a dichroic gemstone to the cell at the base, and, on rotating the polar, observe the shift in needle position. An indication of the sensitivity of the instrument is given by the considerable swing of the needle for a gemstone of such moderate dichroism as peridot, and one has scope for further refinement in the use of the instrument in that a modification can be introduced for yet greater sensitivity.

After a preliminary try-out we are satisfied that the photometer holds possibilities for further work, and we consider that the instrument is sufficiently versatile to bring to the attention of fellow gemmologists who may find other uses for it.

HERBERT SMITH MEMORIAL LECTURE

THE 1961 Herbert Smith Memorial lecture was held at Goldsmiths' Hall, Foster Lane, London, E.C.2. Mr. F. H. Knowles-Brown introduced Professor W. Eppler, of Munich, who had come specially to give the lecture. He also welcomed Dr. E. Gübelin of Lucerne, who, at the end of the lecture, thanked Professor Eppler for his interesting talk.

After surveying the types of synthetics that had been made Professor Eppler said:

The so-called " Igmerald " was produced by the former I. G. Farbenindustrie at Bitterfeld. The mystery of its production was revealed last year by Dr. H. Espig in his paper " The Synthesis of Emerald ". In principle, the method is the same as mentioned by Hautefeuille and Perrey in 1888.

In the production a crucible of platinum has been used, its diameter 7½ inches, and its height approximately 2 inches. In this the so-called oxide mixture of berylliumoxide and alumina were placed. Above the mixture a melt consisting of acid lithium molybdate, in the composition of $Li_2MoO_4 . 1{\cdot}66\ MoO_3$, was added. On the top were placed some pieces of silica-glass, which furnish the SiO_2. Now, it has been found that at the optimum temperature of 800°C (equal to 1470° Fahrenheit), the oxides on the bottom of the bowl are dissolved by the melt and, by diffusion, brought upwards to the surface. Here, they act with dissolved silica particles and form clusters of synthetic emerald.

It is a crystal growth at random. To avoid this, seed crystals of synthetic emerald are placed below the surface of the melt and held in position by a platinum sieve. Thus, the seeds are situated in the region of preferred crystallization, where the three components of the emerald are joined and react with each other. Besides the formation of emerald crystals, the seeds enlarge at a certain rate.

The process described depends upon a well defined concentration of the oxides in the melt. As the concentration diminishes in the same rate as emerald is grown and the seed crystals enlarged, it is necessary to add from time to time new material to the amount of the oxide-mixture—in practice every second day. This is carried out by a vertical tube of platinum in the centre of the crucible which, by the way, also bears the sieve. A removable funnel of plati-

num easily allows the additional feeding material to be brought down the tube to the bottom of the crucible, even if the apparatus is in action. Each run of crystallizing or synthesizing lasts between two and three weeks. Then, the enlarged emeralds are removed from the melt, cleaned from smaller and undesired crystals by polishing the crystal faces and, according to their size, they are prepared for another run or given to the cutter.

The economic side of this process is very interesting. The time it takes to synthesize an emerald crystal, big enough to be cut into a one-carat-stone, is calculated by Espig to be one year. Most probably, this long time has been the reason why the Igmerald has never entered the regular market.

My own experiments to synthesize emerald have been done to find an answer to two questions. Firstly: what is the reason for the healing fissures in synthetic emerald ? Secondly: are the crystal inclusions in synthetic emerald really phenacite ?

The experiments carried out by me followed the paper of Hautefeuille and Perrey, which was published in the Comptes Rendues in 1888. Small crucibles were used, three of which could be placed simultaneously in an electric heated furnace with automatic control of temperature. For most of the time, three such furnaces were working.

The melt consisted of acid lithium molybdate, and the time of each run was between two and ten weeks. The size of the largest

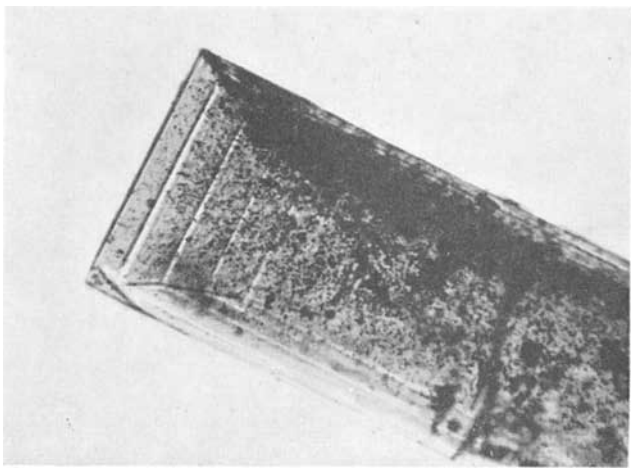

FIG. 1 *Zonal structure in synthetic emeralds; 65x*

emeralds thus produced was up to two millimeters or nearly one tenth of an inch. This was found to be large enough for further investigation.

To the first question a ready answer was found: it depends on the rate of growth, if healing fissures are produced or not.

The regulation of the growing rate is easily done by increasing or lowering the temperature, or by altering the concentration of the melt, or by adding crystallizers.

During the experiments it was found that a regular adding of the feeding material caused zonal growth (Fig. 1). Some emeralds preferred the direction of the c-axis, as in this direction, on the basal plane respectively, more material is deposited by crystallization than on the faces of the prism zone. The relation between the length and the width with these crystals is equal to 2·64 : 1 (Fig. 2). Such growth with one preferred direction can often be seen in natural emeralds. Here, an intermittent crystallization is marked by different colouring in different zones (Fig. 3). The growth of this natural emerald occurred by " surges " of the feeding material which, additionally, contained more or less of the colouring agent.

The second and still unanswered question was: are the crystal inclusions in synthetic emerald really phenacite ?

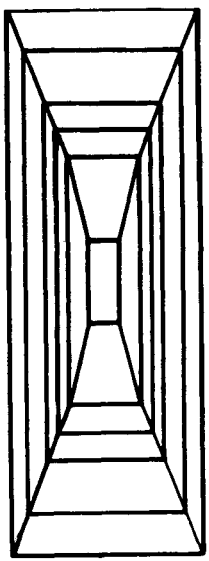

FIG. 2 *Growth zones in synthetic emerald are in a length to width ratio of* 2·64 : 1

To find an answer, it seemed useful also to synthesize the phenacite. This was done in the melt under the known conditions. One of the results is shown in Fig. 4. Besides these, elongated prims of phenacite and rounded groups of very small phenacite crystals are obtained with the same habit as they occur in the Igmerald and in the synthetic emeralds made by Chatham. It may be assumed that the different habits of phenacite are due to a difference in the growing rate, whereas the clusters have most probably been crystalized quickly.

In each case the synthetic phenacite has been tested by conventional means, including an X-ray analysis. And now, the second question can be answered with the confirmation, that the inclusions of phenacite in synthetic emerald are synthetic phenacite.

Some observations when synthesizing emerald from the melt may be of general interest. First is the easy crystallization at the beginning. After twenty-four hours, the greatest part of the oxides has been crystallized into emerald. A week or ten days later, the crystals have a mean size of approximately 250 microns. Then,

FIG. 3 *Growth lines in natural emerald parallel to basal plane; 22x*

the growing rate drops drastically, and to obtain crystals with a length of 0·5 mm and up to two millimeters, the melt must be heated for one month or more.

Another feature of synthetic emeralds obtained from the melt was a regular intergrowth or twinning (Fig. 5). It is known that twins of natural beryl are very rare and when they occur the face (1101) is the twinning plane. The twins of the synthetic emerald are not yet determined, but most probably they follow the planes of steep hexagonal bipyramids. Finally, two-phase inclusions can be observed in this particular kind of synthetic emerald (Fig. 6).

After having acquired some experience with experiments, a starting material of natural beryl instead of the oxides was tried. Crushed natural beryl was used, together with a little chromium oxide. After three days, it was dissolved entirely by the melt, and a multitude of six-sided plates of *tridymite* were grown. By maintaining the melt on the working temperature for a fortnight's time, little crystals of emerald appeared which grow very slowly. The experiment reveals that it is possible to recrystallize natural beryl into synthetic emerald by using a melt. But it is not possible to have a seed crystal of natural beryl enlarged in a melt with added oxides, as the natural beryl is disintegrated at a temperature of 800°C and dissolved by the melt. This has been proved many times. Therefore, no " cultivated emeralds ", to use the incorrect name for Chatham's synthetic stone, can be crystallized from a natural emerald with the diffusion melt method.

In his paper on the synthesis of emerald, Espig suggests the use of a lithium-molybdate melt as a solvent, by which other crystals can be obtained. He reports to have grown by this method the following synthetic crystals—phenacite, willemite, zircon, garnet, magnetite, sphene, rutile (brookite).

While the Igmerald and the synthetic emerald of Chatham are true synthetics, it is not quite so with the " coated beryl " made by J. Lechleitner. I imagine that you are familiar with the paper of Holmes and Crowningshield about the so-called " Emerita" which paper an abstract appeared in THE JOURNAL OF GEMMOLOGY. It contains worthwhile detail about this material.

The method which is used is a hydrothermal one. An autoclave is used, in which the coating takes place. The conditions of the process are not known in detail, but they can be guessed easily.

After the filling of the bomb with the three oxides BeO, Al_2O_3 and SiO_2 in the required proportions and after adding chromium-oxide for the green colour, the completely cut beryls—mostly of poor colour—are placed in it. Then water is added in such a quantity that at the chosen temperature a pressure of approximately 700 to 1,000 atmospheres (or 10,000 to 14,000 pounds per square inch) is realized. The temperature will be, most probably, about 450 to 500°C. or 840 to 930° Fahrenheit.

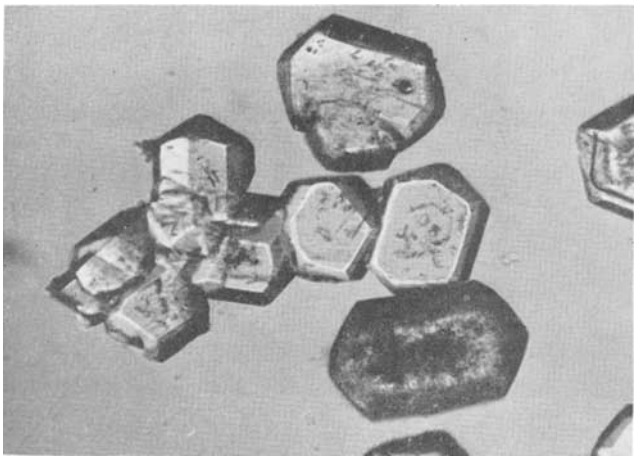

FIG. 4 *Phenacite crystals from a lithium-molybdenum melt; 120x.*

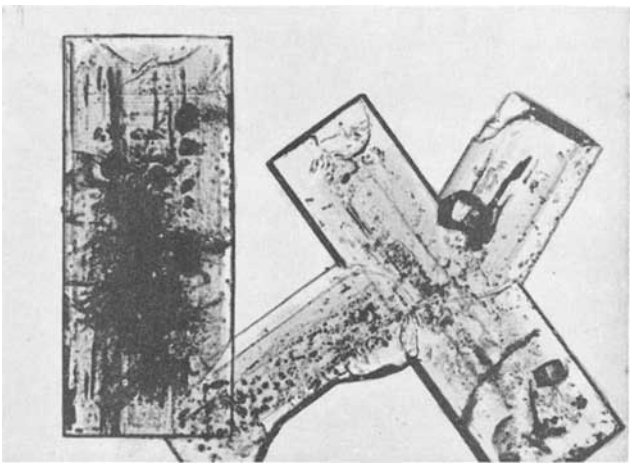

FIG. 5 *Twins af synthetic emerald with inclusions of phenacite; 65x.*

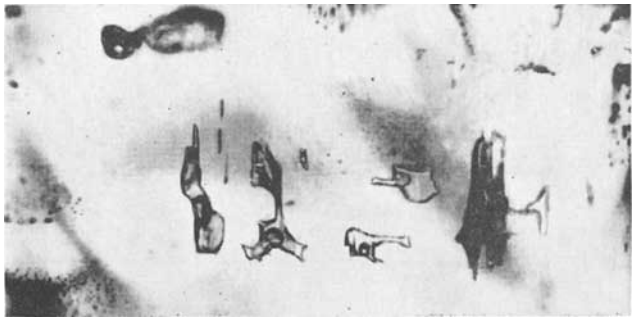

FIG. 6 *Two-phase inclusions, along the prism zone, in synthetic emerald; 220x.*

The conditions are super-critical with respect to water. The coating is a crystallization of new material, and it has to be regarded as a continued growth of the beryl. Only the emerald-green colour of the deposited material and its synthetic nature makes it different from the natural core. The thickness of the coating is different according to the crystallographic directions. On the average it is less than half a millimeter on the repolished stones.

A particular feature of the new material are fine lines which can be observed with a pocket lens and, better still, under the microscope. They have been mentioned by Holmes and Crowningshield and by Dr. E. Gübelin in *Gems and Gemology* and in THE JOURNAL OF GEMMOLOGY. The lines are parallel to the basal plane of the coated beryl, and they offer a reliable means of easily identifying such stones.

The lines represent healing fissures, which are broad enough to be present after the stone has been repolished. In most of the cases, they are crossed by another system of healing fissures, which are parallel to the prism zone of the beryl. A second type of inclusion consists of little tubes parallel to the c-axis. Mostly they start from a solid inclusion, like hematite or ilmenite. They are always pointed at one end. They contain a liquid and a they start from a solid inclusion, like hematite or ilmenite. Also they are always pointed at one end. They contain a liquid and a gas bubble and by this they represent typical three-phase inclusions.

Similar inclusions, which remind one of " tie-pins ", are present in the synthetic emerald made by Nacken. Here, a tiny crystal of synthetic emerald has been the cause of the formation of

the tubes, which, by the way, indicate the direction of growth of the host crystal. Such primary inclusions of synthetic emerald can also be present in the coating of the Lechleitner stones, but in most of the cases they are not.

The boundary between the beryl and the coating of synthetic emerald is well defined by the green colour. Finally, it is easy to understand, that the big core may have inclusions which are typical for beryl.

One difficulty remains: how should the product, to be sold as " Emerita ", be described ? It is a beryl or an aquamarine, with a thin layer of synthetic emerald. For the moment, the expression " synthetic-coated beryl " seems to be the best, even if it does not satisfy every aspect.

EKANITE

Ceylon Gemmologist Discovers New Mineral

By R. KEITH MITCHELL

INEVITABLY the course of years and the spread of gemmological knowledge has widened the field of rare minerals which may be used as gems. In many cases these are already known to mineralogists but have suddenly been found in cuttable well-crystalized gem quality previously unknown.

In other and far rarer cases they are entirely new minerals, unknown until they are found in gem quality crystals. Brazilianite was an example of this; an unusual one in that comparatively large crystals were found in quantity. Taaffeite is another example which springs to mind, a gem which exists in three known specimens totalling less than 2·5 carats in weight. A rough crystal of this mineral has yet to be recognized. The gem was discovered as a cut stone by the Dublin gemmologist Count Taaffe after whom it was named. Another mineral, which exists in only two known specimens, is cuttable but is preserved in its crystal form. This is Painite, named after A. C. D. Paine, a mining geologist, who discovered it.

So it can readily be seen that in the world of minerals new ones which may be used as gems are of extremely rare occurrence and it is always an event when one is found and is recognized as hitherto unknown by the finder. When this discovery is made by a gemmologist rather than a mineralogist the occasion is very remarkable.

In 1953 I received from my friend, F. L. D. Ekanayake of Colombo, Ceylon, a round cabochon-cut gem of dark green colour, which exhibited a faint four-ray asterism. Mr. Ekanayake is a good and painstaking gemmologist with a flair for the unusual and an almost inspired ability to find and identify the rarer stones in the gem gravels of Ceylon. His letter accompanying the stone on this occasion stated quite simply " I am sure that this is a new mineral ".

The stone was a dark zircon-green in appearance and a straightforward examination quickly established that it was amorphous, with S.G. 3·28 and R.I. 1·60, and that the asterism was due to reflection from large numbers of short acicular inclusions oriented at right-angles in two directions.

The colour and the amorphous structure suggested that the stone was some kind of natural glass and, at my request, Mr. B. W. Anderson, seeking confirmation of this, submitted the gem first to the British Museum (Natural History) and then to Dr. D. K. Hill, of the Sheffield University Department of Glass Technology.

An early spectrum analysis at the Chamber of Commerce Laboratory had revealed silica, calcium and traces of lead, which according to Anderson made it virtually certain that the material was an artificial glass. And at this stage we had more or less accepted it as such and I reported it as a glass in a short paper in this journal at that time.* But at the back of everyone's mind the fact of the oriented inclusions still lingered as an incongruous feature, which was as yet unexplained. Ekanayake, informed of this, stuck to his original contention with admirable tenacity and still said that the substance was mineral and a new one.

D. K. Hill, in correspondence with B. W. Anderson, at first confirmed the glass idea and then, during a spectrographic analysis found the radio-active element thorium present in large quantity. It is a matter of comment that he *estimated* at this stage that the thorium oxide content was about 26 to 27% of the total. Subsequent chemical analysis of another specimen at a much later date gave a figure of 27·6%, a tribute to the accuracy of this estimate.

Anderson at once realized that the material could not be either artificial or a glass and that the lead, which was present in a very much smaller quantity than had at first been thought to be the case, was in fact the result of the disintegration of the thorium to its end product. It was now obvious that the stone was a metamict mineral analogous to low-type zircon, which it resembled in colour.

At this point in the investigation an attempt was made to return the slice, which had been taken from the stone for experimental purposes, to its original crystal form. To this end the fragment was heated to an increasing series of temperatures, which at first lowered the density but did little else. Unfortunately a final heating to 1000°C failed to produce the desired result and altered the material to an opaque putty-coloured mass on which little further work could be done. The remains were sent to the British Museum but apparently were not investigated any more at that time.

*Journal of Gemmology. Vol. IV No. 5, 1954

There the matter rested for some years with my friend in Ceylon still hoping somewhat sorrowfully that his " new gem " would obtain some recognition. Meantime one other specimen of the material was received from a West of England jeweller by the laboratory, but was not used for the chemical analysis which was now lacking from the investigation.

Early in 1959 I received three further specimens of the mineral from Ekanayake. These included a large water-worn piece of rough and were all from the same gem pit at Eheliyagoda, Ratnapura, as the original specimen. These were passed to the Laboratory but, for a variety of reasons, it was not possible to get a final analysis done until early this year, when I handed these three pieces of the material to Dr. G. F. Claringbull, Keeper of Minerals at the British Museum (Natural History), for the difficult matter of micro-analysis and the elimination of known minerals.

The results of this investigation were finally published in *Nature* (June 10th, 1961) and the mineral at last established beyond doubt as a new one. Details are given below. The name Ekanite has been given to the gem in recognition of the gemmologist who found it more than seven years ago and who never lost faith in his discovery.

The results of the long investigation, as published in *Nature* show the chemical composition to be (Th, U) $(Ca, Fe, Pb)_2Si_8O_{20}$. The uranium, which is about 2% of the total, was a puzzling constituent, which was resolved only in the last stages of analysis.

Density and refractive index are quoted as 3·280 and 1·5969 respectively. Heating and recrystallizing produces an ordered atomic lattice with tetragonal symmetry. Because of the directions of the oriented inclusions it had already been assumed that the mineral was originally tetragonal.

Finally, it should be realized that ekanite is extremely rare and, even with all the rough so far found, converted to cut stones, not more than about a dozen specimens are known.

Gemmological Abstracts

GÜBELIN (E.). *Farbe und künstliche Farbveränderung von Diamant.* Colour and artificial coloration of diamond. Deutsche Goldschmiede-Zeitung, Vol. 59, No. 2, February 1961, and No. 4, April 1961.

Really colourless diamonds are chemically pure and very rare and expensive. The cause of colour in diamonds is not known, but is presumed to come from the presence of foreign atoms or from local irregularities in the atomic lattice. At first it was believed that all colour in diamonds must come from some trace element, but this was doubted by the Indian scientist Raman who made his experiments mainly with yellow and brown stones and found the colour to be mainly caused by irregularities in the lattice. New methods using very sensitive spectrographs have shown a millionth of a trace element to be sufficient to give diamond some colour. Most diamonds were shown to contain about 14 different elements. Correlation in the case of a pink diamond is shown by the absorption spectra. From reports about synthetic diamonds it is assumed that the colour is determined by pressure and temperature. In order to improve the colour of a diamond many experiments with X-rays, cathode-rays and radium have been made. It has now been shown that it is possible to colour a white or pale diamond blue, green, yellow, brown or even red by bombarding it with deuterons, protons, neutrons, alpha-particles or gamma rays. Various experiments are described.

The most important method of colouring diamonds is by means of neutron bombardment. The method is described in detail. If a diamond thus artificially coloured is heated later on, the green colour is reduced either to a pale green or yellow-brown depending on the length of bombardment. Natural green and black diamonds do not loose their colour by thermal treatment. It has been shown that the original colour of the diamond cannot be reconstituted, white diamonds keeping a slight yellow tinge, however high the temperature of the thermal treatment. The importance is stressed

of finding methods of differentiating between naturally coloured and artificially coloured diamonds. It has been seen in many cases that the artificial colour is very thin and is removed when the surface is polished. Those green stones artificially coloured by bombardments and whose surface colour is very thin, have a peculiar colour reflex, in the form of a dark edge inside the girdle when the stone is put with the table onto a white piece of paper. If the stone has been bombarded from the other side, this colour reflex can be observed as an umbrella-like formation in the culet. For newer types of artificial bombardments, the differences in the absorption spectrum are of help. Details of the differences in this absorption spectrum are given.

E.S.

SCHLOSSMACHER (K.). *Beryll mit Auflage von synthetischem Smaragd.* Beryl with synthetic emerald surface. Zeitschr. d. deutsch. Gesellschaft f. Edelsteinkunde, No. 33, pp. 5-7. 1960.

Article about the method by J. Lechleitner (Journ. Gemmology, Vol. VIII, No. 2. 1961) of crystallizing synthetic emerald onto a pale beryl. Various methods of detection are discussed.

E.S.

JAKOB (E.). *Die Saeurebestaendigkeit von synthetischem Rubin.* Acid resistance of synthetic ruby. Zeitschr. d. deutsch. Gesellschaft f. Edelsteinkunde, No. 33, pp. 7-8. 1960.

In the bearing industry the stones were fixed in position during their working by means of shellac, etc., which afterwards had to be removed by acids. These acids were shown to attack the surface of the synthetic rubies. A microphotograph of such surface is shown. It has been found that the synthetic ruby bearings are not attacked by concentrated nitric acid, but mainly by concentrated sulphuric acid.

E.S.

HOLMES (R. J.): CROWNINGSHIELD (G. R.). *New emerald substitute.* Gemmologist, Vol. XXIX, No. 353, pp. 224-233. December 1960.

The article on the Lechleitner emerald coated beryls reprinted from the original in Gems and Gemology. (Abstracted Journ. Gemmology, Vol. VII, No. 8, p. 309. October 1960).

R.W.

SCHLOSSMACHER (K.). *Die Entstehung der Achate.* Formation of agates. Zeitschr. d. deutsch. Gesellaschaft f. Edelsteinkunde, No. 33, pp. 11-16. 1960.

E.S.

SWITZER (G.). *35th Annual report of the diamond industry 1959.* Jewellers' Circular-Keystone, 1960.

Although world production was less than in 1958, the year reviewed was a prosperous one for the diamond industry. The survey follows the pattern of previous years.

S.P.

ANGUS (J.). *Cultured pearl problems.* Gemmologist, Vol. XXX, No. 354, pp. 1-2. January 1961.

The report of an unusual pair of cultured pearls which had apparently been formed of two halves of, maybe, blister pearls. They weighed 66·56 and 65·20 grains respectively and that the core was mother-of-pearl was proved by Laue diffraction pattern. 1 illus. R.W.

DOWDING (R. R.). *Opal in the Eulo district.* Australian Gemmologist, No. 1, pp. 12-15. November/December 1960.

An interesting and informative article on the types of opal found in the Eulo district. A number of unlisted fields are mentioned, particularly the Blackgate field and others on the Toomooroo holdings. The many different types of opal found in the Yowah field are discussed. Some notes are given on the seeking of opal and the article closes with a poem written by the authoress.

R.W.

FISCHER (W.). *Die Technik der Jade-Bearbeitung in China.* The technique of working jade in China. Deutsche Goldschmiede Zeitung, Vol. 59, No. 2, pp. 69-72. February 1961.

Jades were already worked in China from 1122-246 B.C. while in Turkestan during the Han-dynasty (202-220 B.C.) nephrite was worked. Details of the production methods are not well known, although illustrated descriptions were published in 1176 and again in 1341. Originally the centre of jade working was Soochow, and since 1644 in Peking. The illustrations now published are taken from a work published in 1906 and notes taken in 1954. The illustrations show (1) crushing, washing and sieving of the polishing powder, which consists of emery, almandine, quartz sand and

ruby dust; (2) sawing of the rough jade; (3) sawing of the smaller pieces; (4) forming of the jade object; (5) first polishing of the jade. The surface is then even enough to draw on it the ornamentation; (6) hollowing the material. This is done by means of a round cylindrical steel drill; (7) engraving of the ornaments. This is done by means of small steel wheels which can be either round with sharp edges (ting-tzu or nails) or with thick edges (yat'o); (8) If the ornaments consist of lace work, a diamond drill is now used; (9) In this case a diamond with bow is used; (10) the drilling of holes into small objects, say mouth-pieces for pipes or small boxes is done underwater by a diamond drill; (11) shows the wooden polishing lap, which is impregnated with diamond dust or paste. For very fine work a small lap is made out of the skin of a pumpkin; (12) shows a leather lap for the finest polish. This consists of four or five layers of leather sewn together with a linen thread. The diameter can vary from 2-3 inches to a foot.

E.S.

EPPLER (W. F.). *Ungewöehnliche Kristall-Einschluesse in Aquamarin.* Unusual crystal inclusions in aquamarine. Deutsche Goldschmiede-Zeitung, Vol. 58, No. 12, pp. 736-738, 1960, and Vol. 59, 1, pp. 13-15, 1961.

Inclusions of apatite in aquamarine are recognizable by their hexagonal crystallization, by their R.I., which is about 1·63-1·64, i.e. higher than that of aquamarine, and by their basal cleavage. There are five photomicrographs illustrating apatite in aquamarine and four showing mica inclusions in aquamarine. Mica is found as an inclusion in the emeralds of the Urals, Transvaal and from the Austrian Habachtal. In aquamarine they seem to be rare.

Two photomicrographs show petalite inclusions. These are small, doubly refractive crystals, which have a tumbled look. These inclusions are probably formed by an excess of Li_2O in the mother liquid. Usually these petalite inclusions in aquamarines are rare and very small, so that their determination is difficult. One of the photomicrographs shows a fairly large inclusion of this type. Inclusions of haematite are a great rarity. A few photomicrographs are shown. The author mentions the existence of various other undetermined inclusions in aquamarines, and hopes that soon they will all be known and recognized.

E.S.

BURKART (W.). *Das Trommeln von Bernstein.* Tumbling of amber Deutsche Goldschmiede-Zeitung, Vol. 59, No. 1, pp. 21-22. January 1961.

The article describes the production of tumbled amber beads. The diameter of the tumbling drum is about 60-70 cm. These drums are filled to nearly half their capacity with a mixture consisting of two-thirds tumbling balls and about one-third amber. The process takes about 10 hours.

E.S.

ANON. *Neues vom Tuerkis.* News about turquoise. Zeitschr. d. deutsch. Gesellschaft f. Edelsteinkunde, No. 33, p. 16. 1960.

The surface of pale turquoise is treated with acid and a layer of blue resin poured over the stones, thus impregnating the attacked surface. When polished the treated stones are very difficult to discern with the naked eye.

E.S.

HASCHMI (MD Y.). *Der orientalische Tuerkis.* Oriental turquoise. Zeitsche. d. deutschen Gesellschaft f. Edelsteinkunde, No. 33, pp. 16-24. 1960.

Detailed list of occurrences in the East with bibliography of 34 items.

E.S.

SCHLOSSMACHER (K.). *Falschbezeichnung von Zuchtperlen.* Wrong nomenclature of cultured pearls. Zeitschr. d. deutsch. Gesellschaft f. Edelsteinkunde, No. 34, pp. 5-6. 1961.

Cultured pearls are often named " real cultured pearls ". The author draws attention to this wrong nomenclature.

E.S.

BANK (H.). *Smaragdvorkommen in Kolumbien.* Emerald occurrences in Colombia. Zeitschr. d. deutsch. Gesellschaft f. Edelsteinforschung, No. 34, pp. 7-23. 1961.

Occurrences of emerald outside Colombia in Africa (Egypt, Transvaal, Rhodesia), in Asia (Urals and India), in Europe (Austria and Norway), unimportant finds in Australia and North America and in South America (Brazil) are mentioned. A detailed description and map of the mines in Columbia are given, as well as historical data of the mining in the Colombian emerald mines, mainly in Chivor, Muzo and Coscuez, which are near to Muzo and

also belong to the Colombian nation. Two small new mines are mentioned, Buenavista and the Mine de Vega de San Juan. The mines are described from a geological point of view, and the production and importance discussed. The article ends with a short survey of the chemical and physical properties of emerald.

E.S.

TISDALL (F. S. H.). *Spessartite garnet from California.* Gemmologist, Vol. XXX, No. 357, pp. 61-62. April 1961.

Reports the examination of some spessartite garnets from the " Little Three Mine ", Ramona, California. The stones were a yellowish orange in colour and the density was found to be 4·17. The refractive index was greater than 1·81 (above the limit of the refractometer), and the absorption spectrum is discussed. Comment is made on the peculiar inclusions.

2 illus. R.W.

JOHNSON (P. W.). *All about emeralds.* Lapidary Journ., XV, 1. 1961.

A general survey covering both natural and synthetic gems.

S.P.

JAHNS (R. H.). *Gem stones and allied materials.* Chapter 18 in Industrial minerals and rocks. Amer. Inst. Mining, Metall., and Petrol. Engrs., pp. 383-441. 1960.

Following the introductory remarks on terminology and classification the properties of 103 gem minerals and other gem materials are tabulated and the influence of these properties on preparation and on both decorative and industrial uses are discussed. The origin and geologic occurrences of gem minerals are outlined and the geographic distribution of gem materials is tabulated (though one might express surprise at the listing of the British Isles as having appreciable commercial output of gem varieties of apatite and axinite): the problems of prospecting, mining and concentrating are briefly noted. Following a statement on synthetic and imitation gem materials, the production, cutting, consumption and marketing of natural gemstones are reported and the comparative retail values of cut but unset gemstones, exclusive of diamonds, correlated with colour, size and other features, are listed.

20 Figs. R.A.H.

TWINING (LORD). *A history of the crown jewels of Europe.* London (Batsford), 1960, 230 pls. Price £16 16s.

R.A.H.

BENSON (L. B.). *Developments and highlights at the Gem Trade Laboratory in Los Angeles.* Gems and Gemology, Vol. X, Nos. 3-4, pp. 75-80 and 92. Fall 1960 and Winter 1960/61.

A very full discussion on colour-dyed and colour-treated pearls and upon the correct terminology to use in reporting them. The results of many experiments are given. In the case of treated pearls the effect was inferred to be due to the darkening of the conchiolin content by chemical means. The recutting of a flat diamond which had been damaged, yet maintained its value, is mentioned. The results of the examination of a number of pieces of jewellery which had suffered fire damage are reported. Plastic-bonded and paraffin-treated turquoise is discussed. Exceptional stones examined by this laboratory were a $\frac{3}{4}$ carat cat's-eye demantoid garnet and a 2·78 carat benitoite.

4 illus. R.W.

GÜBELIN (E. J.). *More light on beryls and rubies with synthetic overgrowth.* Gems and Gemology, Vol. X, No. 4, pp. 105-113. Winter, 1960/61.

A survey of the hydrothermal rubies made by the Bell Telephone Laboratories, and those produced by Carroll Chatham. The method and the apparatus used to grow the Bell crystals are described. The physical and optical characteristics of Chatham rubies, which use a " seed " of Burma ruby, are similar to those of natural rubies. Distinction lies in the inclusions of the overcoat of synthetic ruby. The writer admits that it is not easy to observe these features. The article continues with comments on the Lechleitner emerald-coated beryl called " Emerita ". The characters of such stones are similar to those of natural beryl and do not have the lower density and refractive index as do the Chatham synthetic emerald. Again it is the inclusions seen in the overgrowth which are the dominant features indicating the nature of the stone. These are more easily observed than in the case of the above-mentioned ruby. One of the safest tests may be by lateral examination in a liquid having an index of refraction about 1·57, when the coating will betray itself by the dark green relief.

18 illus. R.W.

WEBSTER (R.). *A new ultra-violet lamp.* Gemmologist, Vol. XXX, No. 357, pp. 67-69. April 1961.

Describes the characteristics of a British twin fluorescent tube lamp (the Allen lamp) for long-wave ultra-violet light. Comparison is made with the American " Burton " lamp, which is similar in major characters. Reports are given on experiments designed to show the efficiency of the Allen lamp for various tasks.
2 illus. P.B.

RAAL (F. A.). *Artificial colouration of diamond.* Gemmologist, Vol. XXX, No. 357, pp. 63-66. April 1961.

Electrons with energy of about one million volts will give a bluish colour provided the stone is kept cool during irradiation. Higher energies give a blue-green colour. Colouration is only skin-deep. Heating such blue-coloured stones at 300°C results in a limited reduction of colour and at 600°C the colour changes to green and finally to a permanent yellow. An explanation of " radiation damage " is given. The article concludes by giving some tests for artificial colouration and the writer comments on the " coating " of diamonds by a film of dyestuff in order to whiten off-coloured diamonds.
1 graph. R.W.

ANON. *The Maori Heitiki.* Australian Gemmologist, No. 3, pp. 5-6. March 1961.

This article, reprinted from an illustrated booklet issued by Whitcombe & Tombs Ltd., discusses the legends of the Heitiki, the neck pendant of grotesque human form used by the Maori people for adornment.

R.W.

TUFFLEY (J. R.). *The relationship between refractive index and specific gravity.* Australian Gemmologist, No. 3, pp. 7-9. March 1961.

An investigation of the relation between refractive index and specific gravity of gemstones. Resort is made to a statistical method —the " method of mean squares "—to produce a straight-line graph. The part the atomic lattice plays in determining the refractive index and the density of a solid substance is explained. The gemstones which form exceptions to the straight-line graph are discussed.
1 graph. R.W.

CROWNINGSHIELD (G. R.). *Developments and highlights at the Gem Trade Laboratory in New York.* Gems and Gemology, Vol. X, Nos. 3-4, pp. 67-74 and 92; 114-123. Fall, 1960, and Winter, 1960/61.

Discusses some of the specimens submitted to the laboratory in New York. These include a 48·12 grain freshwater pearl from Ilinois and a carved pink topaz in which difficulty was encountered as normal testing techniques were not able to be carried out and short-wave ultra-violet light was used as a convincing answer. A suite of cat's-eye blue topazes is referred to. Two " cave pearls " (pisolites) were examined and on being X-rayed showed a darker spot, which was considered to be a single calcite crystal. A soudé type stone of emerald-colour was found to consist of two pieces of beryl which showed the inclusions to be continuous through the two parts. There is a report of a radium-treated diamond set in an old ring and comments are made of the possibility of the danger of the legal liability of anyone who sells such a stone. Other stones which were sent in for testing were a brown scheelite, a cut azurite, a pink scapolite, a purplish star-sapphire, a translucent variscite, a 32-carat andalusite, a cut crocoite, a green idocrase cameo and a purple glass cameo. Marble cameos also had been submitted. A note is given on pearls dyed rosée, pink synthetic sapphires showing " needles " and round beryl beads artificially coloured by green plastic placed in the string canal. More and better quality non-nucleated cultured pearls are reported. A large blister pearl having a hollow centre filled with small pearls and buckshot, and the use of black coral in jewellery are mentioned. A note is given on burned diamonds and on the schiller seen on some natural emeralds. A new synthetic star-stone is reported. This consists of a cabochon of synthetic corundum or spinel on the base of which is engraved three sets of fine lines, and this cabochon is backed with a metallic film on a ceramic base.

29 illus. R.W.

BENSON (L. B.). *Planning and using your new diamond room.* Gems and Gemology, Vol. X, No. 4, pp. 99-104 and 127. Winter, 1960/61.

Describes lay-outs for a *diamond room* in a retail establishment. The types of decoration, use of mirrors, illumination and furnishings are discussed. The diamond sales room should be provided with

suitable instruments, such as a " Diamondscope " or " Gemolite " and a " Diamondlite ".

1 illus. R.W.

WEBSTER (R.). *Tanganyika tourmaline.* Gemmologist, Vol. XXX, No. 356, pp. 41-45. March 1961.

A green tourmaline, first suspected to be chromiferous owing to its red residual colour through the Chelsea colour filter, had been found by Professor Bassett, to be vanadiferous and not chromiferous. The stones emanate from the Gerevi Hills in Tanganyika. A number of such stones were examined by the writer and the data gained from this examination are set out in the paper.

3 illus., 1 map. P.B.

WEBSTER (R.). *Fluorescence in gemstone identification.* Lapidary Journal. Vol. XIV, No. 6, pp. 492-509. February 1961.

The article commences with an outline of the history and the nature of photo-luminescence. The difference between long- and short-wave ultra-violet lamps, and their respective filters, are discussed. The differential responses of substances to stimulation from different wavebands of ultra-violet light is mentioned and the " crossed-filter " technique described. The luminescent response shown by some thirty gem materials is given, and there is a short list of references. A useful article which is enhanced by a double-page coloured plate of fluorescing minerals.

8 illus. P.B.

SHREVE (R. N.). *Jade cutting to-day.* Gems and Gemology, Vol. X, No. 3, pp. 81-89. Fall, 1960.

The story of a jade carving works in Hong Kong which was instituted by a Chinese refugee from Pekin. Some history of jade carving is given, the various processes explained, and the time taken to produce jade carvings is mentioned. Notes on the origin of jade minerals are given. Minerals other than jade, such as rose-quartz, African tiger's-eye, South American green quartz, amethyst, rock crystal, agate, turquoise and lapis-lazuli are carved. There is another group of hardstone carvers at Taipei in Formosa.

11 illus. R.W.

PING-HENG (P.). *Jade carving.* Australian Gemmologist, Vol. 3, No. 3, pp. 13-17. Sept. 1960.

A general article on jade carving. It deals mainly with the historical and folklore aspect of the designs and of the blending of the colour streaks in the rough material to bring out effects in the carving. Jadeite from Yunnan, nephrite from Sinkiang, coral from Taiwan, amethyst and smoky quartz from Hopei Province, and agate from Inner Mongolia are the materials used in carving. Some notes on carving methods are given. R.W.

WIRTH (A. A.). *Alexandrite.* Australian Gemmologist, No. 2, pp. 11-12. Jan./Feb. 1961.

A popular article on the species chrysoberyl, with particular reference to alexandrite. The ethics of naming as alexandrite any green chrysoberyl with only the slightest trace of colour change is commented upon. The simulation of alexandrite by andalusite and by synthetic corundum and spinel is mentioned, and the localities where chrysoberyl are found are given. R.W.

ANDERSON (B. W.). *Nitrogen in diamond.* Gemmologist, Vol. XXX, No. 355, pp. 21-22. February 1961.

The article is based on the paper by W. Kaiser and W. L. Bond in which these workers report that they had found the element nitrogen in Type 1 diamonds, and to this they ascribe the main absorption effects of this type of diamond. Kaiser and Bond found that the strength of the 78,000Å band in the infra-red is exactly proportional to the strong band in the ultra-violet at 3060Å, and, further, that the strength of these bands is proportional to the nitrogen content, no less than 0·2% of nitrogen being found in Type 1 diamonds. A test for the ultra-violet bands in Type 1 diamonds using a short-wave mercury lamp and elementary photographic apparatus is mentioned. R.W.

HARDY (E.). *Diamond through the ages.* Gemmologist, Vol. XXX, No. 355, pp. 39-40. February 1961.

A general story of the use of diamond from early times. Some notes are given on the discovery of the method of cutting diamond by its own powder, and on the chemical nature of the stone. Notes are given on the mining areas and on the Israeli diámond cutting industry. R.W.

ANON. *The art of the Tassies.* Gemmologist, Vol. XXX, No. 355, pp. 36-37. February 1961.

James and William Tassie made, mostly in a readily fusible glass, a vast number of medallions and reproductions of intaglios. Over 20,000 Tassie gems are in the National Gallery of Scotland.

R.W.

ZWAAN (P.). *Some notes on the identification of the pyrope-almandine garnets.* Proc. Koninkl. Nederl. Akad. v. Wetenschappen, series B, 64, 2, 1961.

It is possible to differentiate between garnets of two groups (pyralsite and ugandrite) by means of X-ray powder photographs. From the gemmological point of view, the best way to determine a garnet is by the measurement of the physical properties, of which the absorption spectrum is very important.

S.P

ANON. *The peridots in the gem collection of the Museum of Geology and Mineralogy,* Leiden. Leidse Geol. Mededelingen, No. 22, 501-516, 1959.

A survey of the peridot collection in the museum. Stones from Egypt and Sibera show diagnostic inclusions.

S.P.

SINKANKAS (J.). *What do we really know about the formation of agate and chalcedony?* Lapidary Journ., XV, 2, 1961.

The problems of explaining the formation ot chalcedony need far more study before convincing explanations can be advanced.

S.P.

SCHLOSSMACHER (K.). *Fortschritte in der Diamantsynthese.* Progress in diamond synthesis. Deutsche Goldschmiede-Zeitung, Vol. 59, No. 4, pp. 207-208, April, 1961.

During the last two years many other laboratories apart from the General Electric in the U.S.A. have produced synthetic diamonds. The General Electric Co. says that the first stones produced were dark and weighed only a few thousand of a carat, now they weigh up to a tenth of a carat and are of very good industrial quality.

E.S.

SOME EXPERIMENTS WITH COLOUR

By NORMAN H. DAY

There must be many who read with interest the article by B. W. Anderson, entitled " Revolutionary Experiments in Colour Vision ", which appeared in the October, 1959, *Journal of Gemmology*.

He described in outline the history of experiments with colour and the results of experiments carried out by Dr. Edwin H. Land and his colleagues, of the Polaroid Corporation of America, during the previous five years. These investigations into a previously unnoticed chromatic phenomenon have given rise to new ideas in the conception of how the eye works regarding colour vision.

An important new discovery in the field of colour is of great interest to gemmology; many gemstones can be described as Nature's most permanent colour filters and Dr. Land's work could produce new principles in the understanding of the nature of their colour.

After reading B. W. Anderson's article my head buzzed with ideas. So as the saying goes . . ." Seeing is believing ", I started making a Camera/projector to repeat some of Dr. Land's experiments. Despite the crudeness of my equipment, the results obtained underline the fundamental nature of the phenomenon. In this article I will describe the practical experiments that I have carried out and leave the interested reader to consult the published works of E. H. Land[1] where he describes in a full and understandable way how this new discovery effects the whole conception of colour vision.

To begin with Land made a pair of black-and-white lantern slides of a group of coloured objects. One is referred to as the " Long Record " and the other as the " Short Record". Both are taken through the same lens and from the same viewpoint. The Long Record Negative is exposed using a light filter transmitting light above 5850Å and absorbing all light of a shorter wavelength. The Short Record negative is taken using a light filter which passes light below 5850Å and absorbs all light of longer wavelengths. (Figs. 1, 2 and 3). When we examine a pair of positive transparencies made from the negatives, such as those illustrated in Fig. 5, the Long Record shows the " R " red section with less density than that section on the Short Record. The densities vary according

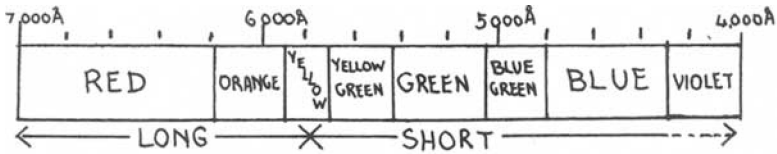

FIG. 1. *The visible spectrnm*

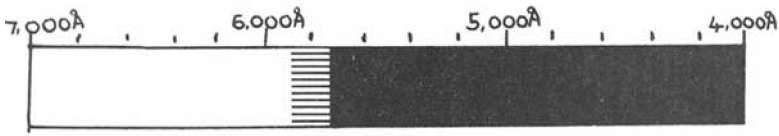

FIG. 2. *Absorption spectrum of filter used to make Long Record*

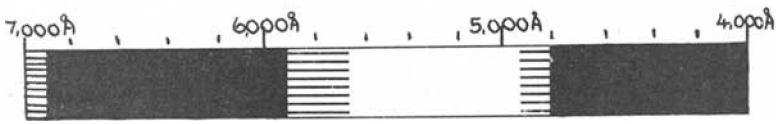

FIG. 3. *Absorption spectrnm of filter used to make Short Record*

to the light transmitted by each filter. Having made a suitable Long and Short Record Land proceeded to carry out some of Newton's original experiments with colour.

Newton's Original Experiments

Newton passed a narrow beam of white light into a large glass prism, refraction causing dispersion of the various component wavelengths of the white light so that a band of " rainbow colours " were produced on a screen placed in a suitable position. The rainbow colours, which we know as the visible spectrum, could be re-combined to form a patch of white light. Further, if some of the spectrum is blocked out, for instance, by allowing only the red and green parts to re-combine, then the apparent colour is yellow, the colour half-way between the original two colours.

E. H. Land repeated this last experiment using two different sections from the yellow part of the spectrum. As would be expected the result was a yellow patch of light. He then took the Long and Short Record that he had made; passing the longer yellow light through the longer record and bringing it to focus on a screen.

The picture was in yellow monochrome according to the densities on the black and white transparency. He then passed the shorter yellow light through the Short Record and brought it to focus exactly superimposed on the other picture. Now instead of a monochrome yellow picture all the coloured objects depicted were *in their natural colours*. Red objects were red; yellow were yellow; green, green; blue, blue; purple, purple; brown, brown; and more surprising, white was white and grey was grey.

For further research into this chromatic phenomenon Land transferred the transparencies to a pair of projectors mounted side by side and focused onto a screen. Instead of the nearly monochrome light of the Newton experiment he used light filters; these pass a much wider band of wavelengths. So long as the Long Record was illuminated with a filter transmitting light of a longer wavelength than the filter being used to illuminate the Short Record there was colour on the screen. Further, he found that if when the Long Record was illuminated with a red filter and no filter at all (white light) was used for the Short Record the screen was fully coloured. In the case of the last experiment it has been found possible to record the coloured picture produced on the screen upon an ordinary normal coloured photograph; but, in the cases when smaller parts of the spectrum are used, the screen, though it appears coloured to the eye, does not record on the colour film; thus illustrating the great adaptability of the human eye.

In 1959 Land demonstrated a whole series of experiments using projectors to the American Academy of Sciences; these are recorded in the proceedings of the Academy.[1]

Mr. David Grey, a colleague of Dr. Land made a monochromator and together they examined combinations of wavelengths from the whole visible spectrum. From these results they have found the limits in producing colour; charts illustrating these and other measurements are included in Land's " Experiments in Colour Vision ".[1]

Apparatus required to repeat the experiments using filters

To make the negatives of the Records, Land used a process camera. This type of camera divides the light, after it has passed through the lens, into two parts by means of half-silvered prisms.

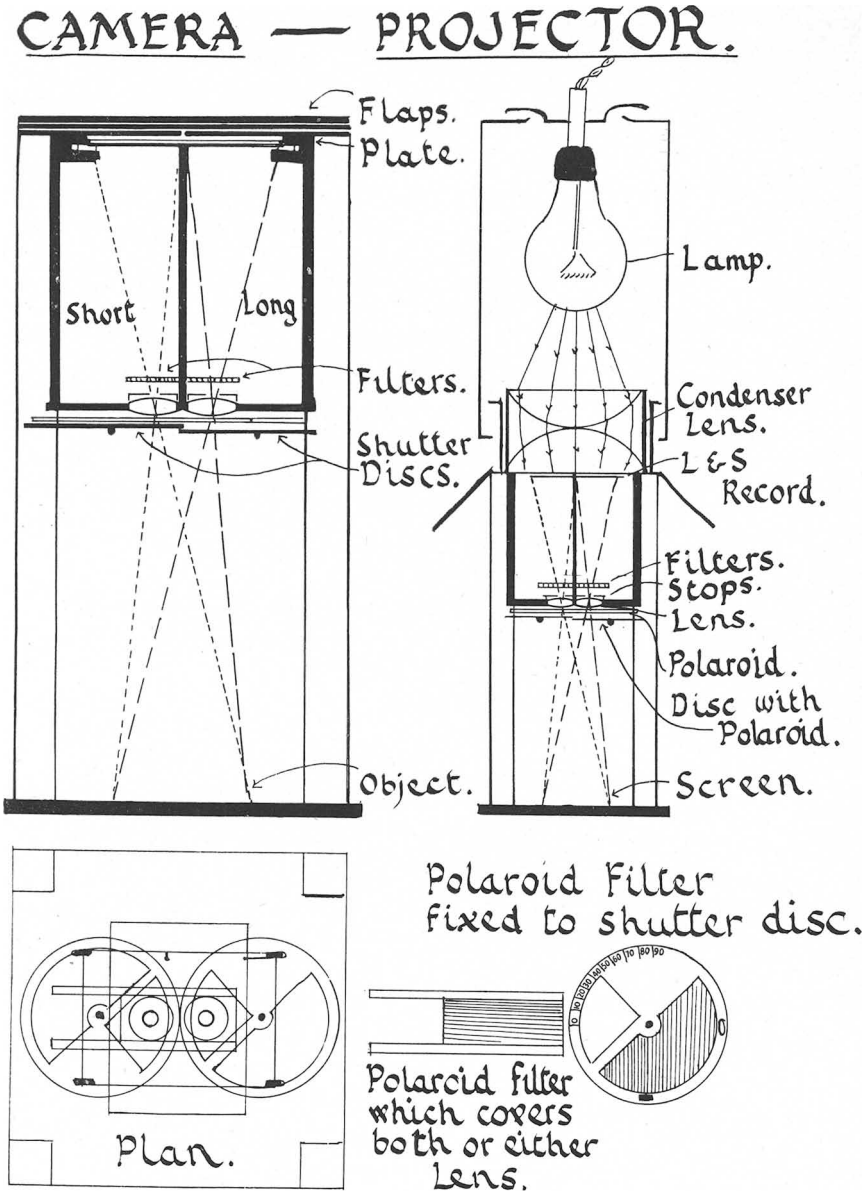
CAMERA — PROJECTOR.
Flaps.
Plate.
Short
Long
Filters.
Shutter Discs.
Object.
Lamp.
Condenser Lens.
L & S Record.
Filters.
Stops.
Lens.
Polaroid.
Disc with Polaroid.
Screen.
Plan.
Polaroid Filter fixed to shutter disc.
Polaroid filter which covers both or either Lens.

FIG. 4.

Fifty per cent is reflected through the red filter onto the Long Record negative, the other 50 per cent is reflected through the green filter onto the Short Record negative.

To produce the combined image of the two positive records on the screen he used a pair of identical projectors fixed side by side. In front of each projector's lens are fitted a pair of polaroid filters (polaroid itself is one of Land's important discoveries). One filter remains stationary, while the other can be revolved. When they are orientated in a parallel position the maximum amount of light is passed; as the filter is turned less light passes until, when crossed, no light is transmitted. By this means the amount of light reaching the screen from each lens can be controlled.

To build the apparatus it seemed that a pair of identical lenses was necessary. The only pair that I possessed with a suitable focal length were the objectives from a pair of opera glasses. These had a focal length of 105 mm. and were only partly corrected. From the illustration (Fig. 4) it will be seen that I made a camera, divided into two compartments, and fitted to a stand so that it had a fixed object-lens-image distance. One of the lenses produces an image of the object on one half of the plate, while the other lens forms a second image on the second half of the plate. It could be argued that this arrangement is similar to that used in a stereoscopic camera and that the twin negatives are not strictly identical, but when a two-dimensional object, e.g., a coloured picture, is used with a small stop this difference is insignificant.

When making the negatives, the camera is used in the dark-room; four flaps cover the plate during exposure. The size of the plate is $2\frac{1}{2}'' \times 3\frac{1}{2}''$. During exposure the plate, emulsion side downwards towards the lens, rests on four clips, the thickness of the plate from the bottom of the recess. The positive transparency rests on the bottom of the recess the clips being turned one side out of the way; the positive faces upwards away from the lens. In this way the emulsion/lens distance remains the same. Below the plate recess on the long side is a long pin and on the short side is a short pin: during the exposure these shadows record (see Fig. 5). They are a great help in placing the positive in the correct position.

One side of each compartment opens to allow access to the back of the lens so that the stops or filters can be changed.

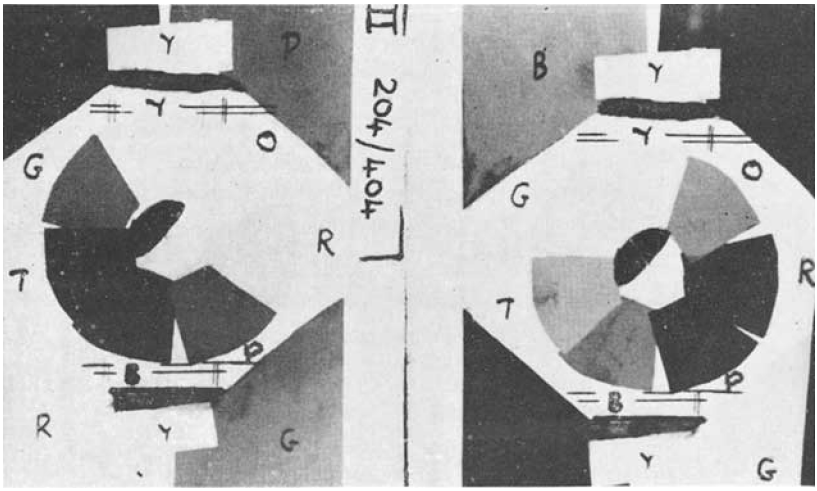

FIG. 5 *The Long and Short Record. Plate II.*

To the side of each lens is a disc so made that one quarter is open, a second quarter is filled and acts as a shutter, while the other half is filled with polaroid. A rectangular polaroid filter is so arranged that it can cover both lenses or each lens in turn. This filter and the filters in the discs are so orientated that when they are parallel the maximum amount of light is transmitted. As the disc is turned less light can get through, until, the disc being turned 90 degrees, the filters are crossed and no light is transmitted. The discs are calibrated in degrees and it is useful to use this scale to indicate the amount of light being transmitted.

To use the camera for projection the flaps at the top are left open. The positive is placed in the recess; upon this is placed the condensing lens. The condenser consists of a pair of plano-convex lenses mounted convex side facing convex side. A $2\frac{1}{2}'' \times 3\frac{1}{2}''$ plate requires a 5″ diameter condenser. Above the condenser mount is a ventilated box containing the lamp: this bulb can be adjusted to the optimum position. This whole set-up is similar to that used in many photographic enlargers.[2]

Making a Long and Short Record

In many of his experiments Land used Wratten Filters No. 24 and No. 58. I have for many years been interested in the use of light filters and have built up a complete range of Ilford gelatin

filters. Naturally I was anxious to use these. A complete description of these is given in " Colour Filter Book ", published by Ilford.[3]

The Wratten series of Filters is made by Kodak and fully described in " Wratten Color Filters ", published by Eastman Kodak.[4]

These two ranges of light filters are not identical, though by using these two books it is possible to choose many which match in the essential requirements.

Using a camera, I placed on the Long side Ilford 204 Tricolour Red, which absorbs all light below 5800Å and transmits all the longer wavlengths. On the short side was placed Ilford 404 Tricolour Green; this transmits light of wavelengths 4900Å to 6000Å and absorbs most other wavelengths.

The emulsion chosen was Ilford H.P.3, which is panchromatic medium grain with moderate contrast. Full technical information, including wedge spectrogram, filter factors, development, etc., are given in " Technical Information Books ".[5]

The object, a coloured chart (Fig. 5), was illuminated from 5 ft. with two 75 watt lamps, the type with built-in reflectors. The lens stop used was f.25 and the exposure was one second on the " short " side and nine seconds on the " long " side.

The recommended developer at the temperature and the time to obtain a normal negative should be used. If the subject has a short tone range, such as that in Figs. 5 and 6, it will be found that a positive made from Ilford Contact Lantern Plates gives the best results, while in the case of Fig. 7 the gemstones with their highlights have a much longer tone range: in this case I found Ilford Ordinary N30 plates made the best positive.

Using Filters to produce full colour

The first subject from which I made a pair of records was a haphazard arrangement of coloured squares of paper. This was quite successful, but in order to arrange so that the densities of the black and white Records could be easily compared, the chart, Fig. 5, was made. This chart was made from papers from an Ostwald Book (see footnote on the Ostwald Colour System*) from the NA range in which the hues are on matt painted paper. The NA paints have 83·4 per cent saturated colour, 5·6 per cent white and 11 per cent black pigment. In the third chart (record III, Fig. 6)

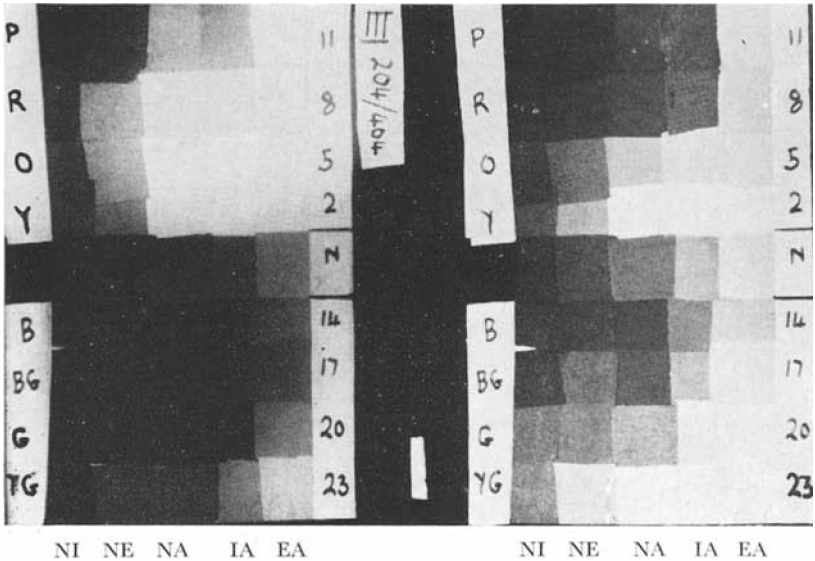

FIG. 6. *Long and Short Record. Plate III.*

besides the NA Range, which are the brightest colours and are in the centre, above are the IA and EA ranges, which have an increasing proportion of white pigment, while below are the NE and NI ranges, which have an increasing amount of black pigment. The neutral scale runs between yellow and blue.

Record IV, Fig. 7 is of a collection of well known gemstones: despite the fact that it shows the undesirable stereoscopic effect, it is useful to use objects of well remembered colours.

To obtain adequate light for the projector I used a 500 watt pearl bulb, which in most cases can be used with a pair of f.25 lens stops. These are the same size as those used for making the negative. When the light is not enough the lens stops can be changed for a pair of f.12·5, giving four times as much light, or even a pair of f.4·5, which give thirty-two times as much.

Using my apparatus to demonstrate the phenomenon, plates II, III and IV were used in the following ten experiments.

The paired polaroid filters are adjusted to compensate the different transmission values of the light filters.

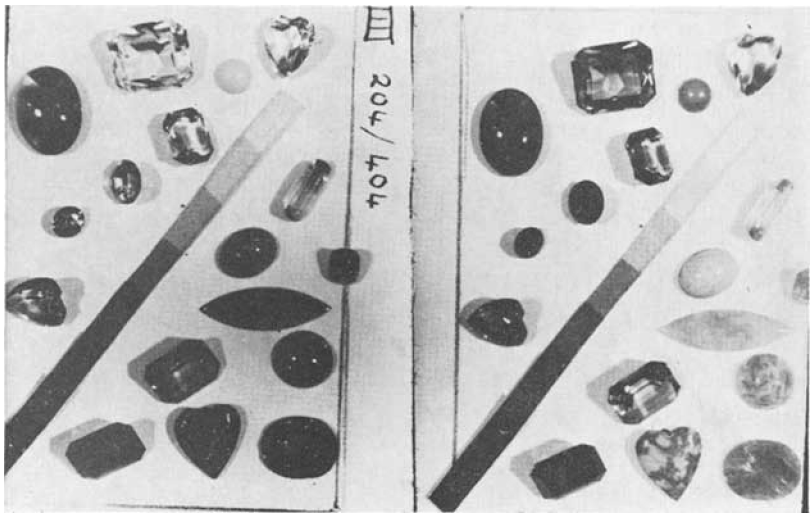

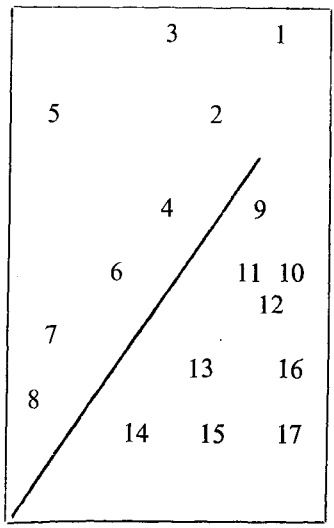

1. Citrine.
2. Coral.
3. Syn. Yellow Sapphire.
4. Cairngorm.
5. Amethyst.
6. Syn. Ruby.
7. Pyrope Garnet.
8. Amethyst.
9. Red/Green Tourmaline.
10. Demantoid Garnet.
11. Turquoise.
12. Bright Green Jadeite.
13. Syn. Blue Sapphire.
14. Syn. Lt. Blue Spinel.
15. Turquoise Matrix.
16. Malachite.
17. Dark Green Jadeite.

FIG. 7. *Long and Short Record. Plate IV.*

Set-Up	*Long Side*	*Short Side*
A.	204 Tricolour red.	404 Tricolour green.
B.	204 Tricolour red.	no filter
C.	no filter	404 Tricolour Green
D.	no filter	204 Tricolour red.
E.	404 Tricolour green.	no filter
F.	607 Spectrum orange.	606 Spectrum yellow.
G.	607 Spectrum orange.	605 Spectrum yellow-green.
H.	607 Spectrum orange.	no filter
I.	606 Spectrum yellow.	no filter
J.	205 Narrow cut tricolour red.	no filter

In Set-up " A ", using plate III the range of colours red, orange, yellow, green and blue are visible: the blues are rather greenish. Now remove Short Filter 404 Tricolour green and it is Set-up " B ", but the colours remain. The blue is true blue, the greens are not quite so vivid and the purple is distinguishable from dark red. Using Plate II, all colours are natural and the pure whiteness of the white is most noticeable. In "B" and Plate IV the colours of all the gemstones are natural despite a red line round part of each stone caused by the stereoscopic effect. The amethyst (5) shows typical bands of colour. The turquoise matrix shows the blue of the stone and the brown of the matrix, while the reds of the ruby and pyrope garnet are easily distinguished.

Set-up " C " with all plates shows monochrome green.

Set-up " D ": this shows near reversal of colours with Plate III. The red, orange, yellow, show up in various shades of green while the greens and blue show as orange and warm shades of brown. Using Plate IV reversal is distinct. The pink coral is bright turquoise blue, the synthetic yellow sapphire looks like the synthetic light blue spinel, the ruby is an apple green, turquoise is light brown and green jadeite brown.

Set-up " E " with all plates gives monochrome green.

Set-up " F " with Plate III. Red, orange, yellow green, but no blues; general overall greyness.

Set-up " G " with Plate III. Red, rather yellowish and blue, greenish.

Set-up " H " with Plate III. Full range of colours; some general greyness.

Set-up " I " with Plate III. Very pale colouring, greens show up best.

Set-up " J " using Plate III. This narrow cut red filter produces bright clear colours, but the red is a little too bright.

Wonderful and interesting as these demonstrations of the phenomenon are, the important thing is that from them Dr. Land has been able to form a new theory on how the eye computes colour from the stimuli it receives.

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2. *Manual of Photography.* Ilford.

3. *Colour Filter Book.* Ilford.

4. *Wratten Color Filters.* Eastman Kodak.

5. *Technical Information Books.* Ilford.

* THE OSTWALD COLOUR SYSTEM.—Using the form of a sphere, the girdle is imagined as carrying the fully saturated colours of the spectrum and is numbered 1 to 24. From the top through the sphere to the bottom is a neutral scale A to P: white at the top through greys to black at the bottom. On the surface more white is mixed with the saturated colour the nearer it is to the top, while more black is added to the saturated colour the nearer it is to the bottom. Colours inside the sphere have more grey added according to their nearness to the neutral scale. In this way a colour can be given a position in the colour sphere which can be described by two letters and a number. This system is still used by some paint manufacturers, but for scientific work it has been superceded by the CIE System.

ASSOCIATION NOTICES

ANNUAL MEETING

The 31st Annual General Meeting was held at Saint Dunstan's House, Carey Lane, London, E.C.2, on Friday, 5th May, 1961. Mr. F. H. Knowles-Brown presided.

In commenting upon the work of the year (the annual report having been circulated) the chairman stressed the importance of international co-operation and said that as the synthesis and imitating of gemstones were on the increase it required the maintained vigilance of all gemmological organizations and groups frequently to exchange information and ideas and to continue their researches. The chairman also expressed appreciation of the work of Mr. Trevor Solomon whilst he was chairman of the Midlands Branch.

The following officers were re-elected:—

President, Sir Lawrence Bragg, F.R.S.
Chairman: Mr. F. H. Knowles-Brown.
Vice-Chairman: Mr. N. A. Harper.
Treasurer: Mr. F. E. Lawson Clarke.

Miss I. Hopkins and Messrs. E. H. Rutland and W. C. Buckingham were re-elected to serve on the Council.

Messrs. Watson Collin & Co., chartered accountants, signified their willingness to continue as auditors to the Association.

MIDLANDS BRANCH

The annual meeting of the Midlands Branch of the Association was held at the Imperial Hotel, Birmingham, on Friday, 21st April, 1961. Mr. A. E. Shipton presided.

In his report on the work of the year Mr. Shipton referred to the continued confusion in the jewellery trade about the use of the word " Topaz ". It was still extensively misused. There was the complication of the general use of the term " topaz " in Germany when citrine or golden quartz was sold. The amount of topaz proper which was used by the trade was very small. Mr. Shipton thanked the committee of the Branch for their help during his term of office.

Mr. W. W. Bowen was elected Chairman of the Branch, in place of Mr. Shipton who had been elected as Midland Region Chairman of the British Jewellers' Association, and Mr. J. Shaw was elected Vice-Chairman and Secretary. Mrs. M. Middleton and Messrs. K. Hoskyns, J. Rossiter and S. F. Watts were elected to serve on the committee.

GIFTS TO THE ASSOCIATION

The Council of the Association gratefully acknowledges the following gifts:

Specimens of synthetic emerald crystals produced by Professor W. F. Eppler and presented by him.

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TALKS BY MEMBERS

BLYTHE, G.: " Gemstones ", Church of England Men's Society, Leigh on Sea, 11th April, 1961. Canvey Dining Club, 21st June, 1961.

WELLER, C. J.: " Gemstones and their imitations ", St. Mildred's Guild, Croydon, 7th May, 1961.

NORWEGIAN GEMMOLOGICAL ASSOCIATION

The Norwegian Gemmological Association has recently elected Mr. A. Andersen, of Tonsberg, as their President. Mr. A. Oiesvold, Aarnes, has become Secretary and Mr. B. Petterson, Oslo, has been appointed Treasurer. The Officers who have retired are Messrs. H. Myhre and G. Sunde, both of Oslo, who played a leading part in the formation of the Association. They continue as members of the Council of the Norwegian Association and resigned their offices to allow younger members to play a leading part.

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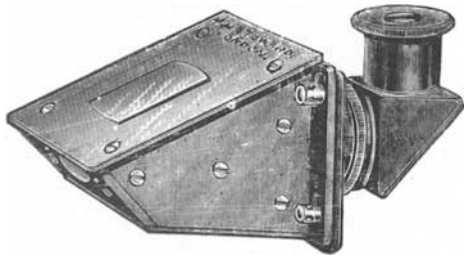

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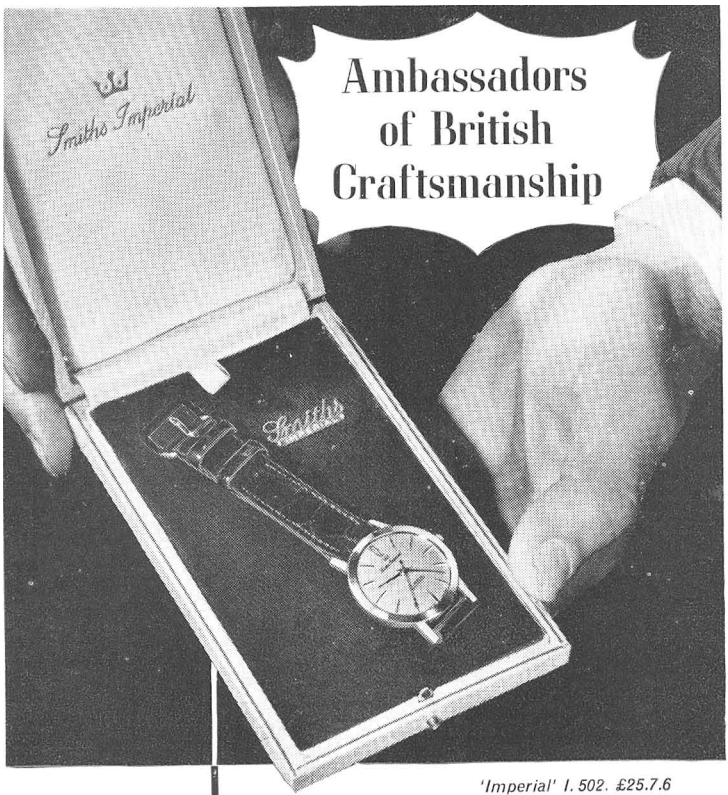

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No. 3
July, 1961

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THE JOURNAL OF GEMMOLOGY

and

PROCEEDINGS OF THE GEMMOLOGICAL ASSOCIATION OF GREAT BRITAIN

GEMMOLOGICAL ASSOCIATION
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Vol. VIII No. 4 OCTOBER 1961

RAYNER GEMMOLOGICAL INSTRUMENTS

New Selling Arrangements

The Gemmological Association of Great Britain has pleasure in announcing that it has been appointed world distributing agents for all Rayner gemmological instruments and accessories. As a consequence of this new arrangement the Association will handle all sales, encourage the development of new instruments and the improvement of existing ones.

Messrs. Rayner & Keeler Ltd. have recently discontinued their sales direct to customers of various optical and general scientific instruments and has generously given the Association the agency for Rayner gemmological instruments, which will continue to be manufactured by Messrs. Rayner at their Sussex factory. The Association will continue for the time being to respect all overseas agency arrangements previously made with Messrs. Rayner.

Arrangements are also being made for the Association to act as United Kingdom agents for the gem testing instruments marketed by the Gemological Institute of America.

The National Association of Goldsmiths of Great Britain is kindly co-operating in the Association's new venture by undertaking certain financial and staffing arrangements

THE CHIVOR EMERALD MINE

By PAUL W. JOHNSON

COLOMBIA has five operating emerald mines. They are in descending order of size : Muzo, Chivor, Gachalá (Vega de San Juan), Buena Vista and Cosquez. There are two principal emerald districts in Colombia, Muzo and Chivor. The Muzo district is composed of the Cosquez and Muzo mines. The Chivor district comprises the Buena Vista, Gachalá and Chivor mines. Muzo and Cosquez are owned by the Colombian Government and are operated under contract by the Bank of the Republic. Buena Vista and Gachalá, under a law of 1959, are concessions from the Colombian Government and pay a 25 per cent royalty. Recently a new mine has been discovered near Muzo. The Chivor Mine, previously known as the Somondoco Mine, as Somondoco was the nearest town, is the only operating emerald mine in Colombia not controlled by the Colombian Government. Chivor is an Indian name, the original meaning of which is not known. It is situated in the township of Almeida, Department of Boyacá, Republic of Colombia, South America. Located at approximately 4° 52′ north latitude and 73° 22′ west longitude, Chivor is composed of two mining claims, each about one square kilometre and about 1,000 surface acres—including timber and pasture land. The mine is approximately 2,350 metres above sea level, at the junction where the Rucio and Sinai Rivers form the Guavio River.

Located in the Eastern Mountain System of the Colombian Andes, the Chivor Mine area is the only place in the Andes where the *llanos*, or " Plains of the Orinoco," are visible. A visitor most adequately described the area as " vertical real estate." The inaccessibility and ruggedness of the terrain make mining difficult. The slopes are extremely steep and very slippery when wet and muddy. Surrounding the Chivor Mine is a moderately populated agricultural area that is essentially self-sufficient.

The climate at the Chivor Mine is invigorating, with average mean temperatures ranging from seven to 18 degrees centigrade. There are two seasons at Chivor : the dry from October to March and the wet the remaining part of the year. The wet season brings an average annual precipitation of over four metres. The rains are cold and on most of the days during the wet season the operations are shrouded in mist and clouds. Drainage during this time is

amazing ; an hour after a deluge most of the water has disappeared.

In the Guavio Valley are the Gachalá, Buena Vista and Chivor mines. On the western slopes of the Monte Cristo Range individuals are working small deposits of emeralds on their own property. Father Carlos Restrepo, local priest in Chivor Village, reported that microscopic emeralds had been found in the bedrock just west of Chivor Village. This proves that the emerald bearing fluid or vapour must have impregnated quite a large area, most of which was cut down by the combined action of the Sinai, Rucio, Guavio, Murca, Pedrera and Gachetá rivers.

The vegetation of the Chivor area is tropical. Varying in height from one to twenty metres, the growth includes a tree fern (genus *Cyathea**) left over from prehistoric times. Ferns of various types are abundant in the shaded areas around the mine. For visibility and security reasons, the overgrowth of this vegetation is controlled by periodic burning.

HISTORICAL SKETCH

In Inca days the Chivor Mine was the only known source of emeralds in North and South America and was worked by the Chibcha Indians long before the Spanish conquest. No emerald mines have ever been found in Peru and it is assumed that the Incas, as well as the Aztecs and Mayas, received their emeralds from Chivor by trading. All the emeralds looted by the Spanish conquistadores must have been mined at the Chivor Mine, as the Muzo Mine had not then been discovered.

The Spanish General Jiménez de Quesada, conqueror of New Granada, presently the Republic of Colombia, detailed Captain Pedro Fernández de Valenzuela to search for the Chivor Mine. On 12th March, 1537, General Quesada, through the efforts of Captain Valenzuela, saw the first *esmeraldas* (emeralds) discovered by the Spanish in the Western Hemisphere. The Spaniards employed about 1,200 men to work the Chivor Mine. Caged in the tunnels, the miners were forced to produce emeralds as the price of their meagre rations and sometimes their lives. Many died under this treatment and the Spanish practically exterminated the local labour supply.

The first recorded grant on the Chivor property was given to Señor Francisco Maldonado de Mendoza, probably in the first part of 1592, by Antonio Gonzalez, the President of Colombia. The

* Personal communication with Dr. Jose Cuatrecasas

inhuman treatment of the local Indian labour force by the Spanish resulted in a thirty-nine article decree promulgated on 22nd September, 1593, by President Gonzalez, for the protection of the labourers. On 29th December, 1593, this decree was followed by a Spanish Royal Order insuring the liberty of the local Indians. King Felipe III, of Spain, in 1602, issued a writ calling for the enforcement of the laws protecting the Indians. In 1643, the Chivor Mine was leased by the heirs of Maldonado to Miguel Soriano for seven years. The mine became the subject of litigation and was finally closed by Charles II of Spain at the persistence of Pope Clement X and abandoned in 1675. After the Spanish abandoned the mine it became overgrown with dense tropical vegetation and was lost for two centuries. That the Spanish accomplished considerable work at the mine is testified by the

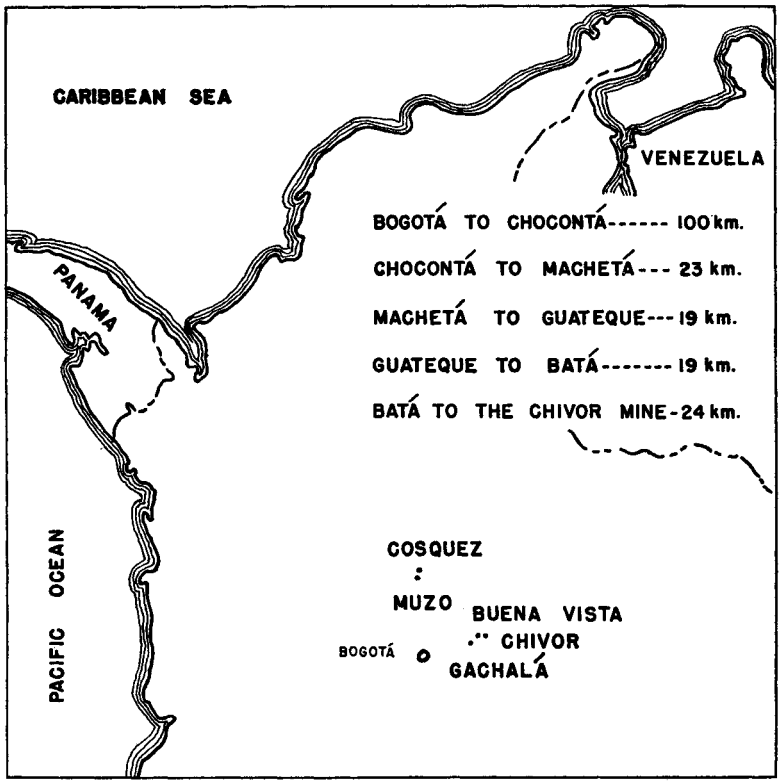

Location of emerald mines in Colombia ; and distances from Bogotá to the Chivor Mine.

shafts, adits and man-made canyons still visible to-day in the lower south-eastern section of the mine.

Don (Pacho) Francisco Restrepo, a native Colombian mining engineer, in 1896 rediscovered the emerald mine. In the National Archives of Colombia he read the Spanish description that the Chivor Mine was located at the only spot on the inner Andean range from which the *llanos* or " Plains of the Orinoco " were visible. With this seemingly insignificant description Señor Restrepo started his search. It would have been less arduous to have sought the elusive needle in the haystack. They chopped their way through the dense tropical vegetation and finally one day stumbled on a caved-in reservoir. Señor Restrepo sent a man up a tree and across the valley was the gap in the Monte Cristo Range with the *llanos* and 1,000 kilometres further the famous Orinoco River. Searching the immediate area Señor Restrepo and party found the overgrown mine terraces and thus a deserving Colombian was rewarded after a long and hard search.

Fritz Klein, from Germany, first visited the Chivor Mine in 1911. On 2nd August, 1912, and in August 1913 the Supreme Court of Colombia laid down a decision which exempted the Chivor Mine from further taxation or other obligation to the government. This decision was largely made possible through the efforts of Klein.

A German syndicate obtained an option on the mine, but subsequently lost it during the First World War. Americans became interested and purchased the option in 1919. Since then the Chivor Mine has changed hands among various American companies.

Chivor was managed by many famous managers, including Christopher E. Dixon from England and Peter W. Rainier, author of the book about the Chivor Mine, *Green Fire*.[10a]

Corporate Background

The Colombian Emerald Syndicate first gained control of the mine and subsequently sold out to the Colombia Emerald Development Corporation, which was later reorganized as the Chivor Emerald Mines, Incorporated. The Chivor Mine, at the present, is owned by the Chivor Syndicate, Incorporated, and the Chivor Emerald Mines, Incorporated. Currently Chivor is being operated by a trustee in receivership by order of the Colombian courts.

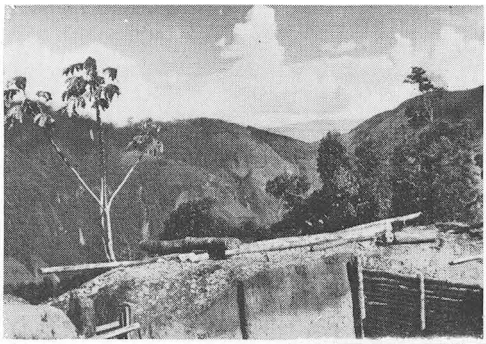

FIG. 1. *With a partially completed reservoir in the foreground, used for the mining operation, the* llanos *or "Plains of the Orinoco" are seen through the notch in the Monte Cristo Range. The* llanos *are grass plains which stretch from the foot of the Andes to the Orinoco River—1,000 kilometres to the eastward.*

FIG. 2. *On the trail by horseback to the Chivor Emerald Mine; Willis F. Bronkie, left, trustee and Dr. Pedro Moreno, a mining consultant.*

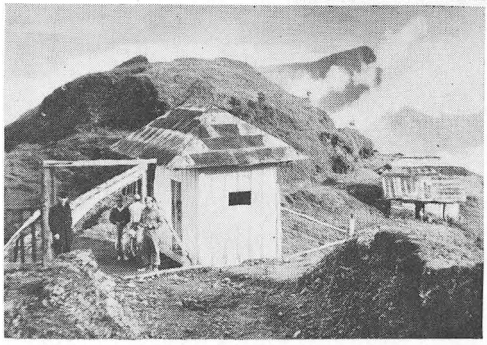

FIG. 3. *Main entrance to the Chivor Mine, which is guarded at all times by the Colombian National Police. The wooden flume framed by the mine gate is part of the canal which brings the water from a river source 18 kilometres from the mine.*

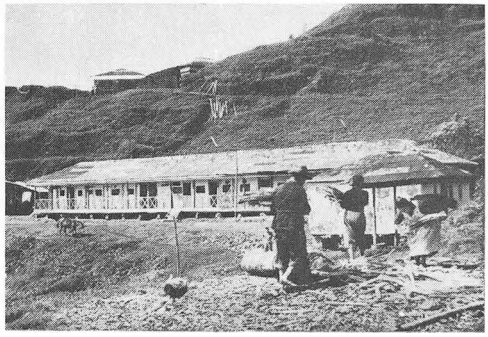

FIG. 4. *The administration building and quarters consisting of 12 rooms, a main office and dining room with a fireplace. The fireplace is used to advantage every evening throughout the year as the mine is at an altitude of about 2,350 metres above sea level.*

Transportation and Administration

The road from Bogotá, Colombia to Batá (Puente Batá), a distance of 161 kilometres, passes through the towns of Chocontá, Machetá and Guateque. The road is paved from Bogotá to Chocontá. From Chocontá to Batá a graded gravel road is passable and fairly well maintained, though it becomes a little muddy in the rainy season. The town of Somondoco, the name of which was previously used for the Chivor Mine, is by-passed on the way to Batá. Pack horses are obtained at Batá for the final 24 kilometre horse-back trip to the mine, which usually requires from four to seven hours, depending upon the weather and condition of the trail. Three-fourths of the way to the mine there is a settlement called Chivor Village, which has a population of approximately a hundred.

The administration building has twelve rooms with a dining room, kitchen, office and two showers. The dining room, with a radio for nightly news and entertainment, has a fireplace which is used to advantage every evening throughout the year. A two-way radio is used for communication with Bogotá. All water except drinking is obtained from a gravity flow water system. The manager or trustee, chief inspector, inspectors and visitors reside in the administration building.

People of the District

The Colombians of the Chivor area, mainly of Chibcha Indian extraction, are of a primitive nature. Most of them are hard-working and industrious. They have been relatively unaffected by the encroachment of civilization. As always, courtesy, gentleness and an awareness of their timidity before strangers, will help to ease the gap of time and custom.

The miners, like many of us, do not conform to any set pattern. Some work well, others are indolent. Every miner carries his own *peñilla* (belt knife), usually about 25 to 50 cm long, with which he is sometimes prone to settle his arguments. Most of the older miners have worked at the Chivor Mine since they were 14 to 16 years old. In 1928 there were as many as 500 men working the ridge. To-day no more than a hundred miners are employed. They work an eight-hour day, five and one-half days per week, finishing at noon on Saturday.

The miners generally live in a wooden or a log and mud constructed one-storey house. Some houses have a wooden floor,

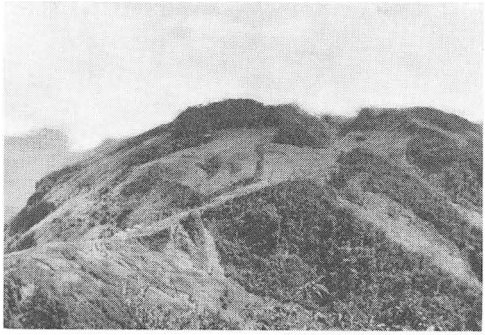

FIG. 5. *The Buena Vista Emerald Mine located across from Chivor. The mine dump and buildings can be seen in the lower left portion of the picture. The Buena Vista Mine is a concession from the Colombian Government and pays a 25% royalty.*

FIG. 6. *A reservoir being filled with water from the canal. When the reservoir is full the gate is raised by means of a lever thus creating a man-made flash-flood which is used to wash the overburden and debris of mining into the Guavio Valley, shown in the background.*

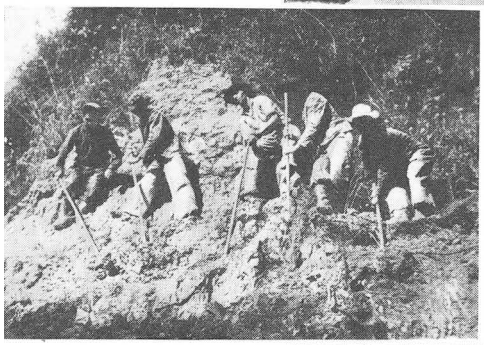

FIG. 7. *Emerald miners using the bar in the typical manner in which the Chivor Mine has been worked for centuries. To-day about 100 miners are searching for the elusive emerald.*

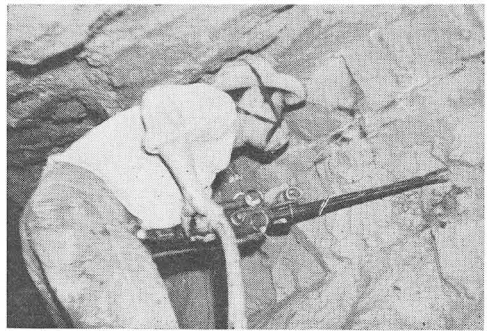

FIG. 8. *Senor Argemiro Vaca, a 25 year old miner, uses a compressed air drill to remove part of an emerald vein in the* Coliflor *tunnel. He has worked at Chivor for 12 years.*

while others have only dirt. The sides of the houses are usually rough sawed boards with some type of a rusting galvanized iron roof. They are built by the miners on company-owned property. Their bed customarily consists of a rough lumber frame with a woven mat of straw-like material for a mattress.

Chivor's manager must be versatile, as he is boss, counsellor, judge, jury, and doctor to the miners. The manager hires the inspector force, store keeper, cooks, house boys, labourers, mechanic and bulldozer operator. The labourers are paid about 34 cents per day. Each tunnel area has an inspector who is on the company's pay roll. The company also has a chief inspector for all the tunnel areas. The mine is patrolled by regular members of the Colombian National Police. The company pays the Colombian Government and the government reimburses the police according to their rank.

On most tasks the company tries to contract for the work. The contracting tends to improve manager-employee relationships, since the miners are working for a fellow Colombian and not a foreigner. The mining *contratistas* (contractors) are provided with only a place to work. The miners furnish their own clothing, shelter, tools and usually their food. The contractor hires his own men, rents the heavy power equipment from the company and purchases his own dynamite. Each mining contractor signs a 50-50 per cent division of the find contract with the company. The 50 per cent is based on the sale of the emeralds by the company. Each contractor divides his half differently among his miners. Some keep 25 per cent for themselves and distribute the remainder evenly among their men.

Security

Security at the Chivor Mine is strict. The National Police maintain 24 hour surveillance 365 days per year. By hiring trustworthy men, burning the thick tropical vegetation and constantly watching the miners by means of the inspectors, police, manager and chief inspector (inspector of the inspectors), highgrading and theft are kept at a minimum. In the past, however, bands of roving *contrabandistas* (highgraders) have worked Chivor at will during periods when the mine was not being operated. Individual miners have on occasion broken down the doors at the entrance to the tunnels and worked all night. In the morning they fled. The *lista negra*, or black list, of these men is posted on the bulletin board. They will never again be hired by the Chivor Mine.

Mining Methods

Some of the production methods to-day are essentially the same as those employed by the Chibcha Indians, with refinements introduced by the Spaniards. Tunnelling has been practised intermittently. However, step-cutting or terracing is favoured as being cheaper and more efficient, for the emeralds occur so irregularly in a formation that adits and drifts are likely to pass within centimetres of a rich pocket or vein without any indication of its presence. Policing the miners in the tunnels is always more difficult than when outside in broad daylight.

The Chivor Mine is being step-mined (terraced), tunnelled and bulldozed simultaneously. The tunnelling will soon be stopped. Then the top of the ridge can be worked with the bulldozer and the steeper areas exploited by step-cutting.

Originally the tropical forests were cut down and burned before the mining operations started. In working the slopes or banks the steps are first cut from the top of the bank to the bottom and obliterated on the return up the ridge. Occasionally beds of indurated shale are encountered and have to be blasted. In blasting a vein the shots are angled in and a low-powered dynamite or black powder is used, so as to minimize damage to any emeralds that might be encountered. The steps are worked from side to side with the miners lined up next to each other. They use a hoe or steel bar three metres long, which weighs about 14 kilograms. The bars are wedge-shaped at one end and pointed at the other. The debris and overburden are washed into the valley below by a flood of water from the reservoir. The steps are again cut into the side of the ridge and the process is repeated. By this method very deep V-shaped cuts are formed. Most of the cuts are over 50 metres in vertical height and give an imposing effect to the landscape.

When emeralds are encountered in the veins the operation slows down and the emeralds are carefully hand-removed by one of the inspectors and put in a leather bag. The *peñilla* (belt knife) is sometimes used as a digging tool to remove the emeralds from the vein.

In the past when an emerald-producing vein was being worked and had to be left at night, it was sealed with clay on which the foreman would write his signature. Then several tons of material were deposited over the vein. In the morning the overburden was

removed and the signature examined to see if any attempts at theft had been made during the night.

The tunnels are mostly shallow and penetrate less than 80 metres. Little timbering is required as the hard argillite supports the tunnels very well. During the rainy season water is usually found in the bottom of most of the tunnels. The water seldom exceeds one-third of a metre in depth, and the miners by wearing rubber boots up to the knee can proceed with normal mining operations. When drilling in the tunnels the dust and noise are quite bothersome to the miners. Chivor has several large compressors to furnish the power required by jack hammers.

To-day only one tunnel area (*Piedra de Cal*) is in operation. This will be stopped soon and open cut operations started there. In the past eight tunnel areas were worked. Facing south clockwise around the ridge they were: *Piedra de Cal* (limestone), *Coliflor* (cauliflower), *Peña Negra* (black rock), *El Taladro* (the drill rod), *El Martillo* (the hammer), *El Cristal* (the crystal), *Klein* (for Fritz Klein, a former German manager), and *Numero Cuarto* (number four). In April of 1958 there were 96 men and nine contractors working all but the *El Cristal* and *Numero Cuarto* tunnel areas. Some of the tunnels are dangerous and have been caved-in to protect the miners.

A bulldozer is used by the company to remove the overburden and also to follow the emerald veins. With a large quantity of soft overburden and the majority of the veins occurring in material soft enough to be worked by the bulldozer, it is definitely used to advantage. The bulldozed overburden is washed away by a man-made flash-flood from the reservoir.

By terracing and bulldozing every square inch of dirt is moved with less chance of missing the elusive emeralds. Emerald mining is extremely haphazard and sporadic. Mining may go on for months without a single production; one never knows when a vein will develop into a real producer or a pocket will appear.

The Canal

The present day canal follows for the most part the course of the old Spanish canal, which aided greatly in constructing the new. This ancient waterway supplied the old reservoirs with water brought from a river source about ten kilometres from the mine. The old Spanish canal was approximately two-thirds of a metre wide and one-third of a metre deep. The present day canal, which

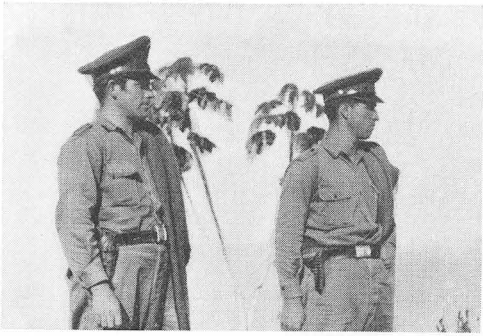

FIG. 9. *Members of the Colombian National Police maintain a constant guard at the Chivor Mine. Shown on the left is Alfredo Vargas and Marcos Fuentes. Notice the* ruana, *the Latin American version of our coat, thrown over their left shoulder. The* ruana *is a four foot square piece of hand-woven material with a diagonal slit, through which the head is inserted. Hanging down in front and behind, like a poncho, it protects the wearer from the high Andean rain and cold.*

FIG. 10. *Terracing or step-cutting is an efficient mining method used by the Chibcha Indians before the Spanish conquest of South America. Each terrace is about two metres high and two-thirds of a metre wide. The present surface level is estimated to be three metres lower to-day than it was originally over one solid square kilometre.*

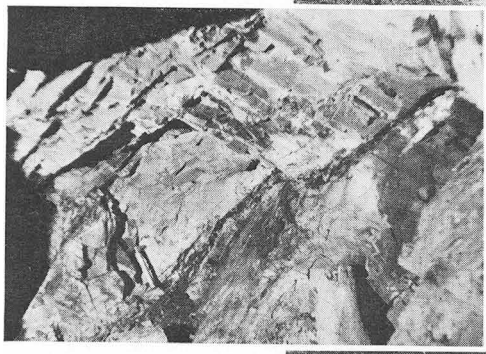

FIG. 11. *Interior view in the* Coliflor *tunnel. A production worth about* $*7,000 (£2,467) was taken from the area that is shown in this photograph. In September 1957 over* $*100,000 (£35,714) was taken from a vein within two metres of this area. Just to the right of the geologist's pick is a goethite stained emerald vein.*

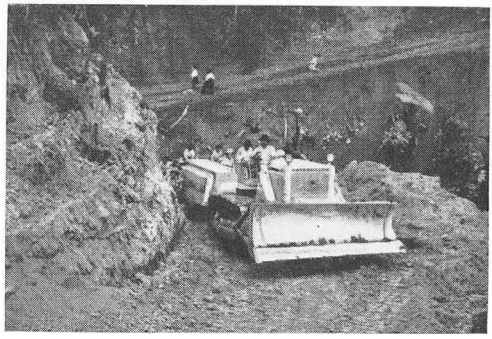

FIG. 12. *Bulldozer pulling an air compressor and making its own road through Cretaceous shale on the way to the mine. The bulldozer is used during the mining operation to remove the overburden.*

feeds all of the reservoirs, flows through natural ground in part and in a wooden flume with the same dimensions previously mentioned, for a total distance of 18 kilometres.

A reservoir, or as the Spanish called it a *tambre*, is used to create a man-made flash-flood in order to wash the overburden and debris from the mining operation into the valley below. The steep slopes are ideal for this purpose. Each reservoir is an area excavated in a strategic location so that the rush of water can be delivered to a particular mine area being worked.

Previously the reservoirs were established in areas which would withstand water pressure on as many sides as possible. The remaining sides of the reservoirs were reinforced with logs packed with clay on both front and back. Currently, however, the reservoirs are made of concrete and have completely replaced the older type. The reservoir gate is raised by a lever which requires from five to six men to open. Lack of water during the dry season makes the use of the reservoirs impossible.

The average reservoir holds approximately 100 metric tons of water. A reservoir is only filled prior to use, in about one-half hour, and requires less than five minutes to empty.

Description of Emeralds

Emerald, the green variety of beryl, is chemically a beryllium aluminium silicate, with the formula $Be_3Al_2Si_6O_{18}$. At Chivor the emeralds crystallize in both hexagonal and dihexagonal prisms. The terminations are usually flat, but domed and pointed terminations also occur. Refractive indices taken on 12 specimens ranged from 1·565 to 1·579 (see table I). The specific gravity on 11 different stones varied from 2·646 to 2·730 (see table II).

The colouring of emerald is due to a small amount of chromium oxide, probably less than one per cent. (See spectrographic analysis). The colour of Chivor beryl varies from colourless to a dark green with the gem quality ranging from grass-green to a verdant green fire. Emeralds sometimes occur with colour zoning. The amount of chromium present during the crystallization of emerald was not always constant, as some from this mine have a core of almost pure white beryl upon which was grown outward successive layers of darker material. The depth of colour is dependent on the amount of chromium oxide. The more chrom-

ium present at the time of crystallization the deeper the green colour imparted to the beryl. Chromium disrupts the beryl lattice and causes internal strain. The more chromium the greater the strain on the lattice. It is believed that chromium ions fail to mesh well within the crystal lattice and tend to poison it with what is called " chrome-ion poisoning."

Emeralds with a pointed termination have rarely been found at Chivor. (Fig. 17.) They are usually very small and seldom exceed one-half carat. The pointed terminations occur on a beautifully clear six-sided prism.

Tapered emeralds, some of which have a hollow interior, have been found only sparingly at the Chivor Mine. (Fig. 16.) They have been found in the *Coliflor* tunnel. Some of the tapered emeralds have a hollow cavity in the centre which extends from an opening on the termination the entire length of the crystal. Completely tapered emeralds are rare since the cavity in the centre causes most of them to fracture in the middle along a plane perpendicular to the c-axis. Most of these emeralds do not exceed 2 cm in length. All of the tapered emeralds formed six-sided prisms with a single flat termination, some of which have the S, P and O faces developed. Specific gravity of the tapered specimens cannot be determined accurately due to the cavity in the interior of the crystals.

The emerald was probably deposited from a hydrothermal fluid or vapour. Where conditions were favourable, it crystallized and formed the clear emerald, while elsewhere it appears as the opaque *morralla*, which means rabble or trash in Spanish and is very appropriately named. Side growths and twinning occur in the *morralla* specimens. One *morralla* crystal was found with a quartz crystal which had crystallized on its surface. This is a rare mineral association at Chivor. Most *morralla* is cut in India where labour costs are lower than in Colombia.

Morralla is a diagnostic indicator that gem quality emeralds may be found. Acicular crystals of emerald are reported by Gilles as a possible indicator of gem-quality stones. However, the entire vein which contains *morralla* and or small needlelike emerald crystals could be completely devoid of gem-quality material.

Flattened *morralla* crystals have been found in the *Coliflor* tunnel area at Chivor. They are about 20 mm wide, 10 mm thick and of various lengths up to 50 mm. The flat crystals, which look as if

they had been squashed, occur on a gray argillite matrix, with albite and pyrite present on the surface.

X-ray diffraction has shown that the *morralla* has a smaller unit cell than a high quality emerald, as shown by the peak shift. The emerald peak was 22·40 degrees and the *morralla* peak was 22·46 degrees. The *morralla* crystals have a broader diffraction peak than single emerald crystals, indicating either a smaller crystallite size or higher degree of disorder.

Inclusions

Inclusions in emeralds from Chivor include the microscopic three-phase, quartz, albite, pyrite and goethite (limonite) type. The brown inclusion in the emeralds is goethite formed by the alteration of pyrite. Quartz is sometimes a common inclusion and can on occasion be found as well formed crystals. Albite is the rarest of the inclusions found in the emeralds from Chivor. A pyrite crystal is occasionally found as an inclusion in a Chivor emerald, thus providing a focal point from which a unique gem can be faceted.

The three-phase inclusion is characterized by having an elongated or jagged outline. It is part of a healing fissure, sometimes called a "feather." The solid in the three-phase inclusion is halite.(4) The liquid is probably water, or a saturated solution of sodium chloride. The gas has not yet been identified. Three-phase inclusions can usually be found near the base, or the termination, and are generally oriented parallel to the c-axis. Most bubbles in the three-phase inclusions from Colombia are stationary. After leaving the microscope light on an emerald from Chivor for about five minutes, the gas bubble started to move periodically back and forth in the liquid ! The movement in this interesting specimen was probably caused by the heat from the microscope light.

Scattered and irregular groups of almost invisible liquid inclusions occur beside the characteristic three-phase ones. These usually have a jagged and elongated outline with tail-like formations.

Spectrographic Analysis

A spectrographic analysis on a dihexagonal crystal of emerald with a full basal pinacoid on one end, conchoidal fracture opposite end, from the Chivor Mine was made. The sample was from the

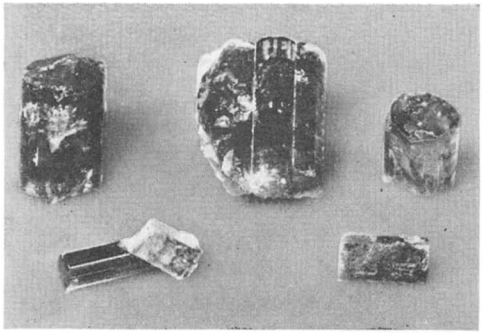

FIG. 13. *Fifty carats of rough emerald crystals from the Chivor Mine. The fine gem quality crystal in the lower left weighs 2·5 carats, the crystal in the upper left weighs 11·4 carats and the emerald in the upper centre weighs 26·6 carats.*

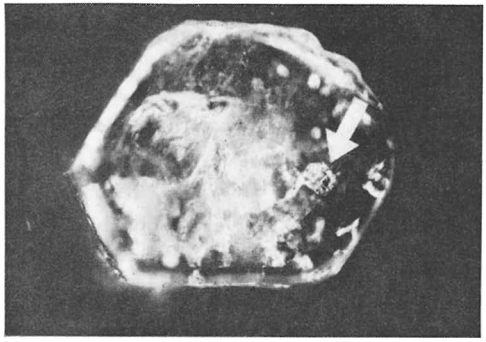

FIG. 14. *Pyrite crystal (arrow) inclusion in a 1·4 carat emerald from the* El Taladro *tunnel area. Pyrite inclusions are characteristic of Chivor emeralds.*

El Taladro tunnel area, and weighed 0·0846 grams.

Determinations:

Silica : (SiO_2)	60 to 70%
Alumina : (Al_2O_3)	15 to 20%
Beryllium oxide : (BeO)	10 to 15%
Magnesium oxide : (MgO) ...	·01 to ·1%
Lime : (CaO)	Nil
Iron oxide : (Fe_2O_3)	·001 to ·0001%
Chromium oxide : (Cr_2O_3) ...	·0001 to ·00001%
Vanadium oxide : (V_2O_5) ...	·00001 to ·000001%
Sodium oxide : (Na_2O)	·00001 to ·000001%
Manganese oxide : (MnO) ...	Nil
Potassium oxide : (K_2O)	Nil
Copper : (Cu)	Nil
Nickel : (Ni)	Nil

Spectrographic analysis was made for the author by the San Diego Testing Laboratories; analyst, M. P. Christensen.

Grading and Valuation of Emeralds

No two emeralds are exactly alike and they are difficult to classify. The Colombian Ministry of Mines divides the emeralds into six colour grades each with subdivisions. In grading emeralds in Colombia the numerical part designates colour. Number one is the best colour, number six the poorest. The alphabetical part of the grading designates the freedom from flaws. " A " would have very few flaws, whereas " D " would have many.

The highest grade of emerald is in Colombia called *gota de aceite*, which translated means literally " drop of oil." Small pencil-like crystals of emerald are called *cañutillos*. These long slender crystals can be of any quality as the name describes the shape only. *Cañutillos* are used for making religious crosses and sometimes for lower priced jewellery. Poor quality opaque emerald is called in Colombia *morralla*, which has a commercial value as inexpensive jewellery.

The value of an emerald depends upon transparency, freedom from flaws, evenness of colour, weight and shade of green. Colour is the most important factor. A rough idea of uncut retail emerald prices would include: 1B—$1,000 per carat; 1C—$500 per carat; 2B—$300 per carat; and 3A—$60 per carat.

Emerald Veins

The emeralds are found commonly in veins—rarely in pockets, and occur in thick beds of shale. The veins are usually filled fissure cracks, which resulted from the folding and faulting. They generally run parallel to each other along the strike of the structure, as that is the point where the hydrothermal fluid or vapour had a chance to fill up the then existing fissures and joints. Cross veins along fissures formed by folding occur between the veins and often contain emeralds, particularly at intersections. At that point the fluid or vapour had freedom for growth because of release of pressure, time to cool and a gradual loss of heat.

The veins vary from a fine line to 15 cm in thickness, usually not exceeding 65 metres in length or 35 metres in depth. A thin section on an emerald vein from the *Piedra de Cal* tunnel area showed that the black argillite had been metamorphosed by the fluid or vapour that formed the emerald and albite to a depth of 3·4 millimetres.

Emerald veins can be divided into three groups : pyrite, albite and pyrite with albite. Each of the three vein types occur with *morralla* and where conditions were favourable—emerald. So far no emeralds at Chivor have been found in calcite and calcium carbonate has never been found in an emerald vein.

In a vertical cross section running from the top of the ridge upon which the mine is located, the sedimentary deposits are separated by three horizontal layers known as " iron bands." These bands are easily located, running as they do straight across the face of the hill, where they appear as red streaks in a yellow to grey shale background. The productive emerald veins do not extend more than 50 metres below the lower " iron band."

The emerald pockets generally occur associated with the vein. It appears sometimes that emeralds are found imbedded in shale in pockets, but on close examination one can always find a small stringer, sometimes practically invisible, that served to carry the fluid or vapour. Occurrences of this type are generally under a cap of impervious harder material that served to localize the deposition. There is nothing definite about the pockets and no two occur exactly the same. They may be as small pockets with goethite, albite and pyrite, or in vugs or larger pockets. The emeralds in the pockets or vugs are frequently found incrusted with iron oxide and sometimes occur loose within the cavity. A pocket will generally produce stones of the same quality. Some pockets have been good producers while others have yielded entirely " frozen " emeralds which will crumble apart in one's hands.

Associated Minerals

The common minerals of Chivor include albite, pyrite and emerald. The principal gangue minerals of the emerald-bearing veins are pyrite and albite. Other common minerals are goethite (limonite) pseudomorphous after pyrite, hematite and goethite (limonite). Moderately common are calcite and quartz crystals. Less commonly occurring minerals include massive quartz, halloysite, goshenite, allophane, muscovite, fuchsite, specularite and hyalite. Other than albite and pyrite the only minerals found in association with emerald are goethite (limonite) pseudomorphous after pyrite and very rarely massive quartz. As the albite alters to clay it would also be possible to find the emeralds in association with clay minerals.

Albite is a very common vein mineral usually occurring as white streaks on both sides of the veins with the emeralds and *morralla* in the middle. The bladed variety of albite known as cleavelandite occurs with the emeralds and is common in the *Piedra de Cal* tunnel area. Under hot acid conditions it is possible for the albite to be altered to kaolinite, sericite, halloysite, allophane, etc.

Pyrite is quite abundant at Chivor and occurs in attractive cubes, octahedrons and pyritohedrons, or combinations of these three forms. Some of the faces on the cubes are striated and slightly curved. Most of the pyrite crystals are less than 7 cm in diameter. Pyrite crystals are found quite commonly in the *Coliflor* tunnel. The pyrite alters to goethite ($HFeO_2$), most of which was formerly called limonite,[2] and then to hematite (Fe_2O_3).

Goethite (limonite) pseudomorphous after pyrite is found in the " iron bands." Some of these specimens are only partially altered and still contain a bright pyrite core.

Calcite in typical white rhombohedrons is common at Chivor. Showy specimens of white calcite with included crystals of pyrite, from the Klein tunnel area, make attractive cabinet specimens.

Quartz crystals occur in the *Peña Negra* tunnel area. The quartz is usually a well terminated clear prism less than 10 cm in length and five cm in width. Some doubly terminated smaller crystals can be found as well as internal phantom crystals. In the past evidently larger quartz crystals were found. Gilles[3] reports five or six pound quartz crystals were sometimes found in the " iron bands."

Geology

The emerald zone runs about ten kilometres east and west, and five kilometres north and south. The Chivor deposits are mainly on a sharp north-south trending ridge which passes through both of the two mining claims owned by the corporations. The ridge is composed of sedimentary clay and shale of Cretaceous age with a small amount of limestone. The limestone which occurs at Chivor may be float material. The most prominent feature of the ridge is the loosely consolidated yellow shale, which makes up a great portion of the upper stratigraphic sequence. The ridge is highly folded and faulted and the strike and dip of the beds is variable. Much of the ridge surface has been destroyed by previous intermittent mining operations over approximately the last 500 years.

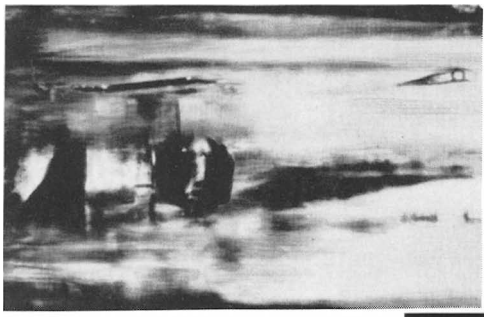

FIG. 15. *Three-phase inclusion in a Chivor emerald. To the left of the black round gas bubble is the square outline of a halite crystal. Notice the elongated outline of the inclusion cavity. These inclusions are part of a healing fissure. Usually the bubble in a Colombian three-phase inclusion is stationary. Recently a moveable bubble has been found.*

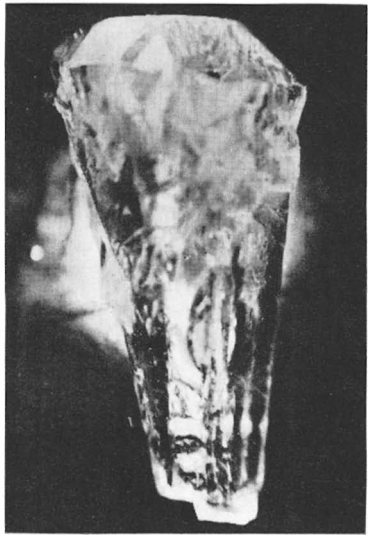

FIG. 16. *Tapered emerald, a rare specimen, from the* Coliflor *tunnel. Notice the peculiar growth along the sides of this crystal which weighs 2·3 carats and is 12 mm long.*

Tightness of fold curvature is an index of gem possibilities, the more compressed synclinal structures being considered most favourable. If a vein is discovered travelling in the trough of a syncline the production of stones may be immense.

The petrological sequence of the Chivor area from the top of the ridge to the bottom includes: white and tan clay, loosely consolidated yellow shale, black limestone, white to buff argillite, grey argillite, pyritiferous black argillite, black laminated silty shale and black argillite.

The occurrence of emeralds in veins traversing shale at Chivor is in sharp contrast to the world-wide occurrence of beryl minerals in pegmatites. Gilles has reported that no igneous rock was observed on the Chivor property nor at any place in the vicinity

of the mine. Granite has also never been found at the Chivor Mine.

The " iron bands " previously mentioned are about 50 metres apart. In these bands are found large pyrite crystals which are being altered to goethite pseudomorphous after pyrite. The noticeable red colour of the bands is caused by the oxidation of the pyrite. No emeralds have been found in the bands themselves, but rather between them. Very few have been discovered above either the upper or the middle bands, more between the middle and lower, with the great bulk below the lower. From the lower band downward, for a distance of about seventy metres, is located the area where most of the development has been done. Gilles reports that up to 1930 three-quarters of the emerald production had been produced below the lower " iron band." It is in this area that the greatest future production hopes lie.

Recently, as a result of the bulldozer operations, a small production of emeralds above the upper " iron band " was recorded. The " iron bands " have been described by Gilles[3] as horizontal faults, while Mentzel claims they are not !

Paleontology

In the Colombian Bureau of Mines in Bogotá, three species of fossils are recorded from the Chivor Emerald Mine area. They were labelled: *Astieria astieri valanginiense* d'Orb., an ammonite ; *Trigonia hondaana* Lea, a bivalve; and *Cladophlebis dunkeri* (Shimper), a fern.

Taxonomically at the present time these three species would probably be: the ammonite *Olcostephanus astierianus* (d'Orbigny)*; a bivalve *Trigonia hondaana* Lea, 1940** and the fern *Cladophlebis dunkeri* (Shimper) Seward.***

Theory on the Origin of the Tapered Emeralds

Experimental growth of beryl in the laboratory indicates that pressure, temperature, changing composition of the solution, and the dilution or strength of the melt—all these and other factors can singly or together affect the habit.† The taper in the Chivor emerald undoubtedly finds its source in the above-mentioned factors and in particular to diminished nourishment during growth.

* Personal communication with Dr. Ralph W. Imlay
** Personal communication with Dr. Norman D. Newell
*** Personal communication with Dr. G. Arthur Cooper
† Personal correspondence with Dr. Richard H. Jahns

FIG. 17. *Pointed termination, rare and characteristic of Chivor emeralds. This tiny hexagonal crystal is 5·6 mm in length and weighs 0·36 carats. Emeralds with a pointed termination were probably grown under optimum conditions.*

FIG. 18. *Justo Daza, now 71 years old, has worked at the Chivor Mine intermittently since 1912. Justo, affectionately known as Tío Justo, found in 1920 the largest emerald (Fig. 19) discovered thus far at the Chivor Mine.*

THEORY ON THE ORIGIN OF EMERALD

A geosyncline formed in the eastern part of what is to-day the Republic of Colombia, South America. The geosyncline, which was formed about 120 million years ago during the Cretaceous Period, was filled with marine sediments including a few ammonites, etc. The sediments reached a depth of over 10,000 metres. As the sedimentary material became deeply buried the strength was reduced by heat and pressure. The trough was filled until a state of balance was reached and the thickness of the sediments could not be increased. The argillaceous sediments were indurated to shale, and as the strength was reduced the sediments were folded. After the relaxation of the forces which produced the geosyncline the Eastern Cordillera of the Andes in Colombia was formed. During or just after the folding aqueous fluid or vapour introduced the chemical components of pyrite, albite and emerald. As the pressure built up the fluids or vapours were forced upward through the path of least resistance: the joints, fractures and weak areas in the shale—caused by faulting and folding. Where two or more fissures

crossed, the possibility of pressure release was greater and the chance for crystal precipitation increased.

Some pyrite probably began crystallization first, followed by the albite and then emerald. Pyrite has been found as inclusions and growing on the surface of the emeralds; thus suggesting that the pyrite was formed both before and after the formation of the emerald. Along the fissures where the magmatic fluids or vapours were still under pressure and were rapidly cooled, they crystallized as the massive opaque *morralla*, while elsewhere, maybe even in the same vein, crystals of gem quality emerald were formed.

Published Errors

Numerous authorities have published errors on emeralds and emeralds from the Chivor Mine. The biggest fallacy seems to be the story that emeralds flaw, fracture and splinter upon exposure to the air. This is not true. Secondly, all emeralds from Colombia are not found in calcite or limestone veins as reported by many authors who have used the Muzo Mine, where this is true, in generalizing about the whole Republic of Colombia. Neither do the emeralds from Chivor occur in a pegmatite, but rather in veins or pockets in a thick section of shale.

The Largest Emerald

The largest and most famous emerald from Chivor, weighing 632 carats, was found by Justo Daza, in December 1920. (Fig. 19.) Justo was in charge of a group of men working in the hard rock area on the south-east side of the Klein wash, about a hundred metres down from the top. Holes had been drilled in the hard buff argillite. Justo was asked by Fritz Klein, then in charge, to remove his men from the area since they had found nothing. Justo removed his men as ordered, but stayed behind himself and blasted the holes that had already been drilled. In the area that had been ripped apart a single pocket with the large emerald inside was found. Justo said, " The emerald was lying in the sand as though it were asleep in bed." Also that, " The ends of the emerald were covered with a brown (goethite) stain that was easily rubbed off with my handkerchief." The outside edge of the pocket was covered with a goethite stain.

This emerald sold for $60,000 (£21,400) early in 1921. Known as the " Patricia " emerald, it is owned by and on display at the American Museum of Natural History in New York City. Justo's

TABLE I

REFRACTIVE INDEX ON EMERALDS FROM THE CHIVOR MINE, COLOMBIA, SOUTH AMERICA

Number	*Collection Number*	*Gem Refractometer*	*Rayner Spinel Refractometer*	*Remarks*
1	C-87	1·569 – 1·576	1·570 – 1·576	1·815 carat rough crystal
2	C-88		1·572	2·531 carat rough crystal
3	C-89	1·575	1·575	3·093 carat rough crystal
4	C-92	1·569 – 1·575	1·572 – 1·579	11·437 carat rough crystal
5	C-93	1·57	1·579	26·596 carat rough Xl. with Qtz. inclusions
6	C-94	1·57	1·565 – 1·571	0·789 carat cut stone
7	C-96	1·575		11·515 carat rough Xl., goethite inclusions
8	C-102	1·565		4·115 carat rough Xl., best tapered specimen
9	C-102	1·57		rough crystal
10	C-102	1·57		rough tapered crystal
11	C-102	1·572		rough tapered crystal
12	C-102	1·575		rough crystal

Data by Charles J. Parsons, C.G., F.G.A.

TABLE II

SPECIFIC GRAVITY ON EMERALDS FROM THE CHIVOR MINE, COLOMBIA, SOUTH AMERICA

Number	*Collection Number*	*Weight in Carats*	*Specific Gravity*	*Remarks*
1	C-85	1·545	2·646	doubly terminated hexagonal crystal
2	C-86	1·771	2·725	doubly terminated dihexagonal crystal
3	C-87	1·815	2·663	doubly terminated hexagonal crystal
4	C-88	2·531	2·681	single termination on a hexagonal crystal
5	C-89	3·093	2·701	single termination on a hexagonal crystal
6	C-90	3·753	2·652	single termination on a hexagonal crystal
7	C-91	5.642	2·687	single termination on a dihexagonal crystal
8	C-92	11·437	2·684	single termination on a hexagonal crystal
9	C-93	26·596	2·675	doubly terminated, with quartz inclusions
10	C-94	0·789	2·730	faceted stone, emerald cut
11	C-95	1·393	2·663	doubly terminated, with pyrite inclusion
12	C-100	4·545	2·593	*morralla* from the *El Taladro* tunnel area

Data by the author using a Voland analytical balance calibrated in carats.

bonus for finding the emerald was ten pesos (about ten dollars, £3 12s.).

The " Patricia " emerald was probably found in the centre of the pocket as described by Señor Daza, but was originally grown attached at one end. The opaque " Patricia " emerald is dihexagonal with a single flat termination and fractured on the bottom, with three side growths.

After the find the men were called back to work the area. Four days later a heart breaking discovery. A second pocket was found which appeared to have contained a larger emerald crystal. This pocket was blown apart in the blast and nothing was recovered except small pieces. Both pockets contained green sand (probably *morralla*) and both had a single large crystal. Large boulders came down on the work area from above and finally work was terminated when a slide completely engulfed the area. Both pockets were about a foot in diameter and are the only ones that were ever found in the Klein tunnel area.

Early Operation Costs

Gilles in his 1930 unpublished report on the Chivor Mine lists the following early operation costs. Notice that from 1926 through 1929 the mine registered a deficit of $10,785.42.

Table III

Total cost of operation in 1926	$40,557.19
Total cost of operation in 1927	$95,523.83
Total cost of operation in 1928	$56,523.84
Total cost of operation in 1929	$83,696.90
Total cost of operation from 1926-1929	$276,301.76
Total selling value of emeralds produced from 1926 to 1929	$265,516.34
Average price received per carat for the period 1925 to 1929	$1.99

Production Statistics

Mine costs sometimes exceed the value of the emeralds mined. Production is sporadic and mining may continue for months without a single production.

Emerald production, like all other gem production, is variable. Production figures are never accurate since intermittent operation and the frequent change of administrators contribute greatly to inaccuracy. Records have been lost, never recorded at all, or if noted are lower than the actual production. The recorded produc-

TABLE IV

RECORDED PRODUCTION OF THE CHIVOR MINE, COLOMBIA, SOUTH AMERICA

Year	*One B*	*One C*	*Two A*	*Two B*	*Two C*	*Two D*	*Three*	*Three A*	*Three B*	*Three C*	*Three D*	*Four A*	*Four B*	*Four D*	*Five*	*Five A*	*Five B*	*Five C*	*Six A*	*Total Emeralds*	*Total* Morralla
	Carats	*Carats*	*Carats*	*Carats*	*Carats*	*Carats*	*Carats*	*Carats*	*Carats*	*Carats*	*Carats*	*Carats*	*Carats*	*Carats*	*Carats*	*Carats*	*Carats*	*Carats*	*Carats*	*Carats*	*Carats*
1921																				30,207	
1925																				4,234	
1926			1,020	2,150				400				5,600	5,900			28,400				43.470	76,000
1927			420	4,192				1,597	10,339			3,038	12,516			5,443				37,545	70,000
1928			300	205				2,784	944	6,940		1,964		2,335	7,240					22,712	
1929	769		3,015	1,745				5,885	1,360	3,055	4,915		125					8,575		29,444	35,035
1930		350	930	2,380				1,100	6,745			6,420				3,220	14,360			35,505	30,000
1931		1,200			6,300					8,710		1,400	11,840			600	16,200			46,250	21,585
1937–1940					298	383	1,242	2,044	2,652	85		2,051	1,479			12,743	5,860			28,837	73,633
1948			1,638	3,044	1,450	1,144		3,644	3,857	1,751	1,062	17,941	3,028			11,176				49,735	38,766
1949			1,467	933	269			5,351	4,010	343		22,967	371				30,735	4,070		70,516	47,299
1950			16					58	21	192		1,762				8,166			292	10,507	12,102
1951												2,462				7,547	423		2,024	12,456	16,453
1952												1,816				13,317			3,797	18,930	5,027
1953												2,813				4,057			8,965	15,835	3,118
1954												471	193			5,036	403		1,122	7,225	31,628
1955												2,131				3,669			1,758	7,558	154,717
1956								447				2,049				6,624				9,120	198,700
1957								1,940				7,461				12,878				22,279	287,819
Totals	769	1,550	8,806	14,649	8,317	1,527	1,242	25,250	29,928	21,076	5,977	82,346	35,452	2,335	7,240	122,876	67,981	12,645	17,958	502,365	1,101,882

Compiled by Willis F. Bronkie.

FIG. 19. *The "Patricia" emerald found by Justo Daza at the Chivor Mine in December 1920. It was found in a pocket in a hard buff argillite of the Klein tunnel area. This 632 carat dihexagonal crystal is now owned by and on display at the American Museum of Natural History, in New York City.*

tion from 1921 to 1957 is shown in table IV. In 1929 Rainier reported 480,000 cubic metres of earth and rock were removed producing 29,444 carats of emeralds, or 16 cubic metres per carat. The ratio of emeralds to overburden is then about one to 90 million.[3]

From the first of June to the first of December 1921 the mine was managed by Christopher E. Dixon. During this period 30,207 carats of emerald were recovered worth at that time an estimated $179,911.75.[3]

ACKNOWLEDGMENTS

I am deeply indebted to Willis F. Bronkie, Trustee of the Chivor Mine, for his hospitality, sincere interest and encouragement in this project. He made it possible for the author to do field work at the Chivor Mine.

At the United States National Museum I wish to thank Drs. Jose Cuatrecasas, G. Arthur Cooper and Ralph W. Imlay. For the identification of the clay mineral to Dr. Ralph E. Grim, Dept. of Geology, University of Illinois. For the information on inclusions the help of Dr. Edward J. Gubelin, F.G.A., of Lucerne, Switzerland, has been invaluable. At the American Museum of Natural History I wish to express my appreciation to Drs. Brian Mason and Norman D. Newell. Dr. Gustav Arrhenius and Miss Clio Hood at Scripps Institution of Oceanography, University

of California, kindly did X-ray diffraction curves on unidentified minerals. The refractive indices were taken through the generosity of Charles J. Parsons, C.G., F.G.A.

For suggestions and proof reading the manuscript the following individuals were generous with their time: Nathalia Crane Black, G.G.; Vete George Black, G.G., F.G.A.; Willis F. Bronkie; Dr. Vernon J. Hurst, geologist, State of Georgia; and Dr. Gordon Gastil, Dept. of Geology, San Diego State College.

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NEW STYLE OF DIAMOND CUTTING

A NEW style of diamond cutting was exhibited at Messrs. Garrard, the Crown Jewellers, at a jewel exhibition held in October. The name of the new cutting style is Princess cut and it is claimed that it is the most important development in the more than 480 years old history of gem diamond cutting. The outstanding feature of the cut is its constant diamond thickness of 1·50 mm. At this thickness stones display fine brilliance. The patented cutting process makes it possible to produce a range of attractive modern diamond shapes not used before. The cut is distinctive and will be used for genuine diamonds only, the patent safe-guarding against competition from cheap imitations.

Carving of diamonds is also now possible from the new cutting methods which have been developed by Mr. Arpad Nagy, managing director of Diamond Polishing Works Limited, who are marketing the Princess-cut diamonds. Mr. Nagy has spent many years in developing his new cutting technique. An important factor for the diamond mounter is that the high precision necessary in the new process means that stones can be supplied which are extremely accurate in size.

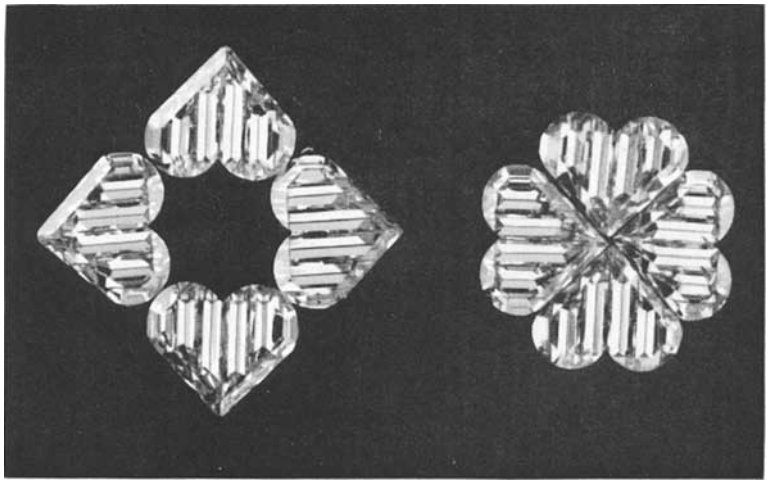

PRINCESS CUT FOR DIAMONDS

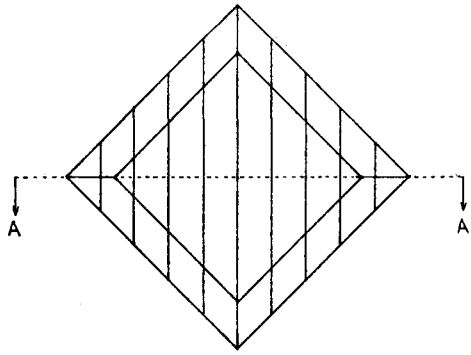

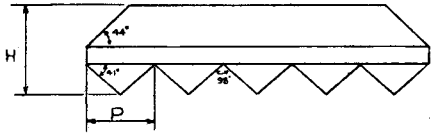

Elevation of A - A

Square Stone Profiled

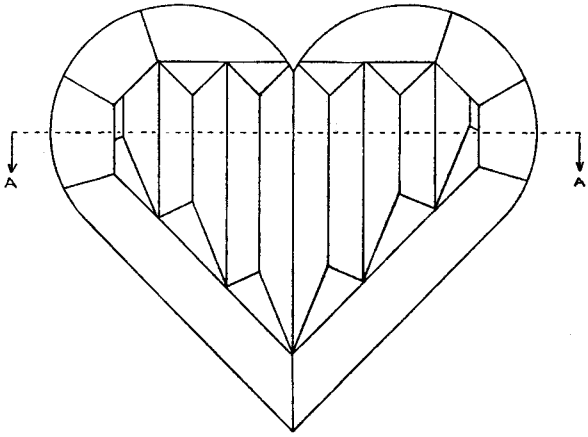

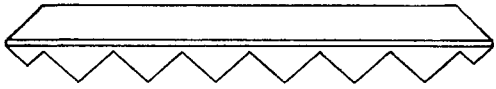

Elevation of A - A

Heart-Shaped Princess

Gemmological Abstracts

SINGH (LAKHBIR). *The colour problem of ruby.* Nature, Vol. 181, pp. 1264-1265, 1958.

The critical concentration of 8 mol.% Cr_2O_3 in synthetic ruby compositions appears to have the same magnetic significance as the Curie temperature.

1 fig. R.A.H.

WHITE (E. A. D.). *Synthetic gemstones.* Quart. Reviews, Vol. XV, No. 1, pp. 1-29, 1961.

Following a discussion of the various crystallization processes used in the synthetic production of gemstones, details are given of the production of diamond, corundum, spinel, rutile, strontium titanate, quartz, garnet, emerald, and blende. The physical properties of gemstones are reviewed and future trends discussed.

4 figs, 4 pls. R.A.H.

HOLMES (R. J.). *Synthetic and other man-made gems.* Foote Prints, Vol. 32, No. 1, pp. 3-25, 1960.

Following a discussion on the nature of gems and their identification, details are given of imitations, assembled and reconstructed stones, the Verneuil flame-fusion process and the production of synthetic corundum and spinel and their identification.

R.A.H.

ANON. *New emerald find in Colombia.* Gems and Gemology, Vol. X, No. 5, pp. 142 and 158. Spring 1961.

Reports on the examination of some emerald crystals from a new source near Borur about 100 miles north-west of Bogatá. The colour of the stones was a clear deep-green and the crystals showed prism faces and, with those which showed terminations, the basal pinacoids had small bi-pyramidal faces of the same order as the prisms. The refractive indices were found to be 1·569–1·576 and the density, taken on a twenty-carat crystal, was 2·704. Three-phase inclusions were noted and one crystal contained two large cavities with movable bubbles. The stones were found to fluoresce somewhat more strongly than other natural emeralds.

1 illus. R.W.

WILSON (A. F.). *Zircon—the mineral and gemstone of rising fame.* Australian Gemmologist, No. 5, pp. 6, 7, 14. May 1961.

The report of the Presidential address to the Gemmological Association of Australia. In 1789 Klaproth isolated the element zirconium from zircon. Most common rocks contain zircon and erosion of these rocks produces the zircon sand and rolled pebbles. Zircon sand consists of crystals of four-sided prisms capped with four-sided pyramids and are only about three-tenths of a millimetre long. The characters of zircon are given as well as its commercial use.

R.W.

FUNSTON (W. E.). *Working conditions in a South African diamond mine.* Australian Gemmologist, No. 5, pp. 8-9. May 1961.

The natives are hired under contract and must live in the compound for not less than four months. The mine shaft (Premier mine) is located within the compound. The natives usually cook their own food which is bought from the non-profit making compound store. Continuously running stoves are made available for this cooking. Underground the workers are formed into groups of four to twenty men under a " boss boy ". Operation is continuous by working three eight-hour shifts. Sleeping accommodation is in dormitories, each being under the control of a " boss boy ". Educational and sports facilities are provided.

R.W.

ANON. *Making diamonds.* Gemmologist, Vol. XXX, No. 360, pp. 130-131. July 1961.

At the open day of the National Physical Laboratory it was disclosed that diamonds had been made during experiments with high pressures. A tetrahedron of pyrophyllite containing the test material is squeezed uniformly by an anvil pressing on each face. Under high pressure the pyrophyllite flows and applies pseudo-hydrostatic pressure to the test sample. Diamond was synthesized using nickel as a catalyst.

1 illus. R.W.

MAHAJAN (B. S.). *Gifts from India for the Queen.* Gemmologist, Vol. XXX, No. 360, pp. 122-123. July 1961.

During their visit to India H.M. the Queen and Prince Philip were the recipients of several gifts, among which were an agate

bangle contained in an agate box which was presented to the Queen by the State of Gujarat, His Royal Highness received a symbolic gift of a ship and lighthouse carved from chalcedony. A crescent in yellow jasper on a pedestal of green jasper was another gift made to the Royal visitors. The material used was obtained from the Little Desert of Cutch.

1 illus. R.W.

LIDDICOAT (R. T.). *A report on European laboratories.* Gems and Gemology, Vol. X, No. 5, pp. 131-141 and 157. Spring 1961.

Describes visits the author paid to the gemmological laboratories in Italy, Germany, France, Switzerland and England. In every case, except that in London, these laboratories provide training facilities. There are four laboratories in Italy, the one visited, that run by Professor Cavenago-Bignami at Valenza-Po, near Florence, was found to be well equipped with up-to-date instruments including X-ray, endoscope and photographic equipment. Unlike the other laboratories, except that in Paris, the stones submitted for testing are identified by number rather than by the owner's name, and they are sealed in a transparent envelope. Prof. K. Schlossmacher's laboratory in Idar-Oberstein was also visited. This laboratory is well equipped and has a diffraction and radiographic unit for pearl testing. Comment is made on the horizontal polarizing microscope which was designed by Prof. Schlossmacher. The Paris laboratory under the direction of Mons. G. Göbel was also found to be well-equipped and much emphasis is placed on the use of inclusions both in routine testing and in teaching. A very full description is given of the laboratory run by Dr. E. Gübelin. There are actually three laboratories. One is in the main sales floor of the Gübelin firm and is mainly used for diamond grading. The other laboratory on the firm's premises is probably the most efficiently equipped laboratory the author visited. Many of the instruments are of Dr. Gübelin's own design. The third laboratory is the Director's own private laboratory. Photography plays an important part in the work of these laboratories and most of the optical instruments were found to be equipped with Leica cameras. The London laboratory, directed by B. W. Anderson, has equipment which is less elaborate but which has been used to great advantage. Mention is made of the contributions to gemmology made by the staff of this laboratory. The

history of this laboratory and its staff, and notes on the research work carried out are given.
16 illus. R.W.

RUFF (E.). *Jade of the East.* Gemmologist, pp. 41-47; 84-88; 117-120; 133-138; 147-152; 170-176 and 187-191 of Vol. XXIX (March to October 1960) and pp. 11-16; 30-35; 54-59; 70-75 and 91-96 of Vol. XXX (Jan-May 1961).

A very extensive series of articles covering many aspects of jade. A vast amount of information is given on the history of jade, on the localities where it is found, on the various colours and types of jade, the symbolism of jade and notes on the carving of this material.
10 illus. R.W.

ANDERSON (B.W.). *Cultured pearls with split nuclei.* Gemmologist, Vol. XXX, No. 358, p. 86. May 1961.

Describes a peculiarity found in some cultured pearls in which the bead core had apparently cracked.
1 illus. R.W.

KENNEDY (N.W.). *Gold in Wales.* Gemmologist, Vol. XXX, No. 358, pp. 87-89. May 1961.

A short account of the gold resources in Wales. The richest deposit was said to be in the Mawddach river area between Dolgelly and Barmouth where extensive faulting has caused the veins of auriferous alluvial to peter out. A general discussion of the gold mining prospects of the area is given.

R.W.

HUNEK (E.). *Regenerated precious opals.* Gemmologist, Vol. XXX, No. 359, pp. 101-102. June 1961.

Details some experiments in the regeneration of precious opals from the Hungarian National Museum, which had been heavily damaged by fire during the 1956 uprising. The stones were treated by using water under vacuum. Slight success was noted using a vacuum of 350 mm but a more satisfactory result was achieved by using a vacuum of 700 mm for eight to twelve days. Up to the present time the regeneration appears to be permanent.

R.W.

PING-HENG (P.). *Jade carving to-day.* Gemmologist, Vol. XXX, No. 369, p. 106. June 1961.

Written by the Deputy Director of the Pekin Arts-Crafts Research Institute the article is a reprint from The Australian Gemmologist. (Abstract Journ. Gemmology, Vol. VIII, No. 3, p. 109).

R.W.

ANDERSON (B. W.). *Spessartite garnets.* Gemmologist, Vol. XXX, No. 359, pp. 108-109. June 1961.

A comment on F. S. Tisdall's article on the spessartite garnet from Ramona, California. (Abstract Journ. Gemmology, Vol. VIII, No. 3, p. 104).

R.W.

DEANE (N.). *Gold in Wales.* Gemmologist, Vol. XXX, No. 360, pp. 121-122. July 1961.

Describes a visit paid to the Clogau St. Davids mine at Bontddu near Dolgelly in North Wales. The gold occurs in quartz veins in a band of " Clogau shale " which extends in a curve from Barmouth round to Dolgelly and then in a northerly direction towards Bala lake. Associated minerals are listed. Speculations as to this and other probable gold resources in the British Isles are made. Spessartite garnet is said to be present in the district.

R.W.

BENSON (L. B.). *Developments and highlights at the Gem Trade Lab. in Los Angeles.* Gems and Gemology, Vol. X, No. 5, pp. 143-147. Spring 1961.

Synthetic spinel doublets in a variety of colours were examined. These stones are said to be obtainable in sixteen different colours. A crystal of hambergite is commented upon and the finding of hexagonal crystals in three-phase inclusions in emerald is mentioned. A natural pearl which showed a greenish overtone when viewed under a standard fluorescent tube lamp, but not under tungsten light, provided a very puzzling effect. A new opal substitute comprised a rock crystal cabochon backed by a piece of abalone shell. A new Gemological Institute of America spectroscopic unit is described.

3 illus. R.W.

CROWINGSHIELD (R.). *Developments and highlights at the Gem Trade Lab. at New York.* Gems and Gemology, Vol. X, No. 5, pp. 148-153 and 158. Spring 1961.

A synthetic quartz of tourmaline-green colour; beryl to beryl doublets, and a star-sapphire doublet consisting of two parts of natural sapphire are reported. Notes on a black dyed cultured pearl in which the nucleus had moved, and a hollow centred cultured pearl are mentioned. Examples of treated turquoise and ruby in green zoisite are other specimens referred to.

9 illus. R.W.

BOOK REVIEWS

SINKANKAS (J.). *Gemstones and minerals. How and where to find them.* Van Nostrand Co. Inc. 67s. 6d. pp. 387. 133 photos and figs. Princeston, 1961.

The U.S.A. and Canada are rich in gem minerals and prospecting is enthusiastically undertaken by many thousands of collectors and lapidaries. John Sinkankas's lucidly written book provides a wealth of information about methods of prospecting and collecting, preparation of specimens, storage, exhibition and marketing. There are chapters about the use of tools, the classification of rocks and field features of mineral deposits.

Once again Mr. Sinkankas has made a good book and, although it will appeal mainly to readers in North America, there is much in it which will inform collectors in any country where the finding of gem minerals is possible.

S.P.

BRUTON (E.). *Diamonds.* True Books. London. 1961. 144 pages. 8s. 6d.

This volume is one of a series of " True Books ", which are written on many subjects, and which are primarily intended for the teenager. In this work Eric Bruton has covered the subject adequately and lucidly in twelve chapters and with 28 illustrations. The nature of diamond; conjectures on the formation of diamond, and something of its occurrence and its uses are told. There are stories about the finding of diamonds in India, Brazil and South Africa, and entertainingly recounted are the early days in

South Africa and the battle for power of Cecil Rhodes and the Barnato Brothers. The histories of some of the South African mines and of the Williamson mine in Tanganyika are given, and there is a chapter on the more important famous diamonds. The mining of diamonds by the primitive methods as used in South America and the more modern equipment used in the South African mines, as well as something of the Russian mining techniques of diamond mining are described. There is an interesting chapter on the sorting and marketing of the rough crystals, on the cutting of diamond crystals into gemstones and the methods used in selling the fashioned stones to the jeweller. The various uses to which diamonds have been put in industry, some scientific facts, and the synthetic production of diamond, form the bases of other chapters. Stories of diamond smuggling help to make the book even more interesting, and in conclusion there is told something of Hatton Garden, the laboratory of the London Chamber of Commerce and the Diamond Research Laboratory in Johannesburg, and some ideas on how to tell a diamond from other gems. Hints on cleaning are given. This book can be recommended, as it is easily read and most absorbing. It should be a valuable addition to a student's library, for the information given is accurate.

P.B.

ASSOCIATION NOTICES

MIDLANDS BRANCH

A party of 30 members and friends visited Luton Hoo on 2nd July, 1961. The collection of fine arts belonging to Sir Harold and Lady Zia Wernher enchanted the visitors, especially the works of Carl Faberge, the Russian collection and the tapestries and tableware of the dining room. Other interesting features were the Brown Jack trophies, carved ivories and examples of fine porcelain.

WEST OF SCOTLAND BRANCH

The well-attended summer outing of the West of Scotland Branch to Leadhills, Lanarkshire, was held on Sunday, 28th May, 1961.

As the name implies, the Leadhills have been worked for their lead, and the written history of lead mining goes back to the 13th century, although they are believed to have been worked for at least 200 years prior to this. Subsequently, silver was mined quite extensively, the ore having been sent to Belgium for refining. A substantial amount of gold has also been found there.

It is not surprising, then, that numerous crystals of Galena were found. Great quantities of clear colourless quartz were also picked up; but no single crystals of any great size. Calcite was prolific in its distribution and many crystals of pyrites were unearthed. One member discovered a large piece of this latter mineral weighing well over a pound but unfortunately displaying no crystal form. Although the lapidaries are unlikely to see any of the specimens collected, the mineral collections of the members present received some useful additions.

MEMBERS' MEETINGS 1961

Dec. 4 Reunion of members and presentation of awards, Goldsmiths' Hall, London, E.C.2. Reunion 6 p.m., presentation 7.15 p.m. Mr. Herbert Tillander, Chairman of the Finnish Gemmological Association had kindly consented to present the awards.

Meetings of the Midlands Branch will be held in November, January and February and branch members will receive details in due course. The November meeting will be a visit to the stone cutting department of Shipton & Co., Birmingham.

OBITUARY

Lester B. Benson, Jr.

In the sudden death of Lester B. Benson, Jr., at the age of 39, the Gemological Institute of America have lost a brilliant and creative gemmologist. Lester Benson was responsible for the development of many of the Institute's instruments and he devised the method of taking curved-surface readings on the refractometer. He was a patient and understanding teacher and was an unfailing inspiration to co-workers and students.

SOLE DISTRIBUTING AGENTS — RAYNER GEMMOLOGICAL INSTRUMENTS

The Gemmological Association of Great Britain has been appointed sole distributing agents for gemmological instruments and accessories manufactured by Messrs. Rayner & Keeler, Ltd.

COUNCIL MEETING

A meeting of the Council was held at the Association's offices on 28th June, 1961. Mr. F. H. Knowles-Brown presided.

The following were elected :—

FELLOWSHIP

Edge, William S., Glenelg, S. Australia. D.1960

Kelly, Allen E., S. Harrow, Middlesex. D.1939

ORDINARY MEMBERSHIP

Azevedo, M. Arthur, California, U.S.A.
Bhushan, Vidya, New Delhi, India.
Burns, Robert, California, U.S.A.
Crank, Helen E. (Mrs.), London.
Davis, Merle, New Jersey, U.S.A.
Garg, Satya P., Jaipur City, India.
Ketelaar, Johann G., Holland.
Males, Pamela A. (Miss), Dulwich Hill, N.S.W., Australia.
Reymer, Hans W., Montreal, Canada.
Schweder, Richard P., Christchurch, New Zealand.
Zeff, Clive M., Johannesburg, S. Africa.

PROBATIONARY MEMBERSHIP

Roca, Rogelio, Jr., Barcelona, Spain.
Searle, Ian V. H., Norwich.
de Silva, S. P. R., Singapore, Malaya.
Vogel, Georg, Lucerne, Switzerland.

A revised syllabus of examinations was approved for use commencing with the 1962 examinations.

Arrangements were made for the presentation of awards to be held on 4th December, 1961, at Goldsmiths' Hall (by kind permission of the Wardens of the Goldsmiths' Company).

COUNCIL MEETING

A meeting of the Council of the Association was held at the Association's offices on 23rd August, 1961. Mr. F. E. Lawson Clarke presided.

The following were elected to membership :—

ORDINARY

Elze, Jacques Hercules, Bussum, Holland.
Fraley, Lawrence, Wheelersburg, Ohio, U.S.A.
Smith, Benjamin Henry, Jr., Wilmington, N. Carolina, U.S.A.
Spink, Brian Stanley Francis, Barrow in Furness.

PROBATIONARY

Camberg, Michael Ralph, Johannesburg, S. Africa.
Grant, James Ros, Carlisle.
Humphreys, Alan Lewis, Andover.
O'Mahony, Michael Dennis, Epsom.
Quick, Rodney John Anthony, Torquay.
Statton, Richard Herbert David, Taunton.

The Council received details of an offer by Messrs. Rayner & Keeler, Ltd., to appoint the Association as sole distributing agents for all Rayner gem testing instruments and accessories. It was resolved to accept the offer, upon terms to be agreed, and the Council recorded appreciation of Messrs. Rayner's gesture. The Council also accepted the services of the National Association of Goldsmiths in connexion with the organization of the agency.

TALKS BY MEMBERS

KENNEDY, N. : "Gemstones and gem materials," British Assoc. Chemists (Merseyside Section), 20th October, 1961.

BAGLEE, G.: "Gemstones," West Hartlepool Ladies' Circle, 11th September, 1961.

EXAMINATIONS IN GEMMOLOGY, 1961

In the 1961 examinations in gemmology 182 candidates presented themselves for the preliminary examination and 106 for the diploma. Centres for the examinations were established in Norway, Switzerland, South Africa, Kenya, Ceylon, Canada, Holland, Finland, New Zealand, Southern Rhodesia, Sweden, Poland, Italy and the United States of America, apart from the United Kingdom.

The Rayner Prize in the preliminary examination has been awarded to Mr. Ernest W. Penner of Islington, Canada. Upon the recommendation of the examiners the Tully Medal and Prize were not awarded.

The following is a list of successful candidates, arranged alphabetically :—

DIPLOMA

Qualified with Distinction

Ainsworth, Kenneth John, Blackburn
Beasley, Barbara Ann, Windsor
Butler, William Charles Finlay, Paisley
Cozens, Jonathan Roper, Taunton
Green, Leslie, Rainhill, Nr. Liverpool
Harrold, David John, Southend-on-Sea
Hayes, Denis, London
Hodgkinson, John Alan William, Aberdeen
Keller, Jean-Pierre, Lucerne
Stout, Cornelius Andries, Rotterdam
Synan, Martin Thomas, Slough
Wallington, Laurie, Scarborough, Canada
White, John Anthony, Frome
Whitehead, Bernard, Birmingham

Qualified

Aarne, Eino Leo, Helsinki, Finland
Abdeen, Mohammed Maharoof Zainul, London
Agius, Frank J., Sliema, Malta
Allen, Michael H., Ilford
Arkiomaa, Pia Gunnari, Helsinki, Finland
Axon-Ryder, Albert Roy, Bolton
Bacon, Frank Hedley, Bedford
Badrutt, Reto J. P., Geneva, Switzerland
Bills, Raymond Frederick, Solihull
Bishop, Trevor, London
Bradley, Czeslawa, Nairobi, Kenya
Conyers, William Edgar, Stockport
Ellis, John Rodney, Norwich
Francis, Roger, Birmingham
Gray, Eleonora, Paris
Greeph, Mayer, Manchester
Heasman, David John Alfred, Colchester
Heesom, Thomas Henry, Altrincham
Hewson, Robin John, Egham
Hill, Dennis Alan, Glasgow
Hiscox, Sieglinde Elsa, Solihull
Hunter, John Waddell, Garrowhill
Jean, Wilmer Francis, Pittsburgh, U.S.A.
Joseph, Timothy Richard, Knowle
Kaksonen, Yrjö Edvin, Helsinki, Finland
Ketelaar, Johann Gottliel, Heemstede, Holland
King, Archibald Vallance, Edinburgh
Lusty, Kenneth Charles, London
McCarty, Fay Veronica, Birmingham
Micinski, Czeslaw Zbigniew, Manchester
Morris, Clive Raphael, London
Musoeus, Hans Bjarne, Oslo, Norway
Nuttall, John, Manchester
Piper, Robert William, Guernsey
Preston, Iris Winifred, Iver
Price, Denis Edward, Smethwich
Rouvier, Andre Edmond, London
Rowe, Alan David, East Molesey
Sanford, Peter, Hatfield
Siltanen, Ismo Kalevi, Jyväskylä, Finland
Silva, Edward Herbert Leslie de, Colombo, Ceylon
Sundqvist, Arvo Johannes, Helsinki, Finland
Sloman, Peter, Southend-on-Sea
Smith, Lawson Bathgate, Birmingham
Smith, Reginald Albert, Oxford
Snaddon, James, Sale
Stirton, Kenneth Geekie, Ripon
Szymczyk, Joseph, London
Webb, Herbert H., London
Wiik, Viggo Harald, Oslo, Norway

Preliminary Qualified

Aho, Risto Aleksander, Helsinki, Finland
Angell, David John, Tonbridge
Asprey, Maurice, London
Bacon, Stephen Jasper, London
Berkel, Joannes Victor Maria van, Utrecht, Holland
Blanshard, Philip John Anthony, Croydon
Blyth, Elizabeth Rhoda, Nanaimo, Canada
Borgen, Annemarta, Oslo, Norway
Bradley, Czeslawa, Nairobi, Kenya
Bradley, Robert Charles William, Didcot
Carlman, Rolf Ryno, Stockholm, Sweden
Chesebrough, Rosser, Sherman Oaks, U.S.A.
Coop, Norah Marian Nita, London
Crank, Susan Elizabeth, Bolton
Cropp, Alan Reginald, Cambridge
Dahl, Leiv Eyvinn, Oslo, Norway
Dahlsveen, Jon Olav, Trondheim, Norway
Dahlsveen, Eirik, Trondheim, Norway
Dale, Rita Olive, Birmingham
Davidson, Terence Malcolm John, London
Donaldson, Helen E. J., Toronto, Canada
Dowse, John Edward, Birmingham
Egli, Ernest, Geneva, Switzerland
Elze, Jacques Hercules, Bussum, Holland
Farrant, Eric Raymond, London
Feltell, Raymond, Birmingham
Fine, Jay, Orilla, Canada
Foulkes, Peter Clarence Albert, London
Frey, Erich, Pretoria, South Africa
Fraleigh, Jack Philip, Toronto, Canada

Gillougley, James Hugh, Glasgow
Glendinning, Harold, Newcastle-upon-Tyne
Gould, Henriette, Johannesburg, South Africa
Griffiths, John Arthur, Kidderminster
Gronqvist, Tarmo, Helsinki, Finland
Harper, David Charles, Sutton Coldfield
Hencher, Brian, Blackpool
Hinton, Bernard A., Toronto, Canada
Hodgetts, Patricia Marion Ann, Birmingham
Hollens, John Frank, Pinner
Hudson, Douglas Geoffrey, Whitstable
Irwin, Eric, Liverpool
Johne, Vera Asta, Oslo, Norway
Johne, Thor Aksel, Oslo, Norway
Jokinen, Pertti, Helsinki, Finland
Jones, David Colin Barry, Leamington Spa
Jones, Kenneth Peter, Stourbridge
Jørgemsem, Per, Oslo, Norway
Keller, Jean-Pierre, Lucerne
Kern, Edward E., West Hartford, U.S.A.
Klerk, Anthonius Franciscus C. de, Oud-Gastel, Holland
Lahtinen, Åke Johannes, Vartokylä, Finland
Lappalainen, Ritva, Helsinki, Finland
Lee, Raymond George, Torquay
Leimu, V. Heikki K., Hämeenlinna, Finland
Lieberman, Ian Stuart, Ilford
Lodge, John William, Newcastle-upon-Tyne
MacKenzie, Iain Fraser, Manchester
Malone, Michael A., Leeds
Marno, Raimo Atte Uolevi, Helsinki, Finland
Marshall, John Frederick, Sutton Coldfield
Marshall, Nigel Francis, Birmingham
McChlery, George Michael, Glasgow
Merritt, Helen Claire, Toronto, Canada
Micinski, Czeslaw Zbingniew, Manchester
Moi, Gerd, Oslo, Norway
Morgan, Ralph John Alfred, Torquay
Mullen, Joseph, Glasgow
Musoeus, Hans Bjarne, Oslo, Norway
Nadort, Edward Adri, New Westminster, Canada
Nash, Roy, Birmingham
Newberry, Bianca Elizabeth, London
Nolan, Constance Jessie Cowlam, Gomersal, Nr. Leeds
Parker, David John, Birmingham
Parviainen, Aira Annikki, Matinkylä, Finland
Petzall, Ossi George, Ilford
Pochee, Farouk Ozair, Edinburgh
Porter, Joseph David, Rochdale
Potterat, Raymond, Geneva, Switzerland
Pressley, Charles Reginald, Worthing
Preston, Iris Winifred, Iver
Pudner, Robert Arnold, Liverpool
Pulkka, Helka Elina, Oulu, Finland
Pulkka, Hilkka Irene, Oulu, Finland
Ranger, Clive James, Bromley
Robinson, David Michael, Liverpool
Sealey, Roger Malcolm, Totton
Selvon, Dennis Ralph, Woodford Green
Slaven, Ronald William, Loanhead
Smart, Lawrence Paul, Birmingham
Solomon, Anthony Leopold, Harrow
Stanley, Edward, Manchester
Stewart, John Linn, Edinburgh
Stockall, Collin John, Richmond
Sweet, Alfred William, Plymouth
Thompson, Colvin Graham, London
Thurlby, Paul Anthony, Birmingham
Travis, Denis John, Esher
Turnbull, Elizabeth, Sunderland
Turton, Philip John, Solihull
Virkkunen, Marjatta, Roihuvuori, Finland
Walker, Leslie, Liverpool
Wallington, Laurie, Scarborough, Canada
Ward, Charles John, Harrogate
Waters, Peter Aloysius, Manchester
Weinstein, Eric, Surbiton
Werkhooven, Piet J. K. van, Hilversum, Holland
Weston, Raymond, Lapworth
Whitehead, David, London
Wiik, Viggo Harald, Oslo, Norway
Wijkstrom, Gunna, Stockholm, Sweden
Wilkins, David, Swindon
Woodhouse, Michael Lesley, London

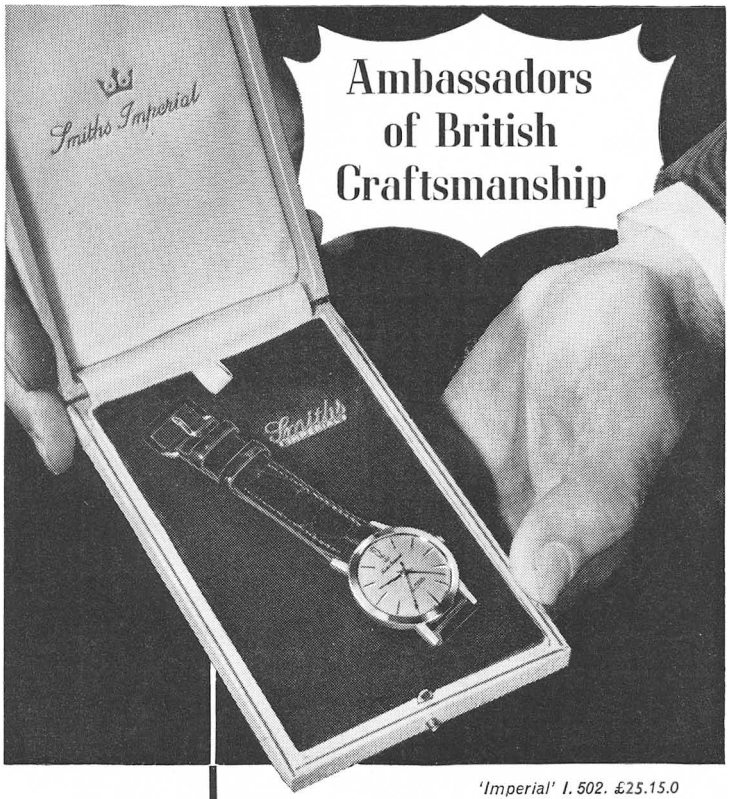

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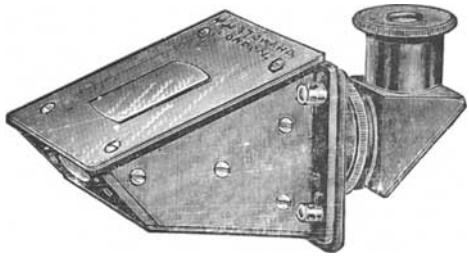

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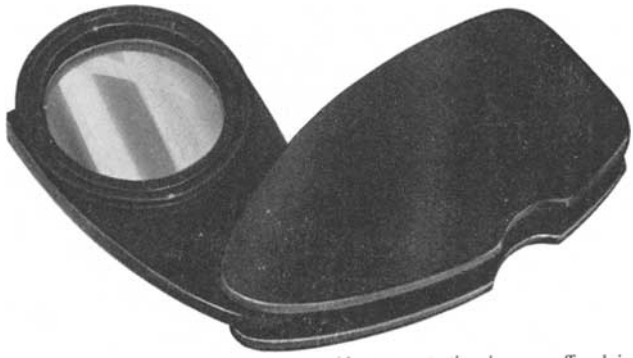

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and

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Vol. VIII No. 5 JANUARY 1962

FIRE MARKS ON GENUINE SAPPHIRE

By W. F. EPPLER

FIRE marks, sometimes also called " chatter marks ", are crack-like markings which are often to be seen on the polished surfaces of synthetic corundum (synthetic ruby and synthetic sapphire, Fig. 1). They are reported to be caused by local overheating during the polishing process.

The marks exhibit different forms of which Fig 1 only gives one example. In each case, a parallelism is remarkable which can be observed with the main directions and with corresponding parts of the cracks as well. Obviously, the designation as chatter marks is derived from similar markings on the surface of turned steel, or other metal, as shown in Fig. 2 and 3. Here, an overlapping of displaced metallic particles took place, the reasons for which are to be found in a possible vibration of the lathe, or in an overcharge of the chisel or the mandrel, or by an unsuitable turning speed, or by other technical reasons. The shifted metallic parts are typically outlined and closely resemble the markings on polished corundum.

In nearly every book of gemmology, these markings are suggested as an indication of the synthetic origin of corundum. E. J. Gübelin first pointed out the fact that these chatter marks can also be found in genuine corundum. In his book " Inclusions as a Means of Gemstone Identification " (Los Angeles 1953, p. 45) he mentions:

" These marks do not afford conclusive proof that the stone is synthetic for they also occur in natural corundum. They are

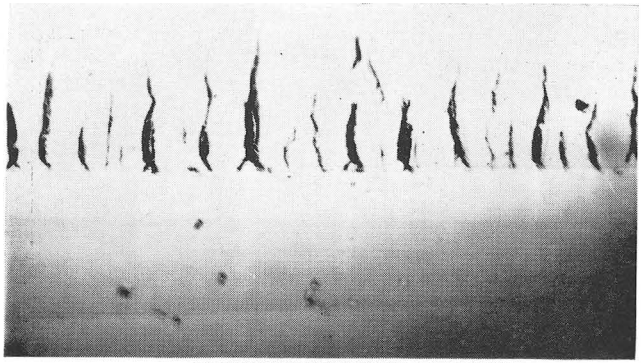

FIG. 1. *Synthetic sapphire showing "fire marks" on its surface. 65X*

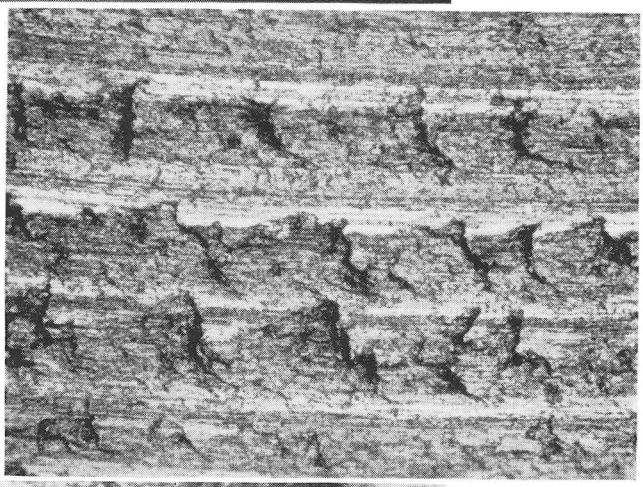

FIG. 2. *Chatter marks on turned steel. 120X*

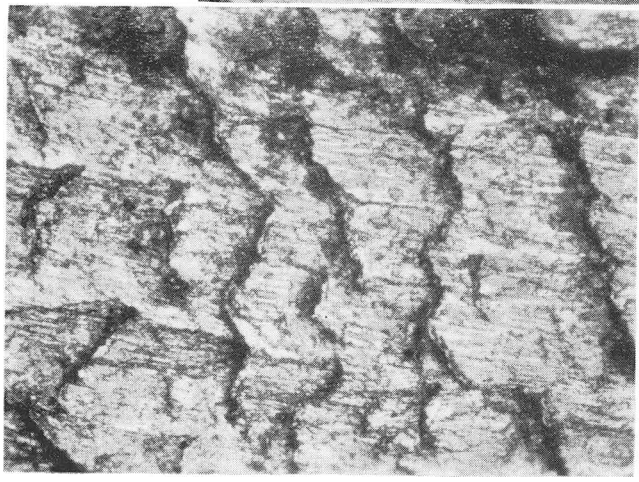

FIG. 3. *Chatter marks on turned steel. 200X*

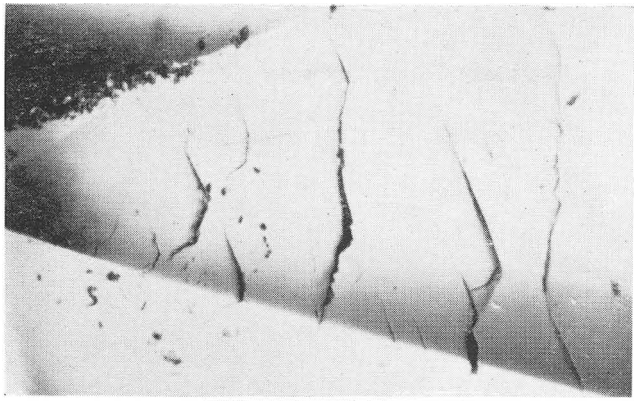

FIG. 4. *Fire marks on sapphire from Ceylon. 65X*

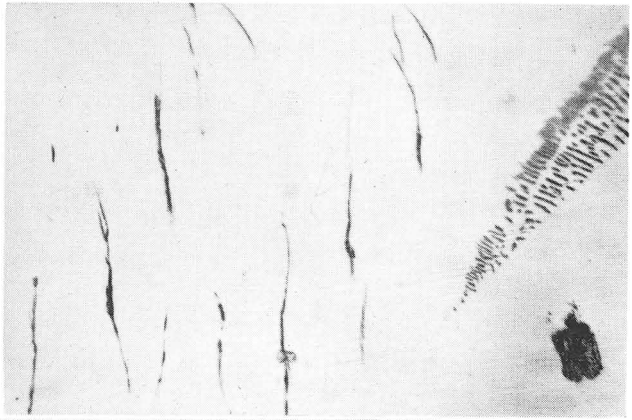

FIG. 5. *Rose-coloured sapphire from Ceylon exhibiting fire marks and a pointed healing fissure consisting of small liquid inclusions (right). The dark spot down right is a dust particle resting on the surface of the stone. 65X*

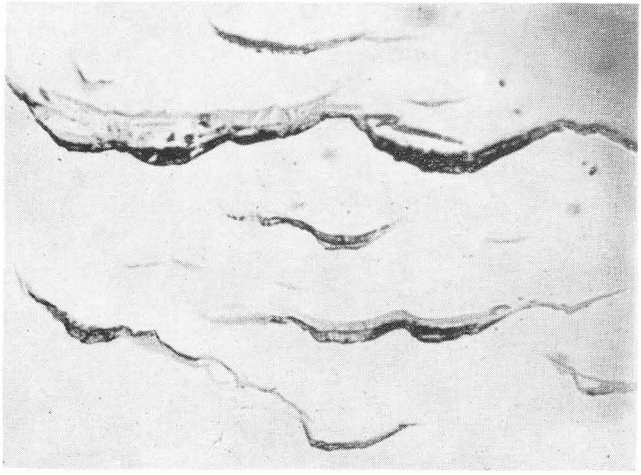

FIG. 6. *Greenish-blue sapphire from Australia with fire marks. 65X*

merely a feature of stones of the corundum species that have been polished too rapidly."

It seems to be regrettable that this observation has not yet entered much of the gemmological literature—and the mind of students likewise.

Fire marks on the facets of natural sapphire of different colours and localities are shown in Figs. 4–7. The marks exhibit some peculiarities from which their origin can be deduced. There is, firstly, the already mentioned parallelism; secondly, certain angles can be observed which, in Fig. 4 for instance, are not far from 90°, while in Fig. 6 and 7 the angles do not deviate much from 120°. Sometimes, the marks are broad and in other cases they are fine lines like small fissures (Fig. 5). An informative feature is revealed in Fig. 7. It represents a fire mark from which only the borderline with the polished surface of the stone is in focus. But it is obvious that the mark continues to deeper regions of the stone thus indicating that it is a wedge-like crack.

In accepting the idea that the cracks are caused by too rapid a polishing or by local overheating during the polishing process—an assumption which certainly is correct—it is most probable that the local overcharge of the surface causes a parting of the corundum along the planes of the primitive rhombohedron. Then it depends on the situation of the polished facet with respect to the planes of the rhombohedron in which direction the parting fissures occur, and also which forms and angles are generated. There exists, as indicated by the pictures, a multitude of possibilities.

Fire marks also occur on the surface of natural ruby, and for their origin the same explanation can be given.

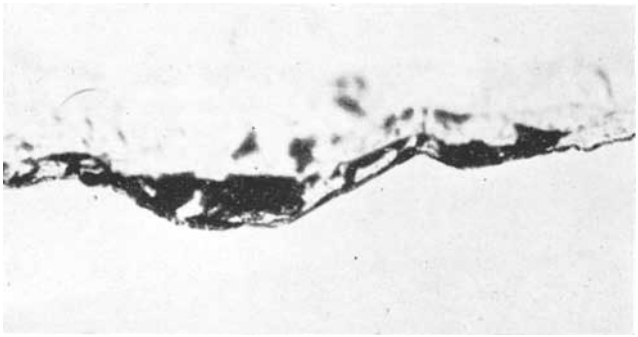

FIG. 7. *Part of Fig. 6. 200X*

THE GREAT TABLE DIAMOND OF TAVERNIER

By S. TOLANSKY

IT has often been repeated in successive books dealing with the history of diamond that Tavernier, when in India in Golconda in 1642, saw a remarkable table diamond weighing 242 carats and which has since vanished. More than one author has wondered what happened to this gem, which Tavernier says was " the largest he ever saw in a merchant's hands".

I am going to show here that previous historians have probably made a mistake. Tavernier's stone was probably *not* a diamond. It was almost certainly a ruby.

The description of this stone occurs in Chapter XIX of Part II of Tavernier's *Travels in India.* This very brief chapter is devoted solely to the description of one plate on page 148 (English translation, London, 1684) in which six different stones are illustrated, two of them twice.

The key to my conjecture lies in the chapter heading which is to Chapter XIX, " Observations upon the fairest and largest diamonds and rubies which the author has seen in Europe and Asia, represented according to the figures in the Plates; as also those which the author sold to the King upon his last return from the Indies, with the figure of a large topaz and the fairest pearls in the world ". This material is followed by five plates of illustrations which refer to this chapter and to Chapter XX, headed " The forms of twenty rubies which the author sold to the King".

We are concerned with the first Plate and Chapter XIX. The first plate is reproduced in Fig. 1.

The critical point is that Tavernier says he is making observations on the largest diamonds and RUBIES which he has seen. Let us look at his descriptions. For Fig. 1 he writes, " This DIAMOND belongs to the great Mogul . . . it weighs 279 9/16ths carats ". For Fig. 2 he writes, " The figure of a DIAMOND belonging to the Great Duke of Tuscany. It weighs 139 carats ". For Fig. 3 he writes, " *A STONE* that weighs 242 5/16th carats. It was the biggest that I ever saw in my life in a Merchant's hands. It was valued at 500,000 Rupees ". For Fig. 4 he writes, " A DIAMOND which I bought. It weighed 157¼ carats ". For Fig.

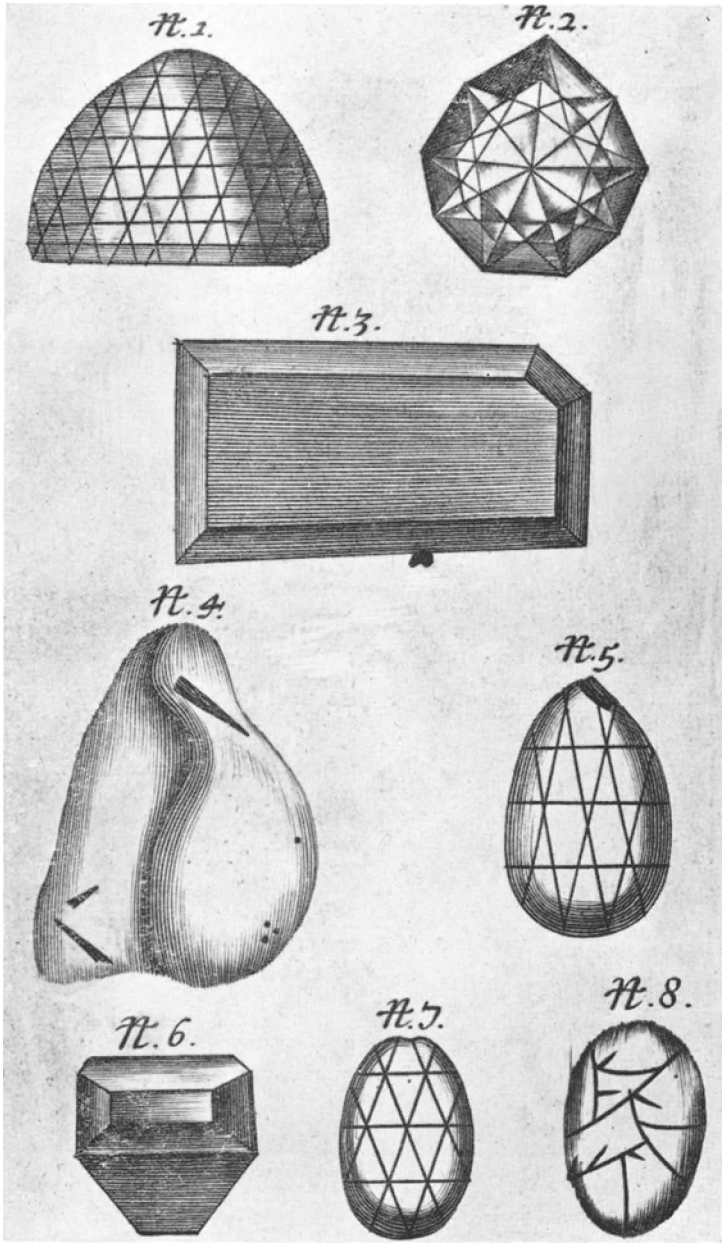
N.1.
N.2.
N.3.
N.4.
N.5.
N.6.
N.7.
N.8.

5, " The fore-mentioned diamond after it was cut ". For Fig. 6, " Another DIAMOND I bought. It weighs 63⅜ carats ".

For Figs. 7 and 8 he is more explicit and this is equally important, saying, " Two pieces of a *STONE* that was cut in two, which being entire weighed 104 carats. Though of good water it seemed foul in the middle. A Hollander bought it and cutting it in two found in the middle of it 8 carats of filth like a rotten weed. The small piece happened to be clean but for the other wherein there are so many cross flaws there was no way but to make seven or eight pieces of it ".

This completes the essential whole or written content of the chapter, apart from some minor insignificant wording I have left out. Now there are two important points. The first is Tavernier. gives a heading where he says he is describing both *diamonds* and *rubies*. Then he describes four gems which he specifically calls DIAMONDS and another two he definitely calls STONES. Clearly the STONES are the rubies. There are several points supporting this theory. To begin with his table stone, Fig. 3, is completely anomalous as a diamond. Nothing resembling it has appeared before or since. If indeed it were part of a huge octahedron worked to a table cut, why is the lower octahedron half not shown as it is in Fig. 6 which is recognizably a large octahedron polished down to table cut ?

However, far more striking are the notes about the STONE of Figs. 7 and 8. We are told the Hollander *cuts* this in half. How, if it is a diamond ? Was it sawn ? I do not believe it. True, Mawe in 1823 describes how small stones can be laboriously sawn by a wire charged with diamond dust. I have found also, in seeking the origin of diamond sawing, that Jeffries, writing in 1751 (*Treatise on Diamonds*) says that diamonds have been sawn to make them into rose-cuts but " this practice was attended with a great expense of workmanship ". Knowing the time taken to saw stones to-day with high-speed rotary saws, a charged wire would have taken months and months, over a year, to have sawn through a diamond weighing 104 carats, and surely Tavernier would have enlarged on this. Mawe mentions that a large stone takes 10 months to saw and large to him was certainly far less than 100 carats ! Then again after cutting, part was cut into seven or eight pieces. Again how ? All this is not early diamond practice at all. All this certainly

does not sound like manual operation on a diamond in 1641, but is reasonable for a ruby.

Of course there is always the possibility that when Tavernier says the Hollander cut the stone he was implying a cleavage. This seems a remote possibility for three reasons. First it would be unusual to find the cleavage plane so convenient as to split the stone so really in half, second there is little evidence that such practices were ever carried out on large diamonds and thirdly, Tavernier goes on to say that the flawed part is cut into seven or eight pieces, and clearly, from the picture this could not be done by cleavage. Evidently the same method as is used to separate the small parts was being used to cut the whole crystal. Clearly then it had not been cleaved.

Now it cannot be too strongly emphasized that Tavernier at the head of his chapter says he is describing both diamonds and rubies. It seems perfectly clear that STONE in Figs. 7 and 8 refers to a RUBY and likewise I conjecture STONE in Fig. 3 also must refer to a RUBY. This being so, the mystery of the disappearance of Tavernier's so-called table-diamond is solved. It never was a diamond. Tavernier at any rate never said explicity that this was a diamond. He called it a stone, whilst using the word diamonds virtually in the same breath for other gems. It is in the following Chapter XX that he goes on to describe the 20 rubies he sold to the King of France and topaz and pearls. I therefore conclude that Tavernier has been simply misrepresented and that he has never stated he saw a huge table diamond. On the contrary with his usual great care, he describes only a great table STONE which he has seen.

ULTRA-VIOLET LIGHT AS AN AID TO GEM TESTING

By R. WEBSTER

THE fascination of the glowing colours which are shown by many substances when they are irradiated by electro-magnetic vibrations below those of the visible range has led to their use both in science and in the arts. Such phenomena may be used as an additional test in the identification of gem materials.

The history of luminescent phenomena is most interesting.

The first reference to a glow of light developed in a substance, that is apart from the so-called " phosphorescence of the sea ", decaying fish, and later on the oxidation of phosphorus, all of which are due to chemical causes rather than to stimulation by radiation, was probably as early as 1570, when a blue luminosity of the tincture of a certain wood when illuminated by sunlight was observed. The first recording of phosphorescence in a solid body was in 1602. At that time Vincenzo Cascariola, a cobbler and dabbler in alchemy who lived in the City of Bologna, calcined barytes, a barium sulphate mineral, which, probably owing to impurities present, produced a phosphorescent alkaline sulphide. This was called " Bologna stone ". The calcined barytes was often of porous appearance and led to the notion that the stone simply soaked up light like a sponge and released it in the dark. This idea was disproved in 1652 by Zecchi, who illuminated such a stone with different coloured lights and found that the colour of the phosphorescence was unchanged. Therefore it was not just a storing up of the incident light and re-emission in its original form.

Many scientists examined the problem of the luminescence produced in different substances when they are irradiated with sunlight. Of particular note is the postulation by David Brewster, who, in 1833, considered that the phenomenon when seen in liquids was internal dispersion. Brewster thought that the effect was due to diffusion or dispersion of the impinging radiation. Later, however, George G. Stokes in a classic paper " On the change of refrangibility of light " put forward the theory that the light was a new creation due to the absorption of rays of shorter wavelengths. Stokes proved his contention by an elegant experiment, that of using crossed filters. He used a source of white light and pairs of

complementary filters between which was placed the fluorescent substance. In one of the experiments he used, as one of the pair of filters, a glass flask containing a deep blue solution of ammoniacal copper sulphate, through which the beam of white light was passed. The beam of blue light so produced was found to be quite invisible when viewed through certain yellow-coloured glasses.

The copper sulphate filter passes only blue and violet light and the yellow filter only the red, orange and yellow rays, so that if a suitably luminescent material was placed between the filters and the glow could be seen through the yellow filter the glow could not be part of the incident light. The incident light must therefore have been absorbed and re-emitted as visible light of a longer wavelength. Indeed, Stokes postulated that the exciting radiation causing the luminescence is of shorter wavelength than that of the resulting fluorescent light. B. W. Anderson has resurrected this " crossed filter " experiment of Stokes and has applied it to gem testing.

The change of refrangibility (wavelength) described above suggests that blue light, or perhaps those radiations below the visible violet and known as ultra-violet rays—or ultra-violet light—might provide the best exciting radiations to produce a glow in responsive materials, and this is certainly the case in many gem materials.

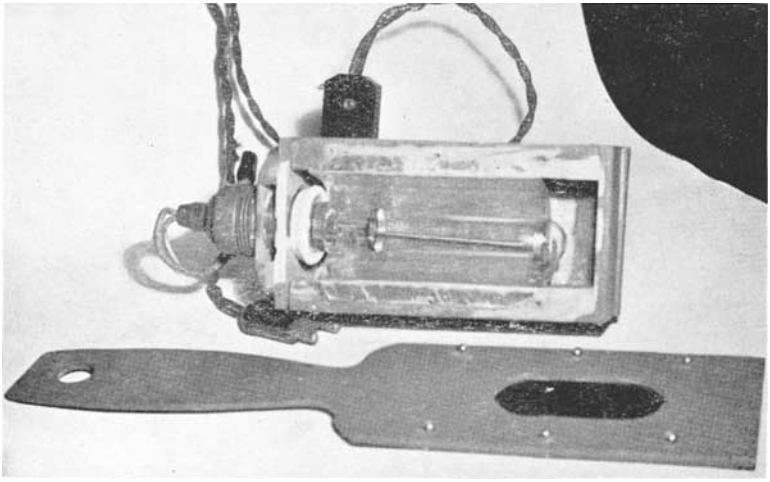

A PHILIPS T.U.V.7 tube in a home made housing. The cover containing the CHANCE O.X.7 filter has been removed to show the lamp.

Admittedly rays of still shorter wavelengths, such as X-rays and gamma rays, will produce luminescence in certain substances. X-rays, and less commonly cathode rays, which are fast moving electrons, have been used in experiments in gem testing, but apparatus for the production of these rays is not readily available.

Ultra-violet light as we understand it is made up of those radiations of shorter wavelengths than those of visible light; those wavelengths below, say, 4000Å. Ultra-violet rays are said to range from this wavelength down to below 150Å. Of this large range of wavelengths there are physical reasons why those below about 2000Å cannot be utilized. The useful range of ultra-violet light is therefore from 4000Å to 2000Å.

These wavelengths are conveniently divided into two sections; those between 4000Å and 3000Å, a section which is designated as " long-wave ultra-violet light ", and the range between 3000Å and 2000Å, which is known as " short-wave ultra-violet light". The importance of these divisions lies in the fact that luminescent responses of materials may differ considerably when different ranges of ultra-violet light are impinging on them. This differential effect may in certain cases assist in the determination of a specimen.

Luminescence is a term used for all the various manifestations producing a glow of visible light in a substance which is not in a state of incandescence. In fact luminescence is " cold light ". When the glow is caused by transformation of waves of shorter wavelength incident on the specimen, as outlined above, the effect is termed *photoluminescence*, and the term *fluorescence* is used for the glow of visible light which occurs while the exciting radiations are impinging on the substance. If the glow persists after the exciting rays are turned off the effect is known as *phosphorescence*. This " after-glow " can be of quite short or long duration. The observation of phosphorescence may also be of use in gem identification.

The physical causes of luminescence concerns the movement of planetary electrons which surround the nucleus of all atoms and any attempt at a full explanation would be out of place in this article.

Dissipation of the absorbed radiation by a solid will give rise to one or more of four distinct effects. The most common is that an increased thermal motion of the atoms occurs and this will account for some or all of the absorbed energy in nearly every case. A photochemical reaction resulting in a permanent change in the

solid can occur, or the emission of photo-electrons producing a photo-electric effect. In this case transfer of energy from the incident light to the electrons in the substance irradiated may give rise to a photo-electric current when the system is included in a suitable circuit.

The effect which is of most interest in this article is that in certain cases the absorption of light energy causes the emission of photons (quanta of radiant energy). The substance is then said to luminesce, but this luminescence may or may not be in the visible range.

Solid substances which luminesce are called phosphors and these are divided into two classes, the first of which, the intrinsic phosphors, are those substances in the pure state which luminesce. There are few pure substances which show luminescence and these, except one, have little interest to the student of gemmology. The exception is diamond, the luminescence of which was at first thought to be due to an impurity, but it is now known to be due in many cases to an intrinsic property of the pure gem, the luminescent centres probably being carbon atoms near lattice imperfections in the crvstal.

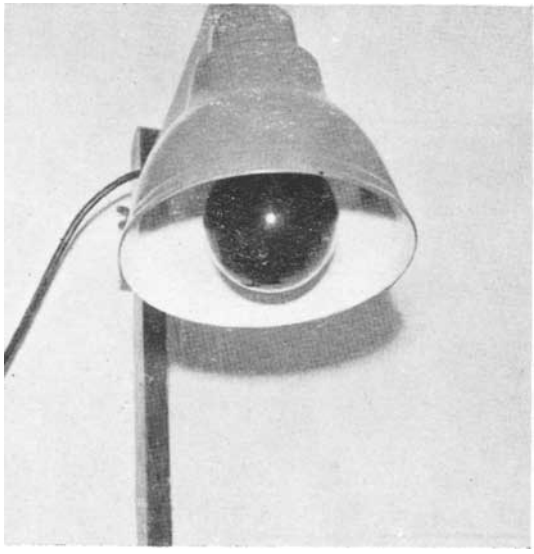

A " Black bulb " long-wave ultra-violet lamp in reflector. This lamp has a small high-pressure mercury burner at the centre of an envelope made of Wood's glass.

Most luminescing materials owe their glow to the presence of impurities and such phosphors are known as impurity-activated phosphors, the impurity being called the activator. The activator atoms (or ions) together with their neighbours in the phosphor form luminescence centres, or, as they are sometimes called, impurity centres.

Very briefly put, luminescence is the absorption of radiant energy by the substance. This raises an electron from a stable orbit (the so-called ground state) to a state of higher energy level, called the excited state, from which it immediately returns giving up its energy in the form of some type of light emission. This is fluorescence. If, however, as in some cases the excited electron does not immediately return to ground state but becomes trapped in a metastable level it cannot return to ground state. It is then necessary for the electron to receive further energy in order to bring it back to the excited state from which it can return to ground state with the emission of light. Thus there is a delay in return producing an " after-glow ", or, as it is called, phosphorescence.

The next question to consider is " How may ultra-violet light be produced " ? Sunlight is rich in ultra-violet rays and it is to these rays that sun-tanning of the skin is mostly due. The earth's atmosphere, however, absorbs practically all ultra-violet rays blow 2850Å, and even below about 3000Å in areas of industrial pollution. Despite the limitation of range of the ultra-violet rays reaching the earth from the sun, it was sunlight which was used by all the early experimenters in the field of luminescence.

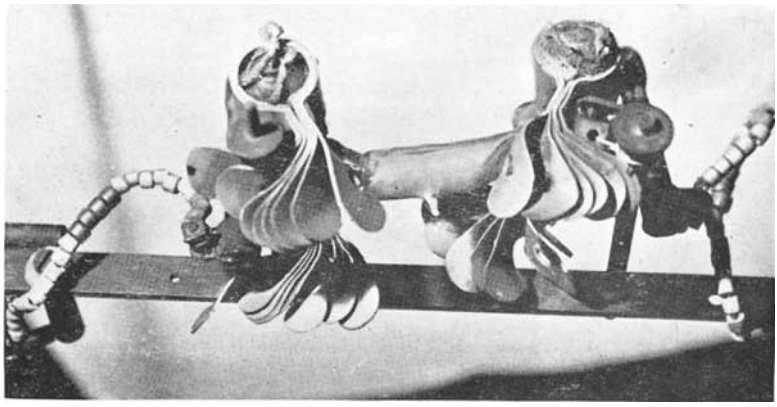

The burner of a Hewittic mercury vapour lamp on its rocking bar.

A gas lamp burning carbon disulphide vapour in an atmosphere of oxygen or nitric oxide gives a rich source of ultra-violet rays and was used by some earlier workers despite its difficulty of operation. An electric spark discharge between metallic electrodes may also be used as a source of ultra-violet rays down to the shorter wavelengths. Here again the high-tension apparatus needed to initiate the spark is not easy to operate.

The electric arc, particularly if provided with special ultra-violet carbons or with certain metal electrodes, such as iron or tungsten, gives a powerful source of ultra-violet rays right down to below 2000Å. The disadvantage of the electric arc is that it is rather " messy " to use as it tends to give off noxious fumes and needs a lot of ventilation.

Photoflood lamps which use an over-run filament produce a source of ultra-violet light, and simple flashbulbs have been used when phosphorescence only is required to be observed. The expense of these bulbs seems to preclude their use to any extent, and, further, owing to the glass envelopes of either of these photographic lamps absorbing ultra-violet rays below 3000Å no experiments with short-wave ultra-violet light can be performed.

A small electric discharge lamp which has a glass bulb filled with argon gas has the attraction that it takes very little current

The American BURTON lamp. A long-wave fluorescent tube lamp having twin filter glass tubes.

and does not heat up. The disadvantage of this lamp is that its lower output is not much below 3900Å, so only in certain cases is it useful. Moreover these argon lamps, although fairly easily obtainable in the United States of America, are not commonly marketed in England.

A hydrogen discharge tube gives a spectrum continuous from the infra-red to the short-wave ultra-violet rays. This lamp, which operates by an electric discharge through hydrogen gas, has a quartz glass tube which passes the shorter radiations. Such a lamp needs special electric equipment to run it and in some lamps may need special cooling. It is mainly an expensive laboratory instrument.

The most convenient and efficient generator of ultra-violet light is an electric discharge through mercury vapour and all modern ultra-violet lamps use such a burner with the mercury, or mercury vapour, enclosed in a quartz-glass tube. Electric discharge lamps, including the aforementioned argon and hydrogen lamps and the electric arc using metal electrodes, have a spectral radiation consisting of sharply defined spectral lines. These are " bright " lines on a " black " background. The light from the sun and from tungsten lamps produce a " continuous spectrum ". With certain " bright line " emissions the lines are so numerous and so close together that they approximate to a continuous spectrum.

The earliest type of electric mercury-vapour lamp used for the fluorescence of gem materials was the Hewittic lamp, which was

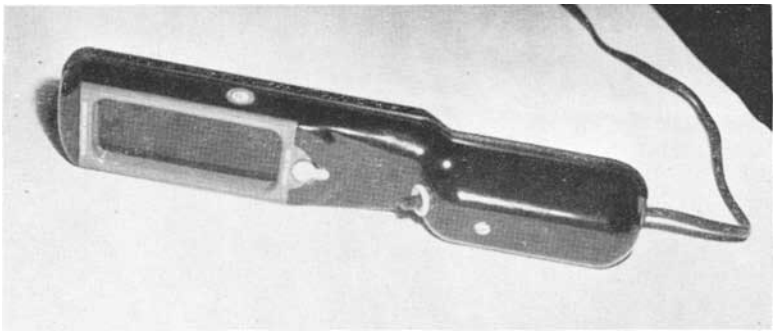

The American MINERALITE short-wave ultra-violet lamp.

supplied to the trade in 1922 as a possible method for the detection of cultured pearls. The Hewittic lamp had a burner consisting of a quartz tube with a bulb at each end containing mercury. When the electric current (and direct current was needed for this lamp) was switched on—a resistance coil being incorporated in the circuit—the burner needed to be tipped in order for the mercury to join momentarily and complete the circuit. This vapourized the mercury and produced the arc—an electric discharge through mercury vapour which emitted, besides strong ultra-violet rays, an intense bluish-white visible light.

Modern quartz-tube mercury-vapour ultra-violet lamps operate on an alternating current (special models by direct current) and are much more convenient to operate. They may be small enough to be portable, or, as in some laboratory models, may be designed for table use or on floor stands.

There are two distinct types of mercury-vapour lamps. The first is the so-called " high-pressure " mercury arc, in which the mercury vapour is at a pressure of one to ten atmospheres. The spectral range of such lamps extends from about 14,000Å or higher in the infra-red to about 1800Å in the ultra-violet. Radiation in the visible part of the spectrum is concentrated mainly in a pair of yellow lines at 5791 and 5770Å and a green line at 5461Å. There are intense lines in the blue at 4358, 4347 and 4339Å as well as two in the violet at 4078 and 4047Å. The intense bluish visible light emitted by these burners is due to these emission lines.

In the ultra-violet region the emission lines are centred at 3654 and 3650Å, and these lines produce the long-wave ultra-violet light used for many fluorescence experiments. The major emission lines below these are the powerful " resonance line " at 2537Å, and another at 1849Å. It is the 2537Å line which is used to produce short-wave ultra-violet light. The high-pressure burner is only suitable for long-wave fluorescence experiments.

The other mercury discharge lamp to be discussed is the low-pressure lamp where the mercury is at a pressure of only one or two millimetres—that is sub-atmospheric. In these low-pressure lamps the spectral strengths of the various mercury lines differ markedly from the high-pressure lamps. In the low-pressure lamp the visible emission is much less, the 3650Å band less strong, and the 2537Å line relatively more pronounced. The low-pressure lamp, a type of which is made commercially for germicidal purposes, needs

an envelope of quartz-glass or a special glass in order to allow transmission down to about 1800Å.

There is a third type of ultra-violet lamp which has a value in gem testing. This may be said to be a " hybrid " lamp for it is a long-wave lamp but operates on the low-pressure system. In this lamp the inside of the glass envelope—made of a glass which does not transmit short-wave ultra-violet rays—is coated with a powder which " fluoresces " with long-wave ultra-violet light under the influence of the short-wave radiation given off by the electric discharge through the mercury vapour. In this lamp the long-wave ultra-violet rays, emitted from the powder lining the inside of the tube, produce a continuous spectrum and not a line spectrum.

These " fluorescent " lamps operate similarly to the fluorescent tube lamps so popular for lighting to-day except that the internal coating of the tube emits long-wave ultra-violet light instead of the bright visible light of the lighting tube. However, there is some bluish visible light given off by the ultra-violet tube.

The high-pressure lamps emit an intense bluish visible light and there is always some visible light produced by the short-wave

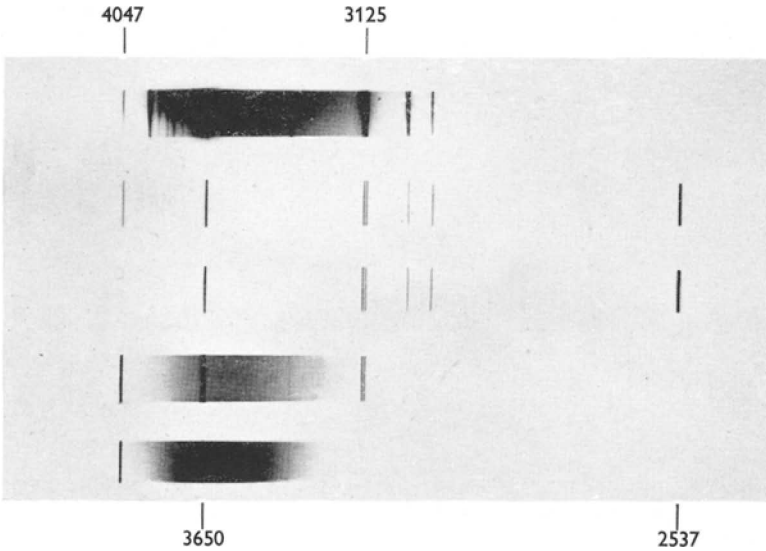

Spectrograms of various ultra-violet lamps.
(Top) High-pressure lamp with Wood's glass filter.
(Next two) Two makes of short-wave low-pressure ultra-violet lamps.
(Bottom two) Two makes of long-wave fluorescent tube ultra-violet lamps.

ultra-violet lamp. Such visible light precludes the observation of fluorescence effects which have to be seen in comparative darkness. The lamps, therefore, have to be fitted with some type of filter which will cut out as far as possible the visible components of the emission and the ultra-violet bands not needed.

For the high-pressure lamp a filter made of a cobalt-nickel glass is used. This glass, devised by R. W. Wood, and known as Wood's glass, cuts out most of the visible light and also the rays below 3000Å. It does transmit the important emission band at 3650Å.

For the separation of the short-wave emission at 2537Å a completely satisfactory filter—that is one which will cut out the visible light and the long-wave ultra-violet rays but pass the short-wave band—does not seem to be possible. The commercial " dark glasses " available are a compromise. Such filters do cut down the visible light from the lamp and also the long-wave ultra-violet rays but do not completely absorb them. They do pass a considerable amount of the 2537Å band.

A short-wave filter in front of a high-pressure lamp will not work. This is because far too much of the strong visible light from the lamp is passed by this filter, and also much of the 3650Å band. The latter mixes with the short-wave emission passed and confuses the results.

It is for this reason that the short-wave filter—and there are a number of short-wave filters of variable efficiency available—must be used in conjunction with a low-pressure burner for such a lamp emits a very much smaller amount of visible light and relatively less of the long-wave ultra-violet rays. These short-wave filters tend to lose their transmiscibility after some 200 hours use. They may be re-habilitated, however, by careful heating to 400°C and then slowly cooling to room temperature.

All ultra-violet lamps need a good housing in order to prevent visible light straying, and the ventilating louvres needed with the high-pressure lamps should be so designed with this in mind. Ultra-violet lamps should be fitted with aluminium reflectors as polished aluminium provides the best reflecting surface for ultra-violet rays. Some ultra-violet lamps are made with the necessary filter glass as an integral part of the lamp, but even with these lamps a suitable reflector is an advantage.

The " hybrid " fluorescence type of lamp, owing to the type of " black glass " filter used, emits further into the long-wave lengths of ultra-violet, and indeed into the violet and blue, than does the high-pressure long-wave ultra-violet lamp fitted with a Wood's glass filter.

The best results with any lamp are obtained when the stones are placed on a black background—such as a black velvet mat—and the room needs to be in comparative darkness or the specimens viewed in a dark cabinet which surrounds the lamp.

Observation of phosphorescence (after-glow) may in some cases be of diagnostic value. To do this it is necessary to shut off the ultra-violet rays from the specimen. It might be thought that switching off the lamp will do all that is necessary. Simple as this appears the method is not efficient for there may be a delay in the final extinction of the rays after switching off. This may tend to mask phosphorescence of short duration. Further, there are electrical characteristics of the high-pressure lamp which precludes it re-lighting again immediately after switching off. Some three to five minutes need to elapse for the burner to cool before it will re-light. Low-pressure lamps do not show this effect as they run cool and will switch on and off at will. A shutter arrangement might provide adequate and speedy shutting off of the ultra-violet rays, or the stone may be quickly removed from the beam.

The luminescent effects shown by the more important gemstones are given in succeeding paragraphs.

Diamond

The first thing which strikes the observer when examining the fluorescence of diamonds is that they vary considerably in the intensity of their glow and in the colour of the light given off.

When irradiated with long-wave ultra-violet light the fluorescence colour most commonly seen in diamonds is a violet or blue and this can vary from a very weak dark violet to a brilliantly bright sky-blue. Some diamonds, however, glow with a green, orange or yellow light.

Colourless and yellowish diamonds, the so-called " Cape " diamonds, glow with a violet or blue light, while brown and greenish-yellow stones fluoresce green. Some colourless, bright yellow (Canary diamonds) and brownish-yellow stones give off a yellow glow. Pink diamonds appear to fall into two groups in that they

may display a bluish fluorescence or exhibit a strong orange glow with a persistent orange phosphorescence. Natural blue diamonds are usually inert.

Under the short-wave lamp the effects seen are similar, but usually much weaker. Most diamonds when under either long- or short-wave ultra-violet rays show a yellow phosphorescence which is more pronounced the stronger the fluorescent glow exhibited by the stone.

In the case of diamonds artificially coloured by bombardment with atomic particles the ultra-violet lamp may aid in distinguishing them from diamonds of natural colour. Many of the treated stones show a green fluorescence. Therefore, as the stones usually treated are of the " Cape series ", stones which normally show a blue fluorescence and in the absorption spectrum the strong line at 4155Å, a green fluorescing stone which also shows this absorption line should be suspect.

It is fairly well authenticated that natural blue diamonds are Type IIb and are transparent to short-wave (2537Å) ultra-violet rays. The artificially coloured (electroned) blue diamonds do not pass rays below 3000Å. A test, therefore, which would show whether a stone was transparent to short-wave ultra-violet light would

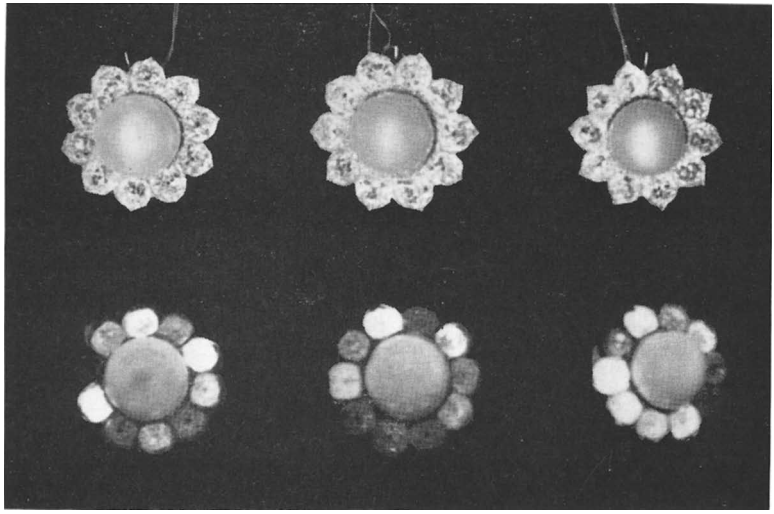

Three diamond and pearl brooches photographed in ordinary light (top picture) and by their fluorescent glows (lower picture). This shows the differential fluorescent intensities of diamonds.

supply the answer as to whether the colour was natural or not. R. W. Ditchburn devised an apparatus using a short-wave ultra-violet lamp, a stone holder and a fluorescent screen in a suitable viewing box for this test to be carried out. The more recently proposed test—that for electro-conductivity which is based on the discovery that natural blue diamonds are electro-conductive—provides a much easier test in this case. No electroned blue diamonds so far tested have shown electro-conductivity.

It has been proposed to take advantage of the difference in intensity of the glows shown by diamonds for the preparation of identity documents concerning pieces of jewellery set with many diamonds. The piece of jewellery is photographed while the diamonds are fluorescing under a beam of ultra-violet light. An ordinary camera is suitable for this provided that an ultra-violet absorbing filter be placed over the camera lens. Such a picture will show the different intensities of fluorescence of the various stones. It is considered outside the bounds of probability that any facsimile piece of jewellery will have the stones glowing with the same intensities in the same places.

Corundum

Ruby exhibits a crimson glow under ultra-violet light which is caused by the trace of chrome oxide which has entered the crystal lattice. The glow emitted by ruby is always, red but the intensity can vary a great deal. Very chrome-rich rubies fluoresce less strongly than those of less saturated colour, or even than the paler red Ceylon rubies. Owing to the trace of iron in the make-up of Siam rubies they show a much duller glow. It has been suggested that this difference in intensity of glow might be used to distinguish between Burmese and Siamese rubies, but the method breaks down in those border-line cases in which it is most needed.

Synthetic rubies show a brilliant crimson red under the long-wave lamp, and when under a beam from such a lamp, it is sometimes possible to pick out the synthetic rubies, by their stronger glow, in a mixed parcel of rubies.

Under the short-wave ultra-violet lamp the red glow shown by rubies is less intense but is often more useful as a diagnostic aid in the detection of synthetic rubies. It is more helpful when dealing with parcels of rubies than it is for individual stones, even when comparison stones are used.

The red fluorescence shown by ruby may be induced by blue light. Therefore if a ruby be bathed in a strong blue light—by filtering a strong white light source by a flask containing a saturated solution of copper sulphate, which allows green, blue and violet light to pass but not red, orange or yellow light—and then viewed through a filter which only passes red light, the stone will be seen glowing red on a black background. Such a method, which is based on Stokes's original work, is useful in sparating rubies from red garnets, doublets and pastes, which do not exhibit a glow under such conditions.

Blue sapphires exhibit very little response under the long-wave ultra-violet lamp, an inertness probably due to the trace of iron always present in natural blue sapphires. An exception is in the case of some Ceylon sapphires which contain a trace of chromic oxide. These are the stones which appear a good blue in daylight and purplish in artificial light. Such sapphires show a weak red glow under the long-wave lamp. It is also true that synthetic blue sapphires do not respond when under this lamp.

Natural blue sapphires are also inert under the short-wave ultra-violet lamp, but the synthetic sapphires show a velvety green glow. Care is necessary in looking for this, as the visible light from the lamp tends to produce reflections of bluish light which tend to mask the fluorescence colour. It has been found best to turn the stone sideways, so that the ultra-violet beam strikes across the girdle. It is well to turn the stone and view it from different directions.

Colourless natural sapphires show an orange fluorescence under either range of ultra-violet light. Synthetic white sapphires are inert under the long-wave lamp but show a deep blue glow under short-wave ultra-violet rays, but occasionally a whitish glow may be seen in these stones which is similar to that shown by synthetic white spinels. Yellow sapphires from Ceylon show an apricot-coloured glow, but the iron-rich Siamese and Australian

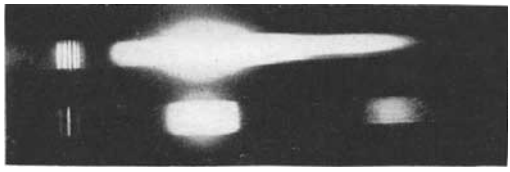

Fluorescent spectra of (upper) natural red spinel and (lower) ruby.

sapphires, and also all natural green sapphires, do not fluoresce. Most synthetic fancy-coloured sapphires show an orange or red glow when in the beam of either range of ultra-violet light.

BERYL

The luminescence of emerald can vary greatly. Under the long, or short-wave lamps many natural emeralds fluoresce with a weak green glow, but some stones may be found to show a reddish glow. Synthetic emeralds usually show a fairly strong red glow. The " hybrid " fluorescent type of lamp, which has its emission further into the visible violet, may be better than the ordinary long-wave lamp for this red glow to be seen. A red fluorescence seen in emerald should indicate that further tests are needed in order to confirm that the stone is synthetic and not a rare red-fluorescing natural emerald. The " crossed-filter " technique, using a copper sulphate filter and a red glass, will in this case perform a similar purpose.

The ultra-violet lamp is an effective tool in distinguishing the Lechleitner synthetic emerald-coated beryls, for under the lamp the thin coating of synthetic emerald glows and outlines the stone with a red rim.

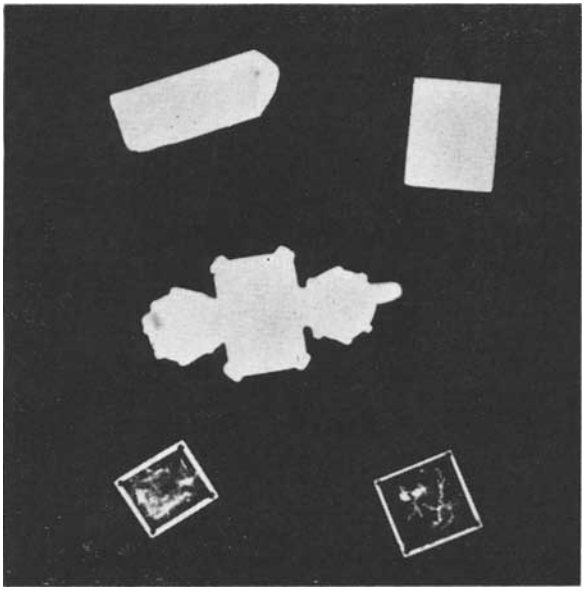

Transparency picture of natural emerald (3 at top) showing the lack of transparency to short-wave ultra-violet light, and the much more transparent synthetic emeralds (bottom two images).

It is known that a natural emerald absorbs ultra-violet radiations below 3100Å, while the synthetic emerald is transparent to rays as far down as 2300Å—that is, the synthetic emerald will pass the 2537Å emission line of the short-wave lamp. Therefore this lamp may be used to ascertain the degree of transparency, for natural emeralds will not transmit these rays, while the synthetic emeralds will.

The technique necessary to do this is to place the suspected stone, with control stones of natural and synthetic emeralds, on a piece of slow photographic printing paper (preferably the old P.O.P.) which has been placed at the bottom of a water-filled dish. A short exposure from the short-wave lamp held about twelve inches above the dish is given, and the photographic paper removed and developed in the normal way. The synthetic emeralds will be distinguished by the greater darkening of the image.

Aquamarines and yellow beryls do not exhibit any diagnostic glows. The pink beryl may show a weak lilac coloured fluorescence.

Chrysoberyl

The yellow and brown chrysoberyls, including the cat's-eyes, do not respond to ultra-violet radiations. Alexandrites show a dull crimson glow under both waves of ultra-violet light and thus may generally be distinguished from the synthetic fancy-coloured corundums which are made to imitate them, for these latter stones usually show an orange fluorescence.

Zircon

A mustard-yellow glow is usually seen with zircons, but the glow can vary from a bright yellow to practically nothing. Care should be taken when testing the white and blue heat-treated zircons, for they tend to change colour (revert to their original brown shade) if kept for only a short time under the lamp.

Spinel

Red and pink spinels behave like rubies in that they show a crimson glow under ultra-violet rays. This can be observed by the " crossed-filter " technique. If the glow be examined by a spectroscope, the fluorescence spectrum will show a group of five or more bright lines, two of which are stronger than the others. This is unlike that of ruby, which shows one strong bright line with a diffuse red band on the side of shorter wavelength. This will clearly distinguish natural red spinel from ruby. The rarely met synthetic

red spinels, however, show a single line somewhat reminiscent of the fluorescent spectrum of ruby.

Dark blue spinels are inert under ultra-violet light. The other colours of natural spinel are inert under the short-wave lamp, but the long-wave radiation produces various coloured glows. Pale mauve, pale blue and violet-blue spinels exhibit a green glow, while the deeper-coloured mauve and purple stones exhibit an orange or red fluorescence.

Colourless synthetic spinels do not luminesce with long-wave rays but usually show a bluish-white glow under the short-wave lamp. This strong white glow, usually masked by the body colour of the stone, is present in all colours of synthetic spinels. The exception is the pink synthetic spinels, which are inert, and the yellow and yellowish-green synthetic spinels, which fluoresce under all radiations a strong apple-green.

Other Stones

Brown topaz shows an orange-yellow glow and kunzite a golden-pink or orange fluorescence. Peridots, tourmalines, garnets and quartz are usually inert under ultra-violet rays, and the rays have little diagnostic value in the case of opal, turquoise, lapis-lazuli and the jades.

The short-wave lamp is useful in the testing of moonstone, for the true moonstone shows a weak reddish-orange glow, while the " schillerized " synthetic spinel which is made to imitate it shows the typical bluish-white fluorescence. The " burnt amethyst " imitation is inert under this lamp.

Neither scheelite nor benitoite glow under the long-wave lamp, but both fluoresce with a blue colour under the short-wave lamp; thus benitoite can be readily distinguished from blue sapphires.

The whitish glow given off by pearls and cultured pearls under the ultra-violet lamps is insufficiently different for distinction to be made between them. By the " crossed-filter " technique natural black pearls can be distinguished by their reddish glow from black pearls which owe their colour to artificial staining, which do not glow.

Ordinary glass (paste) does not fluoresce under the long-wave lamp but may do so under short-wave rays. The glow then may be a misty pale green or a brightish blue. Here lies a danger, for this glow resembles that shown by the synthetic white spinels.

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An English long-wave ultra-violet lamp, the ALLEN lamp, is a fluorescent tube lamp with twin tubes and has a separate filter attached to the removable cover.

LINES AND LINE SYSTEMS IN THE FLUORESCENCE SPECTRA OF DIAMOND

By B. W. ANDERSON

THE results of research on the already much-studied subject of diamond fluorescence continue to appear in the physical journals. Particularly valuable contributions have been the papers by Dyer and Matthews on " The Fluorescence of Diamond"; by Dean, Kennedy and Ralph on " Particle Excited Luminescence in Diamond " ; and by Ralph on " Radiation induced changes in the cathode luminescence spectra of natural diamonds ". These three papers[1,2,3] have brought to a conclusion a wide and fundamental survey of absorption and emission characteristics of natural and irradiated diamonds which has been carried out during the past five or six years by teams working at Reading University under Prof. R. W. Ditchburn, and at King's College, London, under the direction of Prof. F. C. Champion. Thanks to these and other workers we now know a great deal about diamond behaviour in these fields, but there is still much to learn.

The physicist, with the facilities of a large laboratory at his disposal, naturally works at low temperatures (– 180°C) where the fluorescence spectra are both sharper and more intense than under ordinary conditions. He also employs spectrophotometer readings which are of course vastly more valuable for giving a true picture of events, not only in the visible but in the ultra-violet and infra-red regions, than the small hand spectroscopes used by gemmologists.

The purpose of the present article is to give a brief survey of the subject of luminescence phenomena, and particularly of line spectra, in diamond so far as these can be observed at room temperatures and with hand spectroscopes, and to record sharp line spectra in the yellow to red regions recently observed by the writer, which seem to warrant further investigation.

Early accounts of luminescence in diamond were nearly all purely descriptive and led to no fundamental conclusions. The wide variations in the colour and intensity of the fluorescent glow were put down to differing " impurities " in the stones or to their origination in different mines. In his researches on the phosphorescence of diamond and other minerals in 1859 E. Becquerel was ahead of his time[4]. Credit also should be given to Sir William

Crookes who gives some interesting observations about the fluorescence (he calls it phosphorescence) of diamonds under cathode rays in his little book " Diamonds ". This was published in 1909; but the actual work was done over thirty years earlier. He mentions (pages 96 and 97) a green diamond with a strong greenish white fluorescence in which bright lines at 5370, 5130 and 5030Å could be seen. These wavelengths agree very closely with measurements made in more recent years. Crookes also writes of diamonds which phosphoresce red and " show the yellow sodium line on a continuous spectrum ", and of a Brazilian diamond with a bright reddish-yellow phosphorescence in which he " detected the citron line of yttrium ".

This statement, though fallacious, is highly interesting. Miss A. Mani(5) describes a strong emission line at 5895Å shown by one of the diamonds used in her work, and as this is virtually identical with the position of the famous sodium doublet, it was almost certainly this line which Crookes observed. As for the " citron line of yttrium ", it is on record that this was the name given by Crookes to a line actually due to dysprosium, at wavelength 5740Å. This is very close to the sharp line at 5750Å which will receive frequent mention later in this paper.

It was not until the early nineteen forties that certain basic patterns were recognized, which enabled some sort of law and order to be introduced into the apparently chaotic fluorescent behaviour of diamonds under the stimulus of ultra-violet light and other radiations.

In particular, the existence of two main emission systems, one in the blue, based on a line at 4155Å, and the other in the green, based on a line at 5040Å, was established. These important lines can appear either as absorption or emission (fluorescence) lines, and, as Miss Mani showed, they represent the heads of a series of bands spaced at nearly equal frequency or energy intervals—an absorption series lying on the short-wave side, and emission on the long-wave side, of the main " hinge " positions. There is in fact a remarkable " mirror image " symmetry between the emission and absorption peaks on either side of the key positions. The vast majority of Type I diamonds show both these systems in fluorescence though greatly differing in absolute and relative strength.

The presence of a yellow-green component even in diamonds which apparently display a pure blue fluorescence is revealed by the

appearance of a yellowish after-glow when the stone is removed from the rays which excite the fluorescence. As Becquerel found, the blue component disappears almost instantly, but it remains " locked in " at room temperatures. It is released when the stone is heated as the so-called " thermo-phosphorescence ". A neat way of showing this is to pre-heat the specimen gently (conveniently in the flame of a small spirit lamp) before placing it under the rays. When removed from the rays while still sufficiently hot the stone will continue to glow with a *blue* colour. Experiments carried out by the writer showed that the temperature of boiling water (100°C) is insufficient to display this effect, but that it can be demonstrated clearly if the stone is heated to 200°C. That *all* blue fluorescing diamonds show a yellowish phosphorescence is one of the few invariable facts in a complex field of phenomena and a very practical aid in the identification of the mineral.

With many diamonds the green component is strong enough to impart a greenish tinge to the fluorescent colour, and in other cases patches of green may be seen against the blue background of the remaining parts of the stone. More rarely, the fluorescence appears to be entirely green or greenish-yellow in tint. Such stones include brown diamonds and also stones of a curious vaseline colour: an appearance which is due to the strong yellow-green fluorescence which is induced even by ordinary daylight. In green-fluorescing stones the key band at 5040 can usually be detected in a hand spectroscope, both in absorption, as a rather faint narrow line (often accompanied by another line at 4980), and as an emission line when the stone is fluorescing. Similarly in strongly blue fluorescent diamonds, the key band at 4155 can be seen, and less distinctly other bands on the long-wave side of this. Approximate measurements for these bands, made with a Beck " Wavelength " spectroscope, gave readings of 4285, 4390, 4520, and 4670Å. The latter two bands were hardly distinguishable from the general background of continuous emission in this region. There are also true " canary " yellow diamonds, which have a clear yellow fluorescence and no observable discrete lines either in emission or absorption, at least at room temperatures. Diamonds of this type which have been examined by the writer have shown the ultra-violet transmission of Type II diamonds.

In addition to the now well-established blue and green components, it has long been realized that other regions of fluorescence

extending to the red end of the spectrum exist in certain diamonds, but no satisfactory scheme of mirror-image fluorescence and absorption bands hinged on a key wavelength has yet been observed or agreed upon for this region.

Stones emitting a notable red component can be picked out with ease from any sample of diamonds under long-wave (3650Å) ultra-violet light, or even under " copper sulphate " light, simply by viewing them through a good red filter, when the few stones showing the effect will seem to emit a red glow while the other stones will cease to show any visible fluorescence. Diamonds of this type have particularly interested the writer since his discovery of a type of pink diamonds showing an orange-yellow glow under ultra-violet and other rays—a fluorescence which could be analysed through a hand spectroscope into a well marked series of lines headed by a prominent member at 5750Å. The first stones of this type to be observed were a large (34·64 carats) diamond, almost certainly a Golconda stone, and a smaller (2·83 carats) specimen, both distinctly pink in colour. These were described in a previous article in this Journal(7). More recently a further gem diamond of over 20 carats has been examined, which showed a precisely similar fluorescence spectrum. This stone was also pink, though very pale in tint. The emission lines were not quite so pronounced as those previously reported in the 34 carat pink diamond, but were sufficiently clear to yield a reasonably good photograph, as can be seen from Fig. 1, where a mercury arc spectrum taken on the same plate serves as a

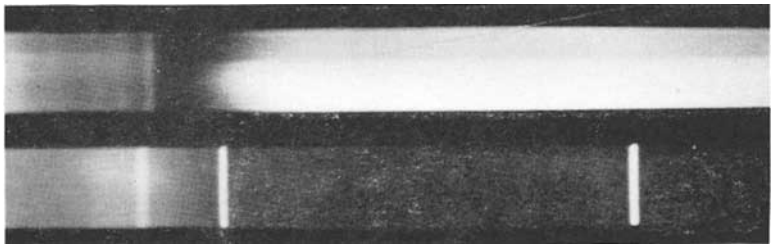

FIG. 1. (*a*) *Fluorescence spectrum of Type IIa pink diamond under light filtered through copper sulphate solution. Ilford H.P.3 plate, 40 minutes exposure.*
(*b*) *Mercury fluorescent tube spectrum for comparison.*

wavelength guide. This was taken with a small quartz spectrograph on an Ilford HP3 plate. The stone was bathed in blue light concentrated through a flask containing copper sulphate solution, the source being a 250 watt projection lamp, and the exposure time 50 minutes. A photograph taken under similar conditions with the 34 carat diamond but under 3650Å ultra-violet light, is also reproduced for comparison (Fig. 2).

A notable feature of all three of the pink diamonds mentioned was that the same orange-yellow fluorescence was produced under all available forms of radiation: visible blue light, long ultra-violet and short-wave ultra-violet rays, and even X-rays. Another notable feature was a persistent phosphorescence of the same colour. Tests showed these stones to be of the Type II category at least so far as ultra-violet transmission is concerned.

Pink diamonds of any kind, let alone of this particular type, are rarely seen in our Laboratory and not easily borrowed, but it was thought worth while to sort through parcels of " ordinary " diamonds, to see whether any could be found which showed at least the 5750 emission line in similar manner. A parcel of fair quality industrial stones from Sierra Leone, were kindly made available for this purpose by the West African Selection Trust. Of the 208 stones examined, 19 were picked out as having a strong blue fluorescence under ultra-violet light; 22 stones showed a rather weaker blue glow; 28 a dull blue; while there were 27 stones in which the fluorescence was green or yellow. The emission spectrum of those stones from the above categories which showed a

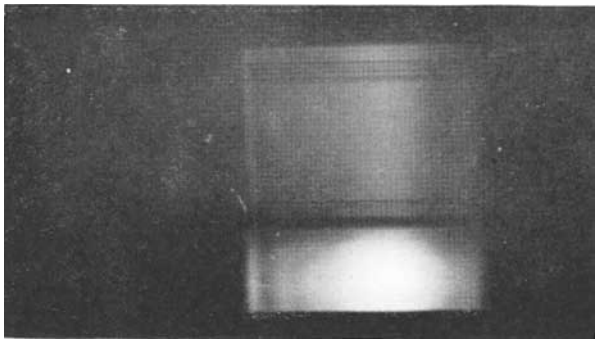

FIG. 2. *Fluorescence spectrum of large pink Type IIa diamond, under 3650Å light. Ilford H.P.3 plate, 50 minutes exposure.*

residual glow through a red filter was then closely examined through a direct vision prism spectroscope, both under " copper sulphate " visible light, and under a large Hanovia mercury lamp with Wood's glass filter.

The quest was surprisingly successful; no fewer than 8 stones showing the 5750 line feebly but very clearly. Four of these stones were from the strong blue fluorescers, two from the weaker blues, and two from the greens. In some cases, and unexpectedly, a bright line at 5370Å was seen in addition to the 5750 and this was equally sharp and clear. An absorption line at 5370Å had several times been observed in the past in brown diamonds, which also showed the 5040 and 4980 lines, but to see it as an emission line and in conjunction with the 5750 line, which is the head of a series extending into the orange, was indeed surprising.

A warning is necessary to anyone seeking these lines under a mercury source of ultra-violet light, or in a room illuminated by fluorescent lighting which emits a mercury spectrum. It so happens that the powerful yellow doublet at 5791 and 5770Å emitted by a mercury arc and the mercury green line at 5461 are very near to these emission lines in diamond, and any leakage of unfiltered mercury light can be reflected from the stone under examination and give any observer with a hand spectroscope a precisely similar effect. This points to one great advantage in using the less conventional and less powerful stimulus of visible tungsten filament light filtered through a flask of copper sulphate solution, since any bright lines seen with this as the only illuminant can, of course, come only from the feeble luminescent light emitted by the diamond.

A further parcel of industrial diamonds, in this case from Ghana, was later loaned for examination by the West African Selection Trust. The search for stones showing the 5750Å emission line was again successful, though in this instance only one example was found to show the effect, and this only under the stimulus of blue-violet " copper sulphate " light. The fluorescence of this stone under long-wave ultra-violet was blue. A third parcel, in this instance comprising well-formed crystals of " silver cape " quality from S.W. Africa, was kindly made available to the writer by Mr. Arpad Nagy, inventor of the revolutionary " Princess Cut " for diamond. Here again only one stone of those examined was found to show the yellow line. Further search with diamonds from

other localities and of different qualities will be carried out as time and opportunity permit.

The writer's first experience of the 5750 line had been in 1957 with one of the stones from a parcel of small brown diamonds which owed their colour to bombardment and subsequent annealing. All these stones showed the tell-tale 5920 absorption line (which Dugdale[8] and later Crowningshield[9] found to be typical of treated diamonds) very clearly, but the specimen mentioned was exceptional in displaying an orange fluorescence under 3650Å ultra-violet rays, and under " copper sulphate " light. G. R. Crowningshield and Dr. Edward Gübelin, who are both skilled spectroscopists and vitally interested in diamond fluorescence, have independently observed an orange fluorescence and the presence of the 5750 line in certain bombarded diamonds—particularly in a few stones of pinkish tint which occasionally crop up as " freak " stones. One such stone was sent to the writer by Mr. Crowningshield and later kindly presented to me by Mr. Theodore Moed, an American supplier of treated diamonds. This stone showed a remarkable spectrum with a sharp absorption line at 6360Å, a weaker absorption doublet centred at 6170, and the 5920 line. Under " copper sulphate " light the 5750 emission line is clear, and 4 or 5 weaker lines of the series are visible.

In the paper by Dean, Kennedy and Ralph on " particle excited " luminescence in diamond, to which reference has already been made, the appearance of a yellow " system " having a principal line at 5755Å is described in detail. The other wavelengths given by these authors for lines in this series are 5870, 5980, and 6170Å. Undoubtedly this is the same system as that seen by the writer in the three pink diamonds mentioned above and photographed in Figs. 1 and 2. But it must be remarked that Dean and his co-workers were using not ultra-violet or blue-violet light, but cathode-ray excitation. In fact Ralph in his further paper states that the 5755 system has not been reported where ultra-violet or X-rays were employed. Further, the lines were recorded by these workers at the low temperature of $-180°C$ at which both the intensity and sharpness of fluorescence lines is known to be far greater than at normal temperatures. Thus the appearance of really sharp emission lines at 5750 and 5370Å under violet and ultra-violet light at room temperatures seems decidedly noteworthy.

The fluorescent behaviour of five of the Sierra Leone diamonds is summarized below in tabular form.

Stone	*Carats*	*Under* $CuSO_4$	*Under* 3650Å	*Under* 2537Å	*Trans.*
A	1·57	5750 5370 sharp	Greenish 5750 5370 clear	Greenish	2600Å
B	2·03	5750 only	Dull bluish 5750 weak	Weak blue	2400
C	1·25	5750 only	Strong blue 5750 only	Strong blue	2400
D	1·52	5750 only	Mod. blue 5750 5370 clear	Mod. blue	2400
E	1·36	5750 only	Dull blue 5750 5370	Mod. blue	2400

Table showing fluorescent behaviour under various radiations, and transparency to ultra-violet of five Sierra Leone industrial diamonds.

In their paper, Dyer and Matthews describe yet another series of narrow bands, in this case in the orange-red, which they found in the emission spectrum of certain Type I diamonds in addition to the far stronger blue and green emission systems. These emission " peaks " could only be recorded at liquid air temperatures. The four bands measured formed a true " system " based on wavelength 6195Å, with others at 6291, 6363, and 6494Å. Incidentally, Miss Mani recorded emission bands at 6177, 6265 and 6358Å which may refer to the first three just mentioned, but she did not envisage them as a separate series. She also referred to an emission band at 5758, giving it as part of the 5040 group. Dyer and Matthews also table a band at 5758Å as found, unassociated with any system, in some Type II diamonds.

There are records of lines still further into the red, e.g. bands at 7250 and 8000Å, found by Dean, Kennedy and Ralph in diamonds excited by cathode rays. The writer has seen undoubted " structure " effects in the deep red with certain fluorescing diamonds, but has been quite unable to measure these, as they occur in a region of very low visual acuity.

Another worker who has recently discovered sharp lines in the emission spectrum of an orange-fluorescing diamond, is A. Jayaraman of the Raman Research Institute in Bangalore. It was from this Institute that a rich flow of papers on diamond behaviour issued during the nineteen forties. Jayaraman describes[10] a series with its principal line at 5786·27Å (recorded at −180°C). The decimal places imply great accuracy of measurement, but if, as seems almost certain, Jayaraman is referring to the same line as that we have recorded as 5750 and Dean *et alii* as 5755Å, so great a discrepancy in the estimate of wavelength is extremely puzzling. Even a glance at the spectra reproduced in Fig. 1 will show that the strongest luminescence line is on the shorter wavelength side of the mercury doublet at 5791 and 5770Å. Jayaraman was working with long-wave ultra-violet light and at liquid air temperatures. In addition to the 5786 series, he found other " new electronic emissions " at 4958 and 5106Å, and bands associated with these.

By rather a strange coincidence yet another reference to orange fluorescence in diamond has recently appeared in the literature. This is in a paper by a Czech scientist, J. Koursinsky, summarized in Mineralogical Abstracts, and describes a study of the fluorescence of 8949 diamonds from a Museum collection. Only one stone, Koursinsky states, showed an orange fluorescence, and this was a reputedly Bohemian diamond. He speculates whether the unusual fluorescence is a unique sign for a Bohemian stone. No spectral analysis of this orange glow was apparently attempted. It would be interesting to know if the stone was a 5750Å emitter.

Before concluding, the writer would like to record the curious luminescent behaviour of a pale steely-blue diamond, examined rather more than a year ago. This was mounted in a ring, and weighed about 3 carats. The stone proved to be semi-conductive, though to only a slight degree, and it transmitted ultra-violet light down to slightly below 2300Å. On this basis, and on account of its natural bluish colour, it could be claimed as one of Dr. Custers' Type IIb diamonds. The stone showed no noticeable fluorescence under either long or short wave ultra-violet light, but, in place of the usual blue phosphorescence usually shown by this type of diamond after exposure to short-wave light, this specimen showed a dull but persistent orange glow not only after this form of excitation, but after stimulation by long-wave ultra-violet and even by visible light.

Phosphorescence of any diamond, no matter of what category, after exposure to visible tungsten light is so unusual that experiments were carried out with light from a 500-watt projection lamp passed through a series of colour-filters, to ascertain which regions of the spectrum functioned as the most vigorous stimulus for the orange after-glow. The stone was exposed in turn to red, orange, yellow, blue, and 3650Å light for ten seconds, then, after a pause of twenty seconds, placed for 20 seconds in contact with an Ilford LRS plate. There was a long interval between each experiment to allow the phosphorescence to die down completely between each test. The plate was finally developed, and a print from this is reproduced as Fig. 3. It would appear from this that yellow light was the most productive of the phosphorescence, but the test is not very exact, since the yellow filter used transmits from the green onwards. As can be seen, the result under red light is very slight; nevertheless, to obtain any effect at all with light of such low energy (the filter cuts out at 6100Å) was sufficiently astonishing.

This grey-blue stone showed an orange fluorescence under X-rays, but this was not strong, and no line structure could be seen through the spectroscope.

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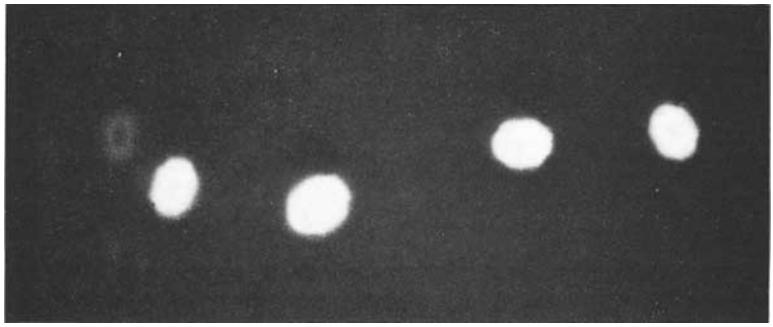

FIG. 3. *Autophotographs of orange-red phosphorescence of Type IIb grey-blue diamond on Ilford LRS plate. 20 secs contact after 10 secs. exposure to (reading from left) red, orange, yellow, blue, and 3650Å light.*

Gemmological Notes

TESTING WITHOUT INSTRUMENTS

A. E. FARN

During my six years' war service I was often sent on courses and lectures and returned to my unit aglow with enthusiasm and eager to dispense instructions. Nothing was more calculated to deflate one's buoyancy than the well-worn phrase so beloved of our Sergeant Instructor, " You can forget all that stuff they taught you on the course—you'll do it our way ".

Somewhat similar I think must be the feelings of the new F.G.A.'s as they emerge from their second year course. Their exams. behind them and the whole gemmological world at their feet, they enter the post-diploma course prepared for a leisurely approach to a much wider range of stones and to enjoy unalloyed wallowing amidst paraphernalia gemmological ad nauseam. How deflating then to find that one of the first lectures is entitled " Gem Testing Without Instruments "—almost as if to say to the budding F.G.A. " now forget all that practical work you have done, we'll show you just how unnecessary instruments really are". Though this is in fact true in part, it is only true because of the knowledge and practice gained at classes,

We do not discount those useful instruments, the microscope, refractometer and spectroscope; they are an essential to all round gem testing. The lecture usually takes one along the paths of logical conclusions based on knowledge and aided by observations with a lens. " An example of such testing is to examine a piece of lapis-lazuli with a lens—this is testing without instruments on a fairly easy basis ". Most people probably know their lapis-lazuli before they start classes. There are of course very many obvious examples which could be quoted of gems which can be identified by use of a lens without recourse to other instruments. However, this ability to test in such a manner rests solely upon a good technical training backed by sound theory.

I do not intend to reproduce here the substance of the third year lecture except to say that in it is a vast store of accumulated knowledge which would make a most useful adjunct to the rule of thumb knowledge and practice of jewellery dealers.

It is a very nice feeling to buy a garnet-set brooch at a garnet price knowing that the red stones happen to be Siam rubies. This I have experienced once or twice; it is a most rewarding feeling. This is gemmology with a plus !

Quite recently I was looking in a shop window fairly liberally dressed with interesting secondhand items of jewellery. Trying to assess their respective merits with a view to making a purchase, I was intrigued to see an obviously antique half-pearl cluster ring flanked by two small rubies with a square colourless centre stone. This centre stone looked wrong—it should have been a red stone of some kind. Peering through the window at the stone I was able to see by judiciously craning my neck the reflection of a lamp bulb used in the window illuminations. The table facet of this square stone was fairly small but had a polish which gave a perfect reflection of the word " OSRAM ". Re-focusing on a shelf bracket above I was able to bring this straight edge into my line of vision as a reflection on the table facet and slowly move my eye, causing the reflected edge to travel across the polished surface of the stone. This it did with razor sharpness and precision and not a trace of wobble anywhere. I knew that only diamond could give such plane-perfect reflection, so I went in and bought it, and subsequently sold it at a profit. This sort of thing gives a fillip to more mundane testing.

RHODESIAN ALEXANDRITE

JOHN PROBUS

Well-formed crystals of alexandrite, though not of gem quality, have been found near Fort Victoria, Southern Rhodesia. The crystals are very dark in colour but a colour-change is apparent in many of them. The occurrence is in a grey mica schist.

SYNTHETIC EMERALD

JOHN PROBUS

In the U.S.A. and Canada the recently produced synthetic emerald-coated beryl (a thin coating of synthetic emerald grown onto a faceted core of natural beryl) is being sold as Linde synthetic emerald. Thus the gemmological nomenclature tends to become more ambiguous.

COVER IMMERSION OBSERVATION

S. BUZALEWICZ.

Observation of the interior of a stone requires its immersion in a suitable fluid. During microscopical observation the immersion fluid usually remains in an open glass, which creates difficulties and inconvenience in the keeping of the fluid suitable for microscopical observation, and during the observation itself. The shape of usual immersion containers requires the immersion fluid to be kept in a closed bottle. Before microscopical observation the immersion glass must be cleaned, and during observation the surface of the fluid remains exposed and can become dirty by dust from the air. The surface of the fluid moves (especially by the turning during the microscopical observation for the optical birefringence of the stone), sometimes causing distortion of the image of the immersed stone. During manipulation of the microscope tube there arises a possibility of touching the liquid with the objective of the microscope, thus making it dirty by the oily immersion fluid. After observation the immersion fluid must be poured back into the bottle, and the glass, after cleaning, should be placed in a box. Such slow manipulation requires laboratory facilities and can scarcely be successfully applied in usual trade conditions.

Application of this important gemmological test in commercial practice could be made easier by cover immersion. This relies upon observation of a stone which has been immersed in a specially designed glass container. This container has on one side a long neck closed by an outside screw. This glass is always filled with an immersion fluid and kept in a dark shakesafe box, ready for immediate use. The upper wall of the immersion glass when not plain but curved acts as a lens. The base of the cell consists of a convex lens inside and is flat at the base. Use of the lens as the bottom of the immersion cell gives two advantages; the greatest transparency of the glass and the hollow for the stone in the centre of the field of view. Use of the lens in the upper part of the immersion cell gives also greatest transparency of the glass and forms the curvature of the fluid surface for the purpose of increasing the image of the viewed stone. By putting the stone in the cover immersion cell it falls into the hollow in the centre of the bottom and remains in this central position of the field of view during rotation of the cell. It is obvious that the turning around of the cell must be made so that the centre of the viewing part of the cover immersion cell

remains always in the field of view of the microscope. The manipulation with the stone in the cover immersion cell can be done by means of curved stone tongs, by which the stone can be turned on the bottom, raised from the bottom and turned inside the cover immersion cell in the same manner as in the open immersion cell.

Cover immersion observation needs little preparation. The cover immersion observation can be carried out in closed glass (opened only a short time during the putting in and taking out of the stone and during change of the position of the stone in the immersion liquid), thus the liquid remains clean and safeguarded from the dust from the air. Any dust would rise to the surface of the immersion liquid in the neck of the glass and not in the field of view of an observed stone. The liquid surface does not move during the turning of the glass and the microscope objective is prevented from occasional touching of the liquid. The high neck of the glass makes a reservoir of fluid enabling observation of a great number of stones without the need of adding new fluid. It also makes unnecessary any portable reservoir bottle and of pouring in and out of the immersion fluid.

Cover immersion enables observation of the interior of a stone, pleochroism, birefringence and colour, with the application of optical filters, and light can be focused parallel, and be dispersed, from below, from the side or from above. It allows also the simultaneous approximate testing of specific gravity of the tested stone by means of a stone's behaviour in the neck of the glass fluid.

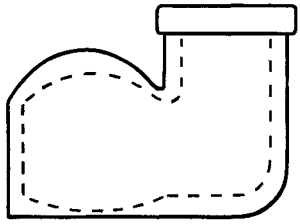

NEW JEWELLERY CLEANER

A new cleaner, named "Jewellax", has been developed primarily for the jewellery trade and provides an effective means of removing dirt and residual polishing composition from filigree work and gem settings.

"Jewellax" is supplied in small bottles of convenient size and is in the nature of a syrupy concentrate which is diluted in the proportion of one part to thirty parts of water before use.

The jewellery or other articles are immersed in the cleaning solution, which is maintained at a temperature of 180° to 200°F and may be contained in any suitable vessel such as a plain steel tank or vitreous enamelled utensil.

A few minutes soaking in the hot cleaner usually suffices to remove soil and impacted polishing composition without recourse to mechanical means. Gentle movement of the articles assists the operation and light brushing is only essential in the most stubborn cases.

Applications other than for jewellery include the cleaning of instruments parts and other small components with indentations, perforations or serrations, in which polishing residues tend to be retained. "Jewellax" is packed in 4 oz. bottles, price 7s. 6d. and is marketed by W. Canning & Co. Ltd., Birmingham.

HILLS OF GOLD

G. A. White

This is the name sometimes given to the Harlech Dome which lies between the Mawddach estuary and the vale of Ffestiniog in North Wales. Geologically this consists of a dome of Cambrian strata, the top having been eroded away, and mineralization occurred on the margins of the dome in the Vale of Ffestiniog on the north, and the Dolgelley gold belt on the south side.

At various points in the region, notably Clogau St. Davids, Gwynfynydd, Prince Edward and Graigwen, gold has been mined for many centuries from the N.E.–S.W. lodes, some would even suggest since Roman times.

The presence of the "Roman steps" is possibly evidence of the gold traffic from the Trawsfynydd area to the former port at Harlech Castle. Evidence exists of the discovery of gold in 1843 and mining operations well established by 1850, operations proceeding in the hills north of the Mawddach estuary between Barmouth and Dolgelley.

The Clogan Gold Company reached a peak of production in 1872 with £30,000 of metal, but this was greatly reduced by 1900.

The Royal family have for many years had wedding rings made from the gold of this area.

Gold bearing quartz veins are still to be located in this district, particularly where Clogau shale bands are found embedded in the quartz reef. Spasmodic mining has been proceeding for the past thirty years as shown by production figures for Merioneth below:—

1844 – 1865	...	13,600 ozs.
1866 – 1907	...	104,600 ozs.
1908 – 1957	...	9,900 ozs.

BOOK REVIEW

PARSONS, CHARLES J., C.G., F.G.A., and SOUKUP, EDWARD J., G.G., F.G.A. *Handbook of Gems and Gemology.* 168 pp., illustrated, paperback. $3.00. Gembooks, Mentone, Calif., U.S.A., 1961.

A most useful book for the amateur rockhound, lapidary and gem collector. It is well written and contains sufficient detail for the hobbyist to gain a general idea about identifying gemstones and gem materials. Gem testing instruments are also described. It is pleasing to see that reference is made to incorrect descriptions which are given to some gemstones. The book is well illustrated with over 200 drawings and photographs.

H.W.

ASSOCIATION NOTICES

GIFTS TO THE ASSOCIATION

The Association is indebted to Mr. Stephan Barczinski, F.G.A., of Rio de Janeiro, for specimens of tourmaline, beryl and a synthetic emerald-coated beryl.

REUNION OF MEMBERS AND PRESENTATION OF AWARDS

With four of the first Tully medallists present at this year's well attended annual reunion and with another Tully medallist presenting the awards the gathering at the Goldsmiths' Hall on 4th December was of a somewhat special nature. This was shown, moreover, by the fact that to be present at it, prize-winners had travelled from Glasgow and Guernsey, Paris and Taunton.

In the absence of the chairman owing to ill health, Mr. Norman Harper, Vice-Chairman, welcomed members to the newly decorated but 125 years old Hall. For many of them that evening represented the culmination of two years of hard study, but he stressed that gemmology was a continuing science. They would be able to learn more and, he hoped, contribute more in the years ahead.

They had 182 entrants in the Preliminary examination, the second highest figure in the history of the Association, and 123 passed. In the finals there were 105 entries with 65 passes. The Tully Medal, won by a Finnish student last year, was not awarded this year, but the Rayner prize had gone to a Canadian.

He was glad to be able to welcome Mr. Herbert Tillander, President of the Gemmological Society of Finland, who won the medal in 1935, who was visiting them again with his wife. Mr. Tillander had done much to encourage the study of gemmology in Finland and the Finnish Association had enriched the Association's collection of minerals by the gift he made at a gemmological conference held in Milan.

After presenting the awards to the successful candidates, Mr. Tillander said:

" I very much appreciate having been invited by the Gemmological Association, of which I am a overseas member—a hybrid, part jeweller—part devotee—part scientist, in other words a typical F.G.A.

" It is a great honour to be asked to present the awards, but all the credit is due to the affiliated group of gemmologists in Finland, which apparently is considered to have made a good start.

" I congratulate those who have gained awards and sympathize with those who have unfortunately for some reason not been successful, but have at least acquainted themselves well with the subject. Since the standard of the diploma examination is very high and since few students are able to devote more than their spare time for study, there is no question about it being a real achievement to qualify for a diploma. It could be said without much exaggeration that a normal student has less chance to pass than to fail. In some cases, also, factors outside the control of the student may have disturbed the normal rhythm of studies and

practice in gemtesting. It really needs enthusiasm and sacrifice of time during two long years and a very good head for study to pass the examination with distinction.

" There is a tendency among some members of various gemmological associations to strive after recognition after a short time as gem experts by the public and even the courts of justice. A very dangerous ambition indeed, since theoretical knowledge must be coupled with long experience in the trade and constant handling of such gems that have to be competently tested and appraised. The only men who can distinguish the subtle differences between the various degrees of perfection in exceptionally fine gems, be it diamonds, pearls, rubies, sapphires, emeralds, alexandrites, or cat's-eyes are those who constantly are engaged in the business of buying and selling such treasures. It may often be difficult for the average gemmologist to find such a specialist and perhaps as difficult to get his honest opinion, since he may be interested to acquire such stones below their market value. It may therefore be necessary even for the very proficient gemmologist to deny himself the pleasure of a statement and recommend the appropriate colleague for the particular case, even though he may not yet be holder of a gemmological diploma.

" Most of you need constant practice with gems in order to know them better and this is now possible without the strain of an examination ahead of you. I am sure you will get very much pleasure and satisfaction from such a study.

" You will all have to keep well informed about new developments in the gemmological field in order to remain up to date. Many of you have, perhaps, the intention to build up a small laboratory of your own—in such case remember there are also other and perhaps for your needs more suitable instruments than those used during studies. You can find such described in earlier issues of gemmological periodicals, some may be of foreign make, some you may even be able to build yourself.

" The diploma alone does not make you an expert. In every profession, in every science and even in your hobby you are more or less a beginner when you have received your diploma, but you have all the qualifications to achieve the reputation of a real expert if you proceed. The jewellery trade in the world needs people with a scientific gemmological training and it must be noted with much satisfaction that through voluntary work the number of gemmologists is constantly growing. A great number of these gemmologists are associated with the trade and their theoretical knowledge and its application, particularly in the retail trade, must help a great deal to improve the reputation of the jeweller.

" Modern man wants to spend his surplus cash on things he is interested in and believes he understands. This is why intelligent presentation of gems have become more and more a necessity. And finally, since I am here to-night representing the Gemmological Society of Finland, you may expect to learn some details about the activities of this association. The first group of 12 diploma students sat for their examination in spring 1960. One of them only failed, seven qualified, three qualified with distinction and one gained the Tully medal. Everyone of the 11 who qualified applied for membership as an F.G.A. and as a research member of the Finnish association. This means an obligation to do research work on some particular subject and read a paper at one of the monthly gatherings of the group. We have now 17 research members who are all doing post-diploma

work and prepare to read the results when their turn comes. The diploma holders are also engaged in the training of new students and fairly busy as lecturers at various public occasions as well as writers on gemmological subjects for newspapers and magazines. In a small country like Finland with only 4½ million inhabitants the gemmological influence on the trade has already been marked."

The Treasurer of the Association, Mr. F. E. Lawson Clarke, in thanking Mr. Tillander, said:

" I would like to express our warmest thanks to you for especially coming to London to present the Awards this evening, and we are delighted that Mrs. Tillander has come with you.

" To undertake the journey from Helsinki to London is some measure of Mr. Tillander's interest and enthusiasm, for gemmological affairs. So is the fact that it is Mr. Tillander and his colleague Mrs. Mikkola, who are responsible for a great deal of the enthusiasm that is shown for gemmology in Finland.

" Mr. Tillander is a leading Finnish Jeweller, and has successfully applied his knowledge of gemmology to his business. Retail gemmologists in this country could well take a leaf out of his book, and benefit their business by making more use of their specialized scientific knowledge of gem stones. They would find a great interest displayed by their customers in this aspect of the jewellery trade, and one worth cultivating.

" From my own experience in retail business I have found that many of my customers are quite ignorant about gem stones, but at the same time they are hungry for knowledge, and most grateful for any carefully chosen information that is given them. Retail gemmologists can serve their own interests, and the interests of the trade as a whole, very well, if they make it a part of their business philosophy to propagate their expert knowledge about gem stones.

" There is one thing that the retail gemmologist must guard against —he must never attempt to blind his customer with science. A very nice discretion must be exercised when imparting scientific knowledge to the buying public.

" But, it is quite a different question between gemmologists themselves—while there is simply no point in trying to blind each other with science, there is everything to be said for the exchange of ideas and the results of research, not only within the bounds of our own countries, but more important that we interchange these ideas, and these results, on an international basis.

" The overseas entries for the examinations are always strong. We have entries from all over the world, from Los Angeles to Hong Kong, and this year, for the first time, from behind the Iron Curtain. The standard set by the examiners is a very high one, and the results of the examination are excellent indeed. I would say that the candidates well deserved their awards—they certainly had to work hard for them, and those who did not win awards, deserve praise and mention for the same reason.

" Mr. Tillander I feel, is, a shining example of all the qualities to be looked for in a gemmologist. When he arrived in London, he called to see me at business, and before leaving, said in his droll way " The nicest visitors stay the shortest time". How true that is of him, his flying visit to London is so short, that by that standard he must be the nicest sort of visitor.

" On behalf of the Gemmological Association, I would, again like to thank him, for specially coming to present this year's Awards, and Mrs. Tillander, for gracing this occasion so charmingly."

COUNCIL MEETING

A meeting of the Council of the Association was held at Saint Dunstan's House, London, E.C.2, on 4th December, 1961. Mr. N. A. Harper, Vice-Chairman, presided in the absence of the Chairman who was indisposed.

The following were elected.

Fellowship

Aarne, Eino L., Helsinki, Finland
Agius, Frank J., Sliema, Malta
Ainsworth, Kenneth J., Blackburn
Allen, Michael H., Ilford
Axon-Ryder, Albert R., Bolton
Bacon, Frank H., Bedford
Badrutt, Reto, J. P., Geneva, Switzerland
Beasley, Barbara A., Windsor
Bills, Raymond F., Solihull
Butler, William C. F., Paisley
Francis, Roger, Birmingham
Greeph, Mayer, Manchester
Harrold, David J., Southend-on-Sea
Hayes, Denis, London
Heesom, Thomas H., Altrincham
Hill, Dennis A., Glasgow.
Hiscox, Sieglinde E., Solihull
Jean, Wilmer F., Dallas, Texas, U.S.A.
Joseph, Timothy R., Knowle
Kaksonen, Yrjo E., Helsinki, Finland
King, Archibald V., Edinburgh
Lusty, Kenneth C., London
Morris, Clive R., London
Musaeus, Hans B., Oslo, Norway
Price, Denis E., Smethwick
Rouvier, Andre E., London
Rowe, Alan D., East Molesey
Sanford, Peter, Hatfield
Siltanen, Ismo K., Jyvaskyla, Finland
Silva, Edward H. L. de, Negombo, Ceylon
Sloman, Peter, Southend-on-Sea
Snaddon, James, Sale
Stirton, Kenneth G., Ripon
Stout, Cornelis A., Rotterdam, Holland
Sundqvist, Arvo J., Helsinki, Finland
Synan, Martin T., Slough
Webb, Herbert H., London
Whitehead, Bernard, Sunderland
Wiik, Viggo H., Oslo, Norway

Ordinary Membership

Catulle, Marcel, Brussels, Belgium
Dambrink, K. W., Apeldoorn, Netherlands
Kan, Noah, Hong Kong
Milito, John T., Toronto, Canada
Pandurangiah, V., Madras, India
Sanz de Madrid, Miguel A., Barcelona, Spain
Nickolds, Ann M., London
Parsons, Joan, Harrow
Tomes, Simon C., High Wycombe
Scholl, Werner, Zollikerberg, Switzerland
Selvon, Dennis R., Woodford Green
Silverberg, Lily (Miss), Pretoria, S. Africa
Wyer, Philip G., Birmingham

Probationary Membership

Blake, Robert, Tilbury
Blatter, Robert, Toronto, Ontario, Canada
Fowler, Barry Richard, Dundee
MacKenzie, Iain F., Manchester
Mayhew, Coral J., Salisbury, S. Rhodesia

The Council agreed the fees to be paid by instructors in the U.K. who wished to acquire the correspondence course papers and set up a committee to consider the improvement and development of gemmological instruments.

It was also agreed that the 1963 Herbert Smith Memorial Lecture should be held in Birmingham.

TALKS BY MEMBERS

CAFFELL, E. W.: " Gemstones ", Wokingham Townswomen's Guild, 17th October, and Cobham Young Wives Group, 18th October, 1961.

BLYTHE, G. A.: " More about gems ", South East Essex Natural History Society, 19th October, 1961.

DONN, L.: " Gemstones", Prestwich and Whitefield Ladies' Circle, 18th September, 1961.

BETTS, G. N.: " Precious stones ", Bradford Tory Society, 4th September; " Gemstones ", Allerton Young Conservatives, Bradford, 22nd September; Haworth Road Methodist Guild, 11th October; R.N.L.I. Guild Luncheon Club, 12th October; Moor Allerton Luncheon Club, Leeds, 12th October; Bingley Parish Church Young Wives Club, 8th November; Elland Young Conservatives, 13th November; "Jewellery", Carr Manor Townswomen's Guild, 6th December; " Gemstones ", Brighouse N.S.P.C.C. Ladies' Luncheon Club, 7th December; Cleckheaton Women's Luncheon Club, 12th December, 1961.

WELLER, G. T.: " Gemstones ", Hawkenbury Church Young Wives' Club, 18th October, 1961.

1961 EXAMINATIONS

In the October, 1961, issue of the journal the name of Mr. W. E. Cooper (Stockport) appeared incorrectly in the examination results as W. E. Conyers, and the name of Mr. B. Conyers (London) was inadvertently omitted from the list of those who qualified in the Diploma Examination.

AWARD OF TULLY MEDAL

After the 1961 presentation of awards the examiners drew attention to what appeared to be a misunderstanding of their recommendations regarding the award of the Tully Medal. In confirming that, in fact, the medal should be given to Mr. Laurie Wallington, Scarborough, Ontario, Canada, they emphasised that the high standard required for this success had been attained. In view of the report to the contrary, that was made at the presentation, the Council is particularly gratified that the misunderstanding has been cleared up.

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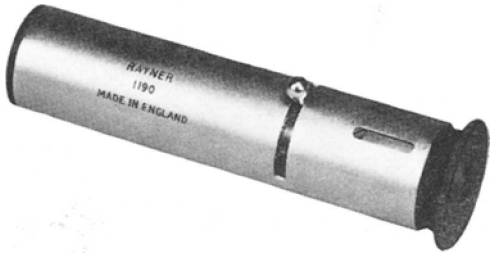

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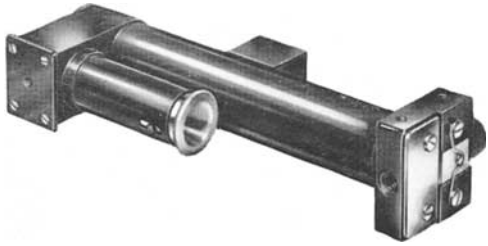

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THE JOURNAL OF GEMMOLOGY

and

PROCEEDINGS OF THE GEMMOLOGICAL ASSOCIATION OF GREAT BRITAIN

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Vol. VIII No. 6 APRIL 1962

TWO UNUSUAL LABORATORY TESTS

By B. W. ANDERSON

TWO cases recently encountered in the course of routine laboratory testing were sufficiently unusual to seem worthy of record.

The first case concerned a dark red stone of perhaps one and a half carats, mounted with two small diamonds as a three stone ring. The stone was isotropic, had a refractive index of 1·744, and showed no perceptible fluorescence under ultra-violet light or between crossed filters. A stone with these properties might well pass as pyrope garnet.

Under the microscope, however, there was seen an extensive " feather " consisting of octahedral inclusions, which virtually proclaimed the stone to be spinel, and this was confirmed by a study of the absorption spectrum in which the positions of a number of fine lines in the red were measured as well as the approximate wavelength at which the broad absorption region in the green was centred. The measurements of the lines were as follow:— 7030Å, strong; 6940, weak; 6820, strong; 6730, very weak; 6620, very weak; 6550, strong; 6480 and 6410, weak. The broad absorption extended from approximately 6000 to 4800Å, giving a central position of near 5400Å. In pyrope the narrow chromium bands are seen as a doublet at 6870 and 6850Å, sometimes with weaker lines at 6710 and 6500Å, while the broad absorption region is centred near 5700Å—that is, 300 Angstroms further towards the red than in spinel.

The high refractive index of the stone under discussion, its numerous absorption lines, deep colour, and lack of fluorescence all signified an unusual amount of chromium in this spinel. The highest refractive index we had previously observed in red spinel was 1·736, and even this was considerably above any other we have encountered, 1·730 being a more normal limit for stones of gem quality. It was most regrettable that the density of this phenomenal spinel could not be measured to complete the record. Previous experience in plotting a density/R.I. graph for these two minerals had shown that in pyrope there is a far steeper rise in density proportionately to refractive index—and though the refractive index of the lowest pyropes overlaps that of the highest spinels there is still a small density gap between the highest we have recorded for red spinel (3·611) and the lowest for red garnet (3·643). Even in the case of this exceptionally chrome-rich spinel, one would guess the density to be not more than 3·63, whereas the many garnets we know with a similar index (1·744) have a density around 3·70.

That a red spinel can attain such heights and may then show no fluorescence is worth knowing by practising gemmologists.

The second case was interesting chiefly as an exercise in technique. It concerned a hoop ring set with alternate panels of three diamonds and three emeralds, there being in all 12 stones of each species. Except for one Siberian and one Colombian stone, identified by their inclusions, the emeralds were palpably Chatham synthetic stones, as seen by their colour, inclusions, and effects under the Chelsea filter and ultra-violet light. Refractive index measurement was, however, not possible owing to the small size of the stones and to the fact that their tables were flush with the metal setting of the ring.

To overcome this difficulty an immersion contact photograph was then attempted with some success considering the difficulty implicit in such small stones enclosed in a setting. Bromobenzene was chosen as the immersion fluid, as calculation based on its previously measured dispersion showed that for the blue-violet light operative for the photograph this liquid would have an index above that of the synthetic stones and below that of any natural emerald: and so it proved. In the dark-room, the ring was fixed with plasticine to the edge of a glass dish in a slightly tilted position with one panel of the synthetic emeralds resting on or near the bottom of the dish containing the bromobenzene. A loose synthetic emerald

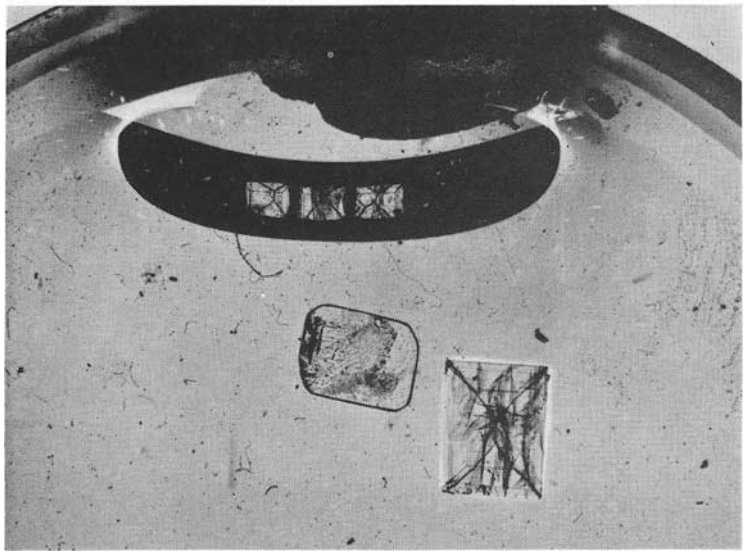

FIG. 1. *Immersion contact photograph using bromobenzene showing a panel of three synthetic emeralds mounted in a hoop ring, with a natural emerald (left) and synthetic emerald (right) as controls.*

and a Colombian stone were placed nearby in the same dish to act as indicators. A narrow beam of light was projected vertically downwards through an enlarger housing and allowed to fall on the specimens and on to a piece of fine-grained film underneath the dish—the exposure being some ten seconds. The film was developed and fixed, washed and dried, and a slightly enlarged print of this is reproduced as Fig. 1. It can, I hope, be seen quite clearly that the dark lines representing the facet edges of the loose synthetic emerald exactly match those of the synthetic emeralds in the ring. The Colombian emerald shows no such effect, and the dark surrounding border reveals that the index of this stone is slightly above that of the liquid.

A RARE SYNTHETIC

By R. KEITH MITCHELL

A SHORT while ago a good friend in America sent me a very beautiful brilliant-cut stone weighing about half a carat, sage green in colour with the lustre and fire of a fancy diamond. The refractive index was obviously well above the range of the normal refractometer and since the stone was appreciably harder than corundum it was perhaps as well that my friend had written the name of the material on the stone paper !

The gem is in fact, an extremely rare example of a material which exists only as a synthetic substance, and which, paradoxically, is manufactured in very large quantities indeed. This material is the abrasive silicon carbide (SiC) or carborundum, and the stone I now have in my collection is rare simply because crystals of a size and quality suitable for cutting are unusual. In addition, they require special cutting techniques because of their hardness, and only diamond dust is hard enough to facet and polish them. My friend, an amateur lapidary of quite exceptional skill, had to wait several years before crystals suitable for cutting were found.

The material is interesting since it provides an example of yet another method of synthesis. Descriptions of the Verneuil, the hydro-thermal and the melt-diffusion processes are already familiar to most gemmologists, but carborundum is produced on a far vaster scale than any of these in an electric arc furnace, which is quite unlike the apparatus used for any other synthetic gem.

It is interesting to note that this substance, like so many others, was first made accidentally. In 1891 E. G. Acheson, a chemist, was trying to produce diamonds by heating electrically a mixture of coke and clay, when he obtained what he thought was a compound of carbon and aluminium. Since aluminium oxide was already called " corundum ", he gave the new product the analogous name of " carborundum ".

However, it was quickly realized that the new material was in fact a compound of silicon and carbon, to which the chemical name silicon carbide was given. But Acheson's " carborundum ", which was first used as a trade name, has stuck and is now a " household " word throughout the machine shops of the World.

To-day this valuable abrasive is made on a large scale, usually in places like Niagara where considerable hydro-electric power is

available. A mixture of low-ash coke and glass sand (pure SiO_2) is placed in a large brick box (anything up to 60ft. × 20ft. in size) a central channel is scooped out and filled with metallurgical coke, which is in contact at either end with carbon electrodes. A very heavy current of 500 volts and up to 40,000 amps is used to reach a temperature of between 2000° and 2600°C.

As the resistance of the core (SiC is a good conductor) gets lower the voltage is decreased to about 75V. The process releases considerable quantities of carbon monoxide gas, which burns on the outside of the oven and helps to reduce heat loss. The process has to be stopped before the growing core of silicon carbide reaches the brick container, since the temperatures involved are high enough to fuse any refractory brick. This results in a multicrystalline porous mass of the material in which individual crystals (which are hexagonal in symmetry) are usually minute and rarely exceed 1 cm in length. When the material is pure these are pale green in colour, but less than 1% of impurity will render them black and opaque. The major proportion of the material produced obviously is not pure, since it is intended only for use in industry.

Many readers will be familiar with spectacular crystals of carborundum to be seen in some museum collections. These are commonly iridescent in vivid hues, due to the fact that an ultra-thin film of SiO_2 forms when the crystal is heated to 1000°C in air. These museum crystals are exceptional in size and have probably grown in fissures or holes in the mass and it seems probable that air has reached them during cooling and resulted in the iridescent film being formed.

As would be expected, the cut stone in my possession shows no trace of such iridescence. The lustre is better than adamantine, and with quoted RIs of 2·648 and 2·691 (higher than diamond) the birefringence of ·043 is easily seen with a lens through the side facets. Rather surprisingly this stone appears to have been cut across the hexagonal prism so that the direction of single refraction is straight down through the table into the stone. This serves to make it very much like a green fancy diamond in appearance. A figure for dispersion is not available but it appears to be rather greater than that of diamond. Specific Gravity is about 3·20, low for a material of such refractivity, but to be expected in view of the composition. The great hardness (usually quoted as 9½ on Mohs' scale) is also to be expected.

One very interesting feature is the presence of many platey hexagonal inclusions. These appear to be negative and are evidently oriented parallel to the parent crystal since they all reflect light at one angle, and the hexagonal outlines also seem to be in parallel although the relative development of faces differs from inclusion to inclusion. One or two appear to be orthorhombic in outline, due to the almost complete suppression of two of the opposed sides of the hexagon. Most of the inclusions are opaque, but many of the larger ones are transparent for about a quarter of their area. The accompanying illustration gives a general picture of these inclusions.

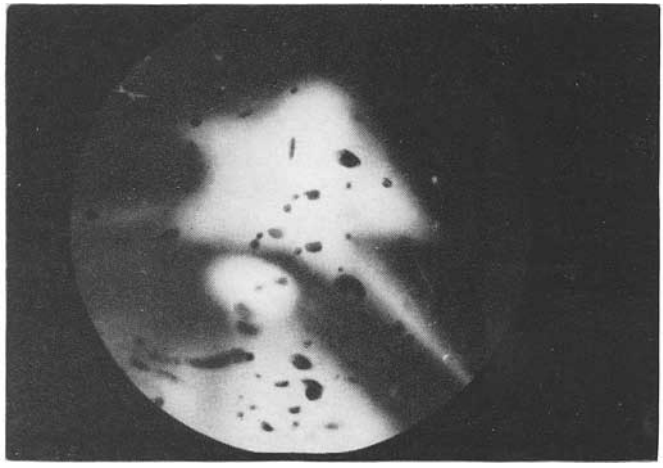

Finally, bearing in mind the high prices asked and paid for synthetic emeralds and for the strontium titanate " fabulite ", one is moved to wonder how long it will be before someone sees the possibilities of this " new " gem. A small scale production under controlled conditions, directed specifically at obtaining stones of gem size and using very pure ingredients, does not seem an impossibility, and the resulting stones would be both attractive and very hard wearing !

COMPACT SODIUM LIGHT SOURCE

THE use of a light of single wavelength, which eliminates the white light spectrum, has been of great benefit to gemmologists when using the refractometer. The early gem enthusiasts used salt burnt in a gas flame, because in those days it was inexpensive and the sodium light sources then available were expensive and somewhat cumbersome.

Messrs. Rayner have recently developed a monochromatic light source with slide fitting for the Rayner standard refractometer. The illustration shows the refractometer in position. By using sodium light readings of greater accuracy can be obtained. The lamp strikes immediately it is switched on and after a maximum of five minutes gives an almost pure sodium emission. Readings may be taken within a few seconds of switching on.

The ballast choke, starter and switch are housed in a metal casing which measures $6\frac{3}{4} \times 3\frac{1}{2} \times 3\frac{1}{4}$ inches, and the lamp hood enclosing the lamp measures $2\frac{1}{2} \times 1$ inch diameter. The lamp hood has two apertures, which measure $1 \times \frac{3}{16}$ inch, and which are set opposite to each other.

The new instrument has been wired for direct connection to 110/130 or 210/240 volts a.c.

Most gemmologists consider that the three most important gem-testing instruments are the microscope, the refractometer and the spectroscope. A sodium light source is almost indispensable for use with the standard type of refractometer and the two together are likely to be known as the jeweller's pair.

Most serious gemmologists, once having taken accurate refractive index readings by using sodium light, rarely have recourse to ordinary light when using a refractometer. The extremely sharp shadow edge which is obtained makes refractometer work a pleasure and when a doubly refracting stone is being tested the behaviour of the two shadow edges can be more easily observed.

The sodium source unit, with slide fitting, costs £18 15s. 0d. A spare sodium lamp is £7. The Rayner standard refractometer is obtainable for £19 15s. 0d. (complete with refractive index liquid) and all these items are distributed by the Gemmological Association.

If the special polarizing filter for doubly refracting stones is used it is possible for each shadow edge to be taken separately. This filter, which costs £1 10s. 0d., also assists in determining whether the optical sign of a stone is positive or negative.

WHEN HOMER NODDED

B. W. Anderson

Being at present engaged in some research on the behaviour of low-type zircons, I have had occasion to dip into some of the older books on gemstones to learn what was generally known in each period of the peculiarities of zircon behaviour.

Turning to " Precious Stones ", L. J. Spencer's translation (1904) of Max Bauer's classic " Edelsteinkunde ", I was astonished to read, in the course of a description of zircon, the following sentence: . . . " On the other hand, the refractive indices for different colours do not differ much, hence the dispersion of zircon is small and its play of prismatic colours correspondingly insignificant, so that, although in brilliancy and lustre it may compare with diamond, yet in the former respect no comparison is possible ".

It seemed unlikely that a scholar who later became so famed for his bibliographical accuracy as Spencer could have made a mistranslation (except as a deliberate act of revision), but I turned at once to the original passage in the (1896) German edition of

" Edelsteinkunde " to read : . . . . " Dagegen weichen die Brechungskoefficienten für die verschiedenen Farben nicht viel von einander ab, die Farbenerstreuung ist also gering ". . . . So the translation was not at fault.

Another passage in the same sense is to be found in Goodchild's " Precious Stones ", published not long after, and was almost certainly derived from reading Bauer's work, to which Goodchild refers specifically on several occasions. The passage runs: " The dispersion, however, is feeble so that the mineral when cut shows a lack of fire ".

The mistake cannot be ascribed to the continuance of a false tradition, since reputable authors writing *before* Bauer were quite clear on the subject. A. H. Church, for instance, in the 1891 edition of his "Precious Stones", wrote of zircon: " . . . its ' fire ', owing to its high dispersive power, comes next to diamond ", while G. F. Kunz in his " Gems and Precious Stones of N. America " (1892) states that zircon " exhibits more ' fire ' than any other known gem except the diamond ".

Reverting to books written *after* Bauer we find (as one would expect) that Herbert Smith, in his first edition of " Gemstones " (1912), has the matter right: "Of all the gemstones zircon alone approaches diamond in brilliance of lustre and it also possesses considerable fire ". To quote further authorities would be tedious and unnecessary, but one should perhaps record that Prof. K. Schlossmacher when revising and largely rewriting Bauer's " Edelsteinkunde " in 1931, states unequivocally of zircon " Die Dispersion ist stark ".

What makes this matter more extraordinary is that Spencer, who had the opportunity to revise as well as translate, and Goodchild in his own book, should follow the master in his error, since both were trained mineralogists with normal eyesight.

This is not intended as an attack on Bauer, for whose immense contribution to the literature of gems more than one generation had cause to be grateful: but it does serve, I think, as a useful reminder that even Homer can nod, and that reading and quoting authorities is no substitute for making use of one's own eyes and relying on one's own experience wherever possible, in matters which are within one's competence.

TESTING A SAPPHIRE

By A. E. FARN

I HAD considerable pleasure chatting to an Australian gemmologist recently and discussing testing methods. We each had our strong points and particular methods, but what impressed me was the question of a clean sapphire with no inclusions. How could this be determined ? Obviously an absorption spectrum was the answer, and the 4500Å line was mentioned. Now this started the question of the spectroscope and its use. First of all I must mention that having been brought up, gemmologically speaking, by B. W. Anderson, it is obvious I have used the spectroscope in routine gem testing rather more than any other instrument, except a lens. We have our own train of thought regarding gem-testing and, I suppose, because of years of practice we readily recognize many gemstones and therefore test with the obvious instrument in the shortest time. This may sound a little clever or presumptuous. It is not meant to be, but rather to help in pointing out a normal reaction and approach to routine testing.

Take for instance a perfectly straightforward sapphire in a diamond cluster surround ring; the sapphire is to be tested. A brief glance usually indicates whether the stone is genuine or synthetic. The colour, cut and appearance of the stone convey a wealth of information—which only comes with the constant handling of stones. In other words we " get our eye in ".

The next step is to use the microscope on the stone in the ring (or a lens if it is a stone of 1½ cts or more). A careful examination back and front and turning the stone will usually show an inclusion or group of inclusions such as silk, crystals, laths, twin planes, liquid feather, two phase inclusions, zoning of colour, etc. These should be ample to decide the stone being genuine and also to the experienced gemmologist the provenance of the stone. Turning the stone during examination under a microscope also gives other aspects of information, such as dichroism when the stone is viewed at right angles to the table facet, which is always a useful guide and clue to correct cutting as against haphazard cutting of a boule of synthetic sapphire (or ruby). When examining the stone the doubling of the back facets can also be seen, which eliminates paste or blue spinel.

Although these all seem fairly obvious statements the critical use of the microscope can reveal much to the expert eye.

Another useful factor is the shatter marks (due to excess heating when cutting and polishing). These are mostly seen on cheaply cut synthetic stones and although not proof positive can also be an added factor towards establishing the nature of a stone. Some people call these small erupted scars on the underneath facets of sapphire (and rubies) shatter marks and others chatter marks. I cannot recall I have ever seen such marks on a well cut natural ruby or sapphire of any importance.

Having now dealt with the stone which contains natural characteristic features, the next step is finding the stone to be perfectly " clean ". Inspection by microscope will reveal the stone to be homogeneous, and doubling of the back facets will prove that it is not paste or blue spinel, dichroism is apparent and because of the cleanliness of the stone the next thing to do is to take its refractive indices to check it being corundum. This may seem a late step to take, but normally I never bother with a stone which has typical Ceylon, Siam, Burma or Kashmir inclusions. This stone though is clean blue corundum. Here the spectroscope really comes into play. Most genuine blue sapphires have an absorption spectrum centred around 4500Å, and this is diagnostic. This band at 4500Å is lacking in synthetic sapphires.

Now, the method of measuring or seeing an absorption spectrum.

Always check the slit of the spectroscope against daylight, when the Fraunhofer lines will be seen and adjust the slit to actual sharpness. I always view spectra with red on the left and blue on the right. The best hand spectroscope for the job is the Beck 2458 prism model. The spectroscope is so immediately diagnostic that it supersedes many established methods, since it is accurate with both rough and cut material and does not wear out. There are quite a few limitations, however, to the spectroscope, as indeed there are in most instruments designed for gem testing.

To teach yourself spectroscopy it is necessary to obtain specimens of gemstones, such as almandine garnet, sapphire, ruby, zircon, chrysoberyl, emerald, spinel. Three ingredients are necessary to see an absorption spectrum easily—a light source, microscope (or condensing lens) and a spectroscope (and, of course, a stone).

After having adjusted the slit of the spectroscope by checking the spectrum in daylight, the microscope is placed in front of a light source and the eye-piece removed from the microscope so that only the draw tube, condenser and objective remain. Now take a piece of ground glass and place it over the draw tube where the eye-piece should be and switch on the light source and focus on the filament of the lamp bulb itself until it appears visible as a magnified glowing bright wire on the ground glass screen. The ground glass obviates glare and saves eyestrain and helps concentration and observation. Next place the sapphire on the glass slide of the microscope stage when it will be very readily seen in the ground glass as a blue stone (still mounted in its setting). It is obvious that the stone is now in line of light transmission and light now hitting the ground glass screen has passed through the sapphire. Take away the ground glass screen and place the spectroscope upon the tube of the microscope and look into the spectroscope. Here should now be seen a fine line like a pencil streak vertically down the blue sections of the spectrum. This line is diagnostic of genuine blue sapphire. At first there will be hitches as in all new techniques—none of them are serious and to the gemmological enthusiast they only serve as an added incentive to that goal of gemmology where one can say safely and assuredly one has seen and is able to recognize with the spectroscope the absorption spectrum of sapphire.

The hitches one will encounter will be varied. Firstly a light of sufficient intensity is necessary—of 150 watt upwards. Secondly, it is possible to put too small a specimen on the stage and so flood the tube of the microscope with light as to blind oneself to the comparatively weak affect of the absorption band. This is easily and speedily remedied by placing the stone on a piece of cardboard with a hole punched through to allow the stone to sit in and thus allow only light through the stone and blank off all extraneous light. Another hitch can be in the variety of strengths of bands seen at 4500Å.

The Australian sapphires score heavily here since so much iron is in their composition that the band is virtually a complex centred at 4500Å up to 4600Å (which appears as a block more than a pencil thin vertical line) in the blue portion of the spectrum. Ceylon sapphires are the reverse having rather a medium to weak spectrum and here it pays to turn the stone in order to get the

strongest possible concentration of transmitted light. Needless to say one needs practice, it being quite easy to say what should be seen whereas in practice at first it may not be so readily seen. There are one or two tips which will help. When dealing with a sapphire and the blue end of the spectrum—if a line seems vague it does help to tilt the spectroscope to the right, remembering that the law is red on the left, blue on the right. This tilting seems to enhance or bring into stronger or better focus those vaguer lines at either end of the spectrum.

It is better to commence the study of absorption spectra of sapphires with natural stones in order that the spectrum can be seen and its position fixed in one's mind's eye. Then as one becomes more familiar and assured in one's diagnosis it is possible to extend and extemporize, and to obtain diagnostic results from variations of the set-up of lamp, microscope and spectroscope. A word of warning here on high wattage lamps; these generate a fair amount of heat, especially when focused and condensed through the microscope onto the stage glass slide. If this small focal spot of heat is projected to a stone and left for a while the stone could suffer damage—at least one good turquoise suffered this way. One well-established method of overcoming this trouble is to use a glass chemical flask such as can be purchased at any laboratory suppliers. The flask filled with water acts as a condensing lens and as a cooling filter to the heat rays from the filament of the lamp. A second flask filled with a solution of copper sulphate can act as both cooler, condenser and colour filter and will often help accentuate weak lines in the blue portion of the spectrum since the copper sulphate solution cuts out the red end of the spectrum. The copper sulphate solution is made up from distilled water and ideally is kept just below saturation point or else crystallization will occur with temperature variation of room heat. As one grows more proficient one can vary the depth of copper sulphate filter and keep them labelled as being suitable for various wavelengths.

Gemmological Abstracts

GÜBELIN (E. J.). *Ekanite.* Gems & Gemology, Vol. X, No. 6, pp. 163-179, Summer 1961.

A very full account of the new metamict mineral named ekanite. The stone is said to come from Ellawala, north-east of Ratnapura in Ceylon. It is found in the illam which lies at a depth of 35 to 40 feet. The stone, which has an appearance like that of kornerupine, is a greenish-brown to yellowish-green in colour. It is usually rather turbid and is in some cases asteriated or chatoyant. This optical effect was found to be due to clouds of tiny inclusions with definite orientation. The types of inclusion present are described. The refractive index—the stone is singly refractive—is 1·595, and the dispersion 0·0183. The density was determined as 3·28. Two weak and blurred absorption bands were observed at 6551Å and 6375Å. Chemical analysis showed that Ca, Th, Si, Al and Pb were present, but neither the rare earths nor zinc were detected. The stone was first thought to be a glass. The stones were found to be strongly radioactive and comments are given of the radioactive intensities for the α, β and γ rays. There was a general intensity comparable to that of a fresh watch dial. Discussion is made on the probability of the original mineral from which ekanite evolved. The age of the mineral assessed from thorium lead dating method is given. This article is a very full exposition of the new mineral. (J.G.VIII, 3)
14 illus., 2 tables. P.B.

BENSON (L. B.). *Developments and highlights at the Gem Trade Lab in Los Angeles.* Gems & Gemology, Vol. X, No. 6, pp. 187-190, Summer 1961.

Describes the wearing to barrel-shape of a string of cultured pearls which was probably due to acid exudation from the skin of the wearer and the cosmetics used. Some of the pearls were more lustrous than others and these were less affected. Comments are made on a high type of green zircon and on a cloudy peridot.

" Cape May diamonds " are rock crystal from Cape May in New Jersey, but one such stone tested was found to be a synthetic white spinel.
2 illus. P.B.

BASTOS (F. M.). *The gemstones of Brazil.* Gems & Gemology, Vol. X, No. 7, pp. 195-201, Fall 1961.

An account of the gem resources of Brazil. The gemstones found in each of the main States of Brazil are discussed. The stones mentioned are the agates from Rio Grande do Sul, from which state is also found much amethyst and rock crystal, diamonds from Parana, and diamonds, sapphires and emeralds from Goiás and Mato Grosso. Espiranto supplies citrine quartz and andalusite, and in Bahia there is found amethyst, sodalite, amazonite and prase (?) which is a heat-treated quartz. In the states of Rio Grande do Norte and Ceara, garnets, aquamarines and amethysts are found. Minas Gerais is the most fruitful producer of gem materials, particularly of all colours of beryl. Greenish beryl is heat-treated to produce the blue aquamarine and yellowish pink beryl to improve the colour to a good pink. Other stones from Minas Gerais are tourmaline, citrine, garnet, euclase, chrysoberyl, peridot, andalusite, opals and some corundum, feldspar, brazilianite, kyanite, topaz and diamond.
4 illus. P.B.

CROWNINGSHIELD (R.). *Developments and highlights at the Gem Trade Lab in New York.* Gems & Gemology, Vol. X, Nos. 6 and 7, pp. 180-186 and 191; 216-223, Summer and Fall 1961.

Reports on star-sapphire doublets with cobalt-coloured dye between, on crackled synthetic rubies and on a carved pearl shell. Vivianite, williamsite and andalusite are discussed and comments made on their absorption spectra. Mabe pearls are discussed. This seems to be a term used for cultured blister pearls. Purple clam pearls and abalone pearls are mentioned. Early pearls with non-fluorescent cores are reported. There is an interesting record of a series of experiments on the reaction of pearls to vinegar and eau-de-Cologne. A coated diamond crystal and a cabochon of the mineral carnotite are described.
31 illus. P.B.

VIERTHALER (A. A.). *Wisconsin diamonds.* Gems & Gemology, Vol. X, No. 7, pp. 210-215, Fall 1961.

The origin of the diamonds found in Wisconsin and the history of the diamond finds there is given and mention is made of some of the diamonds found in the locality.
4 illus. P.B.

WEBSTER (R.). *Corundum in Tanganyika.* Gems & Gemology, Vol. X, No. 7, pp. 202-205, Fall 1961.

A report on the corundum crystals found in Tanganyika. The ruby crystals occur in a green zoisite rock, which is used as an ornamental stone, called anyolite. The article mainly describes the crystals found in the Gerevi Hills of Tanga Province. The sapphire crystals from this locality are squat hexagonal prisms. The colour along the " c " axis is bright blue but is marred by a yellow core, which seems to be characteristic for Gerevi Hills sapphire. The density was found to be 3·99. No refractive indices are given as no polished material was available. The absorption spectrum shows the 4500Å complex distinctly. The fluorescence under long-wave ultra-violet light was distinctly reddish with the yellow core glowing with a strong orange light (cf. Ceylon yellow sapphire). The inclusions consist of irregular oval crystals, often in groups, and long needles or canals parallel to the prism and rhombohedron. Ruby crystals from this locality assume a more rhombohedral habit. They are of fair colour. The density of two specimens gave a value of 3·98. Absorption spectra and fluorescence in both stones examined were rather weak. The area is now said to be under the control of a group of Greek prospectors.
3 illus. P.B.

JOHNSON (P. W.). *The gem minerals of Baja California.* Lapidary Journ., Vol. XV, No. 4, pp. 456-466. 1961.

Short descriptions of the gem minerals of a district divided into a Federal Territory in the south and a state of the United States of Mexico on the north. Many gem minerals are found, an occurrence of sphene in abundance being the most important discovery in the early 1950's.

S.P.

DAKE (H. C.). *Synthetic garnets produced.* Mineralogist, 28, 11-12, p. 236. 1960.

Garnet has been produced from common hornblende by the General Electric Company. The method used is similar to that of diamond manufacture. A metal dehydrator, such as tantalum, must be present. By changing the type of hornblende the Company claim that any one of the seven varieties of garnet may be produced. According to the inventors the synthetic product cannot be distinguished from natural stones by chemical, physical or X-ray crystallographic tests. (J.G.VIII, 4)

S.P.

MAHAJAN (B.). *Gem cutting in India.* Lapidary Journ., Vol. XV, No. 4, pp. 410-413. 1961.

Gem cutting in India is inexpensive. In addition to primitive-looking simple tools the Indian cutter also uses the diamond saw and steel and copper laps. Many women drill and polish beads. Much of the work is most skilful and there is scarcely any waste of material.

S.P.

TOLANSKY (S.). *A notable growth spiral on synthetic diamond.* Nature, Vol. 190, p. 992, 10th June, 1961.

A well-defined single growth spiral has been observed on an incomplete cube face of a synthetic diamond made by de Beers, Johannesburg. The height of the spiral step is about 1300Å. Such spiral growths are rare.

R.A.H.

MILLEDGE (H. J.). *Coesite as an inclusion in G.E.C. synthetic diamonds.* Nature, Vol. 190, p. 1181, 24th June, 1961.

Coesite has been identified as inclusions in synthetic diamonds from the G.E.C. Laboratories. This supports the view that any crystalline SiO_2 found in natural diamonds can be expected to be a high-pressure form rather than quartz. Any reported inclusions of quartz are probably in reality instrusions.

R.A.H.

GÜBELIN (E.). *Rubin mit synthetischem hydrothermalem Ueberzug.* Ruby with synthetic hydrothermal coating. Zeitschr. d. deutsch. Gesell. f. Edelsteinkunde, No. 35, pp. 7-12. Spring 1961.

A description of the hydrothermal process developed by R. A. Laudise and A. A. Ballman of the Bell Telephone Laboratories. The author has investigated two synthetic rubies, said to have been produced by Chatham by his hydrothermal process. The physical constants were the same as those of genuine rubies. The largest part of each stone consisted of a genuine core. The synthetic coating was comparatively thin. Under the microscope, therefore, inclusions in the core could be misleading. The synthetic skin, however, was full of minute gas bubbles with a sharp division between core and skin. The overall picture was more indicative of growth from a melt than of a hydrothermal process.
4 illus. W.S.

THURM (R.). *Das Krüss-Juwelierspektroskop.* The Krüss jewellers' spectroscope. Zeitschr. d. deutsch. Gesellsch. f. Edelsteinkunde, No. 35, pp. 12-14. Spring 1961.

Description of a new German prism spectroscope arranged for gemmological work by Dr. P. Krüss. A condensing lens is fitted in front of the slot, making the instrument dustproof. The stand is inclined like the Mitchell stand. It seems that the arrangement allows for inspection under reflected light only.

W.S.

GÜBELIN (E.). *Beryll mit synthetischem Smaragdüberzug.* Beryl with synthetic emerald overgrowth. Zeitschr. d. deutsch, Gesellsch. f. Edelsteinkunde, No. 37, pp. 6-12. Autumn 1962.

The author investigated a series of " Emerita " stones, i.e. beryls with a synthetic emerald coating, produced by J. Lechleitner. A blue aquamarine and a yellow heliodor of good colour assumed the same emerald colour when they were provided with a sufficiently thick synthetic emerald layer. The physical constants did not permit differentiation between genuine stones and Lechleitner synthetics, but microscopic inspection gives clear indications to the gemmologist. Seven photomicrographs of great interest show typical inclusions in the coating. One illustration shows a side view of a beryl with hydrothermal emerald coating. The " mantle " is

clearly visible as a dark rim under the polarizing microscope at 10 × magnification. Indicative is the termination of the inclusions in the coating at the surface of the core. In some cases this surface appears covered with " dust particles ", which were in reality euclase and phenakite crystals. Two-phase wedge-shaped inclusions in the coating and the familiar system of cracks, which at times assume a net-like appearance, appeared to be diagnostic features.

(J.G.VIII, 2) W.S.

THURM (R.). *Sternkorunde.* Star-corundums. Deutsche Goldschmiede-zeitung, Vol. 60, No. 1, pp. 18-19. 1962.

In 1947 the Linde Air Products Co., produced the first synthetic star-corundums. The recognition of this type of stone is easy. A drop of methylene iodide placed on the back of the stone shows a star in the real but not with the synthetic corundum. Soon the Germans made a synthetic stone which was recognizable by the concentric composition seen under slight magnification. Both corundums have a very sharp star, the American star being thinner, the German star being broader. All these synthetics are distinguished from the genuine stones by their crystal inclusions, feathers, etc. A new synthetic star-sapphire is now available, which is much more difficult to determine, but small bubbles arranged in long chains, as in the American synthetic corundums, are present. There is also some difference when the stones are viewed under crossed nicols, the new synthetic showing interference rings. For the last six years star-rubies and star-sapphires have been found in Mysore in India. The material is very opaque, but the star is good. They are not more expensive than synthetic star-corundums.

E.S.

BURKART (W.). *Indien-Ceylon Impressionen.* Impression of India and Ceylon. Deutsche Goldschmiede-zeitung, Vol. 60, No. 5, pp. 294-295. 1961.

Short illustrated description of a journey to India and Ceylon. Pictures show the mines in Ratnapura, the washing of the gem-containing " illam ", the sorting of the rough gems, a gem auction and the sawing and polishing in Ceylon.

E.S.

GÜBELIN (E.). *Farbe und künstliche Farbänderung von Diamanten.* Colour and artificial colouration of diamonds. Deutsche Goldschmiede-zeitung, No. 2, pp. 59-62. 1961; No. 3, pp. 130-133. 1961; No. 4, pp. 204-207. 1961; No. 5, Vol. 60, pp. 282-285. 1961.

The differences between the naturally blue diamonds and those which were artificially coloured blue proved to be interesting. The differences between Type I and II are discussed in detail. The colour of the artificially blued diamond seems to be less stable than the naturally blue stone. The first becomes green when heated to 550°C. Natural blue stones can be heated to 1250°C without losing their colour. This leads to the assumption that the colour-centre of the natural blue diamond was formed together with the diamonds millions of years ago. It is likely that the study of the alteration of properties of the diamond which can be brought about by disturbing its lattice will lead to a better knowledge of the internal structure and those properties which depend on this, i.e. absorption, colour and luminescence.

E.S.

EPPLER (W.). *Einschluesse im Diamant II.* Inclusions in diamond II. Deutsche Goldschmiede-zeitung, Vol. 60, No. 9, pp. 543-547. 1961. (Translated from Journal of Gemmology, VIII, 1, 1961.)

Inclusions of garnet, ilmenite, olivine, apatite, gaseous inclusions, healing cracks and sometimes negative crystals occur in diamonds. The solid inclusions were examined after their removal from the host crystal. Very probably other inclusions could also be found in diamond. Graphite and quartz was not found, but only industrial diamonds were examined, the origin of which was not known. The article is illustrated with 24 photomicrographs. (Part I was published in Deutsche Goldschmiede-zeitung, No. 8, pp. 462-465. 1961.)

E.S.

VLASOV (K. A.) and KUTUKOVA (E. I.). *Emerald mines.* Pub. Acad. Scie., U.S.S.R., pp. 250, figs 118. 1960.

A detailed description of beryl (including emerald) and other gem minerals which occur in the middle Urals is contained in this volume. About eighty minerals are described and the genesis of the Uralian emerald occurrences is considered in detail.

S.P.

CHUDOBA (K. F.). *Zur Deutung der Amethystfarbe.* An explanation of the colour in amethyst. Der Aufschluss, No. 9, pp. 233-248. 1961.

After having listed the peculiarities of colour in amethyst and having reviewed previous work on the subject, the author summarizes general opinion which assumes that the violet colour is caused in the first instance by iron but also by radiation. Occasionally the Fe pigment plus radiation is considered as the probable cause of amethyst colour. To investigate the problem more closely, the author chose striped amethyst specimens with alternate layers of violet and white (i.e. colourless) quartz, allowing the study of colour producing factors of two colour varieties of quartz on one and the same crystal. Microscopical investigation, spectrometric analysis, X-ray radiation, X-ray diffraction and density determinations showed good co-ordination between the different specimens. Amethyst lost its colour between 475 and 525 deg. C. and resumed its violet colour after exposure to X-ray radiation. White quartz did not change its colour when treated in the same way. Important factors were the amount of Fe (determined by spectrometric methods). Previous syntheses showed that Fe^2 or Fe^3 ions caused only green to nearly black or yellow to brown colours, i.e. iron alone cannot cause amethyst colour. Colourless faces too can contain iron. In this case they became amethyst-coloured after exposure to X-ray radiation. It can be assumed, therefore, that amethyst colour as radiation colour depends on the presence of iron in the quartz lattice. The co-ordination of absorption spectra of natural and synthetic amethyst allowed the conclusion that also in nature iron in combination with exposure to radium causes amethyst colour. The alternate layers of amethyst-coloured and white quartz in the same specimen were caused therefore by different Fe content. Dependent on a certain critical value, one layer became amethyst coloured and the other white when exposed to natural Ra rays. A factor may have been the rate of growth, the white layers having grown quicker, as shown by the wealth of inclusions. Detailed speculations are made on the accommodation of the Fe in the quartz lattice. The analogy to the replacement of Al^3 ions by Fe^3 ions in smoky quartz is discussed. In this connexion the preferential accommodation of Fe ions in distinct zones of the growing crystal is mentioned. This phenomenon explains the different concentrations of colour in natural amethyst crystals. It

also explains why natural colourless quartz becomes smoky brown when exposed to X-ray radiation; the small iron content had not been activated before into colour centres. Finally the different colour changes of amethyst of various localities under heat treatment are mentioned. No final explanation can yet be given.

W.S.

WURMBACH (I.). *Farbänderung von Diamant durch Bestrahlung.* Colour change of diamond through radiation. Zeitschr. d. deutsch. Gesellsch. f. Edelsteinkunde, No. 38, pp. 3-12. Winter 1961/62.

Interesting survey of literature with bibliography. Natural alpha rays emitted from radium bromide (Crookes 1909, Lind and Bardwell 1923) cause a blue-green radio-active layer of 0·002 mm thickness. Cyclotron bombardment (alpha particles, deuterons and protons: Ehrmann and Bermann, Crookes 1942; Scherrer 1948; Hamilton & Coll. 1950) causes a blue or green coating. Gamma rays from ^{60}Co radiation affect the whole stone and ^{60}Co causes a green or blue-green colour. The colour can be removed through heat treatment at 450 deg. C. Electron bombardment causes a blue colour which becomes paler at 300 deg. C. and turns via green into yellow at 550 deg. C. Neutron bombardment (in a nuclear reactor) causes a green colour. Heat treatment (250-900 deg. C.) results in yellow to brown hues. Three absorption curves are shown and available methods discussed for the differentiation between treated stones (especially blue ones) and natural diamonds.

W.S.

PENSE (J.). *Elektronmikroskopische Untersuchungen zur Fasertextur des Achates.* Electron microscopical investigations of the fibrous structure of agate. Zeitschr. d. deutsch. Gesellsch. f. Edelsteinkunde, No. 38, pp. 12-20. Winter 1961/62.

The author specializes in the investigation of the fibrous nature of agate especially with regard to its property of absorbing or rejecting dyes. The resolution power of optical microscopes is not sufficient to reveal the relevant pores. The electron microscope offers the resolution power required for this work, and the author discusses the difficulties encountered before obtaining satisfactory replicas of etched surfaces.

6 illus. W.S.

BOOK REVIEW

LEECHMAN, F. *The Opal Book.* 255 pp., 9 colour plates, 10 photos, maps and drawings. 42s. (45sA.). Ure Smith, Sydney, 1961.

A concise and readable account of opals and opal mining past and present. Apart from detailed information about the nature of opal (including theoretical considerations about the cause of the display of colour) the notes on the occurrence of opal, in Australia, Europe, the Americas and Honduras are excellent. Mr. Leechman has pleasantly re-captured the tales of early days in the Australian opal fields. The story of the old-time miners is fascinating.

The merit of the book is that it is an authoritative work, adequately illustrated, about opal from the mine to a beautiful gem of adornment. Myths and legends are also discussed and there are brief accounts of some famous opals. The appendices form a useful section of the book and include a glossary and hints on opal polishing. The bibliography is particularly helpful. Also at the end of the book Mr. Leechman shows an awareness of the poetry about opals.

Mr. Leechman concludes that opal " is not simply a hardened jelly, not completely an amorphous solid but a jel which contains here and there patches where crystallization is just commencing. It is not a pure jel either. Small percentages of aluminium, calcium, magnesium, sodium and potassium are inherent ; natural opal, perfectly pure, does not exist ".

It was the aim of Mr. Leechman, an Englishman who has travelled extensively in Australian opal fields in search of his material and who is also an experienced lapidary with his own opal workshop in Sydney, to record the story of opal in a reliable and straightforward manner and he has succeeded admirably. His book will be appreciated by many gemmologists and all who regard opal as one of the most fascinating and beautiful of gems.

S.P.

SIR CHARLES HARDINGE. *Jade, fact and fable.* 67 pp., 10s. Luzac & Co., Ltd., London, 1961.

Soon after the First World War, Sir Charles Hardinge began to collect jade carvings as an extension of an earlier hobby of collecting models of animals in stone.

After forty years of patient and costly accumulation, the Hardinge collection of Chinese carved jades and other hard stones became one of the finest in the country, and in 1960 it was generously presented intact to the Gubelkain Museum of Oriental Art in the University of Durham.

Being a collector of jade and a man of intellectual curiosity it was natural that Hardinge should delve into the voluminous literature, and soon be confronted with the confusions, contentions, misconceptions and mistakes which have made an initially difficult subject still more complex. One source of confusion is the fact that the same term " jade " has been (and still is) applied to two distinct mineral species, now distinguished as nephrite and jadeite, as first established by Damour in 1863: and further owing largely to an indiscriminate translation of the Chinese character Yü by the word " jade ", a number of other minerals have wrongly been accepted as such in the older literature, clouding the issue still further.

These facts have contributed to the difficulty of being sure of the origins of the jade material used by different cultures. Despite the 2000 years' preoccupation of the Chinese people with jade, it seems certain that their supplies came not from any source in China proper but from Chinese Turkestan (nephrite) and Upper Burma (jadeite) only. The source of Maori jade presents no problems; but the origin of the jadeite (often brilliantly coloured) used by the ancient Mexicans is a mystery only partly solved by the recent discovery of a deposit of this jade in Guatemala. Still more difficult to discover are the places where stone-age man found the material for the celts, axes, etc. (which often consist either of nephrite or of a form of jadeite) found scattered over many parts of Europe.

Sir Charles Hardinge has over the years transcribed and read with a critical eye some millions of words in original papers on these and other jade subjects, and corresponded with mineralogists and museum authorities in many parts of the world in an attempt to arrive at the true facts about the history of jade. For our great benefit he has been persuaded to carry out the difficult task of distilling this disordered mass of information and misinformation and giving us the essence of the matter within the compass of sixty-seven pages.

The first part of the book consists of a learned yet very readable account of the facts and problems still unsolved connected with the history and prehistory of the jade minerals. The second part is

headed " The Lists ", and consists of the more credibly reported finds of the jade minerals, (1) *in situ*, (2) as unworked eccentrics and rollers and (3) shaped by prehistoric man. In each case the type of jade, where known, is indicated, and the sources are listed under the different continents. The book concludes with a list of references to the literature used in the text.

The author devotes several pages to a discussion of the name jade, which is derived, through the French, from the Spanish " piedra de yjada " (stone of the flank) which is said to have been first used in a book by the physician Monardes in 1569; and of the name nephrite, which was derived from " lapis nephriticus ", a latinised version which in the 17th century came to replace piedra de yjada as the standard name for jade (there are apparently no words for the material in classic Greek or Latin). Both versions of the name refer to the same widely-held superstition that these stones served as a cure or palliative for kidney troubles, either worn as an amulet, applied to the afflicted part, or ground and swallowed as powder.

More than a century after the supplies from Mexico had died out the first examples of jade from the East began to reach Europe. It was assumed that this was the same material as Mexican jade, and the same names were applied. It remained for the French chemist Damour, in 1863, to prove, after a series of careful analyses, that the Chinese jades consisted of two distinct minerals, only one of which could be correlated with the Mexican variety.

Early in his career as a " jadeologist " Hardinge was struck by the fact that, after his discovery, the terms *jade* and *jade néphritique* (nephrite) were applied by Damour to the amphibole material from China which had never been associated with the kidney-cure legend, while he used the modified term *jadeite* for the pyroxene mineral, with which, in its Mexican form, the legend had been strongly associated. Hardinge maintains that the names should have been reversed, and in this book refers to Damour's " mistake " and later to his " solecism " in making his suggestions.

To the reviewer these strictures seem to be unjustified. The fact is that Damour was only in a position to act as godfather to *one* of the jade minerals, the pyroxene: the other had already been christened. This can be shown by referring to standard texts dating shortly before Damour's announcement, such as Dana's Manual of Mineralogy (1862), which describes under " nephrite "

what was undoubtedly amphibole jade, and Bristow's Glossary of Mineralogy (1861) and also to older works such as Phillips' Mineralogy (1819). These texts all refer to the kidney-cure legend as a reason for the name.

Rather more surprisingly, the French savant M. J. Brisson, in his tremendous work " Pesanteur spécifiques des corps ", which was published in 1787, gives three density determinations of " jades " which he made with specimens in the King's cabinet. These are: jade blanc, 2·950; jade vert, 2·966; and jade olivâtre, 2·983; all typical nephrite values.

Damour thus had no choice but to adhere to the name jade or jade néphritique for the amphibole, and his difficult task was to find a suitable name for the mineral which, although it had been known and used for centuries, was " new " in the scientific sense. To divorce the pyroxene entirely from the name jade would be to deprive it of is birthright : hence the decision merely to add the customary mineral termination " ite " was a reasonable compromise.

Unlike jadeite, nephrite is not the name of a distinct mineral species, but is descriptive of the compactly fibrous forms of tremolite or actinolite, or of specimens intermediate between the two: it is thus a most convenient term in practice. In short, though Sir Charles Hardinge would prefer the terms " amphibole jade " and " pyroxene jade " where a clear distinction is required, the gemmologist is quite content to use the long-accepted and clearly understood terms nephrite and jadeite, untroubled by the unsound bases for these names as the mineralogist is untroubled by the false presumption contained in such a name as " pyroxene " itself.

It may seem that in a short review a disproportionate amount of space has been given to this matter of nomenclature; but it is, after all, one of the main themes of the book itself. All those who are interested in jade from the historical, cultural, or archaeological angle will want to read and own this unpretentious but important little book. It contains more true substance than many of the larger, lavishly illustrated tomes which have been published on this fascinating subject.

B.W.A.

ASSOCIATION NOTICES

MIDLANDS BRANCH

On 19th October, 1961, the Branch held an interesting stone quiz devised by Mrs. Middleton.

In November over 40 members visited the stone cutting department of Shipton & Co. Ltd. of Birmingham, when members saw the cutting of various stones in process. Some of the members were given the opportunity to try stone cutting and polishing themselves and each visitor was given a piece of amethyst geode on departure.

On 6th February, 1962, the Branch heard Mr. B. W. Anderson speak on " The spectroscope and its uses in gemmology ". Mr. Anderson began by remarking that although various aspects of spectroscopy had been discovered in the 17th century, the impact upon gemmology, and its possibilities in gemstone identification were not realized until recently. He illustrated his talk with slides of numerous absorption spectra, especially those of zircon and diamonds which had been subjected to irradiation.

Over one hundred members and students were present at the talk which was held at the Jewellers and Silversmiths' School, Birmingham, by kind permission of Mr. R. Baxendale, the headmaster.

The annual dinner of the Midlands Branch was held on 14th March, 1962, at Quinton, near Birmingham. Mr. W. Bowen, Branch Chairman, presided, and welcomed Mr. and Mrs. Rex Joseph, Mr. and Mrs. R. Baxendale and Mr. and Mrs. H. Bishop as principal guests. In proposing the toasts of " The Guests " Mr. Brown called for greater co-operation and liason between various sections of the jewellery trade and between the various trade associations. Mr. Joseph replied on behalf of the guests.

TALKS BY MEMBERS

BETTS, G. N. : " Jewellery ", The Women Drivers Association, Huddersfield, 9th January, 1962; "Gemstones", Association of Home Economists of G.B. Leeds, 15th January, 1962; Buttershaw St. Pauls Young Wives, Bradford, 17th January, 1962; "Precious Stones", Headingley Townswomen's Guild, Leeds, 12th February, 1962 ; Bolton St. James Young Wives' Group, Bradford, 22nd February, 1962; " Jewellery ", National Savings Movement, Keighley, 15th March, 1962 ; " Gemstones ", St. Francis Ladies' Fellowship, Fixby, Huddersfield, 5th April, 1962; " Precious Stones ", Rishworth Women's Institute, Halifax, 17th April, 1962.

HAVEM, U. (Miss) : " Genuine and synthetic gemstones ", Gaa Norwegica (association of geological students) and Proton (association of chemical students), University of Oslo, 16th November, 1961, and 25th January, 1962.

GILLOUGLEY, J.: " Gems of the sea ", Paisley Business and Professional Women's Club, 12th February, 1962.

MEMBER'S MEETING

Members who responded to the invitation to participate in the meeting and exhibition arranged at the Goldsmiths' Hall on 22nd February, 1962, found that this was an occasion when knowledge and information was most easily digested in an atmosphere of social conviviality. Students from the Northern Polytechnic had a field day but there was also a good gathering of qualified gemmologists, all of whom spent an interesting evening seeing new things, meeting old friends and making new ones.

The exhibits included quite a remarkable number of " first time ever " items about which much had been heard but only few people had actually seen. Thus, for instance, the rows of test tubes filled with synthetic industrial diamonds. Such boart is only rarely seen by the gemmologist and this was undoubtedly the first time it had been on display in relatively large quantities.

The emphasis was mainly upon synthetic stones, more of which are coming on to the market, so that the gemmologist could make firsthand acquaintance with some of the latest types. Examples included some that were comparatively well known to the expert such as strontium titanate but there were also the Lechleitner emeralds made in Austria. These consist of colourless or pale coloured aquamarine or yellow beryl, cut and polished, upon which is deposited by hydrothermal methods a coating of synthetic emerald. Its surface is then lightly polished.

Then there was lapis-coloured sintered synthetic spinel produced as an imitation of lapis-lazuli. The matrix, it was explained on the informative cards that described all the exhibits, is made of grains of synthetic spinel, which is pigmented with cobalt oxide. The grains are then pressed together and sintered in an oven. The method of creating an imitation of a moonstone from synthetic spinel was also shown together with examples of Prof. Eppler's synthetic emeralds.

These exhibits did demonstrate the fast moving developments produced by scientists which call for effort—or an exhibition of this kind—to allow the gemmologist to keep pace.

From Japan had come the latest in non-nucleated cultured pearls. The ingenious method used in growing these is by inserting into the body of the Japanese freshwater mussel, a small piece of mantle. But they can be distinguished because they fluoresce brightly under ultra-violet light and an X-ray picture of them shows distinctive markings.

Then there were old friends, spinel doublets, and demonstrations of the newer technique of producing imitation star-stones by scratching on the base of either synthetic ruby or glass cabochon, three sets of fine lines crossing each other at 120 degrees.

Knowledge was conveyed and brought up to date in other directions.

There were examples of stones that have been found in unexpected places and from new sources. Ekanite, for example, a new mineral discovered in 1953 by Mr. F. L. D. Ekanayake in Ceylon. It takes its name from its discoverer. Examples of nephrite, ruby and sphene were also on view from Rhodesia, Tanganyika and California, respectively.

For gemmologists who are also acquainted with electronics and very ultra-short wave radio there was a lot of interest in the work that the General Electric Company is doing in growing synthetic rubies for the first time at their Research Centre for " Maser " and " Laser " apparatus. These rubies are produced from a lithium fluoride melt and may be used in micro-wave transmission and reception.

More within the region of the practical man of the trade was an illustration of the way that diamond jewellery may be " finger-printed ". This can be carried out by putting a piece of such jewellery under an ultra-violet light and photographing the different intensities of fluorescence that are then displayed.

The simple method of identification by immersion contrast was also shown. Here were photographs that showed how a number of different stones, placed in a liquid of known refractive index and illuminated with a single overhead light, looked when photographed from below. The stones with a higher refractive index than the liquid having bright faceted edges and dark borders and the reverse for those with a lower refractive index. A mirror can be used instead of a film.

Simple and slightly more elaborate electrical conductivity apparatus was also shown which the amateur could make up for himself. It consisted of a simple electrical circuit using a dry battery, a clip and probe to make contact with a stone and a pair of headphones. Slightly more complicated, but still easy to assemble, was a mains circuit using a neon type tester. Such a piece of apparatus would be of use in checking a diamond that had been coloured by electronic radiation, such as a sample shown.

As a contrast, perhaps, from such simple apparatus, there was a " Gemolite " microscope with a " zoom " lens. It had come, of course, from the United States and is a lovely instrument with which one can scrutinize the smallest aspect of a stone in " close-up " degree that reminded one of the television camera. It is extensively used by members of the Gemological Institute of America.

And not only did the exhibition bring its visitors right up-to-date with the results of world wide research and development, but there was the reminder that its leading personalities are equally abreast of the times. For these, with the promise that it will be out in May, were some of the proofs of the new book by Mr. Robert Webster on gems, their sources, description and identification.

The exhibits were of interest and value, but when to these can be added the meetings and conversations of the evening, it can be said that this was one of the high-spots of the Association's new year.

The Council of the Association is indebted to Mr. Robert Webster, who undertook the major work of arranging the exhibition and to the staff of the G.A., who suggested it.

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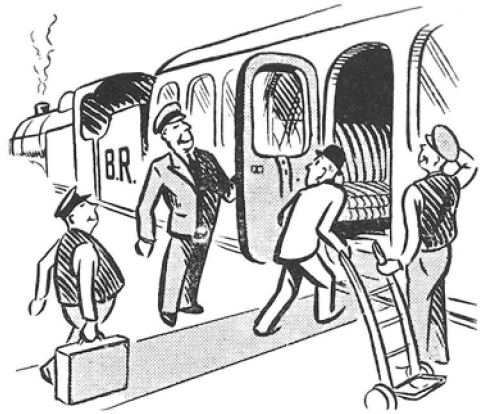

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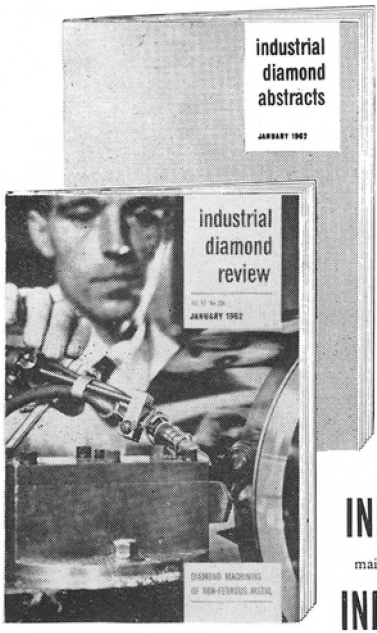

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THREE-PHASE INCLUSIONS IN EMERALD, AQUAMARINE AND TOPAZ

By W. F. EPPLER

THREE-phase inclusions are a reliable diagnostic feature of genuine emeralds, particularly for those from Colombia. They exhibit different forms according to their position within the host crystal. If they are parallel to a face of the prism zone, they are characterized by jagged forms, the points of which indicate the direction of the c-axis of the emerald crystal (Fig. 1). This kind of inclusion is originated by disturbances during the crystal growth. The peaks of the inclusions can be described as negative planes of steep pyramids, sometimes elongated into prong-like forms.

The other kind of three-phase inclusion in emerald is found parallel to the basal plane of the host crystal (Fig. 2). They also develop irregular forms but they exhibit a more complex shape. Not seldom, they are more or less elongated and rounded. These inclusions represent the remains of a healed fracture originally generated as a cleavage plane during the growth of the emerald crystal.

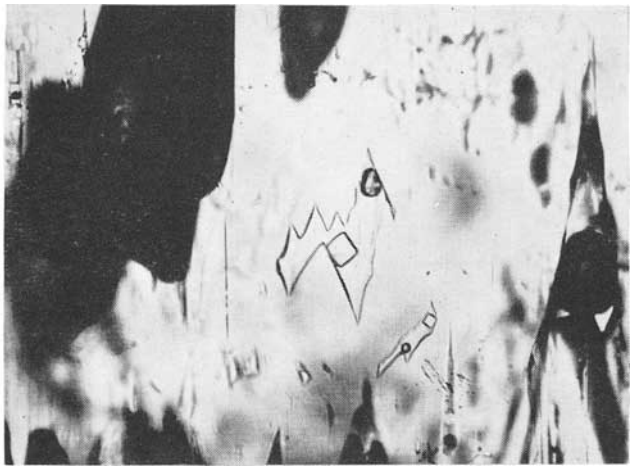

FIG. 1. *Three-phase inclusions parallel to a face of the prism zone of a Colombian emerald. 120X*

Both kinds of inclusions are identical with regard to their contents. A rounded gas bubble indicates the presence of a liquid, and a regularly developed crystal of rectangular shape represents the solid phase. The crystals are said to be cubes of rock-salt (or halite, NaCl), an explanation which sometimes has been doubted.

As early as 1870, F. Zirkel gave a convincing proof about the nature of the solid component of three-phase inclusions, not in emerald but in quartz (Fig. 3). By microscopic examination he made it plausible that the isotropic cube could be nothing else than a rock-salt crystal. But he found other reasons to confirm his assumption. He crushed to a fine powder some quartz rich in these inclusions and boiled it in distilled water absolutely free of chlorine. Then he added a solution of silver nitrate and obtained a milky precipitation from which follows, that by the boiling water the rock-salt was dissolved and its part of chlorine identified by the precipitation of the indissoluble silver chloride.

Next he held with platinum-tipped tweezers a coarser piece of the quartz in the colourless flame of a bunsen burner. Some moments later, the little piece of quartz started to crackle and to break up whereby each time a sudden yellow colouring of the flame occurred. A very simple and reliable proof for the presence of sodium.

Now, after these convincing tests for the presence of sodium chloride or rock-salt in quartz, it seems to be obvious that the little cubes within the three-phase inclusions in emerald are also rock-salt, not only on account of their cubic crystal form but also with regard to their isotropic character. Additionally, the pegmatitic origin of the emerald makes it very likely that the similar three-phase inclusions in quartz and emerald respectively are of the same nature.

Besides this, it has been confirmed in modern times that rock-salt and sylvite (KCl) occur as a solid phase not only in liquid inclusions in quartz, but in beryl and topaz also. A very interesting publication of Lemmlejn and Klewzow (among many others) mentions this particular fact. So we can be sure that the little cubic crystals in liquid inclusions in emeralds are rock-salt, which mineral can sometimes be accompanied by the rarer sylvite.

The method used by the Russian scientists consists in cooling the material in question until the liquid of the inclusion congeals. They cooled, for instance, a quartz with a three-phase inclusion down to minus 26·8-27·8°C., at which temperature the liquid became frozen. By calculation they found that this freezing point is characteristic for a saturated solution of NaCl and KCl with 2-3% $MgCl_2$.

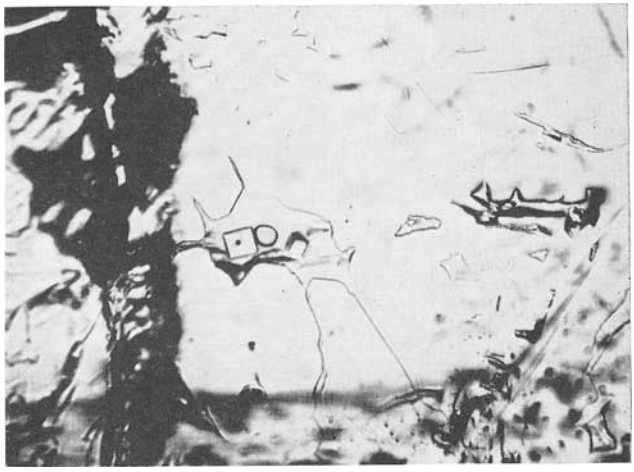

FIG. 2. *Emerald from Burbar, Colombia, with three-phase inclusions parallel to the base plane. 65X*

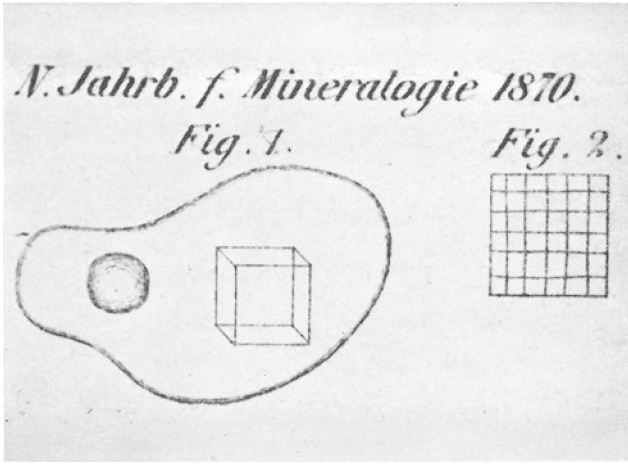

FIG. 3. *Copy of an original drawing of F. Zirkel* (1870). *A three-phase inclusion with a cube of rock-salt in quartz.*

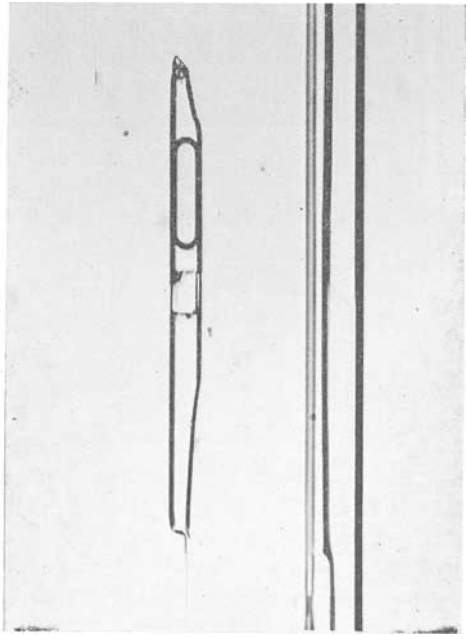

FIG. 4. *Three-phase inclusion in an aquamarine from Bom Jesus das Meiras, Bahia, Brazil. 240X*

The author often tried to detect similar inclusions in beryls other than emerald, especially in aquamarine. Until now, they

could not be found in gem material. Only in a poorly coloured but well developed slender crystal of aquamarine from Brazil, tube-like three-phase inclusions could be observed, of which Fig. 4 gives an example. Obviously, this inclusion represents a tube of growth, so common and well known in aquamarines. It follows, naturally, the direction of the host's c-axis. The little cube, most probably of rock-salt, is colourless, singly refractive, and it bears in its upper left corner a minute dark dot, such as can often be seen on the cube face of the rock-salt crystal in this particular kind of inclusion (see also Fig. 2). It could not be determined if this dot is an additional micro-bubble or a tiny particle of solid material.

Recently, some three-phase inclusions could be observed in a bluish-coloured topaz of gem quality from Brazil. Sometimes, the inclusions are very similar to those found in emerald parallel to its base plane (Fig. 5). In other cases, they cover a relatively large area. They are always parallel to the basal plane of topaz, a direction which represents the perfect cleavage of this crystal. Therefore, they can be regarded as the indigestible remnants of a cleavage crack which healed during the further growth of the topaz crystal.

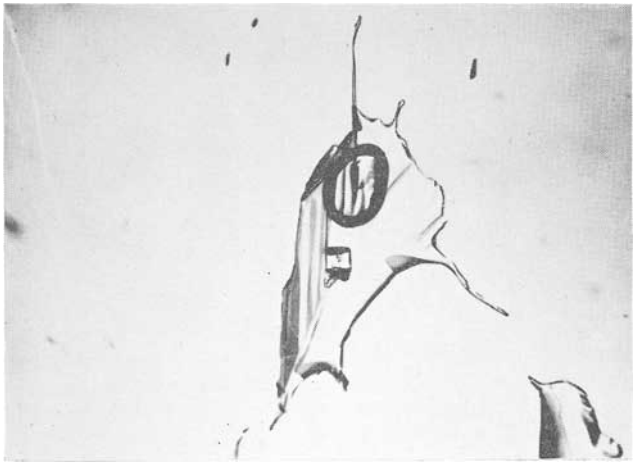

FIG. 5. *Topaz of gem quality from Brazil, exhibiting a three-phase inclusion of irregular shape parallel to the basal plane. 120X*

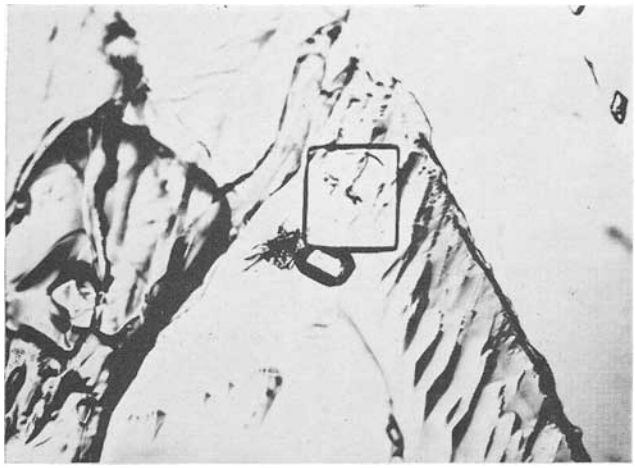

FIG. 6. *Part of a large three-phase inclusion in topaz. 120X*

Fig. 6 shows a part of a large three-phase inclusion in the same topaz. The left part of the picture with its darker appearance is a section of the large gas bubble. The square in the upper middle represents a cube of rock-salt. It overlays a dark-rimmed smaller and doubly refractive crystal of unknown nature. In 1955, M. M. Iwantischin reported the presence of rock-salt and sylvite as primary inclusions in topaz. So, this little contribution offers no new discovery, but another confirmation for the long-known nature of the solid component of these particular three-phase inclusions.

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PEARL TESTING THROUGH ONLY ONE X-RAY DIFFRACTION PATTERN

By JORGE ANGUS

It is known that in a determined position a cultured pearl can produce a diffraction pattern like a natural pearl. This makes necessary a second X-ray of the pearl, turned to a 90° angle according to the first position each time, if the first result was of a hexagonal diffraction pattern. If the second testing gives the same hexagonal symmetry, then this means that the pearl is a natural one. But if the symmetry shows a rectangular form it indicates that the pearl is cultured.

In the " Laboratorio de Gemologia Y Ensayo de Materiales del Banco Municipal de la Ciudad de Buenos Aires " a Rich Seifert X-ray diffraction equipment has been installed with its corresponding Laüe's chamber. The classical method is used with satisfactory results.

However, due to internal demands at the Bank for quick testing, it has been necessary to reduce the time involved. The procedure is as follows.—A special device, as indicated in Fig. 1, was installed to obtain a rotation movement of the pearl during exposure to the X-rays. This rotation is obtained with the help of Debye-Scherrer's chamber motor (Fig. 2). A one minute revolution of the pearl is sufficient. The film was placed as Laüe's technique requires and the method is only a combination of the techniques of crystal rotation and Laüe's. By this method the natural pearl shows a hexagonal symmetry pattern (Fig. 3). The cultured pearl shows a rectangular symmetry, as shown in Fig. 4.

The best results were obtained by working with 0·6 mm diaphragm, 20 mA 53 Kv and 4 cm from the pearl to the film. The X-rays film used was Kodak KK, with 6-8 minutes exposure time according to the pearl size. An intensifying screen was not used. After the first attempts it was very easy to centre the pearls correctly. It was also possible to do this by hand, mounting the pearl on a little wax cone. The method described has been a great saving in time and costs, and has been extremely useful in cases of pearls which were irregular in shape.

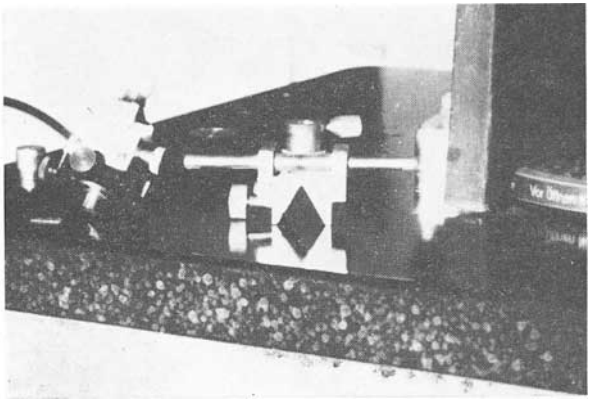

FIG. 1

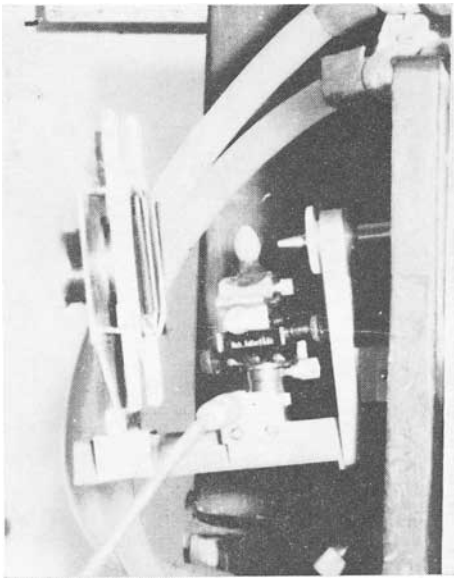

FIG. 2

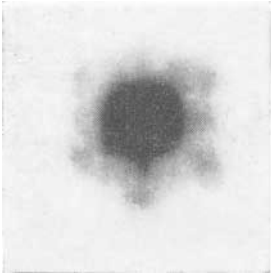

FIG. 3

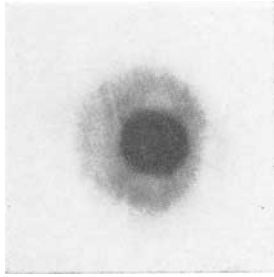

FIG. 4

Gemmological Abstracts

TOLANSKY (S.). *Folklore & history of diamond.* Gemmologist, Vol. XXX, Nos. 361, 362, 364, 365, pp. 155-158; 167-170; 205-210; 232-235, August, September, November and December 1961.

An article based on a paper presented to the Royal Society of Arts. The early references to diamond are discussed and particular regard is had to the early engraving of diamonds. Some of the curious myths applied to diamonds in the early days are mentioned, with special note of the notions of the indestructability of diamond. The historical aspects of cleavage are discussed and the fabulous ideas on diamond which were current in medieval times are given. The history of the techniques for polishing diamonds from the 15th century to the present day is given and there is discussion on the origin of the carat weight. A number of the famous diamonds are referred to and their histories mentioned. There is a note on the modern diamond mining methods.
9 illus.

R.W.

AREND (R.). *Austrian synthetic emerald examined.* Gemmologist, Vol. XXX, No. 362, pp. 161-164, September 1961.

Reports the examination of 31½ carats of synthetic emerald-coated beryls (Lechleitner synthetic emeralds). The density was found to average 2·738 (2·725 to 2·752). The overgrowth on the cut beryl core is only about 0·3 mm. The refractive indices were found to lie between 1·565 to 1·568 for ε and 1·570 to 1·573 for ω. These are values lower than those given by other workers. The absorption spectra, fluorescence, colour filter and microscopic observations were made and recorded.

R.W.

TISDALL (F. S. H.). *Synthetic red spinel.* Gemmologist, Vol. XXX, No. 362, pp. 165-166. September 1961.

A synthetic red spinel had a refractive index of 1·722, and the density 3·66—taken by flotation and refractive index method.

The stone showed curved structure lines which had an effect rather like a Venetian blind. The fluorescence spectrum is compared with that of ruby and natural red spinel.
2 illus.

R.W,

SPRIGG (R. C.). *The Burma jade mines.* Gemmologist, Vol. XXX, No. 364, pp. 211-212, November 1961.

The jadeite is found in a remote area of the northern provinces and at the time of writing the article this area was in insurgent hands so that the author could not visit the mine personally. The mines are at Tawmaw in the Myitkyina district. The jadeite occurs in dykes of jadeite-albite rock bounded on the margins with amphibolite and chlorite in a country rock consisting of serpentine. The rocks are said to be of cretaceous age. The various Burmese names for the different colours and qualities of jadeite are given. Some historical aspects and something of the mining methods are discussed.

R.W.

LEE (H.): WEBSTER (R.). *A pearl encysted crab.* Gemmologist, Vol. XXX, No. 365, p. 231, December 1961.

A small crab was found to be the nucleus of a blister pearl.
1 illus.

R.W.

KOMKOMMER (J.). *The great blue diamond.* Gemmologist, Vol. XXX, No. 365, pp. 224-226, December 1961.

Tells the story of the Wittelsbach blue diamond which weighs 35·56 carats, not 35·32 carats as usually reported.

R.W.

TRUMPER (L. C.). *Stibiotantalite.* Gemmologist, Vol. XXX, No. 361, pp. 141-142 and 146, August 1961.

A report on the examination of two small specimens of pale yellow stibiotantalite, presumably from Madagascar. The refractive index, found by using the author's design of reflectometer, was 2·45 and determinations of density gave values approximate to 7·63. The cause of the increase in density is discussed. The stones were doubly refractive, had an adamantine lustre, and the

inclusions seen in the stones were short rods and liquid filled feathers. Dichroism was distinct and the absorption spectrum showed only a general absorption below 5200Å. There was no fluorescence. Stibiotantalite is a double oxide of antimony and tantalum with some columbium (Sb (Ta, Cb) O_4) and crystallizes in the orthorhombic system. It has a hardness of $5\frac{1}{2}$; a double refraction varying between 0·060 and 0·083 and the dispersion is about 0·060. Stibiotantalite is also found in the Himalaya mine, San Diego, California.

R.W.

ZAVERI (C. K.). *Gemstones of India.* Gemmologist, Vol. XXX, Nos. 356 and 361, pp. 46-52 and 143-146, March and August 1961.

Emeralds and garnets are found in Rajasthan; diamonds at Panna and blue sapphire in Kashmir. These comprise the stones found in the northern half of India. These are mostly mined by organized operation for the Government or for private companies. Many other species, mostly the less precious stones, are found in the southern half of the country. Here the stones are mined by individuals rather than by organized groups. The gemstones found are diamond, emerald, chrysoberyl, garnet, aquamarine, amethyst, moonstone, green aventurine, moss agate, bloodstone and star-corundums. Apatite, beryl, apophyllite, euclase, iolite, kyanite, rhodonite, tourmaline, spinel and calcite are also found. Famous Indian diamonds are referred to and the early methods used to recover diamonds (taken from Streeter's book) are given. Mention is made of the diamond mines at Panna and those of the Kristna River. There are notes on the sapphire from Kashmir, the emeralds from Ajmir and Jaipur and the garnets from the latter district. A brown tourmaline from Rajasthan and a blue aventurine quartz are mentioned. In southern India, Mysore and Madras are the major gem producing states, Kangayam being the main locality for most of the stones. Aquamarine is the costliest material found in this area. Amethyst is found here also. Iolite is an important mineral and is known as Kaka Nilam (uncle of sapphire). There are moonstones of white, milky-white, pink, green, grey, chocolate, and black colours from this area. Star-ruby and sapphire, the latter in various colours, come from Mysore,

which state is also the supplier of green aventurine. Near Trivandrum chrysoberyl cat's-eye is found. Agate, particularly moss agate, cornelian, bloodstone and jasper are found in the state of Bombay.
1 map.

R.W.

WALTER (D. R.). *A star-beryl find.* Gemmologist, Vol. XXX, No. 361, pp. 159-160, August 1961.

Describes two specimens of star-beryl from Brazil, one being a golden bronze colour and the other in silver tones. The asterism is said to be due to inclusions of oriented crystal plates of ilmenite. The stones resemble the Australian black star-sapphire. There is a note on the polishing of such stones.

R.W.

OSTWALD (J.). *An introduction to the optics of gemstones.* Australian Gemmologist, No. 10, pp. 8-14, December 1961.

This is part of a series. Reflection, refraction, total internal reflection and double refraction are discussed. Some historical detail is included.
6 illus.

R.W.

TUFFLEY (J. R.). *Cleavage.* Australian Gemmologist, No. 9, pp. 5-7, September 1961.

The structure of the atom and the formation of compounds are discussed in order to give an outline of atomic bonding relevant to cleavage. The silicate minerals forsterite and mica are given as examples of bonding giving little and perfect cleavage. The types of cleavage and their value or otherwise in the case of gemstones, are mentioned, as well as the reasons why some minerals show no cleavage. There is a note on parting.
5 illus.

R.W.

ANON. *G.J.'s quick course in gemmology.* Goldsmiths' Journal, pp. 204-208 (May 1961); 252-256 (June 1961); 304-307 (July 1961); 348-351 (August 1961); 396-399 (September 1961); 446-449 (October 1961); 542-543 (December 1961); 10-12 (January 1962); 58-61 (February 1962); 115-116 (March 1962).

The first ten instalments of a series of articles on practical

gemmology. The series does not follow the accepted pattern of progression used by the normal text books, each section being a unit in itself. Some unexpected but useful sections are included, such as the best colours of paper to be used in stone packets. The series has eye-catching sub-headings and is profusely illustrated with unusual line drawings.
80 illus. R.W.

WALTER (D. R.). *Chiastolites from the Olary Province of South Australia.* Australian Gemmologist, No. 6, pp. 5-9, June 1961.

The chiastolite variety of andalusite was first found in Australia in 1901. Specimens come from Bimbowrie, Alconie and Mount Howden. A description of the crystals is given. There is a discussion of the reasons for the cross-like inclusions and the effects of subsequent metamorphic geological strains on such crystals.
10 illus. R.W.

CHALMERS (R. O.). *Gemstones of Australia.* Australian Gemmologist, No. 10, pp. 15-17, December 1961.

A reliable article (reprinted from the Australian Museum Magazine) giving the locations where Australian gemstones may be found. The opal localities are first discussed. In recent years the opal production of New South Wales has fallen off and the two South Australian localities at Coober Pedy and Andamooka are the principal sources. Sapphire in blue, golden and green colours is obtained mainly from Anakie. Ruby is not found in Australia. Aquamarines are occasionally found in the Emmaville and Torrington district of New South Wales. Emerald is found near Emmaville in the same state and at Poona in Western Australia. Topaz, with tints of blue and green, is found in New South Wales. Zircons, deep red to golden yellow in colour, are found in New South Wales and Queensland, and some pale straw-yellow to colourless crystals have been found in the Strangeways Ranges of Central Australia. These have been cut at Alice Springs. Almandine garnets are widely distributed. Rock crystal, cairngorm, citrine and amethyst are found in the Australian Highlands. Green and pink tourmaline is found in Kangaroo Island off the South Australian coast. Diamond is found in every State except in the Northern Territory. The diamond crystals are small and are generally considered to be harder than those from other sources.
R.W.

WEBSTER (R.). *Diamond cuts and colours; Detecting diamond simulants.* Watchmaker, Jeweller & Silversmith, pp. 60-65 (April 1961); 74-77 and 102 (May 1961).

The first two parts of a sub-series on gemstones for the series " Salesmen need facts ". The characteristics of a diamond points to look for in identifying a diamond are given. The effects of artificially altering the colour are discussed. Diamond doublets and how they may be detected are described together with such simulants as white zircon, fabulite, synthetic rutile, white sapphire and spinel, and lustrous pastes. Mention is made of those natural gemstones which may resemble coloured diamonds.
12 illus.

P.B.

WEBSTER (R.). *Pearls; Cultured and imitation pearls.* Watchmaker, Jeweller & Silversmith, 78-83 (June 1961); 70-75 (July 1961).

Describes the formation and structure of pearl and the methods used in fishing for the pearl oysters. The shapes and colours of pearls are mentioned and notes are given on the care of pearls. The difference in structure of the real pearl and the cultured pearl is shown. Non-nucleated cultured pearls are mentioned and details are given of the ways cultured pearls are detected, both by visual observation and by the use of instruments. The article covers imitation pearls and other objects resembling pearls such as hematite, " cave pearls" and " coco-nut pearls ".
16 illus.

P.B.

WEBSTER (R.). *Ruby and sapphire: Emerald and aquamarine: Alexandrite, cat's-eyes and topaz; Tourmaline, zircon and peridot; Garnet and sphene.* Watchmaker, Jeweller & Silversmith, pp. 62-67 (August 1961); 104-109 (September 1961); 102-107 (October 1961); 98-103 (November 1961); 68-73 (December 1961).

Describes each of the stones in so far as the salesman needs to know them so as to be sufficiently conversant with them to answer a customer's questions. The synthetic counterparts and simulating stones are discussed in each case.
42 illus.

P.B.

ANDERSON (B. W.). *An orange metamict zircon.* Gemmologist, Vol. XXX, No. 365, pp. 221-223, December 1961.

Reports the examination of an orange-coloured zircon of low type. The density was found to be 4·008 and the refractive index 1·823. The stone had an absorption band at 5200Å. Most metamict stones are green. A table of density and refractive indices of a number of all types of zircons is appended. The unusual absorption spectrum of the stone and other anomalous absorption spectra in zircon are discussed.

R.W.

SPRIGG (R. C.). *A flying visit to opal country.* Gemmologist, Vol. XXXI, No. 366, pp. 11-13, January 1962.

A popular account of a visit to the Queensland opal area near Canaway Downs; and of the Hayricks opal mine.
2 illus.

R.W.

CRIBB (H. G. S.). *The Hayricks opal mine.* Gemmologist, Vol. XXXI, No. 366, pp. 7-11, January 1962.

A sandstone boulder type of opal is found as irregularly distributed elongated concretions. The article is a geologist's report on the nature of the rock formations and the opal boulders. Mining operations and the quality of the opal are discussed.
1 map.

R.W.

ANDERSON (B. W.). *Alteration in absorption spectra and properties of metamict zircons induced by heat treatment.* Gemmologist, Vol XXXI, No. 367, pp. 19-23 and 36. February 1962.

Experiments made to study the effect of heat treatment on metamict zircons showing the anomalous 5200Å band and other metamict and near metamict zircons are described. Careful measurements of density and refractive index before and after each experiment were made. A zircon showing the 5200Å band was heated to 600°C for three hours and found not to alter. After a further two hours heating at 800°C a strong and clearly defined series of about twelve bands were seen in the absorption spectrum. They were not in the normal positions of the zircon bands in the spectrum, but the arrangement was similar. The density and refractive index were found to have lowered from 4·04 to 3·89 and

1·819 to 1·785 respectively. Further heating to 900°C caused a further decrease in refractive index to 1·778. Experiments were repeated with other metamict zircons with similar results. The author has attempted to discover the " watershed ", that is the point below which heating produces a decrease in constants and above which the stone will increase in density and refractive index when heated. From these experiments it was found that this " watershed " lies virtually as the dividing line between Stevanovic's " a " and " c " classification. During the latter series of experiments one stone was found to be anomalous in this respect.
1 illus.

R.W.

WEBSTER (R.). *Quartz varieties; Chalcedony, agate and jasper; Opal.* Watchmaker, Jeweller & Silversmith, 62-67 (January 1962); 74-79 (February 1962); 70-75 (March 1962).

Descriptions of the various types of quartz and quartzite are given and the inclusions seen in rock crystal, amethyst and Venus hair-stone are illustrated by photomicrographs. Quartz cat's-eyes, crocidolite and the many forms of agate are mentioned. The staining of agate and the various types of jasper, including the dyed blue jasper called " Swiss lapis", are described. Localities for opal are given. Opal doublets and the rock-crystal-topped triplet are used as substitutes for opal.
24 illus.

P.B.

VANLANDINGHAM (S.L.). *Unakite.* Gems & Minerals, 1962, 297, p. 28.

Unakite is a variety of granite containing green epidote, quartz and pink feldspar. Epidote must always be present for this ornamental rock to be called unakite.

S.P.

BOOK REVIEWS

SELWYN (A.). *Retail Jewellers' Handbook.* Seventh edn. revised by J. J. Adler and G. F. Andrews. 42s. Heywood, London, 1962.

The revised edition of this standard work has gained by elimination of unnecessary text and the additions made in the light of changes which have occurred in the trade. Some of the illustrations are not as clear as in earlier editions and the chapter on watches could have been more complete. In spite of these minor blemishes Selwyn's book, which was first published over sixteen years ago, is still the leading work of its kind. The National Association of Goldsmiths continue to use it as a textbook for their courses for retail jewellers in Britain.

S.P.

NEUMANN (R. VON). *The design and creation of jewelry.* 45s. Pitman, London, 1962 (Amer. edn. Chilton Co. 1961).

A useful book for the designer-craftsman, the section upon manufacturing techniques being particularly well written. Although the setting of faceted gems is clearly described, the illustrations showing modern design are mostly in metal devoid of gemstone embellishment.

The author has aimed at stimulating interest in creating beautiful articles of adornment, which can give so much pleasure and pride in achievement, and he has succeeded admirably.

S.P.

WEBSTER (R.). *Gems: Their sources, descriptions and identification.* Two vols. (476 pp. Vol. 1; 328 pp. Vol. 2). 20 colour plates. £9 10s. Butterworths, London, 1962

A review of this important new work on gemstones will appear in the October issue of the Journal.

J.R.H.C.

ON THE REFLECTION AND ABSORPTION OF NORMALLY INCIDENT PLANE-POLARIZED LIGHT BY POLISHED GEMSTONES

By J. OSTWALD
B.Sc., F.G.A.A., A.M.Aus.I.M.M.

Introduction

This short paper is concerned with some of the simpler mathematical aspects of the electromagnetic theory of reflection and absorption, especially those formulae which are of use in quantitative studies. As far as the author knows, this subject has not been treated in any of the gemmological text-books. The subject may be looked upon as of theoretical importance only at the present time, but with precision apparatus for measurement with reflected light becoming more readily available it seems likely that such physical properties of gemstones as reflectivity, colour and pleochroism will become the subjects of quantitative studies. The theoretical side of the study is not without its difficulties, some of which will be indicated in the following pages.

The Nature of Polished Gemstone Surfaces

Before proceeding to investigate the effects which polished crystal surfaces have on light it will be necessary to inquire into the nature of the surfaces themselves. For if we are to be concerned with the action of polished surfaces on light, it is necessary first to have a clear understanding as to what a " polish " is. The most common definition is that a polished surface is one which is specularly reflecting at normal incidence and in which the separation of surface irregularities is less than the wavelength of the light. The actual physical nature of the polished surface is still a matter of dispute.

The most widely accepted view, and the one which is described in the gemmological text-books, is that the final polish given to an already smooth surface is the direct result of local fusion of the surface, with the spreading over it of a liquid-like layer of ultramicroscopic depth, the Beilby Layer. Four possibilities are thought to exist for this layer.

1. The structure may not show fusion and thus no Beilby Layer forms. Polishing in this case is a very fine grinding, e.g. diamond.

2. The Layer recrystallizes after formation with the same atomic orientation as the crystal, e.g. quartz.
3. The Layer recrystallizes on certain atomic structure planes only (such as cleavage surfaces), e.g. calcite.
4. The Layer remains amorphous, e.g. zircon.

This theory was originally put forward by Beilby (1921), who at the time was not able to explain the mechanism of flow, although he thought it was possibly a surface tension effect. The discovery of very high local temperatures when solids are rubbed together, by Bowden and Hughes (1937), was taken as a possible point in favour of the theory, as it could lead to a fusion of the surface layer. Even more important to the theory were the experiments of Thomson (1930) and French (1933). These workers found that the electron diffraction patterns of polished metal surfaces showed two diffuse halos, similar to those obtained from the surfaces of liquids.

Recently (1959) research work at the New South Wales Branch of the Defence Standards Laboratories has brought to light a number of objections to the theory. The more important are listed as follows:—

1. By the use of phase-contrast microscopy and reflection electron microscopy, it has been found that even the most perfectly polished surfaces are covered in innumerable fine scratches.
2. Beilby's theory argued that there should be no loss of material during the final polishing. Samuels (1952) proved that material was removed at quite definite rates during final polishing.
3. Epitaxed deposits are able to grow on mechanically polished surfaces.
4. Electron diffraction studies of polished silver crystals indicate that the surface layers are crystalline but have been disorganized by plastic deformation.

Samuels and his co-workers believe that polishing is essentially a very fine grinding. The finer the abrasive used the finer the grooves produced until finally the surface is " polished " within the meaning of the definition. The surface layer is crystalline but plastically deformed, the amount of deformation decreasing with increasing fineness of polish.

Basic Principles of Reflection and Absorption

When light is normally incident on the surface of a polished gemstone its initial intensity Io is reduced in passing into the crystal

by—

1. reflection at the upper surface
2. scattering by inclusions in the crystal
3. absorption by the atomic structure of the crystal.

As gem crystals are usually perfect and free from major inclusions we can neglect (2).

We can define the reflectivity of a crystal surface (R) as the percentage of normally incident light reflected from the surface.

$$R = \frac{\textit{Total Reflected Light}}{\textit{Total Incident Light}} \times 100\%$$

If the crystal is not perfectly transparent to the incident wavelength, then the intensity of light will decrease as the wave-front passes through successive layers of equal thickness in the crystal. The following formula defines this decrease.

$$I = Io \cdot e^{-(4\pi kd/\lambda)}$$

where

Io = the initial intensity
I = the final intensity
e = the base of natural logarithms
d = the distance moved by wave
k = the Absorption Coefficient
λ = the wavelength.

It will be seen that, except in the case of perfectly transparent crystal, two constants are necessary to define completely the passage of light through a crystal (and its reflection). Thus a generalization of the concept of refractive index should include " n " (the usual refractive index) and " k " (the absorption coefficient just defined). Now as early as 1837 James MacCullagh of Trinity College, Dublin had proposed an imaginary refractive index (involving the square root of -1) for metals and absorbing substances. The real nature of the refractive index was discovered by Paul Drude as a result of an analysis of Maxwell's equations in absorbing media. Solutions of these equations in this case yielded complex dielectric constants and further analysis showed that the generalized refractive index was a complex number of the form

$$\mathcal{N} = n - i\,k$$

where

n is the ordinary refractive index
i is the square root of minus one
k is the absorption coefficient.

Both n and k are constants for a particular crystal lattice direction. Isotropic crystal can have only one value, i.e. $n - i\,k$. Anisotropic crystals, in which the atomic structure of the lattice has different patterns in different directions can have either two or three principal refractive indices. Those for uniaxials are $\mathcal{N}_E$ and $\mathcal{N}_O$ those for biaxials are $\mathcal{N}_x$, $\mathcal{N}_y$ and $\mathcal{N}_z$. This theory is well described in any good text-book on crystal optics. If these anisotropic crystals are absorbing then the principal complex refractive indices are:

$$\text{UNIAXIAL} \quad \begin{matrix} \mathcal{N}_O - ik_O \\ \mathcal{N}_E - ik_E \end{matrix}$$

$$\text{BIAXIAL} \quad \begin{matrix} \mathcal{N}_x - ik_x \\ \mathcal{N}_y - ik_y \\ \mathcal{N}_z - ik_z \end{matrix}$$

Certain difficulties exist in defining the complex indices for the absorbing crystals of the orthorhombic, monoclinic and triclinic systems. It was first proved in 1880 by Laspeyres that the axes of least, intermediate and greatest absorption for these crystals do not necessarily coincide with the principal directions of the indicatrix. These crystals likewise do not possess true optic axes. These are replaced by four rotation axes, which are inclined in pairs to the optic axial plane and which become more widely inclined as the absorption increases. No simple explanation of their nature is available.

TRANSPARENT ISOTROPIC GEMSTONES

In this case we can assume there is no absorption and thus we are concerned only with reflection. The reflectivity is given by Fresnel's equation.

$$R = \frac{(n-1)^2}{(n+1)^2} \times 100\%$$

A little thought will show that the higher the refractive index of the gemstone the higher the reflectivity. No fractional phase change occurs on reflection.

If the refractive index is known then the reflectivity can be calculated from the above rule. In the same way, if one can measure the reflectivity then it is a simple matter to calculate the refractive index. Two methods are commonly used to measure R.

1. *Visual Comparison Methods using the Microphotometer*

Various types of apparatus are now available by means of which the reflectivity of a polished specimen can be compared with some standard reflecting surface. One method involves the use of a reflecting type petrological microscope (mineragraphic microscope) with the eyepiece replaced by a Berek microphotometer. This latter consists essentially of a horizontal tube near the eyepiece with a light source, the intensity of which can be varied by rotating a polaroid disc between two fixed parallel discs of polaroid. In the middle of field of view of the eyepiece is an inclined comparison surface, illuminated by the light source in the horizontal tube. The specimen is placed under the microscope, and the polaroid plate rotated in its graduated holder until the specimen and the comparison surface are equally illuminated. The same is done for the standard. Since the intensity of illumination of the comparison surface is proportional to the fourth power of the sine of the angle of rotation it is possible to measure the reflectivity of the unknown relative to the standard. For opaque ore minerals polished pyrite is the standard, with $R = 54{\cdot}5\%$. This is rather too high for transparents, and diamond, with $R = 17{\cdot}2\%$ may be used. In the case of cut stones all surfaces except the one under study should be painted black and the specimens placed in a small cavity lined with black velvet to eliminate back reflections.

2. *Photoelectric Measurements*

In this case a mineragraphic microscope is used, the ocular being replaced by some type of photocell. The technique is very similar to that employed in the previous section. Photocell readings are taken on the standard and on the specimen and the two are compared. The main source of errors lies in fluctuation in mains voltage and frequency, for the intensity of illumination of the specimen and standard must remain constant during the taking of readings. This has been overcome by the use of a stabilization circuit (Bowie, 1957).

Transparent Anisotropic Gemstones

The optics of these crystals are best described by means of the theory of indicating surfaces. The Fletcher indicatrix is a three dimensional geometric figure, which has a definite orientation

inside each crystal for each wavelength of light, and which shows the variation in the refractive indices of light waves in their directions of vibration. Any radius vector from the centre of the figure to its surface shows a vibration direction in the crystal whose length measures the refractive index of a wave vibrating parallel to it.

The Fletcher indicatrix has two basic shapes. In the case of tetragonal and hexagonal crystals it is either a prolate or oblate spheroid of rotation about the vertical crystal axis. This direction is termed an optic axis and it is a direction of isotropism. A little thought will show that light moving in this direction is vibrating at right angles, in a plane which cuts the indicatrix always in a circle. In the case of orthorhombic, monoclinic and triclinic crystals the indicatrix is a triaxial ellipsoid, with three planes of symmetry so that the three principal refractive indices of light in their directions of vibration are equal to its three mutually perpendicular semi-axes. A mathematical analysis of the equations of this figure reveals the fact that there are two, and only two, possible circular sections and thus two optic axes inclined at an angle to each other. A full description of this most interesting theory is to be found in any of the advanced texts on crystal optics.

But one point is essential to what follows and this is the definition of the principal directions of a crystal section. If a ray of light is propagated in a direction defined by its wave normal, then a plane section through the Indicatrix is, in general, an ellipse. The dimensions of this ellipse completely define the nature of the transmitted light. It moves in the form of two plane-polarized waves, vibrating parallel to the two principal axes of the ellipse (the principal directions of the section).

Now, for any polished gemstone surface each principal direction has its own refractive index, and, by Fresnel's equation for isotropics, its own Reflectivity; using visual or photoelectric methods it is easy to measure the maximum and minimum values of reflectivity of the surface. The numerical difference in these readings is the bireflection of the surface studied. The bireflection of the crystal is the maximum bireflection for all possible sections of the crystal.

Let N_1 and N_2 be the refractive indices for the principal directions of the section. Then their reflectivities R_1 and R_2 are defined by—

$$R_1 = \frac{(N_1 - 1)^2}{(N_1 + 1)^2} \times 100\%$$

$$R_2 = \frac{(N_2 - 1)^2}{(N_2 + 1)^2} \times 100\%$$

The reflectivity for a normally incident plane-polarized wave making an angle of x with a principal direction is defined by

$$R = R_1 \cos^2 x + R_2 \sin^2 x$$

In general, if plane-polarized light is incident at an angle (azimuth) of x with a principal direction, then it can be shown, by an analysis of Maxwell's equations, that the reflected light is still plane-polarized, but has been rotated in azimuth through a small angle.

If x is the incident azimuth ($x = 45°$) and y is the reflected azimuth then—

$$\tan (x - y) = \frac{N_1 N_2 - 1}{N_2 - N_1}$$

(Wright, p.420)

The rotation angle of the section is defined as the rotation in azimuth of the reflected beam when the incident beam is at 45° to the principal directions. It is possible to measure this rotation angle using the reflecting polarizing microscope. Accurate measurement of this angle requires a microscope with rotating analyser, and some type of bi-quartz accessory plate, such as a Nakamura plate which is sensitive to small rotations, and thus can be used to get the correct analyzer setting.

Absorbing Isotropic Gemstones

Those isotropic gemstones which are not perfectly transparent to white light are termed absorbing. The amount of absorption varies widely. If the absorption is strong over the whole spectrum the material may be called opaque. This latter term requires some definition. Many crystals, opaque in large pieces become transparent (and coloured) when cut down into thin slices for petrological study. Other, notably the ore, minerals are opaque even at this thinness. It has been found that the human eye can detect a light intensity as low as 10^{-6} of the bright field of a microscope. Any crystal which transmits less than this intensity is

termed opaque to the incident wavelength. It is possible for a crystal to be quite opaque to white light and yet be quite transparent to, say, infra-red. Stibnite, antimony sulphide, a steely gray metallic mineral, is extremely transparent to infra-red radiation.

Coloured gemstones owe their colour to selective absorption of various wavelengths of white light by the crystal structure. This absorption can readily be studied in a qualitative way using a direct-vision spectroscope.

The Reflectivity of an absorbing isotropic gemstone of complex refractive index $n - ik$ is

$$R = \frac{(n-1)^2 + k^2}{(n+1)^2 + k^2} \times 100\%$$

If we consider the case of the black garnet (perhaps a black variety of andradite) with index 1·94 – 0·058i, substituting 1·94 and 0·058 in the above formula R for black garnet is found to be 10·2%. (Note: the above values are constants for mercury yellow light, not sodium yellow.) Yellow sphalerite, a mineral sometimes used as a gemstone, has a complex refractive index of 2·38 – 0·01i for sodium light. For comparison gold, the precious metal, has a complex index 0·366 – 2·82i and silver 0·18 – 3·65i.

These metals have reflectivities (observed) of 73·4% and 93·8%. The high values of R are the result of the extreme values of k for these metals, the real part of the index in each case being quite small.

As to the nature of the reflected light, if the incident light is plane-polarized the reflected light is also plane polarized. No rotation effects occur. Various methods have been devised to measure n and k for these crystals. If the value of k is small (as it often is for gem crystals) the absorption can be measured using a thin piece of the material of known thickness. The decrease in intensity of the transmitted light when the thin sheet is placed under the microphotometer is measured and the absorption calculated by a formula given by Hallimond.

If k is not very small the above method cannot be used, for a plate of measurable thickness will be completely opaque. One excellent method exists by which n and k can be calculated (that of W. A. Wooster, 1949) but as it involves the use of oblique incident light it is outside the scope of this paper.

ABSORBING ANISOTROPIC GEMSTONES

In this section we include all non-cubic gemstones which are either coloured (pleochroic and non-pleochroic) or opaque. The optics of these crystals are best described by means of the complex indicatrix, a double shelled surface in space with similar properties to the Fletcher indicatrix. It is used to give the principal vibration directions, refractive indices and absorption co-efficients for any section of a crystal. But owing to the fact that in many of these crystals the directions of absorption (the absorption axes) do not necessarily coincide with the principal directions of the indicatrix, and because the vibrations inside the orthorhombic, monoclinic and triclinic crystals are in general elliptic, it is only possible to plot sections of the complex indicatrix for planes of crystal symmetry.

We will first concern ourselves with the non-pleochroic crystals. For uniaxial crystals, those belonging to the tetragonal and hexagonal systems, if the normal to the reflecting surface coincides with the optic axis of the crystal, then the surface can be considered to be isotropic. For other orientations the surfaces are anisotropic. Plane-polarized incident light with vibrations parallel to the two principal directions are reflected as plane polarized waves, but if the incident vibrations are at an angle to these directions then there will be a rotation effect (due to different absorption in the two components) together with a phase difference (between the components). Thus elliptically polarized light is reflected, the ellipse being in general long and narrow, and its long axis inclined to the azimuth of the incident light.

A fuller treatment is as follows. In general, the normally incident beam is resolved at the surface into a plane containing the optic axis and another plane at right angles. Let these directions have complex refractive indices $N_1 - ik_1$ and $N_2 - ik_2$ and reflectivities R_1 and R_2. Then

$$R_1 = \frac{(N_1 - 1)^2 + k_1^2}{(N_1 + 1)^2 + k_1^2} \times 100\%$$

$$R_2 = \frac{(N_2 - 1)^2 + k_2^2}{(N_2 + 1)^2 + k_2^2} \times 100$$

If the incident azimuth is x, then the intensity of reflection is—

$$R = R_1 \cos^2 x + R_2 \sin^2 x$$

The two reflected components have phase shifts

$$\tan d_1 = \frac{2\,k_1}{N_1{}^2 + k_1{}^2 - 1}$$

$$\tan d_2 = \frac{2\,k_2}{N_2{}^2 + k_2{}^2 - 1}$$

There is in general a phase difference $(d_1 - d_2)$ and the reflected light is elliptic.

Orthorhombic crystals have only three planes of crystal symmetry. If the normal to the reflecting surface and the plane of polarization of the incident light be in one of these planes then the reflected light is plane-polarized. In general, the above is not the case. When a plane-polarized wave enters the crystal, due to absorption, etc., it can be resolved into two principal elliptically polarized beams with semi-major axes at right angles, travelling with different velocities. In the same way, two plane polarized beams are reflected, differing in amplitude and phase, and thus these can be looked upon as one elliptically polarized reflected wave.

While, in general, two elliptical waves are transmitted there are four directions, termed rotation axes, along which only one circularly polarized ray is transmitted. These are closely related to the two optic axes of low-symmetry transparent crystals. Their position in space depends on the strength of the absorption and the

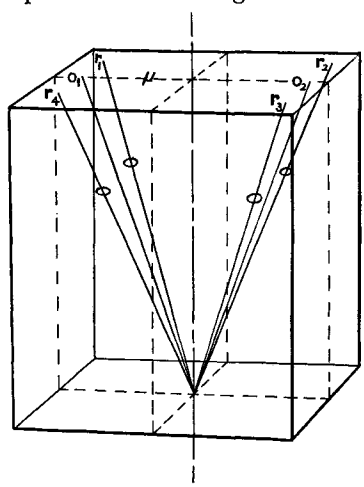

Fig. I

wavelength of light. Figure 1 shows the four axes r_1 r_2 r_3 r_4 in an orthorhombic crystal.

Monoclinic crystals have one plane of crystal symmetry, and triclinic have none. It is still possible to obtain plane polarized light by reflection at certain crystal orientations but in general both the transmitted and reflected light is elliptic. Directions which govern the production of plane polarized light are directions lying in a conical surface in the crystal termed the plane polarization cone (Woodrow, 1950).

Pleochroic crystals, those in which the absorption of wavelengths of white light is different in different directions are perhaps of more practical importance to the gemmologist than the opaques just studied. In the case of uniaxials, the strength of the pleochroism (dichroism) is termed the biabsorption, and this can be defined as $k_E - k_O$ where k_E and k_O are the absorption coefficients for the extraordinary and ordinary rays. For pleochroic "biaxials", the three main values of the absorption coefficients are k_x, k_y, and k_z and the difference between the maximum and minimum values is the biabsorption.

We will finally consider, in a general manner and without any of the experimental details, a method by which the optical properties of a pleochroic sheet or an opaque polished surface may be ascertained. If the material is transparent a petrological microscope may be used, but if it is opaque then the situation requires a mineragraphic microscope. We will deal with the latter case first as it is the most fundamental.

The polished opaque surface, normal to the axis of the microscope (with nicols accurately crossed), is rotated on the microscope stage to find the four extinction positions. It is then rotated 45° from extinction. To return the mineral (as near as possible) to extinction the analyzer is rotated through an angle known as the apparent rotation angle (Ar).

The accurate position of extinction is obtained with the use of a Nakamura plate, a thin bi-quartz accessory sensitive to small rotations, which is placed in the slot of the rotating Wright eyepiece. In Figure 2, if OP and OA_0 are the polarizer and analyzer directions, OE_1 and OE_2 are the resolved components of the incident light parallel to the vibration directions of the mineral. Owing to differential absorption these are reduced to OR_1 and OR_2, the components of the reflected light. Since there is a phase difference,

the reflected light is elliptic, the ellipse being inside the rectangle p^1 *NML*. OA_1 is the position of the analyzer at extinction.

If there was no phase difference between the reflected components then there would be no ellipticity and the apparent rotation angle would be the true rotation angle. As there is a phase difference of " *d* " between the components OR_1 and OR_2, " *d* " must be measured, and also the ellipticity of the ellipse, " *e* " the angle whose tangent is the semi-minor axis " *b* " divided by the semi-major " *a* ". This ellipticity is measured using an elliptic mica compensator.

It is thus possible to measure

1. The apparent rotation angle " *Ar* "
2. The phase difference " *d* " between the two reflected components
3. The ellipticity of the ellipse.

For transparent non-pleochroic crystals, on the stage of a petrological microscope, if the vibration directions are at 45 degrees to the analyzer-polarizer directions, then two rays are transmitted with a phase difference. This is the same as an elliptical vibration, the axis of the ellipse at 45° to the analyzer. If the crystal is pleochroic the transmitted light is still elliptic, but the ellipse is of a different shape and no longer at 45° to the analyzer. The angle of rotation of this ellipse is related to the intensities of the

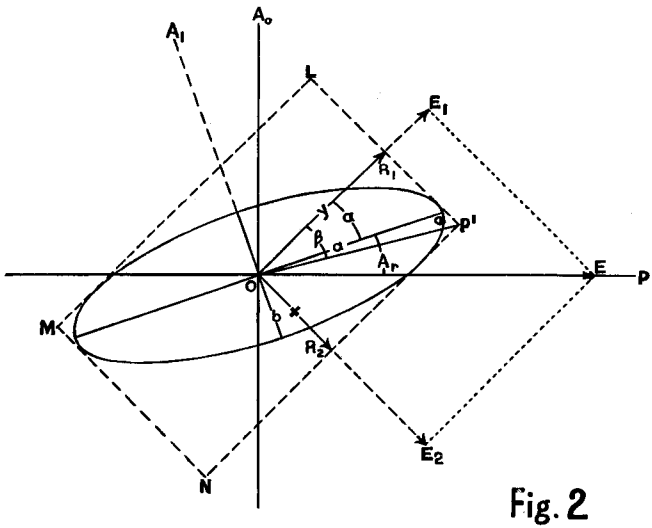

Fig. 2

two transmitted rays, and thus to the biabsorption. Using Figure 2 to indicate the measurements, it is necessary to measure the angle " alpha ", between one vibration direction and the long axis of the ellipse, and also the ellipticity.

A rotating Wright analyzer and elliptic mica compensator are used. The apparent rotation angle Ar and the phase difference for the ellipse can then be measured.

Now " alpha " is $45° - Ar$ and from the phase difference the ellipticity and thus the ratio of the two semi-axes of the ellipse may be measured. From these values the ratio of the intensities of the two transmitted rays can be calculated. If we consider uniaxials we can find the ratio of I_o to I_E and thus

$$I_o = I_E \cdot e^{(4\pi d/\lambda)(k_E - k_o)}$$

where $k_E - k_o$ is the biabsorption.

For the experimental details, mathematical formulae, etc., reference should be made to the original papers.

It might be well to mention another constant for opaque anisotropic surfaces. This is the " characteristic angle " of Berek. It is defined as the phase shift imparted by reflection at the specimen, between light vibrating parallel and perpendicular to the vibration directions of the polarizer. If the reflected ellipse is long and narrow (as it usually is) it is possible to measure " e ", the tangent of the azimuth referred to the polarizer direction and " d " the ratio of minor to major axes of the ellipse.
Then

$$\tan T = \frac{d}{e}$$

where d is the Phase Coefficient
e is the Polarization Coefficient
T is the Characteristic Angle.

T is found to be a constant for all sections of tetragonal and hexagonal crystals, and it varies between $-90°$ and $+90°$ for crystals of lower symmetry. Finally, T is found to vary with amount of polishing.

Conclusions

Though there are still some outstanding difficulties, theory has now reached a stage where it can be of use to the laboratory experimenter in gemmology. The necessary apparatus is costly, involving such items as research petrological and mineragraphic microscopes and accessories, visual and photo-electric photometers

and a spectrophotometer, but if the gemmological laboratory has this apparatus then quantitative studies of absorption and reflection by gemstones are now possible. Such measurements will not necessarily revolutionize determinative gemmology but will rather be in the way of an addition and a refinement to pre-existing methods.

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COUNCIL MEETING

Mr. F. E. Lawson Clarke (Treasurer) presided at a meeting of the Council of the Association held at Saint Dunstan's House, Carey Lane, London, E.C.2, on 5th April, 1962.

The following were elected:—

FELLOWSHIP

Keller, Jean Pierre, Lucerne, Switzerland
Nuttall, John, Manchester

ORDINARY MEMBERSHIP

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Hoad, Cecil V., Richmond, Surrey
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U. Thein, Rangoon, Burma
Lwin,
McCorquodale, Samuel, Selangor, Malaya
Major, Robert J., Wyton, Hunts.
Pearl, Mignon W., Colorado, U.S.A.
Sheriff, Hassan, London
Thain, Eric M., Shenfield, Essex
Webster, Rosslyn, London
Macpherson, Harry Gordon, Edinburgh

PROBATIONARY MEMBERSHIP

Pai, S. Sundaresa Eknakulam, S. India
Hathaway, Norman, Swansea, Glam.
Houghton, Michael J., London

The Council made nominations for submission to the next annual general meeting. It was reported that it had not been possible to complete arrangements for the 1962 Herbert Smith Memorial lecture.

MIDLANDS BRANCH

Mr. W. W. Bowen presided at the annual meeting of the Midlands branch of the Association held at the Imperial Hotel, Birmingham, on the 6th April, 1962. In commenting upon the work of the year the Chairman especially referred to the summer coach outing to Luton Hoo to see the Wernher Collection, the visit to the lapidary works of Shipton & Co. Ltd., where Mr. Bert Shipton had arranged for actual cutting and polishing to be in progress, and a lecture on the spectroscope and its uses in gem testing by Mr. B. W. Anderson, B.Sc. Director of the London Chamber of Commerce gem testing laboratory. Mr. Bowen mentioned that the final event of the season had been the annual dinner dance.

The following officers were elected: Chairman, Mr. W. W. Bowen; Deputy Chairman, Mr. A. E. Shipton; Vice-Chairman, Mr. J. R. Shaw; Committee: Messrs. K. Hoskyns, D. King, J. Rossiter and T. P. Solomon. Mrs. S. E. Hiscox was elected Secretary in the place of Mr. J. R. Shaw. Two short colour films were shown at the end of the meeting—" Jewels in the Sun " and " The Golden Reef ".

WEST OF SCOTLAND BRANCH

The West of Scotland Branch of the Association held their annual summer outing on Sunday, 24th June. The outing, to Dunure, Ayrshire, was arranged in conjunction with the Scottish Mineral and Lapidary Club, Edinburgh. For the autumn the following dates have been arranged:—

25th October: Film Show.

22nd November: General discussion and exhibition.

For 1963: On 24th January there will be a talk by Mr. W. C. Butler on the manufacture of synthetics; a talk and display of specimens by Mr. J. McWilliam on 28th February.

TALKS BY MEMBERS

BLYTHE, G.: " Gemstones ", Inner Wheel Clubs for Romford, Ilford, West Ham and Leigh-on-Sea at East Ham on 3rd April, 1962; " Gemstones ", Royal Institution of Chartered Surveyors, Essex Branch, 28th April, 1962.

BAGLEE, G.: " Diamonds ", Sunny Brow Women's Institute, Darlington, on 18th April, 1962; " Gemstones ", Bishop Auckland Business and Professional Women's Guild, 16th May, 1962.

DYCE, S. B.: " Gemstones " at Spalding on 17th April, 1962.

BETTS, G.: " Gemstones ", Beeston Townswomen's Guild, Leeds, 1st May, 1962.

KENT, D. G.: " Gemstones ", City of London Tradesmen's Guild, 16th May, 1962.

ROOTS, J. L.: " Gemstones ", Tanganyika Police Inspectors, Maidstone, 30th April, 1962.

CAIRNCROSS, A.: " Gemstones ", Crieff Trefoil Guild, 25th September; Crieff South Church Social Club, 4th October; Rhynd W.R.I., 18th October; Dunbarney Parent Teacher Association, 16th November; St. Leonards in the Fields Youth Fellowship, 10th December, 1961. "Gemstones", Scone New Church Youth Fellowship, 14th January; Forteviot W.R.I., 1st March; Letham Youth Club, 21st March; St. Paul's Evening Work Party of Women's Guild, 27th March; Letham Kirk Fellowship for Young Mothers, 1st February, 1962.

ANNUAL GENERAL MEETING OF THE GEMMOLOGICAL ASSOCIATION

Mr. F. H. Knowles Brown presided at the 32nd annual meeting of the Association held at Saint Dunstan's House on the 11th May, 1962. Commenting on the annual report, he spoke of the ties which existed between gemmologists throughout the world, who shared information, results and friendship. He paid a tribute to the efficient way extra work had been handled by the staff since the Association had become the sole world agency for all Rayner instruments. The agency was a fine thing for the Association he said, and one which would increase Rayner's already world-wide reputation among gemmologists.

The Chairman welcomed Mr. Dean Field, a Fellow of the Association and founder of the Canadian Gemmological Association. Mr. Field spoke of the friendship which existed between both Associations. His Association, he said, had been founded in 1958. The Association membership, now 52, was made up almost equally of members who had close ties with the British Gemmological Association and those who had ties with the American counterpart. It was hoped membership would be 100 by the end of the year.

The annual report and audited accounts for the year were adopted and the following officers were re-elected: President, Sir Lawrence Bragg; Chairman, Mr. Knowles-Brown; Vice-Chairman, Mr. N. Harper; Treasurer, Mr. F. E. Lawson Clarke. Messrs. E. J. Ewing, W. Stern and R. Webster were re-elected to the committee. Messrs. Watson Collin & Company, chartered accountants, continue as auditors to the Association.

LETTER TO EDITOR

DEAR SIR,

Having read Mr. A. E. Farn's very useful and practical article " Testing a Sapphire " (Journ. Vol. VIII No. 6), I have two comments to make.

Mr. Farn says he has never seen cutting cracks, or chatter marks (often called fire marks in Birmingham) on a natural ruby or sapphire of importance. About a year ago a fine, clean, light blue stone of (from memory) 8 to 10 carats was sent for testing to the writer, precisely for that reason, i.e. that it did have these marks. This fact, together with its almost entire freedom from internal evidence in the way of natural marks, threw suspision on the stone. The microscope, however, did reveal a small, but unmistakably natural feather, and, furthermore, the spectrum contained the well-known band at 4,500Å. True, these cutting cracks are very seldom seen in natural corundums, but their presence is not altogether unknown.

The second point I would raise is the question why short-wave (2537Å) ultra violet light is not more frequently used in testing doubtful sapphires. All synthetic sapphires I have so far tested in this way fluoresce, natural sapphires do not. It seems to me to be a test quite as valuable as the spectroscopic one—for " difficult " stones that is. Many, as Mr. Farn remarks, are quite easily identified by marks easily seen with the 10 × loupe.

It would be interesting to learn if any practical gemmologist has discovered any exceptions to this reaction (or absence of it) of sapphires to short-wave U/V. light.

Yours faithfully, F. S. H. TISDALL.

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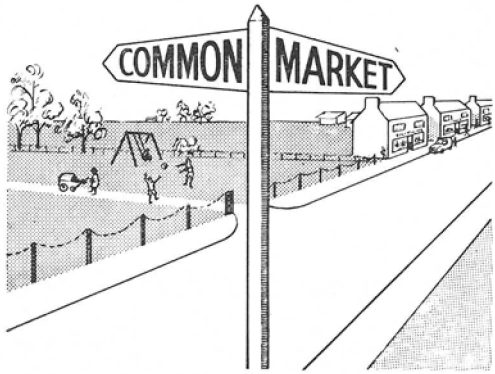

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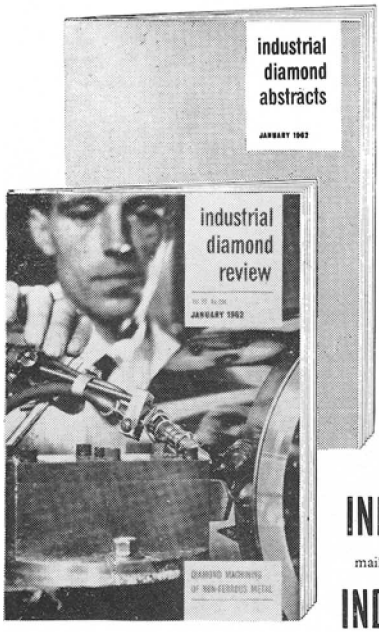

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UNUSUAL GEMS IN JEWELLERY

By P. HINKS

Amongst the fascinating miscellany of jewels sent for sale at Sotheby's during the past season was included a small antique bracelet set with a gay assortment of coloured stones. It was a pretty thing in black champlevé enamel daintily traced with gold feather scrolls. Rapid examination with the lens disclosed that two of the more luridly tinted stones were pastes. Less commonplace, however, was a pale blue stone, its interior wrinkled with cracks and fissures in a curious but not entirely unfamiliar fashion. As I turned it in the field of the loupe, the agreeable violet blue faded to a nondescript capey colour. The refractometer gave the expected reading of 1·54—it was, of course, iolite. I had encountered this stone commercially before, on the last occasion cut as a sphere and supporting the splendidly enamelled figurine of a Pope.

The other problematic stone was of yet more exotic identity. Its deep molasses brown shade seemed to indicate tourmaline, but a more critical examination revealed a reddish twinkle in the heart of the stone suggesting andalusite. The refractometer read 1·675-1·685, and the dichroscope showed two browns, one darker than the other and with a purplish suffusion. The stone was axinite.

It is pleasant to be reminded from time to time that rare stones do occur in the normal course of business, far from the rarified atmosphere of the geological museum, and finding two such species in one ornament must be answer enough to the cry that these things are a waste of the gemmology student's time.

A VARIATION OF THE BECKE LINE EFFECT

By R. K. MITCHELL

I SUPPOSE gemmologists the world over must have examined countless thousands of faceted gems immersed in highly refracting liquids. In most cases they will have peered earnestly through the instrument while racking up and down and watched facet edges change from blurred shadows to clear-cut lines as sharp focus is reached. I am puzzled to know why a certain significant fact of this procedure has only once appeared in print as far as I am able to ascertain, and then in German*. I am even more amazed that the significance of the phenomenon described below should have escaped my own notice until a short while ago. It is an observation of the simplest kind, yet other gemmologists I have mentioned it to seem to have been as unaware of it as I was.

Friedrich Becke, the eminent Austrian petrologist, contributed a great deal to the science of petrology and in the field of thin section rock microscopy his name will always be linked with the so-called " white-line " effect. Briefly, he observed that when two transparent minerals (or mineral and balsam) are side by side in a rock section, if the microscope objective is raised out of exact focus a line or edge of light will be seen to move towards the optically denser of the two media.

This Becke line effect is known to most gemmologists, but somehow it is not an easy test to apply to cut gems, probably because a girdle edge is far less sharp than the edges existing in thin rock sections. The observation described below must be regarded as a supplementary effect due to the same cause as the Becke phenomenon and closely connected in this respect with the Anderson immersion contact method of R.I. comparison.

Earlier this year I was examining two red stones by microscope. The stones, both of which looked like fine Burma rubies, were immersed in methylene iodide (R.I. 1·742) and were remarkably clean. The first one examined yielded no obvious inclusions but there were signs of the treacly colour distribution of the Burma ruby. To make this more obvious I lowered the substage condenser and closed its diaphragm to a very small aperture—a trick which often helps to throw into prominence such things as curved colour

*The phenomenon is described by Prof. K. Schlossmacher in his book "*Edelsteine und Perlen*", published in 1954, and among German-reading students it is known as the Schlossmacher effect.

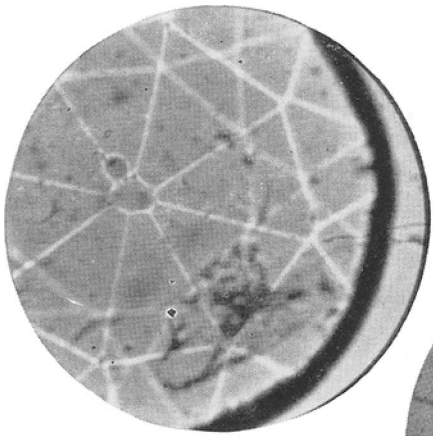

FIG. 1. *Ruby in methylene iodide. Focus is in the liquid.*

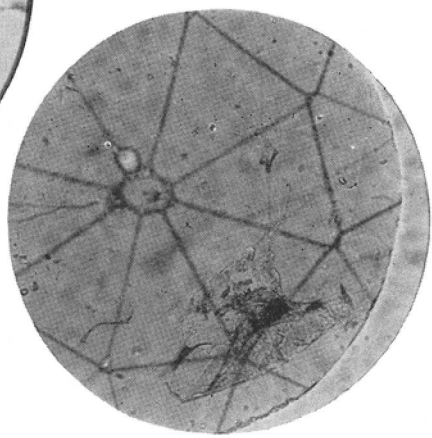

FIG. 2. *The same ruby when focus is lowered into the stone. Note how inclusion shows up under these lighting conditions.*

zoning in synthetics and so on. This brought the " treacle " into clear relief and proved the stone a genuine ruby without further test.

Another feature of this stone was the presence of " chatter " or " fire " marks, fine wavy cracks running roughly at right-angles to the facet edges. These were formerly considered to be signs of a synthetic corundum since they are thought to be due to the " pull " of rapid polishing with fine diamond powder. However, to-day many lapidaries use diamond on natural ruby and, unless care is exercised, the real stone may also show " chatter " marks.

Examining these cracks and racking the focus of the microscope up and down I noted quite subconsciously that the out-of-focus facet edges appeared as blurred white lines when the focus was above them, fig. 1, and then focused to black satisfying edges which remained black, blurring more and more as the focus travelled down into the stone, fig. 2. (The stone used for these two

pictures is a Siam ruby, not the Burma stone mentioned in the text.)

Turning to the second stone I racked down to focus and realized at once that something different was happening. The facet edges now appeared black before the focus reached them and became white as it travelled into the stone. A refractometer reading showed at once that this second stone was in fact a red spinel of unusually good colour. In other words its R.I. was *below* that of the liquid.

Further experiment showed that here indeed was a sensitive test which was much easier to apply to cut gems than was the normal version of the Becke-line test. The only rule to remember is that the out-of-focus facet edges appear *black* when the focus of the microscope is in material of *higher* R.I. Thus in ruby (R.I. 1·76-1·77) they were dark when I focused into the stone, while with spinel (R.I. 1·72) the edges were black when the focus was still in the liquid (R.I. 1·742). Just to clarify this—I am speaking of the point of actual focus, not of the nose of the objective.

The effect is much less noticeable when the substage condenser is high or when the iris diaphragm is wide open. Further work showed that the substage condenser could be removed and that best results were obtained when the diaphragm allowed only a thin pencil of rays to reach the stone.

An immediate parallel with Anderson's immersion contact technique occurred to me, and I was delighted to find that the well-known reversal effect is present in this " new " version. Thus when facet edges appear dark, the outline of the stone is bright, and vice versa.

As in the case of the Anderson method, and of the Becke test, the phenomenon appears to take no account of birefringence (which can be detected simply enough by other means). The effective R.I. in a birefringent stone seems to be the upper one, as might be expected. When a peridot (R.I. 1·65-1·69) was immersed in a liquid of R.I. 1·67 it reacted as having the higher optical density.

An indication of the sensitivity of the test was obtained by preparing a liquid with R.I. 1·565. This successfully separated synthetic emeralds from natural ones. The former showing light facet edges when the focus was in the stone and the latter showing dark edges in the same position.

There is some variation in the intensity of the effect, as conditions vary. It is generally more pronounced when the R.I.'s of liquid and stone are widely different. The sharpness of the angle between the facets also has some effect and of course the width and intensity of the blurred edges varies with the degree to which they are out of focus.

Stones are best examined table downwards and it is necessary to be sure that the facet edges examined are in fact those of the pavilion. If the crown facets are examined through the stone the whole effect is reversed—with confusing results.

The parallel with the Anderson effect, seen in immersion contact photographs, has been mentioned. The present method is obviously another version of the same phenomenon and is perhaps easier to observe. It is, however, reversible as shown in figs. 1 and 2.

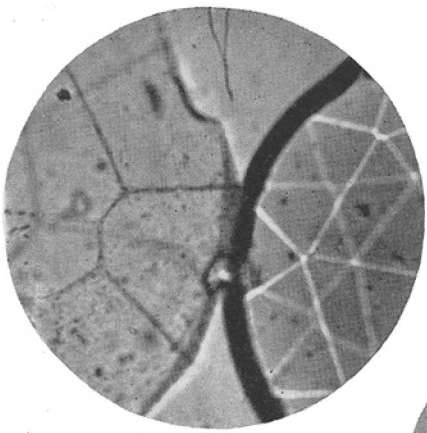

FIG. 3. *Spinel and ruby in methylene iodide. Focus is in the liquid above the stones.*

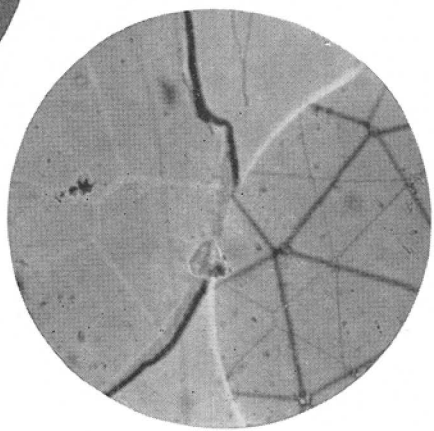

FIG. 4. *The same stones when focus is lowered.*

Figs. 3 and 4 show the effect as I first saw it. A spinel and ruby are side by side in methylene iodide. In fig. 3 the focus is in the liquid (1·742) and the ruby (right) has light facet edges and dark outline, while the spinel has dark facet edges and bright outline. In fig. 4 the focus is now inside the stones, with complete reversal of the effects. In both cases the *dark* facet edges are seen when the *focus* is in the medium with the higher refractive index. It is thus shown that the liquid R.I. is lower than that of ruby and higher than that of spinel.

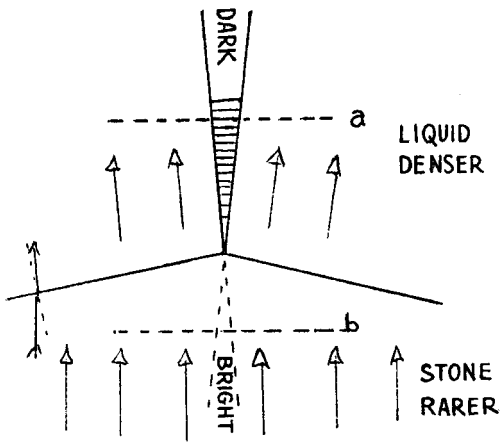

FIG. 5. *Parallel light refracts towards the normal to give two divergent beams.*

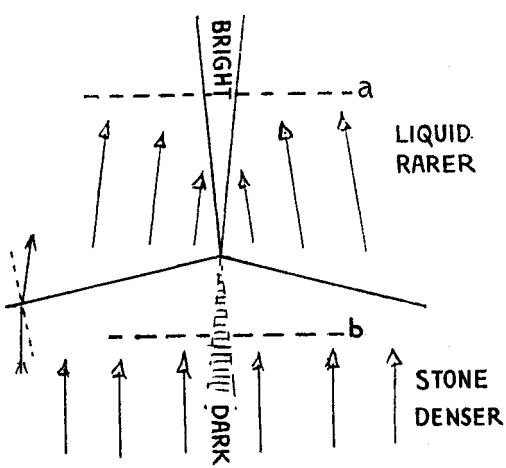

FIG. 6. *Light is refracted into two convergent beams giving rise to a virtual area of darkness within the stone.*

Figs. 5 and 6 explain diagrammatically the reasons for the phenomenon. Light passes up to the stone as a near parallel vertical beam and, refracting out of the stone via two mutually inclined facets, it becomes two beams which converge if the liquid is of lower R.I. than the stone, fig. 5, and diverge if the liquid has the higher R.I., fig. 6. Therefore light reaching the microscope is no longer parallel and focusing on level *a* will show overlapping beams (bright line) in fig. 5, and an area of darkness (dark lines) in fig. 6. Focusing on level *b* within the stones the light reaching the microscope is still in the air and follows either the convergent or the divergent path. Therefore a virtual dark area is seen in fig. 5 and a virtual overlap (light area) in fig. 6.

For me the importance of the test lies in the fact that in examining immersed gems an indication of the R.I. relative to the liquid used is immediately to hand. In large parcels of rubies or sapphires chance spinels or pastes stand out in marked contrast to the rest. Such stones as topaz or citrine can be separated quite easily, even in settings which will not permit the use of the refractometer, by simply observing the effect when they are immersed in bromoform (R.I. 1·59).

Used sensibly I feel that the test adds once again to the great versatility and usefulness of the microscope. But if it serves no more useful purpose than to introduce the reader to the idea of closing the substage diaphragm when he is examining a stone for inclusions (fig. 2 is a good example of its effectiveness) it will have justified its publication.

A NEW TURQUOISE SIMULANT

By R. WEBSTER

A NEW departure in the realm of turquoise imitations is the mineral howlite, which has been stained to a turquoise-blue colour. The pieces examined were baroques fashioned by the tumbling process, and they made a very good imitation of turquoise.

Howlite, sometimes known as silicoborocalcite, is a snow-white mineral which often has black or dark brown veins, but it is little known as a gem material outside the United States of America. The mineral consists of a mass of microscopic flattened crystals having monoclinic symmetry, the whole forming cauliflower-like nodules. The composition is that of a hydrated silico-borate of calcium. However, in the published literature, there seems to be some divergence of opinion as to the true chemical formula of this mineral. That given below is taken from the 6th edition of Dana which gives as the formula: $4CaO\ 5B_2O_3\ 2SiO_2\ 5H_2O$.

Named after Professor H. How, of Nova Scotia, howlite was first found near Windsor, at Brookville and at Winkworth (now known as Wentworth) in Hants County, Nova Scotia. The mineral is found embedded in gypsum and anhydrite, and a mixture of these minerals with howlite has been called winkworthite. The most important sources of howlite are in California where it is found in the borate beds of Calico, San Bernardino County, and near Frazer Mountain, north of Lockwood Valley in the north-east of Ventura County. The source of the gem material is, however, in Tick Canyon, an offshoot of Mint Canyon, in Los Angeles County. The nodules, which are found in a bed of grey clay and shale capped by sandstone, are usually some three to four inches in diameter but can be as large as eight to ten inches across. There is some carbonaceous matter present in the mother-rock, and it is suggested that the delicate black veining shown by much howlite may be caused by this.

The hardness of howlite is given in the literature as about $3\frac{1}{2}$ on Mohs's scale, and the specific gravity as between 2·53 and 2·59. John Sinkankas, in his work "Gemstones of North America", gives the refractive indices as α1·586, β1·598 and γ1·605 on material found at Windsor, Nova Scotia; and on material from Ryan,

California, he gives the following values—α1·583, β1·596 and γ1·605. Thus the birefringence, which is negative biaxial, is 0·019 and 0·022 respectively. In the case of the massive material only a vague shadow-edge about 1·59 would be seen on the refractometer. Sinkankas also states that howlite is easily soluble in dilute acids. The mineral fluoresces a brownish-yellow when irradiated with short-wave ultra-violet light (2537Å), and some Californian material glows with a deep orange light under the long-wave lamp (3650Å) and does not respond to short-wave irradiation.

Examination of specimens of the blue-stained howlite showed that the hardness was about 4½ on Mohs's scale, for this stained material was found to resist scratching by fluorspar but was scratched by apatite. As no specimens of unstained howlite were available for comparison tests, whether this greater hardness is due to the effect of colour staining, or the natural unstained material can be harder than reported, could not be proved.

Determinations of density were made on seven of the specimens, the following results being obtained:—

1.	12·15	carats	2·505
2.	11·96	,,	2·499
3.	13·20	,,	2·555
4.	8·10	,,	2·551
5.	15·71	,,	2·536
6.	20·00	,,	2·571
7.	13·78	,,	2·555

The refractive index, as far as could be measured by the vague shadow edge seen on the refractometer scale, was about 1·59.

The absorption spectrum, observed from light reflected from the surface of the specimens, showed these dyed howlites to exhibit a band in the red which appears to be a fairly sharp line which forms a cut-off to the red end of the spectrum. There is also a weak broad absorption band in the yellow-green centred at about 5650Å. No bands were observed in the blue part of the spectrum, as are seen in true turquoise. The absorption spectrum shown by the dyed howlites is probably due to the dyestuff used in the colouring. What this dyestuff is, is not surely known, but it certainly permeates throughout the material as was seen when a specimen was sawn in two pieces. The colouring, too, does not appear to be subject to fading, for no fading was found to occur to a

dyed specimen of howlite after exposure to a carbon arc for over a hundred hours.

A number of pieces of this blue-stained howlite were examined under the ultra-violet lamp, the long-wave lamp (3650Å) being found to give the best response. Most of the specimens showed glowing patches of brownish or orange-yellow light. These were mainly specimens where the colouring itself was patchy; uniformly coloured material was generally inert. From this it may be assumed that the colouring agent has an adverse effect on the production of luminescence.

Experiment has shown that a specimen of dyed material was easily and apparently (on a small sample) completely soluble in dilute hydrochloric acid. The resulting solution was a " gel ", the dyestuff also having dissolved without decomposition. Thus, a spot of acid placed on the specimen will give an indication, even if not a full test, for these turquoise simulants. However, the test should be made on an inconspicuous place for at best the test will remove the polish, although it does not remove the colour, or do worse damage.

The howlite used for processing into these "simulated turquoises " comes from Tick Canyon in Los Angeles County, California. The treatment is carried out by a firm at Ramona in the same State, and the material is marketed for what it is, no attempt being made to pass it off as true turquoise, of which it makes an excellent imitation.

The writer's thanks are due to Mr. Hugh Leiper, of Del Mar, California, who sent over the specimens from America, and to Mr. Harold Lee who carried out the fading experiments and some of the chemical tests.

Gemmological Abstracts

SCHULKE (A. A.). *Artificial coloration of diamonds.* Gems and Gemology, Vol. X, No. 8, pp. 227-239, Winter 1961/2.

Three main groups of radiation are used to colour diamonds. Those in which charged particles (protons, deuterons, alpha particles and electrons) penetrate the stone and remain there, form the first group. The second group consists of those in which uncharged particles (neutrons) penetrate the stone and may or may not remain. Lastly, pure energy, as in the case of X-rays and gamma rays, is used. Cyclotrons are used to produce the first group (with the exception of electrons), nuclear reactors second group; and electrons are produced by an apparatus called a Van de Graaff generator. Cyclotrons, using an energy of about 5 Mev (million electron volts), accelerate the particles to such a speed that they will enter the diamond, but only to a very small depth, a depth depending upon the energy of the particles. A graph shows this. The coloration is confined to the penetration area and is usually less than 20 mils. The colours produced are greens which, by subsequent heat treatment, change to yellow, gold or brown (even red-brown), the final colour being related to the original shade of green. The smaller electron particles from a Van de Graaff machine have an energy of 0·5 to 3 Mev. However, owing to the smaller size of the particles the range of penetration in diamond may be up to 1000 mils. Colours produced are blue to blue-green, depending on the initial energy of the particles. Canary-yellow stones can sometimes be obtained by subsequent heating, and rarely a pink colour is obtained by electron bombardment. A theory that high-energy electrons from lightning discharges may account for the colour of some natural coloured diamonds is propounded. With neutron bombardment the particles displace electrons indirectly by bouncing off carbon atoms energizing electrons, and these displaced electrons cause the coloration, as in the case of cyclotron accelerated particles. In this case the stone is coloured right through, but the green colour produced is said to

be duller than the green produced by cyclotron bombardment, and radiation damage may occur. The various side effects found are mentioned and the heat treatment described. A temperature of about 1600°F is needed. The times necessary to irradiate and the costs of irradiation are discussed. Newer cyclotrons now being built will accelerate the heavier atoms of lithium, beryllium, boron etc. Experiments at the General Electric Research Laboratory have shown that by this process small amounts of boron may be got into natural and synthetic diamonds which then become blue in colour and also become electro-conducting, thus changing them into the rare Type IIb diamonds. X-rays and gamma rays have not been found useful for diamond treatment.
2 illus., 2 graphs. R.W.

SINKANKAS (J.). *World's largest kunzite crystal.* Gems and Gemology, Vol. X, No. 9, pp. 274-277 and 287, Spring 1962.

A large kunzite crystal from Brazil weighed 7,410 grams. Mention is made of the fading of kunzite and the result of heat treatment to improve the colour. There are notes on the examination of quartz crystals to assess their use for piezoelectric purposes, and the heating of smoky quartz to find out whether it will turn to citrine colour for gem purposes.
4 illus. R.W.

CROWNINGSHIELD (R.). *The spectroscopic recognition of natural black pearls.* Gems and Gemology, Vol. X, No. 8, pp. 252-255, Winter 1961/2.

Reports the results of the examination of the absorption spectrum of the shells of pearl-bearing oysters. The conchiolin from the shell of *Pinctada martensii* absorbed light from approximately 5150Å to the end of the violet, and the red above approximately 6700Å. The author found that the absorption spectrum of one type of red-brown conchiolin from a black pearl bearer showed an absorption spectrum similar in essentials to that shown by *Pinctada martensii*, except that in the transmission region of between 6700Å and 5150Å there appeared some four dark bands centered at 6300Å (moderate), 5775Å (strong), 5500Å (strong) and 5350Å (weak). Further experiments were carried out on grey and black coloured pearls and on the conchiolin from many shells. The

article gives a general survey of the identification of stained pearls, of which spectroscopic examination is a part.
6 illus. R.W.

CROWNINGSHIELD (R.). *Developments and Highlights at the Gem Trade Lab. in New York.* Gems and Gemology, Vol. X, Nos. 8 and 9, pp. 242-246; 281-283, Winter 1961/2; Spring 1962.

A number of radium-treated diamonds were examined. Some Burma jade was found to be serpentine which showed, by its absorption spectrum, signs of chromium coloration. A type of jade known as Yunnan jade was examined as well as a Brazilian emerald and a bluish-green chrysoberyl resembling a pale bluish-green aquamarine. " Purpurine " glass is discussed. Reports another diamond found at the Murfreesboro mine. A sapphire with a colour change from green to light violet-red and a foil-backed diamond are mentioned. An imitation star-moonstone was found to be a milky synthetic spinel with a very thin mirror at the back. A rare blue jadeite and an unusual pyrope garnet with a refractive index of 1·731 were other unusual materials. A diamond with an unusual absorption spectrum was encountered.
18 illus. R.W.

CROWNINGSHIELD (R.). *Freshwater cultured pearls.* Gems and Gemology, Vol. X, No. 9, pp. 259-273, Spring 1962.

Cultured pearls without a bead nucleus are produced in the freshwater mussel *Hyriopsis schlegeli.* Cultivation is carried out in Biwa lake in Japan. The mussels are not propagated artificially as yet, native mussels being used. The mussels are procured during October to April and the methods of gathering them are explained. The insertion of a piece of mantle tissue, which forms the pearl sac, is made in the mantle of the animal and not into the body as in bead nucleation. Some ten incisions are made in each half of the mantle, so that a maximum of twenty pearls may be formed at one time. After the insertion operation the mussels are kept in cages suspended in the lake for a period of three years. The life span of these freshwater mussels is some thirteen years, and, if there is no disturbance of the body tissues of the animal, a second " crop " of pearls, and in some cases a third " crop ", will grow from the same mussel. A description of these pearls and their colours is given. There was experimental bead nucleation of such

mussels, and X-ray pictures of such pearls reveal that drilled beads have been used for the nucleus. It seems that such drilled beads are necessary when using a special device for locating the nucleus in a nonvulnerable spot in the animal's body. The complicated twisted intestines make it difficult to place the nucleus without injury. The methods of distinguishing such non-nucleated cultured pearls by X-rays and fluorescence are mentioned. There is a discussion of the terminology to be used for these pearls. There is production of non-nucleated pearls in salt water oysters in Australian and Burmese waters.

15 illus. R.W.

LIDDICOAT (R. T.). *Developments and Highlights at the Gem Trade Lab. in Los Angeles.* Gems and Gemology, Vol. X, Nos. 8 and 9, pp. 274-251; 278-280, Winter 1961/2; Spring 1962.

The fading of dyed jadeite and a " faded " unstained jadeite are mentioned. An insurance claim on a damaged diamond and a diamond which was suggested to have been damaged by ultrasonic cleaning are discussed. Synthetic (alexandrite type) sapphires and the Princess cut are referred to. Data on Australian emerald (per E. Gübelin) are given. "Antique " ear-rings set with synthetic emeralds and a grey opaque sintered synthetic corundum set in cuff links have been encountered. An enstatite-hypersthene, an unusual three-phase inclusion in an emerald, dyed rosé cultured pearls, and abalone pearl, and a black star-sapphire are other items discussed.

2 illus. R.W.

MAYERS (D. E.). *The Curlew amethyst deposit.* Gemmologist, Vol. XXXI, No. 369, p. 62, April 1962.

Reports the occurrence of amethyst in Northern Rhodesia in a mine known as the Curlew Amethyst Deposit. Amethyst was first found in this locality by Alice Sumner Tait and others. The amethyst occurs in the top soil as the result of weathering of amethyst veins in the underlying rock. Production, owing to the inaccessibility of the region and lack of water, is difficult. The tips of the crystals alone are well coloured and are as a rule insufficient to cut into faceted stones, but the material allows the cutting of cabochons.

R.W.

RAMAN (C. V.). *Two kinds of diamonds.* Gemmologist, Vol. XXXI, No. 368, pp. 39-44 and 58, March 1962.

Summarizes the research results carried out at the Raman Research Institute at Bangalore, India. The studies comprised infra-red spectrometry, examination between polaroid plates, ultra-violet fluorescence and transmission. Two fundamentally different types of diamond are postulated one of which can be considered as the perfect diamond. Most diamonds contain both types of crystal architecture. Diamonds fall into three groups. Of the stones tested about 10% are in group A and are considered to be perfect diamonds. 10% are in group B, stones which have very different characters to group A. The remaining 80% of the stones tested were shown to be composite diamonds in which the structural characters of both A and B are present side by side. Group A are truly isotropic and are opaque to near ultra-violet light, and they show a blue luminescence. They have eight different frequencies of free vibration in the infra-red. These are at 1332, 1273, 1219, 1176, 1087, 1010, 746 and 624 Cm^{-1}, and they show first, second and third order spectra. The B group show anomalous birefringence, are transparent to ultra-violet light but do not exhibit luminescence. In this group the first order infra-red spectrum is absent. The composite nature of Group C was deduced from their behaviour under the four forms of testing. Experimental procedures are explained.
5 illus. R.W.

ALTMANN (J. D.). *The opal market.* Australian Gemmologist, No. 11, pp. 13-14, March 1962.

Australia produces nearly all the opal used in the world and the value produced now exceeds £A1,000,000 per annum. Some 80 to 85 per cent of Australian opal comes from the South Australian opal fields at Andamooka (mainly green, orange and blue colours) and from Coober Pedy (red, white and orange colours). Lightning Ridge in New South Wales still produces a limited amount of black opal, and some boulder and matrix opal comes from Queensland. Andamooka opal is much in demand by Japanese buyers, for the green colour is prized by these Oriental people. Some information on mining and mining conditions are given.

R.W.

TUFFLEY (J. R.). *An X-ray examination of synthetic spinel.* Australian Gemmologist, No. 11, pp. 15-16, March 1962.

The nature of spinel and the differences between natural and synthetic spinel are given. The ways in which the excess alumina in synthetic spinel might be accommodated in the lattice are suggested. Confirmation of the possibilities are then deduced from X-ray powder photographs. The results obtained seemed to indicate that the excess alumina, in gamma (cubic) form, may not all be in solid solution and that some remains to form a mixture of compounds. The possible results of subsequent heat treatment is discussed. The author refers to sintered synthetic spinel and states that is is made in a different manner to the normal Verneuil furnace production. The method is said to be as follows. The pure oxides of magnesium and aluminium, plus a small amount of colouring agent, are mixed together, first dry and then wet. The mixture is then formed into briquettes. After the briquettes have been thoroughly dried, they are subjected to a temperature in excess of 1600°C. This is the minimum temperature required for the formation of spinel from MgO and Al_2O_3.

R.W.

TISDALL (F. S. H.). *Tests on Madagascar garnet.* Gemmologist, Vol. XXXI, No. 371, pp. 102-103, June 1962.

A report on the examination of garnets from Madagascar. The colour of the stones was a pleasing shade of purplish-red; the density was found to be 3·84, with an index of refraction of 1·762. These values are borderline figures for pyrope and almandine and are practically the same as for the rhodolite garnet from North Carolina. The absorption spectrum showed the usual almandine bands. Strong anomalous double refraction was observed. A test for magnetism using a long thread suspension and a small magnet showed the stones to oscillate when the magnet was brought near. It was noticed that red spinel does not respond to the magnet and this may provide a test for distinction between red spinel and pyrope garnet. The inclusions seen were crossed rutile needles, transparent crystals, and one stone showed a " radiation halo ".

R.W.

JOHNSON (P. W.). *Organic gem materials of Baja California, Mexico.* Gemmologist, Vol. XXXI, Nos. 370 and 371, pp. 79-83 and 89; 104-110, May and June 1962.

The terrain of Baja California (Lower California) which stretches like a finger southwards from the State of California, is described as being something of a wilderness. Tortoiseshell from the Pacific marine hawksbill turtle (*Eretmochelys imbricata squamata*) has been used for ornamentation for many years. It was exploited by the Spanish in the 18th century. The smallest of the marine turtles, the animal ranges from Baja California to Peru. There are notes on the preparation of tortoiseshell and how it may be distinguished from horn and plastic imitations. The word *carey* is locally used both for the turtle and for its shell; from this the tortoiseshell worker is called a *careyero.* Amber is found in Baja California, but it is too friable to be of use in the arts. Both the shell of and the pearls found in the univalve animals called abalones (earshells) are used for ornamentation. There are several varieties of these abalones, and the highly coloured shells are used for inlay. Circular plates cut from the shells are often wrongly sold as " abalone pearls ". The second part of the article deals with the fisheries and fishing for the many different types of pearl-producing molluscs in the Gulf of California. The diving is usually carried out by nude Yaqui divers. Punta San Francisquito is a renowned pearl locality and this place is well described. The types of mollusc fished and some idea of the value of the pearls found are given. Baja California is noted for the black pearls it produces. These are called " La Paz " or " Panama " pearls. Some data are given on the density of the pearls and shell from this part and of their behaviour under ultra-violet light.

8 illus. R.W.

ANON. *Sorting diamonds by light.*

The well-known methods of diamond recovery are by concentration and grease table and by electrostatic separation. The new light separation method depends on the fact that diamond reflects light not only from its surface but also from its interior and these scattered reflections can be seen from every angle. Other heavy particles from the concentrate being completely opaque only reflect light from their surfaces. A description of the apparatus used is given.

1 illus. R.W.

MATHEWS (C. R.). *The gem market today.* Gemmologist, Vol. XXXI, No. 372, pp. 119-121, July 1962.

A general survey of the present day supply of gemstones from the main localities. Few new sources of gems are found to take the place of the old mining areas of Burma, Ceylon, Thailand (Siam) and Colombia. Kashmir sapphires have not been seen in the raw state for many years. Siam supplies small sapphires and rubies up to a carat in size, while Australia produces sapphires of a similar size but of a dark inky blue colour. Burma is still the best source of rubies and from that country also come sapphires in all sizes and from a bright light blue to a rich blue in colour. Ceylon supplies sizeable sapphires, star-sapphires and pink rubies from the Ratnapura area. Here the native cutters make the stone as heavy as possible and these stones need recutting. Africa is now supplying rubies, sapphires, amethysts and emeralds. Rhodesian emeralds are small but are of good colour, whereas the emerald from the Transvaal is always cloudy or opaque and not of high value. A new source of emerald has been found in Pakistan. Colombia is still the source of the best emeralds. It is envisaged that the demand for fine gems will outstrip production for a long time yet.
3 illus. R.W.

SHREVE (R. N.). *How jade is cut today.* Gemmologist, Vol. XXXI, No. 369, pp 63-70, April 1962.

A comprehensive article on jade cutting in Hong Kong. It is a republication of the article published in Gems and Gemology. (Journ. Gemmology abstracts. Vol. VIII, No. 3, p. 108, July 1961).
11 illus. R.W.

TISDALL (F. S. H.). *Spessartites from Madagascar.* Gemmologist, Vol. XXXI, No. 372, pp. 124-125, July 1962.

The stones examined were a rich orange-red in colour, some dark and some light in tint. The density was found to be 4·17. The absorption spectrum of the stones showed the manganese bands at 4840Å and 4610Å quite strongly, and these were in conjunction with the almandine bands. The stones were found to be inert under ultra-violet light. They showed some magnetism, for when suspended on a long thread they oscillated when a magnet was brought near, and if it was brought close enough

they were found to adhere to the magnet. Most of the stones were " clean " and few inclusions could be seen. Some fine striations were seen in the case of one specimen.

R.W.

MURPHY (M. O.). *The Kelly blue-green gem.* Lapidary Journal, Vol. XVI, No. 2, pp. 224-226, May 1962.

Blue-green smithsonite was obtained from the Kelly mine, New Mexico, and the mineral was named after James L. M. Smithson and is a zinc carbonate. The hardness is 4 to 4½ on Mohs's scale, the density 4·3 to 4·5, and the principal indices of refraction are 1·62 and 1·85. The mineral is found in vugs and has a botryoidal or stalagmitic habit. The blue-green material (Herrerite) is coloured by various copper salts. There are other varieties of smithsonite, such as dry bone ore which is friable and not useable in the arts. Monheimite, a variety containing iron, is pinkish to dull brown. Turkey-fat ore has a yellow colour and this is due to included greenockite, a cadmium mineral; such material has occasionally been cut into small cabochons and faceted stones. Pink smithsonite is coloured by cobalt (cobaltismithsonite), and manganese gives a deep purple to nearly black colour to the mineral. Smithsonite sometimes forms stalactites which, when polished, are spectacularly ringed with alternate bands of yellow and blue-green. It is not uncommon to find smithsonite as pseudomorphs after molluscs and crinoids. Much information is given on the cutting and polishing of the mineral. During 1907 and 1908 the firm of Goodfriend Brothers of New York marketed the blue-green mineral, and they coined the name " Bonamite ", after the French *bon ami* (good friend), for the material. The Kelly mine is now unsafe and entry is barred.

3 illus. R.W.

SINKANKAS (J.). *San Diego's gem-studded tiara.* Lapidary Journal, Vol. XVI, No. 3, pp. 300-314 and 323-324, June 1962.

A comprehensive survey of the gem mines of San Diego County, California. The mining districts are considered in groups and the mines in each group are discussed separately. There is an important list of references.

21 illus. R.W.

WHITE (E. A. D.). *The synthesis and uses of artificial gemstones.* Endeavour, Vol. XXI, No. 82, pp. 73-84, April 1962.

The history of the attempts to make gemstones is a long one. No great success was achieved until 1904. The article tells of the methods used since that time. The syntheses involving ultra-high pressure were first carried out at low temperatures for the equipment used would not withstand the extreme heat as well as the high pressure. This difficulty was overcome by using internal heating and pyrophyllite gaskets. It was by different types of such apparatus that diamond was first synthesized. Two types of such apparatus are discussed—the " belt " type and the tetrahedral ram type. Comments are made on an undisclosed Dutch method of diamond synthesis. The flame fusion method of Verneuil for the production of single crystals, and modern variants of the method, including rapid rotation of a seed crystal, by the use of an arc-image furnace and by plasma-jet furnaces are mentioned. Hydrothermal syntheses using autoclaves and a temperature-gradient method, fluxed-melt growth and other growth techniques are told. The problems of crystal growing are discussed and there are sections on the synthesis of diamond, corundum, spinel, rutile, strontium titanate, quartz, emerald, garnet, blende and some gems of minor importance. The scientific and industrial uses of synthetic gem crystals are considerable.

4 line drawings, 12 coloured illus. R.W.

POUGH (F. H.). *The Brazilian gem market.* Lapidary Journal, Vol. XVI, No. 2, pp. 242-247, May 1962.

The first of a series of articles on the gem markets of Brazil. The author is not optimistic about the economic future of the country, for there are no great resources of mineral fuels and metals and the prospects for agriculture and grazing are not good. The geology of Brazil is favourable for the formation of gem crystals such as beryl, tourmaline and topaz. Owing to the nature of the rocks the recovery of the gem crystals is difficult, and this is further hampered by the local system of taxation. Dealing in gem crystals is always carried out by an agent and not by the miner. Currency problems present other difficulties to the overseas gem buyer. There is much information on the hazards of the country. The article is embellished with excellent coloured plates.

4 coloured plates. R.W.

POUGH (F. H.). *Stones of the Brazilian market.* Lapidary Journal, Vol. XVI, No. 3, pp. 316-323, June 1962.

Through the years Brazil has produced little in the way of new gemstones, except perhaps brazilianite. The types of tourmaline and where they are found are given. Recently a large find of spodumene (kunzite) was made. The colour of the crystals are greyish-green to pale blue-violet and the author suggests that the dark colour may be due to irradiation whilst in the earth. Some kunzite is heated in order to get a pink colour. The amblygonite from Brazil is discussed.
3 illus. Coloured plate. R.W.

WEBSTER (R.). *Salesmen need facts.* Watchmaker, Jeweller & Silversmith, pp. 66-69 and 98 (*Turquoise*); pp. 80-85 (*Jade*); 64-67 and 95 (*Lapis and ornamental stones*), May, June and July 1962.

General articles on the various gemstones written as a guide to the jeweller and his salesman. The simulants in each case are described.
18 illus. P.B.

OSTWALD (J.). *An introduction to the optics of gemstones.* Australian Gemmologist, Nos. 11 and 12, pp. 18-22, 5 to 9, March and June 1962.

Part 2 of this series (Journ. Gemmology Vol. VIII, No. 7, p. 256) gives an outline of the wave theory of light. The relation between wavelength, frequency and velocity is explained. The optics of crystals are comprehensively explained in Part 3.
10 illus. R.W.

ANON. *G.J's. quick course in gemmology.* Goldsmiths' Journal, pp. 158-161 (April 1962); 252-255 (June 1962); pp. 302-303 (July 1962); 350-352 (August 1962).

This series continues with the descriptions of density tests; composite stones; the geology of gem materials; crystal imperfections including chatoyancy and asterism; improving the colour of gems; the colours caused by interference; and anomalous double refraction.
23 illus. R.W.

OBSERVATIONS ON GARNET

By L. C. TRUMPER, B.Sc., N.D.A., F.G.A.

MR. B. W. ANDERSON, writing in the JOURNAL OF GEMMOLOGY[1], pointed out that garnets do not in fact intermix with one another but comprise two distinct groups, intermixing only taking place to any extent between members of the same group. The first group comprises pyrope, almandine and spessartite and the second group comprising grossular, uvarovite and andradite. The article is exceedingly interesting and when my copy of the Journal came back from the binders a few months ago, I read this article again and resolved to devote my spare time during the winter months to putting the facts therein set out to the test as detailed below.

In building up my collection of garnets over the years my first aim was to obtain representative specimens both of rough and cut of each variety, secondly to expand each variety into representative specimens exhibiting all typical colour variations. Whilst four or five spessartites, demantoids and hessonites met these requirements, in the case of pyrope and almandine, colour variations ran into twenty or thirty, from pale pink to deep red, orange to violet, rose red to purple and Imperial purple. Only true yellow and blue seem to be missing.

Some years later, a third selection was made from over two thousand garnets sent to me for the purpose. Examination with a binocular microscope led to some extremely interesting specimens ranging from completely clean stones of several different colours, to stones with large well formed crystals, long fine needles, short rods, specks only, few needles and small well shaped prismatic crystals, myriads of fine long needles characteristically intersecting at 110°, rounded crystals, dendritic inclusions not orientated, feathers or finger print inclusions in several planes, shred-like inclusions and so on.

Inevitably, my first step was to examine my already extensive records and check up that I had all the refractive index readings and that all the specific gravity determinations had been made using toluol and further that in the case of small stones, the smallest possible suspension had been used. This meant many fresh determinations followed by re-checks of the spectrum examinations

all of which kept me very busy and very interested through most of the winter months.

My next step, which I commend to fellow gemmologists because it is so simple to do, was to set up the co-ordinates for a large scale graph on thick white paper on a drawing board, scaling off refractive index on the vertical co-ordinate from 1·7 to 1·90 in steps of ·01 and of specific gravity on the horizontal co-ordinate from 3·38 to 4·4 in steps of ·025.

Then the positions of the constants were marked for the " calculated " constants of the species, namely:—

Garnet	*Composition*	*Density*	*Ref. Index*
Uvarovite	$Ca_3Cr_2Si_3O_{12}$	3·78	1·86
Grossular	$Ca_3Al_2Si_3O_{12}$	3·53	1·735
Andradite	$Ca_3Fe_2Si_3O_{12}$	3·83	1·895
Pyrope	$Mg_3Al_2Si_3O_{12}$	3·51	1·705
Almandine	$Fe_3Al_2Si_3O_{12}$	4·32	1·83
Spessartite	$Mn_3Al_2Si_3O_{12}$	4·18	1·80

As explained in B. W. Anderson's article, it will be readily seen that the first three can be joined to form a straight line and similarly that the last three can also be joined to form a quite differently placed straight line.

I next inserted on the graph the figures for actual stones quoted by Anderson, including an additional one which he kindly provided me with for an actual garnet as near as possible to a colourless garnet. To these I then added the positions of the fifty eight stones listed in the accompanying table. Had the two distinct groups of garnets been capable of mixing to any extent, this would have been shown presumably by the position on the chart being midway or some appreciable way towards the second line. As will be seen, some stones are on this side of the line, but no more than are of similar distances to the other side. There is therefore no evidence of intermixing on these grounds at all. As to the divergences on one side of the standard line or the other, this may be due to impurities, or indeed to experimental error for of course the scale is very large indeed on the original chart some nine times the size of the reproduction. It may possibly be significant that hessonites do group themselves between the two graphs. This may be due to a greater readiness to intermix when the constants are closer together.

As was to be expected, the several species in general segregate themselves into moderately distinct groups as indicated on the chart, which was carefully examined to see if any other characteristics stood out.

Colour did not seem to have any bearing. The colour of some hessonites is almost identical to that of spessartite. The green of demantoid can rarely be almost matched by some grossular. Blood red occurs in both almandine and pyrope as does purple and pink and orange red.

Spectroscopic examination merely confirmed what was already known. Traces of the Almandine spectrum were detectable almost throughout the Almandine/Pyrope Graph range.

Deep purple almandines did appear to have the 5750 and 6200Å bands more strongly pronounced. Superb purple garnets ranged in specific gravity from 3·91 to 4·12.

Finally, could the groups be differentiated by their inclusions? Much work has already been done on this most interesting subject by Dr. E. Gübelin, Mr. B. W. Anderson and many others and numerous examples have already been published and it is generally agreed that the following characteristics are to be found in the different garnets.

GROSSULAR—Usually green, pinkish or white and translucent with black specks.

HESSONITE—Very characteristic rounded crystal inclusions on an oily background of swirls.

DEMANTOID—Emerald green to yellowish green, transparent sometimes clean but usually containing one or more radiating tufts of asbestos fibres.

ALMANDINE—Frequently fine needle-like inclusions orientated so as to appear at an angle of 110° (similar needles in corundum are orientated at 60°).

SPESSARTITE—Characteristic inclusions of a shred-like nature of irregular outline, sometimes scattered about or twisted around.

PYROPE—(*a*) Bohemian—characteristic deep fiery or crimson red colour and frequently containing well formed crystals of quartz in groups.

(*b*) Pale pink—often clean, sometimes with irregular small crystals, rarely a few fine needles.

(*c*) South African—more orange red colour, fine or coarse orientated needle like inclusions.

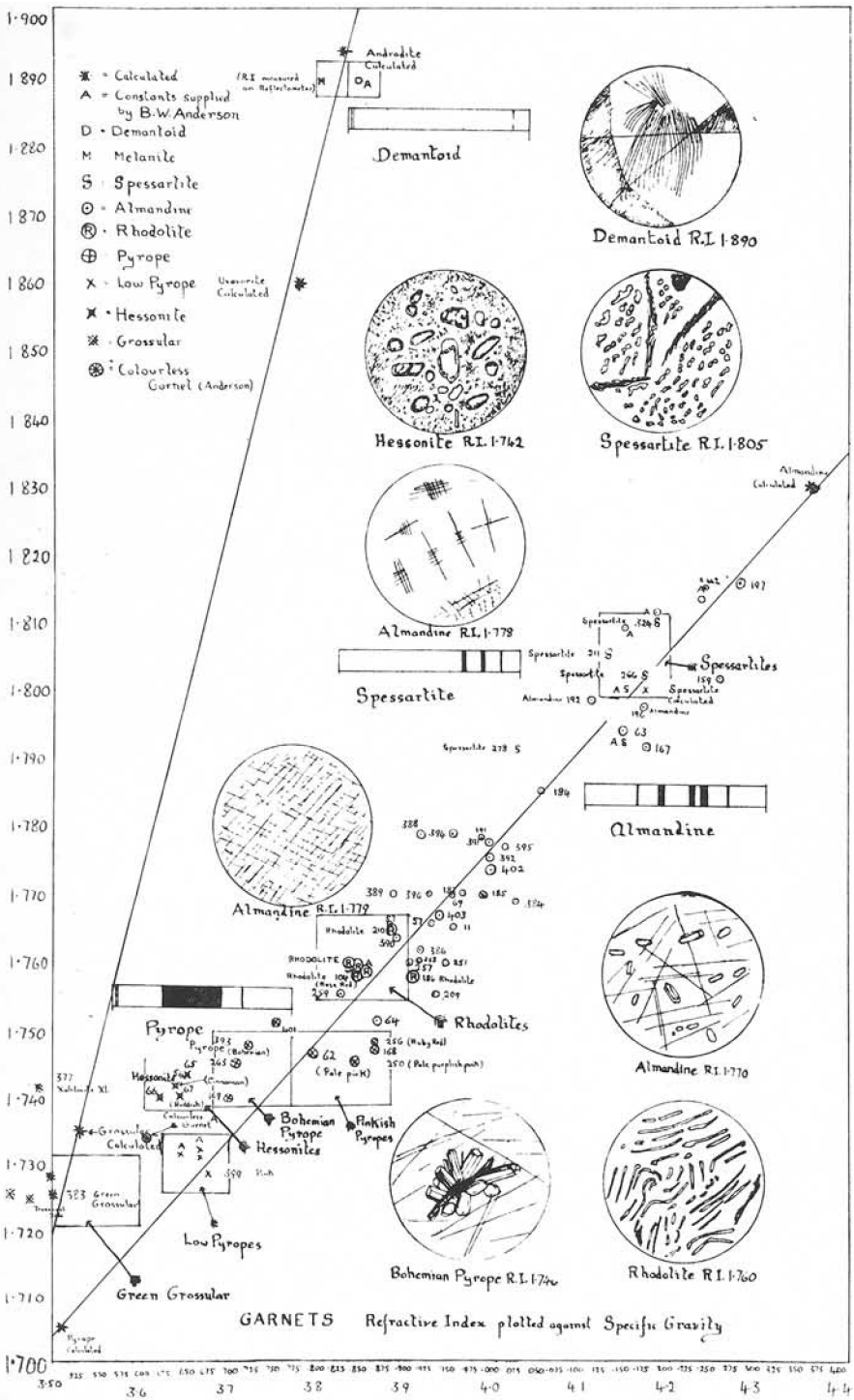
GARNETS Refractive Index plotted against Specific Gravity
✱ = Calculated
A = Constants supplied by B.W. Anderson
D = Demantoid
M Melanite
S Spessartite
⊙ = Almandine
Ⓡ = Rhodolite
⊕ Pyrope
X = Low Pyrope
✱ = Hessonite
✱ Grossular
Colourless Garnet (Anderson)
Andradite Calculated
Demantoid
Demantoid R.I. 1·890
Hessonite R.I. 1·742
Spessartite R.I. 1·805
Almandine R.I. 1·778
Spessartite
Almandine
Almandine R.I. 1·779
Almandine R.I. 1·770
Rhodolites
Pyrope
Bohemian Pyrope
Pinkish Pyropes
Hessonites
Low Pyropes
Green Grossular
Bohemian Pyrope R.I. 1·74n
Rhodolite R.I. 1·760
Grossular Calculated
Pyrope Calculated
Almandine Calculated
Spessartites
Spessartite Calculated
Uvarovite Calculated
1·900
1·890
1·880
1·870
1·860
1·850
1·840
1·830
1·820
1·810
1·800
1·790
1·780
1·770
1·760
1·750
1·740
1·730
1·720
1·710
1·700
3·50
3·6
3·7
3·8
3·9
4·0
4·1
4·2
4·3
4·4

RHODOLITE—This is not strictly a separate garnet species, consisting as it does of two thirds pyrope and one third almandine, and I cannot recollect seeing any published details of inclusions. I was therefore interested to observe in the garnets to hand that as the rhodolite position was reached on the graph from either direction, the typical garnet inclusions became less pronounced with instead small irregular colourless crystal inclusions, and two garnets that were " spot on " for rhodolite contained liquid filled finger-print patterns or feathers in different planes, quite unlike inclusions found in any other garnet and much more like similar types of inclusions so frequently found in Ceylon sapphires.

The only other observation of interest that I was able to make concerned a pale pink garnet kindly given to me by Mr. A. E. Farn with the very low constants of S.G. 3·679 and R.I. 1·729 and which contained no typical garnet inclusions but, instead, wavy dendritic hair-like feathers not in any way orientated.

In conclusion, I would again emphasize the value to be secured by charting garnets in the way explained above, as the visual picture thus presented conveys far more than the mere possession of the constants would lead one to expect.

SCHEDULE OF GARNETS EXAMINED AND CHARTED

No.	*Gemstone*	*Colour*	*S.G.*	*R.I.*	*Inclusions, etc.*
	Demantoid	green	3·856	1·89	Asbestos tufts
378	Melanite	black	3·802	1·89	—
197	Almandine	greyish purple	4·290	1·815	Numerous small prisms and some red-coloured XLs
159	Almandine	wine red	4·268	1·802	Many unusual XLs
324	Spessartite	reddish orange	4·193	1·81	Shred-like liquid-filled
167	Almandine	deep red	4·182	1·792	Fine round needles
196	Almandine	blood red	4·180	1·797	Fine round needles
63	Almandine	pale purple	4·155	1·794	None
266	Spessartite	coppery yellow	4·178	1·803	Shred-like and feathers
211	Spessartite	orange	4·136	1·806	Shred-like and feathers
397	Almandine	purple	4·134	over 1·81	Needles and radioactive zircons
192	Almandine	imperial purple	4·120	1·798	Needles
184	Almandine	deep red	4·060	1·785	Fine round needles
395	Almandine	deep red	4·017	1·778	Few fine needles
278	Spessartite	orange	4·030	1·792	Feathers and shreds
384	Almandine	blood red	4·030	1·769	Short rods
392	Almandine	deep red	4·000	1·776	Long fine needles
402	Almandine	red	4·004	1·775	Long fine needles
195	Almandine	very deep red	4·000	1·779	Rounded XLs with XLs radiating from them like a sea mine
391	Almandine	purple	4·000	1·778	Minute specks
191	Almandine	purple	3·990	1·778	Short needles
185	Almandine	deep red	3·990	1·770	XLs and fine needles
69	Almandine	purple	3·959	1·770	Short rods
11	Almandine	blood red	3·960	1·765	None
187	Almandine	imperial purple	3·970	1·770	Fine needles
394	Almandine	wine red	3·957	1·779	Large number of fine needles
251	Almandine	deep red	3·950	1·760	Very few needles
403	Almandine	deep red	3·943	1·767	Rounded XLs and fine needles

209	Almandine	blood red	3·940	1·756	XLs and fine silk
396	Almandine	deep red	3·930	1·770	None
386	Almandine	blood red	3·923	1·762	short rods and specks
258	Almandine	rose red	3·920	1·760	Fine needles
257	Almandine	imperial purple	3·910	1·760	Almost clean
388	Almandine	wine red	3·923	1·779	Large number of fine needles
57	Almandine	blood red	3·887	1·766	Short rods
389	Almandine	blood red	3·890	1·770	Lond needles, small well defined XLs
186	Almandine/Rhodolite	rose red	3·890	1·758	None
210	Almandine/Rhodolite	rose red	3·890	1·765	Silk
390	Rhodolite	rose red	3·894	1·766	Rods and feathers in different planes
64	Rhodolite	rose red	3·874	1·752	Feathers and XLs
168	Pyrope	blood red	3·870	1·748	XLs and short needles
256	Pyrope	blood red	3·870	1·747	XLs and short needles
250	Pyrope	pale red	3·845	1·745	Small streamers
400	Rhodolite	rose red	3·852	1·759	Feathers
104	Rhodolite	rose red	3·850	1·758	Feathers
259	Pyrope	pale rose red	3·830	1·756	Short rods
62	Pyrope	pale purple	3·794	1·748	Very few needles
401	Bohemian Pyrope	crimson	3·754	1·752	Rounded XLs
393	Bohemian Pyrope	crimson	3·697	1·748	Large well defined prismatic XLs
169	Pyrope	crimson	3·700	1·740	Large XLs and silk
399	Pyrope	pink	3·679	1·729	Dendritic feathers
65	Hessonite	reddish brown	3·653	1·744	Rounded XLs on oily background
67	Hessonite	reddish brown	3·646	1·740	Rounded XLs on oily background
56	Hessonite	coppery yellow	3·642	1·741	Rounded XLs on oily background
66	Hessonite	orange	3·622	1·740	Rounded XLs on oily background
377	Xalstocite	white	3·475	1·742	(An opaque XL)
383	Grossular	emerald green	3·448	1·728	Small black specks
385	Grossular	pink	3·388	1·720	(Translucent only)

REFERENCE

1. Anderson, B. W. *Properties and classification of individual garnets.* Journ. Gemmology 1959, **7**, 1-7.

BOOK REVIEW

WEBSTER (R.). *Gems: their sources, descriptions and identification.* £9 10s. Butterworth, London, 1962.

About five years ago a series of papers in *The Gemmologist* was prefaced by a statement that they were extracts from an entirely new and comprehensive book on gem materials being written by Mr. Webster, and since then gemmologists have been eagerly looking forward to the publication of the promised work. It has now made its long awaited appearance and they will not be disappointed.

This is a book of nearly 800 pages with over 500 black-and-white illustrations in the text, printed on highly calendered and, therefore, heavy paper. It was a wise decision to avoid unwieldiness and to divide it into two reasonably handy volumes weighing a little over 3 and a little under 2 lbs respectively. It invites comparison with Prof. Cavenago-Bignami's *Gemmologia*, which, with 1110 pages in one volume, weighs nearly 6 lbs. The two books are on the same ambitious and all-embracing scale and both cost £9 10s. in this country; but Mr. Webster's has the advantage—at least for this reviewer—of being written in English, and, being published five years later, is of course more up to date. In addition to the black-and-white illustrations, there are 20 colour plates; it is impossible to do justice to a gemstone in a picture, but the 16 plates taken from Dr. Gübelin's *Edelsteine* give as good an idea of the stones illustrated as any I have seen; two plates shewing cabochons of ornamental stones and crystals respectively are exceptionally pleasing, and the remaining two are the colour plates of absorption spectra already made familiar in the *Gemmologists Compendium* but with their colouring somewhat improved.

The first volume consists principally of " descriptive " gemmology. After a brief chapter on the origin and recovery of gemstones—covering the essential elements of geology—some 200 pages are devoted to describing the better known gemstones (diamond, corundum, beryl, chrysoberyl, spinel, zircon, peridot, spodumene, garnets, feldspars, quartz, opal, turquoise, lapis, jade), some 80 pages to marcasite, natural glasses, marble and lesser known ornamental and gem materials, some 50 pages to synthetic,

imitation, composite and artificially coloured stones, some 50 pages to pearl (natural, cultured and imitation), followed by 36 pages on the other organic gem materials; and a chapter on the fashioning of gemstones is sandwiched somewhat incongruously between the composite stones and the pearls. The descriptions include rather brief sections on lore and legend and extensive details of occurrences as well as particulars of crystallization, chemical and physical properties, refraction, absorption spectrum, luminescence, inclusions, cutting, synthesis and simulation.

The second volume is devoted mainly to " determinative " gemmology—to setting out the methods used in identifying gemstones, explaining the scientific principles on which these methods are based and describing the instruments used. Some 60 pages are devoted to crystallography, hardness and specific gravity, followed by over 80 pages on the effect of light on gemstones (or vice versa), including refractive index testing, absorption spectra and much discussion of the causes of colour. The microscope has a chapter of 50 pages to itself and there are separate chapters on inclusions, luminescence, X-rays, and electrical and magnetic phenomena. Finally there are nearly 40 pages of identification tables and some appendices. The identification tables include 6 black-and-white plates shewing 54 absorption spectra and the appendices include a lengthy list of unusual names for gemstones (misnomers, trade names, and all) as well as a brief bibliography and a list of individually named diamonds.

It is a critic's job to criticize, and if I list a number of minor faults it is in no spirit of denigration of what by any standard is a remarkable and valuable piece of work.

As readers of this *Journal* well know, Mr. Webster's style is straightforward and conversational. Its usual clarity is, however, occasionally obscured by inadequate or misplaced punctuation and by a curious habit of ending a sentence in apparent forgetfulness of how it began (e.g., ' This hardness may be due more to the variation of grain . . . than to an actual greater hardness ").

The absence of footnotes and of references to authorities will probably be welcome to the majority of readers, but it can sometimes be frustrating. Is it worthwhile, for instance, referring to " the Chhatrapati Manick so charmingly described by V. Clarke " without indicating who V. Clarke may be or where the charming description may be found?

Nor is the author always sufficiently exact in his use of words. " A galaxy of lovely colours " is a misuse of language, whatever exciting visions it may conjure up of the night sky in Technicolor! Although the gem gravels of Ceylon may be prolific of zircon, zircon itself cannot be said to be prolific there. And it is regrettable to find that he has repeated the inaccurate description of the monoclinic crystallographic axes from his *Practical Gemmology*.

A book of this calibre deserves a first class index, and perhaps the most serious criticism is inadequacy in this respect. The index runs to 25 pages and must contain some 3,000 headings, but several minerals and occurrences referred to in the text find no place in it, some items indexed have less page references than they are entitled to, and the alphabetical order is not impeccable—some items being out of order because they are misspelt and some for no apparent reason at all. Misprints are rather frequent, but most of them are not significant.

It will be observed, however, that none of these weaknesses in this indefatigable worker's *magnum opus* has much to do with gemmology. Mr. Webster has recorded within the covers of these two volumes an enormous amount of accurate information relating to gems and gem materials, the results of a lifetime of practical study, patient research and laborious record-keeping. Although it will also have an appeal to a wider public, this is essentially a gemmologist's book—on gemmology, for gemmologists, by a gemmologist. To the serious gemmologist it will be—like his microscope, his spectroscope and his refractometer—a useful tool and a valued possession.

J.R.H.C.

ASSOCIATION NOTICES

COUNCIL MEETING

Mr. F. H. Knowles-Brown presided at a meeting of the Council of the Association held at Saint Dunstan's House on 29th June, 1962.

The following were elected:—

ORDINARY MEMBERSHIP

Fraleigh, Jack P., Toronto, Canada
Herring, John T., Radcliffe-on-Trent, Notts.
Zanowitz, Herbert, Willowdale, Ont., Canada
Kidger, John D., Sheffield
Loupekine, Igor S., Nairobi, Kenya
Manning, Edward P., Calcutta, India
Massey, William J., Jr., Birmingham, Michigan, U.S.A.
Miles, Richard S., Nottingham
Sommerfreund, Henry, Panama, R.P.
Tyler, Charles R., London
His Grace The Duke of Wellington, K.G., Reading

PROBATIONARY MEMBERSHIP

Julie Gaydon, Surbiton

Arrangements were made for the 1962 presentation of awards to be held at Goldsmiths' Hall, London (by kind permission of the Wardens) on 5th November. The Council invited Mr. Robert Webster to present the awards and congratulated him upon the publication of his book *Gems*.

MIDLANDS BRANCH

For their annual outing this year, members of the Midlands Branch of the Gemmological Association visited Woburn Abbey, at the beginning of July. The chairman, Mr. W. W. Bowen, had made arrangements with the comptroller of the household for members to view the Abbey in a private party. Members had tea at the Abbey and dinner at Ryton-on-Dunsmore.

EXAMINATIONS IN GEMMOLOGY, 1962

In the 1962 examinations 213 candidates sat for the preliminary examination and 135 for the diploma. Centres for the examinations were established in Malaya, Spain, Norway, Holland, Germany, Hong Kong, Ceylon, Switzerland, Canada, Finland, Sweden, South Africa and United States of America, apart from the United Kingdom.

Upon the recommendation of the examiners the Tully Memorial Medal has been awarded to Mr. P. A. Waters of Manchester. The Rayner prize has been awarded to Mr. A. Cooper of Swinton.

The following is a list of successful candidates, arranged alphabetically:—

Tully Memorial Medal

Waters, Peter Aloysius, Manchester

Qualified with Distinction

Allnutt, Anthony John, London
Bradley, Robert Charles, Didcot
Davidson, Terence Malcolm John, London
Fine, Jay, Orillia, Canada
Fraleigh, Jack, Toronto, Canada
Heidelberger, Martin, Zurich, Switzerland
Hinton, Bernard, Toronto, Canada
Humphreys, Alan Lewis, Andover
Kan, Noah, Hong Kong
Johne, Thor Aksel, Oslo, Norway
Kern, Edward, West Hartford, U.S.A.
Lappalainen, Ritva, Helsinki, Finland
Moi, Gerd, Oslo, Norway
Morgan, Ralph John Alfred, Torquay
Nickolds, Ann Margaret, London
Penner, Ernest, Islington, Canada
Waters, Peter Aloysius, Manchester
Williams, Geoffrey Francis, Esher

Qualified

Aho, Risto Aleksanteri, Laaksolahti, Finland
Asprey, Maurice, London
Bacon, Stephen Jasper, London
Berkel, J. V. M. v., Utrecht, Holland
Blanshard, Philip John Anthony, Croydon
Blyth, Elizabeth Rhoda, Nanaimo, Canada
Borgen, Annemarta, Oslo, Norway
Borgen, Per Otto, Sarpsborg, Norway
Bound, Una Marion, Sidcup
Burke, Frieda, Philadelphia, U.S.A.
Charles, Russell, Camp Hill, U.S.A.
Chesebrough, Rosser, Sherman Oaks, U.S.A.
Crank, Susan Elizabeth, Bolton
Cropp, Alan Reginald, Lucerne, Switzerland
Dowse, John Edward, Birmingham
Egli, Ernest, Geneva, Switzerland
Erichsen, Björn Thorstein Nygärd, Horten, Norway
Evans, Rennie, Toronto, Canada
Farrant, Eric Raymond, London
Fleming, John Alan, Auckland, New Zealand
Foulkes, Peter Clarence Albert, London
Freedman, Israel, London
Gillougley, James Hugh, Glasgow
Gould, Henriette, Johannesburg, S. Africa

Green, Edward William, Scarborough, Canada
Griffiths, John Arthur, Kidderminster
Gronqvist, Tarmo, Helsinki,Finland
Gunaratne, Herbert Stanley, Colombo, Ceylon
Harper, David Charles, Welling
Hollens, John Frank, Pinner
Hudson, Douglas Geoffrey, Whitstable
Johne, Vera Asta, Oslo, Norway
Jokinen, Pertti, Helsinki, Finland
Jones, David Colin Barry, Leamington Spa
Jones, David Winzer, Crawley Down
Klerk, A. F. C. de, Oud-Gastel, Holland
Lee, Raymond George, Torquay
Lieberman, Ian Stuart, Ilford
Leimu, Heikki, Hameeneinna, Finland
Lodge, John William, Newcastle upon Tyne
Marno, Raimo Atte Uolevi, Helsinki, Finl and
Marshall, John Frederick, Sutton Coldfield
Marshall, Nigel, Birmingham
Maunton, Frederick John, Bromley
McChlery, George Michael Armstrong, Glasgow
McGoldrick, Bernard, Liverpool
Moller, Jorgen, Copenhagen, Denmark
Otteren, Karl-Jorgen, Trandum, Norway
Parker, David John, Birmingham
Pettersen, Egil, Fredrikstad, Norway
Petzall, Ossi George, London
Potterat, Raymond, Geneva, Switzerland
Ranger, Clive James, Bromley
Robinson, David Michael, Liverpool
Rybom, Lena, Fredrikstad, Norway
Searle, Ian Victor Herbert, Ilford
Selvon, Dennis Ralph, Woodford Green
Sheriff, Hassan, London
Shotton, John Joseph, London
Thompson, Colvin Graham, London
Tivol, Harold, Kansas City, U.S.A.
Travis, Denis John, Esher
Turnbull, Elizabeth, Sunderland
Turton, Phillip John, Solihull
Tyerman, John Thomas, Harrogate
Virkkunen, Marjatta, Helsinki, Finland
Weighell, Stephen Nicholas, Cullompton
Werkhooven, P. J. K. van, Hilversum, Holland
Weston, Raymond William, Solihull
Wilkins, David, Swindon
Woodhouse, Michael Lesley, London

Preliminary Examination

Rayner Prize

Cooper, Alfred, Swinton

Qualified

Abbott, Henry Charles, Liverpool
Addis, Clare Weston, London
Allaby, Frank Edmund, Warrington
Allnutt, Anthony John, London
Andersen, Ragnhild, Oslo, Norway
Barrett, Robert Clive, Southampton
Bell, Raymond Alexander, Liverpool
Berry, William, Kirkcaldy

Bickley, Michael, Birmingham
Bilby, David, London
Björn-Hansen, Eva, Oslo, Norway
Bowers, John William, London
Bromley, Ivan Paul, London
Brown, Diana Mary, London
Bound, Una Marion, Sidcup
Calmus, Michael, Nottingham
Camberg, Michael Ralph
Johannesburg, S. Africa
Campin, Andrew John, Mansfield
Capel, Donald Edward, London
Chiles, Barry Gordon, Warlingham
Church, Derek Arthur, Wallington
Clarkson, Roland Norman,
Chessington
Cooper, Alfred, Swinton
Coupar, Florence, London
Dambrink, Karel, Apeldoorn,
Holland
Davies, J., Sutton Coldfield
Davies, James Meredith, Worthing
Demaline, John Thomas, Dundas,
Canada
Earnshaw, James Albert,
Middlesbrough
Edmunds, Ronald Charles, Strood
Einari, Virtanen Pentti, Helsinki,
Finland
Engelbert, Peter Harry, Sweden
Evans, Rennie, Toronto, Canada
Fairbotham, Alen Geoffrey,
Middlesbrough
Fleming, John Alan, Auckland,
New Zealand
Fraley, Lawrence, Wheelersburg,
U.S.A.
Fuller, Robert George, Ruislip
Gann, David Alexander, London
Gatrell, Michael Leonard, London
Gatward, Robert Bradley, Caterham
Gaydon, Julie Hazel, Surbiton
George, Stanley William, London
Giblin, Michael, Bury
Hall, Lilian Rosemary, London
Hall, William Hardwick, London
Hamp-Gopsill, Garth,
Burton-on-Trent
Herring, John Thomas,
Radcliffe-on-Trent
Hopkins, Peter James, Derby
Horton, Joanna Percival, Plympton
Houghton, Michael John, London
Huddy, William John, Newton
Abbott
Hudson, Felix, Dundermline
Humphreys, Alan Lewis, Andover
Hutchings, Peter Frank, Birmingham
Kallioniemi, Eero, Tampero, Finland
Kan, Noah, Hong Kong
Kari, Raija, Lahti, Finland
Kenney ,Francis Joseph, Hockley
Kudlatz, Harold, Glasgow
Kiuas, Eljas-Jussi, Pukinmäki,
Finland
Krzempek, Evelyn, Nottingham
Lamb, Michael, West Bromwich
Lampert, Ronald John, Plymouth
Lammond, Joseph, Liverpool
Lewis, Sylvia, London
Lugtigheid, Gerharda, Oosterbeek,
Holland
Manning, David, London
Major, Keith Roy, East Grinstead
Meddings, Ann Elizabeth,
Burton-on-Trent
Miles, Richard Stanley George,
Nottingham
Moller, Jorgen, Copenhagen,
Denmark
Morgale, David Alex, London
Morton, Ian, London
Mundie, Ian, Falkirk
Nickolds, Ann Margaret, London
Olswang, Kenneth Joseph,
Manchester
O'Toole, John, Liverpool
Otteren, Karl-Jorgen, Trandum,
Norway
Paine, Alan, Glasgow
Panjabi, Hero, Hong Kong
Porter, Hamish Robb, Carnoustie
Quartermaine, Helen Laurie,
Kuala Lumpur, Malaya
Reekie, Robert, Kirkcaldy

Ripatti, Ida Maire Lrene, Tapiola, Finland
Roca Salamanca, Rogelio, Barcelona, Spain
Rooke, Kenneth Turner, Aylesbury
Rudman, Philip, Oldham
Sanz, Miguel Angel, Barcelona, Spain
Saunders, Robert, London
Scholl, Werner, Zollikerberg, Switzerland
Schwartz, Raymond Noah, London
Searle, Ian Victor Herbert, Ilford
Sher, Morris Michael, Glasgow
Sheriff, Hassan, London
Silva, S. P. Ranjee de, Hong Kong
Smith, Benjamin Henry Jr., Wilmington, U.S.A.
Snell, Richard Geoffrey Fox, Bournemouth
Spacey, Peter William, Sutton Coldfield
Storgmeir, Inkeri, Orapihlajatie, Finland
Straiton, Timothy, Hove
Szejko, Anna-Liisa de, Linnaistentie, Finland
Szejko, Wiktor Ingolf de, Linnaistentie, Finland
Talbot-Ponsonby, Peter William, London
Tarkiainen, Paavo Akseli, Helsinki, Finland
Tarratt, Christopher David, London
Taylor, John Livsey, Blackpool
Teisala, Hannu Herkko, Helsinki, Finland
Thorne, Anthony Reginald, Devonport
Tivol, Harold, Kansas City, U.S.A.
Trotter, Michael Duncan, Birmingham
Vogel, Georg, Lucerne, Switzerland
Walton, Edward Bryan, Chester
Weighell, Stephen Nicholas, Cullompton
Wesselingh, Ank, Zoeterwoude, Holland
Wight, Peter Martin, Wallasey
Wilson, William David, Liverpool
Wood, Mary Bayne Haddow, Sidmouth
Wyer, Philip George, Birmingham
Yates, Paul, London

OBITUARY

The Council has recorded with regret the death of Ing. Johannes Hammes, of Zeist, Holland. Mr. Hammes was the foundation President of the Netherlands Gemmological Association and a former President of the Examining Committee of the Netherlands Goldsmiths' & Silversmiths' Federation, an organization with which he was associated for many years. A pioneer gemmologist in the Netherlands he became a Fellow of the Gemmological Association in 1948. He wrote an important work *Goud, Zilver, Edelstenen.*

SPECIALIST COURSE ON GEM DIAMONDS

A specialist course on gem diamonds was commenced at the School of Jewellery and Silversmithing, Vittoria Street, Birmingham, at the end of September with Norman Harper, F.R.G.S., F.G.A., as lecturer and demonstrator.

This Course is the first of its kind to be established in Europe, and admission is restricted to qualified Fellows of the Gemmological Association of Great Britain. The Course was heavily oversubscribed. The Syllabus is comprehensive and practical, and diamonds in their cut and polished form have been made available for practical work.

GIFTS TO THE ASSOCIATION

The Council of the Association acknowledges with gratitude the following gifts:—

Samples of howlite, stained blue to imitate turquoise, from Mr. R. Webster.

An anonymous donation of £50 for the Association's library.

An opal doublet and pieces of rough opal from Wilson & Gill Ltd., London.

Six demantoid garnets and a pink tourmaline from Mr. Dean Field, Toronto.

LETTER TO THE EDITOR

DEAR SIR,

In your Vol. VIII, No. 7, July 1962, Letter to the Editor, F. S. H. Tisdall asks about sapphires and short-wave ultra-violet light.

Perhaps the answer is given in the chapter " Fluorescent Gem Stones and Lapidary Material" in the book "Ultraviolet Guide to Minerals" by Sterling Gleason (Van Nostrand, 1960). The following is an extract of his remarks on sapphire:

" Titanium, often present, is credited with producing the typical sapphire blue and probably modifies the fluorescent color in many sapphires. Iron, frequently found, accounts for the number of stones that are nonfluorescent.

"Blue natural sapphires are often nonfluorescent, but a good many, particularly those from Ceylon, fluoresce red to orange or salmon, long wave. Some stones fluoresce blue, short wave.

"Synthetic blue sapphires also are often, but not always, nonfluorescent. Experts are able to pick out the natural from the synthetic stones in a tray of mixed stones by the different shades of greenish-blue fluorescence under the short waves".

Yours sincerely,

New York. GORDON V. AXON.

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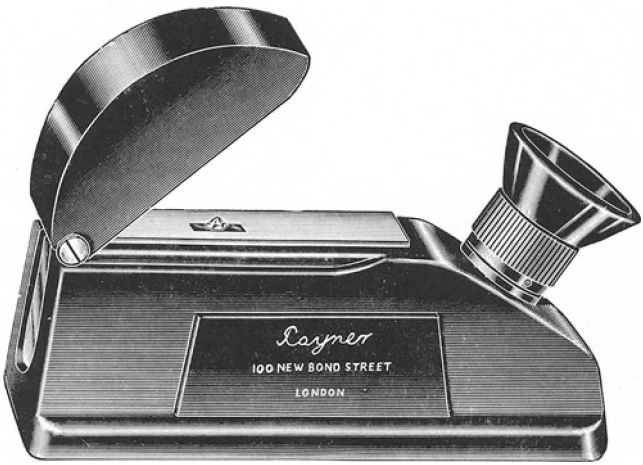

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ABSORPTION SPECTRA AND PROPERTIES OF METAMICT ZIRCONS *

By B. W. ANDERSON

THE absorption bands shown in the spectrum of light transmitted through a mineral can usually be ascribed to atoms of one particular element, though in the past mistaken ascriptions have often been made. These "colouring" atoms may be present either as an essential or (more often) as an "accidental" constituent of the mineral concerned. But the actual positions of the bands depend primarily on the electric field surrounding the atoms, on their "polarization"—that is, on the crystal structure of the host mineral.

Striking examples of this are shown not only in the extreme similarity between absorption bands seen in closely-related minerals (enstatite and hypersthene; jadeite and spodumene) but more subtly by similarities between minerals which may seem to belong to quite different chemical or crystal groups, and yet have an underlying structural affinity. Thus, the spectrum of taaffeite is very similar to that of blue spinel, and the spectrum of sinhalite is closely allied to that of peridot—one reason why its discovery was so long delayed.

Now in zircon the gradual breakdown in crystal structure, which can be conveniently measured by the density of the stone, can

* Substance of a talk given at the 9th International Gemmological Conference at Helsinki 1962.

also be clearly followed by the gradual deterioration of the uranium absorption bands from the sharp lines displayed by normal fully crystallized zircon, through weaker and vaguer development of the same bands until, with completely metamict zircon, the usual absorption spectrum consists merely of a vague band in the red near 6500Å, sometimes accompanied by a narrow band in the green at 5200Å—the latter a band not seen in normal zircon.

The reverse process can be demonstrated quite simply in the case of intermediate zircons by heating a pebble to bright redness for a few minutes in a bunsen flame, when the sharpness of the spectrum lines will be found to have been notably enhanced by this treatment, and the density of the specimen to have risen.

With zircons of lowest metamict type, however, the writer has found quite a different effect to be the rule. With these stones, heating at 800-900°C will induce a strong and clear-cut series of absorption bands, not of the normal zircon spectrum, but in a different pattern and at different wavelengths. The main differences between the spectra are, that whereas in the normal zircon spectrum the strongest band is in the red at 6535Å, in the anomalous spectrum the most powerful band is a rather broad one at 6690, flanked by a doublet at 6910 and 6855 on the long-wave side and a band about 6525 on the other side, forming a "triple band" effect, and also that in the blue and violet regions, where the normal spectrum shows two powerful bands at 4830 and 4315, the anomalous spectrum has very strong bands quite differently placed, at 4730 and 4510Å. The diagram reproduced here shows the distribution of absorption bands in the normal and anomalous spectra, as seen through a grating spectroscope.

The anomalous spectrum has already been observed in several untreated low metamict zircons, but these are exceedingly rare. By an extraordinary chance, the zircon in which we first saw absorption bands was of this type, and in 1957 Dr. P. Zwaan published a detailed account of another such specimen which he found in the Museum collection at Leiden. Dr. E. Gübelin, in a private letter, has recently sent the writer particulars of yet another stone displaying the anomalous bands: the properties of all these are given in the table below.

The discovery that these anomalous bands can be developed in *any* specimen of low metamict zircon simply by heat treatment

came as a complete surprise. The experiment was first undertaken with zircons showing the strange 5200 band which had been observed and collected over a number of years. Interest in this band had been brought to a head by being shown a fine *orange* metamict stone by Dr. E. H. Rutland, through whom the stone was purchased. This had the 5200Å band more clearly developed than in any other specimen seen, and served as a reminder of the need to try and elucidate its origin. It was decided to ascertain whether this band could be enhanced by heat treatment, as are the bands of the normal spectrum.

The first experiment was with a roughly polished specimen weighing 2·70 carats. This had a density of 4·04 and a single refractive index of 1·819. The spectrum showed the usual blurred red band of metamict zircon plus a weak narrow band at 5200Å which was the focus of interest. An initial heating for two hours at 600°C had no effect either on the absorption bands or on the physical properties of the stone. But after heating for three hours at 800°C the strong anomalous spectrum already mentioned made its appearance, while the density and refractive index had fallen to 3·98 and 1·785, respectively.

Experiments with other low metamict zircons, some rough and some cut, gave exactly parallel results, and it was found that stones not showing the 5200 band behaved in a precisely similar manner. The results on several such specimens are tabulated below and data for the few unheated natural stones which show the anomalous spectrum are also given for comparison.

Properties of metamict zircons showing the anomalous spectrum

Natural			Induced		
Cts.	*d*	*n*	*Cts*	*d*	*n*
5·19	3·95	1·792	2·32	3·975	1·778
12·64	3·965	1·792	1·20	3·96	1·799
Zwaan	3·965	1·778	1·55	3·96	1·784
Gübelin	3·918	1·780	1·95	3·935	1·783

With sufficiently low-density metamicts, in which no trace of the original zircon spectrum remains, the development of the

anomalous spectrum on heating seems inevitable. In one case, a very small pebble was heated in the flame of a bunsen burner for not much more than a minute, and even this was sufficient to produce the anomalous bands. With zircons having a density of 4·08 or over or with any zircon showing even traces of the normal spectrum lines, the results of heat-treatment are quite different: the density and refractive index are found to have increased and a normal zircon spectrum makes its appearance. The "watershed" between the two represents the dividing line between Stevanovic's "a" class of zircons of lowest density and his "c" or intermediate group. In one curious case having density as high as 4·08, but showing in its spectrum only the red smudge and 5200Å band, the stone seemed to be sitting astride the watershed, since heating produced a strong mixture of normal and anomalous bands, while the density had increased slightly to 4·12.

Not only in the positions of the bands does the abnormal (A) spectrum differ from the normal (N) but in the fact that it is unpolarized whereas the N spectrum is clearly polarized. This seems to suggest that the uranium is now inhabiting a cubic lattice—possibly the cubic form of ZrO_2 reported in metamict zircons by some X-ray workers. Dr. G. F. Claringbull and others are now investigating this and other possibilities.

Heating to 900° resulted in no change in the anomalous spectrum though further diminution in density and refractive index

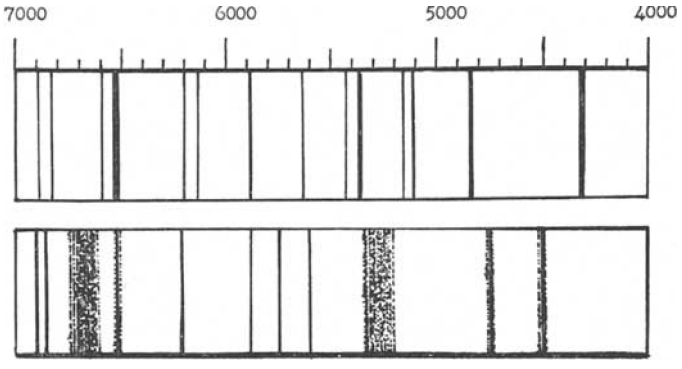

Absorption bands in the normal zircon spectrum (above) and the anomalous spectrum (below)

were observed. Professor W. F. Eppler has kindly subjected chosen stones to higher temperatures. Two hours at 1000° still resulted in no change in the A spectrum, but at 1100° two of the chosen stones showed some development of lines of the normal spectrum, with polarization evident, and in one of these the density had undergone an increase from 4·00 to 4·21—definitely a sign that it was on its way back to normal zircon.

Similar reversion towards crystalline zircon when low metamict types had been heated to 1250° was noted by Lietz (1937), while Chudoba has stated that when heated for a long period at 1450°, all zircons revert to normal. This temperature is approaching that for the actual melting point of the mineral.

The curious lowering of an already low density and refractive index on moderate heating before beginning the long climb towards full crystallinity, "reculer pour mieux sauter", as the French phrase puts it, is not unique to zircon. The same effect was observed in experiments on that new metamict gem mineral, ekanite, and it confirmed the opinion that this was indeed another metamict. Possibly because of their variable hafnium content these low metamict zircons differ slightly from one another in their properties, though 3·96 for their density and 1·78 for their refractive index seem good average figures. With ekanite the figures for density (3·28) and refractive index (1·597) compare well in constancy with those for a pure crystalline mineral, which is very remarkable. Measurable amounts of double refraction are sometimes observable in even these metamict zircons: it is possible however, that this may be due to the so-called "form birefringence" seen, for example, in chalcedony.

The specimens dealt with in this study have all been Ceylon stones. Ceylon zircons have undergone internal changes more than those from most other localities, not only because of their vast geological age (Pre-Cambrian), but because their content of radioactive elements is relatively high. Traces both of thorium and uranium are frequently present in zircons: thorium belongs to the same sub-group of the periodic classification of elements, and both thorium and uranium compounds are isomorphous with their zirconium analogues. In this connection, Mr. T. G. Jones, at the A.E.R.E., Harwell, kindly obtained the following readings on a sensitive beta-gamma ray counter. For a zircon from Indo-China,

nil; from Burma, 160; Ceylon, density 4·14, 267; Ceylon metamict, 365; Ceylon metamict with anomalous spectrum, 334 c.p.m. One may note that zircons from Indo-China are normal types and show only very faintly the uranium absorption lines. Burma zircons are also normal, and have a larger uranium content than Ceylon zircons, as indicated by both their emission and absorption spectra, but are geologically younger.

It is clear that this investigation is incomplete. All that has so far been established is an interesting and apparently invariable pattern of behaviour in low metamict zircons, in which heat treatment at 800-900°C causes a reduction in density and refractive index accompanied by the development of a series of strong absorption bands in a pattern which is not that of the well-known spectrum of normal or intermediate zircon. The mystery of the 5200Å band which started the investigation and of the crystal phase in which the anomalous spectrum is developed is still unsolved, but is being pursued by other workers.

Fifteen years ago, an article was published under the heading "Zircon—no longer a gem of mystery": an excellent article, but with certainly an optimistic or pessimistic title, according to one's viewpoint.

For the research-worker, at least, it is a matter for rejoicing that so many mysteries remain to be solved, not only in zircon but in almost every precious stone.

WORN EDGES ON DIAMONDS

Recently there has been seen a number of diamonds which have shown "worn edges", and owing to the fact that zircon commonly wears on the edges, such "worn" diamonds have been questioned as to whether they are truly diamonds.

The cause of such "wearing" at the edges has never been adequately explained. The usual conjecture has been that the stone or stones had become abraded by rubbing against other diamond set jewellery in a jewel case, or by "paper wearing" whilst in a stone packet with other diamonds. The first conjecture was found to be less tenable when a diamond cluster ring, which had the central stone "proud", showed the surrounding diamonds to have their inner edges "worn", those edges which were protected by the mounting of the central stone. The second conjecture, that of

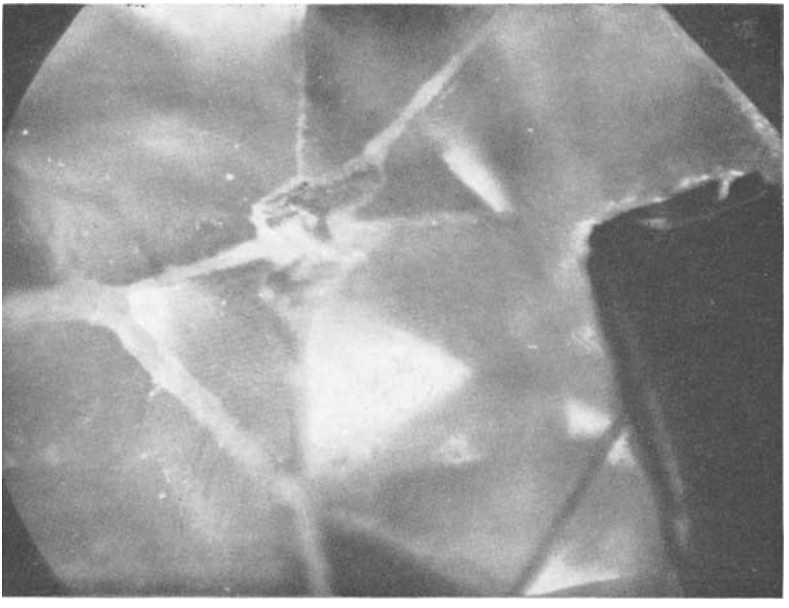

"paper wearing" in a stone packet, was not completely convincing. Another consideration was that there could have been a failure of the edges to meet correctly during the cutting process. This appeared to be rather "far-fetched", but it may not have been so improbable as first thought.

Professor S. Tolansky in his latest work, "The history and use of diamond", mentions the following:—"An alternative to the old classical scaife for polishing diamond has been introduced in the form of a metal or resin-bonded diamond-impregnated scaife instead of the old cast-iron scaife which used loose diamond grain. Such an impregnated wheel polishes faster than the traditional scaife. Furthermore, it is actually possible to polish both with and against the grain, much to the surprise of the traditional craftsman.

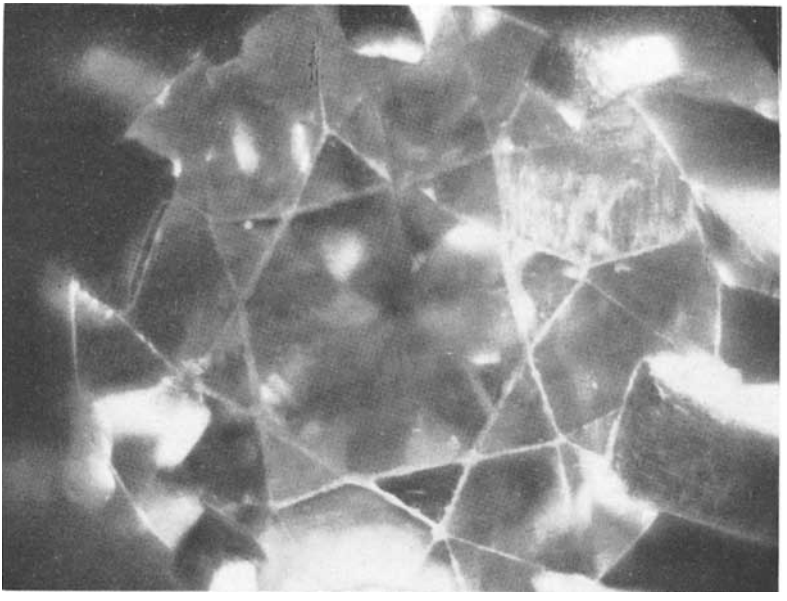

In spite of the greater speed and power of the impregnated wheel, the classical scaife is still likely to be used by the gem polisher for a long time because the impregnated scaife has one quite serious drawback: it has been found that it is difficult to produce sharp edges between the two meeting faces by this procedure".

Is this a probable answer to the recent prevalence of diamonds with "worn facet edges"?

R.W.

SOME OBSERVATIONS ON AQUAMARINE AND QUARTZ

By W. F. EPPLER

PEGMATITE signifies a particular kind of rock somewhat similar to granite but of later origin. It is characterized by crystals of sometimes considerable size, i.e. feldspar and quartz, and furthermore by other crystals containing rarer elements like fluor (topaz), lithium (kunzite, hiddenite), boron (tourmaline), beryllium (emerald, aquamarine, euclase, chrysoberyl, alexandrite), and others. It is said that the pegmatite originated after the main solidification of the granitic magma, filling smaller and larger fissures in the granite and in the adjoining rocks. The conditions under which the pegmatite and its minerals crystallized are called pneumatolytic to hydrothermal and this means that elevated pressures and higher temperatures were effective together with gaseous agents of great chemical efficacy. After the solidification of the system by very slow cooling, the more resistant gem crystals became obtainable by the weathering of the mother-rock.

We mostly are accustomed to see the pegmatite minerals of gem quality in museums, or private collections, or shaped into well cut gemstones. Our gems represent only a very small percentage of the crystals found in nature. The more abundant material is not suitable for gem-purposes and rejected. But it often contains interesting inclusions which reveal significant marks of growth of the host crystal for which the aquamarine offers more than one example.

On the basal plane of an aquamarine crystal (approximately half an inch in diameter and nearly one inch long) some "dust" was observable which could not be removed by scraping or by using strong acids (HF not used). The dust must have adhered very strongly. Figs. 1 and 2 reveal the dust to be an irregularly distributed accumulation of small crystals other than beryl or aquamarine. Near the centre of the pictures, the black and nearly square-shaped spot represents a magnetite. The dark-rimmed and rounded grains are epidote, while the slender and elongated crystals were found to be apatite. These heterogeneous crystals are attached to underlying splinters of quartz, shown better in Fig. 2. Here, the chips of quartz resemble a pavement with

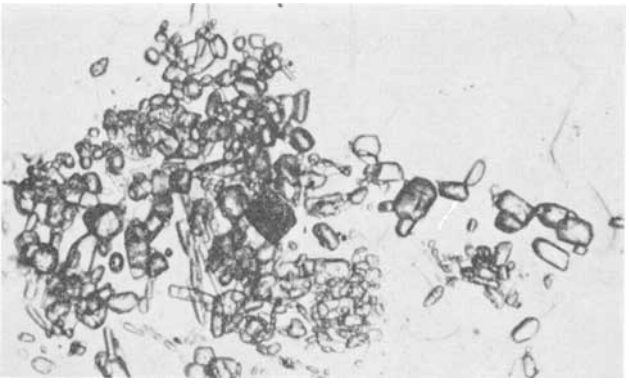

FIG. 1. *Quartz splinters with epidote, apatite, and magnetite adhering to the basal plane of an aquamarine, embedded in bromobenzene. 120 ×.*

FIG. 2. *As Fig. 1, crossed polarizers. 120 ×.*

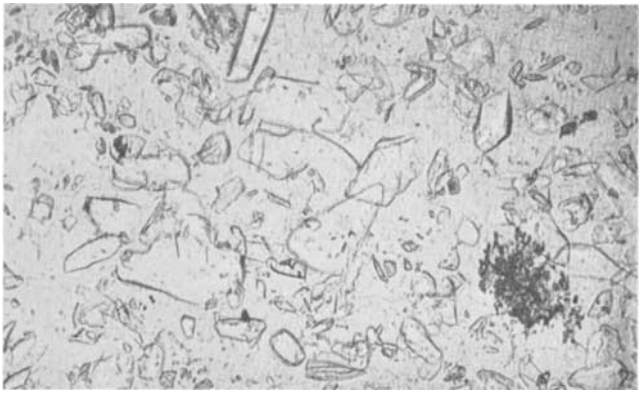

FIG. 3. *Chips of quartz on the top of a synthetic beryl, immersed in bromobenzene. 120 ×.*

different orientation of each chip. The quartz in its turn adhered to the base of the aquamarine crystal.

A very similar phenomenon could be observed in experiments for synthesizing beryl according to the hydrothermal method. Under certain conditions, the upper side of the seed of beryl used was covered with irregularly formed chips of quartz, as one of the nutrient components (Fig. 3 and 4). They also could not be removed and proved to be fixed by the growing layer of synthetic beryl during the cooling at the end of a run. This observation gives an explanation for the presence of the closely attached heterogeneous crystals on the basal plane of a natural aquamarine as follows:—

Firstly, it can be assumed that in the hydrothermal bomb at supercritical conditions the solid parts of the nutrient are moved by a convectional current up and down the reaction chamber.

Secondly, it can be deduced that within the pegmatite in its hydrothermal state convectional currents were also active, transporting the mother-liquor and small solid particles in directions given by the local circumstances.

Thirdly, it is a fact that the quartz chips only started to grow together with the top layer of the synthetic beryl at the beginning of cooling. Therefore it can further be assumed that in the natural pegmatitic phase a temporary drop in temperature also caused the attachment of solid particles to the aquamarine. Such an assumption makes it possible to accept the idea that with a following rise in temperature the aquamarine continued to grow and included the attached particles. Indeed, this also can be observed in natural beryl as demonstrated by Figs. 5 and 6. Such groups of inclusions are encountered at different levels of the same aquamarine crystal, indicating that a temporary drop of temperature is far from exceptional during the growth of aquamarine. On the contrary, most of the gemstones of the pegmatite series reveal growing marks from which growth in surges can be deduced with certainty, and it is in all probability that this phenomenon is caused by alternating temperatures.

Now it is worthwhile to speculate where the dustlike particles come from. The pegmatite filled fissures in rocks which formerly were compact. The fissures or clefts were opened by tectonic activity by which event the rock was partially crushed and shattered. Something resembling " clouds of dust " must have been pro-

FIG. 4. *As Fig. 3, crossed polarizers. 120 ×.*

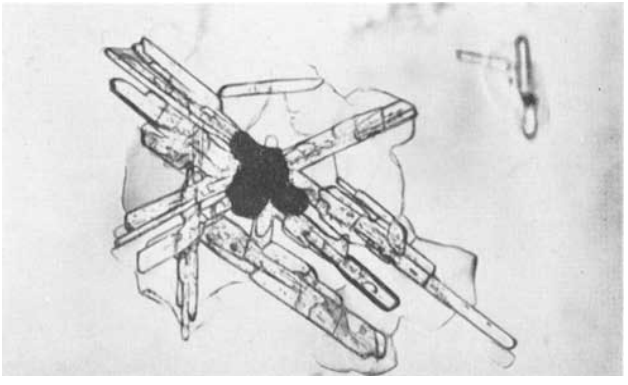

FIG. 5. *A group of heterogeneous crystals as inclusions parallel to the basal plane of an aquamarine. Black—ilmenite; elongated crystals—apatite; partly resorbed particles with only a faint relief—quartz of varied orientation. 120 ×.*

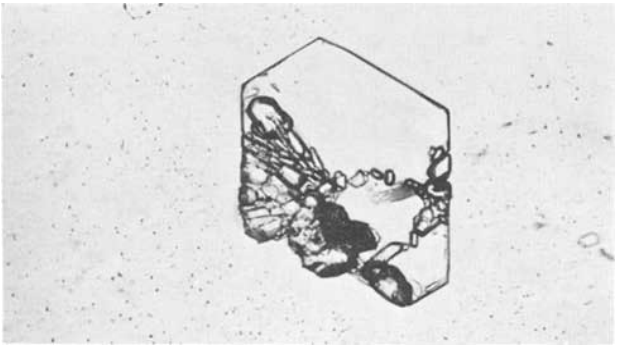

FIG. 6. *A quartz plate bearing small crystals of ilmenite, epidote, and other minerals as an inclusion parallel to the basal plane of an aquamarine. 120 ×.*

duced by the parting of subterranean mountains, after which event an immediate entering of highly tensioned gases into the new gap followed. The gases—or the mother liquor in supercritical condition—reacted with the walls of the fissures and with it débris, and formed the pegmatite and its typical crystals with inclusions of some of the dust. Such a version possibly explains the presence of the very interesting particles on and within the aquamarine.

In Figs. 5 and 6, the extraordinary inclusions are shown parallel to the basal plane of the aquamarine. Perpendicular to this direction, i.e. parallel to the prism zone, the heterogeneous crystals prefer to follow the direction of the c-axis. In Fig. 7, a rod-like quartz is regulated in this direction and it is covered with grains of epidote and with tiny apatites. Fig. 8 exhibits the same kind of inclusions with partly resorbed forms, while in Fig. 9 a pavement of slightly rounded chips of quartz bears elongated crystals of apatite. It seems likely that the growing aquamarine deposited the undesired material in suitable places with regard to its crystal lattice, and this is the direction of the c-axis.

Retrospectively, the observations of this particular kind of inclusions in aquamarine, and their origin, give an explanation for the presence of similar inclusions in a star-beryl owned by B. W. Anderson (*Journ. Gemmology*, Vol. VII, No. 5, Jan. 1960, 183-191). Here also, very similar chips of quartz are in tight contact with rounded crystals of epidote accompanied by apatite. They are not so strictly orientated with regard to the host crystal but, most probably, they have been originated and embedded by a similar process of pegmatitic action as shown before.

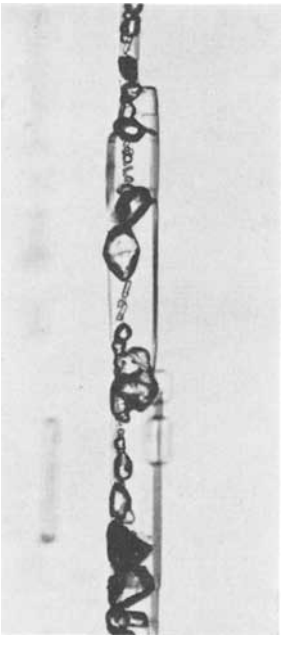

FIG. 7. *A rod-like quartz follows the c-axis of an aquamarine and is covered with epidote and tiny apatites. 120 ×.*

Just by chance, another example of this unusual kind of inclusions was found, this time in a rock crystal from Brazil. Gemmologists are familiar with the ghost-like crystal planes in quartz,

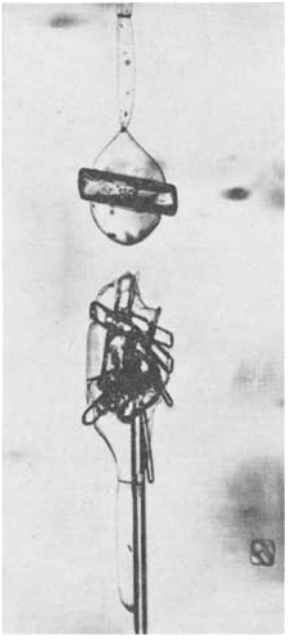

FIG. 8. *Upper part: a heavily resorbed quartz carries an elongated epidote and ends in a thin apatite.*
Below: a partly resorbed quartz is covered with elongated apatites and bears two grains of epidote.
The system of inclusions follows strictly the direction of the aquamarine's c-axis. 120 ×.

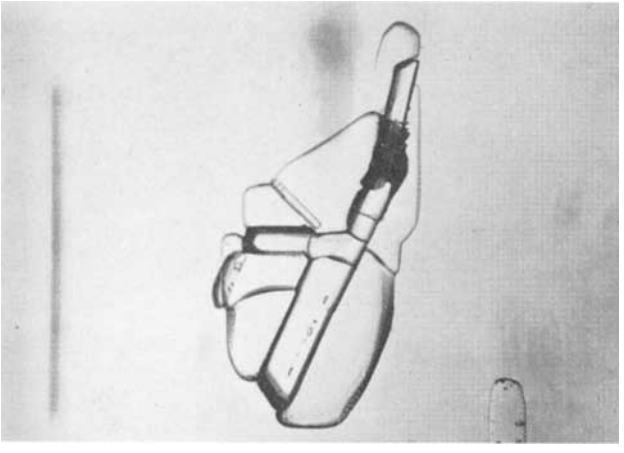

FIG. 9. *Partly rounded chips of quartz are attached to overlaying apatites. The dark spot in the upper part is lepidocrocite. The group of inclusions is parallel to the prism zone of an aquamarine. 120 ×.*

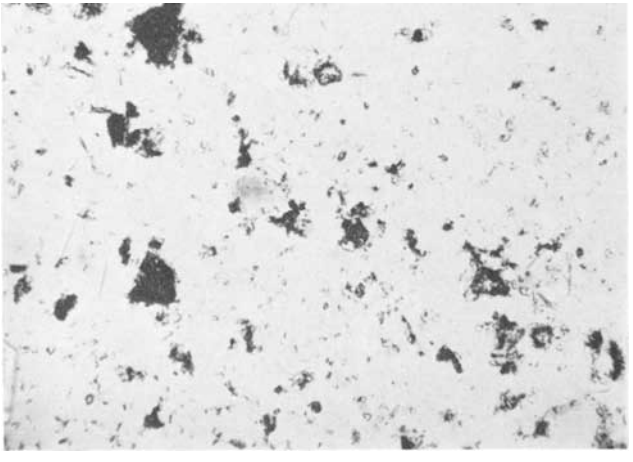

FIG. 10. *Prism face of a ghost quartz with unknown crystals (black) and chips of quartz. 65 ×.*

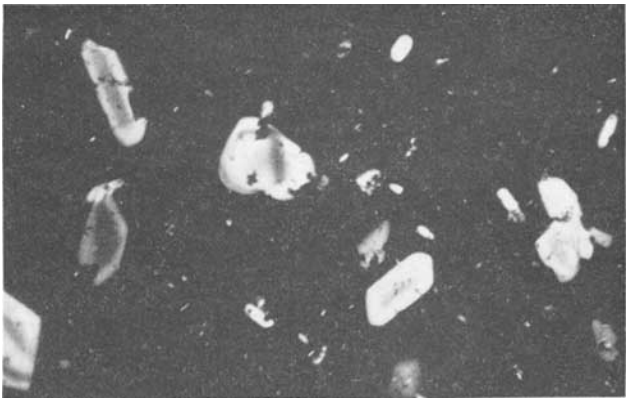

FIG. 11. *As Fig. 10, crossed polarizers. 65 ×.*

following the outer crystal faces and producing the impression of a smaller quartz crystal embedded in a larger one. Sometimes, two or even three such rock-crystals seem to be put one onto the other, always parallel to each other. Obviously, the smaller ghost-like crystals indicate steps of growth in the course of which the former crystal faces are covered with some foreign material which makes them visible.

Fig. 10 exhibits a view on the prism face of a ghost quartz embedded in a rock-crystal. The tiny dots and the black spots are crystals or groups of crystals not yet identified. Besides these, larger chips of quartz are irregularly distributed over the plane, much better visible with crossed polarizers, as shown in Fig. 11.

A view along the prism face in the direction of the c-axis (Figs. 12 and 13) reveals the borderline between the ghost quartz (below) and the rock-crystal (above). It consists of a multitude of small crystals among which greater chips of quartz are attached to the former prism in a direction parallel to the basal plane. It is not difficult to understand that the quartz splinters were generated during the pegmatitic activity in a manner very similar to the origin of the chips of quartz included in the aquamarine.

In summarizing, these unusual inclusions in aquamarine and in quartz are able to give an idea of the impetuous and very vigorous forces which were active to create the pegmatite and its beautiful gem materials.

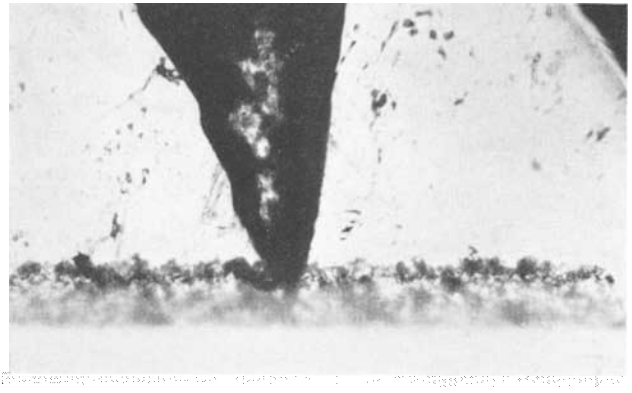

FIG. 12. *View parallel to the c-axis of a Brazilian rock-crystal showing the borderline of a ghost quartz. The black funnel represents a tube of growth parallel to the base plane. 120 ×.*

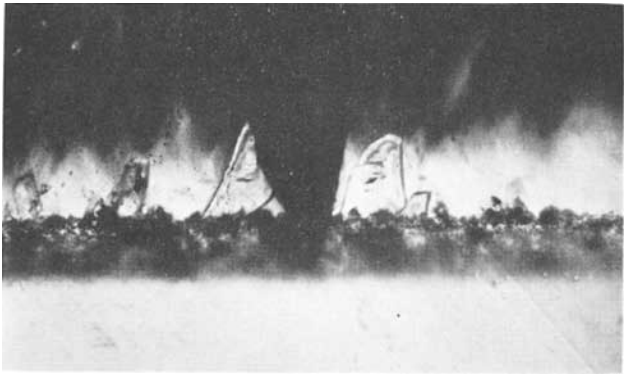

FIG. 13. *As Fig. 12, crossed polarizers. 22 ×.*

Gemmological Abstracts

MURPHY (M. O.). *Turquoise in the Cerrillos Hills.* Lapidary Journal, Vol. 16, No. 8, pp. 720-740 and 806, November 1962.

A full account of the history of the turquoise deposits of the Cerrillos Hills of New Mexico. The geography and geology of the hills are first discussed. Archaeological researches have established that the earliest mining of turquoise, at Mt. Chalchihuitl, was during the late Basket Maker culture, which flourished about 500 to 700 A.D. The early mining was carried out by the Indians using stone hammers and wedges, and using fire and water to fracture the rock. The open pit dug by these early miners is said to be 130 feet in depth and 250 feet in width. Some ancient Indian mining was carried out by tunnelling. There is considerable information about the finding of turquoise ornaments at Pueblo Bonito, and about the trade in turquoise in those times and later. The use of the name chalchihuitl is discussed. It is said that a tragic caving in of one of the turquoise mines was a chief cause of the uprising which finally drove out the Spaniards. The modern mining of turquoise from this locality started during the last half of the 19th century, and a note is given about the Tiffany Turquoise Mine and its connexion with G. F. Kunz and the Tiffany Jewellery Company. The Tiffany Company disputes having had any controlling connexion with the mine. There is a review of the future possibilities for the recovery of turquoise from the Cerrillos Hills. 26 illus., 14 refs. P.B.

WEBSTER (R.). *Turquoise; natural, treated, synthetic, and simulated.* Lapidary Journal, Vol. 16, No. 8, pp. 758-777 and 806, November 1962.

A general article on turquoise from all localities; on the minerals which simulate turquoise, on the various treatments carried out to improve turquoise and on the various artificial substances

made to imitate it. The ancient names applied to turquoise are discussed and something of the old lore and superstition is told. Good accounts are given of the geology of the Sinai and Persian deposits and of the mining at these places. Other oriental deposits are mentioned and there is a good general survey of the North American localities. Artificial treatments applied to turquoise in order to improve the colour or to "bond" the more porous types are discussed in detail. Variscite, lazulite, chrysocolla, shattuckite, and a new mineral papagoite, as well as the recently produced dyed howlite, are described as simulating materials. There is a good account of odontolite. The various types of imitation turquoise are discussed and a number of tests are given.
12 illus., 65 refs. P.B.

SMITH (I.). *Turquoise of the south-west.* Lapidary Journal, Vol. 16, No. 8, pp. 786-793, November 1962.

A valuable article on the turquoise jewellery of the American south-west with particular reference to the work of the Salado people (1300 A.D.). Many of the turquoise mines are described as well as the mining and fashioning of the turquoise both in olden times and the present day.
12 illus., 50 refs. P.B.

SEAL (M.). *The surface structure of diamonds.* Gems and Gemology, Vol. X, No. 10, pp. 309-314, Summer 1962. (Reprinted from Engelhard Industries Technical Bulletin of Sept. 1961.)

Describes the surface structures on natural and synthetic diamond crystals under examination by optical and electron microscopy.
16 illus. P.B.

CROWNINGSHIELD (R.). *Developments and highlights at the Gem Trade Lab. in New York.* Gems and Gemology, Vol. X, No. 10, pp. 304-308, Summer 1962.

Reports on specimens of turquoise which have been painted and subsequently coated with plastic; conch shell used as white coral, a very shallow diamond mounted with a smaller diamond below it, and three ordinary type diamond doublets. Various

colours in quartz triplets (soudé stones), carved jade-like serpentine and an unusual Chinese-drilled cultured pearl are mentioned. Unusual minerals encountered were a large faceted brazilianite, brown kornerupines, a rare cat's-eye hambergite, a green euclase and a very rare transparent hodgkinsonite.
12 illus. P.B.

LIDDICOAT (R. T.). *Developing the powers of observation in gem testing.* Gems and Gemology, Vol. X, No. 10, pp. 291-303 and 319, Summer 1962.

A timely article explaining the value of an initial observation by the unaided eye or by the use of a lens in assessing the nature of a stone. Characters, such as the doubling of the back facets, strong dispersion, types of characteristic fractures, curvature of the facets (concave facets in moulded glass) and inclusions, will give important data. Abrasions of polished surfaces, which might inhibit later instrumental tests, should be looked for. The finding of taaffeite is given as an illustration that even small doubling of the facets can be seen. There is a short discussion on corrected and uncorrected lenses. The use of the hand-lens is adequately discussed, particular attention being paid to the various ways of illuminating the specimen under examination. Notes are given on how to find out whether a spot is inside the stone or on the surface. Observation of the lustre as a guide to the refractive index and the difference in lustre of the two parts of a garnet-topped doublet will tell a lot. Types of fracture and certain optical effects will often provide indications, or even conclusions, as to the nature of the stone.
15 illus. P.B.

LIDDICOAT (R. T.). *Developments and highlights at the Gem Trade Lab. in Los Angeles.* Gems and Gemology, Vol. X, No. 10, pp. 315-319, Summer 1962.

The use of hydrochloric acid as a test for lapis-lazuli is mentioned. Unusual stones examined in the laboratory were cat's-eyes in apatite, zircon and kornerupine. A natural "padparadscha" sapphire is mentioned and other stones examined were ekanite, dyed serpentine, colourless brazilianite and a ruby-coloured tourmaline. The Plato method was used to determine a colourless sapphire brilliant as a synthetic stone.
4 illus. P.B.

ANON. *Diamonds mined off the seabed.* Mining Mag., Vol. 107, pp. 40-41, 1962.

A brief report on the first results of prospecting for diamonds off the coast of South-West Africa, and near the Cape of Good Hope: 45 diamonds were obtained from the South-West Africa coast.

R.A.H.

DAVIES (R. G.). *A green beryl (emerald) near Mingaora, Swat State.* Geol. Bull. Punjab Univ., No. 2, 51-52, 1962.

Green beryl occurs along shear zones in carbonate-talc rock or in quartz veins, in broken lenses of ultrabasic rock consisting of antigorite, talc, chlorite, calcite, chromite, and magnetite, near Mingaora, Swat State, Pakistan.

R.A.H.

EPPLER (W. F.). *Die diagnostiche Beduetung der Einschlusse in Edelsteinen.* The diagnostic significance of inclusions in precious stones. Umschau in Wissenschaft u. Tech., 62 472-475, 1962.

S.P.

FONTES (C.). *Sobre os diamantes Brasileiros.* Gemologia, 25, pp. 31-35, 1961.

A brief note of some of the outstanding diamonds found in Brazil, with details of colour, weight and ownership of the 16 largest.

S.P.

BOOK REVIEW

TOLANSKY (S.). *The history and use of diamond.* Methuen, London, 1962. 21 half-tone plates, 11 line illus. Small f'cap 4to. 30s.

Professor Tolansky is well-known for his studies of the microstructure of diamond surfaces and it is a pleasurable and rewarding surprise to read this simply written and entertaining account of diamond. It does not pretend to be a text-book—for instance a chapter on the wearing of diamonds by women touches upon an aspect usually absent from texts about the gem—and in many ways it gains because of this. Aimed at interesting people in diamond it succeeds admirably, and those who browse through its 166 pages should be encouraged to probe the subject more deeply.

S.P.

THE IRRADIATION OF GEMSTONES

By THOROLD JONES

Atomic Energy Research Establishment, Harwell

Read at the Eighth International Gemmological Conference, Milan October, 1960

INTRODUCTION

It would not be inaccurate to say that from the time material things began to exist, changes in them must have taken place. It is logical to assume therefore, that the changes in which we are particularly interested have also been occurring, and whilst one does not ponder on, say, the changes effected by heat, it can also be assumed that a simple mineral such as rose-quartz would have lost its beautiful colour after sufficient exposure to the sun's rays many millions of years ago. There is no known record of when gemstones first were deliberately heat-treated with the intention of changing their colour, and incidentally, how far back the heat-treatment of zircons can be traced has yet to be revealed. A more accurate picture, however, can be shown in regard to colour changes effected by the bombardment of gem stones with particles of various energies. During the last century diamonds were exposed to gamma rays emitted by radium[1] and this resulted in a change of colour. The discovery of X-rays and their uses, made available an additional source and various workers used this means for treating minerals and gem stones. Once again, colour changes resulted. One must not forget, too, the natural bombardment of minerals with particles emitted by naturally radioactive elements occurring in the earth's crust and studies of these effects have been going on for nearly one hundred years. Evidence that such irradiation has taken place in respect of diamond is presented by Dugdale[2]. The whole field presents a fascinating subject for study, which will probably receive attention in the future.

IRRADIATION SOURCES

When nuclear fission made its impact on civilization it brought with it an entirely new era which has affected nearly everything in life. With this era came new sources of energy with which to treat materials and as is now widely known much benefit is derived from the research work on irradiation. There is insufficient time to

dwell even broadly on this aspect and remarks must be confined to the work which has been carried out on minerals and gemstones.

Atomic Particles and Collisions

There are a number of elementary particles which can be used for bombardment of solids. One of the more important of these is the neutron which is an electrically uncharged or neutral particle capable of penetrating matter and colliding with and displacing the atoms composing that matter. When it does collide with an atom it imparts some of its energy to that atom which can move far enough to collide with and displace yet another atom (Plate I). "Knocked-on" atoms cause the most damage to the lattice and this affects the physical properties of the crystal and in some cases causes severe changes. When beryl, which has a similar structure to quartz, is irradiated sufficiently there is so much distortion of the lattice that the crystal does in fact become non-crystalline or amorphous. It seems almost superfluous to mention that the colour of gemstones can be due either to inherent constituents (idiochromatism) or to impurities (allochromatism) which form part of the electronic

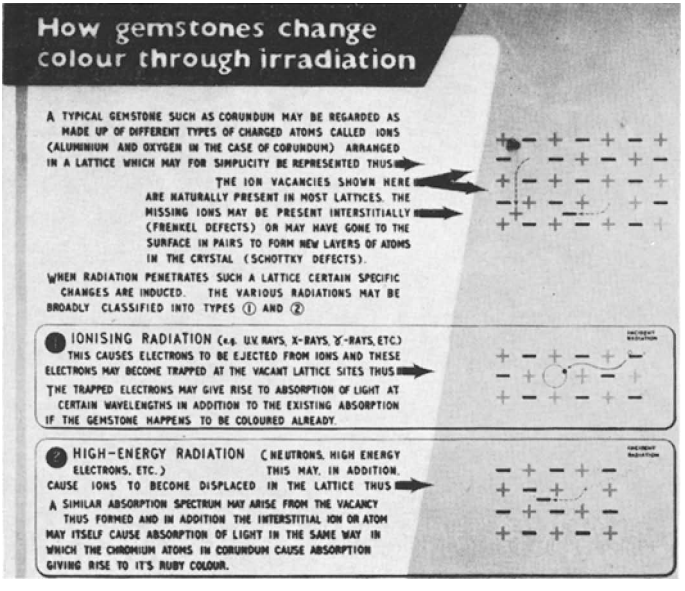

Plate I

structure of the lattice and it is on the nature and arrangement of this lattice that the selective absorption of light depends. The irradiation changes the lattice arrangement and so it might be expected to change the light absorption also. Often this change is in the visible region of the spectrum and so the stone changes colour. Now in the same way that fabricated metal is relaxed or annealed by heat treatment it is possible, to a limited extent, to restore the original arrangement of the atoms in a non-metal by controlled heating. Many of the pleasantly coloured diamonds owe their colour to this treatment and provided care is exercised no damage to the stone is likely to occur.

Examples of gemstones that have been irradiated with interesting results are: chrysoberyl, phenakite, topaz, garnet and zircon.[3]

A phenakite and a zircon belonging to B. W. Anderson were irradiated both in BEPO for one hour at $9 + 10^{11}$ n/cm^2/secs. (n.v.t.), and in the Van de Graff accelerator for three hours at $\frac{1}{2}$ MeV continuously and in each case an unattractive yellow colour was induced, which was removed by heat-treatment at 500°C.

A diamond was irradiated in BEPO for three weeks when it became black and opaque and heat treatment at a temperature in excess of 1500°C failed to restore any of its original transparency. A similar phenomenon is reported by Crawford and Wittels.[4]

First Experiments at Harwell

In the early days at Harwell the graphite moderated uranium reactors were used for very many purposes, one of them being the irradiation of diamonds with neutrons, and this work was carried out by Dugdale.[5] The results of the experiments were not significant and they caused little comment in the commercial world.[6]

Interest revived in recent years mainly because it was thought that a poor quality stone could be improved sufficiently to enhance its colour and, of course, its value. As is now known this idea has been proved to be erroneous but in spite of this, however, diamond dealers continue to have their poor quality stones irradiated[7] and heat-treated and it appears that there is a very slowly growing demand for irradiated stones which are mainly bluish-green and yellow in colour. At least one patent specification for diamond treatment has been filed in the British Patent Office. In the United States the main selling point is that such stones are marketed

as "Cyclotron diamonds".[8] The point should not be missed, however, that this is likely to be a novelty market of limited duration. The chief method now employed for treating diamonds is the one using fast neutrons resulting from the fission of uranium in an Atomic Pile or Reactor, as it is now commonly called. The use of particle-accelerator machines or "atom smashers" for colour alteration is expensive but some of the stones so treated are attractively coloured. In a typical electron irradiation the depth of the damage region might be a fraction of a millimetre in contrast to neutron irradiation where the damage is distributed randomly throughout the irradiated material. It is not surprising, therefore, that the discolouration of an electron-bombarded stone is often only superficial and it could be removed by very drastic repolishing.

A collection of other precious stones was assembled in duplicate and one set was irradiated in the uranium graphite reactor BEPO for periods varying from three to six days. The result of the treatment from the gemmologist's point of view is interesting, and disappointing, because none of the stones have been improved in appearance but as could be seen from the absorption spectra quite definite changes have occurred. No measurable changes have occurred in the physical properties of these stones but it should be remembered that they have had a comparatively short period in the reactor.

Methods of Detection

It is reassuring to know that natural blue diamonds can almost infallibly be identified and a recent simple device, based on the fact that they are semiconductors of electricity and invented by Custers, Dyer and Raal,[9] can be set up and operated with a minimum of expense and complication. One must, however, be quite clear about the difficulties attending differentiation between naturally-coloured diamonds and diamonds that have been coloured by bombardment; modern stones whose colours have been altered by nuclear machine or pile-irradiation, have a radioactivity of limited duration. Dugdale[2] confirms that residual radioactivity in diamond after irradiation is undetectable with a Geiger counter quite soon after bombardment. It is therefore necessary to observe the behaviour of suspect stones when they are subjected to ultra-violet rays or viewed through the spectroscope.[10] In general, however, it

does appear that there is still no clear-cut diagnostic test in regard to irradiated diamonds.

It is interesting to note that although the collection of irradiated gem stones is now some years old, it still retains measurable radioactivity indicating that some of the stones contain elements which possess a long half-life, that is, they take a long time to lose their activity. Using a sensitive beta-gamma counter an approximate radiometric survey was carried out on all the stones exhibited. It must be appreciated however, that whilst effort was made originally to assemble pairs, the specimens were not, as can be seen from Table I, strictly comparable.

TABLE I

RADIOMETRIC ANALYSES OF IRRADIATED GEMSTONES

BETA – GAMMA COUNTER

Specimen	*Counts per Minute*		*Remarks*
	Standard Stone	*Treated Stone*	
Green Tourmaline	Nil	136	
Kunzite	1	84	
Peridot	1	4,384	
Orthoclase	Nil	115	
Rhodolite Garnet	1	666	
Demantoid Garnet	4	74	
Almandine Garnet	3	2,293	
Natural Ruby	4	9	
Natural Sapphire	Nil	8	
Synthetic Ruby	Nil	513	
Synthetic Sapphire	7	5	
Synthetic Sapphire	3	—	
Natural Blue Spinel	—	2,393	
Synthetic Ruby	4	10	
Synthetic Sapphire ("Alexandrite")	Nil	33	
Synthetic Sapphire	Nil	211	
Synthetic Pink Sapphire	6	10	
Cairngorm	Nil	12	
Amethyst	7	4	
Rose Quartz	4	Nil	
Opal	Nil	95	Recent irradiation
Zircon	2	1,242	
Zircon	Nil	1,051	
Zircon	19	4,633	
Zircon	11	4,760	
Brazillian Topaz	10	8	
Brazillian Topaz	7	Nil	
Beryl	5	2,636	
Spinel	Nil	4,549	
Spinel	11	6,959	
Emerald	Nil	93,693	Recent irradiation
Periclase	13	—	
Cultured Pearl	Nil	—	
Cultured Pearl	12	—	
Cultured Pearl	10	—	
Natural Pearl	6	—	
Cultured Pearl (Neutron)		2,778	Recent irradiation
Blister Pearl (Neutron)		3,402	,, ,,
Baroque Pearl (Neutron)	—	184,000	,, ,,
Cultured Pearl (Electron)		3	,, ,,
Cultured Pearl (Electron)		2	,, ,,
Cultured Pearl (Electron)	—	4	,, ,,
Synthetic Rutile		50	,, ,,
Blackened Diamond (Neutron)		10	,, ,,
Blue Diamond (Electron)		8	,, ,,
Blue Diamond (Electron)		9	,, ,,

All the standard stones gave low readings whereas, with few exceptions, all the irradiated stones gave significant and in some cases high readings. After a further large collection had been examined (Table II) there is some justification for accepting a critical radiometric analyses as a guide to the origin of a specimen.

TABLE II

RADIOMETRIC ANALYSIS OF UNTREATED JEWELLERY AND GEMSTONES

BETA – GAMMA COUNTER

Specimen	*Counts per Minute*
Three-stone diamond ring	7
Rough industrial diamond	3
Pink synthetic sapphire ring	7
Natural Yellow sapphire	Nil
Natural rough corundum	2
Natural black "Silky" sapphire	Nil
Natural blue star sapphire	3
Natural dark green sapphire	Nil
Natural blue sapphire	14
Green zircon and white sapphire ring	178
Orange zircon ring	Nil
Eleven stone green zircon bracelet	972
Yellow zircon	73
Crystal of brown zircon	98
Blue zircon	11
Orange zircon	21
Crystal of Red spinel	Nil
Crystal of Red spinel	5
Rough Madagascar aquamarine	6
Colourless beryl	Nil
Morganite (beryl)	Nil
Aquamarine	1
Hessonite garnet	7
Pyrope garnet	Nil
Pyrope garnet	Nil
Pyrope garnet	Nil
Hessonite garnet	Nil
Hessonite garnet	4
Green glass	12
Yellow glass	Nil
Green glass	47
Green glass	Nil
Soude emerald (quartz)	Nil
Green tourmaline	Nil
Green tourmaline	Nil
Green tourmaline	Nil
Yellow tourmaline	12
Parti-coloured tourmaline	9
Peridot	Nil
Peridot	Nil
White topaz	Nil
White topaz	11
Pink topaz	Nil
Orange topaz	1
Amethyst	Nil
Kunzite	1
Apatite	Nil

DICHROISM

Work on the collection of irradiated stones was started in 1957.[11] Some striking dichroic effects were seen in what were previously colourless stones and novel though this appears, it must be remembered that a coloured birefringent stone could be expected to exhibit some pleochroism. The rhomb of calcite irradiated in connection with the pearl experiments, exhibits strong dichroism.

Kunzite, which normally displays distinct dichroism of pale pinks, presented a sharp contrast of pink and brown after irradiation, and it is worthy of note that the irradiated stone was originally bombarded with X-rays, after which it became a delightful "hiddenite" green. Unfortunately, however, this colour disappeared and the stone reverted overnight whilst it was beneath an ordinary tungsten filament lamp and Pough[12] comments on the need for such specimens to be kept cool and in darkness. The colourless sapphire boule after irradiation displayed distinct dichroism, whilst the irradiated ruby boule twin-colours contrast markedly with those of the untreated one.

A cut blue zircon after irradiation displayed no dichroism yet a synthetic sapphire ("alexandrite"), normally showing two shades of pink, showed a sharp contrast of pink and orange after treatment.

The square-cut synthetic blue sapphires, normally blue and mauve, changed to green and mauve and what was taken to be a natural blue sapphire was matched for colour with a synthetic blue sapphire. Quite inadvertently a natural blue spinel has been selected and this stone became a rich brownish-red, which is no doubt related to the colour seen when natural blue spinel is viewed through the Chelsea colour filter.

There was nothing consistent in the behaviour of naturally pleochroic stones after irradiation, therefore no significance should be attached to these results, and indeed as would be expected, there is in some cases considerable disparity in the absorption spectra of the pairs of stones.

In 1942[13] Cork wrote of experiments carried out at the University of Michigan. He bombarded crystals with deuterons in a cyclotron, and on occasions, instead of forming colour centres in the bombarded area, colour formed at the edges and he puts this reversal down to too intense a bombardment.

He found, as did the writer, that X-ray bombardment produced an ephemeral effect but neutron-treated stones, which were permanent at room temperature, would revert if subjected to annealing temperatures of 500°C.

It is interesting confirmation that his rose-quartz experiment produced a result comparable with that produced at Harwell and the disparity between his diamond annealing temperatures and those of other workers tends to support the view that these temperatures are not critical.

At Princeton, Bass[14] studied the effects of gamma irradiation on certain minerals and concluded that no important changes had been effected other than those concerned with colour, in minerals of interest to gemmologists which included quartz, fluorspar and epidote.

Fluorescence

The collection of irradiated stones was examined under a concentrated beam of ultra-violet light emitted by a quartz-mercury vapour lamp and, whilst no significant data accrued, it was noted that outstanding differences in fluorescence were always related to severe colour changes after irradiation.

Pearls

The irradiation of pearls, natural or cultured, has not, so far, occupied the attention of many workers,[15] but one case of colour change has been reported from Japan. Neutron bombardment of pearls was carried out in BEPO and the results can scarcely be called dramatic, the colours are not very attractive and subsequent heat-treatment would, without any doubt, effectively drive off combined-water and decompose the organic constituents. Profiting by the experience gained with diamonds it was thought a good idea to subject pearls to electron bombardment in the Van der Graaf Particle Accelerator and the first mild dose of fast electrons of 1 MeV at 1 microamp for one minute produced a greenish colour. As considerable heat is evolved during the process special precautions were taken to cool the pearl. Rather surprisingly, a further identical dose caused a reversion and the pearl became white again but whether this was due to auto-annealing by the second attack or whether it was due to excess heat is not clear, but severe superficial cracking would indicate the latter (Plate II). A repeat of the experiment with two pearls again resulted in the green colour. One of these pearls was then placed under a powerful quartz mercury-vapour ultra-violet lamp for three hours but this had no effective annealing action. Petrological examination of some of the specimens was carried out employing conventional techniques. The pearls were lapped onto glass slides using "Hyprez" diamond paste and fluid. Next, the specimens were secured to the slides with "Araldite" Resin and after curing at relatively low temperature,

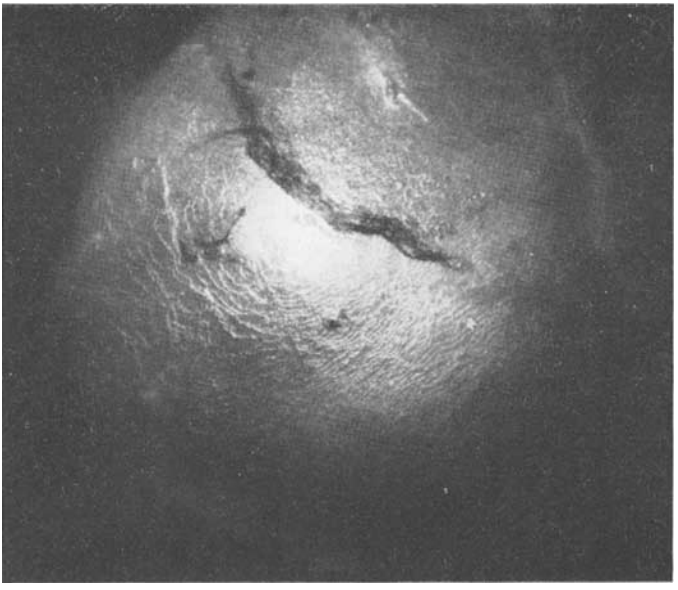

PLATE II

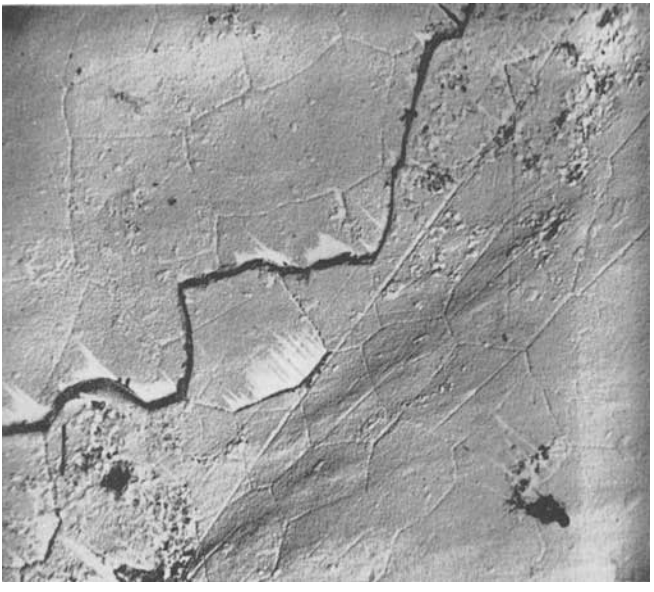

PLATE III

cut with a thin diamond wheel. Final lapping was achieved with "Hyprez" diamond paste and fluid on a disc of high-alumina porcelain. So thin were the ultimate sections that they suffered damage during the final stages but it clearly could be seen that bombardment had effected the organic layers and there was no discernible change in the calcium carbonate layers, apart from the platey layers and hexagonal cross-sections having an increased relief after irradiation, and this shows up extremely well in the electron micrograph (Plate III). A cultured pearl was cut into two, one half irradiated in BEPO and the two halves polished and macrophotographed. No further evidence is necessary of the damage sustained (Plate IV). A baroque Australian pearl was sectioned and one half irradiated with neutrons in BEPO and microscopic examination revealed a considerable amount of damage. Under an ultra-violet analytical lamp it was observed that the faint greenish fluorescence of all the pearls had slightly deepened in colour after irradiation.

The cause of the discolouration of pearl after irradiation is not entirely clear in spite of further experiments carried out on the constituent carbonate. A specimen of clear crystal calcite was

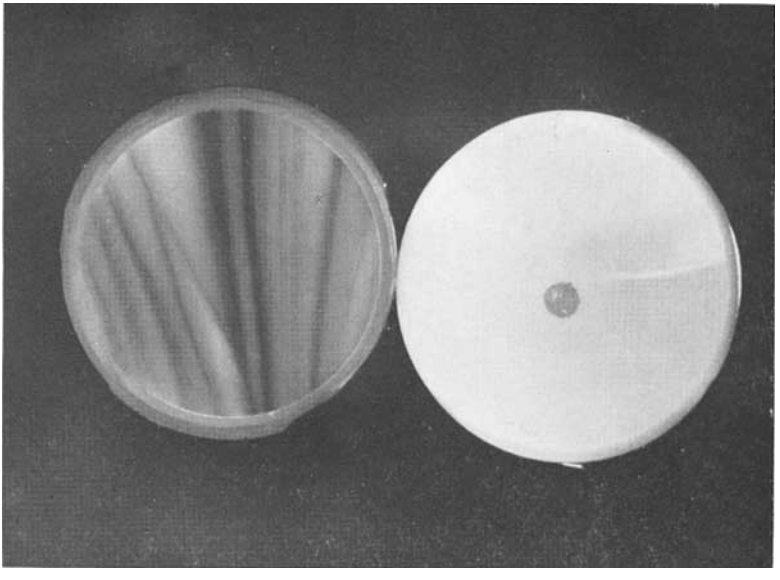

PLATE IV

bombarded with neutrons in BEPO for 56 hours at a flux of $11{\cdot}6 + 10^{11}$ nvt, after which it became a deep yellow in colour. It is possible that decomposition of the conchiolin contributes to the colour change but after microscopical examination the conclusion to be drawn is that a change has occurred in the surface platelets, which, by diffraction and interference, produce the much-prized "orient".

This change, subtle though it may be, could be responsible for selective absorption affecting the diffraction-interference effect and resulting in the greenish "orient" now to be seen in the irradiated pearls.

Conclusions

It will be seen that several interesting effects arise from the irradiation of gemstones. It appears impossible at present to predict colour changes of diamonds on irradiation and bombardment of precious stones usually results in deterioration in appearance. Interesting effects relating to dichroism and fluorescence, which require further investigation, have been noted.

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DIAMOND CUTTING IN LILLIPUT

Dean Swift failed to include in his book the practice of the diamond cutting art by the Lilliputians, but an attempt to make up for this omission has been made by the inventor of the A. D. Leveridge Mm. Gauge-Estimator.

Illustrated is Mr. Leveridge's latest creation, which is the fruit of a long period of patient and painstaking work. To obtain an idea of the diminutive size of the diamond cutting factory, which he personally constructed, note the maker's hand and a pencil shown in the picture. The full length of this group of four different work benches is only 24 inches, and their height only 4 inches. Each bench has its electric lamp, motor, and robot workman.

The cleaver's hammer drops rhythmically upon his knife, which he positions each time, all in a life-like manner. The girdling machine, the sawing machine and the scaife are only one inch in length or diameter. In like proportions are the cleaver's boxes, and all the loupes, dops, tangs, weights, tweezers, bunsen burners, hammers, wrenches, lamps, motors, belts—even diamond papers and rough stones.

The tiny factory has attracted much attention in the U.S.A. and it is expected that it will be exhibited at diamond trade shows.

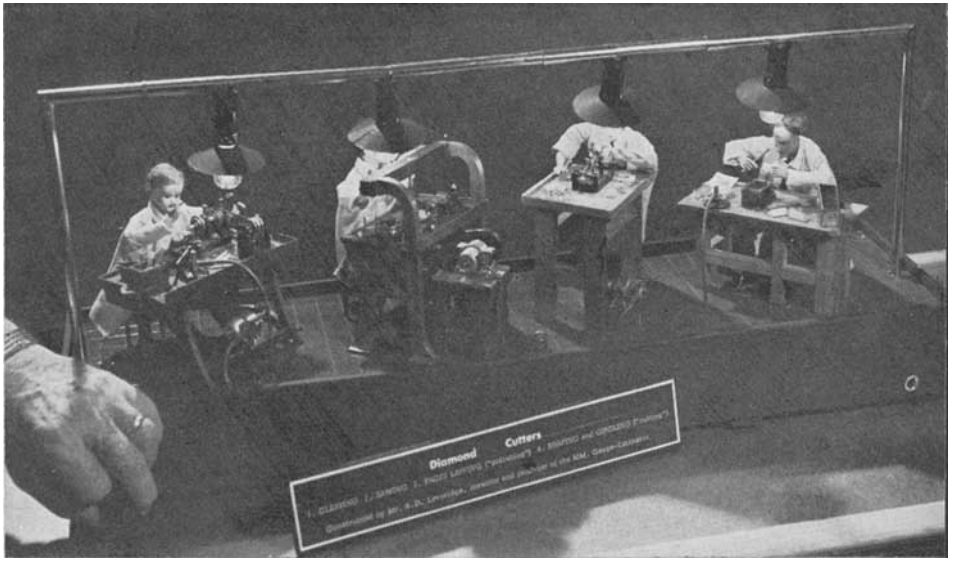

ASSOCIATION NOTICES

PRESENTATION OF AWARDS

Fellows of the Association from all over Britain and successful students coming from places as far away as Auckland, New Zealand and Pennsylvania, U.S.A., gathered at the Goldsmiths' Hall on 5th November, 1962, for the annual reunion and prize presentation.

The presentation was made by Mr. Robert Webster under whom many had studied and with whose books even more are familiar. He took the opportunity of making a forecast concerning the way in which gemmological knowledge might—and needed—to be advanced in the future.

Mr. Webster recalled that it was 28 years since he walked up the steps and on to the platform at the Hall for the first time to receive his diploma. In the early days, he said, gemmology was much simpler. Provided students could absorb and communicate a lot of data and figures they usually succeeded in the examinations. The percentage of failures was low. By the mid-thirties things had begun to change. New instruments and new techniques were introduced which affected practice more than theory and this development had continued. It was one reason why the third year of study had been introduced during which some modest research could be done.

After the war the change had been complete. This had mainly been caused by the search for new minerals with possible war uses and many found their place as gem stones. This had continued until to-day there were present problems in gemmology to which the answer was not known.

Because of this and further developments he forecast that the gemmologist of the future would need to know far more of chemistry, physics and even electronics than he knew to-day. He saw the role of the gemmologist in the future as one that was split into two, with the split ever widening.

Most of the students who took the examinations were jewellers. He realized that with all their other commitments, the jeweller could not take on an extra-gemmological series of studies, however valuable it might be to his trade. Already the jeweller had to know far more than in the past about more subjects. The basic training he could get in his Fellowship course should, however, be sufficient for his trade needs. There was another group of students who were not connected with the jewellery trade but took up gemmology from an inborn liking for the subject. They often had a good grounding in science. They could be a valuable help to the Association and indirectly to the trade in the knowledge they gained.

Unfortunately, said Mr. Webster, the trade was made up of small firms that were unlikely to get together to establish a laboratory for research in the way that large firms did in their different fields. Pure research work in gemmology was needed and not just the odd bits of work that might be sandwiched between routine jobs. A small but expert group of Fellows might be able to get together and do such research. They often had access to the necessary equipment that could help them. Such a group might produce the answers to some of the problems which at present, lacking the time and equipment, we cannot.

Thus he saw the gap between the ordinary "trade" gemmologist and the scientific gemmologist continually widening, because there would have to be much greater attention paid to research in the future.

Presiding over the gathering was the Chairman, Mr. F. H. Knowles-Brown, who took the opportunity of thanking the Worshipful Company of Goldsmiths for the hospitality afforded them and reminded those present that a Hall had stood on the present site for over 600 years. The Chairman congratulated Mr. Webster on his latest book and acknowledged the great work he had done for gemmology and was sure that be would not mind his mentioning that as a colleague of Mr. B. W. Anderson great things had been expected of him as B. W. Anderson was, in his opinion, probably the world's most eminent gemmologist.

Mr. B. W. Anderson, in proposing a vote of thanks, spoke of his link with Mr. Webster over the past twenty years or so as student, colleague and friend. He said it was particularly appropriate that Mr. Webster should have made the prizegiving on this occasion, the year which saw his new book published. Moreover, Mr. Webster was the man who had helped so many of those who had received awards, to pass the examinations by the teaching he had done.

He recalled that the very first class he had taken at the Chelsea Polytechnic had been a star one, including among its students not only Mr. Webster, but also Mr. Keith Mitchell, Mr. W. Flower and Mr. Ross Popley. It was also the 1934 class at Chelsea that marked the period of the evolution of the Chelsea filter, now used throughout the world as a useful gemmological tool.

MIDLANDS BRANCH

A meeting of the Midlands Branch of the Association was held at the Imperial Hotel, Birmingham, on Friday, 26th October, when the Chairman, Mr. W. W. Bowen introduced the guest speaker, Mr. Lionel Burke, Publicity and Group Public Relations Officer to De Beers Consolidated Mines, whose subject was "Diamond Distribution".

Mr. Burke began with a brief historical review of De Beers and explained that the syndicate came into being because of the need for consolidation among individual diggers, in order to protect their interests. At the beginning of this century, the discovery in the Transvaal of a chain of gem-quality diamonds almost ruined the company, but to-day De Beers control some 40% of the world output of diamonds.

On the question of markets, Mr. Burke named Amsterdam, Antwerp, London and New York as the largest and most significant, and said that in London each registered buyer (of which there are several hundreds, all cutters and dealers)

receives an invitation to apply for inclusion in the monthly "sites", where carefully graded diamonds are sold in series only—and for cash. He emphasized the importance of a stabilized market to the whole of the diamond industry.

At question-time, Mr. Burke answered several interesting points raised by members, and the meeting closed with a sincere vote of thanks to Mr. Burke, proposed by Mr. Norman Harper, Vice-Chairman of the Association.

COUNCIL MEETING

A meeting of the Council was held at Saint Dunstan's House, Carey Lane, London, E.C.2, on Monday, 5th November, 1962. Mr. F. H. Knowles-Brown presided.

Details were received of the specialist course in gem diamonds, which had been commenced at the Jewellery and Silversmithing School, Birmingham, with Mr. Norman A. Harper as lecturer. The Council agreed in principle to act as an examining body in connexion with the course.

The following were elected to Fellowship, Ordinary and Probationary membership:—

Elected to Fellowship

Aho, Risto, Laaksolahti, Finland
Allnutt, Anthony J., London
Asprey, Maurice, London
Bacon, Stephen J., London
Berkel, Joannes V. M. v., Utrecht, Holland
Borgen, Annemarta, Oslo, Norway
Borgen, Per O., Sarpsborg, Norway
Chesebrough, Rosser, Sherman Oaks, Calif, U.S.A.
Crank, Susan Elizabeth, Bolton
Dowse, John E., Birmingham
Egli, Ernest, Geneva, Switzerland
Erichsen, Bjørn T. N., Horten, Norway
Evans, Rennie M., Toronto, Canada
Farrant, Eric R., London
Fine, Jay, Orillia, Canada
Foulkes, Peter C. A., London
Freedman, Israel, London
Gillougley, James H., Glasgow
Goad, Michael J., Toronto, Canada
Griffiths, John A., Kidderminster
Gunaratne, Herbert S., Colombo, Ceylon
Harper, David C., Welling
Heidelberger, Martin, Zürich, Switzerland
Hinton, Bernard A., Toronto, Canada
Hollens, John F., Pinner
Hudson, Douglas G., Whitstable
Johne, Vera A., Oslo, Norway
Johne, Thor A., Oslo, Norway
Jones, David C., Leamington Spa
Klerk, A. F. C. de, Oud-Gastel, Holland
Leimu, Veikko H. K., Hämeenlinna, Finland
Lieberman, Ian S., Ilford
Marshall, John F., Sutton Coldfield
Marshall, Nigel, Birmingham
Marno, Raimo A. U., Helsinki, Finland
Moi, Gerd, Oslo, Norway
Møller, Jørgen E. R., Copenhagen, Denmark
McCarty, Fay V., Birmingham
McGoldrick, Bernard, Liverpool
Otteren, Karl-Jørgen, Sandnes, Norway
Pettersen, Egil N., Fredrikstad, Norway
Petzall, Ossi G., Falkoping, Sweden
Potterat, Raymond, Geneva, Switzerland

Robinson, David M., Liverpool
Sarin, Baldev K., London
Shotton, John J., London
Simpkins, Una M., Caddington
Thompson, Colvin G., London
Travis, Denis J., Esher
Turnbull, Elizabeth, Sunderland
Turton, Phillip J., Solihull
Virkkunen, Leena K. M., Roihuvuori, Finland
Waters, Peter A., Manchester
Weighell, Stephen N., London
Werkhooven, P. J. K. van, Hilversum, Holland
Weston, Raymond W., Solihull
Wilkins, David, Swindon
Williams, Geoffrey F., Esher

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Blyth, Elizabeth R., Nanaimo, Canada
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Fleming, John A., Auckland, New Zealand
Fraleigh, Jack, Toronto, Canada
Gould, Henriette Johannesburg, S. Africa
Humphreys, Alan L., Andover
Jones, David W., Crawley Down
Kan, Noah, Hong Kong
Kern, Edward, West Hartford, U.S.A.
Lee, Raymond G., Torquay
Lodge, John W., Newcastle-upon-Tyne
McChlery, George M. A., Glasgow
Maunton, Frederick J., Bromley
Nickolds, Ann M., London
Penner, Ernest, Islington, Canada
Ranger, Clive J., Bromley
Searle, Ian V. H., Ilford
Selvon, Dennis R., Woodford Green
Sheriff, Hassan, London
Simpkins, Una M., Sidcup
Tivoli, Harold, Kansas City, U.S.A.

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Scott, William N., Melbourne, Australia
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Städelin, Alwin, Lucerne, Switzerland
Sunder, Dularamani, Hong Kong
Tillander, Edith U. M., Helsinki, Finland
Watson, Maurice, Welwyn Garden City
Watts, James W., Grimsby
Windsor, Dharmadasa, Singapore

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Davis, Max, Wembley
Forbes, David R., Salisbury, Southern Rhodesia
Kay, John C., Harrow
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The, Tiong-hien, Djakarta, Indonesia
Tillander, Gemma D. A., Helsinki, Finland
Torres de Goytia, Rafael, Valencia, Spain

HANDBOOK OF GEM IDENTIFICATION

The Gemological Institute of America has recently announced the sixth edition of R. Liddicoat's "Handbook of gem identification". The price is $8.75 (£3 5s. 0d.) plus postage, and copies may be obtained from the Association.

TALKS BY MEMBERS

BLYTHE, G.: "Gemstones", Women's Fellowship Group, Pritewell, 1st October, 1962.

BAGLESS, G.: "Gemstones", Darlington Ladies' Circle, 19th September, 1962.

WEBSTER, R.: "Gemstones and their modern simulants", Norwich and District Jewellers' Association, 10th September, 1962.

KENT, D.: "Jewellery", N. W. Kent Townswomen's Guild, Beckenham, 12th December, 1962.

MEMBERS' MEETINGS 1963

Feb. 15th Photographic evening Medical Society of London, Chandos Place, W.1. 7 p.m.

Feb. 27th Midlands Branch Dinner and Dance, King's Highway, Quinton, Birmingham.

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A GARNET PROTRUDES

By A. E. FARN

WORKING in the laboratory has compensations in the fact that one either becomes known or gets to know fellow gemmologists (both in the trade and outside of the trade). Buying and selling is much more interesting and rewarding if one is dealing with goods whose qualities, physical, optical and/or financial are appreciated by both sides.

I am often shown pieces of jewellery for interests' sake, or shall I say, for their gemmological interest. Quite recently a friend, Oscar D. Fahy, sent to me as an item of interest a small diamond which had broken and presumably was a replacement job in jewellery. The stone weighed 0·12 cts and was brilliant-cut with a slice broken away from the girdle as a chord is to a circle. On close inspection a real interest became immediately and vividly apparent. We have known of garnet inclusions in diamond before and seen photographs of them but here was an inclusion with a difference. A garnet certainly was "included" in the broken portion but another, which had caused a plane of weakness and strain, was centred in the rough breakage plane and was still embedded half in and half out of the diamond. The garnet literally protruded from the cleavage face of the break and at first sight it looked as if it had been planted there by artificial means. I know that exhibits of diamond in blue ground are suspect, i.e. they are often put in for show purposes, but this piece really was startling in

it's revealing the garnet quite sharply. Yet in so small a stone of only 0·12 ct. it was easily seen with a 10 × lens. My first reaction was to covet the stone from an interest point of view. Here I was very fortunate indeed because on request for a loan of the stone to do more to it, I was generously given it by Mr. Fahy. Having burned my boats by saying I wanted to write it up I was faced with the fact that in an article people like pictures. R. K. Mitchell, to whom I am indebted, took a keen interest in the matter and spent quite a lot of time and patience in obtaining the photographs of the emergent garnet crystal. I understand this is far from an easy job and in fact I was supplied with a small roll of negative of exposures taken of the stone. When one considers that the *stone* is only 3 mm across and the "inclusion" barely 1 mm in length and about 0·1 mm in thickness, it was quite a feat to photograph it with any real sharpness. Had colour photography been possible it would have been a very impressive sight indeed since the garnet was such a vivid red. At first, although garnet seemed to be the obvious solution, I wasn't happy with it's colour since other garnets used as indicators did not seem to have the fine red colour, even in smaller pieces.

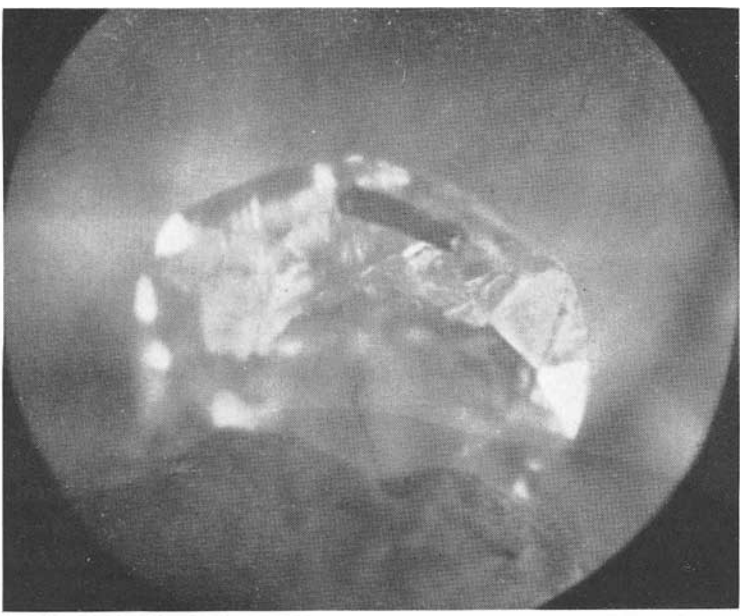

My first rather quick check on the garnet by spectroscope showed no absorption spectrum, neither proving or disproving it to be garnet. As I had a lurking suspicion that it could be spinel I placed it very carefully between crossed filters and had absolutely no reaction for chromium—here I felt sure that such a critical test would have given a reaction (since "colourless" synthetic sapphires have glowed faintly between crossed filters due to the finest trace of chromium in their manufacture. Had the inclusion been a spinel—with such colour—it would have glowed a fierce red between crossed filters. This spurred me to further efforts with the spectroscope. By sitting the diamond on a thin wafer of lead and piercing a hole just large enough for the inclusion to fit, I was able to force light through the stone and obviate glare from my eyes. I must confess to little success in this transmitted light method and did not see any spectra.

Later I tried using a two-thirds objective and an eyepiece to focus the stone in the manner described for the spectroscope set up as described in the Journ. Gemmology, April 1962, and, leaving the frosted glass screen on the microscope eyepiece (usually one removes it), I was able to place the spectroscope slit practically on the image of the garnet and, to my relief, I was able to see something like a pyrope spectrum, which since the stone in all probability came from Kimberley was not surprising. The provenance of a stone can be useful in clinching a determination when all other factors add up to 99% and although one "knows" the stone to be whatever it is by sight and rule of thumb, it is very satisfying to know your tests stand firm against all doubts and aspersions now and tomorrow.

Sometimes a stone is presented for checking and one is told it has doubts cast upon it and that one has tested it years before and stated it to be genuine. It is always comforting to find that one's determination of weight, size, shape, spectra, etc., all add up to 100% positive and literally "no stone was left unturned".

NOTES ON THE GEM VARIETY OF THE OUTOKUMPU CHROME-DIOPSIDE

By Y. VUORELAINEN

THE Outokumpu copper ore is situated in Northern Carelia. It is closely connected with quartzite in the Kalevian mica schist formation. The zone is characterized by a number of Ni- and Cr-bearing ophiolites, which have intruded into the rupture zones of the schist formation. In addition to these, there are also skarn rocks, which have been formed by the reaction between the dolomitic varieties of the ophiolites and quartzites. Their most common minerals are Cr-bearing silicates, such as chrome-diopside, chrome-tremolite and chrome-garnet (uvarovite). Chrome-epidote (tawmawite), chrome-tourmaline and kaemmererite are also met with, as rarities. In addition to the silicates and carbonates, oxides also occur, the most common of which are picotite, chromite and eskolaite, Cr_2O_3. A considerable amount of chrome-mica fuchsite is encountered in quartzites. A common feature characterizing the chrome-silicates of most of the occurences is their beautiful, deep emerald-green colour. Due to this colour, attempts have been made to use many of them as gemstones, but only the chrome-diopside has turned out to have any value in this respect.

An almost monomineralic chrome-diopside rock with a width varying from a few centimetres to a few metres is often encountered at the contacts of quartzites. In these rocks the lengths of the biggest, board-like crystals can attain as much as two metres. Usually the mineral has a greyish, emerald-green colour, showing a distinct cleavage, and consequently it is unsuitable for cutting. In limestones and pure quartzites some very beautifully shaped, deep-coloured crystals are encountered, often suitable for cabochon-cutting. In the cabochons, cut along the *c*-axis, a beautiful cat's-eye phenomenon can sometimes be observed.

Extremely rare is zoned chrome-diopside occurring in dolomitic skarns, where the bright emerald-green layers alternate with those of the grey or almost white ones. Among the varieties described above a glassy, beautifully coloured, slightly transparent material, suitable for cutting is only seldom encountered. The first crystals of gem quality were discovered by the author in 1948 among the

waste material. The crystals—the biggest of them being 2 by 0·5 cm—were completely embedded in sulphidic material, which in this case was pyrrhotite. Their colour was bottle-green, only the tops having a deeper colour.

Due to this first discovery I began to study the sulphide apophyses which penetrated from the ore body into the skarn rocks. In some pyrrhotite dikes gem quality crystals were found, but their colour was not very good. In 1954 I finally encountered perfectly clear, beautifully coloured chrome-diopside crystals on the walls of apophyses, rich in chalcopyrite, which had been caused by local tectonic movements. Later observations showed that this is the only mode of occurrence of fine chrome-diopside in Outokumpu. The crystals are almost invariably twins, the twinning plane being 100. The biggest, gem quality crystals attain 20 carats. Some of the crystals, which were quite faultless at the moment of discovery, broke a few days after they had been taken to the surface. Unfortunately the number of the good crystals found is rather small; perhaps only a few hundreds have been found. The Smithsonian Institute is probably the only public collection where some of these stones are displayed. Three of them are beautiful, cut specimens, and one is a crystal of about 10 carats, embedded in the matrix.

The mineral is distinctly pleochroic, the colour changing from yellowish emerald-green to deep, pure emerald-green.

Data

R.I. determination with Rayner refractometer

$\alpha = 1{\cdot}668$
$\beta = 1{\cdot}678$
$\gamma = 1{\cdot}700$

Hence opt. +, 2V = ca. 60^0 corresponding ordinary diopside with 6–9% hedenbergite.

X-ray powder diffraction diagram was typically that of diopside.

With a spectroscope three lines in the red were observed, the first one the broadest; there was general absorption from blue onward.

An average density figure of 3·286 was obtained by Dr. P. Zwaan, of Leiden, from very small specimens of less than one carat. In view of the smallness of the specimens other values are possible.

THE CLASSIFICATION OF DIAMONDS ON THE BASIS OF THEIR ABSORPTION AND EMISSION OF LIGHT

By B. W. ANDERSON

MOST of the gem minerals have peculiarities of physical behaviour which have made them profoundly interesting to scientists who care nothing for their ornamental or monetary value. Diamond, incomparably the most important gemstone in commerce, is an excellent example of this. Despite the apparently simple composition and structure of the mineral, each individual diamond is less predictable in its reaction to electrical or electro-magnetic energy than a stone of any other species. In particular, in the absorption of infra-red, visible, and ultra-violet rays and in the emission of light in the form of fluorescence and phosphorescence, diamonds are notoriously variable

This paper consists of a brief review of the discoveries in this field over the past 100 years or so, and a more detailed account of recent attempts to bring some sort of order and pattern into these aspects of diamond behaviour by classifying diamonds into various recognizable " types ".

In the last two decades physicists have entered the lists and have accurately measured and codified the phenomena in an attempt to explain matters on their own fundamental level. The gemmologist can gain in understanding by a careful study of their work, but on his own account, with his more limited apparatus and skills, has developed methods of observation which enable him to cope with some success with such urgent practical matters as the discrimination between natural coloured diamonds and those which owe their colour to irradiation.

LUMINESCENCE

The scientific study of luminescence in diamond can be said to have started a little more than a century ago when E. Becquerel,[1] in one of the really " great " papers in the history of science, described the reactions of diamond and other minerals in his newly-developed phosphoroscope. In this ingenious apparatus he was able to study the spectrum of phosphorescent light from diamonds a fraction of a second after they had been illuminated by light from

the sun. He found that the phosphorescent light was usually blue when the observations were made only some 1/1000th of a second or less after irradiation, but changed to yellow when the interval was longer. Thus early he discovered one of the interesting facts of diamond luminescence which in our experience is invariable—that a bright blue-fluorescing diamond displays a persistent yellowish phosphorescence. This forms an important practical test for diamonds in jewellery. Becquerel also depicted, in the drawing accompanying his paper, the range of the luminous glow from diamond, showing it to extend from the orange to the blue with a break between the E and F lines of the Fraunhofer spectrum—i.e. between 5270 and 4861Å.

Among other early observers on diamond fluorescence and phosphorescence was Sir William Crookes[2] who obtained spectacular results under cathode rays, including the rarer green, yellow, and even red fluorescence which some diamonds display. Crookes recorded the wavelengths of several bright lines seen in the strong greenish-white fluorescence of a green diamond as 5370, 5130 and 5030Å, which accord closely with more modern measurements. He further mentions seeing " the yellow sodium line " and the " citron line of yttrium " in light from diamond. These are almost certainly lines at 5895 and 5750Å, since established in luminescent diamonds.

Up till about 20 years ago the fluorescence of diamond and its variation were plausibly ascribed to the presence of impurities—the almost invariable cause in other minerals and in chemicals. Spectroscopic analysis does indeed reveal the presence of many trace elements in the mineral, of which Al, Si, Ca, Mg, Cu, are the most commonly present; but even the most careful and thorough experiments, such as those of Chesley[3], failed to provide any consistent connexion between colour, fluorescence, and any specific impurities. Nor did there seem any definite connexion between fluorescence and the locality where the diamonds were found.

In the early 'forties, Sir C. V. Raman and his co-workers in Bangalore investigated with great thoroughness the absorption and emission spectra of diamond and showed the intimate connexion existing between these phenomena. Though they did not interest themselves in the question of colour in diamond, it is largely due to their work that the " impurity " school of thought has been abandoned, except perhaps in certain special cases, and the lattice

of diamond itself and defects in the structure of the lattice have been held accountable for variations in fluorescence, absorption, and hence colour of the mineral. In recent years the extensive changes in colour, absorption and fluorescence of diamonds which can be brought about by bombardment with sub-atomic particles have provided further powerful evidence to the same effect.

Relation Between Absorption and Fluorescence

In 1941 P. G. Nayar [4] (of the Raman school) published three papers on the luminescence, absorption, and scattering of light in diamonds, in which he showed that a mirror-image symmetry existed between emission lines or bands in the visible spectrum of a blue-fluorescing diamond and absorption bands found in the near ultra-violet. The " hinge " on which both these systems turned was an important band in the violet at 4155Å, which could appear either as an absorption or as an emission line. This absorption band had been first observed in many diamonds by B. Walter in 1891[5], as described later. Nayar was convinced that there existed a direct relationship between the strength of fluorescence and the strength of the 4155 and associated absorption bands. Our own experiments did not bear this out: many diamonds with a powerful 4155 band are virtually inert under ultra-violet rays. On the other hand, we found that the strength of the 4155 band went step by step with that of another series of bands in the blue and violet, of which one at 4780Å is the most important, and that all these bands increased in strength as the depth of tint in diamonds of the " Cape " series became more and more pronounced.

Another important absorption and fluorescent system in diamond based on a line at 5040Å was found by the writer and C. J. Payne to be characteristic of green-fluorescing diamonds, and a suggestion was eventually made (1943)[6] that diamonds could be classified on the basis of their three main fluorescence colours into 3 groups, as follows:—

Blue-fluorescing diamonds, belonging to the " Cape " series, with absorption bands at 4155 and in the near ultra-violet, accompanied by bands at 4780, 4650, 4520, 4350 and 4230Å and fluorescence maxima at 4285, 4390, 4520, 4650Å;

Green-fluorescing diamonds, belonging to the " Brown " series, with absorption bands at 5040, 4980, 5370, 5120Å, of which all save 4980 can appear also as fluorescence lines;

Yellow-fluorescing diamonds, including true " canary " yellow diamonds, showing no visible absorption or fluorescence lines at normal temperatures.

Anna Mani[7] (another of the Raman school) published an important paper in the following year (1944) in which she was able to give full details of the 5040 system, and show that here too there was mirror-image symmetry of absorption bands on the shorter wave-length side and fluorescence bands on the longer wave-length side of the " key " 5040 position.

The absorption bands or lines listed above, and delineated in the illustration can be seen quite sharply through a hand spectroscope at room temperatures, but the fluorescence lines are normally not clearly resolved against the background of a broad emission band unless the stone is at low temperatures such as that of liquid air.

Absorption in Diamond

Having now reached a point in this brief survey where the interdependence of absorption and emission bands in diamond had been recognized, it will be convenient to trace the discovery of the absorptive properties of diamond. Discrete absorption bands were first reported by Walter in 1891, as mentioned above. Using sunlight he found that all the 50-odd diamonds over 1 carat that he examined showed a narrow absorption band which he called " alpha", in the violet near 4155Å, and in yellowish stones other bands, of which the strongest was at 4780Å.

In 1934 came the classic and often cited paper by Robertson, Fox and Martin[8] on " Two Types of Diamond ", in which the now

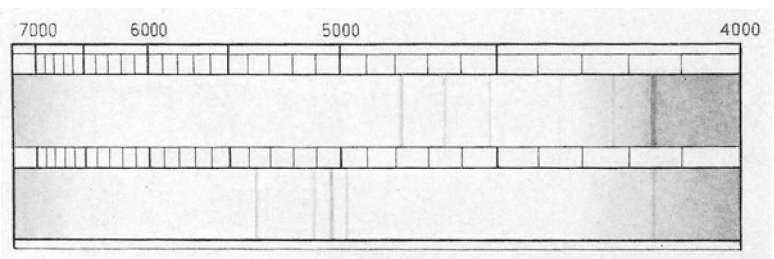

Absorption bands as seen in diamond through a prism spectroscope
(*top*) *Yellowish diamond of the "Cape" series, blue-fluorescent;*
(*bottom*) *Brown diamond, green-fluorescent.*
(*from a drawing by T. H. Smith*).

familiar division into Type I and Type II diamonds was first made. Type I diamonds have an absorption band in the infra-red at 7.8μ and are opaque, or nearly so, to ultra violet light beyond 3000Å, while the rarer Type II diamonds have no band at 7.8μ and are transparent to about 2250Å. There are other differences, e.g. in photo-conductivity, fluorescence, and X-ray diffraction patterns, but the most conveniently assessed is the ultra-violet transmission.

Many years earlier (1862), Professor Miller[9] of King's College, London, had noticed that two out of three diamonds he tested transmitted much further into the ultra-violet than the others, and Peters[10] made a similar observation in 1893 without following it up. Robertson, Fox, and Martin's paper provides a good example of how much the facts determined depend upon the apparatus and experimental conditions, for, though they studied a large number of diamonds and were well aware of Walter's work, they were able to detect the 4155 absorption band in only one of their specimens and thus dismissed it as not an essential or important feature in diamond. They would have been astonished to know how readily this line can be seen in almost any sizeable diamond with a simple hand spectroscope.

The distinction between Type I and Type II diamonds and (in Type I stones) between the blue-fluorescing "Cape" series based on the 4155Å band and stones of the green-fluorescing "Brown" series based on the 5040 band continues to form a useful broad basis for classification, though many diamonds are found which are intermediate in behaviour and in most fluorescent diamonds both emission systems are functioning, though in very variable absolute and relative strengths. The fact that all strongly blue-fluorescent diamonds show a yellow-green phosphorescent afterglow, as already noted, demonstrates that the green component is also present though masked in this case by the stronger blue glow. The blue component remains frozen in the stone and can be seen as a blue thermophosphorescence when a stone which has been exposed to 3650Å mercury light is later heated. Another way of demonstrating this is to heat a blue-fluorescing diamond to about 200°C. and then expose it while still hot to ultra-violet light. When the hot stone is withdrawn from the rays it then continues to show a blue glow in place of the usual yellowish green. The strength of fluorescence varies enormously: many stones, as is well-known, remain virtually

inert under ultra-violet light. Under X-rays there is far greater uniformity of behaviour, almost all Type I stones showing a sky-blue to whitish-blue glow of fair strength, though usually with little or no phosphorescence. Outside these categories are stones showing pure yellow fluorescence under all exciting radiations, including X-rays, and those showing orange or red fluorescence and phosphorescence[11]—though these, by virtue of their ultra-violet transparency, should perhaps be classed as Type II diamonds.

Type II Diamonds

To distinguish rigidly between Type I and Type II diamonds has in fact not been found possible in many cases. While in general Type II diamonds are less fluorescent than those of Type I, Raman's workers found that strongly blue-fluorescent stones transmitted further into the ultra-violet than the usual limit at 3000Å: moreover, very thin pieces of normal Type I diamonds have been proved to pass light down to 2250Å.

Dr. J. H. F. Custers[12] discovered in 1952 that all natural blue diamonds available for test belonged to a separate category which he designated Type IIb. These are characterized by showing phosphorescence after exposure to short ultra-violet rays, and by pronounced electrical conductivity. Sutherland, Blackwell, and Simeral[13], in an article in " Nature " on " The Problem of Two Types of Diamond " (1954) referred to results by Dr. J. Grenville Wells (now Dr. Milledge) on anomalous X-ray streaks which are normal to Type I being found in some stones which transmit light beyond 2400Å, and exhibit further anomalies in the infra-red absorption region. Since the absolute absorption edge in diamond should (by analogy with high-branched hydrocarbons such as adamantane) be in the 2200Å region, these workers suggested that the anomalous absorptive properties of Type I diamonds may be due to impurity centres consisting of foreign atoms, or carbon atoms which are not in the same electronic state as the majority of atoms in the diamond lattice. More recently the astonishing discovery was made that such impurity centres do exist, and consist of nitrogen atoms, which can be present to the extent of 0.2% in Type I diamonds.[14]

Type II diamonds are far less rare than they were originally thought to be: especially perhaps in stones from certain localities,

and in industrial diamonds. Custers[15] has stated that the four largest diamonds examined in his laboratory since 1951 were all of Type II. These were pure white stones weighing respectively 34½, 66, 160, and 426½ carats. He also expressed the opinion that nearly all the larger gem diamonds belong to this category. In this connexion it may be remembered that two of the three stones tested by Miller were marked transparent to short ultra-violet. Of the four " portrait " diamonds randomly collected by the writer, three were transparent well beyond the 3000Å limit, and a large pink diamond tested also showed a Type II transmission. The few yellow-fluorescing diamonds so far tested in our laboratory have all passed the 2537 mercury line quite freely, while Prof. Kathleen Lonsdale has stated that all the synthetic diamonds she has so far examined have shown Type II X-ray patterns.

Irradiated Diamonds

It is by now well known that the irradiation of diamonds by alpha-particles, neutrons, deuterons, electrons, and even gamma rays, has a pronounced effect upon the colour of the stone; also, that the resultant colours can be further altered by subsequent heat-treatment or " annealing ". The earliest treatment of this kind was carried out by Crookes at the beginning of the century by placing diamonds in close contact with radium salts for several months. The effect was to turn the stones green—from light to dark tourmaline green, depending on the time of exposure to the alpha particles from the radium. The colour at one time was thought to be due to a thin layer of graphite which might well have formed at the surface: very thin scales of graphite were found to show a grey-green tint by transmitted light, and in heavily-treated stones little dark discs were seen under the microscope to have formed at the surface. Radium-treated stones were easy to test, as they had acquired a pronounced degree of radioactivity which could not be removed even by drastic chemical cleansing. This radioactivity has been shown to persist at least forty or fifty years, and can only be removed by repolishing the stone or heating it for several hours at 450°C, when the colour also will have disappeared. It is now realized that the induced colour was due to damage caused to the lattice by the violent atomic bombardment, and the appearance of the 5040 line in so many of these stones was highly significant, as will be seen in what follows.

The absorption and fluorescence of diamond are markedly affected by all forms of bombardment, and it is of great practical concern to gemmologists that they should be able to recognize from the evidence afforded by these phenomena whether or not a given " fancy diamond " owes its unusual colour to nature or to artificial treatment. Since it is probably true to say that none of the absorption or fluorescence bands in irradiated stones are entirely foreign to natural diamonds, it will be realised that the investigator is faced with no easy task. In the absence of a detailed absorption curve, obtainable only with a spectrophotometer and preferably at liquid air temperatures, there is, in fact, no easy cut-and-dried solution for every case; but as the result of long experience and patient experiment certain features have emerged which are of very real assistance in making such distinctions, using only simple apparatus.

R. A. Dugdale, who had at his disposal the resources of the A.E.R.E. (Harwell), carried out a series of controlled experiments on the colour changes induced in diamond by different forms of bombardment, and the further changes brought about by heat-treatment of the bombarded stones. These were described in admirable detail in a paper published in 1953[16]. Fortunately for the gemmologist he also recorded changes in the absorption spectra and fluorescence of his specimens at each stage.

Neutron bombardment in the atomic pile produced the most consistent results, shades of green deepening to black being induced in all cases, depending on the size of the stone and the dosage given. The green colour was very similar to that produced by the alpha particles from radium described above, and unlike the more apple-green tints seen in the rare natural green diamonds. Unlike radium-treated stones, these displayed only a short-lived radioactivity. Any luminescence in the original stone was almost completely quenched by the bombardment. Apart from general absorption in the red and violet no notable changes were seen in the absorption spectra of the treated stones. Subsequent heat-treatment of the deeply " greened " stones produced a change of colour to brown, then to brownish yellow and yellows of attractive shades as the radiation damage was more or less completely annealed away—though it should be noted that a bombarded diamond never quite returns to its original colour.

When the bombarded stones were heated for some hours at

350°—400°C., Dugdale found that the absorption line at 5040Å appeared in considerable strength, sometimes accompanied by a band at 4920Å. After heating to 425° these bands vanished completely. The writer has recently repeated this experiment on a rose-cut diamond " greened " in the pile with the same remarkable result. Heating in the range 600°—1000°C. resulted in the appearance of a line at 5920Å., though this was not seen in all cases. After heating at 700°—1000°C. in an inert atmosphere the 5040 line again made its appearance, with sometimes a companion line at 4970Å. After heating in the 650°—700°C. range many stones showed a greenish fluorescence, and, when heated to a higher temperature, the original fluorescence of the stone tended to reappear, though this often seemed to be only a surface effect.

Dugdale also observed bands in the deep red: a line at 7350 and diffused bands at 7230, 7000, and 6700Å after heating near 600°C. Occasionally we have seen bands in this region, but never clearly enough for measurements to be made.

During all these changes in absorption due to bombardment and heat treatment the line at 4155 and the band system at 4780, 4650, etc., if originally present seem relatively stable: it is the 5040 line with its nearby associates and the mysterious 5920 line which are definitely induced by treatment. In natural diamonds the 5040 line is found typically in brown or greenish diamonds having a green fluorescence. It is *never* seen in yellow or yellowish stones having a strong Cape spectrum. Since the latter are frequently chosen for treatment owing to their low commercial value, these are important aids to discrimination. A clear 5040 line (usually accompanied by a line at 4980Å), if seen in addition to a Cape spectrum is a strong indication that the diamond has been treated.

Evidence that the 5040 line is induced by bombardment was already forthcoming in our earlier observations on radium-treated stones. It was, indeed, first seen (1933) in a green stone of 0·30 carat which had been radium-treated some years earlier. The majority of radium-treated stones tested since then have shown this line, usually accompanied by the 4155 band, indicating that the stone chosen for treatment belonged to the " Cape " series. It has been suggested that natural brown or greenish diamonds owe their colour to bombardment by radiations emanating from radioactive minerals with which they have been in contact. This certainly seems plausible in the light of modern knowledge.

The line at 5920Å is not often so easily detected, being very narrow, weak, and with a faculty for disappearing altogether when the stone is warmed, which is most disconcerting. But, when seen, it acts as a very valuable indicator that the diamond concerned is a treated stone. Though the appearance of the line in treated stones was first observed by Dugdale (as noted above) it was G. R. Crowningshield of the Gem Trade Laboratory in New York who was able to check its almost universal appearance in yellow and brown diamonds which had been pile-treated and later annealed. With characteristic thoroughness he examined some thousands of such stones, and was also privileged to examine stones before and after treatment. Crowningshield's article in Gems and Gemology[17] is the most helpful to the gemmologist that has yet appeared on the subject. Our more limited experience agrees with his. The 5920 line is exceedingly rare in natural diamonds: we have, in fact, only seen it in some six specimens. In the writer's absorption notebook an entry dated Feb. 1943 reads as follows: " When examining brown diamond crystals from Obanghi (French N.W. Africa) to check the constancy of the 5040 line, I observed in two or three specimens a faint unresolved line or band in the " rare earth " (Dy) region. Measured with some difficulty owing to its elusive nature... as 5950Å approx." It is worth noting that the " elusive " nature of this line was evident on its first appearance. A later note (1950) records the line as 5920Å when it was measured in a yellowish Sierra Leone crystal.

In addition to dark green, brown, and yellow stones, dealt with above, diamonds of aquamarine or zircon blue tint may be produced by electron bombardment, perhaps with subsequent annealing treatment. In such stones the colour is only skin-deep, and may be removed by a thorough re-polishing. Custers who, as stated earlier, discovered the rare Type IIb category of diamond, maintains that all natural blue diamonds belong to this category and are thus readily recognised by their pronounced conductivity. A simple arrangement for making a conductivity test has been issued from the Diamond Research Laboratory in Johannesburg, and alternative circuits have been independently assembled by Lester Benson in Los Angeles, Edward Gübelin in Lucerne and Robert Webster in London, and have proved effective for making this test. It is interesting to note that the famous " Hope Blue " was tested with the G.I.A. conductivity apparatus and was duly

proved a Type IIb diamond. The amount of current passed by these stones is very variable, but so far no exceptions to the rule have been reported. Thus, any blue diamond which passes no current may be assumed to have been electron-treated.

The main distinguishing features of natural green, brown, yellow and blue diamonds and of those owing their colour to irradiation techniques have now been dealt with. Observations on certain unusual types of diamond, though interesting in themselves, have not been included here as they would tend to confuse further an already complicated picture. Some of these are dealt with in a recent paper by the present writer on " Lines and Line systems in the fluorescence spectra of diamond ".[18]

Some indication will have been gathered from the foregoing of the ways in which physicists in many centres are devoting their energies to research in diamond. The Diamond Corporation and its subsidiary organizations have been most active in fostering pure research in this field. There can be no doubt that many of the idiosyncrasies of diamond will eventually receive a rational explanation. But sometimes, in the mood of Ralph Hodgson's lines—

> " *Reason has moons, but moons not hers*
> *Lie mirror'd in her sea,*
> *Confounding her astronomers,*
> *But O! delighting me* ".—

one may be forgiven for hoping that some mysteries will remain, and that in some aspects of its behaviour this incomparable mineral will remain for ever unpredictable.

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Gemmological Abstracts

CROWNINGSHIELD (G. R.). *Developments and Highlights at the Gem Trade Lab. in New York.* Gems and Gemology, Vol. X, No. 11, pp. 336-341, Fall 1962.

Mention is made of a number of imitation and " compressed " turquoises. A report is given on black treated opals in which the opal has a granulated mosaic structure. The results of tests made on such pieces are given. Other specimens referred to are a glass cat's-eye sold as synthetic cat's-eye, a cut willemite, two faceted zincites and a colourless brazilianite. A brilliant-cut yellow tourmaline, a boracite dodecahedron, a pyrope garnet of 16 carats, and some odd colours in sapphires and diamonds are also mentioned. Emeralds coated with green plastic are noted.
10 illus. R.W.

DUYK (F.). *Ein Erkennungsmal von Brillianten.* Identification marks on diamonds. Zeitschr.d.deutch.f.Gesell.Edelsteinkunde, 1962 no. 39, pp. 22-24.

Photographic methods of identifying individual stones, not only diamonds. The table facets of each stone are photographed with a micrometer, so that on the photographs one can read off the size of each separate table facet. These facets are bound to vary slighty and the same set of figures will not be found on any other stone.

W.S.

JOHNSON (P. W.). *Cerro de Mercado Mine.* Mineralogist, 1963, 31, 1, pp. 4-6.

Cerro de Mercado hill is Mexico's chief source of iron ore. Yellow apatite crystals (locally called *amarillos*) are found in the locality. Much of the apatite is fractured during the blasting for the iron ore but high grade material is obtainable from miners in the nearby town of Durango.

S.P.

LIDDICOAT (R. T.). *Developments and Highlights at the Gem Trade Lab. in Los Angeles.* Gems and Gemology, Vol. X, No. 11, pp. 342-346, Fall 1962.

More serpentine than ever has been seen in the lab, and a number of pieces of plastic imitations of amber, which are sometimes sold as " Chinese amber ", have been examined. More treated turquoise is referred to. Unusual stones examined were pollucite, cassiterite, datolite, diopside, sinhalite, beryllonite and feldspar cat's-eye. An interesting item consisting of a diamond and platinum brooch contained many different colours of diamonds. It is remarked that it is not yet possible to make definite statements about the colour of green diamonds. A report is given on a red spinel and a black star-sapphire, which had been damaged. The scaling of some pearls was found to be due to the peeling off of a coating of hair setting lotion which had got on to the surface of the pearls.

2 illus. R.W.

WEBSTER (R.). *Howlite—natural and stained.* Australian Gemmologist, No. 17, pp. 10-11, November 1962.

A general article on the mineral howlite which has been used in an unstained condition for ornamental objects. The mineral is tumbled and stained blue, when it represents turquoise.

P.B.

OSTWALD (J.). *An introduction to the optics of gemstones.* The Australian Gemmologist, (Part 4) No. 13, pp. 5-10, July 1962. (Part 5), No. 17, pp. 5-9, November 1962. (Part 6), No. 18, pp. 5-10, December 1962.

Part 4 of this series deals extremely fully with the behaviour of light in anisotropic crystals. Conical refraction is discussed as well as specific rotation. Amethyst is referred to in respect of optical activity in crystals. In part 5 the writer deals with the reflection of monochromatic light. The final part (part 6) treats of dispersion, diffraction, interference and selective absorption. The F and V centres are discussed and also luminescence and fluorescence. Pleochroism is gone into very fully. The text is somewhat mathematical.

17 illus. R.W.

GÜBELIN (E.). *Ekanit, ein neuer metamikter Edelstein aus Ceylon.* Ekanite, a new metamict gem material from Ceylon. Zeitschr. d. deutsch. Gesell. f. Edelsteinforschung, 1962, 40, 14–34.

A detailed account of the new gem material found in Ceylon, similar to those which have appeared in other gemmological journals (Journ. Gemmology Abs. 1962, VIII, 7, 228).

S.P.

MEEN (V. B.). *Gem hunting in Burma.* Lapidary Journal, 1962, 16, 7, 636–653; 16, 8, 720–741; 16, 8, 816–835.

A fascinating three-part article describing a visit to the Burmese gem areas. Occurrence and methods of mining, cutting and marketing are discussed in detail.

S.P.

POUGH (F. H.). *Hong Kong is a lapidary center too!* Lapidary Journal, 1962, 16, 8, 838–845.

An interesting account of the lapidary work carried out in Hong Kong and details of the many carved gem materials available.

S.P.

CURTIS (G. E.). *Diamond hunting in British Guiana.* Lapidary Journal, 1962, 16, 8, 846–854.

British Guiana is rich in mineral resources and diamonds are recovered from the gravels of the Mazaruni area. Mining statistics for 1900–1961 are given; in the latter year 112,679 carats were recorded.

S.P.

LEIPER (H.). *How did British Guiana diamonds get there?* Lapidary Journal, 1962, 16, 8, 855.

The conjecture that Africa and South America were once a single land mass is briefly discussed but the question about the alluvial occurrence of diamonds in the colony remains.

S.P.

HARDY (E.). *Pearl-producing molluscs.* Gemmologist, Vol. XXXI, No. 375, pp. 194-196, October 1962.

Biologically it is possible for " pearls " to be formed by any mollusc lining its shell with nacre. Pearls are said to be occasionally found in the common mussel, oyster, scallop, cockle, periwinkle and pinna. There is an old reference which tells of pearls being found under the shield of the sea slug. In Scotland locations mentioned are Loch Ern, Tay Rannoch and Lubuaig and the rivers Don and Leith. The Irish fisheries and those of France are also mentioned. The cultured pearl industry of Australia is said to have grown up owing to the bad times the Australian pearl shell industry experienced, this being to a great extent due to the advance of the plastics industry and their button production.

R.W.

ANON. *Growing of artificial emeralds.* International Electronics, Vol. 5, No. 2, p. 21, 1963.

A new method of growing artificial emeralds for microwave masers includes a variety that is piezo-electric and fluorescent. The technique uses dehydrated beryl, berylium-oxide, ammonium-chromium-sulphate and vanadium-pentoxide heated in a platinum crucible. By varying the amounts of chromium impurities, Bell Labs scientists can grow beryl single crystals of emerald green or lighter colours.

T.B-S.

The Rangoon newspaper *The Nation*, February 6th, 1963, has reported that:

Foreign nationals have been ousted from the jade mining industry in the Kachin State following an order of the Kachin State Affairs Council last month decreeing that only Burmese citizens should work the mines.

Chinese nationals are specially hard hit by this order, because they formed the majority of foreigners operating the mines. In the past, only a few foreign nationals were in this industry, but subsequent to the Government's take-over of the pawnshop and the liquor-distribution business, which for years had been monopolised by the Chinese, Chinese nationals turned to other fields of enterprise. For various reasons, they were attracted to the jade mining industry, and many of them rushed to the Kachin State to sink

their idle capital in the industry.

Most of the jade mines are situated in the Kamaing Subdivision of the Kachin State. They are clustered around a string of villages such as Phakan, Tamakhan, Maimaung, Hwekha and Tawmaw. Places along the Uruchaung creek are also noted for their deposits of jade.

The mines are of two kinds—those worked by mechanical pumps and those worked by manual labour. The former are situated on low, level land, especially in the valley of the Uruchaung creek, and need varying amounts of capital investment for purchase of pumps. The latter are dotted along the mountain sides and need no more capital than payment of wages for labour. Each small mine has to employ four workmen.

At present, there are about 1,000 jade mines in the area, and more than half these are owned by Chinese nationals.

Operations in all the Chinese-owned mines have since been suspended, resulting in some 2,000 workmen being thrown out of employment. The state Affairs Council has reportedly assured them that foreigner-owned mines will be transferred to them if they want to work them on a collective or co-operative basis.

HANDEL (S.). *Natural and synthetic crystals in electronics.* Electronic Equipment News, Vol. 4, No. 9, pp. 60-61, December 1962.

Less than ten years ago the accepted definition of an electron device was one in which conduction of electricity takes place principally in a vacuum or a gas. The addition of the phrase " or in a semiconductor " in recent years is a belated recognition of the growing importance of certain crystalline solids in which electrons are transported in unusual ways compared with true metals, electrolytes or gases. Progress in these semiconductors is so rapid that information on them can barely be kept up to date. The use of crystal rectifiers antidates the thermionic valve of Fleming in 1904, fifty years before which the rectifying properties of copper oxide were known. Some comparison of the thermionic valve with crystal rectifiers is made, and mention is made of the point contact transistor and of the theory of electrons and holes in semiconductors. The ideal crystal contains no foreign atoms nor any irregularity in the crystal lattice. It is the slighty imperfect crystal which is, however, the basis of crystal devices. Semi-

conductors are insulators in the pure state, and they conduct at normal temperature only when they contain impurities. Natural blue diamonds, which are said to be true p-type conductors are used for certain apparatus. The article provides a brief survey of the nature and use of crystalline materials and indicates possible future developments. There is a table of the electronic applications of crystalline materials.

R.W.

TISDALL (F. S. H.). *More about garnets.* Gemmologist, Vol. XXXI, No. 376, pp. 199-200, November 1962.

The author compares the properties of rhodolite garnet from North Carolina with similar material from Madagascar which he had earlier reported upon. (Abstract. Journ. Gemmology. Vol. VIII, No. 8, p. 296, October 1962). Higher density and refractive index were found in the case of the N. Carolina stones examined than are usually ascribed to this garnet. The absorption spectrum and magnetic attraction are described. Both the Madagascan and N. Carolina stones showed anomalous double refraction with four times darkness through a complete rotation. The article also refers to a repaired diamond.

R.W.

HOPKINS (I.). *Diamond mining in Sierra Leone.* Gemmologist, Vol. XXXI, No. 374, pp. 159-163, September 1962.

Diamonds are mined from the alluvial deposits of the Sewa and Bafi rivers for the mines of the Sierra Leone Selection Trust in Kono District. The methods of mining the gem gravel are explained as well as the methods used in the recovery of the diamonds. The diamond crystals are found as octahedra, dodecahedra, cubes and combinations of these forms.

7 illus. R.W.

TISDALL (F. H. S.). *Some notes on iolite.* Gemmologist, Vol. XXXI, No. 373, pp. 139-140, August 1962.

A general survey of the mineral iolite. Some constants are given and discussion is made on the absorption spectrum and on the inclusions seen in the stones.

R.W.

THURM (R.). *Ungelöstes Geheimnis Amethyst.* Unsolved mystery of the amethyst. Deutsche Goldschmiedezeitung, 61, 1, pp. 29-31, 1963.

Amethyst was known 3000 years ago. In all its properties it is a quartz. Seen between crossed nicols, a slice of the amethyst cut at right angles to the optic axis shows a very lively colour play. The cause of the colour is not known. It has been attributed to colloidal distributed manganese, but no trace of this element can be found with the spectroscope. The colour is not heat-resistant. Between 400°C and 500°C amethysts become yellow, and are then saleable as citrines. Over 575°C they lose all colour, resembling moonstones. These quartz "moonstones" when viewed under UV light appear slightly green, while the orthoclase moonstones are definitely pink. The synthetic spinel which imitates moonstone fluoresces green-blue. There are also glass moonstone imitations on the market which fluoresce light blue. There are no synthetic amethysts on the market.

E.S.

(ANON). *Neue Synthesen und Imitationen.* New syntheses and imitations. Zeitschr. d. deutsch. Gesellsch. f. Edelsteinkunde, no. 41, pp. 24-27, 1962; no. 42, pp. 27-28, 1962/3.

Some white corals are being imitated by mother-of-pearl. Diamond doublets are on the market with the top of diamond and bottom of synthetic spinel. Turquoise is imitated by the mineral howlite. A short note is added on improvements in the synthesis of diamond. Serpentine is sometimes miscalled "new jade". Diamond has now been synthesized in Japan by the firm of Tokio-Shiwaura-Electric. A fairly poor imitation of black opal is on the German market, as is also a glass imitation of cat's-eye.

E.S.

THURM (R.). *Verschiedene Methoden der spektroskopischen Edelsteinuntersuchung im reflektierten Licht.* Various methods of examining gems by spectroscopy in reflected light. Deutsche Goldschmiedezeitung, May 1962, 5, 60, 345-346. Zur Technik

des Spektrokopierens. Technique of spectroscopy. Zeitschr.-d.deutsch. Gesell.f.Edelsteinkunde, 1962, 39, 30-31.

Both these articles deal with an adaptor for the microscope. The stone to be examined rests on the spectroscope stand, but mounted gems can also be tested. Good results are claimed even with such small stones as diamonds of 0·01 cts. The 4155 Å line in a diamond of 0·02 cts. usually cannot be seen under transmitted light with a microscope, while by reflected light it was easily visible. All larger diamonds showed this line also in transmitted light. Good results were obtained with a fixed slit model, which is simpler to handle than the wavelength instrument. The same slit-width is used, only the focussing and lighting being varied.

E.S.

EPPLER (W. F.). *Spectrolite — Labradorite.* Deutsche Goldschmiedezeitung, 61, 3, 161-162, 1963.

For some time a mineral called "spectrolite" has been on the market. It looks like labradorite, has a dark basic colour, and a beautiful colour play of blue and red, also green, yellow and reddish. This material is found in alluvial deposits in the south-eastern part of Finland. The author compares the material with the labradorite mined in Labrador and also with the labradorite mined in Madagascar and in the beginning wrongly classed as moonstone. There are six photomicrographs, two of each occurrence.

E.S.

BOOK REVIEWS

SINKANKAS (J.). *Gem Cutting.* A Lapidary's Manual. 2nd edn. D. Van Nostrand. 1963. 297 pp., 191 illus. $11.75 (84s.).

The second edition of John Sinkankas' standard work on gem cutting has been usefully enlarged and wisely pruned. A chapter on collecting gemstones and references to the origin of gems and unnecessary lists have disappeared as they are covered in other books by the author. More attention has been given to the tumbling of gems and techniques required for carving and mosaic

work, while cabochon and faceting work, which remain the most important styles, are still given most consideration.

The author has emphasized the need for keeping up-to-date with the new ideas and techniques which are rapidly taking place in the lapidary world.

The author's style is straightforward and each aspect of lapidary work is broadly described. An interesting feature is the advice given on buying rough gem material with advice for obtaining good results. The crisp sentences make for easy reading and the second edition of Gem Cutting is the most comprehensive work on gem cutting yet published.

S.P.

LIDDICOAT (R. T.). *Handbook of Gem Identification*, Gemological Institute of America, Los Angeles, sixth edition, 1962 396 pp. $8.75 (63s.).

Fifteen years have passed since the first edition of this book appeared, and a comparison between the earlier version and this latest issue provides a most interesting picture of the way in which American Gemmology has altered and developed during this short but fruitful period. The author is still quite a young man; and I hope one may be forgiven for saying that in the fifteen years he too has developed considerably. What formerly was written largely by rote, from principle and theory, now springs from the more valuable basis of practical knowledge and experience gained in grappling with the problems of all kinds of gem-testing in a laboratory of world status. This has resulted in a very readable and very useful book on its highly specialized subject.

The " Handbook " is just short of 400 pages in length, printed on good paper, and there are 156 black-and-white illustrations in addition to no fewer than 114 realistic drawings (by G. R. Crowningshield) of absorption spectra. The first nine chapters (112 pages) are devoted to instruments and methods used in gem testing. Then follow chapters on synthetic gemstones, on assembled stones and imitation gems, on pearls, cultured pearls and imitation pearls, before returning to instruments again with a chapter on the spectroscope.

Undoubtedly it is in the recognition of the importance and value of the hand spectroscope in gem-testing that this edition of

Liddicoat's book differs most markedly from his earliest issue, where a reference of only 8 lines was considered a sufficient cover for the subject. Though Crowningshield's drawings (mentioned above) are in black and white, they approach more closely to what is actually seen through a prism spectroscope than any previous attempts have succeeded in doing, and by dint of giving several drawings of the spectra seen in most of the gem varieties, he has been able to delineate many of the differences in the prominence of the bands, etc., seen in stones having a different depth of tint, which the beginner often finds so puzzling when there is only a single rather idealized drawing to help him. The general absorption at each end of the spectrum, which is often disregarded, is particularly well rendered in these drawings. The instrument used as standard by the G.I.A. and recommended to their students is the Beck prism model incorporating a superimposed wavelength scale. For this reason the drawings are unfortunately given with the red end on the right, presenting a strange appearance to the British gemmologist unless the page be turned upside down. The name of the gemstone is printed under each spectrum drawing: if these names were in bolder type it would greatly assist those whose eyesight is no longer good. The " star " system for assessing the diagnostic importance of the various spectra has been adopted here. Some of these assessments are rather surprising—that idocrase (Californite variety), for instance, should have been awarded three stars, while zircon should have been awarded a maximum of two!

Chapter 14 gives a brief résumé of " Instruments essential to gem testing "—presumably as a guide to those forming their own laboratory. Next comes a series of brief but very useful " Descriptions and property variations of gemstones " arranged in alphabetical order. This occupies fifty pages, and brings us to page 247. The remainder of the book is taken up with systematic identification procedures as recommended for stones in a large number of different colour categories. An excellent feature in these is the emphasis laid on the importance of preliminary inspection of the stone under examination, using a 10 × loupe. In a number of cases this may lead to a positive identification without any further tests, while in all cases it will serve to narrow considerably the range of possibilities. To an experienced gemmologist, of course, this preliminary inspection and mental sorting-out

process is largely automatic, but for the beginner a systematic approach of the type suggested by Mr. Liddicoat is of great assistance.

The book concludes, as one might expect, with a number of " Property tables ". Of these, the refractive index and specific gravity tables are very full, but the birefringence list contains, for some reason, only 18 entries, and thus is far too brief to be a really useful reference guide for this important diagnostic property. Anyone who has had to compile tables of constants will know how difficult it is to decide on the best typical figure for each stone. In this book Mr. Liddicoat has chosen his values so wisely that even one so fanatically interested as the reviewer in accuracy in these matters can only find a few he would wish to alter. Among these may be mentioned 3·71 as a preferable figure to 3·73 for the density of chrysoberyl, and 2·99 instead of 2·94 for brazilianite: ·036 rather than ·038 for the birefringence of peridot, and ·022 rather than ·028 for the dispersion of pyrope garnet.

The bulk of the text has been so well written that there is far more to admire than to criticize. The chapter on specific gravity, however, could be much improved: it remains too elementary to encourage the keen student of the subject to obtain really accurate measurements of this highly important constant. To avoid the difficulties attendant on the high surface-tension of water in making hydrostatic determinations, the use of either commercial carbon tetrachloride (" Carbona ") or of water to which one twentieth of its volume of powered detergent has been added is recommended by Mr. Liddicoat. In the former case the student is instructed simply to multiply his results by 1·59—the approximate density of the fluid. Where accurate results are sought by using liquids of low surface tension it is worth-while, surely, to take the trouble to obtain an exact correction factor for the particular sample of liquid used, linked always with the temperature at which the experiment is carried out. In our experience, ethylene dibromide is the most suitable liquid, and a sample, once calibrated, can be used for years if kept in a stoppered bottle.

One must take exception also to the derogatory remarks on the X-ray diffraction method for distinguishing between natural and cultured pearls. This, one feels, may be due to the fact that the G.I.A. Laboratories do not employ this technique. In the first place, the diffraction patterns shown, reproduced from a paper by William H. Barnes, are of insufficiently good quality to

give a fair idea of the capabilities of the method. Properly used, diffraction photographs can save the gemmologist from possible error in cases where natural pearls show a sharply defined spherical " nucleus " of natural origin, or in cases (admittedly rare) where a cultured pearl has been grown on a drop-shaped or a button-shaped nucleus, giving a misleadingly genuine appearance to radiographs of the specimens. Pearl radiography, as developed in the U.S.A., and used by an experienced operator, is undoubtedly the more generally useful, speedy, and flexible technique; but we in the London Laboratory would feel very unhappy if we were unable to make use of diffraction pictures in certain doubtful cases.

In conclusion, it should be said that the reviewer has derived both profit and pleasure from reading Mr. Liddicoat's book, and can heartily recommend it to anyone undertaking practical gem-testing or interested in the techniques, sometimes very simple, sometimes highly exacting, for identifying gem materials.

B. W. ANDERSON.

HAMMES (J.). *Edelsteinen.* Gemstones, 157 pages, 7 colour plates. Dfl. 3·95. Phoenix pocket No. 77. De Haan, N.V., Zeist, The Netherlands.

In this paper-back the subject of gemstones is looked at from all aspects in a manner intelligible for the lay reader. The book is interspersed with anecdotes, legends and historical stories which make the described subject-matter come alive.

The difficult question of the nomenclature which, as used in trade, often deviates from that used in science, is touched upon at the right moments and misnomers have been left out on purpose, a principle which should be welcomed.

Gemstones and their physical properties are competently described, particularly the optical phenomena. Some mention is made of gemstones and man, then of gemstones and jewels. Another chapter deals with a description of diamonds, together with cutting process, some famous diamonds and the diamond-trade. Next, ruby and sapphire are considered, followed by emerald and a number of common gemstones. Attention is paid to Biblical and zodiacal stones, as well as synthetics.

A table with the properties of the most important gemstones and a list of references conclude the booklet. This is a most useful work which, unfortunately, the author did not live to see published.

P.C.Z.

THE PFUND HIGH INDEX REFRACTOMETER

By J. OSTWALD

IN 1948, in the "Journal of the Optical Society of America", the late Professor A. H. Pfund of Johns Hopkins University proposed in principle a refractometer which could read the R.I. of crystals up to $n = 2{\cdot}6$. An experimental model was constructed in his laboratory and the R.I.s of some half dozen minerals were determined. The main advantage this new type of instrument has over the standard type is that it needs no contact liquid and the upper limit is governed purely by the R.I. of the transparent hemisphere of the instrument. Professor Pfund used a hemisphere of synthetic rutile, with $N_o = 2{\cdot}610$.

Basic theory of the Pfund refractometer

(1) *Fresnel's Equations:* In Fig. 1 a ray of monochromatic light is incident at an angle α to the normal on a block of isotropic crystal. Part is reflected, and part is refracted at an angle of β to the normal. Now let E_p, R_p and D_p be the components of the incident, reflected and refracted rays in the plane of incidence while E_s, R_s and D_s are the components at right angles to the plane of incidence. Then the following relations hold.

Reflected amplitudes:

$$R_s = -E_s \frac{\sin(\alpha - \beta)}{\sin(\alpha + \beta)} \tag{1}$$

$$R_p = E_p \frac{\tan(\alpha - \beta)}{\tan(\alpha + \beta)} \tag{2}$$

Refracted amplitudes:

$$D_s = E_s \frac{2 \sin\beta \cos\alpha}{\sin(\alpha + \beta)} \tag{3}$$

$$D_p = E_p \frac{2 \sin\beta \cos\alpha}{\sin(\alpha + \beta)\cos(\alpha - \beta)} \tag{4}$$

These equations were originally derived by Fresnel in 1823 from the elastic solid theory of the ether and they can also be derived from electromagnetic theory.

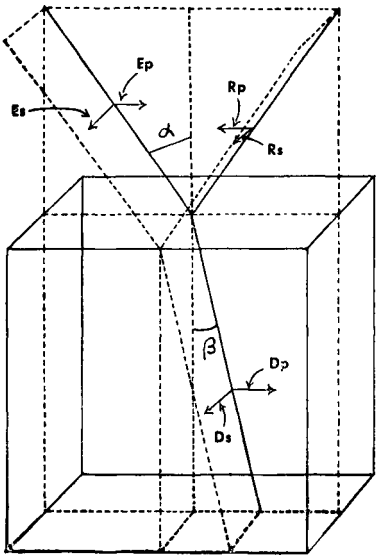

FIG 1

Now if we apply the basic law of refraction

$$\frac{\sin \alpha}{\sin \beta} = \frac{V_1}{V_2} = \frac{\sqrt{\varepsilon_2}}{\sqrt{\varepsilon_1}} = n \tag{5}$$

we can obtain the following equations:

$$2E_s = D_s\left[1 + \frac{\sqrt{\varepsilon_2} \cdot \cos \beta}{\sqrt{\varepsilon_1} \cdot \cos \alpha}\right] \tag{6}$$

$$E_s\left[\frac{\sqrt{\varepsilon_1} \cdot \cos \alpha}{\sqrt{\varepsilon_2} \cdot \cos \beta} - 1\right] = R_s\left[\frac{\sqrt{\varepsilon_1} \cdot \cos \alpha}{\sqrt{\varepsilon_2} \cdot \cos \beta} + 1\right] \tag{7}$$

$$2E_p = D_p\left[\frac{\cos \beta}{\cos \alpha} + \frac{\sqrt{\varepsilon_2}}{\sqrt{\varepsilon_1}}\right] \tag{8}$$

$$E_p\left[\frac{\cos \alpha}{\cos \beta} - \frac{\sqrt{\varepsilon_1}}{\sqrt{\varepsilon_2}}\right] = R_p\left[\frac{\cos \alpha}{\cos \beta} + \frac{\sqrt{\varepsilon_1}}{\sqrt{\varepsilon_2}}\right] \tag{9}$$

(2) *Total Reflection:* When a ray of light is incident at the boundary separating an optically dense from a less dense medium, the refracted ray vanishes for angles of incidence greater than a certain critical value, the energy being totally reflected. We will

analyse this case. Here β is not real. Let us substitute $\frac{\sin \alpha}{n}$ for $\sin \beta$ in the above equations. Thus

$$\cos \beta = \sqrt{\left(1 - \frac{\sin^2\alpha}{n^2}\right)} \tag{10}$$

which is imaginary if

$$\sin \alpha > n$$

We can write this in the form

$$\cos \beta = -i\sqrt{\left(\frac{\sin^2\alpha}{n^2} - 1\right)} \tag{11}$$

where $(i)^2 = -1$.

Now if we consider the effect of these equations on equations (6) and (8) above it will be seen that the refracted amplitude is not zero so some of the energy penetrates a small distance into the second rarer medium. It can be shown by analysis of Maxwell's equations that the electric and magnetic forces in the rarer medium are proportional to the real parts of the following expression.

$$e^{i\frac{2\pi}{T}\left(t - \frac{x \sin \beta + z \cos \beta}{V_2}\right)} \tag{12}$$

Now if we eliminate β with the use of equation (11), we obtain (12) in the following form.

$$e^{\frac{-2\pi}{T V_2}\sqrt{\left(\frac{\sin^2\alpha}{n^2} - 1.z\right)}} \cdot e^{i\frac{2\pi}{T}\left(t - \frac{x \sin\alpha}{n V_2}\right)} \tag{13}$$

This formula represents a wave moving along the boundary of the two media in the plane of incidence. The amplitude is seen to decrease rapidly with the depth of penetration and it is zero within the order of one wavelength. Another (apparently) strange fact is that these boundary waves are no longer transverse. However, according to Quincke, if the second rare medium is quite thin, of the order of one wavelength then this wave of variable amplitude is converted into one of constant amplitude.

The existence of these waves can be demonstrated experimentally if a convex lens of large radius of curvature is placed in contact with the surface under study. At the point of contact there is a circular patch over which total reflection fails.

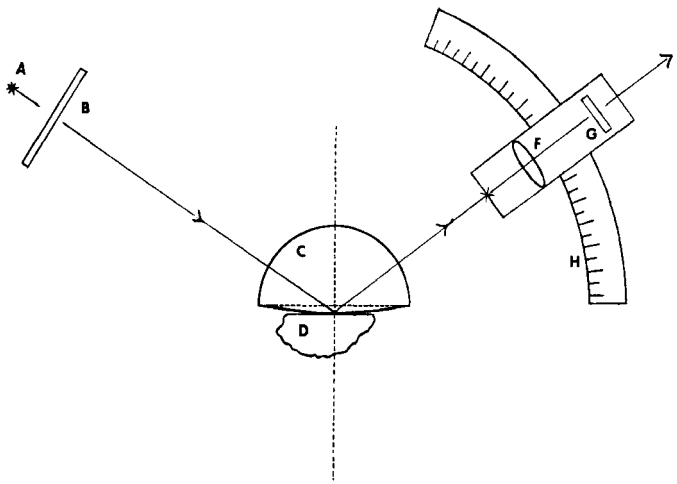

FIG 2

Apparatus and use

The apparatus used by Professor Pfund is shown in a schematic fashion in Fig. 2. A is a sodium light source, B a frosted glass diffusing plate, C the hemisphere of high index material with slightly convex lower surface, D the material under test, F a converging lens, G a polaroid disc and H a graduated scale.

The essential feature of the apparatus is C. This was made from clear synthetic rutile, with $N_o = 2{\cdot}61$ and $N_e = 2{\cdot}897$, of 11 mm radius, the radius of curvature of the lower face being 15 cm. The polaroid in the eyepiece is necessary to eliminate the effects of the extraordinary ray.

The phenomena observed in the eyepiece are as follows:

Case 1—Angle of incidence less than critical angle of air and rutile. A central black spot surrounded by Newton's Rings will be seen. This should be centered in the eyepiece.

Case 2—Angle of incidence exceeds this critical angle. The Newton's Rings disappear, leaving the black spot.

Case 3—If the telescope is moved slowly, a point will be reached when the black spot will disappear. Here the angle of incidence has just exceeded the critical angle of rutile and the test material.

Using this apparatus Professor Pfund studied the R.I.s of the following five minerals. The figure in each case depends for its

accuracy on the N_o of synthetic rutile, assumed = 2·61. These values may be compared with figures taken from Winchell, probably measured by the spectrometer method.

	A. H. PFUND	A. N. WINCHELL
Zircon N_e	1·991	1·968 – 2·015
Zircon N_o	1·936	1·923 – 1·96
Diamond	2·419	2·419
Calcite N_o	1·658	1·658
Corundum N_e	1·760	1·7599 – 1·7613
Corundum N_o	1·768	1·7681 – 1·7695
Fluorite	1·434	1·434

Fig. 3 shows in a graphical manner the relationship between the refractive index and the critical angle for a material under test, for the Pfund rutile refractometer.

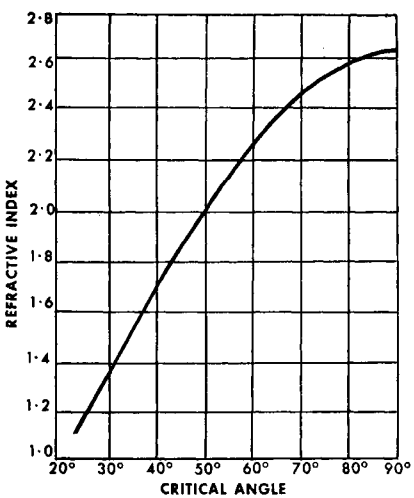

FIG 3 (AFTER PFUND)

Conclusions

With the use of a refined optical system and compact arrangement of parts the apparatus should be of great use in the determination of the refractive indices of crystals, polished mineral surfaces and gemstones up to about $n = 2·6$. No immersion liquid is necessary, though a drop of oil on the hemisphere would perhaps prevent scratching. On the other hand a sodium light must be used, on account of the high dispersion of the rutile hemisphere.

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ASSOCIATION NOTICES

COUNCIL MEETING

A meeting of the Council of the Association was held at Saint Dunstan's House, Carey Lane, London, E.C.2, on Wednesday, 30th January, 1963. Mr. N. A. Harper, Vice-Chairman, presided.

The following were elected:—

FELLOWSHIP

Jokinen, Pertti, Helsinki, Finland
Rybom, Lene, Fredrikstad, Norway

ORDINARY MEMBERSHIP

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McCann, James C., Dublin, Ireland
Sirett, Benjamin, London
Stäedelin, Alwin, Lucerne, Switzerland
Weatherill, Katherine, Long Beach, U.S.A.
Wood, Mary B. H., Sidmouth

PROBATIONARY MEMBERSHIP

Collard, Edwin, Bridgwater
Smith, Lance C., Bognor Regis
Duncan Taylor, Lynne, London
Weare, Roy, Harrow
Wilkinson, Ben R., Croydon

The Council approved the arrangements made by the Midlands Branch for the Herbert Smith Memorial Lecture to be held at the Auctioneers' and Surveyors' Institute, Birmingham, on 26th April. Mr. E. D. Lacey, B.Sc., A.R.C.Sc., F.G.S., of the department of geology, Birmingham University, had kindly consented to give the lecture, which would be entitled "Perfect and imperfect crystals".

A draft syllabus for the diamond course examination was approved.

MIDLANDS BRANCH

A meeting of the Midlands Branch was held at the Imperial Hotel, Birmingham, on 24th January, 1963. Mr. M. Bowen, the Branch Chairman presided, and introduced the guest speaker, Mr. Hans Caesar, Chairman of the Deutschen Edelsteingesellschaft, who spoke about the gem-cutting industry of Idar-Oberstein. In Idar local cutting dates back to the 11th century and the first official documents to 1454. During 1618-1648, in the 30 years war, practically all cutting mills were destroyed, which brought stonecutting to a standstill. When in 1700 the first goldsmiths began their work, the demand for gemstones became greater

and stonecutting revived. From Novgorod, the Russian commercial city, came unpolished lapis-lazuli, malachite, and Persian turquoise. Towards the end of the 19th century, with the arrival from India of the first garnets, rubies and sapphires, new cutting methods had to be developed because of the extra hardness of these gems; thus lapidary cutting came into existence. By 1914 Idar Oberstein had become the world's greatest stone cutting centre. Now some 2,000 men are employed on diamond cutting and polishing, about 900 on lapidary work and 600 approximately on polishing agate; this gives some idea on the vast extent of the industry there.

Mr. Caesar concluded his talk by showing a special film on Idar Oberstein including a 14th century water mill with all its old world charm, to its present day modern factories, with their exquisite examples of polished agate bowls, carved chrysoprase leaves and flowers, amethyst and other gem ornaments, and lapidary work with fine examples of aquamarine, citrine and many other gems.

Many questions were put to the speaker

Mr. Norman Harper proposed the vote of thanks to Mr. Caesar which was heartily endorsed by all present.

The Midlands Branch of the Association held a Dinner and Dance at Quinton, Birmingham, on Wednesday 27th February, 1963. Mr. W. W. Bowen, Chairman of the Branch, welcomed guests who included Mr. E. D. Lacy, of Birmingham University, Mr. N. A. Harper, Chairman of the National Association of Goldsmiths and Mr G. F. Andrews and Mr. H. Wheeler from Head Office. It was a very successful evening. Mr. Bowen expressed the Branch's indebtedness to the Secretary, Mrs. S. Hiscox, for the arrangements.

MEMBERS' MEETING

A meeting of members was held on Friday, 15th February, 1963, at the Medical Society of London's Hall, when several members showed and described various coloured slides they had taken. The slides were varied and included modern and antique jewellery, photography of fluorescence, inclusions and objets d'art. Contributors included Messrs. W. Stern, E. Bruton, R. K. Mitchell, R. Webster, M. Webb, E. R. Levett, and J. E. Edwards.

GIFTS TO THE ASSOCIATION

The Council of the Association is indebted to Mrs. Gladys E. Cox, of Chilliwack, B. Columbia, for a specimen of nephrite from British Columbia.

OBITUARY

Leechman, George Francis (Frank), 9th February, 1963. Mr. Leechman, a former Master Mariner, gained his diploma, with distinction, in 1938, and later was awarded the Association's Research diploma for his work on the cause of colour in opal. When he left the Merchant Navy Mr. Leechman took up lapidary work and had a business in Cornwall. Subsequently he went to Australia and became greatly interested in opal. At one time he was Secretary of the Gemmological Association of Australia. His admirable book *The story of Opal*, published in 1961, is a standard work appreciated by all who regard opal as one of the most fascinating of gems.

TALKS BY MEMBERS

RAVEN, R. H.: " Gems ", Chelmsford Ladies' Circle, 17th January, 1963.

BLYTHE, G. A.: " Gemstones ", Southend E. Conservative Assoc. (Women's Section), 26th November, 1963; Young Conservatives, Southend, 31st January, 1963; West Leigh Townswomen's Guild, 20th February, 1963.

BAGLEE, G.: " Gemstones ", Stockton-on-Tees, Y.W.C.A., 10th January, 1963.

BAYLISS BROWN, A. J.: "Gemstones", Geological Society, King's College, London University, 8th March, 1963.

SAMPSON, Mrs. E.: "Pearls", Gerrards Cross Club for Women, 6th February, 1963.

CAFFELL, E. W.: "Gems", Racal Works Canteen, Bracknell, 4th February, 1963.

HAVEM BJÖRLYKKE, U.: "Natural and man-made gemstones", Geological Museum, Oslo, 10th February 1963.

KENNEDY, N. W.: "Gemstones of the British Isles", I.C.I. Ltd., (General Chemicals Division), Widnes, 29th November, 1962. "Gemstones and gem materials in the field of the chemist", London University Convocation (Manchester University), 8th February, 1963.

JEWELLERY TRADE CENTRE IN EXETER

A technical centre was formally opened in Exeter on 11th March for the benefit of trainees in the retail jewellery trade. The centre has been made possible by the trustees of the R. W. Yeo Trust and although juniors from the R. W. Yeo group of companies will be the first to receive assistance in their careers it is intended that as the scheme progresses to make training facilities available to trainees from other firms.

The centre, which contains sections on gems, watches, clocks, modern and antique silver and jewellery making and repairing (and a jewellery repairing workshop), is extremely well-equipped and many firms, apart from the trustees, have contributed many items of outstanding educational interest. The gemmological section is strong, with an adequate number of instruments and an excellent display of gem minerals in rough and cut form.

The originator of the scheme, Mr. R. W. Yeo, obtained his diploma with distinction in 1929 and has cherished the idea of an educational centre for young persons in the jewellery trade for many years.

WEST OF SCOTLAND BRANCH

An extremely interesting evening was held by the West of Scotland Branch on 21st February, 1963, in Glasgow, when Mr. W. C. F. Butler spoke to members about "The manufacture of synthetic gems". Mr. Butler illustrated his talk with many examples of synthetic stones, including an early specimen of synthetic ruby made by Fremy down to the latest synthetic emerald-coated beryls.

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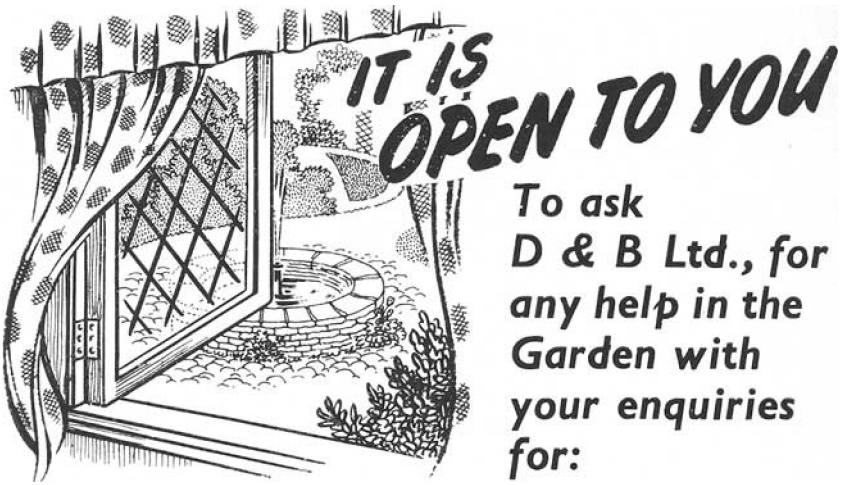

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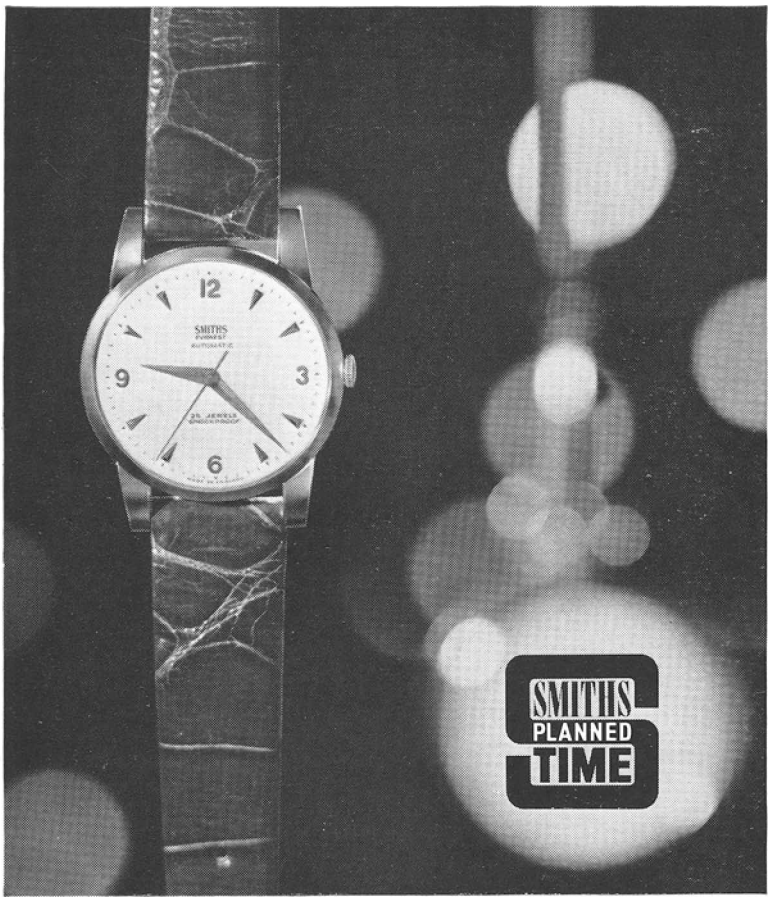

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Vol. IX No. 3 JULY 1963

TESTING A RUBY

By A. E. FARN

THE three essential properties necessary to a gemstone are beauty, durability and rarity. Seldom does one find all three together and if one does, then size very often acts as a neutralizer in commerce.

The three main instruments a gemmologist requires are microscope, refractometer and spectroscope. Seldom will all three be necessary together to test a gemstone, and, if the occasion does arise, then rest assured that the stone which calls for these three tests has beauty, durability and rarity. One of the most frequently tested stones, and one about which a good deal has already been written, is ruby.

Ruby fulfils all the requirements of a gemstone; it has beauty, durability and rarity (if of any size). It certainly needs all three tests since the refractometer does not yet tell synthetic from genuine, neither can the spectroscope, but certainly the microscope will. I know that many eminent gemmologists require only a microscope or lens plus experience to test their rubies and they are usually correct. Maybe when a person of eminence in the trade states positively a stone is genuine, no further challenge is forthcoming, and, to all intents and purposes, the stone lives happily ever after in its " proper " setting, giving pleasure to its owner, and every one is happy.

Fortunately a laboratory test states a fact backed by specific tests which double check and allow for no speculation or doubt. Because of this rigid adherence to correct scientific principles, it behoves us (although years of practice make it seem wasted labour) to carry through strict routine to prove a stone we know by practice to be genuine or synthetic as the case may be. That is why earlier I have stated the case where ruby needs all three tests—microscope, refractometer and spectroscope. There are instances where one uses extra techniques, such as X-ray fluorescence and phosphorescence and transparency to X-rays and immersion contact photography. These latter cases are usually last resort extremes in the case of the clean synthetic ruby or clean genuine ruby.

To proceed in an orderly manner therefore to test a ruby—let us dispense with the usual routine of a parcel of red stones (beloved of examiners) and stick to a red stone.

First checks are usually made by looking and deciding by colour and appearance that the stone is a ruby. Then examination by lens, looking through the stone. Very often to a laboratory gemmologist this is sufficient an indication; being an expert in lens testing, he will have seen perhaps " silk ", feathers, " treacle ", or crystal twin planes, which he will then confirm by using his microscope for a more intimate examination. Every now and again one comes across a case which pulls one up short and delivers a chastening blow to one's know how. This can be very useful because, being human, we all tend to relax somewhat and this surprise gives us personal food for thought which can be far more effective than advice or caution from an outside source. In similar manner, a successful dealer who has a run of good buying and selling sometimes gets a little careless.

Usually a glance is sufficient to the expert for him to decide a stone's provenance and authenticity. Sometimes, however, one comes across the small, fine, exquisite stone which is so strong in colour that it *looks* synthetic, or the ruby which looks like a fine garnet and one cannot say for sure which it is. As is well known, the better selling rubies are those from Burma, although in my opinion Siam stones are lovelier to look into. However, since it is money which lubricates the wheels of commercial jewellery, it is the Burma stones which count. Some chrome-rich Burma stones literally suffer from an overdose of this colouring matter and look quite dark and from the outward appearance *look* like Siam stones.

Inevitably they are labelled Siam, thus emphasizing one of the aspects of beauty, i.e. colour. The trade sells its goods on appearance. Fine colour rubies are Burma and poor, darker ones Siam. By and large this rule is roughly correct in provenance too. To the uninitiated, some very fine deep red spinels can slip by as rubies and I have seen a superfine red tourmaline with a small liquid feather accepted as a ruby.

When tackling the problem of testing a ruby (as gemmologists) we mostly rely on the microscope. Perhaps it is here then that we betray this 100% confidence which earlier I have stated has the occasional jolt which is beneficial in deflating our ego. The testing of a ruby requires the absorption spectrum and internal structure to be checked.

A ruby has to be proved firstly to be corundum. To do this is elementary by use of either refractometer or spectroscope. I would advise the spectroscope as opposed to the refractometer since there is no wear on the spectroscope and standard refractometers' prisms soon wear and are costly to re-polish.

The absorption spectrum of ruby is a nice easy one to recognize. Although the following measurements are given it is not necessary to measure them each time since it is such a distinctive pattern seen through a spectroscope that it *cannot* be confused with any other red gemstone. In the red end of the spectrum will be seen two bright lines at 6928Å and 6942Å close together appearing as one line or doublet. Covering most of the yellow and green portions of the spectrum is a broad band centred at 5500Å. In the blue portion of the spectrum are three dark thin absorption lines at 4765Å and 4750Å (these two very close together) and another at 4685Å. This spectrum pattern of bright red line and two dark thin lines in the blue is distinctive and diagnostic for ruby (synthetic and genuine).

If no spectroscope is available, then a refractometer will suffice to establish corundum with readings at 1·76 to 1·77 and a double refraction of ·009, the pure reading being 1·759 to 1·766. Having established the material as corundum, it is now necessary to prove genuine or synthetic. Perhaps here I should step back a little to point out that in the case of a very small stone or a very rubbed stone, the spectroscope scores heavily over the refractometer. If the stone is rubbed or too small, then it is the soft glass prism of the refractometer which scores.

If a ruby is in a ring, then no tongs will be required since the shank will facilitate handling and rotating. A straightforward examination by simple microscope of not much more than 30 × magnification should be sufficient. If nothing much can be seen the stone should be cleaned in a weak detergent solution to remove grease and collected dust from the back facets. Being an aqueous solution, care should be taken to dry the stone since, it if has to be later immersed in methylene iodide or monobromonapthalene the detergent will cause a general soupiness or immiscibility of liquids. Having now immersed the stone, the examination will now reveal diagnostic features. The main inclusions to be seen in a typical Burma ruby are silk, crystals, treacle and feathers. Silk is an effect created by criss-crossing at 120° of fine rutile needles, generally finer and shorter in Burma than in Siam stones. When stones are cut " en cabochon " this causes a three ray (six legs) star effect, thus making a star-ruby. (This effect is also seen in sapphires for the same reason.) Crystals are generally rounded and/or angular inclusions of other materials, or same materials. Very often zircons are included as crystals and these stand out in high relief against a background of ruby. These crystalline inclusions are transparent or opaque. When transparent they have a much more open centre to them than do the included gas bubbles of synthetic stones. The gas bubbles of synthetics are highly refractive and have a jet black polished look with only a pin point of light transparency in their centres. " Treacle " is the effect of the colouring matter of ruby, i.e. chromic oxide occurring in denser proportions in certain parts of the stone. This has an effect similar to that of a thick sugar solution of syrup or treacly consistency being poured into water of lesser density. It is visible by its viscosity and higher refractive index as a pouring effect. In rubies it is a fine rich carmine on a red background. This can give an appearance similar to swirl striae seen in some pastes. I can remember an occasion when a dealer friend brought a ruby for testing which he thought was a gemmological curiosity, being a ruby with swirl striae and silk. It was his first introduction to treacle. I think that treacle as a rule is seen in Burma stones and not in Siam stones.

Feathers are a structure in themselves, less typical for Burma than Siam stones. The feathers so typical of Siam are delightful in their structures and appearance and are virtually a form of

hallmarking. Sometimes in the Laboratory on a carbon copy, not the customer's portion, among the hieroglyphics will be seen succinct statements such as " Siam feather hallmark ", which gives a vital shorthand description of a feature seen in a microscope test.

Feathers generally are a form of network or lacework two-phase liquid droplets forming something like a veil in a stone and are a beautiful feature when studied for themselves alone. They are not solely to be relied upon as a diagnostic feature since synthetics have been known to exhibit a series of queer shaped gaseous bubbles joined together in something like an aspect of frogs spawn, which does have a natural look about it.

Some feathers in Siam rubies are rounded, halo-like, tight-knit feathers with rounded opaque hexagons in their centres. Care must be taken in looking at these dark Siam stones since the rounded opaque hexagons tend to look like gas bubbles in synthetics.

From the description of some of the internal structures in rubies it sounds very much as if some features are easily mistaken for synthetic inclusions or paste inclusions. Theoretically yes, but practice will soon dispel any doubts. If one keeps a typical synthetic ruby as a comparison stone, its included bubbles—whether rounded or profilated—have such a typical gaseous look to them that they will present no real difficulty in detection.

Fortunately it is always easy to procure a good cheap Siam ruby, full of inclusions. Some of them are delightful studies of criss crossing of twin planes and lath-like inclusions, together with their " poached egg ", feather and crystal formations. Burma rubies, of course, are dearer but a poor one or a pink one, which has too many obvious signs in it to be of commercial value, is ideal for observation and comparison.

Having in general become " au fait " with inclusion spotting, one's eye also becomes attuned to colour and, very shortly, one can say without much hesitancy where a stone comes from by just looking at it by eye alone. Having reached this rather useful and happy stage, one is cut down to size by the advent of a clean, fine looking red corundum which one's instinct and knowledge insist upon being synthetic by its very outward appearance. Since practical proof has to be forthcoming and not sheer instinct, one must refer to routine testing. After routine check by microscope

and no signs seen, it is then necessary to immerse the stone either in monobromonaphthalene or methylene iodide. The former is the cheaper liquid; the latter, closer to the refractive index of ruby, is preferable. These liquids, if left on a microscope stage to become slightly over luke-warm, will irritate the sensitive membranes of the nostril, causing a slightly allergic person very considerable suffering from all the characteristics of hay fever! Keeping the eye glued to the eyepiece of the microscope places one's nostrils in an ideal position to inhale the vapours of the warm oil in the dish below. The mere fact of a stone necessitating prolonged study inevitably means lengthy immersion and heating of oil.

If possible, a glass dish with a concave floor to it is ideal since this automatically centres the stone. There is nothing quite so frustrating as chasing with a pair of tongs an elusive small red stone around the perimeter of a dish under the magnifying effect of the microscope.

If no obvious signs are immediately apparent it is possible that glare is obviating accurate inspection. Lowering of the condenser will help enormously. If gas bubbles are not seen and the stone is obviously (suspect) synthetic, then curved structure lines must be searched for. These can also be somewhat fugitive and palely loitering. Here again a lowered condenser will help. After having rotated the stone slowly through 360°, the closing down of the iris diaphragm will help towards a " dark ground " effect as well as the tilting of the mirror to give a glancing effect of light through the structure lines. The combined effect of mirror-tilting and lowered and closed condenser will often suddenly reveal line structure in a fleeting glimpse, and one can track back until one achieves the ideal position for optimum effect. This effect of racking up and down slowly of the coarse adjustment by the left hand whilst the stone is turned slowly in the tongs by the right, or alternatively tilting the mirror backwards and forwards with the left hand as one again rotates the stone, gives many added variations of focus and field. One often sees banding either hexagonal in pattern or curved in structure under these conditions. It is necessary to guard against racking down too far into and through the stone so that bubbles or swirl striae can be seen through the ruby which may be in fact in the glass of the cell. Increased magnification will seldom be more revealing since the faintest

curvature of a fine line seen in small sections of length will, by increased magnification, appear straight. When one has been peering for too long in liquid at one colour one's eyes become fatigued and it is a good thing to leave the stone and liquid to cool. If a small pin-point bubble is found, then it is permissible to leave the stone and bubble in focus and use a higher power objective in order to bear more intimately upon the suspect bubble. I can remember once finding small localized groups of dust-size bubbles which had the outward appearance of minute bubbles but they looked like dust and X-ray transparency tests later proved the stone genuine. Since then I have seen similar dust-like bubbles in a stone which, because of their similarity to the case just mentioned, helped me to diagnose a genuine clean ruby (with other tests, of course).

Considerable searches by microscope are usually conducted only for bubble and/or curved structure formation. Feathers, silk, crystals, twin planes, and similar features are always seen much more readily and easily with lower powers. When no amount of diaphragm manipulation, condenser-lowering or mirror-tilting will reveal possible fugitive bubbles or curved striae, then one must adopt other techniques. Such techniques are immersion, contact photography, X-ray transparency and X-ray fluorescence and phosphorescence. To a laboratory worker, after a short period of microscopy with nil result, the next move is to subject the stone to X-rays. The ruby will *fluoresce* with a red glow under X-ray excitation when observed in the dark through the protective lead glass observation screen. If it is a synthetic it will continue to glow (phosphorescence) after the X-rays are switched off. This effect is quickly and easily seen under ideal conditions, but caution is to be observed in not jumping to conclusions. I can remember a five carat ruby a few years ago which was clean to a frustrating degree and looked superbly synthetic, but the dealer who owned it did occasionally have very fine rubies. Placing this particular stone over the aperture of the X-ray window I saw it glow red under excitation (fluorescence) and as I switched off, so did the stone (no phosphoresence). This I repeated several times and felt that the stone must be natural. However, thanks to sounder experience, a suggestion to keep on looking for a few seconds after switching off showed a latent build up of phosphorescence after cut-off. This phosphorescence of synthetic ruby is a very, very strong diagnostic feature. Although

X-ray apparatus is not easily available to the average gemmologist, a short-wave ultra-violet light is. Short-wave ultra-violet light under dark room conditions will show synthetic rubies to glow brighter than genuine stones when a parcel of mixed rubies is examined. (This is not an X-ray set up but a short-wave lamp.) One stone on its own cannot be tested, whether genuine or synthetic ruby, under short-wave ultra-violet light, because some fine Burma stones glow beautifully and some chrome-rich stones do not, and Siam stones are not so active. The use of the mineralight has to be considered as an additional test and is *not* safely diagnostic on its own. (Neither is it for sapphires; most synthetic blues glow greenish, but so do some natural Ceylon stones.)

Immersion contact photography, a very pretty test in every sense of the word, developed by B. W. Anderson from tests and techniques appertaining to the measurement of refractive indices, can show the contrast of various refractive indices of stones in liquids of known refractive index *and* also show structure within the stone. A contact photo of a stone often reveals its refractive index and its curved structure which is not always visible under the microscope. Thus, sometimes very fine evanescent curved structure lines are revealed.

Another simple test which can be very revealing is to immerse the stone in methylene iodide. Place a sheet of matt white paper on a desk, tilt a desk lamp onto the paper at 45° and observe the stone, holding the cell in the left hand over the paper whilst a low power lens is held in the right hand. Sometimes this much lower power will help, particularly against a matt background. There probably are other refined techniques, but what I find impressive is the fact that with ruby, not only are the refractive index and the absorption spectra the same for natural and synthetic, but if one did a chemical analysis the results would be so close as to allow no clear-cut diagnosis to be obtained.

Rarity, durability and beauty—these three, but the greatest of these is beauty. Beauty is in the eye of the beholder, and beauty in a stone is an outward expression of internal structure and inclusions. Ruby combines the best of the requirements of gemstones and necessitates for certain identification refractive index, absorption spectrum and internal inclusions, and the greatest of these is inclusions. One may safely say that, in conclusion, it is inclusions that reveal the truth to the exclusion of all others.

FINE ZONING IN AUSTRALIAN SAPPHIRE

By E. H. RUTLAND

A parcel of some 30 blue Australian sapphires was recently sent to me by Mr. John Fleming, of New Zealand. They had attracted his attention by the extremely close spacing of their growth zones. The resulting fine striations were of the same order of size as those found in synthetic corundum and strongly resembled these except that they showed no sign of curvature. However, the stones were only from $\frac{1}{2}$ to 1 carat in size and in small stones cut from a large boule the curvature is occasionally not marked, particularly at strong magnifications. A typical picture of the zoning found in the Australian stones is shown in Figure 1.

Further search produced some convincingly hexagonal zoning (Figure 2) and healing fractures. No other features of special interest were found. The density was a little greater than that of the 3·995 sapphire kept as a check in the Clerici solution in which the stones were tested. The refractive indices lay between 1·765 and 1·780 (Rayner refractometer in sodium light). Dichroism was marked, in green and purple shades of the blue body colour. No signs of strain appeared between crossed nicols, nor any signs of twinning (which I had rather hoped for). The stones were a rich blue, a little on the dark side.

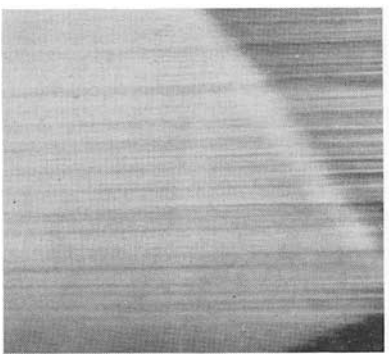

FIG. 1. *Straight zoning in a blue Australian sapphire.*

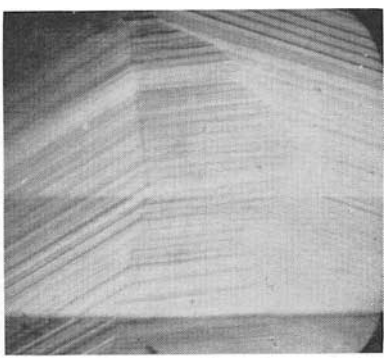

FIG. 2. *Hexagonal zoning in another sapphire from the same source.*

SOME NOTES ON THE MINERALOGY OF LAPIS-LAZULI

By J. OSTWALD

INTRODUCTION

Some time ago the author had the opportunity to examine in detail a collection of mineral specimens from the Sludyanka river area, at the west end of Lake Baikal, in Siberia.

For some hundreds of years this area has been one of the few sources of the rare and beautiful rock called lapis-lazuli. Little has been written on the area in English scientific journals, but Bauer, in his great work on gemstones, states that the rock is found in the beds of three streams—the Talaya, Malaya Bistraya and the Sludyanka—at the west end of the lake. The deposits are stated to be in white granular limestone near the contact with granite. The material is in many cases inferior to the Badakshan lapis-lazuli and contains less pyrite. The colour is said to be most variable, ranging from dark blue, violet to green and pink. The mines on the Sludyanka are situated eight miles from the town of Kultuk. The rock is found near the contact of white marble and granite and gneiss and pebbles of lapis-lazuli are also found in the bed of the stream. Fig. 1 is a geological map of the area.

As well as making a study of the Siberian minerals the author studied thin sections and carried out microchemical tests on similar material from Afghanistan and Chile. The purpose of this study was to determine the mineralogical nature of the rock, as the text books seem to have different views on just what is the composition of lapis-lazuli.

MINERALOGY

(*a*) *Lazurite:* $Na_4(NaS_3 \cdot Al)\ Al_2Si_3O_{12}$

Isometric. In cubes and rhomb-dodecahedra. Usually massive and compact. Cleavage: dodecahedral, imperfect. Fracture uneven. H = 5-5·5. G = 2·38-2·45. Lustre vitreous. Colour rich Berlin-blue or azure-blue, violet, greenish blue. Translucent.

Analysis: Brögger and Bäckstrom, Zs. Kr., 16,236, 1890.

	SiO_2	Al_2O_3	CaO	Na_2O	K_2O
Central Asia:	32·52	27·61	6·47	19·45	0·28
	SO_3	S	Cl		
	10·46	2·71	0·47	= 99·57%	

Note 1. Before 1869 lapis-lazuli was thought to be a simple mineral. In an old copy of Dana's "Manual of Mineralogy", the 1852 edition, p. 196, under "Combinations of a Silicate and a Sulphate", lapis-lazuli is described as a monoclinic azure-blue mineral of composition: silica 45·5, alumina 31·8, soda 9·1, lime 3·5, iron 0·8, sulphuric acid 5·9, sulphur 0·9, chlorine 0·4, and water 0·1.

In the "Glossary of Mineralogy" by Bristow, 1861, the same material is described as a simple mineral, but of cubic symmetry. In 1869 Fischer discovered that it was heterogeneous and Vogelsang in 1873 proved it to consist of an isometric ultramarine blue mineral mixed in various proportions with crystalline calcite and scapolite. This blue mineral was named lasurit by Brögger in 1890, who in the same year, with Bäckstrom, had arrived at the analysis given above.

Note 2. The mineral was known to the ancient world under the name of sapphire. In the most ancient text on mineralogy, the *Περὶ λίθων* of Theophrastus the mineral is named *Σάπεφιρος*. Pliny, in his "Historia Naturalis" translated this as "*sapphiros*" by which name it was known in scientific circles until the sixteenth century, for Agricola in his "De Natura Fossilium" of 1546 calls it *Sapphirus*, though he may have used the word to describe two different minerals. Some of his descriptions of sapphirus are certainly not of our lapis-lazuli, but could easily be our sapphire, blue corundum.

The present day name originated in the Middle Ages, being an Anglicized version of an Arab word "al lazward", meaning "the blue sky". It appears in the "Gemmarum et Lapidum Historia" of de Boodt in 1609.

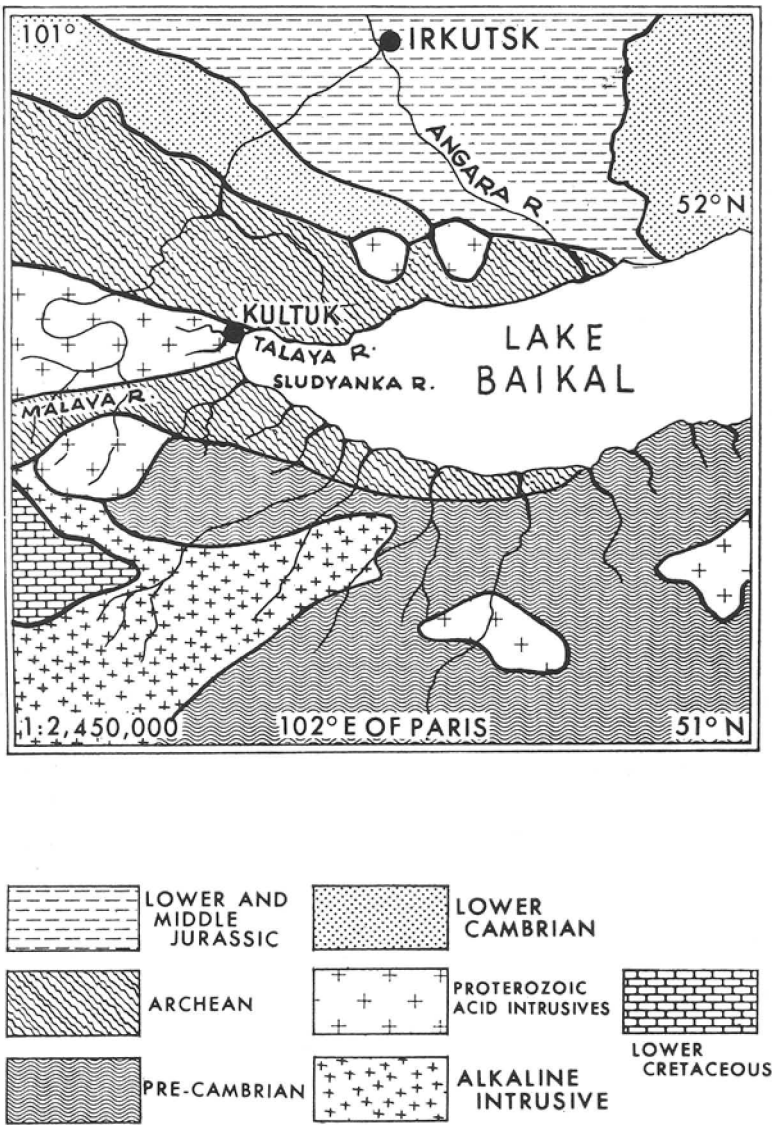
101°
IRKUTSK
ANGARA R.
52° N
KULTUK
TALAYA R.
SLUDYANKA R.
LAKE
BAIKAL
MALAYA R.
1:2,450,000
102° E OF PARIS
51° N
LOWER AND MIDDLE JURASSIC
LOWER CAMBRIAN
ARCHEAN
PROTEROZOIC ACID INTRUSIVES
LOWER CRETACEOUS
PRE-CAMBRIAN
ALKALINE INTRUSIVE

FIG. 1.

Note 3. It is interesting to note that Brögger suggested that lazurite, sodalite, hauyne and noselite, along with the helvite group could be included in the garnet family. His reasons were:

(1) All are usually isometric;

the feldspathoids have chemical formulae which are closely similar to $\overset{II}{R}_3 \overset{III}{R}_2 (SiO_4)_3$ the garnet formula. Helvite, with formula $(Mn,Fe)(Mn_2S)Be_3(SiO_4)_3$ may also be considered a garnet if the bivalent group—S–Mn–S—take the place of a bivalent element R and 3Be correspond to 2Al.

Another point of geochemical interest is the apparent lack of garnets from feldspathoid deposits. Lime garnets are perhaps the most typical minerals from "skarns" (metasomatic limestones). Could it not be that the feldspathoids are the equivalent minerals in the metasomatism of other limestones?

(*b*) *Sodalite:* $Na_8Al_6Si_6O_{24}Cl_2$

Isometric. Rhombdodecahedron form common, often twinned. Generally massive, or in concentric nodules. Cleavage: dodecahedral, distinct. Fracture conchoidal to uneven. Brittle H = 5·5-6. G = 2·14-2·3. Lustre vitreous, sometimes greasy. Colour gray, greenish, yellow, white, sometimes blue or pinkish. Transparent to translucent. R.I. = 1·4827 (Na).

Analysis: Brögger and Bäckstrom, Zs. Kr., 18, 223, 1890.

	SiO_2	Al_2O_3	CaO	Na_2O	Cl
Lake Baikal (blue)	36·74	31·96	0·11	25·95	7·11
	K_2O	SO_3	IGN		
	trace	0·11	0·17	= 102·15%	

Note 1. Sodalite and lazurite are closely related minerals. In the latter, sulphide ions replace the chloride ions of typical sodalite. While the two minerals are so closely related chemically sodalite has a much wider distribution. It is a rare mineral in the volcanic and plutonic rocks of the nepheline-syenite family. The main differences are listed in the following table.

	SODALITE	LAZURITE
Fracture ...	Sometimes conchoidal	Uneven
Hardness ...	Greater than 5·5	Less than 5·5
Colour ...	Dark blue	Ultramarine blue
R.I. ...	Up to 1·487 Na	Around 1·50
S.G.... ...	2·14–2·40	2·38–2·45

The presence of free sulphide (iron pyrite) in the lazurite is often a help in identification.

(*c*) *Hauyne:* $Na_4(Na_2, Ca)\ Al_6\ Si_6\ O_{24}(SO_4)_2$

Isometric. Octohedra, rhombdodecahedra, often in rounded forms. Commonly twinned. Cleavage: dodecahedral, good. Fracture, flat conchoidal, uneven. H = 5·5–6. G = 2·4–2·5. Lustre vitreous or greasy. Colour shades of blue common, sometimes pinkish, yellowish, green. Translucent. R.I. = 1·49–1·51 Na.

Analysis: Brögger and Bäckstrom, Zs. Kr., 18, 230, 1890.

	SiO_2	Al_2O_3	CaO	Na_2O
Locality unknown	32·0	27·38	8·21	18·03
	K_2O	SO_3	Cl	
	0·35	12·62	0·31	
	MgO	S		
	0·11	0·44 = 99·75%		

Note 1. The following microchemical test may be carried out under the microscope to separate the three feldspathoids so far studied. A few scrapings are placed on a glass slide covered in nitric acid. A hot blast of air will accelerate evaporation. After a while small cubes of sodium chloride may form indicating sodalite, or monoclinic prisms of gypsum, indicating hauyne. If the gas hydrogen sulphide is evolved, recognized by its characteristic smell, then the mineral is lazurite.

Note 2. The standard English text-book on gemstones states that the blue component of lapis-lazuli is a variety of hauyne, and advocates that the term lazurite be dropped. However, the author has subjected a number of pieces of Siberian gem

lapis-lazuli to the test in Note 1 and has only once detected hauyne in the material. Thin section studies of other rough material (from dealers in the stone) have likewise been tested and it was noted that the blue colour of the mineral was remarkably evenly developed in the crystals, not patchily as in most hauyne crystals from syenites. Bauer, however, states that in lapis-lazuli hauyne is always present in the largest amount.

(*d*) *Diopside*: Ca Mg $(SiO_3)_2$

Monoclinic. In prismatic crystals, often slender; also granular and massive. G = 3·2–3·38. Colour white yellowish to shades of green. Transparent to translucent.

Note 1. The pyroxene usually recorded from lapis-lazuli deposits is iron-free diopside. Van Hise gives an equation showing the possible alteration of dolomite to diopside

$$MgCaC_2O_6 + 2SiO_2 \rightarrow MgCaSi_2O_6 + 2CO_2$$

The specimen studied from the Lake Baikal deposit is a dark olivine green colour and most probably the variety of hedenbergite called baikalite. Its S.G. is approx. 3·5.

(*e*) *Tremolite:* $CaMg_3Si_4O_{12}$

Monoclinic. In prismatic crystals and fibrous. Commonly in compact bladed aggregates. G = 2·9–3·1. Sometimes transparent and colourless. Usually translucent to opaque, white to dark gray.

Note 1. An aluminous variety, Koksharovite, named after the Russian mineralogist, N. von Koksharov is found in the Lake Baikal district. Its analysis is given below.

	SiO_2	Al_2O_3	FeO	MgO	Na_2O
Lake Baikal:	45·99	18·20	2·40	16·45	12·78
	Na_2O	K_2O	IGN		
	1·53	1·06	0·60 = 99·01%		

(*f*) *Calcite:* $CaCO_3$

Hexagonal, rhombdodecahedral. Crystals variable, tabular or prismatic, often with sharp termination. Twins common, also massive, stalactitic, earthy. Cleavage rhombdodecahedral perfect. H = 3. G = 2·714. Lustre vitreous. Colour white or colourless and other pale colours. Streak white. Transparent to opaque.

Note 1. The calcite from the Lake Baikal area is often of a sky-blue colour. The author tested the stability of this colour by heating crystals in a laboratory oven at 300° for a few hours and the blue colour disappeared entirely. No thermo-luminescence was observed during heating but on being stood in direct sunlight for a few hours the blue colour returned, but now much paler. It seems likely that the colour arises from colour centres.

(*g*) *Pyrite:* FeS_2
Isometric, pyritohedral. Cube and pyritohedron or striated cubes. Twins common, also massive, granular, radiating, etc. Cleavage indistinct. Fracture conchoidal to rough. H = 6–6·5. G = 4·95–5·10. Lustre metallic. Colour a pale brass yellow. Streak greenish-black.

Note 1. Both in the Bible (book of Job) and in Pliny the small crystals of pyrite in lapis-lazuli were called gold, an idea which still exists among some of the general public to the present day.

(*h*) *Humite:* $H_2(Mg,Fe)_{19}Si_8O_{34}F_4$
Orthorhombic. Crystals and penetration, twins common. Cleavage distinct. Fracture subconchoidal to uneven. H = 6–6·5. G = 3.1–3·2. Lustre vitreous to resinous. Colour white, yellowish, brown.

Note 1. Humite is found in limestones ejected from Vesuvius and Monte Somma. It is also recorded in Dana's "System" from the Ladu mine near Filipstad, Sweden, from Andalusia and Brewster, N.Y. M. J. Barthoux in 1933 recorded humite from the Badakshan limestones, along with lazurite, phlogopite, forsterite and pyrite.

(*i*) *Forsterite:* Mg_2SiO_4
Orthorhombic. Prisms, pinacoids, pyramids common, also granular and massive. One distinct cleavage. Fracture uneven. H = 6–7. G = 3·21–3·33. Lustre vitreous. Colourless, yellowish, also greenish.
Analysis: Rath, Pogg., Ann., 109, 568, 1860.

	SiO_2	MgO	FeO
Mt. Somma:	42·41	53·30	2·33 = 98·04%

(*j*) *Phlogopite:* $\dot{R}_3Mg_3Al(SiO_4)_3$ where $\dot{R}$ = H, K, MgF
Monoclinic. Six sided pseudo-hexagonal prisms common. Cleav-

age: perfect basal. Thin laminae tough and elastic. H = 2·5–3·0. G = 2·78–2·85. Lustre pearly. Yellowish brown, often with a coppery reflection. Also colourless, greenish, brownish.

Note 1. Phlogopite is similar to common biotite but it contains little iron. It is usually recognized by its association with serpentine and crystalline limestone and dolomite. Large deposits of the mineral occur in the Sludyanka area according to Nalivkin, in association with pegmatites of upper Proterozoic age.

(*k*) *Scapolite:* An isomorphous series of variable composition between marialite $Na_4Al_3Si_9O_{24}Cl$ and meionite $Ca_4Al_6Si_6O_{25}$ as end members. Tschermak includes common scapolite and missonite (including dipyre) as intermediates. Tetragonal, commonly in prisms terminated by pyramids, also massive and granular. Cleavage good in two directions. H = 5–6. G = 2·66–2·73. Lustre vitreous to pearly. Colour white, blue, greenish, pink, purple. Usually transparent.

Note 1. The variety of common scapolite from the Sludyanka river is termed glaucolith and is massive and of a light bluish colour. Its composition is (Rath, Pogg., Ann., 90, 101, 1853.)

	SiO_2	Al_2O_3	FeO	CaO	
Lake Baikal:	47·49	27·57	1·54	17·16	
	MgO	Na_2O	K_2O	H_2O	
	0·47	4·71	0·58	0·48	= 100%

G (measured by the author) = 2·72

(*l*) *Epidote:* $HCa_2(Al,Fe)_3Si_3O_{13}$
Monoclinic. Crystals elongate prisms, striated along length. Perfect basal cleavage. H = 6–7. G = 3·37–3°50. Colour pistachio green to black.

Note 1. This mineral was detected by the author in small crystals just inside the granite - lapis-lazuli contact. Determination was based on:

(*a*) colour and pleochroism
(*b*) high birefringence measured by a Berek compensator of 0·036
(*c*) large 2V, OPT.(—)

(*d*) strong inclined dispersion
(*e*) parallel extinction in elongate sections.
Epidote is a fairly common contact mineral, but the author has not come across any reference to it in lapis-lazuli deposits.

(*m*) As well as the minerals previously listed lapis-lazuli often contains smaller amounts of feldspar, apatite, sphene and zircon. These are rarely seen in material from the gem-dealer and their presence is of interest to the mineralogist mainly because they may give some clue in the perplexing problem of the origin of lapis-lazuli.

The Mineral Composition of the Deposits

Lapis-Lazuli is found in the following areas:

1. Badakshan:—Lazurite, hauyne, sodalite, pyrite, calcite, scapolite, forsterite, humite, diopside.
2. Lake Baikal:—Lazurite, sodalite, phlogopite, pyrite, epidote, calcite, tremolite, diopside.
3. Chile, the Andes of Ovalle:—Lazurite, calcite.
4. Monte Somma, Italy:—Sodalite, hauyne, lazurite (rare), calcite.
5. Latium:—Lazurite (exact composition not listed).
6. Dattaw Valley, Upper Burma:—Lapis-lazuli is recorded from the ruby-earths of Burma by Bauer, but Wadia, in his "Geology of India", does not record it, and this occurrence is not listed by Dana and Ford, Berry and Mason or Miers.
   A detailed review of the Mineral production of India for the years 1898-1903 by T. H. Holland, F.R.S., Director of the Geological Survey of India does not mention the mineral. However, J. Coggin-Brown notes the presence of a lazurite-diopside-epidote rock in the Myaungok district associated with augite gneiss, enstatite gneiss, granulites and pyroxenites. This is perhaps the material noted by Bauer.
7. Gunnison County, Colorado:—Mineralogical composition not known, but good lapis-lazuli is mined near the top of the North Italian mountain in this area.
8. San Bernardino County, California:—Lazurite (in patches and grains in a mica-diopside schist. A. F. Rogers considered it to be a sulphide-bearing hauyne).

Lapis-lazuli has also been recorded (rather doubtfully) from China, Tibet and the Ditro area of Transylvania.

Fluorescence Phenomena

The Lake Baikal rocks exhibit in some instances striking fluorescence colours under longwave ultraviolet light (3650Å). The crystalline limestone near the contact with the lazurite rock glows like coals of fire—no better or nearer description can be given —when illuminated by ultra-violet light in a darkened room. Isolated patches of the fenite also glow with a pale blue colour and some of the metamorphic actinolite rocks are seen to be shot through with minute crystals fluorescing bright blue.

Owing to the fact that the fire—like fluorescence in the calcite—occurred mainly in a definite thin line along the contact, the writer at first imagined the presence of a thin band of previously undetected mineral, perhaps scapolite. A more detailed optical examination with the aid of a Berek compensator revealed no notable difference in birefringence between the fluorescing and non-fluorescing areas in the limestone and it was therefore presumed that the fluorescence was caused by some lattice disturbance or perhaps the manganese content of the calcite.

The pale blue fluorescing areas of the fenite proved to be small patches of a highly decomposed mineral. A similar fluorescence seen on weathered faces of rock from the area could be attributed to the same unknown mineral.

The small bright blue fluorescing needles proved an easier mineral to identify. Under high power oil immersion they showed the fairly high relief, second order colours and extinction angle of 16° to 18°, of tremolite.

Origin

Lapis-lazuli must be looked upon as a rather unusual product of the contact metasomatism of dolomitic limestone. According to W. Lindgren (1933) metasomatism is defined as "the process of practically simultaneous capillary solution and deposition by which a new mineral of partly or wholly differing chemical composition may grow in the body of an old mineral or mineral aggregate". The term differs from metamorphism in that chemical material is migrating forward and back across the contact zone between the

FIG. 2. *Normal blue Siberian lapis-lazuli. The fine grained lazurite is set in course grained calcite and a few opaque cubes of pyrite are also visible. Diameter of field approx. 1.8 m.m.*

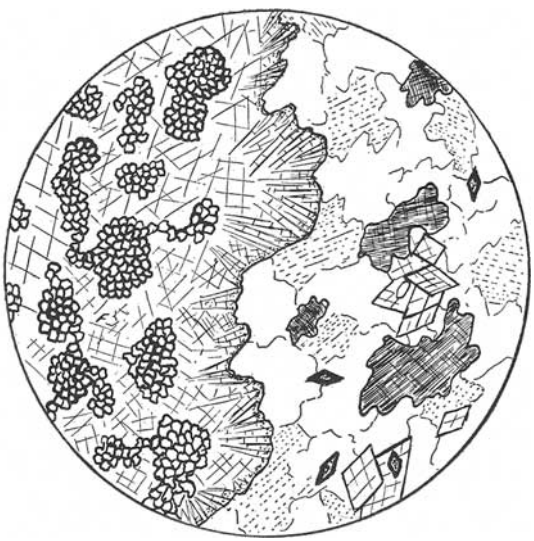

FIG. 3. *Contact of "granite" and lapis-lazuli. The lapis-lazuli is similar to that in Fig. 2. But the calcite is finer and tends to show "fan structure" at the edge. The "granite" consists of colourless and dotted alkali feldspars, dark aegirine, calcite crystals showing diamond-shaped cleavages and small crystals of sphene with very dark borders. Diameter of field 1.8 m.m.*

igneous rock and the country rock while the latter is subjected to greatly increased heat and pressure. We must think of chemical alteration of the intruding rock as well as the intruded.

A small distance off the contact zone crystals of calcite are easily visible (in thin section) inside the igneous rock. These may be crystals of the limestone not yet absorbed by the invading "granite" or they may be crystallizations of calcite injected in a magmatic state into the "granite". Actually the "granite" is a syenitic rock composed of alkali feldspars and aegirine. In fact it may itself represent a particular type of alkali metasomatism in which ordinary granite is altered to a syenitic rock by a process Brögger terms "fenitization". This writer, in his great memoir on the igneous rocks of southern Norway noted the association of "fenite" with pure carbonate rock (carbonatite). Numerous thin sections of the granite from the Lake Baikal area showed the presence of fenite containing crystalline calcite. (Fig. 3).

At the present time two slightly different hypotheses are mentioned in the literature to explain the feldspathoidal zone between granite and limestone. *These are summarized below:—*

(*a*) *Daly-Shand hypothesis:* This is the classical idea dating from 1910. In this year Daly postulated that a granite magma could be desilicated (desaturated in silica) by assimilation of carbon dioxide (from carbonate rocks), water (from sediments) and lime and/or magnesia (from dolomites). This syntectic magma then crystallizes and differentiates to give the feldspathoidal class of rock—the nepheline syenite family.

(*b*) *Adams-Barlow hypothesis:* Shortly after the publication of the original paper by Daly in 1910 Adams and Barlow published an account of their studies of the nepheline-bearing syenites of the Haliburton-Bancroft area in south east Ontario. Here high-grade rock of the Grenville Series (dolomitic marbles, amphibolites and paragneisses) have been intruded by pre-Cambrian granites. Granitization is widespread and the syenites are situated in the granitized belt. The authors considered that the syenite, far from being a simple contamination product of the granite magma, is a massive replacement body. It is often strongly banded and this they regard as a "ghost" structure of the foliation and banding of impurities in the original limestone. They therefore postulate a definite

nepheline syenite magma resulting from the processes of metasomatism and granitization.

At the present time both hypothesis are repeatedly mentioned in the literature. Associated with the production of the nepheline syenite type of rock is the problem of the origin of "carbonatites" and "fenites". Carbonatites are carbonate rocks, mainly calcitic, which appear to be injected into their present position in at least a "plastic" condition, or more probably as an actual magma. They were first described by A. G. Hogböm from the Alnö island off Sweden in 1895, which area remains a classic location for their study.

For many years most petrologists opposed the idea of a carbonate magma on the grounds of the high melting range of anhydrous carbonates. This led Pecora in 1956 to state that the carbonatites had their source in highly concentrated hydrothermal solutions rather than pure magmas. Only as recently as 1958 was this difficulty resolved. Then Patterson reported the rapid complete melting of calcite at 1000°C and insipient melting at 900°C at a combined carbon dioxide and water pressure of only 50 bars. Thus the magma state seems a possibility.

Near the contact the author often noted a peculiar flow structure in the calcite and lazurite (lapis-lazuli) rock. The whole pattern on a much finer scale is reminiscent of the "flow" or "trachytic structure" so often seen in trachytes and other lavas in thin section. It thus seems as if this rock may have been in a "plastic" or sluggish magmatic state during its formation.

Fenitization of the granitic rocks is a common alteration associated with the production of carbonatite magmas. Fenite—an orthoclase, albite, aegirine, apatite rock—often contains calcite in well crystallized grains.

Another factor possibly of prime importance in the development of feldspathoidal zones is the association with rift valleys. According to Tilly the close relation between the alkali rocks of the carbonatite centres of Africa, from the Transvaal in the south to Uganda in the north, within and along the Great Rift Valley seems to suggest that the operating mechanism lies deep in the crust. The author noted in his studies of the Lake Baikal material the association of alkaline rocks (nepheline syenite and granite-porphyry probably related to those of the Aldan alkaline complex) with granites and limestones of Cretaceous age in the Lake Baikal rift valley. Possibly the same mechanism is operating here?

Even supposing a primitive nepheline mineralization of rocks, both granitic and calcic, in the contact zone, the process by which nepheline is subsequently converted into the other rarer feldspathoids is not clear. Clarke, in his "Data of Geochemistry" classes sodalite, hauyne, lazurite and nosean as derivatives of nepheline. To explain their rather rare development we must consider at least two types of metasomatism.

(*a*) *Sulphur metasomatism:* The lapis-lazuli rocks and the contact "skarns" in other areas are usually full of small crystals of pyrite, and in most cases this mineral has been attributed to the reaction between iron-bearing silicates (such as biotite, etc.) in the country rock and magmatic hydrogen sulphide. It seems possible that the same magmatic gas assists in the alteration of the primitive nepheline minerals to the sulphate-bearing hauyne and nosean.

(*b*) *Chlorine metasomatism:* The appearance of scapolite in a carbonate rock during metasomatism is usually caused by introduction of chlorine from magmatic gases. It is perhaps this process along with the introduction of sulphur which results in the development of lazurite.

So we can see that a number of conditions must be fulfilled before a lapis-lazuli assemblage of minerals can develop in a granite-limestone contact zone. These are listed below:

(1) Development of a feldspathoidal zone between dolomitic limestone and desilicated igneous rock. In the Lake Baikal area this zone is probably the result of metasomatism and migmatization (at least partial fusion of the country rock to give localized magmas of carbonatite and nepheline syenite type). A zone of mobility develops in which the lazurite later develops.

(2) Introduction of sulphur and chlorine from an adjacent igneous rock. These are usually believed to have been introduced during a pneumatolytic stage. It is also possible that sulphides of iron are introduced at a later stage in liquid solution.

Synthesis

It is difficult to say if the essential component of lapis-lazuli, i.e. lazurite, has ever been produced in the laboratory. Artificial

"ultramarines" of variable composition have been in production since 1828 and as they are very variable in composition and never stoicheiometric, and have the same X-ray powder pattern irrespective of colour, it is quite possible that natural lazurite (not the more complicated mixture, natural lapis-lazuli) has been synthesized.

This lazurite (ultramarine) is produced in the solid state by allowing a mixture of oxides to react in a crucible under the action of heat. Complete reaction is slow, as it depends on the rate of diffusion of the elements. The result is a deep blue mass of often ultramicroscopic crystals.

Colour of lapis-lazuli

The colour of lazurite is an intense blue. It is not therefore surprising that many attempts have been made to determine the cause of this colour. And to anyone versed in modern solid state physics it is not in the least surprising that the beautiful blue mineral still retains its secret.

Before attempting to explain the blue colour of natural lazurite it is well to keep in mind three sets of facts.

(1) The light blue lazurite from Afghanistan is often converted into the normal dark blue material by the action of heat.

(2) In the following table the "ideal" compositions of various coloured artificial "ultramarines", produced by different chemical processes, are compared with the blue component of lapis-lazuli.

Sulphate Process	*Sulphate Soda Process*	*Soda Process*	*Natural*
White $Na_{10}Al_6Si_6O_{24}S_2$	White $Na_{12}Al_6Si_6O_{24}S_3$	White $Na_{14}Al_6Si_6O_{24}S_4$	
Green $Na_8Al_6Si_6O_{24}S_2$	Green $Na_9Al_6Si_6O_{24}S_3$	Green $Na_{10}Al_6Si_6O_{24}S_4$	
Blue $Na_6Al_6Si_6O_{24}S_2$	Blue $Na_7Al_6Si_6O_{24}S_3$	Blue $Na_8Al_6Si_6O_{24}S_4$	Blue $Na_{10}Al_6Si_6O_{24}S_6$

A glance at these formulae will show that there are two variable components, the alkali and the sulphur, and it is only reasonable to assume that colour changes are associated with changes in proportion of these.

(3) According to Jaeger, all ultramarines, regardless of colour, all lazurite, nosean and hauyne have the same powder diffraction patterns. Sodalite, on the other hand, gave an entirely different pattern.

Mineral colour is usually the result of the removal of certain wavelengths from white light by the mineral's structure. The eye reacts to the transmitted or reflected wavelengths as to a simple colour. Just what is the cause of the absorption is difficult to say. Both sodalite and lazurite have strong blue colour, a troublesome fact for the beginner in mineralogy, though the two colours are definitely different.

The lapis-lazuli minerals are usually classed as idiochromatic, i.e. the coloration is structural rather than produced by the presence of traces of impurities. Even in idiochromatic minerals there is variation in colour and this in most cases is yet unexplained.

There seem to be at least two theories which have been put forward to explain the blue colour:

(*a*) Theory of Hofmann and Ostwald. This classical theory relates the colour to the presence of colloidal sulphur in the crystal lattice. Coloured compounds containing colloidal sulphur can be obtained from ferric chloride and sodium thiosulphate, or by the addition of sulphur to fused halite. A number of other artificial compounds can be prepared, all containing sulphur, which give colours ranging from pink to green to blue (the lapis-lazuli colours) and all more or less related to the ultramarines. Ostwald and Auerback attempted to relate the variation in colour to the degree of dispersion of the colloidal sulphur. Later workers, however, including Podschus and Leschewski, basing their ideas on X-ray studies, consider that colloidal sulphur cannot exist in this structure, though the association of the blue colour with polysulphide sulphur is, however, not disputed.

(*b*) Theory of Weyl. According to Weyl the colour of lapis-lazuli is the result of absorption caused by the relatively large and easily polarized sulphur ions in the lattice.

In any crystal the particles which occupy the "points" of the structure are atoms or ions. We may furthermore assume that these particles are small spheres with fairly definite radii, the whole structure being a packing of small spheres touching one another.

These radii can be measured in the laboratory with accuracy and it is found that they depend on the nature of the element, its state of ionization and its mode of linkage with other adjacent atoms. As an example the radius of the sodium atom in the metal is 1·86Å while the radius of the ion in sodium salts is 0·97Å. Thus the radius is not equal to the radius of the outer electron shell.

However, this idea of an ion as a rigid sphere is only true as a first approximation. In structure of low or irregular co-ordination, in particular the AX compounds, where A is any of the cations Na^+, K^+, Rb^+, Mg^{++}, Ca^{++}, Sr^{++}, etc., and X any of the anions H^-, F^-, Cl^-, Br^-, I^-, etc., polarization, or the deformation of an ion in the presence of its neighbours, occurs. For in an electric field both the nucleus and the electron shells shift with respect to one another causing the particle to become a dipole. In fact, if the polarization is extreme a complete electron transfer may occur from anion to cation with the formation of a non-polar bond.

The extent to which we can expect polarization to occur in any special structure depends on the polarizability and polarizing power of the ions as well as the co-ordination. The polarizability depends on size and looseness of binding and for this reason marked polarization is confined to fairly large anions.

The polarizing power of ions is determined mainly by its electric field and this is greatest for small ions of large charge. In the following table, after Grimm 1927, the variation of polarizability and polarizing power among common ions is shown.

As below ↑

O^{2-}	F^-	Ne	Na^+	Mg^{2+}	Al^{3+}
S^{2-}	Cl^-	A	K^+	Ca^{2+}	Sc^{3+}
Se^{2-}	Br^-	Kr	Rb^+	Sr^{2+}	Y^{3+}
Te^{2-}	I^-	X	Cs^+	Ba^{2+}	La^{3+}

Decreasing Polarizability
Increasing Polarizing Power →
Decreasing Radius

Although some degree of polarization is to be expected in most ionic structures this is not likely to effect their physical properties. When extensive polarization occurs, however, changes

in solubility, melting points, etc., occur, and characteristic optical properties develop. According to Weyl the large sulphur ions are very easily polarized and the resulting absorption causes the deep blue colour.

Conclusions

Lapis-lazuli—perhaps the earliest mineral product systematically mined by man, if we exclude flint—still presents difficulties to the scientist. Its mineralogical composition is complex and this complexity is increased by lack of agreement among writers as to just what distinguishes one feldspathoidal mineral from the other. This latter fact, one is certain, will be definitely cleared up when the volume (or volumes?) on the silicates of the seventh revised edition of the Dana's "System" is published. The mode of origin is still only known in outline, and the origin of the blue colour, so amazing to the chemists of the early 19th century, can hardly be said to be yet fully understood.

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Gemmological Abstracts

POUGH (F. H.). *Cultured pearls.* Lapidary Journal, 1963, 16, 11, pp. 1014-1019; 16, 12, pp. 1090-1095; 17, 1, pp. 6.

A competent survey of present day cultured pearl production in Japan. Truly fine cultured pearls are comparatively rare in spite of large production. The 2 to 4 mm. nuclei can be grown on in about a year, with 80 to 85% of the oysters surviving the operation of mother-of-pearl bead insertion. 5 to 10% of the product can be classified as acceptable for necklaces. The 5 to 6 mm. nuclei take at least two years to become 6 to 7 mm. cultured pearls, and the yield for fine quality necklaces is between 3 and 5%. When 10 to 11 mm. cultured pearls are produced from 9 mm. nuclei the oyster mortality is about 80%, and the quality percentage is as low as 1%. An oyster may receive one or two bead nuclei.

The usual thickness of the " cultured " layer on a Japanese cultured pearl is half a millimetre thick. Larger cultured pearls (above 9 mm.) are grown in *Pinctada maxima*, in Pacific waters, and are marketed as " South Sea " pearls. The mother-of-pearl nuclei for Japanese cultured pearls comes from a freshwater clam obtained from river tributaries to the Mississippi River in the U.S.A. The reason for the use of the American mussel shell is that it has a weak lustre. There is concern about future supplies because of river pollution.

S.P.

SINKANKAS (J.). *Chromian sphene.* Lapidary Journal, 1963, 17, 1, pp. 4-5.

An emerald-green variety of sphene has been located in Baja California. Analysis by a commercial laboratory has shown that the mineral contains about 1% chromium, and examination of available mineralogical literature has not revealed any varieties of sphene in which chromium is more than a trace element. It is suggested that this sphene may be an important new variety of the species and may deserve the description *chromian sphene.* The find

was made in a region about 30 miles east of San Quintin, on the west coast of Baja California. The size of the crystals so far discovered is small, but a gem of 2·25 carats has been cut, which is almost flawless.

S.P.

BUTLER (B. C. M.). *An occurrence of nephrite jade in West Pakistan.* Min. Mag., 1963, 33, pp. 385-393.

A description of two pebbles of good quality nephrite found in the river bed of the Teri Toi in the Kohat district of West Pakistan. The find appears to be the first authenticated record of either of the true jade minerals occurring in Pakistan or India and a full description of the pebbles and the locality is given. One pebble was greenish-white and the other a clear spinach green in colour. The former gave a specific gravity figure of 2·954 and the latter 3.021, determined by flotation method.

S.P.

DALZIEL (A.). *New find of nephrite jade in situ made in New Zealand.* Lapidary Journal, 1963, 16, 11, pp. 1000-1008.

Nephrite *in situ* has been found in the southern Alps of New Zealand along the Arahura River below Olderog Creek. The occurrence is at the base of a large exposed outcrop of serpentine resting on schist. Large water-polished boulders of green and white material have been encountered weighing up to seven tons.

S.P.

LUNGHI (A.). *Colour grading of diamonds.* Diamant, 1963, 49. p. 5.

There are several colour-grading systems for diamond in the jewellery trade. In the U.S.A. one system uses letters from D to X and another numerals from 0 to 10, subdivided into units of 100. In other countries a series of names, such as Rivers, Crystals, top Capes, or White, Commercial White, Yellows, is used. A series of names is useless unless every stone is based on and referred to a master sample. A commonly used denomination has different meanings in different colour-grading systems. There is a lack of uniformity, and, unless a rational method of classification is relied upon, much colour-grading of diamond is meaningless.

S.P.

SCHLOSSMACHER (K.). *Chrysoberyll-Katzenauge-Alexandrit.* Chrysoberyl cat's-eye alexandrite. Zeitschr. d. deutsch. Gesell. f. Edelsteinkunde, 1962, 40, 9–12.

Article generally surveying gems of the chrysoberyl group. Various chemical and physical properties are discussed. Specific gravity, 3·71–3·72, is high enough for the gem to be found alluvially. Chrysoberyl, chrysoberyl cat's-eye and alexandrite are discussed in detail, and their occurrences mentioned.

W.S.

SCHLOSSMACHER. (K). *Neue Synthesen.* New synthetics. Zeitschr. d. deutsch. Gesell. f. Edelsteinkunde, 1962, 40, 13.

Two new types of " synthetic " moonstones are on the market. Both are made of synthetic spinel. The first is backed with blue enamel and contains rutile needles. The second does not contain rutile needles, and is lacquered at the back.

SCHMIDT (P.). *Die Edelsteine in Israel, einst und heute.* Gems in Israel, then and now. Zeitschr. d. deutsch. Gesell. f. Edelsteinforschung, 1962, 40, 34–38.

Article surveying mentions of gems in the Bible, including the breast plate of the High Priest. Difficulties of old nomenclature are discussed, as the ancients tended to group all types of stones of the same colour together.

E.S.

WURMBACH (I.). *Die Diamantentstehung aus der Sicht seiner Synthesis.* The formation of the diamond as seen from its synthesis. Zeitschr. d. deutsch. Gesell. f. Edelsteinkunde, 1962/63. 42, pp. 10-23,

Detailed article with bibliography of 43 items. The various syntheses are described, mainly those of G.E.C. of America, De Beers in South Africa, Carnegie Institute in Washington, one Swedish method, and two more American experiments. The behaviour of carbon at various temperatures and pressures is shown in a curve. The crystallographic and optic properties of diamond are discussed. The conclusion deals with the conditions of formation of the natural diamond, starting with the occurrence, paragenesis and origin of carbon.

E.S.

(ANON). *Neue Edelsteinvorkommen.* New gem occurrences. Zeitschr. d. deutsch. Gesell. f. Edelsteinkunde, 1962, 41, pp. 21-24, and 1962/3, 42, pp. 25-26.

Diamond mining from the sea is shortly discussed. Ricolite is a combination of serpentine and talc used in various crafts and is found in New Mexico. Drayite, a brown tourmaline, has been found north of New York and new occurrence of chrysoprase is in the state of Goias in Brazil. Ruby from the Longido mine in Kenya is now cut into very pleasing stones. In the north of the state of Maine in the U.S.A. jasper is found, but the red colour is usually poor, though the stones take a very good polish. Spessartites from Madagascar have an orange-red colour, sometimes dark, sometimes light. Amethysts have been found in a new district of Minas Gerais in Brazil. Diamond is being looked for in Czechoslovakia.

E.S.

SALLER (X.). *Ueberraschungen in der Zuchtperlen-Herstellung.* Surprises in the production of cultured pearls. Zeitschr. d. deutsch. Gesell. f. Edelsteinkunde, 1962/63, 42, pp. 4-9.

A survey of to-day's cultured pearl production. It is shown that the newer methods more and more approach the natural growth of pearls. Also components which made differentiation easier are not used any more. In future there will be great difficulty in differentiating between genuine and cultured pearls, necessitating a new terminology in the field of pearls. The article deals mostly with the new technique of S. uda, who uses the mantle of the pearl as a seed in the production of Biwa-lake fresh-water pearls. A large part of the produced pearls have a nucleus, but those produced by the described methods are without nucleus. An X-ray shows a drop pearl without nucleus, 18mm × 13mm, skin free of blemishes.

E.S.

BENECKEN (K.). *Studien zur Diamant-Spektroskopie.* Studies in diamond spectroscopy. Zeitschr. d. deutsch. Gesell. f. Edelsteinkunde, autumn 1962, 41, pp. 14-18.

Various practical tests are recounted the results of which, together with other results, are summarized in a table listing 32 stones.

E.S.

RUFF (E.). *The Jade story.* Lapidary Journal, 1963, 16, 11, pp. 1046-1056.

The nineteenth and concluding part of a series of articles which have covered the occurrence and use of jade in Asia, New Zealand, America, Australia and the Pacific Islands. S.P.

Institut für Edelsteinforschung, Idar-Oberstein. *Neue Beobachtungen an echten und synthetischen Smaragden.* New observations on genuine and synthetic emeralds. Zeitschr. d. deutsch Gesell. f. Edelsteinkunde, winter 1962/3, no. 42, pp. 29-32.

Article dealing with Sandawana emeralds and synthetic Chatham emeralds, and their inclusions. There are 4 photomicrographs, one of a tremolite rosette in a Sandawana emerald, and three of various wisps in synthetic Chatham emeralds. The Institute makes a point of calling the latter "Chatham synthetic emeralds" instead of " Chatham emeralds " in order to make sure that people know their origin. E.S.

THURM (V.). *Das Karat gestern und heute.* The carat weight yesterday and to-day. Zeitschr. d. deutsch. Gesell. f. Edelsteinkunde, 1962, 41, pp. 27-29.

Survey of the historical development of the carat weight, which before 1906 was different in most countries. England started using the metric carat in 1914. E.S.

MILES (E. R.). *Diamond coating techniques and methods of detection.* Gems and Gemology, 1962/63, 12, 10, pp. 355-364 and 383.

The article discusses the methods used to coat diamonds in order to make yellowish-coloured diamonds appear whiter, and what methods may be used to detect such treatment. Colouring by the use of solutions made from an indelible pencil or similar inks is mentioned. More resistant coatings were produced in the 1940's, and in 1950 one firm offered a service for coating diamonds, and by 1962 traffic in coated diamonds had become big business. Some legal enactments are mentioned. Various methods of detection are suggested. These are by observation under different lighting conditions; by abrasive action; by use of solvents and by application of heat. The article is completed by a list of cautions.
16 illus. R.W.

CROWNINGSHIELD (R.). *Developments and highlights at the Gem Trade Lab in New York.* Gems and Gemology, 1962/63, 12, pp. 376-383.

Mentions abraded facet edges of diamonds, three-phase inclusions in fluorite, and unusual inclusions in peridot and sinhalite. Induced "moss-agate" effects in staines chalcedony and repeated twinning in natural and synthetic ruby are also discussed. Green plastic covers have been made to fit loosely over the pavilions of emeralds to heighten the colour. These plastic caps were found to enhance the red residual colour seen through the colour filter. Diamond doublets are discussed, as well as colour-zoning in Chatham synthetic emeralds. Black non-nacreous pearls and treated black opal are mentioned. Odd orientation of rutile needles in corundum, wax-treated rubies, and the naming of greened amethyst are other matters discussed.

19 illus. R.W.

LEE (H.); WEBSTER (R.). *Imitation and treated turquoise.* Australian Gemmologist, 1963, 19, pp. 7-13 and 20, pp. 7-10.

A reprint of an article published in the Journal of Gemmology, July 1960. R.W.

OSTWALD (J.). *Mineral colour.* Australian Gemmologist, January 1963, No. 19, pp. 5-6.

A general survey on the causes of colour in minerals. The transition elements as colouring agents are mentioned, and there is a discussion of "colour centres" and of the various types of lattice defects. It is suggested that the colour of yellow sapphire is due to radioactivity.

R.W.

First International Congress on Diamonds in Industry—Paris 1962. Industrial Diamond Information Bureau, 1963.

A valuable collection of papers, both technological anp scientific, read at the Paris meeting. Subjects included the semi-conductivity, hardness, graphitization of diamonds and the optical properties of electron and neutron-irradiated stones.

S.P.

Gemmological Notes

NO DIAMONDS IN CANADA

The most thorough prospecting for diamonds ever undertaken in Canada has ended in disappointment. Although kimberlite, the parent rock in which diamonds are found, was traced no diamonds were found. The project, which was carried out at Coral Rapids, north of Cochrane, in Ontario, has now been abandoned.

MARBLE CUTTING IN THE U.S.S.R.

A cutting factory in Leningrad uses a new milling method for cutting marble and granite and thereby substantially reduces the cost of fashioning these ornamental materials. Wheels incorporating waste material from the cutting of brilliants are used.

SMITHSONIAN INSTITUTION

The Smithsonian Institution in Washington, D.C., has added a smoky quartz from Brazil (1,695 carats), an extremely fine sapphire of 423 carats and a Ceylon kornerupine of 21 carats, to its collection. An emerald crystal (176 carats) from Colombia was donated to the Institution.

GEM TRADING DIFFICULTIES

The political and economical problems of Brazil, Burma and Ceylon are making it difficult for gem traders to carry on their normal business. Governmental action and possibilities of some form of nationalization have caused prices to increase beyond what would usually be required. In Brazil mining is sometimes frustrated as miners do not know whether they will have to sell their goods to the Government at an uneconomic price or even be allowed to retain them for trade purposes.

Developments in Burma are somewhat similar. A correspondent writes:

" I was deeply disappointed about the development for the worst which I encountered in Burma. The political as well as the

economic situation is catastrophic, tourists are unwanted, and people interested in buying precious stones are shadowed like spies.

" The Burmese used to give visitors the impression of being a happy-go-lucky people to whom laughter seemed second nature, and a charming smile was always hovering upon their faces. However, twelve months of General Ne Win's dictatorship and control by his army and police troops have changed this to a serious and gloomy expression on their features. Interference with unimportant details in the people's private affairs, complicated red-tapism, as well as the progressive nationalization of industries, import-export, banks etc., are creating great uncertainty and doubt. Export declarations of business men are not accepted but passed around among competitors to control the statements. Thus people are deeply scared, and trust as well as confidence, previously a natural feature of the true Burmese character, have become a rarity. Exporters who follow the official legal way in declaring their goods are 'punished' for their behaviour by endless red tape procedures and unbearable delays; buyers from abroad are delayed in granting the necessary visas—an endless list of similar vexations could be established, which render it most unpleasant for buyers and impossible for tourists to visit this fascinating land of sunshine.

" We had to report to the Immigration Officer, the township office, and the police at every village we visited, and we were followed and controlled by official informers. The local brokers were even afraid of forwarding the stones sold to persons in foreign countries. Buying precious stones was most difficult in various places in Rangoon because the sellers won't give you any bills, but if you wish to export your stones you have to produce the bills to the Ministry of Import and Export, as well as to the Foreign Exchange Controller. But with these officials new difficulties arise, because they detain you for days on end before giving their signature to a form which you have to fill in yourself. In one of these places when I implored the chap to give me his signature because I was leaving in two days and still had to take that form to two more offices, he retorted ' I don't care whether you leave to-day, to-morrow or next week '."

Doing business in Ceylon is likewise problematical, and in all three countries there has been a consequential resort by some traders to methods of business which cannot be regarded as normal.

ASSOCIATION NOTICES

ANNUAL MEETING

The 33rd annual general meeting of the Association was held at Saint Dunstan's House, Carey Lane, London, E.C.2, on 3rd May, 1963. In the absence of the Chairman, the Secretary, Mr. G. F. Andrews, was appointed to act as chairman of the meeting.

In commenting upon the work of the year the Secretary said that history was made in 1962 in as much that examination entries were the highest ever, being 213 in the preliminary and 135 in the diploma. He recalled that in 1913 the respective numbers were 12 and 8. It seemed that the record might be exceeded in 1963 for already 39 examination centres had been established.

The annual meeting was an opportunity for thanking those who had contributed to the work of the Association, continued Mr. Andrews. He expressed thanks to the active persons in the two Branches, the Midlands and West of Scotland. The Goldsmiths' Company had always been generous in placing various rooms at the disposal of the Association for meetings and examinations and the G.A. was very grateful to them.

The instructors and examiners, who did excellent work were also thanked, as well as those responsible for gemmology classes throughout the country, which did not come under the aegis of the Association. These people made a substantial contribution to gemmology.

The Secretary expressed his appreciation of the work of the Vice-Chairman, Mr. Norman Harper, who had been so enthusiastic in establishing a specialist diamond course in Birmingham, and thanked the United Kingdom Diamond Publicity Committee for so kindly arranging for rough and cut stones to be made available for teaching purposes. Mr. Andrews also thanked Professor S. Tolansky and Mr. Cyril Ginder for their assistance with the proposed examination. He also expressed the association's indebtedness to Mr. J. R. H. Chisholm for his kind assistance with the *Journal of Gemmology* and Messrs. H. and D. Wheeler who did so much work after office hours.

The Secretary then moved that the audited accounts and annual report be adopted. In calling upon Mr. P. Riley to second the motion Mr. Andrews recalled that Mr. Riley was a Rayner prizeman and had gained his diploma with distinction. Last year he had won the premier award in the retail jewellery examinations of the National Association of Goldsmiths and, as a result, had recently had the Freedom of the Goldsmiths' Company conferred upon him.

Mr. Riley formally seconded the adoption of the annual report and accounts, which were approved.

In the absence of other nominations the Secretary declared the following officers re-elected.

President, Sir Lawrence Bragg; Chairman, Mr. F. H. Knowles-Brown; Vice-Chairman, Mr. N. A. Harper and Treasurer, Mr. F. E. Lawson Clarke.

Mr. Andrews said that the Association was greatly honoured that Sir Lawrence kindly continued as President and he expressed the meeting's appreciation of the work of the other officers.

Messrs. T. H. Bevis-Smith, C. T. Mason and E. Levett, who were present, were re-elected to serve on the Council, and it was reported that Messrs. Watson Collin & Co., chartered accountants, would continue as auditors.

The meeting then terminated and members met informally in the Sir James Walton Library.

TALKS BY FELLOWS

GILLOUGLEY, JAMES: Film Lecture " Gems of the Sea ", Johnstone (Renfrewshire) Townswomen's Guild, 17th October, 1962; Paisley & District Ladies' Circle, 19th November, 1962; Irvine (Ayrshire) Inner Wheel Club, 27th November, 1962; Paisley & District Catenian Association, 6th March, 1963; Paisley Abbey Townswomen's Guild, 20th March, 1963; Paisley Soroptomist Club, 28th March, 1963. Talk on " Gemstones ", Paisley Soroptomist Luncheon Club, 14th March, 1963; Glasgow Central Soroptomist Luncheon Club, 22nd April, 1963.

CROYDON, J. F.: Mr. Croydon has just given his 75th talk on gemstones to organizations which have included Women's Institutes, Grammar Schools, Townswomen's Guilds, Rotary and Round Table Clubs.

FORSEY, P. (Mrs.): "Precious stones", Dunville Women's Association, Ontario, Canada, 13th March, 1963.

BAGLEE, G.: "Diamonds", Richmond (Yorks) Inner Wheel, 6th June, 1963.

WEST OF SCOTLAND BRANCH

The tenth annual meeting of the West of Scotland Branch of the Association was held in Glasgow on Thursday, 18th April, 1963. In the absence of the Chairman, Mr. I. Mackenzie, the chair was taken by Mr. J. McWilliam.

In a brief report Mr. McWilliam commented that the Branch had had an interesting year and he particularly mentioned the talk on synthetic gems given by Mr. W. H. Butler.

The following officers were elected: Chairman, Mr. C. D. Wade; Secretary, Mr. W. H. Butler. Messrs. I. Mackenzie, J. Hunter and A. Inglis were elected to the committee.

It was arranged that the Branch's summer outing should be to Balmarino, Fife, on 9th June, 1963.

MIDLANDS BRANCH

The annual meeting of the Midlands Branch was held at the Imperial Hotel, Birmingham, on 5th April, 1963. Mr. W. W. Bowen presided and reviewed the activities of the year. Mr. J. Shaw was elected as Chairman of the Branch in succession to Mr. Bowen. Mr. N. A. Harper was elected as Vice-Chairman, and Mrs. S. E. Hiscox re-elected as Secretary. Messrs. G. W. Davis, K. Hoskyns, D. King and J. Rossiter were elected to serve on the committee. The past Chairmen of the Branch, Messrs. T. P. Solomon, A. E. Shipton and W. W. Bowen, became *ex-officio* members of the committee.

Mr. J. Shaw expressed the Branch's indebtedness to Mr. W. Bowen for his work as Chairman.

After the meeting members enjoyed the film " The eternal gem ".

HERBERT SMITH MEMORIAL LECTURE

The 1963 Herbert Smith Memorial Lecture was given by Mr. E. D. Lacy, B.Sc., A.R.C.S., F.G.S., of the Dept. of Geology, Birmingham University, on Friday, 26th April, 1963, at the Birmingham and Midland Institute. Mr. J. Shaw, the newly-elected Chairman of the Branch, presided, and before introducing Mr. Lacy gave brief biographical details of the late Dr. G. F. Herbert Smith, who was born in Birmingham in 1872.

In his lecture Mr. Lacy said that in gemstones we recognize crystalline material outstanding in perfection and beauty; in common parlance we speak of crystal clarity. We may ask, " How perfect are crystals?".

Long ago it was noticed that while the external form of crystals showed departures from perfection of proportion the interfacial angles were not affected by the accidents of growth. Many mineral species show much variety in the faces developed, but in any species the different forms are related geometrically in conformity with the fundamental symmetry. Surface features such as striations and etch marks are blemishes due to accidents of growth or subsequent history. The internal symmetry of a crystal structure is elegantly revealed by X-ray photography.

A twinned crystal contains two or more regions distinguished by differing orientation of the internal structure. The surface separating two regions may be planar and the aggregate may resemble two crystals " glued " together. Other twins show repetition of lamellar units. Others again may show an extremely irregular and complex disposition of the separate orientations which may greatly reduce the value of the material for technical usage, e.g., quartz for the telecommunications industry.

The surface topography of natural crystals, as seen highly magnified, is complex. Features originating during growth include trigons on diamond, growth layers and growth spirals, e.g., on beryl. The latter are surface manifestations of screw-dislocations, which constitute one type of fault in the atomic packing. Another type of dislocation is the edge variety. A good natural crystal may contain 10^{12} dislocations per cubic centimetre.

Mosaic structure, consisting of blocks of about 5000 Å side tilted with respect to each other at an angle of a fraction of a degree, has been demonstrated in many crystals. Dislocations may be situated about 300 atoms apart in the boundary

regions between blocks. Real crystals are always much weaker than would be expected of perfect material.

Many crystal species show zoning, a compositional variation from the core outwards, that is either progressive or repetitive. Such variation is governed by the rules of crystal chemistry. Solid solution in some types of crystal is extremely extensive and complex, e.g., the garnet family. Such structures are not fully ordered.

Natural silicate crystals are normally formed at elevated temperatures. On cooling, ordering processes may come into operation or ex-solution may take place. Moonstone is alkali feldspar material in which sub-microscopic ex-solution segregation of the constituents is present.

The solid-state physicist recognizes a whole series of defect structures in crystals. These include point defects (vacancies, interstitials, foreign species), and line defects (screw or edge dislocations), electrostatic defects (free electrons). Such defects are often intimately concerned with optical absorption effects (coloration). Their incidence is related to the temperature of formation and to other factors.

Radiation damage has been recognized in many natural mineral species and has been produced artificially by X-ray and by neutron bombardment. In extreme cases the crystalline structure is totally destroyed and the material is said to be metamict.

The lecture was illustrated by slides, models and specimens.

At the end of the lecture Mr. Norman Harper thanked Mr. Lacy for his interesting lecture, and said that the great preparation that had gone into it had provided an interesting and stimulating evening. He presented Mr. Lacy with a copy of Herbert Smith's " Gemstones ".

NEW MEMBERS

The following have been elected:—

Fellowship

Blanshard, Philip J. A., Croydon
McKay, Robin I., Thames Ditton
McKeen, Joseph D., Belfast

Ordinary Membership

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Chow, Cheng C., Hong Kong
Clogg, John D., Wimbledon, S.W.19
de Couto, Albert B., Kobe, Japan
Delbarre, Armand A. D., Colombo, Ceylon
Gow, William F., London, N.W.11
Khan, Jamil A., Birmingham

Kaufmann, E. Pius, Montreal, Canada
Levon, H. (Dr.), Welkom, O.F.S.
Patching, Stanley W. F., Letchworth
Primavesi, Thomas, Montreal, Canada
Rice, Robert, London, S.W.1.
Roberts, Alan M., Colombo, Ceylon
Rolls, William D., Ontario, Canada
Sidebottom, Eric C., Cliftonville
Tenbroeck, Sophia, Bangalore, India
Whistance, Mary M. N. T., Bangalore, India
Davies, David L., Teignmouth
Imai, Taichiro, Tokyo, Japan
Franks, Ivor S., Holborn, London, W.C.1

PROBATIONARY MEMBERSHIP

Gehr, Terence P., Streatham, London, S.W.16
Himsworth, Robert M., York
Jochems, Cornelie, The Hague, Holland
Siripala, D. D. M., Ipoh, Perak, Malaya
Utian, Yvan Leo, Johannesburg, S. Africa

RHODESIAN GEM AND MINERAL SOCIETY

The Rhodesian Gem and Mineral Society has become affiliated to the Association. The Society fosters and encourages the study of minerals and gemstones and the appreciation of their beauty. Eventually the Society will institute courses which will enable members to sit for the Gemmological Association examinations.

PRESENTATION OF AWARDS

The 1963 presentation of awards (preceded by a reunion of members) will be held at Goldsmiths' Hall, London, on 28th October.

GEM DIAMOND EXAMINATION

In September 1962 a specialist course in gem diamonds was commenced at the School of Jewellery and Silversmithing, Birmingham, under the instruction of Mr. Norman Harper, Vice-Chairman of the Gemmological Association. The course, the first of its kind established in Europe, was restricted to Fellows of the Association.

The first examination was held in June in Birmingham and the thirteen candidates who entered were successful in obtaining the qualifying standard. Professor S. Tolansky, D.Sc., F.R.S., Royal Holloway College, University of London, assessed the theoretical papers, and Mr. Cyril Ginder, M.A., of Cyril J. Ginder and Co. Ltd., and the Hon. Iain Balfour, M.A., of De Beers Consolidated Mines Ltd., assisted with the preparation and assessment of the practical section of the examination.

Professor Tolansky composed a searching theoretical paper and in the practical section candidates were required to assess the colour, purity, make and weight of cut diamonds, the colour, purity and shape of diamond crystals and to identify diamond simulants.

The following is a list of successful candidates arranged alphabetically:—

BATTY, Jack	Birmingham
GRYSKA, Stephen	Worksop
JONES, David C. B.	Leamington Spa
HOSKYNS, Kenneth	Handsworth, Birmingham
LEAKE, Douglas M.	Nuneaton
MARSHALL, John F.	Sutton Coldfield
PEPLOW, Miss Sarah A.	Worcester
PEPLOW. William A.	Stourbridge
PEPLOW, William R. H.	Worcester
SALLOWAY, John M. S.	Lichfield
TURTON, George G.	Bromsgrove
TURTON, Philip J. F.	Solihull
WESTON, Raymond W.	Lapworth

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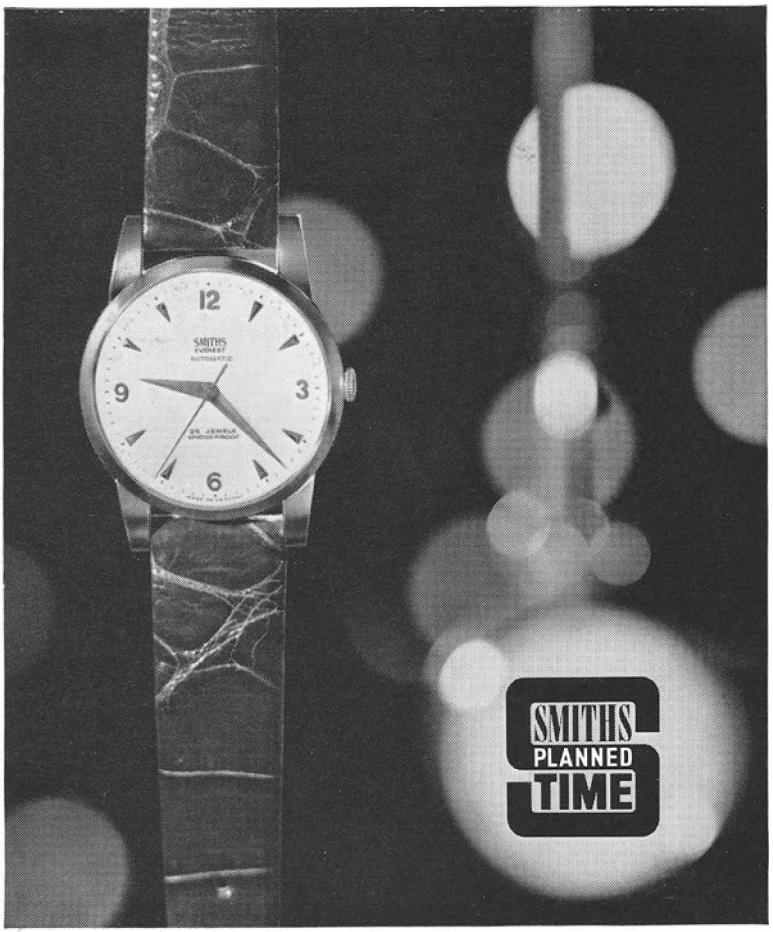

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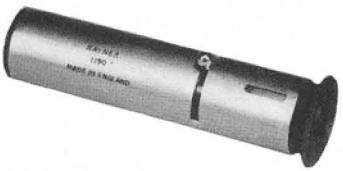

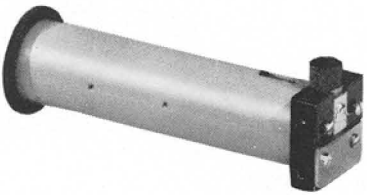

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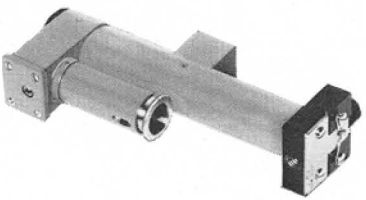

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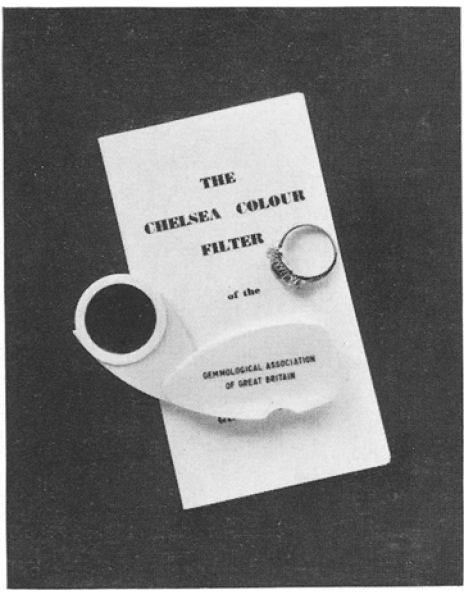

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THE JOURNAL OF GEMMOLOGY

and

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Vol. IX No. 4 OCTOBER 1963

MEASURING ABSORPTION BANDS IN GEMSTONE SPECTRA

By F. S. H. TISDALL, F.G.A.

IT has often been stated that when using the spectroscope for diagnostic purposes there is no need to measure the exact position of the bands in the absorption spectra of gemstones, the characteristic appearance of any given spectrum being sufficient for identification; all that is necessary is to familiarize oneself with the configuration of the bands appearing in the spectrum of a given gem in order to be able to recognize it at sight, so rendering measurement superfluous. In general this is prefectly true, and the practical gemmologist thus escapes the necessity of purchasing an instrument equipped with a measuring device, buys himself an efficient prism instrument, and learns by experience what the various spectra look like, and so adds a very valuable method of gem testing to his accomplishments. Not a very great deal of practice is necessary, for instance, to recognize at sight the spectra of rubies, almandine garnets, and other stones possessing distinctive and readily memorized spectra, but, while this is undeniably so, I have always felt that there is room in my testing equipment for a spectroscope with which I can measure, and so verify exactly, the wavelength of any absorption band. As a matter of fact I possessed and used a Beck wavelength grating spectroscope a long time before acquiring a prism instrument; and it was only after many years that I realized the great practical value of the latter, and how rapid and positive it is in use.

It is, then, normal practice to-day to use a prism instrument to identify species and varieties that crop up regularly; but there are gems that one meets with only comparatively rarely, and although the spectra of even these are admirably illustrated in several well-known books dealing with the subject it is very reassuring to have an instrument with which bands can be measured. Such gems as spessartite garnet, enstatite and sinhalite display absorption spectra which have considerable diagnostic value, but they are not frequently seen, and when encountered for the first time may prove puzzling. Measurement of the absorption bands will resolve the perplexity. There is, too, always the possibility of discovering and measuring a hitherto unknown band, such as the one at 4190Å I saw and measured recently in a beautiful rose-red tourmaline. I could find no trace of such a band in the descriptive literature which I have available, though it may be (and probably is) recorded in the exhaustively complete descriptions of all known gem spectra made by Messrs. Anderson and Payne some years ago.

A difficulty, however, arises: unless one is prepared to go to the rather considerable expense of purchasing a Hartridge "reversion" spectroscope, the wavelength grating instrument made by Beck cannot be invariably depended upon to give a high degree of accuracy. Although it is always possible to measure sufficiently accurately for purposes of identification, yet if one is going to measure at all it enhances both the value and the pleasure of the operation to know that it has been carried out with something very close to absolute precision. I have often found that, due to parallax, my measurements have been anything up to 20Å out, and it was with the object of eliminating this error that, with the aid of a toolmaker friend, I devised a stand for supporting the spectroscope rigidly and firmly in an erect position above the body tube of the microscope.

Most gemmologists are familiar with the usual set-up employed when using a spectroscope in conjunction with a microscope. The accompanying photograph (Fig. 1) illustrates both the method and also the stand which I use. The eyepiece is removed from the body tube of the microscope; a gem is placed, table downwards, on a glass plate in the centre of the stage; by means of the substage-mirror and condenser a strong beam of light from the lamp is focused on the gem, and the transmitted light, by adjusting the focus of the microscope, is made to flood the body tube with light. It is this

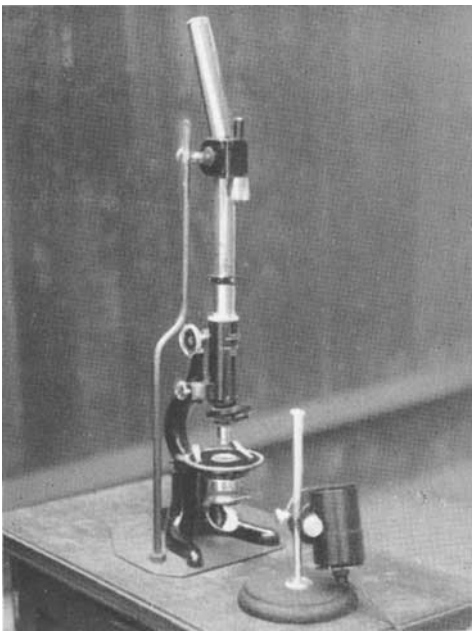

FIG. 1.

brilliant concentration of transmitted light that is analysed by the spectroscope.

Practical-minded gemmologists, whether having toolmaker acquaintances or not, may like some details of the stand shown in the photograph:

The base plate is made from $^{15}/_{32}''$ brass, and measures, at its longest and widest, $7\frac{9}{16}'' \times 7\frac{3}{8}''$, the corners being bevelled off as seen in the plan (Fig. 2). The supporting rod, shown in the elevation (Fig. 3) is centred 2″ from the front of the plate, and $\frac{15}{16}''$ from the side. Fig. 2 will make these measurements clear. The rod itself (Fig. 3) is of $\frac{3}{8}''$ steel; it is rivetted to the plate and the bottom $\frac{3}{4}''$ is threaded. A large hexagonal nut was screwed up the thread before the rod was rivetted; then by screwing the nut hard down on to the plate the rod was secured firmly in an upright position. The top of the rod stands $19\frac{1}{2}''$ above the upper surface of the base plate, though its actual length is $\frac{1}{2}''$ or so greater than this, for, to bring the spectroscope above the body tube of the microscope, the rod is cranked, as Fig. 3 shows, giving a lateral displacement of

about $1\frac{1}{2}''$. The top $2\frac{5}{8}''$ of the rod are turned down to a diameter of $^{11}/_{32}''$ to take a double clamp (bought entire at a tool shop) which serves the dual purpose of holding the bolt which is screwed into the threaded hole, made for the purpose in the centre of the spectroscope, and of clamping the spectroscope to the rod.

The method I employ to obtain accurate measurements is as follows:

The microscope lamp and spectroscope are set up as shown in Fig. I and a synthetic ruby placed on a glass plate in the centre of the stage. A synthetic ruby is always used for this purpose because it can always be relied upon to give a good spectrum; because the principal absorption bands are narrow and "sharp"; and because these principal bands are found at both ends of the spectrum, i.e. in the red, and in the blue.

The light is switched on, and the mirror and the focus of the microscope (the eyepiece being removed) adjusted so as to flood the body tube with light. Next the spectroscope is clamped into position, but not tightly. Then the drum of the spectroscope is turned until the crosswires are brought into the position corresponding to 6942Å, which is the wavelength of the line in the fluorescent doublet nearest the deep red. Finally the spectroscope itself is carefully positioned so

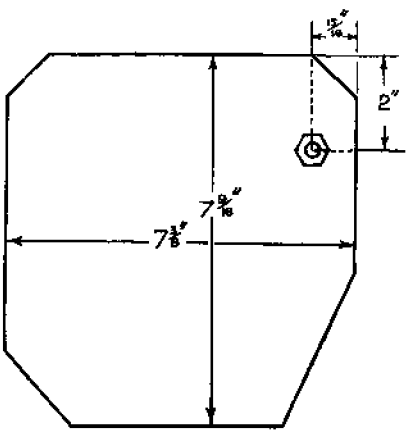

Fig. 2.

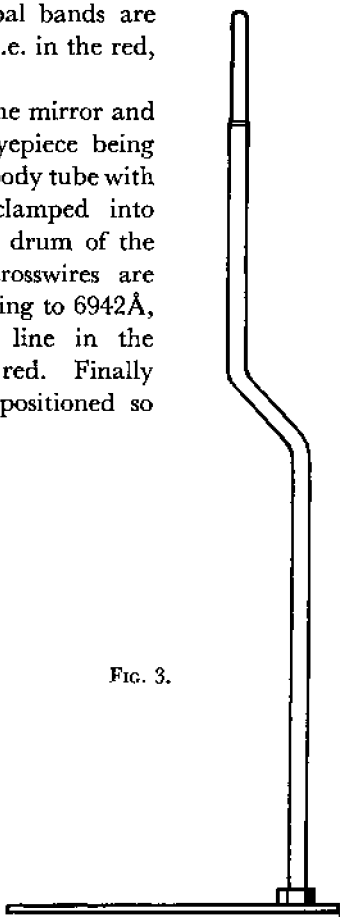

Fig. 3.

that the centre of the crosswires corresponds exactly with the 6942Å band, and the clamp is then screwed up firmly. Care is needed during these operations as all subsequent measurements depend on the accuracy with which they have been carried out. Confirmation of the correct centring of the crosswires on the 6942Å band may now be obtained by measuring the position of the other bands, both in the red and in the blue. If the initial adjustment has been carefully made it should be possible to measure the other bands to a high degree of precision—often exactly, and never with an error greater than ±5Å.

It should be noted that high accuracy is obtainable only when the eye is sensitive, and rested. Continued experimenting will result in tiring the optic processes and greatly impair the power to make accurate measurements.

Having adjusted the spectroscope and clamped it firmly in position it is now possible to replace the ruby by any stone, the spectrum of which it is desired to examine. The spectroscope must be left positioned and the stone itself gently moved about on the glass plate (or the plate may be moved) looking through the spectroscope eyepiece after every movement. Eventually a position will be found (patience will be necessary) which will yield a clear spectrum and any line or band may then be measured with the same degree of accuracy as that with which those in the spectrum of ruby were measured.

If the makers have correctly adjusted their instrument, all bands will be measured accurately when the axis of the collimator of the spectroscope is exactly coincident with the axis of the body tube of the microscope, and the method I have outlined will enable this position to be found. Tilting the collimator forward (i.e. towards the lamp) will bring the crosswires nearer towards the violet, and tilting it in the opposite direction will bring the crosswires towards the red—the error known as parallax. Faults of this kind may result in discrepancies of up to 20Å, hence the need for a method of securing the spectroscope firmly once the correct position has been found.

The only disadvantage accompanying the above process is that when observing the spectrum the red end is towards the right instead of the left, the other way round being the convention current in the gemmological world. This drawback is, however, not a serious one, and in no way affects the validity or accuracy of a measurement.

A word as to the method of use. By placing the base plate of the stand upon the tiled fender of a fireplace (a good, firm support, about 6″ above the floor level) I find that the eyepiece of the spectroscope is brought comfortably to eye-level when one is seated in an easy chair. Observations can be made by leaning forward, always remembering not to continue for too protracted a period lest the eye becomes tired and accuracy be impaired.

A final word with regard to the spectrum of red spinel. It is well known that red spinels very seldom display a spectrum at all by transmitted light, but when illuminated by "scattered" light most of them show what has been aptly called the "organ pipe" spectrum, consisting of five or more fluorescent bands. This is an enchanting spectrum to observe and is, of course, completely diagnostic. By raising the high intensity lamp to a level well above that of the microscope stage, extending the focusing sleeve in order to concentrate the beam, and then directing this small, bright spot of light *downwards* on to the stone a fine fluorescent spectrum may be obtained, and the bands measured if desired. A little patience may be necessary to achieve the best result. A good position for the stone is resting on its base facets with the table facing the lamp; but sometimes *too* bright illumination tends to obscure the bands, and by rotating the stage of the microscope a position may often be found in which the overall luminosity of the spectrum is reduced and the fluorescent bands will then stand out well. This method of top lighting is also suitable for detecting the often difficult to see 4320Å band in turquoise. To avoid searching it is helpful to set the crosswires at 4320Å to begin with and then one knows exactly where to look.

EMERALD FROM BURBAR, COLOMBIA

By W. F. EPPLER

A NEW occurrence of emerald in Burbar, Colombia, should not be confused with emerald from another new locality, the Vego de San Juan Mine, near the village Gachala. Perhaps the location "Burbar", which is reported to be situated between Bogotà and Muzo, is identical with "Borur", about one hundred miles north-west of Bogotà, and somewhat south of Muzo (Gems and Gemology, Spring, 1961, p. 142).

The physical properties of the stones mined in the new area are practically the same as for the other Colombian emeralds. Judging from the material available to the author, the stones exhibit a poor colour and they look like shattered pieces of former bigger crystals, with many cracks and fissures.

Some of the inclusions are typical for material from Colombia, with beautiful groups and single crystals of pyrite, many of them bearing a liquid-filled and pointed tube, which usually reveals the presence of a gas bubble (Figs. 1 and 2). These particular three-

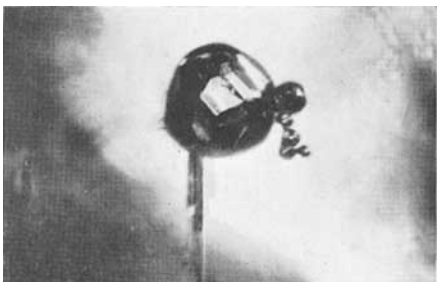

FIG. 1. *Emerald from Burbar, Colombia. Crystals of pyrite from which a tube of growth started in the direction of the c-axis; reflected light.* 120 ×

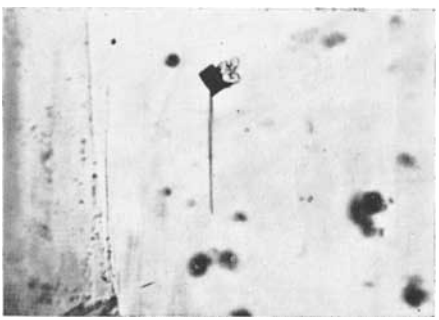

FIG. 2. *Pyrite and calcite and a tube of growth. The dark spots out of focus are also pyrite; transmitted light.* 65 ×. *Emerald from Burbar, Colombia.*

phase inclusions indicate a disturbance of growth. The pyrite was pre-existing and when it was reached by the growing emerald crystal and finally embedded, the host crystal started to leave behind it parts of the "mother-liquor" unsuitable for its lattice. For these reasons it is understandable that a kind of "wake" originated following strictly the direction of the c-axis and narrowing steadily until it ended in a point. Generally, these features indicate a hydrothermal origin so often seen with other minerals of similar genesis.

Another similarity with Colombian emeralds from the known localities are "normal" three-phase inclusions. Those parallel to the c-axis exhibit surprisingly a singly refractive but lozenge-shaped crystal as the solid phase, the form of which hitherto was claimed as a reliable criterion for Russian emeralds only. The three-phase inclusions parallel to the base plane have ragged outlines (Fig. 3), sometimes ramifying in a system of flat channels. New as an inclusion in emerald from Colombia seems to be a network of irregular tubes with strange forms, also parallel to the basal plane of the host crystal (Figs. 4 and 5). They are filled either with a

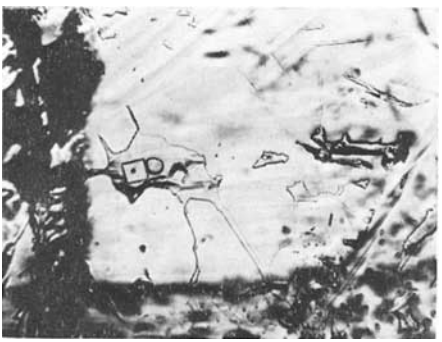

FIG. 3. *Emerald from Burbar, Colombia. Three-phase inclusions parallel to the basal plane.* 65 ×.

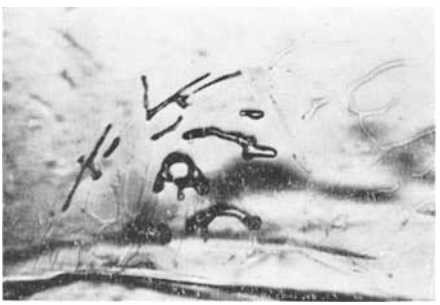

FIG. 4. *Emerald from Burbar, Colombia. A network of liquid (bright) and gas (dark) inclusions in a healed crack parallel to the basal plane.* 65 ×.

liquid, having a faint appearance, or they contain a gas bubble and exhibit a dark rim and a strong relief. Sometimes they are very flat. Without doubt, they are the indigestible remnants within a healed crack.

In studying these sometimes irritating healed fissures—because they may appear to be artificially made—it is necessary to be cautious if the stone is immersed in a suitable liquid, for example in monobromobenzene. As some of the cracks are extended to the outer surface of the stone they are filled with air. In submerging the stone, the fissures are not totally filled with the liquid, but large flattened air bubbles, or films of air, are entrapped exhibiting unusual forms (Fig. 6). During a longer observation under the microscope, they may diminish, alter their outlines or even disappear as the result of the slow rise in temperature of the stone due to the intense illumination. At first sight, they look very strange and they can easily be mistaken for a particular feature.

Of the other inclusions, two kinds of transparent and doubly refractive crystals are unusual. One kind (Fig. 7) is a small but well

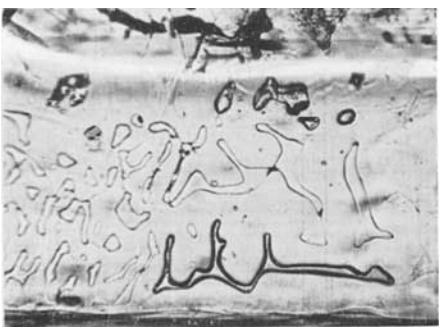

FIG. 5. *Another healed fissure parallel to the basal plane with liquid and gas inclusions.* 65 ×. *Emerald from Burbar, Colombia.*

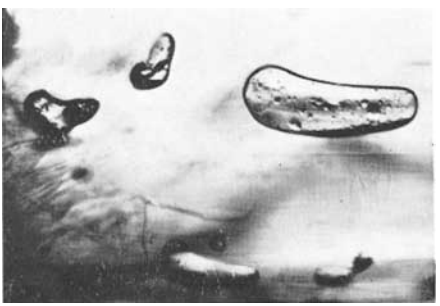

FIG. 6. *Emerald from Burbar, Colombia, embedded in monobromobenzene. An unhealed crack with flat air bubbles.* 65 ×.

developed single crystal with a R.I. greater than emerald (1·58). Possibly, but not certainly, it could be calcite. The other prefers to form crystal groups (Fig. 8) or even clusters. The R.I. is lower than 1·58 and its nature is still unknown.

In case the emeralds from Burbar, Colombia, should enter the market in greater quantities, it should easily be possible to distinguish them from stones of other deposits by their marked inclusions.

The author is indebted to Dr. E. J. Gübelin, Lucerne, for having placed so generously at his disposal the material with which these observations have been made.

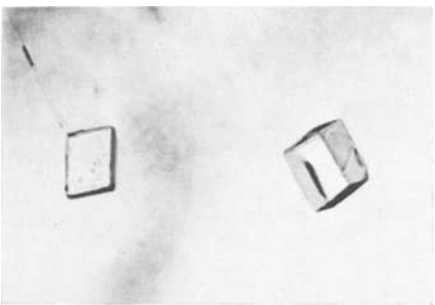

FIG. 7. *Well developed transparent and doubly refractive crystals with a R.I. greater than* 1·58, *possibly calcite.* 120 ×. *Emerald from Burbar, Colombia.*

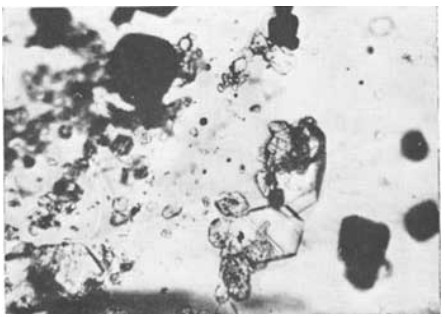

FIG. 8. *Groups of birefringent crystals of unknown nature with a R.I. lower than* 1·58. 22 ×. *Emerald from Burbar, Colombia.*

OBSERVATIONS ON GARNET

By R. A. HOWIE, M.A., Ph.D., F.G.S.

THE garnets have always attracted the attention of mineralogists as well as gemmologists, both for their well developed natural symmetry and for their range of colour and physical properties. In a recent paper in this Journal, L. C. Trumper[1] advocated the plotting of refractive index against specific gravity for the garnet group of minerals as an aid to determining whether any intermixing takes place between the grossular-uvarovite-andradite (ugrandite) series and the pyrope-spessartine-almandine (pyralspite) series. This useful plot of actual determinations for 58 garnets was superimposed on straight lines joining the "calculated" constants for the six end-member molecules quoted by Anderson[2], and as calculated originally 48 years ago by Ford[3] and later modified by Fleischer[4]. These authors used a large number of collected analyses of garnets to establish by extrapolation the most probable values for the end-member garnet molecules, and these values served for many years as an invaluable aid in estimating the composition of unknown garnets from a consideration of their refractive indices and specific gravities and also their cell edges as determined by X-rays. Natural garnets corresponding in composition to the end-member molecules are unknown, however, and although examples of grossular and andradite occur which are fairly close to the end-member composition other garnet species are less "pure", and in particular pyrope garnets with more than about 75 per cent of the pyrope molecule have not been recorded. Thus the calculated end-member properties involved very considerable extrapolation and were correspondingly and of necessity somewhat inaccurate.

This situation was, however, transformed by the synthesis in 1955 by Coes[5] of the five commonest pure end-member garnet compositions, i.e. almandine, andradite, grossular, spessartine and pyrope, and by the subsequent determination by Skinner[6] of their optical and physical properties. It is the purpose of this note to draw attention to these determinations in the belief that they greatly advance the study of this absorbing mineral family.

End-member constants as measured by Skinner. Earlier extrapolated values given in brackets.

	Density	*Ref. Index*
Almandine	4·318 (4·325)	1·830 (1·830)
Andradite	3·859 (3·835)	1·887 (1·895)
Grossular	3·594 (3·594)	1·734 (1·735)
Pyrope	3·582 (3·510)	1·714 (1·705)
*Spessartine	4·190 (4·180)	1·800 (1·800)

* The name spessartine is preferred for the manganese aluminium garnet, spessartite being used by petrologists as a name for a lamprophyric dyke rock.

It may be of interest also to mention the two diagrams constructed by Winchell[7] in which specific gravity in the garnets is plotted as a contour, the refractive index and cell edge being taken as independent variables and used as ordinate and abscissa, while the chemical compositions of the end-member molecules and the specific gravity are plotted as functions of the two variables. Using these diagrams it is possible to estimate compositions in terms of the three-component or four-component composition field. The use of such diagrams and of such data is, of course, based on the assumption that the optical and physical properties represented are additive functions of the molecular proportions of the end-members. This is in general true for an isomorphous cubic series and has been demonstrated to hold for the synthetic almandine-pyrope and grossular-pyrope series[8].

Reverting to the object of the plot used by Trumper, which is to ascertain whether any intermixing takes place between the two garnet groups, reference may be made to a dark apple-green andradite-spessartine garnet[9] from Pajsberg manganese and iron mine, Sweden, which has a molecular composition $Alm_{1\cdot2}$ $And_{70\cdot6}$ $Py_{0\cdot4}$ $Spess_{27\cdot8}$ (with Ref. index 1·893, Density 3·98) and to a peach-tan garnet[10] from Nevada containing roughly equal amounts of spessartine and grossular; the analysis of this garnet indicates a composition $Spess_{42\cdot8}$ $Gro_{41\cdot4}$ $Alm_{12\cdot4}$ $And_{3\cdot4}$ (Ref. index 1·780, Density 3·92). In the pyralspite group, there is more general evidence of intermixing with small amounts of the other group. Examples from mineralogical tests[11] listed below show, where Ugr. represents the molecular percentage of the ugrandite series present, from 18·5 to 35·9 per cent. intermixing. It may be of geological interest to note that these six garnets all come from relatively high-

And.	*Gro.*	*Ugr.*	*Alm.*	*Py.*	*Spess.*	*Ref. index.*	*Density*	*Rock*
9·6	19·0	28·6	57·3	12·0	2·1	1·795	4·08	eclogite
11·8	20·0	31·8	53·4	13·0	1·8	1·801	4·04	eclogite
15·3	20·6	35·9	47·6	16·4	0·1	1·787	3·82	schist
4·1	16·5	20·6	29·3	49·4	0·7	1·756	3·76	eclogite
4·0	14·5	18·5	35·1	45·7	0·7	1·7615	3·835	eclogitic
2·7	21·7	24·4	12·1	5·2	58·3	1·798	4·14	schist

grade metamorphic rocks where under conditions of high pressures and temperatures any intermixing of the two series would be more likely to take place.

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SPESSARTINE OR SPESSARTITE?

A note in the preceding article by Dr. R. A. Howie points out that the name spessartine is to be preferred to spessartite for the manganese aluminium garnet which gemmologists know by the latter name. Various authors refer to the word spessartite as being derived from the Spessart district of Bavaria, where this garnet was first found, though the occurrence did not appear to have any gem significance, and also mention spessartine as the French form of the word.

Whether gemmologists should concede that the work preferred by mineralogists and petrologists is the better term for this garnet is arguable, though in Great Britain pronouncements by mineralogists have usually been followed. Gemmologists, however, still prefer to use iolite for the gem mineral which mineralogists refer to as cordierite.

NEW-TYPE INCLUSIONS IN CHATHAM SYNTHETIC EMERALDS*

By F. DUYK

FROM examination of recently produced synthetic emeralds made by Carroll Chatham, it is evident that there are two new elements in the nature and disposition of the inclusions. Firstly, the liquid canals are more elongated and more strictly oriented. Secondly, a new type of inclusion, a brownish elongated fissure in the shape of what may be described as a bird's feather has been observed. It is evident that the introduction of new chemicals in the production formula is the cause of these alterations in the inclusion pattern.

The physical and optical properties remain unchanged and discrimination between natural and synthetic emeralds can still be effected by the usual methods.

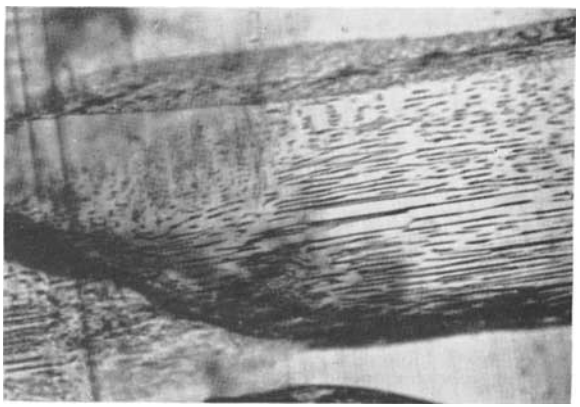

Elongated liquid canals in Chatham synthetic emerald

*(This note has been translated, with permission, from *Technica*, June, 1963, (Journal of the National Committee of Jewellers & Watchmakers in Belgium). The photos reproduced are by the author, who is President of the Belgian Gemmological Society.)

Brownish elongated fissure in shape of a bird's feather.

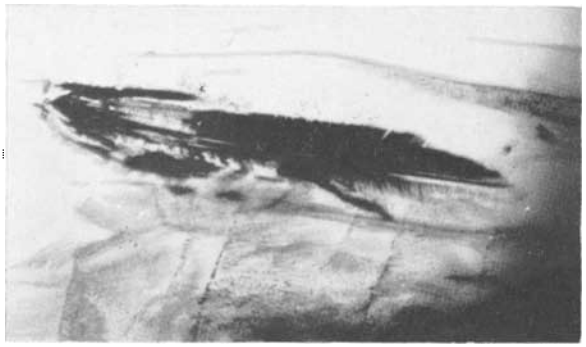

Other inclusion patterns seen in Chatham synthetic emerald.

CORUNDUM AND AMETHYST FROM TANGANYIKA

By E. H. RUTLAND, Ph.D., F.G.A.

THE old Roman saying that something new keeps turning up in Africa surely applies to gemstones. As the vast continent is opened up, perhaps it is not surprising that new deposits are found, but the gem wealth already produced in Africa must greatly exceed that of the whole rest of the world put together. One cannot help feeling that Africa has had its fair share, and more.

The two kinds of gems described below were shown to me by Mr. Charles Mathews, of Hatton Garden, through whose firm so many rare and interesting gemstones have reached the market. Mr. Mathews spent three weeks in Tanganyika last year and visited some new corundum mines during his stay. The stones he brought back exhibit some unusual features and the locality does not yet appear to have been described. A few notes may therefore be appropriate.

The mines are situated in bush country on the upper reaches of the Umba river, some 50 miles inland from Tanga. The lower part of the Umba river forms the boundary with Kenya, but its upper course lies wholly within Tanganyika.

The corundum occurs in a vermiculite from which it is easily separated by hand. There is only slight evidence of wear by water on the rough material. The gem quality corundum consists mainly of broken pieces up to $1\frac{1}{2}''$ in diameter, but tabular hexagonal prisms are also found. Much of the material is fractured internally but there are also fine clean pieces of excellent transparency. The output of the mine could be very substantial as it covers a vast area.

The stones are found in a large range of red, blue, purple and other tints and parti-coloured stones are frequent. In these, the colour changes from the prism faces inward, either towards a lighter or a darker shade. The outside might be blue and the centre yellow; or a dark red centre might be surrounded by pale brown material. The finest colours are rare, as always, but pleasant fancy tints occur, similar to the best that can be found in Ceylon. Several stones had a very fine rich amethyst purple that turned much redder in tungsten light.

The most striking feature of the stones is their exceptionally strong dichroism. In many stones this could be seen plainly with the

FIG. 1. *Twinning planes in Umba sapphire.*

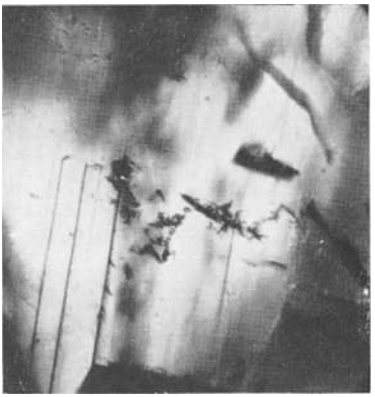

FIG. 2. *Tubes and crystal aggregates in Umba ruby.*

FIG. 3. *Tube with jagged edges in Umba sapphire.*

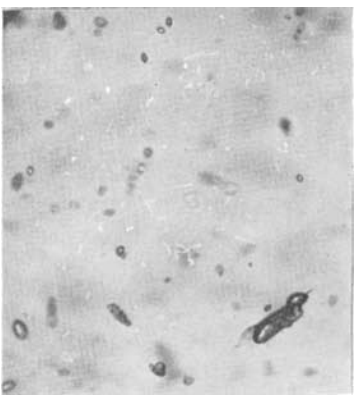

FIG. 4. *Rounded crystals in Umba sapphire.*

naked eye as they were turned about. The colour changed from a pale pink to a dark magenta or from yellow to brown. So pronounced was this effect that it was sometimes difficult to describe the colour in simple terms. Some problems will arise when it comes to cutting the stones to present their best colour.

The inclusions were reminiscent of other corundums but had a distinct tang of their own. There were well marked twinning planes (Fig. 1) and most stones evidenced twinning between crossed nicols. There were long tubes with jagged edges, like lances with

pennants fluttering from them (Figs. 2 and 3). There were crystal aggregates, somewhat similar to those found in Burma ruby; and also more sparsely scattered rounded crystals (Fig. 4). Finally, there were short tubes in parallel arrangement. Both large and small trigons occurred on the pinacoid (Fig. 5) and several surfaces showed long tube-like ridges. These may conceivably be of the same origin as the tubes found inside the stones, mentioned above.

The constants that were measured conformed to those usual in corundum. The refractive index measured in sodium light on a Rayner refractometer, ranged from 1·76 to 1·77 with a birefringence estimated at ·008. The specific gravity, measured hydrostatically on three specimens was very slightly below 4·00.

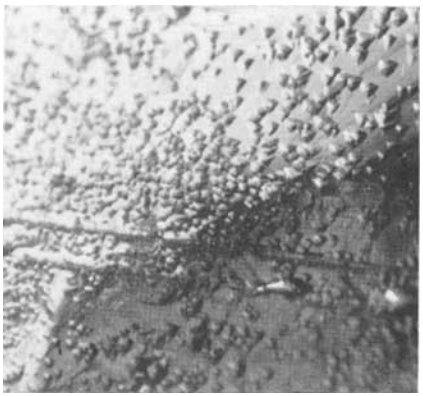

FIG. 5.
Trigons and tubes on the surface of an Umba sapphire.

AMETHYST

Another gem brought back by Mr. Mathews was amethyst of a fine colour. He obtained a quantity of the rough material at Dar es Salaam but was unable to ascertain its provenance. He was assured it came from Tanganyika.

Here again the material came in broken pieces, but Mr. Mathews also gave me a well-formed prism capped with pyramids at either end. This and many other pieces were of a rich colour inside covered with a layer of translucent white milky quartz. In good pieces the colour was strong and pleasing, without being too dark, and with a distinct red tone. The ordinary ray carried the red hue whilst the extraordinary ray showed a paler and colder tint.

A special feature of some of these stones was an abundance of

fibrous rutile inclusions arranged in sprays and bundles radiating from a common origin (Figs. 6 and 7). Some were geniculated and all were so thin that they were not at all obvious to the naked eye. Only when light was reflected from the fibres was a sheen visible. Thin slices might nevertheless make attractive "Hair Stones". In other respects the stones were clean and conformed to all the usual characteristics of quartz.

FIG. 6. *Rutile fibres in Tanganyika Amethyst.*

FIG. 8. *Rutile fibres and colour zoning in Tanganyika Amethyst.*

AN INTERESTING DOCUMENT ABOUT EIGHTEENTH CENTURY GEM TRADING IN THE ASSOCIATION'S LIBRARY

THE eighteenth century document, reproduced, greatly reduced, on the opposite page, relates to a commercial transaction between London and the East Indies. An interesting feature is the apparent importance at that time of rough coral and coral beads as items of trade. Another point is the inclusion of the words "diamond boart" in printed form in a commercial document. This might not here mean a form of industrial diamond but an inferior grade of gem diamonds, for returns were to be made in "Pearls, Diamonds and Diamond Boart and other Precious Stones or Jewels". The boart could have been for use in cutting diamonds but the word was not clearly defined at that time.

The document is dated 1756 and is a form of indemnity given by Joseph Salvador, a trader, to the United Company of Merchants of England trading with the East Indies.

Joseph Salvador, whose signature and seal are on the document, was a person of considerable commercial interests, including a substantial trade in precious stones. Upon completion the transaction would have resulted in a substantial profit and at one time Joseph Salvador was an extremely wealthy merchant.

The document was acquired by the Association in 1956 and is in the Sir James Walton Library.

The Association would be interested in receiving from members any information about other old documents relating to transactions in precious stones. Some of the older publications on gems are required for the library and the librarian would be pleased to have details of any texts available.

KNOW all Men by these Presents, That I Joseph Salvador of London Merchant held and firmly bound unto The United Company of Merchants of *England*, Trading to the *East-Indies*, in the Sum of Three thousand five hundred Pounds of lawful Money of Great-Britain, to be paid unto the said United Company, or their certain Attorney or Successors: To which Payment well and truly to be made I bind Myself my Heirs, Executors, and Administrators, firmly by these Presents. Sealed with Seal. Dated the One and Twentieth Day of January in the Year of our Lord One Thousand Seven Hundred and Fifty Six and in the Twenty Ninth Year of the Reign of our Sovereign Lord George the Second by the Grace of GOD, of Great-Britain, France, and Ireland, King, Defender of the Faith, and so forth.

WHEREAS the *Court of Directors* of the above-named *United Company of Merchants of* England, *Trading to the* East-Indies, have at the special Instance and Request of the above-bounden Joseph Salvador Licenced and Permitted Him the said Joseph Salvador to send on the Ship Walpole Captain Francis Foster Commander Mark-marked I S F N°5 Cont^a Coral Beads Value £500 — I D^o I S F Cont^a D^o value £430 — I D^o S B N°5 Cont^a D^o value £460 — I D^o S B Cont^a Rough Coral value £200 — I D^o G M N°7 Cont^a Rough Coral value £100 — Value together One thousand Seven hundred and Fifty pounds for Fort St George

in the *East-Indies*, there to be invested, and Returns made in Pearls, Diamonds, Diamond Boart, or other precious Stones or Jewels, and in no other Goods whatsoever, upon the Conditions herein after contained, He the said Joseph Salvador having consented and agreed, and consenting and agreeing, to run the Risque and Hazard of all Losses, Damages, Misfortunes, and Casualties whatsoever, of, upon, or relating to the same, and to free and discharge the said Company therefrom. **Now the Conditions** of this Obligation are such, That if the said Joseph Salvador His Executors, Administrators, or Assigns, do and shall Consign the said Corah Beads and Rough Coral to the President of Fort St George together with any other Person or Persons He shall think fit, and do allow the said President Two Pounds *per Cent.* Commission for the same, and do pay, or cause to be paid, the Duties usually payable on Coral Beads and Rough Coral at Fort St George aforesaid, on Importation there; And if He the said Joseph Salvador His Executors, Administrators, or Assigns, or His Agents or Attorneys, do lay out and expend or employ the said Adventure, and every Part thereof, in Pearls, Diamonds, Diamond Boart, or other precious Stones or Jewels, and not in any other Goods, or at Interest, or in other Trade, or on any other Account whatsoever; and if such Pearls, Diamonds, or Diamond Boart, precious Stones, and Jewels, shall within Thirty Six Months after the Sale of the said Coral Beads & Rough Coral at Fort St George aforesaid be put on Board or Loaden on one or more Ship or Ships, employed in the Service of the said *United Company*, and bound for *London*, and if Oath shall be made before the said President of the real Cost of the said Pearls, Diamonds, or Diamond Boart, precious Stones, and Jewels, before the Shipping or Loading thereof, and if the said Pearls, Diamonds, or Diamond Boart, precious Stones, and Jewels, be brought into the Treasury of the said *United Company*, in order to be Sold at the said *Company*'s Candle (the Danger of the Seas, and other unavoidable Accidents excepted) then this Obligation to be void and of none Effect, or else to remain and be in full Force and Virtue.

Sealed and Delivered (being first duly stamp'd) in the Presence of

Philip Cray

Robert

Joseph Salvador

BLUE-DYED FOSSIL CORAL
(Tampa Bay, Florida)

By ROBERT WEBSTER, F.G.A.

THE existence of chalcedonic pseudomorphs after coral from Tampa Bay, Florida, U.S.A. has been known since 1825 and a very detailed article on these corals has been written by James G. Manchester[1] and is well referenced.

Charming as specimens, especially when sliced and polished, these silica fossils have more recently been fashioned as a gem material in baroque form by the tumbling process, or cut as cabochons.

Some few weeks back the writer received through the courtesy of Mr. A. M. Ramsay, of Glasgow, further specimens of this material, including three specimens which had been dyed a turquoise blue colour.

Greenish-blue in colour the three pieces are pitted with depressions of various sizes and degree of penetration which mar the overall appearance of the finished stones. The refractive index, taken by the distant vision method, gave a value near 1·53. The density, owing to the extreme porosity of the material, could not be assessed with any accuracy, and further, the ethylene dibromide used in the place of water for the direct weighing method of density determination tended to debase the blue colour. The hardness was about 7.

Examination of the absorption spectrum showed a diffuse band in the red part of the spectrum, which is centred about 6480Å. This is rather typical of a dyestuff absorption. Under the ultra-violet lamp, either the medium-pressure long-wave lamp (3650Å) or the fluorescent tube lamp giving the best results, a greenish or greenish-yellow glow was seen on the less heavily stained parts. This is in keeping with results obtained on unstained material where a yellow and a blue glow may be seen in different areas.

The unstained fossil coral is quite attractive in itself and it is difficult to explain why it was found necessary to "gild the lily".

REFERENCE

1. Manchester (James G.) *Collecting semi-precious stones in Florida.* Rocks & Minerals. Vol. 16. No. 12.

Gemmological Abstracts

POUGH (F. H.). *The synthetic emerald family.* Lapidary Journ., 1963, 17, 3, pp. 380-387.

A survey of the methods of synthetic emerald production used by Hautefeuille and Perry in the 1880's, and Nacken, Espig, Chatham and Lechleitner in the present century.

S.P.

PUGH (H. L. D.), LEES (J.) and BLAND (J. A.). *Synthesis and X-ray analysis of diamond.* Nature, Vol. 191, No. 4791, pp. 865-867. August, 1961.

Diamonds have been synthesized by heating a disc of nickel in contact with a rod of graphite at approximately 2,000°K. and 6,000 atmospheres, using a modified type of tetrahedral anvil apparatus. The largest diamonds so produced are $0{\cdot}3 \times 0{\cdot}3 \times 0{\cdot}4$ mm.

R.A.H.

JOHNSON (P. W.). *New sapphire find in Baja California.* Lapidary Journ., 1963, 17, 3, p. 449.

A blue opaque sapphire has been found in the central part of the Sierra Juarez of Baja California. Clear material has not yet been found.

S.P.

LEIPER (H.). *Gem sphene discovered in San Diego, Calif.* Lapidary Journ., 1963, 17, 3, p. 448.

Gem-grade sphene has been found in San Diego County, California. Two faceted stones of a little over a carat each in weight are greenish yellow and free of inclusions.

S.P.

CROWNINGSHIELD (R.). *Care of gem materials and their substitutes in manufacturing, repairing, displaying and wearing of jewellery.* Gems and Gemology, 1963, XI, 1, pp. 3-11.

An excellent article summarizing some of the difficulties experienced when handling jewellery. Emphasis is placed upon

the importance of jewellers and jewellery repairers not only to know the identity of stones but also the treatment they may have undergone. Heat-treatment, colour fading, and cracking or splitting from sudden change of temperature are considered. One means of removing an artificial coating on a diamond is dry heat and the heat necessary to size a ring or repair a claw may be all that is needed to change the colour, unless the stone is unset before the repair is commenced. Pearls and turquoises can be harmed by hair sprays and perfumes.

The article concludes with a comment about some of the fantastic examples of retail jewellers' negligence when returning items they have borrowed.

S.P.

LIDDICOAT (R. T.). *Rapid sight estimates of diamond cutting quality.* Gems and Gemology, 1962/3, 11 and 12, pp. 323-335 and 365-375.

An informative article on estimating the accuracy of cutting of a brilliant-cut diamond. Describes methods of estimating, without actual measurement, the correctness of the facet angles by observation of the reflection of the table facet on the pavilion facets, and similarly of the reflection of the bezel facets. The article gives a number of examples and is copiously illustrated by photographs taken by Jeanne G. M. Martin.

31 illus. R.W.

BROCK (T. J.). *The pride of India.* Australian Gemmologist, No. 21, pp. 8-9, March 1963.

The story of the jewel-encrusted embroidery called the Pride of India.

R.W.

HEMRICH (G.). *Variscite—An American gemstone.* Gems and Minerals, 1963, 311, pp. 15-17.

Occurences of variscite found in the U.S.A. are confined to Utah, Nevada and Arizona. Variscite is predominantly a hydrated phosphate of aluminium. When iron is present in any but trace amounts, it becomes strengite. There are many hydrated phosphates associated with variscite, which have been made for

their discoverers or for their localities with the usual abandon that characterizes mineral nomenclature.

Very small vivid green orthorhombic crystals of variscite have been found lining cavities in quartz or chert but usually the mineral is found in nodular form. S.P.

THEISEN (V.). *Das Karat gestern und heute.* The carat weight yesterday and to-day. Zeitschr.d. deutsch. Gesell. f. Edelsteinkunde, 1962, 41, pp. 27-29.

In the July, 1963, issue of the Journal the above abstract was incorrectly attributed to V. Thurm and not to the author, Verena Theisen.

WEBSTER (R.). *Jewellery and the expert witness.* Medicine, Science and the Law, 1963, 3, 4, pp. 228-245.

A brief outline of some of the factors which need to be considered in relation to jewellery, silverware, and gems and evidence given by an expert witness in a Court of Law.

S.P.

BOOK REVIEWS

GUMP (R.). *Jade—Stone of Heaven.* Doubleday and Co. Inc. 1962. 256 pp., $8.95 Can.

It does not take the reader long to realize that jadeite, as distinct from nephrite, is Richard Gump's first love, and to realize too that the wonderful jadeites produced during the latter part of the Ch'ien-lung era (1736-1796 A.D.) and following, represent, for this author, the most desirable of all. His enthusiasm does not cover the earlier portion of the Ch'ien-lung in quite the same way—a period before "caution" and "fitness' were thrown to the winds.

This is a book by an American who has lived with jade for the greater part of his life. Indeed, he was born into its atmosphere. He is a third generation member of a San Francisco family of jade collectors.

Jade burst upon the Western world in 1840 with the sack of the Summer Palace, and it was not long before large collections were assembling in Europe. Yet it is stated in this volume that the Western world "has been artistically aware of jade for less than

50 years". While this may apply to the U.S.A., it is certainly not true of Europe. One can think of exclusive stores in London alone where jade displays have been current for more than fifty years and customers were not just jade collectors and specialists.

The author's style is commendable. It makes for easy reading and there is a wealth of good illustration. In fact, it is over-illustrated. To read a book on so specialized a subject as jade is to want *meat*, not a catalogue. Constantly one is here interrupted to study illustrations and to read captions before turning the page, and this often involves going back to pick up the thread of the text. The usual cry is that illustrations are lacking in this type of material and illustrations are of course extremely important. Yet, unless one is merely idling through a volume, as one turns the pages of a well-produced magazine, too many illustrations can be very irritating.

There are mistakes in this book that could easily have been avoided. On page 41 there is a design of a New Zealand *mere*. This is not a *mere* but a *patu-patu*, a design never carved in nephrite. It is commonly made of wood or whalebone. Nor, as stated, was the *hei-tiki* worn only by women during pregnancies. Captain Cook recorded both men and women wearing *tikis* in New Zealand. Whether or not the design represents the human embryo is debatable. It is merely one of many hypotheses. Mention is also made of a *mere* in New Caledonia. This island had no *mere*, unless one that chanced to be there by trade. What it had was a jade *nbouet*—a circular jade disc with a sharp cutting edge. This disc was set into a wooden handle and used primarily as a cleaver or cutter.

Certainly corroboration of jadeite occurrences in both Turkestan and China itself is still awaited, but there are too many contradictions to be positive, one way or the other. The great Bishop collection has jadeite carvings that pre-date the 18th century, i.e. the period when commercial quantities of jadeite entered China from Burma and lapidaries began to discard nephrite for the more colourful medium.

It is refreshing to find the author asking questions regarding the mystery of jade. On pages 45 and 46 he appears to come close to an answer. Certainly man's basic urge, and need, are the things that make for survival—food, clothing, shelter. Of these three, food comes first, since tribes existed, and still exist, without either clothing or shelter. Because of this basic importance to man he made a rite of eating—even eating one's enemy was often more a religious rite

than a necessity. With man's emerging mind he wanted not only to survive (which is instinctive) but to survive under rather better conditions than those of the animal. For this purpose he needed tools and fine tools were of some hard stone. The best obtainable implement, then or now, outside of metal, was jade. In colour this jade was usually green or greenish. Nature herself is mainly green. To early man green meant vegetation, something edible, something vital. The jade implement must therefore have appealed strongly to his colour sense, and with a highly polished implement man could hardly fail to be fascinated. Quite apart from the intrinsic value of the implement there was the psychological value in a Stone-age society. It amounted almost to worship.

The development of jade would therefore appear to be: use, beauty (ornamental perhaps), symbol, in that order. And here the author seems happiest. His divisions on the subject of symbolism are very good indeed.

Yet it is not necessary to fool ourselves—even about the symbolism of jade. Symbolism is not greatly mysterious, however indispensable some people feel it to be. The need of symbols is basically economic. There is always some sort of gain involved, in money or goods or virtue or a life-hereafter. A reward of some kind is implicit—if I do this I get that.

For the person anxious to own a good piece of jade and who feels compelled to know something about the subject, this book is excellent. With the serious student of jade it needs far more documentary evidence. For instance—it is stated that the people of Persia attributed power of immortality to jade. This is interesting and no doubt correct, but where did the author cull this bit of information? There are few enough references to the jade of Persia.

When we get to the last two chapters, the author is again on very familiar ground and able to draw on his extensive experience. His final chapter—Buying a piece of Heaven—is informative and full of sound advice for the aspirant.

This is a commendable book and one that every jade lover will want to add to his library. If only as a reference to the various jade pieces it is of value.

E.R.

WILD (K. E.). *Die Edelsteinindustrie in Idar-Oberstein und ihre Geschichte.* The precious stone industry in Idar-Oberstein and its history. Spring 1963. Special brochure of the Zeitschrift d. Deutsch. Gesellschaft f. Edelsteinkunde. 52 pp., illus., bibliography.

This special issue of the German Gemmological Association is a very well written account of the industry, with emphasis on the historical development. The information is accurate and concise and the illustrations are well chosen. Only in a very few instances would an informed reader detect in his own field of work slightly erroneous statements. This is not surprising considering the jealousy with which many of the small and specialized firms guard their secrets and the vastness of the subject ranging from the importation of rough material from all over the world to the cutting, treating and selling of diamond and precious, ornamental and technical stones.

W.S.

A NEW POLARISCOPE INCORPORATING BENCH LIGHT FOR REFRACTOMETER

The new Rayner polariscope, with refractometer light, is a useful instrument for the gemmologist. There are two glass-mounted polaroids with a distance of 2¼″ between them. This allows quite large specimens or pieces of jewellery to be tested. The bottom polaroid is illuminated from a lamp built into the body of the instrument.

At the front there is an aperture against which the Rayner refractometer can be placed for illumination from the lamp. The weight is 28 ounces and the instrument is designed for use on 230/240 volts Ac.

U.K. price £7 15s. 0d. Postage, packing and insurance extra.

ASSOCIATION NOTICES

TALKS BY MEMBERS

CAFFELL, E. W., "Gemstones", Farnborough Clockhouse Townswomens' Guild, 18th July, 1963.

BLYTHE, G. A., "Diamonds and their substitutes", Southend G.H.S. Scientific and Geographical Society, 17th September, 1963.

RAVEN, R. H., "Gems", Billericay Round Table, 28th August, and Soroptomist Club of Chelmsford, 26th September, 1963.

MEMBERS' MEETINGS

1963

28th Oct. Reunion of members and presentation of awards, Goldsmiths' Hall, London. Reunion 6 p.m., presentation 7.15 p.m. Mr. Lionel Burke, Public Relations Manager of De Beers Consolidated Mines Ltd., has kindly consented to present the awards.

30th Oct. Midlands Branch. Norman Harper on "Classification and grading of diamond crystals".

20th Nov. Midlands Branch social evening.

1964

30th Jan. West of Scotland Branch meeting. J. Gillougley, F.G.A., will speak on "Pearls".

5th Mar. London meeting. Photographic evening at Goldsmiths' Hall.

26th Mar. West of Scotland Branch meeting.

9th Apr. Herbert Smith Memorial Lecture by Sir Lawrence Bragg, F.R.S., Royal Institution.

30th Apr. West of Scotland Branch annual meeting.

WEST OF SCOTLAND BRANCH

On Sunday 9th June, 1963, a joint field outing to Balmerino, Fife, was held by members of the West of Scotland and East of Scotland Branches of the Gemmological Association, and the Scottish Mineral and Lapidary Club.

The parties arrived simultaneously at their rendezvous—the Seymour Hotel, Newport, and guided by Mr. R. Bennett of the S.M.L.C. drove down to the sea shore. This proved unproductive, so a move was made to Balmedowside Farm. In the woods above the farm agate and cornelian were strewn on the surface of the gound in amazing profusion. The pieces were small but the quality of some of them was good, and all members found something to bring home. A small group attempted to dig away the side of a hill, but soon gave up, concluding that the Lapidary Club had been there before them and taken all. They were completely demoralized when a large and promising looking nodule painstakingly extracted by Mr. E. Macdonald proved to be grey chalcedony all the way through.

It was an excellent outing and enjoyed by all who attended.

EXAMINATIONS IN GEMMOLOGY, 1963

In the 1963 examinations 215 candidates sat for the preliminary examination and 132 for the diploma. Centres for the examinations were established in Australia, Canada, Ceylon, Finland, Holland, Hong Kong, India, Kenya, Lebanon, Malaya, New Zealand, Norway, Portugal, South Africa, Southern Rhodesia, Sweden, Switzerland, United States of America, and West Cameroon, apart from the United Kingdom.

Upon the recommendation of the examiners the Tully Memorial Medal has been awarded to Mr. G. V. Axon, of New York, U.S.A. The Rayner Prize has been awarded to Mrs. M. Davis, of Wembley.

The following is a list of successful candidates, arranged alphabetically:—

Diploma Examinations

Tully Memorial Medal

Axon, Gordon Vose, New York, U.S.A.

Qualified with Distinction

Abbott, Henry Charles, Liverpool
Axon, Gordon Vose, New York, U.S.A.
Blatter, Robert, Toronto, Canada
Cooper, Alfred, Swinton
Dambrink, Darel W. J., Apeldoorn, Holland
Forbes, David Reginald, Toronto, Canada
Fryer, Charles William, San Diego, U.S.A.
Gaydon, Julie Hazel, Surbiton
Ghisalberti, Danilo, Lucerne, Switzerland
Holländer, Helmut, Pforzheim, Germany
Hopkins, Peter James, Allestree
Houston, David F., El Cerrito, U.S.A.
Kiuas, Eljas-Jussi, Pukinmäki, Finland
Loupekine, Igor Serge, Nairobi, Kenya
Porter, Robert George, Brisbane, Australia
Quartermaine, Helen Laurie, Kuala Lumpur, Malaya
Spacey, Peter William, Sutton Coldfield
Teissala, Hannu, Helsinki, Finland
West, Peter John, London
Wilson, Douglas, St. Morris, Australia

Addis, Clare Weston, London
Allaby, Frank Edmund, Warrington
Berry, William, Kirkcaldy
Bilby, David, London
Bromly, Ivan Paul, London
Campin, Andrew John, Mansfield
Coop, Norah Marian Nita, London
Dahlsveen, Jon, Trondheim, Norway
Feltell, Raymond, Birmingham
Fernandez, Cyril William Anthony, Bombay, India
Fernando, Kurukula S. L. T., Colombo, Ceylon
Franklin, Jerry Neal, Parkersberg, U.S.A.
Fraley, Lawrence, Wheelersburg, U.S.A.
George, Stanley William, London
Giblin, Michael, Bury
Graham, Martin James Peel, Reigate
Herring, John Thomas, Radcliffe-on-Trent
Horrox, Conrad, Manchester
Hudson, Felix Nettleton, Dunfermline
Irwin, Eric, Liverpool
Jensen, Bjarne Anfin, Bergen, Norway
Kari, Raija, Lahti, Finland
Kaufmann, E. Pius, Montreal, Canada
Krzempek, Evelyn, Nottingham
Lahtinen, Åke Johannes, Helsinki, Finland
Mackenzie, Iain Fraser, Warrington
Mäki, Kalero, Riihimäki, Finland
Meddings, Ann Elizabeth, Burton-on-Trent
Morrell, Anthony, Knaresbrough
Mullen, Joseph, Glasgow
Nairis, Henno Jaen, Stockholm, Sweden
Neerbye, Erling, Oslo, Norway
Nimalasuriya, Nanda, Colombo, Ceylon
Paananen, Erkki, Helsinki, Finland
Primavesi, Thomas, Montreal, Canada
Pudner, Robert Arnold, Liverpool
Pyke, John Stopford, Higher Bebington
Reekie, Robert, Stratford upon Avon
Rintala, Berit, Riihimäki, Finland
Scholl, Werner, Zollikerberg, Switzerland
Schwartz, Raymond Noah, London
Slaven, Ronald W., Loanhead
Smith, Benjamin Henry, Wilmington, U.S.A.
Snell, Richard Geoffrey Fox, Bournemouth
Städelin, Alwin, Lucerne, Switzerland
Stanley, Edward, Manchester
Storgmeir, Inkeri, Helsinki, Finland
Straiton, Timothy, Hove
de Szejko, Anna-Liisa, Hämeenkylä, Finland
de Szejko, Wiktor Ingof, Hämeenkylä, Finland
Tarratt, Christopher David, London
Taylor, John Livsey, Blackpool
Thomson, Patrick Norman, Cape, South Africa
Thorne, Anthony Reginald, Plymouth
Thurlby, Paul Anthony, Birmingham
Virtanen, Pentti Einari, Helsinki, Finland
Watts, James Wilfred, Grimsby
Wight, Peter Martin, Wallasey
Wood, Mary Bayne Haddow, Sidmouth

PRELIMINARY EXAMINATION

RAYNER PRIZE

Davis, Margaret, Wembley

Adshead, Christine V., London
Allan, Christine, Colchester
Allport, Leslie, Birmingham
Anderson, Doris, London
Axon, Gordon Vose, New York, U.S.A.
Bagi, Julius, Toronto, Canada
Baguley, Kenneth, Liverpool
Bailey, Ronald, Plymouth
Barker, Brian Michael, Pinner
Barrett, Susan Mary, Birmingham
Baxendale, Paul Donovan, Birmingham
Beckwith, John Martin Emmerson, Darlington
Bell, Ronald, Thornaby-on-Tees
Bird, Albert James, Liverpool
Blackburn, Brian Joseph, Solihull
Blatter, Robert, Toronto, Canada
Böhmke, F. C., Shabani, S. Rhodesia
Bond, Cecil Allen, Waltham Abbey
Bourne, Francis Frederick, Blackwood, Australia
Brimelow, William, Grantham
Brooks, Lorraine, London
Burslem, William Arthur, Liverpool
Campbell, Ellie, Toorak Gardens, Australia
Chambers, Edwin Joseph, Dagenham
Climie, Robert, Newton St. Boswells
Clough, Michael Bernard, Bolton
Colclough, Albert Cecil, Rainham
Cornish, Stanley, Birmingham
Davis, Margaret, Wembley
Delaquaize, J., Hong Kong
Demaline, Charles Tracey Stewart, Hamilton, Canada
Dowie, Frederick Gordon, Christchurch, New Zealand
Forbes, David Reginald, Toronto, Canada
Forrest, Samuel Porteous, Troon
Foster, Angela, Liverpool
Francis, George Meredith, Fallbrook, U.S.A.
Franklin, Jerry Neal, Parkersberg, U.S.A.
Franks, Ivor Selwyn, London
Fryer, Charles William, San Diego, U.S.A.
Gatling, George, Orpington
Gasser, Josef, Lucerne, Switzerland
Ghisalberti, Danilo, Lucerne, Switzerland
Gold, Leslie Trevor, London
Goode, Alastair R., Solihull
Graham, Martin James Peel, Reigate
Green, John Wilson, Toronto, Canada
Greene, Jane B., Princeton, U.S.A.
Griffiths, Francis Thomas, Scunthorpe
Harris, Stephen James Gray, Bristol
Hartley, Mary Louise, Liverpool
Heaven, John Peter, Walsall
Hill, Lewis Stanley, Glasgow
Hill, Roger Colin, London
Holländer, Helmut, Pforzheim, Germany
Houston, David F., El Cerrito, U.S.A.
Hunt, Anthony Gerrard, Nottingham
Hunt, Elyane M., London
Johnson, Arthur William, London
Jones, Alfred, Coventry
Jones, Kenneth, Birmingham
Kaufmann, E. Pius, Montreal, Canada
Kelly, Hugh, London
Kerry, Stewart Michael, London
Kevorkian, Bedros, Beirut, Lebanon
King, Michael Leslie, Esher
Koller, Tibor, Melbourne, Australia
Laing, John, London
Larcher, David Marshall, Shipley
Lewis, Kenneth Charles, Rainham
Logan, David James, Ayr
Loupekine, Igor Serge, Nairobi, Kenya
Lowbridge, Sydney Evelyn, London
McCorquodale, Samuel, Selangor, Malaya

Marapana, Bhadra, Ratnapura, Ceylon
Mason, Fitz Robert, Kumba, West Cameroon
Mathers, Maureen, Nuneaton
Mensah, James Sarkodie, London
Nairis, Henno Jaen, Stockholm, Sweden
Nielsen, Iver Linde, Oslo, Norway
Østby, Per Bredo, Oslo, Norway
Østby, Tor Martin, Oslo, Norway
Paanenen, Erkki. Helsinki, Finland
Pellet, Pierre, Geneva, Switzerland
Perks, Barbara Joyce, Solihull
Porter, Robert George, Brisbane, Australia
Primavesi, Thomas, Montreal, Canada
Rae, Alexander Coventry, Toronto, Canada
Richardson, Kenneth, Birmingham
Robson, Frank, Houghton-Le-Spring
Rødli, Erling, Trondheim, Norway
Rogers, Norman Frederick, Rosefield, Australia
Rowley, Robert Edward, London
Sander, Nils A., Bergen, Norway
Scheer, Dirk Bernard van der, Oegstgeest, Holland
Schiffmann, Charles A., Geneva, Switzerland
Scharader, Paul J., Killeen, U.S.A.
Schriber, Urs, Lucerne, Switzerland
Städelin, Alwin, Lucerne, Switzerland
Sutherland, Michael Bruce, Basildon
Sutton, A. Warren, London
Swain, Ernest Montague George, Netherby, Australia
Wackett, Alan George, London
Wain, Edward Hollis, Ipswich
Walters, George Christopher, Leicester
Warren, Philip Arthur, Southport
Watts, James Wilfred, Grimsby
Welham, Roy Ernest, Twickenham
Wetton, Roy Nevil, Stafford
White, James C., Frome
Wilson, Douglas Newton, St. Morris Australia
Wrigglesworth, Anthony, Leeds
Wright, Harold David, Ilford

CRYSTAL COLOUR SLIDES

At the request of the Association Mr. R. Keith Mitchell has prepared a set of colour slides of gem crystals. The cubic, tetragonal, hexagonal, trigonal, orthorhombic, monoclinic and triclinic crystal systems have been covered. More than 160 crystals are illustrated together with crystal drawings.

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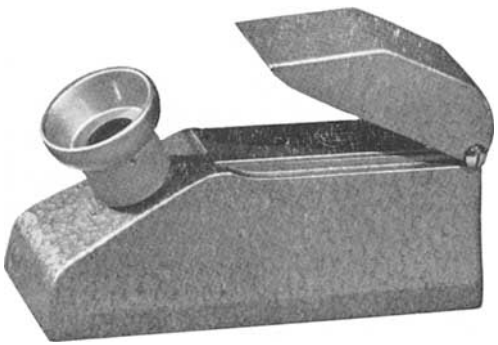

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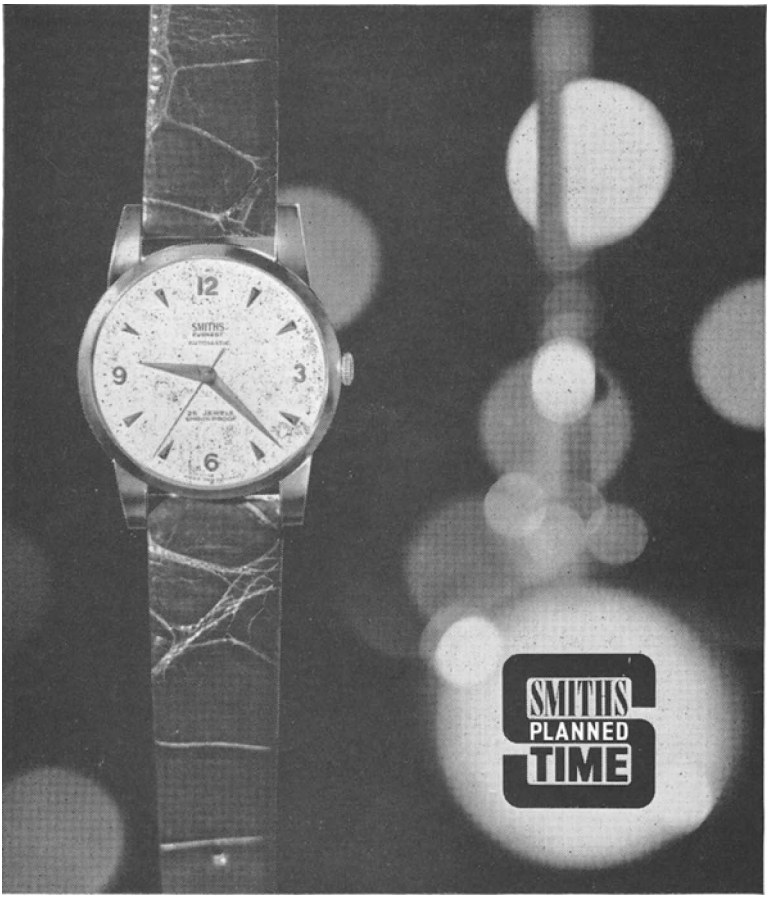

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and

PROCEEDINGS OF THE
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PHOTOMACROGRAPHY OF GEMSTONES AND JEWELLERY IN 35 mm COLOUR

By E. LEVETT, F.G.A.

FOR the very large number of present-day users of colour film, photography is still just a pleasant way of taking shots of the family at home, on holiday or on social occasions, to be projected later for the pleasure of the few, but without much interest for the discriminating viewer unless some real pictorial quality or impact is present. Yet with the aid of photomacrography a series of close-ups of subjects can be recorded, which will interest the layman and also allow a library of reference to be built up which at any time can give information that would otherwise need many written words plus a sketch. This has already been of great importance to the medical, biological and some natural history sciences, to name but a few, and many a viewer has been thrilled by being able to examine in large detail the wonderful antennae of a moth or the pattern of a seed head, and all in colour.

A lot of most excellent photographic work on the internal structure of gemstones has been carried out by a number of microscopists, but to achieve a really high standard in this field fairly expensive equipment is required and, for the average user, a lot of film, whereas the recording of jewellery and gemstones by photomacrography can be achieved with the minimum of equipment and time and result in quite a high percentage of good results, provided that certain facts are appreciated.

Firstly, photomacrography occupies a position between general photography and photomicrography and is usually considered to be in the image scale limits of 1:10 and 25:1. For most jewellery items an image scale of 1:8 to 1:2 will be found to be sufficient, in fact it has to be, as the depth of field (D. of F.) is the limiting factor, as table A indicates.

Secondly, photomacrographic slides are of little use unless there is excellent definition, because slides to be seen at their best must be projected and screen sizes 50 times that of the original are quite usual and any faults in focusing, exposure or fuzziness due to movement can be seen, with a disheartening effect on the photographer.

Focusing faults and fuzziness can be overcome by the simple yet correct equipment, but exposure is largely a matter of experience, coupled with certain tables of figures as guides.

The basic equipment required is:—

(1) A single lens reflex camera (S.L.R.) with U.V. filter and cable shutter release.
(2) A rigid support for camera (tripod).
(3) A 50 mm extension tube that enables sections of a $\frac{1}{4}$ and a $\frac{1}{2}$ to be used.
(4) A plus 2 dioptre (D) and plus 3D supplementary lenses that will fit together to give a plus 5D power.
(5) An extinction meter.
(6) Magnifying eyepiece.
(7) Electronic flash (E.F.) or other means of artificial illumination.

Anticipating criticism, it is appreciated that the non-reflex cameras, such as Leica or Contax, are well able to take shots at the image scales quoted above, but the initial cost is more and the gadgetry is greater and a minimum of equipment is to be desired. Twin reflex cameras can also be used, but again the cost is greater and specially matched pairs of close-up lenses must be used to avoid parallax errors.

The S.L.R. is supreme as to cost, worries about parallax do not exist, there is greater versatility (e.g. a simple attachment and photomicrography is available) and one can observe before releasing the shutter what is the actual D. of F. with different aperture numbers.

With regard to the tripod, one that extends well above a

table height is required, complete with ball and socket head, as it will be found that generally it is very much easier to place items to be photographed on a flat rigid surface, and anyone who has tried to arrange a necklet for vertical taking will appreciate this. Of course bellow extensions can be used instead of tubes, but the latter are cheaper and practically indestructible.

If money were no object, a few lens manufacturers have produced special " macro " lenses that focus down to 4″ without tube or supplementary lenses, but these are in the range of £50 to £75 each, and as this article is based on equipment which in total should be bought for this figure (the S.L.R. will have to be secondhand) a lens at that price is not being considered. (U.K. prices quoted).

If a S.L.R. is being purchased, there is no need to buy one with the standard lens having an aperture larger than f 2·8, as all photomacrographic work will be done by using apertures of f 5·6 or smaller, and f 2·8 will cover all general photographic needs with ease. The saving in cost of the f 2·8 over the larger apertures will pay for all or part of the ancillary equipment.

Item No. 7 lists E.F. etc. One should try to take as many shots as possible using daylight, but as it simplifies technique if film of one make and kind is always used, then E.F. is the best artificial illumination, as it can be used with daylight film with no extra filters.

Having the equipment, its use is towards (*a*) top quality definition and (*b*) correct exposure, and this is where the first table becomes necessary and is based on a circle of confusion of 1/500th″.

TABLE A

DEPTH OF FIELD IN INCHES

Image Scale of Reproduction	*Lens Aperture in f*		
	11	16	22
1:10	4·75	6·75	9·40
1:8	3·10	4·50	6·40
1:6	1·80	2.60	3·25
1:4	0·85	1·20	1·70
1:2	0·25	0·36	0·50
1:1	0·08	0·12	0·16

This table applies to all focal length lenses at the same image scale and f number.

Most jewellery items and gemstones measure in depth between $\frac{1}{4}''$ and $1\frac{1}{2}''$ (to give approximate figures) so that by measuring the depth of the item to be photographed and looking at the table above, it will be seen what image scale will give the amount of D. of F. needed. It is not suggested that f 11, 16 or 22 can alone be used, as obviously if the scale image is as small as 1:6 or 1:8, then there will be sufficient D. of F. using f 5·6 or f 8 and this is where the S.L.R. is such a help, as this can be seen at the time. Having decided on the image scale, the next table B will give what is needed in extension tubes and/or supplementary lenses to give this scale, and the table is based on using a 50 mm f 2·8 Tessar. Other cameras having a standard lens of 52, 55 or 58 mm focal length can use this table as the variation will be very small.

TABLE B

Image Scale	*Supplementary Lens in Dioptre power*	*Extension Tube*	*Lens Focused at*	*Distance of Front Lens from subject to nearest $\frac{1}{2}''$*
1:8	Plus 2	Nil	∞	21″
1:6	Plus 3	Nil	∞	13″
1:4	Plus 2	Nil	0·5 metre	$8\frac{1}{2}''$
$1:2\frac{1}{2}$	Plus 5	Nil	0·5 metre	5″
$1:2\frac{1}{2}$	Nil	12·5 mm.	0·5 metre	5″
1:2	Nil	25 mm.	∞	5″
$1:1\frac{1}{2}$	Plus 3	12·5 mm.	0·5 metre	$3\frac{1}{2}''$
1:1	Nil	50 mm.	∞	3″
$1\frac{1}{2}:1$	Plus 5	50 mm.	0·5 metre	$1\frac{1}{2}''$

The last set of figures giving an image scale of $1\frac{1}{2}:1$ which, of course, is larger than actual size is the maximum that can be achieved with this combination. However, by reference to table A, it will be seen that the D. of F. has now become too small.

There are 30 combinations in which the three sections of tubes and the two supplementary lenses can be used, but the nine given above cover the image scale in whole or half numbers.

The final step is to decide the correct exposure. Using daylight of a calculated value with the film speed allows the shutter speed and f number to be chosen. When using E.F. the guide

number (given by the makers) for the film used divided by the distance of the flash head from the subject indicates an f number suitable, but at distances of 18″ or less it is largely a question of personal experience and a certain amount of wasted film until correct results are obtained. One maker suggests that between 18″ and 6″ two stops be added.

As E.F. lasts for only 1/1000th sec. approximately it is necessary to use a shutter speed on a focal plane shutter when it is fully opened and this is generally between 1/25th and 1/50th sec. according to make of camera, and in many cases the speed dial is marked. In compur or between-lens shutter cameras the speed of the shutter is usually at about 1/200th sec. The one criticism of the use of a focal plane shutter, when E.F. is used as a fill in, is the danger of a ghost image with the shutter speed being so slow, but, as jewellery and gem stones are static subjects, there is no real worry here.

The camera world is constantly changing, and even as this article is being written a camera with a focal plane shutter is being made available which enables E.F. to be used at a shutter speed of 1/125th sec. The f number selection can be a source of incorrectly exposed (*i.e.* underexposed) shots when extension tubes are used, because the lens-to-film distance is increased and the f numbers marked on the lens and known as the actual (A.) are not the new *effective* (E) numbers, and the following table C shows both, again based on a 50 mm focal length lens.

TABLE C

Length of Extension Tube	A f	E f	A f	E f	A f	E f	*X Factor*
12·5 mm.	11	**14**	16	**20**	22	**28**	$1\frac{1}{4}$
25 mm.	11	**17**	16	**24**	22	**33**	$1\frac{1}{2}$
50 mm.	11	**22**	16	**32**	22	**44**	2

These new f values must be used when calculating the shutter speed in daylight or the nearness of the flash head to the subject when using E.F.

When using supplementary lenses, as there is no increase in the camera lens-to-film distance, the f numbers are not altered. Going back to table B it will be seen that either a plus 5 D or an extension tube of 12·5 mm. give the same image scale of $1:2\frac{1}{2}$. By using the supplementary lenses, no alteration in f values occurs and it is

easier and quicker to slip on the two close-up lenses than to remove the camera lens, fit on the tubes and refix lens. So wherever possible the use of supplementary lenses is to be recommended.

The use of the extinction meter rather than the photo-electric type is preferred, as with the short distances from lens to subject, which are generally between 3″ and 10″, a very accurate light value needs to be known.

With regard to the make of the colour film used, this is very much a personal choice. All makes seem to give good results provided that the particular colour bias of any given make of film is taken into consideration, and corrections can be made using coloured backgrounds to reduce or emphasize this bias; but once again the continued use of one make is to be recommended.

Correct colour balance allows little latitude in exposure, and if it is a special piece that is being photographed then it is wise to take an extra shot half a stop or time equivalent above and below what is calculated to be correct.

With regard to the background, this again is a matter of personal choice. Various materials can be used (wood, textiles, textured or coloured Formica-type boarding are examples), but, if E.F. is used, a non-reflecting surface is essential; otherwise highlights may distract from the subject in the slide.

There is such a thing as reciprocity failure which occurs when very high or low speeds upset the normal balance between time and light intensity, but this need not be considered when using E.F. and only for exposures longer than one second, when half a stop should be added to exposures up to three seconds and one stop between three and five seconds, or time equivalent if D. of F. is important.

Finally to summarize the procedure:—

(1) Check D. of F. required and from table A decide image scale.

(2) For this scale obtain from table B the close-up lens and/or tube required.

(3) Focus the subject through the magnifying viewer using the largest aperture. If one is using a camera with a pre-set iris, remember to return to selected f before exposing. Cameras fitted with automatic or semi-automatic iris ensure this when supplementary lenses are added, but not in some cameras when extension tubes are used.

(4) Ascertain exposure required, remembering E f where

applicable. Set aperture and speed and press cable release.

It is as well to keep a detailed record of each shot, so that obvious mistakes can be avoided in the future, but, when the failures occur even with the most careful operator, a really first-class slide is more than sufficient compensation.

Notes to illustrations using 50 mm focal length lens.

(*A*) Brazilian topaz brooch. Daylight. Kodachrome 2. 25 mm tube and plus 5 D. E f 16. One second.

(*B*) Giuliano pendant. E.F. 15″ from subject. Kodachrome 2. Plus 5 D. f 16. Shutter set at 1/25th sec.

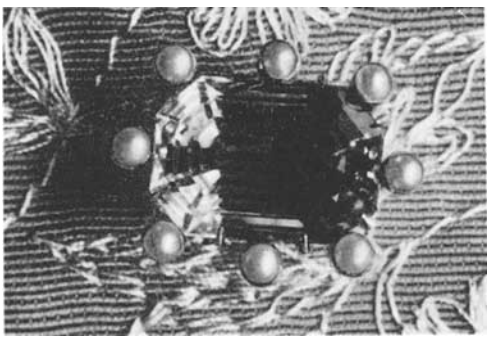

AZURITE

By L. C. TRUMPER, B.Sc., F.G.A.

IN the gemmological literature, azurite is almost invariably described as an azure blue massive mineral and, in the course of collecting gemstones, several such specimens have come into my possession, together with a small specimen of more or less radiating opaque crystals probably from Chessy, near Orleans in France, which is usually quoted as the typical locality and which gave the mineral its alternative name of Chessylite.

However in June 1961, I was agreeably surprised when Mr. K. Parkinson, on his return from one of his visits to Idar Oberstein, kindly sent to me a step-cut stone of 2·508 carats, which was not only flawless but to my surprise was also completely transparent, though of an exceedingly deep and intense azure-blue colour. The lustre was vitreous to adamantine, and there was no fluorescence under ultra-violet light. The specific gravity, carefully measured by using Toluol, was 3·80.

I next measured the refractive indices, or rather in this case index, for azurite is one of those few interesting examples where the lowest of the indices can be read on the refractometer and not the highest, for this latter is above the upper limit of the instrument. Azurite is biaxial and positive in sign. The lower reading of 1·73 was readily obtainable, but on rotating the polaroid filter, the shadow continued right up to the upper limit. The higher reading is quoted as 1·838, giving a double refraction of 0·108.

I made some efforts to try and get the upper reading on my total reflectometer, but it is difficult to do this where there are two indices of refraction and a reading somewhere in the middle is obtained.

Azurite is said to be pleochroic with two shades of blue, but I was unable to obtain any evidence of this. The hardness is given as 3·5 to 4 with a prismatic and basal cleavage, according to Sir James Walton[1]. Azurite is monoclinic.

The chemical composition is that of a hydrated copper carbonate, with the formula $2CuCO_3.Cu(OH)_2$, and it is very similar to the green mineral malachite with which it is usually found. Indeed, massive material and crystals are frequently intermingled or with malachite one end and azurite at the other.

Whilst showing a greenish colour under the Chelsea filter,

examination with the spectroscope disclosed a cut-off throughout, except for a window of deep blue between about 4,400 and 4,600Å.

Well-formed crystals have also been found at Tsumeb, S.W. Africa, where they assume many different forms, some of which are said to be of quite considerable dimensions and even up to six inches in size.

Azurite is found also in a number of other localities, including Siberia, and Clifton and Bisbee, Arizona, U.S.A.

A small specimen in my collection exhibits some quite well-formed crystals, which also appear to be quite transparent, in among a matrix of massive material, all completely blue without any sign of malachite.

Some years ago a friend gave me a specimen of azurite of quite considerable dimensions which had been on his rockery for years! This specimen consisted of innumerable small more or less roundish crystals but of the familiar and unmistakable azure blue colour.

REFERENCE

1. Walton, James. *Pocket Chart of Ornamental Stones.* London, 1954. 42-43.

COMPOSITE STONES
A survey of their types and their properties

By R. WEBSTER, F.G.A.

A COMPOSITE, or assembled, stone is no new device. Such objects have been known from the days of the Roman Empire, for they were mentioned by Pliny in his *Historia Naturalis*(1), and the Roman lapidaries constructed their *Jaspis Terebinthizusa* by cementing together three different coloured stones with Venice turpentine. Many different types of doublets were mentioned by Camillus Leonardus, of Pesara, about 1502(2). King(3) mentions Italian glass intaglios of the 18th and 19th centuries, which could not be distinguished from the real except by a file, and to baffle this mode of detection the dealers used the ingenious contrivance of backing the paste with a slice of real stone of the same colour. When set in a ring with the junction concealed, a test with a file (presumably the test would be made on the underside rather than risk damaging the incised carving on the front) would enable the gem to be passed as real. King also refers to the fact that the same method is used for forging all the precious coloured stones, the ruby, the emerald and the sapphire; a paste of proper colour being backed by a suitably faceted rock crystal. Weinstein(4) states that the modern type of doublet, but he does not state what type, was invented by Cartier, a Frenchman, in the year 1845.

Composite stones are generally described as *doublets* when the stones consist of two main pieces; and *triplets* when three pieces are used. Internationally there are some slight differences in the nomenclature, for in North America the modern soudé-type stones are known as triplets, while in Europe these stones are called doublets.

What are the reasons for the manufacture of these composite stones? The fundamental reason in many cases is to obtain a larger stone from given natural material; or to produce a stone of much better colour and appearance. Other considerations are the provision of a harder wearing and more lustrous surface to a glass imitation, which is probably the reason underlying the making of the garnet-topped doublets, although it has been suggested that the use of garnet here is to overcome the testing by a file.

Further, doublets may be made for the purpose of supplying a rigid support for gem material which can often be found only as thin and easily damaged slices. This is the most logical reason for the production of opal doublets.

True Doublets

Literature always mentions the *true doublet*, or *genuine doublet*, which consists of two parts, constructed by cementing together two suitably fashioned pieces, one for the crown of the stone and another for the pavilion, both pieces being cut from similarly coloured material of the same species. Thus true doublets can be made of two pieces of diamond, or of ruby, sapphire, emerald or other species of stone. Except in the case of opal on opal doublets, true doublets are very rarely met with.

Semi-Genuine Doublets

When a piece of genuine material of the stone simulated forms the crown of the composite stone and this is cemented to a pavilion cut from a less valued stone, or even glass, the stone is known as a *semi-genuine doublet*. The most important stone of this type is the *diamond doublet*, a composite stone where the crown consists of a piece of real diamond and the pavilion of any suitable colourless stone, such as rock crystal, white topaz, synthetic white sapphire or spinel, or even glass.

When unset such diamond doublets may easily be detected, not only by the join at the girdle which may be seen when the stone is inspected with a hand lens, but convincingly when the stone is immersed in methylene iodide or monobromonapthalene, when the difference in relief of the diamond top and the inferior material of the base is readily seen (Note: it may not be advisable to immerse doublets in which the join is made with cement or balsam, as the organic oils used for immersion may have a deleterious effect on the cement and cause pseudo-flaws or even allow the two parts to separate).

Most often the jeweller encounters diamond doublets as set stones, and usually they are set with a rubbed over setting(gipsy setting) which effectually covers the junction of the two pieces. Despite this apparent limitation diamond doublets may be readily detected, for, as reported by Tisdall[5] and also by the writer[6], if the jewel be so held that the table facet of the stone is slightly tilted

Schematic diagram of a true doublet.

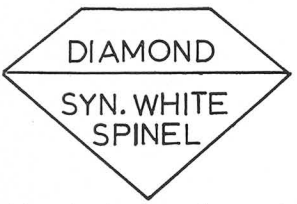

Schematic drawing of a semi-genuine doublet (in this case a diamond doublet).

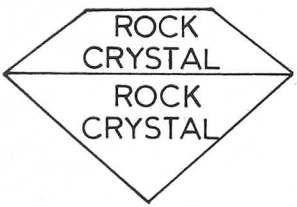

Schematic diagram of a soudé (quartz type) stone where the two pieces are made of rock crystal and the coloured layer along the girdle is gelatine (early type) or sintered glass (modern quartz type).

An unusual type of doublet. The stone is white or very pale pink topaz and the tip of the pavilion is made of natural blue sapphire. The effect was not very good, and the expected total blue coloration of the stone by total internal reflection did not occur.

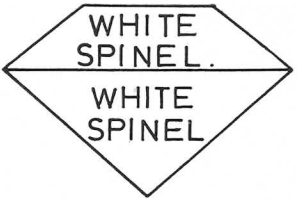

Schematic diagram of a spinel (soudé type) doublet.

Schematic diagram of a hollow doublet.

Schematic diagram of a garnet-topped doublet.

Schematic diagram of a false doublet.

Schematic diagram of a triplet.

away from the observer there will be seen a dark border to the opposite facet edge of the table. This is due to reflection of the facet edge on the cement layer. Further, there may be seen prismatic colours of films due to air which has penetrated along the junction layer where the cement joining the two pieces has deteriorated.

Except in the case of some opal doublets, and the diamond doublets, semi-genuine doublets are rarely if ever met with, but it would be rash indeed to say that stones with ruby, sapphire or emerald crowns cemented to base material pavilions have never been constructed. Garnet-topped doublets might be said to come under this category but in view of their being so much more commonplace they will be treated separately.

False Doublets

The so-called *false doublets* are composite stones where the crown consists of rock crystal or other colourless stone which is cemented to a pavilion of suitably coloured glass. The writer[7] reported some years ago on three specimens of such doublets, one of a sapphire-blue colour, another a purple and the third a yellow colour.

In all cases the refractive indices of the crown were 1·544-1·553, *i.e.* that of quartz, and the glass base gave for each stone an isotropic reading of 1·51.

The blue stone had a density of 2·61, exhibited the absorption spectrum of cobalt coloration, and, when immersed in water and looked at through the side, the crown of the stone was clearly shown to be colourless and the pavilion to be blue. Microscopical examination showed that there was no bubble layer at the junction of the two parts, but a few large bubbles were seen in the coloured glass base. When the stone was irradiated with long-wave ultra-violet light the characteristic fluorescence of the cement layer was seen as a bright line around the girdle of the stone.

The purple stone had a density of 2·56 and showed a faint cobalt absorption spectrum with a fainter band in the blue. Bubbles and swirl marks were seen in the glass base and the cement layer similarly showed up under ultra-violet rays. The danger of such a stone as this is that should a measurement of refractive index alone be taken the stone could be mistaken for an amethyst, which it closely resembles.

The yellow stone had an appearance very much like that of the yellow synthetic spinel, which exhibits such a strong yellow-green fluorescence under ultra-violet light; and indeed this doublet also showed a strong and similarly coloured glow from the glass base. Examination with a spectroscope showed that the glow exhibited a discrete spectrum (banded or fluted spectrum) and indicated a uranium coloration for the glass. This green glow was sufficiently intense to mask the glow from the cement layer. As in the case of the other two stones the glass base showed swirl marks and gas bubbles and no layer of bubbles was seen in the plane of joining. Examined between " crossed polars " this stone, as well as the other two, was found to show extinction at 90°. The density of this yellow stone was found to be 2·55.

Hollow Doublets

Bauer[8] mentions *hollow doublets*, a type of composite stone which the writer has not so far encountered. They are said to consist of an upper portion of colourless rock crystal or glass, which is hollowed out below, the walls of this hollowed out portion being highly polished. The cavity is filled with coloured liquid and the whole closed in with a base plate, or a pavilion, of the same material as the crown. Such composite stones are said to be readily " spotted " for the cavity of coloured liquid is visible when the stone is looked at from the side.

Imitation Doublets

This term is usually applied to doublets which consist of two pieces of colourless glass cemented together with a coloured cement.

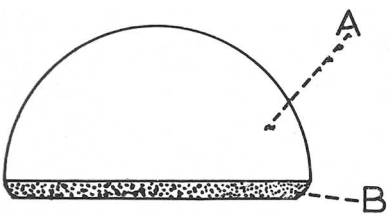

Schematic diagram of a star-rose-quartz doublet. A: cabochon of natural star-rose-quartz; B: mirror and backing.

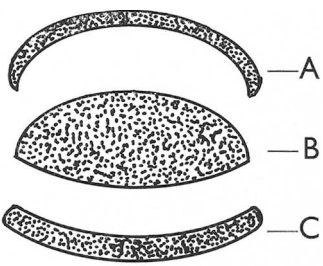

Schematic diagram of an "exploded" jadeite triplet showing the component parts.

Two such imitation doublets in the possession of the writer are made of two pieces of glass having an index of refraction of approximately 1·52 and densities of 2·478 and 2·488 respectively. It was interesting to note that the red colouring layer between the glass crown and pavilion had an absorption spectrum reminiscent of that of almandine garnet, for there were two strong bands in the yellow and green part of the spectrum and a weaker one in the blue part. These were centred at approximately 5720, 5330 and 5020Å.

Triplets

True triplets are constructed of three pieces, the crown being some real stone, such as quartz, and the tip of the pavilion of similar material, the central portion being, usually, coloured glass. The idea behind this type appears to be that not only will the crown resist a file but the lower part of the pavilion also. Such triplets are not common.

Garnet-Topped Doublets

Such composite stones are one of the more commonly met types of doublets. They are made by fusing a thin slice of almandine garnet to a blob of coloured glass. There are many colours, such as those imitating the ruby, sapphire, emerald, amethyst, topaz, peridot, and even colourless stones have been produced. It is the colour of the glass which controls the colour of the finished stone, the thin layer of garnet having little or no influence on the resulting colour.

An intriguing problem was to find out when these garnet-topped doublets first appeared. It was thought that it would have probably been during the second half of the 19th century, or even a little earlier. It was significant, however, that no specific mention was made of this type of doublet in the long series of Herbert Smith's *Gemstones* until the 1940 rewritten edition[9]. However, Michel[10] in his book dated 1926 does give a very full account of garnet-topped doublets. In a personal note Dick Larkham, Senr., who has had considerable experience of the gem trade, says that to the best of his memory these doublets came out about 1923. There is a much earlier reference to the " fusing " of two parts of a doublet together, for Schrauf[11] states:—" The half-genuine doublets consist of a very thin upper layer cut from a true precious stone and cemented or *fused* to a base of glass " (my italics). Whether this

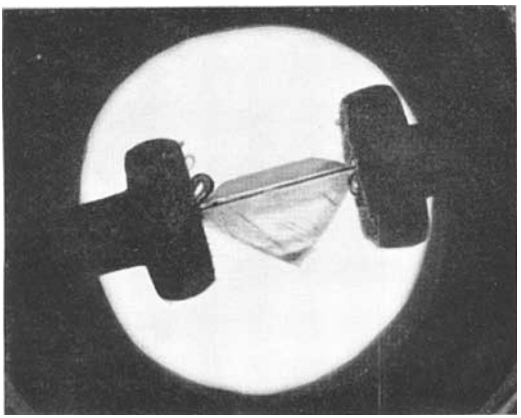

A soudé stone immersed in liquid showing the colourless crown and pavilion and the dark line of colour across the girdle.

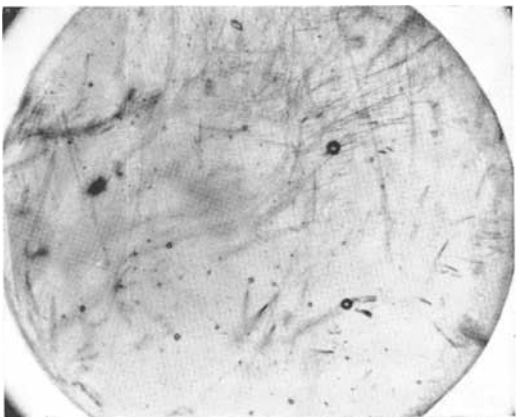

Photomicrograph of a garnet-topped doublet showing the layer of bubbles in one plane and needle inclusions in the garnet top.

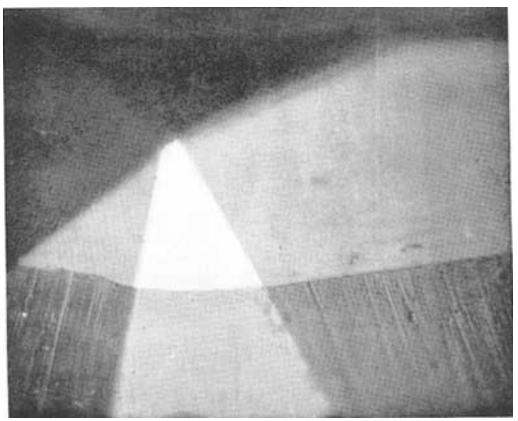

Photomicrograph showing the difference in lustre and the plane of joining in a garnet-topped doublet.

applied to the garnet-topped doublet as we know it to-day is a matter of conjecture. Garnet is the only stone which will easily fuse to glass, so the report might well be that of an earlier production which later faded out, and the production in the early nineteen twenties was a resuscitation of the method. Why such objects should be made at a time when the synthetic gems were well in production is puzzling.

These garnet-topped doublets are cut from the blob of glass to which is fused the slice of garnet. Rarely is any care taken to get the plane of joining of the garnet and glass in the plane of the girdle in the finished stone. Hence, the slice of garnet may show the join, perhaps, halfway up the side facets of the crown, and may not even be at a regular distance from the girdle all round. Examination with a hand lens will show this join and, what is just as important, will show the difference in lustre of the garnet top and the glass base. If the stone be loose and laid table facet down on a sheet of white paper a red ring will be seen round the stone. This is fairly obvious in the case of all colours of garnet-topped doublets except those of red colour where the effect is masked by the red glass.

Due to the fusing of the glass a layer of bubbles in one plane may be seen at the plane of junction of the garnet and glass when the stone is examined by a low-power microscope. Further, natural inclusions, such as crystals or a reticulation of needles may be seen in the garnet top, and if the examination be carried out by using an immersion oil the difference in relief of the garnet top and the glass will be strikingly revealed.

The almandine garnet used for the top of these doublets has a refractive index between 1·77 and 1·80, and the glass has usually an index of between 1·62 and 1·69, but occasionally a glass with an index as low as 1·51 has been found in these doublets. The density of these doublets can have no significance and a table of this constant for these stones would be of little value.

Under ultra-violet radiations the glass of these doublets may, in some cases, show a whitish or greenish glow as against the inert garnet part. It may be found that the glass gives a better response when the short-wave ultra-violet lamp (2537Å) is used.

Soudé-Type Stones

(a) Early type of soudé emeralds

These stones consisted of two pieces of rock crystal forming the

crown and pavilion of the stone, and these two pieces were cemented together by a green coloured gelatine. They were made to imitate the emerald and were thus called *soudé emeralds*. A rare variation of this stone is where two pieces of pale beryl are used instead of rock crystal. The disadvantage of such early soudés is that the green colour tended to deteriorate and turn a yellow colour, thus producing a " citrine ".

Quartz, or beryl, soudé emeralds are easily identified, for, if they be immersed in a cup of water and viewed sideways the top and base will be seen to be colourless with the dark line of colour in the plane of the girdle. The refractive indices of 1·544 and 1·553 of the rock crystal will, of course, indicate the nature of the stone unless the green colour has turned to yellow, when the stone might be mistaken for citrine. If beryl be the material used for the two pieces, then the indices of refraction will be of little help, nor will the density help in this case, for the gelatine layer makes very little difference to the specific weight. With the quartz type the density would be significant, the value obtained being slightly below that of quartz. Usually the value is near 2·62. Under ultra-violet light the cement will glow at the girdle and this will give an indication that the stone is a doublet, for neither quartz nor beryl will glow under the rays. One danger with these green-coloured early soudés is that they show red through the Chelsea colour filter, due to the dyestuff used in the gelatine.

Certain quartz soudés have been made with coloured gelatine layers in colours other than green. The writer has examined(12) two such stones. The first of these, an oblong cushion-shaped stone weighing 7·45 carats, was unusual in that its appearance in daylight was a slaty-green and in this resembled the fancy-coloured synthetic sapphire made to imitate alexandrite. Indeed, this slaty-green colour turned to purple like the " alexandrite-type " fancy-coloured synthetic corundum. The absorption spectrum of this stone showed the cobalt lines very strongly and also a very intense band in the blue-violet part of the spectrum and a weaker band in the blue. The density was found to be 2·62. When irradiated with long-wave ultra-violet light this stone appeared to glow with a purplish haze due to fluorescence of the cement layer. Under the Chelsea colour filter this stone showed a purple colour with daylight and an orange residual colour with tungsten electric light.

The other stone was an oval mixed-cut sapphire-blue stone weighing 4·27 carats. Again there was some change of colour to a purple colour when the stone was viewed under tungsten electric light. The density was 2·62 and the absorption spectrum showed the three bands of cobalt coloration. There were no bands in the blue part of the spectrum. Under the colour-filter the stone showed an orange residual colour.

No bubble layer was seen in either of these two stones, although in one or two cases bubbles in the gelatine layer have been observed in some soudé emeralds. Both these fancy-coloured soudé stones, when examined between " crossed polars " with the table facet at right angles to the light path, showed no extinction on rotation of the stone between the " polars ", the field showing a more or less continuous brightness. However, when the stone was turned sideways and similarly viewed, so that the crown and pavilion were in the field at the same time, it was seen that on rotation each part extinguished separately but the extinction of each part was four times during a complete rotation. This proved that the two pieces of rock crystal did not have the same orientation.

(*b*) *Modern quartz-type soudé stones*

These composite stones, which it is believed came on the market about the same time, or a little earlier, as the garnet-topped doublets (say about 1922), are similar in construction to the early type of soudé emerald. This newer type of soudé stone has the rock-crystal crown and pavilion in two separate pieces but differs from the earlier type in that the coloured layer, the unstable gelatine, is replaced by a layer of coloured and sintered glass; or at least this is thought to be the case. The colour is probably due to a metallic oxide and not an organic dyestuff, as is probably the case in the early gelatine types, and is therefore stable. The stones give the refractive index for quartz, but the specific gravity is found to be much higher than for quartz. Anderson [13] gives the density of these composite stones as about 2·8 and ascribes this high density as being due to the heavy lead glass of the coloured layer. An alternative suggestion is that the extra specific weight could be due to an organo-metallic colouring compound; in the case of the soudé emerald the colour is undoubtedly due to a copper compound, but what compound of this metal is not known. That the colouring agent is the cause of the high density is now considered to be less likely. Density

determinations on modern quartz soudé emeralds are given in the table below:—

Weight	*Density*
4·38 carats	2·77
—	2·79
—	2·81
1·18 carats	2·82
8·26 carats	2·83
1·15 carats	2·84
1·98 carats	2·89
2·25 carats	2·90
3·54 carats	2·96

The density must depend upon the thickness of the sintered glass layer, and it is owing to this layer that American gemmologists prefer to describe the soudé stones as " triplets ". It is understood that other colours than green have been produced, but so far the writer has not had the opportunity to examine other colours in these quartz soudé stones. Unlike the earlier type of quartz soudées, this type with a sintered glass layer does not fluoresce under ultra-violet light, and, further, the emerald-colours show green and not red through the Chelsea filter.

(*c*) *Synthetic spinel doublets*

In 1951 Jos Roland, of Sannois, France, produced a type of soudé stone in which the crown and pavilion were made of colourless synthetic spinel instead of quartz. These *soudé sur spinelles* as they are called, were examined and reported upon by the writer when they first came on to the English market[14]. This type of composite stone is now made in all colours, the colouring layer being most probably a sintered glass, as in the case of the modern quartz type. Again the density of these spinel soudées is higher than for the bulk material, *i.e.* synthetic spinel which has a density of 3·63, but as was to be expected the rise was not so great as in the quartz type. As the different colours were found to give similar rise in density it seems that it is the lead glass which gives the added density rather than the colouring. Below is appended a table of the densities found in the case of various colours.

Colour	*Weight*	*Density*
Black	3·81 carats	3·63
Emerald green	26·39 carats	3·66
Peridot green	5·60 carats	3·66
Emerald green	—	3·66
Peridot green	8·98 carats	3·67
Amethyst colour	6·36 carats	3·67
Topaz colour	5·15 carats	3·68
Emerald green	4·15 carats	3·68
Emerald green	—	3·68
Aquamarine colour	14·54 carats	3·68
Peridot green	2·39 carats	3·69
Dark topaz colour	8·97 carats	3·69
Blue zircon colour	7·59 carats	3·69
Sapphire blue	5·53 carats	3.70
Emerald green	3·76 carats	3·70
Emerald green	4·19 carats	3·70

The refractive index in all cases was found to be 1·73, and like all synthetic colourless spinel there is no fluorescence under long-wave ultra-violet light, but under the short-wave lamp the strong bluish-white glow is seen and the cement layer shows up as a non-fluorescing line against the fluorescing synthetic spinel. This effect was first noticed and described by Liddicoat[15]. No characteristic absorption spectra were seen whatever the colour of the stone.

Under the Chelsea colour-filter, the emerald and peridot-green coloured stones showed a green residual colour. The blue zircon and aquamarine colours also showed greenish through the filter and *not* orange as in the case of the similarly coloured synthetic spinels. The amethyst-colour and the sapphire blue stones did show an orange colour when examined through the filter, but there was no characteristic effect with the topaz colours of these spinel doublets.

It has already been mentioned that when a quartz soudé is immersed in water and looked at sideways the stone appears colourless except for the dark line of colour across the girdle. With the spinel doublets, owing to their higher index of refraction, it is better to immerse the stones in methylene iodide or monobromonaphthalene in order to see the effect clearly; with water it is less easy.

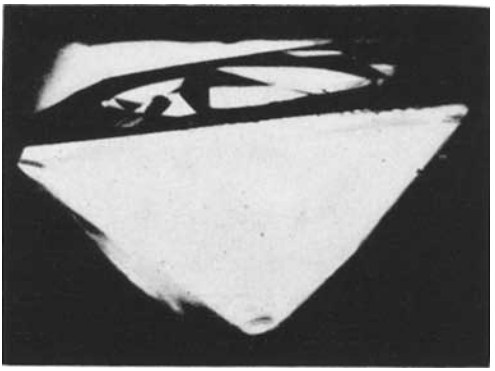

A diamond doublet immersed in a highly refractive liquid showing the high relief of the diamond top and the low relief of the material of the pavilion.

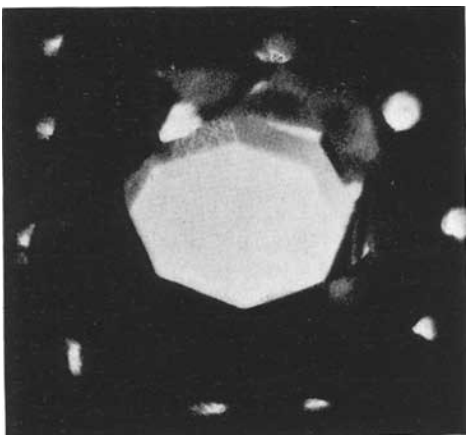

Reflection of the table facet edge on the cement layer in a diamond doublet.

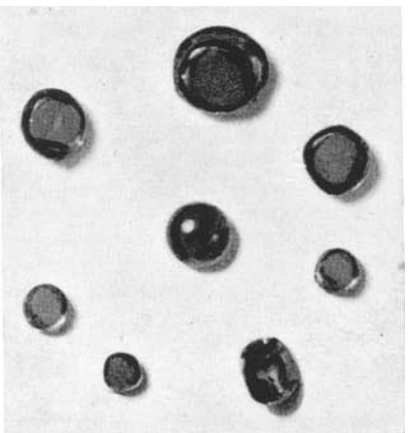

Seven uncut garnet-topped doublets and one cut stone. The centre specimen is upside down to show the ball of glass, the others all show the slice of garnet fused to the ball of glass.

Opal Doublets

Opal which shows a fine play of colour is often found in too thin a vein to cut any solid gemstone from it. Such pieces are then backed with either common opal (potch opal, which shows little or no play of colour), by black onyx, or by a black glass called " opalite ", which is obtained from Belgium. Such a device supports the thin piece of colourful opal and allows the stone to be set into jewellery. Opal doublets on black onyx or black glass are fairly easy to detect, but opal on opal doublets are much more difficult, and when in a setting it may be impossible to be sure. The reason for this is that many natural opals are cut with the natural backing of the original seam wall and when this is fairly straight the stone can resemble to a great extent a doublet and careful examination with a lens is needed in order to distinguish between the two.

A new departure is the *opal triplet*, called by the trade-name " Triplex opal ". This is a simple opal doublet, usually with a common opal backing, to which is cemented over the top part of the opal a suitably fashioned cabochon of rock crystal. The idea is to present a better wearing face to the opal and to give the opal a better brilliancy, as to some extent the quartz cover acts as a lens. The effect produced by this cover generally makes the stone appear somewhat unreal.

An imitation opal, which could be termed a false doublet, consists of a cabochon of rock crystal or glass to the back of which is cemented a slice of iridescent mother-of-pearl, either from the pearl oyster or from the colourful paua shell (Haliotis), or abalone, as it is called in the United States of America.

Jadeite Triplets

In recent years a triplet of jade has been made and marketed which has the colour of Imperial jade. Such stones have been adequately described by Martin Ehrmann[16]. These stones are made up of three pieces, the components being a hollow cabochon of very fine translucent white jadeite about one half a millimetre all round, a cabochon of smaller size cut to fit into the hollow cabochon, and a flat oval piece to enclose in the back. The central piece, the oval cabochon, is coloured with a jelly-like dye of Imperial green colour. This dyed centre-piece is inserted into

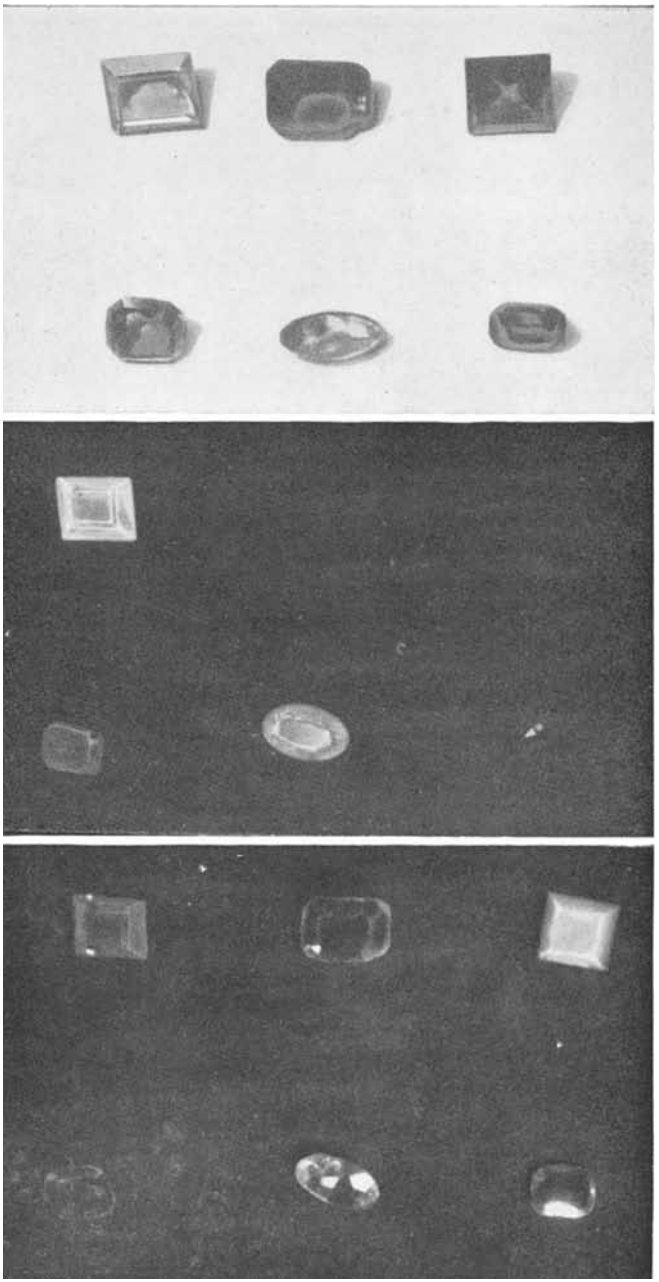

the hollow one and the bottom piece cemented on and repolished to make a perfect fit. These triplets make attractive stones but when unset the join of the baseplate and the hollow cabochon top is clearly visible. It is when the stones are mounted with this edge concealed that they are so deceptive. They can be detected, however, by the characteristic dyestuff absorption spectrum of a broadish band in the red part of the spectrum.

Star-Rose-Quartz Doublets

An ingenious composite stone made to imitate the star-sapphire is constructed by preparing a cabochon cut from a correctly oriented piece of pale star-rose-quartz, to the back of which is cemented a blue-coloured mirror, and this may be further backed with a baseplate of some other stone. In some cases the " mirror " is sputtered on. Although rose-quartz does sometimes show asterism by reflected light (epiasterism), the best effect is found by transmitted light (diasterism), and this is the reason for the mirror at the back. The light incident on the stone travels through it and is returned by the mirror enhancing the star-effect. Unlike the star-corundums and other natural star-stones, it is generally found that when the star in star-rose-quartz doublets is viewed under an electric light, an image of the electric lamp is seen at the crossing of the rays of the star. The nearer the lamp is brought to the stone the larger the image becomes. The colour of these star-doublets is not quite like that of natural star-sapphire. Some of this difference in appearance may be due to the transparency of the rose-quartz being greater than that of natural star-sapphires, and, of course, the lustre is not so pronounced with quartz as with star-corundum.

Top Picture. *Taken in ordinary light.*
Top row: *Old type quartz soudé emerald.*
New type quartz soudé emerald.
Synthetic spinel soudé type emerald.
Bottom row: *Glass top with quartz base and gelatine layer.*
Quartz top and coloured glass base.
Garnet-topped doublet.

Centre Picture. *Same stones under long-wave ultra-violet light. Here the stones with a gelatine layer show a glow from this layer.*

Bottom Picture. *Same stones under short-wave ultra-violet light. Here the stone which is most conspicuous by its fluorescence is the synthetic spinel doublet. The rest of the stones appear to show up owing to the fact that the short-wave filter does not cut out the visible light from the lamp burner as the Wood's glass used with the long-wave lamp.*

Cameo and Intaglio Doublets

Cameo doublets, where the raised portion is separate and is only cemented on to the base, are only occasionally met, except perhaps in some cameos made of porcelain. Intaglio doublets have been made, and these date back to Roman times, if not before. Such objects are occasionally encountered. These are usually two pieces of glass, the upper piece either engraved, or more commonly moulded, for the intaglio and joined to the glass base with a reddish brown cement, so that the stone imitates a cornelian. The pigment is not very stable and the layer soon shows crazing due to deterioration. A more stable result is obtained by using a backing of true cornelian.

Moss Agate Doublets

These doublets are produced by placing some chemical, such as manganese dioxide, with gelatine on a glass plate and allowing the " tree " to form on the gel, after which the plate is gently heated so as to drive off the excess water. Another clean glass plate is then cemented on to the top and the whole is then ground and polished to a suitable cabochon form. When the stones are unset the join between the glass plates readily reveals the fake, and even when set the greater transparency to true moss agate would indicate that something was wrong.

Turquoise Doublet

Unimportant, but mentioned for the sake of completeness, is the turquoise doublet constructed by cementing a base of blue stained chalcedony to a low cabochon of turquoise-coloured opacified glass.

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Gemmological Abstracts

GENTILE (A. L.), CRIPE (D. M.) and ANDRES (F. H.). *The flame fusion synthesis of emerald.* Amer. Mineral., Vol. 48, pp. 940-944. July-August 1963.

The metal oxides (BeO 16·0g, Al_2O_3 18·0, SiO_2 67·0, Cr_2O_3 0·5) were mixed for 8 hours, ground, sintered at 1050°C. for 5 days, and treated by the Verneuil (flame fusion) technique. Two emerald boules were grown, both with an outer coat of mullite. The emerald is blue-green in colour, colourless in thin section but showing blue-green to light green pleochroism in thicker sections; it contains gas bubble inclusions. Refractive indices (ω1·561-1·562, ε1·566-1·567) are compared with those for other synthetic emeralds. The Chatham process is reported to require a run of 6 months duration.

R.A.H.

MARTIN (H. J.). *Some observations on Southern Rhodesian emeralds and chrysoberyls.* Chamber of Mines Journ., Salisbury, Vol. 4, 34-38, 3 figs., 5 pls. No. 10, 1962.

R.A.H.

SHAH (C. J.) and LANG (A. R.). *An unusual distribution of precipitates in a diamond.* Min. Mag., Vol. 33, pp. 594-599. September, 1963.

The central region of a type I stone was found by optical and X-ray topographic examination to be densely populated by small inclusions. X-ray studies showed these to be precipitates formed after the growth of the stone: they were of two sizes, 1 μ or less and around 5 μ. Nothing can yet be said about the chemical nature of the precipitates.

R.A.H.

KANIS (J.). *Notes on Southern Rhodesian aquamarine and other gemstones.* Chamber of Mines Journ., Salisbury, Vol. 4, 39-41, 2 pls. No. 10, 1962.

R.A.H.

CROWNINGSHIELD (R.). *Developments and highlights at the Gem Trade Lab. in New York.* Gems and Gemology. 1963, XI, 1, pp. 23-27 and 2, pp. 38-44.

Investigation of emeralds set into green plastic cups, the "doublet" effect in "fish-eye" diamonds, and orthoclase cat's-eyes. Pink grossular garnet is sometimes referred to by the misnomer "pink jade". An electro-conductive diamond, a yellow-fluorescing brown diamond containing dense clouds of minute inclusions and a pale green cyclotroned-diamond are referred to. A dark greenish-brown diamond showed no absorption lines but did exhibit a bright fluorescent line at about 6300Å, which was probaby related to the strong orange fluorescence under short-wave ultraviolet light. A "bull's-eye" effect in a Mysore star-ruby and the inclusions in a star-almandine are reported. An unusual surface structure was seen on a fresh-water clam pearl and sections of nautilus shell were met with in jewellery. Petrified dinosaur bone is used for the cutting of cabochons by amateur lapidaries. Other points discussed are knots and dragmarks on a diamond, banding in synthetic emerald, a quartz cat's-eye with unusual vermiform canals, a yellow cat's-eye apatite and stained lapis-lazuli.
29 illus. R.W.

DRAPER (T.). *Diamond mining in Brazil.* Gems and Gemology. 1963, XI, 1, pp. 12-16 and 2, pp. 45-49.

A continuation of an article first published during 1951 concerned with the Grão Mogol, which is an extension of the Diamantina diamond field. The story of the Maria Nunes mine which comprises part of the original bed of the Jequitinhonha river is mentioned. Much is told of the financing by U.S.A. citizens of the various Brazilian mines, many of which proved to be disastrous ventures. A table is given of the estimated production of diamonds and gold in the area.
9 illus. R.W.

WEBSTER (R.). *Gem laboratory in Paris.* Gemmologist (Horological Journal). 1963, pp. 313-314 and 341-342.

Details the working of the Paris pearl and gem testing laboratory and some comparison is made with the work done in the London laboratory.
6 illus. P.B.

LIDDICOAT (R. T.). *Developments and Highlights at the Gem Trade Lab. in Los Angeles.* Gems and Gemology. 1963, XI, 1, pp. 17-22 and 2, pp. 50-57.

Reports a diamond with clouds of cottony inclusions, a diamond-and-emerald brooch and matching earrings in which the stone in the brooch was an emerald but those in the earrings were glass containing "feathers" of bubbles, and an "emerald" which proved to be fluorite. Tests made on topaz from San Luis de Potosi, Mexico, are detailed. "Lava" cameos were found to be fine-grained marble or limestone, but a grey-coloured one was found to be glass. Mention is made of scorodite, transparent staurolite, opalescent quartz and transparent lapis-lazuli. Fabulite sold for diamond is reported. An unusual phenacite of pale greenish-blue colour had strong dichroism with "twin colours" peacock blue and violet red, and R.I. of 1·654-1·670, a density of 3·00 and an ultra-violet light fluorescence of light blue colour. A letter from G. H. Marcher decries the use of the term *triplet* for the soudé emerald and claims that it should be correctly termed a *doublet*. A 40-carat rich yellow diamond was found to have been irradiated, and a 16-carat good colour diamond was found to have been cut in an unusual manner in that the corners of the emerald-cutting consisted of three sets of facets instead of the usual one. A discussion is given on the recutting of "old mine" stones and something is told of the inclusions seen in diamond. The Pluto effect is referred to. Other stones mentioned were fine Imperial green jadeites, lazulite, a 4·5 carat benitoite, a chrome-green sphene, a transparent rhodochrosite, a violetish-pink tremolite, a brownish-red feldspar and a yellow zoisite.

17 illus. R.W.

WEBSTER (R.). *Massive grossularite.* Gems and Gemology. 1963, XI, 2, pp. 35-37 and 61.

Fifty specimens of massive grossularite from the Transvaal, South Africa, were examined. Apart from green colours, known under the misnomer "Transvaal jade", a number of other colours were found, such as red, pink, yellow, brown and white. The refractive index was found to be near 1·72, and the density varied from 3·06 to 3·66 but was mainly in the range 3·36 to 3·57. The absorption spectrum of the green material showed a band centred at 6000Å, the greenish and greenish-yellow material a band at

4635Å. The material showed little fluorescent response under ultra-violet light, but under X-rays most of the material glowed with orange light. The material takes a good polish and makes an attractive addition to the range of ornamental materials.

P.B.

RUZIC (R. H.). *Gem mines in Thailand.* Gemmologist (Horological Journal). 1963, pp. 247-248.

Describes a visit to the Thailand (Siam) gem mines. The methods used in mining and the varieties of corundum found are discussed. There are, with gold, some 38 minerals found there and these include zircon, spinel and garnet. Some tecktites are found in the country.

R.W.

MIYAUCHI (T.). *New cultured pearl technique.* Gemmologist (Horological Journal). 1963, p. 342.

Reports the effects on the use of the antibiotic aureomycin chlortetracycline in order to obtain an improved rate of pearl production.

R.W.

MALES (P.A.). *Colour of prase and chrysoprase.* Australian Gemmologist. 1963, 26, pp. 11-12.

A comparison of chrysoprase from Mount Davies, South Australia, with prase from Coolgardie, West Australia. Prase is said to be a granular mosaic of chalcedonic quartz containing coloured impurities while chrysoprase is comparatively colourless chalcedony with aggregate and fibrous structure. Chrysoprase contains nickel and prase does not.

R.W.

O'MATE. *Hungarian opal.* Australian Gemmologist. 1963, 25, pp. 8-9.

A note on the history of the Hungarian opal deposits from ancient times until the present day. The mines are now considered to be no longer a commercial proposition.

R.W.

OSTWALD (J.). *Etruscan gemstones and jewellery.* Australian Gemmologist. 1963, 26, pp. 5-6.

A short note on the history of Etruscan jewellery and the gemstones used in it.

R.W.

ZWAAN (P.). *Edelstenen en hun dubblegangers.* Natural and artificial gems. Technisch-Wetenschappelijk Tijdschrift, 1963, 32, 7.

A survey of gem-testing methods, including identification of pearls by Laue method and transparency technique. Distinguishing between different gems and the synthesis and technical application of artificial stones are considered.

S.P.

BOOK REVIEWS

QUICK (L.). *The Book of Agates.* Sir Isaac Pitman and Sons Ltd., London, 1963. (U.S.A. edition by Chilton Co., Philadelphia). 63s.

This book deals largely with the collecting places for agate in North America, and has aimed at encouraging collectors not only to go out into the field to gather stones, but to cut, polish and arrange specimens. The history of agate and definition of its types are adequately dealt with. There are three good colour plates and most of the numerous black and white illustrations are adequate. This is not a scientific text but a useful general work which can be commended.

S.P.

DOUGHTY (O.). *Early diamond days: the opening of the diamond fields of South Africa.* London (Longmans), 1963, X+237 pp., 16 pls., 1 map. Price 25s.

A fascinating description of diamond mining in the Kimberley area from 1870 until the foundation of De Beers organization in 1888, enlivened by quotations from first hand accounts.

R.A.H.

SOME RARE BLUE GEMSTONES

By J. OSTWALD, B.Sc., F.G.A.A.

Introduction

A couple of years ago the author was asked by a gemmologist friend to identify a blue emerald-cut stone which did not seem to fit any of the descriptions in his textbooks. Knowing his friend's technical skill to be above question the author suspected the presence of some new species. However, a glance down the lists in Dana's "Textbook" (and in Herbert-Smith's "Gemstones" also) proved the mineral to be the known but rare species dumortierite. Since this time the author has studied a number of other blue minerals, not mentioned in the gemmological texts, some from museums, some cut, and some, unfortunately, only from the textbooks and scientific papers. The purpose of this study was simply to enlarge the list of possibilities. While this may make identification of some perhaps common stone longer, it might stop some rare stone being overlooked because it was "not in the book". The minerals and gemstones studied included dumortierite, lawsonite, sapphirine, grandidierite, serendibite, catapleiite.

Mineralogy of the rare blue minerals:

1. *Dumortierite* $(Al, Fe)_7 O_3(BO_3) (SiO_4)_3$

Orthorhombic. Usually massive, fibrous or radiating. Blue or pink. Transparent to translucent. Vitreous lustre. H = 7. S.G.3·26–3·36. $\alpha = 1{\cdot}675$. $\beta = 1{\cdot}685$. $\gamma = 1{\cdot}692$. (The above for blue dumortierite). Birefringence moderate, 0·017. Pleochroism strong, generally in blues.

Found in metamorphic rocks and rarely in pegmatites. Mainly from Lyons, France; Madagascar; Brazil; California; and Nevada.

The author was able to examine two cut specimens, one quite small, the other 4 carats.

2. *Lawsonite* $H_4 Ca Al_2 Si_2 O_{10}$

Orthorhombic. Euhedral crystals common, also massive. Colourless to pale blue. Transparent; vitreous lustre. H = 8. S.G. 3·08–3·09. $\alpha = 1{\cdot}665$. $\beta = 1{\cdot}669$. $\gamma = 1{\cdot}684$. Birefringence 0·019. Pleochroic, X = blue, Y colourless to pale yellow.

Occurs in amphibole schists in California; with saussurite in Italy; and in New Caledonia.

A cut specimen of about 2 carats was studied and its R.I.s were found to agree with the figures above.

3. *Sapphirine* $Mg_5\ Al_{12}\ Si_2\ O_{27}$

Monoclinic. In tabular crystals, of prismatic shape. Usually massive; pale blue. Transparent. Lustre vitreous. H = 7·5. S.G. = 3·42–3·48. $\alpha = 1{\cdot}704$–$1{\cdot}729$. $\beta = 1{\cdot}707$–$1{\cdot}733$. $\gamma = 1{\cdot}708$–$1{\cdot}734$. Birefringence weak, 0·003–0·006. Pleochroism weak.

Occurs in mica schists in Greenland, and in Western Australia.

No cut specimen was observed and the material in the rough state does not seem very promising.

S. H. Ball, the American geologist and expert on the precious stones of antiquity, states that sapphirine occurs in Roman jewellery. The determination was by E. H. Warmington (no reference given).

4. *Grandidierite* $H_2Na_2\ (Mg, Fe)_7\ (Al, Fe, B)_{22}\ Si_7O_{56}$.

Orthorhombic. Crystals anhedral, also massive. Blue to green. Transparent; lustre vitreous. H = 7·5. S.G. 2·99. $\alpha = 1{\cdot}602$. $\beta = 1{\cdot}636$. $\gamma = 1{\cdot}639$. Birefringence strong, 0·037. Pleochroism extreme with X = dark blue, Y colourless, Z dark blue.

Occurs with quartz, feldspar and garnet in pegmatites in Madagascar. A rare mineral.

Only massive material was available for study, and even this by reflected light showed extreme pleochroism.

5. *Serendibite* $(Fe, Ca, Mg)_5\ Al_5\ B\ Si_3O_{20}$

Triclinic. In plates and masses. Blue; transparent. H = 7. S.G. = 3·42. $\alpha = 1{\cdot}701$. $\beta = 1{\cdot}703$. $\gamma = 1{\cdot}706$. Birefringence 0·005. Pleochroic from pale blue to deep blue.

Occurs in a layer with diopside, green spinel, scapolite in the moonstone quarries near Kandy, Ceylon. A rare mineral. No specimen was available for study, but as the material is derived from a noted gemstone locality it is included here.

6. *Catapleiite* $H_4\ Na_2\ Zr\ Si_3\ O_{11}$

Monoclinic. In euhedral crystals, twinned, also massive. Blue to violet in the soda catapleiite, reddish to yellow in ordinary sodium-calcium catapleiite. H = 6. S.G. 2·8. $\alpha = 1{\cdot}591$. $\beta = 1{\cdot}592$. $\gamma = 1{\cdot}627$. Birefringence moderate 0·035.

Occurs in pegmatites and alkali syenites in Langesunfjoid, Norway; and in Greenland. The massive material available for study was from the former area, and was reddish-yellow and not likely to be used as a gemstone.

DISTINCTIONS

In the following table the important physical properties of the rare and common blue minerals are listed.

Mineral	*H*	*S.G.*	*R.I.*	*D.R.*	*Pleochroism*
Sapphire	9	3·99	1·76 –1·77	0·008	Strong
Benitoite	6·5	3·67	1·75 –1·80	0·047	Strong
Kyanite	4–6	3·69	1·71 –1·73	0·016	Strong
Spinel	8	3·60	1·72	—	—
Serendibite	7	3·42	1·701–1·706	0·005	Weak
Sapphirine	7·5	3·42–3·48	1·704–1·734	Variable	Weak
Dumortierite	7	3·26–3·36	1·675–1·692	0·017	Strong
Lawsonite	8	3·08–3·09	1·665–1·684	0·019	Moderate
Tourmaline	7	3·10	1·62 –1·64	0·020	Strong
Catapleiite	6	2·8	1·591–1·627	0·035	
Cordierite	7	2·59	1·53 –1·54	0·009	Strong

With the use of a modern refractometer there should be little difficulty in determining the above minerals.

REFERENCES

Iddings, J. P. (1911). *Rock Minerals.* John Wiley & Sons.
Dana, E. S. (1903). *The System of Mineralogy.* John Wiley & Sons.

ASSOCIATION NOTICES

PRESENTATION OF AWARDS

An exceptionally large number of members and friends attended the annual presentation of awards held at Goldsmiths' Hall, London, on 28th October, 1963. Mr. F. H. Knowles-Brown, the Chairman of the Association, presided and in his welcoming remarks thanked the Worshipful Company of Goldsmiths for once again allowing the Association to use its hall. The chairman commented that 1963 marked the 50th anniversary of the first examination and that the Association had achieved much since the first small examination in 1913. He specially welcomed those present who had taken the examinations some thirty or forty years ago.

This year the number of entries for the examinations was only one less than last year's record, though there had been more failures, due largely to the enthusiasm of candidates exceeding their ability. Mr. Knowles-Brown commented that failure in an examination could be due to various factors and he hoped that those who had not been successful would be encouraged to sit again. Acquisition of knowledge was the most important thing.

The Chairman paid tribute to the examiners, who had maintained a high standard over the years, and to the instructors for all their patience throughout the year. He also thanked the staff for a monumental piece of work in arranging the examinations at centres throughout the world.

Mr. Knowles-Brown referred to the first gem diamond examinations that had been conducted by the Association. He specially thanked the Vice-Chairman of the Association, Mr. Norman Harper, who had devised the course with the enthusiastic co-operation of the Headmaster of the Jewellery and Silversmithing School in Birmingham. The Chairman also thanked the U.K. Diamond Publicity Committee, for making it possible to obtain cut and uncut diamonds for teaching purposes, and Professor S. Tolansky, F.R.S., of Royal Holloway College, London, Mr. Cyril Ginder, M.A. and the Hon. Iain Balfour, M.A., who had assisted in assessing the papers. They had set a similar high standard as that required in the diploma examination.

Mr. Knowles-Brown then welcomed Mr. Lionel Burke, of De Beers, who had kindly come along to present the awards. De Beers had always taken a kindly interest in the Association's work.

Mr. Burke, responding after the presentation had taken place, referred to the prestige and influence of the Association and said that in his constant visits to other countries he had always heard admiration expressed for the Association. It was a pioneer in gemmological work and he said that his colleagues at De Beers would wish him to congratulate the Association on having had its first examination fifty years ago. De Beers were particularly gratified that there was an examination for the Association's Gem Diamond Certificate and he added his thanks to Mr. Norman Harper. He knew that the contact which De Beers had with the jewellery trade was most valuable and the company appreciated all that the Association was doing and had done to encourage interest in gemstones.

The Vice Chairman offered the thanks of the meeting to Mr. Burke.

MIDLAND BRANCH

The "classification and grading of diamond crystals" was the subject of a talk given to the Midlands Branch of the Association on October 30, by Mr. Norman Harper, vice-chairman of the Gemmological Association and of the branch. The talk was a condensation of a lecture on the subject which forms part of Mr. Harper's Diamond Course lectures at the School of Jewellery and Silversmithing in Birmingham. It was illustrated by the diamond crystals which were provided by the U.K. Diamond Publicity Committee for the diamond course. This particular subject was chosen by Mr. Harper because he felt that while many people in the trade were clear about the grading of cut diamonds, few really understood De Beers methods for grading crystals.

COUNCIL MEETING

A meeting of the Council of the Association was held at Saint Dunstan's House, Carey Lane, London, E.C.2, on 28th October, 1963. Mr. F. H. Knowles-Brown presided.

The following were elected:

Elected to Fellowship

Wad, M. B., Edgware, Middx.
Abbott, Henry C., Liverpool, Lancs.
Allaby, Frank E., Warrington, Lancs.
Allden, Arthur G., London, S.W.14.
Berry, William, Kirkcaldy, Fifeshire
Bilby, David, London, S.W.4.
Campin, Andrew J., Mansfield, Notts.
Dahlsveen, Jon, Trondheim, Norway
Feltell, Raymond, Birmingham
Fernandez, Cyril W. A., Bombay, India
Franklin, Jerry N., Washington, U.S.A.
Fryer, Charles W., San Diego, U.S.A.
George, Stanley W., London, S.E.9.
Giblin, Michael, Bury, Lancs.
Holländer, Helmut, Pforzheim, Germany
Hopkins, Peter J., Derby.
Horrox, Conrad, Manchester, Lancs.
Irwin, Eric, Liverpool, Lancs.
Kari, Raija Helena, Lahti, Finland
Kiuas, Eljas-Jussi, Pukinmäki, Finland
Krzempek, Evelyn, Nottingham
Lahtinen, Ake J., Helsinki, Finland

Mäki, Juho K., Riihimäti, Finland
Meddings, Ann E., Burton-on-Trent, Staffs.
Nairis, Honno J., Stockholm, Sweden
Nimalasuriya, Nanda, Colombo, Ceylon
Pudner, Robert A., Liverpool, Lancs.
Pyke, John S., Higher Bebington, Cheshire
Reekie, Robert, Stratford upon Avon
Rintala, Berit, Riihimäki, Finland
Snell, Richard G. F., Bournemouth, Hants.
Spacey, Peter W., Sutton Coldfield, Warks.
Storgmeir, Inkeri, Huopalahti, Helsinki, Finland
Straiton, Timothy, Hove, Sussex
De Szejko, Anna-Liisa, Hämeenkylä, Finland
De Szejko, Wiktor I., Hämeenkylä, Finland
Tarratt, Christopher D., Leicester
Taylor, John L., Blackpool, Lancs.
Teissala, Hannu H., Helsinki, Finland
Thurlby, Paul A., Birmingham
Virtanen, Pentti E., Helsinki, Finland
West, Peter J., London, E.7.
Wight, Peter, Wallasey, Cheshire
Paananen, Erkki, Helsinki, Finland

Elected to Ordinary Membership

Anderson, William J., London, S.W.1.
Antonucci, Francesco, Rome, Italy
Boggs, Charles A., Valley Stream, N.Y., U.S.A.
Bowcock, Leslie, Newcastle, Staffs.
Bradburn, Gwendoline, Bondi, N.S.W., Australia
Buckingham, Anthony C., Upper Hartfield, Sussex
Cain, Winifred, London, S.W.5.
Drew, Frank H., Wanganui, New Zealand
Dugas, Joseph V., Rhode Island, U.S.A.
Fishberg, Michael S., London, N.3.
Fullerton, Kenneth J., Bridgend, Glam.
Harley-Mason, Robert J., Nairobi, Kenya
Harpin, Joyce A., Seekonk, U.S.A.
Harris, Victor, London, N.16.
Hoffman, Lanrence E., San Francisco, U.S.A.
Hooker, Grady A., Cheshunt, Herts.
Howie, Robert A., London, W.C.2.
De Krassnokutski, Leo K., Johannesburg, S. Africa
McBain, Sherman W., Valley Center, California, U.S.A.
Mangold, Thomas, Geneva, Switzerland
Marshall, Sheila, Ibadan, Nigeria
Martin, John F., Kansas, U.S.A.
Moore, Henry, Solihull, Warks.
Moyse, Claude A., Hanau (Main), Germany
Myers, Julia H., Double Bay, N.S.W., Australia
Myers, Leah M., Double Bay, N.S.W., Australia
Oesterlin, Winhelmina P., Mosman, N.S.W., Australia
Padley, Alastair C., Tunbridge Wells, Kent
Pfau, Robert G., Pala, Calif., U.S.A.
Ridgeway, Robert F., Greenville, U.S.A.
Rius, Carlos E. R., Barcelona, Spain
Rowbury, William G., San Francisco, U.S.A.
Rush, Hazel S., Cincinnati, U.S.A.
Schiffmann, Charles A., Geneva, Switzerland
Williams, Wanda F., Wanganui, New Zealand

Elected to Probationary Membership

Anderson, Brian M., Orpington, Kent
Bergseth, Idar, Burnaby, Canada
Bloom, Harry, Johannesburg, S. Africa
Carr, Philip, Blackburn, Lancs.
Chernencoff, Wade, Coquitlam, Canada
Clough, Michael B., Bolton, Lancs.
Cook, Murray E., Vancouver, Canada
Drew, William H., Wellington, New Zealand
Fruitman, R. Lawrence, Toronto, Canada
Gatward, Anna B., Hitchin, Herts.
Goudriaan, P. A., Kampen, Holland
Hanley, Clive E. M., Rugby, Warks.
Hudson, John D., Woodford Green, Essex.
Jochems, Cornelie, The Haag, Holland
Kamil, Mohamed S. M., Weligama, Ceylon
Legg, Susan, Finchampstead, Berks.
Lewis, Elliott A., Salford, Lancs.
Riel, Christa, Heim St. Ludwig, Austria
Smith, Stephen S., Doncaster.

Transferred from Ordinary and Probationary Membership to Fellowship

Axon, Gordon V., New York, U.S.A.
Blatter, Robert, Toronto, Canada
Coop, Norah M. N., London
Dambrink, Darel W. J., Apeldoorn, Holland
Fernando, Kurukula S. L. T., Colombo, Ceylon
Forbes, David R., Melbourne, Australia
Fraley, Lawrence, Wheelersburg, U.S.A.
Gaydon, Julie H., Surbiton, Surrey
Ghisalberti, Danilo Lucerne, Switzerland
Herring, John T., Radcliffe-on-Trent
Houston, David F., El Cerrito, U.S.A.
Hudson, Felix N., Dunfermline
Jensen, Bjarne A., Bergen, Norway
Kaufmann, E. Pius, Montreal, Canada
Loupekine, Igor S., Nairobi, Kenya
Mackenzie, Iain F., Warrington
Mulien, Joseph, Glasgow
Porter, Robert G., Brisbane, Australia
Primavesi, Thomas, Montreal, Canada
Quartermaine, Helen L., Kuala Lumpur, Malaya
Scholl, Werner, Zollikerberg, Switzerland
Schwartz, Raymond N., London
Smith, Benhamin H., Wilmington, U.S.A.
Städelin, Alwin, Lucerne, Switzerland
Stanley, Edward, Manchester
Thomson, Patrick N., Cape, South Africa
Watts, James W., Grimsby
Wood, Mary B. H., Sidmouth, Devon

The Council gave consideration to problems consequential upon the considerable number of entries that had been received during recent years, particularly concerning accommodation and the preliminary examination.

MEMBERS' MEETINGS

The following meetings have been arranged:—

1964

30th Jan.	West of Scotland Branch. Talk on pearls by Mr. James Gillougley, F.G.A.
31st Jan.	Conversazione. Goldsmiths' Hall, London, 6.30–8 p.m. Exhibits.
5th Mar.	Photographic evening. Goldsmiths' Hall, London, 7 p.m. Members are invited to submit for selection not more than six 2″ × 2″ slides illustrating jewellery or any aspect of gemmology. Slides should be submitted, with full details, by 21st February.
26th Mar.	West of Scotland Branch meeting. Mr. L. G. Burke, of De Beers Consolidated Mines, Ltd., on "The sorting classification and marketing of rough diamonds".
9th April	Herbert Smith Memorial Lecture. Royal Institution, London, The President of the Association, Sir Lawrence Bragg, F.R.S. will reminisce about early problems with minerals.
17th April	Midland Branch annual meeting.
30th April	Annual meeting of West of Scotland Branch in Glasgow, followed by an illustrated talk on the " Regalia of England and Scotland ", by Mr. W. C. F. Butler, F.G.A.

TALKS BY MEMBERS

BLYTHE, G. A., "Gemstones", Southend-on-Sea Young Conservative Organization, 1st October, 1963. St. Clement's Young Wives' Group, St. Clement's Hall, Leigh-on-Sea, 19th November; Belfairs Branch, Young Conservatives, Leigh-on-Sea, 25th November, 1963.

HUDSON, F. N., "Gemstones", Inner Wheel, Dunfermline, 14th November, 1963.

OBITUARY

Mr. F. H. Neale, F.G.A., (aged 70) director of Conroy Couch Ltd., Torquay, and of the R. W. Yeo (Associated Companies) Ltd. He gained his diploma, with distinction, in 1933 and was awarded the Tully Memorial Medal, the fourth time that it had been awarded.

WEST OF SCOTLAND BRANCH

A meeting of the Branch was held at the Royal Hotel, Glasgow, on 26th September, 1963, when a film show was held.

GIFTS TO THE ASSOCIATION

From Mrs. Rhoda Blyth, F.G.A., British Columbia, a crystal of star-sapphire from Montana, U.S.A.

LETTER TO THE EDITOR

Synthetic Emeralds

DEAR SIR,

It is still an unanswered question why the values of synthetic emerald from different producers differ so markedly. For instance:

Synthetic emerald made by	$n\omega$	$n\varepsilon$	$n\varepsilon-n\omega$	*S.G.*
Chatham	1·564	1·561	0·003	approx. 2·65
Lechleitner	1·576	1·570	0·006	approx. 2·7
Zerfass, quoted by Schlossmacher[1]	1·561	1·555	0·006	2·66

Of course, the methods used are different. While Chatham and Zerfass synthesize within a melt, the synthesis of Lechleitner is the result of a hydrothermal process. But, this does not explain the differences in full, as the stones of Chatham and Zerfass still differ a certain amount, particularly with the birefringence values of 0·003 and 0·006 respectively.

With regard to this situation, it seems to be worthwhile to refer to an article of W. T. Schaller and collaborators[2]. It describes an unusual beryl from Arizona, U.S.A., unusual in respect of the extremely high values of this particular beryl. In the paper, an average chemical analysis is given which reveals the presence of a large number of extraneous ions within the beryl's lattice. And these additional ions—or chemical impurities—are the cause of the unusual properties of the beryl in question, according to the authors.

A general view is given of the variation in the properties of beryl, depending on the amount of foreign material, as follows:

Beryls	*Percentage of constituents other than* SiO_2, BeO, Al_2O_3, *excluding* H_2O	$n\omega$	$n\varepsilon$	$n\varepsilon-n\omega$	*S.G.*
Colourless synthetic ...	0	1·560	1·557	0·003	2·635
Synthetic emerald ...	3	1·567	1·563	0·004	2·67
Common	1–5	1·570 to 1·590	1·564 to 1·584	0·006 ±	2·67 to 2·76
High cesium	7–10	1·599	1·590	0·009	2·86 ±
Arizona	15	1·608	1·599	0·009	2·92

Even if the origin of the synthetic emerald in the table is not mentioned and the given values are not in full accordance with those mostly quoted for Chatham's synthetic emerald, a constant increase of the values with an increasing percentage of the "impurities" is evident.

Besides other considerations, this may give a hint of the reason for the varying values of synthetic emeralds: the lower the amount of chemical impurities, the lower also the values, and the more such impurities are present, the higher are the values. In evaluating such a conception, the synthetic emerald of Zerfass should be the "purest".

1. K. Schlossmacher: Eine neue Smaragdsynthese, Zeitschrift der Deutschen Gesellschaft für Edelsteinkunde, Heft 43, Frühjahr 1963, 27–29.
2. W. T. Schaller, R. E. Stevens and R. H. Jahns: An unusual beryl from Arizona, American Mineralogist, 47 1962, 672–699.

Yours sincerely,

W. F. EPPLER.

SYNTHETIC EMERALDS

ROUGH OR CUT

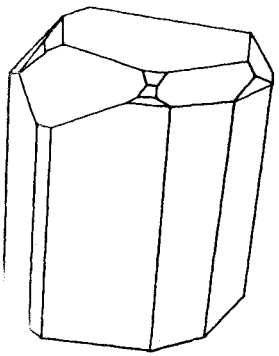

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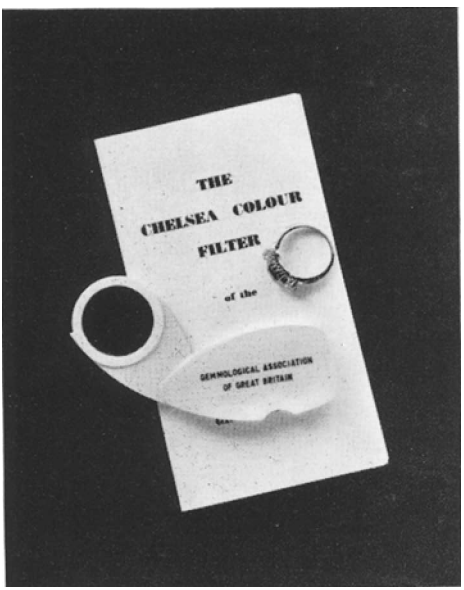

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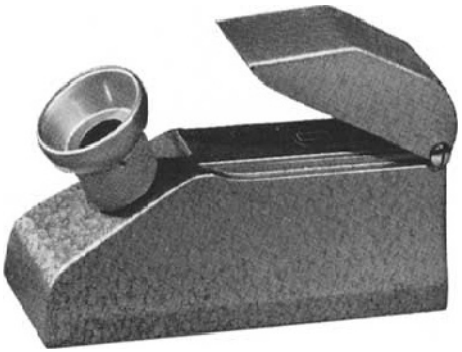

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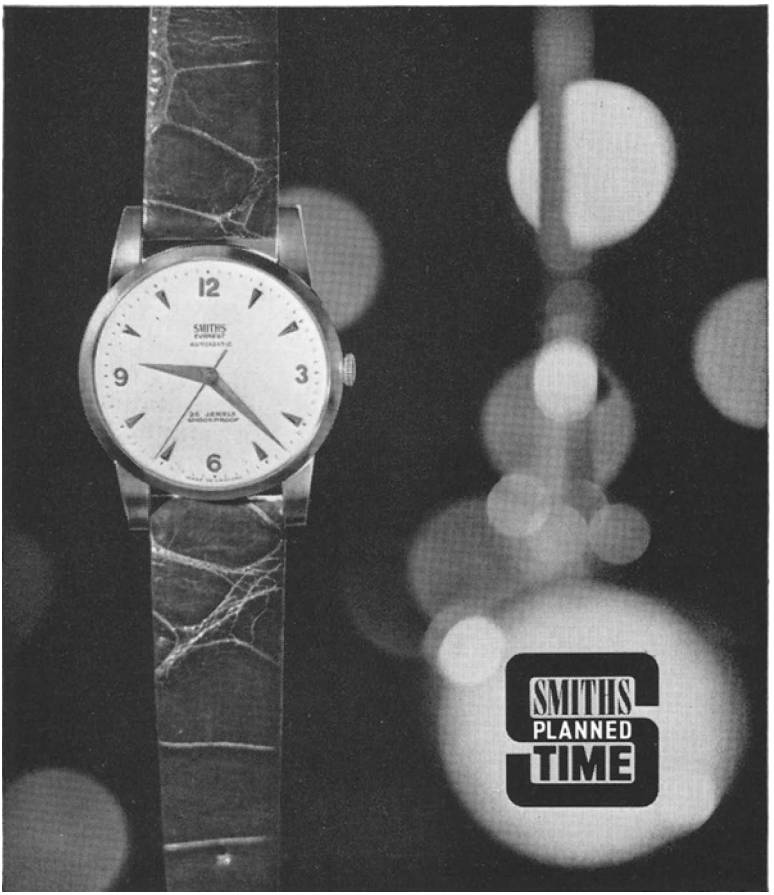

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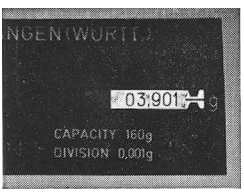

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Vol. IX No. 6 April, 1964

THE JOURNAL OF GEMMOLOGY

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THE FRENCH SYNTHETIC EMERALD

By ROBERT WEBSTER, F.G.A.

THE synthesis of emerald has been known since 1848 when J. J. Ebelmen made the early experiments. These and the later experiments by other workers have been well recorded in the literature. However, it is the commercial synthesis made by Carroll F. Chatham of San Francisco which has been of most importance and the characters of these stones have been continuously under review.

If the Lechleitner emerald—the synthetic emerald-coated beryl—be excluded, the Chatham synthetic emerald was until recently the only synthetic emerald sold on the gem market. 1963 produced two new synthetic emeralds. One of these is a German production and the other French. The German stones are produced by W. Zerfass, of Idar-Oberstein, and the characters of these stones have been fully reported by K. Schlossmacher[1]. The French synthesis is the product of Etablissement Pierre Gilson, Compagne les Wardriques, Pas de Calais, and by the courtesy of that firm two specimens of these synthetic emeralds have been made available for examination and form the basis of these notes.

The methods used by Chatham and Zerfass, in their respective syntheses of synthetic emerald, are not known for sure. W. Eppler, after careful examination of the inclusions, has suggested that the Chatham synthesis is a flux-melt process. Pierre Gilson, however,

Euhedral crystals, probably phenakites, in a French synthetic emerald.

implies in his sales literature that a hydrothermal method is used for growing the French synthetic crystals.

The colour of the two stones of this French synthesis examined is a good emerald-green; perhaps more yellow than the bluer-green of the Chatham production. To the writer the Gilson stones seem to have the more pleasing colour. The cut stones examined weighed 3·38 carats and 2·81 carats and were fashioned in the usual octagonal trap-cut style, *i.e.* the emerald-cut. The maker, in his trade handout, states that the stones may be up to twenty carats in weight, but whether this applies to cut stones or crystals is not clear.

The density of the stones was found to be 2·65 and to vary from this value only in the third place of decimals. The refractive indices were determined to be $\omega = 1{\cdot}562 : \varepsilon = 1{\cdot}559$, giving a birefringence of 0·003, and the dichroism was seen to be distinct with twin colours yellow-green and blue-green. As it is the extraordinary ray which has the deeper blue-green colour, and in the case of the two stones examined the table facet was found to be cut nearly at right angles

to the optic axis, this may explain the yellower-green colour of the samples seen. The absorption spectrum, typical of emerald, was found to be strong.

The stones examined through the Chelsea colour-filter showed the residual colour to be a dull red, and when viewed between crossed filters (a flask of copper sulphate solution and a spectrum-red gelatine filter) the stones showed a red fluorescence. Under the Burton (fluorescent tube) long-wave ultra-violet lamp the stones glowed with a mustard-yellow colour, and under the Hanovia mercury-vapour lamp with Wood's glass filter, a lamp which gives an optimum emission at 3650Å, the fluorescent glow shown by the stones was more a greenish-yellow. When irradiated with short-wave ultra-violet light from a Mineralight lamp the glow produced by the stones was orange in colour, and the shorter wavelengths produced by X-rays induced a very dull red glow in the stones. These fluorescent characters differ from those seen in the Chatham synthetic emeralds, which show a strong red under all radiations.

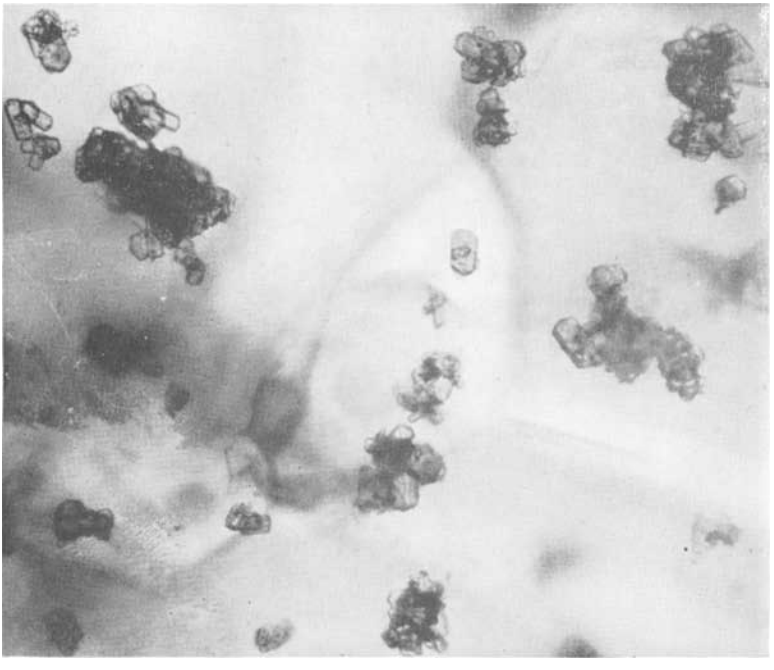

Clusters of crystals, probably phenakites, in a French synthetic emerald.

It was noticed that perceptible phosphorescence could be observed in the case of the Gilson synthetic emeralds after they had been irradiated with X-rays. This effect was also found to occur when the Chatham synthetic emeralds were so irradiated, but this effect does not seem to have been previously reported.

Some photographic experiments on the ultra-violet transmission of these French synthetic emeralds seem to show that they do not transmit as far down into the ultra-violet as do the Chatham synthetic emeralds[2]. The degree of transmission is probably more akin to that shown by natural emeralds. This lack of transparency was later confirmed by B. W. Anderson who took a spectrum plate with the aid of a quartz spectrograph.

The inclusions observed in the specimens of synthetic emerald of French manufacture showed that they have many similarities to the inclusions seen in other makes of synthetic emeralds in that

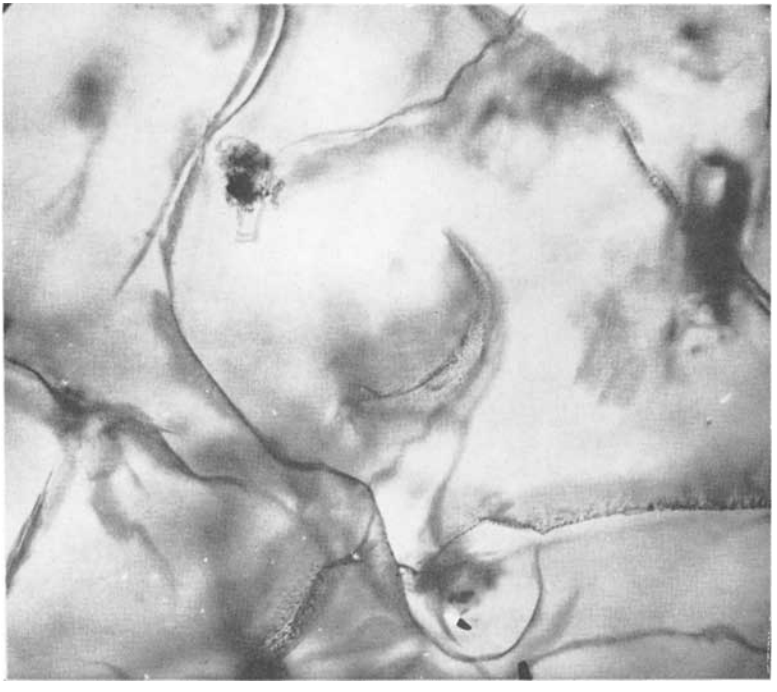

Veil-like feathers in a French synthetic emerald.

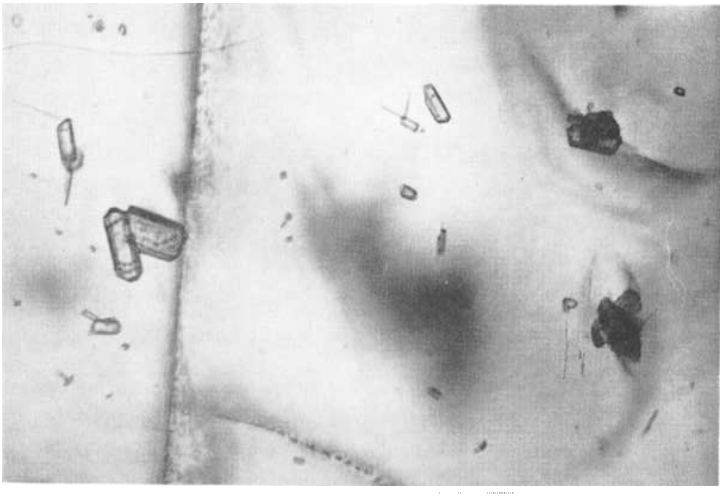

Inclusions in a French synthetic emerald.

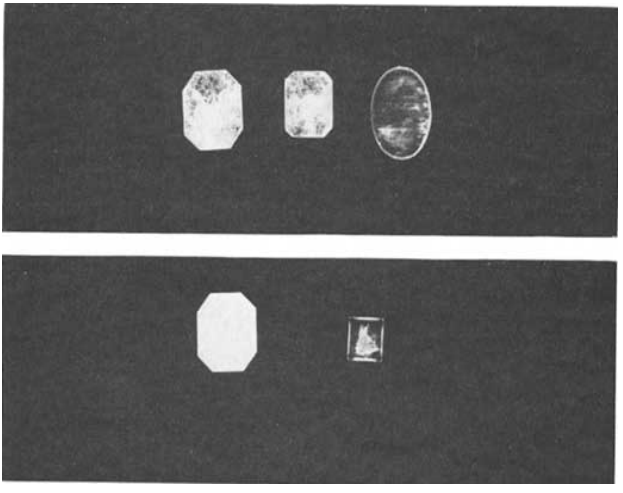

Ultra-violet transmission pictures of the new French synthetic emerald and others.

Top left: *The French synthetic emerald.*
centre: *A natural emerald.*
right: *A Chatham synthetic emerald.*
The American synthetic emerald is rather flat and does not have the depth of the other two stones.
Bottom left: *The French synthetic emerald.*
right: *An American (Chatham) synthetic emerald.*
The American stone, although appearing much smaller than the French stone has nearly a comparable depth.

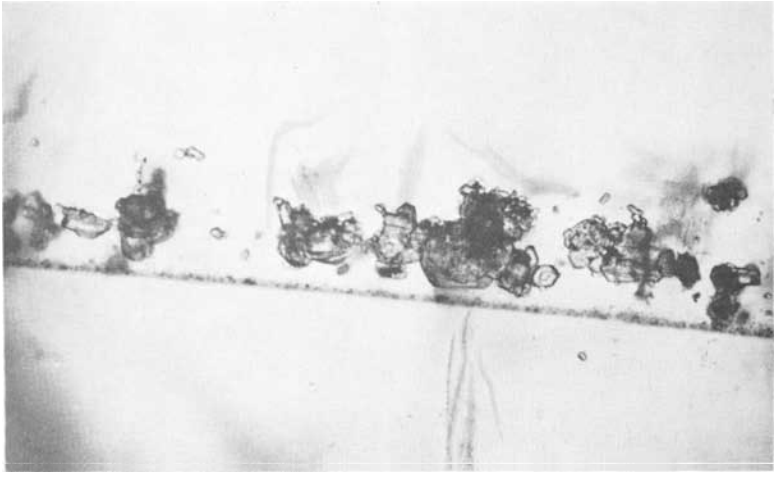

Line of crystals along a crystallographic plane in a French synthetic emerald.

they contain veil-like feathers of two-phase inclusions. These feathers seem to be much more open and wider apart than those seen in the Chatham synthetic emerald. Another feature of the French stones examined was the number of euhedral crystals and groups of such crystals which were profusely scattered throughout the stones. These crystals have the habit of, and probably are, phenakite. Lines of such crystals along definite crystal planes seem to be to some extent peculiar to the French stones. Between crossed polars the stones showed coloured strain-patterns and they did not clearly extinguish at every ninety degrees.

To sum up, these samples of the French production show that, except for the anomalies of the fluorescence under ultra-violet light and the lack of ultra-violet transmission, the stones conform to the usual tests for synthetic emerald of other makes and no difficulty should be encountered in testing them.

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2. Anderson, B. W. *A new test for synthetic emerald.* Gemmologist, 1953, 264, pp. 115-117.

TREATED BLACK OPALS

By E. GÜBELIN, Ph.D., C.G., F.G.A.

SEVERAL parcels of dyed black opals have recently been offered in the European market. I am indebted to Mr. Arthur A. Wirth of Sydney, Australia, who kindly enabled me to acquire a number of treated black opals of varying quality for investigation.

To the uninformed jeweller and to the naked eye, these treated opals display a normal appearance and do not look suspicious in the least. It seems, therefore, appropriate to publish a word of warning and to inform the readers of the distinguishing features of this new product. The most reliable means of distinction is rendered by the microscope. While in white and black opals of natural colour the gelatinous body material appears rather homogeneous, the treated samples teem with granular black dots resembling black dust, which are formed by the dried residue of the artificial colouring agent. This dust is very easy to perceive even under weak magnification, and its appearance is so characteristic that distinction from undyed opals becomes quite simple. (Fig. 1).

The dye does not seem to penetrate deeply into the stone, but on the contrary is rather concentrated in the cutaneous layer, which becomes apparent in rather translucent specimens at a depth of about 2 mm, where the clean white substance of the previously white opal shines through. This confinement of the colour concentration to a thin portion at the surface may lead to a complete loss of the coloration if the artificially coloured opal is repolished. The texture of the surface, as well as the distribution of the black dots, leads to the conviction that a rather porous material with many cracks is being subjected to dyeing. In some parts of the stone the " black dust " is densely accumulated, while in other less porous areas it is much less evident, producing a cloudy look (Fig. 2). The grey and cloudy white patches thus form the sparse dissemination in which the colouring residue is especially conspicuous. In some opals of inferior quality there exist along certain cracks, veins and patches of a dense white matter (possibly agate) which remain clean and free from the dyeing agent, it being impossible for the dye to penetrate these dense areas.

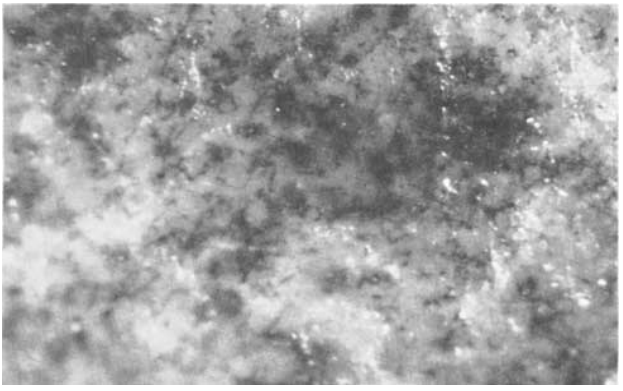

FIG. 1

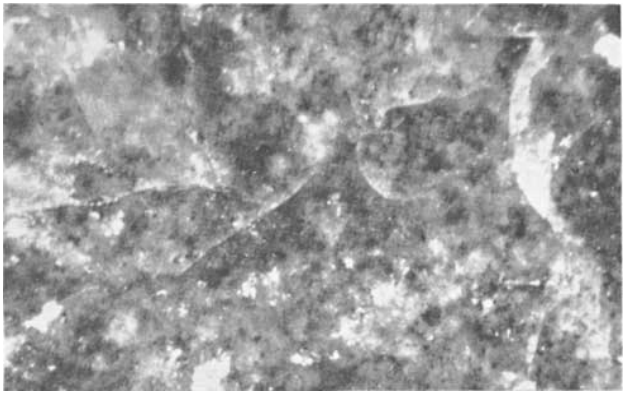

FIG. 2

The accompanying photomicrographs illustrate more adequately the appearance of these new treated opals than words can do.

The black coloration proved to be resistent against the action of any ordinary reagents such as acetone, hydrochloric, nitrous, sulphuric acid and aqua regia, as well as some organic liquids as benzene, carbontetrachloride and ethylenedibromide. The Gem Trade Laboratory in New York reported*, however, that the black substance was quickly removed by warm sulphuric acid. The possibility of removing the coloration either by chemical reaction or by recutting makes it imperative to mark these treated opals with the unmistakable designation: artificially treated opal.

*R. Crowningshield, *Black Treated Opal,* Gems and Gemology, Autumn 1962, p. 336.

SAPPHIRE FROM RIO COXIM, MATO GROSSO, BRAZIL

By W. F. EPPLER

ABOUT four years ago, Professor J. E. de Souza Campos of the University of Sao Paulo, Brazil, reported on a new sapphire from Brazil[1]. He mentioned strange inclusions, unknown until now in sapphire and resembling rounded gas bubbles so typical of synthetic corundum. At the author's request, Professor de Souza Campos very kindly made available two cut stones of this sapphire and later some raw material, which could be tested more easily.

The locality of these sapphires is quoted by de Souza Campos as Jauré and Quilombo, Rio Coxim, Mato Grosso. He found the refraction for sodium light to be $n\omega = 1{\cdot}770$, $n\varepsilon = 1{\cdot}762$, and the birefringence 0·008. The dichroism for blue-coloured stones is ω = blue to violet blue, ε = green; for greenish-coloured stones ω = green, ε = yellow-green. With the hydrostatic balance he determined the specific gravity at 3·952 to 4·052.

The stones exhibit a dark blue colour but, regrettably, the transparency is considerably reduced by many inclusions. At a first sight through the microscope, many of them indeed resembled rounded gas bubbles (Fig. 1). But when using a higher magnification, it is seen that two kinds of inclusions are present: liquid and gas-filled discs (Figs. 2 and 3) and negative crystals (Figs. 4 and 5), many of them exhibiting rounded forms.

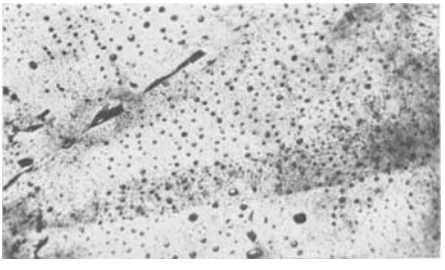

FIG. 1. *Sapphire from Rio Coxim, Mato Grosso, Brazil. Liquid discs and negative crystals in a healed fissure.* 22 ×

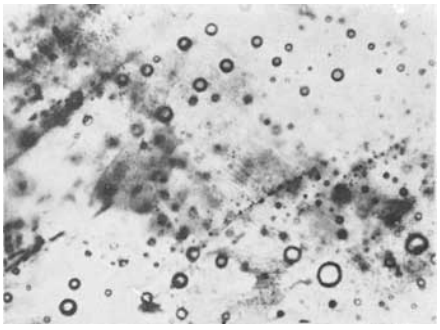

FIG. 2. *Sapphire from Brazil. Discs filled with a liquid or with a gas.* 65 ×

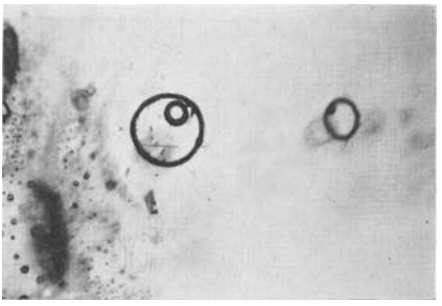

FIG. 3. *Sapphire from Brazil. Disc-like liquid inclusion with a libella.* 120 ×

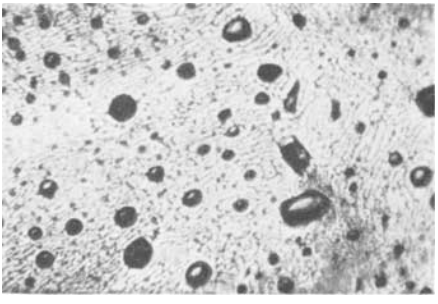

FIG. 4. *Sapphire from Brazil. Rounded gas inclusions and negative crystals in a healed crack.* 65 ×

FIG. 5. *Sapphire from Brazil. A negative crystal containing needle-like crystals (most probably rutile) and a liquid with two libellae.* 120 ×

In reflected light, the discs appear in bright interference colours, which differ according to their thickness. This is one proof of the discs being flat liquid inclusions. When observing in transmitted light, another proof is given by the thin rim of the discs (Fig. 2), which demonstrates that they are flat and filled with a liquid. Therefore, they cannot be confused with ball-shaped inclusions. The final proof for the nature of these particular inclusions is shown in Fig. 3. It reveals that the disc-like inclusions by the presence of a libella are filled with a liquid.

To complete the observations, the effect of transmitted light was calculated when passing the included discs and compared with the results when the light had to pass included balls. In both cases, it was presumed that the inclusions were filled either with a liquid or with a gas.

For the calculation, which in principle followed the statements of E. Klüppelberg[2], the refractive index for sapphire was taken at 1·767, for the liquid at 1·33, and for the gas at 1·00. The results are given in diagrams. Fig. 6a represents the path of light through an included liquid-filled disc seen from the side, while Fig. 6b gives the view from above, as seen through the microscope in transmitted light. The liquid-filled disc deflects on its border the incoming light less than the gas-filled disc. Therefore it shows only a small rim when observed from above, whereas the gas-filled disc exhibits a much broader rim (Figs. 7a and b).

Similar differences are found with a ball-shaped inclusion in sapphire filled with a liquid and compared with another ball filled with a gas. Figs. 8 and 9 demonstrate this phenomenon and they make it obvious that the rounded inclusions in Figs. 2 and 3 are not

FIG. 6. *Path of light through a liquid-filled disc, included in sapphire,*

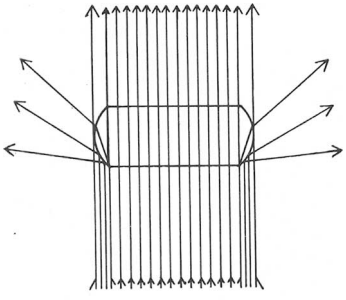

(a) seen from the side,

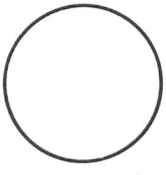

(b) seen from above.

FIG. 7. *Path of light through a gas-filled disc, included in sapphire,*

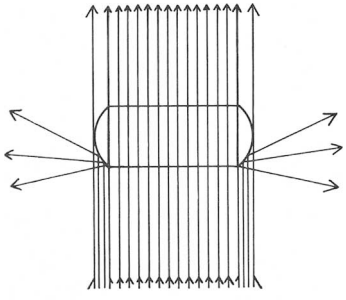

(a) seen from the side,

(b) seen from above.

FIG. 8. *Path of light through a ball-shaped inclusion, filled with a liquid, in sapphire,*

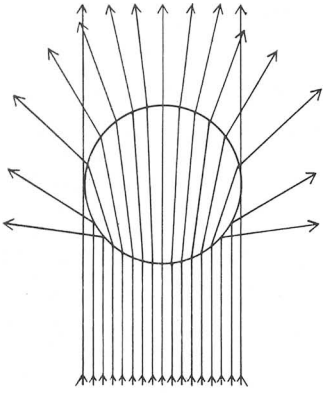

(*a*) *seen from the side,*

(*b*) *seen from above.*

FIG. 9. *Path of light through a ball-shaped inclusion, filled with a gas, in sapphire,*

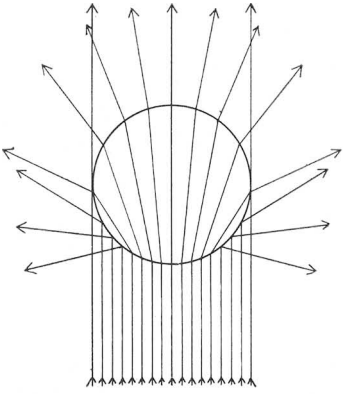

(*a*) *seen from the side,*

(*b*) *seen from above.*

ball-shaped. Of course, in Fig. 2 the broader rimmed inclusions are discs filled with a gas.

With the negative crystals, as the other kind of inclusion, it is not possible to decide in all cases whether they are filled with a liquid or with a gas. The larger inclusions in Fig. 4, which appear totally black, and those which have only a very small bright spot, are certainly not filled with a liquid, while the others with a large bright spot near the centre contain a liquid. But, as most of these inclusions deviate from the shape of a ball and are flattened also, a decision about their contents is not always certain. There are many negative crystals which are filled with a liquid, as shown in Fig. 5.

Another feature of the new sapphire consists of small healed cracks underlying a negative crystal, as seen from the side in Fig. 10. In this particular case, a twin lamella nearly coincides with the healed fissure (Fig. 11). A view from above is given in Fig. 12.

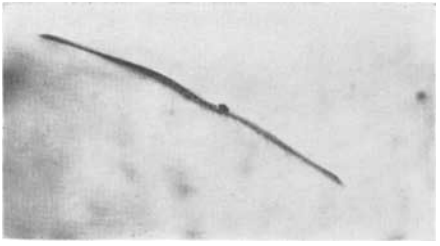

FIG. 10. *Sapphire from Brazil. A healed crack underlying a negative crystal, side view.* 65 ×

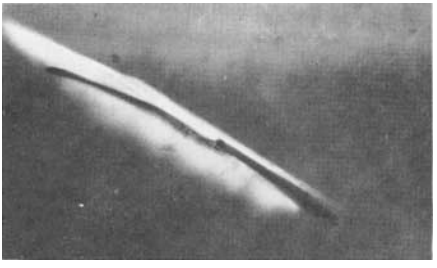

FIG. 11. *Same as Fig. 10, crossed polarizers.* 65 ×

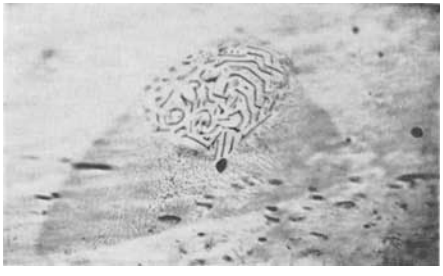

FIG. 12. *Same as Fig. 10, seen from above.* 65 ×

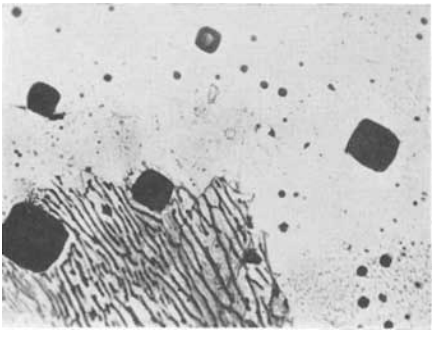

FIG. 13. *Sapphire from Brazil. Opaque, brown, cubic crystal inclusions of unknown nature.* 120 ×

It reveals the former crack and the now healed fissure to consist of a network of coarser and finer channels which contain a liquid. In reflected light and when properly adjusted in the correct position for a reflection, this system of inclusions appears in beautiful colours of interference indicating that the channels are flattened and very thin. Other healed cracks of approximately the same size have more rounded or oval shapes, but they always underlie one negative crystal, so that a relationship between them seems to be very likely.

Finally, small crystal inclusions must be mentioned (Fig. 13). They are opaque, brown and exhibit cubic crystal faces; they could be an ore, but their nature is not yet known.

In conclusion, it must be emphasized that the new Brazilian sapphire is a surprise with regard to its unusual inclusions. These reveal new aspects in the genesis of both the host crystal and its inclusions, particularly the negative crystals. It is to be hoped that further investigations will yield other results.

The author is indebted to Professor de Souza Campos, São Paulo, Brazil, for the very interesting material.

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1. de Souza Campos, J. F. *Safiras do Rio Coxim, Mato Grosso,* Gemologia No. 21, Ano VI (1960) 1-8, and: *Nota Adicional sôbre as Safiras do Rio Coxim, Mato Grosso,* Gemologia No. 24, Ano VI (1961), 61-62.
2. Klüppelberg, E. *Beobachtungen an Gaseinschlüssen in Glas und synthetischen Steinen,* Deutsche Goldschmiede-Zeitung 10, 1956.

Gemmological Abstracts

HOLLAENDER (H.). *Cordierit, ein Edelstein mit Zukunft.* Cordierite, a gem with a future. Deutsch. Goldschmiedezeitung, 1963, 61, p. 661. Zeitsch. d. deutsch. Gesellsch. f. Edelsteinkunde, 1963, 43, pp. 25-26.

During the last few years cordierite has changed from being a rarity to a fairly popular gem. It is found in Ceylon, Burma, Madagascar, Madras, N.W. Canada, Norway, Finland and in Bavaria. Its hardness is 7-7½, and it is called after the French geologist P. L. A. Cordier, although the name iolite is also used. Under U.V. lamp it shows no luminescence. D = 2·57-2·63, n = 1·535-1·545. The one good visible line in the spectrum is 4560 Å.

E.S.

EPPLER (W. F.). *Was ist " Bernat "?* What is " bernate "? Deutsch. Goldschmiedezeitung 1963, 61, pp. 662-663.

Bernate is a plastic, not very easily distinguished from amber. This imitation can also be charged electrically by rubbing it, and will then pick up bits of paper just as amber does. It is sold with natural inclusions, i.e. parts of plants and insects, which of course are recent. If real amber is touched with a very hot pin-point an aromatic smell is produced. When bernate is treated thus, the smell produced is disagreeable and somewhat " chemical ". A safer method of differentiating is the specific gravity, which is 1·08 for amber, but 1·22-1·23 for bernate. The R.I. (1·54 for amber, 1·54 for bernate) does not help in distinguishing the products.
4 illus.

E.S.

BANK (H.). *Zoisitamphibolit mit Rubin aus Tanganjika (Ostafrika).* Zoisite amphibolite with ruby from Tanganyika. Zeitschr. d. deutsch. Gesellsch. f. Edelsteinkunde, 1963, 44, pp. 4-11.

A map shows the occurrence of the stone. It is shown to consist of hornblende, feldspar, zoisite, mica, rutile and corundum. 4 illus. bibliography.

E.S.

WILD (K. B.). *Das Steinschneide—bezw. Edelsteingraveurgewerbe in Idar-Oberstein.* The stone cutting and engraving craft in Idar-Oberstein. Zeitschr. d. deutsch. Gesellsch. f. Edelsteinkunde, 1963, 45, pp. 20-31.

Very interesting review of the engraving industry in Idar-Oberstein, dealing with the historical development of the cutting of cameos and intaglios and the carving of animals and flowers out of agate and other stones.
5 illus.

E.S.

BALFOUR (I.). *Die Bedeutung eines geordneten Systems für den Absatz von Diamanten.* The importance of systematic organization for the sale of diamonds. Zeitschr. d. deutsch. Gesellsch. f. Edelsteinkunde, 1963, 45, pp. 5-14.

Review of the founding 75 years ago and the workings of the " syndicate " as a central selling organization for diamonds.

E.S.

GÜBELIN (E.). *Spektrolith—ein neuer Schmuckstein.* Spectrolite—a new gem. Zeitschr. d. deutsch. Gesellsch. f. Edelsteinkunde, 1963, 44, pp. 2-4.

This stone was found by the Finnish professor Laitakari. It is a type of labradorite found on the Finnish-Russian border, and shows on its polished sides all the colours of the spectrum, from green and blue to yellow and orange to red. Most of the material is used in the building industry, and good material for cabochons or small plates is rare, perhaps 5 kg per month.

E.S.

THEISEN (V.). *Die beiden " Taeuscher " Apatit und Phenakit.* The two deceivers, apatite and phenakite. Zeitschr. d. deutsch. Gesellsch. f. Edelsteinkunde, 163, 44, pp. 11-15.

The names of both these stones are derived from the Greek and both mean " deceiver "; both are not easily distinguishable. Apatite is often thought to be tourmaline, beryl or spodumene, but recognized by its small double refraction and its low hardness. It has also very little dichroism. Phenakite is often thought to be topaz, beryl, spodumene, rock crystal, sapphire or colourless tourmaline. If any colour is present, the dichroism is strong.

E.S.

THE SCIENTIFIC GEMMOLOGIST

By G. V. AXON, F.G.A.

THE purpose of this article is to examine the current status of gemmology, to make a few comments thereon, and to report a minor research project on distinguishing man-made from natural crystals.

There seems to be a general feeling among active gemmologists that gemmology as a science is somehow up against a brick wall. There is a great deal of useful, interesting, and informative writing, but there is a tendency to spread the well-known techniques over a greater area instead of developing new techniques to deal with problems which currently are without solution or present considerable difficulty even to experienced and highly regarded gemmologists.

Thus to a newcomer, such as this writer, there seems a tendency to emphasize the obvious, to repeat the well-known, and to avoid facing up to the fact that gemmology as a science needs a new structure in its intellectual basis—perhaps, in fact, a radical decision to recognize the existence of two types of gemmologists. These are, of course, the ordinary trade gemmologists and those who by reason of their training, interest, and experience are, in fact, scientific gemmologists whether they are in the trade or not.

Gemmology, to-day, is rather like a snowcap on a mountain. It is the most interesting part of the mountain. It sparkles in the sun like so many diamonds. It attracts mineralogists and geologists quite apart from members of the trade and trade laboratories, and hobbyists. One can well understand its attraction. But so many of those interested in the snowcap have never bothered to understand why the snow is there, and why it stays there. They are content to play with the snow and have a good time. They are simply not interested in understanding the massive structure on which the snowcap rests.

The result is that many in the gem field are walking around on intellectual stilts and might topple over at any time. They would be hard put to explain why no chromium is found in the feldspars, and why fluorine and hydroxyl ions are found in silicate minerals such as topaz and tourmaline.

This is not to criticize: it is merely to point out that gems are delightful things to study and handle, and that quite apart from this the vast majority of gemmologists are not engaged in any full-time capacity in the gem field. Even those who have qualified seldom dig deeper into the intellectual basis of gemmology.

Of equal importance is the fact that gemmology has long been regarded as a step-child of mineralogy. The basic reason for this, of course, is that the most valuable substances used as gems are minerals, and that, without minerals, gemmology and the jewellery industry would be very much the poorer.

Yet since time immemorial many of the substances used in jewellery have been man-made. Ancient civilizations have yielded very many examples of man-made gems; they have yielded only a few valuable natural gemstones. Yet because the natural gemstones are by far the more valuable, and because natural gemstones are the flowers of the mineral kingdom, gemmology has had to be content with playing second fiddle to mineralogy.

Plainly, this is no longer acceptable. It is not only that natural gemstones, especially the finest, are becoming increasingly rare, but that the substances used as gems are increasingly varied and increasingly difficult to distinguish. To-day, gemmologists, having relied probably for far too long on mineralogists, are faced with having to reconstruct the intellectual basis of their profession. The problem is basically one for the scientific gemmologists.

Clearly, the first approach must be to shift the intellectual basis of gemmology away from the glittering and inviting snowcap to the uninviting and less glamorous rock base. There is a need for a far more fundamental approach to the study of gemmology. It should surely start with the formation of the universe, the development of the elements, the formation of the earth, and how the elements came together to form various substances known as rocks, minerals, and crystals.

As some gem material is of organic origin, there should be at least some attempt to explain, as far as possible, the development of organic from inorganic life, and the organic structure of the various organic gem materials.

To-day, the gemmologist is faced not only with a wide variety of man-made substances used as gems, but also with an increasingly wide range of man-made crystals. Only those gemmologists who have had time to look into this growing field of man-made crystals

can fully appreciate its extent. Not only is there a vast variety of crystals in element and compound form, but many of these crystals may be doped by other substances for various scientific and industrial purposes. It would be almost impossible for gemmologists to keep up with developments even if they had the time. As for distinguishing the man-made from the natural crystal material, it will obviously become more rather than less acute.

Even though many of these man-grown crystals are not suitable for use as gems, the intellectual problem remains. In the United States, especially, there are thousands of amateur lapidaries who are only too willing to test their skills on anything they can put their hands on, from man-grown crystals to coprolites. Sooner or later, these curiosities find their way to the gem trade laboratory.

It was with the intention of discovering any new techniques that inquiries were made of some two dozen crystal-growing firms and scientists in the United States. The idea sprang from a comment on Carbon 14 in correspondence to this writer from J. R. Jones of Sydney, Australia. It was thought that if techniques were so advanced in one field, perhaps similar techniques (without destroying the material, of course) could be applied to the gem field. There must surely be some differences between natural crystals, say sixty million years old, and crystals being grown this minute in factories and laboratories.

The enquiries yielded a meagre harvest. Some of the comments received are listed below mainly out of curiosity. Only in one case, dealt with later, was a basically new idea (at least, new to this writer) advanced.

1. Synthetic quartz crystals cost about twelve times as much as natural quartz.
2. Synthetic quartz crystals often have complete faces whereas natural quartz crystals often have many faces missing.
3. Synthetic crystals are much purer as a rule.
4. Synthetic production techniques often use no water, whereas natural crystals have often been produced by hydrothermal forces. Thus they contain microscopic water pockets (partially filled vacuoles). Unfortunately, analysis techniques destroy the material.

5. The majority of man-made quartz is grown in a sodium hydroxide or sodium carbonate solution. Thus the sodium content is usually higher in the synthetic.
6. Synthetics show fewer absorptions when analysed by infra-red spectrographic methods.
7. X-ray analysis, neutron activation, and electron and neutron diffraction, were also given as possible methods.
8. X-ray diffraction topography will show a greater concentration of dark lines in the synthetic when measured against a natural crystal. Spectrographic analysis, which requires the grinding of some of the material, usually shows a greater concentration of some elements in the synthetic.

Of particular interest is the electron paramagnetic resonance spectroscopy (EPR) developed by Varian Associates, Palo Alto, California, U.S.A. Unfortunately, the instrument costs some $30,000 (nearly £11,000), and the fee quoted tentatively for each spectrum was $25 (about £9). Although one test may not suffice for full identification, such a test may be able to establish that a gemstone was not natural.

The basis for EPR lies in minute chemical and structural anomalies. The extremely complex instrument is an extremely sensitive, non-destructive way of detecting impurity levels in crystals. A synthetic would be relatively pure. The result is basically a graph showing straight and jagged lines, hills, and valleys, which vary according to the structural perfection and molecular structure of the material analysed.

According to the material supplied by the company, it is now possible to use the magnetic properties of *electrons* (as well as of nuclei) to reveal chemical structure and bonding characteristics.

Just as nuclei have charge, mass, angular momenta, and magnetic moments, so do electrons, and it is upon this that EPR depends. If the electron has not only an intrinsic magnetic moment along its own spin axis, but also one associated with its circulation in an atomic orbit, the electron will possess a total magnetic moment equal to the vector sum of these magnetic moments. The ratio of this total magnetic moment to the spin value is constant for a given atom and environment, and is called the *gyromagnetic ratio* or *spectroscopic splitting factor* for that particular electron. The fact that these ratios differ for various atoms and environments and the

fact that local magnetic fields depend on the structure of matter permit the spectral separation and study according to the method of Electron Paramagnetic Resonance Spectroscopy.

It must be emphasized that not all atoms and molecules are susceptible to such study. There must be a resultant electronic magnetic moment associated with the atom or molecule under investigation; for example, effects may be observed for electrons in unfilled conduction bands, transition element ions, odd molecules and free radicals, biradicals, colour centres, radiation damage sites, impurities in semi-conductors, and triplet electronic states.

The principal components of the EPR Spectrometer are an electromagnet, a sweep generator, a stable microwave oscillator, a resonant cavity, a bolometer or crystal detector for demodulating the microwave power reflected from the resonant cavity (for the sample), an audio amplifier and a phase-sensitive detector, and a graphic recorder.

Possibly, this instrument has not been used much, if at all, in gemmology, but the description given above may plant a seed in minds better prepared in gemmology than that of this writer. Certainly the idea is of great theoretical interest in the crystal field, and it seems to offer possibilities to the gemmologist. It is becoming quite impossible to determine, by ordinary gemmological methods, the nature of all crystals. If the synthetics and man-made can be weeded out and certified as man-made, it should then at least be easier to concentrate on determining the nature of the natural crystal material.

ASSOCIATION NOTICES

MEMBERS' MEETING

There was good company, rare gem stones and fine surroundings to make successful the London social evening at the Goldsmiths' Hall on 31st January. Treasures collected by the gemmologists vied with the collection of the Worshipful Company. Members had come from as far as Scotland for the occasion and the gathering was graced by more than one Tully medallist, including Mr. C. M. L. Carr who gained award No. 1. Even a television personality was there, in the person of Mrs. J. Thomas-Ferrand, who has made so many screen appearances in the Eastern counties area.

There was much to see and much to talk about. Dr. Ernest Rutland had sprung a delightful surprise with a collection of very unusual stones, including a specimen of delicate rutile, which must have been extracted with loving care from its rocky bed, and a transparent example of rhodochrosite. More surprises were a clear, white brazilianite and a fine white example of scheelite of more than nine carats, though where size was concerned a 122·2ct. blue topaz took the prize for magnificence.

Africa provided a large number of the exhibits. There was a varied range from Rhodesia and a collection of grossular garnets of all colours from the Transvaal. Nearer to home was an example of pectolite, from Scotland, a fine translucent stone. A crystal of diopside brought confessions of ignorance from some, but Mr. R. Webster was on hand to bring them up to date in their knowledge.

A case holding nearly 110 varied gems was itself an exhibit, because it showed how a collection can be attractively shown, yet be already cased for transport and have the details of the collection inscribed on the lid of the case. Finland provided the source of another varied collection of interesting stones, but perhaps for sheer beauty these were overshadowed by a collection of water opals.

MIDLANDS BRANCH

An interesting evening was held by the Branch on the 10th January 1964 at the Imperial Hotel, Birmingham. Various members of the trade spoke briefly on topics connected with the jewellery trade. Mr. W. A. Peplow spoke about Bateman silver and Mr. J. Davis posed the question of prospects for youth in the future of the trade. The subject of valuation of gemstones, and particularly of diamonds, was stressed by Mr. J. Batty. Other speakers included Mr. P. Spacey, who talked of his experience gained in Ceylon; Mr. C. Houchin, who gave a discourse on the history of pawnbroking; and some of the difficulties encountered in

grading and matching diamonds in the course of the normal duties of a diamond merchant, were explained by Mr. D. Marshall.

There were many lively questions and members agreed to hold a similar meeting in the future.

TALKS BY MEMBERS

BLYTHE, G., " Gemstones ", Rayleigh Round Table, 3rd January; Hawkwell Women's Institute, Hockley, 6th January; Salisbury Club, Southend, 8th January; Blenheim Townswomen's Guild, 9th January; Southend Round Table 106, Westcliff-on-Sea, 13th January; " Diamonds and their substitutes," Rotary Club of Basildon, 10th January; " Gems ", Basildon Business and Professional Women's Club, 20th January, 1964.

COZENS, J. R., " Diamonds ", Bishops Lydeard Women's Institute, 9th January, Taunton Branch United Commercial Travellers' Association, 24th January; Bridgwater Young Conservatives, 4th February; South Petterton Women's Institute, 24th February; Taunton and District Welsh Society, 26th February; Taunton Young Farmers' Club, 5th March; West Buckland Women's Institute, 10th March, 1964.

HUDSON, F. N., " Gemstones ", St. Margaret's Association, Dunfermline, 10th March, 1964.

GILLOUGLEY, J., "Pearls", Glasgow South Soroptomist Club, 24th February, 1964.

CAFFELL, E. W., "Gemstones—Decorative and Abrasive", Slough Branch of the Purchasing Officers' Association, 10th March, 1964.

LANGTON, E. G., "Diamonds and other gems", Literary and Arts Society, Muswell Hill Presbyterian Church, N.10, 11th March, 1964.

INDIAN ACADEMY OF SCIENCES

B. W. Anderson, B.Sc., F.G.A., who has been in charge of the Diamond, Pearl and Precious Stone Laboratory of the London Chamber of Commerce for 35 years, has recently been elected to an Honorary Fellowship by the Indian Academy of Sciences.

This is an honour given to only 3 or 4 people each year, and Mr. Anderson owes it to his work on precious stones, and especially diamonds. Sir C. V. Raman, a former President of the Academy, is well known for his own diamond studies, and has expressed his interest in Mr. Anderson's work.

WEST OF SCOTLAND BRANCH

On 30th January, 1963, members and guests of the West of Scotland branch had the pleasure of hearing Mr. James Gillougley, F.G.A., F.B.H.I., lecture on pearls.

Mr. Gillougley started with a brief description of the anatomy of the oyster, and of the structure of its shell, and with the aid of an excellent diagram showed the areas which secreted each of the shell and pearl producing substances. He then considered the whole range of pearl bearing molluscs, giving details of their habitat and the type of concretions they produce.

Following this general survey the production of cultured pearls in Japan was treated in considerable detail, this portion of the lecture being illustrated by means of a colour sound film. Mr. Gillougley pointed out that the film gave a somewhat romanticised picture of some aspects of the industry, for example the removal of pearls from the oysters, and he told members of the much more practical, if less attractive, techniques actually employed.

Before and after the lecture members were invited to examine a most comprehensive series of exhibits. Mr. Robert Webster had kindly lent a selection of wild pearls of various colours, and Mr. Wallace Allan a number of Scottish River pearls and a shell of the mussel which produces them. A most impressive selection of strung cultured pearls ranging in price up to £115 (retail) per strand had been provided by Messrs. Bolton and Redfern, whilst Mr. S. G. Ritchie had lent some very beautiful multiple strand necklets of black (dyed) and white cultured pearls.

There was no doubt that those present enjoyed a most interesting and informative evening as they showed by their enthusiastic response to a vote of thanks proposed by Mr. W. C. F. Butler.

GEMMOLOGICAL INSTITUTE OF AMERICA

The Institute has announced the retirement of Dorothy Jasper Smith, who joined the staff in 1932. She had served the Institute for a longer period than any other person. Her departure constitutes a real loss to the organization for she efficiently handled the duties of bookkeeper, registrar and the varied tasks of executive secretary.

OBITUARY

Henry Newton Sprague, aged 69, a director of John Bull & Co. (Bedford) Ltd., died in January 1964. He gained his Fellowship diploma in 1928.

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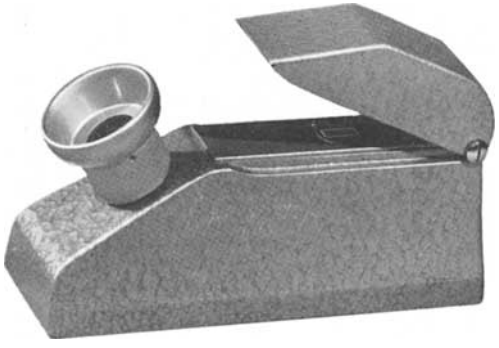

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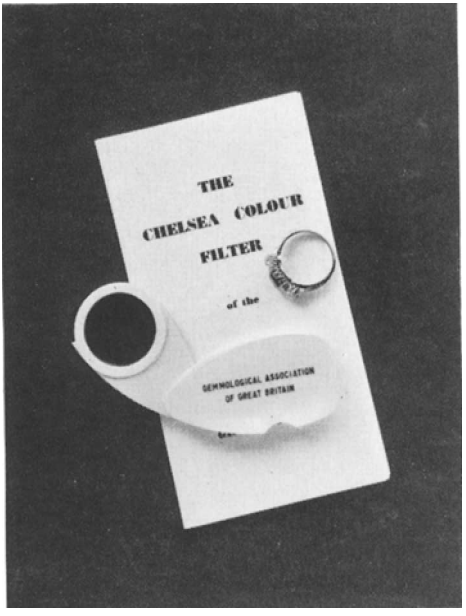

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THE JOURNAL OF GEMMOLOGY

and

PROCEEDINGS OF THE
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Vol. IX No. 7 JULY 1964

THREE STONES FOR THE RECORD

By B. W. ANDERSON, B.Sc., F.G.A.

BEYOND the beauty which delights the connoisseur, the rarity which intrigues the collector, or the potential profit which is the main concern of the dealer, there are, for the gemmologist, aspects of a stone's behaviour which should add a further dimension to his pleasure in an unusual specimen. In the past few months three stones have been encountered in the course of routine testing which serve to illustrate this fact. Each has shown properties to make it seem worthy of record for the benefit of fellow-gemmologists, but two of them, at least, were commercially too unimportant to interest a dealer and had not enough beauty to attract a connoisseur, while the third, though rare and lovely enough to be prized in all its aspects by any lover of gems, will almost certainly go through all its life as a jewel without its owners suspecting one of its most exciting properties.

One has to admit that, even to the gemmologist, a mere recital of the properties of these three stones might not make them seem very remarkable, but by filling in the background a little the writer hopes at least to justify his own interest in the three speciments.

(1) *A "high" gahnospinel*

The first of the three stones was a small blue spinel weighing 0·87 carat—ostensibly quite insignificant. Fortunately this was submitted as a loose stone, which made it possible to obtain both

density and refractive index measurements: it was mainly the outstandingly high figures for these two simple properties which made the stone for us so supremely interesting.

The story of the zinc-rich blue spinels (for which our name "gahnospinel" has been accepted) began in 1935, when T. W. Oliver, then a student in the gemmology classes at Chelsea Polytechnic, drew attention to a blue spinel in his possession which puzzled him because of its reading of over 1·74 on the refractometer. There seemed to be no easy explanation for this, since the spinel was normal or even rather pale in colour and thus obviously not excessively iron-rich. Moreover the density, which proved to be 3·947, was even higher than could be found in the series which leads, via "ceylonite" or "pleonaste", to the pure ferrous-iron spinel, hercynite.

C. J. Payne and the writer then began a diligent search in parcels of blue spinels, and amongst rough pebbles of blue spinel which are, next to zircons, the commonest constituent of the Ceylon gem gravels. This led to the discovery of a whole series of these "high" spinels, which had previously escaped notice. Such stones are admittedly rather rare: for example, out of over 300 specimens of cut blue spinels examined in one test only four were found with densities greater than 3·85.

The colour of these high-reading stones gave no clue to their properties: some were rather dark, others were pale steely-blue. To find the cause for these anomalies, we obviously had to search for some divalent element of relatively high atomic weight compared with that of the magnesium it was replacing, and one which was *not* one of the transition elements with their tendency to affect colour. Our guess was zinc, since the pure zinc spinel, gahnite, was an established mineral, and the densities and refractive indices of our specimens, when plotted graphically, lay convincingly close to the straight line leading from pure magnesium spinel to pure gahnite (see diagram). Qualitatively, this was easily proved by employing a small grating spectrograph, which showed the degree of prominence of the zinc lines in the visible spectrum to increase step by step with the density and refractive index of the specimens tested. Incidentally, the surprising fact emerged that in no case are blue spinels from Ceylon entirely free from zinc.

To clinch the investigation, Dr. M. H. Hey of the Mineral Department of the Natural History Museum carried out a quantitative analysis of one of our "top" specimens—a pale blue stone having

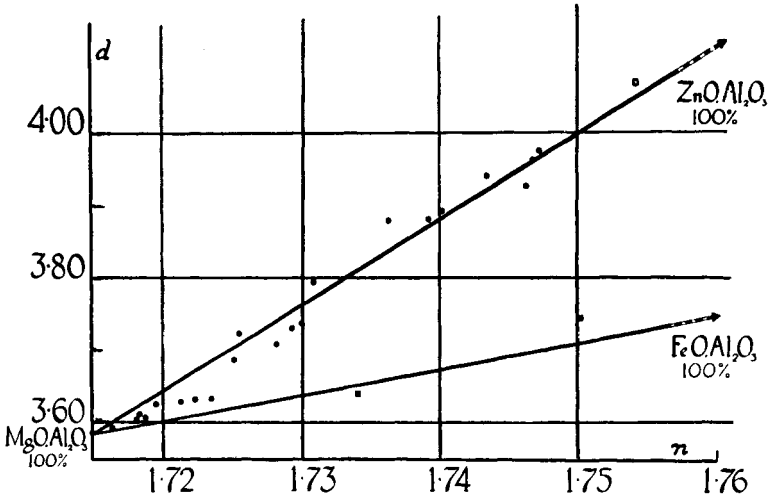

Diagram showing relation of density and refractive index in blue spinels of the zinc-rich (garnespinel) series and iron-rich (cylonite) series.

density 3·967 and refractive index 1·7465—and found it to contain as much as 18·21% zinc oxide. The MgO content of the same specimen was 16·78, while 1·93 FeO accounted for the colour. Our "prize" specimen at the end of this investigation was a stone with density 3·981 and R.I. 1·7469.

In the natural course of events we have frequently encountered gahnospinels since that time, and always give them a friendly nod of recognition in passing, but we have had to wait more than 25 years before finding one to beat our previous best, and in particular to exceed the figures 1·750 for refractive index and 4·00 for density, which for us had formed a "target" analogous to the athlete's four-minute mile. The present small specimen did this handsomely: the refractive index was found to be 1·7542 on the Abbe-Pulfrich refractometer, and the density, also carefully measured, was 4·060. At less than a carat, the stone was not large enough to give a very reliable reading for density by hydrostatic weighing, even when using ethylene dibromide and an aperiodic balance reading to a tenth of a milligram, as is our practice. We therefore chose several low zircons in the target area which were large enough for their density to be well established, and compared these with our spinel specimen when suspended in a specially mixed Clerici solution. Having done this, we feel satisfied that the density quoted is accurate to within ±·002.

Here, then, is an excellent example illustrating the truth of the opening sentence of this article. In general appearance this small blue spinel had nothing particular to commend it, and the fifty shillings for which it was purchased was probably more than its strictly commercial value. But to us, as gemmologists to whom gahnospinel meant something "special", it was a profound pleasure to meet this stone and to add it to our collection of gemmological rarities.

(2) *A chrome-rich red spinel*

The second stone to be recorded was also a spinel, but in this case a deep red example and, unfortunately, mounted in a 3-stone ring. As with the gahnospinel described above, the stone had no great beauty or commercial value to commend it. Its interest to us lay chiefly in its refractive index, which at 1·7439 was typical, not of red spinel but of pyrope garnet. This reading was at least 0·020 higher than for the normal run of red spinels, and 0·010 above the previous high record.

There is a practical issue here: it constitutes a challenge to the gemmologist to distinguish with certainty between the two red gem minerals pyrope and spinel. The minerals are close to one another in appearance and properties, and the distinction is made more difficult from the fact that both are optically isotropic and that each belongs to a group of isomorphous minerals in which variations in chemical composition and physical properties are to be expected and no exact margins can be established. Even the mineralogist, to whom "no holds are barred" in the matter of destructive tests (such as a rough analysis to determine the presence or absence of silica) has sometimes gone astray in distinguishing these two rather common minerals.

During the war years it happened that the writer investigated this problem in some detail, and even ventured to read a short paper on the subject before the Mineralogical Society. The conclusions then were:—

(1) That though the "highest" spinel might overlap the "lowest" pyrope slightly in refractive index, in all specimens encountered till then a small density gap remained between the highest spinel at 3·611 and the lowest pyrope at 3·643. This is not much to go on, but

in the vast majority of examples the gap between the R.I. and S.G. of the two minerals is far larger and more conclusive.

(2) Fluorescence under ultra-violet light (or as since determined by the more powerful "crossed filter" technique) provided the quickest means of distinction and could be applied equally well with mounted or unmounted gems and with uncut specimens. Pyrope, with its inevitable heavy content of some 6 to 15% of ferrous iron, *can under no circumstances show any trace of fluorescence*, whereas red spinel in general can be relied upon to give a red fluorescent glow which, as analysed by a hand spectroscope, is seen to consist of a highly characteristic "organ pipe" group of lines.

(3) The absorption spectra of the two minerals are also normally distinctive. The broad central absorption region, due to chromium in each case, in spinel is centred in the green near 5400Å, while in pyrope the corresponding band is centred in the yellow near 5750Å, and this can be seen even without measurement to be much nearer the red end of the spectrum. As a further sign, the pyrope spectrum commonly reveals to the practised eye the strongest absorption peak of the almandine spectrum as a rather narrow band at 5060Å. Lastly, in chrome-rich spinels a number of fine absorption lines can be seen in the red end of the spectrum. In pyrope, though the doublet in the deep red may be visible, any further lines in the red are seldom seen.

(4) Inclusions are also revealing. In spinel these are generally octahedral in shape and grouped in serried ranks in one plane as extensive "feathers". In pyrope, inclusions vary according to locality, but either intersecting needles of amphibole or small rounded zircon crystals are the most common features.

(5) If the minerals are in the rough state and to some extent expendable, the behaviour of a small piece when placed in a carbon arc can be distinctive. In the high temperature of the arc-flame pyrope fuses readily to a black bleb of glass. Spinel, on the other hand, fuses reluctantly, and then (as behoves a mineral that can be synthesized under the drastic conditions of the Verneuil furnace) it recrystallizes immediately as a white reticulated mass of linked octahedra.

(6) A further test which has been found effective is to observe the response of the specimen to a powerful pocket magnet. When the stone to be tested is placed on a suitable "insulating" block (such as a large cork) on the pan of a sensitive balance, and exactly poised with weights, etc., on the other pan, the close approach of a small powerful magnet (such as the "Eclipse") to the specimen will be found to upset the poise quite clearly in the case of any pyrope garnet on account of its iron content, while with spinel no appreciable effect can be noted.

So chrome-rich was the spinel described above that it showed no trace of fluorescence even under crossed filters, and this fact, combined with its very high refractive index, could easily have led to its wrong identification as pyrope. The absorption of light was so intense that with transmitted light only the red end of the spectrum was visible. In this red "window", however, were numerous clear-cut lines, and we were able to measure these as having wavelengths *7073*, 6940, *6820*, 6730, 6620, *6550*, 6480, 6410Å, which agreed with those we had recorded in the past for chrome-rich spinels. These observations made the identification as spinel quite certain. Further evidence was provided by the inclusions, which showed a distinctive ghost-like "feather" of octahedra; while lastly there was no sign of any magnetic pull on the balance.

As already noted, the stone was unfortunately mounted (with diamonds) as a three stone ring, with the result that the density of this exceptional stone remains unknown. Probably it would have proved to be in the region of 3·63.

(3) *A remarkable blue diamond*

The third stone to be described, a blue diamond mounted as a ring, was of very different calibre, being at least as notable for the beauty and rarity of its colour and presumably for its value as for its great interest for the student of unusual diamond behaviour. The specimen was deeper in its blue colour than any we had previously seen, though having rather the hue of a fine indicolite than that usually associated with sapphire. It had a spread of about 3½ carats, step-cut, and was handsomely mounted in a single-stone ring.

Dr. J. H. F. Custers' claim that all natural blue diamonds belong to a special type which he called "type IIb" has so far proved true without exception and this makes it possible to check in the laboratory the authenticity of the colour in any blue diamond

without much trouble. This peculiar type of diamond shows no fluorescence under long-wave ultra-violet rays, but after exposure to short-wave rays shows a persistent phosphorescence—this at least is its usual behaviour. A more definite distinction from other types of diamond lies in its electrical conductivity. Normally diamond is an insulator, as are other transparent crystals, but type IIb diamonds can conduct more or less freely when a potential difference of 100 to 240 volts is applied to two sides of the stone. While the stone is conducting a current, blue flashes of "electro luminescence" may be seen, and in some cases the stone may become very hot if the current is allowed to flow for some time.

In the present case, when the mains voltage of 240 volts was applied on the special "hook up" constructed for this purpose by Mr. Robert Webster, the stone caused a voltage drop only to 200 volts, while a brilliant sparkle of blue electroluminescence could be seen around the probe. So far the diamond, though rare in colour, was behaving "according to plan". It was in its luminescent behaviour that it showed its exceptional character. It did indeed show phosphorescence after exposure to 2537Å mercury light: but phosphorescence could be similarly noted after exposure to long-wave ultra-violet or even to visible blue light, and moreover in all cases the glow was distinctly *red* in place of the more usual green or yellowish hue.

Under X-rays a particularly striking effect was noted. There was here visible a dullish mauve fluorescence which, on switching off the rays, did not at first change perceptibly in colour or intensity, but then gradually faded and changed into the red hue seen in the case of the other radiations mentioned above.

Only one diamond had previously been encountered which showed comparable effects. This was a steely blue stone, also mounted as a ring, which was reported upon in a previous article. Though this stone also showed a red glow after stimulation by all types of radiation including visible light, the electrical conductivity was markedly lower than in the dark blue diamond here recorded.

SIMPLE PHOTOGRAPHIC EQUIPMENT

By B. ERICHSEN, F.G.A.

AFTER studying the literature I felt that it would be somewhat expensive to purchase the equipment necessary for photomicrography and I decided to make my own equipment. I took a thin plate of copper and made a funnel with a cylindrical holder to fit the ocular of the Rayner microscope. At the other end of the funnel I made a holder for a cut flat film casket, 6 × 9 cm. (Fig. 1). I made the whole non-reflecting with matt black camera finish. I focused the camera by means of a screen used in place of the film casket and for fine focusing used a pocket magnifier. The advantage of using cut flat films instead of roll films enables one immediately to rectify a wrongly exposed photograph. The accompanying illustration (Fig. 2) shows what can be achieved with this simple apparatus.

FIG. 1. *Rayner microscope with home-made photographic equipment.*

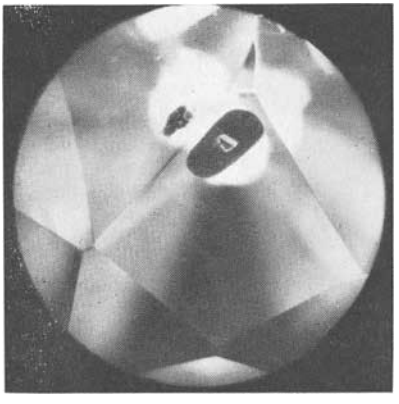

FIG. 2. *Ilmenite inclusions in diamond.*

PLEASE TEST EMERALD

By A. E. FARN, F.G.A.

NOT too long ago many jewellers were happy men who looked at green stones through a filter and said, "It's red, it's emerald". That constituted emerald testing. True, they had to have worrying things like ruby and sapphire tested (albeit reluctantly) and gave grudging admission that there was something in this gemmology business.

However, with the pre-war manufacture of the "Igmerald" in Germany and the Chatham synthetic emerald from America just after the war, it became apparent that the reign of the Chelsea colour-filter devised by B. W. Anderson and C. J. Payne (one of the many very very useful adjuncts to gem testing from these eminent gemmologists) was ending—that is, as a straightforward first-class spot-on test for emerald—but it still has very many uses in the hands of the competent gemmologist. Most people I have seen in the trade seem to hold the stone up to the light (lamp bulb) and look at it through the filter. Actually, best results will be obtained if the stone is held under a light or behind it and then examined, when a much better colour-result will be seen. If the stone is but faintly coloured by chromium and held *against* the light the effect will be weakly seen or not seen at all.

However, circumlocutious as that may be, facts are facts and one is that emeralds in jewellery present a problem to the jeweller, mounter, auctioneer, and dealer. The more recent advent of the synthetic spinel soudé and "emerita" has now practically forced the hand of all jewellers in having their stones tested. Whilst it is not assumed that many present-day gemmologists cannot expertly test emeralds, neither is it assumed that many well established jewellers of much experience do not know their emeralds when they see them. It is still very much a fact that "emeralds" in settings can spring from a variety of sources.

Earlier I wrote an article[1] discussing the relative merits of Standard versus Spinel refractometers (the latter used to be termed the Anderson-Payne Spinel refractometer since again it was a product of their gemmological ingenuity). The spinel refractometer comes very much into its own when testing emeralds and emerald-like stones.

To begin with, then, it is necessary to list the green stones, including emeralds, which could be emerald.

Suppose (as is usual) an emerald in a cluster ring is received for testing. Usually a note briefly states: "Please test green stone in cluster ring". I like to look at a stone with a lens first of all and make up my mind right away before I do a proper test. I like to put into practice all I have been taught in the use of the lens, i.e. double refraction, inclusions, surface structure, etc. Obviously on first seeing a stone the general appearance or "look" of the stone gives a strong indication. Most jewellers or stone dealers have such a fund of "rule of thumb" knowledge that mostly on sight they are able to distinguish a stone. Since emeralds command such fantastically high prices in world markets it is essential to be right every time when dealing in thousands or merely hundreds of pounds. Therefore, having had a look at a stone, then an examination by lens to gain a quick intimation, a proper test takes place. Here, then, the Spinel refractometer takes pride of place, since it is just the right instrument for the job and range of indices to be measured.

A first reading on the refractometer will usually settle the problem or point the line to be followed. If the reading should be 1·571–1·577 and the stone has a chromium absorption spectrum, three-phase inclusions with perhaps pyrite included, then it is certain the stone is a Chivor stone from Colombia, S.A. This is perhaps a rather straightforward nice and easy stone to test. There can be others. For instance, the stone could be backed and foiled as was the last steep cabochon I tested. Superficially it looked all right and pinky red under the filter. The foiled cabochon had two-phase inclusions more typical of green or colourless beryl than the three-phase inclusions of Muso, Chivor, etc. The distant-vision reading by the Lester Benson method (sometimes termed the spot method) gave a mean reading approximate to 1·57 and of course no double refraction. The lens also showed that the foiling was partial, i.e. there were small patches at the back of the stone which were or appeared to be colourless. This rather indicated painting. Although the stone appeared pink under the filter it gave no absorption spectrum or fluorescence bright line due to chromium. A stone must be coloured by chromium to be an emerald. Viewed sideways against a bench lamp, without benefit or bias of the backing, the whole of the side-view of the stone appeared colourless, thus proving it to be a beryl and not true emerald. It would have

been possible to immerse the stone and view it sideways in a liquid such as beryl-benzoate, which is a very good match for beryl, but some might have crept under the setting and spoiled the appearance of the stone. Merely to mention three-phase inclusions as being typical of genuine emerald barely touches the edge of the possibilities of the characteristics of emeralds. Recently, at a third year post-diploma course lecture on emeralds, a list of provenance, specific gravities, refractive indices and type inclusions was given by Mr. B. W. Anderson, who lectures regularly at Northern Polytechnic. This list I am reproducing as given to the lecture class. It affords a very condensed but practical list of stones from the lowest refractive indices of Chatham synthetics to the highest of Pakistan emeralds.

Provenance	*Specific Gravity*	*Refractive Indices*	*Birefringence*	*Inclusions*
Chatham synthetic	2·65	1·560–1·563	·003	Curling feathers and phenakite crystals.
Zerfass synthetic	2·66	1·555–1·561	·006	Similar to above
Gilson synthetic	2·65	1·560–1·563	·003	Possibly a yellower green in colour.
Lechleitner "Emerita"	2·69–2·81	1·566–1·571	·005	Crazing on surface structure.
Brazilian	2·68–2·69	1·568–1·573	·005	Usually very clean and pale.
Chivor	2·69	1·571–1·577	·006	Pyrite crystals and three-phase inclusions.
Muso	2·70–2·71	1·574–1·580	·006	Calcite and three-phase inclusions.
Siberian	2·72–2·74	1·581–1·558	·007	Actinolite blades and flaky structure parallel to basal plane.
Habachtal	2·74	1·584–1·591	·007	
Indian	2·73–2·74	1·585–1·592	·007	Hockey stick patterns. Stumpy comma.
Sandawana	2·74 2·76	1·586–1·593 1·588–1·595	·007	Curved fibres of tremolite.
Transvaal	2·74–2·76	1·586–1·593	·007	Fuchsite micaceous inclusions.
Pakistan	2·74 2·77	1·588–1·595 1·590–1·598	·007 ·008	Insufficient data.

In the list some sources such as Muso and Chivor overlap somewhat, which is not surprising since they are both Colombian stones. Not a lot can yet be written about typical inclusions in Pakistan emerald. By and large the finest stones come from Colombia. "Possibly" the finest colours (but small stones) come from Sandawana. I purposefully put "possibly", since as in all cases it is a matter of opinion on colour. Basically, the straightforward test for an emerald that is mounted is the refractometer, and preferably the spinel refractometer. The refractive indices and amount of birefringence are the proving factors and, if unmounted, of course the specific gravity. Fortunately the Chatham synthetic and its European counterparts, the Gilson and Zerfass synthetics, have very low refractive indices of 1·560 to 1·563 and double refraction of only ·003. These factors keep synthetic emeralds well away from the next on the list, the Brazilian stones—coupled with the added factors that, stone for stone, synthetic emeralds, both Chatham and Gilson, are relatively a fiercer red under the filter and have typical curled liquid-drop feather inclusions (they are so typical of synthetic emerald and are one of the safest possible signs to be seen in testing). These feathers are, of course, more plentiful in the cheaper grades of synthetic emerald (not that recent synthetics seem cheap); the feathers which are included have a tendency to curl and interlock with each other and are easy to recognize. The Gilson synthetic emerald has a yellower green look than the Chatham and possibly a higher proportion of feathers as against feathers and phenakite crystals of the Chatham synthetic. The higher grades of synthetic emeralds are comparatively clean, but their refractive indices and specific gravity remain constantly low. Because a stone is clean and looks good it will command a high price (high means astronomical in the emerald market). If a stone commands or purports to command a high price—serious thinking and testing must result. It cannot be over-emphasized that it pays to have emeralds tested.

Synthetic emeralds when loose are even more obliging and literally give themselves up. A density liquid with a colourless quartz suspended in it will be sufficient to check any synthetic emerald. Better still, a density liquid with a known laboratory-tested sample of synthetic emerald suspended in it will serve as a ready means of identification. The synthetic emeralds have a density of 2·650, lower than any other genuine emerald, and very close to the 2·6508 of quartz. Whilst most synthetic emeralds will

turn red under the excitation of long and short wave ultra-violet lamps, this colour-change is not by itself a reliable diagnostic feature, since some natural emeralds have this tendency.

Lechleitner "emeralds", known as "Emerita" stones, are pre-formed cut stones of beryl of colours from colourless, pale green to pale pink beryl, which are used as a seed. They are then given a coating of synthetic emerald, presumably hydrothermally. Thus the stones have natural inclusions, appear red under the Chelsea filter, have refractive indices probably in ranges from 1·566 to 1·571 but which may be higher according to the seed used. The density can be from 2·69 upwards. Fortunately since the coating of synthetic emerald does not "take" readily on the beryl surface (it is not in an acceptable growth orientation) a crazing appearance is seen when the surface is examined by lens. The appearance of emerita under the filter gives an indication of red only around the perimeter of the stone. Similarly under ultra-violet light a red outer rim is seen on Emeritas. Of course, good trade practice and knowledge will tell a stone dealer that the stone looks wrong.

Next in line come the Brazilian emeralds. These can be a bright, pleasing, somewhat pale green and often almost clean. I would consider them to be the most taxing of all stones, especially when in a closed-in or awkward setting. The refractive indices of Brazilian emeralds are 1·568 to 1·573, giving a birefringence of ·005. The specific gravity is given as 2·68 to 2·69, and if there are any distinctive features in Brazilian stones they are usually two-phase and more indicative of beryl than emerald. However, in this case, provided chromium fluorescence can be seen as a bright line in the red end of the spectrum and the refractive indices are close to 1·568/1·573, then it is safe to term it emerald, and not synthetic.

Chivor and Muso mine stones come from Colombia, South America, and are the world's finest stones. Their refractive indices, birefringence and specific gravities are very close indeed to each other, but the Chivor stones are distinguished (although I think it straining one's gemmological faith a little) by the pyrite inclusions and three-phase inclusions which are common to them from the Muso stones, which have calcite rhomb inclusions and occasionally pink rare earth inclusions (parisite). This latter fact I can remember seeing demonstrated by the late Sir James Walton, who was terribly excited by the queer absorption spectrum seen in a portion of an emerald he possessed. One end of the stone (or crystal) had a band

of parisite as an inclusion and it gave a distinctive strong rare earth spectrum, bearing out exactly what the better written text books depicted or told. The fact that parisite is an inclusion in emerald is interesting and a reminder of how enjoyable was the enthusiasm of Sir James, whom it was a privilege to have known. Chivor stones' refractive indices are 1·571 to 1·577 with birefringence of ·006 and specific gravity 2·69, three-phase inclusions of jagged outline and frequently pyrite as an inclusion. Muso stones range from 1·574 to 1·580, have a density of 2·70 to 2·71 and double refraction of ·006, and have calcite as an inclusion but three-phase inclusions as well.

Siberian emeralds from the Ural Mountains are red under the filter, slightly heavier with S.G. 2·72/2·74, have refractive indices 1·581 to 1·588 and double refraction of ·007, and are much more interesting under a microscope since they contain actinolite fibres, which have lines or cracks crossing them giving them the appearance of the growth structure seen in some woody shrubs akin to a bamboo shoot. This latter description comes from B. W. Anderson and I cannot alter it, better it—or omit it.

Closely related in characteristics are the slightly mysterious emeralds of Habachtal. The emeralds (seldom seen) are mined in Austria, in the district of Salzburg, in mountainous regions 7000 feet above sea level. Since they and the Russian emeralds come from similar rock formations they have similar structures inside. Their refractive indices are 1·584–1·591 (a birefringence of ·007) and their specific gravity is 2·74. The Habachtal mines have been worked intermittently and possibly are uneconomic, but in London to-day there are a few thousand carats of genuine Habachtal emerald crystals waiting to be purchased by some keen, wealthy or commercially minded gemmologist.

Indian emeralds are heavier, deeper and a somewhat more saturated green and do not go red under or through the Chelsea filter. Fortunately Indian emerald inclusions are strongly characteristic, resembling a short stumpy hockey stick. They have slightly higher refractive indices again, at 1·585 to 1·592, a density of 2·73 to 2·74 with birefringence of ·007. The important factor to note is that, although when these characteristics are listed in an ascending order of R.I. and S.G. they do not seem to be much removed one from another and the variations are small, the birefringence coupled with the refractive indices and specific gravity of syn-

thetics are lower in all cases than those of the lowest of genuine emerald. This is quite a clear-cut division and is seen to best advantage on the Anderson-Payne spinel refractometer.

Sandawana, one of the more recent finds of emerald from the continent of Africa, apart from being beautiful, are very interesting indeed in their inclusions, these being a series of criss-crossing curved tremolite needles—an instance (and there are many) where nature does not adhere to rigid straight line formation seen in the usual silk and colour zoning of stones. The curved nature of the included tremolite needles in Sandawana is quite delightful. It is not usual to find large sizes in Sandawana emeralds; they usually run small and very good or large and coarse. Sandawana emeralds have a specific gravity of 2·74 to 2·76 and refractive indices of 1·586 to 1·593, giving a birefringence of ·007.

Higher on the scale are the emeralds from South Africa (Gravelotte). These emeralds are a sad colour, usually almost a touch of yellow/brown to them owing to the predominance of mica plates as inclusions. Usually these Transvaal emeralds do not show red through the filter, but are coloured by chromium, as the spectroscope will prove. Their S.G. ranges from 2·74 to 2·76, a birefringence of ·007 and refractive indices 1·586 to 1·593. Lots of Transvaal emeralds are of very poor quality and were exported to India until political crises stopped their importation.

Pakistan emeralds at the moment have the highest constants, being 2·74 to 2·77 S.G. and refractometer indices 1·588/1·595 with birefringence ·007. Very few consignments of these emeralds have so far been examined. They are a good deep green, go a darkish red under the filter and their inclusions are quite varied but are each in themselves to be seen in other types of typical emerald. That is to say, they have micaceous inclusions, two-phase inclusions, feathers, etc., in fact they have a whole host of natural inclusions, none of which to me so far seem typical for Pakistan but fit most emeralds.

Broadly speaking, the foregoing are the emeralds and synthetic emeralds at present upon the market, and it is surprising, with so many to write of, one seldom sees any emeralds of superb colour, size and cut.

Stones which surprisingly enough are sent for testing and which one presumes to be imitating emerald, are glass, paste soudé, garnet-topped doublets, fluor, aventurine, microcline, backed, foiled and/or painted beryl, heat-treated tourmaline, peridot, demantoid, zircon,

stained chalcedony, chrysoprase, jadeite. These are quoted for the simple reason that at some time or other they have been presented for testing. Straightforward glass which is faceted, is easy on the refractometer—particularly the spinel refractometer—or is given away by bubbles and/or swirl striae and/or the heavy cross seen between crossed polaroids, which is due to strain. Paste is a little higher up the scale in refractive index and usually is revealed by the colour fringe due to its high dispersion, seen on the scale of the spinel refractometer when a reading is taken. Swirl striae and bubbles are often apparent—sometimes (as a word of warning) it is possible to have a cluster of small gas bubbles, closely knit and linked together, forming a kind of feather-pattern which, viewed quickly, can be most deceptive. Soudé emerald is readily detected by the reliable spinel refractometer; some soudés go red under the filter but not many.

Garnet-topped doublets seem to puzzle many people and I have known one well known "expert" buy a garnet-topped doublet graduated bracelet as the finest range of demantoids he had ever seen. However, the red glints or reflections seen from the garnet top and the flattened bubbles (of trapped air) all in one plane should in themselves be sufficient indication. Sometimes the garnet top has natural inclusions, but these are different from what is expected in an emerald (rutile needles and diopside crystals as opposed to three-phase inclusions, etc.).

In a green stone which is a garnet-topped doublet it is very often possible to see the junction if the garnet, top edge with the glass base. Sometimes the garnet top is very thin indeed, almost a flashing of garnet. It is seldom symmetrical, but if it is not closed in by the setting careful scrutiny with a 10 × lens will reveal the junction, since the garnet has a higher refractive index and takes a better polish than the glass base and it is impossible to obviate the difference showing where these two meet. It is quite rewarding to spot the doublet. In point of fact the garnet-top doublet doesn't offer any serious problem to a jeweller who applies even one test to the stone—he may not detect it, but he knows it isn't emerald.

Green fluorspar, especially if it is carved, can be a teaser. Fluor turns red under the filter but fortunately is much heavier than emerald, S.G. 3·18; and its refractive index is single at 1·434. It is soft—very soft—and usually exhibits marked signs of cleavage, which is its weakness. Because of its low refractive index fluorspar when

cut has a very empty lack-lustre look which gives it a very poor glass-like appearance. No confusion could possibly occur if the spinel refractometer were used; even the Lester Benson method would give a sufficient indication to identify a cabochon or carved piece. One of the strengths of the distant vision method is that whilst no very sharp reading can be taken, say, of 1·434 or 1·575, it is capable of giving an indication of the area of mean refractive index sufficiently to distinguish between emerald and fluor.

Green aventurine quartz, which appears red under the filter, is coloured by flakes of fuchsite mica which give it a spangled effect, and when examined internally by lens or microscope an apparently regular wealth of somewhat irregular inclusions, all of similar outline, defy comparison or mistake for any sort of emerald inclusion. Admittedly the specific gravity of aventurine is 2·65 and its refractive index 1·55, but its external and internal structure divorce it even from synthetic emerald.

Microcline feldspar, or amazonstone, is a bright hard blue-green stone which does occasionally look something like coarse green beryl but should not be considered as emerald. The name microcline indicates that in its crystal structure one of its axes is slightly inclined (orthoclase feldspar is monoclinic, amazonite is triclinic). Amazonite cleaves very readily and easily and has two directions in which this occurs. It is because of this so called incipient or easy cleavage occurring during polishing that a series of minute flats reflect light back from the polished surface and give a twinkling or shimmering effect, especially if the article is rotated. Having a density of approximately 2·57 and refractive index between 1·52 and 1·53, it would be difficult indeed to consider microcline as a serious possibility as emerald.

Heat-treated tourmaline can be a very attractive bright green stone, since the heating tends to lessen the dichroic effect. Attractive as it is, green tourmaline is quite easily separated from emerald, since it has distinct double refraction of 1·620 to 1·640, a wide birefringence of ·020. It does not go red under the filter and, all told, is merely a green stone easily separated from emerald. Peridot is in the same easy group as tourmaline, because it has wide birefringence of ·038, refractive indices 1·650–1·688, a specific gravity of approximately 3·35 and a distinctive absorption spectrum. Demantoid garnet, possibly the world's loveliest stone, has the deep true green of emerald but a much superior fire. Demantoid turns red

under the filter but usually has some trace of asbestos fibres included, usually of a horse-tail plume in aspect. The high refractive index of 1·88 or higher separates it from emerald. Green zircon is a most attractive stone, which by heft alone should warn the jeweller—however, as it never truly resembles emerald it should give no worry. No reading is possible under normal conditions, either with the standard or spinel refractometer, and a quite distinctive absorption spectrum totally unlike any other green stone helps to distinguish it from emerald. Green zircon remains one of our least appreciated colourful gems. Light grey chalcedony, stained rather bright green by chromium solutions or lesser apple-green by nickel solution, when seen in a closed setting could be imagined as emerald. The former will appear red under a Chelsea filter.

Fortunately the spinel refractometer serves admirably to show form birefringence typical of the cryptocrystalline varieties of quartz. The fixed reading of about ·004 between refractive indices of 1·530 to 1·540 steer this material away from even the lowest possible emerald reading. This "form birefringence" seen in chalcedonies is not solely typical for quartz familes but can be observed in other materials of mixed varieties. True chrysoprase does not turn red under the filter, because it is not coloured by chromium but by nickel. Chrysoprase is a scarce material, but its indices of refraction and specific gravity are those of stained chalcedony.

Jadeite, cut "en cabochon", when particularly fine could look like an emerald cabochon. When jadeite is so fine it is termed emerald jade or imperial jade. Like emeralds, jadeite owes its wonderful green to chromium.

Fortunately a Lester Benson distant vision refractive index reading will easily differentiate between the mean refractive index of emerald 1·57 (approx.) and jadeite 1·66 (approx.). Jadeite, because of its variable hardness, shows a dimpled surface structure which seems to be a characteristic (when seen) not shared by any other material of similar quality of colour. Jadeite, of course, is much heavier than emerald, its S.G. being approximately 3·33. The absorption spectrum of emerald-green jadeite and fine quality emerald are not easily sorted out by average gemmologists, but the refractometer once again serves as the reliable testing instrument.

Having now thought of most green stones which could, with a little licence, look like emerald (and I don't doubt there are others which do not spring readily to my mind), it behoves us to consider

those stones which literally do look like emerald, have the refractive indices of emerald, turn red under the filter and are often found in an antique setting, foiled or painted. Usually the article is not suitable for immersion and here one has to use skill in determining emerald or not.

At first sight, because of the quality of the mount and intrinsic value of the item, one assumes emerald (mentally noting foiled but possibly even a better colour than immediately apparent). It has been found that some emeralds foiled by the Victorians or having a black matt-finish background as a backing actually prove to be better emeralds when removed from settings. It is usual, though, to find that foiling, backing, etc., are used as a means to accentuate or "improve" that which nature was lax in doing. Since human artifice can seldom vie with nature at her best, it is palpably evident when an attempt has been made to "gild the lily".

Very often when a stone purporting to be an emerald is in a closed setting in an antique piece of jewellery it will often turn red or paler shades of red, red pink, or brown-red, through the filter. This can be misleading, especially if the stone has natural-looking inclusions related to beryl. Then, unless the stone is taken out, it is only possible to deduce emerald by the absorption spectrum by reflected light. Here one finds the Beck intensity-lamp with its focusing device extremely useful for pin-pointing a strong beam of white light on to the stone in question. The spectroscope, held in the white light on to the stone in question. The spectroscope is held in the hand close down to within a half inch of the stone and the slit of the spectroscope slowly carried across, and up and down over the stone in order to pick up the corresponding angle of reflection at its optimum point of light quality. Here, then, when one gets the absorption bright line fluorescence indication of chromium one can say the green stone is emerald, no matter how pale the stone may be. If no chromium spectrum is seen, even though red under the filter and full of natural inclusions typical of beryl, the stone is not an emerald.

The method of using an intensity-lamp to pin-point light specifically on to a backed stone need not be thoroughly followed in detail, since any sort of improvisation will bring results. The set-up used in "Testing a sapphire"[2] with a microscope and flask of water will work quite well if a smaller lens is used to focus the condensed light from the flask onto the stone. Emphasis has been laid in

these instances of backed or foiled stones on obtaining an absorption spectrum by scattered light—obviously stones which are not backed can be treated as with transmitted light through the microscope in the accepted manner. I am fond of coining phrases, but some phrases already coined seem so apt as to defy improvement. Such a phrase, well known to readers of gemmological journals, is "If there's a doubt, have it tested". Never were so few words succinctly coined to describe the many reasons for having all emeralds tested.

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Gemmological Abstracts

NEWNHAM (Robert E.) and co-workers. *Crystal structure, synthesis, and magnetic properties of chrysoberyl.* Laboratory for Insulation Research, Massachusetts Institute of Technology Technical Report 183 (Nov. 1963).

"The study of gems has proven fruitful, not only to the jewelry trade, but to the scientist and engineer as well. Numerous publications describe the properties and applications of synthetic diamonds, rubies, emeralds, spinels and garnets. By comparison, relatively little interest has been shown in chrysoberyl".

Robert E. Newnham and co-workers at the Laboratory for Insulation Research at Massachusetts Institute of Technology have synthesized crystals of yellow chrysoberyl and alexandrite up to several carats by a flux-fusion technique. (A satisfactory composition for producing chrysoberyl was found to be PbO 66·6, Al_2O_3 16·7 and BeO 16·7 mole percentage, for alexandrite $LiMoO_4$ 40·4, MoO_3 50·6, Al_2O_3 : Cr 4·5 and BeO 4·5 mole percentage, the furnace temperature being held at 1375°C for 5 hours in the making of chrysoberyl, and at 1000°C for 2 hours for alexandrite). Chrysoberyl has an orthorombic space group. The authors show that the two crystallographic sites for Al differ appreciably in size and symmetry, and that the trivalent Fe and Cr ions substituted for Al in $(Al,Fe)_2$ BeO_4 and $(Al,Cr)_2$ BeO_4 prefer one of the Al-sites to the other.

Information on colour, pleochroism, inclusions, S.G., R.I. or dispersion is not given. The authors state, though, that further experiments on chrysoberyl, alexandrite, and the isomorphous olivine family are in progress, including optical absorption and fluorescence spectroscopy, besides electron paramagnetic resonance.

U.H.B.

GRANTHAM (D. R.). *The diamond deposits of Panna, Central India.* Industrial Diamond Rev., pp. 30-35, No. 279, Vol. 24. February 1964.

The author of this important article has drawn the facts from official publications and from his own observations made on a recent visit to the area. Panna, in the state of Madhya Pradesh, lies at an altitude of about 1100 feet above sea level, and the diamond fields, which have been known for several centuries, stretch in two belts. The streams of the area drain into the Ganges basin. There are three different types of diamondiferous deposits; pipes, conglomerates and alluvials. The geology of the area is explained and the ancient workings discussed. Full details are given of the Majhgawan pipe and mention is made of a second pipe at Hinota some two miles away from Majhgawan. The second type of deposit, the conglomerates, consists of pebbles of jasper, quartz or quartzite, which are either in fine-grained and loose material or hard-cemented with silica, and some are simply pebbles in shale. The alluvial deposits are extensive and lie along the Baghain river east of Panna. The diamonds found in the Panna region are distinctive for the high degree of curvature of their faces, causing the diamonds to be nearly spherical. Something is told of the colours and qualities of the diamonds found in the area, and of the values obtained. The methods of mining, recovery and the sale of the crystals are given.
5 illus. R.W.

HANNAFORD (G. B.). *Diamond mining and recovery to-day.* Gems and Gemology, pp. 67-79, No. 3, Vol. XI. Fall 1963.

Details of the author's visit to the African diamond mines and fields. The Williamson mine, the pipe mines around Kimberley, the Premier mine and the fields of South-west Africa were those visited. The various mining operations and methods used to recover the crystals are considered in detail.
6 illus. R.W.

CROWNINGSHIELD (R.). *Developments and highlights at the Gem Trade Lab. in New York.* Gems and Gemology, pp. 88-87, No. 3, Vol. XI. Fall 1963.

Records interesting items which have been handled by the New York laboratory. A blue sapphire intaglio, a crystal-like

bubble seen in a glass stone, wear on the facet edges of a diamond, growth lines in another diamond and some notes on orange-coloured cyclotroned diamonds are mentioned. A bluish-green treated diamond which transmitted light beyond 7000Å and which showed clearly lines at 7350, 7230 and 6700Å with a moderate line at 4300Å, and also the unusual behaviour of a highly conductive grayish-brown diamond were two other interesting items. Mauve-dyed jadeite, tinted amber, surface-stained limestone beads imitating dark-blue turquoise, dyed lapis-lazuli and an eight-foot long necklet of jet are mentioned. Red-brown quartz crystal groups (ferruginous quartz) which had been mounted on a chain bracelet, treated opal and new types of synthetic emerald are also mentioned.
12 illus. R.W.

LIDDICOAT (R. T.). *Developments and highlights at the Gem Trade Lab. in Los Angeles.* Gems and Gemology, pp. 88-92, No. 3, Vol. XI. Fall 1963.

The Gem Trade Laboratory refers to "black pearls" without orient (one in particular being with an almost metallic lustre, having an R.I. of about 1·70 to 1·75 and a density of 1·30), a pearl necklet of Biwa non-nucleated cultured pearls and a large Tridacna pearl. Imitations of "cross twin" crystals of staurolite are referred to and notes are given on the ultra-violet transparency test for natural and synthetic emeralds.
5 illus. R.W.

MALES (P. A.). *An unusual colour pattern in precious opal from Andamooka.*

A type of opal with an unusual play of colour is explained as being due either to unreplaced oolites surrounded by a cement of precious opal or to the replacement or partial replacement of the oolites by precious opal. Two references are given.

R.W.

WALKER (W. H.). *A new type of simulated heat-treated "black opal".* Lapidary Journal, p. 655, No. 6, Vol. 17. September 1963.

Opal matrix from Andamooka is treated in order to produce a "black opal". As far as could be found out by the author during a visit he paid to Australia, the method used to treat the opal is as

follows. First the cabochons are cut and polished and then they are heat-treated in an oven under carefully controlled conditions. They are then removed from the oven and placed in a sugar solution for an undetermined time and then into sulphuric acid. This treatment, which is analogous to the production of black onyx, darkens the matrix which brings out the colours of the opal part, which itself is not altered in colour by the treatment. The best stones are those in which the matrix is coloured throughout; when only the surface is coloured black the stones are not so satisfactory.

R.W.

POUGH (F.H.). *The gem collection of the American Museum of Natural History, New York City.* Lapidary Journ., 1964, 18, 1.

A concise account of the gems in the Morgan Hall of the Museum. The collection owes much of its present magnificence to the pioneer work of Dr. G. F. Kunz and to the generosity of J. Pierpont Morgan.

S.P.

JOBBINS (E.A.). *The gemstone collection of the Geological Museum, S. Kensington, London.* Lapidary Journ., 1964, 18, 1.

A description of the gemstones housed in the museum and the methods of displaying them. The coloured illustrations of gems, which are included with the article, are better printed than the museum's own sheet, well known to U.K. gem collectors, and which was issued in 1952.

S.P.

NAUSSAU (K.). *Growing synthetic crystals.* Lapidary Journ., 1964, 18, 1.

The first of a five-part series on the growing of synthetic crystals. The two major methods used are growth from solution and growth from melt. Flux growth and the Czochralski technique (a method for the growth of single crystals) are discussed in the first article.

S.P.

BANK (H.). *Fundortsangaben bei Edelsteinen.* Publication of occurrences of gems. Zeitschr. d. deutsch. Gesellsch. f. Edelsteinkunde, 1963, 44, pp. 15-18.

This article discusses the difficulty of finding out where any particular gems have been found. In Africa and South America the author found that either he was not told at all where the gems came from or in the place given no such gems had ever been found; this may be due to the facts that the miners do not attach much importance to the geological question—this is even more true of the dealers, who are also interested that their customers do not know where the stones come from—and also that the gems change hands many times before they are bought by the interested collector. Various examples are given.

E.S.

GÜBELIN (E. J.). *Two new synthetic emeralds.* Zwei neue synthetische Smaragde. Zeitschr. d. Deutsch. Gesell. f. Edelsteinkunde, 1964, 47, pp. 1-10.

Two new synthetic emeralds have appeared on the market recently. Chemically, physically and in appearance they are emeralds. The quality is quite good and may be compared to second rate genuine stones of several occurrences. However, differentiation from genuine stones is easily effected due to lower physical constants and typical inclusions, i.e. lace-like feathers as seen in all synthetic emeralds. Slight variations in the inclusions and of appearance under UV light allow the gemmologist to identify synthetic emeralds of different manufacture.

The first of the new synthetics was described over a year ago by Prof. K Schlossmacher. The producer is W. Zerfass, of Western Germany. The second made by P. Gilson appeared on the market at the end of 1963. It is produced in Northern France. Table 1 shows some of the properties of the Zerfass and Gilson synthetics together with those of the Chatham and IG Farben synthetic emeralds. Apart from the constants and properties listed in the Table, each synthetic displays characteristics which are described in detail. The Zerfass synthetic emerald, with its low refractive index, allowed Prof. Schlossmacher to observe variations of the Becke line effect. These were described in detail by R. K. Mitchell (*Journal of Gemmology*, 1963, VIII, 2, p.280). Schlossmacher also drew attention to the honey-comb pattern of the lace-like

feathers. This pattern can best be seen if the stone is viewed in a direction parallel to the C axis. At right angles to the optic axis the walls of the honey-combs can be seen to be formed by liquid-drop feathers, which consist of parallel channels. The feathers do not penetrate the stone for long distances parallel the C axis but are interrupted and thus form bands and streaks more or less parallel to the basal plane. So far good quality stones up to ½ cts have been produced. Bigger stones have not been satisfactory. The smaller stones described by the author were of a vivid deep blue-green colour similar to genuine Chivor or Gachala Columbian emeralds. They showed distinct dichroism. The author points out that the honey-combs could be observed especially in the centre, creating the impression that a hexagonal cell had existed first and been surrounded afterwards by other prisms. Looked at in this way the crystal growth could be visualised. Parallel to the basal plane the author observed the zonal bands described by Prof. Schlossmacher. Between straight dark lines, bands of different hues of green to colourless could be seen. Most of these parallel layers contained liquid feathers, others were completely clean. This seems to indicate that the synthetic crystals did not grow continually but in stages, depending on the temperature and concentration of the solution. During these periodic intervals germ crystals can be formed which are either emerald (if the composition of the solution remains constant) or phenakite, if the solution lacks aluminium. Most of the layers were under stress, causing cracks into which the solution could penetrate. The cracks could thus partly heal and form the well known feathers. Within the bands the liquid inclusion formed small channels parallel to the C axis, causing a streaky appearance. The arrangement of these parallel feathers is much more regular than in other synthetic emeralds. Tapered tubes were similar to those observed in Nacken and Lechleitner synthetic emeralds. They "stand", probably, on minute phenakite crystals and taper off in a direction parallel to the C axis. These tapered tubes are two-phase inclusions (liquid and gas bubbles) which allow the conclusion that Zerfass made use of a hydrothermal method in contrast to the diffusion-melt method of Chatham.

The Gilson synthetic emeralds display a warm green colour with a yellowish tint and resemble good quality genuine stones from Muzo and Sandawana. They are comparatively clean but still show the familiar lace-like feathers of all synthetic emeralds. The

feathers are similar to those of the Igmeralds or the Chatham synthetic and allow the conclusion that the French product is made by the diffusion-melt method. Accordingly no phenakite inclusion of any size was found.

TABLE 1

COMPARISON OF PHYSICAL PROPERTIES OF SYNTHETIC EMERALDS

Producer	*Refractive index*		*DR*	*SG*	*Fluorescence*		
	ε	ω			*3650Å*	*2537Å*	*crossed filters*
I G Farben (Igmerald)	1·559	1·562	·003	2·65	strong red	strong bright red	glowing red
Chatham	1·560	1·563	·003	2·65	strong red	strong bluish-red	glowing red
Zerfass	1·558	1·562	·003–·004	26·6	strong red	dull bluish-red	glowing red
Gilson	1·558	1·562	·004	2·65	olive green	weak olive-green	glowing red

W.S.

PLEOCHROISM IN CRYSTALS

By J. OSTWALD, B.Sc., F.G.A.A.

Introduction

The phenomena of pleochroism are perhaps so well known to students of minerals that it may seem out of place to discuss them in a scientific journal. Be this as it may, the author, in his studies of the optics of ore minerals was forced to admit to himself that there was more to the subject that what he had learned as a student from the textbooks, and, what was more important, the statements on the subject in some of the older and more elementary texts were definitely incorrect. This short paper then is an attempt to systematize the author's knowledge on the subject. The complete theory cannot be given here, as it involves the electromagnetic and quantum theories, but rather those parts of the subject which are of fundamental importance or are useful in laboratory investigations are described.

Historical

Possibly a study of some of the older texts on mineralogy would reveal the first reference to the phenomenon of pleochroism. Perhaps it was discovered in the same way as the author discovered it, by accident, as a first year student of Geology. He was holding to the light a fine crystal of green transparent aegirine and was surprised to note it change from green to yellow as he rotated it through a right angle. Actually of course, the light reflected from the window glass must have been partially plane-polarized and this explained the colour change. Epidote will give the same effect.

In 1819 Sir David Brewster first noted the "houppes" on the surfaces of a cleavage fragment of phlogopite mica in ordinary light. These dark brushes or idiocyclophonous figures are actually the result of pleochroic absorption.

By 1838 the phenomenon was well known among mineralogists and physicists, for in that year Babinet published the result of his studies of absorption in crystals. He found that most negative crystals—calcite, corundum, tourmaline, emerald, etc.—absorbed to a greater extent the ordinary ray, while most positive ones—zircon, smoky quartz, etc.—absorbed more the extraordinary ray. He thus claimed that the greatest absorption in a crystal coincided

with the direction of greatest refractive index. He also found that certain minerals, mainly red tourmaline and ruby, transmitted rays of their own colour without any polarization.

The invention, in 1845, of the dichroscope by Haidinger is a point of importance in the history of the study of pleochroism. Wilhelm von Haidinger, born in Vienna in 1795, was the son of a famous Austrian mineralogist. After studies at the University of Vienna and the famous School of Mines at Freiberg in Saxony, he travelled widely in England and Europe and in 1840 became director of the Cabinet of Minerals in Vienna. It was while he held this position that he developed the familiar tube with low power eyepiece and iceland spar rhomb for the study of the twin absorption colours of crystals.

In 1880 H. Laspeyres published in the "Zeitschrift fur Krystallographie und Mineralogie" a description of the absorption axes of pleochroic minerals. Just as in the case of refractive indices, he found that certain biaxial crystals had direction of least, intermediate and greatest absorption and, more fundamental, the axes of absorption did not always coincide with the Fletcher indicatrix axes. At this time absorption of monochromatic light was expressed in terms of the coefficient of absorption α where α is defined by the following equation:

$$I = I_o \cdot e^{-\alpha d}$$

where I_o is the intensity of incident light.

I is the intensity of the light after passing through a distance d.

e is the base of Naperian logarithms.

About the same period Mallard proposed his "ellipsoide inverse d'absorption". It we imagine rays of monochromatic light moving radially outwards from a point in a coloured crystal, then if it is anisotropic each ray has its α. If we lay off on each ray a distance proportional to $\frac{1}{\sqrt{\alpha}}$, using the α for that direction then the surface obtained gives us a mental picture of the brightness of rays vibrating in all possible directions in the crystal.

Mallard further recognized three cases:

(*a*) *Singly refracting crystals* — The surface for every colour is a sphere. There is thus no pleochroism.

(*b*) *Uniaxial crystals* — The surfaces are rotation ellipsoid, the rotation axis being the optic axis direction. By the

symmetry of these figures only two values of α are possible for each colour, namely α_1 for rays whose vibration directions are normal to the optic axis and α_2 for rays with vibration directions parallel to the optic axis. But every wavelength has its α_1 and α_2 and thus for different colours the absorption surface has not only a different size but also a different shape.

(*c*) *Biaxial crystals* — For each colour the surface is a triaxial ellipsoid, with axes equivalent to the absorption axes of Laspeyres. In white light the colours arising from the absorption of rays vibrating parallel to these axes are termed axial colours, and at least two observations with the dichroscope for directions at right angles must be made to determine the colours.

In the hand specimen, without the instrument, we can see none of these colours separately. The colour we see is a mixed colour, the facial colour (the Flächenfarbe of Haidinger).

About 1885 Professor P. Groth, of the University of Munich, proposed a modification of Radde's International Colour Scale for the designation of pleochroic colour. This was to consist of wedges of glass of different colours so that the intensity of the colour (measured by the thickness of the wedge) could be stated as well as the colour itself.

Between 1880 and 1900 Voigt and Drude, with the aid of Maxwell's electromagnetic theory, produced the elements of the modern theory of pleochroism and differential absorption in crystals. It is largely on the work of these two authors that the following elementary notes on theory are based.

Theory of Pleochroism

When a ray of monochromatic light of intensity I_o passes into a coloured isotropic crystal its intensity is decreased by (1) scattering, (2) reflection at the crystal surfaces, and (3) atomic absorption. We must neglect (1) owing to the difficulty of its measurement—usually it is small in a clear crystal but must take into account (2). If n is the R.I. of the medium and I_t the true intensity and I_m the measured final intensity then

$$I_t = I_m\left[\frac{(n+1)^2}{4n}\right]^2 \qquad (1)$$

We may measure the atomic absorption by the following equation

$$I = I_o \cdot e^{-(4\pi kd/\lambda)} \tag{2}$$

where k is the absorption coefficient.

According to Drude the R.I. of a coloured isotropic crystal is $n - ik$ where i is the square root of minus one.

In the case of a thin parallel-sided piece of coloured isotropic crystal k may be measured by the formula:

$$k = \frac{2 \log_{10} (1 - R) - \log_{10} D}{4\pi d \log_{10} e} . \lambda \tag{3}$$

where R is the reflecting power of the surface. This may be calculated from Fresnel's equation $R = \frac{(n-1)^2}{(n+1)^2}$ (4)

if k is small, or actually measured with a photocell if k is appreciable. D is the observed transmission ratio, λ is the wavelength, and d is the thickness.

Now on entering a low symmetry crystal (i.e. orthorhombic, monoclinic or triclinic) in general a ray of normal light is split into two elliptically polarized waves. The two ellipses have the same ellipticity but have their axes at right angles. In certain directions (the plane polarization cones of J. Woodrow, 1950) the ellipses degenerate into lines and the crystal transmits two plane-polarized waves. These crystals have also four rotation axes in place of the normal two optic axes. For a fuller description of the transmission of light by coloured crystals the reader is referred to the paper by the author in this journal July, 1962.

Pleochroism is generally stated in a qualitative way by stating the colour for vibrations along the principal axes of the indicatrix and also by noting any difference in intensity, e.g. tourmaline: e yellow, o brown, $o > e$.

For measurements of a quantitative nature the pleochroism is stated as $k_1 - k_2$ where 1 and 2 may be any of the symbols ε, ω, α, β, γ, the use of which in relation to refractive indices of crystals, is well known. For example in the case of a red ruby measured by J. A. Mandarino, at 5000Å, $k_\omega = 104 \times 10^{-6}$, $k_\varepsilon = 75 \times 10^{-6}$ and thus, at this wavelength $k_\varepsilon - k_\omega = 29 \times 10^{-6}$. This is the biabsorption. To be of any practical value curves should be plotted showing the variation in k_ε and k_ω across the spectrum and thus the range of biabsorption.

It might be well here to digress a little and distinguish between dichroism (the simple case of pleochroism now under discussion) and dichromatism. In the first case the transmitted colour depends on the appropriate value of k, which depends strictly on Beer's exponential law. Thus the greater the thickness the greater the saturation of the particular colour. In the case of some crystals, such as alexandrite, and some organic solutions, such as cyanine and nitroso-dimethyl aniline in alcohol, the above law does not appear to hold true. In these the colour depends on thickness. For thicknesses greater than the critical thickness the substance is red, for lesser thicknesses it is green. Not only these two colours are possible—cyanine layers and cobalt glass sheets can show either red or blue. In alexandrite the intensity of the green is greater than that of the red. If we use the old-fashioned term co-efficient of transmission "a" where $I = I_o \cdot a^x$ (5)

with the usual notation with x as a thickness then we may assume that a_g (coefficient of transmission for green light) is less than a_r (coefficient of transmission for red light).

Thus for small thicknesses $I_g \cdot a_g^x$ will be greater than $I_r \cdot a_r^x$ and the reverse for thick layers. At a thickness equal to x, the

Critical Thickness defined by $x = \dfrac{\log I_g - \log I_r}{\log a_r - \log a_g}$ (6)

the intensities of the red and green will be equal. More important in our case is the fact that, for any thickness, the transmitted colour will depend on the incident light. This is the cause of the change in colour of alexandrite.

Biabsorption may be calculated from the intensities of transmission by the use of the following formula (given for uniaxials).

$$k_\varepsilon - k_\omega = \lambda . \frac{ln\ (I_\omega / I_\varepsilon)}{4\ \pi\ d} \qquad (7)$$

Another (unrelated) phenomenon is mentioned by Weinschenk. This is pseudodichroism, which occurs in colourless crystals and is probably a diffraction effect. If the crystal contains a large number of oriented inclusions with R.I. markedly different from that of the crystal, then rays vibrating parallel to the direction of the inclusions are dispersed, while rays vibrating at right angles are not effected. Weinschenk lists brown and grey as possible colours, and this is perhaps independent of mineral or R.I. difference between inclusions and mineral.

LABORATORY MEASUREMENT

In this Journal for July, 1961, p. 86-87, E. J. Burbage and T. G. Jones advocated the use of a cadmium sulphide photocell for the quantitative measurement of pleochroism. This idea is not new, for as far back as 1934 Vogel investigated absorption in ruby and emerald with a photocell. In both cases absorption is indicated only by galvanometer reading.

One of the greatest difficulties in the measurement of pleochroism is the fact that a parallel sided sheet of the material of known thickness must be studied. This is not an impossibility in the case of uncut natural crystals as sets of parallel facets may be cut at critical positions on the crystals, or actual slices cut from them in these directions. But in the case of specimen crystals and cut gemstones (except perhaps some emerald—or trap—cut stones) parallel surfaces are not usually present, and, if by accident they are, they are not usually in critical positions.

Of the laboratory methods the Mandarino or double image method is the simplest. Here the pleochroic sheet is arranged between a monochromatic light source and a Wollaston prism. When the vibration directions of the prism and sheet are parallel two images are seen in the eyepiece. One image represents the intensity of light transmitted by the ordinary ray of the sheet, the other by the extraordinary. A nicol (between eyepiece and Wollaston prism) is now rotated from zero until the two images are equal in intensity. Now $\frac{I_\omega}{I_\varepsilon} = \tan^2 \alpha$ (8)

where α is the angle of rotation of the polar for equal brightness.

If the two images are of unequal brightness before the pleochroic plate is introduced then the nicol may have to be rotated from zero by a small angle β.

If so,

$$\frac{I_\omega}{I_\varepsilon} = \tan^2 \alpha \cdot \cot^2 \beta \tag{9}$$

from this we obtain

$$\frac{I_\omega}{I_\varepsilon} = e^{-(4d\pi/\lambda)\ (k\omega - k_\varepsilon)} \tag{10}$$

from which the biabsorption may be found. This gives the value for one wavelength. To be of value the variation across the whole visible spectrum should be measured and plotted graphically.

Conclusions

It is not the object of this paper to go more deeply into such interesting aspects of the subject as the interference figures of pleochroic crystals, the possibilities of katoptric measurements or Drude's classification of absorbing crystals. Rather its purpose is to demonstrate the complexity of what is often passed over as a simple property of some coloured minerals.

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ASSOCIATION NOTICES

TENTH ANNIVERSARY OF THE DANISH GEMMOLOGICAL ASSOCIATION

To celebrate the tenth anniversary of the Danish Gemmological Association, an invitation was extended to B. W. Anderson to give a talk to assembled members in Copenhagen on 7th March.

After an excellent dinner, for which the menu began with " Soup Aventurine " and continued with " Roast Pork Ribbon Agate ", etc., Mr. Anderson was invited to talk for as long as he pleased around the general title " Some stories from London's Precious stone Laboratory ". Under the influence of an interested and friendly audience, and with no sense of the pressure of time, the talk extended to three hours. The great debt that the Danish Association owes to the enthusiasm and guiding influence of Mr. Ove Dragsted was mentioned by Mr. Jorgen Möller in a short after-dinner speech.

GIFTS TO THE ASSOCIATION

The Council of the Association is indebted to Mr. S. Barczinski, F.G.A., Rio de Janeiro, for a gift of a Brazilian blue apatite crystal and a green beryl crystal.

OBITUARY

John P. Turton, F.G.A. (Diploma 1962), March 1964.

REQUIRED BY THE ASSOCIATION

Back numbers of the *Journal of Gemmology* from 1947 up to and including Vol. IX, No. 1 (January, 1963) are required. Please send details to the Secretary of the Association.

LETTERS TO THE EDITOR

DEAR SIR,

Mr. R. Webster's article on "Composite Stones" in the January 1964 issue brought back memories of my apprenticeship days in the Jura mountains, after the First World War.

After the day's work and our evening meal, a small pile of doublet moulds were put on the kitchen table, together with a packet or two of thin slices of garnet

and also a mound of glass squares. Everyone sat down to their respective job, even neighbours who called in to pass the evening with us. Some put in the garnet, others would place a piece of glass on top.

The moulds were made of baked clay, measured about 16″ × 10″, and the number of indentations to take the doublet depended on the size required. I recall making doublets size SS4. One had to be young and have good eyesight to undertake such trying work. Actually, it was a very pleasant way of passing an evening, refreshments were ad-lib and the conversation always interesting and amusing.

Friday was an important day, the kiln was stacked with the prepared moulds, the fire lit and heated to the correct temperature. Best of all, the fire heated the water system and we were able to have our weekly bath, this, in the heart of the mountainous countryside was certainly a luxury in those days.

Next morning the moulds having cooled, were removed, the results put into their different colours and sizes ready to be given to the local craftsmen who cut them in their homes. Cutting was then a homecraft.

Perhaps the following will help Mr. Webster with his dates. Firstly, in my opinion the sales of doublets began to slacken about 1923, synthetic stones having then become so cheap that doublets were not worth making.

Again, I have been in communication with an elderly relative who is now 84 and she remembers working on the moulds as a child, shall we say, 10 years of age? This takes us back to 1890.

For further proof I quote from a little known book, "L'Industrie Lapidaire" by G. Burdet, who in chapter 6 attributes the invention of the doublet, as we know it, to Cartier, lapidaire de la Combe de Mijoux, in 1845.

Yours faithfully,

April, 1964. FRANK E. GOLDIE.

Mr. Axon and the Scientific Gemmologist

DEAR SIR,

On reading Mr. G. V. Axon's interesting article in the April *Journal*, many gemmologists will be inclined to echo the sentiments incorrectly attributed to Voltaire in disagreeing whole-heartedly with his opinions, whilst stoutly upholding his right to express them. Many worthy gemmologists are no doubt lamentably shaky on the subject of petrogenesis, and it is arguable that, given infinite time, a sound knowledge of geology, physics, and chemistry would provide a useful basis for one's gemmological studies. However, like the Lesser Sacraments in Anglican theology, these studies, although valuable, are not essential to salvation, and, having regard to the complexity of modern science, Mr. Axon's programme for extended education into the basic drills is Utopian rather than practical. After all, one may legitimately use a table of logarithms when remaining blissfully unacquainted with the exponential function, and a total ignorance of colloid chemistry does not inhibit one from becoming a competent photographer.

It is to be hoped that Mr. Axon's thesis that a divergence exists, and will develop, between "trade" and "scientific" gemmology is without foundation, as

such a development would not be in the interests of the trade, or of science. Moreover, it will be an unhappy day when the gemmologist has to rely on complex and expensive gear of the type described. Such apparatus could be owned only by a very few lavishly-endowed institutions, where, one suspects, the average gemmologist would be *persona non grata*. Much worthwhile research has been carried out by pioneers using means of the crudest and most makeshift character, and one instinctively feels that advances in gemmology may more hopefully be expected from workers who look to Woolworth's for experimental material, rather than in the direction indicated by Mr. Axon.

Yours sincerely,

E. S. BURBAGE

May, 1964. THOROLD JONES.

HERBERT SMITH MEMORIAL LECTURE 1964

The 1964 Herbert Smith Memorial Lecture was given by the President of the Association, Sir Lawrence Bragg, F.R.S., on Thursday, 9th April, at the Royal Institution, Albemarle Street, London, W.1.

Sir Lawrence spoke about "Early problems with minerals and how ideas about their structures came into being", and explained how his school in Manchester 30 years ago had played a big part in establishing the structure of minerals. The lecturer pointed out that the earth's crust was very thin in relation to the whole mass of the earth and that in this crust were some 92 elements; were they all to combine with each other there would be an infinite number of compounds. There was no such infinite number. The truth was that the minerals were limited in number and indeed only half-dozen or so minerals composed most of the earth's crust.

Minerals are typical inorganic bodies. From the ph6sicist's point of view this implies that they are composed of charged atoms or "ions". A redistribution of the electrons between the atoms takes place in such a way that each atom, by gaining or losing electrons, attains a number appropriate to a structure in a symmetrical state; symmetry leads to a structure of low energy and hence stability. In an organic compound electrons are shared between atoms, and this implies bonds as if the atoms were riveted together at definite points. In the inorganic structure, on the other hand, there are no such bonds. The ions are held together by the attraction of positive and negative charges. They are quite free to move relatively to each other, as if they were slippery spheres. The condition for stability is that the electric field between them should have as low an energy as possible.

This basic physical character of inorganic bodies is the prime reason for the existence of a limited number of minerals. Only certain patterns of ions fulfil the condition of lowest energy, which must hold for bodies of the lasting nature of minerals. It is just these patterns which one finds in nature.

The greater part of the earth's crust is composed of silicates, and the silicon-oxygen pattern is the backbone of the mineral. The ratio of silicon to oxygen varies from one type of silicate to another, but it is found that invariably every silicon atom is surrounded by four oxygen atoms at the corners of a tetrahedron. In some minerals such as olivine this corresponds in a simple way to the formula (e.g. Mg_2SiO_4) and analysis shows in fact that there are independent SiO_4 groups. In others the proportion of oxygen to silicon is less than 4 to 1, but the tetrahedral groups are still there. The lower ratio is realized by a sharing of oxygen atoms between neighbouring groups, and it is the extent of this sharing which determines the characters of the main groups of silicates. This was illustrated by means of tetrahedral groups attached magnetically to a board. There are separate tetrahedra (olivines), tetrahedra linked in strings (pyroxenes and amphiboles, asbestos), tetrahedra in sheets (mica, talc, clay) and tetrahedra attached by all corners in a three-dimensional framework (feldspars and zeolites).

The feldspars were very common minerals and very light, which accounted for their being found on the surface of the earth's crust, as distinct from the denser minerals which only appeared when thrust to the surface by volcanic eruption or similar phenomena.

It had been a long standing puzzle that in the feldspars one had crystals of identical chemical constitution and very similar form, but widely different optical properties. An X-ray study has showed that this was due to what is generally known as the "order-disorder" phenomenon. The nature of this phenomenon is spectacularly shown by iron. Below the "Curie Point" iron is highly magnetic because the atomic magnets are aligned parallel to each other in "domains". Above the "Curie Point" the heat motion destroys the order, and iron ceases to be ferromagnetic. To demonstrate this a powerful magnet was suspended above a sheet of asbestos. A lump of red hot iron was placed on the asbestos and while the red heat remained the iron was not attracted to the magnet. As soon as it had cooled sufficiently for its structure to return to the normal state, it was attracted to the magnet with a loud "clunk".

The order in the case of the feldspars is one of arrangement of the iron and aluminium atoms in its framework. At high temperatures these atoms replace each other in a random way. At low temperatures they are in ordered arrangement. It requires the vast times of geological ages to attain this order. A study of the feldspar gives an indication of the conditions under which it was formed.

The lecturer also referred to the curious character of some of the platy structures, the clays, which had a different character on one face from that on the other. This led them to curl up like drying sheets of bread and butter, and hence to crystallize very imperfectly. Clay hence consists of minute spangles, a most fortunate circumstance for life because the finely divided clay sheets held the elements on which plants depend for their food.

In summary, minerals are characteristically structures in which the atoms have been so arranged as to be in a state of the lowest possible energy. Since any rearrangement of the atom would lead to a state of greater energy, they are extremely stable structures which indeed they must be to have lasted in the earth unchanged for so long a time.

Minerals stand at the opposite extreme to the organic structures of living

bodies, where the directed bonds between atoms make structures possible which are very far from being ones of the lowest energy and are of the greatest complexity In contrast with these living structures, a mineral, just because it is so perfect, obeys such rigorous laws, and is so incapable of change for the better, is the most dead thing we can imagine.

Mr. B. W. Anderson proposed a vote of thanks to Sir Lawrence and said the audience were greatly indebted to the President for providing them with such an interesting and entertaining evening and in explaining in a manner which enabled everyone to understand something about the structure of minerals.

ANNUAL GENERAL MEETING

The Thirty-Fourth Annual Meeting of the Association was held at Saint Dunstan's House, Carey Lane, London, E.C.2, on 15th May, 1964. Mr. F. H. Knowles-Brown presided and in commenting upon the work of the year suggested that demand for services might outweigh the strength and resources of the Association in the future. He recalled that 1963 marked the 50th anniversary of the first gemmological examination. It was well, he said, to consider the progress that had been made during those 50 years and the problems which expansion would bring in the future.

The audited accounts and annual report were adopted. The following Officers were re-elected:—

President:	Sir Lawrence Bragg, F.R.S.
Chairman:	Mr. F.H. Knowles-Brown
Vice-Chairman:	Mr. N. A. Harper
Treasurer:	Mr. F. E. Lawson Clarke.

The Chairman said they were very grateful that Sir Lawrence, who had so kindly given the Herbert Smith Memorial Lecture this year, was continuing as President.

The following Fellows were re-elected to the Council:—

Miss I. Hopkins, Dr. E. H. Rutland and Mr. W. C. Buckingham.

Messrs. Watson Collin & Co., chartered accountants, signified their willingness to continue as auditors to the Association.

TALKS BY MEMBERS

CAIRNCROSS, A., " Gemstones ", St. John's Episcopal Mothers' Union, 8th January; Pitlochry Rotary Club (Pearls), 14th January; St. Andrew's Church W.G., Blairgowrie, 20th January; North Kirk Mothers' Union, Perth, 5th February; Wilson Church W.G., Perth, 18th February; St. Leonards Youth Fellowship, Perth, 23rd February; Balbeggie W.R.I., 12th March; St. John's Episcopal Young Wives, 18th March; Brighter Moments, Wilson Church, Perth, 25th March; Glencarse W.R.I., 6th April; Meikleour W.R.I., 8th April; Balmerino W.R.I. (Scottish stones), 13th May; Handicapped Children, Blairgowrie, 21st May, 1964.

CAFFELL, E.W., "Gemstones and the story of diamonds", '61 Fellowship and Senior Anglican Young People's Association, Cobham, Surrey, 19th April, 1964.

MIDLANDS BRANCH

Mr. Robert Webster was the speaker at a meeting of the Branch held in Birmingham on the 12th March, 1964. His subject was "Some Highlights in Gemmology; old and new". Mr. Webster referred to the 18th Egyptian dynasty, a time when the colour of stones was more important than their genuineness. He surveyed the introduction of reconstructed rubies towards the end of the 19th century, which were superseded by synthetic corundum produced by the Verneuil method. Reference was also made to the discovery of new gemstones, such as Brazilianite (1944), Taafeite (1945), Painite (1957), Ekanite (1953).

Mr. W. A. Perry proposed a vote of thanks to Mr. Webster.

Branch members then inspected a fine collection of both rare and beautiful gems which Mr. Webster had brought along.

The evening concluded with a stone quiz, arranged by the Secretary, in which Mr. C. Drapkin received 1st prize.

* * *

Mr. J. R. Shaw presided at the annual meeting of the Midlands Branch of the Association held at the Imperial Hotel, Birmingham on 17th April, 1964. The Chairman reported on the past year's activities, which included the Herbert Smith Memorial Lecture, held for the first time in Birmingham. The speaker on this important occasion had been Mr. E. D. Lacy, of Birmingham University. At the Autumn Meeting, Mr. N. A. Harper gave a very instructive lecture on " The classification and grading of diamond crystals ", and in November a dinner and cabaret at " La Reserve " had been enjoyed by members and their friends. The new year commenced with a most lively Branch Meeting in the form of an open forum. In March, Mr. Robert Webster addressed the Branch with interesting highlights in gemmology.

During the past year, the British Association for the Advancement of Science had given approval for the Branch to become affiliated to its own West Midlands Branch.

The following officers were elected: Chairman, J. R. Shaw; Deputy Chairman, W. W. Bowen; Vice-Chairman, N. A. Harper; Committee: Messrs. G. W. Davis, K. Hoskyns, D. E. Price, P. W. Spacey. Ex officio: Messrs. W. W. Bowen, A. E. Shipton, T. P. Solomon; Secretary, Mrs. S. E. Hiscox.

The evening then concluded with two films: " Brilliant Fire "—the formation of diamond and its mining through to cutting; and " A hundred Million to One " —mining and recovery of diamonds from desert coast of South West Africa.

Mr. P. Spacey on behalf of members present thanked Mr. Solomon for bringing along his projector and equipment and for making this film show possible.

PRESENTATION OF AWARDS

A reunion of members and the presentation of the 1964 awards will be held at Goldsmiths' Hall, by kind permission of the Wardens, on Monday, 26th October, 1964.

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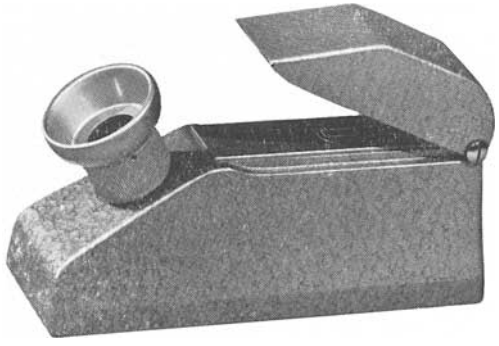

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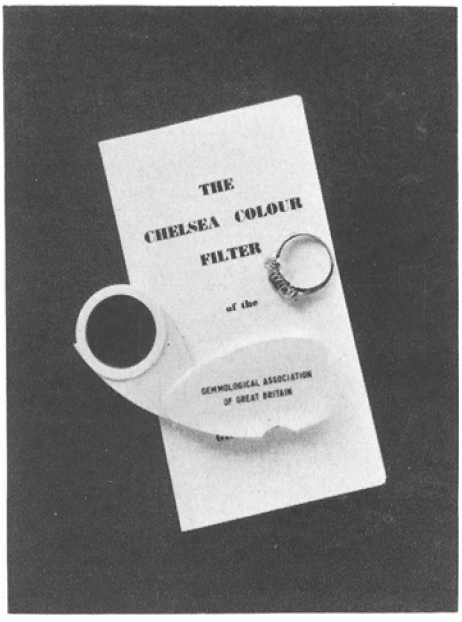

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THE JOURNAL OF GEMMOLOGY

and

PROCEEDINGS OF THE
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COSMETICS AND GEM MATERIALS

By R. WEBSTER, F.G.A.

LITTLE has been recorded in literature of the possible effects on certain types of gem materials and pearls by the action of cosmetics used in beauty treatments, despite the fact that the embellishment of the natural appearance of women, and men, by the application of various preparations of mineral, animal and vegetable nature have been used since prehistoric times. The extensive use of the modern artificially made products used in beauty treatments to-day makes consideration of their effects of some importance.

It is quite clear that no harm will come to those gemstones cut from single crystals, except that the greasy components of some cosmetics may adhere to the setting and backs of the stones causing them to lose their brilliancy. This, of course, is most important with diamond, a stone which collects grease so readily, and whose optical properties depend so much on the total internal reflection of light from the rear facets. Periodical cleaning is the answer here, and as this should be done anyway, there is no problem.

Those gem materials which are to some extent porous (and, indeed, these are the gems which can be artificially coloured by stain or dye) are obviously those most likely to be adversely affected by the haphazard use of various cosmetic preparations. The most important of such gems are pearl, turquoise, opal and jade, and possibly agate and coral. Pearls are the most likely to suffer damage owing to the nature of their structure and to the fact that in

the case of necklets especially, and to some extent earrings, they, when worn, lie close to the skin or hair.

When it is realized that cosmetic preparations cover such fields as hair dyes and bleaches, depilatories, skin creams and face powders, hair-setting lotions and sprays, as well as eye shadow, lipstick and nail varnishes, and that each manufacturer has a different formula for his various products, it is obvious that any complete investigation would need the full time services of several workers. This, from economic considerations alone, would be out of the question. Some experiments and some actual cases which have been investigated and which have been reported from other workers are here recorded.

Pearls

Experience has shown that there are two distinct ways in which cosmetics can affect pearls. These are surface contamination and contamination which has worked inwardly through the string canal.

Surface contamination mostly occurs through the use of hair-setting sprays, perspiration deodorant sprays, and atomized perfumes. Hair-setting sprays often contain a synthetic cellulose derivative, such as methyl cellulose, and this, if used when pearls are worn, may give a coating of lacquer to them. Such an accidental "lacquering", as has been shown by experiment, so coats the pearls that a pin drawn across the surface will "dig-up" this coating in a similar manner to the effect shown when a pin is pressed against a solid glass type imitation pearl. Further, this coating tends to mask the "suture marks", that is the overlapping edges of the aragonite platelets, and this also tends to give the impression that one is dealing with an imitation pearl.

When this extraneous coating ages, or has collected on the pearls rather as droplets than as a complete covering, the coating may peel or flake off and give the impression that it is the pearls that are flaking away. It is well for the jeweller to be mindful of this, as it has not been unknown for a customer to complain of this "flaking" of her pearls.

The second type of contamination, inwardly, may be illustrated by an actual case where an investigation was carried out. Briefly, a cultured pearl necklet was restrung by a jeweller on behalf of a customer and after about three months had elapsed the lady brought the necklet back and complained that since the pearls had been restrung a number of pearls had turned to a blackish colour. The

jeweller's assistant who saw the lady fully agreed that some of the pearls had blackened and asked her to call again and discuss the matter with the manager. Instead of so doing the lady took the necklet to another jeweller, who had previously valued the necklet for insurance purposes. As would be expected the value now placed upon the necklet was considerably less than before, whereupon the indignant lady took the pearls to the local police station and lodged a complaint against the first jeweller.

The police interviewed the jeweller and suggested that a laboratory investigation should be made. The necklet, now in pieces, for the police had cut from the necklet all the blackened pearls, came into the hands of the writer for an investigation as to the cause of the blackening of the pearls. From previous experiments it was known that some pearls appear to darken by possible sulphiding of a metallic compound, which may have adventituously been taken up by the organic part of the pearl, or by dirty grease entering the pearl through the stringing canal. There is a further, but unlikely, contingency that silver nitrate, which is used in some hair dyes, might be the activating factor, just as it is used for dyeing pearls black.

Examination of the string of the necklet under investigation showed some grease to be present, and that the snap itself was covered by grease, and to such an extent that one of the diamonds set in it was completely covered and could not be seen. Grease was evidently the answer here, but for completeness of the investigation a test for sulphiding was carried out. This gave a negative result.

Some of the discoloured pearls were then degreased by using a Soxhlet extraction apparatus. After this treatment the pearls were found to be much whiter, and grease was recovered from the solvent used for the degreasing.

What had happened here was that grease, presumably from cosmetic creams, had entered, by capillary attraction, along the stringing canal and up and around the discontinuation layer between the bead nucleus and the outer nacreous layer. The grease had darkened, owing to ageing and admixture with dirt, and this showed through the translucent pearly outside layer and made the pearls appear dark coloured.

Turquoise and Jade

Most turquoise has been treated in some way to improve the

colour and substances used for this treatment may be affected when cosmetic preparations get on to the surface of the stone. Even good coloured non-treated turquoise may be affected by certain cosmetics. Robert Crowningshield refers to a case in which turquoises had discoloured, apparently from the effects of cosmetics. There has been no report that jades have been affected by beauty preparations, but as jadeite can be dyed, deleterious effects could conceivably occur with this material.

Chalcedony

The only case of possible attack by cosmetics on chalcedony was one referred to the writer some time ago, and for which, at the time, no decision was reached, particularly as the change seemed so fantastic. Here, a ladys' signet ring, set (presumably) with a black onyx, was submitted for investigation. The story which came with the enquiry was that the black stone was originally red (cornelian or stained agate) and had turned black. The owner of the ring was said to be a hairdresser and it was questioned whether chemicals used for hair-treatment could have caused the change of colour. No information was given as to the nature of the chemicals used, or the type of hair-dressing preparations used by this hairdresser. The only question asked was whether such an occurrence had been encountered before. To the best of my knowledge it had not, or at least had not been reported, and the matter rested there.

However, intrigued by the effect which, presumably, had occurred with the stone in the lady's ring, some experiments were carried out. A piece of cornelian, probably dyed agate, was immersed in a tube of 25% sodium sulphide and left for some time, after which it was removed and dried. No apparent effect was then noticed, but some time later, after the stone had lain on a shelf open to daylight, the stone was seen to have darkened, but admittedly did not turn black but to a very dark brown. The notion underlying this experiment was that as the colour of cornelian was due to iron, the action of the sodium sulphide might produce the black ferrous sulphide (FeS).

To perform the second experiment a small piece was broken off from the blackened specimen and immersed in a 20-volume solution of hydrogen peroxide and left for twenty-four hours. On the removal of the piece from the solution it was seen that it had returned to the original reddish colour, that of cornelian. Another piece

was broken off the darkened specimen and immersed in ordinary tap water in order to check whether the darkening was just surface deposit which could be washed off. No lightening took place even after three days immersion. Whether the hydrogen peroxide solution would return the colour when other dyes were used is a matter for debate and further experiment.

To get further information the writer approached the technical staff of Golden Ltd., the makers and distributors of the hairdressing products of L'Oreal of Paris, who were good enough to submit specimens of cornelian to treatments with some of their products. These tests involved immersion in samples of *Pastel* and *Progress* cold-wave lotions, *Ciloreal* skin-stain remover, and a number of basic chemicals used in the manufacturing of L'Oreal products, both for hair colouring and permanent waving. Tests were also carried out by the Golden technicians with a 10% sodium sulphide solution; and one stringent test was with a *Pastel* cold-wave No. 1 at a temperature of 75°C. for eight hours. On the return of the stones, in no single instance was any blackening of the stones noticed. Later, however, after the stones had been kept in a stone paper for a few months, two of the pieces did seem to have somewhat darkened in colour, but they certainly had not turned black.

It is clear from the above that any change in the colour of cornelian could only occur after prolonged treatment, as in the case of the hairdresser who could well be using cosmetic chemicals daily, and would anyway be of rare occurrence, and not an expensive item to replace, but it does illustrate what troubles can be encountered.

The object of this article is to warn the jeweller that cosmetics, when incorrectly used, may have a deleterious effect on certain types of gem materials. This is no criticism of beauty preparations in themselves when they are used with common sense, but so often ladies are oblivious to the fact that they are wearing their jewellery when completing the final touches to their make-up; then the jeweller is challenged as to the resultant changes.

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MINERAL NOMENCLATURE AND THE GEMMOLOGIST

By B. W. ANDERSON, B.Sc., F.G.A.

GEMMOLOGISTS are well aware of the difficulty in attaching a universally accepted meaning to certain names of precious stones. "Topaz" is one outstanding example, though here at least the weight of informed opinion is all on one side, and in time the problem will be resolved by limiting the name to the rarer of the two claimants. Attractive and ancient names like "jacinth" and "chrysolite" have been virtually abandoned by gemmologists because of their ambiguity.

Terminology in mineralogy has usually been more precise and systematic, but even mineralogists have had, and continue to have, their troubles over names. Many even of the well-known species, for instance, are known by different names of almost equally respectable lineage, though it is not of course so dangerous to have two or more alternative names for the *same* species, as to have one and the same name for *different* species.

There now exists an international "Commission of New Minerals and Mineral Names", which is attempting to resolve old difficulties and to prevent new ones arising. The Council of the Mineralogical Society of America now urges authors of papers describing new minerals submitted to the "American Mineralogist" to submit any proposed new mineral names to the Commission prior to publication.

The Commission now publishes an annual review of approved and disapproved names, and also a review of agreements reached, either unanimously or by a large majority, on older alternative names. Decisions reached for the years 1959, 1960, and 1961 are summarised on pages 223 and 224 of the *American Mineralogist* for Jan./Feb., 1964.

Ekanite is the only new species name for a gem material in the period under review. Henwoodite (a name suggested for Cornish turquoise) and the unlovely "shattuckite" are names for gem materials which are now discredited.

Some decisions reached on older alternative names are of some interest to gemmologists. The following, for instance, were among those unanimously agreed:—
Feldspar, not felspar; grossular, not grossularite; hematite, not oligiste; hemimorphite, not calamine; spessartine, not spessartite; spodumene, not triphane; wernerite to be the species name, scapolite the group name. And, by a large majority, the following:—Orthoclase, rather than orthose; rhodochrosite rather than dialogite; sphalerite rather than blende. No agreement was reached concerning alternative names for idocrase, kyanite, and sphene—while iolite = dichroite = cordierite does not seem to have been discussed.

AN OLD FRENCH BOOK ON GEMMOLOGY

By A. E. FARN, F.G.A.

"C'est presque toujours du Pérou que nous sont venues les plus belles émerauds que nous voyons dans le commerce."

Thus wrote Placide Boué[1] in Paris, in the early part of the nineteenth century, in his second tome of a series on goldsmithing, the jewellery trade and gemstones.

Today, whilst not actually coming from Peru, it is true that the world's finest emeralds are found in Colombia, S. America. Discussing emerald Boué writes that it is a little harder than quartz but scratched by topaz. Emerald, he states, has a "pesanteur specifique de 2·72", which is a very readily recognizable figure for the specific gravity of emerald.

No confusion need arise between green tourmaline and emerald, he states, since the specific gravity alone suffices to distinguish it. There are literally literary gems in abundance in this discourse and he is obviously a man of very sound gemmological persuasion. Discussing the habit of applying the term "noble" to a stone free from flaws and of good colour he derides the term as meaningless and puerile—emphatically stating, "Ne point surcharger notre memoire de noms insignifiants". This, as a broad truism, could be usefully taken by some authors who have to perpetuate fancy misnomers or coin a new name for an old stone. Speaking of

peridot, Boué says "il jouit de la double réfraction à un très haut degré", which sounds very exciting compared to our distinct double refraction.

This old book is very much in accord with today's gemmological thinking. There are very many diagrams and scale drawings of carat sizes and cuts together with a full list of specific gravities and characteristics. It is a book one can pick up, open a page at random and become immersed in touchstones for testing gold or details of unusual stones specifically included to help out with a jeweller's alphabet or word manufacture. Even in those days they had trouble with U, X, Y and Z. There is little doubt that Placide Boué was something of a rarity—a learned gemmologist who was a jeweller, whereas today gemmology suffers from an overdose of scientists often out of touch with the trade which made gemmology possible.

"Une odeur aromatique très agréable" is what one discovers on burning amber, which gives the description a little headiness not unassociated with French perfumes. In those days most people quite happily rubbed their amber pieces and attracted small pieces of paper to them, and this amazing fact seemed satisfactory as proof of amber.

All told then this is a well written authoritative book, refreshingly tackled, very much in advance of its day.

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CULTURED PEARLS FROM HONG KONG

Cultured pearls from the farms established in the Tolo Channel and Port Shelter areas of Hong Kong were harvested in the first part of the year. The first farming is reported to have produced spherical cultured pearls of good quality. Blister cultured pearls were also collected.

A FEW UNUSUAL ITEMS

By G. V. AXON, F.G.A.

CURIOUSLY enough, there seems to be a tendency among jewellers, mineralogists, and some gemmologists to refer in a rather casual and slighting manner to odd stones which are often called "stunt stones" or "whims". It is queer that this should be the case, for some of these unusual stones could well find their way into jewellery, and it is a hundred-to-one against any average jeweller recognizing them for what they are.

What is more, many of them have quite a distinctive beauty, and in a world which is becoming more and more a mass-produced and mass-educated culture, it might be thought that something unusual and beautiful would be appreciated.

The fear among mineralogists seems to be that a fine crystal will be destroyed to produce an almost worthless gemstone. Jewellers may be secretly worried that they will be "taken". Gemmologists may be concerned that they will not recognize something without a great deal of testing.

Among keen lapidaries, of course, any mineral offers a great challenge, not only in the cutting but in the polishing to bring out the full beauty of the stone. Even colourless minerals with little else to recommend them may become quite attractive when correctly cut. After all, it is not too difficult to obtain a dioptase crystal, but how many cut dioptases are there? How many faceted dolomites? Or clear rhodochrosites? The answer is not very many. Faceting and polishing dioptase is surely a very highly skilled business, and it seems not unreasonable to regard a faceted dioptase with some respect.

Comments on a few recent unusual personal acquisitions are given below:

Ajoite, a copper aluminium silicate from Ajo, Arizona, is a fairly recent mineral, having been discovered about six years ago. It produces a very attractive blue cabochon hardly distinguishable from shattuckite and planchéite.

Amazonite can hardly be called a curiosity, but it certainly is a rare stone in its crystallized form. Broken Hill, Australia, seems to provide a few such crystals from time to time, and they yield smallish stones looking rather like pale emeralds.

Apatite, too, is hardly a rarity except in various varieties, such as the fine colourless crystals from the Tyrol and the bright green stones from Burma. The usual green of apatite is hardly very attractive, but the bright green more resembles a very fine tourmaline or chrome diopside.

Axinite, also, is not usually considered rare, at least in the United States, for there seems to be a fairly steady supply of crystals from Mexico which yield small flawed stones. The author was pleased to obtain two considerably larger stones—one over 7 carats, the other over 8 carats. The former is almost flawless, while the latter, although somewhat flawed, is not unattractive for it has a purplish hue in one direction.

Azurite, cut from the crystals, has been mentioned before in this journal. The cut stones are indeed curiosities, and a stone of nearly 8 carats must probably be assumed to be a rather large and unusual specimen.

Cassiterite in the form of "wood-tin" hardly seems to be available these days, so two cabochons from Mexican material were welcome. The "grain" of this massive brown variety is rather odd, but it comes also in darker material with no "grain" at all. This latter variety is not very attractive.

Coral does not qualify as rare, but these days one has to be thankful to obtain even a small specimen of the fine white Mediterranean coral.

Datolite, like petalite, comes in gem and massive form, the latter type, from the Lake Superior region copper mines, producing cabochons which could well be made into brooches. The copper is sometimes finely disseminated throughout the material, and sometimes occurs as blobs and streaks making fanciful shapes, or very attractive patterns.

Dioptase, known for its fine green crystals, not only has almost perfect cleavage in all three directions but is heat-sensitive as well. Thus usually only the finest crystals are capable of producing stones, and these are often only a fraction of a carat. Yet they are a very fine green and possibly the finest green of all gemstones.

Dolomite is hardly known as a gemstone, yet the mineral produces fine crystals which may be cut into quite sparkling stones. Its cleavage usually prevents the production of a perfect stone, so a stone of about $2\frac{1}{2}$ carat which is fairly clean must be something of a rarity as well as a curiosity.

Domeykite, too, is rather unusual, yet the mineral may be cut into fine "golden-like" cabochons which tarnish but may easily be made sparkling again by an ordinary jewellery polishing cloth. Odd, really, that a copper arsenide is capable of producing a rather attractive "golden" cabochon.

Euclase is hardly rare, yet the cleavage makes clean stones fairly rare, especially if they have a hue. Thus a clean straw-coloured euclase of over one carat made a welcome acquisition.

Fluorite is so common that only rare hues may be classified as unusual. A pink fluorite of 12·9 carats excited some apprehension until it was discovered that the colour came from having been exposed for several years to the hot sunshine of Arizona. The mine usually yields blue-green material which, on the dump, turns purple in the sunshine, then peach, then pink, and finally colourless if left for many years. Once taken out of the sun, the hue at that particular time seems to be permanent. This is rather odd, for the pink fluorite octahedra from Switzerland were formed under high temperatures. Care should be taken, therefore, when buying pink fluorite, for the octahedra are not very likely to have been cut, while the recrystallized pink fluorite from optical factories is simply not acceptable to the purist collector. It is, in fact, the air-contaminated rejected material which, while producing a deep pink stone, has simply acquired its form and hue by man's intervention. The dump material also is not as it was in the mine, but in this case it is simply not possible to produce it by the bucketful, or sweep it up from the floor of the factory. The ability to produce so many gemstones by artificial means, however, does point up the continuing need for research, for some stones, such as scheelite, now being produced artifically, are very expensive items, in large sizes, when genuine.

Friedelite was once not uncommon in the New Jersey area of the United States, but it too is now classified as something of a rarity, or curiosity, even the reddish-brown translucent material cut into cabochons. It was formerly used for all sorts of carvings, slabs, and paperweights.

Labradorite is hardly a curiosity, yet few gemstones yield a range from the colourful opaque, through the colourful translucent, to the colourless transparent. Three specimens, one of each, show the gradations effectively.

Idocrase of the golden-brown transparent variety is quite well known, yet a stone of 2·60 carat from Laurel, Quebec, must be considered in the rare or curious class even though not absolutely clean.

Jadeite is common enough, but a cabochon said to be "petrified-wood-jadeite" would appear to be something of a curiosity. A test has not yet been made, but the material is greenish and with "wood-like" bandings, so the purchase of wood, "petrified" by jadeite, may yet be substantiated.

Kyanite, too, is common enough really, yet a clean faceted green stone with a centre banding of blue is something not seen too often.

Opal which is truly black must be considered a curiosity. Coming in a cabochon, it was said to have been carefully dug out of the matrix and then cut. It appears to be rather like the dyed black chalcedony at first sight, yet it is clearly of low specific gravity.

Petalite in its transparent form is not too common, hence the owner of a crystal is likely to want to get the most out of it even if it means cutting a "fish-eye" stone. Yet even a somewhat "fishy-eyed" petalite of 1·75 carat is not to be turned down too readily.

Rhodochrosite, also, is a stone which in its fine transparent qualities is not seen too often. Thus a deep-pink faceted parallelogram of 5·50 carats cut from the author's crystal weighing some 80 carats probably may be classified as a rare curiosity. The 80-carat uneven crystal was ground down, rather than cut, into a preform of about 9 carats, and then faceted. The considerable weight loss was apparently necessary to obtain a fairly clean stone, the difficulty being due to cleavage.

Violane is not quite so common as some textbooks make out, so a small cabochon of violane in matrix was accepted with good grace. The source was given as San Marcello, Val Aosta, Italy, which is the classic source for this variety of diopside.

Willemite, of fine facet quality, is rare and usually of a bright lemon-hue. The orange variety is even rarer, so a stone of nearly 2¼ carats must be considered something of a rarity and curiosity.

Zincite, unlike proustite, is not often seen in large crystals, and the faceted stones, usually dark and not too transparent, are often rather small. Two crystals bought a couple of years ago yielded three stones the largest of which was 5·85 carats. The smallest stone, of about a carat, had in part a bright red hue showing

just what a fine stone zincite can be in its best qualities, even if not capable of being used in jewellery.

Collectors of oddities are for the most part fully aware of the beauty of crystals, and they do not usually wantonly destroy fine crystals just to obtain a faceted stone. A dealer may do just this, for in this way he takes a risk in the cutting yet gets a better price for a faceted stone than he would for the crystal, but it is not unknown for a collector to put a fine crystal in his collection and regard it as a faceted stone. Few collectors would cut a fine twinned staurolite, or a pseudocube of boléite, just to make a cabochon. Probably most lovers of fine stones are also lovers of fine crystals. The mineralogists need not worry too much.

LECHLEITNER SYNTHETIC EMERALD

It has been reported that Johan Lechleitner, of Austria, is now producing stones consisting of layers of white beryl with a tablet of synthetic emerald between the layers. The whole is then covered with a synthetic emerald overgrowth. The emerald tablet is at least two millimetres thick and approximately fifteen millimetres in diameter.

The method of production would appear to be that several very thin layers of identical oriented white beryl are placed in the growth chamber and synthetic emerald is then produced so that the spaces between are filled. This method produces the depth of colour which was lacking in the earlier Lechleitner stones. These first stones had a synthetic emerald overgrowth on a faceted pale beryl.

THE BEACH GEM MASTER

A FELLOW of the Association, Mr. M. L. Beach, of Twickenham, has designed and produced an inexpensive yet high quality gem-cutting machine for the stone collector.

The Beach Gem Master is a serious attempt to produce a machine that will give years of profit or pleasure for the stone collector. Compact and easily handled it is essential to any efficient workshop. Jewellers will welcome the usefulness of such a machine. Geologists will find it invaluable and technical schools will appreciate its quietness and safety.

The diamond-charged grinding wheels supplied with the machine ensure trouble free cutting. Unlike normal grinding wheels there is little noise, no mess or loose grits and no danger to the fingers. Stones can safely be held in the fingers and shaped directly on the diamond wheels—if too small or extra care is needed they are cemented onto the wooden dop sticks with the cement supplied and handled with ease.

Built onto the machine is an anodized one-pint aluminium water can with special tap and feed pipe. The necessary water lubrication, needed during cutting, is supplied by turning on the tap so that it drips slowly onto the wheel.

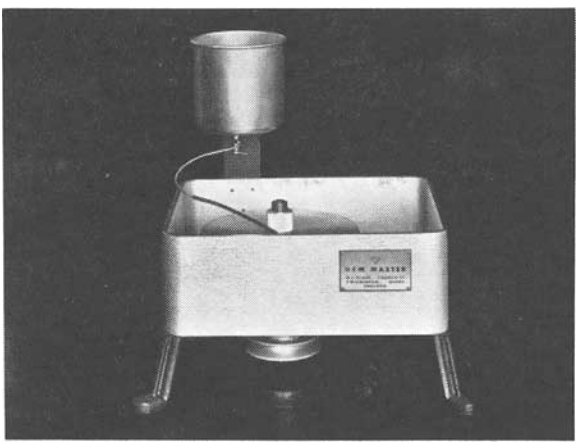

Three 6″ diameter diamond-charged wheels are supplied with the machine, a coarse one for roughing out, a medium for shaping and a fine for semi-polishing. The life of these wheels is surprisingly long and only the coarse wheel is subjected to heavy wear. Even so, with moderate care, this wheel will last for the cutting of many hundreds of stones before it needs recharging and this can be done at a very nominal price.

The convenience of diamond wheels has to be experienced to be appreciated. With these modern diamond wheels it is necessary only to replace one wheel with another, the diamond powder being locked into the wheel.

The felt wheel and polishing powder supplied will be found suitable for most gemstones. Quick results are possible and by using the softer gem materials cabochons can be cut and finished in minutes. A carborundum wheel is supplied for rough shaping of coarse specimens.

Great attention has been given to the finish and durability of the machine and substantial bearings and accurately made parts aid its long life. It is easy to set up and to clean. To run it a 1/6 to 1/3 H.P. electric motor is needed and there are many suitable inexpensive makes on the market.

The Gem Master is not intended for high class professional lapidary work. For the amateur who just wants a pleasant hobby it has much to offer. Many can derive much enjoyment from turning gem mineral pebbles into attractive objects.

Gemmological Abstracts

CANNAWURF (C.). *Die Frühgeschichte der Smaragdsynthese.* Early history of emerald synthesis. Zeitschr. d. deutsch. Gesellsch. f. Edelsteinkunde, 1963, 46, pp. 7-11.

Synthetic emerald was first produced in 1848 by Ebelman, the director of the Sèvres factory near Paris, by heating boric acid with powdered emerald; the colour was produced by the addition of chromic oxide. Hexagonal prisms resulted, but these were too small to be used commercially. The next synthesis also only produced crystals of 2 mm length. This was in 1889 by Hautefeuille and Perrey. Colourless beryl was synthesized in 1894 by Traube. In 1924 H. Espig started his experiments, but it was not until 1935 that they were successful. In the meantime Prof. R. Nacken produced cuttable crystals by the hydrothermal method. It was only after the 2nd world war that with Chatham's success synthetic emeralds became commercially available, and since then various other producers have brought synthetic emeralds on to the market.

E.S.

Fortschritte in der Edelsteinsynthese. Advances in gemstone synthesis. Zeitschr. d. deutsch. Gesell. f. Edelsteinkunde, 1963, 46, pp. 11-20.

A summary of papers read at a meeting of the mineralogical group of the Geological Society of Germany in February 1962. The original papers were published in the Berichte Geol. Gesellsch. DDR Vol. 7, 1962, pp. 447-568. The papers were: (1) H. Espig, Synthesis of the emerald and various other minerals. (2) C. Barta, Tendencies in the development of the Verneuil process. (3) J. Zemlicka, The synthesis of large corundum crystals. (4) R. Baumgärtel, Some colour effects in corundum crystals after production by the Verneuil method. (5) A. Neuhaus and P. Brenner, Growth, habit and colour in rubies produced by the hydrothermal method and their relation during the synthesis to the pressure used. (6) J. Smid and J. Kvapil, A few notes on the hydrothermal synthesis of single quartz crystals.

E.S.

. . . Das Polariskop von Rayner, London. *Rayner's polariscope.* Deutsch. Goldschmiedezeitung, 1964, 62, 3, p. 196.

Short article with illustration explaining the use of the polariscope. It mentions that the stone to be examined should be viewed from various angles, and that in the case of cut and polished stones best results are obtained if they are viewed with the table facing down.

E.S.

ROEMER (W.). Polieren und Auffrischen von Edelkorallen. *Polishing and reconditioning of corals.* Deutsch. Goldschmiedezeitung, 1964, 62, 3, p. 184.

It is common practice to dye inferior corals with red wax; these corals soon loose their colour when they are worn. But also good corals become matt in the course of time, although they stay a deep red. These corals can be reconditioned by polishing them first with emery paper, then with a soft leather, using a little tripoli compound. No ammonia should be used. Instead of tripoli a little corundum can be used. After the polishing process, the corals must be oiled.

E.S.

EPPLER (W. F.). Ein neuer synthetischer Smaragd. *A new synthetic emerald.* Deutsch. Goldschmiedezeitung, 1964, 62, 3, pp. 183-184.

A new synthetic emerald has been produced by Walter Zerfass. This synthetic stone has D. of 2·66 (natural 2·71, Chatham synthetic 2·65, Lechleitner 2·7) and especially low values for its RI, i.e. 1·561, while its double refraction is very high. Under the microscope one finds small liquid inclusions which are feather-like and are arranged along the c-axis like honey-combs. Some photomicrographs of these are shown. Rarely can one also find phenakite crystal inclusions.

E.S.

PATEL (A. R.), GOSWAMI (K. N.) and RAMANATHAN (S.). *Spiral patterns on synthetic diamonds.* Proc. Physical Soc., 1963, Vol. 81, pp. 1053-1055.

Spiral growth patterns on the faces of synthetic diamonds are discussed.

R.A.H.

GOMON (G. O.), KARAPETYN (G. A.) and YUDIN (D.). *Paramagnetic resonance in diamonds.* Zap. Vses. Mineralog. Obshch., 1963, 92 (5).

Diamonds from various deposits, differing in type, colour and other properties were studied for EPR. These and other diamonds, which were irradiated in a cyclotron and nuclear reactor, did not give any signal in the EPR spectrum for colourless stones, and the spectrum for coloured diamonds and stones irradiated with neutrons defied analysis. In come instances the colouring, luminescense and EPR spectra had some relationship. S.P.

GNEVUSHEV (M. A.) and FUTERGENDLER (S. I.). *Traces of magnetic melt trapped by diamond crystals.* Zap. Vses. Mineralog. Obshch., 1963, 92 (5).

By an X-ray study of a diamond crystal from the Yakut area it was found that these crystals consisted of large ($\approx 10^{-3}$ mm) disorientated blocks (≈ 5-$6°$). On Laue photographs many of these were observed as a series of rings. The inter-plane distances of these rings corresponded closely to the inter-plane distances of the olivine crsytallographic lattice. There is the likelihood that the olivine in the composition of the diamonds studied is the result of the crystallization of glass of ultrabasic origin, i.e. the magnetic melt trapped by the rapidly grown crystal. S.P.

SUSSE (C.), EPAIN (R.) and VODAR (B.). *Synthèse du diamant dans un appareil a pistons profiles.* Bull. Soc. française Min. Crist., 1963, Vol. 86, pp. 437-438.

Using tungsten carbide pistons in conjunction with compressible pyrophyllite joints, a pressure of 65 kilobars is applied, the graphite-nickel mixture is heated to 1850°C at the centre of the chamber (corresponding to 1580°C at the level of diamond formation) and this temperature is held for 8 minutes, before the heating is stopped and the pressure slowly dropped. Black diamonds up to 0.7 mm in size have been produced. R.A.H.

Matrixopal gefärbt, ein Ersatz für schwarzen Opal. *Dyed matrix opal, a substitute for black opal.* Zeitschr. d. deutsch. Gesell. f. Edelsteinkunde, 1964, 47, pp. 16-20.

This communication, from Miss Verena Theisen of Dr. E. Gübelin's laboratory at Lucerne, points out that dyeing can be

detected with a lens. In contrast to genuine black opal, the surface is not of a homogeneous structure but contains dark grains or dust which can be dissolved in hot sulphuric acid.

W.S.

BUTCHER (J.) and WHITE (E. A. D.). *A study of the hydrothermal growth of ruby.* Mineralog. Mag., 1964, 33, 266, pp. 974-985.

Experiments to determine the optimum conditions for the hydrothermal growth of ruby show that the most rapid growth on seeds of corundum takes place in a normal solution of rubidium carbonate. To obtain the necessary purity the autoclave must be lined with platinum. The deep pink ruby colour is produced by adding potassium dichromate, to give ruby with a chromium content of about 0.1%. Compared with flame-fusion ruby, the hydrothermal crystals show a more uniform distribution of chromium as opposed to the large scale inhomogeneities of the former. Growth is slow, rarely exceeding 1 mm. over a period of 14 days.

R.A.H.

Die Systematik der Perlen. *Systematic cataloguing of pearls.* Gold und Silber, 1964, 7, pp. 16-17.

The article subdivides pearls and explains various differences between them.

E.S.

Vorsicht beim Röntgen forbiger Perlen. *Care must be taken when x-raying coloured pearls.* Gold und Silber, 1964, 7, p. 19.

There is a certain danger of causing damage, such as brownish spots, when subjecting coloured pearls to the x-ray diffraction method. It is therefore advisable to use straight x-ray methods or ask permission of the owner before use of diffraction method.

E.S.

Farbe und Farbänderung beim Topas. *Colour and colour changes of topaz.* Gold und Silber, 1964, 7, pp. 33-34.

Commercially unimportant, but of great minerological interest, is the occurrence of topaz in Saxony. In 1757 some of these stones were accidentally burned and lost their colour, becoming glass-like in appearance. Colourless topaz is often found in nature and is sometimes known as "pingos d'agoa"—water drops. The topaz

found in Saxony is yellowish, occasionally greenish, while the stones found in Brazil are mostly yellow or brownish-yellow. Brazil still yields most topaz but many beautiful stones are found in Ceylon. In Russia topaz is found in many colours. Brazilian stones which are dark brown are heated to 450°C, lose their colour, but become pink to purple when they are cooled. The difference between naturally pink topaz and topaz which are pinked by heating is a strong pleochroism of the latter.

E.S.

WEBSTER (R.). *The fading amethysts.* Watchmaker, Jeweller & Silversmith, pp. 127 & 133, September, 1964.

Discusses the cause of fading in amethysts. The suggestion is made that the cause is usually due to adventituous heating, and gives a warning to working jewellers to take care when working with jewellery set with amethysts.

P.B.

THEISEN (V.). Achtung voe kunstlich schwarz gefärbtem Opal. *Warning—artificially coloured black opal.* Deutsche Goldschmiedezeitung, 1964, 62, 8, p. 679.

Poor opal material is cut en cabochon, heated and then put into a sugary solution. The sugar is impregnated in the opal. Then the cabochon is dipped into sulphuric acid, which blackens the sugar in the opal. Under a lens it is easy to see this deception, as the dark parts are irregularly distributed and one can still see parts of whiteish opal. When a suspicious opal is cut, one can see that the coloured layer is only acout 2 mm. deep.

E.S.

SALLER (X.). Schace der Synthese. *Stalemate to synthesis.* Deutsche Goldschmiedezeitung, Vol. 62, No. 8, Aug. 1964, pp. 663-664.

An extract of a lecture read by the author to the annual meeting of the Gesellschaft der Edelsteinfreunde in Wiesbaden. The author warns of the increasing influence of synthetic stones. He contends that there is no such thing as a synthetic mineral, as a mineral must have a specific lattice, a definite chemical formula and must have evolved naturally.

E.S.

THE DRAGON'S MOUTH

ALTHOUGH small, this is an excellent example of a drusy cavity in a mineral vein. Here there was room for well-formed crystals to grow. The crystals are calcite having scalenohedral habit, a form known as "dog-tooth spar". The surrounding rock is limestone and on the exposed surfaces are dentritic patterns made by another mineral, which may well be pyrolusite (manganese dioxide). On each end of the specimen are larger ill-formed crystals of calcite.

A feature of this specimen is the beautiful luminescence seen when it is irradiated by ultra-violet light and by x-rays. Under the long-wave u.v.l. lamp the calcite crystals glowed with a lovely rose-red colour, with the edge forming the border to the crystals, and the limestone rock was outlined with a yellowish-white fluorescence, which showed a green phosphorescence when the rays were turned off. Under short-wave ultra-violet radiation the rose-red glow of the crystals was less strong but the whitish border produced a more intense and persistent phosphorescence. Under x-rays the calcite, as usual with this form of calcium carbonate, glowed strongly with an orange light, and, further, showed a strong and very persistent phosphorescence of similar hue. After irradiation with x-rays for about two or three minutes this phosphorescence persisted for about 45 minutes, and the calcite at the point where the rays had impinged had photo-coloured to a faint brownish colour, but this faded as the phosphorescence diminished.

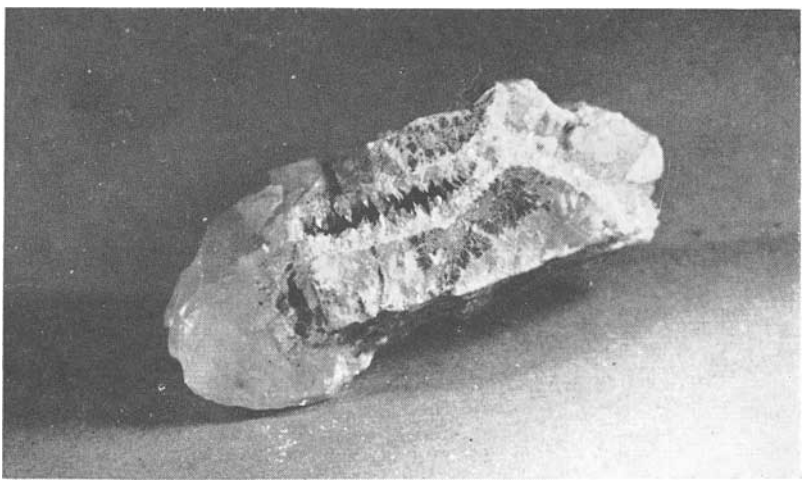

ASSOCIATION NOTICES

GEMMOLOGICAL ASSOCIATION OF SWITZERLAND

The Gemmological Association of Switzerland, presided over by Mr. E. Frischknecht, held their Annual General Assembly and ensuing Instruction Course on 8th, 9th and 10th June, 1964 at Villars sur Ollon, above the Rhône Valley.

In order to clarify the rather confusing recommendations suggested by the French delegation at the last meeting of the International Confederation of Jewelry, Silverware, Diamonds, Pearls and Stones, held in Paris on 27th April, as a compulsory ruling, the Swiss Association affirmed its own ruling that a magnification of 10 × should be used as a standard for grading the purity of diamonds of any size and consequently stated on certificates that may be issued by traders.

The Instruction Course was mainly devoted to imitations of any kind and synthetics. The lectures on the first day dealt with the various processes of production, the diagnostic properties and the reliable methods of testing. On the second day practical exercises in gem-testing were carried out and this gave the members numerous opportunities of becoming acquainted with all kinds of man-made stones and of comparing them with their genuine counterparts. Later in the day Dr. E. Gübelin described the gem deposits of Thailand and their mining methods by means of descriptive colour slides which he had made on his last visit to those deposits in January and February of this year. On the morning of the third day the Association visited the near-by and important factory of synthetic stones owned by Mr. A. Djevahirdjan. He explained the greatly improved processes of production in his highly modernized plant, while in the well equipped laboratory, the development of new controlling instruments, as well as amazing experiments with ruby lasers and sapphire window discs, were demonstrated. This most instructive Course found its worthy conclusion in a visit to the remarkable old treasure of the Monastery at St. Maurice.

COUNCIL MEETING

A meeting of the Council of the Association was held at Saint Dunstan's House, Carey Lane, London, E.C.2, on Tuesday, 30th June, 1964. Mr. F. H. Knowles-Brown presided.

The following were elected:—

ORDINARY MEMBERSHIP

Anthony, I., London
Azzopardi, J., Malta
Blick, R. C., Guildford
Fink, A. B., Virginia, U.S.A.
Griffin, Mrs. F., Radcliffe
Hack, Miss E. O., Birmingham
Howard, D. D., New Orleans, U.S.A.
Jhaveri, J. C., Hong Kong
Larcher, D. M., Sheffield
Lyons, D., Leicester
van Moppes, M., Basingstoke
Reid, Mrs. R., Salisbury, Rhodesia
Taniji, J., Kobe, Japan

PROBATIONARY MEMBERSHIP

Fuchs, R., Frankfurt
McDowell, B. M., Wellington, N. Zealand
Montague, J. C., Wellington N. Zealand
Strange, R. L., Romford

The Council agreed that candidates should not be permitted to sit for the preliminary and diploma examinations in the same year unless approval be given by the Council.

Mr. P. W. T. Riley was invited to serve on the Council as a co-opted member.

The Council agreed to review the gemstone nomenclature approved by the Association and, at the same time, to consider a request from the National Association of Goldsmiths regarding the use of the term "flawless" when applied to diamonds.

GIFTS TO THE ASSOCIATION

The Council of the Association is indebted to the South Australian Branch of the Gemmological Association of Australia for samples of rough opal from Coober Pedy, Andamooka and Lightning Ridge, and three pamphlets on opal and the gemstones of South Australia, and to F. N. Hudson, Esq., for a booklet on gem localities of Scotland issued by the Scottish Mineral Lapidary Club.

Mr. Karl A. Sack, F.G.A., of San Diego, California, U.S.A., has kindly presented the Association with several twin crystals of twinned "chrome" sphene, from the San Simon district of Baja California, together with samples of associated minerals.

POST-DIPLOMA GEMMOLOGY CLASS

Students in the London area who have passed their Diploma examination are reminded that there is a Post-Diploma class available to them which is held from 6 to 9 p.m. on Monday evenings at Northern Polytechnic, Holloway Road, N.7.

In this class they are able to gain valuable experience in practical gemmology, a wealth of cut and uncut specimens being provided for examination. There are also periodic lectures which deal with recent developments, or which cover a wider field than was possible in the Diploma course, since there is no longer any need to conform to a rigid syllabus.

Many gemmologists have attended these classes for a number of years in succession, since they have enjoyed the informal atmosphere and the regular contact with fellow-enthusiasts, as well as benefiting professionally from the knowledge gained.

The Post-Diploma class is conducted by Mr. B. W. Anderson, assisted by Mr. A. E. Farn. The 1964 enrolment dates at the Polytechnic (to whom all inquiries should be made) are:—Tuesday, 22nd September and Wednesday, 23rd September, 5.30—7.30 p.m. (Telephone: North 6767).

TALKS BY MEMBERS

COOP, Miss N. "Gemstones", Blackheath Townswomen's Guild (N. Kent section), 14th July, 1964.

KENNEDY, N. "Gemmology", St. Andrew's Parish Church, Bebington, Cheshire, 30th June, 1964.

OBITUARY

Leonard C. Trumper (D. 1948), July, 1964.

MEMBERS' MEETINGS

1964	
21st October	Midlands Branch dinner, Birmingham.
26th October	Presentation of awards, Goldsmiths' Hall, London. Mr. A. E. Shipton, F.G.A., President of the British Jewellers' Association, will present the awards.
13th November	Midlands Branch meeting, Birmingham. Mr. T. Solomon, F.G.A. will talk about antiques.
1965	
22nd January	Midlands Branch meeting.
11th March	Conversazione, Goldsmiths' Hall, London.

GEM DIAMONDS EXAMINATION

The Gem Diamonds Examination of the Association was held in Birmingham at the School of Jewellery and Silversmithing, Birmingham, on Wednesday, 3rd June, 1964. The following is a list of successful candidates arranged alphabetically:—

Richard J. Collick	Solihull, Warwicks.
John E. Dowse	Solihull, Warwicks.
Roger Francis	Birmingham, Warwicks.
Paul H. Higgs	Walsall, Staffs.
Fay V. McCarty	Birmingham, Warwicks.
Nigel Marshall	Birmingham, Warwicks.
Robert Reekie	Stratford-upon-Avon, Warwicks.
Paul A. Thurlby	Birmingham, Warwicks.
Leslie N. Wells	Abergavenny, Mon.

GEMMOLOGICAL EXAMINATIONS, 1964

Centres for the 1964 examinations of the Gemmological Association of Gt. Britain were established in Australia, Canada, Ceylon, Germany, Holland, Hong Kong, India, Japan, Kenya, Malta, New Zealand, Nigeria, Norway, Portugal, Sierra Leone, South Africa, Southern Rhodesia, Sweden, Switzerland, United States of America, apart from the United Kingdom. 273 candidates sat for the Preliminary and 139 for the Diploma examinations.

Upon the recommendation of the examiners the Tully Memorial Medal and prize have been awarded to Mr. F. G. Dowie, of Christchurch, New Zealand. The Rayner Prize has been awarded to Mr. F. Riding, of Preston, Lancashire.

The following is a list of successful candidates, arranged alphabetically:—

Diploma Examinations

Tully Memorial Medal

Dowie, Frederick Gordon, Christchurch, New Zealand

Qualified with Distinction

Algar, Forbes, Hamilton, Canada
Dowie, Frederick Gordon, Christchurch, New Zealand
Larcher, David Marshall, Sheffield
Snider, James Ralph, Willowdale, Canada

Qualified

Adshead, Christine Violet, London
Bagi, Julius, Toronto, Canada
Baguley, Kenneth, Liverpool
Barker, Brian Michael, Pinner
Barrett, Robert Clive, Cuckfield
Beckwith, John Martin Emmerson, Middlesbrough
Bjørn-Hansen, Eva, Oslo, Norway
Bond, Cecil Allen, Waltham Abbey
Bradburn, Gwendoline, Sydney, Australia
Burslem, William Arthur, Liverpool
Calmus, Michael, Nottingham
Chambers, Edwin Joseph, Dagenham
Climie, Robert, Newtown St. Boswells
Colclough, Albert Cecil, Rainham
Cornish, Stanley, Birmingham
Davis, Margaret, Wembley
Greene, Jane Bannard, Princeton, U.S.A.
Harris, Stephen James Grey, London
Hartley, Mary Louise, Liverpool
Hunt, Elyane Marguerite, London
Hunton, Andrew S., London
Johnson, Arthur William, London
Johnson, Donald Haskall, Kitwe, Northern Rhodesia
Kelly, Hugh, London
Kerry, Stewart Michael, London
King, Michael Leslie, Freetown, Sierra Leone
Knox, Christine Gray, Hamilton, Canada
Koller, Tibor, Forest Hill, Australia
Kothari, Ramesh Rasiklal Madras, India
Lechleitner, Paul A., Lucerne, Switzerland
Major, Keith Roy, East Grinstead
Marshall, M. Sheila, Ibadan, Nigeria
Miles, Richard Stanley George, Nottingham
Myers, Julia Helen, Double Bay, Australia
Nilsson, Carl Allen Gunnar, Boliden, Sweden
Pearce, William M., Athens, U.S.A.
Reid, Wilmet P., Kitwe, Northern Rhodesia

Richardson, Kenneth, Birmingham
Rowley, Robert Edward, Tapworth
Schiffman, Charles A., Geneva, Switzerland
Schriber, Urs, Lucerne, Switzerland
Wain, Edward Hollis, Ipswich
Walters, George Christopher, Leicester
Wyer, Philip George, Birmingham

Preliminary Examination

Rayner Prize

Riding, Frank, Preston

Qualified

Algar, Forbes, Hamilton, Canada
Allan, Ian Edward, Birkenhead
Allsopp, Royston A., Toronto, Canada
Armour, Anthony James, Beckenham
Ash, Grahame David, London
Azevedo, M. Arthur, San Francisco, U.S.A.
Azzopardi, Joseph, Malta
Bailey, Charles Hunter, Wallasey
Baker, Antony R., Warrington
Balhatchet, Frederick William, Sutton Coldfield
Bana, Homi Ratansha, Bombay, India
Baugerod, Gunnar, Porsgrunn, Norway
Beadle, John Christopher, Sunderland
Beaman, Ronald David, Birmingham
Beaumont, Gordon, Huddersfield
Bergseth, Idar Conrad, Burnaby, Canada
Bernet, Edith, Arth, Switzerland
Billingham, Roger, Birmingham
Blackburne, James William, Liverpool
Borrini, Lucia, Horw, Switzerland
Borrmann, Björn, Fjellhamar, Norway
Boruszak, John K., Blackpool
Bradburn, Gwendoline, Sydney, Australia
Bridgen, John Stephen, London
Brookes, John Anthony, Birmingham
Bulley, Michael John, London
Burnett, Douglas Norman, Edinburgh
Butler, June Iris, Waltham Abbey
Carr, Philip, Blackburn
Chernencoff, Wade J., Coquitlam, Canada
Clarke, John E., London
Collard, Edwin, Bridgwater
Collins, Michael John, Plymouth
Conway, Stephen, London
Cook, Murray Ernest, Vancouver
Cooper, Sydney Bernard Nikon, Staines
Cruthers, Margaret T., Glasgow
Cutting, Derrick Charles Ambrose, Wakefield, Canada
Deakin, Brian, Powick
Douglas, David Norman, Manchester
Drew, Frank Henry, Wanganui, New Zealand
Drew, William Henry, Wellington, New Zealand
Dunkley, Peter John, Coventry
Dunne, Michael Bernard, Marple
Ekanayake, Oswald D. W., Dehiwala, Ceylon
Evans, John, Birmingham
Ewart, Myra, Glasgow
Falcon, Lionel James, Leicester
Fancett, Paul, London
Farley, Peter Frederick, Reading
Fassnidge, Ray Denis, Leatherhead
Feakes, Raymond Howard, Middlesbrough
Fehrmann, Justus Johannes, Cape Town, South Africa
Fillan, Ian, Huddersfield
Fournet, B., Hong Kong
Frizzell, Alan, Motherwell
Frost, Allan Robert, Cardiff
Fruitman, Lawrence, Toronto, Canada
Gamble, George Brian, Bradford
Gatward, Anna Bradly, Hitchin

Gauntlett, Gillian, Haslemere
Gow, William Frederick, London
Grant, Christopher Stanley, Burgess Hill
Gray, David Melvyn, Newbiggin-by-Sea
Griffin, Fiora, Radcliffe
Grusd, Alan Ivor, Cape Town, South Africa
Gunn, David Michael, Dover
Gunn, Raymond Diamond, Glasgow
Hallett, Martin A., Bristol
Hallett, Timothy Robert, Purley
Hanebach, Stanley, Scarborough, Canada
Harley-Mason, Robert John, Nairobi, Kenya
Harrison, John Christopher, Liverpool
Hilton, John David, Macclesfield
Hodge, A. D. B., Birmingham
Hogervorst, Lia Angelique, Gouda, Holland
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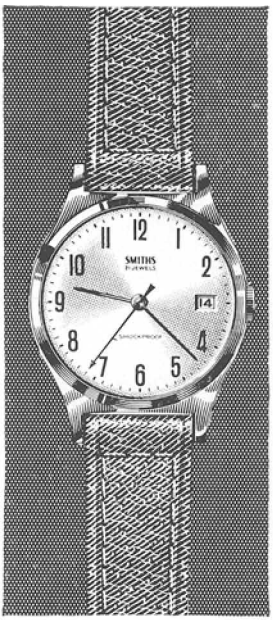

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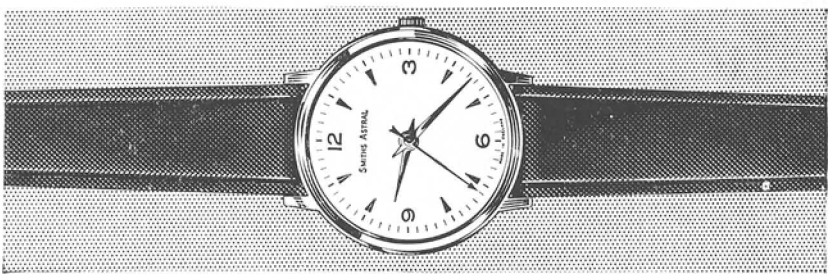

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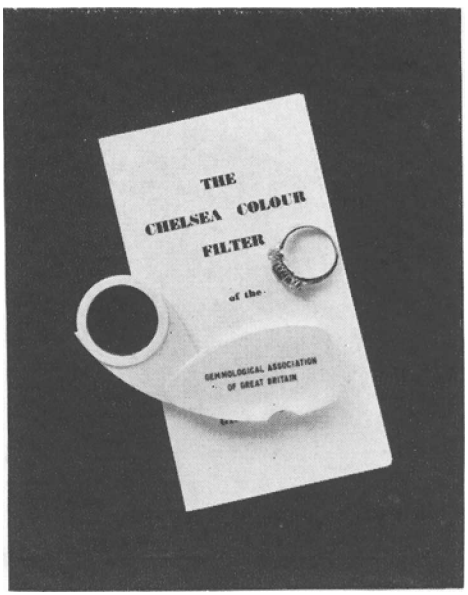

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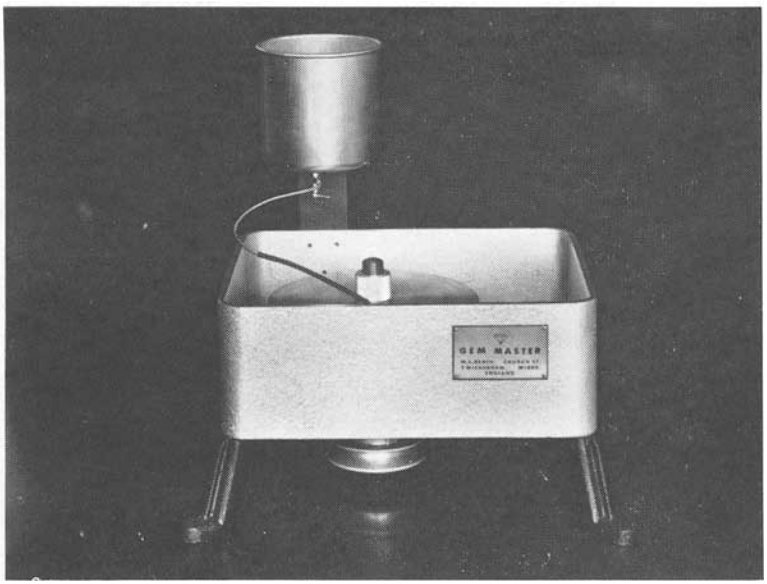

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THE JOURNAL OF GEMMOLOGY

and

PROCEEDINGS OF THE
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Vol. IX No. 9 JANUARY 1965

AN UNUSUAL DYED AGATE

By P. C. ZWAAN, Ph.D., F.G.A.

INTRODUCTION

At the beginning of last year I received a letter from Dr. R. van Tassel, a mineralogist at the Royal Belgian Institute of Natural Sciences in Brussels, who wrote about a problem for which he asked my assistance.

An Italian, living in Brussels, had requested him to identify a cabochon-cut agate; in particular he wanted to know whether the included material, resembling the head of a negro, was of natural origin.

Although Dr. van Tassel could not believe that this inclusion was natural, he was not able to prove it. He measured the specific gravity of the stone (2·58) and made an X-ray reflection diffraction photograph from which he concluded that the stone was a quartz (chalcedony). At the edge of the stone he could not find a junction plane so that, according to him, the stone in question was not a doublet.

The owner of the stone, Mr. Fedeli, came to Leiden to show me the stone, together with certificates, written in Italian, from the beginning of this century, on which the inclusion was described as being natural.

Though I saw immediately that the inclusion could not be natural, I was not able to prove this within a short time. Indeed

there was no question of the agate being a doublet. The stone was left at my disposal so I got full opportunity to make a close examination.

FIG. 1. *Left: natural moss-agate. Right: agate with "moss" imitation.*

FIG. 2. *The stone in question.*

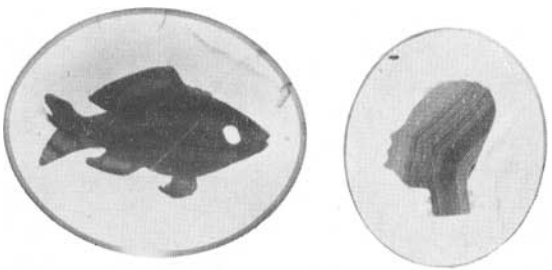

FIG. 3. *Agates with "moss" imitations, made by B. F. M. Collet.*

Properties of the Stone

The stone has a milky-brown colour and weighs 8·98 carats. It is a cabochon-cut oval translucent stone and its size is 21·5 × 16·6 × 3·7 millimetres. The specific gravity is 2·585, the refractive index 1·538. The characteristic agate structure can distinctly be observed.

After studying the inclusion I spoke about the matter with our draughtsman, Mr. B. F. M. Collet, for it came into my mind that here was the possibility of "staining".

There were two important arguments which are contradictory to a natural origin. Firstly the inclusion lies in one plane only which is never the case in natural moss-agate, for there the "dendrites" have expanded in three dimensions (Fig. 1). Moreover the likeness to a negro-head is too startling (Fig. 2). Mr. Collett affirmed my opinion. The dark-brown negro-head has been made artificially by staining locally for at least four times. This is seen under the microscope as the different layers do not completely cover each other. The white layers of the agate have, as usual, not absorbed the dye and are clearly observable in the negro-head. Probably the stone was repolished after treatment.

The inclusion is not found lying on the surface but below. This means that the dye was made to penetrate before letting it take effect. Silver nitrate is very suitable for this, as in the dark it simply penetrates and as soon as it is put in the light, it stains the stone. However, through the whole stone pigment spots of the dye can be noticed. Under the microscope they give the stone a speckled appearance.

In order to trace whether this statement was right, Mr. Collet carried out a few experiments with different "white agates". He also stained these stones locally with silver nitrate. The results are shown in Fig. 3.

It became evident, however, that the structure of the agate has a big influence on the success of this "staining process", and also the colour. With yellow to yellow-brown coloured stones, as well as with pearl-grey "agates" he obtained the best results. Stones with thick white (hard) layers were not suitable.

It is nevertheless obvious that a procedure, as described above, can lead to the same result as is seen in the stone in question. Therefore it goes without saying that this stone has been treated in such a manner.

THE GREAT DIVIDE

By A. E. FARN, F.G.A.

TESTING gemstones always sounds an exciting and interesting business and possibly conjures up visions of scientific types surrounded by "complex" apparatus, occupied with distinguishing parcels of "erudites" or some such stones.

There are two kinds of gemmology to my mind, commercial gemmology and gemmology proper. Commercial gemmology is the one which keeps the other going, whilst gemmology proper keeps commercial gemmology on the right lines. There is no easy way for commercial gemmologists to acquire knowledge sufficient for them to expedite their own gem testing without learning certain of the gemmologist proper's syllabus. However, it has always been my impression that somewhere along the line a series of articles could be produced to illustrate the main requirements of commercial gemmologists.

In jewellery to-day, the demand for coloured stones has increased and will increase but not for anything or even a little, "erudite". It is interesting to think back upon the more or less straightforward names of gemstones such as ruby, sapphire, emerald, garnet, zircon, spinel, tourmaline, topaz, peridot, jade, diamond, amethyst, citrine, opal.

All of these latter have been used to a very large extent in jewellery and to-day, with a more affluent age and teenage demand, very many more dress rings, brooches, etc., are being sold.

To-day's manufacturers, using casting methods, can produce rings very cheaply and the accent is upon colour. Because of this demand for coloured stones it is obvious that synthetics (which are very pretty stones) will play an increasing part in decorative effect. Other stones very much in demand are tourmalines, peridots and garnets, with half pearls (cultured) as cluster variations. These, to my way of thinking, do not demand too much of a gemmological knowledge.

Nowhere, to-day, does one see stones in jewellery (modern) with any of the more recent gemmological named stones in them. Taafeite is still very scarce and not very decorative, and andalusites, whilst occurring in batches every now and again, do not seem to catch on with the public, and benitoite, although very pretty, is not a sought after stone for jewellery. Even jadeite causes con-

fusion—people like their jade to be Chinese, not Burmese. Curiously, the Americans like their alexandrites to be Russian.

It is almost certain that stones whose names end in *ite* do not make the cash registers ring, let alone finger rings.

And here we come down to basics, the jewellery trade retail, wholesale, secondhand, manufacturing, stone-sellers, dealers, mounters, etc., all revolve upon supply and demand, which can harshly be termed "how much".

It is the "how much" section which keeps the gemmologists going commercially and they seldom deal in stones which have a termination of *ite*. There are exceptions to this but by and large there does seem to be a great divide between retail jewellery stones and dilettante gemmologists' stones.

In a like manner I have recently been busy in a more mundane fashion on gem-testing for non-gemmologists by encouraging the use of a lens only and have harped (monotonously) on double refraction of back facets and 10x lens to such an extent that I thought of stone testing approaches in terms of D.R. or S.R.

Here again there seemed to be a great divide and for some time I bemused myself wondering why some were doubly refracting and some singly refracting.

Taking very ordinary well known gemstomes which are fairly common I tabulated them and tried to find a reason for the division of D.R. and S.R. stones but failed, except to note that because of the orderly structure and close packing of their atoms they imposed no alteration to the directional properties of light passing through them, other than normal refraction on passing from a rarer to a denser medium.

The cubics, it would seem, are the squares of the gemmological world and the others are the deviationists! The isotropics and anisotropics have good in each camp, as do the trade and erudite gemmologists. The common factor which bridges the great divide between "commercial" and "proper" is that they all must eat.

DICHROISM THROUGH THE MICROSCOPE

by R. S. G. Miles, F.G.A. and J. T. Herring, F.G.A.

The disadvantages encountered in the observation of dichroism under the microscope by conventional methods, include the facts that only one of the dichroic colours may be seen at any one time, and, that the stage must be revolved for any change of colour or shade to be seen. Thus the eye must "remember" these changes as they pass before it. Similarly, the dichroscope, although not suffering from the above drawbacks, has difficulties of its own, particularly in relation to the holding and rotation of the specimen, especially if it is mounted.

A simple aid which we have devised minimises these problems by combining the advantages obtained by using the above instruments, while eliminating some of their disadvantages.

We took a piece of ordinary polaroid sheeting and cut from it two semi-circles, from edges at right-angles to each other (Diagram 1), so that, when fitted together to form a circle, their respective

DIAGRAM 1 (polaroid sheeting)

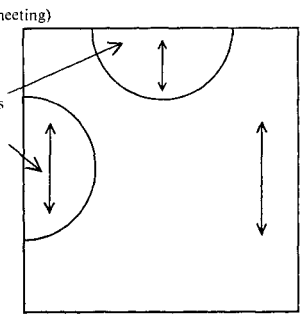

DIAGRAM 2
Semi-circles of polaroid forming circle.(directions of polarisation at right-angles).

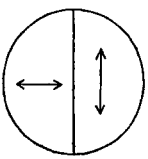

DIAGRAM 3

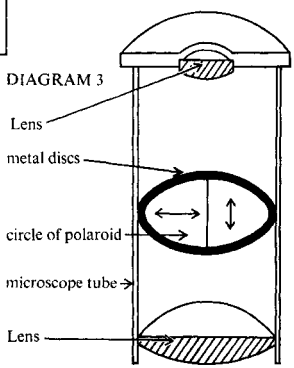

directions of polarization were also at right-angles to each other (Diagram 2). These were then carefully placed within the tube of a microscope eyepiece (secured between two metal rings) in such a manner that the circle they formed was orientated centrally within the tube and parallel with the eyepiece lenses (Diagram 3). The eyepiece was replaced, polarizer and analyser removed, and the microscope focused with a coloured stone upon the stage. Since each semi-circle of polaroid was orientated with its vibration directions perpendicular to the other, and there was a variation in the colours seen in the two semi-circles, we knew that this difference in colours must be due to differential selective absorption of light, and, therefore, the stone must be dichroic. When the stage (or eyepeice) was rotated through 360°, dichroism was seen to vary from a maximum to a minimum (nil) quantity, four times during the rotation, the dichroic colours alternating in each semicircle, through consecutive variations.

The advantages of this device are: (1) The stone can be rested in a dish or on a slide, and rotated with ease, thus eliminating the fixing or holding necessary when using the dichroscope. (2) Weaker dichroism can be observed because the dichroic colours can be observed side by side, thus eliminating the necessity for the eye to "remember" the colour changes. This is not possible with ordinary microscope methods.

When using this method, it must of course be remembered that if no dichroism is evident at first glance, (A) the stage may need to be rotated to a position which will show maximum dichroism, or (B) it may be necessary to re-orientate the stone in order to avoid an optic axis.

It will be apparent that an eyepiece fitted with this device cannot be used in the microscope in conjunction with polariser and analyser. We, in fact, used a spare eyepiece, which we have retained for this purpose.

Gemmological Notes

GREEN BERYLS

Among recently tested stones were some fine green beryls which looked like emerald of good medium quality. They were green when viewed through the Chelsea filter, had a density of 2·72 and were inert between crossed filters. They showed no trace of chromium in their absorption spectrum. They were fairly clear stones but, immersed in monobromonaphthalene, revealed thin layers of phenakite (?) crystals. The refractive indices were 1·588 to 1·594. The owner said they were from a new mine in Brazil but would not vouchsafe its actual location. Later, from another source, two hexagonal broken green crystals were submitted for testing. After a flat had been put on the crystals their refractive indices were found to vary from 1·587–1·593 to 1·585–1·592. The S.G. was 2·72 and inclusions were observed of a similar nature to those of the cut stones. They were green when viewed through the Chelsea filter and when viewed under the mineralight and Burton Lamp. These stones are a pleasing green, have natural inclusions, give beryl readings, and remembering that Transvaal emeralds look drab through the filter and have refractive indices of similar nature, they could be dangerous where a little knowledge of gemmology exists.

A.F.

* * * *

NOT IN DANA

A report made in the Summer 1964 issue of the American journal *Gems and Gemology* mentions an unsual product of an amateur lapidary who had produced "gemstones" by polishing the hardened paint drippings from the painting room of one of the major automobile manufacturers.

This note recalls to mind that during the Gemmological Association's meeting of November 1956, one member, who had connexions with the paint industry, exhibited such a paint specimen which had been polished as an "agate slice".

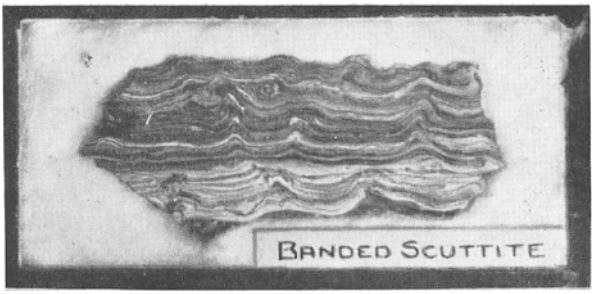

The witty caption read: "A unique specimen of a foliated concretion occurring in later geological period, differing from most by forming on the vertical surfaces of carboniferous or, in some cases, organic matrix. Notable for its fine range of colouring considered as accidental and allochromatic. The essential composition of the basic material varies within comparatively narrow limits. Not yet listed in Dana's Textbook of Mineralogy".

R.W.

* * * *

JADE AND NOT JADE

Recent oriental motif carvings, looking very much like deep green Bowenite and having very misleading patches or flaking in their structure and yielding rather readily to a carefully applied needle point hardness test, have proved to be nephrite.

Although bulky it is possible to do a specific gravity test by means of spring balance, bucket of water and thread suspension. The bulk will average out crudities of the balance. A useful figure of 2·9 to 3·00 was obtained for the carvings tested.

Similarly, green-coloured carvings sold as "jade" or "new jade" have been found to be bowenite. Jewellers should be on their guard when offered "new jade".

A.F.

Gemmological Abstracts

LIDDICOAT (R. T.). *Developments in the synthetic emerald field.* Gems and Gemology, 1964, XI, 5, pp. 131-138.

A general discussion on the new French synthetic emerald. This agrees in substance with the descriptions given by other workers. The second part describes, for the first time, a new departure in the Lechleitner synthetic emerald-coated beryl. This new stone consists of alternate layers of synthetic emerald and white beryl. The layers of synthetic emerald show the same characteristic inclusions as are seen in the Chatham synthetic emerald. The refractive indices differ for the two different types of layers, being 1·560-1·563 for the synthetic emerald layers and 1·564-1·569 for those of beryl. The density—the average for two specimens—was found to be 2·678. The polariscope showed both the overgrowth and the beryl body; and the layers in the new type gave single crystal reactions. The synthetic emerald layers showed a mosaic pattern of interference colours, and this was also true of the French synthetic emerald. The luminescence of the Lechleitner stones was found to be crimson and it was noted that the effect was stronger under the long-wave ultra-violet lamp. The layered stones are a better emerald colour than the original synthetic emerald-coated beryls.

R.W.

GÜBELIN (E. J.). *Two new synthetic emeralds.* Gems and Gemology, 1964, XI, 5, pp. 139-148. Repeated in Australian Gemmologist (with different illustrations), 1964, 38, pp. 5-11.

A survey of the German Zerfass and the French Gilson synthetic emeralds. Both types showed characteristic inclusions which are similar in essentials with the American synthetic emeralds. The low density of these new synthetic emeralds, about 2·66, is again similar to that found with the Chatham synthetic emeralds. The Zerfass synthetic emeralds are reported by the author, to have R.I. 1·558-1·562, with a birefringence of 0·003. This is normal for synthetic emeralds of American, French and early German syntheses, but disagrees with the measurements reported by K. Schloss-

macher, who gave 0·006 as the double refraction of Zerfass synthetic emerald. The behaviour under crossed filters and under ultra-violet light is discussed. The article states that the glow under ultra-violet light given by the French synthetic emerald is olive green; other workers state that there is a yellow glow shown by this stone. The article includes a comparison table and a short list of references.

R.W.

CROWNINGSHIELD (R.). *Developments and highlights at the Gem Trade Lab. in New York.* Gems and Gemology, 1963/4, XI, 4, pp. 99-106.

Describes and explains the multi-drill holes often seen in the beads of cultured pearls when radiographed. These extra drill holes are said to be used to direct bleach on to the conchiolin layer in order to whiten the pearls. Notes are given on an unusual star-effect seen in amethyst, wax-treated amazonite beads, and the alteration in colour in turquoise by the action of cosmetics. Notes on inclusions in a Mexican topaz, and in an alexandrite cat's-eye are given. The Mohs's scale hardness given for synthetic spinel is questioned. A synthetic fluoride (?) boule is described.

R.W.

LIDDICOAT (R. T.). *Developments and highlights at the Gem Trade Lab. in Los Angeles.* Gems and Gemology, 1963/4, XI, 4, pp. 114-121; 1964, XI, 5, pp. 149-156.

Describes a number of interesting articles submitted to the Los Angeles laboratory, among which were a transparent labradorite feldspar, blue-dyed plastic-coated marble beads, an early type of synthetic star-sapphire and a synthetic scheelite. Comments are made on a number of diamonds submitted. These included a note on the effects of heat on the surface of diamonds, twinning in a pink diamond, a cyclotroned diamond, an unusual spectrum in a brown diamond, and how an estimation of the weight of a damaged diamond before and after recutting may be made. A synthetic bromellite (beryllium oxide), a star-labradorite, and a coated glass intaglio were other specimens mentioned.

R.W.

GÜBELIN (E. J.). *Black treated opals.* Gems and Gemology. 1964, XI, 5, pp. 157-159.

Describes an examination of the treated black opals and some notions as to how such stones may be detected.

R.W.

DRAPER (T.). *A new source of emeralds in Brazil.* Gems and Gemology, 1963/4, XI, 4, pp. 111-113 and 124-125.

A cattle herder named Abel knew of green pebbles found on the Fazenda Sao Thiago, near Salininha, Municipality of Pilao Arcado, in the State of Bahia. In 1950 he tried to find out what they were, but it was not until 1962 that any attempt was made to mine the stones. The locality may be the one Coutinho discovered in 1612, but he died without revealing the source. It is an entertaining article in which the author describes the country and the background stories of the finding and exploitation. Other sources of emerald in Brazil are also mentioned.

R.W.

OSTWALD (J.). *On the microstructions and origin of emerald.* Australian Gemmologist, 1964, 35, pp. 7-10.

Reasons are suggested to account for the formation of emerald in both mica schist and in calcite. Notes on the emerald-bearing locality at Poona, near Cue, in Western Australia are given, and on the emeralds which are found there. The inclusions in these stones are said to be andradite garnet, staurolite and spots of a black material, with two types of liquid inclusions. Correlation between the orientation of the inclusions and the mica schist mother-rock was experimentally shown by the author. Some reasons are deduced for the chromium present in the emeralds from the calcite veins in S. America.

R.W.

GORTON (V.). *Fossicking for sapphires.* Australian Gemmologist, 1964, 37, pp. 5-8.

An interesting article describing the hunting for sapphires by visitors to the Anakie fields. There is a description of a screen and how to make one. Full details of construction are given.

R.W.

STEVENS (D.). *The Opal—Queen of Gems.* P. & O. Lines quarterly "Posh". Reprinted in Lapidary Journal, 1964, 18, 8, p. 882.

A short article noteworthy for the magnificent coloured photographs of Jeanne G. M. Martin, of the Gemological Institute of America. S.P.

POUGH (F. H.). *Topaz.* Lapidary Journal 1964, 18, 8, p. 868.

An interesting article, containing information not usually encountered in text books. S.P.

BASTOS (F. M.). *The Topaz Mines of Ouro Préto.* Lapidary Journal 1964, 18, 8, p. 918.

Ouro Préto, in the state of Minas Gerais, is virtually the only production district for yellow and yellowish-red topaz. S.P.

SCHLOSSMACHER (K.). Der Gang einer Edelsteinuntersuchung. *Gem testing.* Zeitschr. d. deutsch. Gesell. f. Edelsteinkunde, 1964, 48, pp. 27-32.

This article was first published in the Diebener's Goldschmiedejahrbuch 1964 (Diebener's Goldsmiths' Almanack for 1964) and gives a general survey of gem testing, explaining the basic gemmological instruments, their use and application.

E.S.

THEISEN (V.). Die Gruppe des Epidots. *The epidote group.* Zeitschr. d. deutsch. Gesell. f. Edelsteinkunde, 1964, 48, pp. 24-27.

The name epidotes derives from the Greek "epidotos", meaning added, because to the basis of the prism an edge has been elongated, i.e. added. The other common name is "pistacite", from the green pistacio colour. The chemical composition is $Ca_2(Al\ OH)\ Al_2(SiO_4)_3$. If there is less calcium but more magnesium or iron, the variety is either piemontite or zoisite. Without aluminium, but with instead either iron, manganese, cerium or yttrium, the resulting mineral is called allanite. Piemontite is manganese—containing epidote. There are other combinations, such as orthite and clino-zoisite. Epidote is monoclinic, with hardness 6·5, spec. gravity 3·25-3·50. The mineral is mainly green, but other colours are found as well. A table shows R.I., varying from 1·716-1·78,

with the double refraction varying from 0·005-0·039. The most beautiful specimens are found in the Untersulzbachtal in the Tyrol. There are also occurrences in Norway, Bohemia, Saxony, France, Italy, Switzerland. Zoisite is found with rubies in Tanganyika, allanite in Sweden, Greenland, Canada and California.

E.S.

BANK (H.). Smaragdvorkommen in Südrhodesien. *Emerald occurrences in Southern Rhodesia.* Zeitschr. d. deutsch. Gesell. f. Edelsteinkunde, 1964, 48, pp. 14-21.

Details of occurrences, with three maps of the district. The history, geology and geography of the finds are discussed. There is a bibliography, and chemical composition, physical data and details of inclusions are given. The most important finds are at Sandawana, Filabusi, Novello and Chikwanda.

E.S.

BURKART (W.). Zum Schleifen und Polieren von Elfenbein. *Cutting and polishing of ivory.* Deutsche Goldschmiedezeitung, 1964, 62, 9, pp. 765-766.

It is suggested that ivory should be polished with Italian pumice powder, if possible of the grain size 3·0, mixed with water. To obtain a better polish it is advised first to use the grain size 3·0, and then the finer grain size 5·0, both made into a paste with water. For the last polish one uses a wax, but care has to be taken that no metallic oxides are included in these waxes; especially Fe_2O_3 and Cr_2O_3 must be avoided. The last polishing wax must be used dry.

E.S.

EPPLER (W. F.). Ungewöhnliche Kristall-Einschlüsse im Aquamarine. *Unusual crystal inclusions in aquamarine.* Deutsche Goldschmiedezeitung, 1964, 62, 9, pp. 769-770. 7 photomicrographs.

In the Deutsche Goldschmiedezeitung, 1960, 12, pp. 736-738 the author considered an inclusion in a Brazilian aquamarine to be apatite. It was pointed out that the inclusion was "mica-like" and consequently the aquamarine was cut so as to examine the inclusion more thoroughly. It was then found to be biotite, that is a magnesium-iron mica. The presence of these minerals in aquamarine

is rare but not surprising as both are pegmatite minerals. In the course of these examinations it was also found that on rare occasions garnet is found in aquamarines, most probably pyrope.

E.S.

FISCHER (W.). Facettiert oder gemuggelt? *Facets or cabochons?* Deutsche Goldschmiedezeitung, 1964, 62, 9, pp. 781-782.

Short explanation as to when to apply faceting and when to fashion a stone in cabochon style. An article for the apprentice.

E.S.

PARSONS (C. J.). *Practical Gem Knowledge for the Amateur.* Lapidary Journal, 1964, 18, 7, p. 750.

The first of a series written to assist in the acquisition of fundamental knowledge about gemstones. There will be four main sections—descriptive, determinative and historical knowledge, and gemstone nomenclature. In the first article condemnation of the use of incorrect names is not emphatic enough.

S.P.

POUGH (F. H.). *Rare Faceting Materials.* Lapidary Journal, 1964, 18, 7, p. 730.

The beginning of a series on silicates. This follows an extensive series, in the same Journal, which has dealt with the faceting of phosphates, borates, carbonates, sulphates and oxides.

S.P.

THURM (R.). Spektrographische Studien am Amethyst. *Spectrographic studies of amethyst.* Zeitschr. d. deutsch. Gesell. f. Edelsteinkunde, 1964, 48, pp. 34-37.

Detailed spectrographic examination of amethyst showed strong lines for silica, aluminium, chromium and copper. The copper content was metallographically determined as 0·03%. Weak traces were found of magnesium and titanium, but hardly any of iron, while the amethyst-coloured synthetic corundum has a ruby spectrum, as it is coloured by the addition of TiO_2, Fe_2O_3, Cr_2O_3.

E.S.

BÖLSCHE (R.). Das Schicksal der Habachtal Smaragde. *The fate of the Habach valley emeralds.* Zeitschr. d. deutsch. Gesell. f. Edelsteinkunde, 1964, 48, pp. 32-34.

There is a constant theft of emeralds from the district. This is not due to serious mineralogical students or collectors, but to "poachers". The owner is now offering students a free holiday in return for guarding the sites.

E.S.

GUEBELIN (E.). Absorptionspektren von Edelsteinen. *Absorption spectra of gems.* Zeitschr. d. deutsch. Gesell. f. Edelsteinkunde, 1964, 49, pp. 14-20.

Tables of the latest figures for the absorption spectra of gems, incorporating the results published by B. W. Anderson. The gems are grouped as follows: A. Zircon, B. gems coloured with Cr_2O_3: pyrope, ruby, red spinel, pink topaz, alexandrite, chrome diopside, chrome enstatite, demantoid, disthene, euclase, hiddenite, jadeite, emerald, C. gems coloured with iron: almandine, aquamarine, axinite, chrysoberyl, diopside, cyanite, enstatite, epidote, hypersthene, idocrase, iolite, kornerupine, green obsidian, olivine, orthoclase, sapphire, sinhalite, blue and violet spinel, yellow spodumene, green tourmaline, vesuvianite, D. absorption spectra caused by manganese: hessonite, rhodochrosite, rhodonite, spessartite, red tourmaline, E. absorption spectra caused by other ions: blue apatite, azurite, sphalerite, chrysoprase, dioptase, yellow fluorite, taaffeite, willemite, Zn-spinel, F. absorption spectra caused by the actual structure of the gem: yellow and brown diamond. G. absorption spectra of rare earth: andalusite, apatite, danburite, didymium glass, green fluorite, idocrase, calcite, sphene. H. the spectra of 14 synthetic stones are listed under this heading, 9 spinels, 3 corundums, one emerald, and one rutile. I. This deals with 6 different types of glasses. K. green-coloured chalcedony, green-coloured jade and artificially coloured yellow, green and pink diamonds.

E.S.

BANK (H.). Imitationen von Smaragdkristallen. *Imitations of emerald crystals.* Zeitschr. d. deutsch. Gesell. f. Edelsteinkunde, 1964, 49, pp. 20-23.

Most articles deal only with cut and polished synthetic or imitation emeralds. The author relates a case where rough crystals

were imported from Colombia. Some of these crystals were from Muzo, some from Chivor and some from Barbur. There was also a small lot which was said to come from a new find, the mine of Vega de San Juan de Gachala, or Gachala in short. This mine was discovered in 1954 and is about 9 km away from Chivor. The Gachala lot consisted of 11 stones weighing 37·24 cts. At a first glance these crystals seemed real enough, even having traces of the matrix. The crystallography, however, gave rise to some suspicion, and it was found that these crystals were in fact glass. The R.I. varied from 1·51 to 1·64, no double refraction and no dichroism were found.

E.S.

THEISEN (V.). Der wiedergefundene Wittelsbacher Diamant. *The Wittelsbach diamond found again.* Zeitschr. d. deutsch. Gesell. f. Edelsteinkunde, 1964, 49, pp. 40-42.

This historic blue diamond weighs 35·5 cts and was first mentioned about 300 years ago, when it was part of the wedding ornament of Margareta of Spain and Emperor Leopold of Austria. In the year 1722, by the wedding of Maria Amalia to Karl Albrecht of Bavaria, the diamond came into the possession of the house of Wittelsbach, and from then on it kept that name. In the year 1931 a Wittelsbach tried to sell the diamond in London, but the offer was too low, and nothing more was heard of it till 1961, when it was bought by some Antwerp diamond merchants who recognised it.

E.S.

CROWNINGSHIELD (R.). *Developments and highlights of the Gem Trade Lab. in New York.* Gems and Gemology. 1964, 6, XI, pp. 180-184.

Jewellery set with synthetic emerald overgrowths on beryl have been submitted for examination. Green-dyed chalcedony and chrysoprase-coloured opal are noted. Stained jadeite which had not faded and plastic-coated and dyed jadeite are mentioned. Two bytownites, diamond doublets, stained marble beads, dumortierite quartz and a fine green enstatite are some of the stones examined in this laboratory. A hololith ring, probably of magnesite, a magnetite in tiger's-eye, clam pearls, and the alteration of colour in a jadeite after steam-cleaning are discussed. A tumbled "agate" consisting of a mass of paint drippings is mentioned.

3 illus. R.W.

LIDDICOAT (R. T.). *Development and Highlights at the Gem Trade lab. in Los Angeles.* Gems and Gemology. 1964, 6, XI, pp. 185-189.

Items submitted to this laboratory included an emerald in which a flaw indicated staining but was proved to have the higher colour due to reflection from deeper coloured parts of the stone. Also seen was an emerald with a large three-phase inclusion—a long multi-strand pearl rope, an opal doublet and swirl lines in aquamarine. Some notes on diamonds are given.
9 illus. R.W.

MILES (R. R.). *Coated diamonds.* Gems and Gemology, 1964, 6, XI, pp. 163-168.

Further notes on the "colour correction" of diamonds by coating the back facets with a suitable film—a treatment more extensively carried out in America than in Europe. The points suggested to be looked for are—an unclassifiable colour when colour grading by colorimeter is carried out and that despite the coatings' resistance to chemical attack they are not necessarily resistant to abrasion. The results given by examination with phase-microscopy are discussed and techniques for the best viewing of the bluish streaks and the metallic lustre of the coatings are given.
8 illus. R.W.

EPPLER (W. F.). *Polysynthetic twinning in synthetic corundum.* Gems and Gemology, 1964, 6, XI, pp. 196-174 and 191.

The existence of polysynthetic twinning in synthetic corundum is ably discussed. Reference to the Landmeier/Plato effect is made. This shows a lozenge-shaped pattern running parallel to the first order prism. There is another kind, much like that seen in natural corundum, which lies parallel to the faces of the primitive rhombohedron. Some suggestions are made to account for these, and a warning is given that "twin-planes" cannot be a wholly reliable sign for natural corundum.
8 illus. R.W.

ANTON (B.). *The pink pearls of Pakistan.* Gems and Gemology. 1964, 6, XI, pp. 175-179 and 191.

Pink pearls have been found in nine districts of East Pakistan. They have been known since the Mogul period of Indo-Pakistan

history. The producing molluscs are *Lamelliden perreysia* and *Lamelliden jenkinsianus*, and they are fished by gypsies and nomad fishermen. A number of these pearls, mounted in jewellery, were on display at the Pakistan pavilion at the New York World's Fair. There is much information of a local nature but little scientific description of the pearls.
13 illus. R.W.

BOOK REVIEWS

LIDDICOAT (R.) and COPELAND (L.). *The Jeweler's Manual.* Gemological Inst. America. 1964. ($4.95).

This book has its ancestry in R. M. Shipley's *Jeweler's Pocket Book*, first published in 1947. The present work has a new format and differs in scope and purpose from the original work It is a useful handbook, mainly for the N. American jewellery trade, with much information for new entrants to the trade. In the gemmological section the term "semi-precious" receives further condemnation and recommended names for the more important gemstones coincide with those of the Gemmological Association of Great Britain,with two minor exceptions. In the U.K. the term "cinnamon stone" is no longer used for describing hessonite garnet and almandite garnet is not an acceptable alternative for almandine garnet. The plethora of trade names used in the U.S.A. for synthetic stones is formidable, and the manual sensibly sets out how each should be described. In the chapter on diamonds there is a useful section on the grading and evaluation of diamonds.

S.P.

WEBSTER (R.). *The Gemmologists' Compendium.* N.A.G. Press Ltd., 1964. 25s.

A revised edition of a standard work first published in 1938 as *The Gemmologists' Pocket Compendium.* The compendium includes information about many of the newer gem materials fashioned as gemstones and it is an extremely valuable book of reference for all interested in gemstones.

S.P.

SINKANKAS (J.). *Mineralogy for amateurs.* D. Van Nostrand, 1964. 97s. ($12.50).

This is another classic from the pen of Captain Sinkankas. The subject is thoroughly discussed, from atomic structure, physical properties, optical properties, the formation and association of minerals to identification procedures and tests. 250 minerals are well described, and the book has 136 photographs and 191 line drawings prepared by the author. A useful feature in the descriptive part of the book is the derivations of mineral names and their current pronunciation.

S.P.

CAVENAGO-BIGNAMI. (S.). *Gemmologia.* Holpli, Milan, 1965 (2nd edition). Lire 30,000.

An extensively revised and augmented edition of the most impressive book on gemmology yet published. Many illustrations, both in colour and black and white, have been added, and the text has been revised to take account of developments in gemmology since the first edition was published in 1959. The quality of the colour illustrations is excellent. The nomenclature has been tidied, though some misnomers still remain. The book has had impressive sales in Italy. It is a desirable book for the many colour plates and illustrations alone. One wishes for an English edition, but unfortunately there seems little likelihood of this.

S.P.

WHEATLEY (W.). *Isaac le Gooch, the King's Jeweller and Benefactor.* Hammersmith History Group, 1964. 10s. 6d.

Mr. Wheatley's small booklet is the result of a painstaking quest into the life of a Court Jeweller whose charitable bequests included gifts to the Dutch Church of London and the Latymer Foundation of Hammersmith. Isaac le Gooch was jeweller to King Charles II. He was born in Antwerp and came to England in 1656.

S.P.

METZ (R.). *Precious stones and other crystals.* Thames & Hudson, London, 1964. £8 8s. 0d.

I have never seen colour photographs reproduced better than the eighty-nine which illustrate Dr. Rudolf Metz's book. It is difficult to know who deserves the most praise, Mr. Arnold E. Franck who photographed these remarkable specimens from the museums and private collections of Europe, or Messrs. Thames and Hudson, the publishers responsible for their reproduction. All one can say is that the blockmaking and the printing are worthy of a set of truly magnificent photographs. It is indeed hard to believe as one leafs over the pages that these are illustrations to a text book. But then this is a curious textbook, lavish and splendid and pleasant, discursive, its author ranging about the world of crystallography like a traveller in a strange and fascinating city. He pauses for a moment to consider lustre and colour, and then goes on to delve into the question of specific gravity and then gives us a few paragraphs on the formation of minerals. He ends up by drifting back into the past and into mythology, tracing the history of gem cutting, and then, perhaps inevitably quoting Plimy the Elder, who set down the belief that amethyst "is not only safeguard against drunkenness if one writes the name of the moon or the sun on it and hangs it round one's neck with baboon's hair or swallow's feathers, it protects one against sorcery, is helpful to those who have to deal with kings, and wards off hail and locusts". As Mr. Georg O. Wild, the well known Idar-Oberstein stone dealer and collector, says in his introduction: "Rudolf Metz, who is a mineralogist and geologist, has very lucidly and with scientific thoroughness set down the data which will give us a fuller understanding of the structure and origin of minerals". And perhaps for once the writer of a preface might have gone further in praise of his author, for besides being lucid and learned, Dr. Metz is also a gracious and an entertaining writer.

K.B.

LEIPER (H.). *Gem-cutting shop helps.* Lapidary Journal, Calif., U.S.A. 1964. $3.95.

This book, compiled with the assistance of Pansy D. Kraus, consists of valuable aids to the gem-cutter that have appeared in the Lapidary Journal over the past seventeen years. In some instances

there is duplication and the authors have wisely not made any eliminations, as different approaches to the same problem add to the interest of the book. This selection of broadly written articles should encourage the beginner to probe more deeply into his craft or hobby.

S.P.

ANDERSON (B. W.). *Gem Testing*. Heywood (Temple Press Books Ltd.). Seventh Edition. London. 1964. 377 pages. One coloured plate 123 black and white illus. 60s.

It would not be expected that a book which had already passed through six editions would require much in the way of a review. This cannot be said about the seventh edition of Anderson's "Gem Testing", for the volume has been enlarged by some fifty more pages and much new material has been added.

In general the book follows the arrangement of the earlier editions, except that two new chapters have been included. The introduction has been partially re-written and there follows a completely new chapter on "Collecting, handling and housing gemstones", in which the use of the loupe and tongs are described and the way to make a stone paper is told in words and pictures.

The chapters on refraction, colour and density have been increased by the inclusions of notes on R. K. Mitchell's modification of the Becke line examination and a new section on dispersion. A very practical method for obtaining the density of large specimens by the use of a camera tripod and a spring balance is explained. The addition of notes on the new French and German synthetic emeralds, and on the Lechleitner emerald-coated beryl brings the chapter on synthetic stones up-to-date. In the chapters on the individual species (or varieties) much more information is given on the artificial coloration of gem diamonds. Scheelite and zinc blende are added as diamond simulants. The rubies from the new sources in Tanganyika are mentioned.

The chapter on zircon has been re-written and much more information is given of the characters of this stone. Small additions are made to other chapters in order to bring them up-to-date. The beautifully written chapter on pearl is completed with a new section on non-nucleated cultured pearls. The author, who has a great interest in the subject, has embellished the chapter on lum-

inescence with much new material on diamond fluorescence.

The inclusion of notes on "electron volts"; "frequency"; "laser" and "maser"; "micron" and "millimicron" are timely. The determinative tables have been increased to take in a fuller range of gem materials. A list of recommended reading is given and the book concludes with a very full index.

There is very little that can be criticized in this work, but the reviewer does take exception to the implication (on page 106) that acetylene is used in place of hydrogen in the furnace used to make synthetic rutile. This notion apparently came from a report on the initial experiments carried out by the scientists of the National Lead Company who used an *oxy-acetylene torch*, not necessarily with acetylene, in their first experiment. (Journ. Gemmology, pp. 131-140. No. 4. Vol. II. October 1949). The author will agree, I think, that to-day a three-cone Verneuil type furnace is used. It is perhaps a pity that references to the crystal systems were not amended to the seven systems as now agreed in the Gemmological Association's examination syllabus—and the author is an examiner to that body. The older spellings "disk" and "conchyolin" make quaint reading but may tend to confuse a young reader as no other book on gem materials seems to use these spellings.

The type is clear and printed on a better quality paper than used for the earlier editions. The colour plate is excellently chosen and printed and does much to illustrate the text on crossed filter technique.

R.W.

Begriffe und Bezeichnungen für Edelsteine, Schmucksteine, Perlen, Korallen sowie Synthesen, Dubletten, Imitationen und Phantasieerzeugnisse. RAL 560 A5. (Definitions and nomenclature of gemstones, ornamental stones, pearls, corals, as well as synthetics, doublets, imitations and fancy products). German Bureau of Standards, 1963, 5th edition.

This being the 5th edition of the German Nomenclature, only the amendments and additions create interest. And they are both interesting and disturbing.

The preface boldly claims that this work is based not only on the BIBOA nomenclature of 1935 but also on the American Federal

Trade Commissions Rulings of 1957 and the British Nomenclature of 1961.

Most surprising is the statement that a letter of full agreement dated the 12th June, 1962, has been received from the president of the International Confederation of Jewelry, Silverware, Diamonds, Pearls and Stones (CIBJO), in which organization the following countries are represented: Austria, Belgium, Denmark France, Great Britain, Italy, the Netherlands, Spain, Switzerland and Western Germany.

The work is further backed up by 31 Western Germany trade organizations and by the Centre International de Promotion de la Qualité, in Paris, and has been lately joined by the Instituut tot Voorlichting bij Huishoudelijke Arbeid, which seems to be an organization promoting good cooking recipes for Dutch housewives.

No wonder that this so universally accepted nomenclature is published also in French and Italian. An English translation is in preparation, it is stated, but the German text shall prevail (Massgebend ist allein der deutsche Wortlaut).

The new edition contains three divisions, viz., definitions and trade rules; a table of permissible trade names; an alphabetical list (a small dictionary) accredited to a well-known professor. The first part is reasonable. It repeats the rule that all stone names must conform with the scientific names; it is not permitted to apply the same name for two different species; the naming of a stone must exclude the possibility of the stone being classed under a different mineralogical category.

A curious paragraph, also inherited from the former edition (but not from BIBOA etc.), recommends the qualification of gemstones by adding such words as "natural", "precious", or "noble", although it is also stated that a stone shall always be understood as genuine when it is not preceded or followed by any qualifying words.

To ascertain the purity of diamonds, the 10x lens is recommended. It is gratifying that this rule is accepted by the CIBJO, since they have adopted, some time ago, a resolution to the effect that the loupe used should enlarge *not more than* 10 times. (No minimum was stated).

How does the willing spirit of these trade rules permeate the second and third part of the work?

New names have been inserted in the table. One is *rhodocrosite* (sic), for no obvious reason spelt incorrectly. Another new

name is the alternative for the German *zinkspat*, viz., *smithsonite*, but this is repeatedly spelt "smithonit", although the species in question is named after James Smithson, the founder of the famous Smithsonian Institution in Washington. An alternative name for cordierite is now given as *iolite*, unfortunately spelt "jolith" in the table, despite the fact that the name is derived from the Greek word ion, which bears the accent over the letter i and not over the o. Another addition is the name cairngorm, persistently spelt "cairngorn".

Conjured up afresh is the most unlucky name "topaz" for various varieties of quartz. This misnomer did not exist in any of the previous editions. But the 5th edition states, in a footnote under "permissible trade names", that in commerce citrine is often called goldtopas, madeiratopas, palmeiratopas (sic), or bahiatopas. And in the same table, "smoky topaz" is now confirmed as a permissible denomination for smoky quartz.

The misuse of the name topaz is in sharp contrast to the rules in the first part, and there can be no doubt that it has been inserted on purpose. For this reason it appears rather audacious to claim, as does the preface, that this new edition is based on American and British nomenclatures.

After this disheartening discovery it is tempting to look into part 3 to see what the professor writes about topaz. He states "Topaz = citrine. False name for natural citrine (yellow crystal) or burned amethyst. *Vide* also precious topaz".

So we learn that topaz is both equivalent to citrine *and* a false name for citrine. It is not stated that a topaz is a topaz which, in fact, is the only thing it can be. There is a reference to precious topaz, and under this caption we are told that precious topaz is the same as topaz! And since we already know the learned meaning of the word topaz, we find it meaningless to stay in this merry-go-round, which cannot possibly be the work of the esteemed professor. As a final word "opalisieren" (opalescence) is used for the girasol effect seen in some fire opals, as well as for the play of colours in precious opal.

F.J.

TWO TRICKY ITEMS

by G. V. Axon, F.G.A.

The pleasure one gets from "guessing" an identification and then "proving" it to be correct is always to be offset by the tendency to read the various gem instruments incorrectly with the guess uppermost in mind. Two stones recently gave the author a rather sharp lesson.

The first stone, about half-a-carat, was bright green, and with "horse-tail" inclusions. The stone appeared pink with red flashes under the ordinary colour filter, and even in ordinary light without the filter appeared to give off red flashes. The second stone, of some 22 carats, was quite a lively brown.

The first "guess" was demantoid garnet. The stone turned out to be chrome sphene. The second "guess" was heat-treated amethyst. The stone was golden calcite. Neither chrome sphene nor golden calcite is seen frequently, the former because it is still rather rare, and the latter because it is so difficult to cut and so fragile.

Here were two very good examples of tricky looks. Of course, closer examination would have revealed that the "horse-tail" in chrome sphene did not appear to radiate, and that the doubling of the black facets in the calcite was apparent. The same would no doubt apply to a small clean chrome sphene examined under a lens.

Both stones were extremely tricky items, to say the least, for the "horse-tail" inclusion of demantoid has practically become its most important single identification, yet here was a stone with very similar inclusions and almost identical in appearance. Thus "horse-tail" inclusions will have to be watched rather more closely now.

As for golden calcite, so few specimens are to be seen that few jewellers will ever encounter them. Even so, heat-treated amethyst is by now almost recognisable at sight—at least I thought it was, but after the shock of receiving a golden calcite and finding what appeared to be a heat-treated amethyst, I have again learned the importance of never taking anything for granted, and of always making at least two tests, exluding the first "informed guess".

SCHILLER AND PSEUDOCHROMATISM IN MINERALS AND GEMSTONES

By J. OSTWALD, B.Sc., F.G.A.A., A.M.Aus. I.M.M., F.G.S.

As indicated by its title this short paper is simply an attempt to define two phenomena found in a variety of minerals, some of which have minor importance as gemstones. The author feels the necessity of such a definition as a variety of terms have been used in this connexion, some not too happily, while a number of explanations as to the origin of the phenomena do not seem to fit the observed facts. In the following pages the nature and origin of schiller inclusions and pseudochromatism are studied with particular reference to the pyroxenes and feldspars.

The following terms and definitions may be found in the text books in any geological library. In each case the authority for the definition is given.

Schiller

1. A bronze-like lustre or iridescence due to internal reflection in minerals which have undergone schillerization. (Fay)
2. A type of mineral structure which is manifested by a play of colour. (Herbert-Smith)
3. A bronze-like lustre in definite crystal directions. (Groth)
4. A nearly metallic lustre. (Rutley)
5. A lovely blue sheen. (Herbert-Smith)
6. A term (from the German) applied to the peculiar lustre, sometimes nearly metallic observed in definite directions in certain minerals. (Dana's Text Book)
7. Minute plates of iron oxides systematically distributed through individual crystal. (Wahlstrom)

[NOTE 1. The definitions of Dana (6) and Groth (3) are to be preferred.]

Schillerization

1. The development, along certain planes in a mineral of minute inclusions which reflect light simultaneously and so give use to the appearance known as "schiller". (Holmes)
2. The charging of a mineral with definitely oriented inclusions. (Rosenbusch)

3. A deep-seated metamorphic process resulting in the presence of inclusions of a secondary origin. (Teall)
4. The development along certain planes within the crystal of tabular, bacillar or stellar enclosures which, reflecting light falling on them at certain angles, give rise to the peculiar phenomenon known by the name "schiller". (Judd)

Perthite

1. An intergrowth of potassium and sodium feldspar, probably crystallized as a result of exsolution. (Challinor)
2. As first described, a flesh-red aventurine feldspar from Perth, Ontario, called a soda orthoclase, but shown by Gerhard to consist of interlaminated orthoclase and albite. (Dana's Text Book)

(NOTE. Herbert-Smith, though he does not use the term just defined, says that the optical effects seen in moonstone result from thin layers of orthoclase and albite.)

[NOTE 2. Though many aventurine feldspars are perthitic this does not imply that the aventurine reflection results from the perthite layering. It seems likely that in this case exsolved plates may most easily be orientated at the junctions of potash and soda rich layers.]

Chatoyancy

The property of having a lustre resembling that of the eye of the cat at night. (Dana's Text Book).

Play of colours

A term used to describe the appearance of several prismatic colours in rapid succession on turning the mineral. (Dana's Text Book)

(NOTE. Rutley speaks of play of colour in relation to diamond. There can be no excuse for such loose terminology, when the correct term, dispersion, is so well known.)

Change of colours

An expression used when each particular colour appears to pervade a larger space than in the play of colours and the succession is less rapid, e.g. labradorite. (Dana's Text Book)

Iridescence

The exhibition of prismatic colours in the interior or on the surface of a mineral. (Dana's Text Book)

A display of prismatic colours due to the interference of rays of light in minute fissures which wall in thin films of air or liquid. (Rutley)

(1) This latter "definition" seems to be totally inconsistent if we take it that "prismatic colours" are those which are produced by a prism.

(2) Herbert-Smith terms the labradorite colours iridescence colours and states that they are due to its lamellar nature, the results of repeated twinning.

Pseudochromatism

The property of being pseudo-chromatic, that is to say, the colour they show is not a true colour but rather a play of colour produced by certain physical effects e.g. precious opal, labradorite. (Berry and Mason)

Schiller plates

Tiny platy inclusions arranged in varying sets of parallel planes. (Read and Watson)

Aventurine structure

Having the appearance of a glass containing gold coloured inclusions. (A.G.I. Glossary)

(Bauer relates the "improbable" story that the artificial aventurine glass of Venice was produced by accident (*par aventure*) when copper fillings were dropped into a vat of molten glass. The art was lost until 1827 when Bibaglia, a glassmaker, rediscovered it.)

Microplakite structure

Inclusions of small rectangular plates of a brownish colour, strongly pleochroic, generally parallel to the base of hypersthene crystals. (Johannsen)

(The term "schiller" was probably first used in 1819 by K. von Raumer, as a term (from the German, schillern, "to vary in colour") to describe the peculiar optical reflection seen in "schillerfels" (hypersthene)).

From the above list, which is not exhaustive, one may see the wide range in terminology and definition used. It will also be

seen, however, that we are dealing with two types of phenomena. These are as follows:—

1. *Reflection phenomena*

   This occurs when a more or less transparent silicate has orientated inclusions of a platy nature arranged in certain crystal planes. If these inclusions have metallic lustre it is reasonable to assume that the mineral will have a metallic lustre in certain directions and its normal appearance in others. This is "schiller".

2. *Interference—Diffraction—Scattering phenomena*

   According to the wave theory many colourful phenomena may be explained by assuming that colours are removed from white light on reflection by destructive interference of waves, as in the case of thin films, while coloured spectra may be produced by reflection off striated surfaces (diffraction gratings). Tyndall scattering may also produce a blue and a red colour in some cases.

In the former case the colours are subtractive, as may be seen with a simple spectroscope, whilst in the latter they are pure spectral colours. This phenomenon is here called "pseudo-chromatism". It is this which occurs in precious opal and perhaps occurs in labradorite. It is also interesting to note that whilst the colours of opal were generally assumed to be subtractive colours due to interference, the term "play of colours" was generally used in this relation, though Dana had stated that this term referred to "prismatic colours".

Figs. 1 to 4 are sketches of typical examples of the phenomena discussed above.

The origin of "schiller structure"

The changing metalloid lustre seen at certain orientations in the minerals of the enstatite-hypersthene group was first studied in the late 18th century. The name "schillerspar" was used by J. C. H. Heyer in 1786, in Crell's Annalen, to designate the mineral we call bastite, a decayed and altered ortho-pyroxene. Bronzite, a name applied to schillered enstatite dates from 1807. The first extensive studies in the nature of the inclusions were those of

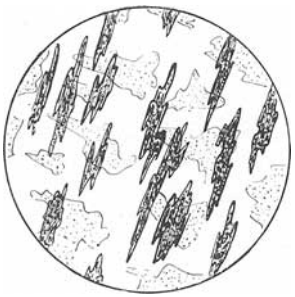

Fig. 1.

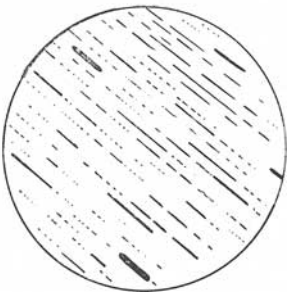

Fig. 2.

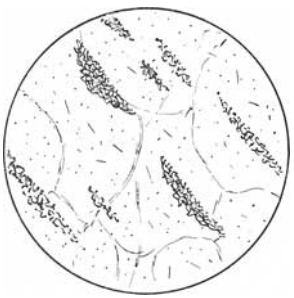

Fig. 3.

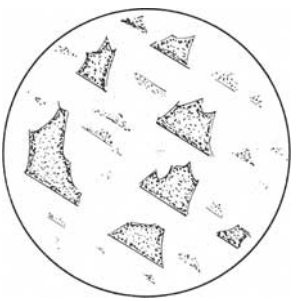

Fig. 4.

Trippke (1878) and Kosmann (1869). These authors found that among the more easily identifiable inclusions of magnetite, apatite and zircon in hypersthene there were commonly developed "tabular microlithic interpositions", lying in three different directions, with their plane faces parallel to the principal cleavage face (010). These plates are generally rhombic or irregular, and appear in thin section as thin opaque strips or even points in all sections which are not parallel to the plane of the most perfect cleavage. In colour they range from dark brown and opaque, through shades of red, brown and yellow, to almost colourless. In reflected light the thicker opaque plates have a metallic habit, while even the transparent ones are sub-metallic. Generally the elongation of these plates is parallel to the "C" crystal axis. Both Trippke and Kosmann thought them to be of secondary origin, and found that in diallage they were isotropic in nature. From this they deduced them to be opaline.

The extensive researches of J. W. Judd stemmed from an investigation in 1885 on the peridotites of Scotland. In these basic rocks, which he believed to have formed at considerable depth

and under great pressure, he found the crystals of feldspar and ferromagnesians to be "shot through" with minute rods and plates of a more or less definite form. As an example, the feldspar of the Cuchullin Hills, Skye, was full of minute black rods and plates often occurring in layers in five planes, those of the pinacoids and prisms, producing the labradorite play of colours. The pyroxenes, both monoclinic and orthorhombic showed similar orientated inclusions. Judd regarded the inclusions as amorphous in nature, being composed of hydrated oxides, such as opal, hyalite and limonite. He further decided that these inclusions were of secondary origin, the result of a deep-seated metamorphic process which he termed "schillerization".

In his paper of 1886 Judd proposed a theory of schillerization based on five postulates. These are as follows:

1. If a crystal is subjected to intense strain, planes of easy solution arise parallel to the directions along which the strain is exerted and as a result certain cavities filled with liquids or solids, the products of the solvent action, will be formed along such planes.
2. In every crystal, in addition to the cleavage planes and the glide planes, Judd postulated the existence of a third set of structural planes along which chemical action occurred most readily. These planes of chemical weakness had a definite crystal orientation.
3. Under great pressure solvents act in these planes of chemical weakness to produce cavities, or negative crystals. These often become filled with decomposition products. At any one depth the plane of greatest chemical weakness is attacked first.
4. There appears to be a definite relation between the planes of cleavage, gliding and chemical susceptibility.

In proof of this hypothesis Judd put forward the following observations:

1. In faulted pebbles from the Old Red Sandstone from the Highlands, cavities filled with liquid and secondary solids were found in planes parallel to the faulted surface. These cavities were produced by solvent action in directions of strain.
2. Since their discovery by Daniell in 1816, etch figures on crystal faces have received much study. But it was not until 1884 that Von Ebner of Gratz discovered the presence of the solution planes (Lösungsflächen). Mainly studying calcite and aragonite Von Ebner was able to show that certain planes exist in

these crystals in which chemical action takes place most easily.

3. According to Mugge there is evidence to show that cleavage planes and glide planes are mutually interchangeable. In actual experiment it was found that cavities developed under pressure in twinning planes just as in natural cleavage planes.
4. In many plagioclases the minute black enclosures are parallel to the albite and pericline twinning planes.
5. In certain feldspar crystals from a gabbro at Humlebak Scharf, Norway, albite twin lamellae and layers of inclusions may be seen under the microscope in those parts of the crystal which have suffered most deformation.

Thus, briefly, Judd believed that "schiller structures", commonly seen in pyroxenes, feldspars and olivines were structures characteristic of deep-seated rocks and were produced as secondary phenomena by pressure. In this theory he is followed by A. G. MacGregor (1931) who, however, regarded them as a result of regional metamorphism. In favour of the theory is the fact that the labradorite and hypersthene from the great Archaeozoic "shield" of the Labrador area of Canada both show orientated inclusions, as though they were developed as a result of strain (or regional metamorphism). If, on the other hand, the inclusions are primary, it seems rather a coincidence that two "classic" examples of the phenomenon should occur side by side.

It would be wrong, however, to assume Judd's theory is the only one which can explain the lineation of micro-inclusions in feldspars and pyroxenes. In fact most modern petrologists believe these textures are the result of unmixing in solid solutions. During certain conditions of cooling these solid solutions unmix, producing in minerals special exsolution textures. The moonstone structure is certainly produced by this phenomenon. Kozu and Suzuki have shown in this case that the x-ray pattern of this gemstone indicates the presence of two space lattices at room temperature (one orthoclase, the other albite), and this is no doubt the result of unmixing during slow cooling of an original homogeneous potash-soda feldspar. In the case of enstatite-hypersthene (and perhaps plagioclase) unmixing may produce schiller structures. Perhaps the relationship between schiller structures and deep-seated origin may then not be due to the ideas Judd put forward, but rather to the results of slow cooling which occurs in these bodies; rapid cooling would prevent unmixing.

This concept of solid solution in minerals was discovered early in the 19th Century, soon after the development of accurate methods of chemical analysis. Minerals were found, not to be constant in chemical nature but rather, they were variable within certain limits. Minerals were then looked upon as mixed crystals, as though a single perfect crystal could contain molecules of two or more substances. We now know, however, that there are no molecules in ionic crystals, only an ordered pattern (or lattice) running through the whole crystal, with atoms of various elements situated in various parts of the lattice. The whole structure might be made up mainly of atoms A and B, but here and there atoms X take the place of an A, and Y takes the place of B. Mason illustrates the concept with the idea of a bricklayer who, when he runs short of red bricks for a wall, incorporates a yellow brick here and there. But the yellow bricks must fit the red bricks and must be of the same size, or double the size or three times and so on. Certain definite conditions govern the atomic replacement. These may be found in textbooks such as Goldschmidt's "Geochemistry" or Winkler's "Structure und Eigenschaften der Kristalle".

Identification of "schiller" inclusions

Within the last two decades a powerful x-ray technique has been applied to the identification of orientated inclusions in minerals resulting from exsolution, alteration or partial inversion. This method uses oscillation photographs i.e. the crystal under study is made to rotate slowly around an edge (say, the C axis) and the x-ray reflections are recorded on a cylindrical film whose axis coincides with the rotation axis of the crystal. In the pyroxenes studied by this method, by Bown and Gay in 1959, the crystal was made to oscillate in two 15° ranges, across the normals to (100) and (010). These experimenters made use of a general principle called by them "the intergrowth symmetry principle", to determine the nature of the orientated intergrowth. Basically, this means that orientated crystallites give spots on the photograph governed by the host symmetry, not by their own symmetry or orientation. Now if a similar photograph is taken of a "pure" pyroxene and the two photos compared, certain spots will be seen on the first photograph which are due to the inclusions.

The problem is one of (*a*) identification and (*b*) orientation of inclusions. If the inclusion is also a pyroxene it may be identified

by matching similar photos of pure substance spots and "inclusion" spots as to position and relative intensity. For example, augite lamellae in schillered hyperthene could be identified by comparing the inclusion spots with the spots of pure augite. The orientation of the lamellae would be the same as the orientation of the "pure" augite crystal. More difficult identifications and orientation studies may involve the use of powder photographs.

Some of the combinations studied by Bown and Gay included: (1) Augite + (001) Pigeonite lamellae; (2) Augite + (100) Hypersthene lamellae; (3) Pigeonite + (001) Augite lamellae; (4) Hypersthene + (100) Augite lamellae; (5) Hypersthene + (100) Magnetite lamellae; (6) Hypersthene + Ilmenite + Hematite lamellae; (7) Augite + (100) and (001) Magnetite lamellae.

Some of these no doubt include the common schillered hypersthenes, bronzite, etc. Fig. 5 (*a*, *b*, *c*), shows the orientation of inclusions in cases 1, 2, and 4 above.

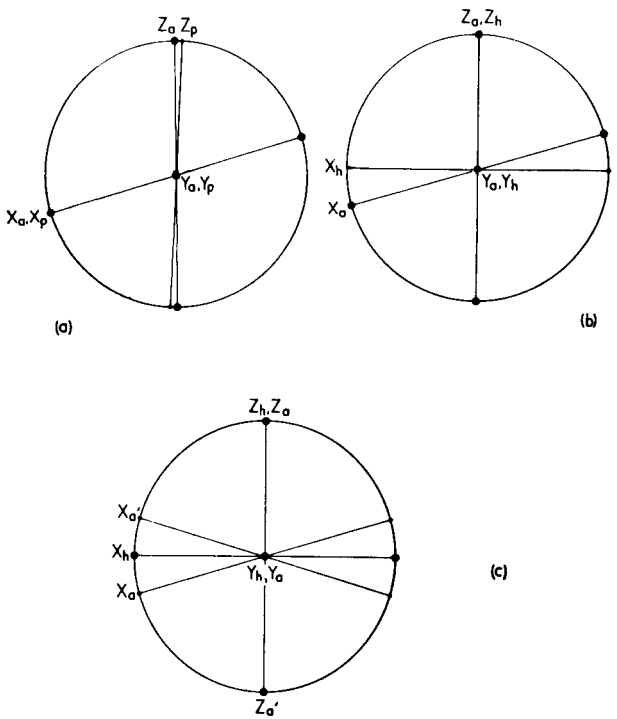

The aventurines

Apart from the coloured glass, the term "aventurine" is usually applied to varieties of two minerals, quartz and feldspar. Only the latter shows a true schiller. This is essentially a potash feldspar containing orientated exsolved plates of a reddish coppery mineral, which is usually thought to be hematite, though O. Anderson discovered an aventurine labradorite from Modoc County, California, in which the inclusions were metallic copper. The main deposits of aventurine feldspar are in Norway, near Lake Baikal, U.S.S.R; near Archangel; and in U.S.A.

Aventurine quartz is essentially a translucent granular quartz containing scattered glistening spangles of silvery, reddish and green micaceous minerals (the green from India containing fuchsite) without definite orientation. Owing to its hardness this is more suitable than the feldspar for cutting but it is inferior to feldspar in beauty.

A "schillered" quartz from Manhattan Island, described by Scott, appears to be quartz containing thin films. The term "schiller" is used incorrectly.

Conclusions on schiller

The phenomenon of schiller arises from the development, either by exsolution or secondary alteration, of orientated lamellae, which have a definite relation to certain crystal structural planes. If these lamellae are metallic in lustre, then the host mineral shows a brilliant metallic reflection in certain orientations. This is true schiller, resulting from simple reflection. If on the other hand the lamellae are transparent it is possible that interference effects may be produced, though in this case the phenomenon is not a schiller as defined above.

Pseudochromatism

This term is used by Berry and Mason as equivalent to the term "play of colour" of the older writers. In this section only the pseudochromatism of labradorite will be discussed at any length, as the writer feels that the results of modern studies on precious opal are too well known to be described here.

Labradorite

The mineral now known to us as labradorite was discovered in 1770 by Moravian missionaries, who found it in use by the Esquimaux of the Labrador coast. The first specimens reached Europe in 1775, some specimens consisting of pure labradorite with its beautiful deep blue play of colour, while others were slabs of an igneous rock containing, as well as labradorite, crystals of hypersthene, with a beautiful coppery red "schiller". The rock, a norite, occurs on the Isle of St. Paul and along the adjacent mainland.

Soon afterwards, in 1781, similar labradorite was discovered, as boulders, at Peterhof, near St. Petersburg, in Russia. Here the boulders showed the characteristic blue colour, but weaker than that of the Labrador material. Near Kiev it occurs again *in situ* in a gabbro, along with diallage. Here single crystals of labradorite measure up to five inches, though most are smaller. Many other localities occur in Russia.

About 1825 specimens were discovered in Finland, near the iron mines of Abo. Here the material tends to be transparent and colourless, with beautiful colours, often in concentric zones about a dark nucleus. The United States of America has a number of important localities, in New York State, and in Pennsylvania, Arkansas and North Carolina. Bauer, in his "Precious Stones", states that some fine material had come on the market from Brisbane, Australia. No such material was known to the writer, who was a student of geology in that town, though some large boulders of "augen" gneiss containing labradorite in the Botanic Gardens, reputedly brought from South America (?) as ballast in the days of sail may have provided the material.

Incidentally, as would be expected, Bauer gives an excellent account of the material and its play of colour. He notes the general opaque nature of the mineral, its ash gray colour and the magnificent display of colours at one particular orientation. In this position it shows metallic sheen and the colour together. As Bauer states: "There is no art by which a reproduction or an imitation of it in any way comparable to the original may be produced". He likens the colour to that seen on the wings of certain South American butterflies, to the blue of *Morpho cypris* and M. Achilles and the green of *Apatura seraphina*. Also, although he does not pretend to have made a detailed scientific study of the cause of the play of colours, he notes particularly that the colours may be

produced in more than one way, the yellows and greens in one way, the characteristic blues in another. This fact will be referred to later.

The first scientific study was made by Von Hessel in 1827. With the aid of a two-circle goniometer he discovered the following facts: (1) The play of colours occurs at only certain definite orientations. (2) The reflection of coloured light came from certain definite planes. He attributed the play of colours to reflections from inner cleavage planes. In 1829 Brewster stated that: (1) The reflecting plane made an angle of 10°52′ with the cleavage face P. (2) The colour of the transmitted light is complementary to the reflected. His theory was that the colour was produced by reflection from an infinite number of planes.

In the same year Nordenskiold, after studying the Finnish material noted that the colours are sometimes concentric and the reflecting plane may be a cleavage plane. He further postulated that the atoms of transparent crystals can be arranged for the refraction of light in different ways.

Senff, also in 1829 (a great year for the study of labradorite) discovered that in Finnish labradorite the colour was visible when the crystal was turned 22°30′ from the plane of the (010) cleavage.

In 1830 Bonsdorff postulated a reflection from layers of silica in the material. Reusch in 1863 imagined the colour was due to reflection from minute cleavages.

Far more important was the work of Vogelsang in 1868 This experimenter divided the colour into 2 classes:

Class A. The common blue colour which he thought was a polarization phenomenon due to its lamellae structure.

Class B. The golden reddish "schiller" with the rarer yellow and green, due to the presence of black acicular microlites and yellowish red microscopic lamellae.

Anderson, writing in the "American Journal of Science". describes the play of blue and green colours as a "glaukisiren" and makes the very important statement that the colours are probably due to light scattering by submicroscopic inclusions.

Rayleigh in 1923 made some interesting observations on the subject. His conclusions were:

1. The colour of the mineral results from reflections of two types.
2. The first reflection is specular, from micro-inclusions in the

cleavage plane (perhaps (010) though crystal notation is not used in this paper). This is a blue or sometimes a yellow reflection. (A thin plate colour.)

3. The beautiful colours of the "play of colours" occur as a diffuse reflection from a plane about 15° from the above cleavage.
4. The nature of the particles which make up this diffuse plane is not easy to determine, though they are parallel sided, irregular in outline approximately 0·005 mm in dimension and distributed at random in depth. (Also variable in thickness.)
5. The bright colours are probably the result of interference of streams of light from the two surfaces of each "patch".
6. The brightness of the colour is explained by a large number of reflecting "patches" adding their effects, without definite phase relations, such as would give use to regular interference.

In 1924 Boggild studied both labradorite and peristerite. His boservations included:

1. Play of colour only occurs in plagioclases of composition 92.5–85.5 AL and 49–38 AL.
2. Peristerite has only one plane of reflection of coloured light.
3. Labradorite has 3 planes of reflection of coloured light.
4. In all cases the coloured material is either twinned or laminated.
5. In peristerite the reflecting plane is between $(0.8.\bar{1})$ and $(\bar{1}.21.\bar{2})$.

However, Boggild notes that gedrite from Avisiarfik, in Greenland, also shows colours reflected from the (010) plane, without any visible twinning or lamenations.

Parsons, in 1930, put forward a list of points which he thought to be of prime importance in the study of the play of colours:

1. Iridescent colour in crystals is reflected from definite crystallographic planes.
2. In most cases the material that has been examined was twinned.
3. The colours are interference colours of the first and second order.
4. The colours of the iridescent light is complementary to that of the transmitted light at a given angle of incidence.
5. The coloured light is not plane polarized.
6. The atoms of crystals can be so arranged that light will be refracted in different ways.

7. The colours of plagioclase are shown only by those of certain chemical composition.

Statement 6 in the list is considered most important by Parsons, who concludes that the colours are produced by optical interference from large numbers of atomic structural planes which make angles of $23°15' \pm 1°$ with the (010) face. Yet further on in his article he states that the particular tint of colour seen is determined by the thickness of the twinning lamellae, variation in colour (in concentric zones) being due to bending of the twinning layers. So the paper seems to oscillate between attributing the colour to twinning lamellae and certain structural atomic planes.

The most recent investigation of the labradorite colours is that of Raman and Jayaraman in 1950. According to these workers the colours are not due to the visible inclusions (the layers of rod-like structures so commonly seen) because of their irregular distribution. Rather they believe that the colour, particularly the metalloid blue, is due to variations in the mineralogical nature of the soda-lime feldspar. In fact they consider that most labradorites are grey and translucent rather than transparent because of the presence of an extremely fine micro-perthite structure of orthoclase microliths in the labradorite host.

While the albite twinning of labradorite is not fundamental to the development of the colour it does govern the orientation of the orthoclase microliths. In albite twinning 010 is both a composition plane and a reflection plane. Now if we number the twin lamellae, clearly visible in the 001 face, in the order 1, 2, 3, 4, 5, 6 etc., then the orthoclase microliths in layers 1, 3, 5 are parallel to each other, as are those in 2, 4, 6, but the orientations of microliths in the two sets would be different.

Raman and Jayaraman put forward five criteria of prime importance:

1. Every specimen of labradorite which is twinned according to the albite law and shows iridescence should display the latter in two distinct settings of the specimen, if the direction of incidence of light and the direction of observations are constant.
2. For the same reason, for any given position of specimen and light the iridescence should be observable in two divergent directions.
3. The two reflections have their origin in different parts of the

crystal, namely the two differently orientated parts of the albite twin.

4. The two sets of reflections show similar colours.
5. The settings of the crystal required for observing the two independent sets of reflections should make equal angles with the setting required to obtain a specular reflection from the composition plane.

The author then describes in some detail slight complications due to the presence of pericline twinning. In (5) above the angle of maximum intensity of iridescence is 14° on either side of the 010 face.

As to the origin of the colours themselves the writers are rather indefinite, and more or less propose that they are "labradorite colours". The concentric distributions, so commonly red-brown, yellow and pale blue, set in a background of metalloid blue, is not a thin film colour or Newton's rings colour. The writers however state that the colours seen depend on the size and distribution of the orthoclase microliths in the layers. In their finest state they scatter light and presumably the metalloid blue is a Tyndall blue scattered by small particles. The other colours are interference colours due to interference of light in particles of dimension in excess of those required to give the first order Newtonian colours.

So, basically the remarkable metalloid blue is thought by Raman and Jayaraman to be a Tyndall blue.

The writer has in his collection a beautiful thin section of labradorite (0·03 mms thick) which is crowded with parallel rod-like inclusions and which shows the most striking metalloid blue in certain orientations. With the aid of a 5-axis universal stage he was able to determine: the crystal orientation of the thin section; the crystal orientation of the rod-like crystallites; the orientation of the metalloid blue reflecting "plane" (the "diffuse plane" of Rayleigh).

(No details of orientation procedure are given here, as this paper is concerned with results rather than experimental studies, but the interested reader should refer to the Geological Society of America Memoir 8, "The Universal Stage" by R. C. Emmons; a standard text).

The results of the above study are listed below:

1. The rod-like crystallites (some of which are actually cavities rather than crystals), occur in the (010) plane.

2. The metalloid blue reflecting plane (the diffuse reflecting plane of Rayleigh) in centred 22°30′ off (010). This figure is essentially that of Senff (1829) and Parsons (1930). The axis of rotation used was in the (010) plane, and at 90° to the elongation of the crystallites. At 14° (Raman, 1950) and 15° (Rayleigh, 1923) no blue was observed.
3. A rotating Wright analyser indicated that the metalloid blue light was plane polarized to a certain extent. This plane polarized light was not confused with that produced at the Brewster angle, approximately 57°.

Another cut specimen in the author's collection shows a yellowish-red colour by transmitted light and the normal metalloid blue by reflection. The former colour is very similar to the "red" fringes seen on the edges of the isogyres in biaxial crystals showing dispersion.

Conclusions on labradorite

It seems likely that the striking blue reflection of labradorite, a remarkable example of pseudochromatism, is a Tyndall effect. Tyndall scattering occurs also in some chalcedony, and in the so-called blue quartz. A major point of distinction between these and labradorite seems to be that the scattering particles have a definite orientation in the latter, while in the former they are randomly distributed in the host mineral.

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ASSOCIATION NOTICES

PRESENTATION OF AWARDS

A reunion of members was held at Goldsmiths' Hall, London, on Monday, 26th October, 1964. This was followed by the annual presentation of awards at which Mr. Norman Harper, Vice-Chairman of the Association, presided. He said: "The Gemmological Association are very pleased and happy to welcome you all to this presentation ceremony, and to congratulate all the successful candidates in our recent examinations. Once again we are able to do this in this delightful and impressive Livery Hall of the Worshipful Company of Goldsmiths, and our sincere thanks go out to the Company for their kindness in allowing us this privilege. The Gemmological Association is now entering its second half century, and is stronger and healthier than ever. This year we had the largest entry for our examinations in the history of the Association, when 273 entered for the Preliminary and 139 for the Diploma. The examiners have been at pains to ensure that the Standards required in the examinations have been maintained. It is our aim to favour neither a brilliant theoretical person, nor a particularly excellent practical worker, but a balanced gemmologist who does not fall too low in any branch of the subjects covered by our syllabus. For the second year the Association has arranged the examinations for the Diamond Certificate, and once again all the candidates passed both in theory and practice. I would like on behalf of the Association to thank De Beers for their help and all their interest in these Courses.

"I would also like to take this opportunity of placing on record the Association's indebtedness to the Midlands Branch, and the West of Scotland Branch for their continued keenness and enthusiasm. Their is one person to whom special tribute is due, and that is our Secretary, Mr. Gordon Andrews. He has been our Secretary for 25 years, and has done a splendid and dedicated job of work. I am sure we all hope that Mr. Andrews is our Secretary for many years to come.

"I specially welcome Fellows and visitors from overseas including Miss U. Tillander, Finland, Dr. H. Nairis and Dr. C. Neilsson from Sweden, Mr. P. Vanderkelen of the Gemmological Association of Australia, and Mr. J. A. Fleming, New Zealand. I am also glad to welcome Mr. J. Pike, of Messrs. Rayner and Keeler Ltd., who so kindly present the Rayner and Tully prizes.

"We now come to the object of our gathering here tonight, which is to present diplomas and certificates to successful candidates in our examinations and I am extremely pleased to introduce you to Mr. A. E. Shipton, President of the British

Jewellers' Association, who will perform this ceremony. Mr. Shipton is well known in the jewellery trade, and he became a Fellow of the Association in 1932. He was for some time Chairman of the Midlands Branch of the Association and in that capacity did some splendid work. He is managing director of an important firm of precious stone cutters and merchants in Birmingham, and it is a great pleasure to us to have him with us during his term of office."

Mr. Shipton, in congratulating the successful candidates, said they were only at the start of their career. Often they would have to be tactful when they were shown a magnificent "alexandrite" bought at a bargain price in Gibraltar.

The treasurer of the Association, Mr. F. E. Lawson Clarke, in thanking the B.J.A. President, said that those who studied gemmology were introduced to new worlds of interests, such as those of optics, mineralogy, microscopy, photography and the work of the lapidary, which was Mr. Shipton's special interest.

MIDLANDS BRANCH MEETINGS

Members of the Midlands Branch of the Association visited the Barber Institute of Fine Arts, Birmingham University, on the 25th September, 1964. They were welcomed by Dr. Garlic, a member of Professor Ellis Waterhouse's staff, who outlined to members the history of the Barber Institute, and discussed examples of the varied European schools of painting exhibited there. Members were able to inspect the four galleries and, apart from paintings, were shown a carved jade bowl and drinking cup of the Ching Dynasty and a bloodstone bowl with silver-gilt settings by Paul Storr.

* * * *

An informal social evening was held by the Branch at "La Reserve", Sutton Coldfield, Warwickshire, on Wednesday, 21st October, 1964.

TALKS BY MEMBERS

CAFFELL, E. W. "Gemstones", Heston Congregational Church (Ladies' Friendship Club), 22nd September, 1964.

GILLOUGLEY, J. H., JNR. "The Diamond Story", Ralston and Oldhall Townswomens Guild, Paisley, 15th October, 1964.

KENT, D. G. "Gemmology", Bromley (Branch) Young Conservaties, 4th November, 1964.

OLIVER, R. J. N. "Diamonds", Liverpool 41 Club, 6th November, 1964.

JONES, T. G. "Gemstones", Abingdon Abbey Townswomen's Guild, 10th October; "Science of gemstones", Haselmere Natural History Society, Surrey, 14th November, 1964.

CAFFELL, E.W., "Gemstones", Coulsdon Rotary Club, 16th November, 1964.

WEST OF SCOTLAND

A meeting of the West of Scotland Branch was held in Glasgow on 22nd October, 1964. It took the form of a film show, at which "Diamonds in the West" and "The Conquest of Time" were shown.

OBITUARY

Mrs. Gordon Glennie (née Elsie Ruff), at Barbados, 1st November, 1964. Miss Elsie Ruff will be remembered by her many friends for her inate courtesy and for the painstaking researches which she made in connexion with the problem of jade. Her book "Jade of the Maori", published by the Association in 1950, won her great esteem and since that time she had published, in various gemmological journals, her studies of the occurrence, nomenclature and working of jade in Europe and the Americas. She became a Fellow of the Association in 1924.

COUNCIL MEETING

A meeting of the Council of the Association was held at Saint Dunstan's House, Carey Lane, London, E.C.2, on Wednesday, 30th September 1964. Dr. W. Stern presided. The following were elected.

ELECTED TO FELLOWSHIP

Adshead, Christine V., (Miss), London, E.12.
Algar, S. Forbes, Hamilton, Ont., Canada
Barker, Brian M., Pinner Middx.
Bromly, Ivan P., London, N.10. (D.1963)
Colclough, Albert C., Rainham, Essex.
Graham, Martin J. P., Reigate, Surrey
Kelly, Hugh, London, W.1.
Kerry, Stewart M., London, N.W.11.
King, Michael L., Witham, Essex
Koller, Tibor, Melbourne, Australia
Lechleitner, Paul A., Lucerne, Switzerland
Reid, Wilmot P., Kitwe, N. Rhodesia
Snider, James R., Willowdale, Ont., Canada
Bagi, Julius, Toronto, Canada

TRANSFERRED TO FELLOWSHIP FROM ORDINARY OR PROBATIONARY MEMBERSHIP:

DOWIE, Frederick G., Christchurch, New Zealand
Larcher, David M., Sheffield
Bjørn-Hansen, Eva (Mrs.), Oslo, Norway
Bond, Cecil A., Waltham Abbey, Essex
Bradburn, Gwendoline (Mrs.) Sydney, Australia
Climie, Robert, Newtown St. Boswells, Roxburgh
Greene, Jane B., (Mrs.), Princeton, U.S.A.
Hunt, Elyane M. (Mrs.), London
Johnson, Arthur W., London
Knox, Christine G. (Miss), Hamilton, Canada
Kothari, Ramesh R., Madras, India
Marshall, M. Sheila (Mrs.), Ibadan, Nigeria
Miles, Richard S. G., Nottingham
Myers, Julia H. (Miss), Double Bay, Australia
Schiffman, Charles A., Geneva, Switzerland
Wyer, Philip G., Birmingham

ELECTED TO ORDINARY MEMBERSHIP

Austin, Virginia S. (Mrs.), Phoenix, Arizona, U.S.A.
Bastos, Francisco M., Minas Gerais, Brazil
Beattie, Floyd E., San Francisco, Calif., U.S.A.
Berkowitsch, Leo, Zurich, Switzerland
Blondel, Vera A. (Miss), Guernsey, C.I.
Butland, William M., Natal, South Africa

Decoster, Micheline (Miss), Brussels, Belgium
Dryden, Kenneth E., Spalding, Lincs.
Holcombe, John W., Queenstown, South Africa
Hightower, Jackson C., Twin Falls, Idaho, U.S.A.
Kasliwal, Nemichand G., Bombay, India
McTeigue, Walter J. Jr., New York, U.S.A.
Machlup, Harry, Johannesburg, South Africa
Meyer, Frederic W., San Francisco, Calif., U.S.A.
Okayama, Jiro, Tokyo, Japan
Owen, Stephen E., Talgarth, Breconshire
Parsons, Carlos D., Burbank, Calif., U.S.A.
Price, Robert A., Welling, Kent
Reed, George W. H., Dar-Es-Salaam, Tanganyika
Schneider, S. Herman (Dr.), Zurich, Switzerland
Silver, Nevis G., Auckland, New Zealand
Sonne, Sigurd V., Copenhagen, Denmark
Stanislaus, Saverimuttu J. L., Colombo, Ceylon
Simpson, James E., New York, U.S.A.
Stroud, Gerald M., London, E.C.1.
Suzuki, Tadahiko, Hokkaido, Japan
Taylor, Allan M., New York, U.S.A.
Van Starrex, Gertrud (Mrs.), Colombo, Ceylon
Ward, Muriel J. (Mrs.), West Perth, W. Australia
Weber, Adolphe, Geneva, Switzerland

ELECTED TO PROBATIONARY MEMEBERSHIP

Bachmann, Peter J., Guernsey, C.I.
Blom, Karin S. (Miss), Schwabisch Gmund, Germany
Bloom, Harry, Johannesburg, South Africa
Dryden, John F., Spalding, Lincs.
Foulser, Terence F., Hatch End, Middx.
Gadebusch, Dedo-Alexander, Koln, Germany
Gilewicz, Richard N., Southampton, Hants.
Maynes, Georgina (Miss), Belfast, Ireland
Nicholson, William, Botcherby, Carlisle
Reiter, Peter O., Zurich, Switzerland
Roos, Peter, Amstelveen, Holland
Sansford, Paul V., Weymouth, Dorset
Thomas, Graham A., Mold, Flints.
Ubben, Els (Miss), Roermond, Holland
Winkler, Gunter, Jr., Augsburg, Germany

The Council gave consideration to matters arising in connexion with examinations. The Chairman emphasized that the Association was taking great care to ensure that the standard required for qualification in the examinations was being maintained.

The Council considered a request received from the National Association of Goldsmiths for advice concerning the definition of a flawless diamond and also considered comments made on the gemstone nomenclature draft by the Association, which was in the course of being revised in the light of current trade practices.

GIFTS TO THE ASSOCIATION

From Nigel Kennedy, F.G.A., a group of phenakite crystals, showing twinning. From Professor S. Cavenago-Bignami, Milan, a copy of the second edition of her book *Gemmologia*.

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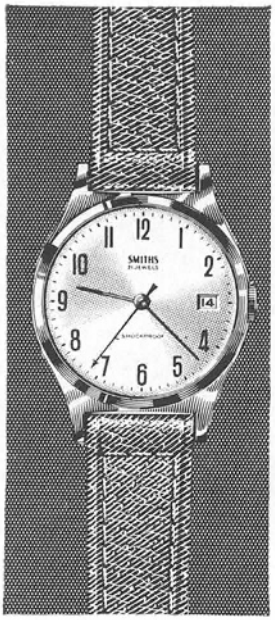

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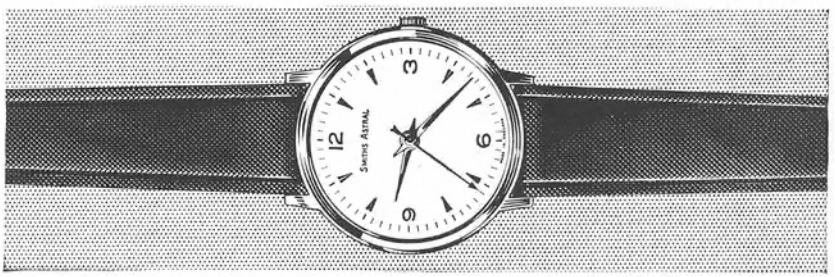

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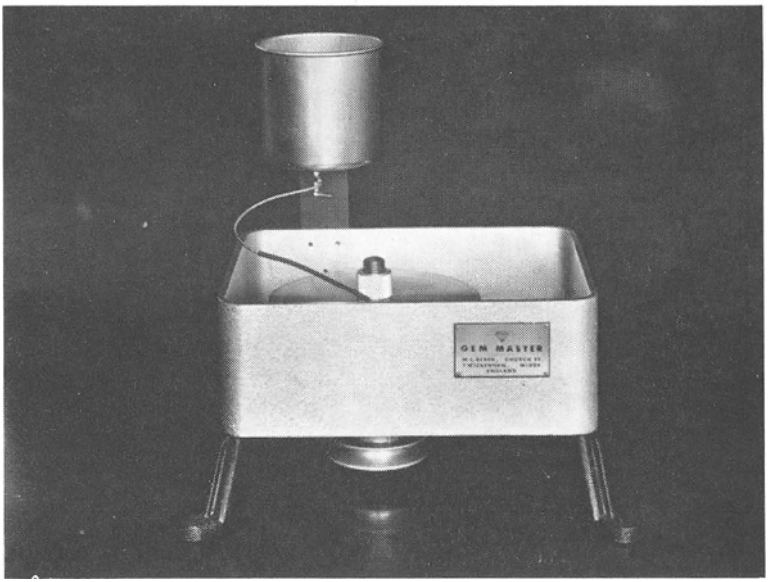

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and

PROCEEDINGS OF THE
GEMMOLOGICAL
ASSOCIATION
OF GREAT BRITAIN

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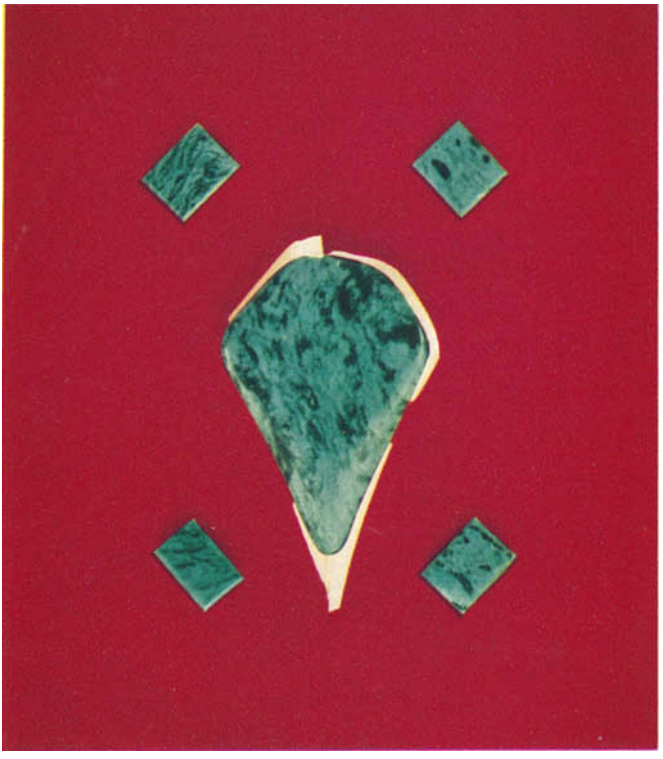

Maw-sit-sit. A decorative gemstone from Burma.

Photo: E. Gübelin

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MAW-SIT-SIT—A NEW DECORATIVE GEMSTONE FROM BURMA

By E. GÜBELIN, Ph.D., C.G., F.G.A.

Maw-sit-sit is an attractive green albite rock, named after the Upper Burmese locality near Namshamaw where it has been found. The following notes describe the author's introduction to this decorative stone.

WHILE visiting the Ruby Valley of Mogok in Upper Burma two years ago I received the welcome invitation from Mr. Lee San Chiek—one of the important jade traders—to undertake an excursion to the jadeite area along the Uru valley in the Myitkyina district of northern Burma. I profited from the last eight days allowed on my tourist visa, hired a jeep and travelled to Mogaung, where my wife and I were very cordially received by our host and greatly enjoyed his hospitality. Next morning, while strolling around in Mogaung, watching the jade lapidaries and their curious implements (Fig. 1), I noticed a few polished slabs and buttons of an unusual, very bright and pleasant green hue, nicely patterned by dark green to black spots and veins, lying on one of the lapping benches. They appeared completely unlike any other green, opaque gemstone that I had seen before and my hunting interest was immediately aroused. The language barrier made it impossible to obtain further information from that lapidary, but from the words "kyauk maw-sit-sit"

FIG. 1. *Jade lapidary squatting behind his low bench is polishing small cabochons and buttons.*

FIG. 2. *Straw thatched "long house" of a Christian Kachin family is marked with a white cross.*

FIG. 3. *A side lane in the picturesque miners' village of Hpakant on the Uru river.*

FIG. 4. *Before a jade mine is opened the jade Nats are propitiated by the miners.*

repeated several times, I could grasp that the specimens were either "stones called Maw-sit-sit" or "stones from Maw-sit-sit". When I mentioned the case to our host, he confirmed that the material was jade from Maw-sit-sit and that this particular jade quality was usually called Maw-sit-sit jade. The following day we left Mogaung early at daybreak in order to pass the gate at Kamaing before 9 a.m. (because no jeep was allowed to drive the 65 miles on the narrow track up into the jade area afterwards) and after passing several picturesque villages of the Kachins, with sparsely scattered long-houses—some of them marked by a white cross by their Christian owners (Fig. 2)—we reached the famous Uru river, which we crossed on a wobbling pontoon bridge, which was being repaired with the assistance of log-carrying elephants. On the other bank we stopped at a tea house in Lonkin. Several of the local traders and mine owners approached our host to show him some of the prize pieces they had recently found, and among them

there were also a few small, rough boulders of that brilliant green Maw-sit-sit material which, Mr. Lee explained, originated in a small place in the neighbourhood of Tawmaw. At Lonkin the track forked away to the right, leading to the region of the primary jadeite deposits surrounding Tawmaw at a distance of 21 miles, and to the left to a higher section of the Uru river where the alluvial river deposits and the boulder conglomerates are centred round the small mining village of Hpakant. The picturesque mining village Hpakant is an important mining centre (Fig. 3), and workings for jadeite exist in numerous places along the river and in the hills along the south bank. As Mr. Lee wished to examine some river mines which he was operating we followed the left track. Thus I had no further opportunity of investigating the actual source of the mysterious Maw-sit-sit which intrigued me so much, but decided to return here again next year and spend more time in the region in order to visit the outcrop mines in the vicinity of Tawmaw.

Upon returning to Europe I found that the Maw-sit-sit material had already reached the western gem market and that several lapidaries were already cutting it into all sorts of decorative articles. In the West the stone is being offered under the name of Chloromelanite, which certainly is a misnomer, because the material has nothing in common with Chloromelanite, not even its colour. This confusion inspired me all the more to convert my decision into action and after overcoming enormous difficulties, which were the expression of a strongly xenophobic attitude of the Burmese officialdom, I revisited the distant jade region again in March 1963. This time I was accompanied by my eldest daughter. The conditions had greatly changed during the interval of twelve months. The Burmese government under General Ne Win, a complete dilettante in state affairs, had issued a new decree outlawing the Chinese owners of jade mines and many jade traders had left, Mogaung was disturbingly quiet, numerous jade mines were abandoned and the country was being haunted by dangerous bands of insurgents. Mr. Lee was just as hospitable and helpful as the year before and extended his kindness and co-operation from the distance of Hong Kong, in that he let me use his jeep and had his family offer my daughter and me comfortable accommodation wherever we needed it. As we had prepared to spend ten days in the district we had ample time for visiting all the jade mining sites along the Uru river and around Tawmaw.

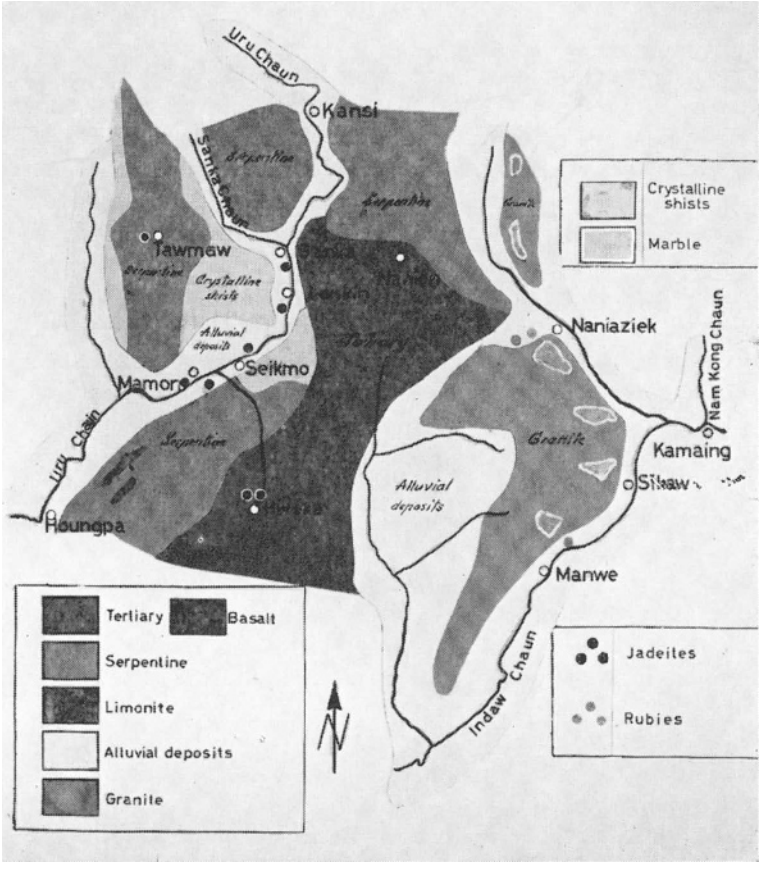

Geological map of the area in which Maw-sit-sit is found.

The area so far known at present in which the mineral jadeite is found in Burma is situated in the Myitkyina District around the draining waters of the Uru river. The exact course of the Uru is still not exactly plotted because there are serious difficulties in the way of detailed geographical, let alone geological, mapping as survey work is greatly impeded by the almost impenetrable jungle, which in places is so thick that it is possible to see only a few feet ahead, and it is still inhabited by numerous tigers and infested by nasty insects. The region is a highly dissected upland, consisting of ranges of hills which form the Chindwin-Irrawaddy watershed. It is higher in the north than in the south, and Tawmaw, where the

true outcrop jadeite mines are situated, is lying on the plateau at an altitude of 2,755 feet above sea level. It is about 165 miles by road, i.e. track, from Mogaung. The Uru river is an important stream, and its banks and small feeders are the scene of much mining activity for jadeite.

Within the area much of the surface is occupied by Tertiary rocks to the west of which lies a great intrusive complex consisting essentially of serpentinised peridotites, the outcrop being elongated north-east to south-west and being roughly oval in shape. This complex is surrounded by crystalline schists which include types derived from both sedimentary and igneous rocks. The sedimentary types appear to represent the country rock into which the plutonic complex was injected. The Uru boulder conglomerates of Pleistocene to sub-recent date occupy a considerable area north eastwards from Tawmaw and it is important on account of its jadeite workings.

The jadeite-bearing intrusions in the serpentinised peridotites consist of the following rock types which grade into one another: jadeite, albite and amphibolite. The jadeite is an exceedingly tough rock, normally white (supplying the mutton-fat jade), but it is irregularly streaked and spotted with emerald-green by chromite, apple-green to brown by iron and lavender-blue to violet by manganese. In some cases the rock is mono-mineralic and this is the densest type, with a specific gravity of 3·34, which furnishes practically all the precious gem material.

The jadeite-albite rocks are intrusive into the serpentinised peridotites of the district, either in the form of dykes or rather in the shape of sills, as is evidenced in the field by the appearance of the outcrops at Tawmaw. The immediate parent of the jadeite-albite rocks of present state was a soda-granite-aplite produced as a normal product of differentiation from the granite magma represented in the district by the types mentioned before. The complete assemblage of igneous rocks in the district comprises various ultrabasic rocks of several types (peridotites, gabbros, amphibolites etc.), and granites of several kinds including pegmatites and aplites, the latter consisting of quartz and albite. The jadeite-albite rocks were derived from the magma represented by these aplites. The aplitic magma, a residuum from the granite magma, on coming into contact with the ultrabasic wall, rock suffered desilication, with the consequent elimination of the quartz and the conversion of

much of the potential albite Na Al Si_3O_8 into jadeite. The silica released from the magma was used up in converting the orthosilicates of the peridotites into metasilicates. It is important to note that the desilication is only partial, as the rocks still contain large quantities of albite, with only some jadeite. The latter is sometimes closely associated with albite in albite-jadeite rock; but in other cases it forms lenses of nearly pure or quite pure jadeite-rock, embedded in equally pure albite rock. The amount of jadeite present appears to be directly proportional to the quantity of albite. It has to be understood that these reactions took place under almost unique conditions, presumably involving very high pressure.

The outcrop mines at Tawmaw:

The most prolific outcrop mines of jadeite are situated in the region of Tawmaw. The methods of mining consist of two kinds of ordinary quarry working. Before work is started, the Jade Nats (spirits) are propitiated by almost every worker irrespective of nationality, in that fresh flowers, bowls filled with water or rice and occasionally some fruit, are offered on a bamboo erection gaily decorated with coloured paper banners (Fig. 4). In most of the open pits, which are not numerous, the working methods are usually very crude, as the rock is broken by crowbars or mamooties and the jade veins, which vary from a few millimeters to several centimeters in thickness, are hewn out of the boulders by chisels, wedges and hammers. The prevailing method of extracting jadeite in this region of primary deposits consists of sinking a number of relatively wide vertical shafts about fifty feet down to the jadeite dyke along which inclining tunnels and intermittent stopes are driven, following the inclining course of the dyke for several hundred feet (Fig. 5). At some of the larger and more entreprising mines steam hoists and compressed air drills were being used when I visited the mines. (Blasting was forbidden from fear of misuse by the insurgents, who haunted the country.) In the deepest working chambers the miners simply work with blunt chisels, wedges and hammers.

The alluvial deposits along the Uru river:

The Plateau Gravels of Upper Burma are represented in the north of the Myitkyina district by a boulder conglomerate, named the Uru Boulder Conglomerate after the river Uru which was

responsible for its formation. The age of this conglomerate, and hence the formation of these secondary alluvial deposits of jadeite, is probably Pleistocene to Sub-Recent, for the conglomerate has not yet solidified but is still rather loose. The outcrop of the conglomerate attains to a length of several dozens of miles and an average width of two to four miles. The thickness or height of the formation must exceed a thousand feet in places, as is evident from a traverse along any of the tributaries of the Uru and as I noticed by the hills worked at Hpakant, where the cliffs overlooking the stream are entirely composed of the conglomerate. The workings along the Uru river can be classified into (*a*) Stream-bed workings where mining is possible throughout the whole year (Fig. 6 and Fig. 7), (*b*) Hillside workings where the rock is quarried during the rains

FIG. 5. *At Tawmaw wide and deep vertical shafts are sunk down to the jadeite dykes. Here a primitive lift is operated from a simple bridge consisting of jungle wood beams and bamboo rods.*

FIG. 7. *Details of the river mining at Hpakant. Small claim in the foreground. Machine pump hoists ground water through metal hose back into the river.*

FIG. 6. *River mining along the bank of the Uru at Hpakant. The dams enclose different claims.*

FIG. 8. *Small open quarries and a few scattered, primitive miners' huts at Maw-sit-sit.*

which help in sluicing away the overburden and the alluvial matrix of the conglomerate. A more detailed report on the geography and geology of the area, on the mining and the cutting methods, as well as on the trade conditions in Burma and Hong Kong, will be published later in the *Schweizer Goldschmied* as part of an extensive paper about the "Gems from Burma".

The locality with which we are most concerned within the rather limited compass of the present article's subject is the small mining field of Maw-sit-sit (Fig. 8). It belongs to the so-called Namshamaw dyke, which constitutes part of the wide spread outcrop mines in the jadeite-albite rocks of the vast jade region of Tawmaw. The small workings at Maw-sit-sit, of which most were deserted when we visited them, are situated about half a mile west-north-west from the tiny hamlet of Namshamaw in a stream and adjoining it. The oldest mines were swamped with deep water, thus making it impossible to study the outcropping rocks and their relationships, while the few younger pits were not then profound enough to yield full information on the nature and association of the primary rocks. The dyke runs in the direction north-west to south-east with a tendency to run west-north-west to east-south-east. Blocks of jadeite of irregular shape, which seem to have travelled short distances only, occur in red earth formed by the decay of the serpentine. Very likely the jadeite boulders excavated here represent disintegrated portions of a dyke which has either not been exposed yet or lies a little to the west.

The local miners distinguish two varieties, which they call:

(*a*) Maw-sit-sit, the brilliant green hue of medium tone with yellowish tinge,

(*b*) Kyet tayoe, the bright green variety of paler shades.

Of the two varieties, Maw-sit-sit meets with more favour as a decorative gem stone. The rare beauty of the vivid colour fascinated me instantly, but judging by its appearance, delicate polish and waxy lustre I was convinced that it was not jade. However, it could have been an unusual variety of Chloromelanite or the much rarer Tawmawite (chromepidote). Of the latter I knew that it was extremely rare and so far had only been found in the Mienmaw dyke. The important locality of Mienmaw was worked spasmodically by several people. There is a heavy overburden of red earth with abundant iron concretions—25 ft. to 30 ft. in thickness. Nothing of the relationships of the rocks of the dyke could be

gathered since the old pits were filled up with red earth washed down from higher levels. Serpentine and chloritic schists (byindone) could be observed in places. In one place chrome-epidote was seen with albite (so-called "palun"), and this is considered as a favourable indication of the occurrence of fine green jadeite in the neighbourhood. Chrome-epidote is formed where chromite is present in serpentine, and the associated minerals—albite and jadeite—are coloured as a result of absorption of the epidote.

I purchased several samples of the Maw-sit-sit with the intention of investigating it more closely at home. Unfavourable circumstances, however, prevented me from carrying out my plan immediately. Now, after subjecting the collected stones to various methods of scientific examination during the last few weeks, I feel satisfied to present some preliminary and surprising results.

Appearance and optical examination:

Summarising the afore-mentioned statements, the rough material may be described as an opaque stone of bright to brilliant green colour of medium tone with a yellowish tinge. The homogeneous or sometimes cloudy distribution of the colour is irregularly traversed by fine veins or spotted by uneven specks and patches of a very dark green to black alien substance, which most likely is caused by a concentration of the pigment. The fracture is granular in concurrence with the stone's texture, while the surface appears somewhat spathose, on account of the sparkling of cleavage planes of individual albite grains. The majority of the material is marred by numerous cracks and fine fissures, which causes cuttable gem-material of good quality to be extremely rare. The cut stone assumes a smooth polish and displays a delicate waxy lustre, which betrays a lower hardness degree than jadeite. Its hardness of 6 corresponds with that of feldspar. The refractive indices, measured on the Rayner refractometer, were found to vary from 1·52 to 1·54.

The specific gravity, obtained from a great number of pieces, averages 2·77. These values of R.I. and density gathered by the orthodox gemmological methods disclose very clearly that the substance could be neither jadeite, nephrite, chloromelanite nor chrome-epidote (tawmawite). Consequently further research became necessary, for the reliable accomplishment of which I am gratefully indebted to Prof. Dr. M. Weibel, of the Institute for

Crystallography and Petrology, at the Swiss Federal High School of Technology in Zurich.

Microscopic investigation:

Thin sections, cut across the stone in random directions, yielded various informative observations which are elucidated hereafter:

(*a*) The main body consists of albite forming in a granoblastic texture. The medium size of the grains measures 0·05 to 0·1 mm (Fig. 9 and Fig. 10).

(*b*) An irregularly disseminated pigment appears black under low magnification, while innumerable pale green grains may be recognized through a high power lens. The diameter of these grains, varying from 0·005–0·01 mm, is approximately ten times smaller than that for the albite grains.

(*c*) Individual crystals surrounding the concentrations of pigment appear to be a little larger than the pigment grains, with which

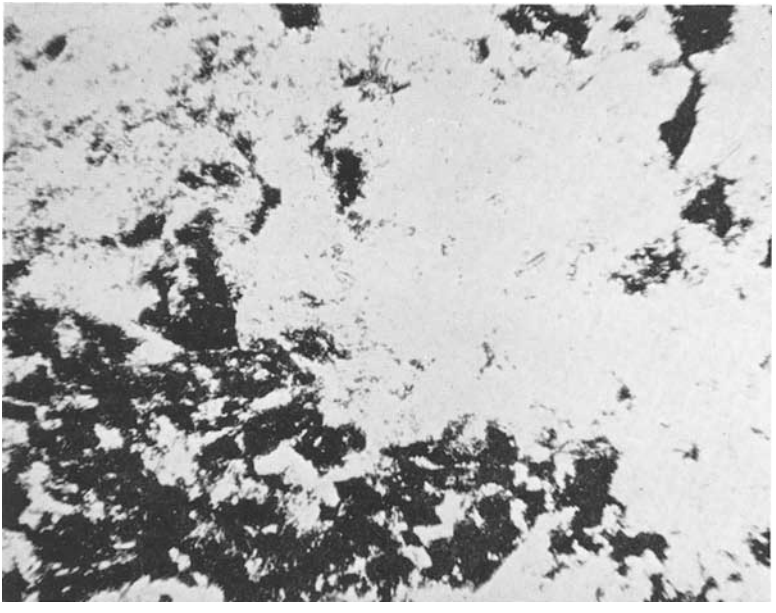

FIG. 9. *Photomicrographs of Maw-sit-sit. White parts = albite; black patches = pigment. The pigment appears rather homogeneously extended and on account of the low magnification it is not dissolved into individual grains, thus creating the misleading impression of constituting a rather important component.* (25 ×)

they seem to be identical. These larger crystals are isometric to elongated, pale green and transparent. In all cases their size was smaller than the thickness of the thin section (Fig. 11 and Fig. 12).

(*d*) Some colourless, finely granular aggregates of a tabular mineral are embedded singly in the albite mass.

(*e*) Minute areas of intensive emerald green colour seem to occur quite sporadically and may constitute an extremely fine mixture of the pigment with some other mineral (Fig. 13 and Fig. 14).

Chemical analysis:

The following table, in which for the sake of comparison the chemical compositions of pure albite and jadeite are also presented, renders evidence of the result of the chemical and spectroanalytical investigation and manifests the quantitative composition of the stone.

	Maw-sit-sit	*Pure Albite* $Na\,Al\,Si_3\,O_8$	*Pure Jadeite* $Na\,Al\,(Si\,O_3)_2$
$Si\,O_2$	66·0	68·7	59·5
Al_2O_3	16·5	19·4	25·2
Na_2O	11·1	11·8	15·3
Cr_2O_3	2·6		varying amount
Fe_2O_3	·8		varying amount
$Mg\,O$	2·2		
H_2O	·6		
	99·8		

Li_2O, K_2O, CaO, MnO and TiO_2 proved to be further components which were present in small amount varying between 0·01 and 0·1%.

The analysis of the Maw-sit-sit allows certain conjectures with regard to the pigment. It is most likely to be a composition which contains sodium and silicon besides chromium, yet very little or no aluminium. The ratio Na:Al:Si of the total analysis revealed more Na and Si to be present than is necessary for the formation of albite. Maybe the mineral which accounts for the colour is a member of the aegirine group, in which iron is partly substituted by chromium. One might suspect the occurrence of a new mineral, not described heretofore. However, this is mere speculation and so far with regard to the pigment the total analysis of the Maw-sit-sit only permits the conclusion, that the colouring

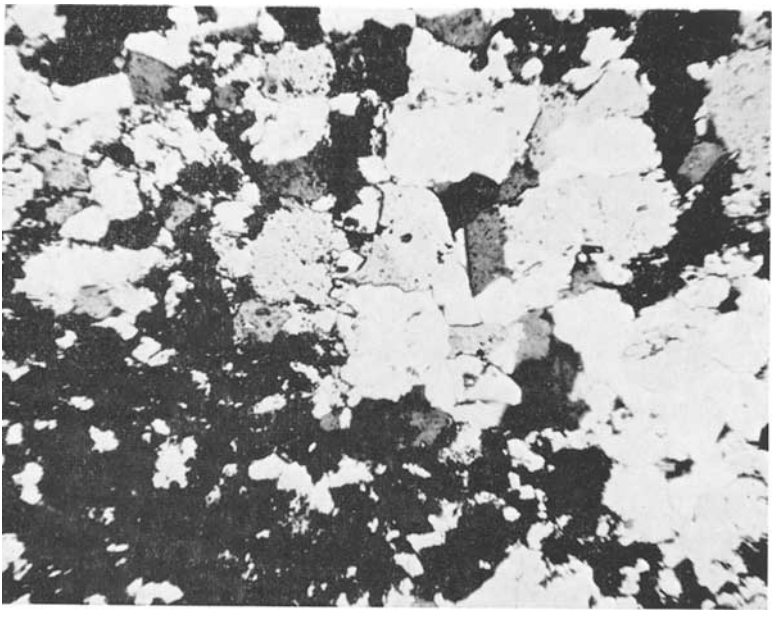

FIG. 10. *Same as* 9 *but through crossed polaroids. Now the granular texture of the albite mass becomes very conspicuous.* (25 ×)

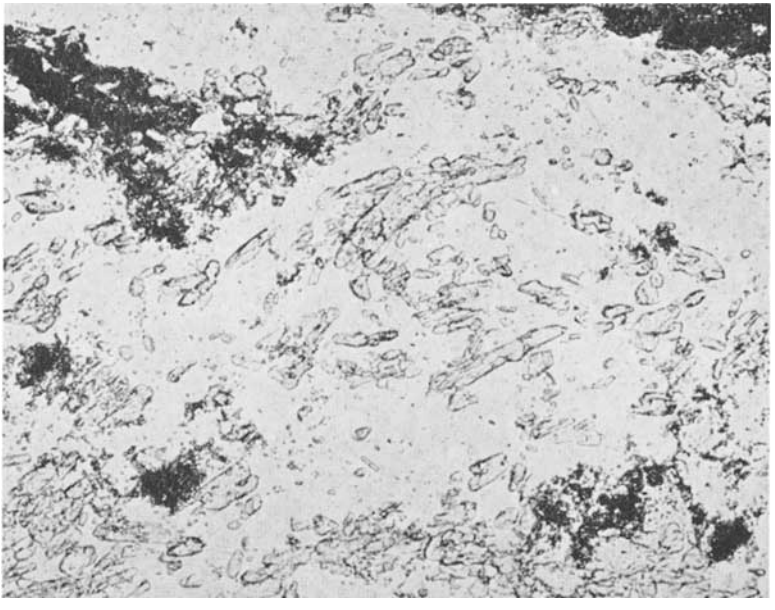

FIG. 11. *Individual grains are irregularly disseminated through the white mass of albite. They seem to be identical with the minute grains of the dense pigment patches.* (40 ×)

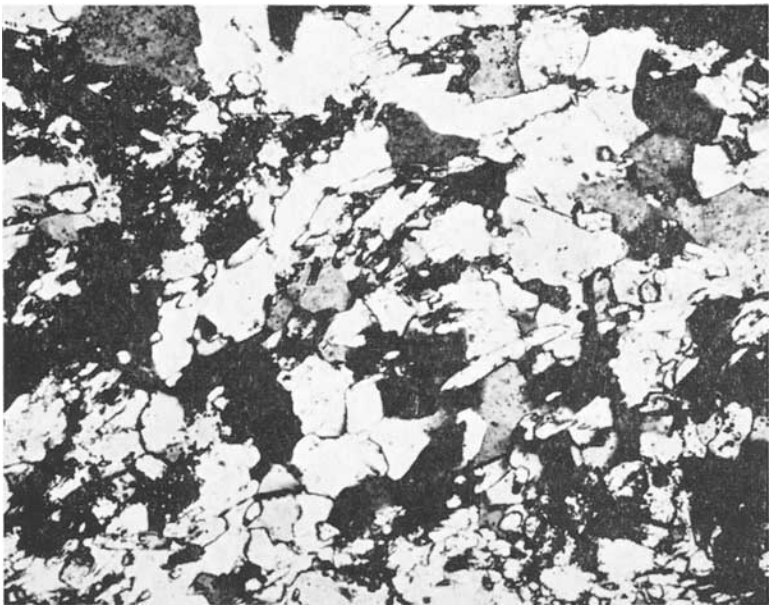

FIG. 12. *Same picture between crossed polaroids manifests the granular texture of the albite mass. Some of the pigment grains may still be recognized near the left top corner.* (40 ×)

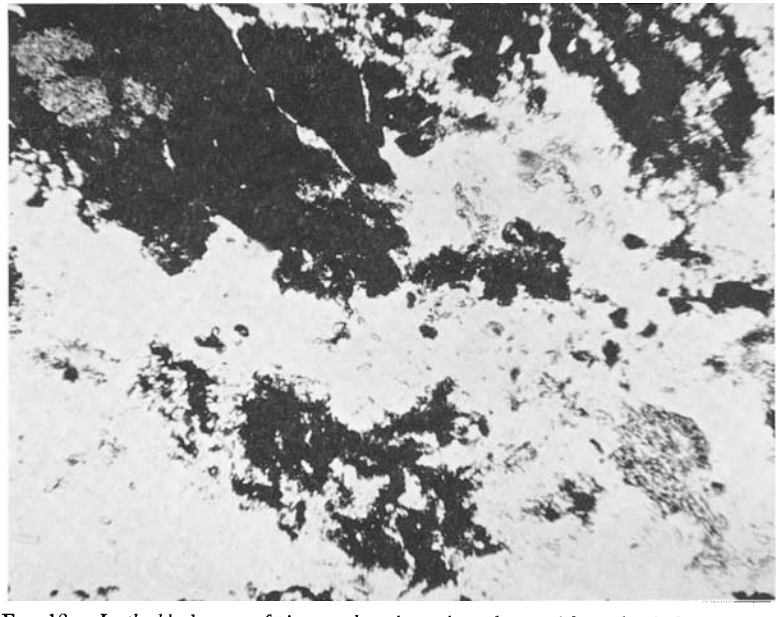

FIG. 13. *In the black mass of pigment there is an irregular greyish patch which represents one of those curious emerald-green areas consisting of an aggregate of extremely fine grains of unknown nature.* (100 ×)

agent in question is a chromium composition, whose chromium content in view of the small proportion of pigment must be relatively high.

X-ray examination:

The powder diagram of Maw-sit-sit depicts practical concurrence with albite. A very small number of three or four additional lines, which were certainly produced by the pigment or other accessory minerals, was not sufficient to identify the accessory components responsible for the green colour. The chromium minerals which appear to account for the colour of the Maw-sit-sit, seem to be chromiferous varieties whose x-ray diagrams have not yet been established. On the other hand, it must be considered that also albite does not display a uniform x-ray diagram but slightly varying line positions depending upon the phase condition.

The problem of the pigment:

Albite is relatively easily dissolved in hydrofluoric acid.

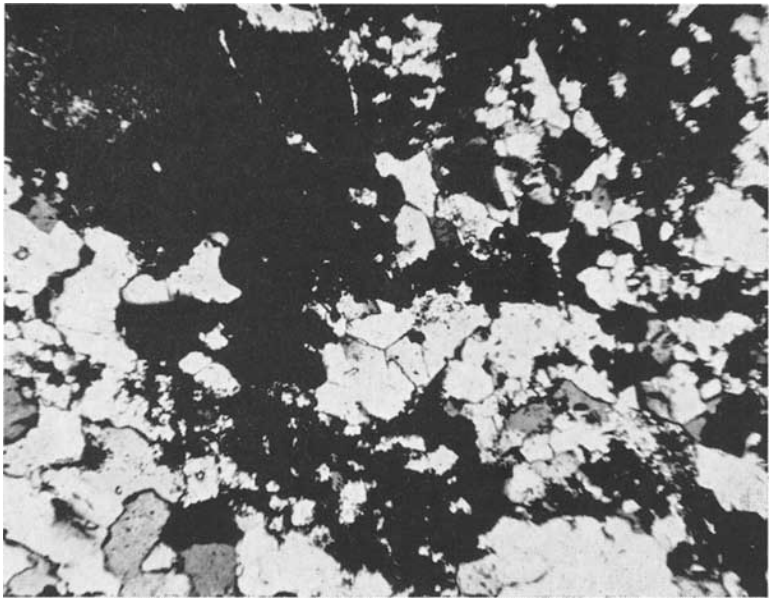

FIG. 14. *Same picture as* 14*a*, *observed between crossed polaroids.* (100 ×)

Attempts selectively to dissolve albite and thus concentrate the pigment unfortunately failed—most probably because of the extremely fine distribution of the pigment. The residue, which produced X-ray diagrams differing from that of the Maw-sit-sit, consisted of conversion products of the albite and contained even less chromium than the original Maw-sit-sit.

Some consideration concerning the occurrence of chromium in other minerals may be interesting at this point. Trivalent Cr (ion radius 0·63) usually replaces trivalent Fe (ion radius 0·64) and Al (ion radius 0·51). The average content of chromium in the crust of the earth has been estimated to amount to 0·01%, this value however, is uncertain, because of the great differences of Cr contents in basic and acid rocks. Apart from chromite the element chromium relatively rarely forms minerals in nature—referring to their geographic distribution as well as to the number of their species. Consequently the chromium varieties of other minerals are very little known. Chromite, the most important chromium mineral, may contain more than 50% of Cr_2O_3. In the shape of thin splinters or in the minute dimensions of accessory grains in rocks it appears brown, and not green as observed in the thin sections described above. Therefore, the identity of chromite with the pigment seems to be excluded and chromite cannot be responsible for the green colour of the Maw-sit-sit. The highest content of chromium in silicates, amounting to 27% Cr_2O_3, has so far been found in the chrome-garnet Uvarovite. Chrome-epidote (Tawmawite) from Finland contains 6·8% of Cr_2O_3. No jadeite that has hitherto been subjected to a detailed chemical analysis has boasted a greater amount than 0·01% of Cr_2O_3.

Conclusion:

The optical, chemical, spectroanalytical and röntgenographical investigations lead to the conclusion that the intensively green Maw-sit-sit essentially consists of finely granular albite, which owes its vivid green colour to a chromiferous pigment that is delicately disseminated through the stone's body. The nature of the substance accounting for the colour could not be determined, but it was found to prevail as minute crystals which are irregularly distributed in the albite mass. Attempts to enrich the pigment by selective dissolution of the albite failed on account of the extreme smallness of the grains. At least one or two further green (chromium-

bearing) minerals seem to occur as subordinate components, whose nature also could not be identified because of their very small sizes. Contrary to the impression the relatively homogenous coloration might imply, chromium is not directly incorporated in the albite, but it is rather present in high concentration in a mineral of unknown nature which acts as a pigment. Up to date, chrome-albite has not yet been mentioned, and it is rather doubtful that chromium could be integrally built into the albite structure. It is difficult to corroborate this assertion, but the microscopic observation has established the clear evidence that in Maw-sit-sit a green mineral is present besides the albite. From the results discussed above, the following knowledge can be inferred: Maw-sit-sit is not a mono-mineral but a mixture of minerals, that is, a rock. The body-substance consists of albite, which is irregularly interspersed with an alien chromiferous mineral inducing the vivid green colour. With a rock, chemical formulae can only be established for the individual components. In Maw-sit-sit albite forms the principal component, whose formula is $Na\ Al\ Si_3O_8$; on the other hand the chemical formula of the pigment is not yet known. Only a method which enables operation with extremely minute quantities of material may provide a solution to the problems of the Maw-sit-sit, and it is therefore intended to carry out further investigations by means of a latest model of an A.R.L. electron microscope. In view of the fact that Maw-sit-sit consists mainly of albite, it seems appropriate to give this new decorative gemstone a name which carries the name "albite" as principal word, yet as long as the pigment is not determined, the native name of Maw-sit-sit may just as well serve as a distinctive designation.

Pictures by Mary Helen Gübelin. Photomicrographs by the author.

IF THERE'S A DOUBT HAVE IT TESTED

By A. E. FARN, F.G.A.

THIS advertising phrase is apt and very rewarding. In the world of gem testing there were some stones which hardly needed testing, since they were impossible to copy or imitate successfully. Emeralds used to be easy—if red under a filter, it was an emerald. Black opals were once a certainty, but nowadays there are treated or carbonized opals of a very attractive appearance but which are not exactly as one would expect when a stone is termed "black opal".

Possibly one of the least tested stones is the diamond. By diamond I mean transparent white diamond, not any fancy colour or hue, since the detection of possible treatment is a separate and very technical problem on its own.

Diamond is the hardest known gemstone and in what one terms "the good old days" an anvil was said to be shattered quite readily when a diamond was tested upon it by striking! Apart from being the hardest known gemstone it also has a now well-recognized weakness, i.e. cleavage. We all know what would happen if we placed a diamond on an anvil and struck it a heavy blow.

A gem-testing laboratory sees more unusual stones from hopeful jewellers than most people in this trade. Some people specialize in certain stones such as star-stones and cat's-eyes, emeralds and opals, or rubies and sapphires. Diamond-dealers proper seldom mix with the coloured stone trade. It is interesting, sometimes, to see an obvious large synthetic ruby brought in by a dealer who usually specializes in diamonds only.

Whilst there are coloured-stone dealers, and diamond dealers, there are dealers who dabble in many gems including corals, pearls, ivories, etc. and seldom do these people manage to specialize in any particular one.

How much more difficult then is it for the retail jeweller who has to consider all these, together with watches, clocks, gold, silver, plated wares and repairs and estimates.

Small wonder then that the jeweller who is suddenly confronted with a "pearl" necklace, a chrysoberyl cat's-eye ring or a fine pink sapphire in a cluster surround sometimes feels himself at a loss to identify such gems.

"Are they diamonds" or "is it a diamond" is the kind of question which brings quick reaction. But, and it is a very big but, once doubt is sown in the mind then fermentation takes place and the slogan "If there's a doubt have it tested" pays its dividends.

In the laboratory quite recently we had an old-cut long cushion-shape thick diamond of good quality brought in by a slightly irate though somewhat apologetic diamond dealer. I thought he wanted it weighed to settle a point one way or the other. He said "I want it tested". To me, it was so obviously a diamond. I could not help pointing this out as diplomatically as possible (after all he was a diamond dealer). To my relief he immediately agreed, "Yes, indeed I know it is a diamond but someone has doubted it because it is an old stone". Thus we had the crux of the matter—a doubt. This particular case, one of a few I can recall, was outstanding in its sharpness of doubt and certainty. Others, of course, are a good deal more nebulous.

Some while ago a dealer asked me if I was interested in a parcel of rose-cut diamonds and on being shown them I suggested he had them tested. He protested that they were all old Indian stones but to me they looked like zircon—and a check by spectroscope confirmed the diagnosis.

Another dealer had a diamond and onyx eternity ring, which had been fished up from the sewers by a sewerman, and the diamonds were very rubbed indeed—no one could have said what the stones were by just looking.

It is my experience that pawnbrokers above all seem to be considered fair game to the unscrupulous. Most pawnbrokers are open not only to lend money on valuables but are very often more liable to buy jewellery from the public than many retail jewellers. Therefore more people "try it on" with pawnbrokers than otherwise. I am, perhaps, specifying the pawnbroker at the moment because the average retail jeweller buys from regular suppliers mostly new goods. These in turn are obtained from manufacturers who are buying their diamonds direct from well known sources of supply. It is not these kinds of goods I have in mind.

Quite frequently a very pleasing ring (with, say, a circular amethyst or golden quartz) is mounted in a cast setting with a cluster surround of synthetic white spinels. Very clean and newly polished it looks very pleasant because the cast is from a very good pattern and perhaps the finish of the ring by the polisher has been

well done. This kind of ring after being worn a little (with a little dust, or powder or soap accumulation behind it) if offered over the counter under artificial light at a reasonable asking price, can cause an error. When goods are offered too cheaply suspicion is aroused. If offered at a reasonable price—then commerce overcomes gemmology (if there is any gemmology).

Sometimes it happens a diamond is cut with too much spread to make it look more for the money and the stone looks a little "laxey", a term somewhat similar to "lasque", which is used to describe a very thin flat style of cutting from India. When a diamond is cut in a manner which is not familiar to the jeweller then he is troubled. A very tricky point arises sometimes when a stone is a baguette-shape and used as a shoulder stone to a ring, and is set flush with the metal. This allows very little chance of inspection, due to the mount immediately obtruding when by turning the ring the stone is examined.

Artificial lighting can mislead when quickly looking at a cluster-set ring, especially if one has approached the problem by examining the centre stone and assuming a diamond cluster surround. Lack of "fire" can thus be put down to general dirtiness at the back and a mental note that it will improve if the ring is cleaned. It is usually the next day, with daylight to help and a clean-up of the accumulated debris from behind the stones, that the truth becomes apparent.

By these observations it is not intended or suggested that jewellers and pawnbrokers are constantly being taken in by unscrupulous methods, because the majority make their living adequately enough to disprove any such opinion.

With the advent of strontium titanate, however, I think it to be a little dangerous to assume too readily that diamonds never need testing. One afternoon, about 2 years ago, I had a strontium titanate single stone ring in to test from a West End jeweller. Immediately following we had a cluster ring from the National Association of Goldsmiths to test for one of their members. The centre stone was a strontium titanate with a cluster surround of reasonably good quality diamonds. The whole effect was good and if a little dirtier could have passed quickly as a very fine all-diamond cluster. Two rings in immediate succession one afternoon having strontium titanates in them was remarkable.

"Diamonds are forever", as a title, indicates the inherent hardness and durability of diamonds. This hardness of diamond is its important factor—it is related to the quality of polish the stone can take, and upon the finish of the facet edges. In fact, a hard look and finish. Because of its simple chemical and molecular structure diamond has a single refraction and a characteristic optical clarity. Such is this impressive quality that when viewed through the table facet with a lens the culet seems to be very close to the table.

The stones which are most commonly used in jewellery in place of diamonds or as diamond simulants are: (1) Synthetic Spinel, (2) Synthetic sapphire and natural colourless sapphire, (3) Zircon, (4) Synthetic Rutile, (5) Strontium Titanate, (6) Paste, with high refractive index. There may be others—one can cite almost any colourless stone, but I think the stones listed are the most commonly used and reasonable to expect.

Jewellery which is "diamond"-set, if suspect, should be cleaned in order that information can be obtained by visual methods. A clean stone or stones in settings are much more easy to test if light can readily be transmitted.

In a cluster setting synthetic spinels are very quickly identified by immersing in methylene iodide because their refractive indices very nearly match at 1·728 and 1·74 respectively. The effect can be quite startling, the stones tend to disappear from their settings and an empty mount is left.

Since natural spinels do not exist as colourless stones (they always draw a little colour in comparison to a parcel of diamonds or synthetic spinels), it is safe to assume the synthesis of the spinels. Synthetic sapphires, as opposed to diamond, are doubly refracting (as shown by a doubling of the back facets or the effect seen when a piece of jewellery is revolved between fixed crossed polaroids). Although it is safe to assume that all spinels which are colourless in a setting are likely to be synthetic it is not the same case with colourless sapphires.

Usually, of course, one is not trying especially to identify the suspect colourless stone—only to avoid buying it as a diamond. Natural colourless sapphires are very bright stones and it is not unusual to find them in cluster settings surrounding a genuine blue sapphire in jewellery emanating, say, from Ceylon. Examina-

tion by microscope will sometimes reveal crystalline inclusions, feathers, silk, etc. in even very small stones.

Synthetic colourless sapphires will very often show included gas bubbles much more readily than synthetic spinels. A thorough cleaning of the backs of small cluster-set jewellery is really important when examination has to be made by microscope. Being a cheap product synthetics are very seldom well cut or polished and reveal this by certain small useful factors such as fire or chatter marks on the new face. These marks are caused by heating due to pressures in polishing and are seen as slight surface cracks in a slightly zig-zag manner. They are more frequently seen on synthetic stones than on genuine ones.

Colourless zircons, because of their superior "fire", are a very good imitation of diamonds. With zircons, providing one is a reasonably well-versed jeweller, gemmologist or probationer, it is a fairly easy matter to see quite distinct double refraction evidenced by the doubling of back facets. I have quoted jeweller, gemmologist or probationer because one presumes that readers of the JOURNAL OF GEMMOLOGY are just that. Colourless zircons are brittle and soft and usually reveal this by the very frequent chipping and worn appearance of the facet edges. Zircons have a muzzy look when viewed through the table facet with a lens. This "out-of-focus" appearance is due to the marked double refraction.

Should very small rose-cut or brilliant-cut colourless zircons be used in a cluster setting the stones may be slightly rubbed or no double refraction easily recognizable, and then the spectroscope comes into its own. The well-known absorption band seen in the red end of the spectrum at 6535Å is completely diagnostic for zircon—very easy to find and practically infallible in showing (besides other lines) in zircon. The spectroscope knows no barriers of size, cut, polish, rough, or water-worn.

Synthetic rutile with its play of colour should never cause any hesitation even to a non-gemmologist jeweller. Its large double refraction is so startling as to make the doubling of back facets look like separate distinct facet edges. Synthetic rutile is the extrovert among stones. Rutile does not exist in nature as cuttable rough material and certainly no rough or natural rutile ever looked like a poor relation to the poorest quality in diamond used in jewellery. Synthetic rutile in any case cannot get that white or colourless

aspect of diamond. It always looks a little yellow or off-white.

Strontium titanate is the most dangerous to the jeweller. Although it has too much fire in its pristine state it can be dangerous when a little rubbed or dirty. Strontium titanate is very soft and has a slightly moulded look if observed carefully at the facet edges with a lens. Apart from an old-fashioned (but very practical in this case) hardness test, there is little one can do to identify a strontium titanate except by examining certain abrasive marks seen under laboratory conditions. For an artificial stone it is quite expensive—the smaller sizes are more expensive per carat than the larger sizes. Its brilliance and fire cause it to stand out as superior to diamond but its soft look and rounded facet edges betray it. Strontium titanate is much heavier than diamond and if a stone is loose this factor can be used against it. Quite recently a friend of mine ordered a Strontium titanate with a 1-carat diamond spread. In actual fact it weighed 1·61 cts. So that comparison of a stone by gauge to actual scale weight can be very informative.

High refractive index pastes are sometimes deceiving. One always thinks immediately of swirl striae and bubbles, but they are not always seen. In an antique ring of backed table-cut stones it is not always wise to attempt a hardness test. If a spinel refractometer is available a refractive index reading is often possible and here information is quickly gained if the resultant reading seen on the scale of the spinel refractometer has a colour fringe. These colour fringe readings indicate paste as opposed to glass. Because of the high dispersion of most pastes a coloured fringe or edge is seen as the reading on the refractometer scale. Pastes from 1·61 upwards especially towards 1·65, 1·66, 1·67, etc. show this effect clearly. Similarly if a paste-set article cannot be checked on a refractometer for various reasons often it will yield information if immersed in monobromonaphthalene. Monobromonaphthalene has a refractive index of 1·66 and pastes around this reading will tend to disappear or the facet edges fade when a stone or jewellery is immersed. In contrast, diamond will stand out clearly. Certainly it is helpful also to find swirls or bubbles, but immersion will readily distinguish paste from diamond, and it is the elimination of suspects from diamond we aim at in this article, not necessarily complete identification of the simulant.

We have dealt with the stones most likely to be met with as "diamonds" and discussed their characteristics. What if the

stones are diamonds? Nowadays with the decline in horse drawn traffic anvils are not so common, so the gemmologist usually equips himself with a large cheap synthetic ruby or sapphire with a large table to it. Diamond will scratch synthetic ruby or sapphire. Brute strength is not required. Diamonds have a clarity and brilliance unapproached by any other stone. Very often the girdle of a diamond has a small "natural" unpolished face left on it, either by design or fortuitously, and this is very helpful. Although this is not a laboratory test, I have frequently noticed how even a light touch of the finger on the table facet of a diamond leaves an imprint of grease from the skin (or fingerprint) very sharply defined indeed bearing ample witness to the well known affinity diamond has for grease. Diamonds will stand out sharply in methylene iodide. Diamond facet-edges have a quality of finish and a degree of hardness not seen in any other stone. Simple tests to prove diamond are the hardness test against synthetic corundum and high relief in methylene iodide. Laboratory refinements, of course, are infinite, and include fluorescence, under X-ray excitation or long and short wave lamps. Electro-conductivity tests also play their part, but by and large it is: Look first, lens second, opinion third and then proof by whatever method seems obvious, expedient and positive. The X-ray excitation or short-wave lamps, etc. are refinements but all add to and play very useful parts in this identification of diamond, this common stone that seldom needs testing—or does it?

A reiteration of factors in the foregoing to eliminate diamond simulants from diamond may be helpful here. Synthetic spinels are singly refracting, disappear in methylene iodide, and are scratched by sapphire and diamond. Synthetic sapphires are doubly refractive, often have bubbles and chatter marks, and are scratched by diamond. Zircons are soft, brittle, strongly doubly refracting, have a 6535Å line and are heavy stones. Synthetic rutile has tremendous double refraction, strong play of colour, and is markedly off-white. Strontium titanate—tremendous fire, singly refracting, soft facet edges and girdle, "centipede" outline scratch marks. High R.I. pastes—sometimes bubble and swirl marks, are very soft, and disappear in monobromonaphthalene; heavy, colour fringe on spinel refractometer; single refraction.

Diamond is singly refracting and has an affinity for grease. It will easily scratch all other gemstones including sapphire and ruby (both natural and synthetic). Sharp relief is shown in

methylene iodide. It has optical clarity, extreme hardness and polish, and sharp facet edges. Diamond fluoresces milky-blue when excited by X-rays. It has characteristic carbon inclusions and may show naturals on the girdle.

RADIO-ACTIVE DIAMONDS

By R. WEBSTER, F.G.A.

The first of these stones was a round brilliant-cut diamond of dark "tourmaline-green" colour weighing over six carats, which was found to be one of the strongest radio-active diamonds seen. When placed on a Levy-West screen (activated zinc sulphide) the scintillations observed were strikingly beautiful, and even when the lens used to view these flashes of light was removed, a halo of light could be seen surrounding the diamond. When the stone was placed one inch (2.5 cms) away from the edge of the screen the radiations were found to just reach it, causing scintillations at its edge. A Geiger counter test, by courtesy of the Officers of the Overseas Geological Surveys, showed the diamond to have radio-activity as great as, or greater than, a radium watch dial. The illustration (Fig. 1) shows the auto-radiograph produced by this diamond when left on an Ilford double-coated x-ray film for about 60 hours. The photo also shows signs of directional intensity of the radio-activity.

The second example consisted of a two-stone diamond ring, one stone being green in colour and the other white, both being about three carats in weight. A preliminary test on a Levy-West screen showed the green stone to be radio-active, which indicated that the colour was undoubtedly due to radium treatment. When an autoradiograph was taken for confirmation, most surprisingly the white diamond also gave a self-picture (Fig. 2). The cause of this makes an intriguing problem. Had the radium-treated green diamond induced radio-activity in the white diamond, or was it some reflective effect of the alpha particles by the white diamond?

FIG. 1

FIG. 2

As the stones could not be unmounted a subsidiary test on each stone singly, which might have proved either of these hypotheses, was not able to be carried out. This is the first time such an effect has been noticed although other jewels containing radium-treated green diamonds mounted with white diamonds have been so tested on previous occasions.

R.W.

Gemmological Notes

A FEW GEM ODDITIES

The textbooks are not always correct. How many collectors, on being unable to find their rare gemstone in the reference books, have taken it for granted that "something was wrong somewhere", and have even attached a new label to their gem just to conform with well-known books?

Many reasons exist for this state of affairs. Gemstones come and go. Also, there is a limit to any one person's knowledge. Most collectors are limited financially and consequently never get offered many of the rarer and costly varieties. Few of us can expect to develop a collection containing top-grade specimens of all varieties. We have to be content with what we can afford. Thus the tendency to say, "Such stones just don't exist", has to be restrained. They may quite well exist.

The following are a few items which the author has come across in recent months.

Apatite, of a deep hue, is rarely met with, yet Brazil supplied a sapphire-blue apatite full of unusual inclusions. The stone weighed 1·12 carats.

Aragonite is not usually encountered among faceted stones. Crystals from Horschenz, near Bilin in Bohemia, afford quite large stones with a pearly finish.

Barite is also rarely met with in collections mainly because it is so difficult to handle. Blue barite from Sterling, Colorado, affords stones which look somewhat like aquamarine.

Diaspore is one of the hydrous oxides. The manganiferous variety from South Africa provides small stones of a rose to dark red hue.

Dickinsonite—a hydrous phosphate—is one of the minerals usually ignored by gem textbooks. Yet crystals have enabled one or two small stones of olive-green hue to be cut.

Natrolite is usually presented in textbooks as being available in fibrous form or in needle-like crystals. Thus faceted stones are

usually very fragile. However, a granular vein of natrolite encases the benitoite in San Benito County, California, and this locality provides material good enough for the cutting of stones of two carats or more.

Phosgenite, a chlorocarbonate of lead, is sometimes found in fine crystals large enough to cut stones of over 30 carats. This mineral is usually not mentioned in textbooks on gems. Oddly enough, phosgenite is also found at Laurium, Greece, as a result of the action of seawater on ancient lead-slag dumps. So in this locality, man and nature have combined their efforts to produce a natural gemstone.

Prehnite is quite well-known, but the clear faceted variety is rare. One source is Argyll, Scotland, and stones of several carats have been cut.

Pyroxmangite yields small but beautiful stones of an attractive red hue. One current source is Honshu, Japan. One wonders what a gem trade laboratory would do if faced with such an unusual stone. No doubt the equipment of the mineralogist would be necessary in this case. In this case, the mineral textbooks, too, do not provide much information as to sources or the possibility of obtaining faceted red stones from the crystals.

Smithsonite is well-known in cabochon stones of beautiful pastel hues, and crystals from Tsumeb provide faceted stones.

Sphene is familiar gem, but a faceted stone of 27·25 carats must be considered something of a rarity even though it is not flawless.

Tourmaline of the colourless variety has long been known to be rare. The Himalaya Mine of Mesa Grande, California, is one source.

G.V.A.

A DUBIOUS ROSE

A rose-cut diamond of about 4ct. spread mounted as a single stone ring with closed-in setting was examined recently.

The under-side of the ring was rounded and a double rose-cut diamond set in gold was indicated. Examination gave an appearance of doubling or a doublet. The top "half" certainly was diamond. Wisely the stone was unset and found to be a straightforward flat-backed rose-diamond slightly off-white, weighing 2 cts.

The hollow rounded cradle of the ring was seen to be not only foiled but the foiling was faceted! This was the reason for the appearance of depth in the stone. Needless to say it was an expensive overseas purchase.

A.F.

PROBLEMS IN BURMA

One way of obtaining a valuation of gems is reported in the February 1965 *Lapidary Journal*. An extract says:—

"Recently the present Burmese government, which is completely Communistic in its national policies, held a purported 'auction sale of seized gems' in Rangoon from 1st December to 12th December. Supposedly the ordinary passport and visa regulations were relaxed for this purpose in order to attract foreign gem experts. The sale, it was said, was meant only for gem dealers and stone sellers.

"Reliable persons who were inveigled to attend from outside Burma have now returned disappointed and report that the whole thing was a fake. The government only wanted to get a free appraisal of the gems from gem experts and dealers through written bids on each item of gemstones. This seems to be the only purpose for such a fake sale. Persons who made offers in writing were answered by slips under their hotel room doors stating that the gems they bid on were not for sale. Many persons complained about losing their valuable time and their own transportation money in this deal.

"It is widely known that the gem mines of Burma have been 'nationalized', that is, seized by the Communistic dominated government authorities and that all former owners have been dispossessed, particularly and especially the Chinese who owned the principal gem mines in the ruby district of Mogok and in the jadeite regions of upper Burma".

Gemmological Abstracts

HARRISON (E. R.) and TOLANSKY (S.). *Growth history of a natural octahedral diamond.* 1964, 279, pp. 490-496.

The growth history of the diamond was studied by examining eleven successively polished cubic sections of the complex structure of an octahedral diamond.

S.P.

POLUTOFF (N.). *Die Sibirischen Diamantlagerstätten.* The Siberian diamond finds. Zeitschrift f. Erzbergbau und Metallhuttenwesen, 1964, 17, 8 pp. 440-443 and 9, pp. 500-503.

Small finds of diamonds in Siberia, between the rivers Lena and Jenissei, were reported in 1898 and again in 1937. Soviet scientists then started prospecting for diamonds, assuming that most finds were situated in the world's older plateaux. Diamonds were found in 1949 and the first primary occurrences in 1954/55. The first kimberlite pipe was found in 1954 by the young female mineralogist, L. Popugaewa. She at first assumed the presence of diamonds because she found pyropes very similar to those found in South African kimberlite. The prospecting was very difficult owing to the climatic conditions and working in virgin land (Taiga). Aircraft were a great help in this respect.

The diamond finds are limited to the eastern half of the middle Siberian plateau, to the north of which is the tundra. There is not much snow during the winter, which lasts about 6-7 months with temperatures usually under –40°C, sometimes even –60°C. The air is dry. Rivers are the only ways of transport, apart from reindeer and aircraft. The article gives details of the geological character of the region and of the prevailant magnetism. A detailed map of the area is also published, together with sketches of the actual pipe. The Siberian diamonds have been classified into 10 morphological types, which make up about 75–90% of all crystals. There are only 3 or 4 crystal habits. Isometric diamond crystals are rare, most common being octahedra and rhombic dodecahedra and habits between the two. There are few cubes but quite a number of twins. Most of the Siberian diamonds are colourless, which vary from each other mainly by their degree of

transparency. There are very few coloured crystals, the few there are being mostly green-yellow. There are very few pigmentation spots, but occasionally there are grass-green spots to be observed. Inclusions are not numerous, those present are mostly graphite, olivine and sometimes pyrope. Inclusions of diamond in diamond are very rare.

The first big stone was found in 1956 and weighed 32·5 cts. In 1957 a stone weighing 37·35 cts. was found and in 1962 the stone "Mirnyj" was found weighing 56·2 cts.

The Soviet production, including industrial diamonds, was in 1958, 650,000 cts.; 1959, 800,000 cts.; 1960, 950,000 cts.; 1961, 1,000,000 cts.; 1963, 2,750,000 cts.

E.S.

TSUJII (T.). *The Change of Pearl Colours by the Irradiation with γ-ray or Neutron ray.* Journ. Rad. Rea., 1962, 4, 2-3-4, pp. 120-125.

Pearls produced either in pearl oyster or in fresh-water mussel change their colours into black by the irradiation with either γ-rays or neutron rays. In this coloration, blackish pigments are found chiefly in the inserted nuclei of the pearls produced in marine molluscs and also in the nacreous layer of pearls produced in fresh-water mussels, but seldom in Japanese pearl oysters. The insertion nucleus is made of the nacreous layer from the shell of fresh-water clams.

The nacreous layer either in the shell or in the pearl or fresh-water clams easily changes colour from the original to black by the irradiation. In order to clarify the mechanism of the coloration, the coloured pearls were observed, using chemical and physical methods.

In physical observations, in the coloured pearls examined submicroscopically, using electron microscope and x-ray diffractometer and heat-effects, no physical differences were found before and after the irradiation.

In chemical observation, the shell of fresh-water clams contains comparatively larger amounts of Mu than marine molluscs.

T.T.

LEIPER (H.). *Occurrences of gem topaz in north America.* Lapidary Journ., 1964, 18, 8, p. 956.

S.P.

FERNANDES (L. L.). *The gold and diamond deposits of British Guiana.* Proc. 5th Inter-Guiana Geol. Conf., Georgetown, 1959 (Publ. 1961), pp. 273-283.

Alluvial diamonds are found in the Pakaraima Mountains escarpments in a 15 mile wide belt. Since 1887, 2,700,000 carats of diamonds have been produced.

R.A.H.

TOLANSKY (S.). *Synthetic diamonds: growth and etch phenomena.* Proc. Roy. Soc. London, series A, 1962, 270, pp. 443-451.

Microscope studies of de Beers synthetic diamonds showed growth spirals on cube faces.

R.A.H.

EVANS (T.) and PHAAL (C.). *Imperfections in type I and type II diamonds.* Proc. Roy. Soc. London, series A, 1962, 270, pp. 538-552.

Electron microscopy revealed impurity platelets, probably of nitrogen, on (100) planes in type I natural diamonds but not in type II. Dislocations are common to both types.

R.A.H.

THEISEN (V.). *Es sieht aus wie Türkis.* It looks like turquoise. Deutsche Goldschmiedezeitung, 1964, 12, 62, pp. 1144-1147.

This article is the continuation of one published in the same journal, no. 11, pp. 1033-1036. This part of the article deals with various imitations, mostly with so-called "Wiener Türkis" (Vienna turquoise), "New" turquoise and the use of howlite. The first type is produced from malachite, aluminium hydroxide, phosphoric acid, which are heated to 100°C under strong pressure; the second type has a very similar composition, while howlite is found in North America, together with gypsum and anhydrite, and is dyed to simulate turquoise. At the end of the article there is a table, which is very useful. The materials tabulated are turquoise, dyed turquoise, turquoise with impregnated surface, dyed and hardened turquoise, reconstructed turquoise (natural material bonded together with blue resin), odontolite, amatrix (which is utalite and wardite), kallainite (a clay phosphate), lazulite, dyed chalcedony, glass or china imitations, elatite (a mixture of copper carbonate and blue azurite), chrysocolla, "Vienna turquoise", "new" turquoise

and dyed howlite. In each case special characteristics are given together with hints on how to recognise them. Apart from these, the following details are enumerated: chemical composition, appearance, RI, spec. gravity, hardness, absorption spectrum, luminescence in UV light.

E.S.

. . . *Die synthetischen Smaragde.* The synthetic emeralds. Deutsche Goldschmiedezeitung, 1964, 12, 62, p. 1148.

Short notice referring to "Diebeners Goldschmiedejahrbuch" (Goldsmith's Almanac) for the year 1965. In this Dr. W. F. Eppler published an article on emerald synthesis, dealing with productions by Chatham, Lechleitner, Zerfass and Gilson. It is mentioned that the latest synthesis by Lechleitner is a complete synthesis, as the emerald is built up in layers. The colour is very good and the layers can only be observed when the stone is viewed from the side in a liquid having similar refractive index.

E.S.

. . . *Mikro-boy, ein Mikromessgerät für Brillianten.* Micro-boy, a micrometer for brilliants. Deutsche Goldschmiedezeitung, 1964, 12, 62, p. 1162.

A new instrument made by the firm "Micro-boy" in Zürich, which should prove useful for anyone concerned with the measurement of stones. It is as large as a pocket watch, very light, easily adjusted and its scale is graduated to 1/100 mm.

E.S.

LIDDICOAT (R. T.). *The G.I.A. photoscope.* Gems & Gemology, 1964, 7, IX, pp. 195-199.

Reports an ingenious adaptation of the Polaroid Land automatic 100 camera so that it may be used for photomicrography. This camera has a shutter which opens manually but closes electronically when sufficient light to expose the film is recorded by a photo cell. The adaptation lies in the use of an armoured flexible fibre optical light wire connecting the photo cell to the second ocular of the binocular microscope.

10 illus. R.W.

BOOK REVIEWS

FISHER (P. J.). *Jewels.* B. T. Batsford Ltd., London, 1965. 112pp., 4 colour plates, 49 photographs and 32 drawings. 35s.

Jewels is essentially a brief and well-illustrated introduction to Gemmology, aimed especially at "young people and others who would welcome a book written in simple terms". There is room for such a book, and Mr. Fisher has on the whole succeeded very well in his purpose. There are more than 80 illustrations, derived mostly from excellent black-and-white photographs, in addition to 4 plates in colour. Of these, three were specially taken for this volume and reproduce fairly faithfully the appearance of most of the gems described in the text: the fourth, which is also reproduced on the cover, is a superb plate of diamond crystals of varying colour and habit, provided by De Beers. A sister plate to this has already graced the jacket of Webster's *Compendium.*

After a first chapter on "Gems through History", which includes notes on the making of modern jewellery, there follows one on "The Nature of Gems" into which are crowded basic facts of the chemistry, crystal form, etc., of gem minerals, the nature of light, and its reaction upon cut gems. This chapter is rather too "instructional" in tone, and in places seems to assume that the reader is not only young but dim-witted: for instance, "Everybody today has heard of that most terrible weapon known as the atom bomb. Do not imagine that our beautiful gemstones have anything to do with that fearsome thing, but they do have in common the fact that they are composed of atoms, as indeed are all things in our world". There are a number of ways in which this chapter could be improved: as it stands it may quench the ardour of a beginner before he breaks through to the easier reading of the chapters beyond.

The stones selected for treatment in the descriptive sections are sensibly limited to the 20 or so species utilized in commercial jewellery, together with the organic gems amber, coral and pearl. The only stone outside this canon which is allowed to intrude is sphene—the name of which has acquired a certain mystique amongst dealers, even if they have never seen a specimen in their lives.

The chapter on diamond is good, though scant treatment is afforded to important fields outside South Africa. Since such things are interesting to the general public, rather more might have been given of stories of diamond discoveries, together with production figures for gem and industrial diamonds. For the other gems the descriptions are fairly adequate, if rather on the dry side. The explanation given of "High" and "Low" zircon is not really accurate, and one or two paragraphs could do with rewriting here.

Jade is so important a material in human history, pre-history, and culture that the author might have spared more space in which to bring it to life for the layman. In the mere 300 words or so actually given to the jade minerals there are several inaccurate statements. For instance, nephrite was *not* worn by the ancient Greeks as a protection against kidney troubles; it is probable that neither the Greeks nor the Romans knew anything about the jade implements which were later found in their countries. Nor has jadeite been valued by the Chinese "since the dawn of history", but only from the eighteenth century onwards when the lovely material from Upper Burma first became available to the Chinese craftsmen. Mr. Fisher should also have included the important North American deposits of nephrite jade in his list of sources.

The chapter on pearl is very well written and illustrated, but pink (conch) pearl should have been mentioned as it has some commercial significance, and its distinction from coral needs to be indicated.

The seventh and last chapter in the book, on "Testing Gems", is excellently done, and cleverly compresses the essentials of the subject into a dozen or so pages. Extended captions under the photographs of instruments make for clarity and save the author from having to give this information elsewhere in the text. In dealing with the spectroscope, Mr. Fisher makes the statement that "various metals often cause the dark lines which appear in definite positions in the absorption spectra of minerals, and in this way it is even possible to discover the composition of the stars in the universe. . . ." This shows a confusion between the narrow, fixed lines appearing in the emission or absorption spectra of the vapour of an element with the absorption bands in the solid state. The latter of course vary in position according to the host mineral—hence their usefulness in identification.

The book concluded with "Gem Tables" and a short combined index to both text and illustrations. The "Tables" consist in fact of one useful comprehensive table, giving the composition, hardness, density, refractive index and occurrence of the main species. For some reason, sphene, spodumene, fluorspar and lapis-lazuli, which are described in the text, are missing from this table..

Mr. Fisher suggests only two books for further reading: *Gem Testing*, and Robert Webster's comprehensive *Gems*. Perhaps a word as to the scope of these might have been added to save the innocent reader from plunging into waters deeper than he intended. Herbert Smith's *Gemstones* as revised by F. Coles Phillips might also have been recommended, as it still provides the best one-volume coverage of the whole subject.

B.W.A.

EYLES (W. C.). *The book of opals.* C. E. Tuttle Co., U.S.A. and Japan, 1964. 224 pp., 13 colour plates, 28 photographs and 8 drawings. 60s.

A useful contribution to the literature on opal. In discussing geological explanations of opal origins no conclusion is reached about the cause of colour. The book is entertaining in the parts dealing with mining methods and the history of opal as a gem. The major opal producing areas are described in detail and this section of the book benefits from the author's visits to several of them and his own mining experiences. Reference is made to some of the outstanding opals that have been found, though the list is incomplete. The index is irritatingly inaccurate.

S.P.

ASSOCIATION NOTICES

JOURNAL OF GEMMOLOGY

Secondhand copies of back numbers of the *Journal of Gemmology* urgently required. Vol. IX No. 1, and Vol. IX No. 3 1963, are particularly needed. Will members having copies for disposal please communicate with the Secretary.

TALKS BY MEMBERS

BENSON-COOPER, P., "Gemstones", Ash Vale Women's Liberal Club, 30th January, 1965.

BLYTHE, G. A. "Gemstones", St. Saviour's Women's Fellowship, Westcliff, 3rd November, 1964; Women's Branch British Legion, Southend, 4th February, 1965; Institute of Petroleum, Shell Haven, 24th February, 1965.

KENNEDY, N. W., "Women and gemstones", Poulton and district Ratepayers' Association, Bebington, 9th February, 1965.

LANGTON, E. G., "Pearls", Soroptomists' Club, Hornsey, London, N.8, 27th January, 1965.

ANNUAL MEETING

The 35th annual meeting of the Association will be held at Saint Dunstan's House, Carey Lane, London, E.C.2. on Wednesday, 5th May, 1965, at 6.30 p.m. to transact business usual to an annual general meeting.

Officers:

The Council has made the following nominations:—

President: Sir Lawrence Bragg, F.R.S.
Chairman: Mr. Norman Harper
Treasurer: Mr. F. E. Lawson Clarke
Vice-Chairman: Mr. P. W. T. Riley

The following members of the Council retire in accordance with the Articles of Association and, being eligible, offer themselves for re-election: Messrs. D. J. Ewing, W. Stern and R. Webster.

Messrs. Watson Collin & Co., Chartered Accountants, have signified their willingness to continue as auditors.

MEMBERS' MEETING

A meeting of members was held at the Films and Art Theatre, London, W.1. on Thursday, 28th January, 1965, when the following films were shown: "Diamonds in the West", "The Cleaver" and "Diamonds in the stone industry".

LETTER TO THE EDITOR

DEAR SIR,

Pleochroism through the Microscope

I read with great interest the article "Dichroism through the Microscope" by R. S. Miles, F.G.A. and J. T. Herring, F.G.A. (Journ. Gemm., 1965, IX, 9). Possessing a very simple microscope, without compensating eyepiece, rotating stage, polarizing equipment and spares, I approached the problem in a different way:

A piece of polaroid film was cut in two and the pieces were placed at right angles to each other on a $\frac{3}{8}''$ washer, which has an outer diameter of 21 mm.

The polaroids were stuck down with transparent adhesive tape dividing the aperture field into four quarters.

After trimming the surplus tape the washer is placed on the field aperture which is found between the collecting lens and the ocular lens of the $\times 5$ Huygens ocular. On rotating the ocular, four colours are seen in pleochroic gemstones, such as andalusite, iolite, etc.

If the washer is placed the wrong way on the field aperture, the polaroids are out of the picture plane and there appears dichroism only.

Yours truly,

RUDOLF THURM.

Ludenscheid,
W. Germany.

MIDLANDS BRANCH

Mr. R. A. Jones, an Executive of De Beers Corporation of West Africa, spoke about "Diamonds in the West" at a Midlands Branch meeting held in Birmingham on 22nd January, 1965. Dimonds were first discovered in Sierra Leone in 1919, in the Berry River, but it was not until 1924 that extensive mining began. Many diamonds were smuggled into Liberia at first. A state buying operation, financed by De Beers, is now in force and much of the buying is organized by the Sierra Leonians. After the showing of the film "Diamonds in the west" Mr. Jones answered questions. Mr. A. E. Shipton proposed a vote of thanks.

OBITUARY

David Keefe Lynch, 21st February, 1965, after a long illness. Mr. Lynch gained his diploma in 1951.

Raimo A.U. Marno, Helsinki, 27th October 1964

MEMBERSHIP

The following were elected on 1st February, 1965:—

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Gibson, Henry G. W., London, N.W.2.
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Hanebach, Stanley, Scarborough, Ont., Canada
Ison, John P., Farnborough, Hants.
Lucas, Richard G. H., Sittingbourne, Kent
Mansoor, Ahamed Y. M., Puttalam, Ceylon
O'Donnell, Arthur L., London, S.E.3.
O'Grady, Royston J., London, N.19.
Ono, Tsutomu, Hyogo Pref, Japan
Pearson, Malcolm D., London, E.3.
Subhan, Mohd., London, E.C.1.
Gibson, Craigie A., Causeway, Rhodesia

PROBATIONARY MEMBERSHIP

Boruszak, John K., Blackpool, Lancs.
Taylor, Andrew W., Newton Abbot, Devon.

COUNCIL MEETING

At a meeting of the Council held on 1st February, 1965, Mr. Norman Harper, Vice-Chairman, presided.

The following elections took place:—

ELECTED TO FELLOWSHIP

Bagi, Julius, Toronto, Canada
Baguley, Kenneth, Liverpool, 10, Lancs
Barrett, Robert C., Ansty, Sussex
Beckwith, John M. E., Middlesbrough, Yorkshire
Burslem, William A., Liverpool, 14, Lancs.
Calmus, Michael, Nottingham, Notts.
Chambers, Edwin J., Dagenham, Essex
Cornish, S., Birmingham, 22A, Warwicks.
Grey Harris, Stephen J., Bristol, 7
Hartley, Mary L. (Miss), Liverpool 8, Lancs.
Johnson, Donald H., Kitwe, Zambia
Major, Keith R., East Grinstead, Sussex
Mooney, Eugene, Edinburgh, 10, Scotland
Nilsson, Carl A. G., Boliden, Sweden
Pierce, William M., Athens, Ohio, U.S.A.
Richardson, Kenneth, Birmingham 9, Warwicks.
Rowley, Robert E., Tadworth, Surrey
Schriber, Urs, Lucerne, Switzerland
Wain, Edward H., Ipswich, Suffolk
Walters, George C., Leicester, Leics.
Barrett, Henry M. S., Lewes, Sussex

ELECTED TO ORDINARY MEMBERSHIP

Austin, Virginia S. (Mrs.), Phoenix, Arizona, U.S.A.
Downes, Bryan, Silkstone, Yorks.
Earthy, Peter B., Newbury, Berkshire
Ek, Stig Yngve, Vallingby, Sweden

Franke, Lois E., Hollywood, California, U.S.A.
Holdroyd, David M., Hong Kong
Huish, Diana (Mrs.), London, N.2
Inkersole, Denis, London, E.9
Johnson, Douglas A., Nuneaton, Warwickshire
Kerez, Christoph J., Baden, Switzerland
McLean, Eldred M., Orkney, Transvaal, S. Africa
O'Shea, John P., Orpington, Kent
Ponahlo, Johannes (Dr. Ing.), Wien 22, Austria
Salt, Ilse (Mrs.), Vancouver 8, B.C. Canada
Salt, Thomas E., Vancouver 8, B.C. Canada
Sarkodie-Mensah, James, London, N.W.6
Sweet, Ronald D., Sidcup, Kent
Wardulenski, Witold, Montreal 26, Quebec, Canada
Ozolins, Nikolajs, Willowdale, Ontario, Canada

Elected to Probationary Membership

Bartolotti, Anna (Miss), Lucerne, Switzerland
Bullock, Gabrielle J. D. (Miss), Worcester, Worcs.
Burgerhout, Saskia, The Hague, Holland
Gauntlett, Gillian (Miss), Haslemere, Surrey
Lewis, Leslie J., London, E.5
O'Donohoe, John P., Dublin, 2, Eire
Popper, Madeleine C. (Miss), London, N.W.3
Simmonds, Stephen J. M., London, S.W.1
Stadler, Othmar, Lucerne, Switzerland

The Council decided to form a separate company to handle the sales of gem-testing instruments. Directors of the Company would be appointed by the Council.

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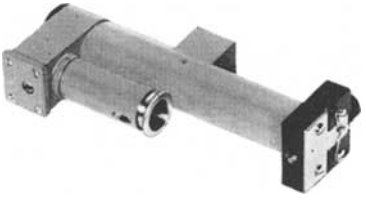

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April, 1965

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Vol. IX No. 11 July, 1965

THE JOURNAL OF GEMMOLOGY

and

PROCEEDINGS OF THE GEMMOLOGICAL ASSOCIATION OF GREAT BRITAIN

GEMMOLOGICAL ASSOCIATION
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THE JOURNAL OF GEMMOLOGY
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Vol. IX No. 11 JULY 1965

THE GILSON SYNTHETIC EMERALD PROCESS

By F. DUYK

IN the production of synthetic materials the chemist usually seeks only the ultimate results of his experiments, unworried by any fortunes that may follow. This was true of Ebelmen and Moissan, whose works are famous in the history of chemistry. Certain synthesizing experiments, notably those of Professor E. Nacken of Vienna, did not get past the laboratory door. Some who have aimed to put their manufacture on a legitimate industrial plane have been successful and the latest French synthetic emerald process of Pierre Gilson found itself surrounded by publicity after its announcement.

In connexion with synthetic emeralds some important observations have been made. Professor W. F. Eppler has discovered crystals of ilmenite in the Gilson synthetic emeralds and has drawn a comparison in structure between the Gilson process and those used by Nacken and Carroll Chatham in the U.S.A.(1).

The same statement has been made by Dr. E. Gübelin, who indicates the presence of phenacite(2). In the last samples which have been submitted to us we have also established the presence of small hexagonal fragments of ilmenite, some agglomerated crystals of a whitish nature and, amongst others, some of a brownish colour showing bubbles of gas on their surfaces (Fig. 1).

Figure 2 gives a general view where one can trace the usual liquid inclusions. These channels, containing liquid and bubbles of gas, are shown considerably magnified in Figure 3. Synthetic emerald crystals, though well formed, usually have smooth terminal faces.

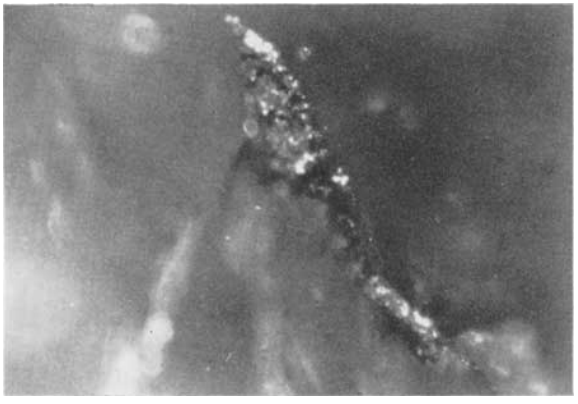

FIG. 1

←FIG. 2

FIG. 3

FIG. 4

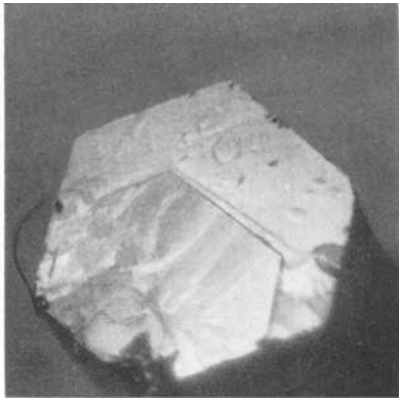

FIG. 5

Analysing these surfaces has caused much interest, and it has been noticed that there is a similarity in the formation pattern of the products of Chatham (Fig. 4) and Gilson (Fig. 5). The latter shows more perfectly made crystals, but the two terminal faces show similar distortions.

The distinction between natural emeralds and the Chatham and Gilson synthetic stones is made easy by the process instituted by Professor K. Schlossmacher[3]. This is by immersion in benzyl benzoate (R.I. 1.569) and observation of the facet angles. If, when the focus is raised, the angle lights up, the emerald is natural. If the angle goes black it is one of these two synthetics.

In a solution of bromoform diluted with xylol, a piece of rock crystal may be immersed so that it just rises to the surface. In the liquid so prepared the synthetics will float and the natural emeralds will sink. Under the microscope, with nicols crossed (dull polarization), the synthetics appear in bright colorations and their irregular forms seem to be the result of internal tensions, whilst the true emerald shows chromatic polarizations following the line of crystallization, i.e., rectilinear. Under ultra-violet rays the Chatham synthetics react with red fluorescence and the Gilson synthetic emeralds show olive-green.

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MAW-SIT-SIT proves to be JADE-ALBITE

By E. GÜBELIN, Ph.D., C.G., F.G.A.

IN a previous report the first phase of a comprehensive investigation to determine the nature of a decorative gemstone from North Burma and its colouring agent, present in the form of ultra-minute green grains, was described and the preliminary results were elucidated. It was found that Maw-sit-sit was a rock whose ground-mass consisted essentially of albite, which received its vivid green colour from a green pigment-mineral, the chemical composition of which failed to be disclosed by the analytical methods employed[1].

In face of the extreme difficulty of separating the pigment-mineral from the albite ground-mass and concentrating it in sufficient quantity to carry out a chemical or X-ray analysis, it was decided to examine the highly polished surface of a small piece of Maw-sit-sit in the Electron Microprobe Analyser, which had meanwhile been installed at the Institute of Crystallography and Petrology of the Swiss Federal High School of Technology in Zurich (Fig. 1). One of the most significant advances in new

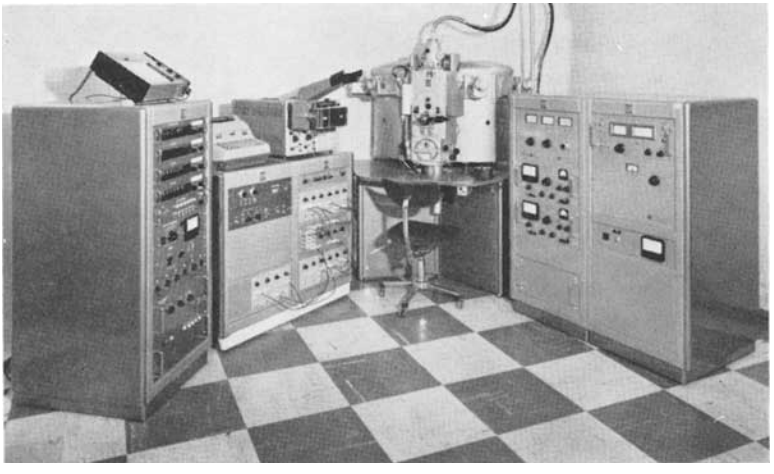

FIG. 1. *The EMX Mark II Electron Microprobe X-ray Analyser made by the Applied Research Laboratories, Inc. (Glendale, California, U.S.A.). The basic EMX installation consists of three sections: microprobe spectrometer, probe electronics and recording console.*

analytical techniques during the last few years has been the development of electron-probe micro-analysis. This new technique provides a non-destructive elemental analysis of extremely minute volumes at the heterogeneous surface of a solid specimen, in that the qualitative and quantitative analysis of a volume of a few cubic microns (1 micron = 0·001 mm) can be readily accomplished. The apparatus yielding this interesting information is called a microprobe.

A finely focused beam of electrons is directed at the highly polished surface of the specimen under examination exactly on the spot to be investigated. This electron bombardment causes characteristic X-rays to be emitted by the atoms affected by the electron excitement. Crystals of appropriate materials are employed to diffract the X-rays into their component wave-lengths and the selected rays are focused onto X-ray detectors. The X-ray photons entering a detector are converted into pulses of electrical energy. The number of the pulses is directly proportional to the intensity of the X-radiation entering the detector, which in turn bears a relationship to the mass concentration of the element producing the X-rays. The pulses of energy from the detectors can be utilized in various types of read-out systems.

Analyses can be performed for all elements above atomic number 10 (thus H, He, Li, Be, B, C, N, O, F, Ne are excluded). The sensitivity (limit of detectability) of this method of micro-analysis ranges from 1 part in 10^5 (0·001%) to 1 part in 10^3 (0·1%) depending upon the analyte, matrix and spot size. The relative accuracy is 1–2% if the concentration is greater than a few per cent and if adequate standards are available. The spatial resolution in some cases is 1 micron or less.

Although microprobe analysis finds primary application in metallurgical research it lends itself excellently for the investigation of the heterogeneous composition of rocks.

In this apparatus the polished surface of a tiny sample of Maw-sit-sit was bombarded with electrons, from the reflective behaviour of which information could be obtained about the nature of the various elements forming the surface. With an aperture of 11μ of the diaphragm the examination yielded the following composition of a pigment grain: chromium, iron and silica were present in great quantity (amount X0%), with a ratio chromium: iron of 3:1. Titanium, calcium and potassium represent the minority

(amount only X%). Sodium and aluminium could not be analysed on account of their atomic weight being too low. The ratio of iron to chromium concurs with that found by the chemical analysis in the previous communication (p. 339)[1]. This evidence corroborates that Cr and Fe are present in the pigment only. On the polished surface of the sample under examination the distribution of the individual elements could be studied. The observation that the reflection of the electrons is much more intensive from the pigment grains than from the albite ground-mass further substantiates that the chemical elements constituting the colouring substance possess a higher atomic weight on the average than those of the albite rock, whereby the areal distribution of the intensities of chromium, iron, calcium and potassium also correspond to the relative concentration of the pigment grains. Thus the experimental proof has been established, that the pigment in the Maw-sit-sit is a chromiferous mineral (as well as iron-bearing). This result substantiates the formerly described observations through the evidence delivered by the microscopic examination (p. 338 [1])

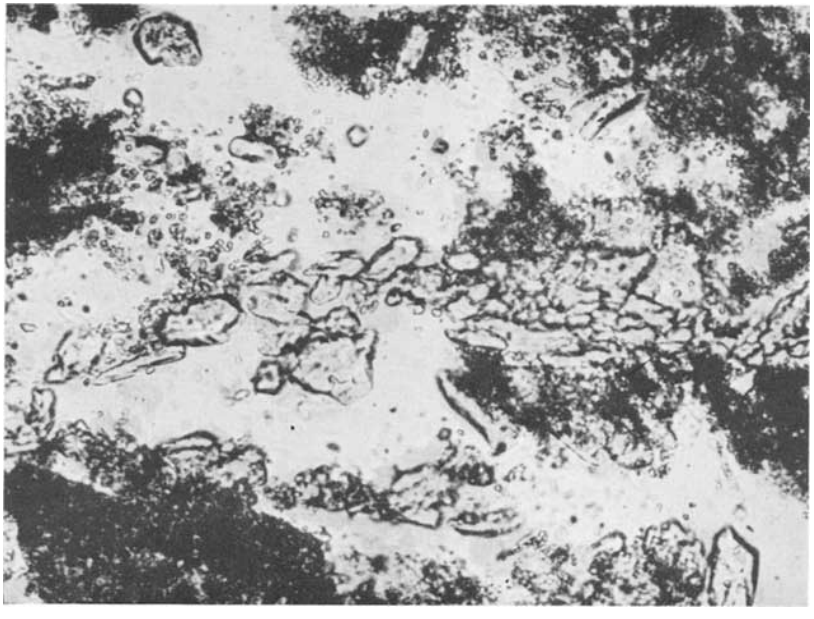

FIG. 2. *Strong magnification of green pigment grains irregularly disseminated in the white albite rock.* 250 ×

which clearly showed that the green colour of the stone was induced by the irregularly interspersed green grains of an alien mineral (Fig. 2).

Unfortunately, the single crystals of the pigment material proved to be still too tiny to enable a quantitative analysis with the electron microprobe analyser, and it became imperative to find still another method of recovery and concentration. However, the scope of speculation grew considerably narrower, because the examination with the electron microprobe had confirmed beyond any doubt that the colouring pigment in the Maw-sit-sit was a chromiferous mineral of the pyroxene group and akin to the jadeite ($Na\ Al\ Si_2O_6$) or to the aegirine ($Na\ Fe\ Si_2O_6$).

As far as the author is informed, such a mineral has not yet been described, as all analyses published up to date do not mention higher contents than 0·01% of Cr_2O_3—even for imperial jade. Hence one might have expected a new species at this stage of the research: however, as long as the results of this investigation did not yield definitely clear results, it was preferable to wait until possibly proclaiming a new species, especially as the direct proof of sodium in the pigment-mineral was still missing.

So far the solution of the problem was frustrated by the difficulty of precipitating a sufficient concentration of the pigment-mineral, and consequently the attempt of another new procedure became necessary, which eventually proved to be successful. A fragment of rough Maw-sit-sit was pulverized in a vibration-mill, until a grain size of less than 10μ was obtained, while the concentration of the pigment (whose specific gravity on account of the chromium content was heavier than the albitic ground-mass of the rock) became possible by centrifugence of a mixture of methylene-iodide and tetrabromo-ethane. The mixture had a density of 2·75 (albite = 2·61). The accumulating sediment appeared a much more intensive green colour than the primary material and the floating fraction.

The sequel of the following examinations now proceeded in the reverse succession of events as against the previous phase and first another X-ray examination was carried out.

X-ray examination

With a Vernier-Guinier camera new powder diagrams of the concentrated pigment fraction, of ordinary augite, of diopside, of

aegirine and of jadeite were established after the method of de Wolff (Cu Kα—irradiation, exposure 12 hours) (Fig. 3). The distribution of lines thus obtained doubtlessly indicate a mineral of the group of the alkalipyroxenes (to which jadeite and spodumene also belong) (Fig. 4). Additional lines which are also present mainly belong to the albite, which could not be entirely removed quantitatively. A comparison of the diagrams of aegirine, jadeite and the pigment-mineral revealed that the colouring agent must lie between jadeite and aegirine. Contrary to aegirine at least two of the three lattice distances are somewhat shorter, because considerable quantities of iron are substituted by aluminium. On the other hand, the replacement of $Fe^{\cdots}$ by $Cr^{\cdots}$ would hardly show by the line intervals of the X-ray diagram, since both types of atoms have practically equal ion radii.

(The X-ray diagrams were made by Mr. H. Scheel of the above-mentioned institute, and he also helped with their interpretation.)

In order to attain a clear verdict and to establish a definite

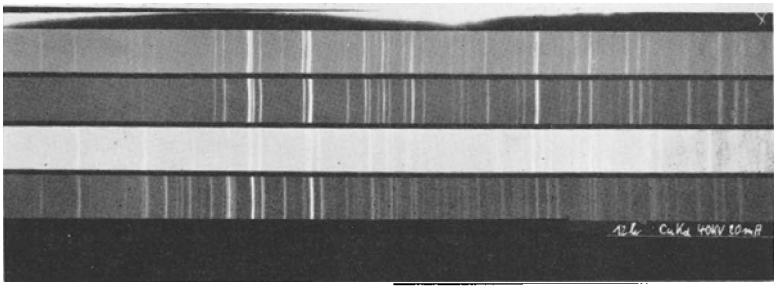

FIG. 3. *Comparison of X-ray powder diagrams after de Wolff of alkali-pyroxene minerals.*
Diagram 1 = Augite
2 = Diopside
3 = Aegirine
4 = Chrome-jadeite, i.e. pigment-mineral in the Maw-sit-sit.
The coincidence of most of the lines proves that the pigment-mineral belongs to the same isomorphous group of alkali-pyroxenes. (12h CuKα 40 KV 20 mA Al-foil)

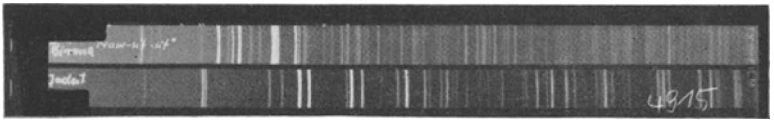

FIG. 4. *Comparison of X-ray powder diagrams after de Wolff of Maw-sit-sit and Jadeite. The difference of the line positions offers clear evidence that Maw-sit-sit is not Jadeite.*

chemical formula the chemical analysis of the concentrated pigment fraction obtruded itself at this phase of the examination. Since the pigment was not present in absolutely pure state, merely a partial analysis was carried out, which supplied the following result:

Molecules	*Pigment concentrated to* 70%	*Maw-sit-sit* (*p.* 339 (1))
Na_2O	10%	11·1%
Cr_2O_3	7%	2·6%
Fe_2O_3	4%	·8%

In face of the fact that the content of sodium has hardly changed as against the first analysis (p. 339 (1)), the pigment must be a mineral with approximately 10% Na_2O, and the following impure alkali-augite minerals may be considered: jadeite or aegirine. Pure jadeite contains 15% Na_2O and pure $NaCrSi_2O_6$ (hypothetical chromium alkaliaugite) 13.5% Na_2O. The amount of chromium is about three times greater than in the primary material. Consequently one may conclude, that the pigment-mineral comprises about 10% of Cr_2O_3 while its share in the Maw-sit-sit amounts approximately to 20 to 25%. The portion of iron is somewhat higher than what the concentration factor of three times would justify: presumably because the analyte became contaminated by iron in the course of the various operations.

Chemical formula

The exact chemical composition of the pigment-mineral could not be determined, because a sufficiently accurate separation of the accompanying minerals (particularly albite) was not possible on account of the ultra-minute size and the intimate aggregation of the crystals. However, the present investigation shows that the examined composition stems from the alkali-pyroxene jadeite ($NaAlSi_2O_6$), in which considerable quantities of aluminium are substituted by chromium and iron. Sodium is only slightly replaced. Thus the slightly idealized chemical formula of the influential pigment-mineral in the Maw-sit-sit may be expressed as: Na (Al, Cr, Fe) Si_2O_6, whose chromium content reaches approximately 10% Cr_2O_3. Pyroxene minerals with chromium are rather rare in nature. Chromium-diopside of the formula (Ca, Na) (Mg, Fe, Cr) Si_2O_6 is mentioned most often. The highest proportions of chromium which have been published so far, amount to

2% Cr_2O_3, e.g. five times less than the chromium content in the Maw-sit-sit[2, 3, 4].

The pigment-mineral in the Maw-sit-sit represents a new, hitherto unknown member of the alkali-pyroxenes, for which the mineralogical name *chrome-jadeite* seems appropriate. A completely new name would only be justified for the more or less pure mineral at the end of the isomorphous series or, if the molecular ratio of the chromium compound:jadeite exceeded at least the proportion of 50:50. In the pigment-mineral of the Maw-sit-sit the chromium content totals *ca* 10% only, whereas the pure end member chrome-jadeite $NaCrSi_2O_6$ would have a chromium portion of 33.5%. The molecular-ratio chromium compound: jadeite in the pigment mineral of the Maw-sit-sit reaches about 30:70.

Nomenclature

In view of the fact that the present investigation has established that the new decorative gemstone from North Burma consists essentially of albite, which owes its vivid green colour to a secondary, chromiferous accessory mineral, which is irregularly and intricately disseminated through the host substance of the albite, all the names heretofore used in the trade are misleading misnomers. The rock with its native name Maw-sit-sit—described in this study—is neither jadeite (jade), nor chloromelanite, nor epidote, but definitely a fine-grained albite whose colour is induced by a pigment-mineral which has been determined to be a chrome-rich jadeite (chrome-jadeite). Consequently it is logical and imperative from a linguistic as well as scientific point of view to confer on this gemstone a name which contains the mineral name "albite"; and hence the name "Jade-albite" is suggested, which however does not exclude that the original native name Maw-sit-sit may continue to be used in future.

Summary:

After numerous unavailing attempts the optical, microscopic, chemical, spectroanalytical and X-ray examinations afforded the corroborative evidence that the decorative gemstone originating from North Burma, where it is called Maw-sit-sit, mainly consists of granular albite which owes its vivid green colour and irregular black veins and patches to a chromiferous pigment-mineral that is intricately disseminated through the albitic ground mass. The nature of the substance which is responsible for the colour could not

be determined at first, because the infinitesimally small size of the colouring crystals made the separation from the albite grains extremely difficult. Only after many tantalizing experiments was it possible, by means of modern analysing instruments, to identify the pigment-mineral as a member of the isomorphous alkali-pyroxene group which may be named "Chrome-jadeite". The tiny crystals of this chrome-jadeite reach sizes of 10μ only. It was not possible to carry out an exact chemical analysis, because the separation did not take a quantitive course. The chromium content of this chrome-jadeite amount to approximately 10% Cr_2O_3, and the chemical formula of the pigment-mineral corresponds to $Na(Fe, Cr, Al)Si_2O_6$. The portion of the pigment in the albitic ground mass was found to be 20%. No description of chrome-pyroxenes has hitherto been published which contain a similar proportion of chromium. On the basis of these data gathered from the second phase of the investigation it appears logical to call this decorative gemstone "Jade-albite".

Grateful acknowledgement is extended to Professor M. Weibel, of the Institute of Crystallography and Petrology at the Swiss Federal High School of Technology in Zurich, for his continued interest as well as the successful accomplishment of the analytical examinations and their interpretation. In addition I wish to thank Dr. Robinson and Mr. Scheel for their valuable co-operation.

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SIX CENTURIES OF DIAMOND DESIGN

By H. TILLANDER, F.G.A., C.G.

THE first authentic description of the "modern" method of diamond polishing, given by Benvenuto Cellini around 1568, is aptly supplemented by the illustration of the coat of arms of the Nuremberg diamond polishers' guild, showing clearly the dop, and two faceted diamonds. Paul Grodzinski stated, in 1953: "There were diamond polishers in Paris and Nuremberg in the 13th century, but the usual secrecy and obscurity covers their methods, which were probably quite different from those used by the ancients".

Without evidence regarding the year of execution it is not possible to draw definite conclusions, but one is perhaps not much mistaken in saying that the shaping of the earliest table-cuts in the Western World coincides with the time when women began to wear diamonds, in other words well over 600 years ago.

S. Tolansky in his "History and use of diamond" states that grinding away the tip of an octahedron was the method used by the ancients to produce the table-cut. This he believes was done at least around 1300. The earliest shaping of diamond may have been done in India some 2,000 years ago.

There are, however, two German authorities, Dr. Walter Fischer and Professor Dr. Siegfried Rösch, who both say that the earliest faceted diamonds appeared only during the second half of the 16th century, and that diamonds generally believed to have been polished before that were either natural crystals or cleaved fragments. Dr. Fischer illustrates his article with such jewellery from the period around 1500. In addition he believes that the early table-cuts were produced by sawing the rough crystal in two and not by grinding away the tip. The author has observed traces of sawing in a number of old diamonds and therefore suggests that both methods must have been used.

During mediaeval times extensive trade with the orient, appreciation of minor arts, or at least a highly luxurious life must have existed in a city, before this became a diamond centre. It remains to be discovered when trading developed into purchase of rough for subsequent cleaving and polishing before sale.

Alexander the Great was responsible for first revealing the

FIG. 1. *Coat of Arms of the Nuremberg Diamond Polishers Guild (From "History of diamond polishing" by P. Grodzinski).*

wealth of diamonds in India, but only some 1,500 years after his death (in 323 B.C.) did regular trade develop between India and the West.

Early diamond centres were Alexandria, Venice, Bruges, Nuremberg and Paris. Places like Lisbon, Valencia, Barcelona, Madrid, Antwerp, Amsterdam and London became important much later.

The earliest price-list for diamonds is given by the 12th century Arab author Teifashius and in Alexandria, since 31 B.C., there was a very large trade centre which had gradually developed into an important transit place for Indian diamonds.

Quite early, around 900 A.D. Venice became a dominant centre for industry and trade and only lost importance together with other Eastern Mediterranian ports, after Vasco da Gama, in 1498, had explored the sea route around the South African coast to the far East. Venice and Florence produced famous diamond experts, such as Marco Polo, Nicolo Conti, Matteo del Nessaro, Benvenuto Cellini, Hortensio Borgius, Giulio Mazarini, Vincenzio Peruzzi, and many others.

Bruges became another large and very important commercial town and diamond centre during the 12th and 13th centuries, but lost importance to Antwerp at the end of the 15th century from where again after the Spanish Fury in 1585 the diamond cutters moved to Amsterdam.

Nuremberg, an inland town at the cross roads of travel and trade, developed equally early into a diamond centre and between

FIG. 2. *An early method of grinding away the tip of an octahedron (From Ars Memorativa 1480)*

the 14th and the 17th century was one of Europe's most important cities for trade, art and technical inventions (modern horology, famous artists, wealthy merchants, etc.). It may thus very well have contributed to the development of diamond cutting.

Paris. In France the great passion among royalty and nobility for the minor arts dates as far back as to the 7th century, when no less than three jewellers Eloi, Alban de Fleury and Theau were canonized. But then only monasteries had workshops and almost a monopoly of craftsmen. Clotaire II established, on an isle of Paris city, a workshop of goldsmith monks, free from all cares and wars, a life in silence devoted to sacred arts. The reign of Charlemagne (771–814) was one of magnificence, goldsmith's art coming foremost. In the 12th and 13th centuries, the zenith of the curve was reached and France was the cultural centre of the continent. Secular jewellers became strongly established. In 1319 the French Queen Clemence of Hungary (King Louis the Quarreller's

wife) is said to have worn a diamond-studded necklace and Queen Jeanne d'Evreux (wife of Charles IV) possessed rich collections of personal jewellery. This was almost a century and a half before the death of Agnes Sorel in 1450.

Small wonder if royal splendour brought diamond polishing to Paris at a very early period. Although Paris suffered an eclipse in 1415 particularly after Agincourt, this mattered little, since the Dukes of Burgundy, who also reigned over all of Flanders, made Bruges and Ghent, periodically with Paris, their residence and spent lavishly on jewels when the Kings had no means, as it happened when Charles VI became insane in 1392 and his son—with the appearance of Joan of Arc—became crowned only in 1429. There was thus no interruption as far as Paris is concerned. New and detailed information on the early evolution of diamond polishing will soon be available as a result of extensive research by a French diamond expert, M. Sirakian.

In the following analyses the universal principles for measuring diamond proportions are used—essentially the same as have within recent years also been adopted by the American gemmological organizations, but an effort has been made to introduce new signs and abbreviations, such as can be easily understood world-wide, and are easy to type or write. They have been found most practical throughout the research work.

The original brilliant-cut is the natural, perfectly developed octahedron, with a girdle of 1%, a crown height of $70\frac{3}{4}$%, the same pavilion depth, a total height of 142·5% and with both crown- and pavilion-angles, equal to the octahedral angle of 54° 44′ 8·3″, or almost $54\frac{3}{4}$°

Eventually the octahedron was slightly improved through cleaving and primitive polishing. Together with several other regular forms of diamond crystal and cleaved fragments (the early baguettes) this "diamond-point" was used in jewellery for more than 1,500 years.

It is not known when the first attempts were made to repair broken tips of otherwise perfect octahedra.

The early diamond cutter found, probably without fully appreciating the value of his invention, the softest of all planes, the cubic. S. Tolansky believes that early workers often decided to grind away the tip until the width of the table face was 50%, involving a total loss of 1/16th or 6·25%. Other authors have

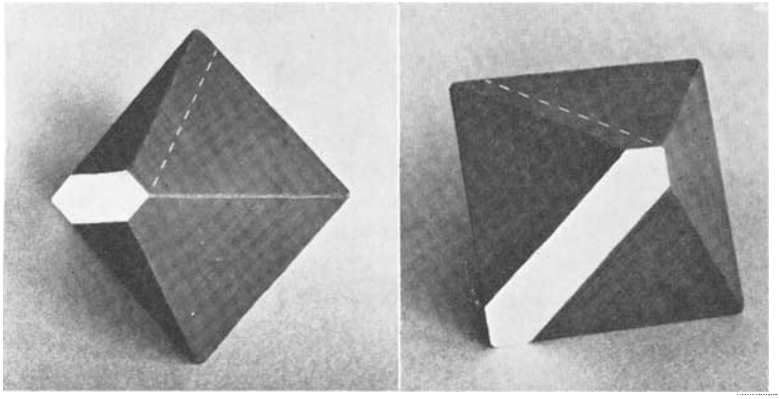

FIG. 3. *How the earliest "Baguettes" were cleaved from a diamond octahedron.*

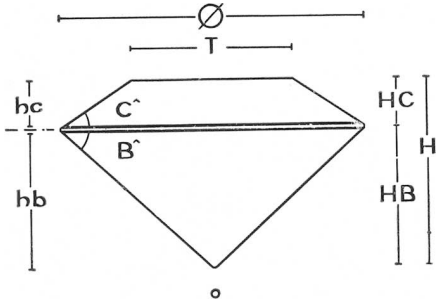

FIG. 4. *Abbreviations and signs used in proportion analyses.*

Ø	*Diameter of stone (usually the shortest)*
T	*Table size (in brilliant-cuts between opposite corners, but in certain other shapes between opposite sides)*
o	*Culet size (measured as the table size)*
hc	*Height of crown* x)
- - -	*Average girdle thickness*
hb	*Height of base (=depth of pavilion)* x)
H	*Total height (from table to culet)*
C^	*Crown angle*
B^	*Base angle (=pavilion angle)*
x)	*without girdle thickness*

quoted figures between 4 and 5 ninths. Experiments with synthetic spinels and comparisons with descriptions of fine table-cuts, old designs and photographs of authentic mediaeval jewellery show clearly that not less than 5/9th of the top pyramid had been ground or sawn off in perfect full-bodied table-cuts.

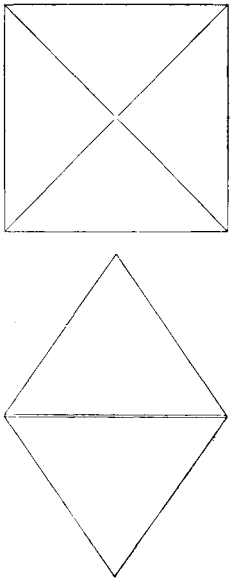

FIG. 5. *The perfect "diamond-point* (4/4)

hc 70,75% C^ 54°44′8,3″
--- 1,00%
hb 70,75% B^ 54°44′8,3″
H 142,50%

(*With a girdle thickness of* 1% *the "diamond-point" has a Ø of* 99,6% *compared with the width of the perfect octahedron. For this reason the depth figures differ from the measures of a crystal without "girdle"*).

The ideal table-cut has therefore been reproduced with 4/9th of the top pyramid as a crown and 8/9th as pavilion leaving a table of 56% and a culet of 11%. The magical total depth figure of 100% is not yet arrived at. These proportions remained ideal figures almost as long as the octahedral angles persisted.

Obviously the table-cut only developed very gradually into this perfect and fully symmetrical shape and few if any cutters adhered strictly to these rules, probably as few as to-day aim to produce ideal brilliant-cut stones.

From the evidence of the numerous reproductions of known jewellery in museums and private collections, no doubt remains about the dominance of the primitive table-cut up to the beginning of the 18th century, when it rapidly declined. The same applies to the "point-cut", in so far that this persisted in sizes, which to-day would be called mêlée, until they were gradually replaced by small table-cuts and then by different types of single-cuts.

Further evolution was slow and haphazard. Inspired by the results achieved in shaping softer gems and possibly also due to various shapes of rough diamond the first table-cuts with polished corners appeared. These may be termed "Octagonal table-cuts".

FIG. 6. *Natural diamond crystals resembling table-cuts.*
(From "Der Diamant" by Fersman u. Goldschmidt)

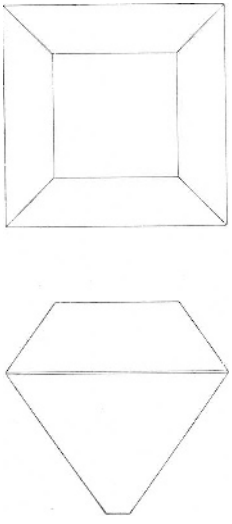

FIG. 7. *The ideal full-bodied square table-cut* (4/4)

T	56,0%	(*measured between opposite sides*)	
o	11,0%	(*square in shape*)	
hc	31,2%	C^	54°44′ 8,3″
- - -	1,0%		
hb	62,8%	B^	54°44′ 8,3″
H	95,0%		

This shape however never became popular or generally accepted, and must be considered merely as a repaired table-cut and a step towards the proper single-cut with 8-fold symmetry in the girdle outline as well as in the shape of the table facet.

The perfect old single-cut with 8 facets in the crown and 8 in the pavilion is thought by Professor W. Eppler, a well-known German mineralogist and gemmologist, to date as far back as to the 14th century, but in case he is right it remained a rarity for well over 200 years.

The next improvement was the rounded single-cut, the first diamond where table size should be measured, as in a modern

brilliant-cut, from corner to corner, instead of between opposite facet edges.

Diamond with richer faceting cannot be dealt with in a strict chronological order. The reasons are that techniques once learnt put no limits with regard to the number of facets that could be applied to a diamond. The rose-cut had been introduced in Europe very early in the 16th century and other richly faceted Indian diamonds, such as the "Sancy" and the "Florentine", without too much geometrical symmetry, became well known in the West.

It remained only to "invent" the final shape of the full-cut brilliant. This was achieved during the 17th century, whereas somewhat less complicated designs were created for the mêlée sizes.

The English star-cut had 16 facets in the crown and 8 in the

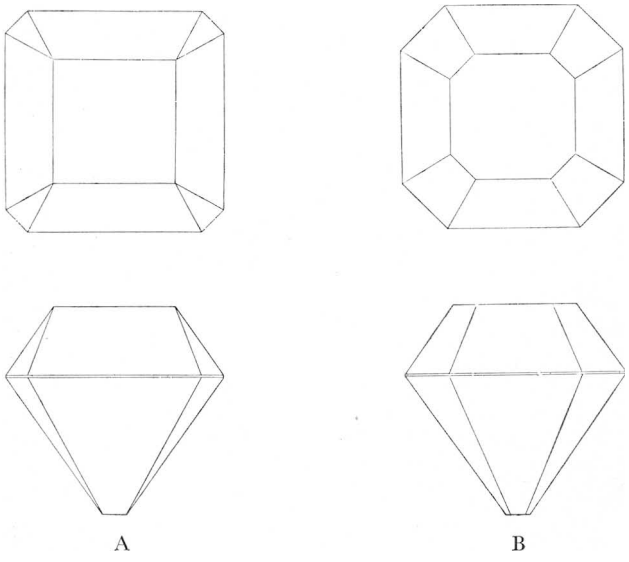

FIG. 8. *Ideal full-bodied octagonal table-cuts* (8/8).

A. *The first step towards the proper single-cut with a square culet and the table size measured between opposite sides. Length of outer edge of main facets is* 80% *of Ø.*

B *A shape, which persisted in mêlée sizes, with an octagonal culet and the table size measured between opposite sides. Length of outer edge of main facets is* 60% *of Ø.*

(*The proportions are equal to those listed under Fig. 7*)

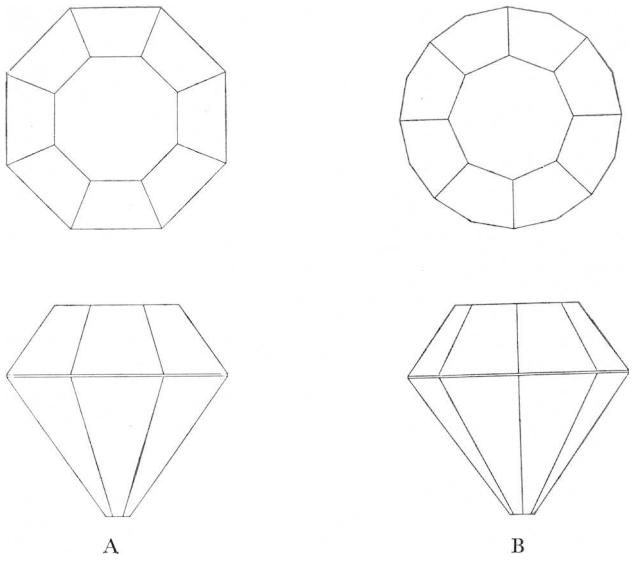

FIG. 9. *Ideal octagonal and rounded full-bodied single-cuts* (8/8)
Both have octagonal culets and proportions equal to those listed under Fig. 7.
A "T" *is measured between opposite sides*
B "T" *is measured between opposite corners*

pavilion. The first stones in this pattern were no doubt cut with octahedron angles and the same ideal proportions as in earlier diamonds.

The English square-cut brilliant had a different girdle outline, the same amount of facets (16) in the crown, but 12 instead of 8 facets in the pavilion. Here, as in the following brilliant-cut, the table size must again be measured between opposite facet edges.

Now comes the Mazarin-cut brilliant. This was used in all sizes, also for large stones. It was in all probability older than the two previous shapes and was perhaps introduced around the year 1620, well before the era of Cardinal Mazarin.

The 17th century contributed to physics by discovering the laws of refraction and by introducing analytical geometry. There was rapid development in all fields of science. Diamonds with deliberately chosen angles and proportions no doubt appeared. Ideal proportions obviously changed. Only the table size remained 56%.

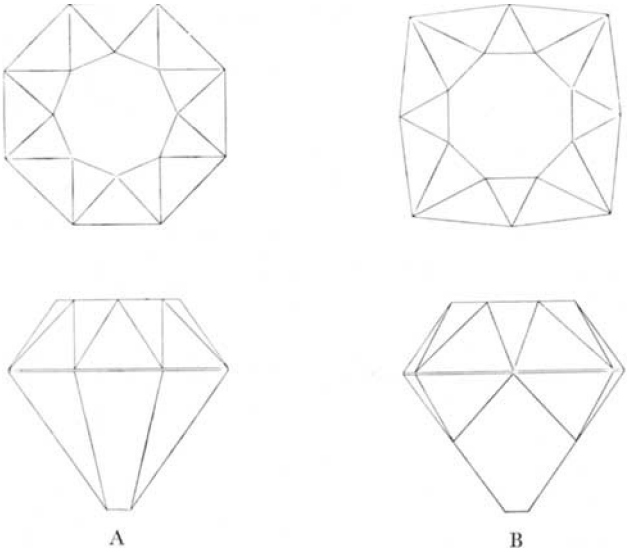

FIG. 10

A. *The ideal full-bodied English star-cut* (16/8)
The culet is square and the proportions equal to those listed under Fig. 7.

B. *The ideal full-bodied English square-cut* (16/12)
The culet is square and the proportions equal to those listed under Fig. 7. The girdle facets in the crown and in the pavilion have the same height, but a different shape. The distance between the "corners" is 90% *of* Ø.

The following quotation in a letter by Marquise de Racan, a member of the French Academy, written in 1644 to Madame de Thermes, may be one reason for the wrong belief that Mazarin invented the 16/16 facet-cut: "The Cardinal has demanded a cut with 16 facets above and 16 below the girdle; he makes a triumph of this double cut".

But this cut existed, as did the rose-cut, well before 1644. 16/16 facet-cuts are mentioned in connexion with Queen Henrietta Maria who gave such diamonds in 1640 to the French Duke of Epernon as security against loans. These must have been acquired much earlier, since her husband, King Charles I, started in 1625 to dispose of his valuables; this was the first year of his reign.

The truth about Mazarin is probably that he just became a fabulous collector of large and exquisite diamonds and thus learnt more about them than others. He purchased diamonds from

Tavernier and other merchants, he acquired the "Sancy" and the "Mirror of Portugal" and many other stones, which had belonged to royalty in distress, such as Charles I, Henrietta Maria, Queen Christina of Sweden, and many others. Almost one half of the large diamonds listed in his bequest to the French Crown were—strange as it may sound—table-cut and only subsequently, after his death, recut into new shapes. Mazarin followed the example of earlier nobles, such as Seigneur de Sancy, Henry IV and his Queen Marie de Medici, Louis XIII and his Queen Anne, Cardinal Richelieu and many others.

A few years after the death of Mazarin large full-cut brilliants appeared on the market, the earliest yet known to the author.

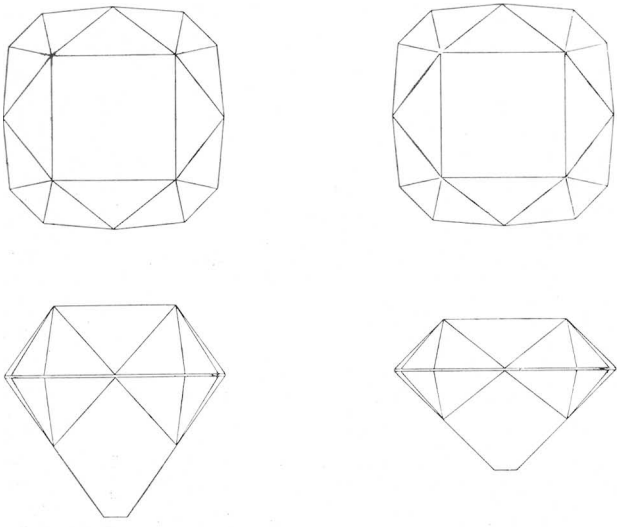

A
Full-bodied

B
With 45° angles

FIG. 11. *The ideal Mazarin-cuts* (16/16)

The distance between the "outer corners" is 94% *and between the "inner corners"* 64% *of Ø. The culet is square and the girdle facets above and below the girdle are identical in size and shape.*

A. *The proportions are equal to those listed under Fig. 7*
B. *The lower Mazarin-cut has the following proportions:*

T	56,0%		
o	10,0%		
hc	22,4%	C^	45°
- - -	1,0%		
hb	44,8%	B^	45°
H	68,2%		

One is a 19 ct brilliant-cut stone from the Green Vaults in Dresden with a full-cut crown but a "single-cut" pavilion. The crown angle is 34°. But much more fascinating is the lately re-discovered great blue diamond of 35½ carats, now also called "The Wittelsbacher". The appearance of this stone is particularly striking because of its unusually fine polish and the absolute flatness of the facet surfaces. It is amazing how this brilliant-cut stone can have such a deep fire and look so attractive with a total depth of only 38·6%. It has recently been studied by the author and his team. The following proportions may be of interest: Table 65·8%, Culet 31·1%, Height of crown 12·4%, Depth of pavilion 25·2%. The crown and pavilion angles are both exactly the same, 36 degrees. The size in millimeters is 24·4 × 21·46 with a depth of 8·29. The number of facets is 40/40.

All that is known of the early history of this stone is that in 1664 it was presented by the Spanish King Philip IV as part of the dowry for his daughter the Infanta Maria Teresa, who married Emperor Leopold in 1667 and that it came from "a new acquisition of precious stones from India and Portugal".

A very similar brilliant-cut stone, only without the extra facets in the crown, is a distinctly yellow diamond of 13·48 carats among the treasures of the Green Vaults. It has a table size of around 50%, a crown angle of 33° and an equally modern pavilion angle

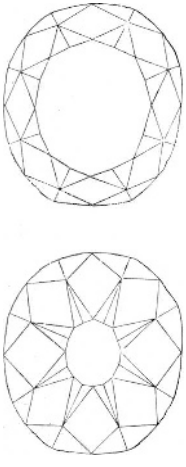

FIG. 12. *The Wittelsbach diamond* (40/40)
(*The pavilion is reproduced as if seen through the crown. The dimensions of the actual stone are* 24,5 × 21,5 *millimeters.*)

T	66,0%		
o	31,0%		
hc	12,5%	B^	36°
---	0,5%		
hb	30,0%	C^	42°
H	43,0%		

of $41\frac{3}{4}°$ with a total depth of some 60%. The additional 8 facets in the pavilion are apparently applied because of the rather large size of this stone. The total amount of facets is thus 32 in the crown and 32 in the pavilion.

The famous "Regent diamond" is a 40/32 faceted brilliant-cut stone of very similar type. It was shaped between 1707-1717 with a distinctly rounded outline. The rough crystal was sawn in two, an operation which lasted almost a year. The instrument used was apparently a hand-operated saw, similar to the one described by De Boot in 1604 and to those used earlier for table-cut diamonds. There is an exceptionally even distribution of fire all over the surface of the crown. Not one of the main facets in the pavilion can be seen through the stone. This is due to an ideal pavilion angle of some $41\frac{3}{4}°$ discovered 200 years before Marcel Tolkowsky published his book on diamond design. The cutter, Harris by name, also found an ideal crown angle, near 45° which in the flickering candlelight of those days shows off the diamond's fire to perfection. In the Regent the culet is reflected in the centre of the main facets, which Mawe in 1823 described as a criterion of ideal proportions. In practically every old-miner the culet reflects either higher or lower.

The size of the culet is 10·35%, the height of the crown 25·9% and the pavilion depth 39·6% with the knife-sharp girdle giving a total depth of $65\frac{1}{2}$%. It was, may be, only a happy chance that the Regent received these beautiful proportions, since David Jeffries, although he was full of admiration for this stone in his publication of 1750 quotes 45° as ideal both for crown and pavilion. The same statements are repeated by practically every author until the introduction of the circular diamond-saw.

The three diamonds described are stones of considerable size and received for that sake alone additional facets. Smaller diamonds were certainly simultaneously polished with the classical amount of facets 32 in the crown and 24 in the pavilion as we are used to see them this very day. It has therefore been impossible to resist the temptation to reproduce a normal brilliant-cut stone with the same proportions as in the "Regent".

Contrary to the present-day taste the culet was apparently much admired. In stones which were cut in brilliant style with the octahedron angles of $54\frac{3}{4}°$ the culet acted as a mirror for a considerable amount of light entering through the crown facets.

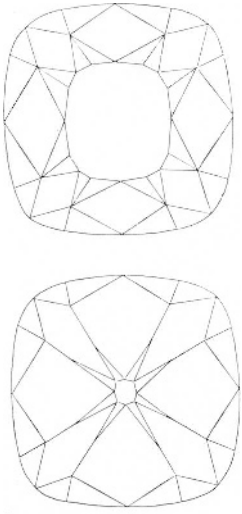

FIG. 13

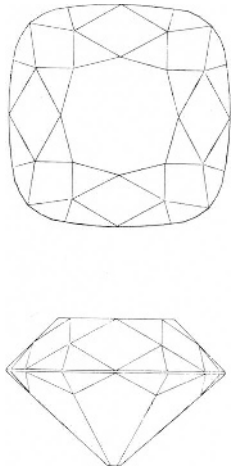

FIG. 14

FIG. 13. *The Regent diamond* (40/32)
(*The pavilion is reproduced as if seen through the crown. The dimensions of the actual stone are* 30 × 29 *mm*)

T	46,55%	(16-*sided*)	
o	10,35%	(8-*sided*)	
hc	25,90%	C^	45°
- - -	0,00%		
hb	39,60%	B^	41¾°
H	65,50%		

FIG. 14. *The corrected "Regent-cut" with* 32/24 *faceting.*
This may have been the ideal shape of the earliest brilliant-cut diamonds with four-fold symmetry in the table and 150° *and* 120° *angles. The four larger main facets are symmetrical lozenges, but the girdle facets are of a different size and shape in the crown and the pavilion; the proportion in height is around* 12:10.

T	53,0%		
o	6,0%		
hc	23,5%	C^	45°
- - -	1,0%		
hb	42,0%	B^	41¾°
H	66,5%		

The distance between the "corners" is 82% *of* Ø.

Other early brilliant-cut stones are worth mentioning, such as "Tavernier A" and "Tavernier C", 51 and 31 carats in size, and the little "Sancy Diamond", a stone of 34 carats. Their whereabouts are not known and unfortunately they can therefore not be analysed for design and proportions.

"Le Grand Condé" a pink, pear-shaped, brilliant-cut diamond weighing 50 carats, said to have been bought in India in

1643 is, however, still on display in the Chateau de Chantilly, near Paris. It is probably even older than the Wittelsbacher and would therefore testify that full-cut brilliants existed when Mazarin still collected table-cuts and admired rose and sixteen-cuts. But definite conclusions cannot be made without further research.

Finally comes the story of Vincenzio Peruzzi, the 17th century Venetian lapidary who is credited with first employing the brilliant

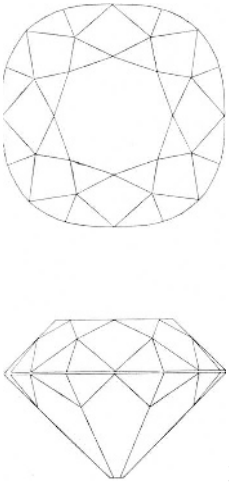

FIG. 15

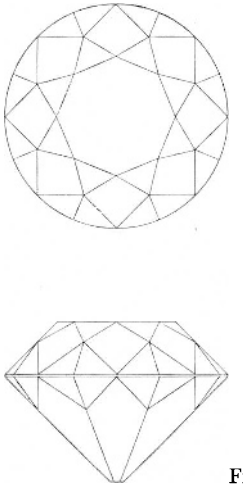

FIG. 16A

FIG. 15. *The almost round early brilliant-cut* (32/24).

This shape is mid-way between Fig. 15 and the completely round brilliant-cut, with a distance between the "corners" of 76% *of* Ø. *The symmetry of the table is still four-fold with angles of* 127,5° *and* 142,5°. *The main facets in the crown are all kite shaped and proportioned to please the eye only. The girdle facets in crown and pavilion have all a height of* 15% *but a slightly different shape.*
The proportion figures are different from the "Regnnt-cut" since the lower pavilion angle of around 41¾° *was apparently never generally accepted.*

T	53,0%		
o	6,0%		
hc	23,5%	C^	45°
- - -	1,0%		
hb	47,0%	B^	45°
H	71,5%		

FIG. 16. *The ideal perfectly round early brilliant-cut* (32/24)

A. *The table has eight-fold symmetry with* 135° *angles. The meeting points of the main facets in the crown are found by drawing a circle mid-way between the corners of the table and the girdle. The girdle facets in crown and pavilion have all a height of* 14½% *and are identical also in their shape.*
The proportion figures are the same as listed under Fig. 15.

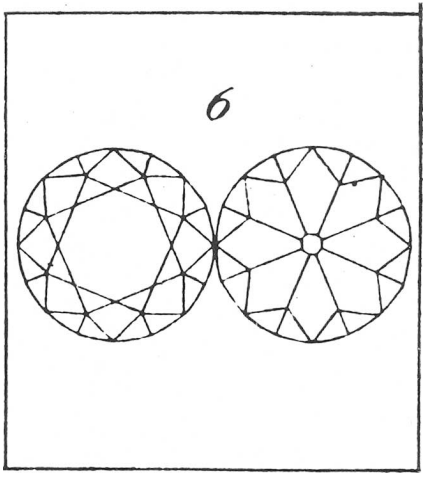

FIG. 16B

B. *The same early brilliant-cut, as illustrated by David Jeffries in 1750, but with larger table* (58%) *and culet* (11). *Judging from this diagram the proportion figures may have been* $41\frac{3}{4}°$.

form of cutting. This credit, which appears in prcatically every gemmological publication, cannot possibly be correct.

Investigations and research covering a period of several months have not disclosed the secrets about this legendary person. If he ever existed is an open question. David Jeffries did not mention Peruzzi's name in his publication of 1750. So far his name seems to have been unknown or forgotten until 1833, when a French gemmologist A. Caire, in his book "La science des Pierres Précieuses", mentions Peruzzi as the inventor of the brilliant-design. The Spanish author Miró repeats the statement in 1870, but such a famous author as Professor Max Bauer was not aware of his existence when, in 1896, he published the first edition of his "Edelsteinkunde". In the second edition of 1909, however, he repeats Caire's and Miró's remarks, probably due to information given by Henri Polak, chairman of the Amsterdam Diamond Workers Union, who in several pamphlets published between 1890-1900 mentions Peruzzi, but again without giving any sources for his statements. Genealogical researches in several European libraries gave no positive answers, except that the family Peruzzi was not of Venetian, but of Florentine origin. This is why inquiries in Venice

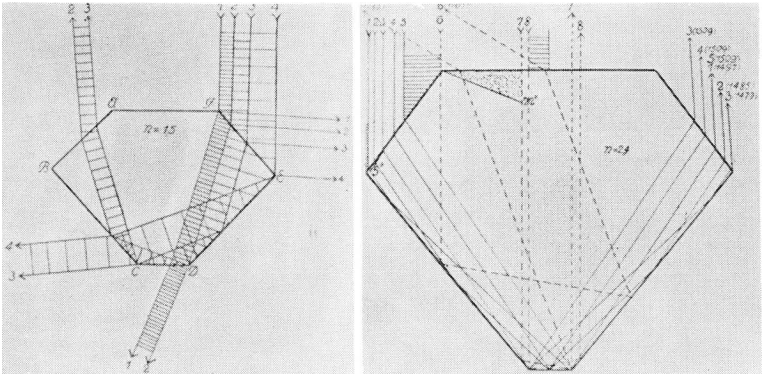

A B

FIG. 17. *Leakage of light in brilliant-cut diamonds with a culet.*
A. *With* $54\frac{3}{4}°$ *angles* B. *With* 45° *angles*
(*From "Brillanten und Perlen" by W. Maier*)

have not led to any results. Further investigations may possibly reveal Vincenzio Peruzzi, if not in Florence, perhaps in quite another place. Perhaps he was one of the 75 diamond cutters then active in Paris, perhaps one of Amsterdam's 600 diamond workers. It is, however, quite possible that he lived in India, where so many Italian diamond cutters worked at different periods, and from where during the second half of the 17th century brilliant-cut, beautifully shaped, and therefore not native-cut diamonds were thought to have been imported into Europe.

Commenting upon the achievement attributed to Peruzzi, Dr. Wilhelm Maier is full of admiration for the perfect geometrical symmetry in his design. ("Brillianten und Perlen, Stuttgart, 1949"). He describes the overall-size star-design, the parallel facet edges throughout the stone and the symmetrical facets. He believes Peruzzi to have known earlier brilliant-cut designs, such as previously described in this paper, since his creation is actually nothing but a definite improvement in the way of beautiful symmetry, in fact so perfect, that nothing near to it has been achieved, earlier nor later. It therefore remained to find out if this statement was correct and if a shape with complete symmetry could be reconstructed.

Series of experiments with paper and pencil were carried out.

Then several pounds of transparent, pure rock crystal were consumed before it was possible to produce perfect symmetry paired with acceptable proportions.

It is not known if the Peruzzi design was executed for octahedral angles, which were at that period already practically abandoned for the then "modern" and generally accepted angles of 45°. The proportion figures with $54\frac{3}{4}°$ were: T = 53%, o = 7%, hc = 33%, —— = 1%, hb = 66% and H = 100%. The figures with the 45° angles were: T = 53%, o = 6%, hc = 23·5%, —— = 1%, hb = 47% and H = 71·5%. Even these figures show a surprising exactness of symmetry. No deviations from these proportions are permissible. With 8-fold symmetry in the table, its size must have been 53%—again Tolkowsky's figure. The girdle outline is equally fixed, with a distance between the corners of 94% and between the dividing edges of the girdle facets of 97%.

Now if this theory can be generally accepted as correct and the Peruzzi design thus established it remains to find actual diamonds corresponding to these rules, examine them for fire and brilliancy and make comparisons with other shapes and types. They should

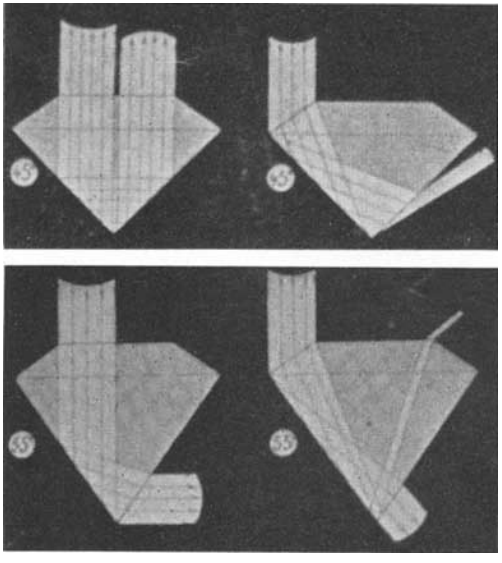

FIG. 18. *Leakage of light in brilliant-cut diamonds without a culet.* (*From Deutsche Goldschmiede-Zeitung Nr.* 5-1926, *pg.* 48.—*Mitteilungen aus dem Laboratorium fur Diamantforschung, Düsseldorf-Oberkassel, Krumbhaar & Rösch.*)

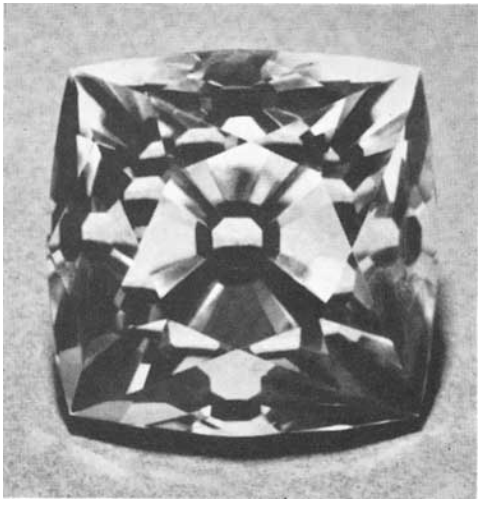

FIG. 19. *The Peruzzi design reproduced in rock crystal. The culet can be seen reflected in the centre of the four main facets, according to Mawe a criterion of ideal proportions.*

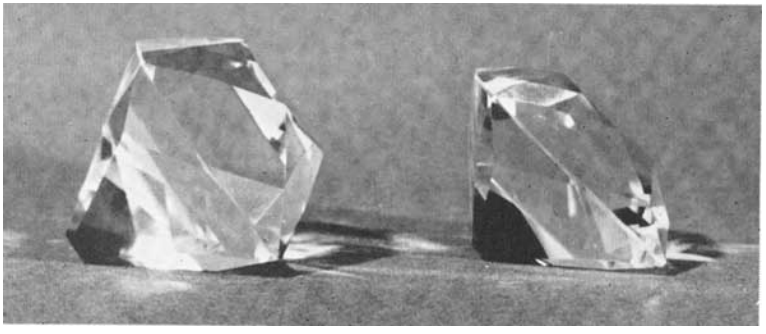

FIG. 20. *Side views of the Peruzzi design reproduced in rock crystal with* $54\frac{3}{4}°$ *and* $45°$ *angles.*

be preserved from recutting and treasured as precious examples of a truly artistic and unique creation from the end of the 17th century.

The Peruzzi-cut must be extremely rare, since, for instance, in the Dresden Green Vault not one such diamond has been found. Although it is a very precise design and utmost accuracy is necessary to reproduce it; with the aid of a simple metal gauge, the sides of which had only to be divided into four equal parts with a pair of ordinary compasses, any patient diamond cutter should have been able to produce the perfect Peruzzi-cut.

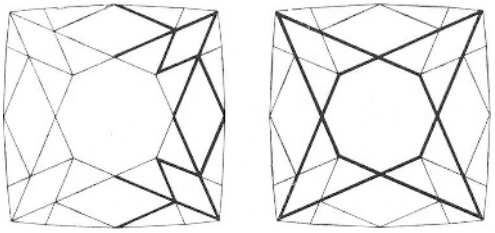

FIG. 21. *Diagrams of the Peruzzi design with the heavier lines drawn to accentuate the elements of symmetry in the crown.*

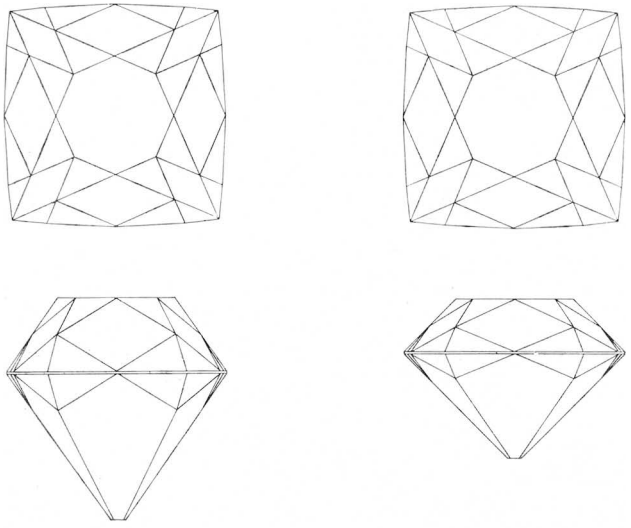

A B

FIG. 22. *The Peruzzi designs* (24/32)

A.	T	53,0%			B.	T	53,0%	
	o	7,0%				o	6,0%	
	hc	33,0%	C^	54°44′ 8,3″		hc	23,5%	C^ 45°
	- - -	1,0%				- - -	1,0%	
	hb	66,0%	B^	54°44′ 8,3″		hb	47,0%	B^ 45°
	H	100,0%				H	71,5%	

But in reality few cutters ever aimed to achieve perfect proportions—we recognize the situation to-day—and very inferior old-mine cuts, many of which did not even have a symmetrical girdle outline dominated the market.

This is probably one of the reasons why the older type, the nearly circular-girdle brilliant-cut remained in demand and finally outmoded the square-girdled stone. The further development of

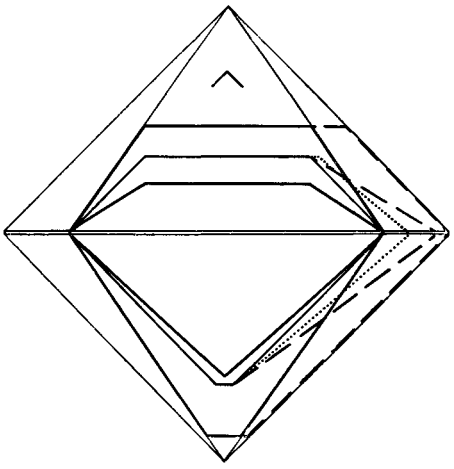

FIG. 23. *Diagram showing the evolution from "point-cut" to modern brilliant-cut. (The octahedron, the table-cut, the early brilliant-cut, the Peruzzi cut and the modern ideal brilliant-cut.) As a simplification one table size only,* 53% *has been used.*

the "rounded shape" is outside the scope of this paper and therefore only suggested in a couple of diagrams.

With the invention and introduction of the bruting machine and rotary diamond saw about the end of last century the brilliant-cut became perfectly round and quickly developed into the now accepted depth proportions.

ACKNOWLEDGEMENTS

I am indebted to my two collaborators. Ulf Pettersson, F.G.A., designer, photographer, gemsetter and workmaster has not only produced all the final illustrations, but also sketched the innumerable suggestions necessary for the search for correct solutions. Tauno Paronen, F.G.A., able lapidary, but without experience in diamond cutting found great pleasure in experimenting first with synthetic spinel and then with rock crystal in order to find out if the proposed shapes could actually be executed in three dimensions. In several cases his skill and imagination helped to solve problems. The reconstruction of the Peruzzi design could never have been done without the assistance of these able members of my research team. I am also greatly indebted to several scientists and friends: Professor W. F. Eppler, Dr. Walter Fischer, Mr. Manuel Massó, Professor R. Rösch, M. Pierre Verlet, Mr. Renatus Wilm and others for assistance freely given. My daughter Ulla Tillander has done valuable research work in museums and libraries in Amsterdam, Antwerp, Paris and London. A special vote of thanks goes to

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Weinstein, Michael. *The World of Jewel Stones,* 1959.
Wilm, H. J. *Gold Treasures Untold,* 1954.

Gemmological Abstracts

FLANIGEN (E. M.), BRECK (D. W.), MUMBACH (N. R.) and TAYLOR (A. M.). *New hydrothermal emerald.* Gems and Gemology, 1965, XI, 9, p. 259.

The new synthetic emeralds made by hydrothermal process by the Linde Division of the Union Carbide Corporation, U.S.A., are reported to be comparable in quality to the finest natural emeralds from Chivor, Muzo and the Urals. Crystals as large as seventeen carats and faceted stones of three and four-carat sizes have been produced. The refractive index range of the new synthetics is $\varepsilon = 1\ 566 - 1\ 572$, $\omega = 1\ 571 - 1\ 578$, with birefringence 005 – 006. Specific gravity is given as 2 67 – 2 69. The new synthetic has higher refractive indices and specific gravity than those of previous synthetics. The Linde product shows a bright red fluorescence under short and long-wave ultra-violet light and a very bright red residual colour under the Chelsea colour-filter. The Linde stones are stated to be flawless macroscopically, or under 10x magnification. Because of the optical clarity the stones are quite brilliant. Under a magnification of 400x, two-phase inclusions and phenacite have been observed. The authors of the paper suggest that, although the physical properties of the synthetic resemble those of natural emerald, the bright fluorescence and residual colour under the Chelsea filter should differentiate it from most natural stones. Differences in crystal inclusions and optical clarity should provide additional means of distinction.

S.P.

DARRAGH (P. J.) and SANDERS (J. V.). *The origin of colour in opal.* Australian Gemmologist, 1965, 46, pp. 9-12.

An important article submitting reasons for the play of colour in opal. The workers used an electron microscope for this investigation. From the results it is postulated that precious opal is formed from spherical particles of amorphous opal. These are uniform in size and are packed together in a very regular manner, the basic feature of precious opal being the regularly arranged spheres and the "holes" between them. The silica spheres are themselves optically transparent but some light is scattered at the

surface of the voids because there is a change of refractive index at the interface. As these are arranged regularly in three dimensions they form a three-dimensional grating, and when the spacing is about the wavelength of visible light, Bragg diffraction of light occurs. Some explanation of the effectiveness of black backgrounds is given, and this is said to be why dyed opal and doublets are so effective. The cabochon cut provides the best form in which to cut opal in order to obtain the best play-of-colour. Potch does not show a play-of-colour owing to the irregularity of the arrangement of the spheres. The authors state that it is still not known how the regular structure occurs.
10 illus. R.W.

BURLS (J.). *Diamonds.* Geographical Magazine, 1965, XXXVIII, 2, pp. 141-154.

A popular article on the diamond mining in Africa and elsewhere. It is an informative article and is profusely illustrated. It comprises a general discussion of the mining, recovery, sorting and marketing of diamonds. Something is told of the fashioning of diamonds and of the making of diamond jewellery. The use of diamond in industry forms the concluding part.
28 illus. (3 in colour). R.W.

BANK (H.). *Lichtbrechung, Doppelbrechung, Dispersion, Dichte und Gitterkonstanten bei Turmalinen.* Refraction, double refraction, dispersion, density and lattice constants of tourmalines. Special number, Spring 1965, of the Zeitschrift d. deutsch. Gesell. f. Edelsteinkunde, 32 pp., 16 illustrations and bibliography.

The methods used for measuring refraction, double refraction, dispersion and density are described and their accuracy discussed. The results are published in detail and the various combinations scrutinized. The lattice constants are determined by X-rays and compared with the other results. It was shown that (*a*) there is a linear relationship between the refraction and double refraction, (*b*) between refraction, double refraction and density, (*c*) this linear relationship can also be observed between lattice constants refraction and density and (*d*) the dependance of all these phenomena on the chemical composition is obvious. For the time being the

classification of tourmalines into mixed crystal series is only possible either by chemical analysis or X-rays. For diagnostic purposes the determination of refraction, double refraction and density is suitable also in the case of cut specimens, especially using the ND-Diagram (refraction-density comparison).

E.S.

BANK (H.). *Pegmatite Suedrhodesiens und ihre Edelsteinminerale.* The pegmatites of Southern Rhodesia and their gem materials. Zeitschr. d. deutsch. Gesell. f. Edelsteinkunde, 1964/65, 50, pp. 13-25.

The occurrence of mica pegmatites in Southern Rhodesia was known at the beginning of this century and the presence of beryl pegmatites was known in the 1920s, but only after the last war were the claims worked to any extent. In 1960 Southern Rhodesia was the second largest beryl producer in the world. The geology of the district is described and there are two maps showing the gem occurrences. Apart from chrysoberyl (with alexandrite) and emerald, there are many gem minerals found in pegmatites, the following of which, together with some of their physical and optical characteristics, are described: oxides: quartz mainly amethyst, but also some smoky quartz, citrine and rose-quartz, and spinel; silicates: beryls, including aquamarine, golden beryl, morganite and goshenite. Other minerals found include euclase, amazonite, phenakite, topaz and tourmaline.

E.S.

SCHMIDT (P.). *Namen von Edelsteinen nach historichen Personlichkeiten.* Gems named after historical personalities. Zeitschr. d. deutsch. Gesell. f. Edelsteinkunde, 1964, 50, 9-10.

A number of rarer stones are called after the person who discovered them. These include kunzite, named after the American mineralogist, G. F. Kunz, and hiddenite, after W. Hidden. Other examples are chudobaite, after Professor K. Chudoba, garnierite after the Frenchman Garnier and various others. Taaffeite, named after the Irish Count Taaffe, is not mentioned.

E.S.

THEISEN (V.). *Zur Farbbestimmung von Diamanten.* Determining the colour of diamonds. Deutsche Goldschmiedezeitung, 1965, 63, 2, pp. 142-143.

The difficulty of exact determination of the colour of a diamond is discussed and the international colour scale given. This has twelve stages from finest white to yellow. Apart from these colours there are the fancies, such as pink, blue, brown, etc. Stones should be examined in north light, from above, below and at the side. The article describes two instruments which have been developed to help to differentiate between the various colour types, the Coloriscope by Dr. E. Gübelin and the Electronic Colorimeter, developed by the American Gem Society. Both instruments are described in detail. It seems that it is difficult in Europe to obtain the American product.

E.S.

NEUE SYNTHETSEN UND IMITATIONEN. *New synthetics and imitations.* Zeitschr. d. deutsch. Gesell. f. Edelsteinkunde, 1964/65, 50, pp. 30-34.

A new synthesis of sapphire has been perfected by Czochralski. The crystals grow to a height of about 2·54 cm and are up to 2·54 cm wide, and have little internal stress. The alumina is put under pressure of 10,000 lb. per sq. inch and afterwards heated for two hours at 1800°C. Australian opals, which have been dyed with carbon at a temperature of 400-450°C in oxygen, have shown to be as colour constant as natural black opals. Chrysoprase, produced in Australia, consists of chromium-coloured chalcedony. Synthetic garnets were first produced for scientific purposes, but now can be used for technical and gem purposes. There are diamonds on the market, especially in U.S.A., which are covered with an unknown material in order to improve their colour. The covering material might be fluoride. The colour is greatly improved, but the stone loses some of its brilliance and the cover itself is fairly soft and therefore has scratchmarks, which under a 10x lens can be recognized as threadlike black flaws. The cover is dissolved when the stone is boiled in concentrated sulphuric acid.

E.S.

PENSE (J.). *Elektronenmikroskopische Untersuchungen an Calcedon und Edelopal.* Examinations under the electron microscope of chalcedony and precious opal. Zeitschr. d. deutsch. Gesell. f. Edelsteinkunde, 1964/65, 50, pp. 25-27.

Extract from an article in the Fortschritte der Mineralogie published by the German Mineralogical Assoc., 1963, 41, 2. Photomicrograph of precious opal enlarged 33,000x. The opal shows a crystal lattice with an elementary distance of 2000 AE. The play of colour is explained by the refraction of the visible light by the lattice.

E.S.

CANNAWURF (C.). *Neues vom Biwako See.* News of the Biwako lake. Zeitschr. d. deutsch. Gesell. f. Edelsteinkunde, 1964/65, 50, pp. 27-30.

In 1962 X. Saller first published details of the fresh-water cultured pearl production from the Biwako lake in Japan. This article is based on the observations of H. Hahn, from Idar-Oberstein, who saw the cultured pearl farms at the end of 1964. The lake is near the old town of Kyoto and easily reached. There are 15-20 farms many of them still being built up. The larger farms keep up to about 300,000 oysters. As the lake is sheltered the harvest is independent of any seasonal changes. The original lots are bought at an auction by "makers", who have to be admitted by the Japanese pearl association and who then "improve" the pearls. Exporters try to buy directly at the farms, but this is very difficult. All pearls, i.e. those with and those without nucleus, are creamy, grey or yellow-pink and are generally bleached by the "makers". The oysters are surprisingly large, about 15 cm long and 8 cm wide and are kept in the usual wire baskets hung on bamboo sticks in the water. The fresh-water pearl can accommodate nucleii of up to 9 mm and nearly 10% produce well formed and well coloured pearls. The oysters are fed additionally with plancton, which increases the growth of the oyster and of the pearl substance. Cultured pearls without a nucleus often reach 6-8mm after a year and a half or two years. If the oyster lives after the first harvest it is used again and sometimes even a third time.

E.S.

ASSOCIATION NOTICES

ANNUAL GENERAL MEETING

Mr. Norman Harper, Vice-Chairman, presided at the 35th annual general meeting of the Association, which was held at the registered offices on Wednesday, 5th May. In commenting upon the work of the year the Vice-Chairman referred to the great increase in the study of gemmology since the end of the war. In 1964 there were 412 candidates for the examinations and for 1965 there was likely to be more than 450. He hoped that it would be found possible to commence gem diamond classes in London, similar to those that had been held successfully in Birmingham for the past three years. The annual report and audited accounts for the year ended 31st December, 1964, were adopted.

Sir Lawrence Bragg, F.R.S. was re-elected as President. Mr. Harper was elected as Chairman, in place of Mr. F. H. Knowles-Brown who had resigned because of ill-health. Mr. Harper paid tribute to the work of Mr. Knowles-Brown and hoped that they they would see him at a future meeting, when they could thank him personally and make a presentation. Mr. Knowles-Brown was elected as a Vice-President of the Association. Mr. Philip Riley, a Rayner prizeman, who had also gained the highest award in the retail jewellers' examinations of the National Association of Goldsmiths, was elected Vice-Chairman and Mr. F. E. Lawson Clarke was re-elected as Treasurer.

Messrs. D. J. Ewing, W. Stern and R. Webster were re-elected to serve on the Council.

Messrs. Watson Collin & Co., chartered accountants, signified their willingness to continue as auditors to the Association.

MEMBERS' MEETINGS

A meeting of members was held at Goldsmiths' Hall, London, E.C.2. on Thursday, 11th March, 1965. It was an informal occasion at which members and others were invited to display various items of gemmological interest. One stand had a display of some of the books written by members of the Association. The range was considerable. There were books by three former Presidents, *Mineralogy* by the first President, Sir Henry Miers, F.R.S., *Concerning the Nature of Things*, by Sir William Bragg, O.M., F.R.S. and *Gemstones* by Dr. G. F. Herbert Smith. The well known books on gemmology were represented, including the second edition of *Gemmologia*, by Professor Cavenago-Bignami. Somewhat away from gemmology were *Geology for the young naturalist* by Allen White, *An Introduction to Old English*

Silver by Judith Banister, B.A., F.G.A., and a thriller by Eric Bruton, F.G.A., called *The Smithfield Slayer*. Dr. E. Gübelin's book on *Precious stones*, which is the only modern book on the subject to be published in English, French and German, was there together with J. Hammes' *Goud, Zilver, Edelstenen*, Elsie Ruff's *Jade of the Maori*, Sir James Walton's *Physical Gemmology, An Introduction to crystallography* by Professor Coles Phillips and a Finnish book on gems, *Jalokiviopin Perusteet*, by H. Tillander.

There were some outstanding gemstone exhibits including a 10·15 ct. andalusite, a danburite of 18·65 cts. a 15·50 ct. phenakite, and a magnificent star-ruby of 32 cts. Fine quality aquamarines, tourmalines and peridots were also shown. There were rare crystals of rhodonite and a collection of coloured diamond crystals. A beautiful collection of water opals was also on display, together with other items to interest gemmologists.

Some pocket refractometers, as developed by Dr. G. F. Herbert Smith, were shown, including a Bertrand type by S. Henson (1893) and Smith's experimental model made by J. H. Steward. A spectroscope by Adam Hilger (1894) and an early dichroscope by Feuss (1881) were also exhibited.

Members enjoyed themselves, meeting old friends and exchanging reminiscences. The Executive Committee of the National Association of Goldsmiths were present as guests and on display was the Arms of the National Association who, in the words of the card describing the Arms, "started it all in 1908 by proposing that courses and examinations in gemmology should be arranged".

* * * *

A meeting of members was held at Goldsmiths' Hall on Monday, 12th April 1965, when Mr. Herbert Tillander, F.G.A., Helsinki, was the guest speaker.

In welcoming Fellows and members Mr. Norman Harper, Vice-Chairman, presided and gave special mention of Mr. O. Dragsted of Copenhagen and Mr. A. Bonnebakker of Amsterdam. Other jewellers of international repute who were present were Mr. W. Meister of Zurich and Mr. Y. Chaumet of Paris.

The Vice-Chairman recalled that Mr. Tillander was a Tully Medallist in 1935 and that many would remember the charming talk he gave when he presented the awards at Goldsmiths' Hall in 1961.

Mr. Harper said "Mr. Tillander has very kindly offered to talk to us tonight on his way back from a meeting of the American Gem Society in Chicago and the title he has chosen is "Six Centuries of Diamond Design". (The lecture is reproduced as a main article on p. 380.) Mr. B. W. Anderson proposed a vote of thanks to Mr. Tillander.

OBITUARY

Ansel, William H., of Polegate, Sussex, 24th April, 1965. (Diploma 1938.)

Ramsay, Alexander M., Glasgow, March, 1965.

GIFTS TO THE ASSOCIATION

From Mrs. C. Watson, Rhodesia, a selection of Rhodesian gem minerals.

From D. Bradshaw, Esq., a sample of the jade-albite known as Maw-sit-sit.

COUNCIL MEETING

A meeting of the Council of the Association was held at Saint Dunstan's House, Carey Lane, London, E.C.2. on Wednesday, 5th May, 1965. The Vice-Chairman, Mr. Norman Harper, presided.

The following were elected to membership:—

FELLOWSHIP

Cooper, Alfred, Swinton, Lancs. D.1963

Thorne, A. R., Halesowen, Warwicks. D.1963

ORDINARY MEMBERSHIP

Armstrong, John H., Honolulu, Hawaii

Badenoch-Jones, Harwood G., St. Annes-on-Sea, Lancs.

Badshah, Mohamed Yusuf, Birmingham, Warwicks.

Callea, Carmen J., New York, U.S.A.

Cross, Samuel S., Beckenham, Kent.

Dwumfuo, Peter K., Hanau, W. Germany

Gaganakis, George J., Nairobi, Kenya

Hann, Alan H., Kuala Lumpur, Malaya

Hanna, Major Joe D., Jr., St. Louis, U.S.A.

Hardy, Alan, Hyde, Cheshire

Heys, Leonard, Poulton-Le-Fylde, Lancs.

Igarashi, Kyoko (Miss), Tokyo, Japan

Jamieson, Sara B. (Miss), Coleraine, N. Ireland

Kotedia, Rameshchandra, S., London, W.11.

Lee, Joseph I., Jr., Raleigh, U.S.A.

Lodhia, Jamnadas R., Crater, Aden

Murray, William R., York

Spink, Brian S. F., Birmingham, Warwicks.

Tester, Robert E., Gibraltar

Vleck, Jan G., S. Pedro do Estoril, Portugal

Yau, Mo Yin, Kobe, Japan

PROBATIONARY MEMBERSHIP

Brooks, Pauline M. (Miss), London, N.W.7.

Clarke, John E., London, W.8.

Husselman, Lucas J., Haarlem, Holland

Munt, Bisley J., Haverfordwest, Wales

Reece, Gail U. (Miss), Causeway, Rhodesia

Staub, Hugh, Salisbury, Rhodesia

Weerakoon, Ranjith L., Poruwedanda, Ceylon

McDowell, Peter W., Malahide, Ireland

The Council agreed to submit the name of the retiring chairman, Mr. F. H. Knowles-Brown, for election as a Vice-President at the 35th annual general meeting. It was also decided to invite Mr. Maurice Asprey to serve as a co-opted member of the Council.

Arrangements were made for the 1965 Herbert Smith Memorial Lecture to be given at Goldsmiths' Hall (by kind permission of the Wardens) on 9th November at 7 p.m. The lecture would be given by Mr. Robert Webster.

DANISH GEMMOLOGICAL ASSOCIATION

In May, the Danish Gemmological Association invited Mr. Robert Webster, F.G.A. to Copenhagen to talk on the subject of opaque and semi-opaque stones and their identification. Black, blue and green stones were mainly considered and this brought in the difficult questions of jades and the jade-like materials, and of turquoise. Mr. Webster spoke of the difficulty of identifying those ornamental materials which consist of a mixture of minerals and are really decorative rocks. The talk was illustrated by demonstrations of chemical reactions, flame and streak tests, and by the electro-conductivity shown by some materials. Over one hundred ornamental stones were displayed to the audience. During the dinner which preceeded the talk, Mr. Webster was presented with a silver paper knife set with a piece of Danish amber containing two flies.

In May also Mr. Webster was elected a member of the British Academy of Forensic Sciences.

MIDLANDS BRANCH

By courtesy of Messrs. Steele and Dolphin, Ltd., members of the Midlands Branch of the Association were able to visit the new factory of Steele and Dolphin on 4th March 1965. Members were able to meet designers and craftsmen at work during the stages of ring manufacture, and to see the modern tools and machinery used. At the conclusion of the visit the firm kindly provided refreshments.

The annual meeting of the Branch was held on 9th April, 1965, at the Imperial Hotel, Birmingham. The following officers were elected: Chairman, Mr. Norman Harper; Deputy Chairman, Mr. J. R. Shaw; Vice-Chairman, Mr. D. N. King; Secretary, Mrs. S. E. Hiscox. Mr. Harper was elected Chairman of the Branch at the annual meeting held on 5th May, 1965.

TALKS BY MEMBERS

CAIRNCROSS, A. D., "Gemstones"; Dundee and Angus Watchmaker's and Jeweller's Association, 20th February, 1965; Forgandenny W.R.I., 17th February, 1965; Kirkfother Feus W.R.I., 18th March, 1965; Glenshee and Glenericht W.G., 19th March, 1965; Almondbank R.S.N.D. Wives' Club, 7th April, 1965; Letham Youth Fellowship, 4th April, 1965; Leven Business and Professional Women, 24th April, 1965; Scottish Milk Marketing Board Conference, 5th May, 1965.

BLYTHE, G. A., "Gemstones"; Leigh Round Table, 13th May, 1965.

COOP, NORAH (Miss). "Gemstones", Society of Walton Women, 10th December, 1964, Kew Bond (Methodist) Wives' Fellowship, Richmond, 9th March, 1965.

PARRY, GWEN (Mrs.). "Precious stones", Heath Branch of Red Cross, 8th March; Royal College of Nursing (Cardiff Branch), 10th March, 1965.

SAMPSON, E. (Mrs.). "Gemstones and jewellery", Chalfont St. Peter Women's Institute, 20th January; South Bucks. Young Conservatives, 25th January; Hornchurch Women's Institute; 6th April; American Women's Club, London, S.W.3, 21st April, 1965.

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THE JOURNAL OF GEMMOLOGY

and

PROCEEDINGS OF THE
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ASSOCIATION
OF GREAT BRITAIN

GEMMOLOGICAL ASSOCIATION
OF GREAT BRITAIN
SAINT DUNSTAN'S HOUSE, CAREY LANE
LONDON, E.C. 2

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Washing and separating rubies at a ruby mine in Mogok, Burma

Photo: E. Gübelin

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Vol. IX No. 12 OCTOBER 1965

THE RUBY MINES IN MOGOK IN BURMA

By E. GÜBELIN, Ph.D., F.G.A., C.G.

THE ruby mines in Burma have been known for centuries and the large mining district of Mogok above a lovely lake has always proved to be of great interest because of the wonderful rubies found there. Mogok itself is full of mysteries and whoever goes there for the first time is delighted with its beautiful streets and the soft music of the bells from the temples and pagodas. The author visited this valley for the first time three years ago, after his second stay in Ceylon, and was in no way disappointed.

The western mountainous Shan-plateau rises towards the east over the middle Irrawaddy valley; there are mountains in the north and the lake to the south. The valley of rubies is narrow and long and towards its lower end lies Mogok. It is about 700 km north of Rangoon and 150 km north-east of Mandalay, the last residential town of the Burmese kings. Only 145 km east of this town is the frontier of Burma with China. The township lies about 1500 metres above sea level and is surrounded by mountains sometimes reaching a height of 2500 metres, all covered with thick jungle. The climate is agreeable, although there is a great difference of temperature between the very hot hours around noon and the cold nights. It rains often and the rainfall during the summer months of the monsoon can reach more than 250 mm. It is very rare that the temperature during the winter drops to freezing point.

At the time of writing the visa given to foreigners does not exceed 24 hours, which makes it impossible to leave Rangoon, but before this additional difficulty arose, there were several ways of going to Mogok. Mandalay can be reached by a slow train taking two days for the trip or by a four to six hour flight by the Union of Burma Airways. From Mandalay there are again several ways of reaching Mogok. One can fly on to Momeik and if one has any friends in Mogok ask them to fetch one by Jeep. One then travels along a good mountainous road. But as it was well known that many robberies occurred at the time of the visit, the author thought it safer to use the official coach. The coach uses many dusty roads, full of ox-carts, along the Irrawaddy towards Thabeikyin. Then it crosses the Irrawaddy valley on a very bumpy road and then slowly rises on a narrow but good road through beautiful mountain country towards Mogok, where it arrives twelve hours later. Four days after the author's safe arrival three private jeeps travelling down the valley were ambushed and robbed.

There are neither hotels nor boarding houses in Mogok, and if one wants to stay in the bungalow for government officials, one has to supply one's own bed linen and either cook one's meals, or eat in one of the small Chinese stalls. The author was very lucky and was invited to stay in the house of his Burmese interpreter and agent and was thus able to take part in the daily life of the family. They were all very kind and hospitable and tried to make the visit as agreeable as possible. There are only a few streets in Mogok, the most important being macadamed and at their sides are beautiful houses. Most of these are made of wood, some using teak. In the last few years a few villas were erected from stone. Around the town and in the surrounding villages the houses are made of interwoven bamboo sticks, built on piles. These airy rooms usually form the workshop and the gems are polished here. Unfortunately only the older houses are covered with straw, tiles or brick, the newer houses being covered with corrugated metal sheets, which are not attractive. Many small shops and stalls along the two main roads form the "business quarter", where one can buy most consumer goods from a tea cup to a "loupe" or a washing basket made of bamboo strips to household articles made of plastic. Of the greatest interest is the "Bazaar", where there is a market every five days and the inhabitants of the surrounding districts and

mountains gather in their colourful costumes to sell vegetables, herbs, baked articles, tobacco and all sorts of home-made goods and who seldom return home without looking at, or even buying a few rubies. One must also mention the water-works and sewage arrangements, which work very well, and a very old-fashioned electricity plant which sells its electricity (220V) during the day to the mines and only after 6 p.m. to the townspeople, so that one can only then use the electric light. It is then used so much that the voltage falls from 220 to 110, so that one can hardly read. The foreign visitor is well advised to take a torch along together with a sufficient supply of batteries. There is no official waste disposal, so it is not surprising that there are often cases of malaria, dysentery and typhoid. The visitor must be careful in every respect. Apart from various nature-cures and quacks, there are also a few good doctors in Mogok, but hospitals, old peoples' homes and orphanages are not necessary since all these services are given by the family. There is always much life in the streets. Most goods are still transported on a shoulder-yoke or by ox-cart. There are many bicycles, and few cars and vans. The richer mine owners have land-rovers, and there are various jeeps which are used as taxis to which transport people to the surrounding villages.

Although the whole district is only a few square miles and Mogok itself only a small town, there must be about 20,000 people living in the district. The inhabitants are very mixed: apart from Burmese, there are Ghurkas, Hindus, Chinese and the romantic looking people from the Schan tribe. On each side of the street, in market places, in front of the tea-houses and bazaars, there are small groups of squatting women showing each other small brass bowls with rubies. One soon has the impression that the whole population from the earliest youth to the oldest age is involved in the prospecting, production and sale of rubies, whether as a mine worker, mine owner, gem merchant, polisher, host or tradesman. The people are very friendly, helpful and open: the few that speak a foreign language like to talk to visitors.

The famous ruby mines are secondary deposits, that is, they have been brought down into the valley from decomposed primary deposits. Such alluvial deposits are found in most of the smaller and larger valleys of the district, and everywhere there is prospecting for rubies. Mogok lies in the lower part of a larger valley on what used to be the most profitable deposits. When the population

FIG. 1. *Women ruby dealers showing each other their goods.*

FIG. 2. *Large water reservoirs in a mine field in the valley of Mogok.*

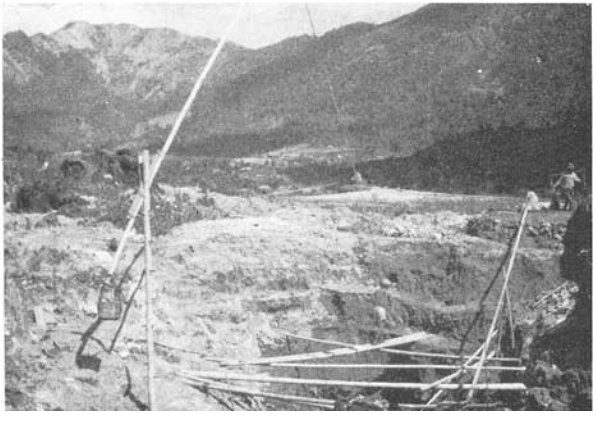

FIG. 3. *Shallow mine with a small bamboo bridge showing a lever arrangement.*

realized this, they moved their township to the lower part of the hills so that they could mine the rubies in the valley. When there were no more rubies, the craters which were formed by the mining operations filled with water, forming the lovely Mogok lake, which to-day beautifies the valley. In the neighbouring valleys the yellow clay is full of holes, and looks like a volcanic field of craters.

Prospecting and mining licences are only given to Burmese. The owner who wants to open a small mine registers his intention with the district officer, who examines the claim. Depending on the size of the mine, the owner pays several hundred Kyats (1 kyat = 1s. 6d.) for the licence. The licence for a so-called machine-mine is about 1000 kyats. The licence cannot buy the land, which is only rented from the state for mining purposes. When mining operations are finished it is not necessary to fill in the craters and holes, contrary to practice in Ceylon. This is a defect in the law and leaves the valleys full of holes and unsuitable for agricultural purposes. For each employee the mine owner pays a monthly licence fee of 10 kyats and as a receipt obtains a small oval disc, which each miner must wear to facilitate inspection. Most mining is still done by hand with the help of water—without the local water supplies the mining could not have developed as it has.

Most of the stones are found in open-cast mines. The small narrow holes are widened with sticks and spades. The earth is put into woven bamboo baskets and lifted to the surface where it is emptied onto a heap. When the ruby-containing-the "byons"-layer is reached, a "byon" heap is started, whence the earth is transported to the washing hole. Within a few weeks the small hole has become a mine of about 100 metres in diameter, perhaps reaching a depth of 20-30 metres, when the water level is reached. From a neighbouring water tank water is hosed over the "byon" layers. The softened earth is pumped, either electrically or with a petrol engine, to a washing plant built from wood or stone and measuring perhaps four square metres and consisting of a basin which is about $\frac{1}{2}$-1 metre deep and from which there is a step-like arrangement of "locks". Usually the earth is mined during the afternoon and then worked and washed the following morning, so that the gem-containing "byon" earth can settle during the night. In the morning clear water is pumped into the basin, washing away the top layer of waste earth, whilst the heavier gems settle in a series of boxes. During this time the washers stir up the deposit, so

FIG. 4. *Washing and separating the rubies.*

FIG. 5. *The lower part of the valley is combed with many trenches in which the "byon" containing the rubies is carried and deposited in the lowest part of the mine.*

FIG. 6. *View of the upper part of the so-called "machine-mine" in which a pump raises the softened "byon" or the washing water to the working level.*

FIG. 7. *Preliminary washing.*

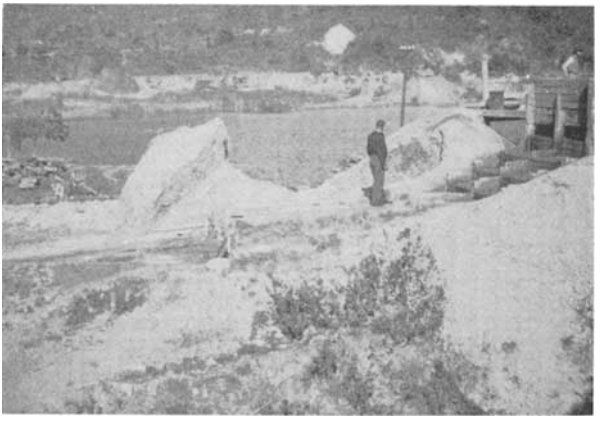

FIG. 8. *Step-like arrangements of "locks" in the washing process.*

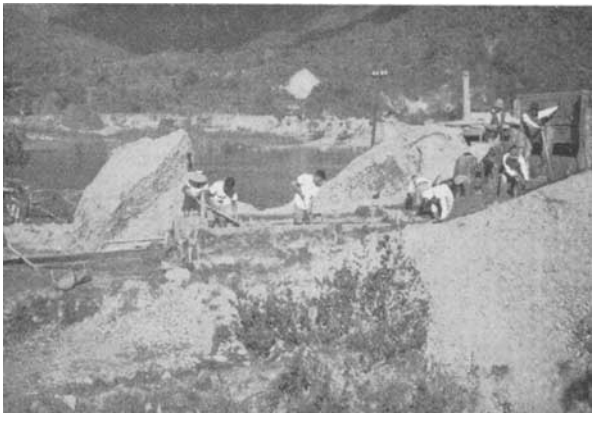

FIG. 9. *Another view of the washing.*

FIG. 10. *Rubies being washed in the lowest "lock".*

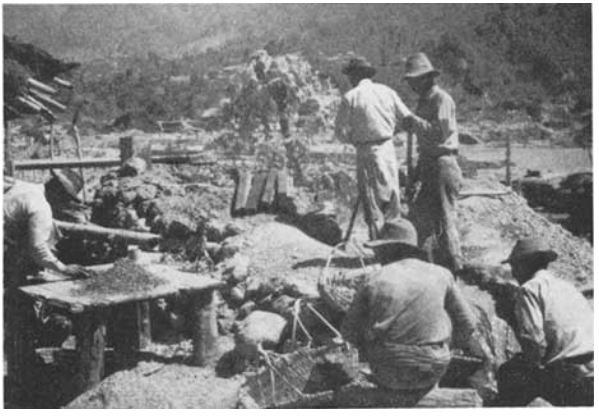

FIG. 11. *A smaller working arrangement. The two men on top are roughly sorting the stones, the two lower men are washing the rubies and at the table sits the sorter.*

FIG. 12. *A sorting table surrounded by children who all help.*

FIG. 13. *Deep mines in the dry earth of Kathe lying very near to each other.*

FIG. 14. *The product of a deep narrow mine being winched up.*

FIG. 15. *Waste earth being built into a "slack" heap, ruby containing "byon" is carried to smaller heaps.*

that it may be rinsed with water and carried away to a lower "lock". Starting at the top the washers scoop some of the deposit up with their hands and shake it in a rough wire-mesh sieve to get rid of the large stones, the finer and medium deposit is then put into a shallow basket, from which the so-called "therbat" is put on the sorting table. The sorter, who in the case of small mines is the same man as the owner, combs through the "therbat" with a wooden comb and picks out the rubies. Just as the washing of the deposit below the last "lock" is free to everybody, so friends and relatives look through the waste from the sorting table either without remuneration or against a small fee. In this way all the innumerable small rubies which are used for adorning pieces of jewellery are won.

About 10 kilometres west of Mogok, in the small townships of Kathe and Kyatpyin, the valley is very dry and water not abundant and thus a new method of mining has developed. Parallel to each other long narrow trenches are dug, which are often connected under the surface by horizontal channels. These workings are usually co-owned by three to five men. At the opening of the shaft one or two winches are erected which help to bring to the surface the baskets which have been filled by a miner with the gem-containing earth or "byon". The last man carries the basket either to the "slack" heap or the "byon" heap, which grows during the dry months from October to the end of April, and then is washed and worked during the summer monsoon season. Characteristic of the whole district is that there are no specially rich localities, but the precious stones can be found anywhere or everywhere, in a brook, in a rice field or in a mine. Ruby is the most looked for stone, but not the most common gem; there is one ruby found to every five spinels. There are fields which yield mainly rubies, others spinels, or moonstones or sapphires, and it has been known that certain mines produce certain colours, but in one basket of "byon" all types of unusual gems can be found. For the gem collector and gemmologist the mines of Mogok are a real paradise, for apart from rubies, spinels, sapphires, moonstones and peridots, which are found in quantities, one also finds almandine garnets, amethysts, beryls, chrysoberyls, spessartites, topazes, tourmalines, zircons and citrines and mentioning some rare gems the following have been found as well: amblygonite, blue apatite, danburite, diopside, disthene, enstatite, violet fluorite, fibrolite,

FIG. 16. *At the side of the mine field Kanesima women deal in small rubies.*

FIG. 17. *Small rubies on thin sticks are worked into cabochons.*

FIG. 18. *Larger cabochons are worked on grinding wheels covered with carborundum.*

iolite, kornerupine, scapolite, titanite and others. The inhabitants of the districts know very little of these various gem types, and it is not surprising that one is often offered these stones under a wrong name. For instance, pink scapolite is known as pink moonstone and every yellow to brown stone as topaz. But if one knows anything about these stones, and in addition even possesses a refractometer, one can enrich a collection with many beautiful and rare specimens. There is trade with rough rubies everywhere, along the mines, along the streets, in the bazaars, in the market places, in the back yards, and, of course, in the houses of the mine owners and gem dealers. Because there are always people looking on, a sign language using the fingers has been developed, with which one can express all numerals. Offers and acceptances are communicated under a cloth or in the wide sleeves of the engyis worn by the natives, so that none of the onlookers and strangers are any the wiser.

A large part of the gems found in Mogok and surrounding district are cut locally. Taking into account the very primitive grinding wheels the quality of the produced goods is fairly good, and quite usable according to Western standards. Depending on the resulting style the cutter chooses his tools and his method. Small stones, which are made into small cabochons, are usually worked by children and young girls. The rough stones are fixed onto a bamboo stick; five to ten of these sticks are held in each hand, then held onto a horizontally rotating grinding wheel. It is most instructive and enjoyable to watch how the hands lead the sticks on the wheel and how a few minutes later a number of cabochons are produced.

Large cabochons and star-stones are produced by men who use special grinding boards with a carborundum covering; these boards have grooves of various widths in them which are also covered with various grades of carborundum. The rough stones are again fixed on bamboo sticks, which are pushed forwards and backwards in these grooves using finer and finer carborundum until the finished cabochons show a smooth highly polished surface.

The smaller facets are made by young boys, girls and women. The stones are fixed in a simple dop and the first facets are ground roughly on a carborundum board. After they have received their first rough shape they are fixed again onto sticks which can be held

FIG. 19. *The stone is rough-ground while being held in a primitive dop and rubbed on a carborundum-covered surface.*

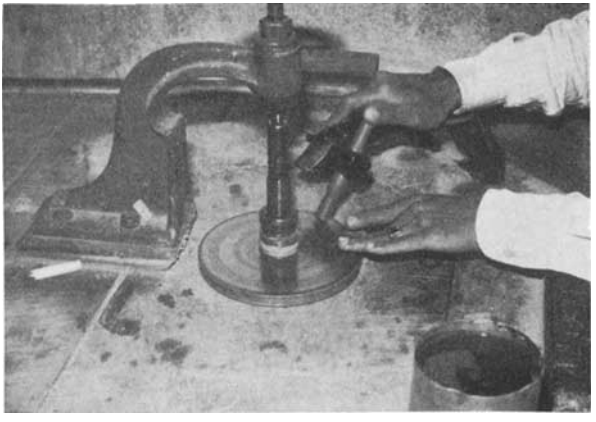

FIG. 20. *The polisher uses a very simple dop and sets the rough ground stone onto the grinding wheel.*

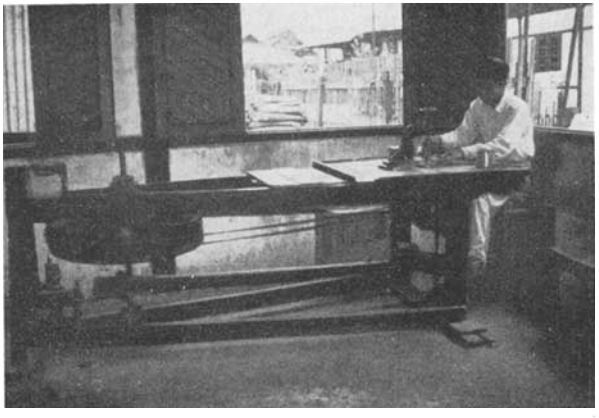

FIG. 21. *Typical grinding wheel in Mogok. The wheel is rotated quickly by a treadle arrangement.*

in a simple dop. The facets are then cut and polished on horizontally rotating grinding wheels, and from time to time checked by eye to ensure that they are even.

The large faceted stones are produced by a similar method, but only older and experienced cutters are allowed to make them. The advice of these cutters is welcomed by owners and dealers alike. The grinding wheels are rotated with the feet by a sort of treadle arrangement, as the old-fashioned electricity plant is not powerful enough to work all the wheels. Special large crystals are sometimes sawn before being cut and polished. In the whole of the district there is only one specialist who does this; he uses a machine which looks similar to an old sewing machine. It has a horizontal spindle on which a diamond sawing wheel is rotated by a foot pedal. Although the tools of their trade are primitive, most cutters are masters of their craft and know how to obtain the best results from an irregularly coloured stone, or how to place inclusions or cracks in the stone into a position where it is extremely difficult to see them. Often stones with cracks are put into pea-nut oil so that the cracks become invisible. It is also amazing how the Mogok cutters produce stones with such even facets and regularity of geometrical planes. All these points show that their technical knowledge is greater than that of the Ceylonese cutters.

The buying of gems in Mogok is a time-consuming but very interesting business, which needs absolute concentration and denial of western habits. It takes a long time for one to meet the people who sell the goods one wishes to buy. Once one has found them it needs a lot of patience until the stones are shown. Of the thousands of stones which are shown, only a few are of really good gem quality. Doubtless the families keep the very best stones to themselves and events in Burma have shown the wisdom of this. But now and then a very fine gem is offered for sale. When the author was in Mogok, only after days of bargaining did the most important dealers show him a really good ruby or sapphire. The author was thus very impressed by the rarity and value of the finest gems. Most dealers show many lots of smaller and medium as well as a few larger rubies, but these lots are only shown one at a time, and much time and patience is needed to look through them all and wait for the appearance of better stones. The deal is never finalized without the wife giving her consent. The women of Mogok not only wear the jewels, they are also important in the mining, pro-

duction and trade. In fact, the female gem merchants in Mogok are much tougher than the men and understand the fine qualities especially well.

The unit of weight is not the carat, but the Burmese rattie (1 rt = 0·90 cts). The price of fine rubies has risen very sharply during the last 15 years. This has been caused not only by the increase in rarity, but also by the purchases of Indian merchants who pay too high a price for the rubies, as they earn some money on the transaction of the rupie-kyat exchange. The inflationary and political uncertainties in Burma also play a part. The Burmese Government is nationalizing all industries and has now also forbidden private businesses such as gem mining and dealing. The gem production is guarded by the army and all gems have to be sold to the Petrol and Mineral Development Corporation. The PMDC has now tried to sell the gems on the western markets, but was unsuccessful because of the low quality offered. During the first half of last December 180 gem dealers from 25 countries were invited to an officially organized sale, but most of these visitors were disappointed because of the poor quality offered to them. Many did not purchase anything as the poor qualities cannot be resold on the western markets. It seems a pity that most important gem-producing countries have made free trading so difficult. For these countries the loss is usually only a few per cent, while the loss in the free world is quite noticeable. These circumstances do not help to make the gems any cheaper, and every jeweller who has a few fine specimens is proud of them and knows how to treasure them.

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A NEW HYDROTHERMAL SYNTHETIC EMERALD

By FREDERICK H. POUGH, Ph.D.

EARLY in August, at the trade show in New York, the Linde Division of Union Carbide, makers of the synthetic Linde star-sapphires, announced a wholly synthetic, hydrothermally grown, emerald now being grown in Linde's Indianapolis plant, by Dr. F. R. Charvat and E. M. Comperchio. After distributing the Lechleitner stones for a few years, Linde has abandoned the unsatisfactory coated-aquamarines in favour of a uniformly coloured stone, throughout synthetic, developed in their own laboratories by Miss E. M. Flanigen, Dr. D. W. Breck and N. R. Mumbach. Since, despite attempts at obfuscation, it is common knowledge that until now commercialized synthetic emeralds have been grown by the simpler flux-melt method, we expect to find some differences between Linde's stones and the others. However, with such brief experience with the relatively few first stones, a description of the distinctive characteristics can only note some of the present similarities and differences. We cannot be sure that evolutionary changes in Linde's procedure will not alter either or both of the major clues which can be used to recognize the present Linde stones.

The brilliant red fluorescence that is typical of synthetic emeralds has not been dimmed in the new stones: on the contrary, it seems to be intensified in the newest product. Since few natural emeralds fluoresce red, even though many show red in the emerald filter, the response to ultra-violet light is still the best indication. From a distance, and to the naked eye, many of the new stones seem nearly flawless, but they do have inclusions which may prove to be as typical as the wisps we know in the Chatham *et al.* stones. The refractive indices of the Linde stones are in the same range as those of the natural stones. Hence, the simple clue to a Linde stone, at present, is an intense fluorescence, which is coupled with normal emerald refraction. Both the Gilson and the Chatham synthetic stones combine unnaturally low refractive index readings with strong (Chatham) or variable (Gilson) fluorescent responses.

A major, and perhaps more invariable, difference lies in the nature of the growth irregularities. For a number of years, the

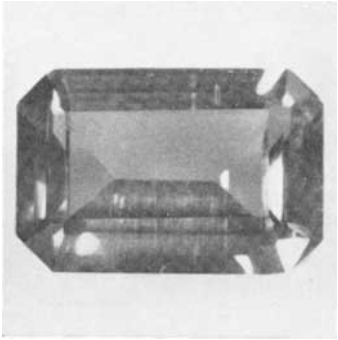

FIG. 1. *Linde synthetic emerald approximately two carat.* ×4.

"wisps" of tiny bubbles threading their way through the Chatham stones have been the dependable indication of their synthetic origin. Even the early Gilson crystals showed them, as did the Igmeralds of Hitler's day. In the Gilson crystals, which are seeded on a basal-cut and grown into very flat plates, the c-face of the crystal presents a mosaic of clear "wells", walled by veils of the tiny bubbles in a pattern that very slightly reflects the hexagonal symmetry of the structure.

Linde's experience has shown that crystals that grow from a flux-melt tend to develop as stout prisms with large flat bases. The rate of growth is a probable factor, for Chatham has found that with a somewhat slower growth, his crystals, though smaller, are better in quality and develop some pyramidal faces. Although Gilson's crystals are seeded, Chatham's appear not to be, but to be volunteer growths, for he has clusters and crusts of crystals in which there is no visible seed. The wisps tend to align themselves somewhat vertically in the crystals. Since the more desired larger stones can usually be had by cutting more parallel to the c-axis, Chatham stones are usually cut with their tables in the wrong direction for a natural emerald, and a certain amount of dichroism can be observed through the table. The early Gilson crystals seen were so flat that they had to be properly cut, with the table parallel to the base, but this had the unfortunate result of emphasizing the vertically aligned clear wells and bounding streaks of flaws. A very much better recent sample from M. Gilson shows that this has been partially eliminated in recent production: perhaps he is now growing his crystals deeper.

Linde has found that, in contrast to flux-melt experience

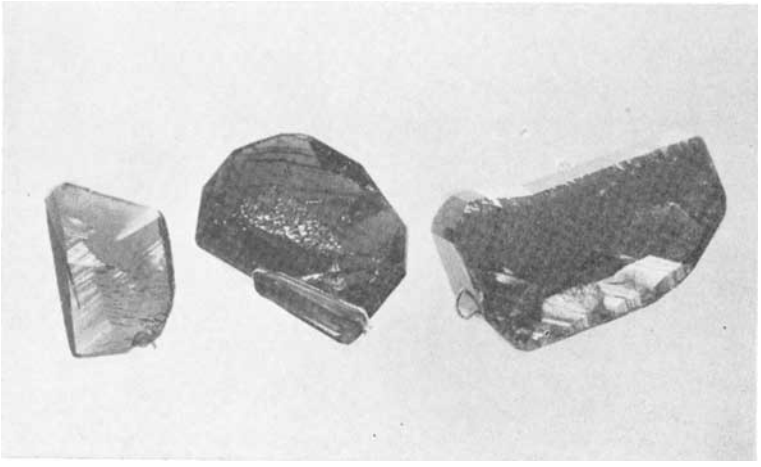

FIG. 2. *Completed hydrothermally-grown Linde synthetic emerald crystals following four growth cycles.* ×2 (*Photo Linde Co.*).

based on Hautefeuille and Perrey's pioneer work, hydrothermally grown crystals enlarge most rapidly on a pyramid face. Hence, Linde's seeds are cut at an angle to the c-axis and, as with synthetic quartz that is also grown on an oblique slice, it is almost impossible to orient a remotely hexagonal-looking crystal out of the final lump. Once it is oriented, however, it becomes possible for a crystallographer to identify a number of the common beryl forms on its surface.

The base is very easy to recognize once it has been pointed out. It makes a thin edge, but one that is marked by sharp hexagonal growth accessories. They take the form of low six-sided pyramids. The descending prism faces, now identifiable, are smoothly striated. The dominant face, however, remains the pyramid parallel to which the two sides of the slender seed plate have been sliced. This face promptly develops a very irregular pitted surface, with small pits more or less uniformly scattered over the entire surface. Visible at every growth stage, they seem to persist through the entire life of the crystal. As the crystals grow larger, the other faces (lagging directions) gradually close in, and in time the fast-growing pyramid form would disappear entirely. The reader will readily understand that the faces on a crystal are often those of the slowest growth direction, as fast growing faces eliminate themselves. One wonders

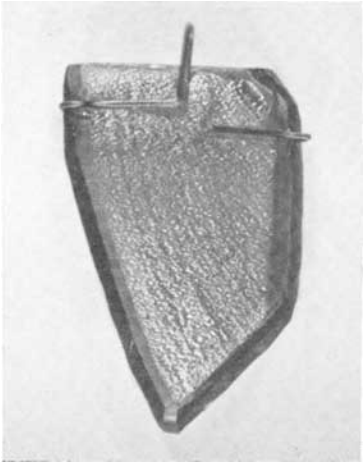

FIG. 3. *Seed plate showing rough surface following one growth cycle.* ×3 (*Photo Linde Co.*).

if Chatham might not achieve faster growth if he did seed his crystals; perhaps the slow rate he claims is partly due to the shape his crystals assume. Linde finds they can grow their crystals in a much shorter time.

Although growth is rapid, in the sealed, small, high pressure "bomb" with which Linde works, it does not continue very long before the solutions are exhausted. As a result, Linde grows its emeralds on and on, over and over again, 3 or 4 times, returning each rack of seeds to the cylinder to add additional layers and build up the thickness to a point where the original seed can be wholly eliminated in the cutting, leaving them with a stone that is all synthetic. Building sufficient thickness on the seed, without, at the same time, developing, parallel to the c-axis, one of the cracks that were troublesome to Lechleitner, and which, once started, are likely to extend out through all the growth layers, is still one of Linde's problems.

Even though a Linde stone may look nearly flawless to the naked eye, it does have inclusions that are distinctive. Even in apparently clean stones one can commonly find tiny phenakite crystal inclusions. From each there extends an elongated bubble, partially filled with liquid to make a two-phase inclusion. (Since the phenakite crystal is tightly encased and outside of the bubble, it cannot properly be regarded as a three-phase inclusion like those noted in Colombian emeralds.) Even when the phenakite is

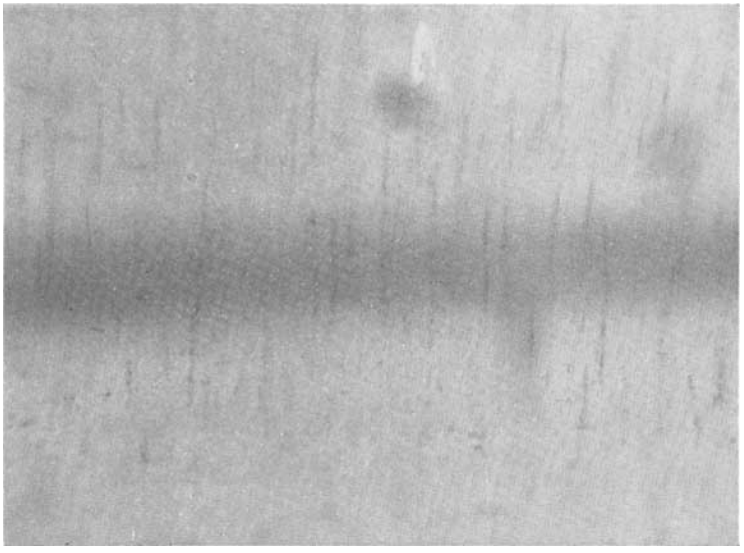

FIG. 4. *"Brush-stroke" threads which characterize the current Linde synthetic emeralds. (Photo F. H. Pough).*

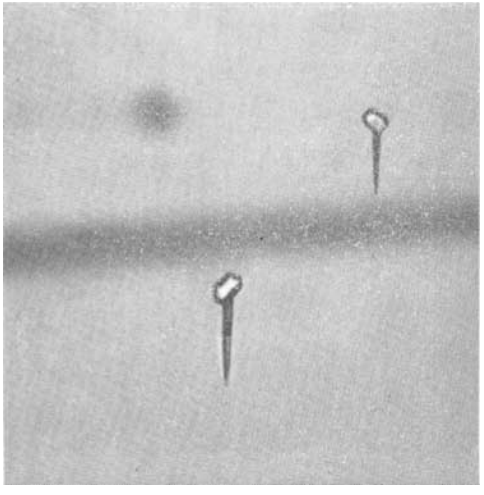

FIG. 5. *Tiny included crystal at the start of a two-phase void. Probably phenakite, its refractive index is considerably above that of the enclosing beryl. (Photo F. H. Pough).*

FIG. 6. *Two-phase cuneiform inclusions in Linde synthetic emerald* ×400. (*Photo Linde Co.*).

absent, there are likely to be parallel swarms of the little bubbles, which gradually taper to nothing: they have been called cuneate or cuneiform inclusions from their arrangement and shape. Lastly, the bubbles fade out into thread-like markings that continue through the stone, like a series of parallel brush-strokes.

The brush-stroke pattern seems to be characteristic of present production. It can probably result from the numerous pits on the growing surface. Since these are bounded by crystal "faces", each direction has a different affinity for the various ingredients, particularly the impurities, in the solution. One of the plane surfaces may be slightly more accessible to Cr than others, with the result that the final mass is streaked by very minor compositional differences that evidence themselves in this brush-stroke pattern. At the very middle of each growth centre there is a slightly less transparent thread, perhaps the locus of immeasurable impurities banished from the aligning molecular ranks.

The effect of these marks is not unpleasant, for they give the Linde stones a slightly softer look, making it look less glassy in spite

FIG. 7. *Rack and seeds after one growth cycle, with the bomb being used in the early development work. This may be altered in actual production later on. (Photo E. M. Flanigen, Linde Co.).*

of its clarity, much as a Kashmir sapphire owes its luminosity to microscopic inclusions. However, it is too soon to say that these will always be definitive for Linde stones, and a change in the orientation of the seed, with a consequent difference in the growth figures on the plate's surface, would be likely to modify, and perhaps even eliminate, the "brush-marks".

Returning for a moment to the fluorescence, it can possibly be said that the Linde emeralds with their ultra-purity have carried fluorescence to an extreme where it might become a handicap. When the stone whose inclusions are illustrated in Figures 4 and 6 was placed upon the microscope stage, and lit by an intense tungsten light, fluorescence was evoked which tended to wash out the green, while a red glow was kindled in the shadowed areas. A comparison with other synthetics showed that the Linde stone was the only one to respond in this way. In long-wave UV light, compared even with Chatham's, the redness of the lighter and more brilliant Linde stones is marked, nearing the appearance of a ruby in the same light. Through an emerald filter, too, the brighter hue of the Linde red is reminiscent of a ruby, so light is it. If the stone were often to be seen under such lighting conditions it could be

detrimental; though, under normal conditions of wear and observation, the fluorescence will probably not be noted.

To summarize the properties of the new Linde synthetic emeralds, as reported by their developer, Miss Edith Flanigen, the density is 2·67 to 2·69, the refraction (0) 1·571 to 1·578 and (E) 1·566 to 1·572 compared with Chatham's 1·562 to 1·564 and 1·559 to 1·561, respectively. The Gilson stones are slightly higher (1·564 and 1·561 to 1·567 and 1·562). These figures are identical with some that Linde made by the lithium molybdate flux-melt method in which they put .2 to .5% Cr. The Zerfass and I. G. Farbenindustrie stones are still lower in refractive index. It has been published that the latter was crystallized from a lithium molybdate flux.

Intense fluorescence combined with the normal refractive indices is the most obvious mark of a Linde stone. As long as growing conditions remain the same, we can confirm it with the phenakite crystal inclusions and the innumerable "brush-strokes" which generally are oriented to descend from the table facet.

APATITE CRYSTALS IN A CEYLON SPINEL

By P. C. ZWAAN, Ph.D., F.G.A.

Introduction

During the winter of 1958/59 I spent three months in Ceylon where I got the opportunity of visiting the gem pits in the well known Ratnapura district of Sabaragamuwa Province. From one of the pits (Pelmadulla) I collected many pebbles of minerals, mainly corundum, garnet and quartz.

Back in Holland I sent a number of these pebbles to Idar-Oberstein, in Germany, to be cut. I got back, among others, an oval-shaped faceted stone of 3·20 carats, having a violet-blue colour and containing many inclusions of crystals with a prismatic habit (Fig. 1). The stone has a refractive index of 1·717, and is isotropic. Its specific gravity, measured with the balance and using ethylene dibromide, is 3·599. The absorption spectrum shows the pattern of natural blue spinel. The stone therefore appeared to be a spinel.

At the Gemmological Conference in Helsinki in 1962 I spoke about this stone to Prof. W. F. Eppler, who expressed the wish to examine it. So I sent the stone in question to Freyung and after a few weeks Prof. Eppler returned it together with some of his famous colour slides. In his comment on the stone he said that the inclusions were very interesting but he did not know to what sort of mineral they belonged. I suggested that, in my opinion, they were crystals of zircon (because I only inspected the stone quickly), but Prof. Eppler replied again that this was impossible because the refractive index of the crystal inclusions was much lower than that of the stone. So the case of the crystal inclusions became a problem which had to be solved.

After a week or so I wrote him to say that these crystals might be either beryl or apatite. Prof. Eppler replied that this preliminary result was very interesting but he did not believe that it was true, on the ground of the birefringence which, according to him, should be rather large. Afterwards it was found that the high interference colours were due to the thickness of the crystals.

Optical Investigation

The conclusion that the crystals must be beryl or apatite I drew from the following observations:

First of all it was seen that the crystals have a six-sided habit

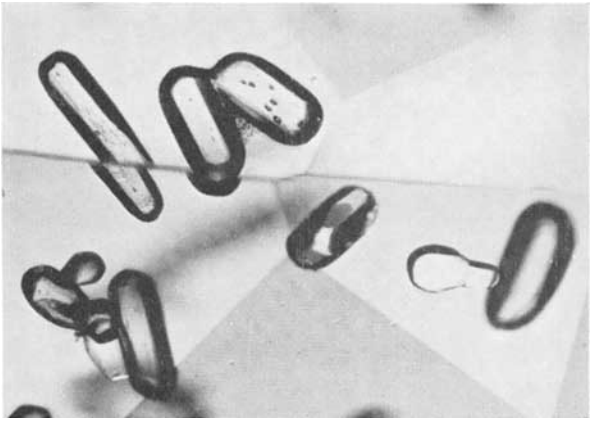

FIG. 1. *Crystal (apatite) inclusions in the spinel* (40 ×).

and that they are built up by prism faces terminated by pyramid faces at both ends of the longest direction (Figs. 2 and 3). The crystals have a parallel extinction and the optic orientation, observed by using a gypsum plate, is as follows:
$N_x^l = E$ and $N_z^l = O$, supposing that the crystals are uniaxial, which is almost certain.
Moreover, a distinct dichroism in tones of yellow (O) and blue (E) can be seen, in which $E > O$.

From the above-mentioned data it is obvious that the optic sign of the crystals is negative.

Measurements of the thickness of one of the crystals, having an interference colour grey of the first order, indicated approximately 0·050 millimeter, so that the double refraction must be small, in any case smaller than 0·005. These measurements have also been taken of other crystals with higher interference colours. They all led more or less to the same conclusion. Finally, it was seen that the refractive index of the inclusions was smaller than that of the spinel, but it was impossible to obtain an estimated value from crystals touching the surface of the stone.

From these data the nature of the inclusions could not be determined with certainty although apatite was indicated on the ground of the crystal form and the occurrence in the spinel.

X-RAY INVESTIGATION

Mr. C. F. Woensdregt, of the Geological Mineralogical Institute of Leiden University, made a rotation photograph of one

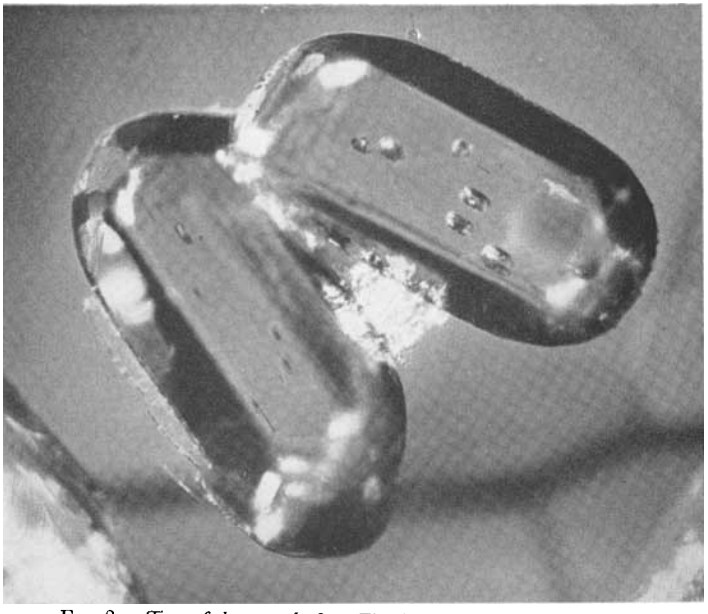

FIG. 2. *Two of the crystals from Fig.* 1 *in reflected light* (100 ×).

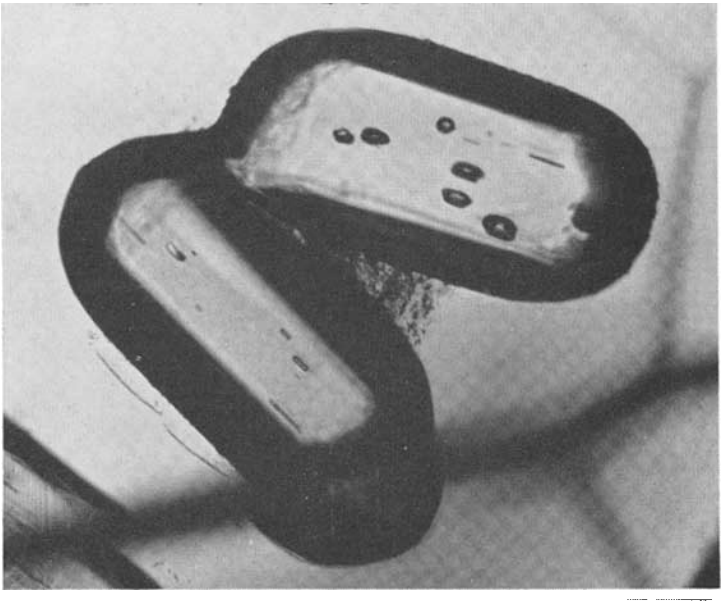

FIG. 3. *The same inclusions as in Fig.* 2 *in transmitted light* (100 ×).

of the crystals, using Cu-radiation with Ni-filter, oscillating it over 15 degrees round the longest direction. He compared his results with a photograph, made under the same conditions, of an apatite crystal from St. Gotthard, Switzerland, and was almost certain that the crystals in question are apatite crystals.

Finally, an X-ray powder photograph (No. m m 1017) was taken, using Fe-radiation and a camera with a diameter of 114·6 millimeters. The sample was obtained by scraping down part of a crystal touching the surface, with a steel needle. The material obtained appeared to be much weaker than the surrounding spinel. Use was made of the so-called "sphere" method, because only very small amounts of material were available. This method, introduced by S. A. Hiemstra[1] and used with great success by A. H. van der Veen[2], is as follows:

A small grain, transferred to a clean glass slide, is immersed in a tiny drop of thin rubber solution by using the point of a steel needle. The immersed grain is then covered with a second clean slide. Thus the grain can be ground without losing any material.

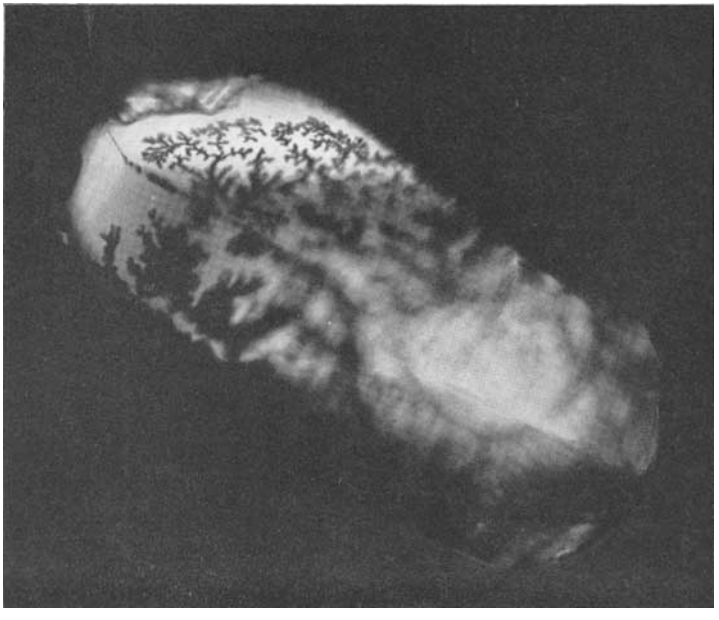

FIG. 4. *Dendritic forms on crystal faces of one of the inclusions* (190 ×).

By circular motion the solution, loaded with powder, is worked to a ball, measuring 0·2 to 0·5 millimeter in diameter. The ball is mounted with a little glue or similar solution on top of a Lindemann glass capillary. This is then placed in the camera with the mounted ball placed before the centre of the collimator hole. The exposure time is increased (for our sample until ten hours). The loss of weight of the spinel was 0·0002 grams, so that its weight in carats has not been altered.

The X-ray powder photograph obtained gave a pattern of diffraction lines, characteristic for apatite. The X-ray data for some of the strongest lines are as follows:

d(*in* Å)	*Intensity* (*estimated*)	*hkl*	(*d in* Å)	*Intensity* (*estimated*)	*hkl*
3·42	5	002	1·801	2	321
2·81	10	211	1·773	1	410
2·78	7	112	1·749	2	402
2·70	6	300	1·711	3	004
2·62	3	202	1·636	2	322
2·25	2	301	1·471	2	502
1·935	3	222	1·448	2	323
1·884	1	312	1·431	2	511
1·832	4	213			

By comparison of these data with those stated in the index to the X-ray powder data file of The American Society for Testing Materials (Nos. 3-0736, 9-432 and 12-261), it turned out that they agreed well with the corresponding data of hydroxylapatite.

My colleague, Mr. C. J. Overweel, identified the type of apatite as follows:

He made use of the data of Gottardi, *et al.* (3) on the $2^{\theta}{}_{Cu}$ values of the diffraction lines 140 (or 410) and 004.

According to Gottardi the following data are found:

hydroxylapatite $2\theta_{140} = 51{\cdot}275°$
$2\theta_{004} = 53{\cdot}178°$
chlorapatite $2\theta_{140} = 50{\cdot}08°$
$2\theta_{004} = 54{\cdot}08°$
fluorapatite $2\theta_{140} = 51{\cdot}550°$
$2\theta_{004} = 53{\cdot}175°$

Mr. Overweel measured $2\theta_{140} = 50{\cdot}96°$ and $2\theta_{004} = 53{\cdot}34°$ for a blue apatite from Matale in Central Province, Ceylon. The X-ray powder photograph (No. m p 1053) was made by using a

camera with a diameter of 19 centimeters and Cu-radiation, the preparate being mixed with $12\frac{1}{2}$ weight percent NH_4Br (ammoniumbromide) for standard purposes.

He plotted the obtained data in a diagram, made by Gottardi, *et al.* and found that this apatite is a chlor-hydroxylapatite with ± 25 mol.% Cl and ± 75 mol.% OH.

As the apatite preparate from the included crystals in the spinel was too small to mix with NH_4Br, Mr. Overweel made another X-ray powder photograph of this material (No. m p 1018) with the same large camera and Cu-radiation and measured the relative distance between the reflections 004 and 140, using a Cambridge Universal Measuring Machine. This distance appeared to be $3{\cdot}34 \pm 0{\cdot}01$ millimeters.

For the Matale apatite (No. m p 1053) he found a relative distance between the reflections 004 and 140 of $3{\cdot}90 \pm 0{\cdot}01$ millimeters.

Further it is known that the same distance in a pure hydroxylapatite is $3{\cdot}25 \pm 0{\cdot}01$ millimeters.

From these data Mr. Overweel concluded that the apatite, included in the spinel, is a chlor-bearing hydroxylapatite. In Ceylon both apatite and spinel occur in the same type of rock, that is a crystalline limestone.

Occurrence

Regarding the presence of apatite crystals in spinel, it is known that both spinel and apatite may be formed during contact metamorphism. In Ceylon, especially, crystalline limestones occur in which both spinel and apatite are present. I visited a quarry at Matale (Pitakande Road), in Central Province, in which nice crystals of blue apatite, up to a few centimeters in length, could be found together with purplish spinel. On the other hand I collected crystalline limestones near Hakgala, in Central Province, in which blue spinel, blue apatite and forsterite were present. Anyway, the occurrence of spinel with apatite is common in Ceylon. It is important to note that the included crystals all have somewhat eroded crystal faces. This erosion effect is not likely due to erosion but rather to partial solution, after which the crystals were included in the spinel. The dendritic forms on some crystal faces also say much for that (Fig. 4). It is remarkable that in some of the

included apatite crystals long tubes can be observed, being two-phase inclusions, together with distinct negative crystals (Fig. 3).

Finally, in this case shows again, apatite does not belie its name, for as is known, the name has been derived from the Greek word for "to deceive".

ACKNOWLEDGMENTS

I am indebted to Mr. C.F. Woensdregt, who was so kind as to make a rotation photograph of one of the inclusions. I also acknowledge the help of my colleague Mr. C. J. Overweel for the identification of the variety of the apatite.

Last, but not least, I am grateful to Mr. J. J. F. Hofstra and Mr. J. van der Linden of our technical staff, who prepared the X-ray powder photographs.

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2. Van der Veen, A. H. *A study of pyrochlore,* Verhandelingen van het Kon. Ned. Geol. Mijnbouwk. Genootschap, Geol. Serie, 1963, 22, 1-188.
3. Gottardi, G., et al. *La determinazione roentgengrafica del contenuto in fluoro dell'apatite delle ossa fossili,* Rivista di Scienze Preistorich, XII, fasc., 1957, 1-4, 1-37.

Gemmological Abstracts

ANON. *New Technique Grows Emeralds in Laboratory.* International Electronics, U.S.A., 1965, 10, 2, p. 5.

Scientists at the Naval Ordnance Laboratory, White Oak, Md., U.S.A., have created synthetic emeralds of gem quality in about 2 minutes. The crystals are attracting attention in the semiconductor electronics field because of the maser characteristics of emerald.

A high-temperature, high-pressure technique was developed to produce clear single crystals of emerald directly from beryl powder, and in far less time than is taken with the hydrothermal, flux or flame-fusion methods of synthesizing crystals.

Laboratory scientists also report that the colour of the crystals can be controlled easily by substituting various amounts of metallic oxides, particularly chromic oxide, in the basic beryl powder.

The pressure vessel used at the laboratory is made of several binding rings around a tungsten carbide cylinder to obtain up to 60,000 atmospheres of pressure in the test capsule. The capsule is of pyrophyllite material for the transmission of pressure, a carbon sleeve to serve as furnace, and a cylindrical capsule to isolate the beryl powder from the pyrophyllite during the crystallization. Pressure is transmitted to the test capsule through tungsten carbide pistons by means of a 300-ton press.

The capsule, which contains the beryl powder, is about 1/4-inch (6·34 mm) in diameter and about 3/8-inch (9.5 mm) in length, but this volume can be scaled upwards to obtain larger crystals.

In one process for the synthesis of emerald, the pressure is increased to 15,000 atmospheres and the temperature is raised to 1500°C to melt the beryl. Then, the carbon is shut off abruptly. Since there is a large mass of steel surrounding the sample, the temperature is reduced to near room temperature in a matter of minutes. Under these conditions the melt fuses into a clear single crystal of beryl.

The crystals obtained by the high pressure method are, by outward appearance, clear crystals of beryl. X-rays indicate that the samples are single crystals. The addition of 1% of weight of chromic oxide produces a green colour identical to the colour of the best natural emeralds. The density of the samples was determined to be $2{\cdot}715 \pm {\cdot}005$ gm/cm^3.

The quality of the crystal depends on the pressure, the temperature, the time during which the temperature is applied, and the material of the capsule that contains the beryl powder.

S.P.

JONES (J. B.), SANDERS (J. V.) and SEGNIT (E. R.). *Structure of opal.* Nature, 1964, 204, pp. 990-991.

X-ray patterns of opal show a complete gradation from the α-cristobalite pattern, given generally by common opal, to amorphous patterns, given generally by precious opal. Electron micrographs of crystalline opals, however, show a relatively fine-grained surface, whereas amorphous opals have discrete areas of close-packed aggregates of uniformly-sized silica spheres. These differences may reflect differences of genesis.

R.A.H.

SANDERS (J. V.). *Colour of precious opal.* Nature, 1964, 204, pp. 1151-1153.

The close-packed array of regular silica spheres constituting the structure of precious opal (see preceding abstract) forms a three dimensional diffraction grating. The play of colours results from the satisfaction of the correct conditions for diffraction by different wavelengths of light at different angles.

R.A.H.

MILLEDGE (H. J.). *Synthetic diamonds.* Science Progress, 1963, 51, pp. 540-550.

A general survey is given of the experiments leading to the production of artificial diamonds. The "doping" of diamonds with impurities during or after growth is described and the possibility of producing diamonds by explosive processes is touched upon.

R.A.H.

NEUE EDELSTEINVORKOMMEN. *New gem occurrences.* Zeitschr. d. deutsch. Gesell. f. Edelsteinkunde, 1964/65, 50, pp. 34-35.

There is a new find of mitrax opal in Australia which is of the quartz matrix type. The opal is very porous and ideal for dyeing. In a mine in Arizona a fluorspar of 12·9cts of pink colour was found; this mine usually produces blue-green material which is usually kept in the sun and then turns first purple, then pink and after many years becomes colourless. When removed from the sun the colour of the stone stays constant. Dr. E. Gübelin called a certain albite feldspar Maw-sit-sit; he first found this stone with jade cutters in Burma. The material is dark green and black and the name is the native word for the stone. Work has begun on a new diamond mine 140 miles west of Kimberley; the mine was bought in 1963 by DeBeers from its discoverers. The pipe is circular and covers a district of 16,200 square miles.

E.S.

SEAL (M.). *Structure in diamonds as revealed by etching.* Amer. Mineral, 50, pp. 105-123, 23 figs. Jan.-Feb. 1965.

Several different types of structure have been observed in diamonds by etching polished sections with fused potassium nitrate Both rectilinear and curved line structures occur; layer growth parallel to $\{111\}$ is common. A difference is reported between the internal structures of type 1 and type 2 diamonds (infra-red classification). No correlation has been found between internal structure of natural diamonds and geographical origin.

R.A.H.

DEINES (W.). *Ein weiterer Beitrag zum Thema; echt oder synthetisch.* A further article on the subject of genuine versus synthetic, Zeitschr. d. deutsch. Gesell. f. Edelsteinkunde, 1954/65, 50, pp. 11-13.

A further article on the subject of genuine versus synthetic which was discussed by X. Saller. The author insists that the difference must be advertised and the advantages and disadvantages of possessing the real or synthetic article brought home to the public.

E.S.

BOOK REVIEW

SCHLOSSMACHER (K.). *Edelsteine und Perlen.* Precious stones and pearls. E. Schweizerbart'sche Verlagsbuchhandlung, Stuttgart, Germany, 1965. 4th revised edition, 368 pages, over 100 illustrations, several tables, plates and two colour plates.

The fourth edition of Professor Schlossmacher's "Precious stones and pearls" is a largely increased version of his well received book (first edition 1954—280 pages). This is due only partly to the incorporation of his "Guide for the exact Determination of Precious Stones" in the present publication. Additions were required by developments in the fields of synthesis, imitations, doublets, improvements of colour and new occurrences. Inevitably the book had to lean a bit more to the scientific side, but the author still manages to keep it a book of the middle road which caters for all those with an interest in gems, whether jeweller, goldsmith, lapidary, gem and pearl merchant or novice gemmologist. Some overlapping and repetition is slightly disturbing to the reader but probably beneficial in a text book for students in gemmological classes.

In the sections on diamond (p. 126) and diamond polishing (p. 336) the "art of cleaving" is considered to be obsolete and superceded by sawing. In reality "cleaving" is a thriving industry, though not at Idar-Oberstein, where the author is head of the Gem Testing Institute. Prior to polishing, a large quantity of rough diamonds has to be shaped by cleaving. The "sawables" are usually only closed goods which are sawn into two "halves" ready to be girdled. In many other cases cleaving along an octahedral plane (without weight loss) is the better proposition.

In a book which covers the whole field of gemmology one or the other error of this kind is unavoidable and does not distract from the great interest of this publication for any gemmologist or enthusiast who can read German. Amongst the tables in the appendix are two new ones; one listing pleochroism, the other (prepared by Dr. E. Gübelin) listing abosrption lines and bands in Ångstrom units. Three plates with 16 photomicrographs and 2 X-ray diffraction patterns have also been added.

W.S.

LIGHT SOURCE FOR SPECTROSCOPE

By C. M. ROBB,

IT is just two years ago that last year's Tully Medal winner Fred Dowie showed me a parcel which had been released by H.M. Customs. It contained a Beck prism spectroscope which, according to the various books on gemmology and the diagrams we had studied, would aid us in the identification of certain gemstones. Alas, we tried night after night to see at least some sort of line in the spectrum but nothing eventuated. We were getting desperate —Mr. Dowie wrote to Mr. R. Keith Mitchell and I wrote to a good friend, Mr. J. R. Jones of Sydney, Australia, whom I had met on a short visit to Australia some two months earlier. He had spoken of the use of the spectroscope in gemmology. I pointed out to him the difficulties we were experiencing and that over here it was a case of the blind leading the blind. Could he give us some help as our nearest gemmologist was some 700 miles away? Most helpful replies were received to our queries and we were also advised to see Dr. M. J. Frost, of the Geology Department at the University in Christchurch.

Dr. Frost adjusted the slit, used a high intensity light source and the absorption spectrum was seen of one of the stones, which up till that time had not let us see anything of note in the spectrum. We were now on the road to progress. This was the beginning of experiments in light sources for our own use. It must be realized that here in New Zealand owing to import restrictions, one cannot just walk into a supplier and try out two or three different makes of high intensity lamps to see which is the most suitable for one's need. Not feeling like placing a firm order for an unknown item it was a case of experiment and improvisation. We tried 230 volt lamps of 100, 150 and 200 watts and low voltage high intensity lamps fitted with suitable holders and various types of reflectors but still did not obtain the results for which we were striving. We then tried using a projector and this was the break which was needed. A watchmaker's eyeglass held in front of the projector lens gave even better results.

The writer feels that there must be many gemmologists and gemmological students who have a projector and, by a small amount of "do it yourself" woodwork and metalwork, could make up a

light source which is far superior to that obtained from four commercial types of high intensity light sources with which this set up has recently been compared. The only drawback is that the home-made outfit takes up so much room. Maybe someone will use a prism and suitable holder and do away with having to set the projector up at an angle of 45°.

The final arrangement which I now have in use is shown in the Fig. 1. It consists of a baseboard of seven ply, 25 inches by nine inches with a 24 inch strut of 2 inch by 1 inch dressed timber. This is hinged at the top and a length of picture cord is attached between the board and strut to keep the angle at 45° to the table top on which the set up is used. Near the top, two holes are drilled through the baseboard and two more are drilled part way through to enable the back and front legs of an Aldis 303 projector to sit in same so that the projector needs no further fastening to hold it in position.

Ten pairs of $\frac{1}{4}$ inch holes, spaced 1 inch apart are drilled 1 inch in from each side of the base board. These permit the metal brackets holding the 9 inch by 8 inch viewing table to be raised or lowered to suit.

A metal cone 5 inches long with a $1\frac{1}{2}$ inch focus watchmaker's eyeglass fitted to the lower end is a push fit onto the front lens

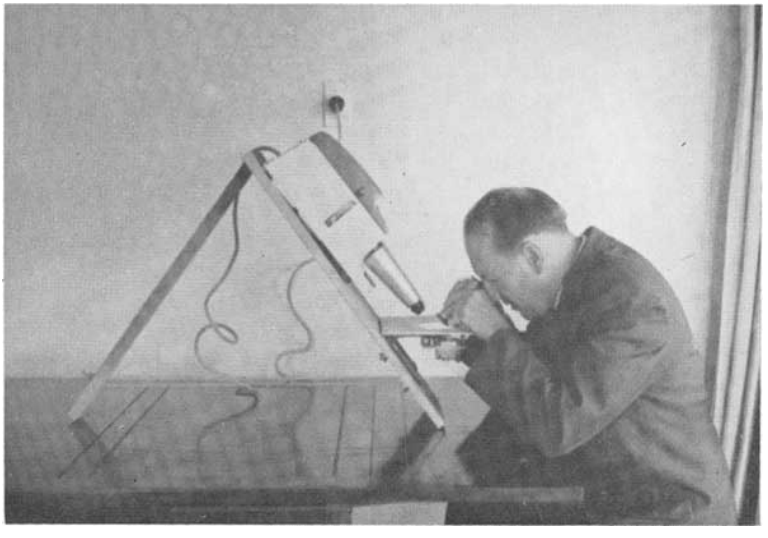

mounting of the projector. By this means a concentrated spot of light is directed on to the stone to be tested. As a further refinement I have fitted a 12 volt A.C. synchronous reversible motor to the underside of the viewing table. This turns a $\frac{1}{2}$ inch diameter revolving table set flush with the viewing table. I did this after reading in various publications to "turn the stone" to get the brightest spectrum. Two small push-switches set in a wooden box and operated by one's foot complete the installation.

It is a real joy to be able to concentrate on viewing the spectrum and not worry about turning the stone manually. If a line is noted when the stone is turning, it is only necessary to remove one's foot from the switch, depress the other switch and the stone goes back the other way and the line is seen again. There is no taking one's hand off the spectroscope, shifting one's field of view or turning the stone by hand and looking again.

There is one interesting phenomenon which I have noticed when electrically rotating a sythetic sapphire and a pink tourmaline and using copper sulphate solution in a flask. A "flash" appears at the red end of the spectrum as the stone goes round. When these stones are viewed through crossed filters or under long wave ultra-violet light no fluorescence is noted. On viewing under short wave ultra-violet light the stones fluoresce. Perhaps a reader will be able to suggest the reason for this.

In conclusion I trust that the above information will save others from hours of frustration and that, if they own a projector, by spending very little time and money they can have a light-source for spectroscopy which gives excellent results.

ASSOCIATION NOTICES

GEMMOLOGICAL EXAMINATIONS, 1965

Centres for the 1965 examinations of the Gemmological Association of Great Britain were established in Australia, Austria, Brazil, Canada, Ceylon, Channel Islands, Cyprus, Egypt, Germany, Hawaii, Holland, Hong Kong, India, Ireland, Japan, Malaysia, New Zealand, Norway, South Africa, Southern Rhodesia, Spain, Switzerland, United States of America, Zambia, apart from the United Kingdom. 265 candidates sat for the preliminary and 176 for the diploma examinations. The entry for the diploma examination was the largest in the history of the Association.

In the diploma examination there were two candidates eligible for the Tully Memorial Medal who obtained equal marks and upon the recommendation of the examiners two medals have been awarded, one to Miss Christa Cannawurf, of Frankfurt, and one to Mr. Andrew W. Taylor, of Exeter. The Rayner prize has been awarded to Miss Sheila Heffernan, of London.

The following is a list of successful candidates arranged alphabetically:—

Diploma Examination

Tully Memorial Medals

Cannawurf, Christa, Frankfurt, Germany

Taylor, Andrew William, Exeter

Qualified with Distinction

Baxendale, Paul Donovan, Birmingham
Cannawurf, Christa, Frankfurt, Germany
Kerez, Christoph J., Baden, Switzerland
O'Sullivan, Timothy, Dublin, Eire
Parker, Lovell Wilfred, Dublin, Eire
Riding, Frank, Preston
Smout, William Walter, Rhyl
Taylor, Allan Maurice, Melbourne, Australia
Taylor, Andrew W., Exeter
Thomas, Graham Anthony, Mold

Allan, Christine Mary, Colchester
Allan, Ian Edward, Birkenhead
Armour, Anthony James, Beckenham
Bailey, Ronald, Dudley
Bana, Homi Ratansha, Bombay, India
Barratt, Susan Mary, Birmingham
Beaumont, Gordon, Huddersfield
Bethel, George Clayton, Hialeah, U.S.A.
Bird, Albert James, Liverpool
Borrini, Lusia, Horw/Lu, Switzerland
Brimelow, William, Southport
Bulley, Michael John, London
Carr, Philip Wood, Blackburn
Clarkson, Roland Norman, Shepperton
Clough, M. B., Bolton
Cole, Kenneth Charles, Salisbury, S. Rhodesia
Cook, Murray E., Vancouver, Canada
Cooper, Revd. S. B. Nikon, Staines
Cross, William George, Moor Park
Davies, James Meredith, Worthing
Drew, William Henry, Wellington, New Zealand
Dunkley, Peter John, Leeds
Edmunds, Ronald Charles, Plymouth
Evans, John, Birmingham
Farley, Peter Frederick, Bath
Franke, Lois E., Hollywood, U.S.A.
Frost, Allan Robert, Cardiff
Gadebusch, Dedo A., Koln, Germany
Gasser, Joseph, Lucerne, Switzerland
Gauntlett, Gillian, Haslemere
Goode, Alastair Richard, Solihull
Hanebach, Stanley, Scarborough, Canada
Hanna, Joe D., St. Louis, U.S.A.
Heaven, John Peter, Birmingham
Hesse, Kenneth R., Oceanside, U.S.A.
Hogervorst, Lia Angelique, Gouda, Holland
Holmes, Milton John, Owen Sound, Canada
Howarth, Harry, Altrincham
Imai, Taichiro, Tokyo, Japan
Inkersole, Denis, London
Jackson, David, Watford
Jones, Alfred, Coventry
Jones, Robert John, Ross-on-Wye
Laing, John, London
Lee, Joseph Ira, Raleigh, U.S.A.
Lewis, Kenneth, Rainham
Lewis, Leslie John, London
Lloyd, Philip Samuel, Chester
Millar, Maurice Alan, Dannevirke, New Zealand
Mole, Christopher John Sherwood, Blackheath
Moore, Henry, Solihull
Morley, George Kenneth, Sutton Coldfield
Myers, Leah Miriam, Sydney, Australia
Nicolau, Jose G., Madrid, Spain
O'Donnell, Arthur Lewis, London
Oesterlin, Wilhelmina Pearl, St. Mosm, Australia
Ogden, Glendower Morritt, Harrogate
O'Grady, Royston Joseph, Stafford
O'Shea, John Patrick, Worthing
Podhorodecki, Josef, Nottingham
Randle, Rodney Charles, Birmingham
Sher, Morris Michael, Glasgow
Simmonds, Stephen Maurice John, London
Smith, Stephen Spencer, Hull
Stern, Marion Judith, Wembley Park
Soma, Erling, Stavanger, Norway
Stocker, Christobel, London
Thomson, Harry, Lichfield
Toole, John Lewis, Stouffville, Canada
Ungar, Michael Scott, Ruislip
Wetton, Roy Nevil, Burton-on-Trent
Wheeler, Jennifer Mary, Bristol

RAYNER PRIZE

Heffernan, Sheila, London

Qualified

Adams, Robert, Johannesburg, S. Africa
Ansar, Mohamed Jabir Mohamed, Beruwela, Ceylon
Armstrong, John Henry, Honolulu, Hawaii
Ashby-Crane, Paul Robert, Exeter
Ashwell, Paul, London
Astley-Sparke, Jeremy Peter, London
Barrett, Mrs. Francis Irene, Stockport
Barrett, Roger, London
Bastos, Francisco Muller, Minas Gerais, Brazil
Batty, Susan Gillian, London
Beech, Lemuel Trevor, Bury
Bennett, Peter, Enfield
Berge, A. V. D., Hoofddorp, Holland
Bethel, George Clayton, Hialeah, U.S.A.
Blom, Karin Schrøder, London
Blondel, Vera Audrey, Guernsey
Bond, Mrs. Joan Maud, Waltham Abbey
Bosch, Hilmar Dirks, Salisbury, Rhodesia
Bowers, Norman, Middleton
Brookes, Jacqueline, Coventry
Brooks, Pauline Mary, London
Buchanan, Alistair McKenzie, Edinburgh
Buckingham, Lionel James, East Croydon
Burgess, Clifford, Little Neston
Butland, William Martin, Pietermaritzburg, S. Africa
Byworth, David Roy, Brookmans Park
Cameron, Donald Albert, Ottawa, Canada
Cannawurf, Christa, Frankfurt, Germany
Chamberlain, David Alan Victor, Wallasey
Charles, Lesley, Edinburgh
Chatterley, David Michael, Egham
Chikayama, Akira, Kofu, Japan
Clifford, Geoffrey Roy, Maidstone
Collier, Alan, Burscough
Collier, Rowley Walter, Hornchurch
Collings, Christopher John, Romiley
Connolly, John Patrick, Wilmslow
Cook, John William, Chelmsford
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Di-Nitto, Gordon Frank, Sheffield
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Downes, Bryan, Silkstone
Dryden, John Francis, Spalding
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Salt, Thomas E., Fort Nelson, Canada
Samuels, Stephen Jeffery, London
Sanford, Frank Edgar, London
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Scott, Colonel Conroy, Salisbury, Rhodesia
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Wilkins, Robert F., Playa Del Rey, U.S.A.
Winkler, Gunter, Augsburg, Germany
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Wong, Brian Peter, Liverpool
Wood, Frederick Arthur, Basildon
Woodall, Christopher, Streetly
Woodhead, William Webster, Montreal, Canada
Woods, Norman Ronald, Stocksbridge
Zara, Louise Vida, Leicester
Zwollo, Paul, Oosterbeek, Holland

GIFTS TO THE ASSOCIATION

From Mrs. G. van Starrex, a collection of corundum crystals.

GEM DIAMOND EXAMINATIONS

In the 1965 gem diamond examinations of the Association, which were held in June, at the School of Jewellery and Silversmithing, Birmingham, the following were successful in obtaining the qualifying standards:—

Peter Bryan Cook, Birmingham
William Edgar Cooper, Middleton
Kenneth Richardson, Birmingham
George Christopher Walters, Oadby
Peter John West, Birmingham
Philip George Wyer, Birmingham.

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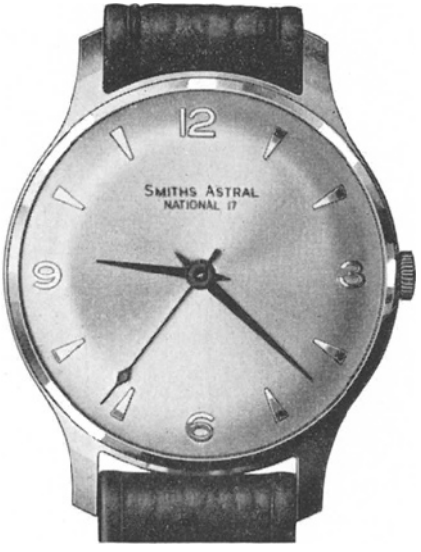

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Vol. 10 No. 1 JANUARY 1966

STUDIES ON INCLUSIONS IN SOME INDIAN GEMSTONES*

By SUDHA PHUKAN
Geological Survey of India

ABSTRACT

DIFFERENT types of inclusions in sapphires from Kashmir and aquamarines from Chitral, Monghyr and Coimbatore have been described. The Kashmir sapphires are often zoned, cornflower blue in colour with a milky or a hazy appearance. Inclusions in Indian sapphires in general, are similar to those from Ceylon, particularly in respect of rutile needles, liquid feathers and colour zoning; they even contain zircon haloes, considered typical of Ceylon sapphires. However, they differ from Ceylon stones in containing euhedral crystals of zircon without haloes, which are said to occur in Burma stones. These are reported for the first time in Kashmir sapphires. Liquid feathers and brown liquid films seem to characterize Indian sapphires. Colourless-tube like inclusions in Chitral and Monghyr aquamarines resemble those from Rhodesia. The brown colour of the tubes in Coimbatore aquamarines is due to iron stains and not due to brown liquid as reported from other localities. The two-phase inclusions, of liquid and gas, and the liquid feathers running at right angles to each other, appear peculiar to Chitral and Monghyr aquamarines only.

* Published with the kind permission of the Director General, Geological Survey of India.

Introduction

Almost all gemstones, even the best, contain microscopic inclusions. During the past two decades, their study has developed into an important branch of gemmology, particularly because of the detailed work of Gübelin (1952). The study finds many applications, not only in distinguishing natural from synthetic gems, but also in tracing the place of origin of natural stones. Besides, inclusions provide clues on the species of gemstone, and its mode of origin. Since very little is known regarding inclusions in Indian gemstones, their studies are being carried out in the Central Petrological Laboratories of the Geological Survey of India. A comparative study was made of the inclusions of a number of cut and uncut Indian sapphires (9) and aquamarines (12) from the collections of the Geological Survey of India in the Indian Museum. The present studies are based solely on microscopic examination, using high-index immersion liquids wherever necessary.

The studies have established that while the Indian gemstones examined in general are comparable to the gemstones of other countries, they also possess distinctive peculiarities. The results obtained from the studies have been presented in this paper. The inclusions in the gemstones are solid, liquid and gaseous in nature. Among the different types of inclusions described by Gübelin (1948), rutile needles, zircon crystals, liquid feathers, fingerprint inclusions, healing feathers, flat films of liquid, feathers with dark opaque crystals in centre, negative crystals, tube-like inclusions, and colour-zoning have been distinguished.

Inclusions in Kashmir Sapphire

The Kashmir sapphires are cornflower blue in colour, often zoned with a slight milky or hazy appearance. Both solid and liquid inclusions are common in them.

Solid inclusions

Rutile.—Long and fine needles of rutile are common. The needles are widely spaced and oriented in three sets meeting at 60°. They traverse the entire stone and appear as criss-crossing canals (Fig. 1). In some cases the needles have decomposed leaving canal-like cavities, which give the stone a shining white sheen, popularly known as "Silk".

Fine dust.—Dust-like particles are either scattered in between

the rutile needles, or are concentrated into a cloudy patch of extremely fine particles.

Zircon.—Inclusions of zircons are rare. Zircon crystals are often found with dark brown halo of fractures round it, giving it a "winged" appearance (Fig. 2). In a few cases euhedral crystals of zircons without haloes, are also observed (Fig. 3).

Opaque black prismatic crystals.—Opaque black prismatic and rounded crystals surrounded by liquid feathers are also observed in two cases (Fig. 4).

Liquid inclusions

Liquid feathers.—Such feathers are found almost in all the stones. Tiny drops of liquid are often arranged in rows or are scattered haphazardly and form a feather-like pattern—whence the name.

Fingerprint inclusions.—These are very common. Here the minute drops of liquid are curved like a thumbprint, hence the name, "fingerprint" inclusions.

Healing feathers.—They are so called because the liquid has healed the cracks by crystallization. These are less common. The liquid which has entered the cracks is distributed in small drops of bizarre shapes, often producing mesh like patterns.

Flat liquid films.—Inclusions of flat irregular liquid films are quite common. The liquid is often brown or yellow in colour (Fig. 5). These are formed of filling up of cavities, due to irregular growth of the crystal—the crystal growing around and enclosing a "cyst" or a pocket of liquid (*cf.* Parsons and Soukup, 1961, p. 670).

Among the inclusions noted above, zircons and opaque black crystals are of special significance. From a study of Ceylon sapphires, Parsons and Soukup (1961, p. 69) and Gübelin (1950, p. 5) opine that zircon haloes are characteristic of the locality, and are due to radioactive disintegration of metamict zircon; however, recently (*cf.* Webster, 1962, p. 652) it has been suggested that these may be formed due to stress generated by thermal expansion. Mitchell has suggested that the expansion may not be thermal, but due to increase in the size of the embedded zircon crystal which has degenerated to metamict type. It is interesting to record that the zircon haloes are also present in Kashmir sapphires (in two out of nine stones examined). In two stones euhedral zircons without haloes have been observed; this contrasts with those of Ceylon where zircon crystals always show haloes. Opaque black prismatic

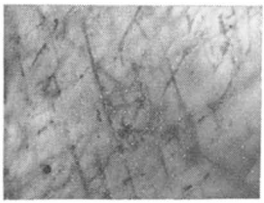

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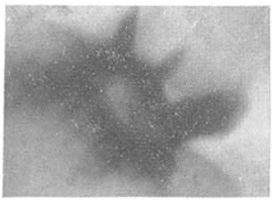

Fig-2 70x

Fig-3 65x

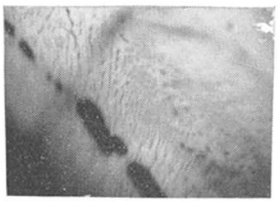

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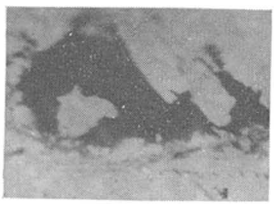

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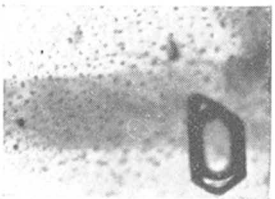

Fig-6 45x

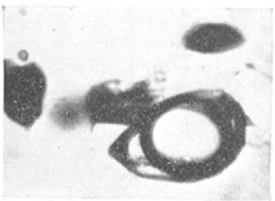

Fig-7 80x

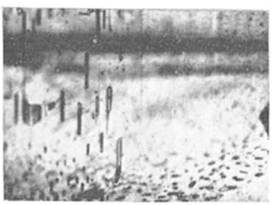

Fig-8 35x

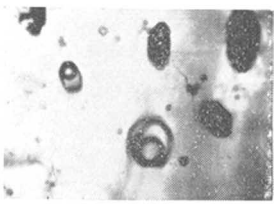

Fig-9 45x

FIG. 1. *Rutile needles in Kashmir sapphire*

FIG. 2. *Zircon haloes in Kashmir sapphire*

FIG. 3. *A zircon crystal without haloes in Kashmir sapphire*

FIG. 4. *Opaque black prismatic and rounded crystals, surrounded by liquid feathers in Kashmir sapphire*

FIG. 5. *Irregular flat liquid films in Kashmir sapphire*

FIG. 6. *Negative crystal with well developed crystal faces in Chitral aquamarine*

FIG. 7. *Two phase inclusions in Chitral aquamarine*

FIG. 8. *Negative crystals and liquid feathers oriented at right angles to each other in Chitral aquamarine*

FIG. 9. *Two phase inclusions in Monghyr aquamarine*

crystals in Kashmir sapphires resemble those from Siam stones. The nature of these prismatic crystals have yet not been determined because of the dark colour of the Siam sapphires which has rendered their study difficult (Gübelin, 1950, p. 6).

Inclusions in Aquamarines

The Chitral aquamarines are sky blue in colour, and show tube-like inclusions, negative crystal cavities and liquid feathers.

The tube-like inclusions are straight, fine, parallel tubes, oriented parallel to the prism faces. The negative crystals are two-phase inclusions, i.e. they are filled with liquid and bubble of gas. Some of the negative crystals show well developed crystal faces (Fig. 6), whereas some do not (Fig. 7). They are oriented parallel to the C-axis. The liquid feathers are oriented parallel to the basal plane. The negative crystal and the liquid feathers, oriented at right angles to each other (Fig. 8), suggest that there are two generations of inclusions—the negative crystals being primary autogenic in origin, and the liquid feathers being secondary in origin, the liquid apparently made its way along cracks and weaker planes of the basal cleavages (0001).

Aquamarines of Monghyr, Bihar

Aquamarines from Monghyr are yellowish-green in colour. They show two-phase (Fig. 9) inclusions, liquid feathers and straight fine tubes. As in the Chitral aquamarines the negative crystals, or the two-phase inclusions, are oriented parallel to the C-axis, and the liquid feathers lie parallel to the basal plane.

The tubes are oriented parallel to prism faces, and some of them are filled with iron stains.

Aquamarines of Coimbatore, Madras

The Coimbatore aquamarines are light blue to light green in colour. They are comparatively clear, the only inclusions observed in them are brown-coloured tube-like inclusions. The tube walls are often filled with iron stains giving them a brown colour.

Comparison with the Inclusions in Gemstones from other Localities

The present studies indicate that most of the inclusions in Indian sapphires and aquamarines are comparable to those of other localities, and some differ slightly, whereas some considered typical

of certain countries, are also found to occur in Indian stones; some of the inclusions noted here, do not appear to have been reported in the literature.

The liquid feathers, healing feathers and fingerprint inclusions are comparable to those in Ceylon sapphires. In some cases the feathers differ slightly in colour, the constituent liquid being yellow or brown instead of colourless. The rutile needles are comparable with those of Ceylon in being long and widely spaced, and they differ from Burma stones, where they are short and dense (Webster, 1962, p. 71).

The opaque black prismatic crystals surrounded by shredded drops of liquid (Gübelin, 1950, p. 6) and flat liquid films of brown colour (Webster, 1962, p. 70) are similar to those of Siam stones.

The tube-like inclusions in Chitral aquamarines are comparable with the Rhodesian aquamarines (Webster, 1962, p. 93). The brown-coloured tubes described only in some cases are said to be filled with brown liquid; however the Coimbatore aquamarines do not seem to contain any liquid; their brown colour appears to be due to iron stains. Liquid feathers in aquamarines have not been described earlier, and the negative crystals are reported only in few cases (Webster, 1962, p. 93). These negative crystals and the liquid feathers running at right angles to each other, are not reported from any other locality and are noted for the first time.

Conclusion

Most of the Indian sapphires are cornflower blue in colour, often zoned with a milky or hazy appearance. The most common inclusions in them are liquid feathers and rutile needles. Liquid feathers and flat liquid films of brownish colour seem to characterize the sapphires from Kashmir. The inclusions in Kashmir sapphires in general, resemble those from Ceylon, particularly in respect of rutile needles, liquid feathers, and colour-zoning. Zircon haloes are not peculiar to Ceylon sapphires only, as they have been found in Indian stones as well. Euhedral crystals of zircons, without haloes, reported for the first time in Kashmir sapphires indicate that zircons are not always accompanied by haloes in Indian stones.

The aquamarines are usually found flawless, but Indian aquamarines, specially from Chitral and Monghyr, are full of inclusions. The arrangement of two-phase inclusions and liquid feathers at right angles to each other seems peculiar to Indian stones

only; these inclusions characterize aquamarines from Chitral and Monghyr, whereas the Coimbatore aquamarines show only brown and colourless tube-like inclusions. The brown-coloured tubes in Coimbatore aquamarines are filled with iron stains and not any liquid.

ACKNOWLEDGEMENTS

The author is greatly indebted to Dr. E. J. Gübelin for critical reading of the manuscript and valuable suggestions, to Dr. M. V. N. Murthy, Superintending Geologist, Geological Survey of India, for guidance. The author's thanks are also due to Shri P. R. Sen Gupta, Geologist, Geological Survey of India, for his inestimable help in the preparation of the paper, and Shri S. P. Sanyal, Geologist, Geological Survey of India, for the photomicrographs.

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"OSMENDA PEARLS"

By ROBERT WEBSTER, F.G.A.

Some time ago the writer was asked if he knew of the so-called "Osmenda pearls" and later a specimen of this type of pearl was sent so that it could be examined.

Simple observation gave the impression that it was none other than the "Coque de perle", which has been known in literature for some time. The "coque de perle" is constructed by cutting the central whorl of a nautilus shell, filling it with wax or cement and backing it with a flat piece of mother-of-pearl. An x-ray picture taken some years ago showed the structure to be as described. The "osmenda pearl" now in the writer's possession showed an x-ray picture which is much more revealing, for the inner septa so characteristic of nautilus shells were seen to be present. It is said that in the true "coque de perle" these septa are removed and used for inlay purposes.

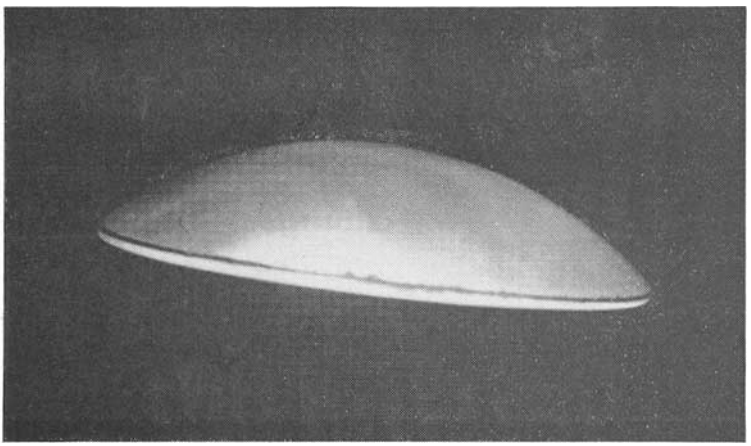

FIG. 1. *Side view of "Osmenda pearl" showing join of backing plate.*

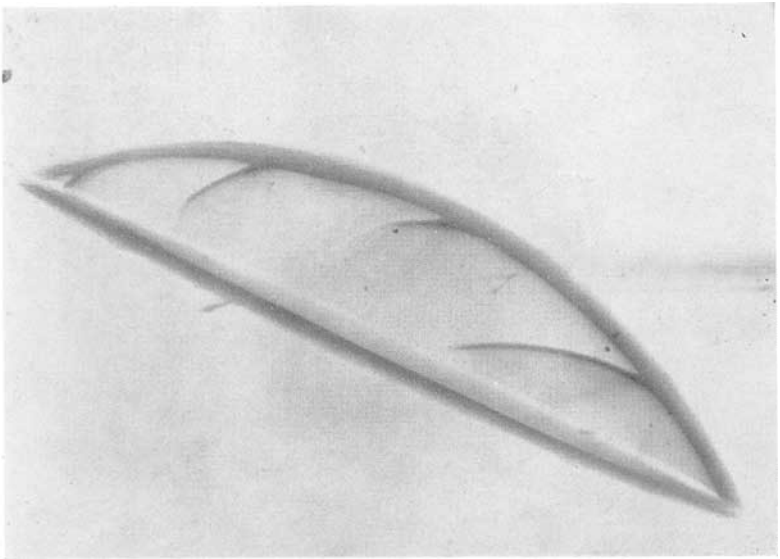

FIG. 2. *X-ray photograph of "Osmenda pearl" showing septa of the nautilus shell.*

"MIHAMA PEBBLES"

Seen in a shop in a south-west coast resort was a display of pebbles to which the name "Mihama pebbles" was given. The remarkable description attached to the dish of pebbles reads:—"On the beach of 'Shichiri Mihama' in Kumano (Japan) emitting black lustre, there are mounted with various nice pebbles glittering as though they were 'jewels' and are soaked through the odour of 'Kuroshio' tide. Now, let us trace the origin of the beautiful pebbles. In the mountain range on the basin of the river Kitayama in Kii province, there are many fantastic rocks and stones of various colours. These blue, green, black and white, or red rocks have been broken into pieces by the clear streams of the rivers Kitayama and Kumano carried away by rushing current passing through the Canyons of Torohatto and Kurikyo, polished for fundreds of years by raging waves rolling on the sea of Kumano and scattered on the beach of 'Shichiri Mihama'."

When tested the pieces had a density of about 2·69 and are jasper pebbles.

NEW CUTTABLE GEM MATERIALS FROM MEXICO

By FREDERICK H. POUGH, Ph.D.

DURING the last decade the little known desert which makes up most of Baja California has been invaded by the mineral collectors and amateur lapidaries who have largely exhausted the easy pickings to the immediate north, but who, in the south, have turned up a number of interesting minerals. Geologically Baja California is an extension of the great Coast Batholith which first appears near Riverside, California and continues south through San Diego County into Lower California. San Diego County has long been famous for its pegmatites and for many years was a source of fine tourmaline, topaz, beryl and garnet, and was the place where gemmy spodumene, kunzite, was first found. However, for some reason, until very recently, the national border was regarded as a geological limit, and prospecting for gemstones was not pursued into Mexico. In the past few years investigations have shown that many of the San Diego County minerals do continue right on down into Mexico and that there seems to be an excellent chance of finding additional deposits of typical pegmatite crystals. Some fair tourmalines, at least one of which attained considerable size and wound up in the U.S. National Museum, have been discovered, and it is reasonably certain that additional finds of this sort will be made.

A trip down the peninsula reveals a country somewhat reminiscent of the region of Paraiba, Rio Grande do Norte and Ceará in Brazil. In both places the plateau happens to be eroded to a surface that is approximately the level of the old roof of the batholith. Since it is an uneven surface, there were roof pendants which now form islands of metamorphic rock in a granitic sea, and elsewhere there are truncated cupolas which are homogeneous granodiorite without interesting mineralization. Erosion in northern Brazil has reached about the same level and the relief has been influenced by the mineralization. The improved durability of schistose rocks, into which pegmatite dikes have been injected, combines with the protection from erosion provided by the solid quartz cores. The end result has left most of the pegmatites on hilltops and given the mines in Brazil the name "Alto". The Baja pegmatites

seem to have been smaller and have not resulted in the exaggerated relief that marks north-eastern Brazil. They do stand out, however, and are readily prospected.

As in Brazil, metamorphic rock roof pendants are sometimes gneissic or schistose, and elsewhere may be lime rich. Tungsten in the form of scheelite ($CaWO_4$) is found in the lime-rich rocks. The usual associates of scheelite will be grossularite garnet, idocrase and epidote, or clinozoisite (there is much of the latter, some of it gemmy, in Baja California) and, when boron was present, axinite.

For the first time, a new find of axinite has made considerable quantitites of this mineral available for amateur and professional lapidaries. It is particularly unusual in that many of the crystals are thick enough to leave to the lapidary the selection of the orientation, rather than making the stone, by its thinness, the dictator of the location of the table.

The principal find appears to have been a single pocket of large, loosely intergrown crystals embedded in soil or decomposed rock, and with little merit as mineral specimens. The crystal faces are dull, with many coated with a white skin; it has been said that the gemmiest have such a concealing layer. The few faces they show are typical for the mineral, as is the pleochroism. However, as most gemmologists know, the colour seen through axinite's broadest face is a light yellowish to grayish-brown. The "clove-brown" hue always quoted in mineral texts is a hue observed in the second of the thinner dimensions. There is also a rich purple direction, of which one gets a momentary flash when the angle of viewing is just right. Usually it is the thinnest direction.

Some of the recently found crystals are as much as 2 cm through and when they are cut with their tables at right angles to the broad face, the stones come out a rich reddish brown. Large ones are actually a little too dark, a complaint that is unexpected in cut axinites. Unfortunately, none of the crystals is completely free of flaws; they are cobwebbed with streaks of little bubbles, so all of the larger stones that have been cut are more or less flawed. The easily obtained 4 to 6 carat stones may sometimes be practically clean. A brilliant-cut stone of 16½ carats was shown at a recent "Rockhound" show but was almost too dark to be good. Still bigger ones have been promised, but it is likely that they, too, will be so dark as to be lifeless. In any case, the flaws will certainly lessen their brilliance.

Most cut stones are of the deep red-brown colour that is euphemistically called "red" by cutters. Finishing a stone to bring out the violet colour will be difficult, but with careful orientation it should be possible.

Some of this new rough has found its way to commercial cutters, so some cut stones will probably be offered by Idar cutters of the rarer gemstones. The account of the one large pocket estimates that 550 kilos of axinite were found, though by no means was all of it cuttable. Axinite has since been coming in from other peripatetic suppliers, and it is very possible that more than one good find has been made. If the end of the story turns out to be anything like the experience five years ago with sphene, we can look for the continued offering of a good many grammes of reasonably desirable cuttable material before the supply runs out.

A second important stone from Baja California is that sphene which by now has been found in a great many gem pockets, sometimes in very large crystals. The occurrence seems to be in small pegmatite dikes cutting a dark dioritic rock, and associated with epidote. The first crystals were found at a favourite picnicking spot, very near Baja's main highway, a one-track dirt road that, insignificant as it seems, reaches all the way down the peninsula. It was favoured because it is shaded by a single large pine tree that for miles is the only thing to cast a shadow on the road and, though the region is completely uninhabited, it is a spot designated by frequenters of the route as Solo Pina, "the lonesome pine". A collector, after lunching, was taking a stroll through the brush when he noted some small gemmy sphene fragments in the sand at his feet. Excavation eventually produced a good many grammes of gem sphene, in colours ranging from emerald green and yellow-green to a fairly dark brown. This discovery eventually led to the intensive prospecting of the whole area. First alerted by Californians from the San Diego area, the natives have learned that there was interest in and a sale for the worthless little stones they had not earlier heeded. In time, considerable numbers of crystals were turned up. As with the axinite, none was very attractive as a specimen; the best single crystal is, perhaps, a flat and obviously largely transparent though dull-surfaced twin now in the collection of the U.S. National Museum. It is about 6 inches in its greatest dimension and about an inch through. Even larger ones were found, but this $750 one is about the best individual specimen.

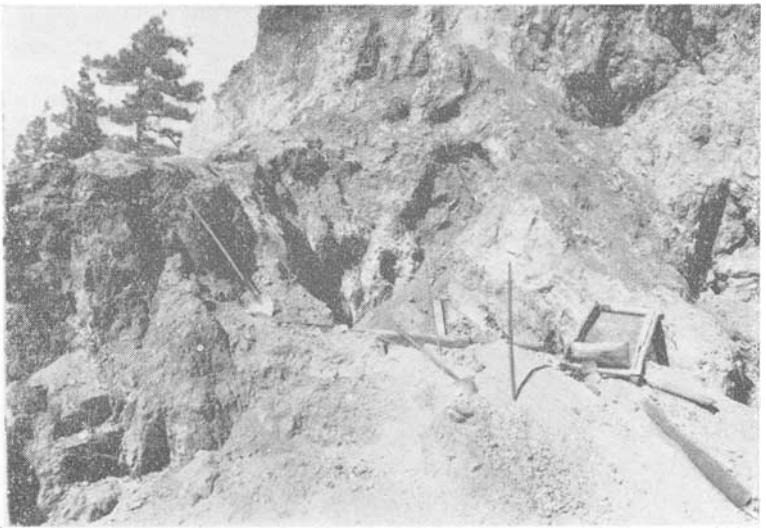

The scene of the fabulous axinite strike. The miners' tools can be seen in front of the pocket area. The rock exposed is garnet and diopside rock. (Photo courtesy of Lapidary Journal).

Close-up of axinite pocket in centre of photo. From a space of about one cubic yard better than 550 kilograms (1210 lbs.) of all grades of axinite was removed. Not all of this is of facetable quality by any means. (Photo courtesy of Lapidary Journal).

Of course, the immediate effect of the find was to depress the market value of cut sphenes to its all-time low. The connoisseur demand has never been great enough to absorb very much more than the Alps could turn out each year, so any influx of new material was obviously an oversupply. In spite of the large size of some of the specimens, however, the development of the story is not unlike that of the axinite just described. The clear areas in most crystals are not very large, and even though at first we confidently expected to see a number of 50 carat brilliant-cut stones come from such rough, there have been in fact, very few good stones weighing over 10 carats or so. Most are even smaller, and many of them, even, have flaws, and are very dark to boot. The bearish effect on the sphene market of such a large supply was perhaps unduly exaggerated, since it seemed at first as if there would be many more fine stones than the sphene-appreciating market could absorb in years. We know now that this was not to be the case, and that anything over ten carats, combining good colour and fire, with reasonable cleanliness, is still an unusual and valuable gem. Emerald-green crystals are the least common and the smallest, so cut green stones will seldom be over a carat or so. While the brown brilliants show fine red glints that are due as much to dichroism as to dispersion, the brown is commonly too dark to be really attractive. The light greens and green-yellows, much like many of the old Swiss stones, are about the best. Rough is still being found and is still available, but even now very little of it seems to have found its way into the hands of commercial cutters. There is a lot of very sparsely settled land in Baja California, so it may be some time before all of it has been prospected.

Before leaving Baja California to look at one further Mexican mineral with gemmy characteristics, the earlier-mentioned clinozoisite should be discussed a little more fully. Clinozoisite is a lighter-hued, lower-iron variety of epidote, one can say, and it is often difficult to know where to draw the line between the two. Much of the epidote associated with the garnet at the northern Baja California scheelite mines is transparent enough to be called clinozoisite. As specimens the incomplete crystals have little merit, but they are more or less transparent and they do exhibit pleochroism in the lighter greens. No clean gemstones of any size can be cut, but, since cuttable transparent bits of this group of stones are not often encountered, any are worth mentioning. Sooner or later, of

course, the once-in-a-lifetime 550 kilo pocket of gemmy clinozoisite might be encountered, but so far that one still eludes the collectors. Present supplies come, as did axinite until recently, as rewards for crawling around on old mine dumps chipping out a bit here and a bit there, normal collector-activity for this region. The Mexican miners, of course, were not interested in anything but the scheelite, so all else wound up in the spoil banks.

The remaining mineral now coming in notable quantities from Mexico and affording collectors some cutting material, is danburite. The locality is an old, well-known one, the Charcas Mine near San Luis Potosi. However, only in the past few years have the workers reawakened to the worth of the specimens that are found there in considerable abundance and obtained them for sale to various itinerant buyers who have then brought them north and passed them on to U.S. mineral dealers. Danburite is usually considered a rare mineral and until the abundance of the Mexican material was rediscovered, two Japanese occurrences were considered the world's most important. Even now the ordinary gemmologist will not be overly familiar with the mineral. It is a calcium borosilicate that occurs in a variety of conditions; in metamorphic rocks, in veins and even in pegmatites. It was named for a now-lost, Danbury, Conn. occurrence, which seems to have been veins in metamorphics. In Japan it is associated with axinite in vuggy veins, and in Switzerland its very small crystals project into the typical Alpine pockets and seams. Corroded fragments have come from Burma and till now have sold at relatively high prices. A straw-coloured danburite from Burma is still unique, for the mineral does not show this hue in its other appearances though the colour can be temporarily imparted by irradiation of colourless material.

With a history of appearing rather sparsely at a reasonably large number of localities, it could not have been anticipated that it would ever prove as abundant a gangue mineral as it appears to be at the Charcas lead mines. It is associated with sulphide ore, together with a little pyrite and considerable calcite. The calcite is often in basal plates, an indication of fairly high temperature deposition. The danburite has all the appearance of a major gangue mineral; the specimens, which commonly consist of projecting clusters of crystals, can only be compared with the groups of quartz crystals found in so many ore veins. It would almost seem as if

danburite had taken the place of the more usual quartz in this deposit.

Danburite has formed during at least three different stages of the vein formation, all late and after most of the sulphide mineralization had ceased. Calcite is still later and, in some cases, earlier; coarsely crystallized danburite has been attacked, particularly around the base of the crystals, and replaced by calcite. Many of the danburites are also coated later with more calcite, and attempts to acid-etch them out often result in the detachment of many of the early crystals, as their bases are weakened with the solution of calcite that also replaced the original mineral. The earliest crystals seem to be very large, up to as much as four inches long and an inch and a half or two inches across. Some are very faintly pink; the tips tend to be clearer and more glassy, while the bases, where they are in contact with other crystals, have become cloudy and corroded. Many specimens show two sets of crystals, the earlier ones somewhat milky and opaque, the later clear and gemmy. Terminations are often very complex, the more numerous faces being those on the crystals of middle size, that is about one inch by one-fourth inch gemmy prisms. Lastly we see druses of tiny crystals coating some of the larger ones.

Some fair-sized stones have been cut from the tips of some of the larger crystals. Relatively few are pink enough to give a stone which will retain any colour as a cut stone, so almost all are colourless. The clear areas are not nearly as large as one might hope for with the big crystals. In general, 5 or 6 carats is about all even an optimistic view warrants. Crystals suitable for 1 or 2 carat stones are very common and can cost only a few cents. From the material seen in the dealers' hands, one suspects that many of the crystals are found already loose in pockets, freed from a matrix by the basal alteration to calcite in combination with subsequent natural solution. On occasion we encounter doubly terminated crystals, but it is apparent that the danburite usually formed quartz-like crusts of erect crystals, often crowning a band of ore minerals.

With the addition of this material to the limited market, danburite can no longer be considered a rare stone and, except for the unusual gem, its cost is now nominal. Straw-coloured Burmese stones are still uncommon and probably reasonably valuable, and a cut stone which actually showed some pink should certainly be considered a great rarity. Ordinary colourless danburite, with its

refractive index only about 1·63 now has little to recommend it, no longer even the charm of rarity. In recent months the supplies seem to be diminishing a little, but there is still no shortage of specimens, nor of the loose crystals that have been bought by the wholesalers at so much per pound. It is unlikely that the cost of any but an exceptional danburite will be very great in the foreseeable future.

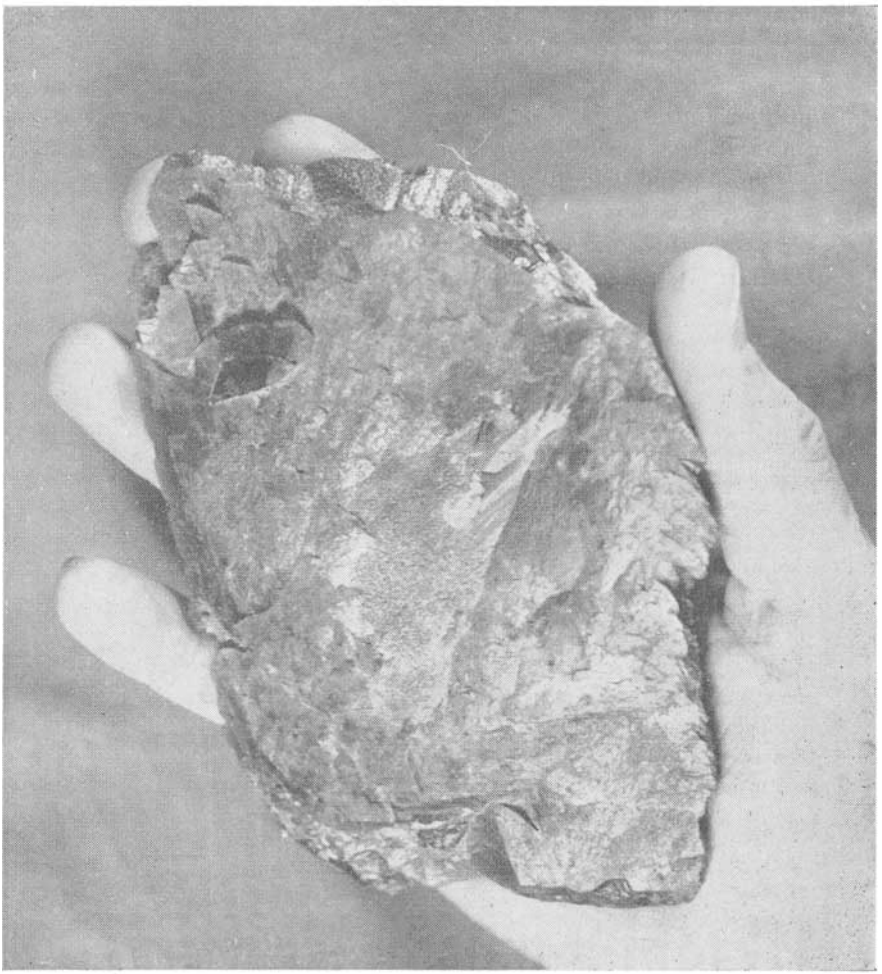

A large sphene crystal, rich in gem material, from Baja, California. (*Photo: courtesy of the Lapidary Journal*)

GEM-TESTING

By A. E. FARN, F.G.A.

GEM-testing could well be the title of a book, a lecture, or merely the sum of all that gemmological students imagine is the itinerary of a laboratory gemmologist's day.

Gem-testing, generally speaking, is a mixture of items in infinite variety; and if variety is the spice of life—ours is spicy! We are fortunate in having no strictly routine work (in an orderly sense), but because of gemmological classes, trade associations and earlier retail experience, we are fortunate in having contact with many aspects of the trade.

Gem-testing to the student is usually visualized by stones being tested on the refractometer, or careful wavelength measurement by a spectroscope, crossed-filter work, immersion inspection by microscope, suspension in jars of clerici solution or density work by balance — plus, of course, the mysteries of the endoscope, that unique instrument understood only by a few and capable of use only by the very dextrous, X-rays, fluorescence, phosphorescence, short-wave lamps and electro-conductivity tests on rare and pale shades of diamonds. These together with immersion contact photography, Lauegrams and direct radiographs, all join to add to the importance and interest of gem-testing.

Strangely enough, a good sense of colour, cut and make of stones together with a 10 × lens still remain the most useful versatile and flexible adjuncts to the trained gemmologist.

Gemmology, and by that I really mean "jewellery" testing, is basically a bread-and-butter science revolving chiefly round the stones which matter. Stones such as diamond, emerald, sapphire, ruby, chrysoberyl, peridot, tourmaline, topaz, zircon, quartz, spinel and beryls. These together with opal, pearl, and turquoise, constitute the major importance in the world of gems.

Practically all the money in the gem trade is made by use of these stones in settings of precious metals. The occasional advent of a rare stone in jewellery is interesting to the collectors and non-trade gemmologists. Here lies their skill and expertise. Many non-productive hours may be spent in the pursuit of interference figures, refractive indices, indications of positive or negative signs

in uniaxial or biaxial stones. Enjoyable as these results may be, they net no cash and cash spells quite a lot of useful things even to gemmologists non-trade!

However, fortunately for us, there are still a lot of people who want to know what the centre blue stone in a cluster is, or whether the emerald in their Aunt Jane's pendant is real or not. Probate valuation of deceased persons' jewellery, where the beneficiaries cannot agree as to who should have Aunt Maria's pearls, can be a very useful source of gem-testing, for here even the smallest items must be detailed, if only to please the Inland Revenue.

All in all, gem-testing, whilst varied, is mundane and concise—very ordinary jewellery set with usually quite small gemstones or pearls of the well-known varieties and, like many other trades or professions, it always seems more interesting to the non-participants. Like watching a plumber wiping a joint—someone else's job always makes my fingers itch, which brings me to a case in point.

A very good friend of mine, watching with keen interest a test being carried out on a customer's ring said, "You know, you go the wrong way round in your testing. You fly to the most spectacular instead of the more fundamental test in routine matters".

Here was a challenge flung down on our own doorstep. However good an amateur may be (and he may well be ten times as enthusiastic as the professional)—he does testing for love whereas the professional does it for money.

To a professional gemmologist, even though he may be a little jaded, the challenge remains constant. He must be right, backed by incontestable facts. To say his facts must be crystal clear (as the gemmologist punned it) are the remarks of a gemmological pundit.

The stone in question was oval, mixed-cut, set in a gold ring—the stone was about $1\frac{3}{4}$ carats in size. Viewed through the microscope I could see angular zoning of colour with a small crescent-shaped feather and on the surface of the stone small zig-zag erupted fractures known as shatter or chatter marks (and doubling of the back facets).

So far as I was concerned, the test was complete. Here was a typical natural blue Ceylon sapphire. My good friend, at home in his own (very efficient) set-up, would have taken the refractive index first. Nothing wrong in doing that, of course, provided you only use your refractometer once or twice a week and there is plenty of time to clean and put it away, etc. *But* if you test

a dozen different pieces of jewellery of all shapes, sizes and categories in a morning between the opening of the registered post and lunch-time, you may well forget (we are all human) to wipe off the liquid. You may also (and I have) leave the stone on the refractometer when answering the telephone and later search frantically for a lost stone—to find later, as a result, crystallization of sulphur crystals on the soft glass prism of the refractometer. If in business you suffer no interruptions—you are obviously not doing much business. It is the unavoidable interruptions, the imperious note of the telephone bell (someone wanting to know how much it will cost to test a string of pearls is the usual—and the answer can take time). Even shopkeepers who are busy are guilty of time wasting. Witness the retailer who is offered a pearl necklace to value—he hasn't a clue but telephones to find out how much it would cost to test.

In the middle of testing a cluster calibré ruby setting to a brooch—the telephone rings, you lose your place and then the customer starts. Usually they have not counted the pearls, they are not conversant with grain size, they did not realize it would possibly have to be cut if genuine, X-rayed if cultured. They cannot give you a lead and are appalled by the charge because they do not realize till then how much is involved. Having courteously dealt with the customer one returns to the brooch and commences again. None of this matters very much provided that along the line of stones inclusions are seen and continuity of testing takes place and you can say that all of the stones you tested are in fact genuine rubies, or synthetic rubies, as the case may be. But how about that one clean stone which gave away nothing? It was a ruby because one saw doubling of the facets and shatter markings—it looked a slightly different red to the others, but because of the nature of the mounting little else other than a vertical sighting in a stone of total diameter under 2 mms could be obtained. So here you are and the customer is calling back in a quarter of an hour for the brooch and you have had a lovely time answering the telephone to a probably non-productive caller.

This is not the time for one's friends to suggest that your methods are not ideal! These occurrences cause certain delays with which our gemmological enthusiasts do not have to contend. Gemmologists usually deal with loose stones of reasonable size with nice flat facets. Our testing is usually in second-hand jewellery—seldom at its pristine best, with worn facets usually and if the mount

is open at the back it is usually clogged up with a fine debris resulting from the onset of talcum powder, cold cream, hand-lotion, soap and all the rest of the lotions, potions and detergent deterrents with which the modern woman's hands are often in contact. I have never had a second-hand piece of jewellery sent in which has been cleaned by the sender for the purpose of testing.

Another *bête noir* can be the customer who is very important (and knows it) and likes immediate attention, and can hardly bear to wait. I have had such persons who bring in, say, a ruby ring for testing. They are usually very shrewd judges of colour and have bought a ring and spent a considerable time testing it in their own office, only to be baffled by a perfectly clean stone. What they see tells them it is real but reluctantly they have to have a laboratory test. They then expect some immediate magic in ten seconds—as soon as it is held under the microscope they ask, "Is it O.K.?" even before one has focused the thing! However, life is not all like that, but most of our customers like to call at least next day for their goods (tested of course).

Having said all this, it now behoves me to settle down to pointing out that despite all the know-how and gadgetry available we cannot always give a definite result while the stone is in a setting. This may seem a little feeble, but in actual fact we seldom ask to have a stone taken from its setting and if we do we usually state our opinion beforehand in order not to appear wise after the event.

Mostly, when we ask for a stone to be taken from a setting, it is a very small synthetic corundum where the curved striae (if any) are running parallel to the girdle and setting. Other difficult cases can be backed baguette colourless stones in a sunken setting precluding refractometer work—these are quite a trial to prove without any doubts lingering.

At one time when we had a colourless cluster surround to a coloured centre in brooch or ring, we could safely say that the colourless stones were not diamond, and usually the customer was not further interested, since money matters.

Nowadays, we usually get asked what the colourless stones are, and surprisingly quite a large number of colourless/white sapphires in Ceylon jewellery are natural sapphires, which rather goes against the usual run of colourless sapphires, which are usually synthetic.

Quite recently we had a pale-pink stone set in a very ordinary

4-claw gold ring. No shoulder stones—just a straight-forward native-cut, slightly lumpy, rounded, cushion-shaped stone. At first glance it could be a fancy spinel, a tourmaline or perhaps a pink topaz. Doing the job the wrong way round, according to my learned friend, I looked at the stone through the microscope. Except for doubling of the back facets—a suggestion of a D R of about ·009—that was all. It could not be topaz, since topaz does not easily or readily show D R. It was not tourmaline, because the bi-refringence was too small, and it did not quite have the typical colour of synthetic or natural pink sapphire. A horrid thought crossed my mind—Taafeite. Fortunately for the peace of the laboratory, it did in fact yield a very positive D R for sapphire. My friend, who did not like my method of approach, would have been vindicated by this since he would have put it on a refractometer first of all. Unfortunately, I have a fetish for trying to pin things down by look, colour, heft, and then microscope to find D R, inclusions, dichroism, shatter-marks, etc. This pink stone ring set me back a few minutes in probing, but now I had to get started and do the obvious, test for synthetic or genuine. Back to the microscope and a dish of methylene iodide. The stone was very clean; in fact, after quite a lengthy session of turning and turning the stone in the ring, lowering the condenser, closing the diaphragm and doing all kinds of useful manoeuvres, I came to a full stop. The stone was a clean pink sapphire with not a sign of curves or bubbles, or any feature whatsoever appertaining to natural. After half an hour of concentrated study under ideal conditions, refiltered liquid, cleaned eye-pieces, objectives and mirror, I changed my mind several times and then gave it up from a microscopic point of view.

One test we often use as a subsidiary is the well known phosphorescence after fluorescence under X-ray of synthetic ruby and pink sapphire. Here, at least, we would get a lead—but no, the stone was completely inert. So it could be genuine. Unfortunately the phosphorescence was only useful to confirm a synthetic whereas the reverse was not so. Our other refinement is to take an immersion contact photograph, hoping, as is so often the case, that structure-lines not readily visible to the naked eye would be revealed by the sensitivity of the film. Once again the result was negative. Somewhat reluctantly we telephoned the customer to ask him to take the stone out.

After the stone was taken out, we found a slight indication of

"treacle" and, I think, if my memory serves me, a few lines of silk. This was not a stone suitable for the diploma examination. We returned it to our customer finally certified as genuine.

Trouble seldom comes in small doses, for a short while after we had a succession of small insignificant rings with microscopic stones in the centre of clusters or as cluster surrounds, and suddenly it seemed as if we were continually asking for stones to be taken out of their settings. However, when one considers we tackle hundreds of items a month of mounted stones, our record is very good.

Recently, a rather rubbed brown cabochon stone in a ring with a reasonable ray to the stone came in for test. At first glance the stone looked a quartz cat's-eye, by the coarse nature of the ray. However, as the stone was worn by bad usage, it could be partially the reason for a poor chrysoberyl looking like quartz. The stone was backed; this prevented one looking at the back of the stone for a hint of quality.

However, the very useful distant vision reading method of taking a refractive index soon solves the question of quartz or chrysoberyl cat's-eye. Maybe I am going a long way round to bring the point home, but the telephone rang whilst I was looking at the stone in question, and having dealt with that matter I returned to the stone, put a spot of liquid on the refractometer and took a spot reading. I saw quite a reasonable changeover light bar at 1·74 which seemed reasonable enough—completely divorcing it from quartz. Automatically, I turned the spot intensity lamp on and tried to see the chrysoberyl absorption spectrum and could not. I was not surprised; there was a lot of glare from a reflected light (the stone was backed). Something did not seem quite right, so I took the distant vision again and got a good quartz reading!

Then the penny dropped—after answering the telephone I pulled the refractometer towards me and put on methylene iodide as a contact liquid (I have two dropping bottles and two refractometers). The methylene iodide gave a good spot pattern for itself and the quartz being rubbed it did not react as strongly as it should.

There seems to be some sort of moral here about keeping bottles separate, but actually at the moment of writing we are threatened with a telephone strike at night. Well, all I say is, let us have it by day and get our testing done without interruptions.

Gemmological Abstracts

HARRISON (E. R.) and TOLANKSY (S.). *Growth history of a natural octahedral diamond.* Proc. Roy. Soc. London, Ser. A, 1964, 279, pp. 490-496.

The pressure and temperature conditions under which natural diamonds grow is still largely unknown. Crystal growth appears to have taken place in layers which often do not lie in crystallographic planes with simple indices. R.A.H.

STEVENSON (P. C.). *Diamond and its origin—new approaches* (Presidential address). Mercian Geologist, 1965, 1, No. 2, pp. 79-88.

The properties of diamond are reviewed and its terrestrial and meteoritic occurrences are described. The conditions for the production of synthetic diamond are considered, and are related to the temperature and pressure postulated for the Earth's upper mantle and to the global distribution of diamonds.
3 figs. R.A.H.

STEINERT (R.). *Suesswasserperlen und Zuchtperlen in Mitteleuropa.* Fresh water and cultured pearls in central Europe. Zeitschr. d. deutsch. Gessel. f. Edelsteinkunde, 1965, 52, pp. 28-30.

During the Middle Ages many pearls were found in Central European rivers, especially in Saxony and Northern Germany on the Lueneburg Heath. Nuns used pearls for precious embroidery and the squires were plagued by pearl thieves. Many pearls were found. It is known that in one year, in 1706, in two rivers only in the Lueneburg Heath area, 295 "ripe" pearls were found. Just as many were found in Saxony and Bavaria, but during the 17th and 18th centuries the industry decreased and it was supposed that the pearl oysters had died, although there are still some pearls found in a few rivers. In the twenties Riedel started to produce cultured pearls in Austria in the "Doblbach" (Dobl river) according to the then Japanese method. He operated on about 150 oysters per year. After his death in 1935 the plant was auctioned. Only 80 pearls were found, but also 400 pearls which were not grown sufficiently yet and would have reached their full beauty a few years later.

E.S.

BANK (H.). *Zur Diagnostik der Edelsteine.* Diagnosing gems. Zeitschr. d. deutsch. Gesell. f. Edelsteinkunde, 1965, 52, pp. 17-28.

The author suggests testing gems using mainly their refractive index and specific gravity and preparing a diagram from these two physical properties of each stone. The method is explained with two examples, a tourmaline and a beryl. There are eight diagrams shown and there is also a bibliography.

E.S.

KLING (W.). *Die chemische Zusammensetzung der Glasimitationen.* The chemical composition of glass imitations. Zeitschr. d. deutsch. Gesell. f. Edelsteinkunde, 1965, 52, pp. 13-17.

The author shows the relation between the chemical composition of glasses and their properties as gem imitations. As the atomic weight of the oxides of the elements used is increased, so the density and the refractive index of the imitation glass also increases. Colouring substances are then added.

E.S.

SCHLOSSMACHER (K.). *Naturbernstein und Pressbernstein.* Natural and pressed amber. Zeitschr. d. deutsch. Gesell. f. Edelsteinkunde, 1965, 52, pp. 10-13.

Pressed amber is produced from very small carefully cleaned pieces of amber, usually sorted according to colour, which are heated under hydraulic pressure to about 200°-250°C in vacuo. The material produced has about the same homogeneity as natural amber. A useful method of differentiating between the two is to polish the stones with an oily woollen cloth and some polishing material like chalk till it is fairly hot. Natural amber becomes smoother and shinier while pressed amber will become matt in places. There is some difficulty about the nomenclature, as according to German law it must be clearly stated whether the amber is pressed or natural. E.S.

BANK (H.). *Systematik der Edelsteine auf kristallchemischer Grundlage.* Systematic classification of gems based on their crystal chemistry. Zeitschr. d. deutsch. Gesell. f. Edelsteinkunde, 1965, 51, pp. 23-33.

The article starts with a historical survey of classification. In

1802 gems were classified as gems for jewellery, gems used in medicine and gems used in ornaments. In 1860 gems were subdivided into precious and semi-precious gems, each category again subdivided according mainly to value. There were various other suggestions, mainly classification according to the chemical composition. The author proposes the following main categories, which can then be sub-divided: (1) elements, (2) sulphides, (3) halogenides, (4) oxides, (5) (a) carbonates, (b) borates, (6) (a) wolframates, (b) sulphates, (7) phosphates, (8) silicates, (9) organic compositions. A bibliography is given.

E.S.

THURM (R.). *Ein neues Polariskop und Konoskop.* A new polariscope and conoscope. Zeitsch. d. deutsch. Gesell. f. Edelsteinkunde, 1965, 51, pp. 38-42.

A 40-watt lamp is used as a light source. Above this lies the polarizex, which is a polaroid filter, and above this is the lens on a rod; then comes the analyser and a lens, both of which can be rotated and adjusted in height to suit the size of the stone examined. Bibliography.

E.S.

BANK (H.). *Die Smaragdsynthese von Hermann Wild* 1912. The emerald synthesis by Hermann Wild in 1912. Zeitschr. d. deutsch. Gesell. f. Edelsteinkunde, 1965, 51, pp. 43-47.

Wild synthesised emerald in 1912. This synthesis was described a year later by Brauns and in 1914 by Michel. The crystals produced were only 1 mm long, some were transparent, some had tiny inclusions, the specific gravity was 2·654. Photographs of these synthetic emeralds are reproduced.

E.S.

DENNING (R. M.). *Directions of no-image doubling in crystals.* Gems and Gemology, 1965, 10, XI, pp. 299-301.

Discusses the "doubling of the facet edges" seen in doubly refractive stones, and mentions the difficulty of this effect being seen in topaz. It is explained that no doubling will be seen when the view is taken along an optic axis nor when viewed through any facet which is parallel to an optic axis in uniaxial stones or when viewed along either α, β or γ in biaxial stones. R.W.

GÜBELIN (E. J.). *Maw-Sit-Sit proves to be jade-albite.* Gems and Gemology, 1965, 10, XI, pp. 302-308.

Further experiments on the composition of this stone are recorded. Use is made of an electron micro-probe analyser, which is described, on the green mineral which forms the colouring of Maw-Sit-Sit. The results imply that this mineral has a chemical formula corresponding to Na (Fe,Cr,Al) Si_2O_6, and that it has 10% of Cr_2O_3, and may be said to be a chrome jadeite. From these experiments Maw-Sit-Sit may be logically called a jade-albite.
4 illus. R.W.

GÜBELIN (E. J.). *Maw-Sit-Sit.* Gems and Gemology, 1964/5, 8, XI, pp. 227-238 and 255.

A similar version of the article published in the Journ. Gemmology (No. 10, Vol. IX, April 1965), but with different half-tone illustrations.
17 black and white and 1 coloured illus. R.W.

POUGH (F. H.). *Mallorca and imitation pearls.* Gems and Gemology, 1965, 9, XI, pp. 273-280.

Describes a visit to an imitation pearl factory in Mallorca (Majorca). Various qualities of imitation pearls are produced. The better types, which have a glass core, are coated with a number of "coats" of essence, one of which is fish-scale essence (essence d'orient), the others being synthetic essences. A new method of making the glass beads involves the use of a slurry coated wire which allows the glass beads after forming to be easily slipped off the wire. This avoids the dissolving out of the wire by acid.
10 illus. R.W.

DARRAGH (P. J.); SANDERS (J. V.). *The origin of the colour in opal based on electron microscopy.* Gems and Gemology, 1965, 10, XI, pp. 291-298.

A similar report to that published in the Australian Gemmologist. (Abst. Journ. Gemmology, pp. 402/3, No. 11, Vol. IX, July 1965).
7 illus. R.W.

CROWNINGSHIELD (R.). *Developments and highlights at the Gem Trade Lab. in New York*, Gems and Gemology, 1964; 1964/5; 1965, 7, 8, 9 and 10, pp. 214-218; 242-246; 265-272; 309-312.

Descriptions are given of a number of stones tested in this laboratory. Outstanding items mentioned are a change-colour tourmaline, a green topaz, a chromeless (?) emerald, odontolite, a carved psilomelane, flame-fusion synthetic rubies, a grey-blue kornerupine and a yellow apatite cat's-eye. A "piggy-back" diamond ring in which two stones are mounted on one another is mentioned and there are notes on the examination of a number of "painted" diamonds. Brief details are given on the examination of a synthetic alexandrite and on other specimens of synthetic stones of garnet type.

45 illus. R.W.

LIDDICOAT (R. T.). *Developments and highlights at the Gem Trade Lab. in Los Angeles.* Gems and Gemology, 1964; 1964/5; 1965, 7, 8, 9 and 10, XI, pp. 219-221; 247-253; 281-286; 313-317.

The laboratory reports on a dyed alabaster and fluorite pink and green bead necklet, a brooch with a frame of tortoiseshell which had a carved limestone figure mounted on it, a drop-shaped pink pearl which had been divided into two to give two half pearls, a chatoyant nephrite called "pigeon's-eye", macro-curved structure lines seen in both a ruby and a sapphire, black serpentine simulating jade and an unusual "painted" jade cabochon mounted in a ring. A periclase was submitted with the request as to whether it was natural or synthetic. This could not be determined but the customer implied that it was synthetically produced.

38 illus. R.W.

POUGH (F.). *New Brazilian source for a well-known gemstone.* Lapid. Journ., 1965, 19, 6, p. 688.

Reasonably clean crystals of alexandrite, which were exhibited in California in the summer of 1965, came from Brazil. The locality, presumably in the Minais Gerais district, is given as Agua Vermehla, with the mine name as Mina de Cristolite. Other crystals of alexandrite from Brazil have also been reported.

S.P.

WHITE (L.). *New beauty in petrified Wood.* Lapidary Journal, 1965, 19, 8, p. 870.

A short account of petrified wood with remarkable examples by the author of colour photography made by using a process described as "reflective light". The areas of petrified wood photographed were about the size of a pin-head. The technique of photographing the small cells found in petrified wood, which give rise to a wonderful play of colour, took a long time, including a year and a half to construct a special camera and find the right lens.

S.P.

ZAVERI (C. K.). *The gemstone industry of India.* Lapidary Journ., 1965, 19, 8, p.938.

An interesting account of the less expensive gemstone business in India. It is unfortunate that the author uses the meaningless term "semi-precious" to describe several of the lovely gem materials which India can provide.

S.P.

NEYS (A. de). *Diamond cutting through the ages.* Diamant, 1965, 8, p. 49.

A short account in English, Flemish and French.

HERRMANN (R. C.). *New discovery of gem quality rhodonite in British Columbia.* Lapidary Journ., 1965, 19, 7, p. 792.

A deposit of gem quality "Inca rose" rhodonite has been discovered near Fulford Harbour, Salt Spring Island, British Columbia.

S.P.

AGEE (L. M.). *Asterism in garnets.* Lapidary Journ., 1965, 19, 8, p. 910.

A short account of the largest known placer deposit of garnet in the world, in Idaho, in a small range of mountains between Fernwood and Clarkia. Notes on the cabochon cutting of garnet, in order best to display the phenomenon of asterism, are given.

S.P.

BOOK REVIEW

BRAGG (L.) and CLARINGBULL (G. F.). *Crystal structure of minerals* G. Bell and Sons Ltd., London, 1965. 70s.

This is volume four of a series "*The Crystalline State*", which Sir Lawrence Bragg is editing. To gemmologists Sir Lawrence, who is director of the Davy Faraday Laboratory at the Royal Institution, is better known as the President of the Gemmological Association and Dr. Claringbull is Keeper of Minerals at the British Museum (Natural History) and senior examiner of the association.

This is an erudite treatise intended partly for present-day degree courses mineralogy and is beyond the scope of most gemmologists. The book brings up to date the work "*The Atomic Structure of Minerals*", written by Sir Lawrence in 1937. A chapter on feldspar has been added by Dr. W. H. Taylor of Cambridge University. In order to keep the book within reasonable bounds, selection had to be made of the crystal structures described and illustrated. It will be essential reading for many mineralogists.

S.P.

ASSOCIATION NOTICES

OBITUARY

FRANK HENRY KNOWLES-BROWN

The Council has recorded, with deep sorrow, the death of Mr. F. H. Knowles-Brown, on 30th November 1965 at the age of 68.

Mr. Knowles-Brown, or 'K.B.' as he was affectionately known to his many friends in the jewellery trade, gained his diploma with distinction in 1930, whilst in business with his brother in a retail jeweller's in Hampstead. Upon qualifying as an optician he was elected a Fellow of the Spectacle Makers' Company.

In 1939 he became Vice-Chairman of the National Association of Goldsmiths and was Chairman of that organization from 1941 until 1944. In 1944 he was elected as Treasurer and served in that capacity until 1961.

The Gemmological Association was honoured when he became Chairman in 1946. In 1955 he was succeeded by Sir James Walton, but when Sir James died a few months after his election, the Council of the Association invited K.B. to serve again as Chairman. This he did until May of 1965, when ill health compelled him to give up all his activities. K.B. was a founder member of the Antiquarian Horological Society, and became its first Chairman in 1953, an office he held until 1961.

K.B. thrived upon hard work and endeared himself to many members of the jewellery trade, gemmologists and horologists, by his enthusiasm and dedication to the causes in which he believed. He held strong views on the dignity of the jewellery trade being maintained by high standards. K.B. had a remarkable way of making people feel at their ease — a trait which was greatly appreciated by the many jewellery trade candidates who came before him when he was an examiner to the National Association of Goldsmiths. Above all he had a wonderful sense of humour and it is perhaps this that caused him to be regarded with affection by those whom he inspired to do hard work. He had leadership, the ability to inspire, and a great sense of fun. Although a competent optician and jeweller, he was more of a philosopher than a man of business, and this made him all the more lovable. K.B. was a distinguished person who will be sadly missed.

GIFTS TO THE ASSOCIATION

An example of the Juliana cut, in white synthetic spinal, from Don Hartley of E. Detroit, Michigan.

COUNCIL MEETINGS

A meeting of the Council of the Association was held at Saint Dunstan's House, Carey Lane, London, E.C.2, on Tuesday, 14th September, 1965. Mr. Norman Harper, the Chairman, presided, and welcomed Mr. Maurice Asprey, who was attending his first meeting since being co-opted a member of the Council.

Sixty ordinary members, eight probationary members were elected and thirty-eight diploma holders were elected to Fellowship (as set out below).

The Council discussed the report of the 1965 examinations (details are set out on p. 36) and heard from the examiners, who were also present at the meeting, of the care that had been taken in assessing the papers to ensure that no injustice had been done to any candidate. It was decided to examine the conditions under which prizes were awarded in the examinations at the next meeting of the Council.

At the meeting held on Tuesday, 14th September 1965, the following were elected:—

To Fellowship:

Jones, Robert J., Ross-on-Wye, Hertfordshire. D.1965

Smith, Stephen S., Hull, Yorks. D.1965

To Probationary Membership:

Banks, David F., Lawrence, Kansas, U.S.A.
Forman, Stephen Michael, Manchester, 8, Lancs.
Hartmann, Carolus J., Eindhoven, Holland
Hill, Raymond J., Burlington, Ont., Canada
Major, Peter Wm. E., Horsted Keynes, Sussex
Mure, Patrick, Geneva, Switzerland
Wetton, Roy Nevil, Alrewas, Staffs.
Wright, Rodney B., Maurewa, Auckland, New Zealand

To Ordinary Membership:

Arends, Henri, Amsterdam, Holland
Bass, Paul, Purley, Surrey
Baxter, James, Edinburgh 9, Scotland
Bhavnani, K. J., Bombay 1, India
Bowley, Malcolm A., Bukuru, N. Nigeria
Boyd, Arthur F., Christchurch, New Zealand
Brown, Judith A. (Miss), London, N.W.8
Buchanan, Kenneth R., Tulsa, Oklahoma, U.S.A.
Bull, Rudolf, Lucerne, Switzerland
Cherns, Jack J., London, N.W.3
Cooper, Revd. S. B. Nikon, Staines, Middx.
Craft, Herscu R., Caracas, Venezuela
Culver-James, Frederick W., London, S.W.17
Cutting, Derrick C. A., Montreal, Quebec, Canada
Dam, Kristian F. J., Watford, Herts.
Dani, M. N., Bombay 4, India
Delplace, Claire (Mrs.), Brussels 15, Belgium
Devries, Jacob, Curacao, Neth. Antilles
Dodd, Albert V., Elko, Nevada, U.S.A.
Dudek, Clelan F., Pendleton, Oregon, U.S.A.
Eales, Adrian H., Lusaka, Zambia

Farringer, Dale E., Annandale, Va., U.S.A.
Firth, Roy, Ambleside, Westm.
Fleming, Clifford Jack, Southsea, Hants.
Gaal, Robert, Los Angeles, Calif, U.S.A.
Gerboth, Niles R., Los Angeles, Calif., U.S.A.
Goldsby, Reginald H., Bradford 9, Yorks.
Haenni, Heinz, Zurich, Switzerland
Hartley, Donald W., Detroit, Michigan, U.S.A.
Hutchinson, Ronald F., Akwatia, Ghana
Jemison, Edward T., Tokyo, Japan
Johnson, Terence R., Salisbury, Rhodesia
King, A. I., Jersey, C.I.
Klaassen, Ferdinand, 's Hertogenbosch, Holland
Kotani, Toshiji, Osaka, Japan
Levy, Marion D., Atlanta, Georgia, U.S.A.
Lewis, Curtis W., Raleigh, N. Carolina, U.S.A.
Loung, George R., Georgetown, Demerara, British Guiana
Luder, Johan G., The Hague, Holland
Lunsford, David W., Huntsville, Alabama, U.S.A.
Mano, Koichi, Osaka, Japan
Moyse, Edith (Miss), Toronto, Ont., Canada
Mumford, Ronald B., Kuala Lumpur, Malaysia
Myer, Lewis L., Huntington Beach, Calif., U.S.A.
Nussbaum, Eric E., Geneva, Switzerland
Owen, Robert E. L., Portmadoc, Caerns.
Prieler, Willy, Vienna, Austria
Radcliffe, William A., Johannesburg, Transvaal, S.A.
Saunders, Gordon N., Kitchener, Ont., Canada
Saxe, John R., (Green Bay), Wisconsin, U.S.A.
Sitzer, Danial H., New York, U.S.A.
Smith, Roger, Keynsham, Somerset
Smith, Wilbur E., Washington, U.S.A.
Stoll, F., Florida, Transvaal, S. Africa
Thornton, Timothy M., Cranbrook, Kent
Treece, Walter E., Pittsfield, Mass., U.S.A.
Watney, B. M., (Dr.), London, N.W.3
Weisler, Joseph, New York, U.S.A.
West, Lionel W., Hatfield, Herts.
Westall, Erica (Miss), Cape Province, S. Africa

TRANSFERS FROM ORDINARY AND PROBATIONARY MEMBERSHIP TO FELLOWSHIP:

Bana, Homi R., Bombay, India
Brimelow, William, Southport, Lancs.
Carr, Philip W., Blackburn, Lancs.
Clough, M. B., Bolton, Lancs.
Cole, Kenneth C., Salisbury, Rhodesia
Cook, Murray E., Vancouver, Canada
Cooper, S. B. Nikon, (Rev.) Staines, Middx.
Drew, William H., Wellington, New Zealand
Franke, Lois E. (Miss), Hollywood, U.S.A.
Gadebusch, Dedo A., Koln, Germany
Gauntlett, Gillian (Miss), Haslemere, Surrey
Hanebach, Stanley, Scarborough, Canada
Hanna, Joe D., St. Louis, U.S.A.
Holmes, Milton J., Owen Sound, Canada
Imai, Taichiro, Tokyo, Japan
Inkersole, Denis, London

Jones, Robert J., Ross-on-Wye
Kerez, Christoph J., Baden, Switzerland
Lee, Joseph I., Raleigh, U.S.A.
Lewis, Leslie John, London
Millar, Maurice A., Dannevirke, New Zealand
Moore, Henry, Solihull, Warwicks.
Myers, Leah M. (Miss), Sydney, Australia
O'Donnell, Arthur L., London
Oesterlin, Wilhelmina P. (Mrs.), Mosman, Australia
O'Grady, Royston J., Stafford
O'Shea, John P., Worthing, Sussex
O'Sullivan, Timothy, Dublin, Eire
Riding, Frank, Preston, Lancs.
Simmonds, Stephen M. J., London
Smith, Stephen S., Hull, Yorks.
Taylor, Allan M., Melbourne, Australia
Taylor, Andrew Wm., Exeter, Devon
Thomas, Graham A., Mold, Flints.
Ungar, Michael S., Ruislip, Middx.
Wetton, Roy Nevil, Burton on Trent, Staffs.

* * * *

A meeting of the Council of the Association was held at Saint Dunstan's House, Carey Lane, London, E.C.2. on Tuesday 9th November, 1965. The chairman, Mr. Norman Harper, presided.

The following were elected:—

FELLOWSHIP

Allan, Christine M. (Miss), Stanway, Essex
Allan, Ian E., Birmingham 28, Warwicks.
Armour, Anthony J., Beckenham, Kent
Bailey, Ronald, Dudley, Worcs.
Barratt, Susan M. (Miss), Birmingham. 11, Warwicks
Baxendale, Paul D., Birmingham 16, Warwicks.
Beaumont, Gordon, Huddersfield, York.
Bethel, George C., Hiaeah, Florida, U.S.A.
Bird, Albert J., Liverpool, Lancs.
Cannawurf, Christa (Miss), Frankfurt, Germany
Clarkson, Roland N., Shepperton, Middx.
Cross, William G. (Dr.), Moor Park, Middx.
Edmunds, Ronald C., Wembury, Devon
Farley, Peter F., Bath, Somerset
Frost, Allan R., Llanblethian, Glam.
Gasser, Josef, Lucerne, Switzerland
Goode, Alastair R., Solihull, Warwicks.
Heaven, John P., Birmingham, Warwicks.
Hesse, Kenneth R., Fallbrook, Calif., U.S.A.
Hogervorst, Lia Angelique (Miss), Gouda, Holland
Jackson, Christopher D., Chipperfield, Herts.
Jones, Alfred, Coventry, Warwicks.
Laing, John, London, S.W.12.
Lewis, Kenneth C., Rainham, Essex
Mole, Christopher J., Birmingham
Morley, George K., Wymondham, Norfolk
Nicolau, Jose G., Madrid, Spain
Ogden, Glendower M., Harrogate, Yorks.
Parker, Lovell W., Dublin, Eire
Podhorodecki, Josef, Sherwood, Notts
Randle, Rodney C., Birmingham, Warwicks.
Sher, Morris M., Glasgow S.3, Scotland
Stern, Marion J. (Miss), Wembley Park, Middx.
Thomson, Harry, Lichfield, Staffs.

Toole, John Lewis, Stouffville, Ont., Canada
Wheeler, Jennifer M. (Miss), Melbourne, Australia
Bridges, Reginald J., Chigwell, Essex

PROBATIONARY MEMBERSHIP

Arbeid, Martin J., London, S.W.1.
Bates, Denis Wm., London, S.W.9.
Berwick, Keith J., Portsmouth, Hants.
Blowfield, Ian S., Pinner, Middx.
Boers, Leonie, Naarden, Holland
Chalfen, Brian J. L., London, N.W.10.
Chamberlain, David Alan V., Wallasey, Cheshire
Cohen, Raymond, London, N.14.
Cutts, Michael J., Surbiton, Surrey
Dando, Nigel J., Bath, Somerset
Davies, Derrick K., Harlington, Middx.
Lazarus, John S., Edgware, Middx.
Lowe, Peter J., Chester
McBryde, Michael G., West Harrow, Middx.
Miller, Elizabeth A. (Miss), Wolverhampton, Staffs.
Miller, Fanny (Mrs.), Toronto, Ont., Canada
Newham, Frank Edward, London, E.10.
Pryke, Christine M. (Miss), Colchester, Essex
Rees, David, Hounslow, Middx.
Russell, Madeleine (Miss), Ilford, Essex
Sanitt, Neil, London, N.W.10.
Spicer, Malcolm F., Gerrards Cross, Bucks.
Ward, Michael I., Enfield, Middx.
Halls, Norman E., London, E.6.

ORDINARY MEMBERSHIP

Abubaker, Haji, Karachi, Pakistan
Bradbery, Jean I. (Mrs.), London, N.W.3.
Burnstein, Burton A., Los Angeles, Calif., U.S.A.
Caspart, Peter, Mainz/Bretzenheim, Germany
Chan, George K., Kowloon, Hong Kong
Chartier, H. P., Esher, Surrey.
Cramer, Marvyn H., San Francisco, Calif., U.S.A.
Cunningham, J. Lester, Chicago, Illinois, U.S.A.
Dittrich, Marion, Toronto, Canada
Dunkley, Peter J., Coventry, Warwicks.
Forman, Evelyn M. (Mrs.), Buckingham
Gani, Usman H., Karachi, Pakistan
Gillon, Mary (Mrs.), Glasgow, Scotland
Hammond, Dudley E., Vancouver, Ont., Canada
Huddlestone, Roy V., Melton Mowbray, Leics.
Hunter, Wilfred, Ambleside, Westm.
Imai, Kiichi, Tokyo, Japan
Jayasundera, A. B., Badulla, Ceylon
Karpovitch, Stefanie S. (Miss), New York, U.S.A.
Klassen, Ferdinand, 's Hertogenbosch, Holland
de Leon, Anthony, London, W.6.
Mendis, Cynthia M. (Mrs.), Kingston on Thames, Surrey
Miller, William H., Wolverhampton, Staffs.
Mitchell, Kenneth G., London, S.E.15.
Nixon, Rolf, Washington, U.S.A.
Pearce, David M., Colchester, Essex
Piguet, John A., Le Sentier, Switzerland
Regan, James P., London, N.17.
Stoll, Kurt P., Hong Kong
Sun, Loo Chin, Penang, Malayasia
Wright, Dorothy Willow (Mrs.), Marville, France
Osmond, Leslie P., Akwatia, Ghana

The Council considered the conditions governing the award of the Tully Memorial Medal and instruments prizes presented by Messrs. Rayner & Keeler, Ltd. It was decided that the medal should be awarded to the candidate in the diploma examination who submitted the best papers, which were of sufficiently high standard to merit the award, and that the Rayner Preliminary prize and the Rayner Diploma prize of gem-testing instruments (made by Rayner or Carl Zeiss (W. Germany)) should be awarded to the candidates submitting the best papers of sufficiently high standard in both examinations who, in the opinion of the Council, are members of the jewellery industry. The Council's decision in all matters appertaining to examination results and the award of prizes would continue to be final.

It was reaffirmed that because of the great care taken in assessing and re-assessing the examination papers any subsequent reconsideration of scripts after the results had been announced was not necessary.

The Council also decided not to depart from the long standing practice of not publishing suggested examination answers or of the marks obtained in the examinations.

Appreciation of the generosity of Messrs. Rayner & Keeler, Ltd., for continuing the award of instrument prizes and the work of the Honorary Branch secretaries was recorded.

TALKS BY MEMBERS

BLYTHE, G. A. "Gemstones"; Basildon Inner Wheel Inter-Club, Southend-on-Sea, 21st October 1965.

COOP, N. (Miss): "Gemstones", Townswomen's Guild, Luton Ichnield, 6th September, St. Paul's Girls School, League Social Club, 21st October, Barnes Club for the Blind, 1st November, Senior Wives' Fellowship, London Branch, 1st December, 1965

HUDSON, F. "Gemstones"; Electrical Association for Women, Dunfermline, 5th October, 1965; Women's Guild, Holy Trinity Church, Dunfermline, 11th October, 1965; Trefoil Club, Dunfermline, 4th November, 1965; Scottish Gliding Union, Scotlandwell, 13th November, 1965; Ladies' Circle, Dunfermline, 19th January, 1966.

JONES, T. "Gemmology"; Abingdon Rotary Club, Abingdon Inner Wheel, Bicester Inner Wheel, October and November.

LANGTON, E. W. "Diamonds"; Highgate Young Conservatives, London, 15th October 1965.

PRESENTATION OF AWARDS

Sir Cyril Dyson, President of the National Association of Goldsmiths, the retail jewellers' organization, presented the Diplomas and prizes to the successful students who sat for the Gemmological Association's 1965 examinations. Ten students had qualified with distinction in the Diploma examinations, and two Tully medals were given. This is only the fourth time in the Association's history that two of the medals have been given in one year. One of the winners was

Miss Christa Cannawurf of Frankfurt, who came from Germany to receive the medal. The other winner was Mr. Andrew W. Taylor of Exeter.

Introducing Sir Cyril Dyson, Mr. Norman Harper, the Association Chairman, said that there were successful students present in the hall from Japan, Germany, Holland and Eire, as well as the successful British students. The Chairman commented "1965 has been a record year. The Association has had the greatest number of course enrolments, the biggest ever examination entry and the most enrolment from overseas. More new members have been elected than ever before and tonight is the biggest gathering we have ever had at Goldsmiths' Hall".

Mr. Harper acknowledged the indebtedness of the Gemmological Association to the National Association which, in 1908, had been responsible for setting in train the educational scheme that led to the teaching of gemmology. He felt sure that it was a matter of pride and satisfaction to the N.A.G. to realize that their sister organization had been so successful.

In asking Sir Cyril to present the prizes, Mr. Harper mentioned that Sir Cyril had been to 10 Downing Street as a result of an invitation to see the clocks there that he had received from Mrs. Wilson on the occasion of the opening of the International Watch and Jewellery Trade Fair at Earl's Court.

Sir Cyril, after giving out the certificates and prizes, recalled how in his father's time a stone was either a natural stone or a piece of glass, a pearl was either real or imitation. Today, with all the synthetic stones and cultured pearls about, life was much more difficult for the jeweller, he said, and a trained gemmologist was a tremendous asset to any jeweller. He explained that he was an horologist and an optician and only had a Preliminary certificate for gemmology, but it was impossible to study everything at once. He spoke to the audience about the 300 clocks in Windsor Castle. In concluding, he said he hoped that the Diploma winners would not only continue their work but would derive satisfaction from the very fascinating and absorbing subject.

Thanking Sir Cyril, Mr. B. W. Anderson said it was gratifying that they had someone to present the prizes who had done so much for the retail jewellery trade. Students had been told that after gaining their Diplomas, they were in a position to start learning something about gemmology. There was always something new which needed studying again and the advantage was to know what to do about it. He wondered if it was not possible for some organization to be set up to pass round interesting gemstones, as so many students after they had qualified lacked the opportunity to handle many stones.

At the end of the meeting the Chairman expressed the Association's thanks to the Worshipful Company of Goldsmiths for once again lending their beautiful Hall for the Presentation.

HERBERT SMITH MEMORIAL LECTURE

The 1965 Herbert Smith Memorial Lecture was given by Mr. Robert Webster, F.G.A., at Goldsmiths' Hall, London, on 9th November. Mr. Norman Harper, chairman, presided, and introducing the lecturer referred to his distinguished work in the cause of gemmology.

Mr. Webster commenced the lecture by referring to the artificial colouration of diamonds by bombardment with particles of atomic size. He recalled that diamonds coloured green by radium emanations had been known since 1912, and that some diamonds so coloured were still occasionally met with. Their residual radioactivity allowed easy distinction and they presented no problem of identification.

Although as early as 1942 reference had been made, he said, in scientific literature to the artificial colouration of diamonds by atomic bombardment, it had not been until well after 1950 that the process became a commercial proposition.

The first of these methods had been by the use of a cyclotron which emitted high speed atomic particles. This treatment had produced a green colour only skin deep. Subsequent heat treatment had produced a golden brown or yellow colour in the greened diamonds. This method seemed now to have been generally superseded by treatment with fast neutrons using an atomic reactor. The colour changes were again similar; green, or after subsequent heat-treatment golden or yellow, the stones in this case being coloured throughout. The third type of colouration was by fast electrons and here the stones, again only coloured skin-deep, were turned to an aquamarine or to a bluish green colour.

Despite the fact that the trade didn't quibble about the colour alteration which produced the sky-blue zircons and the pink topazes, the alteration in the colour of diamonds was considered in a different light and the gemmologist was expected to identify those diamonds which had been artificially coloured. Mr. Webster then went on to describe the tests which revealed this artificial colouration.

Mr. Webster next went on to talk about new sources of gem material. As far as the corundum gems were concerned, he said, there had been some new sources of supply: Finland, Mysore in India, and most important in Tanzania. The ruby crystals in green zoisite from just north of Kilimanjaro, in Tanzania, normally used together in the rock as an ornamental stone, had produced small cut stones. Further south, along the Umbo River, sapphire and ruby had been recovered which produce cut stones; the sapphire often of fancy colour matching the rhodolite garnets found in the same locality. Verneuil's flame fusion method still seemed to be the only commercial method of synthetic corundum production, and the only improvements seemed to be in the automation of furnace feeds and by, in one case, using crushed Montana sapphire as a feed material. The newer techniques such as flux-melt and hydrothermal methods of growing ruby crystals are mostly used for growing maser and laser crystals, and such products had not as yet become a gemmological problem.

It was with the beryl group, particularly the emerald, that a number of new aspects had come up recently. Recent finds of green beryl in Brazil needed comment, he said. Recently some green beryl of pale emerald colour had been examined in this country and in the United States. The material did not seem to show a typical absorption spectrum and was considered chromeless and therefore not emerald. Some people, however, proposed to take it as a borderline case, and on the grounds of the colour suggested that it should be called emerald. To further complicate matters analysis both in the United States and in this country had disclosed a trace of chromium in the composition. This material was said to

come from the district of Salininha, in the municipality of Pilao Arcado in Bahia, Brazil. Some similar material seemed to be coming from Brumado in the same State.

What was becoming of increasing importance, he went on, was the synthetic production of emerald. Until last year the synthetic emerald made by Carroll Chatham was the only commercial production. Now we had the French type made by Pierre Gilson and the Zerfass German production, though these did not at the moment seemt to have much commercial significance. Then quite recently the Linde people of America had published details of their hydrothermal production, but did not as yet seem to have marketed them. No specimens of this emerald had been seen in this country as yet.

Later in his lecture he spoke about non-nucleated cultured pearls which he said were unknown before 1953. They were produced from a freshwater mussel by inserting into the edges of the mantle pieces of graft tissue cut from the mantle of another mussel. This acted as an irritant which then initiated the formation of a pearl which was white in colour, but was usually bun-shaped. These pearls were grown in the freshwater lake Biwa Ko in Japan. They usually showed when an X-ray direct picture was taken, peculiar and characteristic cavities and also a strong yellowish fluorescence under X-rays. When such pearls are cut open the peculiarity of the structures was dissimilar from those shown by natural pearls. A characteristic of this culturing process was that a second crop of pearls might form in the places where the original cultured pearls were formed, and had been removed, as in this method of cultivation the mussel was not killed in the process. Some large pearls have been grown in Australian waters by this method. The characters are similar, but as they were sea-water pearls these did not fluoresce under X-rays.

A new type of nacreous natural pearl was the pink pearl, he said, found in East Pakistan, which had recently been shown in America and London. These were river pearls and were quite pretty and might make a good addition tothe pearl range.

Another innovation was the use of mother-of-pearl beads as the cores of imitation pearls. These had been advertised as "shell-base imitation cultured pearls". The fact that when such pearls are held before a light the "stripes" of the layers of the mothr-of-pearl showed through might give an impression that the beads were thin-skinned cultured pearls.

After question time the chairman thanked Mr. Webster for what had been an outstanding talk and invited the audience to inspect the collection of recent gemmological developments which Mr. Webster had arranged.

Before the lecture, early arrivals had the opportunity of a pre-view, by courtesy of the Goldsmiths' Company, of an exhibition of jewellery by the well-known Swiss designer, Mr. Gilbert Albert.

The chairman expressed the appreciation of the Council of the Association for this facility and for the use of the Livery Hall for the lecture.

MIDLANDS BRANCH

A meeting of the Midlands Branch of the Association was held at the Imperial Hotel, Birmingham, on 22nd September, 1965. Mr. Norman Harper, the

National Chairman who has also taken the chair of the Midlands Branch this year, presided and introduced the speaker, Mr. Trevor Solomon, F.G.A. Mr. Solomon, who has given several interesting talks to the Branch enchanted his audience by speaking about "Biblical and historical stones".

WEST OF SCOTLAND BRANCH

Mr. A. Monnickendam, of London, was the guest speaker at a meeting of the Branch, which was held in Glasgow on 14th October. The title of Mr. Monnickendam's talk was "Diamonds in a world of unsettled economy" and it provoked numerous questions, enjoyed both by the speaker and his audience.

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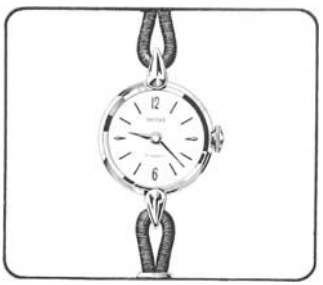

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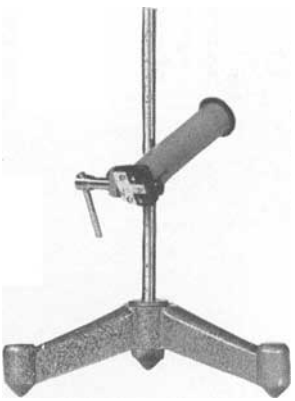

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Vol. 10 No. 2 APRIL 1966

CHROMIUM AS A CRITERION FOR EMERALD

By B. W. ANDERSON, B.Sc., F.G.A.

NO-ONE can deny that the finest reds and the finest greens in the whole field of gemstones are due to the presence of small quantities of chromium in an intrinsically colourless host mineral. Ruby and emerald serve as the best and most typical examples of each case, and it is significant that these are by far the most valued varieties of corundum and of beryl.

That emerald owes its colour primarily to traces of chromic oxide was recognized at least one hundred years ago by scientists. In his standard work "Manual of Mineralogy" by J. D. Dana (1862) for instance, the author stated: "The *emerald* includes the rich green variety; it owes its colour to oxide of chrome. *Beryl* especially the paler varieties which are coloured by oxide of iron . . . *Emerald* contains less than one per cent of oxide of chromium".

Later and lesser authors have voiced a less positive opinion; and while the evidence had to rest upon the *supposed* effect of a *supposed* small amount of chromium estimated by the laborious methods of quantitative chemical analysis, there was some justification for doubt and for alternative suggestions as to the cause of colour in emerald beryl. But during the last half-century or so when the evidence of analysis has been reinforced by the synthesis of emerald, and where absorption spectroscopy can be used to give

quick and positive evidence, not only that the element chromium is present, but also that it is affecting the colour of the beryl crystal in a particular and characteristic way—the evidence has become so strong as to be unassailable.

And the reverse proposition should also hold. Since all emeralds owe their fine colour to chromium, no beryl lacking chromium should be called an emerald. This view was voiced over thirty years ago by the noted German gemmologist and dealer, G. O. Wild, who had pioneered in making a thorough study of the cause of colour in gemstones.[1] He wrote (1934), "The criterion for emerald is solely a content of chromium and possibly vanadium, to which the colour is due", and, later in the same article, "Any beryl whose colour is not chiefly due to chromium must in future be refuted as a true emerald". It must in fairness be added that Wild in an article "What is an Emerald?" written thirteen years later, finds it more difficult to hold to this unequivocal position. He was troubled by a difficulty in categorizing as emeralds or as green beryls stones from a Brazilian locality, Ferros, in Minas Gerais. These stones showed a chromium and vanadium content, but in some specimens were certainly not emerald from the commercial standpoint. The question is raised again to-day by the appearance of other Brazilian beryls, on this occasion from the Salininha locality in Bahia. These have been promoted as "emeralds", and even accepted as such in some quarters in the U.S.A., despite the fact that they contain no perceptible chromium. True, a quantitative spectrochemical analysis of the Salininha green beryl (kindly sent to me by Mr. Hugh Leiper, Editor of the *Lapidary Journal*) showed the presence of 0·0003% chromium in addition to 0·15% vanadium, 0·7% iron. Now this amount of chromium is equivalent to 3 parts in a million, and is quite insufficient to affect the colour of the mineral in any way. Reputable analyses of emeralds from the well-known localities have indicated the presence of from about 0·1 to 0·5% of chromic oxide, according to the depth of colour: thus it would require something like 100 times as much of the oxide as occurs in the Salininha crystals to produce a deep enough emerald green to be acceptable as a precious stone.

For the cause of colour in the Salininha beryls one must in fact look to iron and to vanadium. Iron is a well known "competitor" with chromium in the production of reds and greens in minerals, and is probably always present to some extent both in natural ruby

and in natural emerald, modifying the brilliance of their colour and diminishing the strength of their fluorescence. So ubiquitous is iron in nature that it is only in synthetics that one can find entire freedom from the element. The colour of aquamarine and other green beryls is primarily due to iron, which causes a strong absorption of the red end of the spectrum when white light is passed through it, and absorption bands in the deep blue and violet. In contrast, pure chromium-coloured beryl (emerald) transmits freely in the deep red. Moreover it has quite a pronounced red fluorescence when stimulated by blue, violet, or long-wave ultra-violet light, whereas the iron-coloured beryls have no fluorescence whatever. It is, of course, the red transmission and emission that causes pure emeralds (in particular synthetic emeralds) to appear bright red through the Chelsea filter when they are strongly illuminated by a tungsten lamp; it also explains the diminution or disappearance of the red effect in emeralds from localities where iron plays its modifying role in the mineral.

Vanadium is the "mystery" element in the emerald story. It is present in greater or lesser degree in emeralds from almost all the known localities, and being one of the same group of "transition" elements as iron, chromium, copper, cobalt, etc., would be expected to exert some influence on the colour of any mineral in which it was present in appreciable amount, but we have very little information as to just what this effect may be, and what features in the way of absorption lines or bands one could take to be proof of its presence. The only natural gemstone we know about in which vanadium "shows its colours" is a variety of tourmaline from Tanganyika, which was investigated and described by Mr. Robert Webster some years ago. This type of tourmaline contained some 1·5% of vanadium, was green in colour, and showed vague absorption bands in the red and appeared red through the Chelsea filter—features which might lead one to suppose that chromium was present. There is also, of course, the well-known variety of synthetic corundum in which the vanadium present gives rise to a curious plum-coloured tint in daylight, changing to an emphatic purple under tungsten light, which is so widely sold as "synthetic alexandrite". Here there are no lines at all in the red end of its absorption spectrum (unless chromium has been added), but instead, a very useful and beautifully fine line in the blue, at 4750Å.

According to Flanigen, Breck, *et alii*,[2] in an article describing

the Linde synthetic emerald, the effect of vanadium in beryl is to sadden the colour and lessen the fluorescence. While admitting freely that vanadium frequently plays some modifying role in most natural emeralds, its effect on colour is so obscure that its presence cannot be considered as an essential: still less can it be allowed to act as a sort of *locum tenens* in the absence of chromium which can enable a green beryl to conform to the emerald standard. Incidentally, a recent analysis[3] of Chivor emerald gave chromium 0·14%, iron 0·12% and vanadium only 0·05%.

To the layman, all this insistence that chromium must be present in effective quantity to justify the use of the term "emerald" for any given green beryl may seem absurd and academic. But the facts are that all the emeralds honoured for their beauty and rarity from the earliest times until the present day have had this one thing in common to distinguish them from less precious beryls which we can definitely fasten upon as a criterion, and that all the scientists who have succeeded in growing emerald crystals have used chromium compounds as their colourant. The term emerald carries with it such prestige that it must not be lightly applied. In past times the only arbiter was the unaided eye with its clear recognition of what constituted "emerald green". The same expert judgement of true emerald colour can still, of course, be relied upon in almost every case to-day. But where a laboratory decision has to be made, something more than expert colour judgement is required. Colour analysis, either by means of a colorimeter or by using a spectrophotometer to prepare an absorption curve, could undoubtedly provide useful information, but such methods require elaborate apparatus and are highly time-consuming. And to be of any value in reaching a decision, international agreement on the limits of "emerald green" in terms of colorimetry, etc., would have to be reached. A simple observation with a hand spectroscope is, on the other hand, a quick and practical test, and the strength of the chromium narrow-line doublet at 6830 and 6800Å in the deep red, and its companion line at 6370Å can give a very fair indication of the amount of chromium present. In very chrome-rich specimens such as Chatham's synthetic emeralds, a narrow line in the blue at 4775Å can also be detected. This spectrum can also be seen by reflected light if the stone is correctly angled in the beam, and may serve to determine whether a beryl in a backed setting having an apparent emerald colour owes this entirely or only partly

to painting or foiling: whether, in fact, it can be called an emerald or not.

If these typical chromium lines can definitely be seen in a beryl specimen, it is suggested that this should be accepted as emerald. Where the lines are only just discernible, the colour, so far as the chromium content goes, will be so pale as to be practically commercially worthless: but the trade and the public between them will reject such stones in any case, just as it will also reject emeralds with a strong chromium colour which are too flawed and full of inclusions to be used except as beads.

Even when this simple criterion is universally accepted there are bound to be border-line cases where judgement is to some extent subjective, just as in the case of an alexandrite in which a trace of chromium is essential if it is to be elevated above the ranks of ordinary chrysoberyl. But at least if it be agreed that, gemmologically speaking, a beryl must contain appreciable chromium ("appreciable" that is, by means of a hand spectroscope), and that no green beryl lacking chromium shall be classed as emerald, this will serve as a useful and fundamental basis for decisions in difficult cases.

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COLOUR IN OPAL

By R. KEITH MITCHELL, F.G.A.

ONE wonders why it has taken so long for someone to get around to investigating the structure of opal with an electron-microscope. This has now been done by a group of scientists on the Commonwealth Scientific and Industrial Research Organization in Australia. On their findings a new and convincing explanation of the play-of-colour in opal has been formulated.

An account of their work has appeared in a paper by one of them in *Nature*(1), and in the *Australian Gemmologist*(2). A slightly edited version of the latter paper also appeared in the American Journal *Gems and Gemology*(3). (*Journ. Gemm. Abstrs.* 1965, IX, 11, 12 and 1966, 10, 1).

In an earlier paper(4) the same workers had shown that, while some common opals give X-ray diffraction patterns indicating a structure approaching that of α cristoballite, precious opals and their associated "potch" show little or no signs of this structure and may be regarded as essentially amorphous. On this evidence they consider that the two groups of opal are structurally different and have probably originated differently. This also seems to suggest that the theory that play-of-colour was due to interference at thin films of α cristoballite can no longer be upheld.

In the electron-microscope investigation it was only possible to examine surface structures and those, in a sense, "by proxy". This is commonly the case, since the immense magnifying power of this type of microscope has very little penetrating ability. In most cases it is necessary either to "shadow" the object under investigation by volatilizing a metallic film onto it, or to use a similar process to obtain an absolute replica of the surface contours which can be chemically floated off and examined.

In this case exact replicas of broken, and in some cases etched, surfaces of a large number of specimens were taken with a thin film of carbon, which was then removed with hydrofluoric acid. This was examined in the microscope at magnifications of 20,000 or more times.

Under this enormous magnification one fact was at once apparent. Every specimen of the group containing precious opal was composed of minute spheres of amorphous silica. These were

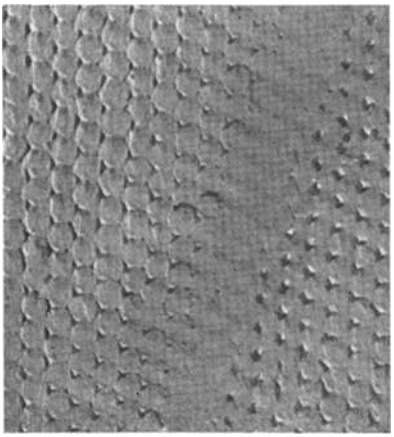

Illustration shows the spherical structure of precious opal magnified 20,000 times. The diagonal band in which no spaces or voids are seen marks an area in which pressure has compacted the material and would probably indicate the end of one colour patch and the beginning of another.

in close packed arrangements giving rise to more or less regular lattices of spheres and voids (the spaces where the spheres were not in contact). When the spheres were all of one size and their diameter was approximately the same as the wavelengths of visible light, the resultant sphere/void lattice was regular and gave rise to diffraction (Bragg diffraction at a lattice of voids) and hence to the play-of-colour of precious opal. When the spheres vary in size the lattice is insufficiently regular to produce diffraction and the milkiness of potch opal results.

The investigators went on to show that the longest wavelength obtained at a given lattice of equal spheres was approximately double the diameter of those spheres. Thus spheres with diameter of 2500 to 3500Å were observed to give deep red-flash with wavelength of 7000Å. Such specimens when turned through a decreasing viewing angle would give colour flash varying from red through the spectrum to green or blue. The actual extent of this "degrading" of wavelength depends to some extent on the curve of the cut surface, since a flat surface would stop the shortening wavelengths at green owing to total reflection. Smaller spheres, on the other hand, might give an optimum wavelength for blue light which could then only degrade to violet as the stone was turned relative to the light source and the viewer. This explains why a red-flash opal can also show yellow, green or blue flashes, while a blue-flash opal cannot show red. In every opal there must be a spectral point dependant on the sphere size beyond which cutting, polishing and stone turning cannot improve the colour of the flash.

The investigators also point out that translucent opal is best seen against a black or dark background. This is because a light background will not absorb transmitted light, but returns it. By so doing it dilutes the play-of-colour and reduces the effect very considerably. This visually observable fact can apply equally to other theories of colour-play origin. It is suggested that the above discoveries may contribute to the possibility of producing a synthetic opal.

Backed as it is by the irrefutable evidence of the electron-microscope, this new theory must be given considerable credence. It would seem that it supersedes all those theories involving interference at thin films. But the fact remains that much of the colour in opal is observably in clearly defined, sharp edged areas which have no apparent depth and are decidedly layer or film-like. Also, in some instances such films appear to be birefringent when viewed between crossed nicols, suggesting either crystallization or, more probably, strain.

If we are to reconcile the new theory with these and other observable facts it is necessary to consider most specimens of precious opal to consist of highly involved mosaics of differently oriented areas of equal spheres forming flakes, layers and grains of regular lattices randomly mixed with other areas in which the lattices are less perfect. "Twinning", faulting and other dislocations of these structures must be common, repeated and of great complexity to give rise to the heterogeneous play-of-colour with which we are familiar.

The tremendous magnification of the electron-microscope limits observation to very small areas of exposed surfaces only, but even in these it has been shown that such faults and changes of orientation do occur commonly in opal. In view of this there seems no reason why the theory should not be considered acceptable within the restrictions of our present understanding of the nature of light itself.

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3. Darragh, P. J., and Sanders, J. V. *The Origin of Colour in Opal.* Gems and Gemology. Summer 1965.
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THE ORIGIN OF NEGATIVE CRYSTALS IN GEM STONES

By W. F. EPPLER

AN interesting explanation of the origin of negative crystals as inclusions in gem stones is given by E. Roedder in his article "Ancient Fluids in Crystals"(1). Principally, the author regards the negative crystals as the final phase of a healing process of a fracture, during which the fracture was still in contact with the mother-liquor. He demonstrates the steps of the healing and the formation of negative crystals in a block diagram, which is reproduced in Fig. 1.

His observation could be confirmed by heating a synthetic ruby having a fracture at temperatures below the melting point of corundum for a considerable time. Before heating, the synthetic ruby was boiled in water to expel the air from the fracture and to replace the air as far as possible by water. As shown in Fig. 2, a certain amount of air still remained in the fissure indicating that the walls of the fracture are not perfectly even.

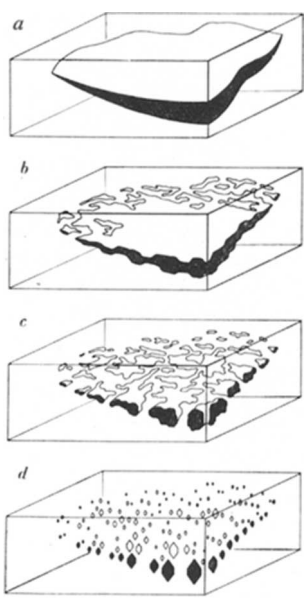

FIG. 1. *Secondary negative crystals formed in the fracture of a crystal:*
(a) *Crystal with fracture embedded in a liquid;*
(b) *Solution and redisposition of material from the liquid on the fracture surfaces results in dendritic growth;*
(c) *which meet and close off small volumes of liquid;*
(d) *these gradually lose surface area and become rounded masses or hollow negative crystals (after R. Roedder).*

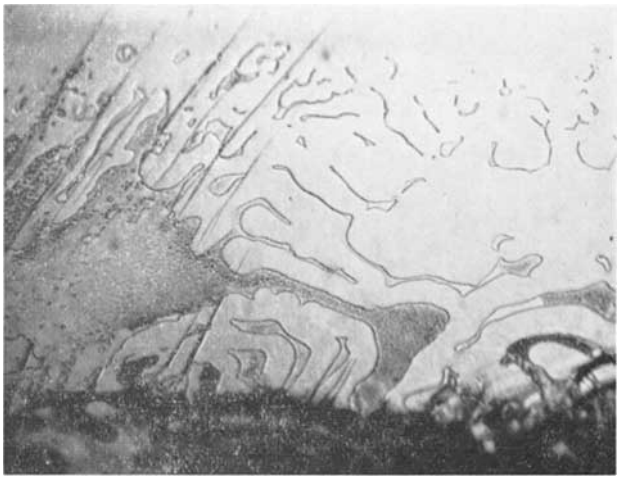

FIG. 2. *A synthetic ruby with a fracture, which is partially filled with water. The dark parts of the fissure, including the "channels", are films or hoses of air, while the bright or transparent rest of the fracture is filled with water.* 65 ×

The result of the first period of heating (7 days at 1950°C) was surprising as the structure and the arrangement of the "inclusions" are heavily altered (Fig. 3). Besides the strongly developed channels of air, there are still thin films of water with a very weak relief.

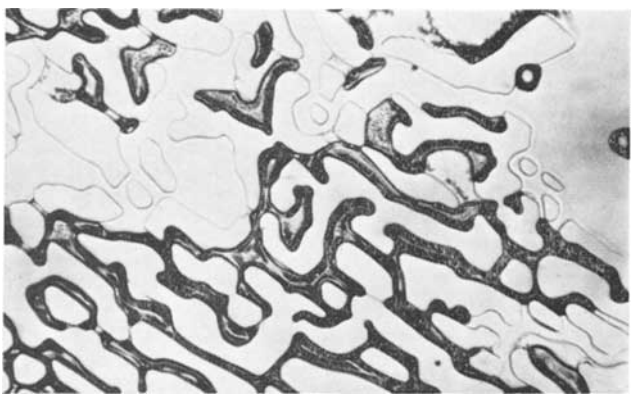

FIG. 3. *Same crack after heating the synthetic ruby during 7 days at 1950°C. The dark network of channels is filled with air, while the bright and transparent and irregularly-formed patches are films of water.* 65 ×

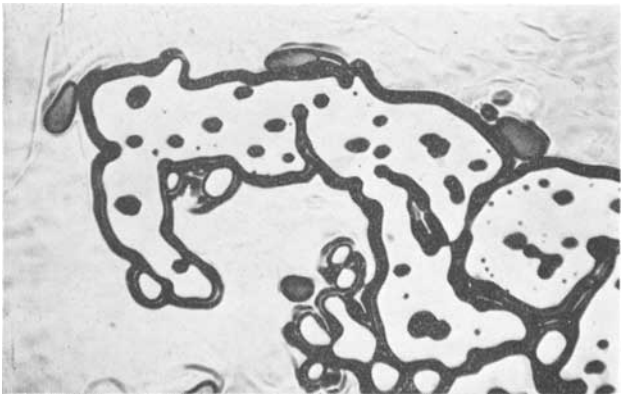

FIG. 4. *Same crack after heating the synthetic ruby during two months at 1800°C. 65 ×*

It is hard to understand that a certain amount of water did resist the heat-treatment at such an extremely high temperature. In some way, the dendritic network in Fig. 3 can be compared with the intercommunicating hoses in certain natural sapphires.

In continuing the heat-treatment for a very long time (two months at 1800°C), the pattern of the inclusions altered drastically. The hoses diminished in number and a concentration of the channels took place in such a way that they parted into smaller sections. This change was caused by a progressive healing process of the

FIG. 5. *Part of Fig. 4. Newly formed and parallel orientated negative crystals. 120 ×*

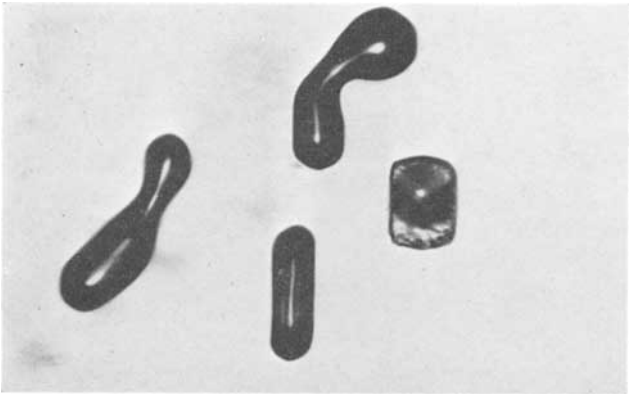

FIG. 6. *Same crack of the synthetic ruby after prolonged heating, with incipient negative crystals and with a kind of two-phase inclusion (right). 450 ×*

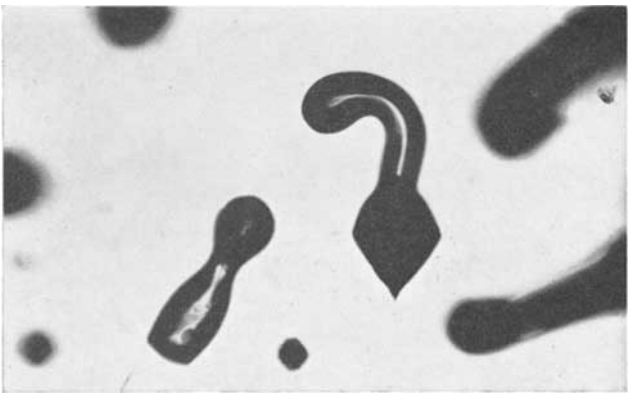

FIG. 7. *Another negative crystal starting from a curved air-filled hose. Same crack as in Fig. 4. 450 ×*

fracture. At the same time, the hollow and air-filled sections of the former hoses started to crystallize, i.e. their walls became crystal faces and their longest extension follows now a preferred crystallographic direction of the host crystal, the c-axis. In Fig. 4, a general view is given while in Fig. 5 the newly formed negative crystals are shown at a greater magnification. At a still greater enlargement, the crystallizing of the "air bubbles" can be observed and also the tendency to be regulated into a distinct direction according to the lattice of the surrounding synthetic ruby (Fig. 6 and 7).

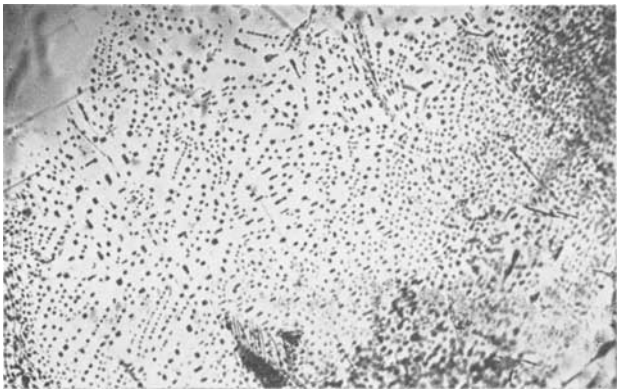

FIG. 8. *Blue spinel from Ceylon. General view of a healed crack which now is marked by a multitude of rectangular black inclusions. 40 ×*

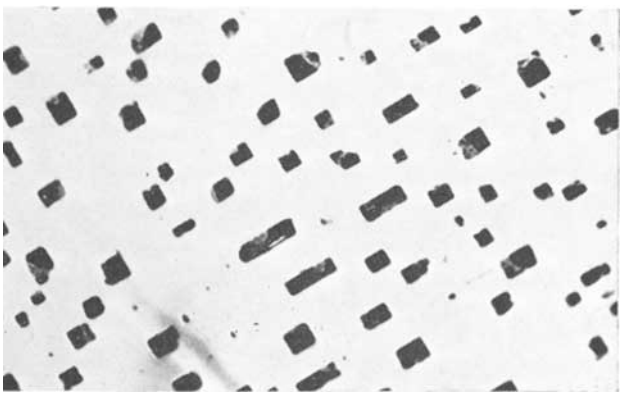

FIG. 9. *Same as Fig. 8 at a magnification of 240 ×*

With natural stones, a good example for this kind of negative crystals is given by the spinels. As is shown in Fig. 8, a former crack, which now is healed, contains a very great number of dark and rectangular inclusions which sometimes have been mistaken for tiny octahedrons of magnetite—another member of the spinel family. At higher magnification (Fig. 9), the dark inclusions are seen to be negative crystals which are filled partly with a black and opaque material, partly with transparent and doubly refractive crystals. They seem to be the deposits of material which is unsuitable for the healing process of a crack within the spinel.

In summarizing, the described negative crystals are originated by the healing of a crack. On that account, they are of secondary origin with respect to the host crystal.

On the other side, there are known other negative crystals which are originated as the result of a defect of a growing plane or as a disturbance in the growth of the host crystal. They are also characterized by crystal faces which in many cases are not so well developed as those of the secondarily formed counterparts. Obviously, they are grown simultaneously with the corresponding plane of the host crystal in small steps which is indicated now by a fine striation as shown in Fig. 10, or by irregular forms as it is demonstrated by

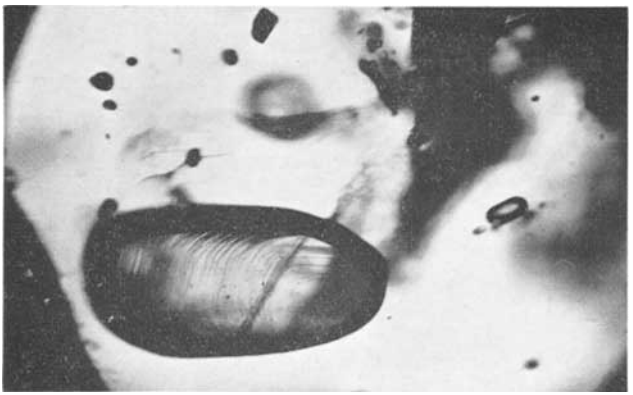

FIG. 10. *Ruby from Burma with negative crystal.* *110 ×*

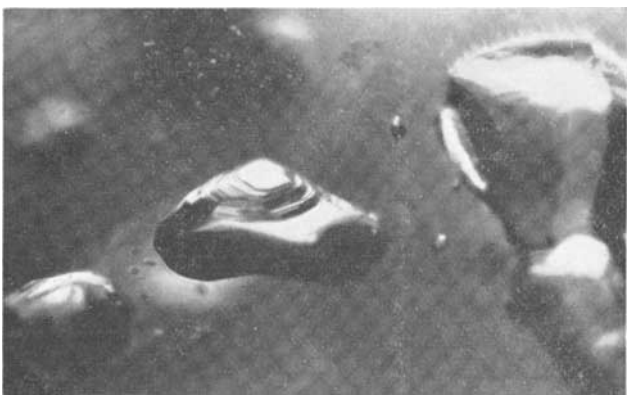

FIG. 11. *Ruby from Burma with negative crystals.* *190 ×*

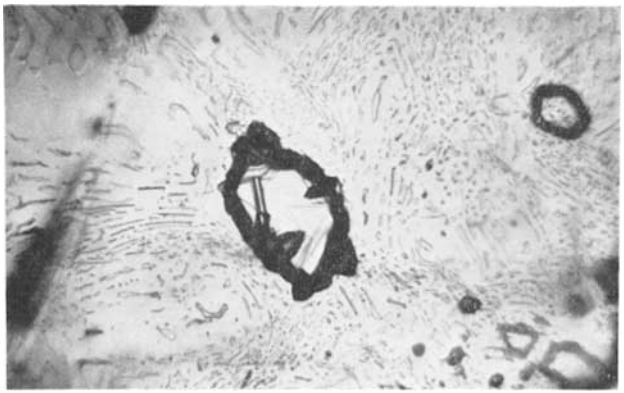

FIG. 12. *Brownish beryl from Madagascar with negative crystal.* 70 ×

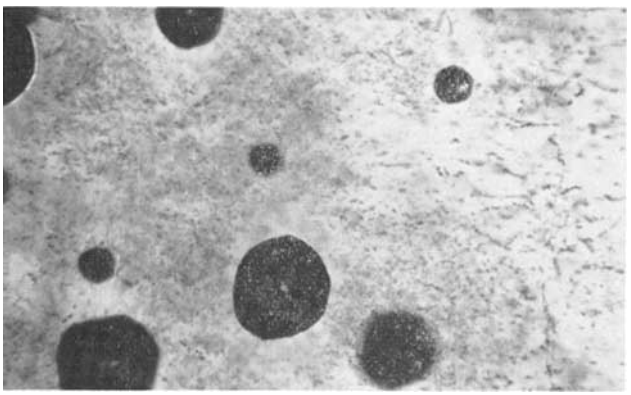

FIG. 13. *Peridot from Hawaii with rounded gas bubbles = negative crystals.* 65 ×

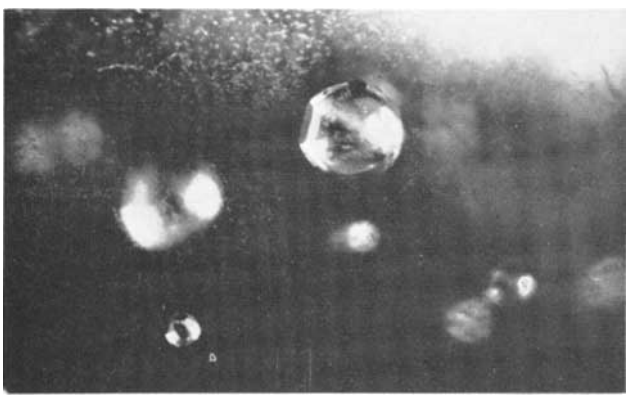

FIG. 14. *Same peridot in reflected light.* 65 ×

Fig. 11 and Fig. 12. This kind of negative crystals has to be regarded as primary inclusions which, as a rule, occur single and in greater sizes.

SUMMARY:

Secondary negative crystals as inclusions in gem stones are small or tiny and they occur crowded or in great numbers. In most cases, they follow a more or less curved plane which represents a former crack.

Primary negative crystals occur singly and have different sizes. Most of them exhibit greater dimensions than the secondarily formed crystals. Additionally, a peculiarity must be mentioned, the peridot from Hawaii. This particular gem stone is known to contain rounded gas bubbles as shown in Fig. 13. In reflected light, however, the bubbles exhibit crystal faces which indicate that the puzzling inclusions are negative crystals (Fig. 14). The origin of the bubbles is considered to be primary, i.e. they are originated during the growth of the peridot crystal. It is interesting to speculate whether a subsequent rise of temperature during growth caused a partial evaporation of the peridot material and if by such a process the bubbles, or the negative crystals respectively, have been formed in different sizes. On the other side, the origin of the negative crystals in peridot can be regarded as analogous to the genesis of gas bubbles in synthetic spinel, which sometimes display crystal faces and are negative crystals likewise. For these, E. Gübelin gives two instructive photomicrographs in his book on inclusions(2).

Finally, it must be mentioned that in the material which was available for the investigation, no glassy drops of similar appearance could be observed.

The author is indebted to Mr. B. W. Anderson, London, for his generous gift of two chromium peridot pebbles from Hawaii beaches.

REFERENCES

1. Roedder, E. *Ancient Fluids in Crystals.* Scientific American, Oct. 1962, 2-11.
2. Gübelin, E. J. *Inclusions as a Means of Gemstone Identification.* Gemological Institute of America 1953. Fig. 21 and Fig. 22 p. 57.

PATHS STREWN WITH GARNETS

By W. CAMBELL SMITH

DURING the years of the last war a school for evacuee children was opened in Abbots Langley, Hertfordshire, and boys from this school, playing round a pond near their sports field found round the edge of the pond a number of small garnets. This came to the notice of Mr. W. G. Rose, a member of the Geologists' Association, living in Abbots Langley. After the War he went to see the site for himself to verify the story. Sure enough he soon found garnets round the pond and, after searching for some time, he collected about a dozen. They were mostly small, not more than a few millimetres in diameter, reddish brown in colour, and they showed little sign of abrasion. They proved to be almandine, with a refractive index well over 1·74.

On further visits made by Mr. Rose after heavy rain he found more garnets, particularly on bare ground round an oak tree near the pond. Also a bucketful of mud and sand from the bottom of the pond, near the edge, yielded great numbers of garnets—but no other "heavy" minerals.

What was the explanation of this rich deposit of garnets round the pond. The clue was eventually supplied by a very old inhabitant of Abbots Langley with whom Mr. Rose had become acquainted. This man had been a gardener's boy at the "big house" not very far from the pond where the garnets were found. He remembered some bags of special sand or fine gravel arriving at the house. He thought they were intended for the garden paths but, while the bags stood in an open shed, the pigs got at them and burst one of the bags so that the sand ran out and then it was not long before the children of the house were playing with it and carrying some of it off on their own ploys.

The full story was soon supplied by the "lady of the big house", to whom I was able to write through some mutual friends. She and her family had long since left Abbots Langley but she remembered clearly about the garnets, how they arrived, and what became of them.

While the family was living at Abbots Langley a Mexican gentleman came to stay. He was given to making graceful compliments and on this occasion he was so impressed by the charm of his

hostess that he vowed that her path should be strewn not merely with flowers but with precious stones, and to make good his promise, as nearly as he could, he sent three sacks of garnets to be put down on the walks of her garden.

The rest of the story was substantially as told by the old gardener. The children used up the garnets from the broken sack, putting some round a pond across the fields from the house and using others for decorating match-boxes for Christmas presents and to make garnet paths in their own little gardens. Eventually the two remaining sacks-full were strewn on the garden paths as the gallant guest had hoped they would be.

We have told this story, Mr. Rose and I, as one day someone else may find more garnets at Abbots Langley and will wonder how they come to be there in a district where the underlying rocks contain none.*

Many years after the finding of these garnets I came across another instance of "paths strewn with garnets", but this time used as top dressing for a main road.

After having attended meetings of the Pakistan Association for the Advancement of Science at Peshawar as one of the delegates of our British Association I was taken by Professor Mirza Anwar Beg on a brief trip to the lovely Swat Valley on the north-west frontier of West Pakistan.

After passing Abua on the main road from Amandara to Saidu Sharif, near the village of Gurdar we chanced to meet some road men who were applying a top dressing of coarse sand to the newly surfaced road. I was amazed to notice that this was garnet sand. When asked, the road men were able at once to tell my companion that the sand was obtained from the bed of a nearby river, a tributary of the Swat River. We took a road up the valley of this river, the Kandak Kwar, and soon found, down by the stream bed, conical heaps of sand some fifteen feet high. These consisted of the garnet sand which was being used as top dressing on the State roads. The sand is gathered from the dry gravel bed of the river and garnets form a very high proportion of it. It seems that the garnets are derived from garnetiferous schists which were formerly exposed round the headwaters of the river. Like the Abbots Langley garnets these, too, are almandine.

*The pond has now been filled in. It was beside the drive leading to the "Ovaltine Farm" marked as "Parsonage Farm" on the 1951, O.S. 1:25,000 map. The map reference of the pond is TL095025.

AN ALBITE-TREMOLITE DECORATIVE ROCK

by R. Webster

IT is manifest that this article should commence with some explanation of what is implied by the term rock as used in the title. Briefly, rocks are usually an aggregation of a number of minerals which in themselves may be large enough to be clearly identifiable, or to be so intimately disseminated throughout the rock mass for identification to be made only with considerable analysis. In some cases, however, the rock can consist of one mineral only, and such a rock is the white marble from Carrara in Italy, which is practically a pure calcite in the form of irregularly oriented grains. Granite, on the other hand, is a rock consisting of recognisable feldspar, mica and quartz.

Although rocks have been used for architectural ornamentation from the earliest of times, they have until recent years had little place as jewellery stones, although there are exceptions. Lapis-lazuli has been known from ancient days and the Indian peoples have known the green aventurine quartz, which is a quartzite rock with green fuchsite mica disseminated through the rock, for centuries. The new rock called Maw-Sit-Sit reported by Dr. E. Gübelin in the *Journal of Gemmology* (1965, 9, 11) is stated to be a jade-albite rock, the chrome-rich jadeite being intimately dispersed in the feldspar. Another rock which attempts have been made to market as a jewel-stone consists of intimate intergrowths of massive idocrase and massive grossular garnet.

The purpose of this article is, however, to discuss another rock, which has received some prominence in the United States of America as a material for tumbled stones and polished pieces.

Samples of this material, which has a bright green and pale green mottling, have been examined. The density determinations showed the material to have a range of 2.80 to 2.95, but most were fairly constant at about 2.84. The index of refraction, as far as it could be assessed by gemmological techniques, was about 1.56, and no luminescence could be observed when the stones were viewed under either range of ultra-violet light. Under x-rays some patchy whiteish fluorescence could be seen, which had also a slight phosphorescence. There was no electro-conductivity.

An X-ray powder photograph, taken by the officers of the

Geological Survey, on powder scraped from one specimen of this material gave the information that the constituents were mainly albite feldspar and the tremolite variety of the amphiboles.

The stones examined may be the same as the material listed by certain American mineral dealers as "snowflake jade", and, further, the writer has been credibly informed that there is an intention to market this stone under the name "Wyoming jade". This poses the question of nomenclature.

The name jade may only rightly be used for the mineral consisting of a compact mass of fibrous crystals of the tremolite-actinolite series of the amphibole group—that is *nephrite*—or the more highly prized pyroxene mineral known as *jadeite*. Whatever the source of the rock reported on by the Geological Survey (and it is not known for sure where it comes from) it may well be from Wyoming in the United States of America. True nephrite jade is also found in this American State, and it would be incorrect to call a rock which consists of a mixture of two distinct minerals by the name jade. There is some justification, however, for calling the material *jade matrix*, a term which has a precedent as in the case of "turquoise matrix", "emerald matrix" and others.

A NEW INVENTION

Scientists employed by Decca Radar have recently invented and developed an electronic machine for counting small objects at great speed. This is the Decca Mastercount. This machine has been an instant success in counting such objects as varied as transistor parts, nuts, bolts and seeds.

Specific problems posed by adapting the machine to counting diamonds and precious stones, both rough, cut and polished, have now been overcome, and the Mastercount is now able to count diamonds and precious stones at a speed of 500-600 per minute, with an amazing accuracy: achieving a level of accuracy of the order of 1 in 1,000, much higher than any other method.

J. Aardewerk (Diamonds) Ltd. has the sole distribution rights for Great Britain and Belgium, in the diamond and jewellery trades.

Gemmological Abstracts

ANON. *Data on Brazilian emerald.* Gems and Minerals, 1966, 340, p. 34.

A report that the Institute of Industrial Technology of the Brazilian School of Mines has not found chromium in specimens of green emerald obtained from the Salininha deposits in Brazil. Chromium is reported to be present in specimens obtained from deposits at Caraniba, but the method of spectrographic analysis is not mentioned. The tests on the Salininha specimens correspond to direct vision spectroscopic tests made on crystal from the same area made available in the U.K.

S.P.

RAAL (F. A.). *A scientific study of the Hope diamond.* Ind. Diamond Review, 1965, 25, p. 250.

Examination of the Hope diamond showed it to be a type IIb stone, which is typical for blue diamonds. When exposed to irradiation from a high pressure mercury lamp with a quartz envelope the stone showed a strong pinkish-red phosphorescence. In type IIb diamonds the phosphorescence is usually light blue and the author is unaware of a pinkish-red colour being observed in type IIb stones before.

S.P.

ANON. *Nitrogen in diamonds governs their shape and colour.* South African Mining and Engineering Journal, 1965, Dec. 17.

Short account of the work being done at the I.D.D. Research Laboratory in Johannesburg on the influence of stray nitrogen atoms in diamond structure on colour and form.

Nitrogen atoms replace carbon atoms in random positions in the lattice. The carbon outer shell has four electrons; nitrogen has five. In low concentrations this surplus electron influences absorption of light and causes yellow colours. When nitrogen is present in greater than 1 part per million absorption changes and a greenish

tinge results. Natural blues contain no nitrogen. Concentrations of greater than 1 part per 1000 result in the nitrogen coming together to form platelets of atoms and the free electron is taken up in the bond. In this state they no longer absorb visible light. An intermediate state is believed to cause brown shades.

By regulating the nitrogen content of synthetic diamond the Laboratory has been able to produce "squarer" crystals, which give improved cutting qualities and longer life to the material. These also are yellow in colour.

R.K.M.

BROOKS (J. H.). *Marlborough Creek chrysoprase deposits.* Gems and Gemology, 1965, 11, XI, pp. 323-330 and 351.

An important article on the occurrence of the chrysoprase found in Queensland, Australia. The geology of the area and the associated minerals are fully discussed. The chrysoprase is found in vein form, and the veins have an average width of 2 inches for the best quality material, and up to 8 inches for that of poorer quality. The results of mineralogical and chemical examination are recorded. The colour is stated to be due to hydrated nickel silicate; 2·38% of nickel being found in the best quality material and 0·65% in the inferior pale green chrysoprase. This is compared with the 0·5 to 1·0% of nickel oxide found by Goodchild in Silesian chrysoprase. The chrysoprase is found as veins in serpentinite over an extensive area and it is considered that more will be found as prospecting intensifies.

1 map; 2 tables. R.W.

LIDDICOAT (R. T.). *Developments and Highlights at the Gem Trade Laboratory in Los Angeles.* Gems and Gemology, 1965, 11, XI, pp. 339-341.

Quartzite beads dyed violet-red were found to show an absorption spectrum consisting of a strong band between 5500Å and 5900Å. Other items mentioned were a slag glass, an emerald-green tourmaline and a diamond showing colour banding.

4 illus. R.W.

CROWNINGSHIELD (R.). *Developments and Highlights at the Gem Trade Laboratory in New York.* Gems and Gemology, 1965, 11, XI, pp. 331-338 and 351.

This quarterly report on the activities of the New York laboratory mentions a large Montana sapphire crystal and a red spinel crystal which contained striking inclusions. Other items discussed are a synthetic sapphire with natural-looking inclusions, a metamict zircon, and a reddish chalcedony cameo, which owed its peculiar reddish colour to bright red oddly formed inclusions. A treated diamond with an unusual absorption spectrum is reported, and a yellow-green laminated diamond was found to be electro-conductive. Some synthetic emeralds with an unusual "melted" surface were examined and the conclusion reached was that the stones had been subjected to heating to a high temperature. Mention is made of green massive idocrase ("californite") from Pakistan and the name "jade-albite" suggested for Maw-Sit-Sit is criticized on general grounds of nomenclature.
17 illus. R.W.

MALES (P. A.). *The geological environment of Australian precious opal.* Australian Ge nmologist, 1966, 55, pp. 5-7.

The precious opal of Australia, unlike the deposits in most other countries, occurs in sedimentary rocks. The article deals with the types of these rocks and details their variation in the various Australian opal fields. Some notes are given on trace elements in opal. There is a list of references.

R.W.

BOOK REVIEWS

DICKINSON (JOAN Y.). *The book of diamonds.* Crown Pubs., New York 1965 and F. Muller, London, 1966. 42s.

A popular account of the fascinating story of diamonds, of interest more to the lay reader than the serious gemmologist. As well as a short history of the diamond and famous diamonds there are some intriguing items of information. In the chapter on cutting the dubious claims about Lous de Berquem and Vincent Peruzzi are repeated. There is much of excellence in a chapter which discusses diamonds in the world of fashion and useful hints in another section

about purchases. This entertaining book is profusely illustrated and ends with a short glossary. In a bibliography the author lists various sources which she used, most of them reliable but one or two not dependable.

S.P.

McCallien (W. J.). *Scottish gem stones.* Univ. Microfilms Ltd., 1965. 30s.

Originally published in 1937, the author's intention was to write a book "for those who hope to collect precious stones in Scotland, and who at the same time want to identify their finds for themselves. It also aims at telling them something of the natural history of our gem stones".

There are chapters on identifying minerals, and descriptions of various gems. One chapter is devoted to discussing where stones are to be found and why. There are 36 line drawings and maps within the text.

The 120 page octavo reprint is bound in good quality bookcloth and tilted in gilt on the spine. All illustrations in the text have been reproduced but the coloured frontispiece has been omitted from this limited edition.

K.M.

Pearl (R. H.). *An introduction to the mineral kingdom.* Blandford Press, London, 1966, pp. 254 and 35 colour photographs. 25s.

This book has been edited and adapted by Prof. J. F. Kirkaldy, London University, from a work by Prof. Pearl which has run to several editions in America. The text is in language which should appeal to the general reader and student seeking first information about minerals. Student gemmologists should find the work stimulating enough to encourage them to further studies. The chapter on gemstones is brief, but there is sufficient in this well-written book to attract the student gemmologist.

A.G.

ASSOCIATION NOTICES

GIFTS TO THE ASSOCIATION

The Council is indebted to Col. A. G. T. Gould, of West Moors, Dorset, for a gift of books, specimens and gem-testing instruments, which are a valuable acquisition to the Association's collection.

The Council is also grateful to the following who responded to the Association's request for back copies of the Journal of Gemmology:—Mrs. F. L. Tully, Mr. S. N. Weighell and Messrs. Rayner & Keeler, Ltd.

ROSSER REEVES RUBY

A 138·7 carat star-ruby, which is claimed to be the largest in the world, has recently been presented to the Smithsonian Institution. The curator of the Smithsonian, Dr. G. Switzer, has described it as "one of the most important acquisitions in a long time". It will be displayed alongside the Hope diamond and the sapphire known as the Star of Asia. The former owner of the stone, Mr. Rosser Reeves, who was responsible for its presentation, is chairman of the advertising firm of Ted Bates and Co.

OBITUARY

February 1966. Mr. J. S. Miles, F.G.A., of Acton, London, who gained his diploma in 1933.

March 1966. Mr. L. P. Waites, F.G.A., of Birmingham. (Dip. 1953).

March 1966. Mr. P. J. Hopkins, Biddulph, Staffs. (Dip. 1963).

TALKS BY MEMBERS

WELLER, R. J. H. "The production of cultured pearls"; Norwich & District Jewellers' Association, February, 1966.

PATCHING, S. W. F. "Gemstones"; Officers' Wives' Clubs, 1st and 3rd Malaysian Rangers; Australasian Institute of Mining (Malaya Section); Batang Padaung Club of Hydroelectric Power Scheme staff; Dept. of Mines Research Division, Ipoh, 1965.

CAFFELL, E. W. "Gemstones"; Cobham Branch, Anglican Young Peoples' Association, 6th March 1966.

McWilliam, J. "Pearls"; Glasgow Pawnbrokers' Association, 28th February 1966.

Anderton, B. W. "Gemmology on a shoestring", West of Scotland Branch of the Association, Glasgow, 10th March 1966.

MEMBERS' MEETINGS

About one hundred and fifty members went to Goldsmiths' Hall, London, on Tuesday, 18th January, 1966, for a film evening. Two films were shown, "Out of the blue", which dealt with diamond mining, and "Deep Level Gold", an intensely interesting film made by the Anglo-American Corporation.

DISPLAY OF INCLUSION PHOTOGRAPHS

As an additional note of interest for a Stores' Swiss Fortnight at the beginning of March, the Army and Navy Stores, London, illustrated Swiss Gemmology by means of an exhibit of large colour prints and transparencies of inclusions in gemstones. Considerable interest was aroused by these very striking photographs. which were very kindly loaned for the occasion by Dr. E. Gübelin, Lucerne. A further selection of prints illustrating mining scenes from gem areas visited by Dr. Gübelin was also shown.

PRESENTATION OF AWARDS

The presentation of the awards gained in the 1966 examinations of the Association will be held at Goldsmiths' Hall, London, on Monday, 24th October.

HERBERT SMITH MEMORIAL LECTURE

The 1966 Herbert Smith Memorial Lecture will be given by Mr. R. C. Chirnside, of the General Electrical Company, on 8th November. By kind permission of the Wardens of the Goldsmiths' Company the lecture will be given in the Livery Hall at Goldsmiths' Hall.

36th ANNUAL MEETING

The 36th annual general meeting of the Association was held at Goldsmiths' Hall, Foster Lane, London, E.C.2, on Tuesday, 22nd March, 1966. Mr. Norman Harper, Chairman of the Association, presided.

After welcoming members the chairman emphasized some of the features of the annual report of the Council, which had already been circulated. He specially welcomed the considerable increase in membership, and thanked members of the Council and others who had assisted in the work of the Association. He also thanked those responsible for the successful year's work of the Midlands and West of Scotland Branches, particularly the local secretaries.

Mr. Harper recalled that four years ago a gem diamond course had been commenced at the Jewellery and Silversmithing School in Birmingham, and he was pleased to say that a similar class was planned to commence in London in the autumn. The classes would not be under the aegis of the Association, but the

G.A. would be responsible for the examination that would be held at the end of the course. It was pointed out that application to join the course should not be sent to the Association.

Dr. E. Thain seconded the motion adopting the annual report and audited accounts, and said that as someone who was not a professional he had derived much pleasure from members' meetings and getting to know so many pleasant and interesting people. The annual report and accounts were adopted.

The President, Sir Lawrence Bragg, was re-elected, together with the Chairman, Mr. Norman Harper, Mr. Philip Riley, Vice-Chairman, and Mr. F. E. Lawson Clarke, Treasurer. Messrs. E. Levett, C. T. Mason and T. H. Bevis-Smith were re-elected to serve on the Council. Messrs. Watson Collin & Co., chartered accountants, continued as auditors to the Association.

After the meeting members went to the Exhibition Room of Goldsmiths' Hall where, in addition to seeing some of the Company's collection of antique and modern silver, a small gemstone exhibition had been arranged.

Mr. Peter Wilding exhibited a most interesting instrument, being a "new or improved optical instrument for the detection of imitation diamonds". Accompanying the instrument was a provisional Patent Specification describing the instrument dated 5th October, 1894, and a complete specification, dated 4th July 1895. (After the meeting Mr. Wilding kindly presented the instrument to the Sir James Walton Library and it will be fully described in the July issue of the Journal).

A magnificent collection of cut gemstones was shown by Mr. Max Davis. Outstanding among these was a superb morganite of 69 cts, a dark blue zircon weighing 79 cts and a 36 ct chrysoberyl, in addition to blue topaz (227 cts), golden quartz (146 cts) and a golden beryl (198 cts).

Mr. Davis also provided a collection of smaller stones, which included a chrome-green sphene, benitoite, green enclase and yellow apatite, and a collection of Zerfass, Chatham, and Gilson synthetic emeralds.

Other interesting cut stones and gem minerals were also on display.

Members were provided with refreshment in the Drawing Room.

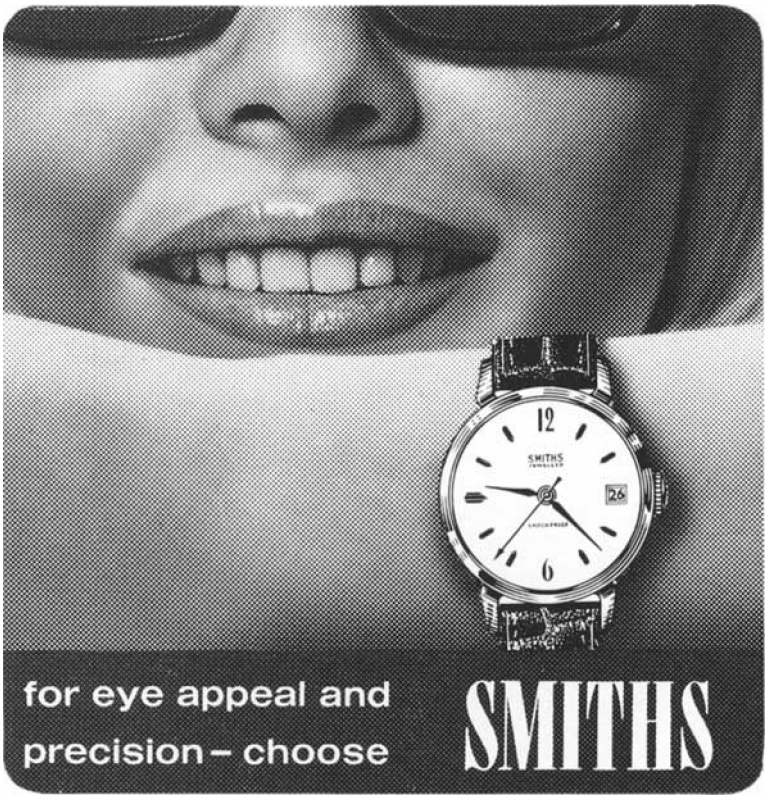

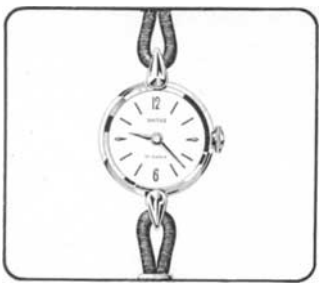

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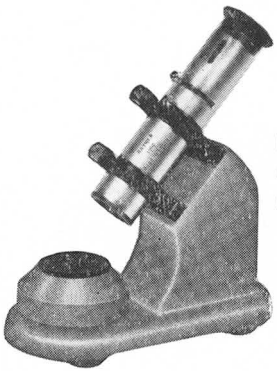

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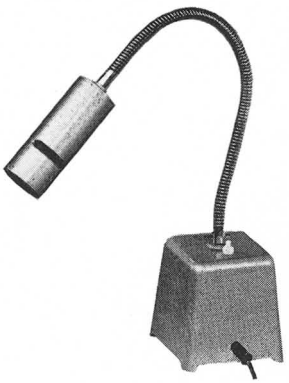

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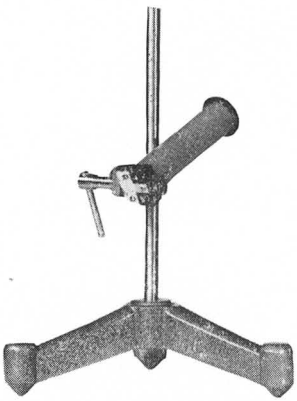

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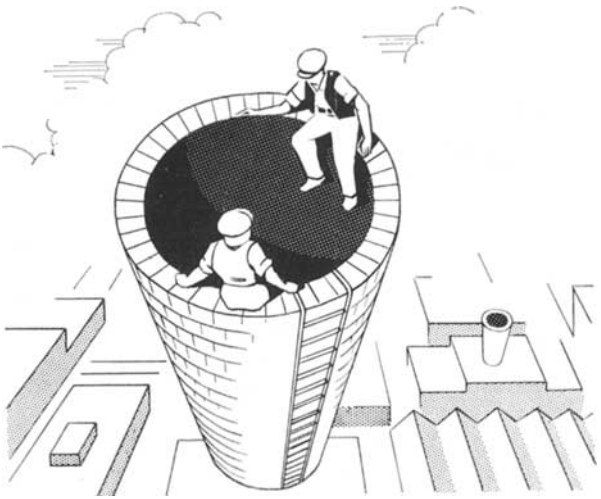

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Vol. 10 No. 3 July, 1966

THE JOURNAL OF GEMMOLOGY

and

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Vol. 10 No. 3 JULY 1966

GEMMOLOGY ON A SHOESTRING

*By B. W. ANDERSON, BSc., F.G.A.**

ON several occasions I have given talks to post-diploma students under the title "Gem-testing Without Instruments", which I believe have been helpful in warning the student, fresh from his examinations, against an over-dependence upon instruments in his endeavours to identify gemstones. "Gemmology on a Shoestring" is intended to follow much the same theme, but the title purposely suggests a little latitude in allowing for the use of quite simple pieces of apparatus, liquids, and so on, which can aid considerably in making firm decisions instead of merely forming opinions in certain cases.

First I must make it quite clear that to solve many of the problems that confront the gemmologist in these days every available instrument may be valuable and necessary if a correct answer is to be ensured. My present intention is not so much to provide easy recipes for individual cases of identification as to persuade those who have gemmological training to use their powers of observation to the full and interpret what is seen in the light of their special knowledge. It has often been said that the limited amount of scientific knowledge absorbed in the two-year course can actually be a handicap to a young jeweller: into every yellow zircon he dreams a sphene, and in viewing a parcel of tourmalines his mind is cluttered with thoughts of kornerupine. There is enough truth in this to sting a little; but

*The basis of a lecture given to the West of Scotland branch of the Gemmological Association in March, 1966.

I strongly maintain that in a "lens only" identification-test a on mixed series of gemstones, the man with a gemmological training should be far more sure of his ground than a colleague of otherwise equal ability and experience. As any good artist knows, it is a fallacy to think that any two people of normal eyesight gazing at a given object are necessarily seeing the same thing. It is the *interpretation* of the image falling on the retina that may enable the artist to see a significant and exciting pattern of shapes, shadows and colours, where his friend may see nothing of any interest whatsoever. In like manner a jeweller who is not a gemmologist, when confronted by a mounted and well-cut white zircon, may well feel that it "doesn't look quite right" for a diamond, but his gemmologist friend, noting the strong double refraction in the stone, will be able to make a quite positive identification.

Sheer economic necessity may deprive the average young gemmologist of the three really essential instruments for gem identification—the microscope, refractometer and spectroscope. Ten years or so ago less than fifty pounds would have been required to buy the lot: to-day one may have to pay at least twice as much as this. Indeed the simple liquids which will be recommended in this talk are now so costly that one must ruefully admit that even "shoestrings" have become expensive. Against this one must realise that in the precious stone trade a mistake may mean a loss of hundreds of pounds or a damaged reputation, and the cost of any instrument which can save such mistakes, or a fee for a laboratory test, is money wisely spent.

To start with, I shall assume that the jeweller has only one "instrument"—a pocket lens, and proceed to consider what he can learn about gems with this as his only aid. A good lens is so vitally important that I do insist—make it a good one, magnifying eight or ten diameters. Lower powers are of comparatively little use, however suitable for the scrutiny of watches or hallmarks—while higher powers are difficult to handle and not nearly so flexible in their application.

In our first assessment of any gemstone we are all inevitably influenced in our thinking by its general appearance, which, when analysed, depends chiefly upon its colour, lustre, degree of transparency, and "fire". If the stone is unmounted, we may notice from our first "feel" of it that it is cold or relatively warm to the touch, that it gives a slippery or a harsh impression when handled,

or that it strikes one as "heavy" or "light" in the hand. Then may follow close examination with a lens. The back facet edges may appear doubled, there may be characteristic inclusions, cleavage chips may appear on the girdle, and so on. All these phenomena may either be accurately measurable or more closely investigated with instruments: our task is to learn all that we can without them—even if later some form of instrument may have to be used as a final court of appeal.

It is a worth-while exercise to make a list of all those gem materials which you believe you can confidently identify by lens inspection only—provided the specimens are clean, not too small, and that the lighting is good. The following list of "recognizable" gems would probably be agreed to by most experienced gemmologists, and could, I am sure, be extended: Diamond, zircon, demantoid, peridot, opal, amethyst, star-sapphire and ruby, chrysoberyl cat's-eye, quartz cat's-eye, iolite, tourmaline, haematite, marcasite, lapis-lazuli, "Swiss" lapis, aventurine quartz, bloodstone, ivory, pearl, pink pearl, cultured pearl, imitation pearl, paste, "goldstone", doublets, synthetic star stones, synthetic rutile, strontium titanate, blue sinter spinel. Such a list of thirty materials at least makes an encouraging start; I shall suggest later the basis on which some of the above determinations may rest, and a few simple accessories which may make these and further identifications more simple and more sure.

That the stone examined should be clean (and here I am not referring to "inner cleanliness") was stipulated just now, and it is certainly well worthwhile before examining a stone or stones to do a thorough job of cleaning. This is usually quite a simple matter in water containing a little liquid detergent, using a soft toothbrush to get into any nooks and crannies of the setting if the stones are mounted. If the stones are then rinsed and shaken, and placed on blotting paper close below the bulb of a desk lamp, they will soon dry. Loose stones, if large, can be handled most safely in the fingers. With small stones, tongs are necessary: these should not be too sharp-nosed, and should have a mild spring. Those who have difficulty in maintaining the correct gentle pressure on the tongs to grip the stone safely while it is being examined may find tongs fitted with a "slide" helpful, as these maintain a fixed pressure. An adjustable desk lamp with an opaque shade is a virtual necessity, enabling a strong light to shine on the specimen without dazzling

the eye of the observer. In using a lens, a light interlocking of the left hand holding the specimen and the right hand holding the lens is essential to maintain steadiness and constant focus.

Let us now consider some of the main attributes which enable gemstones to be recognized for what they are.

(1) *Colour.* This is unquestionably the greatest aid of all, though of course it can sometimes be misleading. An attempt to sort out a parcel of mixed colourless stones will soon convince the sceptic how helpful colour can be. The gemmologist must also be on the look out for parti-colouration, as in many tourmalines; zoned or patchy colour as in amethyst, "burnt amethyst", sapphire; dichroism or change of colour with direction as in ruby, tourmaline, andalusite, iolite, aquamarine.

(2) *Lustre.* This depends, of course upon refractive index, but also upon the perfection of polish, which in turn depends largely upon hardness. The polished surface of a diamond will reflect 17% of a ray of light at perpendicular incidence, whereas quartz under the same conditions reflects only 4½% of the light. Stones of intermediate refractive index, of course, reflect to extents between these two extremes, in accordance with Fresnel's well-known formula. The lustre of a diamond is certainly one of its outstanding characteristics, and lustre can often play a part in distinguishing between similar gems, e.g. between chrysoberyl cat's-eye and quartz cat's-eye.

(3) *Fire.* The gemmologist will know that the effect known as "fire" depends upon the "dispersion" of a stone, which can be stated numerically as the difference between its refractive index for red light of chosen wavelength and for a chosen wavelength of violet light. Fire is most necessary in a colourless stone, if it is to have any beauty and liveliness. Diamond, of course, is our standard here, though considering its high index of refraction its dispersion is decidedly low. By comparison synthetic rutile and even strontium titanate seem to show a rather gaudy display of flashes of spectrum colours. Demantoid garnet owes its lively appearance both to its high lustre and its fire: these features should serve to distinguish it at once from either emerald or peridot, even if its colour did not. Although the dispersion of synthetic white spinel is only a little higher than that of white sapphire, it does show perceptibly more fire and this makes it a more plausible substitute for diamond, particularly in step-cut form.

(4) *Transparency.* This is a contributory factor in the appearance of gemstones which is insufficiently appreciated. Most of the stones used in jewellery would be listed as "transparent", and this would be true insofar as one could read print through a polished block of the stones concerned. But perfect transparency is possessed by very few minerals—diamond, synthetic spinel, and white topaz amongst them—while others, such as zircon, are almost always marred by a slight touch of milkiness. Perfect transparency is, of course, more important in colourless than in coloured stones.

(5) *Double refraction.* The detection of double refraction in transparent gemstones, and the approximate assessment of its strength, are matters of prime importance in the lens identification of a given specimen, and it is here that a gemmologist should score heavily over his unscientific colleagues. The "doubling of the back facets" when viewed through the front of a stone with a lens is very easily seen in zircon (double refraction ·06) and sphene (·13), also in peridot (·036) and even tourmaline (·02): but one may need considerable skill in detecting it in quartz and in topaz (·01, approx.) unless the stone be a large one. It is very important to remember that in all doubly refracting stones there are either one or two "optic axes" along which no double refraction can be observed, and that at right angles to these directions the doubling cannot be seen either, since one image is directly behind the other. Thus one must turn and twist the stone, peering through it at the further facet junctions in all possible directions before deciding whether or not D.R. is present, and if so, approximately how strong. Naturally, the larger the stone the greater the effect, and this must be taken into consideration in any assessment made.

(6) *Hardness.* Hardness as a test has always been considered taboo amongst gemmologists, partly because of the danger it implies of damaging the specimen tested, and partly because of its inexactness compared with refractive index or density determinations. But hardness has a marked influence on the degree of polish that a stone can take and maintain and thus affects the appearance of a stone. The sharp facet edges in diamond, for instance, help one to distinguish it from strontium titanate, where the edges often have an almost moulded appearance. It is as well to realize that hard stones such as sapphire or even diamond may show an astonishing degree of wear, and one should be careful to avoid jumping to

conclusions on this evidence alone. Since the hardness of diamond is unique, a careful trial with an edge of a suspected diamond on a piece of synthetic corundum is sometimes justified. If the specimen "bites" on the corundum and leaves a definite mark, there is nothing else but diamond that it can be. Before the test is done, the corundum surface should be examined with a lens to ensure that no scratches are already there on the part that is to be used; and any mark made by the diamond should be rubbed with the finger and examined with a lens to ensure that it really is a scratch. With jade and the jade-like minerals gentle trials with a knife blade or needle point may yield valuable information, but should only be used where other tests fail, and when one can be sure that no damage results to the specimen. One should also recognize that there may be considerable variations in the hardness of such materials.

(7) *Density.* Before the coming of the jeweller's refractometer devised by the late Dr. Herbert Smith, tests for specific gravity (density) were the only accurate means of determining the nature of any unmounted gemstone. It remains a thoroughly useful test for any stone free from its setting. Every gemmologist knows that a simple trial in a heavy liquid will distinguish at once between yellow quartz and true topaz, or between quartz or chrysoberyl cat's-eyes. To make these distinctions by the "feel" or "heft" of the stone in your hand is a decidedly tricky business, but worth practising. Even when strung as a necklace, the extreme "lightness" of amber can be noticeable, when compared with bakelite or other synthetic resins. The judgement of the weight of a stone in relation to its "spread" is, of course closely bound up with a knowledge of its specific gravity, and here again the gemmologist scores.

(8) *Cleavage.* Where a stone has a marked cleavage, traces of this can often be noticed as flaws or incipient flaws within the stone or on the surface, where any nicks or chips may be seen to have flat sides instead of curved surfaces as in a conchoidal fracture. Cleavage nicks can often be detected round the girdle of a brilliant-cut diamond, especially if the stone had been removed from a setting. This adds one more to the many revealing signs that one can find when examining a diamond.

(9) *Surface structures.* This is rather a comprehensive heading, and can be used to cover such things as the traces of untouched crystal surface ("naturals") that can often be detected on the girdle

of a cut diamond; similar structures on the rear facets (really crystal faces) of a Lechleitner synthetic emerald, where the overgrowth is purposely left to enhance the colour; the "flame" pattern which is so completely distinctive for pink (conch) pearl, and so different from the grained structure of coral; the "engine-turned" pattern on the surface of ivory; the dimpled surface of fine jadeite; the demarcation line (nearly always above the girdle) marked by a sharp change in lustre, when the surface of a garnet-topped doublet is examined in reflected light; the short, parallel crack-like markings ("fire marks") due to careless cutting, seen only in corundum, more particularly in synthetic ruby or sapphire; and so on. A complete list of such surface signs would be a very long one.

(10) *Internal structures.* Internal features or "inclusions" should not really have come so late in the batting order, since such features are often of enormous help in identifying different gemstones and in distinguishing natural stones from their synthetic counterparts. But to study inclusions in their full beauty and detail one undoubtedly needs to examine them under a microscope—preferably a binocular microscope, and immersed in a cell of suitable fluid. Even with a pocket lens some inclusions are completely distinctive: for instance, the "horsetail" inclusions of asbestos fibres which are almost invariably to be seen in demantoid garnet, and the "silk" which is so typical a feature of Burma ruby. In both these cases of course the colour and appearance of the stone will already have put you on the right track. The list of such "dead-sure" identifications by inclusions is not a very long one, however, except at the gifted hands and eyes of a master of the subject such as Dr. Edward Gübelin. One should, however, be certain of an amethyst which shows the curious "tiger-stripe" inclusions; of "goldstone" (aventurine glass) with its glittering triangles of included copper; of a paste when it shows a typical elliptical bubble or so and of a doublet when a layer of bubbles can be seen at the surface where garnet meets the glass. Hessonite garnet, of course, is usually easy to detect with its crowded inclusion-picture of diopside crystals in a treacly golden-brown setting. The curved lines in synthetic ruby may be too finely spaced for a lens to detect, but in sapphire the broader curved swathes of colour are often more visible to the lens than under the microscope. The stone should be viewed against the white background of a sheet of clean paper or blotting paper, and turned in different directions until the right angle for viewing is found.

Immersion in liquid will often help here (I am jumping ahead a little) and will also reveal the straight-sided bands of colour so typical of natural sapphire. The "feel" of a stone and its "coldness to the touch" may also on occasion provide evidence of its nature.

Further simple tests

The tests so far suggested have involved only the use of lens and tongs. I am now going to suggest the use of a few very simple "extras" which I feel can be included under our "shoestring" limit, and which will undoubtedly extend quite considerably the scope and certainty of our gem identification. The first extra is the well-known Chelsea filter, which was developed by A. Ross Popley from a formula worked out by C. J. Payne and myself in the early thirties. In knowledgeable hands, and properly used, the filter can be extremely useful. If used without any knowledge of how it functions, it can be quite misleading. Basically, it is a very efficient "dichromatic" filter, transmitting only a narrow band of deep red light and a narrow band of yellow-green. Thus, through the filter, a stone can only appear red, green, or a mixture of the two. Filters of this type were originally designed to distinguish between emeralds and pastes or doublets. Emerald, unlike most green stones, both transmits deep red light and emits fluorescent red light when it is brightly illuminated. To see the effect at its best, the stone should be held immediately under a good tungsten light and viewed through the filter held close to the eye. The snags in this simple use of the filter for emerald are that two other green stones, demantoid garnet and fluorspar, may show a reddish residual colour when viewed through the filter, that synthetic emeralds appear an even more decisive red than natural emeralds, and that natural emeralds containing enough iron to damp its fluorescence and cause absorption in the deep red do not appear red through the filter. But in my opinion the warning given by the very intense red shown by Chatham synthetic emerald when viewed through the filter is a most useful indication, while its other uses in clearly distinguishing between aquamarine (green appearance) and synthetic blue spinel (orange-red) between stained green chalcedony and chrysoprase, etc. serve to add to its value.

Next, quite another kind of filter: polaroid. This astonishing invention of perhaps the most inventive of modern men, E. H. Land,

has placed polarised light, with all its peculiar and revealing properties, within the reach of everyone, and in a form far more compact and convenient than the old Nicol prism. A number of different formulae have been employed in producing the highly dichroic substances in plastic sheets which constitute polaroid, but the effect in each case is essentially the same—that a ray of light which has passed through such a sheet is vibrating parallel to one direction only—that is, it is completely polarised. Such pieces of polarising film are capable of far more valuable and fundamental uses in the study of gemstones than any colour filter can be, and fortunately the material is quite inexpensive: about four shillings per square inch, up to virtually any size required. The most favoured type transmits 34% of incident white light, and two pieces of this in the "crossed" position give virtually complete extinction.

One of the most obvious ways of using this material in gem testing is to mount two discs of polaroid in the "crossed" position with a space between them enough to accommodate any gemstone, thereby forming that very sensitive instrument for the detection of double refraction known as the "polariscope". A gadget of this kind can be easily home-made, but there are some inexpensive types, carefully designed for convenience in use, which are commercially available. A useful pocket polariscope is one made by Rayner from a design of Dr. E. Rutland's, while the same firm make an extremely convenient table model with a built-in light, which leaves ample room for large specimens, either dry or in a cell of suitable liquid: it can also easily accommodate massive pieces of jewellery, stones in necklaces, etc. can be examined, and both hands are free for manipulation. (Fig. 1).

A gemmologist worth his salt will get much more information from such a polariscope than "four times light, four times dark—there a doubly refracting crystal". He will learn to recognize the characteristic types of "strain birefringence" shown by paste imitations (which often show a crude interference cross) by synthetic spinels, with their "tabby extinction" patterns, by diamond, which is never truly isotropic in gem sizes, but shows brilliant interference colours, usually centred on the various points where tiny inclusions can be located, and so on. He will also learn to use a pocket lens to reveal interference figures, at least in the simpler cases, and the sight of a uniaxial figure through the table facet

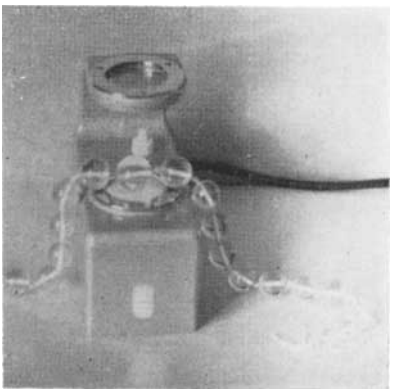

FIG. 1. *Quartz necklace on Rayner polariscope.*

of a ruby or sapphire will give him fairly strong assurance that the stone is a natural one. The unique interference figure of quartz, with its hollow coloured centre can often provide a quick proof for this mineral. This is beautifully and easily seen in beads of rock-crystal or crystal balls, in which the spherical shape makes the figure visible without the use of a lens to provide the "conoscope" effect. (Fig. 2).

Polaroid can also be used to detect dichroism in gemstones. Two pieces can be set with vibrations at right angles to each other in a pair of old spectacle frames, and a specimen viewed in rapid

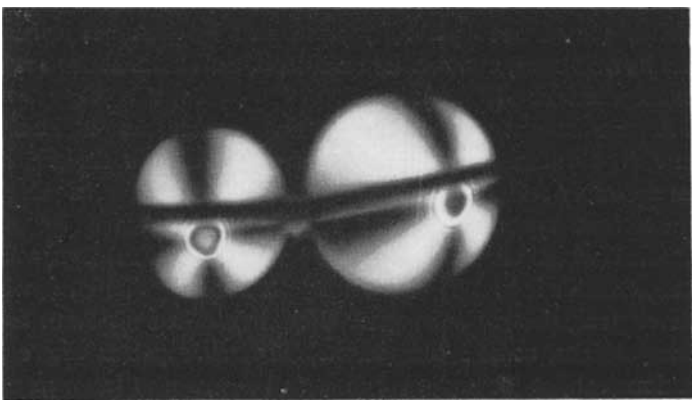

FIG. 2. *Unique interference figure of quartz seen in two beads on the Rayner polariscope. (Photo: Robert Webster).*

alternation first with one eye and then the other, often showing a marked change in colour, or narrow strips of polaroid in alternating vibration directions can be counted on a disc of plain glass which can be mounted at one end of a short metal tube with a low power lens at the other. This forms an effective dichroscope for stones that are not too tiny: a dichroic stone viewed through the tube showing alternating stripes of different colour or depth of colour. Alternatively the polaroid disc at the end of the tube can be cut into four sectors, the top and bottom sectors transmitting light vibrating, say, north and south, while the left and right hand sectors transmit only light which is vibrating east and west. In testing for dichroism it is best to use daylight reflected from a white surface if possible, and always one should turn both the specimen and the dichroscope tube before deciding on the strength of the dichroism—if there is any.

The next simple and inexpensive aids to gem testing that I want to recommend comprise liquids of various kinds, glass cells of suitable depth and diameter, a glass funnel and some filter papers. These can be used in a number of ways: to enable the colour distribution and other internal features of rough or cut stones to be studied with ease: as a rapid test for the density of unmounted stones: and as a means of assessing the refractive index of unknown specimens.

A useful stock to begin with would be two ounces each of methylene iodide, bromoform and bromobenzene, and four ounces of monobromonaphthalene, each in screw-top bottles of brown glass.

When stones are immersed in a liquid of similar refractive index the surface reflections and the effects of refraction are largely eliminated and one is able to "see into" the specimens as easily as though they were parallel-sided plates. The "frosted" effect of the surface of rough gem pebbles is also eliminated when they are immersed in a suitable liquid, and lapidaries are well advised to use this means of seeing the colour distribution, flaws, etc. of rough gems to enable them to be cut to the best advantage.

Gemmologists are familiar with the technique of placing a suspected ruby or sapphire in an immersion cell of liquid before examining it under the microscope, but they may not realize how helpful immersion may be for observations with the naked eye or with a lens. Sapphires in particular can usually be recognized as

natural or as synthetic when immersed in bromonaphthalene and viewed against a white background. Natural sapphires almost invariably show zones of colour with rigidly straight edges, while synthetics show the well-known curved swathes of colour when observed in the correct direction.

A simple and effective means of illumination is to place the stone in its immersion cell on the base of another, inverted glass cell of rather larger size, and direct the light from a bench lamp on to the white blotting paper on which this stands.

For density tests a stone must of course be free from its setting. Granted this, there is no simpler or more decisive way of distinguishing, for instance, between chrysoberyl and quartz catseye, between aquamarine and synthetic blue spinel, or topaz and yellow quartz, than to put the stone in question into a tube of methylene iodide and seeing whether it floats or sinks. On the whole it is advisable to keep your liquids as pure compounds rather than as mixtures, as in that way their densities and refractive indices remain constant, except for slight variations with temperature. A very useful mixture, however, is one of bromoform diluted with monobromonaphthalene until a small clear quartz crystal remains suspended in it. So constant is quartz in its density that this will serve as a virtual identification liquid for any of the transparent quartz gems such as amethyst and citrine. But also it will serve to identify Chatham, Gilson, or Zerfass synthetic emeralds, since the density of these is almost identical to the 2·651 of quartz.

Using liquids as a guide to the refractive index of gemstones has much in common with their use in checking density. In both cases a quite crude test may be all that is required to resolve a doubt, and in both cases quite accurate results can be achieved if this is necessary by taking more time and refining one's techniques. Even with mounted stones liquids can quickly give useful clues to refractive index. If the small diamonds in a cluster ring, for instance, are suspect, a clear decision can be given if the entire ring be immersed in methylene iodide and the stones viewed with a lens. If the stones are diamond the refractive index is so much higher than that of the 1·74 of the liquid that the facets and edges will still appear sharp and clear, while synthetic white spinel and synthetic white sapphire will virtually disappear in this fluid. With loose stones, a very fair idea of their refractivity can be quite quickly and easily obtained by placing the stones table facet down in a fair-sized

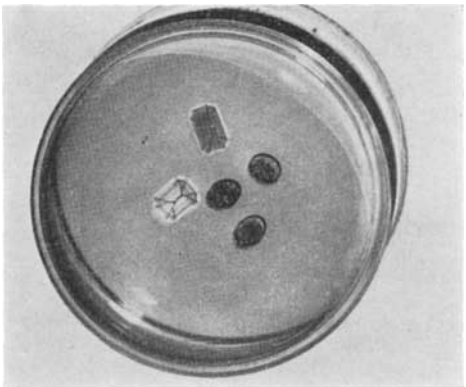

FIG. 3. *Effect seen when three (oval) yellow sapphires and two (step-cut) topaz are immersed in monobromonaphthalene and illuminated by a single overhead light.*

glass cell and pouring in enough monobromonaphthalene (R.I. 1·66) to just cover them completely. The cell should be placed on a sheet of white blotting paper and the stones viewed by the light of a single bulb some distance overhead. Those stones with an index higher than that of the bromonaphthalene will show a distinct dark rim round their periphery, as seen projected on the paper below, and the projection of the facet edges will appear white whereas with stones of lower index than the liquid a pale surrounding rim can be seen with the facet edges as dark lines. (Fig. 3). The degree to which the index of the stone is lower or higher than that of the liquid can be assessed with fair accuracy by noting the width of the dark or pale rim. Unlike the well-known "Becke" methods for gauging whether an immersed grain is more or less refractive than the liquid, this procedure leaves no doubt at all in the observer's mind about which has the higher index. A refinement of this simple test is to place the cell containing the immersed stones on a finely-ground glass sheet which is made to act as a bridge between two four-inch blocks of wood or stiff cardboard. A "handbag" mirror of suitable size is placed at 45° under the cell, enabling the projection onto the glass sheet of the stones, illuminated from above, to be seen in detail and in comfort. The effects seen are really very beautiful as well as revealing. If a permanent record is required, a contact photograph can be easily obtained in a dark room by placing the cell containing the stones over a piece of slow

film and exposing for a few seconds to an overhead light. Those who are photographers can make use of the narrow beam of light from an enlarger stopped down to f22, and thus obtain very sharp and detailed photographs. Internal features of the stones, in particular colour-zoning, show up very clearly on such photographs, particularly where the liquid and stone are of nearly the same index. I have found that the curved striae in synthetic corundums may be discerned in such photographs even if invisible under the microscope. For this, however, carefully filtered methylene iodide is necessary, and one must be lucky in hitting the right direction for showing the lines. I have only had time to give bare outline of these methods: but anyone seriously interested will find details, with diagrams and photographs, in my book "Gem Testing".

I have included bromobenzene in my short list of useful liquids because this fairly pleasant and inexpensive liquid has a refractive index of 1·56. This makes it an ideal immersion fluid for the critical examination of emerald: it enables the thin rim of dark colour to be seen at the edges and corners of the "Lechleitner" type of synthetic emerald, in which a pale, faceted beryl is used as the "seed" on which a thin crystalline layer of synthetic emerald is grown hydrothermally. Quite a few of these stones are now being used in mounted jewellery. The index of bromobenzene is also between that for synthetic emeralds of the Chatham, Gilson and Zerfass types and the indices found in natural emeralds. A good immersion contact photograph of synthetic and natural emeralds immersed in bromobenzene will reveal this. (Fig. 4).

Two pieces of advice I should like to add because I am so convinced of their importance for any budding gemmologist. The first is to start a collection of gemstones, because the ability to compare the appearance and properties of an unknown stone with known samples is of inestimable value in testing. Even a collection of all available synthetics, doublets, pastes, etc. makes a most useful and interesting beginning. For genuine stones the "shoestring" may only permit one to acquire only quite small specimens, or chipped or broken pieces, but one must realize that money spent on any fine specimen is not lost but invested, since the value of these is continually increasing. The second piece of advice is to have at hand one or two reliable reference books. Two by Robert Webster stand out by reason of their accuracy and comprehensiveness. His "Gemmologist's Compendium" contains all the necessary data on

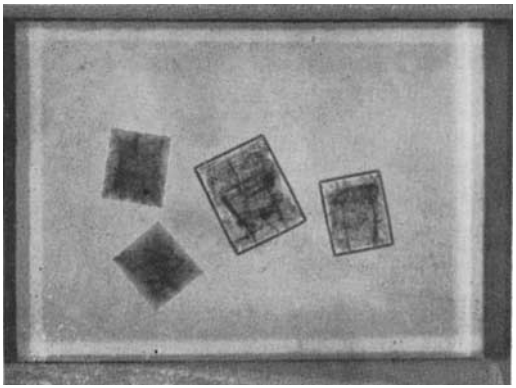

FIG. 4. *Immersion contact photograph of two natural emeralds (dark borders) and two Chatham synthetic emeralds (pale borders) in bromo-benzene.*

gemstones in condensed form, and is very reasonably priced, while his two-volume work "Gems", though expensive, contains such a wealth of information as to be well worth the money for any sizeable firm or jewellers or any serious student of the subject.

A trained gemmologist can go a long way in gem identification by intelligent use of a good lens and a few simple bits of apparatus, but I must repeat the warning that some of the problems confronting the trade to-day need more than this for their correct solution: they need all the facilities and skills of a specialized laboratory.

PHOTOGRAPHIC TECHNIQUES USED IN GEM TESTING

By ROBERT WEBSTER, F.G.A.

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A NUMBER of photographic and radiographic techniques are used in the testing of gems and associated work. In this article it is proposed to discuss the photographic techniques used, some of which have been developed by the staff of the Laboratory of the London Chamber of Commerce. These techniques have proved of great value in identifying individual gems and in proving whether they are natural or synthetic. They are frequently employed in the preparation of photographs to support expert evidence in civil and criminal court cases.

Straightforward photography of articles of jewellery and of single gemstones has little application in this field, except for requirements such as the production of pictures for identity certificates—documents giving all the features of a piece of jewellery so that it can be readily identified on recovery following loss or theft. When a photograph is needed to illustrate an article for publication it is usually taken by a professional photographer, who is better versed and equipped for this work than the normal gem-testing laboratory

The photomicrography of inclusions in the interior of gemstones is very important in the preparation of identity certificates for gemstones and jewellery, for record purposes, for teaching, and for illustrating publications. The usual method of taking these photomicrographs is to use a microscope camera which fits over the ocular of the microscope. This may be just a simple slide carrier mounted on a housing to fit the microscope; the focusing being carried out on a ground-glass screen inserted into the slide carrier in place of the dark slide. Alternatively, an eyepiece microscope camera with an independent eyepiece for focusing can be used in which the image can be observed right up to and during the exposure.

A method, although not strictly accurate, which usually works well in practice, is to use a 35-mm camera. The microscope is first focused on the specimen in the ordinary way and the camera, set at infinity with the aperture fully open, is placed squarely on the microscope ocular. A special ring fitting encloses the camera lens mount to avoid lateral displacement. If the estimated time of

FIG. 1. *Photomicrograph of an unusual inclusion in a diamond.*

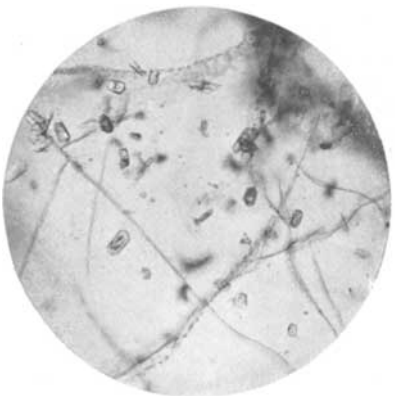

FIG. 2. *Inclusions in a synthetic emerald.*

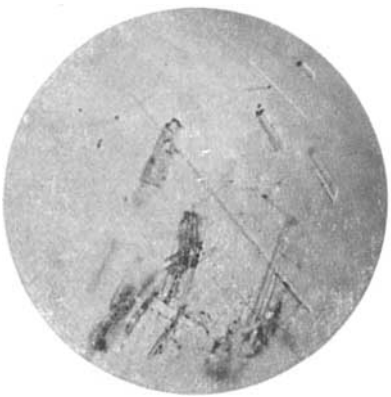

FIG. 3. *Stumpy prisms and rod-like crystals in a Rhodesian emerald.*

FIG. 4. *Flat liquid-filled film seen in tourmaline.*

FIG. 5. *A fly in a piece of Baltic amber.*

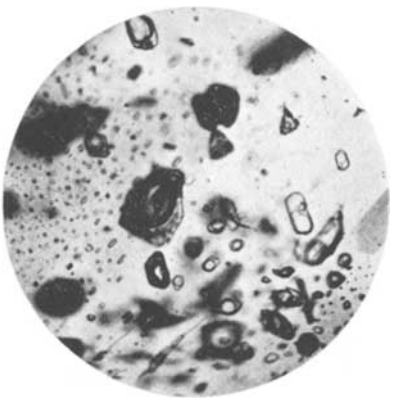

FIG. 6. *Inclusions in yellow beryl from Madagascar.*

exposure (exposure meters being of little assistance here) is in the compass of the camera shutter speeds, the use of the delayed action mechanism assists in the prevention of camera shake. If the exposure is greater than the range of the shutter speeds then the B setting is used and a cable release with a locking fitting is essential.

When photographing the surface structures of a stone, the specimen has to be mounted so that the features to be recorded are in a fairly level plane. This can be achieved by holding the stone on the slide with the aid of wax or plasticine and the features are brought out by top or side lighting.

The internal features of a gem are more difficult to photograph as it is necessary to overcome the reflections from the facets of the stone. This problem is solved by immersing the stone in a liquid with a refractive index near to itself in a cell with a plain glass bottom. Special cells are made which allow the position of the stone to be adjusted while immersed in the liquid. The liquids most convenient to use for stones of higher refractive index are monobromonaphthalene ($C_{10}H_7Br$; $n = 1{\cdot}66$) or methlene iodide (CH_2I_2; $n = 1{\cdot}74$). For the important gemstones of the beryl group (emerald and aquamarine) and the quartz group (amethyst, citrine and rock crystal) which are of lower refractive index, bromobenzene (C_6H_5Br; $n = 1{\cdot}56$) is preferable because of its similar lower refractive index.

Light transmitted through the subject from the microscope mirror and sub-stage apparatus (sub-stage condenser or polarizer) is normally used to photograph inclusions in gemstones. Occasionally, however, dark-ground illumination will reveal features not clearly seen by ordinary transmitted light. Such features are fine growth lines and large opaque crystal inclusions which are shown only as a dark silhouette when transmitted light is used.

An unusual photographic technique came into use when B. W. Anderson (1952) devised a simple method to obtain a near approximation of the refractive index of gemstones without recourse to a refractometer—this is of especial value as the refractive index of a gem is of the highest diagnostic importance. This method is to place a sheet of white paper underneath a glass-bottomed cell containing the gemstone and a liquid of known refractive index; by viewing it under a single overhead point-source light the appearance of the rim of the stone and the facet edges will give the desired information.

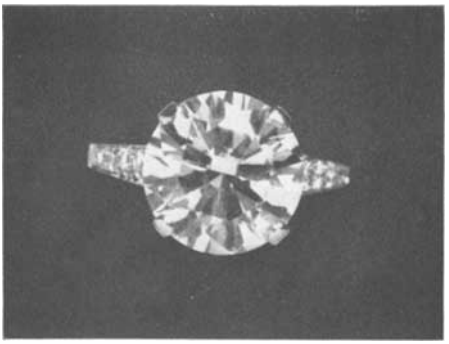

FIG. 7. *One of the photographs used for an identity certificate of a diamond ring. Taken on Ilford Line Film using an enlarger as camera.*

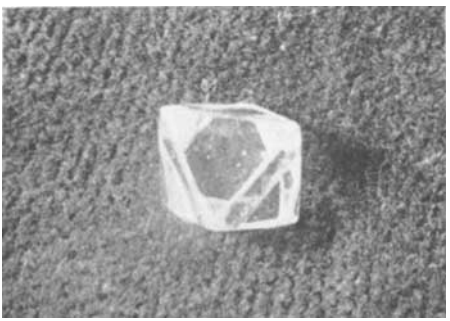

FIG. 8. *Photograph of a "glassie" diamond crystal. Taken with an ordinary camera fitted with a 3-dioptre positive lens.*

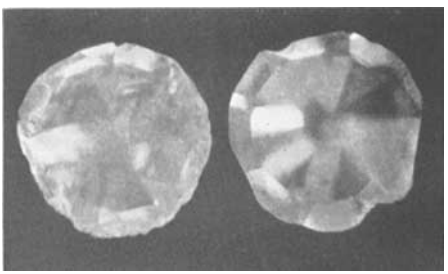

FIG. 9. *Photomicrograph of two very small diamonds showing the broken edges of the stones. This picture was used to support evidence given by an expert witness in a court case.*

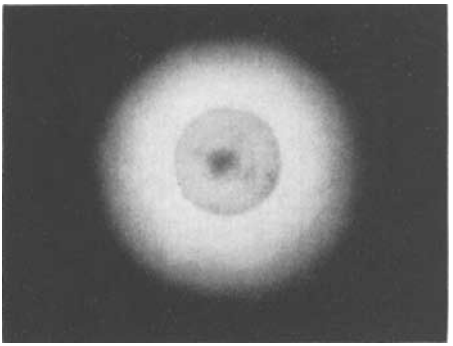

FIG. 10. *An autoradiograph of a radioactive (greened) diamond (positive print).*

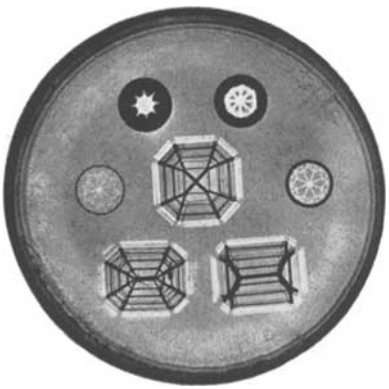

FIG. 11. *Immersion contrast picture of seven different gemstones immersed in monobromonaphthalene, which has a refractive index of 1·66. It will be noted that the four circular stones have an index higher than the liquid and the three other stones.*

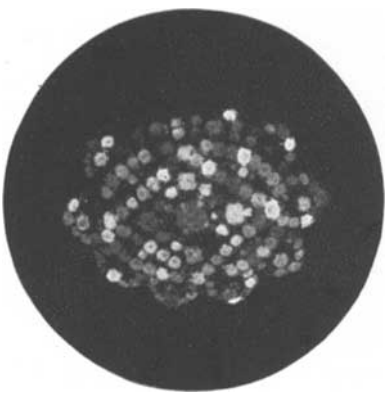

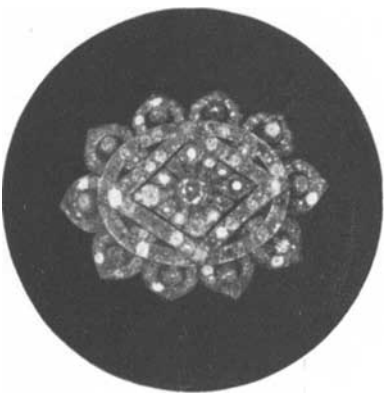

FIGS. 12 and 13. *Photographs of ultra-violet fluorescence of a diamond brooch—using an ultra-violet fluorescent tube lamp (12) and using a medium pressure (Hanovia) lamp with Wood's glass filter (13). An Aviol ultra-violet filter was placed over the camera lens.*

When stones have a higher refractive index than the liquid, they will appear to have dark borders and the facet edges will show as white lines, conversely, if the stones have a lower refractive index than the liquid they will have white borders and dark facet edges. The dark or bright border widens as the difference between the refractive index of the stone and the liquid increases; thus it is possible to make some estimation of the actual index of refraction of the stone. When the liquid and stone nearly match in refractive index, the aforementioned signs tend to disappear and spectral colours are seen at the margin of the stone and liquid. This is because the liquid has a higher colour dispersion than the stone and would be obviated if monochromatic light is used.

A permanent record of this effect can be made by placing a slow photographic film or bromide paper beneath the cell and giving a brief exposure from a point-source light directly overhead. An enlarger makes a suitable set-up. It must be remembered that the result is a negative and the light and dark areas will be reversed. This is important when bromide paper is used, but with a positive print from a film it will, of course, give the correct interpretation.

The photographic materials used for this technique, i.e. Contact or Bromide paper or slow film such as Line film, are only sensitive to blue light and thus the effective refractive indices of the liquids and gemstones will be their higher blue-light values; this may affect the interpretation when the stones and the liquid have a similar refractive index.

If a stone is placed in a liquid which has a closely related index of refraction, the "immersion contrast" picture will be a "life-size" reproduction of the stone showing the distribution of the facets and the outstanding internal features. Such a picture is of value in any future identification of the stone. It has been found, too, that this method has shown up fine structures not apparent by ordinary microscopical examination; this is particularly so with the curved growth lines of difficult-to-prove synthetic stones.

Experiments have shown that most synthetic gemstones are transparent farther into the ultra-violet than stones of natural origin. An example of this is the synthetic emerald from America which transmits down to approximately 2,300Å whereas the natural emeralds absorb below approximately 2,900Å. Thus, this synthetic emerald will transmit the resonance line of mercury (2,537Å) and the natural emerald will not. Identification of the

transmission of this resonance line therefore indicates that a stone is an American synthetic emerald.

A photographic technique has been developed to show up the differences in transparency. A flat-bottomed dish is half-filled with water; water being transparent to the operative range of ultra-violet light. A piece of slow photographic printing paper such as Ilford Contact Paper C2, IP is placed at the bottom of the dish. On this paper, also fully immersed in the water, is placed the stone or stones to be tested together with known specimens to act as controls.

A short-wave ultra-violet lamp consisting of a low-pressure mercury-vapour burner with an envelope transmitting down to about 1,800Å, used in conjunction with a Chance glass OX7 filter, is held some 15 inches above the dish and an exposure of about one to three seconds duration is given. When the photographic paper is developed the natural emerald will appear as little more than a silhouette, for the ultra-violet rays will not have passed through the stone to any extent. There is always a little visible and long-wave ultra-violet light emitted by the lamp and passed by the filter so that if the exposure be unduly prolonged the longer wavelength transmissions may spoil the result. With care there should be no difficulty and the inclusion of control specimens will obviate any error in interpretation.

The glow of visible light given off by many minerals, gemstones and their imitations when they are bathed in filtered ultra-violet light, has been studied extensively by the author. As a result of this research the fluorescence of gem diamonds, which alone among the important gemstones show considerable variation in the intensity of their glow and even in their colour, is being put to practical use. This differential luminescence of diamonds is a means of producing additional evidence for incorporation in identity certificates, which are difficult to prepare for pieces of

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FIG. 14. *Radial asbestos fibres in a demantoid garnet.*
FIG. 15. *Goethite intrusion in amethyst.*
FIG. 16. *Pyrite crystals in an emerald.*
FIG. 17. *Manganese oxide "tree" in rose quartz.*
FIG. 18. *Flake of hematite in aquamarine.*
FIG. 19. *Zonal structure in sapphire.*
FIG. 20. *"Feathers" in sapphire.*
FIG. 21. *Inclusions in peridot.*
FIG. 22. *Crystal in blue apatite.*
FIG. 23. *Rutile crystals in ruby.*

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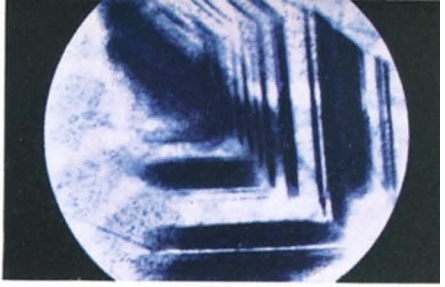

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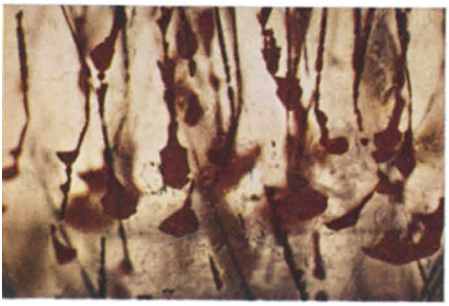

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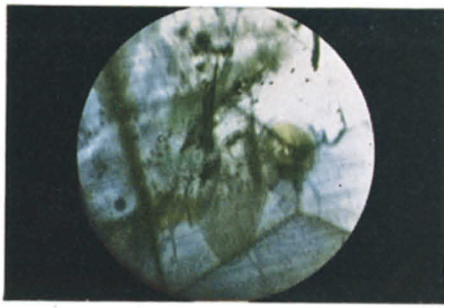

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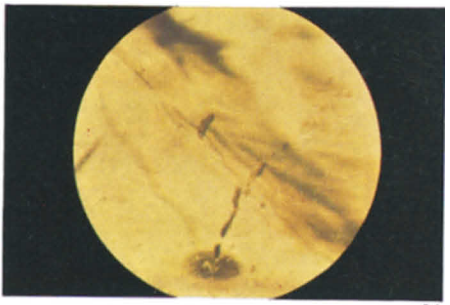

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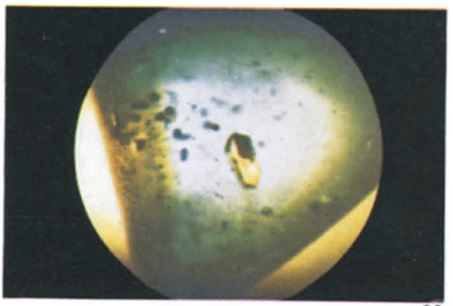

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jewellery made up of a large number of small diamonds. Photographs of this type of jewellery, first under ordinary lighting conditions and then under ultra-violet light, give conclusive evidence of its identity. This is because of a facsimile piece of jewellery would not exhibit a similar degree of fluorescence in the same places. Any difference must betoken another piece of jewellery of similar design, or that some of the stones in the original piece had been changed.

The technique used to photograph these luminescent glows is as follows. The first essential is a source of filtered ultra-violet light. Modern ultra-violet lamps, all of which operate by an electrical discharge through mercury vapour, are of three main types. There is the short-wave lamp mentioned earlier, which has its emission at 2,537Å; and the long-wave lamp which consists of a medium-pressure quartz/mercury burner and has the visible and short-wave radiations filtered out by a Wood's glass (Chance OX1) screen. The latter emits strongly the powerful mercury line at 3,650Å. A third type of ultra-violet fluorescence lamp, now in considerable use, may be described as a "hybrid". This lamp consists of a low-pressure mercury burner in the form of a straight glass tube. On the inside of the tube is a coating which "fluoresces" under the influence of the short-wave radiation given off by the excited mercury vapour. It is analogous to the fluorescent tube lamps commonly used for lighting, but the coating emits ultra-violet light and does not glow very much in the visible range. The filter used in conjunction with this lamp, which gives a continuous and not a line spectrum, allows a broad range of wave-lengths to be radiated from about 3,200Å to about 4,200Å, the latter being in the visible violet.

Each of these lamps may be used for fluorescence photography, but the medium-pressure lamp with Wood's glass screen gives the best result with diamonds. The fluorescent tube lamp is unique in that, owing to the emission reaching into the visible violet, a

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FIG. 24. *"Feathers" in synthetic emerald.*
FIG. 25. *Crystals in natural spinel.*
FIG. 26. *Iron inclusions in beryl.*
FIG. 27. *Curved colour bands in synthetic sapphire.*
FIG. 28. *Crystal and stress cracks on spinel.*
FIG. 29. *Rutile needles in rock crystal.*
FIG. 30. *Bubbles and curved lines in a synthetic ruby.*
FIG. 31. *Cavities with included bubbles in yellow beryl.*

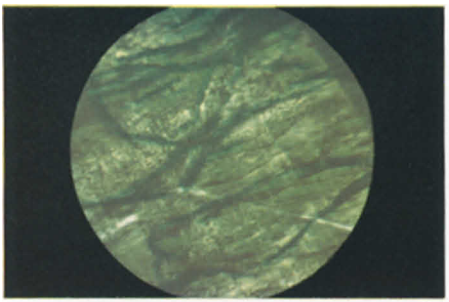

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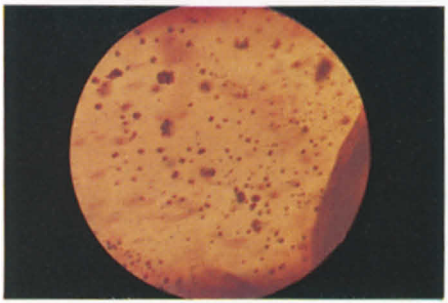

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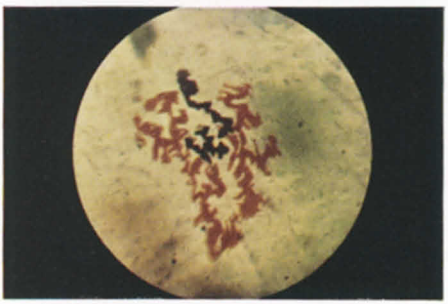

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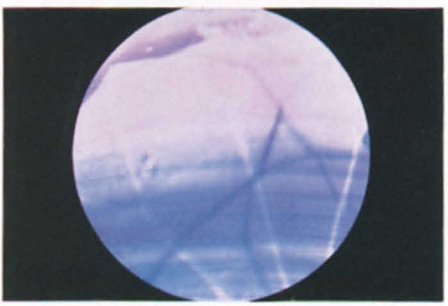

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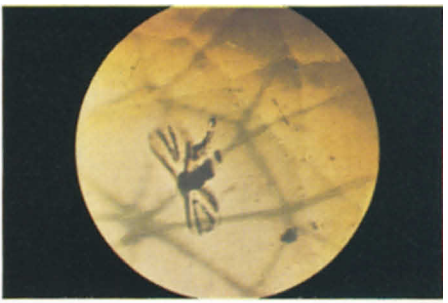

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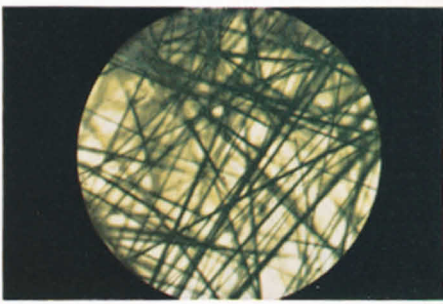

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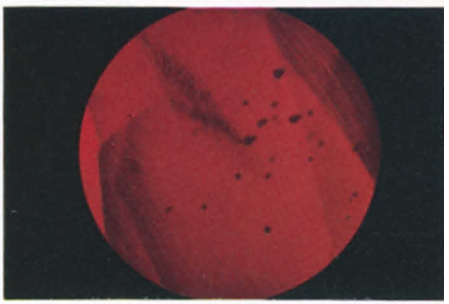

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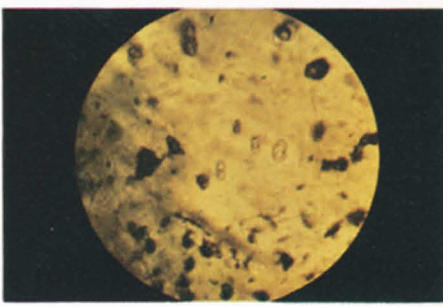

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direct (ordinary) picture is obtained of a piece of jewellery with the fluorescent glows superimposed. This may obviate the need to take two pictures, but the overall effect is not so good as with the medium-pressure lamp.

Any camera is suitable to take fluorescence photographs providing that an ultra-violet absorbing filter is placed over the camera lens. An Aviol filter is suitable. Orthochromatic or panchromatic films or plates may be used, for glows are mainly blue in diamonds. Excellent results have been obtained by the use of colour film, but the added cost is usually unnecessary for the preparation of identity certificates.

Some diamonds are altered to a green colour by bombardment with rays from a radium compound. In such cases the treated stones themselves become radioactive. These "greened" diamonds are tested for their radio-activity by autoradiography. The suspected diamond is taken into the dark room and placed in a box on a piece of X-ray film (or any fast film). To prevent movement, the diamond is lightly packed or, with the main facet upwards, is fixed with plasticine to a piece of cardboard cut to fit the box and then lowered into the box face downwards so that its main facet is in contact with the film. The box is closed, wrapped in black paper and left overnight. The film when developed will be blackened if the stone is radioactive—it will have *taken its own picture* in fact. This method of detecting radioactivity is also of value in testing other stones, and in particular the recently introduced metamict stone called *ekanite*.

In conclusion, the use of a quartz spectrograph should be mentioned. It is employed in conjunction with spectrum plates and has a number of applications: for minor spectrum analyses, for recording absorption and emission spectra, for checking the emission of ultra-violet lamps, and for measuring the degree of transparency of gemstones to ultra-violet light.

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HYDROTHERMAL RUBY

In an earlier issue of this Journal[1], Dr. E. Gübelin described the process of producing hydrothermal ruby and gave details of samples that had been produced in the U.S.A., which he had examined.

Recently the Association acquired a hydrothermal ruby, which had a relatively thick coating of synthetic material deposited onto the seed of natural ruby. When examined by Dr. Gübelin it confirmed the observations which he had previously published.

Observed in dark-field illumination the seed crystal is very easy to see and to distinguish from the hydrothermal surround. The seed contains typical natural inclusions consisting of liquid films surrounding microlites. From the appearance of these natural inclusions Dr. Gübelin suggests that the seed is probably a Siam ruby. In the hydrothermal layer surrounding the seed there are typical gaseous markings, already described[1]. By using dark-field illumination the difference between the natural seed core and the hydrothermal overlayer of synthetic ruby is seen distinctly.

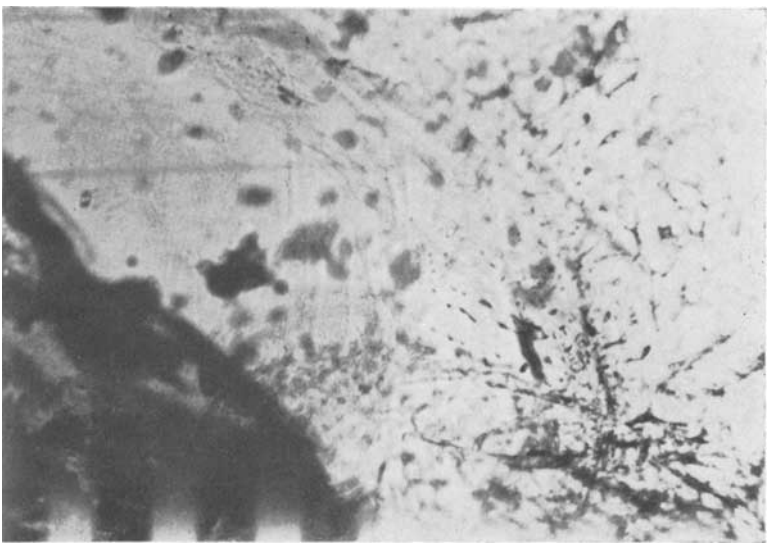

FIG. 1. *Gaseous inclusions consisting of irregular tubes and hoses. The natural inclusions consisting mainly of microlites are out of focus. Photo in transmitted light.*

FIG. 2. *Gaseous inclusions in the hydrothermal overlayer, which are distinctly separated from the seed by dark pairs of growth lines, which meet at angles. This is distinct and characterizes the natural core, while in the lower part along the demarcation line between the natural crystal and hydrothermal overlayer there are numerous gaseous inclusions. Photo in transmitted light.*

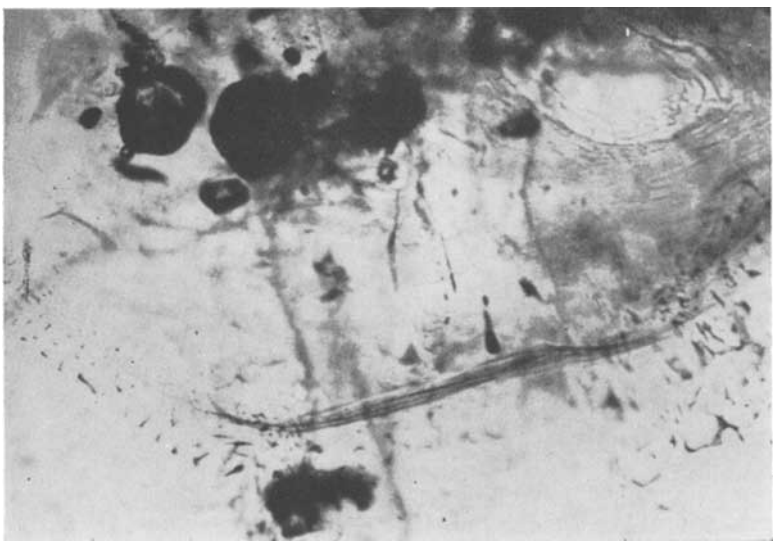

FIG. 3. *Top part of the phenomenological appearance of natural inclusions in Siam rubies. Photo in transmitted light.*

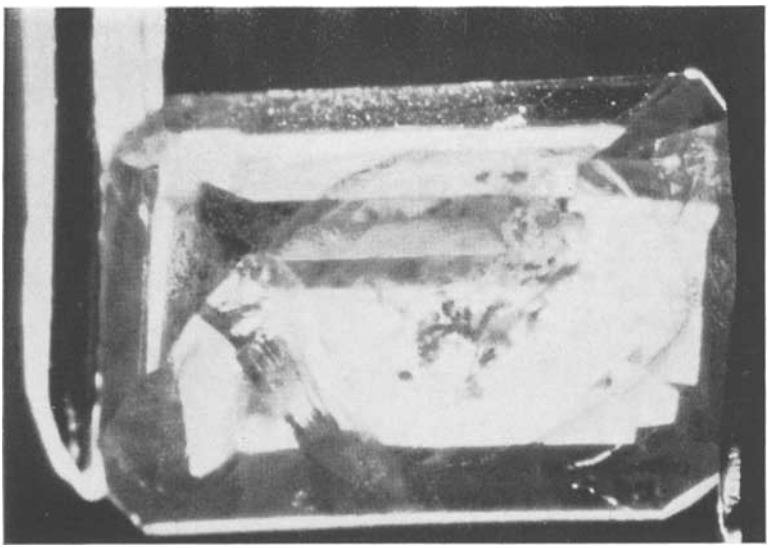

FIG. 4. *Showing difference between hydrothermal overlayer of synthetic ruby and seed core with its natural inclusions.*

The physical data of the stone corresponded to those given by Gübelin in 1961, but the colour of the stone was a dark red. This colour would invite suspicion but one gemmologist, after a cursory glance down a microscope, unwisely concluded that the stone was natural, thus emphasizing the need for caution and careful observation before making a decision as to a stone's nature.

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A NEW FACETING MACHINE

Following the development of his successful Beach Gem Master, Mr. M. L. Beach, F.G.A., of Twickenham, has devised a competent and inexpensive machine, called the Facet Master, with which cabochon work and faceting can be carried out.

The machine requires a small electric motor, with a pulley arranged so that the machine will run at about 1,000 r.p.m. In addition to free-hand cabochon cutting, the machine can be used for sawing. Faceting is the most difficult type of lapidary work and requires considerable practice and patience. The head of the Facet Master has been designed to give good results, but at all types great care in operation is needed. A few hours spent with inexpensive gem material will assist more than the text books, though these are a necessary background to the art of lapidary work.

The accompanying illustration show the simple yet robust construction of the machine, which costs £18 10s. 0d., complete with faceting head. Accessories for the Facet Master are also not expensive and range from cerium oxide polishing powder at 5s. to 4″ diamond-charged copper laps, coarse, medium and fine, at £7 each. A 4″ lapidary diamond saw costs £6 19s. 0d.

The Facet Master is a precision instrument and responds to intelligent treatment, and will give many hours pleasure to many interested in lapidary work.

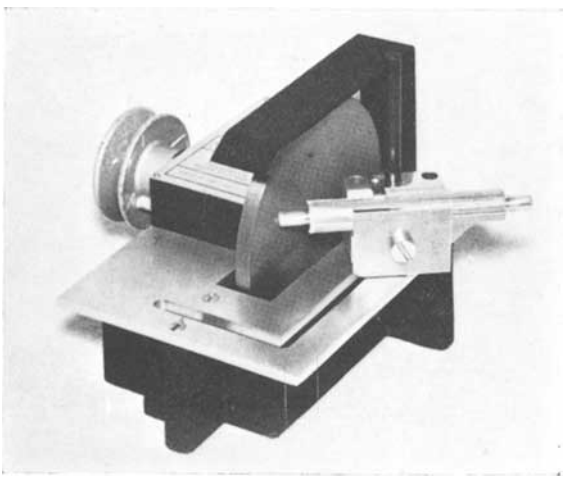

IRIS-OPAL FROM MEXICO

*By JOHN SINKANKAS**

HYALITE opal exhibiting iridescence similar to that observed in chalcedony ("iris-agate") has recently been found at one or more unspecified localities in the State of San Luis Potosi, Mexico. There appears to be no mention in the mineralogical or gemmological literature of the iris-effect in opal and for this reason it is deemed worthwhile to report the results of an investigation into the nature of this new variety of opal.

Specimens of hyalite obtained from Mexico by Mr. and Mrs. Robert Sanchez, of Vista, California, and by Dr. Ronald Olson and Dr. Harry Miller, of Valley Center and Vista, California respectively, were kindly provided to me for examination. The Sanchez' specimens were purchased from a prospector in the city of Durango and were said to have come from alluvium upon the side of a hill near that city. Specimens provided by Drs. Olson and Miller were purchased by them in a parcel of brownish topaz crystals of unspecified provenance; the latter, however, appear to be identical with those described by Barbour (1964) as coming from cavities in volcanic rock near Tepetate and Lourdes, San Luis Potosi. It is probable that the hyalite furnished by Olson and Miller occurs in similar cavities containing topaz because one of the specimens consists of a small topaz crystal incrusted on one termination by a mushroom-like growth of transparent hyalite. All specimens of hyalite are fragments of botryoidal crusts which have broken apart at junctions between adjacent spheroidal growths. Several of the Olson and Miller specimens are stalactitic, consisting of clear hyalite deposited concentrically in cylindrical masses. However, no central filament or acicular crystal could be seen within them about which the opal grew. Within such specimens, and in a few others of non-stalactitic shape, can be seen transparent pale smoky zones. On the other hand, the Sanchez specimens are largely smoky except that in several which were sliced through, the outer zones are colourless while the cores are smoky. An interesting feature of the hyalite is the presence of small white spherical inclusions, some of which have equatorial bulges. These have not been identified but are described and figured by Leiper (1965).

*University of California, La Jolla, California.

A remarkable brilliant-cut faceted gem shown to me by Mrs. Sanchez exhibited flashes of colour reminiscent of the play of colour in precious opal, but much weaker. The colours suffuse the stone momentarily only when the stone is held in certain positions beneath a strong light. They do not seem to be confined to patches, as is the case in most precious opal. The colour display, plus a faint but unmistakable iridescence observable upon the sides of some of the rough fragments, at once suggested that the cause of colour might be due to diffraction from growth bands as in iris-agate. Closer examination of some pieces showed that weathering had differentially etched exposed opal bands, producing a series of minute striae from which light was being diffracted. This further suggested that the growth bands were spaced sufficiently close together to cause the iris-effect investigated and described by Jones (1952) in certain translucent chalcedonies. A similar effect in the Mexican opal could account for the weak colours observed in the faceted gem mentioned above. The iris-effect was confirmed as soon as a cross-section slice of about 2 mm in thickness was taken from one of the rough specimens and polished to remove surface irregularities. As in iris-agate, the effect appears to best advantage when the slice is held at about arm's length before a pinpoint source of light.

Specific gravity determinations were made upon several nodules selected for their freedom from inclusions, cracks, and adhering foreign matter. Determinations were made with a reliability of 0·02 mg by suspension in distilled water; corrections were made for temperature and for the slight buoyancy of the thin platinum wire used to hold the specimens. Three trials were made on three specimens, the average being S.G. 2·257. This is one of the highest specific gravities on record for hyalite (Frondel, 1962).

A polished slab was used for measurement of refractive index upon a Zeiss-Abbe refractometer previously calibrated with distilled water at 23·5°C. Three trials gave $n = 1{\cdot}4625 + 0{\cdot}0003$. This is also one of the highest values recorded for hyalite (Frondel, *op. cit.*). Rotation of the slab upon the prism of the refractometer produced no change in index and indicated that birefringence was absent or too small to measure.

Two trials were made on a General Electric x-ray diffractometer to determine if peaks of quartz, cristobalite, or tridymite could be detected. One trial was made upon a powder sample

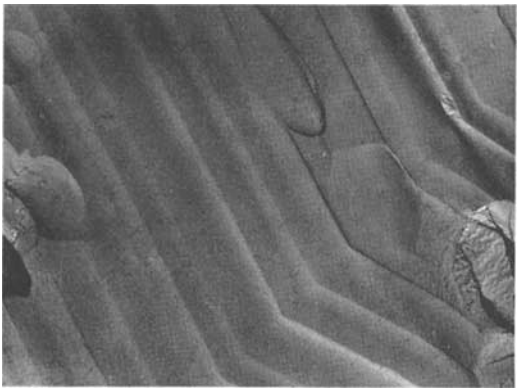

FIG. 1. Layer edges of Mexican hyalite; polished surface etched with HF. 7,800 ×. Replica slightly torn at top and bottom.

and another upon a thin slab which was ground flat with loose 1200 silicon carbide abrasive grain. This slab was fixed in the specimen plane of the instrument. No peaks were found, indicating that the silica crystallites were very small and randomly oriented.

Several smoky specimens were heat-treated to determine if the colour was fugitive. It was expected that such would be the case because a slice taken from one specimen showed it to be surrounded by a layer of colourless material about 2 mm thick, which suggested that the colour had been destroyed in the outer zones by exposure to daylight. The specimens were placed in an oven at room temperature and brought to about 460°C in 30 minutes. At about 200°C it was noted that the intensity of the brownish hue had materially diminished. At the end of 3 hours and 40 minutes the specimens were removed and found to be colourless.

Dehydration experiments indicate that free water in this hyalite is practically absent. A transparent, flawless specimen, free of inclusions or adhering matter, was selected for testing. Initially the specimen weighed 1·908 gm. Three runs were made, the first for 147 hours at 120°C with a negligible weight loss, the second for 4 hours at 200°C, again with a very slight weight loss, and the third for 2 hours at 400°C. At the end of the last run the total weight loss amounted to only 0·001 gm. The specimen did not crack.

Electron-photomicrographs were taken upon a slice of the

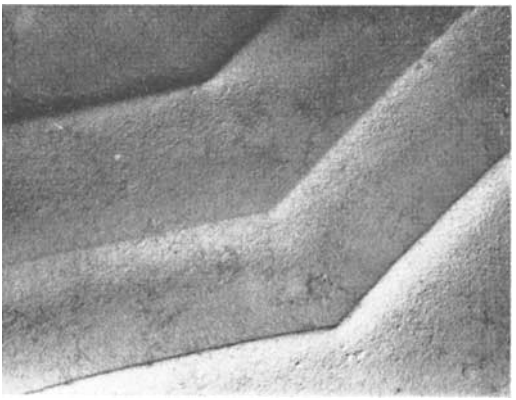

FIG. 2. Layer edges of Mexican hyalite; polished surface etched with HF. Each layer is approximately 2μ thick. 24,000 ×.

hyalite with the plane of the surface oriented across the bandings. The polished surface of the slice was etched for 30 seconds in the fumes of 49% HF to remove the disturbed polish layer and to expose the undisturbed opal beneath. A number of replica photographs were obtained from three different areas in order to count the growth bands and determine the average growth band width. A typical area is shown in Figure 1. A magnified portion of the same specimen is shown in Figure 2, to show how the acid selectively dissolved the opal and by so doing demonstrated slight but important differences in the nature of the opaline material depending upon its position within any band. Figure 3, now much magnified, indicates that the surface of the opal is conglomeritic in texture, each protuberance appearing to be composed of a number of smaller spherules of opal similar to those revealed by the recent work on Australian precious opal by Dr. J. V. Sanders of the University of Melbourne (1964). While Sanders' specimens show a regular cubic packing of spherules, which arrangement is believed to give rise to the intense diffraction effects in precious opal, the spherules in the Mexican material appear to be of widely different sizes and randomly packed. In this respect their appearance corresponds fairly well to the disorder of spherules in Australian potch as shown in Figure 6 of Sanders' report. However, in respect to spherule diameter, those of the Mexican opal are much smaller, approximately 40Å in diameter, while those of the Australian

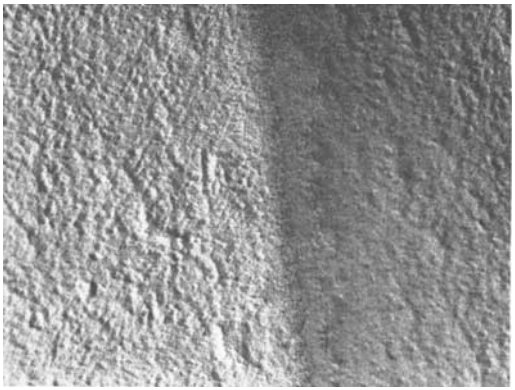

FIG. 3. Junction between layers in Mexican hyalite; polished surface etched with HF. 120,000 ×.

precious opal are 1,500-4,000Å (Sanders, *op. cit.*). The larger aggregates of spherules in the Mexican opal are still only about 250Å in diameter. Thus, if the cause of colour in precious opal is due to diffractive effects from cubic close-packed spherules it cannot be the cause of the diffractive effects in the Mexican hyalite. This leaves diffraction from growth bands as the only likely remaining cause of the iris-effect.

From Figure 3, it appears that the narrow junction zones between layers are occupied by very small opal spherules of uniform size. These are not agglomerated into the larger protuberant structures noted within the bands. It is therefore possible that slight differences in density and hence in average refractive index exist between the junction zones and the bands to account for diffractive effects. However, before diffraction can take place, the spacings between bands must be of the proper order. Jones (*op. cit.*) indicates that any spacing in the range 400 to 15,000 lines per inch, that is from about 160 to 6,000 lines per centimetre, is sufficient to produce the iris-effect if the material is sufficiently translucent; he also states that he has observed the iris-effect in some crystalline organic materials in which the band spacing has been as fine as 30,000 lines per inch, or, 11,800 lines per centimetre. Figure 1, and other photographs not reproduced here, were used to determine band spacings in the hyalite. The average spacing is approximately $2{\cdot}24\mu$, or about 22,400 lines per centimetre (56,900

lines per inch). While the spacing of bands in the iris hyalite is approximately three times as close as that observed in iris-agate, it is still capable of producing the iridescent effect.

ACKNOWLEDGEMENTS

I wish to thank Mr. and Mrs. Robert Sanchez, Dr. Ronald Olson, and Dr Harry Miller for kindly providing specimens of the Mexican hyalite opal. I also gratefully acknowledge the assistance of Mrs. Steven Blankenburg for x-ray work and Mrs. Kurt Boström for electron micrographs of the opal. Dr. Gustaf Arrhenius provided helpful suggestions in the preparation of the manuscript.

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Gemmological Abstracts

. . . *Neuw Synthesen und Imitationen.* New synthesis and imitations. Zeitschr. d. deutsch. Gesell. f. Edelsteinkunde, autumn 1965, 53, pp. 55-58.

A new doublet is being used as a diamond imitation. The upper part is colourless synthetic spinel, the lower synthetic strontium titanate (fabulite). The parting line parallel to the girdle is clearly visible.

Synthetic quartz crystals are now produced in three weeks. The vessel is half filled with natural quartz and some seed crystals (square quartz plates of a good quality) are hung above this. Then caustic soda is added. The temperature used was 350-400°C, the pressure up to 2,000. Large quartz crystals of good quality result.

A new amber imitation was shown on the Ge man market, called "Polybern", consisting of small pieces of natural amber and amber-coloured polyester. The material has a soft, deep polish.

E.S.

BUTLER (W. C. F.). *Diamond synthesis.* Gesa (Babcock and Wilcox Graduates Assn. Journ.), 1964, 27, 1965, 28 and 29.

A detailed survey, based on a paper given before the West of Scotland Branch of the Gemmological Association in 1963.

A.G.

THEISEN (V.). *Regenerieren von Turkisen mit der Soxhlet-Apparatur.* Regenerating turquoises with the Soxhlet apparatus. Zeitschr. d. deutsch. Gesell. f. Edelsteinkunde, 1965, 53, pp. 22.

Through constant use the colour of turquoise usually suffers. The grease of the skin, cosmetics and various sun-tan oils are contributory factors. A Soxhlet apparatus may be used to regenerate stones so affected. A table describes the original colour, details of treatment and resulting colour.

E.S.

GÜBELIN (E.). *Die Lagerstaetten der Rubine und Saphire Thailands.* The occurrences of rubies and sapphires in Siam. Zeitschr. d. deutsch. Gesell. f. Edelsteinkunde, 1965, 53, pp. 27-29.

A description of the mining operations producing sapphires in the valley of the river Kwai and near the hill of Khao Ploi Van, which is about 15 miles west of the town Chantaburi. The latter produces mainly sapphires, but also rubies, spinels, garnets an zircons. The area around the town of Chantaburi has two further ruby-mining areas, namely Klong Van, which has been worked since 1885, and Ban Mai Navang, which has been worked since 1875, and is to-day the most important occurrence.

E.S.

SCHIEBEL (W.). *Kennzeichnung der Edelsteinfarben nach Farbnormen mit Messungen und Berechnungen an synthetischen Steinen.* Determinations of the colour of gems according to colour standards with measurements and calculations on synthetic stones. Zeitschr. d. deutsch. Gesell. f. Edelsteinkunde, 1965/66, 54, pp. 6-30.

The article deals with the difficulties of determining the colour of a gem; this is made especially difficult as the individual eye varies in its sensitivity to recognising colour. There are two standards for recognizing and comparing colour values, the CIE-system (commission internationale de l'Eclairage) and the German standard DIN 6164 for colour cards and DIN 5033 for measurement of colour. All these standards can only with difficulty be applied to the colour of gems. The author deals with the physical nature of light and colour, the alteration of the colour of light and explains how the eye sees colour and is subjectively influenced. The need for a colour comparison method is argued, which can be used in the laboratory making use of colour filters in the colours of transparent stones. Nine diagrams explains the text and there are various tables showing the results of measurements and calculations.
Bibl. E.S.

GUNARATNE (H.S.). *The discovery of a diamond from Ceylon,* Spolia Zeylanica, 1965, 30, 2.

A crystal of diamond was found in a conglomerate of ferruginous pebbles and quartz, collected at Bambarabotuwa in Sabaraga-

muva province. The discovery is the first record of a diamond from the rocks of Ceylon. No details are given about the time or circumstances when the conglomerate was obtained.

S.P.

BOOK REVIEWS

ARGENZIO (V.). *The fascination of diamonds.* McKay & Co., New York, 1966, 184 pp., illus. $5.50.

A short account by a jeweller about the origin and history of diamonds and how they are mined, cut and marketed. An interesting chapter of the evaluation of diamonds contains a lot of commonsense, which should be of use both to jeweller and the lay reader. The author condemns as meaningless such terms as "eye perfect", "blue white" and "commercial white". He also demolishes the "buy it wholesale" myth. A simply written and refreshing book, which should become a useful introduction for the lay reader to the story of diamonds.

S.P.

FRANCO (R. R.) and CAMPOS (J. E. DE S.). *As pedras preciosas.* San Paulo University, Brazil, 1965.

A Portugese text providing a useful introduction to gemmology. The section dealing with physical properties is too brief to give other than a bare outline, and there is no reference to the importance of spectroscopic diagnosis.

S.P.

ASSOCIATION NOTICES

GIFTS TO THE ASSOCIATION

The Council of the Association is indebted to Mr. Peter Wilding, F.G.A. of Liverpool, for kindly presenting to the Association an early optical instrument for detecting imitation diamonds. The Council is also indebted to Dr. G. F. Claringbull, Keeper of Minerals, British Museum (Natural History), London, for assistance in tracing the patent specifications.

Miss Kyoko Igarashi, of Tokyo, has kindly presented a synthetic ruby (hydrothermal type) and a piece of green grossular garnet, and Mr. A. W. Radcliffe, of Johannesburg, has kindly sent a donation of £5 5s. 0d.

The Westland Greenstone Limited of New Zealand has given the Association six specimens of nephrite from the Griffen Mountains in the South Island of New Zealand.

Dr. W. Campbell Smith has kindly presented the Association with some back issues of the *Journal.*

MEMBERS' MEETINGS

24th October, 1966. Reunion of members and presentation of awards, London.

8th November, 1966. Herbert Smith Memorial Lecture, London.

10th November, 1966. West of Scotland Branch Meeting. Speaker: Mr. Robert Webster.

TALKS BY MEMBERS

CAIRNCROSS, A., Northern District P.T.A., 11th January; Perth Business and Professional Women, 13th January; Strathtay and Grandtully W.R.I., 18th January; Blairgowrie Young Wives' Club, 1st February; Letham Kirk Young Mothers' Group, 10th February; Monzie and Gilmerton W.R.I., 5th April; Inner Wheel of Kirkcaldy, 12th April; Bridge of Earn W.R.I., 13th April; Caputh and Murthly Youth Fellowship, 17th April; Perth Child Guidance Centre, 20th April, 1966.

P. Benson-Cooper, "Gems", St. Mary's Church Young Wives, Ash Vale, 8th June, 1966.

COUNCIL MEETING

A Meeting of the Council of the Association was held on Monday, 6th June, at Saint Dunstan's House, Carey Lane, London, E.C.2. Mr. Norman Harper, Chairman, presided.

The following were elected:—

FELLOWSHIP

Howarth, Harry, Hale Barns, Nr. Altrincham, Cheshire. D.1965

ORDINARY MEMBERSHIP

Altermatt, Edgar Curtis, Berkeley, California, U.S.A.

Blackburne, James W., Northampton

Chow, S. K., Hong Kong

Davis, Anthony J., London, W.1.

Font-Altaba, Manuel, Barcelona, Spain

Ford, Ernest S. P. F., Gerrards Cross, Bucks.

Guthu, Steinar, Sandefjord, Norway

Hadate, Shushi, Tokyo, Japan

Hirose, Mitsuo, Tokyo, Japan

Ismail, Mohamed F., Colombo 1, Ceylon

Kelly, Farrol, Keighley, Yorks.

Ketterer (Mrs.), Helene, Geneva, Switzerland

Mann, Bart W., San Angelo, Texas, U.S.A.

Matsuzaki, Shigeru, Tokyo, Japan

Patterson, C. Richard, Garden City, Kansas, U.S.A.

Pattni, C. M., Mombasa, Kenya

Richardson, Sydney H., Auckland, N.Z.

Saleh, Mahmoud A., Cairo, U.A.R.

Talbot, Peter E., Crayford, Kent.

Thomas, Arthur E., Luanshya, Zambia

Uchihara, Keisuke, Osaka, Japan

Wallbridge, Norman W., London, S.E.6.

Webb, Eric W., London, W.3.

PROBATIONARY MEMBERSHIP

Bansept, David A. J., Tunbridge Wells, Kent

Cadman (Miss), Anne Norma, Upminster, Essex

Collier, James E., Chislehurst, Kent

Dingley, Richard M., London, S.W.7.

Hilton, John D., Macclesfield, Cheshire

Lee, Tommy L., Michigan, U.S.A.

Litchfield, Mark E., Chalfont St. Peter, Bucks.

Sutton, Robert M., Bramley, Nr. Guildford, Surrey

Vad (Mrs.), Meena S., Andhra Pradesh, India

A reference from the Annual General Meeting that some form of Association tie should be made available to members was considered. On two previous occasions the suggestion had been submitted, but the Council had found no great support for the idea. It was decided that it would be preferable in the first instance, for the Association to consider obtaining a Grant of Arms. It was agreed that if the matter progressed some reference to the Association's link with the National Association of Goldsmiths should be indicated in the Arms.

Work in connection with the gemmological courses and examinations generally and the Gem Diamond examination was considered.

MIDLANDS BRANCH MEETINGS

The annual general meeting of the Midlands Branch of the Association was held at the Auctioneers' Institute, Birmingham, on 29th April, 1966. The Branch Chairman, Mr. Norman Harper, who is also the national Chairman, presided.

The following were elected as Officers for the ensuing year:—

Chairman, Mr. D. N. King, F.G.A. Deputy Chairman, Mr. Norman Happer, F.G.A. Vice-Chairman, Mr. P. Stacey and Secretary, Mrs. S. E. Hiscox, F.G.A.

Mr. D. N. King thanked Mr. Norman Harper for his interesting year as Chairman of the Midlands Branch and for the many years which he had devoted to the furtherance of the study of gemmology.

On 19th May, 1966, members of the Midlands Branch visited an exhibition of diamonds and special pieces of jewellery set with diamonds at the Birmingham showrooms of Mappin and Webb, Ltd., by courtesy of the directors.

The Midlands Branch held a conversazione on 25th February, 1966, at the Imperial Hotel, Birmingham. Exhibits and talks were contributed by Messrs. H. Tisdall, C. Bereford, D. N. King, J. Marshall G. Porter and N. Deane.

LONDON GEMMOLOGY CLASSES

The gemmology classes which have been held for the past nine years at Northern Polytechnic, Holloway Road, North London, are being transferred to The Sir John Cass School of Art in Whitechapel Road, London, E.1.

As far as is at present known classes will be held at the new college during the 1966/1967 Session on the following days and times:—

1st year (lecture) - -	Monday or Wednesday as directed.	7 to 9 p.m.
2nd year (lecture) - -	Thursday.	7 to 9 p.m.
(practical) -	Tuesday or Wednesday as directed.	6 to 9 p.m.
3rd year (Post-diploma) -	Thursday.	6 to 9 p.m.

Enrolment evenings are to be held on Monday, Tuesday and Wednesday, 19th, 20th and 21st September, 5.30 to 8 p.m. Accommodation is limited and applications should be made by letter to The Principal, Sir John Cass College, School of Art, Whitechapel Road, London, E.1, and not to the Association.

GEMMOLOGY CLASS

A class in gemmology will commence at the end of September at the College of Arts and Crafts, Meeting House Lane, Lancaster. All inquiries should be made to the Principal of the College

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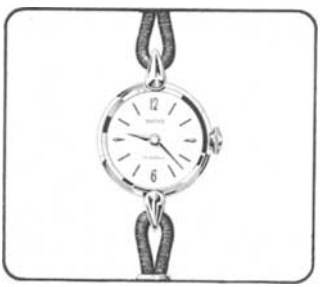

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andalusite (green)
andesine
anorthite
apatite (purple)
bayldonite
brookite
bytownite
crocoite
cuprite
cyprine
dumortierite
durangite
ekanite
enstatite (green)
epidote (green)
euclase (blue), (green), (purple)
fibrolite
gahnite
gahnospinel
glass (Flinders)
glass (Libyan)
hauynite
herderite
hiddenite (Cr.)
hodgkinsonite
hypersthene
idocrase (green)
iolite (bloodshot)
ivory (vegetable)
lazulite
lumachelle
magnesite
melinophane
mesolite
microlite
odontolite
orthoclase (green)
painite
phosphophyllite
pyrophyllite
quincite
realgar
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scapolite (purple)
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and

PROCEEDINGS OF THE

GEMMOLOGICAL ASSOCIATION OF GREAT BRITAIN

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Vol. 10 No. 4 OCTOBER 1966

TRANSPARENT GREEN GROSSULAR—A NEW GEM VARIETY; TOGETHER WITH OBSERVATIONS ON TRANSLUCENT GROSSULAR AND IDOCRASE

By B. W. ANDERSON

ALTHOUGH during the past sixty years there has been an astonishing number of new minerals discovered which can lay some claim to be gem materials (two of which, indeed, were at first only known as cut gems) one has to admit that these stones are still regarded only as collector's items, and have made no impact at all on the jewellery trade.

There are several reasons for this; one being the extreme conservatism of the trade itself, which limits the number of gem species to be seen in the average jeweller's window to a mere dozen or so, even at a time when supplies of the more notable precious stones are woefully short. Another (to be honest) is the lack of real beauty or durability in the newly-discovered materials, which rely rather heavily on the third and least reputable quality required in a gemstone—rarity—to be worth the high prices asked for them. And a third reason is that very rarity which makes it sought after by collectors. That lovely stone benitoite (first discovered in 1907) which has the brilliant blue admired in sapphire added to a fire equal to that of diamond, is a case in point here.

Found only in one locality, and virtually extinct in, so to say, the wild state, it is just not available to the enlightened designer of fine jewellery, who would otherwise surely have come to prize it as he has learned to prize the fire and colour of demantoid garnet.

Demantoid garnet, as gemmologists will know, is a special variety of andradite, the calcium-iron garnet which in its black opaque form is known as melanite. The purpose of the present article is to signal the appearance of another transparent green garnet, in this case belonging to the calcium-aluminium species, grossular. Transparent grossular of brownish-orange colour has, of course, been well-known in jewellery for centuries, under the name "hessonite" or formerly "cinnamon stone". In later years translucent massive grossular in shades of green or pink have also become fairly well known as one of the jade substitutes, and I shall have something to say about this material later in the article.

The transparent green grossulars so far seen were only three in number: they were sent from Pakistan in the hope that they might be emerald. In appearance they did indeed resemble emerald, though not of quite the same colour, and with distinctly more fire. In their fire they were reminiscent of demantoid, but the colour was less yellowish-green. Thus, so far as appearance went, the stones were distinctly puzzling—and, being so attractive, distinctly exciting also. In their properties they matched very closely the hessonite variety of grossular, having refractive index 1·738 and density 3·63. Their absorption spectrum was clearly due to chromium, thus accounting for their almost emerald-green colour. There was a doublet and a number of other narrow lines in the red end of the spectrum, but these were faint and difficult to measure: there was also a broader, diffuse band in the orange-yellow.

The whole effect was very reminiscent of a chrome-rich grossular which had been tested about a year previously. This stone had been sent to this country as "Pakistan emerald", and was in the form of a green broken crystal in which some dodecahedral faces could be recognized, striated parallel to their longer diagonal. On this specimen, measurements of some of the chromium lines were possible though perhaps not very accurate. The usual strong chromium doublet was represented by a line at 6970 A; this was followed by several weaker lines and a more prominent line at 6300 A; a diffuse band was centred near 6050 in the orange, and another in the blue-green at 5050 A. The density of this specimen

was 3·62 and the refractive index (measured on a polished flat) was 1·742.

There could thus be little doubt that the three transparent green specimens were in fact a new form of gem grossular, but as a final check Dr. G. F. Claringbull kindly obtained for me an X-ray powder photograph from traces scraped from the edge of one of the stones. This showed a pattern typical of nearly pure grossular.

The inclusions of the stones were interesting; in one case showing a large and well-developed crystal, possibly of actinolite (Fig. 1), and in others liquid feathers rather in the spessartite manner (Fig. 2): but it would be rash to draw general conclusions from so few samples.

The dispersion for grossular garnet is 0·027 for the B-G range: much lower, of course than for demantoid (0·057), but much higher than for emerald (0·014). The new stones thus have a distinctly lively appearance, and they should prove readily saleable if they become available in reasonable quantity and at a reasonable price. Nomenclature may prove tricky. The misuse of the term "olivine" or "olivene" in the trade for demantoid garnet seems fortunately to have died out, and demantoid is either referred to as such or as green garnet. The grossulars just described can hardly be denied the appellation "green garnet", and confusion with demantoid might well ensue unless the term "grossular" be added.

Massive Grossular and Idocrase

Nomenclature has already proved difficult in a range of massive green grossular garnets which were first mined in South Africa near Pretoria, and were offered as ornamental stones under the misleading term "Transvaal jade". The grossular from this locality has also been found in attractive shades of pink. Recently pieces of translucent material of the same general nature but resembling jadeite much more closely have been sent to this country from a source said to be in Western Pakistan. In testing a number of samples of this kind, it was found that some of them had undoubtedly properties more appropriate to the "californite" variety of massive idocrase then to grossular garnet, and it became clear that in others there was a complete mixture between the two minerals.

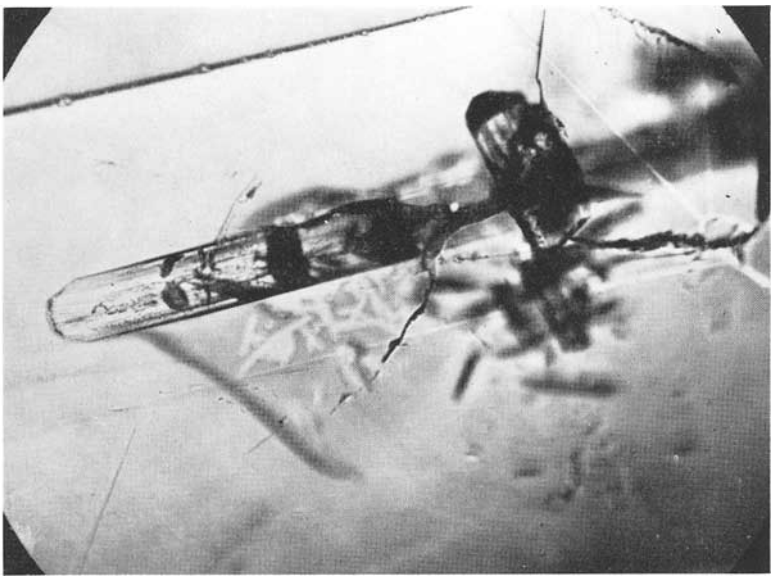

FIG. 1. *Actinolite(?) inclusion in transparent green grossular.* (×25).

It has long been realised by mineralogists that grossular and idocrase are very closely related, both chemically and structurally. The analyses of grossular and of vesuvianite (idocrase) given below will show how little difference there is between them chemically.

	Idocrase	*Grossular*
SiO_2	37·70	39·30
Al_2O_1	19·30	21·93
Fe_2O_3	0·85	0·80
FeO	0·37	0·28
MgO	2·45	trace
CaO	38·30	37·10
Density	3·322	3·506

Analyses of other specimens show wider differences, but those quoted above were from white (and thus presumably unusually pure) specimens, and both were taken from veins in serpentinite in Georgetown, California.

That the structure of the two minerals is also closely related was early realised by Warren and Modell, who carried out the X-ray investigation in 1931. The cube edge of grossular is 11·85 A in pure material, while the corresponding c axis spacing in idocrase is almost the same (11·79 A).

It is not surprising that the two minerals can and do occur as intimate mixtures; and to obtain even an approximate estimate of the proportions in which they are present is no easy task for the gemmologist, confined as he is to methods which are non-destructive and not too time-consuming.

Density determinations and a careful study of the absorption spectra provide useful clues. The most that one can hope to do (and really all that one *needs* to do) is to be able to label those with a considerable preponderance of one mineral "grossular" or "idocrase" as the case may be, and to acknowledge intermediate types to be mixtures of the two.

The density of pure grossular can be taken as 3·60, and that of idocrase is considerably lower, perhaps 3·32—though in coloured crystals 3·40 is a not uncommon figure. The density of minerals in the massive state is generally lower than in single crystals, and 3·50 may be taken as good average figure for a fairly pure massive grossular, and 3·30 for californite (massive green idocrase). Robert Webster[1] carried out density measurements on an extensive range of green and pink jade-like grossulars from the well-known Transvaal locality, and found a surprisingly wide range from 3·36-3·57, with a few pieces even beyond this extensive span. My own determinations on Pakistan material gave a rather similar range: 3·28-3·52.

The chief feature in the absorption spectrum of green idocrase is a strong and well-defined band in the blue at 4610 A, due to iron, and there is a much weaker band in the green near 5300 A. In the case of green grossular the colorant is mainly chromium, and the absorption band most easily seen is a rather broad one in the orange at 6300 A which has a sharp edge on the green side.

It was noticeable that when Pakistan "greenstones" were arranged in order of increasing density, stones with the higher values showed the 6300 chromium band with little or no sign of the idocrase bands at 5300 and 4610 A, while those with low density showed these idocrase bands clearly and no trace of the 6300 chrome-grossular band. The conclusion drawn from these simple

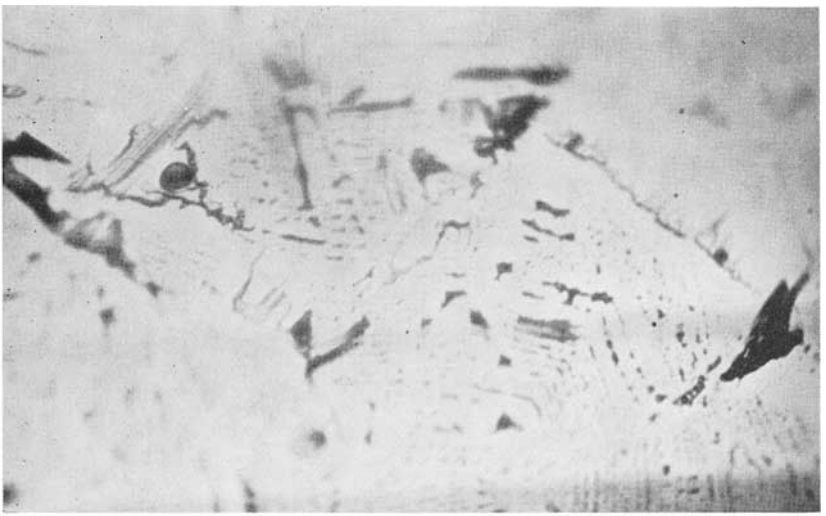

FIG. 2. *Liquid feather in transparent green grossular.* (×25).

gemmological tests, that we have an almost complete range from nearly pure grossular to nearly pure idocrase has been very kindly confirmed for me by Dr. Claringbull, not only by X-ray powder photographs but also by examining thin sections of suitable specimens.

In Transvaal specimens the main idocrase band at 4610 A can be detected in many cases, but there seemed hardly enough chromium present even in the green varieties to register the chrome-grossular spectrum. The presence of zoisite in some of these South African grossulars has been reported, and may in part account for the density variations found in this material.

X-RAY FLUORESCENCE

The orange glow under X-rays (noted by Robert Webster), which is so striking a feature of all massive grossulars, is certainly a valuable confirmatory test for laboratory workers. It has certain drawbacks, however. In the first place the cause of the glow is not known: it does not seem to be intrinsic to grossular itself—almost all such effects in minerals are due to some specific

"impurity". Viewed through the spectroscope the emission is seen as a broad structureless band of light centred in the orange-yellow, giving no clue as to its origin. A study of the trace-element content of fluorescent and non-fluorescent grossulars might suggest an answer.

In the second place, the presence of the phosphor in quite minor amounts will yield the orange glow, which can thus be seen even in some pieces presumed to be californite (idocrase)—a fact which has been recorded by G.I.A. laboratory workers in "Gems and Gemology"[2].

To sum up, the attractive jade-like greenstones from Pakistan have been found to grade from almost pure grossular coloured by chromium to samples consisting mainly of idocrase. The grossulars are marked by densities near 3·5 and by an absorption band near 6300 A in the orange: the californites by densities near 3·3, with the idocrase band at 4610 strongly marked and a weaker band at 5300 A. There are many intermediate types which can only be described (gemmologically) as a grossular-idocrase intergrowth. Almost all specimens may show an orange glow under X-rays in a strength which does not seem to vary consistently with the proportion of grossular present.

Some of this Pakistan material is very pleasing, and at first sight may resemble Burmese jadeite quite closely in appearance, especially in samples where an almost white base is dappled or streaked with patches of bright chrome-green. To market the product successfully will prove difficult unless a good selling name is available. The temptation to describe it as some form of "jade" will be very strong but must be resisted, since only jadeite and nephrite can legitimately be so described. Possibly some broad and non-commital term like "Pakistan greenstone" would prove acceptable for commercial purposes, to which could be added a more specific description for those who are gemmologically interested.

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SMARYLL—A NEW EMERALD DOUBLET

By ROBERT WEBSTER, F.G.A.

THE use of composite stones to imitate the prized emerald is no new thing. Gemmologists have known the green garnet-topped doublets for over half a century, and the "soudé emerald" with a rock crystal crown and pavilion joined together with a coloured layer across the girdle is nearly as old. In 1951 this type was modified by using synthetic colourless spinel for the two main parts of the stone(1).

This latest doublet, which the Americans would probably call a triplet, is made by the firm of Kämmerling of Idar-Oberstein, West Germany, and it consists of two pieces of colourless beryl, pale aquamarine or poor quality emerald, for the crown and pavilion. The two pieces are cemented together with a good emerald-coloured duroplastic cement. The use of real beryl in the making of soudé type doublets is no new thing. Kraus(2) illustrates such a type of stone in his book.

Through the courtesy of the Gemmological Association the writer has been privileged to examine three specimens of these new composite stones. Two of the stones were fashioned in conventional emerald-cut style and weighed 3·36 carats and 1·97 carats respectively. The third stone was cut as a round brilliant and weighed 1·02 carats. The colour is a good emerald-green and is possibly somewhat better in this respect than that of the synthetic spinel doublets. It was noticed that there were slight differences in the shade of colour of the stones.

The refractive indices obtained from the table facets of the two trap-cut stones were found to be 1·591-1·585, but the indices of the pavilion pieces were found to be slightly lower. The refractive indices of the brilliant-cut stone taken on the table facet were 1·588-1·582; the indices of the back facets were not taken owing to the small size of the pavilion facets.

All the three stones showed a green residual colour through the Chelsea colour filter and were dark when viewed through "crossed filters". The absorption spectrum showed woolly bands in the red part of the spectrum, which are reminiscent of those seen with some stained jadeites. The fluorescence shown by the stones under the medium-pressure long-wave ultra-violet lamp (Hanovia

lamp) was a greenish glow,which may well be due to the cement used in joining the two pieces of stones. However, when examined on edge there was no bright green glow along the girdle as would be expected if it was the coloured layer producing the glow. There was no luminescence when the stones were irradiated with short-wave ultra-violet light.

Examined under the microscope the stones showed, in the true beryl parts, mossy and two-phase inclusions and long canals (rain) which are typical of aquamarine. The cement layer showed bubbles in all cases, many of which produced round clear cavities owing to their being "squashed out" by the pressure used in the process of joining. There were also thread-like structures, which it is difficult to account for (Fig. 1). Between crossed polars there was no clear-cut quarterly extinction, which indicates that the two pieces of beryl used were not aligned crystallographically.

FIG. 1. *Photomicrograph of beryl soudé emerald showing the natural canals (rain); the bubbles and the peculiar thread-like marks.*

When the stones are immersed in water in a white porcelain cup and are viewed sideways, the colourless top and base with the dark line along the plane of the girdle are easily seen, as in the case of the normal quartz doublet. This, of course, is less easy to do when the stone is set in jewellery.

The stones make a good simulation of emerald but offer no problems to the gemmologist. There is the question whether the type of dye used to give the green colour is sufficiently stable to light so as not to fade, but time alone can tell this. The present price seems to be too high for the stone to be an effective competitor to the other emerald simulants.

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BLACK TREATED OPAL: AN ANCIENT RECIPE

SOME four years ago a peculiar type of "black opal" made its appearance on the market. The appearance of these stones was very distinctive, the flashes of colour being seen as a small mosaic pattern, and the dark background having a speckled appearance. These were first recognized as treated stones by workers in the Gem Trade Laboratory in New York, but direct proof of treatment was difficult, since the material had the characters of pure opal, and the dark background colour which so enhanced its appearance was unaffected by acids or by other solvents.

Eventually, circumstantial stories as to the nature of the treatment were promulgated, and were without doubt true in substance. One such account stated that suitable Andamooka opal was first heated, then impregnated with sugar solution, and finally "carbonized" by warming with strong sulphuric acid—essentially the time-honoured process used for producing "black onyx". Other informants spoke of heaps of poor quality rough opal being covered with old sump oil, which was then ignited. Whatever method was used, there can be no doubt that the darkening of the originally pale background in these treated opals is due to finely disseminated particles of carbon, which accounts for their remaining unaffected by any of the usual solvents.

All this is recent history: but the gentle art of faking gemstones has its roots in the distant past, and I suppose I should not have been so surprised to find the following passage in the appendix to the 1823 edition of John Mawe's famous little book "A treatise on Diamonds and Precious Stones". Here is what he says, complete.

"*THE OPAL.* Many impositions have been practised in forming imitations, or enhancing the effect, of the opal. The first I shall describe (if indeed that can be called an imposition, which, like the shades of a picture, tends to display to greater advantage its rich and glowing colours) is effected by warming the stone, and immersing it in oil or grease, which is afterwards burnt off. The rents which had absorbed the grease, by this means become dark,

and agreeably contrast with the beautiful iridescence of the stone, which now assumes the name of black or green opal".

Mawe's tolerant attitude towards this form of opal "improvement" may perhaps be better understood when one realises that the fine black opals from Lightning Ridge, or indeed any of the Australian opals, were quite unknown in his day, so that the treated stones probably did present a more beautiful appearance than any of the natural stones then available.

Incidentally, the treated Australian stones have often been referred to as "opal matrix", but the many specimens we have examined in the Laboratory have all been pure opal, as proved by their density range, radiography, and X-ray diffraction.

B.W.A.

STRANGE NOMENCLATURE

In the 1966 Vol. 3, No. 2 issue of the *Japan Watch & Jewellery Journal* (international edition) there is a report of a "new fascinating artificial stone Asia Green Sapphire". It is claimed that the firm making the stones is marketing them as "Asia green sapphire" without any qualification as to whether the stones are synthetic or imitation. As the firm making them is a large producer of jewels for the Japanese watch industry, presumably the "Asia green sapphire" is a synthetic sapphire. Possibly the correct description has suffered in translation, for in the same article there is a reference to an "Asia star ruby sapphire".

S.P.

COLOUR-COMPOSITION RELATIONSHIP IN SPESSARTINE FROM AMELIA, VIRGINIA

by JOHN SINKANKAS, B.Sc., C.G. and ARCH, M. RIED Ph.D

INTRODUCTION

THE characteristic colours of gemstones have been shown to be fairly reliable indicators of composition. Because of such colour-composition relationships, the gemmologist is often able correctly to assign to a cut stone an identity which needs only to be confirmed by one or two physical property tests. In the garnet group, in which miscibility among end-members is the rule rather than the exception, it is, however, far more difficult to draw conclusions as to composition even when property tests are applied in conjunction with assessment of colour. Difficulties arise because property values extend over fairly broad ranges due to the miscibility mentioned, while colours, particularly among the species in the pyralspite group, tend to grade imperceptibly into one another and become, seemingly, less reliable indicators of composition than one could wish for.

The difficulties will be appreciated by considering the data given below upon the ideal end-members of the pyralspite sub-group. These data are from determinations made upon synthetic end-members by Skinner (1956). It is to be noted that all gradations between properties may occur in natural specimens depending upon which end-members are present and in what amounts:

TABLE 1

Properties of Synthetic Pyralspite End-Members

End-Member	Formula	G.	n(Na)
Pyrope	$Mg_3Al_2Si_3O_{12}$	3·582	1·714
Almandite	$Fe_3Al_2Si_3O_{12}$	4·318	1·830
Spessartine	$Mn_3Al_2Si_3O_{12}$	4·190	1·800

As yet, no natural garnets of end-member composition have been reported. Analyses of natural specimens indicate combinations of three or more end-members (Ford, 1915; Heritsch, 1927; Fleischer, 1937; Tröger, 1959). This is reflected in the typical ranges of properties of gem-quality pyralspite garnets as accumulated from gem-testing experience (Anderson, 1964):

TABLE 2

Properties of Natural Gem-Quality Pyralspite Garnets

Principal End-Member	G	n(Na)
Pyrope	3·7-3·9	1·73-1·76
Almandite	3·9-4·2	1·76-1·81
Spessartine	4·16-4·19	1·80

Because of the wide range of substitutions possible in the pyralspite garnets, measurements of density and refractive index serve as guides but do not lead to unique determinations of composition. However, a third property, colour, may be useful in further narrowing the compositional possibilities if it can be shown that specific colours are consistently related to specific end-memb ers While the perception of colour is a subjective response known to vary considerably among individuals, it is nevertheless of great diagnostic value and is commonly used by experienced gemmologists to guide their identification efforts. Gemmological experience indicates that the following hues are characteristic of pyralspite garnets in which the end-member named predominates:

TABLE 3

Hues of Natural Pyralspite Garnets

Principal End-Member	Colour	Characteristic Tinge
Pyrope	Dark red	Red
Almandite	Dark to pale purplish-red	Purple
Spessartine	Dark red-brown to pale orange	Brown to orange

The results of our investigation of fifty colour-graded spessartine samples from Amelia, Virginia, indicate that the colour range in Table 3 is characteristic of spessartine from this locality. When colour is used in conjunction with refractive index measurements it is possible to estimate the composition of the Amelia spessartine garnets.

Our specimens were deliberately colour-graded by visual inspection under conditions of lighting normally used by gemmologists. In order to obtain more precise data on colour, however, we plan at a later time to test each specimen for chromatic absorption over the visible spectrum.

Occurrences of Gem-Quality Spessartines

Several parageneses of spessartine are discussed by Deer, Howie and Zussman (1962), but from the gemmologist's viewpoint, only spessartine from granitic pegmatites consistently provides gem material. Notable sources are pegmatites of the central highland region of the Malagasy Republic, the states of Ceará and Minas Gerais in Brazil, and the Ramona district of California and the Amelia district of Virginia, in the United States. In many granitic pegmatites spessartine occurs as fractured crystals in outer zones and as whole crystals or crystal fragments in cavities. Ordinarily only the spessartine from cavities provides clear areas sufficiently large for cutting into gems.

The spessartine used in this investigation came from the Rutherford No. 2 pegmatite near Amelia, Virginia. This pegmatite formed a dike-like body characterized by a large cleavelandite-lined central vug from which one of us (J.S.) collected a large number of spessartine crystals during mining operations in the period 1958-1959. The spessartine occurs as crude spherical masses up to about 23 cm in diameter consisting of numerous irregular, closely interlocked, etched fragments, all surfaces of which are covered by striations and steps similar to those shown upon the specimen depicted in Fig. 1. The fragments nearest the centre of the masses are darkest in colour (dark red-brown). Toward the

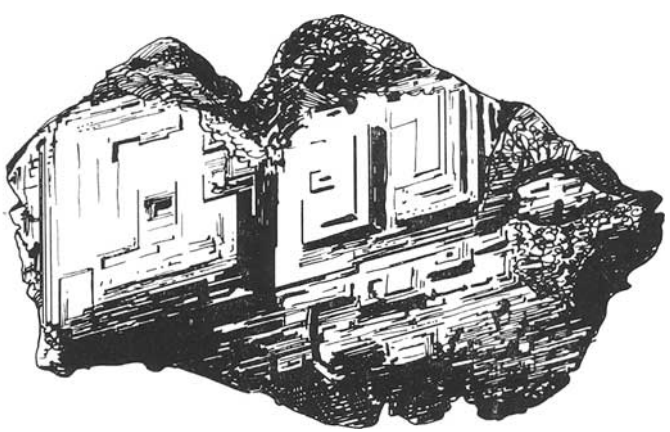

Fig. 1. *Typical etched mass of spessartine from a vug in the Rutherford No. 2 Pegmatite, Amelia, Virginia. Twice natural size.*

peripheries, the fragments gradually lighten in colour until the outermost fragments are red-orange in hue. It appears that each spheroidal mass originally consisted of a single crystal with the colour-change noted above reflecting the decreasing incorporation of iron as each crystal grew larger.

Preparation of Samples

The fifty samples were selected from about 10 kg of core spessartine. Care was taken to choose gem-quality crystals or fragments of about the same size to avoid misleading intensifications of colour due to varying thicknesses. These samples were colour-graded in ordinary transmitted light in the sequence: dark red-brown—red-orange—orange—pale orange. Fragments of 2-3 mm diameter, as flawless as possible, were detached from the master samples and mounted in two circular rows in a single epoxy resin disk of 24 mm diameter. The amount was ground and polished, surface-coated with a uniform conductive layer of carbon. This method assured easy handling in the electron microprobe, a uniformly absorptive carbon-coating, and minimal errors due to instrument drift between readings.

Compositional Results

The samples were analyzed with an Applied Research Laboratories electron probe microanalyzer. Examination of x-ray spectra in the region 1-10Å λ showed that the only major elements present are Si, Al, Mn, Fe and Ca. The detection limit was approximately 0·3 weight per cent under the chosen operating conditions. The major elements were analyzed by comparison with analyzed mineral standards (olivine, plagioclase, rhodonite). Data were corrected for dead-time, drift, background, absorption and fluorescence using the computer programs described by Frazer, *et al* (1966).

Only total iron was determined and the calculations for the end-member garnet molecules (see Table 4) were made on the assumption that all iron is present as FeO. The presence of OH or H_2O was not determined due to the limitations of the method.

Figure 2 is a plot of analyses against sample numbers. The samples are numbered according to colour gradation and are arranged in the colour order noted previously. The plot merely connects data points without attempting to establish smooth curves.

While there are several pronounced deviations in the colour-composition curve and numerous minor ones, the trend is unmistakable and shows that the colours reflect the ratio MnO: (FeO, CaO). It is to be noted that CaO follows FeO which indicates that Ca substitutes in the spessartine in proportion to Fe. The deviations of the MnO and FeO curves are probably due to inaccuracies in colour-grading because of the method used. This view is supported by the refractive index plot of Fig. 3 in which the index values closely follow the deviations of the FeO curve of Fig. 2.

Refractive Index Results

An additional 50 samples of spessartine were detached from the master samples for determinations of refractive index in sodium

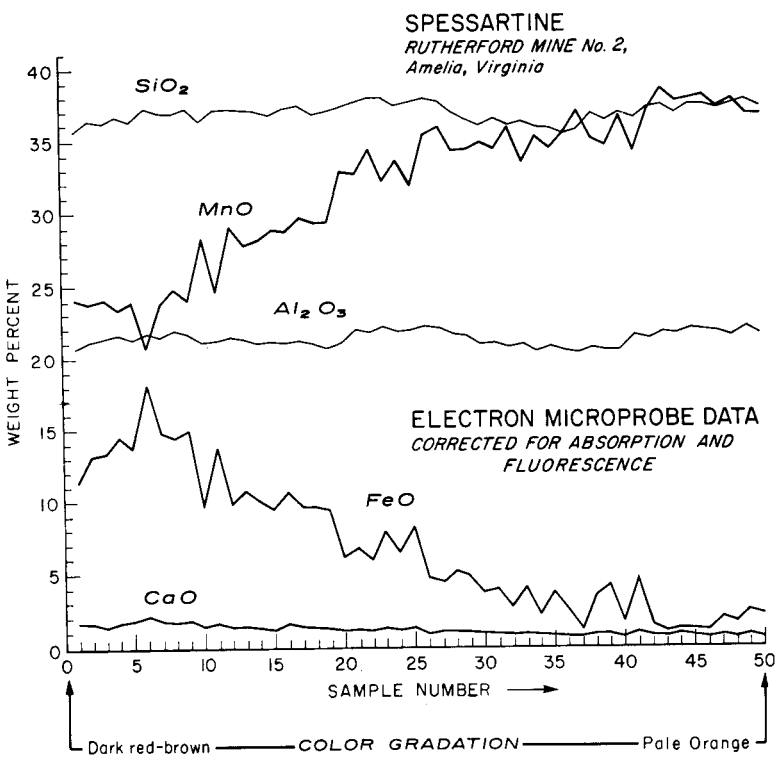

Fig. 2. *Chemical composition of Amelia spessartines plotted against sample numbers according to colour graduation.*

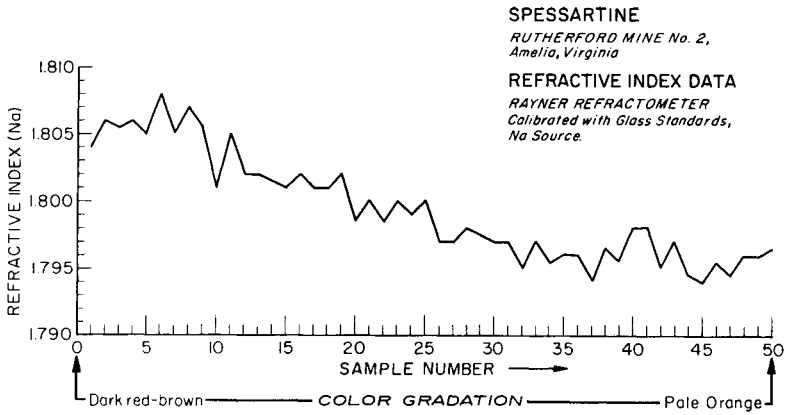

FIG. 3. *Refracted indexes of Amelia spe.sartines plotted against sample numbers according to colour graduation.*

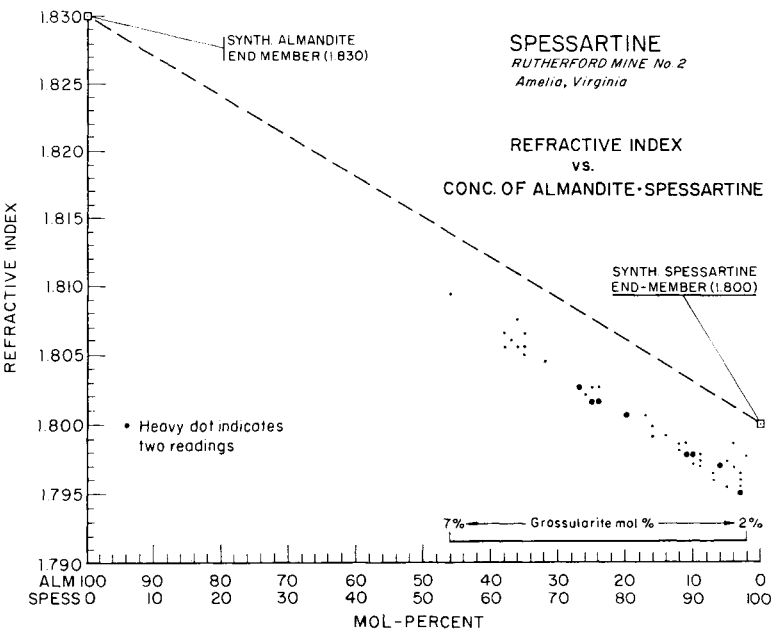

FIG. 4. *Refracted indexes of Amelia spessartines plotted against concentrarion of almandite and spessartine in nol-percents.*

light. Each was imbedded in epoxy resin and ground and polished to provide plane surfaces suitable for determinations upon a Rayner total reflectometer. A suite of polished glass standards, kindly provided by the makers of the instrument, were used to calibrate the instrument. Determinations to the second decimal place were read directly from the instrument but the third decimal place, for which no markings are provided on the instrument scale, are estimates. The results are plotted against sample numbers in Fig. 3 to show the consistent variation of refractive index with the change in the ratio Mn: (Fe, Ca).

To examine the trend of composition-refractive index in another manner, the microprobe analytical data were converted to concentrations (in mol per cent) of spessartine, almandite and grossularite. These data, and others, are presented in order of decreasing almandite in Table 4, while the refractive index data, with almandite-spessartine concentration data, are plotted in Fig. 4. The latter shows a dotted line connecting the ideal almandite and spessartine end-members on the assumption that refractive index is a linear function in the strictly two-component almandite-spessartine system. For purposes of this plot, grossularite in the Amelia spessartine could not be indicated except by a bar in the lower part of the figure showing the range of concentrations from the highest to lowest indexes recorded.

TABLE 4

Spessartine, Rutherford No. 2 Mine, Amelia, Va.
Composition—R.I. Correlations

Sample Nos. Arranged in Order of Decreasing FeO	Weight Per cent FeO	MnO	CaO	Mol. Per cent Alm.	Spess.	Gross.	R.I.
6	18·1	20·7	2·2	43	50	7	1·809
9	14·9	24·1	1·9	36	59	6	1·806
7	14·8	23·8	1·8	36	59	5	1·806
4	14·5	23·5	1·7	36	59	5	1·807
8	14·4	34·9	1·7	34	61	5	1·808
5	13·7	24·0	1·8	34	60	6	1·806
11	13·7	24·1	1·6	34	61	5	1·806
3	13·4	24·0	1·5	34	62	4	1·806
2	13·1	24·0	1·6	33	62	5	1·807
1	11·3	24·2	1·6	30	64	6	1·805
13	10·7	27·7	1·5	26	69	5	1·803
16	10·6	28·3	1·5	26	70	5	1·803

14	10·0	28·1	1·5	25	71	4	1·802
12	9·8	29·0	1·4	24	72	4	1·803
10	9·6	28·3	1·5	24	71	5	1·802
18	9·6	29·0	1·4	23	72	4	1·802
17	9·5	29·7	1·5	23	73	4	1·802
19	9·5	28·8	1·3	23	73	4	1·803
15	9·5	28·5	1·2	24	72	4	1·802
25	8·1	31·7	1·3	19	77	4	1·801
23	7·8	32·2	1·3	19	78	4	1·801
21	6·7	32·7	1·2	16	80	4	1·801
24	6·5	33·5	1·1	15	81	3	1·800
20	6·1	32·9	1·1	15	82	4	1·799
22	5·9	34.3	1·2	14	83	3	1·799
28	5·1	34.4	1·1	12	85	3	1·799
29	4·8	34·4	1·0	12	85	3	1·798
26	4·7	35·5	1·0	11	86	3	1·798
41	4·7	34·1	1·0	11	86	3	1·799
27	4·5	35·9	1·0	11	86	3	1·798
39	4·1	34·6	0·9	10	87	3	1·796
33	4·0	33·5	0·9	10	87	3	1·798
31	3·9	34·5	0·9	10	88	3	1·798
30	3·7	34·8	0·9	9	88	3	1·798
35	3·7	34·4	0·8	9	88	2	1·797
38	3·5	35·0	0·9	9	89	3	1·797
32	2·7	35·9	0·8	7	91	3	1·796
34	2·6	35·2	0·8	7	91	3	1·796
49	2·5	36·7	0·8	6	92	2	1·797
36	2·5	35·4	0·7	6	92	2	1·797
50	2·2	36·6	0·5	5	93	2	1·797
47	1·9	37·2	0·8	5	93	2	1·795
48	1·8	37·7	0·5	4	94	2	1·797
40	1·6	36·7	0·6	4	94	2	1·799
42	1·4	36·9	0·8	3	94	2	1·796
44	1·2	37·5	0·8	3	94	2	1·796
45	1·2	37·8	0·8	3	95	2	1·795
37	1·1	36·9	0·7	3	95	2	1·795
46	1·1	33·9	0·6	3	96	2	1·796
43	1·0	38·4	0·6	2	96	2	1·798

Figure 4 shows that the indexes are clustered about an approximately straight line which appears to be converging toward the synthetic almandite refractive index value. If indexes do vary linearly in the two-component almandite-spessartine system, then the general depression of the line may be due to the effect of the grossularite molecule whose ideal end-member refractive index is only 1·743 (Skinner, 1956). The projection of the index line

away from the almandite end-member to intersect the vertical line beneath the spessartine end-member index results in a figure of about 1·795 as the refractive index of a garnet whose composition is approximately 98 mol per cent spessartine and 2 mol per cent grossularite.

Conclusions

The results of our investigation of the Amelia spessartine show that the colour and refractive index vary directly with the composition such that dark red-brown hues and higher refractive indexes are characteristic of higher almandite concentrations and pale orange hues and lower refractive indexes are characteristic of higher spessartine concentrations. The progression of colours established by this investigation suggests that a pure spessartine will be extremely pale orange in hue or possibly nearly colourless. While all of the samples investigated were spessartines by definition that is, molar concentrations of spessartine exceeded that of almandite and grossularite combined, the progression of colours toward almandite indicate that almandites rich in spessartine may retain a brownish-red tinge until the concentration of almandite exceeds considerably that of spessartine. None of the almandite-rich samples investigated by us showed any trace of the purplish tinge ordinarily associated with almandites.

Table 5 below summarizes the results of our investigation by providing suggested ranges of colour-refractive index according to composition:

Table 5

Ranges of Colour-Refractive Index in Amelia, Virginia, Spessartine

End-Member Mol Per cent				
Spess.	Alm.	Gross.	n(Na)	Colour
50	43	7	1·809	Dark red-brown
95	3	2	1·795	Pale orange

We gratefully acknowledge the helpful suggestions offered by Dr. G. O. Arrhenius, the text figures prepared by Bonnie Swope, and mathematical data prepared by Marjorie Sinkankas.

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LINDE SYNTHETIC EMERALD

THE new Linde (U.S.A.) synthetic emeralds announced sometime ago, are still in the process of being prepared for commercial marketing. Data about them has recently become available.

The synthetic crystals are grown in an autoclave by suspending a seed crystal from thin wire. Although a slow process some very lovely emerald-green crystals result. The time taken for growth and need to replenish the solution from time to time, will keep the price high. In later batches the wire has not been used.

The refractive index range is between 1·566 and 1·571/1·572, with a bi-refringence of about ·005. These indices are somewhat higher than those of the synthetics produced by Gilson, Chatham or Zerfass.

In reporting upon the fluorescence and phosphoresence, Robert Webster states that for a crystal which he examined, there was a strong fluorescence and that phosphorescence (after-glow) was of over thirty seconds duration.

Phenacite is a characteristic inclusion, as well as the veil-like feathers which are often seen in various synthetic emeralds. Webster also reports nail-like inclusions, i.e., a rod-like crystal with a larger or group of crystals at one end, which are somewhat similar to those seen in crystals made by Nacken around 1925. (Some early Nacken crystals in the Association's library do not show such nail-like inclusions, but some crystals had veil-like wisps and rod-like inclusions with flat ends). The nature of the inclusions is likely to be the best basis for discriminating the new synthetic product, together with the strong luminescent characters.

Gemmological Abstracts

CROWNINGSHIELD (R.). *Developments and highlights at the Gem Trade Laboratory in New York.* Gems and Gemology, 1965/6, XI, pp. 20-23 and XII, pp. 359-367.

Notes are given on doctored and imitation turquoise and on odontolite, on a purple-black clam pearl and on solution-grown synthetic rubies. A number of naturally coloured diamonds are reported upon. A "piggy-back" diamond ring made up of three separate diamonds set one below the other is an unusual item discussed. Inclusions in a 6 carat diamond, some of which resembled a growing root and others icicles, and a diamond which had a yellowish coating due to a deposit of iron-rich hard water are mentioned. Some comments on laminated tortoiseshell and fluorescent idocrase (this may well be due to a mixture of idocrase and grossular garnet) are made. The spectrum shown by a synthetic yttrium-aluminium garnet is described and illustrated.
29 illus. R.W.

GÜBELIN (E.). *A visit to the ancient turquoise mines of Iran.* Gems and Gemology, 1966, XII, pp. 3-13.

The history of Egyptian turquoise and the various names applied to the gem preceeds very full notes on the composition and properties of turquoise, and on the nature of its formation. The article then tells of a visit to the mines of Iran (Persia). The writer gives a fine geological survey of the area from his own personal observations. A description of a turquoise mine is given. The methods used by the native cutters in fashioning turquoise are given and the names given to the various qualities of the gem are mentioned. The turquoise mines are owned by the Iran Government. An important and informative article.
11 illus. R.W.

LIDDICOAT (R. T.). *Developments and highlights at the Gem Trade Laboratory in Los Angeles.* Gems and Gemology, 1965/6, XI pp. 24-29 and XII, pp. 368-376.

The usual quarterly reports mention a number of interesting stones examined in the Los Angeles laboratory. These include an unusually coloured emerald and intense colour banding in a flat hexagonal crystal of emerald mounted as a brooch. Although not yet on the market, several Linde synthetic emeralds were examined and were found to have a very strong red fluorescence under short-wave ultra-violet light. A new colour—chrysocolla blue—has been noted in stained chalcedony. Some cameos made of two-coloured plastic are mentioned. Pink dyed quartzite has been sold as "pink jade". Some star diopsides, a deep red topaz and pressed amber are mentioned. Photomicrographs, some at 200x, help to show the effect of the coating on a diamond. The results of the examination of a number of flux-fusion rubies are given. The effect of a strong alkaline cleaning fluid on the surface of opals is remarked upon.

29 illus. R.W.

PARSONS (C. J.). *The terminology of gem colours.* Australian Gemmologist, 1966, 58, pp. 7-8.

A good simple survey of the names applied to gem colours. The meaning of the terms hue, tone and intensity are explained. Other terms sometimes used are described. A colour circle illustrates the various hues.

1 illus. R.W.

HAMILTON (J.). *The Black opals of Lightning Ridge.* Gems and Gemology, 1965/66, XI, pp. 355-358, and XII, pp. 14-19 and 31.

An account of the Lightning Ridge black opal fields. The history of the finding of opal in the area to the present day is given. The story is told of the endeavours made by T. C. Wollaston to popularize the gem. It was not until 1910 that black opal became really saleable. The methods of mining are described.

6 illus. R.W.

CRAM (L. G.). *Boulders of opal.* Australian Gemmologist, 1966, 57, pp. 12-13.

The story of the finding of the Hayricks opal mine on Mount Canaway in Queensland, Australia. Boulder opal is the type of opal found in the mine.

R.W.

POLUTOFF (N.). *The Siberian diamond deposits.* Gems and Gemology, 1965/6, XI, pp. 342-349, 351, 377-379.

An important article detailing much of the history of the finding of diamonds in Yakutia. The geology of the locality is given. The story of the finding of the first "pipe" by a young lady mineralogist named Z. Popugaewa is fascinatingly told. The shapes and the colours of the diamonds found in the various "pipes" are given and something is told of the inclusions present in the stones. A few crystals of over 40 carats have been found. The economics of the Russian diamond fields is discussed.
1 map. R.W.

BOOK REVIEW

COPELAND (L.L.). *Diamonds . . . famous, notable and unique.* Gemological Inst. America, 1966. 188pp., 8 colour plates and many black and white illustrations. $7·50.

A comprehensive survey of the great and near-great diamonds of history, with useful references to some lesser-known stones. It is the best compiled work of its kind yet published and will be a useful reference source to many gem enthusiasts. Considerable trouble has been taken to verify information and some interesting and hitherto unknown facts have been brought to light.

S.P.

ASSOCIATION NOTICES

OBITUARY

Caudell, Peter, 4th July, 1966. (Diploma 1952).

WEST OF SCOTLAND BRANCH

The summer meeting of the West of Scotland Branch was held on 25th June, 1966, and took the form of a day's hunting for garnets in the Pass of Killicrankie. Some rocks were found completely covered with garnets but only on the surface. Many well formed garnets were also found weathered out of the parent rock but only one was recovered which was a gem quality. Members considered that the 1966 outing was the most successful and interesting so far.

GIFTS TO THE ASSOCIATION

The Council of the Association is indebted to Viktor Kämmerling of Idar-Oberstein, who has presented three specimens of beryl doublets simulating emerald (see article on page 120).

Mr. Thor Johne of Oslo, has kindly presented the Association with a ruby crystal mined at Froland, S. Norway.

GEM DIAMOND EXAMINATIONS

In the 1966 Gem Diamond Examinations held by the Association, there were fifteen entries and the following, arranged alphabetically, is a list of successful candidates:—

Passes

Brian Oswald Bailey, Handsworth Wood, Birmingham
Ronald Bailey, Dudley
John Evans, South Yardley, Birmingham
Alfred Jones, Coventry
Eljas-Jussi Kiuas, Helsinki, Finland
Mrs. Evelyn Krzempek, Mapperley, Nottingham
Donald Ashton Light, Four Oaks, Sutton, Coldfield
Rodney Charles Randle, Bournville, Birmingham
Frank Riding, Ribbleton, Preston
Anthony Reginald Thorne, Halesowen
Francis Sidney Hope Tisdall, Sutton Coldfield
Roy Nevil Wetton, Alrewas, Nr. Burton-on-Trent

TALKS BY MEMBERS

COOP, N. "Gemstones", Women's Institute, Cholesbury-cum-St. Leonards, 1st March, 1966; Townswomens Guild, Norbury (A) Croydon, 3rd May, 1966; Townswomens Guild, Portsmouth Waterlooville, 16th May, 1966; Soroptimists, Barnes & Sheen, 1st June, 1966; Senior Wives' Fellowship, Rochester, 7th June, 1966.

GEMMOLOGICAL EXAMINATIONS 1966

Centres for the 1966 Examinations of the Gemmological Association of Great Britain were established in twenty-six overseas countries, apart from the United Kingdom. Three hundred and eight candidates sat for the Preliminary and 195 for the Diploma Examinations. These figures represent the highest in the Association's history.

Upon the recommendation of the Examiners the Tully Memorial Medal has been awarded to Bernard Frank Martin of Sheffield, the Rayner Diploma Prize of gem testing instruments to Peter Otto Reiter of Lucerne and a similar prize in the Preliminary Examination to Miss Elizabeth Strack, Idar-Oberstein.

The following is a list of successful candidates arranged alphabetically:—

TULLY MEMORIAL MEDAL

Martin, Bernard Frank, Sheffield

RAYNER DIPLOMA PRIZE

Reiter, Peter Otto, Lucerne, Switzerland

QUALIFIED WITH DISTINCTION

Azzopardi, Joseph, Floriana, Malta
Cremer, Viktor, Munchen, Germany
Douglas, David Norman, Manchester
Gatward, Anna Bradly, Hitchin
Korber, Dietlinde, Munchen, Germany
Ponahlo, Johannes, Vienna, Austria
Salt, Ilse Emilie, Fort Nelson, Canada
Sanford, Sheila, Enfield
Theisen, Verena, Lucerne, Switzerland
Wilkins, Robert Festus, California, U.S.A.
Woodall, Christopher, Streetly

QUALIFIED

Ash, Grahame David, London
Bastos, Francisco Muller, Minas Gerais, Brasil
Boruszak, John Kasmick, Blackpool
Bruford, Leslie Gordon Nicolas, Hailsham
Buckingham, Lionel James, East Croydon
Butland, William Martin, Natal, S. Africa
Butler, June Iris, Waltham Abbey
Byworth, David Roy, Brookmans Park
Cameron, Donald Aldert, Ottawa, Canada
Chikayama, Akira, Kofu, Japan
Clarke, John Egbert, London
Collier, Rowley Walter, Hornchurch
Connolly, John Patrick, Wilmslow
Cook, John William, Chelmsford

Crombie, Michael Seymour Ivor, London
Doherty-Bullock, Gabrielle June, Lower Wick
Downes, Bryan, Silkstone
Dunne, Michael Bernard, Southport
Edleston, Carolyn Isabel, Liverpool
Engelsman, Albert, Rotterdam, Holland
Ewart, Myra, Bailliestow
Falcon, Lionel James, Nottingham
Fillan, Ian, Huddersfield
Fournet, Bertrand Pierre, Hong Kong
Frizzell, Alan Stewart, Motherwell
Fuller, Donald George, St. Helens
Geddes, Margaret Hutchinson, London
Gregory, Hugh Milne, Beckenham
Guthu, Steinar, Sandefjord, Norway
Helmen, Karin, Oslo, Norway
Hilton, John David, Macclesfield
Huish, Diana, London
Hunt, Anthony Gerrard, Hucknall
Ingram, Roger, Sheffield
Jones, David Martin, Birmingham
Kilcoyne, Anthony John, Wolverhampton
Kirchner, Brit, Erlangen, W. Germany
Klimek, Karol Stefan, Burham
Laycock, Keith, Sheffield
Leech, Alan Gerrard, Heywood
Lenan, Cornelius, Heath
Levy, Warren Irving Jack, Boreham Wood
Lowe, Peter James, Green Lane
McCorquodale, Samuel, Selangor, Malaysia
McLean, Eldred Mervyn, Transvaal, S. Africa
Menton, Joel, Edgware
Miller, Elizabeth Anne, Wolverhampton
Miller, Jeanne Stratton, Arlington, U.S.A.
Moore, Martin Cale, Birmingham
O'Connell, Sean, Harrow
Pamphilon, Christopher Guy, Birmingham
Perren, Richard B., Toronto, Canada
Popper, Madeleine Charlotte, London
Pryke, Christine May, Colchester
Ranasinghe, Vernon Victor Clement, Colombo, Celon,
Rayner, Denise Ann, Cuffley
Rae, Alexander, Ontario, Canada
Stoddart, Harry, Sheffield
Sutherland, Michael Bruce, Basildon
Sutton, Andrew Leece, London
Sweet, Ronald David, Sidcup
Thompson, Peter Lindsay, Nottingham
Verney, David Laurence, London
Widnall, Harry, Sheffield
Wijkström, Gunnar, Stockholm, Sweden
Wild, Walter Frederick, Liverpool
Winkler, Gunter, Augsburg, Germany
Woods, Norman Ronald, Sheffield
Zwollo, Paul, Oosterbeek, Holland

Preliminary Examination

Rayner Prize

Strack, Elisabeth, Idar-Oberstein, Germany

Qualified

Aase, Nina, Bergen, Norway
Ahrens, David, Ilford
Amedeo, James, New York City, U.S.A.
Andresen, Ragnar, Sandefjord, Norway
Anthony, Ann Catherine, Selston
Arbeid, Martin Joils, London

Arends, Henri, Amsterdam, Holland
Bamford, Roderick, Nottingham
Barlow, Brenda Mary, Totnes
Barlow, Seaton, Totnes
Baxter, James Edinburgh
Beck, Cyril Anthony, Manchester
Becker, Jeffrey, Prestwich
Beevor, Christopher, Pinner
Bergmans, Paul, Schoonhoven, Holland
Berwick, Keith James, Portsmouth
Besant, Bruce, Bristol
Bloom, Victoria Catherine, Sutton Coldfield
Boers, Leone, Naarden, Holland
Bonner, Anthony, Liverpool
Bosworth, John Charles, Salisbury, Rhodesia
Brandreth, Raymond Stanley, Knutsford
Broughton, Timothy John, Knutsford
Brown, Judith Audrey, Altrincham
Brown, Janet Irene, Congleton
Bruford, Leslie Gordon Nicolas, Hailsham
Buchanan, Kenneth Ray, Oklahoma, U.S.A.
Bull, Rudolph, Lugano, Switzerland
Burnstein, Burton Alvin, Los Angeles, U.S.A.
Burr, Rosamund, London
Bytheway, Keith Leonard, Walsall
Carmichael, John Michael, Kirkella
Catley, Reginald Arthur John, Salisbury, Rhodesia
Chan, George Kivok-Leung, Kowloon, Hong Kong
Chartier, Henri Paul, Esher
Cherns, Jack Jacob, London
Collier, James Edward, Chislehurst
Cowbourne, Elizabeth Mary, Bingley
Cox, Edward Michael, Gt. Yarmouth
Craft, Herscu Rozen, Venezuela, S. America
Croydon, Robert William, Norwich
Cumming, Phyllis Eleanor, Kuala Lumpur, Malaysia
Cuss, Christopher Jude, Ipswich
Cutts, Michael James, Surbiton
Daker, Roy Victor, Walsall
Dale, Robert, Carshalton
Dalewski, Orest, London
Dean, David, London
Denley, Peter Gordon, Bristol
Dennis, Jean Elizabeth, Dagenham
Doughty, Mary Forbes, Birkenhead
Duckitt, Catherine Patricia, Rickmansworth
Dudek, Clelan Francis, Oregon, U.S.A.
Edwards, Stephanie Looan, Birmingham
Evans, Royston Thomas, Coventry
Eveleigh, Michael Leonard, London
Everitt, Alan, Liverpool
Fardon, Pamela, Wembley
Farringer, Dale Eldwin, Virginia, U.S.A.
Fjogstad, Kaare, Oslo, Norway
Folkes, Trevor Robin, Cheam
Forman, Evelyn May, Buckingham
Forman, Stephen Michael, Manchester
Gardiner, John Clive, Prestwich
Gavin, Donald Fleming Sinclair, Edinburgh
Gay, Phillip G., Florida, U.S.A.
Giertta, Claes Erik, Stockholm, Sweden
Goldsby, Reginald Henry, Bradford
Goodman, Brian John, Walsall
Glen, Susan Elizabeth, Coventry
Greenhalgh, John Clive, Radford Semele
Gregory, David George, Liverpool
Gregory, Hugh Milne, Beckenham
Gregory, Jack, Barnsley
Halls, Norman Edward, London
Hamilton, Allan Bruce, Formby
Hamnett, Norman, Radcliffe
Harding, James Norman, Northwood Hills
Haunss, Owe Karl Bertel, Farsta, Sweden
Hawdon, Elsie, Hyde

Hartmann, Carolus Johannes, Eindhoven, Holland
Hartley, Donald Wilson, Michigan, U.S.A.
Hayes, Lillian Eveline, London
Heald, Ronald, Manchester
Henriksen, Anne-Marie, Trondheim, Norway
Hill, Samuel, Liverpool
Hilliard, Christopher Paul, Portslade by Sea
Hogwall, Anna Stina, Stockholm, Sweden
Holcombe, John Westray, Queenstown, S. Africa
Holgate, David Edmund, Wirral
Huddlestone, Roy Victor, Baildon
Hughes, Anthony, Bradford
Humphreys, Maurice Norman, Wirral
Hundy, Christopher Leslie, Sutton Coldfield
Hunt, Ian Rodney, Rainford
Jackson, Della Ann, Prestbury
Jacobsson, Rolf, Jakobsberg, Sweden
Jamieson, Sara Blackburne, Co. Londonderry
Jaye, Alan Ross, Canvey Island
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PRESENTATION OF AWARDS

The presentation of the awards gained in the 1966 examinations of the Association took place on 24th October, and the proceedings will be reported in the next issue of the Journal.

HERBERT SMITH MEMORIAL LECTURE

The 1966 Herbert Smith Memorial Lecture will be given by Mr. R. C. Chirnside, of the General Electric Company, at Goldsmiths' Hall, Foster Lane London, E.C.2, on Tuesday 8th November.

1967 MEETINGS

25th January—Film Show, Hanover Street, London W.1.
6th March—Conversazionne, Goldsmiths' Hall, London.
23rd May—Annual General Meeting, London.

WEST OF SCOTLAND BRANCH

"Gems. real or fake". A lecture by Mr. Robert Webster, to be held at the North British Hotel, Glasgow, at 8 p.m. on 10th November, 1966.

COURSE INSTRUCTOR

Applications are invited from Fellows of the Association willing to undertake a limited amount of correspondence course instruction in preliminary and diploma grade gemmology. A good understanding of gemmological crystallography is essential. Applications to Secretary of the Association.

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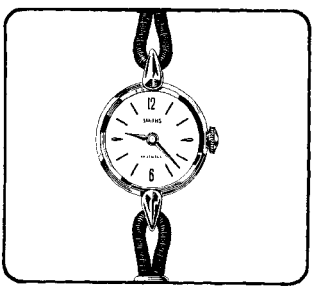

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No. 4
October 1966

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THE JOURNAL OF GEMMOLOGY

and

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Vol. 10 No. 5 JANUARY 1967

ANOTHER NEW SYNTHETIC

By KEITH MITCHELL

A RECENT trade enquiry for demantoid garnets produced two rather unexpected results.

One stone, submitted from abroad, was described in a letter as "— not demantoid, but another kind of green garnet". Having in mind the newly reported emerald-like transparent green grossular garnet, I was full of interest to see the stone. But it was nothing more than a very handsome green zircon, a fact revealed at once by its absorption spectrum. The price asked was something like ten times its value as a zircon.

A second stone, oval, weighing 2·94 carats, was described as "fine green garnet", and was of an attractive medium quality demantoid colour, bright and well cut — a beautiful gem.

A chance request that evening for me to examine and comment on a new light source for the Rayner Microscope when used for absorption spectroscopic work gave me the idea of looking at the demantoid spectrum. This is normally one of the less easy absorptions to see because the areas that matter are at the end of the spectrum where light transmission and optical acuity are least effective.

Having the 2·94 carat stone with me I used this one for the test, fully expecting to get a good demantoid spectrum. The result surprised me.

It gave one of the most impressive arrays of intense sharp absorption lines that I have yet seen. Some ten strong lines with another 20 or so weaker ones to fill in the gaps. (Fig. 1). It was like looking at a brilliant spectrum through irregularly spaced bars. A staggering display and, needless to say, not one to be expected from demantoid garnet.

Fortunately, I remembered seeing a somewhat similar spectrum reported from America. This stone was one of the new "garnets" which have been synthesised in the search for laser materials and which have not yet been officially released for gem use. How this one got through is still not known. It certainly is the first seen by gemmologists in the U.K. and is apparently the first cut specimen to be reported in gemmological literature.

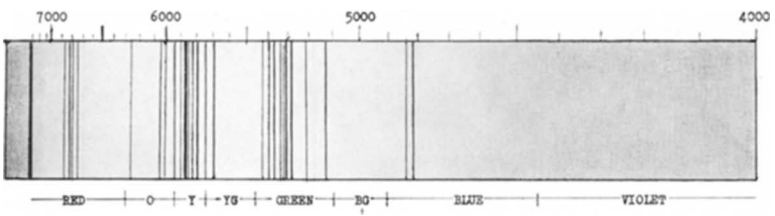

FIG. 1.

The physicists responsible for producing these substances call them garnets simply because they crystallize in the garnet structure but, unlike true garnets, they actually contain no silicon. The three that have so far been reported are YAG (yttrium aluminium garnet), YIG (yttrium iron garnet) and YGaG (yttrium gallium garnet). The present stone was undoubtedly YAG, doped with chromium to give the fine green colour.

A natural-looking flat cavity filled with a reddish fluid (possibly melt-flux) completed the illusion that the stone might be natural. But this was far removed from the byssolite fibres of almost every true demantoid.

Subsequently Mr. B. W. Anderson measured the lines and my drawing is based on his readings. Apart from a slight general shift of our readings towards the blue (the American readings may have

been taken from a super-imposed scale) there are also one or two differences in the intensity of individual lines between the two versions. The lines are thought to be due to one or both of the rare earths generally known collectively as didymium, and to chromium, but the discrepancies suggest that these are either there in different proportions in the two specimens or that some extra impurity is present. If chromium has been used it is almost certainly responsible for the group of lines in the red and probably also for the intense 7320Å line just visible in the very deep red. However, the normally characteristic absorption of a broad band of the orange-yellow-green sector was either absent or so faint as to be missed in the excitement of the other intense lines of this region.

Mr. Anderson, with characteristic thoroughness, checked other features of the stone so that it is possible to give a fairly complete record of its constants. Density was 4·60, considerably higher than for demantoid (3·84). The R.I. for sodium light was 1·834, which is lower than that for demantoid (1·89), but still above the normal range of the refractometer. Dispersion was not measured. But once the nature of the stone was realised an empirical assessment of this property suggests to me that in a demantoid I would have expected to see rather more fire than was in fact present. But this is only an impression and may well be erroneous.

The stone fluoresced strongly in short and long ultra-violet wavelengths, the colour being red. X-rays gave an orange fluorescence with strong phosphorescence. In an intense beam of visible light the stone also glowed reddish through the green. The Chelsea filter test also gave a strong red colour. These last two features also occur in the new Linde synthetic emeralds and argue chromium saturation.

The YAG material is reported to have the formula $Y_3Al_5O_{12}$. Pure, it is colourless, but can be doped with various colorant ions. YIG, the iron-containing version, is opaque with important magnetic properties. Less is known about YGaG, but it has turned up in the form of a small pink cabochon cut stone in America. Again it has a very startling absorption spectrum, substantially different from that of YAG. These spectra appear to be mainly due to rare earth impurities present in the yttrium, but variations in their line content must be expected as the colorant elements are changed.

Perhaps the most disturbing factor of the present stone was its complete unexpectedness. It was offered as a fine green garnet at

a very high price and was handled in all good faith on both sides of the Atlantic by persons of very high repute. Not only did they accept it as demantoid without query, but the present writer was also prepared to do the same.

I hope that the publicity which I am now giving it will prevent other such synthetics being accepted as natural demantoid.

CRYSTALS OF TAAFFEITE FOUND IN CHINA

By B. W. ANDERSON

THAT exceedingly rare gemstone, taaffeite, for many years known only in the form of three small cut specimens, has been found in at least one locality in China, and its crystal structure analysed. The bare details of this work appeared in the Mineral Abstracts in 1964; but being in the "Crystal Structure" section, had escaped the notice of gemmologists, myself included.

The paper itself, "Discovery of 8-layered close-packing crystal structure—analysis of taaffeite" by Pen Chzhi-Chzhuh and Van Kug-zhan, of the Peking Geological Institute, was published in 1963 in Scientia Sinica, and I was able to obtain a copy from the Patent Office Library. It was written in Russian, and I found it rather intriguing to see my own name, in ordinary type, surrounded by a sea of Russian characters. Fortunately, Dr. G. F. Claringbull was able to have a translation made by Miss Fejer of the Mineral Department at the Natural History Museum, where so much of the original work on taaffeite had been done. From the title of the paper it is clear that the discovery of taaffeite crystals was no new thing to the authors: their purpose and their interest lay in elucidating in detail its crystal structure. The only details of the occurrence itself lie in the sentences "the crystals used in our investigation come from one of the localities of our country. They were hexagonal prismatic. They occur in white banded sediments as isolated

crystals together with fluorite and nigerite". Miss A. Fejer reports having seen a taaffeite specimen from Hunnan Province, China, in the Mineralogical Museum of the Academy of Sciences in Moscow—and that is the extent of our knowledge of its occurrence at the moment: let us hope that means may be found to obtain a specimen for the Natural History Museum in London.

Presumably pyramidal faces were present as well as prisms, since the authors were able to make an estimate of the axial ratio a:c = 1:3·227 from goniometric measurements.

The whole story of Count Taaffe's original discovery (in 1945) of the mineral which now bears his name reads like a gemmologist's fairy-tale, and the sequel, too, was sufficiently strange. At that time, at least, Taaffe had no refractometer. His most dependable means of gem identification was by careful examination under a binocular microscope magnifying 21 diameters. On this occasion he was sorting through a mixed parcel of stones selected earlier from a local (Dublin) jeweller's junk-box. According to his usual practice, the stones were first meticulously cleaned, and then sorted by eye into categories, mainly by colour. Amongst some pale mauve spinels was one specimen which puzzled Taaffe greatly because, looking through the stone, every tiny mark or scratch on the back surfaces showed distinct "doubling" which, of course, was out of order for spinel, which in appearance and density (taken with a hand-held balance) it otherwise resembled. As a result, Count Taaffe sent the strange stone to me for a Laboratory identification.

The properties of Taaffeite No. I, as eventually determined, were as follows: Weight, 1·419 cts, density, 3·613; refractive indices, 1·7230 for the ordinary ray, 1·7182 for the extraordinary, giving a double refraction of 0·0048; H = 8. A clear, uniaxial interference figure was seen. The absorption spectrum was almost too faint to be measured, but resembled that of pale blue spinel. An absorption spectrogram revealed a narrow band at 3820 Å in the near ultraviolet, which was missing in spinel.

These properties were unlike any to be found in the literature, and the final identification had to rest on chemical and crystal analysis by Dr. G. F. Claringbull and Dr. M. H. Hey at the Natural History Museum. This, of course, entailed sacrificing part of what was then a unique specimen, and a small one at that. To his eternal credit, Count Taaffe agreed to this being done—only

stipulating that he should receive the remainder back in the form of a gemstone. The tricky operation was performed by the skilled lapidary Mr. G. Bull Diamond, and we were able to return a bright and pretty little stone weighing 0·55 carat to its anxious owner.

After preliminary spectrographic investigation, Dr. Hey later achieved the feat of carrying out a complete chemical analysis on only 6 milligrams (0·30 carat) of the material, which showed the composition to be beryllium magnesium aluminate, intermediate in composition between chrysoberyl and spinel. Dr. Claringbull's X-ray work showed that the new mineral belonged to the hexagonal trapezohedral class of the hexagonal system (the first mineral to do so, with the exception of "high" quartz, stable only between 573° and 870°C).

Despite thorough search amongst parcels of spinels of similar colour, and careful scrutiny of all likely Museum specimens, no further examples of the new mineral came to light until October 1949. A Gemmological Exhibition was being held in the Goldsmith's Hall, and C. J. Payne was working alone and rather late in the Laboratory on an interesting collection of 100 stones in a case. Most of these were green sapphires and pale spinels, but one was a kornerupine, acting as a sort of curtain-raiser for the pale mauve stone which later came to light, and which proved to be Taaffeite No. 2. This weighed only 0·86 carats, was slightly paler than the first, and had slightly lower constants. Fortunately I was able to purchase the stone, and it is now in the Natural History Museum, London.

The completion of the analytical and X-ray work took a considerable time, and so far, nothing had been published concerning the new mineral: even our name for it, "taaffeite" (pronounced tarfite), after its discoverer was unofficial. The discovery was made known and the christening performed, in a letter to "Nature", published in March 1951, while for gemmologists the story was recounted in the following month by C. J. Payne in this Journal and by myself in the *Gemmologist*. The full paper appeared in the *Mineralogical Magazine* in December, 1951.

The hunt was now on; and I for one confidently expected that some enthusiastic gemmologist would soon unearth another specimen, or better, would find a pebble of taaffeite in the illam of Ceylon. There were many "false alarms"; stones which turned out to be spinels, but the finding of Taaffeite No. 3 had to wait until Christmas

Eve, 1957—its discoverer, most appropriately, being our friend G. Robert Crowningshield of the G.I.A. Laboratory in New York. This third sample weighed 0·84 carats, and was amongst a parcel of drop-shaped vari-coloured spinels. Its properties agreed closely with those of the other two specimens. This American stone, after changing hands more than once has, I understand, now found a permanent home in the magnificent collection of gems in the Smithsonian Institution, Washington.

Since then, silence. Hence the shock of surprise to learn of the work being done on the mineral in China. True to form, taaffeite has continued its "first ever" record. It was the first new mineral ever to have been first discovered as a cut gemstone: it was the first mineral to be found to contain both beryllium and magnesium as essential constituents: it was the first mineral to be found belonging to the hexagonal trapezohedral class of symmetry. And now the Chinese workers have found that taaffeite is the first mineral in which the oxygens in the crystal structure lie in a particular form of eight-layered arrangement, which they propose to call the "taaffeite type".

The ripples from that first keen observation of double refraction in Dublin have spread very far. Here is one instance at least where gemmology has been able to repay some of the debt it must always owe to its mother-science of mineralogy.

ORNAMENTAL SERPENTINE

By ROBERT WEBSTER

TO most lay people in Britain, the name serpentine brings to mind the ornaments fashioned from the soft, but attractive, rock-like ornamental stone found at the Lizard peninsula in Cornwall. This is the material called *serpentinite* by the geologist, but there are many other serpentines of interest to gemmology. One of these serpentines, the variety called *bowenite*, is at the present time used extensively for "jade" carvings and thus has considerable interest to the gemmologist. Strangely, however, the scientist does not take due cognizance of this harder variety of serpentine.

What is serpentine? Briefly, it is a hydrous magnesium silicate approximating to the formula $3(Mg,Fe)O.2SiO_22.\ H_2O$, and is derived by the hydration of ultra-basic igneous rocks rich in olivine, amphibole (hornblende) or pyroxene (augite). Serpentine may be a member of an isomorphous series. The mineral never forms distinct crystals and is found mostly in compact rock-like form, but sometimes occurs as more distinctly crystallized fibres, probably of monoclinic symmetry, filling veins in massive serpentine. This fibrous type, which forms the *chrysotile asbestos* of commerce. has no gemmological significance. Serpentine has a world-wide occurrence, but in only certain well-defined areas can be obtained material suitable for ornamental purposes.

There can be many variations of the mineral. Mineralogists, since the beginning of the 19th century, have divided the serpentines into groups, and again into varieties, to some of which specific names have been applied. Most of these have no place in gemmological studies.

A better division of the serpentines—the name *serpentine* being derived from the fancied resemblance to the skin of a serpent—for our purposes is as follows—*precious* or *noble serpentine* comprising the purer translucent and massive varieties, which have a rich oil-green colour. J. Sinkankas confines the noble serpentines to the mineral varieties *bowenite*, *williamsite*, and the resinous-waxy yellow to yellow-green translucent serpentine called *retinalite*. The second type is the so-called common serpentine which includes the rock-like types; the third type is the fibrous serpentine

exemplified by the aforementioned *chrysotile* and some others, including a variety which at one time was used as a gemstone under the name *satelite*. The fourth type comprises the foliated varieties, such as *antigorite* and *marmolite*.

From X-ray studies G. Selfridge divided the serpentines into two groups, *serpentine* and *antigorite*, and he suggested the name *serpentinite* for the rock-like forms of serpentine, antigorite or mixtures of both. E. Whittacker and J. Zussman have more recently divided serpentine into three groups, *lizardite*, *antigorite* and *chrysotile*. Further, there is an aluminous serpentine called *pseudophite*, often referred to in gem literature under the misnomer "Styrian jade"; and the *polyphant stone* from Launceston in Cornwall is also classed as a serpentine. To this list may be added the serpentinous calcites called *ophicalcites*, such as "Connemara marble" and "Iona stone".

The most important variety of serpentine met with in gemmology is *bowenite*. The first use of this material as an ornamental stone appears to have been made by the Maori of New Zealand, who were said to have worked the deposits of the serpentine found in the South Island before and up to the European times. At its best a lovely rich deep oil-green to bluish-green material, bowenite is found at Anita Bay, Milford Sound, on the west coast of Otago County in the South Island of New Zealand.

The Maori called this material by the name "Tangiwai", which means "water of tears". According to Elsie Ruff, who quotes Eldon Best, the mythology of "Tangiwai" tells that it is the result of the weeping of Hina-ahua, wife of Tama-ahua, for her far-distant home in Polynesia, her tears permeating the stone, a story that may have arisen owing to the apparent globules of water seen in polished specimens of New Zealand bowenite when viewed by transmitted light. Another version suggests that the apparent globules are the result of the weeping of the mythical navigator Tamatea for his deserted wives.

A. Finlayson describes the New Zealand bowenite as a translucent variety of serpentine composed of a dense felt-like aggregate of colourless serpentine fibres with occasional patches of magnesite, flakes of talc and grains of chromite. The serpentine occurs as veins in a foliated rock containing the same minerals, but with talc as the dominant constituent.

At one time known under the Persian name of "sang-i-yashm"

is the hard bowenite variety of serpentine which is mined in the hills of Safed Koh on the Afghan side of the border with North-west Frontier Province, in what is now West Pakistan. This material, usually pale apple-green in colour, is found as rock masses at the head of one of the mountain gorges which run into the valley of the Kabul river, and near to the Kyber Pass. This Afghan bowenite was, and probably still is, brought down to Bhera, a trading centre which lies about a hundred miles north-west of Lahore in the Western Punjab. Here the material is cut for sale.

Coggin Brown mentions that there are other deposits of apple-green bowenite not far from Kabul in Afghanistan. Other bowenite of a darker green colour is found (with true nephrite jade) at

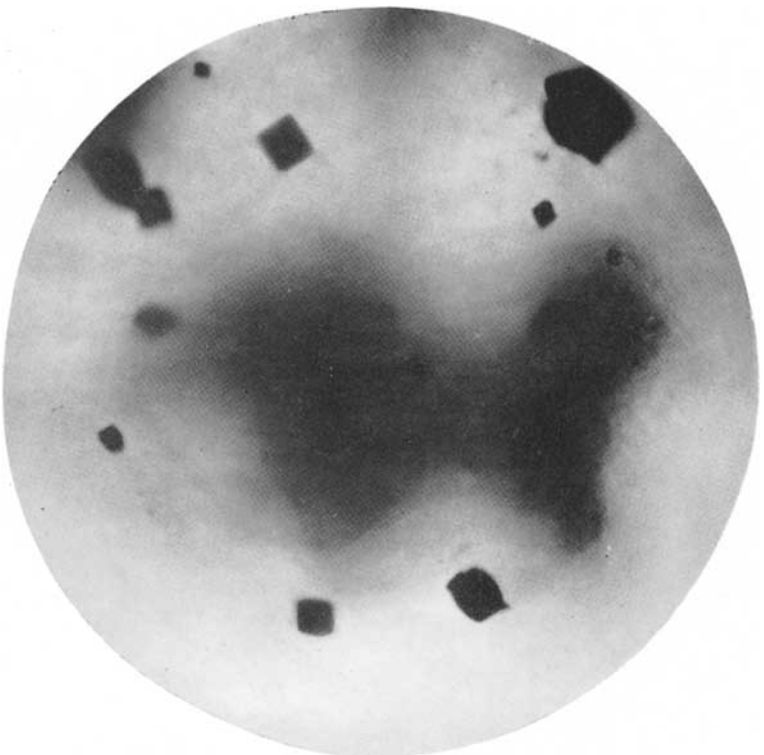

Opaque crystals of cubic symmetry in a specimen of the williamsite variety of serpentine. Transmitted light.

Khotan in the autonomous region of Sinkiang-uigar of China. Both the jade and the bowenite are brought across the frontier and sold together in the Srinagar bazaars. Small quantities of dark and light green bowenite with calcite are found in the Aravalli rocks near Baman Vada, Idar States, Bombay.

The same author also states that a translucent bowenite of apple-, bottle-, grass-, and dark green, and rarely sulphur yellow colours is found in the vicinity of Shigar in Baltistan in Kashmir. The material, which is fashioned into small cups and vases at Shigar, occurs in rocks of doubtful age at an elevation of 18,000 feet above sea-level, so that mining is limited to two months during the year. Coggin Brown further tells that "mottled and veined, dark and light green semi-precious serpentines occur at other

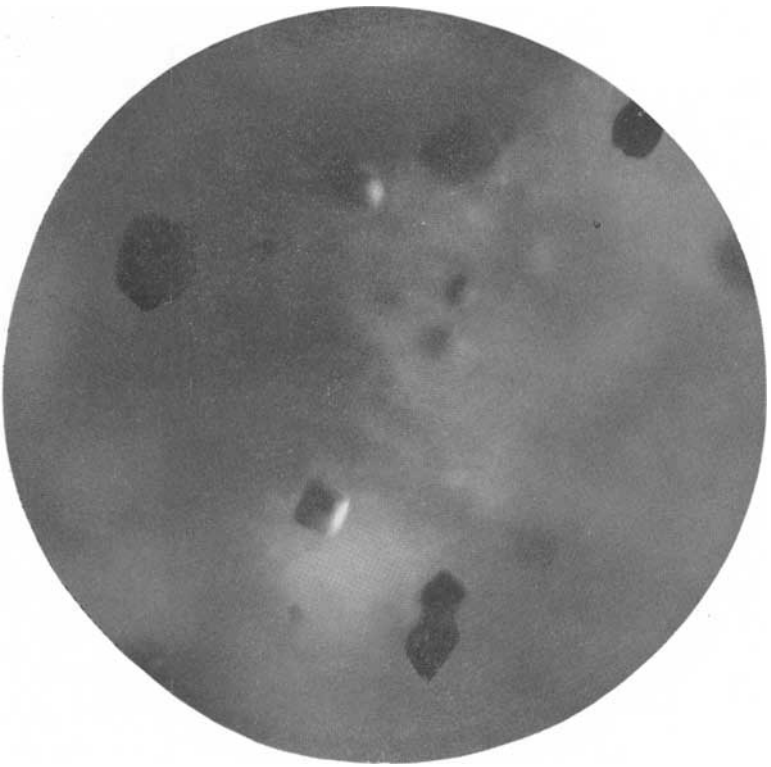

Opaque crystals of cubic symmetry in a specimen of the williamsite variety of serpentine showing that they may have octahedral habit. Reflected light.

A native-fashioned tea cup of serpentine from the Karakoram mountains, Kashmir.

localities in Kashmir and elsewhere, as for example in the Pulivendla area of Cuddapar district of Andhra, but they have so far (1955) not been used by lapidaries".

The interest in the above paragraph is that recently some worked serpentine was examined by the writer, which was said to have been obtained from a location some 16,000 feet up in the Karakoram mountains in an area covered by snow eight months of the year. This is suspiciously like the location mentioned by Coggin Brown, but this material was far too soft to be bowenite as the hardness was found to be about $2\frac{3}{4}$ on Mohs's scale. The density of this material was 2·56 and the index of refraction about 1·56. The absorption spectrum showed a strong band at 4650Å and a weak band about 4970Å. There was no luminescence. From X-ray powder photographs officers of the Geological Survey stated that the material is lizardite with some brucite.

During 1922, G. T. Bowen identified a jade-like mineral from the northern part of Rhode Island State, in the United States of America, as nephrite. The actual locality is given as Smithfield Township but may now be, according to Sinkankas, the Dexter lime quarry of Lincoln Township. A later investigation on this

material (J. D. Dana 1950) found it to be a variety of serpentine and *not* nephrite, and the name *bowenite* was applied to it after the name of the original worker. The bowenite from this source has historical but no commercial significance.

Much of the material used for the carved figurines and other pieces which come from China at the present time is bowenite serpentine. This material varies in colour from that of misletoe berries to a distinct yellowish-green, and it is usually characterized by included whiteish patches, which may be chlorite. Carved pieces of this material are sold under the misnomers "New Jade", "Soochow Jade" or "Korea Jade", but are, of course, not true jade—nephrite or jadeite. It is not known with any certainty where this bowenite is found, but one source is said to be Tuoyuan in Hunan.

Bowenite is generally considered to be a sub-variety of the antigorite group of serpentines and an X-ray analysis of a specimen of "New Jade" taken by the officers of the Geological Survey confirmed the material to be antigorite. The material has an exceptional hardness for serpentine being between 5 and 6 on Mohs's scale against about $2\frac{1}{2}$ for ordinary serpentine. This greater hardness may be due to the interlocking of the fibrous crystals which form the serpentine into a compact mass. The refractive index is about 1·56 and the density is fairly constant ranging from 2·57 to 2·59, but a Maori ear-pendant of rich deep bluish-green translucent material gave a density of 2·617. The absorption spectrum of bowenite is unrewarding. There are vague bands near 4970Å and a stronger band at 4640Å but they can scarcely be said to be diagnostic. Some of the paler bowenite glows with a weak whitish-green fluorescence under all radiations of ultra-violet light and X-rays, but the darker-coloured material seems to be inert.

A variety of noble serpentine sometimes met with in jewellery is *williamsite*, a beautiful emerald-green translucent stone which usually contains square-shaped metallic crystals, which are probably chromite. The best-known locality for williamsite lies on the borders of Maryland and Pennsylvania in the United States of America, where it is found in the chromite mines of the district—mines which have apparently not been worked since 1920. Williamsite is rarely found in large pieces as the mass is extensively fissured with veins of brucite.

Like bowenite, williamsite has a refractive index near 1·56,

but like all these massive materials it only gives a vague shadow-edge on a jeweller's refractometer. The density, as determined by the writer on nine specimens, varied from 2·603 to 2·619, which, except for the bowenite Maori ear-pendant mentioned earlier, is higher than for the bowenites. The hardness was found to be less than that for bowenite but slightly greater than for the ordinary serpentines. One specimen examined was found to be weakly scratched by apatite but not by fluorspar, and could be assessed as $4\frac{3}{4}$ on Mohs's scale. The absorption spectrum shown by williamsite usually exhibits the chromium lines in the red. This is to be expected in view of the chromite environment, it being probable that some chromium replaces the magnesium. Any lines or bands

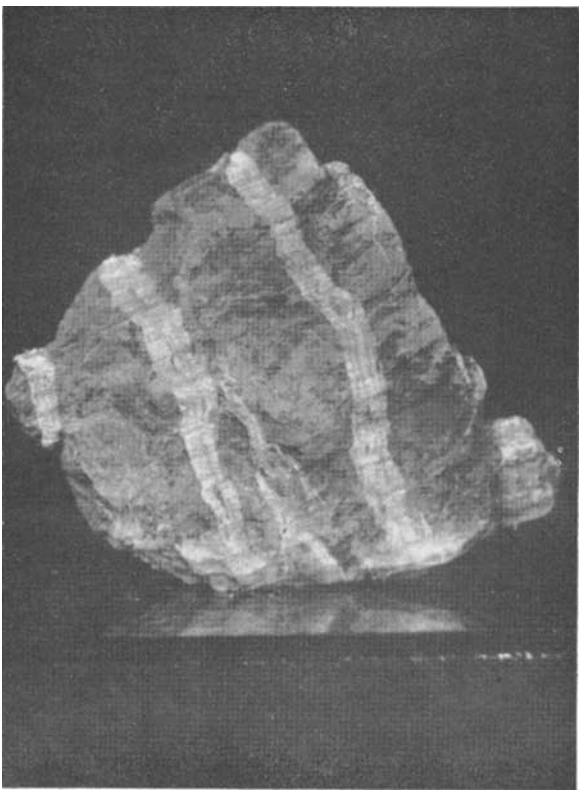

Veins of chrysotile asbestos in serpentine rock (from Conway).

in the blue part of the spectrum so commonly seen in serpentines are either too faint or are masked by the chromium absorption. There is no luminescence seen with williamsite.

Sinkankas mentions some other varieties of serpentine, but as specimens have not been available to the writer they will only be mentioned cursorily. They are *retinalite*, said to be a waxy translucent serpentine in bright yellow or yellow-green colours, *ricolite* from Rico in New Mexico, which is a fine-grained serpentine occurring in curious coloured bands, and *satelite*, a fibrous greyish to greenish-blue coloured material which produces a type of cat's-eye. It comes from California and Maryland in the United States of America.

Serpentinite, the rock-like type of serpentine, is found in many places in the world and is extensively used for the production of small ornamental objects and also for architecture. Predominantly green in colour, although browns and reds are not uncommon, the material owes much of its attraction to the varied and striking mottlings caused by included crystals and veins of other minerals. Sinkankas mentions an unusual serpentine once found near

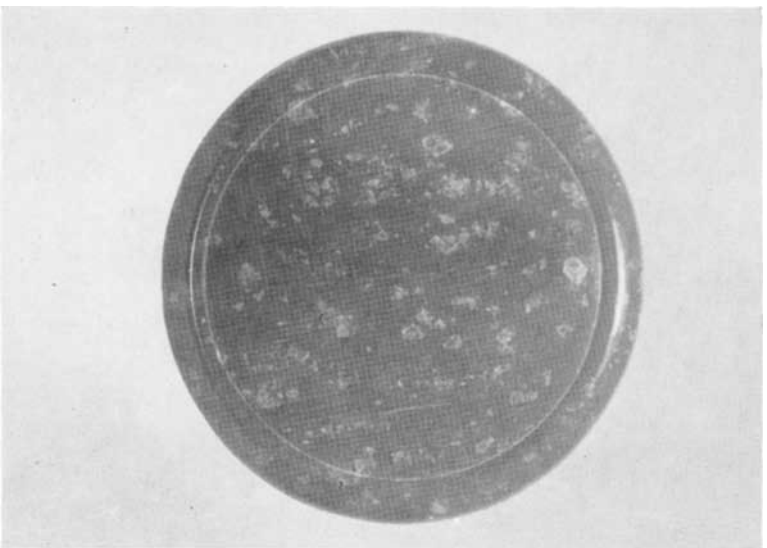

A teapot stand of red serpentine spotted with green crystals. Lizard, Cornwall.

Gouveneur in New York State which is of a peculiar dull grey opaque kind called "London smoke".

Famous throughout the world is the serpentine rock found at the Lizard peninsula of Cornwall. The Lizard serpentine forms a mass of rock nearly circular in outline which is bounded by schists, except where on the coastal side they have been eroded away, the serpentine having welled up and intruded through them.

The domain is ably described by E. Davidson who states that the serpentine occupies a larger area than any other of the Lizard rocks and gives to the area its distinctive character, for the rocks weather to a clayey impervious soil which forms barren moorland. Where it reaches the coast it forms picturesque cliffs and coves and nowhere is this better illustrated than at Kynance Cove, which is made so beautiful by the varied colours of the exposed rocks.

Mineralogically there are three main types of serpentine rocks found at the Lizard. One is the *bastite serpentine*, a rock which contains large shining crystals of bastite (a serpentinized hypersthene or enstatite) profusely scattered throughout the rock, which has a platy cleavage and an almost metallic lustre. This bastite serpentine forms the core of the intrusion and is surrounded by *tremolite serpentine*, a streaky-banded rather fissile rock. The last type, the *dunite serpentine*, is the marginal rock abutting on the schists which surround the intrusion. Dunite serpentine is a dark green resinous to glassy rock traversed by fine satiny veins. The rock shows a conchoidal fracture.

The Lizard serpentine varies considerably in its appearance and in its consistency. Seemingly the best material for cutting comes from the moors behind Kynance Cove and this material varies in colour from a blackish green with reddish markings, or reddish with green spots to a dark green with lighter green spots, but there are many variations in colour and mottling. Towards the Lizard Head itself the serpentine is a light grey-green marked with paler greens and with numerous dark-coloured veins. This material is more porous and less hard than the compact material from the moors.

Most of the serpentines from Cornwall are cut by local lapidaries who supply the gift shops which are a feature of the Cornish tourist centres. These lapidaries, who at the Lizard often carry out the work in small wooden huts in full view of the tourists, use conventional methods in fashioning the serpentine. Large

pieces of the rock are sawn to suitable size by the use of vertical "mud saws", and where necessary these pieces are turned on a simple lathe. The grinding and polishing of flat and curved surfaces is carried out on horizontal laps, using emery or carborundum as an abrasive on the grinding laps and soft powders to put on the final polish. Buffs may also be used.

Other sources of serpentine in the British Isles are those at Portsoy, Banff, in Scotland, where a thin belt of serpentine up to 400 yards wide and six miles long runs SSW from Portsoy itself. The serpentine found here is light to dark green in colour and may be veined with white or black, and sometimes has red spots. Dark green serpentine, sometimes with angular black crystals, is found at Roscolyn in Anglesea, N. Wales.

Of the many other localities for serpentine throughout the world mention may be made of the following—the dark grey-green serpentine from Hospenthal, St. Gotthard, Uri and from near Zermatt in Valais, Switzerland; the garnetiferous serpentine

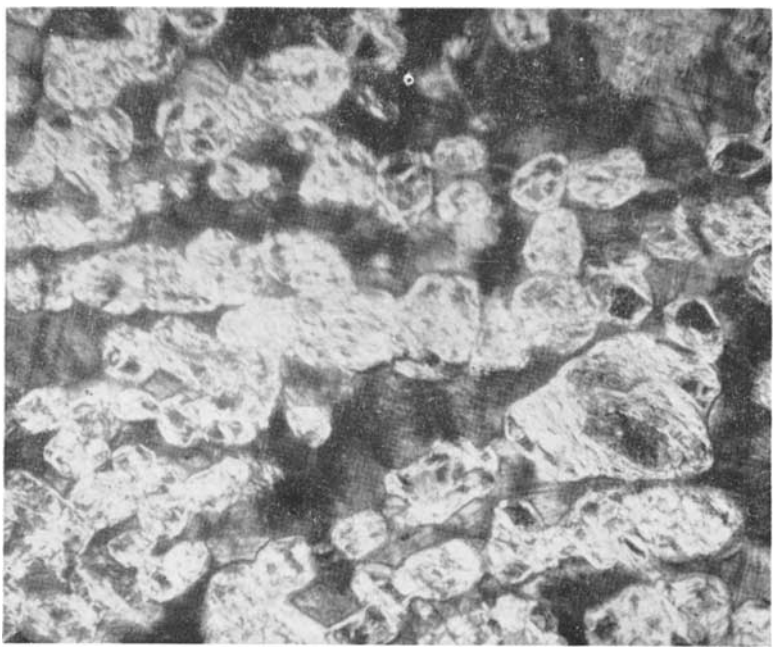

A photomicrograph of a thin section of ophicalcite (serpentine marble).

from Zöblitz in Saxony, which is usually a dark blackish green with nclusions of red garnets, a material which has been fashioned into decorative articles; the serpentine found at New Caledonia, which has been used for beads by the natives there.

Much serpentine is found in Italy and at Snarum in Buskerud, Norway. Finland, Sweden, Rhodesia and the U.S.S.R. are other sources of serpentine, the occurrence of which is in fact world-wide. Some serpentine is a brownish-red in colour and may have a distinctly metallic lustre. From Franklin Furnace, New Jersey there is a manganiferous variety, but it is doubtful whether it has ornamental significance. It has been reported from America that a "black jade" cabochon mounted with other coloured jades

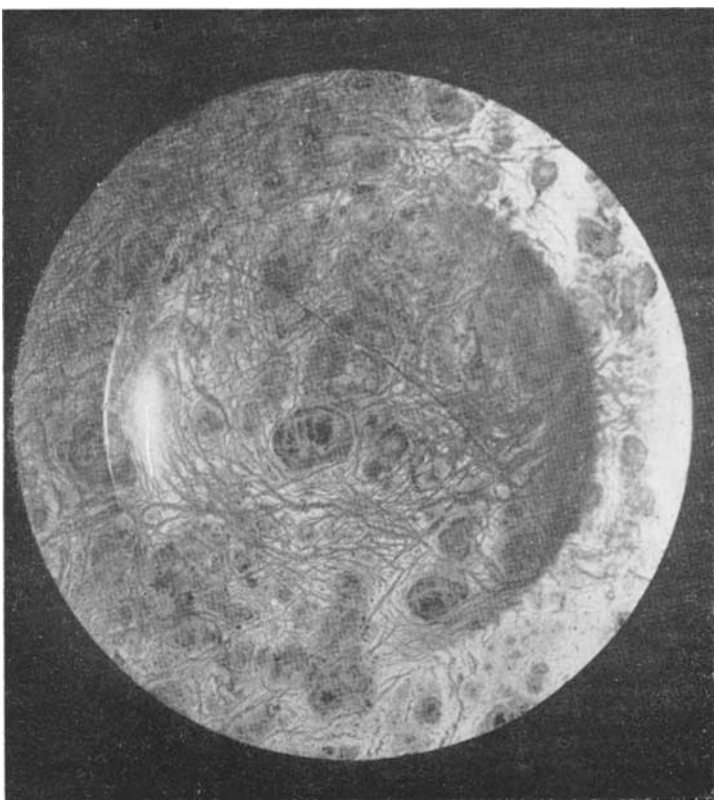

An ashtray of greyish-green serpentine showing attractive veining. Lizard, Cornwall.

was found to be serpentine. This stone may in fact be a very dark green and it is interesting to note here that G. Kunz refers to a serpentine of dark greenish-black colour which admits of a fine polish. It comes from the neighbourhood of Patterson, Caldwell Co., North Carolina.

The properties of the rock types of serpentine, as would be expected with such impure material, vary considerably. The refractive index, about 1·56, can only be measured vaguely on a refractometer, and the hardness too can vary quite a lot, but all rock serpentine can easily be scratched by a knife blade. The density can also show considerable variation. Experiment has shown that a range of from 2·4 to 2·7 may be expected. Some typical values are shown below:—

Green with magnesite; Hoboken, New Jersey	2·44
Light grey-green (soft material); Lizard, Cornwall	2·45
Yellow-green (talcose); Norway	2·49
Grey-green; Portsoy, Banff, Scotland	2·51
Mottled green; Ledalfoot, Girvan, Scotland	2·54
Dark green; Vosges, France	2·56
Green with bastite; Cadgwith, Lizard, Cornwall	2·57
Blackish-green and red; Kynance moor, Lizard, Cornwall	2·59
Green and red (metallic lustre); Lizard, Cornwall	2·62
Dark green; Norway	2·62
Grey-green; St. Gotthard, Switzerland	2·67
Green (schistose); Italy	2·67
Green with light spots; Lizard, Cornwall	2·68
Medium green; Norway	2·69

The vague lines in the blue sometimes seen in the absorption spectra of the rock-like serpentines do not seem to be diagnostically valuable, and, as is to be expected, the electro-conductivity which is usually present, is variable and is sometimes strong.

Another variation of serpentine which forms rock masses is the serpentine mixed with more or less calcite, dolomite or magnesite. This produces a rock of clouded white and pale to medium greens which is called *ophicalcite* or *ophicite*. The material known as *verde antique* is a brecciated serpentine with fragments of limestone and is usually classed with the ophicalcites. This rock was originally brought from Atrax in Thessaly by the Romans and was called by them "Lapis Atracius". "Irish green marble", perhaps better

known as "Connemara marble", is a serpentine marble from quarries near Streamstown, Lissoughter, Recess and Clifton in Connemara, Galway, Eire. Much of the marble from these deposits is fashioned into small decorative objects for sale to the tourists. A similar material is found in the small island of Iona, which lies off the island of Mull in the Inner Hebrides of Scotland. Small pieces of this rock are fashioned into cabochons and other forms and are mounted into jewellery and the trinkets sold to visitors to Scotland. The material is commonly known as Iona stone.

Connemara marble is found in many shades of colour, the best being a fine cloudy green, but yellowish-green is common, and a pale greyish-green with brownish to black veins and spots makes attractive polished specimens. Coggin Brown mentions the beautifully marked serpentinous varieties of the "sauser teksil", which is found in the Chhindwara district, Madhya Pradesh, India as being a serpentine marble worthy of mention.

The ophicalcites may be derived from impure limestones containing silica and argillaceous material, which by metamorphic action develop various silicates of lime and magnesia, such as tremolite, forsterite, diopside and grossular garnet. The magnesium silicates become readily altered into green serpentine by later chemical action resulting in serpentine marbles. An unusual ophicalcite, which at one time attracted much attention, is that from the pre-Cambrian rocks of the Grenville district of Quebec, Canada. This material has the silicate minerals formed as rhythmic bands round more siliceous patches simulating a structure thought at one time to be organic and then given the name *Eozoon Canadense.*

As with serpentinite, the constants of ophicalcites are variable. The hardness is about 3 on Mohs's scale and the index of refraction about 1·56. Readings taken on a refractometer are very vague. As the rock is in the main a mixture of calcite (2·71), dolomite (2·85) and serpentine (approximately 2·50), the material should have a density within this range and experiment has shown that this is generally true, except where porosity lowers the density of the piece or inclusions of other minerals raise it. The range found on determining the density of sixteen specimens extended from 2·48 to 2·77.

The absorption spectrum of ophicalcite (Connemara marble) shows, according to B. W. Anderson, a strong band at 4650Å and

a weak vague band at 4950Å. The material generally fizzes with cold acid and shows a certain amount of electro-conductivity. During electro-conductivity experiments it was noticed that the higher the density of the material the less was the conductivity and also the effervescence with acid was more pronounced with the lower density and higher conductive material.

A compact chlorite, sometimes referred to as an aluminous serpentine, is called *pseudophite*, or may be better known under the misnomer "Styrian jade". The material comes from Bernstein, which lies on the borders of Styria and Upper Austria just south of Vienna, an area which, before the Treaty of Versailles, was part of Hungary. A similar material is *miskeyite*, a "precious serpentine" found at Gurtiphol, near St. Gallenkirch, Montafon valley, Vorarlberg in the Austrian Tyrol. Pseudophite has a hardness of $2\frac{1}{2}$ on Mohs's scale and a refractive index of about 1·57; the density has been determined as 2·69. There is seen a vague absorption band centred at 4980Å in specimens of pseudophite.

The serpentine diabase found near Launceston in Cornwall, called "Polyphant stone", has little application in gemmology. A density determination on a specimen of this material gave a value of 2·86.

Academic experiments on the synthesis of serpentine have achieved success. These syntheses have provided useful information in the scientific study of serpentinization, but they have no commercial significance.

The intention of this article was to give a description of the various types of serpentine used for ornamentation, and to consider aspects which would suggest future lines of enquiry. One of these may be further discussed. It is the question of the chemistry of the iron coloration of serpentine. Perusal of the literature seems to show some difference of opinion as to whether the colour is influenced by iron in the ferric state or the ferrous condition. Anderson suggests, from examination of the absorption bands seen in the various serpentines that ferrous iron (FeO) is the cause of the colour. Some authorities however, probably deducing from chemical analyses, prefer to consider iron in the ferric state (Fe_2O_3) as the cause of the colour in serpentine.

Assuming Anderson's assumption that absorption bands near 5000Å indicate ferrous iron, and that those of ferric iron are positioned near 4500Å, it may be well to give some consideration

A photomicrograph of a thin section of bowenite serpentine from Afghanistan. This shows the interlocking nature of the crystals to which the superior hardness of bowentite may be due.

to the bands seen in the serpentines. In bowenite the strong band is at 4640Å with a weaker band at 4970Å. Williamsite has a vague band at 5400Å; a strong band at 4950Å and a vague band at 4600Å. Connemara marble (ophicalcite) shows a strong band at 4650Å and a weaker one at 4950Å. The same worker mentions the examination of the absorption spectrum of antigorite and found the specimen to have a vague band in the green near 5400Å; a narrow "clear" band at 4950Å of moderate strength; a broad absorption band in the blue ending in a concentration at 4520Å, and lastly a strong band at 4300Å forming a cut-off to the end of the spectrum.

From a study of the absorption bands of various gemstones

known to be coloured by ferrous iron, such as almandine garnet, idocrase, actinolite, kornerupine etc., it appears to the writer that the band about 4650Å may be the more "characteristic" band for ferrous iron.

An interesting report made by N. D. Sobolev might here be mentioned. This worker, from analyses of peridotite from the Caucasus, and in rocks in various stages of serpentinization, showed $FeO = 6{\cdot}96\% - 0{\cdot}43\%$ and $Fe_2O_3 = 0{\cdot}71\% - 7{\cdot}14\%$ and infers that the degree of serpentinization can be assessed from the ferric iron content. The table given by Kunz of the various analyses of serpentine (all prior to 1892) shows that out of 28 analyses referred to, only two showed ferric iron to be present. On the other hand the table given by F. H. Hatch to illustrate the chemical changes necessitated in the conversion of olivine and augite to serpentine seems to show some agreement with Sobolev. On balance it does seem that Anderson's inference from the observed absorption spectra that ferrous iron is the essential colouring agent in serpentine is correct, but it may still be true that iron in the ferric condition can have some influence on the colour.

In conclusion it may be mentioned that the serpentines were known to the Ancients, but none of the specific varieties were named until the beginning of the 19th century. Many of the names known to literature have little present day usage, but, as such names may at times be met with, a list of such varietal names which have at times been used for the serpentines is appended:—

Antigorite.	One of the three major divisions of the serpentines.
Baltimoreite.	A variety of picrolite from Bare Hills, Maryland, U.S.A.
Bastite (Schiller spar).	Enstatite altered more or less completely to serpentine. Mainly chrysotile and/or lizardite.
Bowenite.	A hard compact form of antigorite.
Chrysotile.	One of the three major divisions of the serpentines. Fibrous, and one type of the "asbestos" of commerce.
"*Korea jade*".	A misnomer for bowenite serpentine.
Lizardite.	One of the three major divisions of the serpentines.

"London smoke".	The name applied to a dull grey opaque type of serpentine found at Gouveneur, in New York State.
Marmolite.	A type of serpentine made up of thin folia and found at Hoboken, New Jersey, U.S.A Probably chrysotile and/or lizardite.
Metataxite.	A type of serpentine from Silesia (chrysotile).
"New jade".	A misnomer for bowenite serpentine.
Noble serpentine.	The name applied to the translucent serpentines used for ornamentation.
Ophicalcite.	A rock, a mixture of serpentine, calcite, dolomite, or magnesite. Connemara marble is an ophicalcite.
Ophiolite.	See ophicalcite.
Pelhamine.	A greyish-green serpentine (?) which takes a good polish. From Pelham, Mass., U.S.A.
Precious serpentine.	Same as noble serpentine.
Picrolite.	A type of antigorite serpentine.
Picrosmine.	Similar to picrolite.
Polyphant stone.	A serpentinous diabase from Cornwall, England.
Porcellophite.	A variety name for a type of serpentine. Probably of the antigorite group.
Pseudophite ("Styrian jade").	An aluminous serpentine found in Styria and elsewhere in Austria.
Radiotine.	A serpentine (?) in spherical aggregates of radiating fibres. From near Dillenburg in the Westerwald, Nassau, West Germany.
Retinalite.	A massive yellow to light oil green serpentine with a waxy lustre.
Ricolite.	A fine-grained serpentine with coloured bands from Rico, New Mexico, U.S.A.
Satelite.	A fibrous serpentine found in California and Maryland. Cut as cat's-eyes.
Schiller spar.	Alternative name for Bastite.
Schweizerite.	A variety of serpentine usually from Zermatt, Switzerland. Mainly chrysotile.
Serpentinite.	The name applied to the rock-like types of serpentine.
Serpentine marble.	Any rock-like type of serpentine.

"*Soochow jade*".	A misnomer for bowenite serpentine.
"*Styrian jade*".	A misnomer for pseudophite.
Tangawaite (*Tangiwaite*).	Bowenite serpentine from the South Island of New Zealand.
Thermophyllite.	A variety name for a serpentine from Finland.
Verde antique.	A rock composed of a breccia of serpentine and limestone.
Vorhauserite.	A disused name for a type of serpentine.
Williamsite.	An attractive noble serpentine found in Texas, U.S.A. A variety of antigorite.
Zermattite.	A type of serpentine from Zermatt, Switzerland. Probably a type of schweizerite.

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Carved bowenite serpentine.

LEFT. *Sitting chicken of dark green (nephrite colour) "New Jade".* $4\frac{1}{2}'' \times 3''$ *high.*

RIGHT. *Bird resting on a branch in the more usual pale green bowenite ("New Jade").* $3\frac{1}{2}'' \times 4\frac{1}{2}''$ *high.*

photo by courtesy of Asprey & Co., Ltd.

Gemmological Abstracts

ROESCH (S.). *Messung und Uebersicht von Edelsteinfarben mittels de DIN Farbemkarte.* Survey and measuring of gem colours with the DIN colour chart. Zeitschr. d. deutsch. Edelsteinkunde, 1966, 56, pp. 12-18.

Colour is not a physical property but depends on the impression of the eye. It has been shown that 3 independent numbers are necessary, but also sufficient, to describe a colour. These numbers represent: colour tone, colour intensity and colour lightness. For the actual measuring of colour the author recommends DIN (German standard) colour chart 6165. One difficulty is that the stones are often transparent, which cannot be realistically represented on a chart. A new name is suggested: Colour variation number. This would be a large number in the case of, say, quartz and a small one for, say, citrine or aquamarine. Large bibliography.

E.S.

HAHN (M.). *Zur Frage nach dem Alter der Idar-Obersteiner Edelsteinindustrie.* The question of the age of the gem industry in Idar-Oberstein. Zeitschr. d. deutsch. Gesell. f. Edelsteinkunde, 1966, 56, pp. 24-26.

The oldest document about agate finds in the district is dated 1454, and the first mention of agate polishing was dated 100 years later. Although the whereabouts of these documents is unknown the dates mentioned seem to be correct.

E.S.

HOLLAENDER (H.). *Der Smaragd.* The emerald. Deutsche Goldschmiedezeitung, Vol. 63, 1965, p. 1164.

Short historical essay on emeralds. It is known that the Egyptians knew emeralds in 2000 B.C. and prized them as much as the Incas and Mayas in the New World.

E.S.

ANON. *Die Diamant Syntheses.* Diamond Synthesis. Zeitschr. d. deutsch. Gesell. f. Edelsteinkunde, 1966, 55, pp. 3-7.

A diamond synthesis by the high-pressure and high temperature laboratory of the Mineralogical and Petrological Institute of the University of Bonn. The work was done under the direction of Professor A. Neuhaus. The apparatus used is described and illustrated. The diamonds produced had a length of up to 0·5 mm; they included some slightly yellow or even greenish, but also some colourless. The habits obtained were octahedral and cubic.

E.S.

BAIER (E.) and PENSE (J.). *Edelopaloptik in Kunstprodukten.* The optics of precious opals in man-made materials. Zeitschr. d. Gesell. f. Edelsteinkunde, 1966, 55, pp. 7-20.

The optics of precious opal are discussed in detail and a reflectogram is shown in stereoprojection. By examination with the electron-microscope it is shown that the cause of the particular light reflection of opal is a lattice made up of balls of equal size. The authors discuss the possibility and advantages of a future synthesis of opal by opalising packs made up of SiO_2-balls.

E.S

LENZEN (G.). *Die Farbbezeichnungen des Diamanten als internationaler Handelsbrauch.* Colour-nomenclature of diamonds as used internationally in the trade. Zeitschr. d. deutsch. Gesell. f. Edelsteinkunde, 1966, 55, pp. 20-30.

During the end of the last century certain terms were used for describing the colour of diamonds, these were: Jager, River, Top Wessleton, Wesselton, Top Crystal, Crystal, Top Cape, Cape, and Yellow. These are now known generally as "Old Terms". Before the first World war an alternative nomenclature was introduced: finest blue white, blue white, fine white, finest silver cape, silver cape, cape, light yellow and yellow. These names did not include the brown-reddish types and these were sub-divided into very finest light brown, very very light brown and light brown. Various tables are compiled showing the various terms and comparing the name given to the actual colour of the stone. A RAL (German) standard has been published on this theme, but does not seem to cover the problem.

E.S.

STRACK (E.). *Der Flusspat.* Fluorite. Zeitschr. d. deutsch. Gesell. f. Edelsteinkunde, 1966, 55, pp. 30-42.

Very detailed article dealing with many aspects of fluorite. Chemistry, crystal form and habit, cleavage, hardness, specific gravity and optical properties are given. Pure CaF_2 is colourless but rare. Fluorite is usually found in violet, blue, green and yellow, also pink to red, orange, brown and grey coloured. A certain blue colour can be produced by x-ray radiation, but this fades in day-light. Cathode-ray treatment produces permanent colours—white fluorite becomes violet, pale green changes to pale violet and pink darkens. Luminescence is described. Fluorite is found in England (Cumberland, Durham, Cornwall and Devonshire), Saxony, in the Swiss Alps near the St. Gotthard, also in Austria, Norway, Poland and Italy and Russia. There are many occurrences in North America, British Columbia and in South-west Africa. Apart from gem or ornamental uses fluorite is used in the optical and chemical industry. In optics the low RI (1·434) and low dispersion (0·0045) make it suitable for the production of lenses in microscopes, and the chemical industry used to use fluorite for the production of fluoric acid. It is also used in metallurgy. Fluorite was well known and used by the Romans.

E.S.

BOOK REVIEW

CHUDOBA (K.) AND GUBELIN (E.). *Edelsteinkundliches Handbuch.* Stollfuss, Bonn, 1966. 269 pp., 4 colour pl., numerous illus.

First published under the title of *Schmuck und Edelsteinkundliches Taschenbuch*, there is a change for the second edition. The text has been substantially revised and much new material has been added. More attention has been paid to the importance of absorption spectra in distinguishing between gemstones and the new book is essential to all using the German language who are interested in the study of gemmology.

A.G.

ASSOCIATION NOTICES

UNESCO

A vacancy exists in the Department of Geology, Arts and Science University, Rangoon, Burma, for an expert in gemmology. The work would involve the "teaching and supervising of laboratory work, initiation of research programmes and the improvement of gem collections suitable for training. Experience is required in mineralogy with a knowledge of rubies, sapphires and associated minerals, as well as especially in jade. Language qualification is English. The duration of the appointment is one year commencing April 1967 and the appointment carries a basic salary of the equivalent of $17,400 gross, with adjustments for assignment and family allowances. Travel is provided for the expert and his dependants (spouse and children under 18 years of age). In addition, Unesco contributes towards the cost of installation at the duty station, the education of dependent children, and the medical expenses of the staff member. On separation from Unesco, a repatriation grant is paid".

HERBERT SMITH MEMORIAL LECTURE

The 1966 Herbert Smith Memorial lecture was given at Goldsmiths' Hall, London, on Tuesday, 8th November, by Mr. R. C. Chirnside, Chief Chemist at the Hurst Research Centre of the General Electrical Company at Wembley. Mr. Philip Riley, Vice-Chairman, introduced the speaker.

Mr. Chirnside said that moon projects had made it possible to undertake extensive research in gem synthesis. Most people in his audience, he said, would, when they thought of crystals, think first in terms of those which had been prized for centuries as precious stones. But many crystals were of considerable commercial importance.

He first discussed the quartzes, reminding the audience that 60 per cent of the earth's crust was composed of silicon dioxide. Clear quartz, he said, lacked fire and was little used in jewellery, so that the stimulus to produce synthetic quartz was unlikely to come from the jewellery trade. Its greatest importance, he said, was for optics and telecommunications. The fact that it would transmit ultra-violet and infra-red light made it an ideal lens and prism material. Its oscillation at a standard frequency when activated by an electrical impulse had led to its extensive use in telecommunications.

He recalled that there had been great anxiety both in the U.S.A. and in this country during the war, because we were dependent on Brazil for quartz suitable

for these important uses. This had been the impetus that had led to the synthesis of quartz. The scientists had got silica to dissolve in water and recrystallize at temperatures of over 300 deg. centigrade in an autoclave (a pressure cooker). Crushed quartz was put in a basket and dissolved in this way, then a seed of quartz was put in and the silicon dioxide in the solution crystallized around it. This technique known as the hydrothermal process, made it possible to grow large perfect crystals in a short time. It was this technique that was, he thought, being used to grow the latest synthetic emeralds, and it was possible to grow a great variety of other crystals in this way.

He then went on to describe developments that had taken place in the Verneuil furnace, the flame-fusion process of producing synthetic corundum. These developments had resulted from the demand for synthetic corundum rods for watch and instrument jewels and for very large crystals for maser and laser work.

Then he turned to the crystallization of titanium oxide to form rutile. This, he said, formed a dark grey or black crystal, but it became colourless when heated. It had a higher refractive index than diamond and a very high dispersion, but a slight yellow tinge, and was of course much softer than diamond. The latest development he said had been the crystallization of strontium oxide and titanium oxide to produce strontium titanate, which had been given the despicable name Fabulite.

He then went on to talk about the early attempts to synthesize diamond, and the ultimate success of the G.E.C. laboratory in the U.S.A. in 1954. This had been possible as a result of research into the vast temperatures and pressures which were necessary to achieve this synthesis.

He concluded by saying that while the jeweller preferred the natural stone to the synthetic, the scientists preferred the synthetic because of its greater purity.

Mr. Basil Anderson in thanking Mr. Chirnside said that the gemmologists couldn't have too much first hand information about synthetics, and reminded the audience that Verneuil might be considered to be the father of gemmology. His invention had made gemmology really necessary.

WEST OF SCOTLAND BRANCH

A meeting of the West of Scotland Branch of the Gemmological Association was held at the North British Hotel, Glasgow, on Thursday, 10th November 1966. Mr. J. Gilloughley, Chairman of the Branch, presided.

After welcoming the 115 members of the audience, the chairman called upon Mr. R. Webster, the guest speaker, to present diplomas to two successful candidates in the recent examinations.

Mr. R. Webster then gave a comprehensive review of synthetic stones. After dealing briefly with their history he discussed modern stones, their manufacture and points of difference from natural stones. The lecture was illustrated by colour-slides and many interesting examples of synthetic stones were on display. Following a question time, the chairman announced that Mr. W. C. F. Butler, Vice-Chairman, would be leaving Scotland, and thanked him for all the work and time he had devoted to the Association.

Acknowledging the thanks, Mr. Butler expressed the Branch's indebtedness to Mr. R. Webster for coming to Glasgow and giving such an interesting and stimulating lecture.

GIFTS TO THE ASSOCIATION

The Council of the Association is indebted to Mr. A. Nagy, of the Diamond Polishing Works Limited, for a diamond crystal weighing 1·85 cts.

COUNCIL MEETING

A meeting of the Council was held at Saint Dunstan's House, Carey Lane, London, E.C.2, on Tuesday, 13th September, 1966. Mr. Norman Harper presided. The examiners and instructors attended, and the year's examination results were considered. The Council decided to make an application to the College of Heralds for a Grant of Arms, based upon a design submitted by Mr. H. Ellis Tomlinson, M.A.

The following were elected to membership:—

To Fellowship:

Boudreau, Guy A., Montreal, P.Q. Canada. D.1952
Tyerman, John T., Newark-on-Trent, Notts. D.1962
Ash, Grahame D., London, N.21. D.1966
Zwollo, Paul, Oosterbeek, The Netherlands. D.1966
Ingram, Roger, Sheffield, 11. D.1966
Guthu, Steinar, Sandefjord, Norway. D.1966

To Ordinary Membership:

Beaumont, Roy A., Market Harborough, Leics.
Beers, Larry D., California, U.S.A.
Black, John H., Christchurch 5, New Zealand
Buchanan, Kenneth R. Oklahoma, U.S.A. 74135
Buckner, George D., Florida, U.S.A.
Butler, Terence, Bologna, Italy
Chow, Robert, Kowloon, Hong Kong
Chow, Sammy, Kowloon, Hong Kong
Dingle, Patricia N., Ontario, Canada
Edwards, Roland V., California, 90069, U.S.A.
Evans, David G., Cookham, Berks.
Facchinelli, Carlo A., Trento, Italy
Graves, K. (Mrs.), London, S.W.16
Hamblym, James H., Lower Hutt, New Zealand
Hasan, M., Southall, Middx.
Hopkins, Jr., Norman B., Bowie, U.S.A.
Importservice Imp. Ind. Ltd., Sao Paulo, Brazil
Ishizawa, Shinkichi, Tokyo, Japan
Takahashi, Akio, Tokyo, Japan
Canes, Joel, J., Johannesburg, S. Africa
Kern, Joseph F., New York 11758, U.S.A.
Ledbetter, Susan, Dublin 4, Eire
Mac Leod, Dan M., Vancouver, Canada
Matthews, Pauline, Nairobi, Kenya
McKeown, Peter M., Hastings, New Zealand
Milligan, James C., Aberdeen, Scotland
Namiki, Mosao, Tokyo, Japan

O'Donoghue, Michael J., London, N.W.3
Oki, Yoshiro, Tokyo, Japan
Okumura, Mosahiro, Wakayama City, Japan
Ono, Matuo, Chibaken, Japan
O'Rourke, Edward A., Maryland, U.S.A.
Beyda, Raphael, Geneva 17, Switzerland
Roberts, William N., Johannesburg, S. Africa
Ryding, John S.. Victoria, Australia
Schnetz, John V. P., Kriens, Switzerland
Selormey, Clement E., Kumasi, Ghana
Smyth, John J., Dublin 6, Eire
de Souza, Victor J., Kobe, Japan
Steib, Fred, Illinois 60615, U.S.A.
Suita, Nagayasu, Tokyo, Japan
Wilson, O. G., Kentucky, U.S.A.
Peyerl, Wolfgang, Johannesburg, S. Africa
Yamamoto, Yuji, Osaka, Japan
Yiu, Nellie, Kowloon, Hong Kong
Beckmann, Jr., Frank L., Hitchin, Herts.
Horden, Anthony B. H., Lusaka, Zambia
Psaros, James C., Florida 32925, U.S.A.
Schippers, Gustaaf, Ryswyk, Holland
Schreiber, Ludwig, Auckland, New Zealand
Turner, Peter H., Salisbury
Weder, Anton, Hong Kong
Lam, Lionel K. P., Hong Kong
Beadon, D. V., Kingston-on-Thames, Surrey

To Probationary Membership:

Amedeo, James, New York 13, U.S.A.
Blastiaan, Sluis, Vlaardingen, Nederland
Davey, Christopher M., Nr. Crediton, Devon
Fraley, Robert J., N. Carolina, U.S.A.
Harris, Anthony M., Hove 4, Sussex
Holmes, Graham J., Bexhill-on-Sea, Sussex
Horden, May C., Lusaka, Zambia
Hutchins, Andrew J., Auckland, New Zealand
Kenney, Francis J., Leigh-on-Sea, Essex
Krumpelmann, Georg, Bad Salzuflen, W. Germany
McLachlan, Catherine, Boksburg Tvl, S. Africa
Mitchell, Terence, Salisbury, Africa
Muwaffer, Mohamed R. M., Ratnapura, Ceylon
Pattni, Navinchandra D., Glasgow W.2, Scotland
Piederiet, J. J. M., Breda, Nederland
Rutter, Marilyn J., Ridgmont, Bedford
Smith, Anthony V., Bradford 9, Yorkshire
Soni, Dineschchandra R., Nairobi, Kenya
Staatsen, Albertus C., Utrecht, Nederlands
Viswakula, V. A. N., Colombo 4, Ceylon
Winder-Toole, Angela B., Penzance, Cornwall
Arman, Michel G., Buenos Aires, Argentina

Transfers from Ordinary and Probationary Membership to Fellowship:

Reiter, Peter Otto, Lucerne, Switzerland
Azzopardi, Joseph, Floriana, Malta
Gatward, Anna B., Hitchin
Ponahlo, Johannes, Vienna, Austria
Salt, Ilse E., Fort Nelson, Canada

Wilkins, Robert F., California, U.S.A.
Bastos, Francisco M., Minas Gerais, Brazil
Boruszak, John K., Blackpool
Butland, William M., Natal, S. Africa
Butler, June I., Waltham Abbey
Cameron, Donald A., Ottawa, Canada
Chikayama, Akira, Kofu, Japan
Clarke, John E., London
Crombie, Michael S. I., London
Downes, Bryan, Silkstone
Guthu, Steinar, Sandefjord, Norway
Hilton, John D., Macclesfield
Huish, Diana, London
Hunt, Anthony G., Hucknall
Jones, David M., Birmingham
Lowe, Peter J., Green Lane
McCorquodale, Samuel, Selangor, Malaysia
McLean, Dr. Eldred M., Transvaal, S. Africa
Miller, Elizabeth A., Wolverhampton
O'Connell, Sean, Harrow
Popper, Madeleine C., London
Pryke, Christine M., Colchester
Sweet, Ronald D., Sidcup
Winkler, Gunter, Jr., Augsburg, Germany

LONDON MEETINGS 1967

25th January—Film Show, Hanover Street, W.1.
6th March—Conversazione, Goldsmiths' Hall.
23rd May—Annual Meeting.

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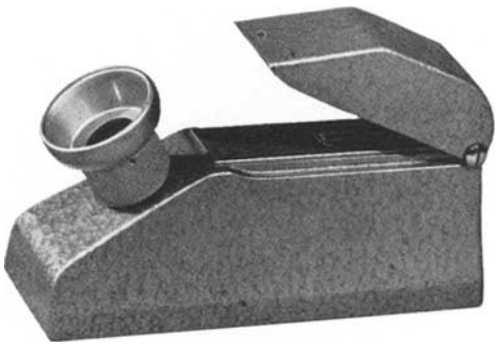

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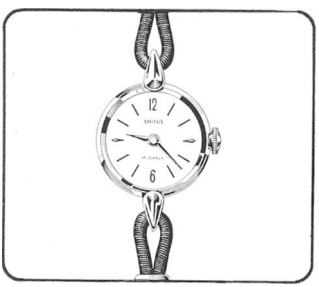

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THE JOURNAL OF GEMMOLOGY

and

PROCEEDINGS OF THE
GEMMOLOGICAL
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Vol. 10 No. 6 APRIL 1967

A NEW IMMERSION LIQUID

By HAROLD LEE

HAVING decided the mineral of which a stone is composed the gemmologist usually asks, "Is it natural, synthetic or artificial?" and, sometimes, "What is its source?" To answer these questions he must examine the interior. The inclusions he sees there are the most rewarding source of information enabling him in many cases to answer any or all of the above questions—hence the time devoted to this work in the training classes.

It has been postulated that the inclusions of a stone can best be seen when the stone is immersed in a liquid having a refractive index fairly near to that of the stone itself. Most of the liquids usually recommended have very undesirable characteristics especially when used in such quantities as are required by a number of students in a training establishment.

What is probably the most efficient liquid, especially for the corundum gemstones and others of high refractive index, is methylene iodide. This is a fairly pleasant liquid to use and has a R.I. of 1·74, but it darkens on ageing and has the disadvantage of being expensive. The liquid most commonly used is mono-bromo-naphthalene, which has a R.I. of 1·66. This is a greasy type of liquid and has an unpleasant odour which is extremely persistent.

"Veiled" feathers in a Gilson (French) synthetic emerald

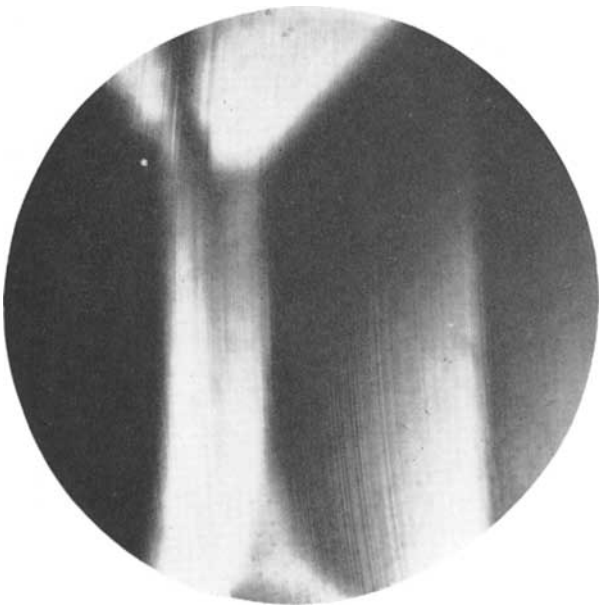

Curved striae in synthetic ruby

Furthermore its vapour is very irritating to the eyes, particularly when after a short time the liquid becomes warm from the heat of the microscope lamp. It also has the minor drawback of attacking certain plastics and if inadvertently transferred by the fingers to a fountain pen, ball-point pen or slide rule, soon renders the surface rough and sticky. For stones of a lower refractive index, in particular the beryls, a number of liquids have been proposed and used. Such liquids include bromo-benzene of R.I. 1·56 and benzyl benzoate of R.I. 1·59. The latter was proposed by Professor K. Schlossmacher, who suggested its use in particular relation to the identification of the synthetic emeralds and the emerald-coated beryls.

Is it always necessary to use a highly refracting liquid to "get into" the stone? One instructor who finds mono-bromonaphthalene obnoxious uses water (R.I. 1·33). The writer, who has over many years in a chemical laboratory developed a natural aversion to many of the halogenated organic chemicals, set out to find an immersion liquid which while being effective was at the same time pleasant to use and considerably less toxic. For some time a variety of solvents have been used, mainly in the examination of stones of lower refractive index and on occasions for the higher refracting stones, where they proved fairly successful, certainly so far as visual use was concerned. Another feature sought for was that the stone on removal from the immersion cell should be quite clean or at most require only a quick rinse in water or methylated spirit. Amongst the substances tried were ethane diol (ethylene glycol) (R.I. 1·42) and di-methyl-phthalate (R.I. 1·51). These liquids appeared to do quite well, are colourless and practically odourless. It was however discovered that on occasions they tended to form small air-bells which adhered to the surface of the stone. This while probably of little importance to the experienced worker may lead to errors of interpretation in the case of students. One of the liquids tried was ethylene-glycol-mono-ethyl-ether, of which the technical product is marketed under the names Cellosolve and Oxitol. This appeared to have the qualities desired without any of the disadvantages. It is water-white, practically odourless and even on violently shaking does not form any air-bells. It leaves the stone in a perfectly clean condition but if desired can be entirely removed by a quick rinse in water, in which it is soluble in all proportions. The refractive index of this liquid is somewhat

Feathers in dark blue Australian sapphire

Typical cracks and unpolished facet showing crystal surface, typical of a synthetic emerald-coated beryl

lower than the others mentioned, and the questions were, would this detract from its usefulness in the examination and more particularly in the photography of the highly refracting stones and also how would it behave in the examination of the beryls, with particular thought to the separation of natural and synthetic emerald and the emerald-coated beryl? This called for more exhaustive tests with a variety of these stones and Mr. Robert Webster kindly undertook to do these. He went into this with enthusiasm and thoroughness and the following details of the results are in the main his own conclusions.

Although the index of refraction is lower than that of the liquids usually used (R.I. 1·408) experiment has shown that one can "get into" the stone without difficulty, even corundums with their high refractive index. True, not all of the stone can be examined in any one position but by turning the stone into different positions a worker will be able to inspect the greater portion of it. As will be seen by the photomicrographs the stones of comparative high refractive index tend to show the facet edges but this is sometimes a good thing as it allows the inclusions to be "pin-pointed", thus acting as a reference. For training students this is often valuable and in fact saves the use of an indicating eyepiece. This is well illustrated in the photograph of the feathers in a dark blue Australian sapphire. The photograph of the synthetic ruby shows how well the fine curved striae can be recorded. Regarding the use of this liquid in the examination of emeralds and beryls the photograph of the "veiled" feathers in a Gilson (French) synthetic emerald and in particular the one showing the typical cracks and the unpolished facet showing the crystal surface typical of a synthetic emerald-coated beryl indicate that this liquid may safely be used in the testing of a wide variety of stones.

Still not being satisfied that his own work was sufficiently searching in the application of this liquid for general use, particularly by students, and to obtain a better evaluation of its use in the classroom, Mr. Webster made use of the liquid at three different classes of practical gemmology at the Sir John Cass College, and sought the opinion of the students on its efficiency. The general impression was that the liquid, being colourless, allowed a clearer view of the inside of the stone. There was a comment on the odour, mainly because it was strange after using the customary immersion liquid, but there were no adverse comments, nor was

there any difficulty found in observing the various inclusions.

He sums up: "The advantages seem to be cheapness, clarity, due to its colourless nature, and the ease of cleaning both the stones and apparatus. The liquid is less detrimental to the metal parts of instruments than the others commonly used. While in certain cases a liquid of higher refractive index may be necessary, the use of this liquid as an immersion medium for general purposes for training and maybe for routine work has many advantages".

As a matter of interest I append the following details:

Ethylene glycol mono-ethyl ether $C_2H_5O.CH_2.CH_2.OH$

The pure material has boiling point 134·5°C; refractive index 1·408; vapour pressure at 20°C 4·5 mm; specific gravity 0·936 at 20°C. The present price in the catalogues of normal chemical suppliers is 7s. for 500 ccms.

I express my gratitude to Mr. Webster for the searching tests he has carried out and also for the excellent photomicrographs illustrating this article.

STAR-DIOPSIDE AND STAR-ENSTATITE

By W. F. EPPLER

ABOUT two or three years ago, star-diopside entered the market, a gemstone which was rarely seen before. It is an opaque material of dark colour, which at its best is black with a greenish hue, and sometimes dark brown to black-brown. Diopside is a member of the so-called "monoclinic pyroxenes", a group of crystals to which, by the way, belong the gem minerals kunzite and hiddenite and jadeite likewise.

The chemical composition of the diopside is represented by the formula $CaMg(SiO_3)_2$ or $CaO . MgO . 2 SiO_2$, with a certain amount of iron replacing the Mg in the formula. The variable contents of iron are responsible for the differences in colour, in the optical properties, and in the specific gravity.

The values for diopside given by Webster(1) are $n_\alpha = 1{\cdot}670$ and $n_\gamma = 1{\cdot}701$ for the refractive indices, with the remark that higher indices are caused by higher contents of iron. The specific gravity is quoted by the same author at 3·29 with the tendency to higher values with higher iron contents.

The measurement of material of dark brown colour available to the author resulted in a refractive index of 1·67 to 1·68, measured by the distant vision method and by observing the Becke-line in suitable liquids. The density was found to be near to 3·33, both by the hydrostatic and the heavy liquid method. A final identification of the material as diopside was kindly made by Professor Dr. H. Jagodzinski, of Munich University, by an X-ray analysis.

The star-diopside came from Nammakal, South India, and with its four rays it looks very attractive (Fig. 1). The asterism is caused by the reflection of light on coarser or finer or even very tiny inclusions, as shown in Fig. 2. The nature of these particular inclusions is not yet known. They must have been originated by a process of exsolution, as they are strictly orientated according to the monoclinic symmetry of the diopside. It may be that they consist of clinoenstatite, $MgSiO_3$ or $MgO . SiO_2$, which is not soluble in diopside at lower or normal temperatures. But this speculation is not yet confirmed and further investigations are necessary to answer this question.

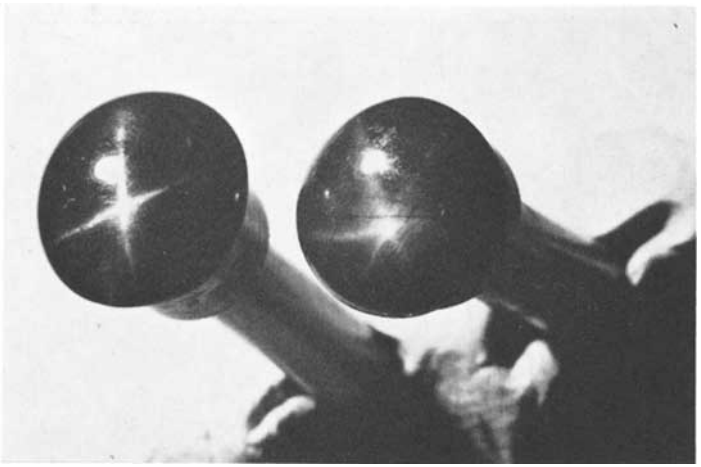

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FIG. 1. *Four-rayed star-diopside (left) and six-rayed star-enstatite (right); approx. magnification.*

Another peculiarity of the elongated crystal inclusions is the fact that they intersect each other at angles different from 90°, which is caused by the monoclinic symmetry of the diopside crystal. The deviation from the right angle is approximately 17°, as can be seen in Fig. 2. Consequently, the rays of the star deviate also from 90° and they include angles of 73° and 107° respectively. Besides this, R. T. Liddicoat, Jr.,(2) mentions a difference of the rays from which two are said to be broader and two to be thinner. This effect could be explained by the coarser and finer development of the needle-like inclusions in different directions. With the material in question, such a variation in the brightness of the rays could not be observed.

Star-enstatite. Quite recently, a six-rayed star-enstatite was encountered, which is also said to come from South India. It looks dark brown and the star is not so strongly developed as with the diopside (Fig. 1). Enstatite is also a member of the pyroxene group but has an orthorhombic symmetry. Chemically, it is characterized by the formula $MgSiO_3$ or $MgO \cdot SiO_2$ with varying contents of iron. Thus the physical properties are slightly variable.

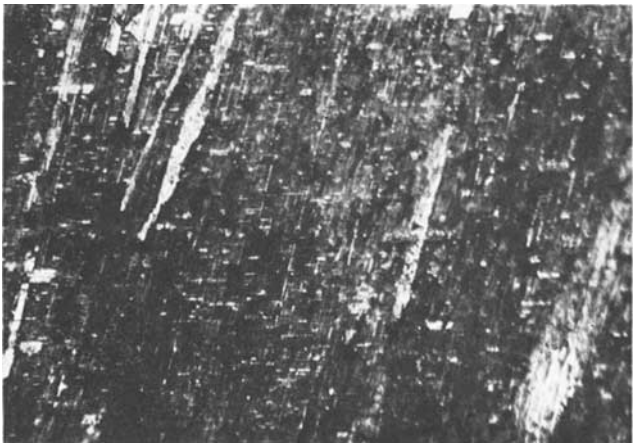

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FIG. 2. *Elongated inclusions in star-diopside are the cause of the four-rayed asterism; reflected light.*

According to Webster[1], the values for green enstatite of gemstone quality are $n_\alpha = 1{\cdot}663$ and $n_\gamma = 1{\cdot}673$ and they rise with the increase of iron. The density is given as 3·26 to 3·28. The star-enstatite, which has not so far been mentioned in the gemmological literature, has similar values to those of the star-diopside. The refractive index was measured as 1·67 to 1·68, and the specific gravity near 3·3 using the same methods as already mentioned before. The final result again was found by an X-ray analysis kindly performed by Professor Jagodzinski.

The asterism is caused by very fine and tiny inclusions of crystal needles, most probably rutile (Fig. 3), which are originated by exsolution. They have a high refractive index and look the same way as the well known rutile needles in corundum. The stone in question was first offered as a star-corundum. At first sight, the six-rayed star seems to be regularly developed, but looking nearer, the rays do not include angles of 60° exactly. Dr. S. von Gliszcynski[3] was kind enough to calculate the possibilities for a six-rayed star in an orthorhombic crystal like enstatite. Starting from a unit cell of a = 18·2 Å and b = 8·8 Å, he found a pseudo-hexagonal net with angles of 51° 36·6′ and 64° 11·7′ and these amounts signify the aberration from a regular star as seen in the trigonal corundum.

The star-enstatite described does not look as attractive as a star-corundum, but it is a novelty and an interesting enrichment of natural star-stones.

The author is indebted to Dr. S. von Gliszcynski, Münster (Westfalen), Germany, for the generous gift of the samples and for the calculations mentioned in the text. He is also most grateful to Professor Dr. H. Jagodzinski of Munich University for the X-ray analysis which enabled the conclusive definition of diopside and enstatite.

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1. Robert Webster. Gems, London 1962.
2. R. T. Liddicoat, Jr. Gems & Gemology, Winter 1965, 66, 370-371.
3. Dr. S. von Gliszcynski, private communication.

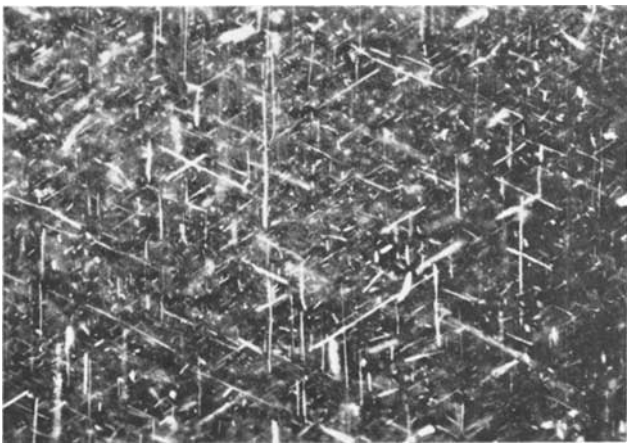

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FIG. 3. *Six-rayed star-enstatite with orientated rutile needles, reflected light.*

DETERMINATION OF SOLID INCLUSIONS IN GEMSTONES

By HENRI-JEAN SCHUBNEL

THE determination of solid inclusions in gemstones is of the greatest importance in proving their natural origins and, in some cases, indicating their presumed sources. It is perhaps useful to point out the various possibilities offered for this type of complicated work by the modern equipment available in mineralogical laboratories. Of course, cut gemstones cannot usually be subjected to destructive tests, but no longer do small inclusions, approaching or being smaller than the 10th part of a millimetre, present insurmountable difficulties in the matter of identification.

Each stone poses its own problem, a problem which can be resolved by testing by different methods, although they cannot be systematized too much in a theoretical way.

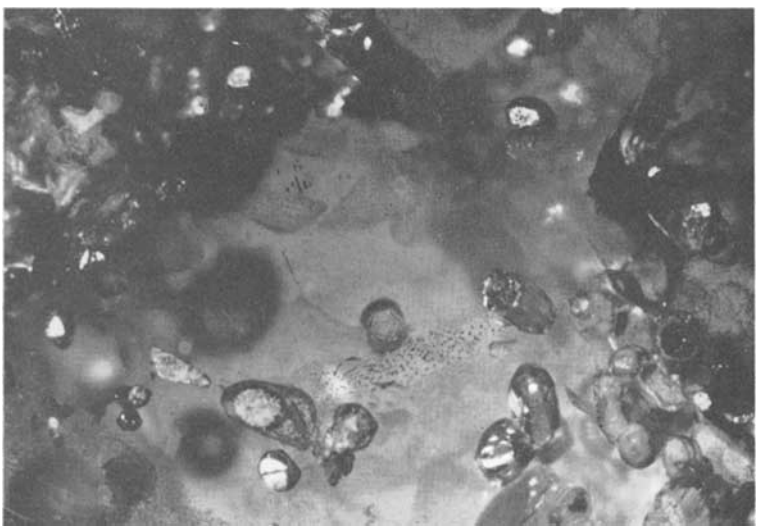

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FIG. 1. *Pyrrhotite and chlor-apatite crystals in a mauve sapphire.*

Some results of the determination of inclusions undertaken in the course of the last two years are given in this paper. Only inclusions touching the surface of cut stones can be directly determined and in some cases it was necessary to polish a face of a rough crystal in order to bring the inclusion to the surface.

Among the techniques employed, three of them were particularly interesting because they suited the problem involved very well.

1. Rapidly performed chemical analysis with an electronic Castaing microprobe which enabled, by spectrography of direct emission of X-rays, the analysis of the chemical composition of inclusions as small as 5-10 cubic microns in volume.

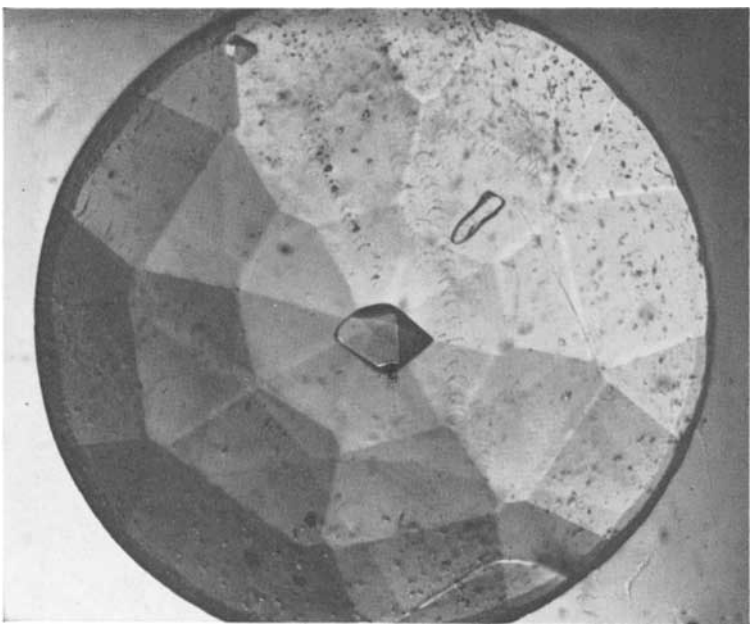

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FIG. 2. *A spinel crystal containing 3% of zinc in a cut ruby.*

2. Microscope using polarized reflected light, which is more often used to observe and measure optical characteristics in opaque minerals.
3. Measurement of X-ray diffraction powder-diagrams of crystalline dust taken from inclusions of rough crystals and subsequently the measurement of hardness with the Leitz "microdurimeter" apparatus, which only leaves square marks a few microns wide on the samples tested.

Using microprobe technique, the nature of various inclusions could be established. The three illustrations show some of the results.

It is probable that distinguishing between natural and synthetic stones will become more difficult as the years go by but by the use of microprobe techniques it should be possible to make a systematic study of inclusions in gemstones that will enable the gemmologist and mineralogist to distinguish various types of inclusions more confidently.

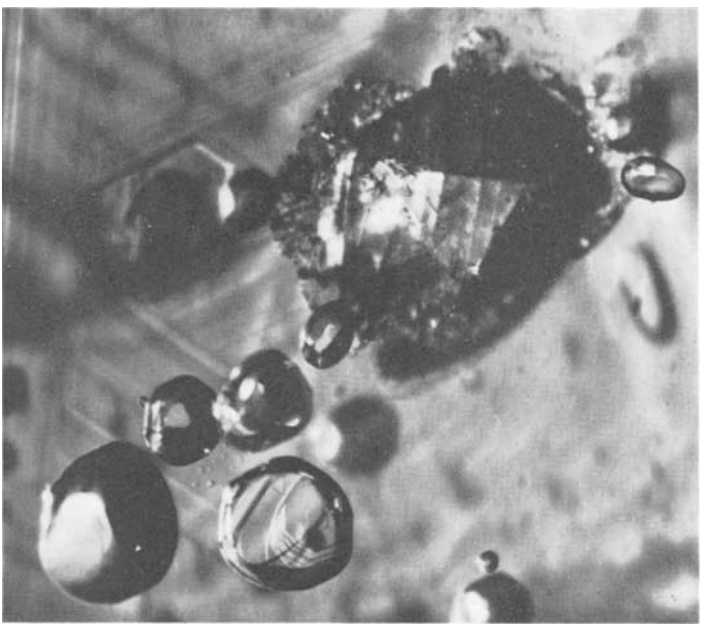

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FIG. 3. *Calcite crystal in a ruby.*

Inclusions in a faceted ruby
A tri-lingual presentation of details of an inclusion in a faceted ruby, which the author suggests might be a suitable technique for specialists in the study of inclusions to use.

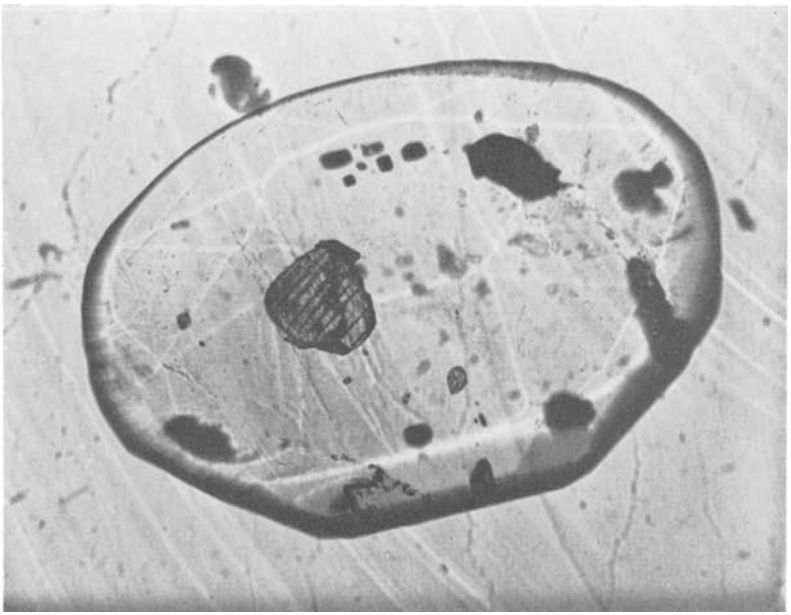

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Rubis taillé avec inclusions
Inclusion de calcite(1), le rubis est immergé dans l'iodure de méthylène; lumière transmise.
Le faciès de la grande inclusion rappelle "La tête de clou".
Les plans de clivages sont nettement reconnaissables.
La grande inclusion atteint la surface et a été déterminée: à la microsonde de Castaing, au microscope en lumière réfléchie et au microdurimètre.
Origine présumée: Birmanie.

Inclusions in a ruby

Inclusion of calcite(1). The ruby was immersed in methylene iodide and transmitted light used.

The faces of the large inclusion look like the head of a nail and cleavage planes can be distinctly seen.

The large inclusion reaches the surface and has been determined using the Castaing microprobe, with the microscope using reflected light and by micro-hardness test.

Presumed origin: Burma.

Geschliffener Rubin mit Einschlüssen

Einschlüsse von Calcit(1). Der Rubin ist in Methylenjodid eingettet; durchfallendes. Der grosse Einschluss errinnert an einen Nagelkopf.

Die Spaltrisse sind deutlich zu erkennen.

Der grosse Calcit-Enschluss reicht bis an die Oberfläche und wurde mit der Castaing-Mikrosonde mikroskopisch in reflektierten Licht und auf die Mikrohärte untersucht.

Vermutlicher Fundort: Birma.

---

(1) Calcite $Ca\,CO_3$
Hexagonal-rhombohedral $D^6_{3d} - R\bar{3}c$.
Density $= 2{\cdot}71$ Hardness $= 3$ $\omega = 1{\cdot}658$ $\varepsilon = 1{\cdot}486$

These notes have been adapted from an article which appeared in the *Bulletin de l' Association Francaise de Gemmologie*, 1967, No. 9.

REFRACTION ANOMALIES IN TOURMALINES

By R. KEITH MITCHELL

TWO dark green gem-quality tourmalines acquired recently from Brazil showed unusual optical properties.

To all outward appearances they are quite normal stones. Refractometer readings, however, reveal the inexplicable fact that the stones each give *four* distinct shadow edges in sodium light; two lower ones for the extraordinary ray at 1·620 and 1·624 and two for the ordinary ray at 1·646 and 1·653. Birefringence is high, whether one takes it as 0·026 or 0·029, or even 0·033, but is within the extreme range for the species.

The shadow edges on the instrument cancel out quite nicely in pairs when polaroid is used to segregate them. Both pairs behave exactly as one would expect, the twin ordinary ray readings remain stationary while the other two move as the stone is rotated.

The stones do not back up their strange behaviour by exhibiting a quadrupling of the back facet edges but, like so many dark-coloured tourmalines, the ordinary ray is almost totally absorbed, and any facet edge image due to this ray is swamped by the much brighter image due to the extraordinary ray. The difference between the two ε rays is too small to be seen with a lens. With strong lighting and using polaroid it is probable that each ray would show doubling under the microscope.

The reason for this very strange duplication of shadow edges is not at all clear, although it seems probable that the stones have been subjected to heat treatment. One possibility is that this may have caused the formation of two types of tourmaline which are existing in close association in the crystal. I have encountered something similar in a tourmaline cat's-eye, which was investigated by X-ray diffraction at the Natural History Museum and found to be an intimate mixture of tourmaline and diopside. But in that stone clear-cut R.I. readings were not obtainable. The present stones behaved normally under this test.

I understand that double reading tourmalines have been reported before by a gemmologist in Denmark. Since I found these two stones another has been found by Dr. G. F. Claringbull, Keeper of Minerals at the Natural History Museum. It seems certain that such specimens are extremely rare and that the full reason for such strange optical behaviour is not yet understood.

TWO CULS-DE-SAC

By E. BURBAGE and T. G. JONES

THE *Journal of Gemmology* shows commendable hospitality in chronicling the successful conclusions of any research, however modest, but understandably, its pages seldom or never record the null results—the stone one could not identify, or the correlation of physical constants which remained obdurately indeterminate. However, we feel the two enquiries to be described are worth recording, for diametrically opposed reasons. In what we might call The Case of the Ingenious Nobleman, we may claim to have assembled a sufficient dossier to write "finis" to the matter, and thus save other gemmologists the chore of duplicating our enquiries, whilst, contrariwise (as Tweedledee would say), in The Case of the Gallic Crystallographer, we have to admit defeat whilst leaving open the possibility that another worker may succeed where we failed.

Item the first stems from a paper which one of us contributed to an early issue of this Journal, collecting and commenting on the scattered references to gemmological matters in the writings of Sir Thomas Browne (1605-1682)(1). It was there noted that, in a communication sent to the Royal Society, a reference was made to a technique for staining agates, practised by Sir Thomas Browne's friend Sir Edmund Bacon, who died in 1649. Such an anticipation of Idar/Oberstein techniques at so early a date seemed worth following up, and a hope was expressed that from Norfolk topographical records or elsewhere, further details might come to light. This hope was not realized, and further enquiries in recent months have led us reluctantly to conclude that no further information exists. By courtesy of the Secretary of the Royal Society, a photostat of Sir Thomas Browne's original communication was secured, which established the correctness of transcripts by Wilkins and Keynes. The City Librarian of Norwich was good enough to search his records, but without success, although he was able to bring to our notice an interesting paper on an allied subject by Kircher in the *Philosophical Transactions* of 1665. Finally, an approach was made to the present Sir Edmund Bacon to ascertain whether his family records contained anything of relevance. In a most cordial reply, Sir Edmund expressed his interest, but regretted that owing

to the dispersal of family papers in earlier years he was not in possession of any supplementary information. There, unfortunately, the matter must rest, with little hope of further pursuing the enquiry.

The background of the second problem is as follows: you are investigating the behaviour, optical or otherwise, of a gemstone, with especial reference to the optical and/or crystallographic directions. Your experimental material consists of cut stones with usual skew orientation to such directions. You can (i) recut the stones—an expensive form of destructive testing unpalatable to most gemmologists, or, (ii) extrapolate calculated data from those which the original cutting permits—not too satisfactory, presenting experimental and theoretical problems which may be difficult or impossible to resolve. This is indeed an impasse, but if the quest is directed toward investigating an optical or physical phenomenon without especial reference to its embodiment in a particular gemstone, there is much to be said for following the excellent example of Dr. A. E. H. Tutton and employing expendable crystalline materal grown from aqueous solutions. Similarly, for demonstrations to the lay public, this plan is capable of application, as was shown by Tutton himself in his brilliant demonstrations before the British Association and elsewhere. Unfortunately, our frustrations over Problem No. 2 arose from an attempted use of a technique described in one of Tutton's books. He quotes some work by the mid-nineteenth-century scientist de Senarmont, on the crystallization of strontium nitrate, using water containing a pigmenting dye, logwood, and yielding crystals which were strikingly pleochroic. Unlike many of Tutton's more esoteric brews, the components described are inexpensive and readily obtainable, and, as we were engaged on some work on pleochroism, some tentative experimentation was ventured upon, but without success. Following this setback, reference was made to de Senarmont's original (1854) paper,(2) which, unfortunately, is vague on the technique of crystallization employed, the relevant passage being as follows—"Lorsqu'on fait crystalliser l'azotate de strontiane, dans une dissolution concentrée de campêche, amenée au pourpre par quelques gouttes d'ammoniaque, on obtient des cristaux volumineux dont la couleur rappelle tout à fait celle de l'alum de chrome".

A great deal of further work was then undertaken, in the hope of achieving a like success to that of de Senarmont, but with complete

lack of success. All possible permutations of temperature, pressure, concentration and composition were tried, but our end product usually proved to be a sludgy brown syrup, and, when crystals were obtained, none showed any pleochroism. We succeeded in interesting some extremely distinguished and highly competent chemists in our quest, but they were equally unsuccessful.

What, then, is the explanation? Frankly, we do not know, and hope some *Journal of Gemmology* reader can provide it. A fake or leg-pull could be remotely possible, although the stakes would appear to be unrewardingly low! A more subtle explanation has been put forward, analogous to that which has been employed to explain the vanished scent of musk, to the effect that the success of the operation hinges on the presence as catalyst of an impurity in one of the components, which was present in the reagents of a century ago, but not today. Certainly logwood chips can be ruled out, and we have no information on any changes in the preparation of strontium nitrate; certainly ammonia comes by a different route today, but one would not expect a minor variation in "quelques gouttes" to have any significant influence. We hope some ingenious "Journal" reader can resolve the dilemma for us.

REFERENCES

1. E. Burbage. *Gemmology and Sir Thomas Browne.* Journal of Gemmology, Vol. 1 (April) 1947.
2. H. de Senarmont. *Experiences sur la Production Artificielle de Polychroisme dans les Substances Cristallisees.* Annales de Chemie et de Physique, 1854 Series III, vol. 14 pp. 319 to 339.

NOTES AND NEWS

By B. W. ANDERSON

An exceptional paste

The oldest of all forms of imitation gemstone, glass, can still have a nuisance value for the jeweller or the gemmologist. Unlike synthetic stones, which can only be used to represent a certain number of species, glass in its almost infinite gamut of colours and degrees of transparency or opacity, knows no limit to the range of natural gem materials it can represent with at least a degree of plausibility.

Another trouble with "pastes" is the wide range in refractive index and density encompassed by the different types of glass used: moreover there is often a difficulty in obtaining a refractometer reading on account of some sort of tarnish on the surface of the specimen.

Experience with the many thousands of glass "gemstones" encountered over the years has shown that in at least 99% of instances the refractive index lies between 1·50 and 1·70. Within this region, of course, lie the indices of a great number of gemstones, but, as it so happens, there are no stones in jewellery which have a *single* refractive index within these limits: a useful fact to remember for those engaged in practical testing.

Until recently, I had only encountered one outstanding exception to this rule-of-thumb, in the shape of a magnificent yellow paste, housed in a special leather case, which was being offered for sale as a specimen topaz. This was made from a heavy lead glass, quite unsuited to withstand any wear and tear in jewellery, and had refractive index 1·77 and density 4·98.

This was thirty years ago, and I never expected to meet another example at all resembling this. Then, some months ago, an oval yellow specimen weighing 15 carats was submitted for test which proved to be a "super-paste" of a very similar kind, in which the density and refractive index actually achieved a new record. Because of this, careful measurements were taken: the density by hydrostatic weighing in ethylene dibromide, giving a figure of 5·116, while C. J. Payne measured the refractive index on an Abbé-Pulfrich refractometer, and found it to be 1·775. The stone was not well enough cut to promise accurate results by the minimum deviation method, so the undoubtedly formidable figure for the dispersion of this freak specimen can only be guessed at.

Curved striae under Short-wave ultra-violet

Practising gemmologists will agree that ultra-violet lamps form a very valuable aid in the detection of certain types of synthetic and imitation stones. They will also agree that results under such lamps must always be treated with a certain amount of caution, and as an accessory rather than as a main test for identification.

There are several types of "short-wave" lamps available, making use of the strong mercury line at 2537 in conjunction with a suitable filter which absorbs most, but not all, of the strong visible light emitted by the mercury vapour, and these lamps are particularly useful in certain cases, notably in the detection of synthetic rubies and synthetic sapphires. Synthetic sapphires commonly show a curious greenish glow or "bloom" under such lamps, which can best be detected by allowing the rays to impinge upon the stone from the side. Unfortunately every now and then an undoubtedly natural sapphire will show a very similar effect: hence the special need for caution, as suggested above.

My purpose in the present note is to draw attention to the appearance of curved structure lines in some synthetic sapphires when fluorescing under the short-wave rays. When seen, the effect naturally provides a complete proof that the stone concerned is indeed a synthetic sapphire. One would expect that such a stone would in any case reveal the striae when examined over white paper with a lens, but I have found cases where this is not so, so that one must give credit to the lamp for occasionally revealing the invisible.

Someone with time to spare might do well to investigate this curious green fluorescence with a view to establishing the chemical nature of the "phosphor".

Manganese lines in andalusite

One of the several interesting stones bequeathed to the London Chamber of Commerce Laboratory by the late Mr. Edward Hopkins was a green pebble of andalusite, polished on one side only, which revealed a striking absorption spectrum, quite unlike that seen in any other gemstone, or indeed in any of the andalusites normally cut as gems. There is an absorption band in the green, shading to a knife-sharp edge at 5535Å which is followed by fine lines at 5505 and 5475Å and a fainter line at 5440: there are further narrow lines in the blue-green at 5180 and 4950Å.

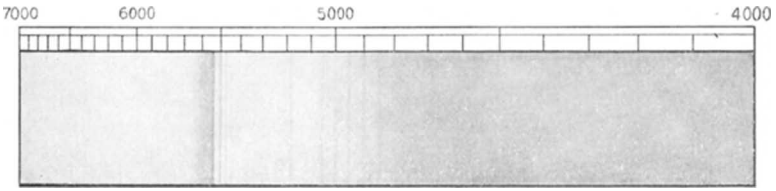

ABSORPTION SPECTRUM OF GREEN ANDULUSITE after a drawing by T. H. Smith

We first measured these bands in 1933, and assumed them at that time to be due to some form of rare earth element or elements because of the extreme narrowness of the lines. Since that time, three small cut specimens of this bright green andalusite have been found in a parcel of demantoids sent in for routine testing (1942), and further samples in the form of rough pebbles have been given me from time to time. The locality is said to be "Brazil" but that is true also of most other andalusites of the more normal kind, in which the only absorption band measurable is one in the blue at 4550Å.

Unfortunately the study of rare earth minerals and salts, and of the descriptions of absorption lines found in these materials failed to reveal any likely cause for the narrow lines, and appeals to one or two workers in the rare earth field also failed to bring forth any likely suggestions.

A paper by John W. Adams, in the American Mineralogist for March-April 1965 on "The visible region absorption spectra of rare-earth minerals", led me to put the problem to him, sending a sample of the andalusite concerned for study and analysis. Mr. Adams showed a most kindly interest in the matter, and before long was able to provide me with the long-sought information—not from his own experiments but from the literature. In a paper by F. Corin "Spectre d'absorption de viridine", which appeared in the Bulletin of the Belgian Geological Society for 1934, a description is given of absorption bands observed in viridine, a rare form of manganiferous andalusite which, together with an accompanying drawing, firmly identifies it with the spectrum described above. Corin writes "Ce spectre d'absorption est caracétrisé par trois bandes sombres, dont deux étroites, accolées vers le milieu du vert du spectre visible, et la troisième, plus large, à la limite du vert et du bleu".

Corin also gives details of the variations in the strength of the bands in the three main vibration-directions of this very dichroic mineral, and includes a line drawing of the spectrum as seen through a prism spectroscope, together with the spectra of monazite and xenotime for comparison. The latter, of course, are rare-earth spectra, and clearly Corin also was impressed with the general similarity between these and the narrow bands in viridine.

It is hardly surprising that manganese should not have been suspected as a possible cause for an absorption spectrum of so delicate a nature by gemmologists familiar with the very characteristic absorption bands to be seen in the gem materials spessartite (which the pundits would prefer us to call spessartine), rhodonite and rhodochrosite. Being commonly transparent, it is in the garnet that the fullest series of bands can be seen, gaining strength, so to speak, as they stride down into the violet and near ultra-violet. Rhodonite and rhodochrosite are virtually indistinguishable in their peculiar rose-pink colour, which is chiefly influenced by a broad absorption band in the green centred near 5500Å. In these crystals manganese is in its most stable, divalent, form. Confirmation that the divalent manganous ion is pink in colour comes from a study of the salts, in which the formate, acetate, sulphate, fluoride, chloride, bromide and iodide are all of this hue.

In andalusite, manganese is replacing aluminium, and would thus be in its trivalent form: there are very few stable manganic salts to act as guides to colour. Manganic fluoride is red, but the sulphate is dark green, which indicates the possibility of this ion yielding a compound of this colour. In Hackh's useful "Chemical Dictionary" is is stated that manganic salts "are generally unstable and yield in aqueous solution the green Mn^{+++} ion, which readily decomposes to the stable Mn^{++} (manganous) state". Unfortunately only the red manganic fluoride (used in tanning) is on the market as a chemical, thus a study of the spectral absorption of the green manganic ion is not possible without undertaking a rather tricky chemical preparation.

The solid-state physics specialists have had some success recently in describing the physical bases for absorption bands in various solids. Eventually they may explain the strange and delicate spectrum seen in green andalusite. All that the gemmologist will then need will be an explanation of their explanation.

THE DUPLEX REFRACTOMETER

THE "Duplex" refractometer devised by the Gemological Institute of America, is the "first instrument designed expressly to give readings for curved polished surfaces as well as flat facets". It is a big and handsome instrument with a broad base enabling it to stand firmly on the work bench, and tall enough to make readings possible without raising it on a block.

The refracting unit consists of a hemicylinder of high index lead glass, the flat surface of which projects slightly above the level of the table of the instrument and measures one inch in length and a quarter inch in breadth. On one side of the refractometer is a plate engraved with the refractive indices of gemstones.

There are two separate 2-element eyepieces—one fixed to the instrument, the other sliding into a collar holding the fixed lens. The light and field of view is controlled by a mirror lit through the window of the instrument and adjustable by means of a knurled knob projecting from the right-hand side. The scale reads from 1·30 to 1·85, and is thus rather "crowded". There is no cover to protect the hemicylinder surface and to exclude unwanted light, but a strong plastic dust-cover is provided. A small bottle of contact fluid (R.I. 1·80) and one of Xylene for cleaning, also a polaroid disc and red colour-filter, complete the kit.

Instructions for use of the Duplex run to 3½ pages of typescript, and merit careful study, since this refractometer must be handled differently from the "Rayner" and other refractometers to which we have become accustomed. Whether for flat surfaces or cabochons, the first eyepiece is removed, leaving the fixed eyepiece, through which the scale is in focus when the eye is some 12 inches distant.

For accurate "spot" (distant vision) readings, the tiniest possible drop of liquid is recommended to make contact. The contact disc is then centred by turning the knurled knob. The eye is then moved up and down the scale and the highest reading recorded where the contact spot is still dark and the lowest reading where it is all light. Between these lies the true R.I. reading, which should be ascertainable to ±0·01. This technique is recommended rather than that of using a slightly larger spot and attempting to read the position where the shadow-edge bisects the disc.

For readings on flat surfaces the scale is again viewed at a distance and the mirror adjusted until a blue-green shadow edge is seen crossing the scale. The second eyepiece is then replaced and with the eye some 2 inches distant a reading taken in the normal way, or two readings if the stone is birefringent, with the usual rotation of the stone to give maximum and minimum readings for full birefringence. Monochromatic sodium light is of course recommended for critical readings—or the red Wratten filter can be used, which registers some 0·005 higher than sodium light readings.

Comments

The refractometer glass seems unnecessarily large, and is very vulnerable to damage. The scale is accurately calibrated, but for flat surfaces only part of the scale is covered by the contact zone, which is disconcerting for one accustomed to have the whole scale covered by light or shadow. The readings are not so easily made as on a Rayner in good condition. On the model tested there are fixed lines crossing the scale at 1·59 and 1·77, giving "false" readings which on occasion might lead to error. In the "spot" method the Duplex is very sensitive in showing an abrupt change from light to dark; but even here readings as accurate can be taken on a standard "Rayner" by the "divided disc" technique.

Gemmological Abstracts

HUANG (C. K.). [*Two gemstones—blue chalcedony and nephrite—from eastern Taiwan*]. Taiwan [Formosa] Mining Industr., 17, 58-65, 1965 (Chinese with English summary).

Blue chalcedony, sp. gr. 2·581, *n* 1·539, occurs in cavities in andesitic agglomerate near Taitung: it consists of spherulitic aggregates of chalcedony with minor chlorite, opal, and iron hydroxides together with veins of quartz and pyrite. It has 0·002-0·035% U and 0·01-0·02% Cu. Spinach-green to yellowish green nephrite, H.6½, sp. gr. 3·007, is found in asbestos at the contact of graphite schist and serpentinite near Hualien, and consists of interfelted tufts of tremolite with minor chromite, picotite, magnetite, garnet, and chlorite, giving black spots and streaks in the nephrite: the amphibole has α 1·609, β 1·620, γ 1·631.

R.A.H.

DARRAGH (P. J.), GASKIN (A. J.), SANDERS (J. V.). *The nature and origin of opal.* Australian Gemmologist, 1966, 66, pp. 5-9.

An important article giving details of a further research into the cause of the formation of the sub-spheroids which, as these workers discovered earlier, were the cause by diffraction of the play of colour in precious opal. Some idea of the possibility of the synthesis of opal is given.

R.W.

MCKAGUE (H. L.). *Hydrogrossular—a hydrogarnet from Transvaal.* Gems & Gemology, 1966, XII, 2 and 3, pp. 49-57 and 74-76 and 95.

Deals mainly with the massive grossular garnet from Transvaal which contains the OH groups and is actually belonging to the hydrogrossular series. Reference is made to the geology of the Brits (Transvaal) deposits and the mineralogy of the rocks. Information is given on the physical properties of hydrogrossular and the chemical analyses are discussed. The lower density of the pink-coloured material as compared with that of the green massive

grossular is ascribed to the pink material containing more of the OH radical. The question of the relation and the admixture of hydrogrossular and idocrase is discussed. This important and authoritative article concludes with a summing-up and gives an excellent list of references.

R.W.

CROWINGSHIELD (R.). *Developments and highlights at the Gem Trade Lab. in New York.* Gems & Gemology, 1966, XII, 2 and 3, pp. 43-47 and 62; 67-73 and 95.

Reports of interesting pieces examined in the laboratory in New York. A diamond ring, manufactured in the Middle East, consisted of a thin rose-cut diamond mounted over a bright metal back which was crimped and moulded to appear like the back facets of a brilliant-cut stone. The whole was set in a closed setting. Another diamond, which had been badly damaged at exposed edges, was found to be a three-point stone with the cleavage direction parallel to the table facet, leaving the edge of the girdle vulnerable to damage. The characteristics of a red-brown atomically-coloured diamond are given, as well as the "umbrella" effect seen in a cyclotroned diamond. Other effects noted in diamonds are "drag marks", dendritic inclusions and a textured effect resembling human skin on the surface of an emerald-cut stone. A fine coloured iolite which had originally been sold as a sapphire, a cat's-eye apatite, and a 2·12 carat uvarovite garnet crystal, as well as an opalized clam, are items mentioned. There is a concise report on solution-grown synthetic rubies, and there is a reference to a necklace of blue enamel beads sold as turquoise.

33 illus. R.W.

ANON. *The rocks bring forth beauty.* South African Panorama, 1966, 11, 2, pp. 24-29.

Well illustrated with colour and black and white pictures this popular article is concerned with the stones found in South Africa and the jewellers of that country. The text concisely covers the subject. The 24 illustrations of rough and cut stones and jewellery give importance to the article.

R.W.

TAYLOR (A. M.). *Bronzite from Anakie, Queensland.* Australian Gemmologist, 1966, 65, pp. 12-13.

Records the finding of bronzite in the Anakie gem fields. Brown in colour, the stone was found to have a density of 3·34 and refractive indices 1·675-1·687, the double refraction being 0·012. The dichroism was marked and the colours yellowish-brown to a very dark olive-green.

R.W.

ANON. *A new doublet.* Australian Gemmologist, 1966, 63, p. 10.

Reports the appearance on the market of a doublet consisting of a crown of synthetic spinel and a pavilion of strontium titanate. Square and baguette-shaped samples have been seen.

R.W.

ANDERSON (O.). *The sapphire fields of Anakie.* Australian Gemmologist, 63, pp. 5-7.

Extracts from "A prospector's guide to the Anakie sapphire fields" published in the Queensland Government Mining Journal of October, 1965. The extracts cover the types of sapphire found in the Anakie fields and their marketing. The blue colours are most favoured by overseas markets, while yellows and greens are more favoured by Australians. Some information is given on the occurrence and on the recovery.

R.W.

TOLANSKY (S.). *Birefringence of diamond.* Nature, 1966, 211, p. 158.

Some 2,000 gem quality diamonds and 3,000 clear, transparent micro-diamonds, which were recovered from tailings from South African mines, revealed that birefringence was present in all the specimens. There is therefore strong evidence to suggest that all diamonds are birefringent. The new suggestion, based upon etch patterns and polariscope examination, is that diamonds grow by successive layer formation and the proposition is made that all diamonds are layer mixtures of type 1 and type 2 material. A very small difference in thermal expansion properties, elastic strength, or lattice dimension of the two types is postulated to account for the correlation between etch pattern and birefringence in a figured position. It is suggested that the shatter observed in diamond at

1885°C could be explained in this way. Previously the explanation for birefringence in diamond was that it was caused by strain.

G.A.

SHARP (W. E.). *Pyrrhotite: a common inclusion in South African diamond.* Nature, 1966, 211 (5047), p. 402.

Examination of large batches of chrushed industrial diamonds. A table is given of lattice parameters of pyrrhotites recovered from the stones. It is concluded that pyrrhotite is a common inclusion in diamond and attention is drawn to the association of pyrrhotite with diamonds in meteorites and diamonds from pipes of kimberlite.

S.P.

BOOK REVIEW

WEBSTER (R.). *Practical Gemmology.* N.A.G. Press, London, 1966. 30s.

The fourth edition of a standard introductory text to gemmology which first made its appearance in 1943. Necessary revisions have been made and there are three new chapters (but still no contents page). The new chapter on the chemistry of gemstones is a welcome and essential introduction to the study of crystals. More attention has been given to the diagnostic importance of inclusions in gemstones and the author's interest in luminescent and electrical properties of gems is shown by additional notes which have been included on these subjects.

A.G.

BOOK NOTICES

BLAKEMORE (K.) and ANDREWS (G.). *Collecting gems and ornamental stones.* W. & G. Foyle Ltd., London, 1967. 5s.

A non-technical introduction to the collecting of gemstones and gem minerals.

S.P.

MCIVER (J. R.). *Gems, minerals and rocks of Southern Africa.* Macdonald, London, 1966. 40 colour plates, 80 photographs and numerous charts and illustrations. £7 10s. 0d. (U.K. only).

S.P.

ASSOCIATION NOTICES

MIDLANDS BRANCH

A meeting of the Midlands Branch of the Association was held on 7th October, 1966, at the Auctioneers' Institute, Birmingham. Mr. D. N. King, chairman, presided and introduced Mr. D. J. Ewing who spoke about his various visits to the gem-cutting district of Idar-Oberstein. The Branch Vice-chairman, Mr. P. T. Spacey thanked Mr. Ewing for his interesting talk.

MEMBERSHIP

At a meeting of the Council of the Association held at Saint Dunstan's House on Wednesday, 1st February, 1967, the following were elected:—

FELLOWSHIP

Buckingham, Lionel J., Whitstable, Kent. D.1966
Byworth, David R., Brookmans Park, Herts. D.1966
Collier, Rowley W., Hornchurch, Essex. D.1966
Connolly, John P., Wilmslow, Cheshire. D.1966
Cook, John W., Chelmsford, Essex. D.1966
Doherty-Bullock, Gabrielle J., Worcester. D.1966
Douglas, David N., Manchester 12, Lancs. D.1966
Dunne, Michael B., Southport, Lancs. D.1966
Edleston, Carolyn I., Liverpool 4, Lancs. D.1966
Engaas, Karin, Oslo 2, Norway. D.1966
Ewart, Myra P., Baillieston, Lanark. D.1966
Falcon, Lionel J., Nottingham. D.1966
Fillan, Ian, Huddersfield, Yorks. D.1966
Fournet, Bertrand P., Hong Kong. D.1966
Frizzell, Alan S., Motherwell, Scotland. D.1966
Fuller, Donald G., St. Helens, Lancs. D.1966
Geddes, Margaret H., London, W.C.1. D.1966
Gregory, Hugh M., Beckenham, Kent. D.1966
Kilcoyne, Anthony J., Wolverhampton, Staffs. D.1966
Kirchner, Brit, 852 Erlangen, W. Germany. D.1966
Laycock, Keith, Sheffield 12. D.1966
Leech, Alan G., Heywood, Lancs. D.1966
Lenan, Cornelius, Cardiff, Glam. D.1966
Levy, Warren I. J., Kenton, Middx. D.1966

Lloyd, Philip S., Johannesburg, S. Africa. D.1965
Martin, Bernard F., Sheffield 7. D.1966
Menton, Joel, Edgware, Middx. D.1966
Miller, Jeanne S., Arlington, Virginia, U.S.A. D.1966
Moore, Martin C., Birmingham 18. D.1966
Pamphilon, Christopher G., Birmingham 20. D.1966
Perren, Richard B., Toronto, Ont., Canada. D.1966
Ranasinghe, Vernon V. C., Colombo 2, Ceylon. D.1966
Rayner, Denise A., Cuffley, Herts. D.1966
Sanford, Sheila, Enfield, Middx. D.1966
Spencer, Edna (Mrs.), Upminster, Essex. D.1956
Sutherland, Michael B., Basildon, Essex. D.1966
Sutton, Andrew L., London, N.W.6. D.1966
Theisen, Verena, Essen-Werden, W. Germany. D.1966
Thompson, Peter L., Nottingham. D.1966
Verney, David L., London, S.W.12. D.1966
Widnall, Harry, Sheffield, 8. D.1966
Wijkstrom, Gunnar, Stockholm, Sweden. D.1966
Wild, Walter F., Liverpool 15, Lancs. D.1966
Wilkins, Robert F., Playa Del Rey, Calif., U.S.A. D.1966
Woodall, Christopher R., Streetly, Staffs. D.1966
Woods, Norman R., Stocksbridge, Yorks. D.1966
Zwollo, Paul, Oosterbeek, The Netherlands. D.1966

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Zawadzki, Ingeburg, Edinburgh, Scotland

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Jordaan, Barend D., Stellenbosch, S. Africa
Lawes, Kenneth J., Salisbury, Wilts.
Levin, Jehuda, Tel-Aviv, Israel
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Manning, Linda J., London, N.3
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Sanderson, Clare, Romford, Essex
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ANNUAL MEETING

The 37th Annual General Meeting of the Association will be held on Wednesday, 3rd May, 1967, at Goldsmiths' Hall, Foster Lane, London, E.C.2. at 6.00 p.m.

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The Council of the Association is indebted to members for the following gifts:– from Mrs. Jeanne S. Miller, Arlington, U.S.A. a donation for the purchase of books; from Mrs. C. Mendis, Colombo, a crystal of yellow sapphire; Messrs. Viktor Kämmerling have kindly given samples of their emerald-coloured beryl doublets, which are sold as "Sinaryll".

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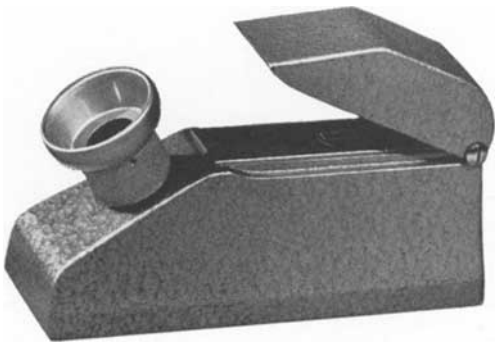

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SYNTHETIC VANADIUM EMERALD

By A. M. TAYLOR, Ph.D., F.G.A.

A NEW and no doubt controversial emerald will shortly appear on the market; this time emanating from the Southern Hemisphere. The cut stones are a rich grass-green colour due to the presence of vanadium, without chromium. They are produced on a small scale by the Crystals Research Company of Melbourne, Victoria. A hydrothermal process is used to grow fully synthetic crystals weighing up to 10 cts, from which faceted stones of 0·5 to 2 ct. size are obtained. Besides presenting an interesting addition to the list of synthetic gemstones, the vanadium emerald does much to explain the intriguing variations in physical properties of natural emeralds.

The cut stones have refractive indices within the ranges $\omega = 1{\cdot}571–1{\cdot}575$ and $\varepsilon = 1{\cdot}566–1{\cdot}570$, with D.R. about 0·005. These values are normal for hydrothermally-grown beryl and emerald (excluding Cr-rich overlays), and they overlap the values recorded for natural emeralds from Brazil and Colombia(1). The small variations from one facet to another result from differences in vanadium content, which are apparent from the marked colour banding seen when the stones are immersed in a liquid of similar refractive index. This banding has been practically eliminated in the most recent productions.

The specific gravity is 2·68, or within the range of 2·67–2·69 characteristic of fully synthetic hydrothermal emerald. The slightly higher figure compared to flux-grown emerald (2·65) is due to the small water content ($\sim 1\%$) of emerald grown from an aqueous solvent. No fluorescence could be detected when the crystals were tested with ultra-violet radiation or X-rays.

Vanadium produces an emerald with a warm grass-green colour, verging on yellowish-green, which is in contrast to the cooler bluish-green of most synthetic chromium emeralds. Dichroism is distinct, with O = yellow-green and E = green. Through the Chelsea filter, cut stones appear greyish-green to a very dull pink. Use of a polaroid plate in conjunction with the Chelsea filter, reveals that the O-ray is green and the E-ray pink.

The absorption spectrum due to vanadium is of considerable interest because of the common occurrence of this element in natural emeralds. The spectra over the range 1000–350mμ were recorded on a Beckman DK-2 spectrophotometer at the C.S.I.R.O. Polarized radiation was passed in the appropriate directions through a polished plate of vanadium emerald cut parallel to the optic axis. The absorption spectra are reproduced in Fig. 1, as seen through a prism-type spectroscope.

The dichroism of emerald is due to appreciable differences in absorption of the ordinary and extraordinary rays. The O-ray of both vanadium and chromium emerald is yellowish-green, with the

FIG. 1.

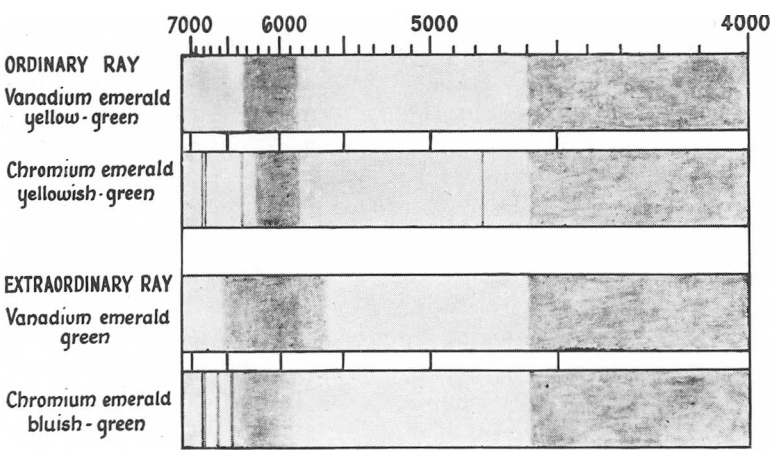

former being more yellowish—close to yellow-green. The vanadium O-ray is characterized by very strong absorption of the violet (absorption edge about 4600 Å) and by a weaker absorption band in the orange centred at 6100 Å; another weak band occurs in the near infra-red at 7640 Å. Maximum transmittance is at 5100 Å. The O-ray absorption for vanadium in beryl was first reported by Emel'yanova *et al.*[2] in 1965; they recorded absorption maxima at 4310 Å and 5950 Å. Their crystal plate was orientated perpendicular to the optic axis and still contained the natural beryl seed-plate. The presence of traces of iron in the latter produced a strong absorption peak at 8000 Å.

The E-ray is an attractive grass-green colour. Its absorption is more interesting and has not previously been reported. Strong absorption of the violet occurs as before, the crystal plate being too thick to measure the full extent and position of this band. The central band in the orange-yellow is wider and asymmetrical. Its maximum is now at 6000 Å, with a shoulder at 5750 Å, and an overlapping band at 6320 Å. The band in the near infra-red is weaker than before and shifted to 8500 Å. Maximum transmittance is at 5200 Å and 7500 Å. The slightly greater absorption of the yellow-green and lesser absorption in the deep red (*cf.* O-ray) causes the E-ray to appear pink through the Chelsea filter.

Whether the weak band in the near infra-red is due to vanadium or iron is not known at present. The spectrum of a natural aquamarine plate gave an intense absorption peak at 8200 Å, the tail of which extends into the red, thus causing the pale blue colour of the crystal. The absorption spectrum of iron in natural beryls is being further investigated as suitable crystals come to hand.

When the spectrum of a cut stone is examined with a direct-vision spectroscope attached to a polarizing microscope, the central absorption band appears weaker than that seen in chromium emeralds of comparable depth of colour. This band is most noticeable in the E-ray spectrum and does not appear to extend as far towards the red as recorded by the spectrophotometer. This may possibly be due to the eye being more sensitive to the yellow than the red part of the visible spectrum.

It is now apparent that spectroscopic examination provides little chance of detecting vanadium in natural emeralds containing chromium. The visible absorption bands of both elements coincide rather nicely—vanadium simply lacks the frills, or fine lines in the

red which are so noticeable in the chromium spectrum (see Fig. 1). The absorption of a natural emerald containing both elements can be simulated by correctly orientating crystal plates of the two synthetic emeralds on a polarizing microscope stage. A significant feature may be that the combined E-ray shows a greater overall absorption compared to the combined O-ray, which is opposite to that observed for chromium alone.

The crystals are grown on seed-plates sawn from earlier-grown crystals, hence the cut stones are fully synthetic. The plates are 1 mm or less thick, and inclined to the c-axis. The reason for this orientation is obvious if the habit of natural emerald is considered. Emerald is always found as somewhat elongated hexagonal prisms capped by the basal pinacoid. The largest faces on a crystal are always those having the slowest growth rates; conversely the smaller faces have faster growth rates and as a result often grow themselves out and disappear. The fastest growing direction for emerald is thus inclined to the c-axis. Use of seed-plates may be considered one characteristic of hydrothermal crystal growth. Although seeds have been used at times to grow emerald in anhydrous molten salts or fluxes, this technique has not been favoured by commercial producers. The best quality flux emeralds are apparently spontaneously nucleated crystals.

Immersion of cut stones in a liquid of similar refractive index will allow the interfaces of the seed-plate to be seen, more or less parallel to the plane of the girdle (Fig. 2). Stones of 1 ct. or larger may show further colour bands indicative of two or more growth periods. No banding is visible when the stones are viewed through the table (Fig. 3). Under high magnification the usual two-phase (aqueous liquid + vapour) inclusions may be seen concentrated as wisps and on new growth surfaces. No phenacite or other crystal inclusions have been observed. It would be premature to describe present inclusions and internal features as characteristic of vanadium emerald, since continuous efforts at quality improvement will before long result in macroscopically flawless stones.

Just what is an emerald? This question deserves some discussion now that we have new data concerning the role of vanadium. B. W. Anderson [3] has aptly stated "vanadium is the mystery element in the emerald story". The mystery is now beginning to unravel itself. I hope this report will cause renewed interest in natural emeralds that might contain this bashful colouring element.

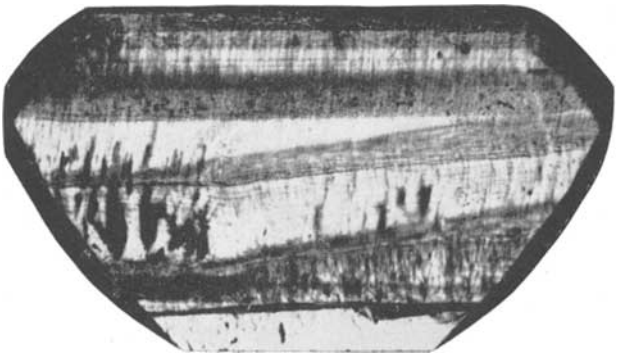

FIG. 2.

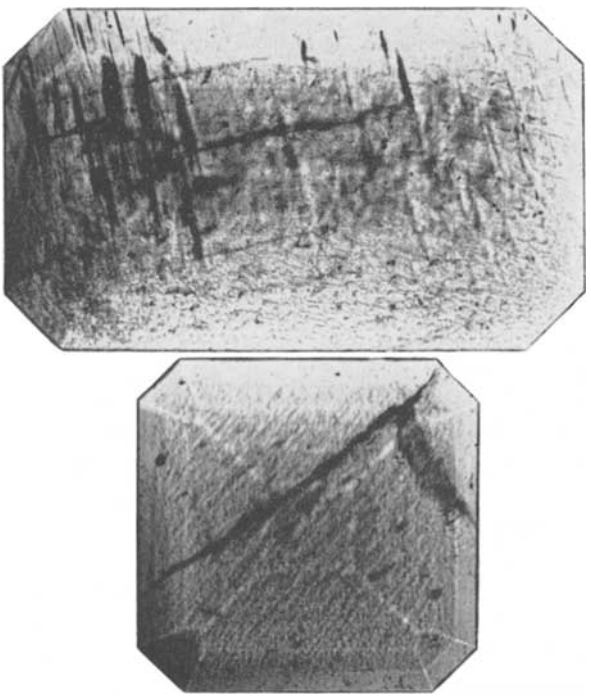

FIG. 3.

The presence of vanadium in natural emeralds was first investigated in 1919 by the renowned geochemist V. M. Goldschmidt[4]. He found 0·9% V_2O_3 and only 0·1% Cr_2O_3 in emerald from Minne, at the southern end of Lake Mjösen, Norway. The yellowish-green Muzo emeralds are known to contain both vanadium and chromium to several tenths per cent [4]. A recent Chivor emerald analysis[5] shows 0·05% V, 0·12% Fe and 0·14% Cr. Several Brazilian localities are known where green beryl and emerald are found to contain appreciable vanadium e.g., Ferros, Minas Geraes[3] and Salininha, Bahia[6]. More detailed physical data and analyses of stones having various shades of green from these localities would be most interesting.

A problem that worries many gemmologists is where the dividing line should be drawn between emerald and green beryl. This necessarily depends on one's definition of emerald. There are two definitions commonly propounded. The one that I support, and which has held sway from ancient times, is simply that "emerald is a bright green variety of beryl". This is more in keeping with other varietal names used in gemmology e.g., heliodor is yellow beryl, morganite is pink beryl, etc.

The other definition is an extension of the first i.e., "emerald is a bright green variety of beryl coloured by chromium". This immediately raises the question of how much chromium is required to be present. It has been suggested that emerald should contain sufficient chromium for its absorption spectrum to be detectable with a hand-spectroscope[3]. The new data presented here shows the extended definition to be unsatisfactory. Vanadium and chromium alone, or together, are able to produce the coveted emerald-green hue in beryl. It is quite possible for good natural (and synthetic) emeralds to have their colour predominantly due to vanadium, and yet still show a chromium absorption spectrum resulting from the presence of lesser amounts of this element. Clearly such stones should not be called emerald by reason of having detectable chromium. It is equally unsatisfactory to extend the definition to include vanadium, because there is still the problem of iron content, which has not yet been considered. Iron is the culprit responsible for spoiling the bright green hue of emerald, when present in excessive amounts. Synthetic crystals containing vanadium and iron are a sad olive-green colour. The only satisfactory solution to the problem is to return to the simpler definition

which is non-commital regarding the colouring element.

The insistence that emerald is coloured by chromium dates back to the time of Vauquelin, who discovered the element in 1797, and was first to detect its presence in emerald. In 1830, Sefström isolated compounds of vanadium from iron ore slag and was impressed by the beautiful colours they displayed in solution. He called the new element vanadium, after Vanadis, one of the names of Freya, the Scandinavian goddess of beauty. As mentioned previously, its presence in emerald was not suspected until the work of Goldschmidt in 1919. It seems that we can blame the ostentatious nature of the chromium absorption spectrum for chromium's mysterious rival, vanadium, being ignored for so long.

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THE SIGNIFICANCE OF THE CULET OF OLD BRILLIANT-CUT DIAMONDS

By W. F. EPPLER

TODAY, we are often astonished when seeing the large culet of an old brilliant-cut diamond. The modern style prefers a shape of the brilliant-cut with a culet as small as possible or with no culet at all, and this particularly with small stones. The culet is often considered as a facet to prevent damage to the pointed part of the pavilion. If this facet is only a little larger than necessary, the brilliant-cut stone loses in brilliance, as the larger culet gives the impression of a "hole". It is a fact that the brilliancy of a modern brilliant-cut stone is reduced in the same proportion as the culet increases.

In former times, all well cut brilliants had a culet of considerable size and this was based on good reasons. In old books, like those of Jefferies(1) and Mawe(2), it is exactly described in what proportions a diamond in the form of a natural octahedron had to be cut to obtain a "perfect" brilliant. Jefferies(1), who must have had some forerunners more than a hundred years earlier, suggests the division of the diamond octahedron into eighteen parts (Fig. 1) and he recommends "to take off $\frac{5}{18}$ in the upper part and $\frac{1}{8}$ in the lower part" of the crystal. Then, the remaining stone has one third of its total thickness above the girdle and two thirds below it. And he adds (in translation):

> "In this way, the table and the small lower facet (the culet) are made which always have these proportions, namely the small lower facet has the fifth part of the width of the table".

This means, in other words that the diameter of the culet is one fifth or 20% of the table diameter, measured between the opposite sides. At the same time, the culet is as large as 11% of the girdle diameter.

A cross-section of such a so-called "thickstone" is shown in Fig. 2 and it exhibits the paths of light when entering the stone in a direction perpendicular to the table or to the girdle plane. With this incidence of light, it can be observed that the culet is an important facet on the base of the stone as it reflects many rays which otherwise would have been lost for the brilliancy of the stone.

The presence of the culet enables an output of light* of 18·9%.

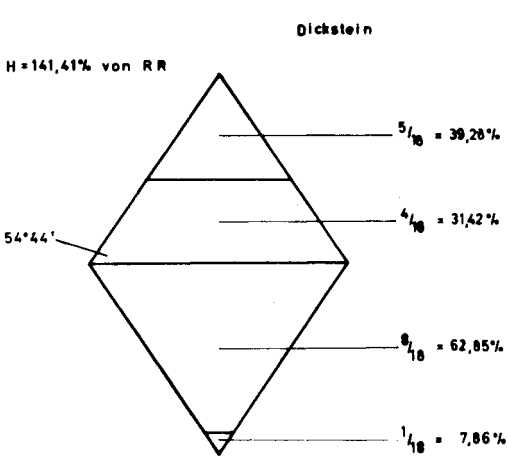

FIG. 1. *A natural diamond octahedron seen from the side, the length of which is divided in eighteen parts. After David Jefferies.*

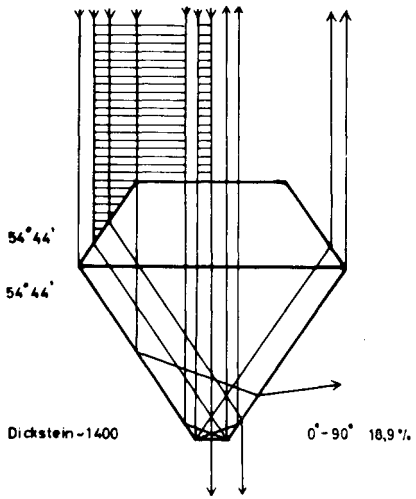

FIG. 2. *Paths of light in a so-called "thickstone" with the proportions recommended by David Jefferies and shown in Fig. 1.*

With an increase in the angles of incidence, the output rises at first until, at approximately 30°, a drastically sharp drop occurs. Further greater angles of incidence again cause a considerable peak in output at 45°, which is followed by further reduction until zero is reached at 90°. The calculation for the output of light* for seven angles gave the following results:

So-called "thickstone" (after Jefferies)

Angle of incidence	Output of light
0°	14·5%
15°	14·1%
30°	0·9%
45°	45·0%
60°	36·6%
75°	21·3%
90°	0·0%
0°–90°	18·9% as the mean value.

In detail, the efficiency of this cut is demonstrated by the diagram in Fig. 3. The first part of the curve, representing the output of light for the angles of incidence between 0° and 30°, is only caused by the culet.

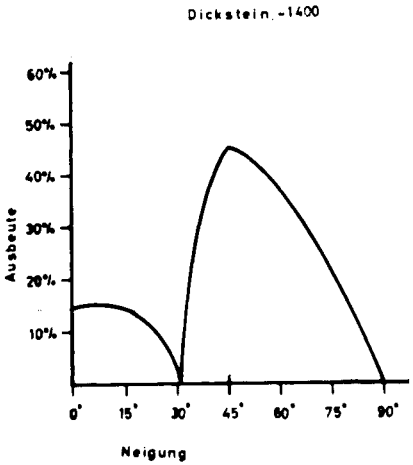

FIG. 3. *The output of light of a so-called "thick-stone" after Jefferies in percents of the incident light and in relation to the angles of incidence.*

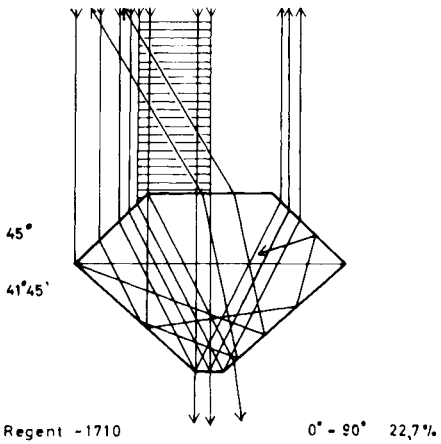

FIG. 4. *Cross-section of the brilliant-cut, after Mawe.*

Another reference about the importance of the culet is given by Mawe(2), but this author must have been the subject of a misunderstanding or, what seems more likely, he used former publications without having taken into consideration the proper correlations of the angles and the proportions. He repeats the recommendation of dividing the raw crystal, as already mentioned by Jefferies(1), with the following words:

> "The rule to be adopted in regulating the height of the brilliant is (supposing the stone to be a regular octahedron), to divide it into eighteen parts. Five-eighteenths are cut away to form the table, and one-eighteenth for the collet, which will reduce the height one-third, and the diameter of the collet will be one-fifth of the table".

But then he demands

> "The inclination of the facets to the girdle ought to be 45°, and the bizel should be inclined to the table at the supplement of the same angle".

This means that the angles of the main facets are altered. Formerly, the angles of the so-called "thickstone" were those of the natural octahedron, i.e. 54° 44′, and now they are reduced to 45°. Without any doubt, this reduction is a considerable development, as will be shown below. But there remains a contradiction between

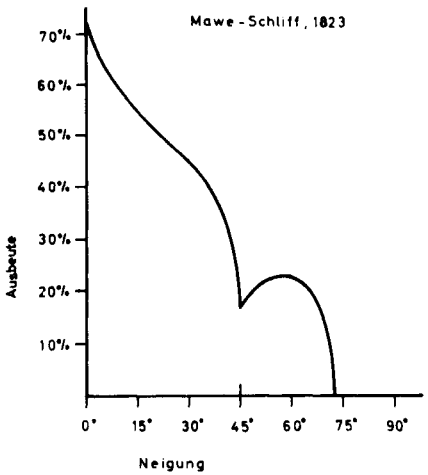

FIG. 5. *Diagram showing the output of light of a brilliant-cut after Mawe in relation to the angles of incidence.*

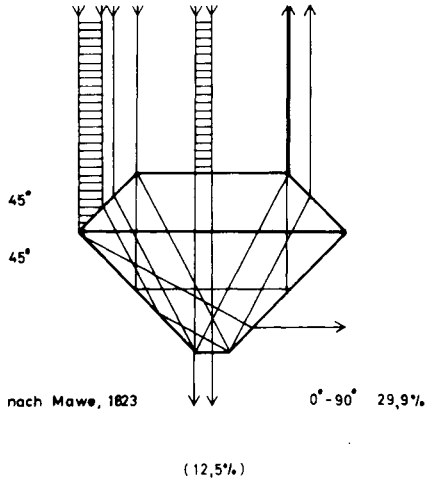

FIG. 6. *Cross-section of the old-cut Regent diamond.*

the rule of dividing a regular octahedron with its proper angles and the recommendation of 45° angles. However, considering the edges of an octahedron instead of the planes—which seems very unlikely to be the real meaning of the prescription mentioned in the text—both postulations can be combined.

The result of calculating a brilliant-cut diamond according to these conceptions is shown in Fig. 4, including a still larger culet of 12·5% of the girdle diameter. The height of the crown is again one-third of the total height and the pavilion two-thirds. For this particular cut, the output of light is surprisingly high. It was calculated as already mentioned, and it results in a mean value of 29·9%. A general view is given in Fig. 5. The great output of light with relatively small angles of incidence depends mostly on the large culet, which therefore has a great importance. This old brilliant-cut must have had a great brilliancy, not too far below that of our modern brilliant-cut stones and with by far a greater effect on the dispersion, i.e. the play of the rainbow colours or the fire.

A good example for stones cut in, or nearly in these proportions is the famous "Regent diamond", which recently has been described by Tillander (3). This author mentions about this very interesting old brilliant-cut diamond, among others:

"There is an exceptionally even distribution of fire all over the

surface of the crown. Not one of the main facets in the pavilion can be seen through the stone. This is due to an ideal pavilion angle of some $41\frac{3}{4}°$".

The crown angle is 45°, and the culet 10·35% of the girdle diameter. It seemed to be worthwhile to examine this particular form in a cross-section. Fig. 6 and Fig. 7 give the results. The mean output of light is 22·7% of the incident light. This is less than the real Mawe cut. The reason is, with respect to the pavilion angle of 41·75°, that the culet is a little bit too large. On the other hand, even this too large a culet increases the brilliancy more than not having a culet at all, and the peak of the curve in Fig. 7 is for the most part due to the presence of the culet.

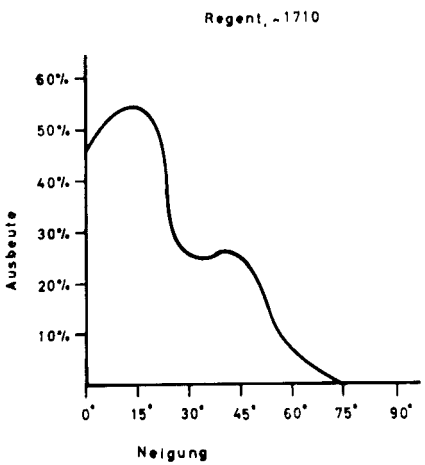

FIG. 7. *Diagram exhibiting the output of light of the old cut Regent diamond.*

In summarizing it can be said, that in old brilliant-cut diamonds, with steep facets or great angles of the main facets in the crown and in the pavilion, a culet of adequate size is necessary to gain a maximum of brilliancy. It is astonishing that the diamond cutters of former time found an improvement in the brilliancy by applying a culet not by calculation but by practice only. In

reducing the angles in crown and pavilion, the culet has less importance, and in the modern "fine cut", with angles of only 33·2° and 40·8° in crown and pavilion respectively, the absence of the culet is an absolute necessity, if it is not applied to minimise damage.

*The "output of light" is the amount of light which leaves a cut stone on the crown in an efficient direction. It is given as a percentage of the incident light.

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SOLID INCLUSIONS IN CORUNDUM AND ALMANDINE GARNET FROM CEYLON, IDENTIFIED BY X-RAY POWDER PHOTOGRAPHS

By P. C. ZWAAN, Ph.D., F.G.A.

INTRODUCTION

THE identification of inclusions in gemstones has been a difficult matter for years because the optical method was the only one which could be used, often giving a more or less doubtful result.

Recently much work has been done by several gemmologists with the aid of other methods, as for instance X-rays. In 1965 I[1] gave the results of an investigation of crystal inclusions in a Ceylon spinel, identified as apatite by the X-ray powder method. Although the optical data were valuable, they could not give definite results. Developments in the technique make it possible nowadays to take X-ray powder photographs when only very small amounts of material are available.

In the present paper results will be given of an examination of inclusions in corundums and almandine garnets from the same gem gravel from which the spinel mentioned was selected. It is important to note that I collected all these stones myself in the Ratnapura district of Sabaragamuwa Province in Ceylon. Therefore we can be certain about their origin, however secondary it may be.

To identify the nature of the inclusions in the stones, being all pebbles, they were partly faceted. Before scraping down part of an inclusion touching the surface microphotographs were taken. Moreover the facets made it also possible to measure the refractive indices of the pebbles on a refractometer and to examine the inner part of them by microscope. The specific gravity of the pebbles was measured using a hydrostatic balance and ethylene dibromide. All X-ray powder photographs were made using Fe-radiation and a camera with a diameter of 114·6 millimeters.

Results of the Investigation

Specimen 81721-1[a] Corundum with included spinel.

This large part of a colourless corundum crystal, weighing 46·39 carats, actually being a thick slab, has refractive indices 1·760 and 1·768, measured on one of the cut prism faces, and a specific gravity of 3·953. It contains a dark reddish-brown inclusion (Fig. 1). The irregular shape of this inclusion prevents an indication about its crystal habit or even its crystal system. Moreover the low degree of transparency makes it impossible to obtain optical data. The X-ray powder photograph (No. mm 1135), taken from this inclusion, gives a pattern of diffraction lines, characteristic for spinel. The X-ray data for some of the strongest lines are as follows:

d (in Å)	Intensity (estimated)	hkl	d (in Å)	Intensity (estimated)	hkl
4·64	7	111	1·276	2	620
2·84	6	220	1·231	3	533
2·42	10	311	1·166	2	444
2·01	7	400	1·131	1	711
1·640	3	422	1·080	4	642
1·548	6	511	1·052	6	731
1·423	9	440	1·011	4	800

By comparison of these data with those stated in the index to the X-ray powder data file of The American Society for Testing Materials (No. 5-0672), it turns out that they agree well with the corresponding data of common Mg-spinel.

Specimen 81721-2 Corundum with included pyrrhotite, apatite and phlogopite.

The stone has a violet-blue colour, and its weight is 9·04 carats. Refractive indices measured are 1·761–1·769. Its S.G. is 3·939. This low value is probably due to the great number of included apatite crystals. Beside silk three different kinds of inclusions may be seen with the naked eye (Fig. 2).

First bronzy-yellow grains with a metallic lustre occur. From the X-ray photograph (No. mm 1136) it is seen that these inclusions may be classified as pyrrhotite. The pattern has been compared

(a) *Registration number of the Rijksmuseum van Geologie en Mineralogie, Leiden, Holland.*

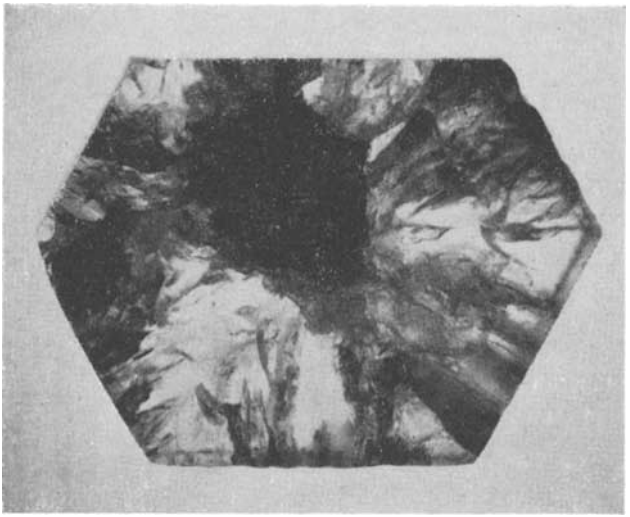

FIG. 1. *Dark reddish-brown spinel in corundum specimen 81721-1* (3 ×).

FIG. 2. *Pyrrhotite with phlogopite and apatite in corundum. Specimen 81721-2, in both reflected and transmitted light* (20 ×).

with the X-ray powder photographs of other pyrrhotites in the collection of the Museum. The d-values of the strongest lines are 2·97 (Intensity 6), 2·64 (Int. 8), 2·06 (Int. 10), 1·719 (Int. 7), and 1·627 (Int. 3). In addition the material is strongly magnetic.

Secondly colourless to white crystals with a hexagonal prism habit are to be seen. They have a parallel extinction and rather high interference colours due to their thickness. Examination of a powder preparate of one of the crystals gave a refractive index of about 1·632, very weak double refraction and a uniaxial negative interference figure. The X-ray powder photograph (No. mm 1137) turned out to be characteristic for apatite. This pattern was compared with those of other apatite photographs in the collection.

Finally brownish platy crystals are present. They are strongly dichroic in tones of deep reddish-brown and pale brownish-yellow.

An X-ray powder photograph (No. mm 1138) made of one of these plates appeared to be characteristic for phlogopite.

Specimen 81721-3 Corundum with included apatite and phlogopite.

This 13·72 carat stone has a reddish-violet colour. Its indices of refraction are 1·760 and 1·768. The specific gravity appeared to be 3·904, the low value again is probably due to the great number of apatite crystals included. The stone has a distinct dichroism and straight colour bands are to be seen. Beside silk two different kinds of crystal inclusions may be observed (Fig. 3).

Numerous colourless crystals with a hexagonal prismatic habit are present. By optical inspection they showed a parallel extinction and rather high interference colours. An X-ray powder photograph (No. mm 1139) made of one of these crystals had a pattern similar to that of a number of apatites in the collection. Therefore it may be concluded that these inclusions are apatite crystals. The other inclusions have the same optical properties and habit as the phlogopite described in Specimen 81721-2. Although the identity was not checked by X-rays, it is almost certain, however, that the inclusions in question are phlogopite plates.

Finally it may be noted that X-ray powder photograph No. mm 1140, taken of material scraped down from the stone, turned out to be characteristic for rutile. Probably some of the silk is responsible for this.

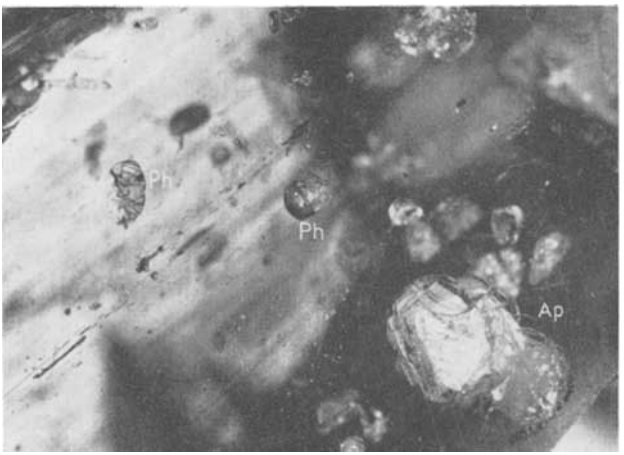

FIG. 3. *Apatite and phlogopite in corundum specimen 81721-3, in both reflected and transmitted light (20 ×).*

FIG. 4. *Spinel octahedron in corundum specimen 81721-4 in reflected light (20 ×).*

Specimen 81721-4 Corundum with included spinel and apatite.

An almost colourless corundum with a weight of 11·38 carats. The refractive indices are 1·762 and 1·770, the S.G. found is 3·957.

In the stone two crystals with a distinct octahedral shape may be seen (Fig. 4). These crystals have a metallic lustre in reflected light, due to a thin film of other material covering the surface.

Because of this they look as if they are opaque but in reality they are transparent and have a very dark bluish colour. It was impossible to examine them by optical methods.

An X-ray powder diagram (No. mm 1141) made from one of these crystals gave a characteristic pattern of Mg-spinel. The diagram is completely identical to that of the spinel included in corundum Specimen 81721-1 and very similar to other spinel X-ray photographs in the collection. In addition a number of colourless somewhat rounded crystals with a hexagonal habit occur in this stone. They have the optical properties as found with the apatites in the stones mentioned. With this experience it is almost certain that these inclusions are apatite crystals, although this has not been checked by X-rays.

Specimen 81721-5 Corundum with included spinel.

In its original state this pebble had the shape of a rounded hexagonal pyramid. Its colour is blue and its weight 5·10 carats. The refractive indices were found to be 1·760 and 1·768 respectively, and specific gravity was 3·921, a low value probably due to the large quantity of inclusions. As might be expected the stone has a distinct dichroism.

The inclusions occurring in the stone are a few octahedra of a very dark colour and much brownish-red powdery material. One of the octahedra has been checked by means of an X-ray powder photograph (No. mm 1143) and was found to be a Mg-spinel. The X-ray diagram was identical to those of the spinels included in the corundums Nos. 1 and 4.

An X-ray powder photograph (No. mm 1142) was also made of the powdery material included in this stone. The diagram was not very clear and it was impossible to obtain a definite result. The data have something in common with those of halloysite and the serpentine group of minerals.

FIG. 5. *Corundum in corundum specimen 81721-6, in reflected light (30 ×).*

Specimen 81721-6 Corundum with included corundum.

This very small colourless stone, weighing only 0·21 carats, with refractive indices 1·761 and 1·768 respectively and a specific gravity of 3·992.

Beside silk some platy colourless inclusions occur (Fig. 5). By optical examination no details may be seen, due to the fact that they are extremely small and that they have an unfavourable position in the stone.

An X-ray powder photograph (No. mm 1149) made of one of these inclusions was seen to be characteristic for corundum. This surprising result was questioned because the preparation could have possibly been made from material of the host mineral.

A second X-ray powder photograph (No. mm 1174) made, gave a pattern of diffraction lines characteristic for carborundum, this material being used as an abrasive to make the preparation.

A third attempt made was succesful, a complete crystal inclusion being isolated. The X-ray powcer photograph (No. mm 1189) made of this crystal turned out to be characteristic for corundum.

Specimen 81721-7 Almandine garnet with included apatite.

The stone has a wine-red colour and weighs 1·01 carats. Its refractive index is 1·768, the S.G. is 3·910. A distinct absorption spectrum may be observed with the well-known pattern for almandine.

A number of inclusions occur in the stone (Fig. 6). They have rather high interference colours but instead of being prismatic they are more or less rounded and they look as if they are isometric. An X-ray powder photograph (No. mm 1144) identified them as apatite crystals, a surprising result because the habit of the crystals differs strongly from that of apatite inclusions in other stones.

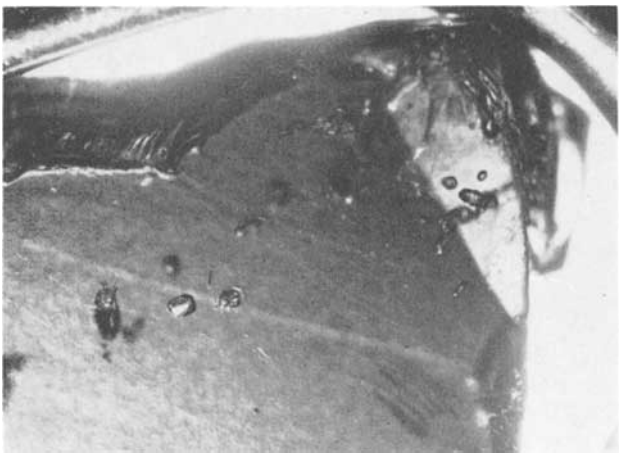

FIG. 6. *Apatite crystals in almandine garnet specimen 81721-7, in both reflected and transmitted light (20 ×).*

Specimen 81721-8 Almandine garnet with included rutile.

A stone with a brownish red colour. Its weight is 2·47 carats, its specific gravity was found to be 3·817. The refractive index is 1·759. A distinct almandine absorption spectrum may be observed. In polarized light the stone has anomalous double refraction.

Some crystals are enclosed, one of the biggest is shown (Fig. 7). In transmitted light they are almost opaque, due to the high refractive index in comparison with that of the garnet. In reflected

light the crystals have a submetallic lustre, they are rounded and short prismatic. Their identity was checked by an X-ray powder photograph (No. mm 1145) and they were found to be rutile.

Specimen 81721-9 Almandine garnet with included apatite.

The weight of this garnet is 11·83 carats, its colour is deep brownish-red. The S.G. is 3·928 and the refractive index appeared to be 1·773. By spectroscopic examination a distinct almandine spectrum may be seen.

In addition an anomalous double refraction may be observed in polarized light.

The large number of included crystals can even be seen with the naked eye. They are all long, prismatic and have a hexagonal shape (Fig. 8). Basal cleavage traces are obvious in some crystals, and this is a characteristic of apatite. The optical properties examined by microscope are equal to those found with apatite inclusions in other gemstones; they are a parallel extinction and high interference colours. An X-ray powder photograph (No. mm 1148) made from one of these inclusions confirmed the opinion that again apatite was found in a gemstone.

Specimen 81721-10 Almandine garnet with included apatite and muscovite.

This brownish-red stone weighs 7·22 carats. The refractive index could not be measured with a Rayner standard refractometer, so it gave a negative reading. The specific gravity was found to be 4·176. Beside the almandine absorption bands an anomalous double refraction could be observed.

In the stone one large inclusion was noted (Fig. 9). At first sight it looks like a piece of calcite with rhombohedral cleavage planes. Optical examination of a powder preparate, however, indicated a material with a refractive index of about 1·635, small birefringence and an uniaxial negative interference figure, hence it has to be considered apatite. An X-ray powder photograph (No. mm 1147) gave a pattern of diffraction lines characteristic for apatite. In addition plates of another mineral are enclosed. An X-ray powder photograph (No. mm 1146) taken from one of these plates was very similar to the X-ray diagrams of muscovite in the collection.

FIG. 7. *Rutile crystal in almandine garnet specimen 81721-8, in reflected light (50 ×).*

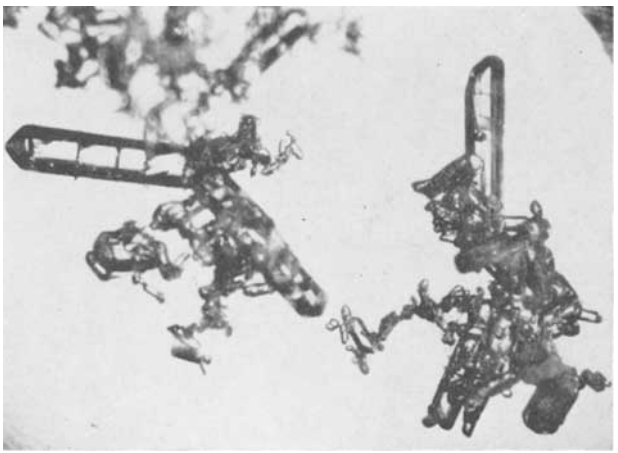

FIG. 8. *Apatite crystals in almandine garnet specimen 81721-9 (20 ×).*

DISCUSSION OF THE RESULTS

Apatite seems to be a very common inclusion in corundum and almandine garnet. Altogether we have found, up to now, apatite in three corundums, nine garnets and one spinel (including gemstones not described in this paper). It is striking that all these

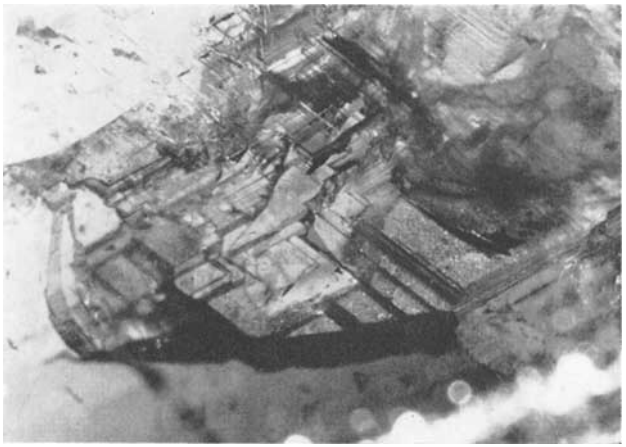

FIG. 9. *Apatite in almandine garnet specimen 81721-10, in reflected light (20 ×).*

apatites have identical X-ray powder diagrams and all belong to the group of the chlor-bearing hydroxyl-apatites.

Spinel, too, is not an uncommon inclusion, especially in corundum.

Apart from this it is clear that corundum may contain a large number of different minerals. Examples described in this paper include, beside apatite and spinel, pyrrhotite, phlogopite, rutile and even corundum. In addition we found calcite in two rubies not described here.

Many of the same minerals are observed in almandine garnet, moreover sphalerite appeared to be enclosed in two garnets not mentioned in this paper. Now it is an important question whether all these inclusions are characteristic for gem minerals from Ceylon. Hitherto one would be inclined to think so, but I am not certain. Much work must still be done before giving any further information.

ACKNOWLEDGMENTS

I wish to thank the technical staff of our Museum for several services. Mr. B. F. M. Collet carefully made the microphotographs, Mr. J. J. F. Hofstra and Mr. J. van der Linden prepared the X-ray powder photographs.

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THE CHARACTERISTICS AND INCLUSIONS OF BLACK STAR-DIOPSIDE*

By B. F. MARTIN, M.D., B.Sc., F.G.A.

FOUR-RAYED star stones are far from common; six-rayed stones belonging to the trigonal system of crystal symmetry are better known, e.g. corundum. An interesting example of the former is black star-diopside which has recently appeared from India. These attractive stones have recently received comment from Webster(1), in an article on black gemstones. He states that they are actually dark green in colour and have a small range of density between 3·30 and 3·40. He observed that the rays are not strictly at right angles and this is significant, since diopside belongs to the monoclinic system of crystal symmetry.

It should be noted that diopside is a pyroxene and is mainly a calcium-magnesium silicate, but some ferrous iron invariably replaces some of the magnesium and imparts some shade of green to gem material. The colour is finer and brighter if some chromium is present as well (chrome diopside). Not unexpectedly the physical constants vary; the refractive index average values are given as 1·67–1·70 (birefringence: 0·020–0·030) and the specific gravity varies from 3·27 to 3·31 (Webster(2); McLintock(3)). With increasing percentage of iron the colour darkens to an almost opaque black and such material, termed hedenbergite, shows higher constants; the refractive index rises to 1·732–1·751 and the specific gravity to 3·60 (Coles Phillips(4)).

Diopside is not often cut as a gemstone and it has the drawbacks of comparative softness (Hardness: 5 to 6) and easy cleavage. Some samples have a fibrous nature and when cabochon-cut show a chatoyant effect. Particularly good chrome diopside cat's-eyes have come from Burma(4).

The author has studied four black star-diopsides, weighing respectively 1·75, 2·12, 2·19 and 2·85 carats. All showed a high polish and a sharp star and in each case it was confirmed that the two rays do not cross at exactly a right angle. In addition, it was noticed that the arms of the two rays do not lie in a straight line and

*This work was submitted almost concurrently with that of W. F. Eppler, whose paper appeared in the preceding issue of this Journal (April 1967), and the results are essentially in agreement.

also the one ray is sinuous since the extremities of its arms curve in opposite directions. It was noted further that the angles between the arms of the rays change a little as the stone is rotated with respect to the light source. An investigation was therefore undertaken to determine the general characters of the stone and its star and a microscopic study was made for inclusions, since chatoyancy or asterism can only occur when long, thin inclusions are present, orientated parallel to one another in one direction to produce chatoyancy and in more than one direction to produce asterism. The inclusions function as thin cylinders which reflect cones of light, and when the stone is cut en cabochon the conical reflection produces a single line which runs perpendicular to the length of the inclusions (Eppler[5]).

General Characters of the Stone

By distant vision, the refractive index of the stones was estimated at approximately 1·67, and the specific gravity at approximately 3·34, since the stones sank very slowly in pure methylene iodide. These constants are near to those given by cabochons of black jadeite, but the lustre of the latter is quite different.

To determine the refractive index more accurately, a flat facet was polished on the base of one of the stones. Although the shadow edges were not very sharp, the readings obtained were 1·674–1·700 (birefringence: 0·026). An accurate specific gravity estimation, kindly undertaken on one of the stones by Robert Webster, gave a value of 3·35. Thus, the refractive index is within the normal range for diopside, and although the specific gravity is slightly higher than that usually quoted, both constants fall below those of black hedenbergite (quoted above), suggesting that their colour is more likely to be due to their inclusions (see later) than to a high content of iron.

A detailed investigation of the effect produced on the star by rotating the stone with respect to a fixed light source was made as follows. The stone was placed over the centre of a metal washer to stabilize it whilst it was rotated on a stage and photographed at 5 × magnification in different positions with respect to a spot source of light from a microscopic lamp, with its diaphragm partly closed. The appearance of the star in two positions is shown for one stone in Fig. 1 (A1 and A2) and in three positions for another stone (B1, B2 and B3). It can be seen that the two rays of the star

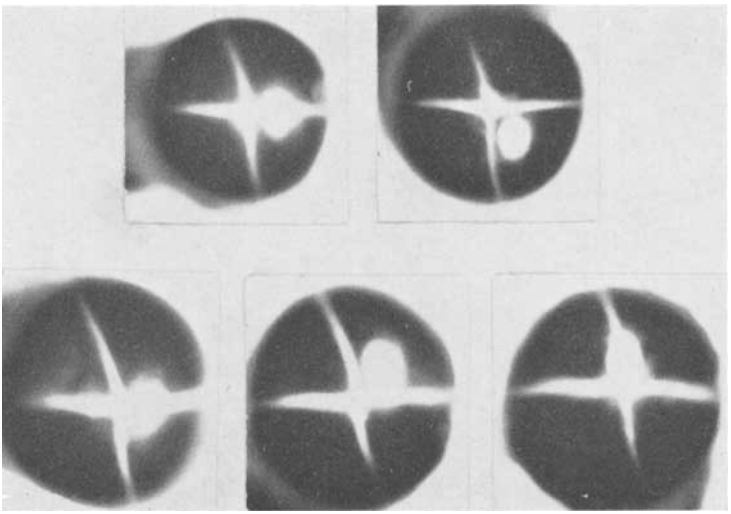

FIG. 1. *The form of the star and the changes in inclination of the arms of the two rays in two lighting positions for one stone (A1, A2) and in three positions for another (B1-3). 5 ×*

do not cross at a right angle, that the arms of each ray are inclined at an angle and that the arms of one of the rays are curved in opposite directions at their extremities to produce a sinuous effect. The sinuous ray is orientated vertically in the photographs. A further point is that the angle between the arms of each ray varies a little in the different positions and a position is reached where the arms of a ray reverse their direction of inclination; compare the arms of the horizontally orientated ray in B1 and B3.

This phenomenon was studied further by photographing a third stone in eight positions during a complete rotation, i.e. when the light spot was directed on each of the four star arms as well as when it was equidistant between adjacent arms. From 30 × print enlargements, tracings of the star-outlines were made and from the star-centre lines were drawn as far as possible along the central axis of each star-arm, so that the angles between the arms could be measured. The results for this stone are illustrated diagrammatically in Fig. 2. It is seen that not only do the angles between the arms of each ray vary, and more so in the case of the sinuous ray, but also that there is a critical position, different for each ray, at which the arms start to incline in the opposite direction. Because of these variations, only an average value can be given for the angle

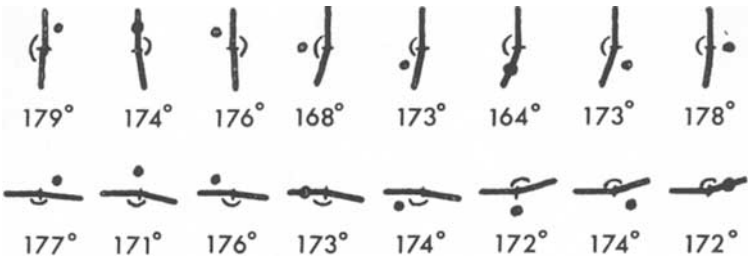

FIG. 2. *Illustrates the changes in inclination of the arms of the two star-rays, following illumination from eight different positions. The position of the incident light spot is shown by a circle and the arms of the sinuous ray are orientated vertically.*

at which the two rays cross. The average obtained from measurement of the obtuse angle between the rays in the eight positions of the stone was 105°, and this is important to note in relation to the inclusions, which remain to be considered.

THE INCLUSIONS

With a bright source of light, small rod-like inclusions could be seen with a 10 × loupe, brilliantly reflecting the light. By using a microscope lamp for illumination and a low-power objective ($1\frac{1}{2}$ inch) it was possible to obtain photomicrographs of the inclusions by incident light. The position of the lighting was quite critical. In many positions the interior of the stone appeared quite dark but in some positions the inclusions were seen, brilliantly reflecting the light against a dark background (Fig. 4a) and in other positions they appeared black in colour against a light background (Fig. 4b). As mentioned earlier, it is likely that the colour of the inclusions is responsible for the body colour of the stone.

Under the low magnification obtainable with incident light, the inclusions appear as rods of varying length, orientated in two definite directions. They are mostly very thin but a few are broader and may then be irregular. From print enlargements it is clear that the thin "rods" are each composed of a row of tiny, rounded particles (Figs. 3a, 3b). The small numbers of broad inclusions are composed of a series of short rows of particles. Each short row follows one inclusion direction but the rows are aggregated in parallel to form a long inclusion, and this follows the other inclusion direction. Such inclusions, being formed of particles in a

compromise arrangement are sometimes of irregular outline and may even be bent (Figs. 3a, 3b); rarely are the particles arranged in an irregular cluster (Fig. 3b).

From prints enlarged to 180 ×, tracings were made of the inclusions so that their angle of inclination could be measured. Although there was some variation, the average result from twenty-five measurements was 105° which, not unexpectedly, was the average angle at which the two rays of the star had been found to cross.

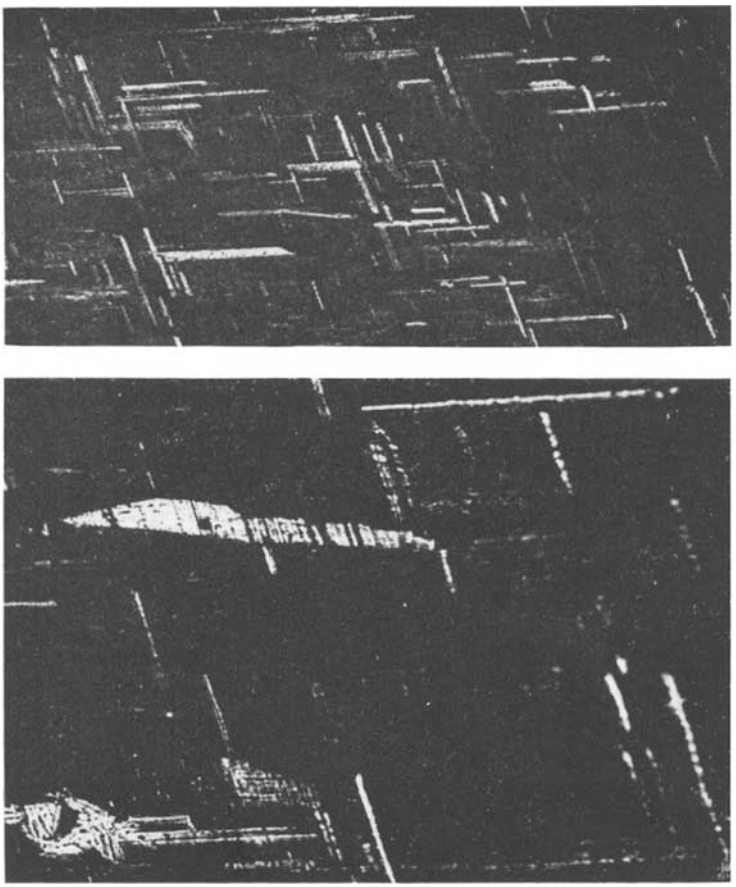

FIG. 3. *Inclusions are reflecting the light against a dark background at 80 × magnification (a) and at 160 × (b). They follow crystallographic directions an dare composed of single rows and occasionally multiple rows of particles.*

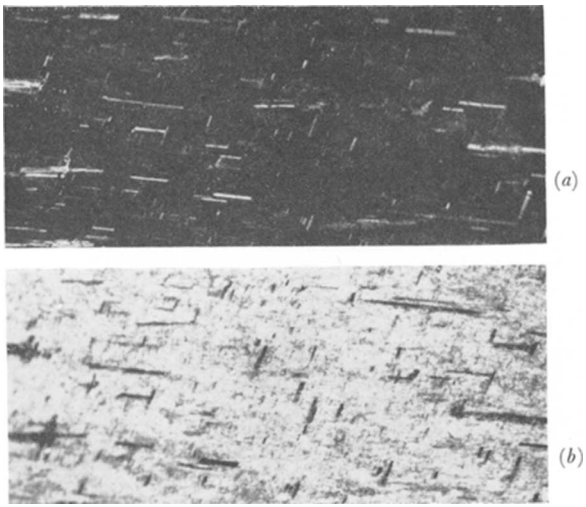

FIG. 4. *Photographs at 17 × through a back facet, showing inclusions bright against a dark background (a) and black against a light background, as the lighting is altered (b). Note their sinuous course*

From these figures, it is clear that the inclusions are arranged according to crystallographic directions. Rogers and Kerr[6] give the β angle for diopside as 74° 10′, whereas Phillips[7] states that the β angle between the x and z axes should be quoted, by convention, as the obtuse angle and this would therefore be a little over 105°.

Although the inclusions follow crystallographic directions, they show an added complexity. It was noted above that bending of an inclusion may be seen, but when low power photographs were taken through a polished back facet it became apparent that the course followed by the inclusions is not straight, and in the one direction their course is sinuous, which would account for the sinuous nature of one of the star rays (Figs. 4a, 4b). The changes in inclination of the arms of the star-rays with change of position of the light source may also be determined by this imperfect orientation of the inclusions. It is known that individual rod-like inclusions may become bent during growth of the host crystal, as Gübelin[8] found in the case of included tremolite needles in Habach emeralds, but it must be an unusual circumstance for inclusions to follow such direction changes as found in the present study.

The nature of the particles composing the inclusions was not determined, but their identification would be of interest. Since they are distributed throughout the host material according to crystallographic directions, they probably fall within the class of solid secondary inclusions, formed by exsolution, which Gübelin[9] has discussed in his classification of inclusions. Eppler[10] suggests that they may consist of clinoenstatite.

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Gemmological Abstracts

LENZEN (G.). *Begrifflicher und Historisches zur Bearbeitung des Diamanten.* Facts and History of the polishing of diamonds. Zeitschr. d deutsch. Gesell. f. Edelsteinkunde, 1966/67, 58, pp. 4-19.

Interesting summary of the polishing of diamond and its history, with a bibliography of 65 items. Cleaving, sawing, bruting and polishing are described, as are the optimum values of Tolkowsky's brilliant-cut and various fancy cuts. It is not known when diamonds were first polished in India; most certainly it was not before the 6th century. The first mention of diamond polishing in Europe was in the 14th century. Diamond cutting seems to have occurred in India as well as in Europe in the 16th century. According to Tavernier the working of the diamond in the 17th century differed between India and Europe.

E.S.

EPPLER (W. P.). *Eilat-Steine.* Stones from Eilat. Zeitschr. d. deutsch. Gesell. f. Edelsteinkunde, 1966/67, 58, p. 23.

This was published in the Deutsche Goldschmiedezeitung 19/1966, and discussed the stones found near Eilat on the Red Sea, in the former copper mines of King Solomon in the 10th century B.C. These mines in Southern Israel are now worked again. The stones are of cuttable quality and of pure turquoise or turquoise with malachite veins. This material is a very lively blue, with green, and its S.G. is between turquoise and malachite, depending on its composition. E.S.

Smaryll. Zeitschr. d. deutsch. Gesellschaft f. Edelsteinkunde, 1966, 57, pp. 47-48.

A new emerald imitation on the market, sold as "Smaryll". The colour is good, both upper and lower part consist of colourless beryl, very pale aquamarine or pale emerald. The two parts are cemented together by an acid-resistant duroplastic of emerald-green colour with a thickness of 0·15 mm. It is interesting that these Smarylls appear green when viewed from the side. Physical

constants are given. The correct name would be "emerald-coloured beryl doublet".

E.S.

SCHLOSSMACHER (K.). *Gedanken zur Ausbildung von Diamantsachverstaendigen.* Thoughts on the education of diamond experts. Zeitschr. d. deutsch. Gesell. f. Edelsteinkunde, 1966/67, 58, pp. 2-4.

At the moment there are three courses in Germany specializing on diamonds. One is a three-day course in Idar-Oberstein organized by the Deutsche Gesellschaft f. Edelsteinkunde, the second is also a three-day course run by the Gesellschaft der Edelsteinfreunde in Hanover and the third is a two-week course of the Köenigsteiner Schule. The author suggests that students should attend all three courses and the results of each course and/or exam. be judged by a Commission.

E.S.

LENZEN (G.). *Geschichte der Qualitätsmerkmale des Diamanten.* History of the signs of quality in a diamond. Zeitschr. d. deutsch. Gesellschaft f. Edelsteinkunde, 1966, 57, pp. 18-39.

The first part of a historical summary about the various aspects of diamonds. The first part deals with colour and the importance of its nomenclature. The author shows that colour was of no importance as far as value was concerned in India (between the 4th and 6th century B.C.). Two monks named Buddhabhatta and Varahamihira summarized colours found in various occurrences; these are listed and compared. The diamonds found in Paundra were said to be grey, those of Kalinga yellow, of Vena colourless and those found in Himalaya copper-red. The different colours were said by the monks to belong to the different gods, and this was carried into the caste system, so that the Brahmans had the colourless stones, while the Sudras had the black stones. With the discovery of the Brazilian deposits it was known that colourless stones were much rarer and thus they became also more valuable. The top (colourless) quality was called Golconda, and this fell by stages to the Bahias, which were light yellow. The author explains the "old terms" such as Jager, River, Top Wesselton, etc., and the names in the yellow and brown series. The difficulties of determining colour are mentioned. Bibliography.

E.S.

PERIZONIUS (R.). *Skapolith. Scapolite.* Zeitschr. d. deutsch. Gesellschaft f. Edelsteinkunde, 1966, 57, pp. 41-44.

Description and physical constants of scapolite. The variety most commonly used as gem is mizzonite, found in Espirito Santo in Brazil and in Madagascar. There are various other occurrences, such as Norway, Finland, New Jersey, Quebec, but these do not yield gem material. Other varieties are dipyrite, which is found in white or pink crystals of 3-5 mm length, marialite, which seems to be the most chemically resistant variety, and mejonite, which is attacked by hydrochloric acid. This latter type is found in a clear colour in Sweden and also in Bolton, Mass., U.S.A., in a grey-green variety. Some pink scapolites and also some dark blue to violet ones have a fibrous structure; when cut as cabochons they show chatoyancy.

E.S.

SEAL (M.). *Inclusions, birefringence and structure in natural diamonds.* Nature, 1966, 212 (57), p. 1528.

Natural diamond crystals can be inhomogeneous in their internal structure, due in many instances to alteration of regions of type I and type II material. The author suggests that some of the inhomogeneity must be the result of subtle changes in the texture.

S.P.

BOOK REVIEWS

VOLLENWEIDER (MARIE-LOUISE). *Die Steinschneidekunst und ihre Kuenstler in Spaetrepublikanischer und Augusteische Zeit.* The Art of stone engraving and its artists in the late republic and at the time of the Augustine empire. Bruno Grimm, Baden-Baden, Western Germany, 1966.

This well-produced book is a collection of gems and intaglios produced in antiquity. There are 100 tables with 577 black and white photographs, with the exception of the first cameo, which is a sapphire and shows Venus with an eagle. This seems to be the largest antique cameo known, measuring 35 mm by 30 mm, with a depth of 8 mm. The text is concise, each item is described and there are indices of the engravers, goldsmiths and jewellers, and of the mythological and real people despicted on the gems.

King's "Antique Gems", which provides the basis of the subject of antique gems, is only briefly mentioned. The last four tables illustrate modern copies of antique cameos and intaglios. E.S.

LENZEN (G.). *Produktions- und Handelsgeschichte des Diamanten.* The History of the production and trade of the diamond. Duncker and Humblot, Berlin, 1966, pp. 280.

This book was originally a doctorate thesis and has now been published in book form. Because of this and of the many details mentioned it is difficult to read. It is well illustrated (38 photographs), has an extensive bibliography and the index is sub-divided into names and geography.

The author deals with the diamond as material, then as a mineral, as gem and as industrial tool. The main part of the book is divided into geographical sections, dealing with diamonds from India, Brazil and Africa. The importance of Russian deposits and of the synthesis for industrial purposes is only fleetingly mentioned.

The historic finds in India are described, as well as the type of production and the way diamonds were traded in the middle ages and up to the present time. A large part of the book deals with African finds, especially finds in the Union. The formation of the Diamond Syndicate is described and also the present structure of the various DeBeers Companies. The author suggests systematic surveying and drilling of Indian and Brazilian deposits, similar to those performed in South Africa.

E.S.

PALMER (J. P.). *Jade.* Spring Books, London, 1967. 15s.

This brief introduction to jade will be best appreciated for the 54 superb colour illustrations. The pieces illustrated are excellent examples of the jade carver's art, as well as showing the richness and variety of the many colours of jade. A bibliography would have been helpful. The author is an Assistant Keeper at the Fitzwilliam Museum, Cambridge. In relation to its excellence the book is very modestly priced.

S.P.

ASSOCIATION NOTICES

ARMORIAL BEARINGS OF THE GEMMOLOGICAL ASSOCIATION OF GREAT BRITAIN

In 1966 the Association made application to the Earl Marshal and Hereditary Marshal of England for a grant of Armorial bearings, based upon a design prepared by H. Ellis Tomlinson, M.A. Mr. Tomlinson was responsible for the design of the Arms of the National Association of Goldsmiths of Great Britain and Ireland, under whose aegis the Gemmological Association was formed in 1931, after being the Education Committee of the N.A.G. since 1908.

The accompanying description of the Arms has been prepared by Mr. Ellis Tomlinson.

Jewel-Blazon

In mediaeval times heraldry, like other manifestations of man's artistry, was subject to fanciful treatment in both language and ornament. One such conceit was the practice of naming the heraldic colours by reference to jewels, especially in blazoning the arms of the high nobility. Guillim in his "Display of Heraldry" (late 17th and early 18th Century) equates the tinctures thus:—
Or (gold) = topaz; Argent (silver) = pearl; Gules (red) = ruby; Azure (blue) = sapphire; Sable (black) = diamond; Vert (green) = emerald; Purpure (purple) = amethyst; Tenne (orange) = jacinth; Sanguine (dark red) = sardonyx.

"These", he says, "are nowhere us'd but in England", but Fox-Davies (Complete Guide to Heraldry) quotes an Austrian grant of arms of 1458 in which ruby, pearl and emerald are used for red, silver and green. He says he is "Not aware of any instance of the use of these terms in an English Patent of Arms", and certainly no such official use has been discovered in recent researches. It is therefore no small distinction that attaches to the official blazon of the Arms of the

Gemmological Association, which, by special dispensation of the Kings of Arms, is couched with obvious appropriateness, in the nomenclature of the mediaeval lapidary, viz:

Arms

Pearl on a cross formy quadrate throughout quarterly ruby and sapphire a closed book bound and clasped topaz the cover set with an emerald environed of pearls between two sapphires in pale and two rubies in fess between in chief within an annulet topaz a rose-cut diamond proper in fess two lozenges pearl each charged with a cross diamond and in base a ring topaz gemmed pearl.

Crest

On a wreath pearl ruby and sapphire a demi-lynx proper holding between the paws an escarbuncle of eight rays ruby each floretty and pommety of a jewel respectively from the base pearl, ruby, jacinth, topaz, emerald, turquoise, sapphire and amethyst.

Motto

Omnemque pretiosum lapidem. The motto is taken from the first Book of Chronicles, 29.2 ("I prepared) all manner of precious stones").

INTERPRETATION

Shield

The cross is a variation of that in the Arms of the National Association of Goldsmiths of Great Britain and Ireland. It is quartered red and blue like the associated Arms of the Worshipful Company of Goldsmiths and the N.A.G. In the middle is a gold jewelled book which represents the study of gemmology and the examination work of the Association. Above it is a top plan of a rose-cut diamond inside a ring, suggesting the scrutiny of gems by magnification under the lens. The lozenges represent uncut octahedra, and the gemmed ring, from the N.A.G. Arms, indicates the use of gems in ornamentation. The colours of the shield are mainly the national red, white and blue, which also cover the main range of gems.

Crest

The lynx is renowned for his keenness of sight and perception, and in ancient times was credited with the faculty of seeing through opaque substances. He represents the lapidary and the student scrutinizing every aspect of gemmology. In his paws is one of the oldest heraldic emblems, an escarbuncle. This is said to represent a very brilliant jewel, usually a ruby, the radiating arms suggesting the light it diffuses. The 17th century heraldic encyclopaedist, Guillim, writes:

"Stones precious are of that sort that we call in Latin 'Gemmae'; which are of estimation either for that they are rarely to be gotten, or for some vertue fancied to be in them, or for that they are such as man's eye is wonderfully delighted withal by reason of their pureness, and beautiful transparent substance. Of which kind are the Diamond, Topaz, Escarbuncle, Emerald, Ruby and such like . . . But of all these several kinds, the Escarbuncle is of most use in Arms . . . This is called in Latin 'Carbunculus', which signifieth a little Coal, because it sparkleth like Fire, and casteth forth, as it were, fiery Rays". (He continues in an amusing postscript: "There is another kind of, but fiery, carbuncle, which Chyrurgeons can best handle; one of those of the lapidaries is more to be desired than ten of the other").

The escarbuncle is, as it were, heraldry's special emblem of gemmology. It is often shown with the *fleurs-de-lis* at the tips and the pommels round the rays in a different colour from the rays and central jewel. Here, the tips and pommels are shown as jewels representing the respective colours of the spectrum, completed by pearl for the white light representing the fusion of the spectrum colours. This is a unique treatment of the escarbuncle, which, with the lynx holding it carefully, represents the aims and activities of the Association.

The right to a coat of arms conferred by a grant of arms, made by the Kings of Arms under the royal authority, is a limited right, defined by the limitations in the patent, and not a right which the grantee can pass on to a third party. Any reproduction of the Association's Arms or any colourable imitation thereof is not permitted without the prior consent of the Council of the Association.

MIDLANDS BRANCH

A meeting of the Midlands Branch of the Association was held on the 12th January, 1967, at the Auctioneers' Institute, Birmingham. Mr. D. King presided and introduced Mr. L. S. Lipkin, who gave a talk, supported with colour transparencies, on "Cultured Pearls".

Everybody who attended the annual meeting of the Midlands Branch of the Gemmological Association held in Birmingham on 19th April had a chance to test their knowledge in a gemmological quiz. Four teams of experts Messrs. Beresford, G. W. Davis, K. Hoskyns, J. F. Marshall, D. E. Price, J. Salloway, J. R. Shaw and P. Spacey brought along uncut gem material and gem-set antique and modern jewellery which they set up for the other members to identify and to estimate weights and values.

This lively and enjoyable session followed the more serious business of the meeting in which Mr. W. Peplow (senior) proposed, and Mr. K. Hoskyns seconded, the re-election of officers *en bloc* to serve for the forthcoming year. They are: chairman, Mr. D. N. King; deputy chairman, Mr. N. A. Harper; vice-chairman, Mr. Pete Spacey; secretary, Mrs. S. E. Hiscox. Committee members: Messrs. G. W. Davis, J. F. Marshall, D. E. Price and J. Salloway.

The Chairman's report for the year gave details of all the meetings and functions held including a visit to Mappin & Webb's (Bull Street, Birmingham) "Diamond exhibition", by courtesy of the directors of Mappin & Webb's. The branch had had the pleasure of interesting guest speakers at three meetings. At one, Mr. D. J. Ewing talked on his visits to Idar Oberstein in Germany. At another Mr. Leo Lipkin talked on cultured pearls and on pearl fisheries in Japan. This was well supported by slides, and Mr. Keith Gardener, sales manager of Lotus Pearls, talked on sales aspects. At the March meeting, Mr. N. A. Harper talked on De Beers "Diamond Symposium" and this had been followed by the film "Out of the blue", dealing with the recovery of diamonds in pipe mines in S. Africa.

Finally, a very successful dinner, dance and cabaret had been held in November at the "Barn Restaurant", Hockley Heath, Solihull.

OBITUARY

May 1967. Oscar Fahy, Birmingham. Mr. Fahy was one of those who qualified in the first gemmological diploma examination held in 1913. He was a well-known gem dealer in the Midlands.

WEST OF SCOTLAND BRANCH

At the annual meeting of members of the West of Scotland Branch of the Association it was decided to change the name of the Branch to "The Scottish Branch of the Gemmological Association of Great Britain".

Mr. J. M. B. McWilliam was elected as Chairman, Mr. J. H. A. McRae, Vice-Chairman, and Mr. D. A. Hill, as Secretary for the ensuing year. In commenting upon the work of the year the out-going Chairman, Mr. J. Gilloughley, recalled the interesting summer outing to the Pass of Kilicrankie, and the talks given by Mr. Robert Webster and Mr. J. M. B. McWilliam. Mr. Gilloughley exhibited the most comprehensive and valuable collection of gem specimens that had yet been shown to the Branch. Members of the organizing committee were thanked for their work in connection with one of the most successful years the Branch had had.

COUNCIL MEETING

At a meeting of the Council of the Association held on Wednesday, 3rd May 1967 the following were elected:—

Fellowship

Cremer, Viktor (Dr.), Winterleitenweg, Germany. D.1961

McNeilly, Henry Hart, Belfast 1, N.I. D.1929

Stocker, Philip Leslie, Welling, Kent. D.1959

Ordinary Members

Ashton, Howard Neill, London, W.2

Barkle, Bessie Edith Mary (Mrs.), Wembley, West Australia

Bennett, Elsa Carol Freda (Mrs.), Keswick, Cumberland

Bosch, Jose M. (Dr.), Barcelona, Spain

Chang, Felix S. Y., Taiwan, Formosa

Coleman, Walter D., Arvada, U.S.A.

Cook, Eric David, Marlborough

Coomans, Hendrikus Eduard, Amsterdam, Holland

Cronstedt, Katharina (Mrs.), Mt. Yokine/W.A. Australia

Eveleigh, Michael Leonard, London, S.W.1

Hayes, Lillian Eveline (Mrs.), London, N.W.9

Hayton, Pauline (Miss), London, S.E.3

Hossen, Abdool Hamid, Port-Louis, Mauritius

Kawashima, Tomio, Tokyo, Japan

Leonard, Paul Lucas, Cobourg, Canada

Newman, Brian Anthony, Cape Town, South Africa
Pous, Joaquin Montoriol (Dr.), Barcelona, Spain
Radford, Herbert George, Jnr., Barrhead, Scotland
Robinson, Geoffrey, London, N.W.3.
Roysko, Aake Lionel, Tampere, Finland
Singer, Herman, Chevy Chase, U.S.A.
Tamiya, Haruaki, Tokyo, Japan
Thim, Tham Yen, Penang, Malaysia
Thurgar, Stanley H., Burlington, Canada
Trenholme, Russell Shannon, Tokyo, Japan
Wasilkowski, Wanda K. (Mrs.), Miami, U.S.A.
Yamamoto, Shigeo, Tokyo, Japan
Yeung, Stanley Kai Yung, Hong Kong
Bramley, Donald, Doncaster, Yorks.
Suddaby, David C., Sutton Coldfield, Warwicks
Horii, Ayako (Miss), Tokyo, Japan
Wadhwa, Pushpa (Mrs.), Eldoret, Kenya
Grimminger, Alfred, Frankfurt, Germany
Pacal, Zdenek, Prague, C.S.S.R.

PROBATIONARY MEMBERS

Birkinshaw, David William, Wakefield, Yorks
Bond, Ian Norman, Whangarei, New Zealand
Covent, Richard Jeffery, Toronto, Canada
Engstrom, Barbara (Miss), Woodford Green, Essex
Heriz-Smith, Nicholas Peter, London, S.W.12
Holton, David John, Wilstead, Bedfordshire
Ishizumi, Momoyo (Miss), Shiga-Ken, Japan
Masterman, Gillian Elizabeth (Mrs.), Gerrards Cross, Bucks.
Porter, Graham Stanley C., Birmingham, Warwicks.
Upchurch, David Ward, Colchester, Essex

The Council received notice that the West of Scotland Branch had changed its title to that of the Scottish Branch of the Gemmological Association of Great Britain.

It was reported that the National Association of Goldsmiths was acquiring additional space in Saint Dunstan's House and that organization was prepared to allocate extra space to the Gemmological Association for dealing with its increasing gemmological educational work and sales of instruments.

ANNUAL MEETING

The thirty-seventh annual meeting of the Association was held at Goldsmiths' Hall, Foster Lane, London, E.C.2. on 3rd May. In presenting the annual report the chairman, Mr. Norman Harper, referred to the problems that the increased demand for the Association's courses and examinations had produced. The Association had had a successful year and he recorded appreciation of the work of the council, local branches and others who had contributed to the steady growth of the Association. Dr. C. T. Cross seconded the motion for the adoption of the annual report and accounts, which were unanimously approved.

The following officers were elected: President, Sir Lawrence Bragg, C.H., F.R.S., Chairman, Mr. Norman Harper; Vice-chairman, Mr. Philip Riley; Treasurer, Mr. F. E. Lawson Clarke. The chairman recalled that Sir Lawrence had been made a Companion of Honour in the New Year's Honours List.

Miss I. Hopkins, and Dr. E. H. Rutland were re-elected and Mr. D. King elected to serve on the Council. A resolution proposing the re-election of Mr. C. T. Mason notwithstanding that he had reached seventy years of age was unanimously approved.

The vice-chairman, Mr. Riley, suggested that it should be ascertained whether a pastel portrait of Sir Lawrence Bragg, which was on show at the summer exhibition of the Royal Academy, could be purchased by the Association.

GIFTS TO THE ASSOCIATION

The Association is indebted to Mr. Jean-Claude Rufli, of Stockholm, for a collection of Swedish and Norwegian gem minerals.

Mr. S. Gunaratne of Ceylon has kindly sent a Ceylon Government publication "Gems of Ceylon".

Mr. Z. Pacal, of Prague, has presented a collection of minerals found in Czechoslovakia.

1967-1968 COURSES IN GEMMOLOGY

The final date for enrolment in the Association's Correspondence Courses in Gemmology is 31st August, 1967. Application for entry into local classes in gemmology should be made to the Principal of the School or College concerned.

MEETINGS OF MEMBERS

A reunion of members, followed by the presentation of awards, will be held at Goldsmiths' Hall, London, on Tuesday, 10th October, 1967, at 6 p.m.

The Herbert Smith Memorial Lecture for 1967 has been arranged for 16th November, in London.

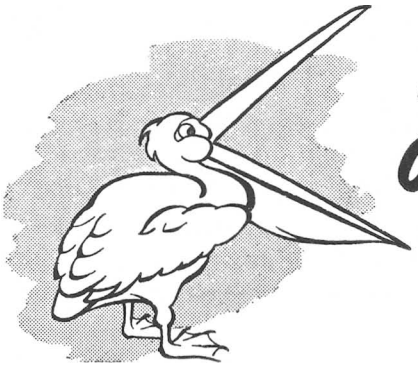

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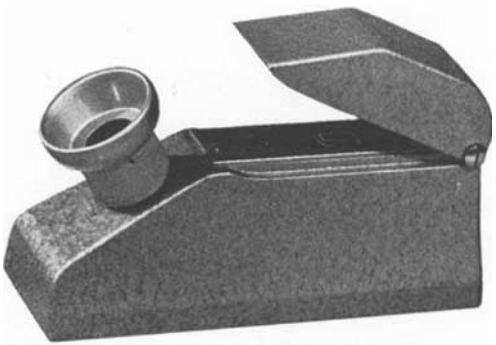

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Vol. 10 No. 8 OCTOBER 1967

THE LAST MILL ON THE IDARBACH

By KENNETH BLAKEMORE

THE cutting industry, that has made the twin towns of Idar-Oberstein famous since Roman times, grew up on the banks of two little streams, tributaries of the Nahe. The most important of these two streams was the Idarbach. The other was the Fischbach. Records from 1450 tell that in those days there were twenty mills on the banks of the Idarbach, where the agate, amethyst, citrine and jasper, found in the hills that rise from its banks, were cut and polished. The waters of the stream were held up by sluices and released down mill-races to spin the mill wheels that in turn rotated the huge sandstone grinding wheels inside the mills. To-day there is only one of these mills left on the banks of the Idarbach. This mill is maintained mainly as a tourist attraction, but agates and many other ornamental stones are still cut there.

The mill looks much as the mills of medieval times must have done—a low tiled shed built of stone with a big wooden wheel on one side of it. The only change that the passing centuries have brought has been that inside the mill shelves have been built above the great sandstone wheels. These were put there to hold labelled specimens to interest the visitors. Also on a bracket attached to one of the pillars, that support the roof, an unusual alms dish has been placed. Visitors can now drop an appreciative coin or two into a section of a large geode filled with fine dark amethyst crystals.

The foundation of the cutting industry on the Idarbach goes back to Roman times. The Romans, in the course of building a road to serve their fortress at Trier, found agates on the rolling green hills above the winding river Nahe, some thirty miles to the north of where the city of Saarbrucken now stands. Previously the Romans had obtained the agates, which they used for cutting as cameos, from around Arcates in Sicily, the town which is said to have given its name to the agate. The Roman invaders of Germany discovered that the agates from the hills around the Nahe were superior to those of Sicily, and set up an industry there, the products of which were sent back to Rome.

The agate deposits around Idar-Oberstein must have been substantial. The grinding wheels in the mills along the banks of the river were kept turning continually until the nineteenth century. Eventually, however, there were no more worthwhile agates to be found. The craftsmen of Idar-Oberstein were thrown out of work.

There is a romantic story that the idle agate cutters formed a choir, and that the choir became world famous. In the course of a tour the choir found itself in Brazil, and one day walking up the

The last mill on the Idarbach.

road to the hacienda of a rich Brazilian ranch owner, they saw that the road they were walking down was paved with agate.

Whether this story is strictly true, it was certainly the agates and the other gem material imported from Brazil that started the mill wheels of Idar-Oberstein turning again. The bad years in the nineteenth century closed many of the mills however. The introduction of electricity to the industry closed the rest, replacing them with modern workshops, which subsequently diversified into faceting diamonds, coloured stones and synthetics. Only one mill was preserved, dependent still on the power of water.

When I visited this mill in the Spring, the little Idarbach was in spate after a week of rain. Even so this winding stream, overhung with willows and alders, seemed hardly adequate to have powered an important industry, but the tiny torrent that bubbled through the mill-race was turning the mill wheel merrily round and round, while inside the mill the three grinding wheels, six feet in

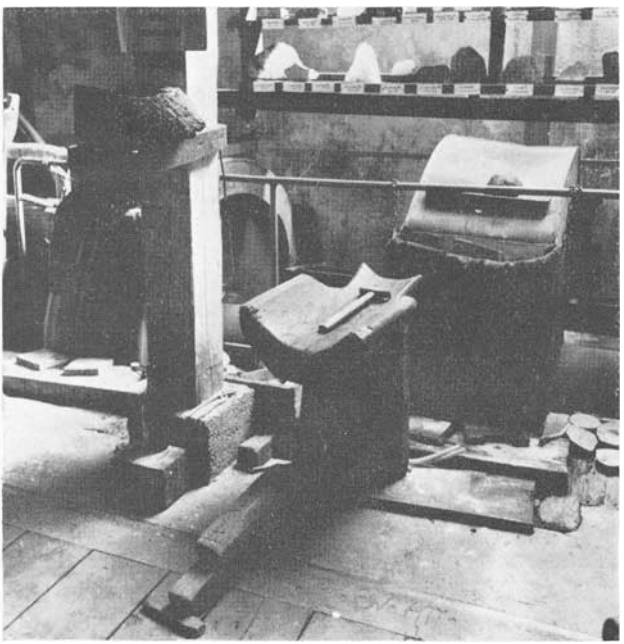

The saddle on which the cutter lies to hold the agates against the sandstone grinding wheels. Above the wheel shelves have been erected to hold specimens of interest to visitors. On a bracket a section of a geode is used as an alms dish.

The cutter lies over the saddle holding the agate against the sandstone wheel.

Herr Heinz sawing agate on a copper saw impregnated with diamond dust.

diameter and two feet thick, were rotating steadily. In these days, when we have so many other sources of power at our disposal, we tend to underestimate the power of water.

The owner of the mill to-day is Herr Heinz. The only thing that differentiates him from the rest of the workers is that he wears a white coat, and the others who work along side him wear drab grey overalls. Herr Heinz's job is to saw the stones into slabs and blocks, using a rotating copper disc impregnated with diamond dust. There is a tang of petrol in the air in the mill because petrol is used as a coolant for the saws. The job that Herr Heinz does is the only one that has been modernized. Before the invention of the diamond-impregnated saw, some eighty years ago, the agates were cleaved into sections with a hammer and chisel.

The "cutting" is done in the same way that it has been done for countless centuries. The cutter lies on a "saddle", a curved stool secured to the floor, supporting his feet on a small beam nailed to the floor boards. The position in which the cutters work is, I found, surprisingly comfortable, as it must obviously be when you think about it, because the men lie like this all day, pressing the agates against the V-shaped face of the sandstone wheels. The grinding wheels are cooled incidentally by running in a trough of water.

A smaller wheel is used for polishing the agate, and the green polishing compound (a chromic oxide) splatters over the workers' hands and clothes.

Not only agates are cut in this mill, but many other decorative stones. I saw rhodonite, jasper and crocidolite from Africa, lapis-lazuli from Chile and nephrite from North America being cut while I was there. The products of the mill vary from the giant agate and rhodonite ashtrays that abound in the offices and homes of Idar-Oberstein, to little specimens for collectors. These one can buy for a mark or two each in the town of Idar-Oberstein.

SYNTHETIC COBALT BERYL

By A. M. TAYLOR, Ph.D., F.G.A.

AN intriguing red-coloured synthetic beryl containing cobalt shows promise as a new gemstone. It is one of the many exotic beryls recently produced hydrothermally and doped with elements of the first transition series. Crystals containing V (green), Mn (greyish-green), Co (pinkish-brown), and Ni (light-green) were first grown by the Russian workers Emel'yanova *et al.*, [1] and the O-ray absorption spectra reported in 1965. These beryls, as well as ones containing Fe (deep-blue) and Cu (light-blue) have been made by the author in Melbourne, Victoria. The cobalt beryl exhibits such startling optical properties that its exploitation as a gemstone seems quite probable.

The attractiveness of this somewhat odd reddish-coloured beryl lies in its unique dichroism. The colour ranges from light-brown to a rich purple for the O and E-ray, respectively. A stone cut with its table parallel to the optic axial plane appears an amber colour from above, but increasingly reddish when viewed from the side. The best red colour is obtained when the table is orientated parallel to the optic axis. Unfortunately, the rich purple of the E-ray can only be fully appreciated with the aid of a polaroid sheet or dichroscope, since otherwise even at best it is blended at equal strength with the pale brown O-ray.

With the Chelsea filter, cobalt beryl provides a beautiful example of what might be called the "traffic-light effect", if the two vibration directions are viewed separately. The O and E-ray appear respectively green and bright red through the filter. A similar effect, but much weaker (green and pink) is exhibited by deeply coloured vanadium emerald[2]. The Chelsea filter is a dichromatic type, transmitting light in two narrow bands, in the deep red near 6900Å and in the yellow-green near 5700Å. The purple E-ray has a strong absorption band in the 5700Å region, thus it appears red through the filter, as do blue cobalt spinel and glass. On the other hand, the brown O-ray transmits light about equally well in both regions and so appears greenish, as the filter transmits more yellow-green than red light.

The absorption spectra of cobalt and other synthetic beryls are being studied at the C.S.I.R.O. using a Beckman DK-2 spectrophotometer over the range 0·3 to 3 μ. For gemmological purposes, only the cobalt beryl absorption in the visible will be presented here. The absorption band positions listed below were measured with a Beck reversion spectroscope, and are mean values of numerous readings on four crystals.

O-RAY			E-RAY		
A	5612Å	weak	A	5860Å	strong
B	5447Å	weak	B	5670Å	strong
C	5256Å	weak	C	5430Å	strong
D	4475Å	strong	D	not detectable	

Measurements reproducible within ±10Å.

The absorption spectra are illustrated in Fig. 1 as seen through a prism-type spectroscope. The startling dichroism is due to the markedly dissimilar nature of the O and E-ray absorption spectra. The brown O-ray has a strong absorption band in the violet and only a weak, hazy triplet group absorption in the green. The purple E-ray, in contrast, freely transmits all the violet, and exhibits to the fullest extent the characteristic cobalt absorption pattern of three

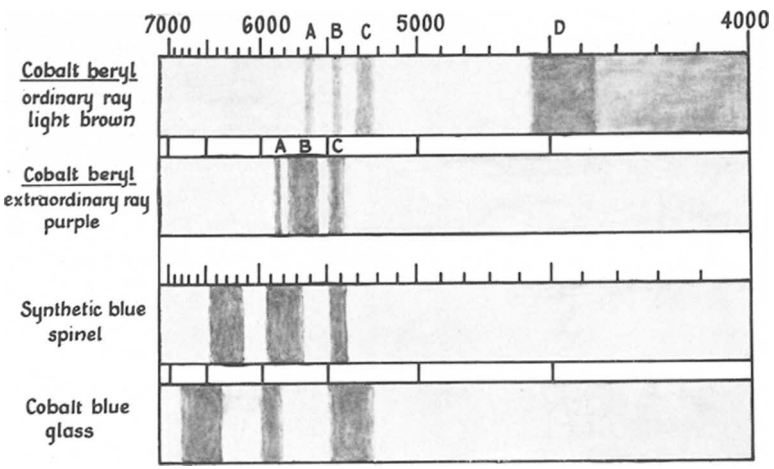

FIG. 1

very intense bands, with the central band being widest, all closely bunched up in the yellow-green part of the spectrum.

The two main factors influencing the position and intensity of absorption bands in substances are:

(*a*) Valence state of the absorbing metal ion.

(*b*) Number of anions (usually 4, 6 or 8) that surround this metal ion and effectively bond with it.

The "sameness" of the familiar chromium absorption spectrum in different gemstones is the result of it nearly always being due to Cr^{3+} substituting for Al^{3+} in sixfold co-ordination with oxygen ions (octahedral sites). Likewise, the three strong absorption bands signifying cobalt in blue synthetic spinel and glass (see Fig. 1) are due to Co^{2+} in fourfold co-ordination with oxygen ions (tetrahedral sites)[3].

The beryl structure $Be_3.Al_2.Si_6O_{18}$, has Be^{2+} and Si^{4+} in tetrahedral sites and Al^{3+} in octahedral sites. Beryl coloured by cobalt could theoretically contain either, or both Co^{2+} and Co^{3+}, located in tetrahedral or octahedral sites. However, the reducing nature of the hydrothermal growth media favours the existence of divalent cobalt in solution. In general, compounds having Co^{2+} in tetrahedral sites are blue in colour, whereas those with it in octahedral sites are pink (e.g. MgO), due to an overall shift of the absorption bands to shorter wavelengths. Thus we may tentatively attribute the cobalt beryl absorption spectrum to divalent cobalt substituting for aluminium in the octahedral sites of the beryl structure. Charge balance could be maintained in various ways, such as by addition of alkali ions in the large, open, channel positions that occur within the Si_6O_{18} hexagonal rings.

The question "Does cobalt beryl occur in nature?" can safely be answered by saying that so far none has been found. Staatz *et al.*[4], who recently published spectrographic analyses of 47 beryl specimens from a range of environments, were able to detect cobalt in three specimens, but only at the 0·0003% level, whereas 0·1% or more would be required to give a reasonable depth of colour. In fact, coloured cobalt minerals are few in number, the most notable being the rose erythrite or cobalt bloom, a hydrated arsenate usually found in the oxidized portions of cobalt ore deposits; pink cobalticalcite sometimes used in lapidary work; and the deep blue lusakite, a cobaltoan staurolite (up to 8% CoO) found in Northern Rhodesia.

With the increasing production of new synthetic crystals in various laboratories around the world, it is inevitable that some of the more attractive ones are fashioned into gemstones by lapidaries who happen to be on the spot. Usually these exotic gems are confined to private collections, but when they do occasionally get into free circulation they often cause much confusion because their physical properties are not widely known (e.g. synthetic garnets).

Cobalt beryl now has the advantage of a prior introduction, so that any chance encounter in the trade, will I hope, result in favourable interest rather than suspicion. Its refractive indices (1·565-1·575) and specific gravity (2·67-2·69) are the same as for synthetic vanadium emerald[2]. Some confusion is perhaps possible with tourmaline due to its strong dichroism, however the traffic-light effect with the Chelsea filter and distinctive cobalt absorption spectrum will readily serve to identify it, leastways, that is until someone produces cobalt tourmaline.

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THE WORLD'S LARGEST TAAFFEITE?

By R. KEITH MITCHELL, F.G.A.

MOST gemmologists know the piquant story of the late Count Taaffe who in 1945, working with only a low-powered microscope, was greatly puzzled by a 1·42 carat pale mauve "spinel" which showed visible double refraction. The strange nature of the stone was confirmed by Mr. B. W. Anderson, and, after further tests by Dr. G. F. Claringbull and Dr. M. Hey of the Natural History Museum, it was found to be a new mineral and named taaffeite after the discoverer.

A further specimen weighing 0·86 carats was found in 1949 by Mr. C. J. Payne, and yet another, weighing 0·84 carats, in 1957 by Robert Crowningshield, of the Gemological Institute of America.

In June this year the story was told again, in a column by George A. Bruce, in the American magazine *Modern Jeweller*. This article inspired a reader to check his own collection of spinels and resulted in the discovery of a fourth taaffeite weighing 5·34 carats. Mr. Bruce reports that this is a purple cushion-cut stone from Ceylon and that it has been confirmed by Richard Liddicoat of the G.I.A. Laboratory. Its density is 3·608 and is reported as having refractive indices 1·720-1·724. These indices are slightly higher than those for the earlier stones which have been encountered.

Further details are not yet available but there seems little doubt that this is by far the largest known faceted taaffeite. A brief report of crystals of the mineral being found in China was dealt with in this Journal earlier this year, by B. W. Anderson,[1] but it seems unlikely that these have been cut, or that they are necessarily of this size or even of gem quality.

1. Anderson, B. W. *Crystals of taaffeite found in China.* Journ. of Gemmology., (1967), 10, 5, p. 148.

MORE ABOUT SYNTHETIC GARNETS

By R. WEBSTER

FOLLOWING the report by R. K. Mitchell (*Journ. Gemmology*, January, 1967) on the find of a synthetic chromium-neodymium doped yttrium aluminium garnet (Y.A.G.) in a commercial stone parcel, the writer records his observations on some other specimens of synthetic yttrium aluminium garnets and of a yttrium iron garnet (Y.I.G.), which have been produced in England and which he has had the opportunity to examine.

The first is a specimen of colourless yttrium aluminium garnet consisting of a piece of crystal, which in form resembled part of a Verneuil-process boule. The section was hexagonal in outline. These synthetic garnets are not grown by the Verneuil technique, but by the "pulling" technique devised by Czochralski.

The weight of the specimen was 25·18 carats and was found to have a density of 4·562. The hardness was found to be about 6, for it was readily scratched by quartz and doubtfully by feldspar (orthoclase). The refractive index and dispersion values must await until a suitable prism of the material is cut and polished, so that measurements may be made by the method of minimum deviation. There was no pronounced absorption spectrum observed although very faint traces of the didymium rare earth lines were noticed. The specimen did not appear to show any major internal features, but between "crossed polars" there was some anomalous double refraction, and along the long axis of the specimen this anomalous double refraction took the form of a pseudo-uniaxial interference figure.

The response to long-wave ultra-violet radiation was a distinct whiteish glow and a similar, but much weaker, glow was seen when the short-wave ultra-violet lamp was used. Under x-rays the stone showed a bright violet glow but, strange for a synthetic stone, showed no phosphorescence. When viewed between "crossed filters" the stone showed a red residual colour—possibly by transmission of the white glow through the red filter. No fluorescence spectrum was seen and there was no electro-conductivity shown.

A small colourless crystal showing a few crystal faces, which was most probably grown from a flux-melt production, gave some anomalous results, for the small stone which weighed only 0·232 carats was found to have a density as low as 4·043. No absorption spectrum was visible using a hand-spectroscope. Examined microscopically the surface was seen to have growth marks in hexagonal arrangement and internally a liquid-filled feather was observed. The stone showed a bright yellow-green fluorescence under both wavelengths of ultra-violet light. A very similar glow with persistent phosphorescence of the same colour was observed when the stone was bombarded with x-rays and after this treatment the stone was found to have photo-coloured to a yellow. The stone did not exhibit any electro-conductivity.

Another small colourless crystal, also showing a few crystal faces, showed strongly the characteristic didymium rare earth absorption spectrum. This stone was found to have a density of 4·6 and was not visibly fluorescent under ultra-violet light, but showed a strong yellow-green with some phosphorescence when bombarded with x-rays. Examination of the interior showed the specimen to contain groups of crystal inclusions. There was no electro-conductivity.

Since Mitchell's report on the green synthetic Y.A.G. garnet, which was undoubtedly "doped" with both chromium and neodymium and/or praseodymium, two brilliant-cut stones recently examined were "doped" with chromium only.

The larger stone weighing 1·605 carats was found to have a density of 4·63, while the smaller stone which weighed 0·527 carats was found to have a density of 4·74. Examined microscopically the smaller stone was seen to have a few drop-like inclusions and faint "mixing" inhomogeneities rather like "treacle". In the larger stone some radial structures were apparent when the stone was viewed between "crossed polars". The main difference between these stones and the stone reported upon by Mitchell lies in the absorption spectrum. These two stones showed no sign of the didymium rare earth lines but showed an exceptionally striking chromium-type absorption spectrum. This consisted of a weak band centred about 7000Å and about 80 angstroms broad; a sharp line at 6870Å and a strong broad absorption band with two "peaks" centred at 6780Å and 6700Å. These were followed by a weak continuum ending at about 6300Å.

Under long-wave ultra-violet light these stones showed an orange-red to crimson glow, and emitted a crimson glow under the short-wave lamp. In neither case was any phosphorescence observed. Under x-rays the stones showed a strong crimson glow and exhibited a strong and persistent phosphorescence. Agreeing with the stone examined by Mitchell these two stones, when bathed in a beam of strong white light, showed strong red gleams, a similar effect to that seen in the Linde synthetic emeralds. No electro-conductivity was observed in these two stones.

The yttrium iron garnet (Y.I.G.) examined weighed 47·83 carats. It was opaque black and showed two flat faces where it had either been sawn or had grown up against flat surfaces. The rest of the stone had lustrous crystal faces. The density was determined as 5·997 and the stone was found to be strongly magnetic but showed no magnetic polarity. No electroconductivity could be discerned. From the crystal faces present it may be inferred that the crystal was grown by the flux-melt method and not by the Czochralski "pulling" technique. Such Y.I.G. crystals are grown as an insulating magnetic material for use in lasers, light modulators, micro-wave resonating media, and in ultrasonic devices. They have little value as a gemstone.

It is clear that more of these synthetic garnets will be met in the future, for not only are yttrium iron garnets and yttrium aluminium garnets being produced, but gallium and germanium garnets have been grown. "Doped" with a number of transition elements all sorts of colours may be expected and indeed pinks mauves, yellows, and blues have already been reported.

AN IMPROVED DESIGN OF STONE TONGS

By B. F. MARTIN, M.D., B.Sc., F.G.A.

NOT all are gifted with manual skill, but even very skilled gemmologists are well aware of the hazards of handling gemstones and small crystals with a pair of stone tongs—also called corn tongs, forceps or tweezers. No less an authority than Mr. B. W. Anderson[1] confesses them difficult to manage, and his views regarding their qualities and management are echoed here.

All too often, a gemstone will spring out of the tongs, sometimes to a surprising distance, and much valuable time is spent, sometimes fruitlessly, in searching bench and floor, including the crevices. After many such annoying episodes, it occurred to the author that the current design of tongs is not conducive to the safe handling of gemstones. The tongs in use are instruments of general utility and find service in a wide variety of trades and professions. Gemmologists use both the rounded and the sharp-pointed varieties and the latter are perhaps the more hazardous to employ.

In designing a pair of tongs for the special purpose of handling gemstones, the author arrived at the following conclusions: (1) they should be lightly sprung, so that the pressure exerted on the stone can be gauged and kept light, (2) the ends should be so fashioned that even small stones can be viewed easily and (3) the pattern of grooving on the inner faces of the ends should minimize the tendency of the stone to slip, and this is perhaps the most important consideration of all.

In the standard tongs, the ends have a series of transverse grooves on their inner faces and thus a poor grip is obtained on a stone unless the tongs approach it vertically and take the girdle between opposite grooves. In practice, however, the tongs are usually held obliquely or horizontally, the latter approach being the more desirable, especially if the stone is to be transferred to the polariscope or refractometer. With a trap-cut stone the girdle cannot now enter the grooves and very little of it (if any) with one of brilliant-cut, so that the highly polished stone, which has little friction, is virtually held between smooth steel faces and if it is at all askew it springs from the tongs. It seemed therefore, that if longitudinal grooves were added to the existing transverse set, to produce a cross-hatched effect, there should be a good chance of the girdle entering grooves in almost any position it may be grasped.

After a successful trial in refashioning an old pair of mild steel tongs, an even better result was obtained with a stainless steel pair, using a standard "Rayner" 5 inch tongs, with rounded ends. Because of the hardness of stainless steel, much of the fashioning was undertaken with carborundum and sandstone wheels. Final fashioning was by miniature file and a high polish was obtained with finer grades of emery paper, followed by burnishing. Comparison of the refashioned with the standard tongs is shown in side view in Fig. 1 and in face view in Fig. 2.

In side view (Fig. 1) it is seen that the two segments of the spring portion are considerably thinned, especially in their middle

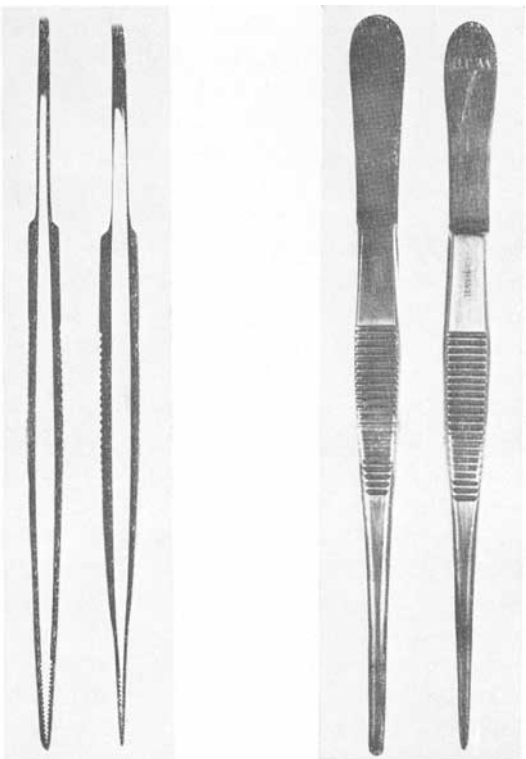

FIGS. 1 and 2. *Comparison is shown between the standard and the refashioned tongs in side view in Fig. 1 and in face view in Fig. 2. The refashioned are the lower pair in both Figs. (4/5th natural size).*

regions. This is achieved by removing metal from their outer surfaces and repeatedly testing the spring power during grinding until it is sufficiently light to satisfy the operator.

The ends of the tongs are reduced by removing metal from their sides as well as their outer surfaces, for a distance of about $\frac{7}{8}$th of an inch. Metal is removed from their outer surfaces until they are very thin and have been bevelled to a narrow edge, the bevelling being particularly fine at the tips. The ends are then straightened a little until they are almost parallel. This results in a somewhat "crocodile" appearance, as shown in Fig. 1. Although it is clearly unnecessary to work to micrometer measurements, it was found in the pair illustrated that the thickness of their ends had been reduced from approximately 60 to 40 thousandths of an inch, i.e. by about one third. As the ends are being thinned, their sides should be gradually reduced and brought to a slight taper as shown in Fig. 2, paying particular attention to the tips which should be elliptical in outline. Although the width diminishes gradually towards the tips, measurement of the pair illustrated showed that near the centre of the grooved area they had been reduced from about 140 to 100 thousandths of an inch, i.e. by about one third.

The last operation before polishing is to cut three longitudinal grooves, very carefully, across the existing transverse set on the inner faces, using a miniature triangular file. A central groove is cut first and then one to each side of it.

The author has found that with such refashioned tongs it is easy to gauge the pressure applied to the stone, a good view is obtained, even of very small stones, since there is little metal to obscure them and they seldom spring from the tongs. In fact, a slight click is often heard a few moments after taking up a stone, indicating that it had started to slip but found its place in a groove. To diminish further the chance of slipping, the stone should be taken up with the tongs parallel to the bench and gently manoeuvered with the opposite thumb and finger until the girdle enters the longitudinal grooves and is felt to be locked in position.

Although fashioning of the tongs entails some hours of labour, the undertaking may be considered as that "stitch in time" which could well save many more hours from waste in the future and perhaps save some valuable stones.

REFERENCE

1. B. W. Anderson (1964). *Gem Testing*, 7th Edit. Temple Press Books Ltd., London.

Gemmological Abstracts

LIDDICOAT (R. T.). *Developments and highlights of the Gem Trade Laboratory, Los Angeles.* Gems and Gemology, 1967, XII, 4 and 5, pp. 118-124, 146-156.

Among items encountered at the Laboratory were flux-grown rubies and emeralds with unusual types of inclusions. Synthetic fluorite, heavily doped with lanthanium, had a density of 4·89 and a refractive index of 1·47. A cyclotron-treated marquise-cut diamond showed two parallel lines, one on each side of the "keel" and not the "umbrella". There is mention of irradiated cultured (Biwa) pearls and similarly treated topaz. In the latter, owing to the low refractive indices, the original material was presumed to be blue topaz, which had turned to a sherry-brown colour by the treatment. A number of unusual stones were also examined including a cerrusite and a kornerupine cat's-eye. A natural legrandite, a hydrated zinc aresenate, transparent and bright yellow in colour, was identified. Flux-grown synthetic gahnite spinel and synthetic greenockite were also encountered. R.W.

CROWNINGSHIELD (R.). *Developments and highlights at the Gem Trade Laboratory, New York.* Gems and Gemology, 1967, XII, 4 and 5, pp. 110-117, 137-145.

Commercially sold rough synthetic rubies were found to have "seeded" crystals. A strontium titanate, which had been sold as a "diamond", shattered when being reset. Identification hazards are illustrated by one case where reflections from curved lines in a synthetic sapphire caused the appearance of "silk". Angular twinning was also seen in a synthetic ruby. R.W.

LIDDICOAT (R. T.). *Diamond proportion grading and the new proportionscope.* Gems and Gemology, 1967, XII, 5, pp. 130-136.

The new instrument, devised by the Gemological Institute of America, enables the measurement of the proportions of unmounted cut diamonds. It is a modification of the profilometer now commonly used in industry, and has a screen suitably graduated for diamond measurements. R.W.

MESSCHAERT (G. W.). *The stone carvers of Kofu, Japan.* Gems and Gemology, 1967, XII, 4, pp. 103-109.

The materials used for carving at the Kofu centre are mainly imported into Japan. The tools and methods of carving are described.

R.W.

AXON (G. V.). *The gemstones of America.* Australian Gemmologist, 1967, 71, pp. 5-6.

A short review of the gemstones found in the U.S.A. The use of anthracite (coal) to make small carvings, and ulexite (television stone), which is able to transmit pictures along the length of the fibrous crystals, are mentioned.

R.W.

WHITWORTH (H. F.). *Amethyst from Onslow, W. Australia.* Australian Gemmologist, 1956, 73, p. 7.

Amethyst has recently been found in the Onslow district of Western Australia. In colour the smaller crystals are a rich purple and the larger ones appear almost black. The tips of the crystals are free from inclusions and gems could be cut from them.

R.W.

BOOK NOTICES

CHOATE (S.). *Creative Casting.* Allen & Unwin, 1966. 50s.

TAYLOR (G.). *Continental gold and silver.* Michael Joseph (Connoisseur monograph), 1967. 25s.

BENDA (K.). *Ornament and jewellery.* Paul Hamyln, 1967. 63s.

This book describes the distinctive Slav contribution to the art of jewellery in the early middle ages.

Ausgesuchte mineralien. Excellent minerals. F. Harrach, Bad Kreuznach.

A folder containing 9 colour photographs of minerals.

ARGENZIO (V.). *The fascination of diamonds.* Allen & Unwin, London, 1957. 30s.

A British edition of an excellent account of diamond, which was first published in 1966. (Journ. Gemmology, 1966, 10, 3, p. 108).

ASSOCIATION NOTICES

EXAMINATIONS IN GEMMOLOGY, 1967

In the 1967 examinations in gemmology organized by the Gemmological Association of Great Britain, 376 candidates sat for the preliminary examination and 196 for the diploma. Centres were again established in many parts of the world and the number of entries for both examinations was the highest in the history of the Association.

Upon the recommendation of the examiners the Tully Memorial Medal and Rayner Prize have been awarded to Miss Elizabeth Strack of Idar-Oberstein, W. Germany.

The Rayner Prize in the preliminary examination has not been awarded, as those who submitted the best papers were not eligible for the award.

The following is a list of successful candidates, arranged alphabetically:—

Diploma Examination

Tully Memorial Medal

Elizabeth Strack, Idar-Oberstein, W. Germany.

Qualified with Distinction

Arps, Charles Edward Samuel, Oegstgeest, Holland
Bodes, Reginald, Voorburg, Holland
Dudek, Clelan Francis, Oregon, U.S.A.
Harding, James Norman, Northwood Hills
Hayes, Lillian Eveline, London
Hopkins, Norman Barton, Bowie, M.D., U.S.A.
Jones, Sylvia Margaret, London
Renfrey, Eric, Ormskirk
Rickenberg, Robert Edwin, Los Angeles, U.S.A.
Strack, Elizabeth, Idar-Oberstein, W. Germany
Trenholme, Russell Shannon, Tokyo, Japan

Qualified

Arbeid, Martin Jolis, London
Astley-Sparke, Jeremy Peter, London
Baugerod, Gunnar, Porsgrunn, Norway
Beaman, Ronald David Birmingham,
Beck, Cyril Anthony, Manchester
Bennett, Peter John, Enfield
Benthall, Richard Pringle, Walton-on-the-Hill
Berwick, Keith James, Portsmouth

Blacklock, Ralph Ellis Macrae, Sunderland
Bodenham, John Edward, Birmingham
Borrmann, Bjorn, Fjellhamar, Norway
Bosch, Hilmar Dirks, Salisbury, Rhodesia
Bowers, Norman, Manchester
Bowley, Malcolm Anthony, Bukuru, N. Nigeria, W. Africa
Brown, Janet Irene, Congleton
Brown, Judith Audrey, Altrincham
Buchanan, Alistair McKenzie, Edinburgh
Buchanan, Kenneth Ray, Tulsa, Oklahoma, U.S.A.
Bull, Rudolf, Sorengo, Switzerland
Bytheway, Keith Leonard, Walsall
Chartier, Henri Paul, Esher
Cherns, Jack Jacob, London
Clifford, Geoffrey Roy, Maidstone
Collier, Alan, Burscough, Nr. Ormskirk
Cowbourne, Elizabeth Mary, Bingley
Croydon, Robert William, Norwich
Cuss, Christopher Jude, London
Cutts, Michael James, Surbiton
D'Arcy, Michael Stephen, Peterborough
Doughty, Mary Forbes, Birkenhead
Earnest, Robert Allan, Santa Monica, California, U.S.A.
Edrisinghe, Barbara, Colombo, Ceylon
Evans, Royston Thomas, Altrincham
Foster, Angela, Liverpool
Franks, Ivor Selwyn, London
Frost, Frank Roger, Oxford
Fuller, Robert George, London
Gardiner, John Clive, Manchester
Gay, Alan Leslie, Birmingham
Gay, Phillip G., S. Miami, Florida, U.S.A.
Gillon, Mary, Glasgow
Goodman, Brian John, Hammerwich, Nr. Walsall
Gregory, David George, Liverpool
Hamnett, Norman, Radcliffe
Hartley, Donald Wilson, E. Detroit, U.S.A.
Hartmann, Carolus Johannes, Dentlaag, Holland
Hemsworth, John Alan, Manchester
Johnson, Cyril Alan, Rugby
Kwok-Leung, George Chan, Kowloon, Hong Kong
Levy, Marion David, Atlanta, Georgia, U.S.A.
Linares, Robert C., Ridgefield, Conn., U.S.A.
Lorimer, Barry Anthony, Cross Roads, Nr. Keighley
McLachlan, Catherine, Boksburg, Tvl., S. Africa
McTeigue, Walter J., New York, U.S.A.
Mechlin, Wilmer, Chevy Chase, M.D., U.S.A.
Mendis, Cynthia Marguerite, Colombo, Ceylon
Mumford, Ronald Broughton, Sunningdale
Nash, Geoffrey Edwin, Walsall
Neary, Geoffrey, Huddersfield
Newham, Frank Edward, London
Newman, Brian Anthony, Cape Town, S. Africa
Nixon, Rolf Thorp, Washington, U.S.A.
Ozolins, Nikolajs, Sao Paulo, Brazil
Parkes, Frederick, Stanmore
Perera, Dixon Chandrasiri, Minuwangoda, Ceylon
Porter, Graham Stanley C., Birmingham
Priestman, Arthur, Manchester
Rees, Dietlinde Maria Augusta, London
Russell, Madeleine, Ilford
Sanderson, Clare, Romford
Sasaki, Edwin, Tokyo, Japan
Schnieden, Harold, Bramhall
Spohn, Winfried, Cologne, Germany
Stokes, Timothy David, Birmingham

Sutton, Robert Michael, Bramley, Nr. Guildford
Swain, Marilyn Janice, London
Talbot, Peter Ernest, Crayford
Warren, Philip Arthur, Hest Bank, Nr. Lancaster
Wilson, Geoffrey Alexander, Urmston, Nr. Manchester

Preliminary Examination
Qualified

Abril, Emilio Armengol, Barcelona, Spain
Alabaster, A. Paul, Moseley (Birmingham)
Altermatt, Edgar Curtiss, Berkeley, California, U.S.A.
Arps, Charles Edward Samuel, Oegstgeest, Holland
Ash, Stephen Leslie, Exeter
Balaguer, Agustin Avila, Barcelona, Spain
Ball, Norman Douglas, Sherborne
Banner, L. B., Kings Norton (Birmingham)
Barreda, Lorenzo Prats, Barcelona, Spain
Barrenger, Jonathan, Weybridge
Bartolo, Cynthia Milvaine, Salisbury, Rhodesia
Bayley, Lyndon John Elsmore, Edgbaston (Birmingham)
Beaumont, Roy Anthony, Market Harborough
Beechey-Newman, Hansel J. A., Falmouth
Benbrook, Alan David, Dagenham
Benthall, Richard Pringle, Walton-on-the-Hill
Berlin, Ronald, London
Beynon, Michael John, Bassaleg (Mon).
Bibby, Rachel Ann, London
Bird, Anthony Thomas, Cardiff
Bird, Thomas John Rees, Llandaff, Nr. Cardiff
Birkinshaw, David William, Robin Hood, Nr. Wakefield
Bisbee, Juan Domenech, Barcelona, Spain
Blacklock, Ralph Ellis Macrae, Sunderland
Blackwell, Alan, Barnehurst
Blockley, Doreen Sandra, Stockport
Blowfield, Ian Stewart, Pinner
Bodes, Reginald, Voorburg, Holland
Bond, Ian Norman, Whangarei, N. Island, N. Zealand
Borque, Felix Valtuena, Barcelona, Spain
Bos, E. G. G., Amsterdam, Holland
Bowley, Malcolm Anthony, Bukuru, N. Nigeria, W. Africa
Brady, Deanna Mary, Birkenhead
Bryant, William, Seymour, Texas, U.S.A.
Bryk, Raymond Alexander, London
Buckingham, Robert George, Witney (Oxon).
Burnham, Norah Elsie, Birmingham
Butler, Barry, Sheffield
Butler, Terence Eustace, Balogna, Italy
Canto, Jaime Sancho, Barcelona, Spain
Capdevila, Juan Vilalta, Barcelona, Spain
Carr, Malcolm, Addington
Carry, Michael R., Manchester
Chapman, Ernest James, Torquay
Chapman, Robert, London
Collin, Alan Arthur, Chester
Connard, John Martin, Southport
Considine, M., Shipley
Coulson, Maurice, Sunderland
Covent, Richard Jeffery, Toronto, Canada
Crawford, Brian Henry, Cape Town, S. Africa

Cros, Adolfo Traveria, Barcelona, Spain
Danby, John, Leeds
Davis, Jack, London
Derges, Leonard Frederick, Paignton
De Silva, Koththagoda Kankanange Danujapala, Colombo, Ceylon
De Souza, Victor Joao, Kobe, Japan
De Vroomen, L. J. M., London
Dickenson, Henny, Salisbury, Rhodesia
Dickman, George Stokes, Haverfordwest
Dingle, Patricia N., Cooksville, Ontario, Canada
Domenech, Tomas Turrents, Barcelona, Spain
Dot, Eduardo Bruquetas, Barcelona, Spain
Dring, Jacqueline Anne, Langrick, Nr. Boston
Dunthorne, Robert Percival, Stroud (Glos).
Earnest, Robert Allen, Santa Monica, California, U.S.A.
Egea, Anthony, London
Eriksen, Einar Aas, Trondheim, Norway
Evans, Michael Stanley, Weston-Super-Mare
Felisart, Francisco Arla, Barcelona, Spain
Felisart, Ramon Arla, Barcelona, Spain
Fieldhouse, John Ernest, Sutton Coldfield
Fischer, Marianne E., Stellenbosch, S. Africa
Flory, Ian, Dundee
Gastager, Max, Bad Reichenhall, W. Germany
Gaylor, John, Loughton
Giesskann, Paul Walter, London
Gimenez, Pedro Sendon, Barcelona, Spain
Goodson, David Lloyd, Tettenhall
Gosling, James Granville, Coulsdon
Grimminger, Alfred, Frankfurt/Main, Germany
Greenlees, Roger Martyn, Bolton
Gull, Peter, Bloxwich (Walsall)
Gunn, John Francis, Hornchurch
Harper, Peter Johnathan, Sutton Coldfield
Hayes, Bernard, Liverpool
Hayes, Brian, Sheffield
Heriz-Smith, Nicholas Peter, London
Hester, David Charles, Gt. Missenden
Hilliger, Harold Arthur, Leaven Worth, Kansas, U.S.A.
Hitchen, Melvin, Stanley, Nr. Wakefield
Holden, Terence, St. Helens
Holmes, Graham John, Bexhill-on-Sea
Holroyd, Philip, Frodham (Cheshire)
Hopkins, Norman Barton, Bowie, M.D., U.S.A.
Horsfall, Robert Rodgers, Andamooka, S. Australia
Houghton, Coralyn Diana, Bolton-Le-Sands, Nr. Carnforth
Huguet, Joaquin Solans, Barcelona, Spain
Hulme, Elizabeth, London
Hung, Lau, Hong Kong
Huston, Jane Elizabeth Claire, Groomsport, Co. Down
Hutchins, Andrew John Francis, Remuera, Auckland, New Zealand
Jackson, Colin William, Darlington
Jackson, P. J. R., Rudgwick
Jenkins, James Alexander, Monaghan, Eire
Jones, Carole A., Newton-Le-Willows (Lancs).
Jones, Diane Roberta, Salisbury, Rhodesia
Jones, Stephen Richard, Stockton-on-Tees
Jordaan, Barend Daniel, Stellenbosch, S. Africa
Karpovitch, Stephanie Sophia, New York, U.S.A.
Karslen, Britta, Oslo, Norway

Kjendlie, Karl Magnus, Oslo, Norway
Lane, Stuart Howard, Bideford
Ledbetter, Susan, Dublin, Eire
Lewis, Dqvid Trevor Keyes, Borrowash (Derbyshire)
Lewis, Lawrence, London
Lewis, Richard, London
Ligaard, Anne-Britt, Oslo, Norway
Lluch, Jose Pladellorens, Barcelona, Spain
Lopez, Bartolome Montoro, Barcelona, Spain
Lyons, Leslie, Blackpool
MacLeod, Dan Murdoch, Baden Baden, W. Germany
Marsden, David Norman, Blackburn
Masterman, Gillian Elizabeth, Gerrards Cross
Matsuzaki, Shigeru, Tokyo, Japan
Mayr, Ute, London
McAleese, David A., Toronto, Canada
McLachlan, Catherine, Boksburg, Tvl., S. Africa
McNeilly, Sheila, Belfast
Meagher, G. V., Islington, Ontario, Canada
Mercer, Ian Frederick, Romford
Messias, Marvin, Stanmore
Metcalfe, Alan, Lancaster
Metcalfe, David, Lancaster
Michel, Gerard Armand, Beunos Aires, Argentina
Millar, David Moore, Napier, Hawkes Bay, New Zealand
Millington, Grenville Arthur, Smethwick (Staffs).
Milton, Geoffrey Seymour, Liverpool
Milton, Mark Seymour, Liverpool
Mitchell, Frank Richard, Frampton-on-Severn (Glos).
Moen, Anthony Peter Michael, Stellenbosch, S. Africa
Mollet, Federico Estrada, Barcelona, Spain
Moore, James Laurence, Wallasey (Cheshire)
Mordaunt, John Forsyth, Buxton
Morgan, Deryck, Pontypridd
Morrow, Roger Anthony, Rixton, Nr. Warrintong
Mosey, Irene, Lancaster
Muir, Philip Louden, Wilmslow
Nadelhofer, Hans, Burgdorf, Switzerland
Neal, Jennifer Joanna, Balsall Common, Nr. Coventry
Nidd, David Robert, Sutton Coldfield
Nussbaum, Eric E., Geneva, Switzerland
O'Donoghue, Michael John, London
Pairman, Gordon Sinclair, Leven (Fife).
Pardoe, Paul Roger, Worthing
Pass, John, Haslington, Nr. Crewe
Peddie, Thomas Donald, Leven (Fife).
Peters, Anthony Gayton, Exeter
Peyerl, Wolfgang, Johannesburg, S. Africa
Pichon, Jean-Daniel, Geneva, Switzerland
Piederiet, J. J. M., Breda, Holland
Pilley, Brian, London
Pitt, Robert, Sutton Coldfield
Pragnell, Jeremy Martin, Stratford-on-Avon
Prigg, Leonard Ernest, Cardiff
Purchon, Eric, Bradford
Pye, George Anthony, Kings Winford (Staffs).
Raisin, Daniel, Geneva, Switzerland
Raphael, Beyda, Geneva, Switzerland
Ravenscroft, Jean, Wirral
Reilly, Hugh Joseph, Burntisland (Fife).
Richards, Avril, London
Rio, Carlos Moreno Del, Barcelona, Spain
Ripoll, Miguel Moncada, Barcelona, Spain
Roy, William Dick, Leven (Fife).
Ruiz, Carlos Baguena, Barcelona, Spain

Sadler, David A., Ayr
Santasusagna, Ramon Nicolau, Barcelona, Spain
Sasaki, Edwin, Tokyo, Japan
Schnetz, John V. P., Kriens, Switzerland
Silcock, James Barry, Southport
Sluis, Bastiaan, Vlaardingen, Holland
Smith, Charles Rubin, Selfridge AFB, Michigan, U.S.A.
Smith, William Alexander, Salisbury, Rhodesia
Smyth, John Joseph, Dublin, Eire
Staatsen, Albertus Claudius, Utrecht, Holland
Stadelmann, Fritz, Schaffhausen, Switzerland
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GIFTS TO THE ASSOCIATION

The Association is indebted to Capt. J. Sinkankas, California, for a collection of N. American gem minerals.

A set of polaroid photographs for teaching purposes has been kindly sent by John Fuhrbach, of Amarillo, Texas, U.S.A.

A specimen of milky star-quartz, found in Norway, from Per Chr. Sæbø, Oslo.

OBITUARY

THOROLD G. JONES of Abingdon, August 1967. (D.1926).

From the late nineteen twenties until 1950 (apart from the war years), Thorold Jones guided and encouraged many student gemmologists when he was assistant to Mr. I. Jardine and later Mr. B. W. Anderson, in the gemmology classes held at Chelsea. At that time his work at the Geological Survey and Museum at Piccadilly and later at South Kensington, was a great help to him in fostering the study of gemmology. After the war he transferred to the Atomic Energy Authority at Harwell, where he was employed at the time of his death. His painstaking efforts helped many gemmological students to master the techniques of the microsope and refractometer and to develop a keen eye for identifying stones by using only a hand-lens. He will be remembered with affection by many who qualified in their examinations from the gemmological classes at Chelsea Polytechnic.

* * *

Winnert, George, of Loughborough, 16th June, 1967. (Diploma 1949).

COUNCIL MEETING

At a meeting of the Council of the Association held on 12th July, 1967, the following were elected to membership:—

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GEM DIAMOND EXAMINATION

In the 1967 Gem Diamond Examination held by the Association there were 23 entries, and the following is an alphabetical list of successful candidates.

Qualified with distinction: Gabriel June Doherty-Bullock, Worcester

Qualified:

Berry, William, Leicester
Blanshard, Philip John, West Wickham
Boroszak, John Kasmick, Blackpool
Clarke, Hilary Anne, Hampstead, London, N.W.3
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Leese, Peter Francis, Northwood
McKay, Robin Ian, Thames Ditton
Miller, Elizabeth Anne, Wolverhampton
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Moore, Martin C., Birmingham
Petzall, Ossi George, Ilford
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Selvon, Dennis Ralph, Woodford Green
Smith, David John, Hove
Stern, Evelyne, Wembley Park
Weller, Raymond John, Croydon

MEMBERS' MEETINGS

During a brief summer visit to the U.K. Capt. John Sinkankas, of San Diego, California, U.S.A., kindly gave a talk to members at the Medical Society of London's Hall, Chandos Street, London, W.1, on 27th June, 1967. Capt. Sinkankas spoke about various gem localities in North America and, with the aid of many interesting coloured illustrations, described various localities from Ontario, Canada, to California, U.S.A. The fact that Capt. Sinkankas had visited the localities described, made the talk intensely interesting. Capt. Sinkankas gave a detailed account of the occurrence of many gems at the various sites and charmed his audience not only by the extent of his knowledge but also by many humorous asides. The Association is indebted to him for an excellent talk.

Mr. B. W. Anderson, in his introduction to the meeting, described Capt. Sinkankas as a first class lapidary and the author of two books which had made a splendid contribution to gemmological literature. A vote of thanks was proposed by Mr. Robert Webster, who expressed appreciation of the information that had been given.

MIDLANDS BRANCH

The summer outing of the Midlands Branch of the Association took place on 9th July, 1967, when members visited the Blue John Mines at Castleton, Derbyshire. Afterwards a visit was made to Chatsworth House, the Home of the Duke of Devonshire. On the return journey dinner was taken at the White Hart Hotel, Uttoxeter.

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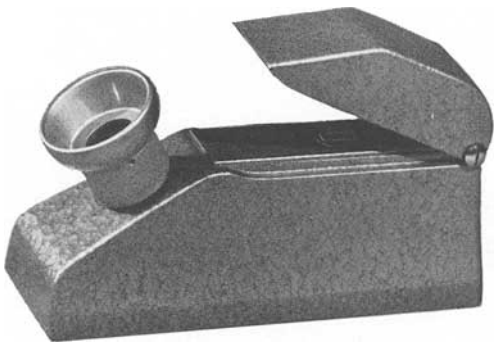

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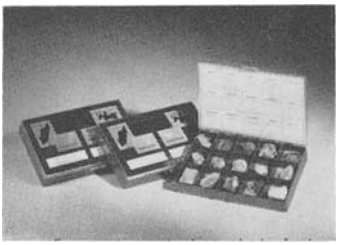

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THE JOURNAL OF GEMMOLOGY

and

PROCEEDINGS OF THE

GEMMOLOGICAL ASSOCIATION OF GREAT BRITAIN

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Vol. 11 No. 1 JANUARY 1968

TRIPLE BILL

Three items of interest to Gemmologists

By B. W. ANDERSON

1. Blue zoisite: a new gem variety

For the keen gemmologist it is always an exciting event when a new gemstone or a new variety of some already known gemstone makes its appearance. Unfortunately such new arrivals seldom have any commercial importance—they may be too rare, too soft, or insufficiently attractive to make them more than collector's items.

Some fine transparent blue-violet crystals, eventually identified as zoisite, have recently been arriving from an East African source. This is said to be in Tanzania near the Kenya border, in the Gerevi Hills, and is near where some interesting vanadium-rich tourmalines have previously been found, as described by Mr. Robert Webster in the *Gemmologist* (March, 1961). These blue zoisites are unlike anything so far seen, and bid fair to be a really interesting addition to the coloured-stone range. It is too early to judge just how plentiful this material is, but enough sizeable pieces have been seen from several trade sources to indicate that it is not too scarce to be commercially handled.

Hitherto, zoisite has been known to gemmologists only in two massive polycrystalline forms suitable for decorative purposes. One of these is the pink variety, thulite, which owes its colour to a little manganese: the other is the handsome green chrome-rich variety which accompanies black amphibole and large hexagonal crystals of ruby in the Matabutu Mountains, Tanzania.

This blue variety was at first reputed to be dumortierite, which is known to occur in blue or violet massive forms with properties not dissimilar from those of the E. African crystals. But the only transparent monocrystalline specimen of dumortierite on record is a brown cut gemstone brought home from Ceylon in 1950 by Mr. Kenneth Parkinson, and purchased by the writer. This was at first thought to be a new mineral, as its properties did not match any given in the literature. However, chemical and X-ray analysis carried out in the Mineral Department of the Natural History Museum proved its identity beyond doubt. For the record, here are the properties of this unique specimen: refractive indices, 1·686, 1·722, and 1·723 for the three principal rays, showing a strongly negative birefringence of 0·037: density, 3·41, and hardness, 8½. The astonishingly high hardness was measured quantitatively for us by Dr. W. Stern, using an indentation method.

The discrepancies between this brown dumortierite and the blue crystals from E. Africa (the properties of which are given below) were so considerable that it was reassuring to have the mineral correctly determined as zoisite by X-ray analysis in the laboratories of the Geological Survey and the Natural History Museum.

Crystals of the blue zoisite so far examined have all been incomplete, showing an odd prism or pinacoid face or two, but never a complete zone. It is uncertain therefore whether the habit is the usual one given in text-books for this orthorhombic mineral. There is one perfect cleavage (said to be parallel to the 010 plane) and on one cleavage surface C. J. Payne was able to obtain accurate refractive index readings on our Abbé-Pulfrich refractometer. The values were, $\alpha = 1{\cdot}6917$, $\beta = 1{\cdot}6927$, $\gamma = 1{\cdot}7005$. The birefringence was thus 0·0088, and strongly positive. The density of a number of pieces was determined by hydrostatic weighing in ethylene dibromide, and proved to be remarkably constant at 3·354-3·355. Two pieces which had slightly lower

densities were seen to have hollow tubular inclusions, which readily accounted for the difference. The hardness was 6 or perhaps a little higher, the mineral scratching window-glass but being itself scratched by a sharp fragment of quartz.

The spectroscope revealed a fairly broad absorption band in the orange-yellow, centred near 5950Å. The strength and position of the band varied somewhat with direction through the mineral, as might be expected from so pleochroic a substance (see under). There were two fainter broad bands in the green (5280Å) and blue (4550Å). It was interesting also to detect several narrow lines in the deep red, resembling weak chromium lines. These, and the broad 5950 band, are reminiscent of the green vanadium tourmalines described by Webster, and it seems quite possible that the colour of this blue-violet zoisite is due to traces of vanadium.

There was no noticeable fluorescence under long-wave or short-wave ultra-violet, nor under crossed filters—thus chromium was presumably absent. Under X-rays there was a feeble bluish glimmer.

Probably the most remarkable feature of this new zoisite lies in the strength and beauty of its pleochroism. The three colours belonging respectively to the three principal vibration directions and seen, two at a time, through the dichroscope when the stone is turned in different directions, are a magnificent sapphire-blue, a rich purple, and a rather pale sage-green. Where possible, the lapidary would be well advised to cut the stone in such a way that the two deeper colours are those seen in directions at right angles to the table facet. The crystals actually vary considerably in depth of tint. The paler types may prove a little insipid when cut, like a pale mauve spinel, sapphire, or amethyst; but those of deeper colour should provide gemstones of very considerable beauty.

2. An inexpensive spectroscope

The spectroscope has for many years been recognized as one of the three really essential gem-testing instruments; but the young gemmologist may well hesitate to buy one for his own use owing to its high price. Before the war the most suitable prism spectroscope for viewing the absorption spectra of gemstones (the Beck 2458) was priced at under £4, while to-day it costs more than £20.

This represents a higher relative increase than that for any other instrument—more than fivefold, as compared, for instance, with the threefold increase in cost of a standard Rayner refractometer.

Thus, to find in a catalogue of miscellaneous instruments and scientific gadgets issued by "Sound and Science Ltd." (a firm with several London branches) a direct-vision prism spectroscope priced at only £6 15s. 0d. (Nov. 1967) was extremely interesting, and I thought it worth while obtaining one of these instruments and giving it a trial to see whether it was suitable for gemmological use. I may say at once that I was impressed at the excellence of its workmanship and performance.

It consists of a simple tube, 3·6 inches in overall length, containing a collimating lens and the usual train of prisms. At one end is a fixed slit and at the other the eyepiece, focusing being achieved by means of a smoothly sliding knob in the side of the tube (see illustration). Both the slit and the eyepiece ends are safely sealed from dust by a glass window. The width of the slit (which is simply a narrow slot in a metal plate, probably cut with a diamond saw) is perfectly chosen for the observation of sharp, bright line spectra such as those emitted by mercury, neon, or sodium vapour lamps. This is obviously the prime object of this simple instrument and the added refinement of an adjustable slit is quite unnecessary for emission spectroscopy. The gemmologist, on the other hand, often needs to search for bands in the obscurity of the blue and violet part of the spectrum where there is also

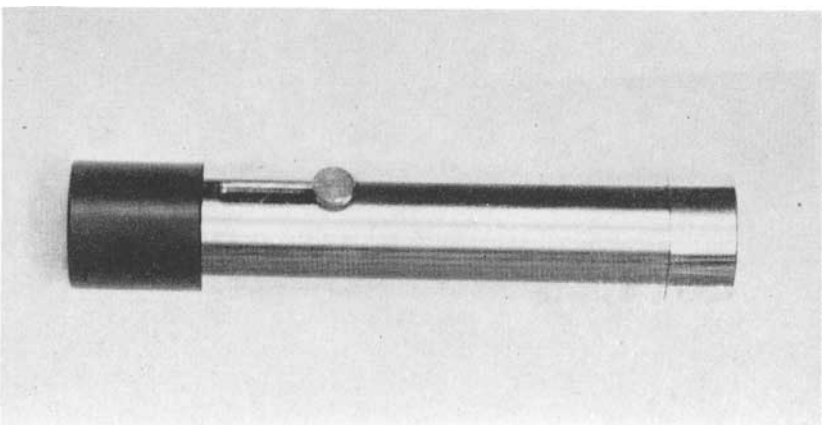

considerable general absorption, and then the ability to open the slit slightly to admit more light, even though it means some loss of definition, is a very real advantage.

The dispersion of the spectroscope under review is slightly greater than that of the Beck 2458 to which we are most accustomed, and which is probably ideal in that it enables the viewer to cover the whole visible spectrum with ease—but towards the red end of the spectrum the new instrument scores in revealing the narrow chromium lines in ruby, emerald, and alexandrite in unaccustomed detail, while under good conditions the important diamond line at 4155Å could be detected. An added pleasure is the complete absence of dust streaks, while the focusing is very smooth and positive, and requires little adjustment between one end of the spectrum and the other.

On balance one can say that this little hand-spectroscope is a very good buy for the gemmologist who feels debarred from using any of the standard instruments of this kind on the grounds of cost. He must, however, be prepared to provide himself with a really powerful source of light, such as a 300 or 500 watt projection bulb, suitably housed, condensed by means of flasks of pure water or containing copper sulphate solution, according to the part of the spectrum to be examined. The spectra of ruby, emerald, alexandrite, red spinel, zircon, almandine, didymium (in various host minerals), enstatite, peridot, sapphire, are amongst those which should be clearly visible. Only the absorption bands in the violet, such as the jadeite 4370 and turquoise 4300Å bands, should be appreciably more difficult to obtain than in the more expensive spectroscopes with adjustable slits.

The "hand spectroscope" described above has no special number or title. It is snugly housed in a plush-lined box, and is made in Japan.

3. A pearl from the common whelk

It is well-known that a number of shell-fish other than the recognized salt-water "pearl oysters" or fresh-water "pearl mussels" are capable of producing pearls of a sort, though these are seldom of much commercial value. The nature of the pearl or concretion must necessarily depend largely upon the texture and type of lining found in the shell of the mollusc—since the normal function

of the cells which secrete the "pearl" is simply to build a shell in which the soft-bodied creature can live with a fair degree of safety. Thus the nacreous beauty of the pearls most valued in commerce can only be derived from molluscs whose shells are lined with mother-of-pearl.

Certain non-nacreous pearls, however, in particular the "pink pearls" found in the giant conch (*Strombus gigas*) are sufficiently attractive to find a place in jewellery. These have a porcelain-like surface (in common with that of the shell lining) enlivened by a curious sheen at certain angles, having a characteristic and attractive flame-like pattern. Conch-pearls, as their alternative name suggests, are usually pale pink in colour. Very similar pearls, but white in colour, are occasionally found in the giant clam (*Tridacna gigas*). A characteristic of these products is a density around the 2·85 mark which is appreciably higher than that of the coral they somewhat resemble, or of nacreous pearls.

It was something of a shock when a pretty little pearl showing the typical "flame pattern" of conch pearl, though having very little colour, was sent to us by the National Association of Goldsmiths with the story that it had been found in the flesh of a common whelk, *Baccinum undatum*, so extensively used for food amongst those who have a taste for shell-fish. In addition to the surface structure, the density of the whelk pearl, which weighed 1·23 carats was found to be high (2·80), though not quite up to the usual conch value.

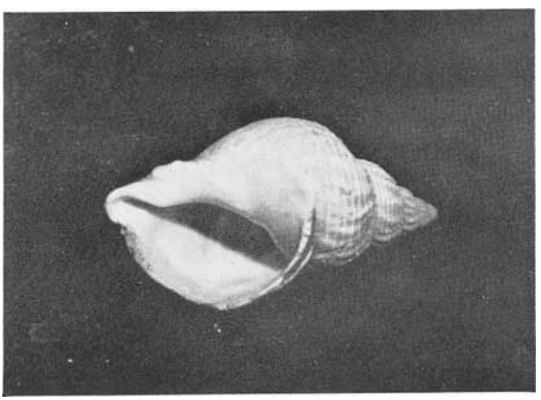

FIG. 2. *Common whelk.*

PEANUT OBSIDIAN FROM SONORA, MEXICO

By PAUL L. BROUGHTON

SEVERAL years ago a new American lapidary material entered the market of Southern California and its use gradually spread throughout the country and nearby Mexico. The material is popularly referred to as peanut obsidian, though it is, in fact, a spherulitic perlite. This black natural glass contains, in amounts up to one half of its volume, quarter-inch in diameter hematite-red spherulites. When cut on cabochon it produces a pleasing effect similar to bloodstone, except red on black. The matrix and spherulites take an even glassy polish, both equally matched in hardness to prevent serious undercutting.

Thin section examination reveals the perlitic texture of the "obsidian". The spherulites consist of thin rod-like radiating crystals of feldspar, stained red by hematite. Secondary chalcedony appears to encase each spherulite and constitutes the fill of the cracks in the spherulite itself. An X-ray diffractometer analysis of the spherulite verified the presence of interstitial cristobalite, as well as the feldspar being near oligoclase in composition.

The original material was discovered by one Alberto Maas near Alamos, Sonora, Mexico. In the proximity of the original outcrop, a deposit of an agatized variety was later discovered. The matrix of this variety had been altered to an earthy grey colour. The spherules in this case are relatively large, up to two inches across, and consist of red, grey, white and brown concentric layers. Another variety of the material is with a porcelain-like matrix with the typical quarter-inch red spherulites. Dr. Frederick H. Pough asserts that it was altered by devitrification to bentonite,[1] rendering it too soft for most lapidary uses.

The term "peanut obsidian" has its own interesting etymology. Originally, the term "almasite" was proposed by one James Kraft, a renowned American jade carver, who formed the financial backing of Alberto Maas' exploitation of the Alamos deposit. As it turned out, the name had already been applied to a lead metasilicate from a small gold and copper prospect nearby. Gradually, the term peanut obsidian, in reference to the red "peanut" spherulites, received acceptance by the lapidarists familiar with the material.

REFERENCE

1. Maurice Hebner, *Written Communication*, March 19th, 1966.

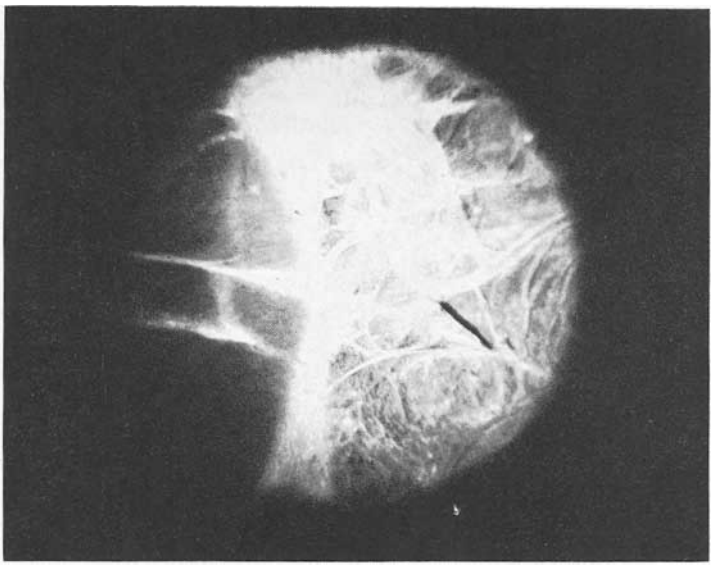

A rare agatized variety of peanut obsidian Specimen about three inches across.

Photomicrograph of the contact between the spherulite (left) and the perlitic structure obsidian (right). Note the wide chalcedony (vertical white streak) deposit at the contact.

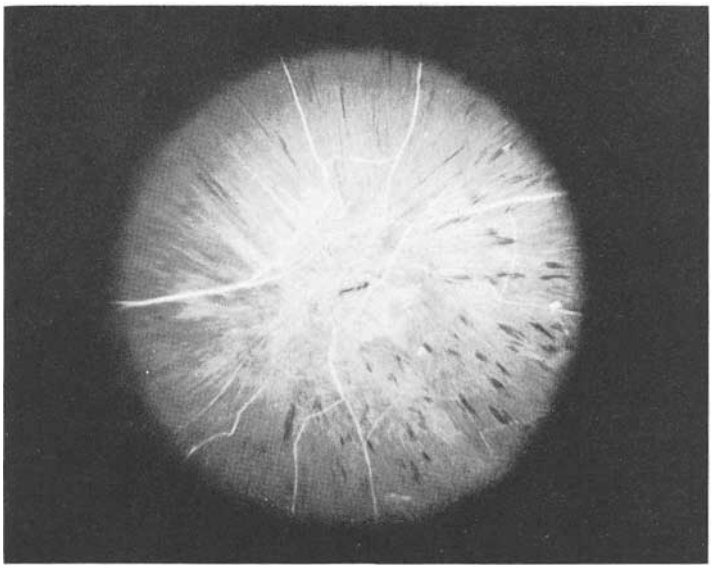

Full view of the spherulite showing cracks filled by secondary chalcdony.

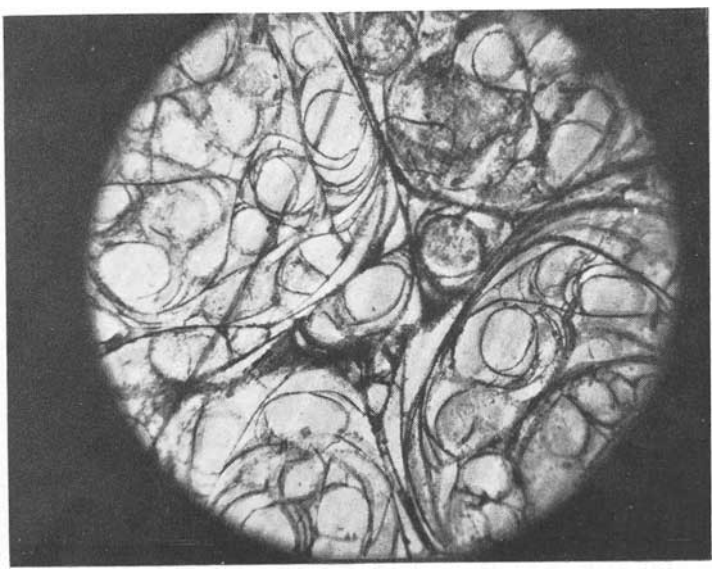

Typical texture of the peanut obsidian perlitic texture.

POSTAL GEMS

By S. B. NIKON COOPER

FOR the benefit of any impecunious gemmologist who would like to start a gem collection but lacks the wherewithal to do so, I would suggest that a collection of crystals and minerals in postage-stamps be made. This need not be a reversion to old school-day habits; it can be an informative and interesting pastime. There are many countries which have chosen to portray gems and crystals on their postage-stamps, and this number will doubtless increase as the "thermatic" side of the hobby spreads, with the countries concerned realising the economic and prestige value to themselves in supporting this.

Switzerland leads the field with a whole series of "Pro Patria" issues. These, designed by N. Stoecklin, give particularly colourful and life-like illustrations of gem crystals, showing clearly matrix and gem-habit, with details of symmetry and striation, etc., well in evidence for the student.

Quartz is well represented, with illustrations of smoky quartz (1960), rock crystal (1958), amethyst (showing a rare "sceptre" crystal (1959), and with, I think, a poor-ish, highly coloured illustration of fortification-agate (also 1959).

There are two illustrations of fluorite: one (1958), showing a typical interpenetrant twin, and the other (1961), giving an illustration of the classic Chamonix pink octahedral form. Feldspar (1960), almandine garnet (1958) and tourmaline (1959) are also included in this series.

The Russians, with a superb set of stamps, issued in 1963, have portrayed their own, Ural, gem region. These are particularly beautiful stamps showing malachite, rhodonite, ribbon-jasper, amethyst and emerald—and the one no-one interested in crystallography should be without: a topaz of the "Ural" type, with the "c" face particularly prominent.

S.W. Africa, too, has contributed a series on its native gems, but I would wish the standard of printing here were as high as that of the first two countries mentioned. This series, showing crystals and cut stones, is of tourmaline, topaz, golden beryl and diamond.

Diamond, of course, as a symbol of national prosperity is featured by several countries: a stylized representation from S. Africa (1966) marks that country's association with the Queen of Gems. An issue from Tanganyika (1961) serves to remind me, at least, of the Williamson pipe discovery in that country. Another (1967), comes from the new territory of Lesotho (Basutoland), and finally, the gem-cutting industry of the Low Countries has not been forgotten and is marked by an issue from Belgium (1965).

Rhodesia has recently produced two "gem" stamps, showing crystals and cut stones, reminding us of her own Sandawana emeralds.

Lastly, though hardly gem-minerals, E. Germany has come into the stamp field with her 1965 issue, featuring two illustrations: of sulphur and proustite.

All in all, a colourful little collection can be built up, and one which I believe will grow as other countries follow the lead. One looks forward to the day when Brazil—to name at least one—will issue her stamps. Again, such a collection has one great factor in its favour: whereas stamps have value, these issues are, all of them, of recent date, and mercifully not in the same price-range as the gems they represent.

INCLUSIONS IN BLACK STAR-PYROXENE

By J. F. R. PONAHLO

QUITE recently B. F. Martin[1] studied diopsides of black colour exhibiting a type of asterism and published some photographs of inclusions. In another paper in this journal W. F. Eppler[2] studied the phenomenon of asterism in a brown diopside and suggested that the exsolved material could possibly be clinoenstatite. In his publication reference was made to an article by R. Liddicoat[3], who reported on the formation of both broad and narrow rays of a four-rayed star, obviously also seen in cabochon-cut black diopsides.

It was during a recent visit of the author of this article to Idar-Oberstein that a number of black star-pyroxenes could be inspected, and from a quick glance upon more than 100 specimens and after investigations of samples with a 12 × lens it became evident that the rays of the star intersect at nearly the same angles of roughly 105°, thus corroborating the findings of Martin on a larger number of specimens.

Since more than a year such star-stones had been intermittently investigated in the author's own laboratory and a short summary of this work might be of interest to gemmologists.

Density measurements, determinations of the refractive indices by means of a Rayner-refractometer and preliminary tests with a microscope gave results that were consistent with the findings previously published, only the values of the double refringence of 0·028-0·030 were higher than those found by Martin. No specimen tested was of other colour than a deep satin-black. All samples were polished cabochons. It was said the raw material would come from India, but the author's endeavour to get a piece in the rough was frustrated. According to Eppler they are of a brown colour, but obviously this was a different material, for brown colours could only be found in thin, translucent slices of unpolished sections.

To get a better insight into the nature of the inclusions it was necessary to prepare thin slides, polished flat samples and some fine powder for the X-ray analysis of this opaque pyroxene.

When polishing a cabochon on its flat base for subsequent studies in incident light, strong reflections from small inclusions were observed which, under low magnification, showed an unmistakably metallic character. During the preparation of a powder for X-ray analysis a strong magnetism of the particles was observed. It was very difficult to separate this powder into magnetic and non-magnetic particles. Even in fine powders the effect of magnetism was noticeable.

The diffraction diagrams taken on a Philips X-ray goniometer with Cu-Kα radiation of two specimens gave consistent results. The host material was a monoclinic pyroxene of "augite" structure C2/c, to use the notation of Bown and Gay[4]. Of other reflections only those of magnetite could be found. As expected a number of reflections from magnetite coincide with some from the host-mineral indicating also epitaxy. Only the most prominent lines of magnetite which reinforce some rather weak reflections of the augite, and two characteristic reflections of magnetite which were free from coincidence could be used for the identification of the inclusions. The diagrams were compared with data from literature and checked against diagrams taken from natural, light-green diopside and black augite crystals.

It is known from Bown & Gay[4] that in naturally occurring pyroxenes only magnetite and ilmenite are found as magnetic inclusions. By comparison of the X-ray data ilmenite was certainly absent. Under the microscope and in incident light these coarse, plate-like inclusions with a sort of metallic lustre were isotropic, whereas ilmenite should be hexagonal-rhombohedral. Therefore these inclusions could only be magnetite.

In thin slides prepared in the laboratory the width of these inclusions could be measured and values were found between 30 and 150 microns, their length being ten to twenty times their width. Inclusions of such dimensions cannot cause asterism—which would be based on an interference phenomenon.

Higher magnifications than 150 × revealed the existence of

a matrix of brown material. It consisted of a system of fine lamellae showing signs of orientation similar to those of the broad and large inclusions. These lamellae were short, usually between three to ten microns, very rarely extending to 40 microns. The thickness seemed to be half of the width. Although with the equipment at hand no accurate measurement could be made, the average width of these inclusions (thickness) was certainly less than one micron, possibly not more than 0·4 microns. The excellent contrast these inclusions showed against the surrounding pyroxene can only be due to marked differences in the refractive index of both phases.

From Bown & Gay we know about the types of exsolved pyroxene phases which could occur in pyroxene host material. But it is most unlikely that such exsolution lamellae of less than one micron in diameter could be distinguished from the surrounding at magnifications between 250 × and 500 ×. Moreover, taking into consideration the colour, the high relief, the similar orientation to the coarse of magnetite, this would lead to the conclusion that these lamellae could also be magnetite. The only other alternative would be TiO_2, either as rutile or as brookite. As the amount of this phase is too small to be identified by means of X-ray methods and as special oil-immersion systems would be needed to trace the optical character of these inclusions the final answer should be left to a future investigation. Occasionally some mica was found, where the coarse magnetite plates are broken into small fragments.

Returning to the question of what causes the star-effect the following explanation can be given. If the coarse phase of plate-like inclusions of magnetite is the only cause for this effect, the observed asterism is but a phenomenon of reflection and should be designated as "schiller". Reflection from smaller and broader plates of magnetite can easily account for the difference in the width of rays as observed by Liddicoat in some cases. The other effects reported by Martin can be ascribed to small deviations of the angle between the two principal directions of the oriented magnetite plates and to a non-linear arrangement of some of these inclusions, both of which could be seen during observation in transmittent and incident light.

As the author is going on to study the orientation of both inclusion systems relative to each other and to the host it is too

early to predict whether there exists an interference phenomenon in addition to the schiller-effect. From what is known in the present state of investigation it seems rather unlikely that the schiller-effect would be accompanied by an interference phenomenon. So far we can only compare this star-effect with similar ones found among the orthorhombic members of the pyroxene family.

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Gemmological Abstracts

ANON. *Non-metallic minerals, No.* 2. A review of resources, production, trade, consumption and prices relating to sulphur, gypsum, and anhydrite, asbestos, asphalt and bitumen, magnesite, graphite, mica and diamonds. London (Commonwealth Secretariat), vi + 170 pp., 77 tables, 1967. Price 35s.

Synthetic diamonds for industrial uses are now being produced in Sweden, the Irish Republic, Japan, the Soviet Union, and Czechoslovakia as well as in the U.S.A. and South Africa: total production is probably around a fifth of that of all natural diamonds, and a quarter of that of natural industrial stones alone. Known resources of gem diamonds in non-Communist countries will probably last for little more than another 15-20 years at 1965 rates of production but for the existence of offshore deposits.

R.A.H.

HUDON (D. R.), WILSON (A. F.) and THREADGOLD (I. M.). *A new polytype of taaffeite—a rare beryllium mineral from the granulites of central Australia.* Min. Mag., 1967, 36, 279, p. 305.

A green mineral found in the Musgrave Ranges in central Australia during 1966 was found to be a 9-layer rhomohedral polytype of taaffeite. It is pale olive-green, with refractive indices $\omega = 1{\cdot}739$, $\varepsilon = 1{\cdot}735$, and a specific gravity of 3·68. It contains 6·78% of FeO.

S.P.

FRONDEL (C.) and MARVIN (U. B.). *Lonsdaleite, a hexagonal polymorph of diamond.* Nature 1967 Vol. 214 (5088) pp. 587-589 (May 6).

From observations on the carbonado in the Canyon Diablo iron meteorite, it is suggested that irregular masses and morphological single crystals of diamond occur together as they do in terrestrial diamond deposits and that both have been more or less completely converted to micro-crystalline aggregates of the hexagonal, wurtzite-like polymorph by terrestrial or preterrestrial shock.

S.P.

MEEN (V. B.), TUSHINGHAM (A. D.) and WAITE (G. G.). *The Darya-i Nur diamond and the Tavernier "Great Table"*. Lapid. Journ., 1967, 21, 8, p. 1000.

A report, based upon a study made possible through a grant from the Henry Birks Family Foundation, Montreal, Canada, of the examination of the pink Darya-i Nur diamond in the Iranian Crown Jewels. The authors believe that the Darya-i Nur is the major portion of the "Great Table" diamond seen by Tavernier in 1642. A pink brilliant-cut diamond, the central stone in the tiara of the Empress Farah, is considered to be part of the Darya-i Nur stone. S.P.

MARION (C.), PICOT (P.) and SCHUBNEL (H-J.). *Nature des inclusions du diopside noir etoile de l'inde.* Assoc. Francaise de Gemmologie. Bull. 12, 1967.

Studies made with cabochon-cut brown-black diopside from India, displaying asterism, indicated that the inclusions causing the asterism are ex-solutions of thin lamellae, which are mainly formed by magnetite, together with ilmenite and spinel. S.P.

FLANIGEN (E. M.), BRECK (D. W.), NUMBACH (N. R.), and TAYLOR (A. M.). *Characteristics of synthetic emeralds.* Amer. Mineralogist, 1967, 52, pp. 744-772.

Large single-crystals of synthetic emeralds have been grown by both hydrothermal and molten flux techniques and are of excellent quality comparable to the finest natural gemstones from Colombia and the Urals. Emeralds grown from lithium molybdate, vanadium pentoxide and lithium tungstate fluxes are described. Crystals as large as 25 carats have been grown: a seed plate cut perpendicular to the *c*-axis is used, to give a hexagonal prism-shaped crystal. Cr varies from 0·05 to 1·4%; for gems 0·2-0·4% Cr seems to give the most aesthetically pleasing colour. The properties and characteristics of the various varieties of synthetic emeralds are listed and the distinctions between the varieties are outlined. The origin of an emerald (natural, synthetic flux or synthetic hydrothermal) can be defined by determination of characteristic properties. R.A.H.

WHITE (W. B.), ROY (R.), and CRICHTON (J. McK.). *The "alexandrite effect"; an optical study.* Amer. Mineralogist, 1967, 52, pp. 867-871.

An investigation of the crystal field environment giving rise to the well known change from green to reddish purple when the lighting on an alexandrite is changed from daylight to a low colour temperature incandescent light shows that this colour change is due to presence of trivalent chromium in a distorted octrahedral site in the crystal structure. The effect is related to the critical wavelength minimum in the absorption spectrum and is not unique to alexandrite or to the trivalent chromium ion. In synthetic stones, generally corundum, the presence of trivalent vanadium gives a similar effect. R.A.H.

LIDDICOAT (R. T.). *Cultured pearl farming and marketing.* Gems and Gemology. 1967, XII, 6, 162-172.

An abridged version of a talk given at a Conclave in Boston. In addition to a general survey of cultured pearl production and farming, there is information about a new strain of *Pinctada martensi* (i) in the warm waters of Kyushu. These grow to a larger size than the oysters from Age Bay and may produce larger cultured pearls. The rate of nacre deposition on the bead nucleus is discussed, and something is told of the bleaching and staining of cultured pearls. The article closes by describing an appraisal system.

11illus. R.W.

ANDERSEN (O.). *A Prospector's guide to the Anakie sapphire fields.* Gems and Gemology, 1967, XII, 6, 173-178 and 192.

Extracts from an article under the same title published in the Queensland Government Mining Journal. A similar article extracted from the same source was published in the Australian *Gemmologist* (Abstracts; Journ. Gemmology 1967, 10, 6, 206). This extract discusses the location and occurrence of the Anakie fields of Queensland. A list of associated minerals—those which give an indication of the presence of sapphire—are given. The methods of recovery and tools used for the mining are discussed.

R.W.

CROWNINGSHIELD (R.). *Developments and highlights of the gem trade laboratory in New York.* Gems and Gemology, 1967, XII, 6, 179-182.

Psilomelane has been used as a substitute for hematite, and it can be detected by the fact that a drop of concentrated hydrochloric acid dissolves the area of the surface upon which it is placed and releases chlorine gas which can be smelt. Sintered synthetic corundum of pink colour and the staining of lapis-lazuli are discussed. Other items mentioned are an emerald doublet made of a flawed beryl crown and a green glass pavilion, green-dyed quartzite as a jade substitute, and the fluorescence of a black cultured pearl.

5 illus. R.W.

LIDDICOAT (R. T.). *Developments and highlights at the gem trade laboratory in Los Angeles.* Gems and Gemology, 1967, XII, 6, 183-190.

Discussions on unusual diamonds comprise most of this article and include mention of "sugar-cube" and needle-like inclusions, odd types of facets on a cut stone, Ghanaian crystals and an extraordinary cylindrical crystal produced by elongated growth along an octahedral direction. A canary-coloured diamond bathed in a beam of blue light from a copper sulphate filter showed a rather bright red. It is stated that the effect had not been seen before. (The London laboratory has a natural canary diamond which behaves similarly.—ED.). Other items mentioned are kinked striae in a synthetic garnet-red coloured corundum, andradite garnet from Arizona, a scapolite catseye, chrome-rich chalcedony, synthetic rubies made by the flux-fusion process, and a snuff bottle made out of white serpentine.

17 illus. R.W.

MCLEAN (E. M.). *Chrome chalcedony.* Lapid. Journ., 1967, 21, 9, p. 1188.

A translucent material similar to chrysoprase is considered to be chrome chalcedony. Sample analyses show 0·2% and 0·3% chromium. The mineral occurs at the north-western limit of the Great Dyke which runs through the centre of Rhodesia.

S.P.

ASSOCIATION NOTICES

HERBERT SMITH MEMORIAL LECTURE

The 1967 Herbert Smith Memorial Lecture was held at Goldsmiths' Hall, London, on 16th November. Mr. Norman Harper, chairman of the Association, who presided reminded the large audience about the valuable work that Dr. Herbert Smith had done for the Association and the cause of gemmology. He was the author of the standard text *Gemstones*, which first appeared in 1912, and he had also been President of the Association. Mr. Harper welcomed Dr. Max Hey, Senior Principal Scientific Officer at the British Museum (Natural History) in the Department of Mineralogy.

Dr. Hey spoke about meteorites and began by discussing the various disbeliefs that had persisted for a long time about meteorites and tektites. Although much more was now known, the study of meteorites still produced its problems and controversies. His lecture was illustrated by many interesting pictures. One particularly showed the falling of a meteorite, with ball of fire head and a whip-like tail. There were still doubts about the origins of some meteorites, though the reasonable theory that they arose from a breaking up of heavenly bodies, commanded considerable support.

After a series of interesting questions, mainly about tektites, Mr. B. W. Anderson thanked Dr. Hey for an extremely informative lecture.

GIFTS TO THE ASSOCIATION

The Council of the Association is indebted to Mr. S. P. Barnett, F.G.A., who has presented the gemmological diploma presented to his father in 1913. The diploma is numbered D.1 and the Council is grateful to have the document for its records. Mr. Barnett also gave the Association a part-coloured corundum showing well-defined blue and red zones.

Mr. R. Webster has kindly presented specimens of stichtite, grossular garnet and sodalite from South Africa and Rhodesia.

A specimen of Australian opal was kindly presented to the Association by Mrs. B. E. M. Barkle of West Australia.

A gift of £10 has been received from Mr. Toyoji Kato, of Tokyo.

SCOTTISH BRANCH

On the 31st October, 1967, a record audience of Scottish Branch members heard Mr. Norman Harper, Chairman of the Association, talk on "A Hundred Years of Diamonds".

Mr. Harper stressed the difficulties in discovering how diamonds occurred orginally in nature and how to reproduce them in a laboratory. Even now after years of extensive study nobody can say exactly how or why diamonds occur where they do in the world. After a short résumé of his work in aid of gemmology and how he organized the postgraduate diamond diploma course in Birmingham, which is now available in London, he presented two copies of his notes and challenged the Scottish Branch to start it in Glasgow.

Mr. Alastair Cairncross proposed a vote of thanks to Mr. Harper. Consequential upon Mr. Harper's talk the Scottish Branch has circularized local members to ascertain whether they would be interested in attending classes in connection with a Gem Diamond Course.

MIDLANDS BRANCH

Mr. F. S. H. Tisdall, F.G.A., was the speaker at a Meeting of the Midlands Branch of the Association held on the 29th September, 1967. His subject was "Natural and Synthetic Emerald" and he described some easy methods in which the synthetic could be differentiated from the natural gem. In his talk Mr. Tisdall said:

It all depends what is meant by 'easy'; but for the purpose in hand the apparatus required consists of a high intensity lamp; or other concentrated source of white light; a blue filter, or flask filled with copper sulphate solution (as illustrated in colour in 'Gem Testing' by Mr. B. W. Anderson); a deep red filter; an emerald, or 'Chelsea' filter; a refractometer; a small tube of heavy liquid blended to a definite, and rather critical density; and, of course, the usual ever useful 10 × loupe. A microscope is a very useful accessory but not absolutely essential as will be shown. Indeed it often happens that a 10 × loupe in skilful hands, coupled with an experienced eye, will enable an emerald to be classified with certainty, either as synthetic or natural.

So for discriminative purposes the first approach, as with any gem, is to subject the stone to a careful optical examination with a good hand lens. And let it be said at once that nothing, nothing can be a substitute for experience. Patient and prolonged examination of many stones is essential in order correctly to interpret the significance of what is seen in them. Excellent photomicrographs showing clearly the types of inclusions to be met with in both synthetic and natural emeralds are to be found in many books, and with care one learns to correlate the illustrations with what is seen in an actual specimen. If a microscope is available, giving a degree of magnification of some 30 ×, not only can a stone be identified as real or synthetic, but, if real, its provenance may be determined. However, the present purpose is concerned chiefly with deciding whether a stone is natural or synthetic; and in many synthetics (not all—especially the more recent products)—in many synthetics the curved, wispy feathers, which when seen, serve absolutely to identify them, can be discovered with nothing more than a 10 × loupe. Mention must also be made of the phenakite crystals

which occur in many synthetics (again, not in all), but as their detection needs a microscope and as their appearance is not so highly characteristic of the synthetic as that of the feathers, and, moreover, as the emphasis in this talk is on the word 'easy', this passing reference is all that will be said of them.

Should an optical examination not lead to any very definite conclusion that well-tried and most useful piece of apparatus, the refractometer, should next be called into service.

Emerald is a doubly refracting gem and the R.I's of the natural stone have a fairly wide range extending from 1·568 to 1·590 for the extraordinary ray, and from 1·573 to 1·598 for the ordinary ray; the lower figures being those for pale stones from Brazil, and the higher those for emeralds from Pakistan. Between these extremes are a series of R.I's corresponding to stones from other localities. The amount of birefringence varies from ·005 to ·008. The variation in these figures is accounted for by the presence of impurities, especially iron and the alkali metals, which tend to raise them. On the other hand the constants characteristic of synthetic emeralds, on account of the purity of the ingredients from which they are manufactured, vary scarcely at all.

For the present purpose it is necessary to take account only of the lowest indices possessed by any natural emerald, which are 1·568 to 1·573, for ε and ω respectively, and that the minimum birefringence is ·005. These figures are very important, for careful use of the refractometer reveals that the R.I's for Chatham & Gilson synthetics are not only perceptibly lower than those of the natural stones, but also that the amount of double refraction is only about half. Chatham & Gilson stones read 1·560 to 1·563, or very, very close thereto.

For accurate determination of these figures monochromatic light or a deep yellow filter is required. A spirit lamp upon the wick of which a pinch of salt has been placed will provide the former if care be taken to shield the flame from air currents. However the Anderson-Payne spinel refractometer is ideal for the purpose in hand as accurate readings may be made by ordinary electric lighting without having recourse to filters or spirit lamps. And, as is the case with the observation of characteristic inclusions, so with careful determination of R.I's—the result can be quite definitive. But although this *is* so, reliance should not be placed upon one test only; especially where considerable sums of money may be involved; always make at least two, or, preferably three tests.

A very simple test—the simplest of all—relies for its efficacy upon the difference between the S.G's of natural and synthetic emeralds. Just as the R.I's of synthetic emeralds are lower than those of the natural stone, so, obligingly enough, are the S.G's lower. It is, of course, necessary that stones be unmounted to carry out this test, which is a very useful and convincing one. Again, no doubt owing to the presence of various impurities, the S.G's of natural stones have a fairly wide range, varying between 2·68 for those from Brazil, and 2·77 for those from Pakistan; it is only the lower figure which is of interest. The S.G. of Chatham & Gilson synthetics is constant at 2·65. Thus, if a heavy liquid be prepared, such as a mixture of bromoform and toluene, in which a known synthetic will just float, then in this same liquid all natural stones will unfailingly sink.

We have now dealt with tests involving inclusions, R.I's, and S.G's, any one or all of which can yield information which will lead to a definite conclusion

one way or the other. What is, perhaps, the most interesting and spectacular test has been left until last—that depending upon fluorescence. It is a well established fact that the cause of the beautiful velvety green hue of a fine emerald —natural or synthetic—is the presence of minute quantities of chromium, which replace aluminium in random positions in the crystal lattice. It is also an element the presence of which, unless inhibited by the dampening influence of iron, gives rise to fluorescence, which can be a most helpful property when a diagnosis is to be made.

This seemingly mysterious property is not really difficult to understand even though the explanation now offered is somewhat over-simplified; light of short wavelength, such as X-rays, ultraviolet light, or even visible light at the violet end of the spectrum is possessed of high energy. On its passage through a transparent, fluorescent crystal some of this energy is absorbed by the atoms which compose it—in this particular case by the chromium intruders—which then become activated, or excited. When these excited atoms revert to normal they do not do so all at once, but in small stages or 'jumps'. At each jump a light impulse is given out which must have less energy, or, what comes to the same thing, a longer wavelength than the original exciting radiation. This explains why radiation of a wavelength too short to be within the range of vision. can give rise to light of a wavelength long enough to be visible. Hence we have fluorescence.

Fluorescence in emerald can be observed in three easy ways:

The simplest is to view a brightly illuminated stone, held, for instance, close to a 100-watt bulb, through a Chelsea filter. Most natural emeralds of good colour will appear red, or at least pinkish. Synthetics will appear a bright red, which is a very useful indication of their true nature, though it must be borne in mind that fine Colombian stones are reputed to approach closely to this colour; although the present speaker has yet to encounter a natural emerald of any kind that shows as bright a red through the filter as a synthetic.

Parenthetically it may be noted that a filter should not be used like a loupe with both stone and instrument held close to the eye. Place the loupe, held usually in the right hand, close to the eye, and hold the stone to be examined at arm's length close to the source of illumination. From personal observation, the writer has noted that not all jewellers, or even gemmologists, appear to be aware of this technique.

Natural emeralds from the Transvaal and India will still look greenish through the filter as they contain iron in their composition, the presence of which inhibits fluorescence. Mr. Anderson also states that some soudé emeralds look red through the filter, so obviously this simple piece of apparatus must not be relied upon implicitly. It is, nevertheless, still true that bright red through the filter is strong evidence of synthesis, and any such stone must be the subject of further scrutiny.

A second method of exciting fluorescence is to expose emeralds to the rays from an ultra-violet lamp in a darkened room. Synthetics will fluoresce more brightly than natural stones, those from the Transvaal and India remaining almost inert.

The most satisfactory and convincing results are to be obtained by the third method, which is what is known as the crossed filter technique. This

method of observing fluorescence was first devised by G. G. Stokes over a century ago.

The stone for test is placed on a dark background, together with one or two stones of known origin to serve as controls and illuminated by a beam of light that has been passed through a blue filter or a flask filled with copper sulphate solution. They are then observed through a deep red filter. For this experiment the room need not be in absolute darkness providing it is only dimly lit. The reaction of the synthetics is very striking; they will fluoresce a bright red. A fine Colombian, or other emerald of good colour (except African and Indian stones) will also fluoresce, but none to the same extent as the synthetics, which seem actually to glow.

In this talk I have not mentioned the Lechleitner synthetic emerald coated beryls as the primary object is the detection and differentiation of synthetics, and the general appearance of these stones is likely to deceive no one who has had any experience of emeralds at all. Furthermore, the speaker understands that the vogue for these stones, never very great, is now, for practical purposes, over. The market for synthetics is now adequately supplied by Chatham & Gilson stones. Indeed, to give credit where it is due, the degree of clarity and beauty of colour achieved by some recent examples seen by the writer seem to constitute for practical purposes what must be regarded as perfection in the art of synthesis.

Linde emeralds, though extensively marketed in America, have so far not reached this country as a commercial product. A Linde crystal has been examined and reported on in a recent article by Mr. Webster, appearing in the *Retail Jeweller;* he concludes his article by stating the Linde stones 'will be readily identified by their strong luminescent characters, and by the nature of their inclusions'.

The Zerfass emerald also has not yet reached England. I do not expect any particular difficulties in differentiating it from the natural stone should it do so. The only Zerfass stone the speaker has so far seen contained many of the highly characteristic wispy feathers. So far our problem in this country lies in distinguishing between the natural stones on the one hand, and Gilson & Chatham synthetics on the other. It may not always, or even for long, be so. It behoves the gemmologist perpetually to be on the *qui vive.*

Summarizing what has been said we may say that the first approach, as with *any* stone, is to give it careful scrutiny with a 10 × loupe, and/or a microscope. In many cases this will prove to be all that is necessary when once the observer has familiarized himself with the types of inclusions to be expected.

Next, if unmounted, the simplest test is the heavy liquid one, provided the operator is careful to ensure by means of a control stone that his liquid is of the correct density, which is critical.

Whether mounted or unmounted a careful R.I. reading will provide positive evidence. A spinel type refractometer is recommended.

Finally, a fluorescence test between crossed filters will add to the cumulative evidence of the other tests, and in conclusion, the speaker maintains that an emerald, natural or synthetic, which reacts in an anomalous or inconclusive manner in all four tests described does not (so far, at any rate) exist.

JOURNAL OF GEMMOLOGY

Readers of the *Journal* are invited to submit suitable articles for publication, which will be paid for. Upon request up to 25 reprints of any article published are available to the author.

COUNCIL MEETING

At a meeting of the Council of the Association held on Thursday, 16th November, 1967, the following elections took place:—

FELLOWSHIP

Arps, Charles Edward Samuel, Netherlands, Holland
Astley-Sparke, Jeremy Peter, London
Beck, Cyril Anthony, Manchester
Blacklock, Ralph Ellis MacRae, Sunderland, Co. Durham
Bodenham, John Edward, Halesowen, Worcestershire
Bodes, Reginald, Voorburg, Holland
Borrmann, Bjorn, Fjullhamar, Norway
Bowers, Norman, Heywood, Lancs.
Brown, Janet Irene (Miss), Congleton, Cheshire
Buchanan, Alistair McKenzie, Edinburgh
Bytheway, Keith Leonard, Walsall, Staffs.
Chan, George K. L., Kowloon, Hong Kong
Clifford, Geoffrey Roy, Maidstone, Kent
Collier, Alan, Burscough, Lancs.
Cowbourne, Elizabeth Mary (Miss) Bingley, Yorks.
Croydon, Robert William, Old Catton, Norwich
Cuss, Christopher Jude, London
D'Arcy, Michael Stephen, Peterborough, Northants.
Doughty, Mary Forbes (Mrs.), Birkenhead, Cheshire
Earnest, Robert A., California, U.S.A.
Edrisinghe, Barbara (Mrs.), Colombo, Ceylon
Frost, Frank Roger, Upper Wolvercote, Oxford
Fuller, Robert George, Chesham, Bucks.
Gay, Alan Leslie, Birmingham
Goodman, Brian John, Walsall, Staffs.
Gregory, David George, Waterloo, Liverpool
Gunnar, Baugerod, Porsgrunn, Norway
Hamnett, Norman, Radcliffe, Lancs.
Johnson, Cyril Alan, Rugby, Warwicks.
Jones, Sylvia Margaret (Miss), London
Lorimer, Barry Anthony, Keighley, Yorks.
Mechlin, Wilmer, Maryland, U.S.A.
Neary, Geoffrey, Huddersfield, Yorks.
Parkes, Frederick, Stanmore, Middx.
Priestman, Arthur, Manchester
Evans, Royston Thomas, Timperley
Rees, Dietlinde Maria Augusta (Miss), London
Renfrey, Eric, Ormskirk, Lancs.
Rickenberg, Robert E., Los Angeles, U.S.A.
Schnieden, Harold, Bramhall, Cheshire
Spohn, Winfried, Cologne, Germany

Stokes, Timothy David, Birmingham
Strack, Elizabeth, London
Warren, Philip Arthur, Hest Bank, Lancs.
Wilson, Geoffrey Alexander, Urmston, Lancs.

Ordinary Membership

Amli, Reidar, Oslo, Norway
Balkind, Michael, London
Barr, Charles J., Texas, U.S.A.
Beck, Russell Joseph, New Zealand
Brown, Ernest Kennedy, Angus, Scotland
Brown, Kenneth John, Australia
Campbell, Ian Colin Cecil, Rhodesia
Cheong, Choong Boo, Penang, Malaysia
Clarke, D. P. (Mrs.), Camberley, Surrey
Cook, Arthur, Hendrik Ido Ambacht, Holland
Dacremont, Roger, Belgium
Donahue, Jack Northcutt, California, U.S.A.
Fischer, Clarence S., New Jersey, U.S.A.
Fryer, Douglas John, Lewes, Sussex
Giles, Roy, New South Wales, Australia
Glover, James J., Ontario, Canada
Gosbee, Roger Fred, Havant, Hants.
Grange, Doreen Mary (Mrs.), Sherborne, Dorset
Hammersley, Gordon John, Michigan, U.S.A.
Haralambides, John A., Florida, U.S.A.
Harris, Gerald, London
Hayhurst, Christopher Edward, Glasgow
Heathcote, Frederic Roger, Birmingham
Holmes, Kenneth, London
Hubble, Leslie Albert, New Guinea
Jewell, Patricia May (Miss), Whitby, Yorkshire
Kaneko, Masao, Tokyo, Japan
Kato, Toyoji, Tokyo, Japan
Kitayama, Shigeru, Kyoto City, Japan
Lapworth, Patricia Barbara (Miss), Guildford, Surrey
Leitch, Thorburn Alexander Thomson, Kuala Lumpur, Malaysia
Liep, Tjan Hok, Surabaja, Indonesia
Maas, Geerlof D., Rotterdam, Holland
Marschner, Helga (Mrs.), Berlin, W. Germany
Maruyama, Hayashi, Tokyo, Japan
Mertens, Rudolf, Buchenbusch, Germany
Monger, John, Great Tey, Essex
Morgan, Alfred Douglas, Birmingham
Marsland, William Woodworth Bourne, Horncastle, Lincs.
Murphy, Ronald Patrick, Custon, Kent
Onojeghuo, Clement J. O., London
Pala, Anantray Ratilal, Lourenso Marques, S.E. Africa
Parker, Laurence K., Lagos, Nigeria
Paul, Lloyd G., Quebec, Canada
Pezie, Louise, Netherlands, Holland
Potts, Lawrence Donald, Tennessee, U.S.A.
Raisin, Daniel, Geneva, Switzerland
Reed, Brenig, London, N.12
Roth, Leo N., Zurich, Switzerland
Rowley, Gwendoline Mary (Mrs.) Glam.
Sakamoto, Fujio, Japan
Saluja, Narinder Singh, Thailand
Sato, Toshiji, Tokyo, Japan
Turner, George Maurice, Airdrie, Lanarkshire

Van Deijl, Wilhelm Jacobus Ernst, Bellville, S. Africa
Valberg, Christopher Harold, Johannesburg, S. Africa
Waker, J. Wolfgang, Pullach, Germany
Watanabe, Kojiro, Tokyo, Japan
Webb, William James Ellison, Guildford, Surrey
Widdup, Kenneth, Lancaster, Lancs.
Wilson, Stella Grafham (Miss), London
Westphal, John C., Illinois, U.S.A.
Yamamoto, Noboru, Tokyo, Japan
Vaughan, Alan John, Invercargill, New Zealand
Gardner, William Fraser Thomson, Bo'ness, West Lothian, Scotland
Aoki, Ryo, Tokyo
Aso, Yoshio, Hiroshima Pref., Japan
Eto, Hiroyuki, Fukui Pref., Japan
Fukuda, Jutaro, Aichi Pref., Japan
Hasegawa, Yoshio, Ehime Pref., Japan
Hyodo, Toyosaku, Tochigi Pref., Japan
Ishigami, Michizo, Hyogo Pref., Japan
Ishikawa, Shizunori, Ibaragi Pref., Japan
Ishita, Nobuo, Gunma Pref., Japan
Ito, Toshio, Saga Pref., Japan
Iwaori, Takashi, Aomori Pref., Japan
Izumi, Isao, Tokyo
Kaido, Yahichi, Fukui Pref., Japan
Kitaoka, Toshitaka, Mie Pref., Japan
Kiyota, Sukeo, Kumamoto Pref., Japan
Mikan, Misao, Yamaguchi Pref., Japan
Mitchell, Mrs. Joyce, Leven, Fife, Scotland
Niita, Yoshihisa, Shimane Pref., Japan
Naito, Jiro, Aichi Pref., Japan
Nakamura, Hideo, Ibaragi Pref., Japan
Nakaoka, Takuzo, Hiroshima Pref., Japan
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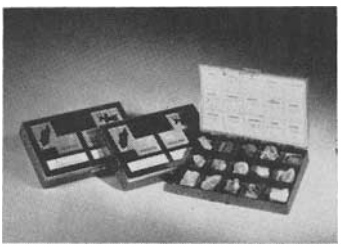

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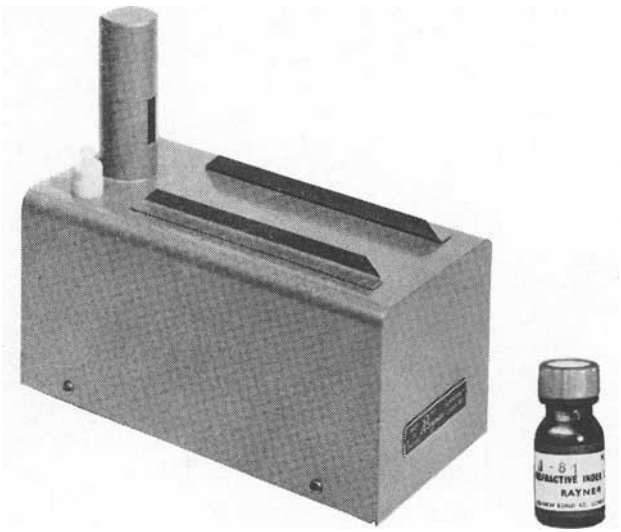

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MINERAL MINING IN QUEENSLAND

By VICTOR G. C. NORWOOD

THE warning, crudely daubed in white paint on a sun-warped board sign, read, "BEWARE of snakes, red-back spiders, and lunatics . . ."

The latter reference was probably added as a touch of humour. But, as I can confirm from personal experience, nobody but a lunatic would voluntarily accept, for long, the punishing conditions pertaining to sapphire prospecting around Anakie, one-time bonanza of the pioneer diggers.

I left Melbourne during one of the longest drought periods on record, with the intention of investigating geological reports of sapphire, opal, and agate discoveries in areas previously considered to be worked out. My transportation was a motor caravan equipped with bed, water-tank, cooking facilities, etc., and I planned a tour of some 8,000 miles. I undertook the journey alone.

It has long been suspected that extensive sapphire and opal fields remain to be discovered in arid regions of Australia's vast Outback. Recently, there has been keen interest in the commercial possibilities of agate, and a small factory for cutting and polishing agate, and for the manufacture of agate jewellery and components used for electrical insulators, etc., has been opened in Cairns, North Queensland.

I had been guaranteed 5s. per pound for agate delivered to the factory, and had acquired mineral rights over a large tract of barren wasteland not far from Cairns. I also had markets for all the opal and sapphires I could supply.

Travelling up country from Victoria, I considered it practical to make Anakie and The Willows my first halt. The demand for sapphires in industry is constantly increasing, and Queensland has produced some of the world's finest gemstones. The largest star-sapphire in existence came from the great ridge known as "Klondyke", two miles from Anakie. Cut from a rough crystal weighing 1,165 carats, it now weighs 733 carats and is known as the Star of Queensland, is larger than a hen's egg, and is 170 carats bigger than the previous record holder, the beautiful blue-grey gem named Star of India.

Among other fabulous sapphires found in this part of Queensland are the Abraham Lincoln (2,302 carats), the George Washington (1,997 carats), the Dwight D. Eisenhower (2,097 carats), and the Thomas Jefferson (1,743 carats), all so named because likenesses of these American Presidents have been sculped with diamond drills upon the finished gems.

Just a month prior to my visit, The Willows gemfield yielded a star-sapphire in excess of 100 carats. Reduced to 67 carats in the cutting, it is now in the possession of veteran prospector and gem-cutter Peter Laws, through whose capable hands most of the sapphires found at Anakie and The Willows in modern times find their way.

Dry-wash mining is a heart-breaking and back-breaking occupation bearing no similarity to gold and diamond recovery by the use of flume and sluice-box, or suction dredge. The nature of terrain in which sapphires occur defeats enterprise. The process involves no machinery or labour-saving devices whatever.

The site for operations is selected after inspecting likely places recognized from experience, usually a ridge or the dry bed of a former creek, for "indications" most commonly associated with sapphire, i.e., carborundum, quartz, jasper, tourmaline, and conglomerate sandstone.

Large rocks and dead wood must be removed, then the overburden spaded away and a pit dug deep enough to expose the gravel "wash". Strong poles are cut and lashed together to form a tripod from which an oblong sieve bottomed with very strong

Sapphire mining (Queensland). Shaking the sieve (no water).

steel mesh is suspended, preferably with thick wire, about three feet above the ground.

Gravel is shovelled into the sieve, which is then violently shaken and agitated until sand, dirt, and grit have been removed. Large stones are picked out by hand, hard clay masses broken up. Finally the residue is examined for sapphires and other closely allied minerals such as zircon, garnet, and amethyst.

It is wearying, monotonous work. Most Queensland sapphires are not blue but green or yellow. It takes a keen eye to distinguish a sapphire from the dry gravel concentrate. There is no water available for sluicing in the Australian Outback where rain sometimes does not fall in twenty years. Temperatures range up to 150 degrees. There is no vegetation, no shade, only skeleton husks of termite-riddled gum-trees peeling in decay, gnarled roots, and rocks.

Thirst and loneliness are the sapphire miner's constant companions, together with lizards, venomous snakes and poisonous red-back spiders, huge ants, and voracious flies. Outsize mosquitoes plague the intruder into these desolate regions. Gravel-strewn ridges, choked with fallen branches, harbour lethal brown

snakes, tiger snakes, death adders, and taipans. Scorpions lurk beneath sloughing bark. Dry, curling leaves are infested with enormous ticks whose bite causes intense irritation and sickness.

The hardwood trees, however aged and rotten they may be on the inside, will turn the edge of an axe. Their incredibly tough roots writhe down among great boulders. No machinery suitable for sapphire recovery has yet been introduced to the Queensland gemfields. Methods remain unchanged from what they were 60 years ago when Anakie was the foremost producer of sapphires in the world.

I share the opinion of many prominent geologists that vast new sapphire fields exist in desert regions of Australia. But few white men can work in such intense heat, and the total absence of water often turns these arid areas into death traps. The sapphire miner must carry with him sufficient food and water to last for the duration of his stay. Even when rain does fall it drains off the granite-hard ridges almost immediately, and within an hour of the downpour the terrain is as dry as ever.

Nowadays, Anakie and The Willows, situated some 200 miles west of Rockhampton, attract tourists and drifters more than professional prospectors. Few remain longer than a day or two. There are, however, numerous long-established mines still producing saphires of gem quality, all under private ownership.

But plenty of free land is available for the free-lance. And despite crude recovery methods, sapphires continue to reward time and effort. I myself found more than 60 fine stones at Anakie within two weeks, four of them blue stones in excess of five carats. My locations also yielded a vast quantity of green and yellow sapphires, but most of these had flaws and were useless as gems, though admirably suited to industry.

It might well be worth the expense of using bulldozers to clear rocks and overburden from the old Anakie gemfields to uncover the gravel en-masse, and I am presently concerned with the formation of a company for this purpose. The introduction of mechanical shakers would simplify the work of gravel processing, but I see no alternative to dry-wash recovery.

★ ★ ★

From Anakie I drove west towards Winton, Opalton, and Horse Creek on the fringe of the desert country, all at one time rich sources of gem opal.

Opal mining, or "gouging", requires patience and considerable knowledge of the subject which can only be gained from practical experience. The most beautiful of all gems, opal is also the trickiest. Even men who have spent most of their lives in close association with opal never cease to marvel at its rich variety of form and pattern, and the constant element of surprise in its occurrence. Whether revealing pure lustre, red blaze, iridescent red and green fire, harlequin patterns, or a surface of opaque mystery, opals possess a fascination lacking in most higher priced gems.

Opal occurs not only in familiar forms like harlequin, fire, boulder, Tintenbar, pipe, light, and "potch" or "snide" (opal with no commercial value), but also in fossils and sea-shells. "Black" opal is the rarest and consequently the most valuable.

Boulder opal, formed by intense heat in opposition to water and hydrous silica cracking huge rocks which in time became filled in and solid again, occurs in thin veins in brown and grey ironstone boulders peculiar to parts of Queensland. Because of its more siliceous form, resulting in opalization without appreciable changes of temperature, Tintenbar opal from areas of New South Wales has an unusual depth of colour, and although it has a glassy, apparently oily appearance, the kaleidoscopic play of colours beneath the surface is truly magnificent.

Light opal contains pale hues, green, yellow, and blue predominating. Harlequin contains outstanding multi-colouring with emphasis on red, green, blue, purple, and orange. "Black" opal is usually translucent black on one side but coloured on the other and through its structure, whereas true fire opal reveals a blaze of beautiful colouring like the inner "fire" of a diamond. Potch is white or blue opal lacking the fire of gem-quality opal, but often possesses interesting markings and pattern formation.

The most extensive finds of valuable opal have come from White Cliffs and Lightning Ridge, both in New South Wales, the latter the world's only source of black opal. But Queensland, too, has produced vast quantities of gem opal, and a lot of ground, mostly desert, has yet to be thoroughly prospected. In 1965, I found gem opal in arid terrain west of Tennant's Creek and

Wauchope where there has been no opal mining activity for many years.

A strange factor about opal taken from a seam vertical to the surface is that the colour is always horizontal and on a flat level regardless of in what position the opal lies. When following a seam of potch it may suddenly reveal precious opal colour, and just as abruptly revert to potch. As the whole seam was opalized at the same time at equal temperatures under the same conditions involving identical ingredients of analysis, the change from potch to valuable opal and back to potch remains an enigma.

The colour of opal is unpredictable. A bar of good colour opal may extend right through both top and bottom strata of milky potch. Whatever the angle or position of the rock the true opal bar continues perfectly level.

Many remarkable opal oddities occur, including opalized bone, tusks, wood, and unique formations of gypsum crystals (pseudo-morphs) covered with spikes. Some of these fossils are of great value not only as relics but as gem opals, perhaps the most valuable specimen being the skeleton of a prehistoric sea creature about five feet long.

The reaction created by heat and water passing through the structure of ordinary marine shells over long periods caused them to become opalized where other shells merely crumbled. Fragile opalized corals have been preserved, things of great beauty. Instances of opalized fish and insects are fairly common. E. F. Murphy, a pioneer opal "gouger" and later one of the foremost buyers of precious opal in Australia, once purchased a perfectly preserved replica of a dog shark. Usually, however, the "fish" is merely an impression in clay which became filled with siliceous matter after the actual fish decomposed, as flesh, of course, will not opalize.

"Noodling" (seeking opal on ground previously mined) is a term originating from finds of egg-shaped opals that had formed inside lemon-sized rounds of brown sandstone which later eroded away leaving the opalized core. In Central Queensland, near the Southern Cross Mine, these "yowah nuts" as they are called were found intact and in great quantity. Cracking them open invariably results in the opaline core being split also.

The richest opal is usually found on white desert sandstone slopes, in layered ground with seams interposed between each

stratum and covered on higher levels by sun-baked ground of concrete hardness. In such places, below the sandstone, which may be more than 20 feet thick, lies a gritty layer of "opal dirt" a few feet thick, underneath which is greasy clay seldom containing opal. The first sandstone stratum is usually harder and more siliceous, and it is below this that opal occurs, always forming upwards, never down. Seam opal is found in flat layers of varying thickness, generally in pieces which can be fitted together to form a whole, rather like a giant jig-saw puzzle, having been broken when, as a cooling liquid, the opal contracted.

Opal consists of 90 per cent hydrous silica and up to 10 per cent water. In a flat seam colour is usually true, and in a vertical seam crosses the stone at a regularly maintained level.

Opalized fossils are found in the "opal dirt" stratum.

Finds of coral and sea shells and the remains of marine creatures establish the fact that an inland sea extending from the Gulf of Carpenteria to Spencer Gulf once divided Australia. Over the passage of millions of years this sea was choked with debris—boulders, timber, clay, and silt deposited by flood waters from the mountains to east and west, and eventually became filled in. Ultimately, a crust formed over this immense cretaceous clay and sand region, known in this day and age as desert sandstone.

The silica content of opal comes from volcanic rock below this former sea bed which, in association with water, generated tremendous heat and formed a boiling silica-water solution that eventually poured from cracks and vertical fissures created by cataclysmic changes, and spread beneath the crust. The remainder found other vents and formed layers of opal at other levels as it cooled, sometimes reaching openings on or near the surface with resulting patches of overflow opal. Whatever objects the flow encountered were opalized.

Opal sometimes occurs with condensed steam imprisoned within its structure. A piece may have brilliant iridescent colour at one end and be blue-grey or white potch at the other, or coloured in the centre and potch at both extremities. Pattern structures, too, vary considerably, from harlequin squares and dots of "pinfire" to curly and twisted patterns, or rolls.

Some opals are basically blue and green: others flame with red, or a riotous blaze of rainbow hues. Still other examples are wholly transparent.

Among genuine black opal, opalized marine fossils, called "nobbies", are most in demand. These include sponges and corals. The rarest "nobbies" are conical with a teat base, and serrated from curling rim to pointed extremity. They are mostly found near surface sandstone, pointed end down. Others are flattened as if subjected at some time to extreme pressure, and are quite round. Having originally been of a delicate nature, black opal coral nobbies are creations of exquisite loveliness exhibiting patterns different from any other kind of opal.

Seam opal is mined by the skilful use of a pick, great care being essential as opal is brittle and easily fractured. To expose boulder opal it is necessary to crack open the rocks with a sledge-hammer—a herculean task in tropical heat often exceeding 140 degrees. Boulder opal, formed by the infiltration of silica-water solution into cracks created by flow's fierce heat, is not opalized right through like matrix, but can be cut and polished to make beautiful cameo pieces.

So-called opal "pipes" found in Queensland, resembling tree roots, are actually steam bores which later filled with liquid opal. Another peculiarity concerning pipe opal is that the consistency of colour throughout the length of the bore's content is either wholly true, or completely faulted.

Wherever opal is present underground there are surface indications such as surface opal or opalized wood. The majority of Queensland opal has been recovered from pressure-blasted vents through which silica impregnated steam escaped, and the crust, easily recognized by heaps of sandstone around the opening, often reveals opal. If this surface opal is of good colour, that below ground is usually of fine quality also. But if only potch is found above ground then excavation is generally a waste of time and energy.

As with sapphire mining, no satisfactory method of expedited recovery has yet been devised. Opal "gouging" involves pick and shovel work only, but the rewards are often well worth the labour.

At Tintenbar, an opal field near Brisbane on the Queensland coast, opal was found in association with basalt, a unique occurrence resulting from volcanic upheaval and a subsequent flow of molten lava over sandstone. A lot of Tintenbar opal contains air bubbles and tends to crack during cutting.

Near Horse Creek, south of Opalton, I found no surface opal, and had to bench down for 20 feet through granite-hard sandstone

littered with quartz pebbles and enormous boulders before I encountered the continuation of an old seam. Much of the opal I obtained was worthless potch, but during the course of a week's hard work I accumulated some nice pieces of light and harlequin opal, and red and green blaze opal of a quality that eventually realized two thousand pounds in Sydney. There was a lot of opalized wood in the area, and numerous fossils of curio interest.

I left Horse Creek convinced that by mounting a properly equipped mining project it would still be possible to recover precious opal profitably over a long period. The difficulty in this day and age would be to get reliable men with field experience to work in such appalling heat, and the undertaking would, at best, be a gamble.

★ ★ ★

The agate, I considered, was a more rewarding proposition taking everything into account. One does not have to look far to find agate—it is there, lying around on the ground, in certain areas, countless tons of it, hitherto regarded as practically worthless.

Open deposits of agate, North Queensland, Australia.

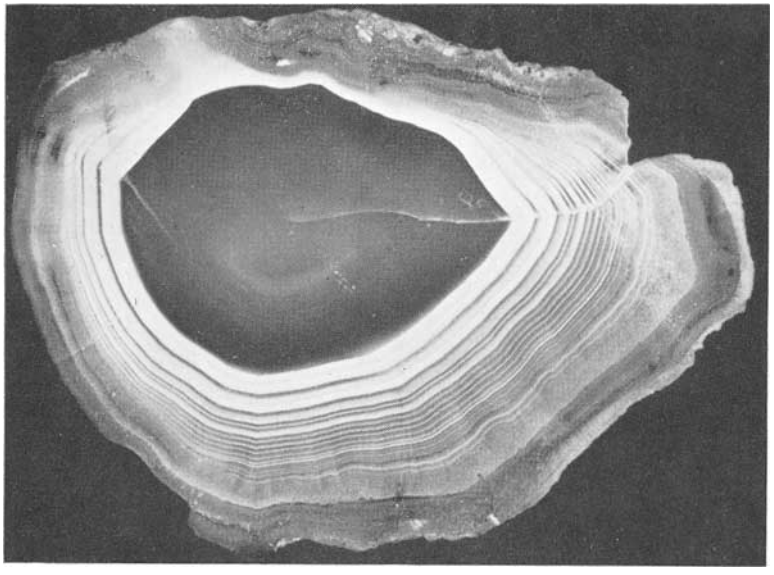

Banded agate from North Queensland.

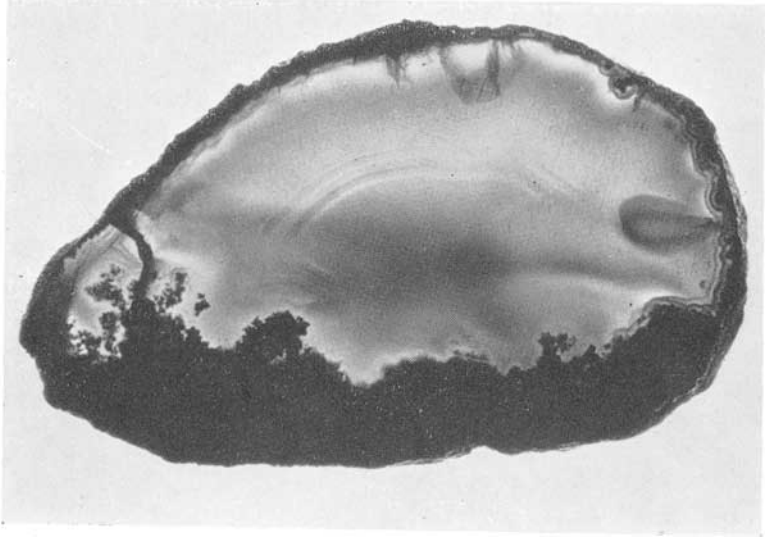

Unusual design in lump of agate from North Queensland.

Using Cairns, in tropical North Queensland, as a base, I acquired a soundly constructed truck, hired half a dozen rugged types who claimed to know something about agate, and eventually established a camp on the remote sector covered by my mining concession.

All I had to do was break up agate boulders into pieces of a size easily handled, selecting the more colourful grades, load the truck and drive to Cairns. The each-way journey took two days, during which time my crew got together other choice loads, improved living accommodation, and eventually devised and constructed a crushing device from balanced hardwood logs shod with iron, a crude but efficient rig that eliminated a lot of back-breaking sledge-hammer work and made the reducing of huge agate rocks to lumps one man could easily carry simplicity itself.

Over a period of six weeks I moved some 40 tons of agate. In addition to exploring new sapphire fields the proposed company will be concerned with opal recovery and supplying agate for industry. The three undertakings will be under separate management.

Meanwhile, having organized these projects, I envisage a return to Guyana where there have been some interesting developments in bauxite mining, and where I already have established diamond recovery interests.

It is just possible that the Australian ventures might provide the capital necessary for machinery to mine bauxite, including high-pressure hoses, diesel operated, for I am reluctant to turn my Guyana bauxite holdings, acquired in 1951, over to any of the major Canadian, American, or Dutch concerns at present monopolizing the industry, and would prefer to form my own company.

Certainly there is no lack of opportunity both in Guyana and Australia, Queensland in particular, for in addition to opals and sapphires I know of several locations within a short drive of Cairns where gold occurs in association with quartz, and black sand. The possibility of a gold mine operating within sight of the Great Dividing Range may well become reality during 1968.

DISPERSION IN DIAMOND

By B. W. ANDERSON

THE great attraction of diamond as a gemstone depends, of course, chiefly upon its optical properties—its high degree of clarity or transparency, its high refractive index, and its dispersion. The effect of fire in a well-cut brilliant-cut stone is so marked and so beautiful that it is understandable that diamond is commonly said to have a high dispersion. High it certainly is in comparison with other colourless stones used in jewellery, but it must be remembered that these have a much lower index of refraction. In cold fact the dispersion of diamond is exceptionally low when compared with the few transparent minerals which have indices of similar value, and indeed is surpassed by many gemstones which have considerably lower indices of refraction.

Students of gemmology will already be aware of these facts, but there is undoubtedly a tendency to think of minerals which surpass diamond in this particular as abnormal or freakish in having so high a dispersion, whereas in reality it is *diamond* which is quite abnormal in this property, as in so many others. An effective way of bringing this home is to draw a graph in which the dispersion figures for the B - G range are plotted against the refractive index for a wide range of gem materials, including diamond. This has been done by the writer and is shown in Fig. 1. Here one can see that there is in general a rough correspondence between the two figures for the majority of gems, and how completely out of line is the "plot" for diamond.

Another way of demonstrating the relatively low dispersive power of diamond in the visible range when compared with minerals of comparable index of refraction is shown in Fig. 2, where the R.I. of strontium titanate (1), zinc blende (2), and diamond (3) for a number of different wavelengths are plotted. This has provided an opportunity to reproduce data not available in text-books. For diamond, I have selected some values from the great range extending from the deep red to 2265Å in the far ultra-violet—i.e. virtually to the ultimate absorption edge of pure, nitrogen-free (type II) diamond—which were given by Fritz Peter in an important but neglected paper in the Zeitschrift für Physik, published in 1923.

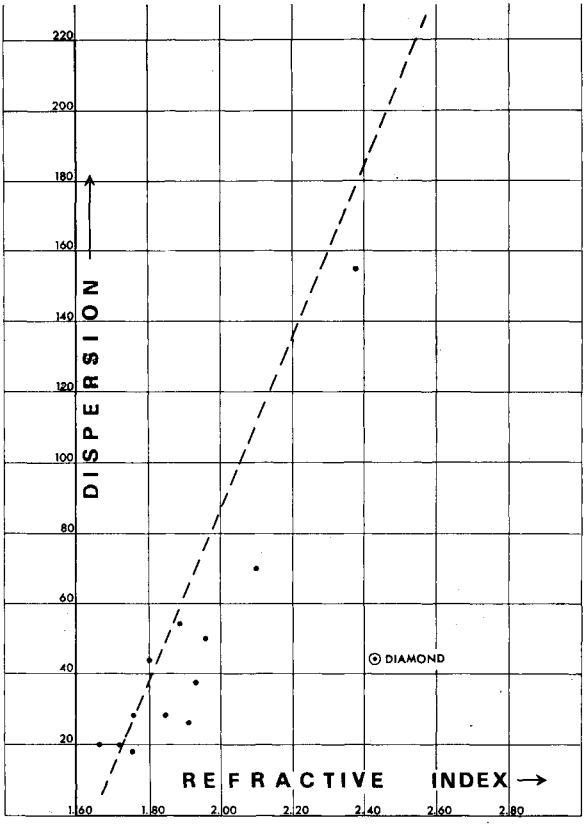

FIG. 1

FIG. 1. *Refractive index for sodium light plotted against the B - G dispersion for diamond and a number of other gemstones.*

Peter was fortunate in that of the thirty diamonds he tested two were transparent in the far ultra-violet: the rare type of diamond which was distinguished as "Type II" in the well-known paper by Robertson, Fox and Martin written eleven years later. For these measurements, a prism of 26° 50′ was used, cut from one of Peter's Type II stones, the deviation being recorded on a photographic plate of rays striking a face of this prism at perpendicular incidence. It will be noticed from the graph that there is a steep rise in refractive index as the absorption limit is approached. This is a common phenomenon with solids, and serves to "explain" why the dispersion

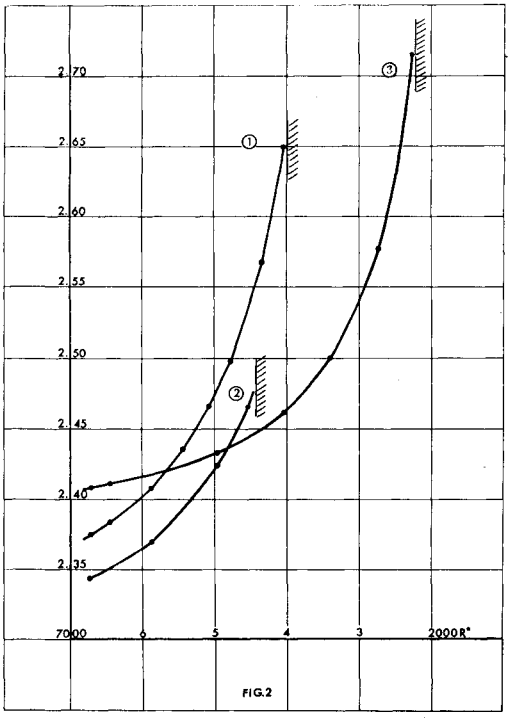

FIG. 2. *Dispersion curves for* (1) *strontium titanate,* (2) *zinc blende, and* (3) *diamond.*

of diamond in the visible region lags so far behind those such as demantoid, zinc blende, strontium titanate, and synthetic rutile where in each case there is a powerful absorption band either in the violet or in the near ultra-violet.

The interval between the B line (6870Å) and the G line (4308) is 2562 Angstroms. Using Peter's results, one can calculate that an equivalent range to this leading up to the ultimate absorption edge of diamond would give the dispersion of the mineral as 0·280, which is close to the dispersion of synthetic rutile and higher than that for strontium titanate for the B-G range. The figures for the dispersion of strontium titanate used in the graph are those recently given by Professor S. Rösch of Wetzlar in the Spring, 1967, issue of the Zeitschrift der Deutsche Gesellschaft für Edelsteinkunde. These agree closely with those obtained by C. J. Payne some years ago, but

are more extensive. The values plotted for the zinc blende are those obtained by C. J. Payne before the war. As Professor S. Rösch points out, the refractive indices of diamond and of strontium titanate are identical for light of wavelength 5680Å, the value being 2·4204.

For his work Peter used mainly lines in the emission spectrum of cadmium: the highest index he recorded for diamond was 2·7151 for the cadmium line of wavelength 2265Å. He also describes similar experiments on quartz and calcite: it is interesting to note that the value for the ordinary index of quartz for wavelength 2265Å is 1·6179, and for calcite, 1·8131.

A SEVENTEENTH-CENTURY NOTE ON GEM PRICES

By M. J. O'DONOGHUE

IN 1652 Thomas Nicols, formerly of Jesus College Cambridge, produced his celebrated book "A Lapidary, or the History of Precious Stones". The copy in the Library of the British Museum has the alternative title-page "Arcula Gemmea, or a Cabinet of Jewels."

A feature of the book is the reference to the value of gems, expressed in crowns or ducats. In Nichols' time a crown was worth five shillings and a ducat about ten shillings.

It has always been difficult to be specific about prices of gemstones at any period of history and Nichols is one of the few writers who mentions them. Here are some examples.

Diamond

A well polished diamond without fault, of the weight of a peppercorn, is worth ten florins or crowns, according to Boethius, who also says that a diamond cut with one plain upper table and four lateral tables two of which are wont to be longer than the other two, weighing one ceratium or four grains, is worth 50 ducats or crowns. Stones cut in pyramidal forms are of less value. According to Cardanus in his book "De Subtilitatibus" (1550), a diamond at Antwerp "wanting one scruple of the weight of an ounce" is valued at 150,000 crowns.

Ruby

If it weigh two scruples* which is the greatest (for seldom any of the excellent ones are found of greater magnitude than a filbert), because of its grateful colour with which it feedeth the sight and because of those glorious beams which it seemeth to dart forth of itself, it is esteemed as of great worth as the most excellent

* a scruple is 1/24th ounce or 20 grains

diamond. If it be found in the weight of four ceratia that is of 16 grains, it is of the same value with a diamond which weigheth so many ceratia.

Balassius (Red Spinel)

It is of much less value than the ruby. Linshortanus saith that one of the weight of one ceratium or four grains is worth ten ducats. A spinel of the old rock, of the weight of one ceratium, cut into a tablet, is worth half so much as a diamond of the same weight, if in its own glory and rosie lustre it be found and free from blemishes.

Garnets

The Bohemian ones are worth 20 shillings a piece and if they be found bigger than ordinary the price of them is increased. The best Oriental ones of the weight of four grains are worth two crowns, and by how many times they are found to be double in weight so many times will double their value . . . as if they weigh eight grains they are worth four crowns and so proportionately . . . but with this proviso that their colour . . . be always the perfect colour of the ruby. (Almandine is classed separately; this jewel is known to very few and therefore scarce of any price).

Amethyst

The Oriental ones, if they be hard without clouds and blemishes, though they weigh but four grains a piece, they are worth many pounds a piece, and as oft as they are double in weight, so oft is their price to be doubled. The best are worth as much as the best Oriental diamond of the same weight.

Pearl

If they be of the weight of four grains a piece, fair and round, they are worth three crowns a piece.

Sapphire

One of the weight of four grains is worth many crowns. The best of these are as much worth as a diamond of the same bigness.

Opal

Their price and esteem is not great in these days: for one of four grains weight of the first and best kind is scarce worth three crowns.

Emerald

The Oriental ones have been esteemed worth a quarter so much as a diamond of the same weight. Linshortanus doth esteem them of greater worth than the diamond and valueth an emerald as big as a diamond of four grains well worth eighty ducats, whereas he esteemeth the diamond of that bigness not worth more than 70 ducats.

Chrysolite (Probably Topaz)

A chrysolite of the weight of eight grains is worth four crowns; one of these excellent ones of 12 grains weight is worth nine crowns and one of these glorious ones of the weight of two scruples is worth 100 crowns.

Gemmological Abstracts

LENZEN (G.). *Geschichte der Qualitätsmerkmale des Diamanten.* History of determining the quality of a diamond. Zeitschr. d. deutsch. Gesell. f. Edelsteinkunde, no. 60, summer 1967, pp. 20-28. Extensive bibliography.

The article is the second in the series and deals with purity and cut. The early Indian period is discussed; the era lasted from about 400 B.C. to 600 A.D. At that time the quality and therefore the price was based on the crystal form and on the optical characteristics. It was considered most important that the octahedra had 6 perfect corners, next the 12 edges were supposed to be present and then in order of importance were the 8 faces. The optical quality was dependent on transparency and lustre.

E.S.

SCHLOSSMACHER (K.). *80 Jahre. Professor Dr. K. Schlossmacher.* Zeitschr. d. deutsch. Gesellschaft f. Edelsteinkunde, no. 61, autumn 1967, pp. 3-11.

This is an issue published in honour of Professor Schlossmacher's 80th birthday. In the beginning of the journal there is a biography of Professor Schlossmacher and there are two congratulatory articles by X. Saller and B. W. Anderson.

E.S.

BAIER (E.). *Gezuechtete Kristalle.* Synthetic crystals. Zeitschr. d. deutsch. Gesellschaft f. Edelsteinkunde, 1967, 61, pp. 12-26.

Survey of synthetic crystals which are used in industry. Various methods of production are discussed. There are 7 illustrations of the final crystals, which include calcium fluoride, quartz copper monoxide, silicon, silicon carbide, etc. The main use for the synthetic crystals are in optical lenses, prisms and filters, in lasers and masers, in x-ray monochromators, in counters, for piezo-electricity, in transistors and semi-conductors and for hard materials such as bearings and needles.

E.S.

BANK (H.) and BERDESINSKI (W.). *Chromhaltiger Turmalin.* Tourmaline containing chromium. Zeitschr. d. deutsch. Gesell. f. Edelsteinkunde, no. 61, autumn 1967, pp. 30-32.

The constants of an emerald-like tourmaline are given in detail. The colour is caused by chromium. Graphs show the relationship between the lattice constants and the axes.

E.S.

BANK (H.) and OKRUSCH (M.). *Mineralogische Untersuchungen am Alexandrit der Novello Claims in Rhodesien.* Mineralogical examination of the alexandrite found in the Novello claims in Rhodesia. Zeitschr. d. deutsch. Gesellschaft f. Edelsteinkunde, 1967, 61, pp. 33-29. 9 illustrations with bibliography.

The geographical-geological occurrence of the alexandrites in the Novello claims in South Rhodesia is described. The crystals were examined by chemical analysis, spectrography and x-ray. These stones are mostly found in triplet form. Density was found to be between 3·646 and 3·768 + 0·002. The pleochroism showed red to darker green. A mean R.I. is 1·748, but many variations are given, birefringence 0·008–0·011. Crystallographic details are described as well as inclusions which are mainly phlogopite.

E.S.

BANK (H.). *Zur Diagnostik von Chrysoberyll.* Determining chrysoberyll. Zeitschr. d. deutsch. Gesell. f. Edelsteinkunde, 1967, 61, pp. 54-57.

The refractive indices of the alexandrites found in the Novello claims in Rhodesia are discussed as the R.I. is particularly high with a birefringence of 0·011. The author advises gemmologists always to use more than one method of determination.

E.S.

EPPLER (W. F.). *Der synthetische Smaragde von Linde.* The synthetic emerald of Linde. Zeitschr. d. deutsch. Gesellschaft f. Edelsteinkunde, 1967, 61, pp. 58-66.

Linde's synthetic emerald has been produced by hydrothermal methods. The crystal examined by the author is 21·2 mm × 11·5 mm × 7·2 mm and weighs 16·07 cts. The surprising fact about this crystal is that apparently it took only 12 days to grow.

The crystallographic and optical characteristics are described fully and there are 12 photographs. The colour is a very good green. There are not many inclusions, but there are a few small phenakite crystals.

E.S.

TILLANDER (H.). *Zur Fruehgeschichte des Diamantschliffs.* The early history of diamond cut. Zeitschr. d. deutsch. Gesellschaft. f. Edelsteinkunde, 1967, 61, pp. 111-114.

The author considers it very unlikely that diamonds were cut in the thirteenth century, and believes that we have to accept the second half of the 14th century as the earliest date. The Black Prince (1351-1356) collected valuable jewellery partially set with diamonds, but mainly forms which occurred in nature and which were polished. The first illustration of a diamond is of the year 1400, on a picture of the English Henry IV. Up to the year 1530 diamonds seem to have been retained in their natural shape and only polished over, then slowly long-cut stones evolved, especially the "scissor cut". The author also doubts the legend of Peruzzi as the inventor of brilliant-cut, which only seems to have come into use about the 17th century.

E.S.

STRUNZ (H.) and WILK (H.). *Zur Morphologie der St. Anne's Topase.* St. Anne's Topazes. Zeitschr. d. deutsch. Gesellschaft f. Edelsteinkunde, 1967, 61, pp. 106-110.

These topazes are of a good blue colour, though hardly useable as gem material, but make good mineralogical specimens. They are found in the Miami region of South Rhodesia and are seldom larger than 7·5 cm × 8 cm. Crystallographic details are given. The colour is not heat-resistant: loss of colour commences at 200°C and at 400°C stones become colourless. On cooling the colour does not return.

E.S.

EPPLER (W. F.). *Le mica dans l'aigue-marine.* Assoc. Francaise de Gemmologie, 1967, Bull. 13.

After mentioning the most common inclusions in aquamarine, non-orientated and orientated inclusions in aquamarine are given and the method of investigation described.

G.A.

NEUHAUS (A.), RECKER (K.) and LECKEBUSCH (R.). *Beitrag zum Farb- und Luminenzproblem des Fluorit.* Colour and luminescence of fluorite. Zeitschr. d. deutsch. Gesellschaft f. Edelsteinkunde, 1967, 61, pp. 89-102.

Detailed article, with many graphs, giving the absorption and luminescence spectra of natural fluorite and radiated as well as unradiated synthetic fluorite. The tests are to be continued.

E.S.

LENZEN (G.). *Lupenrein; Geschichte und Geschichten.* Loupe-pure stones: history and stories. Zeitschr. d. deutsch. Gesellschaft f. Edelsteinkunde, 1967, 61, pp. 86-88.

Discussion about how the "purity" of a diamond is handled in various trade centres and bourses over the world.

E.S.

GÜBELIN (E.). *Mineralogisch-gemmologische Untersuchungen an Apatiten von Edelsteinqualitaet aus dem Casaccia Tal, Tessin.* Mineralogical and gemmological tests of gem quality apatites from the Casaccia valley in the Tessin. Zeitschr. d. deutsch. Gesellschaft f. Edelsteinkunde, 1967, 61, pp. 75-85.

The apatites discussed vary from light to dark violet and are of good gem quality; they are fairly large and come from the Tessin district of Southern Switzerland. There are 7 illustrations, two showing unorientated liquid inclusions, two with orientated negative crystals.

E.S.

ARTAMONOV (V. S.). Semi-precious stones in northwestern RSFSR. Materially po Geol. i Poleznym iskopaemym, Severo-Zapada RSFSR, 1962, 3, pp. 195-213 (in Russian).

The distribution of amethyst, almandine garnet, moonstone and sunstone in the Kola Peninsula and Karelia areas of northern Russia is reviewed.

R.A.H.

BASTOS (F. M.). *Diamonds in Minas Gerais.* Lapid. Journ., 1968, 21, 10, p. 1240.

A brief sketch of the history of diamond mining in Minas Gerais is followed by an account of present day conditions in an area

which still has considerable potentiallity for the recovery of diamonds.

S.P.

ZWAAN (P. C.). *Een imitatieparel van ongewone samenstelling.* Edelmetaal, 1967, 1, p. 16.

Imitation pearls having a mother-of-pearl nucleus have been investigated by chemical, optical and X-ray methods. The way how to distinguish them from genuine and cultured pearls is given.

P.Z.

PETCH (H. E.). *Bancroft's star-sapphire.* Rocks and Minerals, 1967, Vol. 42, pp. 563-566.

Asteriated black corundum and sapphire occur in the Bancroft area of Ontario, Canada. The history of corundum collecting and mining in the area is reviewed, with particular reference to the Burgess mine, Carlow township, and the Craig mine, Raglan township. The gem uses of corundum in various cultures are considered.

R.A.H.

CROWNINGSHIELD (R.). *Developments and highlights at the Gem Trade Lab. in New York.* Gems and Gemology, 1967, XII, 7, 199-210.

Such various topics are oolitic opal, black-cored emerald crystals, star-enstatite, crystals in jadeite, and features of an imitation emerald are mentioned. There is a good description of the new blue zoisite. Snuff bottles made of amethyst, citrine, veined common opal and crested hornbill "ivory", a material of yellow to orange-red colour obtained from the beak of the hornbill, are interesting items discussed. In the field of synthetics, flux-fusion rubies and garnet-structured crystals, as well as an anomaly in the refractive indices of a colour-banded Gilson synthetic emerald are reported upon. A low density plastic amber imitation and dyed "angel's-skin" coral are mentioned. Four light blue Type IIb diamonds were recently seen in this laboratory.
29 illus.

R.W.

LIDDICOAT (R. T.). *Developments and highlights at the Gem Trade Lab. in Los Angeles.* Gems and Gemology, 1967, XII, 7, 212-223.

Examination of the 5·34 carat taaffeite found in a parcel of stones in the U.S.A. showed the uniaxial refractive indices to be 1·720–1·724 and the density to be 3·608. The inclusions are described and photomicrographs illustrate them. An unusual cat's-eye doublet consisting of a very transparent chrysoberyl top cemented to a more opaque back is described. Other items referred to were green andesine feldspar; inclusions in and scratches on polished facets, as well as unpolished facets on cut diamonds. An opal substitute made of tiny fragments of precious opal pressed into a resin matrix and a plastic substitute for amber are mentioned. A new source of emerald in Western Australia is reported.
23 illus.

R.W.

TAYLOR (A. M.). *Synthetic vanadium emerald.* Australian Gemmologist. 1967, 75, 10-13.

Expected to enter the gem market is a synthetically produced grass-green beryl coloured by vanadium (*Journ. Gemmology* 1967, 10, 7). The crystals are grown by a hydrothermal method and are produced in Australia. The stones have refractive indices of $\omega = 1{\cdot}571$ to 1·575 and $\varepsilon = 1{\cdot}566$ to 1·570, the double refraction being 0·005. The density varies from 2·67 to 2·69.
4 illus.

R.W.

SMITH (C. C.). *A preliminary account of Rhodesia's new gemstone—chrome chalcedony.* Chamber of Mines Journal. Rhodesia, 1967, IX, 12, 31-34.

A report on the green chalcedony coloured by chromium, which has recently been found in Rhodesia. The author, Craig C. Smith, is Keeper of Geology at the National Museum at Bulawayo and has recently prospected the area. The material was first noticed by M. J. Maclean at the end of 1955 in a small spruit off the western slopes of the Great Dyke and just north of Mtoroshanga. It has now been established that the mineral occurs along a strike of about a mile running north-south along the western edge of the dyke. The material, which is mined by pig-rooting or gophering,

varies in quality from a deep green evenly distributed colour to material which is more variegated. Much of the recovery is sold to Hong Kong but other markets are being investigated. From analyses the chromium content varies from 0·15% to 0·4% and nickel 0·05% to 0·2%. The effect of the chromium and nickel on the colour, and the way the chromium is associated in the mineral are discussed. The refractive index was found to be 1·5395 and the density of 2·593 was found on the specimen determined, but values found by other workers are given. There is no luminescence. The article contains a good description of the geology of the area, and a discussion is made on the question of the correct naming of the mineral. It is suggested that the mineralogical name should be chrome chalcedony, but names, taken from the locality where it is found, have been used in trading. Such names are mtorodite, matorolite and matorodite.

5 illus. R.W.

ILER (R. K.). *Formation of precious opal.* Gems and Gemology, 1967, XII, 7, 194-198. (Reprinted from *Nature.*)

Experiments on the formation of opal structures from silica sols, producing a colourful opaline layer. The experiments are correlated with the sphere theory of J. V. Sanders and throw light on the formation of precious opal in nature, and a discussion is made on this.

1 illus. R.W.

MCDONALD (N. R.). *Synthetic beryllia crystals.* Australian Gemmologist. 1967, 75, 8-9.

Colourless crystals of beryllia (BeO) have been produced by the flux fusion technique. The crystals are of hexagonal symmetry, have a hardness of about 8, and refractive indices $\omega = 1{\cdot}719$ and $\varepsilon = 1{\cdot}733$.

4 illus. R.W.

P.A.M. *Phosphorescence in Australian opal.* Australian Gemmologist. 1967, 75, 18.

Details some experiments of a New South Wales gem research group on the luminescence of opal under long-wave ultra-violet light. It was noticed that while opal from Australian sources fluoresced blue and white, the material from Nevada and Arizona,

U.S.A. showed a yellow-green glow. This difference is being ascribed to the uranyl ion. It was further noted that many Australian opals showed a phosphorescence of greenish-yellow colour not unlike the fluorescence of the American stones, which did not apparently show an afterglow.

R.W.

COOGAN (C. K.). *Diffraction gratings.* Australian Gemmologist. 1967, 75, 19-26.

A brief history and theory of diffraction gratings and the problems of producing them. The various types of machines which have been made for the purpose of ruling such gratings are mentioned. An excellent article on a subject which is usually neglected.
9 illus.

R.W.

WEBSTER (R.). *Forensic problems in jewellery.* Criminologist. 1968, 7, 40-51.

The work of the expert witness in Court cases involving jewellery and gemstones is discussed. Reports of a number of Court cases and remarks upon them are given. The possibility of litigation through damage to jewellery from various causes, by blows or pressure, by heat, by radiation and by cosmetics, is discussed.

P.B.

GUNARATNE (H. S.). *Rocks and Minerals of Ceylon.* Ceylon National Museums Handbook Series, 1967.

Rock types of Ceylon, their component minerals and a brief account of the gemstones of Ceylon is followed by a catalogue of the mineral collection in the Colombo National Museum. A map of Ceylon in the twelth and thirteenth centuries is given.

S.P.

METEORITES AND TEKTITES *

By M. H. HEY

IT has been common knowledge since the dawn of civilization that stones, and more rarely masses of iron, sometimes fall from the sky, to the accompaniment of light and sound phenomena that naturally tended to be confused with thunder and lightning.

The ancient accounts range from bald statements to obviously embroidered tales, but include many clear and excellent records such as this account of the fall of a meteorite:

"the town is Hatford, in Berkshire, some eight miles from Oxford, 9th April, 1628, about 5 of the clock in the afternoon . . . . . in an instant was heard first a hideous rumbling in the air, and presently after followed a strange and fearful peal of thunder . . . . . Amongst all these angry peals shot off from heaven, at the end of the report of every crack, a hizzing noise made way through the air, not unlike the flying of bullets from the mouth of great ordnance, and by judgement were thunderbolts; for one of them was seen by many people to fall at a place called Bawkin Green, being a mile and a half from Hatford; which thunderbolt was by one Mistress Greene caused to be digged out of the ground, she being an eye-witness among many others of the manner of the falling. The form of the stone is three-square . . . . . , in colour outwardly blackish, somewhat like iron; crusted over with that blackness about the thickness of a shilling; within it is soft, mixed with some kind of mineral, shining like small pieces of glass. This stone broke in the fall. The whole piece is in weight nineteen pound and a half, the greater piece that fell off weigheth five pound, which together with other small pieces being put together, make four and twenty pound and better . . . . . for certainty there was one other one taken up at Lecombe, and is now in the custody of the sherrif."

It is one of the outstanding puzzles of meteoritics why, with such plain evidence before them, the scientists of the mid-eighteenth century should have decided that the fall of stones from the sky was incredible—a mere vulgar superstition.

* At the request of various members the full text is given of Dr. Max Hey's 1967 Herbert Smith Memorial Lecture delivered on 16th November, 1967.

The intellectual climate of the time must have had a lot to do with this disbelief—the notion that the Newtonian physics had explained the whole cosmos, in principle if not in detail, and therefore nothing could exist outside the earth's atmosphere but the sun, a few major planets, and the distant stars—a magnificent non-sequitur—; but no doubt the admixture of incredible stories with the more accurate records helped.

In France, the Académie des Sciences decided that the fall of stones from the sky was an impossibility, and that was that: who could contradict the Académie? The fall at Lucé in 1768 was a trifle inconvenient, but was happily explained as stones struck by lightning.

In Britain, eighteenth century science was much less organized, and anyway, who could doubt the evidence of a gentleman of quality who saw these things happen himself? Moreover, the English country gentleman was much less inclined to reject the evidence of his servants and tenants as mere vapourings of an ignorant peasantry. Accordingly, few in this country doubted that the thing happened, though the explanations offered were often a trifle far-fetched. Thus the fall at Pettiswood, Ireland, in 1779, was explained as a concreted mass of sand from a nearby lake, carried up along with water-vapour to the clouds and there congealed.

Gradually the evidence built up; falls at Vago and Siena, Italy, could be attributed to Vesuvius, and even the 56lb stone that fell at Wold Cottage in Yorkshire, could be explained as coming from the volcano Hecla, in Iceland. But between modern, well-attested accounts and the mass of historical evidence collected by Chladni and by King, the sceptics were wavering by the close of the century, and in 1803 the Académie des Sciences admitted that a shower of stones at L'Aigle were real, neither a figment of the imagination nor stones struck by lightning.

Short as it was, this period of scepticism—a mere 60 years or so—had one very unfortunate result: many of the meteorites then preserved in various cabinets of curiosities were thrown away as rubbish. On the other hand, the ten-year controversy stimulated interest in meteorites, and their scientific study was soon fairly launched.

Once it was established that stones, and more rarely masses of iron, fell from the skies, the next question was "whence"? Soon

pretty well every possible origin had been suggested, and their rival merits were hotly debated, though the evidence to decide between them was scanty.

Agglomeration of dust particles in the atmosphere, with or without the assistance of fusion by lightning, was a favourite for many years, until the difficulty of keeping the mass suspended during the agglomeration process was realized.

Many favoured the nearest active volcano, though it might be several hundred miles away; but as the chemical evidence slowly accumulated it was found that meteorites, with a few rare exceptions, differ greatly in chemical composition from terrestrial rocks.

If not terrestrial volcanoes, then what about the moon? Astronomers had been busy mapping the moon, and surely all those obvious craters must be volcanoes? Or again, it had just been shown that the major planets are not the only members of the solar system—the gap between Mars and Jupiter had just been filled by the first few asteroids to be discovered; these were surely the fragments of a planet that broke up and, if so, might not some of the fragments continue to circle the sun in highly eccentric orbits, and ultimately collide with the earth?

Then, once the possibility of a genuinely extra-terrestrial origin was admitted, what about the comets? These bodies were so obviously losing material in those vast tails—might not the meteorites come from them? Or might they not even be visitors from outside the solar system altogether?

The possibilities are numerous, and pretty well all of them had been advanced early in the nineteenth century, but the evidence to decide between them was lacking, and could only be acquired by patient collection of observations at the time of fall and careful study of the meteorites themselves—a task that is still far from complete today.

The fall of a meteorite is usually a spectacular affair, though there have been occasions when little was seen or heard—just a dark object, seen to fall with a bump. But normally a brilliant fireball is seen to move across the sky, and shortly afterwards a number of bangs and rumblings are heard; these are often compared to thunder or to artillery fire. Minor noises such as hissings and cracklings are often heard; the fireball may throw off sparks, or may break into two or more portions, and the break may be repeated.

The trajectory of the fireball could, of course, be anything from almost horizontal to vertical: leaving aside those cases where the sky was heavily clouded, it seems likely that the rare instances where nothing was seen are examples of near-vertical falls. At the other extreme, a procession of some hundreds of fireballs was seen all the way from Saskatchewan to beyond Bermuda (9th February, 1913), and probably fell in the sea some hundreds of miles east of Bermuda.

The fireball is commonly followed by a trail, which may persist for a considerable time or may be thrown into serpentine forms or rapidly dispersed by the winds of the upper atmosphere; by night, the trail is often luminous.

All these phenomena are readily understood in terms of our current knowledge of the physics of the upper atmosphere, and have little to do with the meteorite itself. The minimum velocity of its entry into the upper atmosphere must be seven miles a second, the earth's escape velocity, and at this speed the air is simply swept up and compressed, with the evolution of much heat. The meteorite's kinetic energy is rapidly converted into heat—but only a thin skin on its forward surface is heated; this thin skin is soon melted, and as fast as it melts it is swept off to form the smoke trail. The mechanical shock may fracture the mass, particularly if it has an irregular shape; on the other hand, because the pressure is uniform over the whole front surface, some very fragile meteorites survive; a few meteorites are so friable one cannot pick them up without fragments falling off, yet they came though, though probably with a great loss of weight.

The falling meteorite is soon accompanied by a globe of heated and ionized air, many times its own diameter, and this constitutes the visible fireball; slow recombinations of atoms and ions may give rise to a luminous trail, and electrical effects are probably responsible for the hissing and crackling noises. The bangs, at one time supposed to be the explosions of the meteorite itself, are clearly the shock-wave and its reflections.

By the time the meteorite is some 20-25 miles from the earth's surface it has usually lost most of its cosmic velocity, and the rate of heat formation drops off; the fireball quickly extinguishes, and from this point on a meteorite of ordinary size falls as a dark body, striking the earth with a velocity little greater than that of an object dropped from a high-flying aircraft. The actual point of

impact may be many miles horizontally from the point of extinction, a circumstance that often misleads observers of spectacular fireballs.

The behaviour of a really large meteorite is quite different. Because the kinetic energy increases as the cube of the average diameter, but the average cross-section only as its square, the buffeting effect of the earth's atmosphere decreases with the size of the incoming body. A small object, up to about pea size, will be wholly melted and dispersed as fine dust; such are the common "shooting stars". A still smaller object—a mere dust particle—will be so quickly checked in the outer atmosphere that it is not melted, remains dark, and slowly drifts down to the earth's surface; unfortunately, it is very difficult if not impossible to distinguish such particles from terrestrial dusts. On the other hand, a really large object will retain much of its cosmic velocity, and will still be travelling at several miles a second when it hits the ground. A meteorite about 20 to 25 feet in diameter would weigh roughly 1,000 tons, and at the moderate cosmic velocity of 12 miles a second its kinetic energy, all of which must be released on impact, would be about equal to the energy of the first atomic bomb.

Thus a really big meteorite will literally explode on impact, and will produce a crater, with fragments of meteorite material scattered around it. Fortunately, such events are very rare; the fall of 12th February, 1947 in the Sikhote-Alin mountains of far eastern Siberia produced several craters, the largest about 90 feet across (the event of 30th June, 1908, on the Stony Tunguska river in central Siberia is now believed to have been caused by the head of a small comet, and not by a meteorite proper). But much bigger craters have been formed in the past: one near Flagstaff, Arizona, 3/4 mile across, was originally about 700 feet deep; it has been partially filled by drifting sand, to a depth of some 100 feet. Even bigger craters have been shown to exist in the ancient rocks of northern Canada.

By far the commonest sort of meteorites are the stones; apart from their black fusion crust the casual observer will see little to distinguish them from terrestrial rocks. Most meteorites contain small particles of metal, but these readily escape notice on a freshly-broken surface; they are, however, a sure diagnostic feature, for they consist of a nickel-iron alloy that is peculiar to meteorites; nickel-iron alloys do indeed occur in a few terrestrial rocks, but they are very rare and contain far more nickel than any meteoritic

alloy. Again, microscopic study shows that most meteorites are largely composed of small spherules of olivine and pyroxene, in a texture quite unknown in any terrestrial rock. Indeed, an observer with adequate experience of meteorites rarely has any difficulty in recognizing one, though a few rare types do closely approach certain terrestrial rocks in composition and texture.

Chemically the stony meteorites vary very little in bulk composition, apart from about 5% of rare types. The common kinds all consist mainly of pyroxene, olivine, and nickel-iron alloy, with subordinate feldspar and iron sulphide, and accordingly their chemical analysis as compared to terrestrial rocks shows high magnesium, iron, and nickel, low silicon, aluminium, calcium, manganese, titanium, and sodium, and very low potassium. Almost all the known elements have been detected in meteorites.

The exceptional 5% of stony meteorites are very varied; some are almost pure enstatite, some resemble certain basalts in composition, and a few contain considerable amounts of free sulphur, sulphates, hydrous silicates such as serpentine, and complex carbon compounds.

About 6% of all meteorites seen to fall are solid metal, consisting of a nickel-iron alloy. The great majority contain 8 to 11% nickel, and on a polished and etched surface these show a very characteristic pattern; this pattern has not been reproduced in artificial nickel-iron alloys, because it is not possible to anneal them long enough—calculations show that the pattern probably took some millions of years to develop. A few irons contain as little as 5% nickel, and a few up to 30% or more, and these lack the Widmanstätten pattern.

Though irons are only a small fraction of the meteorites seen to fall, they are more readily recognized as something unusual, and remain recognizable for longer when exposed to the weather; once its black fusion crust has gone, a stony meteorite looks just like any other stone to the casual observer. This is the reason why rather more than half of those meteorites that are found, not seen to fall, are irons.

About 3½% of all known meteorites, and 1½% of those seen to fall, are "stony-irons", with roughly equal amounts of nickel-iron alloy and silicates; they are a very varied group and space does not permit of their further consideration here.

Meteorites contain traces of several radioactive elements, some primordial constituents, others produced by cosmic ray impact during the meteorites' sojourn in space. From a study of the nature and amounts of these radioactive nuclides and their breakdown products, it has been possible to deduce a good deal about the history of the meteorites. They all appear to have been originally formed about 4,500 million years ago, at about the same time as the earth and the other planets, but were originally part of one or more larger bodies. These larger bodies were subsequently broken up by collisions, or at least chipped, and the meteorites now reaching the earth are fragments deriving from collisions that occurred up to 500 million years ago or more; there are as yet not enough data for a consistent pattern to have emerged, but it seems likely that one collision some 25 million years ago may have produced a considerable fraction of the stony meteorites the earth is now encountering.

While the new evidence enables us to exclude many of the early nineteenth century theories of the origin of meteorites, we still cannot be definite about their source; some workers believe that they come from the moon, others that their parent was Mars, while probably most would agree that they originate from collisions among the asteroids. There is a fair body of evidence suggesting that they came from a parent body of the order of 100 to 300 miles in diameter: too small a body could never have melted internally (by radioactive heating), too large a one could not have cooled off quickly enough. But the details of the formation and history of the meteorites are still under dispute, and with a considerable bulk of new evidence becoming available annually this year's theories will almost certainly be out of date in a very short time.

TEKTITES

No account of the meteorites would be complete without some mention of those problematical objects, the tektites.

Should they be included with the meteorites? The question has been in the air now for many years; to some extent it is merely one of definition: if a meteorite is a solid body falling on the earth from outside the atmosphere, australites and moldavites, and probably all tektites, must be classed as meteorites; but if meteorites are defined by their composition or by their presumed origin in the asteroidal belt, tektites are not meteorites.

This, however, is to anticipate the evidence. The first tektites to come to scientific notice, in the late 18th century, were the moldavites, from the basin of the Moldau river in southern Bohemia; small fragments of olive-green glass, they have been held to be volcanic, or fragments from a vanished glass factory, but their composition is too siliceous for either explanation. The mid-nineteenth century saw the discovery of the australites, dark brown to black and often of remarkable and characteristic shape. Other discoveries of glassy bodies of high silica content in localities where igneous origin appeared impossible followed, and in 1900 Suess proposed the non-committal name tektites as an inclusive term for all such glasses. They are now recognized from Czechoslovakia, Indochina, Malaysia, Indonesia, the Philippines, Australia, the Ivory Coast, Texas, and Georgia. There are also glasses of unexplained origin from Tasmania, Mauritania, and Libya that are not usually considered to be tektites.

Chemically, the tektites are highly siliceous glasses (SiO_2 70 to 80%, Al_2O_3 11 to 14½%) with little iron, with potash (2 to 3%) in excess of soda (½ to 2%) and with mere traces of water. Such a composition is very different from the cosmic average (which the meteorites as a whole closely approach), but resembles that of some terrestrial sediments and some acid volcanic rocks, indicating an origin from material that has undergone considerable chemical differentiation. Their trace-element content too is different from the cosmic ratios or those in the meteorites, and generally similar to the average for the earth's crustal rocks.

The tektites are usually small; at one extreme, an indochinite of 3,200 grams has been recorded, but the average in most if not all tektite fields is under 100 grams, and a complete australite weighing only 0.06 gram is on record. In shape they vary from the slabby, layered masses from the Muong Nong area of Thailand to spheroids, pear-shaped, and the remarkably developed button forms, with lens-shaped core and outer flange, of some australites. Some philippinites contain spherules of nickel-iron alloy. Many indochinites are full of bubbles, but australites and moldavites normally have few and very small bubbles; in all cases the gas pressure in the bubbles is very low.

To sum up, the chemical and petrological data all tend to suggest that the tektites from each major field originated in one event, by fusion of material similar to a siliceous sedimentary or

igneous rock, at a temperature far enough above the melting point for appreciable loss of alkalis and other relatively volatile oxides to occur in a short time, followed by rapid chilling. Fusion could well have been due to impact by a giant meteorite.

Indeed, of all the numerous theories of the origin of tektites that have been advanced, only the theory of meteoritic impact remains—but there is no agreement as to the site of these impacts (one for each tektite field).

The main requirements that must be met are: the peculiar chemical composition of tektites, calling for an impact target that can only occur at the surface of the earth or a body that has undergone comparable differentiation; and the peculiar lens-and-flange structure of the australites, which is fairly conclusive evidence that these bodies fell at a high velocity through the earth's atmosphere, and started this flight as cool, rigid masses.

One school of though bases its argument mainly on the facts that possible meteorite craters can be recognized within reasonable range of nearly all tektite fields (with the significant exception of the australites, though here a hypothetical impact crater under the ice of Antarctica has been postulated) and that there is no evidence for materials of the composition of the earth's crust elsewhere in the solar system. This leads to the conclusion that the impacts were on the earth.

The other school relies mainly on a detailed study of the flow lines in australites and their deformation near the forward surface; this is held to indicate that the australites entered the earth's atmosphere with a velocity in excess of the earth's escape velocity and cannot, therefore, have had a terrestrial origin. Instead, they are believed to have originated by the impact of giant meteorites on the moon.

At present it does not appear possible to decide definitely between these rival theories, and the tektites remain, in many respects, an unsolved problem.

ASSOCIATION NOTICES

MEMBERS' MEETINGS

London: An audience of 241 attended Goldsmiths' Hall, London, on Tuesday, 30th January, 1968, to see three films—City of Gold (a re-creation, with the aid of contemporary photographs and based on old-time prospectors' recollections of the Klondyke Gold Rush of 1896); The making of a jewel—(showing scenes at Harry Winston's, the New York); Diamonds (a De Beers film telling the story of diamonds from mining to jewellery).

OBITUARY

Brown, Arthur Bayliss, of Ilford, Essex. (D. 1945).

LECTURES IN CEYLON

The Gemmological, Jewellers' & Tourist Traders' Association of Ceylon, commenced a series of gemmological lectures in January, 1968. The first series of 12 lectures is intended mainly for foreign missions in order to advertise the work of the Association internationally, but other courses for the public and the trade will follow.

GIFTS TO THE ASSOCIATION

The Council is indebted to Mr. C. F. Dudek, Oregon, U.S.A., for the gift of a faceted feldspar (var. bytownite) and to Mr. R. Webster for a collection of gem materials brought from Southern Africa.

Mr. S. Gunaratne of Ceylon has sent a booklet "Gems of Ceylon" written in Sinhalise.

MIDLANDS BRANCH

The Branch held an interesting evening on 22nd March, 1968, when members exchanged views on the merits of gems and their prices.

SCOTTISH BRANCH

On 29th February, the Curator of the Huntarian Museum, Dr. Rolfe, gave a short introductory talk about the development of the Museum and showed members some of the outstanding exhibits. Members were also able to handle specimens not normally displayed.

SITUATION REQUIRED

Solicitor's daughter (aged 20), eight "O" levels, working knowledge French and Spanish, good typist, seeks work in London, E.C.1. area. Studying gemmology. Keen to handle gems. GA/25/68.

COUNCIL MEETING

At a meeting of the Council of the Association held on 7th February, 1968, the following were elected:—

Fellowship

Foster, Angela Maureen (Miss), Liverpool. Dip. 1967.
Hubbard, Kenneth D., Leigh-on-Sea. Dip. 1946.
Kirkpatrick, Maurice Robert, Kenilworth. Dip. 1951.
Nash, Geoffrey Edwin, Walsall. Dip. 1967.

Ordinary Membership

Baker, Kenneth Robert, Whitehaven.
Chambler, Kenneth, Reigate.
Chang, Yut-Ying Jimmy, Hong Kong
Chapman, Edward, North Ferriby, E. Yorks.
Copping, Dorothea (Mrs.), London
Smith, Craig Cameron, Bulawayo, Rhodesia
Eddy, Donald B., Esher
Elwell, Dennis, Cowplain, Hants.
Fairburn, Michael Jeffrey, Reading
Foster, Joseph, Bloomfield, U.S.A.
Kilpatrick, Constance (Mrs.), Aberdeen
Lewes, Cyril Herbert, London
Mirwald, Gerhard, Tokyo
Moore, I. E. (Mrs.), Solihull
Mosey, Irene (Mrs.), Lancaster
Payne, Henry Arthur Sheldon, Harpenden
Ponahlo, Gertrude (Mrs.), Vienna, Austria
Proctor, Hugh C., Don Mills, Ontario
Pyle, Ralph, London
Robertson, John Mackay, Portsmouth
Roca, Rogelio, Jnr., Barcelona
Russell, Lionel Harold, London
Sorsby, Nicholas John, Kampar, Malaysia
Spangenberg, Harry, Milwaukee, U.S.A.
Tammarine, Arthur, Vista, California
Tuckey, Harry Russell, Dartmouth, Nova Scotia
Wang, Archie, Hong Kong
Yamakawa, Masako (Mrs.), Geneva, Switzerland
Yoshimoto, Aiko (Mrs.), Hyogo Pref., Japan

Probationary Membership

Alabaster, Anthony Paul, Birmingham
Bartlett, Stewart Michael, Northwich
Cann, Jonathan D., Fontwell
Heykoop, Nicolaas, Rotterdam, Holland
Lee, Richard, Richmond
Saunders, Geoffrey Peter, Barkingside
Shapiro, Eric, London
Rae, Francis Carl, London
Weerasinghe, Gamani Bandula, Ceylon
Whitehead, Paul, Tamworth

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E/C	Blue	1·28 cts.	£ 7 0s. 0d.	per carat.
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Oval	Blue	5·01 cts.	£15 0s. 0d.	per carat.
Oval	Brown	9·20 cts.	£22 0s. 0d.	per carat.
Cushion	Blue	9·72 cts.	£20 0s. 0d.	per carat.
Pear shape	Mauve	11·42 cts.	£20 0s. 0d.	per carat.
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Cushion	Mauve	12·97 cts.	£30 0s. 0d.	per carat.
Round	Mauve	13·15 cts.	£30 0s. 0d.	per carat.
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Sphalenite	74·50 cts.	orange	Spain
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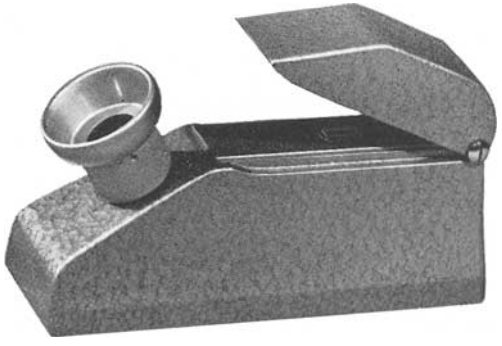

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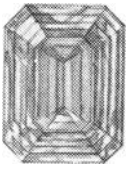

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THE JOURNAL OF GEMMOLOGY

and

PROCEEDINGS OF THE GEMMOLOGICAL ASSOCIATION OF GREAT BRITAIN

GEMMOLOGICAL ASSOCIATION
OF GREAT BRITAIN
SAINT DUNSTAN'S HOUSE, CAREY LANE
LONDON, E.C. 2

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THE JOURNAL OF GEMMOLOGY
AND PROCEEDINGS OF THE GEMMOLOGICAL ASSOCIATION OF GREAT BRITAIN

Vol. 11 No. 3 JULY 1968

SIXTY YEARS OF GEMMOLOGY IN GREAT BRITAIN

THE genesis of the educational scheme, initiated by the National Association of Goldsmiths of Great Britain and Ireland, the representative organization of the retail jewellery trade in Great Britain, which eventually culminated in the Gemmological Association of Great Britain, occurred at the annual conference of the National Association at Manchester on 6th July, 1908, when a resolution, moved by Mr. Samuel Barnett, advocating the formation of teaching courses and examination in gemmology was adopted.

Considerable difficulty was experienced at the outset in launching the scheme, not only on account of the general apathy in the jewellery trade but also because no suitable text-book was at that date available, and, moreover, because so many of the prospective students were widely scattered throughout the country. It called for two years of unremitting efforts before there was sufficient response from the jewellery trade to enable the scheme to proceed. However, interest was maintained by the lectures on gemmological subjects which were given in 1909. The difficulty of establishing contact with distant students was met by the correspondence course of general instruction for jewellers which Mr. Arthur Tremayne was conducting at that time. Further progress was made in the following year, 1910. Mr. Noel Heaton, B.Sc., was appointed Official Lecturer by the Egucation Committee, and

delivered several lectures at various centres in the Country; in consequence increasing interest was aroused in gemmology. A contributing factor was the growing use of the portable refractometer devised by Dr. G. F. Herbert Smith in 1906. Mr. Barnett, indeed, found that it was the invention of this simple, and easily handled instrument which did more than anything else to awaken the jewellery trade to the importance of the study of the characters of gemstones. Dr. Herbert Smith's book "Gemstones", published in 1912, set a standard of accuracy and scholarship that greatly assisted the teaching of gemmology. This classic work reached its thirteenth edition in 1958. Dr. Herbert Smith was appointed as principal examiner and at the same time Mr. Bristow J. Tully was appointed official instructor. Mr. Irvine G. Jardine prepared a correspondence course and eventually became lecturer at the first classes in gemmology at the Chelsea Polytechnic, London, with Mr. Thorold Jones as demonstrator.

As finally adopted, the scheme consisted of an advanced examination, the Diploma, and a much easier Preliminary examination. No essential change has been made in the character and standard of the examinations since the inauguration of the scheme, except for slight modification and widening of the syllabus. The standard set for the Diploma has always been high, and that for qualification with distinction, a variant introduced in 1922, is very high. It is probably this fact that accounts for the high reputation of the examinations not only at home but in other countries as well. The foundation of the scheme was, indeed, well and truly laid.

The first examination was held in 1913, and others followed in 1914 and 1915; but in consequence of the outbreak of the first world war the scheme became dormant. Indeed, it was not at first intended to hold an examination in 1915, but it was found that a few candidates were well advanced in their studies before the crisis developed, and would have been disappointed had there been no examination. Even when happier days returned the series was not resumed until 1922; but since then there has been no interruption in spite of the outbreak of the second world war and the venemous attacks by air upon the country, especially the heavy bombing of the London area. It cannot, indeed, be too strongly stressed how highly creditable it was to all concerned that in such difficult and unprecedented circumstances the classes and examinations were quietly continued without a break.

When the examinations were resumed in 1922 it was decided to divide the successful candidates for the Diploma into two classes: those whose work was on so high a plane as to warrant the award of distinction, and those who qualified at a lower level. To commemorate Mr. B. J. Tully and the eminent services that he had rendered to the examination scheme Mrs. Tully presented a set of dies for striking a medal to be awarded to the best candidate who sat for the Diploma examination in each year; the medal was first awarded in 1930. Subsequently Messrs. Rayner & Keeler Limited of London, kindly made available to the Association an annual award of gem-testing instruments in connection with both preliminary and diploma examinations.

As a result of the enthusiasm and hard work of Fellows various classes in gemmology became established in provincial cities, under the aegis of education authorities.

To meet the needs of students living overseas, the Associateship examination, consisting of the Diploma theoretical papers only, was instituted in 1938. Successful candidates could qualify for the Diploma by passing the practical test at a subsequent examination in London, and several soon took successful advantage of this arrangement. It has, however, been found possible to hold a practical examination at certain centres overseas, and the Associate examination was discontinued in 1950.

With a view to encouraging and recognizing postgraduate study by Fellows the Council instituted in 1945 the Research Diploma. It is awarded for an authorized thesis of adequate quality.

From 1946 until 1950 a prize, donated by Mr. B. W. Anderson was awarded for outstanding work in the practical section of the diploma examination.

The formal inauguration of the Gemmological Association as a branch of the National Association took place at the annual distribution of awards in October of 1931. Holders of diplomas became eligible for election to fellowship with the right to add the letters F.G.A. to their names. In 1938 greater precision was given to the title of the new body by the adoption of the form: Gemmological Association of Great Britain. The final stage was reached on 14th April, 1947, when the Association was incorporated. The Association is an independent entity; but its origin from the National Association of Goldsmiths and the support that it received

and continues to receive from the latter is not and will not be forgotten. The National Association of Goldsmiths continues to provide the clerical assistance needed for the day-to-day work of the Association, and the close links between the two organizations have been an important factor in increasing interest in gemmological studies.

The Association receives entrants for its examination from students all over the world, apart from the U.K., who have studied gemmology at classes or courses arranged by gemmological organizations or under the aegis of local education authorities. The only courses conducted by the Association itself are those by correspondence, to cater for those who have not facilities for attending local classes.

The first official journal of the Association was *The Gemmologist*, in 1931. Subsequently, in 1935, the official publication was *Gemmological News*, which changed its title to that of *The Journal of Gemmology* in 1944. Until the date of incorporation of the Association reliance was placed upon outside publishers for an official publication but upon incorporation in 1947 direct responsibility for publication was undertaken and has been retained since that time. In 1947 it was decided to appoint a Curator of the Association's collection of gemstones.

The first President was Sir Henry A. Miers, who held office from 1932 until 1937. He was succeeded by Sir William H. Bragg, and on the latter's death in 1942, Dr. G. F. Herbert Smith was elected to the office and served until his death in 1953. He was succeeded by Sir Lawrence Bragg, the son of the second President.

The Herbert Smith Memorial Lectures were instituted in 1955, in memory of one who had done so much for gemmology and the Association. Likewise Sir James Walton, the first Curator, was remembered when the National Association of Goldsmiths joined with the Association in establishing a library in his memory.

Three branch associations were formed in 1952 based in the midlands and the east and west of Scotland. The East of Scotland Branch ceased in 1955 and members in the area took part in meetings arranged by the western branch, which, in 1967, changed its title to that of Scottish Branch. The work of the branches has been invaluable in furthering interest in gemmology.

From 1966 the registrar of the National Association of Goldsmiths has assisted with the increased education work connected

with gemmology and the larger number of entries for the examinations.

The Association has assisted in the formation of various gemmological organizations overseas and close contact is maintained between these and similar associations on all matters apertaining to the study of gemmology.

In 1961 the Association was asked by Rayner & Keeler Limited to take over the retail sales of their gemmological instruments. The arrangement has been mutually beneficial and the Association is indebted to Rayner & Keeler for their continued co-operation with the Association. In order not to disturb the permission given to the Association to omit the word "Limited" from its title, a separate sompany was formed to handle sales.

Apart from those who pioneered the study of gemmology the Association has been fortunate over the years in having had assistance from various other eminent and enthusiastic workers. These include Mr. F. H. Knowles-Brown, who served as Chairman for almost twenty years, and Mr. B. W. Anderson whose work both as a lecturer and as an examiner, has been invaluable. Also there is Mr. R. Webster to whom the Association is indebted, and Dr. G. F. Claringbull, who has served as an examiner since 1938. To many other gemmologists in Great Britain and overseas the Association owes a debt of gratitude. Mr. Norman Harper, the present Chairman, initiated and for some time conducted the first courses devoted to the study of gem diamonds, and this has given to the educational work of the Gemmological Association an added dimension. The Association became the examining body and issues a certificate to Fellows who qualify.

In sixty years, as a result of the enthusiasm of many who have been devoted to the furtherance of the study of gemmology, much has been achieved in Great Britain and overseas and the National Association of Goldsmiths can look back with satisfaction at the splendid work that has stemmed from the resolution passed at its conference in July, 1908.

Details of the officers, administration and examination results, are set out in the following pages.

OFFICERS AND ADMINISTRATION 1908-1968

(i) President

1932-37 SIR HENRY A. MIERS, D.Sc., F.R.S.
1937-42 SIR WILLIAM H. BRAGG, O.M., K.B.E., D.Sc., F.R.S.
1942-53 G. F. HERBERT SMITH, C.B.E., M.A., D.Sc.
1954- SIR LAWRENCE BRAGG, C.H., O.B.E., M.C., B.Sc., F.R.S.

(ii) Chairman

(*a*) Education or Gemmological Committee

1908-12 S. BARNETT.
1912-27 G. H. CLAPHAM.
1928-29 C. E. PARSONS.
1929 B. J. TULLY.
1929-30 G. TARRATT.
1930-31 S. BARNETT, F.G.A.

(*b*) Council of the Association

1931-32 S. BARNETT.
1932-35 A. GREENSLADE.
1935-42 E. A. DODD.
1942-46 V. W. CLARKE, Hon. F.G.A.
1946-55 F. H. KNOWLES-BROWN. F.G.A.
1955 SIR JAMES WALTON, K.C.V.O., B.Sc., M.S., M.B., F.R.C.S., F.G.A.
1955-65 F. H. KNOWLES-BROWN, F.G.A.
1965- N. A. HARPER, F.G.A.

(iii) Honorary Treasurer

1912-15 J. DYSON.
1924-25 V. W. CLARKE.
1926-31 A. W. BOATMAN.
1932-42 V. W. CLARKE.
1942-47 J. H. STANLEY, F.G.A.
1947-51 S. F. BONES, F.G.A.
1951- F. E. LAWSON CLARKE, F.G.A.

(iv) Honorary Secretary

1908-12 S. BARNETT.
1931-33 A. TREMAYNE.
1933 S. T. SOLOMON, F.G.A.
1933-38 F. E. LEAK, F.G.A.
1938-39 G. F. ANDREWS, F.G.A.
The office then lapsed.

(v) Curator

1947-55	Sir James Walton, K.C.V.O.
1955-57	G. M. Sprague, M.B.E., F.G.A.
1957-	R. Webster, F.G.A.

(vi) Librarian

1947-	H. J. B. Wheeler, F.G.A.

(vii) Registrar

1966	A. Roebuck.
1967-	Miss J. Burgess.

(viii) Secretary

1912-26	C. L. Burnett.
1927-32	Miss E. Pettifer.
1933-39	E. Trillwood, F.G.A.
1939-	G. F. Andrews.

EXAMINATIONS

(i) Examiners

1931-51	G. F. Herbert Smith, M.A., D.Sc.
1913-23	E. Hopkins.
1924-28	B. J. Tully.
1929-37	A. H. Ward.
1938-	G. F. Claringbull, B.Sc., Ph.D., F.G.S.
1951-	B. W. Anderson, B.Sc., F.G.A.
1955-	J. R. H. Chisholm, M.A., F.G.A.
1964-	A. J. Allnut, B.Sc., Ph.D., F.G.A.
1963-	S. Tolansky, Ph.D., D.Sc., F.R.S.

(ii) Director of Examinations

1913-15	W. A. Steward.
1922-23	B. J. Tully.
1924-26	C. L. Burnett.
1927-29	R. Sawers.
1929-32	A. H. Ward.
1932-33	C. L. Burnett.
1934-38	E. Trillwood.
1939-	G. F. Andrews.

(iii) Research Diploma

1945	M. D. S. Lewis, B.Sc.
1946	R. Webster.
1953	G. F. Leechman.
1957	E. Gubelin, Ph.D.
1959	L. C. Trumper, B.Sc.

(iv) Diploma Examination

(*a*) Candidates

	Entered	Qualified
1913	8	6
1914	6	5
1915	2	2

From 1922 the successful candidates were divided into two grades: Distinguished and Qualified.

	Entered	Distinguished	Qualified
1922	8	3	4
1923	13	2	8
1924	20	4	13
1925	18	3	10
1926	19	3	11
1927	20	7	10
1928	15	4	10
1929	25	5	18
1930	18	6	7
1931	22	7	10
1932	23	4	11
1933	28	9	18
1934	21	9	12
1935	14	7	7
1936	17	2	8
1937	25	10	14
1938	30	8	18
1939	23	7	8
1940	10	1	5
1941	3	2	1
1942	7	4	1
1943	4	2	1
1944	11	2	2
1945	24	5	8
1946	17	7	8

1947	...	...	...	28	...	11	...	10
1948	...	...	...	95	...	9	...	51
1949	...	...	...	104	...	21	...	60
1950	...	...	...	96	...	12	...	59
1951	...	...	...	92	...	16	...	56
1952	...	...	...	101	...	13	...	32
1953	...	...	...	99	...	9	...	39
1954	...	...	...	75	...	13	...	18
1955	...	...	...	84	...	10	...	44
1956	...	...	...	93	...	9	...	52
1957	...	...	...	100	...	6	...	34
1958	...	...	...	100	...	7	...	51
1959	...	...	...	60	...	7	...	41
1960	...	...	...	110	...	13	...	44
1961	...	...	...	106	...	14	...	51
1962	...	...	...	135	...	18	...	71
1963	...	...	...	132	...	20	...	59
1964	...	...	...	139	...	...4	...	44
1965	...	...	...	176	...	10	...	82
1966	...	...	...	194	...	13	...	70
1967	...	...	...	196	...	11	...	79

(*b*) **Tully Medallist**

1930 C. M. L. Carr, London.
1931 G. F. Andrews, London.
1932 F. E. Leak, London.
1933 E. H. Neale, London.
1934 R. K. Mitchell, London.
1935 H. E. Tillander, Helsinki, Finland.
1936 H. E. Smith, Brighton.
1937 J. N. Watson, Glasgow.
1938 J. Vincent, Brighton.
1939 A. P. Ambrose, London.
S. H. Ross, London.
1940 W. H. West, London.
1941 G. F. N. Marriott, London.
1942 M. Henderson (Miss), Dundee.
1943 B. A. Maclean (Mrs.), London.
1944 M. D. S. Lewis, London.
1945 G. I. Parry (Mrs.), Cardiff.
1946 A. S. Braunfeld, London.
E. R. Levett, London.
1947 E. H. Rutland, London.
G. M. Sprague, Edinburgh.
1948 No Award.

1949 P. J. THOMSON, Thundersley.
1950 H. L. ZWIRS, Netherlands.
1951 J. D. WADE, Glasgow.
1952 L. SIEDLE, Colombo.
1953 J. B. KEMP, Bristol.
1954 N. DEANE, Wednesbury.
1955 R. E. MUIR. Wilmslow.
1956 P. G. MARKS, Sydney.
1957 No Award.
1958 J. G. ROACH, Birkenhead
1959 No Award.
1960 H. S. HEIKKILA, Helsinki, Finland.
1961 L. WELLINGTON, Scarbough, Canada.
1962 P. A. WATERS, Manchester.
1963 G. V. AXON, New York, U.S.A.
1964 F. G. DOWIE, Christ Church, New Zealand.
1965 C.CANNAWURF (Miss), Frankfurt. W. Germany.
A. TAYLOR, Exeter.
1966 B. F. MARTIN, Sheffield.
1967 E. STRACK (Miss), Idar-Oberstein, W. Germany.

The Tully Medallists are included among the candidates who gained distinction.

(v) Associate Examination

	Entered	Passed
1941	3	3
1944	1	1
1945	1	—
1947	1	—
1948	6	4
1949	7	3
1950	2	2

This examination was discontinued in 1950.

(vi) Preliminary Examination

(*a*) Candidates

	Entered	Qualified
1913	12	7
1914	15	12
1915	1	1
——	—	—
1922	35	26
1923	28	24
1924	33	26

1925	...	...	...	27	...	22
1926	...	...	...	33	...	26
1927	...	...	...	35	...	25
1928	...	...	...	37	...	31
1929	...	...	...	30	...	28
1930	...	...	...	32	...	28
1931	...	...	...	28	...	24
1932	...	...	...	29	...	26
1933	...	...	...	31	...	29
1934	...	...	...	24	...	22
1935	...	...	...	25	...	24
1936	...	...	...	32	...	31
1937	...	...	...	39	...	32
1938	...	...	...	37	...	33
1939	...	...	...	29	...	24
1940	...	...	...	11	...	9
1941	...	...	...	5	...	4
1942	...	...	...	16	...	6
1943	...	...	...	17	...	15
1944	...	...	...	21	...	14
1945	...	...	...	24	...	17
1946	...	...	...	28	...	23
1947	...	...	...	139	...	113
1948	...	...	...	176	...	143
1949	...	...	...	126	...	85
1950	...	...	...	139	...	96
1951	...	...	...	147	...	117
1952	...	...	...	134	...	50
1953	...	...	...	124	...	62
1954	...	...	...	137	...	83
1955	...	...	...	148	...	100
1956	...	...	...	142	...	90
1957	...	...	...	130	...	81
1958	...	...	...	138	...	73
1959	...	...	...	183	...	102
1960	...	...	...	185	...	105
1961	...	...	...	182	...	123
1962	...	...	...	213	...	119
1963	...	...	...	215	...	112
1964	...	...	...	273	...	176
1965	...	...	...	265	...	169
1966	...	...	...	308	...	217
1967	...	...	...	376	...	232

(*b*) **Rayner Prize**

1938	S. H. Ross.	1953	N. Deane.
1939	No Award.	1954	R. E. Muir.
1940	H. R. Cox.	1955	M. S. D'Argy.
1941	E. G. Mould.	1956	J. A. Jank
1942	R. W. Hester.	1957	I. N. Steadman.
1943	L. Walford.	1958	M. Mendelsohn.
1944	D. P. Guest.	1959	P. W. T. Riley.
1945	E. R. Levett.	1960	D. Hayes.
1946	No Award.	1961	E. W. Penner.
1947	H. P. Bowen-Evans.	1962	A. Cooper.
1948	E. H. Gudridge.	1963	M. Davies, Mrs.
1949	S. G. Warnes, Miss.	1964	F. Riding.
1950	I. N. Instone.	1965	S. Heffernan, Miss
1951	C. I. Belcher.	1966	E. Strack, Miss
1952	T. M. Brook.	1967	No Award.

(**vii**) **Honorary Fellowship**

1938	Prof. K. Schlossmacher.
	G. Gobel.
1938	Victor W. Clarke.
1946	G. F. Herbert Smith, M.A., D.Sc.
	G. F. Claringbull, Ph.D.
1947	W. F. P. McLintock, D.Sc.
	W. Campbell Smith, Sc.D.

(**viii**) **Official Journal**

1931-1934	The Gemmologist (N.A.G. Press Ltd.)
1935-1944	Gemmological News (Heywood & Co. Ltd.)
1945-1946	Journal of Gemmology (Heywood & Co. Ltd.)
1947-	Journal of Gemmology (Gemmological Association)

THE SAXON FIFTY-CARAT DIAMOND

A MODIFIED "PERUZZI"

By H. TILLANDER

DESCRIPTIONS and analyses of historical diamonds have so far mainly been concerned with popular and mythological aspects and in very few instances give accurate and detailed descriptions of the ingenious architecture of the predominant masterpieces among these diamonds.

The aim of this report is to fill this gap and is a part of a series started with descriptions of the "Ideal Peruzzi-cut", as well as the Wittelsbach and Regent diamonds. ("Six Centuries of Diamond Designs"—*Journal of Gemmology*, Vol. IX, No. 11, July, 1965).

The Dresden (or Saxon) White is exhibited in the "Green Vault" of Dresden. It is set in a large shoulder knot (épaulette), the height of this page (8½ of an inch). There is no certain evidence of the origin of this diamond, but according to very detailed investigations by such authorities as Erna von Watzdorf and others it must have been acquired by king Augustus III (Elector of Saxony as Frederick Augustus II) and originally set by Andreas Jacob Pallard, a native of Geneva, who worked as court jeweller in Dresden between 1746-49, then in 1753 and again around 1756. His first assignment seems to have been the remodelling of a Golden Fleece into which the Dresden Green originally had been set and the shaping of this magnificent piece of jewellery would best fit into this same period. Theoretically Pallard may of course have fulfilled his assignment in his Viennese workshop or when he was back again in Dresden in 1753—in that case perhaps the reason for calling him back, but these alternatives are unprecedented. In any case the year 1753 must be the ultimate date, since disastrous wars and consequent poverty followed in 1754. And in 1768, not too long after the Seven Years War, the jewel was transformed by another craftsman, Diesbach. This resulted in a mixture of different styles, not only in design, but also with respect to the diamond cluster of the shoulder knot. The photograph, Figure 1, shows only the original part of the jewel, the Saxon gem in the centre.

The Saxon diamond is a squarish, elongated brilliant-cut stone, very much resembling the "Peruzzi-cut", with overall dimensions of 26 × 23 millimeters, illustrated in correct size and

shadowed in the diagram for easier interpretation of its actual shape.

The pavilion is different with respect to the rectangular shape of its culet (4×2 mm) and the narrower main facets (the bottom corners) are therefore foursided kites, touching the culet at its corners.

The design of the crown shows an elongated octagon ($18{,}5 \times 15{,}6$ mm) which in a normal brilliant-cut would be the table. In this diamond, however, the octagon forms the base of a truncated, extremely flat solid, with four pentagonal faces and a rectangular vertex, which is the table. The height of the superimposed solid is only one third of a millimeter and the unique rectangular table measures $6{,}6 \times 5{,}0$ mm. The inclination towards the girdle plane of the longer pair of faces is 4°, of the adjacent top main facets (quoins) 44°, and of the corresponding pavilion main facets (quoins) $33\frac{1}{2}$°. It is thus a brilliant-cut diamond with ideal 18th (and 19th) century crown angles, but much too narrow pavilion angles. In case the cutter had applied a table face in the normal way, this would have been very large, resulting in a less attractive stone. The four pentagonal apex facets, through which much of the light enters the stone, cause through their inclination slight changes with the path of light and probably improve the brilliancy of the diamond to some extent. Light entering the faces around the rectangular table actually strike the largest two pavilion facets as if their angle was $33{,}5 + 4° = 37{\cdot}5°$.

It is extremely difficult to judge the influence of proportions on the beauty of a large diamond, especially since the diamond is not displayed in the illumination for which it was intended—that of innumerous candles of chandeliers. Considering the fact that this stone must primarily have been cut for size, it can only be admired as a further example of exquisite workmanship and elegance well competing with the Wittelsbach and the Regent. Particularly striking is the beautifully balanced distribution of facets.

In subsequent reports other interesting diamonds will be analyzed.

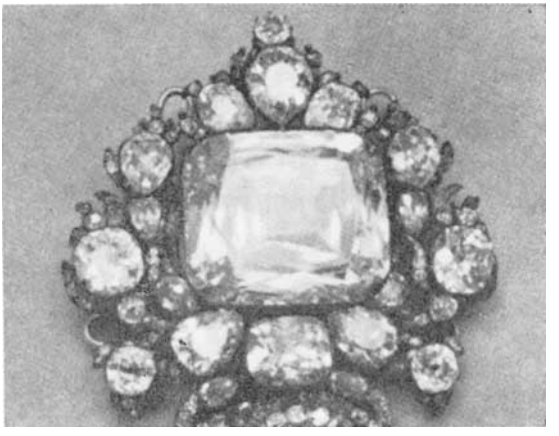

FIG. 1. *The only remaining part of Pallard's composition with the* 49·71 *cts Saxon White diamond. Actual size. (Green Vault, Dresden).*

a FIG. 2 *b*

FIG. 2A. *Top view of the Saxon White with* 36 *crown facets and a table.*

FIG. 2B. *Top view with the centre facets shaded.*

Size of stone	*26,00 mm*	×	*23,00 mm*	= 100%.
Size of octagon	*18,75 mm*	×	*15,60 mm*	= *68,5%.*
Size of table	*6,60 mm*	×	*5,00 mm*	= *22%.*

a FIG. 3 *b*

FIG 3A. *Side view, without girdle, which could not be measured because of the heavy setting.*

3B. *Same shadowed.*

Crown height	*0,35 mm*	=	*1,5 %*	*Total depth*	*11,00 mm*	=	*47,8 %*
	+ *3,65 mm*	=	*15,9 %*	*Culet size*	*4 × 2 mm*	=	*8,7 %*
	4,00 mm	=	*17,4 %*	Angle of facets alongside table			*4°*
Pavilion depth	*7,00 mm*	=	*30,4 %*	Angle of bezel facets			*44°*
				Angle of pavilion facets			*33° 30′*

PSEUDOCROCIDOLITE

By ROBERT WEBSTER

SOUTH AFRICA has one gemstone which can be said to be peculiarly its own; this is the silky golden-brown ornamental stone pseudocrocidolite, which is sometimes better known as 'tiger's-eye'. This stone is usually dealt with cursorily in gem literature and in this short article some attempt is made to amplify the knowledge of this attractive gemstone.

In a part of Northern Cape Province lies Griqualand West, an area which was the original territory of the Griquas, who were a coloured people of mixed ancestry and not necessarily indigenous to the country. The district of Griqualand West, which was incorporated into Cape Colony in 1871, of arid nature and bordering on to the Kalahari desert, is the area in which is found the blue asbestos called crocidolite. It is here that commercially exploitable deposits of this mineral are found in the banded ironstones of the Transvaal system of rocks, which, among others, form the Asbestos Mountains which run in a north-easterly direction from the Orange river.

Crocidolite asbestos is a hydrous silicate of sodium and iron. It is an amphibole of blue colour and is made up of silky fibrous monoclinic crystals which have a cleavage parallel to their length. The material may be said to be a fibrous variety of riebeckite. The unaltered mineral has a hardness of 4 on Mohs's scale, a density of about 3·3 and refractive indices of $\alpha = 1{\cdot}698$, $\beta = 1{\cdot}699$ and $\gamma = 1{\cdot}706$. The mineral shows a silky to dull lustre and the individual fibres are strongly pleochroic. Large deposits of this blue asbestos are found in South Africa, particularly around Prieska, but except for deposits in Australia, there are few of any size in other parts of the world. The commercial value of crocidolite asbestos lies in its resistance to chemical action, particularly by acids and by sea-water—hence its use as an insulator in marine engineering.

It is not, however, the mineral crocidolite which interests the gemmologist, but its silica pseudomorph. In an area north of Prieska, particularly near the village of Niekerkshoop, in Griqualand West, the crocidolite fibres have been altered by a gradual replacement by silica while retaining the general outward appearance of the original asbestos. This silification retains, too, the original

habit of the asbestos which had formed as parallel fibres stretching across a vein from wall to wall, producing the so-called "cross-fibre" asbestos. The veins are rarely more than a few centimetres in thickness and are in a finely grained quartz rock of reddish-brown, coffee-brown or ochre-yellow colour. The host rock, which may be compact or somewhat thinly bedded, may be described as a jasper-schist or an "ironstone."

The original crocidolite is blue and when this is silicified the bluish stone is termed "hawk's-eye" (or sometimes "falcon's-eye") and such material is often cut and polished, or fashioned by the "tumbling" process, producing pleasing stones. Oxidation of the iron constituent of the crocidolite, which can occur either before or after silification, produces the lovely "tiger's-eye". A polished surface of pseudocrocidolite when turned towards the light often shows a series of lustrous bands alternating with bands of duller colour which show little silky lustre. The beauty of the effect is enhanced by the fact that the fibres are not always perfectly straight; they may be curved and often have a sharp bend or twist at a certain place. A change in the incident light results in a reversal of the conditions, the dark bands becoming lustrous and the lustrous bands becoming dark.

The date when "tiger's-eye" was first found is open to some conjecture. Hodgson states:— "the discovery of blue asbestos is attributed to a German geologist named Lichtenstein, who, at some time between 1803 and 1806, was travelling near Prieska in the Orange river valley in South Africa, came upon a mass of heavy asbestos which was lavender-blue in colour. The discovery appears to have been forgotten for many years, to be revived in 1891 by a diamond prospector whose attention had been drawn to the "blue-ground" at Prieska. Diamonds there were none, but it was due to De Beers Consolidated Mines, whose main interests lie in diamond mining, that a company was formed in 1893 to exploit these new deposits of blue asbestos". On the other hand Bauer seems to imply that "tiger's-eye" was known about 1870, when it was said to fetch about 25/- per carat. Wodiska, in his book, states that "'tiger's-eye' is well adapted to and has largely been used for carving cameos and intaglios. It was very popular from about the year 1880 to 1890 in the United States of America". From this it appears likely that "tiger's-eye" was used as a gem material before the mineral crocidolite was itself commercially mined.

The pseudocrocidolite of South Africa is mined by cutting trenches across the terrain, a terrain which is semi-desert and lacks much in the way of flora except for sparsely distributed thorn bushes which have vicious thorns as much as two inches long. The trenches are cut down to some eight or ten feet through the banded ironstones, which are interspersed by parallel slabs of the pseudocrocidolite. When the writer visited the area during 1967 some of

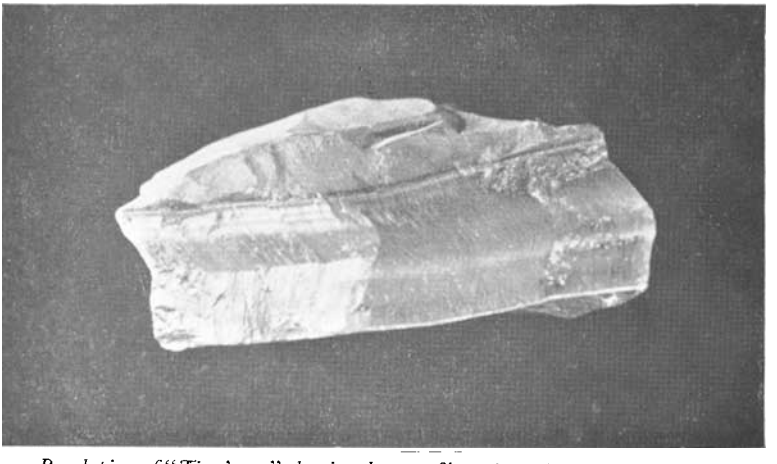

Rough piece of "Tiger's-eye" showing the cross fibre vein in the ironstone host rock.

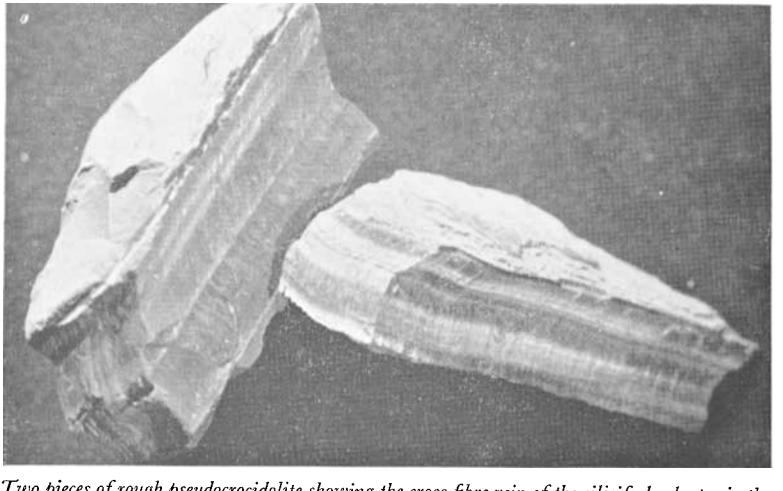

Two pieces of rough pseudocrocidolite showing the cross fibre vein of the silicified asbestos in the ironstone host rock.

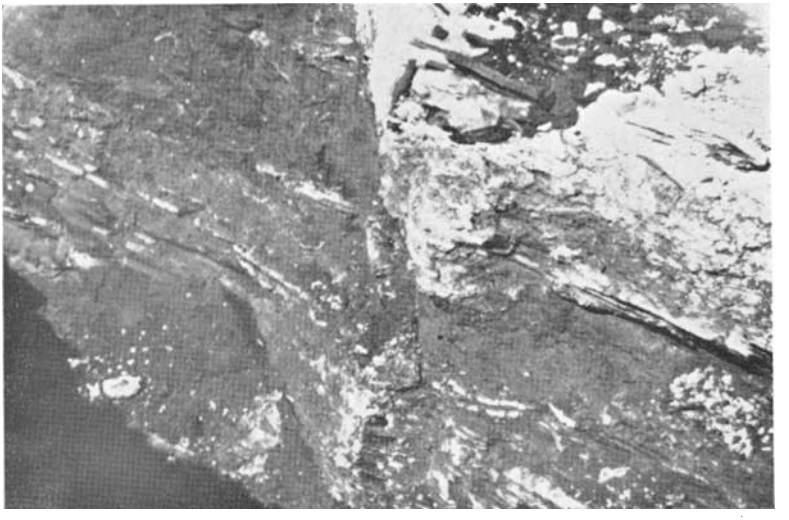

Wall of a trench cut for the recovery of pseudocrocidolite showing the layers of the mineral in the ironstone host rock. North of Prieska, Cape Province, South Africa.

Printed from a coloured transparency

these trenches, or pits, were seen to be undercut, and at one place the rock was being broken down by the "fire and quenching" method, and piles of the recovered mineral were stacked on the ground all around. Much of the recovery, after it has been sorted or graded, goes to Idar-Oberstein in Germany for fashioning and carving, but currently much is "tumbled" into baroque stones in South Africa, for mounting into jewellery for local and tourist needs.

The fundamental colour of pseudocrocidolite is greyish-green to bluish-green and the name "hawk's-eye" is given to material of this colour. The most important variety is the golden yellow "tiger's-eye", which is the primary mineral altered in colour by oxidation of the iron content. However, there are other varieties, such as the variegated material yellow and greenish-blue which is called "zebra", and the bluish and greenish yellow stones termed "cat's-eyes". The term "wolf's-eye" or "wolf's-eye stone" is an unnecessary name for an intermediate colour between "hawk's-eye" and "tiger's-eye".

A red variety goes under the name of "bull's-eye" and the colour of this material is induced by heating. It is suggested that there is an alteration of goethite, or limonite, to hematite by loss of water to account for the colour change. It is conjectural whether this red-coloured material may be caused by the fire and water technique used in breaking through the rock, but undoubtedly most of this material is artificially treated. It may be significant that the writer saw no red material in the piles of recovered pseudocrocidolite. Experiment has shown that heating to a temperature of 250°C for thirty minutes turned a specimen of "tiger's-eye" to a red colour, and, further, heating to 450°C, and at 800°C, gave no improvement on the colour change. The bluish "hawk's-eye" did not appear to respond so readily to colour change by heat-treatment as did the golden "tiger's-eye" material.

The wall of a trench cut for the recovery of pseudocrocidolite, showing the mineral in layers in the iron-stone host rock.
(Reprinted from a coloured transparency)

"Tiger's-eye", when treated with hydrochloric acid, is said to bleach to some extent, and this bleached material when fashioned into cabochon cut stones produces a pale yellowish chatoyant stone. This bleaching with hydrochloric acid does not appear to be readily achieved, for boiling a piece of "tiger's-eye" in hydrochloric acid did not seem to make any appreciable difference to the colour. It may well be that some considerable time is needed for the change to be brought about. The bleached material is sold under the name of "quartz". It appears that many pseudocrocidolite cabochons are stained—vivid greens, blues and blacks, which are obviously stained, have been seen. This staining may be carried out in a similar manner to that used for staining agates.

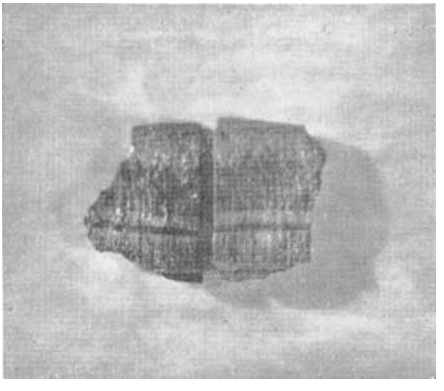

A piece of pseudocrocidolite ("Tiger's-eye") broken in two and the piece on the left heated to 250°C to turn it red.

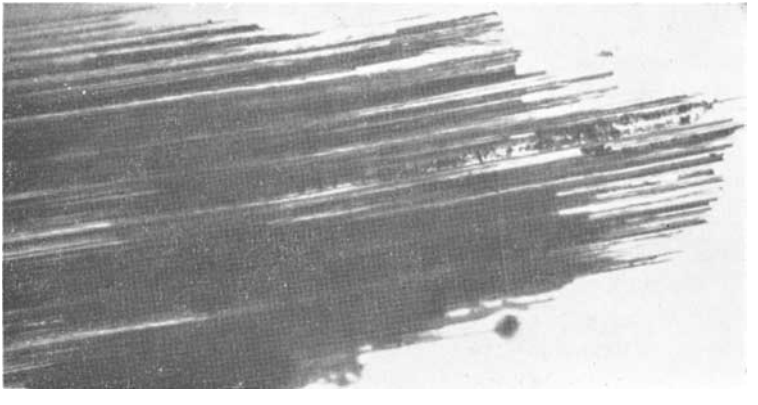

Photomicrograph of a sliver of pseudocrocidolite

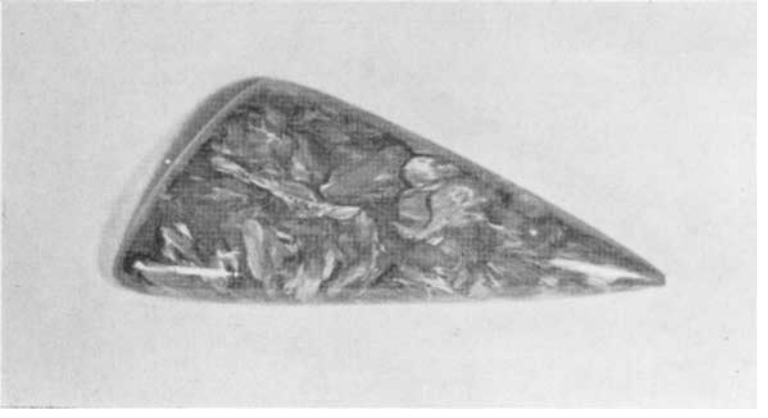

Silicified riebeckite ("Pietersite").

Examination of the properties of pseudocrocidolite showed the hardness to be perhaps a little below 7 on Mohs's scale, for a rock crystal tended to just scratch a polished piece of "tiger's-eye", and the density, taken on 15 specimens, varied from 2·64 to 2·71. The refractive indices were found to be $\omega = 1{\cdot}544$ and $\varepsilon = 1{\cdot}553$, with a bi-refringence of 0·009, values which agree with crystal quartz. It was observed that the direction of single refraction was at right angles to the direction of the asbestos fibres. Some confirmation of this was made when a sliver of "tiger's-eye" was viewed between crossed polars, and it was observed that extinction occurred at right angles to and parallel to the fibres of the original crocidolite. Microscopic examination of these fibres seemd to show that some of the fibres may be empty tubes but that some were filled with a dark material which may be goethite, limonite, or hematite. There was no convincing absorption spectrum to be seen in the natural colours of pseudocrocidolite, nor in the artificially coloured material, except for the green-stained stones, which showed the typical band in the orange-red part of the spectrum and possibly a weak band in the yellow to yellow-green, which is, or are, seen in several other green-stained materials such as the jadeites. No luminescence was observed under either wavelength of ultra-violet light or by x-ray bombardment, and there was no sign of any electro-conductivity.

Although crocidolite asbestos is simply a variety of riebeckite occurring in oriented silky fibres as "cross-fibre" veins, the name riebeckite is usually applied to the mineral when it is in disoriented masses. As a rule this material does not enter the realm of ornamentation, but as silicification of such material does occur it thus may be suitable for cutting and polishing. That this is so is exemplified by an occurrence of silicified riebeckite with limonite which is found in the neighbourhood of Outjo in South-west Africa. Attractive variegated golden-brown cabochons of this material have been prepared and marketed by Mr. S. Pieters a mineral dealer of Windhoek, who sells the finished product under the name pietersite. The density of one such piece was found to be about 2·6 and the Mohs's hardness to be similar to that found for "tiger's-eye". Another alteration product of crocidolite (riebeckite) consists of a mechanical mixture of silica and hydrated iron and has a hardness of 4 on Mohs's scale. This material has been named "griqualandite", but it has no place in our study and is only included in this survey for completeness. A chatoyant fibrous quartz has been obtained on the Cuyuna iron range of Minnesota in the United States of America. No opportunity to examine this material has presented itself.

Mention must be made of the so-called "Hungarian cat's-eyes". These yellowish-green chatoyant quartzes containing fibrous amphibole inclusions are obtained from the diabase of Hof and other places in the Fichtelgeberge in Bavaria. They do not come from Hungary. Such stones are inferior to the "cat's-eyes" found in India and Ceylon, and probably they are often artificially stained different colours.

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Gemmological Abstracts

MILES (E. R.). *South America and the world's diamond market.* Gems and Gemology, 1967/8, XII, 8, 226-238.

A review of the diamond production of Brazil, Guyana and Venezuela. 80% to 90% of Brazil's production is exported to Europe, Israel, Japan and India. The economics of diamond cutting in Brazil are discussed, the most popular styles of cutting being marquise and baguette. There is no stable demand for coloured diamonds. Some details of mining, the districts mined, and the geology of the areas, are given. There is much "local" information in this well-worth article.

9 illus. R.W.

LIDDICOAT (R. T.). *Developments and highlights at the Gem Trade Laboratory in Los Angeles.* Gems and Gemology, 1967/8, XII, 8, 247-253.

The results of the examination of a number of specimens of the new blue zoisite, and of the transparent green grossularite from Zambia, are given. Other items mentioned are carved iolites, oolitic opal, a glass assay button, a cut rhodochrosite, a cobalticalcite, and a tourmaline which showed a slightly biaxial interference figure. An unusual "triplet" consisting of a sapphire cabochon on a base of faceted synthetic spinel is recorded.

15 illus. R.W.

ROLFF (A.). *First Brazilian Diamond Dredge.* Gems and Gemology, 1967/8, XII, 8, 239-241.

In 1966 mining by bucket dredge was commenced on the Jequitinhonha river. Something is told of the dredge used and of the recovery operations. The rate and quantity of diamonds recovered are mentioned. Very small diamonds, called "mosquito-eyes", are cut in Israel.

2 illus. R.W.

CROWNINGSHIELD (R.). *Developments and highlights at the Gem Trade Laboratory in New York.* Gems and Gemology, 1967/8, XII, 242-246 and 257.

Some comments are made on a synthetic emerald which may be of a new type, and on green tourmalines, which, it is suggested, are coloured by chromium and have emanated from Tanzania. Also mentioned are some brownish-purple garnets, which have low constants and are said to have come from a new locality in India. The features of massive lazulite, a faceted cuprite, dyed jadeite and Chatham and Gilson synthetic emeralds are discussed.
12 illus. R.W.

TOMBS (G. A.). *Handling and care of gemstones.* Australian Gemmologist, 1968, 10, 1, 18-19.

Describes the use and types of tongs best needed for the examination of different sized and shaped stones.

R.W.

SIEDLE (L. C.). *Three generations of gem merchants in Ceylon.* Australian Gemmologist, 1968, 10, 1, 7-16.

Strictly speaking this is a history of the Siedle family, but much useful information is given on the pearling and pearlers of Ceylon, and of the gem-dealing in that country.

R.W.

WEBSTER (R.). *"Fingerprinting" jewellery.* The Criminologist, 1968, 8, 44-56.

Describes the nature of an identity certificate for gemstones or jewellery so that they may be re-identified on recovery from loss or theft. A survey is given of the various methods proposed in order to compile such a certificate, and some evaluation is made of these various methods. It is inferred that a central registry is needed and there is a discussion on the economics of the problems of the production of such certificates.

P.B.

BOOK NOTICES

AXON (G. V.). *The wonderful world of gems.* Criterion Books, New York. 1967.

Written in popular style for general reading the book follows the more modern concept by first describing the formation of gems in the earth and the shapes (crystals) they form. This is followed by descriptions of the various gemstones, synthetic and imitation gems, and the organic materials used for ornamentation. The book continues with chapters on colour and inclusions in gems, curious tales of gems, the fashioning of gems, how to appraise them and how to identify them. There is no index, the book being completed with a glossary of terms. The book is adequately illustrated.

R.W.

PEARL (R. M.). *Gem identification simplified.* Maxwell Publishing Co., Colorado Springs. 1968.

A booklet of 43 pages intended to supply in compact form sufficient information for a jeweller, lapidary or gem collector to identify with some surety the more common gemstones, short notes of which are given. Simple methods of testing are described and prominence given to heavy liquid methods. The booklet concludes with tables of constants grouped under colours, translucent and opaque gems, and asteriated and chatoyant gems.

R.W.

IDRIESS (I.). *Opals and sapphires.* Angus & Robertson, London, 1968. 50s.

A guide to opal and sapphire mining in Australia, useful both to prospector and those who wish to have an interesting holiday. The author, who has prospected himself, writes entertainingly and covers the geological occurrence, mining, cutting and polishing of the gems. It is a pity that the outmoded term "oriental" has been used to describe the varieties of sapphire that have been found. There is a useful chapter giving the localities (with maps) in which sapphire has been found.

S.P.

SCHUBNEL (H-J.). *Pietre Preziose Gemme E Pietre Dure.* Ist. Geog. de Agostini, Novara, Italy, 1968. L.1,000.

This book is worthy of addition to any gemmological library for the interesting colour illustrations of gem crystals, gems and jewellery. There is a brief text, in Italian, dealing with the various gems and gems materials.

S.P.

HANSFORD (S. H.). *Chinese carved jades.* Faber & Faber, London, 1968. 5 gns. 8 plates in colour and 96 monochrome.

As one would expect from a Professor Emeritus of Chinese Art and Archaeology in the University of London, this is a scholarly work comparable to the author's *Chinese Jade Carving* (1950).

The present book is the result of painstaking research that have followed the earlier publication. Gemmologists will be interested in the chapter on the material and its sources. Here reference is made to the logic of Sir Charles Hardinge's reasoning concerning nomenclature and the unwillingness of mineralogists to disturb terminology which has stood the test of time. The archeaologist and art lover will find this book most rewarding.

B.J.

BOARDMAN (J.). *Engraved Gems.* The Ionides Collection. Thames & Hudson, London, 1968. 9 colour and 130 black and white illustrations. £5 5s.

A scholarly text dealing with the techniques, materials and the importance of gem-engraving in Greek and Roman times. Except for the use of the word "jacinth", the gemmological terms in the text are correct, and the author refers to the difficulty of identifying without proper apparatus some of the materials used for gem-carving. A book for the specialist interested in engraved gems.

S.P.

SCHUBNEL (H-J.). *Les pierres precieuses.* Presses Universitaires de France, Vendome, 1968.

A concise paper-back in the *que sais-je?* series of the publishers, and a useful introduction to gemmology and gemstones.

S.P.

CHALMERS (R. O.). *Australian rocks, minerals and gemstones.* Angus & Robertson, Sydney and London, 1967 (reprinted 1968). £5 7s. 6d.

The emphasis of this well written book is upon the rocks and minerals of Australia, rather than gemstones. There are detailed references to the many localities of Australian minerals and, although those of New South Wales receive particular attention, the book is a well balanced survey of the geology and occurrence of Australian minerals, with brief chapters on rock formation, crystallography and physical properties. The chapter on crystals is dealt with as simply as this complex subject can be, and the author writes of the rhombohedral or trigonal division of the hexagonal system, instead of treating the trigonal system separately. There are eight plates in colour and numerous photographs, those of geological features and mining scenes being of considerable interest.

S.P.

PERRY (N. & R.). *Australian gemstones in colour.* A. H. & A. W. Reed, Australia, 1967. 35AS. 3$ 50c.(Aust.).

Many of the colour photographs in this book were prepared by Nance Perry and are very good, but with a few the printing colour-registration is not up to standard. The test is simple and this book should be a useful introduction to all who are fascinated by the study of gemstones. In gathering together reliable material about gemstones of Australia and their localities the authors undertook many trips in order to check source material.

S.P.

AN ILLUMINATING DEVICE FOR EXAMINING GEMSTONES WITH THE SPECTROSCOPE

By B. F. MARTIN, M.D., B.Sc., F.G.A.

FOR those who do not possess one of the efficient but expensive high intensity lamps, designed to provide a small spot of intense light, there is difficulty in devising a means of illuminating gemstones adequately for spectroscopic examination.

An efficient general-purpose intensity lamp, of Japanese manufacture, is on the market at a low price (currently 50s.). This lamp, which is illustrated in Fig. 1, gives excellent lighting for general bench work, including refractometry and microscopy.

FIG. 1.

It has a flexible arm connecting the lamp hood to the base, which houses the transformer. Although supplied with a 12 volt, 6 watt bulb, which is quite adequate for general use, a bulb of higher wattage (e.g. 21 watt) can be used if stronger lighting is required.

Without some means of condensing the light, however, the lamp is not adequate for spectroscopy.

The author recently constructed a very simple piece of equipment which brings the lamp into use for spectroscopy. It is made from a short length of brass tubing, a bull's-eye lens and two strips of leather (Fig. 2). When required, it is inserted into the lamp hood as one inserts and twists tight a cork into a bottle. The only problem in constructing such a device is the acquisition of a suitable bull's-eye lens.

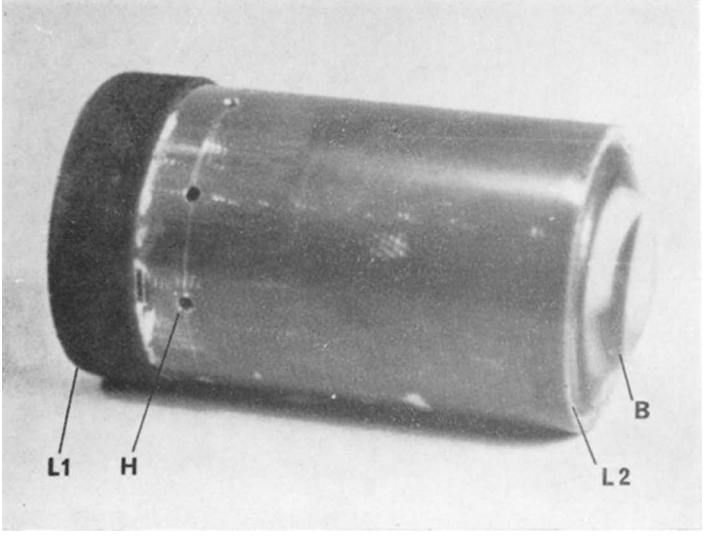

FIG. 2.

It will be noted from Fig. 1 that the lamp hood is funnel-shaped, which allows a tight grip to be obtained on the leather cuff attached to the end of the tube. The lamp hood aperture is $2\frac{3}{16}$ inches in diameter, so that 2 inch-diameter brass tubing, listed as 20 gauge (0·036 inch thickness; approximately $\frac{1}{32}$ inch) is ideal for the purpose.

To one end of the tube, a strip of thin, soft leather is attached with good contact adhesive, to form an external cuff (LI in Fig. 2). The strip needs to be about $6\frac{3}{4}$ inches long, to encircle the tube, and about $\frac{5}{8}$ inch wide. The rougher side of the leather is kept

outermost, to obtain a good friction in the lamp hood and the other side, as well as the adjacent part of the brass tube is roughened a little with a file, prior to applying the adhesive. About 1 inch from the same end of the tube, eight ventilating holes are drilled around the circumference with a $\frac{1}{8}$ inch or slightly smaller drill, and these serve to prevent over-heating (H in Fig. 2).

The bull's-eye lens is fixed into the opposite end of the tube (B in Fig. 2). The lens shown in the illustration was obtained from an old piece of optical equipment and was eminently suitable, since it was $1\frac{7}{8}$ inch in diameter, of short focal length ($2\frac{3}{4}$ inch) and already mounted in a thin brass collar. When held 3 inches in front of the lamp hood, it brought the bulb filament into focus, six inches beyond its own position. The brass tube was therefore cut to a length of $3\frac{1}{2}$ inches, to allow for about $\frac{1}{2}$ inch insertion distance into the lamp hood.

Since the diameter of the lens used was very little less than that of the tube, it was easily fixed in position by means of a strip of leather encircling the interior of the tube (L2 in Fig. 2). A strip of thick leather was cut, about $6\frac{1}{2}$ inches long and $\frac{1}{2}$ inch wide, and both surfaces were worn down with a rasp until the thickness was correct for holding the lens firmly in place. If a lens of smaller diameter were used, it would probably be necessary to fix it in some form of mount, to bring the diameter nearer to that of the tube. It must be emphasized, however, that the focus of the lens must be such that not too great a length of tubing is needed, otherwise the weight will overbalance the lamp. It is inadvisable to substitute plastic tubing for brass, in order to reduce weight, since it is prone to distortion under the heat of the lamp.

The device described has been used for two-hour periods of spectroscopy, using a 12 volt, 6 watt bulb and the results have been very satisfactory. It is shown in use in Fig. 1, with a stone illuminated on a Mitchell spectroscope stand, For those who prefer to hold the spectroscope in the hand, it is convenient to rest the stone on a small piece of coarse black cloth or felt, placed on top of the spectroscope case. The cloth can be kept in the case, together with the spectroscope.

ASSOCIATION NOTICES

ANNUAL GENERAL MEETING

The 38th Annual General Meeting of the Association was held at the Birmingham Conservative Club, Winston Churchill House, Ethel Street, Birmingham, on Wednesday, 3rd April. Mr. Norman Harper, Chairman, presided. It was the first occasion that an Annual Meeting had been held in Birmingham.

In moving the adoption of the Annual Report and Accounts, the Chairman said that the Association had had a busy, though routine year. During 1967 a grant of Armorial Bearings, had been received which was fully described in the July 1967 issue of the *Journal of Gemmology*. The report also drew attention to the continually increasing interest in our courses and examinations. In July 1968, sixty years of gemmology in Great Britain would be celebrated, with a Reception at Goldsmiths' Hall in November,.

The Chairman continued "Our history began on the 6th July, 1908 when at the Annual Conference of the National Association of Goldsmiths, Mr. Samuel Barnet of Peterborough proposed that the formation of teaching courses and arrangements for examinations in gemmology should be undertaken. At that time there was general apathy in the jewellery trade to the new subject of gemmology. It was a time when reconstructed and synthetic rubies had made their appearance on the market and it was imperative that the jewellery trade armed itself with techniques for distinguishing between natural and man-made stones. In 1906 Dr. Herbert Smith devised his portable refractometer, which proved a great boon to the jeweller, and in 1912 his classic work "Gemstones", which is still currently produced in revised form, was published. This set a standard of accuracy and scholarship which has stood the test of years. The first examinations were held in 1913 when twelve candidates entered for the preliminary and eight entered for the diploma. In 1967, 376 candidates sat for the preliminary and 196 for the diploma, 472 in all. The Association can look back with pride and satisfaction on its achievements since it was incorporated as a separate entity in 1947 and also look back with gratitude to the help that it has received from the National Association of Goldsmiths, whose Gemmological Committee was responsible for furthering the advance of gemmology in the United Kingdom.

Some famous names which stand out in our records include Mr. Samuel Barnet, who moved the resolution at the N.A.G. Conference in 1908, and who himself was a successful candidate in the first examination in 1913. Mr. Noel Heaton, the first lecturer, and Mr. B. J. Tully, who was the first official instructor and whose memory is constantly refreshed by the Tully Medal. Then there was Mr. Irving Jardine who wrote the first correspondence course.

Many of us will remember with affection the Chelsea Polytechnic which was the home of gemmology teaching for so many years and our great debt of gratitude to those whose teaching there and published works gave such a cachet to British gemmology, in particular Mr. Basil Anderson and Mr. Robert Webster. We remember Mr. F. H. Knowles-Brown, who was our Chairman for many years and who served us so well and Sir James Walton who was our Chairman for so short a period, but in whose memory a library was founded. We have had four Presidents of rare distinction in Sir Henry Miers, Sir William Bragg, Dr. Herbert Smith and our present President, Sir Lawrence Bragg. To these and many others we are extremely indebted.

We have maintained contact with gemmological organizations throughout the world and have been pleased to watch and frequently help in their formation. The National Association of Goldsmiths started it all and I would like to record and to convey to that organization our thanks for all that they have done and are continuing to do to assist in furthering the study of gemmology".

Mr. D. N. King, in moving the adoption of the report and accounts, pointed out that the annual subscription had remained at £2 2s. 0d. since 1959, and this was creditable to those responsible for the accounts. He also mentioned the high number of examination entries, particularly from overseas candidates, and emphasized the problems in accommodating the entrants at centres in various parts of the world. He also referred to the contacts which the Association had with gemmological organizations in other countries. Mr. King also said that the Association was indebted to Mr. Norman Harper for initiating the Gem Diamond Examinations.

Sir Lawrence Bragg was re-elected as President and the other Officers were also re-elected, namely Mr. Norman Harper, Chairman, Mr. Philip Riley, Vice-Chairman, and Mr. F. E. Lawson Clarke, Treasurer. Messrs. Watson Collin & Co., Chartered Accountants, continue as auditors to the Association.

SCOTTISH BRANCH

In commenting upon the work of the year, the Chairman recalled the excellent summer outing of the Branch to Arran. Later in the year Mr. N. Harper gave a talk on diamonds which attracted a record attendance of 135. There was a well patronized and rewarding evening spent at the Huntarian Museum. Mr. McWilliam commented upon the difficulty of finding suitable speakers. Some talks tended to be too technical, while others were not technical or instructive enough to attract large audiences.

The following Officers were elected for the ensuing year.

Chairman	—	Mr. J. McWilliam
Vice-Chairman	—	Mr. J. Gillougley
Secretary	—	Mr. D. Hill

Messrs. Inglis, McKenzie, McRae, Neil, Turner and Wade were elected to serve on the Branch Committee.

Following the election of Officers, the Branch considered the problems in connexion with establishing a Gem Diamond Course with a view to preparing candidates for the Gem Diamond Examinations of the Association. It was agreed to discuss the possibilities of suitable accommodation with the Glasgow Further

Education Department. After the meeting, two films were shown, "Diamonds" and "Making of a Jewel". Mr. James Gillougley proposed a vote of thanks to the Chairman and Secretary for their outstanding work during the year.

GIFTS TO THE ASSOCIATION

The Council has received for the Sir James Walton Library *Les Pierres Precieuses* and *Pietre Preziose—Gemme e pietre dure* from the author, Henri-Jean Schubnel, of Paris.

The Association is indebted to Mr. J. R. Fuhrbach of Texas for a collection of gemstones for student teaching purposes.

WANTED

Copies of *Jade of the Maori* by Elsie Ruff, published 1950.

MEMBERS' MEETING

Three speakers made up the programme of the meeting held on 20th March, 1968, at Goldsmiths' Hall, London, and it was one which members evidently found attractive, with about 100 being present.

They heard Dr. E. Rutland talking about the highlights of the gemstones at the Geological Museum, about which, despite the short time he has been there, he already possesses a wide knowledge; Dr. W. G. Cross showed by the examples of the fine work he has done just what the gemmologist-craftsman can attain by ingenious methods; and Mr. B. W. Anderson reminded his audience of the long list of new gemstones that have been discovered during the past century.

Dr. Rutland pointed out that the Geological Museum could boast its own collection of gem material going back to its foundation 130 years ago. The idea of the museum was to show the practical uses of minerals to man.

Dating from its earliest specimens was a magnificent carved fluorite some 30 inches high. A lathe had been used to do this work which he doubted was ever done today. There were plates and cups made of this material. They were, perhaps, the most remarkable examples in existence of native ornamental minerals.

The museum went in for what he called "jumbo" exhibits because of its very nature and gem stones were among these. They had large jadeite and nephrite boulders and carvings, and a topaz "boulder" weighing 30 lbs.

This jumbo size applied even to cut stones, the largest they possessed being a step-cut topaz of nearly 3,000 cts., of a fine greenish-blue colour; there was an exquisite kunzite of 425 cts. of a rich pink, a step-cut peridot of 136 cts., a cat's-eye of 77 cts. and a good collection of zircons of all colours.

They had also among smaller stones a good collection given them by a noted member, the late Mr. B. J. Tully.

Dr. Cross had brought his specimens with him and they showed that an enthusiast like himself can evolve ingenious methods to carve jadeite and nephrite. He passed round a bowl that he had made and a small gold mounted box together with a frog made from one of the square pieces and a white jadeite horse on a base of black nephrite.

To give an idea of his methods, he described how he had made the bowl from a block of nephrite about 5½ inches square and two inches deep. To conserve as much of the material as possible for use in the making of rings and bracelet parts, he excavated the centre by use of tube drilling. A number of different sized copper tubes were used for this, their ends prepared and impregnated with abrasive. Thereby he was able to draw their cores for later use. Similarly, he roughly shaped the exterior of the block with a hack-saw, giving himself further raw material. Many of his tools were adapted from those used by dentists.

Mr. B. W. Anderson reminded his audience that though many new minerals had been discovered in the last century, some were very scarce and therefore mainly of interest to the gemmologist.

In contrast, a new gem stone did not necessarily mean a new mineral species. It could be a new colour variety of attractive new form of a long established mineral.

Thus though some eight or nine entirely new gem species had been discovered, they had made no impact on the trade, including such scarce and few specimens as taffeite and painite, though the former—like sinhalite—had been found as cut gem stones before being discovered in the rough state.

The earliest new material discovered in the past 100 years was demantoid or green garnet in 1878. At first this was considered to be olivine but it was now well established and prized for its true worth.

Hiddenite and beryllonite were also discovered in the last century, with kunzite as the first to be found in the 20th century.

Often these discoveries were made partly by chance when somebody thought there was something odd about a stone and sometimes it was the expert rather than the original finder who gained most of the credit.

Benitoite was cut like a sapphire and had been on the market for some time before it was identified. It was unfortunate that this gem occurred only in one locality and, this being almost exhausted, few more would appear unless they were discovered elsewhere.

Among new gem materials which were not necessarily new minerals was the transparent grossular jadeite, which filled in an opening in the jadeite range.

The latest discovery was of blue zoisite from Tanzania, a really fine blue stone, transparent and clear, which, if enough was available, should take its place among the fine gem stones.

COUNCIL MEETING

At a meeting of the Council of the Association held at Saint Dunstan's House, Carey Lane, London, E.C.2, on Thursday, 6th June, 1968, the following were elected:—

Fellowship

Rae, Alexander Coventry, Markham, Canada Dip. 1963

Ordinary Membership

Achim, Donald L., Rochester, U.S.A.
Atapattu, Quenton Donovan, Mt. Lavinia, Ceylon
Bateman, Maureen Mary (Miss), London, N.4.

Bell, Ann Margaret (Miss), Glasgow, S.W.3.
Brown, William Peter, Hillingdon.
Burbanks, Christopher John, Staines
De Swarte, Georgina (Mrs.), Paris 9e, France
Dickenson, Hendrika Jacoba Margaretha (Mrs.), Greendale, Rhodesia
Dickson, David Wishart, Kilmarnock
Donaldson, James Roderick, Seabrook, U.S.A.
Fazli, Mohamed Saleem Mohamed, Colombo 5, Ceylon
Fukabayashi, Hirokichi, Hokkaido, Japan
Gosling, James Granville, Coulsdon
Gunde, Ladislaus Lewis, Limbe, Malawi
Hoberg, Gunter, Idar Oberstein, Germany
Johansen, Walter E., Morgan Hill, U.S.A.
Lang, Lorna Merle (Mrs.), Reservoir, Australia
MacDonald, Robert Dr., Kampala, Uganda
Phebey, Cyril Herbert, East Croydon
Seneviratne, Jinawaradasa Tissera Sandanayake, Ratnapura, Ceylon
Seward Jones, Mary (Mrs.), Crowborough
Telford, Henry, London, W.9
Van Twuyver, Henrik Gerhard, Oosthuizen, Holland
Watson, Lewis Charles, Morden
Westley, Marie Jean (Mrs.), Uxbridge

PROBATIONARY MEMBERSHIP

Cork, Malcolm Ellis, Chesham
Dunstone, Anthony, Fowey
Hooper, Cynthia (Miss), London, S.E.8
Karolus, Martin, Mannheim, Germany
Mooney, Robert Anthony, Birmingham, 6
Wakefield, Graham David, Horsham

FUTURE ARRANGEMENTS

The annual presentation of awards will be held at Goldsmiths' Hall, London, on 23rd October, 1968, at 7.15 p.m.

A reception will be held at Goldsmiths' Hall on 27th November, 1968, to celebrate sixty years of gemmology in Great Britain. Tickets will be required for this occasion and members will receive details during October. Overseas Members who may be in London at the time and who wish to attend should apply to the Secretary for a ticket, apart from official guests invitations will be limited to Fellows and Members.

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Beryls	Garnets	Proustite	Topazolite
Beryllonite	Hambergite	Rhodochrosite	Tourmaline
Brazilianite	Hiddenite	Rhodonite	Uvarovite
Cassiterite	Hypersthene	Ruby	Willemite
Cerussite	Idocrase	Rutile	Witherite
Chrysoberyl	Iolite	Sapphire	Zinc Blend
Clinozoisite	Kornerupine	Scapolite	Zincite
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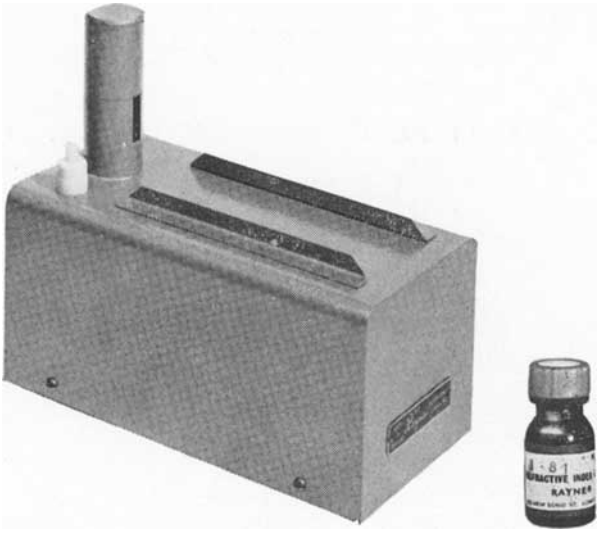

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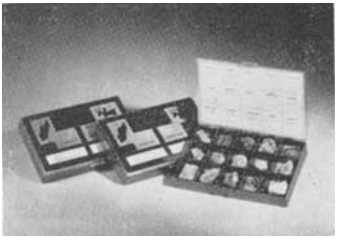

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THE JOURNAL OF GEMMOLOGY

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Vol. 11 No. 4 OCTOBER 1968

UNUSUAL EMERALDS

By CHARLES A. SCHIFFMAN, F.G.A., G.G.

RECENTLY, there has appeared on the market, in cut form, a type of emerald whose unusual characteristics cannot be likened to those of any of the "classical" occurences.

Since 1966, more and more parcels of these stones have appeared, but as their appearance is still not well known, buyers have occasionally mistaken them for synthetic emeralds. In the interest of the trade, and in order to avoid serious mistakes, the author describes below the recent examination of a parcel of 16 stones, of which the average weight per stone was $1\frac{3}{4}$ ct.

To the eye and with the help of a lens, the following clues to this unusual type of emerald are quite obvious:

— a strong grass-green colour
— a general clouded appearance, the emeralds being transparent to semi-transparent, this being due more to their structure than to the presence of a large number of inclusions.
— internally, on the inside face of the facets, the light appears diffused and not as lively as the reflections of a properly cut stone carved from a clear crystal.

The good size of the emeralds under examination allowed for a precise determination of the specific gravity, using the hydrostatic method with dibromoethane. A good reading of the refractive index was also obtained.

Specific Gravity

5 emeralds with very few flaws: 2·7250; 2·7133; 2·7109; 2·7052; 2·7021.

10 emeralds with a few more inclusions: 2·69 (average).

1 emerald with flaws (pockets of air) 2·68 (average).

The mean result for material having few inclusions is 2·70-2·72.

Refractive Index

For the 16 specimens, there is a variation in values between:

minimum:	ω 1·581	—	ε 1·576	d.r. ·005
maximum:	ω 1·587	—	ε 1·581	d.r. ·006
the mean values being	ω 1·586	—	ε 1·581	d.r. ·005

The high values of specific gravity and refractive index immediately attract attention because they are higher than the normal values for synthetic emeralds, being the same as those of Colombian emeralds, and lower than those of Siberian emeralds, or emeralds from Habachtal, India and South Africa, as these appear in progressive order in the following list (taken from B. W. Anderson's Gem Testing[1]:—

Usual Characteristics of Emeralds

Occurrence:	*R.I. ordinary ray*	*Birefringence*	*S.G.*
Synthetic (Chatham)	1·564	·003	2·65
Brazil	1·571	·005	2·69
Colombia, Chivor	1·577	·006	2·69
Colombia, Muzo	1·584	·006	2·71
Siberia	1·588	·007	2·74
Habachtal	1·591	·007	2·74
India	1·593	·007	2·74
South Africa	1·593	·007	2·75

Dichroism

As indicated earlier, the colour is a fairly strong grass-green, well saturated and well distributed within the stone. The dichroism is distinct green and yellow-green.

Absorption Spectrum

This, observed visually in transmitted light on a Gübelin spectroscope, shows the normal lines of beryl coloured by chromic oxide:

6835 Å	marked
6806 Å	marked
6620 Å	weak
6460 Å	weak
6370 Å	marked
6200 – 6000 Å	distinct

FLUORESCENCE

With the ultra-violet lamp, under the two wave-lengths 3650 Å and 2537 Å, the stones are inert. In natural light and crossed filters ($CuSO_4$ plus red filter) they show a distinct red hue. Colour under the Chelsea filter is a pale to distinct red hue.

TRANSPARENCY TO ULTRA-VIOLET

It is generally admitted that the synthetic stones have a border of transparency to ultra-violet lower than the genuine stones. The test under the radiation of 2537 Å allows one to observe this phenomenon easily, according to the method described by Norman Day[2];. A word of precaution, however, is necessary because the reaction is not always infallible, at any rate with emeralds. (The author recently tested a Gilson synthetic emerald of about 4 cts., showing the same ultra-violet opacity as a natural emerald that was tested at the same time. Of course, identification could not be made on that test only, and checking of other characteristics allowed for an easy classification of the synthetic).

However, the method is usable and can be applied in the following way.

The transparency is determined by a short exposure under 2537 Å radiation. In darkness the stones are placed directly onto a piece of photographic paper, this being immersed in water. The lamp rests above it, at a distance of about 30 cm. Some proofs, of known transparency, allow the degree of transparency to be ascertained by the stronger or softer darkening of the paper after development (Fig. 1). In the illustration the paper has darkened under the octagonal quartz, which is transparent to ultra-violet. By comparison the sensitive surface stays unaffected under the natural opaque round beryl, this being due to the presence of iron in its composition. The 16 emeralds tested have the same reaction as the natural beryl.

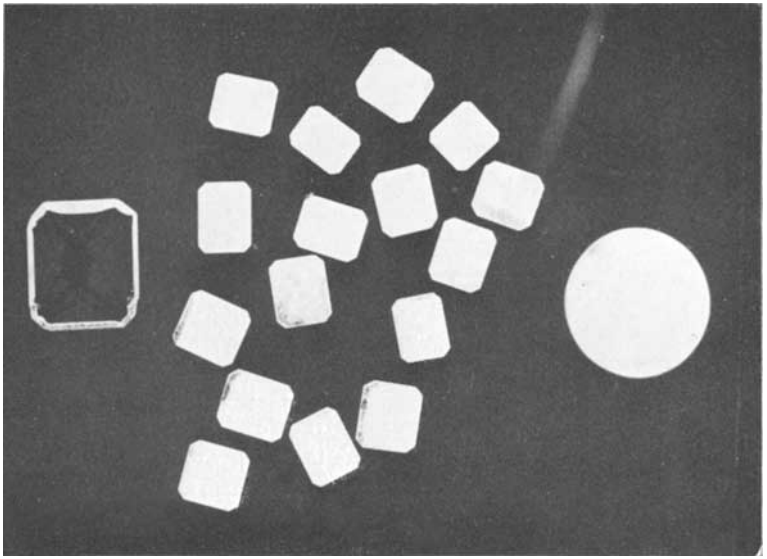

FIG. 1. *Test of transparence to ultra-violet radiation* 2537 Å *with comparison proofs. On the left, the photographic paper has darkened under a natural octagonal quartz, showing its transparence.*

On the right, the photographic paper is clear under a natural beryl, showing also its opacity due to the presence of iron in the chemical composition.

In the centre, under the 16 *emeralds tested, the paper has the same reaction as under the natural beryl, suggesting also the presence of iron.*

Enlargement paper Agfa Brovira, exposure 2 *seconds at* 30 *cm.*

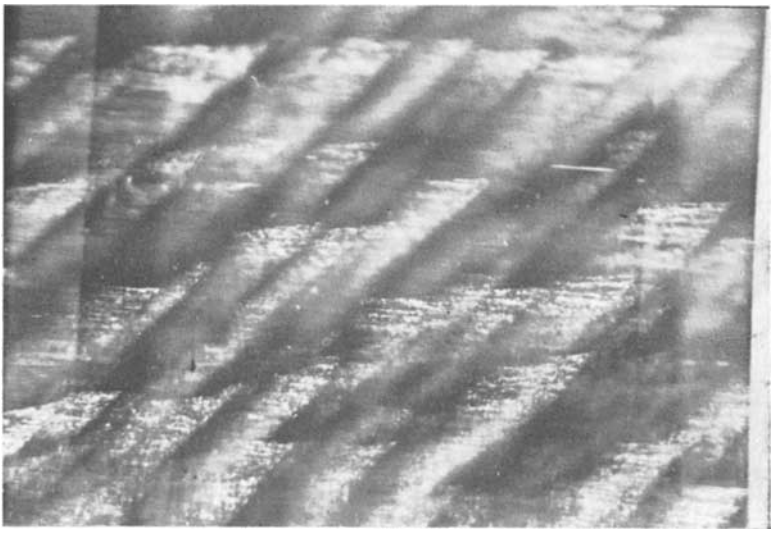

FIG. 2. *Natural emerald: fine channels in parallel bands, the same orientated in successive planes, whose parallel arrangement is impressive. The bands are cut by the table plane at an acute angle of about* 50°, *magnification* 25 ×. *Orange filter.*

Examination under the Microscope

The most interesting characteristics are visible under the microscope. The stones are transparent to distinctly cloudy. This seems to be due not to a great number of inclusions, but more to their own structure. In some way, the appearance of the stones resembles that of a chrysoprase. The most curious of the inclusions are the orientated channels running in parallel bands (Fig. 2). At first sight their general distribution resembles that of synthetic emeralds (see B. W. Anderson: Gem Testing. 7th edn. Fig. 42), which could just as easily cause an error. The difference is, however, seen under stronger magnification. In the synthetics, these inclusions appear like a network of channels spreading without order in all directions.

In the present instance, the bands are arranged in the same direction, all collected together in adjacent planes, and this characteristic is unmistakable. The majority of the stones had been cut in such a way that the plane of the table facet cuts that of the bands at an angle of about 50°.

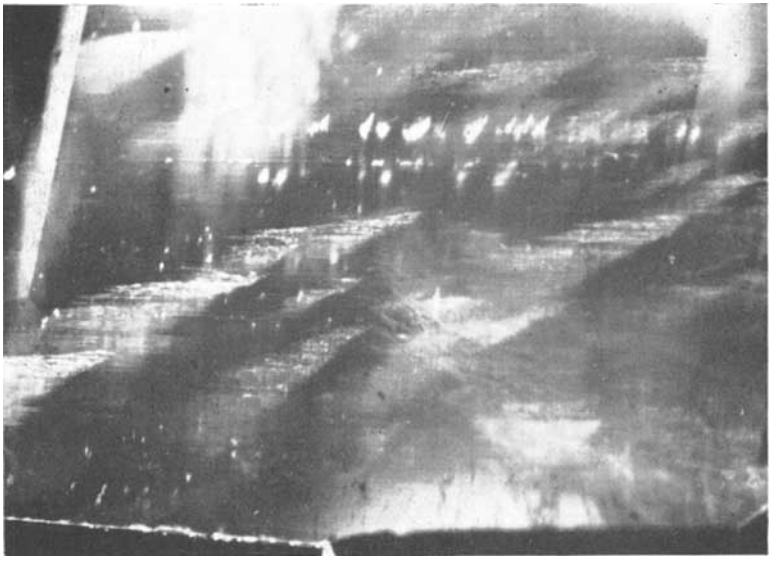

Fig. 3. *Natural emerald: similar bands to those in Fig.* 2 *and small inclusions (fissures) perpendicular to the longitudinal axis of the crystal. Magnification* 25 ×. *Orange filter.*

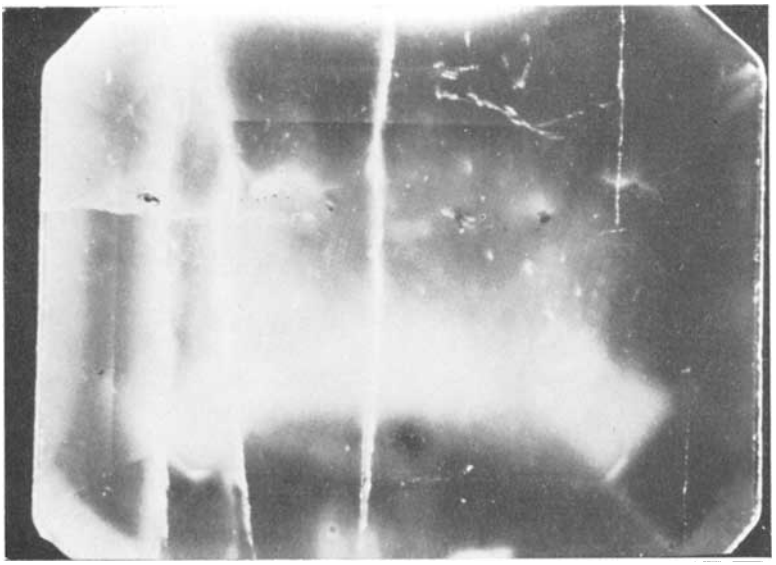

FIG. 4. *Natural emerald: examination under polarising microscope, abnormal extinction between crossed nicols, the stone appearing marbled by diffused zones. Inclusions: thin fissures crossing the whole stone. The general cloudy appearance is well visible. Magnification* 15 ×.

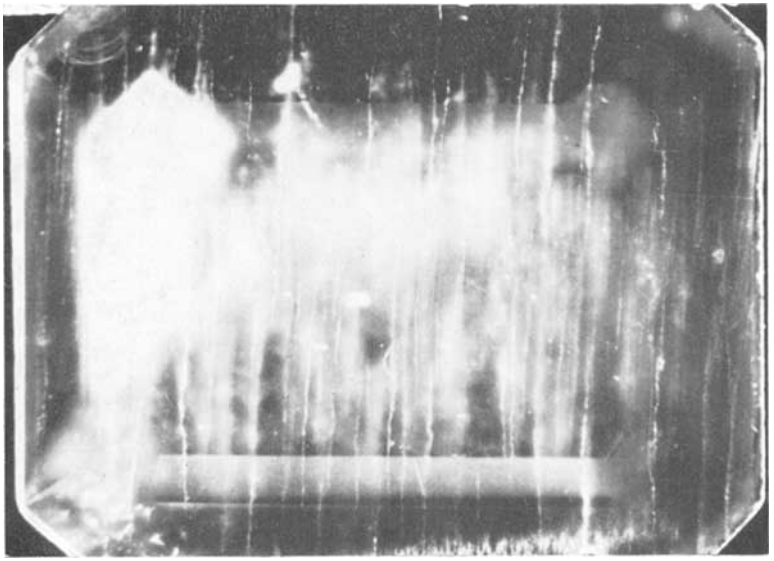

FIG. 5. *Natural emerald: Examination under polarising microscope, abnormal extinction between crossed nicols, typical general cloudy appearance. The marbled distribution, partly recalling the bees nest structure, was more obvious in reality than in this photograph. Inclusions: thin fissures more or less parallel acrosss the stone. Magnification* 15 ×.

Like other inclusions, small clouds of blackish and brownish particles distributed like seeds, as well as brownish films perpendicular to the C axis of the original crystal, have been observed. Moreover, some black granules like those seen in trapiche emeralds can be considered as an indication of natural origin (Fig. 3). Particularly interesting images have been observed while using crossed nicols in a polarizing microscope. On rotation, the extinction is abnormal, i.e. not very striking (Fig. 4). In a favourable position, angular marbled zones feebly resembling the hexagonal structure of a bees' nest, and unevenly coloured, are visible (Fig. 5). Interference colours in parallel belts also appear, recalling polysynthetic twinning patterns.

The various features described, which have not yet been observed together in emeralds of known localities, suggest the possibility of a new source. In the interest of research, it is hoped that complementary observations will soon permit a list of properties of these unknown stones to be established.

Following this line of thought, two recent cases can be recalled.

In 1966, a parcel of six emeralds was examined—the individual weights varying between 0·30 cts. and 1·30 cts.—and the values obtained are as follows:

Refractive index	*Birefringence*	*Specific gravity*
ω 1·586 — ε 1·580	0·006	2·71 to 2·72

The structural characteristics and inclusions were similar to those of the stones mentioned at the beginning of this article.

E. Gübelin, to whom the parcel had been submitted, had not found any clues in the sparse literature existing on this subject. He was then led to consider them to be trapiche emeralds, as a possible source of origin, due—among other things—to the unique character of the black granular inclusions. In order to obtain a reasonable amount of support for his hypothesis, he deemed it necessary to investigate the typical inclusions seen in trapiche emeralds. At his request, an analysis carried out by the Institute of Crystallography and Petrology at the Federal Polytechnic School in Zürich, using the A.R.L. microprobe, has furnished unedited information printed for the first time here.

Three main types of inclusions have been found in the trapiche emeralds examined. Their natures are as follows:

Type 1 Black matter, powdery
Chemical element present: C
Mineral: carbonic substance (possibly graphite)

Type 2 Other matter
Chemical element present: Si
Mineral: quartz

Type 3 Other matter
Chemical elements present: Na, Al, Si
Mineral: albite

There is a similarity with the inclusions of Colombian emeralds, of which the physical and optical properties have been known for a very long time. The analogous properties shown by trapiche emeralds could also well have their source in a parent chemical composition.

The second case is mentioned by F. Duyk, of Brussels, who has recently examined two similar emeralds. The results were as follows:

Refractive index	*Birefringence*	*Specific gravity*
ω 1·592 — ε 1·588	0·004	2·7379

It is interesting to compare these values, somewhat higher than those of the 16 stones mentioned at the beginning of this article, with those of the B. W. Anderson table[1]. As for the inclusions found by F. Duyk, they are of the same character. In an attempt to ascertain the natural origin, he increased the microscope examinations up to X300 and even X1200, and in the reflected light could at last discover 3-phase inclusions (Fig. 6). The smallness of the inclusions reproduced should be noted. The side of the cubic crystal in the centre of the image has the true size of five microns. This beautiful photography represents a technical feat accomplished at the Laboratory of Geochemistry of the University of Brussels by Professor J. Jedwap, who demonstrates the possible presence of three-phase inclusions, until now typical of Colombian emeralds.

Fig. 7 shows a crystal section of trapiche emerald, magnified 15 ×. The photograph (transmitted light) shows the starshaped hexagonal outline developed at the time of growth by the inclusion of opaque granules of blackish material. How, from such a rough crystal, does one obtain cut stones without the blackish zones disturbing the colour? The following hypothesis can be given. If one observes the crystal in elevation, it appears that each of the

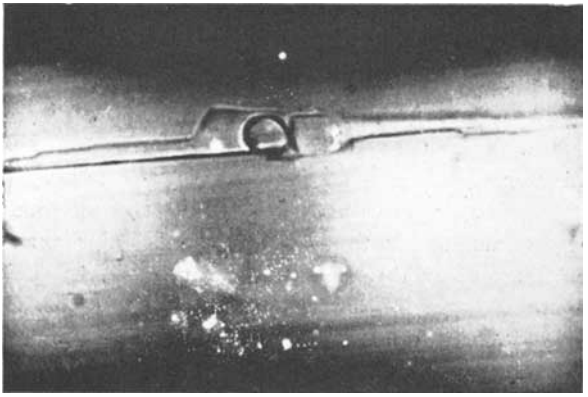

FIG. 6. *Trapiche emeralds: 3-phase inclusions observed in reflected light. The side of the cubic crystal,* 5 *mm on the photograph, measures* 5 *microns in reality. Magnification* 1200 ×.

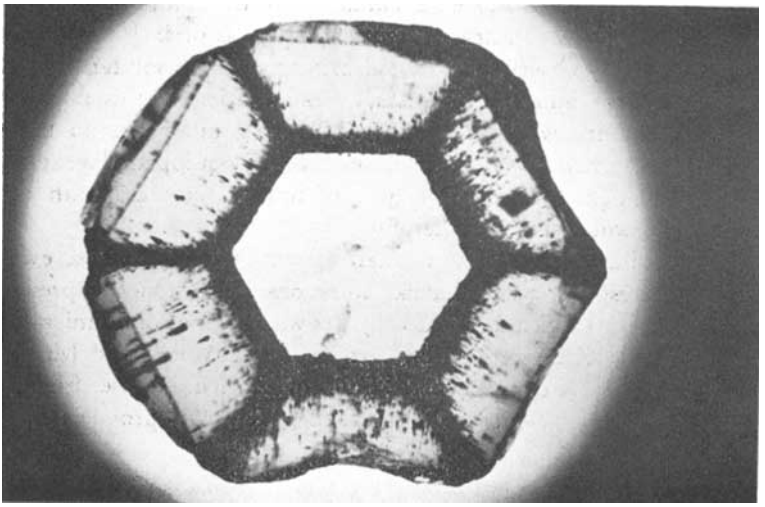

FIG. 7. *Trapiche emerald: Photograph of a section perpendicular to the longitudinal axis of the original crystal. Photographed in natural light. Magnification* 15 ×.

six clear outer zones forms itself into a trapezoidal prism, and the six prisms could be removed individually by sawing across the crystal in the plane of three axes of the star, at 120°. The rough shapes obtained, of a more even colour after the extraction of the blackish parts, which fall away on sawing, could permit the cutting of step-cut stones.

One immediately sees that the arrangement described requires a rough specimen of respectable dimensions. For example, the 16 stones described in this article had dimensions of about 8 × 7·5 × 4·5 mm.

The following question also arises. In what maximum size have trapiche crystals with zonal colour been found until now, of the kind shown in Fig. 7? Statistical information on this subject would be welcomed and would help to solve the problem.

Another question arises. Could another type of trapiche exist, with similar optical and physical properties but, however, without the very marked zonal character of Fig. 7, and which would permit a better use of the material, without having to saw to remove the black bands?

Without doubt the answer to these questions will be given in the near future, because the peculiarities of the stones studied are sufficiently typical to attract attention, and it is desirable that any complementary observation should bring a definite solution to the origin of these unusual emeralds. Classification of this gemmological problem, which actually could bring difficulties to those who do not have on hand the facilities of a well-equipped laboratory, and who might confuse this type of natural emerald with the synthetics, would be most helpful.

The author would like to thank Dr. E. Gübelin, whose ever-lively interest in gemmological questions permitted the present work; Mr. F. Duyk and Professor J. Jedwap for the communication of the results of their research; Professor M. Weibel and Mr. R. Gubser of the Federal Polytechnic of Zürich, whose friendly interest and competence have made the ARL microprobe examination possible.

Source of illustrations: Fig. No. 6—Laboratory of Geochemistry at the University of Brussels (Professor J. Jedwap).
Figs. Nos. 1, 2, 3, 4, 5 and 7—by the author.

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GEMSTONES AT THE I.C.C.G.

By D. ELWELL and J. M. ROBERTSON

THE second international conference on crystal growth (I.C.C.G.) was held in Birmingham in July of this year and formed an important milestone in the development of crystal growth as a scientific discipline. From the earliest attempts by Fremy and others to grow synthetic rubies, crystal growth has been closely linked with gemmology and it is hardly surprising that the ruby is one of the most widely used crystals in scientific devices such as the maser and laser.

In this article an account is given of some of the papers presented at the conference which we felt would be of interest to gemmologists. These examples will indicate some of the recent technical developments which are being applied to the growth of synthetic gemstones.

The methods which have been used to grow synthetic gemstones may be divided into growth from solution and growth from the pure melt. The former category includes hydrothermal growth, in which water at a high temperature and pressure is used as the solvent, and fluxed-melt growth, in which the solvent is a molten salt such as lead fluoride. Growth from the melt is often carried out in the Verneuil oxyhydrogen furnace or by the Czochralski method which involves pulling crystals out of the melt.

Diamonds

Perhaps the most interesting paper from a gemmological viewpoint was that by Angus, Will and Stanko of Case Western Reserve University, Cleveland, U.S.A., who claimed to have deposited diamond onto diamond seed crystals by the decomposition of methane at 1200°C at pressures below atmospheric. The methane gas was passed with helium into a heated zone containing diamonds and the decomposition product was claimed, after careful investigation, to be diamond rather than graphite. However, the proof of diamond formation offered was not wholly conclusive and further study is clearly required.

Work by Dickinson of the U.S. Air Force Cambridge Research Laboratories was carried out to improve the quality of diamonds

grown under high pressure from solutions of carbon in metals. The metal solvents studied were nickel, cobalt, manganese and iron. The best crystals grown using a 600 ton tetrahedral anvil press were normally obtained at temperatures in the region of 1800° to 2000°C. Cobalt and manganese gave the best quality diamonds, the cobalt giving very clear diamonds with less colour than the other solvents. Manganese gave finer quality, almost white diamonds free from inclusions. The size of diamonds was in the submillimetre range and is limited since the operation is carried out in a closed system of rather small volume. Mixed metal solvents are now being studied.

Developments in Heat Sources

Several papers were presented on the growth of rubies using novel types of heat source designed to produce less strained crystals than those grown in a conventional Verneuil furnace.

Adamski and his co-workers at the Air Force Cambridge Laboratories have carried out improvements to a Verneuil burner which have resulted in very good optical quality ruby boules. A three-tube burner was employed to give a larger flame and heat shields were used to prevent radial heat loss and hence to reduce the radial temperature gradient. Particular attention was paid to the alignment of the furnace and the resulting boules were of hexagonal rather than circular cross-section. A slab rather than a cylindrical seed crystal was used and the quality of crystals grown was studied for different orientations of the seed crystal. It was found that the hexagonal boules grown perpendicular to the basal plane of the alumina crystal had the highest degree of perfection.

Field and Wagner, also of the Air Force Cambridge Laboratories, used two 5,000 watt Xenon lamps as heat sources. The radiation was focused onto a ruby rod by the use of a novel mirror arrangement which produced a highly concentrated beam. An additional heater was used to control the shape of the boundary between the molten region and the growing crystal. The growth rate was two centimetres per hour and the chromium distribution very uniform. The quality was better than Verneuil grown material but the diameter was limited to $\frac{5}{16}$ in. so that even more powerful energy sources would be required to produce rods of a size suitable for cutting as gemstones.

Ainger and Bickley of the Plessey Company also described an arc image furnace which produced good quality ruby rods but of small diameter. Thermal strains were reduced in materal grown in this furnace by the use of two lamps. One provided the main energy flux which was sharply focused by parabolic mirrors to produce intense local heating of the alumina rod. The second was of lower power and was focused to give a much larger image in order to reduce temperature gradients across the growing crystal. The resulting crystals were almost strain free but this type of furnace is a long way from becoming a practical rival to the Verneuil furnace for economic production of gem ruby.

The most unusual heat source described was that developed by Class of the Materials Research Corporation (U.S.A.). It involves the production of a discharge in oxygen at low pressure by applying a potential of 1,500 to 2,000 volts. Shaped electrodes focus the discharge onto the central zone in which a polycrystalline rod is located and the ruby crystal is grown by passing the rod slowly through the hot zone as in the arc image furnaces. This furnace aroused considerable interest but is still at an early stage of development.

Growth from Solution

Of a number of papers presented by crystal growers from the Soviet Union, the only one of any gemmological interest was that by Kuznetzov of the Moscow Institute of Crystallography. He reported on the hydrothermal growth of rutile at 800 to 2,000 atmospheres pressure and 500 to 700°C. The crystals were only $\frac{1}{2}$ to 1 mm in size after a six day growth period, which illustrates the very slow growth rates normally encountered with this technique.

Wood and White of Imperial College, London, discussed their method of growing spinel crystals from solution in lead fluoride. The fluoride is evaporated off from a 500 c.c. platinum crucible for 6-7 days at 1200°C and crystals of up to 1 inch in diameter may be produced. The crystals have been doped with nickel, cobalt, manganese, chromium and copper to give turquoise blue, deep blue, yellow, red and pale green crystals respectively, all of pleasing appearance.

Wang and McFarlane of the R.C.A. Laboratories, U.S.A., also used this method and made a detailed investigation of the

quality of the spinel crystals. The lattice parameter varied from 8·079 to 8·085 Angstrom units (10^{-8} cm), compared with 8·085 for Verneuil- and Czochralski-grown crystals, and the mean value was close to the accepted value of 8·080 Angstrom units.

Flux-grown crystals contain small inclusions of the solvent not visible to the unaided eye and most closely resemble natural gemstones under microscopic examination.

The papers presented at the conference will be published in a special issue of the *Journal of Crystal Growth.*

A ROTATING STONE TABLE FOR THE BENCH POLARISCOPE

By B. F. MARTIN, M.D., B.Sc., F.G.A.

As an aid in the identification of gemstones the bench polariscope finds considerable use, and it can often be of service when stones are mounted in jewellery. The instrument is of relatively simple construction and can be made by the handyman.

Essentially, the instrument consists of a box, which serves as the base, and to this is attached a vertical arm which is bent over the upper surface of the box. A disc of polaroid is let into the bent arm and lies directly above a second disc of polaroid, let into the upper surface of the box. The discs are fixed in the "crossed" (or "extinction") position. The box houses a small 15 watt lamp, operated by a switch. The base of the box is attached by screws

so that there is access to the lamp, and in one side there is an air vent to prevent overheating.

Although commercially-made models are constructed of metal throughout, the home-produced model is more easily constructed from a wooden box with a metal arm screwed on. The polaroid discs can be glued into metal rings, such as those which are used for lens attachments to cameras. The rings may be fixed with contact adhesive into accurately cut holes in the box and its arm, making sure that the polaroid discs are in the "crossed" position.

In testing a stone, to determine whether it is singly or doubly refracting, or shows anomalous double refraction, the light is switched on and the stone rotated between the polaroid discs. Although rotation of the stone is the active operation, most commercially-made instruments have not been fitted with any mechanical device to rotate the stone, presumably because the instruments were originally designed for purposes other than gem-testing, such as testing polaroid lenses. The stone therefore is usually placed on the protecting glass overlying the lower polaroid and manipulated with the fingers, or placed on a small glass plate, such as a microscope slide, which is then rotated. Small stones are difficult to rotate steadily with the fingers and a glass plate is rather awkward to manoeuvre through a full rotation.

When constructing a polariscope for personal use, the author found that the addition of a rotating stone table was a considerable improvement. It consisted of a shallow plastic cap, closed at its upper end with a thin glass plate which served as a table for the stones, whilst the open lower end simply fitted over the ring containing the lower polaroid disc. Two small metal brackets were screwed to the box, on either side of the cap, and their extremities bent over the rim of the cap to hold it in position, but allowing for freedom of rotation

The convenience of a rotating stone table was conveyed to the firm of Rayner & Keeler, Ltd., who now equip their bench polariscopes with such a device. (see advertisement XVII).

ANOTHER LECHLEITNER-MADE SYNTHETIC EMERALD

By W. F. EPPLER

FOR some years Mr. J. Lechleitner, of Innsbruck, Austria, has worked to produce synthetic emerald by the hydrothermal method. His first success, from the commerical point of view, was the "covered beryl", a synthetic emerald with a large core of natural beryl covered with a thin layer of synthetic emerald. This was in 1960(1). At first, this synthetic emerald was called "Emerita" and eventually the product was named "Symerald". The core of natural beryl was cut before it was covered and after covering the thin overlay of synthetic emerald had to be polished. During this process it could happen that one or more of the facets of the stone lost the covered part and also the green colour. To avoid such a fault, in the early period of production the stones were covered a second time not with synthetic emerald but with synthetic colourless beryl. In Fig. 1, the core of natural beryl (below) bears a relatively thin but very dark green layer of synthetic emerald, followed by another layer of colourless beryl (above), to protect the green one. The second run to produce the additional colourless layer seems to be worthwhile for two reasons. Firstly, the protection of the green layer against a damage by the polishing process is guaranteed and secondly, the colour-free synthetic beryl has a growing rate greater by far than the chrome-coloured green material. Therefore it is easy to obtain a thick-layered stone with more weight.

Some years later, in 1964(2), the ingenious Mr. Lechleitner surprised the market with the so-called "sandwiched" synthetic emerald, as shown in Fig. 2. This hydrothermally-grown material started from a thin seed-plate of natural (or synthetic) colourless beryl, which in the first run was "plated" with synthetic emerald. Afterwards it was "enlarged" by synthetic colourless beryl. Cut stones of this type exhibit the sandwich-structure only when they are examined from the side, preferably immersed in a liquid of suitable refractive index.

During his work Mr. Lechleitner tried to accomplish a "complete" synthetic emerald. The first results were small pieces of a dark green colour with many imperfections of growth and therefore they were not very attractive. But he improved his

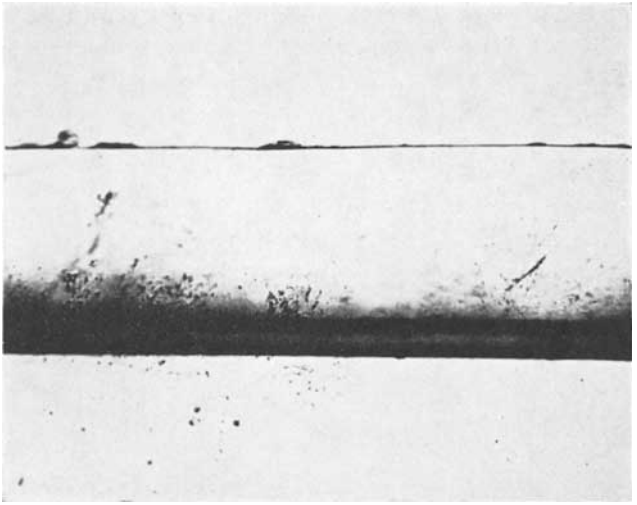

FIG. 1. *Synthetic emerald, so-called "covered beryl". Thickness of the green layer of synthetic emerald is approximateley* 42 *microns, of the colourless coating approximately* 190 *microns.* 120

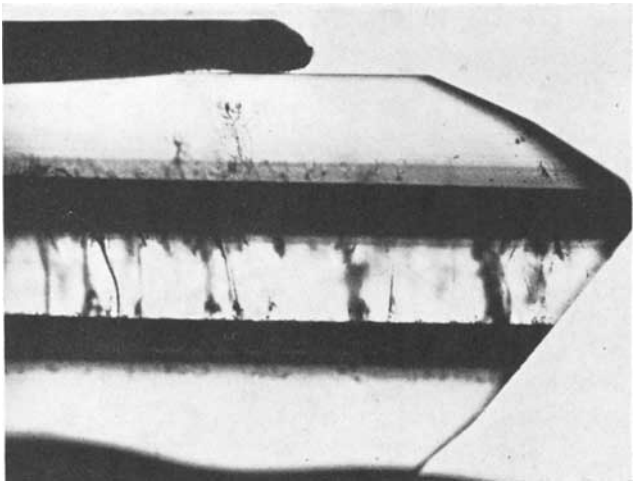

FIG. 2. *So-called "sandwiched" synthetic emerald. The coating of the seed plate has a thickness of about* 300 *microns on each side.* 22 ×

technique until he succeeded in synthesizing an emerald without a core (or a seed) of natural beryl. This happened two or three years ago, but the author obtained samples of it only very recently. The cut stones exhibit a good emerald-green and are fairly transparent. Under long- and short-wave ultra-violet light they produce a weak, dark-red fluorescence.

Using the microscope, it can be observed that this synthetic emerald is grown from a seed-plate of synthetic emerald (Fig. 3), which obviously has previously been grown on a suitable piece of natural beryl. It was sawn off after it had reached the necessary thickness of approximately 0·5 millimetres.

It is evident that the seed-plate of synthetic emerald was placed several times in the autoclave because it was necessary to maintain the supersaturation of the nutrient. But, at the same time, it may be possible that the composition of the nutrient differed a little from that of the foregoing run. This causes an extraordinary striation, as seen in Fig. 3, which is unknown in any other synthetic emeralds.

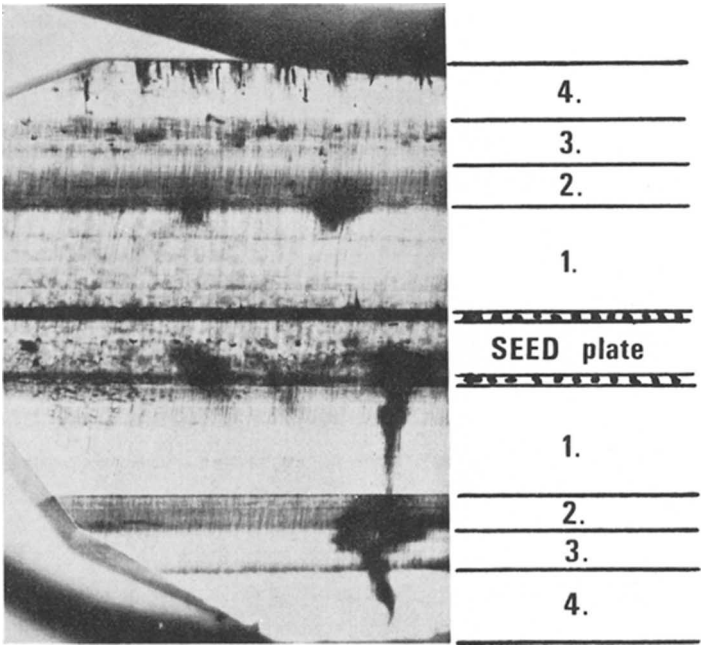

FIG. 3. *The new full-synthetic emerald from Lechleitner. Above and below the seed plate, four grooves of growth can be observed.* 22 ×

In particular, some further irregularities must be mentioned which are not easy to describe. Fig. 4 indicates in some way the "wavy extinction" exhibited by synthetic spinel in polarized light. With a lower magnification, the irregularities resemble cracks or fissures (Fig. 5). In reality, these features, including the darker background of Fig. 5, represent differences in the refractive indices of certain parts of the stone, causing optical boundaries. These phenomena indicate that the growth of the stone was rather difficult.

Another peculiarity of the new synthetic emerald is the very tiny inclusions of rounded material of a brass-like colour. In Fig. 6, some of them can be seen as single spots or in little clusters. In each case, they are the origin of a cuneiformed tube of growth. The presence of this material can only be declared by the supposition that a crystallizer has been used to stimulate the crystallization of the synthetic emerald or its rate of growth respectively.

The physical properties of the synthetic emeralds made by Lechleitner are the following:

	$n\omega$	$n\varepsilon$	$n\varepsilon - n\omega$	S.G.	Colour under UV. light 2540 Å	3650 Å
Synthetic-emerald overgrown on beryl	1·581	1·575	−0·006	2·695	greenish	greenish
Synthetic sandwiched emerald	1·570	1·566	−0·004	2·678	—	—
Full-synthetic emerald	1·574	1·569	−0·005	2·70	dark red, weak	dark red, weak

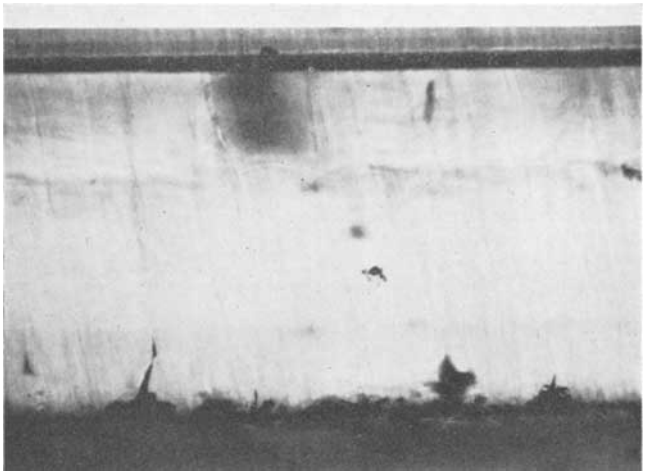

FIG. 4. *Irregular growth of the full-synthetic emerald from Lechleitner.* 65 ×

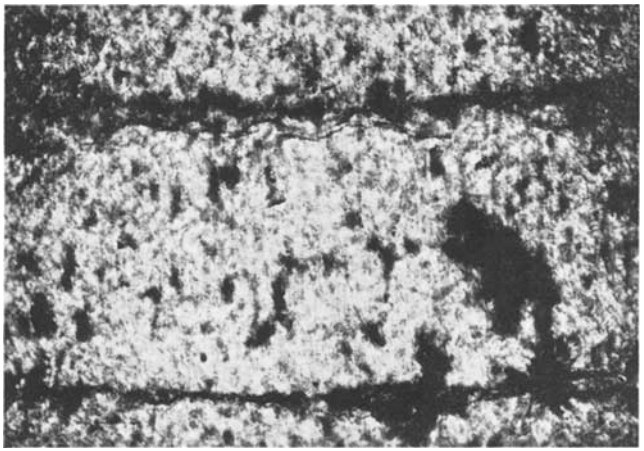

FIG. 5. *Full-synthetic emerald from Lechleitner showing irregular growth.* 22 ×

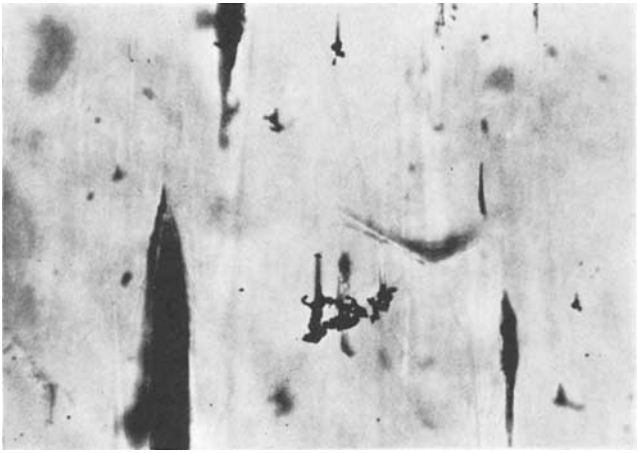

FIG. 6. *Full-synthetic emerald from Lechleitner showing tiny inclusions of brass-like colour, which are the origin of cuneiformed tubes of growth.* 120 ×

ACKNOWLEDGEMENT

The author is indebted to Mr. R. Biehler of Messrs. Ernst Färber, Munich, West Germany, for having placed at his disposal the new material described in this article.

LITERATURE

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2. R. T. Liddicoat, Jr. *Gems & Gemmology*, Spring 1964, 131–138.

AN INDIAN ULTRA-FLAT BRILLIANT-CUT DIAMOND

By H. TILLANDER

THE standard brilliant-cut has an eight-fold symmetry with 32 facets in the crown and 24 in the pavilion, a fairly large table and in most cases a tiny culet. Further it is fashioned with a deep pavilion, a comparatively low crown and a rather thin girdle. The outline is mostly round or nearly round.

This is the normal definition of the shape into which practically all diamonds have been fashioned since the beginning of the 18th century.

Small and very small diamonds have been cut similarly, but with fewer facets. The modern versions of such decorational stones are the "swiss-" and "single-cuts". Very large diamonds usually received additional faceting.

The brilliant-cut is today essentially equal to those cut one, two or three hundred years ago, with the exception only of experimental shapes which have been created at aiming for an improvement of the traditional design. There are also examples of "fancy" brilliant-cuts where the particular rough diamond has not permitted a normal solution.

One such example is analysed here, a "portrait-diamond" designed like a brilliant-cut above and a single-cut below a very thick girdle.

The outline of this stone is clearly triangular. It is a flat hexagonal plate, apparently cleaved from the face of a large octahedron.

The proportions are listed below and compared with a correctly shaped modern brilliant-cut diamond:

Diameter	12 mm	100 %	100,0 %
Table size		54 %	57,2 %
Culet size		6 %	—
Crown height		3 %	14,0 %
Girdle thickness		4 %	1,5 %
Pavilion depth		1 %	42,1 %
Total height		8 %	57,6 %
Weight		1,41 cts	6,00 cts
Crown angle		9,55°	33,1°
Pavilion angle		1,25°	40,1°

The author believes to have found another example of the early diamond cutters' skill and imagination, a further contribution to the descriptions of historical and curious diamonds. Since this diamond was originally in an authentic old Indian pendant (Fig. 4) it has probably been polished in India.

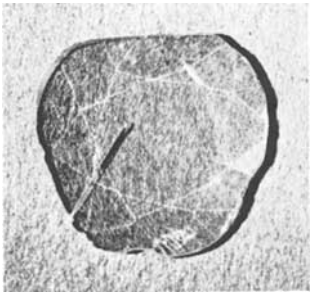

FIG. 1

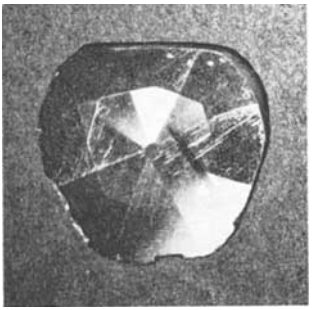

FIG. 2

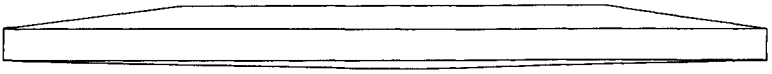

FIG. 3. *A side-view of the diamond showing the extremely thick girdle, the low crown and the hardly distinguishable pavilion.*

FIG. 4

FIG. 1. *Top view of the diamond with the faceting clearly visible.*

FIG. 2. *The diamond viewed from below, the culet in focus and the eight rather badly scratched pavilion facets. The table can be seen through the stone.*

FIG. 4. *A photograph of the Indian enamelled gold pendant with the analysed diamond in the centre. The stone immediately below is a cross-cut rose, the small ones are three-face roses and the hanging drop a briolette.*

THE PETTERSSON PROPORTION-SLIDE

A WELL proportioned diamond is easily recognized by the fine brilliancy of the stone. It is no less difficult to recognize a pronounced "fishy" or an extremely lumpy diamond.

The practice in the trade has been to give an approximate description of the "make" of diamond, stating divergencies from generally acceptable proportions, such as the crown is too low or too high, the pavilion too shallow or too deep, the crown angles too steep, the table too large or exceptionally small.

Modern man is however, not always satisfied with such summary descriptions. He may still trust his jeweller and purchase his engagement diamond without asking "pertinent questions". However, in order to meet the ever growing competition from outsiders the jeweller should start proper grading of his diamonds and be prepared to discuss the merits and details of stones he has in stock, as well as those accepted for valuation.

Diamond-grading of the jeweller's level has been done in several countries for many years and the methods have been improved and instruments developed.

For colour-grading, "master-diamonds" scientifically pre-graded can be obtained and neutral light and surroundings is all that is needed in addition to some efficient training.

Clarity-grading also calls for training. One of the newest tools available to the jeweller is the extensive chart published by the Scandinavian Diamond-nomenclature Committee, with nearly 100 diagrams showing combinations of inclusions.

The "make" has hitherto been the problem to many graders. There is an instrument on the market since early in 1967; it is excellent in every respect, but unfortunately calls for a rather expensive investment. U-J Pettersson, F.G.A. has recently designed a simple slide, which fits into any inexpensive projector and which can be used for exact measuring of diamond proportions.

Fig. 1. The slide with a spring holds the diamond firmly in a rotating stoneholder. When the diamond has been inserted the slide is slipped into the sides of the projector as shown on Fig. 2. If the diamond is over one carat the procedure shown on Fig. 3 should be followed. Fig. 4 exemplifies how to use the projector. It should always be kept strictly horizontal. The Figs. 5, 6 and 7 describe how to take the various measurements. Concentrate

first on the girdle and measure the diameter and the depth of the pavilion. This can be done either using millimeterpaper or a slideruler. Fig. 6 shows how to calculate the crown-height and table size, Fig. 7 the width of the girdle. All results should one way or another be translated into percentage figures. Fig. 8 shows how the angles can be measured by applying an angle-ruler against the shadowedges and Fig. 9 a suggestion to use screens with known proportions—for instance the tolerances for very good, good, medium and poor proportions. If space permits these can be placed so that the size corresponds with the shadow of the diamonds in the slide.

No more detailed rules are given, since the PP-slide can be used in many different ways. It seems advisable for every grader to develop the method he finds most convenient to his specific needs.

The PP-slide is available from: The Gemmological Society of Finland, c/o Tillander, Alexanderstreet 48A, Helsinki.

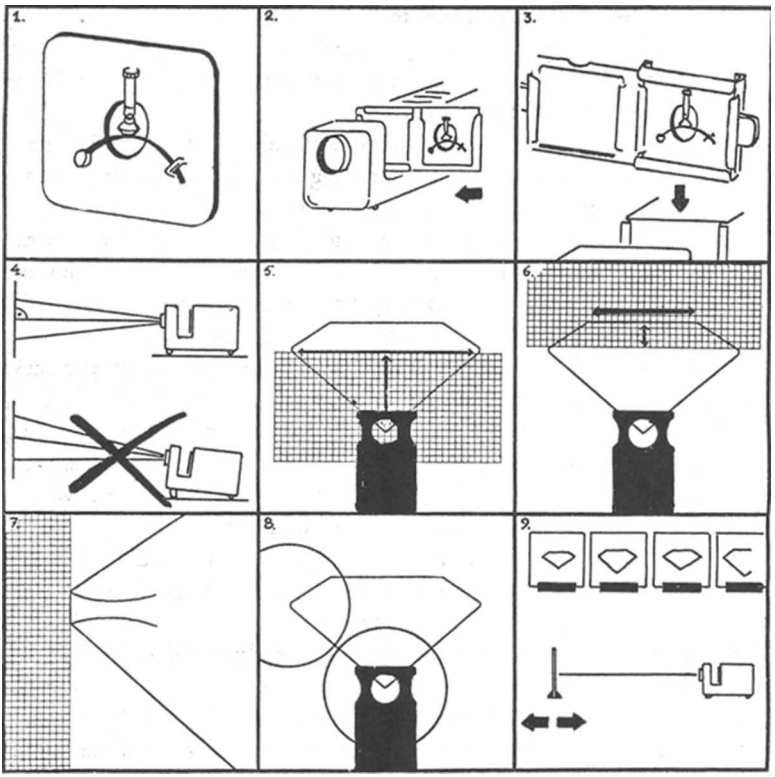

Gemmological Abstracts

HARDER (Hermann). *Zur Farbe der natürlichen Korunde.* Naturwiss., Vol. 54, No. 21, p. 562, 1967.

The relationship between the trace elements content and the colour of natural corundum was investigated by X-ray fluorescence analysis and the electron microprobe. The valence of an iron content ranging from 0·005 to 0·8 per cent was found definitive in determining the colour. Yellow sapphire is characterized by ferric iron. Blue sapphire is characterized by ferrous iron. Sapphire from Khau Ploi Waeng (Thailand) has a uniform total iron content, but is deep yellow on one side and deep blue on the other.

R.A.H.

NASSAU (K.). *On the cause of asterism in star-corundum.* Amer. Mineralog., 1968, vol. 53, 300-305.

Examination by electron microprobe of the fine needles included in pale blue star-sapphire from Ceylon suggests that these needles are Al_2TiO_5. The needles in Linde synthetic star-ruby were too small for a definite conclusion to be drawn as to their composition; from theoretical considerations they could be either TiO_2 or Al_2TiO_5.

R.A.H.

ROLFF (A.). *Topaz in Brazil.* Gems & Minerals, 1968, 371, p. 44.

Clear blue and white topaz has been found in the Federal Territory of Rhondonia, near the Bolivian border. Worn pebbles and well developed crystals are found as a by-product of tin mining in the area.

S.P.

BOOK REVIEWS

BOARDMAN (J.). *Archaic Greek Gems.* 1968. Thames and Hudson, London. £6 6s.

This volume has followed quickly after the author's study of the Ionides collection of engraved gems. Schools and the work of

artists in the sixth and early fifth centuries B.C. are considered in detail. It is the first account of Greek engraved gems of the period.

The gem material mostly used was cornelian. Agate was not quite so popular. Lapis-lazuli is referred to once, and amethyst twice. Clear rock crystal was used mainly for scaraboids, as was pale chalcedony.

The great skill of the artists of the time resulted in a perfection of gem engraving in ancient Greece. Mr. Boardman's painstaking research has resulted in an authoritative companion volume to his earlier work. The text is excellently supported by 15 colour and 372 black and white illustrations.

S.P.

SINKANKAS (J.). *Van Nostrand's Standard Catalog of Gems.* D. Van Nostrand Company, Inc., Princeton, 1968. 276 pages, illustrated. 75s. or 56s. (paper-back).

This is a very important book: much more so than the title might suggest. The author has attempted the seemingly impossible task of placing a range of values on every conceivable type of gem material, and as a useful preliminary has given us a very clear and reasonable analysis of the factors upon which these values and their wide variations are based. Thus he may be said to have extended to some degree the systematic methods of evaluation which in recent years have been increasingly applied to gem diamonds (in which colour, clarity, perfection of cutting, and weight are recognized as the chief operative factors) to the far more complex and varied field of gemstones in general, and even to pearls and cultured pearls.

Anyone who deals in precious stones needs experience and flair, and a knowledge of the particular markets open to him, if he is to be successful in the business: but even the experienced will find such a book as this helpful when some gemstone outside his usual field is offered or asked for; and it will certainly help the beginner from making gross mistakes.

The author, Capt. John Sinkankas, is exceptionally well-equipped for such a monumental undertaking. The earth sciences have interested him since boyhood, and lapidary work and prospecting for gems and minerals been an absorbing hobby—but his skills in these pursuits are of professional rather than amateur standard. Although he has been writing full-time only since 1961, when he retired after 25 years of distinguished service with the air

arm of the U.S. Navy, he has already written a number of books including "Gem Cutting," "Gemstones of North America", and "Mineralogy for Amateurs" which are written with rare originality and accuracy. He quite obviously enjoys writing the kind of book that entails a great deal of hard work.

The "Catalog" opens with a short introductory chapter in which the qualities most desired in a gemstone are enumerated and described. The second chapter, on supply and marketing, contains much useful information not obtainable from other books. Included here are tables of a few weights and measures, which could usefully be extended to cover, for instance, such weights as the Japanese momme and the Indian tola used by pearl dealers in these countries. In this table the grain is given as equal to $\frac{1}{5}$ carat—obviously a misprint for $\frac{1}{4}$ carat, which is the pearl grain. There is apt to be confusion here with the troy and avoirdupois grain which is distinctly heavier (0·324 carat), and should be defined in the table. There is also a very full table for converting the currencies of a large number of countries into terms of the dollar.

The third chapter deals with rough gemstones, and is a massive one of some 80 pages. It opens by discussing the significance to the lapidary of colour, colour-distribution, dichroism, flaws, cleavage, double refraction, etc., and gives practical hints for the critical appraisal of rough material. This part could well have been accorded a chapter to itself. The second part consists of the "Catalog of Rough Gems", in which a very full list of gem materials, including synthetics, is given in alphabetical order, with a range of values in dollars for each according to quality and size. Some of the mineral names included here will be strange to the average gemmologist. At least a score of them are totally unfitted for use in jewellery, as indicated by the author's phrase "collectors' stone only". These only gain inclusion because enthusiastic amateur lapidaries have seen in their fashioning fresh problems to overcome, and because there are collectors avidly seeking for something in the gem world that the other fellow hasn't got. This scraping of the mineral barrel poses quite a problem for authors of books on gemstones who wish to give complete coverage to all minerals used as such, and find it inreasingly hard to draw the line. Water-soluble substances seem so far to have escaped the lapidaries' attentions, so that such things as salt, sugar, and copper sulphate are at the moment safe.

Taaffeite (here spelt with one "f") which is included in the list, is described as "an excessively rare mineral found in pebbles in the gem gravels of Ceylon". Actually this may be regarded as an informed hope for the future, since all four of the known taaffeites have been encountered as already faceted stones. It was quite a relief to find that ekanite and painite are not amongst those present in the "Catalog".

Chapter 4 moves on, logically enough, to consider faceted and cabochon stones, and again consists of two parts which might well be separated. The first 40 pages describe and illustrate the main styles of cutting—and many fancy cuts also, with their appropriate names: the second consists of a price-list for polished stones parallel with that given for rough material. It should be explained that these are much more than mere *lists*. Under each of the more important headings there is a compact description of the stone in question, indications of the sizes available, what constitutes the optimum in colour shades, the main sources, degree of rarity, and so on. Varieties of one species are logically dealt with, as a group. Thus, under corundum, ruby is followed by sapphire; under beryl, aquamarine is followed by emerald, and so on. Under diamond, the grading system worked out for the American Gem Society according to colour, clarity, and cut, is shown in tabular form with their effect on the value of a 1-carat stone. A useful inclusion under diamond is an indication of the value given to irradiated stones. Similarly, under opal one is glad to see values placed upon black opal doublets, and upon treated "black" opal.

The two following chapters deal respectively with engraved gems and with carvings and miscellaneous objects. Each section is again introduced by much general information and advice, including suitability of the various materials for the work in hand. Descriptions, with values attached, of carvings of typical subjects in jade and other hardstones are given as a means of obtaining a rough estimate for a piece which is on offer. Sinkankas is at pains to distinguish between modern mass-produced "commercial" quality carvings, with their lack of detail, crude shaping, and brilliant, glass-like polish, and older carvings of truer merit, the purchase of which he regards as a far wiser investment.

The seventh and last chapter deals with pearls: natural pearls, including saltwater, abalone, conch and freshwater types, but not the shiny black "clam" pearls—and cultured pearls, including salt-

water, freshwater (Biwa) and "Mabe" or blister pearls. The section dealing with the traditional oriental pearl, which for hundreds of years has been ranked with ruby, sapphire, emerald and diamond as one of the supremely precious gems, is perfunctory in the extreme, and in considering their value the author does not bother to explain the "base" system as it is still practised amongst those few merchants who understand and deal in genuine pearls.

Cultured pearls, which now of course dominate the commercial pearl market, provide John Sinkankas with an easy ride home to the end of the book, since there are few more organized and regimented products in the whole of jewellery. Diameter (given in millimetres), colour, and quality are the factors considered, 17 inches being taken as the length of a standard graduated necklace. The rise in price with size is even more marked in the case of cultured pearls than with other gems—the small size of *Pinctada martensi* making large pearls extremely rare. Thus the variation in price for a top-grade rosé graduated cultured pearl necklace is given as rising from 75 dollars for a 2 to 5 millimeter strand to over 5,000 dollars for an equivalent 8 to 12 mm. diameter strand.

The "Catalog" concludes with a list of selected recent books on gems and an excellent index. It is hoped that enough has been said to indicate the great interest and value this new book should have, not only for those who deal commercially in gemstones, but for anyone whose concern for the subject is more than skin-deep.

B.W.A.

FISHER (P. J.). *The Science of Gems.* Charles Scribner's Sons, New York, 1966. (London; Transatlantic Book Service Ltd.) 189 pp., 4 colour plates and 89 illustrations in black and white.

The Science of Gems is essentially an American edition of Mr. Fisher's book *Jewels*, which was published in this country by Batsford in 1965, and was reviewed in the *Journal* for April of that year. Although it bears the imprint 1966 it has only recently arrived in England. The book has been considerably revised for this new issue and additions made both to the text and to the illustrations, and the employment of larger type has also helped the publishers to produce a very handsome quarto volume. The new title also is an improvement, since the term "jewels" normally applies to ornaments set with stones rather than to the stones themselves.

As before, the first chapter, on "Gems through History" treats with the earliest use of gemstones, not only for adornment but because of their supposed magical and medicinal properties, and proceeds to describe the development of the craft of cutting and jewellery making from ancient times to the present day.

The second chapter, on "The Nature of Gems" was probably the most difficult for the author to write and is the least satisfactory in the book. It is notoriously a difficult matter to introduce the necessary elements of science to the general reader. One has to be at great pains to be accurate as well as simple, and to avoid as far as possible an "instructional" manner. The author, unfortunately, has difficulty in forgetting his training from course notes, the bones of which can be seen protruding here and there with unhappy effect, particularly in his treatment of atoms, molecules, and crystals.

The next chapter belongs to diamond, which lends itself admirably to striking descriptions and illustrations. Chapter four contains brief descriptions of the score or so gemstones most used in jewellery, together with spodumene, fluorspar, and sphene. Also included are descriptions of the manufacture of synthetic corundum and synthetic emerald. A picture of Carroll F. Chatham (here given as Carroll S. Chatham) at work, looking young and handsome, is reproduced as Fig. 44 and is a welcome innovation. A photograph of Verneuil products is unfortunately printed upside down, making the boules appear as stalactites instead of the stalagmites they really are. An interesting addition is a description of the functioning of synthetic ruby as a laser material. Synthetic spinel and strontium titanate are briefly mentioned in this chapter, but neither here nor elsewhere is any helpful information offered which might enable them to be recognized. Synthetic spinel, both in its popular "aquamarine" colour and as a substitute for diamond in cluster rings and the like, is so extensively on the market that it merits more attention in the text.

Following a chapter on organic gems, treating with pearl, cultured pearl, amber and coral, comes one on diamond cutting, with a few words on the lapidary's craft at the end. In the diagram (Fig. 70) of dispersion in diamond, white light is shown entering the side facets of the crown and emerging as separated colours from the table. In practice it is light travelling in the reverse direction

which is effectively dispersed, and emerges as coloured rays from the side facets of the crown.

In the last chapter, simple methods of gem testing are described, by specific gravity, refractive index, absorption spectra and inclusions under the microscope. The simplest and most generally useful of all testing instruments, a good 10 × lens, is not mentioned; nor are two other pocket-sized aids to identification—the dichroscope and the Chelsea filter.

The book concludes with three appendices, a glossary, a short bibliography, and a good index. Appendix I consists of the now conventional table of the stones described in the text, with their varieties, physical properties, and occurrence; but the two pages occupied by the other appendices might be more usefully employed. One is a conversion table between grams and carats, which presupposes an inability in the reader to divide or multiply by five. The other gives the numbers of diamond workers in eight main centres: information which could easily have been incorporated in the main text.

Most of the above criticisms and others unuttered are individually of minor importance, but they should be attended to if this is to become not merely a popular, but a *good* popular book on gemstones.

B.W.A.

ASSOCIATION NOTICES

HISTORY OF OPAL MINING IN DUBNIK

The Director of the Technical Museum in Kosice, Czechoslovakia, is compiling a history of opal mining in Dubnik and would be interested to hear from readers of the *Journal* who might be able to assist with information.

In 1901 a Mr. G. A. With, London, and in 1908 Mr. J. Carew Martin, also from London, showed a great interest in the opal mining in Dubnik, and in 1905 Mr. W. H. Shrubsole visited the mines and lectured about them on his return to London. Any information concerning these persons or the early history of the opal mines near Červenica (or in Hungarian known as Vörösvágás, now in Czechoslovakia but formerly Hungary) should be sent to the Secretary of the Association.

GEM DIAMOND EXAMINATION 1968

In the 1968 Gem Diamond Examination held by the Association there were 17 entries and the following is an alphabetical list of the successful candidates:—

Qualified with Distinction

Nash, Geoffrey Edwin, Great Wyrley
Taylor, Andrew William, London

Qualified

Bodenham, John Edward, Halesowen
Brown, Judith Audrey (Miss), Altrincham
Buckler, Albert Norman, Kidbrooke, London
Bytheway, Keith Leonard, Walsall
Cuss, Christopher Jude, London
D'Arcy, Michael Stephen, Peterborough
Gay, Alan Leslie, Bartley Green, Birmingham
Goodman, Brian John, Walsall
Hayes, Lillian Eveline (Mrs.), Aylesbury
O'Shea, John Patrick, Worthing
Popper, Madeleine Charlotte (Miss), London
Sanford, Peter, Hatfield
Sloman, Peter, Southend-on-Sea
Talbot, Peter Ernest, Westcliff-on-Sea
Wade, Michael Balfour, Edgware

MEMBERS MEETING

Mr. Alan Henn, Chairman of the National Association of Goldsmiths, will present the awards to successful candidates in the 1968 examinations at Goldsmiths Hall, London, on the 23rd October, 1968 at 7.15 p.m.

GEM CRYSTAL TRANSPARENCIES

The first series of colour transparencies of crystals of the twelve principal gem minerals was compiled by R. Keith Mitchell, F.G.A. with the idea of bridging the difficulties experienced by some students in recognising crystal habits. In spite of the high cost of colour duplicates the series proved very successful and has been a considerable help in the field for which it was intended.

Since three printings have now been sold, a second edition has now been substituted for the original version. The total number of specimens illustrated has been increased from about 160 to 210. Less than one third of these were used in the first series. The first printing of this new edition consists entirely of direct photographs, produced by using Pentax single reflex equipment. Subsequent printings will be copied with the same apparatus. Thus a greatly improved standard of definition has been obtained when compared with the commercial copies used in the first edition.

With this equipment it was possible to pay particular attention to image size and to fill each frame to give larger and more detailed pictures of most crystals. The directional nature of electronic-flash lighting is also well used and only in one instance has it failed to produce the precise effect desired. In most specimens sharp detail is recorded even to a fortuitous thumb print on a tourmaline crystal which the eye had missed.

In spite of rising costs these improvements have been achieved with only a small increase in cost and gem crystal transparencies are available from the Gemmological Association at £2 15s. 0d. complete, plus postage.

GIFTS TO THE ASSOCIATION

The Council of the Association is indebted to Mr. D. L. Ackworth of Las Vegas, Nevada, for microfilms of volumes 1 and 2 of the *Journal of Gemmology*.

Mr. J. G. Roach of Johannesburg, South Africa, has kindly donated mineral specimens from Swaziland and North Transvaal for the Association's collection.

WARNING RE. SCHEELITE

It has come to the notice of the Association that some specimens of scheelite which have been offered to collectors have proved to be synthetic. Intending purchasers are advised to obtain laboratory reports in cases where doubt might exist.

OBITUARY

Mr. Vete G. Black, age 54, of San Diego, U.S.A., 14th July.(D. 1958).

MIDLANDS BRANCH MEETING

The annual general meeting of the Midlands Branch was held on the 2nd May, 1968, at the Auctioneers' Institute, Birmingham. The following Officers were elected:—

Chairman:	Mr. D. N. King, F.G.A.
Deputy Chairman:	Mr. N. A. Harper, F.G.A.
Vice-Chairman:	Mr. P. Stacey, F.G.A.
Secretary:	Mrs. S. E. Hiscox

A meeting was held on the 6th September, 1968, in Birmingham, at which Mr. Lionel Burke spoke on Mining and Distribution of Rough Gem Diamonds.

SCOTTISH BRANCH

The Annual Summer Outing of the Scottish Branch of the Association took place on Sunday, 9th June, to Usan, by Montrose in Fife.

More than 40 members from Aberdeen, Edinburgh, St. Andrews and the Glasgow area spent the day on the foreshore.

Agates were found on the beach and also in the rocks above the beach. Agates were found *in situ* in the rocks by the beach and also good samples of calcite, quartz and garnet were located.

Below high water mark agates could be picked up from the beach and should prove most interesting.

GEM-DEALING BUSINESS

Englishman 32, interested in small partnership in gem-dealing business. Would appreciate hearing from an established dealer. Replies treated in confidence. GA/68/2, Gemmological Association.

ASSOCIATION TIES

Ties bearing the crest of the Association, in all-over pattern in yellow, are available in terylene or crimplene, price 22s. 0d. including postage.

ADVERTISEMENT

Mr. M. Davis regrets that the colour charts advertised in the July 1968 issue of the Journal (p.ii) will not be available until December.

COUNCIL MEETING

At a meeting of the Council of the Association held on the 10th September, 1968, it was decided to terminate probationary membership. Consequently no new probationary members will be accepted. The membership of those who already fall into this category will continue until the 31st December, 1969.

The Council further agreed that Bye-Law 10 be amended by substituting the words "Arms or emblem of the Association" for the word "seal". This Bye-Law prohibits the exploitation of the emblem of the Association or any colourable imitation thereof without the consent of the Council.

The Council considered that the Association might be consulted from time to time by Weights and Measures Inspectors in connection with the Trade Descriptions Act, 1968, which would come into force on the 30th November (U.K. only). It was agreed to include in the Association's recommended nomenclature a definition for compact limestone and stalagmitic calcites.

The following were elected to membership:

Fellowship

Buckingham, Robert George, Witney, Oxon. D. 1968.

Mitchell, Frank Richard, Frampton on Severn, Glos. D. 1968.

Transfers from Ordinary and Probationary Membership to Fellowship

Alabaster, A. Paul, Birmingham
Arends, Henri, Aerdenhout, Holland
Bartolo, Cynthia Milvaine, Salisbury, Rhodesia
Beechey-Newman, Hansel J. A., Falmouth
Berlin, Ronald, London
Blackburne, James William, Warrington
Bond, Ian Norman, Whangarei, New Zealand
Butler, Terence, Bologna, Italy
Carr, Malcolm, Addington
Coleman, Walter D., Arvada, U.S.A.
Covent, Richard J., Toronto, Canada
Crawford, Leslie Raymond, Pforzheim, West Germany
Dickenson, Henny, Salisbury, Rhodesia
Engstrom, Barbara, Watford Green
Gosling, James Granville, Coulsdon
Grimminger, Alfred, Frankfurt/Main, Germany
Halls, Norman Edward, London
Holmes, Graham John, Bexhill on Sea
Hughes, Anthony, Bradford
Jamieson, Sara Blackburne, Coleraine, N. Ireland
Ledbetter, Susan, Dublin, Ireland
Mitchell, Roger, London
O'Donoghue, Michael John, London
Poultney, Sidney Augustus, Salisbury, Rhodesia
Sadler, David Alex, Ayr
Schupp, Heinz, Pforzheim, West Germany
Staatsen, Albertus Claudius, Utrecht, Holland
Summerhayes, Edward, Gravesend
Swithinbank, Pamela Adele, Lowton, Lancs.
Taylor, John, Bridgend
Turner, George Maurice, Airdrie
Van Den Berge, Anton, Hoofddorp, Holland
Van Starrex, Gertrud, Colombo, Ceylon
Waldegrave, John Geoffrey, Taumarunui, New Zealand

Ordinary Membership

Alyea, Robert, Ontario, Canada
Armstrong, Richard David, Illinois, U.S.A.
Ashelford, Enid (Mrs.), N.S.W., Australia
Badour, Bernard, Manila, Philippines
Bailey, Helen Moyle (Mrs.), Ohio, U.S.A.
Belenke, Burton, Florida, U.S.A.
Blair, Stella (Mrs.), Longtown, Cumb.
Bourgois, Pieter, Ootende, Belgium
Clowry, Raymond Vincent, London, S.W.18
De Vault, Audrey MacBlaine (Mrs). Texas, U.S.A.
Fukuoka, Morihiko, Tokyo, Japan

Farber, Thomas, Strehlgasse, Switzerland
De Gaye, Jeanne F. (Mrs.), London, W.8
Harris, Harold Leslie, Headington, Oxford
Jain, Heera Chand, Jaipur 3, India
Krot, Hendrikus L., Amsterdam, Holland
Leckie, Francis Graham, Dunedin, New Zealand
Lindberg, James David, Texas, U.S.A.
Lowbridge, Sydney, London, N.19
McKnight, H. G., Calif., U.S.A.
Menczer, James B., New York, U.S.A.
Mizuno, Takahiko, Tokyo, U.S.A.
Murthy, K. N., Pahang, Malaya
Paterson, Iris (Mrs.), Botswana, Africa
Perez, Carlos Zapata, Madrid, Spain
Phukan, Sudha (Mrs.), Calcutta 13, India
Pienaar, Herbert Svinde, Stellenbosch, S. Africa
Sally, Mohamed Razeen, Bangkok, Thailand
Shioiri, Yoshihiko, Tokyo, Japan
Stitt, Hamilton, Que., Canada
Stevens, Ronald Claude, Auckland, New Zealand
Stonitsch, Adolf, N.J., U.S.A.
Szungyi, John Peter, Kentucky, U.S.A.
Tims, George B. (Jr.), Texas, U.S.A.
Thomas, Ray, Florida, U.S.A.
Viney, Stanley Herbert, Dodoma, Tanzania
Wharton, John, Natal, S. Africa
Willemse, Engelbertus, de Bilt, Holland
Wilson, Robert Henry (Capt.), Crawley, Sussex
Wing, Leong Kum, Kuala Lumpur, Malaysia
Wonho, Chong, Seoul, Korea
Woo, Shun Wai, Hong Kong
Wood, Robert Matthew, Peterborough, Northants
Yeo, Sandra (Mrs.), Instow, N. Devon

Probationary Membership

Alam, Mohamed Rasheed Shah Mohamed, Idar-Oberstein, W. Germany
Auger, Neil Philip, Rayleigh, Essex
Bennett, Ambrose Early, Carlisle, Cumb.
Brand, Jonathan David, Cape Province, S. Africa
Brereton, Diarmuid Joseph, London, E.8
Canes, Michael Gerald, Johannesburg, S. Africa
Chow, Jimmy, Eastbourne, Sussex
Coldham, Terrence Stewart, N.S.W., Australia
Ishihata, Toshitaka, Osaka, Japan
Izumi, Kazumitsu, Tokyo, Japan
Javeri, Vogendra Kumar Laxminarayan, Bombay, India
Kapur, Ashok, New Delhi, India
Mawson, Alan, Crewe, Cheshire
Meadowcroft, John Frederick, Heywood, Lancs.
Sadler, David Alex, Ayr, Scotland
Sheppard, Richard John, Wanganui, New Zealand
Simons, Paul Armand, Amsterdam, Holland
Smith, Vivian Annesley, Woking, Surrey
Springer, Wilhelm, Idar-Oberstein, W. Germany
Straatman, E. K. V., Bussum, Netherlands
Tanaka, Kenshi, Tokyo, Japan
de Vogel, Johanna Maria (Miss), Bergschenhoek, Nederland

EXAMINATIONS IN GEMMOLOGY 1968

In the 1968 examinations in gemmology organized by the Gemmological Association of Great Britain, 380 candidates sat for the preliminary examination and 244 for the diploma. Centres were again established in many parts of the world and the number of entries for both examinations was the highest in the history of the Association.

Upon recommendation of the examiners the Tully Memorial Medal and Rayner Prize have been awarded to Mr. Stephen Jones of Newcastle upon Tyne.

The Rayner Prize in the preliminary examination has been awarded to Mrs. Jutta Elisabeth Manser of Southampton.

The following is a list of successful candidates, arranged alphabetically:—

Diploma Examination

Tully Medal and Rayner Prize

JONES, Stephen Richard, Newcastle upon Tyne.

Qualified with Distinction

Bartolo, Cynthia Milvaine, Salisbury, Rhodesia
Butler, Terence, Bologna, Italy
Crawford, Leslie Raymond, Pforzheim, West Germany
Dickenson, Henny, Salisbury, Rhodesia
Domenech Bisbe, Juan, Barcelona, Spain
Gastager, Max, Bad Reichenhall, W. Germany
Gosling, James Granville, Coulsdon
Grimminger, Alfred, Frankfurt/Main, Germany
Holmes, Graham John, Bexhill-on-Sea
Jones, Stephen Richard, Newcastle-upon-Tyne
Mercer, Ian Frederick, London
Nwe, Yin Yin, Rangoon, Burma
Pairman, Gordon Sinclair, Leven, Fife
Solans Huguet, Joaquin, Barcelona, Spain
Traveria Cros, Adolfo, Barcelona, Spain
Turner, George Maurice, Airdrie
Win, Soe, Rangoon, Burma

Qualified

Alabaster, A. Paul, Birmingham
Arends, Henri, Aerdenhout, Holland
Arla Felisart, Ramon, Barcelona, Spain
Ash, Stephen Leslie, Exeter
Aye, Tun Tin, Rangoon, Burma
Baguena Ruiz, Carlos, Barcelona, Spain
Ball, Norman Douglas, Exeter
Barlow, Seaton, Totnes
Barrenger, Jonathan, Weybridge
Beechey-Newman, Hansel J. A., Falmouth
Berlin, Ronald, London
Blackburne, James William, Warrington
Blockley, Doreen Sandra, Cheadle
Bond, Ian Norman, Whangarei, New Zealand
Bos, Elisabeth Greet Gerrie, Amsterdam, Holland
Broughton, Timothy John, Knutsford
Bruquetas Dot, Eduardo, Barcelona, Spain
Buckingham, Robert George, Witney

Butler, Barry, Sheffield
Carr, Malcolm, Addington
Coleman, Walter D., Arvada, U.S.A.
Collin, Alan Arthur, Chester
Connard, John Martin, Southport
Covent, Richard J., Toronto, Canada
Dalewski, Orest, London
Derges, Leonard Frederick, Paignton
de Souza, Victor Joao, Kobe, Japan
de Vroomen, Leonardus Johannes Maria, London
Dey, Bimal P., Rangoon, Burma
Engstrom, Barbara, Woodford Green
Fieldhouse, John Ernest, Sutton Coldfield
Gibson, Paul Walter, London
Glen, Susan Elizabeth, Coventry
Goodson, David Lloyd, Tettenhall
Halls, Norman Edward, London
Hayes, Brian, Sheffield
Holden, Terence, Southport
Holroyd, Philip, Frodsham
Htein, Win, Rangoon, Burma
Hughes, Anthony, Bradford
Hulme, Elizabeth, London
Jamieson, Sara Blackburne, Coleraine, N. Ireland
Kaye, David, Leicester
Kjendlie, Karl M., Larvik, Norway
Ko, Ko, Rangoon, Burma
Ledbetter, Susan, Dublin, Ireland
Lewis, David Trevor Keyes, Nottingham
McAleese, David Albert, Toronto, Canada
Millington, Grenville Arthur, Warley (Worcs.)
Mitchell, Frank Richard, Frampton-on-Severn (Glos.)
Mitchell, Roger, London
Moreno del Rio, Carlos, Barcelona, Spain
Morgan, Deryck, Treforest
Morrow, Roger Anthony, Lymm (Cheshire)
Mu, Khin Saw, Rangoon, Burma
O'Donoghue, Michael John, London
Pardoe, Paul Roger, Worthing
Pass, John, Crewe
Pitt, Robert William, Sutton Coldfield
Pladellorens Lluch, Jose, Barcelona, Spain
Poultney, Sidney Augustus, Salisbury, Rhodesia
Pragnell, Jeremy, Stratford-upon-Avon
Purchon, Eric, Bradford
Pye, George Anthony, Kingswinford (Staffs.)
Sadler, David Alex, Ayr
Samuels, Stephen Jeffery, London
Satterthwaite, Frank Clement, Wraysbury
Schupp, Heinz, Pforzheim, W. Germany
Scott, Colonel Conroy, Salisbury, Rhodesia
Sendon Gimenez, Pedro, Barcelona, Spain
Shaw, John Reginald Marshall, Northampton
Smith, Charles Rubin, Michigan, U.S.A.
Staatsen, Albertus Claudius, Utrecht, Holland
Stuckey, Howard, Sale
Summerhayes, Edward, Gravesend
Swithinbank, Pamela Adele, Lowton (Lancs.)
Taylor, John, Bridgend
Thein, Hla, Rangoon, Burma
Thin, Nyan, Rangoon, Burma
Thompson, Michael William, Knebworth
Torrents Domenech, Thomas, Barcelona, Spain
Van Den Berge, Anton, Hoofddorp, Holland
Van Starrex, Gertrud, Colombo, Ceylon
Waldegrave, John Geoffrey, Taumarunui, New Zealand
Williams, Christopher John, West Wickham

Winterson, Martin Richard, Bristol
Wohlwend, Hans Ruedi, Rothenburg, Switzerland
Zara, Louise Vida, Leicester
Zaw, Khin, Rangoon, Burma

PRELIMINARY EXAMINATION

RAYNER PRIZE

MANSER, Jutta Elisabeth, Southampton.

QUALIFIED

Abbott, Arthur Colin, Ripon
Alabaster, Wendy Jane, Stratford-upon-Avon
Ali, Nasim, Sutton
Allen, Rendall James, Darwen (Lancs.)
Almenar, Ibanez Vicente, Barcelona, Spain
Alvarez, Fernandel Laurentino, Barcelona, Spain
Alvarez, Fernandez Manuel, Barcelona, Spain
Ma Amigo, Descarrega Jose, Barcelona, Spain
Andrade, Malde Julio, Barcelona, Spain
Andrews, Robert Eric, Cheadle Hulme
Apter, Alexander, London
Arbunies, Andreu Manuel, Barcelona, Spain
Asami, Yukiko, Tokyo, Japan
Aye, Tun Tin, Rangoon, Burma
Babot, Vizcaino Enrique, Barcelona, Spain
Bartlett, Stewart Michael, Northwich
Bates, William Ernest, London
Beaver, Francis Bertram, London
Beck, Russell Joseph, Invercargill, New Zealand
Bedingfield, Roger, London
Benet, Tejedo Jose Antonio, Barcelona, Spain
Bennett, Augustus, Sheffield
Bloomberg, Maurice, Ilford
Bosch, Senao Ma Pilar, Barcelona, Spain
Bourne, Robert, Dartford
Bowbrick, Richard Donald, Guildford
Bradley, John Raymond, Cardiff
Bradshaw, Stephen, London
Brennan, John Douglas, Birmingham
Brooking, Grassy Alberto, Barcelona, Spain
Broomhall, Alan Richard, West Bromwich
Brown, Kenneth John, Sydney, Australia
Brumpton, Jean Frances, London
Burke, Winifred Mary, Bromley
Cader, M. Fazli, Colombo, Ceylon
Calvert, Leonard Silverwood, Brough (E. Yorks)
Camerer, Carin Elizabeth, Stellenbosch, S. Africa
Campbell, Ian Colin Cecil, Bulawayo, Rhodesia
Campbell, Lucie, London
Carballal, Cirici Montserrat, Barcelona, Spain
Carmona, Angel Zambrano, Barcelona, Spain
Carter, Carlone Frances, London
Cartland, Anthony John, Leamington Spa
Cartmel, Edna, Liverpool
Cartwright, John Frederick Llewelyn, Auckland, New Zealand
Carvajal, Bartolome Carlos, Barcelona, Spain
Castellano, Munoz Carlos, Barcelona, Spain
Castro, Ferrer Jaime, Barcelona, Spain

Chang, Felix Sing Yah, Taipei, China
Christophersen, Elsa, Croydon
Citoler, Tormo Ignacio, Barcelona, Spain
Clark, John Guido Aldo, Guildford
Clarke, Doreen Patricia, Camberley
Collingridge, James William, Tonbridge
Coleman, Walter D., Arvada, U.S.A.
Copping, Dorothea J., London
Cox, Michael Frederick, West Looe
Coyle, Audrey Mary, London
Cragg, George Edward, Leicester
Crawford, Leslie Raymond, Pforzheim, W. Germany
Dales, L. H., Toronto, Canada
Davies, Philip, Birkenhead
Davis, Laurence Alan, London
De Swarte, Georgina, Paris, France
de Villiers, Johan vdS., Stellenbosch, S. Africa
Dey, Bimal P., Rangoon, Burma
Driver, Olive, Bexleyheath
Egan, Thomas, Edinburgh
Egea, Lopez-Vazquez Javier, Barcelona, Spain
Eilers, Berit, Askim, Norway
Engstrom, Barbara, Woodford Green
Farras, Sole Jose, Barcelona, Spain
Farwell, Yvette, London
Fernandez, Gil Enrique, Barcelona, Spain
Ferneyhough, Miles Howson, Henley-in-Arden
Finch, Julia Ann, London
Flavin, Derek Martin, Johannesburg, S. Africa
Flint, Anne Marie, Glasgow
Folch, Bru Rosendo, Barcelona, Spain
Fore, Larry Dean, Norman, U.S.A.
Forester, Philip Andrew, Birmingham
Fowler, Susan Elizabeth, York
Foy, William Michael, Blackpool
Fruhwald, Georg, Hamburg, Germany
Fry, Peter Maurice, Dover
Fryer, Douglas John, Lewes
de la Fuente, Cullell Carlos, Barcelona, Spain
Garre, Alcaraz Felipe, Barcelona, Spain
Gartrell, Mark Paul, London
George, Antony Philip, Horsham
Gibbs, K., Sutton Coldfield
Giles, Roy, Sydney, Australia
Glover, James J., Scarborough, Canada
Gonzalez-Regueral, Adriano, Barcelona, Spain
Gopalapillai, Sabapathy, Ipoh, W. Malaysia
Gowen, Michael Richard, London
Grau, Roca Manuel, Barcelona, Spain
Gray, Robert Irvine, Edinburgh
Grey, Alan Peter, Weybridge
Griffiths, Irfon Jesson, Wrexham
Haberthur, Pia, Lucerne, Switzerland
Hadate, Shushi, Geneva, Switzerland
Hague, Judith Elizabeth, Stockport
Hallam, Gerrard Heathcliffe, Whitby
Ham, Elizabeth Mary, Birmingham
Hammersley, Gordon John, Adrian, U.S.A.
Hampton, Joyce, Higher Bebington
Hancock, Peter John, London
Harding, Jeremy Lance, Copthorne
Harral, Benjamin David, Barnsley
Hawthorn, Graham, Birmingham
Hill, Josephine Ann, Sheffield
Hindle, David Ronald, Exeter
Hird, Frank, Rotherham
Hlaing, Tin, Rangoon, Burma
Hobbs, Robert George, London
Holmes, Kenneth, London
Holtz, Merlin Francis, Johannesburg, S. Africa
Hoogendoorn, Frits, Ysselstein (UTR), Holland
Hop, Janny Catharina Beatrice, Velp (Gld), Holland

Horrii, Ayako, Tokyo, Japan
Horsfall, Richard Thomas Lister, Halifax
Htein, Win, Rangoon, Burma
Hunt, Graham John, Kidderminster
Hunt, John, Aldershot
Inder, Allan Peter, Liverpool
Ingber, Ronald Max, London
Ishizumi, Momoyo, Shiga Ken, Japan
Ismail, Mohammed, Matugama, Ceylon
Jackson, Brian, Edinburgh
Jayasundera, Amarasekera Bandera, Badulla, Ceylon
Jeevendrampillai, Velupillai, Colombo, Ceylon
Jefferis, Marcia Nicoletta, Watford
Jones, Denise May, Liverpool
Kennedy, William, Baltimore, U.S.A.
Kerfoot, Charles, Barnsley
Kitson, Geoffrey Knowles, Sheffield
Knight, Irene, Liverpool
Ko, Ko, Rangoon, Burma
Kocyk, George, New York, U.S.A.
Kutchinsky, Roger Nicholas, London
Lane, Kenvyn Richard, Cardiff
Lapworth, Patricia Barbara, Sydney, Australia
Lattimore, John Christopher, London
Liep, Than Hok, Surabaja, Indonesia
Life, Peter John, Harefield (Middx.)
Llobet, Ocariz Antonio, Barcelona, Spain
Lopez, Soler Angel, Barcelona, Spain
Luk-Sun, Basil Christopher, Cape, S. Africa
Lund, Johnny E., Oslo, Norway
Lwin, Soe, Rangoon, Burma
McCann, Stephen James, London
McCormack, Marjorie J., London
McKay, Angus Saxbee, London
Maas, Geerlof Dirk, Rotterdam, Holland
Madeley, Robert, Liverpool
Manser, Jutta Elisabeth, Southampton
Marshall, Terence, Nottingham
Martin, Kevin John, Manchester
Matthews, Sidney Allen, Liverpool
Maynard, Olive Jessie, Dalry (Ayrshire)
Mertens, Rudolf, Neu-Isenburg, Germany
Miller, Michael Joseph, London
Miravitlles, Torras Carlos, Barcelona, Spain
Manche, Maristany Alicia, Barcelona, Spain
Moncholi, Coscolla Ramon, Barcelona, Spain
Mooney, Robert Anthony, Birmingham
Moore, Margot Wilson, Johnstone (Renfrewshire)
Morgan, Alfred Douglas, Birmingham
Mu, Khin Saw, Rangoon, Burma
Myint, Soe, Rangoon, Burma
Nadal, Cerezo Antonio, Barcelona, Spain
Naim, Edward Joseph, Beirut, Lebanon
Nalliah, Selliah, Colombo, Ceylon
Navarro, Bort Rodolfo, Barcelona, Spain
Nelson, Peter, Sheffield
Nicholas, Alexander, London
Nwe, Yin Yin, Rangoon, Burma
O'Driscoll, Michael Glynn, Birmingham
Offord, Trevor John, Eastleigh (Hants.)
Orme, Terence Joseph, Barking
Osborne, David Leonard, Leigh-on-Sea
Page-Green, Brendon, Lydenburg, S. Africa
Payne, Edward Peter, Oxford
Peaks, Kenneth Raymond, Blackpool
Pearson, Barry Earle, Southport
Pearson, Thomas Usher, Edinburgh
Perera, Bravo Alberto, Barcelona, Spain
Phillips, Walter, Leeds

Pitt, Nicholas Charles Hamilton, Stourport-on-Severn
Potts, Helen Lucy, London
Poultney, Loreto Shiela, Salisbury, Rhodesia
Prada, Sampedro Jose, Barcelona, Spain
Priestnall, Anthony George, Macclesfield
Pujol, Bertran Ma del Carmen, Barcelona, Spain
Pumfrey, Marion, London
Pyle, Ralph, London
Rae, Francis Carl, London
Ramon, Rius Carlos E., Barcelona, Spain
Reichenberg, Sierleja Dieter, Barcelona, Spain
Renton, Brent Sanderson, Preston
Renwick, Stuart Hamilton, Bury
Rhys, Stephanie Barbara, London
Richardson, George, Glasgow
Richardson, Paul Leslie, Preston
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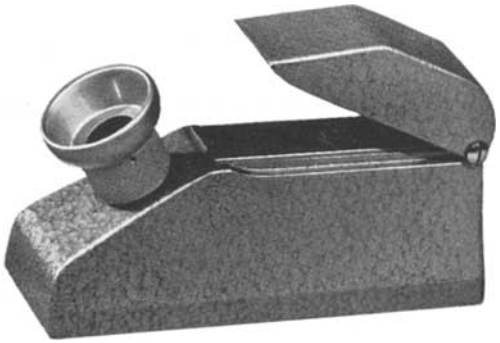

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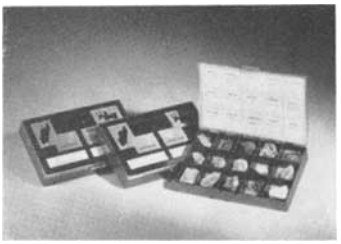

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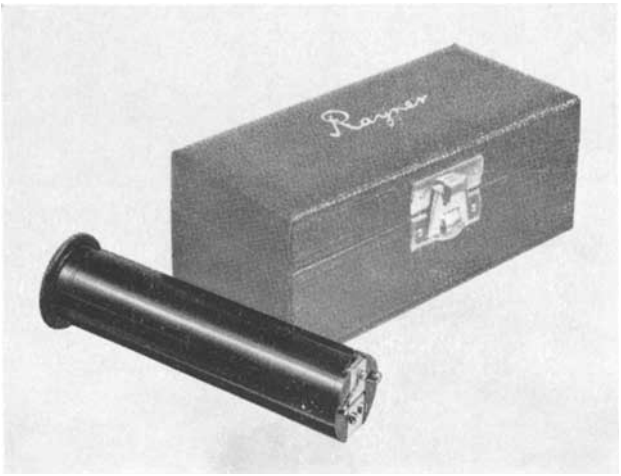

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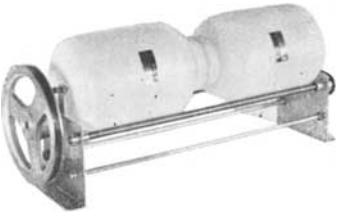

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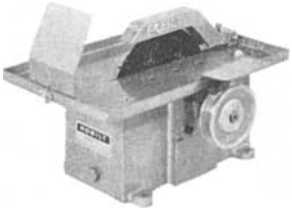

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ON THE NATURE OF MINERAL INCLUSIONS IN GEMSTONES

By E. GÜBELIN, Ph.D., C.G., F.G.A.

AMONG the many types of inclusions encountered in natural gems, where they are regarded as unequivocal criteria of genuineness and often as welcome identification marks of locality, mineral inclusions are of particular interest; for just as, externally, the mineralogical environments of a gemstone in a specific habitat will furnish valuable evidence of that deposit's evolution, the inner paragenesis—i.e. the various mineral inclusions —will yield valuable information about the chemical and physical conditions that must have existed during the formation of their precious host crystal. In a great number of cases, such crystalline formation has been rare enough to be considered unique—witness benitoite—in that the chemical constituents, apart from only once being present simultaneously, have been gathered together at the same time in the proper stoichiometrical relation to the relevant crystalline lattice. During the growth of a gem older minerals, having crystallized during an earlier phase and having temporarily ceased to grow (because of shortage of substance or a phase displacement), were overgrown or fully enclosed by the younger gemstone, which may have grown even more rapidly (Plate A, 1). W. F. Eppler[9] has named such minerals of an older formation "pre-existent mineral inclusions".

A

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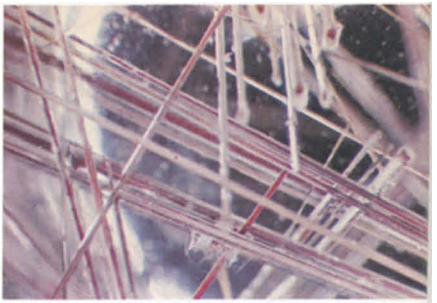

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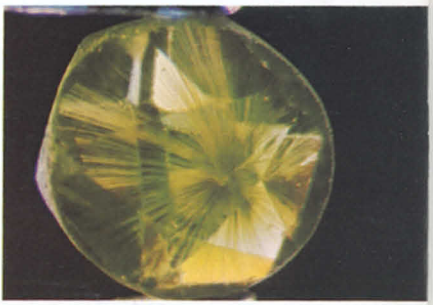

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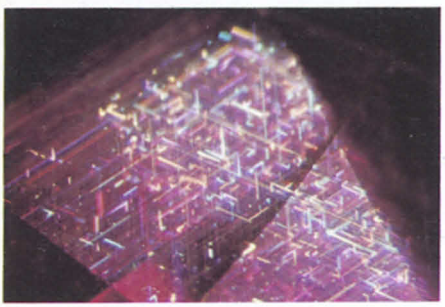

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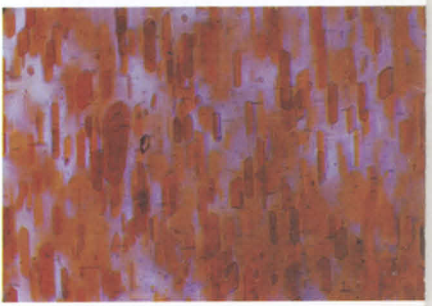

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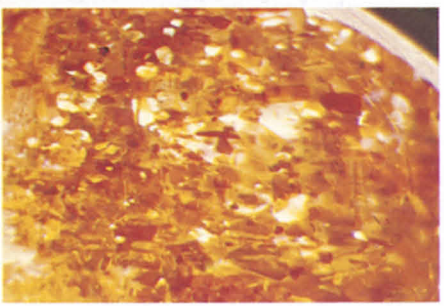

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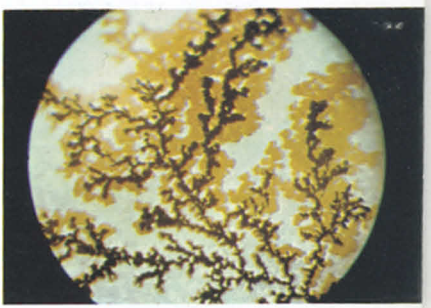

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"Syngenetic mineral inclusions" have crystallized, along with the formation of the gem, from a complex solution or melt in which a number of chemical components were present in a dissolved state. Separated molecules, in their function as building blocks of one mineral or another, may link up with one another or with other molecules of their own type, disregarding completely the crystal structure of other minerals forming at the same time; or they may, with the atoms at fairly equal distances apart (structural affinity), enter into a mutual isomorphic relationship (mixed-crystals) or else grow epitaxially upon their growing faces (orientated intergrowth). In the process, one of the mineral species may cease to grow due to a lack of substance supply. Where such a mineral species has developed rapidly—greedily amassing its components in one direction of growth, as it were—slim, stalky crystals have resulted, such as the rutile (Plate A, 2) and tourmaline (Plate A, 3) encountered in many quartzes, or the byssolite fibres included in demantoid garnet (Plate A, 4). Occasionally, these elongated prismatic or fibrous mineral inclusions have grown independently; more often than not, however, they have formed coincidentally with the host crystal. But the crystallizing process of the gem now including them had not ceased by the time the guest minerals suspended growth: in fact it frequently continued to exist in solution. Simultaneous or subsequent solidification, i.e. crystallization of any such substance remaining in solution, ultimately led to the inclusion of foreign minerals that had been settled on the former crystal faces or had grown freely within the solidifying melt.

With atomic spacings (lattice constants) in the guest and host crystals being virtually equal, the mineral embraced will co-ordinate itself in relevant crystallonomic directions pertaining to its host mineral. An example of this is furnished by olivine whose **pinacoidal** face (010) (the face having all but the closest oxygen packing) will

---

Plate A

1. *Epidote needles embraced by quartz (rock-crystal).*
2. *Rutile needles in rock-crystal.*
3. *Rods of tourmaline in rock-crystal.*
4. *Radiating byssolite fibres in demantoid.*
5. *Exsolved rutile needles in ruby.*
6. *Exsolved platelets of lepidocrocite in iolite.*
7. *Dense concentration of goethite flakes in aventurine-feldspar (Sunstone).*
8. *Secondary, epigenetic formation of psilomelane in dendritic agate.*
9. *Blades of actinolite in rock-crystal.*
10. *Dense felt of amianthus fibres in quartz causing chatoyance.*

grow on the octahedral face (111) (calotte plane with closest C-atom packing) of a diamond in such a way that its c-axis will be in parallel alignment with the octahedral edge. The C-C atomic distance in the primitive cube of the diamond being $a_0 = 3{\cdot}57A$, the simple calculation $2\ a_0.\ \sqrt[2]{2}$ will result in a distance of 10·06A on the octahedral edge, and this is almost equivalent to the lattice constance $c_0 = 10{\cdot}28A$ of olivine. Other known examples are furnished by the orientated rutile needles in almandine and the exsolved fine rutile needles (silk) in corundum.

As opposed to pre-existent and syngenetic mineral inclusions, "epigenetic mineral inclusions" do not form until after the growth of the host crystal is fully completed. Their formation must be ascribed to the well-known process of exsolution. This is a subsequent separation of one, or even of several components (which may likewise exist, and have in fact been identified, as independent minerals) from a mixed-crystal in which they had co-existed in solid solution until the balance of energy was ultimately upset. Precipitation of minority components has usually been caused by changes in temperature (cooling or heating with or without change of pressure) and has led to crystalline differentiation in that microscopic crystals were formed, being mostly or nearly always co-ordinated according to the crystallonomic directions of the major component. Typical examples of such exsolved, epigenetic inclusions are provided by the "silk" in corundum i.e. the fine rutile needles with their sagenite pattern of co-ordination in accordance with the three main directions of the base and rhombohedron (Plate A, 5); and the small slabs of lepidocrocite co-ordinated parallel with the main axis in cordierite (dichroite, iolite) (Plate A, 6); also the dense patches of goethite scale in sunstone (aventurine feldspar) (Plate A, 7).

Since the completion of the manuscript a new analysis has been established in that these slabs are not goethite but lepidocrocite (γ—FeOOH), which has the same chemical composition as goethite. The difference is a morphological one in that the goethite inclusions are fibrous to acicular and lepidocrocite tabular.

Alternatively, foreign mineral substance from outside may have penetrated into the interior of a mineral by way of fissures and channels, where it is now present predominantly in the form of skeleton crystals. Most prominent among the minerals involved in the formation of such subsequent inclusions are iron hydroxide,

manganese hydroxide (psilomelane), and also manganese oxide pyrolusite: in the fissures filled by them, all of these have frequently produced magnificent dendritic forms or a host of other beautiful patterns. Patterns thus formed are particularly prized when occurring in types of quartz such as agate and rose-quartz (Plate A, 8)—also in turquoise, rhodonite.

This deliberately brief excursion into the genesis of mineral inclusions in gemstones was intended to point out just how close a relationship exists between mineral inclusions and their host crystals and what interesting conclusions on the formation of gemstones may be drawn from a thorough knowledge of the inner paragenesis. Mineral inclusions have been the most important witnesses of the mysterious processes of crystallization that were involved in the growth of mineral deposits in great depths below the earth's surface. Bearing in mind their immense analytic value for a reliable reconstruction of the evolutionary processes underlying their formation, and thus to the science of mineral deposits, over the past 100 years scientists have devoted more and more attention to the exact determination of mineral inclusions. As long as thin sections could be obtained, or when in any case the object to be tested could be destroyed, the task was easy enough; but being primarily concerned with studying the cut specimens of gemstones, gemmologists have usually had to confine themselves to crystalloptical scrutiny. Despite an almost inconceivable variety of shapes and forms and an all but unlimited multiplicity of possible combinations, a rather reliable criterion is furnished by the characteristic crystal form of a mineral, and it is due to this or to the relevant habit of an idiomorphic crystalline inclusion that its true nature has often been identified. It is thus that in the relatively early stages of crystall-optical research detection and identification were definitely achieved not only of the afore-mentioned mineral inclusions, but of such diverse members of the amphibole family as actinolite shingles (Plate A, 9), amianthus felt (Plate A, 10) and hornblende needles in rockcrystal (Plate B, 1), bamboo-like canes of actinolite in Ural emerald (Plate B, 2) and blades of tremolite in Habachtal and Sandawana emeralds (Plate B, 3); furthermore, irregular structures of green chlorite (Plate B, 4), brown stalks of epidote (Plate A, 1) and tetragonal bipyramids of anatase in rockcrystal (Plate B, 5), radiating sheaths of goethite in amethyst (Plate B, 6), small pseudo-hexagonal slabs and flakes of brown biotite in Transvaal and Ural

B

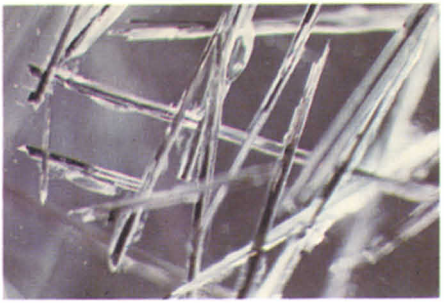

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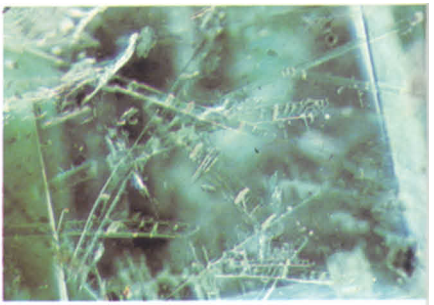

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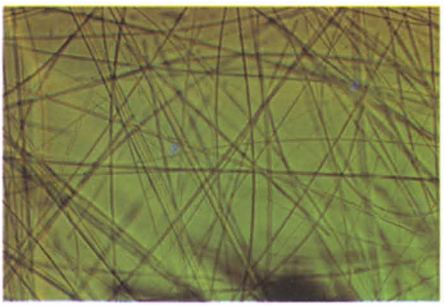

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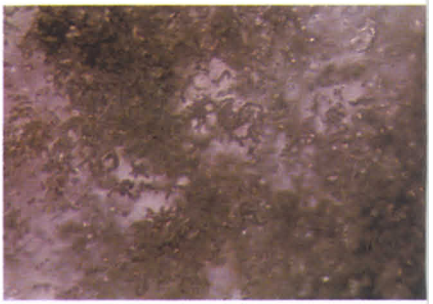

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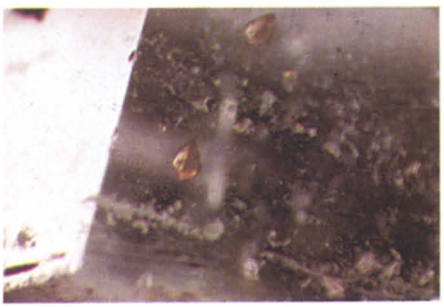

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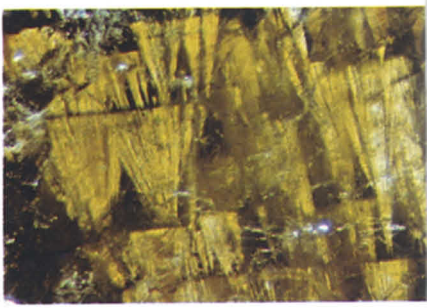

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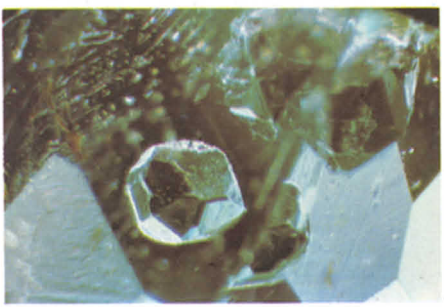

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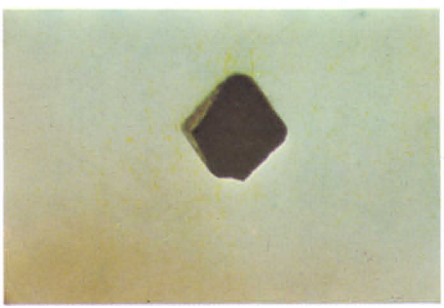

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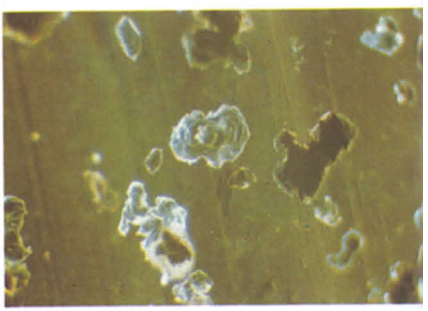

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emeralds; also brassy yellow pyrite crystals in both Chivor emerald (Plate B, 7) and fluorite (Plate B, 8), well-developed spinel octahedra in Mogok ruby (Plate D, 3), euhedral octahedra of chromite in williamsite (Plate B, 9), mica platelets in peridot, hematite in diamond, euclase, corundum, quartz, and topaz (Plate B, 10), and diamond and garnet in diamond.

Owing to the slanting position of the angles incurred by the facets of cut gemstones, even the well-defined forms of a crystal will often appear grossly distorted, and this may easily lead to misjudgment. Furthermore, ideal cases of idiomorphic crystal forms are extremely rare; very frequently crystals viewed under the microscope will not give any elucidation on the nature of the mineral inclusion under observation, seeing that the solid body's shape is irregular, contorted, or completely undefined. Not infrequently, such inclusions will be constituted by resorbed or abraded granules, ill-defined slabs, irregularly edged or spiky aggregates, twisted flakes, splintery chips, or other such indefinable fragments or rudimental structures as would no longer permit morphological assessment; they might at best be identified by virtue of their colour or the difference between their R.I./D.R. and those of their host crystal. Nevertheless, such fragmentary mineral inclusions, being characteristic of certain gemstone species or particular localities, are indeed of some diagnostic value; pending discovery of adequate methods of identification, gemmologists therefore contented themselves with giving such exact descriptions of them as they possibly could. While for the purposes of determining genuineness and distinguishing differences in origin gemmological practitioners could reconcile themselves to the mere availability of a phenomenological description of inclusions, this failed to satisfy the gemmologist with a bias towards mineralogy and, even more so, the mineralogist interested in gemmology.

Plate B

1. *Rods of hornblende in rock-crystal.*
2. *Bamboo-like canes of actinolite in emerald from the Ural mountains.*
3. *Needles of tremolite in emerald from Sandawana.*
4. *Dense concentration of chlorite in quartz (often producing moss-agate)*
5. *Clearly euhedral anatase crystals in rock-crystal.*
6. *Divergently radiating fibres of goethite (Cacoxenite) in amethyst.*
7. *Well-developed crystals of pyrite in emerald from Chivor (Colombia).*
8. *Euhedral pyrite in fluorspar.*
9. *Well-defined octahedron of chromite in williamsite.*
10. *Hematite in topaz.*

C

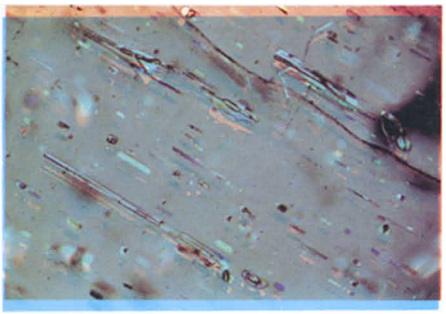

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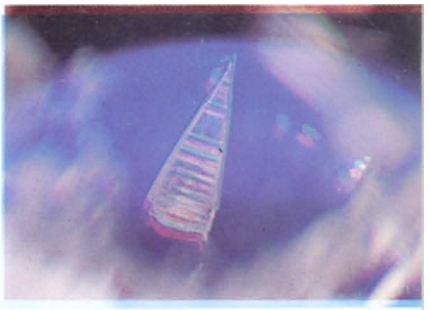

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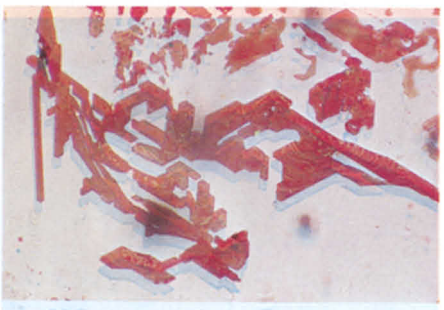

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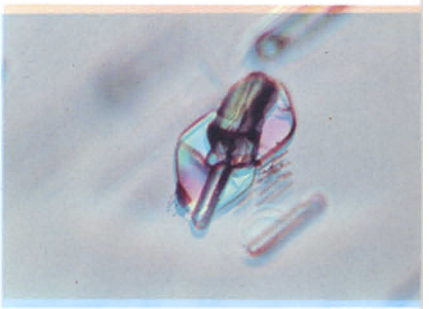

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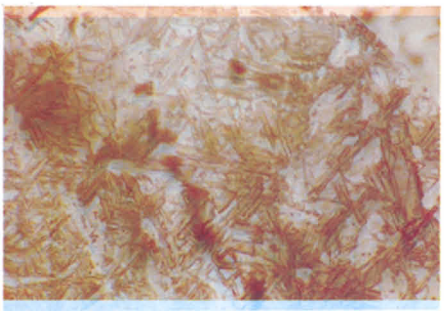

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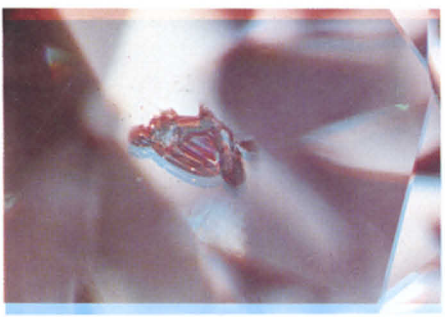

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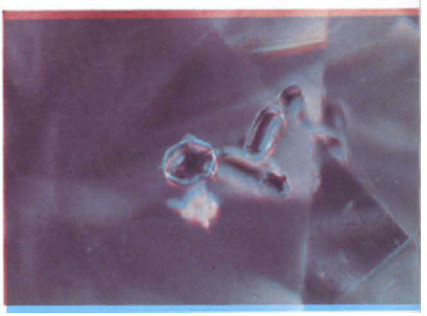

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During the past twenty years, ever-growing numbers of scientists have devoted themselves to painstaking research into the field of mineral inclusions in gemstones, and it is to the outstanding merit of W. F. Eppler that he has dedicated himself to this task systematically and consistently. Applying the orthodox method of crystalloptics in some cases, and extricating the minute mineral inclusions for subsequent microscopic and radiographic examinations in others, he has succeeded in identifying beyond any doubt a host of solid foreign bodies included in gemstones. This has not only added a number of enlightening findings to the field of genetic observation, but it has also considerably augmented the diagnostic techniques that are so important to gemmology. Thus, W. F. Eppler managed to corroborate the occurrence of garnet in diamond and to prove the existence of olivine in diamond shortly after it had been observed by R. S. Mitchell and A. A. Giardini[36]. Eppler was the first to discover apatite as being a member of diamond endogenesis[8]. He also reliably identified, in several other gemstones, certain mineral inclusions frequently recurring and thus diagnostically significant, viz. the filling with granulated quartz, apatite, and epidote of tubes parallel with the c-axis in aquamarine (Plate C, 1); also the presence in aquamarine of individual specimens or batches of hematite, mica (fuchsite, muscovite, phlogopite), garnet, ilmenite skeletons and petalite; and other fascinating cases of quartz intergrown with apatite and epidote (Plate C, 2, 3, 4).

The presence of shingles and needles of sphene crystals in star-spinel, causing the latter's asterism, and having previously been detected by this author using purely crystalloptical methods, has also been confirmed by W. F. Eppler[6] (Plate C, 5).

Since the discovery of the rich Siberian diamond deposits in Yakutia, Soviet mineralogists have exercised admirable exactitude in investigating the inner paragenesis of diamonds mined in the U.S.S.R. However, they, too, did not examine the solid bodies

Plate C

1. *Growth-tubes filled with quartz, apatite and epidote in aquamarine.*
2. *Phlogopite in aquamarine.*
3. *A skeleton of ilmenite in aquamarine.*
4. *Combination of quartz and apatite in aquamarine.*
5. *Orientated arrangement of twinned sphenes in star-spinel.*
6. *Pseudotetragonal olivine prisms epitactically settled on the octahedron face of a diamond.*
7. *Garnet crystal in diamond.*
8. *Combination of distorted octahedrons of chrome-spinel in diamond.*
9. *Emerald-green diopside crystal in diamond.*
10. *Group of pyrrhotine crystals in diamond.*

while still included, but rather, "freed" the mineral inclusions from their host diamond in order to subject these isolated microscopic crystals to crystalloptical and radiographic testing. Proceeding along the same lines as W. F. Eppler, but independent of him, they, too, managed to recognize olivine and garnet as being the most significant and the most frequent accessory minerals in diamonds. The olivine was identified by them as forsterite with approx. 6 per cent fayalite (Plate C, 6) and the garnet as pyralspite with a high content of pyrope (Plate C, 7). They also identified brown chrome-spinel (picotite) (Plate C, 8), green chrome-diopside or chrome-enstatite and diamond (Plate C, 9). An occasional incidence of serpentine, chlorite, biotite, and phlogopite was attributed by them to pseudomorphic changes suffered by mineral inclusions previously syngenetic. Reports of chromite, hematite, ilmenite, magnetite, pyrite, quartz, rutile and zircon—all of them minerals which in earlier works by different authors had been asserted as inclusions in diamonds—were considered doubtful or else refuted by the Soviet mineralogists on the grounds that the purely visual identification method used by earlier authors had given rise to confusion and erroneous identification or that, as in the case of quartz and zircon, it had by no means allowed for the genetic criteria pointing to their pre-existence or syngenetic formation.

The Soviet publications[14, 22, 32, 39] furnish comprehensive information on the findings of research into mineral inclusions with reference to conditions of formation, orientation within the host diamond, R.I. and/or D.R., angles of optical axes, ratios of parameter, lattice constants, and S.G. In places these results are accompanied by illustrative photomicrographs and Laue diagrams. All these findings concerning mineral inclusions in diamond tell that such alkaline minerals as olivine, garnet, chrome-spinel and chrome-diopside (chrome-enstatite) were formed simultaneously with the diamond during the metamorphosis of olivine aggregate into what have been called griquaite nodules (as far as the main mineral constituents are concerned, griquaite is similar to eclogite, but while the first is of deep magmatic, the latter is of metamorphous origin) in intracrustal areas of formation[37], while graphite and serpentine are to be looked upon as pseudomorphoses after diamond and olivine, same as chlorite, biotite and phlogopite, being mutations of garnet, are encountered only as secondary fissure-fillings, having penetrated into cracks and slits at a later stage.

Stimulated by these interesting findings of the Soviet mineralogists, W. E. Sharp of the Adamant Research Laboratory, Johannesburg, using the powder method performed x-ray analysis on a great number of industrial diamonds. The diagram thus obtained enabled him to identify as inclusions of ore minerals various iron oxides such as goethite, hematite, magnetite and possibly even wüstite. He, too, holds that the serpentine and chlorite observed are epigenetic alterations of syngenetic olivine or garnet crystals respectively.

In one isolated case, he even succeeded in obtaining the line diagram of graphite from material he had scraped off a fissure plane—of which he informed the author personally. He has thus, we may take it, corroborated the Soviet observation maintaining that graphite may be caused by graphitization of diamond in places where a carbon structure has been grossly disturbed, i.e. tension cracks or cleavage fissures, and also in the region of stress between foreign bodies included and the diamond substance enclosing them. Evaluating the findings of his elaborate x-ray tests, W. E. Sharp arrived at the conclusion that pyrrhotite (Plate C, 10) is an ore inclusion occurring rather frequently in South African diamonds, where it is often found intergrown with other ore phases. Most frequently it was found integrated with pentlandite; occasionally with pentlandite *and* pyrite. Such intergrowth probably resulted from the exsolution of an earlier high-temperature phase that was later embraced by a growing diamond. Individual formations of ilmenite, pyrite, or rutile were not found by Sharp either.

An exceptionally interesting feat of identification was achieved in an entirely unorthodox manner by B. W. Anderson. During the examination of dense batches of yellowish-brown mineral inclusions in a Colombian emerald, his spectroscope revealed a spectrum of rare earths displaying an abundance of lines which indicated parisite[47]. Parisite is a rare fluocarbonate of the cerium metals ($(Ce, La, Di)_2\ Ca[F_2/(CO_3)_3].C_3{}^4$)—and forming pyramidal to slender prismatic crystals varying in tint between brownish-yellow or yellowish-brown and lilac (Plate D, 1). One of its scarce occurrences being Muzo, Colombia, its presence in emerald may well be considered a welcome locality feature.

Realizing the novel technique of combining microscopy with the x-ray powder method, P. C. Zwaan achieved definite analysis

D

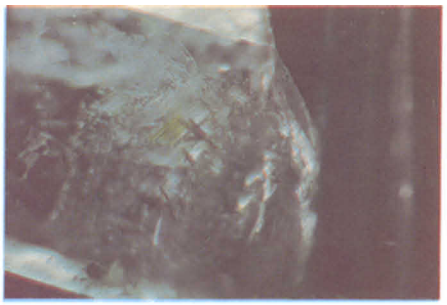

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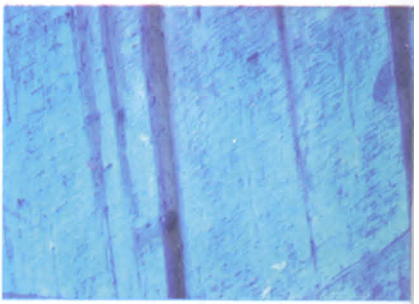

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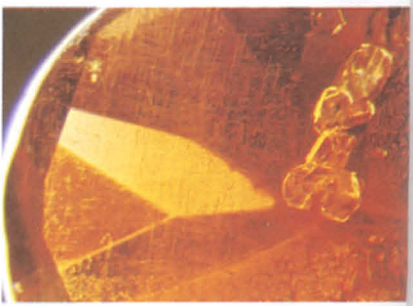

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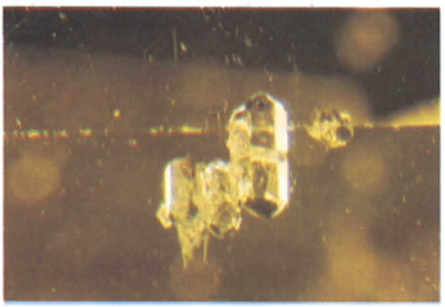

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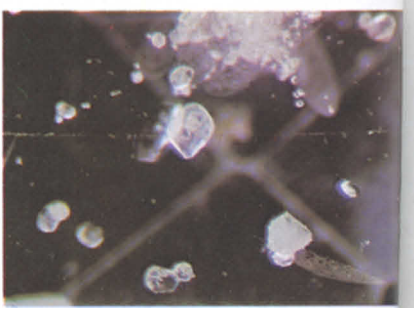

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of a number of internally paragenetic minerals in a variety of gemstones. As early as 1964, several conspicuously hexagonal, prismatic inclusions in a lilac-coloured Ceylon spinel were identified by him as apatite (Plate D, 2)[48], and he has announced the identification of apatite, corundum, phlogopite, pyrrhotite and spinel (the latter confirming earlier observations by this author) in corundum (Plate D, 3) as well as of apatite, muscovite, and rutile (the latter in concurrence with O. Mellis) in almandine[49].

This brief review of the new research techniques developed since the middle of this century, and of the highly noteworthy findings made possible by them with regard to mineral inclusions in gemstones, has—it must be admitted—thrown light on merely a few of the milestones marking the long, often trying, but always fascinating path through this field of investigation: yet it does show how in recent years the most remarkable findings have been made, procuring knowledge which may contribute greatly to elucidating the genesis of gemstones.

Nevertheless, gemmology with its totally axiomatic approach could not rest content with the present state of affairs, since it cannot, in the last analysis, tolerate the destruction of its objects and the great values they so often embody.

Indeed, gemmologists must continue in their search after the techniques and tools that may help them solve their problems without damage to, or even destruction of, their costly materials. In other words, if they wish to abstain from the often destructive methods of mineralogy, they must be concerned with devising instruments that will serve their needs more adequately.

The postulates of gemmology have now been met with to a great extent by the recent invention of the electron microprobe

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Plate D

1. *Slender prisms of parisite in emerald from Muzo (Colombia).*
2. *Idiomorphous prisms of apatite in mauve spinel from Ceylon.*
3. *Euhedral octahedron of spinel in Burma ruby.*
4. *Tiny needles of black magnetite in spectrolite from Finland.*
5. *Rutile needles orientated along the edges of the rhombododecahedron in almandine.*
6. *Group of idiomorphous prisms of apatite in almandine from Ceylon (these apatites proved to contain lanthane and thorium).*
7. *Double-ended apatite crystals in kornerupine.*
8. *Stumpy prisms of apatite in ruby (from Ceylon?).*
9. *Slender stalks of apatite in ruby (from Ceylon?).*
10. *Partly xenomorphous, partly resorbed apatite crystals in mauve spinel from Ceylon.*

analysis, which has brought a revolutionary innovation to the field of analytic techniques. Providing the analyst with completely new ways and means of research, this highly impressive new process is of the utmost importance to him by offering, as it does, an exact and non-destructive method of probing into the chemical constituents, and their quantitative ratios, of the substance being tested. It allows a qualitative and quantitative analysis of solid bodies with volumes far beyond the faculties of the unaided human eye, thus obviously including mineral inclusions in gemstones. This very promising instrument is called an electron microprobe and is an elaborate device of considerable dimensions. It is thus highly unlikely that it will ever be included in the equipment of a gemmologist; rather its installation will be restricted to the big research laboratories. More recently, this new device has been employed for mineralogical research tasks in general and for investigating gemstones and their mineral inclusions in particular, and it is to be expected that this will be increasingly so in the future. For this reason a report on the significant results achieved with the new system is preceded by a brief description of the device and its mode of operation.

The first operating electron probe micro-analyser was constructed by R. Castaing shortly before 1949. Designed as a combination of parts of the electron microscope and an x-ray fluorescence unit, it functions as an instrument for the quick and non-destructive qualitative and quantitative analysis of solid bodies with a volume of only a few cubic microns (1 micron = 0·001 mm). Samples to be tested need not be extracted from the substance enclosing them, but they will of course have to be exposed on the surface of it. It is on account of this improved facility of procedure that microprobe analysis proves to be such an advantageous method of investigating mineral inclusions in gemstones. It yields the solutions to many analytical problems which were previously difficult, if not impossible, to solve by conventional, let alone by optical, methods. The electron microprobe emits a finely focused beam of electrons, directing it onto the minute surface of the sample and producing an x-ray reflection characteristic of the chemical elements affected by the electron excitation. The angle of reflection, the intensity and the wavelength of the characteristic x-rays—all of these being factors determined by the structural elements of the material tested—will then be used to furnish the analytical

data to determine the elements which are present in the target and their relative mass concentrations. Currently, all such elements can be identified that have atomic numbers upward of 11. In typical cases, the spatial resolving power is between 2 and 3 microns, the sensitivity ranges from $1:10^4$ to $1:10^3$ depending on the composition and expansion of the sample, and the relative accuracy amounts to between 1 and 2 per cent if the concentration is in excess of a few per cent. The highly complex equipment comprises (*a*) an electron beam column, (*b*) a number of x-ray spectrometers, (*c*) a light microscope, (*d*) a high voltage power supply and control circuit, (*e*) one or more vacuum systems, and (*f*) a measuring-and-recording system for the analytical information. Fig. 1 shows the

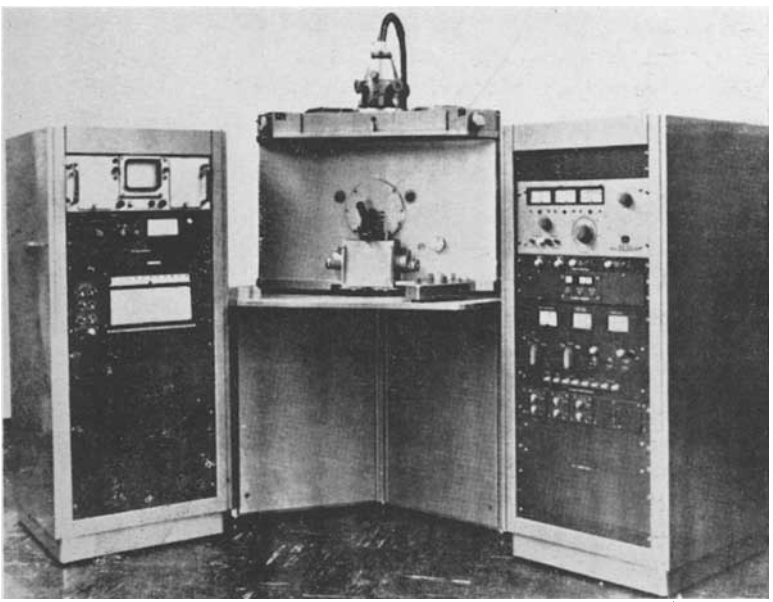

FIG. 1. *A complete electron microprobe laboratory.*

equipment contained in a typical probe laboratory. The most important part of the whole apparatus is the electron beam column housing the electron gun assembly, apertures, magnetic lenses and deflection plates. Fig. 2 depicts a typical example of such an electron beam column. The function of the column is to provide an electron beam of the desired characteristics at the sample surface. The beam must be adjustable in size and density; however, these

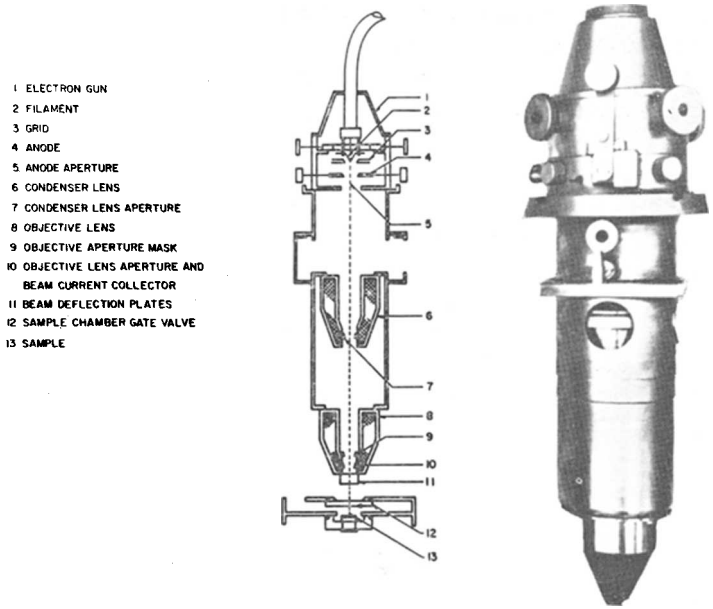

FIG. 2. *Electron beam column with a cross-section diagram.*

parameters must be very stable once established for any programme. The heated filament provides a source of electrons which are accelerated by the field between the anode and source. The acceleration potential may be varied at any time from 2–50 kv, and can be selected by the operator. The first magnetic lens, or condensor lens, focuses and diminishes the beam usually at a point well above the objective aperture. The second magnetic lens or objective lens focuses the image of the first lens onto the surface of the sample and provides a further reduction of the image. The beam-current monitor, shown at the position of the objective aperture, is invaluable in duplicating analytical conditions for the measurement of beam stability.

A stream of electrons, narrowed down to a hair's breadth, is generated by the tube and directed precisely onto the surface of the sample to be analysed—which in the case of mineral inclusions in gemstones is the minute cut surface of the mineral included, which has been exposed on the surface of the gemstone by the cutting of its facets. The electron bombardment produces an x-ray reflection characteristic of the atoms encountered. On the one hand, an angle is formed between the electron beam emitted and the x-ray

beam reflected, its size being determined by the structure of the atoms constituting the chemical composition of the sample. A goniometer may be adjusted to the x-ray leaving the surface at various angles, thus measuring the typical angle of reflection for each element. In this way, the constituent elements of the sample may be determined. On the other hand, crystals of a suitable material are used to deflect the x-rays according to their wavelengths, and the deflected x-rays are picked up by x-ray detectors. The photons of these x-rays entering the detector are converted into oscillations of electrical energy. The frequency of these impulses is in direct proportion to the intensity of the x-ray radiation received, and this, in its turn, is in direct proportion to the quantitative ratio of the elements producing it within the substance being analysed (Fig. 3).

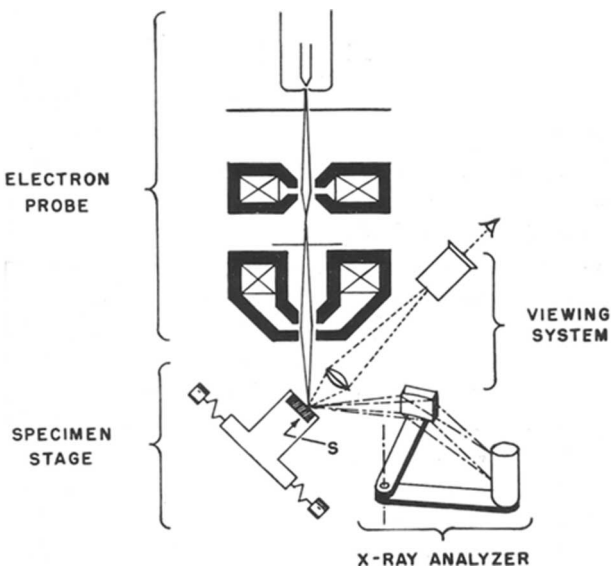

FIG. 3. *Schematic drawing of an electron micro-analyzer showing the relationship of the electron probe, the specimen stage, the viewing system, and the x-ray analyzer to the specimen, S.*

During the relatively short period that has elapsed since the introduction of this revolutionary innovation in the field of chemical microanalysis, it has already established itself in a wide range of research applications, and it is hardly surprising that gemmologists, too, have not been long in showing interest in it and applying it.

Thus, at the 43rd Annual Congress of the German Mineralogists Association[34], O. Mellis, delivering a lecture about the spectrolite occurring near Ylämaa in Finland, was able to prove the existence of a definite relationship between the chemical composition of the spectrolite and its labradorescent colour changes, as well as to the number of opaque needle-shaped inclusions. He also explained that the process of radiographic determination and the analysis carried out by means of a microprobe identified these same black needle-shaped inclusions (Plate D, 4) as magnetite which was, itself, intergrown with fine ilmenite blades (probably secondarily exsolved from the magnetite—author). Notwithstanding the efforts of eminent mineralogists, it had previously been impossible to determine the true nature of the needles intersecting each other (Plate D, 5) in red garnets of the pyralspite family. However, the combined application of optical and radiographic methods by O. Mellis, in conjunction with electron-beam analysis, has since achieved a definite identification of these needle-shaped inclusions as rutile. He is convinced that its formation is not to be attributed to exsolution but to syngenetic epitaxy and thus represents a phenomenon of growth. These rutile needles are predominantly orientated parallel with the edges of the rhombododecahedron. It is only in Madagascar garnet that they have been observed to be co-ordinated also according to the cube. If parallel to the edges of the rhombododecahedron, the needles are invariably twinned; if aligned, however, with the edges of the hexahedron, they are not pure TiO_2 but are invariably mixed-crystals, which is easily recognized by the difference in interference colours when viewed in polarized light. These reliable findings have considerably increased our knowledge concerning one of the most important and most frequent mineral inclusions in red garnet and are, as such, very much to be welcomed[33, 35].

Almost simultaneously with the author, though without being aware of the coincidence, H. J. Schubnel, using a Castaing microprobe as well as applying a number of combined processes, was analysing several mineral inclusions in a variety of gemstones. He found calcite in ruby and sapphire, spinel in ruby, chloroapatite in spinel from Ceylon, also chloroapatite, pyrite, pyrrhotite and rutile in Ceylon sapphire[40, 41]—thus producing findings happily in accordance with those described in Part II of this study. In a more recent publication, H. J. Schubnel reports that by using the

microprobe analysis he has been able to identify as primarily unmixed magnetite the black needle-shaped inclusions responsible for the asterism in Indian star-diopside. These are, themselves, intergrown with secondarily exsolved blades of ilmenite and hercynite[42]. After other analytic methods had failed to detect the colouring chrome jadeite during the examination of jade albite [27, 28, 29, 30] by the author, successful analysis was finally achieved by means of the electron probe following the suggestion of M. Weibel, Professor of Geochemistry at the Institute of Crystallography and Petrology of the Federal College of Advanced Technology in Zurich. The author subsequently obtained permission to use the Institute's AMX electron microprobe to identify the mineral inclusions in a variety of gemstones he had collected over the last 25 years, anticipating the possible discovery of a suitable method of identification. Since a qualitative evaluation sufficed to diagnose the mineral inclusions in question, the author, in an effort to save time, contented himself with a visual assessment of the travel of the graphic indicator, omitting to use the recording attachment which would have traced the relevant spectrograms. A detailed description of the results thus obtained is set out below:

PLATE D, 6 TO 10

Hexagonal prisms of slim to stubby shapes are often encountered in almandine, kornerupine, spinel and ruby from Ceylon. In most cases they are euhedral with a base of medium size. Dipyramids are rare, but the crystals are frequently double-ended, yet sometimes partly or grossly resorbed. At times, they are sporadically distributed; at others they occur in groups. The microlites are either colourless (i.e. mimicking the colour of the host mineral) or they are olive-green (notably in kornerupines). When viewed between crossed polaroids they are conspicuous owing to straight extinction and vivid interference colours. Their R.I. is distinctly lower than that of their host gems. Examination of the crystal inclusions, exposed on the facet surface, by means of the electron microprobe produced readings definitely indicating the presence of Ca and P.

Consequently, these minute crystalline inclusions have been identified as **apatite** [$Ca_5(F, Cl)(PO_4)_3$]. The presence of F cannot be revealed by the microprobe, because its atomic number 9 is below 12, the minimum number detectable by this instrument.

E

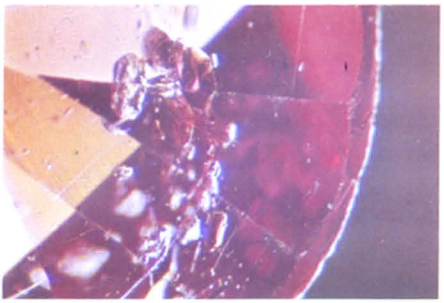

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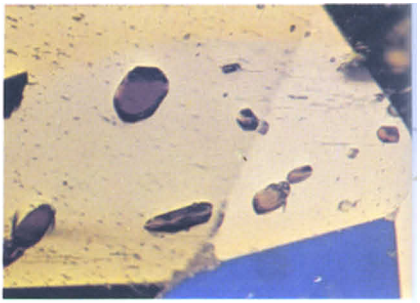

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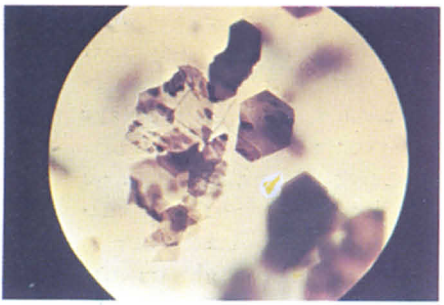

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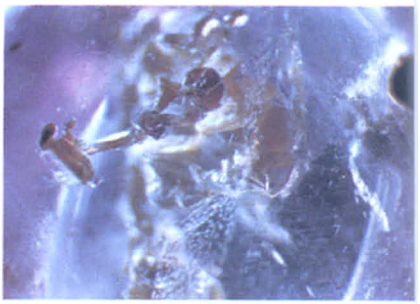

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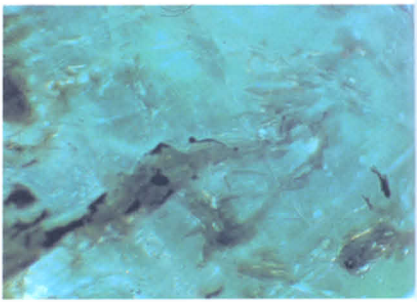

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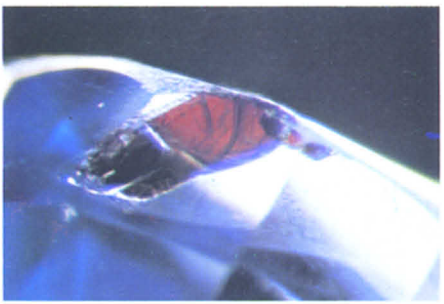

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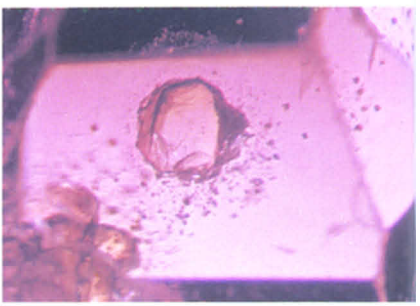

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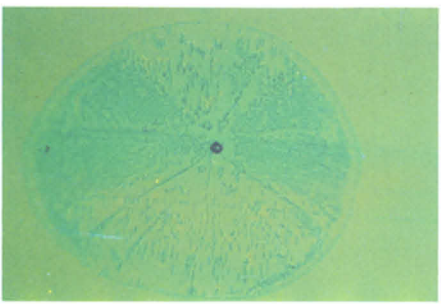

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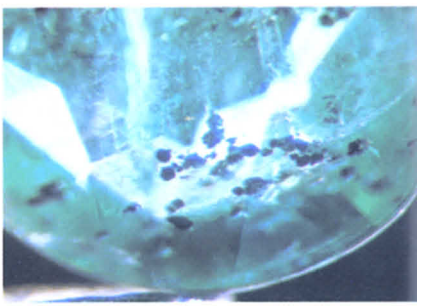

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Apatite crystallizes in the hexagonal system and occurs as long to short columnar or thick tabloid single crystals, or in small crystal groups (as inclusions, they prefer columnar dipyramidal habits). Apatite shows a marked bias for variable chemical composition. Therefore its physical properties fluctuate around the following mean indices: n = 1·642 and 1·646; S.G. = 3·18; H = 5. Owing its existence to a great variety of formation processes, apatite is widespread as a secondary accessory mineral in a multitude of deposits. It is scarcely ever absent from magmatic rocks and is often to be encountered in pegmatite and pneumatolytic formations, but is also occasionally found in hydrothermal sources (veins and alpine crevasses). In the pegmatite phase, apatite is a primary mineral of early crystallization, though it may also be formed at a later stage of this genetic phase. Accordingly, apatite may occur in gemstones either as a pre-existent or as a syngenetic mineral inclusion.

PLATE E, 1 TO 8

The general appearance of inclusions in almandine, kornerupine, sapphire, spinel from oriental deposits, and also of those in peridot from Zebirget and Burma and those in emerald from the mica-schist deposits (Habachtal, India, Rhodesia, the Urals and Transvaal), is often characterized by varying numbers of inclusions of a mineral ranging in hue between yellowish and reddish-brown or between greyish and dark brown and occurring as isolated, irregularly located scaly flakes—some of them twisted—or in the form of stacked slabs. It is only in peridot that they assume the shape of pseudohexagonal slabs; in other gemstones they are characterized by irregular contours or, at best, by a faint suggestion of imperfect crystalline forms. Their R.Is. are in the region of that

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Plate E

1. *Tabular biotite parcels in almandine.*
2. *Brown biotite platelets in kornerupine from Ceylon.*
3. *Pseudohexagonal and spotted biotite platelets in peridot.*
4. *Dense concentration of biotite in pink sapphire from Ceylon.*
5. *Dark green flakes of biotite in emerald from Transvaal.*
6. *Irregular concentration of biotite flakes from the Habachtal.*
7. *Red-brown phlogopite in sapphire (Ceylon?).*
8. *Tabular phlogopite parcel with broken borders in spinel.*
9. *Microlites of chromite in the centre of a residual fluid drop in peridot.*
10. *Irregular aggregates of chromite in emerald.*

of emerald, and they display a very distinct pleochroism. In polarized light, very vivid interference colours will be seen, while the extinction is usually indistinct. Although optical tests suggested that these guest minerals were members of the mica family, determination of their chemical composition, i.e. the distinction between biotite and phlogopite, with their totally different geological environments, was found to be impossible. The mica family in the restricted sense comprises complex, mostly hydrous silicates of monoclinic pseudohexagonal and marked tabloid crystallization. When scanning these (often rather slim) inclusions bared on the surface of a number of gemstones, the microprobe indicated the presence of the following elements in the case of almandine, kornerupine and sapphire from Ceylon, peridot, and emerald: *Fe*, Mg, K, Si and Al, and in the case of dark blue sapphire of unknown origin and red spinel from Burma: Al, *Mg*, K and Si with minute admixtures of Fe and Ti. The constituting elements of **biotite:** $K(Mg, Fe)_3$ $[(OH)_2(Al, Fe)\ Si_3O_{10}]$ were identified in the former case, and those of **phlogopite:** KMg_3 $[(F, OH)_2/AlSi_3O_{10}]$ in the latter.

Both these micas crystallize in the monoclinic system and have a marked pseudohexagonal character. The basal pinacoid is the prevalent, often even the only, recognizable form of growth, and this is why the predominantly tabloid to flaky or fine-scaly form is a feature common to all micas. The biotite flakes may also assume an elongated blade-like shape. Except in peridot, the contours are mostly ill-defined or at least indistinct. For all its chemical variability, the optical properties of mica are fairly constant. The only two criteria subject to relatively wide variation are the size of the angle of the optical axes and the type of absorption. But it is these very features, which often differ so enormously within one and the same mica group, that optical methods fail to distinguish between its chemically differing members.

Biotite: common biotites contain, apart from magnesium, not only divalent but also, for the most part, some trivalent Fe, which is responsible for the prevailing dark-brown tints. $n = 1{\cdot}54–1{\cdot}64$; S.G. $= 2{\cdot}8–3{\cdot}2$; $H = 2{\cdot}5–3$.

Biotite, as the most common kind of mica, is a widespread constituent of most magmatic rocks—particularly of mica schist—but is also a product of contact and depth metamorphism as well as of pneumatolytic and hydrothermal disintegration. It is there-

fore not surprising that it is encountered in many gemstones. It is mainly found, sometimes in large quantities, in such emeralds as have formed as a result of contact pneumatolytic processes in pegmatite veins of adjacent mica schists (Habachtal, India, Rhodesia, the Urals and Transvaal). The biotite enclosed in such emeralds is of pre-existent descent in that it was transferred—as a relic of resorption—from the mica-schist into the growing emerald and thus incorporated by the latter. The biotite in kornerupine and sapphire from Ceylon is probably to be considered as a by-product of contact metamorphism, while in almandine and peridot it may be safely regarded as a product of depth metamorphism. Thus it settled itself syngenetically in these gemstones.

In sapphire, biotite occasionally contains sparse admixtures of titanium, while in emerald it will display traces of chromium.

Phlogopite differs from biotite in that it contains hardly any iron but it frequently includes fluor. The characteristic fluor may, however, be replaced in part by (OH). Where an abundance of Mg-silicate molecules is combined with Al-silicate, the tints are seldom intense because Mg invariably has a bleaching effect. Although these phlogopites, which often contain more than 30% by weight of MgO, are rich in fluor, the electron microprobe can only determine the absence of iron, but neither the presence of the F nor of the (OH) group. The physical properties of phlogopite differ from those of biotite as follows: n = 1·534–1·566: S.G. = 2·75–2·97: H = 2·5–3.

Phlogopite is a typical product of the pegmatitic pneumatolytic phase, but it also occurs as a constituent of granular chalks and dolomites of crystalline slate and its contact. Its occurrence in gemstones resulting from formation processes—e.g. the previously mentioned dark blue sapphire and red spinel from Mogok (Burma)—is therefore to be ascribed to syngenetic growth.

PLATE E, 9, 10

Apart from the ill-delineated brown scales, the elongated blades and the stacks of biotite in emerald, and the small biotite tabloids in peridot with their clearly idiomorphous outlines, irregularly formed black granules of ore having a carbonaceous appearance are also frequently present in the internal paragenesis of the two gemstones. In emerald, they occur singly and loosely dispersed or in dense clusters, even in large coarse lumps, whereas in peridot they

F

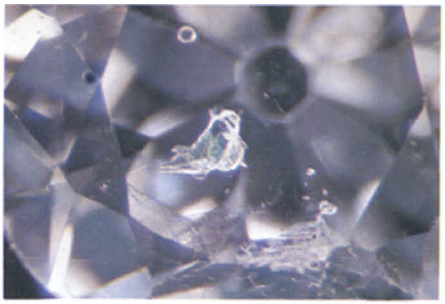

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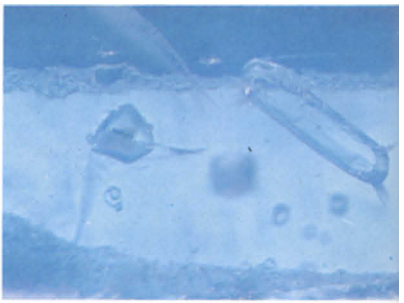

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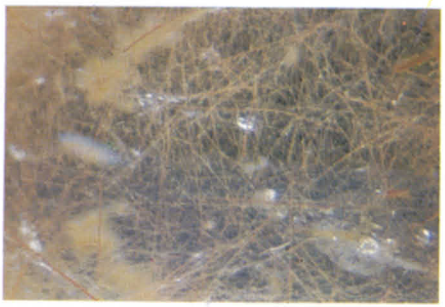

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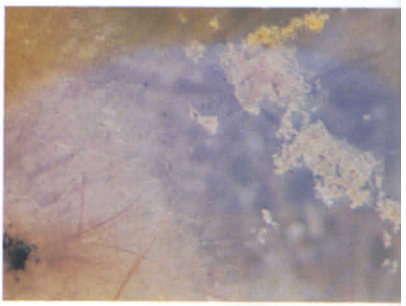

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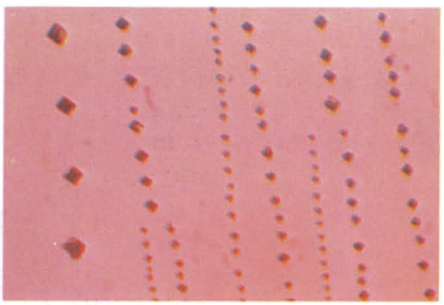

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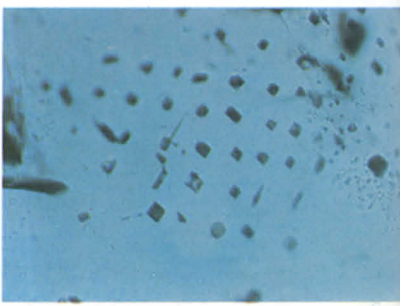

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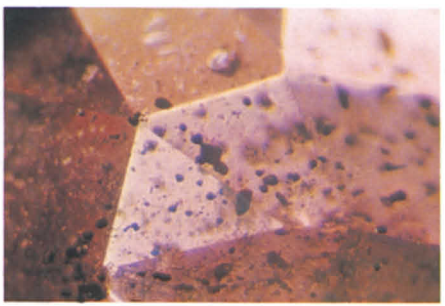

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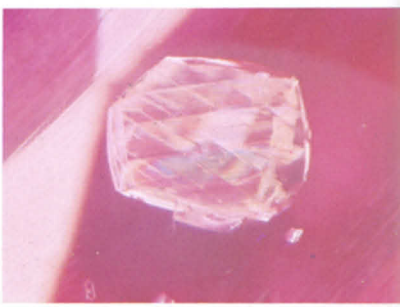

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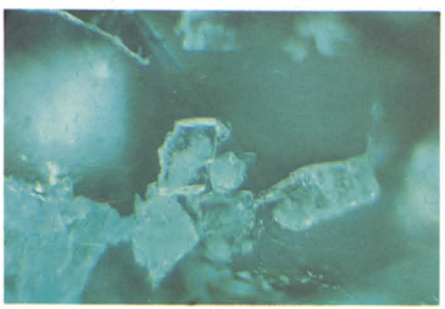

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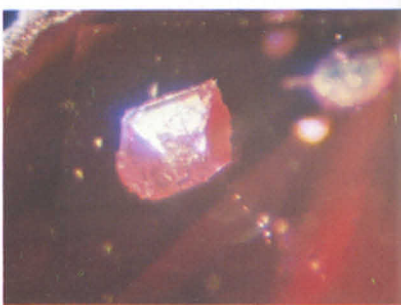

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are always found isolated and surrounded by a residual halo. Occasionally minute or flat specimens may appear dark brown. Microprobe analysis identified the chemical elements Cr, Mg and Fe. The ore inclusions thus turned out to be **chromite** of the chemical formula: $(Fe, Mg)Cr_2O_4$. It is sometimes slightly contaminated by other elements such as Al, Mn, Ni, Ti and Zn. Chromite crystallizes holohedrically in the cubic system. It is not magnetic. n = 2·10; S.G. = 4·5–4·8; H = 5·5.

Chromium ore almost invariably depends on associations rich in olivine and on serpentines originating from them, wherein it occurs as a magmatic precipitate irregularly dispersed or aggregated in clusters. Another indication of its liquid magmatic mode of formation is its occurrence in peridot, in which it was syngenetically produced. The author holds that the halos surrounding each individual granule of chromite are waste liquid drops or dried-up residues of liquid drops which were deposited on growth planes during the growth stages of the peridot, from which small crystals of chromite were subsequently precipitated in the course of a phase displacement. In emerald, however, a syngenetic formation of chromite (which is, after all, a product of magmatic precipitation) would appear to be unlikely since the two minerals are, it must be remembered, separated by a considerable period of genetic construction.

PLATE F, 1

An irregularly shaped mineral fragment of a pronounced light-green colour happened to be exposed in the table of a brilliant-cut diamond, so that one part of the fragment was bared in the surface of the table. This tiny area offered an ideal object for investigation by electron microprobe, and the following elements were detected: Ca, Fe, K, Mg, Cr, Si (no Al). This combination of elements

Plate F

1. *Green fragment of chrome-diopside in diamond.*
2. *Feldspar crystals in sapphire.*
3. *Hair-fine, fox-red fibres of goethite and individual quartz crystals (bright patches) in topaz.*
4. *Dense cluster of quartz grains surrounded by hair-fine fibres of goethite in topaz.*
5. *Tiny octahedra of hercynite arranged in parallel lines in spinel.*
6. *Concentration of hercynite octahedra arranged in parallel array in blue spinel.*
7. *Dense concentration of ilmenite in almandine.*
8. *Idiomorphous calcite crystal displaying a rhombic pattern of lines caused by intertwined twin lamellae in Burma ruby.*
9. *Euhedral crystals, partly well preserved and partly as cleavage fragments, enclosed in emerald from Muzo.*
10. *Calcite, displaying combination of rhombohedron with basal plane, in a red spinel from Burma.*

suggests pyroxene, i.e. augite. Now, pyroxene (augite), having a low alumina and alkaline content with [$SiO_4.SiO_2$] CaMg as its main molecule, is called **diopside.** In very many cases, Mg is partly replaced by Fe. If chromium is also present, the mineral is called chrome-diopside. Diopside crystallizes in the monoclinic system. The crystals, which are often well-developed, are columnar in shape and are not infrequently found in aggregates of a granular or blade-like structure. n = 1·65–1·68; S.G. = 3·3; H = 6–7.

Emerald-green chrome-diopside evolves in olivine rocks and, as the main companion mineral to diamond, is also an important component of its inner paragenesis.

PLATE F, 2

Colourless prismatic or slab-shaped crystals often appear in dark blue sapphires from Burma, Thailand and Australia, embedded either singly or in small groups without bearing any discernible relationship to the crystallonomic directions of their host. Their R.I. is clearly lower than that of the host sapphire, and a more or less oblique extinction can be seen in polarized light. The interference colours change according to the thickness of the small crystals. It is interesting to note that they are almost invariably found in the presence of a red mineral inclusion and black, ore-like grains, which will be mentioned later. Electron microanalysis established the presence of the element groups K, Si and Al, and Ca, Si and Al, thus proving these small bright crystals to be members of the **feldspar** family, more precisely orthoclase ($K[AlSi_3O_8]$) together with another feldspar of the plagioclase species—probably anorthite ($Ca[Al_2SiO_8]$); unfortunately, Na with its atomic number 11 cannot be detected by the electron microprobe. Owing to the considerable mixing ability of feldspars, no absolutely valid constants can be given for these inclusions, only mean values of their physical properties as follows: n = 1·52–1·58; S.G. = 2·56–2·77; H = 6–6·5. All feldspars belong to the same morphological type having little inherent variability. Monoclinic and triclinic feldspars reveal the same form of development. Feldspars constitute an extremely important group of rock-forming minerals which originated during various genetic cycles, e.g. the magmatic, the pegmatitic and the contact-metamorphic. Their occurrence in sapphire might be an indication of the pegmatitic origin of this gemstone—a possibility which is reinforced by the

other accompanying minerals of the inner paragenesis of these feldspar inclusions which were, it may be assumed, syngenetically formed.

PLATE F, 3 AND 4

Remarkable fox-coloured topazes have turned up in the gem trade from time to time. They are interpenetrated with rust-red needles or hair-like fibres, either scattered sporadically or densely accumulated. On one hand, the linear needles appear to be arranged irregularly, without regard to the crystallonomic directions of topaz, and on the other hand the crooked, twisted and folded fibres form tangled skeins. The more abundantly they occur the more intense is the alien red hue and, of course, the optical turbidity of the host. Apart from the pronounced red tint, crystall-optical analysis can give no positive indication because of the sparse morphological clues and the hair-breadth shape of this type of inclusion. The only possible means of investigation in this case was the highly sensitive and subtle scanning-process of electron analysis. It revealed the presence of one main element, Fe, besides traces of Ti and Ca. The results of this analysis, together with optical examination, suggest the presence of **goethite** (α—FeOOH). This indicates a new and interesting occurrence of goethite in gemstones, particularly since in topaz it is to be attributed to syngenetic formation processes and not, as in other cases, to exsolution. Goethite crystallizes holoedrically in the orthorhombic system, and develops prismatic, short-columnar individuals ranging from needle- to hair-shape, which are elongated after the c-axis. They frequently assemble to form scaly, flaky or coarse aggregates, often displaying a texture of divergent fibres. The optical data is high: $n = 2{\cdot}21$–$2{\cdot}35$; S.G. $= 3{\cdot}8$–$4{\cdot}3$; $H = 5$–$5{\cdot}5$.

Goethite is a characteristic product of the weathering zone and the area of circulating waters. Thus, like limonite, it shows an affinity for the oxydisation zones of iron ore deposits. It is also encountered as an independent mineral with calcite or quartz. Quartz (SiO_2), which occurs either in small, perfectly formed crystals or as tiny sandy grains in loose groups, can be observed in the same topazes paragenetically with goethite. Occasionally, these quartzes are found intergrown with chlorite, for which the electron beam revealed the elements Fe, Si and Al. The syngenetic formation of quartz in topaz is certainly compatible with the pegmatitic genesis of these two minerals, of which either may be the guest of the other.

PLATE F, 5 AND 6

Gemmologists interested in inclusions are well aware of the fact that the small, black octahedra arranged in straight or curved lines are a diagnostic criterion of spinel. They were first mentioned and depicted by B. W. Anderson[1]. For a long time they have aroused the analytical curiosity of a number of scientists concerned with inclusions, and some years ago—because of their appearance and the limited possibilities of optical identification—the author claimed them to be magnetites.

These small octahedra, which are black with a metallic lustre, are more or less idiomorphically developed but often strongly distorted. They seldom occur singly, but are usually arranged in large numbers in straight or crooked lines and, as such, traverse large areas of the interior of the host. Thanks to their fairly widespread occurrence in spinels, it was not particularly difficult to find several specimens in which these little black crystals were exposed on a polished facet. Electron bombardment of the grains thus bared on the surface disclosed the chemical elements to be Fe and Al, as well as slight traces of Si and Ca. The latter may be regarded as insignificant impurities. Thus, these small black octahedra are not magnetite (Fe, Fe_2O_4) but a related member of the spinel group, namely **hercynite** (Fe Al_2O_4)—a very welcome discovery which somehow fits better into "the chemo-genetic picture". Hercynite is otherwise known under the pseudonym of iron spinel. Its physical properties are exactly those of a high-ranking member of the spinel group: n = approx. 1·80; S.G. = 3·95; H = 7·5–8. Hercynite is predominantly of liquid-magmatic origin and forms coarse crystals with an indication of octahedral development. It often occurs as an accompanying mineral in titano-magnetite deposits and is also widespread as an exsolution-product of magmatically formed titano-magnetite. Its occurrence may well be attributed to unmixing processes in spinel as well. Lamellar hercynite has recently been identified by H. K. Schubnel[42] as being an exsolved by-product in magnetite, which is responsible for the four-rayed asterism in diopside.

PLATE F, 7

A blackish-red almandine of unknown origin was so thickly interspersed with small black and splintery grains of ore with metallic lustre, that the host had almost completely lost its trans-

parency and appeared unnaturally dark. Crystalloptical methods were unable to yield information as to the nature of these small ore-like splinters of black, ferrous appearance, although many of them were flush with the surface of the almandine. Careful scanning of the surface by the electron beam revealed the presence of Ti and Fe, thus suggesting the titanic iron ore **ilmenite** ($FeTiO_3$).

The titanium-bearing iron oxyde crystallizes in the trigonal-rhombohedral system and is homeotypically akin to hematite. It develops a partly tabular, partly rhombohedral habit. Its R.I. varies according to its Fe_2O_3 content and tends to be higher than $n = 2{\cdot}72$; S.G. $= 4{\cdot}5$–5; $H = 5$–6.

Ilmenite is predominantly a liquid-magmatically formed mineral of alkaline igneous rocks; this, in itself, explains its occurrence in the inner paragenesis of garnet, which originated under identical conditions. It originated syngenetically with its host and was enveloped by the latter as a secondary constituent of the same phase of formation. It is also possible that ilmenite is genetically older and was enveloped by garnet, but ilmenite is known to have formed in crevices of the St. Gotthard, so that syngenetic formation can hardly be excluded. Ilmenite in beryls was previously identified by W. F. Eppler, using optical methods[7], to be an inclusion resulting from exsolution. Moreover, ilmenite, as an exsolved mineral, accompanies other iron ores in gemstones[42], e.g. as lamellae in the magnetite needles in star-diopside or in the pyrrhotite in ruby and sapphire.

PLATE F, 8–10

Colourless, transparent crystals of euhedral habit of the rhombohedral system and their cleavages are known as inner-paragenetic features of rubies and spinels from Mogok, and emeralds from the Muzo mine in Colombia, especially when they occur only sporadically and do not predominate in groups or extensive intergrowth. Many of these guest crystals are distinguished by twin lamellae parallel to $<01\bar{1}2>$ on whose lamellar planes weak interference colours appear when the gem is revolved. Under extreme magnification two systems of alternately broad and slim lamellae can often be recognized. The R.I. is clearly lower than that of ruby and spinel, but roughly corresponds (with variations on either side) to that of emerald; D.R. is very pronounced. There are two reasons for assuming that the enclosed mineral in question is calcite:

the first is the appearance and optical behaviour of the material, the second is the specific occurrence of the host minerals in a source of rock of granular, marble-like limestone, in which they were formed by contact metamorphosis. Since, however, scientific research cannot be content with mere assumptions, the microprobe was the only possible means of obtaining a conclusive answer. All of the exposed samples of the above-mentioned mineral inclusions revealed only Ca. Since C and O cannot be analysed because of their low atomic numbers, **calcite** ($CaCO_3$) is the only possibility here. Calcite is a typical representative of the trigonal-scalenohedral class of crystals.

Its habit and face-development are strongly influenced by accompanying solvents. The number of its various forms of growth, and of their various combinations, is therefore very high. In Burma ruby and in Muzo emerald, the rhombohedral growth and cleavage form would seem to predominate and of the various possible twinnings the most frequent would appear to be polysynthetic lamellation after $<01\bar{1}2>$. $n = 1{\cdot}48–1{\cdot}65$; S.G. $= 2{\cdot}71$; $H = 3$.

As a free mineral, calcite is formed by liquid-magmatic processes under pressure in magmas having a low SiO_2 content, as well as in the last stages of pneumatolytic genesis. Furthermore, sedimentary formations may also supply limestones. Under the influence of metamorphoses the latter may be transformed to marble. Contact metamorphosis of this nature, which took place under the impact of magmatic melts, is the origin of ruby and spinel in Mogok and of emerald in Muzo, and also of the syngenetic precipitation of calcite inclusions in such gemstones.

PLATE G, 1 AND 2

The fact that calcite also occurs in spinel from Mogok may not cause surprise, when it is considered that the growth conditions are the same as for ruby: it came, however, as a surprise when the electron analysis disclosed that calcite does not always occur alone in spinel, but is frequently interspersed with **dolomite** ($CaMg[CO_3]$) and forms interesting intergrowths with the latter. These "double crystals" appear to adopt xenomorphic habits which are either octahedral, hexahedral or even irregularly warped. Their distribution corresponds exactly with the modes of concentration of hercynite, being arranged singly, in groups or in lines. Their

appearance frequently seems to suggest that they might be fillings in negative crystals, half of them consisting of striped (twinned) calcite, the other of dolomite. In polarized light they extinguish alternatingly (i.e. in different positions) and in bright light they reveal vivid interference colours, while the lamellar structure of calcite is conspicuous with strong contrast. The refractive indices of both foreign crystals is markedly lower than that of spinel. Allowing for the fact that the country rock which was involved in the contact metamorphosis from which the spinel originated consisted of dolomitic limestone, it is easy enough to understand the genetic preconditions leading to the development of these interesting double crystals. Alternatively, however, the dolomite might have come into being as a result of partial displacement and metasomatosis of the calcite.

PLATE G, 3

Apart from the two afore-mentioned granular inclusions of chromite in emerald, another guest ore having a leaden-grey hue and a high degree of metallic lustre was observed. It is characterized by a tabular habit with indistinct edges and its appearance distinguishes it unequivocally from all the other ore-like, dark-coloured foreign bodies found in emerald.

The chemical elements Mo and S having been revealed by means of the electron beam, this type of inclusion could be identified as **molybdenite** (MoS_2).

The high R.I., n = 2·03–4·33 is betrayed by the vivid metallic lustre easily perceptible on the inclusion. S.G. = 4·75; H = 1–1·5.

Molybdenite is a mineral characteristic of the perimagmatic to contact-pneumatolytic ranges also being present in pegmatite veins. Consequently it boasts the same conditions of formation as emerald and, therefore, may well have crystallized syngenetically with its host.

PLATE G, 4

In dark blue sapphires from oriental occurrences—probably from Kyaukpyatthat near Mogok in Burma, Kanburi or Bang-Kha-Cha in Thailand—or from Anakie in Australia, pitchblack microlites of a metallic lustre are occasionally revealed under the microscope. They are conspicuous due to their well-defined microtabular or columnar habit, and this will be more marked when the

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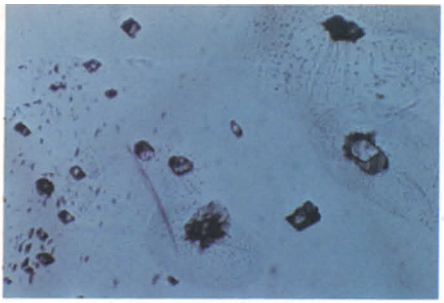

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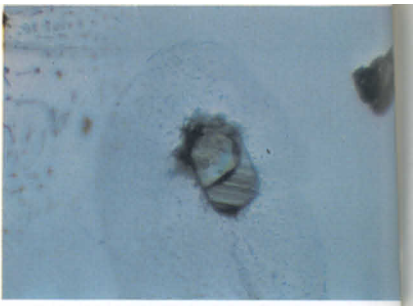

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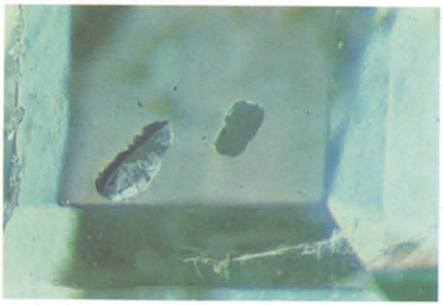

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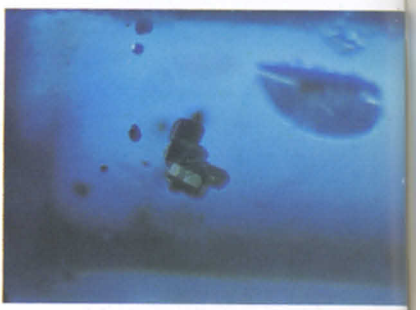

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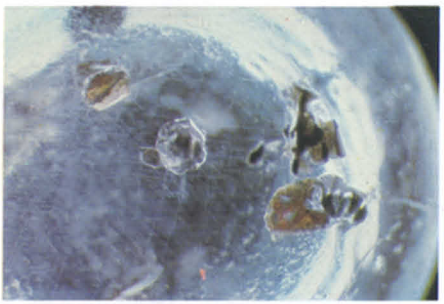

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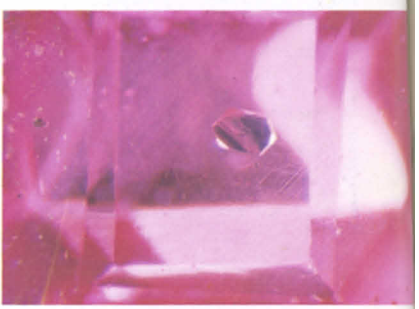

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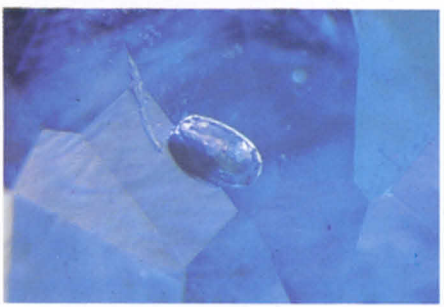

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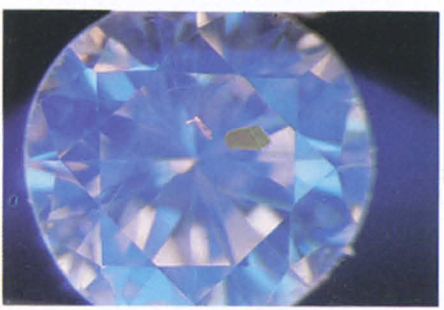

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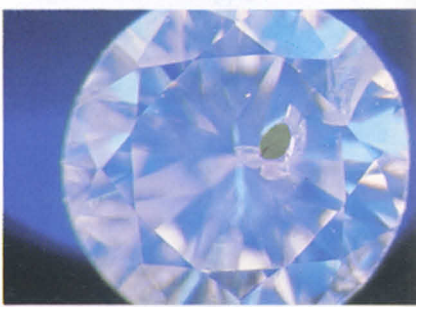

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small crystals occur singly or in small groups; as their numbers increase they rather tend to give an impression of isometric shapes. The quality of polish obtained when they are cut in the surface of a sapphire would indicate medium hardness. The crystalloptical method failed to yield a definite identification of the chemical nature of this type of inclusion. Electron bombardment, however, revealed the presence of the elements Nb, Fe, Mn and some Ta (and, in one case, even traces of Ti), so that the mineral could finally be identified as **niobite** (Fe, Mn) $(Nb, Ta)_2O_6$. Niobite, with its high content of Nb and low content of Ta, is an end member of the isomorphous series collectively referred to as columbite. The guest mineral, having a low content of Ta, crystallizes dimorphically, i.e. in the tetragonal and rhombic systems, involving a divergent form of development: members rich in Nb will prefer tabular or prismatic habits. The refractive index with a value of 2·45 is much higher than that of sapphire, while its specific gravity, amounting to 5·3, will effect an increase of the density of the host when it is present in large amounts. $H = 6$.

Niobite is a widespread and typical companion of granite-pegmatites and its accessory occurrence in sapphire indicates that this gemstone from the above-mentioned deposits emanated from granite-pegmatitic contact melts. We may safely assume that the formation and inclusions of niobite were syngenetic.

PLATE G, 5

Pyrite, the "Jack-of-all trades" of the mineral world, was identified early on by crystalloptical methods. It is conspicuous

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Plate G

1. *Xenomorphous intergrowths of dolomite and calcite partly filling octahedral cavities inblue spinel.*
2. *Enlarged area of Fig. G/1 exhibits the difference between dolomite and calcite in one of the filled cavities.*
3. *Two tabular fragments of molybdenite in emerald.*
4. *Well-developed microlites of niobite in sapphire.*
5. *In the centre of the picture there is a slightly damaged pyrite accompanied by flakes of biotite (brown) and fine "silk" of rutile needles in sapphire from Ceylon.*
6. *Pyrrhotite of ideal development in ruby. Diagonal lamellae of some exsolved minority component are distinctly seen.*
7. *Resorbed pyrrhotite grain in sapphire.*
8. *Grains of pyrrhotite and pentlandite of varying sizes and irregularly dispersed through na emerald.*
9. *A crystal of olivine flush with the table-facet of a brilliant-cut diamond.*
10. *A fragment of chrome-diopside exposed in the surface of the table-facet of a brilliant-cut diamond.*

not only by its unmistakable shade of brass-yellow and its pronounced metallic lustre, but also by its surface physiognomy and its growth forms which are, generally, typically paramorphic. The very fact that it will most frequently precipitate in a variety of formation cycles ensures that it is encountered in many types of rocks and, as an inclusion, in various types of gemstones. A number of completely xenomorphous and pseudomorphous individuals (such as some partially distorted shapes counterfeiting yellowish-brown tetragonally prismatic zircons with pyramidal heads) whose exposed surfaces exhibited a high reflecting power, were subjected to electron micro-scanning. Since pyrite is noted for its tendency to form fantastic aggregates, it did not come as a surprise, on this occasion, when the examination revealed the presence of Fe and S, thus identifying the inclusions as **pyrite** (FeS_2).

Pyrite is remarkable for its extraordinary variety of forms. The habit of its crystals is predominantly cubic, octahedral or pentagondodecahedral involving a score of combinations. The crystals are usually well-defined. In addition there is also a diversity of aggregate formations. S.G. = approx. 5; H = 6–6·5.

Pyrite is known to be ubiquitous among all minerals and can be formed under almost any conditions. When occurring in such gemstones as fluorite, sapphire and emerald (from Chivor), which were likewise generated in completely different formation processes, pyrite must certainly have crystallized syngenetically with its host.

PLATE G, 6–8

The many varieties of black ore inclusions, ranging in appearance from carbon-dull to an adamantine metallic lustre, do not usually permit a definite identification by microscopic methods—although they sometimes display clearly recognizable morphological characteristics. Fortunately, they are mostly present in such large quantities that there are almost always a number of specimens caught on the surface of the host stone, which are ideal objects for electron microprobe investigation. These ore specimens, ranging from black to tombac brown in colour, are seldom euhedrally developed, but are mostly of granular or completely rounded shape: they can be observed in ruby, sapphire and emerald. They are normally microscopic, but they may grow to such sizes that they are perceptible to the naked eye. The microprobe disclosed the

elements Fe and S, occasionally in conjunction with traces of Ni. The ore inclusions examined were thus corroborated as **pyrrhotite** (FeS). S.G. = 4·6; H = 4.

Pyrrhotite crystallizes in the hexagonal system. The rare crystals constitute hexagonal slabs with stumpy prisms, which are frequently characterized by extremely fine, lamellar structure. The low nickel content is present in inserted pentlandite lamellae which were precipitated as a result of exsolution during cooling. The principal home of pyrrhotite is usually the basic plutonic rocks in which it can accumulate in certain areas and form extensive deposits. It is, however, also present in pegmatitic-pneumatolytic phases and in hydrothermal crevices and was thus liable to be precipitated together with the growing corundums and emeralds, and to be included by them.

When the quantitive proportion of nickel is relatively high, the mineral in question is **pentlandite** $(FeNi)_9S_8$—a paragenetic compound which has been shown to be present in ruby and emerald. This nickel ore crystallizes in the cubic system and its lattice is characterized by an extremely close spherical packing of the S atoms. The mineral, which is generally of a coarse texture, very rarely displays clear crystal faces. Unlike pyrrhotite, it is not magnetic, but possesses the same range of colour from bronze to tombac brown. Its hardness is 3–4 and its S.G. 4·6–5. This nickel ore is native to all liquid-magmatic pyrrhotite deposits and its co-existence with pyrrhotite in internal gemstone parageneses may possibly be attributed to pre-existent origin. The former frequently embraces the latter in meshes or cells and is then partly an exsolution product of nickel-bearing pyrrhotite.

PLATE G, 9 AND 10

Crystalloptical and radiographic methods have established beyond doubt[8, 18, 20, 21, 31, 36] that olivine belongs to the family of minerals constituting inclusions in diamond: so that further corroboration would hardly appear to be necessary. Nevertheless, a small colourless crystal found to be cut flush with the table of a brilliant-cut diamond appeared to be such an ideal subject that the author could not resist examining it under the electron microprobe. The little guest-crystal revealed a positively lower R.I. than the diamond. In polarized light it extinguished almost parallel with the c-axis. It also displayed vivid interference colours, and the

hardness of its cut surface proved to be rather low. The diagnosis, duly expected in view of these preliminary observations, was confirmed by the electron beam analysis on account of the detection of Mg, Fe and Si: in other words, the crystal included was identified as an **olivine** crystal $(Mg, Fe)_2SiO_4$, which had grown epitaxially and orientated on the octahedron, as do all olivines in the process of simultaneous diamond growth.

Another small crystal of similar appearance and behaviour was located in another brilliant-cut diamond, again having been exposed on the gem's table. It did not, however, live up to expectations, but instead revealed the elements Ca, Mg, Fe and Si, together with traces of Ti and Al, under electron bombardment and is, therefore, a **diopside** ($CaMg\ Si_2O_6$). This enrichment of the inner mineral-association of the diamond is certainly in accordance with the current hypothesis that diamonds were formed as the by-product of a high-pressure, high-temperature transformation of olivine rock into so-called griquaite nodules among whose constituent minerals olivine and diopside are to be numbered. Consequently, diopside was also formed syngenetically with diamond. Whenever chromium was present simultaneously, emerald-green chrome-diopside could result from the inclusion of minute traces of the pigmenting transition element.

PLATE H, 1–3

The typical aspect of twinned aggregates of the sagenitic textures of rutile needles precipitated as a result of exsolution in blue and red corundum from Burma and Ceylon have long been known and have also been confirmed beyond doubt by optical and chemical tests. When densely accumulated, they are responsible for the well-known and much-prized asterism in rubies and sapphires. While, when viewed in transmitted light, the disassociated rutile needles appear as brown to black dashes, dark-field or lateral illumination will reveal them as bright lines intersecting according to three principal crystallonomic directions. Other morphological shapes are hardly likely to be familiar to a gemmologist, since he is less well-acquainted with the granular to columnar prismatic habit encountered in nature. On the other hand he will presumably be well aware of the fact that rutile occurs in such different tints as golden-yellow, reddish-brown and fox-colour, but will be less familiar with its crimson, dark-brown and black varieties. Such

individual specimens of **rutile** (TiO_2) in sapphire and coarse aggregates in kyanite—which have certainly not subsequently evolved as a result of exsolution but, rather, simultaneously with the formation of the host crystal from the mother melt—were detected by electron-ray scanning, showing Ti to be the main element with Fe occurring as an occasional impurity. The crimson specimens consist of pure Ti, while the brown and black individual specimens obviously owe their dark shades to an admixture of Fe. Morphologically, rutile belongs to the tetragonal system and generally it prefers elongated prismatic habits of stout columnar as well as needle- to hair-like shapes, forming the quaintest knee-twins and polysynthetic or cyclic multiples. Many of the exsolved twins are conspicuous by their lance-like appearance, whose laws of intergrowth have not yet been determined. $n = 2{\cdot}616$ and $2{\cdot}903$; S.G. $= 4{\cdot}25$; $H = 6$. Apart from the fact that rutile frequently occurs as a secondary product of titanium-bearing mineral, it is also widespread as a microscopic secondary constituent assuming the shape of very subtle needles in sedimentary and metamorphic and partly also in igneous rocks. In areas of pronounced metamorphosis, and also in pneumatolytic veins and druses formed hydrothermally, it will occur as large and well-defined crystals. It is certainly this cycle of formation that is responsible for the syngenesis of substantial individuals as well as aggregates of rutile in almandine, disthene, corundum and quartz.

PLATE H, 4 AND 5

Burmese ruby frequently betrays its origin by the pronounced features of its endogenesis, which not only comprise whirly colouring and clustered concentrations of exsolved rutile needles, but also the presence of a diversity of associated minerals. Apart from the guest minerals, already discussed, pale to deep-yellow individual specimens, having a habit reminiscent of the shape of an envelope, have also been encountered. Their broad relief is indicative of a high refractive index, which is considerably above that of the ruby. The high birefringence is expressed in the extinction and the vivid interference colours. In the deep-tinted specimens, the pleochroism is clearly perceptible. The conclusions derived from these observations were confirmed beyond doubt by a number of microlites exposed in the facets of some rubies, in that the electron analysis

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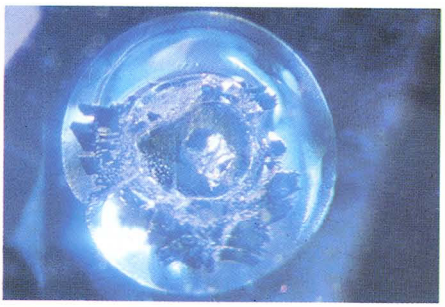

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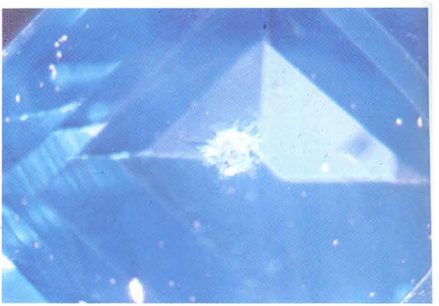

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led to the detection of Ti, Ca, Si (and Al): hence the mineral included is **sphene** ($CaTi[SiO_5]$).

Sphene crystallizes in the monoclinic prismatic system with flat prismatic, tabular, columnar or wedge-shaped habits and yellow, green and brown shades. Its optical properties are quite outstanding: $n = 1{\cdot}90–2{\cdot}05$; $\Delta = 0{\cdot}105–0{\cdot}135$; S.G. $= 3{\cdot}4–3{\cdot}6$; $H = 5–5{\cdot}5$. The mineral is a widespread accessory mineral in intermediate igneous rocks, primarily in metamorphic rocks. Its syngenetic precipitation together with ruby is completely congruent with the process of formation of its host, since in the contact-metamorphic melt the necessary constituting elements emanated from limestone-marble, as far as Ca is concerned, but from granite magma with regard to Si and Ti.

PLATE H, 6

At times, the internal paragenesis of dark blue sapphires is very intriguing because of the presence of small red crystals which, by the intensity of their colour, provide a vivid contrast and liven up the endogenetic picture. The microlite inclusions are encountered singly or loosely grouped and are of such positively idiomorphous shape that, in previous studies of mineral inclusions, the small clearly isometric crystals were thought to be spinels or garnets. In some cases they seem to be closely related to adjacent residual fluid drops from which they may have been precipitated. It is interesting to note that the two feldspars previously described were invariably encountered in the company of such small red inclusions.

It came as a particular surprise when electron-beam analysis indicated a complex compound of the elements Nb, Ca, U, Ti, Fe and Ta, with small quantities of both Th and Si, thus revealing that

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Plate H

1. *Irregular conglomerations of black and red mineral, whose chemical composition of TiO_2 indicates either anatase or rutile in cyanite.*
2. *Huge prisms of red rutile in sapphire from Ceylon.*
3. *Black rutile resorbed into a ball-like shape and surrounded by a stress-halo in sapphirfrom Montana, U.S.A.*
4. *Well-developed crystal of sphene in ruby from Burma.*
5. *Group of pale-yellow sphene crystals in Burma ruby.*
6. *Brilliant red and euhedral crystals of uranpyrochlore (hatchettolite) in sapphire (the bright spots are feldspars).*
7. *Rounded grains of metamict zircon surrounded by tension cracks in kornerupine from Ceylon.*
8. *Bright zircon surrounded by tension cracks which contained trace-impurities of anhydrite and hematite in sapphire.*
9. *Idiomorphous, yet slightly resorbed high-zircon in mauve sapphire from Ceylon.*
10. *Crystal of high-zircon—somewhat irregularly developed—in kornerupine from Ceylon.*

these pretty, red individuals were a member of the pyrochlore group. In fact the presence of U identified it more closely as the **uranpyrochlore** mineral answering to the chemical formula $(Ca, Fe, U)(Nb, Ca, Ti)_2(O, OH, F)_7$ and called hatchettolite.

Uranpyrochlore crystallizes in the octahedral system forming idiomorphous individual crystals. The mineral is predominantly native to granite pegmatite. It is worth-while mentioning that in the course of this study and thanks to the electron microprobe we have come across three typical pegmatite minerals included in sapphire: feldspar, niobite and uranpyrochlore, which leads to the conclusion that at least some sapphires are of pegmatitic origin.

PLATE H, 7—10

The peculiar inclusion characteristics represented by spherical to ellipsoidal grains have been known for some time now and have frequently been the subject of lively controversy. These characteristics constitute a locally typical criterion of the inner paragenesis of almandine, kornerupine, sapphire and ruby from Ceylon. The small, round xenogenetic bodies—traditionally regarded as metamict zircons—may easily be recognized by their single or multifold halos, which B.M. Shaub[44] identified as tension cracks. Isotropization, i.e. the structural disintegration of once-normal high-type zircon inclusions into metamict low-type zircons is always accompanied by an expansion of volume causing fine circular or radiating fissures resulting from internal stress in the embracing gemstone. Under low-power magnification, they faintly resemble the squatty beetle inclusions in amber and they will, occasionally, be distinct from their host crystal by virtue of a pale-yellow colouring and, invariably, because of their broad dark relief. Crystalloptical methods failed to provide better identification of these isotropic mineral inclusions; electron beam microprobe analysis, however, successfully proved the presence of Zr and Si and also, in the fissures emanating from the solid substance, of Fe, Ca and S. Though the mineral inclusion has thus been identified as **zircon** ($ZrSiO_4$), nothing has as yet been established as to its structural condition, i.e. whether it is present in a crystalline or amorphous form. However, it is interesting to find an indication of impurities in the fissures which are indicative of **hematite** (Fe_2O_3) and **anhydrite** ($CaSO_4$). Parallel with the formation of small fissures, traces of the product of disintegration have obviously penetrated the stress-cracks. This

may also explain the brownish coloration of some of these tension halos in that they probably emanate from minute traces of iron which are almost invariably present in disintegrating mineral inclusions. Bearing in mind that green metamictic zircons have been found rather widespread in the gem places of Ceylon, it is not really surprising that metamict zircons should share among the mineral-association included in a good many Ceylonese gemstones. Indeed, zircon in all its structural conditions, i.e. in the form of low as well as medium and high-type zircon, is one of the principal constituents by volume of the island's gemstone deposits.

By virtue of their lower readings, the physical data of the metamictic zircons are distinct from those of normal zircons: n = approx. 1·8; S.G. = approx. 4; H = approx. 7.

Apart from its metamict form, zircon is also present as crystalline specimens with well-defined crystal shapes and has as such been identified by electron microprobe in almandine, kornerupine and sapphire. Individual specimens are the most frequent, although small crystal groups and irregular inter-growths have also been encountered from time to time. Zircon is also found in large numbers as a microscopic secondary constituent in certain syenitic igneous rocks (magmatites). As an accessory it is rather widespread and hence it is also found in crystalline schists and clastic sedimentary rocks. As a mineral of primary precipitation it occurs as a pre-existent mineral inclusion, but owing to separation from metamorphic formation processes it is also encountered as a syngenetic internal companion of its host gems.

Now, because the mineral inclusions identified by electron-beam microprobe have been discussed individually, readers might be misled into thinking that they had been included in each particular host gemstone in isolation, i.e. without the presence of other minerals. This is not the case: in fact they often constitute the inner paragenesis in conjunction with one another and occasionally in conjunction with other minerals, some of which were identified at an earlier stage, while others still remain to be identified as yet. In the gemstones examined, they were encountered in the following groupings:

Almandine:	Apatite, biotite
	Apatite, pyrite
	Ilmenite, quartz, zircon
	Rutile which was found in several almandines in the form of needles, was not considered worthy of further analysis.
Aquamarine:	Quartz with apatite and epidote
	Biotite alone
Diamond:	Chrome-diopside, diamond, garnet, olivine
Disthene:	Potassium feldspar and rutile or anatase
Kornerupine:	Apatite, biotite (chalcopyrite?) (garnet?), zircon
Peridot:	Chromite alone
Ruby:	Apatite, calcite, rutile, spinel, sphene, Pyrrhotite, rutile, sphene
Sapphire:	Biotite (phlogopite), rutile, pyrite, zircon (The mica is often of the titanium-bearing variety.)
	Pyrrhotite and rutile
	Niobite alone
	Feldspar (plagioclase and potassium feldspar), niobite, uranpyrochlore (hatchettolite)
	Rutile alone
	Zircon with hematite and anhydrite.
Emerald:	Biotite, chromite } The biotite is usually of the chrome-bearing variety.
	Biotite, pyrrhotite and pentlandite } The biotite is usually of the chrome-bearing variety.
	Calcite
	Molybdenite
	Pyrite
Spinel:	Apatite
	Calcite alone or intergrown with dolomite.
	Dolomite intergrown with calcite, hercynite.
	Hercynite alone
	Phlogopite
Topaz:	Goethite and quartz, the latter occasionally with chlorite.

It goes without saying that all the aforementioned mineral inclusions will also constitute an inner hermit-paragenesis on their own, i.e. without the presence of companion minerals.

The author's sincere thanks are due to Professor M. Weibel of the Institute of Crystallography and Petrography at the Federal

College of Advanced Technology, Zurich, who by his helpful suggestions, unfailing interest and valuable support made the electron-beam analysis possible, and also wrote the reports of the experimental findings. Thanks are also due to Mr. R. Gubser for kindly agreeing to prepare the samples and carry out the pains-taking examination of them, a delicate and time-consuming task to which he devoted a considerable amount of spare time. The author is also most grateful to Professor F. Laves for his permission to use the instruments and for generously placing colleagues at the author's disposal for this purpose.

The author is also indebted to Professor O. Mellis and particularly to Professor K. Chudoba for their thorough and critical examination of the present study and for their valuable suggestions for its improvement.

The findings published in this article constitute a first report on the initial stages of a steadily growing trend towards a comprehensive investigation of mineral inclusions in gemstones. The author is fully aware that certain of his conclusions regarding genetic conditions are in need of more precise scrutiny and corroboration: nevertheless, he hopes that this preliminary report might inspire some scientists interested in mineral inclusions to persevere in their research into the identity of the numerous mineral inclusions that have not yet been identified, so that our incomplete knowledge of the locally typical associations of mineral inclusions may be completed along with our knowledge of their genetic processes.

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ASSOCIATION NOTICES

RECEPTION

The Officers and Council of the Association held a reception at Goldsmiths' Hall, London, on Wednesday, 27th November, 1968, to mark sixty years of gemmology in Great Britain. The principal guests were the members of the Council of the National Association of Goldsmiths. Mr. Norman Harper, Chairman of the Association, presented two pieces of antique silver to the Chairman of the National Association, Mr. Alan Henn, in appreciation of the work of the N.A.G. in promoting and encouraging the study of gemmology since 1908. During the reception, which was attended by two hundred and fifty people, the Arms of both organizations were on display, together with the world's first gemmological diploma, awarded to Mr. S. Barnett in 1913.

A telegram was received from thirty-four Fellows in Finland sending their good wishes for the occasion.

PRESENTATION OF AWARDS

There was a record attendance at Goldsmiths' Hall, London, on 23rd October, 1968, for the annual presentation of awards. The meeting attracted recipients from many parts of the world, including Burma, Holland, Rhodesia, New Zealand and Spain.

In welcoming members, award winners and their guests, Mr. Norman Harper, Chairman of the Association, specially referred to the presence of Professor M. Font-Altaba and Dr. J. M. Bosch, of Barcelona University. Spain had provided the largest overseas centre and the Association was grateful for all their work. There had also been a substantial entry from Burma. The Chairman recalled the early days of gemmology when in 1913 there had been twelve candidates for the preliminary and eight for the diploma examination. This year there had been 380 and 244 candidates for the preliminary and diploma examinations respectively. He paid special tribute to the examiners, who had a most difficult task, not only dealing with varied writing but problems of translations as well. The Chairman congratulated Dr. G. F. Claringbull, the senior examiner, upon his appointment as Director of the British Museum (Natural History). The Association had been fortunate in the many gemmological enthusiasts who had contributed to the success of the Association over the years.

Mr. Harper recalled that Mr. Robert Shipley, who had founded the Gemmological Institute of America in 1931, had studied the N.A.G. gemmological course while he was in Europe, and it could be that some of that knowledge had formed the foundations for that excellent organization.

Mr. Alan Henn, Chairman of the National Association of Goldsmiths of Great Britain and Ireland, was invited to present the awards. After the presentation, Mr. Henn recalled that in July, 1908, the N.A.G. had proposed the establishment of gemmological courses and examinations. The N.A.G. was proud that its daughter organization had done so well and acquired a respected international reputation. The two organizations were closely associated. The G.A. accepted members from every walk of life and from all parts of the world. The N.A.G. restricted its membership to retail jewellers and its educational work was limited to this field. He hoped that the G.A. would always remember that its success stemmed from the jewellery industry and that it would continue to assist with training those connected with it. Students were expected to absorb more knowledge than those who studied many years ago. A high standard was set in the examinations and he congratulated those who had done well. He also congratulated those who had tried but had not been successful.

In addition to the diplomas, certificates for the Association's gem diamond examination were presented. There was a special welcome, too, for Wing Commander and Mrs. Warren Tassell, who were presented with diplomas of the Australian Gemmological Association. Both diplomas were awarded with distinction and in addition Wing Commander Tassell had won the premier Australian award. The Australian Gemmological Association sent greetings to the British Association.

Mr. Philip Riley, Vice-Chairman of the Association, in thanking Mr. Henn, said that there was no one who could have been more welcome amongst them. They had enjoyed the closest support from the N.A.G. over many years and they were indebted to that association for its foresight in establishing gemmology in Britain sixty years ago. It was particularly gratifying that the title Fellow of the Gemmological Association was coveted all over the world. He thanked the Goldsmiths' Company for again lending their splendid Livery Hall for the presentation.

GIFTS TO THE ASSOCIATION

The Council is grateful for the following gifts:

Mr. E. A. Jobbins has kindly presented the Association with an unusual mottled jade cabochon from Burma.

Mrs. B. F. Ames of California has kindly donated two pieces of spectrolite for the Association's collection.

A green actinolite of 1.04 cts from Mr. Max Davis.

SCOTTISH BRANCH

On 3rd December, 1968, Dr. Colin Gribble, of the Department of Geology, Glasgow University, gave a graphic account of his work for prospecting for diamonds in Tanganyika. In 1958, after De Beers had purchased the Williamson Mine, Dr. Gribble was employed with thirty geologists to survey the whole country in two years. Many kimberlite pipes were found but only one is sufficiently rich in diamonds to justify the tremendous costs of modern mining.

Dr. Gribble then discussed the Williamson Mine itself, describing all the processes used to extract diamonds from the pipe and gave a brief survey of its future. The quality of questions which followed must be partially due to the high standards of the advanced class on diamonds.

Mr. McWilliam, the Chairman, gave the vote of thanks and presented the diplomas gained by two Scottish students in the recent Gemmological Examinations to Mr. G. M. Turner (distinction) and Mr. D. A. Sadler, so concluding a most enjoyable evening.

GENERAL NOTICES

Course instructor

The Association requires an assistant correspondence course instructor to undertake part-time assessment of papers during the period October to May. Only persons resident in the United Kingdom should apply for further details.

Association tie

The tie referred to in the October, 1968, issue of the *Journal* is restricted to Fellows of the Association. A design for a silver-gilt brooch, which ladies who are Fellows could wear, is in the course of preparation.

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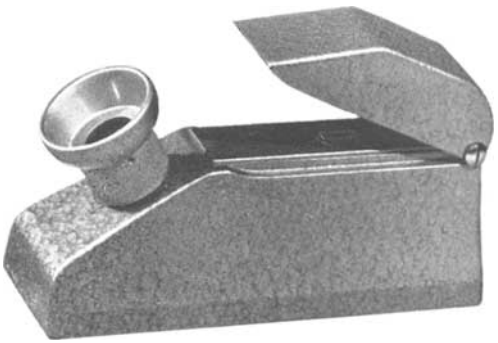

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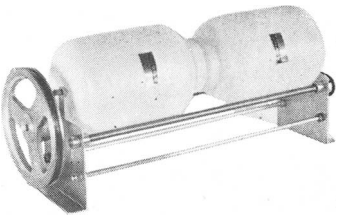

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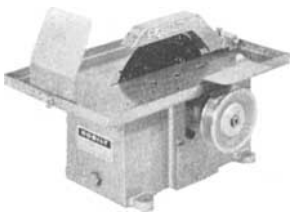

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January 1969

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Vol. 11 No. 6 April, 1969

THE JOURNAL OF GEMMOLOGY

and

PROCEEDINGS OF THE
GEMMOLOGICAL
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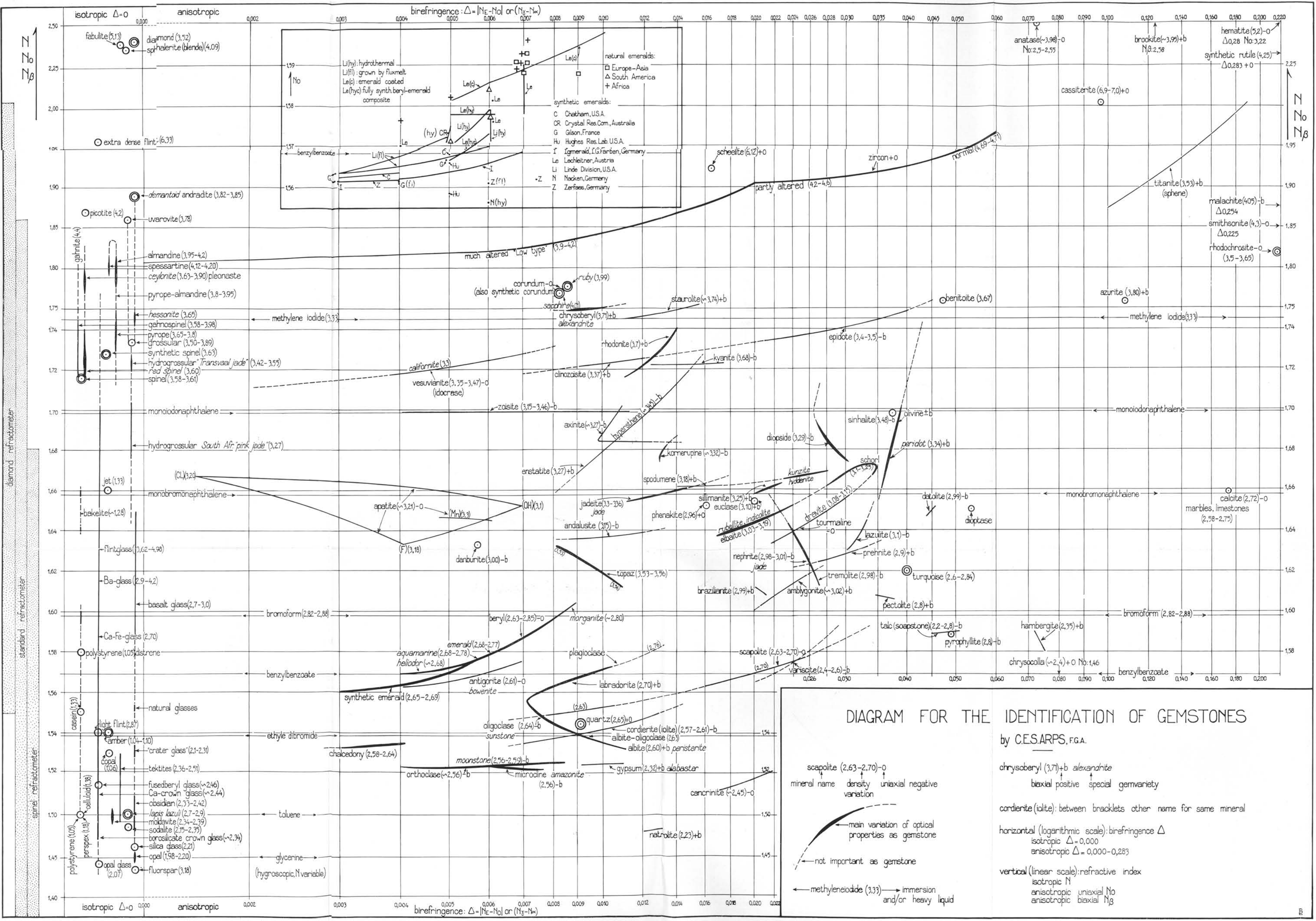
isotropic Δ=0
anisotropic
birefringence: Δ=|NE-No| or (Nγ-Nα)
N
No
Nβ
diamond refractometer
standard refractometer
spinel refractometer
fabulite (5,13)
diamond (3,52)
sphalerite (blende) (4,09)
extra dense flint (6,33)
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picotite (4,2)
uvarovite (3,78)
gahnite (4,4)
almandine (3,95-4,2)
spessartine (4,12-4,20)
ceylonite (3,63-3,90) pleonaste
pyrope-almandine (3,8-3,95)
hessonite (3,65)
gahnospinel (3,58-3,98)
pyrope (3,65-3,8)
grossular (3,50-3,89)
synthetic spinel (3,63)
hydrogrossular "Transvaal jade" (3,42-3,55)
red spinel (3,60)
spinel (3,58-3,61)
methylene iodide (3,33)
monoiodonaphthalene
hydrogrossular South Afr. "pink jade" (3,27)
jet (1,33)
monobromonaphthalene
bakelite (~1,28)
flintglass (3,62-4,98)
Ba-glass (2,9-4,2)
basalt glass (2,7-3,0)
bromoform (2,82-2,88)
Ca-Fe-glass (2,70)
polystyrene (1,05) distrene
benzylbenzoate
natural glasses
casein (1,33)
light flint (2,87)
amber (1,04-1,10)
ethyle dibromide
"crater glass" (2,1-2,31)
copal (1,06)
tektites (2,36-2,51)
fusedberyl glass (~2,46)
Ca-crown glass (~2,44)
obsidian (2,33-2,42)
celluloid (1,36)
lapis lazuli (2,7-2,9)
moldavite (2,34-2,39)
sodalite (2,15-2,35)
borosilicate crown glass (~2,34)
silica glass (2,21)
opal (1,98-2,20)
toluene
glycerine
(hygroscopic, N variable)
polystyrene (1,05)
perspex (1,18)
opal glass (2,07)
fluorspar (3,18)
Li(hy): hydrothermal
Li(fl): grown by fluxmelt
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Le(hyc): fully synth. beryl-emerald composite
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G Gilson, France
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Le Lechleitner, Austria
Li Linde Division, U.S.A.
N Nacken, Germany
Z Zerfass, Germany
benzylbenzoate
(hy) CR
Le(c)
Le(hy)
Li(hy)
Li(fl)
G(fl)
Z(fl)
N(hy)
anatase (~3,98)-o No: 2,5-2,55
brookite (~3,95)+b Nβ: 2,58
hematite (5,2)-o Δ0,28 No: 3,22
synthetic rutile (4,25)
Δ0,283 +o
cassiterite (6,9-7,0)+o
scheelite (6,12)+o
zircon+o
normal (4,69-4,71)
partly altered (4,2-4,6)
much altered "Low type" (3,9-4,2)
titanite (3,53)+b (sphene)
malachite (405)-b Δ0,254
smithsonite (4,3)-o Δ0,225
rhodochrosite-o (3,5-3,65)
corundum-o
ruby (3,99)
(also synthetic corundum)
sapphire (4,01)
staurolite (~3,74)+b
chrysoberyl (3,71)+b alexandrite
benitoite (3,67)
azurite (3,80)+b
epidote (3,4-3,5)-b
rhodonite (3,7)+b
kyanite (3,68)-b
californite (3,3)
vesuvianite (3,35-3,47)-o (idocrase)
clinozoisite (3,37)+b
zoisite (3,15-3,46)-b
axinite (~3,27)-b
hypersthene (~3,45)-b
sinhalite (3,48)-b
olivine ±b
diopside (3,29)-b
kornerupine (~3,32)-b
peridot (3,34)+b
enstatite (3,27)+b
spodumene (3,18)+b
kunzite
hiddenite
schorl (3,1-3,25)
(CL)(3,20)
apatite (~3,21)-o
(Mn)(3,3)
(OH)(3,1)
(F)(3,18)
jadeite (3,3-3,36) jade
sillimanite (3,25)+b
euclase (3,10)+b
phenakite (2,96)+o
andalusite (3,15)-b
danburite (3,00)-b
rubellite, indicolite
elbaite (3,03-3,19)
dravite (3,08-3,15)
tourmaline
datolite (2,99)-b
dioptase
calcite (2,72)-o
marbles, limestones (2,58-2,75)
lazulite (3,1)-b
prehnite (2,9)+b
nephrite (2,98-3,01)-b jade
topaz (3,53-3,56)
tremolite (2,98)-b
turquoise (2,6-2,84)
brazilianite (2,99)+b
amblygonite (~3,02)+b
pectolite (2,8)+b
talc (soapstone) (2,2-2,8)-b
pyrophyllite (2,8)-b
hambergite (2,35)+b
chrysocolla (~2,4)+o No: 1,46
beryl (2,63-2,85)=o
morganite (~2,80)
emerald (2,68-2,77)
aquamarine (2,68-2,78)
heliodor (~2,68)
plagioclase
scapolite (2,63-2,70)-o
variscite (2,4-2,6)-b
antigorite (2,61)-o
bowenite
synthetic emerald (2,65-2,69)
labradorite (2,70)+b
oligoclase (2,64)-b
sunstone
quartz (2,65)+o
cordierite (iolite) (2,57-2,61)-b
albite-oligoclase (2,63)
albite (2,60)+b peristerite
chalcedony (2,58-2,64)
moonstone (2,56-2,59)-b
orthoclase (~2,56)-b
microcline amazonite (2,56)-b
gypsum (2,32)+b alabaster
cancrinite (~2,45)-o
natrolite (2,23)+b
DIAGRAM FOR THE IDENTIFICATION OF GEMSTONES
by C.E.S. ARPS, F.G.A.
scapolite (2,63-2,70)-o
mineral name
density variation
uniaxial negative
main variation of optical properties as gemstone
not important as gemstone
methyleneiodide (3,33)
immersion and/or heavy liquid
chrysoberyl (3,71)+b alexandrite
biaxial positive special gemvariety
cordierite (iolite): between bracklets other name for same mineral
horizontal (logarithmic scale): birefringence Δ
isotropic Δ=0,000
anisotropic Δ=0,000-0,283
vertical (linear scale): refractive index
isotropic N
anisotropic uniaxial No
anisotropic biaxial Nβ

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THE JOURNAL OF GEMMOLOGY
AND PROCEEDINGS OF THE GEMMOLOGICAL ASSOCIATION OF GREAT BRITAIN

Vol. 11 No. 6 APRIL 1969

THE SOURCES OF SUPPLY

By V. G. C. NORWOOD

THE demand for industrial diamond is continually increasing. As yet the gears of synthetic processes grind very slowly indeed. There is as yet no economic substitute for natural diamond. It is from the steaming jungles and arid plains of remote regions that vital supplies of rough diamonds flow to keep the wheels of modern industry turning.

But spare a thought for the men who mine these essential raw materials, the intrepid adventurers who, living in conditions of appalling privation, endure incredible hardships for scant reward, Brazil's colourful "Caboclas", the negro "Port-knockers" of British Guiana (now Guyana), and the Venezuelan "Tejana", all giants in their own particular field of production, and all making their modest contribution to the world's needs.

Much has been written about diamond prospecting. Yet surprisingly little is known about the resolute characters who forage in outlandish places, rugged individuals of every colour and creed, motivated by a common urge, sustained largely by sheer optimism, the eternal promise of "tomorrow". They accept the challenge of Nature, toil in daily pursuit of elusive mineral wealth, driven by an insatiable craving, often working in torrential rain, blistered by the torrid tropical sun, tormented by insects and ravaged by foul diseases—pawns in a game where the stakes

Pork-knockers at work. The old method.

are high but the balance between riches and death is always slender, and governed largely by pure chance.

It is more than mere lust for wealth that starts the diamond prospector on his endless, lonely quest. Adventure is in his blood, the "Call of the Wild" stronger than his will to resist. Prospecting becomes an obsession, irksome at times, and damned hard work. But never boring. The prospector breathes God's pure, fresh air in places where few white men ever venture. He knows the majestic splendour of sweeping hills and awesome crags that instil appreciation of Nature's wonders into his untutored mind, a realization of how insignificant is Mankind, and experiences at the other end of the scale the foetid reek of fever swamps, the sinister threat of gloomy jungle, the squalor of impoverished river settlements and backwater camps.

A man's life, a challenge accepted, the privation, discomfort loneliness and innumerable dangers all discounted against the weight of favourable potential. Few thrills can compare with that of taking a boat through foaming rapids along some mighty jungle river. To tackle such a journey requires nerve above average. Here, in the wilderness, man-power remains supreme, a stout

heart the major driving force, unconquerable spirit and physical strength the true measure of success. There is no turning back. Once committed the course is onward, with muscles knotting, backs straining, hearts pounding, every corded sinew responding with an even greater surge of latent power to meet and overcome Nature's relentless pitfalls.

This then is the world of the diamond seeker. To him, all of life is a gamble. He stakes his stamina and experience against heavy odds. Either the jungle ultimately breaks down his mind, or he endures and becomes inured to the eerie borderline between blaring sound and awesome silence. The years slip by almost unnoticed. "Diamond Fever" has him in its relentless grip, and for this "disease" the sweet smell of success is the only cure.

Diamond recovery methods employed in Guyana and Brazil

A typical "pork-knocker" of the "old school" with the tools of his arduous trade.

Industrial diamond workings (Sierra Leone).

differ vastly from processes followed in Africa. Guyana diamonds, for example, although of extreme hardness, generally have a kind of brown "skin" which resists grease-bed techniques, consequently work is done by hand, a wasteful method employing crude sluice-box washing. The wet gravel concentrate is finally "jigged" (a twirling action) in a cumbersome sieve to centralize any diamond content by centrifugal force. (See "A Handful of Diamonds and Drums Along the Amazon"—T. V. Boardman and Robert Hale Ltd.).

The subject of diamond origin and crystallization is absorbing, and still not conclusively proved. Whatever the nature of rock associated with diamond recovery, whether sandstone, gravel, conglomerate, or metamorphic schist, rarely is diamond found embedded in the actual parent rock wherein it was formed. In instances where diamonds have supposedly been found under such conditions the matrix has proved to be only a deposit formed around the diamond by prolonged contact with eroding soft rocks. Despite extreme hardness diamonds often reveal traces of frictional wear indicative of tremendous distances over which they have been transported in association with abrasives.

In regions where "pipes" of "blue ground" (peridotite or kimberlite) occur the extent of similar gas-blown vents indicates the forcing of matrix from the earth's molten core by internal steam pressure, additional signs and evidence of subterranean upheaval being the uncovering of former underground rivers during excavations, coupled with the alien nature of surrounding rocks to the "blue ground" itself. Peridotite is igneous and devoid of free silicon, while being extremely rich in olivine (peridot). It has a high iron content, the yellow aspect of surface peridotite being due to oxidization. There is seldom any indication of mineral wealth in the surrounding terrain. In South Africa, red, sandy soil covers vast areas containing fabulous diamond deposits. In Guyana and Brazil, rain forests and the vegetation growth of centuries obscures craggy formations from which diamonds are continually being washed into rivers and creeks.

If we accept as fact the contention that the earth's core consists of metallic iron in a molten state, and seismological calcu-

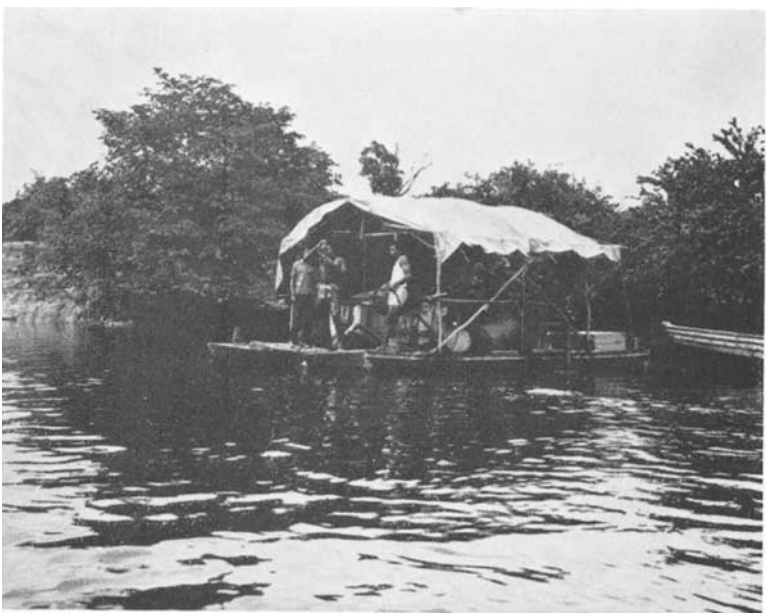

The suction-dredge—the modern method of diamond prospecting in Guyana.

Inspecting gravel concentrate for diamonds.

lations proving increases in temperature relative to depth, we must assume that the inner area of the earth's crust must be plastic, and subjected to tremendous compression imposed by superincumbent, solid upper layers, and by internal stresses. Consequently, water seeping through fissures and forming steam when contacting the molten core would create terrifying forces that, upon encountering comparatively weak points, ultimately blasted gaping vents through which to vomit seething, carbonaceous matter.

The affinity of iron with carbon suggests that in the absence of oxygen, and perhaps assisted by some catalytic mineral as yet not positively identified by science, any free carbon content of plastic peridotite would crystallize as appalling heat and expanding pressures dispersed at the bases of these ruptures. Peculiarities pertaining to diamonds recovered from particular "pipes" make it possible to identify the source through a process of comparison involving various known areas of prehistoric subterranean eruption.

It is not uncommon for diamonds actually to explode soon after being unearthed, due to imprisoned gas bubbles or carbonic acid activated by the sudden release from sustained pressure.

But the average diamond prospector is not concerned with theories or scientific principles. He knows diamond by sight and by touch, and learns through trial and error. The veteran prospector reduces the whole complicated process to a simple formula which, wasteful though it is, includes a reasonable amount of proven method and thus reduces the element of pure speculation.

Prospecting is a hard life, and there is little glamour or romance associated with actual diamond recovery, only hard work and dogged perseverance. Thus the diamond seeker must of necessity be of a breed endowed with endurance above average, and sharing a philosophy peculiar to his kind.

ORIGIN OF THE NAME AGATE

By E. SAROFIM, Ph.D.

THE naming of stones after the area or locality in which they were discovered, has its root in a long-standing tradition. Brasilianite, Amazonite, Utahlite, Labradorite, etc., and lately Tanzanite[1], are a few examples which perpetuate this trend in our modern time.

Agate, this old yet noble stone, is no exception: it is a classical example of this secular trend. To establish the locality which gave its name to this stone, the etymology of the word Agate must first be ascertained. Some authors advanced that it is derived from the Latin "Achates", a river in Sicily[2], while others see its origin in the Greek word "Agatos"[3]. The appearance of the word in English dates only from 1570 A.D.[4] and it appeared about the same time in other European literature.

The comparatively recent appearance of the word in modern languages and in Latin and Greek, while its Semitic transliteration "'Aqiq" in Arabic or "Achit" in Hebrew was used long before, makes it difficult to share the view of a Latin or Indo-European origin.

Egyptologists who found proofs that some 3,000 years before Christ ancient Egyptians used the banded variety of Chalcedony—today described as Agate for an infinity of purposes—are uncertain about the name which was then given to this stone. But the difficulty does not arise for the Semites who about the same time used Agate not only for ornamental purposes but for other usages such as tablets for recording religious verses or important events. It is therefore not improbable that the ten commandments might have been recorded on this stone[5].

The fact that this stone was known to the Semites long before the Romans and Greeks and was called, probably as far back as the dawn of civilization, "'Aqiq" or "Achit", leads us to believe that the origin of the word Agate is Semitic.

Our contention does not rest only on historical findings and on the trilitic formation of the words Agate and Achates, but on the fact that the literal Arabic definition of the word "'Aqiq", the parting of the hair of a new-born baby[6], might well be the only plausible explanation why the use of the word Agate is restricted to banded Chalcedony. Moreover, old Arabic dictionaries state that "'Aqiq" is the name of a valley near Medina[7] (presently Saudi Arabia). In view of the favourable desert surroundings it is more than likely that Agate occurred in this valley which we believe gave its name to that stone, long before the Sicilians named their river.

REFERENCES

1. Name given by Tiffany of New York to Blue Zoisite. See the Wall Street Journal (New York) of 14th October, 1968.

2. See "Edelsteine und Perlen" by Professor Dr. K. Schlossmacher—printed in Stuttgart in 1965, p. 261.

3. a. 4. See the word Agate in the Shorter Oxford Dictionary on Historical Principles—printed in 1944 by Clarendon Press, Oxford.

5. cf. Exodus Chapter 24 Verse 10: It is mentioned that it might have been Sapphire. See also the Midrache Tankhouma Commentaries on Exodus Chapter 34 Verse 1.

6. a. 7. See the Arabic word "'Aqiq" in Moukhtar Al-Sahah—2nd edition printed in Cairo by Boulaq Government Press in 1937, p. 446.

THE "WATER-DROP TEST" IN GEMMOLOGY

By ALBERT TAN HIEN TJWAN

THE method used is very simple, and depends upon the behaviour of a small drop of water placed upon the top surface of a gemstone. Results are indicated by the manner in which the droplet stands or stays on, falls off, or is dispersed. It is to be emphasized that only stones of inorganic origin, having the hardness property of $7\frac{1}{4}$ (beryl), $7\frac{1}{2}$ (zircon and some garnets—with the exception of demantoid garnet), 8 (topaz and spinel), $8\frac{1}{2}$ (chrysoberyl), 9 (corundum) and 10 (diamond) will provide reliable guide tests. On quartz (H. 7) peridot and demantoid garnet (H. $6\frac{1}{2}$) and other stones softer than quartz varieties the test will provide an indication that the stone is comparatively soft. The method is more or less dependent upon the hardness property of minerals, which is characteristic in the individual species, though surface tension and the nature of the polished surface is also a consideration. On the other hand, when this method is applied to gems of organic origin, such as pearl, coral and amber, etc., it is not dependent upon the hardness, but is probably dependent upon their compositions.

An hardness test is to be avoided not because this test has been considered unnecessary, but merely due to the fact that the act of scratching is likely to damage a stone to some extent. The scratching method is only used to test rough materials when no other test is possible. As far as identification of a gemstone is concerned, the gemmologist has other more scientific means available. But the gemmologist is not a walking laboratory. On some occasions he might come across a natural stone of doubtful species somewhere when such instrumentation as the refractometer is not available to test a stone. Perhaps the simplest apparatus a gemmologist can be expected to carry with him is the 10x lens or one or two pieces of Mohs's scale hardness points consisting of Nos. 8, 9 or 10. Supposing that during one of his trips somewhere, someone offered the gemmologist a fine specimen of a faceted golden yellow stone at the price of a true topaz. Based on its inclusions the 10× lens could only tell him that the stone is real, but possibly not its species. The inclusions of the stone are not those of a natural corundum, since they do not represent the typical angular shape of crystals, straight

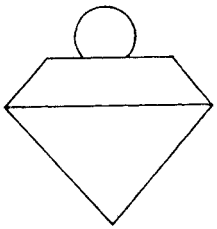

On diamond

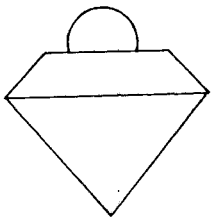

On corundum and synthetic corundum

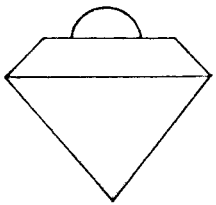

On topaz, spinel, and some garnet, and synthetic spinel

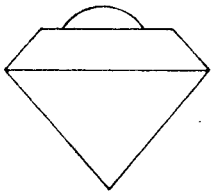

On zircon and morganite

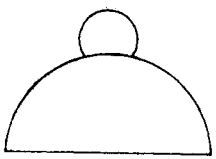

On Chrysoberyl cat's-eye

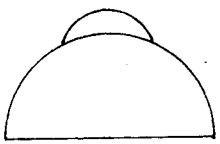

On tourmaline cat's-eye

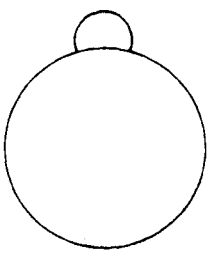

On pearl and coral

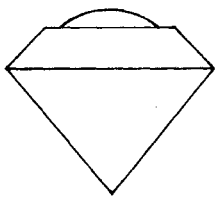

On emerald, tourmaline and aquamarine

Behaviour of small drops of water on surface of gems.

lines, rutile needles and the liquid feathers, etc., some of which are usually present in a natural corundum. Hence the stone offered is not a yellow sapphire. It could be a topaz or a citrine. The 10× lens could not detect which because it is extremely difficult to detect topaz and citrine with a hand-lens. What about the hardness test? If the stone yields easily to the No. 8 of the hardness point, then it is positively not a topaz. But the mere mention of the hardness test is frowned upon by the owner of the stone and besides, it is not for a good gemmologist to scratch a well faceted and well polished stone.

In such circumstances the "water-drop test" method is useful. The test shows that a small drop of water stands on the top surface of a topaz but falls down instantly flat and dispersed on the top surface of a citrine and other stones softer than the quartz varieties.

To carry out the test:

(*a*) The gem to be tested must be kept dry, free from finger-prints, oily substances and cracks, as these will disturb the test. Absolute cleanliness is essential and is not easily achieved.

(*b*) The test on the gem should be exactly on the middle of its surface.

(*c*) Proceed with the test by placing a small drop of pure water on the test centre. The water may be applied by using a dropper or a thin rod of glass or metal. Too large a drop of water will just slide over the surface of the stone, while too small a drop will provide an uncertain result of the test. Larger stones provide a wider test area, so a larger drop of water may be applied, and consequently on smaller stones a smaller drop of water should be applied to the test centre of the gem.

The results of the "water-drop test" method depend solely upon the behaviour of the small drop of water which stands on the centre of the surface of the gem being tested.

(i) On diamond, corundum, chrysoberyl, topaz and spinel (H. 10, 9, 8½, 8) the small drop of water stands firmly, almost spherical in form on the hardest stone, and somewhat hemisphere-like on the softer stones. This hemisphere-like form of the small

drop of water varies slightly from one to another, dependent upon the characteristic hardness of each stone under test. In other words, the small drop of water stands firmest on a diamond, is less firm on a corundum, and is still less firm on a chrysoberyl and so on (see diagram).

It is difficult to note the difference in form of the small drop of water on a diamond and on a corundum of small size, but on stones of larger sizes (5 carats upwards) the slight difference may be observed.

(ii) On stones having hardness of $7\frac{1}{2}$ to $7\frac{1}{4}$, like zircon and some garnets (except the demantoid garnet), tourmaline and beryl, the small drop of water stands less firm and nearly flat. That is, on zircon and some garnets the small drop of water stands less firmly, but on tourmaline and emerald the small drop of water becomes almost flattened.

(iii) On stones having hardness of 7 and less (quartz, demantoid garnet, peridot, nephrite, haematite and opal, etc.), the small drop of water is dispersed, and thus provides an indication that they belong to the category of soft stones.

The "Water-Drop Test" Theory

The property of hardness in minerals is dependent upon the cohesion, or the bonding power which arranged the atomic structure in a regular, closely packed lattice-like pattern. Topaz is harder than citrine, because the atomic structure of the former is more closely packed than the latter. A harder stone will hold a small drop of water more firmly on its surface, but a soft stone has a weak bonding power and consequently gives rise to a less closely packed (lattice-like) atomic structure. A soft stone like citrine (from the point of view of the "water-drop test" method), will not hold a small drop of water on its surface.

The "water-drop test" method is similar to placing an amount of water on a filtering cloth, the construction of which can be likened as the atomic structure in a stone. The water will stay much longer on a filtering cloth of denser construction. On the other hand, the water will soon filter out on a filtering cloth of rarer and sparser construction, similarly as a drop of water is quickly dispersed on the surface of a soft stone.

The "water-drop test" method when applied to gems of organic origin is not dependent upon the hardness property of the gems concerned, despite the fact that a small drop of water stands on the surface of a pearl (H. $3\frac{1}{2}$ to 4·0), coral (H. 3·75) and amber (H. $2\frac{1}{4}$) all of which are relatively soft, but on the manner in which a small drop of water is dispersed.

Coloured glass is sometimes used to imitate the coral and amber, while haematite is fashioned spherically to simulate the valuable black pearl. The "water-drop test" method easily distinguishes the organic gems from paste and haematite.

A probable cause of a small drop of water standing on gems of organic origin is some oily element in the composition of the gems. The pearl is a product of the shell-fish known as mollusc in science. Coral is a calcareous skeleton of tiny animal polyps, while amber is a fossil resin of vegetable origin. We have fish oil, and also vegetable oil. It is therefore logical that some varying amount of oily element may exist in the composition of organic gems or materials. Water is heavier than oil, and consequently it sinks in oil and oil floats on water. This act of separation or rejection is also seen when a small drop of water is placed on the surface of a substance coated with a thin film of oil, on which it stands.

In practice, sometimes a repetition of the test upon a gem is necessary, i.e. when the first test provides an uncertain result.

This can happen in the event of the following:

1. The test is carried out too hastily.
2. The small drop of water applied on the gem during the test is not of suitable proportion.
3. The surface of the gem tested is not clean or dry enough, has cracks or a thin film of oil.

It must be borne in mind that in the case of testing a stone, or a repetition of test, the gem must first be carefully wiped with a clean dry cloth or handkerchief, unstained with any oily element, and the stone must be in a dry condition.

Listed below is a comparison table of the "water-drop test" method of the chief varieties of gemstones and their possible counterparts. The manner in which the small drop of water stands or disperses is indicated above the stones listed.

Firmly	*Less firmly*	*Almost flat*	*Totally flat and dispersed*
Diamond	Topaz, zircon, synthetic spinel	—	Quartz, syn. rutile, strontium titanate.
Corundum (ruby and sapphire), syn. corundum	Spinel, topaz, zircon, morganite, almandine, pyrope, hessonite, synthetic spinel.	Tourmaline, aquamarine.	Quartz (amethyst, citrine and star-rose-quartz) paste.
Chrysoberyl cat's-eye.	—	Tourmaline cat's-eye.	Quartz cat's-eye, tiger's-eye (crocidolite), moonstone.
Green sapphire.	Soude emerald with syn. spinel as crown.	Emerald.	Soudé emerald with quartz as crown, demantoid garnet, peridot, sphene.
—	—	Jadeite, nephrite Some turquoise (less porous), plastic materials.	Some turquoise (porous).
True pearl, cultured pearl, glass bead coated with "essence d'orient".	—	—	Haematite (used to simulate black pearl).
Red coral.	—	—	Paste.
—	Amber.	—	Paste.

The above list is not a table of determination.

Modern gemmology demands conclusive tests, hence the "water-drop test" method should be used together with some other test in identifying a stone.

The Limitations of the "Water-Drop Test"

It does not distinguish:

1. The characteristic hardness of a stone, only giving an indication that one stone is harder than the other.
2. Between natural stones and their synthetic counterparts.
3. Between (*a*) a true pearl and cultured pearl and (*b*) true pearl or cultured pearl from glass bead coated with fish scales known as "Essence d'Orient".
4. Between true turquoise and (*a*) plastic-bonded imitation of turquoise or (*b*) plastic-bonded real turquoise.

A STUDY OF SOME GOLD MINE DIAMONDS

By F. A. RAAL

Diamond Research Laboratory, Johannesburg, South Africa.

ABSTRACT

A non-destructive study has been made of some diamonds recovered during gold mining operations. The stones appear to be ordinary Type I diamonds which had suffered charged particle irradiation and some annealing of the radiation damage at a temperature not exceeding 500°C at some stage of their existence. Two absorption features have not been observed in diamond previously and it is thought that they might be a consequence of the time scale of the annealing process which differs vastly from anything we can practically achieve.

INTRODUCTION

Recently a small diamond was recovered in cleaning out a tube mill on one of the Witwatersrand gold mines. This rekindled interest in some other diamonds—38 in all—which are museum pieces and which have been found in gold mines from time to time. In some of the older gold recovery processes the crushed ore was sent over corduroy which retained the gold particles in its folds and allowed the lighter materials to be washed over. Being relatively heavy the diamonds were found with the gold. A non-destructive study of these unique diamonds, which have kindly been made available to us, has now been made.

APPEARANCE AND MORPHOLOGY

The 38 stones, the largest of which weighs 1·53 carats and the smallest 0·08 carats are shown in Figure 1. As can be seen they are all of reasonable crystallographic habit and a few well-shaped octahedrons and dodecahedrons are in evidence. The diamonds are all coloured various shades of yellowish-green or green, ranging from a barely perceptible green tinge in one instance to a dark-green, almost black, colour in another. The colouration appears to be only skin-deep as is the case, in our experience, with most

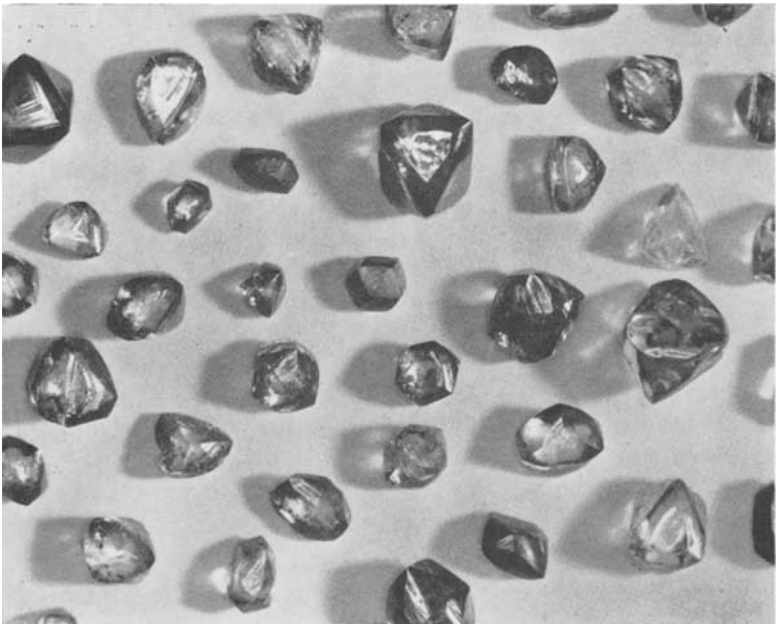

FIG. 1.

green diamonds found. The skin-deep colouration is consistent with the diamonds having been irradiated with high energy alpha- or beta-particles (Dugdale, 1953). These emanated, in all probability from uranium (or one of its degradation products) since this element is quite abundantly present in the gold mines where the diamonds were found.

TYPE DESIGNATION

Robertson *et al* (1934) were the first to draw a distinction between Type I and Type II diamonds and noticed that diamonds of the latter category have nondescript shapes as opposed to those of the Type I variety with good crystallographic features. Kaiser and Bond (1959) showed that all Type I diamonds contain varying amounts of nitrogen in substitutional position in the diamond lattice and that they are characterized by a strong absorption band at 7·8μ in their infra-red spectra. Elliot (1960) proposed that this nitrogen in Type I diamonds is segregated into a layer configuration and Evans and Phaal (1962) observed platelets in (100) planes in

these diamonds which could only be explained as being due to segregated substitutional nitrogen atoms: a qualitative study of the infra-red absorption spectra of the 38 diamonds revealed the presence of the 7·8μ band in all instances. It is concluded, therefore, that as is the case with about 98% of all diamonds from more conventional sources the gold mine stones are all of the Type I variety, i.e. they contain appreciable amounts of substitutional nitrogen in platelet configuration.

Optical Absorption Features and Discussion

Three octahedrons with relatively smooth parallel-sided faces lent themselves to optical studies of a more quantitative nature. The optical spectra obtained for these three stones showed identical absorption features although the strength of the bands varied in degree. Spectra were recorded at liquid nitrogen temperature (80°K) and a typical spectrum is reproduced in Figure 2 where the product of absorption coefficient and thickness of the diamond is plotted as a function of the photon energy of the incident radiation.

As can be seen there are prominent absorption band systems centred at 3·3, 2·6 and 1·7 eV respectively. In addition, there are

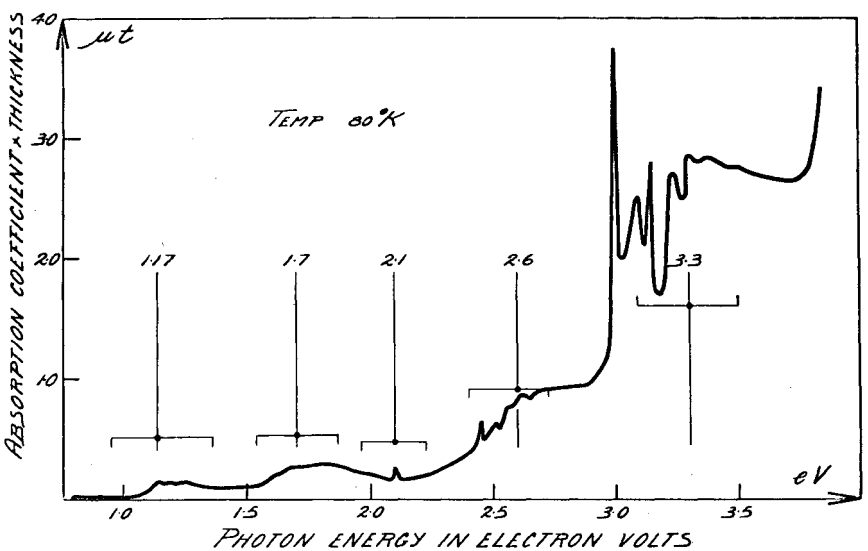

Fig. 2.

present two absorption systems with main bands at 2·1 and 1·17 eV respectively which to our knowledge have never been observed in diamond before. It is probable that these are a result of annealing of irradiation damage in the diamond over many thousands of years at a temperature which might have been well below but not exceeding 500°C as we have reason to believe.

The 1·7 eV band, designated G.R.1, is known to be associated with radiation damage in diamond (Clark *et al*, 1956). Experiments in this laboratory have shown that on heating irradiated Type I diamonds to 500°C G.R.1 can be annealed out completely with time to produce the band at 2·6 eV. At lower temperatures G.R.1 is annealed out only partially and an equilibrium with the 2·6 eV band is reached dependent on the temperature of heating.

Since both the G.R.1 and 2·6 eV bands are present in the gold mine diamonds the inference is that these diamonds were initially irradiated by a natural radio-active source and at some subsequent stage in their histories were heated to a temperature not in excess of 500°C and most likely considerably less than this value to partially anneal out the G.R.1 system.

Figure 3 depicts the absorption spectra at room temperature of one of the selected octahedrons before and after the diamond had

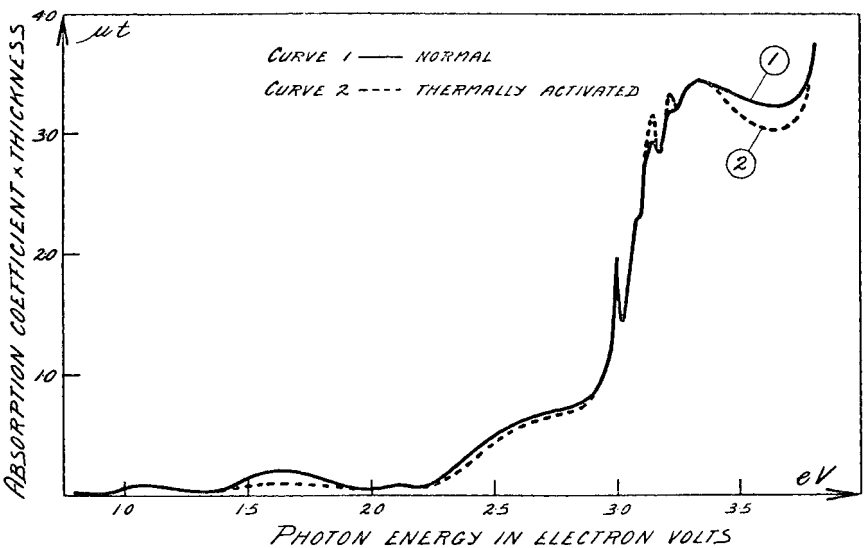

FIG. 3.

been heated in the dark at 400°C for 10 minutes. Curve 1 is that of the diamond in its normal state whereas curve 2, superimposed on curve 1, is that of the diamond in its thermally activated condition. On exposure to ultra-violet light or daylight curve 2 reverts to curve 1, i.e. the activated state reverts to the normal condition.

As can be seen there is a difference in light absorption between the normal and activated states. By heating the diamond in the dark the G.R.1 and 2·6 eV systems are reduced and the one at 3·3 eV enhanced. The G.R.1 and 2·6 eV bands being in the visible part of the spectrum one would expect a visible colour change to accompany the heating and light exposure cycles. This is indeed the case. After heating in the dark at 400°C for a few minutes the diamond appears yellow which colour rapidly changes to yellowish-green or green on exposure to light. Similar observations have been made in this laboratory on natural Type I diamonds which have been irradiated (Dyer and du Preez, 1965). Our understanding of this chameleon behaviour of diamond substantiates the claim that the gold mine diamonds were subjected to irradiation as well as annealing of the radiation damage at temperatures probably very much less than but not exceeding 500°C at some stage during their existence.

ACKNOWLEDGEMENTS

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The Association is indebted to the *Industrial Diamond Review* for permission to reprint Dr. F. A. Raal's article.

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Gemmological Abstracts

ROLFF (A.). *The aquamarine-bearing regions of Brazil.* Lapidary Journ., 1968, 22, 8, 1044.

A brief account of the prolific Brazilian gem area of Teofilo Otoni. S.P.

ANON. *Diamonds from Methane.* Science Horizons, 1968, 98, 6.

Diamonds can now be grown from methane, the gas which is better known as marsh gas. At present the process is extremely slow and is used only to increase the size of industrial diamond abrasive powder. But a long-range goal of the research into methane-produced diamonds, which is being carried out at Case Western Reserve University in Cleveland, Ohio, is to grow a synthetic diamond of gemstone size and quality.

In the experimental process they have developed, methane is passed over a diamond seed crystal at temperatures of about 2,000°F. The gas decomposes and gives off carbon, which deposits on the crystal. The carbon atoms arrange themselves in the same atomic pattern as the seed crystal and it grows. A potential application is the production of diamond for use as electrical conductors at high temperatures.

MORRISSEY (F. R.). *Turquoise deposits of Nevada.* Nevada Bur. Mines Rept. 17, 1968. 36 pp., 2 figs., 1 map. Published by Mackay School of Mines, Univ. of Nevada, price $1·50.

All known deposits of turquoise in Nevada are recorded for their location, production and history of mining.

R.A.H.

MAPLES (ERNEST). *Let's call a jade, a jade.* Rocks and Minerals, 1968, 43, p. 491.

Numerous minerals are incorrectly called jade by dealers in gems and ornamental stones. In these names the term jade is usually modified by a geographical name. Ten examples are cited and correctly identified.

R.A.H.

PETERSON (HELEN). *Black star-corundum.* Rocks and Minerals, 1968, 43, pp. 492-493, 2 figs.

Black asteriated corundum crystals, averaging $\frac{3}{4}$ inch across, occur in nepheline syenite near Bancroft, Ontario. The removal of the crystals from the matrix by using hydrochloric acid is discussed. R.A.H.

ANON. *Gem stones of Western Australia.* Rocks and Minerals, 1968, 43, pp. 651-653.

Comments on major localities are given for diamond, beryl (emerald, aquamarine, heliodor, morganite), opal, topaz, corundum (ruby, sapphire), quartz (amethyst, chalcedony, agate, chrysoprase, prase, jasper), tourmaline, and others.

R.A.H.

POUGH (F. H.). *The Carnaiba Emerald Mine.* Lapidary Journ., 1968, 22, 9, p. 1162.

The Carnaiba Mine, in Bahia, was found four years ago and is the biggest producer at the present time. The majority of crystals found are small and cut stones can only be a carat or so at best. S.P.

MCLAREN (A. C.). *The problems of amethyst.* Australian Gemmologist, 1968, 10, 4, p. 7.

At Monash University, Australia, electron and nuclear spin resonance techniques are being used in an attempt to ascertain how the presence of iron, which is associated with the colour of amethyst, fits into the quartz structure.

S.P.

The German Gemmological Society issued a special booklet in honour of the seventy-fifth birthday of Georg O. Wild, of Idar-Oberstein. Professor Karl Chudoba introduced the booklet with a biographical sketch of Wild and a bibliography of his published work. His position as an evening class teacher of gemmology is also mentioned. Abstracts of the principal articles which appeared in the special issue are set out below.

CHUDOBA (KARL F.). *Ueber die Bedeutung, Entstehung und Klassifikation der Mineral—insbesondere der Edelsteinfarben im geschichtlichen Rückblick.* Deutsche Gemmologische Gesellschaft, 1969, 3, 27-40.

About the importance, formation and classification of mineral colouring, especially colouring of gems seen from a historical point of view. This article includes a bibliography of 55 items and describes the classification according to colour of many minerals or gems starting with Agricola. Gems were at different times subdivided into having metallic or non-metallic colours; or being idiochromatic, allochromatic or colourless(!); he also subdivides inclusions into macroscopic, microscopic and submicroscopic, these being either ultra-microscopic or electron-microscopic.

E.S.

BAMBAUER (H. U.), LEHMANN (G.). *Farbr und Farbveränderung von Quartzen.* Colour and colour alteration in quartzes. Deutsche Gemmologische Gesellschaft, 1969, 3, 41-49. This article includes a bibliography of 16 items, 7 tables and graphs.

Quartz can be sub-divided into macro-crystalline quartz, such as rock-crystal, smokey quartz, amethyst, citrine, etc. and micro- or crypto-crystalline quartz such as agate or aventurine. This article only deals with the first group. The various trace elements in these quartzes are compared. Quartz seems to be one of the purest minerals due to the fact that Si can only be replaced by few ions, and then only to a limited extent. Details are given about rock-crystal and smokey quartz, amethyst citrine, rose and blue quartz.

E.S.

RÖSCH (S.). *Optisches über die Farbe des Amethysten.* Optics of the colour of amethyst. Deutsche Gemmologische Gesellschaft, 1969, 3, 50-54.

The colour of amethyst has usually been examined in relation to the chemical composition of the stone. The author tries to measure and compare the colour of various amethysts with the help of DIN colour plates (German standard colours).

E.S.

EPPLER (W. F.). *Pleochroitische Höfe.* Pleochroic halos. Deutsche Gemmologische Gesellschaft 1969, 3, 55-57.

The importance for gemmology of pleochroic halos or radioactive halos is the similarity to stress cracks in transparent gems. This is illustrated with 3 photographs, one showing a stress crack in a Ceylonese almandine, the other two a pleochroic halo in a zircon inclusion of a biotite at various magnifications.

E.S.

WILD (K. E.). *Produktion und Handelswege der Edelsteine aus Brasilien.* Production and trade in gems from Brazil. Deutsche Gemmologische Gesellschaft, 1969, 3, 73-87. This is the text of a lecture given at the institute in Idar-Oberstein in 1967, with an added bibliography of 19 items.

The lecture included details of the historical development, especially of the special relationship between miners, traders and dealers with Brazil, the geographical situation of the various finds and the development of the trade between Brazil and Germany. The gems mostly traded are agates, amethysts, fired amethyst, citrine, rock-crystal, aquamarines and tourmalines. The author also mentions Brazilian emeralds and diamonds.

E.S.

BANK (H.). *Amethystverkommen in Bahia, Brasilien.* Amethyst finds in Bahia, Brazil. Deutsche Gemmologische Gesellschaft, 1969, 3, 88-96.

Description and maps of the various occurrences of amethyst in Bahia, showing geological formation and geographical details.

E.S.

HAHN (M.). *Edelsteine aus Indien und Ceylon.* Gems from India and Ceylon. Deutsche Gemmologische Gesellschaft, 1969, 3, 97-101.

Historical survey of the gem trade of India and Ceylon, starting with the Romans and later with Marco Polo and Vasco da Gama up to today's financial difficulties.

E.S.

BOOK REVIEWS

GUBELIN (E.). *Die Edelsteine der Insel Ceylon.* Lucerne, 1968, pp. 152. 70s.

This text in German, has many fine colour plates and black and white photographs. It is a concise account of the occurrence, mining, recovery, cutting and selling of the gems found in Ceylon. The various species are considered in detail and there is a useful tabulated guide. There is a comprehensive bibliography. Much of the information stems from the author's first-hand knowledge of Sinhalese gems acquired during periodic visits to the island.

S.P.

RICHTER (G. M. A.). *Engraved Gems of the Greeks and the Etruscans.* Phaidon Press, London, 1968. £18.

A study of Greek and Etruscan gems is singularly rewarding. They span the whole evolution of Greek art, beginning with the Geometric period of the late ninth and eighth centuries, proceeding to the time of heterogeneous Oriental influences and then passing stage by stage to the pure Greek forms of the archaic, the developed, and the Hellenistic periods.

This is the first comprehensive book on the subject since Furtwängler's monumental work published in 1900. Dr. Richter gives a representative selection of 695 Greek and 181 Etruscan examples, taken from all major European and American collections. In most cases an illustration of the intaglio in the original, minute size is accompanied by an enlarged illustration of the impression, which shows the design as it was intended to be seen when used as a seal.

The material is arranged chronologically, with an introductory chapter for each period, preceded by a general introduction dealing with the uses of engraved gems, the choice of designs, the materials used, the technique, and information about the artists.

Etruscan gems are treated in the same way.

The book, which will be followed by a companion volume on the engraved gems of the Romans, is intended to serve as a standard work on an important field of classical archaeology.

P.P.

THE DETERMINATION DIAGRAM: AN AID FOR RAPID IDENTIFICATION OF GEMSTONES

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Introduction

For many years, diagrams similar to the one introduced in this article have been used successfully by geology students from the Geological and Mineralogical Institute of the University of Leiden. They have proved to be a valuable help when minerals must be identified on slides of rocks and grains.

Because of the good results with such diagrams it seemed justifiable to produce a similar determination diagram for the special benefit of the gemmologist. Many minerals of interest, including several scarcely known in gemmology, have been set out in this clear, comprehensive diagram and it is therefore expected that the diagram will be of use even to the more experienced among gemmologists. But it may also be of special interest to those experts, including many jewellers, who can only afford some relatively low cost instruments, such as the refractometer, to supplement the immersion (density) liquid tests.

This chart is not meant to replace the many indispensable textbooks. Its importance lies in the speed with which information can be gained from the diagram, after the initial observations are obtained using the refractometer and/or some immersion (density) liquids. After reading the "possibilities" from the chart, the textbooks may be consulted if necessary.

The Construction of the Determination Diagram

The diagram consists of two fields: a small field on the left where minerals with single refraction (isotropic) are set out and a larger one for the minerals with double refraction (anisotropic).

The coordinates of the fields are the values for birefringence (Δ) along the abscissa (horizontal) and for the refractive index, whether N for isotropic minerals or N_o and N_β for the anisotropic uniaxial

and biaxial minerals respectively, in the direction of the ordinate (vertical). The birefringence is set out logarithmically and the refractive indices linearly with irregular changes in scale.

The optical properties of the minerals of interest to the gemmologists are seldom presented as single points on the diagram but most often as lines. The optical properties (and also densities) vary with the chemical composition of the minerals, and in some cases the process of metamictization causes a decline in the refractive indices, birefringence and density (zircon). All chemical variations known belong to complete or partial isomorphous replacement series (garnets, spinels, some tourmalines, some apatites, and olivines).

For most of the minerals of interest, the mean of the optical variations could be represented sufficiently on the diagram with lines and circled dots, but in some cases the mineral properties are much more scattered than the lines indicate (apatite, variscite, chrysocolla, etc.). In the case of very small variations or when too few analyses were available, the mineral positions on the chart are shown by circled dots.

The physical properties of the minerals in question were mainly obtained from Deer, Howie and Zussman (1962), Winchell (1959), Anderson (1964) and Webster (1962).

The physical variations of most of the minerals are generally greater than the variations in the known gem varieties; therefore, the optical variations are often drawn as dotted lines when these properties are of less importance to the gemmologist (e.g. nephrite is a gem variety of the tremolite-actinolite series; peridot is the gem variety of the olivine series; of the scapolite series two gem varieties are known).

According to their general importance as gem varieties, the minerals in the diagram are indicated by heavy lines and dots circled twice when the more important gems are considered and thin lines and dots circled once for the more or less unusual stones.

Density, another major physical property of the gem varieties, has been added to the mineral names. For the minerals with double refraction, symbols are included to indicate whether the minerals are uniaxial or biaxial, with a positive or negative optical sign, (respectively +0, −0 and +b, −b).

The presence of so many minerals on the diagram clearly emphasizes that certain coordinates which lead more or less to an

important gem variety might also indicate another mineral of minor importance with physical properties very near to the former (examples are peridot and sinhalite; quartz, iolite and scapolite with low birefringence; sillimanite and euclase).

It is evident that when larger quantities of gemstones are to be identified at the same time, the diagram will once more prove its usefulness. The immersion-contrast method is advised here (Gem-testing by B. W. Anderson), thus subdividing the minerals into smaller groups with relatively similar properties. For this reason, the refractive indices and also in a few cases the densities of several of the more important immersion liquids have been included in the chart (methylene iodide, bromoform, benzyl benzoate).

In addition to the many natural minerals, the most important synthetics, glass varieties and other imitations can be found in the diagram.

Special attention has been paid to synthetic emeralds. The optical properties of the known natural emeralds and their synthetic counterparts have been grouped together separately in more detail in the upper left corner of the diagram. It is, however, still important to stress that all natural emeralds have a mean refractive index higher than the immersion liquid benzyl benzoate (1·569), but emeralds with a mean refractive index higher than 1·569 might still include some synthetic emeralds (Lechleitner, Linde). To complete the diagram, the scale ranges of the standard Rayner refractometer (1·30-1·86), the spinel refractometer (1·30-1·68) and the diamond refractomer (1·55-2·05) are also indicated.

The Use of the Diagram

The refractometer readings must be carefully carried out to obtain the most reliable results from the chart. The refractometer determines many important optical details of the minerals in question (Anderson, page 40). Thus it is possible to distinguish between singly and doubly refractive minerals, and very often between anisotropic uniaxial and biaxial minerals.

When a faceted stone is placed with the table facet on the refractometer and only one shadow-edge is seen through the ocular,

the stone will probably be isotropic. Isotropy is proved only when the shadow-edge remains fixed as the stone is rotated on the refractometer. The reason for this necessary check is that anisotropic minerals can behave isotropically when light is transmitted through the stone in the direction of (one of) the optic axis(es). It rather often occurs that uniaxial minerals are cut in such a manner that the direction of the optic axis is parallel to the table facet (beryl, quartz, tourmaline); when the stone is examined through the refractometer, full birefringence will be visible in one position (Δ maximal) but after being rotated over 90°, only one edge will remain ($\Delta = 0$). This edge, the ordinary ray, either corresponds with the higher refractive index when the mineral is uniaxial negative, or with the lower reading for the uniaxial positive mineral. Uniaxial minerals cut this way produce readings which are perfectly suited to the diagram, because the maximum double refraction is equal to the birefringence of the mineral while the stable shadow-edge corresponds with N°. An arbitrarily cut uniaxial mineral placed on the refractomer will, after rotation, be recognized by the fixed shadow-edge (N°), which is always present, and another (Ne′) shifting toward or from the ordinary ray. The maximum distance between the rays must be measured (Δ'). For an arbitrarily cut stone this maximum difference (Δ') will nearly always be smaller than the birefringence (Δ).

Thus $\Delta' \leqslant \Delta = N_e - N_o$ for uniaxial positive minerals, or

$\Delta' \leqslant \Delta = N_o - N_e$ for uniaxial negative minerals

on the other hand, certain cuts of biaxial minerals may behave similarly and uniaxiality must therefore be proved (although this is not always possible) by obtaining refractometer readings from different facets of the same stone. The fixed shadow-edge will always be present; however biaxial minerals are different in that two movable shadow-edges will then be visible. Finding the birefringence of biaxial minerals is also a matter of routine.

$\Delta' \leqslant \Delta = N_\gamma - N_\alpha$ counts for both biaxial positive and negative minerals. N_α, N_β and N_γ are the three principal indices and $N_\alpha < N_\beta < N_\gamma$ always. Thus finding the coordinates of biaxial minerals needed for the diagram means finding the lowest refractive index N_α' (where $N_\beta \geqslant N_\alpha' \geqslant N_\alpha$) and the highest index N_γ' (where $N_\beta \leqslant N_\gamma' \leqslant N_\gamma$) then $\Delta' = N_\gamma' - N_\alpha'$. The average between N_α' and

N_γ' will often more or less correspond with N_β. As Anderson pointed out (page 42), the optic sign of biaxial minerals can also be found, but this is in practice a rather difficult matter. Anderson states that "If the higher R.I. edge is seen to move beyond the half-way position between maximum and minimum readings it must be positive. If the lower R.I. edge moves past the half-way position, the stone is negative". It is clear that it will be easier to evaluate the optic sign of biaxial stones when the birefringence is high. But even when birefringence is high, if at the same time the optical angle of the mineral is large, about 90°, the deduction of the optic sign will be difficult.

Summarizing, it can be said:

1. The measurements suitable for application to the diagram are most exact for the singly refractive minerals (one stable N and $\Delta = 0$).
2. In the case of uniaxial minerals, the ordinary ray will always be visible, while birefringence depends on the orientation of the optical properties of the stone compared with the facets ($\Delta' = | N_e' N_o |$).
3. Measurements on biaxial stones must be carefully carried out to obtain the best results for the diagram; N_β more or less corresponds with the mean refractive index and the double refraction with the maximum possible difference between the highest and the lowest measurable refractive indices — ($\Delta' = N_\gamma' - N_\alpha'$).
4. To distinguish between isotropy, uniaxiality and biaxiality, one must at least rotate the stone on the table facet and it is sometimes necessary to obtain readings from other facets.
5. In the case of cabochon cut stones it is impossible to get these exact results for the optical properties.

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The author is greatly indebted to Dr. P. C. Zwaan, F.G.A. and Dr. P. Hartman for many fruitful discussions on the subject of this article and for critically reading the manuscript.

Many thanks are also due to Mr. B. Lieffering who expertly drew the diagram and to Mrs. G. P. Bieger-Smith for correcting the English manuscript.

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*For information about natural and synthetic emeralds.

ASSOCIATION NOTICES

MEMBERS' MEETING

Mr. Robert Webster was the speaker at a meeting of members of the Association held at Goldsmiths' Hall on Wednesday, 22nd January, 1969. He spoke about a recent trip to associations and gem-testing laboratories in Canada and the U.S.A.

His visits included the Canadian Gemmological Association, the Royal Ontario Museum, the Smithsonian Institution, and the laboratories of the Gemological Institute of America in Los Angeles and New York. Mr. Webster was also able to have discussions with Dr. Kurt Nassau, of the Bell Telephone laboratories.

In addition to describing the various gem-testing techniques which he had seen, Mr. Webster displayed various natural and synthetic gem materials which had been presented to him during his visits. These included synthetic quartz and garnet, flux-grown magnetite and peristerite feldspar, microcline feldspar, sodalite and rose-quartz.

Collections which Mr. Webster showed came from the Royal Ontario Museum, Bell laboratories, Mr. Grant Waite, of Toronto, Mr. Hugh Leiper, F.G.A., Editor of the U.S. Lapidary Journal, Mr. Maziarek of the Venezuelan Dept. of Mines, and Mr. Jerry Call, of the New York laboratory of the Gemological Institute of America.

MIDLANDS BRANCH

A well attended meeting of the Midlands Branch of the Association was held in Birmingham on the 23rd January, 1969. The speaker of the evening was Chief Inspector J. A. Birch, D.P.A., M.I.W.M.A. of the Weights and Measures Department in Birmingham. Mr. Birch discussed the 1968 Trade Descriptions Act at length and subsequently answered questions concerning descriptions that were used in the jewellery trade. Mr. Douglas King, Chairman of the Branch, presided, and Mr. W. A. Peplow of Stourbridge proposed a vote of thanks to the speaker.

SCANDINAVIAN DIAMOND NOMENCLATURE

The Gemmological Society of Finland has recently published a chapter on clarity from the Scandinavian Diamond Nomenclature. It comprises over 180 illustrations, with descriptions of the various clarity grades of diamond to be used in Denmark, Finland, Norway and Sweden. The official version of the nomenclature is in English. Copies of the clarity chapter may be obtained from the Association, price 25s. 0d. including postage.

GIFTS TO THE ASSOCIATION

Mr. Argimiro Santos Munsuri, of Madrid, has kindly donated a copy of his book "La Esmeralda" to the Library of the Association.

The Association is grateful to Mr. Walter E. Johansen of California, U.S.A., who has donated a parcel of synthetic red spinel preforms.

The Association has received various gifts for its library which include a transparent faceted grossular garnet from Central Africa, presented by International Gems of Luxembourg, and a refractometer and polariscope from the Gemmological Association of All Japan.

Mr. John R. Fuhrbach, of Amarillo, Texas, U.S.A., has kindly donated various specimens for student use.

OBITUARY

February 29th, 1969. Mr. John R. Page, F.G.A., of Knockholt, Kent. (D. 1948), aged 62.

COUNCIL MEETING

At a meeting of the Council of the Association held on Tuesday, 25th February, 1969, at Saint Dunstan's House, Carey Lane, London, E.C.2, the following were elected to membership:—

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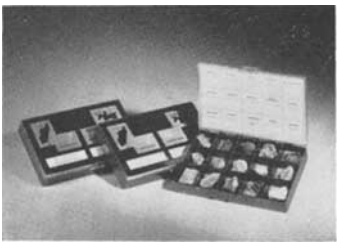

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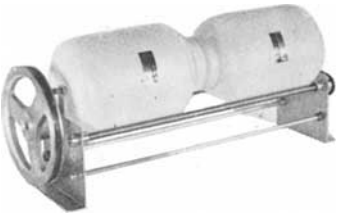

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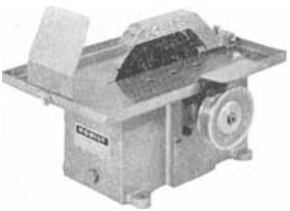

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COLOURED DIAMONDS — NATURAL OR ARTIFICIALLY TREATED?

By CHARLES A. SCHIFFMANN, F.G.A., G.G.
Gubelin Laboratory, Lucerne

SUMMARY

These days the intervention of techniques in the synthesizing and modification of the properties of precious stones is a source of worry for the gem jeweller. An actual case is described here, with the examination of 20 so-called fancy-coloured diamonds. This term covers shades other than those of the usual commercial scale for gem diamonds, which includes colourless stones to those of a yellowish tint. To begin with, the aim was to find out whether the colours of the diamonds under test were of natural origin or due to radiation treatment. The investigations were carried out under the working conditions of a well-equipped gemmological laboratory. The determining characteristics of the stones examined are set out in table form. These results enable definite conclusions to be reached in certain cases whilst in other cases giving only clues but no proof, since the positive signs of treatment are not always evident or at least not perceptible within the limits of the equipment used.

GENERAL

The distinction between natural and artificially induced coloration of diamonds is a topic causing more and more concern. An alteration of the original shade can be effected by simple means, relatively easy to detect; these effects are not permanent and are set out here as a reminder.

1. Coloured Film

A translucent coating or an ink is applied to the underside of the diamond. The dying stuff chosen is generally of a shade complementary to that of the diamond and thus the general colour impression is improved when the shades are mixed by the eye. These coatings are eliminated by solvents such as alcohol or acetone and are easily removed if the stone is set in an open setting.

2. Foiled Back

A process already known for a long time and still being applied nowadays, is the use of a thin reflecting, coloured metallic leaf, or foil, covering the inside of the closed stone setting. The foil acts as a mirror and gives the impression of a better and deeper colour (in coloured stones) by optical blending. It also improves the liveliness of shallow stones or of badly cut stones. The metallic leaf is generally of aluminium. The process is revealed often by dull stains due to superficial oxidation of the metal or to infiltrated dust and liquids. Here, the pocket lens is a good means of identification.

3. Fluor Coating

A more modern procedure is the application around the circumference on the pavilion side of the diamond of a fluoride composition similar to that used in optics for the anti-reflection coating of the lens surfaces. Here, too, the illusion of seeing better colour is due to the mixing of complementary colours by the eye. For example, a yellowish diamond having a bluish coating will appear less yellow. Detection is made by observation of the lustre, because the thin film will not show the typical adamantine lustre. Some iridescence is occasionally visible, and the edge of the coating is shown up under microscopic magnification of about $\times 60$. A treatment in hot acid removes this type of coating.

A much more complex problem is posed by the discoloration of diamonds under the action of ionizing or high energy radiation and by its identification. Since the systematic experiences of Crookes at the beginning of this century (1904) on the modifications obtained by exposing diamonds to alpha particles of radium, analogous processes of discoloration have more than purely scientific research interest and the derived methods have left the laboratory and taken their place in commerce.

The radium treatment is no longer applied because of the costs involved and because the radioactivity imparted to the stones will be retained for years, possibly being dangerous when the diamond is worn close to the skin. Detection is simple, as such stones will fog a piece of film when left in contact with the film from a few hours up to a few days.

The means of irradiation are today the cyclotron, the nuclear reactor, and the Van de Graaf generator. Based on the work of Crookes, Cork, Custers, Dugdale, Ehrmann and others, the experiences of specialists in commercial discoloration have simplified and rationalized the methods. Consequently, the irradiation, or "bombardment", of diamonds has become a relatively simple operation, costing about $60.00 per carat.

Effects of Irradiation Process

Irradiation effected in a cyclotron or in a nuclear reactor, modifies the original colour, turning it progressively green to an opaque dark green, depending on the size of the stone and duration of treatment. On consecutive heating and under progressive temperature in the range +400°—1,000°C [4], the dark green colour reverts to shades of brown, yellow-brown or yellow. Irradiation in a Van de Graaf accelerator results in shades of a pale blue to blue-green.

Selecting Diamonds for Treating

There is no point whatsoever in irradiating gem diamonds of good original colour as this would probably only result in a less prized colour. For this reason, the stones chosen for irradiation are "off-colour" stones which, it is hoped, can be improved in shade or converted to a definite fancy hue, and markedly "piqué" stones, where a new, saturated fancy body colour will help conceal the flaws. Small, old-cut stones and those of mediocre quality are often treated such as they are, because the price of recutting to ideal proportions would be too high in relationship to their colour and purity grade; in such instances, the lack of symmetry of the facets, together with wearing marks, nicks and cracks seen with a lens on such stones, evoke the possibility of treatment when they are observed together with a naturally less frequent shade.

Specification of Artificially Induced Colour

The identification of a treated diamond is not always easy. To avoid mistakes when buying and especially with regard to his responsibility towards his clients, the retailing jeweller will find it to his advantage to keep up to date with this subject. From different sides, efforts are being made to eliminate the use of abusive designations for gemstones and to encourage a more ethical approach in this sphere, particularly with regards to artificial products or artificially treated gemstones. On these lines, "bombarded" stones offered for sale should be clearly defined as such and many national organizations are trying to establish this idea.

Artificially coloured diamonds must be designated as such. Such designations, established by associations for the protection of the buying public, are welcomed by members of the trade who promote and follow an ethical professional policy and are very much aware of their responsibility, thus maintaining the confidence of their customers.

However, the application of rules is not always simple. In effect, when in an economic section a regulation of quality defined by a nomenclature and normed standards is put forward for certain products, the corollary of it is the establishment of an official or private body freely open to all interested circles, thus enabling them to classify or identify their goods. In the jewellery trade, there are control laboratories in some countries, some run on a private basis, others supported by the state or a university. Some of the best known are the laboratories for the identification of gems and pearls in London, Milan, Paris, Idar-Oberstein, Los Angeles and New York. The question of finance raises problems of the establishment of similar laboratories in regions or countries where the small number of interested parties would be unable to support such an institution. Switzerland does not, as yet, have such a body either official or partly supported by the trade. On a private basis, the Gübelin laboratory is striving to help find a solution to such problems and routine identification is undertaken. Often the experiences or discoveries made are so interesting as to be well worth conveying to the trade, as a contribution to the improvement of the general level of knowledge and understanding.

Object of this Study and Description of the Instruments Utilized

The present study has been made on a series of 20 diamonds, varying greatly in colour, in order to determine whether the origin of their coloration is natural or artificial. To overcome the difficulties of colour printing, the stones are shown on Figure 1 in shades of grey, as registered on black and white panchromatic film, without filter; their actual colours, their characteristics as well as the result of the different tests conducted, are given in table form. With reference to the weight of the stones, the reader's attention is drawn to the small size of some of these gems. Thanks to the spectroscopical techniques utilized, even the small stones could be examined at ease with good results. The spectroscope is a diagnostically important instrument, quite resourceful in investigating possibilities, but requiring much practice to master its use. The analysing direction within the specimen under test, its optimal illumination and the correct setting-up of the instrument are often the cause of difficulties, even for people with some experience, as the author has often seen. Of course, nothing would replace a personal demonstration to improve the individual technique but it is hoped that the advice in the following description might help those interested to obtain complete success.

Spectroscopic Examination

As a paradox one could say that white light is a light full of colours, as it consists of all the different and visible wavelengths resulting in a general balanced impression to the eye. The spectroscope is an instrument which spreads and analyses that visible white light in the form of a coloured ribbon of light going from the red, yellow, green, blue through violet, thus bringing to the eye the components of the spectrum or rather what appear to be differentiated steps, for, in reality, the different colours fuse into one another without definite border. The stone under examination is set within the light beam of the instrument and acts as a filter, absorbing some of the radiations and letting through others. This phenomenon manifests itself by narrow or wider black absorption bands, where no light passes, across the bright spectrum and is called the absorption spectrum. The distribution of these lines is often typical for a gemstone variety although by no means all gem materials show definite absorption bands. There are two ways of proceeding to illuminate

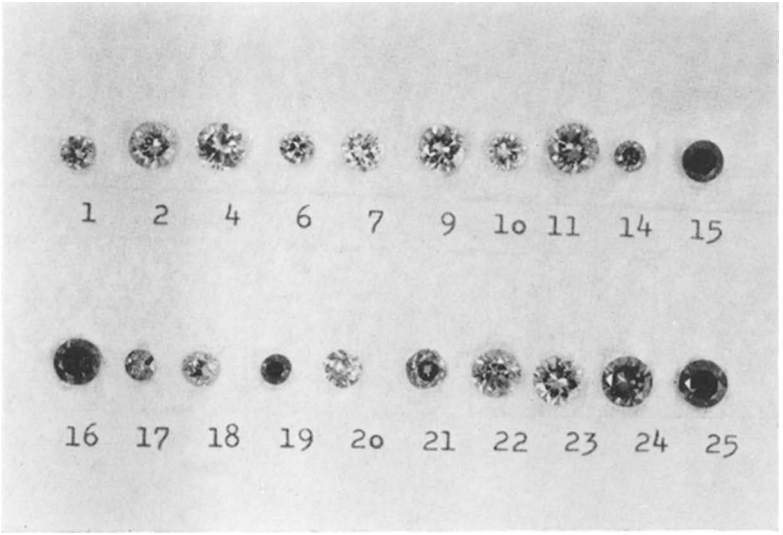

FIG. 1. *The diamonds depicted in shades of grey, as registered on panchromatic Adox KB 14 film. Compare with the actual colours cited in the general table.*

the specimen:

(1) in transmitted light, right through the specimen;

(2) in reflected light.

This second procedure eliminates the disturbing reflections on the facets of a cut stone, which deviates much of the light outside the slit of the spectroscope; in this way, the loss of light is reduced. The method is particularly applicable to cut diamonds, because of their high refractive index. In profile, a cut diamond can be compared to a toally reflecting prism and the light behaves in it in a similar way; with the diamond resting on its table, the beam of a microscopy low-voltage lamp is directed along the normal to the pavilion facets of the diamond, is totally reflected at the inner surface of the table side and escapes through the opposite pavilion facets to reach the collecting lens of the spectroscope, or the slit directly in the simpler instruments. The facets reflections being thus quite well suppressed, and the light efficiently utilized, a brightly illuminated spectrum is obtained even with a small specimen.

Two types of spectroscope have been used:

(1) a modified Krüss model, to which a lighting of the wavelength

scale as well as a powerful microscopy low voltage Zeiss lamp have been added. The narrow beam has the advantage of avoiding dazzling glare, which is particularly important when looking for faint lines, where it is necessary for the eye to make use of its maximum resolving power.

It is not necessary for complete darkness in the room when working with this arrangement. The Krüss spectroscope is efficient, although its fixed angular position limits its use to examination in reflected light. The setting up is shown in Figure 2.

(2) the latest Gübelin, which has been improved with regard to the former model: the optical system is of Zeiss origin. The precise wavelength scale is illuminated at will by a rheostat; a second rheostat controls the intensity of the main lamp, lodged in the foot of the instrument. The details are well visible in Figure 3, where the instrument is normally set for the transmitted light procedure. For reflected light, the lamp in the foot of the instrument is turned off, and the light beam of an additional lamp is directed on to the specimen, itself maintained in the

FIG. 2. *Modified Krüss spectroscope, as described in the text. The mode of illumination is clearly visible, as well as the 50 cc flasks filled with filtering solutions, used as additional light condensers.*

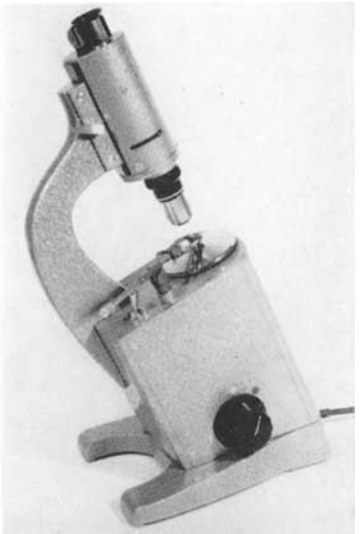

FIG. 3. *Latest Gübelin model, with incorporated Zeiss spectroscope, to be used in transmitted or in reflected light. The additional lamp used in the second procedure is not illustrated.*

removable stone-holder. All these refinements are handy and allow for precision work to be carried out.

Faintly coloured diamonds strongly transmit the yellow-green and the eye, being dazzled by the glare of the brightest part of the spectrum, does not easily see the faint lines in the blue and violet. To alleviate this inconvenience, it is of advantage to use filtering solutions to more or less cancel out the red and yellow end of the spectrum, as described by B. W. Anderson (Gem Testing, 1964 edition). However, instead of the large containers recommended in that book, the author has found it advantageous to use much smaller spherical laboratory Pyrex glass flasks of only 50 cc. capacity. They are very effective, thanks to the small diameter of the microscopy light beam. These spherical flasks have an effective 45 millimeter thickness of filtering solution in their diameter, which acts as a condensing lens and helps to avoid simultaneous undue heating of the specimen. Copper sulphate and liquids of different filtering capacity are used, according to necessity. The setting of the flasks on a laboratory stand provides for an easy exchange of the filters and prevents the eye from being dazzled, thus enabling a quicker eye accommodation.

Spectral Characteristics of the 20 Diamonds Under Test

In the table are noted the absorption bands observed. Some of the specimens (2, 4, 9, 11) show clearly the "Cape" spectrum, its features being a series of bands based on a strong line at 4155Å, of variable width, and of accompanying bands at 4230Å, 4350Å, 4520Å, 4650Å, 4780Å, superimposed upon lines typically due to irradiation and consecutive heat treatment, at 4980Å, 5040Å, 5940Å.

Number 6 showed a weak, orangy fluorescence under copper sulphate solution, with a distinct line at 5750Å, formerly mentioned in similar fluorescing diamonds by G. R. Crowningshield and E. Gübelin. Under the same filter, number 7 had an equally weak fluorescence in the orange-yellow, without sharp limits. In the number 10, there are clues of a naturally coloured diamond, because in the 5040Å and 4980Å pair of lines, the former is predominant, the stone having a greenish fluorescence. Similarly, the number 14 speaks for a natural origin of the colour, although it was inert under UV radiation. The number 18 of yellow shade has a strong yellowish response to the ultraviolet light and shows the features of the "brown" series, with a quite distinct 4155Å line; accompanying

ones at 5370Å, 5040Å, 4980Å, have already been observed in one brown diamond by Crowningshield, as well as in the green fluorescing ones, by Miss Mani, a worker of the school of Raman, in Bangalore. But here, the stone has a yellow response and emits feebly in the red-orange at about 6200Å-6000Å under the copper sulphate light. The two bluish stones 20 and 21 both have a distinct to strong 4155Å line. Let us here recall the hypothesis of Nayar (1941) cited by Anderson on "the proportional ratio of the 4155Å line to the strength of the fluorescence"; after Anderson, the experience has not confirmed this view, as he reports having tested numerous diamonds with a 4155Å line to be inert under ultraviolet radiation. In accordance with these last facts, the 4155Å line is of equivalent strength in the two diamonds, but only one of them fluoresced blue-green (No. 20), the other one (No. 21) being inert.

A test for electrical conduction, performed on the apparatus devised by Gübelin (Fig. 4) proved the two stones to be non-conductor, thus not being of the type IIb to which naturally blue diamonds belong. Furthermore, microscopic examination showed 21 to have curious green to black spots, with round outline, located at the angle of the table, and near the girdle (Figs. 5 and 6).

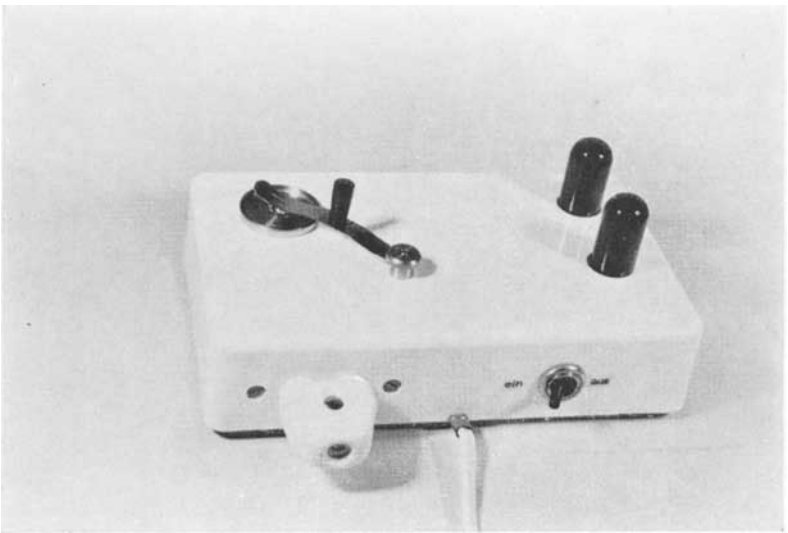

FIG. 4. *Gübelin electro-conducting device, working on 220 volts. The two neon lamps light up when the tested diamond transmits electric current. The stone rests table down on the round metallic cap visible on the left side of the instrument. A flexible metallic strip ensures proper contact on the culet side.*

FIG. 5. *Dark spots due to irradiation, at the angle of table and star facet, on diamond number 21. The depth of penetration is 0·03 mm and was better visible in reality. Magn.* ×25.

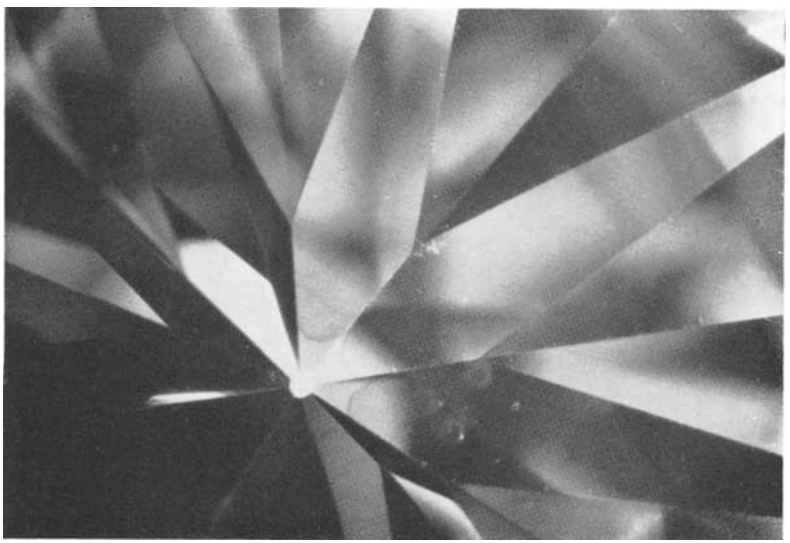

FIG. 6. *Dark green spots with round outline, along the girdle, and due to irradiation. Diamond number 21. Magn.* ×25.

These spots have been found to be 0·03 mm deep, when measured with a micrometric eyepiece used on a newest X10-X70 Bausch and Lomb stereozoom microscope, mounted on a G.I.A. black-field illuminator.

As the stone is an old brilliant-cut, there is no reason to presume that it has been cut in such a way since World War II, that is to say, subsequent to the beginning of the commercialization of diamond-irradiation. The shape of the spots is reminiscent of the ones found in formerly radium-treated stones: for that reason a test was performed for possible radioactivity and turned out to be negative: after five days of contact, a radiographic sheet of film displayed no trace of fogging. Another possible cause of the spots might have been that the diamond, still in its rough condition, had been in contact or lying in the vicinity of a natural radioactive source, as according to Dugdale's[4] observations in green diamonds, the colour of which is not artificially induced. In the occurrences cited by Dugdale, the green shade, accompanied by darker spots, was confined to the surface of the rough diamonds, whereas they were colourless inside the crystals. Such external markings would, of course, have disappeared during the process of cutting. Due to their location on the stones concerned, there are reasons to think that the spots have taken place after the cutting, therefore, that they are due to an irradiation treatment.

In the stone 25 the vague lines seen toward 7000Å, 6700Å, 4820Å, 4780Å (some of them cited by Dugdale) together with a green colour, suggest that the stone has been heat-treated at less than 400°C after irradiation, to lighten the green colour.

In stone 25 the 5040Å line is quite marked (about 25Å wide) whereas the 4980Å one is still just visible. This observation is in contradiction to the rule given by Liddicoat (Handbook of Gem Identification, 1966, p. 231): "Large treated stones may show no 5920Å line, but the presence of the 4980Å and 5040Å lines, with the former stronger, should be considered as proof of treatment". As a set-off, the features observed in number 25 correspond to the description of Miss Mani and B. W. Anderson for green stones with a green fluorescence. The same remark applies to the number 10. Against this, the number 18 corresponds to the indication of Liddicoat, but it is yellow and not green. The two lines of the pair are of equivalent strength in the numbers 2, 4, 7, 9, 11, 19, 22, 24.

As indicated in the foregoing, today it is possible to carry out a good amount of work in spectroscopy applied to gemmology, thanks to the research conducted by numerous workers, like Anderson[1], Crowningshield[3], Dugdale[4] and others, whose findings are a firm base for a project like the present study.

Microscopic Examination

Under black-field examination in the stereomicroscope evidence of a colour modified by irradiation treatment was present in number 11, under the form of curved, darker thin lines around the culet. ("Cloverleaf" or "umbrella" pattern) Fig. 7. This feature is well known in gemmology as being typical; in the present case, however, the pattern partly had a doubled outline consisting of two thin, more or less parallel, lines. Does this mean that the stone had been submitted twice to the irradiation, the first one having failed to result in the desired shade? The question is open.

Among other features observed under the microscope, the green spots of number 21 have already been described. As to the

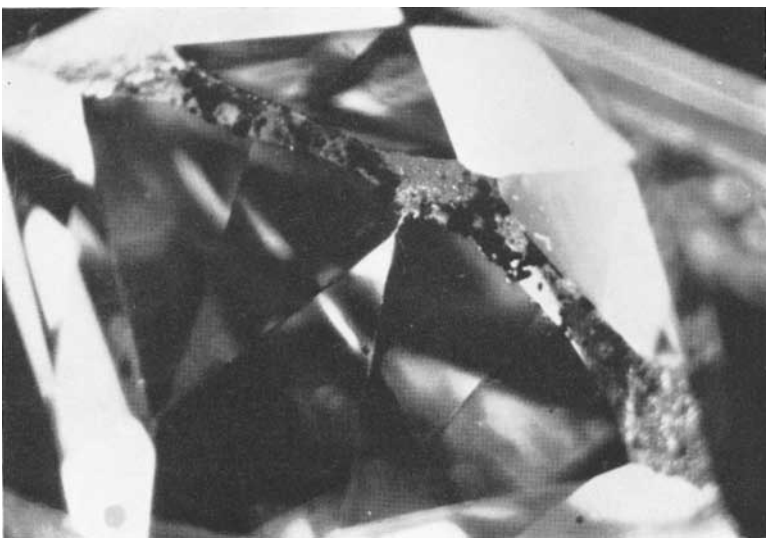

Fig. 7. *Positive signs of irradiation: curved line, partly double, around the culet of the stone, known as "cloverleaf" or "umbrella" pattern. Magn. × 50.*

general quality of the cut, the diamonds were generally somewhat irregular; some were in the old full-cut style with numerous breaks and small cleavages at the girdle, due to rapid bruting. The number 19 had strong, coloured uneven alternate zones of brown colour, as marked as the growth zoning met with often in corundums.

In the numbers 1, 7, 15, 20, under ×70 magnification, thin particles of carbonized matter have been observed in the numerous small cracks open to the surface of the stones. The fact suggests the possibility of a heat treatment taking place after cutting, as practised with the stones, whose colour has been modified by irradiation.

X-RAY FLUORESCENCE AND PHOSPHORESCENCE

Reference is made to the results appearing in the table. The X-ray unit used is a Siemens unit, with a molybdene anode, working under a maximum of 60 KV/17mA. The diamonds were placed in the parallel beam usually used for pearl diffraction radiography. The response was judged by the eye, the tenuity of the reactions involved necessitating a good eye adaption. Consequently, the test is carried out in darkness.

ULTRAVIOLET RADIATION FLUORESCENCE

Under the action of an invisible radiation of a wavelength lying beyond the violet, some substances react by emitting a radiance of a visible, longer wavelength called fluorescence. When the radiance subsists some time after the primary radiation has been shut off, the phenomenon is called phosphorescence. The relative intensity and the colour of these reactions are often typical, and are an important diagnostic element in the identification of gemstones.

Many of the ultra-violet lamps on the market use as an ultra-violet source two of the principal emission lines of mercury vapour called:

Short wave, UV radiation 2537Å

Long wave, UV radiation 3650Å.

The lamp used for this examination is an "Uvanalys" model of German make. The discharge tubes are enclosed in a fairly wide rectangular metal case, lined black inside, and made tight to external light. Opening on the sides permit the introduction of the specimen; windows allow for checking of the reactions. In this way, with the eyes close to the windows, even weak fluorescence is visible

without having to darken the room, being an advantage in the course of rapid investigation.

After the comprehensive experiences of Anderson and Payne, diamonds should be classified into three main groups, according to the colour of their ultraviolet fluorescence—:

Blue fluorescence	Diamonds of the "Cape" series with absorption lines at 4780Å, 4650Å, 4520Å, 4350Å, 4230Å, and a fundamental line at 4155Å. Emission lines may be visible at 4650Å, 4520Å, 4390Å, 4285Å.
Green fluorescence	Diamonds of the brown series with absorption lines at 5370Å, 5120Å, 5040Å, 4980Å, which may appear as emission lines, to the exception of 4980Å.
Yellow fluoresence	Comprising the true "Canary" diamonds, without visible absorption lines at room temperature.

The classification is most helpful in interpreting the practical results gained in examination.

Spectroscopy conducted with the help of elaborate techniques (7) has made possible the discovery of two main systems of lines based on 4155Å, and on 5040Å, in the majority of the type I diamonds showing blue or green fluorescence and in type II diamonds with yellow fluorescence. These two lines seem to be the key positions around which a series of additional lines may appear in a mirror-like position, whether in absorption or in emission.

In the present instance, it has been possible to consider an irradiation treatment as the cause of the colour, when the features of the stones observed, that is, fluorescence, absorption lines, and body colour, did not agree with the generally known data typical of naturally coloured diamonds (see table).

Transparency to Ultraviolet Radiation

A most important diagnostic element in the identification of gemstones is the threshold of transparence to ultraviolet radiation. Usually, synthetics have a lower transparency limit as opposed to natural stones. With diamonds, the experience has shown that the feature of the majority of the type I diamonds are opaque below 3000Å and fluoresce under 3650Å UV radiation, whereas the transparence limit of type II diamonds is situated toward 2250Å and may show a weak fluorescence (7). Another important characteristic of the naturally blue diamonds is their good electric conductability,

due possibly to the presence of aluminium in the crystalline lattice. For that reason, they have been classified in a separate category, according to Dr. J. Custers. Actually, in the light of today's knowledge, a blue non-conductor diamond can be considered as owing its coloration to irradiation. On the principle, the two blue diamonds numbers 20 and 21 have been checked as to their conductibility, using a Gübelin electro-conducting device, working on 220 volts. Both stones did not lead the current, in accordance with their other characteristics, thus proving to be "bombarded" stones.

Ultraviolet transparency to 2537Å can be checked in different ways, of which two simple methods are as follows:

(1) METHOD OF DIRECT PHOTOGRAPHY

In darkness, the stones are placed table down on a sheet of photographic paper immersed in a water-filled shallow dish, with just enough liquid to cover them. Samples of a known degree of transparence, such as an opaque material (natural beryl) and a transparent one (quartz) are placed beside the unknown stones. After a short exposure (about two seconds) to the shortwave lamp—resting at some distance above the basin—the developed photographic paper will be seen to have remained white under the opaque specimen and to have turned more or less grey, according to the degree of transparency of the others under test, or even black under the fully transparent stones.

(2) METHOD BY USE OF SCHEELITE

This mineral has the property of strongly fluorescing under shortwave radiation. As soon as a substance opaque to that radiation is placed between the scheelite and the lamp it will intercept the ultraviolet beam, and the fluorescence will cease. Therefore, it is possible to use an unknown substance as a filter and, from the reaction of the piece of scheelite, deduce if its transparence threshold lies above or below 2537Å. A simple way of proceeding is to enclose a scheelite sample in a small box impervious to light (an old cylindrical tin can used to store 10 meters of 35 mm film will suffice), the lid of which is pierced and accommodates different diaphragms, according to the shape and size of the stone being tested. The stone must lie well over the rim of the diaphragm to avoid the admittance of any stray light from the lamp placed above. The reaction of

the scheelite is observed through a lateral opening in the box. This test is to be made in darkness and precaution in the interpretation of the reactions observed is vital: prior to testing unknown stones, it is necessary to become acquainted with the strength of the reaction of known samples, as the fluorescence involved might be very tenuous. Furthermore, if the diaphragm chosen does not correctly accommodate the shape of the sample, diffused light may entirely distort the value of the test. Last but not least, some synthetics may fail to exhibit a normal transparency.

The 20 diamonds tested by this method all showed opaque and it can therefore be deduced that they all belong to type I ; in other words, that there are no naturally blue ones amongst them.

CONCLUSION

The series of tests conducted on the 20 diamonds has led to the following results:

in 11 stones positive signs of artificially induced colour were observed

in 3 stones clues to artificially induced colour were observed

in 6 stones no signs of artificially induced colour were observed. Within the limits of the investigation methods used and based on present knowledge, their colour can be considered as being of natural origin.

The present study confirms the mysterious nature of the diamond and the oddness of some of its characters. Thanks to the efforts of numerous workers in the study of spectral features, statistics have made it possible to correlate groups of absorption lines with the fluorescence and the body colour. Some of these elements may appear today as anomalies: however, they certainly belong to the logical and coherent laws ruling natural phenomenons. It is hoped that development of the science allows the puzzle to be completed, thus bringing to light the fundamental principles presiding over the appearance changes of these glittering marvels called diamonds. On the practical level of the jeweller, these mysteries result in difficulty in ascertaining the origin of the colour. Nevertheless, numerous experiments and comparisons make it possible for some points of the uncertainty to be slowly enlightened. It is hoped that the included statistical table might be helpful to the gemmologist having to cope with such problems or, more generally, taking interest in new experiments.

OBSERVATIONS ON COLOURED DIAMONDS

Stone No.	Weight ct	Colour	X-ray fluorescence	X-ray phosphoresc.	UV fluoresc. 3650Å	UV transparency to 2537Å	Spectroscope	Microscope	Identity
1	0.33	bright yellow "Jonquil"	inert	inert	inert	opaque	4930Å faint, elusive ~4510 vague 4300 cut-off	Remains of carbonized material at the surface	Clues of natural colour
2	0.90	straw-yellow	weak bluish-green	inert	medium green	opaque	5940Å elusive 5040 distinct 4980 distinct 4850 faint 4780 faint 4650 faint 4155 strong ~4015 distinct		Induced colour, treated stone with "Cape" spectrum
4	1.02	straw-yellow medium intensity	inert	inert	weak yellowish	opaque	5940Å very faint 5040 distinct 4980 distinct 4850 faint 4780 faint 4650, 4510 broad 4155 stark 4015 distinct		Induced colour
6	0.27	pale brownish-yellow	inert	inert	strong orangy	opaque	6400, 6000 emission lines through copper sulphate solution 5750 distinct 4980 elusive 4300 cut-off		Clues of natural colour

OBSERVATIONS ON COLOURED DIAMONDS

Stone No.	Weight ct	Colour	X-ray fluorescence	X-ray phosphoresc.	UV fluoresc. 3650Å	UV transparency to 2537Å	Spectroscope	Microscope	Identity
7	0.65	pale yellow	weak	very faint	medium yellow-green	opaque	6400Å-6000Å some 5940 faint 5040 faint, sharp 4980 faint, sharp ~4870 faint 4780 faint 4155 strong ~4200 cut-off	Bearded girdle with cracks filled with brownish carbonized material Magn. 70 ×	Induced colour
9	0.85	medium yellow	weak bluish	inert	strong yellowish-green	opaque	5940Å very faint 5040 faint 4980 faint 4780 distinct 4620 } broad, 4500 } faint 4155 strong, broad		Treated, induced colour
10	0.42	pale yellow-green	weak bluish	inert	very strong greenish	opaque	5040Å distinct stronger 4980 distinct		Induced colour
11	0.87	golden-yellow	faint	inert	distinct yellowish	opaque	5940Å distinct * 5040 distinct * 4980 distinct 4850 faint 4780 distinct 4640 } broad faint 4500 } 4155 strong, sharp	"Cloverleaf" pattern around culet	Induced colour

* these 2 lines of equivalent strength

OBSERVATIONS ON COLOURED DIAMONDS

Stone No.	Weight ct	Colour	X-ray fluorescence	X-ray phosphoresc.	UV fluoresc. 3650Å	UV transparency to 2537Å	Spectroscope	Microscope	Identity
14	0.24	deep golden-brown yellow	inert	inert	inert	opaque	5040Å very faint 4550 cut-off		Natural colour because of 5040 line and no green fluorescence
15	0.55	deep orangy-brown	weak	very faint short	inert	opaque	5940Å marked to strong 5040 ~4500 cut-off	Carbonized material inside cracks	Induced colour
16	0.80	deep orange	inert	inert	inert	opaque	5940Å distinct to marked ~5680 faint * 5040 distinct * 4980 distinct ~5000 cut-off 6200-5900 stone passes some orange under copper sulfate solution		Induced colour
17	0.21	medium brown (tea-colour)	inert	inert	faint yellowish	opaque	* 5040Å faint * 4980 faint 4200 cut-off	Many cracks and breaks	Clues of natural colour

* these 2 lines of equivalent strength

OBSERVATIONS ON COLOURED DIAMONDS

Stone No.	Weight ct	Colour	X-ray fluorescence	X-ray phosphoresc.	UV fluoresc. 3650Å	UV transparency to 2537Å	Spectroscope	Microscope	Identity
18	0.42	medium yellow (greenish hue)	distinct bluish	inert	strong yellow	opaque	~5370Å distinct sharp 5040 distinct stronger than 4980 distinct wooly 4850 vague 4600 vague broad 4155 faint sharp 6200-6000 stone passes some orange under copper sulphate solution		Clues of natural colour
19	0.24	medium brown	weak	inert	faint yellowish	opaque	5040Å diffuse weak 4980 diffuse weak 4780 diffuse weak 4650 diffuse weak 4200 cut-off stone passes some orange under copper sulphate solution	marked parallel colour zoning	Clues of natural colour

OBSERVATIONS ON COLOURED DIAMONDS

Stone No.	Weight ct	Colour	X-ray fluorescence	X-ray phosphoresc.	UV fluoresc. 3650Å	UV transparency to 2537Å	Spectroscope	Microscope	Identity
20	0.38	very pale blue	distinct bluish	inert	distinct bluish-green	opaque	4980Å very weak diffuse 4620 weak diffuse {4600, 4500} vague 4155 distinct to strong	Many cracks with carbonized material	Induced colour Stone does not transmit electric current
21	0.75	steel-blue	weak	inert	inert	opaque	4780Å faint 4155 strong 4000 cut-off	old cut dark green, round spots 0·03 mm deep: on the table angle around the girdle.	Induced colour Stone does not transmit electric current Not radium treated: negative test after 5 days exposure on X-ray film sheet
22	1.04	pale water-green	marked bluish	inert	marked yellowish-green	opaque	* 5040Å faint * 4980 faint 4155 strong—Cape line		Clues of induced colour
23	0.86	pale green	distinct bluish-green	inert	distinct bluish	opaque	4780Å distinct broad 4650 weak 4510 weak 4155 strong broad		Clues of induced colour Colour does not coincide with Cape lines

* these 2 lines of equivalent strengh

OBSERVATIONS ON COLOURED DIAMONDS

Stone No.	Weight ct	Colour	X-ray fluorescence	X-ray phosphoresc.	UV fluoresc. 3650Å	UV transparency to 2537Å	Spectroscope	Microscope	Identity
24	1.00	pale water-green	faint	inert	inert	opaque	* 5040Å faint * 4980 faint 4780 distinct 4650 faint 4520 faint 4155 strong broad		Clues of induced colour Colour does not coincide with Cape lines
25	0.87	medium to dark moss-green	weak	inert	faint yellowish stronger on culet side, darker rim around girdle; weak yellowish phosphorescence	opaque distinct yellowish phosphorescence	near 7000Å lines partly faint (cited by Dugdale) 6700 faint 6200 weak large 5040 very strong ~4980 thin sharp 4820 distinct 4780 distinct 4650 weak 4200 cut-off		Induced colour Line 5040 is very much stronger than 4970, in contradiction to the rule given by Liddicoat for treated stones

* these 2 lines of equivalent strengh

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Photographs by the author.

SYNGENETIC MINERAL INCLUSIONS IN DIAMOND AS IDENTIFIED BY X-RAY ANALYSIS

Summary of a Paper by J. HARRIS of University College, London, in the "Industrial Diamond Review"

THE inclusion of foreign minerals in diamond crystals is of peculiar interest in view of the mystery surrounding the conditions under which diamond was formed in nature.

Even in the 19th century several workers had described some of the more striking of these inclusions and made more or less plausible guesses as to their identity, and in several of the books on diamond published in the present century resumés of diamond inclusion investigations are given in varying degrees of detail, for instance, in Spencer's translation of Bauer in 1904, in Crookes (1909), Catelle (1911), Escard (1914), and Wagner (1914).

One of the more informed workers was Sutton, who actually worked in the diamond fields for many years and published his observations in his book "Diamonds, a Descriptive Treatise", in 1920. Most of these investigators used the microscope as their main means of identification, relying chiefly on the form and colour of the enclosed minerals, due consideration being given to the types of mineral most likely to be found accompanying diamond in the basic rocks in which, presumably, it had its birth.

By the early 1930's, calcite, iron pyrite, dipside, magnetite, pyrope, olivine and graphite had probably been correctly identified in diamond by various workers. In 1948 and in 1952 Gübelin published extensive observations on diamond inclusions, accompanied by numerous photomicrographs, and the work was carried on by Eppler, who found it possible after crushing suitable industrial rough, to isolate some of the included particles, enabling closer microscopic investigation to be carried out, including determinations of refractive index. By such methods Eppler claimed apatite and ilmenite as diamond inclusions for the first time.

There are, however, limitations to these purely optical methods, and even an accurate refractive index value may not prove conclusive. The figure 1·6585 found by Eppler as average for his apatite particles, for instance, corresponds almost exactly with the average value of 1·652 for forsterite olivine.

PLATE I. *Isometric garnet inclusion* (×64).

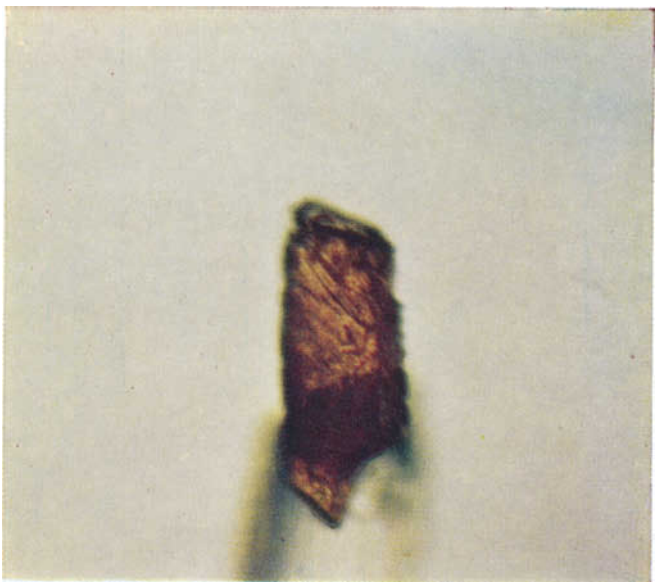

PLATE II. *Etched elongated rutile crystal extracted from a diamond* (×80).

As incidental to a general investigation of diamond a fresh approach to these problems of identification was made in the first place by Mitchell and Giardini (1953) in the U.S.A., who applied the powerful techniques of x-ray diffraction to establish the species of a number of elongated crystals of olivine which were noted in diamond "flats". These crystals were lying parallel to the (111) planes and elongated along the (101) direction of the diamond. Both x-ray rotation photographs and x-ray patterns from a single crystal, superimposed on the diamond patterns, were obtained, and the diagnosis was beyond doubt.

Since that time Russian workers have undertaken a systematic investigation of inclusions in diamond by x-ray methods, and have definitely identified chrome spinel, diamond, diopside, enstatite, graphite, iron hydroxide, olivine, pyrope garnet, and serpentine. In 1961, Milledge of University College was able to establish coesite (a high pressure polymorph of silica) as a rare inclusion in diamond. In 1966 Sharp found by x-ray powder photography that large dark regions in South African diamonds were sulphide ore minerals such as pyrrhotite, pentlandite and pyrite. The latter, however, was not considered to be a syngenetic inclusion.

During the present course of x-ray diffraction studies at University College, which is still in progress, 22 mineral species have been positively identified in diamonds from Southern Africa, Sierra Leone and Ghana. Six of these had not previously been identified by x-ray techniques, and a further three are completely new as diamond inclusions. The inclusions discussed and illustrated in this part of the paper are confined to the so-called syngenetic mineral inclusions; that is, those which are formed contemporaneously with the diamond. The other types of inclusion, not dealt with here, are known as epigenetic mineral inclusions, which are those which have formed subsequently to the formation of the diamond.

A syngenetic mineral must of necessity be one which is associated with the rocks such as peridotites, eclogites, etc., which made up the original environment when the diamonds were being formed. The mineral must also be known to have a stable phase at temperatures and pressures envisaged for the crystallization of diamond.

The illustrations show examples of well-developed syngenetic inclusions in diamond, the magnification of each being noted in

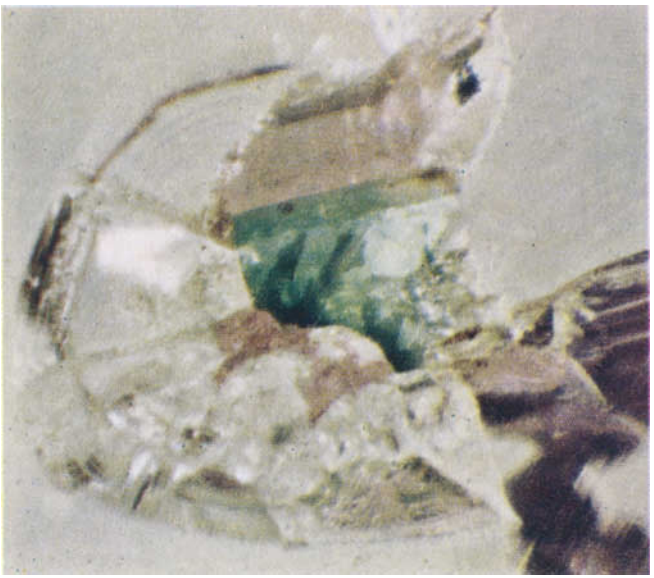

PLATE III. *Diopside inclusion* (× 14).

PLATE IV. *Isometric well-faceted magnetite inclusions* (× 64).

brackets. The photograph in Plate VI depicts one of three diamonds in which a dense white cloud of particles was observed; these being less than three microns in diameter. The shape of the cloud is here rectangular, but may be more rounded in other cases. Only a single line was seen in an x-ray powder photograph, but this at least indicated that the material is crystalline. So far this type of inclusion has been found only in Type I diamonds.

Single crystal syngenetic mineral inclusions vary from less than 0·05 to a maximum of 0·4 mm, and one of the main guides to their nature is their colour. Inclusions of *diamond* itself are usually difficult to see because of the similarity of their refractive index with that of the host mineral, unless the included crystal is "coated" by some other substance. Most included diamonds have an octahedral habit and show no strain birefringence, neither is there any internal fracturing or strain surrounding such inclusions.

Of the two specimens found to contain *coesite* inclusions, one showed a well-formed crystal, the other had multiple inclusions which together gave the coesite x-ray pattern. *Olivine* is the commonest inclusion in diamond, and is usually seen as colourless or faintly green crystals; sometimes well-formed, sometimes irregular in outline. *Enstatite* is a rarer inclusion, and usually a transparent faint green. It is virtually impossible to distinguish between olivine and enstatite inclusions except by x-ray analysis.

Garnet inclusions range from transparent deep red purples to light orange; some having a colour similar to topaz and zircon for which they have probably been mistaken by some workers. Garnet inclusions are commonly well-formed and isotropic. Three *rutile* inclusions found during this study were reddish to medium brown in colour: one of these was transparent and showed straight extinction. Opaque rutile is likely to be confused with goethite. *Diopside* inclusions are either a dull opaque green or transparent emerald green: the colour here forming a useful characteristic.

Magnetite inclusions are black and opaque, either lath-shaped or in long, irregular masses. So far, no octahedral crystals of magnetite have been observed. In very small diamonds (less than ½mm in size) the whole diamond may become attracted by a magnetic field when these inclusions are present. Irregularly shaped magnetite inclusions may easily be mistaken for graphite,

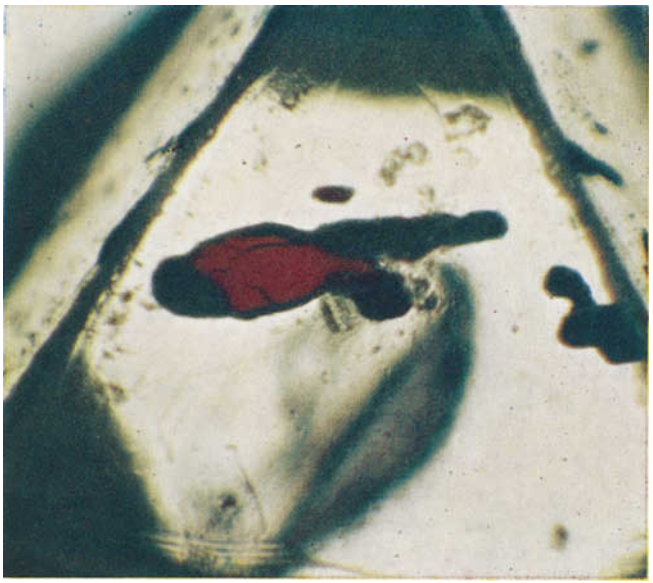

PLATE V. *Globular shaped chrome-spinel inclusion* (× 14).

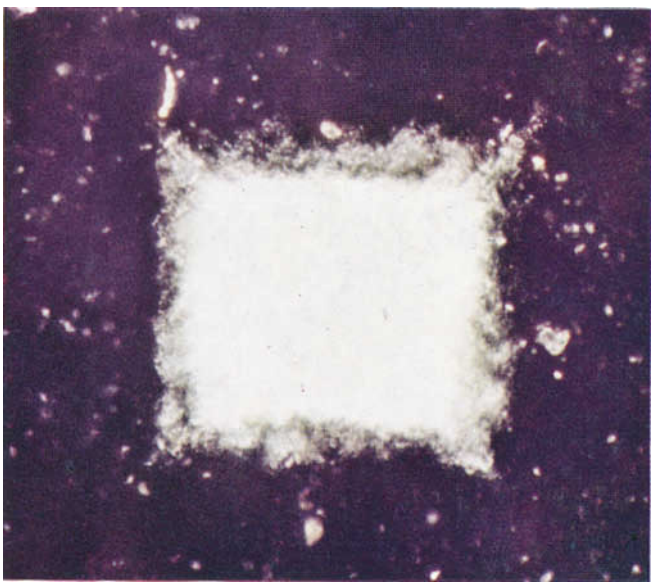

PLATE VI. *Dense white cloud-like inclusion of unknown composition.*

and discrete crystals for chrome spinel. *Ilmenite*, though common in exposed holes on the diamond surface, is extremely rare as an actual inclusion. Chrome spinel can perhaps be characterized by the deep cherry-red colour of these opaque crystals, though these may appear black in larger pieces, and then be confused with magnetite or graphite. Chrome spinel occurs commonly in dumb-bell shaped or rod-like specimens. These were found in diamond from Sierra Leone and Ghana, but doubtfully from South Africa.

Most diamond crystals exhibit internal strain when examined between crossed polars at points which can usually be seen to centre on to an inclusion; and sometimes the strain may be great enough to cause a fracture.

B.W.A

The Association is indebted to the "Industrial Diamond Review" for the coloured illustrations.

INSIGHT

By A. E. FARN

IT has been mooted among people in the jewellery trade that there are two kinds of gemmologist. The one, shall we say, the front-line troops who absorb the assaults of the gem-querying customer. The other, the support troops, who furnish the ammunition to them in the guise of theoretical and practical explanations.

It is said that the late Harry Truman, when President of the United States of America, had on his desk a notice which indicated "the buck stops here". Likewise, we in the laboratory of the London Chamber of Commerce feel the same way about jewellery tests. Provided the item is jewellery in the broad sense—we should be able to furnish the answer. We are not magic, we are almost human, we have certain skills which predominate and between the useful combination of experience, skill, training, aptitude, comparison stones, notes, books and stored-up knowledge, we come to a decision on most items.

Even to a modest expert or the shyest gemmologist there sometimes comes a moment of sheer amazement when, showing proudly a very rare or unusual piece to one's friends, acquaintance or family, they turn round and say is it rhodochrosite or is it an aximite? Just as guileless as that. In my early and possibly more enthusiastic days I bought a necklace of rhodonite beads—I had passed my diploma about six months previously and felt very proud of myself on spotting these beads on a street market stall. I showed them proudly to my wife who said, "Are they rhodonite?" She had helped me with my swotting, so maybe it was feminine insight!

For sheer feminine insight though I think one of the young lady workers in the office of the N.A.G. wants some beating (metaphorically). In the course of routine business we do all kinds of tests on all kinds of jewellery for the N.A.G. and the G.A. We are never very surprised at what we receive or what we are asked to do. Among quite an interesting assortment of stone elephants, jade figures, and similar items, was a box which contained a vanity case to test. We presumed by the outward appearance of the article that it was tortoiseshell or plastic imitation. Since it was very badly damaged we felt it must be a question of insurance replacement. So

we set to work to prove the material. The lid gave a very good distant vision reading of 1·54 and an examination by microscope of the darker portions of the mottling did not reveal the multitudinous dises described in Webster's compendium. The markings of brown/black and yellow in the mottling were also too sharp in their delineation. The conclusive test came about because the item was badly damaged. Working upon the theory that a little more wouldn't do any harm, we heated to red heat a very special hat pin we keep for such delicate tasks, placed it against an inconspicuous portion of a fracture surface and sniffed. Who hasn't smelt burnt milk on a saucepan? Well here was a golden opportunity to refresh ones olfactory senses. When casein—a plastic product with a density of 1·33 and refractive index 1·55—is burned it gives a smell like burned milk—which, since casein is a milk product, is not surprising. Hence the vanity case was casein—a plastic. What really intrigued me though were the instructions on the wrapper of the box containing the vanity case, which were: "Please test case in box". Did the young lady really separate out casein to make it "case in box" or was it feminine insight again?

Gemmological Abstracts

POUGH (F. H.). *The Jacobina amethyst mine in Brazil.* Lapidary Journ., 1969, 22, 10, p. 1306.

Most of the crystals found at Jacobina are a good rich violet colour. Hard-rock digging techniques are used, as the mine lies in solid rock. It is privately owned.

S.P.

EULITZ (W. R.). *The optics of brilliant-cut diamonds.* Gems and Gemology, 1968, XII, 9, pp. 263-271, 5 illus.

This article, as the title infers, deals with the proportions of diamond, and is a continuation, if that word can be used, of the work of Roesch, Eppler, Kluppelberg and Grodzinski. The treatment is mainly mathematical.

R.W.

GUNN (C. B.). *A descriptive catalog of the Drift diamonds of the Great Lakes region, North America.* Gems and Gemology, 1968, XII, 10 & 11, pp. 297-303 and 333-334, 1 map.

A list of the known diamonds found in the Great Lakes region, a "potted history" being given with each stone recorded. This list of stones was originally part of a research on the vexed question of the original source of North American diamonds.

R.W.

MCKAGUE (H. L.). *The serpentine mineral group.* Gems and Gemology, 1968, XII, 11, pp. 326-332 and 356, 6 illus.

A concise article on the serpentines. The text mainly treats with the mineralogical and petrographical aspects rather than those more useful to the gemmologist. The term "Yu-Yen Stone", ascribed to Faust and Fahey, is not a term current in gemmological literature.

R.W.

ANDERSON (B. W.). *The first two taaffeites: an historical note.* Gems and Gemology, 1968, XII, 9, pp. 259-262.

Gives an account, from personal knowledge, of the finding of the first taaffeite by the late Count Taaffe during 1945. The characters of the mineral are given.

R.W.

LIDDICOAT (R. T.). *Developments and highlights at the Gem Trade Laboratory in Los Angeles.* Gems and Gemology, 1968, XII, 9, 10 & 11, pp. 281-288; 311-320; 344-352, 64 illus.

In these reports notes are given on the effect of dust on tourmaline, an emerald with a subsidiary crystal protruding from the unpolished girdle, and an unusual hematite intaglio, which had the surface sand-blasted to give it a roughened effect. Unusual opal doublets and a doublet consisting of a synthetic sapphire cabochon top cemented to a synthetic spinel base are mentioned. By x-ray powder photograph and chemical analysis a pink mineral was identified as benitoite but no information is given as to whether the stone was transparent and suitable for use as a gemstone. Other items were interesting inclusions seen in a chalcedony and extraordinary features in a diamond. There is a discussion on green-coloured yttrium aluminium garnets grown synthetically. The result of x-ray and isotope irradiation of kunzite and morganite is mentioned. Trapiche emeralds are again referred to, and so is another pendeloque-shaped diamond with a double culet. Among other unusual pieces examined were a possible fake amber containing a spider, a carved statuette in banded serpentine, a cut cuprite and an andesine-labradorite cat's-eye. A new source of peridot from North Carolina and emerald from Zambia are reported.

R.W.

CROWNINGSHIELD (R.). *Developments and highlights at the Gem Trade Laboratory in New York.* Gems and Gemology, 1968, XII, 9, 10 & 11, pp. 277-280; 304-310; 335-343, 52 illus.

This laboratory has examined several blue zoisite crystals, one of which weighed more than 1100 carats. The problem of the identification of dyed lapis-lazuli may be got over, it is suggested, by using a swab moistened with finger-nail polish remover which

colours if dye be present. The waxing of lapis-lazuli is also mentioned. An interesting item was a specimen of "Yunnan jadeite" which showed red through the colour filter although it was not dyed. There is a good report on a radium-treated diamond which recorded a radioactivity of 40 milliroentgens per hour. Recorded also were a synthetic blue spinel, which did not show red through the filter, unusual diamond inclusions, a doublet of blue synthetic spinel cemented onto a base of natural star-sapphire, a plastic-coated beryl and an imitation turquoise which revealed itself by turning yellow a spot of hydrochloric acid placed upon it. Intaglios of glass cemented to a base of chalcedony, trapiche emeralds and many varieties of composite stones are recorded. The inclusions seen in transparent green grossular, quartz and tanzanite are mentioned. The testing of a snuff bottle which was probably made of horn is discussed, as well as an unusual synthetic emerald which had a density of 2·73 and indices of refraction of 1·565-1·570. It had odd inclusions which fluoresced yellow and others of the typical veil-like synthetic type. Diamonds with rubbed facet edges, a large "portrait" diamond and a double culet effect seen in a pendeloque-shaped diamond are noted. The question of synthetic and natural brown scheelite is discussed and the absorption spectra of various synthetic scheelites are illustrated. Doublets formed of a crown of synthetic white spinel and a base of strontium titanate, are said to be fused together, but examination seems to show that a modern hard cement may have been used.

R.W.

KAGAYA (B). *Application of goniometry to gemmology.* Journ. Mining Coll., Akita Univ., Ser. A, Vol. V, No. 3, 1-21, 13 figs., 1968.

A method has been developed for the characterization and identification of individual cut diamonds by two-circle goniometry. The angular coordinates of the facets of cut stones are measured to 0·01′. The author has measured 62 diamonds of over 1 carat and considers that goniometric measurement for cut stones is as useful as the fingerprint method for individual people. Assuming the limit of the longitude and latitude of each of the 32 facets $\pm 3°$ and an allowable error of the value of each facet $\pm 3'$ (including personal and instrumental errors), the probability of the occurrence of equal goniometrical data is calculated to be $9{\cdot}58 \times 10^{41}$.

R.A.H.

SMITH (J. V.) & RIBBE (P. H.). *Atomic movements in plagioclase feldspars: kinetic interpretation.* Contrib.Min.Petr., Vol. 21, No. 2, pp. 157-202, 1969.

An advanced structural interpretation of the plagioclases is presented in which the delicate irridescence of peristerite and the labradorescence of plagioclases of intermediate composition are explained in terms of the diffraction of light from alternate lamellae of slightly different structural type. Labradorescence is found in intermediate plagioclases relatively rich in potassium and the lamellae represent segregation of alternate bands richer in sodium and potassium than their neighbours. R.A.H.

BARTOSHINSKIY (Z. V.). *Some features of diamonds from placers in the northeast Siberian platform.* Geol. and Geophys., Acad. Nauk SSSR (Siberian Branch), 1967, No. 3, 60-67 (in Russian; English summary p. 146).

The crystal habit, colour, transparency, photoluminescence, and degree of fragmentation of diamonds from placer deposits of the northeast Siberian platform have been statistically tabulated, and are compared with one another and with diamonds of the Yakutian fields to the south. Rounded crystals and crystals with hackly striations predominate in the northeast Siberian fields, and there is less variation in crystal morphology than in Yakutia. Coloured diamonds are more common in the northeast Siberian fields, with brown and yellow tints predominant. Non-luminescent diamonds predominate, but crystals with blue luminescence are relatively abundant. The degree of crystal fragmentation varies widely among the diamond fields studied, and is attributed to brecciation during emplacement of the source pipes. R.A.H.

BOOK REVIEWS

SUTHERLAND (C. V.). *Gold: Its beauty, power and allure.* Thames & Hudon, London, 1969 (third and revised edition). £2 10s.

Dr. Sutherland's revised and enlarged edition of his classic work is compulsive reading for all who are fascinated by the use of gold down the ages, whether for jewellery, coinage or industry. The effect of gold in the monetary world of today is dealt with in an expanded last chapter, which speculates on its future in a world of credit currency. S.P.

HARLBUT (CORNELIUS S.). *Minerals and man.* Thames & Hudson, London, 1969. £5 5s.

During the past five years various books on minerals and gemstones have been produced, most of which can best be described as "picture books". Professor Hurlbut's "Minerals and man" can, perhaps, be classed as a "picture book", but a "picture book" with a difference, for the text is detailed and entertainingly written and the colour plates are superb.

The book contains 19 chapters commencing with "Minerals and how to know them", a chapter which gives an excellent description of the elements of crystallography and the physical properties of minerals. This is followed by chapters on "Early use of minerals", "The earth and its rocks", "Minor minerals of the rocks", and "Nature's treasure house", a chapter which deals with the pegmatite rocks.

There are chapters in which the minerals and their formations are well described. Minerals which fluoresce in ultra-violet light are given a chapter on their own.

Chapters which concern the gemmologist most are "Minerals of the precious stones", "Quartz", and "Coloured stones and ornamental minerals". Then follows "Minerals for atomic energy", a chapter of modern interest; and the penultimate chapter, "The mines and minerals of Cornwall", is so well covered by this American writer that it can only be supposed that the author spent some time in the Duchy and enjoyed his stay and was intrigued by its history. The final chapter, "An incombustible fabric and a stone that burns", deals with the asbestos minerals and sulphur. The volume is completed by an appendix consisting of a table of the properties of some common minerals, which is more comprehensive than one might expect, but which does not give any optical properties. There is a very full index.

The reviewer finds the text adequate and written with that personal touch which makes so much difference to the ease of reading and, with the beautiful pictures, a real understanding of minerals. There are, however, a few minor points which merit discussion. They mainly devolve upon the fact that a mineralogist, as a rule, does not completely understand the modern conception of gemmological nomenclature, and for the benefit of future editions they may be referred to here.

The terms "hyacinth" and "jacinth", which in earlier times have been used indiscriminately for both zircon and hessonite garnet, are not now current; nor is "chrysolite" now a permitted name, for it has been used for many different species of gemstones in the past. The term "pigeon's-blood" as a colour for ruby, and the prefix "oriental" for colours of corundum common to stones of other species are outmoded terms and should not be perpetuated.

The most common alexandrite simulant is not synthetic spinel but synthetic corundum, which *is* coloured by vanadium, whereas the much less common synthetic spinel appears to owe its changing colour to traces of cobalt and chromium. That amethyst turns colourless at 450°C and yellow at 550°C is not strictly true as experiments by G. O. Wild have shown. It is doubtful whether Blue John can strictly be termed fibrous, and is there a black pyrope garnet? Mention could have been made of the important source of sphene in Baja California, and Macon Co., the source of rhodolite garnet, is in North Carolina, not in Georgia.

Some of the values of density given in the appendix table call for amendment, the most important being the value for lazurite (lapis-lazuli). The value of 2·4-2·45, as given, is probably correct for pure grains, but the ornamental lapis-lazuli is a rock and, as pointed out by B. W. Anderson, the density for the ornamental lapis-lazuli is about 2·8. The density of olivine given both in the table on page 41 and in the appendix table as 3·27-4·37 should be 3·27-3·37. 3·51 for the density of pyrope garnet is too low—it should be, to be more realistic, 3·65. Corundum has a better mean at 3·99, and better values for zircon would be 4·00 to 4·68, in order to cover the metamict low type. The values for beryl need revising for much emerald has a density of 2·69 to 2·71. A better range for beryl would be 2·7 to 2·9, which would cover the higher density of the caesium-rich beryls. Further, 2·2 is too low a value for serpentine, for most of the ornamental serpentines have a density near 2·6.

Despite these minor criticisms "Minerals and man" makes a very fine volume and is a book that can be recommended for popular reading as it gives such interesting insights into minerals and their uses.

R.W.

TOLANSKY (S.). *The strategic diamond.* Oliver & Boyd, Edinburgh, 1968, 119 pp. 7s. 6d.

This is a paper-back in the "Contemporary Science" series of the publishers. Professor Tolansky has written in the style of his established *History and use of diamond* and his book gives a popular account of diamond and its technological uses. A chapter on diamond grits, a favourite subject of the author, is of interest to industry. A useful addition to the literature on diamond, presenting known information in a fascinating way.

S.P.

THEISEN (V.). *Diamanten-Fibel.* Diamond Handbook 1968. Printed in Germany. DM 28·50.

A very well produced book on the determination of the quality of cut diamonds with 300 illustrations, many of them excellent microphotographs. There are tables of weights for the various cuts and formulae are given to determine the weight loss when re-cutting old or damaged brilliant-cut stones.

The chapters dealing with cut and purity are well set out and should prove to be useful to students as well as jewellers, especially the photographs showing the differences between, say, VVS and VS or between first and second piqué, although one could perhaps argue about one or two small points. Of special value is the confrontation of photographs with excellent drawings showing clearly the inclusions or defects under discussion. The illustrations naturally are originally photomicrographs or macrographs. Inspection under the Gemolite, for instance, at 10 × magnification is more critical than under a 10 × loupe, which is the recognized method in the trade. Any other method which tends to enlarge the importance of the smallest natural inclusion should be discouraged.

The chapter dealing with the colour grading suffers from the fact that the book is produced in black and white only, although of course, reasonable colour prints would be expensive and most difficult to reproduce. The way to determine the colour is perhaps not quite adequately described; one really should look at the stone from all angles and certainly along the girdle plane. The chapter on colour is difficult to use because references to different shades of grey and black do not convey very much.

For a jeweller with an understanding of German the book would be an excellent addition to his library.

W.S.

MUNSURI (A. SANTOS). *La Esmeralda.* Instituto Gemologico Español, Madrid. Limited edition 4,000 numbered copies. 63s.

A monograph on emerald, in Spanish, produced on good quality paper, but rather inadequately bound between limp covers. 72 colour plates which are, for the most part, excellent.

The author has devoted the first five chapters to classical references, superstitions and famous historical emeralds. A second part deals with the many sources of the gem in some imaginative detail and includes some places which are not known to produce gem quality material and others where different minerals, such as tourmaline and hiddenite, have been mistaken for emerald. Although the book professes to deal with such other minerals, the reviewer feels that their inclusion among sources of emerald is misleading.

The third section of the book deals with technical (gemmological) details. A coloured schematic representation of the chemical composition contributes little and could be mistaken for an atomic lattice. The few illustrations of absorption spectra are not always accurate. Tables of constants are a little erratic in that there is no attempt to give refractive indices in the same order every time. Chemical formulae are quoted in reverse to the usual order, e.g. $(SiO_2)_6\ Al_2O_3\ BeO$. Olivine (peridot) is listed as a uniaxial mineral.

Most of the illustrations are good and colour reproduction is acceptable. One obvious green aventurine quartz is labelled fuchsite mica and another, purporting to be hiddenite in pegmatite, looks much more like tourmaline in quartz. The illustrations of inclusions, all the work of the author, are particularly good and, for the most part easily interpreted.

This book is the first of a series planned on the major gems. As such its contribution could be limited by the language barrier, although Spanish is third among the major commercial languages of the world.

The single page of bibliography contains 10 or more spelling and other errors, including one in which the book has apparently written the authors. Other mis-spellings and misprints appear in the text. These occur easily where foreign names are set by type-setters unfamiliar with them, and careful proof reading is needed to eliminate such errors.

R.K.M.

YOUNG (S.). *The Queen's jewellery.* Michael Joseph, London, 1969. 35s. 120 illus (12 in colour).

A collection of photographs, with descriptions, of some of the favourite items from Her Majesty's personal jewellery. Diamonds form a considerable part, and sapphires and pearls are also favoured. In many instances the photographs show the Queen better than some of the jewellery.

S.P.

COMMON GEMS OF SAN DIEGO COUNTY, CALIFORNIA

By PAUL WILLARD JOHNSON

With photographs by the author

SAN DIEGO COUNTY is richly endowed with gem minerals. In the 4,258 square miles of the county more than 140 different minerals have reportedly been found. Here, the title "gem basket of the United States" is justly deserved, for no other U.S. county has the profusion, variety and quality of gems so represented within its boundaries. From the ocean on the west through the mountains in the middle to the desert on the east—San Diego County is unique in physiography.

The common gem minerals described herein, occur in pockets, or vugs, in granitic pegmatite dikes or bodies. No placer deposits of gemstones have ever been found in San Diego County. The gem mines are located in a central mountain belt trending from northwest to southeast across the county (Fig. 1). It is peculiar that the pegmatite districts closely coincide with the northwest to southeast

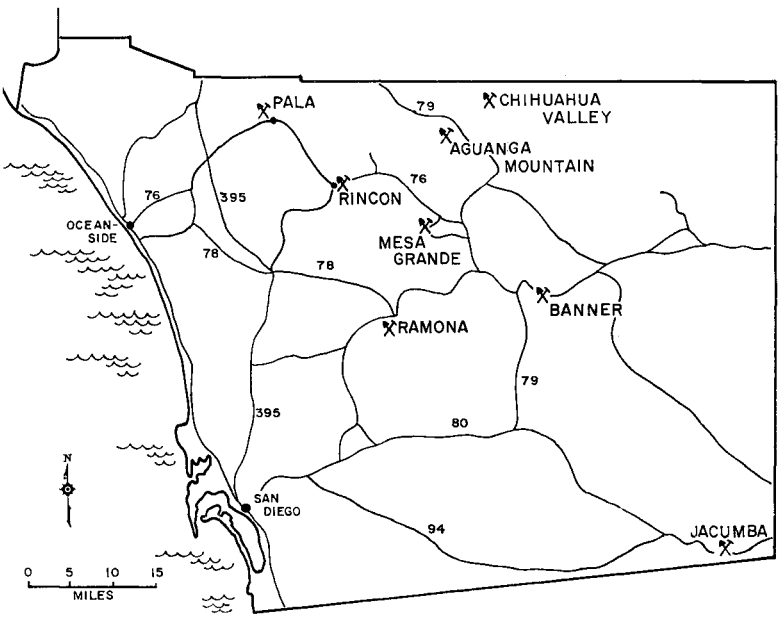

FIG. 1. *Map of San Diego County, California showing the location of the main pegmatite gem mining districts.*

trending fault zones. Most of the gem districts occupy areas of dense chaparral (low vegetation), composed mainly of greasewood (or chamise).

There are eight main pegmatite districts: Aguanga Mountain, Banner, Chihuahua Valley, Jacumba, Mesa Grande, Pala, Ramona and Rincon. These districts are indicated on the map. The two principal mining districts are Pala and Mesa Grande.

Lepidolite seems to be a valuable indicator mineral; without it there is very little chance of finding coloured gemstones. Lepidolite in the Pala district has been dated by John Earl using the rubidium-strontium method and found to be 106, plus or minus six million years old.

Matrix specimens in the past were usually discarded and ended up on the dump. They are currently very much in vogue and specimens of this type from San Diego County grace mineral collections throughout the world.

The most complete permanent collection of San Diego County gems and minerals, mainly a study collection, can be viewed at the San Diego Museum of Natural History in Balboa Park, San Diego, California. A small collection of specimens from the county can also be seen at the San Diego County Department of Agriculture at 5555 Overland Avenue, San Diego, California. During the summer the San Diego County Fair held at Del Mar, California, usually has an excellent collection of San Diego County minerals and gems.

Historical Sketch

Local Indians had been collecting surface tourmaline from the Pala and Mesa Grande districts before white men arrived. In many Indian graves have been found green and pink tourmalines. The first discovery by white men of gems in San Diego County was in 1890, when Charles Russell Orcutt found pink tourmaline at what later became the Stewart mine at Pala (Figs. 2 and 3). This stimulated a local search for other gem deposits.

In 1892, 18 tons of lepidolite from the Stewart mine at Pala were shipped to New York for specimens of pink tourmaline sunbursts on lepidolite. The famous Himalaya mine, in the Mesa Grande district, was first opened in 1898. The Himalaya mine was first worked by C. R. Orcutt, and ater by Gail Lewis and Fred J. Rynerson. The Mesa Grande district was most actively mined from 1902 to 1912.

FIG. 2. *Main entrance on the south side at the Stewart mine, Pala district, San Diego County, California. It was here that gemstones were first discovered in San Diego County. Because of the lilac-colour of the lepidolite (lithia mica) found here it was at first thought to be cinnabar, an ore of mercury. The large white area in the centre right is the mine dump.*

FIG. 3. *Open cut on north side at Stewart mine, Pala district, San Diego County, California. It is here that the compact lepidolite is shot through with pink tourmaline.*

Kunzite was first found at the Katerina mine on Hiriart Mountain, Pala district, in May 1902 by M. M. Sickler and his son Frederick M. Sickler. The mineral sicklerite was named for the son. In May 1903 the famous Pala Chief mine was opened on Chief Mountain in the Pala district.

The Rincon district was first prospected by John Mack in 1903 and was worked primarily from 1903 to 1910. The Ramona district was first discovered in 1903.

The fall of the Chinese dynasty, headed by the dowager Empress Tzu Hsi, in 1912 caused the market for pink tourmaline to dwindle to insignificance. Thus, the Himalaya mine was forced to close down. When the news arrived, the miners left in such a hurry they didn't even bother to remove their tools. Years later when the mine was reopened they found all the miners' equipment, just as it had been left, and open pockets of tourmaline.

Frank A. Salmons was an early developer in the Pala district. The mineral Salmons te was named in his honour.

Morganite, the pink cesium variety of beryl, was first found in the Pala district.

In 1947, George Ashley, known as a fine faceter of kunzite, bought all the mines on Hiriart Mountain in the Pala district. Presently, Norman E. Dawson of San Marcos, controls the Fargo, White Queen and Vanderburg mines on Hiriart Mountain.

Since 1914, gem mining in San Diego County has been on a small scale. Most of the gem mining at present is being done only by individuals or small groups.

PRODUCTION

From 1900 to 1914 about 90 per cent of the gem output of San Diego County was recorded. Over 90 per cent of the gem production has come from five mines: Himalaya and San Diego in the Mesa Grande district and the Pala Chief, Tourmaline Queen and Katerina in the Pala district. Over $320,000 (£133,000) worth of gem minerals have been taken from the Pala district alone in the last 50 years From 1898 to 1952 the Mesa Grande district produced over 244,850 pounds of tourmaline worth approximately $779,700 (£325,000). The estimated market value of cut stones of the Mesa Grande district tourmaline from 1901 to 1912 is 2·7 million dollars (£1·1 million). The Himalaya has produced more tourmaline

(about 100 tons) than all the other mines in San Diego County combined. The total value of gem minerals (in the rough state) in the county has been at least 2·3 million dollars (£958,000).

PEGMATITES

The granitic pegmatite dikes or bodies originate in the north in Riverside County (where they were first found by Henry Hamilton in 1872 on Thomas Mountain)—pass through San Diego County and terminate on the Gulf of California about 350 miles south of the United States border in Baja California, Mexico. The pegmatites are underlain mainly by plutonic igneous rocks of the Southern California Batholith. This batholith is composed mostly of gabbro, tonalite, diorite, granodiorite and granite.

The common gem minerals discussed in this article are all pocket minerals and are found exclusively in the "pocket pegmatite" part of the dike, which usually varies in thickness from a few inches to about four feet. Pegmatite is a plutonic rock that is irregular in texture and usually very coarse grained. It is composed mainly of quartz and feldspar of the perthite variety, with minor amounts of mica and gem minerals.

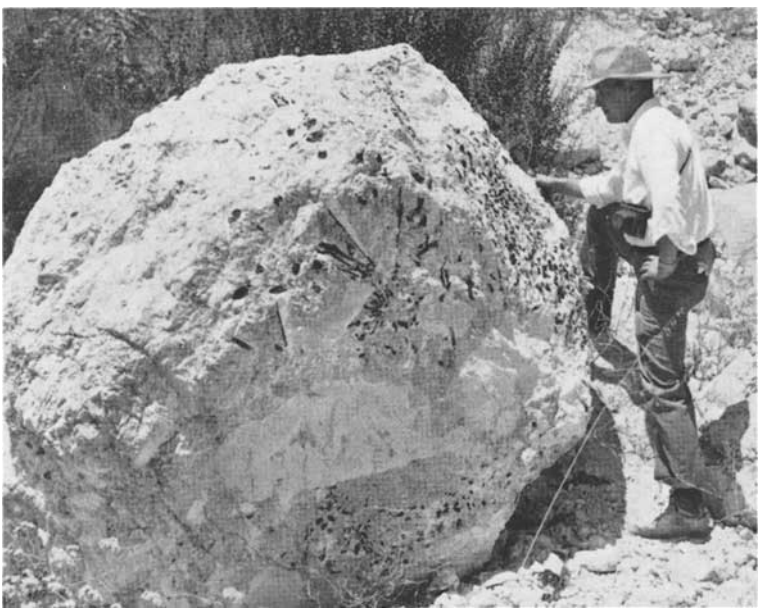

FIG. 4. *Close-up of a large block of pegmatite at the north side open cut of the Stewart mine, Pala district, San Diego County, California. The black spots are black tourmaline.*

Four zones of a complex pegmatite dike are frequently recognized: (1) border zones, or outermost zones, (2) wall zones, (3) intermediate zones, and (4) cores or innermost zones. Graphic granite is usually present in the border and wall zones. It is composed of a cuneiformlike pattern of quartz and feldspar. The intermediate zones, or line rock, are frequently a garnet-rich aplite. Zones of massive (bull) quartz can usually be found between the gem-bearing pegmatites and the sourrounding country rock. "Pocket pegmatite" is customarily found in the cores of the dikes, and is composed mainly of quartz, albite and orthoclase with minor amounts of microcline, muscovite, lepidolite and black tourmaline. It is within the "pocket pegmatite" that the vugs and pockets of gemstones are found. A single pocket in the Mesa Grande district reportedly produced 1,500 pounds of tourmaline. The pockets are usually filled with a red clay composed mainly of the mineral montmorillonite. Most of the gems are encrusted with this pocket clay and must be cleaned to show their beauty. Sometimes in the mining operations pockets are encountered, in which the gem minerals are so friable they will crumble to pieces when touched.

Pegmatite dikes vary in thickness from less than an inch to 100 feet, and in length to about one-half mile. The productive Hmialaya dike averages only four feet in thickness.

BERYL

Crystal description: Hexagonal system, hexagonal division; dihexagonal-dipyramidal class. In San Diego County it crystallizes in beautiful hexagonal prisms, some of which are vertically striated. Also equant to tabular. Faces of the second-order pyramid are commonly well-developed.

Physical properties: Colour; white, blue, yellow, green, and pink. Lustre: vitreous. Hardness: 7·5-8. Specific gravity: 2·63-2·80. Fracture: conchoidal to uneven. Cleavage: imperfect and indistinct. Uniaxial and optically negative. Transparent to subtranslucent. Tenacity: brittle. Not acted upon by acids, with the exception of hydrofluoric. Refractive index: $\omega = 1{\cdot}568—1{\cdot}602$ and $\varepsilon = 1{\cdot}564—1{\cdot}595$.

Composition: $Be_3Al_2Si_6O_{18}$.

Beryllium aluminum silicate. Sodium, lithium and cesium may replace part of the beryllium, thus reducing the beryllium oxide content.

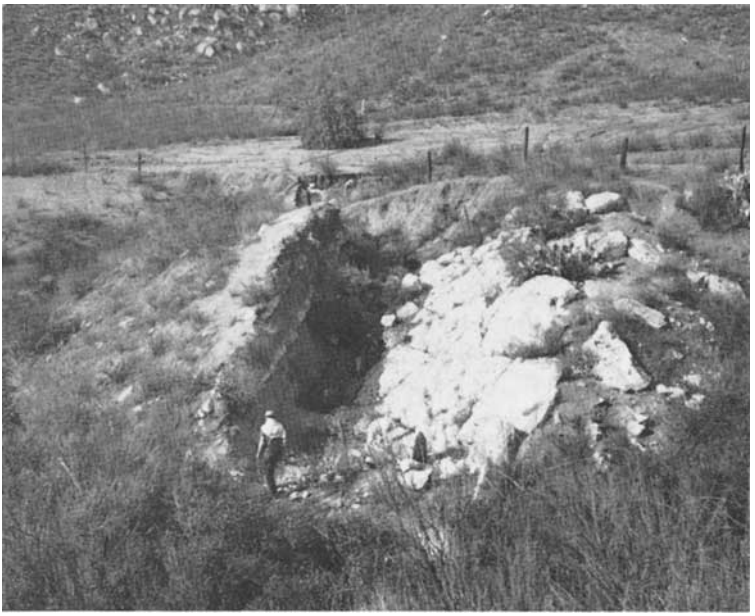

FIG. 5. *Pegmatite dike at the Mack mine, Rincon district, San Diego County, California. The white area in the centre is the dike which is dipping 43 degrees southwest. This mine is noted for prisms of light-green beryl.*

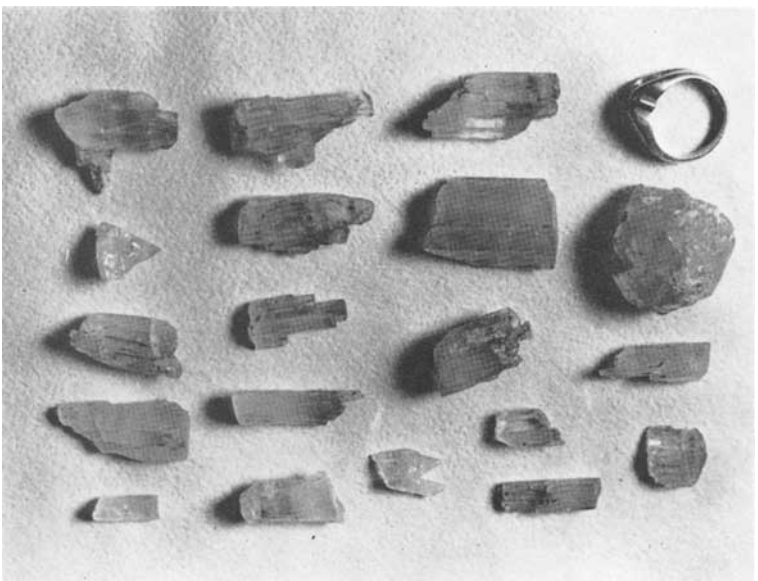

FIG. 6. *Rough crystals of beryl mainly from the Emeralite Number Two mine on Aguanga Mountain, San Diego County, California. The specimen just below the ring (shown for scale) is morganite. All specimens shown are from the author's cabinet.*

Varieties occurring in San Diego County:

Aquamarine—Bluish-green, blue, light green, yellow-green. Golden beryl—Yellow. Goshenite—Colourless. Morganite —Pink, pale rose to peach colour.

Occurrence: In San Diego County beryl has been found in the following districts: Aguanga Mountain, Jacumba, Mesa Grande, Pala, Ramona and Rincon.

Interesting facts: Beryl from San Diego County is associated with quartz, albite, lepidolite, potash feldspar, muscovite and tourmaline. Gem beryl in San Diego County occurs to about six inches in maximum dimensions, with an average of 2·5 inches or less. Non-gem beryls in the county get quite large. The author found one that weighs over 85 pounds. Some of the San Diego County beryls are tapered, probably due to the effects of corrosion.

Morganite beryl was named by Dr. George F. Kunz in honour of the banker John Pierpont Morgan. Morganite is rarer than emerald, although not as popular. Morganite seems to be more common than aquamarine in the county. Morganite and aquamarine usually occur as greatly compressed hexagonal prisms. Some of the prisms have side growths with flat terminations at different levels along the c-axis. Usually the county beryl has a flat basal termination, which sometimes has pyramidal faces developed. Some of the flat basal terminations have a negative cavity due to corrosion paralleling the c-axis. The Mack mine (Fig. 5) in the Rincon district, has produced some flawless light-green prisms of beryl. One beryl from Pala had an aquamarine centre with a morganite edge. The beryls of San Diego County are usually faceted with the emerald-cut and these are usually cut deep to bring out the colour.

Beryl from San Diego County sometimes has inclusions of muscovite, lepidolite, quartz and tourmaline. It commonly has two-phase inclusions with a gas bubble. Two movable bubble inclusions were found out of 26 specimens examined. One movable bubble, after being heated with the microscope light, disappeared. There are also veil-like liquid inclusions.

SPESSARTITE

Crystal description: Isometric system; hexoctahedral class. Commonly in crystals, usually dodecahedrons up to $\frac{3}{4}$ inch in diameter. The larger crystals from San Diego County are usually

simple dodecahedrons. Some are heavily etched and others, usually the smaller ones, are commonly trapezohedral with minor dodecahedral faces. The smaller the crystals of this garnet the more perfect they seem to become.

Physical properties: Colour: orange to dark red or brown. San Diego County spessartite varies according to the GSA rock colour chart from a moderate reddish-orange 10R 6/6 to a moderate reddish-brown 10R 4/6. Lustre: vitreous to resinous. Hardness: 6·5-7·5. Specific gravity: 4·19. Fracture: subconchoidal to uneven Cleavage: none. Transparent to subtranslucent. Refractive index: 1·79-1·82.

Composition: $Mn_3Al_2(SiO_4)_3$.

Manganese aluminum silicate. Ferrous iron usually replaces some of the manganese and ferric iron some of the aluminum.

Occurrence: In San Diego County spessartite is found primarily in the Ramona district; with very minor amounts in the Pala and Mesa Grande districts. In the Ramona district it is found mainly at the Little Three mine, and sometimes at the A.B.C. and Hercules mines.

Interesting facts: Spessartite from San Diego County is associated with albite, quartz, perthite and black tourmaline. For a long time these garnets in San Diego County were thought to

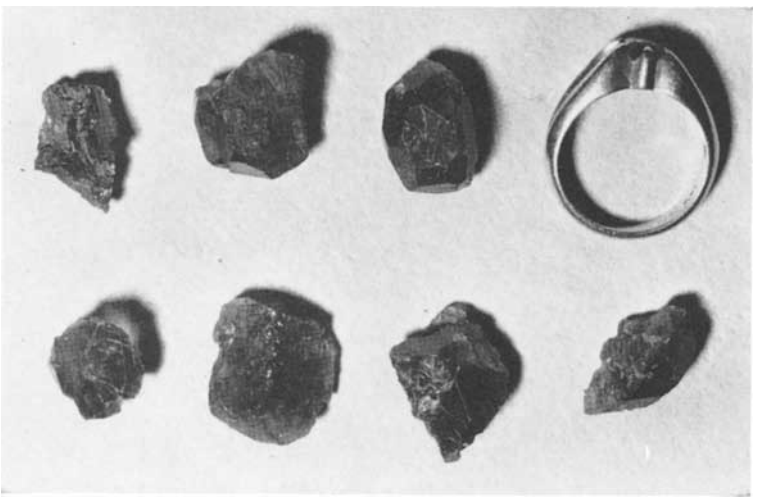

FIG. 7. *Rough spessartite crystals from the Little Three mine, Ramona district, San Diego County, California.*

be essonite (hessonite), which is another name for grossularite. Finally, gemmological tests backed up by x-rays led to the corrected designation of spessartite.

Spessartite when fused with sodium carbonate gives a bluish-green bead (test for manganese). This rare garnet exhibits very pronounced step-like growth on the crystal faces and most crystals have been etched.

Spessartite in San Diego County commonly has two-phase inclusions with a gas bubble. It also has liquid inclusions that are very irregular in outline. It has wispy veil-like inclusions. What looked like a quartz crystal inclusion was found in one crystal. This spessartite rarely has angular three-phase inclusions which contain a liquid, gas bubble and crystal of some unknown mineral.

A garnet found in the pegmatite dikes just west of Tule Mountain, in the Jacumba area, was found by x-ray examination to be half spessartite and half almandite. This garnet, quite a bit redder than the orange-coloured spessartite, occurs on white feldspar and makes very attractive specimens, besides cutting into very colourful gems.

Spodumene

Crystal description: Monoclinic system; prismatic class. In San Diego County the crystals are prismatic, often flattened (lath-shaped) and vertical planes striated and furrowed. Spodumene nearly always shows lamellar twinning on the front pinacoid, with the twin plane parallel to their flat sides. Crystals as long as nine feet and 14 inches wide have been found in San Diego County.

Physical properties: Opaque varieties: buff, white, lavender and greenish; transparent varieties: lilac, colourless, light blue, yellow and green. Lustre: vitreous, on cleavage surfaces somewhat pearly. Hardness: 6·5-7. Specific gravity: 3·13-3·20. Biaxial and optically positive. Fracture: uneven to subconchoidal. Tenacity: brittle. Transparent to translucent. Coloured varieties are strongly pleochroic. Cleavage: perfect prismatic at 87 and 93 degrees. A tough splintery fracture distinguishes it from feldspar. A parting or false cleavage due to twinning is shown by most specimens; it is more readily obtained than the prismatic cleavage and yields many platy masses which may be either thick or thin. Refractive index α 1·65-1·66; β1·66-1·67; γ1·675-1·68.

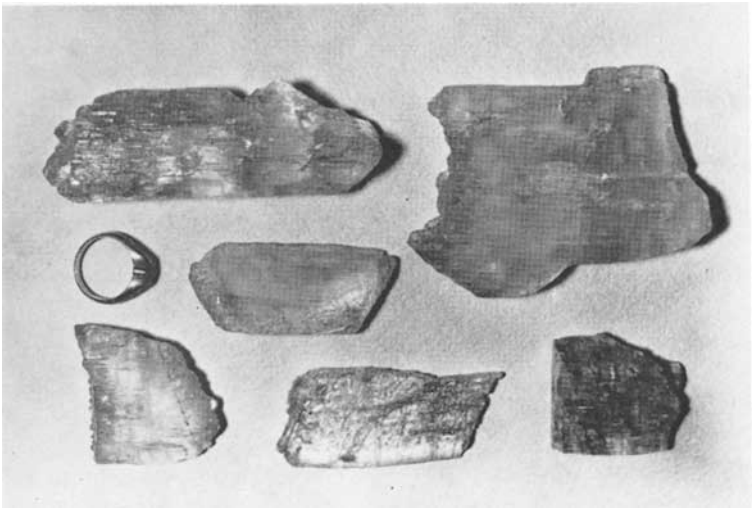

FIG. 8. *Medium-sized crystals of spodumene from the Pala district, San Diego County, California. The three specimens on the right are kunzite and the three on the left are the triphane variety. The crystal in the lower left-hand corner is twinned.*

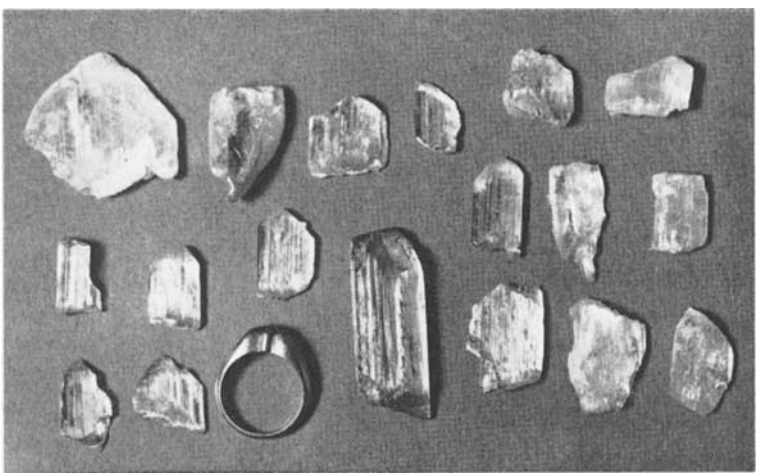

FIG. 9. *Small crystal fragments of spodumene from San Diego County, California. The specimen in the upper left exhibits the typical etched termination on a crystal fragment. Notice the striations.*

Composition: $LiAlSi_2O_6$.

Lithium aluminum silicate. Generally contains a little sodium which replaces the lithium.

Varieties occurring in San Diego County:

Blue Spodumene —Light blue

Green Spodumene—Light green

Kunzite —Pale to rose-pink, violet, lilac

Triphane —Colourless to yellow.

Occurrence: In San Diego County spdumene occurs at Aguanga Mountain, Mesa Grande, Pala and Rincon. Most of the gem spodumene has come from the Pala Chief, Katerina and Vanderburg mines in the Pala district. The Pala Chief mine, on Chief Mountain, has been the foremost producer of gem quality spodumene in the United States.

Interesting facts: Spodumene in San Diego County is associated with quartz, lepidolite, albite and muscovite. All transparent spodumenes are etched fragments of once larger crystals. These crystal fragments are deeply striated in a direction parallel to their elongation. The original lustre of the faces has been removed and the surface is sometimes altered to appear dull and or earthy. Many specimens occur as crystal fragments within altered spodumene. Most of the gem quality fragments have been less than 15 inches long. They also have triangular etch pits (Fig. 10). The deepest colours are seen when the stones are viewed parallel to the long axis of the crystal; the table of cut stones should also be oriented in this manner. Spodumene is usually cut deep so that maximum colour is obtained. The pre-form should be sawed into shape and then finished on a fine lap, as it has a tendency to break near the edges during cutting.

The colour of some stones fades on prolonged exposure to sunlight. Spodumene has had its colour changed to light green by exposure to a strong source of x-rays. This material will revert to its original colour when exposed to sunlight. Gem spodumene is thermoluminescent and fluorescent. Spodumene is strongly phosphorescent when exposed to x-rays, ultra-violet, radioactive emanations and high tension electric currents. Some spodumene is colour zoned with a lilac centre and a colourless to green edge. Hiddenite from a gemmological standpoint is usually reserved for the dark

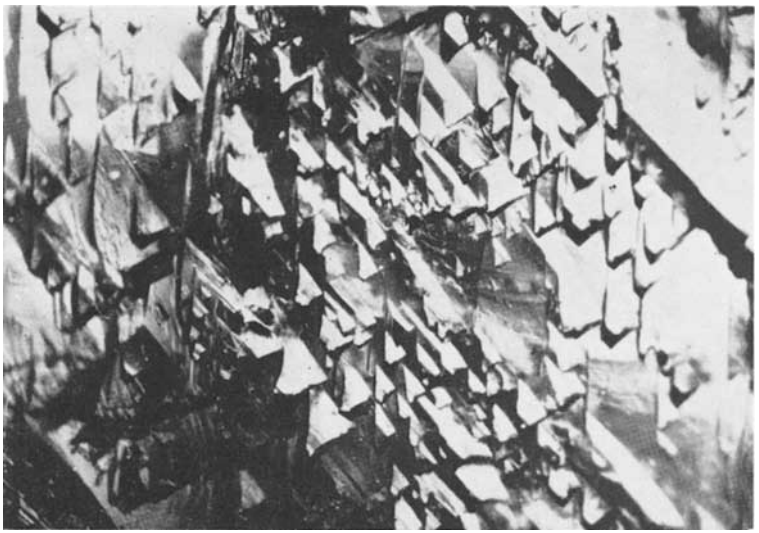

FIG. 10. *Microphotograph of triangular etch pits on the surface of spodumene, variety kunzite from the Pala district, San Diego County, California.*

emerald green variety of spodumene and derives its colour from a small amount of chromium. The light green San Diego County material owes its green colour to iron and therefore the variety name hiddenite is not applicable. It also has a light green colour which adds weight against using the variety name hiddenite.

Kunzite, the rare lilac spodumene, is found principally three places in the world: Brazil; Vanakarata, Madagascar, and San Diego County. Kunzite was named for the late Dr. George Frederick Kunz (1856-1932) gemmologist and former vice-president of Tiffany and Company in New York City. The colour of kunzite is due to manganese.

Blue spodumene, a light blue variety, was re-discovered by George Ashley, of Pala, in 1952. The name spodumene means "ashes" in Greek, in allusion to the fact that this mineral becomes ashy before the blowpipe.

San Diego County kunzite sometimes contains inclusions of what looks like pocket clay. There are also two-phase inclusions in spodumene with a gas bubble; and long, thin, rod-shaped (needle-like) inclusions. There are also funnel-shaped inclusions.

TOPAZ

Crystal description: Orthorhombic system; rhombic-dipyramidal class. In San Diego County, topaz crystals are commonly of short prismatic habit. Very rarely twinned crystals have been found. Crystals of three different terminations occur in San Diego County: one with a broad flat 001 or c-face developed; one which is an inverted V-shape with the 021 or y-face well developed; and a domed-shape with the 111 or o-face and the 112 or p-face developed (see Fig. 921, Dana's *Textbook of Mineralogy*, fourth edition, page 613). Usually, the crystals have only one termination with the base fractured on the perfect basal cleavage. However, where growth conditions were favourable, a few are doubly terminated. Topaz crystals are sometimes slightly striated parallel to the length of the prism.

Physical properties: Colour: white, colourless, greyish and light hues of blue, yellow, brown, green, violet, pinkish brown, pinkish and reddish. Lustre: vitreous. Hardness: 8. Specific gravity: 3·4-3·6. Fracture: subconchoidal to uneven. Cleavage: highly

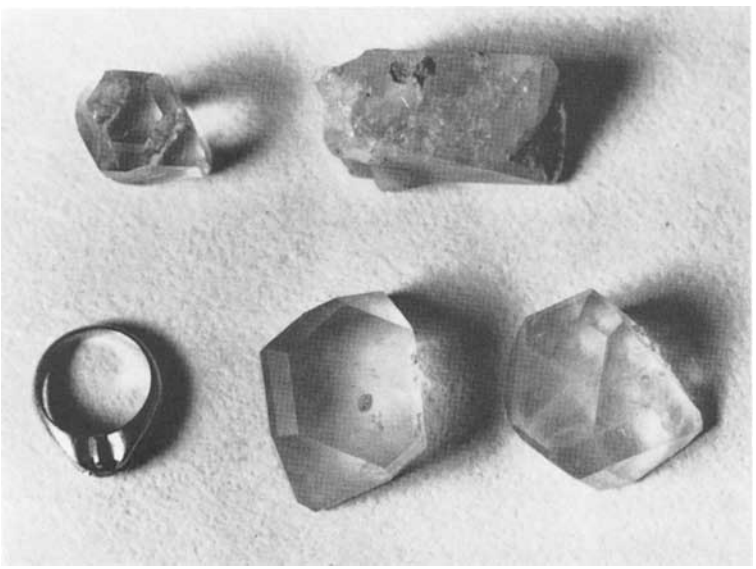

FIG. 11. *Medium-sized crystals of topaz from the Little Three mine, Ramona district, San Diego County, California. The crystal in the upper right is doubly terminated.*

perfect basal. Tenacity: brittle. Transparent to subtranslucent. Biaxial and optically positive. Refractive index: α1.607-1·629, β1·610-1·631, γ1·617-1·638. Pleochroic. It is pyroelectric and piezoelectric. Infusible and dissolves slowly in sulphuric acid.

Composition: $Al_2(F, OH)_2SiO_4$.

Aluminum fluosilicate.

Varieties occurring in San Diego County: The ordinary variety occurs in San Diego County and is usually colourless or white; and less commonly it is a light blue or greenish-blue.

Occurrence: Topaz occurs in San Diego County at the Little Three and A.B.C. mines in the Ramona area; and from the Emeralite Number Two mine on Aguanga Mountain. It has also been found at the Himalaya mine at Mesa Grande and in very minor amounts in the Pala district.

Interesting facts: Topaz from San Diego County is associated with quartz, albite, lepidolite and green tourmaline. The San

FIG. 12. *Small crystals of topaz from the Little Three mine, Ramona district, San Diego County, California.*

Diego County topaz crystals are very similar to those found in the Ural Mountains of Russia. Blue topaz has been found in sizes up to $2\frac{7}{8} \times 3\frac{1}{4}$ inches at the Emeralite Number Two mine on Aguanga Mountain, 13 miles northwest of Warner's Hot Springs. This mine was owned and operated by the late John W. Ware of San Diego. Some San Diego County crystals have frosted surfaces due to etching. San Diego County topaz has inclusions of albite. It also has two-phase inclusions with a gas bubble, and three-phase inclusions, some of which have two nonmiscible liquids, gas bubble and crystal of an unknown mineral. There are also liquid veil-like inclusions.

TOURMALINE

Crystal description: Hexagonal system, rhombohedral division; ditrigonal-pyramidal class. San Diego County crystals are usually prismatic in habit; with divergent radiating groups; also acicular. Tourmaline sometimes shows parallel side growths and columnar composites. Crystals usually display three curved sides in cross-section. They occur in size from microscopic specimens to over a foot long. The most common termination is the flat basal type. Tourmaline with a flat basal termination is called a negative termination; a slightly curved end is called a positive termination. Doubly terminated crystals usually have a flat termination at both ends or a flat end and a trigonal pyramid or modification of it. Rarely, both ends will be terminated by the trigonal pyramid, and occasionally the trigonal pyramid is itself slightly truncated by three faces.

FIG. 13. *Large crystals of green tourmaline from the Little Three mine, Ramona district, San Diego County, California. The crystal on the left has the "positive" termination and the other two the "negative" termination. The centre crystal is encrusted with white cookeite.*

FIG. 14. *Medium-sized crystals of tourmaline, mainly from the Himalaya mine, Mesa Grande district, San Diego County, California. Notice the curved crystal in the top row and the crystal in the bottom row (next to the ring) that has been almost completely etched.*

Rarely tourmaline crystals are found that are curved or bent. Tourmaline crystals are usually vertically striated.

Physical properties: Colour: red, pink, yellow, violet, green, white, brown, black, blue and colourless. Lustre: vitreous to resinous. Hardness: 7-7·5. Specific gravity: 2·98-3·25. Fracture: conchoidal to uneven. Transparent to opaque. Cleavage: poor prismatic and rhombohedral. Tenacity: brittle. Dichroism is developed to a high degree in the darker varieties. Strongly pyroelectric and piezoelectric. A crystal is easily charged with electricity, either by friction, or by heating and shows positive at one end and negative at the other. Uniaxial and optically negative. Refractive index: ε1·613-1·658, ω1·632-1·698. Sometimes fluorescent in short-wave ultraviolet light.

Composition: Lithium sodium aluminum hydroxyl-borosilicate. A complex silicate sometimes also containing: potassium, iron, magnesium, chromium, calcium and fluorine.

Varieties occurring in San Diego County:

Achroite	—Colourless
Bi-coloured	—Red, green, blue, black, yellow, pink, white
Bi-coloured cat'seye	—Pink and white

Cat's-eye	Green, pink, white
Green tourmaline	—Green
Indicolite	—Blue
Rubellite	Pink or red
Schorl	—Black
Tri-coloured	—Green, white, pink; blue, yellow, red
Violet tourmaline	—Violet
Watermelon	—Red or pink and green (colour zoned)
Yellow tourmaline	—Yellow.

Occurrence: Tourmalines from San Diego County are found in all the pegmatite districts: Aguanga Mountain, Banner, Chihuahua Valley, Jacumba, Mesa Grande, Pala, Ramona and Rincon.

Interesting facts: Tourmaline from San Diego County is associated with quartz, albite, lepidolite, beryl, perthite (feldspar), muscovite and cookeite. The colour is sometimes arranged in transverse layers along the length of the prism, producing bi-coloured or tri-coloured stones. The colour may also change from the centre outward showing very definite colour zones. Sometimes, there is a black core with a yellow edge, or a yellow core with a pink edge. The pink core with a green edge indicates the famous watermelon tourmaline. Rubellite with an indicolite edge is sometimes called a blue-skinned rubellite.

Coloured tourmalines show the best colour through the side of the prism or when viewed through its length. Faceted tourmaline is therefore usually cut with the table parallel to the length of the prism, or perpendicular to it, to take advantage of the colour. The emerald-cut and round brilliant-cut are usually used.

Rubellite, either red or pink, was a popular gem in China, where it was carved into beautiful figurines. The fall of the Chinese Dynasty in 1912, however, caused this market to dwindle to insignificance, and the resulting drop in price contributed to the virtual discontinuance of profitable mining in the Mesa Grande district. In the early days of gem mining in the county, occasionally microscopic tourmaline crystals would penetrate the miner's fingers and they would become infected.

Tourmaline is commonly encrusted with the white mineral cookeite. Tourmaline can be cleaned, especially of cookeite, by the use of hydrofluoric acid. Tourmaline is sometimes found with an altered crust revealing a hard nodular core that has a conchoidal fracture and is often flawless. Only about three per cent of the

tourmaline recovered is of gem quality. Etching on tourmaline is sometimes quite pronounced, even to the extent of eating holes in the crystals. Some of the pink tourmaline crystals from the Himalaya mine are encrusted with a very thin coating. They look like they had been sprayed with black paint. Negative cavities sometimes begin on the termination and are oriented parallel to the sides of the prism. A bi-coloured pink and white cat's-eye, with the eye in the white end, has very rarely been found in San Diego County. Rarely, tourmaline is found encrusted with muscovite casts. These casts with a core of tourmaline have been found at the Himalaya mine. Some of the green tourmaline crystals from the Himalaya mine have a black cap, which is terminated by a trigonal pyramid.

The Emeralite Number Two mine on Aguanga Mountain, produced tourmaline that was closest in colour to the GSA rock colour chart light blue 5B 7/6 and light blue green 5BG 6/6. This tourmaline in the past has been called "emeralite". One unusual colour zoned tourmaline from the Tourmaline King mine in the Pala district, had a pink core surrounded by four distinct green bands. Radiating sunbursts of pink tourmaline (called tourmaline suns) in a fine grained lepidolite are found at the Stewart mine in the Pala district. The famous Himalaya mine in the Mesa Grande district has probably produced more tourmaline (about 100 tons) than any other mine in the world. The only colour of tourmaline not normally found in San Diego County is brown.

Small, usually less than an inch, radiating groups of pink tourmaline associated with lepidolite, cookeite, and quartz (which was the last to form) have been found in San Diego County. Some of the small, thin, black looking tourmalines from the Ramona district are actually a beautiful brown when viewed by a strong transmitted light.

San Diego County tourmaline sometimes has inclusions of quartz, albite and the micas. It also has two-phase inclusions with a gas bubble, and is usually very irregular in shape. Very fine, long, rod-shaped inclusions and small elongated cavities that are triangular in cross-section are oriented parallel to the length of the prism. When these inclusions are numerous enough they are the cause of the chatoyancy, or cat's-eye phenomenon.

Tourmaline, that myriad coloured gem that mimics the spectral hues of the rainbow, is the most colourful of the San Diego County gems.

ACKNOWLEDGMENTS

I would particularly like to express my appreciation to Mr. Robert W. Rowland, Curator of Mineralogy at the San Diego Museum of Natural History, for his continual guidance, insistance on accuracy and encouragement in the field of mineralogy. I am indebted to the late Vete George Black, G.G., F.G.A., for permission to examine the collection of San Diego County gems collected by the late Wilburn Wyatt of San Diego, California. Mr. and the late Mrs. Louis B. Spaulding courtesouly provided data on their Little Three mine in the Ramona district. For critically reviewing the manuscript I am grateful to Dr. Florence Williams and Prof. Nathalia Crane Black, G.G., both from San Diego State College, San Diego, California. The map in Fig. 1 was drawn by William M. Burgin. For suggestions to John Sinkankas.

Minerals reportedly found at the Little Three mine, Ramona district:

Albite, var. Cleavelandite $NaAlSi_3O_8$
Allanite $(Ca, Ce, La, Na)_2 (OH) (Al, Fe, Be, Mn, Mg)_3 (SiO_4)_3$
Andalusite Al_2SiO_5
Apatite $Ca_5 (F, Cl, OH) (PO_4)_3$
Axinite $Ca_2 (OH) (Fe, Mn) Al_2 (BO_3) Si_4O_{12}$
Beryl, var. Blue $Be_3Al_2Si_6O_{18}$
Beryl, var. Golden $Be_3Al_2Si_6O_{18}$
Beryl, var. Goshenite $Be_3Al_2Si_6O_{18}$
Beryl, var. Green $Be_3Al_2Si_6O_{18}$
Beryl, var. Morganite $Be_3Al_2Si_6O_{18}$
Cassiterite SnO_2
Columbite $(Fe, Mn) Nb_2O_6$
Cookeite $Li (OH)_6 Al_3Si_2O_6$
Eosphorite $(Mn^{II},Fe^{II}) (OH)_2Al(PO_4)\cdot H_2O$
Epidote $Ca_2(OH) (Al,Fe)_3Si_3O_{12}$
Hambergite $Be_2(OH)BO_3$
Lepidolite $KLi_2(OH)_2AlSi_4O_{10}$
Microcline $KAlSi_3O_8$
Montmorillonite $(Al,Mg)_8(OH)_{10}(Si_4O_{10})_3\cdot 12H_2O$
Muscovite $K(OH)_2Al_3Si_3O_{10}$
Opal, var. Hyalite $SiO_2\cdot nH_2O$
Orthoclase, var. Adularia $KAlSi_3O_8$
Quartz, var. Milky SiO_2
Quartz, var. Rutilated SiO_2 with Rutile
Quartz, var. Smoky SiO_2
Quartz, var. Tourmalinated SiO_2 with black tourmaline
Rhodochrosite $MnCO_3$
Spessartite $Mn_3Al_2(SiO_4)_3$
Stibiotantalite $Sb(Ta,Nb)O_4$
Stilbite $CaAl_2Si_7O_{18}\cdot 7H_2O$
Tantalite, var. Manganotantalite $(Fe,Mn)Ta_2O_6$ Mn:Fe > 3:1
Topaz $Al_2(F,OH)_2SiO_4$
Tourmaline, var. Bi-colour $Na(O,OH,F)_4(Al,Fe,Li,Mg)B_3Al_6Si_6O_{27}$
Tourmaline, var. Green $Na(O,OH,F)_4(Al,Fe,Li,Mg)B_3Al_6Si_6O_{27}$
Tourmaline, var. Rubellite $Na(O,OH,F)_4(Al,Fe,Li,Mg)B_3Al_6Si_6O_{27}$
Tourmaline, var. Schorl $Na(OH)_4Fe_3B_3Al_6Si_6O_{27}$
Zinnwaldite $K_2(F,OH)_4(Li,Fe^{II},Al)_6(Si,Al)_8O_{20}$

Minerals reportedly found at the Stewart mine, Pala district:

Albite, var. Cleavelandite $NaAlSi_3O_8$
Amblygonite $(Li,Na)(F,OH)Al(PO_4)$
Beryl, var. Golden $Be_3Al_2Si_6O_{18}$
Beryl, var. Goshenite $Be_3Al_2Si_6O_{18}$
Beryl, var. Morganite $Be_3Al_2Si_6O_{18}$
Beyerite $Ca(BiO)_2(CO_3)_2$
Bismite Bi_2O_3
Bismuth, Native Bi
Bismuthinite Bi_2S_3

Bismutite $(BiO)_2(CO_3)$
Bornite Cu_5FeS_4
Chalcocite Cu_2S
Chrysocolla $CuSiO_3 \cdot 2H_2O$
Columbite $(Fe,Mn)Nb_2O_6$
Columbite, var. Ferrocolumbite $(Fe,Mn)Nb_2O_6$ Fe:Mn > 3:1
Cookeite $Li(OH)_6Al_3Si_2O_6$
Heterosite $(Fe^{III},Mn^{III})(PO_4)$
Hureaulite (Palaite) $(Mn,Fe^{II})_5H_2(PO_4)_4 \cdot 4H_2O$
Lepidolite $K(OH)_2Li_2AlSi_4O_{10}$
Lithiophilite $Li(Mn^{II},Fe^{II})(PO_4)$
Malachite $Cu_2(OH)_2(CO_3)$
Manganese oxides
Microlite $(Na,Ca)_2(O,OH,F)Ta_2O_6$
Muscovite $K(OH)_2Al_3Si_3O_{10}$
Muscovite, var. Damourite $K(OH)_2Al_3Si_3O_{10}$
Orthoclase, var. Sanidine $KAlSi_3O_8$
Petalite $LiAlSi_4O_{10}$
Pucherite $BiVO_4$
Purpurite $(Mn^{III},Fe^{III})(PO_4)$
Quartz SiO_2
Salmonsite $Mn_2{}^{II}Fe_2{}^{III}(PO_4)_8 \cdot 14H_2O$ (?)
Sicklerite $(Li,Mn^{II},Fe^{III})(PO_4)$
Stewartite $Mn_3(PO_4)_2 \cdot 4H_2O$
Strengite $Fe^{III}(PO_4) \cdot 2H_2O$
Tantalite $(Fe,Mn)Ta_2O_6$
Tourmaline, var. Bi-colour $Na(O,OH,F)_4(Al,Fe,Li,Mg)B_3Al_6Si_6O_{27}$
Tourmaline, var. Green $Na(O,OH,F)_4(Al,Fe,Li,Mg)B_3Al_6Si_6O_{27}$
Tourmaline, var. Rubellite $Na(O,OH,F)_4(Al,Fe,Li,Mg)B_3Al_6Si_6O_{27}$
Tourmaline, var. Schorl $Na(OH)_4Fe_3B_3Al_6Si_6O_{27}$
Triphylite $Li(Fe^{II},Mn^{II})(PO_4)$
Triplite $(Mn^{II},Fe^{II},Mg,Ca)_2(F,OH)(PO_4)$
Vivianite $Fe_3{}^{II}(PO_4)_2 \cdot 8H_2O$

Minerals reportedly found in the Mesa Grande district:

Albite $NaAlSi_3O_8$
Albite, var. Cleavelandite $NaAlSi_3O_8$
Allanite $(Ca,Ce,La,Na)_2(OH)(Al,Fe,Be,Mn,Mg)_3(SiO_4)_3$
Almandite $Fe_3Al_2(SiO_4)_3$
Amblygonite $(Li,Na)(F,OH)Al(PO_4)$
Andradite $Ca_3Fe_2(SiO_4)_3$
Apatite $Ca_5(F,Cl,OH)(PO_4)_3$
Arsenopyrite FeAsS
Bavenite $Ca_4BeAl_2Si_8O_{21} \cdot H_2O$
Beryl, var. Aquamarine $Be_3Al_2Si_6O_{18}$
Beryl, var. Common $Be_3Al_2Si_6O_{18}$
Beryl, var. Goshenite $Be_3Al_2Si_6O_{18}$
Beryl, var. Morganite $Be_3Al_2Si_6O_{18}$
Biotite $K(OH)_2(Mg,Fe)_3AlSi_3O_{10}$
Bismite (?) Bi_2O_3
Bismuth, Native Bi
Bismutite $(BiO)_2(CO_3)$
Cassiterite SnO_2
Chrysocolla $CuSiO_3 \cdot 2H_2O$
Columbite $(Fe,Mn)Nb_2O_6$
Columbite, var. Ferrocolumbite $(Fe,Mn)Nb_2O_6$ Fe:Mn > 3:1
Columbite, var. Manganocolumbite $(Fe,Mn)Nb_2O_6$ Mn:Fe > 3:1
Cookeite $Li(OH)_6Al_3Si_2O_6$
Epidote $Ca_2(OH)(Al,Fe)_3Si_3O_{12}$
Eucryptite $Li(Al,Si)_2O_4$
Fluorite CaF_2
Gahnite $ZnAl_2O_4$
Grossularite $Ca_3Al_2(SiO_4)_3$
Halloysite $Al_4(OH)_8Si_4O_{10}$
Hambergite $Be_2(OH)BO_3$
Hatchettolite $(Ca,Fe,U)_2(O,OH,F)_7(Nb,Ta,Ti)_2$
Helvite $(Mn,Fe,Zn)_8Be_6Si_6O_{24}S_2$
Hematite Fe_2O_3
Heulandite $CaAl_2Si_7O_{18} \cdot 6H_2O$
Hureaulite (Palaite) $(Mn,Fe^{II})_5H_2(PO_4)_4 \cdot 4H_2O$
Kaolinite $Al_4(OH)_8Si_4O_{10}$
Laumontite $(Ca,Na)_7Al_{12}(Al,Si)_2Si_{26}O_{80} \cdot 25H_2O$
Lepidolite $K(OH)_2Li_2AlSi_4O_{10}$
Lithiophilite $Li(Mn^{II},Fe^{II})(PO_4)$
Magnetite Fe_3O_4
Manganite $Mn(OH)O$
Microcline $KAlSi_3O_8$
Microlite $(Na,Ca)_2(O,OH,F)Ta_2O_6$
Monazite $(Ce,La,Y,Th)(PO_4)$

Montmorillonite $(Al,Mg)_8(OH)_{10}(Si_4O_{10})_3 \cdot 12H_2O$
Muscovite $K(OH)_2Al_2Si_3O_{10}$
Oligoclase $(Na,Si,Ca,Al)AlSi_2O_8$
Opal $SiO_2 \cdot nH_2O$
Orthoclase $KAlSi_3O_8$
Pollucite $CsAl_4Si_9O_{26} \cdot H_2O$
Psilomelane $Ba(OH)_4Mn^{II}Mn^{IV}{}_8O_{16}$
Pucherite $BiVO_4$
Purpurite $(Mn^{III},Fe^{III})(PO_4)$
Pyrite FeS_2
Pyrochlore $(Ca,Na,Ce)_2(O,OH,F)_7(Nb,Ti,Ta)_2$
Quartz SiO_2
Sicklerite $(Li,Mn^{II},Fe^{III})(PO_4)$
Spessartite $Mn_3Al_2(SiO_4)_3$
Spinel $MgAl_2O_4$
Spinel, var. Pleonaste $(Mg,Fe)Al_2O_4$
Spodumene, var. Common $LiAlSi_2O_6$
Spodumene, var. Green $LiAlSi_2O_6$
Spodumene, var. Kunzite $LiAlSi_2O_6$
Spodumene, var. Triphane $LiAlSi_2O_6$
Stibiocolumbite $SbNbO_4$
Stibiotantalite $Sb(Ta,Nb)O_4$
Stilbite $CaAl_2Si_7O_{18} \cdot 7H_2O$
Strengite $Fe^{III}(PO_4) \cdot 2H_2O$
Tantalite $(Fe,Mn)Ta_2O_6$
Tantalite, var. Ferrotantalite $(Fe,Mn)Ta_2O_6$ Fe:Mn > 3:1
Tantalite, var. Manganotantalite $(Fe,Mn)Ta_2O_6$ Mn:Fe > 3:1
Topaz $Al_2(F,OH)_2SiO_4$
Tourmaline, var. Achroite $Ca(O,OH)_4Mg_3B_3Al_6Si_6O_{27}$
Tourmaline, var. Bi-colour $Na(O,OH,F)_4(Al,Fe,Li,Mg)B_3Al_6Si_6O_{27}$
Tourmaline, var. Cat's Eye $Na(O,OH,F)_4(Al,Fe,Li,Mg)B_3Al_6Si_6O_{27}$
Tourmaline, var. Green $Na(O,OH,F)_4(Al,Fe,Li,Mg)B_3Al_6Si_6O_{27}$
Tourmaline, var. Indicolite $Na(O,OH,F)_4(Al,Fe,Li,Mg)B_3Al_6Si_6O_{27}$
Tourmaline, var. Rubellite $Na(O,OH,F)_4(Al,Fe,Li,Mg)B_3Al_6Si_6O_{27}$
Tourmaline, var. Schorl $Na(OH)_4Fe_3Al_6B_3Si_6O_{27}$
Tourmaline, var. Tri-colour $Na(O,OH,F)_4(Al,Fe,Li,Mg)B_3Al_6Si_6O_{27}$
Tourmaline, var. Yellow $Na(O,OH,F)_4(Al,Fe,Li,Mg)B_3Al_6Si_6O_{27}$
Triplite $(Mn^{II},Fe^{II},Mg,Ca)_2(F,OH)(PO_4)$
Vermiculite $(Mg,Fe^{II},Fe^{III},Al)_{6-7}(OH)_4(Si,Al)_8O_{20} \cdot 8H_2O$
Zinnwaldite $K_2(F,OH)_4(Li,Fe^{II},Al)_6(Si,Al)_8O_{20}$
Zircon, var. Cyrtolite $ZrSiO_4$ with H_2O

Reported by Jahns and Hanley, and Schaller.

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ASSOCIATION NOTICES

A YEAR OF GEMMOLOGY IN BURMA

A year he spent teaching gemmology at Rangoon University, in Burma, resulting in all 15 students passing the preliminary examination of the Gemmological Association, and 10 of them, in addition, passing the diploma examination —two with distinction, was the subject of a most interesting talk given to members of the Association, at Goldsmiths' Hall, London, on 12th March, 1969, by Mr. E. A. Jobbins of the Institute of Geological Sciences.

Mr. Jobbins started his lecture by giving a few facts about Burma and how he came to be associated with setting up a training scheme at the University.

The army took over the government in 1962 and formed a revolutionary council. In 1963 there was extensive nationalization of all industries and means of distribution, which, with other restrictions, particularly on foreigners, resulted in many of the Chinese who ran the jade industry, Indians, Burmese and British who ran the gemstone industry, and the Japanese who were largely responsible for the pearl fisheries leaving the country.

Again, another result was the loss of the expertise of the people who left, and it became apparent to the authorities at Rangoon University, and others, that outside help in setting up a training scheme and laboratory for gemmological studies was very necessary. It was also considered that those to be trained should be graduates or students about to become graduates.

Putting action to thought, an approach was made to UNESCO for assistance, and Mr. Jobbins was asked in November 1966 if he would be interested in going to Burma. Being keen to go, and having got the blessing of the director of the Institute of Geological Sciences, Mr. Jobbins left for Burma on 19th July, 1967, where he arrived at 7.30 on the morning of 30th July, having called at Delhi and Colombo on the way out.

His first impression while approaching land was of a bright yellowish-green colour, coupled with a general mirror-like reflection which he soon realized was from flooded paddy fields. On disembarking the heat and humidity really hit him. He took up residence in a modern hotel, about five miles from the centre of Rangoon, and this was his home for the rest of his stay—most of the time in a pleasant (and very expensive) flat on the fourth floor, overlooking a lake.

The geology department in the University (now known as the Arts and Science University) where he was to work had a staff of one professor, three lecturers and about 10 demonstrators. Discussions with the professor resulted in agreement that there should be two courses, one for postgraduates and one for undergraduates and that the syllabus for both should be that for the diploma examination of the Gemmological Association, with extensions as appropriate.

The University term in Burma began on 1st November, and Mr. Jobbins was faced with two pressing tasks—to get together the necessary instruments and specimens, and to inaugerate a new laboratory. Both had to be started from scratch, there being only two very corroded and useless Rayner refractometers and no laboratory extant.

Fortunately, the previous professor of geology had been elevated in 1964 to Secretary for Education to the Government. Mr. Jobbins, with virtual direct access to him, found him very helpful throughout his stay. It was through his good offices that foreign exchange was made available for five sets of refractometers, sodium lights and spectroscopes to be ordered from the Gemmological Association, in London, on 15th August. This order was delivered in Rangoon on 8th September—a very quick turnround, for which Mr. Jobbins publicly thanked the GA staff for their co-operation. Specimens were not so easy to obtain, and assuming that nothing would be available in Rangoon, Mr. Jobbins was able to borrow 50 rare and unused stones from Mr. Basil Anderson, 30 stones from the GA, 20 from Mr. Robert Webster (which he subsequently presented to the Burmese) and jade and jade-like specimens from the Natural History Museum. To these Mr. Jobbins added his own collection of 300 specimens, which was used for day-to-day gem testing. No other gemstone specimens were received from other sources until May 1968, so the loan specimens proved indispensible.

The room designated for the laboratory had no fittings, a wood block floor with cracks large enough to lose sizeable gemstones and very poor electrical fittings. The laboratory was replanned and the work was started on obtaining the fittings and building materials of which none were available on the open market, because there was not really an open market. A high proportion of the normal electrical and other shops had closed down, only to be replaced by a few people's shops.

To obtain the necessary electrical fittings, paint, curtain materials, and other commodities, it was first necessary to go to the head of the appropriate trade corporation to obtain the necessary permits, which were then taken to the appropriate people's shops.

The actual fitting out of the laboratory took four months longer than it would have taken in England, but, apparently, quicker than it normally took in Burma.

The laboratory was completed at the end of November, and courses were started at the beginning of December 1967.

The laboratory was designed to take up to nine students, and two practical courses were instituted—the undergraduates formed a group of six and the postgraduates made up another nine. In the latter group were the principal gemmologist, planning manager and two other managers of the Gem Trade Corporation, a mineralogist from the Mineral Development Corporation, a geologist from the Applied Research Institute, and a customs and excise assessor; in effect, all the top Government officials concerned with practical aspects of gemmology.

All students spent two long morning, weekly, on practical work, which sometimes continued into the afternoons, and at least three hours of lectures. By really hard work it was hoped to cover the normal two-year G.A. Course in six months. All of the students had, previously, studied crystallography and some mineralogy, although some of the older men had forgotten most of it.

In October 1967, Mr. Jobbins went to Bangkok, and while there he called

upon the Department of Mineral Resources, and discussed Thai and Burmese mineral production with geologists there. Following this visit he received an invitation to visit the Thai Mining Convention in January 1968, in Bangkok, and he was lucky enough to obtain the necessary approval for the trip.

From the gemmological point of view, said Mr. Jobbins, the most interesting part of the trip was a visit to the gem-mining area of Chantaburi, some 200 miles east of Bangkok towards the Cambodian border. He was accompanied by a Thai geologist. A side issue on this trip was the time he spent one evening bargaining for specimens with a Chinese-Thai who, at one stage, produced a Rayner refractometer which someone had offered him in exchange for specimens.

By then, January 1968, the laboratory was working well and Mr. Jobbins obtained Oertling semi-automatic balances, which were in use by 24th February, and an Olympus stereo-zoom gemmological microscope Model JM, which he said he could thoroughly recommend and which compared very favourably with the American Gemolite miscroscope.

The G.A. examinations took place from 11th to 13th June, but the examination specimens were taken to the examination centre by an assistant commissioner from the customs and opened in his presence. He stayed during the examination and the specimens were sealed up again, in his presence, at the end of the practical examination. The incident had its funny side, said Mr. Jobbins, but it was of considerable practical use because it avoided any subsequent customs trouble.

The examination results were available at the end of August and all 15 students had got through the preliminary examination and 10 of them had also got through the diploma—two (undergraduates) with distinction. The results, said Mr. Jobbins, were very pleasing both to him and the Burmese, and made the front pages in both English language papers and in most of the Burmese, too.

During the time he was in Burma the 4th Gem Emporium was held. Although, in theory, the Emporium is the sole exporting source of Burmese gems, jade and pearls, in fact Burmese gemstones are freely available in Bangkok to where they are known to be extensively smuggled in return for consumer goods.

Broadly, the actual gem-workings are still in private hands and the recovered gems are supposed to be sold to government buyers who make fortnightly visits. Jade recovery, usually in fair-sized boulder, is largely in the hands of the Mineral Development Corporation. who use some modern equipment. The cultured pearl industry is run by the Peoples' Pearl and Fishing Board.

As time was running out, Mr. Jobbins managed to fit in a week's tour to Mandalay and, to his surprise, was invited to visit the new jade factory of the Gem Trade Corporation. The most important fact there was that slabbing of boulders and cutting of cabochons had been mechanized. American machinery was installed and work was to close tolerances, and there was a careful inspection system. Most of the workers were young men and a few of them were being trained in jade carving by a master carver of the old school.

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GIFTS TO THE ASSOCIATION

The Council of the Association is indebted to Miss Verena Theisen, of Dusseldorf, for a copy of her book *Diamanten Fibel* (Handbuch der Diamant-Graduierung) and to Mr. R. Webster for a collection of Canadian gem minerals.

ANNUAL GENERAL MEETING

Mr. Norman Harper, chairman of the Gemmological Association, presided over the 39th annual general meeting of the Association, held at Winston Churchill House, Ethel Street, Birmingham, on 16th April, 1969. Welcoming those who were there, he said the annual general meeting gave members and fellows of the Association a chance to see what the officers had done through the year.

Making his report, Mr. Harper said that last year the Association celebrated the diamond Jubilee of gemmology in Great Britain and on that occasion had presented to the National Association of Goldsmiths of Great Britain and Ireland with two pieces of antique silver. The presentation was made, he said, because they were the people that founded the Gemmological Association.

He went on to say that the annual examinations were attracting more candidates as the years went by, and it was becoming quite a business to organize them. Those people present and the Association generally owed a great debt of gratitude to the permanent staff for handling the work so efficiently. Last year there were a large number of students from Spain and this year there were going to be even more of them. The work involved was not apparent when one read the list of names of people who had passed, but papers were returned from Burma, Japan, Spain, Finland and other countries, and marking of the papers was a formidable task. Mr. Harper then proposed adoption of the report and audited accounts for the year ended 31st December, 1968.

Seconding the proposition, Mr. D. N. King said anyone who read the report would do so with a great deal of pride and pleasure, because it set out the affairs of the Association in a concise manner. It hid, also, a great deal of the work that went into the Association. The Association had, he said, just celebrated 60 years of gemmology and for more than half of that time the affairs of the Association had been in the hands of Mr. Gordon Andrews, himself a fellow, and of him he would say, he knew of no man who ran such an able association, who demanded so little of its members and made so much work for himself. He conducted the Association's affairs quietly, efficiently, and ably and it would be an extremely sad day when he felt the time had come to lay down his office. He hoped it would not be for many years yet. Mr. King continued by saying that he also included the many people who worked with Mr. Andrews and hoped that he would convey to them the meeting's thanks and good wishes.

Turning to the balance sheet, Mr. King said it was years since he read such a plesant sheet which showed such an excellent surplus. He knew the money

was well invested and used as and when the opportunity arose. The Association's expenses were increasing all the time and it was fortunate that it had been possible to accumulate funds for what one might call "a rainy day".

The election of officers followed and the retiring president, Sir Lawrence Bragg, C.H., F.R.S.; chairman, Mr. Norman Harper; vice-chairman, Mr. Philip Riley; and treasurer, Mr. F. E. Lawson Clarke were re-elected, there being no other nominations.

In the election of members of the Council, Mr. T. Bevis-Smith was re-elected; Mr. M. Asprey, who had served on the Council as a co-opted member for several years, and Mr. D. G. Kent, who had taken an active interest in the Association's affairs over many years, were nominated and elected. Messrs. Watson Collin & Co., chartered accountants, signified their willingness to continue as auditors.

After the Annual Meeting Dr. M. J. A. Smith, of the School of Physics, University of Warwick, spoke to members about a physicist's view of diamond.

MIDLANDS BRANCH

The Annual Meeting of the Midlands Branch of the Association was held on Friday, 16th May, 1969, at the Auctioneers Institute, Birmingham. The following Officers were elected:
Chairman: Mr. Peter Spacey. Vice-Chairman: Mrs. S. Hiscox. Deputy Chairman: Mr. D. N. King. Secretary: Mr. D. M. Jones.

The retiring Chairman, Mr. D. N. King, thanked the Committee and Branch members for the support they had given to him during his three years of office. He also thanked the national Chairman, Mr. Norman Harper, for his guidance and support. Mr. King reported that the Branch had had a particularly successful year with many interesting meetings and two social occasions being arranged.

Before the election of Officers was held, Mr. King presented a beautiful bouquet of flowers to Mrs. Hiscox in appreciation of her six years as Secretary of the Branch.

Messrs. J. Marshall, A. Alabaster, D. Price and J. Salloway were elected as Committee members. Minor alterations to the Branch regulations were approved.

After the meeting members were shown two films: "Looking for Gold and Silver" and "Hallmark".

GEMMOLOGY INSTRUCTOR

2nd year theory instructor in gemmology required for evening work at Sir John Cass College, London. Details of qualifications to Dr. E. Rutland c/o the Association.

MEETINGS

9th October, 1969. Herbert Smith Memorial Lecture. Mrs. Nancy Armstrong on "Jewellery". Goldsmiths' Hall, London.

19th November, 1969. Presentation of awards by Professor S. Tolanksy, F.R.S., at Goldsmiths' Hall, London.

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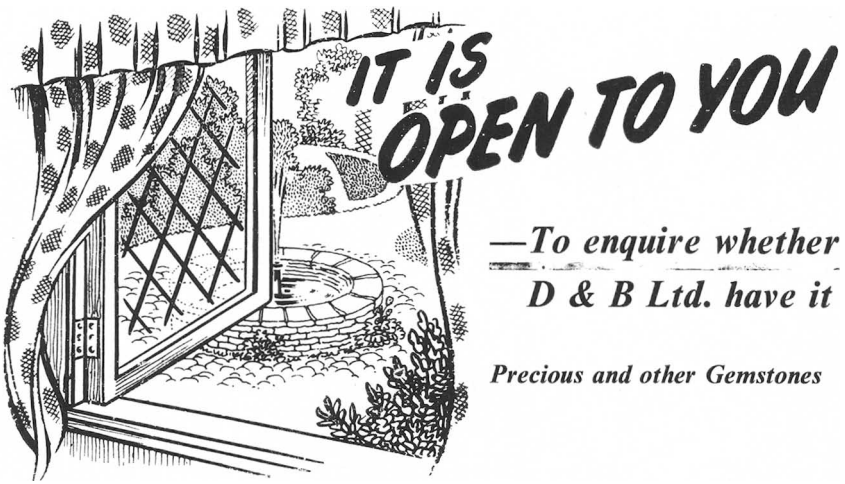

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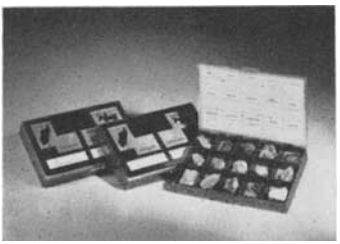

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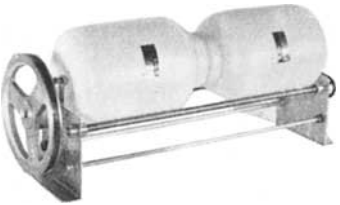

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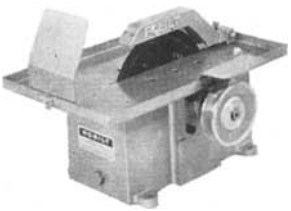

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THE JOURNAL OF GEMMOLOGY

and

PROCEEDINGS OF THE GEMMOLOGICAL ASSOCIATION OF GREAT BRITAIN

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Vol. 11 No. 8 OCTOBER 1969

THREE SYNTHETICS FOR THE RECORD

By B. W. ANDERSON
Director, Precious Stone Laboratory of the London Chamber of Commerce

ONE of the useful functions of a Gem Trade Laboratory is to give warning, through an appropriate channel, to gemmologists less favourably placed, when some unusual type of synthetic, fake, or even natural gemstone is encountered which may be a cause of future trouble to the uninitiated. Of the three synthethics described below only the first is likely to be a serious menace, but it seemed a good opportunity to put the others on record also for the benefit of readers of the Journal.

1. A New Synthetic Emerald

All previous forms of synthetic emerald have been heralded with some degree of publicity. Their producers have been at pains to proclaim the excellence of their wares; brochures have been issued, articles written, and leading gemmologists have published reassuring statements explaining how to distinguish each latest synthetic from earlier products and from the natural emerald.

The type presently to be described crept up on us unawares, being sent in for test in the ordinary run of business, and it caused us quite a bit of trouble, as will appear hereafter.

Ostensibly the stone was an emerald of good colour and quality, weighing about two carats, mounted as a single stone ring.

Suspicion was at once aroused by the inclusions, which were twisted two-phase feathers very reminiscent of Chatham, Gilson,

and other flux-fusion emeralds, but in its properties the stone was different from any other emerald we have met, natural or synthetic. Refractive indices were 1·574–1·580 and (after removal from its setting) the density was found to be 2·72. There was virtually no fluorescence, even between crossed filters, though the chromium lines were clearly visible in the stone's absorption spectrum. The reason for the lack of fluorescence was undoubtedly the presence of iron, since quite a strong absorption band was seen at 4270A in the violet—a band belonging rather to the aquamarine variety of beryl than to emerald.

Despite these anomalies, we were convinced that the stone must be synthetic, but were glad to obtain permission to send the specimen to our good friends in the G.I.A. Gem Trade Laboratory in New York. They in turn elicited the powerful aid of Dr. Kurt Nassau of the Bell Telephone Laboratories, well-known for his skill in the preparation of crystals of all kinds, including laser and gem materials, and for much else besides. It happened that Dr. Nassau had recently concluded some interesting research on the infra-red absorption spectra of natural and synthetic beryls, in the course of which it was shown that all natural emeralds show absorption bands

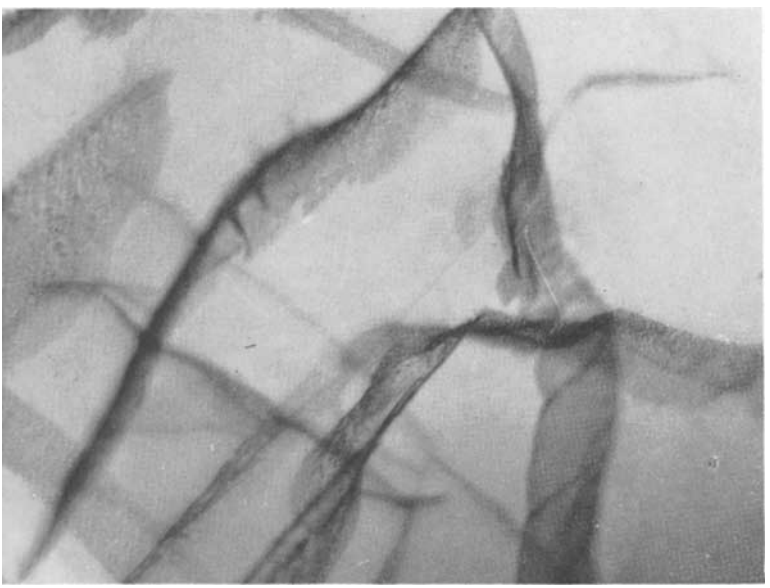

Feathers in new type flux-fusion emerald.

due to water in this part of the spectrum, while in synthetic emeralds these bands are absent when grown by flux-fusion methods. Our "mystery" emerald showed no water bands and was thus confirmed as a flux-grown synthetic: a welcome piece of support not available in a gemmological laboratory. Since then, another such stone has been encountered in routine testing, and we understand that the Los Angeles Laboratory of the G.I.A. has tested similar pieces. The grapevine suggests that the emeralds are produced by a lone individual who is an employee of one of the big U.S. companies.

Low refractive index, low density, an intense red under the Chelsea filter, red fluorescence under long and short wave U.V. lamps, will continue to be useful signals for the flux-fusion emeralds most frequently met with, but it is hoped that the above will serve as a warning that not all flux-fusion emeralds can be expected to show these well-known features. Any stone which shows suspicious inclusions should be submitted for a laboratory test, and a complete absence of fluorescence under crossed filters should warn gemmologists to look for that 4270A band, which we have never observed previously in any emerald. Mercifully, the three-phase inclusions shown so beautifully in Colombian emeralds are so far beyond the skill of the laboratory worker to reproduce in his manufactured crystals.

2. Synthetic Blue Quartz

The process of growing large flawless untwinned crystals of quartz has for many years been a scientific and commercial commonplace. Such crystals are in constant demand in the electronics industry for wavelength control and time-keeping of high accuracy, making use of the well-known piezo-electric properties of the mineral. The gemmologist has been uneasily aware that he would find it difficult to distinguish the man-made material from the natural product should the occasion arise, comforting himself with the thought that the mineral is so abundantly found in the earth's crust that the necessarily slow and expensive method used in its artificial production would make its utilisation for gem purposes unattractive, especially as the "know-how" for the production of desirable coloured quartzes does not seem to have been mastered.

The writer was thus more than mildly astonished to find that a bright blue stone, mounted in a single-stone ring, was not, as at first supposed, a cobalt-blue glass but a veritable crystalline quartz,

with the standard refractive indices, birefringence, and hollow interference figure. The cobalt bands were after the manner of those in glass—that is, well spread and with the central band relatively narrow as compared with cobalt blue spinels. There was no need of course, to look for further proof of synthesis, and a faint memory made the writer turn to a paper in the "American Mineralogist" where was to be found a description of just such a product, complete with absorption curve.

The appearance of such a stone in an ordinary commercial context continues to be astonishing, especially when one learned that it had been bought in Russia, together with another cheap ring containing a green synthetic spinel. Unlikely indeed, perhaps not to be repeated; but worth noting as a curiosity and as a warning to take nothing for granted, but to make sure in one's testing that all possibilities have been considered. This prim advice is needed by the writer himself, who, in testing this particular stone, made a very untidy and unsteady progress towards the truth.

3. Lithium Niobate

As mentioned at the beginning of the article, the third artificial gemstone to be described has not been encountered by the writer in routine testing, but was first shown to him at the Stockholm Conference by Dr. E. Gübelin on behalf of Dr. W. Eppler, who could not attend.

As with strontium titanate, lithium niobate is known only as a synthetic material, not being represented in nature. In America, apparently, it has been on the market for some time under the trade name of "Linobate", a reasonable abbreviation from its chemical full-dress. It has considerable attractions as a gem material, a high refractive index, good dispersion, and a wide range of bright colours, but is low in hardness and has a double refraction high enough to induce a "fuzzy" appearance in the zircon-sphene-rutile manner.

Lithium niobate can be produced either by the Verneuil or by the Czochralski "pulling" method from a platinum crucible. The melting point is 1250°C., hardness 5+, density 4·64, refractive indices 2·30 for the ordinary and 2·21 for the extraordinary ray. Dispersion is about 0·120 for the B–G range. Colours include green (Cr), red (Fe), violet (Co.), yellow (Mn or Ni); the colorants being introduced either as oxides or as titanates.

THREE IMPORTANT PIECES OF JEWELLERY FROM THE PERSONAL COLLECTION OF HER MAJESTY THE QUEEN

By M. J. O'DONOGHUE, M.A., F.G.A.

WITH the gracious permission of Her Majesty the writer was recently able to examine three pieces of great gemmological interest from her personal collection of jewellery. It was possible to make a close examination of the pieces which, together with information kindly supplied by designers and cutters has enabled me to set down some details which are otherwise not easily ascertained. The items chosen for the article were the Andamooka opal, the Williamson pink diamond and the wattle and tea-tree brooch. Photographs are reproduced with the permission of Her Majesty and are Crown Copyright.

The Andamooka opal was found at Stevens Creek Diggings, Andamooka, South Australia, and was recovered in 1946 from a depth of approximately 30 feet. The weight was over 6 oz. Troy and the stone measured 4″ × 2½″. It was then cut by Mr. J. D. Altmann, of Altmann and Cherny Pty Ltd. of Melbourne, and presented to Her Majesty by the South Australian Government at a state banquet in Adelaide during the royal tour of 1953-54.

After cutting the dimensions were 81 × 45 × 5 mm and the weight 203 ct, the form of cut being the oval cabochon. A pair of earrings and a pair of cufflinks were subsequently fashioned from the same rough.

On examination the predominating colours are seen to be green and blue, but on turning the stone the other spectrum colours are seen. There are no areas without good colour and the only slight blemishes, two small sandspots flanking the centre, are scarcely visible to the unaided eye.

Messrs. Wendt, of Adelaide, set the opal in a palladium necklace with 180 white diamonds which are arranged in a scroll motif. The side pieces are hinged in sixteen places with a chain of small diamonds at the back.

In this chain each diamond is set in a diamond-shaped mount alternating with links pierced in the matching scroll designs and finishing with a diamond-set catch. The motif of the earrings is the same as that of the side pieces.

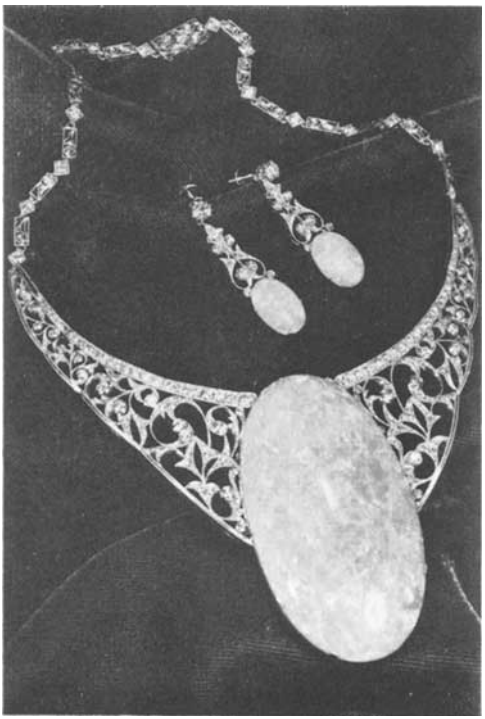

The Andamocka opal necklace and earrings

The necklace and earrings are kept in a box in which is mounted a silver plate reading "Her Majesty Queen Elizabeth II. A token of loyalty and appreciation from the people of South Australia 23 March 1954".

The brooch was presented to Her Majesty by the Australian Federal Government during the royal tour of 1953-54. Two national flowers of Australia are represented - the Wattle or Mimosa and the tea-tree (*Leptospermum*). The blossoms of the tea-tree are composed of golden-yellow diamonds and the stem and leaves of white diamonds, which also form, in baguettes, the leaves of the wattle. In all there are 161 stones with a total weight of 23·14 ct.

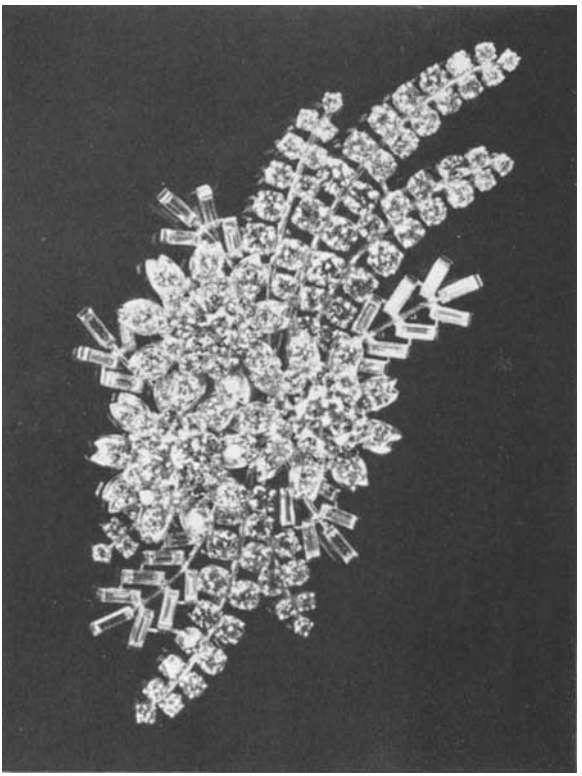

Diamond brooch representing the Australian wattle

This overall weight is made up of:

27 brilliants	with a total weight of	3·43 ct.
44 baguettes	,,	3·82 ct.
87 golden yellows	,,	10·81 ct.
2 large whites	,,	5·08 ct.

The stones were obtained from Messrs. Triefus & Co. Ltd., of Holborn Circus, London, who themselves obtained some of the golden-yellow diamonds from a private collection.

The brooch is made of platinum and was created by Messrs. William Drummond and Co., of Melbourne, whose mark appears on the stem.

I am indebted to Messrs. Triefus and to Messrs. William Drummond for information.

The pink diamond was found by the late Dr. John Williamson at his mine at Mwadui in Tanganyika and weighed 54 ct in the rough. It was presented by Dr. Williamson to Her Majesty, then Princess Elizabeth, on the occasion of her wedding in 1947.

The cutting was carried out by Messrs. Briefel and Lemer at their London factory and Princess Elizabeth accompanied her grandmother Queen Mary to the factory to see the work being carried out. The stone was cut and polished entirely on the scaife and the round shape was achieved by the polisher grinding away the circumference in a series of small straight facets. It took three months to complete the table facet, four top hooks and four bottom hooks, and during this stage a hole in the bottom of the

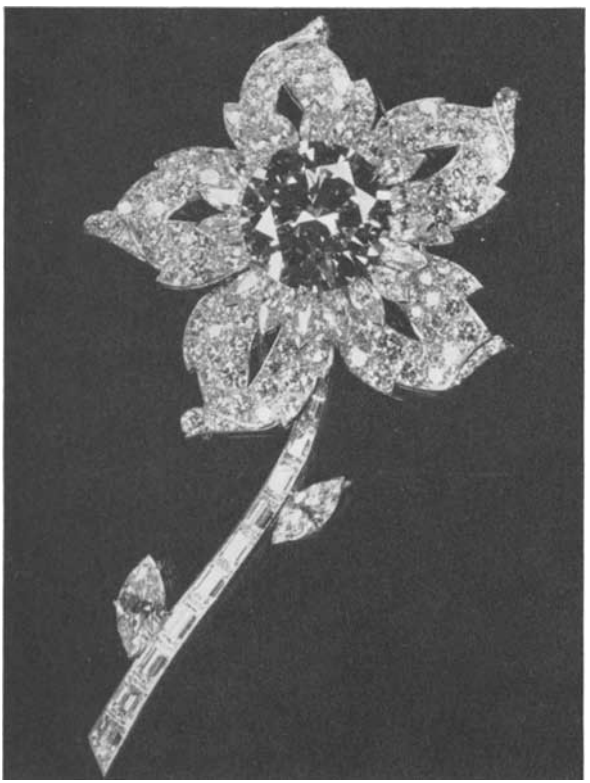

The Williamson Pink which comprises the centre of a flower brooch in the form of a jonquill-shaped spray

stone was worked out. The second stage of polishing to the finished stone took approximately three weeks, much of the work being done in the solder dop of the older type. On completion the weight was 23·60 ct and the stone was completely pure and flawless. I am greatly obliged to Messrs. Briefel and Lemer for this information.

The stone is set as the centrepiece of a jonquil-shaped flower brooch created by Messrs. Cartier of Bond Street, London. The brooch is of platinum and is 4½″ long. The petals are set with brilliants and the pink diamond is surrounded by white navettes. The stem is composed of baguettes with two buds.

All the diamonds in the brooch came from the Williamson mine. There is a two-prong spring fastening and the stem is marked Cartier London. The weights of the white diamonds are:

21 navettes	with a total weight of	9·73 ct.
12 baguettes	,,	4·64 ct.
170 rounds	,,	12·40 ct.

EUCLASE FROM MINAS GERAIS, BRAZIL

By FRANCISCO MULLER BASTOS, F.G.A., G.G.

UNTIL a short time ago, the existence of euclase in Brazil was restricted to the well-known mineralogical area of Ouro Prêto in the state of Minas Gerais. Today, however, the attention of many Brazilians is directed to the northeast of the country.

There, nobody can deny, there have been going on a rapid development and progress which are drastically modifying the environment of this arid region. Perhaps it has been this thrust of interest that has resulted in the discovery of various minerals, among them the euclase. So, this mineral is found also in the state of Rio Grande Do Norte in a place called Alto Do Jacu. However, the crystals from that source, which I had the opportunity to examine, are full of inclusions. They are almost opaque, with a few being translucent. Consequently they are not good to cut.

Ouro Prêto, the former capital of the state of Minas Gerais, is considered today a national monument. This old city is very well-known for its rich history since Brazil's independence. But for the mineralogists and gemmologists Ouro Prêto is famous for the imperial topaz or Ouro Prêto topaz. This area of Ouro Prêto consists of several small towns and villages such as Rodrigo Silva, Gambá, Hargreaves, Bôa Vista, Saramenha, Tripuhy, Burnier, Dom Bosco and Capão Do Lana.

The matrix of euclase is in quartz veins in the crystalline schists, always accompanied by metallic oxides such as specularite. This rock is very similar to the matrix of the topaz. Euclase is also found associated with topaz. I myself found euclase fragments in a typical topaz mine. This mine is called Angelo (Lavra Do Angelo) and is situated near Ouro Prêto.

Also blende and cinnabar can be found together with the euclase. I have heard, that near Dom Bosco and Hargreaves in the Bulho Hill, some blende and sphalerite have been found with euclase. The same thing happens in the Capão farm were some cinnabar with a beautiful adamantine lustre, associated with pyrite, is also found with some euclase.

When the first explorations were made in the area of Ouro Prêto, much euclase was thought to be topaz. Chiefly, the colour-

less and the light and dark yellow euclase were sold as such. I remember very well that many years ago euclases were offered to me as topaz. Later this difference was noted when very good and beautiful specimens of euclase were shown and studied in broad daylight.

The name euclase is derived from two Greek words meaning easy cleavage. The euclase found in the rich mineral district around Ouro Prêto has different colours that vary from the colourless to a medium blue. Some green crystals, that resemble the beryls from the region of Capelinha, are also found. The light yellow or "Kerosene" stone is the most common, whereas the violet-coloured crystal is the rarest. If the crystals were flawless, free of other minerals, they would normally be colourless. The coloured crystals like light blue, light green, bluish-green, yellow (kerosene colour) etc. owe their colour to the presence of small quantities of mineral agents.

Euclase is a beryllium silicate, the chemical formula being $Be(AlOH)SiO_4$. The faces of the crystal are smooth. Euclase belongs to the monoclinic system and the prismatic habit is characteristic. The lustre is vitreous and the fracture conchoidal. In the well formed euclase crystals from Ouro Prêto, proportions of Ca, Fl, Fe, Sn, Al and Si are found in greater or lesser quantities.

The density varies from 3·08 to 3·10 according to the colour. The colourless stones show an invariable density of 3·08. The hardness of 7·5 is constant. In euclase from Rodrigo Silva I found the R.I. to vary from 1·651 and 1·671 to 1·658 and 1·678. It should be noted that all the Ouro Prêto euclase has a small quantity of Sn in its chemical composition. I could not find any characteristic inclusion in this material.

As euclase is a mineral of easy cleavage, some lapidaries have difficulties in cutting the stones. The facets should not be placed on a cleavage plane and the best colour is obtained by a correct orientation of the crystal.

When the stones have the light blue colour, they resemble aquamarines. However, the identification is easy, because the R.I. of aquamarine (beryl) is 1·575-1·582 and the R.I. of euclase is 1·651-1·678. Also the S.G. of aquamarine (beryl) 2·70 is different from the S.G. 3·08 or 3·10 of euclase.

Besides the confusion with aquamarines, euclase is also confused with topaz—especially yellowish or colourless euclase crystals.

This happens with some crystals and cut stones too. The cut stones however, are easily checked with the refractometer: euclase 1·651-1·678, topaz 1·630-1·638. The S.G. also eliminates any doubt with euclase 3·08 to 3·10 and topaz 3·54. Also, some confusion occurs with cut greenish topaz. It, too, resembles euclase. These confusions can be easily eliminated by R.I. and S.G. tests.

From the mines of Ouro Prêto rare and beautiful specimens came to collectors and museums. From the mines of Rodrigo Silva, I have already had the opportunity to see beautiful conglomerates in which euclase is found together with topaz and specularite, forming beautiful specimens. Generally the euclase from this mine has bluish colour. However, the stones from Bôa Vista are yellowish. Also, very rare specimens are found where the three minerals, euclase, topaz and specularite appear to be associated with quartz and mica. In Hargreaves, some euclases were found and continue to be found in the rock crystal. From the old mine called Morro came some of the largest and most beautiful euclase crystals yet found, some of them 6 cms in length.

Finally, we can also include, in the Ouro Prêto area, the villages of Antônio Pereira and Cachoeira Do Campo. In Antônio Pereira principally the discovery of euclase has already been confirmed.

DIAMOND PROPORTIONS

By F. S. H. TISDALL, F.G.A.

THE article describing the Petterson proportion-slide and its use, appearing in the *Journal* for October, 1968, prompts me to describe a simple method which I devised by which may be ascertained the degree of approximation with which a "modern" cut diamond approaches the theoretical proportions for the supposedly perfectly cut stone as worked out mathematically by Tolkowsky in 1919.

The optical properties of gem quality diamond material are constant, and, assuming the proportions of the Tolkowsky brilliant-cut to be correct for obtaining the optimum amount of "fire" and brilliance, such proportions, once determined, will be valid for all time.

The writer prevailed upon the generosity of Messrs. D. & P. Clark, diamond merchants, to provide a "specimen" diamond which Mr. P. Clark himself considered to be of good make, and proportions. It was then necessary to ascertain, by measurement, what these proportions actually were. It is now the accepted practice to express these proportions as percentages of the width of the girdle, which is taken as 100. The actual measurements were first obtained as follows:

A small millimetre gauge, equipped with a vernier scale, permitting measurement to an accuracy of $\pm \cdot 05$ mm, was sawn and filed down as shown in Figure 1.

The required measurements (Fig. 2) were the following:

1. Height of crown (above girdle).
2. Depth of base (below girdle).
3. Width of table.
4. Width of girdle.

Angular measurements of crown and girdle facets relative to the plane containing the girdle necessarily follow from these measurements, and are, therefore, neglected in the experiment. They could be calculated with little trouble.

By placing the diamond as shown in Fig. 3 (securing it in position with a small piece of plasticine) it was by no means difficult by carefully adjusting the slide of the gauge so that its upper jaw

was just level with the girdle of the stone to ascertain the height of the crown. In the writer's view the thickness of the girdle itself, in a well made stone, has a negligible effect on the measurements, and is disregarded. In the case of the stone provided the height of the crown was 1·1 mm. The overall depth of the stone, using the gauge in the normal way, was found to be 4 mm, thus giving two requisite measurements:

Height of crown 1·1 mm.
Depth of base 2·9 mm (i.e. 4-1·1).

The width of the table facet, owing to the transparency and reflective powers of diamond material was, admittedly rather more difficult to obtain. The diamond was seated level in a small lump of plasticine and the width of the table (between the centres of opposite facet edges) measured with a pair of hair dividers. The dividers were then transferred to the millimetre gauge, and, with the aid of the vernier, a measurement was made to a degree of accuracy of ±·1 mm. The girdle width, using the gauge normally presented no difficulty.

(The making of all these measurements is considerably facilitated by the use of a headband magnifier).

The two remaining measurements were:

Width of table 4·3 mm.
Width of girdle 6·78 mm (estimating the second decimal place).

Figure 4 is a sectional sketch of the stone to scale × 10.

In the following table the "ideal" proportions of the Tolkowsky brilliant-cut, expressed as percentages of the girdle (100), are compared with the relative dimensions of the above diamond, similarly expressed:

	Tolkowsky brilliant	*Experimental brilliant*
Girdle width	100	100
Table width	53	63·4
Crown height	16·2	16·2
Base depth	43·1	42·7

From this it will be seen how very close to the mathematically calculated ideal an actual, well made, modern diamond approximates, as assessed by a trained and experienced eye.

Figure 5 shows the sectional outline of the two sets of dimensions superimposed, the unbroken line being that of the actual specimen,

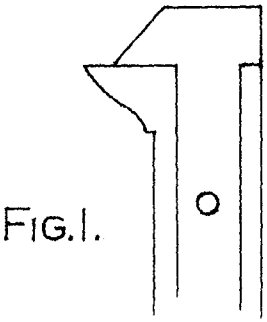

FIG. 1.

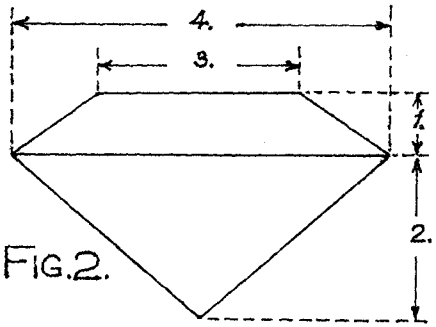

FIG. 2.

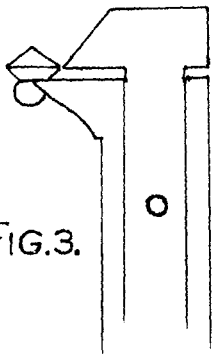

FIG. 3.

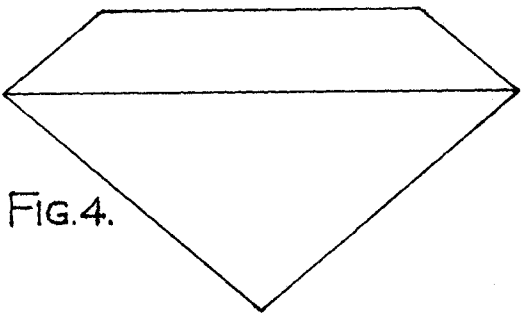

FIG. 4.

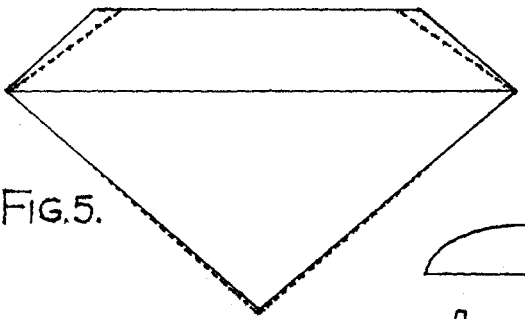

FIG. 5.

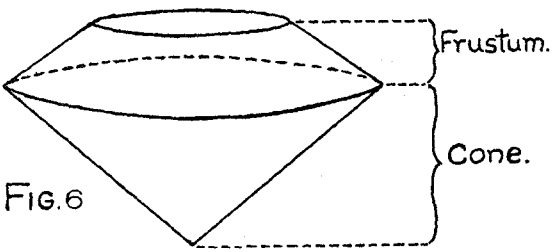

FIG. 6

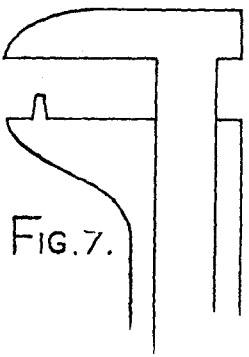

FIG. 7.

and the broken line indicating the ideal. The only major difference between the two sets of measurements is in the width of the respective tables, that of the experimental brilliant-cut being somewhat wider than that of the ideal, which accords with modern practice.

All who handle diamonds regularly will, of course, continue to assess the "make" of a stone by its general proportions, and overall effect of "fire" and brilliance, as apparent to the trained eye; and although the calculated "ideal" will certainly yield these optical effects in the highest degree, it is also true that some latitude is permissible without seriously detracting from them.

Nevertheless, it seems to the writer worthwhile, at such trifling cost and trouble, to have available a simple method of comparing the proportions of any diamond of sufficient size to warrant it with those of the ideal.

A slide rule will facilitate the conversion of actual measurements into percentages.

Finally, the writer's thanks are due to Mr. Clark for kindly providing a specimen diamond.

Calculating the Weight of a Diamond by Measurement

A consideration of the outward aspect of a modern brilliant-cut diamond suggests that it nearly approximates to a frustum (a truncated cone), and a cone, base to base (Fig. 6).

Elementary solid geometry teaches us that the volume, and therefore the weight of such a solid is proportional to the product of its thickness (t) and the square of its diameter (d):

$$\text{i.e. Weight—}ktd^2$$

where k is a constant to be determined.

In the case of diamond, the weight of which it is often necessary to ascertain when mounted (and therefore when scales are of no use), the writer, some years ago, calculated this constant as 6·37.

More explicity the weight of a normally proportioned brilliant cut diamond is given by the formula:

$$\text{Weight (in carats)—}6{\cdot}37td^2$$

where t is the thickness of the stone, measured from table to culet, and d is its diameter, measured across the girdle, the dimensions t and d being expressed in centimetres and decimal parts thereof.

A calculation such as the above, though amounting only to simple arithmetic, is made both rapid and easy by the use of a

slide rule; the only problem is to ascertain accurately the dimensions t and d.

To obtain these the writer has adapted a perfectly ordinary millimetre gauge as shown in Fig. 7. The lower jaw of the gauge was gapped with a small file and a square peg of brass soldered in. The brass peg was then carefully filed circular and slightly tapered until the top measured about 1·5 mm in diameter. The height of the peg above the level of the lower jaw of the gauge was left at exactly 3 mm.

The peg will fit neatly under the back rail of a diamond ring, and by closing the jaws of the gauge so that the top of the peg rests on the culet of the stone, and the upper jaw rests squarely on the table, a measurement of the thickness of the diamond may be made. It is, of course, necessary to subtract the height of the peg (in this case, 3 mm) from the measurement in order to get the thickness of the diamond itself. A high degree of accuracy (with care to ± ·05 mm) may be achieved if the gauge is furnished with a vernier.

The width of the stone is obtained simply by inserting the jaws of the gauge between the claws on opposite sides of the girdles. As the jaws on my particular gauge were on the thick side, I filed them down to a suitable width, and removed the file marks with a buff stick.

It is, of course, true that accurate gauges can be purchased which will do all and more than is claimed for the above simple device, but by the means described a considerable expense is avoided, and one has the satisfaction of producing at negligible cost a piece of apparatus which will perform the desired mensuration both satisfactorily and accurately.

CORUNDUM FROM MALAWI

By E. H. RUTLAND, Ph.D., F.G.A.

THE existence of gem quality corundum on Chimwadzulu Hill, Southern Malawi, was reported by Dr. K. Bloomfield in 1958(1). Subsequently a comprehensive study of a wider area was made by the Malawi Ministry of Natural Resources and this again comprised the corundum locality. The results were published by that Ministry in 1965(2). During 1965 a claim was pegged by Messrs. Gunson (Exports) Limited of Limbe, Malawi, to examine a wide terrain and to exploit the mineral occurrences in it, with special emphasis on the corundum. Following a market survey production of rough corundum commenced and a cutting shop was set up in Limbe in 1967/68 for processing the rough crystals into mountable gem stones. The corundum is now being produced and marketed by an associated company, Kirk Mining and Gem Export Company Ltd.

The ultrabasic body, Chimwadzulu Hill, altitude 5,200 ft.

The corundum occurs *in situ* in an epidotized amphibolite and in gravel on the summit plateau of Chimwadzulu Hill, some fifty miles south of Lake Nyasa, close to the frontier of Portuguese East Africa. Dr. Bloomfield has come to the conclusion that the amphibolite originated from a peridotite intruded into geosynclinal sediments. The corundum crystals are embedded in a coarse aggregate of rounded hornblende crystals up to 5 × 3 cm in size, enclosed in a fine-grained granular grey matrix of epidote and plagioclase. It appears that the south western sides of the hill have been enriched with corundum down to valley level by eluviation. Recovery is at present mainly from shallow pits and surface gravels near the top of the hill.

The rough material examined so far consisted of a parcel of mainly transparent crystals, yellow, green and blue in colour, of which many were parti-coloured. Most were from 5 to 30 mm in length but larger crystals have been submitted more recently and these are on exhibition at the Geological Museum, London, together with some cut stones. The larger rough stones comprise six crystals from 2 to 4 cm in diameter. The colours range from pink

White corundum crystal in gravel, Chimwadzulu Mine.

through yellow and pale green to a dark greyish green. All these crystals show well developed basal pinacoids and some have prominent triangular growth figures on these. Rhombohedral faces are less prominent. The prism faces are rough, the other faces smooth. The crystals are mostly squat to tabular, but one prism is elongated. All have a pronounced basal parting. The rhombohedral parting is rather less prominent. There is some iron staining along the parting planes.

Some cut stones of very attractive colour were examined with the following results:—

	Colour	*Cut*	*Weight in ct.*	$n\omega$	$n\varepsilon$
1.	blue	round, mixed	3·58	1·770	1·760
2.	blue	pendeloque	7·41	1·770	1·761
3.	blue	oval, mixed	6·47	1·770	1·760
4.	pale bluish green	emerald-cut	3·35	1·770	1·761
5.	red	step-cut	0·52	1·771	1·762
6.	red	step-cut	0·51	1·771	1·763
7.	red	pendeloque	2·59	1·772	1·763

The *refractive indices* were measured in sodium light on a Rayner refractometer and are estimated to be accurate to $\pm 0{\cdot}001$.

Dichroism was strong; it ranged from a pale yellowish green to a purplish blue for the blue stones. Even the pale stone No. 4 had quite appreciable dichroism. The red stones had a pale brownish-red ε ray and a deep magenta ω ray.

Inclusions: fine channels were found in all but two of the red stones, one of which had small black crystals and short rods, presumably of hornblende. Between crossed polars, stones No. 1, 3, 4, showed twinning planes, allied in stone 3 with colour-zoning. Stone 5 had a healed fissure containing both liquid and gas.

Spectrum: this was well developed and normal for the rubies. The sapphires showed the three iron lines prominently, the 4500 A line being very clear even in the pale stone No. 4.

X-ray fluorescence: fragments from a pink and a green stone were examined by X-ray fluorescence for elements of atomic number greater than 11 on a Hilger and Watts Fluovac at the Institute of Geological Sciences, London. Apart from major aluminium the pink stone contained minor iron and traces of chromium. These elements were also present in the green stone

but in this case the chromium was minimal and there was a somewhat larger trace of manganese.

Luminescence: the blue stones did not fluoresce under long wave ultra-violet light. The fluorescence of the red stones was weak, presumably in consequence of the iron content.

More recently some parcels comprising several hundred cut stones from the same locality were examined by Mr. E. A. Jobbins and myself at the Geological Museum. These stones had not yet been sorted and graded; they were of all sizes up to some 12 carats and varied widely in cut and shape. The colours of the sapphires ranged from yellow and pale blue and green, through greyish blues and greens to a very fine rich blue and a dark iron blue. The rubies were much smaller and most were pale but some had a very good colour, reminiscent of good Siam stones.

REFERENCES

(1) "The Chimwadzulu Hill Ultrabasic Body"—Transactions of the Geological Society of South Africa, Vol. LXI.
(2) *Bulletin No.* 17: "The Geology of the Kirk Range—Lisungwe Valley Area" by Dr. K. Bloomfield and Dr. M. S. Garson.

Gemmological Abstracts

BANK (H.). *Durchsichtiger grüner Aktinolith (Strahlstein) als neuer Edelstein.* Transparent green actinolith as new gem. Zeitschr.d.-deutsch. Gemmologischen Gesellschaft, 1969, 18, 1, pp. 1-5.

Actinolite is an iron-containing calcium-magnesium hydrosilicate, it is monoclinic and the names come from the Greek actis—ray and lithos—stone. It is pleochroic from light yellow to dark green. The particular stone which the author described was first thought to be a tourmaline, the density was found to be 3·05 and the R.I. 1·620-1·642, the birefringence being 0·022, but was then found to be monoclinic. It has a perfect cleavage. The author then examined about 80 specimens and the results are published in table and graph form. There is a bibliography of 13 items. As origin Africa is given, but no further details.

E.S.

PENSE (J). *Die Fission-track-Methode und ihre Bedeutung für die Edelsteinkunde.* The fission-track method and its importance to gemmology. Zeitschr.d.deutsch. Gemmologischen Gesellschaft, 1969, 18, 1, pp. 6-11.

The author discusses the importance of the fission-track method in the determination of gems, especially synthetic materials, illustrating his ideas with diagram, micro-photograph and two descriptive sketches of lattices. The method is built on disturbances of the crystal lattice. Bibliography.

E.S.

LENZEN (G.). *Farbgraduierung und UV-Fluoreszenz des Diamanten.* Colour gradation and UV fluorescence of diamonds. Zeitschr.d.deutsch. Gemmologischen Gesellschaft, 1969, 18, 1, pp. 12-14.

The article deals with the blue fluorescence of diamonds of the cape series and other off-colour stones. Because of this blue fluorescence some off-colour diamonds seem to be blue-white or over-blue when viewed in white light. The author submits that it is not sufficient to view the stone in daylight or under the

Koloriscope and Diamondlite, but that each stone should also be examined under a UV lamp. E.S.

BANK (H.). *Ueber die Lichtbrechungsindizes brasilianischer Smaragde.* Concerning the refractive indices of Brazilian emeralds. Zeitschr.d.deutsch.Gemmologischen Gesellschaft, 1969, 18, 1, pp. 15-19.

Although some mines in Brazil yield good quality emeralds, the term "Brazilian emeralds" is applied to those found near Bom Jesus dos Meiras (Brumado) in the southern part of Bahia. These are chrome-containing beryls of a pale green colour. It was found that these stones have a higher R.I. than generally presumed, and that other Brazilian emeralds have comparatively high values, such as those found in Carnaiba, near the Campo Formoso in Bahia, or in Salininha, also in Bahia. Tables of the results are given, together with bibliography of 15 items.

E.S.

DRAGSTED (O.). *Der "Sonnenstein" der Wikinger.* The "sun stone" of the Vikings. Zeitschr.d.deutsch. Gemmologischen Gesellschaft, 1969, 18, 1, pp. 20-21.

There is a legend that the Vikings could orientate themselves not only according to the sun and the stars, but in cloudy conditions used a "sun stone". Mr. Ramskou of the Mineralogical Institute was especially interested in this and thought it most likely that cordierite was the stone used as its dichroism can show a colour change from dark violet to nearly colourless and it is found as "pebble" in Norway. He flew to Greenland and it was seen that the cordierite varied only a few degrees from the sensitive sky compass of an aeroplane.

E.S.

HELFRICH-DÖRNER (A.). *Welcher Sinn verbirgt sich hinter den Namen der Edelstein ?* What is the meaning behind the names of the gems? Zeitschr.d.deutsch. Gemmologischen Gesellschaft, 1969, 18, 1, pp. 22-34.

The author gives the origin of the name for various gemstones and usually adds a note as to the usage, or qualities attributed to the stone, or a historical note or anecdote.

E.S

NASSAU (K.) and CROWNINGSHIELD (R.). *The Synthesis of Ruby.* Lapidary Journal, 1969, April, May, June and July.

A painstaking survey of the synthesis of ruby. The so-called "reconstructed" rubies, claimed to have been made from chips of natural ruby in the period 1885-1905, were re-examined by microscopic and x-ray fluorescent analysis. "Reconstruction" experiments involving the partial melting of natural rubies were also performed. It is concluded that the "reconstructed" rubies were manufactured by a pre-Verneuil form of the flame-fusion process using a complex three-step seeding and growth procedure, and using purified alumina and not natural ruby as the feed material. The term "reconstructed" should accordingly not be used for any form of usable gem ruby.

The authors have not been able to establish the originator of the technique that first produced "Geneva" synthetic rubies. The techniques of modern production including Czochralski, pulling the melt, flux growth, hydrothermal growth, and growth from a vapor phase, are described. The Verneuil technique is still used for over 99 per cent of the total production of synthetic ruby.

S.P.

MALLORY (L. D.). *Opal Mining in Western Mexico.* Lapidary Journal, 1969, 23, 3, and 4.

An account of the occurrence, mining and marketing of Mexican opal. The gem does not occur in well defined veins, but in areas of matrix which may not be contiguous. Production in Western Mexico has increased and marketing arrangements do not usually permit the acquisition of opals by the casual buyer. The price of opal is unlikely to decline.

S.P.

TRUEB (L. B.) and BUTTERMAN (W. C.). *Carbonado: a microstructural study.* Amer. Mineral, 1969, vol. 54, pp. 412-425.

Brazilian carbonados consist of mostly anhedral, randomly oriented diamond crystallites ranging in size from a fraction of a micron to over 20 μm. These crystallites are aggregated and interlocked into porous polycrystalline masses with a microstructure reminiscent of ceramics. Aluminium silicate inclusions occur.

R.A.H.

ASSOCIATION NOTICES

A PHYSICIST'S VIEW OF DIAMOND

DR. M. J. A. SMITH, of the School of Physics, University of Warwick, speaking to members of the Gemmological Association at Birmingham, on 16th April immediately following the 39th annual meeting, said:

"One thing which we all have in common is that we share a fascination for diamonds, although my interest is mainly in synthetic stones.

"Some of the most important technological innovations which have come to pass in recent years have been the result of various impurities added to normally pure materials.

"In the case of diamond, it is well known that if you take a blue stone it contains aluminium. The technique which I shall describe to you this evening and the one which we use at Warwick enables us to detect the aluminium and to determine exactly where it is situated in a particular diamond. This we can do without damaging the stone at all, and, moreover, we can see a remarkably small concentration of these impurities. I suppose we can see something like about one part in 100 million if necessary.

"When we come on to synthetic stones, I am sure you are aware that the the commercially available ones which you can obtain from the General Electric Company or De Beers are made by, as I call it, the heating and squeezing technique. You take some carbon, heat it to a high temperature and squeeze it at a high pressure. If you also add some nickel or iron or similar material to the mixture you will end with coloured synthetic diamond.

"Quite a lot of the work which we have done has been concerned with synthetic stones and exactly how nickel and iron goes into a diamond and also with the effect they have on the properties of diamond, in particular on the process of growth. If we could say, for example, that the nickel goes in in this way and in so doing it produces a diamond of given shape or size, I think we can all see this would be quite important to the diamond industry.

"The properties which interest a physicist as far as diamond is concerned, I suppose, range over all its known properties.

"First of all there is the hardness. This has been appreciated for many years and quite a lot of work is going on at the present time particularly at Cambridge on how the hardness varies with the particular direction in which you make the hardness test on a face of the diamond.

"A physicist would also be interested in the optical properties of diamond as it is used a lot in laboratories for high pressure windows. Of course we must know the optical properties of diamond because we might well be looking at the optical

properties of the material inside the high pressure apparatus so that if we did not know the optical properties of the diamond itself, then indeed we could not draw any conclusions about the material inside. Of course as you might imagine these optical measurements enable us in another way to have a look at some of the impurities in diamond.

"As far as the electrical properties of diamond are concerned, it is interesting to note that diamond is being used these days as a thermometer. If I can again refer back to the blue stones which contain aluminium, the interesting point about these, electrically, is that if you take an avometer and place it across the blue stone it should read quite low resistance. What is more this resistance will depend markedly on the temperature, so what we tend to do if we want to measure the temperature of a liquid around 1,000°C—where the diamond would just about be stable over a long period of time—we might take one of these blue diamonds, place an avometer across it, drop it into the liquid and just read the resistance which can then be related to the temperature.

"Another interesting property of diamond concerns its surface and I think this is where probably the physicist may well have a lot in common with those of you who are involved in making jewellery. If you want to make a ring, I am told that you squeeze claws around the diamond and keep your fingers crossed, although I do not suppose it is quite as simple as all that, surface adhesion is clearly important. Some of the work which we hope to do at Warwick in the very near future and which from our point of view has unfortunately been started in Germany recently, is to have a look at diamond which has been subjected to a chlorine atmosphere at very high temperature. The idea of this is to try and induce some sort of surface reactivity on the diamond and to see if we can bind the diamond to something like araldite. It seems to me that it would be of great technological importance if one could bind diamond chemically to another material. It would clearly be of great interest to those who use diamond. So this is a new field, which I think will be pursued over the coming years.

"Probably the final property of diamond in which the physicist might be interested is that of radiation damage. If you take a diamond and put it into a nuclear reactor and bombard it with some particle or other we might ask what happens to it? Now I think that this is of interest at the moment to the physicist because diamond being such an essentially simple material it is therefore very attractive to the theoretical physicist, and if you can irradiate it and distort the lattice in some way then it is interesting to know exactly how the lattice has been distorted and it is in some ways a model system for trying out the theories which you might have about radiation damage. However, I am sure this technique may well become important to people like yourselves because by irradiating diamonds you can change their colour. Sometimes this colour is permanent and sometimes it can be bleached by heating.

"The technique of electron spin resonance ESR, which we use at Warwick to study diamond, is a non-destructive way of looking at the impurity content. A pure diamond consists of carbon atoms, each of which is surrounded by four others, and each carbon atom has four electrons, which form bonds with the neighbouring atoms. In each one of these bonds there are two electrons, which spin in opposite directions. The electrons are, as we say, paired. If you take pure diamond and put it in the ESR machine you get nothing out of it at all.

However, if you take diamond which contains nitrogen, and some natural stones contain large amounts of nitrogen which were presumably introduced during the volcanic action when they were formed, the only difference from our point of view between nitrogen and carbon is that nitrogen has five electrons available for bonding instead of the four which carbon has. When we put nitrogen into diamond it goes in in place of the carbon, four electrons are used for producing paired bonds and there is one electron on its own. This unpaired electron spinning on its axis acts like a small bar magnet, so if I now place a diamond containing nitrogen into a large magnet then indeed this bar magnet will rotate or precess about the axis of the applied magnetic field. If the size of the magnetic field is increased it will precess even faster. It so happens, and this is the reason why this technique became available after the war, that in a magnetic field of a reasonable size which can be produced in a laboratory, electrons from the nitrogen will precess at a frequency of about 9,000 megacycles which is just the same frequency as that used during the war for radar and indeed which is still used for this purpose. If now you shine some of the high frequency radio waves onto this precessing electron so that their magnetic field is at right angles to the large steady field which you apply and if the magnitude of the large magnetic field is increased, when the precession frequency becomes equal to the frequency of the radio waves, the unpaired electron precesses violently and eventually points in the opposite direction. So if you take a diamond which contains many nitrogen atoms then all those which are pointing one way turn the other way and vice versa.

"The important point is this. To return to the case of the bar magnet. If you place a bar magnet into a magnetic field it is true that it can either point so you have NS NS or another stable position is NN SS, but one is slightly more stable than the other. Similarly, with these precessing electrons slightly more of them prefer to be in the lower energy direction (NS NS) than in the other direction. If we change their directions at the same rate then we need to put in a net amount of work because more are going one way than are going the other way. This means that if we measure the intensity of our radio waves then indeed we find that their level has dropped slightly when the resonance effect takes place in the diamond. This is electron spin resonance.

"What we usually do, therefore, is to increase the size of the large magnetic field and observe the drop in the level of radio frequency power which occurs if nitrogen is present. It so happens that in the case of nitrogen you do not just get one dip but rather three dips and there is no doubt that what is being observed is nitrogen, as no other likely impurity would produce this spectrum. This is how we show that there is nitrogen in diamond.

"This work was done in 1959 by another Smith, in America, on natural stones, a small percentage of which are what are called Type 1 diamonds, and contain a lot of nitrogen. We could go further and say that in the case of aluminium, we would again get a dip, but this would have a form characteristic of aluminium. If you were to have iron in the diamond you should again get a dip characteristic of iron, but to the best of my knowledge nobody has seen this yet in diamond. We have seen a resonance from nickel in synthetic stones and so have the people in South Africa. There are a lot of impurities which you can identify by this technique and all you have to do is to put the diamond into a magnetic field and to shine high frequency radio waves on to it.

"We decided we would have a look at synthetic stones and it is very interesting in that they are nearly all Type 1; they all have a lot of nitrogen in them. We thought we would like to see that synthetic diamonds in this respect were the same as natural diamonds so we took a synthetic stone, which as you know is very small, and managed to orientate it along its crystal axes. The ESR spectrum changes as you rotate it and in fact the changes which we observed were exactly the same as the changes which we would get for nitrogen in natural diamonds.

"You might say, 'well this work was being done in 1959 and we were producing synthetic diamonds about that time or shortly afterwards, why didn't somebody else do it before you?' The answer to this is very simple. If you take a synthetic diamond and put it into your ESR machine you find that you do not observe three lines, but only one. What is more it is broad because as I said to you before there are nickel and iron in diamond which are ferromagnetic. When you put synthetic diamond in the magnet the nickel and iron cause a distribution of the magnetic field around the nitrogen, so much so that it effectively obliterates the structure in the spectrum. So what we managed to do was to take these synthetic diamonds and to heat them up to about 1,500°C in a vacuum. This is just like squeezing an orange, the nickel and the iron melt and evaporate. What we did then was to waive a bar magnet over these heated stones and those which were not attracted to the bar magnet were those which had very little nickel and iron in them. We used those stones for our measurements, and sure enough the ESR lines had narrowed from something like 30 gauss down to about ½ gauss and we were able to see all the detailed structure. We were also able to get some other resonances from the nickel and iron before we heated these stones whereas after we had heated them we obtained nothing at all. So I am trying to stress that this can be a very valuable technique for having a look at diamond.

"Something else which we did was to measure the way in which nitrogen actually goes into the synthetic diamond. Does it go in uniformly or does it go in in one bubble and then diffuse out? We managed to resolve this problem by recording the ESR spectra of stones of gradually increasing size. We showed that there was a greater concentration of nitrogen in the smaller stones. Thus it seems to us that within the synthetic diamond the concentration of nitrogen in the centre of the stone is large and it gradually gets less as you go towards the outside. It suggests that you have a bubble of nitrogen when you make these synthetic stones somewhere in your high pressure apparatus and as the stone grows out it tends to grow out from a nickel nitrogen complex in the centre and as it grows out the concentration of nitrogen goes down.

"One interesting thing we found after sorting through thousands of stones was that a few of the stones supplied by the General Electric Company were octahedral in shape rather than cubo-octahedral, which is their normal shape and we thought we would look at them. We put them in our ESR machine, expecting to get a nitrogen resonance because there is always nitrogen in synthetic diamond, but we could not observe one. We tried this experiment a number of times. We also checked the cubo-octahedral stones from the same batch and obtained a very good resonance from them. We then sent these stones to Professor Chasette in the Congo who had done quite a lot of optical absorption measurements on similar stones. He was able to look at the infra-red absorption of nitrogen in these very small synthetic stones and confirmed that he could

detect no nitrogen in the octahedral stones whereas he could in the cubo-octahedral ones. We would suggest, therefore, that nitrogen has a significant effect on the final shape of synthetic diamond.

"A lot of the very interesting work in the diamond field is probably going to come by the controlled addition of impurities into the material. I gather that it is now possible to make synthetic diamonds which you can see through and the size seems to be increasing all the time. You can make a lasar by adding cobalt, chromium or neodymium to glass. The chances are that when you get to this stage with diamond, the good mechanical and thermal properties of this material will be an important advantage. It is extremely exciting, and I think when the problem of adding a wide range of impurities to diamond has been solved, then the physicist will be very pleased."

GIFTS TO THE ASSOCIATION

The Association is indebted to Mr. John Fuhrbach, Texas, for some rhodolite garnet rough.

GEMMOLOGICAL TUITION

South American wishes to visit U.K. for two months to receive private practical tuition. Offers to Secretary of the Association.

MORLEY COLLEGE

Morley College, 61 Westminster Bridge Road, London, S.E.1, has arranged various lectures on the study of gemstones on Wednesdays, 6.30 to 8.30 p.m. Fees for a single course of 35 classes are 42s. 6d. a year plus 10s. 0d. College Registration fee which gives the use of the library, refectory and other facilities. Further courses after the initial one cost an extra 10s. 0d. per course. Terms next academic year are as follows: 5th January to 21st March and 6th April to 27th June. Enquiries should be made of the Principal of the College.

GEM BUSINESS

Gemmology student, 23 years, engaged in the gem and jewellery trade wishes to correspond with those interested in gemmology and gem business. Z. A. Saleh, 63 Britol Buildings, Colombo 1, Ceylon.

OBITUARY

In August Australia lost its most prominent figure in the world of gemmology when Arthur Wirth died after a long illness. He had an encyclopaedic knowledge to which he was continually adding by study and maintaining contacts overseas. Arthur Wirth was a pioneer gemmologist, always willing to assist those who sought his advice, and he will be sadly missed.

Col. Elbert M. Barron, Austin, Texas, U.S.A., 5th Jan, 1969. (Ordinary Member 1953).

Lee, Harold, of Wimbledon, London, S.W., 11th June, 1969. (Ordinary Member 1952).

COLOURED DIAMONDS—NATURAL OR ARTIFICIALLY TREATED?

In the article by Charles Schiffmann in Vol. 11 No. 7 on coloured diamonds, illustrations 6 and 7 were unfortunately transposed.

GEM DIAMOND EXAMINATION

There were 29 entries for the 1969 Gem Diamond Examination arranged by the Association. The following is a list of successful candidates arranged alphabetically:

Qualified with Distinction

Pitt, Robert William, Sutton Coldfield
Thompson, Michael William, London
Turner, George Maurice, Airdrie

Qualified

Alabaster, A. Paul, Birmingham
Allan, Wallace Stewart, Ayr
Barrenger, Jonathan, Weybridge
Bentley, Dennis Cyril, Epsom
Cooper, Sydney Bernard Nikon, London
Fieldhouse, John Ernest, Sutton Coldfield
Fuller, Robert Geroge, Chesham
Gibson, Paul Walter, London
Glen, Susan Elizabeth, Coventry
Goodson, David Lloyd, Wolverhampton
Grey-Harris, Stephen James, Bristol
Hill, Dennis Alan, Glasgow
McRae, Arthur John Hutchison, Glasgow
Menton, Joel, Edgware
Mitchell, Roger, London
Neil, Peter Black, Glasgow
Pardoe, Paul Roger, Worthing
Sadler, David Alex, Ayr
Scorer, Brian, St. Albans
Simmonds, Stephen Maurice John, Stanmore
Whelan, Kenneth James,
Whitehead, Henry John, Edinburgh
Williams, Christopher John, West Wickham

GEMMOLOGICAL ASSOCIATION OF SPAIN

The Gemmological Association of Spain (*Associacion Espanola de Gemologia*) has recently opened impressive headquarters in the centre of Barcelona. The new offices contain two laboratories, classroom and a lecture room in which over eighty people can be seated. This room is also used for films (it has a separate projection room) and receptions. The Spanish Association's headquarters owe much to the enthusiasm of Sr. Juan Domenech.

From small beginnings a few years ago when three gemmological enthusiasts decided to establish an organization the Spanish Association now has 350 members. Sr. Manuel Masso, of Barcelona, a pioneer of gemmology in Spain, is the first President. The Association collaborates with the Instituto Gemologico Espanol, in Madrid, and the G.A. of G.B. in the arrangement of examinations held at Barcelona University. There is also a gemmology group in Valencia. Students are prepared for the G.A. examinations, the Fellowship Diploma being highly regarded in Spain. The first quarterly Bulletin of the Association, *Gemologia*, was produced in March, 1969. Instruction arranged at the Association's premises and the classes and examinations in gemmology conducted at Barcelona University, are under the direction of Dr. M. Font-Altaba, Professor of Crystallography at the University, who is assisted by Dr. J. Bosch-Figueroa, Dr. Montoriol-Pous and others.

The Spanish Association is in the course of establishing a collection of gems, minerals and a library. The University and the Association have made rapid strides in promoting the study of gemmology in Spain.

GEMMOLOGICAL ASSOCIATION OF ALL JAPAN

In September the Association received a visit of twenty-eight members from the Gemmological Association of All Japan, including the Chairman Mr. Wadachi Yamada and the Executive Director, Mr. Akira Chikayama. The Japanese Association kindly presented the Association with a selection of gem materials occurring in Japan, together with a map of their location. Also presented was a Gem Light pen with stone holder attachment for the examination of mounted and unmounted gems.

COUNCIL MEETING

At a meeting of the Council of the Association held in London on 25th June, 1969, the following were elected to membership:

ORDINARY MEMBERSHIP

Ajmera, Prabhu Das, Kowloon, Hong Kong
Allum, Peter Dennis, Shaftesbury, Dorset
Arai, Morimitsu, Tokyo, Japan
Arimura, Kazu, Kagoshima-Ken, Japan
Barlow, Allan Edward, Leicester
Bartlett, Kenneth Joseph, Bicester, Oxon.
Bayne, Irwin, Toronto, Canada
Broomhall, Alan Richard, West Bromwich, Staffs.
Challis, Peter James, Liverpool, Lancs.
Cornwall, John H., North Creek, New York, U.S.A.
Cross, Barry Ian, London, N.2
Curry, Harold L., Eugene, Oregon, U.S.A.
De Bruin, Alphonsus Gerardus, London, N.W.6
Deegan, Paul A., Palmerstown, Ireland
Dunn, Oliver Ralph, Preston, Lancs.
Emmanuel, Peter J., Croydon, Surrey
Farrelly, Ultan Alphonsus, London, W.4
Farrington, Richard Raymond, Toronto, Canada
Folch, Bru, Rosendo, Barcelona, Spain
Fore, Larry Dean, Honolulu, Hawaii
Fukagawa, Koji, Tokyo, Japan
Fukuchi, Katsuo, Tokyo, Japan
Haiduven, Richard G., Freeport, Grand Bahama Island
Hawthorn, Graham, Solihull, Warwicks.
Hemachandra, Amitha Buddhi Wijesurendra, Colombo, Ceylon
Hemachandra, Ranjith Thissa, London, S.W.19
Heyman, Adolf Pelrus Alexander, London, W.12
Higasa, Mituteru, Tokyo, Japan
Hunt, Graham John, Kidderminster, Worcs.
Hutley, Kenneth Michael, Redcar, Teesside
Imai, Takayasu, Nagano Prefecture, Japan
Ito, Yasuo, Aichi-ken, Japan
Jones, George Alfred, London, N.W.4
Kato, Hisaaki, Tokyo, Japan
Kielty, Nikolas, London, W.6
Kirekawa, Jun, Kanagawa-Ken, Japan
Kokubo, Satoshi, Hyogo-Ken, Japan
Larrazolo, Ruth L., Fort Clayton, Canal Zone
Ledsham, David, London, N.W.5
Lithgow, Thomas, East Kilbride, Lanarkshire

Maher, Francis N., Dublin, Ireland
Maiwurm, Frederick William, Newark, Delaware, U.S.A.
Mansuralli, Dhupalia Shamauddin, Paris, France
Mathis, Jr., Robert Chester, Tacoma, Washington, U.S.A.
Melvin, Ena Margaret, Newton Centre, Mass., U.S.A.
Miller, Stanford, Nashville, Tenn., U.S.A.
Nagasawa, Takeo, Hyogo-Ken, Japan
Nashimoto, Hiroshi, Tokyo, Japan
Newbold, Leslie John Claude, Tusmore, S. Australia
Ohmori, Mikio, Osaka-shi, Japan
Oshino, Ken, Tokyo, Japan
Palihena, Arthur Lionel, Talangama, Ceylon
Peeling, Alison Ruth, Hemel Hempstead, Herts.
Pickering, John Pearce PT. Noarlunya, S. Australia
Roberts, David Charles, London, W.2
Saeki, Kenji, Hiroshima-Chi, Japan
Samkay, Han, Malang, Djatim, Indonesia
Stewart, Joanne Lowe, Balboa Heights, Canal Zone
Taniguchi, Riyohei, Aichi-Ken, Japan
Voskamp, George, The Hague, Holland
Wharton, Stuart, St. Albans, Herts.
Wijeratne, Chandrakumara Kamalasri, London, S.W.5
Winstead, Frances F., Eugene, Oregon, U.S.A.
Yamamoto, Hirotake, Hyogo-Ken, Japan
Yamazaki, Shoichi, Tokyo, Japan

FELLOWSHIP

Butler, Barry, Sheffield, Yorks. D.1968
Holden, Terence, Bolton. D. 1968

The Council decided, for purely domestic reasons, to discontinue advertisements in the *Journal* (other than those connected with activities of the Association). Two assistant correspondence course instructors were appointed.

COUNCIL MEETING

At a meeting of the Council held on the 24th September, 1969, 8 Fellows and 118 Ordinary Members were elected, and there were 54 transfers from Ordinary Membership to Fellowship. A list will be published in the January 1970 issue of the Journal.

It was agreed that there would have to be future adjustment in the cost of correspondence course fees and Association membership to take into account increased costs of office occupancy, remuneration, publication printing and other charges. The Council agreed to the Secretary of the Association relinquishing the the title of Director of Examinations.

SYLLABUS OF EXAMINATIONS

Zoisite has been added to the diploma syllabus of examinations under section 4(a)(ii).

EXAMINATIONS IN GEMMOLOGY 1969

In the 1969 examinations in gemmology organized by the Gemmological Association of Great Britain 460 candidates sat for the preliminary examination and 307 for the diploma. Centres were again established in many parts of the world and the number of entries for both examinations was the highest in the history of the Association.

Upon the recommendation of the examiners, the Tully Memorial Medal and Rayner Prize have not been awarded.

The following is a list of successful candidates, arranged alphabetically:—

Diploma Examination

Qualified with Distinction

Bajo Ortiz de Apodaca, Julian F., Pamlona, Spain
Garre Alcaraz, Felipe, Seo De Urgel-Lerida, Spain
Hancock, Peter John, London
Hawthorn, Graham, Solihull
Hindle, David Ronald, Exeter
Jefferis, Marcia Nicoletta, Watford
Karolus, Martin, Mannheim, Germany
Kennedy, William, Baltimore, U.S.A.
Mosey, Irene, Lancaster
Osborne, David Leonard, Leigh-on-Sea
Pienaar, Herbert Svinde, Stellenbosch, S. Africa
Pitt, Nicholas Charles Hamilton, Stourport-on-Severn
Reilly, Hugh Joseph Andrew, Fife
Renton, Brent Sanderson, Preston
Russell, Lionel Harold, London
Sanchis Estrems, Jose, Valencia, Spain
Stewart, Reginald William, Bickley

Qualified

Ali, Nasim, Sutton
Allen, Rendall James, Darwen
Almenar Ibanez, Vicente, Valencia, Spain
Amigo Descarrega, Jose Ma, Barcelona, Spain
Andrade Malde, Julio, La Coruna, Spain
Andrews, Robert Eric, Cheadle Hulme
Arbunies Andreu, Manuel, Barcelona, Spain
Armengol Abril, Emilio, Barcelona, Spain
Baxter, James, Edinburgh
Beevor, Christopher Anthony, Pinner
Berger, Francis, Geneva, Switzerland
Bergmans, P., Rotterdam, Holland
Bloomberg, Maurice, Ilford
Bosch Senao, Pilar, Barcelona, Spain
Bradshaw, Stephen C., London
Brady, Deanna Mary, Pensby, (Cheshire)
Brennan, John Douglas, Birmingham
Brooking Grassy, Alberto, Madrid, Spain
Brown, Kenneth John, Gymea, Australia

Buyce, Milton Raymond, New York, U.S.A.
Carballal Cirici, Montserrat, Barcelona, Spain
Castro Ferrer, Jaime, Barcelona, Spain
Chang, Felix S.Y., Taipei, Republic of China
Christophersen, Elsa, Sandnes, Norway
Citoler, Ignacio Tormo, Gerona, Spain
Clarke, Doreen Patricia, Camberley
Collingridge, James William, Tonbridge
Cragg, George Edward, Leicester
Crawford, Brian Henry, Cape Town, S. Africa
Deeks, Noel William, Luton
Egea, Anthony, London
Estrada Mollet, Frederic I, Barcelona, Spain
Farras Sole, Jose, Barcelona, Spain
Farwell, Yvette, London
Fernandez Gil, Enrique, Valencia, Spain
Ferneyhough, Miles Howson, Henley-in-Arden
Fischer, Marianne Elsa, Stellenbosch, S. Africa
Fruhwald, George, Wiesbaden, W. Germany
Fry, Peter Maurice, Dover
Gartrell, Mark Paul, London
George, Antony Philip, Crawley
Gibbs, Keith Gerald, Sutton Coldfield
Glover, James J., Scarborough, Canada
Gonzalez-Requeral Valdes, Adriano, Gerona, Spain
Grey, Alan Peter, Weybridge
Gull, Peter, Walsall
Gunn, John Francis, Witham (Essex)
Hammersley, Gordon J., Michigan, U.S.A.
Harral, Benjamin David, Barnsley
Hayes, Bernard, Liverpool
Heyerdahl, Sten Scheen, Oslo, Norway
Hill, Josephine Ann, Sheffield
Hird, Frank, Sheffield
Hitchen, Melvin, Wakefield
Hlaing, Tin, Rangoon, Burma
Hkakyi, Rangoon, Burma
Hobbs, Robert George, London
Hoberg, Gunter, Idar-Oberstein, W. Germany
Hodgson, Jean Frances, London
Holm, Franz (Jorgen Flood), Bromma, Sweden
Holmes, Kenneth, London
Horsfall, Richard Thomas Lister, Halifax
Htwe, Win, Rangoon, Burma
Hundy, Christopher Leslie, Sutton Coldfield
Ingber, Ronald Max, London
Jackson, Della Ann, Prestbury, (Cheshire)
Jochems, Cornelie Madeleine, The Hague, Holland
Karlberg, Willy, Oslo, Norway
Kerfoot, Charles, Barnsley
Khaing, Myint, Rangoon, Burma
Kitson, Geoffrey Knowles, Sheffield
Ko, Min, Rangoon, Burma
Kutchinsky, Roger Nicholas, London
Lane, Stuart Howard, Bideford
Lang, Lorna Merle, Victoria, Australia
Lattimore, John Christopher, Harrow
Lay, Khin Maung, Rangoon, Burma
Lay, Mg, Rangoon, Burma
Llobet Ocariz, Antonio, Gerona, Spain
Lopez Soler, Angel, Barcelona, Spain
Luder, Johan Gerard, The Hague, Holland
Lwin, Tint, Rangoon, Burma
McCormick, Wendy Lynette, Victoria, Australia
McCorquodale, Iain Douglas, London

Marschner, Helga, Berlin, Germany
Marshall, Terence, Nottingham
Matsuzaki, Shigeru, Tokyo, Japan
Matthews, Sidney Allen, St. Helens
Milton, Mark Seymour, Liverpool
Mirwald, Gerhard Markus, Tokyo, Japan
Mitchell, Terence, Salisbury, Rhodesia
Morgan, Alfred Douglas, Birmingham
Myint, Than, Rangoon, Burma
Navarro Bort, Rodolfo, Valencia, Spain
Perera Bravo, Alberto, Madrid, Spain
Peris Bataller, Francisco, Valencia, Spain
Pfeiffer, William v., Victoria, Australia
Potts, Helen Lucy, London
Rae, Francis Carl, London
Richardson, George, Glasgow
Ripolles Ferrera, Jose, Valencia, Spain
Rosich Chova, Francisco, Valencia, Spain
Sanchis Estrems, Salvador, Valencia, Spain
Sancho Canto, Jaime, Barcelona, Spain
Sancho Canto, Ma Pilar. Barcelona, Spain
Schnetz, John V. P., Kriens, Switzerland
Silcock, James Barry, Southport
Statham, Patricia Margaret, London
Suter, Peter, Lucerne, Switzerland
Swe, Soe Nyunt, Rangoon, Burma
Swe, Tin Tin, Rangoon, Burma
Tamai, Shyojiro, Tokyo, Japan
Tenhagen, Joseph W., Miami, U.S.A.
Thompson, Ian Trevor, Ripon
Tjwan, Albert Tan Hien, Surabaja, Indonesia
Torres de Goytia, Rafael, Valencia, Spain
Turvey, Jane, Rye
Van Deijl, Wilhelm Jacobus Ernst, Parow, S. Africa
Vaughan, Alan John, Invercargill, New Zealand
Vaughan, Susan Josephine, London
Verges Tuset, Maria, Barcelona, Spain
Villegas Sanvicens, Cesar, Barcelona, Spain
Walker, Patricia Joan, London
Wallace, Lindsay James, Gainsborough
Wallace, Robert James, Fife
Wasilkowski, Wanda K., Miami, U.S.A.
Watson, Vivian Peter, Northwood Hills
Webster, John Henry, Leicester
Widdup, Kenneth N., Lancaster
Wilkes, Ronald, Blackpool
Williams, Alan, Liverpool
Winder Toole, Angela Bernice, Penzance
Wright, William Anthony, Potters Bar
Zelley, Howard Douglas, Norwich

Preliminary Examination
Qualified

Ahmad, Syed Vaqar, London
Alahendra, Anandapala, London
Alam, Mohamed Rasheed Shah Mohamed, Idar-Oberstein, W. Germany
Alforja Matoses, Enrique, Sueca, Spain
Allardyce, Anthony S., Maidenhead
Allen, William, Newcastle-upon-Tyne
Amor Fuentes, Antonio, La Coruna, Spain
Anderson, Leonard John, London

Andres Barbera, Manuel, Valencia, Spain
de Anitua y Lorente, Ezequiel, Vitoria, Spain
Appleyard, John Trevor, Wakefield
Arnoldi, Regine, Idar-Oberstein, W. Germany
Ashelford, Enid, Bathurst, Australia
Atkinson, Arthur, Sunderland
Azagra Aznar, Eduardo, Zarogoza, Spain
Bailey, Helen M., Cleveland, U.S.A.
Bajo Ortiz de Apodaca, Julian F., Pamplona, Spain
Baker, Kenneth Robert, Whitehaven
Baker, Thomas Alfred, London
Balasubramaniam, Muruguppillai, Colombo, Ceylon
Baldi, Annie Fraser, Salisbury, Rhodesia
Barba Albos, Antonio, Cornella de 11, Spain
Barnes, Peter Howard, Swanage
Baro Duran, Valentin, Barcelona, Spain
Barrett, Garry Sydney, Sittingbourne
Barry, Wendy Mary, Bradford
Bayne, Irwin, Toronto, Canada
Belenke, Burton, Miami, U.S.A.
Benson, Ian Thomas, Manchester
Berger, Francis, Geneva, Switzerland
Binns, David George, Hastings
Bjerkedal, Jon, Oslo, Norway
Bjerkek, Jens L., Oslo, Norway
Blunt, David Anthony, Warwick
Boorsma, A., Rotterdam, Holland
Bramwell, Peter, Durham City
Brand, Jonathan David, Pinelands, C.P. S. Africa
Brook, Doreen May, Liverpool
Brooking Grassy, Carlos, Madrid, Spain
Brown-Greaves, Rosemary Lavina, Horsham
Burrows, Patricia Anne, London
Buyce, Milton Raymond, New York, U.S.A.
Byard, Jack, Bradford
Call, Jerry Eugene, New York, U.S.A.
Caplin, Stanley Henry, Southport
Carter, Neil, Toronto, Canada
Carulla Fornaguera, Nuria, Barcelona, Spain
Cerro Elias, Roque Del, Zaragoza, Spain
Challis, Peter James, Liverpool
Chalmers, William Andrew, Manchester
Chard, Keith Scott, Bromley
Christoffersen, Haakon, Oslo, Norway
Clavaguera Duran, Ricardo, Barcelona, Spain
Clogger, Thomas John, Leigh-on-Sea
Cobden, Felix Sydney, London
Connard, Charles Roger, Southport
Cucurella Comellas, Ignacio, Barcelona, Spain
Dack, Gordon Robert, Rochester
de Meillon, Laura, Pietermaritzburg, S. Africa
de Vogel, Johanna Maria, Bergschenhoek (Z-H), Holland
Differenz, Gabriele Monika, Bad Homburg vdH, W. Germany
Donahue, Jack Northcutt, California, U.S.A.
Drake, John William, Coggeshall
Dunstone, Anthony, Fowey
Dyer, Wilbur E., Illinois, U.S.A.
Edwards, Janet Roberta, Bebington
Elfatatri, Abedd Ghani, Leiden, Holland
Emmanuel, Peter John, Addiscombe
Enkovaara, Kristi Maarit, Barcelona, Spain
Esteve Vila, Vicente, Mataro, Spain
Eyre, George, Buxton
Facchinelli, Carlo Alberto, Trento, Italy
Farber, Thomas, Zurich, Switzerland
Fazli, Mohamed Saleem Mohamed, Colombo, Ceylon

Fernando, Charles Rienzie, Nugegoda, Ceylon
Ferre Picas, Eugenia, Barcelona, Spain
Ferrer Olivan, Carlos, Huesca, Spain
Ferrer Tor, Ma Luisa, Barcelona, Spain
Fink, Stewart, Blackpool
Foster, Susan Ellwood, Toronto, Canada
French, Donald Peter, Colchester
Gallart Santamaria, Fernando, Valencia, Spain
Garcia Gimeno, Jose Luis, Zaragoza, Spain
Gargano, Frank, New York, U.S.A.
Gent, Michael Charles, Blackpool
Gold, Stewart, Fergus, Canada
Gould, Trevor Anthony, Natal, S. Africa
Gregory, Susan Margaret, Liverpool
Grieve, Patricia Jenny, Reigate
Griffiths, Peter Haydon, Stourbridge
Grist, Nigel, Sheffield
Guldahl, Jens Ivar, Oslo, Norway
Gunawardana, Panadura Lohakaruge Abhaya, Nugegoda, Ceylon
Haag, Susanne Renate, Kirschweiler, Germany
Haakonsen, Hans Olaf, Sandefjord, Norway
Harding, David, Plymouth
Harris, Harold Leslie, Oxford
Hawes, John, Wakefield
Hayburn, John, Romiley (Cheshire)
Haycraft, Philippa Anne, Haywards Heath
Hayes, John Ernest, Altrincham
Hayward, Richard Alan, Port Talbot
Hazelden, John Norman, Worthing
Heather, John Christopher, London
Heetman, J. A. M. Th., Rotterdam, Holland
Heijkoop, Nicolaas, Rotterdam, Holland
Heyerdahl, Sten Scheen, Oslo, Norway
Heyes, Alan John, Lancing (Sussex)
Hilal, Mohamed Abdulla Mohamed, Colombo, Ceylon
Hiley, Hazel, Shipley
Hill, Brian Douglas, Chatham
Hislop, Hugh Strathern, Johannesburg, S. Africa
Hlakyi, Rangoon, Burma
Hoberg, Gunter, Idar-Oberstein, W. Germany
Hocking, Mark, Truro
Hodgson, Trevor David, Leeds
Holm, Franz (Jorgen Flood), Bromma, Sweden
Holmes, Brian Michael, London
Hooper, Michael Charles, Birmingham
Hovers, T., Tilburg, Holland
Howell, Timothy Joseph, Cirencester
Htwe, Win, Rangoon, Burma
Irizar Terradas, Jorge, Barcelona, Spain
Jacobs, Julius, London
Jamieson, Vivienne, Prudhoe (Northumberland)
Jayawardena, Wadutantri Hubert De Silva, Colombo, Ceylon
Jayetileke, Rienzie Antony Srilal, Ratnapura, Ceylon
Jochems, Cornelie Madeleine, The Hague, Holland
Johnston, Iain Henry, Dumbarton
Johnston, Robert Bruce, Auckland, New Zealand
Jones, Claire Patricia, Redhill
Jones, George Harrison, Burnham
Jones, Kenneth Edmund, Nottingham
Jornet Vila, Enrique, Tarrasa, Spain
Just Chova, Jose Vicente, Valencia, Spain
Kaneko, Masao, Tokyo, Japan
Karolus, Martin, Mannheim, Germany
Keefe, John Anthony, Purley
Khaing, Myint, Rangoon, Burma
Kilpatrick, Constance, Aberdeen

Kirkpatrick, David John, Leamington Spa
Klocke, Christel Elvira, Rexdale, Canada
Ko, Min, Rangoon, Burma
Komlos, Maxine, London
Landau, Henry, London
Lang, Lorna Merle, Victoria, Australia
Lang, Richard, Dartford
Langarita Led, Angel Jose, Zaragoza, Spain
Laug, Monika, Idar-Oberstein, W. Germany
Lay, Khin Maung, Rangoon, Burma
Lay, Mg, Rangoon, Burma
Lewin, David Alexander, Loughton
Lewin, Persephone, Loughton
Lewis, Adolph Lee, La Mesa, U.S.A.
Lieben, Christl, Vienna, Austria
Linden, Howard Morris, Westcliff-on-Sea
Llopart Saura, Jorge, Barcelona, Spain
Lunn, Peter J., Belfast, N. Ireland
Lwin, Tint, Rangoon, Burma
Lyons, Raymond David, Croydon
McAvoy, T. W. G., Worcester
McCarthy, Dennis William, London
McCormick, Wendy Lynette, Victoria, Australia
MacDonald, Robert Charles, Hebden Bridge (Yorkshire)
MacFarlane, Alan Taylor, Glasgow
MacKenzie, David Ian Gruinard, London
McMurrie, Alfred George, Liverpool
Maik, Shwe, Rangoon, Burma
Malde Pardo de Andrade, Alfredo E., La Coruna, Spain
Manifold, Miranda, London
Mark, M. D., London
Marschner, Helga, Berlin, Germany
Marthinsen, Elise, Tonsberg, Norway
Marti Girona, Ma Montserrat, Barcelona, Spain
Martinez, Gonzalez del Campo, Francisco, Cordoba, Spain
Masip del Rio, Mari Carmen, Barcelona, Spain
de Masso, Rosa Maria P., Barcelona, Spain
Mawson, Alan, Crewe
Mensua Alonso, Vicente, Valencia, Spain
Mercade Galles, Jaime, Barcelona, Spain
Meredith, Jack, Stockport
Miller, Elva E., Tennessee, U.S.A.
Miller, Stanford, Tennessee, U.S.A.
Miro Bauza, Antonio, Manacor, Spain
Mirwald, Gerhard Markus, Tokyo, Japan
Monche Maristany, Andres, Las Palmas, Spain
Monereo Vilalta, Juan, Barcelona, Spain
Mones Mendoza, Luis, Barcelona, Spain
Monico Pifarre, Amalia, Lerida, Spain
Monte Domenech, Joaquin, Barcelona, Spain
Moore, Brian, Birmingham
Mori, Masatoshi, Tokyo, Japan
Murdock, Brian, Manchester
Myint, Than, Rangoon, Burma
Narayanamurthy, K., Bentong, Malaya
Nelson, John Joseph, Walsall
Nemoto, Ki, Ankara, Turkey
Newman, William Sowden, Bradford
Nicholson, Christopher, Chatham
Nicolau Marti, Margarita, Barcelona, Spain
Noakes, Norman De Berri, Auckland, New Zealand
O'Driscoll, Thomas Raymond, Sale
Ortiz Corripio, Jose, Madrid, Spain
Parsons, Richard Frank, Chorley Wood
Payan Catalan, Isabel, Madrid, Spain

Peacock, S. B., Coventry
Pearce, Joan Emery, Liverpool
Peris Bataller, Francisco, Valencia, Spain
Perry, Glyn, London
Pfeiffer, William v., Victoria, Australia
Phillips, Frank Xavier, Cooksville, Canada
Phillips, Joan Doris, Manchester
Piederiet, J. J. F. M., Breda, (N.BR), Holland
Pienaar, Herbert Svinde, Stellenbosch, S. Africa
Pilling, Peter Leslie, Salisbury, Rhodesia
Placer Portela, Jose Luis, Valencia, Spain
Platts, Jean Isabel, Sheffield
Pollak, Charles John, New York, U.S.A.
Poole, Susan Elizabeth, Penarth
Post, Pieter, Schoonhoven, Holland
Prats Ballester, Juana, Barcelona, Spain
Presser, Clement Alfred, Victoria, Australia
Priest, Richard, Hartlepool
Racs, Yuval, London
Ratnasekara, Wakkuburage Ariyawansa, Ratnapura, Ceylon
Reeks, Howard Frederick, Toronto, Canada
Ribes Cudinach, Emilio, Barcelona, Spain
Ricart Ribera, Arturo, Barcelona, Spain
Richardson, R. F., Rolleston-on-Dove (Staffs)
Ritchie, Douglas A., Toronto, Canada
Riuttala, Alexander Nikolai, Los Angeles, U.S.A.
Rose, David Michael, Welling
Rowe, Beryl Lorraine, Toronto, Canada
Rubira Pascual, Carmen, Barcelona, Spain
Ruiz Corcoy, Nuria, Barcelona, Spain
Ryan, David Christopher, London
Saadi, Talal Asad Kamal, Durham City
Sallan Lopez, Rafael, Zaragoza, Spain
Sanchis Estrems, Jose, Valencia, Spain
Sanchis, Estrems, Salvador, Valencia, Spain
Sanz Ribera, Jose, Valencia, Spain
Schofield, Neil Stephen, Manchester
Schonrock, Gisela Grete, Zeekoculis/Cape, S. Africa
Schullin, Hans, Graz, Austria
Scott-Taylor, Dorothy Thelma, Chester
Share, Andrew Thomas, London
Shatha, Mohamed Thaha Mohamed, Beruwala, Ceylon
Shepherd, Naomi, Reading
Simkiss, Edward David, Solihull
Simons, Paul Armand, Amsterdam, Holland
Simpson, David, Edinburgh
Smith, Alan Geoffrey, Scarborough
Snipper, Alison, London
Soler Serra, Jorge, Barcelona, Spain
Standard, Alan Kimball, Hawkinsville, U.S.A.
Stephen, Robert Clark, London
Stevens, Ronald Claude, Auckland, New Zealand
Stitt, Hamilton William, Montreal, Canada
Stocks, Malcolm Herbert, Halifax
Stokoe, Colin Edmund, Wallsend
Straftis, C. M., Athens, Greece
Stromsvik, Arne, Oslo, Norway
Swe, Soe Nyunt, Rangoon, Burma
Swe, Tin Tin, Rangoon, Burma
Szungyi, John Peter, Kentucky, U.S.A.
Tann, Jennie, Rhondda
Tasis de Moya, Ma Terese, Madrid, Spain
Templeton, Paul Thomas, Oxford

Thornton, Timothy Mundell, Stocksfield (Northumberland)
Thurgar, Stanley Hughes, Burlington, Canada
Thurm, Rudolf Edmund, Ludenscheid, W. Germany
Tomas Castelltort, Armando, Barcelona, Spain
Tootill, Jack Edward, Toronto, Canada
Upchurch, David Ward, Colchester
Valentine, Max, Bristol
Vila Demestre, Anna, Barcelona, Spain
Wafer, Barbara, London
Walker, Thomas, Sunderland
Walkley, Albert James, Ellesmere Port (Cheshire)
Warrington, Harold G., Toronto, Canada
Warrington, Mairin T., Toronto, Canada
Watts, Terrence Joseph, Whitehaven
Webb, Michael William, Newcastle-under-Lyme
Weerasinghe, Gamani Bandula, Ratnapura, Ceylon
Weerenbeck, S. M. H., Wassenaar, Holland
Wharton, Stuart, St. Albans
Whatton, Edwin Albert, Sutton Coldfield
Whitehead, Buckley, Manchester
Wijeratne, Ckandrakumara K., London
Wild, William, Stourbridge
Williams, Patrick, Sileby
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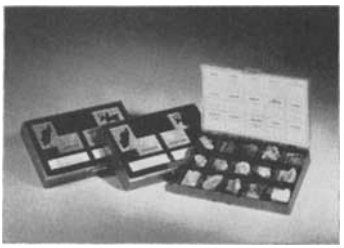

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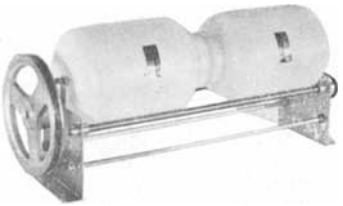

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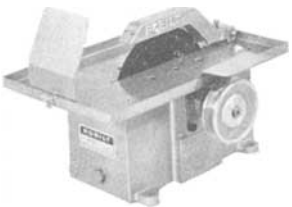

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and

PROCEEDINGS OF THE GEMMOLOGICAL ASSOCIATION OF GREAT BRITAIN

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THE TOWNSHEND COLLECTION OF PRECIOUS STONES IN THE VICTORIA AND ALBERT MUSEUM: NOTES ON GEMSTONE PRICES OF THE MIDDLE NINETEENTH CENTURY

By M. J. O'DONOGHUE, M.A., F.G.A.

THE Reverend Chauncy Hare Townshend was born in 1778 and was educated at Eton and Trinity Hall, Cambridge. He took orders but owing to persistent ill-health, resigned them early and took up a life of collecting and writing poetry. Few of his poems are read today, although one called "Burning of the Amazon" was the best-known. His will, dated 6th August, 1863, named Dickens as one of the executors and in it he left his collections of pictures, drawings and water colours along with the collection of precious stones to the then South Kensington Museum, now the Victoria and Albert Museum.

Many of the stones in the Townshend Collection, now placed in the jewellery room at the museum, came from the celebrated collection formed by Henry Hope—readers will be well acquainted with the blue Hope diamond—of which a catalogue was published in August 1839, "A Catalogue of the Collection of Pearls and Precious Stones formed by Henry Philip Hope, Esq., systematically arranged and described by B. Hertz". A copy of this work in the Victoria and Albert Museum has the prices paid by Townshend for many of the items entered in manuscript, and thus forms one of the few records of the time of the prices of good quality gemstones.

Although the Townshend Collection contains 154 items, only

those stones which were brought from the Hope sales are mentioned below; a catalogue of the whole collection giving the dimensions was last issued by Sir Arthur Church in 1913. It has, unfortunately, not been possible to do more than give the weights quoted in Hertz for some of the stones, as the collection is sealed in a security case.

The stones are set in gold rings; some of them are arranged to swivel in order to display the backs of the stones.

Diamond

A circular lemon-yellow brilliant-cut stone, displaying considerable fire, 5/12″ in diameter, weight 16 grains. Hertz plate 6, p. 27, no. 19. *Price paid £250.* Museum accession number 1177-69.

A green square brilliant-cut stone, closely resembling aquamarine in colour. Deeply cut. 5/16″ by 1/4″. 6½ grains. Plate 7, p. 28, no. 24. *Price paid £85.* Museum accession number 1176-69.

A small brilliant-cut stone, of almost a red spinel colour according to Hertz. 3/16″ by 1/8″, 1½ grains. Plate 7, p. 27, no. 15. *Price paid £30.* Museum accession number 1178-69.

Sapphire

An octagonal white sapphire with a very bright pale bluish-grey hue. 17/32″ diameter, 47¾ grains. Plate 11, p. 40, no. 19. *Price paid £25.* Museum accession number 1257-69.

An oblong sapphire, pale blue-grey in the centre and straw at the ends, 1/2 by 3/8″ and 3/8″ thick, 39 grains. According to Hertz the yellow is seen at the front and the blue-grey at the back. Plate 11, p. 40, no. 13. *Price paid £40.* Museum accession number 1256-69.

An oblong step-cut apricot-yellow sapphire (listed by Hertz under Ruby Spinelle). 7/16″ by 5/16″, 7¾ grains. Plate 9, p. 36, no. 13. *Price paid £18.* Museum accession number 1260-69.

A long oval cabochon sapphire, lavender-blue in colour. Spectrum colours caused by an internal flaw. 13/24″ by 3/8″, 26 grains. Plate 12, p. 42, no. 31. *Price paid £18.* Museum accession number 1238-69.

A faceted oval sapphire of violet colour. 7/16″ by 3/8″, 20 grains. Plate 12, p. 39, no. 10. *Price paid £52 10s.* Museum accession number 1247-69.

An oval cabochon brown corundum with grey chatoyancy showing iridescence from a flaw. Partly transparent and partly opaque. 2/3″ by 7/12″. Plate 12, p. 42, no. 27. *Price paid £31 10s* Museum accession number 1258-69.

An oval cabochon wine-coloured corundum (listed as Ruby Spinelle by Hertz), 3/8″ by 5/16″. Plate 9, p. 37, no. 15. *Price paid £15.* Museum accession number 1259-69.

Topaz

A yellow oblong topaz, showing reddish at the ends. 1¼″ by 2/3″, 5/12″ thick. Plate 26, p. 65, no. 5. *Price paid £25.* Museum accession number 1311-69.

An oblong deep claret-coloured topaz. 5/8″ by 13/24″. Plate 26, p. 67, no. 16. *Price paid £180.* Museum accession number 1309-69.

Tourmaline

An oval rich-brown tourmaline, sherry-coloured according to Hertz. 19/24″ by 7/12″. Plate 28, p. 71, no. 19. *Price paid £50.* Museum accession number 1275-69.

An oblong deep green tourmaline, wrongly classed as zircon by Hertz. 13/24″ by 5/12″. Plate 19, p. 52, no. 2. *Price paid £8.* Museum accession number 1321-69.

An oblong step-cut deep green tourmaline. 1″ by 3/4″ by 5/12″. Plate 30, p. 70, no. 3. *Price paid £80.* Museum accession number 1323-69.

Garnet

A nearly circular crimson almandine garnet, from Syria according to Hertz. 17/24″ by 5/8″. Plate 24, p. 61, no. 13. *Price paid £16.* Museum accession number 1271-69.

A cabochon almandine garnet engraved with a faun. 5/8″ by 1/2″. Plate 25, p. 62, no. 24. *Price paid £15.* Museum accession number 1272-69.

An oblong hessonite garnet (wrongly classed as zircon by Hertz). 1/2″ by 5/12″. Plate 19, p. 53, no. 6. *Price paid £15.* Museum accession number 1318-69.

Peridot

A nearly circular leaf-green engraved peridot. (The subject is hermaphrodite, tree and Greek inscription). 2/3″ diameter. Page 84, no. 7. *Price paid £7.* Museum accession number 1300-69.

Emerald

An oval emerald of fine colour, engraved with Persian characters. 27/32″ by 21/32″. Plate 14, p. 45, no. 7. *Price paid £45.* Museum accession number 1283-69.

A circular emerald with 6-rayed black star. The face and back are centrally flattened. 1/2″ diameter. Plate 14, p. 46, no. 9. *Price paid £12.* Museum accession number 1285-69.

Aquamarine

A round sea-green aquamarine with a large table. 1 5/6″ diameter, 1 1/6″ thick, 7 oz. 7 dwt. 10grs. Plate 16, p. 49, no. 6. *Price paid £60.* Museum accession number 1286-69.

An oval yellowish-green aquamarine with a large table. 1 7/12″ by 1 1/3″ and 11/12″ thick, 1 oz. 5 dwt. 8 grs. Plate 18, p. 49, no. 4. *Price paid £30.* Museum accession number 1287-69.

An oval sea-green aquamarine with a large table. 1 5/8″ by 1½″ and 1″ thick, 1 oz. 17 dwt. 15 grs. Plate 16, p. 48, no. 3. *Price paid £300.* Museum accession number 1288-69.

A nearly square step-cut pale greenish-grey aquamarine, wrongly classed as zircon by Hertz. 1/2″ by 11/24″. Plate 19, p. 53, no. 4. *Price paid £15.* Museum accession number 1293-69.

Opal

A Mexican fire opal of deep amber colour with red and green flashes, shaped as a long oval. 2/3″ by 5/12″. Plate 33, p. 79, no. 26. *Price paid £24.* Museum accession number 1226-69.

An oval Hungarian opal, golden with fine play of colours. 11/16″ by 9/16″. Plate 33, p. 79, no. 28. *Price paid £15.* Museum accession number 1228-69.

An oval pinkish Hungarian opal with play of colour. 3/4″ by 7/12″. Classed as hydrophane by Hertz. Plate 33*, p. 81, no. 42. *Price paid £4.* Museum accession number 1230-69.

An ovate liver-coloured Hungarian opal with purple flashes. 1/2″ by 1/3″. Plate 33, p. 81, no. 39. *Price paid £8.* Museum accession number 1231-69.

An oval Hungarian opal, one third white, two thirds brown with play of colour. 1/2″ by 3/8″. Plate 33, p. 80, no. 34. *Price paid £12.* Museum accession number 1232-69.

An oval deep brown Mexican opal with play of green light. 13/16″ by 5/8″. Plate 32, p. 78, no. 22. *Price paid £70.* Museum accession number 1233-69.

A triangular Hungarian opal with black dendrites and greenish-blue flashes. 1/2″ across. Plate 32, p. 80, no. 33. *Price paid £30.* Museum accession 1234-69.

Quartz

A straw-yellow cairngorm. 5/6″ by 3/4″ and 5/6″ thick. Plate 35, p. 86, no. 9. *Price paid £5.* Museum accession number 1182-69.

A Ceylon twin stone, part smoky, part purple, each half a long oval and 17/24″ by 1/3″. Plate 36, p. 86, no. 10. *Price paid £10.* Museum accession number 1186-69.

A heart-shaped rose-cut amethyst, Siberian. 11/12″ by 11/12″. Plate 36, p. 89, no. 29. *Price paid £7.* Museum accession number 1189-69.

A rich-coloured striped amethyst. 1 1/12″ by 23/24″ and 1/2″ thick. Plate 36, p. 87, no. 19. *Price paid £15.* Museum accession number 1191-69.

A piece of chalcedony on amethyst, the upper layer cut to represent a panther, the convex back of amethyst engraved with a Bacchante. Plate 35, p. 86, no, 5. 5/62″ by 7/12″. *Price paid £15.* Museum accession number 1208-69.

An oval grey mocha stone with black dendrites, classed as opal by Hertz. 1″ by 3/4″. Plate 33*, p. 81, no. 40. *Price paid £15.* Museum accession number 1215-69.

Turquoise

A nearly circular greenish blue turquoise cut with a female head in relief. 5/12″ in diameter. Plate 41, no. 5. P. 91, no. 7. *Price paid £9.* Museum accession number 1261-69.

GEMMOLOGY AND TEETH

By W. G. CROSS, M.B., M.S., B.D.S., F.G.A.

FOR centuries man has striven to repair the ravages of dental decay and extracted teeth with various materials, and in most cases he has endeavoured to match natural teeth as regards colour, hardness and contour. Thus long ago replacements for missing teeth were carried out in various species of bone or ivory, and in recent times in plastic (methyl methacrylate) or porcelain. Cavities have been filled with silicate cements, plastics and porcelain, all of which can give reasonably acceptable aesthetic results, silver amalgam or gold, and teeth may be crowned with acrylic, porcelain, stainless steel or gold crowns.

In general there is a preference for materials which are inconspicuous, but there are many parts of the world where a display of gold or stainless steel is customary. In the past, however, some peoples submitted themselves to decoration, by means of gem materials, of teeth which were free of decay, such materials including gold, diamond, jadeite, haematite, turquoise, rock crystal, obsidian. In Central and South America the Mayas and the nhabitants of Ecuador used to decorate their teeth in this manner; it is probable that decorative filing of the teeth preceded the insertion of inlays. The teeth involved were usually the upper incisors: the crowns of these teeth, especially the central incisors, are normally fairly wide and long, and are usually visible to others, especially

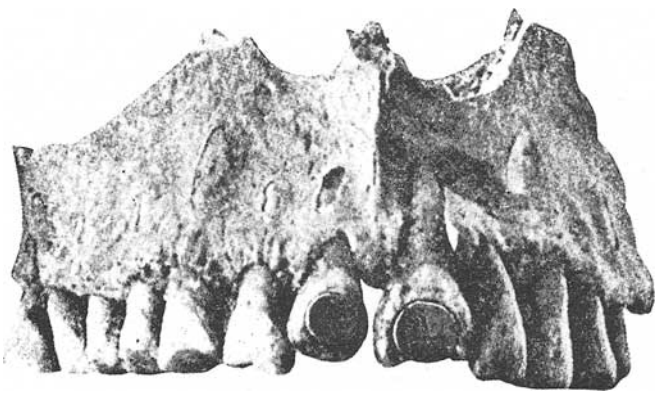

FIG. 1. *Maxilla and teeth of skull with two hardstone inlays.*

when laughing and smiling. Less frequently the palatal surfaces are involved.

The inlays consist, in the main, of one or more circular discs inserted into prepared cavities; in some cases a transverse groove has been formed, with undercuts, so that the inlay is slid into position from one side. In some instances, with the inlay removed, a raised central boss can be seen at the bottom of the cavity, indicating the use of a hollow trephining instrument. This may have been a bone or cane drill, used with an abrasive (sand); chewing of coca may have helped to make the operative procedure bearable (Figs. 1 and 2).

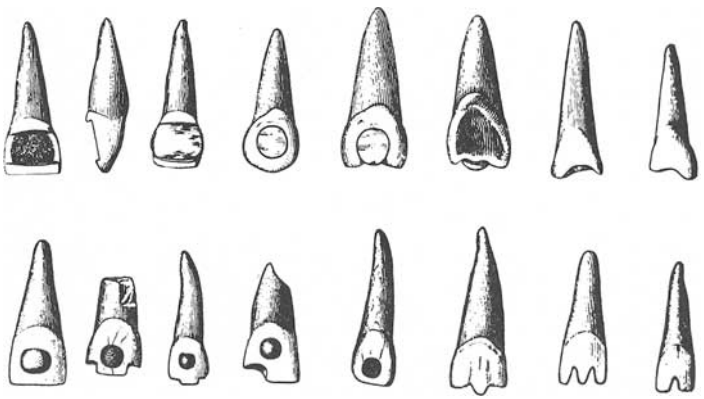

FIG. 2. *Types of decorative inlays and tooth filing found in incisor teeth of the Mayas.*

I was recently asked by Mr. J. A. Donaldson, L.D.S., R.C.S., now Editor of the *British Dental Journal* and at the time the Honorary Curator of the Museum of the British Dental Association, to examine a tooth which had been presented to him by Dr. Brodny, an American physician, who in turn had obtained it from a friend in Mexico. The tooth came from a Maya tomb excavated near the town of Teapa, 30 miles from Palenque, State of Tobasco. The skull had seven teeth, said to be inlaid with turquoise. Its date, late Maya Empire, is about 1000 A.D. Many mutilations and decorations of teeth were found including inlaying with jade, malachite, turquoise, obsidian, pyrites and serpentine.

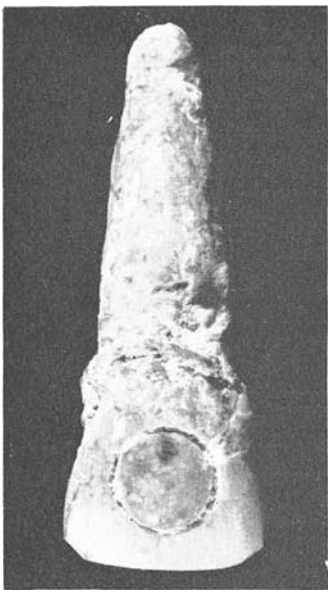

FIG. 3. *Late Maya tooth with jadeite inlay.*

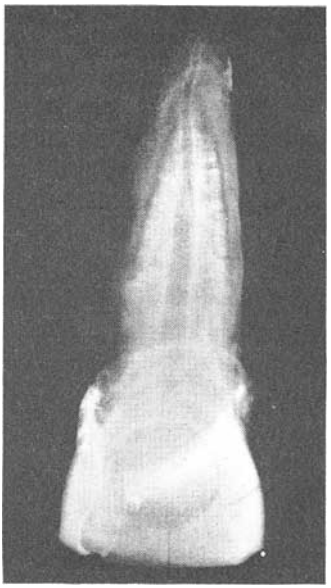

FIG. 4. *Antero-posterior radiograph of tooth in Fig.* 3.

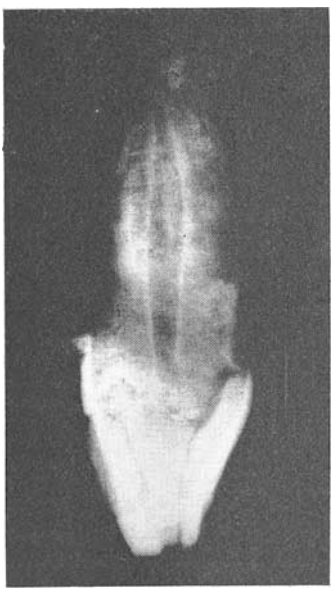

FIG. 5. *Lateral radiograph of tooth in Fig.* 3.

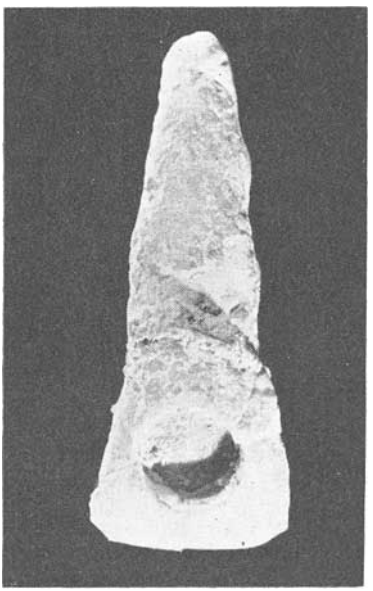

FIG. 6. *Late Maya tooth without jadeite inlay.*

The tooth was an upper central incisor, 25 mm. long and 9 mm. wide at the incisal edge, with encrustations of calcified material on the root surface. The front, or buccal, surface contained a circular greenish-blue disc in a prepared cavity, and it measured 4 mm. in diameter, 2 mm. in thickness, being lenticular in section. It appeared to be jadeite, or perhaps turquoise (Fig. 3). Radiographs, both antero-posterior and lateral, were taken, and from these several additional features could be noted (Figs. 4 and 5).

The root canal, normally rather narrow, was broad through much of its extent: the pulp chamber was nearly missing and there appeared to be an irregular mass of radiopaque material in the place of most of the coronal dentine, being rather more radiopaque than the dentine of the root. One or two cracks suggested that a fracture had taken place and been repaired at some stage with a dental cement.

This was confirmed by an accident which took place while the tooth was being examined. The tooth had been photographed, and whilst being replaced in an envelope dropped to the floor, where much of the crown shattered into a number of pieces. This accident, while unfortunate in respect of the damage to the specimen, did at least permit positive indentification of the material.

An x-ray powder diffraction examination was made in the Department of Mineralogy, Natural History Museum, and the material was found to be an impure jadeite. A further photograph of the tooth, showing the cavity in which the jade disc was cemented, was taken (Fig. 6).

Many teeth subjected to this form of decoration must have suffered from pulpal necrosis due to exposure of the pulp chamber, and thus become a non-vital tooth which in many cases would have to be extracted. The skill, however, with which the operator carried out the trephining procedure must be admired.

I would like to thank Mr. P. Embery of the Mineralogical Department, Natural History Museum, for undertaking the x-ray diffraction picture, and the Photographic Department staff, Eastman Dental Hospital, for the photographs numbers 3 to 6. Photograph numbers 1 and 2 are from Weinberger's work *History of Dentistry*, Volume 1, 1948.

TUGTUPITE

By OVE DRAGSTED, F.G.A.

IN 1960, a new mineral of an intense cyclamen-red colour was described from two localities, far from each other but with close resemblance, Southern Greenland and the Kola peninsula. It was described by the Russian petrologist E. I. Semenov, who had found it as embedded grains of pinpoint size, and by the Danish geologist, Professor Henning Sørensen, who had found somewhat larger, but still quite small, spots in a vein in nepheline-syenites.

The mineral, although close to sodalite, was found to belong to the tetragonal system of crystal symmetry. It is a beryllium-mineral corresponding to the chemical formula $Na_8\ Al_2\ Be_2\ Si_8\ O_{24}$ (Cl_2, S). When the mineral is pure, the specific gravity is 2·36, but it may vary from 2·30 to 2·57 owing to contents of chkalovit, albite, analcime, hochmanite, pyrochlor, aegirine, etc. The refractive indices for yellow light are, for the ordinary ray 1·496, and for the extraordinary ray 1·502, with a birefringence of 0·006. There is a marked dichroism, a darker somewhat bluish red and a lighter more orangy red shade.

The colour is mostly mottled in lighter and darker parts, the lighter ones fading into white in darkness and regaining their hue when again exposed to sunlight. Some of the white spots may also be tugtupite. The fluorescence is most remarkable. Under the long ultraviolet excitation a glowing apricot colour is developed: under the shorter rays a weaker salmon red is observed.

The hardness is between 6 and 7 on Mohs' scale. The material is somewhat porous. The cleavage is parallel to the faces of a tetragonal pyramid. The mineral hitherto found is marred by cleavage cracks and fissures, resulting in a considerable cutting waste. But the cabochons hitherto cut have been admired for their beautiful colour. They take a good polish. Most cabochons are mottled cyclamen and white with occasional greenish black needles of aegirine and gypsumlike, but hard, spots of yellow pyrochlor.

After one of the geologists in Greenland had described tugtupite as "much rarer than diamond", the local population have visited the drill holes made by the research teams and broken away the remainder of the material with hammer and chisel. Before this a minor portion had been sent to Denmark for cutting. The tug-

tupite shows up beautifully when set in gold, and production of tugtupite jewellery is going on on a small scale. It is expected that small occurrences of tugtupite will come to light now and then during the prospecting work of the geologists.

Tugtupite was one of the end products crystallized in the Ilímaussaq intrusion in Greenland. The magma filling a big hole perhaps two or three kilometers below the surface started to solidify 1,400,000,000 years ago, and the end products containing beryllium, niobium, uranium, thorium, etc. did not crystallize until 1,000,000,000 years ago.

The name tugtupite, which was suggested by Professor Sørensen in 1960 and approved by the I.M.A. Commission on New Minerals and Mineral Names, was derived from a small promontory where it was first found in Greenland, named Tugtup agtakôrfia, meaning "reindeer fall-off", and the "fall-off" includes the antlers shed as well as the manure. The first part of the name, tugtup, is reindeer, so tugtupite means reindeerstone.

TESTING TIMES

By A. E. FARN, F.G.A.

FREEDOM is nothing if it has no bounds. We often feel a little irritated at the niggling restrictions with which bureaucracy rings us today. Gemmologically, routine testing of ordinary goods can diminish the enthusiasm of the keenest gemmologist.

In Britain, the Trade Descriptions Act, 1968, serves further to pin-prick inadvertently by causing concern over virtually worthless goods. The law can now be invoked in favour of the trifling customer, and a retailer needs to be a pedantic purist pursuing perfection.

Among the more humdrum routine tests we are asked to carry out, some give more trouble than others. Typical of such tests can be a suite of inexpensive Ceylon jewellery—usually blue or red-colour centre-stones in colourless cluster-surround rings, pendants, earrings etc. A glance would suffice any competent jeweller to inform him that the centre stones were synthetic sapphires and synthetic rubies and that the colourless cluster-surrounds were *not* diamonds.

Fortunate are we in being able to test these, very often, rubbed centre-stones despite their setting or backing. My particular "bête noire" is to be asked to test the white or colourless stone surrounds as well. These, variously, have been proved to be synthetic spinels, synthetic sapphires, pastes, zircon, natural colourless sapphires, topaz or quartz. When, as sometimes has happened, most varieties have been present in various permutations and the stones average about 12 to the carat, one wonders why it is necessary to be so precise. How much or little can one charge for tricky work in smelly liquids in the height of summer whilst suffering a bout of hay-fever? Monobromonapthalene is a great irritant to the nostrils and is not advisable as an immersion liquid for sufferers from hayfever. When the result is found to be synthetic spinels, or some such similar stones, one wonders—does it matter since they obviously are not diamonds?

However, to lift us from our despair at such mundane matters, something of interest comes along.

A very good friend of mine, an eminent gemmologist, uses his refractometer first and foremost—an advocate of refractometry!

I like to sight test first (decide without testing—solely by look, heft, cut and colour). Afterwards, I try to decide by lens, DR, inclusions, dichroism, lustre, patina and polish. Finally, I opt for the microscope, then the spectroscope and then the refractometer. Obviously, if the stone purports to be quartz or topaz I do not use microscope or spectroscope; similarly, for obvious aquamarines or tourmalines. I do not scorn the refractometer; I use all three as needed—spinel, standard and diamond.

Quite recently a 9 ct. ruby was sent to be tested. Doubts were expressed by merchant and shop—both experts in their own field. It was decided a laboratory test was essential.

9 ct. rubies are somewhat rare these days and it is a pleasure to handle such goods after a routine of synthetic red samples. The customer requested permission to wait for the test to be completed—not conducive to cool, calm, collected conditions to have someone literally waiting for you to raise your eyes from the microscope, and, hey presto, it is a ruby!

Looking at the stone in its packet by unaided eye, it looked like a fine, rather dark red spinel. First examination by a 10X lens with a 60 watt bulb bench lamp, showed multitudinous bubble-like crystals similar to diopside crystals seen in hessonite garnets. Since, however, I could see the edges or perimeters of some of the crystals sharply in focus to be doubled, I knew the host material must be doubly refracting, which immediately eliminated spinel and garnet. Spectroscopic examination gave clear cut evidence of a bona fide ruby spectrum.

Since doubts had been expressed by a knowledgeable wholesaler, it seemed commonsense to do a treble check and take the refractive indices. I was taken aback to get a clear single edge reading of 1·76. I have often in the past had poor readings of one of the two shadow edges. This is usually improved by use of a polaroid disc; in this instance, however, it only served to emphasize the single edge of 1·76. After more than routine double checking, it was felt that some form of repeated twinning of the structure caused this unusual reading. Unanimous agreement was that the stone was in fact a natural ruby.

It is only fair to say that the inclusions seen in this stone were not typical of Burmese or Siamese stones. Since most of the trade sell on colour, it is not unknown for a chrome-rich dark red Burma stone to pass as being from Siam. Therefore it is possible that, since

the stone did look like a spinel (failing which, a garnet) a refractometer reading could have given a wrong direction. Even though one's gemmological crest should bear the legend "Leave no stone unturned", on such an occasion it would be more profitable to become more absorbed—gemmologically speaking!

WORLD MAP OF GEMSTONE DEPOSITS

By H.-J. SCHUBNEL

THIS map (36 × 24 inches) specifies, on a 1/40,000,000 coloured background, the distribution of about 150 deposits or mining districts over the whole surface of the globe. The gems are symbolized by plain or variegated bright coloured marks showing the locations.

The relative importance of the deposits is revealed by the size of the marks. The types of primary deposits are specified by the outer shape of the marks. It was necessary to point them out, for some deposits which were thought to be worked out, were in fact only partly exploited (superficial gathering, sorting of eluvial deposits . . .).

The following types were distinguished:

△ - Deposit enclosed in basic volcanic rocks and their vents (sapphire, olivine, pyrope, zircon).

▽ - Decay deposit of volcanic rocks (opal, agate, amethyst).

⌓ - Pegmatite deposit (beryl, topaz, tourmaline and many other gems of granitic pegmatites: emerald of pegmatites injected in mica-schists).

◇ - Lode deposit (amethyst, rhodochrosite, etc.).

○ - Metamorphism deposit (almandine, cordierite, ruby, etc.).

⌔ - Endomorphism deposit:

- alkaline rock in contact with an ultrabasic rock (jade);
- alkaline rock in contact with a magnesian marble (lapis lazuli).

- Weathering deposit (malachite in copper deposits; turquoise in some aluminous rocks in dry climate).
- Other types of deposits: such a mark shows peculiar modes of formation: fossilization of resins (amber); silicification of fibrous minerals (tiger-eye) or plants (fossil, wood, etc.).

Diamond is represented by an octahedron. The deposits where it is mined in the parent-rock (kimberlite) are differentiated from the secondary deposits (precambrian conglomerates, marine terraces, alluvial deposits, etc.).

The worldmap meets a double use: for jewellers, the possibility of exhibiting a map illustrating the distribution of the main mines of diamonds and coloured stones, while being attractive enough to use decoratively; and for specialists, a document summarizing a large number of useful data referring to their work concerning geology, geography and economy.

The map was prepared according to the most modern techniques in mapping and to the method used for the execution of

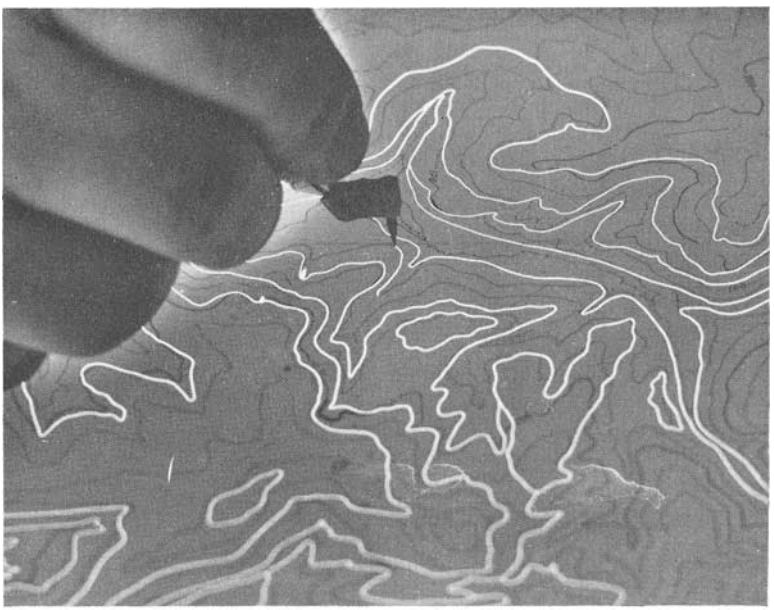

FIG. 1. *The outlines of geological areas are drawn in blue-print.*

geological maps. Such a process relies largely upon the photo-mechanical techniques which allow, thanks to the stability of plastic supports, an accurate placing of colours in the surrounding outlines.

"Registering", the main care of printers, is thus practically resolved.

Here is a concise description of the printing process.

The cartographical drawing proper (outline projection of coasts, etc. . . .) was rapidly drawn on a stable semi-transparent plastic support which was of the same kind for all the plates needed.

The picture obtained was transferred, through a diazoic process, onto a second transparent support coated with an opaque red emulsion, soft enough to be penetrated by a special point, sized to the thickness of the desired line. The tracing thus obtained was clear of the support, which formed a kind of negative from which, through mere contact, a positive film was drawn.

FIG. 2. *Negative of coloured spaces to be covered. The thin cut-out film is stripped from its plastic support.*

This provided the basis for the following:

(1) Achievement of colour plates.
(2) Execution of printing plates.

These colour plates were achieved through the "stripping layer" method. Such a layer was made of a transparent plastic support over which was poured, when heated, a thin film of alcohol-soluble poly-vinyl. Through a photomechanical process, the picture of the positive film was transferred and appeared, after development, as a hollow groove in the thin film. Then it was easy to "peel off" the surfaces of the plate dealt with. A negative of each area corresponding to the various printing values was thus obtained. It was enough to interpose, for each printing plate, the different plates, while getting together those which occurred in the same colour.

Parallel to these operations, the text-plate was achieved through photocomposing on stripping film. Such texts were put in their place on plastic support by mere pasting.

A checking test was carried out by multicolor process, using photomechanical means to obtain a colour-proof on a plastic support.

Conventional offset printing was used to produce the final map.

The map and its brief explanatory account are available in three languages: German, English and French. The English version is available from the Gemmological Association price 35s. 0d. and the French and German versions from the "Department de Documentation" of Bureau de Recherches Géologiques et Minieres, B.P. 818, Orléans (France), price 24 francs (post free—sea mail).

Gemmological Abstracts

NISHIYAMA (S.). "*Victoria-stone*". Lapid. Journ. 1969, 23, 5, p. 696.

Details of a man-made chatoyant stone consisting of a radially developed crystalline mass of fibrous aggregate structure similar to the nephrite of the amphibole group. It contains an excess of the actinolite particles and exhibits chatoyancy when cabochon or bead-cut. The material is produced in various colours and is the result of the work of Dr. S. Iimori of Tokyo. A material called "Meta-made", with properties close to those of natural jade, has also been produced.

G.A.

VISWANATH (N.) *India's diamond industry*. Lapid. Journ. 1969, 23, 5, p. 722.

A review of the diamond industry in India. There are two major fields, one at Panna, in Central India, and the other at Golkonda in Andhra Pradish, Southern India. Both areas are being commercially exploited. Cutting and polishing are also carried on, but the industrv has to depend upon imported material.

S.P.

MALES (P. A.). *Microtextures of Australian Chalcedony, Chert and Jasper*. Australian Gemmologist, 1969, 7, pp. 9-14.

X-ray analyses of chalcedony prove it to be merely a cryptocrystalline variety of the common silica mineral, quartz. Thermal analyses of chalcedony give different patterns from samples of ordinary quartz, due to the very fine grain size of the chalcedonic particles. Very often the name chalcedony is restricted to the cryptocrystalline variety of quartz that shows, under the microscope, a definite microfibrous structure; but microgranular forms that do not show distinct quartz features under the microscope can also be included, owing to their similarity to the microfibrous forms under other tests.

The term jasper is normally used for red, opaque varieties of chert, although it has often been extended to include any strongly coloured chert, whether yellow, brown, or even green or black.

In most cases, however, the colouring is due to iron compounds, and is a distinctive departure from the normal dull greyish varieties of chert. The term jasper should be reserved for the red and reddish-brown varieties of chert to avoid confusion.

There is an anomaly in limiting the term jasper to describe chert deposits of the required colour. Some Australian agates, and the centres of some odd local "thunder eggs" present the typical opaque reddish brown colour of a jasper, and these of course should be regarded as forms of the mineral chalcedony.

S.P.

DUYK (F.). *L'émerande artificielle de synthèse.* Technica, 1969, 279, p. 539.

A brief survey of the methods used to produce synthetic emerald.

S.P.

CRONSTEDT (K.). *The great Australian amethyst mine.* Aust. Gemm. 1969, 10, 7, p. 23.

The great Australian amethyst mine is situated at Wyloo Station in the Ashburton district of W. Australia. There is an abundance of crystal clusters and terminated crystals are common. The colour range is from pale lilac, through purple to a blackish-blue. Often the crystals are only coated with a layer of colour.

S.P.

WIN (U. SOE.). *The application of geology to the mining of jade.* Union of Burma Journ. Sci. Techn., 1968, 1, 445-456, 3 figs.

The mineralogy, genesis, and mode of occurrence of jadeite and the methods of mining it in the Hpakan-Tawmaw tract of Burma are described. Jadeite occurs in albite-jadeite dykes intruding fissures in serpentinites and as boulders in Tertiary conglomerates. At Mawsitsit, the dark green variety locally known as mawsitsit kyauk is mined: uvarovite here occurs with chrome-jadeite. In the Hpalai Hills, 6 miles NE of Mawsitsit, swarms of unexplored jadeite-bearing dykes are known.

R.A.H-

EPPLER (W.). *Das Edelsteinbild.* The gem photograph. Gold. schmiedezeitung, Vol. 67, 11/1969, pp. 1325-1327.

Collection of various photomicrographs and their description.

(*a*) Sandmeier-Plato-striation. Three photomicrographs, one of a German synthetic star-sapphire, one of a ruby from the Umba mine in Tanzania and the same ruby under crossed nicols. The striation is not often illustrated, but maybe this is because it is only rarely shown in such details as in the published photomicrographs. The striation has a thickness of about 0·07 mm and can only be seen in polarized light and only in the direction of the optical axis. This phenomenon was first noticed by D. Sandmeier, Lugano, in 1920 and then confirmed by Dr. Plato in 1949. It has proved to be a characteristic of lightly coloured synthetic corundum, although it has now been shown that this striation is also present in the rubies found in Tanzania.

(*b*) Two beautiful photomicrographs show aquamarines, from Madagascar, with ilmenite inclusions, which form a kind of skeleton as an inclusion.

(*c*) Bronzite is an iron-rich enstatite. The first photomicrograph shows a bronzite with a diamond octahedron inclusion, which is enlarged in the second illustration showing surrounding stress fissures.

E.S.

HURLBUT (C.S., Jr.). *Gem zoisite from Tanzania.* Amer. Mineralogist, vol. 54, pp. 702-709, 1969.

Twenty-six crystals were examined, the largest being 260 ct., 40 forms were identified, 17 of them new for zoisite. A full chemical analysis is given and includes V_2O_3 0·20, Fe_2O_3 0·04, SrO 0·05; the blue colour is attributed to vanadium. Refractive indices for sodium light are α 1·6925, β1·6943, γ1·7015; pleochroism $X = b$ red-violet, $Y = c$ deep blue, $Z = a$ yellow-green.

R.A.H.

KAGAYA, B. *Application of goniometry to gemmology.* Journ. Mining Coll., Akita Univ., 1968, A 4, no. 3.

The author considers that two-circle goniometric measurement for cut stones over 1 carat is as useful as the fingerprint measurement for individuals. The probability of the occurrence of equal goniometrical data is considered to be $9{\cdot}58 \times 10^{-41}$.

S.P.

BOOK REVIEWS

SCHLOSSMACHER, K. Edelsteine und Perlen. Precious stones and pearls. E. Schweizerbart'sche Verlangsbuchhandlung. Stuttgart, Germany, 1969, 387 pp., 115 illustrations, 1 map, 18 photomicrographs, 2 colour-plates, index. 5th edition. In German.

Schlossmacher's book is of course a "must" for the German gemmologist. The additions to previous editions lean to the scientific side, but as before the book caters in the first instance for the practical gemmologist, the jeweller, the merchant, the lapidary and the student of gemmology. A trained mineralogist will find useful information enabling him to widen his field of applied science.

Interesting additions to previous editions are references to two new microscopes; the diamond microscope allowing the investigation of inclusions in a dark field and the Universal diamond and precious stone microscope which allows for immersion, polarization and binocular vision.

New scientific developments relating to diamond are reported such as the influence of nitrogen on the crystal structure.

For the practical gemmologist a concise description of the influence of the "make" i.e. the quality of cutting and polishing of the diamond on the valuation seems of importance.

Newcomers in the field of synthetics are carefully listed, such as the Linde synthetic emerald with high refractive index, synthetic alexandrite and opal.

Small irrelevant inaccuracies contained already in previous editions may irritate the careful reader, but do not detract from the value of the new publication.

W.S.

VARGAS (G. & M.). Faceting for amateurs. 1969, La Mesa, Calif., U.S.A. Published by the authors.

A comprehensive book about faceting, with details of many styles of cutting and how to achieve them. An appendix of species descriptions gives useful information about cutting angles, lap speeds and polishing agents.

S.P.

ASSOCIATION NOTICES

PRESENTATION OF AWARDS

OFTEN called a girl's best friend, diamonds were fast becoming a very good friend to the technologist, said Professor Samuel Tolansky, F.R.S. to members of the Gemmological Association, in Goldsmiths' Hall, London, on 19th November, 1969, after presenting gemmological examination awards to nearly 100 successful students.

Professor Tolansky, author of books and many papers on diamond, its history and structure, expressed surprise and pleasure at the number of overseas candidates present and spoke of the indirect links he had with many of them through former students of his from their countries.

He said he was very much an outsider in the company he found himself as he was not a gemmologist but a crystallographer. His interest in diamond sprang from something he read in the Old Testament. One passage in that stated, "The sins of Judah would be inscribed on the horns of the altar with a diamond". He knew the horns of the altar were of bronze, a hard material, and realized that the prophet to whom the verse was attributed knew also of the hardness of diamond.

Some of the references to diamond he had found surprised him. From a manuscript published in 1450, and which was now in a monastery in Bologna, he learned that even in those far off days people were using diamond to cut glass. Although the drilling of rock was looked upon as a modern development, he discovered from an encyclopaedia published in 1750 a very accurate and full description of the technique of drilling rock with diamond.

Professor Tolansky said he met many technologists and scientists in the course of his work—many who knew diamond—but he had a great respect for the diamond polisher who considered the scientist a thorough idiot and who said his father had taught him to polish diamonds, and his father before him, and all knew a great deal more about diamonds than the scientist; they knew that a diamond was harder in one direction than another by experience. The scientist knew why it was.

He went on to say that he was discussing the subject of diamond with G. A. Secretary, Gordon Andrews, earlier in the evening and they had got round to testing diamonds by the use of instruments in a laboratory. There was a very simple testing method and one he often used. He would transfer a diamond from a table or bench on which it was lying—making sure that he did not touch the stone with his fingers or other warm object—to the tip of his tongue and if it felt ice cold he knew the stone was a diamond. No other gem gave the same

impression. Diamond was a very good conductor of heat and at the same time was an insulator. The test he had described could not be repeated for, perhaps, a couple of hours.

The ability of diamond to conduct heat was becoming of considerable technological importance and during the last few years it had been put to use in small instrumentations which had been devised to give out very energetic radio waves. As the instruments heated up in use the radio waves diminished and it had been found necessary to introduce something to absorb this heat, and diamond had provided the answer.

There were other diamonds which were more transparent and more sensitive to heat rays. This was being used in what was known as an image converter, an instrument which enabled an image invisible to the naked eye in the dark to be seen.

Professor Tolanksy then turned to the work he was undertaking with a sample of moon dust from the Apollo 11 mission and told of the many hours he had pored over it with a microscope to discover any sight of gems. He had been rewarded at last, he said, by the sight of a minute blue particle, which he described as being of a sapphire-blue colour.

The Association's Chairman, Mr. Norman Harper, who presided, said that the Association was pleased to welcome successful candidates from W. Germany, Canada, Japan, Holland and Spain. He specially welcomed the President of the Spanish Gemmological Association, Sr. M. Masso, and Professor M. Font and Dr. Bosch, of Barcelona University. He mentioned that there had been a record number of candidates for the examinations, 460 sat for the preliminary and 307 for the diploma.

Basil Anderson, director of the gemmological laboratory of the London Chamber of Commerce, thanked Professor Tolanksy for presenting the awards and for what he described as the most interesting talk they had heard in many a year. He hoped it would not be long before Professor Tolansky was invited back for the members to hear further interesting aspects of his work as a crystallographer.

MIDLANDS BRANCH

A meeting of the Midlands Branch was held at the Auctioneers' Institute, Birmingham, on the 21st November, 1969. Mr. P. Spacey, Chairman, presided.

The meeting divided into four groups, and members examined gemstones and items of jewellery brought by members of the trade. They were then invited to estimate the weight and retail value of the specimens. The idea of the meeting was to assist members in achieving some form of uniformity in connection with valuations.

GIFTS TO THE ASSOCIATION

The Council of the Association is indebted to Mr. Paul W. Johnson, California, for a copy of his book "A Field Guide to the Gems and Minerals of Mexico".

James E. Glover, of Scarborough, Ont., Canada, has presented a group of good quality Canadian hessonite garnet crystals together with a cut stone of the same material.

COUNCIL MEETING

At a meeting of the Council of the Association held on the 24th September, 1969, the following were elected to membership:

Fellowship

Ferneyhough, Miles Howson, Solihull, Warwickshire. D.1969
Grey, Alan Peter, Weybridge, Surrey. D.1969
Hancock, Peter John, London. D.1969
Jenkinson, Herbert Arnold, Bromley, Kent. D.1948
Kerfoot, Charles, Barnsley, Yorkshire. D.1969
Kutchinsky, Roger Nicholas, London. D.1969
Walker, Patricia Joan, London. D.1969

Transfers from Ordinary Membership to Fellowship

Arbunies Andreu, Manuel, Barcelona, Spain
Armengol Abril, Emilio, Barcelona, Spain
Bajo Ortiz de Apodaca, Julian F., Pamplona, Spain
Baxter, James, Edinburgh
Brooking Grassy, Alberto, Madrid, Spain
Brown, Kenneth J., Gymea, Australia
Castro Ferrer, Jaime, Barcelona, Spain
Chang, Felix S. Y., Taipei, Republic of China
Clarke, Doreen P., Camberley, Surrey
Collingridge, James W., Tonbridge, Kent
Deeks, Noel W., Luton, Beds.
Estrada Mollet, Federic I., Barcelona, Spain
Farras Sole, Jose, Barcelona, Spain
Fischer, Marianne E., Stellenbosch, S. Africa
Glover, James J., Scarborough, Canada
Hammersley, Gordon J., Adrian, U.S.A.
Harral, Benjamin D., Barnsley, Yorks.
Hawthorn, Graham, Solihull, Warwicks.
Hoberg, Gunter, Idar-Oberstein, W. Germany
Holmes, Kenneth, London
Ingber, Ronald M., London
Jackson, Della A., Prestbury, Cheshire
Jefferis, Marcia N., Watford, Herts.
Karolus, Martin, Mannheim, Germany
Kennedy, William, Baltimore, U.S.A.
Lang, Lorna M., Reservoir, Australia
Luder, Johan Gerard, The Hague, Holland
McCormick, Wendy L., Kew, Australia
Marschner, Helga, W. Berlin, Germany
Matsuzaki, Shigeru, Tokyo, Japan
Mirwald, Gerhard M., Tokyo, Japan
Mitchell, Terence, Salisbury, Rhodesia
Morgan, Alfred D., Birmingham, Warwicks.
Mosey, Irene, Lancaster.
Perera Bravo, Alberto, Madrid, Spain
Pfeiffer, William v., Warrarrdyte, Australia
Pienaar, Herbert S., Stellenbosch, S. Africa
Pitt, Nicholas C. H., Stourport-on-Severn, Worcs.

Rae, Francis C., London
Russell, Lionel H., London
Sancho Canto, Jaime, Barcelona, Spain
Sancho Canto, Ma Pilar, Barcelona, Spain
Schnetz, John V. P., Kriens, Switzerland
Tamai, Shyojiro, Tokyo, Japan
Tenhagen, Joseph W., Miami, U.S.A.
Turvey, Jane, Rye, Sussex
Van Deijl, Wilhelm J. E., Parow, S. Africa
Vaughan, Alan J., Invercargill, New Zealand
Vaughan, Susan J., London
Villegas Sanvicens, Cesar, Barcelona, Spain
Wasilkowski, Wanda K., Miami, U.S.A.
Widdup, Kenneth N., Lancaster.
Wilkes, Ronald, Blackpool, Lancs.
Winder-Toole, Angela B., Penzance, Cornwall

Ordinary Membership

Aizawa, Naoshi, Akita-Ken, Japan
Akutagawa, Koichiro, Nagasaki-Ken, Japan
Aloy, Richard N., U.S.A.F.
Aoki, Seishiro, Kanagawa-Ken, Japan
Asano, Yoshio, Tokyo, Japan
Ayton, James, London
Bader, Kushal Chand, Jaipur, India
Berry, Philip Adrian, Johannesburg, S. Africa
Biehler, Rudolf, Munich, Germany
Blackwell, James Robert, Birmingham, Warwickshire
Boyce, Anthony James, Doncaster, Yorkshire
Brumann, Hans R., Makati, Philippines
Bunjapamai, Montri, Bangkok, Thailand
Callaway, P. C., Melbourne, Australia
Chiba, Shinako, Kowloon, Hong Kong
Chlupacek, Joseph M., Gary, U.S.A.
Coker, James Darden, Ft. Belvoir, U.S.A.
Comely, Christopher Norman, Dorchester, Dorset
Daitoh, Yasuki, Tokyo, Japan
Delange, Elizabeth, Stellenbosch, S. Africa
Dewey, Thomas Norman, Bromley, Kent
Differenz, Gabriele Monika, Bad Homberg, W. Germany
Donald, James, Falkirk, Stirlingshire
Eik, Van, Jac J., Utrecht, Holland
Ellis, Suzanne Jean, Watford, Herts.
Eric, Delarue, Geneva, Switzerland
Eto, Motowo, Hyogo-Ken, Japan
Fransein, Eldon E., West St. Paul, U.S.A.
Furumiya, Iwao, Osaka, Japan
Futagawa, Nobuzo, Ibaragi-Ken, Japan
Gandlgruber, Walter H., Sao Paulo, Brazil
Ganster, Doris Erlene, Pico-Rivera, U.S.A.
Gerryts, Petronella, Stellenbosch, S. Africa
Glover, James David, Chicago, U.S.A.
Goode, Robert, Johannesburg, S. Africa
Green, Adrienne, Wembley, Middx.
Green, Arnold, Wembley, Middx.
Goto, Satoko, Ibaragi-Ken, Japan
Hamanaka, Noboru, Tokyo, Japan
Hanaoka, Eichi, Ishikawa-Ken, Japan
Hanna, Neil Randle, Remuera, New Zealand

Harada, Yasuyuki,
Shimane-Ken, Japan
Hirohata, Tomoko,
Osaka-Prif, Japan
Homma, Hisako, Tokyo, Japan
Hongo, Toshio, Miyagi-Ken, Japan
Ikeda, Uematsu, Tokyo, Japan
Iwata, Teruhiko, Gifu-Ken, Japan
Jain, Narendra Kumar, Delhi, India
Jackson, Lilian Isabel,
Reynella, S. Australia
Jevons, Francis Byron,
Goudhurst, Kent
Jogia, Pravinkumar,
Coventry, Warwicks.
Johannes, Biesbroek,
The Hague, Holland
Kameoka, Takeyoshi,
Ehime-Ken, Japan
Kashimi, Kazuhisa,
Ishikawa-Ken, Japan
Kashiwagi, Hideo, Chiba-Ken, Japan
Katsuyama, Mitsuro,
Amsterdam, Holland
Katsuyama, Mitsutoshi,
Osaka, Japan
Kawamura, Masamichi,
Kochi-Ken, Japan
Kimizuka, Yoshitada, Tokyo, Japan
Kon, Helen, Alexandria, U.S.A.
Koyama, Mosao, Tokyo, Japan
Krantz, Ian L. D.,
Johannesburg, S. Africa
Kripalani, Kishan Lal, Delhi, India
Kuge, Georges, Ghent, Belgium
Kurita, Masahiko,
Shizuoka-Ken, Japan
Landa, Brian Malcolm,
Leeds, Yorkshire
Mac Neil, Hugh Allan,
District Heights, U.S.A.
Mamada, Seiji, Tokyo, Japan
Markar, Mohamed S. M.,
Colombo, Ceylon
Martin, Nancy Jean,
Heidelberg, Australia
Matsui, Haruko, Tokyo, Japan
Mimura, Masahiro,
Nagano-Ken, Japan
Murata, Katsusuke,
Aiichi-Ken, Japan
Musselman, Charles D.,
Englewood, U.S.A.
Nagano, Chiyoko,
Kagoshima-Ken, Japan
Nakajima, Shingo,
Nagano-Ken, Japan
Narasimhan, Vankadari Krishnaiah,
Frankfurt, Germany
Nishibayashi, Yoshiharu,
Kyoto, Japan
Nittel, Lothar, Graefelfing, Germany
Norton, Charles Leslie,
Marion, U.S.A.
Ogawa, Seiichi, Tokyo, Japan
Ohtsu, Shigeo
Kanagawa Prefecture, Japan
Okuzumi, Hiroyuki, Tokyo, Japan
Omura, Toichi, Tokyo, Japan
Pasha, Mohamed I.M.M.S.,
Rajagiriya, Ceylon
Penfold, Cecil Edward,
Nairobi, Kenya
Petsinger, Barbara,
Islamorada, U.S.A.
Phillips, Kelley W., Wichita, U.S.A.
Pichon, Jean-Daniel,
Geneva, Switzerland
Pol, Van Der, Maria Johanna,
Utrecht, Holland
Power, John J., Rosemere, Canada
Rensburg, Van, Christina,
Stellenbosch, S. Africa
Ruckli, Robert
Lucerne. Switzerland
Sanbongi, Gen, Hokkaido, Japan
Sanbongi, Hiroshi, Hokkaido, Japan
Schipper, Hilda,
Rotterdam, Holland
Senti, Yves-Andre,
Geneva, Switzerland
Shono, Yoshihiro, Tokyo, Japan
Silverthorne, Richard Leigh,
Johannesburg, S. Africa

Smith, Thomas J.,
Milwaukee, U.S.A.
Takaki, Mitsuo, Hokkaido, Japan
Takaki, Shizuo, Miyag-Ken, Japan
Tarr, Warren T., Delmont, U.S.A.
Thompson, Roger Deane,
Hopewell, U.S.A.
Thomson, Ian, London
Trossarelli, Carlo, Torino, Italy
Tsunoda, Toshimi,
Nagano-Ken, Japan
Tsuno, Syoji,
Yamaguchi-Ken, Japan
Uchida, Sumiko, Nagano-Ken, Japan
Webb, Michael William,
Newcastle under Lyme, Staffs.
West, Kenneth James,
Hove, Sussex
Wijayanayaka, Nihal,
St. Albans, Herts.
Wood, George Douglas,
Stroud, Gloucester
Wycoff, Wesley Frecerick,
Ottawa, Canada
Yamada, Wadachi, Tokyo, Japan
Yamada, Yukihiro,
Aichi-Ken, Japan
Yamashita, Hisao,
Yamanashi-Ken, Japan
Yasuda, Michio,
Saitama-Ken, Japan
Yuasa, Noriko, Ishikawa-Ken, Japan

TRADE DESCRIPTIONS

The Trade Descriptions Act, which became law in the United Kingdom in 1968, has already produced convictions in Magistrates' Courts concerning the misdescription of gemstones. A synthetic emerald sold as a natural emerald, a quartz sold as topaz, synthetic corundum as alexandrite, paste as topaz and synthetic blue spinel sold as aquamarine, have all been regarded as misdescriptions under the Act.

There is no doubt that in the U.K. there has been a marked improvement in the description of gemstones. Now that the description of quartz as topaz has been found to be false under the Act in a Court of Law, it is to be hoped that overseas suppliers selling faceted quartz will desist from the practice of invoicing goods as "quartz-topaz". There is still a limited number of uneducated traders who use gem names to indicate colour. It is a thoroughly bad and misleading practice.

In one case two Fellows of the Association were involved in giving evidence. It was at the instigation of one of them that the Weights and Measures Department of the Board of Trade, responsible for enforcing the regulations, acted with praiseworthy promptness in bringing seven instances of misdescription before a Court.

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ASSOCIATION
OF GREAT BRITAIN

GEMMOLOGICAL ASSOCIATION
OF GREAT BRITAIN
SAINT DUNSTAN'S HOUSE, CAREY LANE
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THE JOURNAL OF GEMMOLOGY
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Vol. 12 No. 2 APRIL 1970

A STUDY OF RHODOLITE GARNET

By B. F. MARTIN, M.D., B.Sc., F.G.A.

IT is well known that a whole series of garnets exists from pyrope to almandine, due to the isomorphous replacement of Fe for Mg in the basic chemical composition, and for those lying near the middle of the series Anderson(1) has proposed the name "pyrandine". It is not so well known that a distinct subvariety of the series is recognized which, because of its rose-red to pale violet colour, has been named "rhodolite" (Gr. *rhodon*, a rose). It is a rare stone and many gemmologists may not have encountered a specimen. According to Phillips(2), this variety was found, in limited quantity, in Cowee Valley, Macon County, N. Carolina. However, a few other sources are known and Sinkankas(3) reports that fine quality material of unprecedented size has recently appeared from Tanzania.

Very occasionally, stones having the colour described for rhodolite are encountered, but carrying no qualification other than "garnet". It seems that there is some reluctance to apply the term "rhodolite" unless it is known that the stone originated from Macon County. If, however, a garnet possesses physical features, in addition to colour, which mark it as a distinctive entity within the pyrope-almandine series, it seems only reasonable that it be granted its status and accorded its value, irrespective of its source.

Rhodolite is a subvariety near to pyrope and Webster(4) notes that its composition lies between pyrope and almandine in the ratio of 2:1. The constants for pyrope show a considerable range and

the figures given by different authors do not exactly correspond, particularly in the upper limits. This is not surprising, since one is reaching the intermediate ("pyrandine") type. Phillips[2] states the R.I. range to be from 1·730 to 1·751, but Anderson[1] gives 1·76 as the upper limit and Webster[4] records 1·77. It is perhaps rather curious that the R.I. of rhodolite, which belongs to this series, has only the single figure of 1·76 recorded against it[2],[4]. The same applies to the S.G.; Phillips[2] gives a range of 3·65 to 3·82 for pyrope and other authors quote similarly, yet the single figure of 3·84 is given for rhodolite[2],[4]. Apart from these two constants, the only definite information recorded in standard works is that rhodolite shows the absoption bands characteristic of the almandine spectrum.

With a view to obtaining data that might prove helpful in the identification of rhodolite, an examination was made of a rose-red stone (0·47 ct.), classified as rhodolite and stated to have originated from Mason's Mountain, Macon County, N. Carolina. This stone will be referred to as the "Carolina" stone. The findings were then compared with those obtained from 11 large specimens which appeared correct for colour but were of unknown source, and these will be referred to as the "test" stones. One of these stones (approximately 2 ct.) was mounted in a ring which had been bought in by an antique dealer. Although stated to be a garnet, the dealer felt somewhat unsure, because of the unusual colour. The other stones consisted of a parcel of 10 large cut specimens of fine quality, ranging from 1·95 to 3·25 ct., and were the property of a firm of manufacturing jewellers. They were stocked as "rhodolites" and destined for better grade jewellery.

General Results

The "Carolina" stone. Examination with a 10 × lens revealed a number of inclusions and this was fortunate since their microscopic investigation proved particularly interesting and will be dealt with separately. The R.I., taken with sodium light, was 1·758. Spectroscopy revealed the three main absorption bands characteristic of almandine, i.e., positioned at 5050, 5270 and 5760 A, and they were of moderate intensity. Through the Chelsea colour filter, the stone's colour appeared a little deeper but was not dulled.

The "test" stones. With the 10 × lens, no included matter was seen in any of the stones. The R.I.'s lay within a very narrow

range and showed the following values: 1·745 (2 stones), 1·747 (5 stones, including the mounted stone), 1·748 (1 stone), 1·749 (2 stones) and 1·750 (1 stone). Thus, each showed a value considerably lower than that of the "Carolina" stone, and their average value of 1·747 is near the middle of the range for pyrope.

With the spectroscope, the three absorption bands characteristic of almandine were seen and of the same degree of intensity as in the "Carolina" stone. The result with the Chelsea colour filter was also the same.

Although accurate estimations of the S.G. of these stones would have been of some academic interest, such an undertaking requires special laboratory facilities in the case of such heavy stones. It is simply recorded here that all the stones sank rapidly in pure methylene iodide, and at about the same rate.

Microscopic Examination

The "Carolina" stone. Examination of this stone, immersed in methylene iodide, revealed that the inclusions seen with the 10 × lens were doubly terminated prismatic crystals (Figs. 1–3). They lay at random and not in crystallographic orientation.

The crystals showed signs of wear, particularly at their terminations, but they appeared hexagonal in form and the ratio of length to breadth was 2:1. When the stone was suitably orientated to obtain an end-on view of the prisms, signs of wear were again evident, but in spite of unevenness of some of the faces and loss of sharpness of some of their edges, a roughly hexagonal outline was preserved (Figs. 4–6). A few crystals showed outgrowths (G in Fig. 1 and possibly in Fig. 6), and several showed a narrow transverse band (Figs. 1, 2). These bands almost certainly indicate basal cleavages. The band in the lower crystal of Fig. 1 appears broad due to light reflection; in other orientations it appeared narrow. Inclusions within the crystals themselves were common and were mostly round to oval, and presumably gas- or liquid-filled cavities (Figs. 1–5), but there were a few two-phase inclusions (Fig. 2).

The optical features of the crystals were as follows. Some of them appeared to have a pale violet tinge, best seen with diminished illumination. They showed birefringence between crossed polaroid, with bright colour changes. As can be seen from the photographs, the R.I. of the crystals differed considerably from that of their

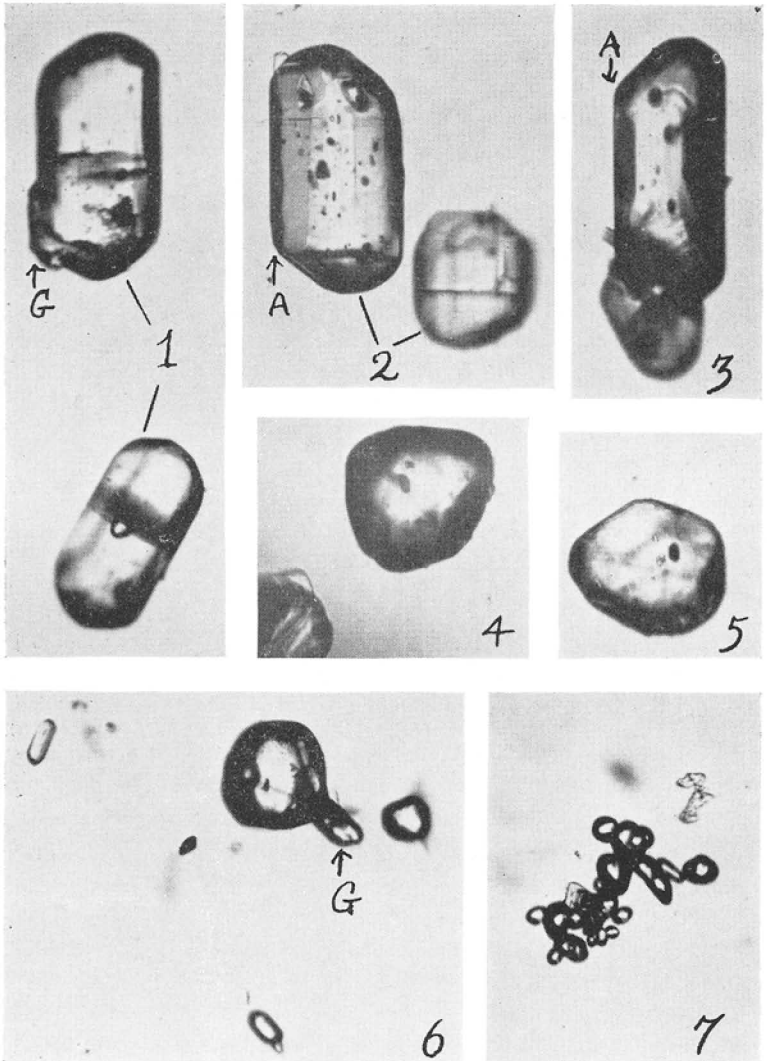

(*Plate* 1. *Figs.* 1-7)

FIGS. 1-3. *Idiomorphic prisms of apatite in rhodolite garnet from N. Carolina. Note their own inclusions, some basal cleavages and an occasional outgrowth (G). Two well defined interfacial angles (A) are seen.* 150 ×.

FIGS. 4-6. *Some of the prisms viewed end-on, showing a roughly hexagonal outline. In Fig.* 6, *G is probably an outgrowth.* 150 ×.

FIG. 7. *Cluster of very small xenomorphic crystals of apatite in a rhodolite of unknown source. Compare the morphology with that of the small crystals in Fig.* 6. 150 ×.

medium. Their facet edges darkened as the focus was raised, indicating that their R.I. was lower than their host (garnet) material, and this was confirmed by a modified Becke line test.

Another investigation possible was approximate measurement of an interfacial angle. In two crystals, one of the angles $(10\bar{1}0 \wedge 10\bar{1}1)$ was sufficiently well defined to admit of measurement (A in Figs. 2, 3). The outlines of these crystals were enlarged from the photographic plate to 600 × and the angle between the normals of the two faces measured. This was found to be 49° in the Fig. 2 crystal and 47° in the Fig. 3 crystal.

Following Gübelin's[5] classification, these crystals are primary xenogenetic inclusions. In general morphology and optical properties they correspond very closely with the crystals reported by Zwaan[6] to be common inclusions in specimens of almandine garnet and corundum from Ceylon, and proved by him to be apatite, following X-ray powder photography. Recently, Gübelin[7] has also described crystal inclusions of the same morphology in almandine garnet, spinel and ruby from Ceylon and in kornerupine, and by use of the electron microprobe he likewise proved them to be apatite.

From the available evidence it therefore seems highly probable that the inclusions found in the "Carolina" stone are idiomorphic crystals of apatite, and this is supported by the interfacial angle measurement. The average of the two measurements was 48° and Dana[8] gives this angle for apatite as between 49° and 50°; it varies slightly with differences in chemical composition of the apatite.

In addition to the crystals, a very small number of rather short, needle-like inclusions were present, and these were crystallographically orientated (Fig. 8).

The "test" stones. Of these stones, seven (including the mounted stone) showed no distinct inclusions. Of the remaining four, one contained small crystalline inclusions but no "needles", and three contained orientated, intersecting "needles". Only one of those containing "needles" showed a few small crystal inclusions, and these were similar in size and form to those found in the other stone.

The crystalline inclusions occurred both singly and in clusters. They consisted of very small round to subround grains and some of the latter showed a roughly hexagonal outline, very similar to that seen in the end-on views of the crystals in the "Carolina" stone

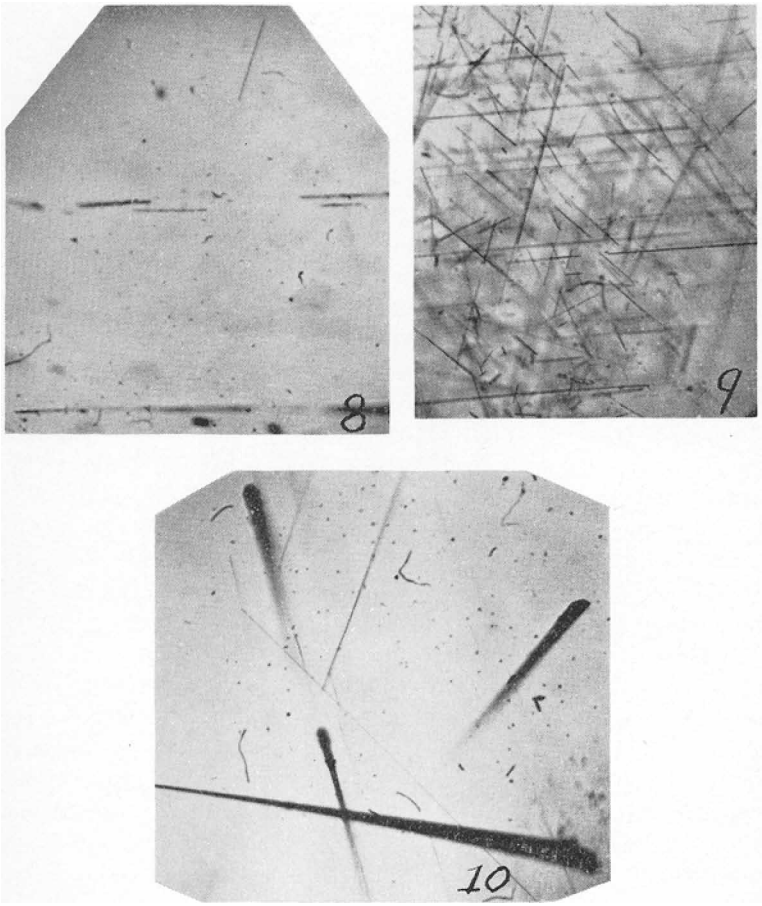

(*Plate* 2. *Figs.* 8-10)

FIG. 8. *Sparse, orientated "needles" in rhodolite garnet from N. Carolina.* 75 ×.

FIG. 9. *Numerous fine orientated "needles" in rhodolite of unknown source.* 75 ×.

FIG. 10. *Orientated "needles" in rhodolite of unknown source, some long and slender and others "comet"-like in form.* 75 ×.

(Fig. 7; compare with Fig. 6). It was also clear that there was the same disparity in R.I. between the crystals and the host material as was observed in the "Carolina" stone (see Figs. 6 and 7). It was concluded that these small inclusions are xenomorphic crystals of apatite.

The needle-like inclusions were very long, thin and few in

number in one stone, in the second they were also thin, but shorter and closely set (Fig. 9), whilst in the third stone they were long but not all were thin; some had a curious club- or comet-like form, and these were probably cavities (Fig. 10).

Discussion of Results

From this study, it is suggested that the essential characteristics of rhodolite garnet are as follows. The R.I. lies within the range for pyrope, yet the stone is of an entirely different colour (rose-red to pale violet) whilst spectroscopy reveals the three main absorption bands of almandine, and these are of moderate intensity.

All 11 "test" stones satisfied the above criteria and, in a sense, more than satisfied, since each showed an R.I. well below that of the "Carolina" stone; their average R.I. was 1·747 whilst that of the "Carolina" stone was 1·758. This result, taken in conjunction with the microscopic findings, brings into focus the question of source and also the need for revision of the constants quoted for rhodolite. The single figures given for the R.I. (1·76) and S.G. (3·84) may have been obtained originally from a small supply of stones from Cowee Valley, and these could well have shown nearly identical values.

The study of inclusions is sometimes of assistance in stone identification and even in assigning stones to a particular locality. In the present study, two types of inclusions were found, namely, orientated needle-like inclusions and crystals, and the latter were almost certainly apatite crystals. The former are fairly common in pyrope and almandine garnet so their presence in a subvariety of the series comes as no surprise. It was perhaps no more than chance in a small sample that "needles" were few when crystals were present, and vice versa.

As noted earlier, both Zwaan(6) and Gübelin(7) have shown that apatite crystals are found in almandine garnet and other gemstones from Ceylon and in these the usual habit was the idiomorphic prism; the xenomorphic crystal was uncommon. Furthermore, the chemical composition of the apatite was the same in all these stones (6).

In the study of crystal inclusions, it is important to establish not only their identity but also their predominant habit, since this may differ in stones from different localities. In this context, it might be pointed out that considerable interest was aroused amongst geolo-

gists when it was noted that although zircon crystals show considerable variation in habit, those obtained from rock formations of a particular locality show a preponderance of a particular habit and, in turn, the habit provides some clue to the early history of the environment (e.g. Callender & Folk[9]; Harris;[10] Larsen & Poldervaart[11]). Apatite, like zircon, is widely distributed, and furthermore its chemical composition is variable, so that a study of its predominant habit and chemical composition in stones of known source, by the refined techniques now available, may prove of considerable value to gemmology.

The results of the present study on rhodolite garnet suggest that the "test" stones were of a different source from the "Carolina" stone, since their R.I. was considerably lower and the habit of the crystal inclusions was different. Their large size and fine quality points tentatively to a Tanzanian origin. However, more data are clearly required from a larger number of stones of known source. Samples of this stone are in short supply and only one from N. Carolina was available for study, whilst of the 11 "test" stones only two contained crystal inclusions, in spite of their large size.

It is hoped that the observations made in this study will serve as a basis for further investigations on this unusual member of the garnet family.

ACKNOWLEDGMENT

I should like to express my thanks to Messrs. Steele & Dolphin, Ltd., Birmingham, for their kindness in allowing me to examine 10 rhodolite garnets from their stock of gemstones.

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STRANGE INCLUSIONS

By W. F. EPPLER

WHEN immersing aquamarine in benzylbenzoate(*), a liquid of a similar refractive index to that of beryl, any inclusions can readily be seen and easily studied. With a value of 1·569, the benzylbenzoate is just below the mean R.I. 1·575 of aquamarine.

On the other hand, this liquid has a higher viscosity than monobromobenzene, for instance, which has a R.I. of 1·56. Occasionally, the higher viscidity can be the cause of very strange "inclusions", of which Fig. 1 and 2 are amazing examples. Fig. 1 represents a cleavage crack parallel to the base plane of an aquamarine. The fissure is filled with benzylbenzoate as the immersion liquid, with the exception of four patches, which now are visible enclosures of films of air. They demonstrate that the cleavage of the aquamarine is not perfect but produces, as is shown in this case, uneven walls, which are the cause for the remaining or entrapping of air in the fissure, when the stone is immersed.

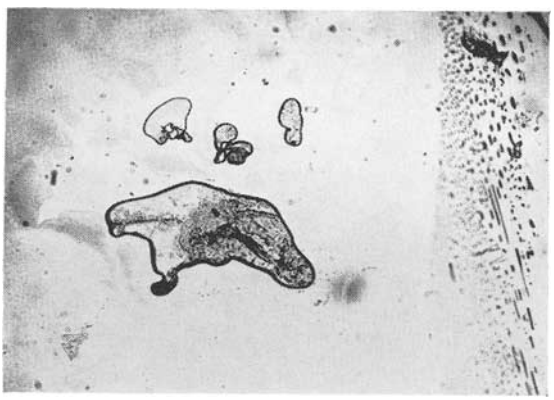

FIG. 1. *An open cleavage fissure in an aquamarine, partly filled with benzylbenzoate. Right: A natural healed fissure.* 22 ×.

* $C_6H_5 \cdot CO_2 \cdot CH_2 \cdot C_6H_5$.

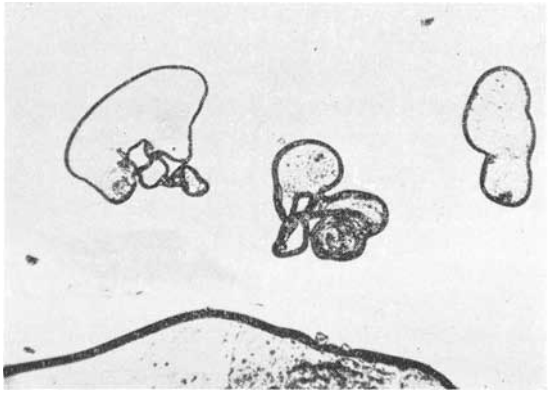

FIG. 2. *As Fig.* 1 *at a higher magnification of* 65 ×.

Fig. 2 exhibits the three upper patches of Fig. 1 at a higher magnification. They look like a particular kind of two-phase inclusion, even if they are only films of air which, due to the roughness of the walls, could not escape when the liquid entered.

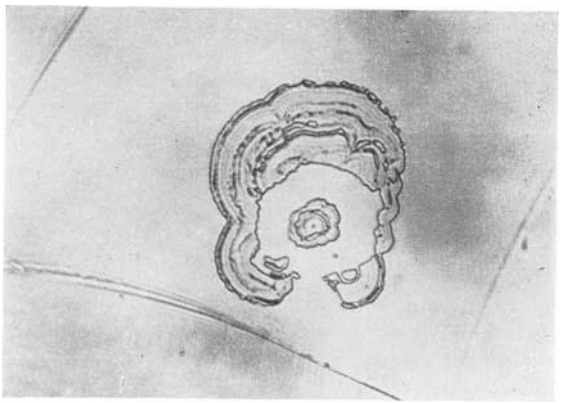

FIG. 3. *Emerald with a partly resorbed air film in a fissure filled with monobromobenzene.* 240 ×.

Fig. 3 reveals parts of a crack of random orientation in an emerald, which is embedded in monobromobenzene. Compared with the benzylbenzoate, this liquid has a lesser viscosity, and this

property is the reason for another surprise. The air in the crack, which could not escape while immersing the emerald, forms a charming pattern, as shown in Fig. 3. But, after a certain time and favoured by the increasing temperature due to the lighting of the microscope, the picture steadily diminishes. After about an hour the air film disappeared with the exception of a small part of the upper rim. The reason for this is a slow diffusion of the air in the immersion liquid. When observing this "inclusion" first, it was totally "closed". The "opening" below and the broad white region around the "island" in its centre was air, emphasising the relief of the walls.

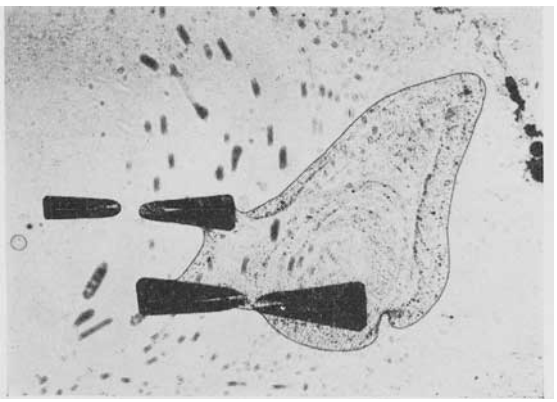

FIG. 4. *A cleavage crack parallel to the basal plane of an aquamarine with negative crystals. The stone is immersed in benzylbenzoate.* 22 ×.

Another strange inclusion is shown in Fig. 4. It is a cleavage crack which runs parallel to the basal plane of an aquamarine from Brazil. It is partly filled with benzylbenzoate and it contains a greater patch of enclosed air. Again, the film of air exhibits a certain roughness of the walls of the cleavage fissure. The strangeness is represented by four negative crystals, the form of which reminds one of a sugar-loaf. These crystals have a threefold cross-section at their thicker end and they are flattened at their point. In Fig. 5, the crude pattern of the cleavage crack can be observed through the brighter part of the negative crystal, a fact which indicates its emptiness. The black areas result from the total reflection of the light and not from a liquid or a solid content. In reflected light, they show a silvery reflection, as is usual with empty bodies or

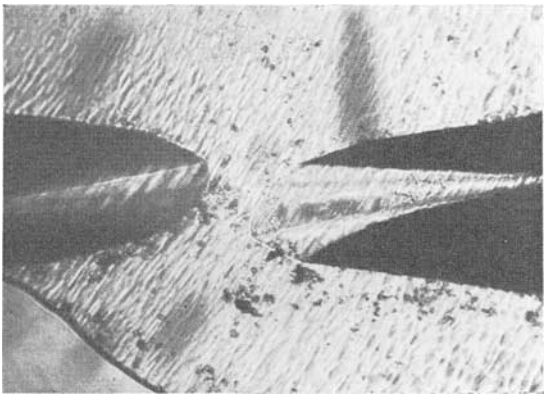

FIG. 5. *Part of Fig.* 4. 120 ×.

gas-filled bubbles within a material of higher refractive index. Also the even planes are characteristic for negative crystals. Fig. 5 also demonstrates that the pattern of the cleavage crack consists of very small cavities, most probably etch-pits. In the picture they follow with their elongation a direction from the upper right to the lower left. This direction and the geometric axis of the negative crystals include an angle of 60°. From this can be concluded that the negative crystals are parallel to the direction of a secondary axis of the aquamarine crystal. Until now, negative crystals of such extraordinary forms and orientation have not been observed, and it is not easy to find an explanation for their origin.

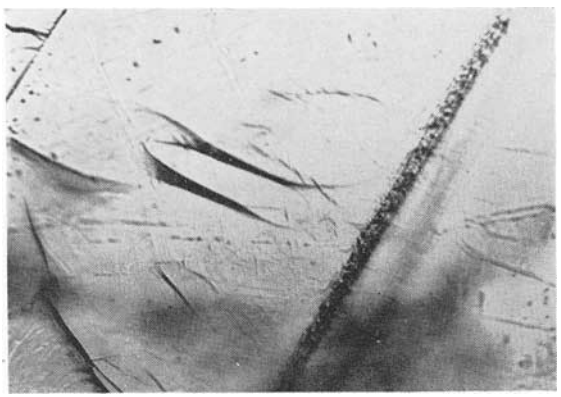

FIG. 6. *Blue sapphire, probably from Burma, with two cracks (centre), which have been mistaken as growth tubes when using a low magnification.* 120 ×.

Fig. 6 is offered as a warning. When first studying the stone, a sapphire of a fine blue colour, which the author owes to the generosity of Dr. Edward Gübelin, the two elongated inclusions in the centre were considered to be tubes of growth, as they often can be observed in synthetic emerald of hydrothermal origin. But when using a higher magnification, the inclusions proved to be cracks. It is therefore recommended to use the possibilities which are given by the greater enlargement of an inclusion, if any kind of doubt exists. The nature of the rod-like inclusion (right in Fig. 6) is not yet known; certainly it is not rutile.

DIAMOND NEWS FROM INDIA

By N. VISWANATH

PRODUCTION of diamonds in India increased fourfold in the past five years. Emerald mining, however, considerably declined in the last two years.

The following table gives production figures of various types of precious stones for the past five years.

Year	Diamonds (*carats*)	Emerald (*carat*)	Sapphire (*grams*)	Gem variety Garnet (*kgs*)	Agate (*tonnes*)
1964	2,260	53,000	203,280	2,554	262
1965	4,466	65,000	224,830	3,651	423
1966	2,113	54,000	185,000	5,170	493
1967	7,626	38,000	188,672	6,828	457
1968	8,764	23,000	194,522	4,986	630

Production of emerald in Rajasthan State went down from 10 kg in 1964 to 4·6 kg in 1968.

Up to the end of 1968, diamonds worth Rs.18·43 crores were exported from India as against Rs.15·72 crores and Rs.11·24 crores in 1967 and 1966, respectively. The main markets were Belgium, Kuwait, Hongkong, Lebanon, Malaysia, Switzerland, the United Kingdom and the United States. Only cut and polished diamonds are exported. Export of rough diamonds is not encouraged because of short supply.

Peerkhan, a tailor of the Panna diamond region in Rajasthan State of India, recently dug up a 28 carat diamond from his small quarry. It fetched about Rs.2·5 lakhs at an auction out of which he had to pay a royalty of 20 per cent to the National Mineral Development Corporation, a government of India concern.

Experts say the diamond is valuable but not rare. Since the discovery of Vijaya diamond about eight years ago, a 40 carat stone was found, but the gem was not publicised.

Peerkhan has not left his tailoring profession and said: "One must live by the sweat of one's brow and not on any windfalls". Half the amount of Rs.2 lakhs which was left over after payment of royalty, he gave his brother who has a share in the small quarry. That gave him just about one lakh of rupees, 25 per cent of which he donated to the local mosque for repairs, keeping the balance amount in a bank fixed deposit.

Diamond mining in Panna goes back at least 250 years. Chattrassi, a local warrior king, is said to have strayed into the vicinity of the Panna mines in his quest for funds to purchase arms to fight the then Moghul Emperors. A Brahmin admirer of Chattrassi blessed him in the following words: "Go forth, O King, and wherever your horse places its hooves the earth will turn into lustrous diamonds". And then he discovered the Panna mines.

A few weeks ago, Kundan, a sweeper of a village in the Saharanpur district, about 300 miles away from Delhi, purchased a fish at the weekly village fair, and, while embowelling it, he found a diamond inside.

Not knowing its worth, he showed it to a few city jewellers who offered him about Rs.10,000 provided he made a legal sale. The offer made him suspicious and without striking a bargain he returned home. Close on his heels, the police came after being tipped off by one of the jewellers, and confiscated the diamond.

The biggest ever diamond to be picked up from the Panna Mines weighed 16·8 carats, and the earlier one was about 14 carats. This is apart from Peerkhan's discovery because the mines are mostly prospected by the National Mineral Development Corporation.

At present India is exporting diamonds worth Rs.38 crores annually.

Recently, a team of British mining consultants have spoken of the "great potential" of the Panna diamond project in India. Mr. Arthur H. E. Taylor, partner of John Taylor & Sons of London, the firm appointed by the British Government to assist the project under technical assistance arrangements, has said: "The potential for diamonds, both at the pipe at Majhkawan and the gravel deposits at Ramkheria, is of major importance, and prospects for development of payable conglomerate deposits are also good". The team expects the project to reach its target figure of 23,000 carats annually.

Referring to the importance of diamond production in India, Mr. Taylor said: "There are also important prospects for discovery of diamonds in Andhra Pradesh which are now being examined by the Indian Corporation. Stones of gem quality will have a ready market both for local consumption and for export, while industrial diamonds will reduce the volume currently being imported into India".

The National Mineral Development Corporation has started bulk purchase of raw diamonds from world markets. This is because India wants to export increased quantities of cut and polished diamonds. At one time India had a monopoly in the world diamond market, but the situation changed completely after the discovery of diamonds in Brazil in 1728 and later in Africa. The current world demand for diamonds is about Rs.400 crores annually, and India's share in this was worth about Rs.30 crores last year.

The diamond cutting industry is concentrated in the Bombay region where about 20,000 skilled workmen are employed by the industry. Cutting and polishing of synthetic stones is done largely in Madras and Jaipur where about 10,000 workers are employed.

Indian jewels are exported to some European countries, West Asia, Japan and America. In an effort to capture markets in Australia and Latin America, the Indian Jewellers' Association is improvising traditional items for modern use. Gem-testing laboratories have been set up at Delhi, Bombay and Jaipur.

THE BURGUNDIAN COURT GOBLET

By H. TILLANDER

THIS magnificent masterpiece of lapidaries' and jewellers' work has not previously been described in any detail. In the catalogues of the jewels in the Treasure Chamber of Vienna the description covers only a few brief lines. In one old inventory only, dated 1476, when the goblet still was in the possession of the Dukes of Burgundy, the diamonds are listed and their design explained.

According to available information the goblet was made in the Burgundian territory around 1425-1450, for Duke Philip the Good. When the Duchess Maria, Charles the Bold's daughter, married Emperor Maximilian I, it went with her as part of her heritage to Vienna, where it still can be admired.

The overall height is 18¼ inches (46 cm). The rock-crystal parts are of superb workmanship and so is the entire gold work, richly jewelled with pearls, rubies and above all with diamonds. To some extent the gold is decorated with enamels in the typical style of the Burgundian era.

A brief visit to the Austrian Treasury in April 1967 revealed to me the exceptional beauty of the very old and rare shapes of the diamonds and I applied for permission to analyse them in detail. This became possible in August 1968 and I decided to study them and in addition all the other antique diamonds in the museums of Vienna. Inspired by the team from the Royal Ontario Museum who studied the Iranian Crown Jewels, I invited my collaborator U–J Pettersson, F.G.A., to join me on the expedition. Equipped with every possible kind of tool we were able to register the essential details of the stones. Unfortunately, however, time did not permit taking exact measurements and even an approximate indication of sizes can therefore not be given this time.

Of the 20 diamonds in the Court Goblet five only are in individual settings, the others are arranged in groups. There are two fleur-de-lis ornaments, with five diamonds in each composition, and one lozenge-shaped figure, also with five diamonds.

For the sake of simplicity the diamonds are described under several headings, each dealing with one type of cut only. The names given to the various shapes are partly traditional and partly entirely new.

I. Point-Cut (Pyramidal Cut)

This shape is usually described as "the earliest form of diamond fashioning, consisting of simply polishing the natural faces of an octahedron". It is a surprising statement, since diamonds cannot be polished in the direction of their octahedral faces. Really perfect octahedra are extremely rare in nature, but they could have been made perfect through cleaving operations. I have examined many hundred point-cuts, but never yet seen one with smooth faces, sharp edges and octahedral angles. I have seen quantities of point-cuts with easily distinguishable natural faces and slight distortion or rounding, but mostly distinctly fashioned point-cuts. These point-cuts have proportions differing from those of the natural crystal. In practically every case the correction of the rough octahedron has been done by cutting towards the apices, with lower double pyramids as a result. The upper and bottom pyramids often received a different height, since the cutter obviously was satisfied when he arrived at a regular shape. It was then up to the jeweller to decide which pyramid should be displayed and which hidden in the setting. In exceptioanl cases only the proportions of the "pavilion" side resulted in satisfactory reflections from the back of the stone through the "crown". Foils, black inks or simply pitch were used in order to improve the light effects.

The diamond in the centre of Fig. 1 is the only point-cut in this collection. It is distinctly elongated and must have been cut from a very fine piece of rough since the angles of inclination towards the "girdle-plane" are only slightly below the crystallographic angles. The faces are faintly rounded, a clear indication of rubbing and polishing by hand and not on a wheel. The proportions can be ascertained by examining the dark square reflection. When its size is such that the corners touch the narrower outline of the diamond they are equal to a natural octahedron. In this case the reflection is just a fraction smaller and the stone thus slightly lowered by the cutter.

II. Table-Cut

In the very interesting article in the April 1968 issue of the "Lapidary Journal", Meen, Tushingham and Waite described the *table-cut* as a truncated octahedron. I share their opinion that the term table-cut should be restricted to this meaning, but I would like to add that a mere truncating hardly ever produced an acceptable

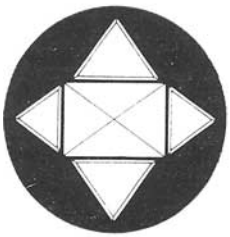

FIG. 1
1 point-cut centre.
4 triangular tablet-cuts.

FIG. 2
1 kite-cut.
2 drop-shaped rose-cuts.
1 elongated tablet-cut.
1 dodecahedral-cut.

FIG. 3
1 drop-shaped rose.
2 tablet-cuts.
1 rooflet-cut.
1 tablet-cut.

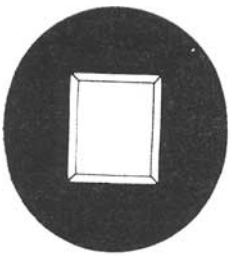

FIG. 4
Tablet-cut.

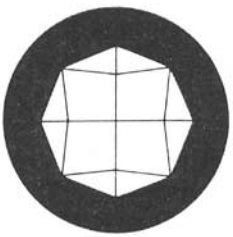

FIG. 5
Dodecahedral-cut.

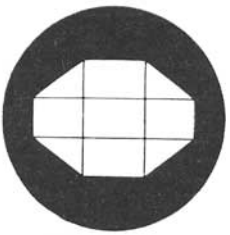

FIG. 6
Cubic-cut.

FIG. 7
6-facet rose-cut.

FIG. 8
Drop-shaped rose-cut.

table-cut. The four main facets both in the crown and in the pavilion were practically always worked down from the original $54\frac{3}{4}$ degree angle to between 50 and 45 degrees. This anybody can easily verify by examining such diamonds in the public collections.

Until quite recently I also found their definition of the *tablet-cut* precise and correct. Some very large "tables"—particularly those in the Austrian Crown Regalia from around 1600—with fine, deep pavilions, small culets, but with extremely flat crowns puzzled me. My theory was then that they might have been produced by sawing off a large part of the top pyramid, like overspread or swindled brilliant-cuts produced today. I then came across a number of models of rough diamond in plastic material. Experiments with two cleavages of identical size, which put on top of each other formed a full octahedron gave most surprising results. One of them was transformed into what I now call a tablet-cut with a square outline, a total depth of 57% and a culet size of 14%. The other had a rectangular outline, a total depth of 63·5% and a culet of 16%. In the first instance the weight loss was found to be around 60% and in the second just over 50% from the perfectly shaped rough.

A very similar diamond is the "Bohemian Crowned Lion," from the Treasury in the Royal Residence in Munich, which has a distinct cleavage plane orientated in such a manner that it must have been cut from rough shaped similarly to my plastic models.

Fine tablet-cuts have two advantages over the normal table-cut. First they can be produced from less expensive and more abundantly available rough and second, if correctly proportioned, they display a fascinating mirroring effect, so often described in inventories from the 15th century. One famous example is the Mirror of Portugal.

They can be described as having been shaped through extensive cutting from flats, maccles, glassies or similar rough, following the design of the table-cut with respect to the pavilion side, but with very flat crowns and very large tables. Since transformation of shape through extensive cutting was necessary for point- and table-cuts it is obvious that the only problems for the earliest diamond cutters were energy and time. The art of cutting a diamond—once learned—permitted any shape to be produced at their will and imagination.

But from the very beginning diamond cutters seem in many instances to have aimed more for size than for good proportions. This resulted in tablet-cuts which were given shallow pavilions and

very large culets. With decreasing thickness of the available rough the tablet-cuts became less attractive and graded finally into the portrait-cut with culets of practically the same size as the tables.

The outline of a tablet-cut is not necessarily square or rectangular, as in the examples from the Court Goblet seen in Figs. 3 and 4. It may just as well be octagonal like the elongated diamond in Fig. 2. It can be triangular, like the four diamonds surrounding the oblong point-cut in Fig. 1 or pentagonal like the two wings in the fleur-de-lis of Fig. 3. In fact any conceivable outline may have been produced, depending upon the character and shape of the rough.

III. Rooflet-Cut

The elongated diamond in the centre of the fleur-de-lis shown in Fig. 3 has two faces only in the crown, sloping down from a central, lengthwise facet edge. It is probably a slightly improved distorted octahedron or a "cleaved baguette". I have the impression these shapes were called "Dos d'anes" (donkeys' backs) by the French during the 15th century.

The pavilion however has been worked following the design of the table- and tablet-cut with four large facets and a culet. In this case the culet is boat-shaped and distinctly rounded. The outline of the diamond is quite irregular, the only rather primitive stone in the goblet.

IV. Kite-Cut

The largest diamond in the fleur-de-lis, reproduced in Fig. 2 has the shape of a kite with four triangular facets in the crown and four very narrow girdle facets. It was not possible to ascertain the design of the pavilion. Comparisons with other similar diamonds of the period give full reasons to believe that this stone was cut from a rough piece of diamond very similar in shape to a cleavage resulting from two subsequent divisions of a perfect octahedron into two equal parts. If this supposition is correct, the pavilion facets in the kite-shaped diamond are haphazardly placed and not worth further study and description.

In many instances kite-cuts have only four main facets and no girdle facets. Depending on the quality of the rough from which they were cut, the outline may be of different proportions, merging eventually into the rhomboid- or lozenge-cut with the main facets of equal size and symmetrically placed.

V. Dodecahedral Cut

There are two diamonds of this shape in the Court Goblet. The largest of them is a splendid example of a very early diamond displaying brilliancy in the modern sense of this word (Fig. 5). It was apparently shaped from an almost perfect dodecahedron and cut with a minimal loss of weight, thus an exceptionally economic shape. This may have been one reason for its popularity during the 15th century. Such stones are frequently described in contemporary inventories as diamonds with four facets polished to lozenge-shape and four to semi-lozenges. In many cases they were just called round faceted diamonds and when of exceptionally fine quality, displaying considerable brilliancy, the attribution "mirroring" was added.

The second dodecahedral cut can be found in the fleur-de-lis ornament in Fig. 2, below the elongated tablet-cut diamond. This stone does not display much brilliancy, apparently due to a mishapen pavilion. The ancient cutters were not always successful with their achievements.

VI. Cubic Cut

This term was chosen for the diamond in Fig. 6, for the reason that it clearly displays all the six cubic planes of a diamond crystal. The girdle outline is an elongated octagon with four rectangular main facets in the crown, inclined towards the girdle from an equally rectangular table. Between these large facets, which appear to form a cross, is in each corner one triangular facet. The girdle is composed of eight large vertical facets, whereas the pavilion design is similar to that of a normal table- or tablet-cut. The culet is small and elongated. The table, the culet and the four girdle facets are all parallel to the cubic planes.

Apart from having achieved an interesting and unique shape with little loss of weight from the rough, the cutter—probably unintentionally—produced an exceptionally brilliant diamond. In fact this is so brilliant that during my first visit to the Treasury in Vienna and after an inspection through the glass of the showcase only, I made a note that this diamond could be a modern replacement. A close and thorough inspection of this stone as well as of all the other diamonds in the goblet showed that, without any doubt, no transformations had taken place. U–J Pettersson, who made all the rough sketches during our visit and who is also responsible for the

final exact designs for this article, is an expert diamond-setter and teacher and thus well qualified to make an assessment.

This cubic cut and the previously described tablet- and dodecahedral-cuts are fine examples of diamonds, dating from as early as around the year 1400, which display beautiful light effects, well comparable to the brilliancy of a modern brilliant-cut diamond. This effect in diamond was thus known practically from the very beginning, but apparently it was not sufficiently appreciated. Other factors were more important, such as the mythological relation between squares, and diamond remained for centuries mainly a symbol of wealth and a talisman, displaying only part of its inherent beauty.

VII. Six-Facet Rose-Cut

There is one six-facet dome-shaped diamond with a hexagonal outline, shown in Fig. 7. The girdle appears to be very thick and the base flat. For these reasons it is classed as a rose-cut. So far no similar stones from early periods have been studied and further remarks would therefore be mere guess-work. It is, however, very tempting to classify this type as a predecessor of the modern six-facet rose-cut.

VIII. Drop-Shaped Rose-Cut

A pair of drops can be recognized in the fleur-de-lis of Fig. 2. They have three main facets meeting in an apex. Beside these four-sided facets two small ones, triangular in shape, have been applied, one on each side. These could perhaps be termed girdle facets. The quality of the cut is rather primitive, with an irregular, partly chipped and partly very rough girdle.

In a separate setting (Fig. 8) is a diamond with a beautiful and exceptionally regular design, a multifaceted drop-shaped stone. It has three rows of facets and in principle an eight-fold symmetry. This elaborately decorated stone is a good example of the cutters' ability to arrange a number of facets at their own will and with free imagination.

Together with other profusely faceted diamonds from the first half of the 15th century this stone seems to prove that diamond cutting was learnt by approximately 1450, with technical improvements only to follow.

Gemmological Abstracts

LIDDICOAT (R. T.). *Highlights at Gem Trade Lab in Los Angeles.* Gems and Gemology, 69, XIII, 2, 63.

High indices in Lechleitner synthetic emerald overgrowths on beryl are reported at 1·59 plus to almost 1·60. The latest Linde hydrothermal emerald examined has had indices of approximately 1·571-1·578 and a specific gravity of 2·678. There was much less fluorescence in both long- and short-wave ultraviolet than in the earlier Linde product. Phenakite crystals at the end of daggerlike spaces were present as well as wispy two-phase inclusions. A flux-fusion synthetic emerald contained a large phenakite crystal.

S.P.

CROWNINGSHIELD (R.). *Highlights at Gem Trade Lab in New York.* Gems and Gemology, 69, XIII, 57.

Examination of zoisite before and after heat-treatment may provide a partial answer to why some stones have fractured following the use of ultrasonic. Most heat-treatment of zoisite, as well as other commonly heated stones, is done after the stones are cut, since insignificant flaws can spread in the rough. It is possible that in some cases ultrasonic has aggravated heat-induced fractures within stones.

S.P.

BANK (H.). *Die Bedeutung der Doppelbrechung für die edelsteinkundliche Diagnostik.* The importance of double refraction in gemmology. Zeitschr. d. deutsch. gemmol. Gesellschaft, 1969, 18, 2, pp. 73-78.

The author discusses the value of double refraction in determining a gemstone. Refractometer and polariscope are the two instruments used. Recognition of the double refraction is subdivided into (*a*) its presence, (*b*) numerical value, (*c*) optical character, (*d*) anomaly and (*e*) aberration, as used in differentiating between natural and synthetic spinels. Absence of double refraction often indicates that one is dealing with an imitation. Bibliography.

E.S.

MORRISSEY (FRANK R.). *Note on Turquoise Deposits of Nevada.* Nevada Bureau of Mines, Report 17, 1968, pp. 30 + map.

Frank Morrissey was for many years an amateur mineralogist although he worked on the editorial staff of the Oakland Tribune. On retirement he specialized in the locating and cutting of turquoise and made many visits to Nevada, assembling quantities of manuscript notes which were checked and put in order by the Bureau of Mines on his death in 1962.

It is believed that Nevada has produced over 30 million dollars worth of rough turquoise, the bulk of it being shipped for mounting in Arizona and New Mexico native jewellery. The majority of the known deposits lie in a belt running NNE across the central part of the state, the host rocks being limestone, shale, chert, intrusive bodies or metamorphosed volcanic or sedimentary rocks. Sixty-nine separate mines or districts known to contain turquoise are listed in the report.

Each location is listed with its full map reference, name of discoverer, occurrence of turquoise and lists of other minerals found with it. A particularly fine stone was found at the No. 8 mine, Eureka County, from which a nodule of spider-web turquoise weighing nine pounds was sold for 1,600 dollars.

M.O'D.

WAITE (G. G.). *The unusual opals of Mexico.* Lapid. Journ. 1969, 23, 9, 1220, 2 col. plates.

Details are given of the more unusual types of opals found in Mexico, and includes the so-called "contra-luz" opal. Finely illustrated by a two-page colour plate.

R.W.

EPPLER (W. F.). *Einschluesse im blauen Zoisit.* Inclusions in blue zoisite. Zeitschr. d. deutsch. gemmol. Gesellschaft, 1969, 18, 2, pp. 56-60.

Generally blue zoisite is exceptionally clear, although there are sometimes negative crystals, hexagonal flakes, which are most probably haematite. The author shows five photomicrographs taken of two stones. These show various healing "tears" and parallel needles, which seem to be iron ore. The advantages of the name "zoisite", as compared with "tanzanite", are discussed. Bibliography.

E.S.

BANK (H.), BERDESINKINSKI (W.), NUBER (B.). *Durchsichtige gelbe und braune Granate (Grossulare) aus Tansania.* Transparent yellow and brown garnets (grossularite) from Tanzania. Zeitschr. d. deutsch. gemmol. Gesellschaft, 1969, 18, 2, pp. 66-68.

During the last few years some transparent green, yellow-green, yellow and brown grossularite from Tanzania have been examined. The lattice values, specific gravity and refractive indices are given. Bibliography.

E.S.

BANK (H.), NUBER (B.). *Rosarote Granate aus Tansania.* Reddish-pink garnets from Tanzania. Zeitschr. d. deutsch. Gesellschaft, 1969, 18, 2, pp. 69-72.

Since the turn of the century one has known about the find of garnets in Tanzania, but only during the last few years has rhodolite been exported. This is a pink to violet crystal of pyrope and almandine. The author publishes his finding of their lattice values, specific gravity and refractive indices. Bibliography.

E.S.

BANK (H.). *Hellbraune bis farblose durchsichtige Zoisite aus Tansania.* Light yellow to colourless transparent zoisites from Tanzania. Zeitschr. d. deutsch. gemmol. Gesellschaft, 1969, 18, 2, 61-65.

Apart from the sapphire blue zoisite Tanzania has exported some light brown to colourless zoisites. These are found in the Mirarani hills near Sambarai, which is in the south-east of Arusha. The mine and the general view of the district are illustrated together with a map with the location.

E.S.

SCHROECKE (H.). *Neuere Aspekte zur Diamantbildung.* Newer aspect of the formation of diamond. Zeitschr. d. deutsch. gemmol. Gesellschaft, 1969, 18, 2 pp. 51-55.

It has been shown that the habit of the diamond crystal is dependant on the conditions prevalent during its formation. A graph illustrates the relationship between the carbon, graphite and the melt. The inclusions in the primary crystallization, say, of the kimberlite magma, are discussed and it is shown that certain

inclusions, for instance pyrite, almandine and mica, prove the inner pressure of the magma to be less than that of the diamond field. Bibliography.

E.S.

DUYK (F.). *L'identification du brillant.* Bulletin de l'Association Française de Gemmologie, 1969, 21, 7.

A method of identification of brilliant cut gems which relies upon the measurement of the base of the triangular star-facets joining the table. It is possible for suitable photographic enlargement to classify stones by this method which weigh 0·10 ct. or more. With larger stones identification is more easily carried out. In an example quoted the base of the triangular star-facets measured 16 mm, 18 mm, 16 mm, 16 mm, 16·5 mm, 18 mm, 16 mm and 17·5 mm on an enlarged photograph of a stone weighing 0·10 ct. The diameter of this stone was 3·2 mm with a height of 2 mm.

S.P.

RÖSCH (S.). *Farbmessungen am Diamanten.* Measuring the colour of diamonds, part I. Zeitschr. d. deutsch. gemmol. Gesellschaft, 1969, 18, 3, pp. 126-140.

This article includes a bibliography of 32 items and gives the measurements of 54 diamonds showing their origin, and also the measurement of some of the 150 coloured diamonds in the De Beers collection. The results are also correlated in 2 CIE colour tables. Not all of the 150 stones were examined. The CIE card and also the German norm DIN 6164 was used, giving the colour shade, the colour saturation and the "darkness" which was the reciprocal value of the "light". Various interesting gems were seen, such as a stone from Vienna (no. 44) the colour of which was comparable to that of an emerald. The author plans a second part of this article in which he will deal with the statistics of colour in diamonds.

E.S.

MALES, (P. A.). *Pseudophite and Precious Serpentine.* Australian Gemmologist, 1968, X, 3, pp. 13-15.

A general review of the serpentine group of minerals, with special reference to Australian sources.

R.W.

BOOK REVIEWS

SUNAGAWA, ICHIRO. *Diamonds—their genesis and properties.* Tokyo (Maruzen), 372 pp., 161 figs., 7 tables, (in Japanese), 1969. Price 600 yen.

This book consists of the following 14 chapters: (1) Introduction—a letter from the depth of the earth, (2) Historical review—various genetical theories on diamond, (3) Conjecture from the results of diamond synthesis—where diamonds are formed, (4) External morphology and surface micro-structures of diamond crystals—mechanism of crystal growth, (5) Curved crystals—evidence of dissolution, (6) Trigons—controversy between growth and dissolution theories, (7) Zonal structures—analysis of growth histories, (8) Internal structures and physical properties—growth histories define the properties, (9) Cleavage of diamonds—relation between cleavage and growth history, (10) Inclusions—clues to the environmental conditions, (11) Impurity elements—nitrogen and alumina, (12) F. C. Frank's new theory on the genesis of diamond, (13) Diamonds in meteorites—a controversy, (14) Evaluation of gem diamonds, and Appendix. The book covers the up-to-date knowledge of the physical and chemical properties and the genesis of diamonds, as well as the results of diamond synthesis.

M.S.J.

LEWIS, M. D. S. *Antique paste jewellery.* Faber, London, 1970. £3.50.

Mr. Lewis's book is the first of a collectors' library series, and is the first book to deal with all aspects of the fascinating subject of antique paste jewellery, including gemmological aspects. There are abundant illustrations, eight of them in colour. A scholarly and authoritative work with general and technical information, particularly concerning the important period of the eighteenth and first half of the nineteenth century.

S.P.

ASSOCIATION NOTICES

BRANCH MEETINGS

A well-attended meeting of the Scottish Branch of the Association was held in Edinburgh on the 11th February, 1970. It was a gemstone quiz evening involving common and less common stones. The specimens were discussed in detail, after identification, by Mr. Maurice Turner, the Branch Secretary. Mr. Dennis Hill, who presided, gave a short talk on the work of the Scottish Branch.

A meeting of the Midlands Branch of the Association was held in Birmingham on the 13th February, 1970. Mr. Bernard Lowe of B. C. Lowe Limited, spoke about the coloured stones seen through his many years as a stone merchant. The second speaker was Mr. C. J. Fox, who emigrated to New Zealand fifteen years ago. He took up prospecting as a hobby and now has 100 acres of land to which he has claims.

At a meeting held at Goldsmiths' Hall, London, on the 27th January, 1970, the following films were shown:

Hallmarking (produced by the Worshipful Company of Goldsmiths).
Celtic Gold in Ireland.

The Refining of Precious Metals from the Sudbury Nickel Ores in Canada.

Members are reminded that there are branches of the Association in Birmingham and Scotland (Glasgow). Anyone who does not at present receive the branch circulars and would be interested in attending meetings in Birmingham or Glasgow should communicate with the office.

GIFTS TO THE ASSOCIATION

The Council of the Association is most grateful for a donation from N. J. Sorsby, Skipton-in-Craven, Yorks., and for a gift of sapphire crystals from M. Bielenberg, Hamilton, Montana, U.S.A.

The Council of the Association is indebted to John R. Fuhrbach, B.Sc., F.G.A., G.G., of Amarillo, Texas, for photographs made with the GIA photoscope and the Polaroid Land 250 camera.

OBITUARY

Robson, A. H. of Leeds, Yorkshire, December 1969. (Fellow 1915).

MEMBERSHIP

In Vol. 12 No. 1 the name Johannes, Biesbroek, should have read Biesebroek, Johannes, The Hague, Holland.

COUNCIL MEETING

At a meeting of the Council of the Association held on Tuesday, 27th January, 1970, the resignation of Dr. G. F. Claringbull as senior examiner was received with regret. Dr. Claringbull has acted as an examiner since 1938 and the Association is indebted to him for his valuable services over the years. Dr. E. H. Rutland was appointed to act as an examiner.

The Council made nominations for submission to the annual general meeting to be circulated with the notice convening the meeting.

Since 1957 the annual subscription to the Association has been £2.2.0. In view of increased administration and other costs it was decided that the subscription for Fellows and Members would be £3 a year commencing 1st January, 1971.

The following were elected:—

Fellowship

Ali, Nasim, Sutton. D. 1969
Allen, Rendall James, Darwen. D. 1969
Andrews, Robert Eric, Cheadle Hulme. D. 1969
Berger, Francis, Geneva, Switzerland. D. 1969
Bergmans, Paul Clemens Maria, Rotterdam, Netherlands. D. 1969
Bloomberg, Maurice, Redbridge, Essex. D. 1969
Bradshaw, Stephen Charles, London. D. 1969
Brady, Deanna Mary, Heswall. D. 1969
Brennan, John Douglas, Birmingham. D. 1969
Christophersen, Elsa, Sandnes, Norway. D. 1969
Cragg, George Edward, Leicester. D. 1969
Crawford, Brian Henry, Monte Vista, Cape Town, S. Africa. D. 1969
Egea, Anthony, London. D.1969
Farwell, Yvette, London. D. 1969
Fruhwald, Georg, Wiesbaden, Germany. D. 1969
Fry, Peter M., Dover. D. 1969
Gartrell, Mark Paul, London. D. 1969
George, Antony Philip, Copthorne, Surrey. D. 1969
Gull, Peter, Walsall. D. 1969
Hayes, Bernard Edwin, Ormskirk. D. 1969
Hill, Josephine Ann, Sheffield. D. 1969
Hindle, David Ronald, Exeter. D. 1969
Hird, Frank, Bournemouth. D. 1969
Hobbs, Robert George, London. D. 1969
Hodgson, Jean Frances, London. D. 1969
Horsfall, Richard Thomas Lister, Halifax. D. 1969
Hundy, Christopher Leslie, Sutton Coldfield. D. 1969
Karlberg, Willy, Oslo, Norway. D. 1969
Kitson, Geoffrey Knowles, Hathersage, Yorks. D. 1969
Lattimore, John Christopher, Harrow. D. 1969

Lay, Mg,
Mandalay, Burma. D. 1969
McCorquodale, Iain Douglas,
London. D. 1969
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PROCEEDINGS OF THE
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EXAMINER'S REWARDS

By B. W. ANDERSON

AN examiner's job has this in common with child-bearing, that a year elapses between each experience, during which interval the worst aspects of the ordeal have been forgotten, enabling one to gather enough determination to go through with the labour all over again.

The marking of some hundreds of exam papers can in fact be a very tedious as well as a very responsible task. By the nature of things most of the answers are humdrum and repetitive, and marks well-earned are hard to find. In general, only two types of paper can give the examiner pleasure, and these lie at the top and at the bottom of the order of merit. From answers in the top grade one derives a legitimate satisfaction in seeing the questions answered in a manner that shows a real understanding of the subject, and even, perhaps, some sense of the style in which an answer should be framed. From answers in the lower strata of the pile come the "howlers", and just a few of these can be really amusing, and serve to provide the examiner's "rewards" referred to in the title of this article.

There is nothing funny, of course, in mistakes as such—the effect of which, in fact, can be saddening if one cares for the success in training young jewellers in the elements of gemmology; but there are some purely accidental turns of phrase or mis-choice of words, which seem too good to lose for ever in the waste-paper baskets of time. The writer has collected a number of these over the years,

and hopes that in reproducing some of them here he may share his pleasure with other readers of this *Journal* who have a like taste for the flavour of the ridiculous.

In carrying out this task two things are essential. One is, that the student's words should be reported accurately in each case, with nothing altered or added in any way for the sake of making the quotation more amusing. The other is, that the contributions should be completely anonymous, and can thus cause no hurt feelings for the students concerned. Both these conditions are observed scrupulously in what follows: the names of students are in any case not known to the examiners—they remain a "number" only: and since the excerpts quoted mostly date from the rather remote past it is hardly conceivable that any of the innocent contributors should remember having written any of the words quoted.

The most perfect example I know was passed to me by one of my co-examiners, Mr. J. R. H. Chisholm. This involves merely the misplacement of a hyphen for its effect. The student was dealing with the precautions to be taken when carrying out a hydrostatic density determination in water, and in the course of his answer recommended the removal of air-bubbles clinging to the stone "by means of a camel's hair-brush".

Spelling mistakes are not often funny, though they may make one marvel at the inadequacy of modern education. In one answer on synthetics no fewer than seven wrong variations on the name of the inventor of flame-fusion were encountered: Vernueil, Vernuile, Vernail, Verneil, Veullein, Veruil, Verneuill. The most common mistake in any technical word is undoubtedly the use of "flourescence" in place of fluorescence. In one partial count I made, those in error amounted to 50% of the total. One feels that teachers are partly to blame in such a case for perhaps not making the derivation of the term sufficiently clear. Possibly the worst example, since only simple words were involved, came in the description of garnets, which were said to be "mostly deap read in colour". A spelling error on one occasion gave rise to the sexiest answer I have yet encountered, written years before the permissive society took over. This was the suggestion that, in testing for a radium-treated diamond, it should be "raped in black paper with photographic film".

More liable to be amusing are examples of malapropism, of

which here are a few picked from the many I have noted through the years:

"Ivory is animal dentures in many forms". "Amethysts are in high command". "Important diamond mines include the Jonker and the Westphal". "Synthetic beryl is manufactured by a hydrothermal conclave bomb". "Zircon often generates to a state of low zircon which is sometimes almost anomalous". "Zircon has a subadalmandine lustre". . . . and talking of zircon still, "Absorption lines in zircon are due to presents of uranium", and "Zircon is a stone which appears to be changing its state at the present time. This is no doubt due to variations of temperature at the earth's surface".

Two pleasing notes on the term "Lauegram": "The Lauegram is of course a very costly and complicated instrument, and is only found in the very best equipped laboratories" (according to one student), while another seemed to be indulging in a little joke when he wrote (on pearl testing) "The Lauegram is another method for distinguishing and gives a spotted pattern on a photographic plate. Very often, however cultured pearls can be spotted without the aid of these machines".

Chemistry often causes trouble. "Turquoise is a complication phosphate". "The closest imitation of amber is cobalt resin". "Pyrope can become different by iron creeping into the formula" while (a very nice piece of knowledge) "Zircon shows traces of the rare element zirconium", morevoer it "turns blue in a decreasing atmosphere". "Lapis Lazuli is a copper and iron sulphate; when viewed the copper can be seen embedded" while (a pathetic thought) "Imitation lapis is produced by dying agates and other poor cherts".

A question on what are the three states of matter brought forth some interesting suggestions: (1) Animal, vegetable, mineral; (2) Igneous, metamorphic, sedimentary; (3) Beauty, durability, and rarity; (4) Crystalline, cryptocrystalline, amorphous; (5) Oxygen, hydrogen, and water; while yet another student described a typical 3-phase inclusion as being "spiked shaped inclusions in groups of three", illustrating his answer with what looked like a series of rather shaggy pawnbroker's signs.

Explaining isomorphism caused some difficulty: one felt that

students had a rough idea of what it meant, but not clearly enough to put it into words. "Isomorphism is a property a gemstone has to have a different chemical composition and physical properties to those which are layed down to it" was one attempt, while another candidate made the whole thing sound slightly indecent: "The garnet family of gemstones are very inconstant due to isomorphous replacement. They all tend to border with one another or overlap". One feels that in flagrant cases they might even be prosecuted, and charged with "bordering and overlapping".

Frank confessions of ignorance are often rather appealing, as in the answer "The colouring matter of emerald has been forgotten, but the writer does not think it is manganese", while one sympathizes with an unfortunate overseas student who had obviously been cramming for dear life, and broke down in mid-stream, with the remark "I have learned too much too quickly, and can no more think of nothing at all".

It is difficult to stop quoting from the many more examples in my note-books, but one does not want to overdo the business. One student notion, however, that the singular of *specimen* must clearly be *speciman* deserves mention before concluding. I can only hope that, thanks to this article, a sprinkling of the best of these student's sayings may be saved for posterity, where otherwise they must certainly have been lost forever.

THE ST. MICHAEL GOBLET

By H. TILLANDER

IN the Museum of Fine Arts in Vienna, a historical goblet is preserved, one about which practically nothing is known. It is made of chased gold and exceptionally richly jewelled. The overall height is 20½ inches (51·7 cm). The name is apparently derived from the sculpture on top of the lid, the Archangel Michael as the dragon's conqueror. The origin of the cup is supposed to be French and the date of manufacture between 1530 and 1540.

There is nothing very special about the goblet itself, but the gems are much more interesting. And among the gems the diamonds are well worth a detailed description. They seem to have been taken from a stock of early 15th century diamonds or, if of later date, they are cut in the same styles and with the same methods as the earliest-known fashioned diamonds. In any case they illustrate extremely well types of design known since the 14th century.

I. Point-cut

There is one point-cut on the stem of the goblet. It was not possible to determine to what extent it had been transformed from the original rough, but it was most interesting to note that this diamond had been placed in the setting in a very original position. One of the octahedral faces forms the "table" and the one directly opposite is the "culet". In other words it has been turned in a manner such as an octahedron would lie on a desk. The setting being very deep, all that is visible to the eye is the "table" and three surrounding half-moon-shaped "main-facets". In Figure 1 the stone is exposed and no parts are hidden by the setting.

Another example of point-cut diamonds set in the same way is in the contemporary drawing (now in the Historical Museum of Basle, Switzerland) of the gold aigrette looted from the tent of the Duke of Burgundy at Grandson in 1476.

II. Tablet-cut

Eight very fine and well-proportioned tablet-cut diamonds are spread all over the goblet. They all have the typically large tables, very low crowns, but beautifully proportioned pavilions and rather

small culets. None of them is thus anything like portrait-cuts or classical tablet-cuts. To the more detailed description of the tablet-cut given in the earlier description of the Burgundian Court Goblet may now be added the latest results of my experiments and researches. The ideal angles for the crown and above all the pavilion is 45°, a magical figure throughout the earlier history of diamond cutting. A square and an elongated tablet is shown in Figures 2 and 3.

III. Six-facet calf's-head-cut

On the chest of the cast figure of the angel (Figure 4), the outline and faceting of a calf's-head can be seen. Around a central apex there are six main facets in the crown, and at both ends in addition a tiny girdle facet. This diamond is not a rose-cut, since a detailed study disclosed a pavilion with four main facets meeting in a short facet edge. All of these facets are four-sided.

The name for this shape was taken from the G.I.A. Diamond Dictionary.

IV. Coxcomb-cut

In the centre of Figure 4 is a shape which, according to old French inventories, was frequently used between 1400 and 1450. The term used then was "Un Dyament Taillé en Façon de creste de coq" and in all probability derived from an ornament, usually worn on top of a helmet since the beginning of the 13th century.

Such fancy cuts during the period were used for diamonds of all sizes—including quite large stones—but for obvious reasons only small ones, never worth recutting, have been preserved. These are mostly encountered in human figures, like the one in the goblet.

At least this specimen has a flat base and could thus in modern English be called a trapeze-shaped bar-cut rose-diamond.

V. Drop-shaped rose-cut

There are several diamonds of this type in the angel (Figure 4). One of them has four facets only, the others have six. Even though I have classed these shapes as rose-cuts, their crown facets do not meet in a point, but in a short, vertically placed facet edge, which thus forms the apex of the rose-diamond.

FIG. 1
Point-cut

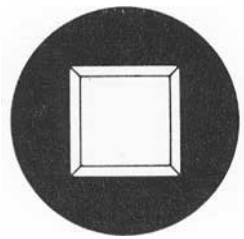

FIG. 2
Tablet-cut

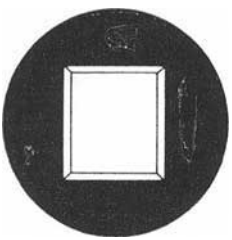

FIG. 3
Tablet-cut

FIG. 4
The Archangel

FIG. 5
The Sepaloid-cut

VI. Three-facet baguette-cut

Seven diamonds of this type can be seen in the angel (Figure 4). Four of them are more or less tapered, much like the modern tapered baguette, two are trapeze-shaped and one has the outline of a kite. All of these seem to have flat bases, but similar diamonds in other objects from the same period have been encountered with pavilions. I feel all these belong to the same category, since the purpose of these shapes was merely decorative and there was certainly no definite rule for height proportions.

VII. Sepaloid-cut

This is a provisional name for a shape of diamond, which is rarely, if ever used, but in combination of several stones in one setting. It indicates that in more intricate patterns a row or rather a circle of such stones is placed in the periphery of a flower-like composition and thus plays the part of sepal leaves. The 12 diamond-flowers in the St. Michael Goblet are of the less complicated type, composed of "sepals" only. This is probably the earliest version of these flowers, or "forget-me-nots" or "rosettes" as they also have been called in French and German. Some of the flowers in this goblet are composed of five, some of six and some of as many as seven individual sepaloid-cut diamonds. Figure 5 shows the richest variety with the dotted circle indicating the central pin, the "pistil" which holds the diamonds in position at the centre. In this particular object the "pistils" are golden knobs, but in rings and pendants they are usually set with an emerald or other coloured gemstone. There is rarely a setting between the diamonds. For that reason they must be very precisely shaped. The box into which the stones are assembled is however filled with black tar, into which they are placed. This could be seen through the narrow slits between the diamonds in a pendant from Dresden and in an object in Munich where one stone was missing. At the blunt end of the stones they are kept in place by golden setting, which is shaped to resemble the stamen of a flower.

The ideal shape of rough diamonds from which the sepaloid-cuts were produced must have been octahedra cleaved into two equal halves, but in the majority of flowers, the diamonds are thinner, which indicates that any type of flats, maccles, glassies or

St. Michael Goblet, Kunsthistorisches Museum, Vienna

similar rough that was not suitable for fine tablet-cuts was shaped into sepaloid-cuts. A substantial amount of labour must have been involved in many cases, since the demand must have exceeded the supply of ideal shapes of rough available. Diamond flowers were in vogue for about a century and a half and many hundreds of them have been registered by the author of this article. In all probability some cutters must have specialized in these shapes, since so far it has not been possible to find one capable of or interested in producing a replica of this cut.

The outline of a sepaloid-cut is fan-shaped with the broader end distinctly rounded. There are three facets in the crown, one half-moon-shaped and one triangular. These are divided by a usually extremely narrow trapeze-shaped flattened facet edge. It meets exactly the corresponding edges of the neighbouring stones in the flower and all together form an attractive frame around the figure formed by the central triangular facets. The entire combination resembles to some extent the modern brilliant-cut, although it is a composition of several small diamonds.

The reason why these flowers were produced, is no doubt a desire for effect. Large diamonds were extremely rare in the western world during the 15th and 16th centuries and therefore "clusters" of some kind had to be created. The design in itself was not new, in fact a favourite pattern from centuries before, and for that reason immediately accepted.

As a conclusion it may be said, that diamond flowers, such as they were executed during this relatively short period, are among the finest combinations of gems ever produced. They have a charm never achieved in more recent times and would be well worth a revival, if it is at all possible.

A NEW LOOK AT RARE GEMS

By GORDON V. AXON

RARE gems fall into several categories. Some, such as ruby, emerald, alexandrite, and hiddenite, are rare, in fine quality, because the colouring chemical element is not too often found with the basic mineral.

Other gems are rare, or fairly rare, as the mineral is difficult to cut. These include crocoite, vivianite, and wulfenite. Cerussite is common enough, but the mineral is usually colourless, and very heat-sensitive to cutting, so cut cerussites are not too common. Kyanite produces beautiful gems, but flawless stones of fine green or blue are not often met with.

Many minerals, usually opaque, rarely produce faceting material. These include cancrinite, dumortierite, diaspore, hypersthene, lazulite, microlite, magnesite, sodalite, zincite, natrolite, hauynite, cuprite, staurolite, rhodonite, bustamite, and prehnite.

Some minerals are rare in particular hues. Apatite is not too uncommon, but red and violet apatites are rare gems. So are green and blue euclase, colourless benitoite, blue scapolite, and yellow scapolite cat's-eye. Colourless tourmaline and colourless spinel likewise are never commonly met with, possibly because of little trade interest but basically from true rarity.

Such minerals as rhodizite, simpsonite, and greenockite are never likely to produce large gems. Most collectors would be glad to have a small one of each.

Some gems get mentioned in gem textbooks, while others do not. Dickinsonite has produced small olive-green stones, but is seldom read about. Pyroxmangite produces small red stones and manages to get listed. Perhaps the colour makes a difference.

The tantalite series remains a rare group, although each specific mineral has probably produced gems of two carats or so at one time or another.

Collectors are sometimes struck by the sheer difficulty of obtaining gems that are casually dismissed in textbooks, while finding supposedly rare gems quite easy to obtain. Quite often, the material is there, but is hardly worth collecting. Quincite may so qualify. Lumachelle can hardly be collected from an

abandoned mine, while true odontolite is seldom seen. A major source of fine proustite crystals is now abandoned. Violane hardly ever comes on the market, while cyprine and hodgkinsonite are even scarcer.

Yet the last ten years have seen many rare gems become moderately easy to obtain. Kunzite, once a rarity, glutted the market some years ago, but is now regaining status. Andalusite is never common, but can hardly qualify as truly rare. Amblygonite and axinite, once luckily obtained in one carat stones, have been found in comparatively large crystals of good cutting quality. Colourless euclase has made its way into many collections recently from the quite large find of crystals of good cutting quality and decent size. Natrolite, once regarded as almost impossible to cut, has been found in chunky crystals that yield properly shaped gems. Petalite, too, has been seen in sizes regarded as almost unbelievable some years ago. Even so, petalite is still quite elusive. Sphene, once very rare in fine quality and colour, became fairly common some years ago but now seems on its way back to rarity.

Of course, many more exist. Opinions vary among collectors, depending often on luck, on what gems truly are rare. Augelite, pollucite, painite, beryllonite, taaffeite, fibrolite, hambergite, magnesite, siderite, scheelite, staurolite, willemite, and clear tremolite, probably would qualify as rare gems for most collectors.

Perhaps the lesson of the last ten years is the simple one that conditions are constantly changing, that some rare gems become fairly common, while others seem to disappear. The earth, as we know from the incredible discovery of tanzanite, is still yielding its secrets. Doubtless, other rich sources of old and new gems will be discovered.

The collector with a good variety should rest content if he adds a new gem every now and again. He will never get them all, but he can come fairly close.

THE TREASURE OF THE MOGHUL EMPERORS OF INDIA

By N. VISWANATH

DURING the 16th and 17th centuries, India was ruled by the Emperors of the Moghul Dynasty. Of them, six were the most powerful and notable. They were: Babar, Humayun, Akbar, Jehangir, Shahjahan and Aurangzeb. With the death of the last Emperor, the dynasty began disintegrating.

It was during the reign of the last three Emperors that the wealth of the Moghuls was at its peak. Historians have been unable as yet to determine exactly how much the Moghul treasure was worth as some of it was looted by subsequent rulers of India.

Fortunately, Emperor Jehangir has left an authoritative account of his treasure and the list still exists. There was bullion in his treasury amounting to seven tons of gold, and 1,116 tons of silver. Among precious stones, there were 80 pounds (more than 5,000,000 carats) of uncut diamonds, 100 pounds each of rubies and emeralds, and 600 pounds of pearls. "Of the other less important varieties of precious stones, the quantity is infinite," says the document.

The royal armoury included 2,000 swords studded with diamond-encrusted handles, and the court furniture included 103 chairs of solid silver and five of solid gold. For high dignitaries and visiting monarchs, there were better seating arrangements. Five gorgeous thrones, two of gold and three of silver, were set apart for such persons. Emperor Jehangir himself had seven diamond studded thrones besides the famous Peacock Throne.

Jehangir's bathtub today, would be worth the ransom of a billionnaire. It was seven feet by five feet in dimensions and was decorated with diamonds "to relieve the drabness of gold".

His son Shahjehan, the fifth Moghul Emperor who built the world famous Taj Mahal at Agra was a great connoisseur himself. It was said of him that there was no jeweller in the East who could value precious stones better than he could and the emperor had all luck in pursuing his hobby. He had the first choice of the world's richest diamond mines, the famous Golconda fields, and only his rejections were allowed to circulate in the market.

Incidentally, until 1726 AD, the major source of diamonds in the world were the Golconda mines in India. The Pitt, the

Regent, and the Kohinoor are a few of the historic diamonds that owe their origin to Golconda.

Sir Thomas Roe, the British Ambassador to Emperor Shahjehan's Court, knew to his cost that there could be no trifling with the Emperor. Sir Thomas had something like the mythical Unicorn's horn to palm off. Knowing Shahjehan's weakness for rare treasure, Sir Thomas tried some sales talk with the Emperor saying that he was offering the horn to him only because the Emperor was the person to appreciate its value.

The horn was supposed to have the rare property of neutralizing any poisonous liquid and as such was considered to be a very welcome gift to sovereigns like Shahjehan, whose life was always in constant danger from enemies. He had hoped this would induce the Emperor to pass it at a high price.

But the shrewd Emperor knew that the horn was not worth the price quoted. He merely thanked the Ambassador and dropped the subject with a courteous expression. The diplomat had to find some other gullible purchaser, and finally, it was disposed of at a cheap price to a Dutch captain.

Shahjehan was no hoarder and often gave away fabulous gems as outright gifts. One day, a diamond "brighter than the Pole Star" came to his hands from the Golconda mines and the "bulwork of Islam" as Shahjehan liked to call himself, decided that this would be a worthy gift to the Prophet's Mosque at Mecca. He immediately ordered that a gold candelabra weighing 14 pounds be selected, embellished it with the "brighter than the Pole Star" diamond, and had it sent post-haste to Mecca. Today, a conservative value of the gift would be about ten million rupees.

Imperial wars also brought treasures to the royal jewel box. When the Moghul forces invaded his domain during the early part of Shahjehan's reign, the King of Golconda found it advisable to make a "peace offering". He sent 200 caskets of jewels to placate the Emperor. But the unfortunate King did not escape his fate. With averice kindled at the gift, Shahjehan ordered his troops to advance, and they returned with booty exceeding 300 million rupees in value.

No historian could make a correct estimate of Shahjehan's wealth of which it was said that it was greater than that of his nearest rivals, the Emperors of France and Persia, put together.

But then, there had to be a place to keep all this booty. One fine morning, the Emperor was told by the Master of the Treasury

that it was choking with jewels, and that something had to be done to the strong room to relieve the congestion. The Emperor mused for a while. The problem was finally solved by the creation of the famous Peacock Throne. In the late 17th century when it was made, the Throne was valued at an amount equivalent to 530 million rupees. The Throne was completed after seven years of unceasing labour by the Emperor's best craftsmen.

The plate and cutlery of Shahjehan's palace weighed 25 tons of gold and 50 tons of silver, respectively. The mere gold content of the plate would today be worth more than 15 million rupees.

In one of his tributes to Shahjehan, Sir Thomas Roe has remarked that the King of Bijapur sent to the Emperor 36 elephants, two of which were adorned with gold chains weighing 400 pounds. There were 50 horses in the gift with trappings worth five million rupees. All possible care was taken that the precious stones were properly graded according to the exacting imperial specifications. For example, the diamonds were divided into 12 categories while the pearls were of 16 varying grades.

The draperies of the palace were valued at ten million rupees, and the furnishings included chinaware to the value of 2,500,000 rupees. All the procelain was imported from China under a special order from the Emperor and was among the best in the era.

The Moghul Emperors were so particular about chinaware that once when a high-ranking officer of the imperial household broke a matching piece of porcelain dish, Emperor Aurangzeb behaved as roughly as an ordinary housewife. He was on a tour of his domains in South India when the hapless official dropped the fruit dish in the capital, Delhi, about 1,000 and odd miles away from the Emperor. The culprit knew full well that his carelessness would bring a halter round his neck and at once despatched a messenger to China to bring back a similar dish to complete the set. He had hoped that the dish would reach Delhi before the Emperor returned from his tour. Unfortunately for him, the Emperor returned far ahead of the schedule, and in course of time, wanted his favourite fruit dish. The trembling official related the accident, and in view of the fact that arrangements had already been made to get a replacement, the official was temporarily excused and suspended pending arrival of the caravan from China.

But the notorious Central Asian robbers made short work of the messengers and the money they carried for purchase of the

chinaware. When the period of grace elapsed and there was no news from China, the irate Emperor gave the official the choice between immediate execution and that of going to China to get the porcelain dish.

The official chose the latter course and began the hazardous journey to Cathay (China). As his whole family was held as hostages by the Emperor, he had to be particularly careful about his life and chose the safe route through the Pamir mountains, the so-called backbone of the world. The ranges of the Pamirs tower to a height of about 23,000 feet and one can very well imagine the plight of the official. Fortunately, Heaven took pity on him and the story of this official reached the court of the then Persian Emperor. This monarch ordered his Grand Wazier to look in the royal Persian cupboards to find whether there was any porcelain dish to match the one for which the official was searching. Happily, such a piece was found, and the Persian Emperor ordered that a gift of this porcelain dish be made to the official. But the poor man was so much broken down in health from the rigours of the journey that he died *en route* by the time deliverance came.

Emperor Shahjehan did not keep all his treasures in one place. They were divided in varying proportions and were kept in fortresses in different parts of the empire. There were seven of these treasure forts, besides the capital of Delhi. They were: Gwalior, Marwar, Lahore, Rantambher, Asirgarh, Rohstsagar, and of course, Agra. The Lahore fort contained the maximum quantity of bullion, while Agra, as the Emperor's favourite citadel, held most of the jewels.

A comparison with monarchs of the present century puts Shahjehan in a very favourable light. The wealth of the British Sovereign is estimated at about 170 million dollars. But at a time when the money value was at least six times greater than that of the present era, Shahjehan's treasury must have held billions of rupees worth of valuables.

The late Nizam of Hyderabad in India, who was a remote descendant of the Moghul dynasty, had treasure and jewellery which it was almost impossible to sell for want of buyers. What can one do with mats woven with priceless pearls and shirts studded with diamonds? He had a paperweight, the famous Jacob diamond, a treasure of 150 carats, the rock-bottom price of which was about Rs.150 lakhs.

Gemmological Abstracts

ANON. *Kashan flux-grown rubies.* Gems and Gemology, 1969, XIII, 2, 30-34, 12 illus.

These rubies are grown by a flux-fusion method by Ardon Associates. They are characterized by numerous dot-and-dash flux inclusions and veil-like feathers, the latter resembling those seen in synthetic emerald. Except for their inclusions and their transparency to ultra-violet light, their properties are almost identical with natural rubies.

R.W.

BANK (H.). *Zur Unterscheidung optisch einachsiger und zweiachsiger Minerale in der Gemmologie.* The differentiation between uniaxial and biaxial minerals in gemmology. Zeitschr. d. Deutsch. Gemmologischen Gesellschaft, 1969, 18, 3, pp. 108-112.

The author stresses the importance of using the refractometer for distinguishing between optically uniaxial and biaxial stones; in some cases this means distinguishing between the natural and synthetic gem. A short list of these stones is given.

E.S.

BANK (H.). *Farbe und Farbveränderungen bei Topaz.* Colour and colour change in topaz. Zeitschr. d. Deutsch. Gemmologischen Gesellschaft, 1969, 18, 4 pp. 171-175.

With the help of an extensive bibliography the author describes colour and colour changes in topaz brought about by heat-treatment and by irradiation with x-rays and radium. During the last few years irradiated brown topazes have been on the market, which can be differentiated from the natural brown stones by their different refractive indices. Certain yellow topazes from Siberia become paler by exposure to daylight, and some pale topazes become pale yellow in the same way.

E.S.

BANK (H.). *Spodumene seine Varietäten. Hiddenit und Kunzit.* Spodumene and its varieties hiddenite and kunzite. Zeitschr. d. Deutsch. Gemmologischen Gesellshaft, 1969, 18, 4, pp. 176-180. Extensive bibliography.

Colour changes in spodumene can be brought about by heating, violet kunzite becoming pink, and irradiation. Irradiated kunzite changed to a grass-green colour similar to hiddenite, but could still be differentiated from that stone by luminescence, which hiddenite does not show. When irradiated with x-rays kunzite does not seem to alter its colour, while hiddenite changes from yellowish to green. Various other examples are given and it is shown how difficult it is to distinguish between kunzite and hiddenite. Physical characteristics are given.

E.S.

BANK, (H.). *Synthetisches Strontiumtitanat.* Synthetic strontium titanate. Zeitschr. d. Deutsch. Gemmologischen Gesellschaft, 1969, 18, 4, pp. 181-183.

Synthetic strontium titanate is easily distinguishable from diamonds by appearance and high specific gravity. A synthetic strontium titanate-topaz doublet has been on the market for some time.

E.S.

BOLTON (H. C.). *Hexagonal diamond—a new crystal form.* Australian Gemmologist, 1969, X, 6, 18-20, 2 illus.

Discusses the synthesis of diamond with hexagonal symmetry. An explanation is given of the atomic arrangement, and there are some observations on the possibility of natural hexagonal diamonds being found.

R.W.

CHALMERS (R. O.). *A new occurrence of precious opal of volcanic origin near Mullumbimby, New South Wales.* Australian Gemmologist, 1969, X, 6, 10-13.

An account of the new find of opal in New South Wales. The geology, occurrence and mineralogy of this new opal are discussed.

R.W.

CLAYTON (N.). *The first discovery of Australian opal.* Australian Gemmologist, 1969, X, 6, 13-14.

A research in the archives at the City of Adelaide have brought to light papers on Johann Menge (often given in literature as Mingaye) and these papers fairly well establish the right of this person to have been the first to discover opal in Australia.

R.W.

COCKS (F. B.). *Photography as an aid to recovery.* Australian Gemmologist, 1968, X, 2, 11-14, 3 illus.

This is the first part of a series and this instalment deals with the suggested use of photography of gemstones and their inclusions as a means for the production of identity certificates which would have a value in assisting the recovery of lost or stolen jewellery. This aspect is understandable when it is realized that the author is not only a qualified gemmologist but also a Police Officer.

R.W.

COCKS (F. B.). *Photography of inclusions in gemstones.* Australian Gemmologist, 1968, X, 3 and 4, 9-12, 12-18, 11 illus.

The second and third instalments of this series deals with the equipment needed and the setting up for taking photographs of the inclusions in gemstones. The article is clearly written and the explanations are in simple terms. Only normal instruments are discussed, the writer refraining from any discussion on high-priced specialist apparatus. The types of lighting needed, the films best to use and the exposure times are gone into, and the use of a copying stand is mentioned. A single-lens reflex camera is the camera advocated.

R.W.

COTTON (W. L.). *A trip to the Carnaiba emerald mines of Brazil.* Lapidary Journ., XXIII, 10, 1360-1363, 12 coloured plates.

A first-hand account of a visit to the emerald mines at Carnaiba. The mines are open-cut workings and the stones are found in a grey-green clay which is an altered pegmatite. The mining is an altered pegmatite. The mining is communal or run by families of miners who own small plots. There is no organized mining by large concerns.

R.W.

CROWNINGSHIELD (R.). *Diamonair—a new diamond substitute.* Jewellers Circular-Keystone, 1969 (December), 50, 6 illus.

A general and factual article on the colourless yttrium aluminium garnet, to which the name "diamonair" has been given.

R.W.

CROWNINGSHIELD (R.). *Developments and highlights at the Gem Trade laboratory in New York.* Gems and Gemology, 1968/9, XII, 12, 372-378, 14 illus.

Reference is made to a type of imitation turquoise which has a refractive index variation of 1·57 to 1·60 and a density of 2·49 to 2·59. A hot needle brought up to the specimen will cause it to "fluff-up" and turn white but give off no smell. Hydrochloric acid when applied to the surface will turn yellow. The article describes the absorption spectra of various types of synthetic scheelites, greenockite and europium and yttrium garnets. These spectra are illustrated by line drawings. A transparent grossular garnet showed a red-orange fluorescence under long-wave ultraviolet light and a yellow-orange under the short-wave lamp. The hazards of steam-cleaning of gemstones is commented upon. Some special features of diamond are mentioned and an unusual fluorescence shown by a synthetic emerald—which showed a stronger crimson glow when under the short-wave lamp than when under the long-wave lamp—is commented upon.

R.W.

CROWNINGSHIELD (R.). *Developments and highlights at G.I.A's laboratory in New York.* Gems and Gemology, 1969, XIII, 3, 89-96, 20 illus.

Items noted were a transparent actinolite, orange-brown and yellow-brown treated diamonds, a smoke-treated opal, tissue-graft pearls and a chrome-green grossularite. Flux-grown synthetic rubies are reported on, one of which exhibited triangular metallic inclusions. It is mentioned that these synthetic rubies glowed with a crimson glow which was stronger under the short-wave lamp. It is reported that Y.A.G. is now called "diamonair". Some stones of this type when cut for maximum yield may show "naturals" on the girdle from the crystal growth marks on the side of the "pulled" crystal.

R.W.

CROWNINGSHIELD (R.). *Developments and highlights in the Gem Trade laboratory in New York.* Gems and Gemology, 1969, XIII, 1, 15-21, 16 illus.

Reports a rock mixture, consisting mostly of opal and grunerite which gives a "tiger-eye" appearance. It has been marketed under the misnomer "Fire Jade". Examination has been made of Tanzanian garnets and other Tanzanian materials. Yttrium aluminium garnets and yttrium oxide are mentioned. A "poured marble" cameo consisting of a ground up and compressed marble was investigated. A zoisite, a "cherry-stone" clam pearl, and damage to a diamond are reported upon. Oddities seen as inclusions were platinum in a cut hydrothermal emerald and "needles" in a glass. An opal imitation consisting of a hollow-backed cabochon of rock crystal filled with opal chips which were bonded in a clear plastic is mentioned.

R.W.

CUTHBERT (D. L.). *Precious opal in Idaho.* Lapidary Journal, 1969, XXIII, 7, 928-930, 6 coloured illus.

Tells the story of the Spencer opal mine, its history and the occurrence and types of opal found in the mine. Some hints are given in the methods of cutting and polishing this opal.

R.W.

DURRAGH (P. J.). *Volcanic gem opals.* Australian Gemmologist, 1969, X, 8, 5-8, 8 illus.

Gives the results of the examination by electron microscopy of the new finds of opal at Mt. Bougrom in Queensland and New South Wales.

R.W.

FISCHER (B.). *The Cybernetic Diamond Polishing Automaton.* Diamant, 1970, 124, p. 5,.

In a Belgian laboratory a cybernetic automaton for the polishing of eight-cuts was developed, which has aroused keen interest in the governments of Belgium and Israel. Representatives of De Beers

and the Technion University at Haifa witnessed the machine at work.

Only cybernetics can bring about an adequate solution to the difficult problem of automatic polishing.

There is no question of automatic polishing if there is no continuous production. But continuous production is only possible if the scaife is kept impeccably.

Up to the present time all efforts at constructing an automatic polishing machine have been limited to making robots, which were capable only—just as pick-ups—of a few stereotyped operations.

Now it is not possible to keep the scaife intact with these small robots.

The slightest error in putting a stone on the scaife, in getting a facet that does not run true in relation to the axis of crystallization, in hitting a naat, causes the immediate and irreparable destruction of the microscopically thin layer—a few microns thick—of boart powder, composed of a infinite number of diamond particles, embedded in the scaife pores.

A cybernetic system had to be designed, which would be able to follow the same line of reasoning as a man, a computer who takes decisions second after second.

The electronic part is so sophisticated that it makes the same decisions as a man, only more precisely and more quickly, for a cybernetic machine does not grow tired and does not err.

The different cutting operations must be followed from second to second by the computer which must be able to make the decisions imposed on it by the information received from the electronic control systems concerning the axis of crystallization, naat if any, or any other element that interferes with normal cutting operations.

The cybernetic automaton is capable of recognising the direction in which to cut and also of finding it.

Moreover, if during polishing a naat appears when three-quarters of a facet is shaped, polishing stops. And the electronic brain will take a decision, which will be either to look for another polishing direction or to stop polishing altogether.

This sophisticated system permits the tackling of whole stones and the solving, owing to as yet not publicly known techniques, of the problems posed by flat naats: whereas skilled workers have many difficulties with these stones the cybernetic automaton easily conquers them.

It is this complicated achievement which constitutes a research instrument that will lead to other still more decisive achievements.

The finished stone is beautifully made, with each facet being perfectly smooth.

The machine accepts all sizes of stones.

A defect, such as an imperfect girdle, due to the cutter, is no obstacle.

Upper and lower parts of the stone are polished equally easily as there is no problem in fixing the size of the facets, which are put on with great precision thanks to extremely accurate systems.

The cybernetical part is such, that it allows the machine to direct itself, which means that it may change its judgement. This is repeated at each new facet, as the constitution of the stone varies—with regard to polishing—according to the parameters, which are the axis of crystallization, naat, etc.

S.P.

GLOVER (J. E.). *Western Australian emeralds.* Australian Gemmologist, 1968, X, 2, 15-17.

A survey of the properties of emeralds found at Poona in Western Australia. Analyses are given, and the exact location of the mine is given by map references. The value of the density of these emeralds is reported to be 2·69 and the refractive indices as 1·578-1·573. It is interesting that no vanadium is shown by the analysis. There is a list of references and one table.

R.W.

GRUBB (P. L. C.), DONNELLY (T. H.). *Colour changes in elbaite tourmaline from Ravensthorpe, Western Australia.* Australian Gemmologist, 1969, X, 8, 15-18, 1 illus., 4 tables.

A record of experiments carried out on tourmalines from the Ravensthorpe area. The tourmalines examined had zonal colouration in red and green. Chemical analyses, optical properties and heating experiments are recorded. It is concluded from the experiments that colour variants in elbaite crystals are determined primilarly by differences in Mn^{2+}/Mn^{3+} and Fe^{2+}/Fe^{3+} ratios.

R.W.

HOLLAND (S.). *Nephrite jade in British Columbia.* Lapidary Journ. 1969, XXIII, 9, 1244-1248, 2 Maps.

Reprinted from the annual report of the British Columbia Department of Mines and Petroleum Resources this article gives an authentic coverage of the subject. Types of jade (nephrite), the range of density, and the structure both in hand-specimens and by thin-section examination are discussed. The nephrite was first found in the Frazer River area during 1938, but the material was not generally known until 1949. An important article completed with a list of references.

R.W.

LEADBEATER (P. W.). *Cameos and intaglios.* Australian Gemmologist, 1969, X, 6, 15-17.

A general article on carved gems giving much of the history of the art and the materials used for these carved gems.

R.W.

LEIPER (H.). *Orienting blue topaz with ultra-violet light.* Lapidary Journ., 1969, XXIII, 9, 1250-1255, 1 illus.

A revision of an article published in 1955 (Journ. Gemmology, V, 3, 135-140). The original work was mainly on topaz from American sources. Now further work has been carried out on blue topaz from other localities.

R.W.

LIDDICOAT (R. T.). *Developments and highlights in the Gem Trade laboratory in Los Angeles.* Gems and Gemology, 1968/9, XII, 12, 379-383, 9 illus.

Linobate (lithium niobate or lithium metatitanate) is discussed. Some mention is made of odd inclusions seen in diamond, opal and in peridot. An unusual star-doublet, which consisted of a corundum cap to a star-sapphire base, and a cat's-eye zoisite are reported.

R.W.

LIDDICOAT (R. T.). *Developments and highlights in the Gem Trade laboratory in Los Angeles.* Gems and Gemology, 1969, XIII, 1, 22-29, 21 illus.

More information is given on the yttrium aluminium garnets,

synthetic greenockite, periclase and chrysoberyl. Changes in the characteristics of synthetic emerald are noted. True doublets consisting of two parts of Montana sapphire have been encountered, and a report is made on some unusual Mexican opals. A bead necklet made of vegetable ivory is mentioned.

R.W.

LIDDICOAT (R. T.). *Developments and highlights at G.I.A's laboratory in Los Angeles.* Gems and Gemology, 1969, XIII, 3, 97-102, 10 illus.

Refers to some unusual opals which had low refractive index, near 1·38, and low density, near 1·42. These opals are probably of Mexican origin. Hornbill "ivory" is another material discussed. Other items referred to are dodecahedral inclusion lines in a diamond, curved fluorescence in a synthetic sapphire, crystallites in glass and inclusions in synthetic and natural emeralds.

R.W.

LÖNS (H. H.). *Die Beschreibung von Ebenen und Richtungen in Kristallen mit Hilfe von Ziffernkombinationen (Millersche Indizes).* Description of faces and directions in crystals with the help of Miller indices. Zeitschr. d. Deutsch. Gemmologischen Gesellschaft, 1969, 18, 4, pp. 164-170.

Well illustrated article. In crystallography it is not essential for the axes to be at right angles and symmetrical. However, in the case of diamond the axes are usually symmetrical and equal; one usually finds cubic, rhombic dodecahedral and octahedral faces.

E.S.

MALES (P. A.). *Opal in volcanic rock.* Australian Gemmologist, 1968, X, 4, 9-11.

The article discusses the sources of opal in Australia which is found in volcanic rocks.

R.W.

MAGILL (S.). *White gold of the Odenwald.* Lapidary Journal, 1969, XXIII, 8, 1097-1102, 12 illus.

An historical account of the ivory carvers of Erbach in Western Germany. The ivory is imported as whole tusks from Antwerp and

Rotterdam. Various types of ivory are discussed. It is a popularly written article and refers to a little known industry.

R.W.

MEEN (V. B.), TUSHINGHAM (A. D.), WAITE (C. G.). *The Darya-i-nur and the Tavrnier Great Table.* Australian Gemmologist, 1968, X, 3, 16-24, 6 illus.

The authors, who formed a group to go out to Iran to examine officially the Crown Jewels of that country, pen this article on the historical aspects of some of the famous Indian diamonds. It is the authors' opinion that the Darya-i-nur is actually the major portion of the Great Table diamond. An informative and entertaining article.

R.W.

MEEN (V. B.). *The largest gems of the Crown Jewels of Iran.* Gems and Gemology, 1969, XIII, 1, 2-13, 13 illus.

Dr. Meen, with others, made a scientific study of the Crown Jewels of Iran (Persia) and in this article details in full the more important gems in this State collection. A remarkable and authentic work.

R.W.

MERTENS (R.). *Die Vielfalt der Granate.* Varieties of garnets. Zeitschr. d. Deutsch. Gemmologischen Gesellschaft, 1969, 18, 3 pp., 113-118.

The author reviews the various types of garnets and includes a useful table, listing hardness, S.G., R.I. dispersion and colour for almandine, rhodolite, pyrope, grossular, andradite, melanite, spessartite and uvarovite.

E.S.

OLDENDORFF, (P.). *Ein Beitrag zur Lösung des Brillianzproblems.* A contribution to the solution of the problems connected with brilliance. Zeitschr. d. Deutsch. Gemmologischen Gesellschaft, 1969, 18, 3, pp. 99-107.

The path of the light rays in differently brilliant-cut stones (Tolkowsky, Eppler) and the importance of the total height of the stone and the radius of the table are discussed.

E.S.

OUGHTON (J. H.). *The direct-vision spectroscope.* Australian Gemmologist, 1968, X, 4, 21-27, 7 illus.

An excellent article surveying the construction and use of the hand-spectroscope. It is clearly and simply written and conveys all the salient points. A perfect resumé for student training.

R.W.

PENZE (J.). *Einschlusse in Edelsteinen und ihre Bezeichnung.* Inclusions in gem stones and their nomenclature. Zeitschr. d. Deutsch. Gemmologischen, Gesellschaft, 1969, 18, 4, pp. 157-163.

There seems to be no difficulty in naming simple inclusions, such as rutile needles or tourmaline crystals, or even gas bubbles. There seems to be some confusion in dealing with two-phase and three-phase inclusions and this the author talks about at some length. Willard Gibbs first described "phases" in 1880. Physical characteristics are described, especially how these phase-inclusions are influenced by temperature, pressure and the quantity of soluble material. There are 2 illustrations of two-phase and three-phase inclusions in Brazilian and Colombian emeralds.

E.S.

PRIDER (R. T.). *Metamorphism and gemstone formation.* Australian Gemmologist, 1969, X, 6, 7-9.

Based on the Presidential address to the Australian Gemmological Association, the article discusses fully the various types of metamorphism and the effect of change in rocks due to them. The gem minerals which form during these changes are mentioned.

R.W.

ROLFF (A.). *A trip to the famous citrine areas of Brazil.* Lapidary Journ., 1969, XXIII, 8, 1152-1161, 11 illus.

Describes a visit the author paid to the mines around the town of Cristalina in the State of Goias. The quartz crystals occur in tectonic cavities and are rock-crystal, morion, smoky quartz and citrine. An interesting and informative article.

R.W.

ROLFF (A.). *The geological environment for emerald in Brazil.* Lapidary Journ., 1970, XXIII, 11, 1488-1501, 16 illus., 4 coloured plates.

A concise survey of the emerald deposits of Brazil. The history, the geology, methods of mining and the actual locations of the various mines in Brazil are discussed. Much information in a short article.

R.W.

RONZIO (A. R.), SALMON (M.). *Trace elements in jade.* Gems and Minerals, 1970, 389, 24.

Results of trace elements in nephrite and jadeite. All samples, 30 nephrite and 4 jadeite, contained iron and nickel, and the majority also contained manganese, chromium, zinc and copper. It is not certain which element is responsible for the colour in pink jade.

S.P.

SANDERS (E. A.). *Modern reefs.* Australian Gemmologist, 1969, X, 5, 21-25, 2 illus.

Although the article is mainly concerned with the coral reefs of Australia and the Pacific Ocean, the article concludes with a short but singularly good resumé of gem corals.

R.W.

SNOW (J. J.). *Combined light and spectroscope.* Australian Gemmologist, 1968, X, 4, 28-29, 2 illus.

Describes a spectroscope and light source constructed as one unit. Full details are given.

R.W.

SNOW (J. J.). *Infra-red photography.* Australian Gemmologist, 1969, X, 5, 26-27, 5 illus.

Details an experimental work which breaks new ground. The photography of the inclusions in gemstones using infra-red light and infra-red film and by dark ground illumination using infra-red light source. Full details are given.

R.W.

SOKLICH (P.). *Recent discovery of dravite in Western Australia.* Lapidary Journ., 1970, XXIII, 10, 1354-1359, 2 illus., one page of colour plates.

A popular article on the mining for dravite (tourmaline) crystals at Yinnietharra, Western Australia. Black tourmaline is also found at this place. The mining is carried out by open-cut methods after blasting the rock.

R.W.

SWITZER (G.). *Russia No. 2 in diamonds.* Lapidary Journal, 1970, XXIII, 11, 1516-1519, 2 illus.

Tells of the present position of the Russian diamond production and discusses its relation to other producers. The article is completed with an up-to-date table of the world production of diamonds.

R.W.

THURM (R.). *A new polariscope and conoscope.* Australian Gemmologist, 1969, X, 6, 22-24, 4 illus.

Details the construction and use of a new polariscope which is so arranged as to incorporate lenses for the production of conoscopic figures.

R.W.

TROUP (G. J.). *The alexandrite effect.* Australian Gemmologist, 1969, X, 5, 9-12, 5 illus.

Mainly a scientific discussion giving explanations for the reason of the colour change in alexandrite and "synthetic alexandrite" (corundum).

R.W.

TROUP (G. J.). *The radiofrequency spectra of gemstones.* Australian Gemmologist, 1969, X, 7, 19-22, 4 illus.

An elegant article on the subject of magnetic resonance spectroscopy using radiofrequencies. The basic principles are given and some of the results obtained. The article concludes with some notes on the use of gemstones as Masers.

R.W.

BOOK REVIEWS

MURRAY, S. J. *Shell Life and Shell Collecting.* The Oak Tree Press, London, 1970, 96 pp., 12 pages colour photographs, many other photographs and drawings. Price £1 15s. 0d. (£1.75).

Shell collecting is an absorbing hobby, leading to an appreciation of art and the sea. The illustrations show how the animals and shells are constructed, and their distinguishing characteristics. The reader is told where to look for perfect specimens, how to clean shells, identify them and how to keep a neat collection. Sonia Murray's book will interest both children and adults.

S.P.

LENZEN, G. *The history of diamond production and the diamond trade.* Tr. from German by Bradley, F. Barrie & Jenkins (1970), 230 pages, 38 illus. 80s.

This volume is the end product of a thesis written by the author for academic purposes and is in general a compilation of data abstracted from ancient, medieval and modern literature. These are correlated and thoroughly discussed. The book begins with a survey of the earliest history of diamond in which some criticism is made of the summing-up given by other authors. The diamond as a mineral, as a gem and as a tool is reviewed and some assessment of the reasons for the prestige of diamond throughout the ages are given. There are two chapters devoted to the Indian deposits. In these chapters there is given a full record of the various geographical areas of India where diamonds were found, and an assessment is made of the trading routes through which diamonds passed out of India in olden days. There is a discussion on ancient gemstone weights, and on the origin of the fashioning of diamond. Much information is given on the price calculation of value of diamonds at various periods of history. There is a chapter in similar vein on the Brazilian deposits. The history of the diamond deposits of Southern Africa is extremely well considered, the author having amassed a wealth of information on the mines and mining companies and how they began and developed. There

is much information given on the production figures and on price control. Little is mentioned concerning the diamond localities of Central Africa and, except for a short note in the postscript, there is but a brief note of the Russian deposits, but there is a short but adequate mention of the synthetic diamond production. At the end of each chapter there is appended an extensive list of notes and references, and there is an extremely full bibliography at the end of the book. There is an index of names and a geographical index, but no subject index. Very few typographical errors were noticed, but the misspelling of Grodzinski as Grodzinsky throughout the text (though correctly put in the bibliography) tends to stand out. The volume is an excellent compilation and as a reference book should be in every gemmological library.

R.W.

GÜBELIN, E. *Pierres Précieuses.* Editions Silva, Zurich, 1969, (In French, German and Italian).

This is not a text-book on gemmology, but intended to be a treasure trove for lovers of beauty. It is an attempt to combine enthusiasm for the fascination and glamour of gems with worthwhile gemmological knowledge. An English version of the book is intended, and a detailed review will be given when this edition is available.

S.P.

BAUER, M. *Precious Stones.* Griffin, London, 1968, 95 drawings and 20 plates. Hard bound (single volume) £8 10s. 0d., paperback (two volumes) £2 10s. 0d.

A reprint of the English translation by L. J. Spencer of the German book originally published in 1904. A new Foreword and Addenda have been propared by Dr. Edward Olsen, Curator of Mineralogy at the Field Museum of Natural History in Chicago.

This classic work in precious stones has long served as the standard work in its field and has been called "the most detailed work on gems" by the *Encyclopaedia Britannica.* Amateur mineral hobbyists as well as professional gem and jewelry dealers will find here a wealth of information on all aspects of gemmology, from assembling collections to cutting and polishing stones.

The book begins with a discussion of the general characteristics and applications of gem minerals, how they are cut, how faults and counterfeits are detected, how the value of a gem is determined, etc. Then, each type of precious stone is discussed thoroughly, beginning with nearly 150 pages on the diamond. 53 additional gem minerals are covered and dozens of varieties, including corundum, spinel, chrysoberyl, beryl, topaz, garnet, opal, turquoise, feldspar, and quartz. Professor Bauer provides detailed information on the chemical composition of each stone, its hardness, colour variations and lustre, distribution and occurrence, types of rock in which the gem is found, how it is mined, and much more. He also relates many of the stories and legends connected with individual stones which are famous for their size or historical associations. Of special interest is a 20-page section giving precise instructions for distinguishing between precious stones with similar appearances and for detecting imitations. An extensive appendix covers coral and pearls.

S.P.

WEBSTER, R. *Gems—their sources, descriptions and identification.* Butterworths, London, second edition, 1970. Price £12 (U.K. only).

The second edition of this comprehensive work has been brought up-to-date by the addition of various chapters, including new information on synthetic stones. New tables on plastics and their identification have also been added. The colour plates of the early addition have been replaced, and those provided by the Geological Survey are particularly well reproduced.

The first edition of Webster's monumental work was in two volumes. The single volume of the second edition is a considerable improvement. The index is extremely detailed and the author, a professional gemmologist, has been painstaking in incorporating as much up-to-date information as possible.

It is the most comprehensive, accurate and readable account of gemstones at present available in the English language.

M.S.

ASSOCIATION NOTICES

GIFTS TO THE ASSOCIATION

The Council of the Association is grateful to Mr. D. Mountfort, F.G.A.A., of Kingsford, New South Wales, Australia, for an opal doublet.

OBITUARY

Nigel W. Kennedy, 2nd April, 1970 (D. 1948). Lecturer in gemmology at the Liverpool College of Art for many years.

ANNUAL GENERAL MEETING

The 40th General Meeting of the Gemmological Association of Great Britain was held on Thursday, 23rd April, 1970, at the North British Hotel, Glasgow. Mr. Norman Harper, Chairman of the Association, presided and said that he was delighted that it had been possible to hold the Annual Meeting in Scotland for the first time. The Council was grateful for the work done by the Scottish Branch in encouraging and maintaining interest in gemmology. It is hoped that it will be possible for the Branch to arrange another Diamond Course in Scotland later this year.

In his report Mr. Harper said that the thing that stood out was the extraordinary enthusiasm for a fascinating subject. Almost every year at the Presentation of Awards a "highest record" examination entry can be reported. Last year 767 people were examined in gemmology and this throws an immense strain on the staff for whom sufficient appreciation cannot be shown. It is also significant that half the membership of the Association is overseas.

Mr. Harper commented that the office is kept busy with

gemmological enquiries from all over the world and two programmes about gemmology on the radio have produced a flood of enquiries from persons in the U.K. In order to cope with the extra work it will be necessary to make a substantial and more realistic contribution to administration costs involved on our behalf by the National Association of Goldsmiths. The council have agreed that from the 1st January next year the annual subscription must be increased from £2 2s. 0d. to £3 0s. 0d., but even at £3 0s. 0d. the subscription, which includes *The Journal of Gemmology*, is very good value. It is 13 years since the subscription was altered and when one considers how costs have risen the Association cannot do otherwise than express gratitude to the National Association of Goldsmiths for enabling the subscription to be kept at such a low rate for so long.

Referring to *The Journal of Gemmology*, Mr. Harper mentioned that articles are always required. They need not be of high scientific standing—a little more light relief such as has crept into some of the recent issues is always welcome. It is hoped that as many members as possible will endeavour to provide worthy contributions.

Mr. Dennis Hill, Chairman of the Scottish Branch, seconded the motion adopting the Annual Report and Accounts.

The following Officers were elected: Sir Lawrence Bragg, President; Mr. Norman Harper, Chairman; Mr. Philip Riley, Deputy Chairman; Mr. Douglas King, Vice-Chairman and Mr. F. E. Lawson Clarke, Treasurer.

Mr. Harper expressed appreciation on behalf of the Council that Sir Lawrence Bragg continued as President. Dr. G. F. Claringbull, who has served as an Examiner since 1938, was elected as a Vice-President. Miss Iris Hopkins was re-elected to serve on the Council.

It was announced that Messrs. Watson Collin & Co., chartered accountants, had signified their willingness to continue as auditors.

BRANCH MEETINGS

The Annual General Meeting of the Scottish Branch was held on the 23rd April, 1970, at the North British Hotel, Glasgow.

This followed the Annual Meeting of the Gemmological Association.

Mr. Dennis Hill, Chairman of the Branch, reported on the work of the year, especially the enthusiasm shown for the Gemstone Quiz. He mentioned, however, that it had not been possible to arrange an Advanced Diamond Course, due to insufficient enrolments, which was most disappointing after the success of the previous year. Mr. Hill went on to report a proposed gemstone exhibition to be held in Glasgow in the autumn of 1971. Concluding, the Chairman thanked the Committee and Branch members for their work during the year. The election of Officers followed and all were re-elected.

The summer outing of the Scottish Branch this year will be to see the Royal Scottish Regalia at Edinburgh Castle and the mineral collection at the Royal Scottish Museum.

COUNCIL MEETING

At a meeting of the Council of the Association held on Tuesday, 14th April, 1970, the following elections took place:—

Fellowship

Almenar Ibanez, Vincente, Valencia, Spain. D. 1969
Davidson, Terence Malcolm John, High Wycombe, Bucks. D. 1962
Fernandez Gil, Enrique, Valencia, Spain. D. 1969
Navarro Bort, Rodolfo, Valencia, Spain. D. 1969
Peris Bataller, Francisco, Valencia, Spain. D. 1969
Ripolles Ferrara, Jose, Valencia, Spain. D. 1969
Rosich Chova, Francisco, Valencia, Spain. D. 1969
Sanchis Estrems, Jose, Valencia, Spain. D. 1969
Sanchis Estrems, Salvador, Valencia, Spain. D. 1969
Torres De Goytia, Rafael, Valencia, Spain. D. 1969

Ordinary Membership

Bowman, David, Loughton, Essex
Cavouras, Evangelos, Rio de Janeiro, Brazil
Coxon, Andrew Michael, Totteridge, London
Daftery, Baboobhai Laxmidas, Bombay, India
Dikhoff, Gerrit Theodorus Herminecus, Sneek, Netherlands
Drake, John William, Coggeshall, Essex
Dusan, Vadnal Ljubljana, Yugoslavia
Franco, Ricardo, Winter Park, Florida, U.S.A.
Fujimoto, Seishichiro, Nagasaki-Ken., Japan
Gardiner, Anthony C., Abadan, Iran

Gopalji, Kantilal P.,
Palmers Green, London
Haag, Susanne Renete,
Kirschweiler, West Germany
Haug, Jan Steiner, Vilberg, Norway
Hawes, John, Wakefield, Yorkshire
Heyes, Alan John, Lancing, Sussex
Ishizuka, Makoto, Yokohama, Japan
Karunaratna, Avanti Yasmin,
Colombo, Ceylon
Kashima, Shigehiro, Tokyo, Japan
Kawahara, Nobuyuki, Tokyo, Japan
Kobayishi, Kichichiro, Tokyo, Japan
Kontani, Fusajiro, Tokyo, Japan
Krishnachari, Dharwar, India
Kubo, Yoshihiro, Tokyo, Japan
Kunitake, Hiroko
Fukuoka-Ken, Japan
Le-Bon, Leo Humphrey,
Surbiton, Surrey
Lumley-Holmes, Barry,
Haxby, Yorks.
Martin, Colin Riley,
Kilmarnock, Scotland
McCormack-Smith, Berry,
Leawood, Kansas, U.S.A.
Morita, Kimiko, Tokyo, Japan
Nakagawa, Hideo,
Takaoka-Shi, Japan
Nakajima, Yukio, Kiriu-City, Japan
Nicolau Marti, Margarita,
Barcelona, Spain
Nishibe, Reiko, Tokyo, Japan
Ohguchi, Hideki, Yokohama, Japan
Okubo, Ryoichi, Tokyo, Japan
Otani, Hiroshi,
Kita-Ku Kyoto, Japan
Phillips, Diana Janet,
Hailsham, Sussex
Saito, Noboro, Kyoto, Japan
Schullin, Hans, Graz, Austria
Shrubsall, Graham Keith,
Comberton, Cambridge
Silva, Andra Baduge Kularatna de,
Singapore
Silver, William Willard,
Mainz, Germany
Snipper, Alison Bernice,
Maida Vale, London
Sool Shick, Kim, Seoul, Korea
Suzuki, Kazuo, Tokyo, Japan
Tabei, Hideo, Gumma-Ken, Japan
Thompson, Harry, Walton, Liverpool
Thomson, Peter, London
Toothill, Jack Edward,
Toronto, Canada
Tsuda, Yo, Okayama, Japan
Uchiyama, Koichi, Iwaki-shi, Japan
Van de Walle, Pierre,
Brugge, Belgium
Webb, Ernest,
Bury St. Edmunds, Suffolk
Welander, Oscar A.,
Feagus Falls, Minnesota, U.S.A.
Williams, Mary Helen,
Bad Godesberg, Germany
Yamamoto, Kenzo, Tokyo, Japan
Yamamoto, Takashi,
Yamanashi-Ken, Japan
Yanagisawa, Akira, Tokyo, Japan
Zarook, Mohamed Hazim, Ceylon
Zook, Theresa F.,
Alexandria, Virginia, U.S.A.

MEMBERS' MEETING

A meeting of members of the Association was held at Goldsmiths' Hall on the 14th April, 1970. Mr. G. F. Andrews presided and introduced Mr. B. W. Anderson, Director of the Diamond, Pearl and Precious Stone Trade Section of the London Chamber of Commerce, and Mr. R. Webster and Mr. A. E. Farn, also of the

Laboratory. The subject of their symposium was "Gemmological Points of View". Mr. Anderson said that it was almost 45 years ago that the laboratory started, the first of its kind in the world, with himself and a commissionaire as the total staff. The first work undertaken was the checking of pearls, and after a shaky first year it was not long before more than a thousand pearls a week were passing through the lab. It was not until a few years later, when Basil Anderson had been joined by C. J. Payne, that a start was made on testing gemstones.

Basil Anderson went on to say that the work undertaken at the laboratory was very different to that undertaken by a gemmological student in the classroom. However skilled a student was, he said, he was unlikely to conceive the type of problems tackled by the laboratory or how they were resolved. Long experience coupled with skill and modern instruments had to keep pace with the increasing complexity of the subject. In the laboratory one had to be sure that the stone was of a particular type and origin—one just could not make mistakes. Mistakes had been made, but he put these no higher than one in 10,000 reports and as something like 70,000 had been completed over the years he thought that was quite a good record of accuracy.

In addition to being accurate the work had to be completed rapidly if the laboratory was to give a satisfactory service to the trade, continued Mr. Anderson. A third way in which the work undertaken by the student and the scientist in the laboratory differed was in the way a stone was presented. Whereas the student received his stone in an unmounted state the laboratory was usually faced with the stone in a mount which was filthy dirty at the back.

Complexities apart, Mr. Anderson said that the apparatus used in the laboratory was very similar to that used by the student in the classroom. The use of binocular microscopes of the Greenough type which allowed the examiner to sit comfortably for long periods were an essential part of the equipment, he said. The main gemmological instruments, he said, the microscope, refractometer and spectroscope, were all in the laboratory as were the very essential accessories—ultra violet lamps, x-rays and a host of bits and pieces which were very valuable at times. He said that when they started gem testing in the early 1930's they tended to use the spectroscope a little shamefacedly but over the years the

laboratory staff had become more than convinced about its value as a gem testing instrument.

Mr. Anderson went on to say that a lot depended on first impressions, when a gemstone was first handed in at the laboratory. The first diagnosis by eye determined the line taken to "prove" the stone. Once the stone or pearl had been proved there was nothing more that could be done that would add to the knowledge alreadv gained and further time spent would only be wasted.

The second speaker was Alec Farn who used as his "text", The Laboratory; Precious Stone Trade, and Commerce, as extracted from the full title of the Laboratory. He said that of the three parts he considered commerce to be the most important. The Laboratory was a compact small team of five members and the work was constantly challenging and constantly changing and called for the co-operation of the talents of all five members to produce a result, which when published stood as a positive statement of fact. He said, putting one's signature to a certificate of a piece of jewellery which would probably be sold for thousands of pounds against the test certificate was a little different to the dealer or trader who just ventured an opinion about a piece.

The last speaker was Robert Webster who discussed giving evidence in courts of law as an expert and the pitfalls attached to doing this. He also referred to the Trade Descriptions Act and how it was being applied to the jewellery trade. Mr. Webster said he had given evidence in Court on many occasions. He pointed out that if one made up ones mind to assist in a matter there was always the possibility that ones presence would be required in Court as an expert witness. It was important to keep full records of all matters handled, as well as copies of reports issued. Often cases did not come to Court, but in many instances he had been consulted. In connection with the Trade Descriptions Act, Mr. Webster did not favour giving assistance to the Board of Trade because the Chamber's laboratory was a private one run for the jewellery trade and the Board had its own facilities for obtaining reports on identification.

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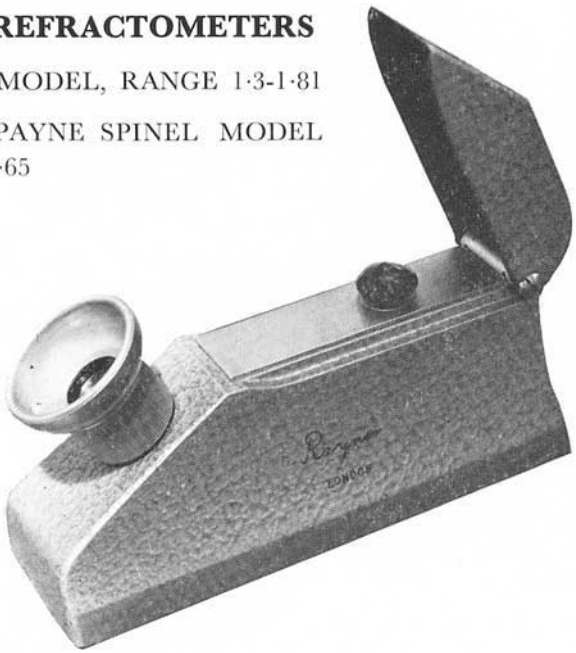

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and

PROCEEDINGS OF THE
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OF GREAT BRITAIN

GEMMOLOGICAL ASSOCIATION
OF GREAT BRITAIN
SAINT DUNSTAN'S HOUSE, CAREY LANE
LONDON, E.C.2

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THE JOURNAL OF GEMMOLOGY
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MODERN SYNTHETIC GEMSTONES

By ROBERT WEBSTER, F.G.A.

SINCE the end of the second world war there has been a spate of synthetic materials grown as crystals which have been produced either for gemstones in their own right, or as the result of experiments in the fields of electronics and space-age programmes. Some of these, too, have been found useful as material for gemstones for personal decoration, and some, still unused, have such a potential. Some of these crystals have no counterpart in nature.

The properties of many of these stones are known, but the literature is scattered throughout many different publications and this article is an attempt to correlate such information, and to incorporate some of the author's findings, so that the characteristics of these stones may be more readily available to the gemmologist.

There are many methods of growing single crystals, such as the well-known Verneuil flame-fusion method, the hydrothermal method, and those using various types of flux-fusion, one of which is the Czochralski "pulling" technique which is commonly used for the production of a number of these crystals at the present time. These methods will not be discussed at length in this article as this aspect has been well covered by Dr. Kurt Nassau of Bell Telephones of America, and by Dr. E. A. D. White of the General Electric Company and Imperial College, London; nor will the synthetic corundums and spinels produced before the war by the Verneuil process, which are well-known as jewellery stones, be covered in this survey, which will include only those stones manufactured since 1946. For ease of reference the stones will be referred to in alphabetical order, either by their chemical name or by their species name, whichever is the better known.

BARIUM TITANATE ($BaTiO_3$)

This titanate has been reported to have been grown as single crystals, but so far has not been met with as a gemstone, although from its properties there seems to be no reason why it should not be so used. Cubic in crystallization, the crystals probably have a hardness of about 6 to 6½ on Mohs' scale. The chemical composition is similar to that of strontium titanate—the well-known "fabulite"—in that the strontium is replaced by the heavier alkaline earth metal barium. The refractive index is, like "fabulite", quite near to that of diamond, and is 2·40, while the density of 5·90 is higher than that of "fabulite".

BERYL ($Be_3Al_2(SiO_3)_6$)

The synthesis of emerald was academically accomplished before 1939, but is was not until the end of the war that the synthesis of this valuable gemstone by Carroll F. Chatham of San Francisco, California, made the synthetic emerald a commercial proposition.

Aided by the investigations carried out on the pre-war synthetically produced crystals, particularly those grown by R. Nacken, and the production at I. G. Farbenindustrie by H. Espig and E. Jaeger at the chemical works at Bitterfeld, now in East Germany, it was found that the Chatham production conformed in character with the earlier syntheses and presented no great problem to the gemmologist.

The factors which gave this distinction from natural emeralds were their low density, and their low refractive indices and bi-refringence. These are illustrated in the table below, which gives the constants for the synthetic emeralds grown by Carroll Chatham and natural emeralds from various sources.

Locality	*R.I's*	*Biref.*	*Density*
Synthetic (Chatham)	1·564-1·561	0·003	2·65
Colombia (Muzo)	1·584-1·578	0·006	2·71
Colombia (Chivor)	1·577-1·571	0·006	2·69
Russia (Siberia)	1·588-1.581	0·007	2·74
South Africa	1·593-1·586	0·007	2·75
Brazil	1·571-1·566	0·005	2·69
India	1·590-1·583	0·007	2·74
Rhodesia (Sandawana)	1·593-1·586	0·007	2·76
Pakistan	1·600-1·593	0·007	2·76
Austria (Habachtal)	1·589-1·582	0·007	2·74
Norway (Eidsvold)	1·591-1·584	0·007	2·75

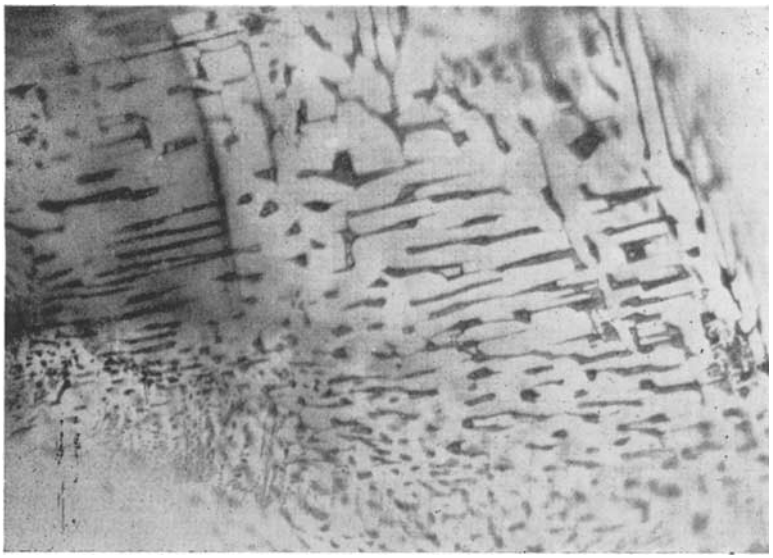

Structure of feathers in a Chatham synthetic emerald.

Typical feathers in a Chatham synthetic emerald.

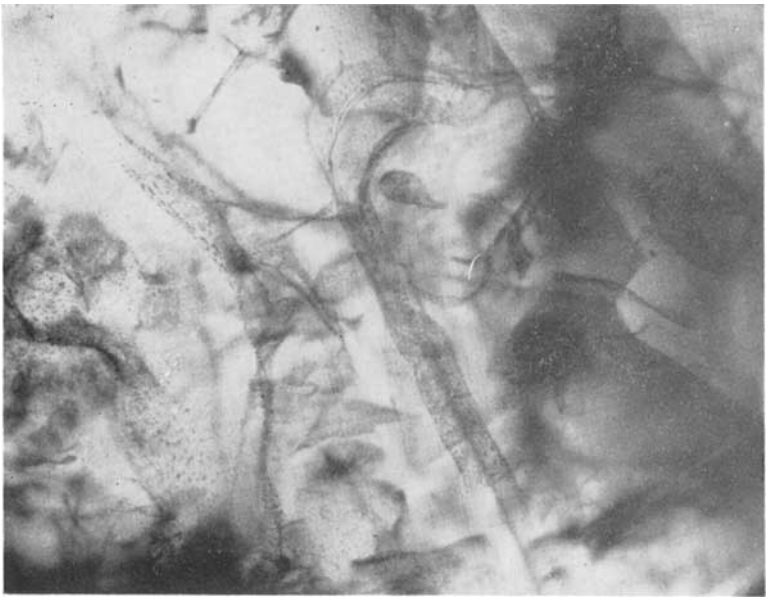

Feathers in a Chatham synthetic emerald.

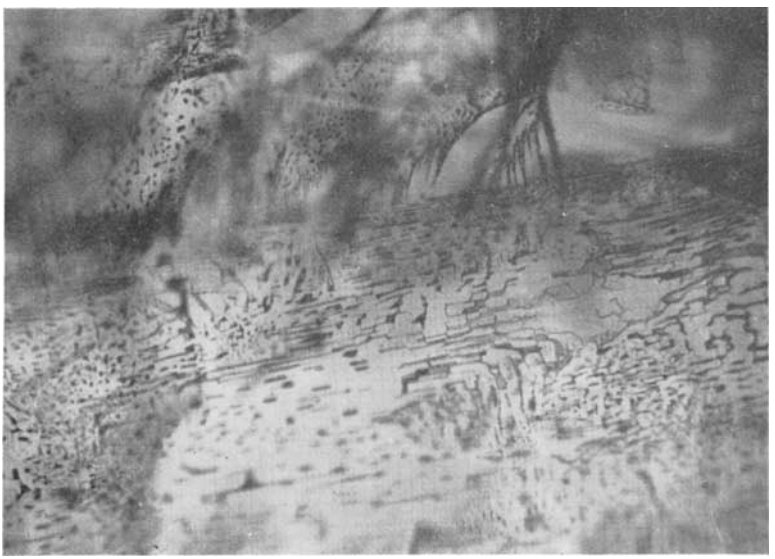

Feathers in a Chatham synthetic emerald.

Further confirmation is given by the strong red shown by the stones when they are viewed through a Chelsea colour filter, or by "crossed filters", and by the strength of the red glow under ultra-violet light. The absorption spectrum is usually more pronounced in the synthetic stones than in the natural, but what is most conclusive are the typical "veil-like" feathers, often two-phased, which are seen as inclusions in the stones. Synthetic emeralds are usually more transparent to ultra-violet light than are the natural emeralds. It is these criteria which identifies the synthetic emerald from those formed by nature. At least this was true up to 1968.

During 1960 there was marketed a new type of "synthetic emerald", the synthetic emerald-coated beryl produced by J. Lechleitner, of Innsbruck, Austria. These Lechleitner stones were first marketed under the name "emerita", but this was later changed to "symerald". They are produced by depositing, by means of a hydrothermal method using an autoclave, an overgrowth of synthetic emerald onto an already preformed (that is a cut stone) "seed" of pale emerald, or more usually pale aquamarine or pale yellow beryl. After a sufficiently thick deposit has been allowed to grow on to the cut stone "seed", the layer being less than half a millimeter in thick-

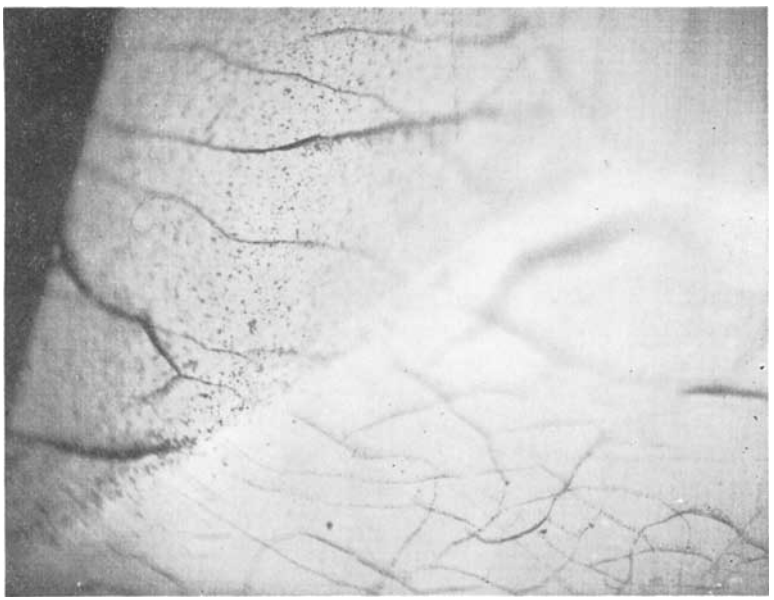

Crack-like reticulation of feathers in an emerald-coated beryl made by the firm of Lechleitner.

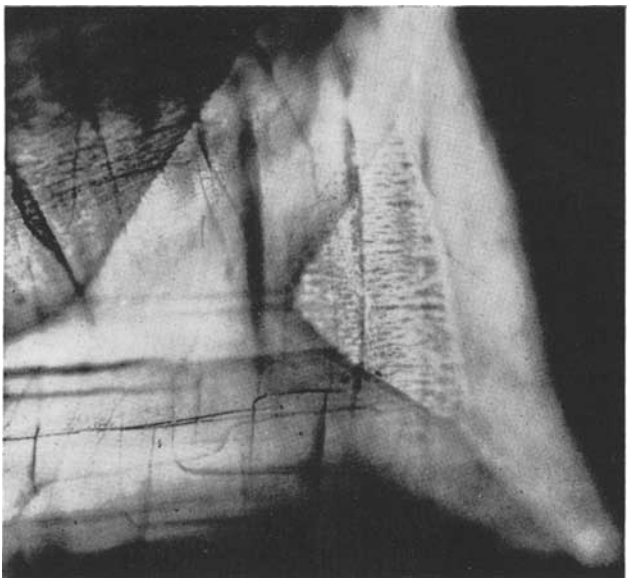

Synthetic emerald-coated beryl, showing an unpolished facet and the reticulation of crack-like feathers.

ness, the stone is removed from the autoclave and the facets finished by giving them a light polishing, although quite often one small facet at the back of the stone is left without a polish and this will assist in identifying the nature of the stone.

The density of these Lechleitner synthetic-emerald-coated beryls is about 2·7 and the refractive indices are near 1·581-1·575, values near to those for natural emeralds. Such coated beryls can be readily detected by the net of inclusions usually seen on the side facets; by the inclusions, which are usually those of aquamarine, such as "rain", and by the rim of red fluorescent light which may be seen when the stone is suitably irradiated, *i.e.* by "crossed filters" or by ultra-violet light In 1964 Lechleitner produced variations of this "synthetic-emerald-coated beryl". These stones were started from a seed plate of natural or synthetic colourless beryl upon which was grown a plating of synthetic emerald and the stone subsequently "enlarged" by growing on synthetic colourless beryl—presumably it is easier to grow synthetic colourless beryl than synthetic emerald. Cut stones of this make have not been examined by the writer, but Eppler states that the "sandwich" structure is only exhibited when

the stones are viewed through the side and when immersed in a suitable liquid of similar refractive index.

This is not the end of the story of the Lechleitner beryls, for a multiple "sandwich" consisting of a central seed plate of synthetic emerald grown upon a suitable plate of natural (or synthetic) beryl has deposited upon it a number of layers of synthetic material produced hydrothermally. Seemingly the stone has to be placed in the autoclave a number of times before the final result is produced. No stones of this type have been examined, or, as far as the writer knows, have ever been seen in this country, although the simple single synthetic-emerald-coated beryls have been encountered mounted in jewellery.

During 1962 there was a report of another synthesis of emerald. This was a modified flux-fusion method using V_2O_3 as the flux, and a "seed" crystal to initiate the process. The writer has two specimens alleged to be of this type of synthesis, which was carried out by R. C. Linares and others. However, some doubt has been felt as to whether the specimens are synthetic or not and there is always the possibility that they are natural crystals which had by mischance become mixed in with the actual synthetic specimens. The method can have had no commercial success or it would have been continued.

The Chatham synthetic emeralds, which were at first called "cultured emeralds" until Carroll Chatham was stopped from using the name by the American Federal Trade Commission, who, however, allowed the name "created emeralds" to be used, held the market until 1964, when both Pierre Gilson of France and Zerfass of Germany produced and marketed their synthetic emeralds. These new synthetic emeralds, except for the earlier production of Gilson, which glowed with an orange and not a crimson light when bathed in ultra-violet rays, had similar characteristics to those of the Chatham synthesis. The earlier Gilson stones had a yellowish-green colour which was quite pleasing but later syntheses are more of a bluish-green colour and are as important commercially as the older established Chatham synthetic emeralds. It is the more recent Gilson production which is important, for certain changes in the synthesis have been made. These will be discussed later. The

Feathers in a Gilson (French) synthetic emerald.

Feathers in a Zerfass (German) synthetic emerald.

Zerfass synthesis does not seem to be so important and few of the stones are seen on the market.

A year later, in 1965, the American firm Linde Air Products reported a new production of synthetic emerald, this time by a hydrothermal process, for the Chatham, Zerfass and Gilson are flux-melt syntheses, although Gilson was said to have started by using a hydrothermal system. The marketing of the Linde stones is confined to their own consortium, the stones not being sold to outside gem dealers but mounted into jewellery at their own factory in Southern California. Emeralds from this synthesis do not seem to have reached England and the few that have been seen in this country were some of the earlier experimental crystals and cut stones. The literature gives the constants for Linde synthetic emeralds as $\omega = 1{\cdot}572$, $\varepsilon = 1{\cdot}567$, with a birefringence of 0·005, and the density of the stones to be near 2·67 or even higher. The inclusions of Linde stones were seen to be veil-like inclusions, so commonly seen in other synthetic emeralds, and also nail-like cavities with the head of the "nail" formed by a single, or a group of, phenacite crystals. F. H.

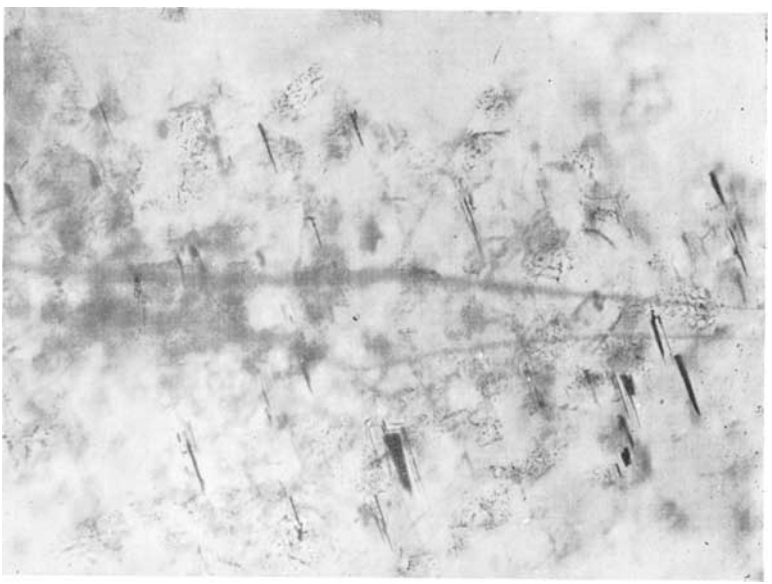

Feathers and "nail-like" inclusions in a Linde hydrothermal synthetic emerald.

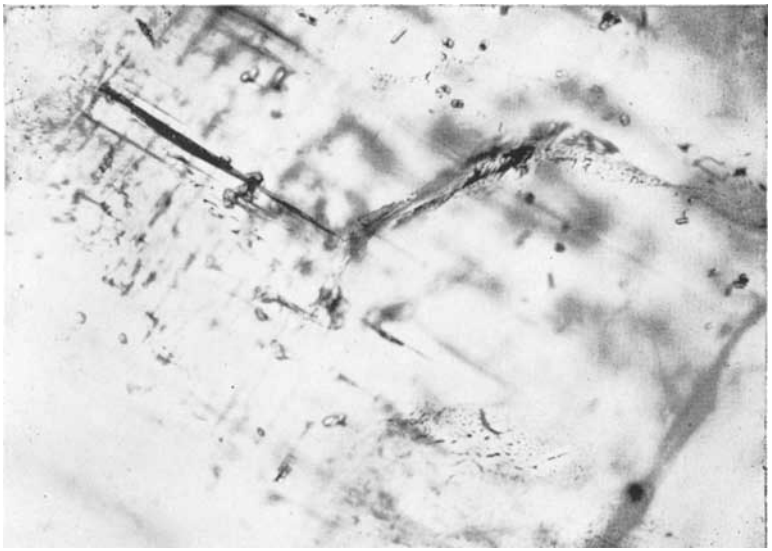

Early Linde synthetic emerald showing feathers and phenacite crystals.

Pough refers to "brush-like" stroke inclusions rather like fine parallel canals. What are, however, the most striking observations made on this type of synthetic material are the strong red light shown by the stone when it is bathed in a fairly intense beam of white light, and also the strong red fluorescence shown by the stone when viewed through a Chelsea colour-filter or "crossed filters" or under ultra-violet light.

Some Linde hydrothermal emeralds examined recently by workers in the United States of America have refractive indices of $\omega = 1{\cdot}578$ and $\varepsilon = 1{\cdot}571$, with a birefringence of 0·007. The density was found to be 2·678. These stones showed much less fluorescence under ultra-violet light, although the red appearance when the stones were in a beam of white light was still a characteristic feature, and so were the nail-like cavities capped by phenacite crystals, as well as the veil-like feathers which are so common in synthetic emeralds.

Recently a few emeralds have been encountered which do not luminesce red under ultra-violet light and have densities and refrac-

tive indices similar to those of natural emeralds, but which, from their inclusions, are undoubtedly synthetic. Where these emeralds emanate from is not known for sure, but there are certainly other firms, and even individuals, growing synthetic emeralds. One stone recently examined had refractive indices of 1·575 and 1·570 giving a birefringence of 0·005, or perhaps 0·006. The stone sank in a mixture of bromoform and monobromonaphthalene, made up just to float rock crystal, and showed a red fluorescent colour when viewed under a Chelsea colour filter and when irradiated with ultra-violet light. The inclusions seen in the stone consisted of the typical veil-like feathers with a plane of oblong-shaped inclusions.

Gilson, too, has openly said that he has changed his formula to include iron in his synthetic emeralds. This inclusion of iron in the chemistry "poisons" the luminescence, hence the stones do not respond to ultra-violet light, nor to the "crossed filter" technique, and it may also produce iron line at 4270A in the deep blue of the absorption spectrum.

The detection of synthetic emeralds is tending to become more difficult, particularly as some of the "freak" emeralds encountered recently may well be from experiments in the production of crystals for solid state physics, and here it may be mentioned that synthetic emeralds have been produced by the Verneuil flame-fusion technique and also by high temperature/high pressure methods. These experiments do not appear to have borne fruit, but there is still the danger that some of these out-of-the-way crystal growths may come into the hands of the gemmologist, who perforce would know nothing about the characters of such stones.

The story of the synthetic beryls must not be concluded without mention being made of the synthetic beryls "doped" with trace elements other than chromium. Crystals have been grown, usually by a hydrothermal method, which have been doped with vanadium, producing green stones not far different from emerald itself, manganese giving a greyish-green, cobalt giving, not a blue, but a pinkish-brown colour, and nickel, which produces a pale green stone. These were first reported by Russian workers about 1964 and further experiments on these lines have been carried out in Australia, where it was found that iron produced a deep blue beryl and a light blue colour was produced by using copper. Specimens of these beryls have not as yet been made available for examination in this country.

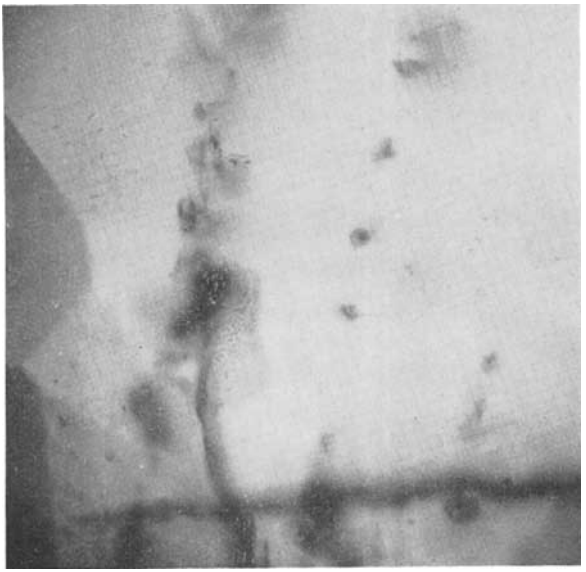

Inclusions seen in a synthetic emerald.
(Make unknown).

Feathers and rectangular-shaped inclusions seen in a synthetic emerald.
(Make unknown).

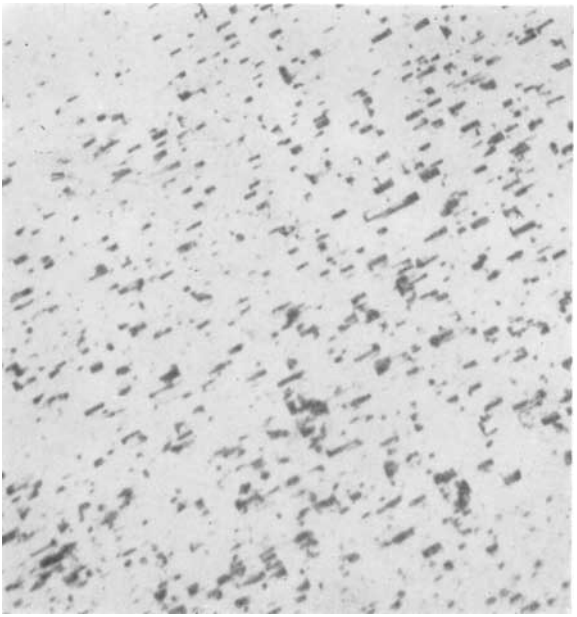

Block-like cavities in a synthetic emerald.
(Make unknown).

Unusual chain of inclusions and fine straight lines (canals?) seen in a recent synthetic emerald.
(Make unknown).

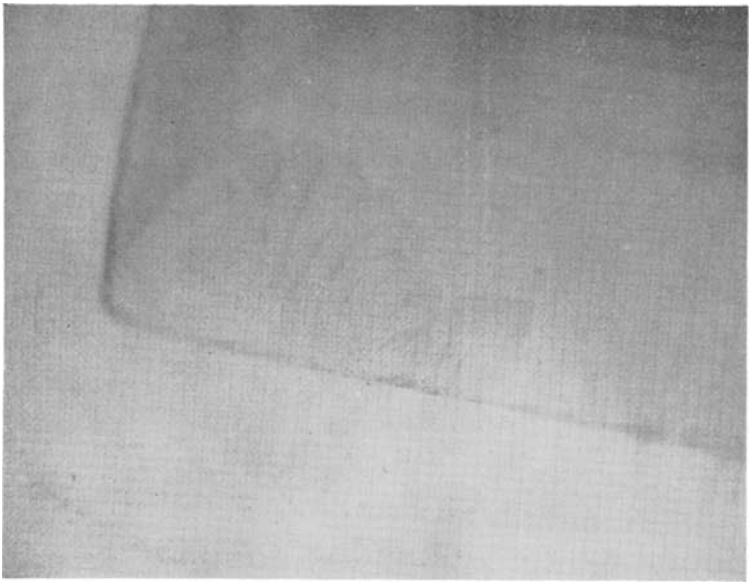

Fan-shaped feathers in low relief with straight zonal lines seen in a recent synthetic emerald.
(Make unknown).

Fan-shaped feathers in low relief seen in a recent synthetic emerald.
(Make unknown).

Boron Carbide (B_4C)

Like the silicon carbide better known as carborundum, boron carbide is a'so produced primarily as an abrasive and sells under the name "norbide". No single crystals of this material have been reported, but if such crystals could be grown, and there seems to be no reason why they could not, they would certainly be a potential gemstone. The density of the material is said to be 2·51.

Bromellite (BeO)

Colourless crystals of beryllia, a hexagonal mineral which in nature is called bromellite, have been reported to have been grown synthetically by a flux-diffusion method. With a hardness said to be 9 on Mohs' scale the stone has the qualification to enter the realm of synthetic gemstones. From details given by American gemmologists who have examined a specimen of the synthetic bromellite, the density approximates to 3·00 to 3·02, and the refractive indices appear to be $\omega = 1{\cdot}720$ and $\varepsilon = 1{\cdot}735$, the birefringence being 0·015 with positive optical sign. Under the long-wave ultra-violet lamp the specimen examined showed a faint orange glow. Against the advantages there is a positive disadvantage in that on grinding the stone during the fashioning process the pulverized dust produced is toxic. This may preclude the use of this material as a gemstone.

Calcium Titanate ($CaTiO_3$)

Orthorhombic in crystallization, although near cubic, calcium titanate has been made synthetically. In chemical composition the material is similar to "fabulite", in which the calcium is replaced by strontium. It is another stone which may well take its place as a gemstone. The density is reported to be 4·05 and the mean refractive index 2·40. In hardness it is probably similar to "fabulite".

Chrysoberyl ($BeAL_2O_4$)

Small crystals of the alexandrite variety of the species chrysoberyl have been grown synthetically, but there is no report extant that they have been grown sufficiently large for gems to be cut from them.

CORUNDUM (Al_2O_3)

Apart from the production by the Linde Company of synthetic star-corundums during 1947, there have been a number of syntheses of ruby both by flux-melt and by hydrothermal methods, but so-far these stones have not ousted the more conventional synthetic production by the Verneuil flame-fusion technique. This may well be due to the higher cost of production using these newer methods for very little gain in appearance. Such stones have, however, been marketed by Carroll F. Chatham, by the Bell Telephone Company (it is doubtful whether the production has been marketed as gems), and by Ardon Associates, who market their production as Kashan flux-grown rubies.

Admittedly the detection of these new types of synthetic rubies presents greater difficulty than is encountered with the Verneuil flame-fusion synthetics. In the hydrothermal types inspection of the internal features may show traces of the "seed" used to start the process, and the stones will certainly show rather typical feathers

Inclusions in an early hydrothermal synthetic ruby.

somewhat reminiscent of those seen in synthetic emerald; and in he flux-grown types similar feathers may often be seen. In the Kashan type of flux-fusion ruby there is seen a typical design of a dot-and-dash pattern of inclusions and these are sometimes like droplets. It has been verbally reported to the writer that the more recent production of Kashan rubies do not show these signs and any inclusions seen are natural-like needles. So far as is known none of these Kashan synthetic rubies have been seen in Britain. These newer synthetic rubies show a greater transparency to ultra-violet light, and if suitable apparatus is available the usually persistent phosphorescence after x-ray bombardment is indicative. In all cases the density and refractive indices are similar to those of natural stones of the corundum species. Finally, no striking advance seems to have been made in the synthesis of sapphires, although one American concern has experimented with the use of ground-up Montana sapphires for the feed powder for the blowpipe used in the Verneuil technique.

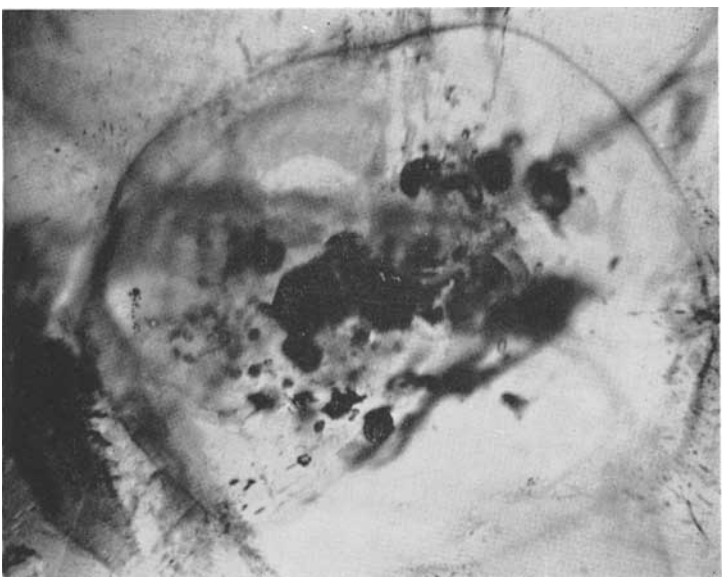

The "seed" crystal in a hydrothermal synthetic ruby.

DIAMOND (C)

The highlight of the period under review was the synthesis of diamond by the General Electric Company of America in 1955. Other firms in other countries produced similar diamonds about the same time or soon after. It was an academic and technological breakthrough but had no gem significance. Production did, however, become commercially important as the minute crystals produced had a use for industrial purposes and De Beers commenced industrial production both in South Africa and in Eire. So did other countries and it is believed that there is a production in the Soviet Union, but what goes on behind the Iron Curtain is to some extent a closed book. On the 28th of May 1970 The General Electric Company of the United States of America released the

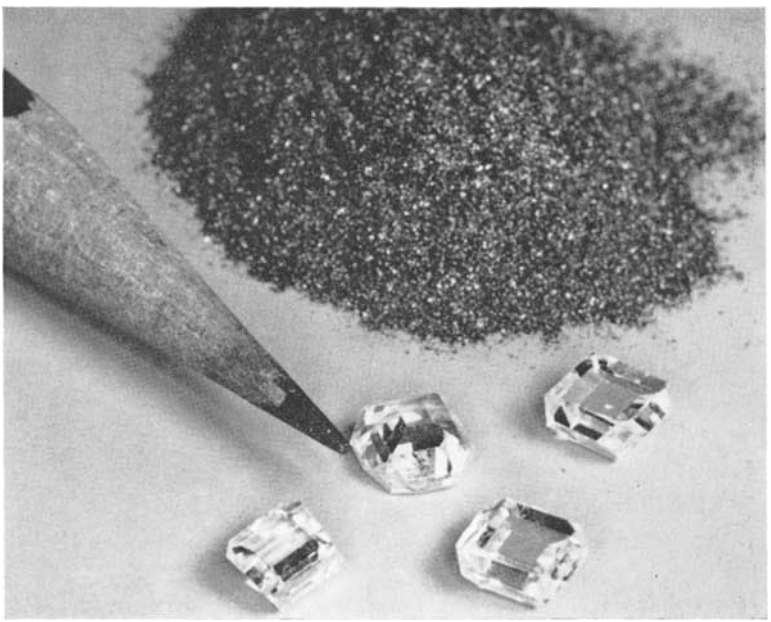

Photo No. RDC-16, 183-9; 16, 183-2

These gem diamonds were created by scientists at the General Electric Research and Development Center, Schenectady, New York. The larger crystals are approximately one carat in weight. Although these diamonds have undergone slight polishing, they have not been cut and retain the shape in which they were "grown" in a special apparatus for subjecting graphite (the pile of black powder) to extreme pressures and temperatures.

Photo: G.E.C. (U.S.A.)

information that they had produced gem diamonds of a carat or more in size. The report was careful to state, however, that the cost of producing such diamonds was much greater than the cost of similar sized mined diamonds. One cannot be complacent, for with the advances in science to-day there must surely come a time when synthetic gem diamonds become a commercial reality. The new materials can be produced in various colours and of those examined by the Gemological Institute of America, the near-colourless and blue stones were highly electrically conductive, highly fluorescent and phosphorescent. A yellow-coloured stone was not conductive. Further investigations are to be made by the G.I.A.

Fluorite (CaF_2)

Synthetic fluorite has been grown for scientific purposes, but the material with its low hardness and low indices of refraction is not a promising material for a gemstone. Some cut stones may have been cut experimentally and for collectors' items. Most of these fluorites are "doped" with various impurities which give, apart from physical and optical differences, such as luminescence, various attractive colours to the crystals. In 1963 a "boule" (?) of vivid green colour was identified as synthetic green fluorspar from its refractive index of 1·45. The density was given as 2·31, but this may well be a misprint for 3·21. The stone exhibited a bright blue

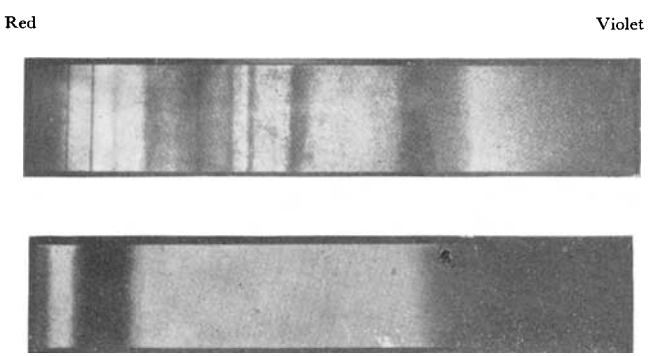

Spectra of synthetic fluorite.
Top. *Deep red colour.*
Bottom. *Green colour.*

fluorescence. However, a specimen of green fluorite examined by the writer gave an index of refraction of 1·435, a density of 3·186 and the stone showed an absorption spectrum with an absorption band in the deep red, a fine band at about 6900A and an an absorption from 6300A to 5800A, with further weak bands at about 5300A and 4900A. There was, in the case of this stone, no perceptible luminescence under either wavelengths of ultra-violet light and only a weak yellowish glow with no phosphorescence under x-ray bombardment. A colourless specimen examined had a refractive index of 1·44 and a density of 3·197. There was no significant absorption spectrum seen, but under ultra-violet light there was a green fluorescence which was more yellowish under the long-wave lamp. No phosphorescence was observed. Under x-rays the green fluorescence was brilliant and there was an exceptionally long phosphorescence of the same colour. Examination of the fluorescence spectrum, which was the same under all wavelengths, showed a discrete spectrum of strong bands in the red and orange and yellow and green with weaker fluorescent bands further into the green. It is suggested that the crystal may have been "doped" with indium. A red crystal with refractive index of 1·44 and a density of 3·181 showed a rare-earth spectrum which had a sharp line at 5650A and a range of nearly equally spaced lines of differing intensities from the yellow to the end of the green. No luminescence was observed in this crystal except for a weak mauve glow induced by x-rays. It may with some reason be suggested that uranium could be the, or one of the, "doping" elements here. Another pale pinkish crystal showed a typical "didymium spectrum" and was most probably "doped" with neodymium.

Gahnite ($ZnAl_2O_4$)

The cubic mineral gahnite is another crystal which has been successfully synthesized, but of its properties little has been so far reported. No specimen has been seen by the writer and the values quoted here have been taken from Dana's Textbook of Mineralogy for the natural gahnite and are as follows—a hardness of 7½ to 8, a refractive index of 1·82 and a density varying from 4·00 to 4·6; however, it may be presumed that the synthetic material would have been the higher values.

Garnet-Type Synthetic Stones ($X_3Al_5O_{12}$)

The past decade has produced a number of artificially grown crystals which have a garnet-like structure, although they contain no silica. Such crystals are grown by the flux-melt method, or more often by the Czochralski "pulling" technique.

There are a number of these synthetic garnets all of which may be said to conform to the general formula $X_3Al_5O_{12}$, and a list of such crystals is given in the table below:—

Element	*Colour*	*Density*	*Ref. index*
Yttrium	colourless	4·57	1·832
Yttrium+	green	4·60	1·834
Terbium	pale yellow	6·06	1·873
Dysprosium	yellow-green	6·20	1·85
Holmium	golden yellow	6·30	1·863
Erbium	yellow-pink	6·43	1·853
Thulium	pale green	6·48	1·854
Ytterbium	pale yellow	6·62	1·848
Lutecium	pale yellow	6·69	1·842

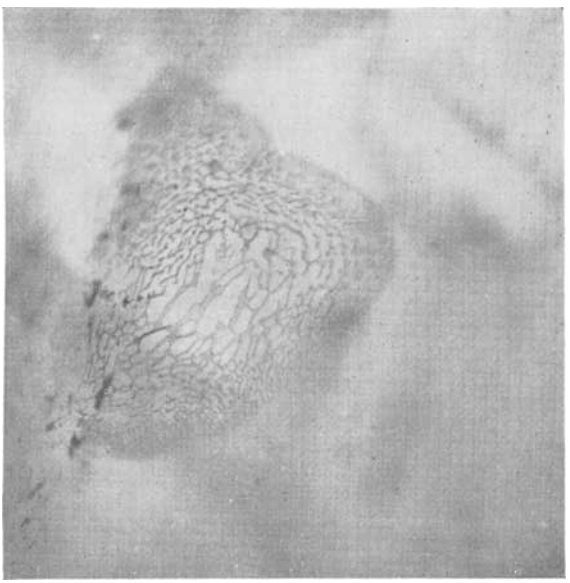

Feather in a flux-melt yttrium-aluminium garnet.

The crystallization is cubic, hence the stones are isotropic and their hardness is about 8 on Mohs' scale.

The most important of these from a gem point of view are the yttrium-aluminium garnets, which are usually known by the symbol YAG. The stones are colourless unless "doped", and it is the colourless stones which have the most interest as they are now being marketed as cut stones for the gem trade, where they are known under the name "diamonair". By the addition of trace elements various coloured crystals may be produced. Chromium will produce green-coloured stones, and some of these chromium-doped YAG's have masqueraded as demantoid garnets. Cobalt will give a blue colour, titanium a yellow and manganese a red colour to these garnets. Some yttrium-aluminium garnets are "doped" with praseodymium giving a pale green colour, or by neodymium which produces a lilac-coloured crystal.

Examination of two colourless yttrium-aluminium garnets (sometimes called diamonair), one of American manufacture and one of English origin, showed the density to be 4·57. The American specimen showed a pronounced yellow fluorescence under long-wave ultra-violet light and a similar but weaker effect under the short-wave lamp. Under x-rays the glow was a bright mauve. The luminescent behaviour of the English stone, although similar, was much weaker. This luminescence, when examined with a hand-spectroscope, was found to be discrete with a strong band in the yellow. These diamonair stones do not have the "fire" of diamond, for the dispersion is only 0·028.

The green stones have been found to vary considerably in their absorption spectra. This may vary from a normal type of chromium spectrum to a composite one composed of the chromium lines in conjunction with the lines of a typical rare-earth spectrum; and one stone showed quite an anomalous spectrum. These green-coloured YAGs show a pronounced red under the Chelsea colour-filter or by "crossed filters", and this, with the obvious spectrum, distinguishes these stones from demantoid garnet.

These inclusions observed in yttrium-aluminium garnets seem to vary with the method of growth. Those grown by the flux-melt

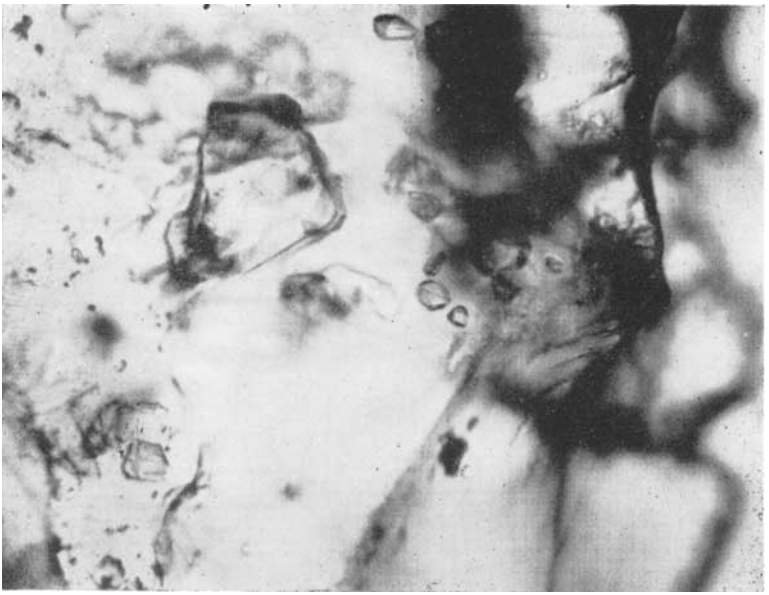

Crystal inclusions in an early flux-melt yttrium-aluminium garnet.

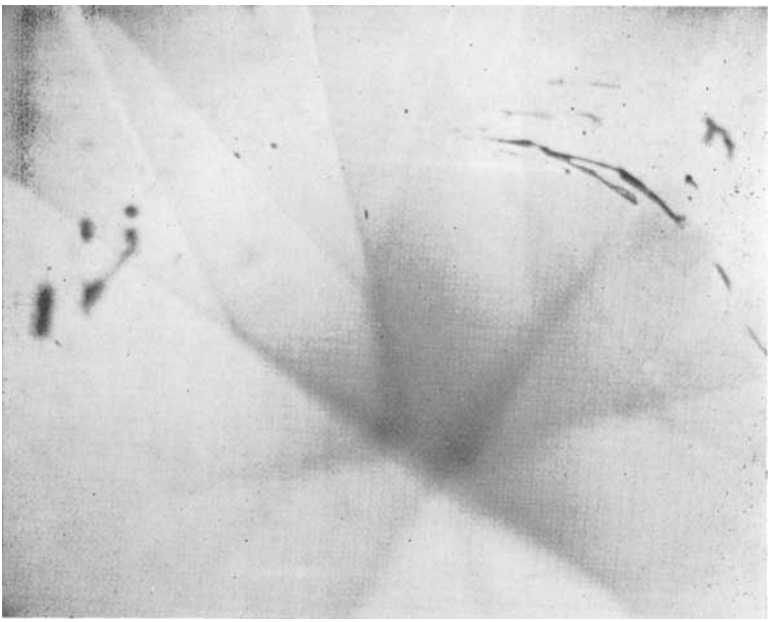

Extended bubble-like inclusions in circular arrangement seen in a "stone" cut from a "pulled" crystal of yttrium-aluminium garnet.

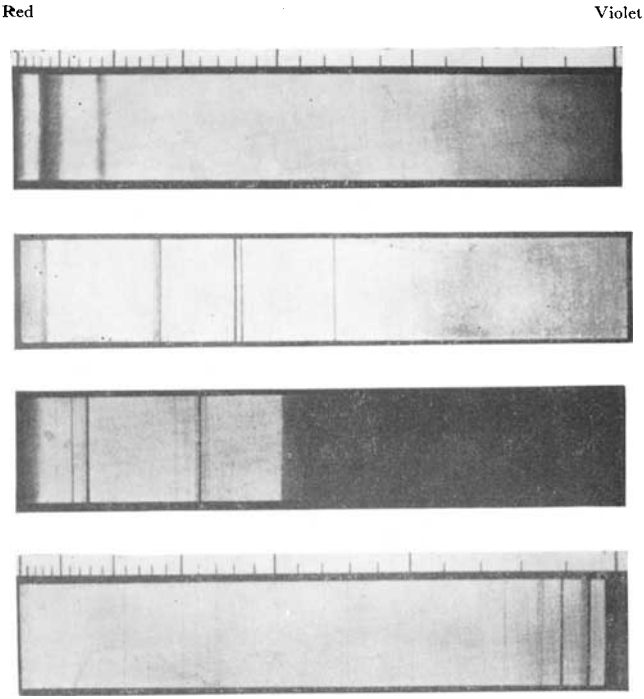

Absorption spectra of synthetic garnet-structured crystals.
TOP. *Light blue-green YAG.*
Green YAG.
Yellow europium garnet.
BOTTOM. *Light yellow YAG.*

method appear to contain natural-looking feathers and crystals, while those grown by the "pulling" technique often show twisted drop-like inclusions and sometimes angular black square or triangular crystals, or the black particles may show no regular shape. Some chrome-rich green stones may show "treacle".

When the yttrium of the composition is replaced by other elements, the colours and particularly the physical and optical constants may vary greatly, as is shown in the table given earlier. In all cases where rare-earth elements are involved, either as a major constituent or as a "doping" agent, the absorption spectra are the most striking characteristics, which differ greatly with different rare-earths. Some of these spectra are depicted in the

illustrations, which are taken mainly from those drawn by Robert Crowningshield of New York, but reversed left to right in accordance with British convention.

The gallium-aluminium and yttrium-gallium garnets are other types which have been made, but again these do not appear to have entered the gem field. However, a pink coloured sample of rough material examined in the United States of America showed the characteristically intense and striking absorption spectrum so common with rare-earth "doped" synthetic crystals.

The so-called YIGs, the yttrium-iron garnets, which are black in colour and uninteresting as potential gemstones, are grown for the sake of their magnetic properties. Such stones are strongly magnetic but do not exh bit e'ectro-conductivity. They have a density near 6. Recently there has come from Rhodesia a synthetic material with a metallic lustre, which in thin slivers is seen to have a deep red colour. The density of the pieces examined was found to be near 4·20 and the absorption spectrum to be that of almandine garnet, and this was confirmed by x-ray diffraction which showed the structure to be almandine garnet. The stones were found to be non-magnetic and do not conduct electricity. They may be said to be an extremely rich iron-aluminium garnet and have been called "hematite-garnet". Cabochon stones cut from this material are said to show an attractive iridescence, but no cut stones have yet been examined.

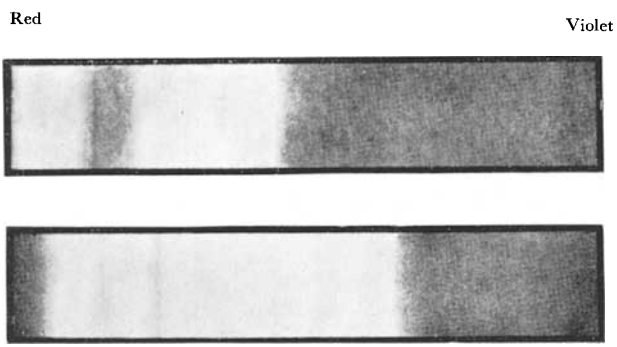

Differences in absorption spectra for green yttrium-aluminium garnets.
TOP. *Intense green-coloured YAG showing an intense red through the Chelsea colour-filter.*
BOTTOM. *Lighter bluish-green coloured YAG which showed no red through the Chelsea colour filter.*

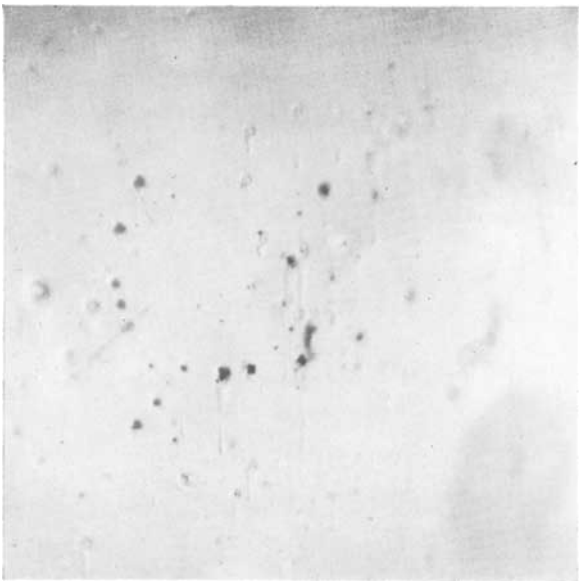

Inclusions in, probably, a "pulled" crystal of green yttrium-aluminium garnet.

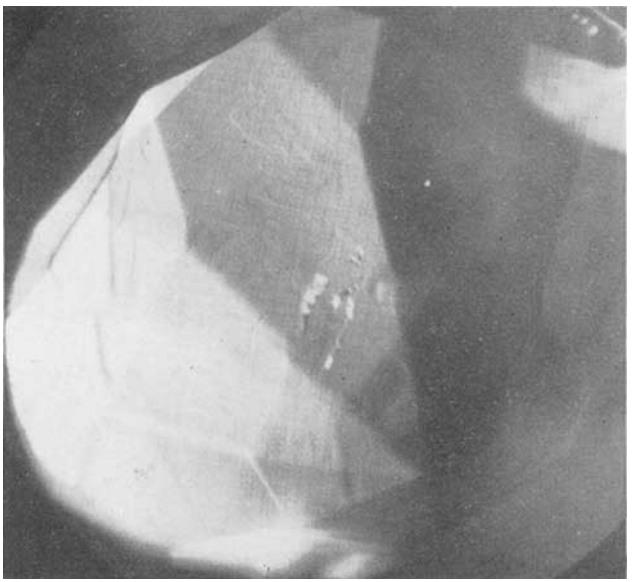

Inclusions and "treacle" in a green yttrium-aluminium garnet.

GREENOCKITE (CdS)

The bright yellow cadmium-sulphide mineral was first described in 1840, presumably from material found at Bishopston in Renfrewshire, and received its name from Lord Greenock who later became the Earl of Cathcart. The natural mineral does not appear to have been cut as a gemstone, for the hardness of approximately $3\frac{1}{2}$ on Mohs' scale is too low for such a use, except perhaps for the type impregnating smithsonite, which is found in Marion Co., Arkansas, U.S.A., and from which material cabochon stones could well be cut.

The constants for the mineral, which crystallizes as hemimorphic crystals of the hexagonal system, are approximately 4·9 for the density and the refractive indices are given as $\omega = 2{\cdot}505$ and $\varepsilon = 2{\cdot}529$, thus having a bi-refringence of 0·024 which is uniaxial and positive in sign. There is a distinct pyramidal cleavage and an imperfect basal one.

It is the synthetically produced greenockite which interests us in this survey, for greenockite is grown as single crystals, usually by the vapour-phase method, which can usually be of fair size, and these have been cut for collectors.

Two pieces of synthetic greenockite have been studied. No measurements of the refractive indices were carried out and it may be assumed that they would agree with those reported for natural greenockite. The density was found to be 4·825 and 4·829. There was no perceptible dichroism and the absorption spectrum showed a nearly complete absorption below 5250A, which appears to be the edge of a sharp band forming the beginning of the absorption. The luminescence shown by these specimens was under long-wave ultra-violet light a very weak orange glow, practically inert under the short-wave lamp, and a strong orange glow, but no phosphorescence, under x-rays. It must be remembered, however, that all synthetically produced crystals often have trace elements, as they are "doped" for special purposes for science and industry, and such "doping" may considerably alter the luminescence response. Both the specimens of greenockite examined exhibited electro-conductivity, with one specimen showing the effect much more strongly than the other.

KTN (niobium-doped potassium tantalate)

At a gemmological conference held in Barcelona a specimen of this colourless synthetic compound was exhibited and the suggestion was made that it would provide a satisfactory diamond simulant. So far KTN has not entered the realm of commercial gem synthetics, and whether it ever will is a moot point. The material is said to have a hardness a little greater than 6 on Mohs' scale, a refractive index of 2·27 and a density of 6·43. The writer has not as yet seen a specimen of KTN in order to examine in fuller detail this synthetic stone.

LITHIUM NIOBATE (Lithium metaniobate) ($LiNbO_3$)

Marketed under the name "linobate", this synthetic material has no counterpart in nature. It is grown as single crystals, usually by the "pulling" method, as colourless material, which, however, can be "doped" with trace elements to give other colours. The following table gives those credibly reported:—

Green	CrO_3
Red	Fe_2O_3 as $FeTiO_3$
Blue or Violet	Co_2O_3 as $CoTiO_3$
Yellow	MnO_2 as $MnTiO_3$
Yellow	NiO as $NiTiO_3$

According to literature lithium niobate crystallizes in the trigonal system, has a hardness of about 5½ on Mohs' scale, a density of 4·64 and refractive indices of 2·21-2·30 giving a birefringence of 0·090, a double refraction which is sufficient to make the cut stones appear somewhat "muzzy". The dispersion for the B to G interval is 0·120, a value which is nearly three times that for diamond.

Examination of some specimens of lithium niobate gave the following results for density:—

Colourless	(0·6280 grams)	4·643
Colourless	(3·3969 grams)	4·644
Yellow	(4·1953 grams)	4·644
Brown	(2·8740 grams)	4·642

Coloured specimens showed distinct dichroism, but there was no characteristic absorption spectrum observed except for perhaps a very weak band in the blue part of the spectrum, nor was any

luminescence observed under ultra-violet light, or under x-rays, to which radiation the stones, like zircon and strontium titanate, are opaque. There was no electroconductivity shown by the linobates.

MAGNETITE ($FeO.Fe_2O_3$)

Included in this article solely for the sake of completeness, this mineral, a black oxide of iron, has been made artificially. No specimens of the synthetically produced material have been examined by the writer, but the literature gives for the natural mineral a density of 5·17, and the mineral is magnetic, hence the name.

MAGNETOPLUMBITE ($2RO.3R_2O_3$)

Another black mineral which has been synthetically produced is mentioned mainly because it has previously been mentioned in gem literature. Magnetoplumbite is an oxide of iron, manganese and lead and crystallizes in the hexagonal system. The density of the natural mineral is given as 5·517, but a determination made on a specimen of synthetically produced material was found to be 5·76. The streak is dark brown and the mineral is strongly magnetic.

PERICLASE (MgO)

The magnesium oxide mineral called periclase is another mineral which has been produced synthetically. The mineral, usually colourless, has cubic crystallization and from investigations by international workers the hardness has been shown to be about 5 on Mohs' scale, with a refractive index of 1·737 and a density of 3·55 to 3·60. Under long-wave ultra-violet light a specimen examined showed a weak whitish glow, which was, maybe, stronger under the short-wave lamp. X-rays produced a dull purplish-red fluorescence without any discernible phosphorescence. Unexpectedly there was a dull red colour seen when the specimen was viewed between "crossed-filters". Some Australian workers have observed weak absorption bands in periclase at 5400, 4850, 4670 and a cut-off at 4160A. The only specimen that the writer has examined seemed to show traces of such absorption bands, but they were too weak to have any great diagnostic value. American workers have mentioned observing square platelet inclusions in an American production of periclase. No electro-conductivity was found in the specimen tested. Periclase synthetically grown has been marketed as a gemstone under the name "lavernite".

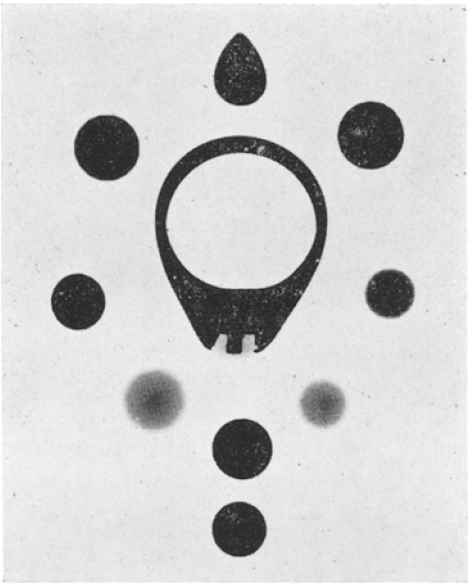

RADIOGRAPH SHOWING THE TRANSPARENCY OF VARIOUS SYNTHETIC STONES TO X-RAYS.

Lithium niobate.

Yttrium-aluminium garnet. *Strontium titanate.*

Diamond in ring.

Synthetic white spinel. *Natural white sapphire.*

Synthetic scheelite.

Glass (Paste).

It will be readily seen that those stones whose constituents are elements of low atomic numbers are more transparent to x-rays than those containing elements of high atomic numbers. For example the spinel and corundum are near diamond in x-ray transparency. Rutile, too, shows some translucency to the rays in keeping with the moderate atomic

No. (22) *of titanium.*

PHENACITE (Be_2SiO_4)

Small green-coloured crystals of phenacite have been grown synthetically but not, so far, commercially. It is interesting to note that similar sized green crystals were grown by Hautefeuille and Perrey during the latter half of the nineteenth century and samples of such crystals are shown in the galleries of the Musee de l'Histoire Naturelle in the Jardin des Plantes in Paris. It seems that there has been little advance over the past eighty years, probably because of its scant use in modern science. However, it is said that larger crystals can be grown. The synthetic phenacite crystal in the possession of the writer is too small to carry out satisfactory tests, but it may be assumed that the constants would be the same as the natural stones, such as a density near 3·00, refractive indices of 1·654-1·670 and a hardness of 7½ on Mohs' scale. Examination of the small crystal showed it to contain many liquid-filled inclusions, but the crystal was too small for any convincing absorption spectrum to be seen. The crystal did not luminesce under either range of ultra-violet light, or under x-rays. Distinct dichroism was observed, the twin colours being green and pale yellowish-green.

QUARTZ (SiO_2)

Rock crystal has been grown synthetically by a hydrothermal technique for a number of years—primarily for its use in certain scientific applications—but the synthetic rock crystal is not likely to enter the gem market as the cost of production is probably greater than the price of the natural mineral. Some cut stones of synthetic rock crystal are extant but they are in the hands of collectors, usually after having been cut for exhibition purposes. It is the coloured synthetic quartz which has more importance in gemmology and synthetic quartz can be "doped" with a number of "impurities" to give colour. Only two colours have so far been met with as commercial gemstones; these are a green, resembling tourmal ne green, which is probably induced by a trace of iron, and a bright blue, which may be called a "French-blue", a colour which is undoubtedly due to cobalt.

The green stones have been found to show rather different inclusions to what one would expect to find in quartz, but some other

stones of English manufacture, including one in the writer's collection, are perfectly clean and show no signs of the synthetic nature of the stone except for the unnatural colour. The blue stones are comparatively easy to detect as the tell-tale cobalt absorption spectrum is seen in these stones. There is some reason to believe that these coloured quartzes have emanated from the Soviet Union.

Brown and other colours of synthetic quartz have been reported to have been made, but it does not appear that they have yet come into the jewel market, and this applies to the prized violet and purple stone—the amethyst—of which it is doubtful whether any production has truly been made. The constants for these synthetic quartzes are the same as for the natural stones of this species and it is only by colour and colour phenomena that they can be identified.

Rutile (TiO_2)

The synthetic rutile, sometimes called "titania", entered the market during 1948. Although grown in other colours, such as brown, red, orange, yellow and blue, the most important at the time was a near colourless variety, which was marred by the fact that it always showed an unpleasant yellowish tinge which precluded the stone from being a successful imitation of diamond. Synthetic rutile, even in its coloured varieties, does not seem to have had much acceptance in the jewellery trade, although there have been some reports that the Japanese have manufactured coloured material for gem purposes in recent years.

Rutile is grown on a modified Verneuil furnace, for titanium minerals (and this includes strontium titanate and other titanates) appear to lose oxygen when near melting point, so that the conventional Verneuil furnace is equipped with a surrounding annular tube supplying an outer envelope of oxygen to the normal oxy-hydrogen flame. The boules are black when taken from the furnace and need to be annealed before they become transparent and suitable for cutting.

Rutile has a hardness of about 6½ on Mohs' scale, a density of 4·25 and refractive indices of 2·62 for the ordinary ray and 2·90 for the extraordinary ray. The crystallization is tetragonal and hence the stones are uniaxial. The birefringence is large, having a value of 0·287 and is positive in sign. The dispersion ("fire") is about

six times that of diamond, and this, with the pronounced double refraction, makes the lighter co oured stones look rather garish. The stones do not show any perceptible luminescence but are usually slightly electroconductive and this may have a directional effect, being stronger along the optic axis than across it. The blue coloured stones are however strongly electroconductive and match the natural blue diamonds n this.

SCHEELITE ($CaWO_4$)

As a gemstone the calcium tungstate mineral called scheelite has little importance, except for those who collect unusual stones. Scheelite has, however, been produced synthetically mainly for certain of its properties which have an importance in modern science and industry. Single crystals of scheelite, reported to have been grown by the Verneuil technique by the firm of Linde Air Products during 1963, were reported upon by American gemmologists. One of these was a yellow colour and the other a lavender colour; the latter was "doped" with neodymium and the specimen showed strongly the rare-earth lines in the spectrum ascribed to this element. Currently the synthetical production of scheelite, which is used for laser production of coherent light, is carried out by the Czochralski "pulling" method of growth from a flux-fusion.

Synthetic scheelite is colourless, but the crystals may be "doped" for various scientific purposes and this "doping" gives various colours to the stones. Colourless scheelite has been cut, and so have the brown and yellow coloured material, and it is these latter stones which have posed problems in identification, for brown and yellow colours are common to natural scheelites. The synthetic stones, however, usually exhibit a stronger didymium spectrum than those of natural origin.

The hardness of scheelite is about 5 on Mohs' scale and the density about 6, there being some justification for suggesting that the density of the synthetic material may be slightly higher, at about 6·1, as against the 5·95 to 6·00 for the natural scheelite. Dana's *System of Mineralogy* gives the indices of refraction for natural scheelite as $\varepsilon = 1{\cdot}9365$ and $\omega = 1{\cdot}9208$, which gives for this tetragonal mineral a positive uniaxial birefringence of 0·0157. These figures are of little use to the gemmologist for they are outside the range of the refractometer.

Red Violet

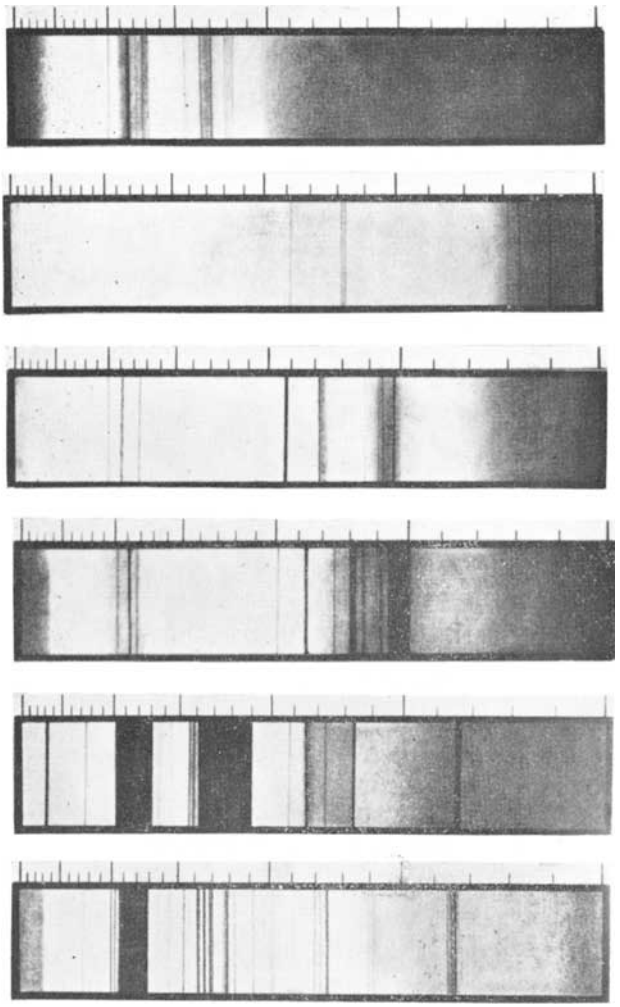

SPECTRA OF SYNTHETIC SCHEELITE

TOP. *Rich red-brown scheelite.*
Pale yellow scheelite.
Pale green scheelite.
Pale green scheelite.
Rich purple scheelite.
Pale purple scheelite.

In common with the natural mineral, synthetic scheelite exhibits no, or very little, fluorescence under the long-wave ultra-violet lamp, but the stones glow strongly with a blue glow when irradiated with short-wave (2537A) ultra-violet light; but there are exceptions. Two pieces of synthetic scheelite of yellow colour, which exhibited rare-earth lines in the green and blue, glowed with a strong orange light under both radiations of ultra-violet light, and under x-rays a pink glow was produced. The density of these pieces was found to be 6·16. There is a report of a synthetic scheelite of a peridot-green colour, which had no recognizable absorption spectrum, and which fluoresced a dull brick or orange-red in only one half of the specimen when under ultra-violet light. Unfortunately no information was given as to the wavelength of the ultra-violet light employed.

Silicon Carbide (SiC)

Better known under the trade name "carborundum" and for its use as an abrasive, silicon carbide is formed by the fusion of 70% sand (quartz) and 30% coke (carbon), although crystals may have been produced by other methods. The reason for the inclusion for this material in this article is that a few stones have been cut from suitable crystals, which are normally thin and tabular. These platy crystals are of hexagonal symmetry and are usually bluish-green in colour, and the cut stones in appearance may resemble some "bombarded" diamonds.

The hardness of silicon carbide is about 9¼ on Mohs' scale and the density is 3·17. The refractive indices are 2·65 for the ordinary ray and 2·69 for the extraordinary ray and the positive birefringence is 0·043. The material has about twice the dispersion ("fire") of diamond, from which it may be identified by the double refraction, distinct dichroism and mustard-yellow fluorescence under long-wave ultra-violet light.

The above refers to the so-called "alpha" type of silicon carbide, but there is a cubic modification—the "beta" type—which is colourless and from its characters could be a possible diamond simulant. However, as far as the writer knows nothing has materialized in this direction.

SPINEL ($MgAl_2O_4$)

The synthetic spinels which have been grown by the Verneuil process since, one might say, 1907 are too well known to need description and this section will deal only with stones of this species which have been produced since 1946.

During 1954 a cobalt-rich sintered synthetic spinel was made to imitate lapis-lazuli. In a few cases small specks of gold were included in the sintered mass in order to simulate the iron pyrite which is so common an inclusion in lapis-lazuli itself, instances of where the imitation is of greater value than the real thing. Detection of these stones is easy, for apart from the strong cobalt absorption spectrum which can be seen by scattered light, the density, which is lower than for the normal spinels, of 3·52 will indicate the nature of the stone. The lapis-lazuli-coloured sintered synthetic spinels do not seem to have entered the British gemstone trade to any extent.

Three years later the schillerized synthetic white spinel came on the market. The schillerization produces a moonstone-effect and presumably the cabochon cut stones are intended to represent the moonstone variety of feldspar. Detection is again easy here for under the short-wave ultra-violet lamp these simulants of moonstone glow with the characteristic strong blue glow, in contradistinction to the true moonstone which glows with a yellowish light under similar excitation. Further, the other simulant of moonstone, the schillerized rock crystal, is inert under these ultra-violet rays.

The one colour of synthetic spinel which had not been made as a commercial production before 1946 was the red synthetic spinel. This was apparently due to the fact that chromium, which gives the red to ruby and the green to emerald, when introduced into the commercial type of boule which contains an excess of alumina, being, usually, $MgO2\frac{1}{2}Al_2O_3$, gives a "tourmaline green" colour. It is only in equimolecular boules, *i.e.* $MgO.Al_2O_3$, that a red colour is produced, and such boules are said to crack so badly that only small stones could be cut from them. However, about 1960 a number of small red synthetic spinels came on the market. These stones, which were only about a tenth of a carat in weight, were used for eternity rings. They do not seem to be prominent in the gem trade to-day. During 1968, whilst in the United States of

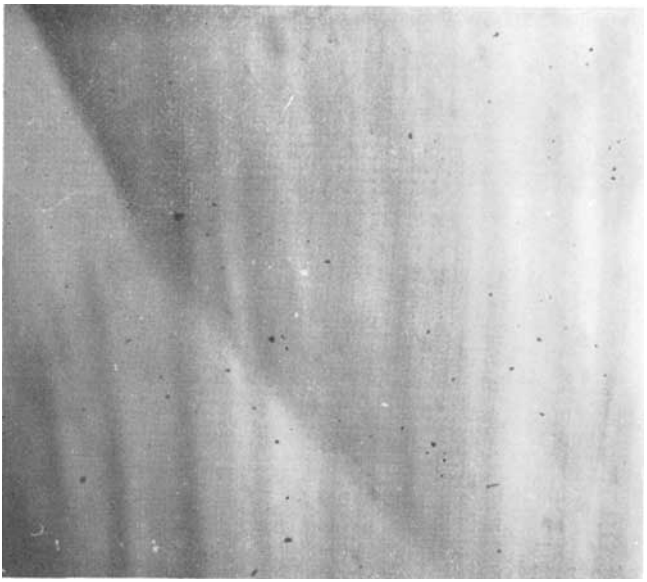

Curved bands of colour seen in an American synthetic red spinel.

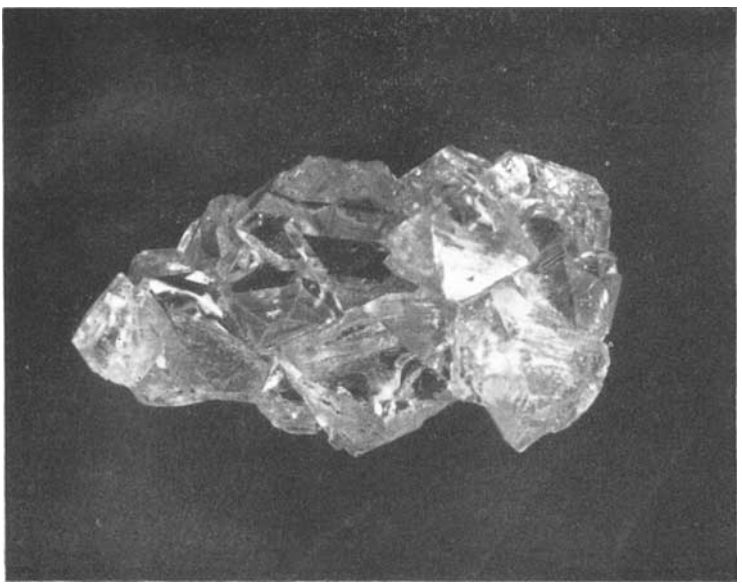

A group of crystals of synthetic spinel grown by the flux-melt method.

America, the writer found that synthetic red spinels grown by the Verneuil process, were available in fairly large sizes, certainly greater than one or two carats.

The smaller stones of the earlier type were found to have an index of refraction of 1·722 and a density of approximately 3·60. The stones varied considerably in their internal structures and often showed pronounced curved colour bands, and/or lines, and included gas bubbles. The larger American stones have a refractive index of 1·720 and densities, taken on two samples in possession of the writer, of 3·580 and 3·594. The structures showed rather broad curved bands somewhat reminescent of the bands in synthetic blue sapphires. In all these stones, both the earlier small ones and the larger American production, the absorption spectra, and particularly the fluorescence spectra, resemble those of ruby in that only one strong fluorescent line is present, the rest being weak, and the whole effect is dissimilar to the "organ-pipe" spectrum seen in natural red spinels. The fluorescence is crimson under both ranges of ultra-violet light and under x-rays, in the latter case there being pronounced phosphorescence.

A more modern type of synthetic spinel is that grown by the flux-fusion method. Primarily intended for scientific purposes the crystals grow as octahedra or groups of octahedra, the latter having the greater gem significance as these groups have been used in the modern concept of jewellery design where uncut crystals form the central motif. Such spinel groups are grown in many colours by "doping" with trace elements, such as red by chromium and blue by cobalt, and there are seen groups with a yellow or pale blue-green colour, the "doping" agent being unknown in these cases.

The characters shown by specimens of these synthetic spinel groups, all of English manufacture, showed two specimens of red colour to have densities of 3·592 and 3·598 both showing a fluorescence spectrum having a single strong line at 6855A and traces of others. This fluorescence spectrum is similar to that shown by the Verneuil flame-fusion synthetic red spinels. Under ultra-violet light of both ranges the glow was crimson and under x-rays the fluorescence was more of a purplish-red and there was a persistent phosphorescence.

The blue-coloured group had a density of 3·600 and showed the typical cobalt absorption spectrum of three bands. Under the Chelsea colour-filter the group showed a bright red, but the group did not show the differential response to ultra-violet light as seen in the Verneuil-type blue synthetic spinels which show red under the long-wave ultra-violet lamp and a greenish- or bluish-white under the short-wave ultra-violet lamp. Indeed in the group examined there was very little luminescence under ultra-violet light or x-rays, except for a possible dull red glow when irradiated with the short-wave lamp. It is always problematical whether such a glow is not reflected from the light passed by the lamp.

The yellow-coloured specimen was found to have a density of 3·609, showed no distinctive absorption spectrum, but exhibited a green fluorescence under long-wave ultra-violet light, practically inert or with a slight dull yellow glow under the short-wave lamp, but under x-rays the glow was a vivid green, there being no phosphorescence. The pale green specimens having densities of 3·601 and 3·589, again showed no characteristic absorption spectrum and only slight luminescent response of indeterminate colour under ultra-violet light, but a dull green glow under x-rays.

Two unusual specimens of similar habit and of a pale bluish-green colour were found to have unusual characters, for the density was about 5·7, and the absorption spectrum showed a fine line in the red and indeterminate lines in the yellow, which may be traces of the didymium series. The luminescence under ultra-violet light and x-rays was a strong yellow. The exact nature of these crystals is not known, but such objects may be mounted in their uncut state, as are the known flux-melt synthetic spinels.

As a footnote to the spinels, although they are unlikely to have any importance in jewellery—until someone wants an unusual black stone—is the flux-grown lithium-iron spinel. A specimen of this material was found to have a density of 4·58 and to be strongly magnetic.

Strontium Titanate ($SrTiO_3$)

A stone which is unknown to nature, strontium titanate, first came on to the market during 1953. Earlier known as "starilian" the stone is now better known as "fabulite". Despite its low hard-

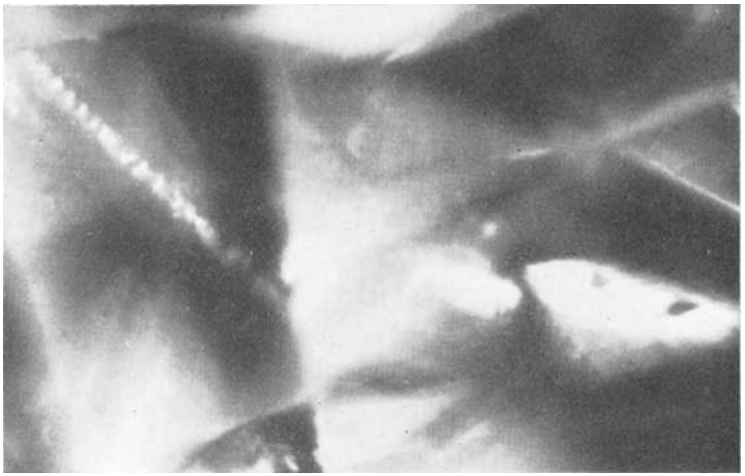

"Ladder" in a strontium titanate.

ness, about 6 on Mohs' scale, this stone has outshone the synthetic rutile as a diamond simulant, for it is whiter in colour and has less "fire" than rutile. However, by its excessive "fire"—some four times that of diamond—it may be distinguished from diamond. The stone can be tricky when viewed in a half-light, but if attention be paid to the facet edges, which usually appear "rolled" (this is generally, but not always, a feature of strontium titanate) no deception need occur. Indeed it is these features, "fire" and "rolled edges", which must be looked for in a mounted stone, as the refractive index of 2·40 is near to that of diamond and is too high to measure on a refractometer. When the stone is unset the problem is easy for the density is 5·13, nearly half as much again as for diamond, hence if such a stone is gauged on a diamond gauge and then weighed, the "error" will be strikingly shown. Further, this difference must be taken into account if an estimate be needed to replace a diamond with a "fabulite".

Unlike diamond, strontium titanate does not fluoresce under ultra-violet light, and "fabulites" are comparatively opaque to x-rays in contradistinction to diamond, which is relatively transparent.

"Fabulites" are generally clean and do not show much in the way of inclusions, but "ladder-like" structures have been seen.

A. E. Farn has pointed out that the "ladders" are surface faults and can be induced by a needle used as a hardness point—a test not to be recommended unless great care be taken. In the same context it must be mentioned that "fabulites" are brittle and are easily damaged, and they have been known to become flawed all over after treatment in an ultrasonic cleaning bath. There should certainly be no difficulty in identifying these stones, but it must be realized that "fabulite" is one of the more convincing simulants of diamond.

Yttrium Oxide (Y_2O_3)

There has been reported from America that crystals of yttrium oxide may provide another diamond simulant. The mineral is cubic in crystallization and has been reported as having a refractive index of 1·92 with a dispersion of 0·050. The hardness is said to be between $7\frac{1}{2}$ and 8 on Mohs' scale, and a density of 4·84 has been mentioned.

Zincite (ZnO)

Another mineral which has been grown as synthetic crystals, by vapour-phase and by hydrothermal methods, is the zinc oxide called zincite. The only specimens of this product seen by the writer are small yellow crystals, but presumably larger ones could be grown.

The hardness and density of the natural mineral are given as $4\frac{1}{2}$ on Mohs' scale and 5·43 to 5·7 respectively. The red to orange-yellow colour of the natural mineral may well be due to manganese oxide, and the refractive indices of zincite, which has hexagonal crystallization, are given as $\omega = 2{\cdot}013$ and $\varepsilon = 2{\cdot}029$.

The small specimens of synthetic zincite examined showed a dull to bright yellow fluorescence under ultra-violet light and a strong yellow or green under x-rays. There was no apparent dichroism nor was there any distinctive absorption spectrum.

Zircon ($ZrSiO_4$)

Zircon is another stone which has been grown synthetically as single crystals. This is not new for there is on show at the Musée de l'Histoire Naturelle in Paris a small crystal which was grown by

Hautefeuille and Perrey about 1890. A crystal of similar size is in the writer's collection, having been given to him by Dr. Kurt Nassau. It was probably grown by Bell Telephone Laboratories. This crystal, approximately 3mm by 2mm has a purple colour and a good tetragonal form consisting of prism and pyramids. Too small for much work to be carried out on it, some observations were, however, carried out of the absorption spectrum and on the dichroism. The absorption spectrum was seen to be dissimilar to that shown by natural zircons, but on such a small stone all that could be seen was a distinctive broad band absorbing the yellow region of the spectrum. There was no apparent fluorescence when the crystal was irradiated by either wave-band of ultra-violet light or under x-rays. What was most striking was the dichroism shown by the crystal. This was exceptionally strong, the "twin colours" being purple and yellow. Presumably the stone is "doped", but what with is not known. It has been mentioned that there is no reason, except perhaps because there is no demand, why larger crystals should not be grown.

This article has been written to record what has occurred in the way of manufacturing synthetic stones since about 1945, and it is hoped that it will serve as a guide to the problems which may well beset the gemmologist in the future.

The writer is indebted to Dr. Kurt Nassau of New Jersey, U.S.A., Mr. Jerry Call of the New York Laboratory of the Gemological Institute of America, and Mr. Grant Waite of Toronto, Canada, for the gift of many of the specimens examined. To Mr. B. W. Anderson and the Officers of the Gemmological Association of Great Britain, thanks are also due for the loan of specimens from their collections. Without the help of these friends this compilation could not have been completed.

TABLE OF CONSTANTS OF SYNTHETIC CRYSTALS

The more important stones are shown in heavy type

	H.	S.G.	R.I.	Bi-ref.
Barium titanate	6-6½	5·90	2·40	Isotropic
Beryl				
Emerald (Chatham)	**7½**	**2·65**	**1·562**	**0·003**
Emerald (Zerfass)	**7½**	**2·66**	**1·562**	**0·003**
Emerald (Gilson)	**7½**	**2·65**	**1·562**	**0·003**
(Gilson recent)	**7½**	**2·69**	**1·572**	**0·005**
Emerald (Linde)	**7½**	**2·71**	**1·575**	**0·005**
"coated" beryl	**7½**	**2·70**	**1·570**	**0·005**
Beryl (other colours)	7½	2·68	1·570	0·005
Boron carbide	9½	2·51	?	?
Bromellite	9	3·01	1·728	0·015
Calcium titanate	6	4·05	2·40	?
Chrysoberyl	8½	3·71	1·745	0·009
Corundum	**9**	**3·99**	**1·764**	**0·008**
Diamond	10	3·52	2·42	Isotropic
Fluorite	4	3·18 +	1·45	Isotropic
Gahnite	7½-8	4·6	1·82	Isotropic
Garnet types:—				
YAG	**8**	**4·57**	**1·832**	**Isotropic**
Terbium	7 +	6·06	1·873	Isotropic
Dysprosium	7 +	6·20	1·85	Isotropic
Holmium	7 +	6·30	1·863	Isotropic
Erbium	7 +	6·43	1·853	Isotropic
Thulium	7 +	6·48	1·854	Isotropic
Ytterbium	7 +	6·62	1·848	Isotropic
Lutecium	7 +	6·69	1·842	Isotropic
YIG	7 +	5·99	?	Isotropic
Hematite garnet	7 +	4·20	?	Isotropic

	H.	S.G.	R.I.	Bi-ref.
Greenockite	3½	4·85	2·51	0·023
KTN	6½	6·43	2·27	?
Lithium niobate	**5½**	**4·64**	**2·25**	**0·090**
Magnetite	6	5·17	?	Isotropic
Magneto-plumbite	?	5·52	?	?
Periclase	**5**	**3·57**	**1·74**	**Isotropic**
Quartz	**7**	**2·65**	**1·55**	**0·009**
Rutile	**6½**	**4·25**	**2·75**	**0·287**
Scheelite	**5**	**6·1**	**1·925**	**0·016**
Silicon carbide	9¼	3·17	2·67	0·043
Spinel	**8**	**3·61**	**1·72**	**Isotropic**
Strontium titanate	**6**	**5·13**	**2·40**	**Isotropic**
Yttrium oxide	8	4·84	1·92	Isotropic
Zincite	4½	5·55	2·02	0·016
Zircon	7½	4·68	1·95	0·059

The values given are taken from literature and checked where possible by personal determinations. Some of the values given are those from the literature on natural minerals where it can be assumed that the synthetic crystals would not depart from them.

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ASSOCIATION NOTICES

GIFTS TO THE ASSOCIATION

The association is indebted to Scandinavian Jewellers' Associations for a bound copy of the first edition (1970) of the Scandinavian diamond nomenclature and grading standards.

The Association is also grateful for a gift of star-stones and cats-eyes from the executors of the late Nigel Kennedy (Cheshire) and for a cut ekanite from Mrs. C. Mendis (Ceylon).

A collection of Indonesian cabochon agates, cut and polished in Indonesia, has kindly been donated by Mr. Tampubolon, Ir. L. C., Djakarta.

GEMS AND GEMOLOGY

Copies of the Spring 1967 and Winter 1968-1969 issues of *Gems and Gemology* are required.

BRANCH MEETINGS

For their 1970 summer outing, members of the Scottish Branch of the Association visited Edinburgh Castle. A private viewing of the Scottish Regalia was arranged, allowing close examination of exhibits which is not possible when the general public are admitted. The Crown Jewels were of special interest. After lunch members visited the Royal Scottish Museum which contains an excellent collection of minerals and gemstones.

The Annual General Meeting of the Midlands Branch of the Association was held on the 12th June, 1970, at the Auctioneers Institute, Birmingham. Mr. P. Spacey presided and in his report recalled the meetings held during the past year. The following

Officers were elected: Chairman, Mr. P. Spacey; Vice-Chairman, Mrs. S. Hiscox and Secretary, Mr. P. West. Messrs. P. Alabaster, J. Marshall, D. Jones and G. Porter were elected to the Committee.

EXAMINATION RESULTS

The results of the 1970 examinations in gemmology will be published in the January 1971 issue of the *Journal.*

SUBSCRIPTIONS 1971

As announced in the July 1970 issue of the *Journal of Gemmology*, Vol. 12, No. 3, the annual subscription for Fellowship and ordinary membership will be £3 0s. 0d. as from 1st January, 1971. The annual subscription for the *Journal of Gemmology* for non-members has been increased to £4 0s. 0d.

EXAMINATIONS 1971

The 1971 Examinations in Gemmology will be held on the following dates:

Preliminary:	Tuesday, 15th June, 1971.
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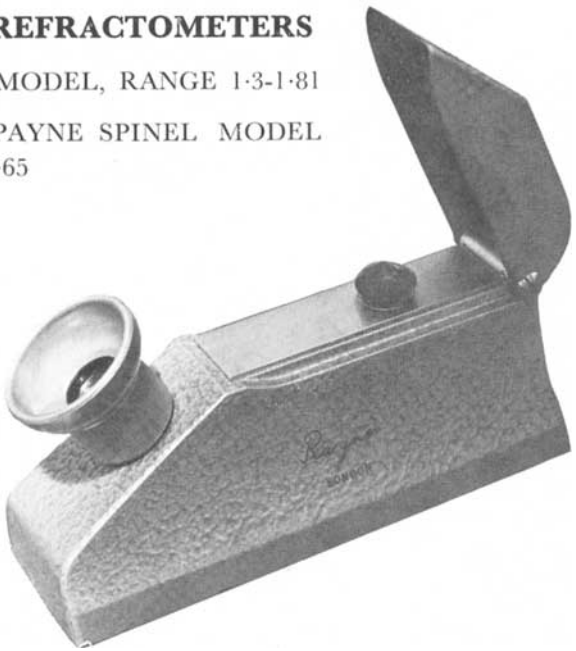

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NOTES FROM THE LABORATORY

By B. W. ANDERSON

THE modern vogue for decorative mineral crystals has led to a marked increase in the number and variety of uncut crystals which are submitted to the Laboratory for identification. The most unusual of these consisted of a handsome group of crystals, apparently growing naturally from a piece of granular rock. This group had been offered for sale to a West-end jeweller as a specimen of the mineral Bieberite, which is a hydrated sulphate of cobalt having a rose-red colour. Being water-soluble, bieberite is of rare occurrence, but it is found as stalactites and crusts in certain old cobalt mines, where it is derived from the oxidation of cobalt sulphide ores.

However, fragments scraped from the specimen gave negative results for cobalt or for sulphate reactions. To save further time and effort in a field outside our own we sought the expert advice of Dr. Max Hey of the Natural History Museum, whose skills both as a mineralogist and as a chemist are second to none. Dr. Hey at once identified the crystals as being **potassium ferricyanide,** a substance well-known as a chemical reagent, but not as a natural mineral. Though certainly an artefact and fraudulently offered for sale, the price asked was so low that this did not constitute a very serious misdemeanour.

This curious incident is perhaps hardly worth relating; but it does serve to underline the fact that the laboratory gemmologist of to-day must be prepared for almost anything to be thrown at him

for identification. In such cases the friendly co-operation of scientists who are skilled in other disciplines is of enormous value, and may often save one from a time-consuming struggle on a matter of very small commercial importance. Such friendly aid is a two-way process: we as gemmologists are often able to provide specimens and advice to pure scientists who are impinging upon our own special field of knowledge.

Synthetic rubies are so cheap and so readily procurable, that one hardly expects other artefacts to be used where **substitutes for natural ruby** are concerned. It was surprising therefore in a hoop ring recently tested which was set ostensibly with calibré rubies, to find the specimens giving rise to a strong didymium spectrum. Pastes coloured by didymium are not uncommon, but they are usually a rather pale pink in colour. It was interesting to note how near to ruby red this material could get when strongly enough "doped" with the two rare earth molecules. Another good imitation of poor-quality ruby was provided (again unexpectedly) by quartz which contained enough natural flaws and fissures to enable it to absorb a suitable red dyestuff and make it decidedly deceptive to the eye.

One of the few **sinhalites** we have officially tested came to hand some months ago. This was an attractive golden brown specimen weighing more than five carats: the asking price, we understand, was twenty pounds per carat. For the record, the density of this stone was 3·48 and its refractive indices 1·669-1·704.

An intriguing problem (which was mentioned by the writer in a recent talk to the Gemmological Association) was posed by the request to test and sort a large number of rough blue transparent mineral pieces which were said to consist of a mixture of **blue zoisite** and **iolite.** A preliminary trial showed iolite to be the preponderant material, and it was further found that the quickest and easiest positive test for this was provided by examining the absorption spectrum of light transmitted through the specimens in their yellow direction. Two bands in the yellow at 5920 and 5860 Å., together with a narrow band at 5350 Å. in the green formed an unmistakeable pattern. The few zoisites failed, of course, to show these bands and showed their own most characteristic absorption band in the orange-yellow at 5950 Å. Just by way of variation the bluest piece of all gave a rich cobalt spectrum, showing it to be a roughed-up piece of cobalt glass.

Not long ago, we were privileged to test the largest specimen of **pink scapolite** we have ever seen. This was a magnificent step-cut stone of possibly 70 carats, mounted with a pink beryl as a brooch pendant. Positive identification was provided by a careful reading on the spinel refractometer, which showed the stone to be uniaxial negative, with 1·570 for the ordinary and 1·549 for the extraordinary index. A further proof was provided by the apricot glow shown by the stone under long-wave ultra-violet—a glow which characteristically revealed a banded structure when viewed through the spectroscope, proving the fluorescence to be due to traces of uranium.

A rough translucent specimen, of which both the green colour and the absorption spectrum resembled emerald rather closely, proved, after investigation, to be **tremolite,** in a form which was new to us. As this showed little variation under crossed polars it was thought at first to be multi-crystalline: but the refractive indices shown when a flat was polished revealed it to consist of a single crystal, or crystals in strictly parallel growth. The indices were as follow: α1·608, β1·624, γ1·636. The density was 2·98, and the absorption bands in the red, due to chromium, were found to be at 6840, 6500 and 6280 Å. These were not so sharp as those seen in emerald: the band at 6840 was quite strong and represented an unresolved doublet.

Mention may also be made of a surprise to all of us when a colourless cabochon stone mounted as the centre piece of a rather elaborate brooch of oriental design was identified as **fluorspar.** This was part of a suite of jewellery, all of which featured centre-pieces of this quite unsuitable mineral, which had no colour or lustre to charm the eye, and must be accounted extremely vulnerable in wear.

A **pale blue spodumene** weighing 35 carats caused us a little trouble, since the colour, combined with the refractometer readings 1·660-1·675 added to a red glow under crossed filters led us to think in terms of euclase or fibrolite. A density figure of 3·185 put us right, and the accurate figures α1·660, β1·668, γ1·675 fitted perfectly for spodumene. The red colour under crossed filters was not the chromium fluorescence that can be seen with both euclase and fibrolite, but an orange-yellow glow of the type emitted by kunzite, as modified when seen through the "spectrum red" filter

used. Our records for the refractive indices of fibrolite are α1·658, β1·659, γ1·676, as against euclase α1·656, β1·660, γ1·675.

These figures serve as a warning that refractometer readings by themselves, even when accurate, do not always provide an easy answer to the identity of a gemstone.

ARRANGING GEMSTONES

By D. G. KENT

IT may be of interest to readers to know how "the other chap" arranges his collection of cut gemstones or crystals.

I remember Sir James Walton, during the time when he was a member of Mr. B. W. Anderson's Post Diploma evening class at Chelsea Polytechnic, bringing his collection of jade and jade-like minerals to show us (about 50 specimens, which incidentally astonished many of the class; I have never been happy with jades since that time!). He had made beds of plaster-of-Paris, about 25mm square, with the stone indented whilst the plaster was wet; the squares were then fitted into a tray—this was very effective, but somewhat heavy to carry.

I keep the majority of cut stones in my modest collection as follows:

A piece of hard wood 34cm × 26cm × 2cm deep, with 130 drilled "cups" of 2cm and 12mm diameter in alternate rows. The whole is painted white and each cup numbered with Indian ink. A piece of 3-ply wood, stained black, of the same size, is hinged as a lid, with catches (from old jewellery cases) fitted to the sides and front to close it down tightly. This enables the box to be transported without any loss. For display purposes a retaining strap is used to hold the lid open at 90° and a card, same size, is laid against it, numbered in the corresponding positions to the cups with the name of the stone above the number. Have Fellows any other ideas?

INCLUSIONS IN THE PANNA DIAMONDS OF INDIA

By SUDHA PHUKAN

ABSTRACT

The study of 200 diamonds from Panna shows that they are essentially characterized by primary solid and gaseous inclusions, *viz.* (1) chromite, magnetite, ilmenite, (2) graphite, (3) olivine, (4) diamond, (5) garnet, (6) diopside and (7) gaseous CO_2, arranged in order of their abundance. Secondary inclusions include hematite and limonite. These inclusions mainly occur as discrete individual crystals; only spinel minerals and olivine-chromite occur at places in aggregates. The physical characteristics and nature of inclusions show that diamonds of primary pipe rock and secondary conglomerate are markedly homogeneous and have a common source. Graphite-CO_2-diamond perhaps maintained a critical P-T condition to form together, but the significance of other inclusions found in Panna diamond is yet to be worked out.

INTRODUCTION

The only productive primary deposit of diamond in India is at Majhgawan (24°38′N:80°4′E) in Panna district, Madhya Pradesh, and its geology has been dealt with by Sinor (1930), Mehr and Dubey (1949), Mehr (1952), Mathur (1953, 1961) and Mathur and Singh (1963). Recently a number of papers appeared in the unpublished symposium volume on "Diamonds" and one of the contributions contained therein is on the mineralogy of altered pipe rock at Panna (Das Gupta and Phukan, 1969). But characteristics of diamond occurring in Panna are little known excepting those given by Sinor (op. cit.). Phukan (1968) studied the inclusions of Panna diamond from both primary pipe rock and secondary deposits associated with conglomerate horizons at Ramkheria (24°49′N: 80°27′E), where large-scale mining operation is being conducted by the National Mineral Development Corporation.

The geological setting of the diamondiferous horizon is quite simple but interesting. The pipe rock at Majhgawan is intruded into the piles of orthoquartzites of the lower Vindhyan System of late Precambrian age. The primary pipe rock is very much altered and

compositionally consists mainly of various types of serpentines, clay minerals, hematite and calcite. Petrographically the rock seems to have been derived from some ultrabasic rock intermediate in composition between peridotite and carbonatite. Diamonds also occur in the two conglomeratic horizons of the Vindhyan System but the conglomerates are younger than the pipe rock. The frequency of occurrence of diamonds in pipe rock is rather constant, whereas in conglomeratic horizons it is quite erratic. Recent transported sediments, mainly along the course of rivers and rivulets, also carry diamonds, but their occurrence is minor and infrequent.

The diamonds show quite a few interesting physical features in shapes and sizes and are characterized by a host of mineral inclusions. The distribution of the mineralogically complex inclusions is in excellent agreement with the inclusions described from diamonds of the other parts of the world, notably South Africa. It is the purpose of the paper to present the characteristics of hitherto unknown features of Indian diamonds with particular reference to their inclusions. About 100 diamonds have been studied from each of the two types of deposits and their sizes vary from 0·10 to 2·50 carats.

Since all the inclusions in diamonds appear black in inadequate light, a powerful source of transmitted and reflected light has been used for examination of diamonds after immersing them in α-Bromonaphthaline ($n = 1{\cdot}66$). The minerals and other inclusions in diamonds have been identified from the colour, shape, habit, form, relief and other morphological features. However, precise determination of the mineralogical composition of inclusions has not yet been possible for want of suitable instruments: but even so the features observed under the microscope are quite intriguing and demand careful study. The result of such observation is given in the following paragraphs.

Morphological Features

Most of the diamonds are colourless, but some of them show a wide range of delicate shades of blue, green, yellow, brown to deep brown. Carbonado or opaque black diamonds have not been found in India.

The surface of most of the diamonds is quite smooth and shows adamantine lustre. Occasionally crystals with rough and pitted

surface are also noted. Rarely is the surface frosted. The surface features are present in all the varieties irrespective of the colour of the crystal. Webster (1962) suggested that the frosty surface of the crystal is due to wearing out of the flaky graphite coated on the surface of diamond. Graphite is found as inclusion in Panna diamonds but not as coated graphite on the crystal faces. Here in Panna the frosty diamond present in the pipe rock is presumably formed by the corrosive action of fluids present in the parent magma.

Crystallographically most of the diamonds have simple octahedral forms while quite a few of them show additional dodecahedral faces. In addition to the normal octahedral forms, complex forms such as hexakisoctahedron, tetrakishexahedron and hexakistetrahedron are also frequent. Simple twins on (111) are also noted. Cubic crystals, so common in South African deposits, are conspicuously absent from the present area.

Some of the octahedral faces and faces of a few complex forms are characterized by surface markings of trigonal shapes—"*trigons*" —the edges of which are parallel to the octahedral planes; the triangular markings often produce an impression of elevations and depressions on the crystal faces.

Inclusions

Most of the diamonds contain one or two types of solid inclusions of different shapes and sizes. The following inclusions which are prominently developed are arranged in order of their decreasing abundance: (i) opaque ore minerals, (ii) graphite, (iii) olivine, (iv) diamond, (v) garnet, (vi) diopside, (vii) gaseous CO_2, (viii) hematite and (ix) limonite.

Opaque ore minerals: Dark opaque inclusions, commonly termed "carbon spots" in the gem trade, are the most common inclusions in diamonds. They occur either as little specks, sprinkled throughout the stone, or as irregular bodies. Such stones are locally classified as "Chhitandar", meaning sprinkled. The specks are commonly taken as carbon, but carbon is likely to be unstable under conditions of diamond formation, and according to Gübelin (1952) carbon is rarely present in diamonds. These carbon inclusions also occur as shapeless, irregular lumps, often with jagged or spiky outline, scattered randomly in the interior of diamonds, sometimes so densely that the entire crystal appears almost black. These irregular dark inclusions, which mainly belong to the spinel group, are crystals of

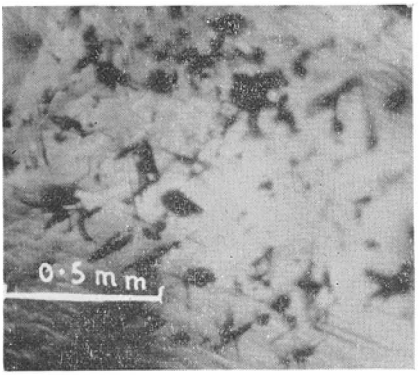

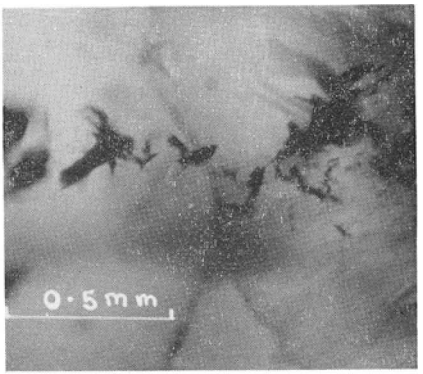

1a 1b

FIG. 1a and b: Bars and rhombs of ilmenite, triangular octahedral plate of magnetite and sub-rounded chromite in diamonds; grains are partly crystallographically oriented by host.

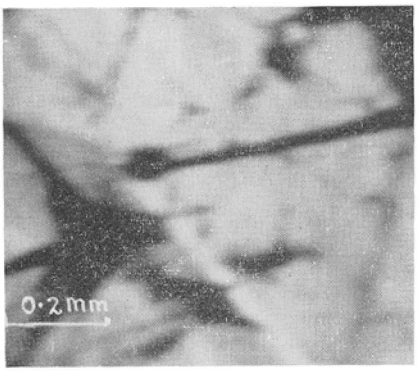

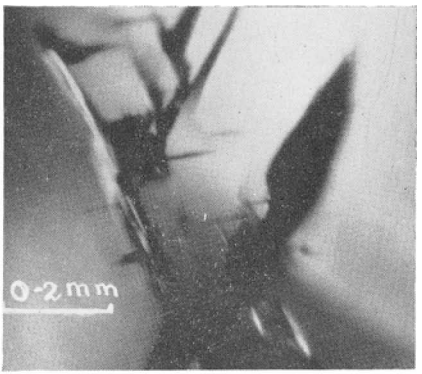

2a 2b

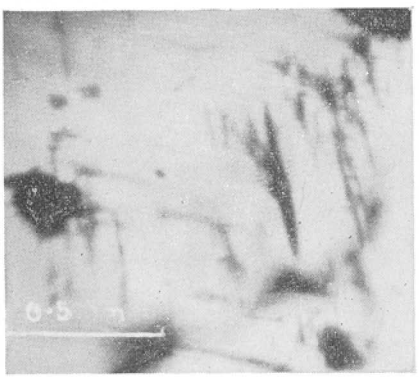

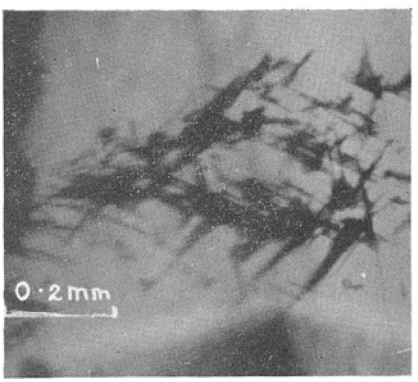

2c 2d

FIG. 2a, b, c and d: Spiky, angular stalked crystals and idiomorphous flakes of graphite in diamonds. Note growth of graphite flakes partially controlled by crystallographic direction of diamonds (FIG. 2c and d).

magnetite, chromite and ilmenite. In Fig. 1a and 1b triangular octahedra of magnetite, fine granular to compact octahedrons of chromite, and bars and rhombs of ilmenite are clearly visible. Some of these crystals have preferentially grown along the octahedral direction of the diamond crystal. These three minerals are intimately intergrown and possibly magnetite and ilmenite are exsolved from chromite. One of the characteristics of this group of minerals is that they occur together in aggregates.

Graphite: Graphite occurs either as thin flakes or as angular grains. Dark-coloured spiky or angular stalked crystals of graphite (Fig. 2a and 2b) are the next most common group of inclusions in these diamonds. But no perfect idiomorphous crystals of graphite, as found in South African diamonds, are present herein. In Fig. 2c and 2d flakes are preferentially controlled by octahedral planes of diamonds.

Olivine: Euhedral olivine crystals are quite frequent in Panna diamonds. They are usually well defined but sometimes rounded too; usually they are oriented relative to the diamond. At places olivine crystals are surrounded by the radial tension cracks formed during metamictization of the crystals. Notably dark haloes are formed around some of these crystals. Unlike other minerals olivine occurs either singly or in aggregates (Fig. 3a, 3b and 3c); occasionally aggregates are associated with inclusions of chromite.

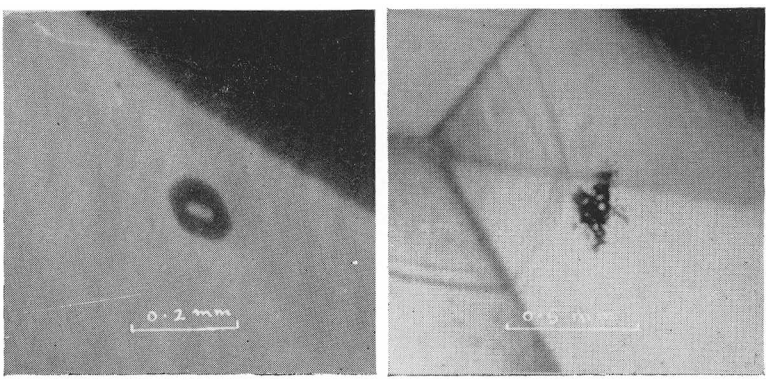

3a 3b

FIG. 3a, and b: A single crystal of olivine (FIG. 3a); aggregates of sub-rounded olivine crystals with tension cracks (FIG. 3b);

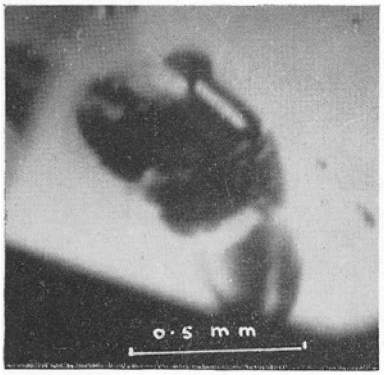

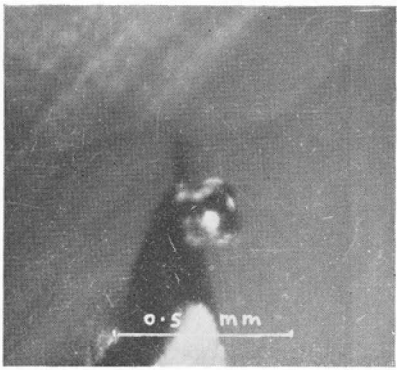

3c 4

(Fig. 3c). Euhedral crystal of olivine surrounded by dark altered haloes.

Fig. 4: Octahedra of guest diamond in well crystallized host diamond. Apparently no crystallographic control.

Diamond: Crystals of diamond are at times embedded within a large crystal of diamond. They are not parallely grown and often the guest crystal is octahedral in form (Fig. 4).

Garnet: Inclusions of rounded to subrounded spots of earthy green mass are very frequent in diamonds. They occur usually as circular spots and rarely do they show an irregular outline. These crystals have been identified as garnet (Fig. 5a and 5b).

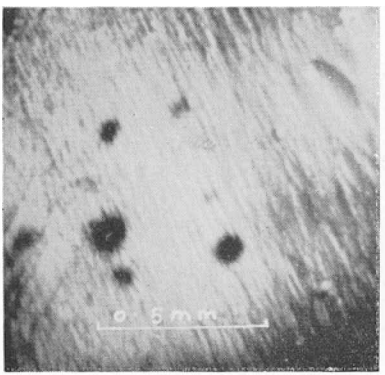

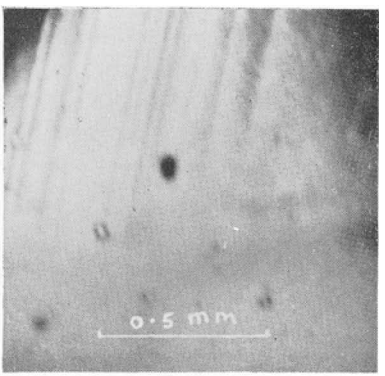

5a 5b

Fig. 5a and b: Earthy green-coloured rounded inclusions of garnet.

Diopside: Anhedral crystals of pale green colour with moderate relief are observed in a number of cases. Their exact mineralogical composition as to whether diopside or enstatite has remained indeterminate (Fig. 6).

FIG. 6: Anhedral crystal of diopside (or enstatite) in diamond.

Gaseous inclusion: These are noted in a few crystals and they occur as minute clouds of dust (Fig. 7) resembling CO_2 inclusions studied by Roedder (1965) in olivine. Sometimes these gaseous

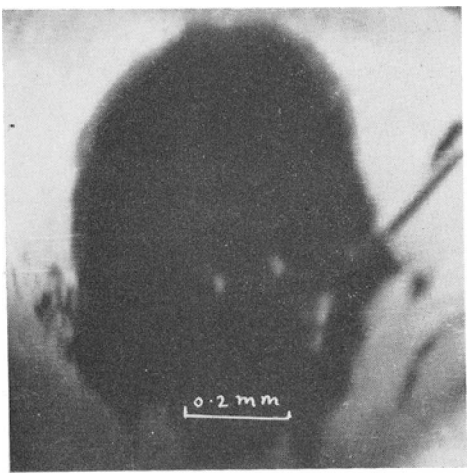

FIG. 7: An inclusion of CO_2 resembling a clot of dusty cloud having irregular periphery.

inclusions have a very pale greenish tinge.

Hematite: It occurs usually in tablets and also as irregular lumps (Fig. 8a and 8b). When observed under reflected light it shows bright internal red reflection. These are secondary products formed after magnetite. When minutely observed, octahedral faces of magnetite are still clear even in the aggregates.

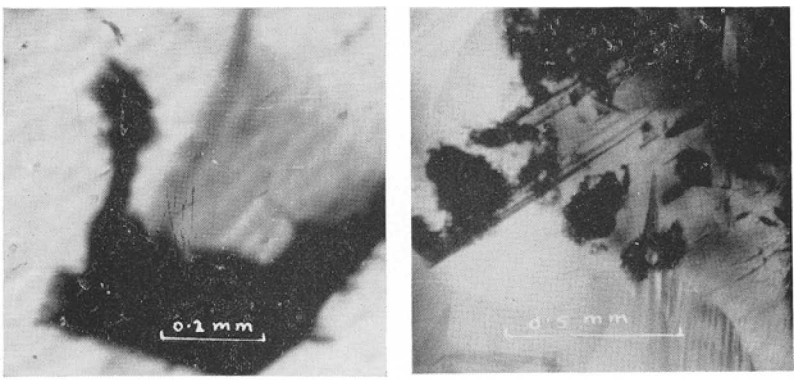

8a 8b

FIG. 8a and b: Tablets of hematite (FIG. 8a); and irregular lumps of hematite (FIG. 8b), developed pseudomorphously after magnetite.

Limonite: These are secondary in origin and they occur as fillings along cracks in the diamonds (Fig. 9). These inclusions are, however, more than superficial.

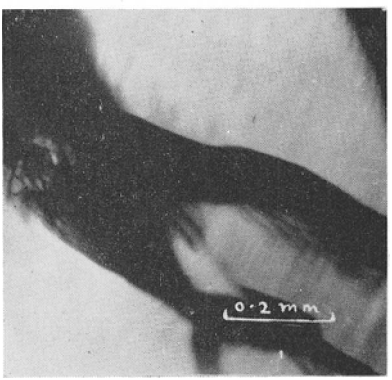

FIG. 9: Secondary limonite along a fracture in diamond crystal.

Discussion

Diamonds are reported to contain inclusions both solid and gaseous, but in Panna mainly solid inclusions are present; only infrequently gaseous CO_2 inclusions are recorded. Excepting hematite and limonite all other inclusions are of primary origin. The presence of primary inclusions and absence of xenomorphous or resorbed inclusions suggests that the Panna diamonds are "first born" diamonds i.e. they crystallized in the magma-chamber much before their intrusion.

In most of the crystals examined only one type of inclusion is present, but in some more than one type are present. Inclusions occur either as discrete single grains, or in aggregates. Some of the opaque minerals, olivine and graphite are crystallographically the opaque minerals, olivine and graphite, are crystallographically oriented by the host diamonds. So far as inclusions of diamonds are concerned there is no difference in the diamonds of pipe rock and conglomerates occurring in Panna. This therefore indicates that conglomeratic diamonds are derived from pipe rocks.

The unaltered crystal inclusions, which are protected by the diamond host against re-equilibration during the course of their journey from their depth of formation to the present site of emplacement, are the only clues for understanding the original composition of the melt from which diamond crystallized. In the present area the presence of graphite and CO_2 inclusions suggests that carbon in the form of diamond maintained a critical pressure-temperature condition for the formation of these three phases rather simultaneously (*cf.* Das Gupta and Phukan, 1969). Phase-equilibria data combined with geotherm for Precambrian shield and theoretical considerations give an idea about the possible temperature-pressure condition of formation of diamond (Meyer and Boyd, 1969). Meyer (1968) and Meyer and Boyd (1969, 1970) studied the inclusions in diamond in detail and suggested how these can be used as clues for understanding the formation of diamond and the nature of earth's mantle. The mineral inclusions which are found in diamond also form the major constituents of diamondiferous host rock—kimberlite and peridotite but the exact composition of the phases found in the Panna diamond are not known. This information will be of valuable aid as to whether diamond and its

associated altered kimberlite were formed under the same P-T conditions or inclusions in diamond, having been protected by diamond, remained chemically inert to participate in sub-solidus equilibration.

ACKNOWLEDGEMENTS

The author wishes to record her deep sense of gratitude to Dr. E. J. Gübelin who has critically read the paper and offered many valuable suggestions; and also to Drs. A. G. Jhingran and M. V. N. Murthy who encouraged the author to do this work. She is further privileged by frequent discussions with Dr. S. P. Das Gupta.

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THE SCANDINAVIAN DIAMOND NOMENCLATURE

By H. TILLANDER, C.G., F.G.A.

DURING recent years a large amount of work has been done in several countries by organizations acting in close co-operation with the jewellery-trade to draw up correct and practical designations regarding the colour, clarity and cut of diamond. The Scan.D.N. contains terms which appear to be fairly universally accepted. It states a "diamond language" based on the development which has hitherto taken place and attempts at the same time to contribute to the clarification of the problems. A uniform terminology—not only in the Scandinavian countries, but also in places all over the world where jewellers may gradually start using the Scan.D.N.—will no doubt be of invaluable benefit to the legitimate diamond trade, as well as a protection for the public.

In the first instance Scan.D.N. is intended to serve the retail jeweller, who alone is responsible towards his customers, the ultimate diamond consumers. Something of this kind had to be produced, since neither the cutting industry nor the specialized diamond wholesalers and exporters have shown any signs of establishing a universal terminology. In addition the several national nomenclatures and grading standards have either been restricted to membership in the respective organization or provided other barriers, such as expensive travel to tuition centres and language problems.

During a visit to Copenhagen in 1967 the author of this article was shown a draft for a Danish Diamond Nomenclature and found this to be an excellent basis for further development. It was immediately decided to form a Scandinavian committee and to meet for an initial conference in Helsinki in January 1968. Full agreement on an improved draft was achieved. The work was further considered in Sigtuna in October 1968, in Copenhagen in March 1969 and concluded in Oslo in November 1969.

The final draft in English was subsequently submitted to the various Jewellers' Organizations in Denmark, Finland, Norway and Sweden and officially approved as standards in those countries.

In March 1970 the official version—also in English—was printed.

It consists of 52 pages in A-4 format ($11\frac{3}{4}'' \times 8\frac{5}{16}''$) in loose leaves, but is also available in hard plastic binding with each leaf inserted in transparent pockets for everyday hard use.

Gradually editions in some seven other languages will appear. This seems to be an answer to the rapidly increasing requests from retail jewellers for an "instrument" which permits them to acquire detailed knowledge of diamond grading.

There are many instances when a retail jeweller does not know the exact grade of an individual diamond and cannot call for rapid assistance from his supplier. He may have purchased a lot of mixed qualities or perhaps a single stone from a private source. He may also be offered a diamond as part-payment on a larger purchase or have been requested to give an estimate at replacement value.

Scan.D.N. is designed to assist the jeweller in all such cases. A detailed knowledge of all the factors influencing the light-effects, the colour and the clarity will reveal the expert retailer and create confidence. Grading can, however, normally be learned only through a detailed study of the subject and some training. Wherever needed local organizations will no doubt be prepared to arrange courses.

However, one problem will remain unsolved. We cannot expect the entire diamond world to accept Scan.D.N. or in any case every detail of it. Some of the contents must be considered as compromises and therefore of a controversial nature. A world-wide agreement on all details will, no doubt, take a very long time.

The American Gem Society will eventually propose new grading standards for assessing cutting grades and CIBJO plans to form a committee to discuss diamond nomenclatures on an international level.

We also know that there will be many misunderstandings between retailers following the "Scandinavian" rules and their conservative suppliers in the cutting centres. One main reason for this is the divergent conception with regard to several terms, which have different meaning with different suppliers. Another is the varying opinion on quality in different parts of the world. This latter can probably never be entirely overcome. The list of varying opinions on how to grade diamonds could be very much extended, but is hardly of importance in this connexion.

The Scan.D.N. Committee does not expect that their standards will facilitate the purchases of diamonds for the average jeweller, since it feels the diamond business should remain as much as ever possible in the hands of the organized trade. It believes, however, that it will greatly assist the established jeweller in his contacts both with his customers and with his local supplier. In the second instance it is hoped to bring forth some grading service from those dealers who supply retailers in their home communities and who aim to foster the integrity of the whole jewellery trade.

CONTENTS

The Scan.D.N. contains rather detailed rules and definitions on treatment, shape, proportions and weight and it illustrates the standard cut with facet names consequently used in the same form throughout the text as are all other terms as well. The "Scan.D.N. Standard Cut" is shown also on another plate with correct angles and proportions clearly indicated. This shape is further explained in the chapter on Cut—both written and with the aid of diagrams—and indicates acceptable deviations from this theoretical "ideal". This Standard Cut has been designed with a table size of 57·5%, a crown height of 14·6%, and a pavilion depth of 43·1%. The illustration of girdle thicknesses indicates maximum figures for various weights of a diamond within the Scan.D.N. tolerances. Of special interest is that the combination of the figures for crown height, inclination of the upper main facets and table size—which govern the passage of light through the crown—could be properly explained with the aid of a simple diagram.

Scan.D.N. recommends a general use of four grades only for proportions *very good*, *good*, *medium* and *poor*, but the well trained grader is offered the possibilities for further subdivision into as many as 11 subgrades.

Considering the average proportioning of diamonds to-day, the Scan.D.N. grade "very good" should perhaps have been called "exceptional". This would have matched the recent proposal for a German nomenclature where, in practice, "medium" is accepted as "correctly cut". Further the grade "poor" may have been said to be below any honest jeweller's standards. The committee, however, decided for neutrality and thought it better to leave it to the individual jeweller to explain the meaning of every grade according to prevailing conditions in his region.

For diamonds below 0·50 ct the principles of grading are the same as for larger stones, but no other instrument than the 10 × magnifying lens should be used. For this reason the broader grades only are applicable.

Also with respect to colour and clarity one detailed and one broad scale is used, because it was felt that there is no commercial need for very detailed grading of diamonds below half a carat.

The chapter on Clarity includes brief descriptions of the various grades. The clarity symbols—similar to those generally used—are illustrated and described.

The chapter on Colour briefly explains the principles of grading and gives some practical hints. It is based on the largely accepted GIA-system (Gemological Institute of America) with its' scale from "D" to "X" and supplemented by readings from the new Diamant-Photometer, developed in Western Germany, in co-operation with the Scan.D.N. Committee.

At the time of publication of this article, the Diamond-Photometer is not yet generally available and the production of the AGS Electronic Colorimeter has been discontinued. Grading centres and official laboratories in several countries will, however, be in the position to assist jewellers all over the world in their selection of sets of diamonds for their every-day colour comparison work. These sets are the jeweller's tool for grading by eye and involves the comparison of the body colour of the stone being tested with these thoroughly pregraded diamonds, using a light source and viewing technique which will assure the greatest accuracy and reproducibility.

With regard to colour, it may further be said that the Scan.D.N. for the larger sizes (0·50 ct and above) has chosen the following terms although they have been so much misused: River, Top Wesselton, Wesselton, Top Crystal, Crystal, Top Cape, Cape, Light Yellow and Yellow. For the smaller sizes the following terms are introduced: Rarest White, White, Tinted White, Yellowish and Yellow. Each grade is explained in detail.

Scan.D.N. does not attempt to solve all the existing problems, but to provide what is believed to be an exact and detailed enough system available to any jeweller who is seriously interested in the exact grading of diamonds.

ODONTOLITE AND FULGURITES

By G. V. AXON

COLLECTORS know only too well that many items casually dismissed in textbooks prove the hardest to acquire. Surely odontolite is one of these, for how many gemmologists have knowingly seen either cut or rough odontolite? So desperate are some collectors to acquire odontolite that they assume something they have already is the coveted item. Thus one collector supplied the writer with a chunk of white ivory, saying it was odontolite, but without explaining how white material could ever be used as a substitute for turquoise. Another collector assumed that blue silicified dinosaur bone was odontolite even though the large cell structure clearly disqualifies it.

Oddly enough, many gemmologists probably have seen odontolite in small fine blue cabochons in old jewellery, and have assumed, without thinking, that it was fine turquoise. Thus odontolite is worth some slight examination.

Basically, the name tells us what it is, for the "dont" is similar to dental, and the "lite" is, of course, the same as lithography, or stone. So odontolite, as the textbooks tell us, is simply tooth-stone. Here, a question arises, for teeth are associated with ordinary bones, yet as we all know there is quite a difference between an ivory carving and a bone carving. Possibly, then, odontolite is limited to teeth, and not to bones, for the cell structure of bone does not produce the very fine material that can reasonably be used as a turquoise substitute. Clearly, this is the case of the silicified dinosaur bone found in the United States, and it may apply to the bones that could be found alongside true odontolite.

Rough odontolite, especially the curved pieces, show clearly that the enamel, as might be expected, is less receptive to change than the inner tooth, so top quality odontolite of fine blue is found inside, while the outside tooth tends to be whitish.

Alas for the collector, most odontolite seems to come in small pieces, quite cracked and fragmented. No doubt this accounts for

the small cabochons of odontolite. Yet the finest odontolite does not seem to need heat-treatment to bring out the colour. It is already there, in the inside of the tooth that has been fossilized, apatite (mainly) replacing the organic material, and the white of the ivory being changed to fine blue by vivianite.

Odontolite is difficult to cut, from the cracks, so epoxy cement may be needed. Whether odontolite is worth all the trouble it causes to the collector is a matter of opinion, but getting rough and cut odontolite is quite an achievement for many collectors, and the little bits they get are guarded as though they were diamond rough.

Fulgurites are quite different from almost every angle. They can hardly qualify as gem material, but are interesting as examples of natural glass.

They are formed, of course, by bolts of electricity as they strike ground containing silica, as in sand, or, sometimes, clay. They are common in the deserts of the United States, and are collected and sold.

What seems to happen is this: lightning strikes the sand and penetrates some distance in many directions, gradually petering out but only after forming a type of tree root. Later, the wind blows the sand away, revealing the stump of glassy pipe, similar to a lead pipe, hollow, but gradually tapering. Collectors see the stumps in the desert, dig them up, cut them up, and sell them as curiosities. Thus for a dollar or so, a collector can acquire an inch or so of the glass piping known as a fulgurite.

Certainly, fulgurites are not too much to look at, and even these days they would hardly qualify for use in jewelry. Still, they have their interesting aspects, and, like odontolite, are hardly ever seen by the average gemmologist.

Gemmological Abstracts

BANK (H.). *Hochlichtbrechender orengefarbener Korund aus Tansania.* Orange corundum with high refractive index from Tanzania. Zeitschr. d. Deutsch. Gemmologischen Gesellschaft, 1970. 19, 1, 1-3.

These orange-coloured corundums are sometimes erroneously called padparadscha. The author deals with a certain type found in the Umba Valley, the RI being 1·760-1·762 up to 1·768-1·770. Bibliography.

E.S.

BANK (H.), BERDESINKI (W.), OTTEMANN (J). *Durchsichtiger smaragdgrüner Grossular aus Tansania.* Transparent emerald-green grossularite from Tanzania. Zeitsch. d. Deutsch. Gemmologischen Gesellschaft, 1970, 19, 1, 4-7.

These newly found grossularites are green like emeralds and red under the filter, so could easily be taken for emeralds if examined under the filter only. The material has also been sold as chrome-tourmaline, a similar material also found in Tanzania. To avoid confusion the various physical characteristics are given: n = 1·742 to 1·744, S.G. = 3·68 ± 0·01. The chemical formula is $Ca_3Al_2(SiO4)^3$. Bibliography.

E.S.

BANK (H.). *Glasimitationen von Orthoklas und "Jade".* Glass imitations of orthoclase and "jade". Zeitsch. d. deutsch. Gemmologischen Gesellschaft, 19 (1970), 2, pp. 64-66.

Three cut, transparent, light yellow pieces of so-called "orthoclase" from Madagascar were examined and shown to have a RI of 1·52, which could just be within the limits of orthoclase. The material was singly refractive and proved to be glass. This was confirmed by the presence of air bubbles.

Jade in the trade covers a multitude of green stones, although it is only correct to call jadeite and nephrite by this name according to accepted rules. At present there is a glass imitation of "jade" on the market which has an RI of 1·540 and was thought by many to be coloured agate. However, it was found to be glass containing

mainly lead, calcium and copper with traces of iron, manganese a little potassium and zinc. It was therefore determined as a calcium-lead glass.

E.S.

CASSEDANNE (J.). *Euclase in Brazil. Bulletin, Association Française de Gemmologie*, 1970, 24.

A new find of euclase at São Sebastião do Maranhão, Minas Gerais, has become the major producer since 1968. The crystals, which are never more than 8 cm in length, are found in geodes of feldspar or mica, for which latter material the area is principally worked. The colour is white, either clear or milky. Crystals 4-5 cm in length and with a section of 3 × 1 cm, of gem qauality, may fetch up to $100 U.S. at Governador Valadares, the chief gem marketing town in the state.

The author gives a brief review of other euclase-producing sites in Brazil, together with a useful map, bibliography and drawings of euclase crystal habits.

M.J.O'D.

CRONSTEDT (K.). *The Green Vaults of Dresden.* Australian Gemmologist, 1970, X, 9, pp. 14-16.

The history of the Green Vault of Dresden, so named as at first in about 1572 the walls of the vault were green. Until the beginning of the 18th century the green vaults, first envisaged as a museum by Augustus the Strong, were used more as a safe deposit than as a museum. Both during the thirty years war and the Second World war (when the city of Dresden was bombed to destruction in 1945), the treasures, of which there are now some 3,100 works, were taken to the Castle of Konigstein and so avoided destruction. Details are given of a number of the exhibits and of the jewellers who made them. 4 illus.

R.W.

CROWNINGSHIELD (R.). *Developments and highlights at GIA's lab. in New York.* Gems and Gemology, 1969/70, XIII, 4 and 5, pp. 112-122; 156-164.

There is a concise report on flux-grown rubies and mention is made of a suspected artificially coloured opal, and on newer

developments in plastic-treated turquoise. Jade-like idocrase from Pakistan, another case of damage to zoisite, a natural sapphire which fluoresced under short-wave ultra-violet light and a chrome "chrysoprase" (chrome chalcedony from Rhodesia?), a hydrothermally grown pink sapphire and a cultured black pearl which glowed reddish under long-wave ultra-violet light are among a number of items discussed. Others are a chrome aventurine quartz resembling jadeite, elephant tooth ivory, a Tanzanian alexandrite-like garnet and there is further mention of Gilson, Chatham and Zerfass synthetic emeralds. 47 illus.

R.W.

EPPLER (W. F.). *Goethit-Nadeln im Topas.* Goethite needles in topaz. Zeitsch. d. deutsch. Gemmologischen Gesellschaft, 19 (1970), 2, pp. 44-46.

Goethite is an iron ore, more specifically the α form of an iron hydroxite FeOOH, which crystallises in the rhombic system. These crystals are sometimes found as very thin, needle-like inclusions, sometimes slightly bent, in topaz, where they are not distributed throughout the stone, but are numerous in various spots, and not found at all in the rest of the stone. 4 photomicrographs, 1 diagram.

E.S.

EPPLER (W. F.). *Nadelige Wachstumröhren als Einschlüsse in synthetischen und natürlichen Kristallen.* Needle-like growth tubes as inclusions in synthetic and natural crystals. Zeitsch. d. Deutsch. Gemmologischen Gesellschaft, 1970, 19, 1, 8-11 and 22-23.

Coloured photomicrographs show needle-like inclusions in the synthetic emerald of K. Nacken, the Lechleitner emerald and the synthetic hydrothermal emerald of Linde (in one case the needle being parallel to the c-axis, in the second case starting from a phenakite crystal inclusion). Further photographs show needle inclusions in a synthetic crystal which was grown from a lithium molybdate melt, also starting from a phenakite crystal inclusion; the sixth photomicrograph shows a growth tube in a natural emerald parallel to the c-axis and a similar inclusion in a green tourmaline from Brazil is shown. The last illustration shows a kyanite with a needle-like inclusion. The author has a theory regarding the crystal inclusions of needle-like tubes which decrease

in size. A small particle was in the path of the "tube" and was "pushed" in front of the tube to form the needle with the slightly smaller diameter at one end. Bibliography.

E.S.

EPPLER (W. F.). *Der "schwierige" Smaragde.* The "difficult" emerald. Deutsch. Goldsmiede Zeit., 1970, 4, 406-407.

Prof. Eppler discusses the problem of testing emeralds. This used to be easy. It would generally be said that synthetic emeralds had a lower SG than 2·67, natural a higher one; apart from that, the RI at 1·569 was a barrier and one could always make sure by looking at inclusions. Eppler now mentions a few exceptions to the general rule, such as the hydrothermal emeralds as described by Liddicoat and B. W. Anderson. Emeralds from a new source in south Rhodesia are also considered. The stones found there cannot be mistaken for those found in the Sandawana mines. Although the values for SG, RI and birefringence are practically the same as for stones from the Chikwanda mine (also southern Rhodesia), the inclusions are completely different and unlike any found in other emeralds. Eleven photomicrographs are published and explained. The nature of some of the inclusions is not given, some are actinolite, one is apatite and mica inclusions are present. The SG of the new emerald is $2{\cdot}74 \pm 0{\cdot}01$, the RI is n_o 1·590, n_e 1·582 and n_e-$n_o = 0{\cdot}008$. The pleochroism is yellow-green and bluish-green.

E.S.

EPPLER (W. F.). *Das Edelstein-Bild.* The gem photograph. Deutsch. Goldsmiede Zeit., 1970, 4, 409-411.

Articles consisting of four different items illustrated with six photomicrographs. (*a*) Crystal inclusions in rock-crystal. The inclusion in this rock-crystal is a long crystal of tremolite with a double refraction of 0·025, while its host has a DR of 0·009. (*b*) The second crystal is a yellow zircon, from Madagascar, which has a particularly beautiful yellow colour and inclusions. These inclusions were found to be disc-like. The photomicrograph shows a disc which is oval, the longer axis being the c-axis. (*c*) Two illustrations show olivine in diamond. In the first case the olivine is surrounded by a heavy shadow; in reflected light (second illustration) this shadow is seen to be "tears" in the stone. (*d*)

The last two photomicrographs show liquid films in aquamarine. In the first case the liquid film is parallel to the c-axis and vertical to the base. The aquamarine has no cleavage plane in this direction, so must have been a growth disturbance. Further growth disturbances in varying thicknesses are illustrated in the second photomicrograph.

E.S.

FRERE (A.). *Opal-Tripletten.* Opal triplets. Zeitschr. d. deutsch. Gemmologischen Gesellschaft, 19 (1970), 2, p. 63.

Opals are often found in thin plates and these are used to produce opal doublets. Usually in these opals a thin plate of precious opal is fixed onto a lower part of opal of a lesser quality or onto black onyx. Lately a number of opal triplets have been found on the market. When viewed in nitro-benzol one can easily see a thin slice of precious opal (about 0·5 mm.) fixed onto chalcedony or lower quality opal. On top of the opal slice one finds a cabochon-cut piece of rock crystal. The advantages of this type of triplets are the ease of setting the stone and the hardness of the surface. The disadvantages are a glassy look and a slightly hazy play of colours.

E.S.

FRYER (C. W.). *Non-fluorescent high-property synthetic emeralds.* Gems and Gemology, 1969/70, XIII, 4, pp. 106-111.

A comprehensive report on the Gilson synthetic emerald illustrating the change in characters of this firm's more recent production. Eighteen unmounted stones were examined of which seven were found to be non-fluorescent; six fluoresced red and five orange-red comparable to the first recorded fluorescence characters of Gilson emeralds. These last five stones had refractive indices of 1·564-1·569 (0·005), a density of 2·65 and typical flux-fusion inclusions with phenacite crystals. These stones had a yellowish-green colour. The remaining stones were bluish-green in colour, six of which fluoresced red and had a refractive index of 1·562-1·567 (0·005/6), a density of 2·65 and had typical flux-fusion inclusions. The other seven stones had refractive indices of 1·571-1·597 (0·008) and a density of 2·68/9. The inclusion of iron is said to be the cause of the change of characters. Confirmation of this notion is by the line at 4270Å which is seen in the absorption spectrum of these stones, and by the opacity of them to x-rays. 9 illus.

R.W.

JARVIS (A. T. C.). *A brief account of the search for diamonds in Australia.* Australian Gemmologist, 1970, X, 10, pp. 31-32.

A historical survey of the finding of diamonds in Australia. Diamonds have been known in Australia since 1851, and have been found in all the States of Australia, including Tasmania.

R.W.

LIDDICOAT (R. T.). *Developments and highlights at GIA's lab. in Los Angeles.* Gems and Gemology, 1969/70, XIII, 4 and 5, pp. 123-133; 148-155.

Synthetic emeralds, a diamond with an unusual spectrum, synthetic yellow and green sapphires and synthetic quartz from Russia are mentioned. A carving in a pure white-green flecked material was identified as diopside. A number of rare stones were examined in this laboratory and these included augelite, creedite, whewellite and simpsonite. Opals of low density which had been treated with black plastic are reported upon. An alexandrite-like synthetic spinel, vegetable ivory and a cat's-eye and a star-peridot have been examined. 34 illus.

R.W.

MCCOLL (D.). *A method for differentiation of natural and synthetic yellow sapphires.* Australian Gemmologist, 1970, X, 11, pp. 9-11.

A discussion of the use of the x-ray spectrograph as a tool for detecting synthesis in yellow sapphire. The criterion is that nickel is generally present in synthetic yellow sapphires and is not present in natural yellow sapphires. A few synthetic yellow sapphires were found which did not show a nickel content but other metal oxides, but these had not been explored at the time of writing the article. 2 illus.

R.W.

NASSAU (K.) and JACKSON (K. A.). *Trapiche emeralds from Chivor and Muzo, Colombia.* Lapid. journ., 1970, 24, 1, 82.

An outline of a detailed examination given in the *American Mineralogist* (55, March-April, 1970) of two types of trapiche emeralds from the Chivor and Muzo mines in Colombia.

S.P.

OUGHTON (J. H.). *Yellow sapphire: natural or synthetic.* Australian Gemmologist, 1970, X, 11, pp. 5-8.

The problem of the determination of yellow sapphires is discussed and methods of testing suggested. The Plato effect is considered as requiring too much expertise. For the average worker more reliance could be placed on the transparency to ultra-violet light. There are some synthetic yellow sapphires which do not follow the ordinary laws postulated and the behaviour of such stones is discussed. A table is given of the various types of yellow sapphires.

R.W.

POUGH (F. H.). *Giant emerald crystals found in Brazil.* Lapid. Journ., 1970, 24, 6, 840.

A concise report about large emerald crystals occurring in the Carnaiba district of Brazil. Their colour is due, probably wholly, to their chromium content, though the abundance of iron inhibits the appearance revealed by Colombian stones under an emerald filter. Dr. Pough indicates that production of the better-coloured Colombian emeralds is minimal and that most of these stones reach the markets by unreliable and devious routes.

The Brazilian Carnaiba crystals provide moderately priced emeralds of acceptable size. An attempt is being made to cut calibrated stones mechanically.

A new African occurrence is reported to be at the Mufulira Mine in Zambia. It is suggested that there is a great potential in Africa for a variety of gemstones.

S.P.

ROLFF (A.). *Gem news from Brazil.* Lapid, Journ., 1970, 24, 3, 514.

Opal, similar to the blue Australian type, has been found in northern Brazil (Piaui State) together with fire opal. The alluvial diamond deposits of Brazil are well-known, but geologists are believed to have located the first diamond pipe deposits to be recognized in Brazil. The report is not confirmed. Aquamarines have been found in the Teofilo Otoni area.

S.P.

SAROFIM (E.). *Gem rich Tanzania.* Lapid. Journ., 1970, 24, 3, 434.

A brief survey of the gem materials occurring in Tanzania. Diamond is the most important stone, with small amounts of rubies and sapphires, garnets and tourmaline. Demand for the recently discovered transparent zoisite exceeds supply and monthly production is about two kilos. The author does not refer to heat-treatment of the material. Other stones are found and there would appear to be a great potential in the country.

S.P.

SCHIFFMANN (C. A.). *A Geological Curiosity*, Schweizer Goldschmied, Aug. 1969, 8.

In 1968 a geological curiosity was discovered which gave rise to certain Swiss newspapers reporting that they were "black fossil pearls of great beauty and great worth". The items were found in the upper marine Swiss midland in a phosphoritic layer rich in alpine water-worn pebbles. The spheres may have had an organic or inorganic origin. It seems likely that the Bernese nodules possibly had an animal origin because echinids have been found in the same vicinity, and excremental balls from these are known. The spheres seem to have been impregnated with calcium phosphate during or after the time of their deposition.

S.P.

SUZUKI (S.). *A new design for brilliance plus dispersion.* Aust. Gemm., 1970, 10, 10, 13.

Brilliant-cut gemstones are often designed purely for brilliance, and colour dispersion is regarded as incidental. As a consequence it is generally believed that not much colour dispersion can be expected in stones with lower refractive indices (lower than say 2·0). It is true that stones with higher refractive indices show more or less satisfactory colour dispersions (due to their inherently larger relative dispersions) even if they are cut for brilliance. And stones with lower R.I. do not exhibit enough dispersion even when cut in what is called the "dispersion design". However, colour dispersion is still a desirable feature for lower R.I. stones as well (except in special cases such as ruby), and it should be quite advantageous if we can bring out more colour dispersion than is obtainable from such lower R.I. stones with current designs.

A new design concept called the "double dispersion design" has been developed, in which dispersion comparable to those usually obtainable only in higher R.I. stones can be achieved in lower R.I. stones without much loss of brilliance.

The double dispersion design brings out a quite distinctive dispersion, without sacrificing the brilliance very much in medium to low R.I. materials for which the current dispersion design is not effective. It is believed that this new design establishes an approach towards the improvement of the design of the standard brilliant cut.

S.P.

TILLANDER (H.). *Diamantgraduierung nach der Skandinavischen Diamant-Nomenclature.* The graduation of diamond according to the Scandinavian standards. Zeitschr. d. Deutsch. Gemmologischen Gesellschaft, 1970, 19, 1, 14-20.

This article deals with one brilliant of 0·32 cts which was carefully classified according to the standard. Four illustrations and three sketches to show how faults, etc. should be marked.

E.S.

TOMBS (G. A.). *Zircon phenomena.* Australian Gemmologist, 1970, X, 10, 26.

A report on an Australian brown zircon which faded on being subjected to a low heat but which returned to its original colour after twenty minutes exposure to sunlight.

R.W.

TRIPP (E. J.) and HERNANDEZ (L. H.). *The complete trapiche emerald picture.* Lapid. Journ., 1970, 24, 1, 97.

An account of the cutting of gems from trapiche emeralds. Pena Blanca and Muzo are mentioned as sources of the emeralds.

S.P.

WEBSTER (R.). *Forensic problems in jewellery.* Australian Gemmologist, 1970, X, 9, pp. 7-13.

An article reprinted from the Criminologist, an English journal dealing with forensic sciences. (Abstracted Journ. Gemmology, 1968, 11, 2, 56.)

P.B.

WOLF (R.). *Look through your magnifying glass.* Australian Gemmologist, 1970, X, 11, pp. 29-30.

A useful article discussing the use of the hand lens in identification of gemstones. What to look for and how to do it.

R.W.

ZEITNER (J. C.). *All American gems.* Lapid. Journ., 1970, 24, 2, 300.

Brief descriptions of gems discovered in America, including morganite, goshenite, kunzite, hiddenite, benitoite and rhodolite. These are the major gems of faceting quality. Others include danburite, bowenite, williamsite, californite, as well as accepted varietal names of other species less well known to the gemmologist.

S.P.

BOOK REVIEWS

Scandinavian Diamond Nomenclature and Grading Standards. Scan. Jewellers' Assns., c/o Tillander, Helsinki. 1970. £7.

A detailed nomenclature for the designation of diamonds. The term "inclusion" is sensibly used instead of the outmoded "imperfect" for describing internal characteristics. There is a comparison of different colour-grading systems, the Scandinavians preferring to use names, e.g. top crystal, crystal, top cape, instead of the alphabetical and numerical systems used in the U.S.A. The nomenclature contains rules for grading and clarity and gives tolerances of the standard cuts for diamond. The informative chapter on clarity, with many helpful illustrations, comprises about half of the nomenclature and it is unfortunate that this chapter was separately published in 1969 at a low price, which now makes the cost of the complete work very expensive.

The Scandinavians are to be congratulated upon formulating a nomenclature which will undoubtedly influence diamond grading language in other countries.

S.P.

Mineral Digest (the Journal of Mineralogy). New York. $12.00 per annum (foreign $16.00) published quarterly.

A new Journal devoted to gem minerals and gemstones with many excellent colour illustrations some of which have been published elsewhere. First contributors include Messrs. P. E. Desautels, F. H. Pough and J. Sinkankas. The aim of this new Journal is to encourage the organized production of the wealth that nature has created and to assist in all who work and deal in those products to obtain fair value for the raw and fabricated materials.

S.P.

PERRY, NANCE and RON. *Australian Opals in Colour*. A. H. and A. W. Reed, Sydney, 1969, 112 pages. £2 5s. 0d. (£2.25).

Dedicated to the people of the opal fields of Australia, this book is a companion to the authors' very popular Australian *Gemstones in Colour*. After an introduction and a glossary, the different opal fields of the continent are covered in detail, with maps and coloured illustrations of the type of opal to be found in each. Means of access to each area are described in detail and interesting vignettes of life in opal mining communities help to bring the life of the opal miner closer to the reader.

The chapter on the nature and origin of opal covers the CSIRO discovery of the cause of the play of colour; the first time this has been mentioned to my knowledge in a book. The different methods of cutting are well-described and illustrated, in particular the method of making doublets and triplets. In this connexion the gemmologist should note the recent appearance of "schnapper-skin triplets" which contain no opal but consist of a layer of fish skin with red or blue dye mixed with the cementing agent. They may be detected by the skin showing grey at the girdle when examined with a lens, and also by the false hues of the reds. Another seldom-treated aspect of opal use is shown in the section on the treatment of matrix opal. The book ends with the method of setting opal chips in plastic containers. These have been seen in this country and although not unattractive, would hardly pass for solid opal.

There are 86 illustrations in colour and the quality is high, particularly so when one remembers earlier attempts to photograph

this gemstone. This book should certainly be found in the collection of every gemmologist.

M.J.O'D.

SAKIKAWA, NORIYUKI. *Jade.* Japan Publications Inc., Tokyo, 1968. 61 pages. £1 10s. 0d. (£1·50).

The author is a professor at the Tokyo Institute of Technology and an authority on gemstones. This is a well-illustrated and accurate book dealing with the jade minerals and their commoner simulants.

Dr. Sakikawa opens with a general summary of the jades and then goes on to treat jadeite and nephrite in separate chapters. He mentions the history of the use of jade and the methods of mining and then deals with the present-day distribution of the best material. An interesting comment is that although the United States Customs forbid the import of jade (at the time of writing) as it is held to be of Communist Chinese origin, in fact Burma jadeite reaches the Western market from Rangoon via Japan or Hong Kong.

Another interesting note mentions magatama, the jadeite found in the Itoi River area of Japan. It was formerly thought that the objects dating from AD 250-552 found in burial mounds were of Chinese origin, but archaeologists now believe that the material is Japanese.

Dr. Sakikawa ends with notes on the commoner jade simulants. Among these is "meta-jade", a material made synthetically and belonging to the actinolites. A colouring agent and an unnamed chemical which induces the formation of crystals are added to a mixture of fused quartz and alumina. The material has been made in green only and has a hardness of 5·5 and a lower density than jadeite though the figure is not given.

The illustrations, in particular those in colour of imperial translucent jadeite are excellent, and the book closes with a distribution map.

M.J.O'D.

ASSOCIATION NOTICES

Presentation of Awards

AUSTRIA, Belgium, Canada, West Germany, Holland, Norway, Sweden and Spain were all represented at the Gemmological Association presentation of awards, at Goldsmiths' Hall, Foster Lane, London, on 16th November. The chairman Norman Harper welcomed all who attended and especially mentioned Senor M. Masso, President of the Spanish Gemmological Association, and Professor M. Font-Altaba and Dr. J. M. Bosch Figueroa of the University of Barcelona, where gemmology had now been made a faculty subject.

In his opening address, Mr. Harper said it had become a habit to say, "This year we have broken all records for the number of examination candidates, and, again, I have got to say it this year, when 811 people sat the examinations."

Mr. Harper mentioned that it was the first year that a Gem Diamond Course had been held in Spain and went on to say that the Gem Diamond Course in Birmingham, the first of the Gem Diamond Courses, had temporarily ceased through lack of support. He then introduced the Prime Warden of the Worshipful Company of Goldsmiths', Ivan Tarratt, a Fellow of the Gemmological Association, and the first Fellow to become a Prime Warden.

In the talk he gave following the presentation of awards, Mr. Tarratt said quite a lot had happened since one evening in the 1930's, when he went along to the Royal Society of Arts, at the Adelphi, to receive his diploma. The number of people attending on that occasion was very few, because only a few people enrolled at all to take the examinations. He said it was very obvious to him that the amount of knowledge acquired now was so much greater than that able to be acquired in the 1930's. Although the course

was basically the same, it had been broadened and lengthened. Also very important was the sort of practical training provided now, it was so much more organized.

He continued by saying that it was never more important than the present time that people in the trade should have gemmological knowledge. The law in Britain was very tough about wrong identification of gem stones, and the continued demand for gemstones meant that everyone was having everything revalued, and those people revaluing gemstones realized just how difficult and tricky this could be.

The Prime Warden said that it seemed to him that the GA had become so united—almost a United Nations, and the international character of what had become the established science of gemmology was truly remarkable and the letters FGA meant something in every part of the world.

Having told his audience that he considered it impudence on his part to continue to talk about gemmology, Mr. Tarratt then spoke about livery companies, saying that while many people had visited the Hall in which they were now seated, "and many of you must have wondered what this 'funny' sort of medieval institution is all about?"

There were he said something like 84 institutions such as the Goldsmiths' Company in the square mile around the Hall. Known as livery companies from their inception up to the present time, they were known as such because in medieval times if a person was a member of one he wore a sort of uniform, or livery to denote the company that he belonged to. The livery was still worn today,said Mr. Tarratt, for special occasions.

The Goldsmiths' Company began shortly after the Norman Conquest, about 1080 AD. Most of the companies were very old, but a few, just a few, had been formed more recently. All the companies began life as a guild by persons in a trade or a craft, to protect themselves and to pass information to each other. They arranged such matters as taking on apprentices and to prevent wrong practices taking pace in their craft. Admittance to a company was afforded to those people of some integrity and misdemeanours were rewarded by expulsion.

No one had really been able to work out the seniority of the companies, there were, however, said Mr. Tarratt, what were known in rather an arrogant way as the 12 great companies, but

they were the oldest and the biggest and started with the Mercers' Company; the Goldsmiths' Company was numbered fifth.

It was the custom in the beginning for members when they died to leave a legacy of money, or a token, or a piece of land in the City of London, and by the time of the middle ages the companies had become very wealthy.

The Lord Mayor of London was elected by the livery companies at a meeting in the Guildhall each year, and the election was done only by a show of hands. When other facilities were lacking, the livery companies made arrangements for charities and education by forming trusts, some of which remained in existence today.

Some of the companies continued to maintain an interest in their craft, and from 1300 AD the Goldsmiths' Company had been required to mark all gold and silver articles to show such articles were up to the required standard. The Company had an Antique Plate Committee to which jewellers could refer when they were uncertain about a certain piece of plate or suchlike in their possession. Also, there was the Technical Advisory Committee advising on matters of technical importance to manufacturers. A third committee was known as the Craft Advisory Committee, and it was the one that really concerned every one listening to him for it set out to promote good relations between the trade and its customers. It also sought out young men and young women designers of talent, to give them every encouragement to ensure that they became established, and which had produced trends in jewellery which the world was noting.

The Company had a magnificent library of books and photographs taken over the last 20 years and also a collection of colour slides, all of which were there to be used and borrowed by members of the trade.

Mr. Tarratt concluded his talk by saying that the Company was truly democratic, for he had come up through the ranks, so to speak. Also, every fourth year there had to be a jewellery craftsman or trader as the Prime Warden.

Mr. Norman Harper thanked the Prime Warden and through him the Company for the facilities granted to the Gemmological Association at the Hall throughout the year. Mr. Harper then turned to an entirely different subject, the retirement of Dr. G. F. Claringbull as an examiner since 1938. Dr. Claringbull's connections with the Association went back to the days when Dr.

George Herbert Smith was president. The standard of gemmological training throughout the world was, said Mr. Harper, due to the consistently high standards demanded by Dr. Claringbull and other examiners. To mark his long and devoted service the Association had decided to give him a piece of silver to start off his collection, and it was understood it was his intention to make some of his own when he retired.

In a witty reply Dr. Claringbull said he had two things to say—having been got on to this platform for a most pleasing surprise—one was that the reason he had been associated with the Association for so long was the very friendly nature of the people he had had to deal with, particularly Basil Anderson, another examiner. The other thing was the very high standard they had been able to maintain despite pressure from certain sections of the trade which had pointed out that the knowledge of about five gemstones was all that was required. The examiners had resisted the demand for standards to be reduced. The need for gemmological knowledge was still there however for, said Dr. Claringbull, it was not many months ago that one could see in a shop in South Kensington a sales ticket which read "a real pearl necklace made by captive oysters."

MEMBERS' MEETINGS

London

A meeting was held on the 9th October, 1970 at Goldsmiths' Hall in conjunction with the British Academy of Forensic Sciences, when the following talks were given: Mr. J. S. Forbes, B.Sc., F.R.I.C., Deputy Warden of the Worshipful Company of Goldsmiths and London Assay Master, on "Forged hallmarks", and Mr. E. G. V. Newman, O.B.E., B.Sc., Chemist and Assayer to the Royal Mint on "Forged sovereigns".

Mrs. N. Armstrong gave a talk on "Late Georgian and Victorian Jewellery" at Goldsmiths' Hall on the 28th October, 1970.

Midlands

At a meeting held on the 10th September, 1970, Mr. R. Webster, of the London Chamber of Commerce Gem Testing Laboratory, gave a talk on modern synthetics illustrated with colour slides.

On the 20th September, 1970, an outing was arranged for members of the branch to the Tower of London for a private viewing of the Crown Jewels. After lunch members visited the museums at South Kensington.

A talk was given on the 19th November by Mr. G. Tomlinson on "Precious Metals in the Jewellery and Other Trades". The film "Precious Metals in Industry" was shown.

Scotland

A talk was given on the 8th October at the Kelvin Art Gallery and Museum on the organization of the proposed exhibition of gemstones to be held at the Museum during autumn 1971.

The films "Diamonds" and "One Hundred Million to One" were shown at a meeting of Scottish Branch members on the 16th November, 1970, at the Station Hotel, Perth.

GIFTS TO THE ASSOCIATION

The Council of the Association is most grateful for the following gifts:

Various mineral specimens from Mrs. E. Rhoda Blyth, Nanaimo, British Columbia, Canada.

A portable gem microscope and copies of the Japanese Association's *Journal of Gemmology*, from Mr. A. Chikayama, F.G.A., Director General of the Gemmological Association of All Japan.

A pocket book on *Precious Stones and Pearls* from Dr. Hermann Bank, Idar Oberstein.

A gift of samples of ruby corundum from a mine in Brazil from Mr. Julio Tanjeloff, President of Astro Minerals and publisher of the *Mineral Digest.*

An illustrated book on jewels in colour published by the Shobido Jewelry Company.

A sapphire crystal from the town of Sapphire in central Queensland, Australia, from Mr. K. Parsons, Plympton, Devon.

A tektite from Mr. K. Narayamamuthy, Pahang, Malaya.

GEMMOLOGICAL EXHIBITION

The Scottish Branch of the Association, in co-operation with the Glasgow Museums and Art Galleries, is arranging a gemmological exhibition at the museum during the last two weeks of

September and first two weeks of October, 1971. The Secretary of the Branch, Mr. G. Turner of "Kimberley", Grahamshill Street, Airdrie, Scotland, would welcome offers of any interesting gemmological exhibits which members might care to lend for the period.

NEW PUBLICATION

Bruton, E. *Diamonds*. N.A.G. Press Ltd., London, 1970. £5 (postage and packing, U.K. 4s. 0d. (20p). The only book in the English language which deals with the important aspects of gem diamonds (to be reviewed April 1971).

GEM DIAMOND EXAMINATIONS, 1970

There were 38 entries for the 1970 Gem Diamond Examination arranged by the Gemmological Association of Great Britain. The following is a list of successful candidates arranged alphabetically:—

QUALIFIED WITH DISTINCTION

Hawthorn, Graham, Solihull
Russell, Lionel Harold, London
Sancho Canto, Jaime, Barcelona, Spain

QUALIFIED

Ali, Nasim, Sutton
Arbunies Andreu, Manuel, Barcelona, Spain
Arla Felisart, Ramon, Barcelona, Spain
Armengol Abril, Emilio, Barcelona, Spain
Baguena Ruiz, Carlos, Barcelona, Spain
Brennan, John Douglas, Birmingham
Burwood, James Raymond, Wolverton
Castro Ferrer, Jaime, Barcelona, Spain
Clarke, Doreen Patricia, Camberley
Collingridge, James William, Tonbridge
Deeks, Noel William, Luton
Farras Sole, Jose, Barcelona, Spain
Ferneyhough, Miles Howson, Solihull
Grey, Alan Peter, Weybridge
Hird, Frank, Sheffield
Hundy, Christopher Leslie, Sutton Coldfield
Jefferis, Marcia Nicoletta, Watford
Pitt, Nicholas Charles Hamilton, Stourport-on-Severn
Pye, George Anthony, Brierley Hill
Rae, Francis Carl, South Harrow
Rouvier, Andre Edmond, London
Sancho Canto, Maria Pilar, Barcelona, Spain
Shipster, Thomas Reginald, Brighton
Stewart, Reginald William, Bickley
Torrents Domenech, Thomas, Barcelona, Spain
Traveria Cros, Adolfo, Barcelona, Spain
Vaughan, Susan Josephine, London
Villegas Sanvicens, Cesar, Barcelona, Spain
Walker, Patricia Joan, London
Watson, Vivian Peter, Northwood Hills
Wright, William Anthony, Potters Bar

EXAMINATIONS IN GEMMOLOGY, 1970

In the 1970 Examinations in Gemmology organized by the Gemmological Association of Great Britain, 510 candidates sat for the preliminary examination and 301 for the diploma. Centres were established in many parts of the world and the number of entries for both examinations was again very high.

Upon the recommendation of the examiners, neither the Tully Memorial Medal nor the Rayner Prize has been awarded.

The following is a list of successful candidates arranged alphabetically:—

DIPLOMA EXAMINATION

QUALIFIED WITH DISTINCTION

Alabaster, Wendy Jane, Birmingham
Allardyce, Anthony Stanley, Maidenhead
Berger, Roland, Ludwigsburg, (Wurtt.), Germany
Enkovaara, Maarit, Barcelona, Spain
Esteve Vila, Vicente, Barcelona, Spain
Figueras Calsina, Jorge, Barcelona, Spain
Fuente Cullell, Carlos De La, Barcelona, Spain
Garcia Gimeno, Jose Luis, Zaragoza, Spain
Hawes, John, Wakefield
Hayward, Richard Alan, Port Talbot
Heather, John Christopher, London
Holmes, Brian Michael, London
Jones, George Harrison, Burnham
Jornet Vila, Enrique, Barcelona, Spain
Just Chova, Jose Vicente, Valencia, Spain
Laub, Theodore, Johannesburg, S. Africa
Laug, Monika, Munchen, Germany
Lewin, David Alexander, Loughton
Marti Girona, Maria Montserrat, Barcelona, Spain
Miller, Stanford, Nashville, Tenn., U.S.A.
Pichon, Jean Daniel, Geneva, Switzerland
Pie De Masso, Rosa Maria, Barcelona, Spain
Raper, Frederick M., Toronto, Canada
Ricart Ribera, Arturo, Barcelona, Spain
Romero Fournier, Maria Del Carmen, Barcelona, Spain
Ruckli, Robert, Lucerne, Switzerland
Sallan Lopez, Rafael, Zaragoza, Spain
Schullin, D. Hans, Graz, Austria,
Shepherd, Naomi, Reading
Thomas, Arthur Ernest, Salisbury, Rhodesia
Thurgar, Stanley Hughes, Burlington, Ont., Canada
Warrington, Harold G., Toronto, Ont., Canada
Wight, Willow, Chambly, Quebec, Canada

Aas, Einar Eriksen, Trondheim, Norway
Ahmad, Syed Vaqar, London
Alahendra, Anandapala, London
Allen, William, Newcastle-Upon-Tyne
Anderson, Leonard John, East Barnet
Andres Barbera, Manuel, Valencia, Spain
Arla Felisart, Francisco, Barcelona, Spain
Arnoldi, Regine, Idar-Oberstein, W. Germany
Aung, Myint, Rangoon, Burma
Aye, Swae Swae, Rangoon, Burma

Baro Duran, Valentin, Barcelona, Spain
Bartlett, Stewart Michael, Eccles
Beaver, Francis Bertram, London
Beck, Russell Joseph, Invercargill, New Zealand
Belenke, Burton, Miami, Fa., U.S.A.
Benson, Ian Thomas, Manchester
Brand, Jonathan David, Stellenbosch, S. Africa
Burke, Winifred Mary, Bexleyheath

Campbell, Ian Colin Cecil, Bulawayo, Rhodesia
Challis, Peter James, Liverpool
Chalmers, William Andrew, Manchester
Chapman, Ross Noel, Thundersley, (Essex)
Clark, John, Lewes
Clavaguera Duran, Ricardo, Barcelona, Spain
Cobden, Felix Sydney, London
Cucurella Comellas, Ignacio, Barcelona, Spain

Differenz, Gabriele Monika, Bad Homburg, W. Germany
Doi, Yoshiko, Los Angeles, Calif., U.S.A.
Driver, Olive, Bexleyheath

Edwards, Janet Roberta, Bebington
Elfatatri, Abdel Ghani Abbas, Leiden, Holland
Emmanuel, Peter John, Croydon
Eyre, George, Buxton
Ferrer Tor, Maria Luisa, Gerona, Spain
Folch Bru, Rosendo B. Barcelona, Spain
Foster, Susan Ellwood, Toronto, Ont., Canada
Fraleigh, Ronald A., Toronto, Ont., Canada
French, Donald Peter, Colchester
Gold, Stewart D., Fergus, Ont., Canada
Grau Roca, Manuel, Barcelona, Spain
Gregory, Jack, Barnsley
Grist, Nigel, Sheffield

Haag, Susanne Renate, Kirschweiler, W. Germany
Hague, Judith Elizabeth, Stockport
Harding, Jeremy Lance, Copthorne
Hayes, John Ernest, Altrincham
Heetman, J. A. M. Th., Rotterdam, Holland
Heyes, Alan John, Lancing
Hill, Brian Douglas, Chatham

Jayasundera, Amarasekera Bandera, Badulla, Ceylon
Jones, Claire Patricia, Redhill
Jones, Denise May, Liverpool

Klocke, Christel Elvira, Rexdale, Ont., Canada
Ko, Aung, Rangoon, Burma
Kuge, Georges, Gent, Belgium

Levy, Hanukah, London
Lewin, Persephone, Loughton
Lieben, Christl, Vienna, Austria

Macdonald, Robert Charles, Hebden Bridge
Macfarlane, Alan Taylor, Glasgow
Mark, Malcolm David, London
Marthinsen, Elise, Tonsberg, Norway

Martin, Nancy Jean, Heidelberg, Australia
Mawson, Alan, Crewe
Mercade Galles, Jaime, Barcelona, Spain
Mertens, Rudolf, Idar-Oberstein, W. Germany
Miller, Elva E., Brentwood, Tenn., U.S.A.
Miro Bauza, Antonio, Manacor, Spain
Nadal Cerezo, Antonio, Barcelona, Spain
Nalliah, Selliah, Colombo, Ceylon
Nicolau Marti, Margarita, Barcelona, Spain
Nicolau Santasusagna, Ramon, Barcelona, Spain
Noakes, Norman De Berri, Auckland, New Zealand
Nuttall, Miranda, London
Parsons, Richard Frank, Chorley Wood
Pearce, Joan Emery, Liverpool
Phillips, Joan Doris, Manchester
Pickering, John Pearce, Port Noarlunga, S. Australia
Platts, Jean Isabel, Sheffield
Pollak, Charles John, New York, U.S.A.
Prada Sampedro, Jose, Barcelona, Spain
Prats Ballester, Juana, Barcelona, Spain
Ramon Rius, Carlos E., Barcelona, Spain
Reich, David K., Tunbridge Wells
Rigau Mestre, Francisco Javier, Barcelona, Spain
Rosner, Marc, Pacific Palisades, Calif., U.S.A.
Saing, Aung Sein, Rangoon, Burma
Sharman, Avril Faith, Plymouth
Snipper, Alison, London
Standard, Alan Kimball, Hawkinsville, Ga., U.S.A.
Stevens, Ronald Claude, Auckland, New Zealand
Stitt, Hamilton William, Montreal, Quebec, Canada
Stokoe, Colin Edmund, Wallsend
Tannum, Bjorn, Fredrikstad, Norway
Templeton, Paul Thomas, Oxford
Torndahl, Arne, Stockholm, Sweden
Troften, Irja, Sarpsborg, Norway
Wai, Minn, Rangoon, Burma
Walkey, Albert James, Ellesmere Port
Warrington, Mairin T., Toronto, Ont., Canada
Weerasinghe, Gamani Bandula, Ratnapura, Ceylon
Wharton, Stuart, St. Albans
Whatton, Edwin Albert, Sutton Coldfield
Wijeratne, Chandrakumara K., London
Wilson, Robert Henry, Caterham
Win, Win, Rangoon, Burma
Wolstenholme, Lawrence Edward, Sheffield
Wood, Robert Matthew, Peterborough
Zarook, Mohamed Hazim, Matara, Ceylon

Preliminary Examination—Qualified

Abellan Lopez, Adela, Barcelona, Spain
Adams, Michael Edward, Middlesbrough
Addis, R. C., London
Aguilar Cabezon, Javier, San Sebastian, Spain
Aho, Matti, Helsinki, Finland
Allum, Christopher, Nottingham
Allum, Peter Dennis, Shaftesbury
Alm, Eila, Riihimaki, Finland
Alm, Rudolf, Hyvinkaa, Finland
Alonso Fernandez, Elena, Leon, Spain

Altaba Artal, Maria Dolores, Barcelona, Spain
Anderson, Arthur Alfred, Guildford
Andres Barbera, Jose, Valencia, Spain
Anttila, Aimo, Lintuvaara, Finland
Ashbaugh, Maurice Donald, Upper Heyford, (Oxon)
Astrain Calvo, Rafael, San Sebastian, Spain
Aung, Myint, Rangoon, Burma
Aye, Mya Mya, Rangoon, Burma
Aye, Swae Swae, Rangoon, Burma
Backshall, Henry George Robert, Hainault
Balmaseda Fernandez, Javier, Palma De Mallorca, Spain
Beach, Rowan Michael, Twickenham
Berger, Roland, Ludwigsburg, (Wurtt.), Germany
Bjorudaleu, Jan, Oslo, Norway
Blakey, Linda, Warley
Blanco Artigues, Jose Maria, Lerida, Spain
Bonnin Valls, Vicente, Palma De Mallorca, Spain
Borgatta, Edgar F., Madison, Wis., U.S.A.
Borge, Grethe, Lillestrom, Norway
Boyce, Anthony James, Doncaster
Bradford, K. J., Westcliff-on-Sea
Bradley, Christina Susanna, Didcot
Brown, Jonathan Philip, Derby
Brumann, Hans R., Makati, Philippines
Buckley, Peter Ross, Halifax
Burgin, Derek Arthur, Nottingham
Butcher, Kathleen Mary, Sudbury
Camberg, Gerald Selwyn, Johannesburg, S. Africa
Cameron, John, Glasgow
Canudas Martinez, Jaime, Palma De Mallorca, Spain
Carballal Cirici, Carmen, Barcelona, Spain
Carter, David Marwood, Sidmouth
Chalk, Christopher Sean, Gillingham
Chapman, Philip Rowland, Luton
Chapman, Ross Noel, Thundersley, (Essex)
Child, Dominick, Warwick
Chlupacek, Joseph M., Gary, Ind., U.S.A.
Christie, Rosalind Seaton, London
Clarke, Anthony Everitt, Northampton
Clowry, Raymond Vincent, London
Coll Llobera, Pedro, Palma De Mallorca, Spain
Collins, Joseph Wray, Niagara Falls, Ont., Canada
Comely, Christopher Norman, Dorchester
Conesa Landines, Bernardo, Barcelona, Spain
Contreras Vila, Pedro, Barcelona, Spain
Cotton, John Alan Day, London
Cox, David Arnold, Doncaster
Coxon, Andrew Michael, London
Crossley, Roy, Halifax
Curry, Harold L., Eugene, Oregon, U.S.A.
De Bruin, Alphonsus Gerardus, London
Delange, Elizabeth Bellville, S. Africa
Dhupalia, Shamsuddin Mansuralli, Paris, France
Dickenson, John W., Liverpool
Doi, Yoshiko, Los Angeles, Calif., U.S.A.
Duley, Roy T., San Diego, Calif., U.S.A.
Dyson, John Allen, Elland, Yorks.
Ebbs, David Crispin, Meols, Cheshire
Etch, Motowo, Osaka, Japan
Ellard, John Eric, Wigan
Ferguson, Louisa, Glasgow
Fernando, M. Padmasiri Noel, Moratuwa, Ceylon
Fernando, S. U. H., Moratuwa, Ceylon

Figueras Calsina, Jorge,
Barcelona, Spain
Fish, Simon Timothy,
Durban, S. Africa
Forbes, Brian Winston Travers,
Johannesburg, S. Africa
Fraleigh, Ronald A.,
Toronto, Ont., Canada
Fransein, Eldon E.,
West St. Paul, Minn., U.S.A.
Frazao, Maria Luiza,
Lisbon, Portugal
Frontera Serra, Onofre,
Palma De Mallorca, Spain
Fukabayashi, Hiroyuki,
Hokkaido, Japan
Fuster Domenech, Jaime,
Palma De Mallorca, Spain
Fuster Fuster, Cayetano,
Palma De Mallorca, Spain
Gallon, Russell, London
Gammage, Michael John Ellis,
Northwood
Ganster, Doris Erlene,
Pico-Rivera, Calif., U.S.A.
Gardiner, Anthony Cluff,
Abadan, Iran
Garrido Ballesteros, Dolores,
Palma De Mallorca, Spain
Garrido Ballesteros, Maria Jose,
Palma De Mallorca, Spain
Gatie, Adrian Patrick, Leeds
Gelaberto Vilagran, Enrique,
Barcelona, Spain
Geyer, Adrian Michael, Birmingham
Gillings, Michael, Manchester
Goadby, John Barrie, Birmingham
Godfrey, Fraser Cranford, Midlothian
Gomez Escola, Ana Maria,
Barcelona, Spain
Gomez Gea, Jose, Barcelona, Spain
Gopalji, Kantilal, London
Grange, Doreen Mary, Sherbourne
Grange, Roger Stanley, Braintree
Grau Miro, Joaquin,
Palma De Mallorca, Spain
Grayson, Peter Ronald, Wallasey
Green, Adrienne, Wembley
Green, Arnold, Wembley
Grim, Roy Ivan,
Laurel, Md., U.S.A.
Guard, Norman Wesley,
Dublin, Ireland
Gyi, Ma, Rangoon, Burma

Hale, Patricia Emmeline, Worcester
Hall, Michael John, London
Hanna, Neil Randle,
Auckland, New Zealand
Harland, James Alfred, London
Harvey, Roger Sweyn, Hull
Heikkila, Juhani, Helsinki, Finland
Hilbourne, Anthony Charles,
Maidenhead
Hinchliffe, Brian, Sheffield
Hirohata, Tomoko,
Osaka-Prif., Japan
Holden, Andrew Neil, Walsall
Holliday, Barrie James, Northampton
Holmes, Eric Charles, Salisbury
Horesh, J., London
Howard, David John, Reading
Htwe, Htwe, Rangoon, Burma
Hubbard, Susan, London
Huddy, Molly, Salisbury, Rhodesia
Hutchison, Alfred Sandison,
Salisbury, Rhodesia

Iivonen, Helena, Helsinki, Finland
Ireland, Kenneth Leslie,
Salisbury, Rhodesia
Irwin, Margaret, Chester

Jackson, Ian, Bradford
Jarvis, Maurice Leslie,
Durban, S. Africa
Jenner, Peter Charles,
Tunbridge Wells
Jervis, John Martin, Liverpool
Jessel, Stephen Malcolm, Potters Bar
Jobbins, Howell Stevens,
Toms River, N.J., U.S.A.
Johnson, John William Sidney,
London
Johnson, Robert Charles, Nuneaton

Kadigamuwa, Piyasena,
Warakapola, Ceylon
Keeling, Judith Mary, Birmingham

Kivimaki, Kauko,
Hameenlinna, Finland
Knappett, William Paul,
New Market, Ont., Canada
Ko, Aung, Rangoon, Burma
Koskinen, Aito, Helsinki, Finland
Krieger, Rolf, Huddinge, Sweden
Kuge, Georges, Gent, Belgium
Kyaw, Aung, Rangoon, Burma
Lackey, Joseph Frank,
Laurel, Md., U.S.A.
Laing, William Stuart,
Troon, Scotland
Langthon, Kjell Odvar, Oslo, Norway
Larrazolo, Ruth L.,
Fort Clayton, Canal Zone
Laub, Theodore,
Johannesburg, S. Africa
Lehtola, Lauri William,
Suomi, Finland
Lehtola, Maire, Helsinki, Finland
Leino, Terttu, Helsinki, Finland
Levy, Hanukah, London
Lewis, Roger Anthony, Wallasey
Lilja, Irmeli, Rovaniemi, Finland
Llopis Pascual, Emilio,
Castellon De La Plana, Spain
Lofberg, William, London
Lopez Sabater, Jose Antonio,
Valencia, Spain
Lopez Verge, Ramon,
Barcelona, Spain
Love, James Bowie,
Kilmarnock, Scotland
Lowe, Christopher Edward,
Burton-On-Trent
MacDonald, Kenneth Charles,
Leicester
McFate, Yale,
Phoenix, Arizona, U.S.A.
Mackie, Irene, Leeds
McLaughlin, Edward Peter, Glasgow
MacLeod, Helen L.,
Washington D.C., U.S.A.
Maehlum, Anne Louise,
Lillehammer, Norway
Maiwurm, Frederick
Newark, Delaware, U.S.A.
Malkavaara, Seppo, Lahti, Finland
Malone, Thomas F. S.,
Dublin, Ireland
Malvarez Martinez, Francisco,
Alicante, Spain
Margarit Morant, Eugenio,
Barcelona, Spain
Martin, Nancy Jean,
Heidelberg, Australia
Maslen, Grant Lewis,
Nairobi, E. Africa
Mather, Spencer Ivan,
Kragero, Norway
Mathis, Robert Chester,
Tacoma, Washington, U.S.A.
Matthews, Barry Edwin, Jersey, C.I.
Minn, Hla, Rangoon, Burma
Miro Cortes, Bartolome,
Palma De Mallorca, Spain
Monche Maristany, Alberto,
Barcelona, Spain
Mones Roberdeu, Luis,
Barcelona, Spain
Moran, John, Blackpool
Morris, Malcolm Colin, Norwich
Munoz Aisa, Maria Teresa,
Barcelona, Spain
Murray, David Ernest,
Stratford-Upon-Avon
Murtagh, Thomas, Dublin, Ireland

Murto, Kalevi K.,
Soukka Espoo, Finland
Narasimhan, V. K.,
Frankfurt/Main, Germany
Nash, Graham E., Petersham
Naumanen, Pertti O.,
Helsinki, Finland
Nemoto, Christine, Khartoum, Sudan
Nemoto, Yoshio,
Fukushima-Ken, Japan
Nittel, Lothar, Freiburg, W. Germany
Noble, Clifford,
Heckmondwike, Yorks.
Norton, Charles L.,
East Brunswick, N.J., U.S.A.
Oates, Harold A.
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EXAMINATIONS IN GEMMOLOGY 1971

The dates for the 1971 examinations are as follows:

Preliminary	Theory	Tuesday, 15th June.
Diploma	Theory	Wednesday, 16th June.
	Practical	Thursday, 17th June or Friday, 18th June (London). Other centres as arranged.

The final date for entry is the 1st March.

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THE JOURNAL OF GEMMOLOGY

and

PROCEEDINGS OF THE
GEMMOLOGICAL
ASSOCIATION
OF GREAT BRITAIN

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OF GREAT BRITAIN
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THE JOURNAL OF GEMMOLOGY
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Vol. 12 No. 6 APRIL 1971

MORE NOTES FROM THE LABORATORY

By B. W. ANDERSON

1. *Detection of Opal Doublets*

One of the more awkward tasks which we are asked to undertake in the Laboratory is to determine whether a given opal is homogeneous or an opal-topped doublet. Usually the stone concerned is mounted in a setting which prevents one from seeing the rim or girdle where the junction layer of a doublet would presumably be visible.

Though the edge of the stone is obscured, its base is often visible. Should this be recognisable as black onyx, then the gem can safely be classed as an opal-on-onyx doublet. On the other hand, if the base consists of grey non-precious opal the question "doublet or not?" remains open.

The first lesson in tackling such cases is *not to give up hope:* determined efforts will usually yield an answer. First, one should scrutinise very carefully with a lens, or better, a low-power microscope, the border of the stone where it meets the setting, viewing it both from above and from below. Surprisingly often there will be some point at which a glimpse of the edge of the specimen can be obtained with the further chance of seeing the tell-tale discontinuity where the thin opal top surface is cemented to the "potch" base.

If this fails, it is a good plan to try and punch a strong beam of light through the specimen. Where the stone is moderately translucent and shows no trace of bubbles, grinding marks, or other

signs of a junction plane, the stone is almost certainly a true opal. In a doublet, on the other hand, flattened bubbles often appear as little bright circular "windows", and straight lines where the surface of the base was ground flat may also be detected. If no appreciable light is transmitted, it is usually rewarding to view the stone from above under a low-power microscope and a good overhead light.

From the nature of things the "precious" top of an opal doublet is both transparent (or nearly so) and thin. It is thus almost always possible to see through it to the plane where it is cemented to the less attractive opal base. When the focus of the microscope is slowly lowered through the surface layer, a careful observer can almost always become aware of a dividing plane if such exists, either by a series of small bubbles all at the same level, or by worm-like irregularities where the cementing has not been an all-over success.

It must be confessed that the above suggested tests yield positive proof only in the case of doublets. Complete proof of homogeneity really does require a good view of the region where the "precious" opal merges into the non-iridescent "potch". Sure signs that all is well are where small "tongues" of iridescent material invade the dull grey of the base. Even in an unmounted stone it is wise to make a very careful inspection of the edge before coming to a final decision.

2. *Pearls from the Giant Clam*

Every now and then the Laboratory is asked to identify "pearls" which though natural molluscan growths are non-nacreous and therefore outside the usual pearl and cultured pearl category.

The commonest of these, and the only type commercially acceptable are, of course, the so-called "pink pearls" from the giant conch (*strombus gigas*), a univalve whose decorative shell is lined with a porcellanous coating of delicate pink. Conch pearls have a beautiful flame-like surface pattern which makes them easily distinguishable (under a pocket lens) from coral or indeed any other substance. Their high density of 2·83–2·86 is also characteristic.

Non-nacreous black "pearls", resembling shining boot-buttons, also occasionally come our way, and though these are generally classed for convenience as "clam" pearls their exact source of origin is confessedly obscure. Their density is rather lower than that of nacreous pearls, and their attraction and commercial value are

virtually nil. We recently had an opportunity to test the more interesting and attractive white pearls found in the giant clam *tridacna gigas*. This enormous bivalve must surely be the most formidable of all shell-fish, the shells being as much as three feet in diameter and weighing up to 500 pounds. The valves are characterized by strongly crenellated edges which enable them to interlock very tightly when closed. The monster shells are found in the Pacific and Indian Oceans, in particular near reefs off the Northern coasts of Australia.

The parcel we examined contained a proportion of well-shaped "pearls" showing a beautiful optical pattern, or sheen, by reflected light, but there were also some very inferior concretions having the appearance of blobs of candle-grease, for the most part drop-shaped, with a lack-lustre finish and no reflection pattern. Typical features of these concretions were raised ridges, looped or festooned, again reminding one of the running of partly melted candle-grease. Both the "pearls" and the other concretions clearly consisted of essentially the same material and were nearly pure aragonite, as revealed by their high density of 2·86–2·89 (pure aragonite being 2·93). It seemed reasonable to presume that the "pearls" were formed in sacs within the ample body of the mollusc, while the unshapely concretions were formed under less favourable

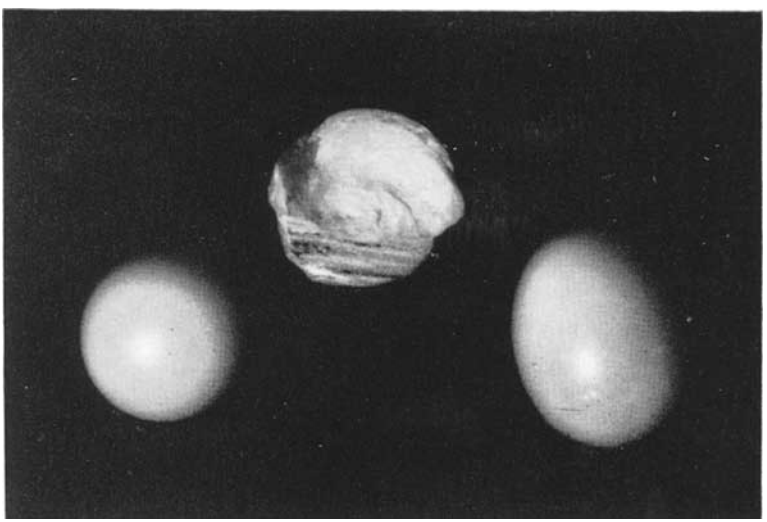

conditions between the body and the shell. The illustration shows two typical tridacna pearls and the broken surface of another.

3. *A Diamond "portrait stone"*

Many years ago I was fortunate enough to acquire (*seriatim*) four "portrait-stone" diamonds. In addition to being most attractive objects—displaying as they do the sheer optical purity and beauty of diamond—these proved admirable for optical study. By a happy chance the four included a normal "Cape" diamond, a Type II stone, and two which were intermediate in their transparency to ultra-violet light, as can be seen in a photograph reproduced in "Gem Testing". These stones were very similar in size, being about 1 cm. in diameter and 1–1½ cts. in weight. It was quite a pleasant shock therefore to have sent to us for test a relatively "giant" portrait stone diamond nearly an inch in diameter and weighing some 10½ carats. The stone was clean and flawless and showed a blue fluorescence under ultra-violet light. The interference pattern between crossed polaroids gave the effect of hexagonal zoning which was very striking. Presumably the stone was cut from a large cleavage flake too thin for it to be fashioned into brilliants or even baguettes.

4. *Blue Zoisite and the Chelsea Colour Filter*

It is generally admitted that the blue zoisite from Tanzania can resemble fine sapphire very closely, especially when heat-treatment has largely suppressed the purple ray that in nature gives this variety an amethystine cast. In consequence one is often asked by dealers "how can I tell it from sapphire"? and since the use of a refractometer is not considered practical politics for over-the-counter or other casual transactions, the answer is not easily given.

Recently, however, it occurred to me that the Chelsea Colour Filter might prove helpful, and preliminary trials seem to confirm this. Those blue zoisites which I have viewed through the filter show a distinctly reddish appearance quite unlike sapphires of comparable colour. Admittedly mauve Ceylon sapphires containing traces of chromium will give a red showing through the filter; but again this is unlike the effect seen in the zoisite.

SYNTHESIS OF FLUORITE

By F. DUYK

FLUORITE (F_2 Ca) is considered as belonging either to the cubic system, or to the pseudo-cubic system (Mallard). Besides, belonging to this group, are minerals such as sellaite (F_2 Mg), which is quadratic and considered as the least refringent of all minerals, ittrocerite, which is also calcic, and fluocerine (F_3 Ce_4) admitted as being hexagonal.

Coming next are the double fluorides—anhydrides and hydrated—such as criolite, phachnolite, and thomsenolite, which are already considerably more distant from the group examined here.

There still exists however a curious variety called chlorophane, which has the property of emitting green light under thermic influence.

My purpose is to point out the tendency of the group to show lattice intricacies. Firstly, the optical and physical properties are as follows:

Synthetic red fluorite

R.I. = 1·43

Polarization = slight anomalous birefringence (in zones)

U.V. = inert

Density = 3·18

H. = 4.

Spectroscopy = nothing

Colour Filter = light red

Micro exam. = straight planes of growth, cristallites, non-communicating channels on level planes, gaseous cavities.

I am indebted to Dr. F. Pough's kindness and competence for the following information regarding the manufacture of synthetic Fluorite: "The Harshaw Division Kewance Oil Co. is the manufacturer. The method used is the Stockbarger one—this method is an improvement of the Bridgman process."

I found a detailed description of this process in a very good essay on the growth of arsenical gallium crystals, by K. Ozolis and E. Kokorisch, published in the *Bulletin of the Soviet Academy of Science* in 1964.

Cr, Nd, Sm, Er, Ho and U are used as colouring agents.

Cr gives light purple	Neodym gives purple
Samarium gives green	Erbium gives reddish
Holmium gives yellow	U.02 gives red purple
U.F4 gives green	Ca.UO 4 gives brown yellow.

When one is faced with the problem of practical identification of fluorite synthesis, one's attention must not be particularly attracted by the lattice constructions, because the synthetic fluorite displays the same straight-line construction as the natural product. Neither must the refractive index and the density be considered as essential, natural fluorite having the same R.I. and density. Even if an abnormal birefringence is obvious or can be detected in synthetic fluorite, one must keep in mind that the natural fluorite also shows abnormal birefringence sometimes, which is broadly to be attributed to an unusual habit of twinning by penetration developed by a rotation around a three-fold axis of symetry.

The examination under crossed polaroids may also offer a certain analogy with synthetic spinel, but as natural fluorite may possess abnormal birefringence, which spinels never display, even this test is not conclusive.

Finally, what is the method to be followed? One must remember that the extreme complexity of the lattice brings about tensions in the crystal, easily observed under crossed polaroids, and this has an unexpected result: unusual cavities, unusual in their shape, are displayed by synthetic fluorite.

Being used to rely on photographs for the detection of what I may find unusual in crystals (an old habit) I photographed these gaseous inclusions and here are the results obtained.

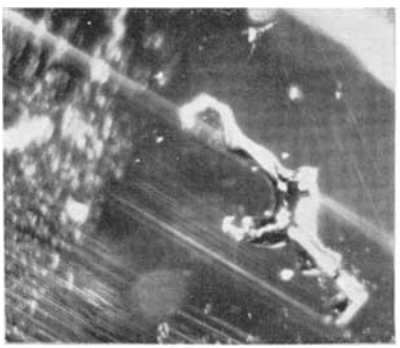

FIG. 1. *Gaseous inclusions.*

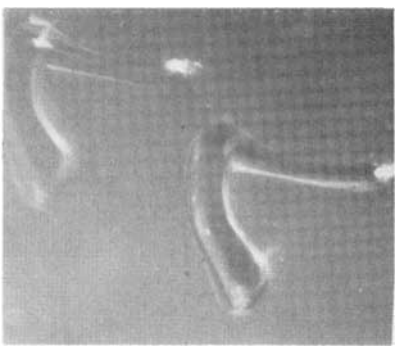

FIG. 2. *Abnormal double refraction.*

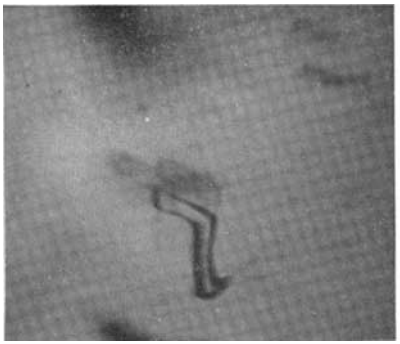

FIG. 3. *Abnormal triple refraction.*

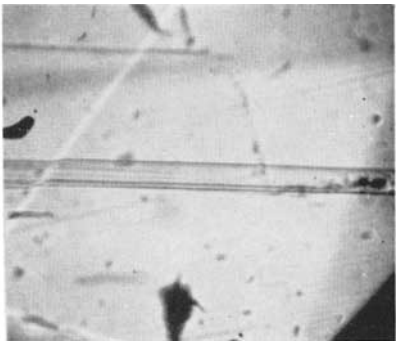

FIG. 4. *Hollow canal.*

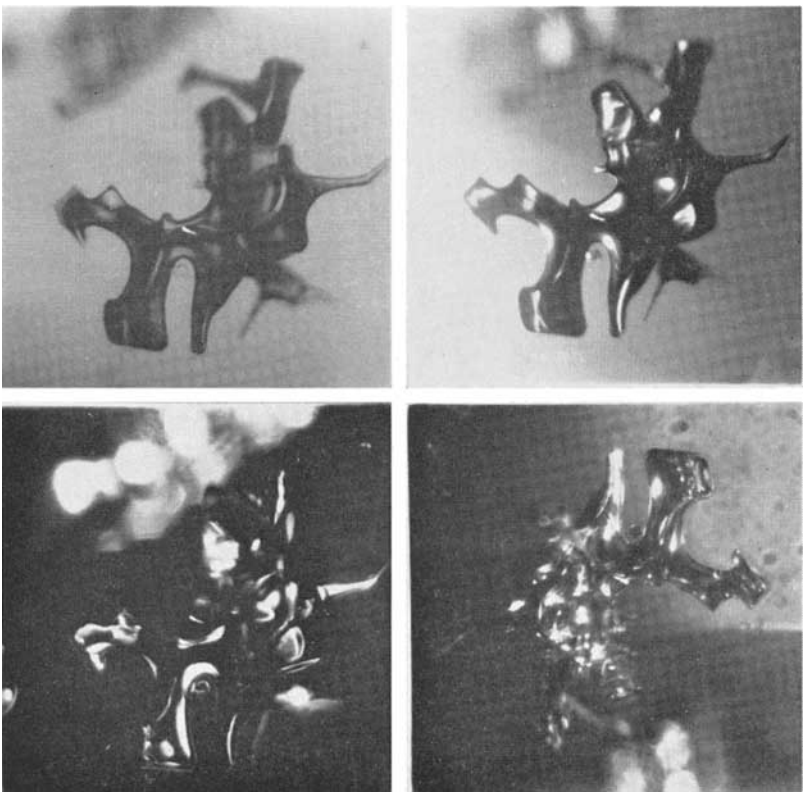

FIG. 5. *Four aspects of a gaseous inclusion.*

INCLUSIONS IN TOPAZ

By MARJATTA VIRKKUNEN, M. Phil., F.G.A. and WIKTOR DE SZEJKO, F.G.A.

THE following minerals have been observed as inclusions in topazes: fluorite (CaF_2), ilmenite ($FeTiO_3$), hematite (Fe_2O_3) goethite ($FeO{\cdot}OH$) and quartz (SiO_2). In connexion with quartz chlorite flakes also have been found sometimes. Advanced research methods have recently made it possible to identify such inclusions which reveal no typical property, shape or colour by the usual methods of determination. The inclusions may be so small that it is cumbersome to detach them from the host stone, even in such a case when the stone is sacrificed to the science.

The research material comprised a number of cut topazes acquired from Leningrad and derived from the Ural mountains. The physical constants of these topazes agree with those given in the gemmological literature for Russian topaz. The following constants were determined: S.G. 3·53 and R.I. 1·609 and 1·619. The R.I. values indicate a richness in fluorine for the chemical composition of topaz.

The stones were nearly colourless, part of them were pale sherry-coloured, the others bluish. They contain clusters of peculiar dark furry-like inclusions. These inclusions are mostly straight but they may change their direction, seemingly due to some crystallographic direction in stone (Figure 1). A closer scrutiny of these inclusions reveals that their centre is hollow, and they are filled with gaseous material and some dark substance. "Hairs" of different lengths surround these hollows in a certain plane and at the outermost tip of such a hair there might be a small colourless bright crystal (Figure 2).

The inclusions were investigated at the Geological Survey of Finland. Such individual stones, where the inclusions were at the polished surface, were investigated by electron microprobe analyses. It was found then that the topaz contained both hematite (Fe_2O_3) and cassiterite, stannic oxide (SnO_2). In all probability the dark filling in the longish central hollows is hematite and the hairs are cassiterite. The small bright crystals did not yield any information, only indications that the stone might also contain some iron-aluminium-silicate. As they seem to be cubic octahedra when looked at with a microscope with great magnification there is the possibility that they are spinel octahedra $(Mg, Fe)Al_2O_4$.

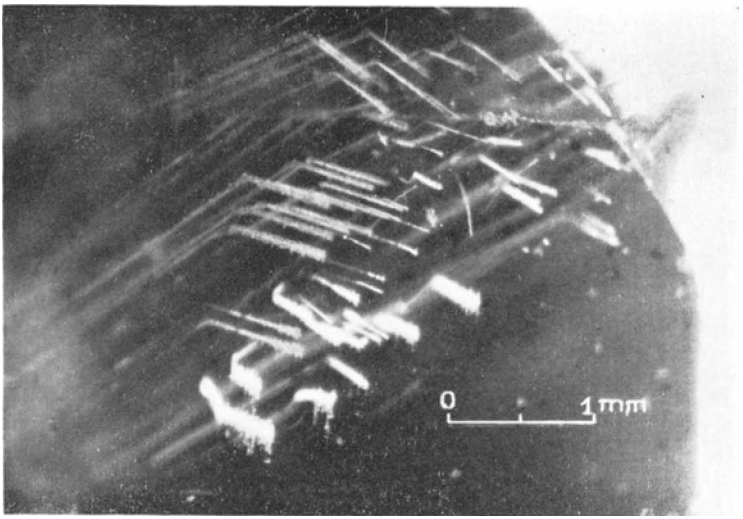

FIG. 1. *Photo: Lotta Orkomies.*

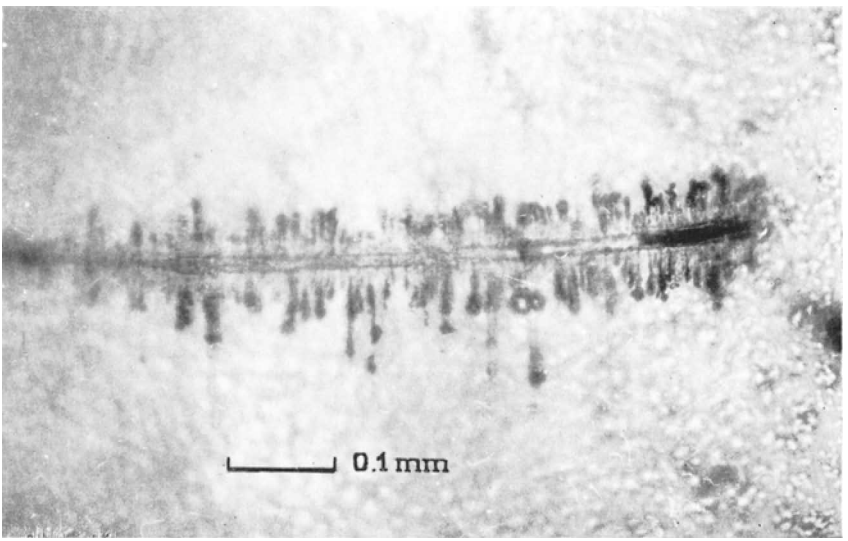

FIG. 2. *Photo: E. Halme.*

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Webster, Robert (1962). *Gems,* Vol. I.

A VISIT TO THE TOPKAPI MUSEUM AND TREASURY, ISTANBUL, TURKEY. 1970

By IRENE MOSEY

THE old Palace of the Sultans of the Ottoman Empire stands on a promontory in the city of Istanbul. It is built high above the Bosphorus with a view across to Asia just over one mile away. Istanbul has been on the trade route between East and West throughout the centuries so that some of the choicest silks, jewels, gold, silver and porcelain reached the city.

The Palace is really a series of pavilions built by successive Sultans around inner courtyards, cooled by many fountains and surrounded by high walls. Here the Sultans lived in the hey-day of the Ottoman Empire.

Originally in the 15th Century, the Treasury was housed in seven towers guarded by 250 Janissaries. The first four towers contained precious jewels, gold coins were consigned to the fifth, whilst the sixth was filled with silver coins. The seventh was reserved for government documents. Sultan Murat III moved the Treasury to seven large rooms in the Palace; and a record taken in the 18th Century showed that it contained 199,371 jewels.

Over the years each Sultan added more to the Treasury and when the last Sultan was deposed in 1919, by Kemal Ataturk, the Palace was turned into a museum, so that the treasures have remained intact.

A visitor nowadays goes first to the Royal Porcelain section housed in the old kitchens containing over 12,000 items of Chinese porcelain, the earliest dated 960 A.D. According to Eastern superstition, these porcelains changed colour and cracked when poisonous substances were applied to them.

In order to obtain an interview, each emissary brought a "small gift for the Sultan" and if the gift was not considered worthy, the unfortunate man was kept waiting and waiting . . . so the gifts included gold cups studded with turquoise and rubies, a chess set carved from agate, gold and silver boxes and ewers. One unusual gift is the seated figure of an Indian maharajah, the body and shoulders comprising a baroque pearl nearly 2″ across with the baggy trousers carved from a large piece of turquoise, the turban

set with small diamonds and another smaller baroque pearl shaped like an egret feather. There is a canopy over the figure in red and white enamels supported by four slender columns set with small diamonds and emeralds.

An impressive gift from India is a gold, jewel-studded musical box which stands on a 3ft. high table with legs shaped like groups of three palm trees. On top of the box is a golden elephant over 12″ long with flexible trunk and tail. Another item is a beautiful clear quartz cup and cover about 5″ high with a baroque pearl knob nearly 1″ diameter.

There are cases of jewel-studded swords, pistols inlaid with gold and mother-of-pearl, rifles with gold inlaid stocks and barrels, large hunting bows and arrows with the quivers embroidered with pearls. Two magnificent daggers nearly 18″ long are displayed with mirrors underneath to enable the reverse sides to be seen. One has four large emeralds of excellent colour over 1″ in diameter set in the handle, with the end emerald hinged to reveal a watch inside the hilt. The scabbard is curved and set with over 60 diamonds and several small baskets of fruit and flowers have been enamelled on the top and reverse sides. The other dagger has a hilt composed of one emerald big enough to be clasped in the hand; the cross hilt is set with diamonds; there are enamelled flowers along the 12″ long scabbard and a long gold chain enables it to be hung from the belt.

A perfect emerald crystal with six equal sides and about 1″ deep has been hollowed out and fitted with a domed lid of gold set with rubies and diamonds to make a beautiful box. There are many caskets. One is made from pieces of faceted quartz which comprise the four sides and the lid, all in gold surrounds, and measuring about 10″ × 5″ × 4″ deep. Other boxes are made of gold and covered with roughly shaped cabochon rubies, moonstones, and peridots in box-settings—over 450 stones were counted on one casket. There are bottles and stoppers in cut-glass inlaid with roughly polished rubies and sapphires, a tankard about 6″ high with a gold rim and base, and many drinking goblets of glass, gold and porcelain elaborately decorated with enamels and set with gemstones.

Other cases display exotic items like fly-whisks made of peacock feathers, Koran cases embellished with jewels, prayer rugs studded

with pearl embroidery and walking sticks with handles of gold, ivory and jade. One showcase is entirely devoted to rows and rows of amber mouthpieces for the narghile or water-pipe, each one having a different decoration of circles of diamonds or pearls or turquoise round the stem. It was believed that amber had the property of not transferring disease as the mouthpiece was passed round whilst the narghile stood on the floor in the middle.

A rather gruesome exhibit is the fore-arm of St. John the Baptist encased in gold and also a portion of his skull, but as similar relics appear all over Europe one wonders how many hands he possessed.

A happier note is struck by the gold cradle set with rubies in large diamond patterns together with gold extension bars for rocking—a much used article considering the size of the Sultan's harem.

An adjoining suite of rooms shows the robes of the various Sultans in silks, embroidered brocades and edged with ermine and sable; the earliest is the cloak of Sultan Mehmet the Second (1432-1481). One of the cases contains the robe stained with the Sultan's blood as he was assassinated, a gruesome piece of history which always seems to attract the tourist! Above the robes are shown the turbans with ornaments of diamonds and pearls topped with white egret feathers.

A collection of the Ottoman Sultans' seals includes one dated 1589 made of white agate with a gold handle; another is carved on a yellow sapphire, yet another on an emerald, but most of them are made of gold with the impression of the monogram.

All the various decorations, medals and orders presented to the Sultans are on view ranging from those given by the Russian Tzars, the Kings of Ethiopia, France and Prussia to the jewelled Star and Order of the Garter presented by Queen Victoria.

An impressive throne is like a low couch with a footstool made with gold inlay and entirely covered in lozenge shapes of alternate light and darker green enamels each containing a spray of flowers studded with rubies with centres of pearls. It was made in India as a gift from the Persian Shah to Sultan Mahmet the First in 1747 and later added to the Treasury.

Over the thrones hung long pendants, each Sultan having one of a different style. They are made of gold encasing large gem-stones—one has three slices of emerald over 2″ diameter, each with six perfect sides set in gold surrounds in a triangular form, so that light passes through them. From the lowest point of the triangle hang 12″ long tassels of pearls—about 30 tassels, each having about seventy pearls. Another pendant has a perfect crystal of emerald—a huge stone the size of a clenched fist surmounted in gold with a domed top inlaid with diamonds, again with the many pearl tassels. Yet another has a single section of emerald over 2″ diameter with six large drop pearls from which is suspended another large emerald pierced down the centre, with ten smaller drop pearls making a ring to hold the pearl tassels. The sheer size and colour of the emeralds in these showcases almost take the breath away.

Three of the largest uncut emeralds weigh 3260 grams (7 lbs. 2 oz.), 1310 grams (2 lbs. 14 oz.) and 590 grams (1 lb. 4 oz.), an unbelievable treasure. Other emeralds of egg-size to pebble-size are tumbled casually in the corner of the showcase!

An enormous pear-shaped diamond of 86 carats belonging to Sultan Mehmet the Fourth (1642-1693) is now set in a double surround of 49 brilliant-cut diamonds.

One of the most beautiful items on display is a short prayer in Arabic lettering completely made in different sized diamonds, the piece is about 8″ long and over 1″ wide and dated about 1839.

The centre piece of the Treasury is a gold throne about 6′ long like a high settee, for the Sultans always reclined, never sat on the throne as in the West. It is covered at the sides and front in beaten gold and studded with 955 topazes, roughly cabochon and in box-settings. Above this throne hangs yet another pendant, this time in gold weighing 96 kg. with 12,564 diamonds which belonged to Sultan Abdulmecit.

Across the courtyard from this "Aladdin's Cave" is the part of the Palace most sacred to all Moslems. Here are the Relics of Islam captured from Egypt in 1517 by Sultan Selim I and placed in this Imperial Chamber. The window through which the Relics are viewed is protected by a solid silver gate about three feet high done in the most intricate scrollwork.

Inside the Chamber is a large silver canopy adorned with gilding, similar to a tent in shape, which was used as the Imperial Throne. It has a vaulted roof decorated with mirrors and is supported on four columns. Inside is a silver table decorated with gold leaf on which stands a large golden casket which contains the Cloak of Mohammed and the Holy Standard. There are also two of the Prophet's swords for which Sultan Ahmet I had made scabbards of solid gold studded with rubies, turquoise and other gemstones.

In a small box is the prophet's seal, an oval-shaped agate the normal size of a ring stone, and the inscription in Arabic on the seal reads "Prophet, the Apostle of God". Other sacred relics are a small piece of the Prophet's tooth, which was broken during action in the religious battle of Ohod, and a piece of hair from his beard kept in a silver casket ornamented with the most delicate filigree design. A blackened piece of parchment is a letter written by Mohammed to Mukavkas, the King of the Copts, in 627 in an attempt to convert the King to Islam. An unusual relic is the footprint of the Prophet's right foot on a porphyry stone. It was found by a regimental commander of the Imperial Regular Forces named Ahmet Bey somewhere in Tripoli, Libya, in 1874 and it was presented to the Sultan who gave him 114,000 kurus as a reward. Later it was enclosed in a gold frame with an engraved lid.

It does seem remarkable that all these treasures have remained intact throughout the centuries of Turkish history to the present day. It would appear that each Sultan upon taking office had to verify that the treasure agreed with the inventory up to that date and had not been dissipated by his predecessor. It became a matter of pride to add to this collection and it was only by the foresight of Kemal Ataturk in converting the whole of the Palace into a museum that we can today view the treasures in their original setting.

Many things have been omitted, but I can say that apart from the delights of the rest of Turkey a gemmologist will find endless pleasure in a visit to this unusual museum.

THE CONSTITUENTS OF PEARLS

By E. H. RUTLAND, Ph.D.

THERE is a tide in the affairs of gems, as in those of men. Capriciously, their supply waxes and wanes in long-term cycles, now scarce, now relatively plentiful. Natural pearls which mainly come from tidal waters are, appropriately enough, no exception. So far as the Persian Gulf is concerned, the tide is right out and only the Far East and the Americas are now the main sources. Additional supplies seem to be coming from freshwater fisheries and the culture of pearls evokes ever more ingenuity.

There is a tide, too, in publications about natural pearls. It must be some years since the technical press produced an article about them and it must be admitted that all essentials have been said and are enshrined in the textbooks. I was therefore more than pleased to meet a serious student of pearls at a recent conference who produced a large number of photomicrographs illustrating aspects of pearl structure of which I had had only a vague notion. He is Mr. E. Bibend, a jeweller of Koblenz, who kindly allowed me to use the pictures here reproduced and supplied the relevant data.

As is well known, pearl oysters and mussels build up pearls much in the same way as they build their shells, by depositing calcium carbonate, either as aragonite or as calcite, until it forms tiny crystals. Concurrently these are cemented together with a horny protein, conchiolin. Both constituents are secreted by the animals' epithelial cells. In the shell-building process some parts of the oysters' skin or mantle, containing these cells, specialize in the deposition of, first, the horny periostracum, composed of conchiolin; then a rigid layer of prismatic crystals, which are finally topped off with a smooth nacreous layer. Conchiolin and calcium carbonate either as prisms or as nacreous platelets can, however, be secreted by any part of the mantle. In the formation of pearls, as distinct from the shell, the nacreous platelets in many species predominate and sometimes wholly supersede the prismatic layers. Growth is seasonal and a new sequence of layers is superimposed on previous layers each year. The rate of growth depends on the species, the vigour of the animal, on the environment and

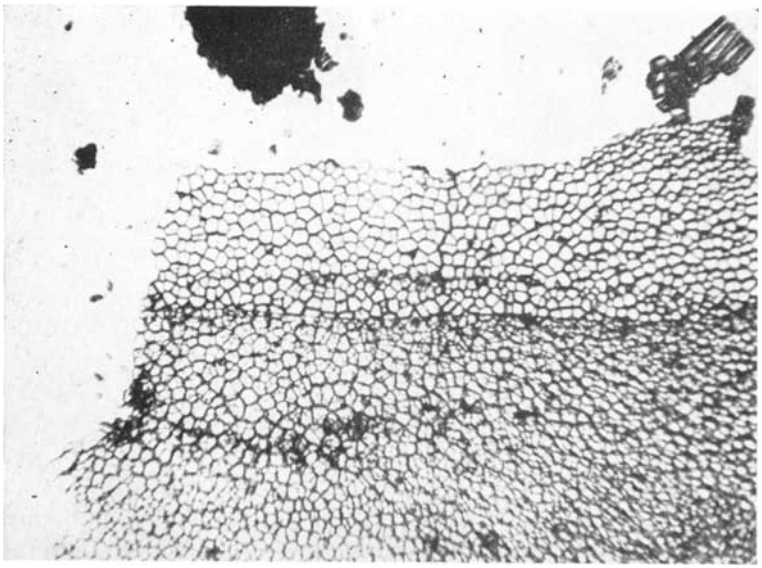

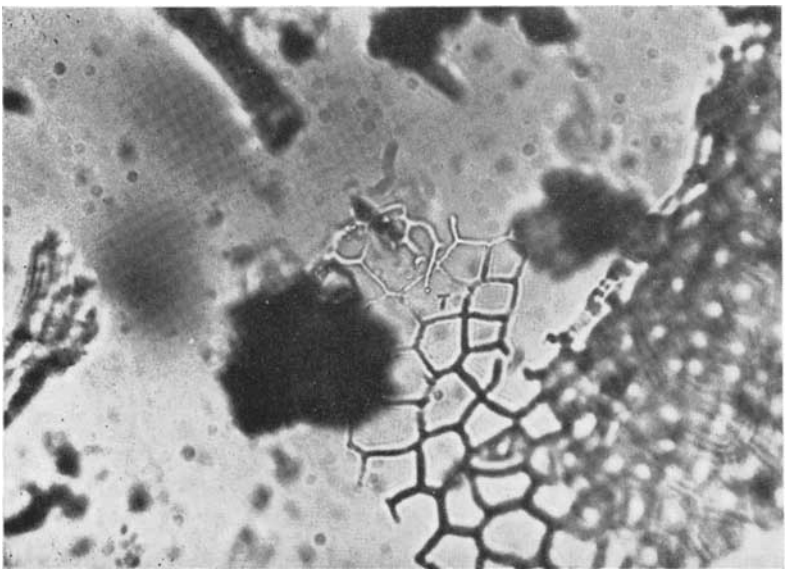

FIGS. 1 and 2. *Conchiolin framework enclosing prisms of aragonite.*

on the benignity of the season. The first year's growth is also usually greater than that of subsequent years.

Sections through pearls, illustrating the concentric and radial structure resulting from the processes outlined above, can be seen in many textbooks. Mr. Bibend's achievement is that he succeeded in dissolving the conchiolin binding between the prisms thus exposing the individual crystallites; and conversely dissolving the calcium carbonate, leaving the conchiolin honeycomb unaffected. He then produced clear photographs showing the result.

Vertical views of the conchiolin network with the prisms removed are shown in figures 1 and 2, while in figure 3 both the prisms and the conchiolin in a yearly layer have been dissolved almost to the base. The outlines of the crystals are by no means regular, though some vagely hexagonal and triangular shapes occur. The whole mass is closely wedged together, no doubt for greater rigidity. In the interstices between crystals Mr. Bibend also found some rods or veins of conchiolin, presumably serving to bind the crystals together still further. These were in lateral arrangement and are illustrated in figure 4. Figure 5 is an oblique view of a husk of conchiolin from which the prismatic crystallites have been dissolved. The rounded tops of the crystals and their lateral striations are clearly reproduced in the conchiolin matrix.

The next picture, figure 6, shows the platy layer between two seasons' growth partly dissolved away, revealing the tops of some of the prisms underneath. These are shown more clearly in figure 7, where the whole platy layer has been removed as well as most of the conchiolin in the interstices. Though the crystal heads are rounded, their combined surface must still be so rough as to necessitate a smooth platy top-dressing.

The remaining pictures show prismatic crystals singly and in groups. To allow for a radial structure, the crystals are thinner at the bottom end. The lines of light along their lengths indicate that their faces are continuous, but the lateral striations make it clear that deposition is not continuous. Growth probably proceeds in daily doses. The layering is particularly conspicuous on the part-crystal shown at the side of figure 8. Figure 10 shows how two successive years' growth fits together. The demarcation line of plates and conchiolin can clearly be seen between the two crystal layers.

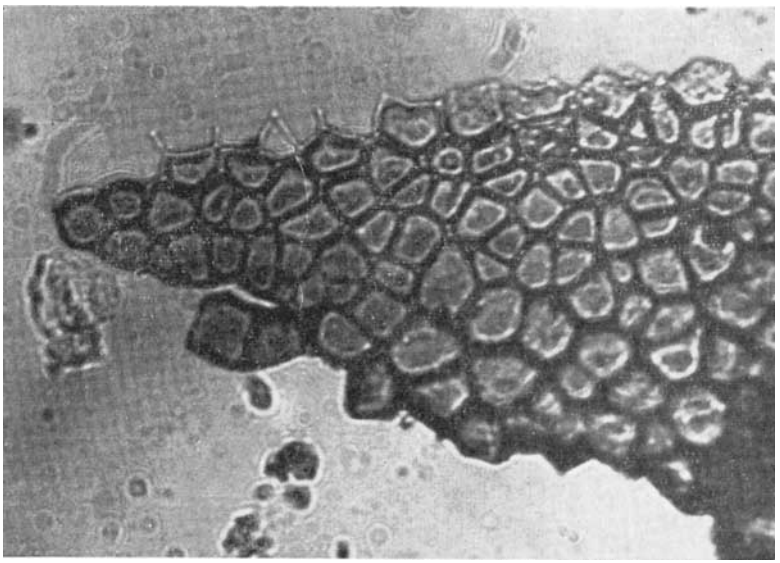

FIG. 3. *Prisms of aragonite dissolved down to base showing conchiolin binding between prisms.*

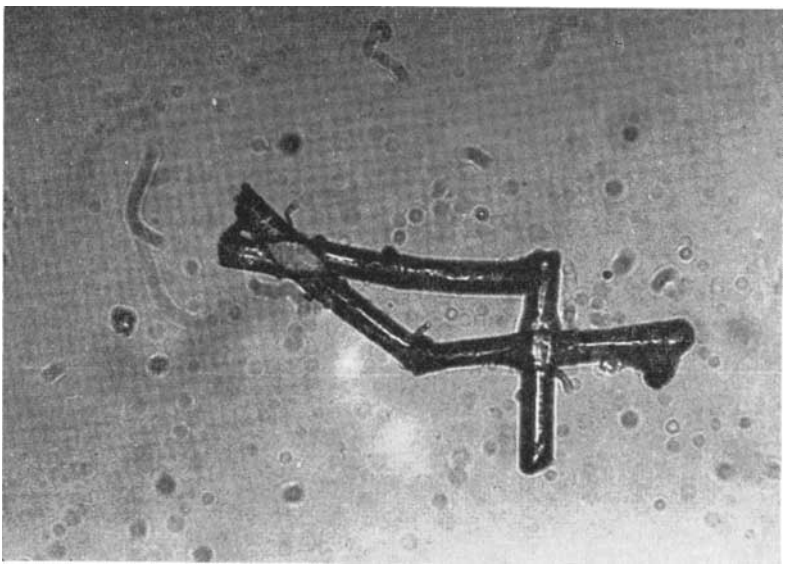

FIG. 4. *"Veins" found in the conchiolin interstices between aragonite prisms.*

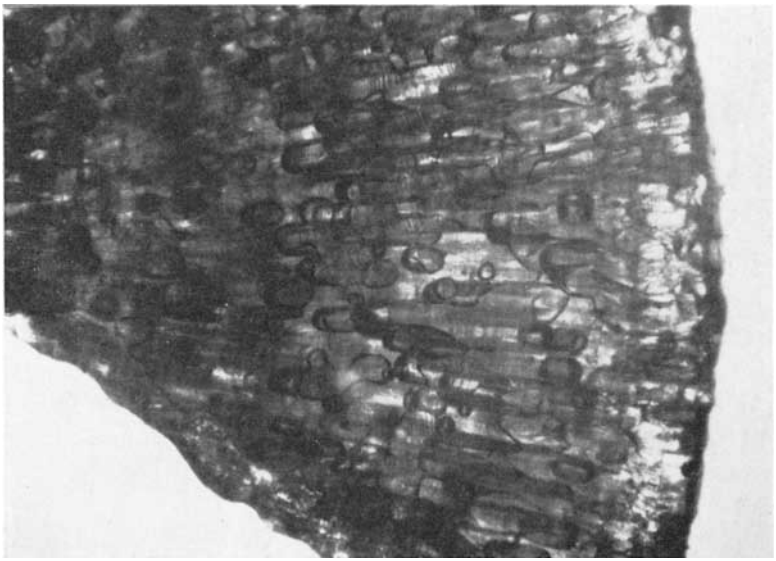

FIG. 5. *Husk of conchiolin from which crystals have been removed.*

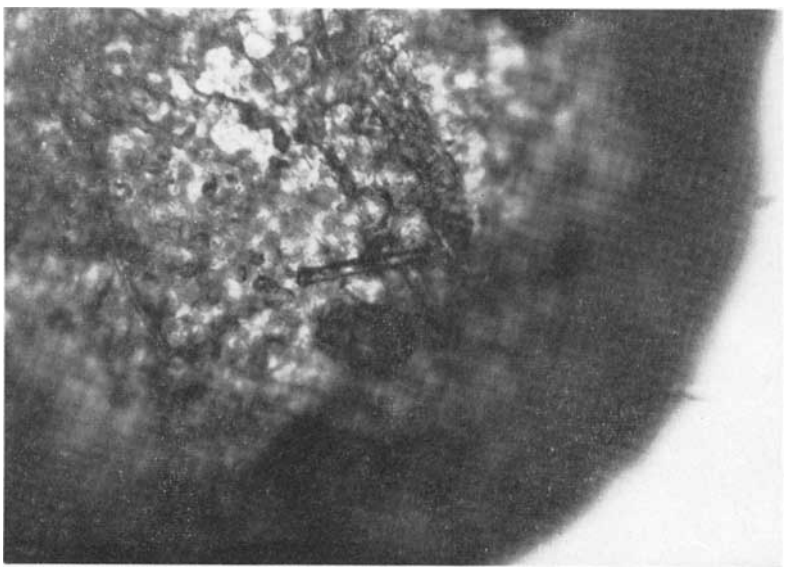

FIG. 6. *View through one of the conchiolin layers of a natural pearl showing tops of aragonite prisms and platelets beneath.*

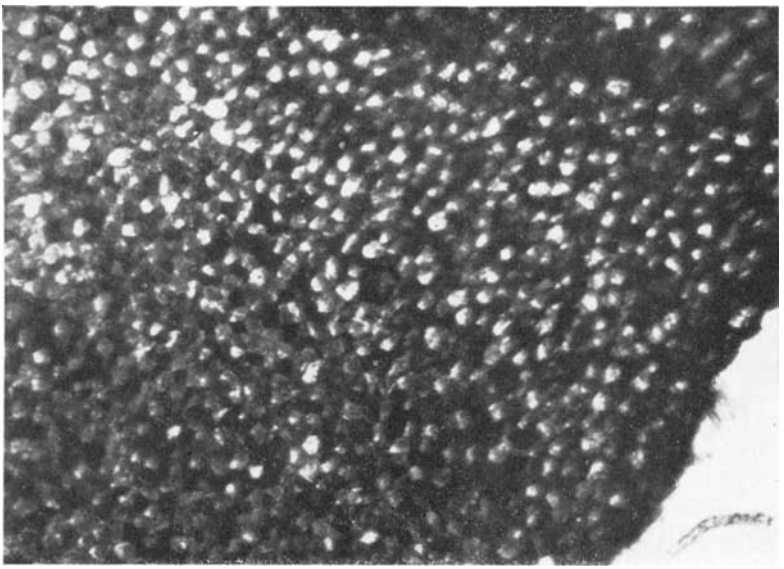

FIG. 7. *Prisms of aragonite forming one layer of a pearl.*

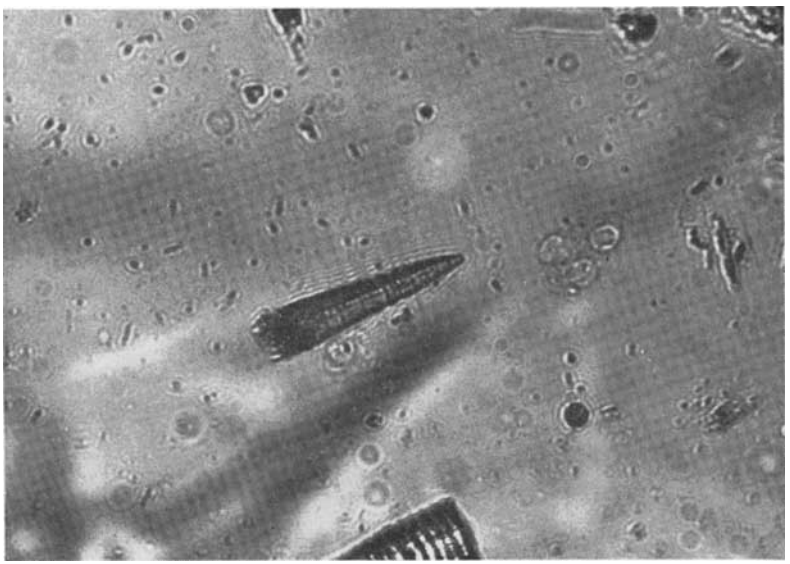

FIG. 8. *Crystals from fresh-water pearl.*

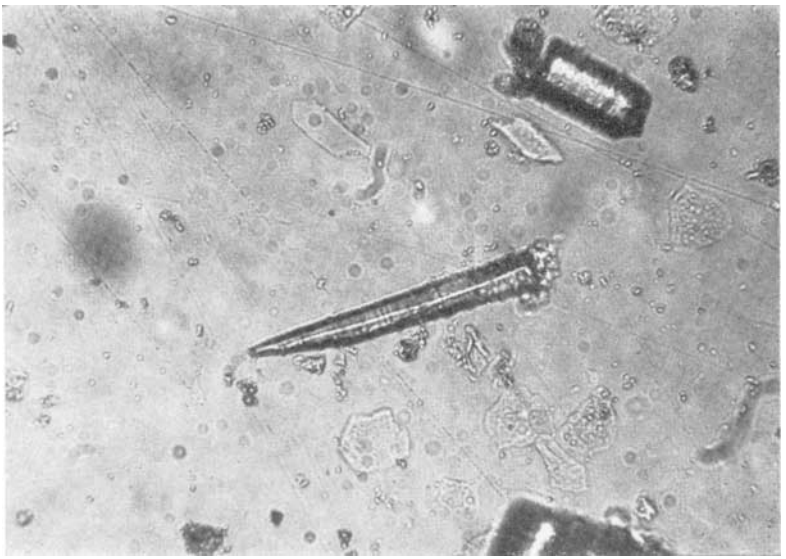

FIG. 9. *Well developed aragonite crystal lamellae of conchiolin.*

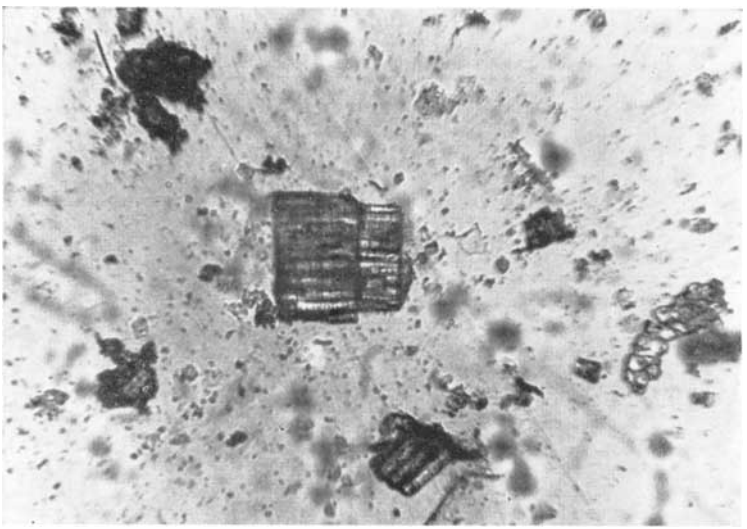

FIG. 10. *Group of crystals showing two successive years' growth fitting together.*

A SIMPLER METHOD FOR PHOTOMICROGRAPHY

By S. B. NIKON COOPER, B.D., F.G.A.

HAVE you ever wanted to get a record—say—of that inclusion, possibly quartz, in andalusite? It is so small that you can spend minutes searching for it again if you lose it.

The answer of course is simple: take a photomicrograph. And there is your record, in colour, for all to see.

There is only one snag with this. In most systems of photomicrography up to now, you have had to make a guess at the exposure time (and this can, and does, vary from 1/50th of a second to a matter of minutes or more). Either that, or a "trial and error" run has to be devised—and that is expensive.

But now the problem of finding the exact exposure time has been neatly and efficiently solved. Below are printed the details, as a tribute to the inventive genius of the late W. R. ("Bob") Hinton, of Farnham, Surrey. His method was simplicity itself, and can be economically made by any handyman.

His ingenious solution was to couple the image (of unknown light intensity) that you see through your microscope, with another —say—of the wall next to where you are working, so that they are seen side by side. The brightness of this latter image can be measured by an ordinary light-meter. It is then a simple procedure of adding neutral filters until the two images match up in intensity. You know the set exposure time for the one (the "wall"); deduct the number of stops corresponding to the number of neutral filters used, and you then have an exact exposure time for the image seen through the optical system of the microscope.

Reduced to bare essentials this consists of a box frame, painted matt-black inside, incorporating a simple lens, placed at its focal distance below a ground-glass plate. These are in direct line with the microscope draw-tube. Adjacent to this is mounted a prism section. In front of the prism is a convenient light-tight holder for the neutral filters (these can be obtained from Messrs. Ilford's, and can be fitted into transparency mounts). If three filters of 50%, 25% and 6¼% transmission are used—corresponding to relative strengths of 1, 2 and 4—any combination of filters up

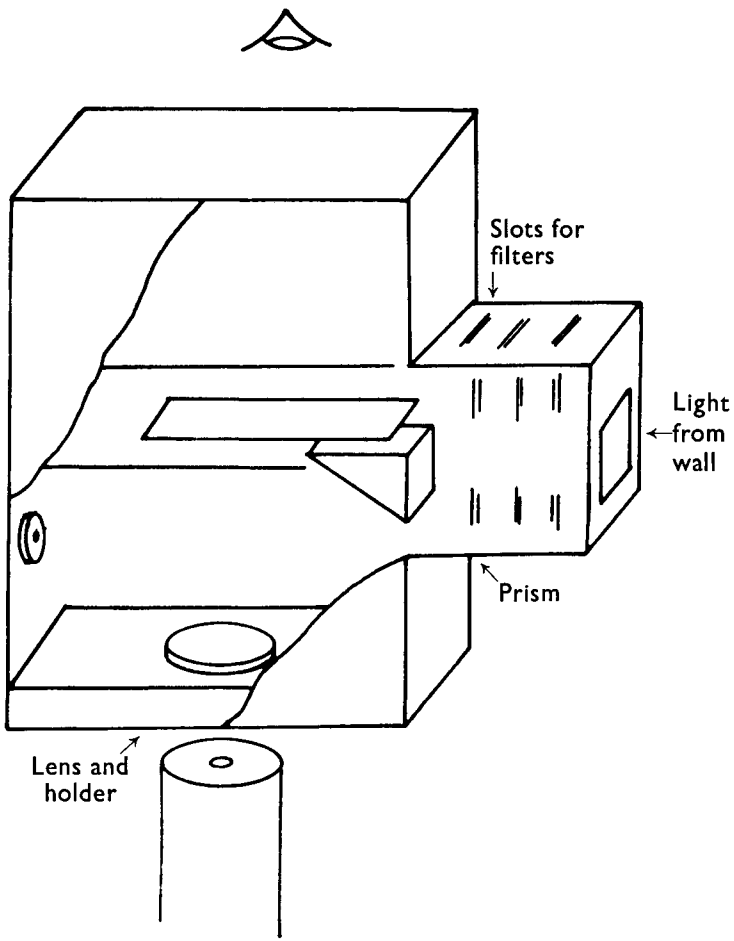

The "Hinton" photometer camera.

to "7" strength may be selected. The whole can be mounted directly onto a microscope draw-tube, or if preferred, secured by a ball-joint mounting at the side.

Procedure:

1. Assemble photometer-camera over microscope (leave the eye-piece in).

2. Focus microscope to give a sharp image on the ground-glass plate.
3. Match brightness of light received through the prism to the point of interest of the image on the ground-glass plate. Do this by using the various neutral filters.
4. Measure the brightness of the area seen by the prism (the "wall") by a light meter.
5. Note the indicated exposure for the widest aperture (lowest "f" number) of your camera.
6. Correct the exposure by deducting the same number of stops to equal the number of neutral filters used in the photometer. (E.g.: if the indicated exposure was 1/50th second, and you have used filters to value of "5", your exposure time is now 5 stops on—so, not 1/50th second, but 1 second.)
7. Set the camera focus to infinity, and the stop to the lowest "f" number.
8. Remove photometer, and assemble the camera over the microscope.
9. Take the photograph using the exposure as at (6) above.

The film should be balanced for tungsten light. If "daylight" type, use the appropriate filter (and do not forget to add *one more* stop to your exposure time).

It works. It is cheap and relatively simple to assemble, and it can open up a whole new world of possibilities to your study of gemmology . . . and it may make you keen to use your microscope on every new stone that comes your way.

Typical examples of photomicrographs obtained using the "Hinton" photometer system are shown.

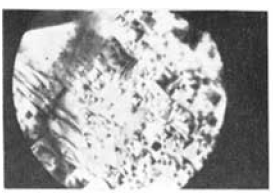

1.

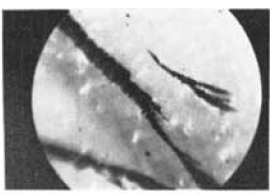

2.

FIG. 1. *Growth marks on cube face of diamond crystal* (1/5 *s.* × 300).

FIG. 2. *Rutile feather in pale amethyst* (1 *s.* × 150).

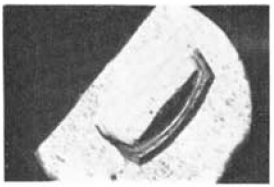

3.

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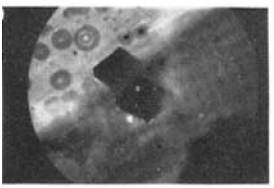

7.

8.

FIG. 3. *Growth mark on prism face, beryl crystal* (1/10 *s.* × 100).

FIG. 4. *Crystals attached to prism face, smoky quartz crystal* ($\frac{1}{2}$ *s.* × 150).

FIG. 5. *Crystal inclusions in fire opal* (4 *s.* × 150).

FIG. 6. *Partly re-sorbed tetragonal crystals in spinel* (4 *s.* × 150).

FIG. 7. *Magnetite inclusion in apatite* (2 *s.* × 150).

FIG. 8. 2 *generations diamond* (4 *s.* × 150).

Gemmological Abstracts

BANK (H.). *Ueber die Lichtbrechungsindizes, die Doppelbrechung und die Dichte des Mischglieder der Skapolith-Reihe.* About the refractive indices, the double refraction and the density of stones in the scapolite series. Zeitsch. d. deutsch. Gemmol. Gesellschaft, 1970, 19, 3/4, pp. 116-121.
Graphs, bibl. E.S.

BANK (H.), BERDESINSK (W.), OTTEMANN (J.). *Orangeroter Spessartin aus Brasilien.* Orange-red spessartite from Brazil. Zeitschr. d. deutsch. Gemmol. Gesellschaft, 1970, 19, 3/4, pp. 123-127.

Garnets of various colours have always been found in Brazil. A new type of garnet was found in the Golcanda district (well-known for tourmalines). The stones vary in colour from dark orange-red to dark red. Refractive indices were 1·803-1·805; S.G. 4·14 ± 0·02. They were found to have 21·08% manganese, 9·53% iron and 0·17% calcium. There was no magnesium, titanium, chromium or vanadium. The authors concluded that the stones in question were spessartites showing a small percentage of almandine. Map, bibl.
E.S.

BANK (H.), OTTEMANN (J.), BERDESINSKI (W.). *Edel-Olivin aus Norwegen.* Precious olivine from Norway. Zeitschr. d. deutsch Gemmol. Gesellschaft, 1970, 19, 3/4, pp. 128-133.

The olivine found in Norway is a forsterite, i.e. an olivine with a small amount of iron and a large content of magnesium. This was shown by x-ray examination and S.G. comparisons.
E.S.

BANK (H.). *Zur Einteilung der Gemmologie.* Classification of gemmology. Zeitschr. d. deutsch. Gemmol. Gesellschaft, 1970, 19, 3/4, pp. 166-173.

The author suggests a decimal classification for gemmology. The whole subject could be sub-divided into general and specific gemmology, the first being sub-divided into characteristics and properties of gems, testing methods and working methods, the

second being sub-divided into natural gems (sub-divided into minerals, sulphides, oxides, etc.) and imitations (synthetics, imitations, and cultured pearls). For instance: 1 = general gemmology; 1·1 = characteristics and properties; 1·14 = physical characteristics; 1·141 = mechanical characteristics; 1·1411 = hardness. To give an example for the second group: 2 = specific gemmology; 2·1 = natural stones; 2·11 = minerals; 2·118 = silicates; 2·116 = beryl; 2·11862 = aquamarine.

E.S.

BANK (H.). *Was ist "YAG"?* What is "YAG"? Zeitschr. d. deutsch. Gemmol. 1970, 19, 3/4, pp. 176-179.

YAG is a synthetic product which has the chemical composition of an yttrium aluminate and can be used as a diamond substitute. The R.I. is lower than that of diamond and the S.G. quite a bit higher (diamond = 3·52, strontium titanate = 5·13, yttrium aluminate = 4·55). It is singly refractive and the R.I. is difficult to determine, but with the help of a heavy solution (Clerici) should be easily distinguishable from diamond.

E.S.

CASSEDANNE (J.). *Le gite de sphene-gemme de Capelinha.* Gem quality sphene from Capelinha. Bul. Ass. Francaise de Gem., 1970, 25, pp. 13-15.

The locality is Campo do Boa in the municipality of Capelinha, 134 km. from Diamantina and 157 km. from Teofilo Otoni, in the state of Minas Gerais. The sphene crystals rarely exceed a decimetre in length and are yellowish-green with a resinous lustre, with some faces (100, 102, 010) striated and corroded. They are frequently fissured, which explains the rarity of cut stones from this source. Hardness varies from 5 to 5½, density 3·52. Single crystals are rare, most occurring as two types of macles, contact and cruciform penetration. Associated minerals are hyaline quartz, magnetite and tourmaline.

M.O'D.

JOENS (H.). *Nordsee-Bernstein.* Amber from the Baltic. Zeitschr. d. deutsch. Gemmol. Gesellschaft, 1970, 19, 3/4, pp. 143-146.

Short historical survey of amber found in the Baltic. Occasionally a carved figure is washed ashore, presumably carved during the

stone age. Today's centre is St. Peter-Ording, where the amber is cleaned and polished. This natural amber has a transparent "bark", which is not found in imitations or in the pressed amber. The latter is produced by heating small pieces to 140-200°C under a pressure of 400-500 atm.

E.S.

MASSO (M.). *Quelques commentaires sur un rubis synthétique.* Some notes on synthetic ruby. Bul. Ass. Française de Gem., 1970, 25, pp. 11.

Seven synthetic rubies were examined giving the following results: optic axis parallel to the length of the stone, strong dichroism, S.G. 4·015–3·996, R.I. 1·760 and 1·768, red fluorescence, absorption spectrum similar to that of normal synthetic ruby with noticeable absorption of the yellow and green. No curved lines were seen but there were masses of both round and oval gas bubbles. Wavy markings resembling those seen in Kashan synthetic ruby were present. Some stones had lines crossing at almost 90°. The origin of the stones is unknown.

M.O'D.

NOEL (A. G.). *Treating opal matrix.* Lapidary Journ., 1970, 24, 7, 914.

A short account about the sugar-acid process for treating suitably porous Australian opal matrix.

S.P.

RÖSCH (S.). *Die Farben des blauen Zoisits von Tansania des "Tansanits".* The colours of the blue zoisite of Tanzania, the so-called tanzanite. Zeitschr. d. deutsch. Gemmol. Gesellschaft, 1970, 19, 3/4, pp. 103-115.

At first sight the zoisite crystal seems disappointing; instead of the blue colour it is khaki-brown. The author explains the absorption spectra of these stones and the way it has to be cut in order to produce the desired blue colour. The colour is then also improved by a heating process. The green zoisite is briefly mentioned. 2 tables, 8 graphs, bibl.

E.S.

RUTLAND (E. H.). *Farbgebende Spurenelemente in Edelsteinen.* Colouring trace elements in gemstones. Zeitschr. d. deutsch. Gemmol. Gesellschaft, 1970, 19, 3/4, pp. 139-142.

The author discusses the role played by trace elements in colouring minerals, in particular gemstones, especially if they are present in very small quantities. In each case the influenced stones are enumerated and a short description of their absorption spectra given. The most common trace element seems to be iron, then chromium. The author deals with manganese, copper, vanadium, titanium, uranium and rare earths.

E.S.

SANTOS MUNZURI (A.). *Consideraciones sobre los granates grossularia.* Gemologia, Bol. Ass. Espanola Gem. (Bul. Spanish Gemm. Ass.), 1969, 1, 3/4.

After a general discussion of the garnets and a note on the Mackowsky diagram showing the inter-relationship of the garnets, the author turns to the consideration of grossular garnet. Ceylon is the principal producer of the hessonite variety of grossular and nearly all cut stones now come from there. They are characterized by inclusions of diopside and zircon, which show their strong birefringence if the stone is examined under crossed polars. Other localities mentioned are Italy, Siberia and Mexico, where euhedral opaque crystals of green or red are found in the Jace Lake area. Fine examples of this material have been sent to China for fashioning into figurines.

Grossular from Pakistan had the following constants (Anderson) S.G. 3·64, R.I. 1·738, with a spectrum showing two lines in the red at 6970, accompanied by a line at 6300, with bands at 6050 and 5050Å. The stones show inclusions of actinolite similar to those displayed by Siberian and South African emeralds. In 1967 grossular from Zambia appeared in England, with constants of S.G. 3·55, R.I. 1·732. These are average values obtained by the author after an examination of 150 cut and rough stones. Canadian grossular has been found in colourless rhombdodecahedra form. They are found in Quebec asbestos mines and display characteristic inclusions of crossed canals.

9 colour photographs.

M.O'D.

WALDECK (H.), BAIER (E.). *Manganverteilung in Zuchtperlen.* Distribution of manganese in cultured pearls. Zeitschr. d. deutsch. Gemmol. Gesellschaft, 1970, 19, 3/4, pp. 99-102.

Using neutron activation it was shown that cultured pearls with and without a nucleus contain more manganese than natural pearls. The higher manganese content seems to be due to the higher manganese content of the implanted marine material. 3 tables, bibl.

E.S.

BOOK REVIEWS

BRUTON (E.). *Diamonds.* N.A.G. Press, London, 1970, 372 pp. 330 illus., coloured frontispiece. Price £5.

It has been suggested that a small boy's idea of paradise would be to be given the Crystal Palace and (conveniently to hand) Brighton beach to throw at it. On a more modest and adult scale it must rejoice a practised writer to become aware of a gap in the literature on a given subject and to know himself very well equipped to fill it.

The actual *doing* of the job is quite another matter. Long before even the thousandth stone was cast our small boy would probably be permanently cured of his propensity. An author is made of sterner stuff and has a living to make, but there are usually times during the creation of a major work when the sheer hard slog involved makes the project seem hardly worth the candle.

The gap in the literature of diamond which Mr. Bruton saw and has now filled so admirably must have become glaringly apparent to him when he came to conduct the Diamond Course at the Sir John Cass College in London. Though there have been many books written on diamond in the last 50 years there existed none which gave anything approaching a complete account of the mineral as a gemstone.

Eric Bruton's new book has the quality and dimensions of a future classic, and one can safely predict that it will pass through many editions, improving as it goes, and be translated into other languages.

The volume is ample in size—372 large octavo pages—and more than adequately illustrated with some 330 excellent photographs and drawings. At the end of each chapter a list of references is given, which is an unusual and welcome feature.

The opening chapter "Diamonds in History" might more aptly be titled "Introducing Diamond", as the sketchy and speculative record of diamond in history only occupies a few paragraphs, the remainder consisting of brief notes on various aspects of diamond which are to be dealt with more fully in succeeding chapters. The statement on page 16 that a half-carat stone weighs "about a twenty-eighth part of an ounce" is a slip which needs correction.

In the second chapter "Where Diamonds are Found" the book gets into its stride. The story of the discovery of the first authenticated diamond pebble in South Africa has perhaps been too often told for it to retain its very real human and romantic interest, but it was good to see so full and accurate an account of it given here. The chain of trust as this 21½ carat crystal was handed on from finder to eventual purchaser was an early example of the way this strange trade was to run in the future. Even the final allocation of rewards for the stone was notably fair. It is a pity that several of the other romantic stories of diamond discovery (such as that of the giant Cullinan crystal) could not be recounted in similar exact detail.

The next few chapters deal with the growth of the big mining companies and with the various methods of mining and recovery used in the main diamond-bearing pipes and alluvial fields. Having visited most of the major mines of South Africa Mr. Bruton is able to give a first-hand account of the highly specialised mining and recovery techniques which are needed to make an economic success where the precious mineral is present in so exceedingly low a concentration.

There follows a chapter on prospecting for diamonds, showing the gradual replacement of the old hit and miss methods ("diamond is where you find it") by more methodical and scientifically planned exploration based on geological knowledge and past experience. A good account is given of Dr. Gavin Lamont's recent successful prospecting in the Kalahari Desert, which entailed systematic sampling of minerals in the surface sand for tell-tale traces of garnets, ilmenite, etc. fished up ages before from lower strata by ants when building their towering nests. One would expect here a

description of the ingenious and pertinacious prospecting methods used by Russian scientists which led to the discovery of the vast "Mir" pipe and other rich deposits in the permafrost regions of northern Siberia, already referred to in a previous chapter. Mr. Bruton pleads insufficient information, but quite a lot of detail was in fact made available five years ago by N. Polutoff in an excellent article in "Gems and Gemology".

Next come chapters on "How the Market Operates", "Sorting Crystals", "The History of Diamond Cutting" and "History of Cuts". This last chapter, with its rather strange-sounding title, is valuable in having many clear diagrams of the various styles of cutting from the earliest roses and table cuts to the modern brilliant with its elaborately worked out scheme of angles and proportions based on Tolkowsky's design which was published in 1919. In this chapter the mis-spelling "facetted" for faceted is very prominent (though not consistently used) and needs carefully weeding out for the next edition.

The next chapter, on "Diamond Manufacture", is particularly well done, and gives in splendidly illustrated detail the whole process of converting a rough diamond into a perfect polished gem. There ensue three chapters on the grading of polished diamonds according to the "three C's" (colour, clarity and cut) which will be of prime value for students in the Diamond Courses. In the table reproduced as Fig. 12. 6. there is an unfortunate error in the colour-scale nomenclature as used in this country. Mr. Bruton gives the order as . . . . Silver Cape, Cape, Light Cape, Dark Cape . . . . and the same error is repeated two pages later. The correct and logical succession is . . . . Silver Cape, Light Cape, Cape, Dark Cape . . . .

The remaining chapters are on "Valuing Diamonds", "Origin and Geological Distribution", "Diamond Crystals", "The Physical Properties of Diamonds" (the first part of which would fit more appropriately into the chapter on crystals), "Synthetic Diamonds: Artificial Coloration", concluding with "Identification of Diamond". A most useful summary of the properties of diamond as compared with its most plausible substitutes is given as a tail-piece to this last chapter. There are appendices giving statistics of the largest uncut and cut diamonds and of world production, photographs showing how to fold a diamond paper, and an excellent index.

A general feature in the production of this book which assists both casual and serious readers to find their way is the subdivision

of each chapter into quite short plainly headed paragraphs. The danger here (not always avoided) is that these headings may not always accurately reflect the contents of the paragraph.

In dealing with a book so full of accurate and detailed information, the reviewer who picks on the inevitable small errors and inconsistencies to be found in the text must seem ungrateful and ungenerous. These can more usefully be brought to the author's attention to assist him in the production of a new edition.

B.W.A.

BUTKOVIČ (Š.). *História Slovenského Drahého Opálu z Dubníka.* History of the Opal Mines at Dubnik. Bratislava, 1970. 268 p. Price Kcs. 30·00.

An excellent treatise in the Czech language about the Dubnik (Cervenica) opal mines. Now in Czechoslovakia, but formerly in Hungary, the mines are situated north of Košice, in the eastern part of Slovakia, in the Libánka and Simonka mountains. Dubnik is the opal centre. The Czechoslovakian stones have a whitish background with delicate hues of blue, green and red. They are better known as Hungarian opals, before the district in which they occur became part of Czechoslovakia. The author has paid attention to the development of the opinions about opal which have appeared in the specialized literature and the bibliography is one of the best yet produced. The excellence of the text is supplemented by substantial summaries (about 16 pages each) in English, German and Russian. There are various coloured plates, but only one captures the beauty of this type of opal. For example, one really needs to see the splendid specimens in the Natural History Museum of Vienna to appreciate the loveliness of the stones. Dr. Butkovič has carried out a painstaking historical study of opal and a detailed account of the occurrences around Dubnik.

S.P.

SEN (N. B.). *Glorious History of the Koh-i-Noor Diamond.* New Book Soc. of India, 1970. ($4.00/£1·25).

This book was first published in 1953 as "History of Koh-i-Noor". Although in a larger format, it is substantially the same. The dedication has been changed and an end chapter in the original (a plea for the return of the diamond to India) has been omitted, though the old plea is still present in the new book.

S.P.

ASSOCIATION NOTICES

COUNCIL MEETING

A meeting of the Council of the Association was held at Saint Dunstan's House, Carey Lane, London E.C.2. on the 26th January, 1971. Mr. Norman Harper, Chairman, presided.

The following were elected:

FELLOWSHIP

Pie De Masso, Rosa M., Barcelona, Spain

ORDINARY

Blackwell, Gordon R., Royston, Herts.
Cambray, Clifford, Banstead, Surrey
Chetty, Samuel F. C., Vasby, Sweden.
Davies, Beryl A., Rhayader, Radnorshire
Rughini, Enrico, Bordighera, Italy
Fujisaki, Yukio, Iizuki City, Japan
Gandolfi, Giovanni A., Milan, Italy
Gilpin, Marriott O. F., Grays, Essex
Hutchinson, David, Sheffield, Yorks.
Leavitt, Joseph M., Orlando, Fa., U.S.A.
LeVine, Michael, Mt. Eden, Auckland, N. Zealand
Massie, George A., Sheffield, Yorks.
Nakamura, Yukio, Kumamoto-City, Japan
Ogden, John M., London
Ono, Koji, Kobe, Hyogo-Ken, Japan
Reston, J. A., Frodsham, Ches.
Robinson, Irvine, Silver Spring, Md., U.S.A.
Romi, Ishtiaq A., Karachi, Pakistan

Further arrangements were made in connexion with the Gemmological Exhibition to be held during the last two weeks in September and first two weeks in October, 1971, being arranged by the Glasgow Museums and Art Galleries and the Scottish Branch of the Association.

The following Officers were nominated: President, Sir Lawrence Bragg, C.H., F.R.S.; Chairman, Mr. Norman Harper; Vice-Chairman, Mr. D. N. King; and Treasurer, Mr. F. E. Lawson

Clarke. It was agreed that Mr. P. Riley should continue as Deputy Chairman of the Association.

Messrs. D. J. Ewing, J. M. B. McWilliam and W. Stern who retire under the Articles of Association in rotation, were nominated for re-election to the Council. Mr. Robert Webster, who retires under the age limit set down in section 185 of the Companies Act, 1948, was also nominated for re-election.

It was agreed to hold a meeting of members on the 12th October and the Presentation of Awards on the 23rd November.

The resignation of the Secretary to take effect in March, 1973, was received and accepted with regret.

MEMBERS' MEETINGS

A meeting of the Scottish Branch of the Association was held on the 19th January, 1971, at the North British Hotel, Glasgow. A talk was given by Detective Inspector H. MacLeod, F.G.A., of the Glasgow Police, entitled "Crime and the Jeweller".

A talk and demonstration of gemstone cutting and polishing was given by Mr. A. D. Hughes to the Midlands Branch of the Association, at a meeting held on the 18th February, 1971, at the Auctioneers' Institute, Birmingham.

GIFTS TO THE ASSOCIATION

The Council of the Association is indebted to Dr. C. E. S. Arps for his monograph Petrology of a part of the Western Galician Basement between the Rio Jallas and the Ria de Arosa (N.W. Spain) with emphasis on zircon investigations.

MEETINGS AND EXHIBITION

A meeting has been arranged for Tuesday, 12th October, 1971, at Goldsmiths' Hall, London, when Mr. Charles Schiffmann of the Gübelin Gemmological Laboratory, Lucerne, will be speaking to members.

The presentation of awards gained in the 1971 examinations will be held at Goldsmiths' Hall, London, on Tuesday, 23rd November, 1971.

An Exhibition of Gemstones is to be held at the Kelvin Museum and Art Gallery, Glasgow, during the last two weeks of September and first two weeks of October, 1971. This is being arranged by the Scottish Branch of the Association, in conjunction with the Glasgow Museums and Art Galleries.

GEMMOLOGY S.G. UNIT

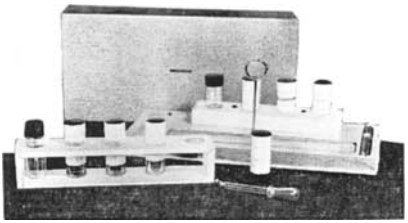

Compact unit with metal cover. Contains liquids made up to densities used in G.A. exams.

Unit consists of:

4 bottles liquids with S.G. 2·65, 2·89, 3·05, 3·32 each with an indicator.

3 bottles monobromonaphthalene, bromoform and methylene iodide for topping-up. 2 spare bottles. 1 glass dropper for topping-up. 1 glass rod. 1 3-prong spring stone holder.

Measurements 30 × 13½ × 7 cms. *Weight 4 lbs.*

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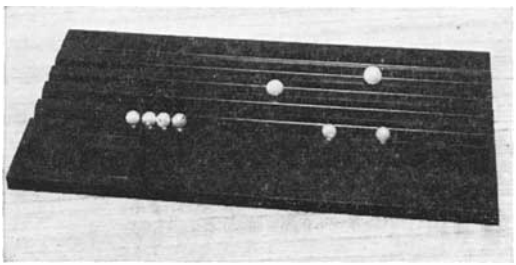

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THE JOURNAL OF GEMMOLOGY

and

PROCEEDINGS OF THE
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THE JOURNAL OF GEMMOLOGY
AND PROCEEDINGS OF THE GEMMOLOGICAL ASSOCIATION OF GREAT BRITAIN

Vol. 12 No. 7 JULY 1971

A 70th ANNIVERSARY TRIBUTE TO BASIL WILLIAM ANDERSON

THIS issue of the Journal is a tribute, by various gemmological friends and colleagues, to Basil William Anderson, who was 70 years of age on the 3rd July, 1971. Director of the Diamond, Pearl and Precious Stone Laboratory of the London Chamber of Commerce since 1925, Anderson is an outstanding internationally respected gemmologist, who, as research worker, author and lecturer, has made numerous major contributions to the study of gemmology. Apart from his work at the laboratory, where much of his enthusiasm has been passed on to his colleagues, Anderson, an eminently precise man, brought a fresh approach to gemmological teaching in Great Britain when he took charge of the classes at Chelsea Polytechnic in 1933. He perfected many new methods of gem testing, including the use of the hand-spectroscope. A dedicated gemmologist, he has been a friend and experienced and trusted counsellor to many people in many parts of the world and has given a dignity to a subject which he has served with great distinction.

G.F.A.

NEW ANALYTICAL RESULTS OF THE INCLUSIONS IN SIAM RUBIES

By E. GÜBELIN, Ph.D., C.G., F.G.A.

IT was a thoughtful arrangement of Mr. B. W. Anderson to publish the 8th Edition of his highly instructive and invaluable book "Gem Testing" in the same year as he is celebrating his 70th Anniversary, in whose honour the present issue of the Journal has been printed.

In the 30 years of its existence the book has experienced an enormous enrichment as regards its text and the increasing number and quality of illustrations. All fresh knowledge and every progressive step in practical gemmology have been considered in each new edition and many new illustrations have replaced the out-dated ones.

As I have always been keenly dedicated to the inclusions in gemstones, I was always particularly attracted by the beautiful and tell-tale photomicrographs of inclusions in Mr. Anderson's book. Consequently when I received my copy of the 8th Edition I first examined the illustrations of inclusions to discover whether some new examples had been inserted and I was particularly pleased to notice that Fig. 74 on page 202 in the 7th Edition portraying those highly diagnostic features of inclusions in Siam rubies appeared again in illustration 11.7 on page 211 in the 8th Edition, accompanied by a new reference in the text reading "The most typical inclusions in Siam rubies are round and opaque, always surrounded by a roughly circular "feather" (see Fig. 11.7); when these are small, careful examination is needed to differentiate them from the bubbles seen in synthetic stones". Indeed, these characteristic inclusions, consisting of a mineral surrounded by a halo of liquid droplets, are so unique of Siam rubies that every ruby containing this kind of inclusion may rightly be acknowledged as a ruby from Thailand.

During the course of the last 30 years I have examined many thousands of Siam rubies and have repeatedly encountered these local peculiarities. In a ratio of 5 to 8 out of 10 Siam rubies are earmarked with this typical feature. At an early stage my interest in their nature and appearance was aroused. It was easily possible to notice different aspects under a microscope but proved impossible

to determine their nature by orthodox gemmological tests. The flatness of the liquid halos is very conspicuous and was referred to by other authors. In fact they differ by this characteristic from the undulated ordinary healing fissures. Careful examination displays that the liquid pools with their accompanying mineral grains are usually lying flat with a twin—or parting—plane. When a great number of these characteristic inclusions are present in a Siam ruby they are often lined up in a row, vertical or inclined against twin—or parting—planes, thus being separated from each other by the individual lamellae. In transmitted light of the ordinary light microscope the mineral grains appear black and opaque. In dark field illumination it is possible to differentiate three different appearances. Some of the grains are black with a strong metallic lustre, others show a yellow or brownish to brown-red colour with a frosted surface, while the third kind is transparent and rather looks like negative crystals. While some of the brown and brown-red frosted mineral grains seem to have a crystal form of the rhombododecahedron, most of the others seem to prefer a pseudohexagonal shape with a large basal pinakoid, medium size rhombohedra combined with very short prism faces, thus displaying the stumpy habit of rubies. Identification of the nature of these mineral grains was delayed until the advent of the electron microprobe. The first attempts with a few specimens containing unusually small mineral grains were not particularly encouraging in that no definite results could be obtained, although the chemical elements analysed suggested the presence of almandine garnet and pyrrhotine. Therefore, I decided to collect Siam rubies in Thailand where I could select samples with particularly large and well developed mineral inclusions. When I visited Bangkok last November in the course of a business trip, I concentrated my attention on Siam rubies of lower quality but possessing their well known internal features. Meanwhile, I have subjected these Siam rubies to an electron microprobe analysis which yielded interesting results, of which I wish to report hereafter. In order to prepare gemstones for a microprobe examination of their inclusions, the stones have to be cut down, commencing from the nearest facet, so that the mineral inclusion becomes exposed. As a result of cutting down the facet until the inclusion became flush to the surface it was apparent that a great number of the transparent and colourless inclusions were actually negative crystals. Whether

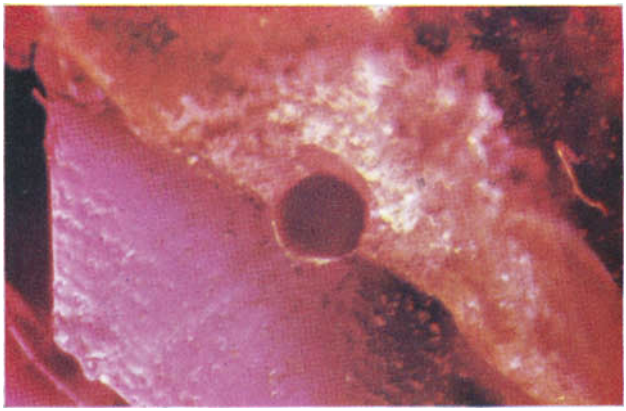

FIG. 1. Hexagonal apatite crystal with stumpy habit at the edge of a large liquid feather. 50 ×

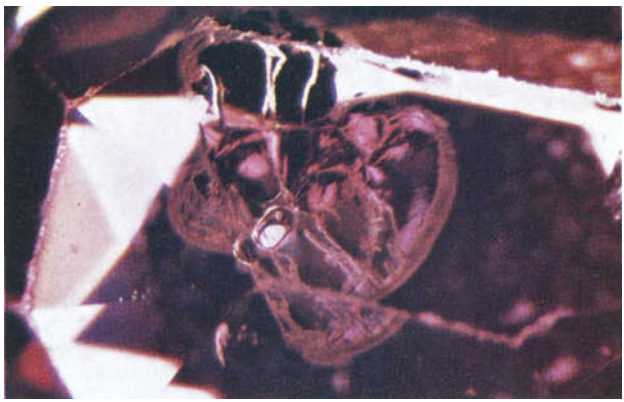

FIG. 2. Xenomorphous, brownish grain of almandine garnet circumflooded by a large film of reticulated fluid. 20 ×.

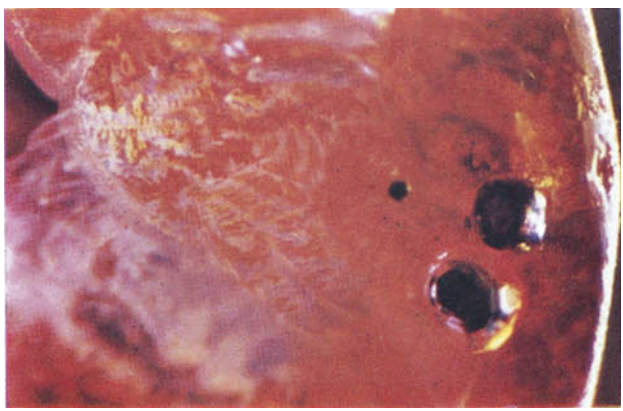

FIG. 4. Black, hexagonal crystals of pyrrhotine with high metallic lustre, and surrounded by large fluid pools with dendritic pattern. 32 ×.

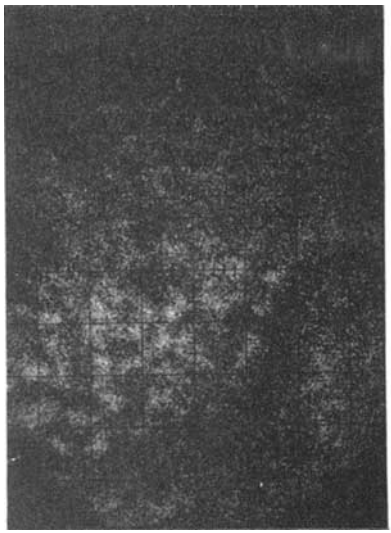

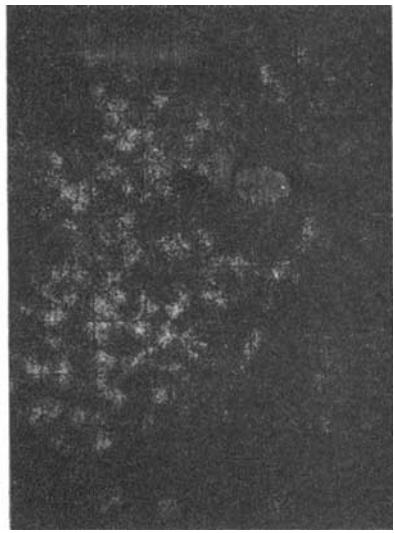

FIG. 8a. Microscanogram of the apatite of Fig. 1 showing the distribution of calcium (Kα). 500 ×.

FIG. 8b. Microscanogram showing the distribution of phosphorus (Kα). 500 ×.

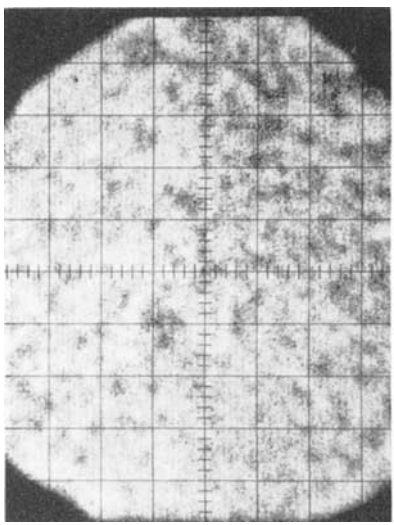

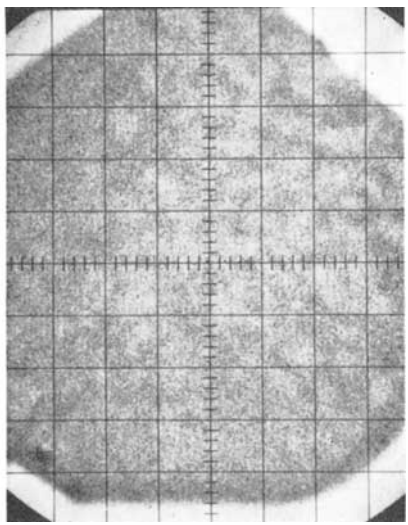

FIG. 9a. Microscanogram of the almandine of Fig. 2 revealing the distribution of the iron (Kα). 500 ×.

FIG. 9b. Microscanogram of the almandine of Fig. 2 indicating the distribution of aluminium (Kα). 500 ×.

they had been filled with a gas or liquid could not be determined because whatever filling might have been present was lost in the process of cutting. Some of them were lined with some yellowish, dirty looking substance. Yellow and brown inclusions revealed a lower degree of surface reflection than the ruby, while their colours remained unchanged. The black mineral grains often showed a rough surface and in many cases they would partly break out. Whenever their surface took a good polish it showed a high metallic lustre. It was also apparent that the black grains were much softer than the host gem.

Under the electron microprobe the yellowish to yellow guest crystals which at times displayed hexagonal shapes reacted to the calcium and phosphorus test; therefore these crystal inclusions were found to be apatite, with a composition of $[Ca_5F(PO_4)_3]$. (Compare Figs. 1 and 8a and 8b).

The brown to reddish-brown mineral inclusions which are very often rounded, but sometimes have a rhombododecahedral shape, proved to be composed of iron, aluminium and silica, thus marking the inclusion to be almandine $[Fe_3Al_2(SiO_4)_3]$. (Compare Figs. 2 as well as 9a, 9b and 9c). Both apatite and almandine might have been pre-existent minerals when they were embraced by the development of the ruby.

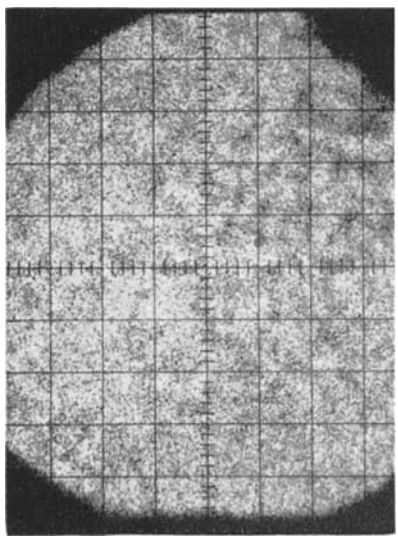

FIG. 9c. Microscanogram of the almandine of Fig. 2 portraying the distribution of the silicium (Kα). 500 ×.

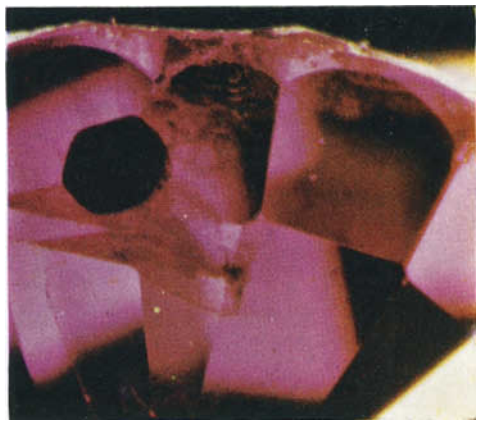

FIG. 3. Black pyrrhotine grain of hexagonal shape surrounded by multiple fluid feather. 20 ×.

The black inclusions proved to consist mainly of iron and sulphur which indicated pyrrhotine—the formula of which is FeS but may vary from Fe_5S_6 to $Fe_{16}S_{17}$ (refer to Figs. 3, 4, 10b and 10d).

Pyrrhotine occurs in large quantities associated with basic igneous rocks from which it has been segregated by some form of magmatic differentiation. It is commonly associated with chalcopyrite, pentlandite, pyrite and magnetite. The traces of nickel usually found in combination with pyrrhotine is most probably due to dissolved grains of pentlandite [$(Ni, Fe)_9S_8$], which is a rather common combination. One analysis yielded particularly interesting results; it was found that a pyrrhotine grain also intermixed with a small amount of nickel was completely encased by an envelope of chalcopyrite [$CuFeS_2$], which was corroborated by the presence of iron, copper and sulphur (see Figs. 5 and 10a, 10c and 10d). Chalcopyrite is a very common copper ore which occurs in metalliferous lodes and in vugs in gneiss and crystalline schists as well as in contact metamorphic rocks. It is closely associated with pyrrhotine and then forms the mixture of chalcopyrrhotine, [$CuFeS_2 - FeS$] assuming the name of cubanite.

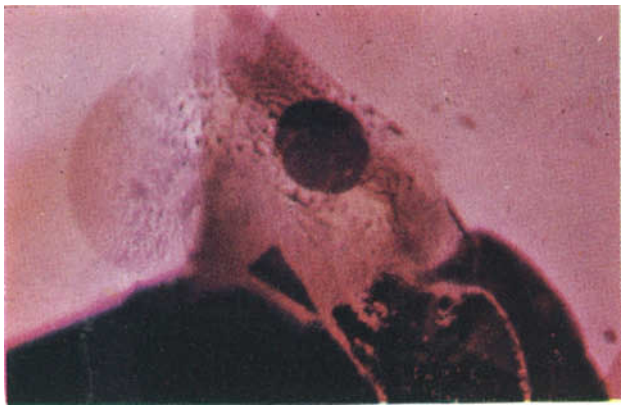

FIG. 5. Black rounded grain of pyrrhotine inter-mixed with minute grains of pentlandite and surrounded by a corona of chalcopyrite. 20 ×.

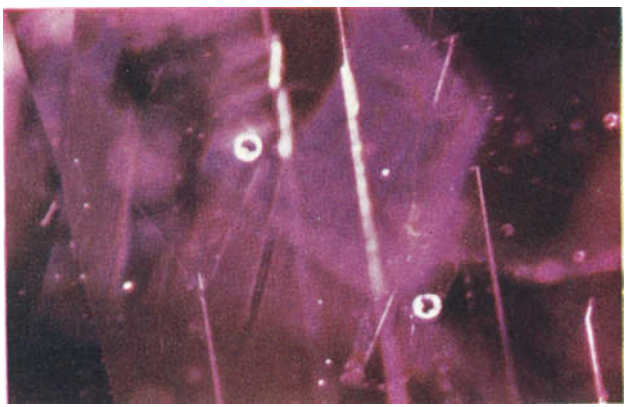

FIG. 6. Clear, transparent, rounded grains of plagioclase, which might easily be mistaken for gas bubbles when observed in an otherwise pure Siam ruby. 16 ×.

FIG. 7. Transparent, slightly greenish crystal of diopside, surrounded by multiple tension cracks. 16 ×.

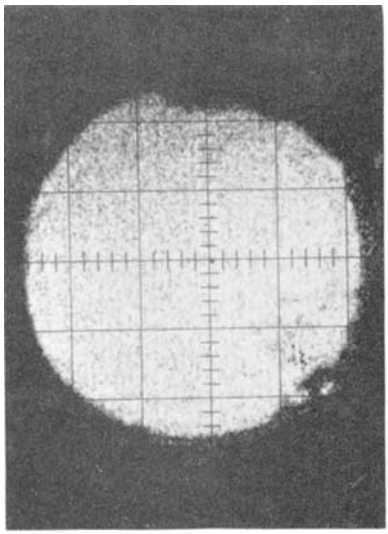

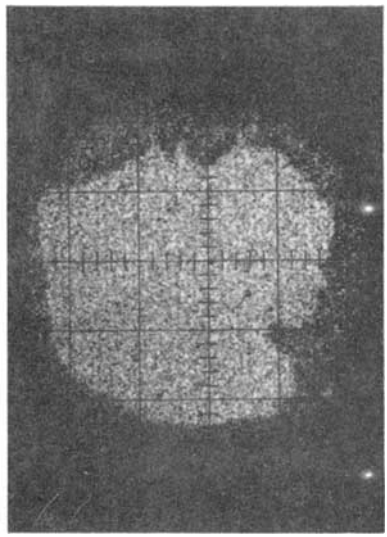

FIG. 10a. Microscanogram of the sulphide ores of Fig. 5 disclosing the distribution of the iron (Kα). 250 ×.

FIG. 10b. Microscanogram of the sulphide ores of Fig. 5 manifesting the nickel content of the pentlandite grains interspersed through the pyrrhotine (Kα). 250 ×.

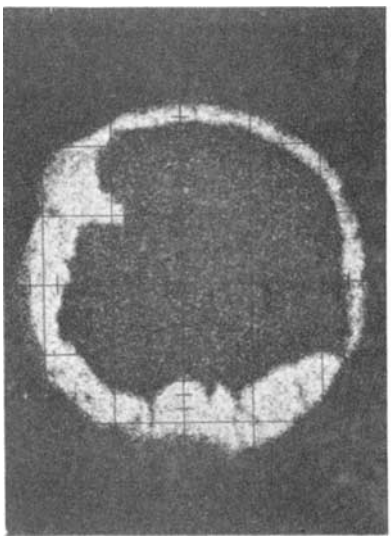

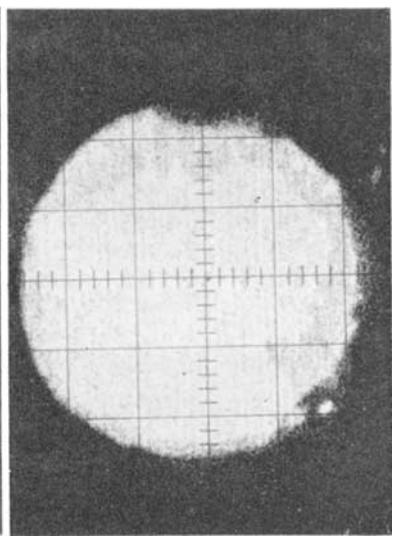

FIG. 10c. Microscanogram of the chalcopyrite corona of Fig. 5 betraying the distribution of the copper (Kα). 250 ×.

FIG. 10d. Microscanogram of the sulphide ores of Fig. 5 depicting the sulphur content (Kα). 250 ×.

These iron, nickel and copper sulphides enclosed in Siam rubies and forming the highly characteristic feature of their internal paragenesis are certainly of syngenetic origin with the host gem. Apart from these mineral inclusions which are always in contact with more or less circular fluid splashes, two other types of minerals have been found and analysed. They do not seem to have any relationship to the fluid pools of the other guest minerals, but they are distinctive because they are colourless and transparent. The smaller ones of these, which quite often appear as round grains and as such might easily be mistaken for spherical gas bubbles, produced readings on the electron microprobe which indicated the presence of calcium, sodium, aluminium and silica with traces of potassium, magnesium and iron. Consequently these small transparent inclusions were judged to be plagioclase, whereas a larger, slightly greenish and rather well shaped crystal was identified as diopside [$CaMg(Si_2O_6)$] by revealing calcium, magnesium and silica with traces only of iron and sodium when examined with the microprobe. From this enclosed dioxide crystal, which was found in one case only, a score of tension cracks projected out into the body of the ruby.

Despite these identifying verdicts of the inclusions it is still rather difficult to present a plausible explanation concerning their mode of formation. Some mineralogists believe that the foreign mineral grains are either of pre-existent or of syngenetic primary heterogeneous origin and that their capture within the body of the host gem caused the latter to develop cracks. These started healing immediately afterwards—a process by which the flat hexagonal or otherwise polygonal platelets were created and which are considered to be healing islets formed around nucleation points. Other scientists suggest that the mineral grains crystallized from drops of alien fluid which happened to be "washed on" by convection currents and to be absorbed by the growth face during the intervals of interrupted growth. The flat film of liquid drops would then consist of the exhausted residual solution, left behind after the mineral grain had "sucked out" the constituent ingredients. Such reactions may readily be observed under the microscope in the course of microchemical spot-tests.

Personally, I do not favour the "healing theory" because I am convinced that the negative crystals and their filling substances,

as well as the fluid inclusions surrounding them are of syngenetic primary origin.

A growing crystal envelopes itself with a coat supersaturated with dissolved substances. The solubility of a crystal growing in its mother melt may increase on account of a chemical change of the mother liquor or also of alien solutions caused by impurities of some sort, so that a considerable supersaturation occurs in the middle or along the borders of the growth faces. The growth speed, which will be delayed by the physical and chemical absorption of the foreign substance on the crystal face, remains normal along the edges of the faces, yet becomes blocked in its centre. This engenders a central vacancy whose size depends upon value and degree of the minimum of the supersaturation. Immediately after a sharp drop of the temperature the vacancy developes a large basal plane, which is the beginning of a negative crystal. The size of the cavity diminishes as the general concentration of the solution decreases, when the crystal is growing in constant temperature in an enclosed *locus nascendi.* This process results in the formation of negative crystals, whose shape need not necessarily be ideal, as well as in the coating of growth faces by liquid feathers, which are characterized by net-like ramifications and resemble the well-known secondary liquid feathers. However, they distinguish themselves from secondary fluid inclusions in that they are flat and level with growth faces.

Other impurities are capable of lowering the solubility of the crystal substance, so that the maximum of the supersaturation becomes situated in the centre of the growing crystal face, and eventually a precipitation takes place in the immediate neighbourhood of the crystal face. The precipitated substances may become enclosed by the growing crystal later on. If the specific absorption on the growing face predominates over the diffusion, then the absorbed layer is marked by groups of growing islets along preferred directions, which are embraced by a reticulation of liquid channels overlaying the growth plane. This, in my opinion, seems to be the explanation of the formation of the fluid sprinkles and their accompanying negative crystals which are filled with gas, liquid or solid substances. The magmatic, hydromagmatic, pneumatolytic and hydrothermal processes of mineral formation

possess numerous faculties of supersaturations and undercoolings, so that we are bound to consider disturbed gradients of equilibrium. The evolution of primary cavities and fluid inclusions in minerals corresponds directly with a disturbed physical-chemical equilibrium.

Wherever the ruby is mined in Thailand, be it at Bang-Kha-Cha, Klong Van, Bo Vien or Bang Thum, it is discovered in deposits of coarsely grained alluvial gravel banks, which have developed from weathered basalts. These are generally fine-grained, dark-coloured igneous rocks primarily composed of calcic plagioclase and pyroxene, with or without olivine.

Apatite and magnetite are almost always present as accessories. Although Siam rubies are now found in widely scattered alluvial placers, the consistency of the inclusions described above yields evidence that the rubies were all formed under the same geological conditions either in one place or in closely adjacent deposits, which so distinctly earmarked their precious product. The presence of apatite, diopside and olivine (the latter was found in one single case only) among the guest minerals might suggest the same process of formation as in Burma. However, the complete lack of calcite, spinel and exsolved rutile (in the form of "silk") seems to indicate an entirely different combination of chemical elements in the mother melt. The composition of the present alluvial deposits and the sulphide inclusions of the Siam rubies hint at the possibility that the rubies are derivates of interactions in contact zones between crystalline schists or granitic pegmatites and basaltic country rocks, which eons ago formed the higher mountain regions between the broad valleys of the Menam and Mekong rivers, a part of the world which not only today but also hundreds of millions of years ago experienced gigantic upheavals.

A FEW OBSERVATIONS RELATED TO SYNTHETIC EMERALD

By F. DUYK

WHEN synthetic emerald is observed under the microscope, one usually proceeds to the examination of its internal characters. The analysis of the shapes and pattern of the internal structure is then made the chief object of the examination.

I discovered that it was just as interesting to make a careful study of the surface of *uncut* crystals. In this case cutting has not taken away peculiarities of construction which are therefore clearly seen and their careful examination is very interesting.

The examination of a very beautiful crystal of synthetic emerald manufactured by Gilson has, in the first instance, under preliminary gemmological tests, given the following results, which are normal:

R.I.: 1·559–1·565 D.R.: 0·006 S.G.: 2·66

Absorption spectrum lines at 6750, 6400 and 5650Å

Fluorescence: red under long U.V.

Chelsea filter: bright red.

The classic internal examination under the microscope shows in addition to outlined formations and small liquid channels, which

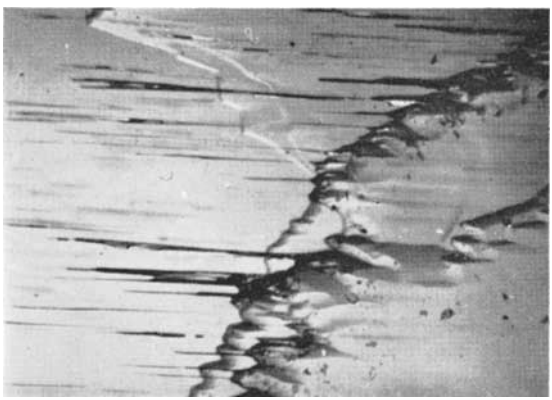

FIG. 1.

have become classic, hollow channels containing not only chromiferous liquid but also crystallites and gas bubbles (Fig. 1). It can be observed that in these channels matter is present in its three physical states: liquid, solid and gaseous. This clearly constitutes the presence in synthetic emerald of *three-phase inclusions.*

This first discovery encouraged me to recommence a study to which in the past I had already devoted some time, namely that of the morphology of the surface of rough crystals.

A first observation clearly showed that the hollow channels were the result of morphological decreases. It happens that when the growth of the crystal thins down, little by little, probably owing to a decrease in the quantity of crystallizable elements, figures or patterns become detectable similar to what formerly used to be termed "Hauy's Vicinal Faces". Active elements immobilizing themselves during the process of crystallization are responsible for the formation of the surfaces. Is it not natural then that elements taking no active part in that process such as water and gas, elements of a fluid nature, find no outlet for escaping and form those channels where one meets crystallites, water and bubbles? (Figs. 2 and 3).

These crystallites present in the hollow channels may have been formed out of non-assimilated silica, as their examination under crossed nicols shows a clear birefringence and some of them also display a fluorescence readily detectable under U.V.

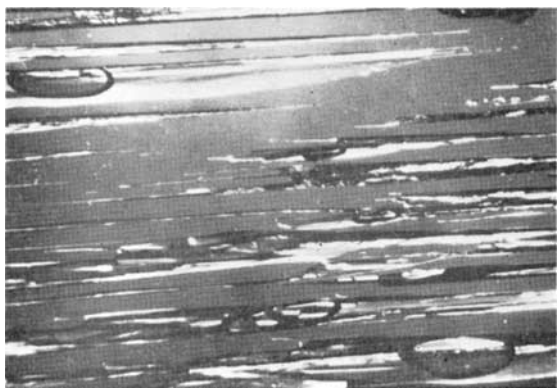

FIG. 2.

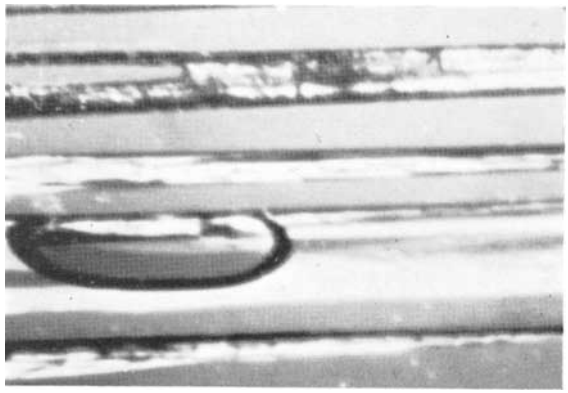

FIG. 3.

Finally, the last photograph shows growths at angles of 90° on the face P, which are quite normal but interesting to observe on account of their regularity.

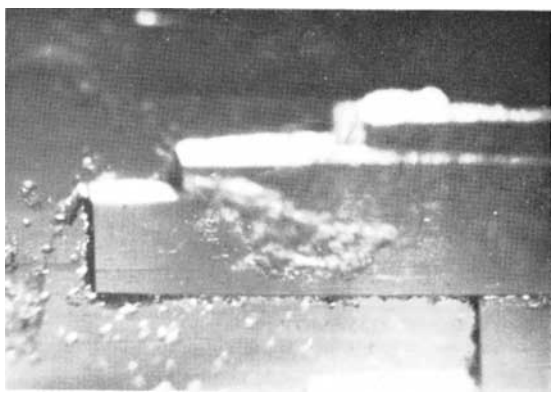

FIG. 4.

SOME RARE MATERIALS

By W. F. EPPLER

Chiastolite is an opaque and massive variety of andalusite which contains a black micaceous schist in the form of a cross or a square or both. Fig. 1 is a thin section of such a "cross-stone", as it was sometimes named. It shows a dark and fine-grained borderline consisting of mica. This line is accompanied on each side by elongated fibres of andalusite, which are followed by grains of the same material of random orientation. They form the whitish-grey part of the stone. The arms of the black cross broaden towards the outer part of the stone and here the mica is much coarser, as shown in Fig. 2. The mica is a muscovite which is darkened by minute platelets of hematite, and biotite, altered in pennine, which is a chlorite. Besides this, an acid plagioclase is present.

To a certain extent, this structure is reminiscent of the trapiche emerald, with the difference that here are only four parts around the centre. As early as 1926, F. Bernauer[1] described the "triplet emeralds", as they were then named, and mentioned that their single parts are nothing else than "pyramids of growth" and he adds (in translation): ". . . just as with chiastolite". This explanation, given 45 years ago, is not easy to understand with respect to this particular kind of crystallization.

Amblygonite, a well known ore of lithium, was first mentioned as a gemstone by A. Schroeder in 1953[2]. J. E. Schunk and N. Deane[3] describe the inclusions in amblygonite as "a white mossy texture plus some of a bright green colour", while E. Gübelin[4] found the inclusions to be parallel or banded clouds which consist of many fine cracks and very small brown and black coloured particles. These descriptions in mind, it was a great surprise to observe in a well coloured amblygonite threadlike inclusions as they are exhibited in Fig. 3. They all run in the same direction, but they are not parallel to each other and one or the other of them is forked. It may be possible that they consist of goethite (alpha-FeOOH), as similar fibres in topaz have been found to be this kind of iron-hydroxide. Besides these inclusions, a few "clouds" are also present in the stone.

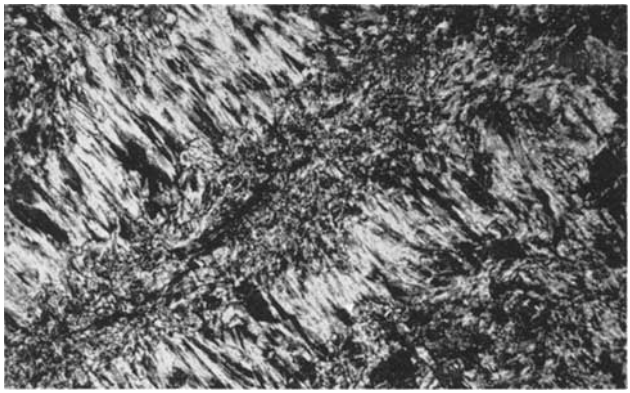

Fig. 1. Chiastolite from U.S.A. Fibres of andalusite; crossed polaroids, thin section. 65 ×.

Fig. 2. Chiastolite from U.S.A. Coarse grained mica crystals, forming the black parts of the stone; thin section. 65 ×.

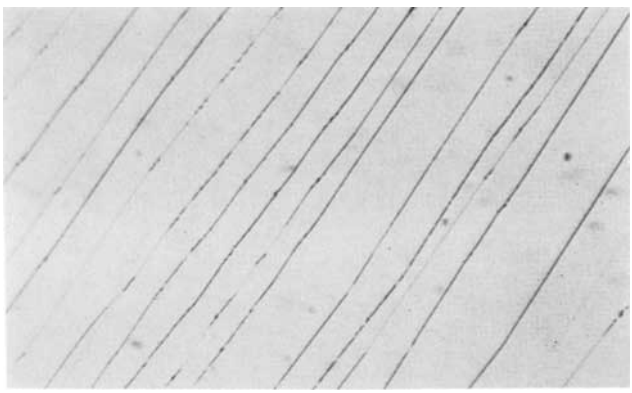

Fig. 3. Amblygonite with threadlike inclusions. 65 ×.

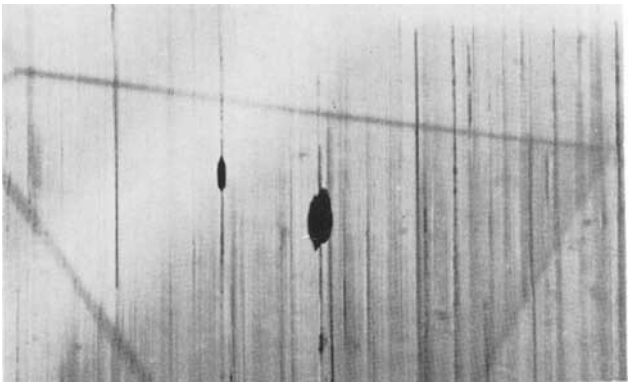

FIG. 4. Dark brown enstatite with fine needles. 65 ×.

FIG. 5. Blue-quartz with tiny fibres of crocidolite. 65 ×.

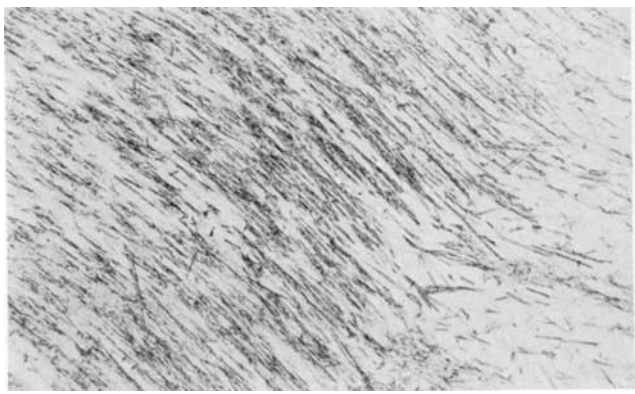

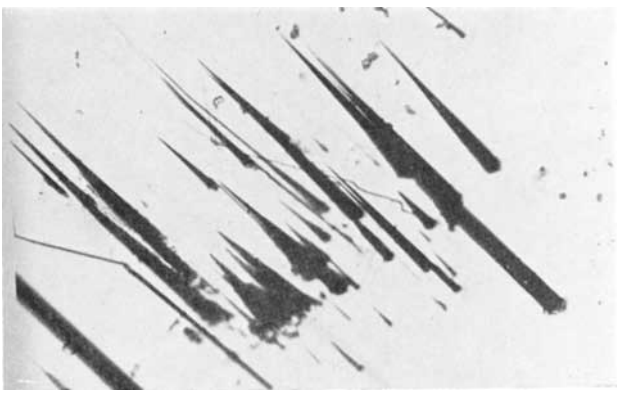

FIG. 6. Bright green grossular with cuneiformed tubes of growth. 65 ×.

Enstatite of a brown colour, reddish-brown to greenish-brown and of transparent nature was recorded for the first time in 1953 by R. K. Mitchell[5]. In 1967, a star-enstatite was described[6] with inclusions of very fine and tiny crystal needles which most probably are rutile. The crystal needles represented in Fig. 4 are embedded in a clear and transparent enstatite of a dark brown, smoky-quartz-like colour with a strong pleochroism. The nature of the needles is not yet known, but they run parallel to each other and are therefore strictly orientated. The stone of 3·5 carats was perfectly fashioned in a trap cut and surprised by its relatively high lustre.

The second edition of M. Bauer's "Edelsteinkunde", 1909, p. 600, gives the description of "sapphire-quartz" which runs as follows (in translation): ". . . it is a crystallized quartz, containing a great number of needles or fibres of a blue substance, most probably belonging to the mineral crocidolite. It occurs in veins in the gypsum of the Gypsumhill at Mooseck near Golling in the district of Salzburg". Just by chance, the author obtained a sample of this "historical" occurrence in Austria. In a thin section prepared of it, a multitude of the fine and tiny crystals of blue crocidolite (Fig. 5) can be seen.

The term "sapphire-quartz" is confusing and not correct, while the other names "lazurquartz" and "siderite" are no more in use, fortunately. So, "blue-quartz" seems to be the best, as it names, what it is, a blue-coloured quartz. By the way, it is not a crystallized rock crystal, but a massive quartz consisting of irregular grains of random orientation, a formation which characterizes the "quartzites". The stone is mentioned here, because not long ago a blue-quartz from another locality appeared on the market. This material has great and beautiful bright blue spots, which own their colour also to needles or fibres of blue crocidolite.

Transparent *green grossular* was first recorded by B. W. Anderson[7] in 1966. The stones have interesting inclusions, "a large and well-developed crystal", possibly of actinolite, and in others liquid "feathers rather in the spessartite manner". They had been sent from Pakistan. Later on, a transparent yellowish-green and an emerald green grossular, both from Tanzania, have been described in the literature[8,9], but without a hint on any kind of inclusions.

Nearly a year ago, the author received two transparent grossulars, originated from Tanzania, the values of which agreed

with those given in the mentioned publications. The colour is a lovely green, a bright green which is very near to the emerald-green. One of the stones has an enclosure of a rounded zircon, while the other contains numerous and cuneiformed tubes of growth, a group of which is exhibited in Fig. 6. They run parallel to each other and indicate the direction of growth.

Silica Glass was found by L. J. Spencer in the Libyan desert in 1932. It occurs in great lumps of a poor greenish-yellowish colour and consists of 97·6% silica. It is not very attractive, and it is only mentioned with regard to the irregularly formed gas inclusions (Fig. 7). They indicate the natural origin of the material, which formerly was doubted sometimes. In artificial glass, the gas bubbles form balls or elongated tubes which are mostly pointed on both ends.

A small but well formed Phoenician vase consists of a colourless and, of course, artificial glass. It is estimated to have been made in 300BC or still earlier. Its surface is opaque and has a fine lusture which resembles the same optical effect of pearls or of mother-of-pearl. It is obvious that this is the result of a weathering. The disintegrated surface consists of small scales which can be easily taken off. When examining one of them with the microscope, it was found that such a scale has several layers, each of which is very thin. The Fig. 8 exhibits two of them which easily can be recognized. Each of the "films" is cracked in irregular pieces, by which many little fissures have been produced. The thin films and the fissures are responsible for an effect of interference which is the reason of the iridescence. In fact, we have in this case a perfect analogy to the lustre of pearls and of mother-of-pearl. An explanation is not difficult.

It is certain, that the vase of glass was embedded in the earth for a very long time, perhaps much longer than 1,000 years. During this time, the easily soluble parts of the glass (the alkali- and the earth alkali-components) could be removed by the humidity of the soil. The remainder was permanently enriched with silica which, in the course of time, started to crystallize. With this process, a reduction of the volume was combined and it produced the layers and the cracks, In polarized light, most of the particles remain dark, which is in conformity with the amorphous state of glass. Other particles are rounded with a convex surface. They

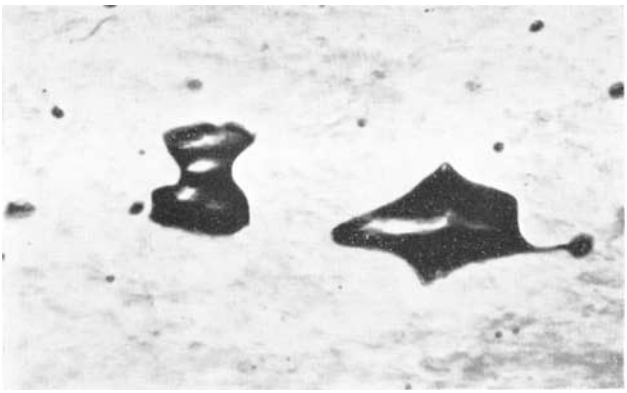

FIG. 7. Silica Glass with irregularly formed gas inclusions. 65 ×.

FIG. 8. The weathered surface of an artificial glass of Phoenician age. 65 ×.

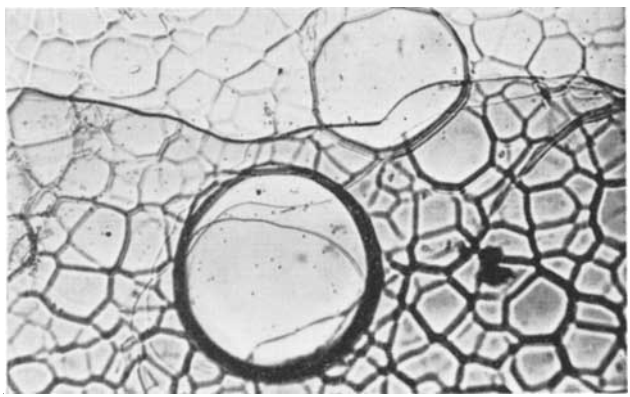

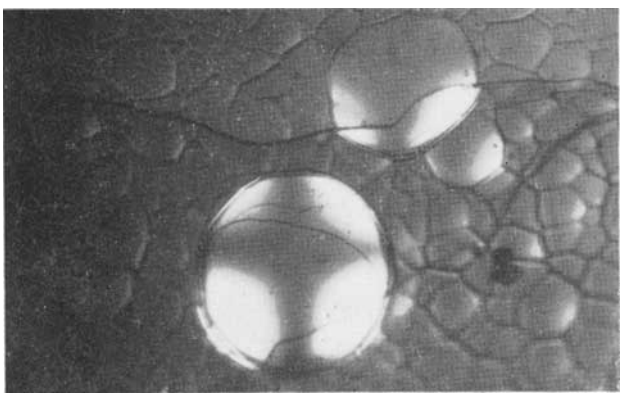

FIG. 9. Same as Fig. 8, but crossed polarizers. 65 ×.

exhibit a dark cross—like the interference figure of a uniaxial crystal (Fig. 9). When applying the mica plate of the red of the first order, the four sectors of the interference figure appear in a distribution of colours in a manner which is characteristic for a crystal with a negative optical character. It can be concluded, that the silica is crystallized, but not as quartz, which is positive in character and has an interference figure with a "hole" in its centre. It is rather an optical negative form of silica as it is represented by crystobalite.

This nice old phial is by far not a gem material, but in every collection it would be estimated without any doubt as a most valuable item.

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NEW CLASSIFICATION OF GEMSTONE COLOURS

By K. F. CHUDOBA

IN the past the colour or absence of colour of gems was always of the utmost importance in their determination. Even today great importance is attached to this obvious property because very often an expert can recognize a gem by its colour or absence of colour. However, such methods of determination are questionable. For this reason one has tried for centuries—apart from determining other physical and chemical properties—to find the natural causes of colouring and to classify these scientifically so as to aid determination.

The most important starting observations and the then following scientific advances which have been found in this connexion are

summarized in tabular form. Metallic colours are divided from the non-metallic ones and in the latter one finds manifold gem colours as well as absence of colour.

In the case of colourless gems examination of colour-causes soon showed that they can easily appear coloured by inclusions of tiny foreign bodies (pigments)[10], as for instance green aventurine (quartz with green mica inclusions) and blue quartz (by refraction of the light caused by very fine rutile needles). These instances of the basis of colour caused J. W. Baumer[2], in 1763/64, to remark that "the usual colours of gems are most probably caused by the admixture of metallic parts". With hindsight one can say that this hypothesis has to some extent been proved.

In those admixtures, whose existence was guessed but could not be seen optically, examinations and determinations were not always successful and the chemical methods which had been developed in the meantime could not always determine the minimal quantities of the colour carrier—the trace elements. Only the systematic use of the spectroscope, which had been developed for gemstone examination, opened the way for a quick and reliable determination.

Most important for this method was the knowledge that certain gem types showed certain characteristic absorption spectra, i.e. that the absorption lines or bands are always to be found in the same place. Similar spectra show the relationship of certain gem types and it follows that they have similar colour pigmentation.

The spectroscopic examination and determination of gems forms the nucleus of many publications of B. W. Anderson, whose work is so well known today. In past decades he has published many works in this field, especially *Gem Testing*, now in its 8th edition[1]. Anderson proved many times that in colourless gems with an undisturbed lattice a colourless ion can be partially replaced by a colouring trace element (isomorphous replacement by a chemical element). In this way a colourless—achromatic—stone is coloured by the addition of a colouring foreign element; this results in allochromatic gems[12].

The colouring matters (chromophores) are of the greatest importance for synthetic gems, as the synthesis is achieved by their addition to colourless material. This results in the repeatable production of stones with a natural colour effect.

In order to classify gem colours it was of utmost importance to list apart from the allochromatic gems those stones which are never colourless and show a characteristic colour caused by their chemical composition in an undisturbed lattice. These colours are caused by a pure chemical substance and they are idiochromatic[12]. Gems of this type include malachite (green), lapis-lazuli and azurite (blue).

It seems to be important to classify the idiochromatic gem colours together with the achromatic ones and not together with the allochromatic ones, which is often done. The latter are colourless stones coloured by foreign elements (see table).

It also seems to be of importance for the classification of causes of colouration to underline the "structure-sensitive" property, that is to consider the lattice structure and its peculiar properties in this respect.

The most obvious example of this seems to be the dimorphous carbon (C), which has a cubic lattice as diamond and a hexagonal one as graphite, the first modification being mainly colourless, the second steel-grey.

According to C. W. Correns[5] this structure-sensitivity relates to typical lattices of certain gemstones which can show structural irregularities, while Tertsch[11] considers that the lattice is in a labile equilibrium; this explanation is based on electro-magnetic light theories and shows how the lattice can be destroyed by treatment with x-, cathode-, radium-, electron- and neutron- and other rays. The disturbed part of the lattice then forms the colour centre, so that minimal disturbances of the lattice can cause colourations, de-colourations and colour alterations, which have to be classified as allochromatic colours in a gem classification (K. Przibram[9]).

Occasionally the disturbance in the lattice causing a new allochromatic colour can also be based on an interlateral addition of another element, while usually the trace elements substitute ions of the normal lattice.

When classifying the gem colours one therefore has to consider the relationship between a lattice disturbance and the bombardment colour (see Table, page 265). Examples of this are the two gems zircon[3] and ekanite [6, 7]; in these cases the disturbed arrangement of the lattice is re-formed (retrocrystallization) at the same time as the original colour is restored.

Results of bombardment have been published many times. Diamond is coloured green or blue[3] by intensive electron bombardment. The cause of the blue colouration has been found to be the C-atoms, which are shot out of their position by the electrons, and the resulting empty place in the lattice (absence of the central tetrahedral C-atom)—at the same time other C-atoms are pushed into an intermediate position.

In the case of some gems the colour is not only caused by trace elements, but by additional bombardment, for instance in the case of amethyst and smoky quartz[3, 4].

From the accompanying sketch it can be seen that the determination of the colour of the stone must be based on the condition of the lattice and it is important to establish whether the colour is caused by a "pure undisturbed lattice" or a "disturbed" lattice[10]. The structure-sensitive properties are only rarely taken into consideration when classifying the colour of gems; even if notice is taken of this important property their relationships are only mentioned without showing their genetic ties. The following table shows the classification of gem colours according to today's knowledge.

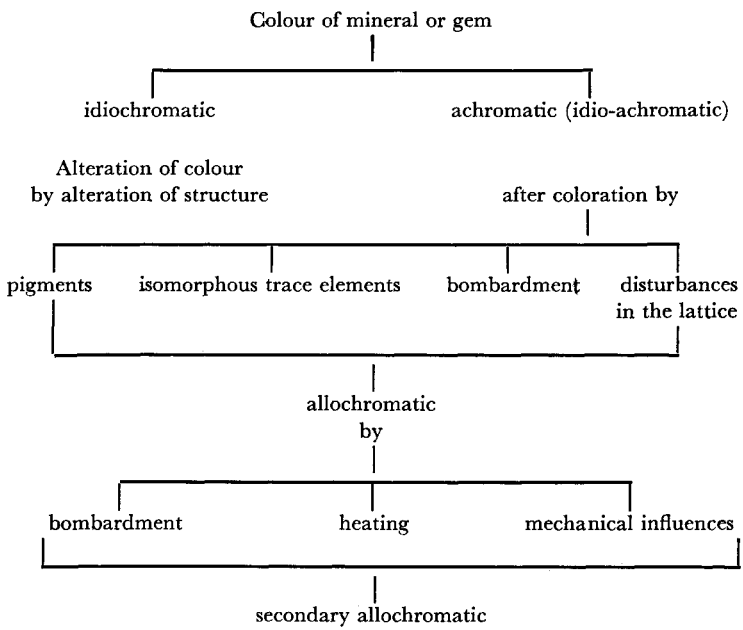

Idiochromatic gems alter their colour only together with their structure, i.e. pigments, trace elements or bombardments do not change the colour, as would be the case for allochromatic colours.

It should also be added further that a colour change can be created in primary allochromatic gems by bombardment, heat, etc.; in these cases the colour is changed or improved—this could be classified as secondary allochromatic colour. An example of this type is amethyst whose primary allochromatic colour violet is changed by heat into a secondary allochromatic colour, i.e. yellow.

To summarize the scientific colour determination of gem colours, one must underline that the basis is given by the colouring trace elements. With the help of these one can re-create the colour of natural gems. It is unfortunate, however, that, for instance in the case of the synthesis of corundums and spinels, various pigments can be added, thus imitating the colour of other gems; because of these "fancy" colours the trade now deals with "alexandrite-coloured synthetic corundums" or "aquamarine-coloured synthetic spinels". This type of synthesis (not included in the table) shows a will to imitate, as the pigments colour the basic gems into gems of a different colour.

Thus colour forms less and less the basis for the determination of a gem mainly because allochromatic colours show their characteristics in various crystal structure problems. In the present classification these were included in certain limits and a purely qualitative sense.

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NEW OCCURRENCES OF GEM MINERALS IN AUSTRALIA

By R. O. CHALMERS, A.S.T.C., F.G.A.A.

with the permission of the Trustees of The Australian Museum, Sydney

NEPHRITE

Greenish grey nephrite, of no significance as an ornamental stone, was recorded as occurring between the ore bodies and the wall rock in gold mines at Lucknow, 6 miles south east of Orange in the Central Highlands of New South Wales. In part the country rock is serpentinite.

Nephrite in association with serpentinite was discovered in the early 1960's by Colin Moore. It is in fairly rugged country in Portion 13, Parish Ogunbil, County Parry, New South Wales, 25 miles east south east of Tamworth in the general area of Dungowan. It lies within the southern New England region of northern New South Wales. The first specimens were received by the Museum late in 1964.

In November 1970, the author accompanied Colin Moore to the site, but unfortunately no nephrite was seen *in situ*. It had been recovered from weathered serpentinite in the form of flattish slabs showing signs of shearing. Several stock piles of nephrite had been left when quarrying ceased but none of this remained on the occasion of my visit. The largest of this type of specimen in the Museum collection, presented by Mrs B. G. Amey, measures 16″ by 12″ and has a maximum thickness of 5″. It weighs approximately 20lb.

Colin Moore has supplied me with the following information. The total quantity produced was 39 short tons, 32 in boulder form, the remainder in reef form. Approximately 22 tons were sent to Hong Kong. The largest single mass was 4½ tons. It is stated that much of this total consignment was of high quality and that various carved ornaments were made such as buddhas, animals, book-ends etc.

I have seen neither the raw material sent to Hong Kong nor the carved ornaments.

The colour ranges from dark green to dark bluish green. It is fine grained and takes quite a good polish.

Both macroscopic and microscopic comparisons were made with the best quality New Zealand nephrite type greenstone (pounamu) that occurs as waterworn boulders in the Teremakau and Arahura Rivers near Hokitika in the Westland Province of the South Island. The Dungowan material is translucent only in very thin slices. A slice 2·5 mm thick was an attractive deep green but not nearly so translucent as a slice from a New Zealand specimen 3·6 mm thick.

Turner (1936) in describing thin sections of the best quality New Zealand nephrite mentions the characteristic felted or interwoven structure of the tufted aggregates of minute tremolite fibres. The thin section examined (D: 41306) showed this structure. The more this structure is developed the tougher and harder nephrite is. Turner mentions gradations between the true nephrites and the semi-nephrites in which the tremolite is much more coarsely grained. The finer grained portions of semi-nephrites show the felted interwoven structure to some degree but there is also an abundance of sheaf like aggregates of relatively coarse-grained stout acicular prismatic crystals of tremolite, arranged in parallel form.

A thin section of the Dungowan nephrite (D: 41850) shows a marked degree of schistosity. Coarser aggregates of long tremolite fibres show mainly parallel structure with little interweaving. The rest of the section is extremely fine-grained and the minute slender fibres of tremolite show interlocking.

A third Australian nephrite occurrence was discovered in 1967. It is on the property of Mr. H. A. Schiller, Section 116, Hundred of Minbrie, County Jervois, Eyre Peninsula, South Australia. It is half a mile south of Mount Geharthy Trig Station and 13 miles north of Cowell.

I have not had the opportunity of visiting the locality and the following description has been kindly provided by Mr. J. E. Johnson of Adelaide, by permission of Geosurveys of Australia Ltd. Mr. Johnson also presented the only specimen in the Museum collection.

"The rocks of the region are of Lower Proterozoic (Pre-Cambrian) age. They consist of a tightly folded series of metasediments among which dolomite beds figure prominently. Near Cowell the dolomites are partly serpentinized, being streaked and spotted with antigorite (a lamellar variety of serpentine). It

forms a handsome 'verde antico' marble which is extensively quarried.

Adjacent to cross-cutting quartz reefs, the serpentinized dolomite has been altered to masses of coarse-grained actinolite separated from the unaltered serpentinized dolomite by soft, weathered dark green serpentinized material. Throughout this is scattered the nephrite which is fine-grained and in the form of nodular masses or fractured lenses".

In the same general area, veins of chrysotile asbestos occur in the dolomite. In places this has been silicified by opaline solutions to form attractive yellow siliciophite, which has been described and illustrated in colour by Chalmers (1967).

The one specimen of Cowell nephrite (D:41885) in the collection is very fine-grained and dark olive green. J. E. Johnson states that it is mostly black or greenish black but sometimes is a fine olive green. In thin section it resembles the extremely fine grained portion of the Dungowan nephrite comprising mainly a dense mass of minute, slender, interlocking fibres of tremolite.

Simple comparisons of hardness and toughness were made between the Australian nephrites from Dungowan and Cowell and those from the Westland Province of New Zealand. Undoubtedly the New Zealand specimens are harder and tougher. The toughest New Zealand specimen (D:31316) was from the Kumaru Diggings. The specimen (D:41306) described above in thin section, broke more easily but this may have been due to it being somewhat schistose. Turner mentions that it is almost impossible to chip the best quality nephrites with a hammer.

Despite these differences it is considered that the physical properties and microstructure of the Australian specimens warrants them being called nephrite, rather than semi-nephrite.

The registered numbers of the Museum specimens examined are quoted above.

Labradorite

Transparent gem quality labradorite from Australia has been mentioned previously (Oughton and Hearnes 1970). The R.I. measured on a cut stone is stated to be 1·556-1·564.

A fine cut stone weighing 6·78 ct and a rough piece weighing 15·93 ct were kindly lent for examination by Diamond Traders Pty Ltd of Sydney. The R.I. reading on the table face is 1·55-1·56

and the S.G. done by hydrostatic weighing in toluene is 2·695. The S.G. of the rough specimen is 2·679. Both specimens were transparent and flawless and pale yellow in colour. The cut stone showed quite a surprising degree of brilliance.

Hearnes (1970) has stated that the source of specimens in his possession had not been disclosed except that it "was somewhere in Southern Queensland", but Diamond Traders were unable to state the exact locality of the specimens they lent me.

Numerous crystal fragments have been found in decomposed basalt soil at Hogarth Range, near Mallanganee, 26 miles west of Casino in northern New South Wales. Some few specimens I have seen are the same attractive yellow colour as the specimens from Diamond Traders. The largest fragment measured 2·5 × 1·5 mm. The majority I have seen are colourless to very pale straw and would range from this size down to fragments measuring about 1 × 0·5 mm but of course smaller ones have also been found.

The Hogarth Range occurrence was first reported to me a few years ago but I have not had the opportunity of visiting the locality.

It is not possible to estimate the total amount recovered because local residents and numerous members of lapidary clubs have all been to the locality. The total weight of good quality fragments collected, very approximately, might be in the order of several pounds.

Small fragments of the Hogarth Range material examined in liquids had an R.I. of approximately 1·55. An S.G. determination of clean, carefully selected fragments done by the pycnometer method gave a result of 2·68.

The R.I. and S.G. results obtained establish the material as labradorite, the intermediate member in the albite-anorthite chemical series of plagioclase feldspars. The values of constants obtained fall within the range of those quoted by Deer, Howie and Zussman (1963).

Dr. A. R. Ramsden of the C.S.I.R.O. Division of Mineral Chemistry has confirmed the identity of this mineral as labradorite by X-Ray diffraction.

There are extensive flows of alkali basalt of Tertiary age throughout the Eastern Australian Highlands. Labradorite is the typical feldspar both as phenocrysts in porphyritic types, as well as in the groundmass. Hand specimens of fresh porphyritic basalt from Hogarth Range are in the Museum collection. Phenocrysts

up to 1·5 mm long of transparent glassy labradorite are a feature of these rocks and undoubtedly the detrital crystal fragments of labradorite in the soil are derived from the weathering of these basalts.

In thin section the groundmass is extremely dense and characterized mainly by an abundance of minute lath-like crystals of labradorite. The phenocrysts show multiple twinning characteristic of the plagioclase feldspars.

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SOME NOTES ON GROWTH-DISTURBANCES FOUND IN COLOMBIAN EMERALDS

By JEAN-PAUL POIROT

IN the absence of disturbing elements and in a continuously constant environment a crystal grows in a regular and homogeneous manner; in nature these conditions do not occur and crystalline growth is usually uneven and, what is more, disturbed, because the various crystals get in each other's way during their formation.

Several centres of simultaneous crystallization can thus sometimes be found in the emerald. Figure 1 shows such a gem observed in the basal plane. The presence of a central core and the centrifugal growth of each seed which from this angle is seen as an hexagonal figure are easy to see. Fine inclusions are thrown out to the periphery of these elements; in the biggest they outline some crystallization ghosts (fossilized stages of growth); one of them even leaves a radial trail of colour starting nearly at the centre. When two cores come together they mutually repulse each other and the limit of influence of their respective areas of activity is represented by an agitated zone where the colour variations are numerous; this zone may be observed to bisect the angle formed by the adjoining faces of the two neighbouring individuals which in these conditions repulse each other with equal force.

A foreign crystal coming into contact with a growing emerald

FIG. 1. Colombian emerald 25 ×. Coloured growth disturbances.

FIG. 2. Colombian emerald 40 ×. Calcite crystals repulsed by growth. The direction of crystallization is from bottom to top.

tends to be repulsed by it; thus Figure 2 shows a calcite repulsed before being trapped in the crystal during growth. Behind this calcite a coloured trail is easily seen; in front of and behind this disturbing element crystalline lacunae may be observed, little canals which greater magnification shows to be filled with brine, salt and carbonic anhydride. These are due to a shortage of material resulting from interference produced by the foreign element, either because it rested on the growing face which repulsed it or because having been trapped by the emerald it provoked a local alteration in the surrounding environment. The canals associated with crystalline inclusions can be more or less long; Figure 2 illustrates this with a small calcite which has induced rather a long elongated crystalline lacuna. The two possible positions for these little canals, in front of and behind the inclusion, clearly indicate the direction of crystallization; in the absence of other elements the direction of crystallization still remains indefinite.

A foreign crystal can also be caught in a strongly disturbed zone undergoing rapid growth. Figure 3 shows a calcite repulsed and pushed about by a growing emerald: the different fossilized positions, the different movements of this inclusion are easily dis-

FIG. 3. Colombian emerald 40×. Calcite crystal causing intense coloured growth disturbance.

cernible; there the little canals associated with the trapped crystal are not parallel, and this indicates and confirms the "maelstrom" which reigned in that area at the time of crystallization.

The successive stages of crystalline growth are often marked by crystallization lacunae which shape and outline the fossil faces as shown by Figure 4. Sometimes, at the next stage, the resumption starts badly in a hole on account of the absence of material, and this produces an irregular cavity. If the general direction of growth, indicated by colour trails or by little canals, remains the same, there can still be various irregularities locally, and a tangential growth of the crystal occasionally gives a broken appearance to some lacunae which is, without this hypothesis, difficult to explain.

Such phenomena may be observed in all gems which show some character (Colombian emeralds, Burma rubies, etc.). The vicissitudes suffered during their crystallization by expecially attractive precious stones thus seem to be one of their essential characteristics, connected with their beauty: the turbulent story of their birth gives an intense life to the light which passes through them and the amateur who contemplates them is through them in communion with creation.

FIG. 4. Colombian emerald 40×. Three-phase crystalline lacunae of different appearances and origins. The direction of crystallization is from bottom to top.

THREADS:

Their types and some of their characters

By ROBERT WEBSTER, F.G.A.

FOR some time it has been the writer's intention to consider some aspects of the nature of the threads used to string pearls and beads into necklets, for the subject, which one might readily admit is not gemmology proper, does have some importance in answering questions sometimes posed to a laboratory.

The reason which has prompted further investigation into this sphere devolves from some remarks made by the late Dr. V. B. Meen, of Canada, after the writer had read a paper on "damage to gemstones" at the XIIIth International Gemmological conference held at Brussels in 1970. During this talk the blackening of some cultured pearls by the action of cosmetic creams was mentioned[1].

Dr. Meen asked if any attention had been paid to the type of thread which had been used in stringing the pearls in the case mentioned, as some types of threads were more prone to attract grease than others. It was possible to show that in the records of this case there was a note to the effect that the string did not appear to be normal, but that this aspect was not pursued.

There may be other problems, too, where some information on the nature of the string used in threading beads may well be needed. This article is an attempt to give a short survey and to provide a basis for any future investigation. It will be readily seen that any full-scale investigation on the types and characters of threads would be a long-term project, but one which might well be worthwhile.

According to Walls[2] threads, the more scientific name being *fibres*, can be classified into four groups as follows:

1. *Animal hairs* such as wool, mohair (Angora goat), camel, none of which have any place in the present study.
2. *Vegetable fibres*, which are divided into two groups.
   (*a*) *Seed hairs*, such as cotton and kapok, cotton being the only one which needs consideration here.
   (*b*) *Bast and structural fibres*; these are exemplified by flax (linen), jute, hemp and sisal. Only flax is of interest.
3. *Fibres produced by the solidification of a liquid extruded through a fine*

orifice; these are again subdivided into sub-groups:-

(*a*) *Natural*, of which silk is the only important member.

(*b*) *Artificial* (*man-made*); there are two well defined groups:-

(i) Those made from animal or vegetable raw materials, such as regenerated cellulose (Rayon); cellulose esters, usually acetate (Tricel, Arnel, Trilon); alginates (from seaweed); regenerated proteins (casein) and others.

(ii) Purely synthetic fibres: such as polyolefines (polyethylene, etc.); polyamides (Nylon, Brilon); polyesters (e.g. Terylene—Dacron in the United States of America—a polyethylene terephthalate); acrylonitrile polymers (Orlon, Acrilan, Courtelle, etc.); vinyl chloride and vinylidene chloride polymers (Vinyon, Saran, and others).

4. *Miscellaneous fibres*; such fibres are natural mineral fibres (asbestos) and fibres of glass, metal, etc., which have no place in this study.

Of these numerous fibres, most of which are used in the textile industry, the only ones which need to be discussed are silk, cotton, linen, and some of the artificial fibres, particularly Nylon.

Silk. The most important fibre used for pearl stringing, silk is produced by the caterpillar of the moth *Bombyx mori*, which, when fully grown, spins a cocoon with a secretion produced by the caterpillar from a pair of tubular spinning glands. Each of these glands produces a single fibre, which is at first in a fluid condition.

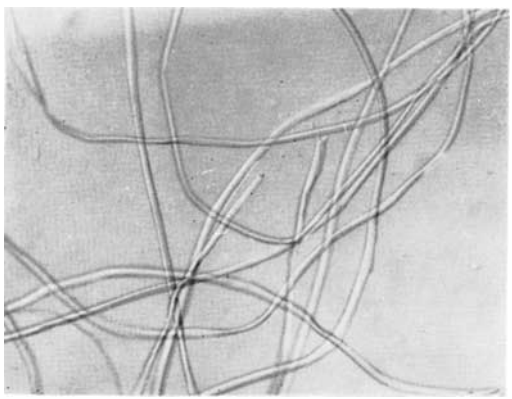

Pure silk 45 ×

These two fibres are then, by muscular action, and possibly aided by another secretion, formed into a single thread. This is silk, an albumoid, and the fibres normally receive certain cleaning treatments before being spun and woven into fabrics.

When a flame is applied to the end of a silk thread it burns, but does not readily flame, and the thread forms a shrivelled blob. The flame does not tend to travel along the thread and is quickly extinguished. Under the microscope the threads are seen to be more or less structureless cylindrical rods which at places may flatten or bulge out. The fluorescence varies considerably due, as mentioned by Radley and Grant[3], to the "fact that *dressing agents*, oils and dyestuffs, often completely alter the colour of the fluorescence", and these writers also state that "small traces of fluorescent dyestuffs added as 'brightening agents' may produce complicating effects in ultra-violet light". Fluorescence can have scant discriminative value in the detection of the fibres themselves.

Cotton. Threads of cotton are not normally used for pearl stringing but some mention is included in this survey for there is reason to believe that they have been used for such a purpose, and, further, they are certainly used for stringing necklets of amber, coral, jet and some ornamental stones, such as malachite and rhodonite. "Star sylko" or Clark's "anchor" stranded embroidery "silks" are often used for stringing such necklets.

The most important of the vegetable fibres, cotton, consists of white or yellowish-coloured fibres which are obtained from the seeds of various species of the genus *Gossypium* of the order *Malvaccae*. Well-bleached cotton is said to be nearly pure cellulose.

When a flame is applied to cotton threads they readily burn with the flame travelling along the thread leaving very little ash. On extinction of the flame the glowing embers emit a smell of burnt wood. When fibres of raw cotton are examined under the microscope the general appearance resembles that of a wrinkled, twisted irregular ribbon which may be likened to an exhausted rubber tubing. After treatment, such as "mercerising", which imparts a lustre to the cotton so that it resembles to some extent silk, the typical appearance of the threads may not be so apparent under magnification.

Linen. The name is derived from the flax plant *Linum usitatissimum*, which is pulled just after flowering. The linen fibre,

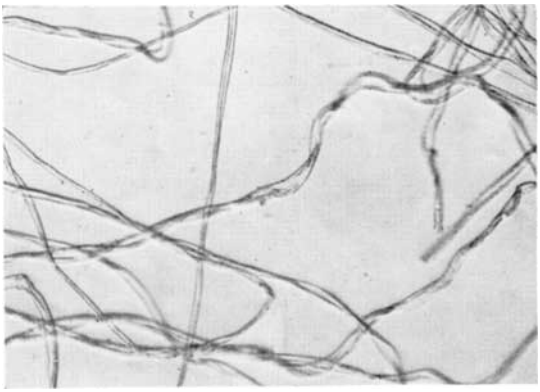

Cotton threads 45 ×

being the first layer under the epidermis of the stalk is separated from the rest of the stalk by retting in stagnant or running water. Following this the mucilaginous substances contained in the flax are removed by suitable treatments.

Like cotton, linen burns fairly readily with, on extinction, a smell of smouldering wood. Examined under the microscope the central canal is not so marked as in cotton and the fibre has notches at irregular intervals, and, further, may show diagonal striations. Linen lacks the convolutions shown by cotton fibres.

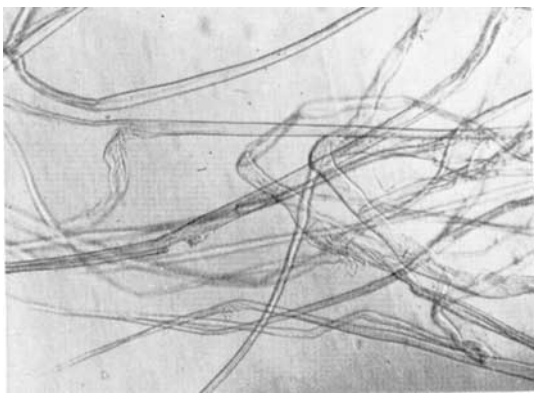

Linen threads 45 ×

Artificial fibres. The beginning of the artificial fibre industry began with the work of Count Hilaire de Chardonnet of France

during the 1880's, although as early as 1665 the idea of making "artificial silk" was mooted by Robert Hooke. Chardonnet's "silk" was a nitrated cellulose, a type of celluloid, and was far too inflammable and, indeed, the sale of this "silk" was eventually banned in France.

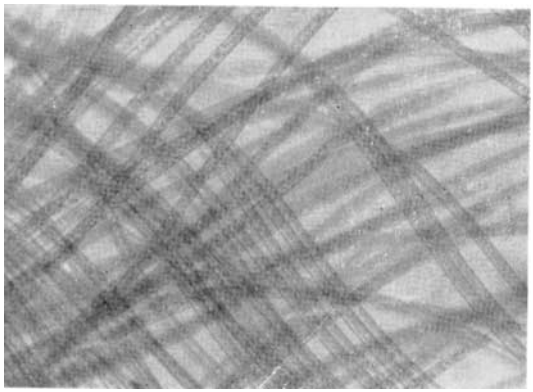

Nylon threads 45 ×

The next advance in the production of artificial silks was due to the work of C. F. Cross and E. J. Bevan, who produced the "rayons". These fibres were and are produced by regenerating cellulose. Plant cellulose, such as cotton linters, wood-pulp, are chemically dissolved and then "regenerated" and extruded through a diaphragm pierced with very fine orifices called a *spinnerette*. Such regenerated cellulose fibres are Viscose rayon, cuprammonium rayon, and acetate rayon, but these fibres have little importance in this discussion.

The most important of the man-made fibres for this study is the super-polyamide called "nylon", the production of which was the outcome of researches carried out by the American plastics chemist Carothers, aided by some of his colleagues. Made from hydrocarbons obtained from coal, and from ammonia, nylon, of which there are at least three types, is said to be twice as strong as silk and to be more elastic. It is probably due to this latter effect that nylon is not favoured for pearl stringing as it does not knot well and is inclined to stretch. There are two kinds of nylon cord which may be purchased for pearl and bead stringing. The first is made up of twisted fibres and resembles the true pearl silk, while

the other, more used for beads than pearls, consists of a single strand, like a flexible rod. There is a variation of this latter type which is wound round with a spiral of fine metal wire and is presumably used for heavy beads. If the single strand nylon cord is used for pearls or lightweight beads the necklet tends to bow and does not hang at all well.

Nylon melts before burning, producing a sticky blob which follows the flame travelling along the string. This blob of molten material, if dropped on to the skin, burns like hot fat. The flame of burning nylon is, however, readily extinguished. Nylons, like most of the other man-made fibres, are usually assumed to be structureless internally, but microscopical examination has shown that there appear to be masses of fine bubbles oriented parallel to the length of the fibre. This phenomenon seems to be more prominent in the case of nylon and this may be accounted for as nylon is extruded from a molten mass and not from a liquid which is expelled through the spinnerettes into a coagulating bath which solidifies the fibres.

In order to ascertain the probability of differential absorption of grease by various fibres a series of experiments were undertaken. A frame was constructed consisting of a length of channel aluminium, bored with eight small holes through both sides, which was screwed down to a suitable baseboard. The metal channel, intended to carry the grease, was closed at each end by aluminium angle plates. A series of different threads were then threaded through the holes in the channel and anchored so that they were fixed at the outer face of the channel. The threads then passed across the channel and across the baseboard for a distance of some 12 centimetres, where the ends were anchored to a fixed wooden strip by the aid of drawing pins. Suitable lettered labels were stuck down on the baseboard in order to identify the strands.

It was considered that a suitable grease would be a cosmetic cream and Pond's cold cream was used. To ascertain if the grease travelled along the string a small quantity of the chemical rhodamine was mixed with the cold cream, the notion being that it would not only give colour to the cream but would show up under ultraviolet light, for rhodamine is highly fluorescent and glows with an orange or reddish-brown light. During the experiment the frame was kept in a glass-topped box.

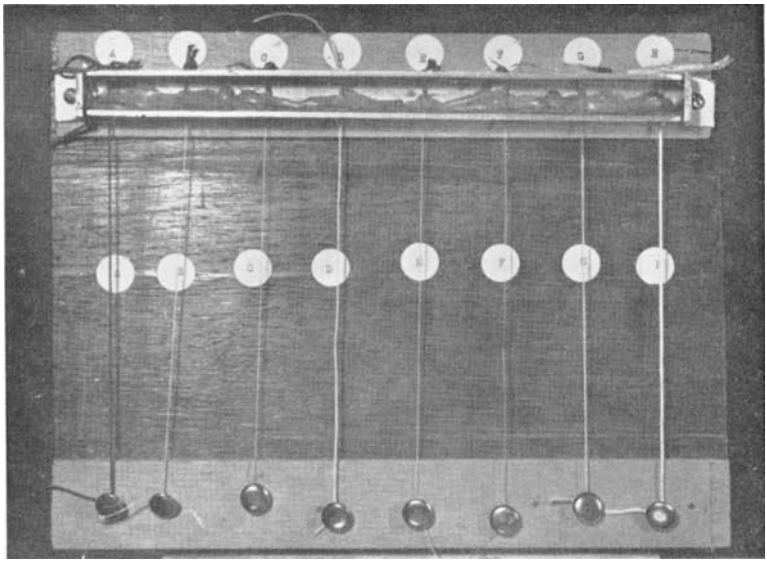

The frame used in grease experiments.

The strings used in the first experiment were as follows:

(*a*) Silk (dyed brown).
(*b*) Pearl silk.
(*c*) "Sylko" mercerized cotton.
(*d*) Linen thread.
(*e*) Terylene thread.
(*f*) Nylon (single thread).
(*g*) Spun nylon pearl "silk" (Nylcord).
(*h*) Clark's "anchor" stranded embroidery cotton.

The result observed after the grease had been placed in the channel was striking in that within an hour the grease had travelled down some of the threads, admittedly not very far but with significant differences. Strangely the seepage seemed to stop at these points and there was little further increase even after a week. The distances the grease, which coloured the strings, had travelled along the strings were then measured, giving the following results:

(*a*) Dyed silk: no apparent effect.
(*b*) Pearl silk: very weak seepage of about 1·5 mm.
(*c*) "Sylko" mercerized cotton: 5mm.

(*d*) Linen: 2 mm.
(*e*) Terylene: 4 mm.
(*f*) Nylon single cord: no effect.
(*g*) Twisted nylon (Nylcord): 11 mm.
(*h*) Embroidery cotton: 3 mm.

The frame was then unstrung and the grease removed and kept, and the frame itself thoroughly cleaned and restrung with different threads as under:

(*a*) A fine tacking cotton.
(*b*) Brown linen thread.
(*c*) Terylene, same type of thread as in (*e*) in first run.
(*d*) Pearl stringing silk. A different source from (*b*) above.
(*e*) Pure silk (yellow dyed Regal).
(*f*) Polyethylene thread (blue dyed).
(*g*) Terylene (Coat's white).
(*h*) Embroidery "silk" (cotton) as in (*h*) above.

The cold cream plus rhodamine, which was removed from the channel after the first run, was then mixed with as much again of the cold cream but no more rhodamine added. Thus the concentration of rhodamine was only half that of the previous mixture.

After some hours the frame and threads were examined, but the results appeared to be disappointing, mainly because the lower concentration of rhodamine did not strikingly colour the threads, and the fluorescence effects were masked by the strong whitish glow emitted by the threads themselves. However, some trace of differential seepage was apparent.

There was always the question of how much body heat would affect the mobility of grease in the case of a necklet worn for some time around the neck. To test this the frame was removed from the glass-topped box and placed on a warm print dryer. This print dryer gave off much more heat than the heat given off by a human body, and, hence, the results obtained would be expected to be much more rapid, as, indeed, they seemed to be as the following shows:

(*a*) Cotton thread: diffuse staining decreasing in intensity up to 5 to 6 cms.
(*b*) Linen: a little staining up to 2 to 3 mm.
(*c*) Terylene: slight tinting for practically the full length of the string.

(*d*) Pearl silk: very slight staining for 3 to 4 cms.
(*e*) Yellow dyed pure silk: very slight staining.
(*f*) Polyethylene: colour of the dyed thread precluded much in the way of observation or by fluorescence.
(*g*) Terylene: weak staining for a considerable distance, and in fact seemed to behave rather like (*c*).
(*h*) Cotton embroidery "silk": staining for about 15 mm.

Note: the very slight staining of the Terylenes (*c*) and (*g*) could only be identified by comparison with thread taken from the original reels.

In conclusion, it may be said that the experiments have shown that there is some justification for the suggestion that there is differential absorption and percolation of grease along fibres of different natures. However, much more information is required and far more experimentation needs to be carried out on a greater number of kinds of fibres for a really full study of the subject. It seems apparent that twisted fibres tend to carry grease more readily than single strand material, as exemplified by the nylon samples tested. This was rather to be expected and most probably due to the greater possibility of capillary attraction between the threads.

Most of the threads carried grease for upwards of two millimetres, and as the nacreous shell of a cultured pearl is seldom more than a millimetre thick, it is clear that the grease would reach the discontinuation layer between the "skin" and the bead of the cultured pearl and tend to travel along it, as indeed, was found to have happened in the case mentioned at the beginning of this article.

What is further to be considered is that the experiments were carried out with static threads on a frame. There is movement of the beads on a necklet when it is worn and this would assist the grease to seep along the string. What does seem to be proved by the experiments is that silk is the best material to use in stringing natural and cultured pearls and to use other types of threads may well lead to trouble for the jeweller.

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PEARL IDENTIFICATION:

Some laboratory experiments

By C. A. SCHIFFMANN, F.G.A., G.G.

THIS article deals with some identification problems, restricted to genuine and cultured pearls. Pearl imitations are not included, as their recognition is usually easy.

Enquiries for genuine pearls have become so scarce that the average jeweller stocks usually only cultured pearls. Hence he may think that their recognition is of little importance since, when buying to renew his stock of cultured pearls, there is no chance of mistake.

Matters are less simple when pearls have to be estimated for insurance or probate purpose, or when bought second-hand. For these reasons the laboratory work brings with it many surprises and has in a way the prickling charm of the unforeseeable: one never knows what new problems tomorrow will bring. For instance, the author remembers having once heard Mr. B. W. Anderson mention that the London Laboratory was entrusted years ago with the identification of a huge parcel of 250,000 pearls, which of course required efficiency and rapidity in testing.

The optical methods (lens examination, observation in transparency and fluorescence, endoscope test) are the first to be used in pearl testing because they are expeditious, with perhaps the exception of the endoscope. However, when typical textures cannot be found, or when the pearls are not drilled, one has to resort to other more time-consuming methods, like determining exactly the specific gravity, above all submitting them to x-rays test by direct radiography where a whole necklace or just single pearls can be tested at one time, and the diffraction method by which only one loose pearl can be tested at one time.

The x-ray methods are both more time-consuming and more expensive, and they should be used logically. Perhaps one day a laboratory will be asked to identify a pearl whose value is not worth the cost of an x-ray identification, and the next day a pearl of high value will be brought for identification when all possible gemmological methods may have to be used.

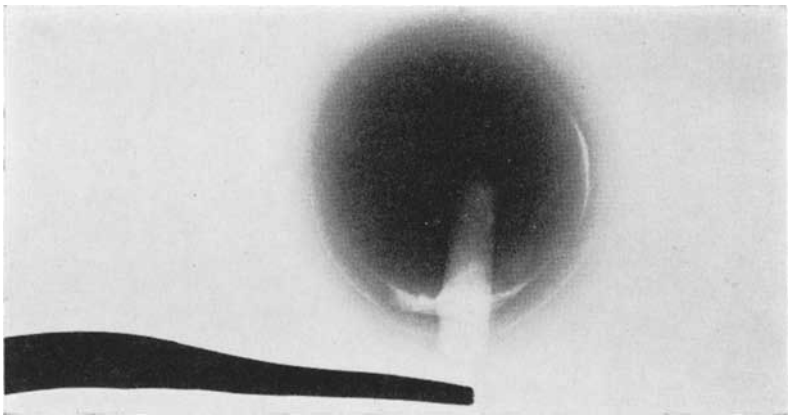

FIG. 1. Direct radiography of 13½ mm cultured South Sea pearl, with 2 concentric conchyolin layers.

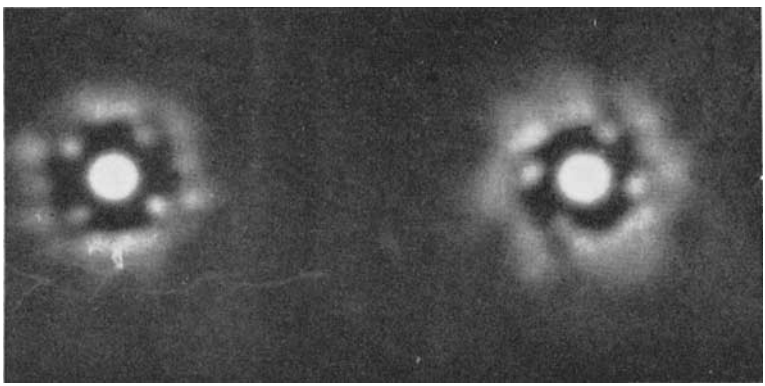

FIG. 2. Left, standard 4-fold pattern of a large cultured pearl with nucleus. Right, distorted pattern of a large cultured pearl with nucleus.

Usually, the first x-ray examination is made by direct radiography. When this first step is not conclusive for a few pearls, they are then tested with the diffraction method. It may be interesting to look at not only fine typical pearl patterns as seen in text-books, but also at diagrams obtained that are not conclusive or difficult to interpret.

Fig. 1 shows the radiogram of a cultured pearl 13½ mm in diameter from the South Seas, with two distinct layers of conchyolin. The outline of the core did not appear as a complete circle and had

a somewhat irregular perimeter, and so for safety the pearl was submitted to a diffraction test, which result appears in Fig. 2, the two images being obtained in two directions at 90° to one another, one showing a standard rectangular pattern, whereas the second pattern is slightly distorted because of an occasional lack of alignment between the x-ray beam and the optimal position of the aragonite prisms of the mother-of-pearl layers.

The spot in the centre of the pattern is the trace of the primary beam. Theoretically, the pattern obtained should have a 4-fold symmetry for a cultured pearl with nucleus, and a 6-fold one for a genuine pearl, or for a cultured pearl with a nucleus along a

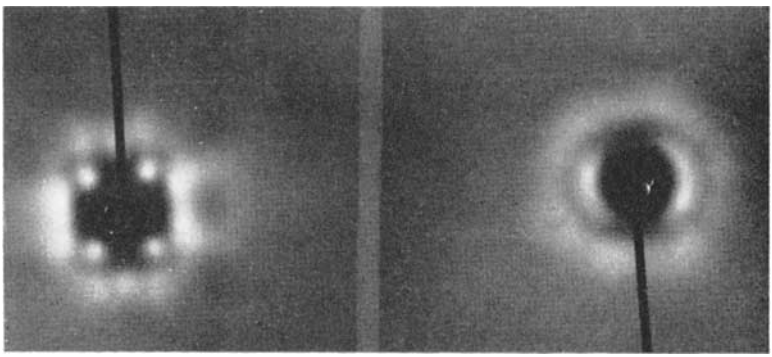

FIG. 3. Cultured pearl, in two positions at 90° to one another.

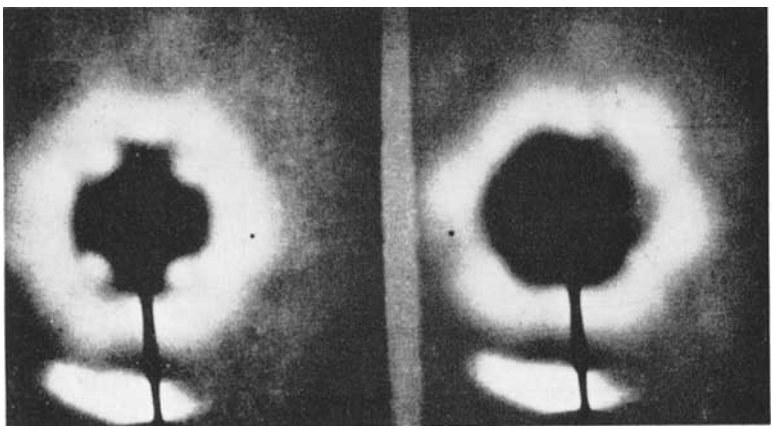

FIG. 4. Cultured pearl, in one direction along the pseudo-hexagonal axis of symmetry one 6-fold exceptional pattern is visible. In the direction at 90° the usual 4-fold symmetry pattern proves it to be a cultured one.

particular direction, or for one without. Nothing is proved if a hexagonal picture is obtained. The pearl has to be turned through 90° and another picture taken.

Fig. 3, left, shows an indefinite pattern intermediate between the optimal positions, whereas in a direction at an angle, a clear pattern has been obtained. On this figure, the action of the primary beam on the film has been prevented by interposing a primary beam catcher, whose holder's shadow is visible as a thin vertical line.

Fig. 4 proves that the advice in some text-books, preferably to test a pearl in two directions at right angles to one another is justified. It shows that an exceptional position along the pseudo-hexagonal symmetry axis of the aragonite crystals may occasionally occur by chance, as it did here. Of course, the pearl could be brought intentionally into that position, but this would require a number of runs until the mother-of-pearl layers were correctly orientated, and this would be time-consuming and also expensive. The instrument setting used for these diffraction patterns is shown on the Fig. 5. Using Polaroid film in a film holder of the same make shortens the exposure time by approximately five times.

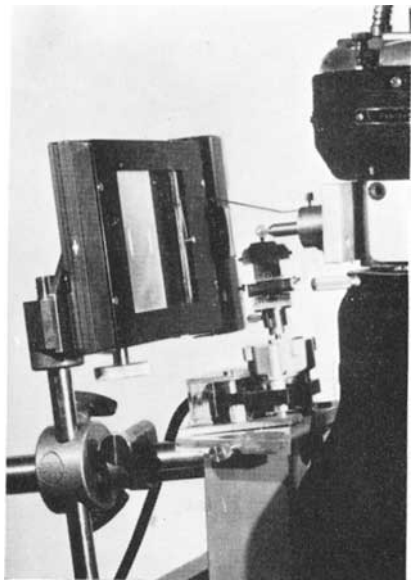

FIG. 5. Photograph of the x-ray unit, set up for diffraction. To the left is the Polaroid cassette; between it and the target, the small white spot is the pearl, supported on a goniometer as holder, itself affixed to the axis of a small electric motor. The beam catcher is visible as a thin thread just above the pearl.

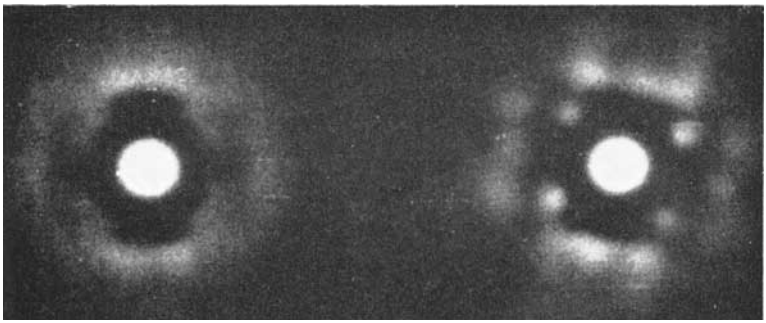

FIG. 6. Cultured pearl: left, revolving, and right, stationary.

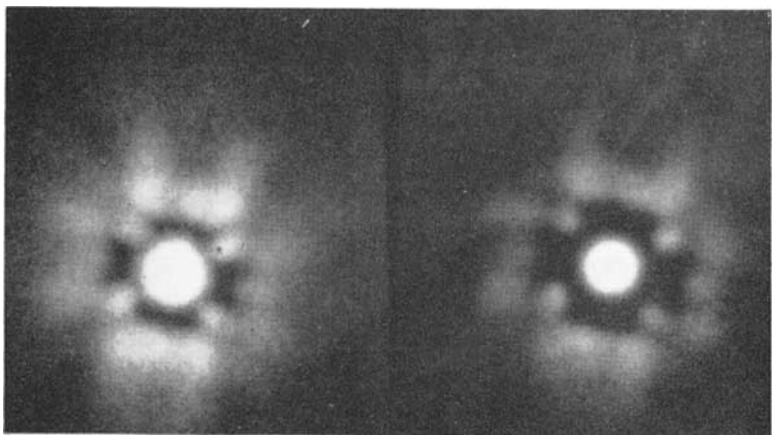

FIG. 7. Two separate runs of the same pearl in rotation.

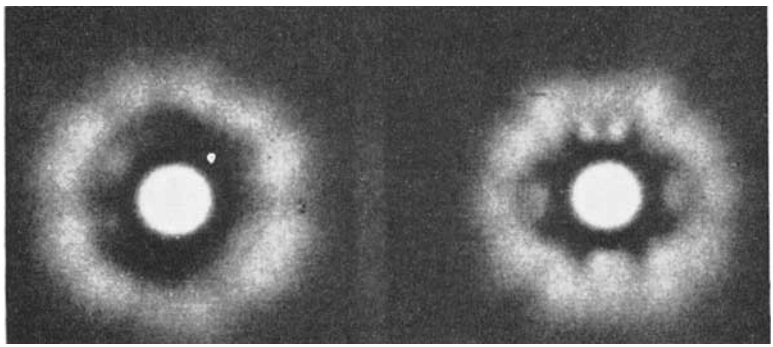

FIG. 8. Pearl in rotation: left, hazy pattern of an irregularly shaped genuine pearl: right, other type of pattern of a cultured pearl.

Here the pearl is affixed to the spindle of a small electrical motor by means of a goniometer, enabling a precise setting. The diffraction pattern may be obtained from the pearl stopped in two positions, or, by a variation of the powder diffraction method of x-ray analysis, the pearl may be rotated by an electrically driven motor, with the advantage that instead of two separate exposures, one single run is enough in the optimum cases, and this reduces the necessary time once more by 50%.

With the pearl rotated, the patterns obtained are somewhat different.

In Figs. 6, 7, 8 and 9 the central spot in the pattern is the trace of the primary beam which had not been shielded.

Fig. 6 shows us on the right the pattern of a cultured pearl in a stopped position, at left when revolving about 1 rev. per minute.

Fig. 7 shows two different exposures of the same cultured pearl in rotation giving both very obvious and regular patterns.

On the left, Fig. 8 shows a somewhat hazy but recognizable design of the 6-fold symmetry in a genuine pearl in rotation. This is due to the fact that the pearl being not quite round, the x-ray beam did not pass exactly in the middle of it. On the right of the same figure there is a somewhat different design given by a cultured pearl in rotation.

Fig. 9 shows two runs on the same button-shaped genuine

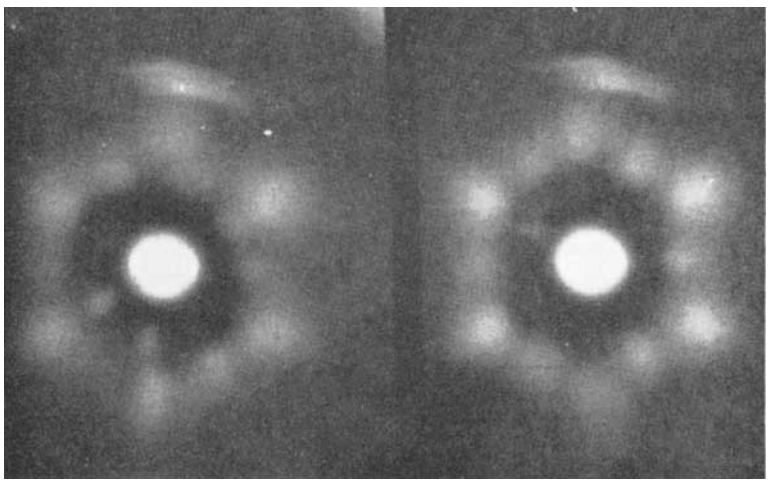

FIG. 9. Genuine pearl in rotation: two runs on the same pearl, along two different orientations

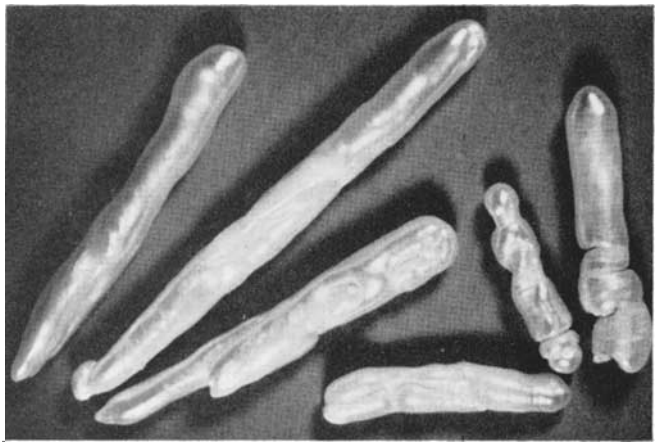

FIG. 10. Lake Biwa pearl formations without nuclei: elongated baroques, the longest one measuring 50 millimeters.

pearl in rotation, but along different directions, the pearl having been set in another orientation between the runs.

Another problem likely to give some difficulties is the identification of Lake Biwa pearls. It is known that these are produced without nuclei. Besides the ones that are rounded and have been bleached, it is interesting to look at some baroque shapes of this type of pearl. Figs. 10 and 11 are macrophotographs. In

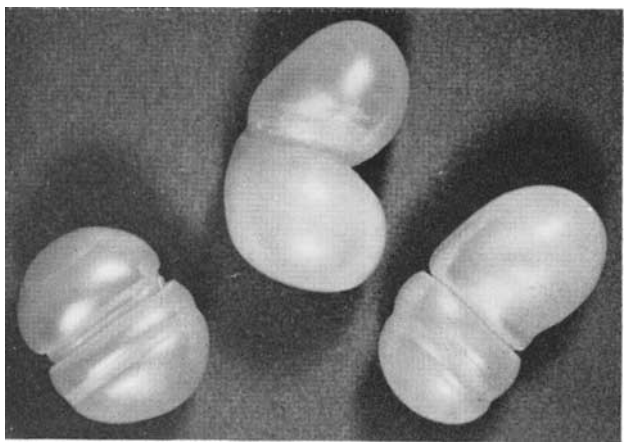

FIG. 11. Other types of baroques of the same origin, some having grown joined two by two. (Three of a parcel).

Fig. 10, the scale is given by the longest bar, which measures about 50 millimeters in length with a diameter of about 6 millimeters. The same baroques were x-rayed and the results appear in Figs. 12, 13 and 14 (on this figure there is a parcel of 9 pearls, from which only three are shown in Fig. 11). Noteworthy are the internal textures, with the irregular deposits of conchyolin.

Another type of Lake Biwa pearl, that is less known, is a type made by use of nuclei, (because of the shortage of molluscs), which may be up to about 12 millimeters in diameter. Fig. 15

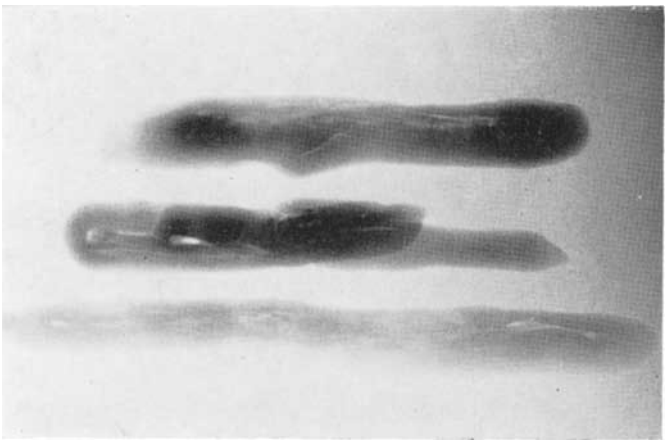

FIG. 12. Radiograph of the pearls of figure 10.

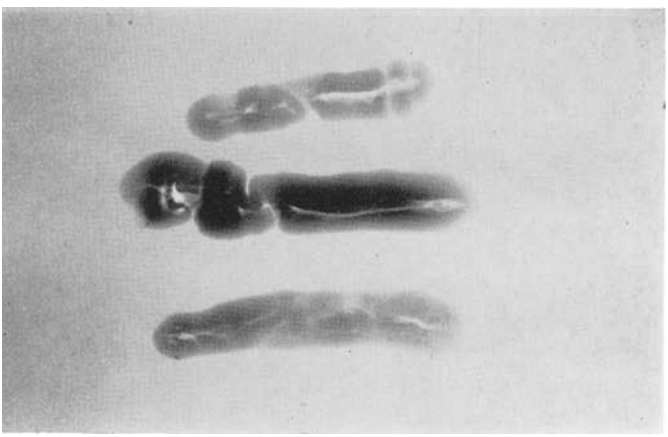

FIG. 13. Radiograph of the pearls of figure 10.

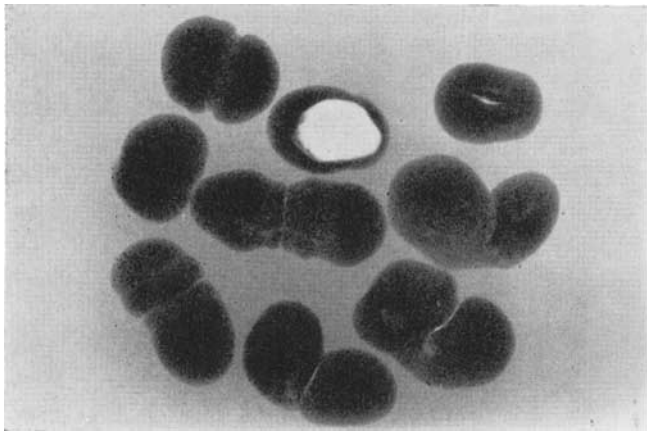

FIG. 14. Radiograph of a parcel of pearls as in figure 11.

shows three of these rather baroque pearls, and Fig. 16 the same which has been radiographed, with the easily recognizable core. It should be noted that the cores are drilled, but that the baroque external layers are not.

Nature sometimes reveals examples of its inexhaustible reservoir of beauty. Considering the Fig. 17, the baroque pearl illustrated bears a definite resemblance to a statue of the Mother of God, which is a rather modern interpretation of the Antiquity where Venus was said to have been born in an oyster!

Returning to the identification of pearls without nuclei, it is known that pearls or mother-of-pearl from fresh waters may show a fluorescence under x-rays, due to a small content of manganese. This would help distinguish between natural pearls (which may occasionally fluoresce) and products like pearls from Lake Biwa or other fresh waters, having a distinct fluorescence, where the core of salt water cultured pearls, made of river shells, can be seen to fluoresce under proper conditions.

A new approach to the detection of manganese in pearls might well be initiated by using Electron Spin Resonance, originally demonstrated by the Soviet physicist Zavoiskie in 1944. This phenomenon is concerned with the absorption of magnetic radiation by materials having unpaired electrons, when subjected to a magnetic field of a specific strength. Interaction between the unpaired electron and its environment gives the technique analytical

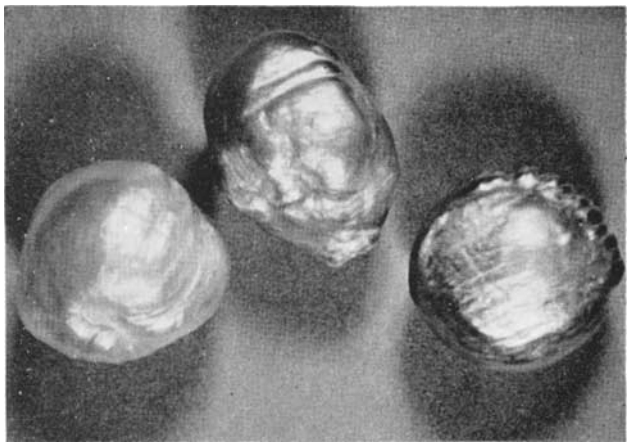

FIG. 15. Macrophotograph of three baroque Lake Biwa pearls with nuclei. Diameter is about 12 millimeters.

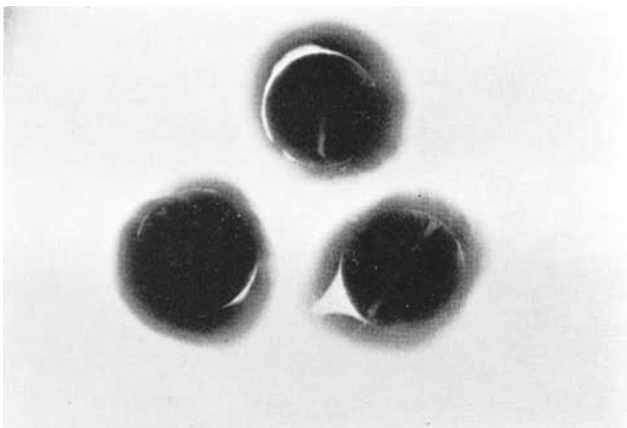

FIG. 16. Radiograph of same with drilled cores, the outside skin being undrilled.

significance. Until recently laboratory apparatus for Electron Spin Resonance consisted of large and heavy machines, but tests have been undertaken on an ESR prototype weighing only about 80 kgs.

The principle of the apparatus is shown in Fig. 18. The sample is placed in a resonator, located between the poles of an electromagnet and submitted to a magnetic field. A beam of microwaves is sent through the sample and absorption through it is

FIG. 17. Lake Biwa pearl without nucleus, resembling a statue of the Virgin. Height 18 mm.

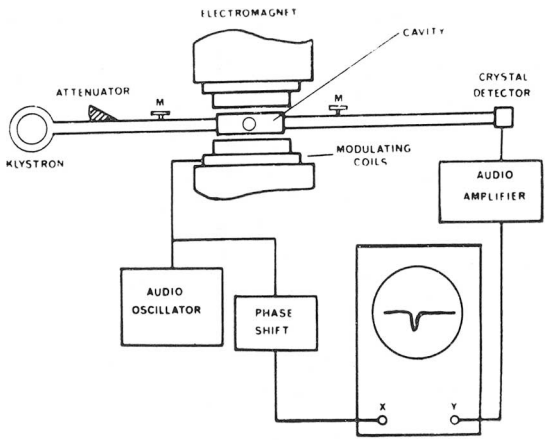

Block diagram of simple room temperature electron resonance spectrometer.

FIG. 18. Principle of the Electron Spin Resonance method.

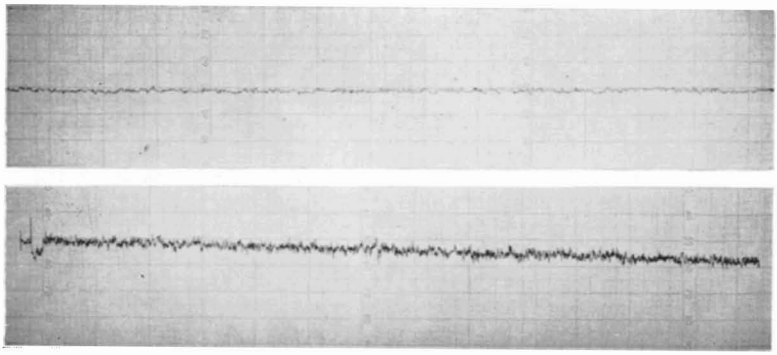

FIG. 19. Electron Spin Resonance curves of two genuine sea-water pearls.

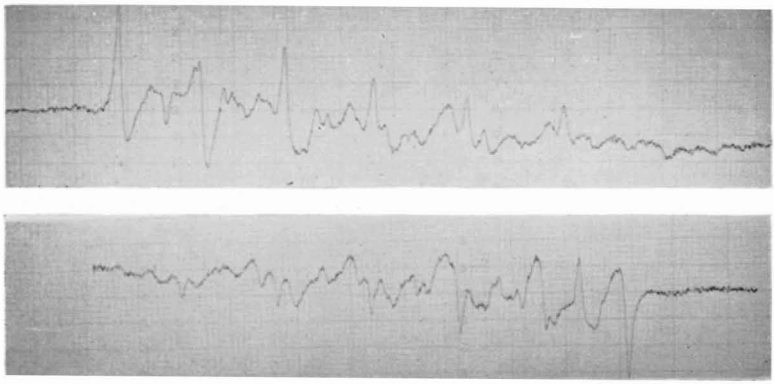

FIG. 20. Electron Spin Resonance curves of two cultured pearls (Salt-water type), with mother-of-pearl nuclei.

analysed in a crystal detector and registered by a recorder. One run necessitates only 5 minutes and the positioning of the sample is quite easy (it is affixed to a non-magnetic, non-crystalline rod and is suspended in the cavity of the resonator).

Thanks to the courtesy of Beckman Instruments, Geneva, it was possible to make a series of tests in their Laboratory on a prototype of their make. The results are provisional and the data not definitive.

The appearance of the resultant curves is strikingly different. The signals given by two different genuine pearls are rendered in Fig. 19 both lines being straight. Quite to the contrary, the signals of two cultured pearls give jagged lines according to irregular absorption presumably caused by a small content of manganese (Fig. 20).

This last method closes this short survey of a number of problems with which the laboratory worker might have to cope, and a few suggestions as to how to try to solve them, thanks to instruments used in other fields of applied science.

With the increasing complexity of man-made or man-modified products, more that ever it is rewarding for the gemmologist to keep his eyes open and his interest keen with regard to the developments of instruments to help him, even if their use may be beyond the financial possibilities of single individuals, and consequently be rather limited to laboratory work.

A GEM GARNET FROM THE ISLAND OF OTTERØY

near Modle, Western Norway

By JENS HYSINGJORD

INTRODUCTION.

Most Norwegian gemmologists made their first acquaintance with the name of B. W. Anderson in about 1949. At that time some enthusiasts had obtained the opportunity to organize gemmological courses in Norwegian, based upon those used by the Gemmological Association of Great Britain. Over the years Norwegian gemmologists have appreciated Anderson's friendliness and willingness to share with others his extensive knowledge and members of the Norges Gemmologiske Selskap will long be grateful for his pioneer work.

GEM GARNET FROM W. NORWAY.

The material described was collected by the author during a visit to Otterøy in the summer of 1963, at the request of Mr. Johs Forberg, jeweller, of Stjørdal, Norway.

The local people are well acquainted with the garnet deposit, and stones have in the past occasionally been sold for gem production.

The gem garnet occurs in garnetiferous peridotite at Uglvik, about three kilometers N.E. of Misund in Otterøy. (The locality is shown on a map published by Tore Gjelsvik (l.c.)). The percentage of garnet in the mother-rock is highly variable. In

certain zones the content was estimated as 10%, but at other places garnet may almost be absent.

The rock itself is altered and contains serpentine, olivine, pyroxene and garnet as chief constituents. Hornblende occurs subordinately, and chromite is an accessory mineral.

The pyroxene is mainly enstatite. Chrome diopside occurs in smaller amounts; it contains 1·9% of Cr_2O_3 according to an analysis of one sample.

The garnet is seen as millimetre-sized crystals in a finegrained groundmass; more rarely it is encountered as centimetre-sized aggregates.

Chemical and Physical Determinations

According to determinations carried out by members of the staff of the Geological Survey of Norway, namely Mr. Per-Reidar Graff, lab. engineer (chemical analysis), and Mr. Magne Ødegård (spectrographic det. of V, Ni and Cu) the composition of the garnet is:

SiO_2	42·32%		
TiO_2	0·00%		
Al_2O_3	21·09%		
Fe_2O_3	0·73%		
FeO	7·11%		
MnO	0·42%		
MgO	19·20%		
CaO	5·03%		
Na_2O	0·06%	Ni	x/1000%
K_2O	0·07%	Cu	x/1000%
H_2O	0·15%		
P_2O_5	0·00%		
Cr_2O_3	3·72%		
V_2O_5	~0·05		
Total	99·95%		

This composition corresponds to a pyrope garnet. Recalculation to an ionic formula where 0 = 12 gives the following numbers:

Si	3·038		Fe″	0·427	2·908
(OH)	0·072		Mg	2·054	
Al‴	1·785	2·037	Mn	0·026	
Fe‴	0·039		Ca	0·387	
Cr‴	0·211		Na	0·008	
V‴	0.002		K	0·006	

Molecular percentage of end members:

Almandine	14·72%	Pyrope	70·81%
Andradite	2·04%	Spessartite	0·88%
Grossularite	0·64%	Uvarovite	10·92%

According to X-ray diagram taken with a 11·8 cm Debye-Scherrer camera, using Fe-radiation and Mn-filter, the cell size is $a_0 =$

11·54 ±0·01 Å.
Index of refraction: 1·747 ±0·001
Sp.G.: 3·715 ±0·005

SPECIAL INVESTIGATIONS

The garnet from Otterøy has very peculiar colour properties. When the quality of illumination is altered, the colour of the mineral changes to such an extent that an alexandrite-like effect is seen. In transmitted daylight the garnet appears violet, in lamp light it is wine-red.

Examination of faceted stones with a hand-spectroscope revealed two broad absorption bands, one of them in the violet part of the spectrum, the other covering the interval from the lower part of red to the higher part of green.

To get a more exact picture of the nature of the transmitted light an examination with a Beckman DB spectrophotometer was undertaken (by Per-Reidar Graff). A garnet plate of 0·8 mm thickness was cut, and glued on to a glass plate with canada-balsam. For zero reference a glass plate with a layer of canada-balsam was employed.

The diagram (p. 299) shows the transmission curve of the garnet with its maxima of absorption (minima of transmission) at 5600Å and 4000Å. The curve explains the observed change of colour, since it shows that light penetrating the garnet mainly consists of red and blue colours. Ordinary daylight has its energy maximum within the short-wave region, lamp light in the long-wave part. When daylight is used, blue colours will accordingly be predominating in the transmitted light. With lamp-light, red will similarly preponderate.

Natural alexandrite is green in daylight and red in lamp-light, and imitations consisting of synthetic corundum coloured with V_2O_5 exhibit a somewhat similar change of colour. According to White, Roy and Crichton the alexandrite-effect with genuine alexandrite is due to a content of Cr_2O_3 and with imitation alexandrite it is due to V_2O_5.

Many of the garnets from Otterøy are transparent with a clear, even colour; further, they are free from cracks. In these respects they are well suited for gem production. Their size is, however, modest. Garnets picked from the peridotite are usually

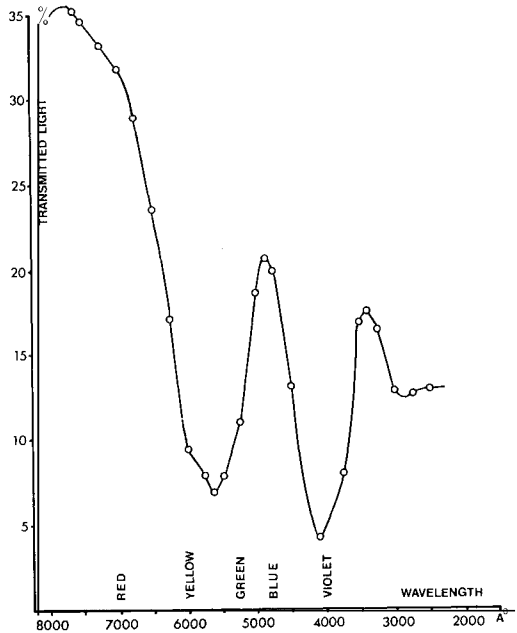

Gem garnet from Otterøy. Transmission of light measured with Beckman D B spectrophotometer.

3-4 mm, more rarely 4-5 mm. The average weight of 73 garnets was 119 mg, or slightly above ½ ct.

Unfortunately it is difficult to extract whole garnets from the mother-rock. If the peridotite is crushed, the garnets usually break into pieces considerably smaller than those referred to above, the average weight of 126 "great" fragments being only 34 mg.

Even if the garnets from Otterøy are beautiful and of a rare colour, their somewhat small average size combined with the difficulty of procuring unbroken specimens render the prospects for the exploitation of the deposit somewhat doubtful.

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X-RAY TOPOGRAPHY OF A NATURAL EMERALD AND A SYNTHETIC EMERALD*

By HENRI-JEAN SCHUBNEL and ALBERT ZARKA

THE present article summarizes the first results we have obtained by using X-ray topographies in studying the structural defects of gem minerals and their imitation in artificial crystals of corresponding chemical formula and similar colour.

The first examples studied by Lang's method are natural and artificial emeralds, and their topographies show clearly that their crystallization took place in extremely different conditions.

We should like to recall to the attention of gemmologists the principles involved in arranging experiments by Lang's method.

I. Method of X-Ray Transmission Topography

A beam of X-rays issued from a quasi point source impinges on a crystal governed under Bragg incidence. A first slit restricts the beam from spreading. It can be separated into plane waves; each gives rise, inside the crystal, to two fields of waves, whose propagation directions are spread between the incident direction AB and the reflected direction AC. Such fields of waves are propagated along the distance Ap and interfere.

The angular size of the reflection profile is of the order of some seconds. So in a perfect crystal only a weak part of the incident beam is reflected; the most important part, the direct beam, merely suffers photo-electric absorption in traversing the crystal. A second slit f_2 then stops the direct beam and isolates the reflected beam which is received on a photographic plate.

If, in a certain area of the crystal, the lattice planes are slightly misoriented, the interference phenomena suffered by the X-rays are modified or even suppressed. In the trace of the beams R_h and R_o can be seen an image called dynamic image.

On the other hand the misoriented planes will be able to reflect part of the direct beam, if the divergence of the beam is not of less extent than the misorientation. The areas which will reflect most are those where the slope of misorientation is strongest.

Thus in the reflected beam R_h an image i is obtained: its distance h′ to the edge of the beam enables the distance h from the defect to the face of the crystal to be calculated.

For this reason it is said that the trace of the reflected beam on the plate represents a *section* of the crystal. To obtain the map or topography of the disturbed areas throughout the crystal, the crystal and the photographic plate must be moved simultaneously.

The method does not allow observation of the defects themselves but of the misorientations which they cause in the crystal lattice.

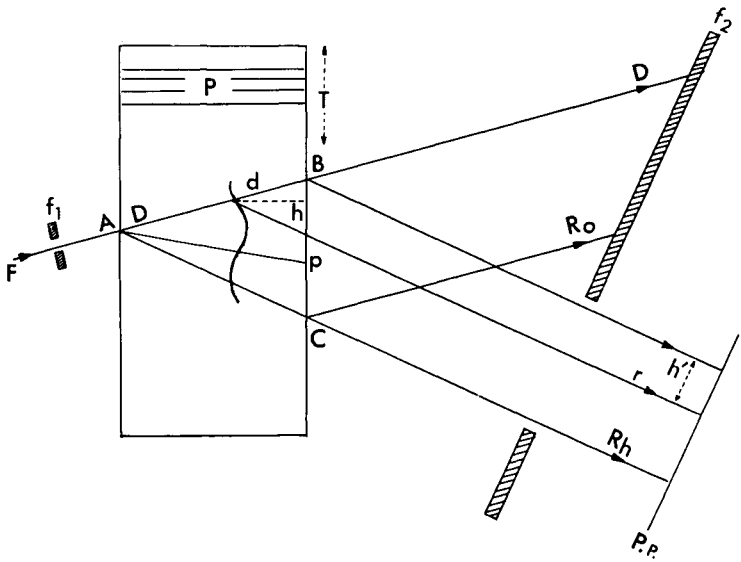

F: Source of X-rays.
f1: Slit restricting the beam's spread.
P: Lattice planes of crystal.
d: Misoriented area.
h: Distance from defect to face of crystal.
D: Direct beam.
Ro: Beam emerging in the direction of transmission.
Rh: Beam emerging in the direction of reflection.
r: Beam reflected by defect d.
P.P.: Photographic plate.
h′: Distance of the image i to the edge of the beam.
f2: Rear slit stopping D and Ro.
T: Direction of movement.

II. Comparison of the Two Types of Topography

Topography of a natural emerald

The specimen studied came from Muzo. A slice of 1·5 mm thickness was cut perpendicularly to the *c* axis in the crystal.

In the topographies shown in Figures 1 and 2, zonings can be seen following the *a* directions. These zonings are related to the growth spirals. The steps are easily visible and are thought to be the result of rather strong misorientations which are produced at

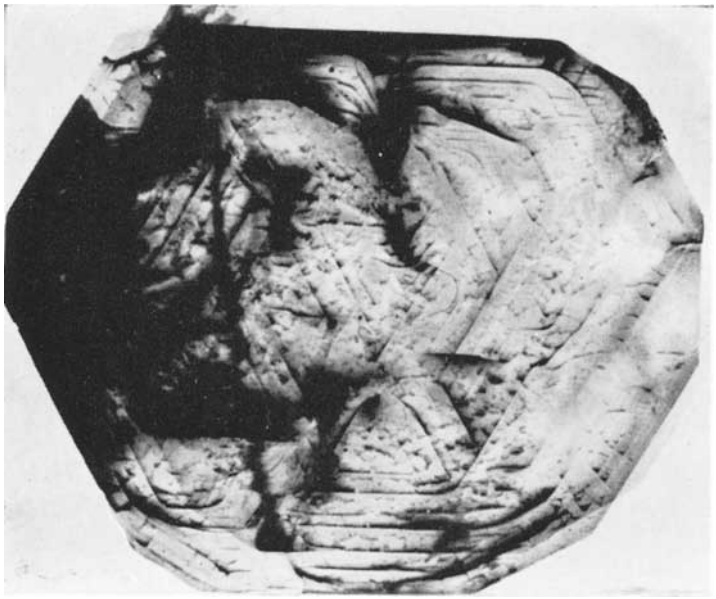

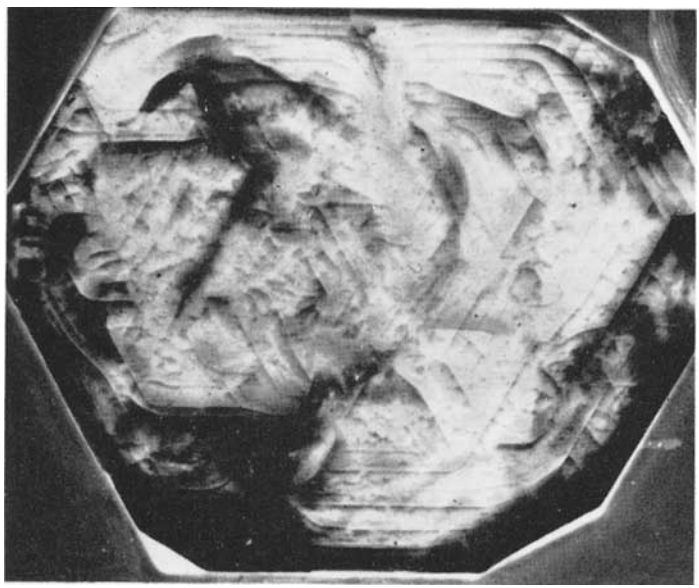

FIGS. 1 and 2. Topography of a natural emerald (Muzo mine).

each resumption of growth and are probably due to their decoration by impurities during each fluctuation of crystallization.

Topography of an artificial emerald

The limpid crystal studied was manufactured by the Gilson organization. A slice of 1·5 mm thickness was cut perpendicularly to the *c* axis.

This slice broke in the course of the cutting and we worked on the biggest fragment (Fig. 3). The presence of sub-grains can be seen, due to very strong internal tensions. There is present a veritable mosaic of juxtaposed grains, misoriented with each other, each grain being itself curved. It is very probable that the dislocation density in the grain boundaries is high.

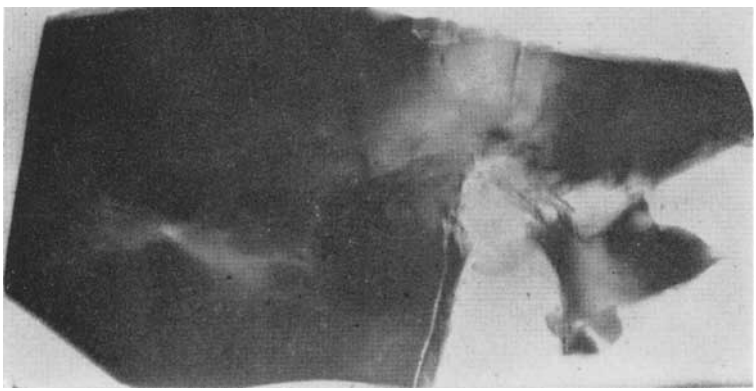

FIG. 3. Topography of a synthetic emerald (Gilson factory).

CONCLUSION

As one of the problems was to know if this method could eventually be applied to cut gems, we then applied to the slices the polishing techniques used by lapidaries. The results have been conclusive, classic polishing giving a very satisfactory surface state which excludes cleavages and chemical attacks formerly used for other crystals (particularly carbonates).

It has been possible to prove the vast differences existing in the architectural organization of the two crystals being studied and that the natural crystal (Muzo mine, Colombia), although showing

inclusions grouped in the form of swirls, was more regular than the synthetic crystal (manufactured in the Gilson factories) which, despite its optical limpidity, has a most disturbed crystalline architecture, as is often the case with synthetic crystals (particularly synthetic spinels).

*Extracted from bulletin No. 25, 1970, of the French Gemmological Association.

YELLOW SCAPOLITE

Another gem-mineral from Umba, Tanzania

By P. C. ZWAAN

National Museum of Geology and Mineralogy, Leyden, Netherlands

INTRODUCTION

In July, 1967 I visited a gem mine in the most north-eastern part of Tanzania. The mine-area is called Umba, according to the Umba River. It is a small location in the jungle. The mine produces a number of minerals of gem quality, especially corundum, garnet and tourmaline. These minerals occur in different metamorphic rocks which, according to Solesbury (1967), are of precambrian age.

Since 1967 a number of papers dealing with minerals from the Umba area have been published. The locality, therefore, is well known now to many mineralogists and gemmologists.

During my visit to the mine the manager gave me a number of different gem-minerals; among others I received two samples of yellow scapolite. Both stones are in the collection of the National Museum of Geology and Mineralogy at Leyden, Netherlands. According to a personal communication of the manager both originate from his mine and are found in secondary deposits.

Meanwhile one of the rough stones has been cut while the other is still in its original state, provided however, with one polished face to facilitate measurements of the refractive indices on an Anderson-Payne-spinel refractometer. The specific gravity of these two stones was measured by using a hydrostatic balance and ethylene dibromide. The X-ray powder photograph of the rough

specimen was made using Fe-radiation and a Debye-Scherrer camera with a diameter of 114·6 millimeters.

Recently Bank and Nuber (1970) described transparent scapolites from Mozambique and Madagascar. It is interesting to compare their results with the ones obtained from these Tanzanian stones.

Description of the Specimens

1. RGM 151264 is an oval-shaped faceted stone of 7·51 carats, having a light yellow colour and containing needle-like inclusions (Figs. 1, 2 and 3). Its size is 14·9 × 10·3 × 7·6 millimeters. The average density, derived from several measurements, is 2·671. The refractive indices, measured on the table, are 1·567 for the ordinary ray and 1·548 for the extraordinary ray, while on one of the back facets the figures 1·568 and 1·550 could be observed. This means that the maximal birefringence which could be measured is 0·019.

The stone has a distinct dichroism in tones of pale yellow and almost colourless. No characteristic absorption bands could be observed.

Under long-wave ultra-violet light the stone has a weak reddish orange fluorescence, while under the short-wave lamp the glow is much stronger in the same colour.

The inclusions are in fact hollow tubes with a tetragonal or orthorhombic prismatic habit. They are filled with soft whitish material and partly covered with a reddish brown powdery material. They resemble the anhydrite tubes sometimes occurring in smoky quartz from Switzerland.

Figs. 1, 2 and 3 show that these needle-like inclusions are oriented in two directions, making an angle with each other of about 60°. Fig. 2 shows a doubling effect, due to the rather strong birefringence of the stone. Moreover in this photograph two black parts are visible, which can be ascribed to a beginning of cleavage against which the transmitted light is totally reflected. In fig. 3 the powdery material covering the needles can be seen.

In regard to the orientation, accepting that the cleavage is parallel with 100, it is seen that the thinnest needles run parallel with the c-axis while the thick tubes lie in the 111 direction.

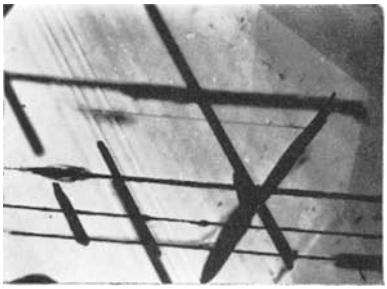

FIG. 1. Needle-like inclusions in scapolite RGM 151264 (25 ×).

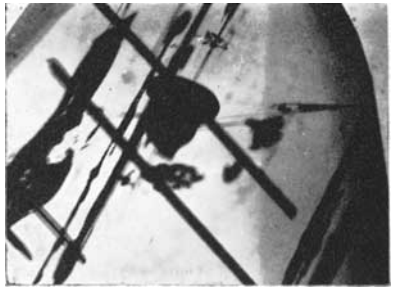

FIG. 2. Needle-like inclusions and beginnings of cleavage in scapolite RGM 151264. The doubling effect is due to the rather strong birefringence of the stone (25 ×).

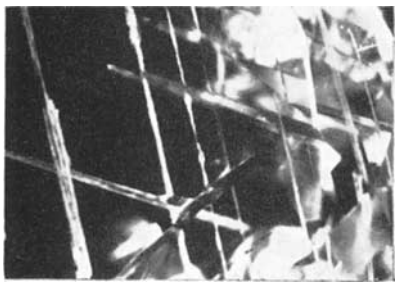

FIG. 3. Needle-like inclusions in scapolite RGM 151264 in reflected light (25 ×).

FIG. 4. Etching figures on scapolite RGM 107194 in reflected light (25 ×).

FIG. 5. Needle-like inclusions in scapolite RGM 107194 (25 ×).

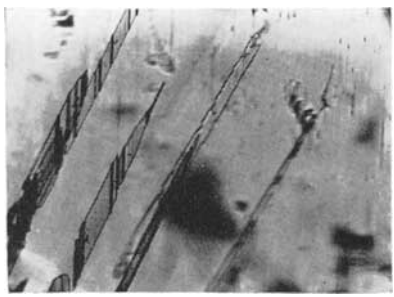

FIG. 6. The same inclusions as in fig. 5 showing the parallel striation in the needles (50 ×).

One may only make a guess at the original nature of these needles, but it is very likely that they were xenogenetic inclusions, according to the classification of Gübelin (1957), from which the contents have been lost in the course of time.

2. RGM 107194 is a rough stone with a yellow colour, weighing 7·23 carats after being provided with a polished face. Its specific gravity is 2·659; the refractive indices are 1·562 for the ordinary ray and 1·543 for the extraordinary ray, hence a maximal double refraction of 0·019 could be measured.

A very distinct dichroism in tones of straw-yellow and almost colourless may be observed, while no characteristic absorption spectrum has been detected.

Under the long-wave ultra-violet lamp it fluoresces weak yellowish orange. Under short-wave ultra-violet light it glows a rather strong yellowish orange.

Although no distinct crystal habit can be seen, there are triangular depressions observable on one of the natural faces of the stone (Fig. 4), probably caused by a natural etching process, or being an irregularity in the crystalline development of the specimen. They are very similar to the inverted triangular depressions often seen on the octahedral faces of diamond crystals.

A remarkable fact is that the needle-like inclusions (Fig. 5) all emanate from the centre of the depressions, like stalactites. In contrast with those of the cut stone these tubes are extremely thin, hence they have a bladed habit. Fig. 6 shows a structure of parallel lines in these inclusions. These lines all lie in an extinction direction of the stone and resemble the cleavage-lines in calcite.

The X-ray powder photograph (No. mm 1714), taken of this stone, gives a pattern of diffraction lines, characteristic for scapolite.

The observed X-ray data are given in the Table and compared with those of three other scapolites, namely one from Mozambique, one from Madagascar and one from an unknown locality. Those from Mozambique and Madagascar are described by Bank and Nuber (1970). The other one is a marialite from the collection of the British Museum, according to the data given by the American Society for Testing and Materials.

Comparison of the Results

As might be expected in an isomorphous group of minerals

TABLE: X-ray powder diffraction data for 4 scapolites

	Mozambique Bank and Nuber 1970		Madagascar Bank and Nuber 1970		Unknown locality ASTM 2-0412		Tanzania RGM 107194	
hkl	d_{obs}.	I	d_{obs}.	I	d_{obs}.	I/I_1	d_{obs}.	I
110					8·49	40	8·49	4
101	6·449	8					6·44	1
200	6·059	8	6·09	8	6·16	40	6·09	2
211	4·400	6	4·422	3			4·42	½
220	4·270	6	4·295	5	4·24	70	4·24	½
310	3·816	100	3·839	10	3·78	90	3·78	8
301	3·557	18	3·569	13			3·55	1
112	3·470	76	3·468	100	3·44	100	3·44	10
202					3·21	20		
321	3·064	100	3·075	24	3·03	100	3·04	9
400	3·016	46	3·032	12			3·01	3
330	2·845	12	2·859	6				
222	2·837	12			2·84	40	2·83	2
411	2·722	16	2·746	8				
420			2·713	7			2·71	2
312	2·690	66	2·699	7	2·68	90	2·68	7
421					2·52	20	2·53	½
510	2·368	2	2·379	3			2·36	½
501	2·301	8	2·311	10	2·29	70	2·29	3
422	2·199	10	2·198	6	2·19	20	2·19	1
521			2·158	3				
440			2·143	13	2·12	70	2·13	3
303	2·142	18						
530	2·072	20			2·05	20	2·06	½
600			2·021	8				
323	2·018	10						
512			2·016	6	1·99	70	2·00	2
611	1·9194	8	1·928	13			1·948	½
413	1·9136	26						
620	1·9087	16	1·9174	5				
004	1·8967	32	1·8967	12	1·90	90	1·907	7
532	1·8178	6			1·81	60	1·807	2
602	1·7775	4					1·774	½
631	1·7514	4	1·7577	3				
503	1·7468	6			1·73	40	1·741	2
710	1·7075	8	1·7143	5	1·69	40	1·698	2
640					1·66	20	1·669	½
721	1·6197	4						
404			1·6078	4	1·61	30	1·607	½
613	1·5608	8	1·5652	4	1·59	20	1·596	½
712					1·55	60	1·553	2
543	1·5116	4			1·50	40	1·508	2
811	1·4692	4						
732	1·4623	8	1·4681	3	1·45	70	1·458	2
215			1·4611	2				
703			1·4295	3				
444			1·4209	3				
305	1·4199	6			1·41	70	1·417	2
723			1·3921	3			1·400	½
325	1·3821	8	1·3849	3			1·379	2
822	1·3655	26	1·3720	14	1·37	40	1·363	4
840			1·3574	3	1·36	70		
624					1·34	20	1·342	½
752			1·3214	2	1·32	20	1·332	½
921					1·31	40	1·316	2
505			1·2868	2	1·28	40	1·286	2
950			1·1780	2			1·172	½
635	1·1602	8					1·161	1
1002			1·1553	3				
426			1·1465	1			1·149	2
725	1·1193	6					1·129	2
1042			1·0793	3			1·084	1
880							1·066	½
1060	1·0349	12					1·035	1

like the scapolites it is very unlikely that even two examples from one locality will have the same properties.

RGM 151264, the cut stone, has the highest values for refractive indices and density. They are very close to those of the Madagascar scapolite, mentioned by Bank and Nuber (1970). This Tanzanian scapolite therefore lies somewhere in between dipyre and mizzonite (after the diagram of Bank, 1970).

RGM 107194 has somewhat lower properties. Plotted in the diagram, mentioned above, these figures indicate a scapolite in the dipyre field. The X-ray data, stated in the Table, however, agree best with those from the marialite of unknown locality. Anyway this scapolite seems to have a chemical composition in which the molecular percentage of marialite is predominant.

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NOTES ON RECENT SYNTHETICS AND THE BLACKENING OF NATURAL OPALS

By RICHARD T. LIDDICOAT, Jr.

IT is a pleasure and an honour to be able to participate in a tribute to Basil W. Anderson on the occasion of his 70th birthday. He is not only recognized throughout the world, but revered for his contributions to the science of gem-testing in too many ways to count. Perhaps the contribution that we in American laboratories appreciate the most is his pioneering work in the use of the spectroscope in gem-testing. We have been able to take advantage of his work and to appreciate the exceptional usefulness of this instrument in testing. There was a time when it was used but rarely in routine testing in our laboratories; however today the

spectroscope has become of equal importance to the refractometer. So many of the tests that we use every day were pioneered by Basil Anderson, that all of us in this field can only say "thank you" to a great man.

Every year brings new examples of the value of the spectroscope in gem-testing. In the last year or two, the development by Pierre Gilson of synthetic emeralds that have properties well within the range of the natural, i.e. approximately 1·572–1·579 in refractive index and about 2·68–2·69 in specific gravity, would have made detection difficult except for the new absorption line introduced by the addition of iron oxide to dampen the fluorescence and raise the properties of the synthetic. With a spectroscope, a line surely caused by the iron is to be seen at about 4270Å in the violet. If no inclusions are to be seen, the 4270Å line will become exceedingly important to the gemmologist seeking to detect a synthetic emerald. Fortunately, to date most of these show an abundance of the wispy or veil-like inclusions we associate with flux-melt grown products.

Certainly, the use of the spectroscope has added a very important dimension to gem-testing, which even though it has been present for quite a number of years, is still one that is enjoyed particularly by the gem-testing fraternity.

New Type of Treated Black Opals

For over a year we have been receiving for testing black opals that we were sure had been treated in some fashion. When we first encountered these very dark opals, we were given a story about the method of treatment, but did not consider it factual, because of certain properties and other characteristics. We learned that the stone first is covered completely with brown wrapping paper. Placed in a crucible, the wrapped opal is heated slowly with a torch until it is hot enough for the paper to burn. We would have expected the opal to shatter, but no evidence of cracking was present. This "smoking" imparts a black colour that penetrates less than 1 mm.

The black opals are beautiful, with a great deal of fire. Every one tested revealed a very, very low refractive index—about 1·37, and an exceptionally low specific gravity—usually about 1·25 (one floated in water until it absorbed enough to sink). When subjected to the point of a needle they seem to indent rather than break out. These treated black opals do not show the evidence of treatment that we use to detect the usual sugar-and-acid treatment.

The only opals we have encountered with comparable properties are semi-translucent white opals from Jalisco, Mexico. They have a similar pattern of fire as well.

A New Yttrium Aluminate

One other material that we feel will be encountered in gem-testing laboratories around the world in the next few months is an yttrium aluminate that, unlike YAG, is doubly refracting. This one has a formula $Y_2O_3:Al_2O_3$ (in contrast to the $3Y_2O_3:5Al_2O_3$ of YAG), which crystallizes in the orthorhombic system. Presumably this material is colourless when pure, but the only specimens we have been able to study were heavily doped with didymium, which imparted bluish-pink to orangy-pink colours. The absorption spectra were spectacular. The drawing by Charles Fryer, below, does not exaggerate the sharpness and intensity of the many lines.

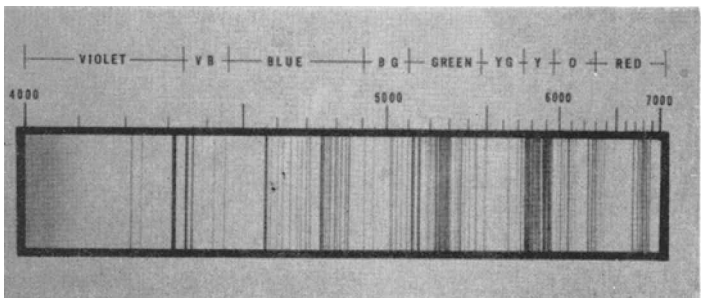

We only have rough, so we have not measured the refractive indices, but the strength of doubling suggests a birefringence in the ·02–·03 range. The manufacturer indicates a refractive index of 1·938 at 6568Å and 1·955 at 4868Å, hardness equal to YAG (8 +) and a specific gravity of 5·35.

This material may soon appear in a colourless form as yet another diamond imitation.

KAKORTOKITE—AND OTHER ORNAMENTAL EUDIALYTE ROCKS

By O. DRAGSTED

IN July 1967, the author visited the Kangerdluarssuk fjord in the Julianehåb district of Southern Greenland. The fjord is beautifully framed with snowcapped mountains, here and there with tiny grassy shelves which once served as pastures for the cattle of a lonely viking family. The aluminium speed-boats cut through the water, glittering cascades shot up like fireworks and then washed over the foredeck, and over the chart which had to be studied all the time to avoid submarine rocks. Sudden swerves when small icebergs were sighted sent showers of water over the crews.

The boats were dragged ashore on the innermost coast near the remains of an old eskimo cottage, under the shelter of a slope covered with heather and creeping bushes of willow and juniper and polar birches which together with the mosses and the yellow arctic poppies and red silenes and bluebells lent their aromatic scents to the air. The song of the snow-birds and Lapland buntings was accompanied by the sound of the waterfalls of the Salmon Brook and the hoarse cries of ravens.

Crossing the delta of the brook we reached, under the instructive guidance of John Hansen of the Greenland Geological Survey, the southern bank of the fjord over which loomed a mountain spectacularly built up of wavy bands of *kakortokite*, some of them greyish white, others nearly black, and all of them spangled with brick-red little spots of the rather rare mineral *eudialyte*. Debris on the beach formed a nice sample range of the many kakortokite varieties. The eudialyte is embedded in white grains of nepheline and some felspar. The black mineral is arfvedsonite[1].

The first report[2] of this mountain, which forms the lower part of the interesting Ilímaussaq intrusion, was given by Karl Ludwig Giesecke (1761-1833) who during 1806-1813 undertook an intensive survey, commissioned by the King of Denmark. Giesecke presumed the red mineral was a type of garnet. His stay was extended over seven years because of the Napoleonic War. By the way, several boxes of rocks and minerals, which he sent home, were seized by the British and found their way to Scotland. In these collections

were discovered two hitherto unknown minerals, *sodalite* (Th. Thomson, 1811) and the amphibole *arfvedsonite* (H. J. Brooke, 1823). But the greater part of the collections reached the European continent, and the minerals were analysed in Copenhagen and elsewhere. The presumed garnet was studied in Göttingen by Friedrich Stromeyer (1776-1835) who found that it was a complex zirconium silicate and named it, in 1819, *eudialyte* (Greek eu = well, dialyein = dissolve, because it is readily attacked by hydrochloric acid).

Because of the zirconium contents of the eudialyte (about 10-15% ZrO_2) the Danish mineralogist K. J. V. Steenstrup (1842-1913) undertook, in 1888 and 1899, to send home loads of the

Eucolite in rock

3 eudialyte crystals (fragments)

Kakortokite rock

Kakortokite oil lamp

naujaite heart and bowl

2 kakortokite cabochons

rocks; the Cryolite Company hoped to create interest therein, but in vain. Remains of the barrel hoops were still spread around. Quarrying took place again in 1946, and now mining of the eudialyte-bearing rocks is again under consideration because of the growing importance of the zirconium metal. If so, the kakortokite mountain will probably disappear from the map, together with the neighbouring occurrences.

Eudialyte is present in the three nepheline-syenites, which N. V. Ussing (1864-1911) named kakortokite, naujaite (the next one according to age) and lujavrite (the youngest one of the three); they build up the Ilímaussaq intrusion, so rich in rare minerals. The age of the formation has been determined by radioactive methods as 1,000,000,000 years.

Also the naujaite (Eskimo nauja = seagull) is most attractive. It is a whitish rock of nepheline and feldspar containing numerous pastel green grains of sodalite and thus has very much the appearance of a seagull's egg. Further there may be dark green aegirine (acmite) and black arfvedsonite included. With red grains of eudialyte the naujaite forms a most attractive decorative rock.

Most of the eudialyte in these rocks lacks crystal faces, but in the small Qeqertaussaq skerry in the fjord specimens with well developed crystal faces may be collected during low water.

Some eudialyte has weathered into the yellowish-brown *eucolite*. The chemical formula of eudialyte has not been easy to determine; it is now usually written $(Na,Ca,Fe)_6Zr[(OH,Cl)(Si_3O_9)_2]$. Eudialyte crystallizes in the trigonal system. The hardness is $5\frac{1}{2}$ Mohs, and the gravity about 2·9. The pleochroism is distinct (under a strong light-source): rose-red and dark brownish red. The mean refractive index is 1·61 with a weak positive birefringence (0·003); eucolite has a mean R.I. of 1·62 with weak negative double refraction. The S.G. of kakortokite ranges from 2·7 to 2·8.

Eudialyte is a brittle mineral—anyway the Greenland material is not suited for fashioning. But when embedded in the nepheline or feldspar it forms a rock which takes a nice polish.

Endeavours are made to make kakortokite a souvenir of the city of Julianehåb (founded 1775). Small bowls (which are not

ashtrays but models of eskimo grease lamps) and other objects of art, as well as cabochons for silver ornaments, have been made. Also the naujaite is being polished on a small scale, and it is hoped that the Greenlanders will utilize these attractive materials and thus earn an extra income.

Mineralogists link another hope with eudialyte, which they intend to establish as the zirconium standard for the microprobe.

Although rare, eudialyte is found in several places around the world. It has been reported, often together with eucolite, from Pilandsberg in Transvaal, from Norra Kär in Sweden, Langesundsfjord in Norway and from Ampasibitika in Madagascar. Famous among American collectors are the well developed eudialyte crystals found in the coarser part of the nepheline-syenite of Magnet Cove, Arkansas. They are of a pink hue. In formations which have much in common with the Greenlandic geology, eudialyte is found in the Khibina tundras in the Kola peninsula in Lapponian Russia and Sedlovatoi island in the White Sea off Archangelsk.

The Russian mineralogist A. F. Fersmann (1883-1945) relates[3] a tale by an old Lapponian woman. Foreigners, maybe Swedes, penetrated into the land of the Saami people and drove them away, depriving them of many reindeer. So the men gathered to fight the intruders and regain their property. But the enemy slew their right flank and they slew their left flank and much Lapponian blood was shed and sprayed out over the mountains and tundras.

"You have seen it, the beautiful stone in the mountains, that it is the blood of the Lapponians, the blood of the old Saami"!

"Blood stains"—a comparison known also from the legend of the heliotrope jasper or bloodstone—is most descriptive for the appearance of the beautiful eudialyte rocks.

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A DIFFERENT POINT-CUT DIAMOND

By HERBERT TILLANDER, F.G.A., C.G.

IT has been said that the fine, symmetrical diamond of octahedral shape—possibly improved through cleaving, but not through polishing—was the earliest example of a gem diamond. This, and the fact that such "glassies" were never exported has been documented by G. Lenzen[1] in regard to ancient India.

The earliest diamonds encountered in Europe (with the exception of those used as tools) are mostly small, translucent octahedra, dodecahedra or twins. Some of these are crudely buffed by hand, many in their natural state. Such diamonds were originally worn as talismans only and their subsequent use in antique jewellery seems to have served similar purposes rather than decorative. A fine example from 1380 is preserved in the treasury of the Royal residence in Munich. It is the bridal crown, worn by Princess Blanche at her marriage to the Elector Ludwig III[2]. In this crown the coloured stones and pearls dominate to the extent that the many small rough diamond octahedra were not mentioned in the catalogues before 1970, when the author's diamond inventory was included[3].

Until the art of cutting was invented, Europe must thus have been a limited market for quasi gem diamonds of regular crystal shapes only. But neither specialists on antique jewellery nor gemmologists have yet been able to disclose when and where diamond cutting originated. Several indications, however, point towards the 14th century and Venice, as well as Bruges, seem to have many supporters as cutting centres of that period. Strangely enough many authors still cling to the tale of a French jeweller who in 1661 claimed that one of his ancesters had invented the method of cutting diamonds in 1476. They seem to believe that the natural crystal faces of the early gem diamonds were just polished and that the first stage of cutting was a mere grinding away of the tip of a natural octahedron. However, such a treatment would not have been possible. Neither the octahedral, nor the dodecahedral faces can be polished even by modern methods. In order to obtain smooth and shiny faces a diamond crystal must be attacked at an angle to the above mentioned crystallographic planes.

It is true that the earliest gem diamonds in the various collections all over the world at first sight appear to have crystalline proportions, but a close examination of thousands of pyramidal- and table-cuts has revealed distinctly divergent angles. The initial stage of diamond cutting seems thus to have been a transformation of more or less unsymmetrical crystals into mirroring gems. The very first diamond cutters obviously had no, or very restricted, knowledge about hard and soft faces or directions. Their success must nevertheless have been immediate since it did not take long before all kinds of fancy shapes appeared on the market. Even with regard to imagination the evolution was concluded around 1450 with some 200 different cuts registered by the author. Further progress was concerned with details of the appliances for precision and power for comfort and speed. No basically new shape has been cut since the middle of the 15th century. It is obvious that at first there was no demand for any other shapes than those similar to the natural diamond crystals. The supply of rough must then have been restricted to these types and many were probably cut into gemstones. In addition diamond had since Biblical days been used as a technological and industrial hard material and this type of rough may well have induced early cutters to experiment with irregularly shaped rough, which was available and gradually found a growing market in Europe.

For reasons of Pythagorean mysticism[1] the pyramidal- and table-cuts were preferred to other shapes and held their ground until the mid-17th century. It is, therefore, not surprising that the cutters very soon had to look for other than octahedral rough.

FIG. 1.

a. The corners of the square reflection touch the sides of diamond when the proportions are equa to the natural octahedron.

b. A small reflection with its corners well inside indicates proportions of the diamond far below the octahedral.

c. A large reflection with its corners outside indicates proportion above the octahedral.

They fashioned, as we have seen before[3] tablet-cuts from "flats" and we shall now see how triangularly crystallized diamonds could be transformed into point-cuts. As briefly explained in a previous article[4] practically all of the historical point-cuts (pyramidal cuts) have been produced from octahedral rough by working towards the apices of the crystal (Fig. 1b). Cutting towards the girdle and therewith reducing the outline (size) and increasing the relative height of the finished gem must have been out of the question. Nevertheless point-cuts of proportions indicating such shaping can be seen in numerous pictures and a few have been preserved from recutting. One of exceptional size and beauty is the stone in an elaborate renaissance ring in the collections of the Green Vault in Dresden (Fig. 2). This ring, together with some other pieces of antique jewellery with diamonds of intricate shapes, was on loan in Helsinki in 1970 and on display at a diamond exhibition arranged by the author.

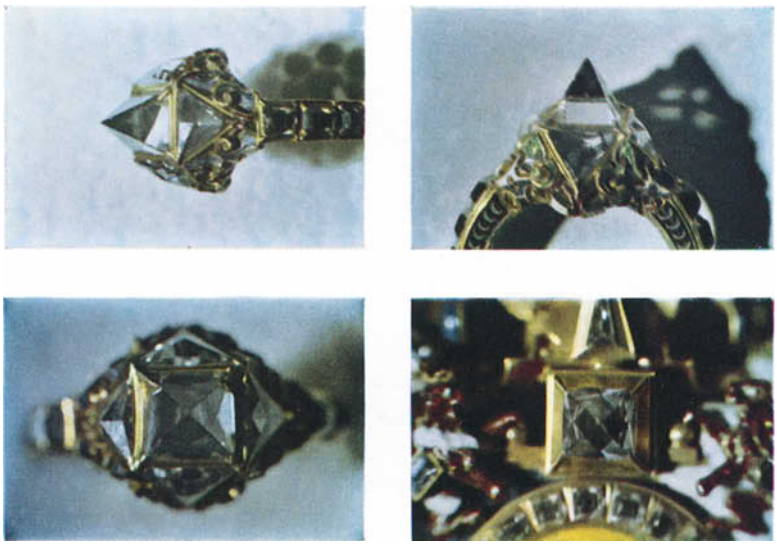

FIG. 2. Photographs of the renaissance ring in the collections of the Green Vault in Dresden.

The pyramidal diamond in this ring was thoroughly examined and found to be of a type not previously described. The visible part of the stone is equilateral in shape and the angle of inclination

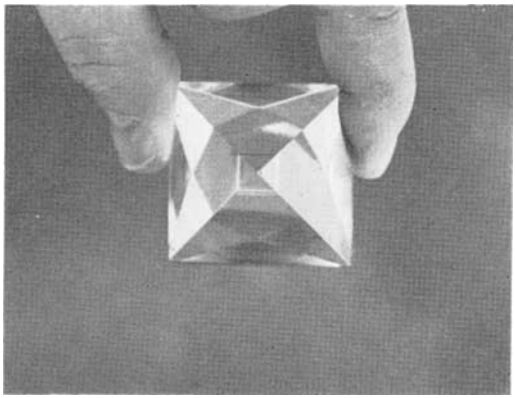

FIG. 3. The reflection picture of the depicted diamond.

of the four main facets towards the girdle plane thus 60° against $54\frac{3}{4}°$ in the octahedron. Obviously also the reflections show an entirely different picture from the normal point-cuts with angles of inclination lower than $54\frac{3}{4}°$. The small square in the centre suggested at first a culet in the pyramidal pavilion, hidden in the closed setting (Fig. 3).

The problem could only be solved through experimental comparisons. During the stage when point-cuts of lower than octahedral proportions were first studied a series of models in plastic (with an R.I. of 1·50) were produced. Professor S. Rösch, of Wetzlar, assisted with a graph permitting correct comparisons with diamond. Subsequently he published a paper on the reflection figures in point-cut and table-cut diamonds. The author further found that if two single pyramids were placed on top of each other no interference took place; the reflections proved to be identical with those of double pyramids made out of one single piece. This observation much simplified the experimental work. Twelve pairs of single pyramids were enough to cover the whole scale of point-cuts encountered in the various collections. They were cut with a basis of 40 × 40 mm and a range of height figures from 8, 12, 16, 20, etc. up to 52 mm covering a sufficiently long series of angles of inclination for diamond from 11° up to $60\frac{1}{2}°$.

Obviously the highest pyramid was found to compare best with the reflections of the diamond in the ring. Surprisingly,

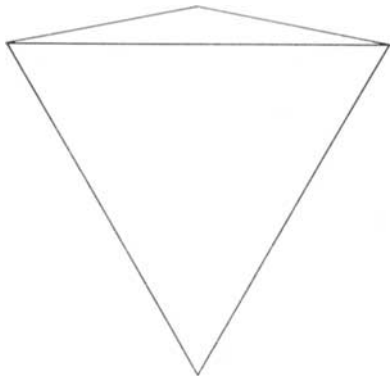

FIG. 4. A crosscut of the Dresden diamond showing the proportions of the double pyramid.

this also displayed the little square in the centre. It was further found that every diamond of higher than octahedral proportions must show a similar square reflection, the size of which is directly related to the height of the pyramid. It then remained to recognize the complete reflection picture. This was found after applying the very lowest plastic pyramid under the highest, thus indicating clearly a crown angle of about 60 or $60\frac{1}{2}°$ and a pavilion angle of some 11°. These proportions are shown in Fig. 4. The story of this peculiar point-cut diamond does, however, not yet end. It was evident that the rough from which it was produced could

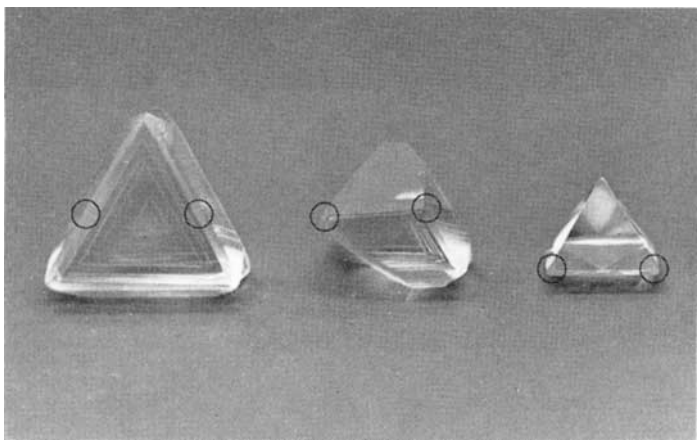

FIG. 5. The sequence of the cutting operation.

not logically have been of octahedral shape. Naturals on two adjacent corners and a tiny, hardly visible cleavage helped to solve this problem. The equilateral, triangular shape of the upper pyramid and the extremely flat lower one suggested a triangular, slightly rounded macle of the spinel-twin type. A plastic model of that shape was therefore made and it was found that this lent itself to cutting into the described point-cut. A further and rather unexpected result from this operation was that two corners remained blunt, thus corresponding with the naturals on the diamond. The direction of the tiny cleavage was an additional confirmation of a correct solution. Finally it was found that only some 40% of the original weight of the rough was lost in the cutting operation—a commercial proposition (Fig. 5).

Just as tablet-cuts have been produced from "flats"[3] it has now been shown that point-cuts have not necessarily been derived from octahedra.

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ASSOCIATION NOTICES

OBITUARY

SIR LAWRENCE BRAGG, C.H., O.B.E., M.C., B.Sc., F.R.S.

The eminent physicist, Sir Lawrence Bragg, died at Ipswich on the 1st July aged 81.

Sir Lawrence, who honoured the Association by becoming its President in 1954 was, with his father, the late Sir William Bragg, awarded the Nobel Prize for Physics in 1915. At the time he was only 25. He was elected a Fellow of the Royal Society at the age of 31. Sir Lawrence was made a Companion of Honour in 1967 for his services to science. During his distinguished career he was Langworthy Professor of Physics, Victoria University of Manchester, Director of the National Physical Laboratory, and Cavendish Professor of Experimental Physics, Cambridge. In 1953 he became Fullerian Professor of Chemistry, Royal Institution, and in 1954 Scientific Director of the Royal Institution, posts which he held until 1966. He was knighted in 1941.

His principal work concerned x-ray and crystal structure and the discoveries of both father and son made it possible to map out the positions of atoms in molecules and crystals with great certainty. Sir Lawrence was awarded the Copley Medal for contributions to crystallography and analysis of molecules by x-ray diffraction in 1966.

ANNUAL GENERAL MEETING

In the absence of the Chairman, Mr. D. King, Vice-Chairman, presided at the 41st Annual General Meeting of the Association, which was held on the 30th April. Mr. King said that as the Annual Report had been circulated there was little about which he could comment as the year under review was one of routine rather than spectacular achievement. Nevertheless, he reported that it had been a busy year with an increased volume of corres-

pondence and enquiries. He said that in the examinations 510 candidates sat for the preliminary and 301 for the diploma, against 460 and 307 respectively for 1969. For the second year running the Tully Memorial Medal and Rayner Prize were not awarded. Mr. King reported that the Association has been particularly gratified at the interest in examinations overseas, especially in Spain and Japan, and it is encouraging that Barcelona University recognized gemmology as a faculty subject.

The Vice-Chairman went on to say that the National Association of Goldsmiths had reorganized the Sir James Walton Library to house, among other things, the two pieces of silver which this Association gave to them in 1968 to commemorate 60 years of gemmology in Britain. Both organizations added to the library from time to time.

Mr. King reported that the Association had agreed to contribute a more realistic sum to the National Association of Goldsmiths for administrative work. He thanked the many people who had contributed towards the work and the success of the Association during the year under review. The audited accounts and report of the Council for the year ended 31st December, 1970, were then adopted.

The following Officers were re-elected: President, Sir Lawrence Bragg, C.H., O.B.E., M.C., F.R.S.; Chairman, Mr. Norman Harper; Vice-Chairman, Mr. Douglas King; Treasurer, Mr. F. E. Lawson Clarke. Mr. Philip Riley continues as Deputy Chairman. Messrs. D. J. Ewing, J. M. B. McWilliam and R. Webster were re-elected to serve on the Council.

The Vice-Chairman announced that Messrs. Watson Collin & Co., chartered accountants, had signified their willingness to continue as auditors.

BRANCH MEETINGS

The Annual General Meeting of the Scottish Branch of the Association was held on the 22nd April, 1971, at the North British Hotel, George Square, Glasgow. Mr. Dennis Hill, Chairman, presided.

Mr. D. Hill and Mr. M. Turner were re-elected Chairman and Secretary respectively.

At the Annual Meeting of the Midlands Branch held at the

Auctioneers Institute, Birmingham, on the 30th April, 1971, Mrs. S.E. Hiscox was elected as Chairman. She is the first woman to become Chairman of a local branch. Mr. J. Marshall was elected as Vice-Chairman and Mr. P. J. West continues as Secretary.

The retiring Chairman, Mr. P. Spacey, outlined the activities of the past year, among which was a visit to the Crown Jewels and a talk by Mr. Robert Webster on "Modern Synthetics".

GEM DIAMOND CLASSES

Gem Diamond Classes, open only to Fellows of the Association, will commence at the Sir John Cass College, Whitechapel High Street, London, E.1. in September. If sufficient students enrol, classes may also be held at the School of Jewellery and Silversmithing, Vittoria Street, Birmingham and the Barmulloch College of Further Education, Rye Road, Glasgow, N.1. It is suggested that Fellows interested in attending should contact the appropriate College as soon as possible.

EXHIBITION OF GEMSTONES

The Exhibition of Gemstones to be held in Glasgow (see April 1971 issue) will be officially opened on the 16th September, 1971 at 7.30 p.m. by Professor George of the Department of Geology, Glasgow University. The closing date is the 10th October, 1971. The exhibition is being arranged by the Scottish Branch of the Association.

GIFTS TO THE ASSOCIATION

The Council of the Association is indebted to the following for their gifts:

The gift of the Gemmological Association of All Japan of an Olympus dark field stereo-zoom binocular microscope, model J.M. The costs of customs clearance and delivery charges were covered by the Metallurgical Services Laboratories Ltd., the U.K. Agents for Olympus Instruments.

A powellite cut stone, a synthetic material produced for scientific purposes, from Mr. E. C. Parrott, Vancouver, Wa., U.S.A.

Holly leaves carved in nephrite and coral, mounted on gold stems and set in a rock crystal jar, have been presented by Mrs. E. Stern, London, to the Sir James Walton Library, a favourite piece of the late Dr. W. Stern.

A series of transparencies and study specimens from Mr. R. Webster, London.

A twin quartz crystal from the Kuro-daira, Koofu City, Yamanashi Pref., Japan, presented by Mr. H. Fukabayashi, Sapporo, Japan.

Tourmaline crystals from St. Just in Cornwall, presented by Mr. Aubrey Bowden, Plymouth.

Specimens of Japanese gem minerals including jadeite, rhodonite and rhodochrosite presented by Mr. P. Tamiya of Cosmo Ltd., Tokyo, Japan.

A pocket guide to precious stones from Mr. P. Ruppenthal, Idar-Oberstein.

A specimen of green opal, Brazil, from Mr. J. Petsch, Jr., Idar-Oberstein.

A collection of study specimens, including Mexican opals, peridots and Montana sapphires, from Mr. A. C. Bonnano, F.G.A., Maryland, U.S.A.

Edelsteine—systematik under beschreibung. A gift from Dr. H. Bank, Idar-Oberstein.

MEMBERS' MEETINGS

A reception for Fellows of the Association was held at Goldsmiths' Hall, London, on Wednesday, 20th April, 1971.

COUNCIL MEETING

At a meeting of the Council held on 20th April, 1971, the death of Dr. W. Stern was recorded with great regret. Dr. Stern gained his Fellowship, with distinction, in 1947 and became a member of the Council in 1950. He contributed much to the work of the Association, particularly with the translation of abstracts for the *Journal of Gemmology*.

The following were elected to membership:

FELLOWSHIP

Ballester, Juana Prats,
Barcelona, Spain D. 1970

Godfrey, Kenneth E.,
Brighton, Sussex D. 1948

Gimeno, Jose Luis Garcia,
Zaragoza, Spain D. 1970

Girona, Maria M. Marti,
Barcelona, Spain D. 1970

Lopez, Rafael Sallan,
Zaragoza, Spain D. 1970

Ribera, Arturo Ricart,
Barcelona, Spain D. 1970

Backshall, Henry G. R., Hainault, Essex
Bearman, Jerry, St. Louis, Missouri, U.S.A.
Bilham-Boult, J., Chelmsford, Essex
Bott, Patricia A., Rugby, Warwicks.
Coventry, Olive P., Liverpool, Lancs.
Coventry, Stanley W. J., Liverpool, Lancs.
Davis, Gerald A., Marion, Ohio, U.S.A.
Eason, John R., Manurewa, New Zealand
Ferguson, Louisa, Neilston, Renfrewshire, Scotland
Fitterman, Murray R., New Bern, Carolina, U.S.A.
Frayne, Samuel F., Hanover, Pa., U.S.A.
Hiok, Ng Seng, Singapore
Holm, Franz, Stockholm, Sweden
Kahn, Stanley B., Pine Bluff, Arkansas, U.S.A.
Leat, William J., Torquay, Devon
Levy, Ralph M., Greensboro, Carolina, U.S.A.
Littman, Herbert, Highland Park, New Jersey, U.S.A.
Loeters, Leo, Diksmuide, Belgium
Longhurst, William A. S., Bexleyheath, Kent
Mylvaganan, Jeyakumar P., Colombo, Ceylon
Nissanka, Geeta S., Colombo, Ceylon
Ramshad, Seyed H., Cambridge
Reyner, Charles S., Greenville, Carolina, U.S.A.
Ruppenthal, Paul, Idar-Oberstein, W. Germany
Shindler, Albert, Harrow, Middlesex
Vogt, Arno R., New London, Conn., U.S.A.
Walpitagama, Karunapala, Gantalawa, Ceylon
Webb, Ronald J., Auckland, New Zealand
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THE JOURNAL OF GEMMOLOGY

and

PROCEEDINGS OF THE
GEMMOLOGICAL
ASSOCIATION
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GEMMOLOGICAL ASSOCIATION
OF GREAT BRITAIN
SAINT DUNSTAN'S HOUSE, CAREY LANE
LONDON, E.C. 2

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THE JOURNAL OF GEMMOLOGY
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Vol. 12 No. 8 OCTOBER 1971

TRAPICHE EMERALD

By M. J. O'DONOGHUE M.A., F.G.A.

ALTHOUGH this type of emerald has been known since 1963 it has so far not been published in a British gemmological journal. The present article, therefore, attempts to summarize the research already carried out and to illustrate it with some specimens from the author's collection.

Trapiche emeralds (the word in Spanish means cane-crushing gear) have been found so far only in Colombia. The majority of the specimens described are up to 1″ long and ½″ in diameter. Most contain a central core of green emerald from which sprout six arms of the same material, in hexagonal form. The interstices of the arms are filled with a whitish-grey material. Other examples have no central core at one end and yet display it at the other. In some pieces the material of the interstices is very thin so that the stone as a whole resembles a normal hexagonal emerald crystal with white or black inclusions following the hexagonal axes. Most of the existing research has been carried out with a view to ascertaining the nature of the white material and to establish the mode of growth.

Nassau and Jackson[1] found that two stages of emerald growth are found in stones from the Peña Blanca Mine, near Muzo. The stones are found in pockets in the Cretaceous shales and clays of the area. The first stage was the growth of the central prism which is hexagonal and slightly tapered while the second stage was the simultaneous growth of beryl and albite with the beryl growing

parallel to the original prism faces and the albite at the corners. Striations parallel and perpendicular to the faces of the prisms seem to indicate that the lateral faces grew with a plane interface which moved out parallel to the original faces of the prism. The authors postulate on this basis that the two-phase growth at the corners was simultaneous with the growth of the central area, since if the reverse were true the growth markings would have been out from the corners rather than parallel to the original prism faces. Growth occurred from a hydrothermal solution containing albite.

The growth of the two-phase material at the corners rather than at the faces of the prism was thought to have been due to the rapid lateral growth of new layers on the side faces of the prisms, suppressing the growth there of the second phase, whereas at the corners the difficulty of starting new layers allowed the continuing presence of the second phase.

By powder X-ray diffraction the material in the central core and the side arms has been shown to be beryl. The white material as shown in Fig. 1 no. 1 is a mixture of beryl and albite. A Laue diffraction pattern showed that the central core and the six arms had the same orientation with the c axis along the hexagonal symmetry axes of the crystal.

It was also found that the white material gave a single crystal pattern in the same orientation as the rest of the crystal, which forced the conclusion that the trapiche emerald is in fact a single crystal with varying amounts of albite as inclusion. The infra-red spectrum of water was found in both the central core and the side arms, the latter containing about 10% more.

The same results from X-ray diffraction were obtained from some specimens from the Muzo mine where the central prism was black (the shale at Muzo has a high carbon content) and the outer sections of clear emerald separated by sheets of dark material. Laue patterns again showed that these stones are single crystals. It is suggested by Nassau and Jackson that the change in composition and colour results from an abrupt reduction in the growth rate which was rapid in the central core, trapping carbonaceous material, and much slower in the arms which are clear emerald, with the impurities diffusing away from the flat faces and being trapped only at the corners. It was also thought possible that the composition of growth medium suddenly changed to one with a much lower carbon content.

Top left: Institute of Geological Sciences (MI 33267).

Top right and centre: Author's collection.

Bottom left (B.M. 1967, 40) and *bottom right* (B.M. 1967, 402), British Museum (Natural History).

Institute of Geological Sciences photograph reproduced by permission of the Director.

Some optical values are shown in the table given by the same authors in another publication:

	nω	DR
Peña Blanca trapiche	1·575–580	0·006–0·007
Muzo trapiche	1·572	0·008
Chivor ordinary	1·577	0·006
Muzo ordinary	1·584	0·006

Schiffmann[2] has described the process of cutting trapiche emerald. In order to get rid of the non-emerald material, the stones are sawn across at 120° in the plane of the axes of the star. The black or white material then falls away, leaving the emerald which may then be cut. Another method of cutting is described by Tripp and Hernandez[3]. Using a thin slitting diamond blade two cuts are made in the stone perpendicular to the centre crystal on each side of the outer pieces. By exerting pressure with a thin knife blade in the cuts the piece of emerald will come away cleanly. The authors also found that the centre crystal was nearly always cracked or broken, although it was more transparent than the outer pieces which however are the better colour. A stone measuring 2″ × 4½″ and weighing about 167 ct has been seen and a stone 20mm in diameter with no apparent centre crystal was cut to produce six fine quality stones each averaging 3 ct.

Schiffmann described some cut emeralds which had a clouded appearance and which were transparent to translucent due to the structure rather than to inclusions. As the constants were similar to other emeralds from the area and as inclusions of albite and carbonaceous matter were found, Nassau and Jackson suggested that they were probably trapiche emeralds and perhaps cut from a crystal 3″ long seen by G. R. Crowningshield, as most other trapiches known were much too small to yield cut stones of the size examined by Schiffmann, which averaged 1 ct and 8mm.

The writer is indebted to Mr. E. A. Jobbins of the Geological Museum for photographing the emeralds and for assistance with source material.

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ANTARCTIC PERIDOT

By A. M. TAYLOR

WHAT appears to be the first discovery of gem material from the Antarctic continent has been made by Professor A. T. Wilson, now of Waikato University, Hamilton, New Zealand. Samples of peridot were recovered during a recent Victoria University of Wellington expedition to the ice-free areas of Ross Island in McMurdo Sound. Two separate deposits were found on opposite sides of the island, near Cape Bird and Cape Crozier. In both areas the material occurred as angular nodules on the surface of loose volcanic debris. In size the pieces ranged from 0·5 to 4 grams. Large phenocrysts of granular olivine 3 to 5 cm across are of fairly common occurrence in a dense black basaltic rock in the general area but no gem quality crystals were found in the solid rock. The deposits are rather similar to other known peridot localities such as at Buell Park, Arizona.

Examination of the material from the two localities revealed that they had practically identical physical properties, which are in the normal range for peridot, viz., specific gravity 3·34–3·35; refractive index $\alpha = 1{\cdot}653$, $\gamma = 1{\cdot}689$, D.R. 0·036. The colour of the cut stones is a pleasant yellow-green without appreciable olive tint. The material so far recovered has yielded slightly flawed but acceptable cut stones up to 2 carats weight and flawless stones of 0·5 carat are possible. The principal flaws consist of veils of two-phase inclusions and minute brown mica plates arranged in parallel orientation.

The discovery is not considered to be of any economic or scientific importance but purely of gemmological interest. The localities are not readily accessible from the McMurdo Sound bases except by helicopter during the summer months. Supply of material at present is limited to that picked up by personnel on official scientific expeditions. Considering the extensive volcanic nature of the terrain we may hope that future geological expeditions will encounter new and better deposits now that an awareness to gemstones prevails.

PENHALONGA AND NOITGEDACHT

By SANDRA YEO

IN the Spring of 1968, my parents uprooted themselves for the second time in their lives and took themselves off to Rhodesia. This time I did not follow, but current involvements very easily led to an interest in their particular roosting place.

R. W. Yeo (Associated Companies) Ltd., in conjunction with a Charitable Trust, run a Technical Centre at Exeter, for the purpose of training jewellers in all aspects of the trade, which, with a magnificent gem museum and adjoining laboratory, is open for study to any interested outside persons. A trip to Africa could well produce some interesting film and material for this Centre, and so in January 1970 Mr. R. W. Yeo and myself set off for a nine week tour around Rhodesia and South Africa.

Arrangements had been made in advance with the Gem and Mineral Society of Rhodesia, and De Beers in South Africa, but the first three weeks were to be spent with my parents in Penhalonga, where we made an unexpected and quite delightful discovery.

The Penhalonga valley is in the Eastern highlands, above Umtali, which is the third largest town in Rhodesia, and about five miles from the Moçambique border. Rhodes himself first entered the country at a spot just above Penhalonga, which goes by the quaint but obvious name of "Divide". The mountain pass over the border is not accessible except on foot, and thus gives exclusive use to the rural Africans whose private interests are dissected by the arbitrary line of the border. The movement to and fro is very casual, and I am not even sure if it is all official. Penhalonga is a delightful spot with an equable climate, caused by the fact that although the whole of Rhodesia is well within the tropics, it lies between 2,000 feet and 6,000 feet above sea level, and Penhalonga itself at around 4,000 feet. However, its scenic beauty was not the attraction to Rhodes, but its gold. The Rezende mine was the first in the country and along with others in the valley enjoyed a boom time, until eventually lodes proved unprofitable and the town was left to decay. The shaft-head buildings still stand on the Rezende site. All around are the waste hills, but somehow—perhaps it is the sunshine

and/or the multi-coloration—gold waste-heaps look less depressing than piles of slag under a drizzly Derbyshire sky.

Recently, with the aid of modern scientific equipment, prospecting has again begun in earnest in the area, but so far no significant finds have been made. However, mining interests seem confident of the possibilities, and some of the miners' houses are now being bought up by Europeans and renovated, obviously in the hope of a resuscitation of prosperity. The Mutari Exploration Co. has flooded one shaft that they had re-opened, but they are continuing diamond-drilling around the hills, and look for a successful strike in the near future.

It was with a view to having a look at some old workings, that we set off one day down a dirt road in the north of the valley, off the main road. At the side of the track, not far along, we came upon a small crudely made board, declaring in hastily written red letters, "Ponderosa Syndicate, Private", with an arrow pointing along the way in which we were going. We passed more arrows and eventually arrived at half a fence with a larger notice, this time giving timely warning to trespassers. Nothing daunted, we decided to investigate, and threaded our way down a track through the Brobdignagian grasses. Quite suddenly, the growth gave way to a clearing, and a sight that seemed straight out of a story book. On our right was an untidy vegetable patch in front of an odd-shaped building made entirely of off-cuts of logs; in front, the path spread itself around a beaten-up Ford Popular, and the entrails of various other cars, and several other buildings, made of the same material as the first, which looked as though they might be living accommodation. A lean, grizzled old man, wearing boots, baggy khaki trousers held up with braces, bush shirt and broad brimmed hat, ambled out to meet us, and, far from being annoyed at us for trespassing, he seemed delighted to have some company. He introduced himself as Fred Green, one half of Messrs. Perhat & Green of the Ponderosa Syndicate.

Paul Perhat is a railwayman five days a week, and a miner at weekends. His father died a poor man after years of prospecting success and failure, and he suffers from the same disease as he calls it; it could more accurately be called an obsession. Fred Green is retired, and spends all his time on the site, supervising the African

labour and generally keeping house: one of the buildings was confirmed as a two-storey log cabin, with living quarters downstairs and Perhat's bedroom upstairs. Modern amenities such as a cooker and fridge are in evidence, though both are of suitable age to fit in with the general backwoods atmosphere. Green has his sleeping quarters in another building. Apart from visitors, they are alone; Perhat does have a family—somewhere.

All the machinery and buildings are of home construction, which explained the presence of the old cars outside. The claim stands on 150 acres of land, and here we saw prospecting at its most raw and fascinating.

Fresh water comes from the municipal supply, but the water for use in the machinery is pumped from a river 1,000 feet away. Perhat has erected a small dam and built a water wheel to run the pump which sends the water, with the ground rising 70 feet in the 1,000 feet, to a reservoir beside the house.

The main workings at present are open-cast, though they do have one shaft sunk, but up till now it has proved too expensive to work. I did climb down to have a look, and climb is the operative word. The sides of the entrance shaft are re-inforced with wooden slats, and foot-rests have been added to these, so that you climb down hand over hand. By the light of Perhat's helmet lamp, I was able to follow the seam of gold bearing rock as it wound through the short narrow galleries, which apparently do not need any re-inforcement, and which for the time being have been left to the bats and the frogs, of which there are many.

Above ground, four Africans do the digging, and the soil and rock is carted by hand to the Crusher, where it is smashed before going into the Mill. The Mill pounds it all to a powder, and the resulting amalgam washes slowly down to the James table. Some of this is collected in a bucket and is used to analyse the gold content of the rock they are treating. Perhat takes a sample in a coffee tin, and one of his men carefully pans this sample until only the heavier substances including the gold, are left. This is then worked around the edge of the pan, and the gold forms into a "tail" behind the other material. According to the length of this "tail", the amount of gold yield per ton of soil can be estimated; if an inch, then the yield will be 1 ounce per ton.

The James Table is a long low oblong table, with slats running diagonally across it. It is mechanically shaken at a steady pace, with the result that the heavier substances are pushed to the back, and eventually wash into a channel at the bottom of the table, while the waste washes off the side.

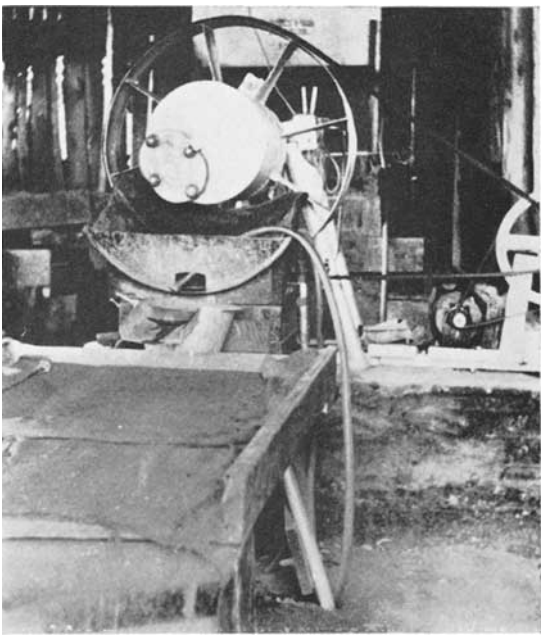

Amalgam drum.

The gold-bearing material is now put into an amalgam drum, which is a rotating cylinder with rods inside, that further pound the materials. It rotates at about 35 revolutions per minute, and this goes on for eight hours, after which time a small quantity of nitric acid and three pounds of mercury are added and the drum is rotated for a further four hours. The gold adheres to the mercury, and after the requisite time the drum is opened and the process of finally washing off the last waste begins. Perhat is allergic to mercury, and this is therefore the job of his senior boy, who could

be 16 or 60 and has been with Perhat long enough to have learnt everything from cooking to stripping down intricate machinery. The washing is carried out in a series of bowls (would you believe pudding basins?) with the aid of a hose, so that the lighter stuff washes down a sloping table into a collecting well, and the semi-liquid mercury and gold gob is left behind. This is kept in water to avoid evaporation of the mercury. The waste, expecially in the case of poor-yielding rock, will go through the amalgam drum again. Finally the mercury is distilled off the gold and kept for use again.

At the time we were there, and for some time prior, the yield was under 5 pennyweights per ton, which indicates a lot of hard work for little return. However, as Perhat says, it is a disease. He and Green and their Africans have little material needs; he is his own boss, and there is always the possibility of making a fortune. In the red of the evening, with a sundowner slipping coolly down the throat, and all around the mysterious, incessant African hum, it is easy to see the attractions of such a life, and it is refreshing to know that romance still exists in this high-speed world of ours.

Unlike Penhalonga, almost everyone has heard of Kimberley. Kimberley of the Big Hole belongs to the World, but there is more to the place than what is shown in the tourist blurbs.

De Beers had again laid excellent plans for us. We were to be taken down a mine, on to the treatment plant and of course to the Big Hole and adjoining museum, but the P.R. people were not sure if we would want to go out to the "diggings". In fact one female guide tried to put us off, which quite naturally decided us to go.

We took off in the car in a south-west direction out of town, and along a road which looked as if it went for a 1,000 miles. In the far distance there was a faint blue line of higher broken ground, but alongside the road was just flat dry scrub, with occasionally a building of sorts, indicating some human purpose to which the inhospitable earth had been put. At some point along this road, we turned off right into the scrub, and threaded and bounced our way along in what seemed to be a series of semi-circles. I have said the scrub was flat, and so it appears until you get amongst it, when it becomes a mass of fuzzy-growthed hillocks, which, though very small, always manage to have their summits just above eye-level.

Suddenly we lurched round a sandy mound and came upon a flat area which actually had two full-grown trees to give some welcome shade. There were also several corrugated iron buildings, one of them being quite obviously a supply store. Thus was our abrupt arrival at the Noitgedacht alluvial diggings. The store is run by an old coloured fellow and his African wife, and has small living quarters at the back. The storekeeper looked an eminently cheerful man, riding out to his own claim on his donkey and cart, and it was touching to see, amidst what can only be described as squalor, his tiny parlour-walls festooned with several formal Victorian style family portraits.

De Beers started this digging project in 1949, mainly to satisfy the individual prospectors, whose fathers and sometimes grandfathers had scratched a living from the ground around Kimberley, and who now found their rights eroded by the expanding uniquitous Anglo-American Corporation. Each claim is 45 feet by 45 feet, and no one person is allowed to have more than four claims running at the same time. Fifty cents is paid per claim and the leases are renewed each month. De Beers are the main buyers of the diamonds found, and they also take a small percentage on the sales. Every Friday the diggers come to the site office and register their finds and obtain a permit to sell. The office is run by a retired electrical engineer from the mines, and the building had once been intended for habitation. All that remains now is a very dirty-looking bathroom and an antediluvian kitchen.

Whilst we were in the office talking to the Manager, Mr. Humphreys, an old Afrikaaner ambled in with two stones he wanted weighed. He spoke little English, but Humphreys spoke Afrikaans, and so conversation was possible. The two stones together weighed 1·30 carats and were of poor quality. However the Afrikaaner intimated, and Humphreys confirmed, that he could expect about £10 a carat. This astounded us, and we were unable to obtain a satisfactory explanation for this apparent high price at ground level. However, it is pretty safe to surmise that these prices are to discourage any illegal sales. From the records, we noted that in the month of January 43 stones weighing 35 carats were registered, realizing R.1,178.

Humphreys took us out to visit one claim, which had been selected because the owner could speak English, apparently a rarity

among the diggers. This is one place where race classification is of no consequence, and a Bantu will work a claim alongside a European. Our site was run by a coloured named Toburn, and his four African labourers. Toburn is a little wiry fellow of indeterminate age with the unruffled air of a man of infinite patience, which he needs must be in his sort of occupation.

The ground, which has already been excavated in the past, is hacked and shovelled by the labourers, and then smashed by hand under a huge sledge hammer. The treatment plant consists of a rotary pan, similar in principle to the sophisticated series of density tanks used at De Beers, and a series of sieves. The pan has a diametrical arm which is rotated by hand through the contents at a slow steady pace. The excavated material is poured into this pan, which already contains the thick muddy water known as "puddle". The viscosity of this puddle is of paramount importance, and is something Toburn appears to have learnt by sheer experience.

Toburn's Gravity Tank.

The theory is that at a certain viscosity the puddle will support all but the heavier materials (including diamond) which sink to the bottom. When Toburn considers enough time has elapsed, he opens a small door in the side of the pan and allows some of the contents to fall into a bucket. The largest of the sieves is then pushed to the bottom of the bucket, gravitated, and brought to the top again. The contents are then upturned onto a table, and the diamonds, if there are any, being the heaviest material will appear on the top. This process is repeated right down through to the smallest sieve. Toburn works over the stones with a tiny spatula, and at an amazing speed, but it seems he doesn't miss anything. Amongst the smallest grit were some dark brown cubes, of varying sizes, but all of perfect shape. Toburn had no idea what they were, and just termed them "blockies". We took them to a geologist later at De Beers head office, and much to his chagrin, he could not identify them, though the discussion did conclude that they might be some form of pseudomorph. So in fact they proved to be: pseudomorphs of limonite in pyrite.

We did not bring Toburn any luck during the time we were with him, and, like the photographs on the storekeeper's wall, he is an anachronism that will soon be smothered under the march of progress. The Government is not issuing any more licences to individual diggers, and originally this Noitgedacht project had not been intended for a long duration. However, the men kept turning up enough stones to make it worthwhile, though by now this particular area must be pretty nearly worked out. In 1951, a man named Venter found the largest stone recorded here, a perfect octohedron weighing 511 carats, and, of the 483 diggers who have had claims since the scheme started, 391 have made finds. In 1966, Toburn found a stone of 21·75 carats, for which he received £200 a carat, so as he says with a grin, "I have to go on". There are now only 26 diggers left, but each one will no doubt go on searching for that elusive fortune until they finally become part of the ground they are now so busy excavating.

HEAT-TREATMENT OF PALE BLUE SAPPHIRE FROM MALAWI

By E. A. JOBBINS

Institute of Geological Sciences, London

A SERIES of pale greenish-blue circular, step-cut, sapphires (ranging from 0·44 to 0·69 carats in weight) from Chimwadzulu Hill, Malawi, was submitted for examination to the Institute of Geological Sciences by Messrs. Gunson (Exports) Ltd.

The heat treatment of gem material is widely practised, but detailed information on the temperature and duration of heating is not commonly released. Since suitable stones were available, and the owners were agreeable, it was decided to carry out a series of carefully controlled heating experiments in air. In order to evaluate possible colour changes, the stones were divided into eight closely matched colour groups of three stones each; one stone of each group being retained as a standard and the other two heated, the first for one hour at the set temperature and the second for five hours. Stepwise heating was carried out over the range of 500°–1200°C at 100° intervals the stone being placed in an unglazed porcelain boat in an electric muffle furnace. The time to reach the set temperature varied from about 40 minutes to reach 500°C to about 2 hours to 1200°C. The stones were allowed to cool overnight in the furnace after heating, and removed about 09.15 hours next morning when the next run started, then usually from about 100°C rather than room temperature.

General visual examination of the whole series showed that heating over the 500° to 700°C range or for one hour at 800°C had no obvious effect on the stones. Heating for five hours at 800°C caused the general blue colour to become paler. In the higher heating range 900°–1200°C all residual blue colour was eliminated and the stones changed to a very pale green colour.

To evaluate the colour changes in more detail the pleochroism schemes for untreated and heated stones were examined. The scheme for the unheated stones is very distinct—from a pale ("commercial") aquamarine-blue for the ordinary ray (ω) to a very pale green for the extraordinary ray (ε). No change in the pleochroism was apparent in the stone heated for one hour at 800°C (or in stones heated at lower temperatures) but heating at 800°C for five hours caused the colour of the ordinary ray to become paler

blue, although there was no discernible change in the colour of the extraordinary ray. Heating to 900°C and above virtually eliminates the blue in the ordinary ray which then appears as a very pale slightly greyish-green, and only a very slight colour change is discernible between the ordinary ray and extraordinary ray (which appears as a very pale, slightly yellowish green). There appears to be little, if any, change in colour of the extraordinary ray between heated and unheated material.

The absorption spectrum of unheated stones exhibits a well-defined narrow band at 4500Å in the blue and a faint but perceptible line at 4600Å with some general absorption between these two bands; a very faint line at 4710Å was also distinguished; the spectrum was seen more clearly in the direction of the darker colour (ordinary ray). It was not possible to detect any change in this spectrum in the heated stones.

The refractive indices of the series were constant at 1·761 (ε) and 1·769 (ω) and no change was recorded on heating. There was no change in weight as a result of the heating.

The heating of pale greenish-blue sapphires from Malawi does not increase the blue colour, which is in contrast to the heat-treatment of aquamarine where the blue colour is often enhanced.

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GEM AND DECORATIVE MINERALS AT HASLEMERE MUSEUM

By EDGAR J. BURBAGE

WHAT does one expect of a Museum? Ideally, that it shall display exhibits of interest and beauty, and also that it shall advance the study of a subject by assembling appropriate material to this end. Few museums other than the national collections at South Kensington and elsewhere manage to attain both objectives, and in far too many provincial museums the dusty exhibits are hopelessly random in character, and are completely useless for study purposes. It is, therefore, a welcome exception to find at Haslemere in Surrey, a museum which, although

having much to interest the casual visitor, is also geared to the needs of the more serious enquirer.

The Haslemere Educational Museum is also exceptional in being a self-supporting unendowed private venture. It is arguable that the "Educational" qualification in its title might well be jettisoned, carrying as it does undertones of earnest endeavour alien to many potential visitors, but it results from the circumstances of the foundation of the Museum. An eminent Victorian surgeon, Sir Jonathan Hutchinson, a Quaker and an enthusiast for education, started a small museum in his home at Inval, outside Haslemere, in 1888, and used his collections to illustrate talks which he gave to local people. The growth of the collections and increasing public interest resulted in the re-siting of the Museum at a more convenient position in the town, and, later, in 1926, its removal to its present central position in the High Street. Essentially, the ideals of the founder have been retained but some degree of specialization has developed over the intervening years, and today the Museum is concerned primarily with the study of natural history and biology, the excellent collections of local interest, "Folk" craftsmanship, "bygones", and so forth, being to some extent peripheral to this main theme. To this end, the Museum is splendidly equipped, with its well-arranged gallery exhibits, lecture hall, and recently-opened Arthur Jewell Laboratory, and extensive grounds. These facilities are used by colleges, schools, and societies up and down the country, including the University of London and its constituent colleges, the Mycological Society, The Quekett Club, teachers' training colleges, and societies interested in entomology, bryology, zoology, botany, ecology, beekeeping, and so forth.

In the field of geology, the founder had very definite ideas, and his schematic arrangement of the appropriate gallery into divisions corresponding to epochs, with characteristic fossils and relevant illustrations is still maintained. The Museum had for many years as its geological mentor the famous geologist Sir Archibald Geikie, who was a member of the Governing Body during and after the First World War, and whose work is still apparent in the collections. (Some of his notebooks, sketches, and field-work impedimenta are displayed there).

The geology gallery includes good exhibits of minerals, both economic and ornamental. Of special interest to gemmologists

will be the handsome mineral groups presented by Dr. F. Percival, including quartz and amethyst. Dr. Percival was responsible in 1951 for the assemblage of a special exhibition of gem and ornamental minerals, which aroused much interest, and in subsequent years it has been possible to arrange a small, but representative, collection of gemstones. Although the display is not large, it fulfils its function in providing an "eye-catcher" for the casual visitor, and a focus of interest for the serious enquirer.

Having regard to the fact that quartz is the one mineral abundantly present in Surrey in the form of sand in the Lower Greensand deposits, and as chalcedony in the Hythe Beds rocks and elsewhere, it was considered worthwhile to devote a showcase to it, variously illustrating its applications in (for instance) glass-making at Redhill, the production of figurines, faceted gemstones, crystal spheres for decoration and clairvoyance, oscillators for electronics, and so on. In another showcase, a revolving table permits the varying reactions of a set of radioactive minerals to be assessed by a geiger counter, and there is also a section devoted to the display of fluorescence of minerals in ultra-violet light.

Occasional special exhibitions of gemmological interest have been arranged from time to time, as for instance in 1956, when on the theme of colour in gemstones a display of gemstones illustrating dichroism, colour-temperature changes, schiller, heat-treatment, etc. was assembled, augmented by a case of irradiated gemstones, together with their untreated counterparts. The latter was shown by courtesy of the Atomic Energy Authority at Harwell, through the good offices of Mr. Thorold Jones, well-known to many past gemmology students at Chelsea Polytechnic and a good friend to the Museum in many ways. On a later occasion, Harwell contributed a further display based on an extra-mural enquiry into the curious "thunderbolt" concretions of sulphide of iron occurring in the chalk, which in years past one would describe as "marcasite" before later research had undermined such confident dogmatism.

In addition to the public displays, there are considerable reserve collections of minerals and rock-sections available for study in the Arthur Jewell Laboratory, and there is a small but useful selection of books on gemstones and minerals in the Library. In an unostentatious fashion, the Haslemere Museum is doing an excellent job in introducing gemstones and minerals to the layman.

INCLUSIONS IN NATURAL TOPAZ CRYSTALS

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Abstract

Inclusions, like channels, isolated oriented square shaped, tree-like, etc., in natural topaz crystals are illustrated and described. It is shown that some of them are trapped at dislocation sites. Correlation of etch-pits on (001) cleavages of topaz crystals with some of the inclusions underneath is analysed. Observations on matched cleavages and on two opposite surfaces of thin flakes are briefly described.

Introduction

Solid, liquid or gaseous material is almost always found included in both natural and synthetic crystals. Study of such inclusions often becomes a tool to derive valuable information of the material (substance) from which crystals grow. Such inclusions vary in size and are normally found in a haphazard manner in the crystal. However, crystallographically strictly oriented inclusions are not uncommon. In some rare cases their walls are parallel to a growing face. A variety of parameters, like variation in the supersaturation of mother-liquor, composition of solution, minor fluctuations in temperature, size of the crystal, etc., govern the formation of inclusions in crystals grown from solutions. Consequently different types of inclusions observed in different crystals may be listed as follows:

1. Relatively large layers of solution whose lateral size substantially exceeds the thickness.
2. Thin, continuous channels or chains of separate inclusions.
3. Distinct small isolated inclusions.

Buckley (1952), Amelinckx (1958), Chernov and Budurov (1964), Joshi and Vagh (1965), Brooks *et al.* (1968), Belyustin and Fridman (1968), and Gross (1970) have observed inclusions in different crystals.

According to Gross (loc. cit.) liquid inclusions in RDX crystals involve the trapping of solvent either interstitially followed

by its migration to dislocations or even directly along dislocation lines.

Natural topaz crystals often contain many microscopic liquid inclusions and this report deals with the study made on them.

Experimental

Fairly good transparent crystals of natural topaz were parted along (001) cleavage planes by giving a gentle blow to the flat head of the chisel with a small hammer, the sharp edge of the chisel being held in a curve almost parallel to the basal plane. By a similar operation thin flakes of topaz crystals were also obtained. Such cleaved surfaces and such thin flakes were then etched in KOH at 440°C for 10 seconds. The cleaved crystal to be etched was held by a nickel hook and with the help of a fork, the hook with the crystal was dropped into the etchant in a nickel crucible placed in the furnace maintained at a constant desired temperature. At the end of etching time the crystal was removed from the etchant and subsequently cleaned with concentrated nitric acid, hydrogen peroxide and distilled water. They were then examined under an optical microscope.

In order to remove the etch-figures produced on a cleaved surface, the etched crystal was dipped for 15 seconds into sodium peroxide melt in a crucible in a furnace maintained at a constant temperature of 510°C.

Observations and Discussion

A variety of inclusions were observed in natural topaz crystals in the present investigation. Such inclusions were observed through unsilvered basal cleavages by slightly racking down the objective of the microscope focused on the cleaved surface under examination. In most of the natural topaz crystals thin as well as thick channels of liquid inclusions were commonly observed. One such case is illustrated in a photomicrograph in Fig. 1. Fluctuations in the conditions of growth may lead to the aggregation of thin channels of liquid inclusions forming thereby bigger channels of imprisoned mother liquor. Some of the cleaved match-surfaces revealed slightly below them presence of small liquid inclusions aligned along curved lines which have exact matching on the two surfaces as illustrated in Figs. 2a and 2b. On etching these matched cleavages etch-patterns were

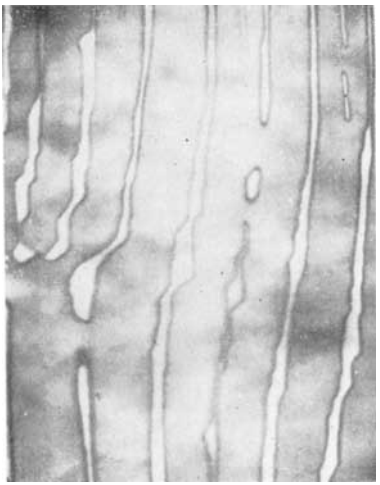

FIG. 1. Channels of liquid inclusions. 350 ×.

obtained having perfect matching on the two cleaved match surfaces as is shown in Figs. 3a and 3b. These pits were observed on the matched surfaces themselves. On racking down the objective of the microscope below the surfaces the same inclusions as shown in Figs. 2a and 2b are observed. On further etching these pits on the matched surfaces grew bigger in size, as was to be expected. By slightly racking the microscope objective up and down it was ascertained that the pits are on the surface and the inclusions are in the body of the crystal right below the pits. All pits are not of the same size on the surface, though the corresponding pits on the two matched halves are identical in regard to their size, shape and position. The exact correspondence of pits on the two matched halves, Figs. 3a and 3b indicates presence of dislocations along these boundaries. From the correspondence between rows of pits and the rows of inclusions as seen from Figs. 3a and 2a or Figs. 3b and 2b, we are inclined to suggest that some, if not all, inclusions occur at dislocation sites. A number of thin flakes, each about 500 microns thick, were obtained, whose both surfaces were basal cleavages. Observations on one such flake showed the presence of inclusions. These inclusions could be seen from either side of the flake. Figure 4a illustrates inclusions in one such flake when seen through one unsilvered surface of the

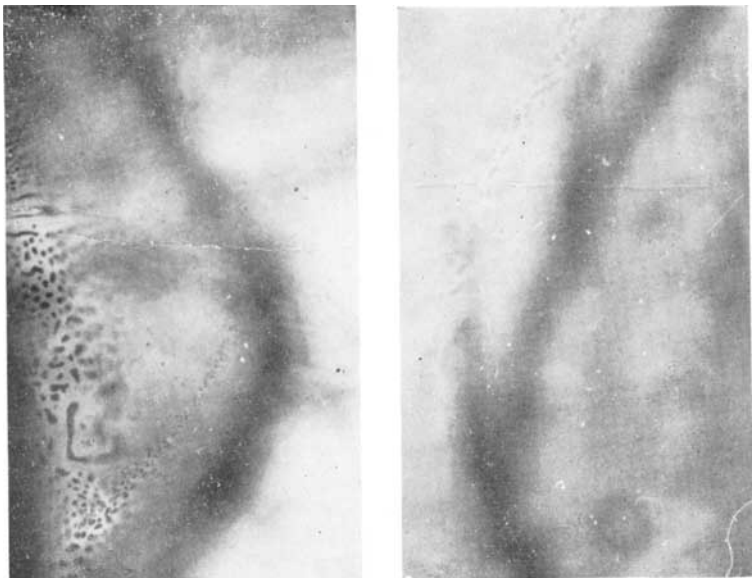

FIGS. 2a and 2b. Small inclusions aligned along curved lines. 350 ×.

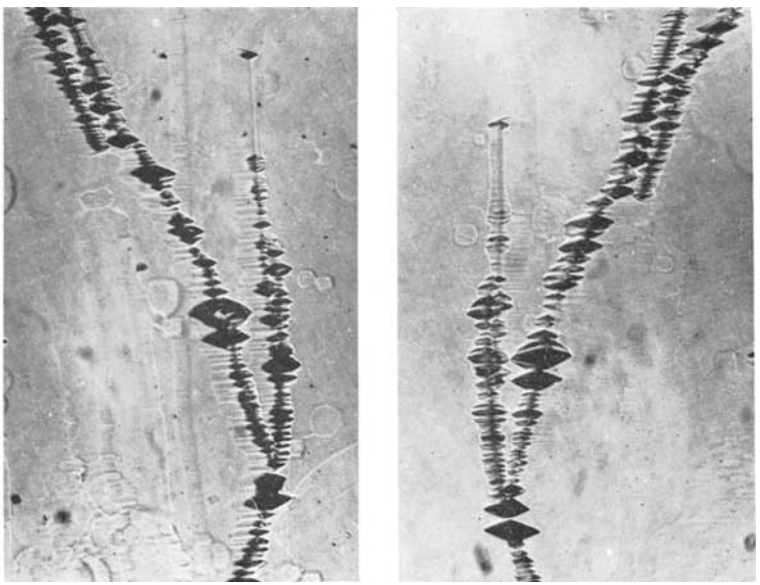

FIGS. 3a and 3b. Etch patterns on regions of Figs. 2a and 2b. 350 ×.

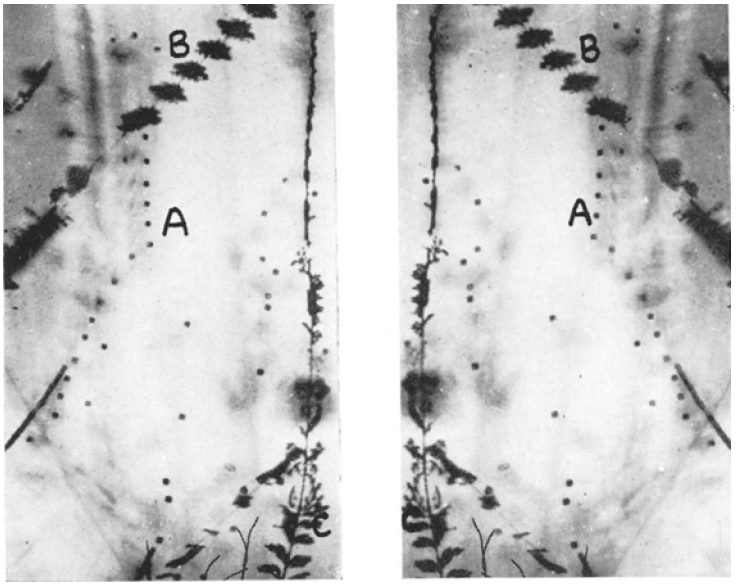

FIGS. 4a and 4b. Inclusions observed through opposite surfaces of a thin flake. 350 ×.

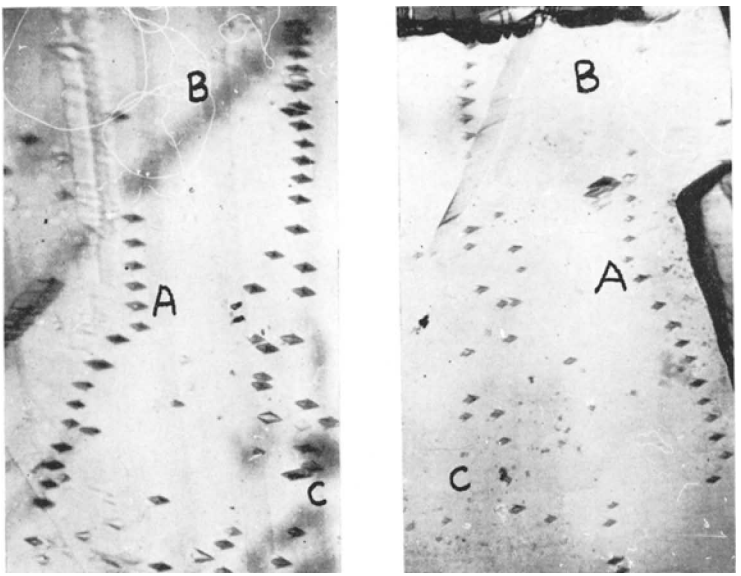

FIGS. 5a and 5b. Etch patterns on the opposite surfaces of the thin flake. 350 ×.

flake, while Fig. 4b shows the same inclusions when seen through the other unsilvered surface of the flake. It is interesting to note three distinct types of inclusions in this case. In the region marked A in Fig. 4a one sees tiny square inclusions, all of almost equal size. They are strictly oriented, are almost equally spaced and are aligned along a curved line. In region B in the same figure there is a row of bead-shaped inclusions. In region C in the right bottom corner of Fig. 4a inclusions having a tree-like structure are observed. All these are seen a little below the surface of the flake facing the objective of the microscope. This flake was then etched as mentioned above. The resulting etch-patterns, as observed through the two surfaces of the flake, are illustrated in Figs. 5a and 5b. Pits in regions A in Fig 5a strictly correspond to the above cited square inclusions illustrated in regions A in the Fig. 4a. It may be noted that there is exact correspondence between pits in regions A on the opposite faces of the flake as seen in Figs. 5a and 5b. Such a correspondence is indicative of formation of these pits at dislocation lines threading through the flake and cut by the opposite surfaces of the flake. Further, the correspondence between the pits in region A in Fig. 5a with the square tiny inclusions in region A of Fig. 4a is indicative of trapping of these inclusions at dislocation sites.

The flake was then chemically polished in sodium peroxide, as explained above, until all the pits on both its surfaces were completely washed off. It was then re-examined. All the three types of inclusions in the regions A, B and C of Fig. 4a and of Fig. 4b were observed through its two surfaces as before. The flake was then etched again as stated earlier, and the etch-patterns on its two opposite surfaces were examined. The pits obtained were found to be identical to those in regions A in Figs. 5a and 5b and also correspond to square tiny inclusions in region A in Figs. 4a and 4b. Such a correspondence indicates nucleation of etch-pits at dislocation sites, and the latter suggests trapping of these inclusions at dislocation sites.

The flake was again polished as mentioned earlier, and then etched for 40 seconds more. The etch-patterns thus obtained on the opposite faces of the flake are illustrated in Figs. 6a and 6b respectively. There is perfect correspondence of pits in region A of Fig. 6a with those in regions A of Fig. 5a and with square inclusions in region A of Fig. 4a. Of course, these pits are bigger

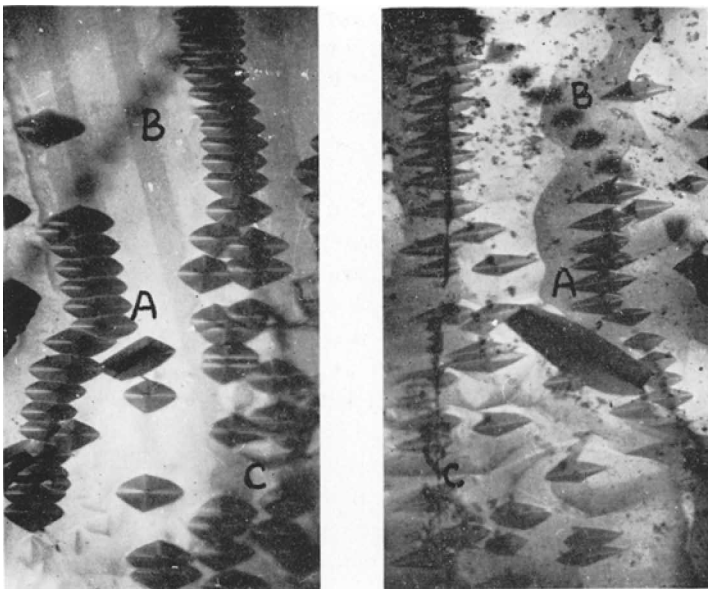

FIGS. 6a and 6b. Etch patterns on regions of Figs. 5a and 5b obtained after polishing and re-etching for 40 seconds. 350 ×.

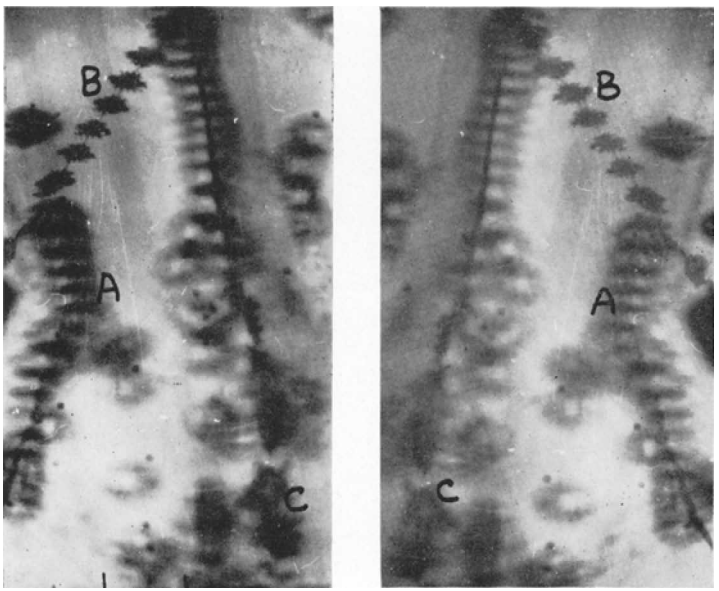

FIGS. 7a and 7b. Same inclusions observed below regions of Figs. 6a and 6b. 350 ×.

in size and are also deeper. Correspondence is also observed in Figs. 6a and 6b, particularly in region A. It is very interesting to note square tiny dots at the centre of pits in regions A of Figs. 6a and 6b, which are the square inclusions below the etched surface. On slightly racking down the microscope objective these inclusions are clearly visible as shown in Figs. 7a and 7b. In these Figs. inclusions in regions B are very much more marked than in other figures reported here. These observations endorse our suggestion that at least the square inclusions are trapped at dislocation sites.

From the observations reported here, and the evidences given thereof, one can safely conclude that since for each pit there is a corresponding inclusion although each inclusion is not necessarily associated with a pit, at least some, if not all, inclusions are certainly trapped at or associated with dislocations.

All etch-pits reported here are not all of the same size. In a particular case the inequality in the size of pits may be attributed to the different strain energies around dislocations or alternatively to the inequality in the size of inclusions if the latter are trapped at dislocation sites.

Conclusion

From the above given observation and discussion it may be concluded as follows:

1. Liquid inclusions are very common in natural topaz crystals.
2. Different forms of such inclusions are present in topaz crystals, some of which are strictly crystallographically oriented.
3. Some inclusions are trapped at dislocation sites.
4. Etching technique is useful for proving the possibility of trapping of inclusions at dislocation sites.

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7. Joshi, M. S. and Vagh, A. S., 1965, *Acta Cryst.*, 19, 627.

Gemmological Abstracts

ANDERSON (B. W.). *Some problems and a few solutions in the field of gem testing with the spectroscope.* Gems & Gemology, 1970/71. XIII, 8, 238-244.

A resume of the address given by the Author to the 13th Gemmological Conference. The absorption spectra of chromium coloured minerals, the spectra due to cobalt and due to rare-earths are discussed. The difference between the absorption spectra of the chrome chalcedony and green stained chalcedony is mentioned, the natural chrome material showing a single band at 6790Å while the stained chalcedony shows three blurred bands at 6340Å, 6650Å and a strong band beyond 7000Å. True chrysoprase shows an ill-defined line in the orange which is presumed to be due to nickel. Cobalt spectra betoken a stone which is not natural. The reason why cobalt produces a blue colour in these stones and a pink colour in natural stones is explained. Of the rare-earth spectra the didymium spectra are mainly described and those seen in the synthetic "garnets" and in the scheelites are mentioned—in the latter case, it being hoped that the examination of the absorption spectra would enable distinction between the natural and the synthetic material to be made. The hoped for success was not completely achieved.

7 illustrations R.W.

BANK (H.). *Transparenter weiss-farbloser Grossular aus Tansania.* Transparent white to colourless grossular from Tanzania. Zeitschr. d. deutsch. Gesellschaft, 1971, 20, 1, 22-25.

The white to colourless transparent grossular from Tanzania was first thought to be a synthetic colourless spinel, but on examination was found to be a grossular, although this particular type had not been found in that country before. Some of its characteristics are described. The author fears that it might offer yet another diamond imitation, but by its low R.I. can easily be recognised as non-diamond material.

E.S.

CROWNINGSHIELD (R.). *A rare alexandrite garnet from Tanzania.* Gems & Gemology, 1970, XIII, 6, 174-177.

The report of an examination of a dark dull rolled pebble, weighing approximately 3½ carats, which appeared green in daylight and red in artificial light. X-ray diffraction tests proved the stone to be a garnet and a chemical analysis showed that apart from the usual constituents of garnet there was 0·54% of chromium, 0·324% of vanadium and 0·1418% of titanium present. It was considered that the vanadium content was the cause of the colour change. The stone, which was cut into a 1·70 carat oval stone was found to have a density of 3·88, a refractive index of 1·765 and a hardness of 7 to 7½. 5 illustrations R.W.

CROWNINGSHIELD (R.). *Developments & highlights at G.I.A.'s Lab. in New York.* Gems & Gemology, 1970/71, XIII, 6, 7 & 8, 192-201, 221-229, 249-254.

Examination has been made of a new diamond simulant to which the trade name YTTRALOX has been applied. The material is an optical ceramic consisting of a specially sintered polycrystalline product containing 90% yttrium oxide and 10% thorium oxide. A cut stone from this material gave a refractive index of 1·92, a dispersion of 0·039, a density of 5·30 and a hardness of 6 to 6½. White star-quartz, a large faceted Trapiche emerald, the inclusions in a green grossular garnet, the spectra of Tanzanian spessarite and of monazite, transparent lazulite and green andalusite are reported upon. There is a discussion of the use of laser beams to reduce dark inclusions in diamonds. The fluorescence of certain diamonds and the use of ultra-violet light in separating green zircons from a parcel of demantoid garnets are mentioned. Difficulties of amber identification, a zincian staurolite and transparent colourless grossularite are other items noted. There are discussions on the staining of ironstone matrix of opal and on the so-called "synthetic jade", "meta jade" or "Iimori stone" which emanates from Japan. It is suggested that the material is a glass with refractive index of 1·53 to 1·55 and density of 2·65 and may show anomalous double refraction due to devitrification. One type was so devitrified as to produce radiating fibres so that the stone when cabochon cut showed a cat's-eye effect. Such stones have been sold under the misnomer "Synthetic cat's-eyes". 40 illustrations R.W.

CROWNINGSHIELD (R.). *World's largest phenakite.* Gems & Gemology 1970/71, XIII, 6, 178-181.

A report on what may be the largest phenakite known. Originally a partially polished rolled pebble, the specimen was cut into a 569 carat oval stone and three others, of which one weighed 36 carats and another 12 carats. The original rough stone was seen to be filled with thin reflective needles, which it was anticipated would make the cut stones appear "sleepy". Much of this was overcome in the cutting by making the table facet at right angles to the optic axis so to a great extent getting rid of the strong double refraction (0·016) causing doubling of the needles. The stone is probably destined for the Smithsonian Museum.
5 illustrations R.W.

ELBE (M.). *Der geschliffene Diamant*—The cut diamond. Zeitschr. d. deutsch. Gemmologischen Gesellschaft, 1971, 20, 2, pp. 57-90.

The author of this article, which is illustrated with many diagrams and some photographs, proposes a theory that, if a diamond were to be cut asymetrically, the "fire" would increase dramatically.

The conventional brillant-cut is based on an even number of symmetrical facets placed in such a fashion that the main facets of the crown and pavillion match exactly. The author has developed three new cuts: a new brilliant, a prismant and a colorant. He suggests that the "fire" is improved by 247% in the case of the new brilliant-cut and by 426% in the case of the other two cuts, for the latter two cause the cutting loss to be decreased by as much as 20%.

The physical and optical properties of diamond are discussed in detail and so are the relevant physiological processes of the human sight and the sensitivity of the eye. Based on these data, the author developed a cut with various objectives in view: to increase the number of reflections, to make the high-lights of the table appear as a single white reflection, to make the light rays which enter the stone appear as coloured reflections by making them enter at an angle of 4°–7°, to improve the "purity" of the spectrum by a perfect polish of the facets and by choosing the entering light rays in such a way that only a small number of

facets are of utmost importance, and also to keep the loss in cutting to a minimum. Not all these objectives were reached.

In the new brilliant-cut the number of reflections has been doubled and the resulting spectrum is much wider: the conventional cut has 57 facets with 8 main facets yielding 100 reflection of 570 light units, the new cut has 78 facets with 11 main facets yielding 182 reflection of 1,063 light units. The exact angles to be used are given.

The prismant is a completely new type of cut, especially suitable for cleaved triangular rough stones. The advantage of this cut, apart from the "fire" and the small cutting loss, is the ratio of the height of the prismant to its diameter, which is only 7%.

The colorant is a completely transparent stone which can be viewed from any side (the cut stone is roughly spherical). The produced spectrum is very "pure" even in dull light. The facets in this cut can be even- or odd-numbered. A diagram illustrates a colorant with 9-cornered facets. A table comparing the "fire" and the light loss in cutting of a brilliant style and a colorant seems impressive. Bibliography.

E.S.

EPPLER (W. F.). *Synthetischer Rubin, nach dem Hydrothermal-Verfahren und aus der Schmelze hergestellt.* Synthetic ruby produced by the hydro-thermal method and grown from a melt. Zeitsch. d. deutsch. Gemmol. Gesellschaft, 1971, 20, 1, 1-5, 5 photomicrographs.

The author describes the history and development of the synthesis of the ruby. He first describes the Verneuil process and then the improved hydro-thermal method by Ballman and others in 1957, when they used a sodium carbonate solution, aluminium oxide and a ruby seed. In 1959 Chatham publicised his synthesis. The next synthesis was by E. A. D. White, who used lead fluorite as a melt. The firm "Ardon Associates" also produced rubies from a melt, and lastly the author describes synthetic rubies marketed by a US firm called "Designer Jewels Ltd." in Houston, Texas, under the name of "Rubies grown by Kashan"—not mentioning explicitly that these stones are synthetics. The colour of these stones reminds one a little of almandine. Various typical characteristics of the various synthetic products are mentioned.

E.S.

LIDDICOAT (R. T.). *The Russian diamond industry.* Gems & Gemology, 1970/71, XIII, 8, 259-265.

A brief history of the recovery of diamond in Siberia since the end of the war. Against some 25,000 persons employed in the United States of America on geological investigation, it is said that the Russian geological strength is nearer 500,000 persons, but numbers are not considered to be the answer to the phenomenal results obtained with diamond finds and other geological surveys, but as much to the fact that the Russian geologist is very well trained and capable. A number of "pipes" have been discovered as well as alluvial deposits, the latter being said to supply fine colour gem material. In 1969 six recovery plants were in operation. Yields per cubic metre of rock mined are not revealed, and the commercial operation differs greatly from that in the free world; costs may to a great extent be disregarded. Marketing of some of the rough is still through the Diamond Trading Company. The Russiams cut much of their gem quality stones. It is reported that the melee sizes are very well cut but the larger sizes have not the make of Western standards. Some of their cut stones are marketed through certain Western importers. The latest claim is that Russia is the second largest producer, by weight, of diamonds in the world

7 illustrations R.W.

LIDDICOAT (R. T.). *Developments & highlights at G.I.A.'s Lab. in Los Angeles.* Gems & Gemology, 1970/71, XIII, 6 & 7, 182-191, 230-235.

Interesting items recorded during the work in this laboratory include some pyrite inclusions in fluorite looking very like table-cut stones and horn carvings which had a refractive index of 1·55 and a density of 1·31. The carvings were stained but gave off an odour of burnt hair when touched with a hot needle and they are said to have shown slight effervescence when using dilute hydrochloric acid. Other items examined were a bi-coloured diamond, a chrysoberyl cat's-eye with high properties, another type of synthetic emerald, a lapis-lazuli *pietre dura* lavalliere, a spessartite garnet with unusual inclusions and iron carbonate (siderite) nodules. A brownish-pink faceted stone with refractive indices of 1·640–1·668, biaxial negative, and a density near 3·06 was

identified as the manganese-aluminium phosphate orthorhombic mineral known as eosphorite. Sinhalite, Mexican treated-opals and chrome fluorite are other items mentioned. There is more information on Linde hydrothermal and Chatham flux-melt rubies.

24 illustrations R.W.

MORTLEY (H. A.). *Measuring wavelengths without a built-in scale.* The Australian Gemmologist, 1971 11, 1, 3-4 & 27.

It is suggested that the wavelengths of the absorption lines seen in a gemstone by the aid of a simple spectroscope not fitted with a wavelength scale can be measured by superimposing a spectrum having lines of known wavelength over the spectrum of the stone under test. A number of media producing suitable "wavelength scales" are suggested, such as the Fraunhofer lines, the lines from a fluorescent lighting tube, different gelatine filters, a dilute solution of potassium dichromate and a synthetic ruby. Methods of using these superimposed spectra are explained.

R.W.

NASSAU (K.). *Synthetic garnets.* Lapidary Journal, 1971, XXV, I, 100-112.

Pre-eminent in the world of crystal growth, Dr. Nassau deals with the relationship of the structure of the synthetic or rare-earth garnets with the structure of the natural garnets. The question of the nomenclature is discussed and reasons given for the use of the name *garnet* for the rare-earth synthetically produced stones. The rare-earth garnets are generally grown by the Czochralski "pulling" technique from a melt at about 1,980°C in an iridium crucible with a high-powered radio-frequency generator. Boules 1″ or more in diameter and many inches in length are grown at 2–6 mm per hour. Small well formed crystals are grown by the flux growth method; the solvent (flux) may contain PbO, PbF_2 and B_2O_3. The growth is at a lower temperature, about 1,300°C cooling to 950°C over a three week period. The uses made of these rare-earth garnets fall into three groups. When "doped" with impurities, such as neodymium, holmium, erbium, thulium or ytterbium the stones show fluorescence and can then be used for crystal lasers. The second group uses the magnetic properties of iron containing

rare-earth garnets and an example given is that a tiny sphere machined from a flux-grown yttrium iron garnet was an essential part of the radio-amplifier in the TELSTAR satelite. The third use is in the gemstone possibilities. The colourless material is said to provide a convincing diamond simulant and cut stones are marketed under various trade names. The hardness is 8½, the refractive index 1·833 and the dispersion is 0·028. Inclusions are faint curved growth rings in the "pulled" material, and straight growth lines and variable amounts of flux inclusions in flux-grown material. Coloured material can be produced by "doping" with various trace elements. A purple colour is produced by neodymium, a green by chromium, a yellow by titanium and pink to red by manganese, and blue, a colour never seen in natural garnets, by silicon and cobalt.

8 illustrations (5 in colour) R.W.

NASSAU (K.) and (J.). *Dr. A. V. L. Verneuil and the synthesis of ruby and sapphire.* Lapid. Journ., 1971, Jan., Feb. and Mar., 1971, 24, 10, 1284, 1442, 1524.

A detailed investigation into the life and work of Dr. A. V. L. Verneuil. The authors' account is based only on reliable primary data which they have been able to verify themselves. Consequently their biographical contribution is extremely valuable.

S.P.

OTTEMANN (J.), BERDESINSKI (W.), BANK (H.). *Die Elektronen-Mikrosonde und ihre Anwendung in der Gemmologie.* The micro-electro-scanner and its use in gemmology. Zeitsch. d. deutsch. Gemmol. Gesellschaft, 1971, 20, 1, 6-13.

The micro-electro-scanner is one of the most sensitive intruments for the chemical analysis of small objects and therefore particularly useful for gemmology. The construction of this instrument and its working methods are described. It can be used to determine the content of a chemical element and its percentage, i.e. it was shown that an olivine from Norway consisted of 90% forsterite and 10% fayalite. The instrument can also be used to find qualitatively the chemical composition of minimal inclusions. Lastly, it can be used for the quantitative determination of a mineral; this is illustrated by the examination of a diopside.

E.S.

POIROT (J-P.). *Application de la radiographie en bijouterie joaillerie.* Dépôt légal Kodak-Pathé, 1970, 4th quarter, No. 152, 1-7 (in French).

A short well-illustrated article on the use of x-rays in the Paris laboratory of the Paris Chamber of Commerce. The article deals solely with pearl testing. The text is short but concise and much information is given by the captions to the x-ray pictures and the line drawings accompaning them. The pictures are "negative" prints showing the structures as would be seen by an operator viewing the negative as is normally done. The x-ray machine used operates at 50–90 kV according to the size of the pearl and a three minute exposure is given using Kodak film Type M.

12 illustrations R.W.

ANON. *The facts about diamond imitations.* Gems & Gemology, 1970/71, XIII, 8, 245-248.

A general survey of the diamond simulants encountered since World War II. A list of the trade names applied to these man-made stones is given and there is a table of their constants.

R.W.

BOOK REVIEWS

ANDERSON (B. W.). *Gem Testing.* Butterworths, London, 1971, 8th edition. 384 pages, 5 coloured plates, 127 illustrations. £7.

The seventh edition of this important book came out during 1964 and was then considerably revised. That a new edition should be called for after only seven years, or rather five to six years as the seventh edition had been "out of print" for some time, is a sound indication of the worth of the book to the jeweller and student.

The new edition follows the same general lines as the earlier editions, but one great improvement is the bringing of the chapter

on "fluorescence as an aid to identification" to a position in the book where it is more in keeping, that is the actual testing methods, instead of at the end of the book which implied that this important method was put in as an afterthought. New sections are on the "direct measurement" method of refractive index measurement, and on the method of minimum deviation. Both of these are clearly written up, but the method of minimum deviation is placed in the chapter on "Double refraction and dispersion" and not in the chapter dealing with refractive index measurement. It is quite logical, for the method is the only exact method for the measurement of dispersion, but a student might not look for it there and the index is no help as neither "Minimum deviation method" nor "Table spectrometer" is in the index.

The timely comment is made that observation of the double refraction by the doubling of the back facets breaks down when the observation is made in a direction at right angles to the optic axis in uniaxial stones as the rays are then directly in line, either before or behind one another and hence cannot be seen. This is the first time that the reviewer has seen this effect mentioned in a text book; however, is not the same effect valid with biaxial stones? According to Professor R. M. Denning (*Gems and Gemology* XI, 10, 299-301) this effect also occurs with biaxial stones and he cites topaz as an example.

The chapter on "Synthetic stones" has been brought up to date and modern problems of identification are discussed. The newer synthetics are mentioned, but the existence of synthetic colourless scheelite seems to have been omitted. There is a welcome insertion detailing the various methods now used to grow crystals. A fuller description is given of the fluorescence of diamond, a subject on which the author has carried out much research. The final chapter on dispersion makes reference to graphs which shows the curves to become "infinitely steep when approaching the wavelength at which a *fundamental absorption edge* for the material in question begins" (reviewer's italics). Would it not be as well in future editions to explain—say in the glossary—what is meant by a fundamental absorption edge? It seems to the reviewer that the definitions for *iridescence* and *opalescence* are to some extent contradictory and could with advantage be clarified. There is a change to the seven crystal systems, in keeping with the Gemmological Association's teaching syllabus. With all alterations of

this nature it is always difficult not to overlook a correction, and such an oversight is apparent in the entry for benitoite in the alphabetical summary. It should read "trigonal", not "hexagonal". There is a good index.

Gem Testing is a volume no gemmologist or jeweller can afford to be without. It is written by an expert who has the student and layman in mind and writes accordingly. The vast majority of the errors in the seventh edition have been corrected and the book is to-day the most up-to-date volume on gemmology.

The book is well bound and is finished in a hard-back black leatherette covered case. The title is in gold and on the spine only and not on the face of the book. By using a smaller type face the new publishers, for the publishers of the 7th edition have now merged with the firm of Butterworths who have produced "Gem Testing" under their own name, have produced a volume only seven pages larger than the earlier edition. A welcome change is the dispensing with any advertising pages, which never do enhance a book. A choice of thinner paper has produced a slimmer volume which weighs 1 lb. 8 oz. as against 2 lbs. 1 oz. for the 7th edition. While accepting that there are four more illustrations, four more colour plates and no advertising, that the book needed to be completely reset, and that the cost of printing has advanced enormously, a price increase of 125% seems rather steep.

R.W.

BECK (R. J.), REED (A. H.) and REED (A. W.). *New Zealand Jade: the story of greenstone.* Wellington, 1970, pp. 106. £1·90.

The apparent inconsistency between title and subtitle is explained by the author in the first (unnumbered) chapter, in which he concludes that greenstone is nephrite but that New Zealand usage often employs the term for bowenite. However, New Zealand greenstone and true greenstone are only used for nephrite.

Later chapters deal with the world location of the jades and the New Zealand locations are described in detail. A separate chapter deals with bowenite locations in New Zealand. A brief review of gem testing methods precedes a list of minerals found in New Zealand and likely to be confused with nephrite. The remainder of the book describes lapidary work including that of the Maoris and there are a number of useful diagrams and photographs

illustrating various stages of jade carving. There is a general glossary and an index which omits specific gravity and density.

Altogether this is a useful and long-wanted book in which the coloured illustrations are particularly meritorious.

M.O'D.

DANEU (A.). *L'Arte Trapanese del Corallo.* Fondazione Ignazio Mormino of the Banco di Sicilia, Palermo, 1964. 176 pages, 39 coloured plates and 32 black and white plates. L.18,000.

Although this is in no sense a scientific or gemmological work, books on coral are relatively scarce and in this case the standard of the illustrations is so high that gemmologists who are interested in organic materials will be pleased to know that this book is on the market.

The book is essentially a study of the fishing and working of coral in the Sicilian province and town of Trapani. Some inventories are reproduced from the fifteenth and sixteenth centuries and the remainder of the book is given over to the fine series of coloured and black and white plates, each of which is described in detail. The artefacts range in date from 1590 to the end of the eighteenth century.

M.O'D.

TESCIONE (G.). *Italiani alla Pesca del Corallo ed Egemonie Marittime nel Mediterraneo.* Second edition, Fausto Fiorentino, Naples, 1968. 506 pages, coloured plates. (Probably limited distribution).

Originally published in 1940, this is the first attempt to reconstruct the history of the Italian coral-fishing industry. The whole course of the coral trade is pursued and footnotes which follow each chapter lead the reader to a large number of additional sources of information. The fine coloured plates illustrate coral artefacts from all periods. The reader has to rely, in the absence of an index, on summaries placed before each chapter. None-theless this is an essential book for both the collector of coral and the student of Italian applied art.

M.O'D.

THE SIGNIFICANCE OF GEMS IN ASTROLOGY

By S. NALLIAH, F.G.A. Dip. Gemmology (Ceylon).

THE cardinal virtues of a gem are beauty, durability and rarity. The beauty acts in various ways in different gems, e.g. in blue sapphire and ruby through the depth of colour and transparency, in diamond through fire, colourlessness and clarity, in opal through a play of colour.

For ages ancient Kings and Queens adorned themselves with ornaments studded with expensive and rare gems. Very often we find that people wear gemstones not because of their beauty but because it is believed they will ward off evil effects or the influence of the ruling planets which affect them most. It is said that there are principally two remedies in astrology to ward off planetary evil. One way is to propitiate the Deities ruling the relevant planets in the manner prescribed. The other is to wear a gemstone correspondent to the planet concerned. When wearing a gem, one side of the stone should be exposed to space and the other side touch the skin of the wearer. The general belief is that the rays of the planet will be absorbed by the gem because it has the power of reflection and refraction of rays of light which, transmitted to the body, resist the evil influence of the particular planet. Thus we find that gems have an additional virtue for people who believe in astrology.

In the matter of selecting gemstones for different planets the Western and the Eastern systems of astrology differ. The Western system of astrology allocates different gems for each month. And each month is ruled by a different planet and the person who is born in that month will have to wear the gem relevant to the planet related to that month in order to derive benefit from the planet. According to the Eastern system the person will have to wear gems in accordance with his ruling planet to ward off the ill-effect.

For instance, if a person is born in Sinha lagna with its lord, the Sun, in prominent position he should wear a gem related to or ruled by the sun and so absorb more of the protective rays of the sun to build up enough resistance to planetary evil. Again some astrologers maintain that stones akin to the planet ruling the current period should be worn to ward off the evils of that planet. That is to say, if one is suffering from the evil effects of Saturn's directions

(dasa) one should wear the gemstone pertaining to Saturn. One may, therefore, select either the stone relevant to his dasa planet or one relevant to his ruling planet of birth, whichever may have the better appeal. Red is the colour for the Sun and for Mars as well, but for the Sun it should be strong and must have a good lustre. Therefore, ruby, star-ruby and sunstone have been allocated to the Sun. For Mars, as the colour is not so strong and the lustre is dull or greasy, garnet, coral and red jasper have been allocated to it. The different gems relevant to the planets according to both systems of astrology are given below. Those who follow the western system of astrology should select a stone according to the month of their birth. As far as the Eastern system is concerned selection should be according to the ruling planets.

Allocation of gems according to the Western system of astrology.

January — Garnet or alexandrite
February — Amethyst
March — Bloodstone or tourmaline
April — Diamond
May — Emerald
June — Cat's-eye
July — Ruby
August — Zircon or aquamarine
September — Sapphire
October — Opal
November — Topaz
December — Turquoise or star-sapphire.

Allocation of gems according to the Eastern system of astrology.

Gems for Sun — Star-ruby, sunstone or ruby.
Gems for Moon — Moonstone, white sapphire or white pearl.
Gems for Mars — Garnet, coral or red jasper.
Gems for Mercury — Aquamarine, green zircon, emerald or turquoise.
Gems for Jupiter — Yellow pearl, golden topaz or yellow sapphire.
Gems for Venus — White zircon or diamond.
Gems for Saturn — Amethyst or lapis-lazuli.
Gems for shadows of the earth
Rahu — Hessonite garnet.
Kethu — Cat's-eye or tiger's-eye.

ASSOCIATION NOTICES

MEMBERS' MEETINGS

On the 20th June, members of the Scottish Branch of the Association enjoyed a very successful day prospecting for agate at Dunure on the Ayrshire coast. Although great difficulty was found in removing the agate intact from the hard rock matrix, some quite good specimens were obtained.

Owing to popular demand a repeated visit was made by the Midlands Branch of the Association on the 26th September, 1971, to the Blue John Mine near Castleton in Derbyshire, and to Chatsworth House, the Derbyshire home of the Dukes of Devonshire, which is one of the most charming stately homes in England.

ASSOCIATIONS OVERSEAS

The Association has been advised that the following organizations have recently been formed:

Gemmological Association of Rhodesia, P.O. Box 8277, Belmont, Bulawayo, Rhodesia. Chairman: Mr. Ian C. C. Campbell, F.G.A.

Gemmologists Association of Ceylon, P.O. Box 1371, Colombo, Ceylon. President: Prof. K. Kularatnam, M.A., Ph.D.(Lond.), Dr.Sc.(Paris).

The Association recently had the pleasure of receiving visits of parties from the Gemological Institute of America and the Norwegian Gemmological Association.

STELLENBOSCH UNIVERSITY

The University of Stellenbosch and De Beers Consolidated Mines have arranged for a lectureship in gemmology to be established at the University—the first of its kind in South Africa.

A diploma course in gemmology will start in 1972 and it is

hoped that diamond grading courses, as well as short introductory lectures in gemmology, will be held in various centres throughout the country from next year onwards. Mr. H. S. Pienaar, senior technical officer in the Department of Geology at Stellenbosch University, has been appointed lecturer in the course.

OBITUARY

Mr. Hugh N. Leiper, for many years editor of the Lapidary Journal, San Diego, California, died on the 13th July, 1971. He was largely responsible for making the Lapidary Journal an internationally respected publication. He qualified as a Fellow of the Association in 1956.

A. C. D. Pain of Exmouth, who discovered and gave his name to the mineral Painite found in the gem gravels at Mogok, Burma, died in August 1971. Painite was identified as an unusual mineral and its nature was recorded in the Journal of Gemmology in October 1957, in an abstract from the Mineral Magazine of March 1957.

GIFTS TO THE ASSOCIATION

The Council of the Association is indebted to the following:

The Gemmological Association of All Japan for a Japanese translation of the *Scandinavian Diamond Nomenclature and Grading Standards.*

The Banco di Sicilia for a copy of *L'Arte Trapanese del Corallo.*

Mr. K. Ambar, Djakarta, Indonesia, for uncut hydrophane (common opal) from West Java, Bantam area.

The Union Carbide Corporation for samples of Linde created emeralds for use in teaching.

E. P. Joseph Ltd., London, for an agate and quartz slice on a gilt stand.

Dimitri Paraskevopulos, San Paulo, Brazil, for specimens of Brazilian sapphire, emerald and brazilianite.

COUNCIL MEETING

At a meeting of the Council of the Association held on the 1st September, 1971, it was decided to adopt the clarity and colour chapters of the Scandinavian Diamond Nomenclature for inclusion in the Association's Gem Diamond Examination syllabus.

The following were elected to membership:

Fellowship

Aye, Daw Swae Swae,
Rangoon, Burma. D.1970
Brown, Jonathan Philip,
Derby. D.1971
Ferrer Tor, Maria Luisa,
Gerona, Spain. D.1970
Hazelden, John Norman,
Worthing, Sussex. D.1971
Sharp, Charles S.,
New York. N.Y., U.S.A. D.1961

Ordinary

Aalbers, K. J. J., Velp, Holland
Anderson, Neil, Walmer, Kent
Arambulo, Belen Luna,
Quezon City, Philippines
Arnold, Alan Price,
New Orleans, La., U.S.A.
Barham, Richard Findlay,
Freeport, Grand Bahama Island
Barr, Stephen Ponsford,
Porirua, New Zealand
Bellucci, Francesco, Bari, Italy
Boghossian, René, Beirut, Lebanon
Brom, Frederick Willibrord,
Johannesburg, S. Africa
Brooks, Julius C.,
West Chester, Pa., U.S.A.
Brown, Stanley Arthur,
Tynemouth, Northumberland
Brunner, Claude,
Carouge, Switzerland
Buck, Philip Frederick,
Stoke-on-Trent, Staffs.
Buckley, Peter Ross, Halifax, Yorks.
Caspart, Peter, Mainz, W. Germany
Cheung, Lap Poon, Norwich, Norfolk
Chew, Handman, Bangkok, Thailand
Chung, Kwang-Yong, Seoul, Korea
Cooras, George,
East London, S. Africa
Cox, Edward Charles,
Auckland, New Zealand
Cummins, Barry William,
Hataitai, Wellington, New Zealand
Da Silva, Jose Pinho Bento,
Johannesburg, S. Africa
De Silva, G. Chandrakanthi Ida,
Singapore
Donkin, Arthur, Assam, India
Farah, Georges A., Tripoli, Lebanon
Farrell, James John,
Tonyrefail, Glam.
Feather, John Robert,
Fairfax, Virginia, U.S.A.
Fernando, Modarage Wijayapala,
Colombo, Ceylon
Fuchs, Alexander Wilfred,
Brisbane, Queensland, Australia
Furuya, Kenji,
Kunitachi-City, Japan
Gerrand, Ian McAra,
Hawera, New Zealand
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Haile, Neville Seymour,
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and

PROCEEDINGS OF THE
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ASSOCIATION
OF GREAT BRITAIN

GEMMOLOGICAL ASSOCIATION
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THE JOURNAL OF GEMMOLOGY
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NOTES FROM THE LABORATORY (THIRD SERIES)

By B. W. Anderson

New Emeralds

The appearance of a new type of natural emerald can be almost as disturbing to the gemmologist as an encounter with a new form of synthetic, since the properties and inclusions often refuse to conform with any of the established and recognizable patterns.

This certainly was the case recently when some emeralds of important size and excellent quality were submitted for test and showed many features we had never seen before. These stones were unusually free from inclusions (regrettably so, from our point of view), but in almost every case showed striking skeletal markings in radial or spoke-like arrangement, with concentric curved cracks joining the "spokes". The low-power photomicrograph reproduced in Fig. 1 shows one of the more spectacular inclusions of this type. In other stones there were just a few of these radii and curves, reminding one somewhat of the pattern produced when a stone is dropped on an iced-over puddle. Another curious feature of these stones was the presence of exceedingly thin inclusions or markings showing a hexagonal outline, and oriented parallel to the basal plane of the original crystal.

The density of these strange emeralds was found to be 2·73–2·74, and the refractive indices 1·581–1·588: in each case higher than for other Colombian stones. The absorption spectrum was

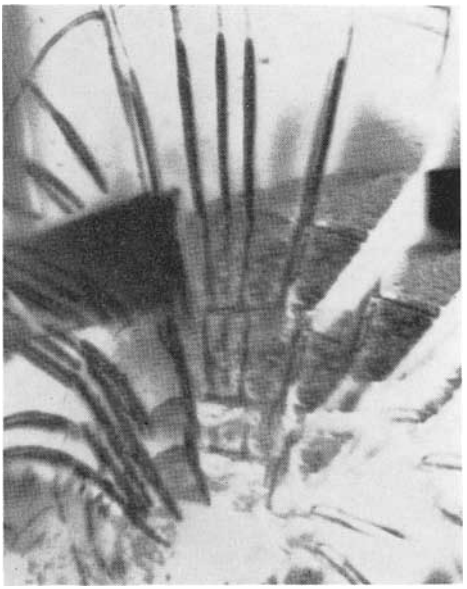

FIG. 1. Inclusions in new source of Colombian emeralds.

perfectly normal, with the distinctive chromium lines in the red which characterize emerald. Experts in Canada and the U.S.A. were so worried by the strangeness of these stones that Dr. Kurt Nassau of the Bell Telephone Labs. was called upon to record their infra-red absorption spectrum, which showed that both alkaline and acid water molecules were present—a strong indication that the stones were natural in origin. Dr. Gübelin was also consulted, and from a study of the inclusions, a subject upon which he has unrivalled skill and experience, he was quite confident that the emeralds were natural. The final seal was placed on their authenticity when the supplier was able to show us rough crystals, which were quite clearly mined material, and a number of further cut specimens, all of which showed recognizably similar features. It is claimed that the stones come from a new Colombian source, the locality of which has not yet been divulged. One hopes that eventually more exact information will be forthcoming, and that the new mine will supplement the scanty supply of fine emeralds.

Linde Synthetic Emerald

On the synthetic side, we were recently given the opportunity to examine fine samples of the emeralds manufactured by the Linde branch of Union Carbide in the U.S.A. A large crystal and a cut stone were loaned by the Company to the Gemmological Association for display at the successful exhibition of gemstones held in Glasgow.

The Linde process is a hydrothermal one, and the crystals, grown on a "seed" plate, are very different in habit from those grown by Chatham or Gilson, which resemble more closely the simple hexagonal habit of those found in the mine. The density of the Linde stones was found to be exactly 2·70, and the refractive indices 1·570–1·576, figures rather higher than those I had previously recorded from Linde material. There was a notably strong red fluorescence under crossed filters, and to a lesser extent the stones fluoresced under short and long-wave ultra-violet and under X-rays. Though these effects were less marked than for earlier Linde products, they would assist materially in differentiating these synthetics from natural emeralds. The most striking inclusions were found to be (as in former samples) showers of pointed hollow tubes, each containing a bubble, and in strictly parallel formation. To those readers who are sufficiently old to remember such antique accessories, one can say that the shape of these inclusions resembles very closely that of the old-fashioned steel gramophone needle (see Fig. 2).

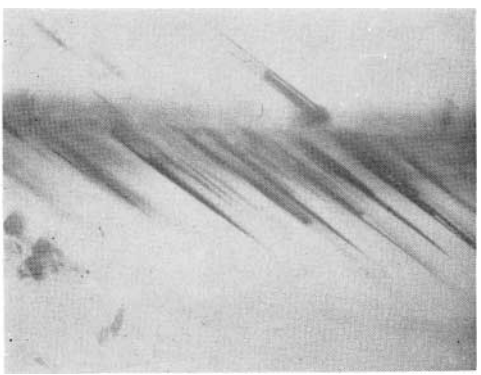

FIG. 2. Inclusions in Linde synthetic emerald.

Sapphire Substitutes

By comparison with its three more expensive brethren in the old "precious" category of gemstones, sapphire has been out of the news for quite a long time—Verneuil synthetics, garnet-topped doublets, and pastes being the most common substitutes, though I suppose the sudden appearance of blue zoisite must constitute a new factor in sapphire identification. Recently, however, two unexpected imitations of genuine sapphire have come to our notice—one as a single and rather comic example was incredibly a step-cut agate, stained blue with greenish stripes and mounted as a cluster ring. This gave an astonishingly convincing appearance of a poor-quality sapphire, the banding enhancing its "natural" appearance. It had in fact been bought and sold as such in good faith by an experienced dealer.

Far more sinister and dangerous, and apparently launched on quite a large scale, is a new doublet, in which a crown of natural Australian sapphire (green or greenish in colour) is skilfully joined to a base of blue synthetic sapphire. The line indicating where the two portions join comes just below the girdle, and can be seen only with difficulty under lens examination in a loose stone. When mounted this would be invisible. These doublets have been offered in parcels at about their apparent value of £50 or £60 per carat, and have in several cases been accepted at their face value until suspicions have been aroused. This is a clever and nasty piece of work, designed not only to deceive the eye but also to pass all but very thorough testing by a gemmologist since natural inclusions appear when viewed through the table facet and a check with the spectroscope will show the 4500Å complex in the blue very clearly—sufficient, until now, to prove the sapphire genuine. In those examined there was no difficulty in seeing their nature, especially when immersed and examined in profile. The lower parts of the stones showed the well-known Verneuil characteristics of bubbles and curved bands very clearly, and also (and this would be useful in a setting) showed the whitish fluorescence under short-wave ultra-violet which is typical of synthetic sapphire. However, the stones were unmounted and we were forewarned: we shall certainly have to keep a wary eye open for these unpleasant fakes, and so will the trade.

Gilson Synthetic Turquoise

Thanks to the kindness of Mr. M. O'Donoghue we have had an opportunity of examining a specimen of what the firm of Gilson claim to be a true synthetic turquoise. Personally I cannot see the sense of embarking on this enterprise. Whereas the synthesis of emerald may seem justified on the grounds of the scarcity and fabulous cost of fine natural stones, authentic turquoise is available in quite adequate supply. The market has already been largely spoiled by the wide-spread practice of impregnating natural poor-quality porous turquoise with wax, plastics, or silicate solutions, not to mention innumerable pressed powders of more or less the turquoise composition—and the production of yet another and more sophisticated substitute cannot fail to bring further into disrepute a gem material which has been prized from ancient until recent times. The stone examined weighed rather more than four carats and was cut in the usual cabochon form. It had a smooth, bland, glossy surface, which under the microscope showed a small-scale speckling of white, not unlike the natural turquoise in appearance. The stone was non-porous and the density was found to be 2·635, which is considerably lower than the values near 2·8 consistently given by the best Persian and Egyptian stones (now seldom seen). A flat surface polished on the base gave a good reading of 1·592 on the refractometer—again lower than that of the best natural stones. The absorption band at 4320Å, which is not always easy to see even in genuine turquoise, was hardly discernible in the Gilson sample. It would be interesting to examine a number of such stones, to see whether the above properties hold true for them all.

Synthetic Quartz

Although the synthesis of quartz has been successfully carried out on an industrial scale for perhaps a quarter of a century on account of the value of its piezo-electric properties in time-keeping and wavelength control, it has only recently impinged on the world of gem materials in the form of attractively coloured pieces. To date, these seem mostly to emanate from Russia, and the first samples seen were in blue and green shades not seen in nature and

thus automatically suspect. More difficult and necessary in terms of identification is a golden yellow form, a good example of which was shown by Mr. Schiffmann at his recent lecture in the Goldsmith's Hall. He has kindly loaned the specimens to me for examination, and also pointed out a significant "mottled" effect which can be seen when these specimens are examined by the naked eye in the direction of their optic axes. In the blue specimen this curious mottling can be clearly seen in ordinary light reflected from a sheet of white paper. In the case of the yellow specimen the effect is best seen when the specimen is placed between crossed polars. That such an effect might be worth looking for was also suggested to me by a British expert in the art of crystal growing, who linked it with the coarse "cobbled" crystal surface on the basal plane of man-made quartz crystals. In natural quartz, it will be realised, the basal plane does not exist as a crystal face. It is quite possible that not all of the coloured synthetic quartzes will show this effect, but at least it is something positive to look for.

"*Dialite*" *Doublets*

One of the latest attempts to imitate diamond takes the form of a doublet in which the crown consists of synthetic white spinel and the pavilion of strontium titanate. The hope behind the production of such a composite stone is that the crown of synthetic spinel will protect the softer strontium titanate used as the base, and also modify to some degree the over-dispersive effect which makes "fabulite" so easily distinguishable from diamond.

The synthetic spinel table facet, of course, yields a refractometer reading of 1·727, and the titanate base still provides colours due to high dispersion in a manner which is excessive when compared with diamond. Viewed at the correct angle, the edges of the table facet can be seen reflected in the junction layer, somewhat as in true diamond doublets. There is more likelihood that these doublets will be wrongly identified as strontium titanate than as diamond. But they provide the jeweller and the gemmologist with one more fake to look out for and one more fancy name, "dialite", to remember (or forget). We are indebted to the Gemmological Association for a sight of this product.

Blue Zoisite Imitation

For anyone to think it worth while to produce an imitation of a newcomer amongst gemstones such as blue zoisite ("tanzanite") is in some measure a compliment, as indicating that the stone in question is both valuable and popular. A cheeky example of this was sent for testing some weeks ago in the form of a blue-mauve stone mounted as a brooch accompanied by an undoubted zoisite crystal of similar colour. So similar indeed was the colour that I fully expected a reading in the 1·70 region on the refractometer, and was quite astonished to find a corundum index—synthetic, of course, and in its context clearly tailor-made to pass as zoisite with its companion crystal. This tale is told more for entertainment than for information, but it does at least emphasize the need for eternal vigilance in gem-testing in these tricky times.

Synthetic Powellite

Synthetic scheelite is a fairly well-known product, which (when suitably "doped") is used by the physicist as a laser material and can also be faceted into very attractive gemstones, which have been passed on occasion as natural scheelite for high prices to ardent collectors. A cut specimen of powellite, which is a closely-related analogue of scheelite, was loaned to me by the Gemmological Association, and can be briefly described for the record, though, being even softer than scheelite ($3\frac{1}{2}$ on Mohs' scale) it is hardly likely to find favour as a gem substitute. The stone, weighing only 0·42 carats, is pink in colour—due probably to a heavy doping with one of the rare earths which, from its absorption spectrum, would appear to be holmium. It shows a fair degree of dispersion, which might be expected from a mineral with the high indices of 1·974 for the ordinary ray and 1·984 for the extraordinary. The density is 4·34 compared with the 6·1 of pure scheelite. This is accounted for by the composition, which is mainly calcium molybdate, while scheelite is calcium tungstate, and the atomic weight of molybdenum is 96 against the 184 of tungsten. Scheelite is, of course, well-known for having a bright blue fluorescence under short-wave ultra-violet light while being unaffected by long-wave (3650Å). A similar effect is seen in the synthetic powellite, but here the fluorescence is green and can be seen in long as well as in short-wave ultra-violet rays.

Canary Diamonds

Now let us turn, admittedly with some relief, to natural gemstones. When, nearly 30 years ago, I ventured to classify diamonds in terms of their fluorescence as Blue fluorescers (Cape series), Green fluorescers (Brown series) and Yellow fluorescers (True "canaries") I did not quite realise how very rare this last category is. In fact it seems to belong to a special category of type II stones, showing none of the absorption bands typical of Cape or Brown series stones. We were recently lucky enough to have for test two of these "canaries", each over four carats and cut in pendeloque form. Under all radiations they showed a strong yellow glow, and their body colour was also a very attractive yellow. Another natural yellow diamond, in this case belonging to the Cape series, showed, in addition to the normal "Cape" absorption bands, a faint line at 5170Å, which I do not seem to have recorded previously.

Gahnite

I was glad to purchase recently a transparent green spinel which turned out to be a nearly pure zinc spinel or gahnite—the end member in fact of the "Gahnospinel" series which we discovered in the Ceylon gem gravels before the war. The density of this stone was 4·64 and its refractive index 1·798. The tourmaline-green colour was clearly due to ferrous iron as its absorption spectrum resembled closely that of normal blue spinel. The bands in fact were found to have the same wavelengths, but the effect was different as their relative strengths were decidedly not the same. The band at 5080Å between blue and green for instance was far stronger in the gahnite.

Actinolite in transparent green pieces suitable for cutting is decidedly uncommon. A pale green transparent blade shown to us by Mr. R. K. Mitchell was found to belong to this species, the figures obtained for its density (3·03) and refractive indices (1·616, 1·633, 1·641), being in almost uncanny agreement with those given by Winchell. There was a faint but clear line in the spectrum at 5030Å—a position where, when one is lucky and in good form, a similar band can be detected in the closely-related nephrite.

ARRANGING A COLLECTION

By GORDON V. AXON

A COLLECTOR faces immediately the problem of arranging his collection. In the United States, where the author currently lives, mineral and gem collecting is probably more advanced than anywhere else in the world, and the mechanical ability of Americans has been applied to the problems facing collectors. As a result, several companies provide a range of cases, cartons, trays, cabinets, stands, and gem holders.

Even so, collectors sometimes still need custom-made boxes, so even in the United States problems are still faced by collectors.

One trouble lies in the variety of acquisitions, since gems come from minerals, and minerals come in all shapes and sizes, on matrix, as separate crystals, and as "rough".

A display cabinet of the type long known in Europe is no doubt the best way to exhibit fine mineral specimens for daily pleasure. Special supports may be needed for large specimens, but, otherwise, the plastic supports commonly available should suffice for medium-sized specimens, while the varieties of "plastic-rubber" will support separate crystals. Good sparkling lighting is essential, with ultra-violet for fluorescent specimens.

Gem collectors are a breed apart, since they usually deal with much smaller items that convey a different type of pleasure and indulge distinct intellectual tastes. Specifically, gem collectors are often concerned with fairly small stones, or with stones that have unusual characteristics.

In both cases, the visual pleasure afforded by a modest collection along these lines need not necessarily be great enough to compel an open collection that can be viewed readily. It may suffice to use stone papers arranged in any way suitable for the user.

Should the visual pleasure be a factor, several facilities are available that combine in varying degree the visual pleasure with ease of access.

A wooden board could be drilled for cavities for the stones that would be protected by a sliding glass top. The trouble here is that the stones would move around and often present less than their must attractive view. Pads of "cotton" (cotton wool) or plastic foam would help.

Yet small plastic boxes that hold a single gem might prove better since they are easily stored in a cardboard box. These small plastic boxes, readily available in the United States, are hinged clear-plastic boxes often with a hard-foam lining, and a soft-foam within the lid. The gem is displayed simply by opening the hinged top. Here, of course, there is no simple visual inspection since all the hinged boxes would have to be opened each time a collection was displayed, but for valuable single gems the idea is worth considering. In a sense, each gem is treated as a ring in a box.

As a rule, foam is superior to cotton wool (known as cotton in the United States) or any other lint-producing substance, since foam provides varying degrees of support, according to type used, and does not produce the irritating strands and wisps of cotton wool.

Several stones can easily be accommodated in the larger plastic boxes complete with foam linings for base and cover. Depressions are easily made in this substance and the stones arranged as needed.

These larger boxes are suitable for several stones of the same mineral variety, or of several varieties, or of the same cut, or of several cuts. Large gems, and crystal or rough and cut to match, can also be accommodated.

Glue, of course, should not be used to fix the stones. There is no need, quite apart from spoiling the stone and the viewing.

Sometimes, gem mounting prongs are useful. These may be home-made or bought. They are suitable for most stones of any reasonable size and consist of flexible plastic or metal strands or fibres attached to a central support that can be pushed into hard foam for display.

Yet all these types of covered boxes suffer from the lack of easy viewing. There's nothing like being able to take a look at a collection without all the bother of opening stone papers or folding back plastic hinges.

One method suitable for gem collectors is the custom-made box of wood, with hinged lid, containing two trays each divided into say 50 small compartments. Each tray base and the inside of the lid are well padded to protect the stones and keep them in place. A simple opening of the box would disclose 50 stones, for instance, while the lifting of the top tray would reveal the other 50—in short, 100 gems on display almost immediately.

A method very suitable for cabochons is the wooden tray lined with foam and covered with glass that can be simply lifted by a tag and removed. These come in many sizes, ranging for instance from four inches by six, to twelve inches by sixteen. The wood, in this particular advertisement, is either pine or mahogany. The foam is blue or white.

Other firms have similar boxes, ranging up to one inch or more deep, that are filled with cotton wool, padding, or plastic foam.

Such boxes, especially the smaller ones, can be very suitable for faceted gems even though the glass exerts some pressure on the stones. This does not matter very much, of course, with cabochons, but faceted gems are another thing entirely. Even so, these trays are very useful for most gems. Those trays with glass tops have the problem of removing the glass when stones are being changed, but that is easily done. The shallow cardboard boxes with glass top in cover have the problem of removing the side pins and taking off the cover. Here again, the problem is minor although the replacing of the tight cover may upset the arranged stones. The pins simply go through the cardboard sides and keep the cover in place. The boxes range from small to large.

These are just some of the many, often ingenious, ways of displaying collections. Of interest to collectors of small mineral specimens are the display cases with rising levels complete with plastic cassettes, or holders, of the small specimens. The result is a minor football stadium, each individual "seat" being a mineral specimen.

Special cases are also available for "thumbnail" specimens and "micromounts" as well as the miniatures.

In short, in the United States, at least, there is a galaxy of choice. There's no doubt that a fine and easy way of displaying adds considerable enjoyment to a collector's pleasure.

ANCIENT IRISH PEARLS

By C. J. ROBB

THE fresh-water pearl of the bivalve *unio margaritifera*, the animated gem, the "na seod" in Gaelic, was found in the crystal-clear meandering rivers of Ireland from the mists of history. It was the prized jewel of the ancient queens, princesses, and fair ladies of those distant times and the hierarchy of the Church regarded it as a token of respect. Bishop Gillbertus of Limerick, gave the Archbishop of Canterbury, St. Anselm, a pearl as a token of his respect in 1094.

Con O'Neill, Prince of Ulster in 1493, bestowed pearls "of riches" on ladies. In 1656 the river Slaney in Co. Wexford was prolific, says Richards'[1]', an English writer, in fine pearls of fair lustre, magnitude and rotundity, not inferior to Oriental gems at prices from 20s. to 40s. to the silversmiths and jewellers of London. Sir Robert Reading'[2]' described pearls from the rivers of Co. Tyrone to the Royal Society in 1688. These gems were mostly of a pale brownish colour, some with a greenish tinge. Some of these of good quality weighing up to 36 carats were valued up to £40. A miller found a pearl in the mill-race, which he sold for £4 10s., and the buyer sold it to Lady Glenawley for which she refused an offer of £80 from the Duchess of Ormond. The Bann river, at Banbridge in Co. Down, was rich in these pearls and a small industry was established to collect, polish and sell them to the best buyers in Dublin, London and Paris. Queen Charlotte had a necklace of Bann pearls valued at £700, one of 4 carats being valued at £60. The river pearls of Ireland had thus an abiding place in the annals of gemmology.

REFERENCES

1. Description of Wexford, 1656. Nat. Library, Dublin.
2. Contained in a letter to the Royal Society dated 13th October, 1688.

CONFIGURATION OF DISLOCATIONS IN NATURAL TOPAZ CRYSTALS

By M. S. JOSHI and R. K. TAKU
Department of Physics, Sardar Patel University, Vallabh Vidyanagar, Gujarat State, India.

ABSTRACT

KOH at 450°C has been used to study the dislocation contents and the configurations of dislocations in natural topaz crystals. Etch patterns on basal cleavages and on matched pairs of basal cleavages are described and illustrated. In the light of these observations it is established that non-parallel linear defects and dislocations in the form of half-loops are commonly observed in natural topaz crystals.

INTRODUCTION

Etching technique is widely used to study defects in single crystals. Comparison of etch figures on matched cleavages gives a good deal of information about the existence and nature of dislocations. Fidelity of an etchant to reveal dislocations in crystals is proved if there is a mirror correspondence of etch pits on two matched halves and pits grow bigger and deeper on progressive etching. One to one correspondence of etch pits results when dislocations are either normal to or are all inclined at the same angle with the face[1, 2]. However, when dislocations branch or bend at or near the cleavage, mis-matching or deviation from one to one correspondence of etch pits on two matched cleavages is to be expected[3-6]. Using selective etch methods, various investigators have studied dislocations in different crystals[7-12]. From the detailed study of surface structures of various habit faces of natural topaz crystals useful information has been obtained by us in regard to development and mechanism of growth of different habit faces in particular and of natural topaz crystals in general (unpublished). A series of experiments to investigate defects in natural topaz crystals have been carried out by us. We have reported various channel-like inclusions, isolated oriented square-shaped inclusions, tree-like inclusions etc. in natural topaz crystals. By correlating etch pits with inclusions we have established that some of the inclusions are trapped at dislocation sites.[13] In the present paper the configuration of dislocations in natural topaz crystals has been worked out.

In the present investigation, matched pairs cleaved along (001) faces were etched in KOH at 450°C. Matched cleavages were selected for our etching experiments because it is easy to secure regions having less concentration of dislocations or defects on these surfaces so that when these surfaces are etched, the region yields less concentration of etch pits. The etched surfaces were thoroughly cleaned, silvered and then examined under a metallurgical microscope.

Observation and Discussion

Examination of etched surfaces revealed the presence of point-bottomed etch pits on them. Since the point bottom of an etch pit is considered to be the terminal end of a dislocation line, by following, at successive stages of etching, the tip of point-bottomed etch pits it becomes easy to map out the configuration of dislocations threading through the crystal lattice. This procedure was employed to find out the path followed by dislocation lines. Etch pits obtained on cleaved matched pairs showed correspondence in their number, shape and size and on successive etching etch pits were found to grow bigger in size and become deeper as is to be expected. A typical case of etch patterns obtained on a cleaved matched pair after 15 seconds of etch is shown in figs. 1(*a*) and 1(*b*). Comparison of etch patterns in these photomicrographs show one to one correspondence in regard to both the number and position of isolated etch pits, which means that the pits are formed at dislocation sites. A close examination of these etched faces revealed the eccentric nature of etch pits. The eccentricity observed in the structure of etch pits indicates that the linear defects are inclined at some angle with the cleavage face. This eccentric nature of point pyramidal pits should become more pronounced with the increase in the depth of pits. To investigate it, this matched pair was again etched for 30 seconds. Figures 2(*a*) and 2(*b*) illustrate etch patterns thus obtained. Here, all the pits have grown bigger in size and depth and are point-bottomed and eccentric. When etched regions in figs. 2(*a*) and 2(*b*) are compared with those in figs. 1(*a*) and 1(*b*) the following points emerge.

1. The cleavage lines are displaced relative to the pattern of pits. It is conjectured that displacement of cleavage lines by etching might be taking place as explained by Tolansky[14].

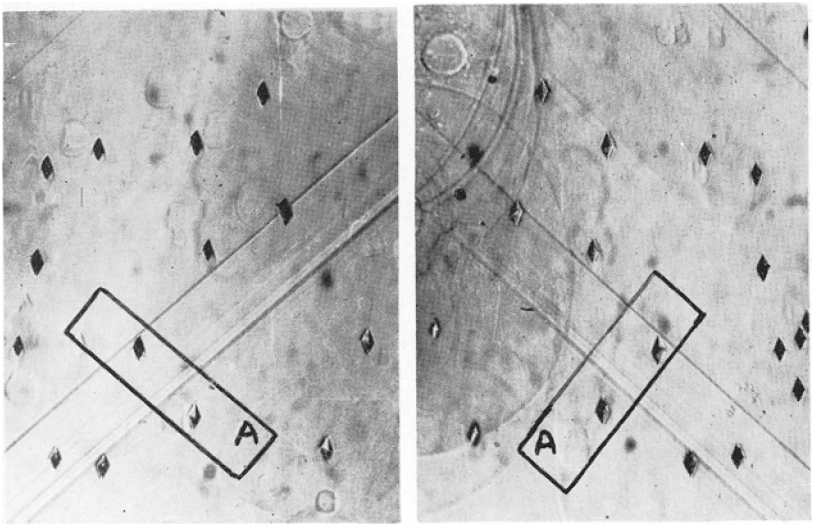

FIGS. 1(*a*) and 1(*b*). Etch patterns produced on two matched cleavage faces after an etching time of 15 seconds (× 175).

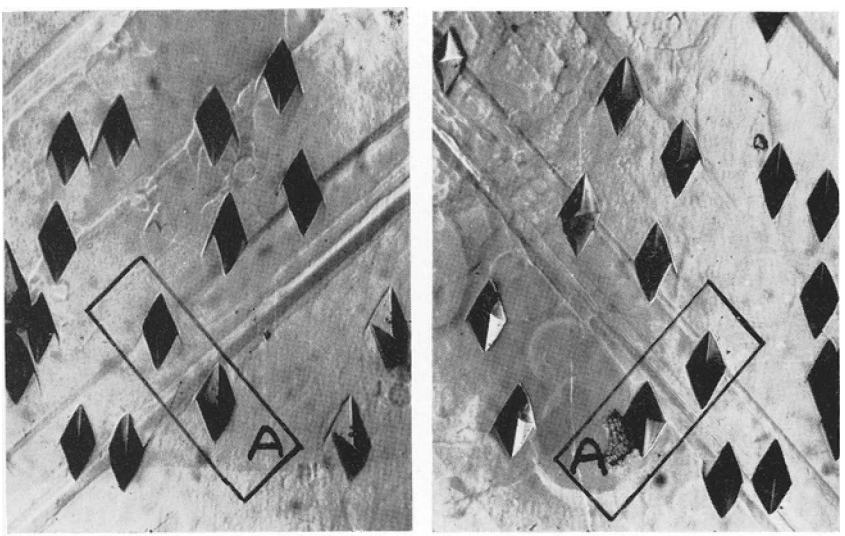

FIGS. 2(*a*) and 2(*b*). Regions of figures 1(*a*) and 1(*b*) after 30 seconds of further etching (× 175).

2. In regions mark A in figs. 1(*a*) and 1(*b*), and figs. 2(*a*) and 2(*b*) it is found that the distance between the geometrical centres of two pits is larger in fig. 2(*a*) than that in fig. 1(*a*) and it is smaller in fig. 2(*b*) than that in fig. 1(*b*). This means that two dislocation lines associated with these pits are divergent as one goes into the interior of crystal below the cleavage face of fig. 1(*a*) and become convergent as one goes towards the interior of crystal below the cleavage face of fig. 1(*b*). In order to see how and where these linear defects converge, the matched pair was again etched for 30 seconds. The etch patterns thus obtained are illustrated in figs. 3(*a*) and 3(*b*). On comparison of etch patterns in figs. 3(*a*) and 3(*b*) with those in figs. 2(*a*) and 2(*b*), we find in region A of these figures the distance between the geometrical centres of two pits in figs. 3(*a*) is larger than that in fig. 2(*a*), whereas on the other matched face the two point-bottomed pits seem to merge together (see fig. 3(*b*)). In the former case, the dislocation lines associated with two pits seem to diverge inside the lattice below the cleavage face of fig. 3(*a*), whereas in the latter case the dis-

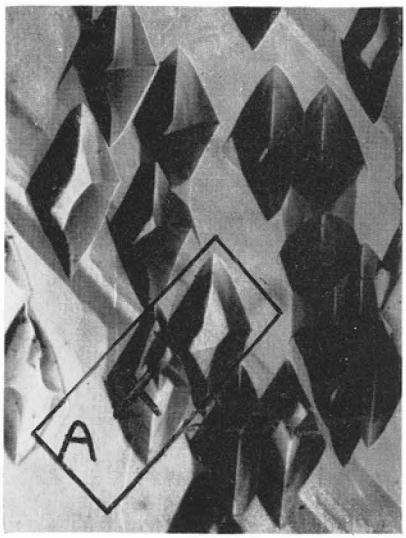

FIGS. 3(*a*) and 3(*b*). Regions of figures 2(*a*) and 2(*b*) after 30 seconds of further etching (× 175).

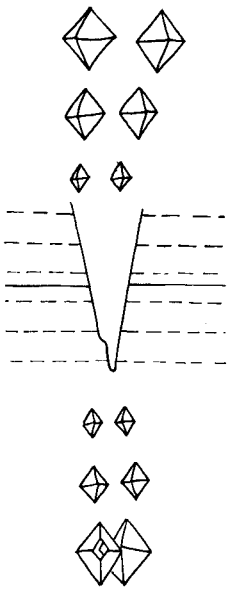

FIG. 4. Schematic representation of configuration of a dislocation half-loop.

location lines seem to converge in the interior of the crystal below the region of cleavage face of fig. 3(*b*). The two pits in region A of fig. 3(*b*) are flat-bottomed. A small point-bottomed pit is also seen inside a flat-bottomed pit marked X, formation of which may be attributed to the stepped nature of dislocation inside the crystal. At this stage it could be conjectured that this newly formed point-bottomed pit and also the flat-bottomed pits would grow wider and deeper and result into a single pit if further etching was carried out. In fact, etching of this matched half for 30 seconds more did result in a single flat-bottomed pit. Thus the dislocation lines associated with these pits converge in the interior of the crystal below the cleavage face of fig. 3(*b*), whereas these linear defects diverge inside the crystal below the cleavage face of fig. 3(*a*), thereby giving rise to the formation of dislocation half loops, schematic representation of which is given in fig. 4. It may be mentioned here that in all the schematic diagrams presented here, the solid line in the centre represents the boundary separating cleavage planes and the dotted lines represent the three stages of etching.

The above-described observation reveals that dislocations are present in topaz crystals in the form of a half loop. A series of etching experiments carried out under the same conditions (as described above) on basal cleavages of natural topaz crystals also proved that in most of the cases the linear defects are, in fact, present in the form of half loops in such crystals. A typical observation made on a basal cleavage is illustrated in figs. 5(*a*), 5(*b*) and 5(*c*) which represent the etch patterns obtained after an etch of 15 seconds, 45 seconds and 75 seconds respectively. By comparing etch patterns in the region marked A of these figures, the following points become noteworthy.

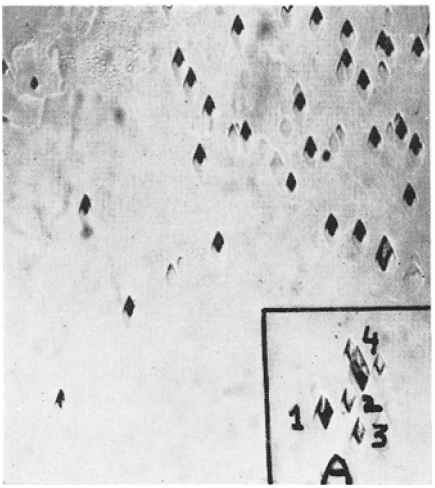

FIG. 5(*a*). Etch patterns produced on a cleavage face after an etch of 15 seconds (× 175).

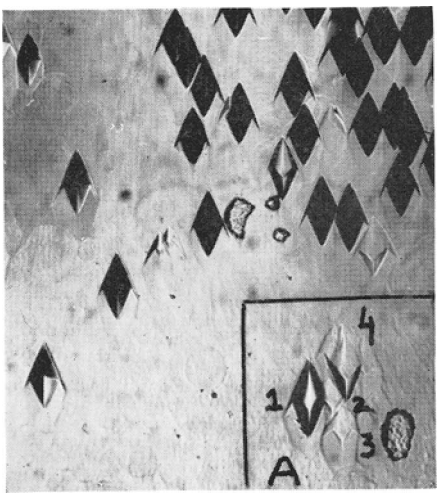

FIG. 5(*b*). Region of fig. 5(*a*) after 30 seconds of further etching (× 175).

FIG. 5(*c*). Region of fig. 5(*b*) after 30 seconds of further etching (× 175).

1. A point-bottomed pit marked 1 in fig. 5(*a*) results in a flat-bottomed pit (see fig. 5(*b*)) and then again becomes point-bottomed as is seen from fig. 5(*c*). In this case, it seems that in the beginning, the dislocation line runs normal to the cleavage face, then changes its direction to become almost parallel to the cleavage face and then bends and runs inclined to the cleavage face.
2. Pits marked 2 and 3 in fig. 5(*a*) are point-bottomed. When etched, they seem to merge together and have their bottoms flat (see fig. 5(*b*)). On further etching, they finally result in a shallow flat-bottomed pit as is observed from fig. 5(*c*). It is suggested that formation of pits in this way gives rise to a V-shaped dislocation configuration.
3. Three pits at mark 4 of fig. 5(*a*) have correspondence with three flat-bottomed pits in fig. 5(*b*). As these flat-bottomed pits grow bigger in size, due to their intergrowth two of the flat-bottomed pits result in a single point-bottomed pit and this point-bottomed pit seems also to merge with the third flat-bottomed pit (see fig. 5(*c*)). Formation of pits here indicates that dislocations associated with these pits are present in the form of half-loops.

   A schematic representation of dislocation configuration of the above mentioned three cases is given in fig. 6 as marked D E and F respectively.

One more case of etch patterns obtained on a cleavage face by etching it for 15 seconds is shown in fig. 7(*a*). Here also all the pits are eccentric and except pits No. 3 and 4, which are quite close to each other, all pits have grown at isolated places. This cleavage face was etched for 30 seconds more and the resulting etch patterns are shown in fig. 7(*b*). Here the pits have grown bigger in size and depth. It is interesting to note that pit No. 1 seems to join pit No. 2 (see fig. 7(*b*)) which means that the dislocation line associated with pit No. 1 is much more inclined to the cleavage face than that associated with pit No. 2. Also, as seen from fig. 7(*b*), pit No. 3 has merged with pit No. 4. At this stage it was felt that these pits may result in a single pit if further etching was carried out. To investigate it, this cleavage was again etched for 30 seconds and etch patterns thus obtained are shown in fig. 7(*c*). Here, as was expected, pit No. 1 has merged with pit No. 2 and

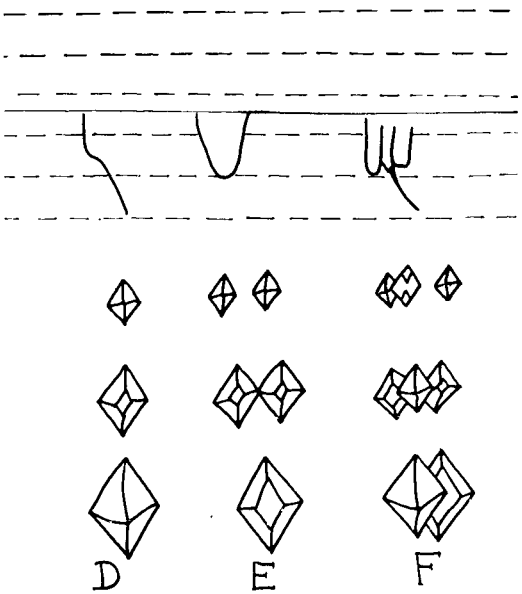

FIG. 6. A schematic diagram of different configurations of dislocations.

the same is the case with pit No. 3 and 4. Development of these etch pits is thus attributed to the formation dislocation half loops.

CONCLUSION

Etching experiments carried out in the present investigation and observations reported here reveal that dislocations in the form of half loops are common in natural topaz crystals.

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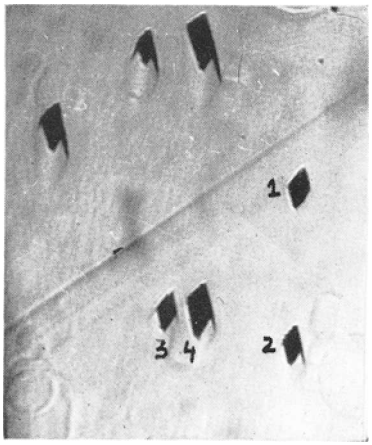

FIG. 7(*a*). Etch patterns obtained on a cleavage face after an etch of 15 seconds (×350).

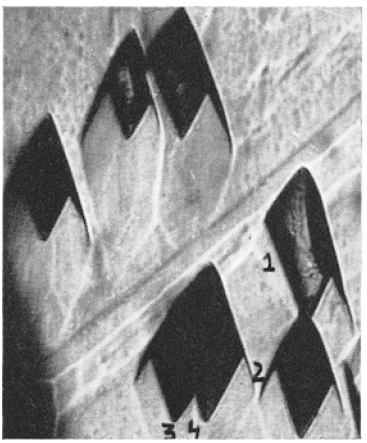

FIG. 7(*b*). Region of fig. 7(*a*) after 30 seconds of further etching.

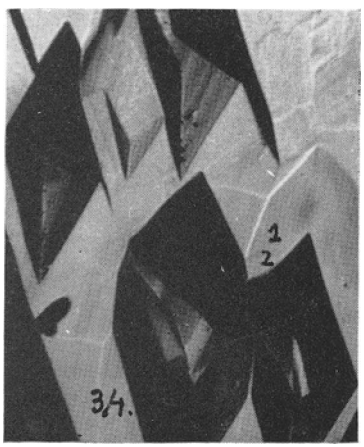

FIG. 7(*c*). Region of fig. 7(*b*) after 30 second of further etching.

GEM EXHIBITION IN SCOTLAND

UNDER the auspices of the City of Glasgow Civic Amenities Committee, and arranged by the Scottish Branch of the Gemmological Association, a "WORLD OF GEMS" exhibition was held at the Glasgow Corporation's Art Gallery and Museum at Kelvingrove from 17th September to 3rd October, 1971.

An official opening ceremony was held in a lecture hall of the Art Gallery on the evening of the 16th of September. This ceremony attracted some 900 guests to hear Councillor Mrs. Constance Methven, the Convenor of the Civic Amenities Committee, with a short well-chosen speech, introduce Professor T. Neville George, Ph.D., D.Sc., D. es Sc., F.R.S.E. who formally opened the exhibition. Professor George explained in simple terms, the nature of gemstones, mainly with reference to their mineralogical aspect, with which of course he is so familiar, but he did refer also to man-made gems and those of organic origin. Mr. Dennis Hill, the Chairman of the Scottish branch replied to Professor George. The exhibition was then declared open.

The exhibition itself was displayed in the Central Hall of the Museum and Art Gallery. On entering one's eye was immediately focused onto a flood-lit case containing a very fine set of replicas of the British Crown Jewels, and on the back of the case on the reverse side were a series of colourful transparencies of the Scottish Regalia, anciently styled "The Honours of Scotland", the symbols of Sovereignty when Scotland was a separate kingdom. At the centre of this second case reposed the "Thistle jewel", an early edition of the Saint Andrew of the Order of the Thistle, this historic jewel having been graciously loaned by Her Majesty the Queen.

The centre stand forming a triangle of cases dealt completely with diamonds. Provided by the De Beers Company, there were replicas of the famous diamonds of the world, and models showing the stages of cutting a brilliant-cut diamond from an octahedral crystal. The second of the three cases showed a magnificent collection of diamond crystals and included a dish of diamond crystals of all conceivable colours. The remaining case showed the final result in a large selection of diamond engagement rings.

A most exciting exhibit consisted of a fine collection of the gemstones found in Burma. This included some excellent crystals of ruby, peridot and topaz. Cut stones were represented by many well-known species which come from the Mogok Stone Tract, particularly the corundums, but there were many less known species, such as fluorite, euclase, scapolite, kornerupine, and sinhalite. This case of Burma gems fronted another larger case containing an excellent collection of the jades, both nephrite and jadeite, and some of the minerals which simulate the true jades.

There was an exhibit of Victorian jewellery, loaned by the Victoria and Albert Museum in London, jewellery mainly set with pearls and turquoise, and also jet. In an opposite case for comparison was a case showing modern jewellery. Naturally there had to be a show of Scottish jewellery and this display on a tartan background consisted of typical Scotch pebble brooches, cairngorms and jewel-set dirks.

Of greater interest to the gemmologist and technician was the case devoted to synthetic and composite stones. Among the more unusual of these were a suite of all the colours of synthetic star-stones, many of which had not been seen in this country before. Synthetic emeralds made by Chatham, Gilson, Zerfass and Linde were on display as well as the newer synthetics, such as, synthetic rutile, strontium titanate ("fabulite"), yttrium aluminate (YAG) and some new colours of synthetic quartz. Many unusual composite stones were on display including the recently marketed doublet consisting of a base of fabulite and a crown of synthetic white spinel, a stone which has been marketed under the unfortunate name "dialite".

Various applications of gem materials to science and industry was the theme of another exhibit. In this display were shown core drills, turning tools, diamond saws, wire-drawing dies, agate bearings, quartz oscillators, record player styli and many others. Ruby and YAG laser crystals were also shown and there were specimens of "doped" calcium tungstate crystals of a blue-violet colour, which indicates coloration by the rare-earth neodymium.

Other exhibits showed "The Zircon Story" telling of the production and native treatments for the production of the popular colourless and blue zircons. Another display showed a wide range of cameos and intaglios in both stone and shell. Ivory and amber

formed another exhibit, and there was shown a fine assortment of crystals and cut stones of all varieties of gem minerals. Pearls, too, were in evidence, among which was the beautiful "Abernethy pearl" fished from the river Tay.

The instruments used in the testing of gems formed another exhibit, and in this, for the first time, was displayed the refractometer with a zinc blende prism, which was the prototype which led to the modern suite of Rayner refractometers. A selection of books on gemstones showed the literary side of gemmology.

At the rear of the hall was a screen decorated with coloured pictures showing diamond recovery, sorting diamonds and their fashioning and marketing, and another exhibit demonstrated the sawing of a large block of stone by means of a diamond-toothed circular saw, and also a diamond-studded head of a rock drill. What was seen to be most popular with the visitors was a continuously operated lantern projecting coloured slides showing the diamond and cultured pearl industries.

The following Fellows of the Association gave lectures during the Exhibition:

Diamond Mining and Marketing by Arthur McRae.
Synthetic Gemstones by M. Turner.
Diamonds by D. Hill.
Pearls by I. N. MacKenzie.
Historical Diamonds by A. H. G. Armstrong.
Diamonds in Industry by H. J. Whitehead.

The organisers who put up this exhibition had to design it not only for the gemmologist but, more importantly, for the general public, and in covering this dual job they produced an excellent show. The broad spectrum of the display and the attendance at the exhibition (reported to be 28,000), showed how well they achieved this endeavour.

Gemmological Abstracts

FEININGER (T.). *Emerald mining in Colombia: history and geology.* Min. Record, 1970, 1, pp. 142-149, 4 figs.

A detailed summary is given of the history of emerald mining in Colombia, with specific reference to the Chivor district and mine, the Gachalá mine, the Muzo district and mine, and the Coscuez and Peñas Blancas mines. Also discussed are the geological setting and associated mineralogy of Colombian emeralds, mining methods employed and production figures, a review of theories on the origin of Colombian emeralds, and comments on identification.

J.A.

HORSZOWSKI (S. M.). *Thermal annealing of natural semiconducting diamond.* Journ. Phys. Chem. Solids, 1969, 30, pp. 669-675, 3 figs.

The annealing behaviour of type II semiconducting diamonds is complex, occurring by several processes with activation energies ranging from <3 to <9eV.

R.G.J.S.

LITVING (YU. A.), LISOYVAN (V. I.), SOBOLEV (YE[E]. V.), BUTUZOV (V. P.). *An X-ray investigation of artificial diamond crystals.* Dokl. Acad. Sci. U.S.S.R., Earth Sci. Sect., 1969, 183, pp. 144-147, 4 figs. Transl. from Dokl. Akad. Nauk SSSR, 1968, 183, pp. 1163-1165.

X-ray investigation shows that there are marked differences between synthetic diamond crystals of the main crystallographic types. The characteristics of the diamond crystals are discussed.

B.E.B.

POUGH (F. H.). *On names.* Lapid. Journ., 1971, 25, 5, p. 680.

An interesting comment about the confusion that exists in connexion with gemstone nomenclature. Dr. Pough refers to the prevalence of the suffix "ite" on new minerals names, which will

make some older names preferable. He refers to grossular being preferred to grossularite. He agrees that the term "synthetic" is not acceptable for some of the man-made products that have no counterpart in nature. There is good reason for calling such laboratory products "man-made". (Andy why not? Far better than "created". According to one's beliefs God or Nature created emeralds, rubies and other gems. Smith, Jones, Robinson or Brown, have endeavoured to copy natural gems. Ed.)

S.P.

SEGNIT (E. R.), ANDERSON (C. A.), JONES (J. B.). *A scanning microscope study of the morphology of opal.* Search (Commonwealth Sci. Industr. Res. Organization), 1970, 1, pp. 349-351, 13 figs.

Electron micrographs of surface replicas of precious opals show that they are composed essentially of close-packed spheres of silica with a diameter of around one-half the wavelength of visible light (M.A. 17–609). Examination of freshly broken and etched samples of various types of opal by scanning electron microscope confirms that sphere-type opals have been deposited by colloidal precipitation. In other types of opal with a structure based on a disordered interlayering of cristobalite and tridymite units crystallization appears to have been the initial process. Opal from a volcanic sequence in Iceland consists of an aggregate of minute tabular crystals of cristobalite produced by reheating of a less crystalline opal by lava flows, causing recrystallization.

R.A.H.

ANON. *Diamond mining in India today—output tiny, gemstone ratio high.* World Mining, 1971, 24, 6, pp. 34-35, 1 map.

The geology of pipe, conglomerate, and secondary diamond deposits in the Panna region, central India, is briefly described. Although African kimberlites carry 0·3 to 1 carat per ton, the developing Majhgan diamond pipe carries only 0·1 carat per ton. However the ratio of gem to industrial stones in African pipes is 1:4 to 1:9, while the Majhgan pipe ratio is 4:1 to 3:1. Secondary deposits contain 0·05 to 0·1 carat per ton.

R.W.H.

BOOK REVIEWS

FIRSOFF (V. A.). *Gemstones of the British Isles.* Oliver & Boyd, Edinburgh, 1971. 152 pp., 45 line drawings, 3 maps, 4 pp. of coloured plates. £2·50.

The title of the book suggests that at last there is a volume of real value to British gemmology but the book does not appear to have attained that status. The problem the author has tackled is not an easy one, as others have found before and usually given up in despair. The reason for this is not far to seek and is due to the steady industrialization of the country, including, although to a less extent, Scotland, and also Eire. Correctly, the author has commenced his researches by studying the older literature, but some of the sites mentioned, more often for mineralogical rather than gemmological reasons, are probably now built upon and not available. Moreover, mineralogists report finds of minerals which are in very small sizes and completely unsuited for gemstones as we know them. The author has done some searching himself and has also had many recent personal communications to assist him and in this the work has a certain value.

The general text starts well and the division into areas, geographical and county, has much to recommend it. In later chapters, the more technical side of the subject fails to come up to this standard, and there are errors in this part. There is a statement that jadeite is found in the rocks of the Lizard in Cornwall, and this is attributed to G. F. Herbert Smith, but the mineral Herbert Smith states is found in the Lizard is not jadeite but saussurite, a different mineral entirely. The caption to the line drawing on page 78 should read *refraction of light in a stone*, not *reflection.* Further, on page 85 the author writes: ". . . gives diamond its lively fire, *unrivalled by the various "pseudo-diamonds" except the colourless zircon*". (Reviewer's italics.) Scheelite fluoresces only under short-wave ultra-violet light and that has not been made clear. There are plenty more errors of similar nature. The misspelling of rhodochrosite might have been a slip had it not been repeated so many times and far too many of the unacceptable older names are given, which in view of the present legislation would have been better omitted.

There are two items mentioned which interested the reviewer.

The first of these was mention of colourless garnet, called "water-garnet", apparently recorded by Heddle in a book dated 1901; and the second, a reference to olivine of a "fine cherry-red colour", which was taken from a book printed in 1858. Whether these could be classed as gemstones I do not know, but the reports are interesting.

The volume is completed with a fairly good index, but it is hoped that before any further edition is contemplated the script will be read by a competent gemmologist or mineralogist before publication.

R.W.

ISLAM (M. F.). *Nowratan.* Dacca, 1971. Rs. 3·50.

A short treatise about pink pearls of East Pakistan, together with brief guidance on other gems. The author is enthusiastic about the lustre and beauty of the pearls. He has discovered 11 pearl-producing districts in East Pakistan.

S.P.

Mineral Digest, Vol. 2 (undated). New York. $3·00.

A comment about the absurdity of the use of the term "semi-precious", a well argued case for the sensible naming of gems and minerals, and some outstanding colour photomicrographs of moon rock, are highlights of this sumptuous publication. There is an article on cameos and one on minerals from Tsumbe, S.W. Africa.

S.P.

ANON. *Gems & jewels.* Orbis Books, London, 1971. £1·25.

Translated from French.

This is an excellent elementary treatise, with an introduction by H-J. Schubnel, of the French Gemmological Association. Its most important feature is 180 plates in colour. Some of these have appeared elsewhere, but the Orbis series is intended to open up an absorbing range of hobbies and pastimes. The colour illustrations are a great interest to the expert in this book.

S.P.

BOEGEL (H.) (edited and revised by J. Sinkankas). *A Collector's Guide to Minerals and Gemstones.* Thames and Hudson, London, 1971. £2·95 net (U.K.).

This is a superbly illustrated book which emphasizes the value of depicting gem crystals by using coloured illustrations instead of a colour camera. This book is suitable for anyone interested in the beauty and fascination of minerals and gemstones; for the beginner it is an authoritative guide and it is comprehensive enough to satisfy more experienced students. It makes no pretence of being a textbook but gives sufficient information about physical properties to make the data given in the text useful and understandable.

John Sinkankas has modified the original text to give a fuller treatment of mineral origin and to give details of a historical and economic nature of many species. The bibliography has been amended to include texts in the English language.

The 154 water-colour illustrations were prepared by Claus Caspari and the translation from the German made by Eva Fejer and Patricia Walker, F.G.A.

S.P.

RICHTER (G. M. A.). *Engraved gems of the Romans.* Phaidon Press, London, 1971. £20.

The second volume of *The Engraved Gems of the Greeks, Etruscans and Romans.* Dr. Richter has again produced a scholarly work, and the printing is of the excellent standard associated with Phaidon Press. The work is more of interest to the archaeologist than to the gemmologist, as it constitutes a supplement to the history of Roman art generally. Although agate, carnelian and chalcedony are the principal stones mentioned, the use of glass was frequent and the glass gems were evidently cast directly from stone originals and then reworked. A fascinating study for those interested in engraved gems.

S.P.

SINKANKAS (J.). *Prospecting for Gemstones and Minerals.* Van Nostrand Reinhold Co., New York, 1971. £3·50.

This is a revised and up-dated version of a book formerly published in 1961 under the title *Gemstones and minerals: how and where to find them.*

S.P.

ASSOCIATION NOTICES

PRESENTATION OF AWARDS

The chairman of the Gemmological Association, Norman Harper, welcomed successful candidates in the 1971 gemmological examinations when they attended a presentation of awards at Goldsmiths Hall, Foster Lane, London, on 23rd November. He said his introduction was very similar to his introductions in previous years, there being some 420 candidates sitting for the preliminary examinations and 307 for the diploma, which was a record. Another record was the number of different centres, 75, scattered throughout the world, and for the first time there was a candidate from Yugoslavia. The postal strike earlier in the year made the posting of correspondence students' examination papers a "nightmare" but all eventually received them. He paid a special tribute to the examiners who, each year, had to undertake a very difficult task.

He then introduced Ove Dragsted, F.G.A., jeweller to the Royal Danish Court, who presented certificates and diplomas to those candidates attending.

In his address which followed Mr. Dragsted said—

"This is a proud day for all those who have won their diplomas in gemmology and their diamond certificates and even more so for the lucky ones who have won awards. The Tully medalist is to be especially congratulated as a few years ago he won the premier award in the retail jewellers' examinations of the National Association of Goldsmiths.

"I recollect how proud and happy I was myself when I received the fine large scroll with the seal of the Gemmological Association

and the signatures of Dr. Herbert Smith, Dr. Claringbull and Mr. Knowles-Brown.

"The standard set for these examinations is high, they are of university level. We are here on the site on which one of the oldest of the livery companies, the Worshipful Company of Goldsmiths, has for more than six centuries set and maintained those high standards which has made British goldsmiths and jewellers world famous for quality and integrity. They may often have been tempted to lower the standards of quality but they refrained from doing so. This is the ancestral background of the National Association of Goldsmiths. So that their members might meet the expectations of the buying public they inaugurated in 1908 an educational scheme for retail jewellers, and as far back as 1913 were held the first examinations in gemmology. The Gemmological Association of Great Britain founded in 1931 is a child of the National Association of Goldsmiths, and what a bright child. This year it celebrates its 40th anniversary—gemmologically speaking this is a ruby jubilee and imagine what has happened during those 40 years.

"Gemmology all over the world is greatly indebted to this grand association. They once set the standards and these standards are followed all over the world by the many gemmological associations which have been formed. The British gemmologists were the pioneers who planned the right way for all gemmological education, that is an outstanding achievement. Your present chairman and his committee have every reason to be proud. Also the Gemmological Society of Denmark is deeply indebted to you for your fine pioneering work and I wish to express our sincere gratitude for all the inspiration and ready assistance we have received from Gordon Andrews, the Precious Stone Laboratory under the leadership of Basil Anderson and the research work carried out by him and his collaborators Robert Webster and Alec Farn. They have accomplished unbelievable results in those very modest premises in Hatton Garden.

"The strictly scientific nomenclature adhered to by the laboratory as well as in the courses and text books prove the descendancy from those 14th century goldsmiths who met on this very site. May I mention that the Zurich Gemstone nomenclature which we completed two years ago and the Scandinavian diamond nomenclature

just published are both inspired by the learning obtained through the diploma courses which you have now successfully completed. There is, perhaps, in some countries a tendency to sell certificates today rather than beauty. The enthusiasts, the lovers of gemstones would stress the beauty of the gemstones. If a lady wants a diamond she does not precisely think in terms of a 41 deg. pavilion angle to the plane of the girdle, she thinks of brilliance, of fire, of sparkling beauty enhanced by a fine jewellery setting. She may also have a conception of the magic of the stone, its long and interesting history, the hidden powers thought to be attached to this very stone and, of course. she thinks of the stone also as a token of love. There are so many facets to gemmology.

"The diploma examinations which you have now sat for is certainly not a terminus, it is an important junction from which many tracks are leading. You may follow a track leading you to research work, or the special diamond track, which many successful candidates have followed which allows you to qualify as a diamontologist. Some gemmologists polish stones in their own private lapidary shops. They gain much pleasure from that. Others construct gem testing equipment. Maybe you have built up an interesting collection. You may seek efficiency in microscopy and photography, or you may branch into the fascinating history of gemstones. You may go on studying mineralogy, or geology and go out prospecting for gem minerals. I have taken part in some thrilling excursions in Greenland in quests for new gem minerals suitable for polishing".

The vote of thanks to Mr. Dragsted was proposed by Basil Anderson, F.G.A., director of the Gem-testing Laboratory of the London Chamber of Commerce, London, who said that he counted Mr. Dragsted as one of his oldest friends in gemmology. He was a founder members of a European gemmological group in which he, Mr. Anderson, was pleased to be included. He praised Mr. Dragsted's speech as being very sincere, the like of which was not often heard today.

Before the presentation Fellows and members of the Association held a short reunion.

MEMBERS' MEETINGS

Mr. Charles Schiffmann of the Gübelin Laboratory, Lucerne, gave a talk to members at Goldsmiths' Hall, London, on the 12th October, which dealt, among other things, with synthetic ruby, Verneuil synthetic red spinel, the analysis of colour with the DIN 6164 Colour Chart, and the use of the spectro-photometer and its application to gemstones. Mr. Schiffmann's talk in article form will be reported in subsequent issues of the *Journal.*

A meeting of the Scottish Branch of the Association was held on the 19th October, 1971, when Mr. Robert Webster, F.G.A. gave a talk entitled "An Outline of Problems in Gemmology today".

On the 21st October, 1971, members of the Midlands Branch of the Association heard Mr. Michael Houghton of Mikimoto Pearls speak on the Cultured Pearl Industry. His talk was illustrated by a film.

On the 12th November Mr. A. Jobbins, of the Geological Institute, South Kensington, gave a talk to members of the Midlands Branch on "The Gems of South East Asia".

MEMBERS' MEETINGS 1972

25th January	Talk by Mr. R. Webster, F.G.A., on "Gems in Court". Goldsmiths' Hall, London, 7.00 p.m.
22nd March	Annual General Meeting, Goldsmiths' Hall, London, 6.30 p.m.
18th April	Talk by Mr. E. A. Jobbins, B.Sc., Goldsmiths' Hall, London, 7.00 p.m.
17th October	Professor S. Tolansky, D.Sc., F.R.S. "Speaking at Random", Goldsmiths' Hall, London, 7.00 p.m.
27th November	Reunion of Members, 6.00 p.m., and Presentation of Awards, 7.00 p.m., Goldsmiths' Hall, London.

GEM DIAMOND EXAMINATION

There were 32 entries for the 1971 Gem Diamond Examination arranged by the Association. The following is a list of successful candidates, arranged alphabetically:

QUALIFIED WITH DISTINCTION

Torres De Goytia, Rafael, Valencia, Spain

QUALIFIED

Ahmad, Syed Vaqar, London
Allardyce, Anthony S., Twyford
Andres Barbera, Manuel, Valencia, Spain
Burke, Winifred Mary, Bexleyheath
Carr, Malcolm Stuart, Addington
Domenech Bisbe, Juan, Barcelona, Spain
Dougan, Reginald William, London
Driver, Olive, Bexleyheath
Fernandez Gil, Enrique, Valencia, Spain
Holmes, Brian Michael, London
Jones, Claire Patricia, London
Lewin, David Alexander, Loughton
Lewin, Persephone, Loughton
Lopez Soler, Angel, Barcelona, Spain
Mark, Malcolm David, London
Mendis, Cynthia Marguerite, London
Navarro Bort, Rodolfo, Valencia, Spain
Nuttall, Miranda, London
Peris Bataller, Francisco, Valencia, Spain
Pie De Masso, Rosa Maria, Barcelona, Spain
Ramon Rius, Carlos Enrique, Barcelona, Spain
Reich, David K., Tunbridge Wells
Rosich Chova, Francisco Luis, Valencia, Spain
Sanchis Estrems, Salvador, Valencia, Spain
Sendon Gimenez, Pedro, Barcelona, Spain
Snipper, Alison Bernice, London
Wilson, Robert Henry, Caterham
Wood, Robert Matthew, Peterborough

EXAMINATIONS IN GEMMOLOGY, 1971

In the 1971 examinations in gemmology organized by the Gemmological Association of Great Britain, 420 candidates sat for the preliminary examination and 307 for the diploma. Centres were again established in many parts of the world and the number of entries for the diploma examination was the highest in the history of the Association.

Upon the recommendation of the examiners the Tully Memorial Medal has been awarded to Mr. Jonathan Brown of Derby.

The Rayner Prize has not been awarded.

The following is a list of successful candidates, arranged alphabetically.

DIPLOMA EXAMINATION—HOME

QUALIFIED WITH DISTINCTION

Brown, Jonathan Philip, Derby
Lewis, Roger Anthony, Wallasey
Ogden, John Mullen, London
Olieff, Peter Michael, Doncaster
Pratt, David, Bradford

Acker Holt, Robert, London
Adams, Michael E., Middlesbrough
Allum, Christopher John, Nottingham
Allum, Peter Dennis, Shaftesbury
Appleyard, John Trevor, Wakefield
Backshall, Henry George Robert, Hainault
Baker, Kenneth Robert, Whitehaven
Barrett, Garry Sydney, Sittingbourne
Binns, David George, Hastings
Bradford, K. J., Westcliff-on-Sea
Brook, Doreen May, Liverpool
Burgin, Derek Arthur, Nottingham
Butcher, Kathleen Mary, Sudbury
Cartland, Anthony John, Leamington Spa
Chalk, Christopher, Deal
Christie, Rosalind Seaton, London
Comely, Christopher Norman, Dorchester
Cotton, John Alan Day, London
Crossley, Roy, Halifax
George, Michael Christopher, Tunbridge Wells
Geyer, Adrian Michael, Birmingham
Gillings, Michael, Manchester
Gooding, Diana Janet, Eastbourne
Green, Adrienne, Wembley
Harvey, Roger Sweyn, Hull
Hazelden, John Norman, Worthing
Hilbourne, Anthony Charles, Maidenhead
Hiley, Hazel, Shipley
Hinchliffe, Brian, Sheffield
Holden, Andrew Neil, Walsall
Irwin, Margaret, Chester
Jenner, Peter Charles, Tunbridge Wells
Johnston, Iain Henry, Dumbarton
Keeling, Judith Mary, Stoke-on-Trent
Kirkpatrick, David John, Kenilworth
Knight, Irene, Liverpool
Lowe, Christopher Edward, Burton-on-Trent
Moran, John, Blackpool
Murray, David Ernest, Stratford-upon-Avon
Naim, Edward Youssef, London
O'Regan, Simon Barry, Doncaster
Poynder-Meares, Christopher Francis, Gloucester
Rajah, S. Senathi, Durham
Ryan, David Christopher, London
Saddington, Tom Frederick, Woking
Slusarczuk, Peter, Stourbridge
Spiers, Richard Anthony, Redhill
Stephens, Arthur Leslie, London
Tattersall, Paul Lawrence, London
Thomson, Ian, London
Walker, Thomas, Sunderland
Walton, Edith M. E., Prescot
White, Donald William, Tenterden
Williams, Anthony Martin, Birmingham
Williams, Robert, Birmingham
Woolf, Michele Debra, London
Wroblewski, Tadeusz, Birmingham

DIPLOMA EXAMINATION—OVERSEAS

QUALIFIED WITH DISTINCTION

Altaba Artal, Maria Dolores, Barcelona, Spain
Berlage, Peter Jurgen, Osnabruck, Germany
Hirohata, Tomoko, Osaka-Prif., Japan
Maslen, Grant Lewis, Nairobi, E. Africa
Mueller, Edith E., Frankfurt, W. Germany
Norton, Charles Leslie, Conyngham, Pa., U.S.A.
Peyerl, Wolfgang, Knights, Transvaal, S. Africa
Riuttala, Alexander Nikolai, Toronto, Ont., Canada
Rogan, Liv Solnor, Oslo, Norway
Schneider, Katharina, Hanau, Germany
Thant, Myo, Rangoon, Burma

Alforja Matoses, Enrique,
Sueca, Valencia, Spain
Alm, Eila, Riihimaki, Finland
Andres Barbera, Jose,
Valencia, Spain
Baker, Ann, Lucerne, Switzerland
Bjorndalen, Jan, Oslo, Norway
Carballal Cirici, Carmen,
Barcelona, Spain
De Bruin, Alphonsus Gerardus,
Heemstede, Holland
De Meillon, Laura,
Pietermaritzburg, S. Africa
Dyer, Wilbur E.,
Joliet, Illinois, U.S.A.
Fowler, Susan Elizabeth, Hong Kong
Fukabayashi, Hiroyuki,
Hokkaido, Japan
Gardiner, Anthony Cluff,
Abadan, S. Iran
Gartner, Heinz R.,
Schmisberg, W. Germany
Gelaberto Vilagran, Enrique,
Barcelona, Spain
Giles, Roy, Sydney, Australia
Grim, Roy Ivan, Laurel, Md., U.S.A.
Gyi, Ma, Rangoon, Burma
Hanna, Neil Randle,
Auckland, New Zealand
Harris, Marian Margaret,
Cape Town, S. Africa
Jackson, Lilian Isabel,
Reynella, S. Australia
Kaneko, Masao, Tokyo, Japan
Kivimaki, Kauko,
Hameenlinna, Finland
Koskinen, Aito, Helsinki, Finland
Krieger Rolf, Huddinge, Sweden
Lehtola, Maire, Helsinki, Finland
Leino, Terttu, Paimio, Finland
Lopez Sabater, Jose Antonio,
Valencia, Spain
Lopez Verge, Ramon,
Barcelona, Spain
Macleod, Helen L.,
Washington, D.C., U.S.A.
Maik, Shwe, Rangoon, Burma
Malvarez Martinez, Francisco,
Alicante, Spain
Mones Roberdeu, Luis
Barcelona, Spain
Monte Domenech, Joaquin,
Barcelona, Spain
Narayanamurthy, K.,
Pahang, Malaya
Naumanen, Pertti O.,
Helsinki, Finland
Nemoto, Yoshio,
Fukishima-Ken, Japan
Nittel, Lothar,
Freiburg, W. Germany
Oates, Harold A.,
Glen Ellyn, Illinois, U.S.A.
Peranko, Pyry, Lahti, Finland
Power, John Joseph,
Rosemere, Quebec, Canada
Pyykonen, Kaarina, Espoo, Finland
Ratnasekera, Wakkumburage
Ariyawansa, Ratnapura, Ceylon
Ritvanen, Hannu, Helsinki, Finland
Roca Cusachs, Juan,
Barcelona, Spain
Rorvik, Trine, Mosjoen, Norway
Salmona Delque, Ana Maria,
Barcelona, Spain
Silverthorne, Richard Leigh,
Johannesburg, S. Africa
Sole Barneda, Domingo,
Barcelona, Spain
Swe, San, Rangoon, Burma
Terry, Robert J.,
Lakewood, Ohio, U.S.A.
Tortosa Calveras, Francisco,
Barcelona, Spain
Trossarelli, Carlo, Torino, Italy
Uchida, Sumiko, Tokyo, Japan
Van Dam, Rudolf Alexander,
The Hague, Holland
Van Eik, Jacob Johannes,
Utrecht, Holland
Winstead, Frances F.,
Eugene, Oregon, U.S.A.

Woo, Shun Wai, Hong Kong
Woolf, David Hirsch, Johannesburg, S. Africa
Woolgar, Michael, Durban, S. Africa
Wrangel, Anna Stina, Bromma, Sweden
Zook, Theresa Fuetterer, Alexandria, Va., U.S.A.

PRELIMINARY EXAMINATION—HOME

QUALIFIED

Alexander, David, Harold Wood
Anderson, Carole, Sandhurst
Atherton, Stanley, Chorley
Banford, William David, Liverpool
Bennett, Frederick Charles Lewis, Manchester
Benson, C., Bangor, N. Ireland
Berry, Herbert, Wallasey
Blayney, Vivien Ingrid, London
Blundell, Raymond Louis, Liverpool
Boddington, William Cecil, Rayleigh
Booker, Peter Edward, Grantham
Burnett, Brian David, Formby, Lancs.
Butterworth, Joan Louise, Rochdale
Campbell, Alan J., Birmingham
Clark, David, London
Clarke, Roger David, Maidstone
Clear, Carol Ann, Dorking
Coulter, Peter, Northwich
Cranton, Keir, Surbiton
Crombie, J. M., London
Davies, Beryl Anne, Rhayader
Davies, Gena M., Pontypridd
De Graft-Hayford, Julian E. S., London
Doman, Eleanor Margaret, Ilford
Faulds, Matthew Christopher, London
Finch, Stephen Reginald George, Cuxton
Fogan, Eleanor Frances Alison, London
Fountain, Alastair John, Glasgow
Frampton, Derek Nigel, Bognor Regis
Frost, Julia Josephine, Cambridge
Frost, Richard Henry John, Northfleet
Garbiakova, Krystina M. J., Reigate
Gardner, Roy Roger, Reading
Gardner, Wilfred Charles, Reading
Gascoigne, Beryl, London
George, Michael Christopher, Tunbridge Wells
Gilchrist, John, Chesham
Gill, Royston Henry, Kidderminster
Golding, Derek Charles, Redhill
Gould, Robert, Southsea
Green, Margot Isabel, Stonehaven
Hammonds, Robert Newcastle-on-Tyne
Hanrott, Michael Richard, Banstead
Harwood, Harvey Anton, Southport
Hayesmore, Linda, Tenterden
Haywood, Stanley Edward, Liverpool
Hemachandra, Ranjith T., Birmingham
Herdman, Peter Robin, St. Boswells
Houlgrave, Peter Baron, Solihull
Howarth, David Harry, Mirfield
Hudspith, Thomas William, Chester-Le-Street
Hughes, Carolyne Sasah, Ilford
James, David John, Sidcup
James, Julia Jacqueline Ann, S. Nutfield
Johnston, Peter, Wallasey
Jones, Claude Barrington, Northampton
Jones, David Lewis, Orpington
Jones, Michael John Bewsey, Sevenoaks
Jones, Michael Noel, Tredegar
King, Michael James, Brighton
Knowles, Leslie Allan, Liverpool
Leaver, Herbert Charles, Virginia Water
Lee, Keith, Hartlepool

Leon, Bernard, London
Linley, W. H., Birmingham
Lyall, Linda, Alloway
Lynch, Eric, Wallsend-on-Tyne
Macaskill, Malcolm M., Glasgow
McCallum, Nina M. W., Motherwell
McCarthy, Christopher, Liverpool
Markowski, Robert W., Gravesend
Marriott, Anthony George Eyre, Chesterfield
Massie, George Alexander, Sheffield
Miller, G. J., Chesham
Moser, Peter Bernhard Stuart, Manchester
Neale, Brian, Middlesbrough
Needham, Brian, Ilford
Nightingale, Stephen, North Wembley
Noble, Patricia Warrington
Page, Michael John, Claygate
Paterson, Katherine E. T., London
Peacock, Pamela Mary, Stourbridge
Penny, Christopher, London
Peter, Stephen J., Leeds
Phillips, Ceinwen Rosalind, Cardiff
Popperwell, Elizabeth, Stockport
Popplewell, Wilfrid, Bristol
Rajah, S. Senathi, Durham
Reeve, R. D., Tunbridge Wells
Renel, Ronald Cecil James, Southampton
Reynolds, James Ian, Mexborough
Richmond, Philip Simon, Leeds
Rogers, Hazel, Sheffield
Rose, Philip Michael, Bournemouth
Sayer, Glynis, Rochester
Schapiro, Simon, London
Scott, Gillian Margaret, London
Scott, Owen Seymour, Welwyn Garden City
Seed, Stephen James, Preston
Speed, Graham Clive, Windsor
Stevens, Peter, London
Sweeney, John Michael, Rowlands Gill.
Taylor, Clive, Gravesend
Taylor, Michael Philip, Enfield
Thompson, Evelyn, London
Ward, Michael, Grimsby
Whitaker, Peter William, Southport
White, S. C., Sutton
Willcocks, Geoffrey Brian, Eastbourne
Wood, Kathleen Alice, Sheffield
Woods, Cecil Clifton, Hailsham
Wright, Frank Simeon, Billingham
Wright, Peter Stephen, London
Zacks, S., Barnet

PRELIMINARY EXAMINATION—OVERSEAS

Abeynayake, Chandani, Mount Lavinia, Ceylon
Alvarado Moro, Odorico, Barcelona, Spain
Amarasuriya, Sunil Tissa, Idar-Oberstein, W. Germany
Anderson, Alice, Toronto, Ont., Canada
Aparicio Miguel, Rafael, Valencia, Spain
Baker, Ann, Lucerne, Switzerland
Baker, Nancy Jane, Manotick, Ont., Canada
Bayarri Bosch, Federico, Barcelona, Spain
Berlage, Peter Jurgen, Osnabruck, Germany
Besteiro Rafales, Josefina, Barcelona, Spain
Bezuidenhout, Mary Elizabeth, Stellenbosch, C.P., S. Africa
Bishop, Paul L., London, Ont., Canada
Bros Font, Ana Ma., Barcelona, Spain
Buijvoets, Marie Louise, Velp (GLD), Holland
Butler, Michael John, Toronto, Ont., Canada
Cameron, Elinor, Ottawa, Ont., Canada

Carbonell Pujol, Rafael,
Barcelona, Spain
Chetty, Samuel Francis Casie,
Upplands Vasby, Sweden
Chikayama, Yoko, Tokyo, Japan
Cook, Marian Esther,
Victoria, B.C., Canada
Cuevas Diarte, Miguel Angel,
Barcelona, Spain
Cummings, Bruce Willard,
New York City, N.Y., U.S.A.
Custer, John J.,
Flushing, N.Y., U.S.A.
Del Monico, Anneliese
West Haven, Conn., U.S.A.
Doole, Rhumina Sukanthi,
Colombo, Ceylon
Dube, Rene Adrien,
Halifax, Nova Scotia, Canada
Eason, John Robert,
Manurewa, New Zealand
Espinosa Gonzalez, Jose,
Marbella, Malaga, Spain
Felix, Karen Hilde,
Schoonhoven, Holland
Ferrandiz Torrents, Pedro,
Barcelona, Spain
Fisher, Emmett W.,
Houston, Texas, U.S.A.
Fowler, Myrtle Winifred Alice,
Gymea Bay, N.S.W., Australia
Fraser, Edith,
Unionville, Ont., Canada
Gaarder, Kjerstin,
Blommenholm, Norway
Gamalath, Shiranie,
Padukka, Ceylon
Gangoso Guillo, Rafael,
Barcelona, Spain
Gans, Louis Benjamin,
Amsterdam, Holland
Garcia I Ainoza, Joan,
Barcelona, Spain
Garcia Cuevas, Joaquin,
Granollers, Barcelona, Spain
Gartner, Heinz R.,
Schmisberg, W. Germany
Gerryts, Petronella,
Stellenbosch, C.P., S. Africa
Girones Manzano, Manuel,
Barcelona, Spain
Gnanaratna, Welihinda Badalge,
Mount Lavinia, Ceylon
Goodger, William Donald,
Don Mills, Ont., Canada
Granda Uson, Ma de Fatima,
Barcelona, Spain
Greig, Donald Hugh,
Auckland, New Zealand
Gunasekera, Dunil Palitha,
Ratnapura, Ceylon
Hagen, Tore W., Oslo, Norway
Halvorsen, Inger, Lierbyen, Norway
Harris, Marian Margaret,
Harris, Marian Margaret,
Cape Town, S. Africa
Jackson, Lilian Isabel,
Reynella, S. Australia
Jayendran, Ariacutty,
Khartoum, Sudan
Juul, Erling, Skien, Norway
Kapp, Hans R., Basle, Switzerland
Karunarathna, Kahandawala
Mudiyanselage P. S., Colombo,
Ceylon
Karunaratna, Avanti Yasmin,
Kandy, Ceylon
Korevaar, H. J., Amsterdam,
Holland
Kurash, Edward,
Toronto, Ont., Canada
La Due, Martha J.,
Middlesboro, Kentucky, U.S.A.
Lopez Barroso, Miguel,
Barcelona, Spain
Lowe, Peter Eric,
Windhoek, S.W. Africa
McCarthy, Dorothy Lovell,
Greenbelt, Md., U.S.A.
Maehlum, Lottie,
Sandvika, Norway
Magnussen, Rita Helene,
Drobak, Norway
Mahavitane, Krishna Manel,
Katubedde-Moratuwa, Ceylon

Marin Calvo, Ma Luisa,
Barcelona, Spain
Maymo Mas, Jaime
Mataro, Barcelona, Spain
Melvin, Ena M.,
Lincoln, Mass., U.S.A.
Mueller, Edith E.,
Frankfurt, Germany
Myluaganan, Jeyakumar
Pakiyajothy, Colombo, Ceylon
Naing, Than, Rangoon, Burma
Newbold, Leslie John Claude,
Tusmore, S. Australia
Nogues Carulla, Joaquin Ma,
Barcelona, Spain
Obiols Mundet, Agustin
Barcelona, Spain
Ohguchi, Hideki,
Kanagawa Pref., Japan
Plotzeneder, Josef,
Salzburg, Austria
Ponsa Aguilar, Jose,
Tarrasa, Barcelona, Spain
Poot, Joost Rogier,
Schoonhoven, Holland
Proussalidis, Efthimios,
Willowdale, Ont., Canada
Rajamuthu, Anthony Nelson R.,
Colombo, Ceylon
Ratera Oliva, Jaime,
Barcelona, Spain
Rehtijarvi, Pentti, Helsinki, Finland
Robinson, John Bruce,
Palmerston North, New Zealand
Romeu Larios, Jose Jaime,
Barcelona, Spain
Rosal Paneda, Ma Jose,
Oviedo, Spain
Roth, Albert L.,
Denver, Colorado, U.S.A.
Rovira Rabell, Manuel,
Barcelona, Spain
Rughini, Enrico, Bordighera, Italy
Sabina Stenson, Ann P.,
Ottawa, Ont., Canada
Sanchez Llorens, Jose Francisco,
Castellon de la Plana, Spain
Sanchez Llorens, Juan Fernando,
Castellon de la Plana, Spain
Sanchez Pinazo, Octavio,
Valencia, Spain
Santala, Ulla Riitta,
Valkeakoski, Finland
Schneider, Katharina,
Hanau, Germany
Schulze, Heinz, Austin, Texas, U.S.A
Senti, Yves Andre,
Geneva, Switzerland
Smidt, Maria Josephina Antonia,
Salisbury, Rhodesia
Soler Serra, Alejandro,
Barcelona, Spain
Straatman, Eduard Karel Victor,
Bussum, Holland
Sukapaa, Ilse, Kauniainen, Finland
Sundqvist, Reijo, Helsinki, Finland
Swe, San, Rangoon, Burma
Thein, Sein Toe, Rangoon, Burma
Tilakaratna, Welihinda Badalge,
Mount Lavinia, Ceylon
Tomas Castelltort, Santiago,
Barcelona, Spain
Vadnal, Dusan,
Ljubljana, Yugoslavia
Van Dam, Rudolf Alexander,
The Hague, Holland
Van Der Pol, J., Utrecht, Holland
Vives Martinez, Silvia,
Barcelona, Spain
Walter, Charlotte A.,
Miami, Florida, U.S.A.
Webb, Ronald John,
Auckland, New Zealand
Westby, Eli, Strommen, Norway
White, James G.,
Rockville, Md., U.S.A.
Wijesuriya, Indrawathie
Swarnalatha, Ganemulla (W.P),
Ceylon
Will, Richard Arnold Franz,
Salisbury, Rhodesia
Wobito, Rudi,
Scarborough, Ont.. Canada

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and

PROCEEDINGS OF THE
GEMMOLOGICAL
ASSOCIATION
OF GREAT BRITAIN

GEMMOLOGICAL ASSOCIATION
OF GREAT BRITAIN
SAINT DUNSTAN'S HOUSE, CAREY LANE
LONDON, E.C. 2

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NEEDLES IN CORUNDUM OTHER THAN RUTILE

By W. F. EPPLER

RECENTLY, a paper was published with the description of inclusions of corundum in corundum[1]. The stones in question are light blue sapphires with a tinge of green or brownish or purple-coloured corundums respectively. They are found in the Umba mine near the river Umba in the Northeast of Tanzania in the neighbourhood of the Kilimanjaro mountain.

The inclusions are elongated needles which, at first sight, seem to be similar to the well known rutile needles that occur in so many corundums. They are shown in Fig. 1. The picture shows that the needles follow three directions, which appear to be at right angles to each other. Fig. 2 confirms this impression, but in reality they differ from the right angle to a small but certain amount. According to the above mentioned publication, they run at right angles to the faces $(42\bar{1})$, $(\bar{2}2\bar{1})$, and $(\bar{2}4\bar{1})$, which represent the faces of steep hexagonal pyramids. With an X-ray analysis it could be found that the "needles" consist of corundum and that they are in "twin positions" to the host crystal. Surprisingly, each of the needles is again twinned parallel to the prism faces of the host corundum. Furthermore, the needles are of secondary origin with respect to the surrounding corundum crystal. This and the fact that the inclusions are the cause of a considerable tension make it likely that the needles are originated by pressure. But this theory is not yet proved.

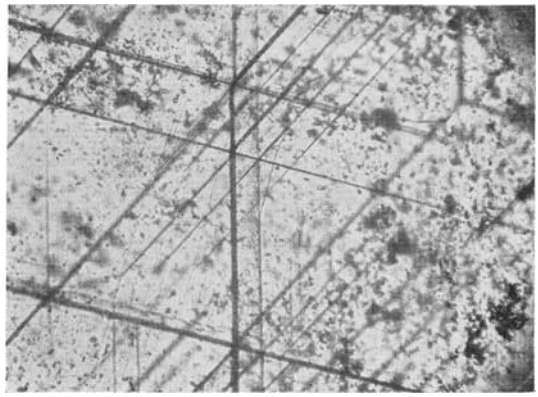

FIG. 1. Light blue sapphire from Tanzania with strictly orientated dark needles of corundum accompanied by a great number of small and rounded zircons (here out of focus). 22 ×

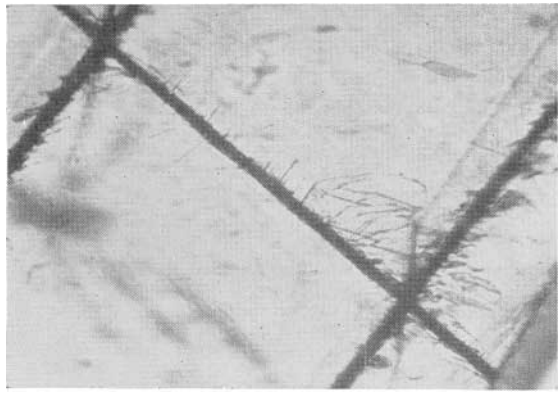

FIG. 2. Same sapphire as in Fig. 1 at a greater enlargement. The needles appear to be perpendicular to each other. 65 ×

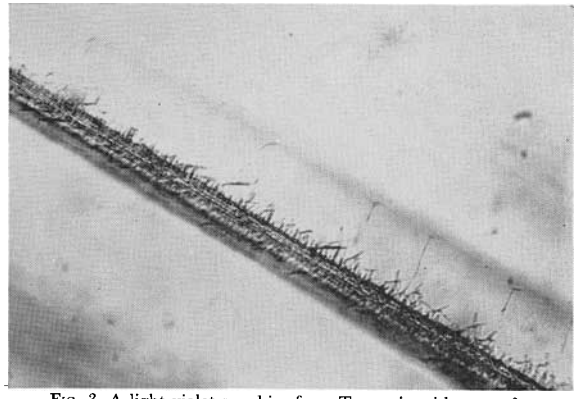

FIG. 3. A light violet sapphire from Tanzania with part of a needle and "fringes". 120 × (As Fig. 1 taken from Ref. 1)

Fig. 2 reveals some very fine cracks starting from the needles. They are shown at a higher magnification in Fig. 3 and are considered to be tension cracks. It is assumed that they are also the cause for the opacity of the needles.

The rubies and sapphires from Tanzania did not reach the market before 1960. Their particular "needles" could be considered as a hall-mark for corundums of this occurrence. But this is not possible, as rubies and sapphires from other and long-known localities include similar needles. In a small but very good coloured blue sapphire from Yogo Gulch in Montana, U.S.A., a group of the same needles could be observed, intersecting each other at nearly right angles (Fig. 4). There is no doubt that they

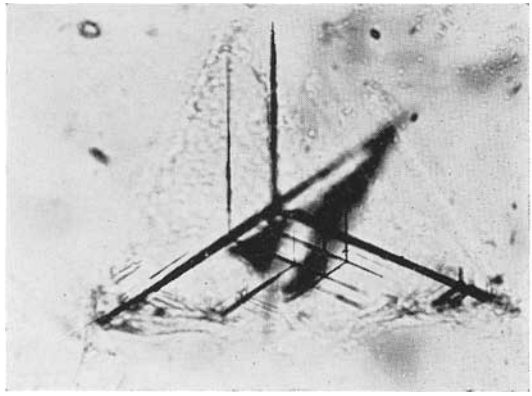

FIG. 4. Montana sapphire with a group of nearly rectangular intersecting needles. 120 ×

also consist of corundum. Even the famous "Mogok Stone Tract of Burma" has produced rubies with these particular inclusions. They are exhibited in Fig. 5. It must be confessed that these corundum needles are very small and that they can be overlooked very easily or mistaken for rutile.

Corundum, as an inclusion in corundum, was first mentioned by P. C. Zwaan[2], who described it as "some platy colourless inclusions". H. J. Schubnel[3] characterized the "needles" in the Tanzanian corundums as a kind of dislocation, an opinion which later proved to be correct.

Another rarity could be observed in a light-brown-coloured sapphire from Tanzania, as it is exhibited in Fig. 6. This needle runs parallel to the base plane of the sapphire. It is colourless and doubly refractive, with a refractive index somewhat lower than that

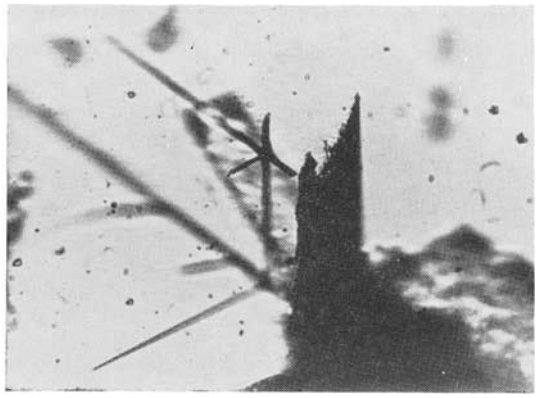

FIG. 5. Ruby from Burma with corundum needles. 228 ×

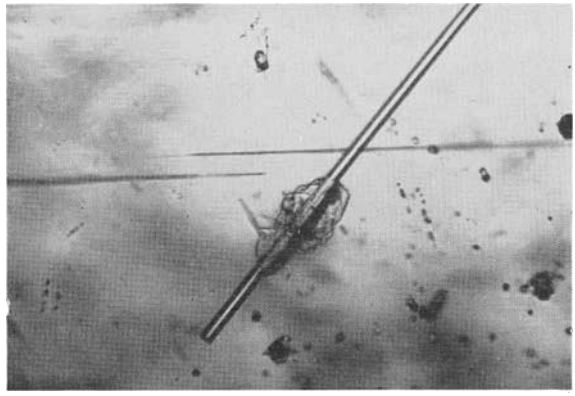

FIG. 6. A long and colourless needle (apatite ?) in a light brown sapphire from Tanzania. 65 ×

of the corundum. Therefore it is assumed, that this needle represents an apatite crystal, the mean R.I. of which is not very different from 1·64 (against 1·76 of corundum). In the lower part of the needle is a small tension crack and in the middle of the picture are two needles of corundum, running horizontal and parallel to each other.

The sapphires from Tanzania with the very interesting needles of corundum are a generous gift from Mr. R. Biehler, the owner of the firm Ernst Faerber in Munich, to whom the author owes a debt of gratitude.

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GEMS IN COURT*

By R. WEBSTER

THROUGHOUT the ages the high value of gems and jewellery has led to villainy. There are notable cases and cases of minor importance in themselves, in which the gemmologist has made a contribution either to convict a villain or to prove the innocence of someone suspected of an offence.

What is probably the first recorded use of science in forensic matters was the problem set Archimedes in the 3rd century B.C., which led to the famous principle which is the basis of density determinations.

The spoils of war rather than pure villainy was the stealing of such famous stones as the Koh-i-noor diamond and the Timur ruby when the Shah Jehan sacked Delhi in 1739. More reprehensible was the stealing of the diamond necklace by Lamotte, a piece of villainy which helped to send Marie Antoinette to the guillotine. Those troubled times in France saw the theft of the Regent and Hope diamonds from the Garde Meuble, but all of these events are part of the history of the world.

The 1880's brought the "reconstructed"—or "Geneva" rubies, stones whose genesis is still in debate. It is recorded that at this time a Berlin jeweller bought a parcel of rubies which were found, by the Paris Syndicate of Jewellers, to be small real rubies fastened together (they did not say how). The Zurich jeweller who sold the stones refused to take them back, as he said that the guarantee was only for the genuineness of the stones and not their size.

A report of 1893 referred to a dealer who had bought a ruby from a jeweller and later had suspicions that it was a doublet. An attempt was made to obtain redress through the process of law, but in those days there was no technical evidence available to guide the Court and the decision was made to cancel the contract.

The famous case (about 1911) of the Max Mayer pearl necklace, which was originally part of the Portuguese Crown Jewels, while certainly a *cause célèbre*, was purely a detective investigation and gemmology was not involved.

1921 brought the cultured pearl and with it immediate problems, for there was at this time no conclusive way by which they

* Taken from a talk given by Mr. R. Webster F.G.A., to members at Goldsmiths' Hall, London on the 25th January, 1972.

could be identified. The cultured pearl dealers wanted this—for them a happy state—to continue and in furtherance of this instigated a prosecution under the Merchandise Marks Acts against a William Bullock, who traded as O. Toshimo, for selling a "cultured pearl necklet" which was actually a shell-based imitation pearl necklet. Normally such a case should have taken little more than an hour of the Court's time. The case took three days, due to the fact that the prosecution called two experts whose main object seemed to be to emphasize that cultured pearls could not be identified unless cut open. These experts were Dr. Lyster Jameson, technical adviser to the Board of Agriculture and Fisheries, and a Mr. A. F. Calvert, a mine owner and expert on pearl culture who had written a book "Pearls and pearl culture". Bullock was fined £20 and the magistrate awarded £20 costs only saying "I have taken into account the excellent advertisement the prosecutors in this case have had".

During 1925 a Paris Court, in respect of a case brought by the *Chambre Syndicale des Negoçiants en perles et diamants* against certain cultured pearl dealers (L.Pohl *et al*), brought in a decision that cultured pearls were real pearls. This left confusion worse confounded. In this same year a William Giles was charged with attempting to obtain money by false pretences in that he passed off a cultured pearl tie-pin as a real pearl. After a preliminary hearing at Marylebone Police Court the case went to the Old Bailey, when it was found that the exhibit produced was not the same pearl pin that had been shown in the lower Court. Despite this the case was thrown out only after considerable argument on the lack of proof as to whether a pearl was cultured or not. Probably through the fact that better methods of detection had then come about the decision of the Paris Court of 1925 was reversed and cultured pearls were ordered to be sold as such and not as real pearls.

The first criminal prosecution in which a qualified gemmologist provided expert evidence was the case of John Rice (1935) who had successfully deceived pawnbrokers with zircon-set rings. B. W. Anderson gave evidence for the prosecution and for the first time used as pictorial evidence transparency pictures taken by X-rays.

The same year brought forth the "synthetic diamond" scare, when a bond Street antique dealer, Victor Jourado, got exceptional press publicity on "synthetic diamonds", which were in reality synthetic white spinels. Owing to the widespread press publicity the London Chamber of Commerce decided to allay the public's fears

by radio broadcast based upon the laboratory report rather than take action through the Courts against Jourado.

About a couple of years later C. J. Payne gave evidence in a civil case where it was inferred that a sapphire in a ring had been sold as a genuine sapphire whereas it was a synthetic stone. The stone presented to the Court, which was indeed a synthetic sapphire, was found to weigh less than the weight of the stone as recorded in the jeweller's stock book, and it was denied that the stone produced was the original stone sold. Under cross-examination the plaintiff disclosed that whilst she was on holiday in the near-east the ring had been given to a local jeweller to repair, and had, therefore, been out of her hands. The case collapsed.

At the beginning of the war there were two reports on diamond doublets, Tisdall reporting on the first one (1941) and myself on the second (1943). This last stone was seen by the Officers of the Diamond Section of the London Chamber of Commerce who purchased it to take it off the market, and, further, as no litigation had occurred in either of these cases, the Board of Trade put out a warning notice. A third diamond doublet was an exhibit in a case which came before a Court at Liverpool, and in 1944 there was a case involving an alleged "painted" diamond.

There have been a number of cases where imitation pearls have been involved. The most important was the trial for murder of Neville Heath, who, after killing a prostitute in Notting Hill, went to the South Coast where he murdered a WREN at Branksome Chine, Bournemouth. The WREN was wearing an imitation pearl necklet and during a struggle this necklet broke scattering the beads, one of which fell into Heath's jacket pocket, later to be found by the police, who also recovered 27 of the beads from around the dead girl's body. These 27 pearls, and the one from Heath's pocket, were taken to the London Chamber of Commerce laboratory for examination in order to see if they matched.

The pearl found in the pocket was prime evidence and could not be damaged in any testing procedure. The pearls were compared with one another for colour and the diameter of the string holes measured and densities taken. The density was found to be 2.53 and was a value lower than recorded in literature for that type of imitation pearl. This difference was attributed to the manufacturer being unable to obtain the normal "alabaster" glass; this was just

after the war when things were not normal. From the data found Anderson testified in Court that the pearls were similar..

Another case concerned a suspect alleged to have stolen a number of imitation pearl necklets from a store. the prime evidence being that a similar necklet was found in possession of his daughter. Sprectrograms taken of the glass of the beads in the necklet belonging to the daughter and those from the stock in the store showed the glasses to be different and the suspect was then released. A third case concerned the older "Roman pearls", hollow glass bead type or wax-filled type. These pearls had been burnt in a fire and for some undisclosed reason the probable date of the pearls was needed. It was ascertained that they were not made in France after about 1930, and indeed it was proved that the owner had visited Paris about that time, and had bought a necklet.

It will be readily seen that for forensic purposes a very different attitude must be taken from that usual in ordinary gemmological considerations. Not only must the nature of the bead, and indeed of the glass, be carefully determined but also the coating, for this can vary greatly, not only in the bonding used for the "fish scales" but in the "fish scales" themselves, for there are a number of synthetic iridescent compounds used. Far too little work has been done on this subject.

The 1950's brought a spate of Court cases including two which concerned burglary. The first of these involved 23 small diamonds weighing together 0.53 carat, which were presumed to have been forced out of jewellery settings with pliers. To illustrate to the Court the likelihood of this a photomicrograph of the broken edges of two stones was produced in Court. The second case concerned a large emerald-cut diamond which had been stolen from the widow of Leslie Howard. Apprehended by the police after he had tried to sell the stone to a jeweller the villain was tried and sentenced. I gave evidence as to the nature of the stone and, when I was preparing my report, Anderson to save time weighed it for me. Right out of the blue I was asked by the defence "Did you weigh the stone?". Somewhat disconcerting and a salutory reminder always to do everything yourself.

There have been several incidents where faked diamond crystals have been found in parcels of rough diamonds. Synthetic sapphire and beryl are among materials which have been cut in octahedral form.

1953 brought the German synthetic diamond fraud where Hermann Meincke and his family defrauded a group of German industrialists. When the manufacture was investigated by a scientific commission it was discovered that Meincke's neice, Edeltraub, was dropping natural diamond crystals, which she had secreted under her long finger nails, into the crucible. Miencke was tried, found guilty and sentenced to three years in jail. The decade ended with the first Court case in England where strontium titanates were used as fraudulent diamonds.

The trials which can beset a jeweller are well exemplified by the following story. A few months after having her cultured pearl necklet restrung a lady found that some of the pearls had unaccountably darkened. Seemingly not satisfied with the jeweller's reply when she went to him, for the jeweller himself could not offer an explanation, the lady went to the police. Laboratory investigation was suggested and this showed the cause to be grease, probably from cosmetic creams, which had percolated via the string to the discontinuation layer between the bead nucleus and the outer nacreous layer.

Two intriguing examples of criminal investigation were carried out by an Australian Police Officer, who is also a qualified gemmologist. The story of the first of these was that an emigrant from England informed the Australian Police that before he left England he was offered an unmounted red stone by a stranger whilst he was in London's east end. The stranger first asked £5 for the stone but no one took up the offer. The stranger said he would throw it away, but eventually gave the stone to the emigrant. This was in 1959, and some years later the emigrant's wife found this red stone among some junk and thought she would like it mounted as a dress ring. The jeweller to whom he took the stone advised him to have it insured as he thought that it was a real ruby. Several jewellers examined the stone but could not be sure of it. The emigrant became worried in case he had received a stolen ruby and took it to the Police for examination and enquiries, and mentioned that he hoped for a reward.

Sgt. Barrie Cox examined the stone and thought that it was a Siam ruby but felt he would like confirmation. He wrote to me giving me all the details he had found on this 11.68 carat stone. The details given were excellent and with the letter there were 16 35mm transparencies of the stone and its inclusions and these were excellent.

There was no doubt that it was a Siam stone. Scotland Yard were informed but despite investigation there was no report of such a stone being lost or stolen. The case was dropped, the stone handed back and that was all.

The second case in which Det/Sgt. Cox was involved was in pursuance of a murder enquiry. It was found that gravel from a suspect's clothing contained small tourmaline crystals having characteristic inclusions, and these matched similar crystals found in the gravel at the scene of the crime. This destroyed the suspect's alibi.

The preparation of pictorial evidence by X-ray photographs can provide surprises. An example of this was when a parcel of diamonds was checked by this method and was seen to contain a "foreigner" which stood out strikingly. No attempt was made to isolate this "stranger" but it was reported in evidence. Probably with a view to discrediting a witness the defence did sort through the parcel and found the piece—it was glass. Another picture revealed a break in a ring shank which had been overlooked during physical examination.

A surprising episode occurred some years ago when a merchant called at the London laboratory and asked whether a stone in a sealed packet could be identified as a diamond or not without the packet being opened. The story was that a dealer had left the sealed packet to cover a loan but that there was some suspicion that things were not quite right. X-ray pictures were taken using various stones as controls, and by the degree of transparency it was proved that the stone was not a diamond but could possibly be a spinel. However, the packet was redeemed and as both persons have died we shall never know the answer.

Another case, which could have gone to law, was the discolouration of a cornelian stone in a pair of cuff-links. Brought in by a manufacturer's agent the stone was seen to have discoloured to a pale yellow around the edges and we were asked to explain this happening. I suspected seepage from a dip bath but it was denied that such a procedure was used. Eventually by dint of questioning it was found that in this particular case this dipping in a sulphuric acid bath had been done.

Anticipating questions from an opposing counsel is a matter always worth considering when acting as an expert witness. Such questions as 'Is it a pigeon's blood ruby"? has been often asked, but

here the answer is easy. Less easy to answer are such questions asking for the meaning of synthetic, artificial or imitation.

Finally, the case of the so-called "Deepdene diamond" last year is a classic example of the value of gemmological investigation, for if it had not been reported, as it was just before the sale, that the stone was artificially coloured, then no one knows what future litigation would have been in store.

THE ORIGINS OF "DIAMOND"

S. B. NIKON COOPER, B.D., F.G.A.

DIAMOND—the gem most used by jewellers, and because of that the most familiar name of any among gemstones. A name of associations; a name to conjure with; and a name also that has a pedigree stretching back to nearly 2,500 years.

Our term comes from the Greek: *'Αδάμας* (*α* privative = 'not'; *δαμαν* = to "subdue", to "conquer") hence: "Unsubdued", "Invincible". We find it first applied to a stone with *Theophrastus*, 4th century B.C. Greek philosopher, in his work: "*Περὶ Λίθων*"—"On Stones". Speaking of "incombustible stones", he almost casually refers to the *'Αδάμας*—which therefore by inference, would be an example well enough known to his students. Unfortunately, he does not go on to describe it, and so we are left with the "unsubdued (by fire)"—a description which could apply to many minerals at his time; but which, almost certainly, did not include our diamond.

Nor do we find any reference to "*Αδάμας*" in the Septuagint (2nd century B.C.)—the "diamond" of our English Bibles being ascribed in every case to some other Greek stone.

The next use of the term comes with *Pliny* (1st century A.D.) in his "Natural History", the letters being simply transliterated from Greek to Latin, with the resulting form: "*Adamas*"—incidentally, the most popular name of any for "diamond" through the ages: we find it occurring with Marbode (11th century); in the 13th century Lapidaries of Arnold, Thomas and Bartholomew; and even as late as 1546, with Agricola (De Natura Fossilium). With Pliny, the legend of diamond's "invincible" character is fully developed: the "hammer-and-anvil" myth, which we will see quoted time and time again by later writers, is given here. A true adamas is so hard that it will "resist the blow . . . cause the iron to rebound, and the

very anvil split asunder." (Book 37: Ch. 15). It is fortunate indeed that the "warm blood of a goat" is near at hand should the stone have to be cleaved!

This departure from his otherwise exact and scientific observations can mean only one thing: the "adamas" was rare to the Romans—so rare that Pliny could not verify the stories that had been told him. But, was it "diamond"? Pliny knew of six "varieties", all of which have been variously identified. However, the fact that he labels most of them as "degenerate" would seem to imply that he knows (even at second-hand) of the true "invincible" stone.

Reverting to the name, the next development is with *Isidore of Seville* (7th century) in his "Etymologiarum", "adamas" becoming "*Adamans*". Incidentally, we can see that with the decay of the Roman Empire the diamond lost its popularity. Smaragdus (emerald) is the first stone. Diamond in fact, in his colour classification, comes after "crystal"; and most of the facts he gives are borrowed, re-told from Pliny. One feels that the diamond now is more valued for its ability to work other stones (. . . "gemmis insigniendis perforandisque.")

And here throughout the Middle Ages the name rests, either "adamas" or "adamans". The only development being with the application of its "powers". Hence by the time of *Marbode* (11th century) the magical aspect is all-important. If it is bound on the left arm it is a sure charm to make the bearer invincible. His enemies will be repulsed; likewise in lawsuits. He will be invulnerable to ghosts, false dreams at night, poisons, and even insanity!

We move on now to the 15th century. This was particularly a time when spelling was of less importance. In some MS. (example: Peterborough 33) we find as many as eight different spellings for the same term. However they show a phonetic trend. Thus, in the *Peterborough MS.*, "adamans" becomes "*Adamant*", with next, the important step of the added extra syllable: "*Adyamant*". A still greater change comes with the *Douce MS.* (Douce 291)—with the dropping of the first "a" of the name. This, although it makes nonsense of the strict derivation (i.e. "diamond" now becomes "vulnerable"!) yet English euphony demanded it, and from now on, all the spellings start with a "D". So "*Dyamaunde*"; or again, even more close to our own, with the "y" becoming "i": "*Diamaunde*". Back in the Peterborough MS., the next stage follows swiftly: "*Diamounde*", and even "*Diamonde*".

Incidentally, these MSS. provide indisputable proof that they were referring to our "diamond". We read (Peterborough 33): "iiij cornered in schap"; "resonable to ye colour of cristall"; coming from "ynd" (India); and again—that faceting, for diamond, is still unknown at this time: "no man may amend him of bewte ne polissh him". To compensate for this, its magical value had now increased: to the previous long list is added the virtue of protecting you from falling off your horse or your wife from a miscarriage!

We have only one more step to take in our journey of derivations—to drop the final "e" to become the diamond of modern-day spelling. This occurs for the first time at the beginning of the next century in the "Speculum Lapidum", or "Mirror of Stones", by *Leonardus Camillus*. He writes of "*Diamond*"—our spelling and our stone. And with him, the Age of Science is almost upon us. No longer are the old statements quite so unquestioned. The first blow against Pliny's "anvil" myth is at last struck: "I have seen many broke with the Blow of a Hammer" says Camillus.

The myth died hard however. Many a diamond had yet to be maltreated in this way before its superiority would be assured for other quite different reasons. But "diamond"—the stone, and the spelling—has now reached the front of the book—the first stone to be discussed—*the* first stone of the jeweller from this time onward.

A COMPARATIVE STUDY OF RHODESIAN RHODOLITE GARNET IN RELATION TO OTHER KNOWN DATA AND A DISCUSSION IN RELATION TO A MORE ACCEPTABLE NAME.

By IAN C. C. CAMPBELL, F.G.A.

THE final remarks by B. F. Martin in his study of rhodolite garnet as published in the April 1970 *Journal of Gemmology* (Vol. 12 No. 2), that more investigation is required of this subject, has prompted me to make some form of a comparative study of what has proved to be rhodolite garnet of known Rhodesian origin. Twelve stones have been chosen for this purpose.

It is hoped that the above-mentioned author will have no objection to the reproduction here of the main points of his study. These constants will be shown again in schedule form later when comparison is made with the results of the Rhodesian stones. The data are as follows:

1. The only constants (R.I. 1·76 and S.G. 3·84) that appear to be quoted to date (apart from Martin's study) are apparently based on rhodolite from Cowee Valley, Macon County, N. Carolina. Martin did in fact measure the R.I. of a known Carolina stone and found it to be 1·758, but the only reference to specific gravity was that it (and 11 other test stones from a different source) sank rapidly in pure methylene iodide and at about the same rate. (The S.G. of methylene iodide being about 3·32–3·33).

2. The refractive indices of the 11 test stones all fell within the narrow range between 1·745 and 1·750, giving an average of 1·747. This falls near the middle of the range for pyrope. It was brought to notice that the apparent variations of the upper limit for pyrope, as given by different authors, are 1·751 to 1·76 to 1·77. (1·77, by Webster, has since been amended to 1·75 in a later edition of "Gems").

3. Definite information recorded in standard works is that rhodolite shows the absorption bands characteristic of the almandine spectrum. Martin's known Carolina stone, as well as the 11 test stones, showed similar results.

4. Difference in the habit of included apatite crystals relative to the known Carolina stone and 4 of the test stones (the others showed no distinct inclusions) suggested that the latter mentioned batch originated from a different source (possibly Tanzania).

5. References were made to the report by Webster that the composition lies between pyrope and almandine in the ratio of 2:1.

6. The important visible feature of rhodolite is that of colour which is said to be from a rose-red to pale violet.

The aforementioned are, in essence, the data extracted from the study by Martin, and would suggest that a further investigation into this variety—particularly from known sources—may assist in clarifying, or widening, the already known optical and physical constants of this variety—furthermore, perhaps even bridging the obvious gap between the previously stated values and those by Martin. The following study of Rhodesian rhodolite garnet (from a known source) appears to fit into this "gap" remarkably well.

The Rhodesian Stones

Robert Webster made available to the writer two known Macon County stones which were used for the purpose of colour comparison with the Rhodesian stones, the latter obviously falling within the qualifying colour range.

The stones are extracted from what is apparently a loose and crumbly, pale green form of biotite at a depth of between five and fifty feet from the surface (which is roughly as far down as the workings have gone to date). The garnets are said to be easily extracted and are in profusion. An interesting development, according to the owner, is that the colour of the stones appears to grade off from an extremely dark red at one end of the claim to a paler pink at the other end—the intermediate colours ranging through the reddish and pinkish to violet. The stones, as found, do not appear to have any particular form and from the batches examined are of a fragmented nature, as though red glass had been taken and broken into smaller pieces.

The test specimens are numbered R.1 to R.12 inclusive. Polished flats were put on approximately opposite sides of most stones in order to make microscopic examination somewhat easier, immersion liquids being used when required. The flats were also necessary in order to measure the refractive indices. A Rayner refractometer and sodium light source were used.

Specific gravity was computed hydrostatically with the use of absolute alcohol. The instrument used was the latest type electric Mettler H.800 C. metric carat balance, the accuracy being to within 0·002 gm. A Westphal balance was used to determine the S.G. of the alcohol at the time of the test.

These values are reproduced in graph form at the end of the article. A direct comparison is thus achieved and is perhaps represented in a more coherent form.

Comparison Tables

Origin	Specimen No.	Wt. Metric Carats	R.I. (Isotropic)	S.G.	Reaction to: S.W.U.V. 2540Å	Chelsea Filter	Almandine Spectrum
Rhodesia	R.1	3·383	1·757	3·87	All stones inert	All stones: Colours a shade deeper	Medium
	R.2	2·646	1·758	3·89			Pale
	R.3	2·510	1·750	3·83			Medium
	R.4	1·886	1·759	3·86			Medium
	R.5	2·280	1·750	3·83			Pale
	R.6	2·540	1·755	3·86			Medium
	R.7	2·279	1·758	3·86			Pale
	R.8	2·290	1·755	3·84			Pale
	R.9	1·990	1·754	3·84			Pale
	R.10	1·318	1·750	3·83			Pale
	R.11	1·047	1·758	3·83			Very pale
	R.12	0·891	1·760	3·89			Medium
Average:	12 stones		1·755	3·85			Moderate to pale
Martin's Test Stones (Tanzania?)	2 stones	Not known	1·745	Values unknown. All stones sink in methylene iodine	Not known	Colours a little deeper but not dulled	3 main absorption bands characteristic of almandine. Moderate intensity
	5 stones		1·747				
	1 stone		1·748				
	2 stones		1·749				
	1 stone		1·750				
Average:	11 stones		1·747	In excess of 3·33			
N. Carolina: established (Av?) values	—	—	1·76	3·84	Not known	Not known	Characteristic of almandine same as above
"Martin's Stone"	—	—	1·758	Sinks in M/Iodide		Colour little deeper but not dulled	
*Webster: Cut	—	0·42	1·761	3·84	Inert.	Shade deeper.	
Rough	—	1·118	—	3·89	Inert.	Shade deeper.	
Average:	—	—	1·760	—	—	—	—

*Webster's two Macon County stones tend to slightly increase the top R.I. value of the N. Carolina Rhodolite to 1·761 and the S.G. noticeably to 3·89 in relation to previously published figures, although probably the already established figures refer to the *average*. It is realized of course that the additional Carolina values tabled above refer to only three stones.

Inclusions:

Needles:

Orientated needles in nearly all stones, typical of almandine. They run in two directions. Some include needles running parallel to each other and in one direction only. Concentrations vary in each stone, some being heavy and others light. Only one did not show needles.

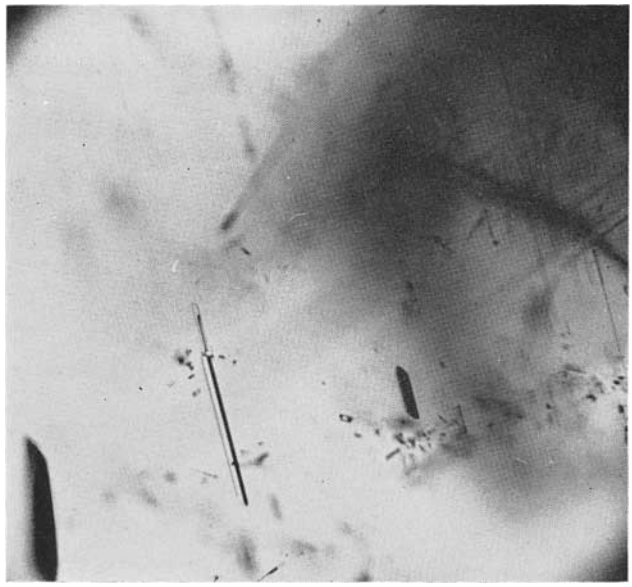

Inclusions in specimen R.6.

Haphazardly arranged tubes in specimen R.7.

"Zircon" Haloes:

Similar to Ceylon garnets. Evident in four stones.

Minute, Irregular Dot-like Crystals:

Evident in half the stones and ranging from pin-prick sizes, through dot sizes to slightly larger. In varying concentrations in each stone.

Feathers:

Of irregular shape and "rough" appearance (R.9, R.10, R.11). Other feathers appearing like fine flower-type petals but these are strongly suspected as internal fractures.

Smooth Tubes with Rounded Ends:

Some orientated in one direction and comparatively small in some stones (R.10, R.11). Others, by comparison, very large and haphazardly arranged; these larger ones being grouped and in heavy concentrations (R.7).

Specimen R.6 Entirely Different to others in respect of Inclusions:

Wide variation:

(*a*) Orientated needles.

(*b*) Two-phase inclusions: typically parallelogram in profile. Similar to calcite rhomb in form with included thick tube running diagonally within.

(*c*) Thick, larger, orientated tubes of apparently same type as that which forms part of the two-phase inclusions.

(*d*) Other irregular and geometric patterns.

Although it is not known, without expert analysis, what the above inclusions mainly are, it is obvious that there is no resemblance (except for the orientated needles) to the Carolina stones and the stones of suspected Tanzanian origin. Nevertheless, and ignoring the needles, these inclusions may well confirm the origin of similar stones of previously "unknown" origin. These come from the Beit Bridge district in Rhodesia.

Opinions may vary in respect of what the hue of colour of rhodolite should be. It is understood that certain quarters favour the decidedly or predominatly pink colour as the correct one, other hues they say being unacceptable. Nevertheless, the description is "rhododendron-red", meaning "rose-red". This is at variance with the "pink only" opinions, although pink is part of the colour range.

In addition to the test stones (R.1–R.12) a batch of 50 faceted rhodolites have been examined by the writer. All of them, in-

Oriented needles and tubes in specimen R.8.

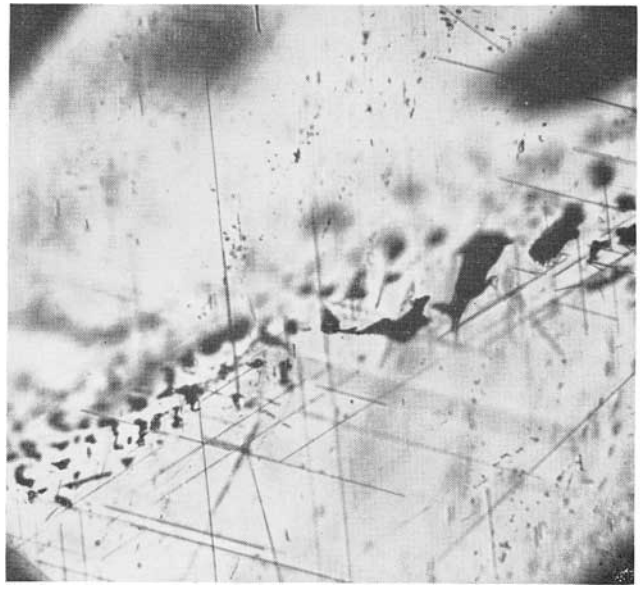

Irregular shaped feathers and oriented needles in specimen R.9.

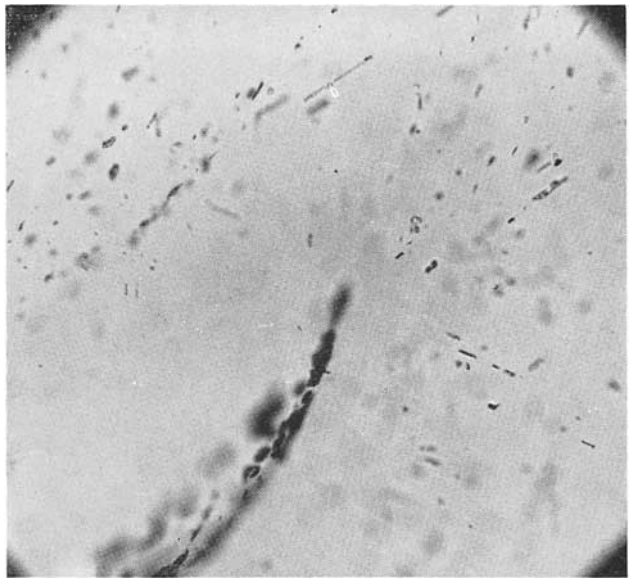

Inclusions in specimen R.10.

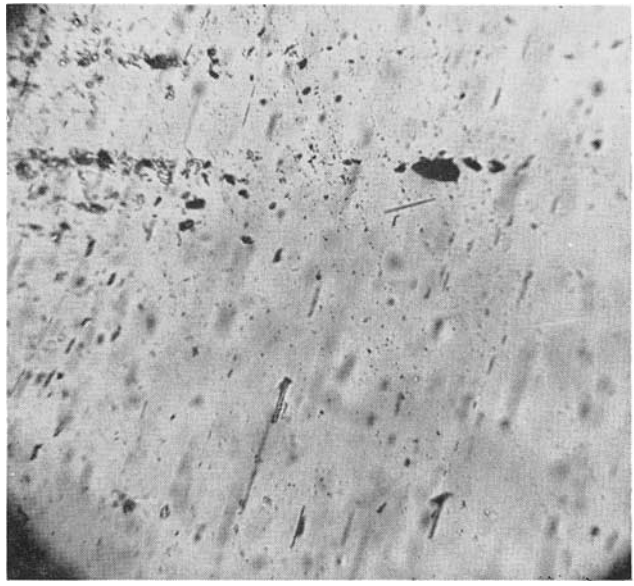

Irregular feathers and inclusions in specimen R.11.

cluding the test stones, were compared with the two known specimens from Macon County kindly loaned by Mr. R. Webster. This proved useful in that virtually 18 per cent of the 62 stones were practically the same hue as the Macon ones—that is to say, with a tinge of violet. The balance varied from medium shades of pink to reddish-pink (rose-red?).

The specific gravity of these faceted stones was not assessed, but the refractive indices of all stones, except one, were between 1·750 and 1·760 as indicated by the original 12 test stones. The exception gave a reading of 1·749. In view of this it is considered reasonable to accept that the range for the Rhodesian stones lies between 1·750 and 1·760.

An interesting side issue has developed in this study, in that test specimens R.1, R.2 and R.7 showed inclusions of zircon type haloes. It is understood that only Ceylon garnets showed these. Specimen R.12 exhibited a poor example of one.

It has been with considerable interest that I have read extracted reports concerning this particular variety of garnet (as well as others) from such well-known authorities as R. Webster, B. W. Anderson, E. Sarofim, S. Sinkankas, R. Crowningshield and P. C. Zwaan. I am indebted to Mr. Webster for the time he took in offering useful constructive criticism as well as encouragement as a result of having seen my initial manuscript dealing with the comparative study of these garnets from three different sources. I wish also to acknowledge with thanks the loan of the Macon County stones for colour comparisons, as well as the above mentioned extracts which were supplied by Mr. Webster. My thanks as well to Mr. Craig Smith, Keeper of Geology at the (Rhodesian) National Museum for his interest in taking the photomicrographs.

The choice of a more acceptable name and the logical difference in approach to this problem by the dealer and laboratory worker:

Prior to stones of fair size and colour having been discovered and mined in Tanzania, the name "rhodolite" has been designated to garnets of the rhododendron-red variety specifically from Macon County, North Carolina, in the United States. Apparently while there was only one source of any appreciable significance the name "rhodolite"—while not being suitably acceptable because it sounds too much like "rhodonite", an entirely different gem

mineral—has nevertheless been, until now, tacitly accepted as such. Since the discovery of the Tanzanian stones and now those from other sources, this appears to have presented a problem insofar as the name is concerned. Prior to these new discoveries this variety was rarely encountered outside North America.

How does one go about trying to find an acceptable name for a "new" variety?—particularly when it is realised that its only difference from other garnets in the pyrope and intermediate range (with almandine at the other end) is colour and colour alone. The optical and physical constants of the garnet under discussion coincide with those in the upper pyrope to the lower intermediate (or pyrandine) range.

One obviously cannot pin a name on them in much the same manner as has been done with pyrope and almandine. These in themselves are in any case subject to what could be considered arbitary maximum and minimum constants respectively. To put this in another manner, this rhododendron-red variety is itself part of the already established pyrope to pyrandine range. In view of the fact that it is recognised that pyrope is usually blood-red in colour sometimes tinged with yellow or purple, and almandine is a darker or more intense red generally tinged with violet (the intermediate range being blood-red through brownish-red to violet-red tints) it should be recognised that a distinct variety exists also by virtue of its colour. Of course one could call it a pink or pinkish-red to rose-red pyrope or pyrandine, but who other than the interested gemmologist is going to test optical constants every time such a stone crops up in order to classify it specifically as such? An accusation would no doubt be made that hairs were being split—particularly by the dealer. Obviously a name is required which covers the whole variety in accordance with its particular colour. "rhodolite" is undoubtedly fine in this respect—if it were not for "rhodonite".

A difference in approach to a common problem may be expected to exist between two closely associated sectors in the same field but with different outlooks. Reference is made in this context to the dealer and the laboratory worker. While there appears to be no record of any real objections by dealers to the name "rhodolite" it has nevertheless been frowned upon by some in the laboratory—with good reason as already stated. Rhodonite is usually known as an ornamental stone also of rose-red colour as the name

COMPARISON OF RHODOLITE GARNET FROM THREE SOURCES

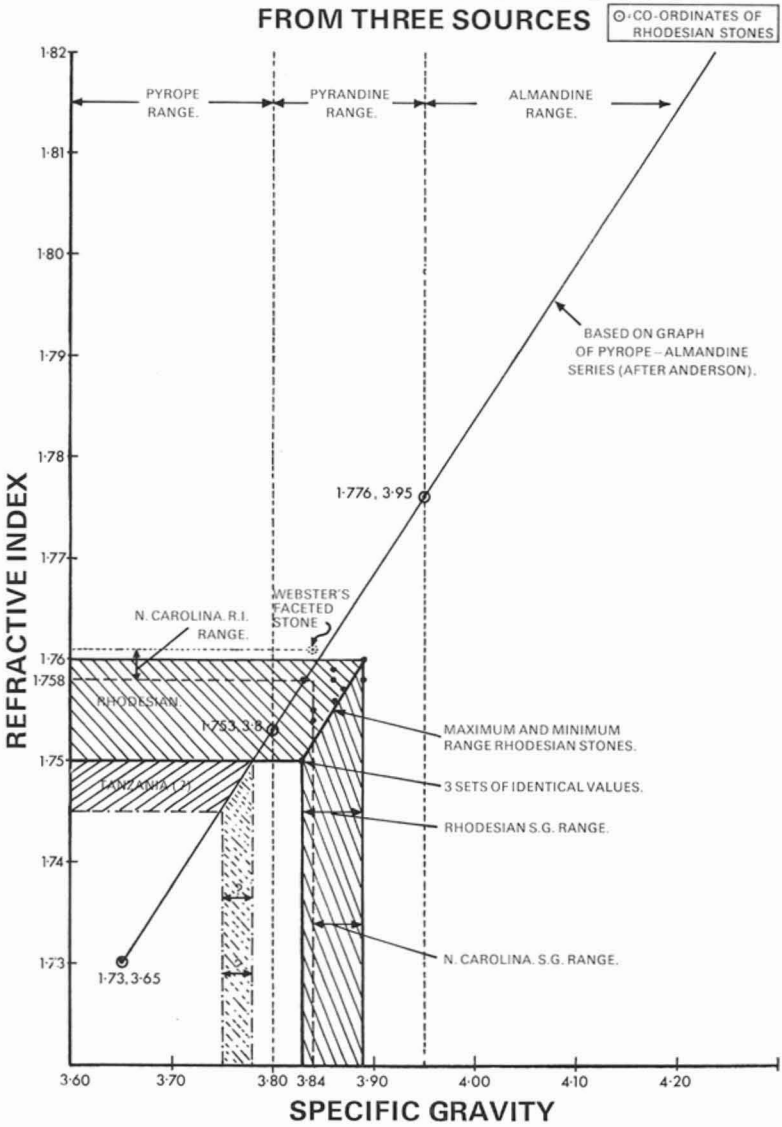

NOTE THAT, BASED ON AVAILABLE FIGURES, MIN. & MAX. S.G. VALUES OF N. CAROLINA AND RHODESIAN STONES PRACTICALLY COINCIDE, ALTHOUGH THE DIRECT RELATIONSHIP BETWEEN THE TWO IN EACH CASE IS DIFFERENT.

implies. Some suitable transparent material has even been faceted for collectors.

It is apparent that whatever name is agreed upon should have some appeal to public tastes. This is once again the whim of human nature. A well chosen name is more likely to become fixed in a person's mind and thus accepted than one which is purely scientific and possibly uninteresting (be it however well suited). This is from the dealer's point of view. The stone, when properly cut, makes a lively and interesting gem due to its paler colour in contrast to the pyrope/almandine series. After all, if it has appeal and is available in commercial quantities, the public will show more than just a passing interest in it. It has almost the same brilliance as a sapphire of the same colour.

This is not to say that this variety is something which is suddenly new, merely that it appears now to command more notice. Quite likely further sources of supply will be brought to notice due to what appears to be an increasing interest in this respect.

Bearing in mind what I have written—the approach of the dealer and laboratory worker—I would like to suggest that the name of "rhodomacon" garnet be considered. The first syllable relates to the colour (Gr. Rhodon—a rose) and the second one acknowledging the fact that this variety was first discovered in Macon County. This name has some definite meaning. In similar context one has labradorite (which was first discovered in quantity in Labrador) and the name has been accepted in spite of the fact of many other commercial deposits being later discovered elsewhere. There are other examples. Furthermore, the name "rhodomacon" is not unwieldy and is still partly based on the variety's colour.

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Some notes on the Identification of the pyrope—almandine garnets, by P. C. Zwaan. (Koninks. Nederl. Akademie van Wetenschappen-Amsterdam. Reprinted from Proceedings, Seriel B.64 No. 2 1961).

Gemmological Abstracts

ANDERSON (O.). *A century of sapphire mining.* Australian Gemmologist, 1971, XI, 3, pp. 11–19.

A slightly abridged copy of an article published in the Queensland Government Mining Journal (1971, LXXII, 832) in which the history of the Queensland sapphire mining is given. Sapphire was first found in Queensland in 1870, the price then being about two dollars (say £1) per ounce. Later the deep blue colour of the Queensland sapphires attracted the nobility of Tsarist Russia and a Russian market was opened up, whereupon the price rose to twenty dollars per ounce (say £10). This trade with Russia carried on until the fall of the Romanoffs. During the period 1922 to 1948 the market was depressed and had to be helped by the Government. To-day there is some serious mining and also some tourist attraction. The present price is much higher, but depends considerably on the quality of the crystals. First quality crystals may fetch anything from one hundred to eighteen hundred dollars (say 40 to 840 pounds sterling). Lower grades may drop to twelve dollars (£5.50). Mention is made of the types of sapphire found. Yellows are increasingly important, greens not highly valued, parti-coloured stones are subject to fashion. There is an "alexandrite" sapphire and dark star-sapphires with a golden sheen. The article tells of the associated minerals, the occurrence and production, much about the mining, prospecting and mining laws, and there is a short list of the large crystals found in Queensland.

R.W.

BANK (H.). *Neue Imitation für Chrysopras.* New imitation of chrysoprase. Zeitsch. d. Deutsch. Gemmol. Gesellschaft, 1971, 20, 3, pp. 132–133.

The author describes a new chrysoprase imitation on the market made out of glass and warns jewellers to be very careful in their examination of these stones.

E.S.

BANK (H.). *Durchsichtiger farblos-weisser bis blassgelber Petalit aus Brazilien.* Transparent colourless-white to pale yellow petalite from Brazil. Zeitsch. d. Deutsch. Gemmol. Gesellschaft, 1971, 20, 4, pp. 172–174.

The stone was found in the Minas Gerais district and at first thought to be a spodumene. It was found to be petalite, the name being formed from the word "petalon" meaning leaf, as the stone has a leaf-like appearance when cleaved. It is monoclinic, has a hardness of $6\frac{1}{2}$, D = 2. 39 – 2.40, and RI = 1.51–1.523. Chemically it is $LiAlSi_2O_6$. H_2O. The author mentions having seen some translucent petalites which were cut as cabochons and showed a cat's-eye effect. E.S.

BANK (H.). *Zoisit-Katzenaugen aus Tansania.* Zoisite cat's-eyes from Tanzania. Zeitsch. d. Deutsch. Gemmol. Gesellschaft, 1971, 20, 4, pp. 175–176.

The author describes chatoyancy in zoisite and stones showing these characteristics have a slightly lower specific gravity (3.29–3.31) caused by the inclusions. E.S.

BANK (H.), BERDESINSKI (W.), NUBER (B.). *Zu den Gitterkonstanten von Topas.* The lattice constants of topaz. Zeitschr. d. Deutsch. Gemmol. Gesellschaft, 1971, 20, 4, pp. 147–151.

Two topazes showing minimum and maximum refractive indices were examined as to their lattice structure. The colourless topaz with the minimum refractive index showed the lattice constants as described in the ASTM index. The violet stone with the maximum refractive index showed larger constants in the a and b direction and a smaller one in the c direction. Thus it was shown that the violet topaz had a larger elementary cell structure.

E.S.

BANK (H.). *Alexandrite aus Brasilien.* Alexandrite from Brazil. Zeitschr. d. Deutsch. Gemmol. Gesellschaft, 1971, 20, 3, pp. 130–131.

The author discusses an alexandrite of 14.17 cts with a good colour change, which is unusual in Brazilian alexandrites. The new stone is said to have been found in Bahia. Former stones from Brazil usually came from Espirito Santo and Minas Gerais. Bibl.

E.S.

CASSEDANNE (J.). *Les diamants de diamantina.* Bull. Assoc. Française de Gemmologie, 1971, 29, p. 7.

30–40% of the diamonds found at Diamantina in the Brazilian State of Minas Gerais are suitable for use in jewellery. The diamonds at this locality are found in association with tourmaline, quartz, disthene (kyanite), phosphates and magnetite but there is no kimberlite nor any of the other minerals usually found with diamond, such as chrome diopside, pyrope garnet and ilmenite. The diamonds are found mostly in quartzites and schists and their occurrence is illustrated with a diagram and a map. Photographs and an account of the methods of extraction leave no doubt of the scale of operations. White stones from this region have a blue phosphorescence.

M.O'D.

CHAMPION (J. A.) and CLEMENCE (M. A.). *Etch pits in flux-grown corundum.* Journ. of Materials Science, 1967, 2, pp. 153–159.

Etch pits were produced in certain planes on ruby and sapphire crystals grown from a fused lead fluoride solution, the etchants used being fused potassium hydrogen sulphate at 700°C from 20–25 seconds, concentrated orthophosphoric acid whose temperature was raised to 290°C over a period of about 75 minutes and an aqueous solution of KOH at 325°C for 10 minutes. It was found that only the $\{0001\}$, $\{1011\}$, $\{1012\}$, $\{1120\}$ and $\{1100\}$ planes would etch. Pitting was found to take place more readily in the basal plane and least readily in the rhombohedral plane. It was thought that the pitting occurred at the ends of dislocations.

M.O'D.

COCKAYNE (B.), CHESSWAS (M.) and GASSON (D. B.). *Single-crystal growth of sapphire.* Journ. of Materials Science, 1967, 2, pp. 7-11.

In an attempt to obtain sapphire crystals in a form other than thin plates which were previously the only forms possible from flux-growth, two alternative methods of growth were tried. The vertical pulling method was modified by alterations to the after-heater. Another technique involved the floating-zone apparatus which was altered to allow the use of a controlled atmosphere preventing excessive oxidation of the heater strip. Tyndall scattering is avoided and some other undesirable effects are minimized, but are not entirely eliminated. However, crystals 100mm long × 15 mm diameter have been obtained relatively free from voids.

M.O'D.

CROWNINGSHIELD (R.). *Developments and highlights at G.I.A.'s laboratory in New York.* Gems & Gemology, 1971, XIII, 9, pp. 284–288. 10 illus.

Diamonds are the main theme in these reports. Reference is made to graining in Russian diamonds. A new design in cutting intending to get rid of the "bow-tie" effect in marquise-cut stones, a cluster ring consisting of diamond doublets, identification of a black diamond and reflections of the culet in the case of an old European brilliant-cut are discussed. Two stones fashioned from red-dyed greyish pink corundum were identified by the glow from the fluorescence of dyestuff used when the stones were examined under a long-wave ultra-violet lamp. A note is given on the nomenclature of Australian opal.

R.W.

CROWNINGSHIELD (R.). *General Electric's cuttable synthetic diamonds.* Gems & Gemology, 1971, XIII, 10, pp. 302–314. 14 illus.

An important article reporting on the first investigation by a gemmologist of the properties of the synthetic diamonds of cuttable quality produced by the General Electric Company of America in 1970. Four stones, near colourless, pale blue, dark blue and intense yellow, faceted and around a quarter of a carat in weight, were examined. Three of these stones are now in the Smithsonian Museum. The stones were colour-graded and examined for inclusions, which included somewhat flattened black inclusions ascribed to the nickel-iron catalyst. Under 10-times magnification there would be nothing to excite suspicion, but under higher magnification random pin-point inclusions were seen. Stress cleavages and rod-like inclusions were observed in some stones. None of the stones was found to be fluorescent under long-wave ultra-violet light, but under short-wave ultra-violet light the colourless and pale blue stones glowed with a persistent yellow phosphorescence showing a quadrant effect with a dark cross. It is suggested that the short-wave ultra-violet lamp may be helpful if synthetic diamonds come on the market. The colourless and blue synthetic diamonds were found to allow oriented electro-conductivity. No convincing absorption spectrum was observed. A strong yellow glow with "after-glow" was seen when some stones were examined under X-rays and this may have possible significance. Little strain was observed when the stones were examined under "crossed polars". The dark blue

stones showed colour-banding and were unlike any natural diamonds. This article must be read for it points to problems which may beset the jeweller in the future. R.W.

HINTZE-CHUDOBA. *Handbuch der Mineralogie.* Handbook of mineralogy. Zeitschr. d. Deutsch. Gemmol. Gesellshaft, 1971, 20, 4, pp. 179–180.

Review of the third additional volume dealing with new minerals and new nomenclature; edited by Prof. K. Chudoba, 684 pages with 60 illustrations, Berlin, de Gruyter 1968—a most useful reference book. E.S.

HUDSON (D. R.). *Gemstones in the system BeO—MgO—Al_2O_3.* Australian Gemmologist, 1971, XI, 2, pp. 5–9. 2 illus.

The minerals within this system include bromellite (BeO); corundum (Al_2O_3); periclase (MgO); chrysoberyl (BeO Al_2O_3); spinel (MgO Al_2O_3) and taaffeite (BeO MgO Al_2O_3). The chemical and physical characters of each of these gem minerals are given. There is information about natural occurrences as well as details of both fused and hydrothermal synthetic equivalents. R.W.

LIDDICOAT (R. T.). *Developments and highlights at G.I.A.'s laboratory in Los Angeles.* Gems & Gemology, 1971, XIII. 9 & 10, pp. 273–283: 315–324. 39 illus.

A composite stone made of a base of black star-sapphire cemented to a crown of padparadscha-coloured synthetic sapphire is described. There is a report of another type of yttrium aluminate with the formula $YAlO_3$. This variety is orthorhombic in crystallization, has indices of 1.938–1.955 and a density of 5.35 and a hardness of 1800 Knoop identical to YAG. The specimens examined, doped with rare earths as they were intended to be used for lasers, are not on the gem market but a warning is given that they might well be met with either as "freaks" for the collector or actually on the market in future. A beautiful red-orange spinel, two snuff bottles made respectively of elephant molar and pressed amber are mentioned. There is a report of a natural blue sapphire which fluoresced in short-wave ultra-violet light showing up hexagonal banding clearly. The laboratory reports an increase in the number of emeralds submitted for testing and this is ascribed to the publica-

tion of the difficulties found with modern types of synthetic emeralds and stones from new localities. Three large stones, a 25lb cabochon sapphire, a Mysore-type cabochon ruby weighing 1795 carats and a faceted green beryl of 1180 carats are mentioned. Some odd types of glasses (probably slag glasses), Tridacna pearls, an unusual cabochon of fluorite (supposedly from Thailand) and a cabochon of yellow-green idocrase are other items mentioned. A further report is given on stained black opals with very low properties. It is suggested that the treatment consists of covering the white opal with brown wrapping paper and heating with a torch until the paper chars—the smoke imparting a black colour. Experiments seem to show that this is feasible. Dyed pale violet jadeite, coated beryl, a spessartite outline, a flux-fusion ruby with a "seed" of synthetic ruby and a black spinel cabochon with a density of 3·84 are mentioned. A "synthetic opal" which turned out to be a "fire agate", a fine water-worn crystal of peridot probably from Burma and weighing 137·5 carats and synthetic quartz from Russia are discussed.

R.W.

OKRUSCH (M.). *Zur Genese von Chrysoberyll- und Alexandrit-Lagerstätten.* The genesis of chrysoberyl and alexandrite occurrences. Zeitschr. d. Deutsch. Gemmol. Gesellschaft, 1971, 20, 3, 114–124.

This article is a survey of literature published on this subject and has a very extensive bibliography.

The rarity of a gem is part of its attraction. The article deals with the special geological conditions necessary for the formation of chrysoberyl. The chemical composition and crystal-morphological and physical properties are listed. The R.I. is similar to that of corundum and there are two bands in the absorption spectrum. The main constituents are oxygen, aluminium and beryllium. Chrysoberyl usually crystallizes out of pegmatic melts which are supersaturated with Be; this can happen in pneumatological and hydrothermal districts, often found together with tourmaline. Chrysoberyl is sometimes found in assimilation pegmatites. The author describes in detail various finds and their geological history and then discusses the conditions necessary for the formation of alexandrite as a chromium-containing variety of chrysoberyl. Certain finds and their geology are discussed, including the Novello claims in Southern Rhodesia.

E.S.

Pough (F. H.). *Calcite.* Lapidary Journal, October 1971, pp. 958–963.

The author discusses the multiplicity of crystal faces that may be displayed by calcite and surmises that while the three distinctly different basic shapes of scalenohedron, rhombohedron and flat plates may be stable under different conditions, the many forms are attributable to static periods during growth when the faces are stationary at a stage intermediate between two of the basic shapes. Other minerals show less variety owing either to their lack of more than one basic form, their greater sensitivity to growth conditions or to their less frequent formation. Many calcite forms are reviewed; among recent discoveries are gemmy orange coloured crystals found with witherite and fluorite in Illinois, fine pink cleavages and white coated rhombs from Naica, Mexico. M.O'D.

Rösch (S.) *Was ist ein Brilliant?* Goldschmiede Zeitung, 1971, 12, p. 39. also Zeitschr. d. Deutsch. Gemmol. Gesellschaft, 1971, 20, 3. pp. 106–113.

In leaving the German title of the article untranslated in an English summary, the Editor of the Goldschmiede Zeitung comments: "This was done because any such translation as "What is a Brilliant?" would inevitably mislead the reader into believing he is about to read a straightforward discussion of the concept of "brilliant" as a noun and adjective; the implication being that this would certainly be an article based on English usage and all the linguistic aspects bound up with it.

"To be sure, the concepts of "Brillant" and "Brillanz" do have their English counterparts in such words as "brilliant" and "brilliancy". Chances are, however, that here is where the parallelism ends. In short, the present article is, of course, based not only on the two terms as such but on the whole complexity implied by them from a German usage point of view. At the same time, one can safely say that this is certainly not tantamount to common English usage.

"Professor S. Rösch's article is a thoroughly reflected and fervently dedicated plea for anyone concerned to try their best soon to reach an agreement on clear-cut definitions of these concepts, particularly so of the concept of "Brillant". Toward the end of his article, Herr Rösch offers a list of new names that might conceivably be accepted by those dedicated to achieving a greater precision of relevant nomenclature, but the article is certainly esoteric in that

it presupposes on the part of the reader a gemmological knowledge and understanding such as can hardly be expected of anyone not trained in the field. Any full-size translation of the present treatise would doubtless tend to confuse the message by adding to it a host of linguistic problems obtaining between English and German modes of thought and language mentalities. Which is one way of saying that translation into English would doubtless add to the esoteric nature of the discussion instilling into it linguistic elements that would needs run counter to the author's intention.

"Translation, though feasible, has thus been considered inadvisable, while on the other hand the article as such was thought to be too valuable to be left unmentioned." S.P.

SALA (J. D.). *Laboratory of gemology and assay of materials. Banco Municipal de la Ciudad de Buenos Aires, Argentina.* Gems & Gemology, 1971, XIII, 9, pp. 270–272. 5 illus.

Describes the laboratory of Buenos Aires, which forms part of the pledging department of the Banco Municipal. The laboratory not only deals with gem materials but also investigates works of art and other valuable objects. The laboratory of gemmology consists of three sections—a well-equipped laboratory, a museum and a library—and is used by insurance companies, jewellers and the public. It is said that a daily average of 150 reports are signed by the specialized University technicians, but the number of staff employed is not given. R.W.

SCHIFFMANN (C. A.). *Farbdiamanten: natürlich oder bestrahlt?* Coloured diamonds: natural or irradiated? Zeitschr. d. Deutsch. Gemmol. Gesellschaft, 1971, 20, 4, pp. 152–171. (See Journ. Gemm. 1969, 11, 7).

The author tested 20 diamonds and found 10 of them to be artificially coloured. Exact details as to weight, colour, X-ray fluorescence and phosphorescence, UV light transparency, spectroscopic analysis and characteristics seen under the microscope are given in table form for the 20 stones, which are also reproduced as colour photographs. The various ways of irradiating diamonds are described including the van de Graaf method and the cyclotron treatment. The instruments used in this test series are illustrated. The author warns the retail jeweller to make sure of his source and take precautions to ensure that a diamond is not artificially coloured. E.S.

SWEENEY, (J. W.). *Rhodesian sapphire deposits.* Lapidary Journ., 1971, 25, 8, p. 1076.

A crystal of 3,100 cts has been recovered from the Barauta mine in north-east Rhodesia. The colour is a fine deep blue. Crystals from the region are found as well formed squat barrel-shaped hexagons. There is often an outer skin of brown to yellow-brown oxidized corundum. Sizes vary from $\frac{1}{4}''$ to $3''$ in diameter. There are two deposits at the Barauta mine, the first alluvial and the second in pegmatite. Various colour types have been found, including some of pale blue with a golden core, others a pale cream with a light blue core, as well as black star-sapphires. M.O'D.

ZWAAN (P. C.) and KORTENBOUT VAN DER SLUYS (G.). *Vivianite crystals from Haren, Noord Brabant Province, the Netherlands.* Scripta Geologica, 1971, 6.

The occurrence of vivianite in the Netherlands was first mentioned by Van Bemmelen (1896, 1897). He described the mineral as a powdery bluish substance associated with iron carbonate from a moor in Drenthe Province. No physical properties were given, nor crystallographic data. The author added a chemical analysis of impure material.

In another paper (1900) Van Bemmelen described vivianite occurring in peat deposits at Ederveen, Drenthe Province, mentioning crystal aggregates with a blue lustre and small cavities filled with crystals showing a metallic lustre. According to Van Bemmelen these crystals originated from ferro-carbonate or iron oxide through interaction with phosphates, the latter being mainly derived from animal remains. In this paper, too, no particular physical or optical data were given.

Subsequently the mineral has been recorded from numerous localities all over the country. It occurs in fossil bones as well as sediments bearing such fossils. A remarkable fact is that these deposits invariably are of a Holocene age, in agreement with Rosenqvist's observations (1970) in Southern Norway. In all these cases vivianite occurred as a powdery bluish material and no crystals could ever be seen with the naked eye.

The material described consists of numerous distinct elongated prismatic crystals up to 6mm long and $\frac{1}{2}$mm thick. They are very dark bluish-green. S.P.

BOOK REVIEWS

DESAUTELS (A. E.). *The Gem Kingdom.* Macdonald, London, 1971. p. 252. Illustrated in colour. £5.25.

Paul Desautels needs no introduction to the gemmologist as he is supervisor of the Division of Mineralogy at the Smithsonian Institution, and author of a number of books including the *Mineral Kingdom*, published in 1970, and of the standard guide to the Smithsonian gem collection. At first sight the present work might appear to be an addition to the family of books dealing in a popular manner with an aspect of natural science, recompensing the serious student for its superficial treatment of the theme by the excellence of the illustrations.

Mr. Desautels' latest book excels, however, not with its illustrations but by its text. First impressions aside, this is, in fact an eminently adequate book for the gemmological student, as not only are common and less common gem stones and ornamental materials covered but there are also chapters on testing, fashioning, prospecting and mounting; this last seldom being treated in the standard textbooks. The style is admirably lucid and there are no discernible errors of fact. A bibliography would have been welcome. The chapter on the jade minerals is especially timely, for it covers some of the ground previously only to be discovered in Hansford's *Chinese Carved Jades*, that is, the working of these materials and the nomenclature of some of the standard forms.

Naturally, at this low price (for today) the ultimate in quality of illustration cannot be expected and the book is, on close examination, not among the first class in this field. Although the publishers claim that the gems are shown "with surpassing fidelity and brilliance", on the whole the examples selected are too large for the best reproduction. Too many show white or faintly-coloured reflections from very large table facets, some are apparently out-of-focus, especially the 118-carat Brazilian green tourmaline on p. 122 and the 177-carat kunzite on p. 114. One or two different species shown on adjacent pages are insufficiently distinguished from each other in colour, for example the red tourmaline and the rhodolite garnet shown facing each other on pp. 122 and 123. Some other examples are, however, very well reproduced. A personal preference would have been for more illustrations of gem testing techniques at the

expense of the numerous reproductions from earlier works which are of uneven quality.

These admittedly minor criticisms apart, this is a book to be possessed by the established gemmologist and to be studied by the student particularly at the beginning of his career, where a spice of illustration often helps the more rigorous diet of gemmological theory to be digested.

M.O'D.

ANON. *Gems and Jewels.* Orbis Books, London, 1971. £1·25.

The text of this book, reviewed on page 28 of the *Journal*, 1972, 13, 1, as well as the introduction, was written by H. J. Schubnel.

S.P.

Gemstones to Jewellery. Edited by Bill James. Second edn. Bailey Bros. & Swinfen, Folkestone, 1967, pp. 184. Black-and-white illustrations. £3·50.

Although the imprint gives the date of publication as 1967 the book has only recently been released on to the British market. The greater part deals with the growing hobby of cutting and mounting gems and various qualified authors cover sections on tools, design, enamelling and ornament. The section on gemstones is found partly in the chapter headed "Earliest of Jewels" and partly under "Rainbows of Fire". In the first of these chapters the examples are selected somewhat oddly, rhodonite appearing in both. The second chapter on gems lists a number of other stones, again with no apparent basis for selection. Useful data for the lapidary given with each stone make interesting reading although there are a number of questionable assertions. It is unusual to see hessonite classed as a green stone; Brazil is not listed as a source for green spodumene, inaccurately called hiddenite; the easy cleavage of kyanite is not mentioned; Mexico is omitted as a source for sphene; balas ruby is a regrettable survival for red spinel. An interesting feature, which is repeated also for the equipment sections, is the provision of a price list at the end of each chapter. Prices should be read with caution as price lists are very hard to standardize and these relate to Australian conditions. For the Australian reader an Appendix lists public facilities for lapidary instruction.

M.O'D.

JAMES (B.). *Collecting Australian Gemstones.* Revised 4th edition, 1972. pp. 191. Illustrated in colour and black-and-white. Distributed in U.K. by Bailey Bros. and Swinfen, Folkestone. Published by Murray, Sydney. £5.

If the first chapter which deals with gemstones in legend is ignored, this is a useful book, particularly addressed to the Australian gemmologist and mineral hunter. Readers in other countries will also find much of interest. An early chapter lists the essential tools of the gem-hunter and this is followed by chapters dealing with typical gem-bearing geological formations, how to apply for licences to mine, and general hints on the dangers and difficulties of prospecting. Chapter six deals with the gemstones to be found on the Australian continent; although in the main the facts are without question, it is particularly regrettable that one of the formerly-believed reasons for the cause of the play of colour in opal is again brought out. In an Australian book bearing the imprint 1972 this is surely an oversight. This whole chapter suggests that all the facts about some gem species, whether or not they are to be found on the Australian continent, have been included. Emerald-green hiddenite has only been found in North Carolina, and not all yellow topaz fades in sunlight. Subsequent chapters are on gold panning and the fashioning of stones. Useful addenda are a table of minerals likely to interest the collector, a glossary of mining terms and maps of the Australian gem fields. The black-and-white illustrations are adequate, but those in colour of poorer quality.

M.O'D.

MAZIAREK (S.). *El mercadeo mundial del diamante.* Caracas. 1971. (Privately circulated).

A paper covered book of 36 quarto sized pages produced from typescript by a photo-copying process. The text is in Spanish. There is a general history of diamond from Indian times, and the present marketing by the various divisions of the Diamond Corporation. There are charts showing the growth of diamond sales by the Central Selling Organization from 1953 to 1969 and the diamond production in thousands of carats in the various producing countries for the period 1961 to 1968. Short sections on the grading of diamonds, on industrial diamonds and the artificial colouration of diamonds are given. There is a section on synthetic diamonds, which is completed with a table showing the production of the major

countries which are now producing synthetic diamonds, and the book is completed with a short bibliography and an appendix on the diamonds of Venezuela. Dr. Maziarek is with the Ministry of Mines in Venezuela, so this appendix on Venezuelan diamonds can be taken as authentic and is a valuable contribution to the literature. The existence of diamonds in Venezuela, was known as early as 1901, but production was not commenced until 1924 when the deposits in La Gran Sabana district of Bolivar were worked. Later finds were made, particularly around San Pedro de las Bocas and more recently in the lower zone of the Caroni river, and there are the deposits of Guaniamo in the region of the rivers Caura and Cuchivero. The production of diamonds in Venezuela from 1913 to 1969 reached 2,546,159 carats, but this does not reflect the present position, for in 1970, with the newer localities of Guaniamo opened up, the total for the year was 508,000 carats. The overseas trade in order of importance is given as—to U.S.A. (40%), Belgium, Holland, Germany, Israel, Canada and Italy etc. The appendix concludes with some consideration of the Venezuelan economy with regard to diamond trading. There is much information packed into 36 pages.

R.W.

WAINWRIGHT (J.). *Discovering lapidary work.* Mills & Boon, London, 1971. £3.60.

An excellent treatise written mainly as a guide for schools but of great use to all interested in the fascinating hobby of lapidary work, including tumbling. The book covers elementary identification, equipment and its use. Some aspects of jewellery-making are mentioned.

S.P.

BANK (H.). *Aus der Welt der Edelsteine.* Pinguin Verlag, Innsbruck, Austria. pp. 191, coloured plates. 298 Sch.

The publishers promise an English edition of this superbly-illustrated work, but even those whose German is rudimentary will wish to have it on their shelves as soon as possible. Although it must be assumed that the book is intended as much for the gemmologist as the general reader, the space given to some aspects of gem testing is insufficient for the student and perhaps too great for the average uninformed reader. The arrangement of the individual gem materials according to mineralogical classification would seem to

suggest that a certain degree of familiarity with the subject is assumed.

After a definition of the gem materials Dr. Bank describes some of their chemical and physical properties and their relationship to gem testing methods. The diagrams illustrating common crystal forms are of an inferior standard of draughtsmanship to those on pp. 86–87, which themselves are unrelated to the surrounding text; it would have been preferable to have placed the two sections together. It is regrettable that more mention is not made to the use of absorption spectroscopy and that there are no illustrations of this technique nor of examples of inclusions which are more fully treated in the text.

The descriptions of the individual materials are good, although one could wish to have SG and RI figures given in addition to hardness. No mention is made of nephrite being the material from which were fashioned the Chinese archaic jades and, rather confusingly, peridot is listed under olivine in the analytical section whereas in the tables the reverse arrangement obtains; fortunately the alphabetically close juxtaposition of the two names prevents serious error. Typographically some of the headings which are marked by italicization are hard to see at a quick glance. Some good locality maps are provided. The photograph of the Russian crown facing p. 164 does not reach the very high standard set by its neighbours.

In all, this is a very fine book; certainly in some respects the best work on gems in German yet to appear. Its reasonable cost demonstrates that good illustrations need not make a book prohibitively expensive; there are a number of works currently on the market priced much higher and with manifestly inferior illustrations and subject-matter. M.O'D.

REFRACTIVE INDEX BY DIRECT MEASUREMENT

By F. S. H. TISDALL, F.G.A.

ENCOURAGED by the directions given on page 32 of B. W. Anderson's latest edition of "Gem Testing" the writer determined to experiment with the "direct measurement" method of ascertaining the R.I. of a gemstone.

Unless a gemmologist has access to a table-spectrometer, and the

time and skill to use it, there is no other way of ascertaining the R.I. of quite a number of highly refracting gems (some of which are synthetics) unless one invests in an expensive refractometer equipped with a "dense glass" made of diamond, or zinc blende. However, by comparing the real and apparent depth of a stone by means of a millimetre gauge and a microscope, using the simple technique about to be described, a very close approximation to its R.I. may be made. As is shown in the table at the end of this article a degree of accuracy to $\pm$ 1% (approx.) would, for instance enable one of the new "doped" Yag garnets to be distinguished from a demantoid garnet; sphalerites, strontium titanates, and scheelites could similarly be identified.

The principle upon which the method depends is quite simply understood from Fig. 1. The real depth of the stone is BO = D. Rays of light emerging from the culet, O, diverge along OA and OC, and, on passing out of the stone, are refracted along AE and CF. The width of the angle AOC is exaggerated for clarity. The ray OAE makes with the normal (broken line) at A the angle of incidence i, and the angle of refraction r. OB bisects the angle AOC, and is, of course, perpendicular to the table of the stone.

Then $<AOB = i$, and $<AIB = r$.

Let the R.I. of the gem be n.

From Snell's Law n Sin i = Sin r.

(The second medium being air its R.I. is unity and is, therefore, neglected.)

$$\text{Then we have } n = \frac{\text{Sin } r}{\text{Sin } i} = \frac{\frac{AB}{AI}}{\frac{AB}{AO}} = \frac{AO}{AI} = \frac{BO}{BI} \text{ (approx.)}$$

since the angles are small.

But BO = D, the real depth, and BI the apparent depth (i.e. the culet of the stone will appear to be located at I).

$$\text{Hence the R.I. of the gem} = \frac{\text{real depth}}{\text{apparent depth}}.$$

Three stones were selected for experiment, the R.I.'s of which were all above the limit of an ordinary refractometer. No doubt was entertained as to what these stones actually were, but it seemed

desirable to ascertain the practical value of the "direct measurement" method. The results would certainly have identified the stones if their identity had not already been known.

A measuring scale incorporated in the focussing mechanism of the microscope is, of course, an advantage, but it is not essential; neither is it necessary for a stone to have a flat culet through which observations are made.

There is on most microscopes a flat surface, or small flat ledge on the top end of the focussing rack (see illustration, p. 123, "Gem Testing"); below this there is a parallel flat surface on the shoulder of the microscope limb, through which passes the spindle of the coarse adjustment wheel. Differences between these levels can be measured either by judicious use of a vernier-equipped millimetre gauge (the nose of the upper jaw of which has been filed off), or a suitable depth gauge. The writer possesses one of the latter, and it is a simple matter to rest the outer edge of the gauge on the top of the focussing rack, and carefully extend the slide until it meets the flat surface above the focussing spindle. (See Fig. 2). With the usual vernier equipment accuracy to .05 mm is obtainable, and estimates may be made of even closer accuracy.

Guided by Mr. Anderson's instructions the technique was as follows: the real depth of the stone was carefully measured by placing it, table down, on the lower jaw of an open, vertically held, millimetre gauge, and closing the gauge until the other jaw touched the culet.

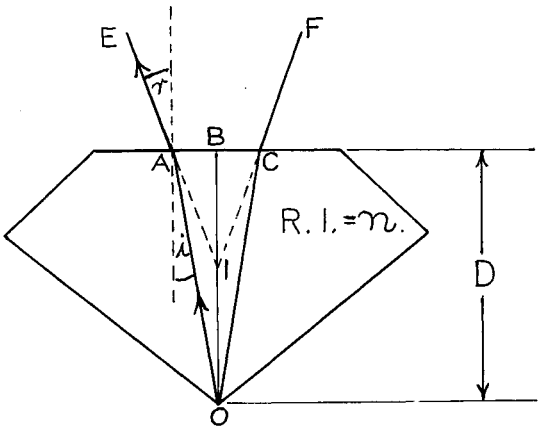

Fig. 1.

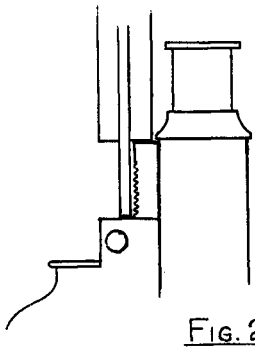

Fig. 2.

(To give unobscured view the focussing wheel is omitted from Fig. 2).

A small pillar of plasticine is pressed in upright position on a glass microscope slide, and the girdle of the stone embedded in the plasticine so that the table of the stone is parallel to the surface of the slide. A little careful manipulation will achieve a result sufficiently accurate for the purpose in hand. It is not necessary for the culet to rest on the slide. The slide is then placed on the stage of the microscope and positioned so that the stone is in the centre of the field. A $\frac{2}{3}$ objective was found to give a sufficiently critical focus. The surface of the stone was then brought carefully and exactly into focus. There are always tiny marks by which this may be done. Measurement is then made between the top of the focussing rack and the shoulder of the limb and noted down.

Next, very carefully, the focus is lowered until the culet, seen through the stone, is sharp. This may take a little time; care and nice judgement are required to ensure that whatever mark is selected on which to focus it really represents as nearly as possible the very lowest part of the stone. Again a measurement is made and noted.

If m_1 is the first measurement, and m_2 the second, then $m_2 - m_1$ = the apparent depth of the stone. And, to complete the experiment, real depth (already measured) divided by apparent depth gives the required R.I.

To focus on the table of the stone an ordinary adjustable 60-watt electric lamp raised above the stone and directed down upon it made focussing on small surface markings easy; to focus on the culet the same lamp was lowered and the substage mirror angled to direct light into the stone from beneath. Illumination can be controlled to a comfortable degree by use of the substage diaphragm.

TABLE OF RESULTS

Name of Stone	*Real Depth* (in mm)	*Apparent Depth* (in mm) (m_2–m_1)	$\frac{\textit{Real Depth}}{\textit{Apparent Depth}}$ = R.I.	R.I. (*from tables*)	% *error*
Strontium Titanate	2.65	12.40 11.31 1.09	$\frac{2.65}{1.09} = 2.43$	2.41	.83
"Yag" garnet	5.00	14.00 11.30 2.70	$\frac{5.00}{2.70} = 1.85$	1.83	1.1
Red Zircon* (no absorption spectrum)	3.80	13.50 11.55 1.95	$\frac{3.80}{1.95} = 1.95$	1.93 – 1.99	

* By inserting the analyser and rotating the microscope stage one ray of the zircon was extinguished to avoid confusion by double refraction. The figure arrived at lies between the limiting values for ε & ω; zircon is positively birefringent & the result probably represents an intermediate value for ε.

ASSOCIATION NOTICES

MEMBERS' MEETINGS

The Midlands Branch of the Association held a practical evening on the 20th January at the School of Jewellery and Silversmithing, Birmingham, by kind permission of the Headmaster, Mr. R. G. Baxendale. Members had the opportunity of testing their own gemstones as well as specimens supplied, with the assistance of Mr. F. Tisdall and Mr. R. N. Wetton.

The Scottish Branch also held a meeting on the 20th January, in Ayr, when illustrated talks were given on diamonds, gems shown at the "World of Gems" exhibition, and hallmarking. A second meeting was arranged on the 24th February at Edinburgh, when Mr. H. Whitehead gave a talk, illustrated by slides, on the "World of Gems" exhibition held in Glasgow during September and October, 1971.

A talk was given by Mr. R. Webster on the 25th January at Goldsmiths' Hall entitled "Gems in Court". A full report is given on page 45.

ANNUAL GENERAL MEETING

The 42nd Annual General Meeting of the Association was held at Goldsmiths' Hall, London, on Wednesday, 22nd March, 1972. Mr. Norman Harper, Chairman, presided. Among the members present were two Fellows from overseas, Frau Katharina Schneider of Hanau and Dr. Roland Berger of Ludwigsburg, W. Germany. In commenting upon the work of the year, the Chairman said:

"Although referred to in the annual report, I must again mention the splendid exhibition that was organized in the autumn by the Scottish Branch of the Association. Our thanks to all those

concerned can well be repeated this evening. It was an extremely well worthwhile undertaking, and rewarding both to those who attended and those who arranged it.

"I must also mention the July 1971 issue of *The Journal of Gemmology*, which was a 70th birthday tribute to Basil Anderson. B. W. Anderson has done so much for gemmology. He retires as Director of the Diamond, Pearl and Precious Stone Trade Section of the London Chamber of Commerce at the end of this month. I shall be adding to these words in some other place and on an occasion other than an annual meeting. So far as the Association is concerned, we are glad that he will be continuing as our senior examiner. In the meantime we give him our good wishes and sincere appreciation for all he has done for gemmology. We wish him well in his retirement and extend our good wishes to his successor, Mr. Alec Farn.

"In connection with *The Journal of Gemmology*, the Association is greatly indebted to Mr. John Chisholm, who does so much in casting his eagle eye over the proofs and thereby helps to maintain the high reputation which the *Journal* enjoys.

"Our examinations were again well supported and again there was considerable interest from overseas. To the course instructors and examiners our grateful thanks. Mr. Robert Webster has joined us as a correspondence course instructor. In fact he seems just as busy as when he was at the Laboratory. Our Secretary will not entirely be lost to us as he will be responsible for the Sir James Walton Library in about a year's time. He created the library, and it is fitting that his long connection with the Association (he was first appointed a member of the Council in 1931) should be maintained in this manner.

"We held a reception for Fellows in this Hall and may well repeat it next year or the year after.

"Both our Branches organized interesting events and we are grateful to all those who helped to maintain the keen interest in gemmology in the Midlands and Scotland.

"Several people made gifts of various kinds ranging from a modest piece of gem mineral to a binocular microscope from the Gemmological Association of All Japan. A gift of gems and gem minerals from the Gemmological Association of Australia was unfortunately lost in transit—we shall never know about the treasures we should have received".

Mr. Robert Webster, in seconding the adoption of the Annual Report and Accounts, said it would give great pleasure to the Association to know that Mr. H. Wheeler would be succeeding Mr. G. F. Andrews as Secretary in April 1973. In view of Mr. Wheeler's long connection with the National Association of Goldsmiths and the Gemmological Association, the secretarial work would be in good hands.

Dr. G. F. Claringbull, B.Sc., Ph.D., was elected as President of the Association in succession to the late Sir Lawrence Bragg. The Chairman recalled that Dr. Claringbull had served the Association as an Examiner from 1938 to 1970. Mr. B. W. Anderson welcomed the election of Dr. Claringbull and he knew that it would give members much pleasure to welcome him into office. Mr. Anderson felt sure that Dr. Claringbull would maintain the scholarship and enthusiasm for gemmology that had been shown by previous Presidents.

Mr. Norman Harper was re-elected as Chairman; Mr. Douglas King as Vice-Chairman and Mr. F. E. Lawson Clarke as Treasurer. Messrs. Maurice Asprey, Thomas Bevis-Smith and David Kent were re-elected, and Messrs. Eric Bruton and Michael J. O'Donoghue, M.A., elected, to serve on the Council.

The Chairman announced that Messrs. Watson Collin & Co., chartered accountants, had signified their willingness to continue as auditors.

In concluding the meeting, the Chairman took the opportunity of expressing the Association's thanks to the Goldsmiths' Company for the ready willingness of the Wardens to place various rooms at Goldsmiths' Hall at our disposal for meetings. The Wardens readily respond whenever it is convenient and the Association was greatly indebted to them.

COUNCIL MEETING

A meeting of the Council of the Association was held on the 18th January. Mr. Norman Harper, Chairman, presided. Mr. H. Wheeler was appointed Assistant Secretary of the Association and designated to succeed the Secretary at the end of March, 1973. Mr. D. Wheeler was appointed a Director of Gemmological Instruments Ltd.

Appreciation of the work of the Scottish Branch of the Association in connection with the "World of Gems" exhibition held in Glasgow during September and October, 1971, was recorded.

The following were elected to membership:

FELLOWSHIP

Allum, Christopher J., Radford, Nottingham. D. 1971
Appleyard, John T., Wakefield. D. 1971
Baker, Ann, Witney. D. 1971
Barrett, Garry Sydney, Sittingbourne D. 1971
Bjøndalen, Jan, Oslo, Norway. D. 1971
Brook, Doreen M., Allerton, Liverpool. D. 1971
Burgin, Derek A., Radcliffe-on-Trent, Nottingham. D. 1971
Butcher, Kathleen M., Sudbury. D. 1971
Carballal Cirici, Carmen, Tron de Dalf, Spain. D. 1971
Cartland, Anthony J., Leamington Spa. D. 1971
Chalk, Christopher S., Walmer, Deal. D. 1971
Christie, Rosalind S., London. D. 1971
Farley, Peter F., Dorchester. D. 1965
Fowler, Susan E., Hong Kong. D. 1971
Gartner, Heinz R., Schmissberg, W. Germany. D. 1971
Geyer, Adrian M., Handsworth, Birmingham. D. 1971
Gillings, Michael, Stretford, Manchester. D. 1971
Harvey, Roger S., Hull. D. 1971
Hiley, Hazel, Baildon, Shipley. D. 1971
Hinchliffe, Brian, Sheffield. D. 1971
Holden, Andrew N., Walsall. D. 1971
Holt, Robert A., London. D. 1971
Irwin, Margaret, Chester. D. 1971
Jenner, Peter C., Tunbridge Wells. D. 1971
Johnston, Iain H., Dumbarton, Scotland. D. 1971
Keeling, Judith M., Stoke-on-Trent. D. 1971
Kirkpatrick, David J., Kenilworth. D. 1971
Kivimaki, Kauko O., Hämeenlinna, Finland. D. 1971
Koskinen, Aito K., Helsinki, Finland. D. 1971
Krieger, Rolf, Huddinge, Sweden. D. 1971
Leino, Terttu, Lahti, Finland. D. 1971
Lewis, Roger A., Wallasey. D. 1971
Lopez Verge, Ramon, Barcelona, Spain. D. 1971
Lowe, Christopher E., Newhall, Staffs. D. 1971
Mones Roberdeau, Luis, Barcelona, Spain. D. 1971
Monte Domenech, Joaquin, Barcelona, Spain. D. 1971
Mueller, Edith E., Frankfurt, W. Germany. D. 1971
Murray, David E., Stratford-upon-Avon. D. 1971
Narayanamurthy, Keecha, Bentong Pahang, W. Malaysia. D. 1971
Naumanen, Pertti O., Helsinki, Finland. D. 1971
Olieff, Peter M., Doncaster. D. 1971
Peranko, Pyry K., Lahti, Finland. D. 1971
Poynder-Meares, Christopher F., Brookthorpe, Glos. D. 1971
Pyykonen, Kaarina, Matinkyla, Finland. D. 1971

Rajah, Sinnathamby S., Ipoh, Malaysia. D. 1971
Ratnasekera, Wakumburage A., Ratnapura, Ceylon. D. 1971
Roca Cusachs, Juan, Barcelona, Spain. D. 1971
Rogan, Liv S., Oslo, Norway. D. 1971
Rorvik, Trine, Mosjöen, Norway. D. 1971
Ryan, David C., Dublin, Eire. D. 1971
Saddington, Tom F., Woking. D. 1971
Schneider, Katharina, Hanau, Germany. D. 1971
Shepherd, Naomi, Reading. D. 1970
Skinner, Ramon, Epsom. D. 1958
Spiers, Richard, Redhill. D. 1971
Tortosa Calveras, Francisco, Barcelona, Spain. D. 1971
Van Dam, Rudolf A., Curaçao, N.A. D. 1971
Van den Berge, Gerard, St. Amandsberg, Belgium. D. 1971
Walker, Thomas, Sunderland. D. 1971
Walton, Edith M. E., Prescot. D. 1971
Williams, Anthony M., Moseley, Birmingham. D. 1971
Windsor, Christine, London. D. 1971
Woolf, David H., Johannesburg, S. Africa. 1971
Woold, Michele D. London. D. 1971
Wrangel, Anna S., Bromma, Sweden. D. 1971
Wroblewski, Tradeusz, Selly Oak, Birmingham. 1971

TRANSFERS FROM ORDINARY MEMBERSHIP TO FELLOWSHIP

Ahmad, Syed Vaqar, London
Allum, Peter D., Shaftesbury
Andres Barbera, Manuel, Valencia, Spain
Backshall, Henry G. R., Hainault
Baker, Kenneth R., Hensingham, Whitehaven
Berlage, Peter-Jurgen, Osnabruck, Germany
Binns, David G., Hastings
Bradford, Kenneth J., Westcliff-on-Sea
Comely, Christopher N., Dorchester
Cotton, John A. D., London
De Bruin, Alphonsus G., Heemstede, Holland
De Meillon, Laura, Durban, Natal, S. Africa
Domenech Bisbe, Juan, Barcelona, Spain
Dyer, Wilbur E., Joiliet, Illinois, U.S.A.
Fernandez Gil, Enrique, Valencia, Spain
Fukabayashi, Hirokichi, Sapporo, Hokkaido, Japan
Gardiner, Anthony C., Abadan, Iran
George, Michael C., Southborough, Tunbridge Wells
Giles, Roy, Sydney, N.S.W., Australia
Gooding, Diana J., Eastbourne
Green, Adrienne, Wembley
Grim, Roy I., Laurel, Md., U.S.A.
Hanna, Neil R., Aukland, New Zealand
Hilbourne, Anthony C., Twyford, Berks.
Hirohata, Tomoko, Toyonaka-city, Japan
Jackson, Lilian I., Reynella, S. Australia
Kaneko, Maseo, Tokyo, Japan
Maslen, Grant L., Nairobi, Kenya
Moran, John, Blackpool
Naim, Edward, London
Navarro Bort, Rodolfo, Valencia, Spain

Nemoto, Yoshio, Iwaki-Shi, Fukushima-Pref., Japan
Nittel, Lothar, Freiburg, W. Germany
Norton, Charles L., Conyngham, P.A. U.S.A.
Oates, Harold A., Glen Ellyn, Illinois, U.S.A.
Ogden, John M., London
Peris Bataller, Francisco, Valencia, Spain
Peyerl, Wolfgang, Knights/Tvl., Rep. of S. Africa
Pie De Masso, Rosa Maria, Barcelona, Spain
Power, John J., Quebec, Canada
Pratt, David, Bradford
Ramon Rius, Carlos E., Barcelona, Spain
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THE JOURNAL OF GEMMOLOGY

and

PROCEEDINGS OF THE
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ASSOCIATION
OF GREAT BRITAIN

GEMMOLOGICAL ASSOCIATION
OF GREAT BRITAIN
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Vol. 13 No. 3 JULY 1972

THE NEW RAYNER DIALDEX REFRACTOMETER

SINCE W. H. Wollaston suggested that measurement of the critical angle of a substance in contact with a glass block of higher refractive index would allow the refractive index of the substance to be determined there have been many different designs of apparatus made to do this. They all depended upon the projection of the shadow edge of the critical angle onto either an ocular fitted with crossbairs, which is fitted to a "telescope" attached to a scale of angular measurements so that the critical angle can be measured, and from this the refractive index of the substance can be calculated, or the shadow edge of the critical angle can be projected onto a scale of arbitrary numbers, or a scale calibrated in refractive indices. Such latter instruments are the well-known jewellers' refractometers.

The new DIALDEX refractometer, the latest in the range of Rayner instruments, has a newer approach in that there is no scale in the field of vision seen through the eyepiece. What is seen is a plain screen upon which the shadow edges are seen, measurement of these edges being made by a sliding *ribbon*, the bottom edge of which can be placed in line with the shadow edges. This *ribbon* is coupled to a drum dial marked in refractive indices from 1·40 to

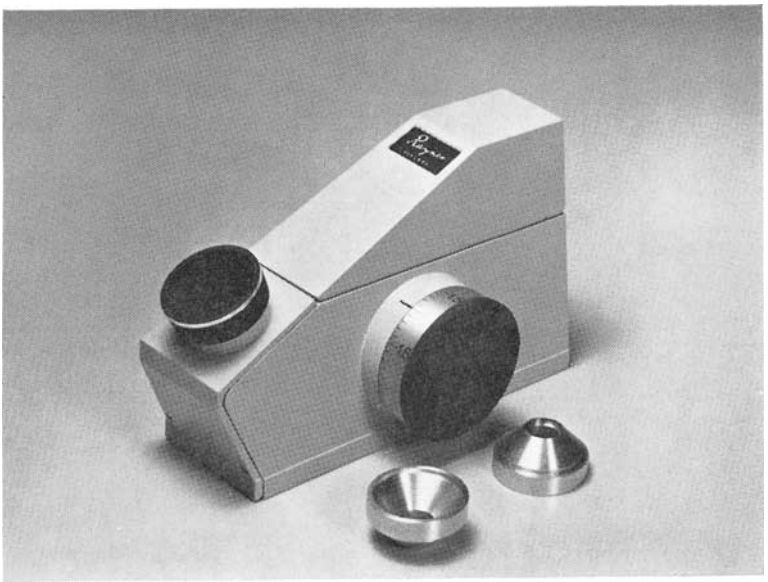

The new Rayner DIALDEX Refractometer

1·81, the divisions, in common with the standard Rayner instruments, increasing in width as the refractive indices increase. The scale on the drum covers a length of about 11 cms, whereas the projected scale on the older instruments, after eyepiece magnification, covers about 3 cms length, hence the second-place decimal marks are much wider apart and this allows for easier estimation of the third place of decimals.

The new instrument has a harder and less dispersive glass for the prism, and this not only makes for a better durability, but it also allows for the two edges of doubly refractive stones to be clearly seen in white light observation. This is due to the fact that the dispersion of the glass prism is nearer to the dispersions of the stones being tested.

A prototype DIALDEX refractometer has been examined for its performance under all conditions of illumination—with white light, with white light in conjunction with a "monochromatic" filter, and with polarizing filters. Tests were also made using sodium light, and the "distant-vision" and "bright-line" techniques were explored. Given below is a report of this examination and an assessment of the value of this radically different refractometer.

The white light tests were made on some 40 stones of different species, ranging from fluorspar to an almandine garnet with index of 1·797, so as to cover the whole range of the scale. The shadow edges were found to be fairly sharp and with birefringent stones having a double refraction of 0·005 or more the two shadow edges were clearly separated and could be measured with some accuracy, but with stones having a birefringence less than 0·005 the edges were less well defined. The calibration of the dial was found to be very accurate for the whole scale. For the next test a "monochromatic" filter was used over the eyepiece in conjunction with a fairly strong light source—a 60 watt tungsten electric lamp seemed eminently satisfactory—and this showed results which were to a great extent comparable to the use of sodium light, and, in many cases, double refraction less than 0·005 could be measured.

The question of stones with small birefringence, with particular reference to the synthetic emerald, was studied. Four small synthetic emeralds and an apatite were used for this test. In none of these cases was a convincing separation of the shadow edges seen, but this may, in part, be due to the small size of the stones or their bad polish. This may be significant for in one case an agate showed "form birefringence" when so examined. The use of sodium light allowed clear double edges to be seen and measured on all these small stones. Tests with sodium light on a number of doubly refractive stones whose two edges could be clearly seen in white light, or monochromatic filtered light, showed the shadow edges to be sharp, but, in common with all types of refractometers, the shadow edges when sodium light is used are less readily seen, and it is usually wise to spot the position of the shadow edges by using white light first.

The use of a polaroid filter to separate the edges may assist in some observations but seems to be less necessary with the new DIALDEX refractometer, for any shift of the shadow edge on turning the stone is readily apparent in relation to the indicator strip.

The admittedly difficult "distant-vision" method for cabochon stones and stones with other curved surfaces seems to be more easily carried out with the DIALDEX instrument, despite the pronounced parallax between the shadow edge and the indicator strip when the head is held away from the eyepiece as is necessary for this technique. Some dozen cabochon stones were tested by this method and the results were most encouraging. Quite good

values were obtained and there appeared to be less error than when the conventional instrument is used. This may well be due to the fact that one does not need to "leave" the eyeview of the shadow edge to see the scale, for the strip indicator, even if somewhat out of focus, is sufficiently well seen in the field at the same time.

Another technique, not too easy to do but valuable in certain cases, is the "bright-line" technique when the normal light aperture is "blocked off" and the light source directed at grazing incidence to the dense glass table. To do this with the DIALDEX instrument the "cover" must first be removed and then the light aperture at the front end be "blocked off" with a suitable object—a matchbox on end is admirable. The light source is then directed parallel to the table of the instrument. Tests showed that this method can be carried out satisfactorily despite the probability of some disturbing phantom bands.

The DIALDEX refractometer is somewhat larger than the standard Rayner instrument. It is 13 cms in length (12 cms in the standard Rayner refractometer); it has a base width of 4·1 cms (4·0 cms), or if the side dial be included the width is 5·9 cms; the dial, which is 4·1 cms in diameter, protrudes from the right hand side for a distance of 1·8 cms. The height of the instrument is 8·4 cms (6·5 cms). The casing, unlike the heavy casting used for the standard Rayner refractometer, is a pressure die-casting approximately 2 mm thick. It is this difference in construction which makes the DIALDEX instrument slightly lighter in weight at approximately 12¾ oz. avoirdupois, or 361·47 grams as against approximately 13·5 ounces avoirdupois, or 382·75 grams for the earlier cast models. The glass prism is larger than in the standard Rayner refractometer, being 5×10 mm (4×10 mm), and the eyepiece focuses by a "push-pull" action, and not by helical screws. The cover slides off to the right on a horizontal pin with a spring-loaded friction stud to prevent the cover "flopping". The cover does not pull off vertically as in the earlier instruments.

From the tests made the DIALDEX refractometer has several advantages over the conventional refractometers. The more open divisions of the drum dial make the estimation of third place of decimals easier; the edge of the "ribbon indicating strip" set on a shadow edge is stationary and any change in the movement of the shadow edge would be immediately apparent; thus, if the edge was not at its maximum (or minimum) position any further turning of

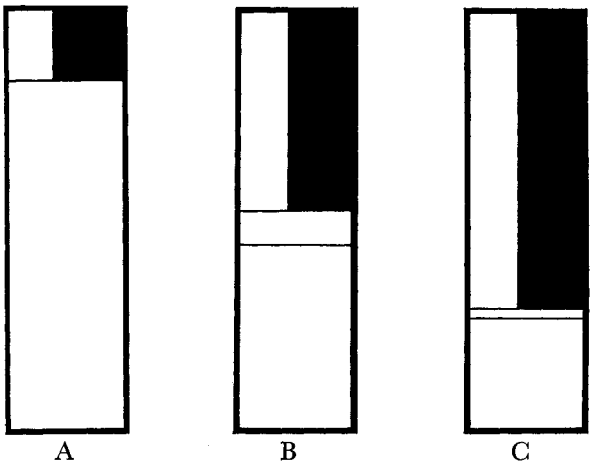

Appearance of the "field" in the DIALDEX refractometer showing the "ribbon" brought down to be in juxtaposition with shadow edges.

A.—Fluorite (singly refractive with index 1·434).

B.—Peridot (doubly refracting; 1·66 and 1·69. Indicator edge on the 1·66 reading).

C.—Sapphire (doubly refracting; 1·76 and 1·77. Indicator edge on the 1·76 reading).

the stone would show the shadow edge movement against the fixed edge of the *ribbon*. It is quite common to miss, or not be sure, of the maximum or minimum position of the required shadow edges, particularly in the case of biaxial stones, when the conventional instruments are used. The use of a less dispersive glass for the prism allowing readings of double refraction to be measured makes, to a great degree, the use of sodium light unnecessary.

R.W.

NOTES FROM THE LABORATORY (FOURTH SERIES)

By B. W. ANDERSON

Dangers of Ultra-sonic Cleaning

Those who use ultra-sonic cleaning apparatus should think carefully before subjecting gem-set jewellery to this drastic process. In some cases the damage is mechanical, being induced by the intense vibration—blue zoisite (tanzanite) being a prime example. In other cases there may be chemical damage caused by the solutions used, one alkaline and one acid. Samples of these shown to me appeared to consist of weak ammonium hydroxide and weak sulphuric acid, respectively. The alkali acts as a vigorous degreaser and oiled emeralds, for instance, emerge from the bath looking very much the worse for wear. A sufferer from the acid bath recently brought to our notice was a small plaque of lapis-lazuli the appearance of which had been effectively ruined by the leaching of some of its mineral content, particularly of the calcite particles. A handsome specimen of my own was subjected to the same treatment and the appearance ruined in a similar way. There was a loss in weight of several points. The stone did regain its handsome appearance after extensive repolishing, but the weight-loss was then quite considerable.

Pink Manganese Quartzite

Bracelets and ear pendants set with polished stones described as "pink jade" were recently examined in the Laboratory. From their granular appearance and hardness our first guess was that the stones were stained quartzite, and this seemed to be confirmed by a "spot" refractive index check, which gave a quartz reading. The spectroscope, however, gave the lie to this plausible theory, not only failing to show the expected dyestuff band in the green, but revealing instead very typical manganese bands in the blue and violet, the most powerful being centred at 4150 Å.

Since we know manganese minerals to be appreciably magnetic, a test was then carried out on our aperiodic balance, and a specimen of the pink mineral "in poise" was in fact found to be sensibly affected by the approach of a small pocket magnet. Finally one

cabochon piece was eased from its setting and a careful density test carried out. The resulting figure of 2·97 indicated a major adulteration, and assuming the manganese to be in the form either of rhodochrosite or of rhodonite there would have to be some 35% present to raise the density to such an extent.

Though no effervescence was observed when a drop of acid was applied to the surface, rhodochrosite would seem the more likely constituent since its softness would ensure that the upper levels of a polished surface would be formed of quartz prominences alone, thus accounting for the misleading refractometer reading.

A startling feature of this little investigation was that X-ray powder photographs taken and examined by experts in one of the museums showed a clear quartz pattern and nothing else whatsoever. Another "score" I would say for the powers of absorption spectroscopy in revealing the nature of gem materials. No reference to manganiferous quartzite of this nature could be found in the literature. The fittings of the bracelet, by the way, were of nine carat Chinese gold and the jewellery had been manufactured rather crudely in Hong-Kong.

Transparent Petalite from Brazil

As with so many "collector's items" for which quite high prices can be obtained, the claim of transparent petalite to be considered as a gemstone depends mainly on the last (and least important) of the well-known trilogy "beauty, durability, rarity". Colour is virtually lacking, hardness is a bare 6½, lustre low and fire missing.

Nevertheless, cut petalites of important size are sufficiently rare to be notable, particularly when they come from a new locality, and we were very glad to have an opportunity to examine two faceted petalites from Brazil which were recently submitted to us by Mr. E. A. Thomson.

These stones were exceptionally large (26 carats for the two), virtually colourless, and demonstrated the "constancy" of this silicate of lithium and aluminium in having almost exactly the same density (2·394) and refractive indices (1·504, 1·510, and 1·517) as those for a petalite from Australia sent to us by Dr. F. H. Pough many years ago. My young colleague Mr. Frank Hird, who worked on the stones, noticed a weak mauve fluorescence under

X-rays. This contrasts with the bright orange glow (with phosphorescence) noted by Mr. Robert Webster on the Australian material.

Dr. Hermann Bank, in the Zeitschrift der Deutschen Gesellschaft für Edelsteinkunde, describes very similar specimens of petalite from Brazil, indicating that the new source may be quite an important one for collectors of such curiosities.

Kashan synthetic rubies

Amongst the man-made gemstones produced in the past few years, "Kashan" rubies have a high reputation and a correspondingly high price. These are of "flux-fusion" origin—that is, they are crystallized from a suitable melt under normal atmospheric pressure. It is said that they are no longer in production, and they have not been exploited in this country, but we studied with interest samples of rough and cut "Kashans" kindly lent to us recently by Mr. M. J. O'Donoghue. The crystals were not of natural habit, being flattened rhombohedra with partially re-adsorbed surfaces. A surprising feature of these specimens was the paucity of chromium, as evidenced by their weak absorption and fluorescence spectrum and the rather subued red of their colour.

Specimens of "Kashan" rubies were extensively studied and described some years ago by workers in the laboratories of the Gemological Institute of America, who referred particularly to what they described as "paint-splash" inclusions of flux material. And in the stones we examined these curiously characteristic flat inclusions were found, though on quite a small scale. These are elongated, with parallel sides and rounded ends, rather like the footprint made by a moccasin, and are arranged in parallel formation in parallel groups. There are also visible twisted lace-like feathers, which are common to most flux-grown stones and, very significantly, there are no included foreign minerals.

Ruby doublets

As a sequel to my notes on natural-on-synthetic sapphire doublets, in which the crown is of natural Australian sapphire and the base of synthetic sapphire, I must now mention a further development in which the natural sapphire crown is based on synthetic ruby—yielding a surprisingly effective ruby substitute.

The blue or greenish upper layer provides the appearance of natural "silk", and the red in the base of synthetic ruby is quite enough to swamp its blue-green colour. The wise and the wary may note that the crown does not fluoresce under crossed filters or ultra-violet light while the base shows a bright red glow. And the same wary observer will not be satisfied with the composite stone's appearance under the microscope: but unless this warning is widely noted and repeated these audacious fakes will undoubtedly deceive many people. I am grateful to the Gemmological Association for sending me samples to examine.

Stained lapis-lazuli

There have for some time been warnings from the U.S.A. that objects cut from genuine lapis-lazuli are liable to have had their colour "improved" by the surface application of suitable blue dyestuff. We have therefore been careful, when objects in this attractive rock have been submitted for test, not only to search for pyrites inclusions and other signs, but also to rub the surface with clean cotton wool dipped in acetone or amyl acetate—available in most households as nail varnish remover. Quite recently our industry was rewarded, when a Chinese carving of very vivid ultramarine blue showed a distinct blue stain on the wool when applied. No great difficulty in this test, but just one more thing for the unfortunate jeweller to watch out for.

Tailpiece

The wording of the little notes or requests accompanying goods sent in to the Laboratory for testing sometimes cause us some quiet amusement. The other day a very obvious and ordinary brilliant-cut diamond in a single-stone ring arrived with the request: "Please state exact chemical composition". No textbooks were consulted.

THE LAKE-MANYARA-EMERALDS OF TANZANIA

By RUDOLF E. THURM

WITH exception perhaps of the benitoite, many types of gemstones have been found up to now in Tanzania. Diamonds, rubies and sapphires of all colour-shades, chrysoberyl, green beryl, deep blue aquamarine and aquamarine with blood-red dendritic inclusions, colourless grossular of the purest water that may be cut and polished as a diamond substitute, golden grossular and emerald-green grossular. There are the rhododendron-red rhodolites and the alexandrite-type garnets with distinct colour-change, which are left *in situ* by the local gemstone miners, as they are mistaken for poor colour grade rhodolite. There are the fine emerald-green chrome tourmalines from Landanai, the chrysoprase and the prase-opal. Last, but not least, the emerald-green zoisite, and not alone the fine crystalline "anyolite" with ruby inclusions from the famous Mundarara-mine, 18 miles off Longido in the bush, but also the emerald-green "tanzanite" from Merelani-Hills. Unfortunately, to the ordinary customer a tanzanite has to be blue. Therefore, the green tanzanites are heat-treated and become a rather pale blue. By my personal opinion, this is not an improvement!

The green stones that were first seen by the gemstone miner, Mr. Khanji, in Arusha, January 1969, were definitely emeralds. The location of the deposit was unknown, the indicated direction usually wrong.

The right direction to the emeralds was known by the Mzee of Babati and the gemstone prospector Hans Peter Kristen struck lucky and found Tanzania's largest emerald deposit in February 1970 at the south coast of Lake Manyara, near the village of Maji Moto (meaning "hot water" because of the hot sulphuric springs in this area).

The emeralds are found, together with alexandrite, in a biotite mica schist and partly in pegmatite.

The emerald deposit is worked now by about 120 mine workers, with bulldozers, washing plant and everything that is necessary for large scale gemstone mining. The output is up to three kilograms per day. The colour of the Manyara-Emeralds is a fine

Manyara-Emerald, × 120

Three phase inclusion and cubic and rectangular crystals.

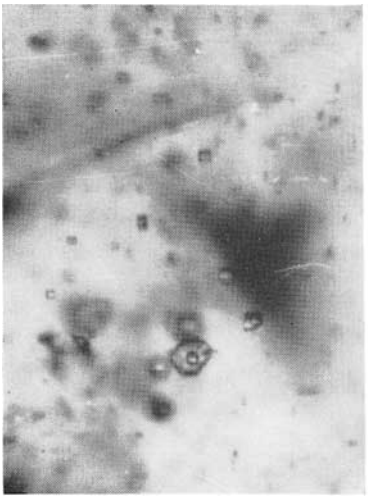

Liquid filled negative crystals parallel to the prism.

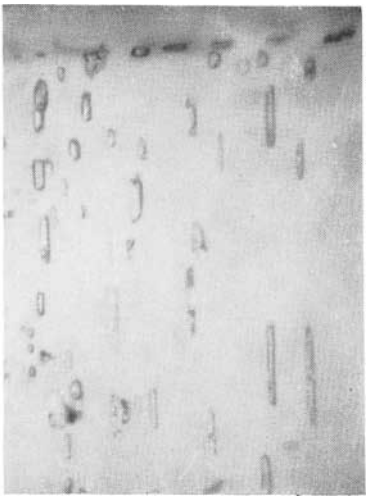

grass-green, some of them show a warm yellowish tinge like the Sandawana stones, others are deep bluish-green. Well developed hexagonal crystals up to 100 grams are not a rarity, but these species are only translucent and suitable for cutting cabochons. Fine, clear emeralds come up to eight carats only and are compared with the finest Colombian emeralds. The three-phase inclusions of the Manyara-Emerald are not of a jagged shape, but more stubby. The cubic and rectangular crystal inclusions are interesting, with a higher R.I. than the host crystal and the liquid-filled negative crystals parallel to the prism.

The dichroism is distinct and the chromium spectrum is the typical emerald-absorption spectrum with chromium absorption lines at 6830, 6806, 6620, 6460 and 6370 Å.

Manyara-Emeralds found in pegmatites do not exhibit a red residual colour under the Chelsea filter, while the very chrome-rich stones from the mica schist show a colour change to pink.

PRECIOUS OPAL MINING IN THE SNAKE RIVER PLAIN RHYOLITES, IDAHO

By PAUL L. BROUGHTON

Department of Mineral Resources, Regina, Saskatchewan

IN north-western United States the Snake River Plain and Yellowstone Plateau resulted from intense Pliocene and Quaternary volcanism. The resulting basalt and rhyolite flows, which molded the Idaho topography, have several occurrences of common and precious opal. In the United States the Idaho opal deposits probably rank second only to the famous Virgin Valley, Nevada, opalized wood deposits.

The very fine precious opal in Idaho has a quality that has been likened to that of the famous Hungarian opal. The body colors incline toward misty whites of high translucency in which medium size color patches of fire brilliance and clarity are observed.

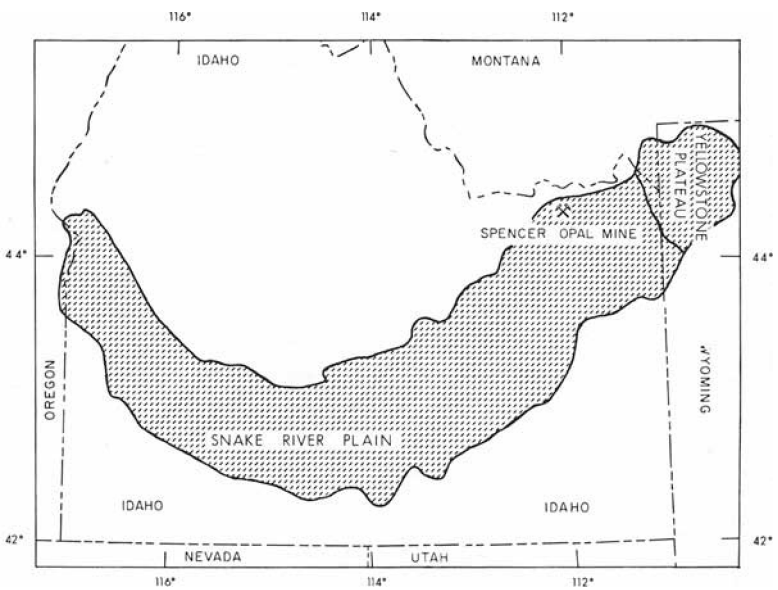

FIG. 1. Location of the Spencer Mine.

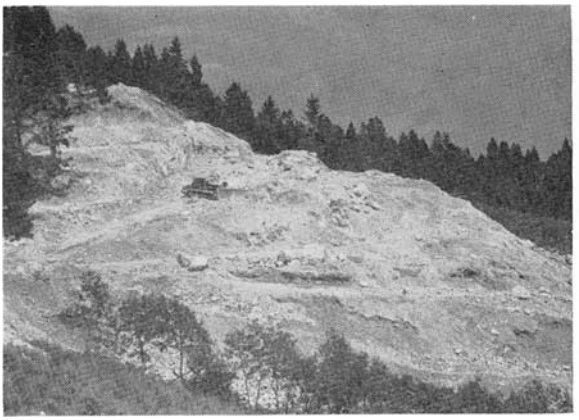

FIG. 2. The Spencer Opal Mine at Spencer, Idaho.

Since the late 1890's precious opal fields have been worked in Idaho with varying, but usually poor, commercial success. At the surface the rhyolites tend to disintegrate making it easier to extract the opal, but deeper down where fresher material is exposed, the opal is virtually impossible to remove on an economic basis.

Today, the main opal interest in Idaho centers on a cluster of small mines east of the village of Spencer, near the north-eastern corner of the state (fig. 1). The largest and most productive mine is the Spencer Mine (fig. 2), operated by M.L. Stetler. The mine was once known as the Lost Deer Hunt claim, and was originally discovered, as the name implies, by a party of lost deer hunters two decades ago.

The Spencer Mine is at an elevation of 7,000 feet on the south slope of the Continental Divide, five miles east of Spencer, Idaho. The mine is operated open pit style, and is essentially a bulldozer and dynamite operation on the mountain slope. The mine is in a light gray to light purplish gray rhyolite flow of Pleistocene to Recent-age volcanism. The best opal occurs as nodular masses and as layers forming the bottom of gas cavities. The nodular masses undoubtedly represent completely filled gas cavities. It also occurs as thin seams, veinlets and crack and joint fillings. In thin section the rhyolite is a highly silicic rock containing phenocryts of orthoclase pseudomorphs after sanidine (fig. 3). No

O. 5 mm

FIG. 3. A large phenocryst of orthoclase alteration of the original sanidine, adjacent to a spherulite, and trains of smaller spherulites.

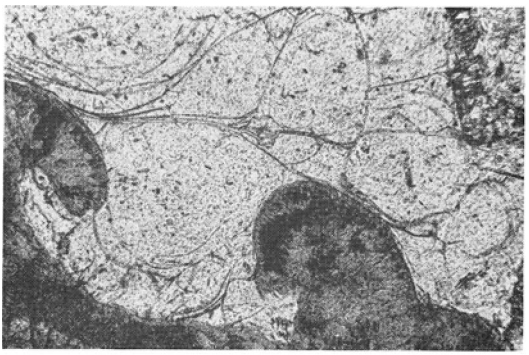

O. 5 mm

FIG. 4. Perlitic structures in the groundmass of the rhyolite.

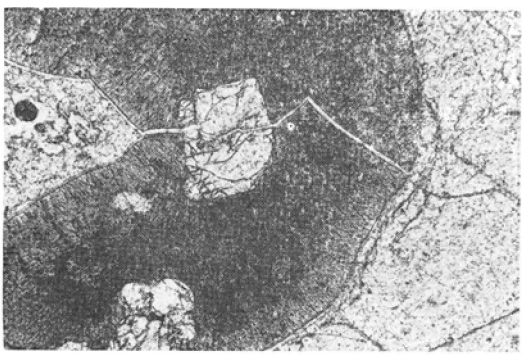

O. 1 mm

FIG. 5. A spherulite composed of radiating fibres of cristobalite and orthoclase, with a phenocryst of orthoclase pseudomorph after sanidine, penetrated by a veinlet of chalcedony.

mafic minerals in more than trace amounts have been observed. The most common were a few green augite crystals. Euhedral crystals of magnetite are rare but sometimes associated with the groundmass, which is completely glassy and often perlitic (fig. 4). This groundmass is essentially a micro-crystalline quartz and alkali feldspar mixture in hazy intergrowths, characterized by flows of microlites.

A specimen of precious opal from a gas cavity was analysed for trace elements by use of a Jarrell Ash 3·4 spectometer with Ebert Grating applied to a direct current arc. Of the 60 elements tested for, the following were present: aluminium, boron, calcium, copper, lithium, lutetium, magnesium, silicon (major), titanium and vanadium.

The upper zones of the rhyolite lava flows exposed at the mine are characterized by variable devitrified and spherulitic black obsidian which forms abundant blocks in the agglomerates at the top of the flow. The devitrification spherulite's fibrous radiating structure is usually a mixture of high quartz, cristobalite and orthoclase. Phenocrysts of sanidine have been recrystallized into aggregates of orthoclase and sometimes high quartz (fig. 7). The phenocrysts occur within the spherulites (fig. 5) as well as in the groundmass (fig. 3). Films of chalcedony usually form an outer margin (fig. 6) on the spherulites. Recrystallization of this chalcedony film into micro-crystalline quartz is rare. Phenocrysts range in abundance from one to ten per cent of the bulk volume, but usually around six per cent.

The nodular opaline masses, one of the two forms common in the mine, are formed in the upper black obsidian zones, that area approximately above the bulldozer in fig. 2. Below this the rhyolite is prolific with gas vugs up to six inches in diameter. The opal forms a secondary deposition in the basin portion of the cavities. Bladed aragonite crystals, additional films of amorphous silica, and malachite green stained alunite laminations are frequently associated with the late-stage secondary deposition. Most of the cavities are either empty or full of common opal. Precious opal is present in roughly ten per cent of the cavities, usually as paper-thin seams amid common opal layers. The thin seams are well suited for manufacture into triplets. Rarer pieces in varicoloured reds, blues and green are found upward of an inch thick.

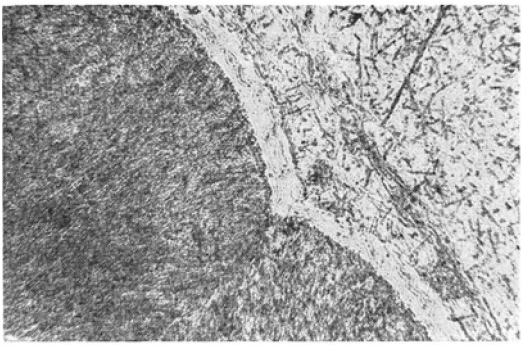

0.03 mm

FIG. 6. Contact zone between a spherulite and the rhyolite groundmass. The contact margin is emphasized by a film of chalcedony. Note the microlites in the groundmass.

The overwhelming majority of the opal has a translucent white background, but the prized dark gray-black variety is periodically uncovered.

For the last three years the mine has been open for public collecting at a moderate fee.

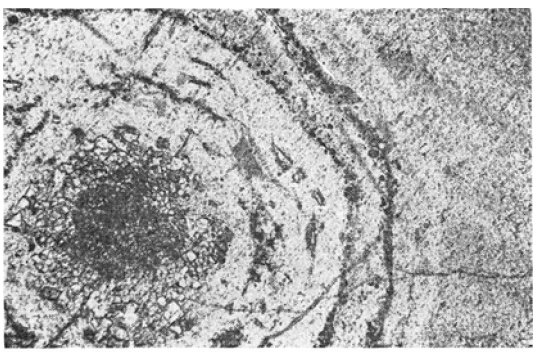

0.5 mm

FIG. 7. A spherical zone which is recrystallizing to an aggregate of small orthoclase crystals (in rhyolite).

Gemmological Abstracts

BANK, (H.) *Transparenter weiss-farbloser Grossular aus Tansania.* Zeits. deutschen Gemmologischen Gesell., **20,** 22–25, 1971.

A colourless transparent grossular from Tanzania first described by the author in 1968 was found to have *n* 1·732–1·736, sp. gr. 3·65, *a* 11·851 ±0·002 Å. E.H.C.R.

BANK, (H.) *Durchsichtiger blassgelblicher Plagioklas aus den U.S.A.* Zeits. deutschen Gemmologischen Gesell., **19,** 134–136, 1970.

A new pale yellow bytownite from a pegmatite at Plush, Oregon, with α 1·565, γ 1·574, sp. gr. 2·73 ±0·02, is described. E.H.C.R.

BANK, (H.) and NUBER, (B.) *Durchsichtiger Skapolith aus Moçambique.* Zeits. deutschen Gemmologischen Gesell., **19,** 47–54, 4 figs., 1970.

Data for a gem quality yellow scapolite from a pegmatite east of Entre Rios (map) are given and compared with those from other localities; ω 1·554–1·556, ε 1·540–1·541; *a* 12·071, *c* 7·588 Å. E.H.C.R.

BANK, (H.) & NUBER, (B.) *Zu den Gitterkonstanten von "Edelaktinolith".* Zeits. deutschen Gemmologischen Gesell., **19,** 55–60, 1 fig., 1970.

X-ray *d*-values are tabulated for a transparent green actinolite from Tanzania. It has *a* 9·848, *b* 17·996, *c* 5·272 Å, β 104·85°; H. 5½; perfect cleavage {110}; α 1·619–1·622, β 1·632–1·634, γ 1·642–1·644; sp. gr. 3·03–3·07. XRF shows Ca, Si, K, Ti, Fe, with some Cl and Al. E.H.C.R.

EULITZ (W. R.). *A new design for brilliance plus dispersion.* Australian Gemmologist 1971, XI, 2, pp. 28–32, 5 figures.

The author comments on the validity of Suzuki's formulae

given in an article in the Australian Gemmologist, 1970, X, 10, pp. 13–24. (Abstracted Journ. Gemmology XII, 5, p. 180), and compares the submissions with the author's (Eulitz) own work. (Gems and Gemology, 1968, XII, 9, pp. 263–271). S. Suzuki replies to this criticism in Australian Gemmologist, 1971, XI, 4, pp. 25–27, 2 figures. R.W.

FANDER (H. W.). *Mineralogy and metallurgy of gold.* Australian Gemmologist, 1971, XI, 2, pp. 3–4.

Report of the Presidential address to the Australian Gemmological Association. Gold is found in many geological situations from hydrothermal to alluvial and usually occurs as native metal, although in some deposits it is in combination with tellurium. South Africa produces about 40% of the world's total, some 1,000 tons annually. In this locality the metal is finely disseminated in a conglomerate and may be hydrothermal in origin, although some workers suggest a "fossil" placer origin. Gold is not rare and is widely distributed in small quantities, but, as in sea water, in too small concentrations to be recoverable. Because of its fine dissemination throughout the rocks extraction is difficult, on the other hand, due to its reluctance to combine with other elements, it is easily smelted and refined. R.W.

HUDSON (D. R.). *Key for identification of common cut and uncut gemstones.* Australian Gemmologist, 1971, XI, 3, pp. 6–7.

Details a system for the rapid testing of gemstones and was devised mainly for student use. By the use of "crossed polars" the optical character of the stones is found and they are separated into two groups—singly and doubly refractive. Each group is then further divided into smaller groups by the densities assessed by heavy liquids. Finally the refractive index is ascertained by use of a refractometer (for cut stones) or by immersion methods for uncut material. A "graph-chart" provides the final reference. This chart, made on graph paper, has the refractive indices to the first place of decimals marked along the top edge at every heavier ruled fifth line. The names of the stones are written up the left margin in order of ascending R.I. and the R.I. of each named stone is depicted by a horizontal line covering the range of R.I's

for that stone. This is similar to the graph-chart published for densities by Professor Karl Chudoba in the *Gemmologist* for June 1936. R.W.

JONES (J. B.) and SEGNIT (E. R.). *The nature of opal. I. Nomenclature and constituent phases.* Journ. Geol. Soc. Australia, 18, 57-68, 6 figs. 1pl.

Natural hydrous silica may be subdivided into three well-defined structural groups: opal-C (well-ordered γ-cristobalite), opal-CT (disordered α-crist instobalite, α-tridymite), and opal-A (highly disordered, nearly amorphous). Lussatite from the original locality is identical with opal -CT; lussatite thus appears to be a legitimate name for this class of opal. Although the main criterion used is the X-ray diffraction pattern, supplementary information from IR absorption, dilatometer, and thermal techniques supports the three-fold classification. The terms opal and opaline silica may conveniently be applied to natural hydrous silica for which there is insufficient information to place the material in one of the three above categories. R.A.H.

LANG (C). *Photomicrography without a camera.* Australian Gemmologist, 1971, XI, 4, pp. 7–12, 8 illus.

A well-written article on the photomicrography of gem stones using the minimum of equipment. There is an interesting paragraph on the optics of a microscope. R.W.

LAPWORTH (P. B.). *The myth of the Geierstein opal.* Australian Gemmologist, 1971, XI, 2, pp. 27–32.

A cogent study of the "bad luck" story in Sir Walter Scott's novel *Anne of Geierstein* which has been suggested as being the cause of the unpopularity of opals. A number of references, other than that of the novel itself, have been examined, but a completely clear decision has not been reached. R.W.

LIDDICOAT (R. T.). *Diamond prices of a century ago.* Gems & Gemology, 1971, XIII, 10, pp. 325–327.

A copy of *The Jeweller's Guide and Handy Reference Book* published by W. Redman in Bradford during 1883 has been presented to the Gemological Institute of America. In the article Mr. Liddicoat discusses the prices of gemstones given in Redman's book. R.W.

McColl (D.). *More confusion with synthetic yellow sapphire.* Australian Gemmologist, 1971, XI, 3, pp. 3–5, 2 tables. A graph, 1 illus.

Investigation by the author shows that there are three types of synthetic yellow sapphire. They are referred to as Type A, which is coloured by iron and manganese and is generally a pale yellow in colour and Type B coloured by manganese and chromium and which has a warmer and more orangy colour. Lastly, Type C, in which iron and vanadium are the colour producing metals. These produce hues of yellow. A Type C stone is reported upon and a table, arranged by J. H. Oughton, is given showing the absorption and luminescent characters of the three types.

R.W.

Milyuvene, (V. A.) and Varshavskii, (A. V.) *Distribution of luminescence centres in diamond crystals.* Soviet Physics—Crystallography, **16,** 157–159, 3 figs., 1971. Transl. from Kristallografiya, **16,** 197–199, 1971.

Examination of about 1000 Yakutian diamonds has shown that luminescence in UV light and birefringence have either a zonal or a sectoral distribution within a diamond crystal. Sectoral distribution in accretion pyramids is related to (100) or (111) faces. The constant nature of the structure of the blue component of the luminescence spectrum and its sectoral distribution show it to be connected with a definite impurity adsorbed only on (111) faces. [Following abstract].

A.P.

Trubin, (V. I.) *Distribution of luminescence centres in diamonds.* Soviet Physics—Crystallography, **16,** 201–204, 5 figs., 1971. Transl. from Kristallografiya, **16,** 244–247, 1971.

A large lot of natural diamonds from various mines was examined [preceding abstract]. Crystals with zonal luminescence are most common, sectoral luminescence is encountered much less often. Among crystals with zonal luminescence blue is most common, while green and yellow are substantially less common. Crystals with several luminescence bands of different colour are quite rare. The optical absorption spectrum of a diamond in the portion showing blue luminescence is contrasted with the spectrum of the portion not showing such luminescence. A.P.

OUGHTON (J. H.). *Fakes and frauds—Caveat emptor.* Australian Gemmologist, 1971, XI, 4, pp. 17–22, 3 illus.

A report on the natural greenish-yellow sapphire topped/synthetic blue sapphire-based doublet. Some yellow sapphires which presumably have had their colour enhanced by X-ray treatment are discussed. The atomic bombardment of large diamonds is commented upon. The "removal" of "silk" in some sapphires is mentioned and there is reference of two synthetic rubies which fluoresced blue when bathed in short-wave ultra-violet light.

R.W.

SANDERS (J. V.) and DARRAGH (P. J.). *The microstructure of precious opal.* Min. Record, 1971, 2, no. 6, pp. 261-268.

Studies of gem opal have established that the spectral colours are due not to chemical impurities or selective adsorption but to optical diffraction from a randomly faulted, close-packed structure of minute, transparent silica particles. The play of colours depends on the size and uniformity of the particles and on the extent of faulting. In the best gem-quality opal the particle size is at least 0·25 mμ diameter. The article is abundantly illustrated by 18 electron micrographs of fractured or etched surfaces of opal showing the lines of silica particles. Gem opal appears to be restricted in occurrence to horizontal layers in or near a bentonitic horizon.

R.A.H.

SHEPHERD, (G. F.) *The story of opal.* Rocks & Minerals, **46,** 363–370, 1971.

An account is given of the history and properties of precious opal. Occurrences in Australia, Czechoslovakia, Mexico, India and Honduras are summarized.

R.S.M.

WEBSTER (R.). *A problem in diamonds.* The Criminologist, 1971, VI, 20, pp. 28–31, 3 illus. (repeated Australian Gemmologist 1971, XI, 4, pp. 5–6).

Illustrates the use of X-rays when it was needed to know whether a stone in a sealed packet was a diamond or not.

P.B.

BOOK REVIEWS

SWEENEY (J.). *Gemmology*, Bundu series. Longman Rhodesia (Pvt) Ltd., Salisbury, 1971, pp. 112, some colour plates. $1.75.

Despite the title this is in no sense a gemmological textbook, although the author gives brief descriptions of some of the standard gemmological tests. The book is rather a guide to the gemstones of Rhodesia and is to be welcomed on that score, since there is no comparable monograph, although various species are described in Geological Survey reports. The author is too inaccurate when dealing with gem testing for the book to be of use to the serious student; the figure described as a cube and showing axes of symmetry is not a cube. Mohs' scale, said by the author to be internationally accepted, is quoted in a version which places apatite at 4, dioptase at 5 and epidote at 6. There are also too many slack phrases and loose definitions. Streak is given for 36 examples but of those given 26 show a white streak.

However, the book is welcome as a guide to the locations in which Rhodesian gemstones may be found. For a book reasonably priced the coloured illustrations are quite acceptable. There are chapters on synthetic and imitation gemstones and on fashioning and inclusions. Some text figures in black and white would have been useful in this section. The book concludes with a short glossary and index.

M.O'D.

LÜSCHEN (H.). *Die Namen der Steine*. Ott Verlag, Thun, 1968, pp. 383, Sw. fr. 34.80.

This is an exhaustive survey, with glossary, of the origin of the names given to minerals and gemstones, including those of legend. A glossary lists 1,200 names and there are numerous black-and-white illustrations of minerals and text figures illustrating woodcuts from early printed books. Chapters of introductory material include an account of the development of mineral names from earliest times through the middle ages to the present day, names met in alchemical treatises, names derived from personal names of discoverers and others.

The glossary contains most of the names familiar to gemmologists, although taaffeite and painite are regrettably absent. There is no attempt to list all the varieties of agate nor do the

entries attempt to include scientific data. The material called topaz by Pliny has correctly been listed as peridot.

This is a book which fills a serious gap in mineralogical literature. The gemmologist may not wish to purchase it, although the price is reasonable, but he will be pleased to know that it will be available in libraries for consultation.

M.O'D.

SCHWEGLER (E.), SCHNEIDER (P.) and HEISSEL (W.). *Geologie in Stichworten.* LIEBER (W.). *Mineralogie in Stichworten.* Verlag Ferdinand Hirt, Kiel, 1969, pp. 160 and 244. Both DM 9.20.

These two books form part of the series Hirts Stichworterbücher and are intended as introductory guides to their respective subjects. The geology text covers first geology in general and then gives a regional geology of Germany. A particular feature is the series of relief diagrams and cross-sections which are clearer than in any other comparable book, notable examples including Alpine structures and illustrations of ice age conditions. A useful bibliography lists works of very recent date.

The mineralogy text from the illustrations alone stands very high among similarly-priced books. Even a reader with no German can profit from a study of the diagrams of the crystal systems, which show the crystallographic axes and also, for each system and class, the way in which full symmetry is attained. Illustrations of other mineralogical details are similarly graphic and the book ends with a list, in traditional order, of major minerals listing crystal system, chemical formula, a diagram of the crystal form, habit, colour, hardness, streak and SG. These details spread over a whole opening so that all can be seen together. A bibliography lists, among other books on mineralogy, a number of German gemmological texts.

M.O'D.

DOHRENWEND (DORIS). *Chinese jades in the Royal Ontario Museum.* Toronto, 1971, pp. 135. Illustrated in black-and-white and in colour. £4·55.

This is a descriptive catalogue of the jades acquired by the Museum since 1910, with illustrations of a large proportion of the collection. Introductory chapters cover provenance, the nature of the material, problems of dating and early sources of information.

The introduction closes with chapters on the types and uses of Chinese jades, their fashioning and the styles adopted for particular purposes. The catalogue proper gives good descriptions, with dimensions, of the collection and the standard of the black-and-white illustration is high enough to enable the reader to distinguish details of ornamentation, but the coloured plates, though adequate, are not of quite such high quality. It is interesting to note, under the heading of ritual jades, how some shapes have still not had a definite use assigned to them, particularly the pi disk which has aroused many colourful speculations over the years. Some items, noted in the catalogue, have been tested by X-ray diffraction analysis. A useful bibliography lists the major works necessary to further study.

M.O'D.

PLATE (W.). *Wörterbuch der Perlenkunde.* Ruhle-Diebener-Verlag KG, Stuttgart, 1957, pp. 60. DM5.80

A useful glossary of terms relating to pearl issued with a table of weights. Some disconcerting absences are *Pinctada* from its expected alphabetical position, and any illustrations, but on the whole the book is a useful quick guide to the commoner terms for the German reader.

M.O'D.

CAVENAGO-BIGNAMI (SPERANZA). *Gemmologia*, Third edition, 1972 Ulrico Hoepli, Milan. Illustrated in colour and black-and-white, 2 vols. pp. 1526. L.40,000.

In preparing this, the largest and most comprehensive work ever to appear on gemmology, the author has doubled the size of the previous editions. The work is divided into sections of unequal size covering basic mineralogy, the gem species, the techniques of gem testing, and tables. The section on gem testing covers only 100 pages which is one-thirteenth of the work. With a book of this degree of comprehensiveness perhaps more space could have been given to this section and less to the mineralogy. The standard of the colour plates, though variable, is exceptionally high at its best, in particular those illustrating inclusions and polarization effects. The diagrams in the text are also clear and the black-and-white plates, again those depicting inclusions, set a new level of clarity. One wonders whether the paper, which began to

discolour at the edges quite early after the publication of the previous edition, will again do so. The bibliography, covering a mere two pages, is quite inadequate for a work of this importance.

These general points covered, a detailed review of the book throws up material which one would hardly have expected to see in a book whose preface is dated 1972. There are illustrations of the General Electric synthetic gem diamonds and of the American flux-grown ruby. The Gilson synthetic turquoise is mentioned and its surface structure illustrated. There appears to be no mention, however, of the work done by Dr. F. A. Raal and his associates on the presence of nitrogen in diamond and its effect on colour and behaviour, though Lonsdaleite (a hexagonal form found in meteorites) is quoted. The sections covering the individual gems are exhaustive and the more important gems have their locations depicted in clear maps. A particularly happy feature is the provision, also for the more important stones, of a table of other stones whose identification could be confused with the stone under review, though, inexplicably, double refraction figures are not given. Some of the materials have no gem use, though moon rock (which is illustrated in colour) may attain a desirability of a kind. In the gem testing section I was particularly pleased to see the greatest prominence given to the location and identification of inclusions—surely the most important test for the future. Absorption spectra are given in black and white with a coloured spectrum for comparison purposes at the top of the page. I should have liked to see details of the work done using the electron-microprobe, such as that described by Gübelin in his paper "On the nature of mineral inclusions in gemstones". However, the inclusions are so well illustrated that the loss will only be felt by advanced gemmologists and those as yet new to the study.

This is indeed a fine production, fit to stand with the other giants of gemmology, Bauer and Webster. It may be that the day of the encyclopaedic work is slowly drawing to its close, at least in so far as science is concerned. No book has been so exhaustive and to repeat much of the detail in later books, in whatever language, will be unnecessary. As gemmology advances as a science, its literature will take the form of the photo-copied laboratory reports and offprints, which now characterize other branches of the earth sciences. If this is indeed the last work on gems of this magnitude, it is the best that could have been contemplated.

M.O'D.

ASSOCIATION NOTICES

GIFTS TO THE ASSOCIATION

The Council of the Association is indebted to the following for gifts to the Sir James Walton Library:

Snr. Elio Rosso, Sao Paulo, Brazil, for two almandine garnet tablet stones containing attractive inclusions.

Third revised edition of *Gemmologia* (2 vols.) from the author, Signora Speranza Cavenago-Bignami, Director of the State Gemmological Laboratory of Valenza and Milan.

John R. Fuhrbach, Texas, U.S.A., for a collection of Brazilian tourmaline specimens, some of which are capped with blue tourmaline.

Mrs. Alice Millard, Liverpool, N.S.W., for Australian opal specimens.

Mr. Dean Field, Toronto, Canada, for a booklet entitled *Jade and its Substitutes.*

FORTHCOMING MEETINGS

On Tuesday, 17th October, a talk will be given by Professor S. Tolansky, D.Sc., F.R.S., entitled "Speaking at Random". This will be held at Goldsmiths' Hall, Foster Lane, London EC2, and will commence at 7.00 p.m.

A Reunion of Members will be held on Monday, 27th November, at Goldsmiths' Hall at 6.00 p.m., followed at 7.00 p.m. by the Presentation of Awards gained in the 1972 examinations.

MEMBERS' MEETINGS

London

A large attendance of gemmologists heard Mr. E. A. Jobbins, B.Sc., of the Institute of Geological Sciences, South Kensington, give a talk on "Jade and Pseudo-Jade", at Goldsmiths Hall, Foster Lane, London, on the 18th of April.

Mr. Jobbins said that members of the Association would see his talk as a petrological one rather than a gemmological one, and started with a coloured slide of aventurine quartz, which he described fully, both as an uncut and as a cut stone.

The slides included thin specimens, which illustrated the colours and structures one found in jades. Magnification on the screen was between 300 and 400 ×.

For the purist looking for true colour in photographs of gemstones, Mr. Jobbins described his experiences with Ektachrome and Agfa colour film and illustrated the differences in colours when specimens were photographed on both makes of film.

During question time Mr. Jobbins described the Geological Museum's definition of jade and near jade.

In a vote of thanks, Mr. Robert Webster said that members had been treated to a stimulating lecture and one which he had not been quite expecting. In the past the Gem Testing Laboratory of the London Chamber of Commerce had experienced a lot of trouble with jade and had been pleased to call upon Mr. Jobbins and his colleagues to undertake tests the Laboratory was not competent to carry out in relation to petrology.

Midlands

The Annual General Meeting of the Midlands Branch of the Association was held on Thursday, 11th May, at the Auctioneers Institute, St. Philips Place, Birmingham.

Mrs. Siglinde Hiscox, F.G.A., was re-elected as Chairman and Mr. John Marshall was re-elected as Vice-Chairman. The Committee included one new member, Mr. Douglas Morgan, who joined Mrs. Susan Spence, Mr. Maurice Kirkpatrick and Mr. Graham Porter. Mr. Peter West was re-elected as Secretary.

In her summary Mrs. Hiscox was able to report a very successful year's activity culminating in the day's outing to Amsterdam, and mention was made of the success of the experiment of appointing

a committee member as Press Officer. His duties included informing gemmological students of branch meetings as well as liaising with the trade and public press.

The meeting was fortunate in having present the National Vice-Chairman, Mr. D. King, F.G.A. He was pleased to hear of the vigorous state of the branch, and spoke of the growing interest being shown all around the world in gemmology.

After the formal business had been concluded the members were given a fascinating illustrated talk by Mr. John Salloway of Lichfield on his recent visit to the diamond and gold mines of South Africa.

The annual dinner and dance of the Midlands Branch was held on Wednesday, 19th April, at the Bank Hotel, Knowle. Forty-two members and their guests attended.

The Branch also arranged a day trip to Amsterdam. This was held on Sunday, 7th May, and included a visit to the Diamond Polishing Exhibition and a cruise around the canals of Amsterdam.

Scotland

The Annual General Meeting of the Scottish Branch of the Association was held on Thursday, 20th April, at the North British Hotel, Glasgow. Mr. D. Hill, the retiring Chairman, presided, and in his report mentioned particularly the success of the "World of Gems" exhibition and the summer outing to Dunure. Thanks to Mr. Wallace Allan, there had been a very large turn-out for a meeting at Ayr.

Mr. Alastair Armstrong was elected Chairman and Mr. G. M. Turner re-elected as Secretary. The Committee now consists of Messrs. D. Hill, I. McKenzie, A. McRae, P. Neil, C. Wade and H. Whitehead.

The 1972 summer outing was held on Sunday, 4th June, when members of the Branch visited Killin (Loch Tay).

IMITATION ZOISITE

In connexion with Mr. B. W. Anderson's note on a blue zoisite imitation (*Journal of Gemmology*, January 1972), Professor I. S. Loupekine of the University of Nairobi has reported that he recently encountered an example of an imitation in a parcel of five

cut stones purchased as Tanzanite. Four stones, ranging from 3·35 to 19·50 cts. were blue-mauve, but differing slightly in hue and strongly resembled fired tanzanite; but the fifth stone—of only 3·30 cts.—was brownish. The blue-mauve stones proved to be synthetic spinel doublets and the little companion was smoky quartz and was undoubtedly added to give a natural feel since off-colour brown zoisite is only too common.

COUNCIL MEETING

At a meeting of the Council of the Association held on Wednesday, 17th May, the following were elected to membership:

FELLOWSHIP

Adams, Michael E., Middlesbrough. D. 1971

Clark, John G. A., Lewes. D. 1970

Gelaberto Vilagran, Enrique, Barcelona, Spain. D. 1971

Solé Barneda, Domingo, Barcelona, Spain. D. 1971

ORDINARY

Altman, Jack E., Savannah, Georgia, U.S.A.
Arch, Boaz Y., Salisbury, Rhodesia
Beebe, Roxanne, Woodside, Calif., U.S.A.
Bella, Carlo, Rome, Italy
Bernard, David A. W., Carshalton, Surrey
Biremberg, Hector y Juan, Mar del Plata, Argentina
Brou, Nicole, Mouscron, Belgium
Brown, William H., Andover, Hants.
Chapman, Ross N., Mackay, Queensland, Australia
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1972 EXAMINATIONS

As the Gemmological Examinations have been held a little later this year, results will be delayed.

The final date for enrolment of *new* preliminary correspondence course entrants is the 31st August. Places, however, will be reserved for successful preliminary correspondence course candidates if the notification of the results has not been made by that date. Results will be issued as soon as possible.

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No. 3
July 1972

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Vol. 13 No. 4 October, 1972

THE JOURNAL OF GEMMOLOGY

and

PROCEEDINGS OF THE

GEMMOLOGICAL ASSOCIATION OF GREAT BRITAIN

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OF GREAT BRITAIN
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THE JOURNAL OF GEMMOLOGY
AND PROCEEDINGS OF THE GEMMOLOGICAL ASSOCIATION OF GREAT BRITAIN

Vol. 13 No. 4 OCTOBER 1972

GEMMOLOGICAL NOTES

By A. E. FARN, F.G.A.

ON Dartmoor recently I sat on a granite boulder and thought of my colleagues at the laboratory—I was on holiday and I suppose it was the stones, boulders, etc. which caused me to think of the laboratory and inevitably other stones of interest. Sometimes considerable interest is aroused in very ordinary subjects when seen in slightly varying guises. To a gemmologist, albeit a commercial gemmologist such as myself, gemmology embraces those gemstones usually set in jewellery for retail distribution, i.e. rubies, diamonds, emeralds, all the way down through chrysoberyl, topaz to peridot, tourmaline, garnet and the ubiquitous quartz family. The more exciting and consequently rarer gemstones, which are vintage wines compared with the normal "vin rouge ordinaire" of everyday diet, are by their exceptional qualities rare and perhaps not conducive to digestion. Quite recently a diamond dealer brought to the laboratory an octahedron of colourless material which normally one would expect from a diamond dealer as being part and/or parcel of his normal stock. In Hatton Garden diamond octahedra are common enough, being the rough from which brilliant-cut stones are fashioned, so why have it tested? In the laboratory of the London Chamber of Commerce we are never (I hope) visibly surprised at the most obvious tests, such as 10ct.

obvious synthetic ruby or straightforward yellow quartz. We realise that our customers very often know the true nature of their goods and that the test is merely to obtain an unbiased authority to quote in the case of valuation for replacement, probate, or some reason, so that we were not entirely surprised by a dealer offering an octahedron for testing. We on the other hand assumed (always dangerous) that here we had a synthetic spinel purposely made to deceive (since no diamond dealer would ever be worried whether diamond or not). Such a dealer would know his diamonds but not necessarily their simulants.

To commence testing with preconceived ideas is always dangerous and usually leads to needless testing by trying to establish a concept which may be the figment of a fertile imagination.

We took a distant vision refractive index measurement of the octahedron since it had slightly curved faces with worn edges. The reading obtained did not fit our ideas of synthetic spinel, in fact a rather poor indication about 1·44 seemed to be too far away, to be accurate. One thing diamond will do is to fluoresce (usually milky blue) under X-ray excitation. This stone did not. It fluoresced a violet-mauvish colour which is a characteristic of yttrium aluminate (YAG)—one of man's latest contributions to the never ending list of diamond simulants. Inspection by microscope showed a form of three-phase inclusion which precluded synthesis so far as we know. A three-phase inclusion indicated beryl to me so we viewed it through the Chelsea colour filter, as all colourless or near colourless beryls will take on an added hint of green. This octahedron however remained obstinately colourless.

Having hovered around somewhat aimlessly trying to short-circuit testing by preconceived ideas we decided to do some gemmology for a change. Using known density liquids we found the specimen sank in bromoform and floated in methylene iodide and at last we decided it had to be fluorspar. The octahedron fluoresced mauve under ultra-violet, and between crossed polaroids it was singly refracting. The distant vision method was doubly checked and a strong hint of 1·44 appearing merely confirmed what is pretty obvious when read; but it lightened a routine day with just a touch of gemmology pure and fairly simple to show how a too commercialized approach by professional gemmologists can go wrong.

As soon as one mentions doublets then one is prepared for all kinds of variations. Recently an opal in a pendant was sent for

testing. Now anyone can tell once a stone is out of a setting and the girdle exposed. However, when one *suspects* an opal doublet which in a setting is somewhat flat (but not too flat) and of good colour-play on top and fairly good complementary colour below, it behoves one to do something other than to suspect it. Usually (a dangerous word) opals which are subtranslucent will allow light through when viewed under the microscope. This one did and in fact look absolutely right, but the setting edge of the pendant showed a small crimped mark as if a skilled setter had unset and reset the stone. The stone to me was slightly loose in its setting and had a fractional shake. Being commercially minded and always suspicious I couldn't help but think that if someone had had this opal out they would have only put it back if it was a doublet. However, it was subtranslucent—most unusual in a doublet—and it had a good colour-play below the girdle. Close inspection by microscope did not reveal any squeezed-out bubbles of air sometimes seen in doublets, but certainly there were some somewhat irregularly shaped transparent patches which all appeared to be in one plane. Having had a good deal of experience of doublets of all kinds this plane emphasized our suspicion.

We decided to tell our customer the stone would have to be taken out of its setting and did not expect to see him again, because by the time he had spent money on resetting, the obvious would be there to be seen and that would be that. However to my pleasure and surprise he turned up next day to ask for a certificate on what now showed itself to be a normal opal-on-opal doublet, looking as if it were connected by black Bostick. This may sound obvious but it is a little unusual to find a doublet which is translucent and I feel that a little gemmological know-how could lead a gemmologist who is a dealer to make a mistake with the stone in its setting if only a lens were used.

Suspicion or a suspicious nature are necessary to a professional gemmologist. Recently we were sent three small green subtranslucent cabochon stones in a cellophane envelope marked "Imitation Jade". On inspection they didn't look like jade (nephrite or jadeite varieties). They had originally, I believe, been stuck to cloth or paper as samples, and under the microscope the two smaller stones had bubbles of adhesive and shreds of material adhering and they looked very unprepossessing. Neither of the smaller stones weighed much above a quarter of a carat and

a cabochon of $\frac{1}{4}$ ct. is not a large stone. If I could have passed the test to someone else I would have done so. However after leaving the two smaller stones to soak in a detergent liquid I looked at the third and largest stone. Under the microscope it showed a beautiful structure of something like fern leaves in radial formation. They were so prolific but so regularly irregular that I knew they had to be an artifact structure since nothing I had ever seen except crystal structure in a chemical test ever had such a profuse repetition. They were in fact a formation somewhat similar to purpurine glass sometimes seen in pinchbeck mounts used for seal-stones. They were a form of devitrification and were so lovely that I asked R. K. Mitchell to photograph them. Having thrilled myself over a piece of glass I returned to the two smaller stones. As they were so small I knew it would not do the standard refractometer table any good by trying a distant vision reading and they were too small for a reliable S.G. I decided to consult an authority on jade substitutes and noted a fact which I had forgotten for the immediate moment. Green grossular garnet fluoresces an apricot-yellow under X-ray excitation. Our two small cabochons obliged by so doing—I felt grateful for a happy decision on what could have been a very small and trying subject. Most of all I was pleased with the visual test of inclusions under the microscope which seen as they were in colour and depth really made one feel happy to be a commercial gemmologist.

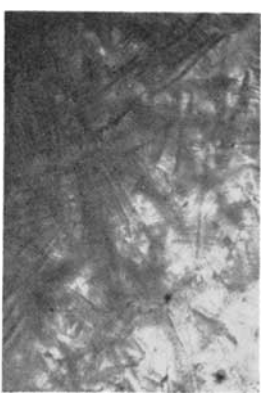

Fernleaf-type inclusions in radial formation similar to those seen in purpurine glass.

TOURMALINES: RARE MULTIPLE INDICES ON THE REFRACTOMETER

By C. A. SCHIFFMANN, F.G.A., G.G.
Gübelin Laboratory, Lucerne

IN optics, some of the laws proceeding from the study of natural phenomena have been formulated so long ago, demonstrated and proved so repeatedly, as to be consciously adhered to by generations of students and regarded as immutable concepts. This also applies to the laws of light propagation in birefringent media.

Occasionally an abnormal behaviour observed in practice differs so manifestly from the rule that the observer is forced to say that this cannot be. Investigation is then required to try to elucidate the phenomenon. This paper deals with refractive index anomalies of cut tourmalines, as observed on the refractometer.

Let us now consider the practice. The appearance on the refractometer scale of an uniaxial birefringent mineral like the flat surface of the cut tourmaline is so well known that it hardly requires a detailed description: let us only mention the two sharp shadow edges at their greatest separation, as seen on an Anderson-Payne spinel refractometer (Fig. 1). If anyone with a knowledge of gems was told that tourmalines have four shadows on their refractometer they would say this is not possible. This would be an understandable reaction as it is a phenomenon which must be seen with one's own eyes in order to ascertain it. Anomaly in this behaviour has been reported (1967) by R. Keith Mitchell[1], each one of two dark green cut tourmalines from Brazil showing four distinct shadow edges on the refractometer scale as observed in sodium light, at 1·653 and 1·646 for the ordinary ray and at 1·624 and 1·620 for the extraordinary ray.

This curious behaviour seems to be extremely rare among cut tourmalines. The present author became interested in the problem and was able to locate some cut tourmalines showing this effect of multiple readings on the refractometer scale to a more or less pronounced degree.

Description of the specimens

The colours of the cut specimens examined were yellowish green, green to bottle green, bluish green, varying from medium light to dark tones. The stones were said to come from Africa and were homogeneous clear specimens.

The work was carried out in monochromatic sodium light. The observations were purposely made on an Anderson Payne spinel refractometer because of the advantage of the spreading of the scale in the refractive indices range for tourmalines. This gave a clearer separation of the basic indices and of their satellite shadows thus enabling an easier interpolation of the third decimal.

To eliminate any error caused by possible defects of the instrument and to ascertain its accuracy, a normal tourmaline was first tested on it, showing the two clear-cut shadows as seen at their greatest separation at 1·642 for the ordinary ray and 1·623 for the extraordinary ray (Fig. 1).

As a further check, the most typical of the anomalous tourmalines with satellite shadows was tested on the following series of refractometers of different models:

1. a Rayner Diamond Prism Refractometer
2. a Rayner Glass Prism Refractometer
3. a second Rayner Glass Prism Refractometer
4. the Anderson-Payne Spinel Refractometer from Rayner used for all the current work mentioned in this paper
5. an Erb and Gray Refractometer
6. a GIA Duplex Refractometer

FIG. 1. Typical refractive indices of a normal tourmaline as seen on an Anderson-Payne spinel refractometer, with $\omega = 1{\cdot}642$ and $\varepsilon = 1{\cdot}623$ in sodium light.

FIG. 2. Anomalous refractive indices of a tourmaline, the two basic indices $\omega = 1{\cdot}642$ and $\varepsilon = 1{\cdot}623$ being accompanied by satellite shadows, see text.

On all these instruments the same effect was clearly observed on the table facet as well as on the largest of the rear facets to give a reliable reading. Of course the satellite shadows appeared more cramped together on some of the instruments used owing to the lesser length of their scales than on the Spinel model.

During the course of testing it was a great surprise to discover that, whereas some tourmalines produced the doubling effect of the two basic indices (four shadows in all), some others showed a triple effect (six shadows in all) more or less developed, that is, three clearly separated shadows for ω, whilst for the ε ray the first satellite shadow was found to be so close to the basic shadow as to be only just separated on the scale, both limits being almost overlapping. Such a case is illustrated in figure 2 with the following indices:

	Basic	*First satellite*	*Second satellite*
ω	1·643	1·646	1·656
ε	1·623	1·623$^+$	1·626
		so close to basic index as to be indistinguishable on the photograph	

One most remarkable tourmaline of green colour reached some kind of a record by exhibiting a four-fold effect for both rays, that is both of the two basic rays being accompanied by three satellite shadows (or eight shadows in all). The readings of this remarkable specimen are illustrated in figures 3 and 4. The effect is as follows (Fig. 3):

When the stone is lying in an orientation with its c axis in line with the optical axis of the refractometer, only the ordinary ray is visible with its basic shadow situated at 1·645. Reading up the scale, next comes a narrow lighter zone, followed by a sharp, narrow shadow line at 1·647 (first satellite line); then comes another slightly larger light zone followed by a slightly less sharp shadow at 1·652 (second satellite line) then comes again a broader light zone followed by a somewhat less sharp, broader shadow lying at 1·660 (third satellite line).

While revolving the stone on the prism of the refractometer it was noticed that each one of the basic index as well as of its satellites moved down the scale until they reached the point of maximum separation corresponding to the position of the ε ray (Fig. 4) with shadows at 1·623$^+$, 1·624, 1·625, 1·629.

FIG. 3. Anomalous refractive index of a tourmaline showing the basic ray at 1·645 accompanied by 3 satellite shadows, that is, 4 shadows in all. See text.

FIG. 4. Same stone as in figure 3. Stone revolved 90° to show both rays. See text.

The two basic indices being clearly recognizable, the birefringence has been calculated by subtraction between these ones without considering the satellite shadows for which no reason is known so that it would be too early to ascertain that the last ones are due to true birefringence.

It was noticed that for all stones the edges of the shadows of the basic indices were very sharp and that the sets of satellite shadows became progressively less sharp, the effect being more obvious for the higher shadows (of the ω ray) than for the lower ones (of the ε ray).

The following table gives a survey of the figures observed.

Range of basic refractive indices and birefringence of the tourmalines showing multiple shadows on the refractometer.

	Double shadows	*Triple shadows*	*Quadruple shadows*
$\omega \pm \cdot 001$	1,640 to 1,647	1,641 to 1,647	1,645
$\varepsilon \pm \cdot 001$	1,620 to 1,625	1,623 to 1,625	1,623+
Birefringence	·020 to ·022	·018 to ·022	·021+

For clarity not all figures observed are tabulated below; only typical values of individual stones are given.

Colour of the stone	4 *shadow effect* BLUE–GREEN		6 *shadow effect* MEDIUM GREEN		8 *shadow effect* DARK GREEN	
	basic	*satellites*	*basic*	*satellites*	*basic*	*satellites*
ω	1,643	1,648	1,644	1,648 1,658	1,645	1,647 1,652 1,660
ε	1,623	1,624	1,624	1,624+ 1,627	1,623+	1,624 1,625 1,629
Birefringence	·020	—	·020	— —	·021+	— — —

Regarding other properties, the dichroism was normal for tourmalines, strong; the colours being green and yellow-green for green specimens and pale blue and dark ink blue for the blue-green ones. The absorption was strong along the direction of the ordinary ray.

The specific gravities measured by the hydrostatic method were found to range for the individual specimens between 3·07 and 3·13, all stones tested being clear and free from vitiating factors (no cracks or large heterogeneous inclusions). With the stones immersed in carboneum sulfuratum with n_d 1·625, microscopic examination revealed most interesting features in some specimens. These were narrow fissures open at the surface of the stones' facets, offering different aspects according to the orientation of the particular facet with regard to the crystallographic directions.

On long facets cut in a plane parallel to the prism edge (the usual orientation for rectangular tourmalines with their long side corresponding to the length of the prism) the fissures are running in roughly parallel sets, some of them being abruptly interrupted whereas new ones start in a laterally slightly displaced position (Fig. 5).

Sometimes, the fissures are interrupted by roughly perpendicularly lying, slightly waving cracks (which look like tension cracks), whereas new fissures occur again in a displaced position on the lip of the crack (Figs. 6 and 7). At one place, two fissures meeting at an acute angle were lying across the set of main fissures; on both sides of this feature the main fissures do not run exactly in the same direction, but at a slight angle (Fig. 8).

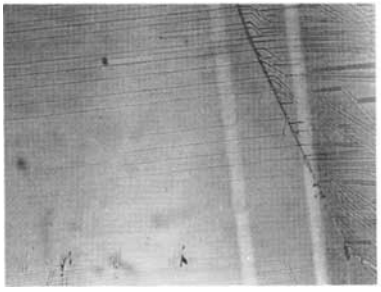

FIG. 5. Tourmaline, fissures open at the surface. Magn. 32 ×, immersion n_d 1·625.

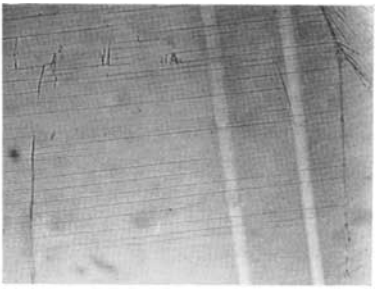

FIG. 6. Tourmaline, fissures open at the surface. Magn. 32 ×, immersion in n_d 1·625

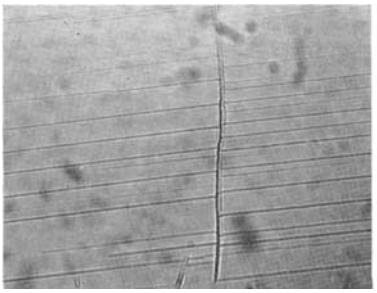

FIG. 7. Tourmaline, fissures open at the surface, interrupted by a tension crack. Same specimen as on Fig. 6, magn. 60 ×, immersion in n_d 1·625.

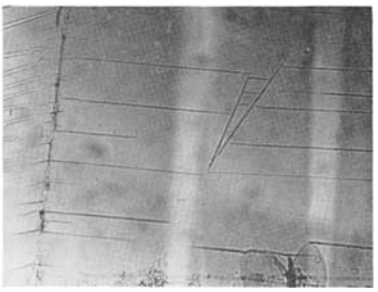

FIG. 8. Tourmaline, fissures open at the surface. Alignment of the main fissures displaced by additional fissures across them. See text, Magn. 60 ×, immersion in n_d 1·625.

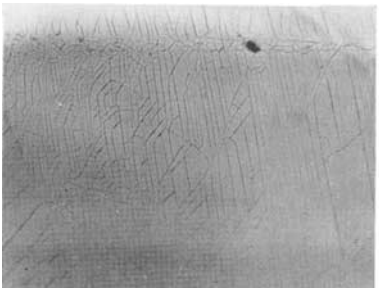

FIG. 9. Tourmaline, fissures open at the surface. Criss-cross pattern on a facet cut across the long axis of the original crystal. The straight zone of smaller patterns at the top of the photograph is the girdle plane. See text. Magn. 32 × immersion in n_d 1·625.

FIG. 10. Tourmaline, fissures open at the surface. Roughly lozenge shaped patterns on a facet cut across the long axis of the original crystal. Magn. 60 ×, immersion in n_d 1·625.

In the Figs 5 and 8, most of the surface of the photograph represents a large facet cut parallel to the prism edge; on the left part of both photographs the next adjoining facet partly visible is cut across the edge of the prism, being part of the small side of the facetted stone. At the junction of both facets, the fissures are seen to bend in other directions, forming irregular patterns of criss-cross lines. This is more distinct when looking in a direction normal to the plane of that facet at the small end of the stone (Fig. 9).

Here the complexity of the design, bordered at the top of the photograph by a straight zone of smaller patterns (this is the plane of the girdle) and on the left by an oblique facet junction edge, past which the fissures run away in another direction, gives the impression that the stone is composed of a bundle of fibres closely packed together to resemble a bunch of asparagus, the facet representing a cross section through it.

Another spot shows more distinctly the patterns of the criss-cross lines (Fig. 10). Examination between polars (partly crossed, to enable some light to pass in this direction nearly along the c axis) shows that the specimen is under strain.

From their appearance, it is evident that these fissures are not defects due to the cutting process, but are related to the texture of the crystals. The reason for these unusual features is not yet understood, nor is it known if there is a correlation with the refractive indices with multiple shadows.

FIG. 11. Tourmaline, same view as on Fig. 10, under not quite completely crossed polars to show internal strain.

One might suggest that firing tourmalines might have had an influence on the existence of the phenomena and perhaps cutting under certain conditions would have caused a sort of Beilby layer to develop modifying the optical properties at the surface.

However, such an explanation seems improbable, as M. D. S. Lewis reports[2] in a paper dealing with the formation of a Beilby layer on crystals: "The fully amorphous layer where it exists is far too thin for effect on refractive index", and further "Mrs. G. Parry who has made extensive researches into the limiting thicknesses of films capable of giving a shadow edge on the refractometer, has kindly provided the writer with some of her calculations. If polished quartz were covered by a layer of amorphous silica, the thickness of the film would have to be about 3000 Ångströms before it would give a reading corresponding to the lower refractive index and with most other gemstones it is of the same order, assuming

similar differences between refractive indices of amorphous and crystalline material. Refractometric readings are therefore useless in attempting to detect the presence of amorphous layers due to polish".

As the sets of fissures and the geometrical patterns are not present on all specimens examined, it may be possible that particular conditions during the cutting process have had an influence on their formation.

Further investigation is being carried out on this subject.

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BLISTER PEARLS

MR. VAN DEN BERGE of Belgium, who recently purchased a blister pearl, decided to find out what had caused the blister. He cut away the base and the cause of the irritation was seen to be a very tiny crab.

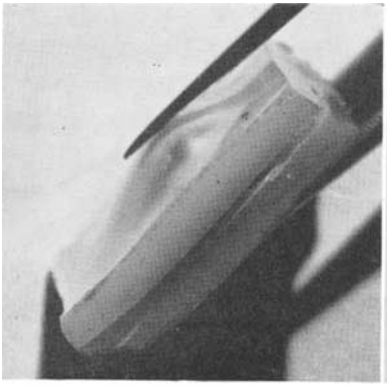

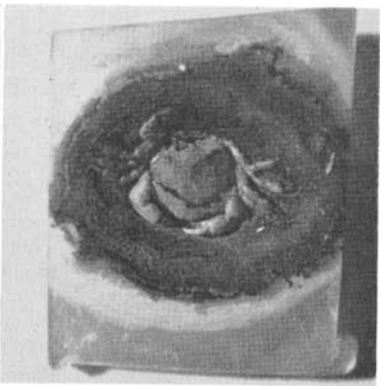

USUAL AND UNUSUAL INCLUSIONS IN A PERIDOT SPECIMEN

By T. F. ZOOK

THIS adventure into the microscopic world of peridot inclusions started with the purchase of a highly flawed, oily-green, ten carat, cushion-cut peridot of unknown origin, as a study specimen. The diameter of the stone at the girdle measured 12 millimeters and its depth from table top to the culet measured eight millimeters.

To the unaided eye the specimen appeared to have, when observed through the table, numerous round "flying saucers" of different sizes. In examining other portions of the stone through the surrounding crown, there appeared to be a dense area of inclusions of an elongated, muddy nature in the pavilion near the girdle.

Examination with a ten-power lens did not resolve sufficiently the inclusions for exacting study. Both 10 × and 30 × magnifications with transmitted light in a binocular diamond grading microscope and magnifications of 25 ×, 50 ×, 100 × and 200 × by transmitted light in a monocular Bausch and Lomb microscope were then used. Photomicrographic studies numbers 1, 2 and 3 show the appearance of the specimen by transmitted light at a magnification of 10 ×.

Under microscopic study, the round "flying saucers", as seen previously, were found now to be of four types:

(1) Platelets of an oval shape which enclosed within their perimeters a relatively clear host material which, in turn, contained tiny long clear thin flat platelets, small black and shadowy opaque bars parallel to the thin platelets and minuscule black opaque "pepper" specks. The thin clear platelets reflected rainbow colours when no polaroids were used, but showed a rather indistinct extinction when polaroid discs were inserted and crossed and uncrossed (photomicrographs numbers 4 and 9).

Roedder and Weiblen, who have studied the petrology of silica melt inclusions in olivine specimens from Apollo 11 and 12 and compared them with olivine specimens from the prehistoric Makaoupi and the Kilauea Iki lava lakes in Hawaii, have reported

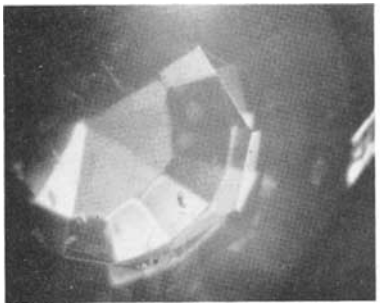

FIG. 1. Peridot—"flying saucer" inclusions table up, 10 ×, transmitted light.

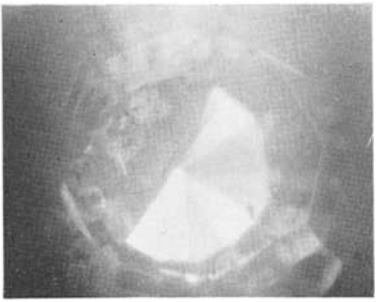

FIG. 2. Peridot—"flying saucer" inclusions table up, 10 ×, transmitted light.

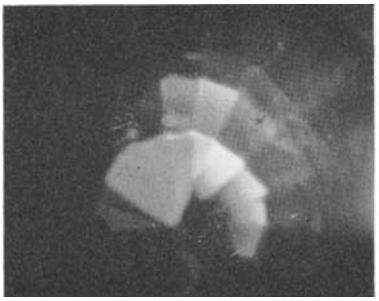

FIG. 3. Peridot—"flying saucer" inclusions culet up, 10 ×, transmitted light.

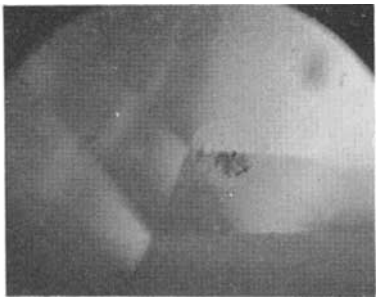

FIG. 4. Peridot—oval inclusion, one type of "flying saucer" inclusion at a magnification of 25 ×, transmitted light.

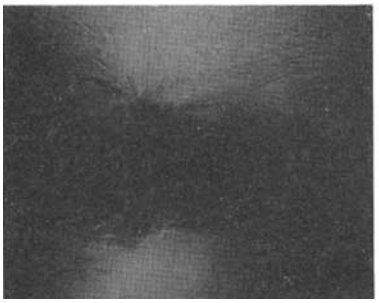

FIG. 5. Peridot—oval inclusion of still another type of "flying saucer", 100 × magnification, transmitted light.

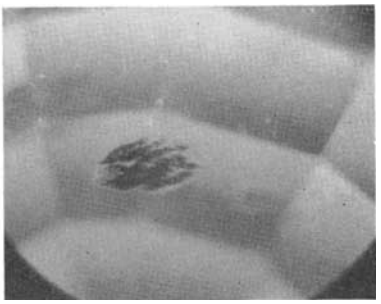

FIG. 6. Peridot—pseudo-hexagonal inclusion, two stacked "flying saucers" filled with brown satiny material, 25 × magnification, transmitted light.

similar inclusions. They were surprised to find in an olivine from the prehistoric Makaopuhi lake in Hawaii a melt inclusion which looked almost identical to those found in the Apollo 11 and 12 samples. These melt inclusions found by Roedder and Weiblen resemble so closely the inclusion shown in photomicrographs numbers 4 and 10, that their electron probe analysis is probably applicable to the present inclusion. Their analyses identified the tiny dark opaque lines as thin plates of ilmenite (these lines appear in photomicrograph number 4 near the tiny opaque "pepper" inclusions); the tiny thin flat light platelets were identified as plagioclase and they lie parallel to and adjacent to the ilmenite platelets; and the minuscule black opaque spots (which appear as "pepper" specks in the present study) as tiny pyroxene crystals. The enclosing host material was identified as olivine[1]. In laboratory experiments, Roedder and Weiblen were able to take sample material from the Hawaiian olivines mentioned and by heating them to homogenize the material. Then, when they slowly cooled the material from 1120°C to 1020°C over an 11 day period the material renucleated several black ilmenite plates[2].

The experiments conducted by Roedder and Weiblen on reheating olivine grains in a vacuum at progressively higher temperatures with subsequent quenching and examination established the following sequence of phase changes: first recognizable liquid stage at <1065°C; then plagioclase crystallized out at 1103 ± 3°C; then pyroxene crystallized out at 1130 ± 5°C; and finally ilmenite crystallized out at 1210 ± 5°C. These experiments on melt inclusions in olivine they believe provide rough estimates of lunar and terrestrial lava temperatures and cooling rates[3].

(2) Platelets of an oval form which enclosed clear material except for a tiny black centre are very similar to the microlites of chromite reported by Gübelin[4] (see number 5).

(3) Platelets of a pseudo-hexagonal form filled mostly with satiny downy material which is separated partially in the interior of the platelet by clear irregular veins were also found (photomicrograph number 6 taken at a magnification of 25 ×).

The platelets just described are probably the mica biotite since they follow very closely Dana's description. He states that biotite is sometimes found in scales of basal cleavage which yield pseudo-hexagonal crystalline forms which when very thin in transmitted

FIG. 7. Peridot—pseudo-hexagonal inclusion and large dendritic feather inclusion 25 × magnification, transmitted light.

FIG. 8. Peridot—large dendritic feather inclusion, 25 × magnification, transmitted light.

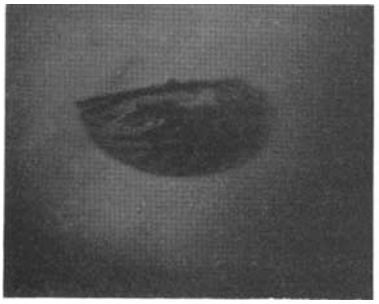

FIG. 9. Peridot—melon slice or lady's handbag inclusion, 100 × magnification, transmitted light.

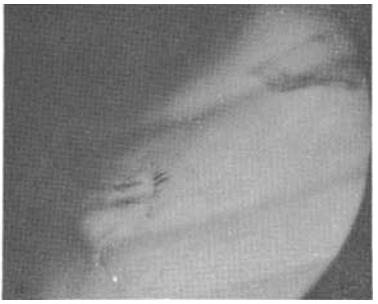

FIG. 10. Peridot—two oval "flying saucer" inclusions, unidentified "frozen in motion" inclusion 25 × magnification, transmitted light.

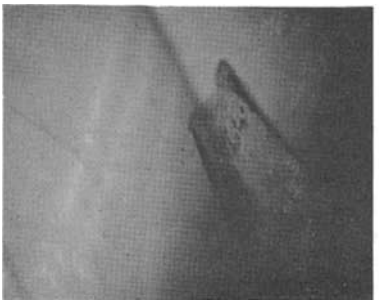

FIG. 11. Peridot—two juxtaposed unidentified inclusions, 50 × magnification, transmitted light.

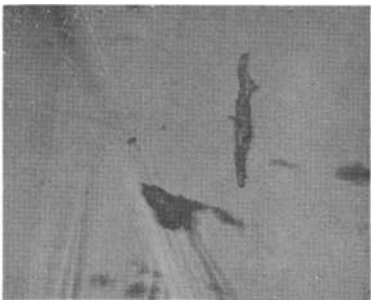

FIG. 12. Peridot—unidentified inclusions, 100 × magnification, transmitted light.

light may show up as having a brown (or green, blood-red, pale yellow to dark brown or rarely white) nature[5].

(4) Pseudo-hexagonal platelets, which are black and which appear opaque except for a tiny clear area in the centre, represent another type of "flying saucer" inclusion. One of these can be observed on the perimeter of the dendritic, feathery mass in photomicrograph number 7. The tiny clear centre of this inclusion stays light as the polaroid analyser is rotated and, therefore, may represent glass which has filled the space where a bubble might have been trapped. Since the surrounding material within the flattened pseudo-hexagonal outline appears to go off and on as the polaroid analyser is rotated, this type of inclusion may also represent a mica platelet.

The large massive inclusions seem in photomicrographs numbers 7 and 8 at a magnification of 25 × probably may contain some pyroxene. Roedder and Weiblen speak of the silicate mass which they studied in olivines as having within it in all the larger and many of the smaller inclusions a feathery dendritic mass which they believed to be pyroxene but whose individual units were too small to study[6].

The study specimen showed many inclusions which took the form of a half slice of melon or what could also be described as similar to a lady's handbag. As seen in photomicrographic study number 9 at a magnification of 100 ×, the half melon slice is filled with black material separated by irregular clear veins and an opaque black crystal protrudes from the top of the slice. No identification has been made of this inclusion.

In peridots previously studied, the inclusion seen in the lower left hand corner of photomicrographic study number 10 has not been observed. At a magnification of 25 ×, this unidentified inclusion appears to have been "frozen in motion". Photomicrographic study number 11 may possibly represent two similar inclusions. The study was made at a magnification of 50 ×. When studied with polaroids, as the analyser was rotated, the black material within remained black and opaque; however, the clear material appeared to disappear. Again, no identification has been made.

Photomicrographic study number 12 again seems to represent an inclusion "frozen in motion" and it too remains unidentified.

The peridot study specimen proved to be a fruitful source of some interesting and unusual inclusions. The many "flying saucers" when studied with a microscope were revealed, at higher magnifications, possibly to include mica and olivine platelets. While the origin of this peridot cannot be definitely ascertained, it was purchased from a dealer in gemstones who buys peridots both from Arizona and Burma. Study of a large number of Arizona peridots does not reveal the same types of inclusions seen in the specimen stone. Therefore, it is believed that the peridot is from Burma, and this belief is reinforced by the fact that the stone is cushion-cut.

REFERENCES

1. Roedder, E., Weiblen, P. W. "Petrology of silicate melt inclusions, Apollo 11 and Apollo 12 and terrestrial equivalents", *Proceedings of the Second Lunar Science Conference*, Vol. I, *Geochimica et Cosmochimica Acta*, Suppl. 2, Levinson, A. A., ed., The MIT Press Cambridge, Massachusetts and London, England, 1971, p. 510, p. 511, figs. 7, 8, and 11.
2. Ibid., p. 510, p. 511, fig. 10.
3. Ibid. p. 507. *Abstract*—Early high temperature.
4. Gübelin, E. "On the nature of mineral inclusions in gemstones", Vol. 11, No. 5 *Journal of Gemmology*, Plate E 9 facing p. 169, p. 170.
5. Dana, E. D. *Textbook of Mineralogy*, 4th edition revised and enlarged by Ford, Wm. E., John Wiley and Sons Inc., N.Y., London, Sydney 1949, pp. 659, 663.
6. Roedder, E., Weiblen, P. W. op. cit., p. 509.

CHALCEDONY IN SURREY

By E. J. BURBAGE, F.G.A.

FOR the mineralogist, the Home Counties countryside is an area of somewhat restricted interest, and it would be idle to pretend that a "rockhound" can find much to concern him there. In consequence, one treasures especially the rare trouvaille, such as sherry-brown gem-quality barytes from the Fuller's Earth near Redhill, and shards of selenite from the same locality. At the other end of the same county, Gertrude Jekyll's "Old West Surrey" is, as MacDonald Davies comments, "that district of beautiful scenery and poor sections", and the paucity of good sections is matched by the dearth of minerals other than the ubiquitous quartz of the Lower Greensand. There, however, it is interesting to find that, on sectioning rocks from this locality, the silica content includes not only quartz grains but a variable amount of chalcedony. Very occasionally this can also be seen in the hand-specimen as a micro-botryoidal patina on the rock surface.

The chemistry and mechanics by which the silica in these West Surrey sandstones appears as chalcedony may well have been established by some earlier worker and have been described in "the literature", but not, it seems, in any recent and readily accessible publication, but one would guess at a secondary origin.

The Hythe Beds sandstone occurring in the wooded heathland areas south of Guildford have yielded many specimens, and as a collector's memorandum it is worth recording that fire-breaks have proved the most rewarding terrain, especially on those dull, wet days which provide optimum conditions of light to make the chalcedonic layers more evident. It is unfortunate that such lamellae, although often of reasonable areas, are usually very thin, and it is not too easy to section them for study, although Thorold Jones succeeded in so doing to aid the completion of a range of slides illustrating the sedimentary petrology of West Surrey. It would no doubt be possible for an amateur lapidary to trim the sandstone back to produce a chalcedony gemstone which might pass muster in these days when uncut and tumbled material finds acceptance in jewellery. From the West Surrey sandstone material it would be difficult to find chalcedony of sufficient depth to cut en cabochon or as a seal-stone, although in the amygdaloidal flints

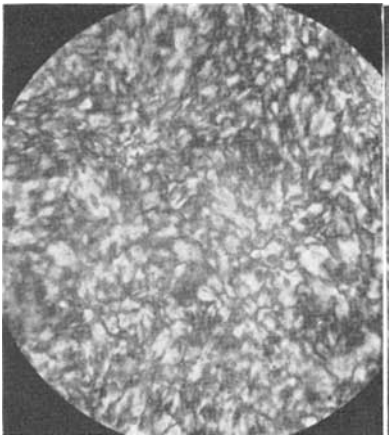

"Tabby extinction" of chalcedony from Surrey Hythe Beds.

Botryoidal surface of chalcedony patina surfacing Surrey Hythe Beds sandstone.

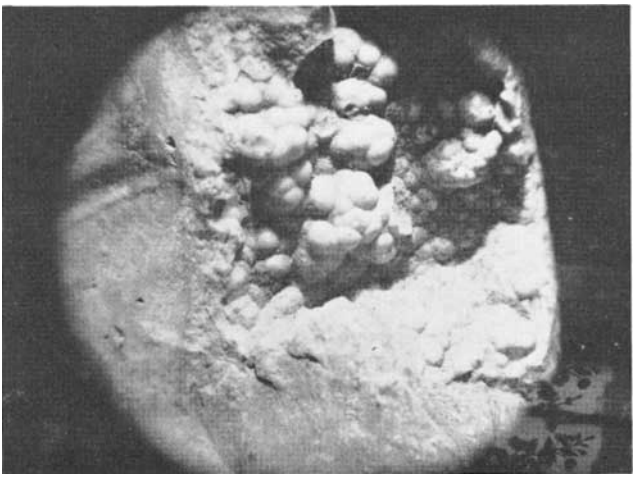

Chalcedony lining cavity in flint, Dorset.

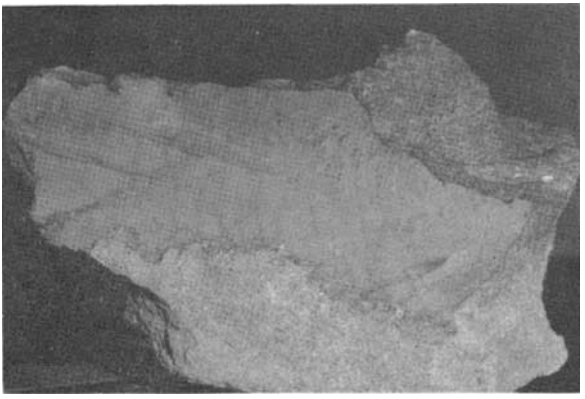

Chalcedony on Hythe Beds sandstone from Surrey.

of the central chalk hills of Dorset material suitable for this purpose can occasionally be found.

Physical properties of this Surrey material seem on casual sampling in line with expected data. Its normal occurrence as a patina, somewhat awkward to separate, renders the determination of a precise S.G. difficult to achieve, but flotation in a bromoform-monobromonapthalene heavy liquid revealed approximate matching with a typical cut chalcedony (carnelian). There is some variation in translucency and colour, the latter, although usually

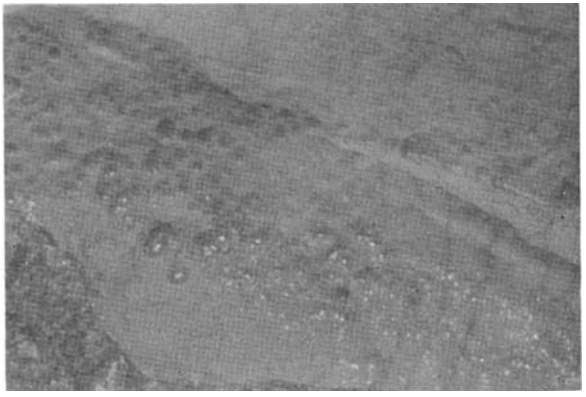

Botryoidal surface of chalcedony from Surrey Hythe Beds.

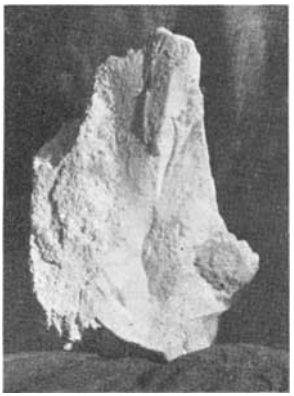

Fragment of Hythe Beds sandstone with thin chalcedony on surface (Surrey).

white, being occasionally a very pale opaline blue. In clearer specimens, thin flakes will transmit light sufficiently well to show "tabby extinction" between crossed polars.

Rather unexpectedly, the Hythe Beds sandstone which provided the specimens examined and which is virtually a monomineralic rock in this area, was found from a set of hydrostatic determinations to have a specific gravity much below that anticipated, ranging from 2·20 to 2·30. This would indicate "pore space" of the order of 15%, which one would not guess either from hand-specimens or microscopic sections. The very useful "Cosmos" handbook, Rudolf Börner's "Welcher Stein ist Das?" does however confirm a wide range in S.G^{s}. for an "einfache Quarz sandsteine" or "simple sandstone" of 2·00 to 2·65, as against 2·60 to 2·65 for quartzite. One could wish that the appropriate Geological Survey Memoirs were more informative on this score, their palaeontological and stratigraphical data being much more comprehensive than that on petrology, which receives somewhat meagre treatment.

Those familiar with the highly attractive countryside from which this material came will not require any additional incentives to visit it, and as the discovery of lacertas and sundews are adventitious rewards for summer explorations, so these odd patinated sandstone fragments provide an occasional unexpected interest for winter journeys. Thanks are due to Haslemere Museum for laboratory and library facilities in connexion with this and other enquiries.

Gemmological Abstracts

ANON. *Large diamond found in Louisiana.* Gems & Gemology, 13, 134, 1969.

An 18·20 carat diamond crystal, a modified octahedron, was found in Princeton, about 18 miles east of Sheveport. G.S.

ANON. *Russian synthetic gem diamonds made in 1967.* Australian Gemmologist, XI, 6, 19, 1972.

A report taken from the *Retail Jeweller* who quote "Diamant" that the Russians had made synthetic gem-quality diamonds in 1967, which is three years before the announcement by G.E.C. of America of their successful synthesis. R.W.

ANON. *Wrong to use Mohs to measure hardness?* Australian Gemmologist, XI, 6, 20-22, 1972 (reprinted from Canadian National Jeweller). 1 graph.

A general discussion on the value of Mohs' scale of hardness in which a number of individuals give their views. This can be summed up with the view that the scale is generally useful and sound, but the numbering of the scale induces in the lay mind the notion that some of the new diamond simulants approach diamond in hardness. R.W.

ARMSTRONG (R. D.). *A study of asterism in quartz.* Lapidary Journ., 25, 1108-1117, 1971, 12 figs.

The easiest method of orienting rough material is by locating the optic axis by a polariscope. The problem of the relative rarity of crystals of rose quartz is discussed: it is believed to be high-temperature quartz containing TiO_2 exsolved as rutile. R.A.H.

BANCROFT (P.). *The lure of Chivor.* Lapidary Journ., 25, 128-131, 1971, 12 coloured photos.

A description is given of a visit to the Chivor emerald mine NE of Bogota, Colombia, and of the open-pit mining methods used. R.A.H.

BANK (H.), OTTEMAN (J.), BERDESINSKI (W.), NUBER (B.). *Schleifwürdiger Childro-Eosphorit von Itinga.* Childro-eosphorite worthy of being polished. Zeitschr. d. deutsch. Gemmologischen Gesellschaft, 1972, 21, 1, pp. 1-3.

Some time ago H. Bank published an article describing a yellow-brown stone which was shown to be a childro-eosphorite, and was said to be of gem quality. In the meantime the source of this stone has been ascertained which was Itinga in the Minas Gerais in Brazil. The stone was carefully examined and various data as to its lattice structure are published. E.S.

BANK (H.). *Durchsichtiger farbloser Apophyllit von Poona.* Transparent colourless apophyllite from Poona, India. Zeitschr. d. deutsch. Gemmologischen Gesellschaft, 1972, 21, 1, pp. 4-6. Bibliography.

The apophyllite is a phyllosilicate and has the following chemical composition: $K\ Ca\ (F\ (Si_4O_{10})_2) \times 8\ H_2O$. It belongs to the tetragonal system. The name is derived from apo = away and phyllon = leaf as it peels easily when being polished. It is found in the Faroe Isles, Iceland, Central Germany and the specimen under discussion came from Poona in India. These stones are exceptionally clear and had a green colour. Because of its cleavage it is nearly impossible to facet the apophyllite which often shows characteristic light effects and a pearly sheen and is therefore sometimes known as ichthyophthalmite (= fish eye stone).

E.S.

BANK (H.). *Roter durchsichtiger Tugtupit aus Groenland.* Red transparent tugtupite from Greenland. Zeitschr. d. deutsch. Gemmologischen Gesellschaft, 1972, 21, 1, pp. 7-8. Bibliography.

In 1962 Sörensen described a new mineral which could be used for gem purposes and which he called tugtupite. It crystallizes in the tetragonal pseudo-cubic system. S.G. 2·36 but varying with impurities from 2·30–2·57. R.I. 1·496–1·502, double refraction 0·006. Up to now it has been located in the south of Greenland and on the peninsula Kola.

E.S.

BANK (H.). *Saphir-Dubletten.* Sapphire doublets. Zeitschr. d. deutsch. Gemmologischen Gesellschaft, 1972, 21, 1, pp. 53-54.

Short description of a sapphire doublet sent to the author from East Asia, the crown being natural sapphire and the pavilion synthetic sapphire. The contact layer was easily discernible once it had been recognized. It is of some interest that imitations of the above doublet were then introduced; these imitations had both upper and lower parts made of synthetic sapphire.

E.S.

BANK (H.). *Durchsichtiger gelblich-bräunlicher schleifwürdiger Eosphorit-* Zeits. d. deutschen Gemmologischen Gesell., 20, 125-126, 1971.

A transparent eosphorite/childrenite of gem quality, presumed to originate in Brazil, has α 1·645, γ 1·680; sp. gr. 3·08 (with inclusions); cell dimensions *a* 10·41, *b* 13·42, *c* 6·92 Å; H 4½.

E.H.C.R.

BOUSKA (V.). *Les moldavites.* Bulletin, Association Française de Gemmologie, 31, June 1972.

An account of the discovery of moldavites in Czechoslovakia with a map and photographs. Some specimens have been analysed chemically and found to contain up to 78% silica. M.O'D.

CROWNINGSHIELD (R.). *America's largest faceted emerald.* Lapidary Journ. 25, 40-42, 1971, 6 photos. (5 in colour).

A 59-carat emerald crystal is reported from the Rist mine, North Carolina. It has a colourless core with an exceptionally chrome-rich rim at least 12 mm thick; ε 1·580, ω 1·588; sp. gr. 2·73; it shows a reddish fluorescence under long UV light (3660 Å). From it a stone was cut weighing 13·14 carats; the only major flaw is a triangular tapering cavity. R.A.H.

CROWNINGSHIELD (R.). *Developments and highlights at G.I.A's lab. in New York.* Gems & Gemology, XIII and XIV. 11, 12, and 1, 344-353; 370-381; 8-13, 67 illus., 1971/2.

The first of these issues refers to the graining of diamond; burnt surfaces on rough diamonds and some unusual inclusions in diamonds. Comment is made on the stability of the cement used in constructing synthetic spinel/strontium titanate doublets and mention is made of the use of a coloured synthetic spinel crown in

such doublets. A similar doublet with a synthetic white sapphire top is mentioned. Blue-dyed sapphires and a dyed chalcedony carving are spoken of. Also reported are synthetic red spinels; black-dyed oolitic opal and a biaxial yttrium aluminate of bright red colour. The second instalment gives a good discussion, illustrated with photomicrographs, of the effects of using holes drilled by laser beams to enable the decolouring of inclusions in diamond. Notes are given on some diamond inclusions; the surface appearance of a burned diamond; unusual girdling on a diamond; undue wear on a diamond and a diamond doublet. The new natural sapphire topped doublets with synthetic ruby and sapphire bases are reported upon. Unusual swirl-like inclusions in a natural sapphire and a tricky synthetic ruby are discussed. Two green coloured glasses and a case of suspected emeralds are fully reported upon. Pink diamonds whose colour is possibly due to treatment is another problem dealt with. The third issue discusses synthetic quartz in colours of blue, purple and green, and also a yellow-brown synthetic citrine. More is told of diamonds set "piggy-back"; non-fluorescent synthetic emeralds and a two-coloured diamond crystal and the new sapphire doublets are again referred to. R.W.

CALLAWAY (P. C.). *Doublets—a continuing factor in the gemstone market.* Australian Gemmologist, XI, 6, 15-17, 1972.

A good survey is given of the various types of doublets. The author keeps to the European tradition to call all composite stones doublets. A soudé type stone using two pieces of tourmaline seems a new development. The article has covered much ground in a small compass. R.W.

FANDER (H. W.). *Fluorite.* Australian Gemmologist. XI. 6, 25, 1972.

The report of an address given to the Federal Gemmological Conference held at Perth, Western Australia. A general description of the crystallography and properties is given. Something is told of the causes of the colours of the mineral, and its behaviour on heating and irradiation. The geological circumstances of its formation and the grades of commercial material used in industry are mentioned. R.W.

N. S. W. Opal Research Group. *The classification of black opal.* Australian Gemmologist, 11, 2, 24, 1971.

Oughton (J. H.). *Some thoughts on opal.* Ibid., 24-25.

Clayton (N.). *A basis for classification.* Ibid., 25-26.

Gemmological Association of Australia. *The G.A.A. definition of black opal.* Ibid., 26.

The term "black opal" is applied for colour only and does not refer to location of source. The term should be used exclusively for those types of solid natural opal consisting right through of opal in a dark grey, dark blue, or black base colour. The precious part of this black opal consists of the play of different colours inside the stone, right through the stone, or as a top layer of this stone, provided it is natural and mined in this way and the appearance has been enhanced only by cutting and polishing. R.A.H.

George (C. D.). *The birth of a pearl.* Lapidary Journ., 26, 474-485, 1972.

An account, illustrated in colour, of the investigation of the method of pearl manufacture by Pinctada maxima in the Exmouth Gulf area of Western Australia. M.O'D.

Gunn (C. B.). *A descriptive catalogue of the drift diamonds of the Great Lakes Region, North America.* Gems & Gemology, 12, 297-302, 333-334, 1968.

Forty-nine diamonds are described. G.S.

Harris (J. W.). *Black material on mineral inclusions and in internal fracture planes in diamond.* Contrib. Min. Petr., 35, 22-33, 1972, 12 figs.

X-ray, electron diffraction, and qualitative electron microprobe techniques have been used to study the black material observed on the surface of crystalline inclusions and adjacent fracture planes in diamonds from Sierra Leone, Ghana, and South Africa; several hundred diamonds were examined. This material was identified as graphite, pyrrhotite, and pentlandite. The possible origins of the black material are discussed. R.A.H.

JOHNSON (P. W.). *Common gems of San Diego County, California.* Gems & Gemology, 12, 358-371, 1968, 1 map, 13 photos.

Occurrences are described for beryl, spessartine, spodumene, topaz, and tourmaline. G.S.

LIDDICOAT (R. T.). *Developments and highlights at G.I.A's lab. in Los Angeles.* Gems & Gemology, XIII and XIV. 11, 12 and 1, 354-362; 382-387 and 18-28. 1971/2, 56 illus.

Discusses a green/pink grossular garnet in which the pink end proved to be hydrogrossular and the green end idocrase. A star beryl is mentioned and some disc-like beads which were probably a type of vegetable ivory are reported on. Mention is made of synthetic and natural emeralds of interest and also a report on a synthetic emerald said to be now made in Canada. A note on oolitic opal is given. Examination has been made on the new synthetic opal made by Gilson and a full report given on it. This showed that the stone had a refractive index of 1·44, a density of 2·02 to 2·08 and was found to have a hardness of $4\frac{1}{2}$ which is slightly lower than for natural opal; some differences were found in the synthetic opals behaviour to short-wave ultra-violet light. Other items discussed are a Pakistani diopside; treated black opal; wear in cultured pearls and comments on laser drilling. Types of serpentine; inclusions in glass; a peculiar aquamarine which showed brown oval blobs as inclusions, are other items mentioned. Notes are given on a new form of turquoise treatment, where white matrix areas had been altered to black, and the absorption spectra shown by a brown diamond and a green spinel. Angular inclusions in a Verneuil synthetic ruby are mentioned. R.W.

MCKAGUE (H. L.). *The serpentine mineral group.* Gems & Gemology, 12, 326-331, 1968.

A summary. G.S.

POUGH (F. H.). *Phenakite.* Lapidary Journal, vol. 4-12, 1972.

A large water-worn phenakite mass has recently been discovered in Ceylon. Resulting in a faceted stone of 568 carats, the original material was slightly cloudy and contained a scattering of rutile needles which, if more abundant, would have produced chatoyancy. The author summarizes the species and speculates on the possible

occurrence of phenakite under conditions favouring the growth of beryl, since phenakite is a common associate of flux-grown and hydrothermal emerald. The author refutes a common textbook error which gives the colours of phenakite as colourless, yellow and pink. In the author's experience all phenakite is colourless and variations are probably due to local colouration on the surface by iron salts. The article concludes with a review of phenakite localities. M.O'D.

POUGH (F. H.). *Are you sure its topaz?* Australian Gemmologist. XI, 6, 17-19 (reprinted from Jewellers' Circular-Keystone). 1972.

When Dr. Pough writes the result is always "spicy" and interesting, and in this write-up on topaz he is no less so. The first part is mainly a discussion on the use of the name topaz and how it came about. The main part of the article deals with the two types, pegmatite and vein, and the mineralogy and locations of gem topaz. There is much of interest in the author's remarks on the behaviour of topaz under heat and radiation. R.W.

SZENBERG (M.). *The Israel diamond polishing industry.* Gems & Gemology, XIV, 1, 2-7, 1972.

An abridged version by the author of his 236-page study on The Economics of the Israel diamond industry. There is a historical survey and the growth of the Israeli diamond industry is given. The structure of the industry is discussed and something is told of the Government policies towards the industry. The article concludes with a survey of future prospects. R.W.

WEBSTER (R.). *The role of gemmology.* Medicine, Science, and the Law, 12, 1, 31-42, 1972, 16 figs.

The problems of identifying synthetic stones and simulants of the double and triple type are outlined briefly. For the routine identification of gemstones their examination by hand-lens, measurement of specific gravity and refractive index, and the study of their absorption spectra are described. The physical properties for diamond and eight common diamond simulants are tabulated. R.A.H.

EULITZ (W. R.). *Die rechnerische Ermittlung der optimalen Brillanz des Brillanten.* Zeitschr. d. deutsch. Gemmologischen Gesellschaft, 1972, 21, 1, pp. 13-43. Detailed bibliography, 16 graphs and diagrams.

The author defines the word "brilliance" mathematically, using the optical data to produce the correct mathematical formula. He first summarizes known results on this subject, describes the law of "brilliance" and its application to the diamond shape, explains the optical-symmetrical brilliant-cut and discusses the grade of brilliance and the limits of application to the brilliant-cut. As appendices he brings the linear proportions of an optical-symmetrical brilliant-cut and the relation between the diamond and the light intensity. After a very scientific exposition the author states as his opinion that, although it might be possible that sometimes in the future a better form could be developed for the diamond, for a long time to come the brilliant-cut is bound to survive.

E.S.

BOOK REVIEWS

Gems and Minerals of Rhodesia. The Rhodesian Gem and Mineral Society, Salisbury. 30 cents.

Details of the 1972 National Gem and Mineral Show, Salisbury.

S.P.

Crystals; symmetry in the mineral kingdom. Introduction by Vincenzo de Michele. Illustrated in colour. Orbis Books, London, 1972, pp. 80. £1·25.

Another of the well-illustrated books to emanate from the Istituto Geografico de Agostini, Novara, Italy, this brief guide to mineral crystals forms the best popular elementary guide to the subject so far seen. For the student of gemmology the illustrations of crystals approaching the ideal in form bring home the conceptions which are too often only to be found diagrammatically in textbooks and on this account are to be welcomed. They will also lead the gemmological student to pursue the study of minerals other than those used as gems—a tendency already noticeable.

The introduction of 15 pages deals with elementary crystallography and this section is illustrated by text figures, largely of

the cubic system. Although a short introduction must necessarily omit some detail, the writer manages to include a section on Bravais lattices and Miller indices, lucidly described. The coloured illustrations are quite magnificent and particularly welcome are the descriptions of the crystal form accompanying each plate.

M.O'D.

RODEWALD (HANS J.). *Zur Genesis des Diamanten.* Verlag Meier & Cie, Schaffhausen, Switzerland, 1960, pp. 69. Sw. Fr. 8·60.

This interesting short monograph is divided into four sections. The first deals with the origin of diamond within the kimberlite pipe and illustrates by means of text diagrams various existing pipes, giving also tables of yield, an account of the chemical processes obtaining at the time of diamond formation, and a short bibliography. The second section reviews the work of Moissan and Prandtl and the third that of Hannay. This section contains diagrams of the apparatus used and of other contemporary and present-day apparatus used for the manufacture of synthetic diamond. The last section illustrates the relationship between colourless and red phosphorus, a relationship analagous to that between diamond and graphite. These sections also contain short bibliographies.

M.O'D.

BRØDSGAARD (K.). *Laer smykkestenene at kende.* Series Berlingske Fritids bøger. Berlingske Forlag, Copenhagen, 1970, pp. 128. Illustrated in black-and-white and in colour. 16Kr.50.

A popular introduction to gemmology forming part of a series covering various useful arts. This book is especially successful in its freehand text illustrations which depict crystal form; inclusion of stones in heavy liquids is worth paragraphs of description. A larger representation of the refractometer scale would be desirable. The colour plates are of good quality. Tugtupite should have been found a place in a Danish book.

M.O'D.

CHASE (S. H.). *Diamonds.* Franklin Watts, London, 1972, pp. 90. Illustrated in black-and-white. 80p.

A popular book consisting largely of illustrations. The author deals with the early diamond discoveries in India and celebrated

diamonds from that continent and then turns to South Africa which is similarly though more exhaustively treated. The shots of diamond recovery are good and the later chapters on the fashioning and use of both gem and industrial diamond are also well illustrated. There are some interesting anecdotes about recent discoveries of large diamonds and the book ends with a short glossary.

M.O'D.

HARTIG (H.). *Edelsteine und Mineralien selbst schleifen* (2nd edition). Verlag Frech, Stuttgart, 1969, pp. 64. Illustrated in black-and-white. DM7·60.

A small but well-produced book introducing faceting to the amateur. The nature of gem materials and their correct orientation for cutting purposes are simply explained, and these opening sections are followed by details of modern faceting equipment, with particular emphasis on the mechanical dops for which tables of appropriate angles are given. A feature of the glossary of gem materials which completes the book is the provision of dispersion figures for the majority of the listed species.

M.O'D.

JUBELT (R.) and SCHREITER (P.). *Gesteinsbestimmungsbuch.* Deutscher Verlag für Grundstoffindustrie, Leipzig, 1972, pp. 178. Illustrated in black-and-white and in colour. Separate folding tables. DM16·80.

Written, according to the foreword, for the benefit of friends of geology, mineralogy and geography, this useful book presents geological and mineralogical data in a form designed for those wishing to study specimens in the field without a background of mineralogical training. A short introduction precedes a description of rocks with East German locations and comprehensive chemical information; particularly welcome are diagrams showing the interrelationship of rock-forming minerals. A section of coloured plates depicts typical rock formations and includes illustrations of thin rock sections which are also shown in black-and-white together with some rock specimens. There is a short bibliography. Separate folding tables cover the rock-forming minerals in traditional order giving constants, and maps. M.O'D.

ASSOCIATION NOTICES

FORTHCOMING MEETINGS

A reunion of members will be held at Goldsmiths' Hall, Foster Lane, London, E.C.2 on Monday, 27th November, 1972, at 6 p.m. This will be followed at 7 p.m. by the Presentation of Awards gained in the 1972 Gemmological Examinations. The newly elected President of the Association, Dr. G. F. Claringbull, B.Sc., Ph.D., has kindly consented to present the awards.

On Monday, 29th January, 1973, at Goldsmiths' Hall, at 7 p.m. Mr. B. W. Anderson will give a talk about his experiences as Director of the Gem Testing Laboratory of the Diamond, Pearl and Precious Stone Trade Section of the London Chamber of Commerce from 1925 to 1972.

Also at Goldsmiths' Hall, on Tuesday, 17th April, 1973, at 7 p.m., Mr. Julius Petsch Jnr. of Idar-Oberstein, will give an illustrated talk to members on new discoveries of gemstones.

GIFTS TO THE ASSOCIATION

The Council of the Association is indebted to the following for gifts to the Sir James Walton Library:

Dr. W. Campbell-Smith, Sevenoaks, Kent, for backnumbers of the *Journal of Gemmology*.

OBITUARIES

We regret to record the death of M. Georges Gobel, one of the very few chosen to be Honorary Fellows of the Gemmological Association, who died in Paris on 24th July at the age of 87.

After early pioneer work on pearl testing in a private capacity, M. Gobel was asked to form and direct an official pearl-testing Laboratory under the aegis of the Chambre Syndicale des Negociants en Diamants, Perles fines et Pierres Precieuses, and by April 1930 this was firmly established, and he enlisted the services of two trusted assistants, Mme. Grossmann and Mlle. D. Level. The work of the Laboratory was soon extended to include gem-testing, and it was taken over by the Chambre de Commerce de Paris. It was thus closely parallel to the Precious Stone Laboratory of the London Chamber of Commerce, and between the two a close and valuable liaison was soon established.

Some years later M. Gobel assumed a dual role when he was appointed Inspector for the Repression of Frauds under the Ministry of Agriculture—a post which gave him powers to put into effect his strongly-held views on fair dealing in the jewellery trade.

During the war (1941) his work was further extended when he was asked to conduct Trade classes in gemmology. His lectures were original and based on fundamental theory, but were strongly reinforced on the practical side by Mlle. D. Level during evening classes held in the Laboratory.

So much for the domestic side of his work: amongst the still surving senior gemmologists of Europe he will chiefly be remembered as an outstanding representative, for more than 30 years, of the French point of view at international gatherings such as the rather grandiose affairs organised by B.I.B.O.A. or the more intimate International Conferences of Gemmologists held since the war.

On such occasions his eloquence was outstanding: his love for fine jewels was clear in his every utterance, and his face was set sternly against all forms of fraud. He could summon a diamond from thin air and place it in the palm of his hand, glittering for all to see. He spoke of a brilliant-cut diamond as "a violin that plays with light", of a ruby as "attracting our glance as does a rose in the deep core of its petals", of a topaz "its very flesh is made of light"—phrases which, in the French tongue which he spoke so superbly, sounded far more impressive than in these lame translations.

Gobel's private life and private thoughts were guarded by an impenetrable reserve, but he was a loyal and warm friend to those fortunate enough to win his trust, and amongst such will always be remembered with admiration and affection.

Mr. John Stanley Harper, Birmingham, who was associated with a well-known firm of Birmingham jewellers for 25 years has died after a long illness. He was 57 and obtained the Fellowship Diploma in 1954.

For 20 years Mr. Harper lectured to students at the Birmingham School of Jewellery and Silversmithing on gemstones.

TIES FOR FELLOWS

An Association tie is available for Fellows. The tie, which is dark blue, bears the crest of the Association in golden yellow.

The price including postage (U.K. only) is £1·25 each. Overseas postage is 10p extra for surface mail, or 40p for air mail.

MEMBERSHIP

MacLeod, Helen L., Washington D. C., U.S.A., D.1971, transferred to Fellowship.

In the list of ordinary members elected at the meeting of the Council held on the 17th May, published in the July issue of the *Journal*, the following names were spelt incorrectly: Elisabeth Lipschitz-Wachsberg was listed as Elisabeth Oipschitz-Wachsberg, and Lloyd C. Melancon as Lloyd C. Melacon.

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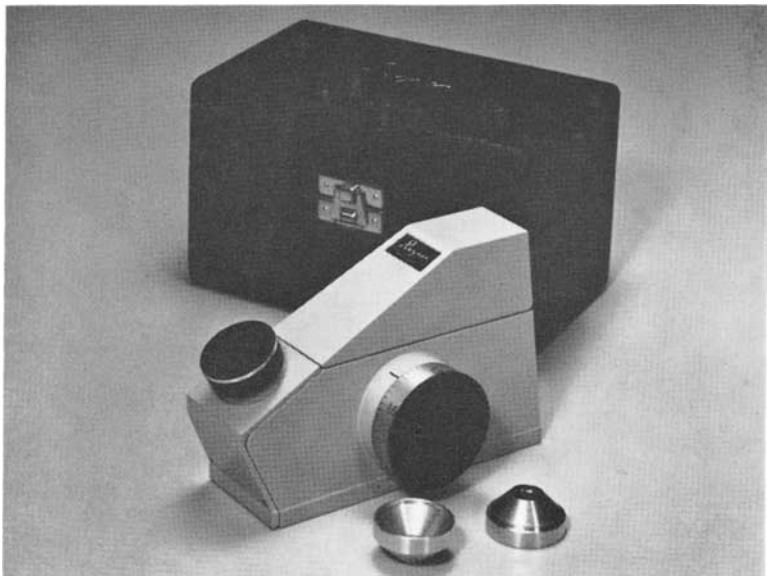

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Vol. 13 No. 5 January, 1973

THE JOURNAL OF GEMMOLOGY

and

PROCEEDINGS OF THE GEMMOLOGICAL ASSOCIATION OF GREAT BRITAIN

GEMMOLOGICAL ASSOCIATION
OF GREAT BRITAIN
SAINT DUNSTAN'S HOUSE, CAREY LANE
LONDON, E.C.2

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THE JOURNAL OF GEMMOLOGY
AND PROCEEDINGS OF THE GEMMOLOGICAL ASSOCIATION OF GREAT BRITAIN

Vol. 13 No. 5 JANUARY 1973

More notes on GILSON SYNTHETIC TURQUOISE

By ROBERT WEBSTER, F.G.A.

THE January 1972 issue of the *Journal of Gemmology* carried an article "Notes from the Laboratory", one part of which was the report on the examination of a specimen of synthetic turquoise produced by the firm of Gilson of France. The following is the report on the examination of another such stone (and subsequently 12 others) and expands the earlier report made by B. W. Anderson.

The stone examined by the writer had been donated by the Gemmological Association for investigation. The stone, an oval cabochon-cut stone, was a pale blue in colour and nearer in hue to the American turquoise than the colour of the better quality turquoise from Iran and other eastern sources. The stone weighed 1·275 carats.

In view of the small size of the stone a density determination was first made by using a heavy liquid method. The stone was found to sink in a liquid in which a rock crystal sphere just floated. A subsequent hydrostatic weighing gave a result of 2·72, a value

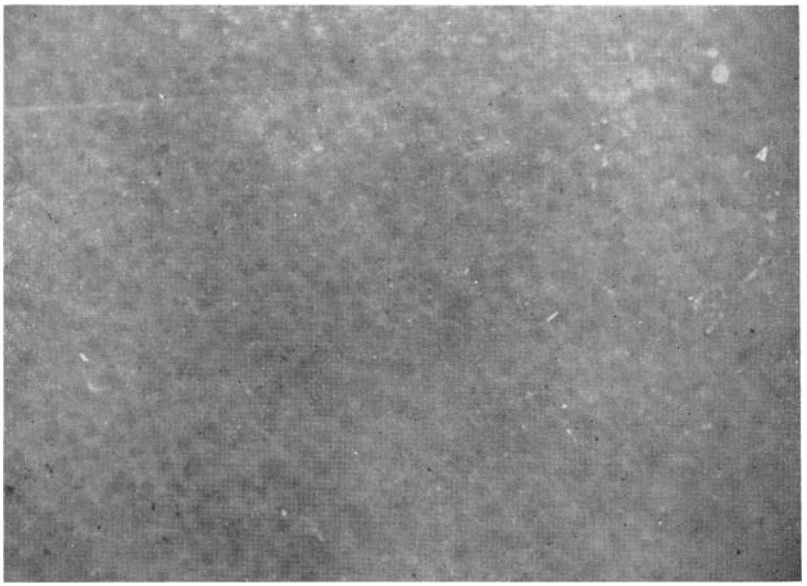

Dark blue angular particles in a Gilson synthetic turquoise

in keeping with the effect in the heavy liquid. The back of the stone was then roughly polished, after which a fairly good refractometer reading of 1·604 was obtained. There was some possible trace of the 4320Å line in the absorption spectrum.

A microchemical test proved the presence of the phosphate radical but copper was not convincingly detected by a flame test. The strong yellow colour imparted to a spot of hydrochloric acid did not occur with the Gilson synthetic turquoise as it does with the so-called "Viennese turquoise" and the German "Neolith".

Anderson, in the report of the stone he examined, mentioned that microscopic examination "showed a small-scale speckling of white, not unlike the natural turquoise in appearance." When the stone in the possession of the writer was similarly examined, using a 32 mm (1½ inch) objective and an 8 × ocular, a somewhat similar picture was seen as described by Anderson, but to the author this did not appear to be convincingly the same as the effect seen in natural turquoise. This notion was tested by using a higher

magnification, the 32 mm objective being changed to one of 16 mm (2/3rds inch). The change of magnification showed the structure to be made up of small dark blue angular particles, and generally with a semblance of parallel arrangement. These blue particles were buried in a whitish groundmass.

That this pattern was not similar to that seen in natural turquoise was more or less confirmed by the examination of some 70 specimens of turquoise, including a number from known localities and a few of doubtful parentage. In no case was the type of structure seen in the Gilson synthetic turquoise apparent in any of these natural stones. A few turquoises did show blue patches on a whitish background but the patches were not angular and had rounded outlines rather like "clouds".

In view of the apparent discrepancy between the observations of Anderson and the writer, and to guard against either of these two stones being a "maverick", a further parcel of 12 specimens was borrowed from the Gemmological Association. These stones are probably from the same parcel as that from which the stone in the writer's possession came.

The result of the examination of these 12 extra stones was that they all had the typical structure of small angular blue particles in a whitish groundmass, as already described.

The 12 extra stones were then tested for density, first by the heavy liquid method when all the stones were found to sink in the quartz liquid. A bulk hydrostatic weighing of the 12 stones, which weighed 11·545 carats, gave a result of 2·74.

The refractive indices, taken by the distant-vision method on the six larger cabochons, showed an index of about 1·60. The absorption spectrum showed what may be a very weak 4320Å line in the blue-violet, but this observation seems to have little value.

Examination under both long- and short-wave ultra-violet light showed the Gilson stones to have a fairly dull bluish-mauve glow. Again this observation had no particular merit from the viewpoint of identification, as observations on natural turquoise under ultra-violet light showed the glows to be variable, ranging from a dull deep mauve to a bright blue, in fact an effect somewhat similar to that shown by diamonds. During this examination it was noticed that the stone which had been used for the hydrochloric

acid test did not glow where the acid had been. This effect did not seem to occur when real turquoises were so tested. Five turquoises from various localities were examined under long-wave ultra-violet light after a sport of acid had been placed on their surface and then dried off with blotting paper. This "off-beat" test with acid is not recommended, as it was found that the acid tended to seep into the stone and, further, tended to lighten the colour. It is inadvisable to do this with any turquoise.

From the observations of 13 stones from one batch it would be rash to draw a conclusion that the structure, and even the acid test with ultra-violet light, would give the answer to the problem of the identification of this new synthetic stone. It is hoped that other workers will carry out further investigation when other specimens become available.

THE GIRDLE OF THE BRILLIANT-CUT DIAMOND

Historical Survey

Notes from the Gübelin Laboratory, Lucerne.

THE first polished diamonds, of Indian origin, revealed the traces of man's ideas in earliest times. The exceptional hardness of the substance made its cutting a long and difficult task, and, since technological progress had not yet evolved to expert cleaving or sawing, the work on the rough diamonds was limited in scope.

The sense of admiration for such extraordinary material was so great that it became superstitiously regarded as a gift of the gods with the belief that cutting lessened the magical force inherent in the stone. Thus the cutter endeavoured to spare as much as he could of the valuable substance and this is reflected up to the present day in the way people in Asia consider precious stones.

The diamond fields of India are exhausted (except those of Panna, with estimated reserves of some three million carats) and precious stones are still being cut in India as sparingly as possible in order to retain the maximum weight.

In the West, centuries of empirical experience have led to the brilliant-cut, the climax of the endeavour to obtain the utmost in brilliancy. The term brilliancy covers three different phenomena: the surface lustre, the interior brilliancy caused by reflection and the fire caused by dispersion. It was only at the beginning of the 20th century that a mathematical statement on optical cutting proportions and angles based on the laws of the propagation of light in crystals was elaborated by Tolkowsky, Rösch and others. On the whole these mathematical formulae agreed quite well with the empirical results obtained by the cutter and led to a still greater yield of light. This was achieved by modifying cutting angles to agree with the optical properties of diamond with regard to total reflection and dispersion of light. Contrary to the old cuts, modern round cuts do not aim at reducing loss of weight to a minimum but at yielding an optimal optical effect.

The brilliant-cut has its own characteristic effect on incidental light. Under practical conditions, as it is the case for diamonds set in jewellery, one may consider that light enters a brilliant-cut

diamond under a great number of different angles, to be practically considered as building a hemisphere on the upper part of the girdle of the diamond. If we put the sum of all light rays entering the brilliant-cut diamond at 100%, then the amount of light reflected by an ideally proportioned brilliant-cut lies at between 32-33%, according to the authorities in print.

Slight deviations of cutting proportions affect the brilliance of diamonds and in turn give each one its own characteristic aspect; thus the expert can appreciate the cutting quality of a brilliant-cut diamond by observing the facet reflection patterns without the assistance of complicated instruments or calculations. The first part of the present century has seen a remarkable improvement in both the precision and the symmetry attained in putting the facets on the stone and it is amazing that cutters can reach such a high degree of perfection in manual work with just the aid of a pocket lens.

The flat surfaces of the brilliant-cut comply with the laws of crystal structure: the only non-plane surface of the brilliant-cut, the girdle, is determined by man, and this determines the size of the stone, together with the final measurements and proportions derived from it.

From the time when stones were still bruted by hand, and even after 1891, when the girdling machine was introduced, right up to the beginning of the second World War, bruting used to be carried out carefully and cautiously. It was only after the war that there appeared on the market brilliant-cut diamonds (usually less than one carat in size) that had been girdled too fast with the result that the girdles were frayed—in fact damaged by small cleavage fissures or cracks.

Considerations on the valuation of diamonds

Three factors have contributed to the increasing demand for gem diamonds:

1. The stability of uninterrupted and continuous price increases
2. The growth of world output
3. Publicity to promote sales

More and more consumers are showing interest in diamonds in a wide range of qualities and prices.

Together with growing interest, several systems of classification and description have been devised for gem diamonds. The RAL 560 system is a series of definitions that has been used for quite

some time by some European trade associations. In the United States the Gemological Institute of America and the American Gem Society have drawn up their own systems, while in Switzerland the Swiss Gemmological Society has set up rules for members. The present trend calls for exact definition of qualities for use by retail jewellers: this has given rise to several new systems of standards.

Differences of opinion amongst people in the trade have arisen concerning the systems of diamond valuation: some claim that by supplying an exact quality description of a given stone, one reduces selling to a technical matter and makes it more difficult by removing the diamond nimbus. As a matter of fact diamonds are now, before all, (apart from the symbolical meaning awarded by publicity or from the poetic notion given them by romantic buyers) a capital investment the value of which rises with the quality.

In modern business transactions it is usual to classify goods exactly according to the demands of clients who want to be able to judge the quality of any product they wish to buy. In purchasing a diamond, clients are all too often obliged to believe a jeweller on his word because they ignore the objective criteria to judge cut, colour and purity. Jewellers, as well as their clients, are inclined to put too much emphasis on the last two subjects at the expense of the art of cutting. This is unfortunate as it is through the art of cutting that man can substantially affect the beauty of a diamond, which is not the case for the other two factors. Most of the time the amounts of money involved in diamond transactions, together with the often considerable differences in prices, due to differences in colour and purity, make one understand why buyers are extremely cautious, endeavouring to inform themselves and to compare merchandise by going to a number of retail jewellers before making their final decision.

In analysing the motives of buyers one finds that they do not like buying blindly. Psychologically, they appreciate having their judgement confirmed by a document in which the properties of the article they have bought are described. This desire for security is making itself increasingly evident. By using a system of valuation we may try to meet this need. It is sometimes suggested that by applying a precise system of grading we create a handicap to sales, as this is sure to hamper the search for stones of finest quality. As a matter of fact it is just the contrary: the aim of a system of description is to facilitate sales of piqué or off-colour diamonds by

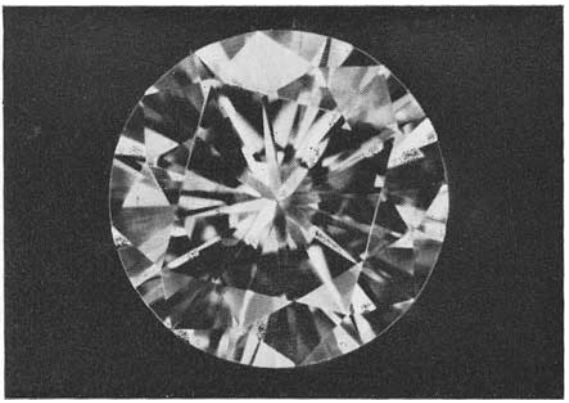

FIG. 1. 0·54 carat diamond, with classically bruted girdle, flawless.

putting down one's cards before the client. Considered in this way, systems of grading actually promote sales. Present trends have led to a growing demand for absolutely flawless diamonds, which over the years have become increasingly scarce. It is evident that extreme care must be devoted to them in cutting. Of the four factors (the four c's) that conventionally determine the value of diamonds, three can only in a limited way be affected by the intervention of man, namely: carat weight, colour and clarity.

It is very easy to affect the shape, in order to obtain maximum beauty from the raw material and therefore it is justified to devote much attention to this factor, the cut.

If we consider how easy it is to influence the cutting and bearing in mind how scarce flawless stones are nowadays, it is difficult to understand how a number of diamonds (usually less than one carat in size) are marketed with bearded girdles, features which are in fact cleavage fissures. In extreme cases the girdle looks like a white circle which affects the brilliancy of the stone. This is caused by inexcusable negligence in the cutting of the originally flawless material. Fig. 1 shows a 0·54 carat brilliant-cut diamond with a carefully bruted girdle (10 ×). Fig. 2 shows another diamond with the characteristics of a flawed girdle looking like a white circle (10 ×).

Fig. 3 is another example of a flawed girdle on a 1·05 carat brilliant-cut diamond, viewed obliquely. Further enlarging (40 ×) shows that the flaws are indeed individual fissures penetrating into the stone (fig. 4).

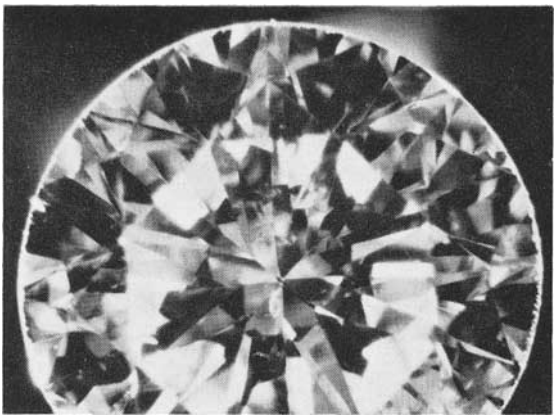

FIG. 2. Diamond with bearded girdle, that looks like a white circle caused by bruting too rapidly (10 ×).

FIG. 3. 1·05 carat diamond with a flawed girdle, seen from a side (10 ×).

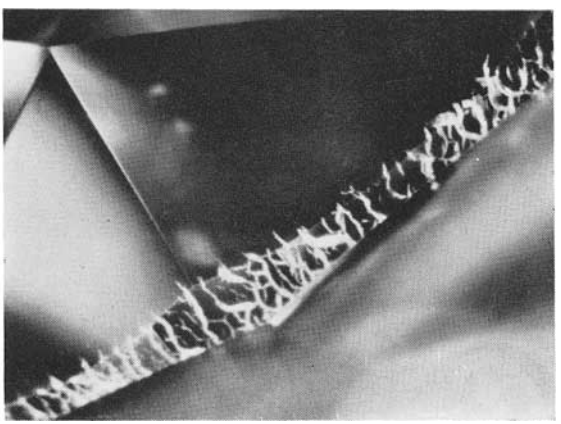

FIG. 4. The same stone as in fig. 3. The enlargement to 40 × proves that the flaws are actually fissures that penetrate into the stone.

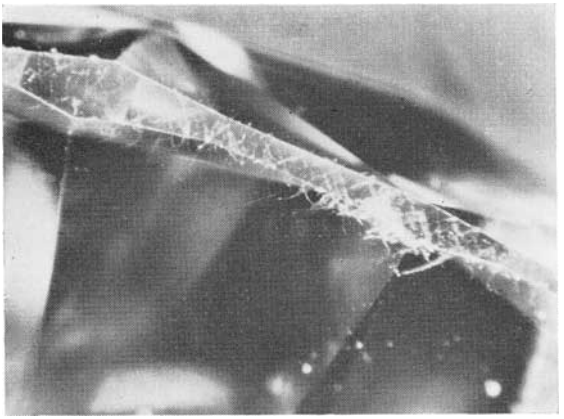

FIG. 5. 1·21 carat diamond. Pronounced fissures under the girdle facets: the stone can no longer be graded as flawless (25 ×).

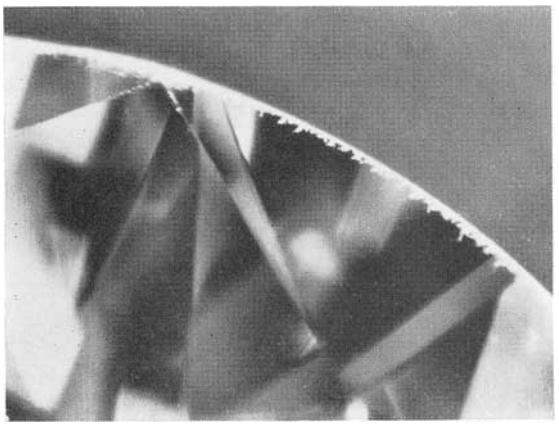

FIG. 6. 1·42 carat diamond. Flawed girdle with white rim (25 ×).

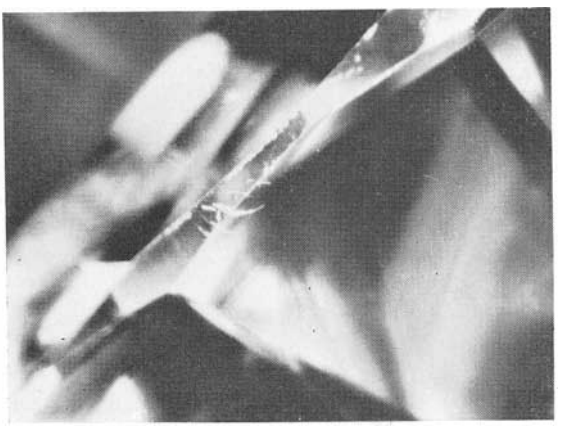

FIG. 7. 1·69 carat diamond. Flawed girdle: separate fissures seen. (25 ×).

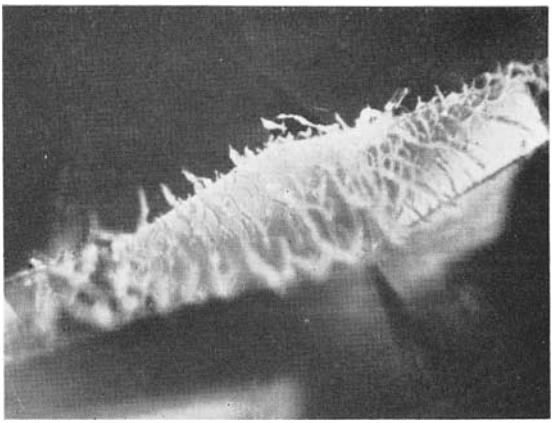

FIG. 8. 1-carat diamond. Flawed girdle (63 ×).

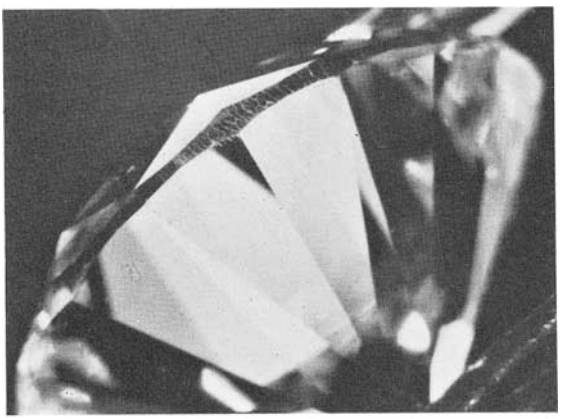

FIG. 9. 1-carat diamond. Bruted girdle with flaws (10 ×).

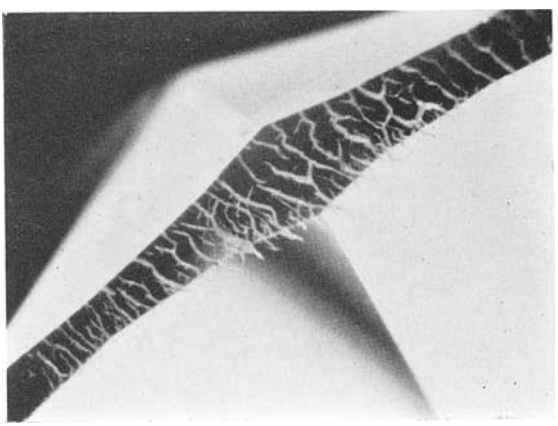

FIG. 10. 1-carat diamond. The same girdle with flaws (40 ×).

In which clarity grade shall we classify such a stone?

Let us remember the definition of a flawless gem diamond, according to international agreement and found in several modern grading systems.

A diamond is considered flawless when found free from inclusions, through expert examination under 10-fold magnification. A flawed girdle with a number of fissures that are clearly visible through a 10 × lens causes the stone—when we want to apply the rules—to be graded as VVS or VS, in spite of the absence of natural inclusions. If only a little more care had been taken in girdling, the stone could have been graded as flawless. It is a mistake to assume that fast girdling is advantageous; the fact that it is lowers the value of a precious stone. Furthermore it is also false to assume that the time-consuming task of faceting the girdle will hide the damage caused by careless bruting. It is a fact that the fissures may still remain visible under the facets. Fig. 5 demonstrates this: strongly pronounced fissures are visible through the girdle facets on a 1·21 carat brilliant-cut diamond.

Figs. 6 to 8 show fissures in other diamonds (25 × to 63 ×). Figs. 9 and 10 show a bruted girdle with fissures.

The pictures prove that even finest quality diamonds of more than one carat have not been spared from this unfortunate treatment despite the rarity of stones devoid from natural inclusions.

It is regrettable to encounter the rare case of a professional activity where the raw material is artifically flawed, although this ought to have been avoided at all costs: the finished product—a flawless diamond, would have been much more valuable.

If only the harm that this practice caused was understood and eliminated hundreds of European retail jewellers (who have attended courses on diamond valuation by modern grading systems) would have the chance to grade more diamonds as flawless stones.

This article aims at drawing the attention of diamond cutters to a retail jewellers' problem, a problem they could easily solve themselves by giving more consideration to exceptional raw material. They would thus contribute to the common interests of everyone in the trade by promoting and facilitating sales.

N.B.—The figures accompanying this article are pictures unretouched, showing the common aspect of fissures under different enlargements.

This article first appeared in *Diamant*, No. 147, Feb. 1972.

EMERALDS REPUTED TO BE OF ZAMBIAN ORIGIN

By I. C. C. CAMPBELL, F.G.A.

RECENTLY I had the opportunity of examining a variety of emerald which is reputed to originate in Zambia. The suppliers who cut these stones would give no details other than that they had originated from claims in the Kitwe district; hence, unfortunately the exact location cannot be given. Kitwe itself is only approximately 20 miles from the Congo border. It is understood that claims may be commercially viable and the cut emeralds are apparently mainly destined for the Continent. Information has been received that one origin of emerald is Miku, Zambia. This name cannot be found by the writer, in even detailed maps of Zambia—it is possible that it is either a new name or, as is often the case lately, an old place that has been re-named. In an exchange of correspondence, Robert Webster is of the opinion that "Miku" could be a mis-representation (spelling?) of a similarly spelt name.

I did not in fact examine a large but poor quality emerald from Zambia in January, 1971. This was referred to in the Minutes of the Third Meeting of the Gemmological Association of Rhodesia in the same month which, at the time, dealt with inclusions in emeralds from different sources. The inclusions in this stone and the test stones referred to in this study appear to be similar, so it is possible that emeralds—at least a limited number—have been coming from the same source for a minimum period of 19 months to date.

It is thought that these additional data on emeralds will be of some use, as some rather interesting aspects have arisen in so far as the inclusions are concerned in this batch of 20 faceted stones.

It would appear that a similar—probably the same—type of emerald is also finding its way to the Republic of South Africa. Stones from that country were also examined and found to fit in perfectly with the results of the Zambian test stones. Although some properties were similar to the Northern Transvaal ones, it is obvious that the stones seen were not from that origin, although some quarters would have one believe otherwise.

The schedule below refers to the properties of the 20 test stones:—

Physical and Optical Properties				
Specimen No.	*Weight Metric Carats*	*Specific Gravity*	*Refractive Index (optic sign: Negative)*	*Birefringence*
1	1·080	2·752	1·583–1·590	0·007
2	0·282	2·751	1·581–1·588	0·007
3	0·262	2·747	Vague	
4	0·281	2·751	Vague	
5	0·248	2·755	Vague–1·590	
6	0·354	2·750	Vague–1·590	
7	0·291	2·751	1·590 Table 90° to C-axis	
8	0·354	2·750	1·583–1·590	0·007
9	0·270	See Text	Vague–1·590	
10	0·312	2·751	1·583–1·590	0·007
11	0·285	2·747	1·581–1·588	0·007
12	0·310	2·751	1·583–1·590	0·007
13	0·308	See Text	1·583–1·590	0·007
14	0·286	2·752	1·590 Table 90° to C-axis	
15	0·211	2·753	Vague	
16	0·257	See text	Vague	
17	0·259	2·751	Vague	
18	0·267	See text	Vague	
19	0·262	2·752	Vague–1·590	
20	0·281	2·748	Vague–1·590	
Average:	0·283 Excluding No. 1	2·747 to 2·755 Av.: 2·75	5 stones: 1·583–1·590 2 stones: 1·581–1·588	0·007

Test stone No. 1 is excluded in the average weight as it is considerably larger than the other 19.

As can be seen from the above listed weights, the average size is relatively small, hence not of optimum size which is required for a study of this nature. The exception is specimen No. 1, which gave a reasonably good refractive index reading on a standard Rayner refractometer. The other six full R.I. readings are considered clear enough to accept. With reference to another five stones, the index of refraction for the ordinary ray (1·590) was relatively distinct. Specimens Nos. 7 and 14 appear to have been cut with their table facets orientated at right angles to the main crystallographic axis (C-axis) of each stone. The two did not show extinction when each stone was orientated under the polariscope either in the normal position with the table facet orientated parallel to the polaroids or in the reversed position—extinction was only evident when each stone was viewed through the sides. The refractometer gave a single, fairly sharp refractive index reading of 1·590 for both of them. The balance of the stones gave extremely vague shadow edges and thus obviously not good enough for reliable readings, although in at least half the cases it was evident that the shadow edge fell between 1·58 and 1·59. Finally, the two different sets of readings leads one to speculate whether or not the relative stones were from two

different sources, although the other tests gave uniform results for the entire group. It is interesting to note that B. W. Anderson (*Gem Testing*, 8th edition) gives the R.I. for Zambian emeralds as 1·581-1·588.

The specific gravity was initially hydrostatically determined with the use of alcohol and a Mettler electric metric balance of accuracy to within 0·002 of a carat. The tests were repeated three times, each time on different occasions, and the S.G. of the liquid was assessed with a Westphal balance at the time of each series of tests. Thereafter, a heavy liquid was mixed to suspend an indicator of S.G. 2.75 and the stones re-tested on a comparative basis. This final procedure proved that the computed values for specimens Nos. 9, 13, 16 and 18 were incorrect. Nevertheless, it was ascertained that the S.G. values of three of them fell between 2·747 and 2·749, while the other one actually suspended in the liquid, thus fixing it at 2·750. The remaining 16 stones behaved in the liquid as one would expect them to in relation to their computed values. It should be noted that of the three values assessed for each stone, the more favourable one was accepted in accordance with the stone's behaviour in the liquid. It is also interested to note that B. W. Anderson (*Gem Testing*, 8th edition) gives the S.G. for Zambian emerald as 2·75. R. Webster (in a letter to the author) gives the value of one stone, also from Zambia, as 2·753.

In view of the foregoing details, the following results for Zambian emerald are given:

Refractive index	: 1·581-1·588 to 1·583-1·590
Birefringence	: 0·007
Specific gravity	: 2·74 to 2·76 (Av: 2·75)

Fluorescence:

Under S.W.U.V. and L.W.U.V. rays: Inert

Under the Chelsea Filter: All the stones fluoresced a reddish hue, some fairly strongly, while others showed a barely perceptible reddish-pink in the smaller stones. None of the stones showed the particularly bright glows normally associated with the majority of synthetic emeralds to date.

Absorption Spectrum:

A Rayner prism spectroscope was used in conjunction with the microscope and direct substage lighting. Not all the test stones were examined, but of those that were the spectrum is due to

chrome: Three strong absorption lines in the deep red, one pair of which is a doublet—the line at about 6830Å being the strongest. Absorption of the deep violet was also seen. No other lines or bands were evident. As this instrument is not calibrated, a precise Angstrom reading cannot be given.

Colour and Some Other Aspects:

It is not easy to give an opinion on colour, particularly when it comes to comparing different hues of what is basically one colour. In the opinion of the writer the colour of the Zambian stones compares favourably with the Rhodesian Sandawana (Belingwe) type of green.

The sizes seen to date give one the impression that the average size compares with that of the average Sandawana stones, although very likely the larger and possibly better quality stones are finding select markets. They are, however, being used in jewellery to good advantage—the effect being quite striking.

The price, at the time of writing, appears to be below that of other comparable emeralds in Rhodesia, probably because it is a new variety in the country—hence not yet as acceptable as the well known Sandawana stones. There is no reason to doubt that prices will increase once the public overcome any unfounded doubts which may exist due to not having seen them before, and provided the supply continues at a reasonable and (if necessary) suitably controlled rate. It is the personal opinion of the writer that the better quality Zambian emeralds (those free of heavy inclusions) compare favourably with normally accepted good quality Sandawana ones.

Inclusions:

The inclusions, tabled hereunder, were examined under a Wild Heerbrugg M.4 binocular microscope using, as required, substage or overhead lighting depending upon whether internal features were to be examined or inclusions shown at the facet surfaces.

The description "mica", used loosely in the following text, refers to the *appearance* of the mineral, as it is equally possible that it could be another mineral which is similar in appearance. Another aspect, as far as these stones are concerned, was the noticeable lack of actual flaws (cracks etc.), although the stones were comparatively heavily included.

Description of Inclusions

Specimen No.	*Magnification*	*Lighting arrangement*		*P/Micro Ref. No.*	*Description of inclusions*
		Overhead	*Substage*		
1	40 ×	√		1/A	"Bread-crumb" type inclusion.
	60 ×	√		1/B	"Bread-crumb" type inclusion at surface where cut by a facet. The two dark irregular shaped spots are in fact openings to a common hollow centre.
	40 ×		√	1/C	"Fragmentation" of bread-crumb type inclusions—pseudo-forms evident. Also pale, almost invisible, flakes of a mineral strongly reminiscent of mica platelets of ultra-thin cross-section (barely visible).
3	40 ×		√	3/D	Coarse "treacly" appearance in places due to comparatively coarse platelets of closely packed "mica"-type flakes. They vary from what appears to be almost colourless to a pale brown tint. Apparently of random orientation. Biotite is also present and is black in colour. See photomicrographs Nos. 14/H and 20/J in relation to better examples of a "treacly" internal appearance.
6	60 ×		√	6/E	"Crochet" type pattern of biotite. Also loose flecks and spots of biotite (all black). Paler flecks are "mica"-type flakes which show as pale brown tints in substage lighting. Fragmented "bread-crumb" type inclusions similar to those seen in specimen No. 1 and others.
12	60 ×	√		12/F	Referring to the two irregular shaped profiles in the centre of the photomicrograph: both are at the table facet surface: (i) L.H.S. (showing less reflection)—pit left after removal of flake of "mica"-type substance with the use of a probe. (ii) R.H.S. (looking somewhat like cotton-wool in this photograph)—is the bright effect seen (in fact it looked irridescent under the overhead lighting) of the same type of "mica"-type substance as in (i) aforementioned, but still *in situ*. It was, however, first disturbed and prodded with a probe. The effect seen was similar to a separate minute plate of mica also examined after the same treatment. This was done for comparative purposes. Both these flakes (the removed one being examined independently) were also examined under 120 × and it is thought that they are mica.
13	40 ×	Combined		13/G	(i) Cloudy (or milky) due to dense, extremely minute pin-point type inclusions. (ii) General view of heavily included matter—mainly of what appear to be pseudo-forms of "bread-crumb" type of inclusions similar to those shown in photomicrograph 1/C; as well as ultra-thin "mica"-type flakes, in random orientations.

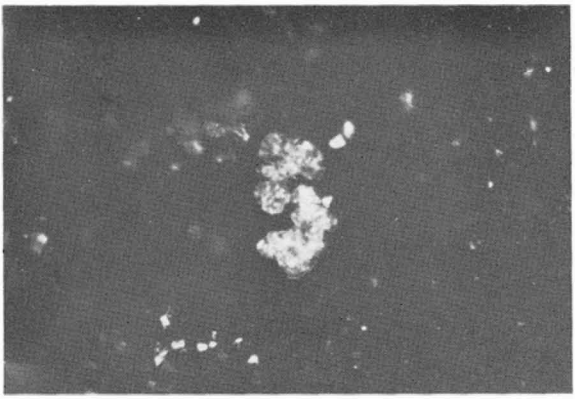

SPECIMEN 1/A.

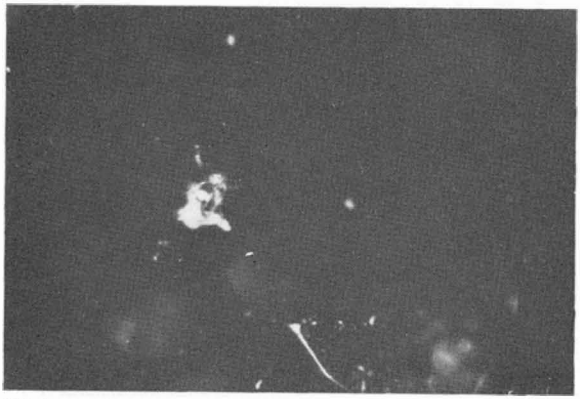

SPECIMEN 1/B.

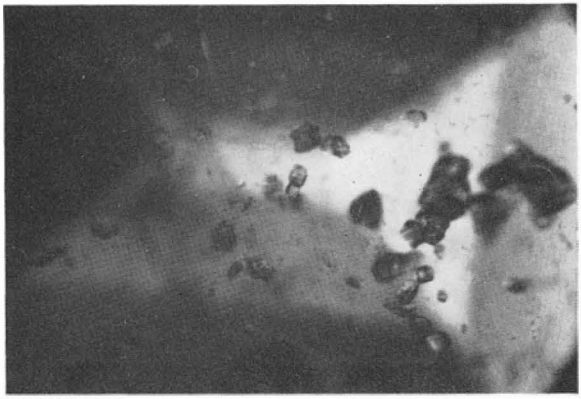

SPECIMEN 1/C.

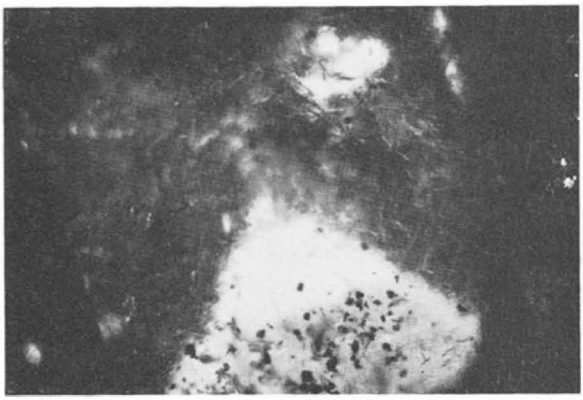

SPECIMEN 3/D.

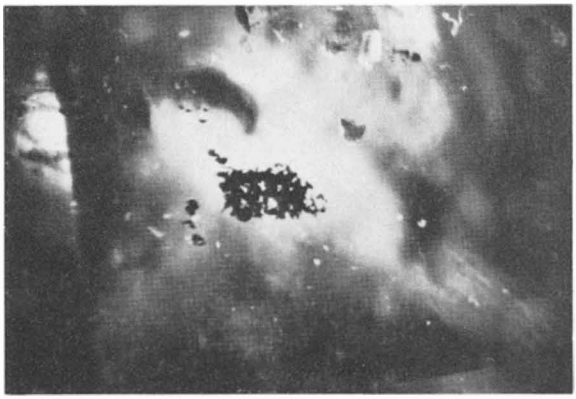

SPECIMEN 6/E.

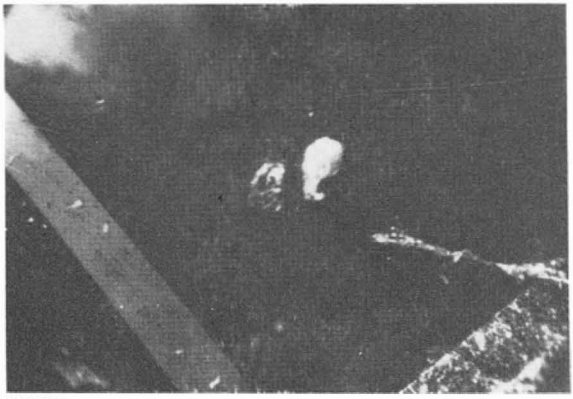

SPECIMEN 12/F.

Specimen No.	*Magni-fication*	*Lighting arrangement*		*P/Micro Ref. No.*	*Description of inclusions*
		Overhead	*Substage*		
14	60 ×		√	14/H	(i) "Treacly" appearance due to excessive number of ultra-thin "mica"-type flakes in random orientation. (ii) A feather (unfortunately, not quite in focus).
20	40 ×		√	20/I	General appearance of inclusions and fairly typical of what was seen in most stones: (i) Black specks of biotite. (ii) Other inclusions which *appear* to be 2-phase—in reality those examined from different angles showed close contact between biotite specks and "mica"-type platelets or flakes (i.e. they are not 2-phase). (iii) An overall view of the type of irregular profiled and rounded "mica"-type flakes—some comparatively large in size.
	40 ×		√	20/J	Focus was just below the surface of the table: (i) Black, irregular shaped inclusions of biotite. (ii) Overall, slightly "treacly" effect or "disturbed" appearance due to concentrations of almost invisible ultra-thin "mica"-type flakes in random orientation. (iii) Larger flecks of "mica"-type flakes, a few of which (and in particular, one) appear to be thicker than the average.

SPECIMEN 13/G.

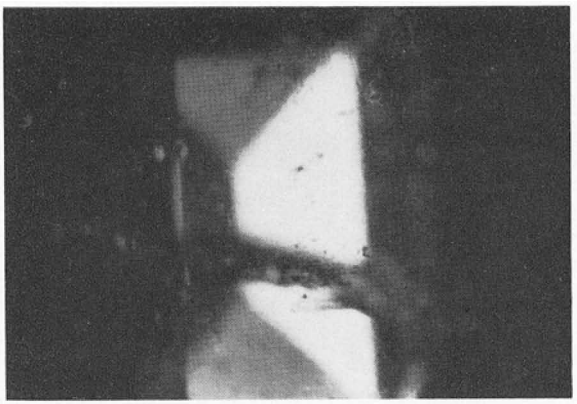

SPECIMEN 14/H.

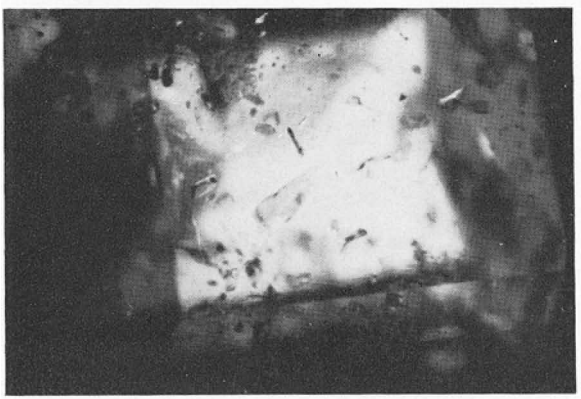

SPECIMEN 20/1.

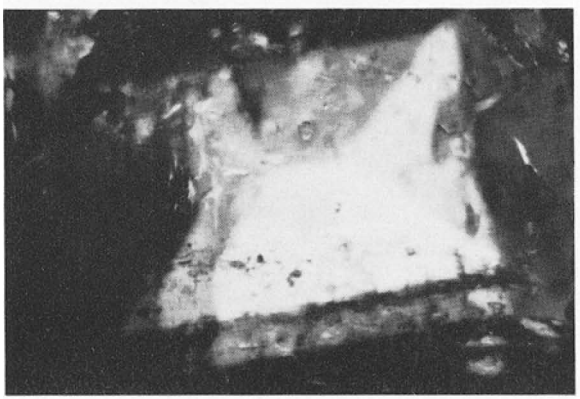

SPECIMEN 20/J.

In Correlation of the Foregoing Findings:

Five types of inclusions are evident in these emeralds:

(1) Black biotite in the form of irregular shaped specks, dots and larger expanded shapes (e.g. the crochet type pattern in one stone).

(2) "Bread-crumb" type inclusions trailing off to what appear to be pseudo-forms—probably hollow in the larger sized ones. These are reminiscent of those seen in some emerald-coloured paste as shown by Webster in *Gems: Their Sources, Descriptions and Identification*, 1962 edition, page 334, figure 173. The resemblance is remarkable.

(3) Mica, or a mineral similar in appearance to mica, was present in all stones to a lesser or greater degree. The size of the flakes varied considerably, their profiles being mainly irregular but rounded as opposed to a geometric outline. The colour in these flakes appeared as a very pale tint of brown to a slightly darker shade. Others appeared colourless (or the colour was masked by that of the host stone) and were of a twisted appearance. The latter inclusions gave some stones an internal "treacly" look. (The term "treacly" can be likened to the temporary effect seen when water is added to a colour tinted spirit, such as alcohol).

(4) Extremely fine pin-point inclusions in some stones giving a cloudy or slightly milky appearance.

(5) Feathers in some stones.

As noted in the schedule of inclusions, in one stone there is a contact between the "mica"-type flakes and a speck of biotite which gives the overall effect of two-phase inclusions—until the host stone is re-orientated, and in some cases the magnification increased, when the true effect is observed.

Conclusion:

A quick appraisal, with the use of a loupe only, of stones of an emerald colour, should be treated with caution as there is no reason to uppose that other "bread-crumb" type inclusions will not appear again in natural emeralds from this source. However, these stones do fluoresce under the Chelsea filter.

The "mica"-type flakes are strikingly similar to those in the Habachthal stones, (*Journal of Gemmology*, Vol. XI, No. 5, January 1969 Page 168, Fig. 6). Nevertheless the Habachthal stones also contain many long slender needles of tremolite. The Northern

Transvaal emeralds also have included mica and biotite, but these stones appear to have a different body-colour and rarely fluoresce.

The specific gravity of known natural emeralds falls within the range of 2·69 to 2·75. The Zambian stones fall within this range and in fact have the same average value for the Northern Transvaal and Rhodesian (Sandawana or Belingwe) stones.

The refractive index range of the species is given by Webster as 1·56-1·57 to 1·58-1·59. The Zambian stones fall within the higher range as do emeralds from Russia, Northern Transvaal, Rhodesia, India and Habachthal—the birefringence of 0·007 being the same for all of them.

In respect of the Zambian stones, the R.I. of 1·583-1·590 coincides with the Indian values, but the inclusions and specific gravity is different in each case. Similarly, the R.I. of 1·581-1.588 coincides with the Russian values, but again the specific gravity and inclusions are markedly different. Admittedly, on inclusions alone the Zambian stones are remarkably similar to the Northern Transvaal stones, but as can be seen, the identification can be made when the other properties are also considered.

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Anderson, B. W. *Gem Testing*, 8th edition.
Gübelin, E. *On the Nature of Mineral Inclusions in Gemstones.* The Journal of Gemmology, Vol. XI No. 5, 168, 169, 170, January 1969. *Emeralds from Sandawana.* The Journal of Gemmology, Vol. VI, No. 8, 340-354, October 1958.

ROMAN IMITATION DIAMONDS

By JACK M. OGDEN, F.G.A.

THE use of diamond in Roman times is well attested but was by no means common.(1) It is thought to have been introduced from the East sometime about 4th Century B.C., possibly as a result of Alexander the Great's conquests in the East. It is found set in rings and other jewellery in the Late Roman Period and the writer knows of no instances of its use prior to the third Century A.D.

The Romans were unable to cut diamonds due to their great hardness and all attested Roman diamonds are mounted in the

naturally occuring form—octahedral crystals.[2] The impossibility of cutting, no doubt, encouraged the name "Adamas" meaning "invincible", the word from which our 'diamond' comes.[3] It would seem, however, that although the Romans were unable to alter the shape of natural diamonds they had no hesitation in copying the shape in other materials, a 2000-year old case of 'if you can't beat it, join it'!

A Roman ring found in Syria and now in the hands of the writer is set with a clear, colourless octahedral stone which, although whiter than the usual murky Roman stones, could, at first glance, be taken for a diamond. In fact the stone is quartz cut into an octahedral form. This ring is by no means unique and several other examples are known by the writer.[4] The explanation must surely be that the Roman jewellers were consciously imitating diamonds.

Glass imitations of gem-stones are common in classical times and, indeed, are known from the earliest periods in Egypt and Western Asia. Normally these imitations are purely colour copies and were cut in the usual shapes of the period. The copying of a crystal shape, as with the octahedral quartz, is obviously due to the impossibility of cutting diamonds and, thus, the octahedral quartz copied the only known shape of diamond. Other copying of crystal forms is possibly to be found in Roman times, a bracelet, also in the hands of the writer, is composed of red glass beads of Romano-Egyptian origin of cornerless cube shape, a shape known from as early as 500 B.C. (Glass beads from Crimea). It is tempting to equate these with small garnet crystals. A ring in the British Museum is set with a green chalcedony cut to form a hexagonal prism, surely an imitation of an emerald.[5] This chalcedony, often called 'plasma' in books on Ancient Jewellery, has whitish blotches and gives a good imitation of poor quality emeralds.

NOTES

1. Examples are found in many museums and private collections. The British Museum has several for example—"Catalogue of the Jewellery Greek, Etruscan and Roman in the Department of Antiquity", British Museum 1911 No. 2954—a Gold seal and "Catalogue of the Finger Rings Greek, Etruscan and Roman in the Department of Antiquity", British Museum No. 779, 785, 787-90.
2. The faceted diamonds occasionally found in Roman Jewellery would seem always to be later additions, for example No. 779 in the British Museum Catalogue of Finger Rings mentioned in note 1 above.
3. For a full history of the word "diamond" see "The origins of 'Diamond'," by S. B. Nikon Cooper in Journal of Gemmology, 1972, Vol. 13, No. 2, p. 51.
4. Two are in the British Museum, see Catalogue of Rings mentioned in note 1 above. No. 800, 846 (?)
5. British Museum Catalogue of Finger Rings (see note 1 above) No. 835.

Gemmological Abstracts

BANCROFT (P.). *The Mineral Museum.* Lapid. Journ., 1972, 26, 4, p. 594.

An account of various celebrated mineral cabinets, illustrated in colour, with details of particularly interesting holdings. Some of the duties and difficulties of the museum curator are explained and a plea is made for greater imagination to be shown in the display of specimens. M.O.D.

BANERJEE (A.). *Ein Beitrag zum Thema Türkis. A note on turquoise.* Z. Dt. Gemmol. Ges. 1972, 21, pp. 86-102. Various illustration diagrams and bibliography.

Because of the increasing rarity of turquoise, various other minerals are used in its stead, and poor quality turquoise is treated and improved. Chemically related minerals are: faustite, coeruleolaktite, chalcosiderite, rashleighite and wavellite. Genuine turquoise can easily be distinguished by its remission line. The absorption lines show a remission maximum at $\lambda = 430$ nm and minimum at $\lambda = 432$. The genuine and improved, as well as imitation, turquoises were also examined by infra-red spectroscopy and the diagrams are reproduced. This examination was particularly useful in identifying treated stones. Turquoise changes colour permanently when heated, i.e. blue material becomes blue-green when heated to 250°C, which then turns green when heated to 400°C. The colour of the material also changed from blue to green when radiated. E.S.

BANK (H.). *Hell und dunkelgrüner durchsichtiger Andalusit aus Espirito Santo, Brazil.* Light and dark green transparent andalusite from Espirito Santo, Brazil, Z. Dt. Gemmol. Ges., 1972, 21, 2, pp. 124-125.

Andalusite in cuttable quantity has been found in Ceylon and in Brazil in Minas Gerais. The stones found in the state of Espirito Santo are described and properties given. E.S.

BERNARD (A.). *Le saphir de Houei-Sai.* Bull. Assoc. Francaise de Gemmologie, Sept. 1972, 32, p. 10.

Houei-Sai in the Upper Mekong area produces sapphire from a basalt in association with orange spinel and some zircon. From 5,000 to 7,000 carats per month are sent to Bangkok for cutting. M.O'D.

DENNEN (W. H.) and PUCKETT (A. M.). *On the chemistry and colour of amethyst.* Canadian Mineralogist, 1972, 11, 2, pp. 448-456.

The colour of amethyst results from the substitution of small quantities of ferric iron for silicon followed by ionizing irradiation. The over-all content of trace elements is not greatly different from that of colourless quartz, but stoichiometric calculations indicate that some or all of the iron present must be Fe^{3+} in tetrahedral coordination. Comparison of colourless and coloured portions of the same crystals shows the iron content to increase both with respect to aluminium and in absolute amount from colourless to amethystine portions. Growth temperatures are calculated to be 70°–285°C with a median of 250°C. R.A.H.

GALIA (W.). *Diagnostische Merkmake synthetischer Smaragde von Linde.* Diagnostic marks of synthetic emeralds by Linde. Z. Dt. Gemmol. Ges., 1972, 21, 2, pp. 112-117.

It had been assumed that Linde synthetic emeralds had an RI less than 1·57, but the author shows that many have an RI higher than 1·57. Under ultra-violet light there is red fluorescence comparable to that of Chatham synthetic emeralds; they also behave similarly under the Chelsea filter (red). The average weight was 2·67 cts. ±0·01. Many stones show coloured layers under the microscope; there are also inclusions which seem to indicate hydrothermal healing cracks. E.S.

GÜBELIN (E.). *Neueste Feststellungen am synthetischen Schmuckdiamanten der GE Co.* Latest observations on the synthetic gem diamond of the GE Co. of America. Z. Dt. Gemmol. Ges., 21, 1972, 2, pp. 103-111.

The jewellery trade was most interested in the possibilities of the GE Co. of America's ability to produce a synthetic diamond in carat-size. It was said that this diamond would lose half its

weight when brilliant-cut. The GE therefore asked the diamond cutters, Lazare Kaplan & Sons in New York, to cut the synthetics in brilliant-cut style and to compare the polishing properties and variations in hardness between the natural and synthetic stones. Cleaving and sawing of the synthetic stones was so easy that the cleaver and sawyer had the feeling of working either with a softer diamond or having a better tool. The stones were then polished parallel to the cube face and this proved to be very easy. However, when the direction was changed and the wheel went against the grain there was strong resistance. Of the six stones polished, five were brilliant-cut and one was faceted in an oval shape. The brilliant-cut stones lost two-thirds of their original weight, but it seems that one would lose less weight when polishing them as carré or emerald-cut stones. The finished stones were beautifully polished and three photographed examples weighed between 0·30 and 0·40 cts, one being colourless, one canary-yellow and one light blue. Under magnification of 15 × the formerly observed dust clouds could be seen, in the case of the blue diamond forming a cross. It was not possible to see these clouds under a magnification of 10 ×, and it is therefore suggested that in future diamonds under 1 carat should be examined with a 10 × or 30 × lens. The coloured stones were definitely of the fancy-colour variety, while the colourless stones were classified as 'crystal', i.e. there was a slight yellow tinge which showed them to belong to the Cape variety. No stones showed any absorption lines and they did not fluoresce in long-wave UV light. However in short-wave UV light (2537Å) the colourless and blue GE stones fluoresced and phosphoresced strongly (which natural ones do not do). The synthetic stones are as transparent to x-rays as the natural ones. Of all the natural diamonds only the blue Type IIb transmits electricity; it is a semiconductor. The colourless synthetic GE diamonds are also semiconductors, while the yellow synthetic diamonds do not transmit electricity and thus behave in the same way as the natural yellow stones. The author has added a very useful table, comparing the properties of the natural to the GE synthetic stones, which are divided into three groups, i.e. colourless, yellow and blue.

E.S.

LINDBERG (J. D.). *Changing the colors of transparent gemstones.* Lapid. Journ., 1972, 26, 4, p. 604.

Experiments carried out by the author, mainly on varieties of quartz, and accompanied by coloured photographs of the various stages of colour change, are detailed together with a theoretical account of the phenomena. The term colour-centre is explained. M.O'D.

MACKENZIE (K. J. D.) and GREEN (J. M.). *The cause of colouration in Derbyshire Blue John banded fluorite and other blue banded fluorites.* Min. Mag., 1971, 38, 296, pp. 459-70.

Techniques including mass spectrometry were employed to try to discover the cause of colouration in banded blue fluorites from Derbyshire. Optical spectroscopy and paramagnetic resonance measurements failed to distinguish this type from other blue banded fluorites. Optical spectra and behaviour under bleaching techniques are consistent with colouration by colloidal calcium. M.O'D.

SCHIFFMAN (C. A.). *Observations on synthetic red spinel grown by the Verneuil method.* Lapid. Journ., 1972, 26, 6, p. 926.

The author has examined both boules and cut stones with an account of the morphology of the boule surface, which was covered by a criss-cross pattern of ridges following the crystal system and enclosing smaller triangular formations. Constants for the cut stones fell within the usual synthetic spinel range. Growth lines were curved but not concentric, meeting at an angle. M.O'D.

SCHOONOVER (M.). *Gem Treasures of Australia.* Lapid. Journ., 1972, 26, 4, p. 628.

A general account of the gem localities of Australia with a background of a continental journey. Detailed descriptions of the fields are given, in particular those bearing opal and sapphire. M.O'D.

STRUBEL (G.). *Hydrothermal Kristallwachstumsprozesse.* Processes of hydrothermal growth of crystals. Z. Dt. Gemmol. Ges., 1972, 21, 2, pp. 58-84. 19 illustrations; extensive bibliography.

Most minerals which are used for gem purposes are produced

from hydrothermal solution or at least in the presence of some water. This article deals with various aspects of hydrothermal solutions, their chemical composition and occurrences. Even small quantities of water influence the speed of reaction of crystallising substances positively and the presence of water can lower the necessary temperature and stability of minerals by several 100°C. Quartz-glass, i.e. the mineral lechatelierite, does not alter even in geological periods if conditions are absolutely waterless. Experiments in an autoclave show three-phase systems at room temperature becoming two-phase systems at experimental temperatures. Other experiments show the stable mica mineral muscovite, which only decomposes at over 1,000°C when heated in a dry atmosphere, showing signs of change between 150-740°C. Various forms of hydrothermally-formed crystals are illustrated and discussed. E.S.

VANCE (E. R.) and ANDERSON (B. W.). *Study of metamict Ceylon zircons.* Min. Mag., 1972, 38, 297, pp. 605-613.

Metamict Ceylon zircons were examined by x-ray, SG, RI and optical absorption techniques. The anomalous absorption spectrum in low zircon is associated with small particles of ZrO_2 in a radiation-damaged lattice in both heated and unheated stones. M.O'D.

VANCE (E. R.) and ANDERSON (B. W.). *Differences among low Ceylon zircons.* Min. Mag., 1972, 38, 298, pp. 721-724.

Low Ceylon zircons showing an absorption band at 5200Å appear to have been more damaged by radiation than other Ceylon stones. Experiments with fission-fragment irradiation showed that low Ceylon zircons showing the anomalous absorption spectrum had been subjected to heat late in their geological history. M.O'D.

WIRSCHING (U.), BANERJEE (A.), PENSE (J.). *Rauchquartzfärbung durch Bestrahlung.* Colouring smoky quartz by radiation. Z. Dt. Gemmol. Ges., 1972, 21, 2, pp. 118-123.

There are two experimental ways of colouring smoky quartz, by electrolysis and by radiation. This article deals with the latter. Not all natural rock-crystals can be coloured this way and not all synthetic stones react to it, especially those that are pure. Untreated smoky quartz is usually less coloured than smoky quartz or rock-crystal which has been radiated. In untreated smoky quartzes

no definite relationship was found between absorption content of trace elements. Rock-crystals with strongly coloured growth sectors showed opposite conditions of colour intensity after gamma radiation. In both natural and radiated smoky quartzes the absorption spectra were similar, as well as their temperature stability luminescence and weakening of colour by ultra-violet rays. E.S.

BOOK REVIEWS

BENNETT (E. M.). *Turquoise and the Indian.* Revised edition. Swallow Press, Chicago, 1970. pp. 152. Coloured illustrations. $5·00.

A first-class account of the occurrence and use of turquoise in the South-Western United States, this book is the result of lengthy research and, more specifically, of a course in ethnology which contributed a detailed knowledge of the craftsmanship of the Indian tribes. The book introduces turquoise as a mineral and continues with a description of early occurrence reports, and of individual mines. Chapters 5-8 are devoted to the fashioning of the stone and its use in traditional Indian jewellery, which is well and simply shown in colour. Concluding chapters are on folklore and archaeology. There is a comprehensive 8-page bibliography and each chapter is followed by relevant footnotes. M.O'D.

BOLESZNY (I.). *Manufacture of artificial gemstones.* Research Service Bibliographies no. 119 of series 4. Compiled under the auspices of the State Library of South Australia, Adelaide, 1969. pp. 38. Price on application.

This is a list of periodical articles and books covering the period 1927-1969. The author abstracts from Applied Science and Technology Index, Chemical Abstracts, Engineering Index, Internationale Bibliographie der Zeitschriftenliteratur aus allen Gebieten des Wissens, Industrial Arts Index and Mineralogical

Abstracts. Only the last quoted would normally be used by the gemmologist and on this score alone it is difficult to praise the author too highly. M.O'D.

CAMPBELL (W. M.). *Minerals and Gems of Maoriland.* Fourth edition. Unity Press, Auckland, New Zealand, 1970. Illus. in black-and-white. pp. 80. Price on application to the publishers.

Designed for use in the field, this otherwise good little book loses some of its value by not illustrating its specimens in colour. The main part of the book lists the stones likely to be found in New Zealand (for which Maoriland, for the purposes of the book, is a synonym). The maps are small but quite clear. A concluding section gives hints which are interesting though in no particular order. M.O'D.

CHIKAYAMA (A.). *Gem identification by the inclusions.* Gemmological Association of All-Japan, 1968. Illus. in black-and-white. In Japanese. pp. 102. 3,000 yen.

A concise description, by the Director of the Gemmological Association of All-Japan, of the commoner gemstone inclusions. Although the text is in Japanese, the chapter headings are in English and it is therefore possible to determine which illustrations relate to particular stones. The reproduction of the inclusions is quite good although giving the impression that the original photographs were of higher quality. The section on emerald, divided into natural and synthetic, is useful. There is a short bibliography in English. M.O'D.

CONROY (N.). *Making shell flowers.* Oak Tree Press (Ward Lock) 48 pp. Black-and-white and coloured illus. £1·05.

Simple instructions for making jewellery and other ornamental items from shells. S.P.

DE MICHELE (V.). *The World of Minerals.* Orbis Publishing, London, 1972. Illustrated in colour. pp. 128. £1·95.

Another of the superbly illustrated books emanating from the Istituto Geografico De Agostinin, Novara, Italy. This book is on a larger scale than the same author's Crystals, symmetry in the mineral kingdom, and contains a foreword by Dr. George Claringbull.

The minerals are shown in Dana order and there are good drawings of the crystals in diagram form accompanying the magnificent colour plates. One might quarrel with the description of the typical benitoite crystal as prismatic where rhombohedral might be preferable, and there are a few unimportant misprints. M.O'D.

DESAUTELS (P. E.). *Gems in the Smithsonian.* Smithsonian Institution, Washington, DC, USA, 1972, pp. 62. Illustrated in colour. (U.K. £1).

First issued in 1965 in a smaller format, this small book gives a brief glimpse of the riches of the National Gem Collection, part of the Division of Mineralogy of the Smithsonian Museum. This collection is notable for the great size of many of its specimens and for the admirable display techniques employed. The coloured illustrations are of good quality and are well chosen to fit the accompanying text, so that the reader is not forced to find his material on more than one page. Emerald, for some reason, is not shown. M O'D.

DRAGSTED (A.). *De aedle stene og deres mystik.* Privately printed, Copenhagen, 1967, pp. 239. 78·00kr. A re-issue of a book first printed in 1933.

The first section of this interesting book contains an alphabetical listing of gemstones with accounts of their mystical properties as quoted in classical and later literature. Astrological, biblical and occult usages are covered and this part of the book closes at p. 191. The rest of the book is more concerned with gemmological data, albeit of a rudimentary nature. An interesting section deals with prices and the book ends with a short bibliography. The reprinted edition contains a few notes about the author and a new preface. M.O'D.

FLETCHER (E.). *Pebble polishing.* Blandford Press, London, 1972, pp. 104. £1.

This is an adequate guide to tumbling which seeks to take the reader through all the processes from the finding of the pebbles to the final stage of polishing. There is nothing new in the geological section of the book and it may be rather alarming to think of crystals being subjected to this somewhat harsh treatment, but the

author certainly describes every part of the work in the closest detail, to such an extent that a child could follow it. The illustrations are good and the style clear though repetitive.

M.O'D.

FROMANGER (H. D.). *Bijoux et pierres précieuses.* Hachette, Paris, 1970, pp. 190. Illus. in black-and-white and colour. 45fr.

A popular guide to famous jewellery, well illustrated and with numerous historical anecdotes. Opening sections deal with the diamond, ruby, sapphire and emerald; other well-known stones are covered briefly. The author's allegation that ruby is found in Sussex (England) needs no comment. Useful illustrations of diamond cutting are included. The rest of the book is devoted to the art of the jewelmaker and is worth reading for the amount of data given which would not easily be found elsewhere. The quality of illustration is high; the value of the bibliography would have been enhanced by the provision of dates for the works included.

M.O'D.

GLEASON (S.). *Ultraviolet Guide to minerals.* Ultra-violet Products, Inc., San Gabriel California, 1972, pp. xii, 244. Some coloured plates.

A handy paper-covered edition of this well-known guide which first appeared in 1960. Early chapters explain the phenomenon of fluorescence, how to employ simple ultra-violet lamps in the field and simple mineral recognition. Tables of fluorescent minerals, arranged under their fluorescent colour, occupy pp. 26-103. A chapter on the fluorescence of gem materials includes a number of specimens with their US localities. The book concludes with the use of ultra-violet techniques in mining, radioactive minerals and prospects for further research. The coloured plates are of fine quality.

M.O'D.

HUTTON (H.). *Practical gemstone craft.* Studio Vista, London, 1972, pp. 103. Illus. in black-and-white and in colour. £2·60.

A very informative and lucid guide to the origin of rocks and minerals, this book endeavours, in the words of the author, to cover the general interests of the lapidary and to create a balance between

the geological background of minerals, descriptions of them and techniques for cutting and polishing them. The opening chapter deals with the main types of rock, with fine photographic illustrations, and goes on to describe crystals and their symmetry. Later chapters deal with lapidary equipment and techniques and descriptions of gem materials. There is a clearly-drawn map of British gem locations, a locality list covering Britain and the United States in some detail, a list of suppliers and a bibliography in title rather than author order.

M.O'D.

JERRARD (R. A.). *The Amateur Lapidary.* D. Bradford Barton Ltd., Truro, 1971. pp. 88. Black-and-white illus. £1·25.

A step-by-step account of the simpler lapidary processes, amply and clearly illustrated. After the inevitable chapter on the tumbling of pebbles the reader encounters surface polishing and grinding, the commoner abrasives and a list of some of the gem materials likely to be fashioned without great expense. Many of the stones listed have appended to them some legendary property, an unnecessary inclusion in a practical manual. Later chapters deal with jewellery making, hall-marking and descriptions of the more sophisticated polishing machines. There is a short bibliography and a list of lapidary clubs, without, however, their addresses.

M.O'D.

JOHNSON (P. W.). *A Field Guide to the Gems and Minerals of Mexico.* Gembooks, Mentone, California, USA, 1965. Illus. in black-and-white. pp. 96. $2·00.

This excellent book lists the best gem and mineral localities in Mexico, including photographs of appropriate mineral specimens and a good deal of data on local conditions, customs and other attractions. Most of the individual mines are listed and there is a useful glossary of mining terms in Spanish and English.

M.O'D.

KALOKERINOS (A.). *Australian precious opal.* Thomas Nelson (Australia) Ltd., Melbourne, 1971. pp. 51. Many coloured illus. $4·95 (Australia).

The best book on Australian opal so far to appear. Dr. Kalokerinos examines the major Australian locations in detail,

covering their geology, the methods of mining, celebrated stones and mining anecdotes. Coloured plates of high quality display the characteristic features of opal of various kinds. Dr. Kalokerinos is particularly informative on the valuation of opal, possible faults and their classification. The reader is enabled to judge for himself whether or not his specimen is likely to be of value from the data given here.

M.O'D.

KIRKALDY (J. E.). *Minerals and Rocks in Colour.* Blandford Press, London, second edition reprinted 1972. pp. 184. £1·20.

A popular guide to minerals and rocks as found in the field, this book is a translation of the Swedish Stenar i färg, which had a text directed at the Swedish reader. For this edition the text has been completely rewritten with the British reader in mind. 290 coloured illustrations open the book and these are followed by chapters on the types of rock, the nature of minerals, and crystals. The minerals are described in traditional order and there is a short bibliography and a glossary. Authoritatively written, the book is conveniently sized for the pocket.

M.O'D.

Lapidary techniques. Craftool Press, Harbor City, California, 1971, pp. 46. Illus. in colour. $2·00.

A simple guide to the growing hobby of lapidary work, with lists of clubs and of the better-known gem materials found in each of the states of the U.S.A. There are also simple instructions for operating tumblers and faceting machines. The book is attractively illustrated in colour.

M.O'D.

MCCAULEY (C. K.). *Gemstone resources of South Carolina.* Division of Geology, State Development Board, Bulletin no. 30. Columbia, S.C., 1964, pp. vi, 34. Price on application to the Division of Geology.

The principal feature of this short guide is the description, in tabular form and accompanied with maps, of the precise locations of gem materials in the state. There is no regular production of gemstones on a commercial basis, although in 1958/59 sillimanite crystals were collected from Oconee County and sold to

tourists and collectors. Earlier sections of the guide contain a table of gem materials with some of their constants and a review of the types of geological formation likely to prove gem-bearing. Some outmoded and inappropriate nomenclature does not spoil a useful and authoritative guide.

M.O'D.

METZ (R.). *Edle Steine.* Photographs by Arnold Fanck. Belser Verlag, Stuttgart, 1965. pp. 256. DM 14·80. Series Belser-Bücker-Reiche 13.

A smaller and much cheaper edition of the authors' large-format work issued in the same year. The quality of the illustrations is a little marred by the unfortunate habit of the paper to curl but the reproduction is still good. The publishers promise an English edition late in 1972.

M.O'D.

PABIAN (R. K.). *Minerals and Gemstones of Nebraska.* Educational Circular no. 2 of the Conservation and Survey Division, University of Nebraska, Lincoln, Nebraska, USA, pp. 80, 1971. Price on application. Illus. in colour and black-and-white.

A useful and sprightly guide which is relevant to the gem collector outside the State of Nebraska. Many specimens are well illustrated in colour and the drawings of crystals and other specimens in the text are particularly good. Nebraska is rich in agates and these are exhaustively treated. There is a good bibliography and a glossary.

M.O'D.

PEARCE (G. A.). *The story of New Zealand jade, commonly known as Greenstone.* Collins, Auckland, 1971, pp. 109. Coloured illustrations. $3·60.

Chapter headings of a generally fanciful conception disguise to some extent the considerable amount of factual matter, which is well-arranged. This is a very good book and the best introduction I have so far seen to the subject of New Zealand nephrite. The author spends little time on imitations but opens with a good and imaginative account of the formation of the material. Under the heading "Jade casts its spell" there is a lucid account of the adoption

of nephrite and its use by primitive peoples. The methods of working the stone are detailed and text-illustrations display the traditional Maori artefacts. Modern methods are also shown and attractive coloured plates depict the recovery of boulders, various forms of nephrite and types of finished article respectively. An account of other materials resembling jade is left for an appendix and there is a bibliography of 20 items.

M.O'D.

ROBERTS (B.). *The Diamond Magnates.* Hamish Hamilton, London, 1972, pp. 335. £3·40.

An account of the lives of the early diamond magnates, such as Cecil Rhodes, Barney and Harry Barnato, the various Joels and others. Some of the controversy and scandal which evolved round the various characters brings to mind that although man's technical ability has advanced remarkably during the present century, his social and moral wisdom has not progressed over the centuries. An interesting commentary about the first diamond tycoons.

S.P.

ROGERS (C.). *A Collector's Guide to Minerals, Rocks and Gemstones in Cornwall and Devon.* D. Bradford Barton, Ltd., Truro, 1968. Hand-drawn text illus. and maps in black-and-white. pp. 48. 40p.

Written with the emphasis on work in the field, this useful and cheap little book would be a welcome companion on a trip to Devon and Cornwall. The author introduces the minerals likely to be found in that area with a word or two on the crystal systems, and then proceeds to list general and specific places where these specimens may be found. The best sections describe the appearance of the minerals and the author sensibly points out that great care should be taken in visiting dangerous places and that many minerals are now very hard to find except by those who can descend the mines.

M.O'D.

ASSOCIATION NOTICES

MEMBERS MEETINGS

Professor Tolansky speaks at Random

Saying that he had been asked by the Secretary to speak at random, Professor S. Tolansky—expert and author of a number of books about diamond—launched himself into a series of anecdotes at a meeting of the Association, at Goldsmiths Hall, London, on 17th October.

He said he did not know much about gems, but a little about diamonds, and this was an accident. It was in 1944 that he developed a technique known as multiple beam interferometry and later wrote a paper on "The Topography of a Face of a Diamond Crystal", when the "atomic energy people" called him in to try and find the isotope of uranium (235)—he was at the time an expert in spectroscopy—and provided, he told the authorities, he was given some uranium he could do the work. Having collected all the instruments together, he had only to receive the 235, when the American army said that they were not releasing any to another country and he would have to go to America. The outcome, said Professor Tolansky, as he was doing the job for nothing, was that he did not go to America. Instead he was given ordinary uranium, which required him to test his instruments to ensure they were good enough for the work, which resulted in him developing a technique to look at the properties and qualities of plane surfaces.

The outcome of all of this was he found surfaces were a lot more interesting than they appeared and he consequently chose to study diamond which, being extremely hard, he thought when it came from the ground it would still retain its virgin growth.

He acquired several interests in respect of diamond, one was the size of diamond and another, the history and folklore of diamond,

"I'm afraid I never acquired an interest in the history of the value of diamond", he said. He continued, "I am often asked by my friends about the value of diamond and I quote them Tavernier's rules." Professor Tolansky said that Tavernier, who lived in the 1600's, wrote a book in which he said that a diamond was valued in proportion to the square of the weight, thus if you said that 1 carat was worth £100, 2 carat would be worth two squared—£400, and 3 carat £900, and 4 carat £1,600. It was, he said, an extraordinary thing but when he had occasion to visit De Beers the rule seemingly applied to the general run of stones. Tavernier described how stones were bought and sold in the market places in India. Tavernier, it appeared, would go to the market place and find a dealer and they would both join hands and these would be covered by a black cloth and then selling and buying would take place according to an agreed code—a knuckle would, perhaps, be so much and a finger something else. The value of this system, said Professor Tolansky, was that the next buyer had no idea of what had been agreed or disagreed between the two previous parties. When Tavernier described the output of diamonds he mentioned a figure of 60,000 people, mainly women and children, scratching the surface of the ground for diamonds.

Professor Tolansky went on to say that diamond was valued because of its hardness, it being believed by the owners that the hardness would transfer to them, a very necessary attribute to the warriors that wore them. He thought that in the past many fine diamonds must have been lost in war.

Polishing of diamonds, said Professor Tolansky, was discovered about 1300 AD and the first polished diamonds consisted of just a table. Then someone discovered that one could polish diamond on the dodecahedral plane and produce a lozenge, and polished diamonds belonging to old families are either tables or lozenges.

Tavernier, wrote that Indians had been polishing diamonds from the beginning of the millenium and had kept the process secret. Pliny described how splinters were fastened in pieces of metal and used to bore great boreholes to extract diamonds. Even 2,000 years ago this was standard practice.

Professor Tolansky said he had spent a lot of time investigating the origin of the glazier's diamond, and discovered some writings by a German of 1050 AD which mentioned diamond cutting of glass.

Professor Tolansky then turned to the subject of the etching of diamond and he discovered it was easily done by immersing a diamond in sodium nitrate heated to about 500°. He used the etching of diamond as part of the process in his research into plane surfaces. By stopping the etching at a certain point he was able to see under a microscope, by the surfaces that were left, the actual growth of diamond.

The subject of diamonds on the moon was then broached by the speaker, who said it was back in the early 1960's that he conjectured that there might be diamonds on the moon. He based his theory on the fact that a very large crater in the Arizona desert, reputed to have been caused by a violent explosion many years ago, has diamonds around its edges. Although of microscopic size he had the impression that these diamonds resulted from the impact. The moon, he said, contained many craters and this gave him the feeling that diamonds were to be found. He had very good reason to believe there was carbon there. There were thousands of millions of tons of carbon on the sun, and, he said, "why shouldn't there be the same on the moon?" He also presupposed that the carbon was in a situation where it could act as a heat-sink, which would be an extractor of heat.

Two or three years after he had suggested diamonds on the moon, American scientists made diamonds by a combination of high pressure and high temperature. He predicted diamonds on the moon, and, he said, he still predicted diamonds on the moon around the crater lips.

Professor Tolansky then spoke of the other material he had received from the moon and the type of stones he had discovered when he investigated this. He illustrated his talk with a number of colour slides, which showed moon-material very much enlarged.

Scottish Branch

On the 31st October, 1972, a "Quiz Night" was held at the North British Hotel, Glasgow. As well as the quiz, during which members were asked to identify various gemstones, a demonstration of the new Rayner Dialdex Refractometer was given.

A further meeting was held on the 19th December, 1972, also at the North British Hotel, when Dr. J. Cunningham gave a talk on the "Art of Lapidary", and specimens of his work were shown.

Midlands Branch

A late summer outing was held on the 17th September, 1972. when members of the Branch visited Blenheim Palace, Woodstock, Oxfordshire. Dinner was taken at the Alveston Manor Hotel, Stratford-on-Avon.

Mr. Alec Farn, Director of the London Chamber of Commerce Gem Testing Laboratory, gave a talk entitled "Instruments for Gem Testing" to members of the Branch at the Auctioneers Institute, Birmingham, on the 3rd November, 1972. In addition to mentioniug simple testing methods members can use to test specimens themselves, Mr. Farn spoke about new developments and techniques used in the Laboratory.

MEMBERS MEETINGS 1973

29th January	Talk by Mr. B. W. Anderson, B.Sc., F.G.A., entitled "1925 and All That". Goldsmiths' Hall, London, 7.00 p.m.
17th April	Talk by Julius Petsch, Jrn., Idar-Oberstein on "New gem location discoveries and the present treatment of gemstones". Goldsmiths' Hall, London. 7.00 p.m.
2nd May	Annual General Meeting, Saint Dunstan's House, London.
29th October	Meeting, Goldsmiths' Hall, London, 7.00 p.m.
19th November	Reunion of Members, 6.00 p.m., and Presentation of Awards, 7.00 p.m. Goldsmiths' Hall, London.

Midlands and Scottish Branch Meetings to be announced.

INSTRUMENTS

A member is interested in acquiring *old* gem testing instruments of any sort. Would anyone having items to offer, please contact the Gemmological Association office.

GEM DIAMOND EXAMINATION

Forty-one candidates entered for the Association's 1972 gem diamond examination. The following is a list of successful candidates, arranged alphabetically.

QUALIFIED WITH DISTINCTION

Martin, Bernard Frank, Birmingham
Mones Roberdeau, Luis, Barcelona, Spain
Verges Tuset, Maria, Barcelona, Spain
Waters, Peter Aloysius, Morecambe

QUALIFIED

Alabaster, Wendy Jane, Birmingham
Altaba Artal, Ma. Dolores, Barcelona, Spain
Andres Barbera, Jose, Valencia, Spain
Bloomberg, Maurice, Ilford
Bradshaw, Stephen Charles, London
Cartland, Anthony John, Leamington Spa
Christie, Rosalind Seaton, London
Clifford, Geoffrey Roy, Maidstone
Davenport, Charles Edward, Coulsdon
Folch Bru, Rosendo, Barcelona, Spain
Fuente Cullell, Carlos de la, Barcelona, Spain
Fuller, Donald George, St. Helens
Gooding, Diana Janet, London
Heather, John Christopher, London
Hilbourne, Anthony Charles, Twyford
Holden, Andrew Neil, Walsall
Just Chova, Jose Vicente, Valencia, Spain
Kirkpatrick, David John, Kenilworth
Lopez Verge, Ramon, Barcelona, Spain
Lowe, Christopher Edward, Burton-On-Trent
Murray, David Ernest, Stratford-On-Avon
Naim, Edward Youssef, London
Nemoto, Yoshio, London
Nicolau Santasusagna, Ramon, Barcelona, Spain
Platts, Jean Isabel, Sheffield
Poynder-Meares, Christopher Francis, Gloucester
Pragnell, Jeremy Martin, London
Reilly, Hugh J., London
Roca Cusachs, Juan, Barcelona, Spain
Saddington, Tom Frederick, Woking
Stephens, Arthur Leslie, London
Tattersall, Paul Lawrence, London
Tortosa Calveras, Francisco, Barcelona, Spain
Woolf, Michele Debra, London

EXAMINATIONS IN GEMMOLOGY 1972

In the 1972 examinations in gemmology organized by the Gemmological Association of Great Britain, 448 candidates sat for the preliminary examination, and 284 for the diploma examination. Centres were again established in many parts of the world.

Upon the recommendation of the examiners the Tully Memorial Medal and Rayner Prize have been awarded to Mr. Edward Jobbins, of London.

The Rayner Prize in the perliminary examination has been awarded to Miss Vicky Procter, of London.

The following is a list of successful candidates, arranged alphabetically.

DIPLOMA EXAMINATION

Qualified with Distinction

Anderson, Alice, Toronto, Ont., Canada
Carbonell Pujol, Rafael, Barcelona, Spain
Cook, Marion, Victoria, B.C., Canada
Doman, Eleanor Margaret, Ilford
Eason, John Robert, Manurewa, New Zealand
Jobbins, Edward Allan, London
Jones, David Lewis, Orpington
La Due, Martha J., Jenson, Kentucky, U.S.A.
Margarit Morant, Eugenio, Barcelona, Spain
Needham, Brian, Ilford
Noble, Clifford, Heckmondwike
Ohguchi, Hideki, Kanagawa Pref., Japan
Peacock, Pamela Mary, Stourbridge
Plotzeneder, Josef, Salzburg, Austria
Pujante Garzon, Francisco, Barcelona, Spain
Ratera Oliva, Jaime, Barcelona, Spain
Reyes Sainz de la Maza, Fernando de los, Sevilla, Spain
Schrader, Hans Werner, Idar-Oberstein, W. Germany

Qualified

Abhyankar, Jagannath Shripad, Poona, India
Amarasuriya, Sunil Tissa, Idar-Oberstein, W. Germany
Anttila, Aimo, Helsinki, Finland
Astrain, Calvo, Rafael, San Sebastian, Spain
Baker, Nancy Jane, Manotick, Ont., Canada
Bennett, Frederic Charles, Manchester
Besteiro Rafales, Josefina, Barcelona, Spain
Bezuidenhout, Mary Elizabeth, Bloemfontein, S. Africa
Blackwell, Alan F.A., Barnehurst
Blanco Artigues, Jose Ma., Lerida, Spain
Boyce, Anthony James, Doncaster
Butterworth, Joan Louise, Rochdale
Campbell, Alan J., Birmingham
Chikayama, Yoko, Tokyo, Japan
Clarke, Roger David, Maidstone
Conesa Landines, Bernardo, Barcelona, Spain
Connard, Charles Roger, Southport
Contreras Vila, Pedro, Barcelona, Spain
Coulter, Peter, Northwich
Cranton, Keir, Surbiton
Crutchley Smith, Betty, Nottingham
Del Monico, Anneliese, West Haven, Conn., U.S.A.
Faulds, Matthew Christopher Mwamlima, London
Ferguson, Louisa, Neilston
Fernando, S. U. H., Idar-Oberstein, W. Germany
Ferrandiz Torrents, Pedro, Barcelona, Spain
Finch, Stephen Reginald George, Rochester
Fisher, Emmett W., Houston, Texas, U.S.A.
Frampton, Derek Nigel, Bognor Regis
Frost, Julia Josephine, Cambridge
Gammage, Michael John Ellis, Northwood
Gans, Louis Benjamin, Amsterdam, Holland
Garcia Ainoza, Joan, Barcelona, Spain
Gardiner, Wilfred Charles, Reading
Gargano, Frank, Rochester, N.Y., U.S.A.

Gomez Escola, Ana Ma.,
Barcelona, Spain
Goodger, W. Donald,
Don Mills, Ont., Canada
Gopalji, Kantilal P., London
Granda Uson, Ma. de Fatima,
Barcelona, Spain
Green, Arnold, Wembley
Gunawardana, Panadure Lohakaruge
Abhaya, Nugegoda, Sri Lanka
Gunther, Birgit,
Idar-Oberstein, W. Germany

Haile, Neville Seymour,
Kuala Lumpur, Malaysia
Hammonds, Robert,
Newcastle-Upon-Tyne
Hayburn, John, Hong Kong
Heikkila, Juhani, Helsinki, Finland
Holgate, Richard Stanley, Blackpool
Hudspith, Thomas William,
Chester-Le-Street

Jackson, Ian, London
Johnson, John, London
Johnson, Robert Charles, Nuneaton
Jones, Claude Barrington,
Northampton
Jones, Michael John Bewsey,
Sevenoaks

Kean, John Snowden, Ayr
Korevaar, Huibert Jacobus,
Amsterdam, Holland

Lee, Keith Alfred, Hartlepool
Lyall, Linda, Alloway
Lynch, Eric, Wallsend-on-Tyne

MacDonald, Kenneth Charles,
Leicester
Magnussen, Rita Helene,
Drobak, Norway
Marin Calvo, Ma. Luisa,
Barcelona, Spain
Martin, John Frederick,
Liberal, Kansas, U.S.A.
Miller, Graham John, Chesham
Modahl, Oivind, Oslo, Norway
Mones Mendoza, Luis,
Barcelona, Spain
Munoz Aisa, Ma. Teresa,
Barcelona, Spain
Murto, Kalevi, Helsinki, Finland

Nemoto, Christine,
Khartoum, Sudan
Nemoto, Ki, Khartoum, Sudan
Nickel, Karin Ingrid,
Los Angeles, Calif., U.S.A.
Nogues Carulla, Joaquin Ma.,
Barcelona, Spain

Ord, Ronald, Harrogate

Par, Maung, London
Penny, Christopher, London
Popperwell, Elizabeth, Stockport
Popplewell, Wilfrid, Bristol
Pschichholz, Dieter,
Wurzburg, W. Germany

Razquin Munoz, Efren,
Barcelona, Spain
Rehtijarvi, Pentti, Helsinki, Finland
Richmond, Philip Simon, Mansfield
Runciman, William Alan,
Aranda, A.C.T. Australia

Sanchez Almer, Francisco Javier,
Castellon De La Plana, Spain
Sayer, Glynis Vera, Rochester
Schapiro, Simon, London
Scharf, Walter,
New York. N.Y., U.S.A.
Scott, Annie Murray, Perth
Shindler, Albert, Kenton
Simons, Paul Armand,
Amstelveen, Holland
Smidt, Maria Josephina Antonia,
Salisbury, Rhodesia
Soler Serra, Jorge, Barcelona, Spain
Soratie, Kyllikki, Helsinki, Finland
Stevens, Peter, Harlington, Middx.
Stocken, Charles Galahad,
Oranjemund, S.W. Africa
Straatman, Eduard Karel Victor,
Bussum, Holland
Sukapaa-Harsunen, Leena,
Kauniainen, Finland
Sweeney, John Michael,
Rowlands Gill, Co. Durham

Van Den Berge, Gerard, St. Amandsberg, Belgium
Vidal Solsona, Jaime, Barcelona, Spain
Vila Demestre, Anna, Barcelona, Spain
Wainwright, Nicholas Anthony, Caldy
Walton, Brian, Dukinfield
Watson, Philip, Rickmansworth
Webb, Ronald John, Auckland, New Zealand
Westerback, Simo, Helsinki, Finland
Wightman, Francis Geoffrey, Nottingham
Wood, Kathleen Alice, Sheffield

PRELIMINARY EXAMINATION

QUALIFIED

Acedo Delgado, Manuel, Barcelona, Spain
Adams, David, New Malden
Adams, John Hilton Trevelyan, Pevensey Bay
Alijas Sanz, Adelaida, Valencia, Spain
Allin, Frederick Garner, Port Elizabeth, S. Africa
Allin, Peggy, Port Elizabeth, S. Africa
Alonso Querol, Montserrat, Barcelona, Spain
Amor Cubeiro, Carmen, Barcelona, Spain
Amukotuwa, Sarathkumara Lakshman Ajith, Colombo, Sri Lanka
Andersen, Lis-Mari, Horten, Norway
Anderson, Sarah Anne, Deal
Andreu Griera, Juan, Barcelona, Spain
Anton Martinez, Miguel, Valencia, Spain
Arano Sierra, Ma. Pilar, Barcelona, Spain
Ashcroft, Vera, Liverpool
Bagant Pons, Jorge, Barcelona, Spain
Barker, Margaret Mary, Southport
Barrows, Mark Coleman, Halesowen, (Worcs.)
Baster, Patricia, London
Begg, Ruth Patricia, London
Bender, Maria Margaretha Agatha, Delft, Holland
Berry, John Hugh, Birmingham
Betts, Stuart Edward, London
Beuken, Maria Ludovica Johanna Adriana, Schoonhoven, Holland
Blackmore, Lynda Muriel, Pinner
Bollen, Neil, Bristol
Bonet Coll, Jose, Barcelona, Spain
Boraks, Victor, Jos, Nigeria
Borao Clemente, Pascuala, Valencia, Spain
Bowden, Desmond John, Colchester
Brown, Anthony John, London
Cain, John Victor, Birmingham
Canals Cadafalch, Ma. Montserrat, Barcelona, Spain
Carbonell Alos, Concepcion, Valencia, Spain
Carlsen, Gunnar J., Haugesund, Norway
Cepak, Livio, Trieste, Italy
Chaloner, Rosemary Jane, Altrincham
Clark, Victoria Elizabeth, Fife
Comas Masmitja, Ma. Pilar, Barcelona, Spain
Constable, J., Birmingham
Cooke, Victoria Jane, Blidworth, Notts.
Costa Ramon, Maria, Barcelona, Spain
Cox, Edward Charles, Auckland, New Zealand
Culi Perarnau, Jose, Barcelona, Spain
Dahlan, M.S.M., Marata, Sri Lanka
Daly, Patrick Joseph E., Chelmsford

Dancer, Joan Elizabeth, Sheffield
De Ligny, Willem Pieter, Hooguliet, Holland
De Silva, S. P. N., Hong Kong
De Vos, Helena Pieternella Gemma, Schoonhoven, Holland
Dewhirst, Stephen Clive, Stockport
Duvert, Gisele, Annemasse, France

Eaton, John, Orpington
Eli Fritsch, Juan Adolfo, Madrid, Spain
Espinosa Munoz, Luis, Barcelona, Spain
Esquerra-Torrescasana Llobet, Jose Eloy, Barcelona, Spain
Estany Volart, Ramon, Barcelona, Spain

Fahie, Charlotte Mary, Colchester
Farreny, Riera, Andres, Barcelona, Spain
Fellows, Norman John, London
Firth, Roy, Ambleside
Flo Tomas, Ma. Rosa, Barcelona, Spain
Folch Soler, Mercedes, Barcelona, Spain
Frodin, Peter John, Gayton, Cheshire
Fryer, Frederick Alfred, London

Gangaramani, Dipak, London
Gasco Pascual, Ignacio, Valencia, Spain
Gill, Robert, Boston
Gonzalez, Juan Manuel, Valencia, Spain
Grainger, Michael George Freethy, London
Grainger, Paul Edward, Manchester
Green, Roger, Leicester
Grice, George Herbert, Dublin, Ireland
Gunther, Birgit, Idar-Oberstein, W. Germany

Haile, Neville Seymour, Kuala Lumpur, Malaysia
Hamel, George Jan Willem, Leiderdorp, Holland
Hammond, Frances, Hamilton, Bermuda
Harris, Robert John, Birmingham
Harvey-O'Riordan, K., London
Hebbrecht, Julien, Gouda, Holland
Heintzberger, Cornelis Petrus, Bilthoven, Holland
Hermanus, Sigmund Damasco, Schoonhoven, Holland
Higham, Joyce Rita, Prescot
Hinchliffe, Roger, Eastbourne
Hinton, Christopher Arthur, Dudley
Hlibchuk, Stephen Roland, Coleman, Alberta, Canada
Holgate, Richard Stanley, Blackpool
Horovitz, Herbert, Geneva, Switzerland
Hussein, Noordeen Mohamadu, Colombo, Sri Lanka

Irwin, Alan, Menlo Park, Calif., U.S.A.

Jaliwala, Mansoor A., Bombay, India
Jakes, Margaret Diane, Sheffield
Jeffries, Colin Levi, Newport
Jimenez Torro, Vicente, Valencia, Spain
Jobbins, Edward Allan, London
Juan Prevosti, Leopoldo, Barcelona, Spain
Jubany Casanovas, Jorge, Barcelona. Spain
Juckes, Lewis Menne, Rotherham

Kaku, Baikei, Kobe, Japan
Kalina, Freda Frances, London
Kawahara, Makio, Fukuoka City, Japan
Klein, Adrian H., London
Knight, Louise A., London
Knight, Lawrence Peter, London
Knoske, Gene, E. Milwaukee, Wisconsin, U.S.A.
Koike, Kiyokatsu, London
Komiakoff, Leo Nicholas, New York, N.Y., U.S.A.
Kramer, Theodore P., Beltsville, Maryland, U.S.A

Krijger, Baldeus,
Schoonhoven, Holland
Kumekawa, Naotake,
Yokohama City, Japan
Laing, Michael Neilson, London
Lancaster, David Joseph,
Johannesburg, S. Africa
Latre David, Fernando,
Valencia, Spain
Latre David, Jose, Valencia, Spain
Liberg, Finn Ove, Hamar, Norway,
Llopis Lopez, Manuel,
Valencia, Spain
Lopez Perez, Oceano,
Barcelona, Spain
Lovell, John Richard,
Auckland, New Zealand
Lupon Escanilla, Clemente,
Barcelona, Spain
McDowell, B. M.,
Wellington, New Zealand
McGrath, David Michael, Bowden
MacOlive, John Richard Woodward,
Krugersdorp, S. Africa
Majo Llopart, Miguel,
Barcelona, Spain
Malin, Kathleen Marian, London
Malone, Benjamin Darley,
Port Charlotte, Fla., U.S.A.
Mant, Kevin John, Walton-on-Thames
Marble, Carolyn Calvin,
APO N.Y., New York, U.S.A.
Marsh, David Kenneth, Leeds
Martin, Stephen Thomas, Rochester
Martorell, Gisbert, Ma. Isabel,
Valencia, Spain
Mason, John, Harrogate
Matthews, Shelagh Joan,
Port Elizabeth, S. Africa
Maury, Robert Lee,
Port Charlotte, Fla., U.S.A.
Merriman, Patricia Jean, Wallasey
Metcalfe, Brian, Lymington
Minty, Janet, London
Mjelva, Halge Roenneberg,
Aalesund, Norway
Moate, George Richard,
Knockholt, (Kent)
Moninos Pellicer, Vicente,
Valencia, Spain
More Andujar, Francisco,
Barcelona, Spain
Morton, Harold, Liverpool
Moxon, Sally, Pinner
Mozolowski, Barbara, Fife
Muller, Helen, Leeds
Munro-Ferguson, Molly Ann Luttrell,
Evanton, Scotland
Muthukumaraswamy, Chelliah,
Wattala, Sri Lanka
Navarro Collado, Clemente,
Valencia, Spain
Neagle, Trevor George,
Norton, Teesside
Nickel, Karin Ingrid,
Los Angeles, Cal., U.S.A.
Nissanka, Geeta Sri,
Colombo, Sri Lanka
Nowak, W., Bexley
Oliver, Graham Denis,
Wellington, New Zealand
Ono, Yoji, Hyogo-Ken, Japan
Pardo Llorens, Emilio,
Barcelona, Spain
Palmer, E. M., Liverpool
Par, Maung, London
Parkin, Lesley Karen, Nottingham
Patak, Alexander O.,
New Castle, Pa., U.S.A.
Patni, Lalitkumar Jayantilal,
Bombay, India
Pavitt, John Anthony Leighton,
Bangkok, Thailand
Pease, Belinda, Geneva, Switzerland
Pechuan Castello, Emilia,
Valencia, Spain
Penny, Michael John, Wisbech
Perlas Zurita, Ma. Lourdes,
Barcelona, Spain
Pike, Ian Kenneth,
Cairns, Queensland, Australia
Procter, Vicky, London
Pschichholz, Dieter,
Wurzburg, W. Germany
Quitllet Pou, Guillermo,
Barcelona, Spain

Rabassa Magrane, Juan Jose, Barcelona, Spain
Ranasinghe, Wilson Peiris, Gampaha, Sri Lanka
Ratnayake, Senaka Banda, Colombo, Sri Lanka
Roberts, James Ian, Worksop
Robson, Edward Nairobi, Kenya
Rosser, Leonard Robert, Lancaster
Runciman, William Alan, Aranda, A.C.T. Australia
Ruplinger, Peter K., San Diego, Cal., U.S.A.
Rust, Izak C., Port Elizabeth, S. Africa
Sanchez Cabello, Antonio, Valencia, Spain
Scarratt, Kenneth, Ilford
Scharf, Walter, New York, U.S.A.
Schenk-Mayenfels, Edith, Idar-Oberstein, W. Germany
Schrader, Hans Werner, Idar-Oberstein, W. Germany
Sekkelsten, Ase M.L., Oslo, Norway
Shanmuganathan, Kandasamy, Colombo, Sri Lanka
Shaw, Sandra, Dublin, Ireland
Sims, Paul Edward, Bristol
Smith, David, London
Sojo Bruguera, Regina de, Barcelona, Spain
Southon, Carolyn Mary, Sevenoaks
Stenberg, Richard M., Springfield, Massachusetts, U.S.A.
Stevens, Eric Leslie, French's Forest, N.S.W. Australia
Stocken, Charles Galahad, Oranjemund, S.W. Africa
Such, Paul Nigel, Heswall, Cheshire
Tait, Alistir W., Edinburgh
Taylor, Alec Ewen, East Lothian
Tenenbaum, Abraham, Bne-Braq, Israel
Thuraisingham, Sangarappillai, Colombo, Sri Lanka
Turner, Alan, Ramsgate
Van Den Berge, Gerard, St. Amandsberg, Belgium
Van Der Heyden, Eveline Louise, Schoonhoven, Holland
Van Der Loo, Albert, Rotterdam, Holland
Van Haeringen, Anne Maria, Schoonhoven, Holland
Van Silburn, John, Walsall
Van Thiel, Carolina Sophia Josephina Maria, Schoonhoven, Holland
Vasudeva, Bharadwaja, Colombo, Sri Lanka
Vendrell Saz, Mario, Barcelona, Spain
Wagstaff, Karen, Newark
Watanabe, Teruo, Tokyo, Japan
Webb, Michael, Solihull
White, Angela Mary, Orpington
Winter, Colin Howard, Dorking
Wright, David, Bury
Yabsley, Anthony John, Guernsey, C.I.
Yang, Jinhua, Tokyo, Japan

COUNCIL MEETING

At a meeting of the Council of the Association held on Tuesday, 10th October, 1972, the following were elected to membership:

Fellowship

Altaba Artal, Dolores (Mrs.), Barcelona, Spain. D. 1971
Alforja Matoses, Enrique, Valencia, Spain. D. 1971
Andres Barbera, Jose, Valencia, Spain. D. 1971
Blackwell, Alan F. A., Barnehurst. D. 1972
Campbell, Alan J., Wolverhampton. D. 1972
Chapman, Ross N., Mackay, Queensland, Australia. D. 1970
Coulter, Peter, Northwich. D. 1972
Cranton, Keir, Surbiton. D. 1972
Doman, Eleanor M., Ilford. D. 1972
Finch, Stephen R. G., Cuxton, Nr. Rochester. D. 1972
Frampton, Derek N., Bognor Regis. D. 1972
Gunther, Birgit, Idar-Oberstein, W. Germany. D. 1972
Hayburn, John, Hong Kong. D. 1972
Hudspith, Thomas W., Chester-le-Street. D. 1972
Jackson, Ian, London. D. 1972
Johnstone, Sheila A. (Mrs.), Calgary, Alberta, Canada. D. 1951
Jones, Michael J. B., Sevenoaks. D. 1972
Jones, David L., Orpington. D. 1972
Lehtola, Maire (Miss), Helsinki, Finland. D. 1971
Lopez Sabater, Jose A., Valencia, Spain. D. 1971
Penny, Christopher, Frampton, Nr. Boston. D. 1972
Pschichholz, Dieter, Wurzburg, W. Germany. D. 1972
Schapiro, Simon, London. D. 1972
Scott, Annie M., Perth, Scotland. D. 1972
Watson, Philip, Rickmansworth. D. 1972
Wightman, Francis G., Nuthall, Nottingham. D. 1972
Fisher, E. W., Houston, Texas, U.S.A. D. 1972

Transfers from Ordinary Membership to Fellowship

Amarasuriya, Sunil Tissa, Idar-Obestein, W. Germany
Baker, Nancy Jane, Manotick, Ont., Canada
Bezuidenhout, Mary Elizabeth, Bloemfontein, S. Africa
Boyce, Anthony James, Doncaster
Chikayama, Yoko, Tokyo, Japan
Cook, Marion, Victoria, B.C., Canada
Del Monico, Anneliese, West Haven, Conn., U.S.A.
Eason, John Robert, Manurewa, New Zealand
Faulds, Matthew Christopher Mwamlima, London
Ferguson, Louisa, Neilston
Frampton, Derek Nigel, Bognor Regis
Gammage, Michael John Ellis, Northwood
Gans, Louis Benjamin, Amsterdam, Holland
Gargano, Frank, Rochester, N.Y., U.S.A.
Goodger, W. Donald, Don Mills, Ont., Canada
Green, Arnold, Wembley
Gunawardana, Panadure Lohakaruge Abhaya, Nugegoda, Sri Lanka
Haile, Neville Seymour, Kuala Lumpur, Malaysia
Holgate, Richard Stanley, Blackpool
Jobbins, Edward Allan, London

Jones, Claude Barrington, Northampton
Jones, Michael John Bewsey, Sevenoaks
Korevaar, Huibert Jacobus, Amsterdam, Holland
La Due, Martha J., Jenson, Kentucky, U.S.A.
Martin, John Frederick, Liberal, Kansas, U.S.A.
Needham, Brian, Ilford
Nemoto, Ki, Khartoum, Sudan
Nickel, Karin Ingrid, Los Angeles, Calif., U.S.A.
Noble, Clifford, Heckmondwike.
Ohguchi, Hideki, Kanagawa Pref., Japan
Popplewell, Wilfrid, Bristol
Runciman, William Alan, Aranda, A.C.T., Australia
Scharf, Walter, New York, N.Y., U.S.A.
Shindler, Albert, Kenton
Simons, Paul Armand, Amstelveen, Holland
Smidt, Maria Josephina Antonia, Salisbury, Rhodesia
Stevens, Peter, Harlington.
Stocken, Charles Galahad, Oranjemund, S.W. Africa
Van Den Berge, Gerard, St. Amandsberg, Belgium
Webb, Ronald John, Auckland, New Zealand
Wood, Kathleen Alice, Sheffield

ORDINARY

Alfsen, Edgar J., Sao Paulo, Brazil
Alfsen, Emmy., Sao Paulo, Brazil
Arnold, Alan P., Metairie, Calif., U.S.A.
Ayache, Nicolas, Chislehurst.
Azeez, R., Singapore
Bae, Hyung Soon, Seoul, Korea
Barclay, John, Orkney, Transvaal, S. Africa
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GEMMOLOGICAL ASSOCIATION
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A MODERN SURVEY OF IMITATION PEARLS

By R. WEBSTER

IN determinative gemmology the identification of imitation pearls is easy. The "blotting paper" appearance under a lens of the surface of the coating, and also the exposure of the glass of the core around the drill-holes, where the pearly coating has been worn away by attrition from the neighbouring pearl, are sufficient to show the nature of these objects. The above is very true, but does the gemmologist know enough about the modern imitation pearl to enable an answer to be given to every question that in some cases may demand an answer?

This is particularly true with regard to the pearly coatings used to give the iridescent appearance to the modern imitation pearl. The current gemmological literature rarely mentions, and certainly never describes, the "synthetic essences" now so often used in place of, or in conjunction with, the well established 'fish-scale' pearl essence. The 'optics' of the iridescent effects produced by these various 'pearl essences' is another factor only cursorily discussed in gem books and needs further consideration. In this article it is hoped to fill in some of these lacunae in our literature.

The history of the imitation pearl goes back a long way and like all ancient history tends to become confused. Probably the earliest imitation pearls were those called "Luli", which, according to Kunz and Stevenson[1], who quote Flinders Petrie, were objects

produced in Egypt during the Roman era. They were apparently made by silvering a glass bead and then 'flashing' it over with another coat of glass.

Dieulafait[2] states that no mention was made of artificial pearls till the beginning of the 16th century, when Venice established a reputation for such objects. These must have been hollow glass spheres suitably filled, for Dieulafait writes as follows;—'At first the glass balls were filled with various materials, generally with a base of mercury'.

Various other assemblages of many different materials have been used in past ages to make simulants of pearls. There is little need to discuss these objects in detail as, except perhaps in archaeology and antiquaria, they are not now encountered. However, one type mentioned by Joan Dickenson[3] deserves repeating. It is as follows:- 'One tribe in North America, however, was way ahead of its time in one area at least; it made artificial pearls much like the imitation pearls of to-day. The bead was of baked clay, and the lustrous surface was made up of layer upon layer of thin mica in careful imitation of the layers upon layers of nacre that constitute the real pearl.'

The first real advance in the imitation of pearls was made by a French rosary maker by the name of Jaquin (other versions giving the name as Jacquin or Jonquin) who noticed that the water in which small fish had been washed contained a lustrous substance which, when concentrated, could be used to produce an imitation pearl. Jaquin then made the so-called 'Roman pearl', a hollow sphere of opalescent glass, often treated by an initial exposure to the fumes of hydrofluoric acid to tone down the glassy look, and to the inside surface of which was put a coating of parchment-size upon which was then applied a film of 'pearl essence'—the 'fish scale essence' of Jaquin. The pearl was completed by being filled with white wax or fine gum arabic. It is said that a few large-sized 'half-drilled' pearls are still made in this way for use as earstuds, but the manufacture of pearls of the 'hollow-glass bead' type for use in necklets seems to have died out about 1930.

The modern imitation pearl consists essentially of a central solid bead, usually made of glass, coated on the surface with pearl essence in a cellulose lacquer. Cores other than glass have been used with varying success. Vegetable ivory has been tried but seemingly

was insufficiently translucent, and various *organic glasses*, the so-called 'plastics', were once used but the beads were found to be too light in weight for necklets made from them to hang well. Much more successful were the cores made of mother-of-pearl, a type which apparently first came on the Western market during the early 1920's and is now currently marketed. They are to-day sold under the titles 'shell-based imitation pearls' and 'imitation cultured pearls'. Thus the modern imitation pearl has two main parts, the core and the pearly coating, and each of these needs separate discussion.

The cores of the glass bead type consist of an opalescent glass which goes under the name 'alabaster'. This is a type of glass and *not* the alabaster so well known as an ornamental stone. Another unfortunate name applied to such glass is 'girasol', a name which is properly given to a type of opal.

The density of imitation pearls has received scant attention in the literature and the only consideration of the subject appears to be in two articles[4, 5], now over 25 years old. At that time it was found that the majority of the hollow-glass bead type had a density just under 1·55. The density of the solid glass bead types was found to lie mostly between 2·85 and 3·18, with the peak between 2·95 and 3·00. A few pearls of this type were found to have a lower density, down to 2·33, and there is another group about 2·53, a value found during the examination of pearls from a necklet worn by the victim of a sensational murder. This value of 2·53 is also given by Dr L. M. Greenstein of the Mearl Corporation of New York City to the Gemological Institute of America in 1950[6]. This was, however, only four years after the English report, and it may well be that for a few years after the war the more usual glasses were not easily obtainable. Experiments on recently produced imitation pearls of this type showed that their density was near 3·00, confirming in general terms the values arrived at by the writer in 1946. The coated mother-of-pearl beads will give a value around 2·75 and would in fact be near the value found for cultured pearls.

The refractive indices of the glasses used for the core of the solid bead type of imitation pearls is less easily determined unless 'flats' are polished on the beads. Some attempt was made to ascertain the index by removing the coating from some pearls having different densities and using the 'distant-vision' technique. The values ranged between 1·50 and 1·60, and, further, it could not be

safely said that the glasses with lower density had the lower indices of refraction.

A point to mention here is that in the construction of these glass beads, by forming them on an iron wire with the aid of a torch, it is usually reported that the iron wire was then dissolved out with acid to leave the string canal. Modern technology has modified this method by first coating the wire with a clay slurry or other compound, which prevents adhesion of the glass to the wire and thus allows easy removal of the glass beads[7].

It is now necessary to consider the coatings, and in particular the modern synthetic essences. The 'fish scale' pearl essence of Jaquin is still used to-day, either alone or in conjunction with the newer synthetic essences.

For reasons which will be apparent later 'fish scale essence' is often called 'organic pearl essence'. It is also well known as 'essence d'orient', a name which may have been derived from the notion that the Chinese knew of this substance much earlier. At one time the crystallites were thought to be silver and this led to the name 'fish silver' for the organic essence.

It is now known that the crystallites in the organic essence are fine platy or needle-shaped crystals of the organic compound called guanine, a substance which is actually a waste material allied to uric acid which forms as crystallites in the skin attached to the fish scales. These crystals, which have a refractive index of 1·85 and a density of 1·6, are, when as plates, about 30 by 6 micrometres (μm, formerly micron) in size; and as needles, 30 by 1μm. The crystals are removed by carefully washing them out by the use of a detergent mixture. They are then purified and made into a paste with 'pyroxylin', a nitrated cellulose. This paste is then diluted to a suitable consistency to produce a lacquer suitable for use in dipping the glass beads to produce the simulated pearls.

The rather high cost of the organic essence has led to the production of synthetic essences, the plate- or needle-like crystals of which are inorganic. Two types seem to be used, the most common being crystallites of basic lead carbonate, and the other crystallites of mica which are coated on both sides with layers of titanium dioxide, generally in the form of anatase. These crystallites, whether they be the organic guanine, the lead carbonate or the titanium dioxide coated mica, are disseminated in the lacquer so that they have some degree of parallel orientation. This is readily achieved

due to the flow of the pyroxylin vehicle and the shape of the crystallites.

The optics of the 'orient' of natural and cultured pearl and the iridescence of the various pearl essences calls for some comment. Herbert Smith[8] states—'The iridescent lustre of the surface of a pearl and of the nacreous lining of the shell is peculiar and characteristic, and is known as orient; it is the combined effect of two optical phenomena: the interference of light from the succession of thin translucent laminae forming the surface, and the diffraction of light from the grating composed of the closely packed lines in which these laminae meet the surface'. In pearl essences the crystallites are embedded in the vehicle and thus there are no surface edges likely to produce diffraction.

Bolomey and Greenstein[9] enlarge on this by explaining that an interference film is a filter which separates incident white light into a reflected and a transmitted component on a black background, and only the reflection colour is observed as the background absorbs the transmitted ray. On a white background the reflection colour is seen only when the coating is observed by specular reflection. At any other angle of observation the transmission colour appears, as the incident light on passing through the film to the white background is reflected back through the film. The two colours appear simultaneously when an interference film (in paint technology often called a 'pigment') is applied to a white curved surface, the reflection colour in the highlight and the transmission colour everywhere else.

These workers also state: 'This phenomenon is observed in nature in the pearl oyster, where the highlight is often bluish or greenish and the rest of the pearl appears orange or pink. The colour of the pearl is produced by multiple interference films consisting of alternate layers of aragonite and conchiolin. The phenomenon is reproduced in simulated pearls in which a translucent white bead is coated with a green- or blue-reflecting interference pigment in a lacquer'.

An excellent survey of iridescence is given by Hilda Simon[10] in her work on the 'structural colours' of birds and insects, and does include, but less fully, something on mother-of-pearl and pearls; in the latter cases the thin layers of nacre are said to produce the colours. In this work the various causes and effects of iridescent colours are clearly discussed and include the colours obtained by

interference of light at thin films, by diffraction from gratings, and also from space lattices where there is a precision arrangement of definite layers of two structures having different refractive indices and forming a Bragg lattice.

From investigations using electron-microscopy this concept of diffraction from a Bragg optical lattice has been found true for many of the colour effects seen in birds feathers and insect scales. How much this Bragg lattice concept can apply to the iridescent effects of pearls and imitation pearls is debatable. This notion of a Bragg lattice may well be the answer to the 'packed spheres' structure of opal as shown by electron-microscopy. As far as the writer knows there has been no investigation of pearl and mother-of-pearl by electron-microscopy. It might supply some helpful answers. Maybe at this time the older idea of phase differences from reflections and refractions at thin films producing colour will be the safer avenue to explore. Indeed Bolomey and Greenstein[11] in their excellent but highly mathematical paper, do not refer to space lattice but only to microscopic platelets of uniform thickness causing phase interference leading to the production of colour.

How the films of titanium dioxide on mica platelets are prepared does not seem to be divulged, nor how the crystallites of basic lead carbonate are produced. These latter are said to be hexagonal crystals, but whether this refers just to the outline and does not imply the system of crystallization is not clear. The natural lead carbonate—cerussite—is orthorhombic and such crystals often do have a six-sided outline. In the titanium dioxide on mica platelets it is the TiO_2 layers which have the same thickness: the thickness of the mica is not controlled and does not seem to be of consequence.

Interference colour is determined by the optical thickness of the film, which is the geometrical thickness multiplied by the refractive index of the film, and it is reported that one complete cycle of interference colours is covered by the range of optical thickness of present commercial TiO_2/mica 'pigments', and two complete cycles in the case of basic lead carbonate. The length of the mica platelet, and maybe this also applies to the lead carbonate platelets, has an effect on the 'pigments', a size range of 2-20 μm producing a soft smooth appearance, while a range of 10 to 50 μm gives a glinty sparkling effect. When the optical thickness of the film is below 200 nm (nm = namometre, earlier millimicron), and specifically in

the range 100-140 nm, the reflection is essentially white and these give the pearl pigments. The properties of interference pigments are shown by the following table from Bolomey and Greenstein's article.

PROPERTIES OF INTERFERENCE PIGMENTS

	TiO_2-coated mica		Basic lead carbonate
Approximate	TiO_2 layers	mica	
Effective refractive index	2·3*	1·58	2·09
Average plate length, μm	20	20	20
Thickness, nm	90-170	250	100-340
Optical thickness, nm	200-400		200-680
Specific gravity	3·5	2·8	6·8

**the value is lower than for conventional TiO_2 because of some porosity in the coating.*

It has already been expressed that as far as determinative gemmology is concerned there is no problem with imitation pearls. The 'fun' begins, if one may call it so, when a much closer investigation is needed. Although such cases may be extremely rare, present day gemmology has extended so far into other disciplines that all sorts of unsuspected problems may call for solution, and, indeed, may call for the co-operation of scientists in other fields.

Ever since the problem of the matching of an imitation pearl found in a murder suspect's pocket with the pearls found around the body of the victim, it has always intrigued the writer as to how far one would need to go in order to prove 'without reasonable doubt' that certain imitation pearls were similar. In the case mentioned the one pearl was 'prime evidence' and could not be destroyed or damaged. In this case then only a few tests were possible, *i.e.* surface appearance, density and size of drill hole. In a hypothetical case where pearls can be damaged or destroyed without consequence, what would be the problems then? There are two main sections to consider; the first to agree the core, and the second to agree the coatings.

Taking the core first; if it be of plastic—polystyrene and perspex have both been used—determination of the type of plastic needs to be made. If the core is glass, as is most usual, the density and the refractive index would need to be determined, and, by spectrographic analysis, the composition of the glass should be found to agree. The diameter of the string-hole may give added

information, but in the writer's opinion this is less trustworthy. Not a lot can be done if the core is mother-of-pearl.

Determination of the coating is much more involved, especially if there is the problem of mixed coatings. Further, there are two factors to be taken into account here—the crystallites producing the iridescence, and the vehicle in which they are embedded, which is usually a cellulose lacquer.

Microscopic examination of the coatings of imitation pearls tended to show the difficulty of resolving crystallites of less than 30 μm in length. Using a $\frac{1}{6}$ objective in conjunction with an 8 × ocular operating with a tube length of $6\frac{1}{2}$ inches gave a magnification of about 200 ×, and observation was made on scrapings from the surface of imitation pearls of different ages. The peelings were placed on a 2 x 1 glass slip, with a drop of amyl acetate in order to dissolve out the cellulose lacquer and free the crystallites.

In ordinary white light and in dark field illumination there could be seen in the undissolved pieces a mass of crystallites whose boundaries could not be resolved and in the still liquid amyl acetate what were probably loose crystallites. However, when the slide was examined between crossed polars the loose crystallites readily revealed themselves by their bright polarization colours as thin needles, whose length could to some extent be measured by using an eyepiece graticule.

The only result of any seeming importance from this microscopic examination is that the crystallites from the coatings of older imitation pearls seemed to have a greater length than the crystallites from pearls of more recent origin and from a sample of 'Neoperl' synthetic pearl essence made by Neogene Paints Ltd. Measurement of these crystallites showed that the longer crystals, probably guanine crystals, had a length of about 28 μm, and in the synthetic material the crystals had a length of 15 to 18 μm—values which tend to agree with the published literature—and this may be of significance in identification.

Finding the chemical nature of the coatings is more the province of an analytical chemist than a gemmologist. However, the results of some tests carried out might be of interest. The vehicle holding the crystallites, most commonly a nitro-cellulose lacquer, may be more or less proved by 'spotting' the surface with a solution made up of diphenylamine in concentrated sulphuric acid, when the spot of reagent will turn blue if the lacquer is nitro-cellulosic.

A number of imitation pearls were so tested and all gave a positive reaction. The reagent is made by dissolving in 10 ml (cc) of concentrated sulphuric acid 0·5 grams of diphenylamine, but the actual values do not seem to be critical.

Testing for the composition of the crystallites is far less easy and would certainly need the services of a trained analytical chemist to produce an accurate answer. The organic guanine crystals ($C_5H_5ON_5$) and the cellulose lacquer, which has a composition near $C_6H_7O_5(NO_3)_3$, are so similar that chemical tests may be extremely difficult to perform. Titanium in low concentration is hard to detect, and so would be the mica platelets, either chemically or mineralogically, when of such small size.

The detection of lead seemed to have a slightly better chance of success, for there are a number of chemical tests for this metal and one of these was chosen for experiment. This was the reagent known as 'dithizone', which consists of diphenylthiocarbazone dissolved in chloroform or carbon tetrachloride. The test reagent used was prepared by dissolving 1 to 2 mg of the diphenylthiocarbozone in 100 ml of carbon tetrachloride, but the actual quantities do not seem to be critical and only a small quantity should be made as the reagent does not keep too well after being made up. The presence of lead is shown by the green colour of the reagent solution turning a red colour.

The reagent was tested by seeing its reaction on an aqueous solution of lead acetate. The colour of the reagent turned from green to red, proving the efficiency of the test. Blank tests were also made on water, amyl acetate and acetone, for the reagent is very sensitive.

Scrapings from the coatings of a number of imitation pearls were placed in depressions in a 'spot plate' or in a micro test-tube and dissolved by the addition of amyl acetate or acetone. A separate test was made on the essence 'Neoperl' and this gave a convincing red colour to the reagent. The coatings of the beads gave varying results, from a strong red to a very weak pink, generally a weak reddish colour around the edge of the liquid in the 'spot plate' depression, the centre still being green. The experiments would have had a much greater value if essences of known composition had been available. It can, however, be assumed that if a strong red colour is produced lead is certainly present.

Another type of experiment was made in an attempt to see if

the layers given to the coating by successive 'dips' into lacquer could be counted in a similar way that a forensic scientist counts the layers of paint from cars or window frames. To do this some imitation pearls were ground down so as to reveal the thickness of the coating which could then be microscopically examined. The experiments were not successful and the coatings due to the various dips could not be identified.

Examination of imitation pearls under ultra-violet light showed that under the long-wave lamp (3650Å) the solid glass bead types showed a weak mauve to a dull yellow glow, whereas the hollow glass bead types showed a strong bright blue glow, perhaps similar to but stronger than the glow shown by natural or cultured pearls. Under the short-wave lamp (2637Å) the results were found to be similar but much weaker. However, the glass beads which had had their coating removed showed a bright blue glow which, when the coating was present, was masked—this probably being due to the short-wave radiation being absorbed by the coating.

Coloured imitation pearls may be made by the addition of dyes to the dip solution or by using 'interference pigments' in which the light reflected is of a different colour from that transmitted by the crystallites. Iridising is another technique modernly used for some of the more expensive simulated pearls. In this scheme each pearl is separately treated by rubbing on to the surface a special powder and then a heat treatment for 24 hours is given which causes the powder to fuse and coalesce into a microscopic film which covers the bead. A final coat of lacquer is then applied in order to protect the iridescent coating.

The coating of imitation pearls is much less hard than the nacre of a natural or cultured pearl and will thus abrade rather easily if such a necklet is 'jumbled' in a jewel case with metallic and gem-set jewellery. Imitiation pearls need to be put away in their case after wearing, or wrapped in soft paper.

The resistance of the coating of imitation pearls to chemical attack from (usually) cosmetic aids is low, and many scents will cause pitting of the surface of such pearls. This can commonly occur if a scent spray is used while wearing pearls. The vapour from the scent does not seem to be at all detrimental but the liquid droplets from a spray are most certainly so. Likewise sprays from hair-setting lotions will cause a secondary coating to form on the surface of pearls which later tends to flake off, leaving the wearer to

think that her pearls are peeling. Careless use of nail-varnish, or worse nail-varnish remover, is detrimental to imitation pearls for they are solvents of the 'pyroxylin' used for the coatings of imitation pearls.

The question of the darkening of imitation pearls from sulphide fumes in the atmosphere does not seem to be a problem, although on the face of things the synthetic essences containing a lead salt should be susceptible. Indeed, the manufacturers state that these types of essences have a poor stability to sulphide. However, as these lead crystals are bonded in a cellulosic lacquer some sort of protection is afforded to them and it is rare to see darkening of imitation pearls.

It is hoped that this article will have shown that there is much more in the study of imitation pearls than was formerly imagined. It is true that even now there are issues which have not been covered; even so, indications have been given of possible lines of enquiry from the gemmological point of view which may act as guides to and for other disciplines which may be able to cover such factors. In conclusion the writer's thanks are due to the technical staff of Cornelius Chemical Company Ltd. and to E. Trillwood, F.G.A., of Pampadour Pearls Ltd., for their advice and assistance.

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OBSIDIAN AND SOME OBSERVATIONS ON THIS TYPE OF NATURAL GLASS

By T. F. ZOOK

OBSIDIAN is a natural glass of brilliant lustre which has a conchoidal fracture. It is generally of rhyolitic composition (a composition corresponding to granite) and is of volcanic origin. Obsidians may be black, grey, red, green or brown and are often banded. They may vary greatly in their chemical composition, but contain from 66-72% of silica.[1] Technically, an obsidian has a very low water content, usually 1% or less, when it is contrasted with other natural glasses of volcanic origin such as pitchstones and perlites.[2]

Common inclusions in Obsidian are crystallites (skeletal crystal embryos which are non-polarizing units, and therefore isotropic, and which cannot be identified as to species). In black, grey, green or brown obsidians it is the presence of crystallite inclusions which helps to identify the obsidians from the other natural glasses of similar colour such as tektites. Obsidians have an index of refraction which ranges between 1·480 to 1·510, with a mean R. I. of 1·495.[3] The specific gravity of obsidians varies between 2·33 and 2·42, at least in the types used in jewellery.[4]

Crystallites are isotropic (this means that when these inclusions are viewed between two crossed polaroid discs they stay dark as the specimen is rotated). Heinrich[3] in his study divides the types of crystallites into six different forms:[5]

(1) globulites—round crystallites
(2) cumulites—grouped globulites
(3) longulites—rod-like forms
(4) scopulites—fern-like forms
(5) trichites—hair-like clusters or snarls
(6) margarites—beaded aggregates.

If there is continued growth of the crystallites, they may become microlites (small polarizing crystals which can be recognized as belonging to a particular species).

Microlites are usually lath or rod-like in form and augite and feldspar microlites are common in Obsidian. Based upon the crystal perfection, microlites may be classed in three categories:[6]

(1) euhedral (idiomorphic, automorphic) where there has been maximum development of characteristic crystal form;

(2) subhedral (hypidiomorphic, hypautomorphic) where there is partial development of characteristic crystal form; and

(3) anhedral (xenomorphic, allotriomorphic) where there has been no development of characteristic crystal form.

Obsidians do not contain many larger well formed crystals (phenocrysts).

If the glass is very old, it may have become microcrystalline by means of a process called devitrification which usually starts along cracks and results in a mixture of rock minerals and their alteration products. Heinrich in his work states that only in some cases can the mineral species be distinguished, but the jumbled mass is faintly birefringent. He states further that rocks older than the miocene generally contain devitrified "glass" rather than true glasses. (Miocene is a division of the cenozoic era in the geological column of earth history. The cenozoic era, which encompasses 60 million years, begins with the paleocene and includes recent times.[7]. Where mineral species have been recognized in cases of devitrification they have included feldspars, clay minerals and various forms of silica.

Other typical inclusions in obsidians include differently coloured bands. Also present are banded structures formed by the alignment of crystallites, microlites and spherulites (small radiating or concentrically arranged aggregations of one or more minerals).[8] Spherulites are formed by the rapid growth of acicular (needle-shaped) crystals in rigid glass about a common centre or inclusion.

Irregular swirls, streaks and turbulent structures, as well as lamellar flow structures are also found. Lithophysae (large, hollow, bubble-like or rose-like spherulites usually having radial and concentric structure) are also found as are highly vesicular perlitic structures (structures produced in homogeneous material by contraction during cooling and which consist of irregular, convolute and spheroidal cracks.[9]

At very high magnifications, Ross reported pyroxene microlites having the form of a coiled spring were found in volcanic glassy flow-rock in New Mexico and Mexico. Pyroxene microlites with the form of a hook of unusually large diameter were also found.

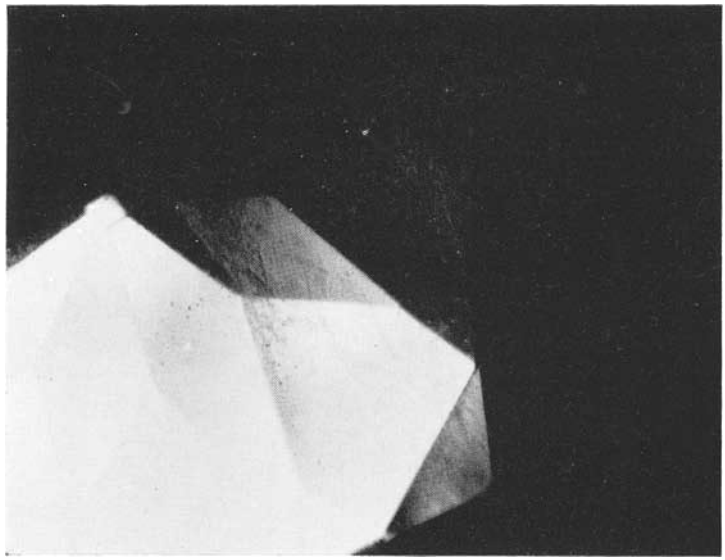

FIG. 1. Obsidian—Coloured bands, and tiny crystallites, transmitted light. 10 ×.

FIG. 2. Obsidian—Coloured bands, tiny crystallites, dust clouds, transmitted light. 30 ×.

Amphibole microlites were found in only a few specimens where they ranged from 0·02 to 0·08 mm. in diameter and from 0·04 to 0·15 mm. in length arranged as stellate groups which radiated out from magnetite grains that served as the points of crystallization. These amphibole needles tapered to very slender points. The magnetite grains were very irregular and occurred in diameters of 0·003 mm. and also as clouds of minute dust-like grains. Biotite microlites were found to occur only rarely. The most frequent type of microlite found by Ross was pyroxene.[10]

Recently, a faceted obsidian from Arizona was studied to see what inclusions it showed in contrast to those already reported by the other researchers mentioned in this article. This obsidian measured 18 mm. in diameter at the girdle and had a depth of 9·6 mm. from the table top to culet and weighed 16 carats. This specimen stone appeared dark brown and could be mistaken easily for a smoky quartz. However, it showed a refractive index of 1·480 and was isotropic. It was also inert to both long- and short-wave ultra-violet light. The spectrum showed a very sharp cut-off at the end of the green, beginning around 5100Å and continuing so that no blue or violet was visible.

Photomicrograph number 1 shows the appearance of the specimen looking down through the tilted table in transmitted light at a magnification of 10 ×. The differently coloured bands can be seen both in the star-facets and the kites. The tiny crystallites appear as minute specks of pepper both on the edge of the table and on the star-facet. Study number 2 shows these same inclusions at a magnification of 30 × and it is now possible to see that some groups of crystallites are arranged in bands and that there is also a cottony banding, which may be the clouds of minute magnetite dust mentioned by Ross. Study number 3 shows the inclusions in the pavilion at this same magnification (30 ×). Looking closely, one can see that there are small black octahedra visible. At much larger magnifications, these octahedra could possibly be taken for chromite on the basis of their being isotropic and having the colour and morphology of this oxide. Study number 4 is included for an interesting study of what can happen in studying inclusions. This was made in transmitted light at a magnification of 200 ×, and it would appear that the stone had tube-like inclusions. Further study showed that these tubes were at or almost at the surface. The way that they are arranged parallel to one another and their orientation to the

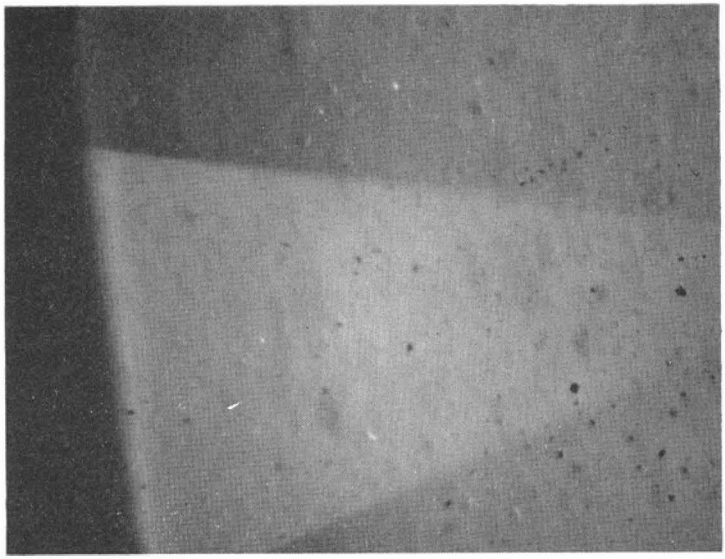

FIG. 3. Obsidian—Crystallite inclusions in pavilion, transmitted light. 30 ×.

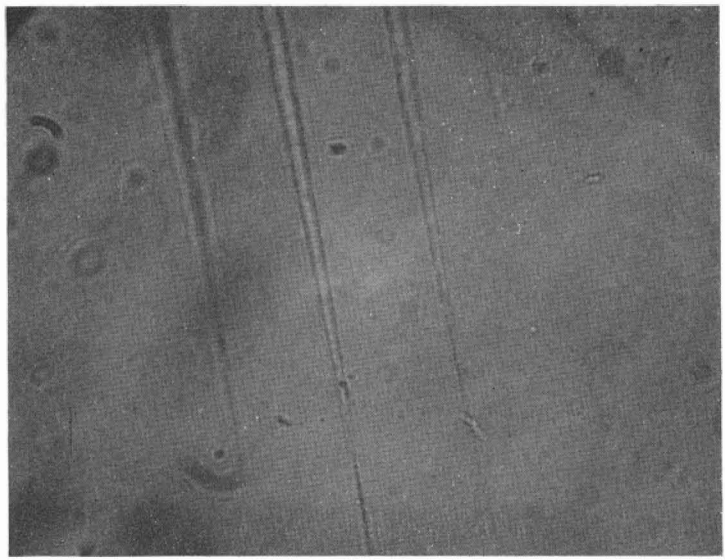

FIG. 4. Obsidian—Tubes which appear as inclusions but are probably end results from the polishing process, transmitted light. 200 ×.

facet junction led to the conclusion that these inclusions are probably the result of the polishing process.

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THE FLUORESCENCE OF SCAPOLITE

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THE fluorescence of scapolite has been attributed to uranium by Webster[1] on account of the discrete nature of the spectrum. The structure consists of the superimposition of a vibrational series on an electronic transition. Structure of this type in a spectrum is not restricted to uranium. Kirk[2] has shown that sulphur is the activator in fluorescent varieties of sodalite and related materials, including scapolite. He manufactured similar materials by the heat treatment of mixtures containing sulphur. Recently it has been suggested[3] that the likely form of the luminescent centre is the S_2^- molecular ion, since the frequency difference between bands in the series is in the range 500-600 cm^{-1}. For comparison, the frequency difference for the uranyl group is in the range 800-950 cm^{-1}.

Simple tests have been carried out which support the role of sulphur. A sample of the opaque massive yellow variety found in Canada had the characteristic strong yellow fluorescence under long-wave ultraviolet radiation. It was found to have 0·57 wt. % of sulphur by electron microprobe analysis. However, a transparent scapolite, probably from Burma, showed only a weak red fluorescence under short-wave ultraviolet radiation. In this case no sulphur was detected by electron microprobe analyses, but iron was found to be present to the extent of 0·16 wt. % and the sample showed an absorption spectrum characteristic of the ferrous ion. Iron is not an activator and tends to quench luminescence. It is not clear what is causing the weak red fluorescence, especially as both manganese and chromium are present to an extent less than 0.06 wt. %.

As a final check on the uranium hypothesis autoradiographs ranging from 3 to 66 days were taken of the two types of scapolite and of a zircon containing 0·57 wt. % equivalent uranium as independently determined by Vance and Anderson[4] using neutron activation analysis. It was shown that equivalent uranium is present in the massive variety to an extent of only 50 ppm and the transparent variety had no detectable uranium with an upper limit of 20 ppm. If the radioactivity is due to thorium it would have to be present in treble the estimates based on uranium. Although it appears certain that sulphur rather than uranium is the principal activator, more research is needed to decide whether small amounts of sulphur are also the cause of the weak red fluorescence in the transparent scapolite. Kirk[5] has also shown that sulphur can cause a weak red fluorescence when suitable mixtures are heat-treated for a short period, but this fluorescence is reported as being excited by long-wave ultra-violet radiation.

I am indebted to the Department of Geophysics and Geochemistry in the Australian National University which kindly carried out the electron microprobe analyses.

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Gemmological Abstracts

BASTOS (F. M.). *Brazil, Land of Tourmalines.* Lapid. Journ., 1972, 26, 8, 1224-1229. 8 illus.

An account of the occurrences of tourmaline in the classic and new Brazilian locations. The best specimens come from Barra de Salinas. Methods of recovery from pegmatites and modes of occurrence are discussed.

M.O'D.

BECKWITH (P. J.), HUTTON (D. R.), TROUP (G. J.). *Optical & radio frequency spectroscopy of impurities in blue zoisite.* Australian Gemmologist, 1972, 11, 7, 20-22. 3 figs.

A study of the impurities causing the colour in blue zoisite with particular interest in the vanadium content, 1% being the amount which gives the colour. The vanadium may substitute for aluminium. The optical spectrum was displayed on a recorder for each of the a, b and c vibration (X-ray) directions, the range of the spectrum being from 4000Å to 8000Å. Measurements on heat-treated stones show that the yellow spectrum becomes identical to the blue. The experiments are proceeding.

R.W.

CASSEDANNE (J.) *Le gite de cordierite gemme de Picui* (Occurrences of cordierite, a gem from Picui.) Bull. Assoc, Française de Gemm., 1972, 33, 10-12.

A description of the discovery of cordierite in the vicinity of Picui, in the State of Paraiba, Brazil. Specimens are found in a mica schist as nodules with sillimanite and garnet found in association. Cordierite is also found in quartz veins. Gem quality stones are found with pleochroic colours of a deep violet and a milky greenish-grey. The specific gravity was found to be within 0·02 of 2·63, the hardness less than 7, and the refractive indices 1·538 and 1·551, giving a birefringence of 0·013.

M.O'D.

COE (J. C.). *Feldspar, a unique mineral family.* Lapid. Journ., 1972, 26, 9, 1286-1290. 9 illus.

A review of the gem feldspars illustrated with colour plates. Common confusions are explained, particularly between aventurine quartz and amazonite. Most of the possible gem varieties of the orthoclase and plagioclase feldspars are discussed.

M.O'D.

COTTY (W. F.) & WIKKS (E. M.). *Differences between diamonds from different sources.* Intern. Criminal Police Rev., 1972, 27, 150-156. 7 figs.

The proportions of unbroken gem quality diamonds in the different morphological forms (octahedron, rhombic dodecahedron, and cube) are variable between different sources but fairly constant for any one source. It is thus possible, given sufficient numbers of diamonds from different sources, to identify the various sources with some degree of certainty. For the Yakutian pipes at least, the size distribution within a mine is constant with depth, thus different sources could also be compared on the basis of a size variation.

R.A.H.

CROWNINGSHIELD (R.). *Developments & Highlights at G.I.A.'s Lab. in New York.* Gems & Gemology, 1972, XIV, 2, 50-57. 18 illus.

Details of a number of jade-like articles including articles made of grossular/idocrase, serpentine/zoisite, hydrogrossular and natural coloured green quartzite. An emerald from Mozambique and an emerald-green YAG with myriads of oriented small bubbles looked a sleepy-green. Foil-backed and abraded diamonds, and a brown diamond with a colourless diamond inclusion causing it to show a strong anomalous birefringent pattern between crossed polars are mentioned, as well as a flux-fusion synthetic ruby with a 'seed' of synthetic Verneuil-grown ruby. The article concludes with a discussion on the laser drilling of diamond.

R.W.

FERGUSON (J.) & FIELDING (P. E.), *The origins of the colours of natural yellow, blue and green sapphires.* Australian Journ. Chem., 1972, 25, 1371-1385. 7 figs.

Spectral analysis of yellow sapphire containing 0·99 wt. % Fe,

from the Anakie field in Queensland, shows that the visible portion of the spectrum is dominated by a complex peak in the region of 22 000 cm^{-1}, which corresponds with the $^6A_1 \rightarrow {}^4A_1, {}^4E$ spin-flip transition of Fe^{3+}. Other spectral features are attributed to Fe^{3+} ion pairs. The blue and green colours of sapphire are attributed to Ti^{4+}–Fe^{2+} interaction, which gives rise to absorption bands at 17 800 and 14 200 cm^{-1}. Absorption in the IR region of blue and green sapphire as well as synthetic flux-grown yellow sapphire indicates Fe^{2+}–Fe^{3+} interaction.

E.H.N.

FURBISH (W. J.). *Unusual Quartz Inclusions in North Carolina Emeralds.* Gems & Gemology, 1972, XIV, 2, 34-37. 4 illus.

Rounded quartz crystals are found as inclusions in emeralds from the mine near Little Switzerland, North Carolina. A study is also made of the inclusions in these included quartz crystals. It is suggested that the inclusions described may well be characteristic for emeralds from this mine.

R.W.

HARTIG (H.). *Entwurf eigener Facettenschliffe.* (Designing one's own facet cuts.) Z. Dt. Gemmol. Ges. 1972, 21, 3, 160-174.

The author encourages amateur lapidaries to try out new ideas and design their own styles of cutting. He has worked out a basic classification listing various traditional and new cuts according to whether the table is 3, 4, 5, 6, 8 or 12-sided (the standard brilliant-cut being 8-sided). According to Hartig a "pure" cut includes the trap, brilliant, star, cross and spiral cuts, but also such variations as the Swiss cut (8/8), zircon, double brilliant and Portuguese cuts. Some of these cuts lend themselves to being produced in various ways, such as a French, a double star and a ray cut, as illustrated in the articles. He then goes on to explain mixed cuts (such as the "ladybird" and the "Juliana") and various fancy cuts, which include the Princess cut by Nagy, the Colorant by Elbe, antique shapes, such as the Mogul, and very modern irregular shapes, such as the cap or bastard cut. From there the author goes on to suggest designing new forms of cutting, some being produced by using a traditional or newer cut and adding or omitting some facets, combining various cuts or altering the ratio of facets to each other. Many ideas are illustrated.

E.S.

LIDDICOAT (R. T.). *Developments & Highlights at G.I.A.'s Lab. in Los Angeles.* Gems & Gemology, 1972, XIV, 2, 38-46. 16 illus.

A repair to a natural ruby by filling with epoxy resin and an unusual synthetic pink sapphire with natural-like parallel formations but given away by a gas bubble are interesting items reported. There is a discussion on the variations of the constants for rhodolite garnet. Three unusual opals are recorded and the results of an examination of a black diamond. A blue Mabe pearl with the colour due to a black pitch-like cement being used to hold in the bead, a crystal of the spinel group which showed pronounced 'trigons' on the octahedral faces, a large rock crystal vase, thought at first to be glass, and a glass 'jade' substitute are mentioned. The story of an opal doublet and a remarkable natural sapphire with an 'alexandrite' colour-change complete the account.

R.W.

MALES (P. A.). *Why Crystallography?* Australian Gemmologist. 1972, 11, 7, 4-6.

A note on the value of elementary crystallography in the study of gemmology. The use of the optical indicatrix is explained and the value of the Miller Indices in its simpler form is discussed.

R.W.

MEYER (H. O. A.) & BOYD (F. R.). *Composition and origin of crystalline inclusions in natural diamonds.* Geochim. Cosmochim. Acta, 1972, 36, 11, 1255-1273. 6 figs.

Monomineralic inclusions (10 to 200 μm) of olivine (11), garnet (14), chromite (6), enstatite (4), and diopside (2), in diamonds from Africa, Venezuela, and Thailand have been analysed by electron microprobe and their cell parameters determined. The chemical compositions of many inclusions resemble those of minerals occurring as xenocrysts and in peridotite zenoliths in kimberlite; however, there are consistent differences. It is suggested that the diamonds formed from igneous melts and that the inclusions crystallized in equilibrium with these melts. In contrast, the minerals in peridotite zenoliths may have equilibrated at lower temperatures either in a volatile-rich liquid or in the solid state. The inclusions would not have participated in this lower temperature equilibration because they were armoured by diamond.

C.M.B.H.

MONFORTE (A.) *A tectónica lineamentar e a repartição espacial e genetica das fontes primárias de diamantes.* (Tectonic framework and particular genetic distribution of primary diamond sources.) Serviços de Geologia e Minas, Angola, 1970, Boletim 22.

A survey of diamondiferous localities in north-eastern Lunda. The concentrations are explained in two distinct theories; that diamonds occur from one primary source only and that their transportation is complex; the other that the diamonds are found from multiple sources with little subsequent movement. A further theory is that many kimberlitic pipes may supply diamonds whose transportation may be complex or simple.

M.O'D.

MCLOUGHLIN (D.). *Gemmology in Japan.* Australian Gemmologist, 1972, 11, 7, 18-19.

An account of a visit to the headquarters of the Gemmological Association of All Japan in Tokio. The Association is not financially supported by outside bodies. Its main income is derived from membership and student fees and the issuing of gem identification certificates. The students gem course takes six months consisting of four full days each month and one course is held each year to allow for lectures to be held in other towns. The Association is accepted as a scientific body by the public.

R.W.

TAYLOR (J. S.). *The story of White Cliffs opal field.* Gems & Gemology, 1971, XIII, 11, 334-343. 8 illus.

Reprinted from the Commonwealth Jeweller & Watchmaker with additions. The story is told of the history of the finding and of the mining of the black opal deposits of the White Cliffs field in New South Wales. Much is told of the personalities of those early days. Nothing is told of the situation after the end of the 19th century.

R.W.

THOMPSON (J.). *Auditing in depth.* Coopers Journal (House Journal of Cooper Brothers, London Accountants). 1972, 21, 17-18. 2 illus.

The story of a trip made by one of the firms auditors to assess the potential of a cultured pearl farm at a small island in the Persian Gulf. Kish Island lies a few miles off the coast of Iran and north of

Abu Dhabi in the Trucial States. The farm and factory is run by the Persian Gulf Pearl Company and is operated by a young Australian couple and two Japanese, with a number of local divers. It is apparently a pilot scheme so far.

R.W.

TOMBS (G. A.). *Valuation principles as applied to coloured gemstones.* Australian Gemmologist, 1972, 11, 6, 9-14,

Taken from an address given by the author to the New South Wales Gem Club, the article takes on an ambitious subject. The author has taken considerable pains and the basis he gives for his pricing has merit. The article makes excellent reading and the author wisely refers to pitfalls. The prices are given in Australian dollars (currently A2·20 dollars to the English pound).

R.W.

WEBSTER (R.). *Some experiences and investigations into damage to gem materials.* Lapid. Journ., 1971, 25, 1077-1084. 2 photos.

Damage to gem materials can be caused either by percussion (knocks, blows, ultrasonic cleaning), by undue heating, by radiation (below the thermal range), or by chemical attack (in the jewellery trade, by household chemicals or by cosmetics).

R.A.H.

WILKINS (R.). *An amateur gemcutter looks at refractometers.* Lapid. Journ., 1972, 26, 432-434. 1 fig.

For a plane polished surface of a transparent material in air with normal incident light, the percentage of reflected light $R = [(n-1)/(n+1)]^2$. For high refractive indices it is thus easier to determine the value of n indirectly by measuring the reflectivity with a photo-cell and amplifier. The working curve, using standards such as quartz and rutile, is essentially linear.

R.A.H.

ANON. *New mosaic triplet.* Australian Gemmologist, 1972, 11, 7, 23 & 32. 1 illus.

An account of a new type of composite stone in which the central layer is a coloured photographic transparency of a coloured polygonal pattern of three basic colours. It is so-far purely experimental.

R.W.

BOOK REVIEWS

Australian and New Zealand Gemstones. Edited by Bill Myatt. Paul Hamlyn Pty. Ltd. Dee Why West, New South Wales, Australia, 1972. pp. 511. Illus. in black-and-white and in colour. Coloured maps. Price on application to the publisher.

This large book is divided into four sections, (a) general information, dealing with prospecting, collecting, jewellery-making and tables, (b) geology, (c) gemstone identification and (d) gemstone localities. Each section is compiled by a specialist team and is accompanied by coloured plates. The book is directed at the serious amateur rather than the professional gemmologist; the section on gem identification would have been helped by tables and more diagrams of testing instruments. There is a short glossary at the end of the geology section and a good bibliography at the end of the book, where it is accompanied by coloured maps with gem locations marked. The index is surprisingly short. In all, an excellent book with high-class coloured plates.

M.O'D.

CAMPBELL (N.) and STONE (D.), *Gemstones of New South Wales.* Jacaranda Press, Melbourne, 1969, pp. ix. 125. Illus. in black-and-white. £1·20.

A brief introduction to gems and their crystal form leads to detailed descriptions of the species likely to be encountered in the fields of New South Wales, individual areas of which are outlined with sketch maps. There are hints for prospectors, notes on polishing methods and a glossary. An interesting book, bearing in mind that the State of New South Wales includes Lightning Ridge and White Cliffs.

M.O'D.

COOPER (L.) and (R.). *New Zealand Gemstones.* A. H. and A. W. Reed, Wellington, 1972. pp. 125. Illus. in black-and-white and in colour. £2·10.

Despite the general nature of the title, most of this book is devoted to the fashioning of gemstones found in New Zealand. There are good maps of gem deposits and the coloured illustrations are good. A useful guide for the New Zealand amateur.

M.O'D.

EVANS (I. O.). *Rocks, Minerals and Gemstones,* Hamlyn, London, 1972. pp. 128. Illus. in black-and-white and in colour. £1·75.

A pleasingly illustrated book which depicts rock formations as well as the colourful crystals excitingly photographed, which one has come to expect from books in this price range, of which this particular item is otherwise a characteristic example. The section on gemstones is loosely written and while mentioning hardness and streak together with frequent allusions to glassy lustre leaves out refractive index. The book ends with a section on cutting.

M.O'D.

HUGHES (G.). *The Art of Jewellery.* Studio Vista, London, 1972. pp. 248. Illus. in colour and in black-and-white. £8·00.

The author suggests that jewellery may be the oldest of the arts and in this survey of the jeweller's craft from prehistoric times to the present day he presents examples of the finest pieces from Egypt, Crete and Babylon up to work created for the Diamonds-International awards. The book opens with an account of the evolution of design, including a particularly interesting survey of art nouveau, examples of which are beautifully illustrated. The next section, under the heading "The Artist Jeweller", deals with design and workmanship in leading countries today. A chapter on technique describes the development of various aspects of the craft; this section also is superbly illustrated. A valuable list of the major jewellery collections and some thoughts on value conclude this magnificent book.

M.O'D.

MACFALL (R. P.). *Gem-hunter's guide.* Fourth edition. Thomas Y. Crowell Co., New York, 1969. pp. 279. $6.95.

A state-by-state guide to the gemstone resources of the United States, with earlier chapters on crystal forms and other means of identification of gem material in the field. Good sketch maps are provided for the more important localities and up-to-date information on availability of access is given.

M.O'D.

ROGERS (C.). *Finding Britain's Gems.* Lapidary Publications, London, 1972. pp. 62. 30p.

Originally published as an article in the magazine *Gems*, this is the work of a number of writers each of whom covers a particular area of the British Isles, listing the gem materials to be found there. No attempt is made to enhance the quality of the specimens and the information given on specific localities is clear and sensible. A useful map shows the major gemstone sites, and the whole book is designed for easy reference and portability.

M.O'D.

SCARFE (H.). *Lapidary in a Nutshell.* Lapidary Publications, London, 1972. pp. 44. 30p.

This handy book provides an introduction to the lapidary arts for the amateur. Most of the book deals with faceting rather than tumbling and the best methods of using the large choice of machinery now on the market are suggested. Diagrams and photographs illustrate various techniques.

M.O'D.

SCHUBNEL (H.-J.). *Pierres Précieuses dans le Monde.* Horizons de France, Paris, 1972. Illus. in black-and-white and in colour. pp. 190. 68F.

The book was originally written as a thesis for the degree of Doctor of Science of the University of Paris and the later sections reflect this earlier ambition. The book opens with a general review of gems followed by an account of their economic importance, including tables of production and consumption and relative values of the important stones over the years. The production tables cover up to 1969 in most cases; these facts are very difficult to find elsewhere, save in the United States Minerals Yearbooks. The author next reviews the museums of the world and explains the reasons for the changes in fashion which affect gemstones. The guide to mineral and gem collections is most useful and it is pleasant to see that the author regards the collection in the Mineral Gallery of the British Museum, (Natural History) as the finest in the world. The next part of the book deals with the occurrence and working of precious stones together with photographs taken at the mines. The final part of the book explains the methods of gem testing, including tables, and an excellent bibliography which

for once contains periodical articles. The best part of this important book is the section on inclusions which is backed up by some fine coloured photographs.

M.O'D.

SINKANKAS (J.). *Gemstone and mineral data book.* Winchester Press, New York, 1972. pp. 346. $8.95.

The book is subtitled "A compilation of data, recipes, formulas and instructions for the mineralogist, gemologist, lapidary, jeweler, craftsman and collector." Chapters begin with weights, measures and conversions, chemicals, lapidary equipment, abrasives and jewellery manufacturing data. From chapter six to the end of the book the material is more specifically gemmological and includes full tables of minerals under their specific gravities, hardnesses, crystal system and habit. Colour changes are listed by mineral and the last chapter deals with the optical properties of minerals and gems.

In the preface the author asks for additional data to be sent to him for inclusion in further editions. One can scarcely imagine anything missing from the existing edition; the only criticism being that the type-face is clear but the layout somewhat cramped—but in a book of such reasonable price this is inevitable. The book is an example of painstaking compilation of data and the serious gemmologist must have this book constantly at hand.

M.O'D.

SMITH (G. F. H.) *Gemstones.* Revised by F. Coles Phillips. 14th Edition. Chapman & Hall, London, 1972. 580 pp. 35 plates (12 in colour). £7·50

Gemmologists should be very grateful to Professor Phillips for undertaking once more the formidable labour of bringing out this up-to-date fourteenth edition of Dr. Herbert Smith's classic work which, for the older ones amongst us, served in its early editions as our gemmological "bible". It is difficult for anyone who has not experienced the trials and tribulations of authorship even of a small book to appreciate the care and hard work needed even to revise a book of this stature.

Surprisingly, the publisher is no longer Methuen but Chapman & Hall, but the printers are still Richard Clay of Bungay, and this has ensured that the book has much the same workmanlike

form and feel as the last edition. Publishers find it wise, in issuing a new edition of a book, to alter the frontispiece if nothing else, as a potential customer, flipping through the pages of the volume in a bookshop will notice any change here and assume it to be symptomatic of other and more important changes. In this fourteenth edition there is in fact no frontispiece, but the wise step has been taken of replacing all the previous colour plates which were based on water-colour drawings by a series of fine colour photographs taken at the Institute of Geological Sciences under the skilled direction of Mr. E. A. Jobbins.

Each of the photographs occupies one half of a page, which provides an adequate scale for the stones to be displayed. The relationship to natural size is not stated and may well vary a little, but the names, the weights and in most cases the origins of the stones are given in an excellently arranged "Key" immediately before the plates, which are grouped together near the middle of the book. The specimens, which include rough as well as cut stones and show all available colour-varieties of each species, are taken from the very fine collection to be seen on the ground floor of the Geological Museum in Exhibition Road, South Kensington. Undoubtedly these plates add very appreciably to the value and (alas!) to the price of the book.

In undertaking the revision of a book there is a natural tendency to think first of the additions that must be made to bring it up to date and to make it more useful to the present-day reader. What is far less easy is to eradicate the signs of old age which often lie dormant in the text for a generation, or can even be seen in some of the illustrations. An example in the present case is seen in Fig. 75—a drawing which represents a balance arranged for hydrostatic weighing. This has been used since at least the 1923 edition, and might now be retired in favour of a more credible piece of apparatus to suit modern times. Illustrations in the refractometer chapter also need a face-lift, where five drawings are concerned with the 1907 model of the Herbert Smith refractometer and its limited scale, and there are none shown of any newer instrument except in Plate I where the recent Rayner "Dialdex" is shown. One recognizes the piety that urged these retentions, since both the book and the refractometer were Herbert Smith's greatest contributions to gemmology, but one feels that he himself would have recognized the need for change.

Another illustration due for correction is on Plate 19, where the zircon spectra shown are in reversed position, with the red absorption bands in the violet and vice versa. This block was taken from the Gemmologist for August 1939, where the bands are shown correctly placed, which is puzzling. The same error was in Coles Phillip's 1958 revision, and we as readers were remiss in not warning him of the fact.

On the positive side there are many useful and welcome additions. The microscopes now recommended include the Olympus Stereoscopic Zoom Model JM, a fine instrument of Japanese manufacture, which is specially designed for the examination of gemstones. This incorporates built-in bright and dark-field illumination and also a special inclined illuminator.

The most important new material, as one might expect, is concerned with the new synthetic stones, which multiply in these days at such a disturbing speed. These are well described, but there is perhaps too complacent an attitude to the danger they represent. Thus to say (p. 195) that synthetic quartz is unlikely to be often encountered in jewellery has already been shown untrue, as synthetic citrine is apparently being marketed on a very large scale. Also the statement (p. 203) that the production of modern synthetic stones has greatly reduced the need for composite stones has not been borne out. Some of the trade's worst headaches in recent years have been ingenious forms of composite stones specially designed to deceive not merely the jeweller or public, but the gemmologist.

Newly discovered varieties of natural gemstones such as blue zoisite and transparent green grossular have been mentioned, but in a book which includes such extreme rarities as taaffeite, painite and ekanite one is surprised to note that scheelite is omitted, since both natural and synthetic scheelite can look quite magnificent when brilliant cut, and have a considerable resemblance to diamond.

The criticisms included in this review are of trivial importance when compared with the excellence of the production as a whole. One can recommend this latest version of a famous book with complete confidence to any serious student of gemmology and indeed to any lover of precious stones.

B.W.A.

TANK (R. R.). *Indian Gemmology*. Dulichand Tank, Jaipur, 1971, 171 pp. Rs.15.

An English version of an unusual book on gemmology published as *Ratna Prakash* in 1961. The book is not a scientific treatise but a classification of gems into their suitability for jewellery; those deemed advantageous for medicinal purposes; those with astrological connections and those needed for the manufacture of toys and, surprisingly mortars., A survey from ancient times about Indian romance and mythology of gems and pearls, intermingled with technical data. Some typographical errors are corrected at the end of the book, and the binding is not impressive. However, *Indian Gemmology* presents a charming and unusual facet of gemmological interest.

S.P.

WALLER (E.). *And there's opal out there*. Lansdowne Press Pty Ltd., Melbourne, 1969. pp. 151, maps. $5.50.

Set as reminiscences of three opal miners this book gives an exhilarating picture of life in the Lightning Ridge opal fields. There are entertaining sketches and maps showing the main opal fields of Australia. A good deal of useful information is given.

M.O'D.

WALTON (Sir James). *Tabellen zur Edelstein-Bestimmung*. Translated by W. F. Eppler. 2nd edition. Rühle-Diebener-Verlag KG, Stuttgart, 1970. pp. 83. DM.20·00.

A translation of the author's *Pocket Chart of Ornamental and Gem Stones*, for some time out-of-print in Great Britain.

M.O'D.

WILLMAN (L. D.). *Gem and mineral localities of South Eastern United States*. Published by the author at Jacksonville State University, Alabama 36265. With maps. 2 vols. Vol. 1. pp. vi. 97. Vol. 2. pp. x. 271. $11.00.

The book is divided into two sections, the first consisting of minerals listed alphabetically and the second giving mineral locations arranged by state and county. A particularly useful feature is the provision of geological maps with gem locations superimposed. The states covered are rich in gem materials and include Alabama, Georgia, North Carolina, Virginia and Tennessee.

The book is reproduced from typewriting but lacks nothing in clarity. The localities are described in full detail including the precise whereabouts of the gem occurrence. Many of the finds are vouched for personally by the auhtor.

M.O'D.

WHITLOCK (H. P.). *The story of the gems.* Emerson Books, Inc, New York, 1963, pp. 206. Coloured plates. £7·50.

A re-issue of a popular American study of gems which first appeared in 1941. The book covers all the better-known gems, with a good deal of historical anecdote, and leaves most of the scientific data for a table at the end where it is accompanied by a short bibliography. The coloured illustrations are representations, not photographs, which would have been preferable in a book of this price.

M.O'D.

WYNDHAM (R.). *Enjoying gems.* Stephen Greene Press, Brattleboro, Vermont, U.S.A., 1972, pp. 128. $4.95.

A small-format guide to the better-known gemstones written for the amateur who is interested in the legendary and historic aspects of stones. The author writes with an engaging flavour of humour and includes some observations on the scientific background to the subject, including references to the cause of colour in amethyst which he admits still causes controversy and to the cause of the play of colour in opal, stated to be due to cracks in the material—an error, but the book does not set out to be a scientific treatise. There are some attractive illustrations and the book concludes with a short bibliography.

M.O'D.

ASSOCIATION NOTICES

JOURNAL OF GEMMOLOGY

Mr. J. R. H. Chisholm, M.A., F.G.A., has been appointed editor of the *Journal* in place of Mr. G. F. Andrews, who has acted in that capacity since 1947, when the *Journal* first came under the control of the Association. For several years Mr. Chisholm has undertaken much of the proof-reading. Mr. G. F. Andrews has been appointed librarian of the Sir James Walton Library, which is jointly controlled by the National Association of Goldsmiths of Great Britain & Ireland and the Gemmological Association of Great Britain.

SITUATION VACANT

The Gem Testing Laboratory of the London Chamber of Commerce and Industry requires a young London-based F.G.A. to augment the present staff.

Applications to Mr. F. T. Atkins, London Chamber of Commerce and Industry, 69 Cannon Street, London EC4N 5AB.

GIFTS TO THE ASSOCIATION

The Council of the Association is indebted to the following for gifts to the Sir James Walton Library:

Mr. I. Pike, Cairns, N. Queensland, Australia, for a collection of mineral specimens of topaz, corundum, peridot, calcite, fluorspar and agate from Queensland, Australia. Also four pieces of black coral from the Great Barrier Reef in Australia.

Mr. D. Bradshaw, London, for a red spinel crystal.

Mr. A. Chikayama, Tokyo, Japan, for his book "Jewellery", printed in Japanese.

Mr. and Mrs. Ki Nemoto, Khartoum, Sudan, for a piece of petrified wood from the Bayuda Desert of North Sudan, approximately 160 million years old.

The China Development Corporation for a book entitled "Chuo Pao Shih Chieh (Jewels World)" by the Corporation's late President, Mr. Felix S.Y. Chang, G.G., F.G.A.

Japanese translation of R. T. Liddicoat's *Handbook of Gem Identification* published to celebrate the tenth anniversary of the Gemmological Association of Japan, presented by Mr. Taichiro Imai, F.G.A.

The Gemmological Association of All Japan for a Diamond Proportional Handscope.

MEMBERS' MEETINGS

London

On the 29th January, 1973, Mr. B. W. Anderson, B.Sc., F.G.A., gave a talk to members at Goldsmiths' Hall, London, entitled "1925 and All That". A full report will appear in the July issue of the *Journal.*

Midlands Branch

Mr. Alan Jobbins, B.Sc., F.G.A., of the Institute of Geological Sciences, London, spoke to members of the Midlands Branch at the Auctioneers' Institute, Birmingham, on the 2nd February, 1973. The subject of the lecture was "Jade".

Scottish Branch

A meeting was held on the 16th January, 1973, at the North British Hotel, Glasgow, when Mr. Alan Jobbins, B.Sc., F.G.A., spoke on "Gemstones of South-East Asia." His talk was illustrated by colour slides.

RETIRING SECRETARY

Mr. G. F. Andrews thanks all those members who contributed to his retirement presentation.

OBITUARY

Professor Samuel Tolansky, Ph.D., D.Sc., D.I.C., F.R.S., who died on Sunday, March 4th, 1973, at the age of 65, was a man of great ability and colourful character, who despite being an exceptionally busy physicist of international repute, found time to set and mark examination papers for the Gemmological Association of Great Britain.

He was known to the general public through his articulate television broadcasts in documentaries and then explaining aspects of the Apollo Moon missions, when he forecast that there would be "industrial" diamonds on the Moon and later, in 1969, that the surface would be covered by tiny glass "marbles". He was one of the first group of scientists to be chosen to study dust brought back from the Moon, and, from his sample, picked out about 200 glassy spherules, each smaller than a pinhead, thus proving his theory in less than a year in the face of learned scepticism.

Professor Tolansky was born in Newcastle-on-Tyne of Russian Jewish parents and was educated at the Universities of Newcastle, Berlin and London, but retained always his Newcastle accent. After 12 years as a member of the staff of the Physics Department of Manchester University, he was appointed Professor of Physics at the University of London and Director of the Physics Laboratory at Royal Holloway College, London University, posts he held for 26 years until his death.

He made significant contributions to the understanding of optical and electronic phenomena, branches of research that are only distantly related. The first concerned interferometric studies and optical studies of surfaces and the second hyperfine structure studies of line spectra and atomic nuclear spin. He and his very active research school were responsible for the introduction of many research techniques.

It was in 1945 that, through the use of his multiple beam interferometry methods, he became interested in diamond, the height and depth features on the surface of which he was able to photograph with an effective magnification of half a million times. This brought him into contact with Dr. J. F. Custers, P. Grodzinski, and many others in the diamond industry, and eventually to his association with the G.A. Some of the research workers who passed through his laboratory also became interested especially in diamond, among them Dr. E. Wilks.

Teaching was supplemented by writing scientific papers, articles and books in simple, concise and very readable manner, whether the book was for the specialist such as "Microstructures of Diamond Surfaces" (N.A.G. Press, London, 1955) or for the general reader, such as "The History and Use of Diamond" (Methuen, London, 1962). Lecturing to audiences such as Fellows

of the G.A. appeared to be almost a relaxation for Professor Tolansky, as he obviously enjoyed the experience as much as his audience.

He was elected a Fellow of the Royal Society in 1952.

The range of activities in which he took part actively was astonishing. They included psychology, music, folklore, history of the Old Testament, and gardening. He was Chairman of the Governors of the Richmond Institute of Further Education and also a Governor of Sir John Cass College, City of London Polytechnic, which houses the centre of the silversmithing, jewellery, and allied trade training in London, including gemmology and gem diamonds. From the start of the gem diamond course in 1964, he enthusiastically accepted the task of examiner and set and marked the papers himself.

PRESENTATION OF AWARDS

The 1972 Presentation of Awards was held at Goldsmiths' Hall on the 27th November, 1972. Mr. Norman Harper, Chairman of the Association, presided, and welcomed members, especially those who had come from overseas. "It is always a pleasure" Mr. Harper said "to hold the Presentation of Awards in this splendid hall and we are most grateful to the Goldsmiths' Company for making it available to us once again."

He announced that 448 candidates had sat for the 1972 preliminary examination, the highest ever, and 284 for the diploma, which was 23 less than the previous year. Overall, however, the number of entries for the examinations was the greatest there had been. In the Gem Diamond Examination there were 41 entries.

Mr. Harper said that he was delighted to see various members of the Spanish Gemmological Association, including their President, M. Masso, who has been attending these occasions for the past five years. "It must be a matter of great pride and satisfaction" the Chairman continued, "to those responsible for gemmology in Spain that when one writes to the University of Barcelona one receives a reply which is headed 'School of Gemmology, Barcelona University'."

In introducing Dr. G. F. Claringbull, who presented the diplomas, Mr. Harper said, "In 1937 the late Dr. Herbert Smith recommended that Dr. Frank Claringbull would be a suitable person to act as an Examiner for the Association. He was appointed in

1938 and served in that capacity until 1970. It was a long stint that interrupted summer holidays and we are most grateful to him for the work he did in that capacity. This year the Association, at its annual meeting, elected Dr. Claringbull as its President, in succession to the late Sir Lawrence Bragg. Dr. Claringbull is an eminent person in his own particular field of mineralogy and crystallography, but he is here tonight to present the awards in his office as President of the Association."

Dr. Claringbull congratulated those who had gained their diplomas and referred to the high standard of the examinations that had been maintained since they had first commenced. That insistence on a high standard had been correct was reflected in the ever increasing numbers of candidates from overseas who wished to obtain the Association's diploma.

He recalled the situation of the early 30s when the advent of synthetic emeralds was causing problems for the jewellery industry and reminded the audience of the subsequent development of other synthetics such as synthetic rutile, strontium titanate, and finally of diamond. One of his early recollections was the forecast that one kind of gemstone which would always defy synthesis was the star stone. This, like many other predictions, had long since been proved false by technologists.

The early production of synthetic corundum and spinel by the Verneuil process had been a direct attempt to produce synthetic materials to substitute for natural stones, although subsequently they had been used industrially for bearings, etc. and more recently in lasers, but the production of the most recent synthetics stemmed from the development of the science of solid state physics. This had come about partly because of the demands of modern technology, which had caused to be made available the large capital investment necessary for the means of production of suitable crystals. Crystal growing had become an industry. One offshoot of this had been the unusual substances like yttrium aluminate (yttrium aluminum garnet) which were offered as good substitutes for diamond under spurious names incorporating anything up to the first five letters of the word diamond and implying a misleadingly close resemblance in properties. None of these products could begin to measure up to diamond in a number of ways. It was interesting scientifically that no substance other than synthetic diamond itself had so far been produced which had the hardness of diamond.

When as an examiner he first came into touch with the Association there were worries about nomenclature including the use of such names as quartz-topaz for citrine, and various prefixes to diamond for rock crystal. It was surprising that after nearly 40 years in which the Association had done excellent work in identifying by its diploma those who were well qualified to discriminate between all types of gemstones, the old problem was still with us in what seemed to him a more subtle form. Ought the Association perhaps to engage in an educational role at the public level by making more widely known the facts about natural and synthetic stones, and especially about the modern simulants of diamond?

Yonder Towan Field Centre

The 1973 programme of the Yonder Towan Field Centre includes:

Rock, gem and mineral hunting 12th–19th May; 8th–15th September; 6th–13th October. Gem hunting and jewellery making 27th October–3rd November.

Details from Mr. M. G. Weller, M.B.E., Yonder Towan Field Centre, Beachfield Avenue, Newquay, Cornwall.

CORRESPONDENTS WANTED

Gemmologist, 26 years, with a fair knowledge of Japanese, wishes to contact and correspond with those interested in gemmology and gem business from all parts of the world. Z. Ameen Saleh, c/o M.A.C.M. Saleh Jewellers & Gem Merchants, 63 York Street, Colombo 1, Sri-Lanka (Ceylon).

COUNCIL MEETING

At a meeting of the Council of the Association held on Monday, 29th January, 1973, the following were elected to membership:

FELLOWSHIP

Abhyankar, Jagannath S., Poona, India. D. 1972
Bennett, Frederic C., Hazel Grove, Cheshire, D. 1972
Butterworth, Joan L., Rochdale, D. 1972
Clarke, Roger D., Maidstone, D. 1972
Connard, Charles, R., Southport. D. 1972
Fernando, Siddhamarakalage U.H., Idar-Oberstein, W. Germany. D. 1972
Frost, Julia J., Cambridge. D. 1972
Gardner, Wilfred C., Reading. D. 1972
Hammonds, Robert, Newcastle-on-Tyne. D. 1972
Johnson, John W. S., London. D. 1972

Johnson, Robert C., Nuneaton. D. 1972
Kean, John S., Ayr, Scotland. D. 1972
Knight, Irene, Liverpool. D. 1971
Lyall, Linda, Alloway, Scotland. D. 1972
Lynch, Eric, Wallsend-on-Tyne. D. 1972
MacDonald, Kenneth C., Leicester. D. 1972
Magnussen, Rita H., Drobak, Norway. D. 1972
Miller, Graham J., Chesham. D. 1972
Murto, Kalei K., Soukka, Finland. D. 1972
Ord, Ronald, Harrogate. D. 1972
Peacock, Pamela M., Stourbridge. D. 1972
Plotzeneder, Josef, Salzburg, Austria. D. 1972
Popperwell, Elizabeth, Stockport. D. 1972
Rehtijarvi, Pentti A., Helsinki, Finland. D. 1972
Richmond, Philip S., Mansfield. D. 1972
Sayer, Glynis V., Strood, Rochester. D. 1972
Schrader, Hans-W., Hamburg, Germany. D. 1972
Smith, Betty C., Nottingham. D. 1972
Soratie, Kyllikki, Helsinki, Finland. D. 1972
Sukapaa-Harsunen, Leena, Helsinki, Finland. D. 1972
Sweeney, John M., Rowlands Gill, Co. Durham. D. 1972
Wainwright, Nicholas A., Wirral. D. 1972
Walton, Brian, Dukinfield. D. 1972
Westerback, Simo, Helsinki, Finland. D. 1972

Ordinary

Adler, Peter, Montreal, Quebec, Canada.
Alden, Philip J., Cape Town, S. Africa
Alexanian, Hagop, Cairo, Egypt
Arseculeratne, Rex F., Gardena, Cal., U.S.A.
Ascher, David S., Santa Ana, Cal., U.S.A.
Ashcroft, Vera, Liverpool.
Ballin, Peter E., Birmingham
Barker, Clement B., Newcastle, Staffs
Baster, Patricia, Enfield
Beattie, Robert, Wisbech
Bergamali, Mario K., Buenos Aires, Argentina
Bergdahl, Sten R., Umea, Sweden
Bishof, James L., Miami Beach, Fa., U.S.A.
Bond, Patricia M., Solihull.
Brown, Anthony J., London
Carter, R. G., Codsall
Clark, Victoria E., Newport-on-Tay, Fife, Scotland
den Brok, Johannes D., Oss, Holland
de Robert, Michel, Paris, France
Fisher, Peter Norman, London
Harris, Louis L., Lincolnwood, Ill., U.S.A.
Hayashi, Hidenori, Tokyo, Japan
Hewitt, Robert H., Gosforth
Hosaka, Masakata, Yamanashi-Pref., Japan
Jenkins, William J., St. Louis, Missouri, U.S.A.
Katoh, Takenori, Kyoto, Japan.
Kerry, Peter E., Wellington, New Zealand
Kobayashi, Shichiro, Yamanashi-Pref., Japan
Kotahwala, Purushottam, D., Jaipur, India

Kubota, Hironobu, Yamanashi-Pref., Japan
Lea, L. A. A., Frankston, Victoria, Australia
Mahuroof, Fahmi N., London
Makidaira, Tadashi, Tokyo, Japan
Marble, Carolyn C., New York, U.S.A.
Mason, John, Harrogate
Merritt, Joan M. B., Richmond
Mills, Joyce, Accrington
Mitsui, Kazuyoshi, Yamanashi-Pref., Japan
Miyabara, Jiro, Yamanashi-Pref., Japan
Mochizuki, Hideko, Yamanashi-Pref., Japan
Mochizuki, Sadae, Yamanashi-Pref., Japan
Morimoto, Tsutomu, Kobe, Japan
Mosielski, Boguslaw S., Toronto, Ont., Canada
Nakamura, Katsuo, Yamanashi-Pref., Japan
Nakano, Satoru, Ooita-Pref, Japan
Nowak, Wladyslaw, Bexley
Oh, David, K. Y. Singapore
Oohara, Minoru, Yamanashi-Pref., Japan
Ono, Hiroshi, Yamanashi-Pref., Japan
Palmer, Eileen M., Liverpool
Pike, Ian K., Cairns, Qld., Australia
Roche, Mary S. R. M., Colombo, Sri Lanka
Rosenberg, Paul, Lake Worth, Fa., U.S.A.
Rossetti, Luigi, Lourenço Marques, Mozambique
Saigusa, Shiged, Yamanashi-Pref., Japan
Scarratt, Kenneth V. G., Ilford
Smith, Brian R., Kingston, Ont., Canada
Takahashi, Norio, Yamanashi-Pref., Japan
Takano, Asatada, Yamanashi-Pref., Japan
Tamura, Yoshitaka, Yamanashi-Pref., Japan
Watanabe, Kunihiko, Yamanashi-Pref., Japan
Watkins, Sandra, Bouldon, Shrops.
Will, Richard, A. F., Salisbury, Rhodesia
Wolfe, Peter H., Windlesham, Surrey
Wood, Ronald S., Peterborough
Yamashina, Toshio, Osaka Pref., Japan
Zacharewicz, Henryk, Toronto, Ont., Canada.

LOOKING INTO DIAMONDS

The British Association for Crystal Growth is arranging a talk "Looking into Diamonds" by Dr. A. R. Lang of Bristol University, which will be concerned with the application of such techniques as x-ray topography. Dr. Lang has many years experience in this field and his work has revealed some interesting features on the growth history of diamonds.

The lecture will be on Wednesday, 18th July, in Lecture Theatre A, College Block, Imperial College, South Kensington, S.W.7., at 6.30 p.m. and members of the Gemmological Association are invited to attend. There is no entrance fee.

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and

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GEMMOLOGICAL ASSOCIATION
OF GREAT BRITAIN
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GEMMOLOGICAL ASSOCIATION OF GREAT BRITAIN

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"1925 . . . AND ALL THAT"

By B. W. ANDERSON, B.Sc., F.G.A.

(being the substance of a talk given to the Gemmological Association in London at Goldsmiths' Hall on 29th January, 1973)

THE title chosen (by Mr. G. F. Andrews) for my talk this evening is, of course, derived from that well-known skit on a schoolboy's garbled version of history, "1066 . . . and All That", as he thought it indicated my theme sufficiently well, while sounding less dry-as-dust than would a more fully descriptive title. The story I have to tell may also seem to you to be "ancient history": but whereas "1066" aimed chiefly at being funny, in my case the amusement will be merely incidental, as I shall be trying to give you as accurate a picture as my memory and the limitations of time will allow of our early struggles in London's Precious Stone Laboratory to come to grips with our science and enlarge its scope and accuracy.

The forty-six years during which I was in charge of the Laboratory of the London Chamber of Commerce can be considered conveniently to consist of four periods. The first (1925–1930) was concerned almost exclusively with pearl-testing. In the second period, ushered in by the World Trade Depression, we (I had been joined by C. J. Payne in 1928 as mentioned later) extended and im-

proved our techniques for gem-testing, and used the leisure forced on us by the Depression to carry out some fruitful research. This was ended by the outbreak of war, and the war, of course, was a very distinctive period of its own. And the last period began in 1946, when, faced with an enormous increase in work, Robert Webster and Alec Farn were added to the strength—our well-balanced team of four thereafter working together for the next twenty-five years.

The Hatton Garden of 1925 which I entered as a young man fresh from the University was very different from the Hatton Garden of today: more romantic, more obviously a street utterly obsessed with the trade in diamonds, pearls and gemstones of all kinds. Only two shops in the street, and one of these a jeweller's sundriesman—in doorways and along the kerbstone, brokers and small dealers gesticulated and bargained and scrutinized through lenses goods fished from dirty stone-papers. Old buildings, long since demolished, were human rabbit-warrens where at the end of dark passages or reached by crooked stairways lapidaries, mounters and other specialists worked long hours in an atmosphere laden with coal-gas.

To begin with, my story was purely a *pearl* story. In the jewellery trade of the 1920s the oriental pearl was queen—incomparable for its beauty, prestige, value, and profit-making possibilities. Recovered from "oysters" which were fished from the waters of the Persian Gulf or the Gulf of Manaar by naked divers operating from sailing dhows much as they had done for some 2,000 years, the pearls were shipped to Bombay, and there prepared for the world markets with amazing taste and skill. The pearls were cleaned, drilled by hand (more perfectly than by any mechanical means), graded for colour, size, shape, and lustre, and assembled into the wonderfully attractive "Bombay bunches", in which short strings of pearls (forming a "size") were finished at each end with braided silver wire and tassels and folded in blue silk. A parchment label attached to the bunch gave the number of pearls in each size, their total weight, average weight and the "once the weight" for the entire bunch. These bunches were imported into London and Paris (then the leading world markets for pearls) by a few wealthy houses, many of whose names, once so important (Max Mayer, Tanburn & Co., Mendes da Costa, Jerwood and Ward), are now remembered only by the veterans amongst us. These bunches were the raw material from which new necklaces were assembled with loving care

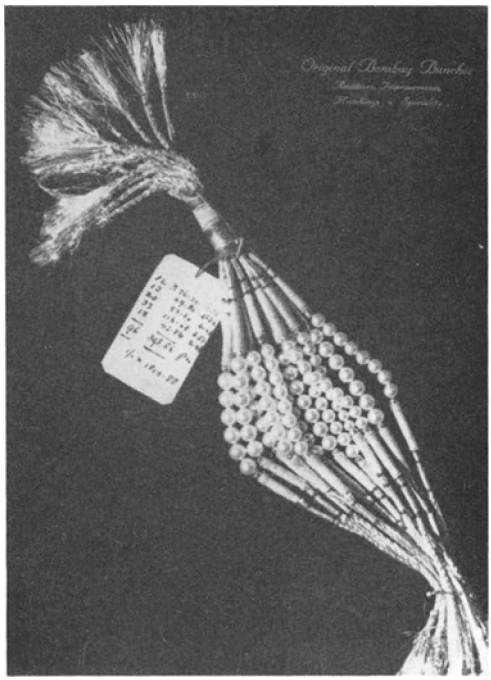

FIG. 1. A typical "Bombay Bunch".

by a few specialists at this work. Every dealer in pearls, as well as the larger jewellers, had their own pearl-stringer, and in Hatton Garden two "pearl doctors"—the Brockmans, father and son—were kept constantly busy improving pearls by removing blemishes, and drilling them or redrilling them.

Early in the 'twenties this profitable trade was rudely shaken by the advent of the whole cultured pearl, and by 1925 things had reached a pitch where the bold and far-sighted step was decided on by the leading dealers to establish an independent testing station under the aegis of the Diamond, Pearl, and Precious Stone Section of the London Chamber of Commerce. In their search for a suitable young scientist to take charge of the work, the Section's Committee were guided by W. T. Gordon, Professor of Geology in King's College (London University), who was on terms of friendship with some of the more important diamond and pearl dealers. I had taken my degree in chemistry (with subsidiary mineralogy) at King's in 1924, and had mercifully failed to find a suitable job as a chemist,

and Professor Gordon suggested that I might care to try my hand at forming and running the proposed new Laboratory in Hatton Garden. It sounded interesting, so I accepted. I had a thorough scientific training in chemistry, and some in mineralogy: I had enthusiasm and an enquiring turn of mind—but of pearls I knew nothing, and had everything to learn. After a short stay in Paris to find out what I could in the methods being tried there to distinguish between natural and cultured pearls, I returned with a heavy piece of apparatus called the "Lucidoscope" and a box of accessories, and with this dubious equipment and a commissionaire who was lacking in geniality and intelligence, I was installed in a small L-shaped room at the top of Diamond House and started to learn my job.

This was in July, 1925. I don't like to remember those first few months. The "Lucidoscope" was essentially a brass turret with a powerful, water-cooled lamp in the base, light from which passed through the pearl to be tested, resting in a saucer-shaped diaphragm on the glass base of a metal cell containing cedar-wood oil or monobromo-naphthalene. In cultured pearls there is a greater transparency to light in directions parallel to the layers of the enclosed mother-of-pearl bead, and, by turning the pearl with forceps in the "Lucidoscope" and observing it from above through a head-loupe, characteristic "stripes" showing the mother-of-pearl structure could often be seen. This was positive enough, but *proof* that a pearl was natural was far from conclusive. Following some work by Paul Kerr in America, I carried out a number of density tests, and established the markedly higher density *on average* of the cultured compared with the oriental pearl—which helped a bit, but it wasn't until the arrival of the first Endoscope in January 1926 that I was freed from the agonizing worry of making decisions, on which thousands of pounds might be at stake, with inadequate apparatus and (far worse) inadequate knowledge and experience.

After a little practice, the endoscope provided a 100% certain test between natural and cultured pearls, assuming these were drilled: and the improved model devised by the pearl dealers Réné and Simon Bloch on the original design of the inventors, Chilowsky and Perrin, enabled one or two hundred pearls to be tested in an hour. And that, for the years 1926, 1927, and the greater part of 1928, was my job. The growing reputation of the Laboratory and the disturbing fact that the freshly imported bunches were being increasingly contaminated with cultured pearls naturally led to more

and more work. The mere 5,000 pearls tested in 1926 had increased to twice that number in 1927 and to 49,000 in 1928, towards the end of which I was working flat out in Lab. hours, and doing overtime testing unofficially for certain firms where an endoscope had been installed. It should be explained that to allow two endoscopes to be sold to the Laboratory at the moderate price of £96 apiece the Committee had to agree to purchase 25 of the instruments, and I had the dubious pleasure of fitting these on their specially designed two-decker tables in odd corners of some of the big jeweller's stores or dealer's offices in Hatton Garden, Holborn Viaduct, and the West End. I call this a "dubious" pleasure, because neither by nature nor by training am I a good electrician, and the endoscope had a highly irregular circuit whereby the body of the instrument itself was "live", and could give rise to considerable electric shocks for the user if there was a direct current supply, unless insulated by a rubber mat. Added to this, the member of the staff chosen to operate the apparatus was usually the unfortunate pearl stringer, who was a scared and reluctant learner, quickly broke the bulk of the delicate needles, and telephoned for help whenever the carbons of the arc lamp needed recharging.

A point was reached where additional staff was essential, and (also through Professor Gordon) the Committee engaged C. J. Payne, who had taken an Honours degree in Geology at King's, to assist me. Payne's first report was issued on 6th November, 1928. And from then until the outbreak of war our work was closely interwoven.

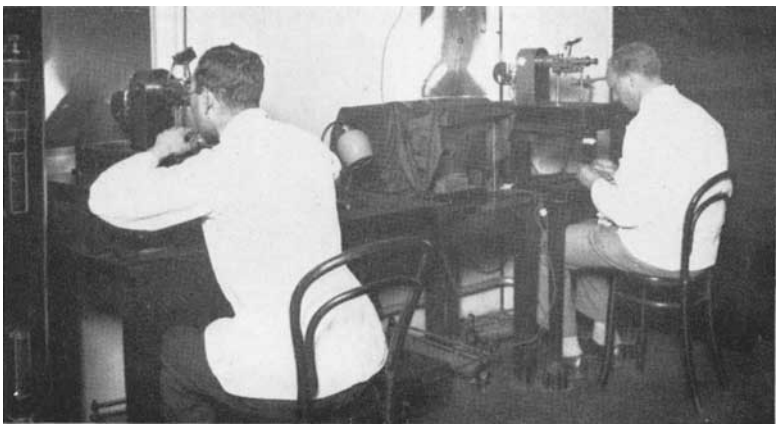

FIG. 2. 1929. In full swing with the endoscope. Anderson (right) and Payne at 55 Hatton Garden.

We continued to be largely chained to our endoscopes, testing bunch after bunch of pearls as well as vetting the whole pearl stock of some of the larger West End shops. But the lack of X-ray apparatus which alone could give decisive results with undrilled and part-drilled pearls was a drawback which had to be remedied, and in July 1929 we moved to much larger premises at 55 Hatton Garden, where running water and dark-room facilities were available, and there our first X-ray equipment was installed. The set was manufactured by Watson & Sons, and designed by C. G. Osment of that firm—a brilliant and resourceful electrical engineer who became a close friend of ours, and later was to design the more versatile X-ray set which is still in daily use in the Laboratory. The use of X-ray

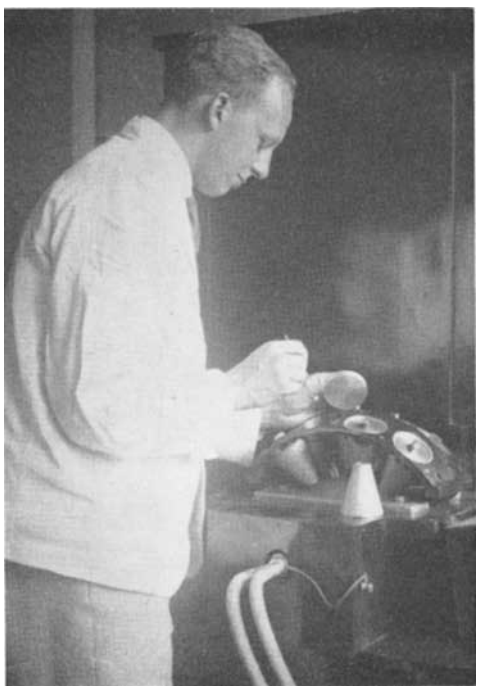

FIG. 3 Anderson using first x-ray diffraction unit for pearl testing at 55 Hatton Garden.

diffraction methods in testing pearls had been proved feasible by Dauvillier (1924) in France and the technique improved by Gallibourg and Ryziger. I paid a visit to Paris to study their methods,

travelling by air in a terrible little 'plane containing one other passenger and a consignment of Amplion loud-speakers. This achieved the journey in a series of swoops and lurches, and I felt so ill that I was reluctant for many years to travel by air again.

In February 1929 what was to become the terrible World Depression in trade had already started in America, and the demand for pearl-testing lessened slightly, and continued to fall, reaching its lowest point in 1931, when only 7,000 pearls were tested. But our interests were beginning to widen and extend to the study and official testing of gemstones of all kinds.

Research Begins: (1) The Refractometer

To the tragedy of the Great Depression we undoubtedly owed the fact that for several years we had enough time to spare from routine testing to carry out quite elaborate and time-consuming experiments. These were usually a happy blend of the practical and the academic. Both Payne and I were sufficiently "dyed in the wool" scientists to rejoice in discovery for its own sake, but, as practising gemmologists, we were delighted when such investigations could be used to good effect in everyday gem-testing.

One of our earliest concerns was to increase the range of the refractometer. For some time the only refractometer available to us was Herbert Smith's 1907 model, made by Steward—a remarkable little instrument which had for the first time made scientific gem-testing possible for the student and the enlightened jeweller. Its weakness lay in the limited scale, extending to 1·79, and this, combined with a contact liquid (sulphur in methylene iodide) which when stale had an index not higher than 1·785, made clear readings for the important corundum gems quite a difficult business. A new refractometer, designed by the jeweller-gemmologist B. J. Tully and manufactured by Rayner and Keeler, employed a hemisphere of very refractive lead glass, allowing the scale to extend temptingly to 1·86. But in practice readings were limited to a bare 1·78 by the contact liquid, and if one attempted to boost the index of this liquid by dissolving iodides of tin, arsenic, antimony, etc., the resulting "soup" played havoc with the surface of the glass.

Our attempts to overcome these difficulties followed two lines. Firstly, to find some contact liquid, known or not yet known, of high enough index to extend the range of such a refractometer as the Tully while not attacking the surface of the glass, and secondly to

explore the possibility of using some isotropic high-index transparent mineral less chemically vulnerable than glass which could be used for the hemisphere of the instrument. The latter experiments were only possible by means of the ready co-operation of Mr. J. Pike of Rayners and his technicians, but the liquid preparations, which were smelly and dangerous, were "all our own work"—and, without the facilities of a chemical laboratory such as a fume cupboard to take away the poisonous vapours and without sinks and running water to deal with water-cooled condensers and so on, would be rightly condemned as foolhardy by a knowledgeable chemist. Smelly gases we removed through a long rubber tube which dangled from the window. Neighbours blamed the mysterious stinks on faulty drains. Water-cooled condensers we filled at one end from a jug and emptied the water from the lower end into a beaker periodically as it grew too hot. We searched the literature for likely compounds of sulphur, selenium, iodine, arsenic, etc., which were known to yield compounds of high refractive index, and studied methods for their preparation which might be possible with our resources. Of the many substances prepared, three seemed to have practical possibilities: the yellow crystalline compound of iodine and carbon known to chemists as tetra-iodoethylene (C_2I_4), which dissolves readily in the previously standard sulphur-saturated methylene iodide to form a liquid of index 1·81 which does not appreciably attack the glass table of the refractometer; selenium bromide (Se_2Br_2), a very dark red liquid which decomposes spontaneously to some extent in air, re-dissolves the separated selenium, and forms a liquid of index rather more than 2·00; and phenyldiiodoarsine, an orange fluid with an index of 1·85. Both the last two fluids attack the glass of the refractometer and the phenyldiiodoarsine ($C_6H_5.As.I_2$) is closely allied to one of the war gases and has a vicious blistering effect on the skin. Nonetheless, when we published our results in *Nature* in January 1934, a transparent liquid of so high an index was welcomed by mineralogists and its manufacture undertaken commercially by Hopkin and Williams. As for the 1·81 fluid, this has become the standard refractometer fluid throughout the world.

We measured the refractive index of all these liquids by introducing them into small hollow glass prisms made from pieces of microscope slides cemented to a glass base, and employing the minimum deviation method on a table spectrometer. This table

spectrometer, which I bought with my own money for only £25, proved enormously valuable to us in many of our researches, and was very much a favourite instrument of C. J. Payne who used it with great skill and "wrote it up" in *The Gemmologist.**

Working on the other line, the most favourable mineral appeared to be zinc blende, which is cubic and has an index of 2·37. This is obtainable in clear yellow pieces from sources in Spain and Mexico. Blende is fairly resistant chemically, but is soft and difficult to fashion and polish on account of its ready dodecahedral cleavage. Attempts to make hemisphere segments with zinc blende were not very successful, and this led Rayners to try the effect of utilizing a truncated 60° prism instead. A successful little blende instrument was in fact constructed, complete with scale reading to 2·20, and with this Payne and I were able to measure the refractive indices and birefringence of a range of zircons for the first time in history. The contact liquid we used for that purpose, by the way, was a phosphorous mixture proposed by West, which tended to burst spontaneously into flames, and lost popularity with me after an accident in which my hands and clothes were badly burned.

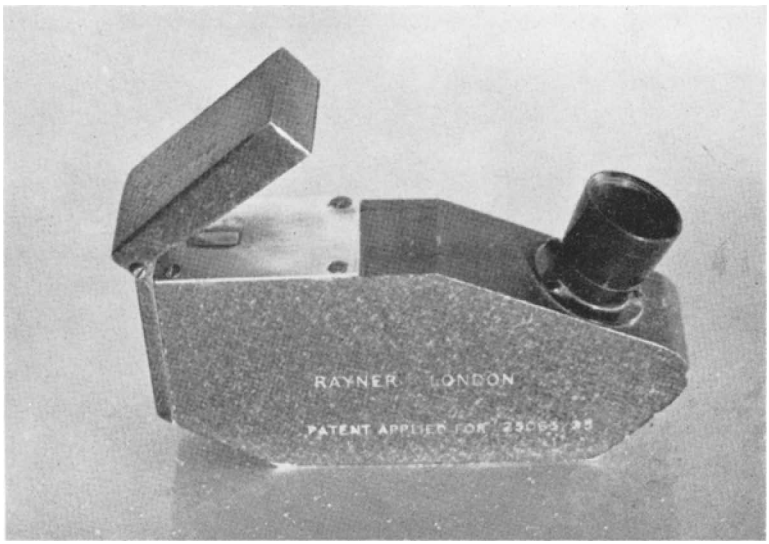

FIG. 4. Experimental Blende refractometer—prototype of Rayner refractometers.

**Gemmologist*, 6, 207-218, April 1937

This change to a prism-shaped refractometer block had far-reaching consequences. It made possible the manufacture of a satisfactory and inexpensive standard glass refractometer: it encouraged Rayner to make for us the first diamond refractometer, the diamond for which was generously given by the Diamond Corporation: and it also enabled that most useful instrument, the spinel refractometer, to be made on a commercial scale. It can thus be seen that our experiments and concern in this field did lead to very practical advantages for gemmologists the world over.

(2) The Spectroscope

The next stage in our progress concerned experiments with the spectroscope which were destined to open up a neglected field of gem-testing which has since become of ever-growing importance.

In the autumn of 1932 an astronomer friend of mine gave me a Maclean's Star Spectroscope for which he had no further use—and "trying this out" with a large green zircon, we were thrilled to see an impressive series of sharp absorption bands when we passed light through the stone. We had read, of course, of Church's discovery of such bands way back in 1866. By a curious chance (there have been many such in the Laboratory's history) this particular zircon was one of those very rare metamict zircons which show an anomalous spectrum, as we were to realize much later. The important thing was that, seeing these bands "for real" and not just as a text-book reference, so excited our interest that we began looking for absorption bands in other coloured gemstones and, to our astonishment, to find them. Previous work by various scientists was hidden away in the journals, as I was to discover subsequently. But, so far as we then knew, the path was still untrodden, and we had all the excitement of almost daily finds of new absorption bands in the many specimens available to us. Our little prism instrument, which we nicknamed "Eustace", was excellent for showing the fine lines in the red due to chromium in ruby, emerald and alexandrite, but its dispersion was too great for proper study of the blue and violet, and for this we switched to "Stubby", the small diffraction-grating spectroscope with adjustable slit, made by Beck. This needed a powerful light-source, and soon we were using a 500-watt projection bulb, with reflector, housed in a large tea-tin which had a suitable circular outlet. C. J. Payne found that a streak-free spectrum was readily obtained by placing the stone to be tested on the microscope

stage, reflecting a powerful beam through it, and using the spectroscope in place of the eyepiece. Soon, we were measuring the wavelength of bands through a Beck "Wavelength" spectrometer, with an accuracy of within ten Ångstroms. For narrow and important lines, such as those in zircon, ruby, emerald, etc., we achieved maximum accuracy by comparison with established emission lines of suitable elements on the table spectrometer, and it is a gratifying tribute to our accuracy that our published measurements have been used and accepted by all subsequent authors.

We sent an adequate description, with wavelengths of the most important absorption spectra, to Dr. Herbert Smith, who incorporated it verbatim in the re-written 1940 edition of his famous book *Gemstones*, and information was also provided in Webster's *Compendium* (1937 and subsequent editions) and my own book *Gem Testing* (1942, etc.); thus I did not feel any pressing need to attempt a complete account of the subject until 1953, when I started a series of no fewer than 40 papers which were published monthly in *The Gemmologist* and illustrated with drawings by my friend the late T. H. Smith. By then the Beck 2458 prism spectroscope or its equivalent by other makers had established itself as the most favourable type for gem identification. I haven't time to dwell further on this important subject. But I often wonder, in a detached sort of way, how we gemmologists would have managed to tackle some of today's problems (such as the detection of stained jadeite and treated diamonds) without its aid, and just how many man-hours and headaches the reassuring detection of the 4500Å band in natural sapphire, the 6535Å line in zircon and the 4155Å line in diamond have saved us in our Laboratory alone.

And now I want to move away from the Laboratory for a while and give you a glimpse of the Evening Classes in Gemmology as they were in the autumn of 1933 when I was invited to teach there in succession to Mr. I. G. Jardine, as I think that as past or present students this may interest many of you. Mr. Jardine had done a tremendous job in organizing these classes, and had been running them very successfully for many years. He had to abandon them suddenly when offered the important post of Inspector of Schools in the Borough of West Ham. Jardine was an excellent organizer and a good teacher in a schoolmasterly way. But the training in practical gem-testing which made the classes so popular amongst the young jewellers of the day was largely left in the capable hands of his

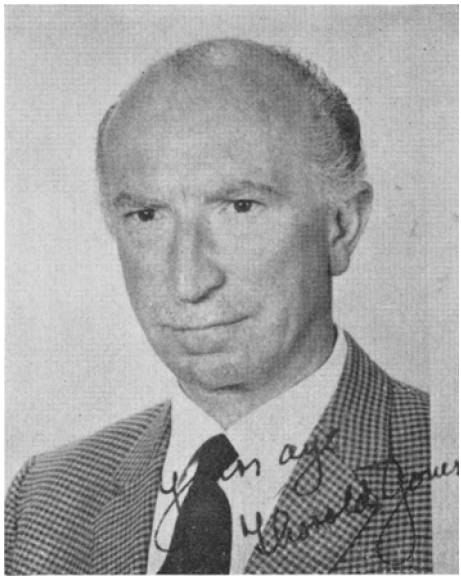

FIG. 5. Thorold Jones—The students' best friend at Chelsea Polytechnic.

assistant, Thorold Jones, whose day-time work was in the Geological Museum as assistant to Dr. H. H. Thomas.

Thorold Jones had a warm and friendly personality and was an excellent practical gemmologist, and I was lucky indeed to have his help until the outbreak of war. He knew where all the instruments were and kept them in good trim, and he knew all the scarred and chipped gem specimens by their Christian names. Conditions for practical gemmology at Chelsea were pretty primitive at that time. There were too few microscopes, and the Herbert Smith refractometers were mounted in cradles for greater ease of reading, while sodium light for these was provided by salt introduced into the flame of a Bunsen burner. I was supremely lucky in my first Diploma class, which included such notable students as Robert Webster, R. K. Mitchell and Ross Popley. I stimulated them with my first-hand news of testing methods used in the Laboratory and with unfamiliar specimens from my own growing collection, while they stimulated me by their enthusiastic response. There were no failures when they took their Diploma examination. The "Chelsea"

colour filter, which was devised in our Laboratory, serves in a way as a memorial to that class. Ross Popley wrote it up in *The Gemmologist*,* and all the students were so convinced of its usefulness that we persuaded the Gemmological Association to market it with the name "Chelsea" attached. Even today it is a most useful gadget to have in one's pocket, provided one has enough knowledge to use it with discretion.

(3) Cleaning up the Constants

If I had time, I should like to tell you of our discoveries of the zinc-rich "gahnospinels" and of kornerupine which lay unsuspected in the Ceylon gem gravels, but I feel that our campaign to improve the accuracy of the "constants" (refractive indices and, more particularly, density) in the standard text-books was of more general importance to gemmology, and can usefully form the last episode I shall give this evening of our struggles to improve our knowledge and techniques and raise the status of our science. This long-term undertaking (or "concern" as Quakers would call it) derived from a rude shock we had when testing for a dealer beads from a fine necklace of lapis lazuli. Despite their convincing appearance, replete with glistening particles of pyrites, when we found that the density of the beads ranged from 2·85–2·87, we felt these figures were so far from the 2·38–2·45 given unanimously by all the best-known text-books, that there must be something wrong with them. Hasty comparison with our own specimens, during which my best uncut piece of lapis got broken in the excitement, and later with some 500 specimens borrowed for the purpose, showed that 95% of the samples had densities between 2·75 and 2·90, the conclusion being that the beads were all right but the books were all wrong. Searching back through the literature, I found that the error had crept into Dana's *System of Mineralogy* between the 1844 and 1850 editions, and derived from a determination quoted by Breithaupt in his *Handbuch* (1847) on "quite pure grains" of lapis, which gave a density of 2·405. Dana's 1850 edition gave this figure a "safety margin" spread of 2·38–2·45, and for nearly 100 years this utterly misleading figure for the rock had been slavishly copied by authors of all the standard books.

That such a thing could happen badly shook our confidence in all the figures (particularly for the density) of gemstones given in

**Gemmologist*, 4, 57, September 1934

text-books, and we set to work to check their accuracy and compile our own tables. First, we had to set our own house in order, and we found it curiously difficult to obtain really consistent results, except by flotation. But eventually, by using a heavy cage and a very fine suspending wire in conjunction with a liquid of low surface tension such as ethylene dibromide, we began to achieve consistency in our hydrostatic work to within one or two units in the third place of decimals. In the course of our studies we became impressed with the fact that gemstones, being pure examples of the minerals they represent, mostly showed "constants" which really *are* constant. They are worth measuring and recording with care, since they are our mainstay in gem identification: and where there *are* variations, these are of significance, serving to sign-post differences in trace elements in different localities, or revealing the ultra-pure composition of a synthetic stone. As with our absorption-spectrum work, we considered the re-written 1940 edition of *Gemstones* a good opportunity for revised constants to be made available to fellow-gemmologists and students, so we handed Dr. Herbert Smith quite a formidable dossier containing our suggestions, of which he very courteously and readily took advantage.

Already before the war (which must put an end to this part of my story) specimens of the German synthetic emerald had become available for examination and caused considerable consternation from the fact that they were grown as crystals, and had natural-seeming inclusions, with none of the features associated with the Verneuil synthetic corundums to which the trade had become accustomed. And here at once the slightly lower constants of the new synthetics made the accurate measurement of these of high importance in establishing their origin. These "Igmeralds" might be said to be a cloud on the horizon "as small as a man's hand" which heralded the post-war shower of synthetics, which now threatens to become a deluge under which only the continued efforts of specialized laboratories such as ours can save the trade from being submerged.

SYNTHETIC QUARTZ FROM THE UNITED STATES

By M. J. O'DONOGHUE, M.A., F.G.A.

THE writer recently received, by courtesy of Dr. Baldwin Sawyer, of Sawyer Research Products, Ohio, some specimens of hydrothermally-grown synthetic quartz. Interest centres around a fine synthetic citrine, weighing 49·28 ct. and cut as a gem. The stone is golden yellow, the colour evenly distributed and the constants are those expected for quartz, SG. 2·651, R.I. 1·544, 1·553. Examination of the stone under a binocular microscope, using dark-field illumination, showed small grouped inclusions, resembling the familiar "breadcrumbs" seen in other material of this type. In this instance they appeared to be grouped in a trefoil pattern, probably fortuitously however. It has been suggested that these inclusions may be particles of the sodium-iron silicate acmite, slender brown monoclinic crystals of which occur in natural quartz; in the hydrothermal process it has been suggested that acmite forms through the reaction of iron with sodium and silica in the solution. As was to be expected, no significant luminescence or absorption spectrum was observed.

Some large crystals of the material also given to the writer showed very clearly the mode of growth from the seed. The ends of the seed are $(10\bar{1}0)$ which face grows very slowly; the sides are (0001), $(2\bar{1}10)$ and (2110) which grow more rapidly. Surrounding the seed is a veil-area, which is usually discarded for optical and electronic use; were it to remain in a cut gemstone, this would furnish a valuable clue to the origin of the material.

The makers state that they can make the growth regions of the crystals visible by subjecting the crystal to ionizing radiation (10^6r) which activates the colour centres, which give rise to the smokiness of smoky quartz. A clear photograph in the literature supplied with the specimens shows the irradiated darkened patches very well.

The rough quartz which is used in the manufacturing process is clear Lascas quartz. A rough green specimen appeared dark and had a distinct colour zone which was probably due to the specimen having been sawn from an area near the colourless seed.

As far as can be seen, the inclusions furnish the only possible clue to the origin, and as these can also be found in some natural stones, they cannot be completely diagnostic. The "paint-splash" inclusions found in some of the other synthetic quartzes were not seen in this specimen.

The writer is indebted to Dr Baldwin Sawyer for his generosity and to Mr Allan Jobbins of the Institute of Geological Sciences, London, for providing the facilities for microscopic examination.

A NEW DEPOSIT OF RHODONITE IN TANZANIA

By RUDOLF E. THURM

A NEW deposit of rhodonite, a spectacular silicate of manganese, $MnSiO_3$, of extraordinary deep purple-red colour (so-called "Imperial Red"), was discovered in Tanzania, near the town of Same, Upare, three miles south-east of Daghaseta school.

The authorized miner and mine manager of the Chambongo magnesite mine, Mr. W. Andersen, was digging there for pyrolusite, a high class ore of manganese, and found an outcrop of very coarse-grained rhodonite on top of Daghaseta hill.

The large boulders, which have been laid free, are completely covered with pyrolusite and have to be blasted with low % gelignite or gunpowder to avoid shattering.

The rhodonite outcrop is in the middle of a highly mineralized quartz lens with a dip of 45°, containing zinc blende, bornite and blooms of native copper on the hanging and on the footwall.

After shifting the outcrop, rhodonite-pyrolusite mining will have to be done underground by room and pillar-system.

Up to now two varieties of rhodonite have been mined. The fine-grained type with cristallites of $\frac{1}{4}$ to 1 mm diameter is of an attractive rose-pink without any brownish tinge, while the coarse-grained type with cristallites of 2 mm diameter and more is of an intense purplish red. Larger crystals are found sporadically, which might be suitable for faceting.

All the rocks have to be cut open and freed from larger parts of black hydroxides of manganese and sorted into different grades, so that the output of gem-quality rhodonite is about 10%.

Daghaseta rhodonite is worked into fine and very attractive cabochon gemstones by the Tanzania Lapidary Corporation Ltd., in Arusha. Other rhodonite material with black veins of manganese hydroxide and yellow veins of spessartite garnet is used for the manufacture of ash-trays, book-ends and clock faces.

Large quantities are exported to Hong Kong for the manufacture of dishes, vases, snuff-bottles, animal sculptures and statuettes. Tanzanian rhodonite should last for many years to come.

Mr. W. Andersen by an outcrop of rhodonite at Daghaseta Hill.

NEW GEM LOCATIONS AND THE PRESENT TREATMENT OF GEMSTONES

JULIUS PETSCH Jr, from Idar-Oberstein, Germany, was the speaker at a meeting of the Gemmological Association in Goldsmiths' Hall on 17th April, when he made his subject new gem locations and the present treatment of gemstones.

Mr. Petsch said he was the third generation of a family in Idar-Oberstein working in gemstones and some 15 years ago he was launched upon his career of finding new gem locations in Africa and Brazil. While gemmologists were mostly used to speaking and thinking of cut and polished stones, he wanted to show how uncut stones were first located. It was not the big mines he was interested in but the little workings, where sometimes a single digger was working under very difficult circumstances. Some 60 per cent, even 70 per cent, of the world's gemstones came from diggings of which few people had heard.

Mr. Petsch then presented a series of coloured slides, upon which he gave a running commentary. The first slide was of a very big safe in his company's offices—the end of a very long journey for the stones from Africa or Brazil. From the safe the stones went to the cutters and from the cutters to the jewellery trade.

The first country visited by slides was Tanzania, a country very rich in stones such as rubies, sapphires, a new emerald deposit, tanzanite and zoisite, tourmaline, and nearly all the fine stones one

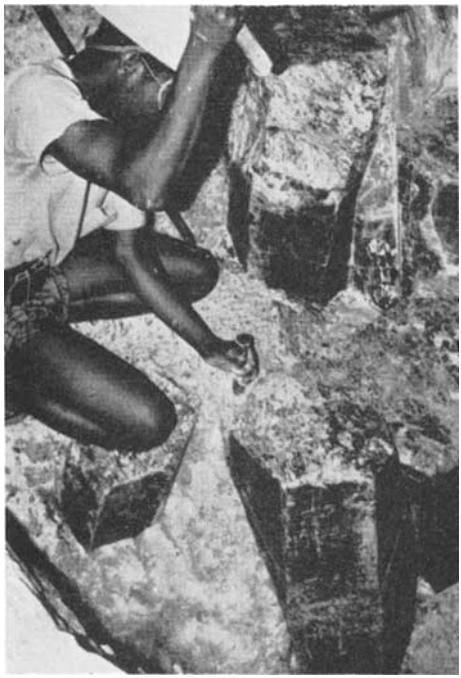

Enormous beryl crystals from which aquamarine could be extracted.

Entrance of the Platveld Amethyst mine.

could imagine. Some 20 years ago the Longedo ruby mine, near Arusha, was opened up, and it was a long slow business following the zoisite veins to discover the rubies imbedded in them. Tanzanite, a blue zoisite, was prized by diggers and was rising in price; one of the reasons was that the diggers had to cut a long deep trench and hope they would come upon a vein. The stone was not always blue; sometimes it was brown and sometimes brownish-blue, but heat treatment to many hundreds of degrees centigrade usually caused the stone to turn to cornflower blue.

In Madagascar, the second country on Mr. Petsch's imaginary journey, his company was responsible for founding a small company to search for aquamarine; notwithstanding that, it had been said that all the workings in that country had been played out. Madagascar was a country of few good roads; the rest were dirt lanes and tracks, and those seeking stones had usually to get from place to place by man-power. The aquamarine mine had some 160 workers, but to reach it one had a good march of something like 35 kilometres, and everything—food, personal baggage and suchlike—had

Large beryl crystal which contains aquamarines suitable for cutting.

to be manhandled to one's destination. Another slide showed a number of large aquamarine crystals weighing something like 2,500 kilogrammes each; this may have been a rare occurrence. It took two years to find them. Previously only small pieces were being found. The stones were something like two or three metres long, but not much of the material was of gem quality.

Mr. Petsch was of the opinion that Moçambique would be the country of the future for mining fine gemstones; already emerald

Beginning of an emerald mine in Moçambique.

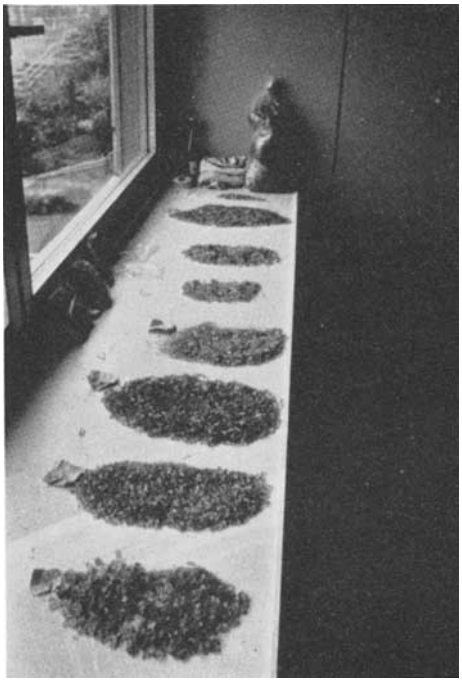

Blue aquamarine, cleaned, hammered and prepared for sale to cutters.

workings there were producing qualities that equalled Colombian stones. Turning then to Brazil, he mentioned the emerald discovery there in 1945. Today some of the mines were 50 metres deep, but there were no lifts or other mechanical devices to take the miners down; they were let down on ropes. Gemstone buyers actually congregated at this mine and made on-the-spot purchases.

During question time Mr. Petsch was asked if it was possible to distinguish stones from different diggings by their inclusions. He replied that it was possible, but only providing one had examined samples from the various locations and was aware of peculiarities and characteristics.

To another question about there still being stones around Idar-Oberstein, he answered that stones—agates—were found there some 2,000 years ago and were still being found there in 1875. In more recent years, however, occurrences had been so small, that it had not been worth looking for them.

MEASUREMENT OF REFRACTIVE INDICES BY MEANS OF A MICROSCOPE AND DIAL-TYPE DEPTH GAUGE

By HAROLD A. OATES, F.G.A.

THE principle is not new. It also is not as accurate as the refractometer, but it is helpful on stones over R.I. 1·81 and on stones which do not have a very good polish. The "apparent depth" method appears in most of the literature, of which Webster's "Gemmologists Compendium" is an example.

The formula used is $\text{R.I.} = \dfrac{\text{Real Depth}}{\text{Apparent Depth}}$

To apply the above principle it is necessary to have a means of accurately measuring the depth of the stone. In this case a dial-type depth gauge was used. See Fig. 1. This one is manufactured in England by J. E. Baty & Co. Ltd. for Scherr-Tumico of America.

The specifications are:

Model CX1	Diameter $2\frac{1}{2}$ in
Reading ·01 mm	Graduation 0-100 mm
Range 12 mm	Cost £5·90(U.K.)

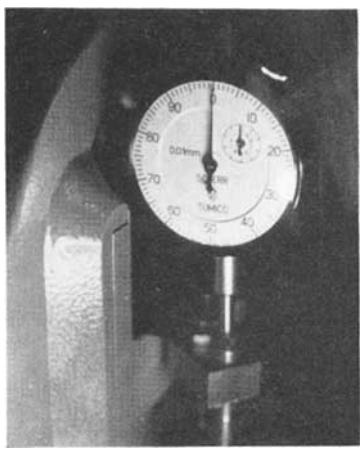

FIG. 1

The gauge can be installed on any good microscope. The one used in this discussion is a Vickers Model 14. Installation was simple. A hole was drilled vertically through the upper part of the arm using a #3 drill and tapped with a $\frac{1}{4}$28 threading die. Mount the dial on the vertical $\frac{1}{4}$ in. rod with adjusting collar. See Fig. 2.

FIG. 2

To arrive at the R.I., the stone in question is placed on a microscope slide with the culet touching the glass (this is important, because if not touching it will give too great a real depth reading—also important is having the table parallel with the top of the glass slide for similar reasons). To hold the stone in place, use putty or beeswax. See Fig. 3.

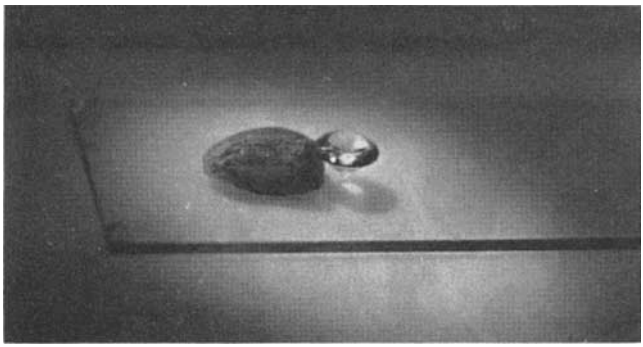

FIG. 3

Focus the microscope (25 × is a good mangification to use) on the table of the stone. See Fig. 4. This is easy because there is always dust on the table. Focus on a small particle of dust. Now zero the indicator using the adjusting screw. See Fig. 2.

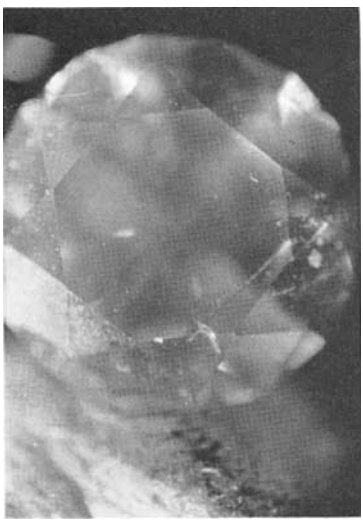

FIG. 4

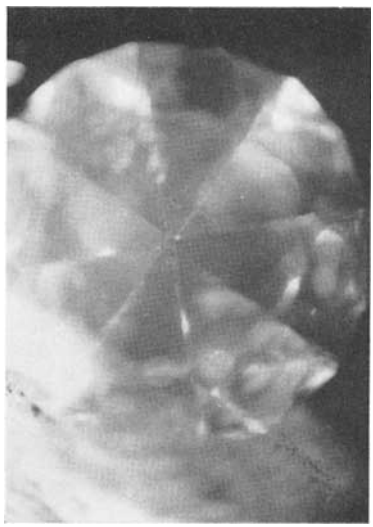

FIG. 5

The next step is to focus on the culet; this is not so easy, but with practice it can be done. (See Fig. 5). The reading on the dial is the apparent depth. Suppose the apparent depth reads 2·03 mm. The slide is moved laterally very slightly so you can focus the dust on top of the slide. Make sure you are not focusing

the dust on the bottom of the slide. The dial on the indicator is read again, 3·90 mm. This is the real depth.

To calculate the R.I. divide the real depth by the apparent depth according to the formula.

$$\text{R.I.} = \frac{3{\cdot}90}{2{\cdot}03} = 1{\cdot}92\text{—probably zircon (the Ordinary ray)}$$

I find that observational discrepancies make it advisable to take more than one reading. I usually take five readings and the average is taken. This takes less time than it sounds.

Below are a number of actual readings taken from several stones:

Blue Zircon: 6 mm round brilliant-cut

Real depth	Apparent depth	R.I.
3·90	2·00	1·95
3·86	2·00	1·93
3·90	2·03	1·92
3·89	2·02	1·93
3·92	1·99	1·97
		9·70/5 = 1·94

Diamond: ·33 ct. round brilliant-cut

Real depth	Apparent depth	R.I.
2·78	1·17	2·38
2·70	1·10	2·45
2·74	1·14	2·40
2·80	1·14	2·46
2·75	1·15	2·39
		12·08/5 = 2·42

White YAG: 1 ct. round brilliant-cut

Real depth	Apparent depth	R.I.
3·71	2·00	1·86
3·67	2·06	1·78
3·68	1·99	1·85
3·70	2·04	1·81
3·66	2·03	1·80
		9·10/5 = 1·82

Almandine Garnet: 4 mm round billiant-cut

Real depth	Apparent depth	R.I.
2·44	1·34	1·82
2·39	1·34	1·78
2·34	1·28	1·83
2·38	1·32	1·80
2·41	1·33	1·81
		9·04/5 = 1·81

Yellow Chrysoberyl: 1 ct. round brilliant-cut

Real depth	Apparent depth	R.I.
3·71	2·13	1·74
3·72	2·13	1·75
3·74	2·11	1·77
3·73	2·14	1·74
3·78	2·14	1·77
		8·77/5 = 1·75

Quartz: 6 × 8 mm cushion-cut

Real depth	Apparent depth	R.I.
7·38	4·76	1·55
7·47	4·78	1·56
7·42	4·78	1·55
7·41	4·76	1·56
7·47	4·82	1·55
		7·77/5 = 1·55

It is interesting to note some other uses for this instrument. The real depth of a mounted diamond which cannot be measured using a Moe or Leveridge gauge can be measured. Just rearrange the formula $\text{R.I.} = \dfrac{\text{Real Depth}}{\text{Apparent Depth}}$ to read Real Depth = R.I. × Apparent Depth.

Also one can read the diameter of the girdle of a stone by standing it up on edge on the slide.

I hope that someone who reads this will start thinking of a better method of doing it. It find it is quite useful.

Acknowledgement: to my son Lou for the photography.

Gemmological Abstracts

BALFOUR (I.). *Les plus gros diamants taillés dans le monde* (The largest cut diamonds in the world). Bulletin, Association Française de Gemmologie, 1973, 34, 6-9.

A list in tabular form of the 40 largest known cut diamonds in the world with their size, colour, cut and present owner, where known.

M.O'D.

BANK (H.). *Leucite, boracite, gaylussite.* Z. Dt. Gemmol. Ges. 1973, 22, 1, 33–38.

Transparent colourless and grey leucite from Italy was examined and it was seen that this stone is found in a cubic form (isotropic) and in a tetragonal form (anisotropic with slight double refraction). A transparent green boracite was examined; this stone is sometimes grey in colour and is found in Germany, U.S.A. and Bolivia, has a hardness of 7 and gets its name from its high content of boric acid. Two colourless, transparent stones were found to be gaylussite, a monoclinic soft ($2\frac{1}{2}$) stone with strong cleavage, making cutting difficult. The stones were found in Kenya, but are supposed to be found also in S.W.Africa, Venezuela and Nevada, and are produced synthetically in soda factories.

E.S.

BANK (H.), SAUL (J.), BERDESINSKI (W.). *Schleifwürdige Olivine aus Kenya* (Gem olivines from Kenya). Z. Dt. Gemmol. Ges. 1972, 21, 4, 216–218.

The authors describe a secondary find of olivines in Kenya; the stones were first thought to be cummingtonite and then recognized as forsterite. Characteristics similar to the Norwegian olivine which is also very rich in Mg.

E.S.

BANK (H.). *Blauer und dunkelgrüner durchsichtiger Lazulith aus Brasilien* (Blue and dark green lazulite from Brazil). Z. Dt. Gemmol. Ges. 1972, 21, 4, 219–221.

Opaque lazulite has long been known in Brazil. Now in the Minas Gerais there was a find of transparent blue lazulite in all colours from dark blue to green. The most important characteristics are listed.

E.S.

BANK (H.). *Die maximale Doppelbrechung als diagnostisches Merkmal* (Maximal double refraction as identifiable property). Z. Dt. Gemmol. Ges. 1972, 21, 4, 225–227.

The determination of the maximal double refraction is most important as this can be used as identification, especially together with minimum refraction. It was shown that it is not sufficient to take the reading along the length as well as the width of the stone, but that it is essential also to take a reading of the reverse side.

E.S.

CASANOVA (R.), SIMON (B.), & TURCO (G.). *A repeated twin in natural diamond from Tortiya, Ivory Coast.* Amer. Min., 1972, 57, 1871–1873. 2 figs.

The geometry of a cyclic twin has been established by X-ray methods. It consists of five tetrahedra in (111) twin position, all having a common [110] direction.

R.A.H.

CHERMETTE (A.). *La fluorine* (Fluorspar). Bulletin, Association Française de Gemmologie, 1973, 33, 11–15; 34, 12–15.

A review of fluorspar with an extensive account of its mode of occurrence and its main localities. Most attention is paid to the French occurrences and France is stated to be the world's fourth largest producer.

M.O'D.

DENNEN (W. H.) & PUCKETT (A. M.). *On the density and colour of amethyst.* Canadian Mineralogist, 1972, 11, 448–456.

The cause of colour results from the replacement of some silicon by ferric iron, with subsequent irradiation. The colour-

banding suggests changes in the growth environment, possibly involving a change from reducing to oxydizing conditions, a change in solution composition from Fe-poor to rich, Al-rich to poor, a rise in temperature and a drop in pressure.

M.O'D.

ELBE (M. G.). *Erstaunliche Schmuckeffekte an Brillanten* (Amazing gem effect in brilliant-cut diamonds). Z. Dt. Gemmol. Ges. 1972, 21, 4, 189–212; 1973, 22, 1, 1–23. 22 illus.; bibliography.

The effect of a brilliant-cut diamond is determined by the angles of the facets towards each other. The author suggests the use of angles which produce a higher reflection of the pavillion facets and claims this to have the optimal effect and also minimum weight loss. The rough stone is put to better use and also yellowish material is improved. The diamond is polished in an improved manner using a diamond-bonded wheel, the pressure on the stones being variable and two stones being polished simultaneously. A special new measuring arrangement is described, which carefully measures angles of facets and surface quality. To obtain the maximum brilliance from this new cut, it is important that the pavillion facets are not hidden by the setting. A suggestion for a suitable setting, holding the stone in four claws, is illustrated.

E.S.

EPPLER (W. F.). *Spodumene.* Z. Dt. Gemmol. Ges. 1973, 22, 1, 24–28.

The name spodumene derives from the Greek "spodios" = ash-coloured; the crystals being not very attractive and also not transparent. A transparent green crystal was found in 1879 in U.S.A. and named hiddenite; the rose-violet coloured variety, kunzite, was found in U.S.A. in 1902. The article deals with etch marks found in these two varieties and describes etch tubes, showing them in magnification of 30 ×, 65 ×, 194 × and 610 ×.

E.S.

FEININGER (T.). *Emerald mining in Colombia; history and geology.* Mineralogical Record, Winter 1970, 1, 4, 142–149.

An illustrated account of the present-day use of the mines comprising the National Emerald Domain of Colombia. Production is still greatly hampered by the activity of smugglers and it is

estimated that only 10% of the total output reaches commercial channels by approved routes. Details of the occurrence of emerald are given.

M.O'D.

HOGARTH (D. D.). *Lapis-lazuli near Lake Harbour, southern Baffin Island, Canada.* Can. Journ. Earth Sci., 1971, 8, 1210–1217. 4 figs.

Two occurrences of lapis-lazuli are recorded in marble near the cores of synforms in southern Baffin Island. The main occurrence covers an area of 3,500 m^2 and contains four zones. The lapis-lazuli consists mainly of haüyne, diopside, plagioclase, and calcite; phlogopite, nepheline, tremolite, and scapolite are abundant locally. The rock could have originated during metamorphism through an exchange of elements between evaporites and interbedded shales. The blue haüyne has an absorption maximum at 600 nm, but at best the absorption coefficient of unheated Baffin Island haüyne is about 2/5 that of average haüyne from Siberia; pale greenish blue haüyne from the smaller Baffin Island outcrop has a second absorption maximum at 400 nm. On heating in air for 30 minutes at 530°C the 600 nm peak is greatly extended and both green and blue haüyne become deep blue. The longest zone at the main occurrence could possibly supply commercial-grade gem and ornamental stone, although the fractured nature and pale colour are handicaps.

R.A.H.

LANDAIS (E.). *Absorción del berilo en el infrarrojo proximo. Su contribución a la diferenciación de las esmeraldas naturales y las suitéticas* (Absorption of beryl in the near infra-red region. Its usefulness in distinguishing natural from synthetic emerald). Boletin de la Asociacion Española de Gemologia, Oct./Dec. 1970, 2, 8, 7–14.

Although the author has been able to distinguish emeralds grown from the melt from the natural stones, it was not possible to do the same with those stones grown by the hydrothermal method. A low-voltage tungsten lamp with a special filter was used as the light source.

M.O'D.

LENZEN (G.). *Ein laser-gebohrter Diamant-Brillant* (A laser-drilled brilliant-cut diamond). Z. Dt. Gemmol. Ges. 1973, 22, 1, 39–41. 4 illus.

Description and photomicrographs of a 1·64 ct. diamond showing eight holes drilled by laser to remove black piqués. The colour of the stone was improved as the "coal" had been changed to white "snow", but the inclusions, i.e. drill holes, which were light in colour, were increased so that the stone was downgraded from 2nd piqué to 3rd piqué, although the overall appearance was lighter. It is suggested that the grading is not really altered by laser drillings.

E.S.

SANTOS MUNSURI (A.). *El jade* (Jade). Boletin del Instituto Gemologico Español, Sept./Oct. 1972, 1, 2, 10–22.

An account of the jades and their simulants, of which 22 are listed. Photographs in colour include the fibrous structure of nephrite magnified 750 times.

M.O'D.

THOMAS (A. E.). *Gem Trials of Rhodesia.* Lapidary Journal, 1973, 26, 11, 1654-1661.

The Miami mica fields and other workings for golden beryl, garnet, staurolite, tourmaline, aquamarine and amethyst are described. A map and photographs are included.

M.O'D.

WEBSTER (R.). *Photographic Techniques in Forensic Gemmology.* Forensic Photography, 1973, 2, 3, 2–8.

Contains a number of useful hints on the use of photography in the realm of the gemmologist. The difficulties and problems involved in photographing jewellery and inclusions in gemstones.

S.P.

BOOK REVIEWS

BECKWITH (J. A.). *Gem Minerals of Idaho.* Caxton Printers, Caldwell, Idaho, 1972. pp. 123, maps and illustrations in black-and-white. $2.95.

The state of Idaho is rich in gem materials. The Idaho batholith, which covers the central area of the state, and the mineral-rich basalts and andesites of the Hell's Canyon region provide garnet, opal, corundum and a number of quartz varieties. The Spencer opal mine is regularly worked and furnishes good-quality material. Other gemstones found include sillimanite (opaque varieties only), tourmaline and spinel. The book contains useful sketch-maps for field trips in gem-rich areas.

M.O'D.

BOLTIN (L.) and WHITE (J. S.). *Color under ground. The mineral picture book.* Charles Scribner's Sons, New York, 1971. Illus. in colour. pp. 62. $6.95.

One of the Scribner Portfolios in Natural History, this book does not consist entirely of high-quality photographs, but contains a useful and lucid introduction to mineralogy. The crystal systems are illustrated in diagrammatic form and each photograph caption includes details of the crystallization of the subject. The minerals covered include those which display the most attractive forms. There is a short bibliography.

M.O'D.

COX (K. G.), PRICE (N. B.) and HARTE (B.). *An introduction to the practical study of minerals.* McGraw-Hill Publishing Co., London, 1967. pp. vi, 233. £2.70.

The publishers have directed this book at first-year geology students and the text concentrates on the practical aspects of crystal and rock identification. Opening chapters cover the crystal systems and a particularly valuable treatment is given on the appearance of thin sections between crossed Nicols. A chart of the polarization colours is provided and the explanation is lucid. The commoner minerals and rock types are discussed with some useful text diagrams of modes of occurrence. This would be an excellent choice of text-book for the gemmology student who wishes to accompany gemmological studies with a degree of mineralogical knowledge.

M.O'D.

DRAGSTED (Ove). *Ædelstene i farver*. Politikens Forlag, Copenhagen, 1972. pp. 345. Illustrated in colour. Kr. 38.00.

An introduction to gem materials and gem-testing enlivened with spirited illustrations. Together with the customary data on crystal systems, which are particularly well illustrated, the author gives details on the setting of stones in jewellery. A large number of gem materials are reviewed in a separate section in which details of absorption spectra would have been welcome.

In the section on pearl, Lauegrams are illustrated, but examples of direct radiography, a method of testing more commonly employed, are omitted. This is a book for the alert jeweller rather than for the gemmologist. A comprehensive bibliography is provided, from which, however, journals are omitted.

M.O'D.

DRAGSTED (Ove). *Guld & aedlestene*. 3rd edition. Høst & Son, Copenhagen, 1972. pp. 114. Illustrated in colour. Kr. 39.50.

Accompanied by illustrations first used in 1953 and now, particularly those of opal, wearing badly, the text of this pocket-book reviews most of the better-known gem materials, giving the usual data with the exception of the absorption spectra where appropriate. A short bibliography is provided and basic testing techniques are described.

M.O'D.

HENRY (D. J.). *California gem trails*. 3rd revised edition. Lowell R. Gordon, Long Beach, California, 1957. pp. 101. Maps. $2.50.

A good example of the amateur prospector's pocketbook, this book loses somewhat through not providing an index of mineral species or of locations in alphabetical order. Useful descriptions and sketch-maps lead the reader right up to the gem-bearing spot. Minerals other than gems are included.

M.O'D.

LADURNER (J.) and PURTSCHELLER (F.). *More about minerals*. Pinguin Verlag, Innsbruck, 1972. pp. 187. Illustrated in colour. 229 schilling.

Nearly one-third of this attractive book is devoted to the study of the principles of mineralogy. Succeeding chapters describe the commoner minerals and there are tables in which the chemical

composition, crystal system, hardness, specific gravity, etc., are given for the species covered by the book. Refractive index is not given, nor is it included in the individual mineral descriptions. Apart from the high quality of the colour plates, a useful feature of the book is the provision of a diagram showing common habit by each mineral description.

M.O'D.

McConnell (D.). *Apatite*. Springer-Verlag, Vienna, 1973. pp. xvi, 111. Applied Mineralogy Series No. 5. U.S. $14.90.

A review of the crystal chemistry, mineralogy, utilization and geologic and biologic occurrences, this advanced book is written for the graduate student who wishes to study further in a field where a good deal of work remains to be carried out. Apatite has been synthesized to provide a single-component white phosphor for the fluorescent lamp industry. Hydrothermal production demands the rigorous exclusion of CO_2. Apatite has been found in lunar rocks, in one instance as inclusions within a new mineral, pyro ferroite.

M.O'D.

MacInnes (D.). *Synthetic gem and allied crystal manufacture*. Noyes Data Corporation, New Jersey, 1973. pp. 221. 42 line drawings. Cloth bound. $24.00.

An unusual book from which much information can be culled. It can best be described as abstracts from patents issued in the United States of America "sewn" together. This purely American aspect limits the story of synthetic gemstone production and is probably the reason why 105 pages are allotted to diamond syntheses and only 102 pages to the rest of the man-made stones.

The first recorded patents described are on synthetic sapphire and dated 1911, so that the opening sentence of the chapter on corundum which states, "The first synthetic gemstones of good quality were synthetic sapphires produced by A. V. L. Verneuil", is not completely true, for no mention is made of the earlier synthesis of ruby. A patent, ascribed to E. G. Sandmeier (Swiss Jewel Company) for "oriental emerald" (green sapphire) describes the use of cobalt oxide, vanadium oxide and a nickel salt. Other patents inform on the methods and apparatus used to produce rod, disc, and slab-shaped boules, and there is one patent describing the hydrothermal growth of corundum.

A patent of 1971 describes a method of producing single crystals of corundum by a "casting" process; and another, by R. A. Dugdale (United Kingdom Atomic Energy Authority) describes a sapphire growth technique using an electron beam process. Some mention is made of various methods of producing a surface gloss on rod boules and other shapes, and on surface coatings for the protection of the polish of different materials. There are patents describing the production of asteriated corundum, and one which tells of the production of star rutile by the addition of magnesium oxide to the boule. Little to do with synthesis are the star stones produced by scratching fine lines at 60° on the base of synthetic and other materials cut as cabochons, and a composite stone has the fine lines engraved on the rear surface of the central part of the triplet.

A three-tube burner is used for the growth of synthetic rutile and other titanium gems. It is interesting to note that there are variations in the distribution of the gases through the tubes in some cases. For rutile the inner tube carries the oxygen and feed powder, the intermediate tube the hydrogen and the outer tube oxygen so as to give an excess, but in some of the methods patented for the growing of other titanium crystals the excess oxygen is carried down the intermediate tube and hydrogen through the outer tube, and this has a larger relative diameter. The resultant boules are black and need subsequent heat treatment to produce the transparent material. There are patents mentioned on the production of strontium titanate and on titanates of other metals in colourless and coloured boules.

The production of single crystals of lithium niobate by the Czochralski "pulling" method is mentioned and so are patents on the hydrothermal growth of many crystals, many of which are not gem materials. The flux growth of synthetic emeralds is covered by the report of only one patent, that of the Union Carbide Corporation granted in 1967. There is no mention of Chatham's flux method —it was believed not to have been patented—nor of Linde's hydrothermal production.

The patents on the diamond syntheses by the General Electric Company of America being more recent are well covered and thus provide a very good understanding of diamond synthesis. There are, too, reports of syntheses in other countries which have patented their processes in the United States. Such are those of Sweden, South Africa and Japan. Patents describing some "off-beat" methods of

diamond synthesis are discussed and there is a section on the modification of the colour of diamonds by radiation. A method of colouring diamond by radiation from Americium 241 is mentioned. This treatment is said to produce stones of a natural green colour and, after heat treatment, a very good shade of gold. The colours produced are stated to be better than those obtained with cyclotron or pile treated stones. The report states that the diamonds irradiated by this means to an emerald green colour show absorption bands at 4980Å and 5040Å and an absence of the 5920Å line and therefore the spectrum is that of naturally occurring diamonds and unlike those of pile or cyclotron treated diamonds. The reviewer cannot agree with this for it is only the "greened" diamonds which have subsequently been heat-treated to yellow which show the 5920Å line (now remeasured as 5940Å).

There is no general index, the Table of Constants, which is more comprehensive than usual, being considered to be all that is necessary. There are short indexes of inventors names and of United States patent numbers.

The book provides much valuable information on the technical production of gem crystals, but being confined to United States patents only it loses much of the colourful history of gemstone synthesis. The gemmologist would find the omission of any information, or even a table, of the constants of the crystals discussed rather irksome and a major defect.

R.W.

OLES (F. and H.). *Eastern gem trails.* Gembooks, Mentone, California, 1967. pp. 80. $2.00.

Written as an account of personal experience in gem exploration, this book also serves as a useful guide to the gem areas of the states of New Jersey, Pennsylvania, North Carolina, Maryland and Virginia. Celebrated localities include Cowee Creek, Amelia Court House, Franklin N.C. and Franklin N.J. Photographs of some of the areas are included and there are some maps.

M.O'D.

VARGAS (G. and M.). *Descriptions of gem materials.* Desert Printers, Palm Desert, California, 1972. pp. x, 155. $7.50.

An alphabetical list of gem materials, giving in each case the chemical composition, crystal system, hardness, specific gravity,

colour, critical angle, refractive index and birefringence, cleavage, dispersion where appropriate and optic sign. Care has been taken to ensure the accuracy of the constants quoted and the authors add useful details of locations, rarity and suitability for cutting. There is a separate section on synthetics which states that zincite has been synthesized in a yellow colour. Concluding sections list materials under their specific gravity, refractive index and under alternative names.

M.O'D.

WARRING (R.). *Rock collecting and making semi-precious jewellery.* Stanley Paul, London, 1972. pp. viii, 112. Illus. in black-and-white and colour. £2.60.

The greater part of this book covers techniques already quite well dealt with in other contemporary works. Unfortunately this section, which is at least unexceptionable, is preceded by an introduction to the gem species which is loosely written and in part inaccurately illustrated. The diagram of the crystal systems does not distinguish the orthorhombic and monoclinic systems; the supposedly twinned quartz is not a twin. Streak is included as a test in a section dealing specifically with gem materials; some exotic specimens occur in the list of gemstone materials, presumably for making into jewellery—they include alunite, anglesite, and jamesonite. Chrysoprase is wrongly spelt. It would seem that out-of-date textbooks have been uncritically raided for the bulk of the information contained in this unsatisfactory book.

M.O'D.

WRIGHT (R. V.) and CHADBOURNE (R. L.). *Gems and minerals of the Bible.* Harper & Row, New York, 1970. pp. xii, 148. $4.95.

Sixty-two materials, not all gems, are reviewed in this interesting book. Each material has a section headed by a description of its nature and properties and a passage from the Bible in which it is mentioned. The Biblical references are not extensive and somewhat uncritical, while the greater part of each entry is devoted to a general account of the stone. The stone "bdellium", which has puzzled scholars, is here surmised to be opal. Historical notes, other than biblical, on the stones are useful. A select concordance would have been useful.

M.O'D.

ASSOCIATION NOTICES

MEMBERS' MEETINGS

London

Mr. Julius Petsch, Jr., Idar-Oberstein, gave a talk, illustrated by many colour slides, to members at Goldsmiths' Hall, London, on Tuesday, 17th April. A full report is given on page 265.

Scottish Branch

The Annual General Meeting of the Branch was held on the 12th April at the North British Hotel, Glasgow. Mr. A. Armstrong and Mr. G. M. Turner were re-elected Chairman and Secretary respectively.

GIFTS TO THE ASSOCIATION

The Council of the Association is indebted to the following for gifts presented to the Sir James Walton Library:

Mr. M. J. O'Donoghue, M.A., London, for a copy of the 1965 edition of Theophrastus' *De Lapidibus*, edited with translation and commentary by D. E. Eichholz.

Mr. E. F. Borgatta, Ph.D., Vermont, U.S.A., for specimens of rough peridot from Arizona with "flying saucer" inclusions—as mentioned in T. F. Zook's article in the *Journal*, Vol. 13, No. 4 (October 1972), p. 133.

Mr. Robert Webster, London, for a specimen of lithium niobate and a large piece of turquoise matrix from St. Austell, Cornwall.

OBITUARY

The Council of the Association has noted with deep regret the death, in February of this year, of Dr. Edward H. Kraus, Ph.D., Sc.D., who had been Vice-President of the Association since 1956. Dr. Kraus celebrated his 97th birthday in December 1972.

GORDON F. ANDREWS

On Tuesday, 20th March, members of the Council of the Association, together with the Council of the National Association of Goldsmiths, attended a dinner held at Goldsmiths' Hall, London. The occasion was to honour Mr. Gordon F. Andrews on his retirement as Secretary. It was a most enjoyable and memorable occasion and the President presented Mr. Andrews with a cheque to which many members throughout the world had subscribed.

Mr. and Mrs. Andrews at Goldsmiths' Hall.
(photo by courtesy of the *Watchmaker, Jeweller and Silversmith*).

ANNUAL GENERAL MEETING

The 43rd Annual General Meeting of the Association was held on Wednesday, 2nd May, 1973, at Saint Dunstan's House. Mr. Norman Harper, Chairman, presided, and in commenting upon the work of the year said:

"Although mentioned in the annual report, I would like to thank the Officers and Secretaries of the Midlands and Scottish

Branches. They were very active during 1972 and held a number of interesting meetings and outings. The Midlands Branch was most enterprising in arranging a successful day-trip to Amsterdam. The Council decided last May that each Branch Chairman should be invited to Council meetings during his year of office.

"Once again entries for the examinations were very high, with a large proportion of overseas candidates. Mr. Alan Jobbins was awarded the Tully Medal and prize and I will have the opportunity very shortly of welcoming him as a member of the Council.

"During the year various gifts were made to the Association, from books to gem specimens (both as crystals and cut stones). Gemmological Instruments Ltd., the subsidiary company which acts as distributory agents for Rayners, gave the Association a diamond refractometer. The new Dialdex refractometer produced a few teething problems with production which, with the large number of orders, has resulted in a delivery delay of about six months. Everything possible is being done by Rayners to reduce this period.

"On a sad note, M. Georges Gobel, who was Director of the Paris Gem-Testing Laboratory for many years, died in July. He was one of the very few persons elected to Honorary Fellowship of the Association.

"As you are all aware, Mr. Gordon Andrews announced that he would be retiring as Secretary of the Association in 1973, and it was decided to ensure that his close interest was maintained by appointing him Librarian. In fact, Gordon Andrews has now retired as Secretary and Mr. Harry Wheeler has taken up the post in his place. His brother, Mr. Douglas Wheeler has been appointed Assistant Secretary."

Mr. David Kent seconded the adoption of the Annual Report and Accounts. Dr. G. F. Claringbull, Ph.D., F.Inst.P., F.G.S., was re-elected President; Mr. Norman Harper was re-elected Chairman; Mr. Douglas King was re-elected Vice-Chairman; and Mr. F. E. Lawson Clarke was re-elected Treasurer. Miss I. Hopkins and Messrs. J. M. B. McWilliam and P. W. T. Riley were re-elected, and Mr. E. A. Jobbins, B.Sc., elected, to serve on the Council.

The Chairman announced that Messrs. Watson Collin & Co., chartered accountants, had signified their willingness to continue as auditors.

On behalf of the Association, the Chairman then took the opportunity of expressing thanks to the Goldsmiths' Company for

placing at our disposal various rooms at Goldsmiths' Hall for meetings.

DIAMOND AND PRECIOUS STONE BOURSE IN IDAR-OBERSTEIN

A new diamond and precious stone bourse will be opened in the old gem trading and cutting centre of Idar-Oberstein in western Germany early in 1974. The building will be 22 storeys high. There will be a large hall suitable for holding auctions, as well as large safe deposits, Post Office, banking and insurance facilities and two exhibition halls, one used for samples of stones, jewellery and fancy goods for the convenience of customers, the other for an extensive exhibition of gemstones and gem materials open to the public.

Some of the floors are reserved for offices and showrooms; these are already partly let to firms in Idar-Oberstein and from other places in Germany and from abroad. The upper storeys will house a hotel with 170 bedrooms, conference rooms, a restaurant and bars.

It is hoped that the bourse will not only get wide-spread local support, but will make its contribution to the international market.

NOTTINGHAM AND DISTRICT

It is proposed to form a Nottingham and District Branch of the Association and to hold an inaugural meeting in September. Will any member who is interested in the formation of such a branch communicate with the Secretary, Gemmological Association, Saint Dunstan's House, Carey Lane, London EC2V 8AB.

INCLUSIONS

The Association Française de Gemmologie (Paris) has produced a plastic folder containing 48 coloured slides on 35-mm. film, each in a separate pocket in four "pages". They illustrate the inclusions seen in gemstones and have been produced for readers of the French Gemmologists' Association's journal. The slides are extremely good as regards colour, the choice of inclusions and the photography. The slides illustrate inclusions in diamond, natural and synthetic ruby and sapphire, emerald and synthetic emerald, of which a highly magnified picture shows a spectacular view of three-phase inclusions in a Colombian emerald. To compare with

the emerald inclusions there are slides of a green doublet, a green paste and one of green fluorspar. Other slides illustrate inclusions in aquamarine, garnet, morganite, topaz, tourmaline and spinel. The slide of chrysoberyl cat's-eye seems to have been photographed with the notion of producing a dual effect (the inclusions and the cat's-eye streak) and the result is less successful than the rest of the slides which are so very good. There are two slides of amethyst which show similar inclusions and it might have been better to have replaced one of these by a slide showing the "tiger-stripes" so characteristic of amethyst. The beautiful slides of a "sunburst" of asbestos fibres in a demantoid garnet, masses of profilated bubbles in a synthetic corundum, the banding in a citrine, and the slide of zircon which shows not only the inclusions but also the facet edges doubled, make informative teaching slides. There are slides of moss agate and another showing the flakes of green fuchsite mica in an aventurine quartz. A colourful slide of opal makes an excellent finale. The folders are available from the Association Française de Gemmologie, 163 Rue Saint Honoré, Paris 1, France, price £10 sterling.

COUNCIL MEETING

At a meeting of the Council of the Association held on Tuesday, 17th April, 1973, the following were elected to membership:

Fellowship

Garcia I Ainoza, Joan, Barcelona, Spain. D. 1972
De Fatima Granda, Maria, Barcelona, Spain. D. 1972
Ferrandiz Torrents, Pedro, Barcelona, Spain. D. 1972
Margarit Morant, Eugenio, Barcelona, Spain. D. 1972
Marin Calvo, Maria Luisa, Barcelona, Spain. D. 1972
Munoz Aisa, Maria Teresa, Barcelona, Spain. D. 1972
Pujante Garzon, Francisco, Barcelona, Spain. D. 1972
Ratera Oliva, Jaime, Barcelona, Spain. D. 1972
Willams, Robert, Birmingham. D. 1971

Ordinary

Barlow, Peter Lewis, Lusaka, Zambia
Beng, Goh Kong, Petaing Jaya, West Malaysia
Bristol, Anthony Paul, Peterhead, Scotland
Bruder, Edward Roy, Brighton

Carter, William Nicholas Fox, Nr. Bracknell
Chapomba, Charles Nash, Blantyre, Malawi
Clayton, Rosamond Susan, Hong Kong
Cross, Willam Henry, Stone Mountain, Ga., U.S.A.
Dean, Joseph John, Ossett
Din, Richard Aziz, Edgware
Douglas-Irving, Ian, St. Georges, South Australia
Dunn, Harry Lee, Endwell, N.Y., U.S.A.
Faulkner, William, Gt. Missenden
Forsey, Stella Ann, Wellington, New Zealand
French, Frank Geoffrey, Wallington
Furumiya, Minoru, Osaka-Fu, Japan
Gray, Sheila Margaret, Crooksbury, Surrey
Gustin, Irene, Hong Kong
Haji, Mohamed, Tanga, Tanzania
Harris, Margaret Rose, Pulloxhill, Beds.
Henmi, Naomitsu, Sinagawa-ku, Japan
Hewitt, Leonard Eric, Lincoln
Inoue, Kazuo, Setagaya-ku, Japan
Inoue, Shigekichi, Nagahama-shi, Japan
Janot, Bernard, Melun, France
Jermansky, Irving, Miami, Fa., U.S.A.
Kawakami, Sadaharu, Kofu-shi, Japan
Kobayashi, Hisatsugu, Kofu-shi, Japan
Kobayashi, Sachiko, Kofu-shi, Japan
Levi, Lennart, Sollentuna, Sweden
Lim, Lily, Petaling Jaya, West Malaysia
McLaughlin, Edward Peter, Glasgow, Scotland
Matsuda, Katsuyoshi, Marugame-shi, Japan
Miller, Charles R., Southfield, Michigan, U.S.A.
Need, Mary, Lelant Downs, Cornwall
Nercessian, Arminé, Rio de Janeiro, Brazil
Nicol, William Maxwell, Dunstable
Nolan, John Gordon, Bradford
Paine, Thomas Hallsten, Everett, Washington, D.C., U.S.A.
Przybyla, Christopher, Whitehaven
Rooney, Eugene A., Alexandria, Virginia, U.S.A.
Round, Anthony William Reginald, Epsom
Shah, Anita, London
Takagi, Takashi, Tokyo, Japan
Turner, Oswald Edward, Port Elizabeth, S. Africa
Van der Laan, George, Utrecht, Holland
Wailes, Rosemary Margaret, Hong Kong
Yamaguchi, Takashi, London
Yamamoto, Satoru, Yamaguchi-ken, Japan

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THE JOURNAL OF GEMMOLOGY

and

PROCEEDINGS OF THE
GEMMOLOGICAL
ASSOCIATION
OF GREAT BRITAIN

GEMMOLOGICAL ASSOCIATION
OF GREAT BRITAIN
SAINT DUNSTAN'S HOUSE, CAREY LANE
LONDON, EC2V 8AB

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THE JOURNAL OF GEMMOLOGY
AND PROCEEDINGS OF THE GEMMOLOGICAL ASSOCIATION OF GREAT BRITAIN

Vol. 13 No. 8 OCTOBER 1973

BLUE BERYLS WHICH ARE NOT AQUAMARINES

By A. E. FARN, F.G.A.

THE blue beryls seen recently upon the market were first tested by the Laboratory in September 1972. We reported upon the stone tested as "blue beryl". Our customers wanted "aquamarine" on the certificate, but we decided it was not an aquamarine colour. The colour of that first stone was that of fine blue zoisite or a deep-colour synthetic blue spinel. Even now, having seen quite a few, they still look wrong or, to put it a little more elegantly, not a colour which looks natural.

This is personal opinion only. In earlier days of post-diploma classes conducted by B. W. Anderson at Chelsea Polytechnic and later at Northern Polytechnic, he, B. W. Anderson, would put in among the stones to be tested some blue beryls from Madagascar. These did not look like aquamarines but were put in to check student reaction to such a blue-colour stone having beryl indices. Since most of our post-diploma students were trade people none put down their results as aquamarine—all put blue beryl. The trade knows and understands what is meant by aquamarine and the colour thereof.

From information given by members of the Laboratory to us on the eventual disposal, i.e. selling and re-selling, of the blue beryl we reported upon, it seemed that some doubts had been raised on the Continent regarding colour. Were they naturally occurring heat-treated beryl or had they been irradiated?

We are fortunate in the Laboratory, in that we have friends on the Continent and in America—friends, that is, gemmologically, and friends such that they are concerned in helping to establish good relations and not trying to vie one with the other or to score points. Needless to say we are all proud of our own particular establishment and each of us has certain strong points. We in Britain owe a tremendous debt to people such as C. J. Payne, Robert Webster and B. W. Anderson, for furthering the knowledge, teaching and science of gemmology.

Among the many useful specimens collected by B. W. Anderson is a piece of pale blue rough material known as "Maxixe Beryl" from the Maxixe Mine (Minas Gerais, Brazil). This particular specimen was donated to B. W. Anderson in 1936 by G. O. Wild, who claimed it as a new mineral in 1933. The Maxixe Mine was then a recent discovery. The figures regarding this material are given as follows: Ordinary ray 1·5920 (cobalt blue), Extraordinary ray 1·58442 (colourless), S.G. 2·805 (B. W. Anderson gives 2·797); and it is stated that the colour fades to yellowish. It is well to remember that stones which fade easily will also be susceptible to treatment and will respond to re-heating or re-irradiating. Zircons which fade to a poor blue can sometimes be improved by heating; pale amethyst can be heat-treated to turn to a permanent golden brown.

The chemical analysis of the Maxixe material was given as:

SiO_2	=	62·52
Al_2O_3	=	18·08
BeO	=	11·30
Fe_2O_3	=	0·03
MgO	=	0·25
CaO	=	0·22
CuO	=	trace
Li_2O	=	0·98
Na_2O	=	1·28
Cs_2O	=	2·80
B_2O_3	=	0·39
Ignition	=	2·20

Since doubts had been expressed upon the nature of the colour in these blue beryls which are now appearing upon the market it was decided to make enquiries. Once a new material or apparently new material arrives, it is not long before interested

parties, i.e. stone-merchants and gemmologists, both amateur and professional, begin to converse, contact and cross-reference each other. B. W. Anderson, who is now in retirement, was asked for his old specimen of Maxixe beryl by Robert Crowningshield of the G.I.A. Laboratory, New York. He, Crowningshield, had received blue beryls to test and he made use of fellow scientists Kurt Nassau, Ph.D., and D. L. Woods, Ph.D., of Bell Laboratories, Murray Hill, New Jersey, U.S.A.

The findings from the researches of these two scientists and notes on "Colour centres" are published verbatim (on pages 296–301 below) by kind permission of the Gemological Institute of America, whose New York director, Robert Crowningshield, speedily sent us all the information he could.

It is interesting to note at this stage that the first blue beryl tested by our Laboratory for a London Chamber of Commerce member started the ball rolling. It is not a betrayal of confidence at this juncture to state that our present Chairman of the Precious Stone Trade Section has recently had blue beryls tested by us. It is also interesting to note that the vendor of the blue beryls was the original vendor of our first blue beryl tested in September 1972. He, the vendor, made a personal visit to the Laboratory and I made tests upon several very fine blue beryls belonging to him. He states categorically that his stones are *not* irradiated and that they are mined in that colour. We saw one piece only of rough material, which obviously was not cuttable but looked reasonably like the cut material. When we placed cut specimens and the rough piece under our short-wave lamp, the cut specimens gave a greenish blue fluorescence and the rough piece did not.

We have tested quite a few blue beryls since September 1972. Recently, because of statements by scientists and mine-owners, we are wording our reports in a manner such that people will be afforded a fair observation upon blue beryls. One other slightly puzzling item is that the Brazilian owner of the Blue Beryl mine also told me that no one (presumably in Brazil) knew the whereabouts of the Maxixe Mine.

Following on from this preamble of Blue Beryls is the account of investigations conducted for the G.I.A. by the Bell Laboratories scientists. Our own findings of the blue beryls are 1·580–1·586 with a strong absorption band at about 6850Å. This line is easily seen by hand spectroscope but not easily measured.

EXAMINATION OF MAXIXE-TYPE BLUE AND GREEN BERYL

By K. NASSAU, Ph.D. and D. L. WOOD, Ph.D.

Bell Laboratories, Murray Hill, New Jersey 07974

ABSTRACT

Blue Maxixe beryl, kept in the dark since 1917, and current blue and green beryl (see R. Crowningshield, Gems and Gemology, Vol. 14, #4 Winter 1972) showing similar characteristics have been examined by absorption spectroscopy, gamma-ray spectroscopy, chemical analysis, and light, heat, and irradiation treatments. All three show an anomalous dichroism (the ordinary ray is more blue than the extraordinary ray, while in aquamarine the reverse is true) and an unusual narrow-band spectrum in the red and yellow regions. In all three cases the colour is bleached by exposure to daylight or on heating and can be recovered by neutron or gamma-ray irradiation. A colour-centre not involving a transition metal such as Fe, Co, Cu, etc. is indicated. Examination of 23 faceted "sapphire"-blue beryl gemstones by gamma-ray spectroscopy indicates that three had definitely been coloured by neutron irradiation; the others may or may not have been treated by irradiation.

INTRODUCTION

About 1917 blue beryl was found in the Maxixe mine in Minas Gerais, Brazil, which had the following unusual properties: it showed a strong anomalous dichroism, a narrow-band absorption spectrum for the ordinary ray which produces a pronounced "sapphire" or "cobalt" blue (distinctly different from the blue of aquamarine beryl); and the colour faded on exposure to light.* These and other properties were reported in 1933 and 1935.[1,2,3] We consider any beryl to be "Maxixe-type" beryl if it shows these three unusual properties: dichroism with blue in the ordinary ray; narrow-banded absorptions in the ordinary ray spectrum; and bleaching on exposure to light or heat. Some recent material of this type has become available, and our attention was drawn to the unusual absorption spectrum by Mr. R. Crowningshield.

*After a brief period of "a lively trade"[1] "there resulted much unpleasantness"[2] (authors' translation).

Experimental

We have examined in detail the following: a piece of the original Maxixe find that has been kept from extended exposure to light since 1917, courtesy of Mr. B. W. Anderson; 23 specimens of currently commercially available deep blue faceted stones (ranging from four to ten carats in weight) as well as blue rough, from an unspecified locality said to be in Brazil; and three dark green stones and some dark green rough, possibly from the same current locality. All exhibit the three properties just mentioned. Although there were some minor differences, all these specimens showed pronounced blue/colourless, blue/pale pink, or green/yellow dichroism with a similar characteristic ω spectrum in the 5000 to 7500 Å region as shown in Fig. 1.

Permission was obtained to expose to light four current deep-blue stones, current deep-blue and green rough, and part of the old Maxixe rough (either to daylight with intermittent sun or to a 100-watt frosted tungsten light bulb at a distance of six inches in an air-conditioned room). After one week all had faded significantly, ending with only about half of the original colour or less. The bleaching was then completed by heating to a maximum of 235°C. (450°F.) for 30 minutes, resulting in a yellow or pale pink colour. By comparison, aquamarine is customarily heated to a much higher temperature (400°C.-750°F.) to improve the colour, which remains stable to light.[4]

Examination of all the specimens by gamma-ray spectroscopy using a lithium drifted germanium detector indicated in three of the faceted stones the presence of a small amount of Caesium-134, a radioactive species with a half life of 2 years. This is absent in nature, but produced by neutron irradiation of natural Caesium-133 in the specimens. These stones must therefore have been treated by neutron irradiation. The other specimens did not show this behaviour and have probably not been irradiated with neutrons. On heating one of the partially bleached cut stones to 150°C. for 30 minutes there was no significant further change in colour. However, after 30 minutes at 200°C. (about 400°F.) only a very pale pink colour remained. Neutron irradiation (15 minutes at 10^{13} neutrons/cm^2/sec) now returned the stone to a blue colour even deeper than its original colour. Another similar stone (blue/pale pink dichroism), when heated by Mr. R. Crowningshield,

bleached completely to pale pink in less than 30 minutes at 95°C. (200°F.). This stone was exposed to gamma-rays (2×10^7 rads from Cobalt 60) and also turned deep blue. This gamma-ray irradiation does not leave any evidence of treatment, producing the usual characteristic ω spectrum. As expected from the ease of heat bleaching, this stone also bleached very rapidly in light (significantly in only 15 hours).

The green material, when bleached to a deep yellow by sunlight, could be returned to green by neutron irradiation, to a weak blue/green by X-rays, but was hardly changed by gamma-rays from Cobalt 60. The re-coloured material (both blue and green) could be bleached again by light. The green could also be changed to yellow by a 30 minute heat-treatment at 150°C., while heating to 400°C. removed the yellow colour as was previously noted in an ordinary yellow beryl[5]; neutron irradiation returned this colourless material to green.

Analysis showed a high iron-content in the green material (about 0·2%), but essentially none in the old Maxixe sample (0·000X%). This is consistent with the spectral evidence that the deep yellow component is due to Fe^{3+} in the octahedral Al site[5], and indicates that Fe is not involved in the narrow-banded ω spectrum. Other transition metals such as Co, Cu, etc., are essentially absent. Since the blue material can be bleached by exposure to light or quite low temperatures and recovered by irradiation, a colour centre[6] (see Appendix) not involving a transition-metal ion is indicated. The minor differences in the spectra in Fig. 1 may well be associated with differences in the total alkali content, the old Maxixe being high (about 2%), the green low (less than 0·1%).

Neutron irradiation was also tried on several of the beryl specimens used in our previous study.[5] One of these, a colourless beryl (#451 of Ref. 5) showed a faint blue colour after irradiation, and on examination showed a weak ω spectrum of the Maxixe-type. Accordingly it appears that not any beryl can be irradiated to give a Maxixe-type colour, but neither does it appear to be necessary to have material from a unique location. Investigation on this point is continuing.

Conclusions

There is some variation in spectrum, iron content, alkali

content, colour, and rate of bleaching by either light† or heat. Nevertheless, in contrast to the many ordinary varieties of beryl known over the centuries, these specimens show sufficient similarity to merit a common designation, and we have used the term "Maxixe-type" based on the first reported occurrence.[1,2,3] At present there is not enough information to decide if this type of material originates from one or several localities. It appears that the colour of some of this material may be as originally found, although some material has definitely been neutron irradiated either to form the colour, to improve the colour, or to return colour which has been bleached by exposure to light or to heat. Some or all of the rest may have been coloured by gamma-rays.

Based on the observations here reported we believe that any blue or green beryl (particularly if the blue colour is of the "sapphire" type) showing anomalous dichroism with the blue colour in the ordinary ray and sharp absorption bands for the ordinary ray in the 5000 to 7500 Å region (Fig. 1 and Ref. 7) should be designated as "Maxixe-type". Such a beryl will fade, either on exposure to light or on heating. Such a beryl may or may not have been irradiated with neutrons or with gamma-rays. It is in fact not possible to determine whether a given stone has been treated or how fast it will fade.

In the words of Mr. Crowningshield ". . . potential buyers should be alerted to the possibility that any stone of this type, which they consider, may fade too rapidly to be a satisfactory jewellery stone".

Our investigation is continuing and a detailed report will appear in the Lapidary Journal, together with colour illustrations.

ACKNOWLEDGMENT

We are grateful to B. W. Anderson of the Laboratory of the London Chamber of Commerce, England, for the original Maxixe specimen; to R. Crowningshield of the Gemological Institute of America, New York City, for arranging for the loan of the faceted blue stones, for helpful discussions, and for obtaining for us the green rough and stones from Mr. H. Rubin of the Gemset Co. of New York City, as well as to S. S. Voris for the gamma ray and Miss B. E. Prescott for the optical spectroscopy.

†A large intensely coloured gemstone may need more than a week in bright sunlight (or 150 hours at 6 inches from a 100-watt frosted light bulb) to show pronounced fading.

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APPENDIX: *A Note on Colour Centres*

Most of the colour in gems and minerals is caused by unpaired electrons in major ingredients such as the copper in malachite and turquoise, or in impurities such as the chromium in ruby and emerald or the iron in aquamarine and citrine. Alternatively there is colour caused by physical structure, as in opal and labradorite (the optical diffraction-grating effect).

But in some materials, where there is no such colour-causing ingredient or physical structure present, it is possible for "colour centres" to cause a variety of colours. Colour centres have been studied intensively, but only few have been understood. Frequently this involves a vacancy (omitted atom) or some other type of defect (sometimes an impurity) which can hold (but does not of itself possess) an unpaired electron.

Examples of colour centres occur in halite or sylvite (made purple to black by various treatments), fluorite (green, purple, etc.) and smoky quartz. A frequent characteristic of colour centres is that exposure to light or to relatively low temperatures may permit the unpaired electrons to pair off, thus removing the colour. Irradiation by X-rays, neutrons, or some other form of penetrating radiation may cause the colour to return by unpairing the electrons again. An unusual, only partly understood colour centre is involved in the amethyst form of quartz which also contains iron as an impurity. Amethyst is turned yellow or green by heat, and can be recoloured with X-ray irradiation. However not just any quartz coloured green or yellow with iron will go to amethyst with irradiation—some specific defect must still be associated with the iron impurity. Synthetic quartz containing iron must be grown in one specific direction to produce this specific colour centre and enable amethyst to be produced on subsequent X-ray irradiation. The colour of amethyst is unusually stable for a colour centre, although it will fade over a period of many years or in hours at

400 to 600°C. The relative ease with which the colour is produced by X-rays is consistent with this stability to light and to heat.

In the case of the deep-blue beryl there does not seem to be any specific impurity present. It is likely therefore that a vacancy is involved which can hold an unpaired electron. The relative ease of fading implies that the electrons pair off readily, and the difficulty of returning the colour is consistent with this instability.

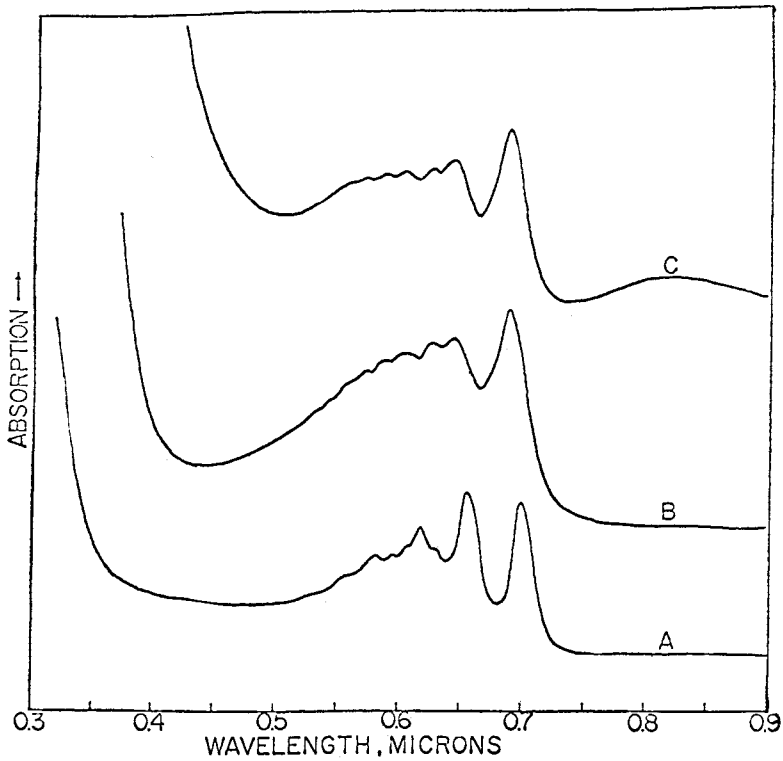

FIG. 1. Absorption spectra of Maxixe-type beryls: (A) 1917 Maxixe specimen; (B) current blue faceted stone; (C) current green rough. Ordinary ray only; extraordinary ray lacks any absorption in the 0·5 to 0·75 micron (5000 to 7500A) region.

SAPPHIRE MINING IN CHANTABURI (THAILAND)

By J. A. L. PAVITT

THAILAND, or Siam as it was formerly named, is a well known source of sapphire, ruby, star-sapphire and zircon, and over the years the skill of the Thai lapidaries has advanced to a very high degree, making Bangkok, the capital city, an important centre for the supply of cut gemstones.

There are a number of gem mining localities in Thailand, many of them in remote areas, but the mines at Chantaburi (also known as Chantabun), 200 miles from Bangkok, can be reached by car in five and a half hours, and soon after our arrival in Thailand in 1971 my wife and I made our first visit to Khau Ploi Waen, or "Hill of the Sapphire Ring", as this mining area at Chantaburi is named. I have since made further visits, the most recent in January 1973 with Mr. Kenneth Parkinson during his two week visit to Thailand.

Chantaburi has a very special place in the history and culture of the Kingdom of Thailand. Situated near the coast, only thirty miles from the border with Cambodia, its inhabitants, although loyal and proud Thai nationals, have ethnic origins connecting many of them with the diverse civilizations which existed thousands of years ago between the borders of China and the Mekong Delta. These origins are still evident in the customs, skills, religions and dialects to be found among the people of this fertile eastern region of the Kingdom.

It was at Chantaburi that King Taksin marshalled his forces after the fall of the ancient city of Ayuthya, and finally defeated and drove out the Burmese invaders. Close to the sapphire mines one can see the rusting cannon and remains of the fortress of King Rama III (1787-1851).

The gem-bearing deposits at Khau Ploi Waen are about six miles south of the town of Chantaburi, near the village of Ban Kacha. Past records indicate that in 1850 the Shans and Burmese were extracting sapphires here and that in 1895 a British Company obtained a lease but failed to make a success of the venture. In 1919 the Siam Mining Act came into force and since then mining has been solely in the hands of Thai nationals.

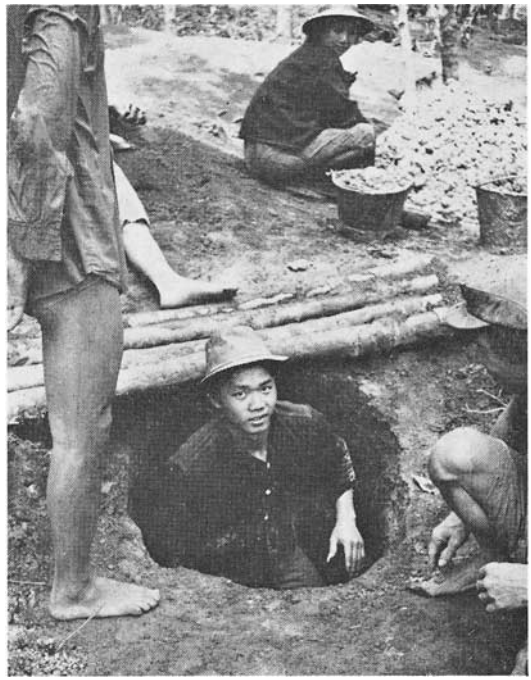

FIG. 1. Typical sapphire mine shaft at Khau Ploi Waen.

The mining area is privately owned and has been cleared of primary growth and planted with rubber trees, although it is obvious that an income from rubber tapping is of minor importance. A lease to dig for gemstones over an area of one "rai" (approx. 0·4 acre) for one year is granted by the landlords for a fee which may be as high as Baht 300,000 (£6,000) for high yield areas which have not previously been worked. A lease area is usually shared by groups or families and there are said to be some 2,000 people mining around Khau Ploi Waen.

The method of extracting the stones is very primitive, as are the tools—a pick, a spade and a rattan basket. A vertical shaft of about four feet in diameter is dug in the red/brown clay soil, in between the rubber trees (see Fig. 1). These vertical shafts sometimes go as far as thirty feet deep and each basketful of soil is lifted to the surface by a crude, but effective, crane arrangement consisting of two bamboo legs and a long bamboo derrick arm with a rope and

FIG. 2. A bamboo crane used for lifting soil from the mine shafts.

basket at one end and a counterbalance of large stones tied to the other end (see Fig. 2).

When a gem-bearing stratum is reached each basketful of soil is placed to one side at the top of the shaft, to be washed and sorted. In some instances a horizontal shaft will be dug to follow the gem-bearing stratum, but as no wooden props or tunnel shores are used the length of these horizontal tunnels is limited by the courage and tenacity of the digger, not to mention his ability to breathe in the tomblike atmosphere. No ladders are provided in the vertical shaft, and entry and exit are effected by bracing the back and hands against one wall and the feet against the opposite side, at the same time exerting the body in a motion that would do credit to James Bond in his tightest spot!

There is no natural supply of water for washing the extractions, so the miners pay for this to be brought from the nearby village by water-tank lorries. A small pond about ten feet in diameter and

FIG. 3. A washing pool.

three feet deep is formed near the shaft and the baskets of soil are washed and broken up by members of the group sitting in the pond (see Fig. 3). As and when the gemstones are found, these are placed in small plastic bags around the perimeter of the pond.

This particular area produces a fair quantity of corundum, most of the crystals being in the form of repeated lamellar twinning. In this form some of the stones can be cut en cabochon to exhibit fine golden six-rayed stars on a dark brown to nearly black background, and on my first visit I met Khun Saengroong, a local dealer and cutter, who had just bought a magnificent hexagonal lamellar crystal of star-sapphire material weighing 1720 carats. This is of course a rare exception and the average size seldom exceeds 15 carats, and even then only very few of the stones will, when cut, show a well centred star without the disfiguration of the prominant zone-lines which are a feature of the stones from this mine.

The local "test" for rough star-sapphire material is to place a drop of water on the stone and to view it from an overhead single light source. In a suitable crystal the "star" will show up clearly when the drop of water is placed in the right position. As is to be expected, a very great proportion of these opaque corundum crystals show a very poor, or no, star-effect, and these fetch very low prices.

In quantity, the second main gem production of this area is green sapphire, followed by blue/green, yellow/green and more

rarely fine blue and yellow sapphire. The hexagonal zoning is easily detected under the lens in a large majority of these stones.

Also associated with the corundum are pyrope garnet (R.I. 1·745 to 1·750) and a fairly large quantity of opaque black stones which take a high polish and are sold both faceted and en cabochon as "Thai Jet". Kenneth Parkinson took ten of these back to the U.K. and has since written to tell me that seven of these have a S.G. of between 4·1 and 4·2 and with a R.I. just visible at the very end of the standard refractometer it seems fairly certain that they are black almandines. The other three stones proved to be black diopside (no star or cat's-eye) with a clear double refraction 1·68-1·71. Although this is slightly higher than the normal 1·67-1·70, Webster (Gems, 2nd Edition, page 264) notes that the R.I. may rise when the material is so dark as to be virtually hedenbergite.

Many jewellers and gem-dealers in Bangkok will inform their customers "These stones come from our own mine at Chantaburi", but it is very doubtful whether any of them actually engage in mining themselves, as those who have taken a lease and employed people to dig for them have usually found that somehow their area seems to produce only low-grade stones. The best-quality stones will find their way into the market, but not through the lease-holder. The local expression is "employ someone to dig and your stone will fly".

Dealers and middlemen gather at a small group of wooden coffee-shops at the fork of two roads leading into the mining area and it is here, in the late afternoon, that the miners bring their daily production for sale (see Fig. 4).

The existence of these sapphire mines and others in the area producing ruby and zircon, has created a flourishing cutting and setting centre in the town of Chantaburi (see Fig. 5). The standard of work is high, and, compared with western prices, cutting costs are very low. A skilled Thai lapidary will be paid about 20 pence for faceting and polishing a zircon of one carat. These low cutting-costs have prompted many of the local dealers to import rough gem-material for cutting in Thailand and eventual export to the major markets in Europe and the U.S.A. When Kenneth Parkinson and I were in Chantaburi we were shown a parcel of fine blue sapphire crystals recently purchased in Australia. One could not help thinking of the expression "bringing coals to Newcastle".

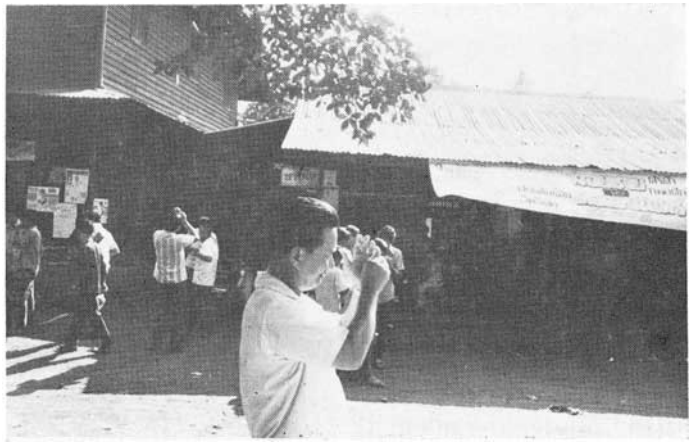

FIG. 4. Dealers examining stones at the village near Ban Kacha.

Although sapphire, ruby and zircon are the principal materials cut at Chantaburi, opal, emerald and other rough is imported for cutting. It is perhaps inevitable that half boules of synthetic corundum are to be seen in many of the gem-cutting shops, and, although the majority of dealers will not offer synthetics as anything but what they are, one suspects that a few will be sorely tempted when selling to some of the gullible foreign tourists who are now starting to visit this area.

FIG. 5. One of the many lapidary shops in Chantaburi.

STAR-DIOPSIDE AND LABRADORITE AS PARAMAGNETIC MINERALS

By DAVID KENT, F.G.A. and ROBERT WEBSTER, F.G.A.

IN 1953 B. W. Anderson[1] referred to some experiments with a pocket magnet which he had carried out. His method entailed using a sensitive balance and a small mathematical calculation, and the scheme was found to have some practical value. In this paper some experiments using a small 'Eclipse' horse-shoe magnet and/or a compass are considered. These experiments indicated that paramagnetic inclusions can cause a non-magnetic mineral to be attracted to a magnet.

One of us (D. K.) was told by an American friend, Mr. Antonio Bonanno, of Washington, D.C., that he had noticed that a black four-rayed star-diopside was attracted to a magnet and, indeed, questioned whether the stone was a true diopside or a magnetite. The second author (R. W.) was approached to find out whether this effect had previously been reported. Another specimen of such a stone was then examined and this too was found to be paramagnetic in that it could be attracted to a magnet. As a precaution green diopsides from Madagascar and from Sljudanka (Baikal, U.S.S.R.), a diopside cat's-eye, small green crystals from Georgetown (California), a large crystal which probably came from Piedmont (Italy) and a piece of rough material of yellow colour from Three Rivers (Quebec, Canada) were tested and found to be all non-magnetic.

The next question was "Why are these star-diopsides magnetic?". It was considered that the answer might lie in the inclusions which produce the asterism and that these inclusions might well be magnetite, a mineral which is well-known for its magnetism. This led to reference to the writings of the two best-known experts on inclusions in gemstones, Professor W. F. Eppler and Dr. Edward Gübelin.

It was known that Professor Eppler had written a paper[2] on star-diopside and star-enstatite soon after these stones appeared on the market, and this article was looked up. These were early days and Dr. Eppler after discussing the star effect stated—"The nature of these particular inclusions is not yet known". Dr. Martin's

work[3] published shortly afterwards threw no further light on this matter. Dr. Gübelin's work on inclusions[4] was then consulted and here we found an answer, for Dr. Gübelin wrote as follows—"H. J. Schubnel reports[5] that by using the microprobe analysis he has been able to identify as primarily unmixed magnetite the black needle-shaped inclusions responsible for the asterism in the Indian star-diopside". Later Mr. Anderson referred us to the article by Dr. Ponahlo of Vienna[6] who had found the inclusions in these star-diopsides to be magnetite and after the material had been powdered-up for X-ray analysis that the particles were magnetic.

Dr. Ponahlo did not infer in his article that the whole stone could be influenced by a magnet so the authors felt that it should be put on record. Further, this led to the consideration of other gem materials which might behave similarly. It is fairly well known that the labradorite variety of feldspar contains inclusions of magnetite, so a number of specimens of this variety of feldspar were examined. Using a hand-held magnet it was found that many of the stones did show paramagnetism, and this gave further evidence that inclusions might produce the magnetic effect.

It is clear that something should be recorded of the actual experiments carried out. As all the stones examined were cabochon cut they were laid, with the domed top surface downwards, on a smooth surface—a sheet of glass or plastic, or a table-top with a good surface—and the magnet was gradually brought near to the stone, which, according to the strength of the magnetism, began to rotate or oscillate and eventually 'fly' to the magnet. In the case of the star-diopsides it was noticed that the stone was attracted to the magnet at a point midway between the arms of the star. It seems, therefore, to show that this effect is due to a resultant of the two forces of attraction produced by each of the two series of inclusions giving rise to the star. There also seems to be some degree of polarity. In general magnetite is not an 'active' magnet; it is only the variety *lodestone* which acts as a magnet. This is clearly stated by Dana/Ford[7] which says—"Ordinary magnetite is attracted by a magnet but has no power of attracting particles of iron itself. The property of polarity which distinguishes the *lodestone* is exceptional".

Several cabochon-cut labradorites, including specimens of the so-called 'black moonstone', were examined and were found to be weakly magnetic, and also appeared to be polar. The magnetic effect is, however, not very strong and only fairly high cabochons will have so little friction between the stone and the table surface as to move readily. The effects may be summed up as follows: the star-diopsides show the effect strongly, the 'black moonstones' much less so, and the more common greyish type of labradorite gave the least response to the magnet. The question of the polarity was less easily disposed of. Although there was certainly some degree of polarity shown, with the apparatus available there was no conclusive proof of this having a *north* and *south* pole. In the case of the labradorites the attraction was found to lie between two sets of inclusions and again may be a resultant of forces.

The results obtained with the above experiments led to trials with a compass needle—a small charm compass, a four-armed button compass and a Service marching compass being used for the experiments. Using the small compass, it was found that each ray of the star-diopsides was polar, one end being *south* and the other *north.* This polar effect was also seen with the large compass, but owing to the shape of the casing of the compass this was more difficult to assess. By placing the stone on the glass cover of the compass over the pivot of the needle, the ring dial being set at the north point, the needle moved to a steady position half way between the arms of the star, and on turning the stone the needle moved through an arc of about 100 degrees.

With the specimens of labradorite the results obtained with the small compass were not so helpful, due perhaps to a lack of sensitivity and the shortness of the needles and to the weak magnetism of the labradorite. Very little movement of the needle could be seen, but when the large marching compass was used there was, in most cases, some movement of the compass needle to be seen, the 'black moonstone' types giving a total swing of about 10 to 15 degrees, while the greyer types only showed a needle movement of about 3 degrees. In some cases, and these were mostly rough unpolished pieces, no precise movement could be seen.

It is clear from these experiments that profuse inclusions of a magnetic mineral can produce response to a magnet even when they are embedded in a host mineral which is itself non-magnetic.

Further, it is apparent that the needle-shaped crystals forming the inclusions in the stone are polar, or under the influence of a magnet can be made so. While the weak response given by labradorite would not provide a satisfactory test, for labradorite is so easily identified by mere inspection, the much stronger magnetism of the star-diopside may have real value in confirming the nature of the stone.

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GILSON SYNTHETIC TURQUOISE:
More Notes

By F. S. H. TISDALL, F.G.A.

AFTER reading Robert Webster's interesting and informative article on Gilson synthetic turquoise,* and being prompted by the hope that he expresses in his final sentence that others would continue to examine these stones, I wrote to Messrs. Gilem S.A. and requested a specimen from them; they very helpfully sent one: a 12 × 10 mm. oval cabochon weighing 5·13 cts.

Mr. Webster's description applies equally to my stone, i.e. the colour tended to be on the pale side, and not the deeper, finer blue of turquoises from Persia. Comparison with an American stone showed a close colour resemblance. The Gilson is, nevertheless, a pleasing stone and has a high degree of polish, superior to that of the natural, and whatever the problems with which they may confront gemmologists one cannot withhold from Messrs. Gilson credit for producing an attractive synthetic. The first impression is, simply, that the stone is "too good to be true"—a feature of most synthetics. The base of the stone is neatly ground to a flat surface with a slightly bevelled edge to assist the setter. There is, of course, an entire absence of limonite or any other form of inclusion. Now that one knows these stones are on the market, this last feature together with such perfect regularity of cut should excite suspicion.

Merely for the sake of confirming Mr. Webster's findings I carried out a hydrostatic S.G. test and obtained the figure 2·70. A "distant vision" R.I. reading on a Dialdex refractometer yielded approximately 1·6. Both constants are characteristic of turquoises from America, so that no diagnostic help is given by these figures.

Not feeling that the use of spectroscope or ultra-violet lamps would prove fruitful I next made a careful examination of the stone's surface under a binocular microscope, the illumination being directed down on to the stone from above; it was this examination which, in my view, led to a clear differentiation between the Gilson and the natural turquoise. In no natural turquoise have I seen a pattern of surface markings like that on the Gilson stone. Mr. Webster describes the surface as "made up of small dark blue

*Webster R. *More Notes on Gilson Synthetic Turquoise*, Journal Gem. 13 (5), 157-160, Jan. 1973.

angular particles . . . buried in a whitish groundmass". That description I cannot better.

Examination of the surface of a 12 × 10 mm. cabochon American turquoise did, in fact, disclose small-scale patchiness of colour, but nothing resembling the almost honeycomb-like mosaic on the Gilson; the polish of the natural stone was much inferior.

Powerful illumination of the surface of the Gilson with a 500-watt photoflood lamp so positioned that light fell at an angle of about 45° disclosed that the whitish groundmass had in many places been etched or polished away, leaving a network of very minute cracks quite unlike anything I have ever seen on a natural turquoise.

The above examination was carried out at a magnification of 35 × ; at 87 × the structure was more easily seen, and also the surface appeared translucent. After removing the stone from the microscope I found that I could just discern the mosaic structure with a 20 × loupe, though not with a 10 × ; keener eyes might do so.

Summarizing: the Gilson stones are a pleasing lightish blue and have a very good polish; there is no sign of inclusions of any kind, and the base is neatly and evenly ground flat. If placed on the stage of a microscope and illuminated from above (a 60-watt pearl bulb will serve) the surface structure as described will be seen and will designate the stone as a Gilson synthetic turquoise.

Not having facilities for chemical analysis it is not possible for me to say whether the composition corresponds to that of a natural turquoise. It is to be noted that Messrs. Gilson do not use the gemmologically preferred description "synthetic" but describe their product as "Gilson created turquoise".

GADOLINIUM GALLIUM GARNET

By M. J. O'DONOGHUE, M.A., F.G.A.

YET another garnet-type synthetic material originally made for the electronics industry is reported to be offered in a cut form in the United States. I am indebted to Dr. Kurt Nassau, of Bell Telephone Laboratories, Murray Hill, New Jersey, for specimens of red, green and colourless material.

Examination of the red and green crystals showed well-developed dodecahedron faces, modified by those of the icositetrahedron. The red stones, according to the manufacturers, are coloured by manganese, and the green by cobalt. Neither stone, however, displayed any marked absorption spectrum.

The colourless stone, in the form of a truncated cone, might be said to be a very pale straw-colour. Although no absorption spectrum can be seen by daylight or tungsten light, a fine fluorescence spectrum is displayed both under short-wave ultra-violet light and X-ray radiation. A strong absorption in the red is accompanied by an emission line; the sodium doublet shows as an emission; there are two distinct bands in the green and two in the blue. The stone fluoresces very pale straw under long-wave, and a peach-colour under short-wave ultra-violet light. Under X-rays the fluorescence is lilac, resembling that of YAG. There is no phosphorescence.

The chemical composition is $Gd_3Ga_5O_{12}$, thus fitting in with the general formula for garnet-type synthetics. The density, at 7·09, is very high for a gem material; the density of gadolinium, a rare earth of the lanthanide group, is 7·88; that of gallium 5·90. The refractive index ascertained by Robert Webster, using the real and apparent depth method, was in the region of 1·92 and the hardness just over 6.

Industrially these garnets are used in microwave filters, where gadolinium may substitute for yttrium.

I am indebted to Alec Farn for placing the X-ray set at the Gem Testing Laboratory at my disposal.

A FURTHER NOTE ON DIAMONDS, REAL AND IMITATION, IN THE ROMAN PERIOD

By J. M. OGDEN, F.G.A.

SINCE the brief note on Roman imitation diamonds by the writer was published in the Journal of Gemmology[1] two fine Roman rings, both set with interesting stones, have been available for study. The first (Fig. 1 *a.* and *b.*) has an attractive openwork-sided setting in which is set an octahedral stone. This stone was at first glance taken to be a rock crystal of the type considered by the writer to be a Roman imitation of a natural diamond crystal. Closer inspection of the stone however revealed the typical surface decomposition characteristics of glass and the stone was, in fact, a yellowish white glass (the term "paste" would

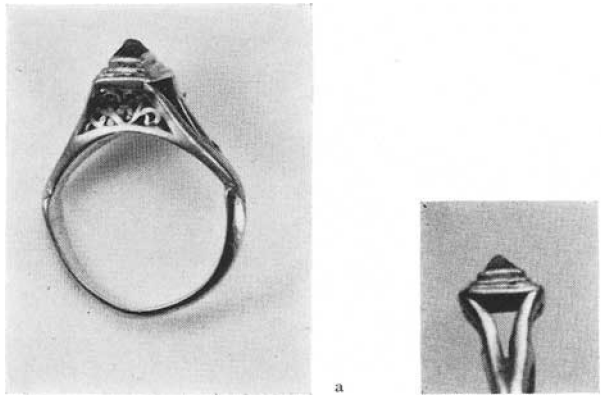

a b

Figure 1a and b

be wrong here, as technically this should only refer to those glasses with high refractive index and brilliancy). The writer knows of other instances of rings set with glass octahedra, and these, like the rock crystals, might be taken to be imitations of diamond crystals. It might be argued that any reasonably knowledgeable Roman could have told glass from the "invincible" diamond, but one would expect that these copies of diamond crystals were more in the nature of moral frauds; in other words they would have been worn by those to whom the diamond was, for reasons of economy or rank,

out of reach. A similar state of affairs can be seen earlier in the Roman period when only free-born citizens were allowed to wear gold rings; slaves and others made do with wearing gilt bronze rings.[2]

The second ring is extremely interesting and possibly even unique, as it is set with a brown diamond. This stone, larger than any other Roman diamond known to the writer, is in the form of rough natural twin octahedra: the general appearance can be seen from Fig. 2 *a.* to *d.*, and in fact it is similar to diamond twin octahedra illustrated by Bruton.[3] Alec Farn of the Gem Testing Laboratory very kindly examined and tested this stone and found it to be a brown-series diamond: two lines, at 4980Å and 5040Å, were visible

a

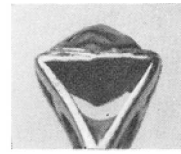
b

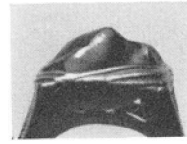
c

d

Figure 2a b, c and d

in the spectrum, and there was a blue fluorescence under X-rays. The weight of the stone was difficult to gauge, but it must have been about 7 carats. The majority of Roman diamonds known to the writer do not have recorded weights, but they generally would seem to weigh under a carat. This large stone under discussion was by no means obviously a diamond from colour or appearance, except to one versed in crystallography; so other stones of a similar nature

might exist, unrecognized, in museum or private collections. In its recent history the stone in this ring has been described in a multitude of ways, most recently as "Topaz." This fine ring is of a similar type to the first ring mentioned above, although it is sturdier and its size would indicate that it was definitely a man's ring. Both these rings were originally in the collection of Count Henri de Clercq Boisgelin, a well-known collector whose ancient jewellery included some of the finest specimens known. There is no cause to doubt that both these rings are genuine, and that they date from the late Roman period (c. 3rd–4th century A.D.). Close examination by the writer revealed no evidence that the stones were not originals: indeed the ring holding the diamond had quite obviously been made for that stone and none other. The colouration, surface appearance under strong magnification and the general "feel" of the gold in both cases would show that the settings were as old as supposed.

No provenance is recorded for either of these rings, though it would seem likely that they were made in Italy or in one of the Eastern Roman centres such as Asia Minor or Egypt. The exact area of origin for the diamond is not known, but it would be likely that it was traded "loose" from India, possibly via Alexandria.

The writer is indebted to Robin Symes, London, for permission to study, photograph and publish these rings.

NOTES

1. Journal of Gemmology, Vol. 13, No. 5 (January 1973), pp. 179–180.
2. The wearing of gold rings in the Roman period is discussed by Marshall in the "Catalogue of the Finger Rings, Greek, Etruscan and Roman, in the Department of Antiquities," British Museum, 1968.
3. Eric Bruton, "Diamonds," London, 1970 fig. 17.18, p. 287.

Gemmological Abstracts

BANK (H.). *Durchsichtiger albit aus Madagaskar und den Alpen.* (Transparent albite from Madagascar and the Alps.) Z. Dt. Gemmol. Ges., 1973, 22, 2, 53-54.

A colourless, transparent stone found in Madagascar and also in the Alps, especially in Austria, was found to be albite. Physical and chemical properties are given.

E.S.

BANK (H.). *Plagioklas-mischkristall a andesin als 'Madagaskar-mondstein'.* (Plagioclase-type crystals of andesine known as 'Madagascar moonstone'). Z. Dt. Gemmol. Ges., 1973, 22, 2, 55-57.

A stone from Madagascar, known as 'Madagascar moonstone' as well as 'precious labradorite from Madagascar', was examined and found to be a plagioclase-feldspar, in particular andesine, which is a mixed crystal between oligoclase and labradorite; these stones show the typical effect of labradorite, a plagioclase rich in calcium. A graph illustrates the R.I.s of a series of plagioclase-feldspars.

E.S.

BANK (H.). *Klar durchsichtige labradorite (plagioklas-feldspate) aus Oregon, U.S.A.* (Transparent labradorites (plagioclase-feldspars) from Oregon, U.S.A.) Z. Dt. Gemmol. Ges., 1973, 22, 2, 58-59.

This article deals with clear transparent labradorite from Oregon, U.S.A. These crystals show less of the characteristic optical properties of labradorite but have a similar effect to that of aventurine.

E.S.

BANK (H.). *Ein neues smaragdvorkommen in Zambia (Miku-deposit).* (A new emerald find in Zambia (Miku deposit).) Z. Dt. Gemmol. Ges., 1973, 22, 2, 60-61.

A new emerald deposit in Zambia, the Miku deposit, is

recorded, and the geographical find described, as are also some physical properties.

E.S.

BANK (H.). *Bleiantimonspiessglanz als haarförmiger einschluss in quartz aus Brasilien.* (Hair-like inclusions of a lead-antimony mineral in quartz from Brazil.) Z. Dt. Gemmol. Ges., 1973, 22, 2, 62-64.

This article deals with needle-like inclusions in quartz from Bahia, Brazil, which were first thought to be rutile needles, but later found to be boulangerite, the iron-free form of lead-antimony. In fact the mineral consists of lead, antimony and sulphur, and was found in a large rock-crystal weighing 650 kg exhibited in the local (Idar-Oberstein) museum.

E.S.

BARIAND (P.). *Lapis Lazuli from Afghanistan.* Min. Digest, 1972, 4, 6-14. 10 colour photos.

A brief history of lapis lazuli from the mines in the Kokcha Valley, Afghanistan, is accompanied by colour photographs, some of them illustrating lazurite crystals in marble and showing dodecahedral form. The lazurite is accompanied by nepheline, sodalite, pale blue cancrinite (afghanite), pyrite, phlogopite, forsterite, diopside, green apatite, and scapolite. The sulphur for the feldspathoids is said to be derived from iron sulphates (magnesiocopiapites).

R. A. H.

BRADT (R. C.), NEWNHAM (R. E.) & BIGGERS (J. V.). *The romance of jade.* Earth & Min. Sci. (Pennsylvania State Univ.), 1973, 42, 29-30. 2 figs.

Fracture strengths of several varieties of nephrite and jadeite have been measured at around 30,000 and 15,000 lb/in^2 respectively, thus exceeding that of most commercially available ceramics (about 10,000 lb/in^2). The average fracture energy for a number of Russian and Alaskan nephrites is 225,000 ergs/cm^2, an exceptionally high value; Burmese jadeites have yielded 120,000 ergs/cm^2. Jade is thus about an order of magnitude tougher than most ceramic materials. The high fracture energy and fracture strength are not related directly to the atomic structure but to the microstructure and the restrictions which this imposes on the propagation of cracks.

Jadeite fracture surfaces seen by scanning electron microscope show a very high proportion of transgranular cleavage fractures; the elongated nature of some of these cleavage steps strongly suggests that fractures occur parallel to the pyroxene chains, on the (110) and ($\bar{1}$10) planes. It is this extensive transgranular cleavage fracture mode that imparts toughness to jadeite. Nephrite has a different fracture topography, with a random orientation of individual fibres, leading to interlocking with an increase in fracture strength. Cleavage planes are parallel to the fibre axis, so cleavage occurs lengthwise and is slowed or stopped when crossing over to a second fibre.

R. A. H.

BURRIDGE (A. D.). *A quarter century of diamond research.* Gems & Gemology, 1972, XIV, 3, 66-76. 4 illus.

The article tells the history of the Diamond Research Laboratory at Johannesburg, South Africa. The laboratory was started on the 21st of April, 1947, and then consisted of one building—the buildings now occupy a nine-acre site. It was primarily designed for research into the problems of the use of industrial diamonds, such as for drills, saws, grinding-wheels etc. Since 1958 experiments at the laboratory have considerably improved the growth of synthetic diamonds, and studies have been made of the best shapes of crystals to use for various industrial applications. The "cladding" of diamond crystals with metal has been investigated, and a number of specialized machines have been devised and built for experimental purposes; some of these are now in operational use in the diamond mines themselves. Much work has been carried out on the physical properties of diamonds and gem diamonds have not been left out of the research projects. New recovery methods have been worked out and apparatus designed. These include scintillation and X-ray fluorescence separators for use in the diamond mines. Investigations into the thermal, electrical and hardness properties of various kinds of diamonds have led to the use of diamonds as 'heat sinks' and semi-conducting devices. It is said that controlled heating in diffuse light of electron-irradiated diamonds induces a colour change, but when these so-called 'chameleon' diamonds are exposed to sunlight they revert to their original colour. It is clearly emphasized that irradiation cannot change a brown or yellow diamond to white, nor make a bad diamond into a good one.

R.W.

CASSEDANNE (J.). *Le diopside de Malacacheta, Bresil.* (Diopside from Malacacheta, Brazil.) Bulletin de l'Association Française de Gemmologie, 35, 5-7.

Diopside, some transparent, is found in the area of the small town of Malacacheta, in the State of Minas Gerais. The material is found in association with quartz, attaining in some cases the size of 30 × 8cm. Perfect crystals are rare, due to the difficulty of extraction. The colour is a dark green, the specific gravity 3·33 and hardness 5½. The refractive indices are 1·705, 1·674 with a DR of 0·031. Although 0·3% of chromium is present, it has little effect on the colour, which is due to iron. M. O'D.

CROWNINGSHIELD (R.). *Developments and Highlights at G.I.A.'s Lab. in New York.* Gems & Gemology, 1972, XVI, 3, 82-86. 9 illus.

A strongly radio-active green diamond is mentioned and so are some 'treated' diamonds examined. These latter included an intense yellow round brilliant-cut stone of some 20 carats and a number of brilliants of an intense blue colour somewhat like the best colour of 'fired' blue zircons. The problems in identifying 'buried' jades is referred to. The effect of heat on some nephrite discs, which caused the strengthening of the 4980Å line and associated lines, absorption lines which were not seen in the unaltered discs, is mentioned. The use of paraffin oil treatment to cracked jades is referred to and some emphasis is given to the danger of such oiling masking cracks so that in setting they are not noticed and breakage occurs. A necklace of pearls, natural white sapphires and uncut (or only partially faceted) crystals of red spinel is illustrated. There is a discussion on a smoky quartz and the report concludes with the mention of a diamond with an octahedral inclusion. R.W.

DERN (H.). *Die Herstellung synthetischer Diamanten im Spiegel der Patentliteratur.* (The production of synthetic diamonds in the patent literature.) Z. Dt. Gemmol. Ges. 1973, 22, 2, 65-75.

The article lists patents referring to the synthesis of diamonds from 12 countries, the earliest being a British patent dated 1930, the latest mentioned a Belgian patent dated 1972. The list mentions 162 separate patents. The article also points out the main differences between the most important patents. E.S.

ELBE (M. G.). *Die rechnerische Ermittlung der optimalen Brillanz von Brillanten.* (The mathematical calculation of the optimal brilliance in brilliants.) Z. Dt. Gemmol. Ges. 1973, 22, 2, 80-82.

It is shown that the equation by Johnsen (submitted to the Journal by Eulitz) is equal to the equation by Elbe.

E.S.

GÜBELIN (E.). *Inclusions in gemstones.* Australian Gemmologist, 1972, 11, 8, 3-14. 42 figs.

The nature and origin of inclusions in gemstones is described. Examples of solid, liquid and gaseous inclusions are illustrated.

D. R. H.

HAMLIN (A. C.). *The emerald.* Min. Digest, 1972, 3, 17-32. 8 colour photos.

An excerpt from *Leisure hours among the gems*, published in 1884, is illustrated by colour photographs of emeralds from Chivor and Muzo, Colombia, including the 632 carat 'Patricia' uncut emerald crystal from Chivor mine, now in the American Museum of Natural History, New York.

R. A. H.

HASSAN (F.). *Amethyst.* Min. Record, 1972, 3, 221-225. 8 figs.

The colour of amethyst is shown to be due to creation of Fe^{2+} and Fe^{4+} absorption centres by irradiation. Permanent loss of colour can be effected by heating amethyst to above 400°-450°C. Detailed study of amethyst occurrences might lead to a useful geothermometer. The occurrence, habit, and physical (structural and optical) features of amethyst are summarized.

J.A.

HEARNES (V. J.). *What is this thing called hardness?* The Australian Gemmologist, 1973, 11, 9, 16-17.

Discusses the different scales of hardness and questions whether a different more accurate system than that of Mohs could be devised and yet not require expensive equipment. Wisely the author states that first an acceptable definition of the term 'hardness' must be made, for the various systems mentioned operate on the measurement of different types of hardness.

R.W.

JONES (R. W.). *Arizona minerals in retrospect.* Lapidary Journal, 1973, 27, 1, 122-134.

Among the less well-known ornamental minerals from Arizona are variscite from Bisbee, fine wulfenite from the Rowley Mine near Theba, cerussite from the Flux Mine, Patagonia Mountains, and turquoise in matrix from Kingman. These specimens are illustrated in colour.

M.O'D.

KATZ (M. B.). *On the origin of the Ratnapura-type gem deposits of Ceylon.* Econ. Geol., 1972, 67, 113-115. 2 figs.

The detrital gem deposits appear to be derived from cordierite gneisses and associated rocks located in the surrounding highlands.

A.J.E.

LENZEN (G.). *Vorher – Nachher.* (Before – After.) Z. Dt. Gemmol. Ges., 1973, 22, 2, 76-79.

The article is illustrated by five photomicrographs showing the removal of two black inclusions in a brilliant by laser beams. The removal of the black spots and especially their reflection improves the stone greatly, but the hole caused by the beam is easily seen. It is suggested that the seller always mentions that the stone has been so treated and a correct definition in the described case history should read: '2nd piqué, laser bored'.

E.S.

LIDDICOAT (R. T.). *Developments and Highlights at G.I.A.'s Lab. in Los Angeles.* Gems & Gemology, 1972, XIV, 3, 86-94. 19 illus.

Two examples of turquoise matrix are described. The first was found to be natural turquoise containing white metallic areas consisting of pyrites and black areas consisting of zinc blende. The second stone was again not treated as such but gaps in the turquoise had been filled in with black plastic containing flecks of pyrites. Other items mentioned were a dark green 'aventurine glass' with spangles consisting of specular iron ore, calcite crystals in quartz and a 'feather' in a spinel which looked very much like a human fingerprint. A 'star quartz' in which a dark star is formed by a concentration of dark red inclusions in stellate arrangement is mentioned. Some effects shown by diamonds which had suffered burning and the lazer drilling of diamonds are discussed. A new

source of opal—in Arizona—is referred to and there is some discussion whether to describe a greyish-blue cabochon of tremolite as nephrite or not. This stone showed an absorption line at 4370Å, which is the position of the jadeite line. A sapphire which showed a fluorescence under short-wave ultra-violet light but did not show the 4500Å line was found to be genuine. A Colombian emerald was seen to show a diamond-shaped solid in a three-phase inclusion, while another stone from the same country contained a plane of small pyrites crystals. A yellow cat's-eye jadeite is described, and the article concludes with references to insects enclosed in amber.

R.W.

MACFALL (R. P.). *The Hall of Jade and what it means.* Lapidary Journal, 1973, 27, 1, 18-45.

An account of the reconstructed Hall of Jades in the Field Museum of Natural History, Chicago. The two distinct minerals to which the name jade is given are reviewed and the major exhibits in the new display illustrated.

M.O'D.

MALES (P. A.). *Lightning Ridge nobbies and the 'Chinaman's hat'.* Australian Gemmologist, 1972, 11, 7, 17-18.

Irregular-shaped opal nodules of uncertain origin are described from Lightning Ridge, New South Wales.

D.R.H.

MALES (P. A.). *Inclusions in opal.* Australian Gemmologist, 1973, 11, 9, 15-16.

Describes a specimen of Lightning Ridge opal potch which had unusual inclusions. The inclusions may be gypsum.

R.W.

NASSAU (K.). *The Hoquiam ruby story.* Lapidary Journal, 1973, 27, 1, 26-32.

The first Verneuil-type synthetic rubies were made in the United States in 1903-1904 by two lumbermen at Hoquiam in the state of Washington. They were assisted by an associate of Verneuil. Examination of the few known boules made at that time shows that the feed powder was made from quite pure alum recrystallized several times from distilled water. Ground natural

ruby was not used. The chromium content of the Hoquiam boules varies from 0·24 to 0·56 and the iron from 0·0040 to 0·0062.

M.O'D.

NORWOOD (J. E.). *Rubies of Wake County, N.C.* Rocks & Minerals, 1972, 47, 645-648. 2 figs.

Small ruby crystals are associated with chromite in dunite bodies near Bayleaf, Wake County, North Carolina. Notes on the geology and history of the area are included.

R.S.M.

OUGHTON (J. H.). *Diamond, YAG and other simulants.* Australian Gemmologist, 1972, 11, 8, 15-18.

The physical characteristics and methods of recognition are given for natural and synthetic gems used to simulate diamond.

D.R.H.

OUGHTON (J. H.). *Some archaic instruments in present day use.* Australian Gemmologist, 1973, 11, 9, 4-13. 10 illus.

An entertaining article describing old instruments, such as microscopes, refractometers, a goniometer (table spectrometer) and balances made in olden days, which found their way to Australia, often hidden for years in cupboards or on store shelves and now brought to light. Some of these are now used by students and gemmologists 'Down Under'.

R.W.

PERRAULT (G.) and RICHARD (P.). *L'Ekanite de Saint-Hilaire, P.Q.* (Ekanite from Saint-Hilaire, Quebec Province.) Canadian Mineralogist, 1973, 11, 5, 913-929.

Small crystals discovered in cavities in pegmatite veins associated with the Mont Saint-Hilaire intrusion in Quebec Province, which were provisionally referred to as "UK—4" pending their identification, have now been established as a variety of the radioactive thorium mineral, ekanite, which was first discovered twenty years ago in Ceylon by F. L. D. Ekanayake, after whom it was subsequently named. The density of the Quebec specimens was measured on a Berman balance and gave a low value of 2·95, the difference between this and the calculated figure of 3·32 being ascribed to the porosity of the specimens.

The refractive index for the ordinary ray was 1·573 and for the extraordinary ray 1·572, while the hardness was 350 on the Vickers scale, equivalent to a Mohs hardness of 5.

Analysis was complicated by the presence of 11·6 per cent absorbed water, but showed a composition very similar to former analyses on material from Ceylon, with two exceptions: (i) no uranium was found (Ceylon, 2-3%), (ii) sodium (3·36) and potassium (3·42) were present as essential constituents, but were missing from the analyses of Ceylon ekanites. While it is clear that ekanite is essentially a silicate of thorium, sodium, potassium and calcium, so far the proportions of the constituents have refused to conform exactly to a stoichiometric formula.

The crystals are tetragonal (space group P4/mcc) and associated minerals include analcite and aegerine. As would be expected from its heavy thorium content (28%), the mineral is radio-active, both α and β particle emissions being measured but (unlike the Ceylon variety) no gamma radiation being observable.

The lead content of these ekanite crystals was approximately 0·005 atoms per million which, supposing the lead to be due entirely to disintegration of thorium, argued an age of about 60 million years for this occurrence.

Abstractor's note

Ekanite provides one of many examples of a gem-quality mineral which, though having no commercial significance, has proved to be of extreme interest to science. Those who wish to refresh their memory of the story of its discovery by Mr. F. L. D. Ekanayake of Colombo twenty years ago, and of the protracted work on its composition and nature which finally established it as a new mineral, can refer to R. K. Mitchell's article in the *Journal of Gemmology* for July, 1961 (VIII, 3, 95-98). Very full details of the investigation and properties of ekanite can be found in a brilliant paper by Dr. Edward Gübelin in the *Gemmologist* for August and September, 1962 (XXXI, 373, 142-152, and 374, 165-169).

As found in the Ceylon gem gravels, ekanite is a green subtransparent mineral in a completely amorphous (metamict) state, the breakdown of its crystal structure being due to internal bombardment by alpha-particles emanating from its large thorium (and uranium) content during a period of 600 million years (ten times the period endured by the crystals found in Canada). Orientation

of the inclusions suggested that the mineral had originally possessed a tetragonal structure and this was confirmed by X-ray powder photographs on material which had been subjected to prolonged heating.

An occurrence in Central Asia of crystallized ekanite containing alkali metals was reported by Russian workers in 1965, but was apparently overlooked by British abstractors.

B.W.A.

POUGH (F. H.). *Meet Tanzania's fancy sapphires.* Australian Gemmologist, 1972, 11, 8, 19-21.

A review is given of the occurrence of gem corundum in Tanzania, with emphasis on the fancy sapphires from the Umba River area.

D.R.H.

RIEMAN (H. M.). *Chrysoprase.* Lapidary Journal, 1973, 29, 3, 559-562.

Study of the cause of colour in chrysoprase has shown that nickel, the colouring agent, occurs as a constituent of the clay mineral pimelite rather than as a separated nickel oxide. Chrysoprase from Silesia contains 96% quartz and just over 1% pimelite. Occurrences of chrysoprase in the United States are rare, one of the best known being in Tulare County, California.

M.O'D.

SANTOS MUNSURI (A.). *Hornbill.* Boletin del Instituto Gemologico Español, 1972, 1, 3, 15-20.

An account, illustrated in colour, of the use of hornbill as an ornamental material. Greatly esteemed among the Chinese, it has a refractive index of approximately 1·54 and may be distinguished, albeit with some difficulty, from horn in which the fibres are concentric.

M.O'D.

TENHAGEN (J. W.). *Muzo emerald mine.* Gems & Gemology, 1972, XIV, 3, 77-81. 6 illus. in black and white.

Tells of a visit to the Muzo emerald mines in Colombia and of the difficulties in getting there. The mines are located in a hot and humid valley with dense vegetation around. The rock faces

worked are called 'banks'. The Tequendama bank, now still being worked, was the site worked by the Spaniards some 400 years ago. At Muzo there are five or six banks (areas), of which only two are currently worked. Open-pit mining is employed, the emeralds being found in white calcite veins in a black carbonaceous shale. Owing to metamorphism the bedding planes of the shale are either vertical or twisted. The emerald-bearing strata are either dynamited or bulldozed and then broken up by hammers. The emerald-bearing strata are often washed down by water and the emeralds recovered from the residue. When found the emeralds are placed in double-locked bags which are later flown by helicopter to the bank at Bogota. Something is told of the inclusions found in Muzo emeralds.

R.W.

TENHAGEN (J. W.). *Muzo emerald mine, Colombia's hidden gem.* Lapidary Journal, 1973, 27, 1, 56-58. 6 illus. in colour.

The text of this article also appears in Gems & Gemology (see abstract above), but here it has coloured illustrations.

M.O'D.

TRUEB (L. F.) & BARRETT (C. S.). *Microstructural investigation of ballas diamonds.* Amer. Min., 1972, 57, 1664-1680, 14 figs.

Brazilian ballas consists of dense, globular aggregates of anhedral diamond crystallites with an average diameter of the order of 40 microns. The grain boundaries, which are often outlined by impurities and inclusions, are interlocked in complex sawtooth patterns and fracture is almost exclusively transgranular. The crystallites have a well developed preferred orientation, each radial direction being an axis of a [110] fibre texture.

A.P.

WEBSTER (R.). *The role of gemmology.* Australian Gemmologist, 1972, 11, 7, 7-16. 12 figs. (reprinted from Medicine, Science, and the Law, 1972, 12, 1, 31-42).

Already abstracted on p. 149 *supra.* D.R.H.

WOLLIN (J.C.). *Tigereye.* Min. Digest, 1972, 4, 97-102, 6 colour photos.

The occurrence of the golden or blue tigereye variety of quartz

pseudomorphous after crocidolite asbestos in the folded Griquatown series of the Transvaal system near Prieska, Cape Province, South Africa, is described. Silicification and oxidation have affected only the upper few tens of feet, giving jasper, tigereye and hematite, overlying the main ironstone formation with shales, limestone, asbestos, chert, and magnetite. The tigereye veins are often only four inches thick and of irregular distribution. The red material is produced by heating the golden variety: the light honey colour is said to be produced by bleaching in oxalic acid.

R.A.H.

ANON. *The attraction of Agate Creek.* Rocks & Minerals, 1972, 47, 600.

Large quantities of agate occur in gravel at Agate Creek, south of Forsyth, Queensland, Australia. Also rough topaz occurs north of Mt. Surprise.

R.S.M.

ANON. *The story of Colombian emeralds.* Rocks & Minerals, 1973, 48, 36-37.

The history of emerald mining in Colombia is summarized. The Chivor, Muzo, and Cosquez mines are most important.

R.S.M.

ANON. *The* 601·25 *carat Lesotho diamond.* Min. Digest, 1972, 4, 92-96. 13 colour photos.

A brief history is given of the discovery of the world's seventh largest rough diamond in the Letsung-la-Terai area, at above 10,000 feet, of its initial sale for $302,400, and of its cleaving by the cutter Pastor Colon, *Jr.* for the Henry Winston firm of New York, the final buyer.

R.A.H.

BOOK REVIEWS

BAXTER (J. W.) and others. *A geologic excursion to fluorspar mines in Hardin and Pope Counties, Illinois.* Illinois Geological Survey Guidebook series no. 11, Urbana, Illinois, 1973. pp. 30. Price on application.

This short guide, illustrated with maps of the fluorspar-producing areas, was prepared for the Ninth Annual Forum on the Geology of Industrial Minerals held in 1973. Diagrams depict the position of the various veins and beds.

M.O'D.

BUCHESTER (K. J.). *The Australian amateur lapidary.* Ure Smith, Sydney, 1967. pp. xix. 211. Illustrated in black-and-white and in colour. £2.75.

A companion volume to the author's excellent Australian gemhunter's guide, this book covers the history of the lapidary art, how it developed in recent years in Australia and the growth of interest in gemmology. Further chapters introduce simple crystallography and pleochroism, refractive index and dispersion. The following sections of the book are devoted to the methods of fashioning stones. The apparatus used is clearly described and illustrated with black-and-white photographs. Special cutting techniques for opal, chrysoprase, amethyst, tiger's eye and rutilated quartz are described. A most useful addition to the normal matter is a review of the methods of assessing the value of gem material. Appendices contain a variety of tables and there is a bibliography.

M.O'D.

FRANCO (R. R.) and others. *Minerais do Brasil.* (Minerals of Brazil). Edgard Blucher, São Paulo, 1972. 3 vol., pp. 426. Illustrated in colour. Price on application.

Apart from a general introduction to mineralogy and summaries of the properties of the various mineral classes, this book consists entirely of coloured photographs of Brazilian minerals, each accompanied by its chemical formula, location and English name. Many of the commoner Brazilian species are covered by several photographs, so that emerald, for example, is depicted five times

from Ferros and Teofilo Otoni in Minas Gerais and from Bom Jesus dos Meiras and Carnaiba in Bahia. There are twenty-six illustrations of tourmaline. The standard of photography of the crystals is good, that of the cut stones which are occasionally shown less so. For the importer and collector of rough material the book is invaluable and as the complete text is given in both English and Portuguese there is no difficulty in understanding the descriptions.

M.O'D.

LENZEN (G.). *Kurzgefasste Diamantenkunde.* (Concise diamond information). 2nd edition. Verlagsbuchhandlung Elisabeth Lenzen, Kirschweiler, West Germany, 1973. pp. 154. Price on application.

The second edition of the author's excellent short course on diamond appraisal, testing and grading, this book is intended specifically for students attending the short residential courses of the Deutsche Gemmologische Gesellschaft.

Additional material includes a table giving world diamond production by country, and in the table linking colour grade and price the grade of Top Wesselton is allocated 95% against the 100% of the River grade whereas the earlier edition gave the grade 90%. Some material has been rearranged.

M.O'D.

MORENZ (O.). *Wie Kauft man Diamanten, Farbsteine, Perlen, Schmuck?* (How do you buy diamonds, coloured stones, pearls and jewellery?) Third, revised edition. Econ-Verlag, Düsseldorf and Vienna, 1970. pp. 224. Coloured illustrations. DM.4.85.

A guide to assist the layman in buying jewellery, this well-produced book is particularly useful to the student of gemstone prices. In addition to its coverage of the more important gem materials the book includes details of precious metals and coins.

M.O'D.

NOTT (S.C.). *Chinese jade throughout the ages.* Charles E. Tuttle Co., Rutland, Vt., and Tokyo, 1969. pp. xx, 193. Illustrated in black-and-white and in colour. £8.95.

A reissue of a classic book on the jades first published in 1936.

Although the function of some of the artefacts is now thought to be different from the author's conjecture, the bulk of the text is authoritative and gives a full introduction to the use made by Chinese craftsmen of both jadeite and nephrite. An introductory chapter deals with the two forms of jade and later chapters are assigned to archaic jades, ritual symbols and works of art arranged in dynastic order. A chapter covers the testing of jade and its commoner simulants and there is a bibliography, including works in Chinese, the study of which is essential for an understanding of the significance to the Chinese of particular forms, symbols and inscriptions. It is now known that a number of these writings were uncritically edited in later times and that the names and descriptions given to particular artefacts are therefore probably not those which archaic times would have recognized. A work of some authority, the Chou li, dating from the third or fourth century B.C., is not included in the bibliography. There are more than 350 photographs, including 39 in colour.

M.O'D.

PEARL (R. M.). *Cleaning and Preserving Minerals.* 2nd edition (revised). Earth Science Publishing Company, Colorado Springs, 1973. pp. 86. $2.75.

During 1947 Dr. Pearl published a work "Mineral Collectors' Handbook", the first section of which dealt with 'Cleaning and Preservation of Mineral Specimens'. This section, with some revision, was republished in paper-back form in 1971 and now a further edition has been published after revision.

This booklet of 86 pages (six pages more than the 1971 edition) deals with the stability and instability of minerals to various influences and discusses the changes which may occur with unstable minerals. The reader is quickly taken on to the care of mineral specimens and their cleaning from dust and grease by mechanical methods such as brushing, blowing, suction, scraping and hand picking. Porous minerals which must not be washed in liquids are listed, and listed are those minerals which must not be treated with acid or alkaline liquids, and much information is given on how to wash mineral specimens in various liquids. Wisely notes are given on how to mix liquids, especially acids and alkalis, as some of them are a health hazard. Something is told, too, of the use of ultrasonic cleaning.

Detailed descriptions are given of the treatment of various near-surface contaminations—such as by smoke, soot, organic encrustations, etc.—and the preparation of various chemicals and chemical mixtures to use for such treatments. Various methods of lacquering specimens so as to prevent future surface attack are mentioned and the alteration of some specimens by loss of water is also discussed, some opal and turquoise being cited as examples. Temperature and humidity are also considered as factors causing damage to mineral specimens. The effects of heat on zircon, topaz and amethyst are cited; changes of temperature and the effects of light, where again a number of gemstones are referred to, are important parts of the book. References to other writers are made throughout the book. There is no index.

R.W.

SABINA (A. P.). *Rocks and minerals for the collector: the Alaska Highway, Dawson Creek, B.C., to Yukon/Alaska border.* Geological Survey of Canada, Paper 72-32, Ottawa, 1973. pp. viii, 146. Map. $2.50.

The area covered by this paper produces, in addition to numerous gold deposits, jasper, nephrite, serpentine, epidote and rhodonite. Cassiterite, locally called "Yukon diamond", is in demand for the fashioning of nugget-studded jewellery. Locations are precisely indicated with the aid of geological maps and there is an extensive bibliography.

M.O'D.

Masterworks of Chinese jade in the National Palace Museum. Taipei, Taiwan, Republic of China. pp. 92. £4.50.

A description, illustrated in colour, of 50 pieces ranging from the Shang (1766-1122 B.C.) to the Ch'ing (1644-1911) dynasties. Each item is described in English, Chinese and Japanese and there is a section dealing with the traditional shapes of ornaments. Although some jadeites are so described, other illustrations do not state the material employed. No reference is made to the possible use of the pi, a circular disk with a central hole, and the ts'ung, a rectangular tube with a hollow centre and horizontal grooving, although these two forms have been the subject of a number of

recent papers. The coloured plates, printed in Japan, are of very high quality.

M.O'D.

Fluorspar in Illinois, by various authors. Circulars 385, 413 and 420 of the Illinois Geological Survey. 1965-68, Urbana, Illinois. Price on application.

Illinois is the leading fluorspar producer in the United States, most of the production coming from underground mines. The mineral is found in the extreme south of the State in Hardin and Pope Counties. Present mining operations centre around the Cave-in-Rock district. Deposits are found in inclined veins and in beds in the host limestone. In association are galena and sphalerite. The areas are illustrated by high-quality geological maps mounted in folders.

M.O'D.

ASSOCIATION NOTICES

MEMBERS' MEETINGS

Midlands Branch

At the Annual General Meeting of the Branch held on 15th June, 1973, at Regent House, Birmingham, Mrs. S. E. Hiscox was re-elected Chairman and Mr. G. S. C. Porter elected Secretary. The films "Of Jewels and Gold" and "The Magic of Diamonds" were shown during the evening.

Scottish Branch

The summer outing of the Branch was held on the 17th June, when members visited Ballater. Many specimens of pink fluorspar, purple fluorspar in veins, and groups of quartz crystals, in matrix, were found.

TIES FOR FELLOWS

An Association tie is available for Fellows. The tie, which is dark blue, bears the crest of the Association in gold, and the price (U.K. only), including postage and VAT, is £1·25. The price outside the U.K. is £1·25 by surface mail or £1·50 by air mail.

OBITUARY

Mr. Stanley S. Belcher, Johannesburg, South Africa, who gained the Association's Diploma with distinction in 1945, died in September 1973.

Mr. Charles J. Parsons, La Mesa, Calif., U.S.A., died on the 14th September, 1973. Mr. Parsons gained the Association's Diploma with distinction in 1952.

GIFTS TO THE ASSOCIATION

The Council of the Association is indebted to the Victoria branch of the Gemmological Association of Australia for first day cover of Australian gemstone postage stamps, depicting chrysoprase, agate, rhodonite and opal.

LETTER TO THE EDITOR

Dear Sir,

B. W. Anderson, in his excellent review* of the 14th and revised edition of Dr. G. F. Herbert Smith's "Gemstones", draws attention to the fact that Plate 19, a reproduction of the absorption spectra of three different zircons, is printed the wrong way round in relation to the colours indicated below the spectra, thus perpetuating an error which first occurred in the 1958 (13th) edition.

For the sake of accuracy I would point out that in the 13th edition the spectra were printed upside down. In other words the photographed part of the plate was rotated through 180° in relation to the numbers and colours around it. Thus in that edition the captions referred incorrectly to the numbered spectra.

The latest edition attempts to put things right by changing the order of the caption. This leads to the spectra being correctly named but with the absorption bands the wrong way round—as noted by your reviewer.

It is perhaps some comment on the efficiency of gemmological teaching on this subject (for which Mr. Anderson is primarily responsible) that no one has drawn attention to the original error. Anyone familiar enough with zircon absorption to notice the error would be too familiar to need to refer to the illustration under discussion.

This confused illustration does not detract in any way from the excellence of this edition so ably revised once more by Prof. F. Coles Phillips. The book remains the standard work on the subject of gems.

Yours sincerely,
R. KEITH MITCHELL

3rd July, 1973.

*Journal Gemmology, XIII, 6, 236-239.—Ed.

MEMBERSHIP

Mrs. Christine Nemoto, Warsaw, Poland, (D.1972) was elected to Fellowship in October, 1972.

MEETINGS 1973 and 1974

1973	
19th November	Reunion of Members. Goldsmiths' Hall, London, 6.00 p.m.
	Presentation of Awards. Goldsmiths' Hall, London, 7.00 p.m.
1974	
25th February	Film Show. Goldsmiths' Hall, London, 7.00 p.m.
26th March	Meeting. Goldsmiths' Hall, London, 7.00 p.m.
25th April	Annual General Meeting, Saint Dunstan's House, London, 6.00 p.m.
9th October	Talk by Mr. B. W. Anderson. Goldsmiths' Hall, London, 7.00 p.m.
25th November	Reunion of Members. Goldsmiths' Hall, London, 6.00 p.m.
	Presentation of Awards. Goldsmiths' Hall, London, 7.00 p.m.

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SAUSSURITE AS A JADE SIMULANT*

By E. A. JOBBINS, B.Sc., F.G.A. and E. H. RUTLAND, Ph.D., F.G.A.

SIX carvings in an attractive green material, often with white and brown areas, have been examined by the authors during the past two years at the Institute of Geological Sciences, London. Reports of similar items from the gem-testing laboratories in London, New York and Los Angeles indicate that more pieces are on the market. Some have been purchased in Hong Kong or China as jade or 'new jade', but the yellowish cast of some and the unusual colour distribution raised doubts as to their identity. However, there is usually an overall resemblance to either or both the jade minerals.

All the carvings have been in the Chinese tradition and traces of green chromic oxide still present in cracks and grooves suggest that they are of recent manufacture. The surface finish of most objects has been smooth and without the slightly textured or dimpled appearance characteristic of many older jade carvings. This suggests polishing by diamond (or possibly one of the harder carbide abrasives), which cuts through the slight differences in hardness between differently orientated component mineral grains; the older and softer abrasives often accentuated these slight variations in hardness.

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Brief descriptions are given below of the carvings examined and, although it is realized that words are no substitute for personal examination or photographs, it is hoped that these notes will help the majority of readers who will not be able to see the specimens but who may be faced with the difficult task of assessing similar material.

Carving A: bird and flower group: several shades of medium green mottled with white. Some parts resemble 'spinach' nephrite jade (see photograph) but the head of the bird (mottled white with green) resembles certain jadeite jades from Burma.

Carving B: bird (goose-like): brown head and neck, brownish-green front part of body, with shades of green to pale green rear of body. The green shades are seen in jade but the browns are unusual.

Carving C: vase with foliage: mostly creamy-white, but with some streaked green and dark green areas.

Carving D: elephant: greyish-white with medium to dark green areas.

Carving E: bird and foliage: pale yellowish-green to dark green.

Carving F: 'leaf dish': streaked white, medium green and dark brown.

It will be noted (see the 'Summary of Determinative Work' on p. 3) that refractive index determinations have been omitted from the tables; they were attempted by the distant vision ('Lester Benson') method, but because of the shapes of the objects and the difficulty of positioning them on the refractometer, consistent readings were not easy to obtain. In general, figures around 1·55–1·56 for the white areas and 1·68–1·70 for the darker areas were observed, but they were not felt to be reliable and are only given as a guide. There was not normally sufficient material to carry out both x-ray powder work and refractive index determinations by the immersion method. However, in the case of specimen A it was possible to confirm the presence of a mineral with R.I. near 1·701, with a birefringence in the region of 0·005–0·009 and straight extinction, and these properties agree broadly with orthozoisite. Other grains of lower index were present, but no albite twinning characteristic of many plagioclase feldspars was seen in the scrapings examined.

SUMMARY OF DETERMINATIVE WORK

Specimen / *Dimensions*	*S.G.*	*Hardness*	*Absorption Spectrum*	*U.V. Fluorescence**	*X-ray Diffraction Results (with film numbers)*	*Notes*
A 22 cm high	3·06	White areas ~6 Green areas ~5	General absorption of blue/violet	Deep brownish	White area (X6805): major Ca-rich plagioclase, zoisite and minor quartz. Green area (X6806): major Ca-rich plagioclase, major diopside, zoisite, minor quartz	Saussurite, probably with significant proportions of parent gabbroic rock
B 9·2 cm high	2·94	> 6 < 7	Brighter green areas show Cr lines in red; general absorption of blue/violet	None seen	Brownish green/green areas (X6807): major Ca-rich plagioclase, minor quartz. Brown areas (X6730, X6807A): major Ca-rich plagioclase	Films show dominant Ca-rich plagioclase (max. S.G. 2·76) but S.G. is 2·94 so denser minerals must be present
C ca. 15 cm high	3·07	White areas > 6 < 7 Green areas (variable) > 5 < 7	Not distinctive	Whitish areas may show creamy-white to dull pink; dark areas inert	(X6351, X6351A): both show zoisite with some Ca-rich plagioclase	Saussurite
D ca. 10 cm long	2·88	Variable > 5 < 7	Not distinctive	None seen		Rounded, highly polished surface: removal of material for testing difficult. Probably saussurite
E ca. 22 cm high	2·85	> 6 < 7	Line in deep violet	Pale green areas show greyish; dark areas inert	(X6678): Ca-rich plagioclase and zoisite	Saussurite
F 14·5 cm long	2·91	> 6 < 7	Brighter green areas show Cr lines in red; darker areas show some absorption of blue/violet	Whitish areas fluoresce pale-buff; dark areas inert	White/greenish area (X6809): Ca-rich plagioclase, major zoisite. Brownish area (X6808): major Ca-rich plagioclase	Saussurite
Saussurite	3·06	> 6 < 7	Not distinctive	Buff fluorescence	(X6830): major zoisite, clino-enstatite	Saussurite, Pen Voose, Lizard, Cornwall. IGS registered number MI 32922
Saussurite	3·22	> 6 < 7	Not distinctive	Inert	(X6829): major diopside, zoisite, minor chlorite	Saussurite, Swiss Alps. IGS registered number MI 23044
Jadeite (typical)	3·33	6½–7	Usually a line at 4375Å (blue/violet); Cr lines in red in bright green varieties	Paler colours often show whitish fluorescence		Often shows fibrous/granular appearance on or just below the surface
Nephrite (typical)	2·8–3·05	6½ but sometimes as low as 5	Indistinct lines may be seen at 6890Å (red), 5090Å (green), 4900Å and 4600Å (blue)	Inert		

*Long wave (3650Å) results, short wave (2357Å) much reduced or inert.

It will be seen that the 'common denominator' minerals in the new material are a calcium-rich plagioclase and, almost always, a zoisite (of the ortho type). This association is similar to that described for saussurite, save that the plagioclase here seems to be rather more towards the calcic end of the plagioclase series than the sodic or albite end which was normally found in saussurites as previously described.

The history of saussurite started in 1780 when H. B. de Saussure described a green material found near the Lake of Geneva. At first he took it to be jade but, as more material of the same kind was found, differences became apparent. Other mineralogists advocated names such as Swiss jade, bitterstein and lemanite (after Lac Leman), but in 1806 his son, N. Th. de Saussure, named it in honour of his father, the discoverer, and this name prevailed. During the nineteenth century the rock was found in Silesia and Bavaria, Styria and Tirol, Switzerland (including some neolithic artefacts from lakeside dwellings, proving that saussurite has been carved for some thousands of years), France, Norway and Turkestan. In the U.K. saussurite was found in Ayrshire, on the island of Unst, Shetland, and at the Lizard, Cornwall; in the U.S.A. in Shasta County, California.

De Saussure had described a material with a hardness of $6\frac{1}{2}$–7 and a density of 3·261. The other localities provided data markedly different and the reason for the differences was found to lie in variations in the composition of the material. T. S. Hunt first recognized its close relation to zoisite in 1858; Cathrein and others showed that various accessory minerals were always present and that saussurite was therefore a rock and not a single mineral (which incidentally is true also of all but the purest jadeites). Though zoisite and plagioclase are the two main constituents, different saussurites usually also contain other minerals, notably epidote, garnet, natrolite, quartz and scapolite. The minerals are usually associated in a fine-grained aggregate and form a tough compact rock, often with a splintery fracture. Some fifty analyses made mainly during the late nineteenth century show very wide variations in composition, viz: SiO_2, 36–65%; Al_2O_3, 17–32%; CaO, 2–32%;

LEFT: 'Saussurite' carving (A); the green areas contain major diopside and are partly composed of the parent gabbroic rock.

BOTTOM RIGHT: 'Saussurite' carving (A); compared with 'spinach' green nephrite jade.

TOP RIGHT: Carving (B); shows as dominant calcic-rich plagioclase by x-ray methods; the presence of zoisite is suspected but not confirmed.

MgO, 0·2–6%; Na_2O, 0–10%; together with minor Fe_2O_3, FeO, K_2O and H_2O. The density range in these analyses is 2·95 to 3·41, but one specimen from Wildschonau in the Tirol went as low as 2·66.

Of the specimens described, C, E and F fall reasonably well into the saussurite bracket, and from its appearance and known properties specimen D can probably be included here also. Specimen A contains diopside as a major constituent with the calcic plagioclase and it is felt that in this case significant proportions of the unaltered or parent rock are present; this rock is certainly very basic, and may be said to have gabbroic affinities. Alteration (probably hydrothermal) of rocks of this type may initially produce lime-bearing solutions from the calcic plagioclase (anorthite), and these solutions will then react with further anorthite to produce zoisite and a more sodic plagioclase. The reaction has been expressed thus:

$$\underset{\text{anorthite (plagioclase)}}{3CaAl_2Si_2O_8} + \underset{\text{lime}}{Ca(OH)_2} \leftrightharpoons \underset{\text{zoisite}}{2Ca_2Al_3Si_3O_{12}OH}$$

but this is probably only part of the story. The albite found in many saussurites may arise as a residuum from the original sodic/calcic plagioclase, when the calcic elements have been removed as illustrated above.

Specimen B is dominantly a calcic plagioclase on the evidence of the x-ray results, but the specific gravity is much too high for a monomineralic plagioclase rock (maximum S.G. 2·76 for pure anorthite) and denser mineral(s) must be present. Zoisite (S.G. 3·25) does not appear to show up well in x-ray powder photographs of saussurite, and this may be part of the reason for its not being detected, *or* the scrapings (from 3 areas) may all have missed zoisite(or other mineral)-bearing areas.

The nomenclature of these new materials is not always easy. Save for the doubts on specimen B (and to a less extent A) they are all composed of dominant or very significant proportions of 'saussurite' and may reasonably be so described. Specimen A is apparently a saussurite/gabbroic rock type in a state of partial alteration, whereas specimens C – F are nearer the end product. All stages of alteration are possible, and it is certainly not desirable to propose a new name for a material of so variable a composition. It is probably best to include specimen A within the 'sack-term' saussurite. The new material is not related to either of the jade minerals, and should certainly *not* be described as 'new jade' or indeed any other name including 'jade'.

It is realized that the testing of these objects has involved the use of highly sophisticated instruments and methods not normally available outside specialized laboratories or university departments, and that the material will create problems in the future for many gemmologists and dealers. The generally lower S.G. and the absence of the characteristic fibrous/granular structure of jadeite surfaces or sub-surfaces will normally distinguish it from that mineral. However, the S.G. does overlap the nephrite range, as does the hardness although saussurite is often more variable in hardness from place to place than is nephrite; neither has any very characteristic absorption spectra. The new material is often streaked, and has a metamorphic aspect, which is less common (but not unknown) in nephrite. If a material resembles nephrite in one area and jadeite in another then the reader should be cautious and suspect saussurite. In all cases of doubt it is recommended that the specimen be tested by a laboratory having access to x-ray diffraction methods *and* the expertise to remove material for examination without disfiguring the object.

The authors gratefully acknowledge assistance from colleagues in the Petrographical Department at the Institute of Geological Sciences without whose co-operation this work could not have been completed; they also thank Mrs. D. Cliffe, Messrs. W. Barrett & Son Ltd and Harrods for the loan of specimens, and Mr. R. Webster for bibliographic details and discussion.

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THE EMERALD OCCURRENCE OF MIKU, ZAMBIA

By PROFESSOR DR HERMANN BANK, F.G.A.

IN the Journal of Gemmology, Vol. 13, No. 5, pp. 169-179, I. C. C. Campbell gives an interesting account of emeralds which are reported to originate in Zambia. "The suppliers who cut these stones would give no details other than that they had originated from claims in the Kitwe district; hence . . . the exact location cannot be given. . . Information has been received that one origin of emerald is Miku, Zambia."

When the writer read this article he remembered that he had seen and examined emeralds from Zambia some years ago; that some of these stones had also been cut and evaluated by his firm. However, he was not allowed at that time to give any details of the mine or even to publish. He therefore wrote now to Zambia and readily obtained(1) a report by A. C. Hickman on the Miku emerald deposit which had been published in 1972 by the Ministry of Mines and Mining Development of Zambia in Lusaka and he therefore now feels free to summarize his experience together with the said report.

Geographical and geological situation

The locality map (Fig. 1) shows that Miku(2) is a river entering the Kafubu river, indeed in the Kitwe district of Northern Zambia. The deposit is called the Miku emerald deposit (sometimes also the Kafubu emerald deposit). It is situated south-west of the copperbelt, SW of Kitwe and WNW of Luanshya at longitude 28° 03′ 30″ E and latitude 13° 04′ 01″ S. It lies immediately south of the Miku stream very close to its confluence with the Kafubu river. The best way to go there takes 50 miles from Kitwe along the St Mary's Mission Road. The shorter way is only 27 miles, but it cannot be used in the rainy season.

Geologically speaking the region belongs to the basement complex of gneiss and foliated granite, garnet-kyanite and staurolite-bearing schist, quartzite, talc-magnetite schist, amphibole schist and quartz-mica schist in which pegmatites (quartz-feldspar-muscovite-tourmaline) and veins with quartz-tourmaline occur. According to Hickman (1972) the occurrence lies in an east-west striking band

(1) Many thanks to Mr. E. K. Horden, Lusaka, for sending the report.

(2) The exact locality has already been mentioned by the author at the International Gemmological Conference at Vitznau, Switzerland, in September 1972.

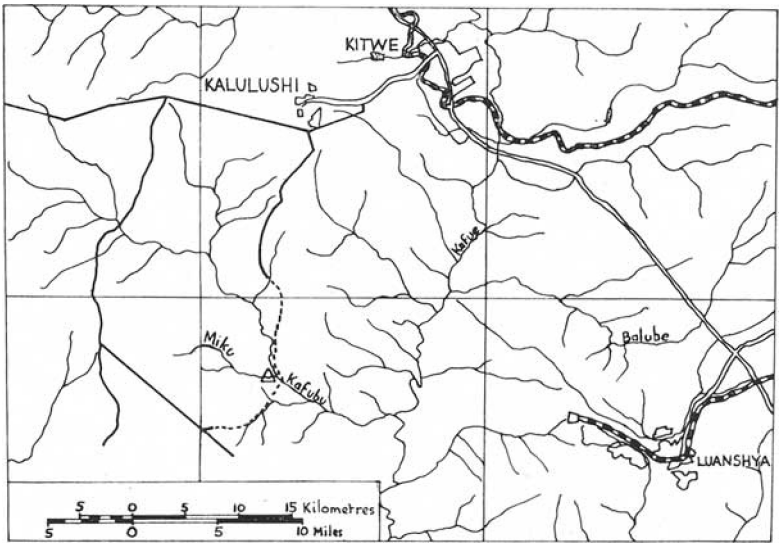

FIG. 1. Locality map showing position of the Miku emerald deposit.

of talc-chlorite-amphibole-magnetite schist, which is almost certainly the metamorphic derivate of an ultra-basic igneous(3) rock (intercalated with metasediments of pre-Katangan age). This schist is easily weathered and then brown, green or red in colour.

The talc-magnetite schist (here also often called country-rock) consists of magnetite (5 to locally 15% of the rock; according to x-ray fluorescence analysis the magnetite contains Cr^{3+} substituting for Fe^{3+}), talc and chlorite; these two minerals form a felty intergrowth containing amphibole (tremolite/actinolite). The schistosity of the rock varies; it is rarely strong, sometimes not even visible.

To the geographic south a sequence of low-grade amphibolitic and quartz-mica schist can be noted, occasionally with sericitic quartzites. To the geographic north a major quartzite crops out (locally called "Muva quartzite"), an almost monomineralic coarsely recrystallized quartzite with veins of quartz, veinlets of iron ore and pods of tourmaline. Further to the north foliated granites, gneisses, and garnet-kyanite or staurolite-bearing quartz mica schists can be observed.

The granites and gneisses consist of quartz, microcline, sodic plagioclase, biotite, and muscovite. Sometimes there is to be seen

(3) The igneous origin is deduced from the composition and the presence of trace amounts of chromium and nickel (proved by x-ray fluorescence) according to a communication from Matheson to Hickman.

a "greisen"-formation and boron metasomatism which results in quartz-tourmaline veins and in disseminated tourmaline in the schists. Geological mapping has also discovered simple pegmatites near the Kafubu river.

Regarding the *tectonic* situation we can say that the area belongs to the southern limb of a pre-Lufilian antiform which is probably overturned to the south. Regional Lufilian refolding has produced north-westerly shearing and is also responsible for the fracturing of many minerals including the emerald (which has probably been produced by mineralizing fluids from pre-Katangan granitization). Since the effects of these movements (folding, shearing, etc.) are widespread it seems unlikely that there are any deposits with unfractured emerald crystals in this region.

The deposit of emeralds, called the Miku-deposit.

Soon after G. J. Baker (1931) had discovered the emerald occurrence as a geologist of the Congo Border Concession Co. he also gave the first report on the Miku emerald deposit. Baker (1931) thought that the deposit was not of sufficient size to be considered as a source of beryl and that it was only a very doubtful prospect as an emerald mine because all the emeralds were fractured. Brock (1940) summarized the work of the Rhokana Concession Geologists (the Company's prospecting licence expiring in 1941) and came to

FIG. 2. Miku Emerald Deposit.

the same conclusion as Baker (1931). In 1953 Rio Tinto Finance and Exploration Co. Ltd acquired the rights. Sharpe (n.d. 1964) described the character of the deposit and Rio Tinto Finance . . . pegged a claim in 1962. Miku Enterprises Ltd purchased the claim some years later and some exploration work was done. Initially trenching was carried out together with field mapping and geographical and geochemical techniques. This led to the discovery of an area of coincident magnetic and beryllium anomalies.

The geological and geochemical field-work was carried out by Hickman; the geophysical measurements were made by Mazac and Hickman. The writer obtained some of the material for gemmological studies, cutting and evaluation. The emeralds occur mainly in a rock which consists almost entirely of biotite/phlogopite (the optical properties are midway between biotite and phlogopite) in which also small crystals of tourmaline of 0·02-0·03 mm are found. Between the host rock and the country rock there is sometimes a transition zone consisting of tourmaline, phlogopite, tremolite, actinolite, and pseudomorphoses of talc after amphibole.

When unweathered, the host rock is deep brown; where chlorite is present, it has a greenish tinge. It can be (1) fine-grained massive, containing the best emeralds, (2) coarser massive or schistose and very coarse (with only few emeralds), or (3) veins of phlogopite. "Knots" of several inches in diameter, in which coarse biotite has grown concentrically, occur singly or in groups and are sometimes associated with the veins. These varieties are not systematically distributed; the more finely grained rock is more common in the northern part of the deposit. Between the host rock and the transition zone chlorite and talc can be found and tourmalines sometimes occur as "suns" in the transition rock. A drillhole showed the distribution in the depth:

57–67 feet:	a green talc-magnetite schist
67–72 ,,	a green talcose sludge
72–93 ,,	a grey to dark-grey quartz-amphibole-chlorite schist with fine veinlets of quartz
93–94 ,,	fragments of vein-quartz and tourmaline associated with phlogopite/biotite
94–111 ,,	a grey quartz-amphibole-chlorite schist.

In *geophysical* context Hickman is of the opinion that since chromium is essential for the formation of emerald it is necessary to find out the extent of the only rock in which chromium has been

traced: the talc-chlorite-magnetite schist. This schist is easily detectable because of its high magnetic susceptibility compared with the other rocks of the region which have a low magnetic susceptibility.

From the *geochemical* aspect there are various good prospecting methods of beryl, since beryllium is a relatively immobile element in secondary geochemical dispersion. A well-defined Be-anomaly with a peak has been discovered.

Crystallization

The emeralds occur (mainly in the fine-grained phlogopite/biotite rock) generally as single crystals of the hexagonal system with prism, pinacoid and bipyramids. They range in size from microscopic dimensions up to two inches in length. Clusters or parallel crystals are found rarely.

Colour

There are beryls of a milky-white colour, pale green beryls and very nice green emeralds. Some of these have the greenish-yellowish tint of Sandawana emeralds (from Rhodesia), some have colours like Colombian emeralds.

Chemical composition

Hesom analysed a purified sample. The Table below shows the result in comparison to Sandawana.

	Miku Hesom, W. G. (in Hickman 1972)	*Sandawana* (acc. to Martin 1962)
SiO_2	62·23%	63·84%
Al_2O_3	15·41	18·06
Cr_2O_3	0·33	0·60
Fe_2O_3	0·04	—
FeO	0·07	0·30
BeO	11·90	13·28
MuO (probably MnO)	0·02	
MgO	0·76	0·75
CaO	0·31	
Na_2O	2·63	2·03
K_2O	2·89	0·05
Li_2O	NIL	0·10
Cs_2O	traces	
H_2O+	2·59	1·07
H_2O-	0·06	—
	99·24	100·08

A spectrographic analysis (Matheson, pers. comm.) showed traces of rubidium, nickel and zinc.

Refraction of light, birefringence, specific gravity

Hickman (1972) mentions optical data supplied by Matheson—refractive indices

$$n_\varepsilon = 1{\cdot}581 \qquad n_\omega = 1{\cdot}585$$

with a very small birefringence of 0·004: optical character, negative. With gemmological equipment Campbell (1973) found a higher birefringence and higher refractive indices—

$$n_\varepsilon = 1{\cdot}581 \qquad n_\omega = 1{\cdot}588$$
$$n_\varepsilon = 1{\cdot}583 \qquad n_\omega = 1{\cdot}590$$

birefringence 0·007 (negative),

and Anderson (1969) already mentioned Zambian emerald—

$$n_\varepsilon = 1{\cdot}581 \qquad n_\omega = 1.588$$

The writer found partly also a somewhat higher birefringence which he published at the Vitznau International Gemmological Conference—

$n_\varepsilon = 1{\cdot}580$	$n_\omega = 1{\cdot}590$	$n_\varepsilon - n_\omega = 0{\cdot}010$
$n_\varepsilon = 1{\cdot}581$	$n_\omega = 1{\cdot}590$	$n_\varepsilon - n_\omega = 0{\cdot}009$
$n_\varepsilon = 1{\cdot}580$	$n_\omega = 1{\cdot}589$	$n_\varepsilon - n_\omega = 0{\cdot}009$
$n_\varepsilon = 1{\cdot}581$	$n_\omega = 1{\cdot}589$	$n_\varepsilon - n_\omega = 0{\cdot}008$

The Specific gravity is given by

Hickman (1972) as—	2·71 g/cm^3
Campbell (1973)	2·74-2·76 g/cm^3
Anderson (1969)	2·75 g/cm^3
the writer	2·74 ±0·002 g/cm^3

Inclusions

Hickman (1972) mentions small flakes of biotite/phlogopite which occur in abundance.

According to Campbell (1973) five types of inclusions are evident in these emeralds supposed to come from Zambia:

1. black biotites in the form of irregularly shaped specks, dots, etc.
2. "bread-crumb"-type inclusions
3. mica or a mineral similar in appearance
4. extremely fine pin-point inclusions giving a cloudy or milky appearance
5. in some stones, feathers.

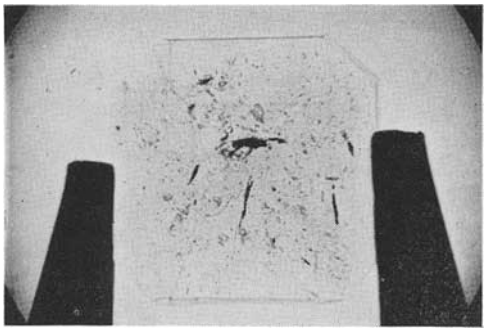

FIG. 3. Biotite/phlogopite inclusions in Miku emerald.

Fig. 3 shows nice biotite/phlogopite inclusions as seen by the writer.

Mineralization

Two aspects of the mineralization are of particular interest—(*a*) the origin of the various elements (especially the minor ones) and (*b*) the emplacement of the tourmalinite vein. Around the deposit there is a widespread occurrence of tourmaline (as a monomineralic rock, together with vein-quartz or disseminated in the country-rock). There is evidence of pegmatitic or pneumatolytic activity (beryllium and lithium). The presence of beryllium and boron and the numerous quartz deposits are a good indication for a pneumatolytic origin of the deposit. Gold is also present which presumably is also of pneumatolytic origin.

The country rock consists of talc $Mg_3[(OH)_2 \mid Si_4O_{10}]$, chlorite (Mg, Al, Fe) $\pi_{12}[(Si, Al)_8 O_{20} (OH)_{16}]$, amphibole (actinolitetremolite) $Ca_2(Mg, Fe)_5[(OH, F) \mid Si_4O_{11}]_2$, magnetite $Fe_3 O_4$, and also contains chromium. The formation of phlogopite $KMg_3[(F, OH)_2 \mid Al Si_3O_{10}]$, biotite $K(Mg, Fe, Mn)_3[(OH, F)_2 \mid AlSi_3O_{10}]$, and beryl $Al_2Be_3[Si_6O_{18}]$, required the introduction of potash (K) and beryllium (Be) respectively. The formation of tourmaline needed boron (B) and sodium (Na). The small amount of chromium (Cr) necessary to produce emerald out of beryl was present in the country rock.

The absence of gradational boundaries to the vein and its cross-cutting mode of occurrence indicate that it originated by crystallization from fluids in a fissure. Residual fluids containing

some boron as well as beryllium, sodium and potash produced the emerald-rich mica-bearing rock.

Hickman (1972) compares Miku with some other emerald deposits and states that with two exceptions (Colombia and Brazil)(4) the country rocks of all important occurrences include ultrabasic rocks or their metamorphic derivates. All deposits also show evidence of pegmatitic activity. So also at Miku the characteristic factors are present:

1. ultrabasic rocks to provide the vital chromium for the colour
2. granitic activity to contribute the beryllium-bearing residual fluids.

ACKNOWLEDGEMENTS

The author wishes to thank Mr. E. K. Horden, of Northern Minerals and Zambia Gemstones Ltd, Lusaka, Zambia, for submitting the emerald specimens and for providing Mr. Hickman's report.

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(4) In Brazil only the old occurrence Bom Jesus dos Meiras (Brumado) is different; the other occurrences (Santana de Ferros, Vittoria da Conquista and especially Carnaiba, etc.) are of the same type as described here.

AN APPETITE FOR GEMMOLOGY

By A. E. FARN, F.G.A.

OBVIOUSLY a pun is expected from such a title, but none was intended. However, one can safely say that none go hungry in our laboratory gemmologically speaking.

Since our move from 15 Hatton Garden to 36 Greville Street much has happened. The Laboratory, which was nurtured and brought from its early beginnings in 1925 to its prominence under the guidance and leadership of B. W. Anderson, has been a landmark in Hatton Garden for a long time.

The wind of change which has blown through Hatton Garden since the redevelopment project of the Gamage building has caused a lot of firms to move and start a desperate hunt for suitable premises —not least among these being our own laboratory, which although not part of the large Gamage site was unfortunate enough to become a separate redevelopment problem at the same time. Despite many fancy ideas, it seemed (and is) imperative that the Laboratory remains in Hatton Garden in or near the centre.

We were to have a series of small crises one after another in this my first nine months in charge of the Laboratory. As well as feeling rather shorn lambs in the untempered wind following Mr. Anderson's retirement we were beset by difficulties of staff shortage. Following the Trade Descriptions Act many small businesses in Great Britain unearthed their little bits and pieces and we were inundated with a never-ending flow of jewellery items consisting often of colourless cluster surrounds to coloured centres in rings, earrings and brooches.

Most were nearly enclosed at the back; almost all were filthy and needed cleaning thoroughly; and it was insufficient to state that they were not diamonds. One had laboriously and messily to immerse, fluoresce, phosphoresce, cross-filter, absorb, float and in fact—short of filing the table facets with a diamond file—do every tetchy type of test beloved of book gemmologists but abhorred by trade gemmologists.

With this plentiful supply of testing and a somewhat new staff we had to keep looking at premises which might be a possibility. We drew plans of layouts to fit the various places we hoped to have and tried desperately to shed ourselves of 50% of our possessions to squeeze our 950 sq. feet of laboratory space into a tight 350 sq. feet

in a prestige position. Good friends offered to store some of our mineral collections and I had my eye on a rather nice early Victorian glazed bookcase should the necessity arise! However, fate took a turn and we were not to be squeezed up on the third floor but spread a little in the lower ground floor of our present abode. The bookcase, alas, still graces our laboratory!

Having finally found and decided upon new premises we then had to interview new potential staff, since one of our recent lads was leaving. So there we were—a move imminent, lots of gemmology awaiting practised hands, and a very new young man to help us. Alan Clewlow is our most recent addition. A B.Sc. (geochemistry) from University College, he started his career with us the hard way, on the day of our move. At least, having taken part physically in the moving and setting up, he knows where things are right from the start.

When we moved, we had about 35 tea chests full of equipment apart from the obvious items of furniture. We had a separate heavy lifting section of the removal people to handle the x-ray set, which is lead-clad for safety. Another firm lowered a new safe down through the pavement lights, while the x-ray was trundled up the old staircase and down the other. The new premises were still being cleaned, decorated, plumbed and rewired as the apparatus flowed down the stairs in a seemingly never-ending stream. It all had to be done at once because of the demands on the services of our very reliable firms of builders and electricians; everyone else on the move wanted them. We moved within seven days of the termination of our lease—a chirpy young lady representing the developers brightly told me I was entitled to stay till midnight of 25th December! It was a tight situation, hardly improved by a fluey cold which worsened daily.

We stripped our old laboratory of everything, much of which had been built over a long period, such as panels of switches for specialist items, transformers, rheostats, many representing the work of Robert Webster, who in his day was our electrician, bookkeeper and, of course, gemmologist. Standing alone in the echoing silence of the old lab., checking that everything had been taken, I looked around at the emptiness, at the marks where apparatus had stood, the stains on the floor, the scars of movement, a rectangle of shiny floor space which had so recently supported my desk. The banisters and sides of the staircase had been removed somewhat

hastily to allow the x-ray set to be lifted through. It looked a battlefield, and just around the corner in Greville Street was waiting a whole lot of items and pressing problems, gas men, electricians, carpenters, all saying, "where shall I put this, where do you want that, do you want a plug here, where is the dark room to be?", etc., etc.

We did manage to unpack nearly all of the boxes; we did get the x-ray set in place and working; we did set up our absorption bench, our pearl table and various benches for general work; and we did make mistakes. By and large though, we have used our past experience to good purpose and I feel the Laboratory in its new habitat with newer staff presents itself ready to tackle the new era of gemmology. It is no use harking back upon the theme of the old days of the Laboratory, for that is an era which will never occur again. We still do very similar work and have even improved our method of record keeping. The amount of work has increased and we are not yet fully staffed and so our day is really full, so much so that I doubt if ever again will a flood of written items flow from this Laboratory. However, we do still have our items of interest which I hope to be able to write up from time to time.

With a new assistant to teach and help I find I am now looking anew at stones which I might have passed by quickly in normal testing time, but now of necessity I am doing my practical gemmology over again and physically leaving no stone unturned! We had a peculiar little stone recently, not at all difficult to test but intriguing because it seemed a wasted effort. It was a composite stone—a rectangular green stone in a ring. The table had a sharp clear reading of 1·52 (glass), a layer of colour in the middle and glass below; it seemed a lot of trouble for the end result. We have had at least two other composite stones recently; both have been beryl on beryl composites with a green layer between. The refractive indices have been fairly high and the top layer clear and colourless, the lower portion being full of inclusions. These stones were green when viewed through the Chelsea filter and had an organic dye-stuff broad band in the red end of their spectrum. Another interesting item was a four-stone half-hoop ring of colourless stones; three were yttrium aluminates giving a violet fluorescence under x-ray excitation and refractive index of 1·835, with one end stone glass with an R.I. of 1·56. Another was a colourless three-stone ring with a centre marquise flanked by a brilliant-cut

stone at each side; all were yttrium aluminates. An interesting fact noticed on a green yttrium aluminate was that despite using only 1·81 liquid on the diamond refractometer we saw a reading at 1·835.

Another interesting stone was a pleasant yellow orthoclase which gave refractive indices 1·522–1·527 and had diffuse broadish bands in the blue end of the spectrum.

The spectroscope is one of our most regularly used instruments —it is so manœuverable and gives results on cut, rough, large and small-sized stones. Explaining to our newest recruit the method of approach to testing a diamond for irradiated colour, I stressed x-ray fluorescence, absorption spectra and long and short wave effects together with crossed-filter work. As I was talking a customer brought in a cinnamon-coloured diamond in a ring. Here was a practical test with which to demonstrate the facts as taught. The stone behaved impeccably. It gave a blue fluorescence under x-ray excitation. The absorption spectrum showed two faint lines at 5040 and 4980Å. Between crossed filters it glowed a straw to yellow brown. Inspection in methylene iodide revealed zoning bands.

Tests seem to run in groups for we had a series mostly of yellow to brown diamonds set in cluster rings to test in a short space of time. Together with these we had a loose pale unhappy green-hued diamond. This looked to be an old-fashioned radium-treated stone. Inspection revealed an elusive but nevertheless discernible line at 4155Å—a Cape stone! X-ray fluorescence was chalky blue, but the stone was inert between crossed filters. We decided to check the stone overnight on a film. The stone under test and a known comparison stone were both placed on a strip of film, and left in a light-tight box overnight in the safe. We were all very pleased to see a good strong autoradiograph fogging the film next morning. The stone under test gave a stronger outline than our known example.

SALMANAS' *METHOD* AND OTHER GREEK FORMULAE FOR THE CARE AND MANUFACTURE OF PEARLS

By P. G. MAXWELL-STUART, M.A.

AMONG the Greek texts which M. Berthelot collected together under the general title of *Collection des Anciens Alchimistes Grecs* (Paris 1888) is a short essay attributed to an Arab technologist Salmanas, otherwise unknown to us, which is remarkably free from much of the mumbo-jumbo and downright nonsense which disfigure the work of many of the Greek chemists and alchemic practitioners. It may be of interest to compare this with other recipes for the care of pearls belonging to anonymous authors of much the same period, whose work is contained in manuscripts of the early Middle Ages, but whose wisdom may have come from earlier experience. As far as I am aware, none of them has been translated before into English.

The methods they describe are somewhat surprising to any trained scientist. They appear to have used a number of weak acids which would have been capable of dissolving much of the pearls' surface dirt, but they threw in so much other junk (if that is the correct word) that what they probably achieved was a coating of the pearl with a white compound. Similarly, where they claim to have made pearls it is more likely that a crystal of some white salt or other had been formed by their efforts. If someone had time and laboratory space, however, it would be interesting to see what resulted from some of these experiments.

I. Salmanas: Method of Making a Round Pearl

1. Take very fine crystals, put them in a glass jar, and pour in citrus juice so that they are quite covered. On top of this liquid scatter a small quantity of (powdered?)(1) *Ulva Lactuca* which has been roasted and pulverized. Next, seal it up; carefully smear the stopper with the clay you have prepared. Hang up this jar so that it can be heated by the hottest rays of the sun for a whole day. Each hour take the jar and shake it vigorously so that the granules inside are shaken up too. Next day remove the stopper and filter the liquid, taking care not to spill the compound which has resulted

1. A question mark after a word in brackets means that the Greek is not clear. Much of the language used is technical and of course we no longer employ these techniques.

from these granules. Put another similar liquid into the jar and do the same thing over again. Repeat the operation a third time. When you see that the crystalline matter has expanded and absorbed the liquid, pour on top another liquid exactly the same. After the granules have dissolved completely and formed a single compound, take the compound and put it into a strainer. Fill this with (distilled?) water, shake up the two together, and then leave the water to settle for an hour. Filter it carefully once more and repeat all this several times until the sharp taste of citrus juice has completely disappeared.

2. Now take this compound and put it into a little glass dish. Cover this dish with another which has a wider rim so that the mouth of the larger envelopes that of the dish underneath. The upper dish should have a hole on top to allow the moisture in the compound to evaporate. This hole must be overlaid with a loose-meshed cloth called *Charerion.*(2) Put it all out in the hottest hours of the sun and when the compound has dried out keep it carefully.

3. Take 1lb mercury and some (ammonium chloride?) prepared with lime; pound it up for 2, 3, 5, or 7 days. When it is dried out sublimate and purify it. Once this compound is dry take ½lb of it and mix it with 1lb mercury. Pound it carefully until all the mercury has disappeared, that is to say, has been absorbed. Now retract the preparation into glass jars above a low fire until you see it become white like snow. Next, take 4 parts of the dry crystalline compound and 6 parts of the mercury compound and mix everything together in a dish of thick glass. Crush and grind it well with a glass pestle; moisten it with the white juice of the plant *Zocaron.*(3) Let the leaven become thick like dough: grind it up well and with care. Take as much of this leaven as you need, put it into a white silk straining-cloth and make from it pellets of the thickness you want. The implements you will need for making up the pellets are a silver pestle, silver tongs, and silver finger-stalls. Make up your pellets with these, but be very careful that your hand does not touch them—do not even sweat—in case the dust (of chloride of mercury) touches you. It is poisonous and it turns dark and becomes useless.

2. From *khárá*, Persian, a strong silk cloth.
3. We do not know what this plant is. The name may be a coinage of the author, since it does not appear elsewhere. Cyranides, a lapidary of the 1st or 2nd century A.D. uses the word *zocros* to refer to a kind of white vulture, but I doubt whether there is any etymological connexion between the two words.

Next, boil the silk cloth and wrap the pellets in pieces of white silk which have been rubbed with grease. Put each of these pellets into a jar, shake it so that they gently roll around for quite a while. When you see that the pellets have become fine and round, pierce them with a silver wire, and after you have done this shake them up again in the jar.

4. After that take some *zocara* and put them on to a clean plate. Make some astringent solution and sprinkle it on the fleshy part of the plants. These will shrink because of the astringency and will throw off viscous matter. Take a small quantity of this and pour it into a jar; roll each of the round pellets in it. Furnish each of them with a silver wire and use it to retrieve them adroitly. Take a strainer (sometimes known as a sieve); make fine holes in it and fix to these holes, from the inside, the wires which support the round pellets. Now take another sieve, fit it to the first, and fill it with cotton which you must press down lightly and spread all round. Take the jar which contains the pearls, place them inside this sieve, and let them dry there for ten days. Finally, put each pellet into a glass jar the shape of a drinking-bowl. Roll them around in it until you hear that they sound like stones. Then give them some shine in the same way as lapidaries do their stones.

5. Take some pool or river fish, the same size or smaller than tunny; split them on the left side and remove their entrails. Wash well the cavity which is left so that no blood remains behind. Then take the large intestine, make a hole in it, insert some powdered nitron, use water to start off a reaction, and then leave it for one hour. Wash the intestines well with this nitron and rub them with your hand. Next, wash them in water and when you have done that take the aforementioned pellets, insert them one by one into the intestine, and attach them by means of a silk thread which has been boiled in water. Fix each pellet by means of its own thread. Put the intestines with their pellets into the hollow bellies of the fish; cover up the split skin with silk and put the whole thing on an earthenware dish. Have ready a small oven; get it really hot so that it turns pale because of the temperature inside. Now put in the fish on their earthenware platter, close the oven tight, and seal up the door. Leave them to cook for three hours. Then take the fish out of the oven and let them cool. Remove the intestines with their pellets. Open them, take out the pellets, put them into a

piece of linen, and wash them with soap in warm water and fish-oil. You will find perfect round granules in no way different from the finest natural pearls.

II. Treatment of Pearls

The sixteen recipes which follow are by various hands, anonymously collected under the general title *Treatment of Pearls.*

1. *Cleaning pearls and the procedure for making them shine, which the author says he has used often.*

First put some oil in a mussel-shell and heat it over a fire of papyrus or other reed. When it has become warm put the pearl in it. Next, remove the pearl from the oil and smear it with an ointment made of pyrites and white lead.(4) Then wash it well in water, smear it again, and let it dry. Wash it once more, smear it again, and do this in all seven times. After treatment and washing, put it into some orange juice. If one mixes this juice with the ointment everything anointed with it becomes white. If the pearl is soaked in wine it becomes scaly. Generally, if one engraves letters on it by means of black and green encaustic the letters will absorb (the encaustic, and so become permanent).

2. *Dissolution of pearls.*

Crush little pearls very fine, put the powder into a glass jar with some acid citrus juice, and put it over a sawdust fire for three days and nights. They will be thoroughly dissolved.

3. *Another procedure.*

Grind some fine wheaten flour, knead it with acid citrus juice and wild cabbage sap. Add willow sap and squill juice. Drop in the pearl and let it dissolve. You know how to continue from there.

4. *Whitening pearls.*

Take some scammony, grind it very fine, and shake it. Take a decoction of pure barley; pound it up with the scammony so that the mixture is fairly fluid, and pour it into a glass vessel. Suspend the pearl in it and protect it with another phial. Encase it in clay and leave it for nine hours. The pearl turns white. Without doing anything else leave it for seven or 13 days in sunlight or in horse's dung. Dissolve the sulphate of lime in very sharp vinegar.

4. White lead is, of course, the common name for basic lead carbonate, a white pigment; so it is possible that the pearls were not being cleaned but having a layer of white pigment added to them. Naturally, in course of time it would wear off.

5. *Preparation of a pearl.*

Take siderite stone, some powdered arsenic, (magnesia ?)[5], and sulphate of lime. Grind them up in equal quantities. Boil them, following the same procedure as for bisulphuret of mercury. Take the sulphate of lime and dilute it with honey. Feed it to a bird but do not give him anything else to eat and do not let him fly free but shut him up in a cage or basket. Put a *kerbion*[6] on top and give the bird the powdered compound. Clean out his intestines by giving him grasshoppers to eat for three days; then feed him the sulphate of lime. You will find, secreted in the *kerbion*, a smooth, shining mystery.

6. *Another procedure*

Take some little pearls. Put them into a glass jar with some strong vinegar and some white juice from Cyrene; let them stand for 16 days. Seal the jar and leave it in a warm place for a night and a day. Next, add some citrus juice, shake it, and leave it alone for a short while. Then let them solidify according to the shape you had in mind. Sulphate of lime is used to fix the shape.

7. *Whitening of dark or dirty pearls.*

Put the pearls inside an onion or a similar (bulb?); cover it all up with wheaten dough and cook it in an oven or stove. The pearls become white.

8. *Another procedure.*

Take some small pearls, put them into citrus juice, and let them absorb the citric acid. Decant this several times until the liquid becomes clear. Then put the pearls into a piece of cloth (and rub them) until the dirt is loosened. After it has become loose wash them for one day and insert the suety lump into the heart of an onion. Put the onion into an oven until the "suet" is cooked; then take it out and let it cool. You will find that the pearls have become white. Clean and polish them as you wish according to the method of a specialist. Afterwards some people make a bird drink from the evening until 6 a.m. and then let the bird die of thirst by depriving it of liquid. When they sacrifice it they find the dirty parts (of the pearls) clean.

5. This is a very vague term, even in the Greek, and may refer to the carbonate, oxide, or hydroxide of magnesium.

6. *Kerbikarion*, a word apparently borrowed from Latin, is found in an Egyptian papyrus of the third century A.D. meaning a receptacle for dates. It can also mean "pillow" and therefore in our context must mean something like a small bag.

9. *Whitening pearls which have turned yellow.*

Take the pearls, place them in white bitch's milk, cork them up, and leave them for seven days. Lift out the pearls, each of which is attached to a single hair, and see if they have become white. If not, put them in the milk again until you are successful.

If you smear a man (with it), he turns scaly (leprous). Such is the power of this liquid, sprinkled with 1 mna of damp Samian earth.(7)

10. *Fixation of pearls.*

Put them in black bitch's milk and when they have become of a waxen consistency put them into moulds.

11. *Whitening pearls.*

Take two spoonfuls of barley paste, rub (them) together, and let the pearl soften up for six hours.

12. *About pearls.*

Put them to harden in fig milk, or spurge juice, or white hellebore juice, and leave them there overnight. When they have become hard model each of them with the viscous matter which you have already strained off and let them dry for a month. Next, put them in quicklime. Sprinkle water gently, drop by drop, until the quicklime has become watery, then leave it until it dries out. When you lift them out you will find the pearls hardened. Let the stuff to be modelled form a hardened mixture with the white gum-water. Dry it out like this. So that the pearls harden easily when you introduce them into the dampened quicklime mixture and after they have acquired the right consistency, wash them well for an hour in pure, clear oil, and suck them (clean). Then, if you find they have not become bright, put them in a bowl of barley paste. Knead them as though you were making a wheaten loaf, then cook them—in an oven. In this way you clean and polish them. You will be amazed at the result. Attach a hair (to each pearl) before trying to harden it.

13. *Whitening pearls which have turned yellow.*

Take the ends and the off-white part of a squill, from the middle of the leaves, and some soap-wort; grind them up in equal quantities. When you have made this preparation, put in the pearls so that they are quite covered. If they are too hard add some virgin's urine and a little pure honey.

7. This is not part of the recipe, of course, but has slipped in from somewhere else by mistake.

14. *Cleaning pearls.*

Take garlic, grind it up with water, and put it in a little jar. Suspend the pearl from the middle of a hair, and let it soak in the liquid for a day and a night. Then await your intuition. If there is no result, powder some more with some very fine ash. Wrap it in a piece of linen cloth and turn (the vase) clockwise over a fire until the ash has disappeared, and the pearl has an offshoot. You will find it white and clean, and it should be healthy from every point of view.

15. *Cleaning the British pearl.*

Take some Cyrene juice, (whisk it up?) with water, and put it into a small flask. The juice does not dissolve but forms a separate layer in the water. Take the pearl and suspend it from a horse's hair. The pearl should have no cracks. Put it into the juice and at once the juice engages with it. Leave it there for a day and night. Take it out, rub it, and you will find it has become clean and white. If it needs to be cleaned still more, leave it for a day and night. Repeat the process as often as necessary, and do it with care until you have succeeded.

16. *Cleaning lead-coloured pearls, according to a monk.*

Take some garlic and grind it up along with the urine of someone who has not yet reached puberty. Put it into a little flask and drop in the pearl. Leave it to soak for three nights and days. Then take some Cyrene juice and a little oil and heat them. Hang the pearl in it by means of a horsehair. Roll it around (in the liquid) until you see that it has become white. First, then, take garlic; then put it in oil, and take it out when the oil is seething. Use this juice. If the result is no good, use balm instead of oil and you will succeed.

III. Polishing Pearls

Finally, here are two further recipes for polishing pearls, once again by anonymous authors.

1. Take a water-melon or a cucumber and open it in the middle. Place the pearl inside and put the cucumber in an oven until it falls apart. (In this way) the pearls become shining.

2. Fry a pearl inside a bird or a pigeon [sic!] and keep it there until the hour of Paternoster. Then split open the bird and take out the pearl.

DIAMOND TESTING BY IMMERSION—A USEFUL GADGET

By DAVID WILKINS, F.G.A.

IN one of the chapters in "Gem Testing"* Basil Anderson suggests immersing a diamond brooch in one of the highly refractive liquids to see if any of the stones "disappear", thus indicating an inexpensive replacement or "foreigner". This is a very simple and convincing test which, unfortunately, doesn't work if the stones are in a closed-back setting.

Usually it is sufficient to prove "not diamond", but occasionally closer identification is required, and to assist in this a working jeweller friend, also an F.G.A., made up for me a small stand, some 20 mm × 13 mm, set with two diamonds, a zircon, a synthetic sapphire, a synthetic spinel and, very difficult to obtain, a clear quartz (see photograph).

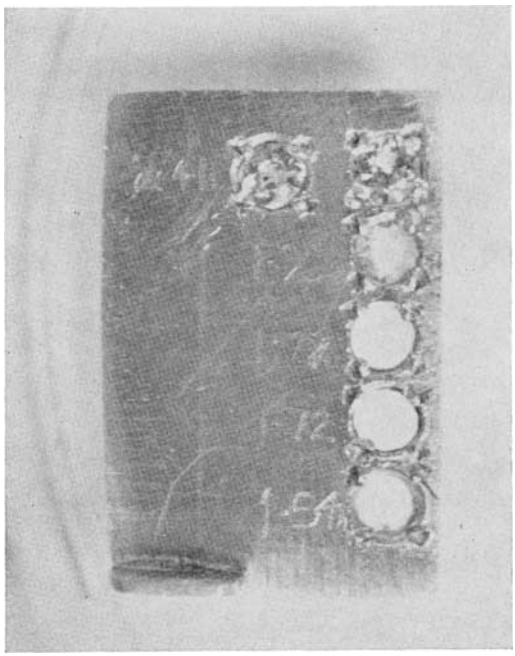

*8th edn.: p. 187.

Placed in the dish containing the brooch and liquid, the degree of "invisibility" is quite surprising, sufficient to convince the most sceptical customer, for this is one of those tests which may easily be carried out on the shop counter.

If you want a really superb demonstration of this effect to startle a class of students, try one of those large perspex models of the various cuts of diamonds immersed in a glass beaker half full of toluene. One word of warning, though—don't leave it in for more than a few seconds or the perspex starts to craze.

I find toluene by far the best liquid for most immersion work, and have never been able to agree with those who denigrate it. It is cheap, clear and highly volatile, such that after taking the brooch out of the liquid, a quick shake, a good lungful of "blow", a few seconds close to the desk lamp and it may be handed back to the customer. Compare that with the scrubbing required to eradicate the mothball smell of monobromonaphthalene.

Gemmological Abstracts

ANDERSON (B. W.). *Spectroscope: an indicator of variation.* Gems & Gemology, 1972/3, XIV, 4, 98-101.

A report of a talk given at the XIVth International Gemmological Conference in Vitznau, Switzerland, the theme being the marked changes in absorption spectra of gemstones with slight changes in their structure. The discussion was mainly in respect of zircon, red spinel and apatite. R.W.

BANK (H.). *Farbloser und blauer transparenter Colestin aus Madagaskar.* (Colourless and blue transparent colestine from Madagascar.) Z. Dt. Gemmol. Ges., 1973, 22, 3, 99-100.

This transparent stone has recently been encountered on the market; it was found to be an Sr-sulphate (Sr (SO_4)), hardness 3-3½, density 3·98, R.I. 1·619-1·631. E.S.

BANK (H.), BERDESINSKI (W.), DIEHL (R.). *Durchsichtiger Rhodonit aus Broken Hill, Australia.* (Transparent rhodonite from Broken Hill, Australia.) Z. Dt. Gemmol. Ges., 1973, 22, 3, 101-103.

Rhodonite is generally not transparent and only rarely translucent, although Webster in 1970 described a transparent faceted rhodonite. The authors have now also found some of this material while examining red manganese pyroxene from Broken Hill. The rhodonite was found to be $CaMn_4$ (Si_5O_{15}), triclinic, density 3·66-3·68, R.I. 1·724-1·737. E.S.

BANK (H.), BERDESINSKI (W.), DIEHL (R.). *Durchsichtiger roetlicher Pyroxmangit aus Broken Hill, Australia und die Möglichkeiten seiner Unterscheidung von Rhodonit.* (Transparent reddish manganese pyroxene from Broken Hill in Australia and the possibilities of distinguishing it from rhodonite.) Z. Dt. Gemmol. Ges., 1973, 22, 3, 104-110.

The submitted material had a deep red colour with a slight brown tinge and was said to be rhodonite. Properties of manganese pyroxene are given, including formula ($(Mn\ Fe)_7$ (Si_7O_{21})),

crystallographic details with optical angles, density (3·76), cleavage, hardness (5-6). The difference between this material and rhodonite is to be found in the lattice constants. The relationship between the axis and the optical axis angles varies as does the double refraction. E.S.

COLDHAM (T. S.). *Sapphire mining in Northern New South Wales.* Australian Gemmologist, 1973, 11, 10, 14-19. 4 illus.

A good account of the sapphire mining in the Inverell–Glen Innes district of New South Wales, Australia. The area has, during the last five years, been more intensively worked using modern equipment. The sapphire is recovered from alluvial gravels, the area first being tested by drilling 3-inch diameter holes in a grid pattern for sampling, or by cutting "costeens", a series of narrow cuts across the river flats. A "proved" area is then worked by removing the overburden to reach the "wash" containing the sapphire. This is removed by dumper trucks to a "dumpbox" where it is washed to remove the larger boulders, after which the residue is passed through trommels and then to pulsators to concentrate the heavy minerals from which the sapphire is hand-picked out with also the larger zircons and garnets. The stones recovered are graded for quality and then marketed through Thailand, Hong Kong and Europe. R.W.

COPELAND (L. L.). *The derivation of gem names.* Gems & Gemmology, 1972/3, XIV, 4, 118-125.

A useful compilation of the etymologies of gem names. Those names commencing with A to J are given and the series is to be continued in a future issue. R.W.

CROWNINGSHIELD (R.). *Developments and highlights at G.I.A's Lab. in New York.* Gems & Gemology, 1972/3, XIV, 4, 111-117. 18 illus.

A discussion is made of the dark blue aquamarine recently marketed and which may be referred to as "maxixe beryl". The fading of such stones is a possibility and further research on these beryls is still being carried out. Some Oriental carvings have been proved to be nephrite, some serpentine, some green grossularite, and some an unnamed rock mixture containing feldspar, zoisite and serpentine. An actinolite cat's-eye, a chrysoberyl cat's-eye which

looked like a doublet and a 40 carat cat's-eye apatite which was damaged when being cleaned up after setting were encountered by this laboratory. A laser-drilled diamond showing a penetration of 4 mm, twice normal, was seen and some discussion made on it. A diamond crystal with a botryoidal surface structure and a "fingerprint" inclusion in a synthetic ruby are mentioned. Some experiments on the hardness of strontium titanate suggest that the hardness is 5 to 6. Some amber examined under the polariscope showed that pressed amber behaves as a doubly refractive aggregate, whereas block amber shows a normal strain pattern. It is suggested that pressed amber may be differentiated from block amber by using ether, the pressed amber softening while block amber does not.

R.W.

DERN (H.). *Ein neuer interessanter Schliff.* (A new interesting cut.) Z. Dt. Gemmol. Ges., 1973, 22, 3, 133-134.

A new cut especially for the amateur cutter, having 28 facets on the upper face, suitable mainly for square-type stones with cut-off corners producing as a basis a type of octagon, leading with a trap cut to an apex which is formed by the four main facets. It was used on a transparent sanidine, but is suitable for other stones, and a patent has been applied for covering also diamonds. The girdle has 32 facets and takes up about one-quarter of the pavillion. E.S.

EPPLER (W. F.). *Ungewöhnliche Dreiphasen-Einschlüsse im Kunzit.* (Unusual three-phase inclusions in kunzite.) Z. Dt. Gemmol. Ges., 1973, 22, 3, 93.

The author describes and shows a photomicrograph of a cut kunzite weighing 15 carats most probably from California exhibiting three-phase inclusions, the second phase being a very thin circle-shaped formation. E.S.

EPPLER (W. F.). *Natürlicher und synthetischer Türkis.* (Natural and synthetic turquoise.) Z. Dt. Gemmol. Ges., 1973, 22, 3, 94-98.

Short history of mining and later synthesis of turquoise, also mentioning the "copper mines" of King Solomon near Elath. The synthesis which is dealt with mainly is the one marketed by Gilson in 1970 and has a lower R.I. (1·60) than natural turquoise (1·62). Various imitations are also listed, such as "Viennese turquoise", "neolith" and "neoturquoise". E.S.

GOWER (W.). *Confirmatory test for sphene.* Australian Gemmologist, 1972, 11, 8, 26.

To add confirmation that a stone was a sphene the distance of doubling of the back facet edges was measured by a scale fitted on to a microscope and compared with that of a similar sized zircon. A similar problem was overcome by using a petri dish in which a hair had been laid on the surface and three stones, a zircon, the unknown and a synthetic rutile laid on top of the hair. By visual observation it could be seen that the relationships were approximately 1 : 2 : 4, which, with other findings, confirmed the unknown stone to be a sphene. R.W.

HUDSON (D. R.). *Gemstones in the system* $BeO–MgO–Al_2O_3–SiO_2$. Australian Gemmologist, 1972, 11, 5, 5-7. 1 diagram.

The relationship between the minerals within the system is given and the characters of these minerals are discussed. The article concludes with an exposition of the geological occurrences. R.W.

LECKEBUSCH (R.). *Farbursachen der Fluorite.* (Causes of colour in fluorites.) Z. Dt. Gemmol. Ges., 1973, 22, 3, 123-126.

Pure fluorite being colourless, the author examined colourless as well as violet, blue, green, yellow and red spectrographically. The absorption spectra are shown. E.S.

LIDDICOAT (R. T.). *Developments and highlights at G.I.A's Lab. in Los Angeles.* Gems & Gemology, 1972/73, XIV, 4, 102-108. 14 illus.

A good account of the examination of the new synthetic alexandrites is given. Their properties are similar to those of the natural alexandrites as they have a density of 3·73 and refractive indices of 1·746-1·755. The colours are reminiscent of the Russian alexandrites rather than those of Ceylon. The inclusions consist of layers of dust-like particles, a tendency to strong banding and natural-looking "fingerprint" inclusions and also the typical veil-like feathers so common as an indication of synthetic stones grown by the flux-fusion technique. Some comment is made on the colour nomenclature of—and on the inclusions in—corundums from East Africa. Unusual banding in a milky-white Type IIb diamond is mentioned, and a number of diamond doublets and a glass cat's-eye are referred to. R.W.

MALES (P. A.). *Rutilated quartz and ilmenite.* Australian Gemmologist, 1972, 11, 5, 3-4.

A discussion on the inclusions seen in conjunction with the rutile needles in rutilated quartz. Are they ilmenite or are they hematite? R.W.

MALES (P. A.). *Diamond crystals from the Isabella River, Oberon District, New South Wales.* Australian Gemmologist, 1972, 11, 8, 23-25. 1 illus.

Two diamond crystals found on the Isabella river, a tributary of the Abercrombie river, were examined. The stones are considered to be tetrahexahedral in form. Some discussion is made of the surface growth marks. R.W.

MACFALL (Russell P.). *The hall of gems of the Field Museum.* Lapidary Journal, 1973, 27, 5, 746-771.

An account of the celebrated gem collection housed at the Field Museum of Natural History, Chicago. Items of importance include material from the cabinet of G. F. Kunz, a 4-carat rhodochrosite from Colorado, a kunzite of 294·8 carats, and one of the world's two largest faceted topazes. American gems include a 137 carat faceted blue beryl from Stoneham, Maine, and an uncut thomsonite from Minnesota measuring $4\frac{1}{2} \times 2\frac{1}{2}$ inches.. M.O'D.

OUGHTON (J. H.). *Another colour-changing sapphire.* Australian Gemmologist, 1972, 11, 5, 4.

Tells the story of a natural white sapphire which changed to a pale yellow after irradiation with ultra-violet light of both long and short wavelengths. The colour was intensified after a further hour's treatment under a short-wave ultra-violet lamp. The colouration reverted in daylight but could be brought back by further irradiation with ultra-violet rays. Comparison is made with the behaviour of a supposedly x-ray treated yellow sapphire. It is suggested that the stone had been treated in some way. Improvement in colour by some type of irradiation of an emerald and blue sapphires is also mentioned. R.W.

OUGHTON (J. H.). *The stone that was nearly a taaffeite.* Australian Gemmologist, 1972, 11, 8, 25-26.

Tells of a lilac-pink stone which seemed to show a clear birefringence of 0·008 for refractive indices of 1·719 and 1·727.

The density was 3·64. The stone was finally identified as a synthetic spinel. No reason, except anomalous double refraction, could be given for the effect. A second "freak" synthetic spinel having similar properties turned up. R.W.

REEVE (R. J.). *Brazilianite.* Australian Gemmologist, 1972, 11, 5, 8-10. 3 tables.

A review of the literature on brazilianite which was first found in Brazil during 1945. The crystallography of the material, its chemical composition and properties are discussed. Something is told of its occurrence and its relation to other minerals. R.W.

RODGERS (Peter). *Gemstones of Kintyre.* Gems, 1973, 5, 5, 13-16.

Rocks of the Old Red Sandstone period overlay a mica schist in the Mull of Kintyre, and amethyst, garnet, malachite, galena and various agates may be found. Cornelian and jasper are plentiful on the beach of the island of Dava. Agates are found in conglomerates of the south coast cliffs. M.O'D.

SASNAITIS (E. R.). *Amber: the gold of the north.* Australian Gemmologist, 1973, 11, 10, 3-7.

A well-written general article on amber. The types of amber and localities where it is found are mentioned and some of the properties of amber are given. Something is told of the mythology and history of amber. Insects and debris of flora and fauna found in amber tell of life in the tertiary period of geological history. The fashioning of amber is discussed and "pressed amber" described and artificial colouration is said to have been practised. Mention is made of forged inclusions in amber and it is stated that equipment is now available which identifies such man-made inclusions. It would have been useful if this had been enlarged upon. R.W.

SMID (J.) and KRISTEK (J.). *Der vertikale Lichtofen—eine neue Apparatur zur Erforschung der Schmucksteinsynthese.* (The vertical light oven—a new apparatus for research into precious stone synthesis). Z. Dt. Gemmol. Ges., 1973, 22, 3, 111-122.

The light oven is an apparatus which heats an object using the optical system of focusing light rays; it has lately been applied to the one crystal syntheses of high melting materials. The article deals

with the general principles of this arrangement showing the application to the syntheses of congruent melting crystals with a melting point of up to 3000°C by means of vertical zone melting. Interesting examples include oxides used in the jewellery industry such as corundum, spinel, strontium titanate, yttrium aluminate. The oven can be used for metallic and non-metallic materials and seems to avoid impurities coming into contact with the growing crystal.

E.S.

STEINERT (H.). *Diamanten-Produkte einer Kavitation?* (Are diamonds the products of cavities?) Z. Dt. Gemmol. Ges., 1973, 22, 3, 129-131.

Differences in diamonds of different pipes seem to point to the fact that they only crystallize during the eruption of the kimberlite magma. But this seems unlikely as it is believed that—together with pyrope—they are formed under terrific pressure deep under the earth's crust. A new theory has been advanced by the Russian E. M. Galimov, who suggests that diamonds are the product of a cavitation process. The kimberlite magma includes various liquids which are rich in gases. When the pressure is low these gas bubbles are eliminated, but under high pressure they produce an implosion with high pressure and temperature. E.S.

STEVENS (Jane Perham). *The treasure of tourmaline at Newry.* Rocks and Minerals, 1973, 48, 4, 219-224.

A find of high-quality tourmaline was made at the Dunton Quarry, Newry, Maine. Colours include reds and greens and minerals in association were lepidolite, clevelandite and beryllonite.

M.O'D.

TILLANDER (H.). *The Scandinavian diamond nomenclature.* Australian Gemmologist, 1972, 11, 5, 21-22.

A reprint of an article published in the *Journal of Gemmology*, 1971, 12, 5, 167-170, on the Scan D.N. diamond classification.

R.W.

ANON. *"Red" diamonds from Siberia.* Australian Gemmologist, 1972, 11, 5, 14-20.

A reprint from the *International Diamond Annual*, this article gives a very good survey of the finding of diamonds in Siberia. Something is told of how they occur and how they are mined and the sizes

and shapes of the crystals are described. The crystals are generally small, but some larger crystals have been found and they are referred to. There are other Russian sources of diamond, such as in the rivers flowing into the Sea of Azov in the Ukraine and in rivers flowing into the Black Sea. There are other finds in the Kola Peninsula and in the area of the Pechora river north-west of the Urals. R.W.

BOOK REVIEWS

FLETCHER (Edward). *Rock and gem polishing.* Blandford Press, London, 1973. Illustrated in black-and-white and in colour. pp. 112. £1·30.

The book enters immediately into the setting-up of lapidary equipment and clear photographs in close-up illustrate the techniques of simple gemstone fashioning. All forms of lapidary work are discussed and particularly useful sections give advice on the selection and purchase of rough gem material, including also lists of societies and clubs. The geological formations in which gems are largely to be found are graphically illustrated and the book ends with a series of maps giving British gem locations. M.O'D.

FRONDEL (Clifford). *The minerals of Franklin and Sterling Hill. A check list.* Wiley-Interscience, New York, 1972. pp. 94. Illustrated in black-and-white. £4·60.

The previous check-list compiled from this highly mineralized area was published in 1935, since which time at least 66 new occurrences have been discovered. Particularly celebrated for the minerals found in association with zinc ores, gemmologists will remember the fine willemite which is at times found in a condition suitable for cutting and which fluoresces bright yellow-green in

short-wave ultra-violet light. Other gem materials found in the area include garnet, sphalerite, corundum, malachite, rhodochrosite, rhodonite (said to fade), tourmaline and idocrase. M.O'D.

POGUE (Joseph E.). *Turquois.* Memoirs of the National Academy of Sciences. Vol. 12, part 2. Second and third memoir. (Reprinted with additional material.) The Rio Grande Press, Glorieta, New Mexico, 1973. pp. 162. Illustrated in black-and-white and in colour. $15·00.

This classic work has been reprinted and augmented by the addition of a bibliography, coloured plates, a list of currently operating mines and a new introduction. The material in the main work is a little dated but the additional data are of the greatest interest and the coloured illustrations of high quality. M.O'D.

ROGERS (Cedric). *Rocks and minerals.* Ward Lock, London, 1973. Illustrated in black-and-white and in colour. pp.144. £1·75.

A well-illustrated book designed to introduce the reader to minerals. The material is lucidly written and includes an account of the development of mineralogy and reminiscences by the author. The simple chemistry needed for mineral study is particularly well handled and the crystal systems, here combining hexagonal and trigonal, are also very clear. Useful hints are given on prospecting and housing a collection. M.O'D.

WILLS (Geoffrey). *Jade of the East.* Weatherhill Orientations, New York, 1972. pp. 196. Illustrated in black-and-white and in colour. £10·00.

This is an account of the jades of Asia and New Zealand with many coloured illustrations of the highest quality. The author discusses the jade minerals with particular reference to their archaeological significance; he gives a résumé of the possible uses for some of the archaic Chinese artefacts, paying tribute to the work in this field of the late Professor Howard Hansford, who was responsible for interring some of the more colourful surmises previously made in this area. An interesting section, accompanied by a map, details the routes by which jade from Turkestan reached China. Later chapters deal with shapes, symbols and decoration and jades from other areas. There is a bibliography and an index. M.O'D.

RIGBEY (L. J.). *The amateur faceter.* D. Bradford Barton, Truro, 1972. pp. 83. Illustrated in black-and-white and in colour. £1·50.

A companion to similar books on the arts of the lapidary and the jewellery maker, the present volume explains the technique of faceting. A brief explanation of the optical principles involved is followed by chapters on suitable materials and their selection, preforming, types of equipment and diagrams of various cuts. The diagrams illustrating the operation of faceting equipment are large and well-drawn. Figures for refractive index are inaccurate for peridot and emerald, almandine is mis-spelt and only demantoid among the garnets can be said to possess a high dispersion. However, these are faults in no way affecting the general acceptability of the book. M.O'D.

Australian Gems & Crafts Magazine. No. 1. Sept./Nov. 1973. P.O. Box 1071J, Melbourne 3001, Australia. Annual subscription $8·50.

This first issue numbers 40 pages and contains articles which maintain a happy balance between serious geology and mineralogy and rockwork exploits. It is interesting to note that a green jade has been discovered near the town of Cowell, South Australia, and to learn more details of the blue lace agate of Tasmania. Fine gypsum crystals have been found on the Yorke Peninsula. The magazine will act as a much-needed clearing-house for Australian gemhunting information and British readers will find much to enjoy. M.O'D.

The Jade Trader. 1973. Published by Jade Sales, P.O. Box 100, Novato, California 94947, U.S.A. Foreign subscription $2·50 by post-paid airmail.

A new quarterly bulletin containing up-to-date information on the jades; so far the American jades have been discussed with particular reference to Wyoming material, and there have been articles on polishing and details of current prices. Further articles, including one on Chinese jades, are planned. M.O'D.

ASSOCIATION NOTICES

GIFTS TO THE ASSOCIATION

The Council of the Association is indebted to the following for their gifts:

Mr G. Massie, Sheffield, for a piece of pyrite on barite from the Glebe Mine, Derbyshire.

Toktraders International, Tokyo, Japan, for two specimens of radiated smoky quartz.

Mr R. Webster, London, for a cut blue synthetic quartz, 16·18 cts.

Mr E. Robson, Nairobi, Kenya, for specimens of kyanite and ruby rough from Kenya.

The Gemmological Association of All Japan, Tokyo, for *Gem Identification by the Inclusions* by A. Chikayama.

Mr E. A. Thomson, London, for a piece of Gilson synthetic rough turquoise.

MEMBERS' MEETINGS

London

A talk was given at Goldsmiths' Hall on the 29th October, 1973, by Mr B. W. Anderson entitled "The Pleasures of Discovery". A full report will appear in a future issue of the *Journal*.

Midlands Branch

A meeting of the Branch was held in Birmingham on the 21st November, 1973, which was entirely devoted to opal. The main speaker was Mr Bernard Lowe.

Scottish Branch

Stirling was the venue for a meeting of the Scottish Branch held on the 12th November, 1973. A talk entitled "Diamonds in Industry" was given, illustrated by colour slides.

THE JOURNAL OF GEMMOLOGY

The Editor apologises for the late appearance of this issue due to printing delays caused by the power-shortage and the consequent three-day week.

Nottingham Branch

The inaugural meeting of the Branch was held on the 1st October, when Mr D. T. K. Lewis was elected Chairman and Mrs B. Crutchley Smith Secretary.

Mr R. Webster gave a talk entitled "The Expanding Horizons of Gemmology" to the Branch on the 12th November. The talk was illustrated by colour slides, and Mr Webster demonstrated how one could differentiate between natural and synthetic gemstones.

OBITUARY

Mr Eric C. Vineall, Southend-on-Sea, who gained the Association's Diploma in 1949, died on the 16th November, 1973.

Mr C. Houchin, Bromsgrove, died in December, 1973. Mr Houchin gained the Association's Diploma in 1928.

PRESENTATION OF AWARDS

Despite travel difficulties, some 300 members and successful candidates at the examinations were present for the reunion and award-giving ceremony at the Goldsmiths' Hall on the 19th November, 1973.

As Mr Norman Harper, the Chairman, pointed out, among those present were members from Holland, Japan, Canada, South Africa, Switzerland and the United States. Over 800 had sat for the examinations, 100 more than the previous year.

Mr Gordon Andrews, who had won the Tully Medal over 40 years ago, presented the awards in a ceremony which was made more picturesque than usual with one of the Japanese candidates being robed in national costume.

Mr Andrews recalled that he had enrolled for gemmological classes in 1929 and had been involved in the subject ever since. In those early days the candidates totalled only about a score or so. In a couple of years, he forecast that the total would be around the 1,000 mark.

As Director of Examinations he had encountered some memorable papers. One was written partly in English, partly in German and partly in Japanese. The examiners were very meticulous in

their assessment of papers. They checked and re-checked. Neither brilliant theoretical nor outstanding practical ability received particular favour, but all-round ability of a high standard was sought.

Success depended on previous preparation, he said, quoting Confucius. He hoped that the new Diploma holders would continue their studies and meet the challenge presented by the many synthetic gems that were about today.

"It is always difficult to distinguish between the true and the false," he said, "but this ability is as essential in life as it is for gemstones."

Dr Claringbull said the occasion marked the culmination of Mr Andrews' association with the G.A. and provided an opportunity to thank him for the long service he had given to gemmology.

He believed that the international character which had evolved upon the Association was due to the high esteem in which its examinations were held, while its work facilitated and encouraged international relationships.

GEMMOLOGICAL ASSOCIATION OF AUSTRALIA

The Gemmological Association of Australia's 26th Conference and 2nd Gemmological Symposium will be held in Melbourne on the 27th and 28th April, 1974. Visitors are welcome. For information please write to: Mr C. R. Stott, G.P.O. Box 5133AA, Melbourne, 3001, Victoria, Australia. Symposium theme—Diamonds, General Topics and Discussion.

"Synthetic Diamonds". Professor H. C. Bolton, B.Sc., Ph.D.(London), Department of Physics, Monash University, Melbourne.

"Marketing Diamonds". Mr B. Corcoran.

"Industrial Uses of Diamonds". Mr Gellie, Anglo-American Agencies.

"Russian Diamond Fields". Dr G. Troup, D.Sc.

"Reciprocal Influence Between Gemmology and Lapidary". Mr J. S. Taylor, F.G.A.A.

"Further Work on Zoisite". Dr D. Hutton.

"Electron Microscope". Mr Dawson, C.S.I.R.O.

UNIVERSITY OF STELLENBOSCH

A new gemmological section (De Beers Laboratory) was established in the geological department of the University of Stellenbosch, South Africa, on 29th October, 1973.

At the end of the inauguration ceremony Professor J. N. de Villiers, Rector of the University of Stellenbosch, awarded Dr E. Gübelin the title of "Honorary Professor" in recognition of his valuable contribution towards gemmological research and successful promotion of gemmology throughout the world.

Needless to say that we are all delighted with this honour although Dr Gübelin considers this not so much for his personal reward but more so because this is the first academic award of its kind ever to be bestowed upon a gemmologist in the narrow sense and consequently to the science of gemstones in a wider sense. He is happy that through this tribute gemmology has been elevated into the ranks of academic dignity.

GEM DIAMOND EXAMINATION

Thirty candidates entered for the Association's 1973 Gem Diamond Examination. The following is a list of successful candidates, arranged alphabetically.

Besteiro Rafales, Josefina, Barcelona, Spain
Bradford, Kenneth J., Westcliff-on-Sea
Bridges, Reginald James, Chigwell
Clarke, Roger David, Maidstone
Coulter, Peter, Northwich
Gopalji, Kantilal P., London
Granda Uson, Ma. Fatima, Barcelona, Spain
Holgate, Richard Stanley, Thornton Cleveleys
Johnson, Robert Charles, Nuneaton
Jones, Claude Barrington, Northampton
Jones, David Lewis, Orpington
Margarit Morant, Eugenio, Barcelona, Spain
Mercade Galles, Jaime, Barcelona, Spain
Miller, Graham John, Chesham
Monte Domenech, Joaquin, Barcelona, Spain
Munoz Aisa, Ma. Teresa, Barcelona, Spain
Needham, Brian, Ilford
Nogues Carulla, Joaquin Ma., Barcelona, Spain
Pujante Garzon, Francisco, Barcelona, Spain
Redknap, Samuel Frederick, Twickenham
Sayer, Glynis Vera, Strood
Sole Barneda, Domingo, Barcelona, Spain
Stevens, Peter James, Harlington
Walton, Brian, Dukinfield
Watson, Philip, Rickmansworth
Williams, Anthony Martin, London
Woo, Shun Wai, Hong Kong

EXAMINATIONS IN GEMMOLOGY 1973

In the 1973 examinations in gemmology organized by the Gemmological Association of Great Britain, 544 candidates sat for the preliminary examination, and 283 for the diploma examination. Centres were again established in many parts of the world.

Upon the recommendation of the examiners the Tully Memorial Medal has been awarded to Dr. George Hamel, of Leiderdorp, Holland, and the Diploma Rayner Prize to Mr. Patrick Daly, of Chelmsford, Essex.

The Rayner Prize in the preliminary examination has been awarded to Miss Lorraine Fish, of London.

The following is a list of successful candidates, arranged alphabetically.

DIPLOMA EXAMINATION

TULLY MEMORIAL MEDAL

Hamel, George J. W., Leiderdorp, Holland

DIPLOMA RAYNER PRIZE

Daly, Patrick J. E., Chelmsford

QUALIFIED WITH DISTINCTION

Ahad, Daisy, Rangoon, Burma
Andreu Griera, Juan, Barcelona, Spain
Bloom, Charles Neil, London
Daly, Patrick J. E., Chelmsford
Estany Volart, Ramon, Barcelona, Spain
Farreny Riera, Andres, Barcelona, Spain
Hamel, George J. W., Leiderdorp, Holland
Hebbrecht, Julien Emiel Petrus, Gouda, Holland
Juckes, Lewis Menne, Rotherham
Knoske, Gene E., New Berlin, Wisconsin, U.S.A.
Krijger, Bart, Amsterdam, Holland
Maury, Robert Lee, Port Charlotte, Fa., U.S.A.
Mjelva, Helge Roenneberg, Aalesund, Norway
Mozolowski Horczyczak, Barbara, Barcelona, Spain
Pease, Belinda Alison Gordon, Geneva, Switzerland
Procter, Vicky, London
Stenberg, Richard M., Springfield, Mass., U.S.A.
Taylor, Michael Philip, Enfield
White, Paul John, Nuneaton
Win, Kyaw, Rangoon, Burma
Winter, Colin Howard, Dorking

QUALIFIED

Acedo Delgado, Manuel, Barcelona, Spain
Addis, R. C., London
Allin, Peggy, Port Elizabeth, Rep. of S. Africa
Amor Cubeiro, Carmen, Barcelona, Spain
Anton Martinez, Miguel, Valencia, Spain
Arano Sierra, Ma. Pilar, Barcelona, Spain

Ashcroft, Vera, Liverpool
Atherton, Stanley, Chorley
Bagant Pons, Jorge,
Barcelona, Spain
Barrows, Mark Coleman, Halesowen
Bayarri Bosch, Federico,
Barcelona, Spain
Betts, Stuart Edward, London
Bollen, Neil David, London
Bonet Coll, Jose, Barcelona, Spain
Bros Font, Ana Ma.,
Barcelona, Spain
Burnett, Brian David, Formby
Butler, Tomiko S.,
Silver Spring, Md., U.S.A.
Chaloner, Rosemary Jane,
Altrincham
Chantara, Kem, London
Chetty, Samuel Francis Casie,
Upplands Vasby, Sweden
Chlupacek, Joseph M.,
Merrillville, Indiana, U.S.A.
Clark, David Jonathan, London
Cooke, Victoria Jane, Blidworth
Cox, Edward Charles,
Auckland, New Zealand
Crombie, Jonathan Mark, London
Culi Perarnau, Jose Ma.,
Barcelona, Spain
Cummings, Bruce W.,
Wilton, Con., U.S.A.
Dabaghi, Khalil, Beirut, Lebanon
De Silva, S. P. N., Hong Kong
Dewhurst, Stephen Clive, Stockport
Dickenson, John William, Liverpool
Dunn, Pete J.,
Washington D.C., U.S.A.
Esquerra Torrescasana-Llobet,
Jose Eloy, Barcelona, Spain
Felix, Karen Hilde, Soest, Holland
Fellows, Norman John, Ascot
Flo Tomas, Ma. Rosa,
Barcelona, Spain
Forbes, Brian Winston Travers,
Eikenhof, Transvaal, Rep. of S.A.
Frodin, Peter John, Gayton
Fryer, Frederick Alfred, London
Fulwiler, Jill Ann,
Los Angeles, Cal., U.S.A.
Gill, Joseph Osborne,
Denver, Colorado, U.S.A.
Grainger, Michael George Freethy,
London
Green, Roger, Leicester
Haakonsen, Hans Olaf,
Sandefjord, Norway
Hanrott, Michael Richard, Banstead
Higham, Joyce Rita, Prescot
Hinchliffe, Roger, Eastbourne
Htay, Han, Rangoon, Burma
James, Julia Jacqueline Ann, Redhill
Jeffries, Colin, Newport
Jordaan, Barend Daniel,
Stellenbosch, Rep. of S. Africa
Juan Prevosti, Leopoldo,
Barcelona, Spain
Kalina, Freda Frances, London
Karunaratna, Avanti Yasmin,
Nelson, New Zealand
Kawahara, Makio,
Fukuoka City, Japan
Kilpatrick, Constance M. P.,
Aberdeen
Klean, Christopher, London
Klein, Adrian Henry, London
Ko, Maung, Rangoon, Burma
Kyaw, Aung, Rangoon, Burma
Kyi, Khin Win, Rangoon, Burma
Leek, Janet Sylvia, Alcester
Liberg, Finn Ove, Hamar, Norway
Linden, Howard Morris,
Westcliff-on-Sea
Littman, Steven David,
Glenside, Penn., U.S.A.
MacDonnell, Mark L.,
Budleigh Salterton
MacOlive, John Richard Woodward,
Krugersdorp, Rep. of S. Africa
Malin, Kathleen Marian, London
Malone, Jr., Benjamin Darley,
Port Charlotte, Fa., U.S.A.
Mant, Kevin John, Southampton
Marble, Carolyn C.,
A.P.O., N.Y., New York, U.S.A.

Mason, John, Harrogate
Massie, George Alexander, Sheffield
Mathu, Ann Mumbi,
Idar Oberstein, W. Germany
Matthews, Shelagh Joan,
Port Elizabeth, Rep. of S. Africa
Melvin, Ena Margaret,
Auckland, New Zealand
Merriman, Patricia Jean, Wallasey
Minty, Janet, London
Mitchell, Stuart Roger, Bradford
Montanes Moreno, Diego,
Malaga, Spain
More Andujar, Francisco,
Barcelona, Spain
Munro-Ferguson, Molly Ann
Luttrell, Evanton
Neagle, Trevor George, Norton
Niinobe, Hiroko, Kobe, Japan
Nightingale, Stephen, Scarborough
Oliver, Graham Denis,
Wellington, New Zealand
Oomen, Joannes Bernardus Andreas
Marie, Oosterhout, Holland
O'Rourke, John William,
Rostrevor, S. Australia
Peterson, David L.,
Mead, Washington, U.S.A.
Reynolds, James Ian, Mexborough
Roberts, James Ian, Worksop
Robson, Edward,
Nairobi, Kenya, E. Africa
Rust, Izak Cornelis,
Port Elizabeth, Rep. of S. Africa
Scarratt, Kenneth Vincent Granville,
Ilford
Scott, Gillian Margaret, London
Sims, Paul Edward, Bristol
Sri Nissanka, Geeta,
Colombo, Rep. of Sri Lanka
Stenson, Ann P. Sabina,
Ottawa, Ontario, Canada
Such, Paul Nigel, Sutton Coldfield
Tait, Alistir Wood, Edinburgh
Taylor, Clive Julian, Gravesend
Thompson, Harry, Birkenhead
Trigg, Roger Clive,
Cape Town, Rep. of S. Africa
Valta, Akseli, Helsinki Finland
Van Der Loo, Albert,
Rotterdam, Holland
Van Servellen, Anne Maria,
Rotterdam, Holland
Vendrell Saz, Mario,
Barcelona, Spain
Walton, Cecil, Prescot
Watanabe, Teruo, Tokyo, Japan
Whitaker, Peter William,
Huntingdon
Win, Thein, Rangoon, Burma
Yamaguchi, Takashi, London
Yang, Jinhua, Tokyo, Japan

PRELIMINARY EXAMINATION

PRELIMINARY RAYNER PRIZE
Fish, Lorraine Alison, London

QUALIFIED

Abbestee, Wouter Pieter,
Amsterdam, Holland
Aguayo Villar, Ma. Isabel,
Barcelona, Spain
Aguilar Casamayor, Carlos,
Zaragoza, Spain
Ahad, Daisy, Rangoon, Burma
Ambjornsen, Truls Petter,
Fredrikstad, Norway
Amoros Angel, Julio, Valencia, Spain
Appleby, Jonathan Mark, London
Ariyaratna, Don Hettiarachige,
Colombo, Rep. of Sri Lanka
Arla Pont, Antonio, Barcelona, Spain
Ashley-Cooper, Elizabeth, London
Attinger, Gina, Zurich, Switzerland
Auddy, Sanjay Kumar, Birmingham
Ayache, Nicolas, Beirut, Lebanon
Ball, Stephen Ewart, London
Ballin, Peter Edward, Birmingham

Barnes, Clifton H.,
Grand Junction, Col., U.S.A.
Bartlet, Kenneth Joseph,
Episkopi, Cyprus
Bates, Andrew, Nottingham
Baxter, Jeannie, Sheffield
Beebe, Roxanne,
Woodside, Cal., U.S.A.
Benas, Ruggero,
Port Elizabeth, Rep. of S. Africa
Bensink, Anna,
Schoonhoven, Holland
Bernal, Virginia Miranda, London
Bernard, David Alfred William,
Carshalton Beeches
Birtley, George, Hull
Blackley, R., Ilford
Blanco Moreno-Lueje, Genaro,
Barcelona, Spain
Blasi Casal, Juan, Barcelona, Spain
Bloom, Charles Neil, London
Boix Morato, Manuel,
Barcelona, Spain
Borg, Raine, Myyrmaki, Finland
Brady, George Clifford, Epping
Brandenburg, Wieger Matthijs,
Schoonhoven, Holland
Bravo Agudelo, Ma. Luisa,
Barcelona, Spain
Bredebusch, Elisabeth, Hong Kong
Breden, Robert J., Kirkby
Bronkhorst, Saskia E.,
Gouda, Holland
Brown, David Bernard, Preston
Buckland, Neil Anthony, Bordon
Buijs, F. J., Schoonhoven, Holland
Burnham, Donald Charles,
Ancaster, Ont., Canada
Butler, Tomiko S.,
Silver Spring, Md., U.S.A.
Butt, Dilriaz Hussian, Bradford
Butterfield, John Phillip,
Huddersfield
Carr, Peter, Royston
Campon Fernandez, Enrique,
Oviedo, Spain
Chaigneau, Edel V.,
Utrecht, Holland
Chantara, Kem, London
Cheung, Matilda Ching Yee, London
Chin, Kian Hee, Johore, Malaysia
Chow, Peter Suet Chung, London
Clark, Stuart Duncan, Sale
Clayton, Rosamond Susan,
Hong Kong
Colom Farre, Jorge,
Barcelona, Spain
Cornelissen, Fleur A.,
The Hague, Holland
Cowen, Margaret H., Hong Kong
Crawley, Annette, Liverpool
Cruella Segura, Ana,
Barcelona, Spain
Cucurull Ripoll, Jose,
Barcelona, Spain
Culley, Stephen John, Harrogate
Cuttilan, T. R.,
Colombo, Rep. of Sri Lanka
Dabaghi, Khalil, Beirut, Lebanon
Dack, Jane P., Hong Kong
Dando, Nigel John, Bath
Danvers, Roger Alan, Birmingham
Davidner, Gail Ruth, London
Davies, David Nigel, Caerphilly
De Silva Samararatne, Ananda,
Galle, Rep. of Sri Lanka
de Zoysa, Nimal D.,
Colombo, Rep. of Sri Lanka
Del Cerro Arrasa, Francisco-Javier,
Barcelona, Spain
Diaz Alabart, Silvia, Madrid, Spain
Dickinson, David, Bath
Dickinson, Nigel William, Bath
Din, Richard Aziz, Edgware
Dix, Peter William, Purley
Dorking, Shirley Jacqueline,
Plymouth
Drayson, Nicholas Keith, London
Dunn, Pete J.,
Washington, D.C., U.S.A.
Duran, David William, London
Durgabakshi, Vinodhini,
Colombo, Rep. of Sri Lanka
Dwyer-Hickey, Peter R., Ilford
Eagleton, David, Sheffield

Elliott, Douglas Howard,
A.P.O. New York, N.Y.. U.S.A.
Ellis, Edwina, London
Fabrega Carbonell, Enrique,
Barcelona, Spain
Fearnley, John Stewart, Seascale
Fearnside, Gerald Michael,
Sutton Coldfield
Fernandez Nunez, Javier,
Valencia, Spain
Fernandez-Monge Glez Audicana,
Manuel, Bilbao, Spain
Fernando, K. S. S.,
Panadura, Rep. of Sri Lanka
Ferrer Arbona, Santiago,
Valencia, Spain
Findlay, Kenneth William,
Johannesburg, Rep. of S. Africa
Fish, Lorraine Alison, London
Fishwick, John, Nottingham
Fletcher, H., Derby
Fojud, Betty Eleanor, Nottingham
Forman, Ian Arthur, Buckingham
Forsey, Stella,
Wellington, New Zealand
Frankham, Elaine, Liverpool
French, Anthony James,
Brockenhurst
French, Frank Geoffrey, Purley
Fulwiler, Jill Ann,
Los Angeles, Cal., U.S.A.
Gabrielle, Louis Michael,
West Hill, Ontario, Canada
Galofre Munne, Ma. Rita,
Barcelona, Spain
Garcia Igual, Arturo,
Valencia, Spain
Gaunt, Adrian J., London
Gayton, Mildred Prudence,
Southport
Gibbons, Frederick Charles, London
Gibson, Sarah, Frizington
Gill, Joseph Osborne,
Denver, Col., U.S.A.
Gonzalez Gimenez, Anastasio,
Barcelona, Spain
Gonzalez Rosich, Daniel,
Barcelona, Spain
Goossens, Johannes Petrus,
Durban, Rep. of S. Africa
Goynshor, Frederick Jay,
Chicago, Ill., U.S.A.
Grupe, William Arthur,
Los Angeles, Cal., U.S.A.
Gunawardana, Panadura Lohakaruge
Gamini, Nugegoda, Sri Lanka
Gustin, I. M., Hong Kong
Hackett, Christopher John,
Chislehurst
Handley, Michael, Crawley
Harrison, Andrew, Harrow
Hart, Frederick Lloyd,
Pottstown, Pa., U.S.A.
Haskings, Theresa M., Nottingham
Heaviside, Desmond, Middlesbrough
Hemans, David Austen, London
Hettema, Jan Anton Hyacint Maria,
Schoonhoven, Holland
Hewitt, Robert Henry, Gosforth
Hindle, Kenneth, Blackpool
Hofelt, Joris, Schoonhoven, Holland
Howell, Philip Edward, Worthing
Htay, Han, Rangoon, Burma
Hunter, Thomas Stuart, Liverpool
Ishikawa, Taeko, London
Jacobson, Brian M., Dublin
Jason, Neville Howard, Prestwich
Jayakody, Don Francis,
Ja-Ela, Rep. of Sri Lanka
Jayasinhji, Prince, of Dhrangadhra,
New Delhi, India
Jones, Peter Richard, Bury
Kamerbeek, Joseph Marie Willy,
St. Maarten, Netherlands Antilles
Kan, Eishi, London
Kenderdine, Fenella Hope, Sevenoaks
Kennedy, Esther I.,
Charlotte, N. Carolina, U.S.A.
Kim, Yong Sung, Tokyo, Japan
Klean, Christopher, London
Ko, Maung, Rangoon, Burma
Korevaar-Van Es, Marianne,
Amsterdam, Holland
Koskiahde, Mauno, Turku, Finland
Kyi, Khin Win, Rangoon, Burma

Larah, Howard Anthony, Manchester
Layton, Margaret Clare, London
Le Roux, Emmerentia Elizabeth, Johannesburg, Rep. of S. Africa
Levy, Moshe, Edgware
Levy, Martyn George, Edinburgh
Lewis, Sheila Judith, Kenton
Lindau, Georg, Munich, W. Germany
Littman, Steven David, Glenside, Pa., U.S.A.
Lo, Louis Yick-Sun, Hong Kong
Lopez Vano, Ma. Carmen, Valencia, Spain
Luff, Gillian Gay, London
Lyall-Grant, Mary Jennifer, London
Lynch, Errol Barrington, London
McDarby, Elizabeth Margaret, London
McDonald, Lori Gay, Palo Alto, Cal., U.S.A.
MacDonnell, Mark L., Budleigh Salterton
MacGregor, Elizabeth Jane, Mozambique, P.E. Africa
McKenzie, Malcolm, Frizington
McLean, John, Welkom, Rep. of S. Africa
Mathu, Ann Mumbi, Idar-Oberstein, W. Germany
Matsuda, Tsuyoshi, Kobe, Japan
Matsumoto, Kikuo, Gunma-Ken, Japan
Mazloum, Charles, Beirut, Lebanon
Mitchell, Stuart Roger, Bradford
Molina Bosch, Juan, Barcelona, Spain
Montane Baro, Miguel, Andorra La Vieja, Spain
Montanes Moreno, Diego, Malaga, Spain
Munne Cardona, Ana Ma., Barcelona, Spain
Nagamatsu, Akira, Chiba-Ken, Japan
Nakaniwa, Shoichi, Osaka, Japan
Nelson, Keith Elwin, Arvada, Colorado, U.S.A.
Nichols, John Howard, London
Nicol, William Maxwell, Dunstable
Niinobe, Hiroko, Kobe, Japan
Nizous, Mohideen Saibo Mohamed, Kalutara, Rep. of Sri Lanka
O'Donnell, Ann, Leeds
Offord, Robert John, London
Oomen, Joannes Bernardus Andreas Marie, Oosterhout, Holland
Oostvogel, Frits Antoine Joan Maria, Schoonhoven, Holland
O'Rourke, John William, Rostrevor, S. Australia
Out, Louis J., Maassluis, Holland
Palomares Carbonell, Remedios, Valencia, Spain
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Parker, Eunice Isabel Anne, Feltham
Parkinson, Joanna May, Chiredzi, Rhodesia
Parkman, David Roderick Bernard, Birmingham
Pascual Rubiella, Laureano, Barcelona, Spain
Pe, Win, Rangoon, Burma
Pedro Arro, Margarita, Barcelona, Spain
Pennell, Ian Murray, Egremont
Peterson, David L., Mead, Washington, U.S.A.
Piccione, Amedeo, San Remo, Italy
Pinder, William Robert, Earlville, N.Q., Australia
Poole, Frederick Lucas, Invercargill, New Zealand
Quera Serras, Pedro, Barcelona, Spain
Rashid, Noorul Fairosa, Colombo, Rep. of Sri Lanka
Raw, D. R. L., Basingstoke
Reynolds, Walter Ernest, Cuffley
Richards, Haik, London
Riche Feliu, Susana, Barcelona, Spain
Rivero Fernandez, Gloria, Barcelona, Spain
Robinson, Rosemary Elizabeth, Plymouth

Roche, Mary Scholastica Rita Margaret, Colombo, Sri Lanka
Rodber, Jocelyn Carol, Bridport
Rogers, John Brandon, Birmingham
Roper, Vicki, London
Romero Abad, Julio, Barcelona, Spain
Rosenberg, Paul, Lake Worth, Florida, U.S.A.
Rowe, Leonard James, Hanworth
Rubia Barrios, Luis de la, Malaga, Spain
Russo, Mario, Bari, Italy
Sapieha, Teresh Jadwica, Nairobi, Kenya, E. Africa
Sanchis Bernat, Santiago-German, Valencia, Spain
Schwartzman, Sonja S., Bethesda, Md., U.S.A.
Scrymgeour, David John, Newton Abbot
Sellas Molist, Juan, Valencia, Spain
Sieders, Margaretha Elisabeth, Schoonhoven, Holland
Simm, Geoffrey, Bolton
Simon, Gail Natalie, Liverpool
Simpson, Maurice, Doncaster
Sluis, Jan, Vlaardingen, Holland
Smith, Dennis Charles, London
Soler Casulleras, Francisca, Barcelona, Spain
Srimal, Vijay Singh, Bangkok, Thailand
Stanford, Paul Lewis, Guernsey
Stubbs, Michael David, Palmerston North, New Zealand
Swetman, Stanley Albert, Croydon
Tanaka, Masakazu, Kobe, Japan
Tasker, Glenn V., Worthing
Taylor, Ian Frank, Doncaster
Teik, Thum Koh, Kedah, W. Malaysia
Teske, Jan, Lisse, Holland
Thomas, Claud, London
Thomas, Geoffrey, London
Thomas, Judy, London
Tormo Cruanes, Delia, Valencia, Spain
Townsend, Michael John, Wakefield
Turner, Oswald Edward, Port Elizabeth, Rep. of S. Africa
Turner, Peter Dennis, Halifax
Turner, Sylvia Lily, Port Elizabeth, Rep. of S. Africa
Twyman, Roger Keith, Maidenhead
Uden, Penelope Alison, Seaford
Ueda, Makoto, Chiba, Japan
Van Der Does, Albert K.Th., Alkmaar, Holland
Van Der Garden, E. P., Arnhem, Holland
Van Der Lubben, Marianne, Rijswijk, Holland
Van Der Molen, Leonora, Schoonhoven, Holland
Van Duijn, Helena, Schoonhoven, Holland
Van Gogh, Johan Roelant, Amsterdam, Holland
Van Gogh, Mieneke, Epe (Gelderland), Holland
Van't Hoff, S. I. J., The Hague, Holland
Van Westen, Linda, Purmerend, Holland
Vaquer Navarro, Ramon, Barcelona, Spain
Villar Lopez, Luis Fernando, La Coruna, Spain
Vos, Ruud, Arnhem, Holland
Vries, Jannie, Schagen, Holland
Wailes, Rosemary Margaret, Hong Kong
Waterhouse, Philip Arthur, Auckland, New Zealand
Watkins, Sandra, Craven Arms
Wechgelaar, Dick J. H., Zaandam, Holland
Weeks, Milton D., Annandale, Va., U.S.A.
Weiss, Dale Sharon, Los Angeles, Cal., U.S.A.
West, Eileen Beryl, Dartford
White, Paul John, Nuneaton
Wicks, Sylvia Beryl, London

Wills, John Wilson,
Durban, Rep. of S. Africa
Win, Kyaw, Rangoon, Burma
Win, Thein, Rangoon, Burma
Wolfe, Peter Howard, Windlesham
Wong, Robert Shing Hang,
Hong Kong
Wood, Ronald Stanley, Peterborough
Woodhouse, Neville, Chesterfield
Woollard, Simon Jeremy, Exeter
Woolley, Henry William George,
Oxford
Wright, Harry, Midlothian
Wright, John Michael, Burnley
Yamaguchi, Takashi, London
Yao, Gladys, Hong Kong
Zacharewicz, Henryk,
Toronto, Ont., Canada

COUNCIL MEETING

At a meeting of the Council of the Association held on Monday, 29th October, 1973, the following were elected to membership:

FELLOWSHIP

Addis, Robert C., London. D. 1973
Allin, Peggy, Port Elizabeth, S. Africa. D. 1973
Anderson, Alice M., Toronto, Ont., Canada. D. 1973
Atherton, Stanley, Adlington, nr. Chorley. D. 1973
Bayarri Bosch, Federico, Barcelona, Spain. D. 1973
Betts, Stuart E., London. D. 1973
Burnett, Brian D., Formby. D. 1973
Butler, Tomiko S., Silver Spring, Maryland, U.S.A. D. 1973
Chaloner. Rosemary J., Altrincham. D. 1973
Cooke, Victoria J., Fountain Dale, nr. Blidworth, Notts. D. 1973
Crombie, Jonathan M., London. D. 1973
De Silva, S. P. N., Hong Kong. D. 1973
Dewhirst, Stephen C., Stockport. D. 1973
Dickenson, John W., Liverpool. D. 1973
Fellows, Norman J., Ascot. D. 1973
Fryer, Frederick A., London. D. 1973
Fulwiler, Jill A., Los Angeles, Cal., U.S.A. D. 1973
Gill, Joseph O., Vancouver, Washington, U.S.A. D. 1973
Grainger, Michael G. F., London. D. 1973
Higham, Joyce R., Ecclestone Park, nr. Prescott. D. 1973
Hinchliffe, Roger, Eastbourne. D. 1973
Kawahara, Makio, Fukuoka City, Japan. D. 1973
Klean, Christopher A., London. D. 1973
Klein, Adrian H., London. D. 1973
Liberg, Finn O., Hamar, Norway. D. 1973
Linden, Howard M., Westcliff-on-Sea. D. 1973
Mason, John A. C., Harrogate. D. 1973
Mathu, Ann M., Idar-Oberstein, W. Germany. D. 1973
Matthews, Shelagh J., Port Elizabeth, S. Africa. D. 1973
Merriman, Patricia J., Wallasey. D. 1973
Mitchell, Stuart R., Bradford. D. 1973
Mjelva, Helge R., Aalesund, Norway. D. 1973
Munro-Ferguson, Molly A. L., Evanton, Ross-shire. D. 1973

Oliver, Graham D., Wellington, New Zealand. D. 1973
Oomen, Joannes, Badgodesberg. W. Germany. D. 1973
Roberts, James I., Worksop. D. 1973
Scott, Gillian M., London. D. 1973
Sims, Paul E., Bristol. D. 1973
Such, Paul N., Sutton Coldfield. D. 1973
Tait, Alistir W., Edinburgh. D. 1973
Taylor, Clive J., Gravesend. D. 1973
Thompson, Harry, Birkenhead. D. 1973
Van Der Loo, Albert, Rotterdam, Holland. D. 1973
Van Servellen, Anne M., Rotterdam, Holland. D. 1973
Walton, Cecil, Whiston, Prescot. D. 1973
Watanabe, Teruo, Tokyo, Japan. D. 1973
White, Paul J., Nuneaton. D. 1973

Transfers from Ordinary Membership to Fellowship

Ashcroft, Vera, Liverpool
Bloom, Charles N., London
Chetty, Samuel F. C., Vasby, Sweden
Chlupacek, Joseph M., Merrillville, Indiana, U.S.A.
Clark, David J., London
Cox, Edward C., Auckland, New Zealand
Cummings, Bruce W., Wilton, Con., U.S.A.
Dabaghi, Khalil, Beirut, Lebanon
Daly, Patrick J. E., Chelmsford
Dunn, Pete J., Washington, D.C., U.S.A.
Frodin, P. J., Wirral
Green, Roger, Leicester
Hamel, George J. W., Leiderdorp, Holland
Hebrecht, Julien, Gouda, Holland
Jordaan, Barend D., Stellenbosch, S. Africa
Kalina, Freda F., London
Karunaratna, Avanti Y., Stoke Nelson, New Zealand
Kawahara, Makio, Fukuoka City, Japan
Kilpatrick, Constance, Aberdeen
Knoske, Gene E., New Berlin, Wisconsin, U.S.A.
Leek, Janet S., Alcester
Littman, Herbert, Highland Park, New Jersey, U.S.A.
MacDonnell, Mark L., Otterton
MacOlive, John R. W., Krugersdorp, S. Africa
Malin, Kathleen M., London
Malone, Ben D., Highlands, N. Carolina, U.S.A.
Marble, Carolyn C., New York, N.Y., U.S.A.
Massie, George A., Sheffield
Maury, Robert L., Port Charlotte, Fa., U.S.A.
Melvin, Ena M., Auckland, New Zealand
Neagle, Trevor G., Norton
Nightingale, Stephen, Scarborough
Nissanka, Geeta S., Colombo, Ceylon
O'Rourke, John W., Rostrevor, Australia
Pease, Belinda A. G., Geneva, Switzerland
Peterson, David L., Los Angeles, Cal., U.S.A.
Robson, Edward R., Nairobi, Kenya
Scarratt, Kenneth V. G., Ilford, Essex
Stenberg, Richard M., Springfield, Mass., U.S.A.
Stenson, Ann P. S., Ottawa, Ont., Canada
Trigg, Roger C., Cape, S. Africa
Winter, Colin H., Dorking
Yamaguchi, Takashi, London
Yang, Jinhua, Tokyo, Japan

Abdulla, Mohamedali G., Mombasa, Kenya
Abeysinghe, Deenabandu, D., Colombo, Ceylon
Airey, Lawrence D., Blackpool
Akagawa, Hikaru, Tokyo, Japan
Akehurst, Richard D., Oxted
Allen, David M.. Blachly, Oregon, U.S.A.
Appleby, John A., Dublin
Appleby, Jonathan M., London
Amamiya, Kumiko, Chiba, Japan
Andres-Gayon y Rosales, Juan I., Madrid, Spain
Arai, Teruko, Tokyo, Japan
Arita, Takashi, Saga City, Japan
Arnold, Alan P., Metairie, Louisiana, U.S.A.
Bartolotti, Anna, Lugano, Switzerland
Bekrova-Doyle, Drahomira V., Rio de Janeiro, Brazil
Benjamin, John, Wembley Park
Besse-Desbiolles, Francoise M., Geneva, Switzerland
Bitomsky, Harold F., Queensland, Australia
Blampied, Richard E., St. Helier, Jersey
Bloomhill, Edward, Bulawayo, Rhodesia
Boers, Leonie, Didam, Holland
Bolder, John A., Didam, Holland
Bolli, Bruno, St. Gallen, Switzerland
Bosher, John P., London
Brummer. J. J., Islington, Ont., Canada
Cadranel, Maurice, London
Caffoor, Ali A. A., Dehiwala, Ceylon
Cann, Denis L., Pevensey Bay
Capell, Eline, Port Elizabeth, S. Africa
Carry, Peter D., Liverpool
Castle, Graeme R. W., Timaru, New Zealand
Chapman, Arthur F., McCrae, Victoria, Australia
Cheung, Matilda C. Y., London
Chiba, Ryuko, Tokyo, Japan
Clark, Frances F., Menlo Park, Cal., U.S.A.
Collie, Ann E., Cape Town, S. Africa
Connelly, Frank S., Dundee
Coutts, J. M., Johannesburg, S. Africa
Croston, John, Salford
Crowley, Anthea M., London
Dagogo-Jack, Sumner K., Port Harcourt, Nigeria, W. Africa
Daras, Edith, London
Demiliani, Vittorio, Genoa, Italy
De Silva, Noeline B., Colombo, Ceylon
Dorn, Moniko M., Johannesburg, S. Africa
Duckworth, Andrew S., Bolton
East-Almond, Beatrice F. C., Malvern, Victoria, Australia
Edomonds, W. P., Salisbury, Rhodesia
Engineer, Thrity P., Hong Kong
Findlay, Kenneth W., Johannesburg, S. Africa
Forsyth, James P., Norfolk, Va., U.S.A.
Fowler, Jonathan A., Mayfield
Franz, Rudolf S., Cape, S. Africa
Freeman, Michael J., Bulawayo, Rhodesia
Freyser-Ligthart, M. W., Vooburg, Holland
Frogley, Warrick G., Wellington, New Zealand
Fujii, Masao, Tokyo, Japan
Fujii, Takayoshi, Tokyo, Japan
Fujimoto, Naomi, Osaka, Japan
Fujiwara, Toshiko, Kobe, Japan
Fullerton, Kenneth J., Singapore
Fullerton-Smith, Richard E. A., Auckland, New Zealand
Garcia, Ruben, Lisbon, Portugal
Gill, Robert M., Boston
Goldberg, Richard, Canberra, A.C.T., Australia

Graham, Kenneth L., Gainesville, Fa., U.S.A.
Guan, Sow H., Selangor, W. Malaysia
Guruswamy, Lakshman D., Colombo, Ceylon
Haefner, Richard, New Paltz, New York, U.S.A.
Hager, Freddy S., London
Hall, Warren S., Croydon
Handley, Michael, Plummers Plain, Nr. Horsham
Harada, Hatsuko, Miami, Fa., U.S.A.
Harada, Kazuo, Fukuoka City, Japan
Hariman, Eddie, Malang, Indonesia
Haynes, Simon J., Henley-on-Thames
Hebbard, Christopher R., Fareham
Heckman, Hayo W., The Hague, Holland
Hendrickson, James E., Los Aitos, Cal., U.S.A.
Hollyhock, William M., Gosport
Honeker, Vera M., Esher
Houghton, Gary, Sarnia, Ont., Canada
Hummel, Frank A., Weiser, Idaho, U.S.A.
Hunter, Robin G., High Wycombe
Ichinose, Kichiro, Hyogo-ken, Japan
Imai, Kiichi, Tokyo, Japan
Imai, Takayasu, London
Inoue, Kazuo, Tokyo, Japan
Ishikawa, Koki I., Tokyo, Japan
Ishikawa, Taeko, London
Itoh, Keiko, Tokyo, Japan
Iwata, Mitsuo, Hyogo, Japan
Javeri, Kishan, Kobe, Japan
Jones, Daniele J. J., Ascot
Jucker, Walter O., Salisbury, Rhodesia
Kaku, Eishu, Kobe, Japan
Kanari, Akiko, Tokyo, Japan
Kato, Yoshio, Chieyu-city, Japan
Kawachi, Akihiro, Tokyo, Japan
Kenai, Seiji, Yokohama-city, Japan
King, Sally A., London
Kitano, Keiko, Yokohama-city, Japan
Kobayashi, Eizo, Kofu-city, Japan
Koh Siew Lian, Ivy, Singapore
Kojima, Mieko, Yokohama-city, Japan
Komar, David I., London
Krasner, Harold. Johannesburg, S. Africa
Kume, Hironao, Tondabayashi-city, Japan
Kurakami, Genji, Kofu-city, Japan
Kurakami, Yukitaka, Kofu-city, Japan
Laing, Michael N., Troon, Ayrshire
Laing, William S., Glasgow
Lally, Kathleen M., Northwood
Lee, Kevin W. T. Y., Hong Kong
Leyser, Gerarda S. M., Arnhem, Holland
Lewis, Sheila J., Kenton
Lim, Audrey S. N., Singapore
Lincoln, Anthony D., Waltham Abbey
Lindau, George, Munich, W. Germany
Logsdon, Maxon A., Wethersfield, Conn., U.S.A.
Lo Wing Yat, Sunny, Hong Kong
Macgregor, Elizabeth J., Lourenço Marques, Mozambique
Maeda, Kikuko, Tokyo, Japan
Marchand, Hummer D., Northampton, Mass., U.S.A.
Maris, Sophia A., London
Matthews, Barry E., Trinity, Jersey
Matui, Yoshihiro, Fukuoka-city, Japan
Mayama, Kozo, Tokyo, Japan
McDarby, Elizabeth M., London
Megel, Gary E., Colorado Springs, Col., U.S.A.
Mehta, Narendra M., Bombay, India
Mills, Peter M., Canterbury
Miwa, Tatsumasa, Tokyo, Japan
Momozawa, Toshiyuki, Tokyo, Japan

Morfett, John, London
Mori, Issei, Osaka, Japan
Morris, Eric F., Christies Beach, S. Australia
Mostert, Stella, Montreal. Quebec, Canada
Mtiiye, Riessen, Moshi, Tanzania
Muchmore, Leslie R., Liskeard
Munasinghe, Shirani R., Colombo, Ceylon
Muraoka, Midori, Tokyo, Japan
Nadarajah, Veeragathy, Colombo, Ceylon
Nagai, Shigeru, Hiroshima-city, Japan
Nagao, Nasae, Tokyo, Japan
Nathan, Alfred F., San Francisco, Cal., U.S.A.
Nemoto, Rikichi, Ishioka-shi, Japan
Newton, Frederick W., Chislehurst
Nichols, John H., London
Nohara, Koichi, London
Ohashi, Naoko, Tokyo, Japan
Ohhashi, Yasuhiro, Tokyo, Japan
Osborn, Leonard V., Johannesburg, S. Africa
Ozaki, Ken, Hokkaido, Japan
Palmer, John R., Hitchin
Parker, Philip A. R., London
Periera, Edwin A., Bangkok, Thailand
Phua Kim Meng, Irene, Singapore
Piasecki, Olgierd, London
Piccardo, Pietro L., Genoa, Italy
Pineda, Jr., Antonio, Taxco, Gro, Mexico
Pritchard, Gordon A., South Shields
Ramsey, Donald I., Eastbourne
Rappitt, Toby J., Maidenhead
Reitsma, Dick, Rotterdam, Holland
Reynaud, Gisele-Genevieve, Watford
Ricci, Otto G., Merrifield, Va., U.S.A.
Richard, Anne, Lausanne, Switzerland
Robinson, John S., Huddersfield
Ruggins, Gordon P., Vancouver, B.C., Canada
Sabatini, Richard J. L., Northwood
Saito, Norio, Kofu-city, Japan
Saito, Yoshio, Kofu-city, Japan
Sallee, Kenneth E., Roseville, Ill., U.S.A.
Salmanpour, J., London
Sano, Shinobu, Tokyo, Japan
Sansone, Riccardo, New Barnet
Sato, Katsuro, Tokyo, Japan
Satoh, Ryuichi, Tokyo, Japan
Scavia, Rosa, Milan, Italy
Shah, Rajendrakumar A., Bombay, India
Shaikh, Shahajuddin J., London
Shez, Richard Y. M., Taipei, Taiwan
Shida, Junko, Yokohama-city, Japan
Shimomura, Junichi, Hiroshima-city, Japan
Shineha, Takaaki, Kyoto, Japan
Siew, Leow Y., Singapore
Simonin, Daniel, St. Gallen, Switzerland
Singh, Susan, Penang, Malaysia
Sithamparanathan, Manickam, London
Sliker, Lawrence S., Neu-Ulm/Do., Germany
Slocum, Marguerite H., Syracuse, New York, U.S.A.
Smee, R. A., Granada Hills, Cal., U.S.A.
Sorrell, John M., Zionsville, Indiana, U.S.A.
Stanford, Paul L., St. Peter Port, Guernsey
Stappenbacher, J., Bamberg, W. Germany
Sterling, Robert W., Miami Keys, Queensland, Australia
Stoxen-Tesink, J., Leiden, Holland
Suganuma, Toshio, Tokyo, Japan
Suger-Buhler, Stefan, Geneva, Switzerland
Sutherland, Brian, Morpeth
Swart, Willem R., Stellenbosch, S. Africa
Taams (Dr.), J., Curaçao, Neth., West Indies

Takahashi, Kiyotada, Tokyo, Japan
Takahashi, Masaharu, Yokohama-City, Japan
Tamatani, Shunichi, Higashi-Osaka, Japan
Tanaka, Masaaki, Kofu-city, Japan
Tanaka, Takeo, Tokyo, Japan
ter Horst, J. H., Ryssen, Holland
Thomas, Geoffrey A., Hertford
Thomas, Rik W., Hong Kong
Tomita, Koichi, Tokyo, Japan
Tsumura, Kooichi, Yokohama-city, Japan
Twyman, Roger K., Maidenhead
Uden, Penelope A., Seaford
Van Horn, James H., Genese, Belgium
Wang, Lui M., Kobe, Japan
Wang, Raymond S. W., Hong Kong
Wang, Shigekuni, Kobe, Japan
Watanabe, Hideo, Kofu-city, Japan
West, Eileen B., Dartford
Wheeler, Malcolm J., Chigwell
Wieman, Jacob, Amsterdam, Holland
Williams, Alfred, Dinnington
Williams, Harumi, Cheltenham
Wisdom, Terence R., Gt. Kingshill
Woods, Kevin J., Idar-Oberstein, W. Germany
Yamaguchi, Misao, Tokyo, Japan
Yamamoto, Kuniyoshi, Tokyo, Japan
Yano, Kiyoko, Kobe, Japan
Yeoman, Michael C., Salcombe
Yoda, Mitukiro, Tokyo, Japan
Yoshida, Hiroko, Tokyo, Japan
Yoshida, Noriko, Tokyo, Japan

EXAMINATIONS 1974

The dates for the 1974 examinations are as follows:

Examinations in Gemmology

Preliminary	Theory	Tuesday, 18th June
Diploma	Theory	Wednesday, 19th June
	Practical	Thursday, 20th June or Friday, 21st June (London). Other centres as arranged.

Final date for entry for Examination in Gemmology—1st March.

Gem Diamond Examination

Theory	Monday, 10th June (afternoon).
Practical	U.K.—Monday, 10th June or Tuesday, 11th June (mornings). Other centres as arranged.

Final date for entry for Gem Diamond Examination—1st April.

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Vol. XIV No. 2 April, 1974

THE JOURNAL OF GEMMOLOGY

and

PROCEEDINGS OF THE
GEMMOLOGICAL
ASSOCIATION
OF GREAT BRITAIN

GEMMOLOGICAL ASSOCIATION
OF GREAT BRITAIN
SAINT DUNSTAN'S HOUSE, CAREY LANE
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THE JOURNAL OF GEMMOLOGY
AND PROCEEDINGS OF THE GEMMOLOGICAL ASSOCIATION OF GREAT BRITAIN

Vol. XIV No. 2 APRIL 1974

NOTES FROM THE LABORATORY

By A. E. FARN, F.G.A.

I WAS asked fairly recently to write a series of articles on synthetics, simulants, and a general commentary on gems commonly used in jewellery. I voiced the opinion that this had been done before many times: without wishing to advertise, two at least of my former colleagues had written tomes on these subjects. I was assured that not everyone possessed such books and that there is always a steady flow of people beginning, new classes starting, and there was always something new for someone. On this premise I have prepared some notes of interest in general terms of work recently done in the laboratory. As some may know, we have a fairly new nucleus of staff, and so of course things occur which to them are new and to others are well established.

A small flat cylindrical piece of deep fine blue lapis-lazuli with pyrite inclusions was sent to test for staining. Much of today's lapis-lazuli is "improved" by colour finishing. This can be readily detected by putting a small drop of acetone on a swab of cotton-wool and rubbing the lapis-lazuli in an unobtrusive place. If staining agents have been used a blue stain will show quickly and easily upon the cotton-wool. We have found that a light rubbing

removes the staining (and if tested a second time no more colour comes away). The piece of lapis-lazuli in question however yielded no signs of staining. It was quite a small piece and the owner remarked, "you can do what you like with it: I am suspicious". We decided to try to extract some colouring and put it into a small test tube with acetone, shook it vigorously and poured the solution through a filter-paper: no staining resulted.

Somewhat reluctantly I felt it must be right, since it had some quite distinct pyrite inclusions. Alan Clewlow, B.Sc., one of our recent additions of staff, fortunately has an enquiring turn of mind and checked recent publications on blue stones imitating lapis-lazuli. So far as I was concerned the nearest approach to lapis-lazuli is sintered synthetic spinel coloured by cobalt. A quick test for this is by viewing through the Chelsea colour-filter. The sintered synthetics appear a blood red, whereas lapis-lazuli and the other simulant, "Swiss lapis" (a blue stained jasper), both appear a liver-brown colour. Further, the sintered spinel is much denser at 3·52. We have also seen opacified blue glass with included copper crystals triangular in shape, which is a blue counterpart to the "goldstone" imitation aventurine-glass. Sodalite (itself a constituent of lapis-lazuli) with a refractive index of 1·48 and a density of 2·30 is in fact a different blue to lapis-lazuli: lapis-lazuli is a deep or saturated blue whereas sodalite is a *bluer* blue, for want of a better term. When one remembers that artists used crushed lapis-lazuli as a colour pigment and termed it ultramarine one appreciates the depth of colour true lapis-lazuli has.

Having exhausted our stock of suspects we decided to try a specific gravity test (we could not obtain a refractive index reading). Lapis-lazuli, being a rock and not a mineral, does not have a fixed characteristic density: it can vary from 2·7 to 2·9, but if much pyrite is present then the density will increase. Alan Clewlow then carried out a series of checks in known density liquids and established a final density of 2·20. Now the alarm bells were ringing loud and clear. Further reading found a description in "Gem Testing"*, by B. W. Anderson, of crushed Chile lapis-lazuli (poor quality) containing pyrite bonded with plastic. We crushed our specimen, poured the contents into a small test-tube and gently heated it. A distinct smell as of burning fat or wax came away and,

*8th edn (1971), p. 312.—Ed.

on cooling, the sides of the test-tube were seen to be coated with a waxy brown substance and at the bottom of the tube there was a charred residue (which we will offer back to our customer). This crushing and burning is *not* our usual custom! We treat emeralds, rubies, black opals and other stones with due care and deference, but when a customer tells us we can do what we like in testing we take full advantage of it. Had this piece been in a pendant or ring, thus disguising the density, and as it had pyrite inclusions, it could have passed.

Bonding with plastic is also used with poor quality turquoise. Plastic bonding has a "wetting" effect upon the turqoiuse, giving it a deeper hue, and, worse, heightens the appearance of the absorption spectrum. For many years we of the older brigade of gemmologists were quite happy with a poorish distant vision reading (I still call it "Lester Benson" after its discoverer on the staff of the Gemological Institute of America). Today's students probably find it puzzling to think that for years we never knew how to obtain this useful reading on a curved surface. When in testing turquoise we found these poor distant vision readings and coupled them with a fairly good absorption spectrum in the blue and violet at 4600Å and 4320Å respectively we were happy that we had proved turquoise. As in all things, one learns by a lot of trial and a little error. This "wetting" which enhances the spectrum is now recognized as a "suspicious" characteristic, whereas earlier we were pleased to think we had a positive indication of turquoise. In defence one could claim that a chemical analysis would yield a compound formula for turquoise—it seems one must have an eternally enquiring mind and suspect everything.

A MOLDAVITE
SOME TYPICAL INCLUSIONS AND THEORIES

By T. F. ZOOK, M.A., F.G.A.

MOLDAVITE is a bottle-green natural glass which is designated as being a tektite. The name comes from the Moldau River. In 1788, Joseph Mayer first described moldavites as having been found within a radius of 50 km of České Budějovice. Then, in 1878 scientists reported finding moldavites in Moravia, west of Brno, in an area extending from Tyebiv south-eastward for about 28 km.(1) The term tektite embraces besides moldavites, australites, javanites, billitonites, indochinites, philippinites, Darwin glass, Ivory Coast tektites, Libyan Desert glass and bediasites.

Two main hypotheses exist to explain the origin of tektites. Summarizing briefly, one theory holds that tektites are of an extra-terrestrial origin, having come from outer space no farther away than the moon; the other theory attempts to relate the origin of tektites to a terrestrial derivation.

One hypothesis for terrestrial origin was explored in 1961 by Gentner, Lippolt and Schaeffer who suggested that the moldavite-strewn fields may have resulted from the same impact which produced the Ries Crater in Southern Germany.(2) In support of this theory they pointed out that both moldavites and the dense Ries glass share two similarities: (1) K/A (Potassium/Argon) ages approximating 15 million years, and (2) a chemical peculiarity which is a marked deficiency of volatiles. In contradiction to the terrestrial shared origin theory suggested above is the fact that a different origin is suggested by the stratographic evidence that the two events were not simultaneous although both belong to the same K/A datings. The stratographic evidence is based on finding a slightly different index fossil *Cepae silvestrina* inside the Ries Crater, which means that the Ries Crater was formed near or at the boundary of the Tortonian and the Samartian Stages while Janoschek (1936) had associated moldavites with an earlier period, the Oncophora layers of the Upper Helvetian.(3)

Moldavites, especially those from Bohemia, show their non-homogeneous nature in a flow-structure which is seen as streaks (schlieren). The streaks are layers of composition and/or orientation of particles which are different from the enclosing glass and are a

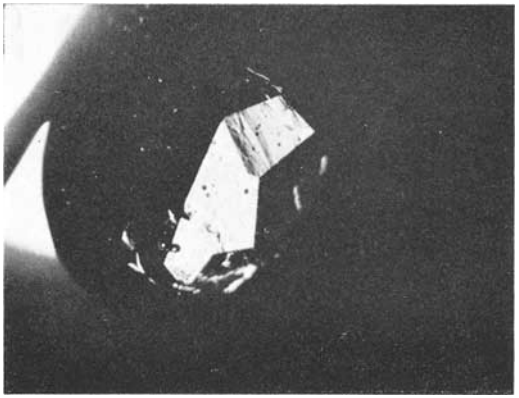

FIG. 1. Moldavite—Bubbles and schlieren, characteristic inclusions, transmitted light. 10 ×

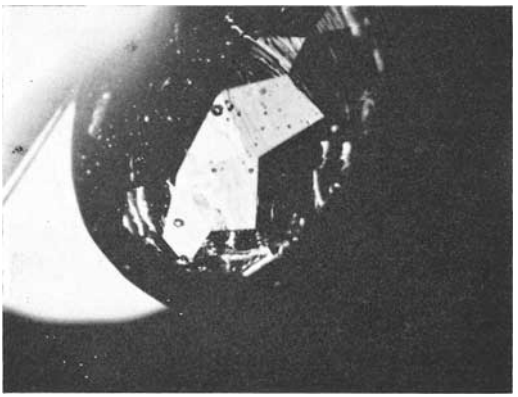

FIG. 2. Moldavite—Round bubbles and schlieren (or flow-structure) inclusions transmitted light. 10 ×.

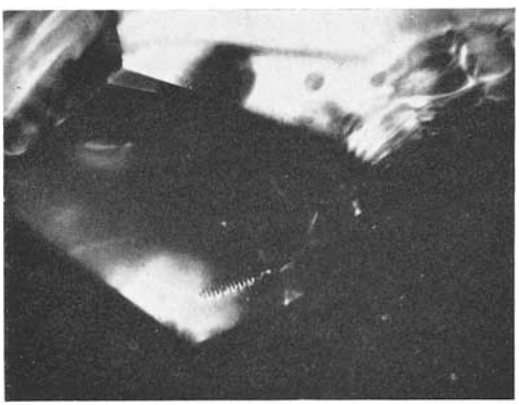

FIG. 3. Moldavite—Schlieren or flow-structure which shows "wrinkled cloth" look, and screw type stringer inclusions, transmitted light. 50 ×.

manifestation of differential movement within the tektite.[4] The streaks are seen in Figs. 1 and 2, but are particularly noticeable in the latter study. Chao in his studies of tektites characterizes the look of the flow-structure under a microscope as looking like a piece of wrinkled cloth (see Fig. 3).

Chao found that the colour-bands in tektites may vary from dark brown to colourless and that the variation is probably due to the oxidation state of the iron content or the minor colouring elements. He attributed the flow-structure to be evidence of rapid fusion and quenching of pre-existent mineral rock or glassy material which formed glasses of slightly different composition. Tektites are therefore composed of glassy materials which did not have time enough to diffuse or homogenize, as is the case with volcanic glasses.[5]

Fig. 7 clearly shows strain-birefringence, a characteristic which Chao found was associated with flow-structure and colour-bands. Barnes in 1939 had found that strain was created by rapid cooling.

Bubbles are another feature of tektites. The shape of the bubble tells something about the conditions of the glass during the cooling process. Specifically, in examining over 500 different tektites for their internal characteristics, Barnes found bubbles to be an important feature of all tektites (except for around 20 per cent of the bediasites from Texas). Spherical bubbles, according to Barnes, show that the glass was not deformed while it cooled. Elongated bubbles show that a deformation took place as the glass cooled. Irregular, branching or unsymmetrical bubbles (which are found particularly in Libyan Desert glass) are the result of trapped intergranular porosity in a glass that did not reach sufficient fluidity to allow the surface tension to draw the bubbles into spheres and therefore indicates a glass formed at lower temperatures.[6]

Fig. 2 shows the spherical nature of most of the bubbles in the specimen moldavite. Chao, in a study of the petrographic and chemical properties of 1330 tektites, found that vesicles (bubble cavities) could vary in size from a few microns (one micron, designated μ, equals one millionth of a metre or a thousandth of a millimetre = 0·001 mm)[7] to more than one centimetre in diameter, although the majority he found to be spherical and less than 500 microns in diameter.[8] Chao suggested that bubble cavities are shrinkage bubbles and that the "sparsity of vesicles in tektites in

FIG. 4. Moldavite—Contorted stringer inclusion of siliceous glass, transmitted light. 100 ×.

general is evidence that the tektites were heated at a very high temperature consistent with the high fluidity of the glass and its inclusions."(9)

An interesting and characteristic type of inclusion found in moldavites is seen in Fig. 4. This contorted stringer type of inclusion is of siliceous glass according to Chao, who found that the R.I. could range from 1·458 to an R.I. of 1·470 for pure silica glass. He found that these stringers were colourless but could appear slightly pink in transmitted light through the microscope because of their low index of refraction.(10) The theory he suggested for the formation of these contorted stringers was that both the tektite and the glass inclusion were highly fluid when formed, and that the "high fluidity or low viscosity of a pure silica melt would suggest a temperature of nearly 2,000°C, in spite of the fact that the quartz may have begun melting metastably at a much lower temperature."(11) Furthermore, Chao explains that because the glass inclusions show a sharp contact with the glass of the tektite which encloses them, the time span for heating must have been extremely short and therefore there was little time for homogenization by diffusion.

The round spherules seen in most of the photomicrographs, but most strikingly in Figs. 5 and 6, have been described in most previous writings as gas bubbles. However, this description should apply only to the transparent clear area in the centre, for it is

possible that the surrounding darker area (which also is spherical) morphologically bears a resemblance to the metallic spherules found by Chao both in Ries impactites[12] and in philippinites.[13] Chao et al. (1962) compared the metallic spherules found in the philippinite tektites with deep-sea spherules, cosmic spherules and nickel and iron spherules from impactites. The similarity of philippinite metallic spherules to those of the Wabar spherules according to Chao appeared to point to a formation by a meteoritic or asteroidal impact in a siliceous medium.[14]

O'Keefe writing on the origin of tektites in 1969 states that tektites probably come as a result of an impact on some surface somewhere and are not volcanic. To O'Keefe the fact that Chao found nickel-iron spheres embedded in tektites together with trace elements found in iron meteorites (specifically schreibersite, which is an iron phosphide, and troilite, which is an iron sulphide) is proof of the impact origin of tektites.[15]

Roedder and Weiblen reported inclusions with similar morphology in olivine samples taken from Kilanea Iki Lava Lake, Hawaii, at a depth of 0·7 feet and they describe the inner portion as a glass inclusion trapped during enclosure by a solid black object. They also found a similar inclusion in the prehistoric Makaopuhe Lava Lake, Hawaii, inside a sulphide globule. In this latter instance, they described the inner area of the inclusion as a relatively small shrinkage bubble typical of inclusions in olivines from these Hawaiian lava lakes.[16]

However, since this suggestion of metallic spherules in Figs. 5 and 6 is based only upon a morphological similarity to the pictures in the works cited of the other studies, and since there is no desire to destroy the faceted specimen stone, the true identification must remain a mystery. Cohen (1963) stated that none (metallic spherules) had been found in a moldavite, so that were it a metallic spherule it would indeed be a rare inclusion in a moldavite.[17]

Fig. 8 shows an interesting, different, and challenging inclusion. The host material within the inclusion shows anomalous double refraction. The indented area near the facet-line shows some tiny clear veining which may possibly be a type of glass different from the host substance. In addition, the darkened area down the middle of the inclusion may represent an isotropic minute granular inclusion.

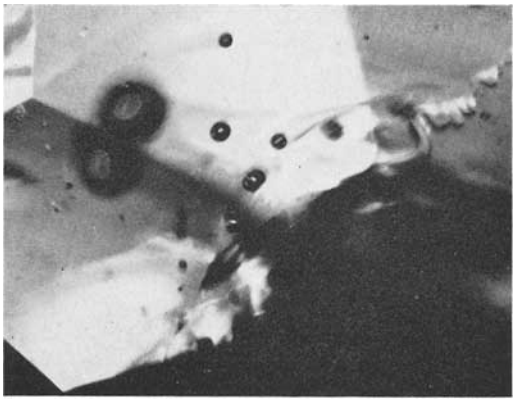

FIG. 5. Moldavite—Dark spherules encircle a clear centre which may be a bubble, transmittedlight. 50 ×.

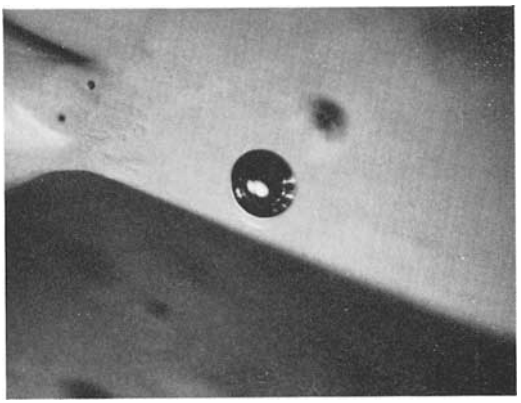

FIG. 6. Moldavite—Dark spherule encircles a transparent centre which may be a bubble, transmitted light. 100 ×.

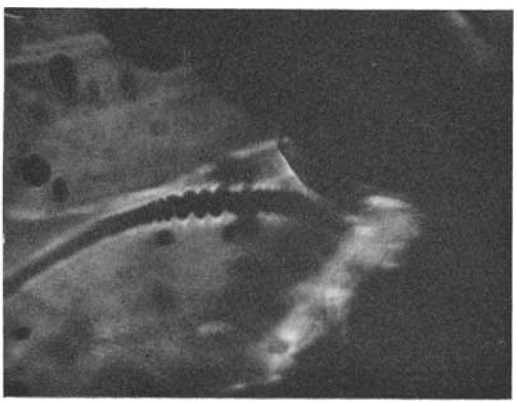

FIG. 7. Moldavite—Strain birefringence, and another contorted stringer inclusion, transmitted light. 100 ×.

An ellipsoidal glass particle, morphologically similar, but considerably smaller than that shown in Fig. 8, was reported in the lunar fines of Apollo 11 and Apollo 12 by Masson, Götz, Jamieson, McLachlan, and Volborth. They described the slightly indented portion of their particle (which portion corresponds in Fig. 8 to the area near the indentation on the broad part of the inclusion near the facet-line) as an impact centre. They have also reported finding all stages of devitrification in lunar glass from fresh clear glass shards, spheres and dumb-bells to completely devitrified optically birefringent and also dark opaque glasses. They theorize that the different recrystallization stages of spheres and dumb-bells may represent what in chondritic meteorites would be called chondrules in different stages of development. Also, they found spheres and dumb-bells in the fines which contained two immiscible glasses with droplets of darker and possibly heavier glass concentration either in the centre or on the rim of the spheres or at the outer ends of the dumb-bells. They believe that the separation of heavier phases outward might be due to spin in the lunar gravitational field. (Please note on Fig. 8 that a slightly out-of-focus dumb-bell inclusion also is present in the moldavite specimen of this article.) They also report finding many rounded mineral grains which are covered by a crust of glass. The results of their studies led them to speculate that there may be present yet undetected mineral phases with discrete silicate framework as microlites or crypto-

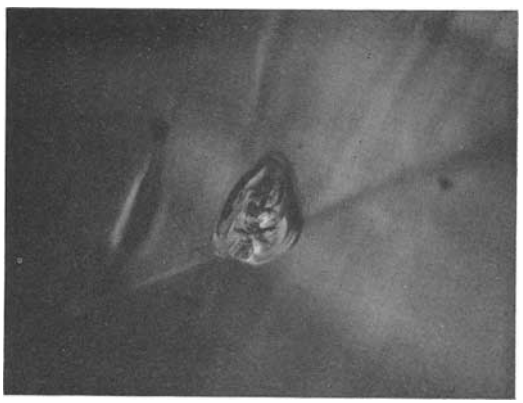

FIG. 8. Moldavite—Ellipsoidal inclusion, possibly glass, enclosing fine black granules, transmitted light. 100×.

crystallites in the shocked and partially melted minerals and glasses in the lunar fines.[18]

The specimen faceted moldavite examined for these photomicrographic studies did not exhibit the following inclusions which have previously been found by Chao in other moldavites:[19]

(1) "finger-print inclusions"

(2) oblong lenticular inclusions

(3) cigar-shaped inclusions

(4) bag-shaped inclusions with enclosed glass particles of low index of refraction

(5) criss-crossing of fine fibres which suggests that the glass inclusions were free in space prior to being embedded and engulfed by the matrix (the fibres in this case remain because the cooling took place rapidly and allowed no time for homogenization). However, in Fig. 8 we did find within the ellipsoidal inclusion aligned inclusions which might prove that the inclusion was derived from a rock rather than a single mineral, as has been suggested by Chao.

The moldavites, which are estimated to be about 15 million years old, are the second oldest group of tektites (the bediasites are much the oldest group since it is estimated that they were formed about 33 million years ago [20, 21, 22, 23] and all other tektite groups are shown in the literature to be of much younger age). Since the chemical data on tektites have suggested to researchers an extraterrestrial origin, it is very appropriate that as the investigations on the moon rocks progress the gemmologist might like to take a closer look at any moldavites or other tektites which are made available to him. Since other gemmologists may have more ready access to numerous tektites, some may wish to conduct more extensive investigations into the definite identification of the inclusions (i.e. where they do not mind destroying the specimen to provide the narrow slices necessary for petrological studies). An understanding of the types of inclusions and the theories for their origin can make this a more interesting study for any gemmologist rather than to think of a moldavite or other tektite as merely a piece of natural glass.

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3. Ibid., O'Keefe, J. A. Chap. VIII "Origin of Tektites", p. 175.
4. Ibid., Barnes, V. E. op. cit., p. 42.
5. Ibid., Chao, E. C. T., Chap. III "Petrographic and Chemical Characteristics of Tektites", p. 65.
6. Ibid., Barnes, V. E., op. cit., pp. 46, 47.
7. Poindexter, J. S. *Microbiology, An Introduction to Protists*, The MacMillan Company, N.Y., Collier-MacMillan Company Ltd., London, 1971, p. 27, footnote [1]. Poindexter on this same page states that a light microscope does not allow visualization of components less than about 200 nanometres (nm or mμ = 0·001 microns) which means that the best light microscope does not allow visualization of components below 0·20 microns or 0·0002 mm. (To achieve this differentiation with a light microscope a high-powered oil immersion lens would have to be used for the study probably.) An electron microscope, however, does allow visualization of components less than 200 nm.
8. O'Keefe, op. cit., Chao, E. C. T., op. cit., p. 63.
9. Ibid.
10. Ibid., p. 61.
11. Ibid., p. 62.
12. Ibid., p. 62. Chao tentatively believed that lechatelierite is derived from quartz and the other impure but highly siliceous glass is probably derived from a mineral fraction such as feldspar. He further believed that any clayey fraction or the mafic (dark) mineral fraction is converted into the matrix glass. Impactites are highly vesicular and they may or may not have a flow structure, while in the case of tektites the flow structure is distinctly shown and the tektites are nearly non-vesicular.
13. Ibid., See Plate V*f* and V*a* by Chao, E. C. T., between pp. 52 and 53.
14. Randall, Charles A. Jr. ed., *Extra Terrestrial Matter*, Proceedings of a Conference at Argonne National Laboratory, March 7-8, 1968, O'Keefe, John A., "Origin of Tektites," p. 71, fig. 3-12, Ni-Fe Spheres embedded in Tektites, courtesy of E. C. T. Chao, Northern Illinois University Press, DeKalb, Illinois, 1969.
15. Ibid., p. 71.
16. Roedder E., and Weiblen, P. W., "*Petrology of silicate melt inclusions, Apollo 11 and Apollo 12 and terrestrial equivalents*," Proceedings of the Second Lunar Science Conference, Vol. 1, "Mineralogy and Petrology," Suppl. 2 Geochimica et Cosmochimica Acta, ed. Levinson, A. A., p. 510, fig. 3, p. 511, figs. 4 and 5, The MIT Press, Cambridge (Massachusetts) and London, 1971.
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18. Masson, C. F., Götz, J., Jamieson, W. D., McLachlan, J. L., and Volborth, A. "*Chromatographic and mineralogical study of lunar fines and glasses*", p. 963, fig. 17, p. 957 Abstract, Proceedings of the Second Lunar Science Conference, Vol. 1.
19. O'Keefe, op. cit., E. C. T. Chao, see Plate IV between pp. 52 and 53, also see pp. 60, 61, and 62. Chao's sample of 1330 tektites included 35 moldavites: see p. 41.
20. Randall, op. cit., O'Keefe, op. cit., p. 61. O'Keefe states that Libyan Desert glass which may or may not be related to the tektite problem is also about 33 million years old. Ivory Coast tektites are about one million years old.
21. O'Keefe, op. cit., V. E. Barnes, Chap. II, "Tektite Strewn Fields", p. 26, refers to the Gentner, Lippolt and Schaeffer study in 1961 which found moldavites to be 14·7 $\pm$ 0·6 million years in age by the potassium-argon method of age determination.
22. Ibid., p. 40, cites the Gentner and Zähringer study in 1960 which found a potassium-argon age of 29·4 million years for the bediasites. Randall, Charles A. Jr., *Extra-Terrestrial Matter*, op. cit. 1969, O'Keefe, John A., "Types and Distribution of Tektites", p. 61 refers to the age of bediasites as being around 33 million years and states that they are found in Texas and more recently in Georgia.
23. O'Keefe, op. cit., Chao, E. C. T., op. cit., p. 68; Chao states that the youngest group of tektites includes the indochinites-philippinites-javanites and australites.

BEFORE AND AFTER: AN ILLUSTRATED DOCUMENTATION ON LASER DRILLING OF DIAMOND

By DR G. LENZEN, F.G.A., G.G.

THROUGH the kindness of Messrs Hans-Dieter Krieger, Idar-Oberstein, the author got to see a 1·76 carat brilliant before the planned drilling by laser to allow him to make comparisons. The stone contained, among others, two black inclusions under the table, one of which was twice reflected in the nearest table and bezel facets (Fig. 1).

After the drilling by laser and the cleaning of the stone the two inclusions showed up white and seemed to be decidedly of a smaller size than before. It was this reduction in size that made the inclusion next to the table much less obvious (Fig. 2).

The drilling of the twice reflected inclusion was effected through a pavillion facet (Fig. 3A, Fig. 4), that of the other inclusion through the table (Fig. 3B). The stone had to be qualified before the laser treatment as Second Piqué because of the occurrence of still other lighter inclusions. An improvement of the degree of purity, e.g. to First Piqué, was not achieved, the more so as particularly the vertical hole through the table was repeatedly reflected in the stone (Fig. 5): the total number of inclusions has even increased by the laser treatment (drilling holes!). In spite of this rather negative instead of positive result diamond dealers confirmed that the treatment has favourably influenced sales opportunities of the stone. Meanwhile, experiments have been going on to fill and seal the drilled inclusions and holes with a refractive fluid. We shall report in due time on the results of these experiments.

For a nomenclaturally correct description of laser drilled diamonds we refer to the decision of the C.I.B.J.O. special commission that will most probably be internationally accepted: "Diamonds with inclusions changed by artificial treatment must be marked in such a way, that the artificial treatment is unequivocally indicated as such". The exact description of the brilliant, discussed here, must consequently read: "Second piqué, laser drilled".

This article first appeared in English in *Diamant*, Sept. 1973, by courtesy of *Zeitschrift der Deutschen Gemmologischen Gesellschaft* (abstracted in *J. Gemm.*, XIII(8), 323).—Ed.

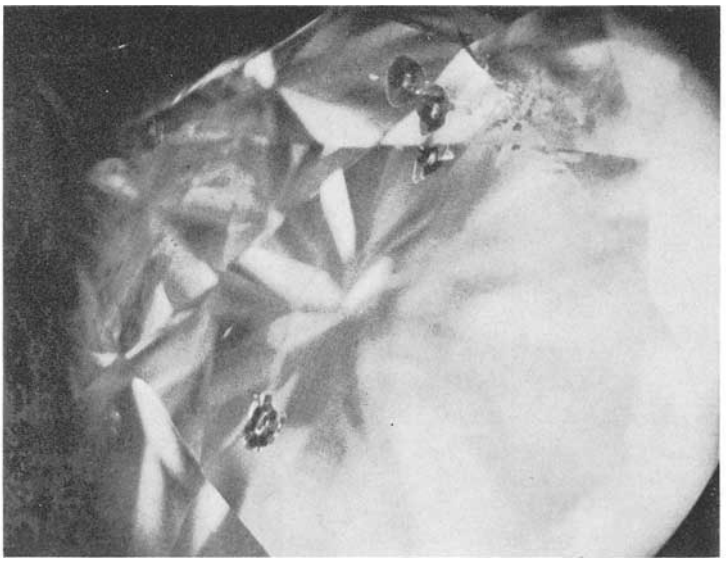

FIG. 1. Brilliant of 1·76 ct weight with two conspicuous black inclusions, of which one is twice reflected in facets on the top.

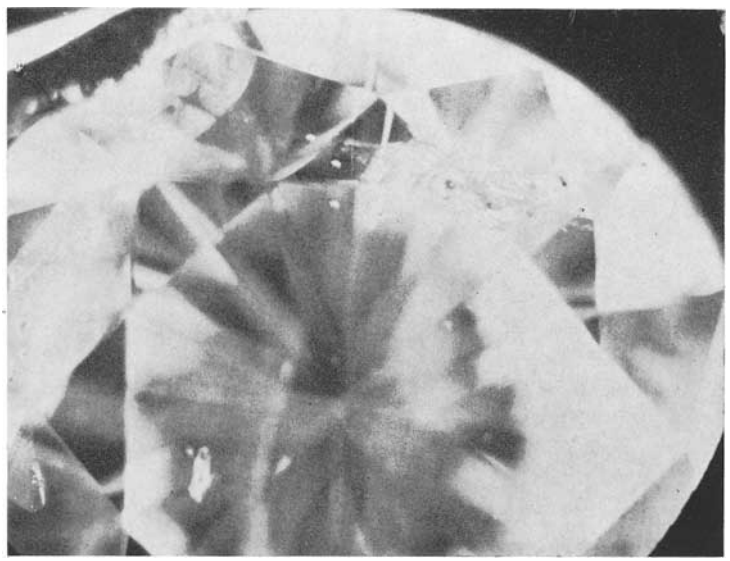

FIG. 2. The same brilliant after laser treatment. The inclusions are clear, their size seems evidently decreased and the reflection is less obvious.

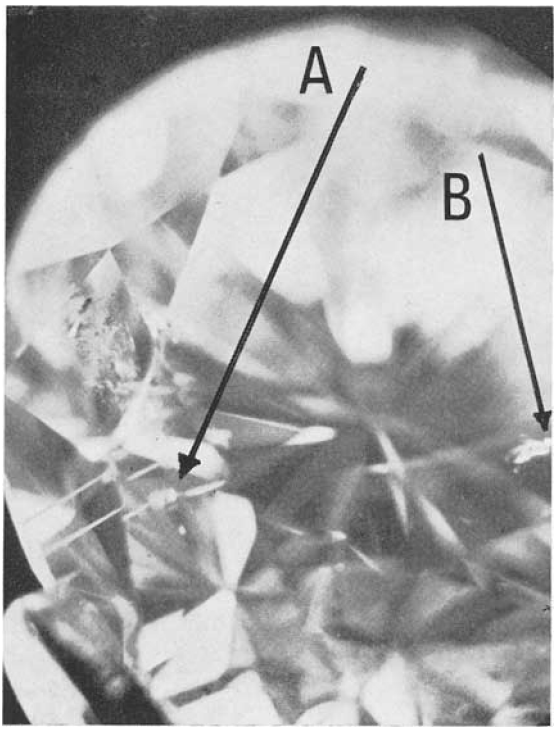

FIG. 3. A. The inclusion reflected along the table edge was reached by drilling through a pavillion half; the drilling hole is reflected in facets of the bottom side when viewed through the table side. B. The other inclusion was reached by drilling vertically through the table.

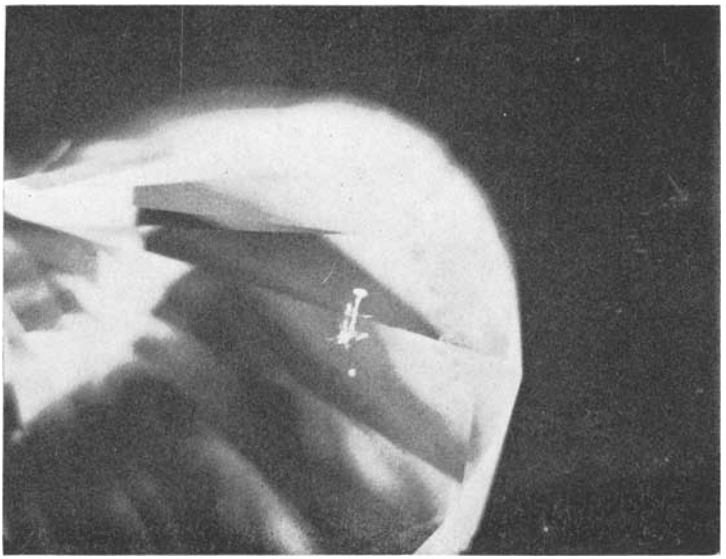

FIG. 4. The laser drilling hole starting from a pavillion facet is clearly visible. As with every drilling hole a new exterior blemish (hole) of the stone has appeared, that must be marked in the drawing of the stone with a green dot, if necessary with an explanatory symbol L (= laser) added to it.

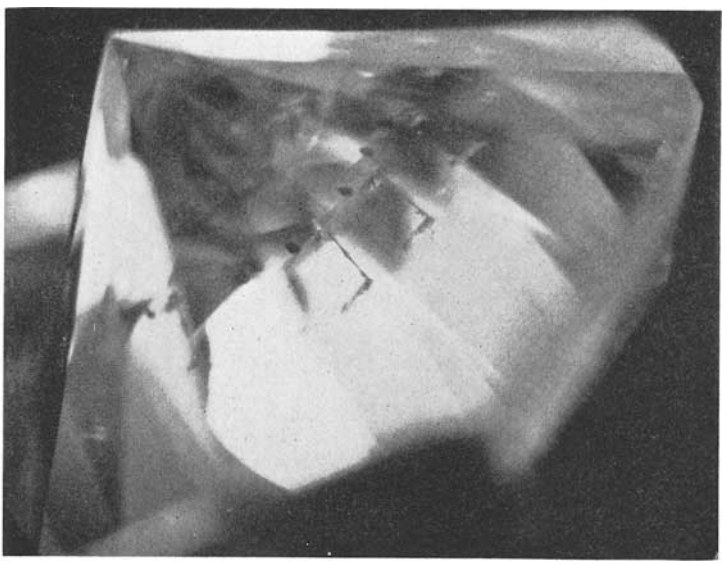

FIG. 5. The repeated reflections of the drilling hole made vertically to the table in the pavillion facets do not contribute towards an improvement of the degree of purity of the stone.

A KORNERUPINE FROM EAST AFRICA

By ROBERT WEBSTER, F.G.A.

WHILE the writer was deputizing at the London laboratory recently a dealer submitted for examination five pieces of rough crystals. Two of these were easily identified by their spectrum as garnets, which, from their colour, might be called "rhodolites". Two of the remaining three specimens were identified as tourmalines, as they showed some crystal faces from which refractive index readings could be taken. One of these was a lovely rich yellow colour and the other a pale green. This latter stone showed a reddish residual colour through the Chelsea colour filter and this implied that the stone was of a type rich in chromium and/or vanadium and could have come from the Umba river area of Tanzania.

The remaining piece of crystal was one of greater interest and gave most trouble. Owing to its very strong dichroism both the dealer and the writer considered zoisite to be a distinct possibility and the first approach was made on this assumption.

The crystal was a broken piece with no prominent crystal faces and had been broken into the rough shape of a cube. It was seen that across two pairs of "faces" the colour was an excellent green reminiscent of some demantoid garnets and through the remaining pair of "faces" the colour was a rich purple.

The absorption spectrum showed little in the way of convincing bands and the density was found to be 3·272, a value which was considered a little low for zoisite. Further, when the crystal was examined under both long- and short-wave ultra-violet light the stone exhibited a strong yellow glow. This also contra-indicated that the stone was zoisite, so to obtain more evidence a flat was polished on the stone and a measurement of the refractive indices made. This produced values of 1·660 and 1·673, giving a birefringence of 0·013.

The values of density and refractive indices agreed with those of the rather rare mineral kornerupine, and some slight confirmation was afforded by the experiment carried out by Mr. F. Hird of the laboratory staff who attempted to obtain an interference figure. This appeared to be uniaxial but was not proved certain. This was, however, certainly significant for it is known that gem kornerupine is pseudo-uniaxial.

Everything then pointed to the crystal being kornerupine, but the fluorescence shown by the crystal did not seem to agree with the only references to be quickly found in the literature[1,2,3], which suggested that kornerupine did not fluoresce under ultra-violet light stimulation. The situation was then re-examined: two specimens of kornerupine were examined under the lamps: these were both stones known to have come from the Ceylon (Sri Lanka) gem gravels and neither showed any fluorescence. However, a specimen of green kornerupine from Burma did fluoresce with a yellow glow, although somewhat less strongly than did the crystal under investigation.

It was then recalled that Payne had written up this green variety of kornerupine from Burma and his article[4] was then consulted. In this there was no mention that the luminescent properties had been examined with regard to the stones that writer had examined; nor was there any mention of any absorption spectrum for these stones. Anderson[5], however, mentions that the green kornerupines from Burma do not show any definite absorption bands. From our investigations a tentative report that the stone was kornerupine was submitted to the jeweller.

The crystal was said to have come from East Africa; the exact locality was not known, but Tanzania was favoured. The occurrence of kornerupine in Africa was not known to the writer at the time, the short note by Anderson[6] having been overlooked. This gives Kenya as a locality for kornerupine. Anderson was asked to amplify the note given in his book "*Gemtesting*" and he wrote[7] "The stone was probably identified by me (B. W. A.) for Dr Saul and was done quickly so that no note of the characters of the stone was made at the time." Later, Gübelin[8] gave the information that he had heard of kornerupine being found in East Africa and that some people had mentioned Kenya and others Tanzania as sources of the material but that no definite information as to localities had been received.

In view of the new types of minerals coming out of Africa it was considered that a further investigation should be made in order to confirm our findings that the specimen was indeed kornerupine. To this end the dealer kindly donated a specimen of this material to the scientists of the Institute of Geological Sciences who, by x-ray powder photography, confirmed that the crystals were indeed kornerupine. There was, however, some slight difference

in the size of the unit cell, but this was attributed to trace elements which may be the cause of the colour. Chromium has been suggested as the cause of the colour in the Burma kornerupines, but there is some doubt that chromium is the complete answer in the case of the East African stones. Vanadium has been suggested as a possibility, and more work on this point is envisaged by the workers at the Institute of Geological Sciences, but this will take some considerable time.

From the first piece of this rough kornerupine a faceted stone has been cut, which, although the writer has not seen it, is said to have produced a beautiful green gem.

Thanks are due to Messrs Wolff of Hatton Garden for the sight of the first specimen and for presenting the second specimen to the officers of the Institute of Geological Sciences for further investigation; and to these officers of the I.G.S. are due the writer's thanks for carrying out the x-ray identification.

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AN OLD SOURCE FOR SPINEL?

By S. B. NIKON COOPER, B.D., F.G.A.

OUR forebears who named the gems might have lacked modern scientific knowledge, but they more than made up for this in the directness and literalism of their descriptions. If a stone looked like a piece of ice (κρύσταλλος)—they called it, simply: "crystal". If it were red (ruber), then "ruby" it became. So the usual derivation of spinel (Italian diminutive "spinella" from Latin "spina" = "spine") = a "little spine", becomes the more intriguing. Admittedly, spinel crystals can be found as sharp-angled octahedra—but spiny? There are many other crystal forms which can (and do!) run themselves into the fingers with greater ease. So, we have to look elsewhere. Obviously there has been a confusion.

Our earliest references to spinel are themselves very late; only from the 16th century Agricola (*De Natura Fossilium*)(1)—"Spinellus", or again, Camillus Leonardus (*Speculum Lapidum*)(2)—"Spinella", as one of the "burning gems".

But are these the earliest references? If we turn to Theophrastus,(3) 4th century B.C. (De Lapidibus II.13) we find Σπῖνος ("Spinos") which was to be found in Thrace. In this passage, Theophrastus refers to various substances, grouped as "anthrakes", one of which he describes; black, combustible, and burning with an appreciable smell of asphalt; the mines at Binas (Spinos?) are mentioned. One thing is absolutely certain, however: these cannot be our spinel.

Or could they. . . ? Note two points: (1) the group title—"anthrakes"; and (2) one particular phrase—". . . it ("spinos") burns all the more fiercely when water has been sprayed and sprinkled on and around it." (II.13).

Now, "anthrax" has two meanings:— "coal" or "charcoal"—which is the one obviously referred to here; but it could also be used, at the same date, as a description for a gemstone having a glowing red colour, like that of burning charcoal. So, the gems: "anthrax", "anthracitis" etc.; or, carrying over to its Latin form: "carbunculus", "carbuncle" and so on—i.e. like charcoal, glowing red gems.

As proof that confusion has occurred, both Pliny[4] (1st century) and Isidore[5] (7th century) following him, as well as other authors, apply Theophrastus' description of "spinos" (a "coal") to their glowing red gems. So Pliny: *Naturalis Historia* XXXVII:27 (anthracitis)— ". . . if they are drenched with water, they become doubly glowing." Again, Isidore: *Etymologiarum* XVI:14:*— ". . . if sprinkled with water, appears to catch fire." Or once more, Albertus Magnus[6]: *Mineralia* II.ii.3 (carbunculus)— ". . . it shines in the dark if clear limpid water is poured over it", and so on. All the ancient authorities, in writing about the "burning gems", follow Pliny and keep alive the memory of Theophrastus' "spinos" (which, you remember, burns brighter when water is sprinkled over it!)

Perhaps a final clue comes in Agricola (16th century) *De Natura Fossilium*. Speaking of the gems which glow like "burning coals", he says:— ". . . all carbunculi are red and brilliant, and variations in this gem have given rise to several species." (His "spinellus", "rubinus", "pyropus" etc.). His yard-stick: ". . . stones that are especially red and brilliant, *but usually small*, are called 'spinellus'", or again:— ". . . if the 'spinellus' were large they would compare favourably with the best, but *they are so small* that they are usually classed among the least valuable." So, the diminutive "-ellus" in Agricola, "-ella" in Camillus Leonardus, is used. "Carbunculus", (its original diminutive sense by then largely forgotten) a "burning coal"; "spinellus", a "*little* burning coal".

Note, of course, that all spinels are red. If they were inconveniently blue, they were of course transferred to a different species.

Another possible derivation for "spinel" has been sought in the Greek word: *Σπινθήρ* = "spark"; but this, whilst reasonable, fails in its etymology, and nowhere occurs in any of the ancient texts— there is no reason, therefore, why it should suddenly be adopted in the 16th century.

We hope we have shown though, that there is reason, and proof, for "*Σπῖνος*". We must remember that the 16th century acted as a kind of watershed in gemmology: before it, myth and magic hold sway; afterwards, science. The true beginnings of mineralogy are seen only now; Agricola has rightly been called

*"Anthracitis vocatus quod sit et ipse coloris ignei ut carbunculus, sed candida vena praecinctus; cuius proprium est quod iactatus igni velut intermortuus, extinguitur at contra aquis perfusus exardescit.

its "father". Confronted with the problem of attempting to systematize the confusion of "red" stones, more names become necessary. What more natural than to go back to one of the ancient sources—Theophrastus—and to use the old name for a new gem? This, especially as we have reason to believe that by a happy coincidence, the text of Theophrastus had just been re-discovered, and was once more available to scholars. Pliny, in the 1st century A.D. used, and cited, Theophrastus; but after him there is a gap; none of the medieval Latin or Arab sources mentions him—until the 16th century, with Agricola, (and a source used by the Italian, Camillus Leonardus(?)). Agricola cites Theophrastus, and, significantly, in this all-important section on the "fiery" gems.

And so "spinellus"—our spinel—comes into the jeweller's vocabulary. Its ultimate derivation; whether a memory of the mine, "Binas", or, even more strangely, that it was first found at a place where the small birds—"spinoi"—a delicacy the Greeks so loved—were caught, still remains a mystery. What is certain however, is that the name, and description, originate with Theophrastus, and have nothing at all to do with spines—even little ones!

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3. Theophrastus, *De Lapidibus*, ed. with Eng. trans. by Eichholz, Oxford, 1965.
4. C. Plinius Secundus (the Elder Pliny), *Naturalis Historia*, ed. with Eng. trans. by Eichholz, Loeb's Classical Library, 1962; Eng. trans. by J. Bostock & H. T. Riley, *The Natural History of Pliny*, Bohn's Classical Library, 1858.
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DEALING WITH DIAMONDS:

Including some practical methods of measuring diamonds for cut and weight (and other set stones for weight)

By DAVID WILKINS, F.G.A.

As practically everyone who has any dealings with diamonds, even in the humblest of ways, will know, the 4C's of colour, clarity, cut and carat weight provide the basis of assessing a stone.

Carat weight is probably the simplest to deal with. If the stone is unset, it may be weighed to two places of decimals, and that is that. If the stone is mounted, then an accurate measurement of diameter and depth and reference to tables can provide a close estimate of the weight. Again, most people will know that the "Leveridge" gauge and tables are pre-eminent in this field.

Clarity is not too difficult after a certain amount of practice: either the marks are in the stone and can be seen or they aren't! It is easier, certainly, if the stone is unset, but in a claw mount, well cleaned and with a watchmaker's bellows to clear the dust specks from the pavillion facets, this aspect may be carried out with some degree of accuracy.

Colour is more difficult, and is subjective. Two people may not even see the same colour, and will possibly put a different name to it anyway. Also the weather conditions or colour of the walls surrounding the viewing area can affect what is seen.

To help overcome this and to provide a standard, no matter what the conditions, the firm for whom I work have had a series of diamonds mounted and a stone may be compared directly with these. There are nine stones, each of approximately half a carat, ranging from "fine white" down to "cape". The difference between the first and last is obvious even to the untrained eye, and, besides being a tool, this is an extremely useful aid in sales at the counter.

Judging cut should be simple, but it is surprising how far many modern-cut stones are removed from the ideal proportions recorded in the text-books, and, whilst one's eye can judge that the cut is not correct, it is good sometimes to have definite measurements from which to work.

The measurements required are diameter of girdle, thickness of crown, thickness of pavillion and diameter of table.

With a Leveridge gauge it is easy to obtain a diameter and a total depth, but not so easy to get an accurate reading for the others. A small metric micrometer proves very useful here. The stone, or shank of the ring if it is mounted, may be embedded in a knob of plasticine, and, with the aid of a desk lamp and a watchmaker's eyeglass, a direct measurement of the table may be taken (see Fig. 1). The lamp should be adjusted so that the table of the stone reflects the light from the lamp straight into the observer's eye. It will then be easy to know when the micrometer has been screwed out to the corners of the octagon forming the table, and the low powered watchmaker's eyeglass makes this easier as well as leaving both hands free.

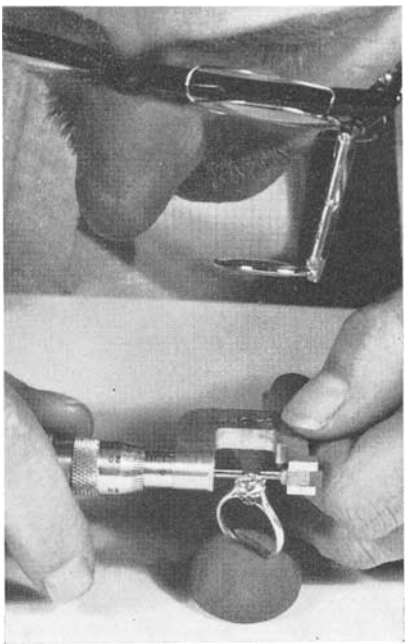

FIG. 1

To measure crown height above the girdle is more difficult, requiring the two measuring points to be offset, or one of much greater diameter than the other. I have achieved this simply and cheaply by using an hour wheel from a scrap alarm clock and

opening out the hole until it fits friction tight on to one spindle of the micrometer. With the table of the stone against this wheel, the micrometer is screwed out until the girdle is level with the face of the other spindle, and the reading is taken. This operation is facilitated if the micrometer is held firm in a knob of plasticine (see Fig. 2).

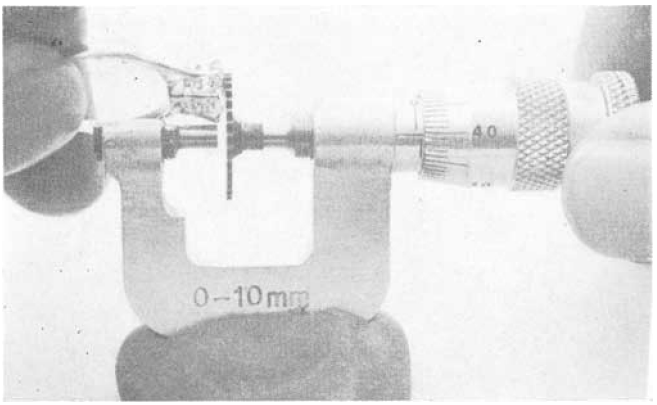

FIG. 2

One part of the tool usually gets in the way and has to be filed off, but this does not ruin it, and in any case a micrometer of the quality used for measuring watch mainsprings and costing less than a couple of pounds is quite sufficient for this work.

To make the conversion of direct measurement to proportion I use a slide rule (the circular "prayer wheel" rather than the straight "guessing stick" type being the more convenient.) As there may be some who think a slide rule is an extremely complicated piece of equipment requiring great mathematical knowledge to work it, may I explain how simple it is? The photograph (Fig. 3) shows a typical example. The outer scale is fixed and is called the "D" scale (labelled next to the 1 arrow), and all the rest of the scales may be revolved against this one. The scale adjoining the "D" is the "C" and these are the only two which concern us. They run from nought to a hundred—or from a hundred to a thousand, or to any size number depending on how many noughts you use or where you put the decimal point. For our purpose we call the "D" scale millimetres and the "C" scale becomes the percentage.

Having measured the diameter of the diamond and found it to be 7·4 mm we turn the "C" scale until the 1 pointer is opposite the 7·4 mark on the "D" scale, and reading around on the "C" scale we find that 57·5 (percentage) is opposite 4·25 (millimeters), so the table diameter should be 4·25 mm and not the 4·70 mm, or 63·5% that it actually is. By a similar examination we find that the crown thickness of 0·96 mm (13%) should be 1·08 mm (14·6%). (See Fig. 3.)

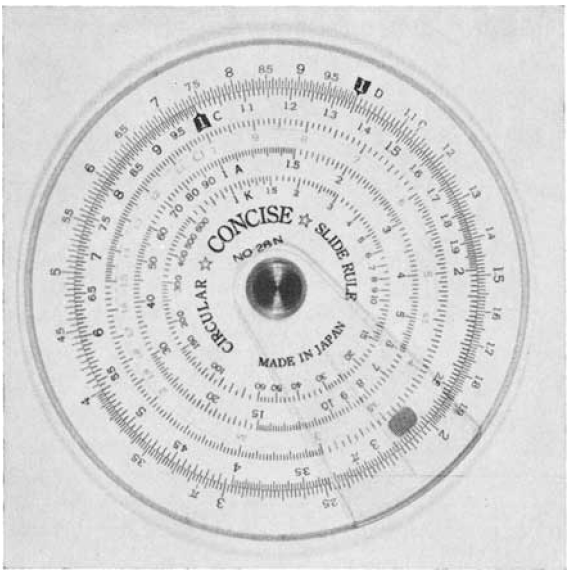

Fig. 3

Pavillion thickness is difficult to measure if the stone is mounted, but to all intents and purposes it is simply total depth minus crown thickness.

The various "make" proportions are summarized in the table below, but it is surprising how few modern stones come near any of these, and to anyone who is used to seeing only this modern type of cutting a stone which does conform to the suggested "ideal" make looks positively old fashioned and lumpy with what seems a very small table.

There are three sets of proportions recognized, all varying slightly, but they take as their starting point the diameter of the stone. The Tolkowsky set is more favoured in the U.S.A. with the Europeans following the other two.

	Diameter	*Crown Thickness*	*Pavillion Thickness*	*Table Diameter*
SCAN	100	14·6	43·1	57·5
Eppler	100	14·4	43·2	56·0
Tolkowsky	100	16·2	43·1	53·0

Calculating Weights

The formulae given in the Leveridge tables to calculate the weight of diamonds larger than those given in the pages of the tables are very useful. Not having tc deal with many diamonds over 7 carats (I wish I did) I find these formulae of greatest use in calculating the weights of other larger but less costly gemstones—the amethysts, aquamarines, tourmalines, etc., found in rings and brooches. The formulae are calculated in the normal way, but, with the addition of another factor to correct the result, the approximate weight of any species may be arrived at. This correcting factor is to multiply by the specific gravity of the stone being examined, and divide by the specific gravity of diamond, e.g. for a citrine $\times \frac{2{\cdot}65}{3{\cdot}52}$

Leveridge gives formulae for calculating the weights of circular brilliant-cut, trap-cut, marquise and pear-shaped stones, but does not mention oval brilliant-cut stones, probably because there are very few oval diamonds. Unfortunately, in stones other than diamond oval is probably the most common shape found, and after some trial and error I have adapted one of the formulae which provides a result fairly close to the actual weight. This is—length less a third of the width, times the width, times the depth, times point zero one one. This would give the result for a diamond and the S.G. fraction must be added for other stones. A long culet or a bulging pavillion can require the addition of, say, 5% to the total, but if the stone comes to a point rather than a line culet, 5% of the discovered weight should be subtracted.

Whilst no formulae can be expected to give 100% accurate results, this method is much better than an inspired guess. The calculations may appear complicated but take only a few seconds with a slide rule, which gives a result sufficiently accurate for our purposes.

Gemmological Abstracts

BANK (H.). *Euclase (von Santana de Encoberto) mit hoher Doppelbrechung.* (Euclase (from Santana de Encoberto) with high double refraction.) Z. Dt. Gemmol. Ges., 1973, 22, 4, 183-184.

This type of euclase is found in a pegmatite in the Minas Gerais in Brazil, about 131 km west of Diamantina. The double refraction is 0·025.

E.S.

BANK (H.). *Vesuvian aus Kenya mit sehr kleiner "maximaler Doppelbrechung".* (Vesuvianite from Kenya with very small maximal double refraction.) Z. Dt. Gemmol. Ges., 1973, 22, 4, 185-187.

The yellow-green cut stone was mineralogically found to be vesuvianite. This stone has a R.I. of 1·722-1·723 and a maximal double refraction of 0·001 which was difficult to determine. The double refraction varies also between 0 and 0·015 depending on the iron content. The stones come from Southern Kenya.

E.S.

BANK (H.). *Farbloser, durchsichtiger schleifwüerdiger Colemanite.* (Colourless transparent colemanite of gem quality.) Z. Dt. Gemmol. Ges., 1973, 22, 4, 188-189.

Fairly rarely found as cut stone, colemanite, first discovered in 1882, is Ca $(B_3O_4(OH)_2) \times H_2O$; density 2·42, R.I. 1·586-1·614.

E.S.

BANK (H.). *Niedriglichtbrechender durchscheinender roetlicher und gruener Grossular aus Afrika.* (Transparent red and green grossular with low R.I. from Africa.) Z. Dt. Gemmol. Ges., 1973, 22, 4, 190-192.

Various tests were made and it was shown that the R.I. of the pink-reddish grossular could be as low as 1·700 and of the green variety 1·720.

E.S.

CASEY (M.) & WILKS (J.). *Cathodoluminescence in deformed diamond.* Nature, 1972, 239, 393-394. 2 figs.

Ring crack damage produced during polishing of a (100) diamond surface is readily detected by means of a reduction in cathodoluminescence intensities. Of two possible explanations for the phenomenon, internal reflections at subsurface cracks preventing emitted light from leaving the crystal, or the effect on emission conditions of elastic strain due to unhealed cracks, the second is preferred.

F.B.A.

DARRAGH (P. J.) & PERDRIX (J. L.). *Precious opal—developments towards synthesis.* Australian Gemmologist, 1973, 11, 11, 17-21. 8 illus.

The authors review the various researches into the cause of colour in precious opal and recount some methods of growing the material in the laboratory. Sodium silicate dissolved in distilled water and run through a series of ion-exchange columns gave a very pure silicic acid solution which was concentrated by evaporation. About 100 hours was needed to produce a reasonable yield of 4000Å particles. Another method involved the use of a silicon ester, either tetraethyl orthosilicate or tetramethyl orthosilicate. Uniform droplets of silicon ester suspended in a water-alcohol mixture are hydrolysed by a mild alkali to form spherical particles of hydrated silica. The problem of hardening the array of spheres gave some trouble. Partial sintering of the array at temperatures between 500° and 800°C caused both the spheres and the voids to shrink and gave quite good strength and hardness. Impregnation with silica gave shrinkage problems, the added silica tending to shrink away from the spheres. The Gilson synthetic opal showed healed cracks under the electron microscope but in other respects its constants fell within the range for the natural stone.

M.O'D.

DERN (H.). *Die nachträgliche Korrektur von Farbfehlern an natuerlichen und synthetischen Korunden.* (Post-operative correction of discoloration of natural and synthetic corundum.) Z. Dt. Gemmol. Ges., 1973, 22, 4, 179-182.

The described treatment is based on U.S. patent 988230 and

1004505. It can improve asterism, the colour or produce change of colour in corundum. It is suggested that the manufacturer could use colourless corundum cabochons and then treat these to obtain required colour. Corundum produced by the flux method is often streaky and this condition can also be improved by this method. The cabochons are heated with the surfaces covered in aluminium oxide, titanium oxide and perhaps another metal oxide as colouring agent. The stones must not touch each other. The vessel containing the cabochons in the oxides is heated to 1700-1800°C (temperatures under 1600°C are not economical) for 2-200 hours depending on the effect wanted and the material used (highly polished stones need more time, rough need less). The oven should provide a natural gas atmosphere mainly consisting of methane. Various "recipes" for treatment of specific stones are given.

E.S.

FOILES (Lewis & Rose). *There is moonstone in Mississippi.* Lapidary Journal, 1973, 27, 8, 1176-1178. 3 illus.

Moonstone was found in gravels near Greenville, Miss. Colours included white, blue, red, smoky, brown, green and black. The degree of transparency varies from clear to completely opaque. Some stones show twinning striations on cleavage faces.

M.O'D.

GARRISON (P.). *The rocks of Texas.* Rocks & Minerals, 1973, 48, 90-92.

Numerous rocks and minerals occurring in Texas can be used as gems. These are described and specific localities are given. Varieties of quartz are included as well as topaz, gadolinite, turquoise, and others.

R.S.M.

HEMRICH (G. I.). *Sealing porous turquoise.* Lapidary Journal, 1973, 27, 7, 1136-1137.

Seam turquoise is placed in a solution of water and sodium silicate and left until the solution is curdled. This process is repeated and the stones then dried for a period of up to a week. Once dry, the stones are heated for 30 minutes at 150° and the temperature is then raised to 300°-350° and the stones left until they are seen to

be covered by bubbles. On cooling the material is ready for cutting. The bubbles have to be ground away during the cutting process. Cabochons cut from turquoise treated in this way are harder and more resistant to grease or chemicals.

M.O'D.

HUEBNER (G.). *Bericht ueber Versuche zur Unterscheidung von Bernstein und Kopal.* (Report about experiments to differentiate between amber and copal.) Z. Dt. Gemmol,. Ges. 1973, 22, 4, 197-199.

When heated, copal resin begins to melt at 125-130°C, when it forms small gas bubbles. When heated above this temperature, the melted mass becomes more viscous, colours brown at about 200°C and carbonizes at 300°C. Amber, however, seems to stay unchanged at about 200°C, the yellow colour gradually turning to brown at about 250°C: at 340°C the sample was practically black. Details of experiment and illustrations of apparatus used are given.

E.S.

MACNIVEN (A. A.). *Sapphire mining in New South Wales.* Australian Gemmologist, 1973, 11, 11, 14-16. 1 map.

Sapphires in New South Wales are found in Quaternary deposits, the most important field being that in the area Inverell-Glen Innes, where the sapphires are found in streams draining the basalt plateau. Pleonaste is a constant associate of sapphire in all New South Wales deposits. Crystals take the form of tapering hexagonal prisms. About 20 per cent of the output is saleable and stones up to 40 ct have been recorded.

M.O'D.

MACOLIVE (J.). *Multirotational microscope immersion cell.* Lapidary Journal, 1973, 27, 7, 1016-1030.

An immersion cell equipped with a universal stone-turning device was constructed from thermoplastic polymethymethacrylate with a R.I. of 1·49 and a 92 per cent transmission of light. The immersion liquid employed in observations with the cell is monobromonaphthalene.

M.O'D.

MUMME (I. A.). *Irradiation of gemstones.* Australian Gemmologist, 1973, 11, 11, 7-10, 3 figs.

A review of the various techniques employed in the irradiation of gemstones. It is thought that when a diamond is subjected to irradiation, carbon atoms are knocked out of their normal lattice positions to vacant interstitial sites. Colour centres, to which the name Frenkel defects has been given, appear to be connected with these vacant sites and with interstitial atoms which absorb certain wavelengths, thus altering the colour of the diamond. Blue colour in diamond is believed to be caused by single Frenkel defects, green by groupings. Radium emanations have been used to deepen the colour of corundums. Citrine and amethyst, discoloured by heating, are reported to have had their colour restored by similar treatment.

M.O'D.

NASSAU (K.) & WOOD (D.). *The nature of the new Maxixe-type beryl.* Lapidary Journal, 1973, 27, 7. 1032-1058.

Dark blue beryl in shades ranging from deep blue to green in colour and stated to be from Goyaz, Brazil, were examined by the authors. The stones were considered after examination to be of the Maxixe type and to be liable to fading. Blue and green beryl may be considered to be of this type if the following criteria are fulfilled: unusual dichroism with the colour being in ordinary ray; narrow absorption bands in the ordinary ray only between 5000 and 7500Å; fading on heating (½ hour at 200F to 450F) or on exposure to light (more than one week in the sun or 150 hours at 6 inches from a 100 watt tungsten lamp bulb). Colour can be returned in most cases by irradiation with neutrons, gamma rays or with x-rays, but it will once again fade with exposure to heat or light. Of 30 Maxixe-type beryls examined, three were proved to have been treated with neutrons.

M.O'D.

RECKER (K.). *Zur kuenstlichen Herstellung von Schmucksteinen.* (The synthesis of gemstones.) Z. Dt. Gemmol. Ges., 1973, 22, 4, 145-178.

This is a reprint of a lecture read by the author to the German Gemmological Association in Bonn 25th-27th May, 1973. 18 illustrations and a bibliogrpahy of 132 items. The article is a

detailed survey of the more commonly used synthetic processes of corundum, spinel, beryl, quartz, rutile, diamond, fabulite and yttrium aluminium garnet. The various choices open to the manufacturer, their advantages and disadvantages are discussed. A very useful table shows the additives that can be added to corundum to produce 23 different colours: a similar table lists 23 additives to synthetic spinel: quartz is produced in seven colours varying from blue to smoky. A chronological table lists emerald synthesis from 1848 to 1969 with short notes on type of synthesis used. The article ends with a survey of synthetic diamonds. The gem quality stones produced by G.E. of America are still many times more expensive than the natural variety and it seems that this state of affairs is unlikely to change. But the methods evolved help us in many ways, not least in obtaining knowledge of the birth of minerals.

E.S.

ROBINSON (G.). *Dekalb diopside.* Lapidary Journal, 1973, 27, 7, 1040-1059.

Gem quality diopside is found in pockets in silicated marble varying in composition between a tremolite schist and nearly pure white diopside. The Dekalb mine is situated along a north-west trending ridge of interbedded quartzite and silicated marble in St Lawrence County, New York. The typical colour is grass-green and the average crystal length is one inch. Good quality cat's-eye may be obtained from associated tremolite cleavages.

M.O'D.

ROESCH (S.). *Ein Diamant mit Innenleben: der Sterndiamant.* (A diamond with an inner life: the star diamond.) Z. Dt. Gemmol. Ges., 1973, 22, 4, 193-196. 5 illus.

Amongst industrial diamonds, probably from Venezuela, Dr U. Kurz-Tesch found a unique diamond of 2·01 ct, a rough octahedron with rounded edges, slightly yellow-grey, showing on all eight faces a six-rayed star, the axes of this star being parallel to the octahedron edges. The star is caused by a very small inclusion: even under the microscope it was not possible to determine whether this inclusion was of positive or negative nature. The actual centre of the "star" was clear, the rays starting a little distance from it. Under the polariscope strong stress double refraction was found.

The stone also has a very interesting infra-red spectrum. After the discovery of this stone, a few more specimens were found by Dr Kurz-Tesch in rough from the same source.

E.S.

RUZIC (R. H.). *Amber in Chiapas, Mexico.* Part 1. Lapidary Journal, 1973, 27, 8, 1300-1305.

Amber deposits in Chiapas are exposed by landslides. The amber is fossilized resin from the miocene and oligocene periods. Most of the material is fashioned into ornaments and prayer-beads.

M.O'D.

SANTOS MUNSURI (A.). *Glosario alfabético de los minerales de cuarzo.* (Alphabetical glossary of the quartz minerals.) Boletin del Instituto Gemologico Español, 1973, 2, 5, 12-31.

A list of the quartz minerals including a number of varietal names for members of the agate family. The list accompanies an earlier article on the quartz minerals printed in the previous issue.

M.O'D.

ANON. *Process of making diamonds in U.S.A.* Diamant, 1973, 16, 166, 42.

A brief report referring to a method of producing and using a greatly amplified shock wave to produce the necessary pressure and heat to manufacture synthetic diamonds from graphite.

H.J.B.

BOOK REVIEWS

DEESON (A. F. L.), editor. *The collector's encyclopaedia of rocks and minerals.* David and Charles, Newton Abbot, 1973. pp. 288. Illustrated in colour. £5.95.

It is difficult to speak temperately of this book, which on first appearance seems useful and is certainly well-produced. The errors are so numerous, however, that the whole aim of the book is vitiated. It would appear that the scholarship of the compilers is limited to the extraction of incorrect data from unreliable sources: the results say little for their scientific integrity. Apart from pure mistakes of attribution, peridot being classed as a variety of tourmaline, heliodor as a chrysoberyl and almandine as a spinel, tired old names appear—for example, oriental emerald for green sapphire. Ruby spinel is classed separately from spinel. There is no bibliography. An octahedron is said to have eight square faces. Ignorance of mineralogy is hardly a serious matter *per se*, but when paraded in a book bearing every sign of haste and poor judgment, offered in a developing market where young enthusiasts need expert guidance, it becomes something very close to cynicism.

M.O'D.

DESAUTELS (P. E.). *Edelstein, Perlen, Jade.* (Gemstones, Pearls and Jade.) Ott Verlag, Thun, 1971. pp. 252. Illustrated in colour. Photographs by Lee Boltin. Sw. fr. 64.00.

A German version of the author's *The Gem Kingdom*, reviewed in *Journal of Gemmology*, 13, 2, 74.

M.O'D.

FIRSOFF (V. A.). *Working with gemstones.* David and Charles, Newton Abbot, 1974. pp. x, 210. Illustrated in black-and-white and colour. £3.50.

Divided into two parts, this book comprises a section on the gem materials and a longer section on the art of fashioning them. The gems themselves are well illustrated in colour by plates originally prepared for the fourteenth edition of Herbert Smith's *Gemstones*. These plates were supplied for that book by the Institute of Geological Sciences, who should have been mentioned. There are

a number of inconsistencies in the first part: the phrase "the rainbow play of reflected light" (describing precious opal) is meaningless: boron nitride is scarcely a gem: silicon carbide is SiC, not Si_3C: streak is irrelevant when considering gemstones. Some unusual examples are chosen to illustrate the crystal systems: dyscrasite, which is shown as an orthorhombic bipyramid, is not known as a gem and its common habit is pseudo-hexagonal. In the chapter on optics the statement that fire depends upon double refraction, among other things, and the assertion that pleochroism means "more colouredness" surely need close attention. The paragraph on polarization is completely confused. The description of asterism in corundum reads in the opposite sense to what actually occurs. The second part of the book, dealing with lapidary work, is very like a number of others recently published and contains no features of note. There is a bibliography in which the name Sinkankas is misspelt and B. W. Anderson's *Gem Testing* listed in its 1958 edition. Readers looking for inspiration or instruction can do a lot better than this.

M.O'D.

GAERTNER (H.). *Achate. Steinerne Wunder der Natur.* (Agate, wonder stone of nature.) Alles/Brillant Fachverlag, Friedrichsdorf, 1971. pp. 71. Illustrated in colour. DM 36.

Thirty-two coloured plates of high quality depict agates in all forms from a number of countries. There are notes on production and fashioning and the standard of photography is far higher than that previously attained in books attempting to reproduce agate colouring.

M.O'D.

JACKSON (Bob and Kay). *A rockhound's guide to metropolitan New Jersey.* Jax Products, Seattle, Washington. 1973, pp. 50. Includes maps. $2.50.

A detailed account of the minerals to be found in the metropolitan area of New Jersey, this short guide lists the mines, dumps and means of access to some of the best-known collecting areas in the United States. Each location is described in detail and illustrated by a sketch map. Prominent in the area are the mines of Franklin and some localities for Herkimer diamonds.

M.O'D.

KUNZ (G. F.). *Rings for the finger.* Reprint of 1917 edition. Dover Publications, New York, 1973. pp. xviii, 381. Illustrated in black-and-white. $3.50.

A survey of the use and significance of the ring from the earliest times to the present. Close attention is paid to the magical and talismanic associations connected with rings and there are numerous reproductions of early representations. Later chapters deal with seal rings and the manufacturing side is well described.

M.O'D.

KUNZ (G. F.). *The curious lore of precious stones.* Reprint of the 1913 edition. Dover Publications, New York, 1971. pp. xiv, 406. Illustrated in black-and-white and colour. $4.50.

The best account at the time of publication of all forms of legendary attributes of precious stones. Subjects included are stones of ill-omen, birthstones, crystal gazing, Biblical stones, therapeutic properties and luminous stones. There are numerous illustrations which have reproduced well.

M.O'D.

LIEBER (W.). *Der Mineraliensammler.* (Mineralogy Textbook). Ott Verlag, Thun, 1971. pp. 274. Illustrated in black-and-white and colour. Sw. Fr. 39.80.

A well-illustrated course in mineralogy, this book is particularly notable for some excellent text diagrams. The crystal systems are depicted with examples of common forms and also combinations of forms, a most useful adjunct for practical study. A lengthy section gives detailed particulars of mineral locations in Germany, Austria, Switzerland and other countries accompanied by maps. There is an index and a five-page bibliography.

M.O'D.

LIEBER (W.). *Kristalle unter der Lupe.* (Crystals under the lens.) Ott Verlag, Thun, 1972. pp. 244. Illustrated in colour. Price on application.

A superbly illustrated book in which 88 mineral specimens are shown magnified and in colour. The range of magnification is from 10 × to 70 × and the instruments used for the magnification and photography are described, with settings quoted for each example. Facing each coloured plate is a diagram of the crystallographic habit of the mineral and a short description.

M.O'D.

ASSOCIATION NOTICES

MEMBERS' MEETINGS

London

A meeting was held at Goldsmiths' Hall on Monday, 25th February, 1974, when the films "The Magic of Diamonds" and "Of Jewels and Gold" were shown.

Scottish Branch

On Tuesday, 19th February, 1974, members attended a meeting at the Royal British Hotel, Edinburgh, when Mr Chaplin of the Department of Geology, Edinburgh University, gave some inside information on practical methods of locating gem-bearing sites.

Midlands and Nottingham Branches

The Annual Dinner and Dance of the Midlands Branch was held on the 25th January, 1974, and that of the newly-formed Nottingham Branch on the 11th February, 1974.

GIFTS TO THE ASSOCIATION

The Council of the Association is indebted to Dr P. C. Zwaan of Leiden, Holland, for a copy of his article "Garnet, corundum and other gem minerals from Umba, Tanzania".

OBITUARY

Mr Josef Podhorodecki, Nottingham, who gained the Association's Diploma in 1965, died on the 3rd September, 1973.

CORUNDUM FROM SALONIKA

It has been reported to the Association, through Greek Government sources, that there are large deposits of an ore which has yielded allegedly gem-quality rubies and sapphires. If any reader is interested in pursuing the matter, please communicate with the Association.

COUNCIL MEETING

At a meeting of the Council of the Association held on Monday, 25th February, 1974, the following were elected to membership:

Fellowship

Bagant Pons, Jorge, Barcelona, Spain. D. 1973
Barrows, Mark C., Halesowen, D. 1973
Bollen, Neil D., London, D. 1973
Haakonsen, Hans O., Sandefjord, Norway. D. 1973
Hanrott, Michael R., Banstead, D. 1973
Klimek, Karol S., Deal. D. 1966
Minty, Janet, London. D. 1973
Mozolowski Horczyczak, Barbara, Barcelona, Spain. D. 1973
Niinobe, Hiroko, Kobe, Japan. D. 1973
Procter, Vicky, London. D. 1973
Reynolds, James I., Mexborough. D. 1973
Whitaker, Peter W., Huntingdon. D. 1973

Ordinary Membership

Ahmad, Masud, London.
Atapattu, Savinda B., Colombo, Sri Lanka
Barbier, Michel E., Lucerne, Switzerland
Barrett, Evelyn, Hemel Hempstead
Bartoli, Anne M., Gex, France
Bates, Andrew, Nottingham
Berkelaar, Pieter L., Commugny, Switzerland
Bickers, O. Martin, Welling
Birch, Peter C., Gloucester
Blackley, Robert, Ilford
Bowker, Malcolm J., Woodthorpe
Brackman, Derek S., Stanmore
Brauns, Sandra M., Hong Kong
Bredebusch, E., Hong Kong
Brooks, Ferriel M., Hong Kong
Bryan, John C., Kriens, Switzerland
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Davis, Lee S., Louisville, Ky., U.S.A.
de Kock, H. M., Gouda, Holland
Diefenthal, Edward L., New Orleans, La., U.S.A.
Dissanayake, Jayasinghe M. E., London
Eramanis, Edward, Singapore
Fitzgerald, Patrick W., Hoo, nr Rochester
Frazier, Claren L., Berkeley, Cal., U.S.A.
Gabel, F., Yorkton, Sask., Canada
Galat-Noumer, Jorge, Bogota, Colombia
Gayton, Mildred P., Southport
Grant, Mary J. L., London
Guenassia, Robert, Courbevoie, France
Haddy, Helen J., Melville, Western Australia
Harrison, Andrew D., Harrow
Haskings, Theresa M., Wollaton, nr Nottingham
Hemachandra, Vidyapathi I. W., Colombo, Sri Lanka
Horder, Heather A., Windsor
Hoskins, Robert C., Annandale, Va., U.S.A.
Houghton, R. J., London
Hudson, Hubert, Kingston-upon-Thames

Hudson, Jeanne I., Kingston-upon-Thames
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Kaji, Yoshimichi, Tokyo, Japan
Katz, R., Johannesburg, S. Africa
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Van, Ann-Catrin, Hong Kong
Wright, Henry K., Llandeilo
Yao, Gladys, Kowloon, Hong Kong
Young, Martin J. P., Aberdeen

Corrigendum

On page 14 *ante* the chemical formula of chlorite was wrongly printed and should read—"$(Mg, Al, Fe)_{12}$ $[(Si, Al)_8$ O_{20} $(OH)_{16}]$".

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THE JOURNAL OF GEMMOLOGY

and

PROCEEDINGS OF THE GEMMOLOGICAL ASSOCIATION OF GREAT BRITAIN

GEMMOLOGICAL ASSOCIATION
OF GREAT BRITAIN
SAINT DUNSTAN'S HOUSE, CAREY LANE
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THE JOURNAL OF GEMMOLOGY
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THE PLEASURES OF DISCOVERY

By B. W. ANDERSON, B.Sc., F.G.A.

(being the substance of a talk given to the Gemmological Association of Great Britain at Goldsmiths' Hall on 29th October, 1973).

IN the talk I gave in January* I described our early struggles in the Precious Stone Laboratory from 1925 onwards, first in learning our main job of pearl testing and later in improving and extending the techniques for testing gemstones of all kinds. To-night, in continuing the inside story of the Laboratory I am proposing to stick pretty closely to one main theme rather than risk getting lost in recalling a host of little incidents: the theme being the story of discoveries of new gem varieties and new gem minerals in which we were lucky enough to be involved to a major or minor extent.

At the present time there are some 2500 separate mineral species known to science. Each year a number of new names are added, but most of them are not only very rare but quite insignificant in form. One sometimes feels rather sorry for some worthy scientist whose name is given by its discoverer as a compliment to some very indifferent mineral! The small importance of most of these is indicated by the fact that in a standard text-book such as the

* *J. Gemm.*, 1973, XIII (7), 249-262.—Ed.

1971 edition of Dana's Manual of Mineralogy only some 200 species were considered worthy of description.

But the discovery of a new gem mineral is a rare event, for it implies that the specimens found are at least large enough to be cut as stones suitable for jewellery, and usually that they are transparent and pleasingly coloured. From the trade point of view the recovery of new varieties of an already known mineral may be much more important. One has only to think of demantoid (1878), kunzite (1902), and tanzanite (1967) as instances of this.

Gahnospinel

Our first investigation into stones which had not previously been described concerned certain blue spinels from Ceylon which had a normal appearance but which were found to have a refractive index, and particularly a density, which was far higher than any quoted in the literature. C. J. Payne and I had already noted several such anomalous stones, but the real challenge came in 1935 when T. W. Oliver, who was then a gemmology student at Chelsea Polytechnic, showed me a blue spinel which puzzled him in having a refractive index of over 1·74 instead of the customary 1·715 or 1·72 of a spinel with so pale a lavender blue. In the Laboratory we found the actual figures to be 1·7432 for the refractive index (using the minimum deviation method), and the density to be 3·947, which was even more startling.

The hunt was now on: we set to work in earnest to search for comparable stones, working through parcels of Ceylon stones borrowed from the rich stock of E. Hahn & Sons, who were in those happy days established in 26, Hatton Garden. We also segregated by means of Clerici solution high-density blue spinels from samples of the Ceylon gem gravels. The rarity of these "anomalous" stones is indicated by the fact that of over 300 spinels examined, only four had densities above 3·85.

Eventually we had in our hands a graduated range of blue spinels ranging from our No. 1 specimen, which was a pebble polished as a prism by Mathews Lapidaries, which gave us the measured figures of 1·7469 for refractive index and 3·981 for density, down to No. 22, which had the normal values of 1·7153 and 3·584 respectively.

We realized that the replacing element causing these enhanced figures had to be one known to form a "spinel" on its own and one

which would have no influence on the colour. Our guess that this element was zinc soon proved to be correct. We prepared a graph on which we plotted the density and refractive index of pure magnesium spinel and the corresponding figures (4·625 and 1·805) for a man-made zinc spinel, known in nature as the mineral gahnite. The zinc-rich spinels of our newly discovered series were found to fit satisfactorily along the line between the two points and were well away from the line leading from the plot for magnesium spinel to that for the iron spinel, hercynite. Our "gahnospinels", as we christened them, varied in colour from pale to dark blue, according to their content of ferrous iron, but this had very little influence on their properties. Any considerable influx of iron causes spinel to become black and opaque and fit only for mourning jewellery. Ceylonite and pleonaste are variety names which have been used for such stones, typical values for which are 3·8 for density and 1·78 for refractive index.

We also used a small grating spectrograph made for us by Bellingham and Stanley to record the emission spectrum of small samples of stones selected from our series, fusing them in a purified carbon arc for the purpose. The spectra not only showed the expected increase in the strength of the zinc emission lines in the higher density samples, but also revealed the unexpected fact that *all* blue spinels from Ceylon contain at least a trace of zinc.

Dr Max Hey, the highly skilled analyst in the Mineral Department of the Natural History Museum, kindly carried out a quantitative analysis of one of our "top" stones and found it to contain 18·21% zinc oxide, 16·78% magnesium oxide, and 1·93% ferrous oxide—to which last the colour and absorption spectrum were due. We then had enough data to justify a paper on these stones, which was published in the *Mineralogical Magazine*(1)—this being the Journal of the Mineralogical Society, which is the accepted vehicle for contributions to mineralogy in this country.

This whole investigation was ideal for our first serious incursion into mineralogy. In those far-off days specimens for our purpose were readily and cheaply obtainable (Ceylon, it may be remembered, was still under British rule); we had recently acquired a Beck table-spectrometer, which enabled us, with suitably cut stones, to measure refractive indices and dispersions to four decimal places, and we were able to make accurate density determinations even on small specimens by suspension in Clerici solution followed by

measurement of the R.I. of the solution to four places of decimals in a hollow prism and working from a graph we had prepared showing the connexion of the density and R.I. of this solution. It also gave us practice in an essential part of all research work—the art of "consulting the literature" to ensure that our findings had not been already written up by other workers.

A brief word on this last process may be of help to beginners in this fascinating business called research. Looking round the shelves laden with scientific journals in a big science library, such as the one in Southampton Buildings off Chancery Lane, which was formerly the Patent Office Library and is now the Science Library of the British Museum (proximity to which was not the least of our blessings), one might despair of making a thorough search. But it is not so difficult as it seems. For the past few decades at least, Mineral Abstracts have existed and a rapid search through the indexes of their more recent volumes under "spinel", say, will lead you to papers on the subject that interests you. Consulting the latest of these will provide you with all the necessary references up to that time: the author will have done that work for you. A knowledge of German may be helpful, but copying facilities are provided by the library, and in ten minutes you can be provided with a photocopy which you can brood over at your leisure.

Before leaving the subject of gahnospinel I might mention that the highest figures yet encountered were in a blue spinel sent for a routine test in 1964. This had density 4·06 and refractive index 1·7542. It is hardly likely that even so extreme a case might be confused with sapphire, but it is not uncommon for stones containing only a small proportion of zinc to have refractive indices around the 1·728 mark—a value associated in the mind with *synthetic* blue spinel.

Kornerupine

One thing leads to another. During our search for blue spinels of high refractive index in parcels of mixed Ceylon stones, we had come across a few specimens which we couldn't identify. These were brownish-green in colour, had a density nearly matching that of methylene iodide (3·33) and refractive indices 1·670—1·683. They were strongly pleochroic from pale brown to dark green and had vague absorption bands in the blue and violet. We put them on one side in a packet, labelled "Y", as we could find nothing in the tables of mineral properties to tally with these constants.

At that time I was very interested in the absorption spectrum of enstatite, since we had found that the attractive green pebbles from Kimberley showed a beautifully clear-cut line at 5060 Å and I wanted to know whether specimens from other localities showed the same. The Natural History Museum had in their collection a cut stone weighing 9·18 carats, which had been rescued from an "idocrase" box by Dr Herbert Smith on the basis of a refractometer test, and more plausibly labelled "enstatite". I asked permission from the then Keeper of Minerals, Dr L. J. Spencer, to examine the stone, and we found that it was not an enstatite, but did tally closely in properties with our unknown "Y" specimens. Naturally the Museum people were now interested, and Dr Claringbull by x-ray analysis was able to identify our unknowns as *kornerupines* of a hitherto unrecorded type. Previously the only gem quality kornerupines known were pale aquamarine-coloured stones from Madagascar, containing less iron and with rather lower constants.

By one of those lucky and highly improbable chances with which we have been favoured from time to time in our work, a mounted kornerupine of "our" kind was sent to us for testing by a York jeweller. I was able to purchase the stone (which weighed 6·74 carats) for a reasonable price: the jeweller was very happy to replace it by a tourmaline rather than to try and sell a stone which had a name quite unknown to the public. A slice was removed from this for analysis, the recut stone weighing 3·50 carats.

Kornerupine is a complex borosilicate of aluminium, magnesium and iron, and the chemical analysis, undertaken by Dr Max Hey, was unusually difficult on a micro-scale, owing to the presence of boron, which several previous analysts had missed. For Dr Hey, this developed into a major piece of chemical research into the best methods for analysis of this difficult subject and a re-assessment of all previous analyses.

Meanwhile our main concern was to prove that these "new-style" kornerupines did in fact come from Ceylon, which we strongly suspected from the company they kept, by the style of cutting, and some of the inclusions. Through the kindness of Mr Hans Van Starrex we were sent two generous consignments of the gem gravel from Matale, and from the first of these, after about an hour's search, we were delighted to find the first recorded kornerupine

from the illam of Ceylon. Twenty minutes later another turned up—but in the second parcel there were none. My method was to segregate the pebbles of likely colour, then quickly run through them with the spectroscope, eliminating all the zircons, which formed the bulk of the parcel. Any stones which seemed possibly to be kornerupine were passed to Mr Payne who examined them with a dichroscope and checked their density in methylene iodide, in which kornerupine remained virtually suspended.

The long chemical investigation naturally involved delay, and it was not until more than two years after the war had started that the full details were published.(2) After the war, Mr Kenneth Parkinson, on one of his several successful visits to Ceylon in search of rare gemstones, returned with a cut kornerupine weighing 9·89 carats and a large piece of rough weighing 24·12 carats. This was unusual in showing traces of prism faces and is now in the collection of the Natural History Museum. And at about this time Dr E. H. Rutland sorted through some 15 lb. of illam provided by Mr. Reggie Mathews, and was able to recover 8 kornerupines, which yielded cut stones ranging in size from 0·30 to 1·15 carats. These were mostly the usual brownish-green, but some were distinctly green and one was yellow.

Before leaving kornerupine, let me say just a word about another "new" occurrence of the mineral which we were the first to establish.

About 1937 we had acquired a small but very pretty green stone weighing 0·22 carat, which had refractive indices and density near those of the Ceylon kornerupines discussed above. After these had been identified by the Museum we realized that this stone, too, must be a kornerupine, but from some other source. Not until August 1952 did we know that this source must be the Mogok stone tract in Burma, for it was then that A. C. D. Pain submitted for test a collection of interesting stones, all from Burma, amongst which was a bright green specimen with only the table facet polished, which we identified as kornerupine. The colour, the inclusions and the properties were close enough to ours to make us sure that the origin was the same. It is curious how the jingle "anything you can do, I can do better" seems to be appropriate when it comes to Burma versus the Ceylon gem-fields.

The War

When Munich made it clear that war must inevitably come, Payne joined the Territorial Army and was trained as a gunner, whilst I enrolled with the Auxiliary Fire Service in London. When war was declared Payne was called up at once and spent the next few years fighting with the Eighth Army, rejoining the Laboratory in September, 1945, just in time to prevent my being totally submerged in a sea of pearl testing. I was able to carry on with such testing work as there was with the aid of Sgt Stelling, a stalwart commissionaire, who had been taken on for the holiday period but who stayed for the "duration". Actually, after the initial shock of war and the London "blitz", the amount of testing work became quite heavy for one person. The number of tests undertaken dropped from the 1938 figure of 776 to 531 in 1939 and 323 in 1940, but had risen to 782 in 1944 and to 1062 in 1945. It was in 1946 that the really great expansion began and we enlisted the help of Robert Webster and Alec Farn, which completed the "Phalanx of Four" which coped with the strenuous testing work of the next 25 years.

I mustn't dwell on those war years, as I want to carry on with the story of discovery of new gem minerals, but a few points perhaps may be worth recalling.

As a safety precaution, our Committee had moved our valuable x-ray equipment to a basement belonging to Johnson, Matthey & Co. in Poland Street. This made the testing of undrilled and part-drilled pearls a very time-consuming business, as I had to go down to Poland Street to take the photographs, and then post back to the Laboratory to develop them.

The Laboratory had several "near misses" with bombs and fire, with minor damage. On the worst occasion I was luckily fighting a fire nearby and obtained permission to see how things were in the Lab. A large cupboard full of chemicals had fallen on its face, making a truly unwholesome mess on the floor. All I could do at the time was to pick up the small bottle containing the spontaneously inflammable yellow phosphorus, which I could see glowing in the dark, and put it into a bucket of water to wait for the morrow. I also had to comfort as best I could our diminutive housekeeper and his tearful wife, who had been sleeping each under one of our endoscopes when the bomb fell, and awoke to find that the apparatus had fallen on and around their legs. It required a good deal of

cannibalization from other endoscopes to get ours into working order again.

During this war period I was able to do some useful work on the classification of diamond absorption and fluorescence, the distinction between pyrope and red spinel, etc. I also became aware for the first time of the advantages of the Beck 2458 prism spectroscope for spotting purposes, and with its aid discovered the "difficult" absorption spectrum of turquoise, which has since proved extremely useful. But now I must resume my main narrative.

Taaffeite

The discovery of the new gem mineral Taaffeite reads like a gemmological fairy-tale. Count Taaffe, only son of the 12th Viscount Taaffe of Corran, Baron of Ballymote in County Sligo, Ireland, was born in Bohemia in 1898, and died in Dublin in 1967. He was the first of his family to be allowed to return to Ireland after its long exile in Bohemia and Austria. Taaffe was a keen amateur both of gemmology and astronomy, and found it both profitable and

Count Taaffe

interesting to peddle in gemstones. Amongst his sources for inexpensive stones were the boxes of oddments which many jewellers keep behind their counters, finding them useful for jobbing purposes. In October 1945 he spent some days looking through the boxes belonging to a friendly jeweller, Mr Robert Dobbie, and paid him £14 for the stones which interested him, which were mostly broken out of jewellery: badly rubbed or chipped in many cases.

Taaffe worked with meagre equipment, but made very effective use of what he did possess. He had no refractometer and no accurate balance. His chief instrument was a Bausch and Lomb binocular microscope without a stage, giving a magnification of 21 diameters.

His first steps, to which he attached great importance, in tackling a mixed batch of stones such as the lot from Mr Dobbie, was to clean the stones very thoroughly and then divide them by eye into batches according to colour. He then examined each stone very carefully, holding it in tongs and scrutinizing it from all angles over a sheet of white paper. The illumination was a flexible desk lamp with a 100 watt bulb.

The stone which, incredibly, was later found to belong to a new mineral species was amongst a group of violet, mauve, and lilac coloured stones. These were mostly spinels, but the stone in question showed in certain directions distinct signs of double refraction. In his own words "every speck of dust on the back and every scratch appeared double, like on a badly wobbled snapshot". Since, as we now know, the stone had a D.R. of only 0·005 and weighed only 1·42 carats, this was a remarkably acute piece of observation. He confirmed that the stone was birefringent by a test between crossed nicols, took a remarkably good density measurement (the average of ten attempts, using a hand-held balance) and finally on November 1st he posted the stone to me at the Laboratory with a covering letter: "This time a new riddle: what is this mauve stone? It seems to me to answer all the characteristics of spinel, yet it shows double refraction: doubling of facets visible under the Greenough, extinction when polarized, though with queer colour effects. Could anomalous double refraction be so strong? R.I. too high for topaz, too low for corundum. What is it?"

The stone as received weighed 1·419 carats. Its shape suggested that it had been cut in Ceylon. The refractive indices were 1·718 for the extraordinary ray and 1·723 for the ordinary ray—

thus the stone was uniaxial negative. It gave a clear uniaxial interference figure through the table facet. The density as then determined by hydrostatic weighing in ethylene dibromide was 3·621—later corrected to 3·613 by our Clerici solution flotation method, using blue spinels as indicators, one slightly denser and the other a little less dense than the taaffeite. The absorption spectrum was weak, but resembled that of blue spinel very closely.

I replied to Count Taaffe on November 5th, stating our findings and asking permission to have an x-ray analysis made if possible without harming the stone.

Preliminary x-ray tests carried out by Dr Claringbull confirmed the optical indications that the stone could not be spinel. To enable more x-ray and chemical work to be carried out Count Taaffe courageously agreed to having first one slice and then another removed from the culet region, stipulating only that the remains of his historic little stone be returned to him as a faceted gem. This work was most skilfully carried out by Charles Mathews Lapidaries Ltd, the stone being reduced first to 0·95 and then to 0·56 carat. With a little imagination one can appreciate Taaffe's feelings, knowing that he had discovered something quite new to science, but with only one small specimen as the representative of the new species.

On small crushed fragments from the stone x-ray powder, rotation and oriented Laue photographs were taken, showing the mineral to be hexagonal and to belong to the hexagonal trapezohedral class of symmetry—a class to which only "high" quartz (formed above 573°C) is known to belong. Preliminary analysis showed the presence of magnesium, aluminium and beryllium, and the final analysis, which was not completed until 1951, and was carried out by Dr Hey on only 6·16 milligrams of material, gave the essential formula as $MgO.BeO.\ 2Al_2O_3$—that is, intermediate in composition between spinel and chrysoberyl. The "Oscars" were mounting up for taaffeite: it was the first mineral to be first encountered as a cut gemstone; it belonged to a very rare class of crystal symmetry; and it was the only mineral known to contain both beryllium and magnesium as essential constituents. Data for an artificial compound of similar composition which were published in 1946 showed only a rough resemblance to those for taaffeite.

Naturally we kept a sharp look-out for further specimens, and examined every pale mauve spinel we could lay our hands on with

extreme care, but it was not until October 1949 that the second taaffeite came to light, the honour and credit falling to C. J. Payne. He was working rather late in the Laboratory on an interesting collection of 104 stones (mostly from Ceylon) sent in by a dealer for a routine test. There were a number of green sapphires and pale blue spinels and one kornerupine, which served as a curtain-raiser for a pale mauve stone weighing 0·86 carat which gave what appeared to be a taaffeite reading on the refractometer. This was confirmed by the observation of a uniaxial interference figure. Payne was naturally enormously excited by his discovery after four years of searching, and rang me up at Goldsmiths' Hall where Webster and I were attending at a Gemmological Exhibition being held there. Next day I was on holiday in Devon and had to carry on some cautious haggling by telephone with Payne as intermediary. At any cost, we *had* to have that stone. By using the kornerupine as a stalking horse we were able to obtain the two stones for £20.

After publication of the taaffeite story in *Nature*, the gemmological journals, and *Mineralogical Magazine* in 1951,(3) keen gemmologists the world over were on the look-out for further specimens, but taaffeite number three did not appear until Christmas Eve, 1957, when it was spotted in the New York Gem Laboratory by our friend Robert Crowningshield. A further ten years were to elapse before a fourth specimen was indentified in America following an article on the subject by George Bruce in the *Modern Jeweler*. This was a "giant" of 5·34 carats, and, surprisingly, dark brownish-purple in colour.

In 1963 came a report that crystals of the mineral up to 1 cm in length had been found in the Hunnan Province of China, though not of gem quality, and specimens are to be seen in the Mineralogical Museum of the Academy of Sciences in Moscow. Since then, tiny green crystals found in the Musgrave Ranges of Central Australia were found to be a "polytype" of taaffeite in which nine subcells instead of four make up the unit cell, giving threefold in place of sixfold symmetry to x-ray patterns. One day, I am sure, a pebble of taaffeite will be found in the Ceylon gem gravels.

Of the four cut taaffeites mentioned, the original specimen was purchased by Mr R. K. Mitchell after Taaffe's death, together with other stones from his small collection; the stone discovered by Payne is where it should be—in the Natural History Museum in South Kensington—while the American stones are apparently both in the

hands of a private collector, though one was on show for a year at the Smithsonian Institute in Washington.

Sinhalite

Less than a year after the paper on taaffeite was read before the Mineralogical Society, Dr Claringbull was able to announce the establishment of yet another new gem mineral, which he named sinhalite from its origin in Ceylon.(4) But on this occasion we were spectators rather than protagonists, though we were able to provide many specimens to aid the work, as sinhalite had been knocking around for some time under the disguise of brown peridot. Robert Webster indeed nobly sacrificed part of his only specimen for Dr Hey to analyse. Whereas, when the taaffeite paper was read, all we had to show was two small cut specimens, Claringbull had a score of sinhalites to show (one a giant of 75 carats) which had crept from their wrongly labelled packets for the occasion. There was even a small pebble of sinhalite which had been picked from a sample of illam by Dr E. H. Rutland.

Credit for the sinhalite discovery belongs properly to Dr George Switzer of the Smithsonian Institution, who took an x-ray powder photograph of scrapings from the girdle of a "brown peridot" in the U.S. Museum collection and found spacings which clearly differed from those of olivine. Knowing this, Dr W. F. Foshag (Switzer's chief in the Institution) cast doubts on a specimen of "brown peridot" in the Natural History Museum when Dr Claringbull was showing him round the mineral gallery, which gave rise to an energetic attack on the problem.

Sinhalite contains no silica, being a magnesium aluminium borate, $MgAl\ BO_4$. Like peridot, it is orthorhombic, and its refractive indices, birefringence and density are very close to those of brown iron-rich peridots or olivines which are occasionally met with in Arizona and elsewhere; the chief difference being in the β index, which in peridot is nearly mid-way between the greatest and least indices, while sinhalite is clearly negative in sign. The absorption spectra are also very similar in the two minerals, but sinhalite shows an extra band at 4630 Å. Sinhalites have been found in packets of golden zircons and of yellow chrysoberyls—they vary in colour from pale straw yellow, but at their best are very attractive, being clean, transparent, and obtainable in important sizes. In fact, of all the newly discovered stones that I am talking

about this evening sinhalite is the only one that has the slightest commercial importance. On the "anything you can do . . ." principle which I mentioned earlier, it was Burma which provided the first well-shaped sinhalite crystal, which C. J. Payne had the the privilege of measuring.

Painite

In painite we have the rarest mineral of them all: in fact I find it rather amusing, considering that no cut stone exists, that a description of the stone occurs in at least five books on gemstones. The original dark red crystal, well-formed though rather water-worn, was found in one of the small ruby mines near Ohngaing village in the Mogok district of Burma. Mr A. C. D. Pain, who suspected it might be something new, sent it to the Laboratory for testing. The crystal at first sight looked as though it were tetragonal, but C. J. Payne, finding the prism angles to be exactly 60° realized that in fact it was hexagonal. It weighed 8·5 carats. The density was found to be 4·01 and the refractive indices 1·8159 for the

A. C. D. Pain

ordinary and 1·7875 for the extraordinary ray, giving a birefringence of 0·0284. The hardness was measured as 3 on Mohs's scale by an indentation method. The dichroism showed a brownish-red for the ordinary ray and deep ruby red for the extraordinary.

Permission was given for a thin slice to be removed from the base of the crystal for Claringbull and Hey to carry out the necessary x-ray and chemical work. Analysis showed the mineral to be a borosilicate of calcium and aluminium, but it proved difficult to ascribe to it a definite formula. The specimen was justly named after its discoverer, and presented by him to the Museum where most of the work on it was done.(5)

Chromium lines were visible in the red end of the spectrum, and the colour was probably due to this, at least in part. In confirmation of this, the stone showed a red glow under crossed filters. It is difficult to judge how attractive a cut painite might be. In bulk, the colour was too deep to be effective, but one might guess that small stones might look very much like Siam rubies.

Ekanite

For the last of my stones we return to the gem gravels of Ceylon, and once more it was a keen gemmologist who set the ball rolling. This was Mr F. L. D. Ekanayake of Colombo, Ceylon, who, in 1953, sent a round cabochon dark green stone showing a faint four-rayed asterism to his friend, Mr R. K. Mitchell, accompanied by a letter in which he stated "I am sure this is a new mineral". After some preliminary work Mr Mitchell allowed us to try our hand at solving the mystery of this peculiar stone. It appeared to be quite amorphous not only optically but to an x-ray beam, and yet the tiny oriented needles to which the asterism was due argued some degree of crystallinity. The density was 3·28 and R.I. 1·60.

An attempt at spectrum analysis in the Laboratory showed the presence of calcium, silica, and traces of lead. This last made me think in terms of glass, and I sent the stone to D. K. Hill, a well-known glass technologist, for his opinion. He at first confirmed the glass hypothesis, but then discovered by a much more skilled spectrum analysis than we could muster, that thorium was a major constituent of the material. Hill's estimate was about 26 or 27% thorium oxide—which later proved to be almost exactly correct. On hearing this news the penny dropped, and I realized that we were dealing with a metamict—a crystal the structure of which had

F. D. Ekanayake
(Reproduced from *The Gemmologist*)

broken down due to 600 million years or so of internal bombardment with alpha particles, as in the case of the green metamict zircons we already knew so well. The trace of lead was also explained—this was the end product of the disintegration of thorium.

During this prolonged investigation, by another of those extraordinary chances of which I have already spoken, Mr Solomon, who was at the time an instructor of students of gemmology in Plymouth, sent me a cabochon stone of this same metamict material, asking if I could tell him what it was since it had puzzled his students! When I told him the story he kindly gave me the specimen.

As one would expect, Ekanayake's stone proved to be quite strongly radioactive, leaving a trace after being placed on a photographic film for a few hours. Using a slice taken from the stone, we tried to return it to its original crystalline state by heat treatment: but heating at 1000°C failed to bring about the hoped for alteration and transformed the stone into an opaque putty-coloured mass.

It was several years before the Museum could proceed with the necessary complete analysis, which entailed a formidable piece of

work, and in the meantime Ekanayake had recovered three further pieces of the mineral from the same gem pit where the original was found—at Eheliyagoda near Ratnapura.

The final analysis, carried out by D. I. Bothwell, showed the new mineral to be essentially a silicate of thorium and calcium, though about 2% of uranium was also present. A preliminary note was published in *Nature* on June 10th, 1961, establishing the new mineral at last, and appropriately honouring its discoverer in the name ekanite. R. K. Mitchell gave an excellent account of the long drawn-out investigation in the *Journal of Gemmology*, and shortly afterwards Dr Edward Gübelin who, unknown to us, had been working intensively on the new mineral, of which he had acquired no fewer than 12 specimens, published a long and brilliant paper on the subject in *Gems and Gemology*, *The Gemmologist*,(6) and elsewhere, which precluded the need for any further work on our part.

Since that time, crystallized forms of ekanite have been reported from Central Asia by Russian workers and from Saint-Hilaire, Quebec Province, in pegmatite veins. The crystals are tetragonal. The reason for these not having been reduced to the metamict stage lies in their much younger geological age—60 million years against 600 million.

One thing that took away much of the pleasure from these investigations into new gem minerals was the long delay between the initial burst of ordinary gemmological work on the stones and the final necessary chemical analysis and crystal structure analysis which had to be performed before the mineral could be properly established and the conclusions published as a scientific paper. One could not very well press for speed from the skilled Museum workers, for work which involved a great deal of time and effort, which had to be added to their own research programmes and routine work for the Department. And we ourselves in the Laboratory found it increasingly hard to find time to work continuously on any project as the demands of essential daily testing work became more and more pressing. Visits to the library became lunch-time snatches, and one felt guilty in doing any work which could be termed purely academic. And most of you know how hard it is to pick up the threads of any piece of work which has been put on a shelf and allowed to grow cold.

Amongst the advantages of such pieces of research are the

sharpening of technical skills, an increased international reputation for the Laboratory and a closer liaison with mineralogists—a liaison which is vital in the present state of our science.

For those of you who have found my topic for this evening too remote from everyday experiences and problems in the Trade to interest you, I can promise a thoroughly down-to-earth talk next October, when I understand that I am going to be allowed to speak to you again.

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AGATE-STAINING IN THE EARLY PART OF THE CENTURY

By M. J. O'DONOGHUE, M.A., F.G.A.

IN 1913 Dr O. Dreher published a book entitled *Farben des Achates*, in Idar-Oberstein. Long out-of-print, there is no copy in the library of the Gemmological Association nor in the British Museum. However, in his recent book, *Gemstone & Mineral Data Book*, John Sinkankas summarizes a number of Dr Dreher's findings.(1)

For obtaining a red colour Dr Dreher recommends a dye solution with the following composition: ¼kg iron nails dissolved in 1kg concentrated nitric acid. When the liquid is clear the agate slabs are soaked for a duration depending on their thickness, e.g. 3 mm thick, 6-10 days, 7-10 mm from 3-4 weeks. Stones are then heated in a closed crucible for 2-3 or 8-10 days again according to the original thickness. Dreher found the iron nitrate supplied by a chemical house less satisfactory than the somewhat cumbersome nail method. S.Hoffmann(2) worked through the same method to obtain red agate.

For blue Dreher used 250 g of yellow potassium ferrocyanide dissolved in 1 litre of lukewarm water. Stones were immersed for 8-14 days. They are then washed and subsequently placed in a lukewarm saturated solution of ferrous sulphate.

For black the stones are immersed in a solution composed of 375 g of sugar per litre in which they are soaked for 2-3 weeks, with the occasional addition of water to replace losses through evaporation. They are rinsed and dried and then placed in a bath of concentrated sulphuric acid. This is warmed for one hour until it is hot. The stones are soaked for 1-2 hours while the acid is brought close to boiling point (340°C). They are carefully washed on removal. It was not necessary to bring the acid to boiling point to achieve carbonization of the sugar.

Green staining is accomplished by the use of a saturated solution of chromium trioxide in 1 litre of water. Immersion lasts from 8-14 days for thin slabs, 2-8 weeks for thicknesses of 3-10 mm. After removal and rinsing the agates are placed in ammonium carbamate acid carbonate followed by heating to redness.

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G.G.G.—A NEW MAN-MADE STONE WITH A GARNET-TYPE STRUCTURE

By ROBERT WEBSTER, F.G.A.

A CUT specimen of gadolinium gallium garnet which has been presented to the Gemmological Association by Mr Walter E. Johansen, of Morgan Hill, California, is the subject of this short article. It is another potential gem material which has no counterpart in nature and some crystals were described by M. J. O'Donoghue in the *Journal of Gemmology* last October.(1) It is said, however, that there is no intention of marketing this type of stone; crystals are grown for scientific purposes, one of which is said to be in connexion with "substrates for magnetic bubble memories",(2) a subject of which most gemmologists are ignorant.

Gadolinium gallium garnet, usually abbreviated to G.G.G., corresponds to the formula $Gd_3Ga_5O_{12}$ and forms colourless crystals, which can, however, be 'doped' to give various colours. Gadolinium and gallium are elements not previously mentioned in connexion with gemstones, so it may be of interest to give some facts concerning these somewhat rare elements.

Both gadolinium and gallium are chemical elements of group three in the periodic table. The rare-earth metal gadolinium, having the atomic number 64 and a density of 7·898,(3) was discovered in 1880 by C. Marignac, who showed that "terbium earth" contained a new element, which was named gadolinium, as well as terbium. Gallium, a member of the boron-aluminium family, has the atomic number 31 and forms grey octahedra with a density of 5·92.(4) The element was discovered by Lecoq de Boisbaudran in 1875 by spectroscopically examining zinc blende from the Pyrenees, the spark spectrum of gallium giving two well-defined lines in the violet at 4170Å and 4030Å. Gallium was one of the elements predicted by Mendeleef in 1869 to fill gaps in his table; at that time he named this then undiscovered but anticipated element as eka-aluminium.

The refractive index of G.G.G., which is of cubic crystallization, is given as 2·01 or 2·03,(2) and the dispersion as 0·038(2) which is not very much lower than that of diamond itself (0·044 B to G). The density is about 7·05(2) (say 7·00 to 7·09) and the hardness is about 6½ on Mohs's scale. The lustre approaches that of diamond.

Visual examination of the stone weighing 1·15 carats presented by Mr Johansen showed it to be a round brilliant-cut stone, colourless with a distinctly brownish tinge and showing a good 'fire'. It would make a very good simulant of diamond, especially if it is produced without the brownish tinge, and this is said to be quite possible. The stone when examined under the microscope was found to be clean except for a group of very small bubbles, and when the stone was viewed between "crossed polars" the field remained dark through a 360° revolution of the stage.

The most important observation made was that of the luminescence of the stone, for under the long-wave ultra-violet lamp (3650Å) the fluorescent glow was found to be a weak orange in colour. This could be seen quite well with the medium-pressure mercury-vapour ultra-violet lamp with Wood's glass filter but scarcely at all with the long-wave fluorescent tube lamp, owing to the residual visible light passed by this type of lamp. Under the short-wave ultra-violet lamp (2537Å) the glow produced was a strong orange but did not appear to show any phosphorescence. This orange glow examined with a hand-spectroscope showed it to be discrete and consisting of a strong sharp band in the orange, which could rather be called a line than a band, and there were some weaker bands, which may be further bands from this luminescent glow or perhaps could be mercury and neon lines reflected from the lamp emission by the facets of the stone. Under x-rays the glow seen was a strong orange-pink with a weak afterglow, which seemed to occur after a short delay and appeared to be a weak bluish or greenish white in colour. Mr O'Donoghue (loc. cit.) using G.G.G. from another source found the glows to be:—

Long-wave ultra-violet (3650Å) = straw colour.

Short-wave ultra-violet (2537Å) = peach, with no phosphorescence.

X-rays = lilac, with no phosphorescence.

In consideration of the facts that the material is of use in "magnetic bubble memories" and that gadolinium itself is said to be ferromagnetic below 16°C,[5] the magnetic effect of the stone was investigated. These experiments seemed to show that the stone did not affect a magnetic needle, at least a cased compass needle, but the stone was found to be weakly attracted to a small magnet. This was further confirmed by noting that a loss of weight occurred

when the stone was arranged on a cork resting on one pan of a balance which was then put in poise. A small magnet held over the stone produced a deflection of the balance indicating needle. The stone was not electroconductive.

No distinctive absorption spectrum was observed, but there may be a very weak band in the blue. Between "crossed filters"—that is, using a flask of copper sulphate solution over a white light source and the stone viewed through a spectrum red filter—a weak reddish glow could be seen, but some of the deeper red filters did not seem to show the effect at all clearly. When the red filter was changed to a hand-spectroscope the bright orange fluorescent line was not observed, nor, indeed, could this fluorescent line be at all clearly observed when the stone was bathed in long-wave ultra-violet light.

To sum up, gadolinium gallium garnet would make an excellent simulant of diamond. Although it is understood that there is no intention of marketing this material as gem material, it must be a potential gemstone if only as the result of amateur lapidaries getting hold of rough material. Its distinction appears to be fairly easy by the high density, or, if mounted, by the orange fluorescence under short-wave ultra-violet light. The magnetism, although an interesting feature, is hardly strong enough to be a test, and certainly not if the stone be in a setting. The most attractive tests for this stone seem to lie in the use of the short-wave ultra-violet lamp in conjunction with the spectroscope to pick up the fluorescence line, and if the stone be unset then the density will clearly identify it.

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A NEW LOOK AT GREEN GARNETS

By G.V. AXON, F.G.A., G.G.

ARE garnets taken for granted? By the public perhaps, but not by the gemmologist or the mineralogist. Somehow, garnets constantly create news from the gem front. The spelling, for instance, seems now to have been agreed upon as pyrope, almandine and spessartine for one isomorphous group, and grossular, andradite and uvarovite for the other. It's a mixed bunch of spelling. More important, perhaps, are the chemical formulae. The addition of iron to the formula for pyrope means that all garnet groups, except grossular, basically are idiochromatic, not allochromatic. Thus grossular should be, and is, the garnet that provides the greatest number of hues, while andradite, because of its ability to substitute other metals for calcium and iron, is the next most important in hue variety. Other garnets allow some substitution of importance. Pyrope, for instance, is made a much brighter red by the addition of chromium, while spessartine loses some of its beauty when iron invades the manganese.

The green garnet known as demantoid is, of course, in the andradite family and is finely coloured by chromium. The only garnet with chromium as part of its formula, uvarovite, is a fine green but has produced only small faceted stones, usually from Asbestos (Quebec) material. The other green garnet sometimes coloured by chromium, grossular, is rare, comes in small pieces from Tanzania, and cuts as a stone that most connoisseurs would probably regard as finer than demantoid. There may be, of course, other sources that the writer is unaware of, but these three chrome-green garnets are worth a slight discussion.

All are rare, although demantoid from the Urals must once have been in good supply, to judge from museum displays. The fibres by which demantoid is identified by loupe, before more exacting scrutiny, are found, probably in greater clusters, in some chrome-green sphenes, even though their chemical composition may not be the same. This clouding of the sphene often precludes easy sighting of the huge double refraction, but the small yet fine chrome-green sphenes that do not contain fibres—material from Pennsylvania, that is, as distinct from Mexican—show the double refraction clearly.

The arrival a few years ago of chrome-green synthetic garnets caused a nuisance to begin with, but that seems to have died down, and little if any trouble has been reported—at least not in New York. Thus gemmologists are faced with relatively few problems in the green garnet field in spite of the many varieties that theoretically at least might come along. Faceted uvarovites are nearly as scarce as hens' teeth. The chrome-green grossulars are almost but not quite in the same category. The synthetics have been exposed and gemmologists should be on their guard. The sphenes that may look like green garnets are rare, and only those sphenes that contain fibres are truly misleading. Demantoid remains almost supreme.

As for the future, probably not too much may be expected from pyrope, almandine and spessartine, but grossular, andradite and even uvarovite may produce surprises. Yellow topazolite in the andradite family is mentioned in textbooks and may turn up again, even if only in small crystals. Uvarovite has produced a few small stones and may produce more. Grossular, in theory at least, provides the best source, although demantoids of fine quality could also again be found in quantity.

The gem world is full of surprises, as tanzanite has proved. The earth's surface has only been scratched, and new gems and new supplies are sure to come. How many gemmologists are aware that catapleiite* and weloganite† have now been found in clear crystals, and that facet-grade lazulite has become almost commonplace? Chrome-green garnets, therefore, may once again become a popular gem variety.

*See J. Gemm., 1964, IX, 5, 183.—Ed.

†$Sr_5Zr_2C_9H_8O_{31}$; in trigonal crystals, lemon-yellow to amber; having H.3½: S.G.3·22 (±0·03) R.I.α1·558, β1·646, γ1·648 (all ±0·003); see Mineral Abstracts, 1970. **21**, 2, 159.—Ed.

GROWTH FEATURES IN SOUTH AFRICAN EMERALD CRYSTALS

By R.M. YU, Ph.D.

Physics Department, University of Hong Kong

ABSTRACT

Growth features in thirty pieces of South African emerald crystals have been studied by transmission, reflection and interference microscopy. Altogether four different shapes of etch pits, four distinctive types of inclusions and one type of striations are classified.

INTRODUCTION

The growth features are birth marks of a crystal. They are useful for identification as well as for deducing the condition under which a crystal was grown. For example, Sunagawa(1) has distinguished between synthetic and natural emeralds by comparative study of their surface structures. In the present study of growth features thirty pieces of the most perfect crystals are chosen from one thousand carats of South African emerald rough. These crystals are in nearly perfect hexagonal prisms with lengths varying from 3 mm to 10 mm and lateral dimensions from 1 mm to 4 mm. The most interesting surface structures observed are the various shapes of etch pits on the $\{10\bar{1}0\}$ faces of the crystals. The hexagonal pyramidal etch pits and the hexagonal prismatic etch pits are frequently observed in many crystals while the long groove etch pits and square pyramidal etch pits are only occasionally observed. Four distinctive types of inclusions are classified. These include feathers, liquid-filled tubular fissures, veils and three-phase inclusions. In some crystals sets of striations perpendicular to the c-axis are also observed.

EXPERIMENTAL METHOD

A Leitz Dialux-Pol polarizing microscope with a universal rotating stage is used for transmission microscopy in polarized light. For reflection and dark field microscopy an Olympus N9 microscope is used. By replacing the objective lens with a Watson 8 mm interference objective and using a sodium lamp as a monochromatic light-source, two-beam interferograms of crystal surface structures can be obtained. This is particularly useful in mapping the contours of the etch pits.

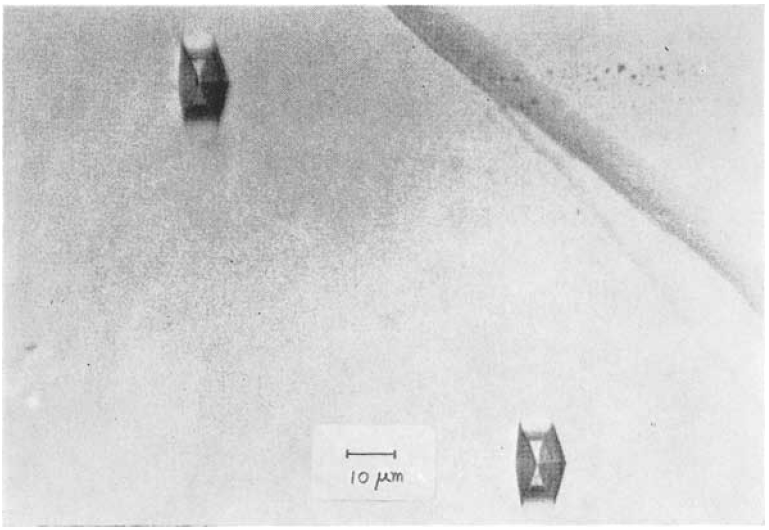

FIG. 1. Hexagonal pyramidal etch pits
(a) reflection micrograph (above)
(b) interferogram (below)

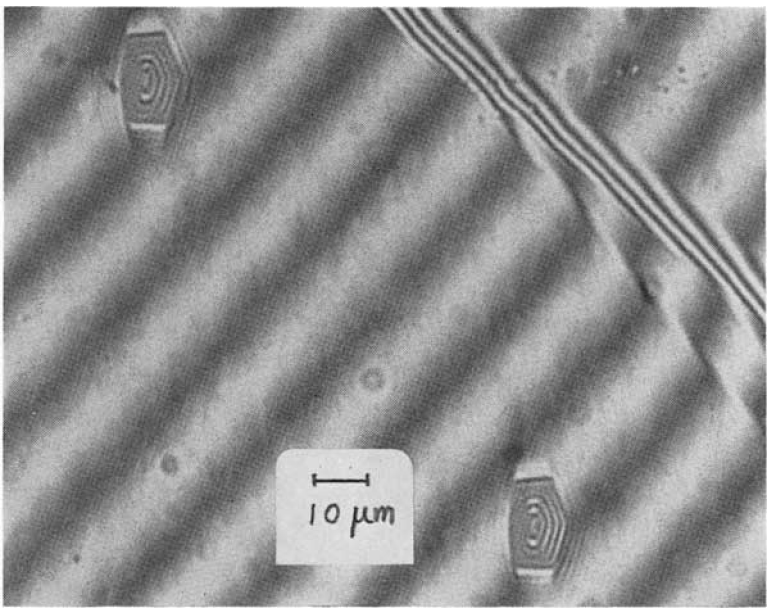

Etch Pits

During the growth of a crystal some part of the molten salt may become undersaturated as a result of temperature fluctuations or compositional changes. Dissolution of the crystal then takes place preferentially at crystal imperfections where the strain energy is released by dissolution of deformed or foreign materials. Thus the emergence point of a dislocation line on the crystal surface is selectively etched to give rise to an etch pit. The shape of an etch pit depends on the crystal structure as well as on the nature and orientation of the dislocation line with respect to the crystal surface. The following four types of etch pit have been observed in the $\{10\bar{1}0\}$ faces of the South African emerald crystals:

(i) Hexagonal pyramidal etch pits.

This is by far the most common type of etch pit in the samples. The reflection micrograph and interferogram of two such etch pits are shown in Figs. 1(a) and 1(b). The dark fringes in the interferogram are fringes of equal thickness spaced apart at 295 nm (half the wavelength of sodium light), thus the depths of these two pyramidal etch pits are about 1·5 μm. The bottom of the etch pit may converge to a sharp tip or a short line.

(ii) Hexagonal prismatic etch pits.

Fig. 2(a) shows a hexagonal etch pit with a truncated bottom while Fig. 2(b) shows three shallow etch pits whose outlines are barely visible. The flat bottoms of these hexagonal prismatic etch pits suggest that the dislocation lines had vanished or moved away at an early stage of the natural etching process. In later stages the etching no longer increased the depths of the etch pits, but only developed their lateral dimensions. To illustrate the difference between the pyramidal and the prismatic etch pits, both types of etch pit are shown on the same micrograph and interferogram in Figs. 3(a) and 3(b) respectively.

(iii) Long groove etch pits.

Figs. 4(a) and 4(b) are micrograph and interferogram of a long groove etch pit together with several hexagonal pyramidal etch pits. The long groove might have resulted from the etching of an edge dislocation line running parallel and very near to the crystal surface. The length of the long groove is then equal to that of the dislocation line. In this case it is 130 μm.

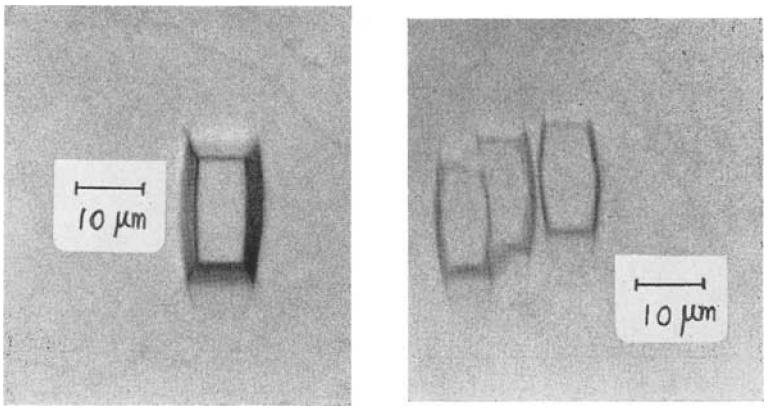

FIG. 2. (a) Hexagonal prismatic etch pit (reflection micrograph) (above left)
(b) shallow etch pits (reflection micrograph) (above right)

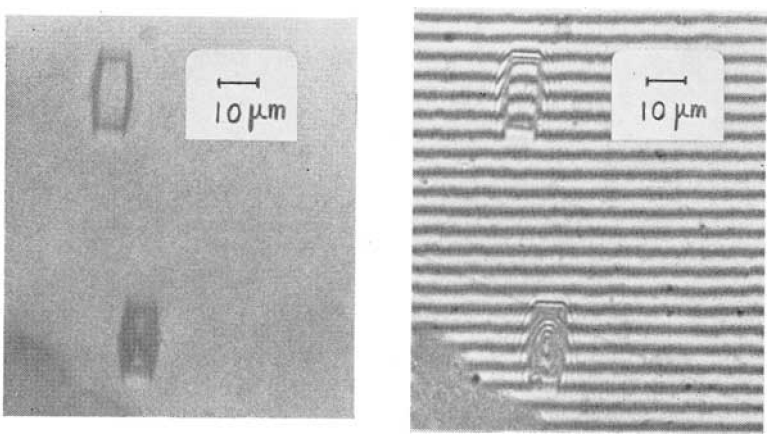

FIG. 3. Pyramidal etch pit and prismatic etch pit
(a) reflection micrograph (above left)
(b) interferogram (above right)

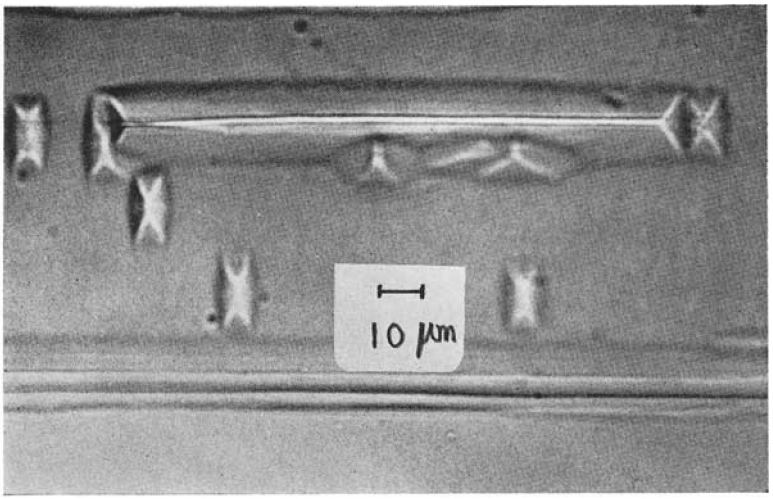

FIG. 4. Long groove etch pit and hexagonal pyramidal etch pits

(a) transmission micrograph (above)

(b) interferogram (below)

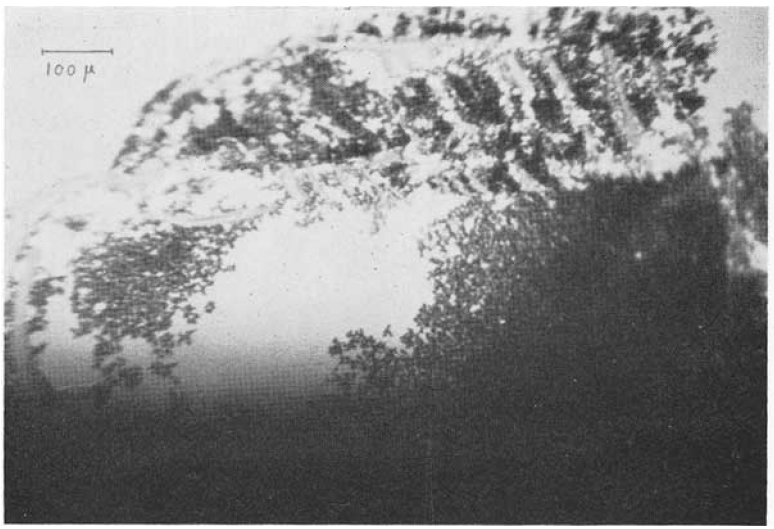

(iv) Square pyramidal etch pits.

In one crystal only (sample No. 27) a large number of square pyramidal etch pits are observed. A chain of such etch pits are labelled (AB) in Figs. 5(a) and 5(b). The chain of etch pits indicates an array of dislocation lines marking a low-angle grain boundary in the crystal.[2] The grain boundary is nearly parallel to the basal plane of the crystal with the dislocation lines perpendicular to the prismatic $\{10\bar{1}0\}$ faces of the crystal. The distances between successive etch pits are measured to range from 2·6 μm to 5 μm. Since the Burgers vector for emerald is 9·20Å long, the misorientation angle lies between 38 seconds and 73 seconds. While square etch pits have been frequently observed in cubic lithium fluoride crystals[3] it is not yet understood why they are also occasionally found in hexagonal emerald crystals.

Inclusions and Striations

As a crystal grows from the melt extraneous particles or fluids may become trapped in the growing crystal to form inclusions. Sometimes impurities which have been dissolved in the molten salt may subsequently coagulate to form separate phases inside the crystal. These inclusions can occur in the solid, liquid or gaseous state and exhibit many different shapes and configurations. In the present samples of South African emeralds the following four types of inclusions and one type of striations are observed:—

(i) Feathers.

These are inclusions which look like feathers under a microscope (Fig. 6). By orientating the optical axis of a uniaxial crystal normal to that of the polarizing microscope four extinction positions can be observed as the crystal is rotated through 360° on the microscope stage. It is found that the feathers in the present samples always appear bright when the host crystals appear dark, and vice versa. This phenomenon indicates that the feathers in South African emeralds are crystalline entities with their optical axes inclined at 45° to that of the host crystals. Liquid feathers have been found in synthetic emeralds.[4] They should always appear dark under crossed polars. The present observation of crystalline feathers serves as an aid in the identification of South African emeralds.

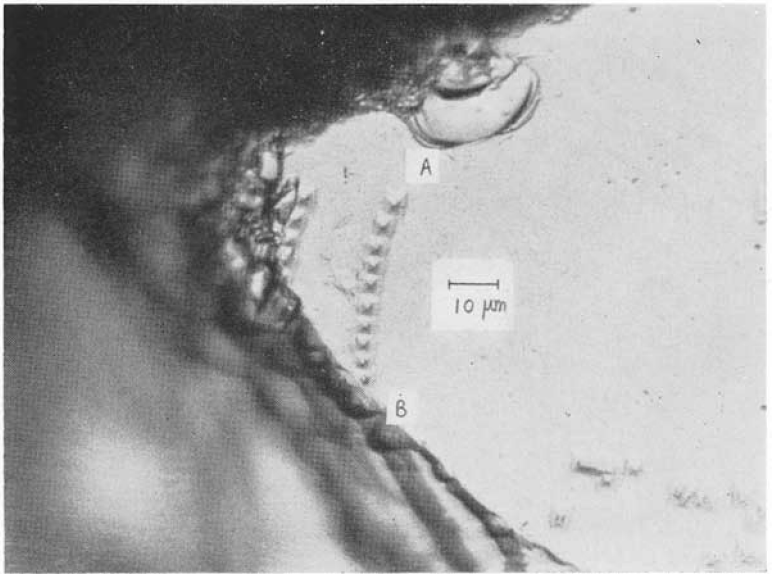

FIG. 5. Square etch pits
(a) reflection micrograph (above)
(b) interferogram (below)

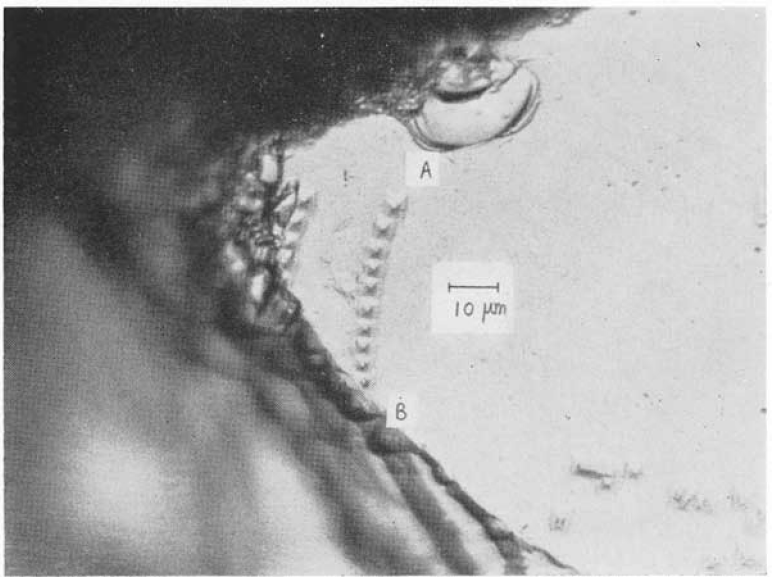

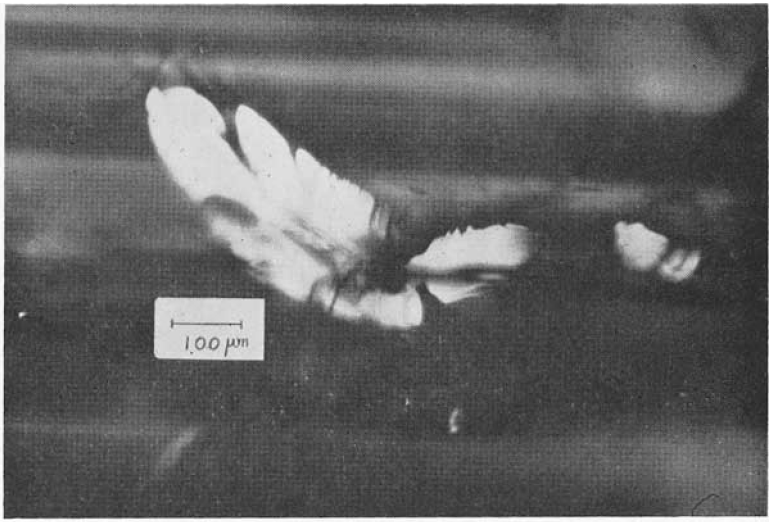

FIG. 6. Feather (transmission micrograph)

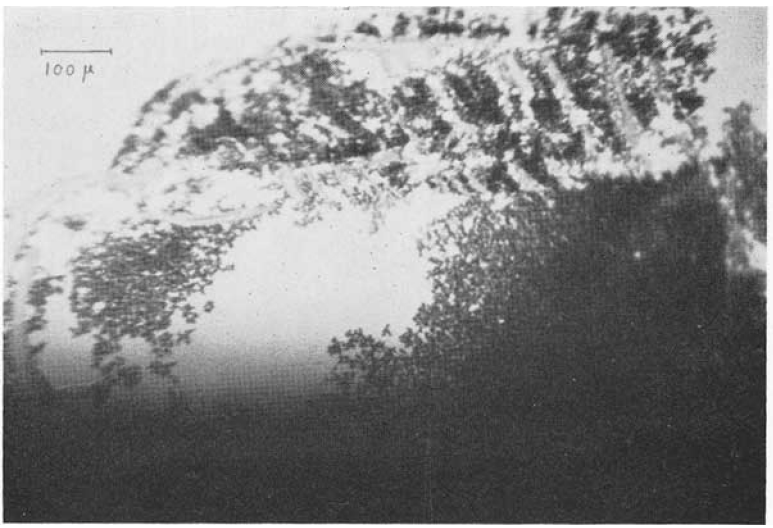

FIG. 7. Veil (transmission micrograph)

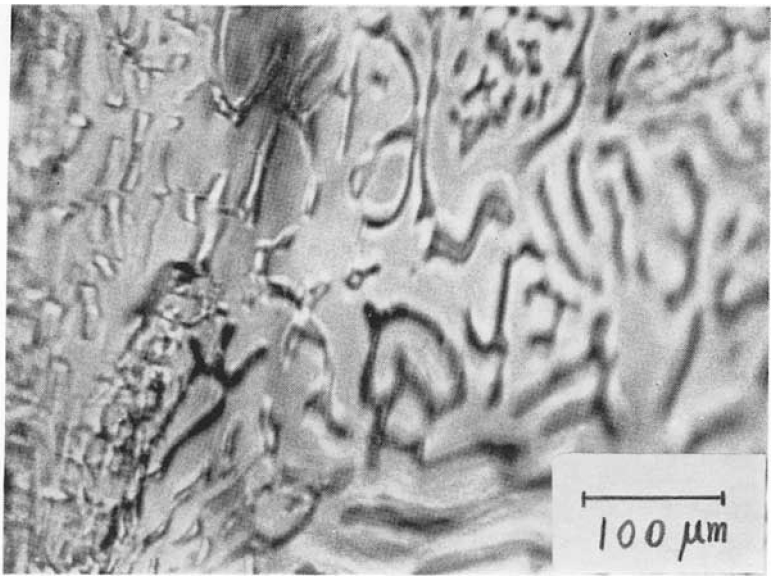

FIG. 8. Tubular fissures (transmission micrograph)

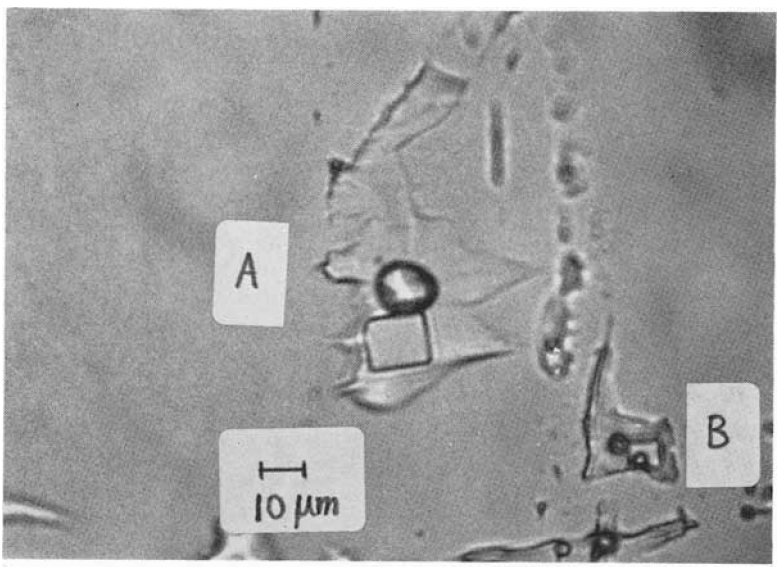

FIG. 9. Three-phase inclusions (transmission micrograph)

(ii) Veils.

These are groups of irregularly shaped tiny inclusions which look like curved veils (Fig. 7). They are non-crystalline and may appear colourless, brownish or black, depending on the angle of illumination. This type of inclusion has also been observed in beryl crystals grown by high temperature flux solution technique.[5] They are attributed to fluxes which have been trapped in conchoidal cracks of the crystals.

(iii) Tubular fissures.

Fig. 8 shows a maze of liquid-filled tubular fissures. The forming process of this type of inclusion may be similar to that of the veils, with the liquid trapped in tubular fissures instead of conchoidal cracks. In order to form the larger tubular drops the liquid in this type of inclusion has to be less viscous than that in the veils.

(iv) Three-phase inclusions.

In this case a crystallite and a gas bubble are formed in the included liquid drop so that the inclusion contains all three phases of matter. Fig. 9 shows two three-phase inclusions A and B clearly in focus. Under crossed polars the crystallite in A is extinguished whenever the host crystal is extinguished, showing that their optical axes are aligned in the same direction. The crystallite in B is grown around a seed of impurity which cannot be extinguished for any orientation of the host crystal. In the present samples all the crystallites are square or rectangular in shape. In this respect South African emeralds are similar to Colombian emeralds and are different from Russian emeralds, which have diamond-shaped crystallites.[6]

(v) Striations.

These are parallel bands of slightly different colours or refractive indices shown up as fine lines under the microscope (Fig. 10). They result from compositional variations due to fluctuations in temperature or purity of the molten salt. The striations are irregularly spaced and are perpendicular to the c-axis of the crystal. No striations parallel to the $\{10\bar{1}0\}$ faces have been observed.

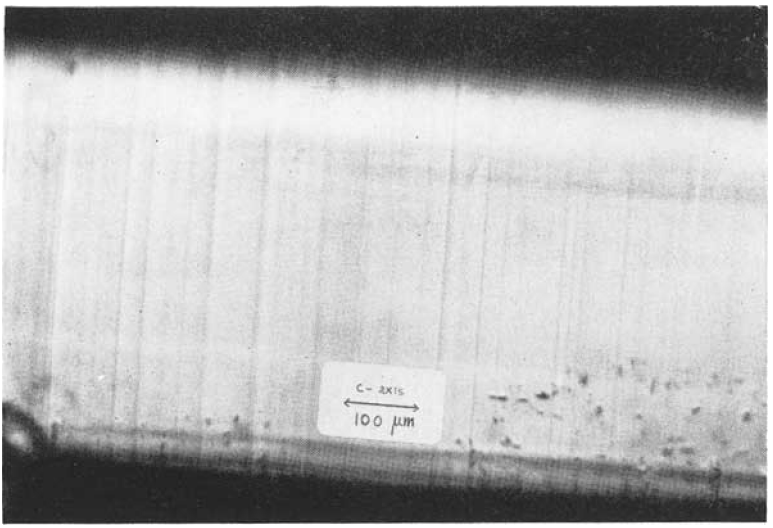

FIG. 10. Striations (transmission micrograph)

CONCLUSIONS

Growth features in thirty pieces of South African emerald crystals have been studied by transmission, reflection and interference microscopy. Four different shapes of etch pits are observed. They are thought to result from preferential etching of the emergence points of dislocation lines at crystal surfaces. The hexagonal contours of the etch pits are likely to be consequences of the hexagonal crystal structure of emerald. It is noted that in cubic lithium fluoride the etch pits have square outlines[3] and in rhombic topaz the etch pits have rhombic profiles.[7] Emerald $Be_3\ Al_2\ (SiO_3)_6$ has a honeycomb structure built up from hexagonal rings of six SiO_3 tetrahedra with Be and Al atoms between the rings.[8] Further theoretical work is being undertaken to establish a definite link between the etch pit configurations and the crystal structure. Four distinctive types of inclusion in emerald have been classified, namely, feathers, veils, tubular fissures and three-phase inclusions.

The crystalline feathers could be formed by a slow process of the dissolved impurities gradually separating from the host material. On the other hand the boundaries of the other three types of inclusions are probably formed quickly by the interface of the included liquid and the host material. In some crystals irregularly-spaced striations perpendicular to the c-axis of the crystal are also observed.

Acknowledgement

Part of the work was carried out while the author was a Leverhulme Fellow at Monash University. He is grateful to the Trustees of the Leverhulme Fellowship for the award of the Fellowship and also to Dr A. C. McLaren and Mr David Marshall of Monash University for their friendship and assistance.

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Gemmological Abstracts

BALL (R. A.) and MALIN (A. S.). *Scanning electron microscopy and opals.* Australian Gemmologist, 1974, 11, 12, 16-19. 3 illus.

A description of the scanning electron microscope (SEM), how it works and what it will do. Its advantages over the optical microscope and over the transmission electron microscope are discussed. There is the result of an examination by such an instrument of a blue-green opal from Lightning Ridge, New South Wales. R.W.

BANK (H.). *Klar durchsichtige gruenliche und graue Vertreter der Aktinolith-Tremolit-Reihe aus Ostafrika.* (Transparent green and grey representatives of the actinolite-tremolite series from East Africa.) Z. Dt. Gemmol. Ges., 1974, 23, 1, 42-44.

Descriptions of actinolite and tremolite found recently in Tanzania. E.S.

BANK (H.). *Farbloser klar durchsichtiger Oligoklas aus Kenya.* (Transparent colourless oligoclase from Kenya.) Z. Dt. Gemmol. Ges., 1974, 23, 1, 45-48.

The plagioclase crystal oligoclase has been known for many years only as sunstone; it has now been found absolutely transparent in Kenya. Its characteristics are described in the article. R.I. 1·540-1·544, density 2·64, hardness just under 7. E.S.

BANK (H.) and BERDESINSKI (W.). *Stark pleochroitischer schleifwuerdiger Kornerupin aus Ostafrika.* (Strongly pleochroic cuttable kornerupine from East Africa.) Z. Dt. Gemmol. Ges., 1974, 23, 1, 49-51.

The material found in Greenland and in Saxony could not be cut, but kornerupine found now in Tanzania south of Handeni yielded cuttable stones, although previously stones from Madagascar had been cut. Details are given. E.S.

BANK (H.). *Alexandrit und seine Nachahmungen.* (Alexandrite and its imitations.) Z. Dt. Gemmol. Ges., 1974, 23, 1, 64-65.

The first imitations of alexandrite to be found were doublets, later alexandrite-like synthetic spinels were used. Now there are

synthetic alexandrites on the market; these are made in U.S.A. and seem to have slightly lower R.I. (1·730 instead of 1·748), but in any case must be looked at under the microscope. They show wisp-like inclusions, as do synthetic emeralds and rubies which have been produced by the melt-diffusion method. E.S.

BURNS (R. L.). *A member of the ugrandite garnet series found in Western Australia.* Australian Gemmologist, 1973, 11, 12, 19-20.

Details the finding and the characters of some tiny green garnets belonging to the ugrandite series of garnets. They were found during the examination of thin sections of rock taken from core drillings obtained during prospecting nickel ore bodies. These green microscopic pieces have at the moment no gem significance and only scientific interest. One small piece of about 5 mm in diameter was found to have an R.I. greater than 1·8 and a density about 3·77. R.W.

COPELAND (L. L.). *The derivation of gemstone names.* Gems & Gemology, 1973, XIV, 5, 154-160.

A continuation of the first instalment now covers K to W. The first instalment was 1972/3, XIV, 4, 188-125 (abstracted in J. Gemm., 1974, XIV, 1, 30). R.W.

CROWNINGSHIELD (R.). *Developments and highlights at GIA's Lab in New York.* Gems & Gemology, 1973, XIV, 5, 134-140; and 6, 172-179. 37 illus.

Much is told about jade and cat's-eye imitations in glass. Unusual inclusions in diamond are mentioned, and to illustrate this further there is an exceptionally good photomicrograph of laser drillings in diamond. Something is told of the Maxixe beryl and experiments carried out on the fading of these stones. One stone faded to a very pale pink, but it is emphasized that so far the proof of gamma ray coloration as against the possibility of natural coloration is not complete. There is some discussion of the use of gamma radiation in the colouring of quartz, topaz and synthetic amethyst. There are some notes on the Gilson synthetic opal, on fire agate and an unusual serpentine. The "wearability of jadeite versus nephrite" is discussed and a note is given on damage to a diamond. R.W.

DELLA SALA (J.), FUENTES (J. C.), HERRERO (M.), LASERRE (N.), and VIAND (J.). *Contribution to the knowledge of the Argentine*

rhodochrosite. Gems & Gemology, 1973, XIV, 5, 141-143. 3 figs., 1 table.

A study of the rhodochrosite from Catamarca, Argentina. Something is told about the geology of the area and the associated minerals. The mean refractive index was determined as 1·59 and the density was found to lie between 3·50 and 3·60. The hardness was 4½ on Mohs's scale. The fluorescence was seen to be red-violet under short-wave ultra-violet light and a black pinkish colour under long-wave ultra-violet light. There was no response under x-rays. The absorption spectrum showed a band at 5350-5360Å in the green part of the spectrum. The chemical composition is discussed. The material is used as an ornamental stone for small objects. R.W.

DOEPEL (E. H.). *Transparent tremolite from Tanzania.* Z. Dt. Gemmol. Ges., 1974, 23, 1, 40-41.

Recently, in the Lelatema grossularite deposit in the Masai district in Tanzania, a light green crystal with prismatic habit and slightly anisotropic was found to be tremolite. This is a silicate, R.I. 1·608-1·616, hardness 5-6, S.G. 3·02 ± 0·06. Transparent crystals up to 25 mm length have been found, up to 8 mm diameter. No terminated crystals have yet been located. E.S.

ELI (H.-A.). *La luz polarizada.* (Polarized light). Boletin del Instituto Gemologico Español, 1973, II, 6/7, 3-9.

Polarized light is of great value when examining gemstones. Such important features as inclusions, growth lines in synthetic stones and interference figures can be examined with its aid. The principles of its production are discussed. M.O'D.

GOODGER (W. D.). *A mineralogical club first.* Lapidary Journal, 1974, 27, 11, 1646-1667.

A party visited the tanzanite mine near Moshi in Tanzania where working on a small scale was in progress. Material on sale in Nairobi included chrome tourmaline, poor quality emerald, ruby in zoisite, transparent green grossular garnet and epidote. M.O'D

HAHN (R. H.). *Die Steinschneidekunst ueber sechs Jahrtausende.* (The art of stone cutting during six thousand years.) Z. Dt. Gemmol. Ges., 1974, 23, 1, 52-61. 36 illus.

A survey of cameos and intaglios, going back to pre-Babylonian times, reaching great heights under the Egyptians and then tracing

its progress via Crete and Mycenae to Greece and Italy. After the 3rd century B.C. the art of engraving stones fell into disrepute, only to be awakened during the Renaissance. Lorenzo Medici collected cameos and intaglios already in the 15th century. The 17th and 18th centuries saw a number of famous men, such as Natter, Hecker, Barnabé and especially Pichler and his three sons, who worked in Rome from 1697-1779. Another Roman artist was Marchant (1755-1812), who later became English. The rest of the article deals with the stone engraving as practised for a long time in Idar-Oberstein. During the middle of the 19th century a few cutters went to Paris and learned the art from engravers there and have in turn produced some remarkable and beautiful works. E.S.

HEMMENWAY (K. M.). *The growing of NiO nickel oxide boules by the Verneuil flame-fusion technique.* Lapidary Journal, 1974, 27, 10, 1544-1545.

An Adamski barrel torch was used to ensure control of the flame pattern and an excess of oxygen was necessary for growing the material, which was dark green in colour. The powder used was originally $NiSO_4.6H_2O$ and was calcined to produce the boule. M.O'D.

HODGES (K.). *William Hidden's gems.* Lapidary Journal, 1974, 27, 11, 1749-1751.

Some hiddenite is still found at the original locality though the colour is a yellow-green. Work in the area is concentrated on emerald and no effort is made to recover hiddenite. M.O'D.

LAWRENCE (M. J.). *Diamond prospecting.* Australian Gemmologist, 1973, 11, 11, 22-29. 4 illus.

In Australia the prospecting of many minerals, diamond included, is carried out by the Bureau de Recherches Géologiques et Minières, a French Government sponsored department of the Geological Survey of France. The article tells of the use of a mobile prospecting unit which this organization uses. The article also gives a general survey of the diamondiferous localities of the world, giving in most cases the dates of the discovery. Something is told of the geology of these diamond localities and of the 'indicating' minerals associated with diamond. There is a brief outline of the prospecting methods and there is a good list of references. R.W.

LIDDICOAT (R. T.). *Developments and highlights at GIA's Lab in Los Angeles.* Gems & Gemology, 1973, XIV, 5, 144-151; and 6, 180-190. 44 illus.

There is an interesting discussion on the laser drilling of diamond. A green turquoise was found to contain no copper but did contain zinc and was a zinc analogue of turquoise, a mineral which has the name faustite. There was more news of the glass called 'meta jade'. Interesting inclusions in synthetic ruby, synthetic emerald and in glass are mentioned and illustrated. A large crystal of parisite from Colombia, a mineral found as an inclusion in Muzo emeralds, has been examined. It has a striking absorption spectrum. A trapiche emerald was also examined and illustrated. The inclusions seen in synthetic emeralds, Umba river corundums, demantoid garnet, and a moving bubble in a quartz crystal are described. An unusual method of mounting diamonds is mentioned, and the original organisms in some fossilized pieces are discussed. The result of twinning on the rays of star-diopsides, unusual inclusions in opal and some gem-quality colourless barytes crystals are other items discussed. A cut specimen of jeremejevite weighing 1·51 ct was examined at this laboratory. Pale blue in colour, the refractive indices were found to be approximately 1·639-1·648, negative uniaxial but with some indications of biaxiality with a small 2V angle. The density was close to 3·30. Hollow glass spheres filled with fragments of opal have long been known but such a glass filled with emerald fragments is a new departure. There is more reported on the inclusions in synthetic ruby and in diamond. A new treatment for turquoise is discussed, but no complete decision could be arrived at owing to the nature of the setting and the time available. A canned oyster said to contain a cultured pearl was found, when opened, to have not a cultured pearl but an imitation pearl inside it. R.W.

MCLOUGHLIN (D.). *The art of niello.* Australian Gemmologist, 1973, 11, 12, 11-15.

An explanation of the nature of niello and how it is produced. A very good historical survey, much consideration being given to the Russian use of niello throughout the ages. An important article on a subject not often considered. R.W.

MALLORY (L. D.). *The fire agate mines of Calvillo.* Lapidary Journal, 1974, 27, 10, 1500-1530.

Fire-agates occur in an area of volcanic activity in the district of

El Terrero, Mexico. The rough material is sold in Queretaro or Guadalajara. Best specimens have a brown background with a play of red, yellow, green and blue. M.O'D.

NASSAU (K.) and WOOD (D. L.). *Examination of Maxixe-type blue and green beryl.* Gems & Gemology, 1973, XIV, 5, 130-133. 1 fig.*

Details the experiments carried out on the 'Maxixe-type' beryls which show an unusual absorption spectrum and anomalous dichroism. First reported from the Maxixe mine in Minas Gerais, Brazil, this material was said to be subject to fading. Recent material having the characters of Maxixe beryl has recently come on the market and there is some notion that some of this beryl has been treated by some form of radiation. This had led to the experiments now reported. The results have not been completely conclusive and experiments are proceeding. There is an appendix on *colour centres.* R.W.

O'LOUGHLIN (J. L.). *Synthetics—their production and detection.* Australian Gemmologist, 1973, 11, 11, 11-13.

The report of a paper read before the Sydney Gemmological Symposium of 1973. The lecturer adopts a general line and gives as complete a survey as possible of the types and methods of producing synthetic stones. Something is told of the methods whereby these stones may be identified. R.W.

OUGHTON (J. H.). *Stones seen and discussed.* Australian Gemmologist, 1973, 11, 12, 25-26.

Examples of badly damaged sapphires caused by heat and by ultra-sonic cleaning are mentioned, as are a number of unusual doublets. These include a stone with a synthetic colourless sapphire crown and a colourless topaz pavilion; and others had synthetic spinel tops and corundum bases. Such stones may be detected by their differential fluorescence under ultra-violet light. A quartz top and red glass doublet has also been seen. R.W.

REEVE (R. J.). *Some gem-bearing pegmatites near Coolgardie, Western Australia.* Australian Gemmologist, 1973, 11, 12, 21-22.

There are three gem-bearing pegmatites of importance within 50 km of Coolgardie. The geology of the areas and the minerals found in the pegmatites are discussed. R.W.

*This paper was also published in J. Gemm., 1973, XIII, 8, 296–301.—Ed.

SANTOS MUNSURI (A.). *El color en el cuarzo sintético.* (Colour in synthetic quartz.) Boletin del Instituto Gemologico Español, 1973, II, 6/7, 11-16.

Synthetic quartz in varying colours has been made in the U.S.S.R. Colours include green, yellow, maroon and blue. The seed is clearly visible in the crystals which have the typical uneven growth on the (0001) face. Colour distribution was found to be uneven. Sawyer Research Products, Ohio, U.S.A., have also made quartz synthetically. In all cases the material is intended for optical and electronic use. M.O'D.

SCHMETZER (K.), BERDESINSKI (W.) and BANK (H.). *Ueber die Mineralart Beryll, ihre Farben und Absorptionsspektren.* (About the mineral beryl, its colours and its absorption spectra.) Z. Dt. Gemmol. Ges., 1974, 23, 1, 5-39. Bibl. of 112 items.

This is a very thorough examination into the colours and absorption spectra of beryls which were not known to exist in nature, such as zoisite-blue, indigo-blue and blue-violet. The absorption spectra of the beryl group are examined according to the cause of their colour, viz., (1) iron, (2) chromium and vanadium, and (3) manganese. Aquamarines are shown to be coloured by different valence states of iron ions. The colour of heliodor and other yellowish beryls is based on the presence of iron ions and/or lattice discontinuity. Morganite is coloured by manganese ions. An orange tone is produced by the combination of yellow and pink colour sources. Emerald's colour is caused by Cr^{3}- ions. Other green emeralds may owe their green to V^{3} ions. The sapphire and indigo-blue beryls, which have recently appeared commercially, exhibit absorption spectra which cannot be attributed to any of the mentioned sources. Since the colours are not stable, it must be assumed that the colours are induced by radiation. E.S.

SCHUBNEL (H.-J.): translated by LAPWORTH (P. B.). *Gems of special importance in the great museum collections.* Australian Gemmologist, 1973, 11, 12, 3-10.

An excerpt from the author's book *Pierres précieuses dans le monde.* The author tells where famous collections of gemstones can be found, seen, and what they have as special items. The division is made by the various countries. R.W.

TILLANDER (H.). *Observations on historical shapes of gem diamond.* Australian Gemmologist, 1973, 11, 11, 3-6. 3 illus.

A very good discussion on the shapes of the earlier cut diamonds and the relation of the shape to that of the original crystals. An interesting survey of an unusual subject which has been built up from a comprehensive investigation. R.W.

UHRIN (R.), BELT (R. F.) and PUTTBACH (R. C.). *The hydrothermal growth of zircon.* Journal of Crystal Growth, 1974, 21, 65-68.

Fluoride mineralizers were used to promote growth on natural seeds, using temperatures of 700°C and a pressure of 25,000 psi. Growth rates reached 0·25 mm per day. The rate was limited by small inclusions of $K_2ZrSi_3O_9$ (wadeite), which occurred when the concentration of KF, which was used in conjunction with LiF as a mineralizer, was too high at a given growth temperature. M.O'D.

WILKS (E. M.). *The resistance of diamond and other gemstones to abrasion.* Gems & Gemology, 1973, XIV, 6, 162-170. 1 graph; 1 table.

Details the experiments carried out on diamond and diamond simulants using the abrasion hardness method. Some anisotropy was found to occur in all specimens tested. The main object of the exercise was to show the vast difference between the hardness of diamond and materials which may look like it. R.W.

ZWAAN (P. C.). *Garnet, corundum and other gem minerals from Umba, Tanzania.* Scripta Geologica, 1974, 20, 1-41.

The mine is situated in the north east of Tanzania near to the Kenya border. The Umba river flows close by and the rocks of the area are metamorphic Precambrian. Garnets are almandines and rhodolites of a good colour, corundums are red, blue, deep violet and stones containing combinations of colour. An orange colour is also found. Other minerals include chrome tourmaline, a brownish orthopyroxene, green clinopyroxene, turquoise, yellow scapolite and zircon. The garnets with the lowest R.I. and S.G. had the highest Mg and the lowest Fe content while those with the highest constants had the highest almandine and the lowest pyrope content. X-ray powder photographs showed a pattern characteristic for pyrope, i.e. almost equal intensities of the diffraction lines 332, 422 and 431. The absorption spectrum was characteristic for almandine. The inclusions were not profuse; rutile was the commonest, occurring in

long and short prismatic needles, either isolated or running in three directions making an angle of 60°. Zircons with haloes were observed in three specimens. The almandine garnets fell within the expected constants and displayed a typical absorption spectrum. An apatite inclusion was identified in one sample. Inclusions in the corundums included rutile, pyrrhotite, apatite, graphite, zircon, spinel, vermiculite and liquid feathers. The orange-coloured corundum displayed an absorption spectrum which appeared to combine that of ruby with that of sapphire. Individual spot analyses of the parti-coloured stones appeared to indicate a possible relationship between Ti and Cr. A detailed investigation of this relationship is shown by six continuous scanning profiles for Ti and Cr-Kα radiations across the parti-coloured corundum more or less perpendicular to the red-blue boundary.

The emerald-green tourmaline showed strong dichroism with colours yellow-green and deep bluish-green. The absorption spectrum showed a weak line at 6995 with a doublet near 6765. A broad absorption band centred between 6105 and 6070 and a general absorption of the violet were also seen. Orange and brownish tourmalines were also strongly dichroic in tones of pale yellow and yellow-orange. They fluoresced a dull yellow under short-wave ultra-violet light. The S.G. varied from 3·053-3·057. All tourmalines showed characteristic liquid inclusions. The scapolite showed dichroism with colours straw-yellow and almost colourless; it luminesced weak reddish-orange under long-wave ultra-violet light with a stronger glow of the same colour under short-wave radiation. A powder photograph indicated that the stone was close to marialite. Needle-like hollow tubes could be seen. Densities of the zircons, which were reddish brown or pale yellow-colourless, varied from 4·667-4·684. The absorption spectrum was characteristic for high type zircon and the stones were almost free from inclusions. Veins of turquoise were embedded in limonite-bearing clay which alternated with sandy layers. Grains showed a mean R.I. of 1·64 and a mean S.G. of not far above 2·63.

M.O'D.

BOOK REVIEWS

GÜBELIN (Eduard J.). *Internal World of Gemstones.* ABC Edition, Zurich, 1974. Illustrated with 360 colour pictures and three in black and white. pp. 236. £25.

From a lifetime's study of the internal features of gemstones, born out of the delight in the patterns he saw through his microscope, Dr Gübelin is the one person who could write a thorough book on gemstone inclusions. This is not the first endeavour to produce a volume on such a single gemmological subject, for in 1953 this same author wrote "Inclusions as a means of gemstone identification", a book, out of print for a number of years, which was considerably consulted for reference and has been very much missed.

After twenty one years Dr Gübelin has presented the world's gemmologists with a thoroughly revised volume on the same subject. Entitled "Internal world of gemstones" this new production has to some extent a similar lay-out to that of the earlier edition but the scope is much wider. Following a preface by Prof. Dr W. F. Eppler and a foreword by the author, there is an introductory chapter which deals with the beauty of the inclusions in gemstones, what they are and their value to the gemmologist. The history of the knowledge and examination of inclusions from the time of Ancient Rome to the present day with its modern microscopes and electron probe is discussed in this chapter.

The second chapter gives a general discussion of how the inclusions in gemstones are formed, classifying these into three groups—those which were present before the growth of the host crystal which in growing enveloped them, such inclusions being called 'protogenetic inclusions'; the 'syngenetic inclusions', which formed at the same time as the growing host crystal; and lastly the so-called 'epigenetic inclusions', which have come about by various causes after the host crystal has formed. A different classification which, as the author points out, the gemmologist may find more practical, is to divide the inclusions into those which are solid, those which are liquid, and those which have cavities filled with gas. This aspect the author covers in the following chapter.

This next chapter treats of the inclusions predominant in the various gemstones and covers those in diamond, corundum, emerald and the beryls, the feldspars, garnets, peridots, quartz, spinel, topaz, tourmaline and zircon. The more unusual gemstones are not

individually discussed although in some cases, in other chapters, their inclusions are illustrated to show types of inclusions.

Then follows a chapter on the inclusions seen in synthetic and man-made stones, including glass. Something is told of the various methods of crystal growth in relation to the type of inclusions seen in these artificially grown crystals. It might be questioned whether the Czochralski 'pulling' method of crystal growing is really a development of the diffusion method, or is, as is more generally accepted, a growth from a pure melt. The discussion on synthetic emeralds, the inclusions of which are such an important diagnostic feature, is particularly interesting, as it is stated that the 'nail-like' inclusions may occur in flux-grown synthetic emeralds. The reviewer always considered this type of inclusion to be a sure sign of hydrothermal growth. Frightening, too, is the remark that three-phase inclusions are possible, or have been observed, in synthetic emeralds. The inclusions seen in man-made stones and in glass conclude the main text. The book is completed with a very good glossary of terms and a bibliography. There is no index.

Written in such a charming manner, which is so typical of Dr Gübelin's style, the book is extremely well illustrated with colour plates of gemstone inclusions which are of exceptional merit. It is a *must* for all discerning gemmologists, for the knowledge of inclusions is of paramount importance in the identification of gemstones. The book may appear expensive, but it must be remembered that the cost of printing, and especially colour printing, has increased alarmingly in recent years. The size of the volume (approx. 11 × 9 inches = 28 × 23 cm) makes it appear that the publishers had a dual purpose in mind; that of an excellent text book and a readable and attractive book for the table. R.W.

KESSEL (Joseph). *La vallée des rubis.* (The valley of rubies). Gallimard, Paris, 1974. pp. 274. Price on application.

An account of the author's visit to Mogok, centre of the ruby trade. The narrative is lively and reminiscent of Louis Kornitzer. Although styled as an adventure, a fair amount of information is given on ruby and other associated topics. M.O'D.

MASON (Anita). *An illustrated dictionary of jewellery.* Osprey Publishing Ltd, Reading, 1973. pp. 389. Illustrated in black-and-white. £5·95.

A first-class book which will enlarge the gemmologist's know-

ledge of the terms and techniques of jewellery and improve the gemmological background of the jeweller and craftsman. I could find no fault with the exhaustive gemmological information included and a large number of outmoded terms are clearly set out as obsolete. The drawings, by Diana Packer, are skilful and imaginative. There is a short bibliography. M.O'D.

PAGEL-THEISEN (Verena). *Handbook of Diamond Grading.* Frankfurt/M, 1973. English (4th) edition. pp. 214. Illustrated in black-and-white with one colour plate. £8·50

The first ever handbook devoted almost entirely to diamond grading was Diamanten-Fibel in 1968; it now appears in English under the title above. The German of Verena Theisen (now Frau Pagel-Theisen) was translated into English by Patricia B. Lapworth of Australia. Pagel-Theisen holds three countries' qualifications in gemmology and has been assistant to Dr K. Schlossmacher in Germany, Dr E. Gübelin in Switzerland, a worker in the G.I.A. Los Angeles laboratory, head of another gem lab. in Germany, and head of one of her own. The book can be recommended for its four exhaustive sections on the four elements of diamond grading. Quality of reproduction of the photographs of diamonds indicating standards of quality among the 360 illustrations is excellent. They are arranged for convenience in a single 34-page section. Grading is based on the R.A.L. (German Standards Association) draft of "individual terms for description of cut diamonds for jewellery purposes", first recorded in 1935. Except for the lowest grades they are almost identical to those used in the U.K. E.B.

ROGERS (Cedric). *Pebble polishing and pebble jewellery.* Hamlyn, London, 1973. pp. 80. Illustrated in black-and-white and in colour. £1·25.

A clear account of the methods of fashioning pebbles and crystals into simple jewellery, this book in no way adds to our knowledge on any aspect of the subject. The market must be well over-subscribed by now. However, the material is unexceptionable, although the author is in some confusion over the terms silica and silicates. Sphene and peridot are given as harder than or as hard as quartz; the spelling of "chrysopaze" seems an unnecessary whimsicality. Diamond is said to be 4 times harder than corundum. With these reservations the book is well-produced and the illustrations, some from the Geological Museum, are good. M.O'D.

ASSOCIATION NOTICES

MEMBERS' MEETINGS

ANNUAL GENERAL MEETING

The 44th Annual General Meeting of the Association was held at Saint Dunstan's House, Carey Lane, London, E.C.2. on the 25th April, 1974 at 6.00 p.m.

The Chairman, Mr Norman Harper, welcomed members and commented:

"The branches have been very active during the year and I would like to thank all those persons who have lent support and made the branch meetings most successful occasions. After the summer the Nottingham Branch of the Association was formed and it got off to a very good start. Fellows have helped by giving talks throughout the year, in particular Mr Basil Anderson, Mr Eric Bruton, Mr Alan Jobbins and Mr Robert Webster."

Mr Harper expressed the Association's thanks to Mr John Chisholm who had done an excellent job during the year as Editor of the Journal of Gemmology.

Entries for the examinations were once again very high and the Tully Medal was awarded to Dr George Hamel, of Holland, and the Rayner prize of instruments to Mr Patrick Daly, of Chelmsford. In the Preliminary examination the Rayner Prize was awarded to Miss Lorraine Fish, of London.

Unfortunately during the early part of the year the Association lost the greatly valued services of Professor S. Tolansky, who died on the 4th March. He had been an examiner of the Gem Diamond Course for many years.

The Chairman said that although Mr Gordon Andrews retired as Secretary at the end of March we did not lose him completely, because in November he came out from his country retreat

into London to present the awards gained in the 1973 examinations. Members may have read about the special dinner held at the Goldsmiths' Hall in conjunction with the National Association of Goldsmiths in March to honour his retirement. Gordon Andrews was instrumental in building up the Association to the strong position in which it finds itself today and the dinner was a fitting occasion to mark such a long period of work for the benefit of gemmology.

"Among the gifts to the Association", the Chairman continued, "I must mention that the Gemmological Association of Australia was good enough to send a large collection of Australian gem minerals which had been donated by its members. This collection is particularly interesting because almost every item gives the mining locality. This is the second time of making this gift. Regrettably the first collection of specimens was lost in the post, but the Australian gemmologists were not to be daunted and set about getting together the second collection.

"Once again Gemmological Instruments Ltd had a successful year and could have sold many more instruments, if Rayners could have improved production. Nevertheless we do thank Rayner and Keeler Ltd for their generosity in continuing to give prizes in connexion with the Association's examinations.

"The Annual report has been circulated and I have only elaborated on some of the important work that has been done during the year."

The Treasurer commented that membership had improved considerably during 1973, which had resulted in a larger surplus at the end of the year. However, the volume of work had increased and it was necessary to increase the staff. This would result in a larger payment to the National Association of Goldsmiths in 1974 to cover the extra cost.

Mr Robert Webster in seconding the Annual Report and Accounts expressed pleasure that it had been a most successful one and thanked the Secretary and staff for all that they had done.

Dr G. F. Claringbull, B.Sc., Ph.D., was re-elected as President of the Association and Mr Norman Harper and Mr Douglas King were re-elected as Chairman and Vice-Chairman respectively. Mr F. E. Lawson Clarke was re-elected as Treasurer. Messrs T. H. Bevis-Smith, M. Asprey and D. J. Ewing were re-elected to serve on the Council.

The Chairman announced that Messrs Watson Collin & Co., Chartered Accountants, had signified their willingness to continue as Auditors.

In concluding the meeting, the Chairman took the opportunity of expressing the Association's thanks to the Goldsmiths' Company for the ready willingness of the Wardens to place various rooms at Goldsmiths' Hall at its disposal for meetings. The Wardens readily respond whenever it is convenient and the Association was greatly indebted to them.

London

An entertaining talk on his travels in diamond- and gem-producing countries was given by Mr Eric Bruton, member of the Council, author of "Diamonds" and initiator of the gem diamond classes in London.

Held at the Goldsmiths' Hall on 26th March it was illustrated from his collection of some 400 slides.

Starting with Guinea in 1960, it covered Lesotho, Botswana, South Africa and the South West coast, together with Ceylon and Thailand.

Many of the pictures illustrated historic aspects of diamonds, such as one showing the monument erected at the spot where the first alluvial stones were found in 1869, and the preserved buildings of Kimberley. Mining was still being carried on in the old manner by individual diggers in an area held by De Beers, he said, though the numbers working the ground had shrunk from hundreds to about a score. There they still used the rotary paddle washers which were similar to those used at the mines, though the Diamond Research Laboratory, which was studying them, still did not understand exactly how they worked.

In the Vaal River area there was a glacial pavement some 250–300 million years old carrying a bushman's engraving 2,000 years old. The bushmen were believed to have been the true discoverers of African diamonds, having been found carrying them from very early days.

He described even more primitive mining methods in Ceylon and Thailand, where one man would work in temperatures of 100°F in a hole from which he would excavate passages. Beer bottles were being used to form Leclanché cells in one "plating shop" he saw.

A photograph of a 10 foot high golden Buddha in Thailand drew murmurs of admiration. He said it had been covered with plaster for 300 years and was thought to weigh 5½ tons. "I reckon it must be worth £10 million", he said.

At the end of the talk he showed some interesting stones including a tetrahedral diamond of about 1 carat, which he had found in a De Beers "junk box". "It had been thrown there because it did not fit into any known category", he said, "and is the only known crystal of its kind in the world. It is being studied by Professor Andrew Seager, of the Geological Department of Birkbeck College, who plans to write a paper on it".

Midlands

On the 22nd March, 1974, an evening was spent by Midlands Branch members at Warwick University, near Coventry. Dr P. W. MacMillan gave a talk illustrated by slides, followed by a tour of his laboratories. Dr MacMillan, the country's leading authority on research into toughened ceramics for industrial use, has produced, as an unexpected by-product of his research, several synthetic gemstones, notably synthetic kunzites.

A talk was given in Birmingham on the 3rd May, 1974. Mr Alec Farn, F.G.A., who succeeded Mr Basil Anderson in charge of the Gem Laboratory in London, spoke on the work of the Laboratory, with the accent on pearl testing.

The Annual General Meeting of the Midlands Branch was also held on the 3rd May. Mr John Marshall was elected Chairman, Mr M. Kirkpatrick Vice-Chairman, and Mrs Susan Spence Secretary. Thanks were expressed to Mrs S. Hiscox and Mr G. Porter, the retiring Chairman and Secretary respectively. Messrs G. Millington, D. Morgan, C. Hundy and G. Porter were elected members of the Committee.

Nottingham Branch

Mr M. J. O'Donoghue, M.A., F.G.A., gave a talk entitled "Gemstones of Central Africa" on the 8th April, 1974, in Nottingham.

On the 27th May members of the Branch visited the Institute of Geological Sciences, South Kensington. This trip was arranged with the co-operation of Mr E. A. Jobbins, B.Sc., F.G.A.

GIFTS TO THE ASSOCIATION

The Council of the Association is indebted to Mr M. Sevdermish, Wembley, for specimens of synthetic diamond, 40/50 mesh, G.E.C., U.S.A., and borazon II, cubic borazon nitride mesh 60/80, nickel-coated.

OBITUARY

Mr Louis C. Siedle, Hong Kong, Tully Medallist 1952, died suddenly on 16th April, 1974, aged 51 years. In 1969 Mr Siedle moved from Ceylon where his family had been prominent members of the gem trade for three generations.

Mr Vernon G. Kirk, Ferring by Sea, Sussex. D. 1930. died on the 10th March, 1974.

EVENING CLASSES IN GEMMOLOGY

At the Poole Technical College, North Road, Parkstone, Poole, an evening class in gemmology is being set up to commence this coming autumn. A lecturer is required and anyone interested should communicate with Mr A. J. Pittam, Lecturer in Charge Geology/Gemmology, at the address given above.

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THE JOURNAL OF GEMMOLOGY

and

PROCEEDINGS OF THE GEMMOLOGICAL ASSOCIATION OF GREAT BRITAIN

GEMMOLOGICAL ASSOCIATION
OF GREAT BRITAIN
SAINT DUNSTAN'S HOUSE, CAREY LANE
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INSPIRING HOURS AS AN INVIGILATOR

By PROFESSOR E. J. GÜBELIN, Ph.D., F.G.A., C.G.
Lucerne, Switzerland

HAVING invigilated over the candidates sitting for the Preliminary and Diploma Examinations of the Gemmological Association of Great Britain in Lucerne, Switzerland, for the past twenty years I am pleased to admit that it has always proved a most rewarding task, also offering considerable personal satisfaction. Over the course of the years the questions have become more and more interesting, acting as a true examination of the candidate's actual knowledge and mastery of the science of gemstones rather than merely challenging his talent of simply memorizing the data. Simultaneously, the test stones for Part III of the Diploma Examination became increasingly intriguing, i.e. demanding a greater empiric proficiency of the candidate, that is to say, his skill of practical testing tactics.

Before the examination was about to commence I have always shared the same tension as the poor candidates, as the envelopes of the questionnaires are opened in front of their anxiously watching eyes, and I have always found it most inspiring to study the questions carefully and answer them for myself. Unfortunately, my answers have never been subject to a corrector. Without seeing the question papers before the examination started, I usually took the liberty of identifying the examination stones.

It has always been my habit to scrutinize any gemstone at first sight by means of the microscope or the pocket lens, and at the same

time to decide upon the manner of procedure and thus determine by which method or methods I would reach an accurate assessment without too much loss of time. Very often I was delighted by a magnificent inclusion and rewarded by its diagnostic shape or nature identifying the gem at my first glance—in the full sense of the expression. Identification by means of the optical spectroscope proved to be another conclusive method which repeatedly found my enthusiasm and enabled identification of an unknown gem "within a matter of seconds". I invariably felt sorry for those candidates taking the practical part of the Diploma Examination on observing their loss of valuable time due to lack of system and practical experience. Empirical knowledge is of indispensible importance—a fact which was overwhelmingly corroborated again last June (1973), when we in Switzerland received a collection of test stones unusually well chosen for rapid arrival at an exact verdict by means of a systematic and proficient procedure.

The test stones of groups A, B and D need not be taken into consideration here because their determination is usually prescribed. All the more interesting were the specimens of the group C which could be identified by means of all tests available. Thanks to some outstandingly diagnostic features, such as inclusions and absorption spectra, it was possible to ascertain their nature within half an hour:

C 1 was a square-cut, grass-green stone resembling an emerald. It betrayed itself at the first glance under the microscope by its tell-tale inclusions which consisted of a typical wisp feather with a characteristic net-pattern of its liquid channels. This feather was accompanied by a well shaped phenakite crystallite (Fig. 1). This test stone was a *synthetic emerald.* In order to verify this verdict the stone's dichroism (bluish-green/yellowish-green) was checked and its refractive power against the immersion liquid (benzylbenzoate had been chosen for this purpose right from the beginning) showed to be lower.

C 2 was a cabochon-cut, translucent leek-green stone and did not reveal any particular feature under the microscope. However, under the spectroscope it showed a distinctive absorption line at 4370Å so conclusive for *jadeite.* The specimen hovering in methylene-iodide (d = 3·33) and giving a reading at 1·66 on the refractometer proved the first finding.

C 3 was a trap-cut gem of a pale straw-yellow colour. Its interior teemed with tiny liquid drops either irregularly distributed in

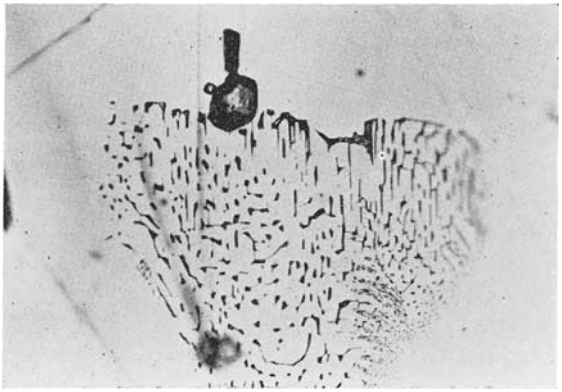

FIG. 1. Characteristic pattern of the "undigested" liquid drops in a wisp-like recreation fracture of a synthetic emerald in the immediate neighbourhood of a phenakite crystal. 50 ×

loose patches or arranged in arrays and then they excelled in "lost form" shapes with serrated border lines. Their indicative character existed not only in an extremely faint relief, advertising a small difference of R.I. between the liquid filling and the host gem, but also in the fact that apart from a majority of two-phase inclusions there were some three-phase inclusions, wherein the solid phase consisted of the ordinary cubic halite crystal announcing the hydrothermal origin of this specimen. All these observations (shape of the inclusions, their weak relief and their three-phase fillings) point to *fluorspar* (Figs 2, 3 and 4). Unchanged extinction between crossed polaroids and a refractive index of 1·44 confirmed the previous verdict.

C 4 a brilliant-cut stone of red colour. The first look through the microscope revealed this stone to be assembled, in that a score of spherical air bubbles appeared in the junction zone. The upper part contained rutile needles of the well-known three-dimensional arrangement, while the pavilion showed rounded facet edges and a smooth conchoidal fracture. Thus the *doublet* consisted of an almandine crown and a paste body. Immersion in water endorsed the conviction of having examined an almandine/paste doublet.

C 5 was a tablet-shaped slice cut across a prismatic crystal with a triangular basal pinacoid. While this contour already served as an excellent hint the thread-like inclusions proved to be even

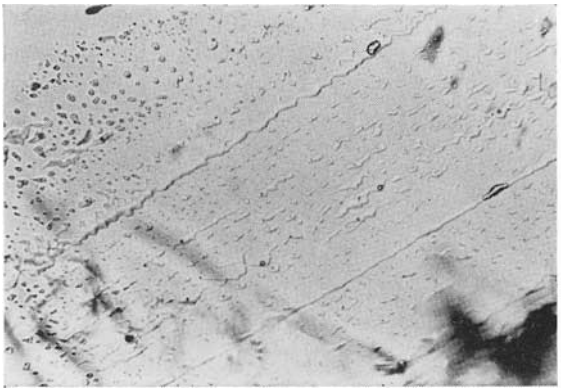

FIG. 2. Parallel rows of residual liquid drops forming two-phase inclusions in a cleavage plane. Their appearance and their lost-form shapes denote their host gem as fluorspar. 20 ×

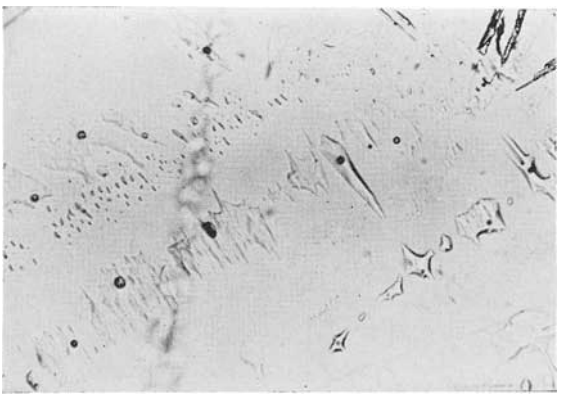

FIG. 3. Two-phase inclusions with spiky contours arrayed along parallel lines in a cleavage fissure. Weak relief and shape of these inclusions betray the fluorspar. 60 ×

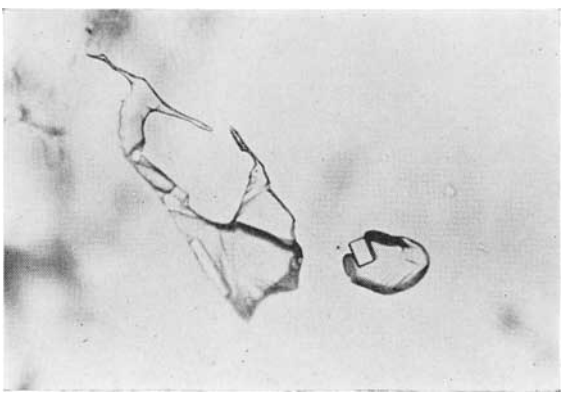

FIG. 4. Three-phase inclusions of this kind are very typical of hydrothermally formed fluorspar. The smaller inclusion embraces a well shaped halite crystal. 100 ×

more conclusive. They disclosed those hair-fine formations with two-phase fillings which are known as trichites and infallibly mark the *tourmaline* (Fig. 5). Further tests with the microscope, such as Becke's method in monochlornaphthalene in combination with the uniaxial conoscopical figure agreed with the internal picture of this specimen.

C 6 a yellowish brown, brilliant-cut gem which under the pocket lens displayed a very strong doubling of the pavilion facets. The suspicion of observing a *zircon* was substantiated by the absorption spectrum which was enhanced by a very strong absorption line at 6535Å.

C 7 seemed by all appearances to be a sapphire—either genuine or synthetic. It had the ordinary mixed cut and was of oval shape and of dark blue hue. It required not much playing under the microscope to discover growth striae which met at an angle of 60° (Fig. 6): keeping the gem in this position and rotating it under the microscope between crossed polars it remained isotropic, while the conoscopical figure was uniaxial. The dichroism was green-blue and deep blue. Although doubtlessly this gem was a *genuine sapphire*, a very strong and broad absorption band between 4500 and 4720Å delivered further proof of this result.

C 8 was an oval-cut faceted stone of a violetish red hue. It did not exhibit a very striking internal world except a few rutile needles running through the gem's body in three distinctly different directions thus designating it as a garnet of the pyrandine group. It could hardly be a pyrope because of its colour and also on account of the acicular rutiles. Absorption bands of moderate strength at 5050, 5370 and 5760Å indicating a medium content of iron and a R.I. of 1·765 identified this test stone as a *rhodolite garnet.*

C 9 a rectangular, step-cut specimen of pale yellow hue and completely devoid of any inclusions offered the greatest difficulty as far as rapid *and* reliable testing was concerned. Since the microscope failed in this case the spectroscope was taken recourse to and indeed it proved to be of decisive assistance in that it disclosed faint, narrow lines between 5700 and 5800Å which are known to be due to didymium. This observation indicated *apatite* and it was confirmed by the refractometer,

FIG. 5. Highly elucidating picture of the inner world of tourmaline consisting of hair-fine liquid channels (trichites) with two-phase fillings. 20 ×

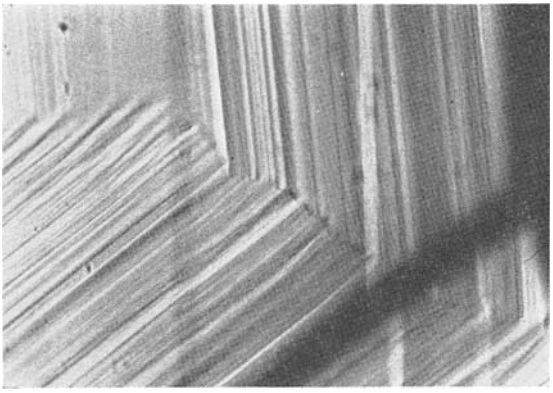

FIG. 6. The well-known zonal structure of genuine sapphire formed by growth layers meeting at angles of 120° and enhanced by unequal coloration. 10 ×

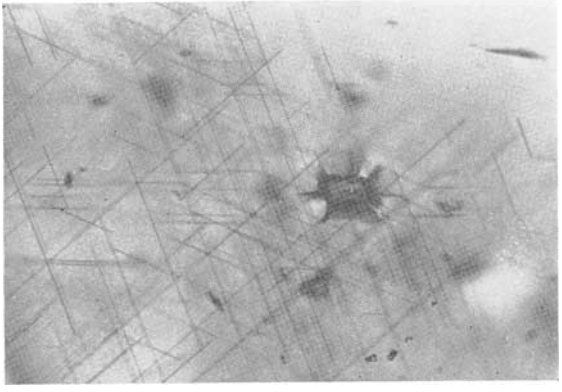

FIG. 7. Loosely woven silk of fine rutile needles aligning along the edges of the rhombododecahedron. The dark rounded grain in the foreground is a metamict zircon with stress halo. 30 ×

which gave readings at 1·640 and 1·644 yielding a birefringence of 0·004.

C10 offered no difficulties at all. It was a faceted, oval, dark red gem with a brownish tinge. Its internal paragenesis was exclusively qualified by that unique pattern of rutile needles running in three-dimensional directions and being so diagnostic for *almandine garnet* (Fig. 7). Further confirmation of this opinion was delivered by a score of heavy and broad bands in the green and the blue regions of the spectrum at 5760, 5270, 5050, 4760, 4620, 4380 and 4270Å—a characteristic spectrum of ferrous iron, which is one of the essential ingredients and the colouring agent of almandine garnet.

With the foregoing report I hope to have convinced the readers —especially beginners and "young" gemmologists—of the eminent importance of the microscope and the spectroscope and I trust to have fostered their confidence in the outstanding reliability of the microscopic and the spectroscopic methods. May these hints encourage students of gemmology to develop their own testing tactics and benefit from the above information by continual expansion and improvement of their personal experience, observations and efficiency.

DEFECTS IN THE COLOURED VARIETIES OF QUARTZ

By D. R. HUTTON, B.A., Ph.D., M.Sc.
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THE use of modern methods in gemmological research has revealed much information about gems, both natural and synthetic. Colouring mechanisms in particular have excited the interest of many workers.

Many of the colours of allochromatic gems are associated with defects or impurities which are paramagnetic, that is, they possess unpaired electrons or nucleons (neutrons and protons) which give the stone unique magnetic properties. The new research methods based on these properties therefore yield data which are valuable in explaining gem colours and interpreting changes.

Electron spin resonance (ESR) and nuclear magnetic resonance (NMR) spectroscopies are sophisticated ways of looking at the magnetic susceptibility of gemstones. ESR gives spectroscopy signals, usually in the microwave region of the spectrum, from unpaired electrons which can arise from defects and broken bonds or from transition metal ion impurities such as iron, chromium, vanadium and cobalt. The spectra allow positive identification of the impurity and its valence state, and give much information about the crystal site of the defect or impurity, for example the symmetry of the crystal field and the axes of any distortions.

NMR signals occur in the radiofrequency band and come from the nuclei of atoms in the gem which have unpaired neutrons and protons. The most mineralogically important of these are ^{1}H, ^{7}Li, ^{9}Be, ^{11}B, ^{23}Na, ^{27}Al, where the superscript gives the number of nucleons in the nucleus. The spectra allow determination of the coupling of the nucleus to the crystal field gradient (quadrupole coupling constant) and determinations of symmetry and directions of cation site distortions. A newer branch of spectroscopy, and indeed one of the most powerful tools yet used for the study of defects, is ENDOR, electron nuclear double resonance. This is a combination of ESR and NMR, and it allows accurate determination of the coupling between paramagnetic nuclei and electrons over large distances within the gem or mineral.

Defects are also studied with dielectric relaxation experiments. Here the experimenter relies on the fact that an aliovalent impurity (for example Al^{3+} replacing Si^{4+} in quartz) usually requires a

vacancy or interstitial ion (e.g. Na^+) to balance the charge in the crystal and these two defects together make up an electric dipole whose electric susceptibility can be studied by application of an alternating electric field. These defect pairs can also often be annealed or removed by heating, and the resulting thermoluminescence radiation, plotted intensity versus temperature, gives the "glow curve" of the mineral or gem.

Finally, the electron microscope deserves a mention for its valuable contributions to defect studies, revealing as it does details of twinning, dislocations, bubbles and inclusions. Of course all of these newer spectroscopies only complement more traditional methods of study such as optical, infra-red and ultra-violet spectroscopy, and the full picture of defects relies very much on evidence gathered by all techniques.

Quartz has received much attention recently, not only because it is a gem of some importance, but also because it is a material used commercially in many areas, from quartz crystal oscillators to oxide layers in FET transistors, where knowledge of its defects is important. Figure 1 illustrates the absorption spectra of some of the coloured varieties of quartz.

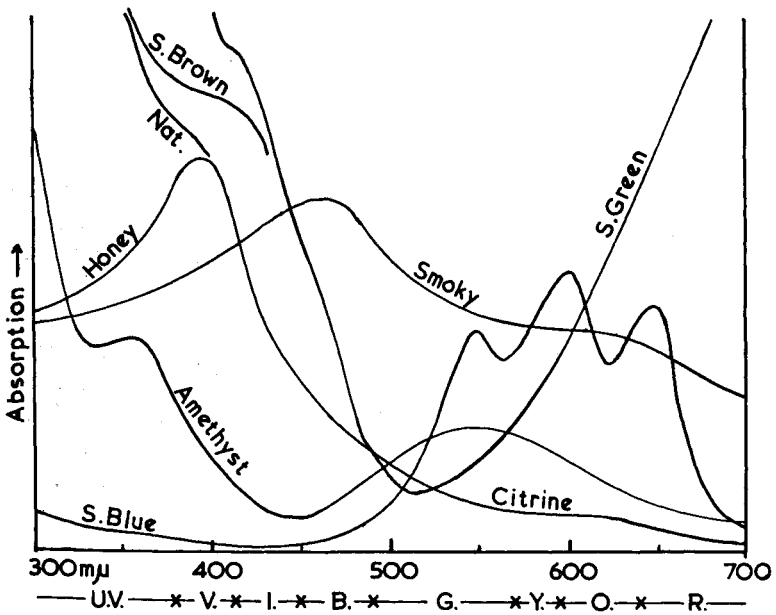

FIG. 1. Optical absorption spectra of some of the coloured varieties of quartz.

The colour of smoky quartz is due to broad absorption bands (Mitchell and Page 1965) in the visible spectrum centred at about 480 mμ and 620 mμ (6200Å). The ESR study by Griffiths, Owen and Ward (1954) resulted in O'Brien (1955) showing that the smoky colour is caused by the absence of an electron from an oxygen, which is next to a defect aluminium, substituted for silicon in the structure. Thus quartz which can be turned smoky on irradiation grows with Al^{3+} ions replacing Si^{4+} ions. To compensate the Al^{3+}, Na^{+} (or Li^{+}) sits near to it in one of the large channels parallel to the c axis. On irradiation an electron jumps from one of the neighbouring oxygens leaving a "hole" or effective positive charge behind. This leaves the defect site with four positive charges without the Na^{+} ion as charge compensator, so this ion diffuses away, trapping the electron as it moves to a stable mooring elsewhere in the crystal. Equation 1 summarizes these processes:—

Perfect Crystal	Crystal as grown		Colour defect
		irradiate	
$Si^{4+} \longrightarrow$	Al^{3+} +	Na^{+} $\rightleftharpoons$	$[Al^{3+} + h^{+}] + [Na^{+} + \bar{e}]$
	↑	↑ 300°C	↑
	substitutional	c axis channel	on oxygen

Figure 2a (after Taylor and Farnell 1962) shows a diagrammatic representation of the aluminium hole defect. The ESR studies show, from the crystal field effects and the magnetic coupling between the hole and the aluminium nucleus, that there are six possible positions for the holes, related in pairs to the three possible aluminium positions. Figure 2b illustrates these positions as seen looking down the c axis of the quartz structure. Taylor and Farnell show that the three pairs can be unequally populated by defects, but that the populations *within* the pairs are always equal unless an electric field is applied. His dielectric loss experiments demonstrate that the holes can jump backwards and forwards between the two oxygens neighbouring the aluminium, thus acting as electric dipoles.

FIG. 2. (After Taylor and Farnell)
(*a*) shows the missing electron or hole of the smoky quartz aluminium defect.
(*b*) shows the atoms of quartz as seen looking down the c axis.

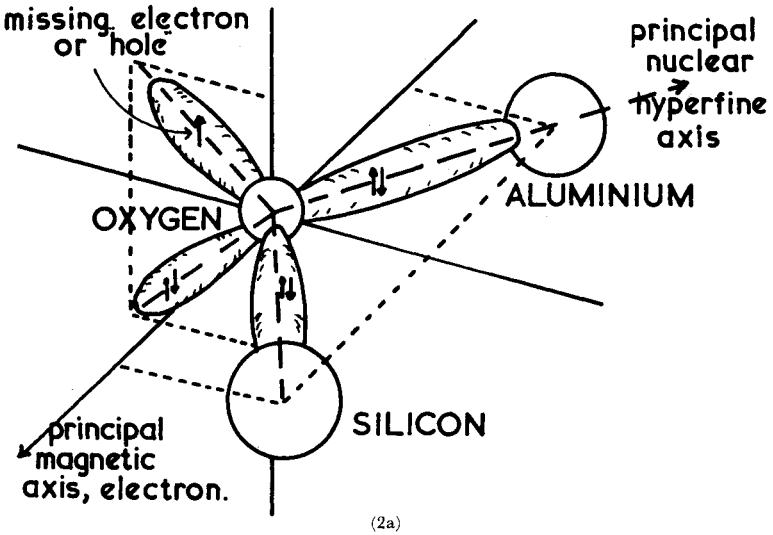
missing electron
or hole
principal
nuclear
hyperfine
axis
ALUMINIUM
OXYGEN
SILICON
principal
magnetic
axis, electron.

(2a)

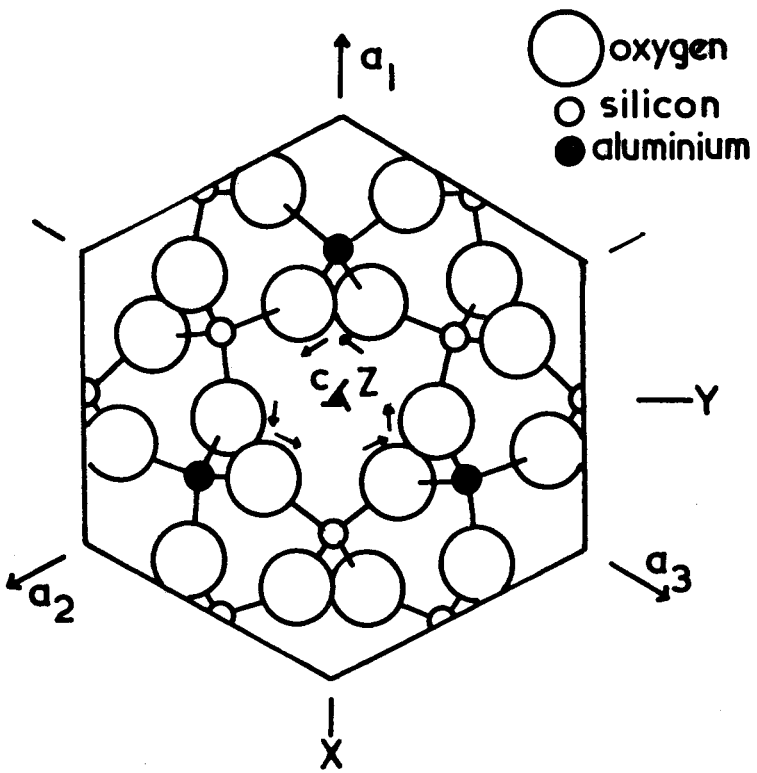
oxygen
silicon
aluminium
a1
a2
a3
c
Z
Y
X

(2b)

Now smoky quartz has been shown to exhibit anomalous pleochroism (Cohen 1956), and Tsinober *et al.* (1967) show that this is due to the unequal occupancy by Al of the three possible substitutional positions during growth of quartz on its rhombohedral planes. This is an interesting case of asymmetrization, the growth of colour-centre defects on a face of lower symmetry leading to a breakdown in the optical symmetry (here pleochroism in a trigonal crystal). If the crystal is heated to temperatures greater than 600°C the aluminium migrates to populate the three possible sites equally. Thus on cooling and reirradiation the ESR shows three equal pair populations and optically the crystals are now dichroic.

As Figure 2b shows, there are four oxygen atoms neighbouring each aluminium and researchers were puzzled as to why the hole came only from two of the oxygens. This problem was resolved by the x-ray results of Smith and Alexander (1963) who showed that two of the Si-O bonds are longer than the other two. Schnadt and Schneider (1970) were able to show, using ESR, that as smoky crystals were warmed up, some of the holes did indeed get excited enough to hop over to the other two oxygens, thus giving six more defect centres in the crystal. De Vos and Volger (1967, 1970) confirmed that holes hopping among equilibrium oxygen sites were the likely causes of smoky quartz's dielectric losses.

There have been many recent studies (e.g. McMorris 1971) to determine the detail of the bleaching of smoky quartz, since it is now realized that the accumulated radiation damage, revealed by the thermoluminescence glow curve produced by the recombination of the defects, can be used for accurate dating (Fleming 1974) of archaeological samples. Although much is now understood about smoky quartz, there is still a lot unknown, for example the detailed mechanism for the light absorption is still not understood; thus active research continues.

Violet amethyst-quartz exhibits many characteristic features (Frondel 1962) which must be explained by any theory of the defect structures. Some of these features are similar to those of smoky quartz; the colour is produced by irradiation, anneals by heating to about 300°C, and tends to be in bands parallel to external faces especially the r growth loci. Although the main absorption band is at 540 mμ, crystals often show anomalous pleochroism with trichroic colours blue, red and orange (Pancharatnam 1954).

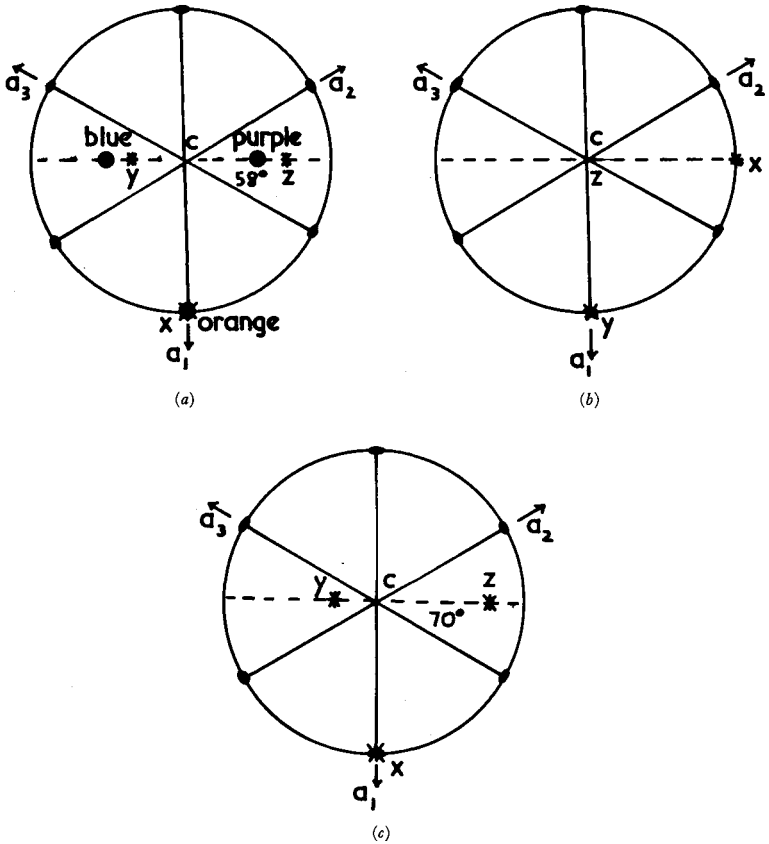

FIG. 3. Stereographic projections showing
(*a*) The distortion axes of the iron substitutional centres (S_1) and the pleochroic axes for amethyst.
(*b*) The distortion axes of the interstitial centres (I) in citrine and synthetic brown quartz.
(*c*) The distortion axes of the titanium lithium centres in rose quartz.

The ESR measurements of Hutton (1964) were the first to demonstrate that iron as Fe^{3+} substitutes into the silicon sites in amethyst with the directions of the distortion axes almost the same as the trichroic colour directions (Fig. 3a). Soon Barry, McNamara and Moore (1965) demonstrated that the unequal site occupation of the Fe^{3+}, produced at the time of growth, explained the observed biaxiality. They also detected alkali ions next to the Fe^{3+} ions by their nuclear magnetic interaction with the iron electrons. McLaren and Phakey (1966, 1968) using electron microscopy

showed that the brazil twin boundaries, very common in amethyst, would act as efficient traps for impurities migrating along the c axis channels. However, the Fe^{3+} defects detected so far could not alone cause the amethyst colour since heating, although it equalizes the distribution of centres and removes the biaxiality, does not remove the Fe^{3+} centres with the colour bleaching. Schlesinger and Cohen (1966) proposed many defects which incorporated electrons or holes but Chentsova *et al.* (1966) quickly pointed out that such defects were not detected by ESR and therefore were not present. Lehmann and Moore (1966) discovered two more Fe^{3+} centres in synthetic brown quartz, this time with distortion axes (Fig. 3b) which indicated both substitutional (S_2) and Interstitial (I) sites.

On the basis of optical spectra and the temperature variation of ESR spectra Lehmann (1967) then proposed for amethyst that, on irradiation, an electron is removed from some of the S_1 centres converting them to Fe^{4+} and transferred to some of the interstitial iron ions converting them to Fe^{2+}. At the same time ferric-hydrogen S_2 centres are produced. Equation 2 summarizes the proposed processes occurring at irradiation and bleaching.

$$\begin{array}{rl} x\,Fe^{3+}(S_1) \longrightarrow x\,Fe^{4+}(S) + x\bar{e} & \text{(oxidation)} \\ x\bar{e} + x\,Fe^{3+}(I_4) \longrightarrow x\,Fe^{2+}(I_6) & \text{(reduction)} \\ y\,Fe^{3+}(S_1) \longrightarrow y\,Fe^{3+}(S_2) & \end{array}$$

$$(x+y)\,Fe^{3+}(S_1) + x\,Fe^{3+}(I_4) \underset{\text{heat}}{\overset{\text{irradn}}{\rightleftharpoons}} x\,Fe^{4+}(S) + x\,Fe^{2+}(I_6) + y\,Fe^{3+}(S_2)$$

The I_4 and I_6 positions are 4 and 6-fold co-ordinated interstitial positions down the c axis channels. Vereshchak *et al.* (1973) think they have detected Fe^{2+} in low symmetry sites in quartz using Mössbauer spectroscopy but their results are not unambiguous. Unfortunately, both Fe^{2+} and Fe^{4+} ions are difficult to detect with conventional ESR techniques but modern developments involving the use of thermal detection of the spectra, and acoustic paramagnetic resonance (APR) which involves detecting the ions by their

effect on vibrational waves propagating in the crystal, offer some hope. However, what is already known about the basis for amethyst coloration has allowed some deductions to be made about the geological conditions for growth, and Dennen and Pucket (1972) have shown that careful, future study of amethysts may give us a useful geothermometer.

Many amethysts when heated to 500°C become citrine-coloured and the colour of "iron" citrines has been shown by the ESR and optical studies of Samoilovich *et al.* (1969a) and Lehmann (1971) to be due to interstitial Fe^{3+} and heterogeneous inclusions of Fe_2O_3. Both of these authors also discuss the rarer radiation "honey" citrine and show that the colour of this variety is due to the presence of aluminium together with a high concentration of hydrogen and lithium. Irradiation then produces hole centres which are similar to those of smoky quartz except that the charge compensators do not diffuse away on irradiation.

X-ray produced, hydrogen and lithium compensated centres have also been detected by ESR in rose-quartz by Wright *et al.* (1963) and Rinneberg and Weil (1972) where the paramagnetic impurity is titanium and not manganese as had long been supposed. Ti^{4+} and Al^{3+} grow into the crystal together with H and Li atoms in the interstititial channels. On irradiation, electrons released from the aluminium centres are trapped by the Ti^{4+} converting them to Ti^{3+}; these in turn attract hydrogen or lithium ions as charge compensators.

$$Ti^{4+} + \bar{e} + Li^{+} \underset{\text{uv, heat}}{\overset{\text{irradn}}{\rightleftharpoons}} [Ti^{3+}, Li^{+}]$$

Figure 3c shows the axis directions for the lithium defect centres. However, these defect centres do not directly cause the optical absorption at 496 mμ which gives the crystals their rose colour, since the defects can be removed by exposure to UV or heating without affecting the colour. The colour-causing defect is probably more complex, perhaps in aluminium and titanium occurring as nearest neighbours in the lattice.

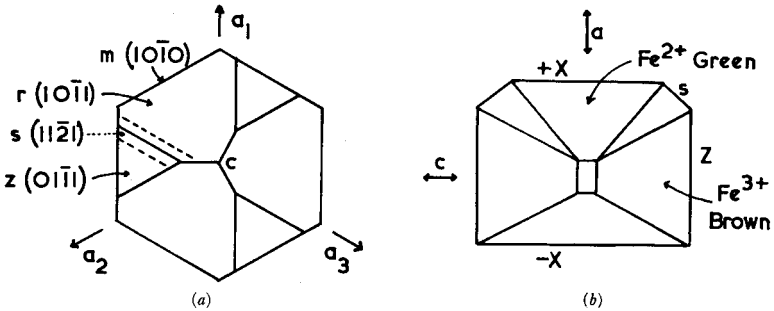

FIG. 4. (*a*) The growth faces of natural quartz crystals.

(*b*) Growth faces and areas of synthetic crystals grown from a seed long along the Y direction, (perpendicular to the page).

Many coloured varieties of quartz have now been synthesized, in both Russia and the U.S.A. (Sawyer 1967), and many studies have been carried out to determine the cause of the colours and the nature of the defects. Lehmann (1969) has shown that synthetic yellow quartz is caused by cobalt Co^{3+} trapped in interstitial six co-ordinated (I_6) positions. Heating such crystals to 500°C changes the crystals to blue and causes a reduction of the cobalt ions to Co^{2+} and their migration to four co-ordinated (I_4) positions.

Growth of crystals from solutions which are rich in iron and alkalies produces colours which depend on the direction of crystal growth and subsequent treatment. Growth perpendicular to X (see figure 4b), perpendicular to Z, and on r (followed by irradiation) produces crystals coloured green, brown and violet respectively. Samoilovich *et al.* (1969b) show that green quartz can be produced by heating brown and deduce that brown, green (and blue) are all due to colloidally dispersed silicates of iron (and cobalt). However, Lehmann (1971) shows that brown quartz is caused by Fe^{3+} in I_4 positions, and green by Fe^{2+} in I_6 positions. It seems likely therefore that "greened" amethyst from Montesuma, Brazil, has had reduction from Fe^{3+} to Fe^{2+} without citrine precipitation.

This article has attempted to survey some of the more recent research on the coloured varieties of crystalline quartz which are already, or are likely to be in the future, of importance to gemmology. The main results are summarized in the concluding Table 1.

TABLE 1

THE COLOURED VARIETIES OF QUARTZ

COLOUR	VARIETY	FORMATION	CAUSE OF COLOUR
Violet	Amethyst	Fe^{3+}, Na^{+}, irradiation	$Fe^{4+}(S)$, $Fe^{2+}(I_6)$
	Synthetic	Growth on r + irradn	$Fe^{4+}(S)$, $Fe^{2+}(I_6)$
Brown/black	Smoky	Al^{3+}, Na^{+}, irradiation	$Al^{3+} + h^{+} (O^{-})$
	Synthetic	Growth with Ge + irradn	Germanium colour-centres
Pink	Rose	Ti rich pegmatites	Titanium colour-centres
Yellow	"Iron" citrine	Heat amethyst to 500°C	$Fe^{3+}(I)$, Fe_2O_3 precipitates Finely dispersed iron silicates
	"Radn" honey	Al^{3+}, hydrogen, irradn	Al — H hole centres
	Synthetic	Growth from cobalt solutions	Co^{3+} (I_6)
Blue	Natural	Ti rich granites	Rutile needle scattering
	Synthetic	Reduction of synthetic yellow by heating	$Co^{2+}(I_4)$, finely dispersed cobalt silicates
Brown	Synthetic	Growth perpendicular to Z	$Fe^{3+}(I_4)$, $Fe^{2+}(I_6)$, finely dispersed iron silicates
Green	Synthetic	Growth perpendicular to X From brown by heating	$Fe^{2+}(I_6)$ Finely dispersed iron silicates
	"Greened" nat.	Reduction of amethyst by heat	$Fe^{2+}(I_6)$
White	Milky	Heat citrine to high temps.	Aggregated inclusions and bubbles in twin boundaries

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NOTES FROM THE LABORATORY

By ALEC E. FARN, F.G.A.

SOME items mentioned are chosen for their gemmological interest somewhat divorced from the commercial side of the laboratory's normal routine work. We do, of course, see marvellous pieces of jewellery, fine pearl necklaces, brooches and rings, superb rubies, large alexandrites, jadeites, nephrites, black opals, demantoids in dozens, the usual run of the mill stuff.

Occasionally we are lifted out of this channel to the higher echelons of gemmology. Beauty, rarity and durability are the three requisites of a gemstone in the commercial world. However, gemmologically a stone can be ugly and unusual, it can be a member of a large family, tourmaline, spinel, garnet or zircon, and providing it has an unusual colour or something different in its makeup it becomes a rarity and desirable to the few connoisseurs who appreciate with knowledge. The other day a parcel of gemstones sent in for testing (the packet incidentally marked "tourmalines") contained everything but a tourmaline—which whets ones appetite for an earthy rarity. One of the stones (about 5 ct in weight) was a very anaemic pale pink transparent stone, which by appearance could be a tourmaline or a spinel—that kind of colour. The routine testing was carried out but my colleague Alan Clewlow, B.Sc., who found it to have a R.I. of 1·730 and a S.G. of 3·70, this latter figure agreed later on by B. W. Anderson. The stone fluoresced a decided pink fluorescence between crossed filters and had a fine thin distinct line in the blue end of the spectrum at 4320Å. This was puzzling, since it seemed like a high reading for spinel or a low reading for garnet: both are singly refracting, but spinel of the two much more likely to have a chromium content. We sent the stone by post to B. W. Anderson for his expertise, who returned it stating it to be a garnet of the pyrope (chromium)-spessartite range, the 4320Å line being the first of the strong absorption bands of spessartite (manganese). He also sent me a typical Anderson graph (Fig. 1) plotting the R.I.s and S.G.s—R.I.s from 1·71 to 1·81 and S.G.s from 3·58—4·22. A line drawn commencing at a theoretically pure pyrope to spessartite reading cut cleanly through our garnet at 1·730 R.I. and 3·70 S.G., which illustrated graphically the variations caused to characteristics of garnet readings

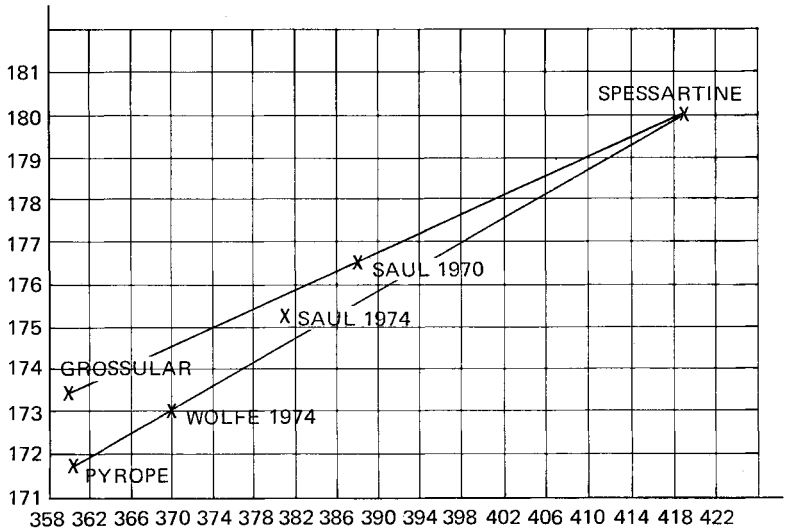

Fig. 1.

due to isomorphous replacement (one might almost say integration). On the same graph was plotted a colour-change garnet written up in *Gems & Gemology*, Vol. XIII, No. 6, pp. 174-177.

Another item of interest was a gift to me by my friend Richard Digby, a well known connoisseur and dealer in intaglios, cameos, etc. of early periods. This stone was to all intents black to look at but by transmitted light a dark green. Sombre and unusual colours intrigue me. This I thought looked like a Ceylon metamict zircon. The spectrum not only confirmed it—it was so tremendously powerful it looked like some permanent grooves cut into the prisms of the spectroscope. I took its refractive index (singly refractive) at 1·782—very, very low for such a sharp spectrum. Alan Clewlow did a density and arrived at a figure of 3·922. Once again it seemed logical to show such a stone to B. W. Anderson, since he is our major expert on spectroscopy and his first good absorption spectrum of zircon was one such zircon which they (B. W. Anderson and C. J. Payne) thought to be typical for zircon!

Needless to say B. W. Anderson enjoyed this stone and commented that the spectrum "was that of one of the very scarce low metamict zircons, which has by some means been heated naturally late in its geological career giving a final shake out to the zircon

broken-down lattice and building up crystallites of ZrO_2 (probably cubic) in an amorphous silica setting". Thus our second stone proved to be a rare metamict zircon from Ceylon with a R.I. of 1·782 and a S.G. of 3·922 and what I like to term a superabundant spectrum.

The third stone of note was already known to be an ekanite by its owner, who was persuaded to have it tested so that its characteristics could be recorded. This test was carried out by B. W. Anderson at the laboratory during my absence on holiday. Most interesting things have happened at the laboratory usually when I am away on holiday or sick. There seems to be a moral here somewhere for me to have more holidays.

The ekanite was (with all due respect) quite ugly, very large (43·84 ct) and blackish in colour. The specific gravity was found to be 3·288 and refractive index was 1·595; the absorption spectrum showed two lines at 6300Å and 6580Å in the orange/red sector of the spectrum. The inclusions were oriented and the stone was found to be strongly radioactive by producing a strong self-portrait on a sensitive photographic film.

It is strange how things seem to run at times—by coincidence, I noted in *Technica*, the Belgian Jewellers' Journal, that Hubert Mornard, their laboratory director and vice-president of the Belgian Gemmological Society, had written an article. He describes two brown stones, said to be uranites by their owner, and a series of tests, including long-wave and short-wave U.V. fluorescence tests, density and R.I., plus heating a fragment and crushing a portion to observe its structure. After contact with a photographic paper for 72 hours one stone showed a sharp line and the other an auto-radiograph of its outline. Final conclusion was *metamict zircon.*

GEM SPODUMENE AND ACHROITE TOURMALINE FROM AFGHANISTAN

By PETE J. DUNN, M.A., F.G.A.

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INTRODUCTION

Beautiful crystals of gem quality spodumene and tourmaline have recently been discovered in pegmatites in Afghanistan. The locality is in a mountain range in Nuristan province, and the closest city is Chigha Sarai, which is north-east of Jalalabad. The spodumene deposit has been worked since late 1970 and spodumene is presently being recovered. It is associated with tourmaline, mica and quartz. The tourmaline described here is from another pegmatite in the same mountain range.

It should be noted that due to local dialects and language differences in this part of Afghanistan the spellings of the place names may vary somewhat. Since the locality is close to the Pakistan border, some of the gems may enter the market through that country.

SPODUMENE

The gem crystals are free of matrix, although one crystal has an attached remnant of watermelon tourmaline. The majority of crystals are stout, prismatic, elongated parallel to the *c*-axis, and vary in length from 5 to 42 cm. The majority of the crystals are twinned on $\{100\}$. One particularly stout crystal was examined which measured $7 \times 12 \times 14$ cm on the *a*, *b* and *c*-axes respectively. Dominant forms are the front pinacoid *a* $\{100\}$, the side pinacoid *b* $\{010\}$, prisms *m* $\{110\}$ and *f* $\{011\}$, and fourth order prisms. These forms are shown in Figure 1, which is a drawing of a typical crystal. The forms are easily discerned by their different surficial characters. The *a* pinacoid is deeply striated parallel to the *c*-axis, and the *b* pinacoid is dull. The prism *f* is quite bright and covered with acute hillocks with their apices pointing to the termination of the crystal. In general, the etching has enhanced the beauty of the crystals. Equal development of *a* and *b* pinacoids results in crystals of square cross-section ideally suited to the cutting of large stones.

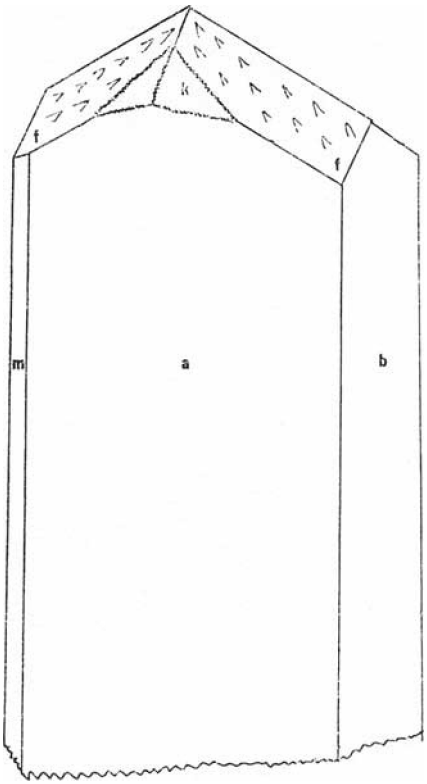

Figure 1. Spodumene from Afghanistan

The gem potential of this material is excellent. The spodumene is found in three distinct hues—yellow, pale violet and violet-blue. The yellow crystals are a deep greenish yellow at the base and lighten at the termination to a very pleasing yellow. One yellow crystal 3 × 4 × 17 cm in length is terminated by a 2 cm zone of light yellow. The yellow spodumene exhibits weak trichroism, which is not noticeable upon casual observation. The pale violet crystals are too lightly coloured to produce significant gems. The violet-blue crystals are violet at the base and change toward the termination to pleasing blue and green hues. The strongly pleochroic violet-blue spodumene, when observed in non-polarized

daylight, has the following colours: for light passing parallel to the *a*-axis, light green; for light passing parallel to the *b*-axis, light blue; and for light passing almost parallel to the *c*-axis, deep blue-violet. The above observations were made on a $4 \times 4 \times 8$ cm crystal so the colours will appear somewhat lighter in cut gems of moderate size. Gems cut with the table normal to the *c*-axis will be of a fine and unusual blue-violet colour, and gems cut with the table normal to the *b*-axis should have a beautiful light blue colour.

TABLE ONE

OPTICAL DATA FOR SPODUMENE FROM AFGHANISTAN

$$\alpha = 1{\cdot}660\ (\pm 0{\cdot}002)$$
$$\beta = 1{\cdot}662\ (\pm 0{\cdot}002)$$
$$\gamma = 1{\cdot}676\ (\pm 0{\cdot}002)$$
$$Z \wedge c = 27^\circ$$
Optic sign (+)

	yellow spodumene	violet-blue spodumene	pale violet spodumene
X	light greenish yellow	deep violet	medium violet
Y	light greenish yellow	light violet	very light violet
Z	colourless	light green	light green

Refractive indices and optical data are summarized in Table 1. There was no measurable difference in the refractive indices for different coloured crystals. No diagnostic absorption spectra were observed. The specific gravity is 3·19. Refractive index determinations were made with chips on the spindle stage of a petrographic microscope, in sodium light.

The spodumene is luminescent in ultraviolet and x-radiation. Under short-wave ultraviolet the yellow spodumene fluoresces a very weak orange. Under long wave ultraviolet the violet-blue and light violet crystals fluoresce a weak violetish pink and the yellow spodumene fluoresces a strong pinkish orange. The yellow spodumene does not phosphoresce; the violet-blue crystals phosphoresce weakly after two hours exposure to long wave ultraviolet. Copper and molybdenum x-radiation cause both the yellow and

violet-blue and light violet spodumene to fluoresce a vivid orange. None of the spodumene is transparent to x-rays. After x-radiation, the yellow spodumene phosphoresces a weak orange and the violet-blue and light violet crystals a strong orange. In both cases the phosphorescence is quite persistent, being visible 10 minutes after a 10-second exposure.

Inclusions

Hollow tubes and clusters of bubbles, so characteristic of spodumene, are found in the Afghanistan material, but clear sections with a minimum of such inclusions are available and large stones could be cut from this material. Also present as inclusions are minute, prismatic, colourless unidentified crystals, in clusters and as single crystals, usually oriented parallel to the *a*-axis of the host. The detailed study of these inclusions must await the procurement of smaller pieces suitable for cutting and preparing for x-ray diffraction and microprobe examination. The 16 crystals examined in this study are much too beautiful to be cut and will be preserved as display specimens.

Tourmaline

The tourmaline occurs in a wide range of colours and hues. Especially noteworthy are the colourless crystals, perfect achroites. The crystals are prismatic and have typical tourmaline morphology. Twelve crystals were examined with lengths varying from 3 to 7 cm. The finest crystals are weakly coloured in pastel hues of pink and green. Some crystals with a light pink or green base have colourless terminations and the finest of these has a $3\frac{1}{2} \times 1$ cm termination that is completely colourless and flawless. The colour-zoning is perpendicular to the length of the crystals. In four of the nine crystals examined the zoning is strong: in the remaining crystals it is gradual and almost imperceptible.

Refractive indices of twelve cut stones were determined on the dialdex refractometer in sodium light. Some are deeply coloured and some quite pale, of a variety of hues of pink and green. The indices varied from $\varepsilon = 1{\cdot}617$ and $\omega = 1{\cdot}635$ to $\varepsilon = 1{\cdot}621$ and $\omega = 1{\cdot}639$, and there was no observed correlation between colour and refractive index. The birefringence in all stones was 0·018. The refractive indices of the achroite are $\varepsilon = 1{\cdot}615$ and $\omega = 1{\cdot}633$ ($\pm 0{\cdot}003$), measured with the dialdex refractometer on a flat prism

face of an uncut crystal. The specific gravity of the cut stones varies from 3·03 to 3·07. The specific gravity of the achroite is 3·02.

The pastel and colourless tourmaline was irradiated with long and short wave ultraviolet radiation, and copper and molybdenum x-radiation, with some interesting results. Although they do not fluoresce in long wave ultraviolet, they respond to short wave. The achroite fluoresces a bright and vivid violet, while crystals of pastel shades of pink and green fluoresce a weaker violet corresponding to the intensity of the colour-zoning. Crystals with sharp colour-zoning do not fluoresce as strongly as those with almost imperceptible colour-zoning. None of the 12 cut stones fluoresced. There was no perceptible phosphorescence observed in any of the tourmalines. No tourmaline from this deposit fluoresced in copper or molybdenum x-radiation. All of the pastel crystals were transparent to x-rays. The only notable inclusions in the Afghanistan tourmaline are small crystals of randomly oriented lepidolite.

The author is indebted to Dr George Switzer and Mr John S. White, Jr, for critical readings and valuable suggestions for improvements in the text.

AN IRRADIATED QUARTZ

By ROBERT WEBSTER, F.G.A.

ARISING from an advertisement in the *Watchmaker, Jeweller and Silversmith*, the Gemmological Association approached the advertisers, Toktraders International, Tokyo, Japan, who kindly forwarded two specimens of their wares for our examination. One of these was a colourless round brilliant-cut stone weighing 9·95 carats, and the other a dark brown trap-cut (emerald-cut) stone weighing 10·11 carats. The first of these seemed to be untreated rock crystal, probably sent for comparison, while the other was presumably coloured by irradiation.

The covering letter from Toktraders International was not too informative and simply said—"Radiated smoky topaz was made through radiation processed rock crystals, with ray of 4-5 mg. Rock crystals are very common stuff as you observe". This wording calls for some comment, the first being that "smoky topaz" should read "smoky quartz". This is not an unusual error but is one that should be avoided in trading. The second part "ray of 4-5 mg" is less easily explainable, for mg is the symbol for milligram and the connexion with irradiation is not at all clear.

The usual units of radioactivity are the *Röntgen* (r), or more commonly the *Curie* (Ci). Experts whom the writer consulted could only suggest that the reference may be a misprint for *milliröntgen* (mr) or *millicurie* (mCi). However, it must be remembered that the *curie* was originally defined as the quantity in radioactive equilibrium with one gram of radium, but is now extended to cover all radioactive isotopes by the definition "that quantity of radioactive isotope which decays at the rate of $3{\cdot}7 \times 10^{10}$ disintegrations per second"(1).

In view of this uncertainty the Gemmological Association again wrote to Toktraders International for clarification of the entries in their first letter. Their reply stated that it should be *megacycles*. This makes the situation even more confusing, for 4-5 (say 4·5) megacycles (more properly Mc/s) is in the high frequency (HF) range of radio waves and works out at a wavelength of approximately 66 metres! The only conclusions one can draw from these replies is that there had been a clerical error in translating

scientific data; or it is the policy of the Company not to disclose the actual method of irradiation. If the latter is the answer, then why do they not say "by a secret process", as is the normal procedure in such cases?

This then leads to the question—What *is* the type of radiation being used to colour these stones? It has been mooted that the *gamma* radiation from the isotope Cobalt 60 is used. The use of *gamma* radiation has recently been investigated in the coloration of such species as quartz, beryl and topaz[2].

Examination of the treated stone showed the refractive indices to be those of quartz, that is 1·544-1·553 with the usual double refraction of 0·009, and the density was found to be normal for quartz. The dichroism was comparable to natural quartz of similar colour, although the effect may be very slightly more distinct in the radiated quartz. No convincing absorption spectrum was observed using a hand spectroscope, nor was there any colour-banding seen by lens or microscope examination, which is an effect often seen in brown quartz. That there was no residual radioactivity was proved by placing the stone on a piece of bare photographic film (double coated x-ray film), with a slice of a rolled pebble of Burma zircon as control, and leaving the stones in position for one week. On developing the film there was no darkening of the film where the irradiated quartz had rested, whereas the zircon had produced a pronounced blackening of the film which clearly outlined the shape of the zircon slice.

The colour of the irradiated stone cannot be said to be attractive and the cutting seems not to be up to professional standards. These criticisms may be to some extent harsh and it may be that more attractive brown colours, such as golden-browns, can be produced; nor is it known what price is to be charged for these stones coloured by irradiation. Brown quartz is not a rare commodity and the commercial viability seems doubtful, unless, as mentioned before, something like a good attractive brown colour can be produced.

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WHERE IS THE DIVIDING LINE BETWEEN EMERALD AND GREEN BERYL?

By IAN C. C. CAMBELL, F.G.A.

THIS is a modification of a paper presented to a meeting of the Gemmological Association of Rhodesia in 1971 by the author.

Much interest has been aroused by the question "Where is the dividing line between true emerald and green beryl?".

It is of particular importance in a country where it is illegal to deal with emerald in the rough without a licence—such as in Rhodesia.

Some authorities say that the trace of chrome as the colouring element in emerald should be evident in the absorption spectrum; others maintain that the inclusions in emerald are so different from those in ordinary green beryl that this is diagnostic; while others yet again suggest that colour and colour alone should dictate what the stone should be classified as.

The problem of correctly designating emeralds arises when consideration is given to a variety of beryl (alias "pale green emerald") from the Filabusi area of Rhodesia. Some of the mines which have produced such stones are: Mustard claims, Pepper claims, Rhodesian Gem claims, Sydkom claims (the Sydkom mine itself basically yields scheelite), and other unknown lesser origins.

The claims just mentioned yield comparatively little and some have, for that matter, closed down. Nevertheless the stones are in existence.

Pale stones of ambiguous colour have also been seen from the Chikwanda claims near Bikita, but these are still very different from the Filabusi stones. The stones from the Mustard claims appear to have a more overall bluish-green appearance and, strictly speaking, are therefore not being considered quite as ambiguous in terms of the colour of ordinary green beryl. However, a closer look later on in this article at those stones may be of advantage.

Gemmologist A. M. Taylor, in his report on synthetic vanadium emerald (J. Gemm., 1967, 10, 7, 211-217) touched on the problem of where the dividing line should be between emerald and green beryl. He states that vanadium or chromium is able independently to produce the coveted emerald-green hue in beryl. In a number of analysed emeralds it has also been evident that vanadium

was present (together with chrome) in sufficient quantity to affect the overall colour in a pleasing manner in that the green was enhanced in some stones. It seems, says Taylor, that we can blame the ostentatious nature of the chromium absorption spectrum for chromium's mysterious rival, vanadium, being ignored for so long. Taylor's definition of emerald is simply that "emerald is a bright green variety of beryl"—no matter what the cause of the colour is—as long as it is the acceptable (?) hue of green. (The question mark in brackets is mine).

As is known, the mineral which has an adverse effect on the colour of emeralds, and indeed is responsible for the damping or complete obliteration of all fluorescence which is useful in testing, is iron. It is also this iron content that is, to a lesser or greater degree, responsible for the poor colour of the emerald in many cases and thus the ambiguity of colour in the comparatively poorer grades.

Chemical and spectrographic analyses of emeralds from two different sources in the Filabusi area (and I refer to the chrome and iron content only) are as follows:

	MUSTARD CLAIMS	PEPPER CLAIMS	
Fe	0·1%	0·1%	Symposium: Pegmatites in Southern Rhod. 1962.
Cr	0·2%	0·1%	

In addition to the above, Mr I. H. Green, of the Geological Survey Department, Salisbury, has done a spectrographic analysis of emeralds from the Mustard Claims (15th November, 1967)—seven specimens were analysed (which I had access to) and I list here only the relevant details (i.e. obviously only part of the analysis):

Chrome content: 3 contained 0·2%, 1 contained 0·25%, 2 contained 0·3%, 1 contained ~ 1%.

Iron content: All ~ 1·0%.

Vanadium: Only 1 contained a trace. < 0·02%.

Nickel content: All contained < 0·02%.

Although spectrographic results are, it is understood, not precisely accurate in the higher concentrations, the results are adequate and reasonably suitable for comparative purposes. With the exception of one specimen (Cr: 0·3%, Fe: ~ 1·0%, Ni: < 0·02%) which was obviously a more grass-green and deep hue of colour, the other stones appeared to be an overall fairly uniform bluish-green—there were in fact differences, but not perceptible enough to

arrive at a useful conclusion. The exception mentioned above contained the highest chrome content, but so did another one which was a more bluish-green in colour (and the analysis was the same as the exception referred to above). This exception, although not fluorescing in the conventional dull red manner, did however show a greyish hue under the Chelsea filter. The balance under the filter merely showed up as yellowish green which was only slightly variable from one stone to another. In addition to this there was no evidence of absorption lines under the Rayner prism spectroscope that indicated a chrome content, although chrome was in fact present as the analysis showed.

The analytical figures are, to a limited extent, given here in relation to the Mustard stones, because they serve as a point of interest when comparing the colour of stones from the same source. This also applies to other "ambiguous" stones from sources in the Filabusi area where, from the same claim, similar variations in colour exist (optical and physical properties, as well as the inclusions, being the same).

The inclusions seen in the pale Filabusi stones are characteristic of the species and different from those seen in ordinary green beryl from other sources in this country and outside our borders. Such stones have also come from the Mustard claims and have been generally classified as "gem beryl" because of their "ambiguous" colour. In many cases the colour can be compared to the paler Colombian stones. Some, of course, do not compare at all.

An analysis is all very well, but one obviously cannot analyse, by destruction, a faceted stone of an ambiguous green colour in order to find traces of chrome, if indeed the stone is to be designated as emerald on chrome content alone. One of these so-called "ambiguous" stones was cut by someone who genuinely thought that it was ordinary green beryl. When it was examined one could see why—particularly when one is familiar with the fine green colour of the well known stones from the Belingwe area and in particular Sandawana. The stone in question could pass as ordinary beryl on sight, yet it could also be technically designated an emerald though be it a very poor one.

The details of the above mentioned faceted stone are as follows:—

Conventional emerald-cut of weight 1·735 metric carats; S.G. 2·73; R.I. 1·575—1·580 (D.R. 0·005). No fluorescence evident under

the Chelsea filter. Absorption spectrum—no indication of chrome content, but a barely perceptible line in the blue (iron). Inclusions are different to those in normal green beryl. What appear to be relatively wide, pale whitish bands at right angles to the C axis are in effect reflections of light from spikey type inclusions concentrated in zones, which in themselves are part of fine tubes and spikey inclusions orientated parallel to the length of the crystal. This may sound contradictory, but it is emphasized that the inclusions are more concentrated laterally in adjacent positions in the same plane, thus giving the appearance that the "bands" themselves are actually at right angles to the C axis as stated. This type of inclusion, with the exception of the above mentioned "band-like" concentrations, has been seen by the writer in numerous emeralds from the Filabusi area, but generally in a much less concentrated form.

Obviously a more detailed study should be made, in the context of this subject, of stones from known sources in the Filabusi area, as well as elsewhere. It is noted that a good authoritative text appears in the published results of a symposium held on "Pegmatites in Southern Rhodesia", arranged by the Southern Rhodesia Section of the Institution of Mining and Metallurgy, held at the University in Salisbury in 1962. The relative chapter (pages 35-39 inclusive) deals with—and in addition to chrysoberyl—emeralds from the Novello mine near Fort Victoria, from the Mustard claims and Pepper claims at Filabusi, the Chikwanda claims at Bikita, and others. That written contribution, by H. J. Martin, is the only detailed study that the writer has seen on emeralds from sources in Rhodesia other than Sandawana origin and is a most welcome and useful text of recorded information. (In that text, reference is made to emeralds from these sources which do however fluoresce—but I am referring to those that do not and are furthermore classified as ambiguous due to their colour—or lack of it).

This article is merely to bring to notice a problem that technically exists (particularly in Rhodesia)—that of being unwittingly legally at fault for dealing with uncut emeralds while genuinely thinking that the stones are ordinary beryl.

Mr Taylor *does* have a valid point when he advocates that the name "emerald" should apply to a "bright green variety of beryl". Furthermore, the trade obviously abides by this opinion and virtually frowns on emeralds of an ambiguous nature in respect of colour.

Gemmological Abstracts

ANDERSON (B. W.). *Short cuts to certainty.* Z. Dt. Gemmol. Ges., 1974, 23, 2, 83-88.

The author writes about his work at the Gem Testing Laboratory and elaborates on some ways to shorten and verify gem identifications, using immersion technique, absorption bands and observing fluorescence and phosphorescence.

E.S.

BALL (R. A.): MALIN (A. S.). *Iridescence in marine shells.* Australian Gemmologist, 1974, 12, 1, 14-15. 6 illus.

A short article on the examination of sea shells by electron microscopy. The structure of the shells was shown to consist of platelets in parallel arrangement whose regularity and thickness (0·2μm to 0·6μm) control the iridescence of the shell.

R.W.

BANK (H.). *Niedriglichtbrechende braune Turmaline mit hoher Doppelbrechung aus Ostafrika.* (Brown tourmalines with low R.I. and high double refraction from East Africa). Z. Dt. Gemmol. Ges., 1974, 23, 2, 93-94.

Brown tourmalines were examined and were found to have relatively low R.I. (1·617-1·641) and relatively high double refraction (0·023, 0·024, 0·025). X-ray examination pointed to dravite.

E.S.

BANK (H.). *Rote Turmaline mit hoher Licht-und Doppelbrechung aus Kenya.* (Red tourmalines with high R.I. and double refraction from Kenya). Z. Dt. Gemmol. Ges., 1974, 23, 2, 89-92.

Red tourmalines from the Narok district in Kenya were examined with high R.I. (1·630-1·659) and high double refraction (0·029, 0·032).

E.S.

BROUGHTON (P. L.). *Precious topaz deposits of the Llano Uplift area, central Texas.* Rocks & Minerals, 1973, 48, 147-156.

Colourless and blue topaz crystals occur in pegmatites in the

vicinity of Mason, Mason County, Texas. Detailed information is given on collecting sites.

R.S.M.

BUCKLEY (B. W.). *Maine tourmaline strike.* Rocks & Minerals, 1973, 48, 308-310, 3 figs.

Gem quality red and green tourmaline crystals occur in pegmatites on Plumbago Mountain, Newry, Maine. A new discovery is reported.

R.S.M.

CASSEDANNE (J. P.) and (J. O.). *Les agates du Morro do Cristal.* (The agates of Morro do Cristal). Bulletin de l'Association Française de Gemmologie, 1974, 36, 9-12.

Morro do Cristal is situated north of Porto Alegre, capital of the state of Rio Grande do Sul. Agates are found on the surface, the rock of the area being a basalt. They are sparsely scattered and are in general of an ovoid form or sometimes spherical. Quartz boules are found in association with the agate, and a fair quality amethyst is found in the neighbourhood.

M.O'D.

CASSEDANNE (J. P.) and (J. O.). *La pegmatite de Baixio (Brésil).* (The pegmatite of Baixio (Brazil)). Bulletin de l'Association Française de Gemmologie, 1974, 39, 4-6.

The area is situated 75 km east of Governador Valadares in the north-east part of the state of Minas Gerais. The pegmatite is more than 200 metres long and runs in a generally north-south direction. In depth it appears not to exceed 10 metres. It is surrounded by decomposed mica schists running locally east-west. Although the general grain size is medium, there are larger decomposed feldspars. Quartz is actively sought and other minerals include garnets of a rose-orange colour. The crystals resemble tetrahedral plaques (320) which have suggested to some that the mineral was morganite. Apatite has also been found. The garnets have a density of ~4·15, an R.I. of 1·810 and a hardness of 7·5.

M.O'D.

CROWNINGSHIELD (R.). *Commercial implications of gamma radiation on gem material.* Z. Dt. Gemmol. Ges., 1974, 23, 2, 95-101.

Gamma radiation is now being used on stones other than diamond to improve their colour, while up to recently only diamond bombardment was well known. In the case of beryls, maxixe characteristics are produced; blue and yellow beryl is produced, the blue variety not fade-resistant. Yellow sapphires fade rapidly; green spodumene fades to kunzite. Experiments were made on pale amethysts, but the colour became smoky. Blue topaz and gamma-treated blue-grey cultured pearls seem to be a commercial proposition. Tourmalines and jadeite are still being investigated.

E.S.

DAHLBERG (J. C.). *Thomsonite, the gem with the Scots name.* Lapidary Journal, 1974, 28, 1, 42-58.

The zeolite mineral thomsonite is found near Grand Marais, Lake Superior. An account of the life of Thomas Thomson is appended.

M.O'D.

DESAUTELS (P. E.). *The Natural Collection of Gems in the Smithsonian Institution, 1965 to 1974.* Lapidary Journal, 1974, 28, 1, 84-100.

Among stones received since the earlier article (*Lapidary Journal*, 19, 1) are the Rosser Reeves star-ruby of 138·72 ct, a bright blue sapphire of 423 ct, a 911 ct blue aquamarine from Brazil, a 113 ct morganite from the White Queen Mine, San Diego County, California, and a 5·34 ct mauve taaffeite.

M.O'D.

EPPLER (W. F.). *Über einige Einschlüsse im Birma-Rubin.* (About some inclusions in Burma ruby). Z. Dt. Gemmol. Ges., 1974, 23, 2, 102-108.

Inclusions in Burma rubies are manifold: only some are described. Most common inclusion is rutile, found in most stones, sometimes in crystal form, often in clouds of thin short needles, rarely as negative crystals parallel to the base. Calcite is also often found, easily recognizable because of its high R.I. (1·658). Quite frequently one finds zircon inclusions in Burma ruby, as well as spinel.

E.S.

FABRIÈS (J.) and SCHUBNEL (H.-J.). *L'origine et le réorganisation des collections mineralogiques du Museum National.* (Origin and reorganization of the mineralogical collections in the National Museum). Bulletin de l'Association Française de Gemmologie, 1974, 37, 9-12.

The collections of minerals at the Jardin des Plantes have been reclassified and the number of specimens on display has been reduced from 23,000 to 4,000. There are 2,000 gemstones and ornamental mineral specimens.

M.O'D.

FUMEY (P.). *L'axinite de l'Oisans.* (Axinite from l'Oisans) Bulletin de l'Association Française de Gemmologie, 1974, 37, 15-16.

Axinite from the Dauphiné Alps has a S.G. of 3·28, hardness of 6·5-7, R.I. of 1·68-1·69 and a D.R. of 0·010. The mineral is found in pockets in a schist in association with prehnite, epidote and quartz.

M.O'D.

GÜBELIN (E. J.). *The emerald deposit at Lake Manyara, Tanzania.* Lapidary Journal, 1974, 28, 2, 338-360.

Emeralds were found in pegmatites and biotite schists at a location 23 miles north-east of Magugu. The emeralds occur where biotite schists are in immediate contact with pegmatite and in the mining process the majority are found in the schist. Relatively few euhedral specimens occur. The colour approximates to a point situated on a line running between 0·20/0·50 and 0·08/0·80 of the C.I.E. colour plate DIN 5033. In general the colour resembles that of Sandawana and Colombian stones. The S.G. is 2·74 and the R.I. (ω) 1·585, (ε) 1·578, with a D.R. of 0·007. So far as inclusions known to be peculiar to the locality have been observed, those already noted include micas accompanied by liquid-filled cavities. Liquid inclusions fall into three types: primary, prismatic or hexagonal/triangular; secondary, of irregular shape. The third form is prismatic negative crystals consisting of growth voids filled with 2-phase contents.

M.O'D.

GÜBELIN (E. J.). *Schwarze Einschlüsse in Diamanten.* (Black inclusions in diamonds). Z. Dt. Gemmol. Ges., 1974, 23, 2, 109-114.

Mineral inclusions in diamond are the best information regarding their formation. The material used was sawn into six segments out of fairly good octahedra, the inclusions being more or less black centrally situated spots surrounded by a system of fissures, also partly clad in a black substance. These fissures were found to be caused by tension, which in turn was caused by the higher thermal expansion coefficient of the mineral inclusion. The black coloration of the fissures was caused by their cladding with magnetite.

E.S.

IRVINE (W. J.). *Inverell—Australian Aladdin's Cave.* Lapidary Journal, 1974, 28, 1, 102-108.

Inverell is in New South Wales, 420 miles from Sydney. Sapphires are found in creeks and gullies, and diamonds are being actively prospected.

M.O'D.

JOHNSON (B.). *Montana's famed Yogo Gulch.* Gems and Minerals, 1974, 30-36.

The sapphires are found 15 miles south west of the town of Utica and are plentiful in small sizes. At present all the production goes to Japan and the area is closed to collectors.

M.O'D.

LENZEN (G.). *Zur Deutung altindischer Diamanten-Imitationen.* (Explaining old Indian diamond imitations). Z. Dt. Gemmol. Ges., 1974, 23, 2, 115-124.

Between 4th century B.C. and 6th century A.D. diamonds were graded according to magical mystery and according to the crystal form, their deviation from the perfect octahedron, inclusions as far as could be seen with the naked eye and colour as far as the colour was of a definite hue. Thus, diamonds, spinels and magnetite were to some extent substituted for each other. An interesting table gives the topographical analyses of the occurrence, type and colour as graded by the old Indian lapidaries.

E.S.

LIDDICOAT (R. T.), FRYER (C. W.). *Three new gem materials.* Z. Dt. Gemmol. Ges., 1974, 23, 2, 125-127.

Three new materials of gem interest encountered by the G.I.A. Los Angeles Laboratory. The first was a green turquoise rich in copper but not zinc, identified as faustite; the second was also turquoise-like material, either prosopite or an yttrium copper. This material is still being tested, semi-translucent to opaque, in appearance like fine turquoise. The third material was a long thin 1·51 ct emerald-cut stone of pale blue colour, found to be jeremejevite from South West Africa.

E.S.

MALES (P. A.). *Gem quality kyanite crystals from Harts Range, Northern Territory.* Australian Gemmologist, 1974, 12, 1, 5-8. 3 illus.

Details the occurrence of gem quality kyanite crystals in the Harts Range of Northern Territory, Australia. Much is told about the crystals themselves, but no optical properties are mentioned and there is no mention of cut stones.

R.W.

MALES (P. A.). *Ilmenite crystals associated with rutilated quartz from Brazil.* Australian Gemmologist, 1974, 12, 1, 11-12. 2 illus.

Small plates of a black mineral found attached to rutilated quartz from Brazil were, by x-ray analysis, found to be ilmenite. Descriptions are given of the habit and properties of these crystals. It was found that they affected a compass needle but were not attracted to a magnet.

R.W.

MITCHELL (R. S.) and TUFTS (S.). *Wood opal—a tridymite mineral.* American Mineralogist, 1973, 58, 717-720.

Although in general opalized fossil wood has a structure approaching high-tridymite, other forms of opal resemble low-cristobalite. Spectrochemical studies show that the silica of tridymite-like opals is more chemically pure than that found in cristobalite or amorphous opals, which contain more Al, Na, B and Zr. The disordered high tridymite structure has been observed in calcareous opal, jasper opal, milk and moss opal and wax opal.

M.O'D.

MITCHELL (R. H.). *Minerals in fact and fantasy.* Rocks and Minerals, 1973, 48, 275-279.

Supernatural powers were once attributed to numerous well-known gems. Some of these legends are reviewed.

R.S.M.

NASSAU (K.). *The effects of gamma rays on the color of beryl, smoky quartz, amethyst and topaz.* Lapidary Journal, 1974, 28, 1, 20-40.

Experiments were conducted in which, under gamma ray bombardment, colourless to pale yellow topaz turned to a sherry colour or to brown, colourless and pale coloured beryl turned deep blue and synthetic quartz gave a smoky or amethyst colour. Some of the colours were not stable to light.

M.O'D.

NOWAK (G.). *Fire opals in the Mojave desert.* Lapidary Journal, 1974, 28, 1, 52-56.

The opals are mined in the El Paso mountains near to the Garlock and El Paso faults. Stones range in size from pinpoints to 2″ across and show a play of colour.

M.O'D.

OUGHTON (J. H.). *Stones seen and discussed.* Australian Gemmologist, 1974, 12, 1, 9-10. 4 illus.

The results of an examination by Dr Eppler of a Poona (West Australian) emerald in matrix are reported. Some ideas are put forward on the mining of such emeralds. Three-phase inclusions are reported to have been seen in topaz from New South Wales, Australia.

R.W.

PETERSON (N. V.). *Oregon "sunstones".* The Ore Bin, 1972, 34, 197-215.

"Sunstone" is a variety of feldspar that exhibits a metallic shimmer due to minute inclusions of hematite or some other impurity arranged parallel to the cleavage. Another term is aventurine feldspar. The "sunstone" found at Rabbit Basin, Lake County, Oregon, is a calcic labradorite which occurs as phenocrysts in a basaltic lava flow, the phenocrysts being formed by primary crystallization in a magma chamber at depth under relatively

uniform conditions at a temperature greater than 1100°C. Most of the phenocrysts are fractured (conchoidal), which resulted from flow movement during eruption. A list of a dozen localities for "sunstone" in the United States is included.

M.H.

POIROT (J.-P.). *Les corindons artificiels commercialement dénommés rubis synthétiques et saphires synthétiques.* (Artificial corundums commercially called synthetic rubies and synthetic sapphires). Bulletin de l'Association Française de Gemmologie, 1974, 37, 13-14.

The manufacture of synthetic corundum has proceeded since the experiments of Frémy in 1877. Flame-fusion, pulling, flux-melt and hydrothermal techniques are reviewed.

M.O'D.

POMARAIS (P.). *Un des hauts lieux de la mineralogie francaise: Chessy les Mines.* (One of the high places of French mineralogy—Chessy les Mines). Bulletin de l'Association Française de Gemmologie, 1974, 39, 23.

Chessylite, a hydrocarbonate of copper with the formula $Cu_3(OH/CO_3)_2$ is found at Chessy, a community situated 30 km west of Lyons. The mineral is found in an area bounded on the south-east by crystalline schists and on the south-west by granite. No working takes place now.

M.O'D.

POUGH (F. H.). *Willemite, an uncommon gemstone.* Z. Dt. Gemmol. Ges., 1974, 23, 2, 128-130.

Article describing the various geological occurrences of the fairly uncommon willemite, an anhydrous zinc silicate, first found in Moresnet near Aachen and named after King William I of the Netherlands. The article deals mostly with the abundant finds in the United States, mainly in Sterling Hill and Franklin, N.J., which are characterized by brilliant fluorescence.

E.S.

ROSS (R.). *Lightning Ridge black opal knobby.* Lapidary Journal, 1974, 27, 12, 1796-1802.

An account, illustrated in colour and with a map, of the opening of the new Black Nobby mine at Lightning Ridge.

M.O'D.

SANTOS MUNSURI (A.). *Hornbill—Ho-Ting.* Gems & Gemology, 1973, XIV, 7, 208-211. 7 illus. (two in colour). (Reprinted from Boletin del Instituto Gemologico Español, 1972, 1, 3, 15-20).

Already abstracted in *J. Gemm.*, XIII, 8, 327.

R.W.

SCHIFFMANN (C. A.). *Beobachtungen an Rubinen aus Prilep, Jugoslawien.* (Observations of rubies from Prilep, Yugoslavia). Z. Dt. Gemmol. Ges., 1974, 23, 2, 131-138.

A lot of rough and cut rubies from Prilep in Yugoslavia were examined, the colour varying from red to reddish-pink, transparent to opaque, usable for gem purposes when cut as cabochon. Impurities account for varying density from 3·80–3·85 to 3·90–3·98, i.e. lower than corundum. The stones had a weak Cr absorption spectrum; the Cr content was 0·09%. Orange and red fluorescence was observed. Rubies with similar properties were found in Campolungo in Switzerland, which have been described mineralogically but are of no practical value.

E.S.

SCHMETZER (K.), BANK (H.) and BERDESINSKI (W.). *Eine seltene rote Varietaet der Mineralart Beryll (früher Bixbit genannt).* (A rare red variety of the beryl type formerly known as bixbite). Z. Dt. Gemmol. Ges., 1974, 23, 2, 139-141.

Further work done on the colour and absorption spectra of a red beryl from Utah.

E.S.

SCHUBNEL (H.-J.). *Chronique des musées de mineralogie. L'American Museum of Natural History, New York.* (History of the museums of mineralogy. The American Museum of Natural History, New York). Bulletin de l'Association Française de Gemmologie, 1974, 36, 7-8.

Notable stones in this collection include the De Long star-ruby, of 32 ct. The Star of India sapphire of 35 ct, from Ceylon, the Patricia emerald from Chivor of 632 ct and a large Brazilian aquamarine of 4438 ct. The De Long Ruby and the Star of India, stolen some years ago, were recently recovered.

M.O'D.

SIM (S.). *Some thoughts about agate formation in Scotland.* Australian Gemmologist, 1974, 12, 1, 16-19 (Reprinted from the Lapidary Journal). 1 illus.

Some theories are advanced on the formation of Scottish agates. A number of well thought-out ideas are mentioned and discussed. The writer suggests that the banded structure of Scottish agates is caused by a seasonal variation of the "water table" of the surrounding rocks and not by osmosis and/or the Liesegang ring theory.

R.W.

STRUNZ (H.) and WILK (H.). *Jeremejewit als Edelstein aus S.W. Afrika.* (Jeremejevite as gemstone from S.W. Africa). Z. Dt. Gemmol. Ges., 1974, 23, 2, 142-150.

Although some colourless pegmatites had been known as jeremejevite previously, some cornflower blue crystals have now been found near Cape Cross, north of Swakopmund. Density 3·313, hardness 7, chem. $AlBO_3$, R.I. 1·641-1·649, double ref. 0·008. Optical details are given and behaviour under x-ray treatment described, as are also common inclusions.

E.S.

TILLANDER (H.). *Le Régent. Un des plus beaux et plus parfaits diamants historiques.* (The Regent. One of the most beautiful and most perfect historic diamonds). Bulletin de l'Association Française de Gemmologie, 1974, 37, 3-7.

The Regent diamond measures 30·53 mm in length, 28·9 mm across and 20·8 mm in depth. The weight is thought to approximate to 140·615 ct. A note on the history is included.

M.O'D.

WAIT (G. B.). *Shaping black coral bracelets.* Gems & Gemology, 1973, XIV, 7, 222. 1 illus. (Reprinted from the Lapidary Journal).

Details how the black coral from the Hawaiian Islands can be shaped into bangles, circular earrings, etc., by taking a long stalk of the coral, heating it with a blow-torch and winding the softened coral around a wooden former. The method is only suitable for the black coral, which is nearly pure conchiolin, and will not operate with the calcareous "noble" coral.

R.W.

WEBSTER (R.). *Some interesting aspects of gem testing.* Gems & Gemology, 1973, XIV, 7, 194-199. 4 illus.

Tells of some unusual materials which had in time been submitted to the London laboratory and details how some of the problems were dealt with. These include black coral, sea shell, horn, seed pods and porcelain.

P.B.

WEBSTER (R.). *Thin section examination of organic materials.* Z. Dt. Gemmol. Ges., 1974, 23, 2, 151-160.

The author discusses the application of thin section examination usually used in petrography to organic material used in jewellery. The preparation of the slides is described and the materials dealt with include ivories, bone, horn, vegetable ivory such as material taken from the corozo nut or doom palm nut, corals and elephant hair. This method facilitates the differentiation between various types of ivories and horn. There are 16 photomicrographs, showing the various materials in longitudinal as well as transverse section.

E.S.

ZWAAN (P. C.). *Über drei gelungene Faelschungen in der Edelsteinsammlung des Rijksmuseum van Geologie en Mineralogie in Leiden, Niederlande.* (About three successful fakes in the precious stone collection in the Rijksmuseum for geology and mineralogy in Leiden, Holland). Z. Dt. Gemmol. Ges., 1974, 23, 2, 161-164.

The collection was originally a gift of King William I in 1825 consisting of 637 stones. In 1938 various valuable stones were stolen from the collection. The article describes three imitation stones in the original collection, a peridot, a tourmaline cat's-eye, and a sapphire, all three being imitated by glass simulations.

E.S.

BOOK REVIEWS

ALLISON (F.) and (J.). *The Allison Collection of rare jewels and gemstones.* Horowitz Publications, North Sydney, 1971. Not paginated. Illustrated in colour. Price on application.

The Allison Collection is housed in the Diamond Traders Gem Gallery in Sydney and this booklet illustrates without text some of the finest specimens. The quality of reproduction is fair, the plates being printed in Japan.

M.O'D.

AREM (J. E.). *Man-made crystals.* Smithsonian Institution Press, Washington, D.C., 1973. pp. 109. Illustrated in black-and-white and in colour. $5·95.

The Smithsonian Institution now houses the National Collection of Synthetics and this has been drawn upon to furnish the very fine illustrations for the present book. Particular attention is paid to the actual use of synthetic crystals in modern technology and a good deal of simplified information is included on such subjects as lasers, bubbles, transistors and integrated circuits. All forms of crystal are dealt with, including some unfamiliar as yet to the gemmologist, bismuth germanium oxide, lead molybdate (wulfenite in nature) and potassium tantalate niobate. A bibliography would have been most useful. There is a glossary of technical terms and an index, which lists gadolinium gallium garnet as GGG only, although it is mentioned three times in the text.

M.O'D.

ARMSTRONG (Nancy). *Jewellery.* Lutterworth Press, Guildford, 1973. pp. xiii, 286. Illustrated in black-and-white and in colour. £8·95.

An unnecessary book. There seems no point in publishing a book with so little scholarship and such a lumpen style, whose sole aim appears to be to boost the reputation of some modern jewellery designers, who would probably not welcome this kind of publicity. Errors are so many that the whole sense of the book is lost; zircon is not a quartz, nor topaz a beryl. It would scarcely seem advisable to use machine oil as a vehicle for the cleaning of opal. Any of the details of the production of jewellery, which have to be sought among the hackneyed legends and half-statements, are quite easily

to be found in other and better books. The illustrations are of fair quality, and there is a bibliography. The information given on education in gemmology is not accurate, but it is hoped that aspiring students will not be reading this book.

M.O'D.

BAUER (J.) and TURZ (F.). *Der Kosmos Mineralienführer.* (Kosmos guide to minerals). Franckh'sche Verlagshandlung, Stuttgart, 1974. pp. 215. Illustrated in colour. DM. 19·80.

Printed in Czechoslovakia, this handy guide is intended for the field identification of minerals, rocks and gemstones. Each species is illustrated in colour and brief descriptions, colour, transparency, hardness, cleavage, crystal system, mode of occurrence and chemical composition occupy the facing pages. There is a short introduction and a bibliography. Although the majority of the examples are shown as crystals, some, including peridot, spinel and pyrope, are shown fashioned, which seems strange for a field guide. Locations are German and Central European.

M.O'D.

BROCKETT (Ron). *The Moscow opal mines, 1890 to 1893.* Published by the author, c/o Lapidary Journal, San Diego, 1974. pp. 63. Illustrated in black-and-white. $3·00 plus postage.

A well-written account of the first commercial opal mine in the United States, this book covers the history of the opal mine established on the property of a William Leasure about 5 miles from Moscow, Idaho. Claims were quickly established when the opal was seen to be of good quality and the book traces the history of the North American Gem Opal Mining Company. Misleading press accounts of the value of the stones recovered and the reasons why the mines ceased to produce are analysed.

M.O'D.

EPPLER (W. F.). *Praktische Gemmologie.* (Practical Gemmology). Rühle-Diebener-Verlag, Stuttgart, 1973. pp. 410. Illustrated in black-and-white. DM. 132.

One of the most important gemmological textbooks to be written for some years, this excellently printed and illustrated work urgently needs an English translation. The book is arranged by stones with tables at the end giving specific gravities, absorption

spectra, refractive indices and pleochroism. There is an index but no bibliography, the one serious desideratum in the book. Each stone is introduced by its constants and its crystal habit is illustrated by text-diagrams and sometimes by photographs. The most important feature, however, is that each stone is accompanied by photographs of its typical inclusions and these photographs are of superlative quality. The section on emerald includes a superb illustration of the inclusions in a Hautefeuille and Perrey synthetic and in a Nacken. The author does not mention that the iron-rich Gilson synthetic emerald was discontinued after a relatively small production. I could find no references to chrome kornerupine, nor to chrome chalcedony, but there is a reference to tourmaline-coloured green gahno-spinel and to the hydrothermal growth of tourmaline. The author does not advance a theory on the colouring agent of Blue John fluorspar. But these are small points which the reviewer is irresistibly led to track down in such a book as this.

M.O'D.

FAIRFIELD (Del). *Lapidary.* English Universities Press, London, 1973. pp. 126. Illustrated in black-and-white. Teach Yourself Books. 50p.

A well-printed and clearly-illustrated introduction to lapidary, this book covers tumbling, sawing, grinding, polishing, drilling and lapping with a section on some of the commoner gem materials. A useful chapter deals with the setting up of a workshop and there is a list of British lapidary societies.

M.O'D.

HAMILTON (W. R.), WOOLLEY (A. R.) and BISHOP (A. C.). *The Hamlyn guide to minerals, rocks and fossils.* Hamlyn, London, 1974. pp. 320. Illustrated in colour. £1·95.

Much better than similar productions in the same field, this pocket-sized guide scores heavily by presenting specimen and description on facing pages. There is a short introduction to the mineral classes and to elementary crystallography and a stratigraphical column is of great assistance to fossil collectors, who have not had, at least in recent years, a guide of this type to take into the field.

M.O'D.

LIEBER (Werner). *Bunte Welt der schönen Steine.* (The colourful world of beautiful stones). 3rd edition. Franckh'sche Verlagshandhung, Stuttgart, 1974. pp. 71. Illustrated in colour. DM. 7·80.

With descriptions facing the stones they accompany, this Czechoslovakian-printed pocket-book forms an excellent introduction to minerals. The specimens are classified in traditional order and there is a short introduction. German and Central European locations are given.

M.O'D.

PARKER (R. L.). *Die Mineralfunde der Schweiz.* (Finding minerals in Switzerland). Wepf & Co., Basel, 1973. pp. xii, 433. Illustrated in black-and-white and in colour. Price on application.

Described in the preface as a topographic mineralogy, this book is a new edition of a work which first appeared in 1940. The task of overseeing the complete work has been entrusted during this time to the Schweizerische Geotechnische Kommission. For the purpose of the book the country has been divided into the massifs of the Aar and the Gotthard, the Pennine, eastern and southern Alps, the massifs of Mont-Blanc and the Aiguilles Rouges, the northern Alps and the region of the Jura. Each of these areas has a section devoted to it and they are also illustrated by panoramas and maps, the major ones depicting the mineralized areas on a scale of 1:200,000. There are excellent illustrations, an exhaustive bibliography and a glossary.

M.O'D.

RUTLAND (E. H.) *An introduction to the world's gemstones.* Country Life, London, 1974. pp. 192. Illustrated in black-and-white and in colour. £3·50.

A freshly-written introduction to gemmology, this reasonably-priced book deserves a wide circulation. Particularly welcome is a departure from the laboured didactic style which characterizes some other gemmological texts, and the reader is conducted naturally from the geological processes to the finished gem. Gem testing is not described in detail and the scope of the book does not call for it; instead there are some useful chapters on synthetics and on jewellery.

There is an index and a short bibliography. The coloured illustrations are fairly good, some of them being from the now celebrated Geological Museum slides first used to illustrate the latest edition of Herbert Smith; one or two of the others are a little pale in colour; this applies particularly to the reproduction of the emerald on page 66.

M.O'D.

SORRELL (Charles A.). *Minerals of the world.* Golden Press, New York, 1973. pp. 280. Illustrated in colour. Gold Field Guides Series. $3·95.

The acknowledged aim of the author was to fill a gap between popular guides and college textbooks. This well-illustrated guide fits easily into the pocket and, like some other recent books of similar type, presents text and illustrations on facing pages, a feature much less often found in past years. An introduction deals concisely with simple mineralogy and a particularly welcome feature is a bibliography in which the scope of the work included is explained. United States locations by state are given for the minerals described. It is a little inaccurate to say that uvarovite is prized as a gem and no distinction is made in the text between hiddenite and green spodumene, though they are differentiated in the plate.

M.O'D.

WEIBEL (Max). *Die Mineralien der Schweiz.* (The minerals of Switzerland). Fourth edition. Birkhäuser Verlag, Basel, 1973. pp. 185. Illustrated in black-and-white and in colour. Sw.fr. 24.

The mineral classes introduce the book, which is then arranged in order of mineral occurrence, beginning with the Jura and passing to the high Alps. Directions for finding the commoner minerals are given and there are some excellent maps. Many of the illustrations depict the various forms of quartz, but some interesting examples of other species are also shown, particularly a fine red grossular accompanied by diopside from the Zermatt area.

M.O'D.

WILHELMY (Herbert). *Geomorphologie in Stichworten.* (Geomorphology in catch words). Verlag Ferdinand Hirt, Kiel, 1971.

3 parts. pp. 102, 227, 184. Illustrated. Price on application.

This excellently-produced book further enhances a series (Hirt's Stichwortbücher) already notable for Geologie in Stichworten and Mineralogie in Stichworten (both reviewed in the *Journal*, July 1972, 13, 3, 111). Intended as a textbook for degree students, the whole subject is simply but adequately treated with diagrams of especial usefulness and clarity. Each chapter includes a bibliography.

M.O'D.

Minerals and their characteristics. Department of Mines, Geological Survey of New South Wales, Sydney, 1973. pp. 26. Price on application.

A short guide in tabular form to some of the commoner minerals. Chemical formula, colour, streak, lustre, cleavage, fracture and hardness are given. It would have been easier to use the book had it opened to show the text vertically instead of horizontally, necessitating turning the book round to read it.

M.O'D.

Gemhunting atlas of Australia. Paul Hamlyn, Sydney, 1973. Not paginated. Illustrated in colour. Price on application.

This atlas which is very well printed falls into three sections, of which the first shows the main gem-bearing areas. The chief geological formations are shown in contrasting colours and fossicking areas are included. The second section is divided by state and shows the road systems by which the gem areas may be reached. The third section is an alphabetical index of towns. The maps are admirably clear and the whole book is an essential for the Australian gemmologist.

M.O'D.

Verzeichnis der Schmuck-und Edelsteine. (List of ornamental and precious stones). Verlag Heinz Wöhrle, Göppingen, 1974. pp. 16. DM. 1·50.

A handy small compendium arranged by groups of stones apparently in arbitrary order. Additional tables list stones by colour and alphabetically.

M.O'D.

ASSOCIATION NOTICES

GIFTS TO THE ASSOCIATION

The Council of the Association is indebted to the following for gifts presented to the Sir James Walton Library:

Mr A. F. Chapman, McCrae, Victoria, Australia, for three slabs of "Nundoorite" from a recent discovery in the Broken Hill area of New South Wales, Australia. The material is Aegterine augite sodic zeolite.

Mrs Vera M. Honeker for 1 crystal specimen of vanadium from South West Africa.

Mr Eric F. Morris, Christies Beach, Australia, for two "Copeton" diamonds. These stones came from the small town of Copeton, which was abandoned last year when the large Copeton Dam inundated the river valley in which it lay.

Mr Richard Y. M. Sze for 2 sets of coloured cards of jade articles which are located in the National Palace Museum, Taipei, Taiwan.

ACTIVITIES BY FELLOWS

In the discussion which followed the delivery of the sixth Chester Beatty Lecture at the Royal Society of Arts on 24th April by Professor R. V. Jones, C.B., C.B.E., F.R.S. on the subject of "Minerals in the History of Science", in which the lecturer referred to one of the earliest successes in growing crystals by artificial means as being that of M. Verneuil of Switzerland in growing artificial rubies for the watch industry, Mr Robert Webster, F.G.A., pointing out that most of Verneuil's stuff was in Paris, queried whether Professor Jones had any extra information about him which might shed some light on the problem of "Geneva rubies" or "reconstructed rubies". The lecturer, however, disclaimed possession of any such information, saying "I think that you know more than I do about this".

An Exhibition of Gemstones and Ornamental Material combined with a Gem Testing Demonstration was given by Mr Robert Webster, F.G.A., and Mr Colin H. Winter, F.G.A., at the Department of Forensic Medicine, London Hospital Medical College, on Friday, 14th June, as one of a series of exhibits held during the 15th Annual General Meeting of the British Academy of Forensic Science. Grateful acknowledgements were made to the Gemmological Association for the loan of an Olympus Microscope, a polariscope and ultra violet equipment, and also to the Academy and staff of the College for their assistance and hospitality during the day.

Mr Colin H. Winter, who gained the Fellowship of the Association with Distinction in 1973 and who had been appointed lecturer to the newly started gemmology classes at Merton Technical College, has now been admitted as a Member of the British Academy of Forensic Sciences.

EXAMINATIONS IN GEMMOLOGY 1975

The dates for the 1975 examinations are as follows:

Preliminary	Theory	Tuesday, 17th June
Diploma	Theory	Wednesday, 18th June
	Practical	Thursday, 19th June or Friday 20th June (London). Other centres as arranged.

The final date for entry is the 1st March.

Entry forms available from the Association.

MEMBERS' MEETINGS

Nottingham Branch

On the 27th May members of the Branch held a wine and cheese evening at the Mechanics Institute, Birkbeck House, Nottingham, and Mr James Gosling, F.G.A., gave an illustrated talk entitled "Gemstones of Guyana and the setting up of a lapidary industry there". This evening replaced the planned visit to the Institute of Geological Sciences, which had to be cancelled.

Scottish Branch

A belated A.G.M. of the Scottish Branch was held on the 5th September, 1974, in the North British Hotel, Glasgow. The

Chairman, Mr A. H. G. Armstrong, reported on the activities during the past year when three successful evening lectures were arranged. Mr A. McRae reported on instruction at the evening classes held in Glasgow. Mr Henry Whitehead was elected Chairman and Mr Alistair W. Tait, Secretary. The following were elected members of the Committee: Mrs C. Kilpatrick, Messrs D. Hill, A. McRae, I. McKenzie, A. H. G. Armstrong, and M. Turner. A vote of thanks was proposed to the retiring Chairman, Mr A. Armstrong, and Secretary, Mr G. Turner.

The evening finished with a talk with slides about the gem-cutting centre, Idar-Oberstein.

OBITUARY

Mrs Jeanne G. M. Martin, San Diego, California, U.S.A., who gained the Association's Diploma with Distinction in 1953, died on the 5th June, 1974. Mrs Martin was from 1954 to 1966 Associate Editor of *Gems & Gemology* and was a G.G. as well as a F.G.A.

INDEX OF GEM MATERIALS

The Worshipful Company of Goldsmiths in London is compiling an index of materials which have been or could be used as gems—this index to include not only natural but synthetic and other man-made materials. Will any reader having unpublished information within this field please communicate with Michael O'Donoghue, 7 Hillingdon Avenue, Sevenoaks, Kent TN13 3RB, England.

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PROCEEDINGS OF THE
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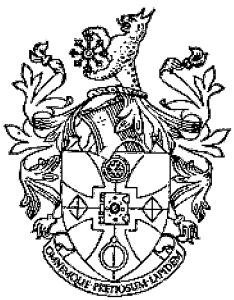

GEMMOLOGICAL ASSOCIATION
OF GREAT BRITAIN
SAINT DUNSTAN'S HOUSE, CAREY LANE
LONDON, EC2V 8AB

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BLUE COLOUR-CHANGE GEM GARNET FROM EAST AFRICA*

By E. A. JOBBINS, J. M. SAUL, ANNE E. TRESHAM and B. R. YOUNG

A SMALL water-worn pebble, weighing 0·078 grams (0·39 carats), was sent to the Institute of Geological Sciences via Mr B. W. Anderson, consultant to the Gem Testing Laboratory, Hatton Garden, in March 1974, for detailed investigation. The pebble along with other gem minerals including corundum, tourmaline and garnets, were obtained over a six year period from a group of Wakamba prospectors who live in Emali, Kenya. Although these prospectors never divulged precise information concerning their operations, it became quite clear in the course of time that most of their prospecting trips were to the lower Umba River Valley, downstream and to the east of the well-known Umba River mine producing pastel shades of gem corundum. The precise area must have been very close to the Kenya/Tanzania border, probably on the Kenyan side. A few stones may have been obtained by exchange or purchased, but even if this was the case it is unlikely that the geological notes given later would be invalidated.

The pebble, of gem-quality material, is greenish-blue in daylight, but shows a distinct magenta by tungsten illumination. The colour change closely resembles that displayed by the synthetic

*Published by permission of the Director, Institute of Geological Sciences, Exhibition Road London.

sapphires which are said to simulate alexandrite. By comparison, a sapphire in the IGS collections (registered number MI 32274) from the Umba river appears greyish-green by daylight and reddish-violet by tungsten lighting.

A small flat had been polished on one side of the pebble and this facilitated the determination of the refractive index as 1·757 in sodium light. The stone is not completely isotropic between crossed polars. Through the Chelsea filter the stone appears bright red (as do the synthetic corundums simulating alexandrite), but between crossed filters it appears a faint red only (in contrast to the bright reds of the synthetic corundums) and no fluorescence spect-

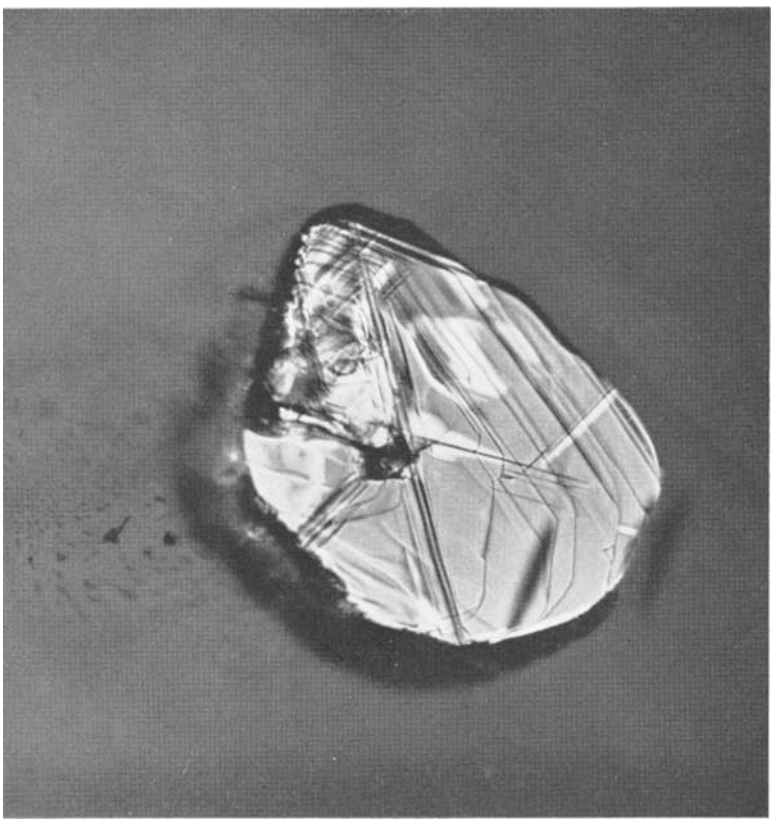

FIG. 1. Photomicrograph of hematite inclusion in colour-change garnet showing growth planes and twinning striae at 60°. A "finger-print" inclusion shows left of the hematite. Magnification × 120.

rum is seen when using copper sulphate solution as a filter. There is no fluorescence either by long or short wave ultra-violet radiation. The specific gravity is 3·816.

Three types of inclusion are present within the stone. The most prominent type is of a dark platy mineral showing a broadly hexagonal outline and resembling biotite mica at first inspection. However, it shows very high relief (in a garnet matrix of RI 1·757) and has a distinct metallic lustre. By reflected light three sets of striae at 60° to each other are clearly seen (see Fig. 1). This mineral appears to be specular hematite showing polysynthetic twinning on the basal pinacoid, and there appears to be a vestigial rhombohedral face. A second small group of interpenetrating hematites is also present. Associated with the larger hematite, but also in other areas, are several liquid feathers of the "finger-print" type. Fine rutile silk, orientated in three directions, shows beautifully by reflected light.

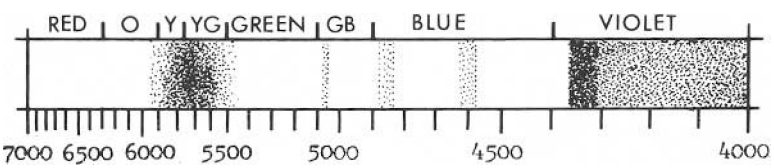

FIG. 2. Absorption spectrum of blue colour-change garnet from East Africa through prism spectroscope.

The absorption spectrum is illustrated in Fig. 2. A strong band is prominent in the 4350Å-4300Å region, but it was difficult to penetrate the gloom of the deep violet regions where there is almost complete absorption. A rather weak band is centred in the 4610Å region and there is another broad band in the 4850Å region. These bands are all consistent with the presence of the spessartine garnet molecule. A faint line near 5050Å and a fuzzy broad band centred around 5750Å (which probably has a strong influence on the colour) are possibly due to the iron of the almandine garnet molecule. Initial consideration of the absorption spectrum suggests that the stone is a modified spessartine garnet with minor amounts of the almandine molecule. However, the refractive index is near the pyrope range and the garnet shows a very unusual colour change which needs explanation.

A small scraping was removed, therefore, and subjected to examination by x-ray methods. The x-ray powder data set out in Table I were obtained from film X 7052B, taken in an 11·46 cm diameter camera, using FeKα radiation (d is the interplanar spacing, I/I_1 is the relative intensity of the powder line and *hkl* are the Miller indices of reflecting planes). The unit cell dimension 11·578Å (at room temperature) was obtained by plotting the values obtained from the high angle lines against $\frac{1}{2}(\cos^2\theta/\sin\theta + \cos^2\theta/\theta)$ and extrapolating to $\theta = 90°$. The intensities were estimated visually by comparison with an intensity scale. The space group is Ia3d. The density calculated from the x-ray data is 3·84, which compares well with that obtained from hydrostatic weighing.

TABLE I

X-ray powder data for colour-change garnet from East Africa

d	I/I_1	*hkl*	d	I/I_1	*hkl*
2·894Å	50	400	1·447Å	10	800
2·589	100	420	1·425	2	811,741,554
2·468	18	332	1·3838	1	653
2·363	20	422	1·2945	10	840
2·271	20	510,431	1·2633	14	842
2·114	16	521	1·2485	1	921,761,655
2·047	3	440	1·2342	10	664
1·878	20	611,532	1·2204	1	930
1·831	3	620	1·1695	3	941,853,770
1·671	16	444	1·1353	1	10,2,0;862
1·606	25	640	1·0750	18	10,4,0
1·547	50	642	1·0569	16	10,4,2
			1·0233	16	880

A preliminary qualitative elemental analysis carried out on the "Stereoscan" scanning electron microscope and the "Ortec 6200" multichannel analyser showed the presence of major Si with subordinate Al, Mn, Mg, Ca and other minor elements including vanadium. A quantitative analysis using the "Geoscan" electron microprobe was then made for the elements shown in Table II using silicates and oxides of known composition and pure metals as appropriate standards. All the elements were analysed using an accelerating voltage of 20kV. The results have been corrected for absorption, atomic number effect and fluorescence using the Mark V version of the BM-IC-NPL computer programme written by Mason, Frost and Reed. In the Table the present analysis is compared with the analyses of typical spessartine, grossular and pyrope garnets (see Deer, Howie & Zussman 1962) and the colour-change garnet described by Crowningshield which has

rather higher physical constants (Crowningshield 1970). The number of cations on the basis of 24 oxygen ions and the molecular percentages of the end-members have been calculated for Crowningshield's data so that all the analyses may be more easily compared.

With the electron microprobe it is not possible to distinguish the valency states of iron, and the faint line at 5050Å and the broad band around 5750Å in the absorption spectrum are not really conclusive evidence for the presence of Fe^{2+} as in the almandine molecule. We give, therefore, two possible interpretations of the analysis into conventional garnet molecules, using divalent and trivalent iron respectively. Essentially the garnet may be considered to be a pyrope-spessartine with subordinate grossular and smaller amounts of an iron-bearing garnet molecule. Titanium is here considered as substituting as a trivalent cation (octahedral or sixfold co-ordinated by oxygen) and is grouped with the Fe^{3+} and Al^{3+} (see Hartman 1969).

Vanadium is known to occur in several valency states (V^{2+}, V^{3+}, V^{4+}, V^{5+}) in its compounds and its role here is not certain. A calcium vanadium garnet (goldmanite) containing 12·5% V has been described by Moench and Meyrowitz (1964) from Laguna, New Mexico, who reasonably assumed that the vanadium was present as V^{3+}. The end-member $Ca_3 V_2 Si_3 O_{12}$ was later synthesized by Strens (1965). We have tentatively allocated the vanadium to the sites usually occupied by trivalent iron or aluminium.

Unfortunately, chromium cannot be detected completely satisfactorily in this specimen by microprobe methods because its emission lines are overlapped by V and Mn lines, and the line energies are so close that it is impractical to separate them by pulse height analysis. However, no Cr lines were seen in the absorption spectrum, nor was any chromium fluorescence spectrum seen, which is normally a very sensitive indicator of the presence of Cr. The influence of chromium on the colour would, therefore, appear to be minimal and the colour change must be ascribed to the presence of vanadium, which has been previously found or suspected to be the cause of the colour in gem tourmaline, zoisite (tanzanite), axinite, grossularite and perhaps kornerupine, all of which were found in the Arusha-Voi-Tanga portion of the Kenya-Tanganyika Province of the Mozambique Mobile Belt.

TABLE II

SHOWING ANALYSES OF BLUE COLOUR-CHANGE GARNET (1), TYPICAL GARNETS QUOTED BY DEER, HOWIE AND ZUSSMAN (2, 3, 4), AND COLOUR-CHANGE GARNET DESCRIBED BY CROWNINGSHIELD (5).

	(1a)	(1b)	(2)	(3)	(4)	(5)
SiO_2	40·3	40·3	35·87	38·96	41·97	38·35
TiO_2	0·05	0·05	tr	0·71	0·24	0·1418
Al_2O_3	21·8	21·8	20·84	19·93	21·73	26·45
Cr_2O_3	n.d.	n.d.	—	—	0·72	0·54
V_2O_3	0·75	0·75	—	—	—	0·324
Fe_2O_3	—	1·33	0·06	3·43	2·36	1·45
FeO	1·2	—	1·78	3·25	6·17	—
MnO	18·2	18·2	38·24	0·03	0·97	16·73
MgO	12·9	12·9	0·22	1·31	20·45	13·1
CaO	5·3	5·3	2·72	32·52	5·52	2·38
$H_2O > 105°C$	—	—	—	—	0·02	—
$H_2O < 105°C$	—	—	0·15	—		—
ZnO	0·03	0·03	—	—	—	—
CuO	n.d.	n.d.	—	—	—	0·0019
NiO	n.d.	n.d.	—	—	—	0·0032
CoO	0·03	0·03	—	—	—	—
	100·56	100·69	99·88	100·14	100·15	99·47
	n.d. = not detected					
n	1·757	1·757	1·798	1·747	1·7385	1·765
$D_{obs.}$	3·816	3·816	4·15	3·599	3·668	3·88
$D_{calc.}$	3·842	3·836	4·13	—	—	—
a (Å)	11·578	11·578	11·62	—	—	—

NUMBERS OF IONS ON THE BASIS OF 24(0)

Si	5·99	6·00	5·97	6·00	5·905	6·00	5·940	6·00	5·977	6·00	5·66	6·00
Al	0·01		0·03		0·095		0·060		0·023		0·34	
Al	3·81	3·90	3·78	4·02	3·943	3·95	3·509	3·98	3·617	3·98	4·26	4·54
Cr	—		—		—		—		0·086		0·06	
V^{3+}	0·09		0·09		—		—		—		0·04	
Fe^{3+}	—		0·15		0·008		0·392		0·251		0·16	
Ti	0·005		0·005		—		0·082		0·025		0·02	
Mg	2·86	6·15	2·85	5·98	0·055	5·83	0·293	6·01	4·334	6·02	2·88	5·35
Co	0·004		0·004		—		—		—		—	
Fe^{2+}	0·15		—		0·245		0·411		0·734		—	
Mn	2·29		2·28		5·333		0·004		0·119		2·09	
Zn	0·004		0·004		—		—		—		—	
Ca	0·84		0·84		0·198		5·306		0·838		0·38	

MOLECULAR PERCENTAGE OF END-MEMBERS

Pyrope	46·5	47·7	0·9	4·9	70·4	53·7
Spessartine	37·3	38·2	87·3	0·1	2·0	39·0
Almandine	2·4	—	4·0	6·8	11·9	—
Andradite	—	3·7	0·2	11·8	6·7	4·5
Grossular	11·6	8·1	7·6	76·4	6·9	—
Uvarovite	—	—	—	—	2·1	1·7
$Ca_3V_2Si_3O_{12}$	2·2	2·2	—	—	—	1·1

1. Blue colour-change garnet, Umba River Valley, East Africa. Electron probe anal. A. E. Tresham. The oxidation state of iron cannot be determined by electron probe analysis and so 1a shows Fe content as FeO and 1b as Fe_2O_3.
2. Spessartine, rhodonite-spessartine-rhodochrosite schist, Arrow Valley, Kawarau Survey District, western Otago, New Zealand. (Hutton, 1957). Anal. C. O. Hutton.
3. Reddish yellow grossular, in crystalline limestone, Liconi, Val d'Aosta, Italy. (Sanero, 1935).
4. Pyrope, pyroxenic eclogite, Čerrín, southern Moravia. (Kokta & Němec, 1936).
5. Colour-change garnet, Tanzania. (Crowningshield, 1970). Semi-quantitative spec. anal. Pacific Spectrochemical Lab., Inc.

The colour-change garnets and virtually all of the other gems from this region had their origins in the Basement Complex rocks which are assigned to the Mozambique Mobile Belt. This underwent its last phase of metamorphism during the so-called Pan-African event. Ages obtained from metasediments and pegmatites in this part of East Africa date this event at around 550 million years ago (Cahen and Snelling 1966).

Gem almandine (rhodolite) and spessartine garnets are reliably reported to have been seen *in situ* in metasediments just east of the ultrabasic intrusion in which the pastel-shaded corundums are found. Tourmaline is also found in association with the ultrabasic intrusives and scapolite, clino- and ortho-pyroxenes of gem quality are among the other gem minerals found in the area. Gem zircon also occurs. More than one ultrabasic intrusion is known in the region and the possibility of their continuity at depth should not be excluded.

A possible origin for some of the garnets with unusual properties may have been the interaction between ultrabasic intrusions and garnets of various compositions found in the metasediments and other deposits. This occurred especially, perhaps, in the contact aureole which at the mine for the pastel-shaded corundums is complex and zoned.

The ultrabasic intrusives of East Africa have not been adequately dated, but, if the existence of a single gem-forming phase is confirmed, a case can be made for assigning a *circa* 550 m.y. or slightly younger date to the emplacement of these rocks.

The authors gratefully acknowledge assistance from colleagues in the Petrographical Department at the Institute of Geological

Sciences without whose co-operation this work could not have been completed; they also thank Mr B. W. Anderson for much helpful discussion and Mr J. M. Pulsford for the inclusion photograph.

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INCLUSIONS IN BERYLLONITE FROM STONEHAM, MAINE, U.S.A.

By PETE J. DUNN, M.A., F.G.A.

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BERYLLONITE, $NaBePO_4$, is a rare gem material originally found at Stoneham, Maine, U.S.A., in 1886. The mineral was originally noted by Dana in 1888 and described by Dana and Wells in 1889. Beryllonite was found as highly modified etched monoclinic crystals in a soil containing feldspar, quartz and common pegmatite minerals. The three prominent cleavages produce blocky, rectangular sections well suited to oval, cushion and emerald cuts. Beryllonite is colourless, has low refractive indices of $\alpha = 1{\cdot}552$, $\beta = 1{\cdot}558$, $\gamma = 1{\cdot}561$, weak dispersion, a hardness of $5\frac{1}{2}$, and is uncommon, hence it is not frequently encountered in jewellery but is cut as a specialty stone for gem collectors and museums.

Four cut stones weighing 2·5, 3·3, 3·9, and 5·0 carats, and 55 uncut crystals and crystal fragments in the Smithsonian Institution collections were examined for inclusions. Although Dana and Wells noted apatite inclusions in their description of beryllonite,

apatite was not observed in the gem material examined in this study. The most obvious and abundant inclusions in Stoneham beryllonite are very fine, parallel tubes oriented parallel to [010]. Healed fractures, resembling a trellis, and very thin curving acicular crystals (Fig. 1) are less frequently observed.

The most interesting inclusions in the Stoneham beryllonite are two-phase inclusions consisting of a liquid and one or two gas bubbles (Fig.2). These are of two types: irregular flat cavities and elongated cylindrical tubular cavities. In both cases, the long dimensions of the inclusions are normal to the *b*–axis. The tubular cavities, which are of variable length, and the irregular cavities are usually concentrated in planes parallel to {010}.

FIG. 1. Unknown acicular crystals rarely observed in beryllonite from Stoneham Maine. (N.M.N.H. Specimen B-12474). (40 ×).

In the course of photographing these inclusions, a 5 carat cushion-cut stone was exposed to the heat from the illuminator of a darkfield gemscope. The warming of the stone (to about 55°C) caused the expansion of an inclusion and produced a minute fissure cleavage parallel to {010}. The inclusion was observed to boil as the cleavage occurred and the escaping liquid and gas formed an evaporite residue on the clean polished surface of the gem (Fig.3). This residue was x-rayed, utilizing a Gandolfi powder camera and CuKα nickel filtered radiation. Examination of the x-ray pattern indicated that the evaporated residue was halite, NaCl, and

FIG. 2. Two-phase irregular inclusion in beryllonite from Stoneham, Maine. (N.M.N.H. gem #423). (40 ×).

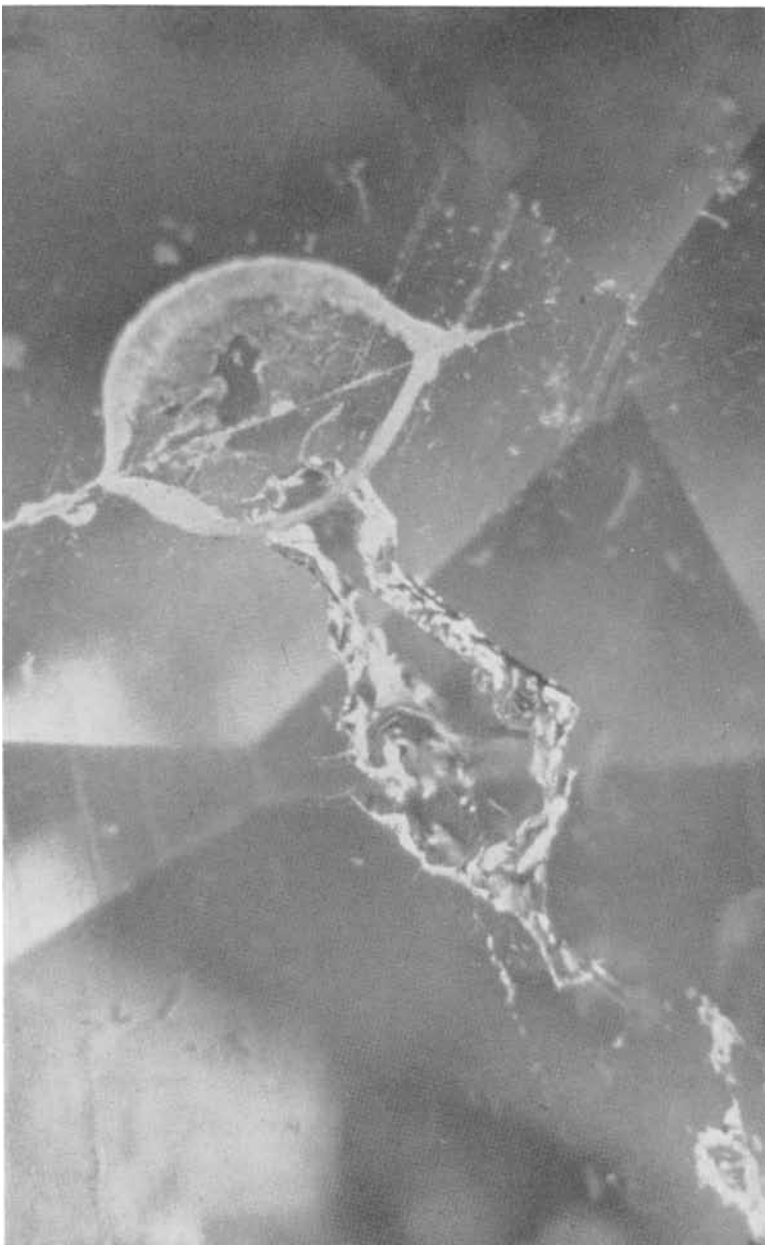

FIG. 3. Same inclusion as Fig. 2 (at 20 ×) showing minute fissure cleavage and evaporated residue on a facet of the gem.

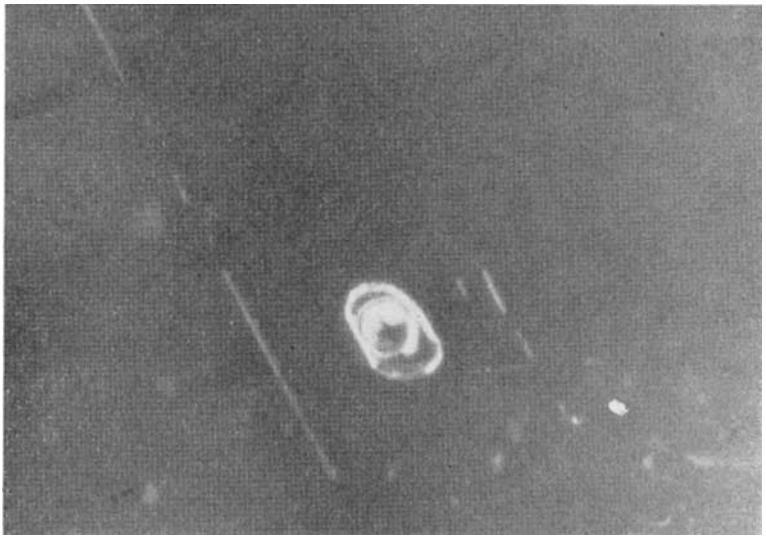

FIG. 4. Two-phase inclusion in beryllonite from Minas Gerais, Brazil. (N.M.N.H. Specimen #128109). (60 ×).

nahcolite, $NaHCO_3$, suggesting that the original inclusion was comprised of a sodium chloride bicarbonate solution and CO_2. The presence of CO_2 was also postulated by Dana and Wells (1899). Figures 2 and 3 show the inclusion before and after the escape of the liquid and gas components. The gas bubbles in this material comprise less than a third of the volume of the inclusion.

Gem beryllonite from Minas Gerais, Brazil, also has similar inclusions with the same crystallographic orientation. The tubular inclusions in the Brazilian beryllonite have a larger gas bubble which comprises more than half the volume of the inclusion cavity (Fig. 4).

The author wishes to thank Mr John S. White, Jr, for his critical reading of the manuscript and Mr Grover Moreland and Mr Richard Johnson for the preparation of polished samples.

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LE MARCHÉ COMMUN

By A. E. FARN, F.G.A.

XENOPHOBIA has been attributed to me by my friends (gemmologically speaking) but this is not so. Insular and conservative yes, but I enjoy my holidays particularly if I can manage to go abroad for them.

As a country, its people and tongue, I thoroughly enjoy France. Paris, the capital, has an excellent laboratory of which Monsieur J.-P. Poirot is the director. We have exchanged visits whilst on holiday and find we have an accord which bodes well for each country. When time permits perhaps I may have the pleasure of meeting other of our Common Market friends.

One such friend (an anglophile) is Monsieur Hubert Mornard. He runs the Brussels Laboratory in a very capable manner single-handed. He, shall we say, took the bull by the horns and came to London on a good-will visit just over a year ago and spent an agreeable period in and around Hatton Garden, the offices of the Gemmological Association and our laboratory.

One hears constantly of the work of eminent gemmologists of the larger laboratories for which all of the gemmological world and trade at large are grateful. In this persent day of synthetics founded upon isomorphous structures, seeded hydrothermal rubies, synthetic black opals, bombarded diamonds, and not forgetting non-nucleated third growth cultured pearls (which are a pearl-tester's nightmare), we do need well-equipped laboratories.

We are particularly grateful to our American friends who send out a stream of useful information in their *Gems and Gemology* (their *Journal of Gemmology*).

It is difficult in these days of staff shortage and increase of work to find time to digest all that is published, let alone comment upon it. A very old friend of the London laboratory is Mlle Dina Level, who writes beautifully on gemmological historic items in the bulletin of the Association Française de Gemmologie. Their bulletin no. 35 has an article entitled "Les Mystères de la Coupe Verte, racine d'émeraude, prase ou . . . ?" This is a typical Dina Level article written with great love and understanding of gemstones as only someone literate, French and poetic could hope to achieve.

Among other publications emanating from the Common Market (and there are many) is *Technica*, a jewellery magazine/

journal published in French and Flemish, which in itself gives it a unique flavour. It is quite interesting to read a subject in French when one knows most of the phrases and then read across the page its equivalent in Flemish. Among the many interesting articles on jewellery, watches and everyday news items (such as are found in their British counterparts over here) are gemmological notes chiefly emanating from Hubert Mornard. Apart from running his own jewellery business (two shops I believe) he finds time to run the laboratory gem-testing and writes up items of interest for its readers. Browsing through a few recent copies of *Technica*, I found a very succinct and workmanlike account of synthetic quartz samples donated to the Brussels laboratory by Sawyer Research Products Incorporated of Ohio, U.S.A. Among the specimens were a rough crystal of 1·051 ct and a golden-yellow stone of 52 ct. Due to the rapid growth in the autoclave, some anomalies occur in the crystal morphology. A description is given of the various faces, which with the appearance of the seed crystal within are reproduced in photographs. Mornard notes that the dichroism of synthetic yellow quartz is more obvious than that of burnt amethyst, and that natural quartz is more transparent to long-wave ultra-violet rays (3650Å) than synthetic quartz.

Among other stones tested were a 5·32 ct moldavite, a stained quartzite, an opal of bluish-black colour sprinkled with small iridescent points of blue and green on the cabochon surface and of blue only on its base. The opal was not porous, plasticized or apparently treated. No reaction to acid or acetone was found. Rather more than a treated opal it seems, but on sight it looked like a treated stone. Perhaps not noteworthy to some, but obviously a laboratory is expected to come up with an answer. A dealer can give an opinion which is not binding. This day and age of, dare one say, 'clever' techniques of gemmology aimed at the gemmologist make life very trying for the laboratory worker—particularly one on his own. Perhaps we shall all benefit from our entry into the Common Market; at least gemmologically speaking we have a common interest.

NOTES ON SYNTHETIC PRECIOUS OPAL

By P. J. DARRAGH, B.Sc.(Hons) and J. L. PERDRIX

Commonwealth Scientific and Industrial Research Organisation, Australia,
Division of Mineralogy

IN many compounds colour is caused by selective absorption and the resulting colour is of a complex nature, the absorption being caused usually by foreign ions in the structure. Bayliss and Males (1965) have shown that there is little or no difference in the chemical composition of precious and potch opal from the same areas. This suggests that the colour in opal is not due to impurities. It was recognized about the middle of the last century that the colours produced by precious opal were pure spectral colours, and hence were not related to chemical properties. Early efforts at synthesis of precious opal were directed towards some physical structure which would produce diffraction; however, these efforts were handicapped because the structure of precious opal was not deducible simply from optical effects. Its structure was discovered by Jones, Sanders and Segnit (1964) with further details given by Darragh and Gaskin (1966). CSIRO (1968) is the holder of patents for the production of opaline materials.

Precious opal is composed of uniformly sized silica spheres, which stack to form a regular array. The voids between the spheres are also regularly spaced and these act as optical discontinuities, giving rise to three-dimensional diffraction. The maximum wavelength (λmax) of the diffracted light is related to the radius of the sphere (R) and is dependent upon the type of stacking. For face-centred cubic stacking

$$\lambda max = 4{\cdot}74R,$$

and for hexagonal stacking

$$\lambda max = 5{\cdot}02R \text{ (Sanders 1968).}$$

Natural opal occurs in two distinct environments. In many parts of the world precious opal occurs associated with volcanic rocks, and such opal is also found in Australia, for example at Tintenbar. However, most of Australia's production of precious opal comes from a sedimentary environment. These differing environments produce two distinctly different types of opal, each having different optical properties. The smaller voids found in volcanic opal give it greater transparency, and the more uniform orientation of the particles produces broad bands of colour rather

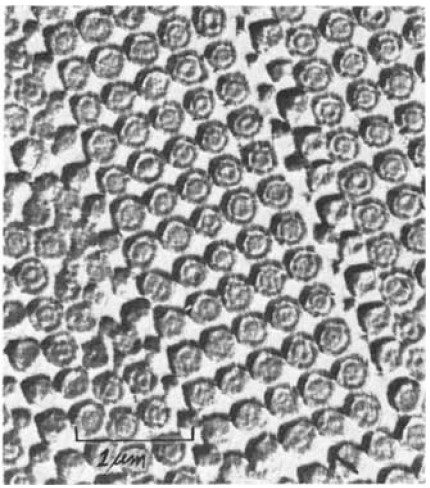

FIG. 1. Electron micrograph of etched surface of sedimentary opal showing concentric rings within the spherical clusters of silica.

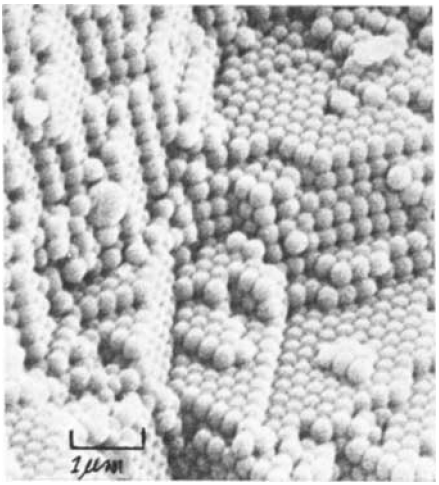

FIG. 2. Scanning micrograph of stacked latex spheres. By courtesy of Dr C. A. Anderson, CSIRO, Division of Textile Industry.

than a distinct pattern. Generally, etching of volcanic opals before examination by electron microscopy does not indicate structure within the sphere, although there are some exceptions—Rocky Bridge and Warrumbungle material for instance. On the other hand, sedimentary opals show detailed structures within the spheres (Figure 1). A primary sphere of 100-500Å diameter is often seen to be acting as a nucleus, with other similarly sized spheres surrounding it, giving a larger spherical cluster capable of diffracting white light. The expression above shows that spheres or clusters of spheres of 1700-3800Å diameter are required to diffract white light. It could be mentioned that similar diffraction effects have been observed in materials other than silica. For example, latex spheres of the correct size will produce prismatic colours (Figure 2). A similar effect is reported to occur in tobacco mosaic virus crystals (Wilkins *et al.* 1950).

Natural opals grow by the concentration of silica solutions and the subsequent precipitation of silica, even though the solubility of monomeric silica is only about 120 parts per million at room temperature. In the authors' first method, sodium silicate was used as the starting material for the growing of the spheres. It was found that this was too slow, that the spheres produced have too

large a range of particle size distribution (Figure 3), and that unless great care was taken the silica cross-linked to form sheets or needles rather than spheres. It has also been found that silica particles will grow by aggregation if dilute solutions of silicic acid are allowed to stand for some months. This is so slow that control of particle size has not been investigated.

Stöber, Fink and Bohn (1968) developed a method for the controlled growth of monodisperse silica spheres which could be used for instrument calibration, etc. and this became the basis of another method to produce opal. The starting material is a silicon ester, either tetraethyl orthosilicate or tetramethyl orthosilicate, and the technique produces uniform droplets of silicon ester suspended in a water-alcohol mixture. The droplets of ester are then hydrolysed by mild alkali, such as ammonia, to form spherical particles of hydrated silica. This process is adjusted to produce uniformly sized droplets and hence uniformly sized silica spheres (Figure 4), the actual sizes of which are controlled by the concentrations of water and ammonia in the system. It was found that more uniform spheres were obtained when the silicon ester was added slowly over a period of several minutes to a gently agitated mixture of the other

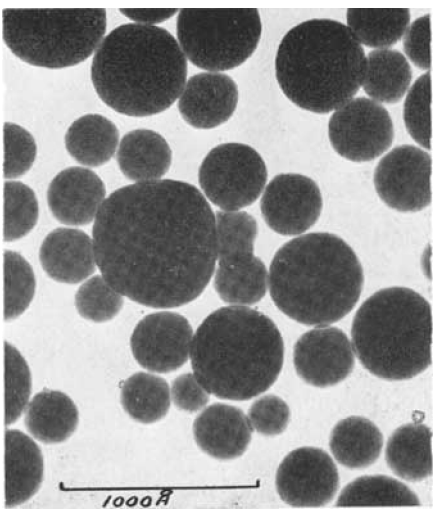

FIG. 3. Electron micrograph showing particle size distribution of silica spheres produced from sodium silicate.

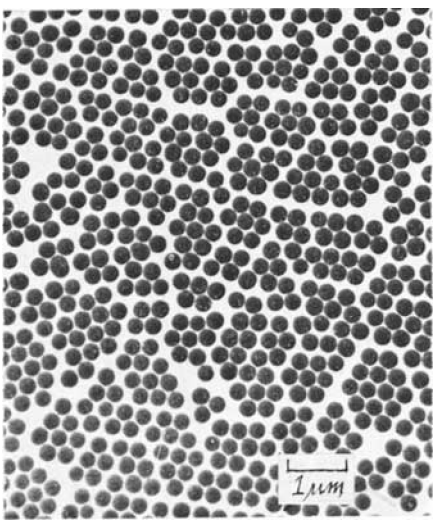

FIG. 4. Electron micrograph showing particle size distribution of silica spheres produced from tetraethyl orthosilicate.

reagents, with agitation being continued for half an hour or so after the addition is completed.

In order to achieve a narrow particle size distribution of the range required for precious opal, it is essential to control accurately both the concentrations and volumes used of the reagents, which should be of the highest purity. Figure 5 shows stacked silica spheres which diffract white light. These arrays were obtained by allowing the particles to settle over a period of several weeks. The final stage in the process is to harden the arrays of stacked spheres, and this has proved to be quite difficult.

The unconsolidated arrays of spheres made by these processes may show quite good colour when the voids are filled with liquid. If the liquid is removed, then the body becomes white and opaque due to the scattering of light and a considerable amount of colour is lost. A similar effect is observed in hydrophane opal. For best results, the refractive index of the liquid filling the voids should be close to, but not identical with, that of the silica spheres. However, to produce a material approaching natural opal these voids must be reduced in size or permanently filled.

The authors' first approach to this problem was to impregnate the arrays with plastic, which, by definition, would produce an

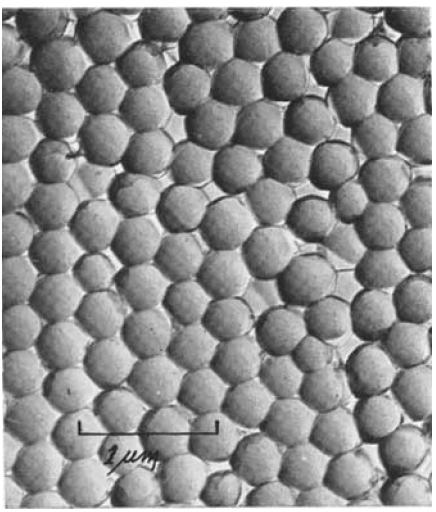

FIG. 5. Stacked spheres in synthetic opal as shown by the electron microscope.

imitation rather than a synthetic opal. This procedure is successful only if the shrinkage of the plastic on polymerization is very small. Impregnation with silica is much more difficult as the shrinkage is much higher and the added silica tends to shrink away from the spheres. Repetition of impregnation becomes more difficult as the permeability decreases.

The application of heat to produce partial sintering causes both the spheres and the voids to shrink, and quite good hardness and strength may be obtained at temperatures between 500 and 800°C. Most precious opal is amorphous, and heating creates another problem, since above about 800°C a phase change from an amorphous structure to crystalline tridymite takes place. A sample made from silicic acid heated for half an hour at 1200°C produced a mixture of cristobalite and tridymite; however, at lower temperatures it was found that sintering occurred without crystallization. This work is still being investigated by the authors.

In 1972 the authors learned that the New York jeweller, Benedict, had announced the coming sale of a synthetic opal early in 1973. A small sample of the material manufactured by Pierre Gilson, Saint Sulpice, Switzerland was made available to CSIRO. This is the only specimen which has been studied in detail by CSIRO, although some even better quality material was made available briefly for non-destructive investigation. The physical properties of the Gilson opal are well within the range covered by natural opal, so that no simple diagnostic test appears likely. As opal is an hydrous mineral, the water content of the Gilson opal was compared with that of some natural opals. A non-destructive test was desirable, so infrared spectroscopy was used. Although the Gilson opal contained considerably less water than most natural opals, it did contain detectable amounts comparable to those in some Queensland boulder opals studied by the authors—in the order of 3%.

Examination of the Gilson material in the electron microscope showed very many cracks in the opal (Figure 6), many of which have healed during manufacture. These cracks appear characteristic of Gilson material as shown in Figure 7. This is a scanning micrograph of a finished Gilson gem, again showing numerous cracks. These cracks are probably due to stresses developed during manufacture and are not the normal crazing types common in some opal. Although not obvious in the scanning mode, the

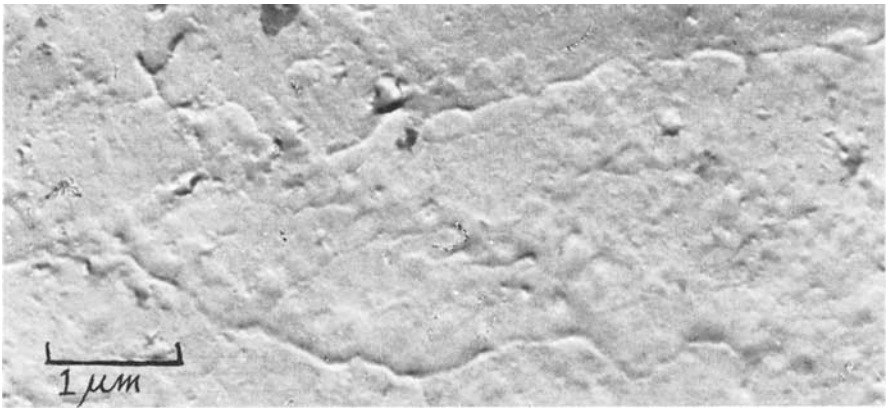

FIG. 6. Electron micrograph of synthetic opal produced by P. Gilson showing healed cracks.

internal structure of Gilson opal (Figure 8) as seen by transmission microscopy is quite different from any natural opal that the authors have examined.

Most opals found in nature are not pure silica, but contain small, however significant, amounts of other elements, notably aluminium and calcium. Table 1 lists some of the impurities found in precious opals from a number of areas together with their total water. When the Gilson specimens were examined in the electron microprobe, neither aluminium nor calcium were detected, yet the small amount of aluminium in the Californian sample is within the detectable range of this instrument.

The examination of the microstructure and the detection of aluminium and calcium require expensive specialized equipment not readily available to the gemmologist. Until further samples have been examined, the authors are not prepared to state that physical properties are likely to lead to positive identification. Even the presence of numerous cracks common to the two specimens could be misleading; however, at the present state of the authors' knowledge, this constitutes the easiest test for recognition of Gilson opal. The comments on Gilson synthetic opal in this article apply only to the original specimen supplied by P. Gilson to CSIRO. The authors have not examined any of the specimens in Plate 1.

The authors thank Dr J. V. Sanders and Mr B. Dawson for the electron micrographs.

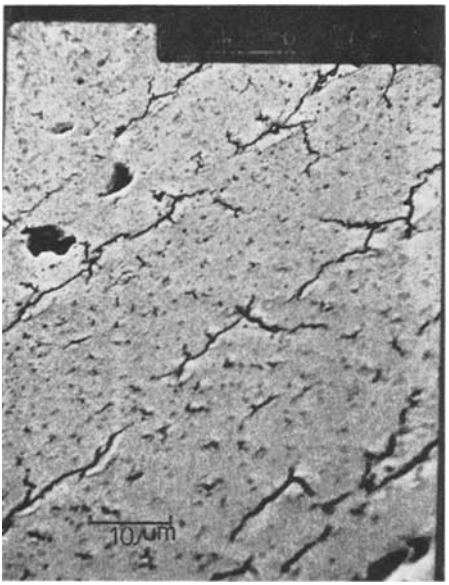

FIG. 7. Scanning micrograph of Gilson gem showing cracks.

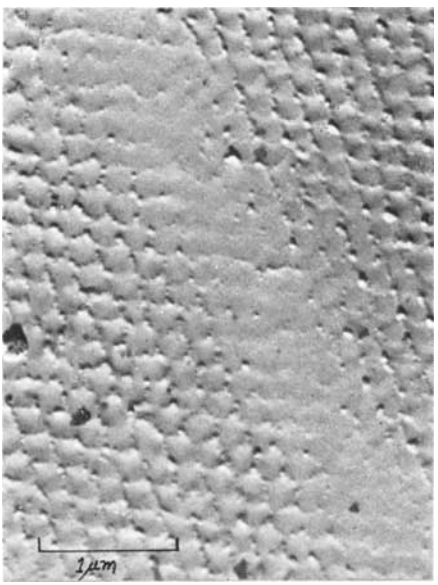

FIG. 8. Electron micrograph of synthetic opal produced by P. Gilson showing microstructure.

PLATE I. Specimens of the new Gilson synthetic black and white opal.

TABLE I

PARTIAL ANALYSIS OF PRECIOUS OPALS

Specimen:	1	2	3	4	5	6	7
Al_2O_3	0·7%	0·9%	1·6%	0·1%	2·5%	1·8%	1·3%
CaO	0·1	0·1	0·5	0·01	0·9	0·8	0·3
Fe_2O_3	0·06	0·2	0·2	0·1	0·3	0·2	0·2
MgO	0·02	0·04	0·09	0·005	0·1	0·05	0·05
Na_2O	0·06	0·2	0·05	0·04	0·4	0·4	0·05
H_2O	8·5	6·1	10·2	4·2	6·0	6·4	5·7

Specimen locality and type:

1. Mullumbimby, N.S.W.; volcanic
2. Mexico; volcanic
3. Indonesia; volcanic
4. California; volcanic
5. Lightning Ridge, N.S.W.; sedimentary
6. Coober Pedy, S.A.; sedimentary
7. Andamooka, S.A.; sedimentary

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TWO NOTES

By M. J. O'DONOGHUE, M.A., F.G.A.

1. GILSON SYNTHETIC RUBY

THROUGH the kindness of M. Pierre Gilson the writer recently received a large piece of the new synthetic ruby manufactured at Campagne-Lez-Wardrecques in the Pas de Calais.

The crystal is of tabular form displaying uneven upper and lower pinacoids, pyramidal, prism and rhombohedral faces. Some of the faces show striations, and from two faces protrude pieces of the platinum wire used to suspend the seed in the autoclave during manufacture.

The colour varies from orange to a dark red, reminiscent of Siam ruby. Dichroism is marked showing the same two colours. The absorption spectrum is typical for ruby, though with no emission line—this is probably due to an iron content, as the dark red colour seems to suggest. There is only a faint luminescence under ultra-violet radiation and the stone appears a very dark red through the Chelsea colour filter.

The inclusions are those to be expected in a flux-melt manufactured material, "paint-splashes", twisted veils and a haziness in some parts which presumably are adjacent to the seed. The R.I. was measured at 1·764 and 1·776.

The seed was visible when the stone was examined through the pinacoid face, this direction also giving the best colour, more like ruby than in the other directions. I am grateful to Mr Keith Mitchell for this observation.

Although this particular specimen is rather dark, I have seen others of a much lighter shade of red, inclining to pink. These specimens were in the form of groups of thin platy crystals, which are offered for sale presumably as an ornamental material, as they were too thin to cut; this form of ruby has also been offered by the makers of the Kashan synthetics.

It remains to be seen whether M. Gilson produces a fine-coloured stone; experience with his other productions suggests that this will not be far off.

2. A NEW DOUBLET TO IMITATE DIAMOND

THE writer recently received, through the kindness of M. Eugène Naftule, of the firm of Naftule, Geneva, three specimens of a doublet made with a crown of synthetic corundum and a pavilion of strontium titanate. At first glance the fire still seems to be considerable and greatly in excess of that to be expected from diamond. On one of the stones the join is so far below the girdle as to show a prominent ring which is visible without a lens; the other specimens are better made and the junction coincides with the girdle. The crown gives a normal R.I. for corundum and the stones are free from heavy inclusions, though the ladder-like cracks typical of strontium titanate were visible in the pavilion of all three stones.

TEN TANZANIAN COLOURLESS GROSSULAR GARNETS AND THEIR PHYSICAL CHARACTERISTICS

By T. F. ZOOK, M.A., F.G.A.

TEN colourless grossular garnets were found in a parcel of eighty-one purchased from a company which formerly had owned the mine from which they were taken in Tanzania. The garnets ranged from three and a half to four millimetres and were cut in modified brilliant-cut form.

The group of ten had a total weight of 2·43 carats. The specific gravity of the entire group by the hydrostatic method was 3·62.

Only four stones gave a clear-cut refractive index reading of 1·735. Six stones gave readings indicative of anomalous double

refraction with five readings showing a range from 1·732–1·738 and the sixth showing a refractive index from 1·735–1·738.(1) Many inclusions were found in the stones with a refractive index range and fewer inclusions were found in the four stones which gave a single refractive index. However, all ten stones showed evidence of anomalous double refraction when examined with the polariscope.

All ten colourless grossular garnets fluoresced a strong apricot colour under short-wave ultra-violet light and nine fluoresced a weak apricot under long-wave ultra-violet light. The tenth garnet was an exception in that it fluoresced apricot colour more strongly under long-wave ultra-violet light than it did under short-wave. A mirror was placed under the garnets while performing this test and all showed a translucency to ultra-violet light.(2)

According to Anderson most colourless or nearly colourless stones do not show absorption bands, since in such stones the colouring oxides which produce bands are absent; however, some off-colour white diamonds (e.g. Cape diamonds), synthetic rutiles, and white zircons do show absorption bands.(3) Therefore, it seemed pertinent to examine these colourless grossular garnets with the Beck prism spectroscope. The spectroscope scale showed that there

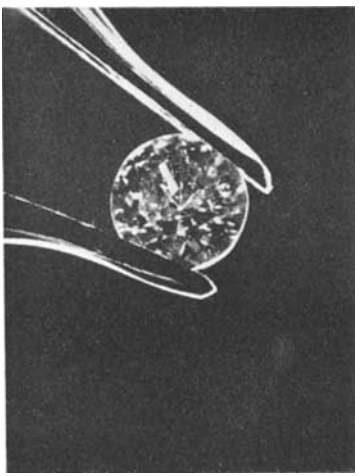

FIG. 1. Breadcrumb-like and bubble inclusions. 10×.

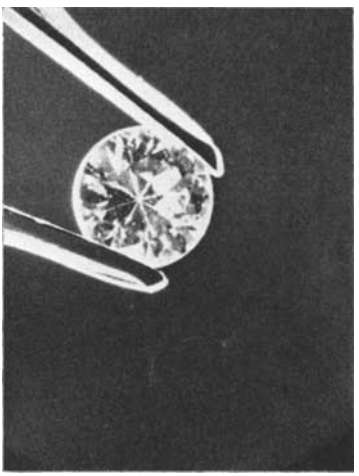

FIG. 2. Fingerprint inclusion. 10×.

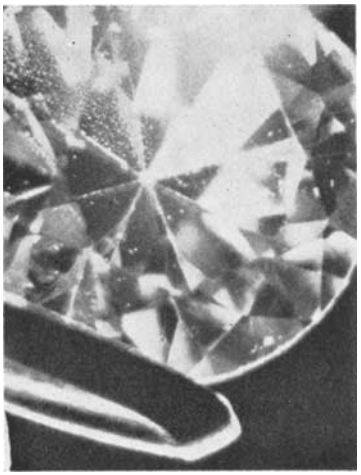

FIG. 3. Same stone—fingerprint inclusion. 30 ×.

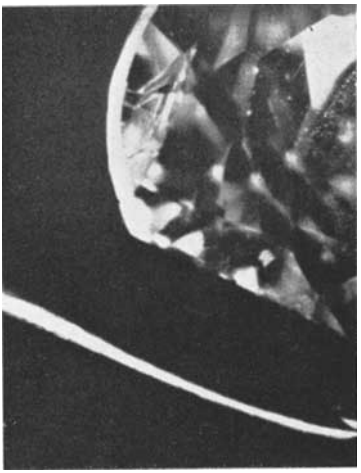

FIG. 4. Two-phase inclusion. 30 ×.

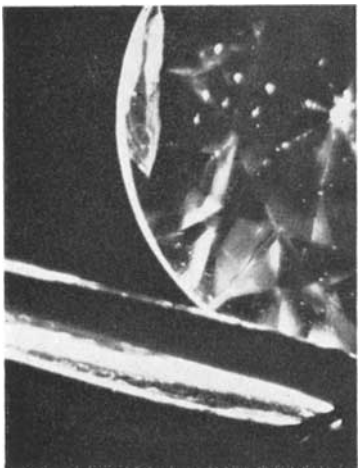

FIG. 5. Three-phase inclusion; octahedral and tube inclusions. 30 ×.

FIG. 6. Tube inclusion. 30 ×.

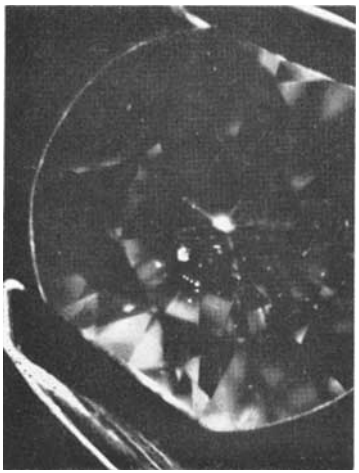

FIG. 7. Bubble-chain inclusion. 10 ×.

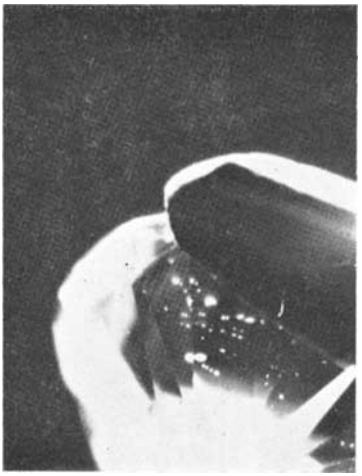

FIG. 8. Same bubble-chain inclusion. 30 ×.

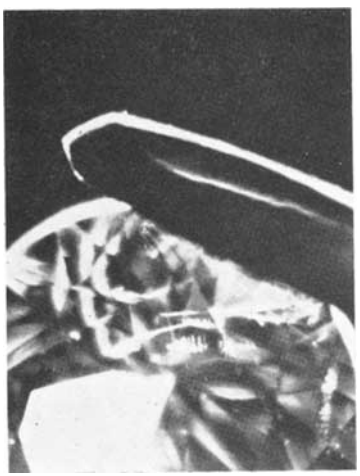

FIG. 9. Feathers in parallel orientation. 30 ×.

FIG. 10. Ladder-like inclusions. 100 ×.

was a sharp cut off in the blue at 4900 Å and absorption in the red from 6750–7000 Å for all ten garnets in the study.

Inclusions found in the ten garnets included:—

Breadcrumb-like and proliferated bubble inclusions (Fig. 1)
Fingerprint inclusion (Figs 2 and 3)
Two-phase inclusion (Fig. 4)
Three-phase inclusion (Fig. 5)
Octahedral inclusions (Fig. 5)
Tube inclusions (Figs 5 and 6)
Bubble chains (Figs 7 and 8)
Feathers in parallel orientation (Fig. 9)
Ladder-like inclusions (Fig. 10) which at higher magnifications of 200 × resolved into parallel lath-like forms (not shown).

From close examination of the first three photomicrographs (Figs 1, 2 and 3), it can be seen that care must be used in the identification and differentiation of colourless grossular garnets from colourless synthetic spinels. The slightly higher refractive indices of the colourless grossular garnets together with their apricot fluorescence should be decisive determinants in their separation from synthetic colourless spinels.[4]

REFERENCES

1. Other researchers have reported slightly different results, for example: Bank, H. *Transparenter weiss-farbloser Grossular aus Tanzania*, Z.Dt. Gemmol. Ges., 1971, **20,** 1, 22-25, (*Mineralog. Abstr.*, Jan. 1972, **23,** 2, 106, #72-1183) reported *n* 1·732-1·736, S.G. 3·65, based on the examination of one colourless grossular garnet from Tanzania.
Liddicoat, Richard T., Jr, *Handbook of Gem Identification*, G.I.A., 9th edn, 1972, p. 363, states that the R.I. of colourless grossular garnet from Tanzania is slightly above 1·73 and the specific gravity is about 3·60.

2. Liddicoat, op.cit., pp. 363-364, states that grossular garnet shows a weak green fluorescence to short-wave and a weak orange to long-wave ultra-violet light, and the strong orangy-yellow fluorescence to x-ray which characterizes grossular is present.

3. Anderson, B. W. *Gem Testing*, 8th edn, Butterworth & Co. Ltd, 1971, pp. 146-147.

4. Anderson, op.cit., p. 180, states that most white synthetic spinels fluoresce with a strong bluish glow under short-wave ultra-violet light.

Gemmological Abstracts

BANK (H.). *Aus der Fortbildungspraxis.* (Items from further studies). Z. Dt. Gemmol. Ges., 1974, 23, 3, 217-223.

The author discusses five different items. Differentiating between natural spinel and taaffeite is sometimes difficult, as is occasionally recognizing synthetic spinel; chalcedony can be mistaken for opal; synthetic spinel, glass and garnet are sometimes mixed up; and lastly the author discusses zonar built emeralds, synthetic "sandwich-emeralds" and emerald/emerald doublets. E.S.

BANK (H.). *Hochlichtbrechender vanadiumhaltiger Beryll aus Minas Gerais, Brasilien.* Vanadium-containing beryl with high R.I. from Minas Gerais in Brazil). Z. Dt. Gemmol. Ges., 1974, 23, 3, 212-213.

A new beryl from the Minas Gerais district in Brazil with emerald colour was shown to be coloured by vanadium (not red under the Chelsea filter). It had a very high R.I. (1·595—1·586), high density (2·75) and also high double refraction (from 0·008 to 0·01). E.S.

BANK (H.). *Durchsichtiger grüner Grossular (granat)—Unterschiebungen bezw. Imitationen.* (Transparent green grossularite (garnet)—substitutions and imitations). Z. Dt. Gemmol. Ges., 1974, 23, 3, 195-198.

Characteristics of grossularite, also known as "Transvaal Jade", are enumerated. Instead of the chrome-containing grossularite, chrome-containing tourmaline (specially from Tanzania) is sometimes sold. Comparatively easily recognizable are glass, and grossularite/glass doublet imitations, although lately grossularite doublets as well as glass of very similar colour and same R.I. as grossularite have been on the market and it may need an examination under the microscope to distinguish them. E.S.

BANK (H.). *Durchsichtige Grüne Enstatite aus Tansania.* Transparent green enstatites from Tanzania). Z. Dt. Gemmol. Ges., 1974, 23, 3, 192-194.

Orthopyroxenes (or orthaugites) are important rock-forming minerals rarely used as gems. Sometimes they are found in transparent form and cut—enstatite, bronzite, hypersthene. Their characteristics are enumerated and a new find of green enstatite from Tanzania is described. E.S.

BANK (H.). *Farbloser durchsichtiger geschliffener Whewellit.* (Colourless transparent cut whewellite). Z. Dt. Gemmol. Ges., 1974, 23, 3, 189-191.

Another colourless transparent substance which was found in a cut and polished condition was whewellite, a calcium oxalate; it is monoclinic, usually forms small crystals, often heart-shaped twins, hardness 2½, density 2·23, R.I. 1·49-1·65, has a mother-of-pearl lustre, found in Germany, USSR, Bohemia and Alsace (France), often together with anthracite. E.S.

BANK (H.), BERDENSKI (W.), OTTEMANN (J.) and SCHMETZER (K.). *Durchsichtiger rötlicher eisenhaltiger Rhodonit aus Australien.* (Transparent reddish iron-con-containing rhodonite from Australia). Z. Dt. Gemmol. Ges., 1974, 23, 3, 180-188.

Detailed examination of a rhodonite from Australia, with density and refractive index readings, chemical composition and absorption values. Bibliography of 21 items. E.S.

BUNDY (F.P.). *Superhard materials.* Scientific American, 1974, 231, 2, 62-70. 7 illus. 4 graphs and 1 table.

An important article, written by one of the team who produced the American synthetic diamonds, discusses the hardness of substances and the methods used to evaluate hardness, with particular reference to diamond and boron nitride. Corundum, the mineral ranked next to diamond on Mohs's scale, is said to be only a fifth as hard as diamond. The Knoop indenter hardness measurement is discussed in relation to Mohs's scale and to the Mohs-Wooddell scale which depends on the loss of weight after grinding for a standard time. Covalent bonding produces hard materials, while substances bound ionically are relatively soft. Comparison is made between the crystal lattices of diamond and boron nitride. The cleavage of diamond is referred to and much is told of the plastic flow of diamond under pressure and heat. Type II diamonds deform more easily than Type I diamonds. There is a discussion of the thermal conductivity of diamond and in this connexion much is told of uses and possible uses of diamond in the realm of "heat sinks" and as semi-conductors. It is said that in principle it is not impossible to find a substance harder than diamond, but the chances are small. An article which must be read. R.W.

COLLINS (A. T.). *Visible luminescence from diamond.* Industr. Diamond Rev., 1974, 131-137. 10 figs.

The major emission systems in diamond which give rise to luminescence in the visible region are reviewed. Blue photoluminescence is characteristic of type Ia diamond; blue cathodoluminescence is often observed from all types of natural diamond, but is particluarly strong for type II samples. Most unirradiated synthetic diamonds exhibit a green cathodoluminescence; green photoluminescence is seen in natural diamonds which have been subjected to radiation damage and thermal annealing. No H4 cathodoluminescence (zero phonon line at 496·2 nm) has ever been observed from synthetic diamond. Red cathodoluminescence in the 575 nm system is characteristic of type II or type Ib diamonds which have undergone radiation damage. Emission characteristic of radiation damage may also be observed in the vicinity of dislocations in the diamond. R.A.H.

CROWNINGSHIELD (R.). *Developments and Highlights at the GIA's Lab in New York.* Gems & Gemology, 1973/4, XIV, 7, 212-215; 8, 230-240. 27 illus.

Fade tests on gamma irradiated quartz and topaz are discussed and some remarks are made on the turquoise used in south-west American made jewellery, much of which is pale coloured and not treated in any way, although one piece was found to have been dyed. Something is told about dyed lavender jadeite and of experiments carried out on this material. More notes on the laser drilling

of diamonds are given, and mention is made of a misidentification by a jeweller, who scratched the soft direction of a diamond with the hard direction of the test stone. Several cases of damage to diamonds are reported where stones had been set too close together and damaged one another. A new opal doublet had an irregular back consisting of powdered ironstone, some opal, and plastic, probably an epoxy resin. Another unusual opal is mentioned. Damage to stones which are heat sensitive is recorded. A black tourmaline needle travelling from culet to table produced a striking picture by reflection and gives thought to interesting possibilities. Yellow conch pearls not often seen are mentioned. A parcel of natural sapphires were found to fluoresce under both ranges of ultra-violet light and this was found to be due to the stones being heavily oiled. Greenish-yellow or yellowish-green 'citrines' which look like chrysoberyl or some peridot are mentioned and there is some evidence that these stones have been treated by gamma radiation plus gentle heating: they may fade. Unusual diamond imitations are described—one, a yellow stone which fluoresced sulphur yellow under ultra-violet light and by its absorption spectrum was found to be europium "doped" yttrium aluminate, and the other a light brown stone which turned out to be gadolinium gallium garnet (G.G.G.). Problems in the testing of carved articles are discussed. R.W.

ELLINGHORST (G.) and BRÜCK (G. K.). *Über die Haerte von Diamanten.* (About the hardness of diamonds). Z. Dt. Gemmol. Ges., 1974, 23, 3, 207-210.

The authors discuss the crystallography of the diamond crystal. They point out the connexion between cleavage and hardness. This means that the maximum hardness of a diamond is its octahedron face; this fact is applied in diamond cutting—"softer" parts of the diamond can be worked fairly easily. E.S.

EPPLER (W. E.). *Natural and Synthetic Turquoise.* Gems & Gemology, 1973/74, XIV, 8, 226-229. 5 illus.

A short article on natural and synthetic turquoise, including some man-made simulants. It is suggested that the Gilson synthesis was developed from the original work of Hoffman in 1927. Most of the study has been carried out by microscopic examination of thin sections. Rather surprisingly the Eilat Stone from Israel is classed as a turquoise. R.W.

LIDDICOAT (R. T.). *Developments and Highlights at the GIA's Lab in Los Angeles.* Gems & Gemology, 1973-4, XIV, 7, 200-207; 8, 248-255. 36 illus.

A diamond which exhibited an unusual fluorescence is reported, as are some other diamonds with unusual characters, such as a diamond with a "halo", a diamond with a natural on the culet and a diamond with an inclusion which was reflected from all the crown facet surfaces. Cameos made of a clam shell and another of green beryl are mentioned. An "alexandrite" glass and "Venetian blind" inclusions in a natural sapphire are described. Said to have come from British Columbia was a cabochon which was found to consist of nephrite with grossular garnet and/or andradite garnet. A note is given on synthetic turquoise and a chrysoprase ring with a rotating setting. Interesting inclusions in a diamond and in glass are mentioned. Unusual amber pieces are described as is a jadeite

cabochon showing a coarse pyroxene crystal. A strange way of forming a glass bead is illustrated as well as a Colombian emerald full of pyrite crystals. A "fingerprint" pattern of bubbles was seen in a synthetic sapphire. A star sapphire with a double star effect was assumed to be a twin. A rich blue kyanite, probably from East Africa, was examined. R.W.

MALES (P. A.). *Brazilian precious opal.* Australian Gemmologist, 1974, 12, 2, 56-57.

Describes the examination of a number of opals from Brazil and compares them with the opals found in Australia. The writer mentions that the Brazilian opal does not react to long-wave ultra-violet light, as does the similar opal found in Australia. There is a short list of references. R.W.

MARINER (T. H.). *Crystal-balling future synthetic gemstones.* Gems & Gemology, 1973/74, XIV, 8, 241-247. 9 illus, 4 diagrams.

A survey to consider what synthetics would be likely to be produced in the future. A list of the stones which are currently synthesized, as far as the twenty principal gemstones are concerned, the method of growth in each case being given. The reason why some stones which could be grown are not, is probably economic. Jadeite might be the next stone to be synthesized, but whether it would be a true synthetic or not is debatable. It is considered that the synthesis of organic gem materials is impossible. Nothing is said of the likelihood of other man-made stones coming on the market. R.W.

MARSHALL (C. E.). *The Jet Age.* Australian Gemmologist, 1974, 12, 2, 42-54 8 illus, 2 graphs and 1 table.

The article is the report of the Presidential address given to the Gemmological Association of Australia. In this a very full study of jet is made. The history of its use in ornamentation through the ages is given as well as details of the recovery and working of Whitby jet and the rise and fall of the industry. The material itself and its relation to the coals are discussed. The physical and optical properties are given with much information which was found out by thin-section examination. This important article is completed with an excellent list of references. R.W.

MATTHEWS (W. L.). *Gemstone occurrences at Sisters Creek.* Technical Rept Dept Mines Tasmania, 1973, 16, 13-15. 1 fig.

Zircon and sapphire are found in the beds of two small creeks, about 15 km W. of Wynyard, NW. Tasmania. The minerals may either be derived from Devonian granite or from Precambrian sedimentary rocks. E.L.M.

MENDELSSOHN (M. J.) and MILLEDGE (H. J.). *Computing the consequences of differential growth, etch and abrasion rates in diamond.* Diamond Research 1974, 26-32. 9 figs.

It is shown that computer graphics can be used to systematize quantitative information on diamond morphology in the three main categories—natural, synthetic, and shaped. Once such a system has been set up, it should be possible not only to analyse the history of natural diamonds but to specify the conditions for growth of synthetic diamonds of a particular morphology and to analyse the time-honoured procedures used in diamond-cutting. R.A.H.

MORNARD (HUBERT). *Un examen Difficile.* (A difficult examination) Technica, 1974, 336, 360-363.

In the examination of an emerald, which at first sight could be taken for a Chatham or Gilson, the distribution of canals in strands gave an aspect of certain hydrothermal structures without the typical curled or twisted feathers usually seen in current synthetics. Refractive indices 1·573-1·580 plus S.G. 2·71 indicated Colombian emerald. Inert to S.W. lamps, inert to Chelsea filter, but distinctly reddish between crossed filters. Spectroscope showed a doublet in red, 6850Å and 6700Å, and a diffuse band in the region of 6500/6450Å. Under 12 × magnification two flaws showed a jagged/tufted structure closely resembling flux-fusion pattern. The strands formed by numerous minute liquid canals were rigidly sharp and parallel, with no signs of "flow" structure due to convection currents of mother solution usually seen in artificial stones. Under 200 × magnification the structures seen in the flaws appeared to have contained colouring mixture (chromium?). Confirmation by Professor Duyck based on R.I., S.G., inertia under U.V.L., the absence of accompanying elements seen in synthetics, plus the arrangement perpendicular to the flaws which gemmologists describe as "rain". A.E.F.

MÜCKE (A.), STRUNZ (N.) and WILK (H.). *Chalcosit-Gestein von Ambatofinandrahana/ Madagascar.* (Chalcosite type rock from Ambatofinandrahanan in Madagascar). Z. Dt. Gemmol. Ges., 1974, 23, 3, 169-177.

The article is illustrated with 13 photomicrographs, one in colour, and a map of Madagascar showing the location of the find, which is in the centre of the island. The chalcosite consists of about two thirds of a reddish-brown potassium feldspar and green plagioclase, which have definite contact lines and thus present a decorative colour contrast, and about a third of quartz and mica, mainly biotite, but also some muscovite; the biotite is very black and increases the beautiful colouring. Throughout the rock there are veins of copper. The copper silicate chrysocolla in the oligoclase is of secondary formation. E.S.

NICHOL (D.). *Opal occurrences near Welbourn Hill Homestead.* Min. Resrcs Rev., South Australia, 1971, 135, 164-168. 1 fig.

Precious and common opal occur in Lower Cretaceous or Tertiary sediments at Ouldburra Hill and Sarda Bluff, west of Welbourn Hill, 900 km northwest of Adelaide, South Australia. The geology of the occurrences is briefly described and an origin for the opal involving entrapped supergene water is proposed. Petrographic descriptions of the opal and enclosing rock type are appended. J.L.K.

POUGH (F. H.). *Three fashionable minerals.* Mineral Digest, 1973, 5, 24-32.

Chrysoberyl, autunite and erythrite are reviewed and illustrated in high-quality colour. The finest pure autunite comes from the Daybreak Mine, Spokane, Washington, though crystals from Limoges, France, and Guarda and Urgereica in Portugal make the finest specimens. The finest erythrite comes from the Bou Azzer mine in southern Morocco. Autunite is $Ca(UO_2)_2(PO_4)_2$ $10\text{-}12H_2O$. Erythrite is $CO_3(ASO_4)_2.8H_2O$. M.O'D.

REAM (LANNY R.). *Washington gem jade.* Lapidary Journal, 1974, 28, 4, 708.

A new location for nephrite has been found in the western foothills of the Mountains about 7 miles west of the community of Darrington. The nephrite is found in serpentine at an elevation of 3,000 feet on the south side of Mt Higgins. Colours include green to grey, which are the commonest, blue-grey and yellowish-grey. Some white pieces contain gold and silver wires. M.O'D.

RIEMAN (HARRY M.). *The blue rock called lapis lazuli.* Lapidary Journal, 1974, 28, 5, 866-870.

A review of the types, localities, tests and imitations relating to lapis lazuli. Some lapis is produced by mines in California and Colorado. M.O'D.

SCHMETZER (K.) and MEDENBACH (O.). *Chrom-diopsid aus Kenya.* (Chrome-diopside from Kenya). Z. Dt. Gemmol. Ges., 1974, 23, 3, 178-179.

During routine tests on the absorption spectra of vanadium-containing cornerupine from Kenya an individual light-green stone was separated. It was found to be chrome-diopside, density 3·31. Chemical composition and absorption spectra are given. Previously these stones were only found in Finland, the USSR and rarely in Brazil. E.S.

SOROKIN (YU. P.) and PEREVOZCHIKOV (B. V.). *Ruby from glimmerites of the Rai-Iz ultrabasic massif (Polar Urals).* Zap. Vses. Min. Obshch., 1973, 102, 692-696, (in Russian). 3 figs.

The glimmerite vein complex occurs in rocks of the dunite-harzburgite series. The phlogopitic glimmerites consist of phlogopite 92·67, ruby 5·13, and chromite 2·20 wt%. Isometric grains of ruby have a short-columnar and prismatic habit and are polysynthetically twinned along the $(10\bar{1}1)$ plane. Morphometric data of the mineral are included. The carmine-red ruby has a vitreous lustre, hardness 1830-2370 kg/mm^2, sp.gr. 4·003; ε 1·766-1·722, ω 1·776-1·784. Chemical analysis gave TiO_2 0·39, Al_2O_3 92·04, Fe_2O_3 2·86, CaO 0·93, Cr_2O_3 3.72, V_2O_5 0·06, = 100·00. The optical absorption spectrum shows a maximum in the 550 nm wavelength region. X-ray powder data are included. R.A.H.

SURROCA (ALFREDO). *El cuarzo como cristal piezoelectrico.* (Quartz as a piezo-electric crystal). Boletin del Instituto Gemologico Español, 1973, II, 8, 9-21.

An illustrated article summarizing the history of research into the piezo-electric properties of quartz and comparing them with those displayed by other crystalline materials. M.O'D.

SUTHERLAND (F. L.) and HINGLEY (J. E.). *Gemstones in and out of the Australian Museum collections.* Australian Gemmologist, 1974, 12, 2, 31-35. 5 illus.

Tells of the growth of the collection of gemstones in the Australian Museum in Sydney. Owing to repeated depredations by burglars the main and valuable part of the collection is kept in bank vaults. The collection has, besides the important Australian gemstones, a wide variety of gems from other countries. Some of the specimens are of large size. R.W

THORNTON (A. G.) and WILKS (J.). *The polishing of diamonds in the presence of oxidizing agents.* Diamond Research 1974, 39-42. 11 figs.

The presence of an oxidizing agent ($KClO_4$ or KNO_3) considerably alters the mechanism of the polishing of diamond by diamond powder on a scaife and gives a much smoother surface. R.A.H.

ZARA (LOUIS). *The tourmaline.* Mineral Digest, 1973, 5, 33-46.

The first instalment of a series on the tourmaline reproducing in colour the illustrations form A. C. Hamlin's The Tourmaline (though this is not stated). The early search for tourmaline in the Mount Mica area of Maine is recounted. M.O'D.

ZEITNER (JUNE CULP). *Quartz gems, the lapidary favorite.* Lapidary Journal, 1974, 28, 4, 612-622.

Interest in and use of the quartz gems are increasing and prices are rising as a consequence. Top quality jasper may cost up to $50.00 for a thin slab and rough chrysoprase may cost up to $75.00 a pound. M.O'D.

ANON. *Passion for Opals.* Mineral Digest, 1973, 5, 80-85.

An account of the work of Dr Archie Kalokerinos on the opal of Australia with magnificent coloured illustrations. M.O'D.

BOOK REVIEWS

CHUDOBA (Karl F.) and GÜBELIN (Eduard J.). *Edelsteinkundliches Handbuch.* (Handbook of information on precious stones). Wilhelm Stollfuss Verlag, Bonn, 1974. pp. 409. Illustrated in black-and-white and in colour. DM 65.

The new edition of this well-known text follows familiar lines. The first 160 pages are occupied by a glossary including cross-references to later sections of the book and details of synonyms, incorrect names and constants. Following this section is an account of the crystal systems and other physical and chemical data. The section on absorption spectra is expanded and improved in this edition with clear diagrams of spectra pertaining to the newer synthetics.

As may be expected in a book by these authors, the chapters on inclusions are comprehensive. Although illustrations in the text would have been useful here (and generally throughout the work), there is a booklet of black-and-white photographs of inclusions in a pocket at the end of the book.

A chapter on synthetics includes such unlikely candidates as BaF_2 and MgF_2, the first of which is slightly water-soluble; but there is no mention here or anywhere in the book of gadolinium gallium garnet, now on the market as a cut diamond simulant, nor of Gilson synthetic opal. This section is, however, very well written

and comprehensive. A reading of Linde for Gilson on p. 340 is one of the rare misprints.

For a book of this size and scope the coloured illustrations are not worthy and the world map of gemstone deposits is too crowded. A more serious criticism is the presence of material in the body of the book which appears neither in the glossary section nor in the short index. However, the usefulness of the work is considerable. M.O'D.

DESAUTELS (Paul E.). *Rocks and minerals.* Ridge Press/Hamlyn, London, 1974. Illustrated in colour. pp. 159. £2·50.

The illustrations, which occupy a full page in most cases, are already familiar to many readers, since they emanate from the Smithsonian Institution. Apart from the cheapness, this book closely resembles a number of others which have appeared during recent years. The paper leaves a good deal to be desired and a bibliography would have been useful. M.O'D.

GILMAN (J. J.). *The art and science of growing crystals.* John Wiley & Sons, New York and London, 1963. pp. ix, 493. £13·60.

Beginning with general principles this major guide to crystal growth covers the specific substances, metals, organic compounds, sulphides, silicon, silicon carbide and ice under the general heading vapour growth, elements, ionic salts, silver halides, hydrothermal growth, and molten salt solvents are included under the heading precipitation from liquid. Further sections cover solidification, including the Verneuil method, and the final section deals with recrystallization. Each chapter includes a bibliography. M.O'D.

KRÜGER (Karl). *Das Reich der Mineralien und Gesteine.* (The kingdom of minerals and stones). Safari-Verlag, Berlin, 1974. pp. 383. Illustrated in black-and-white. DM 29·80.

An account of the present-day work of the mineral prospector and description of the methods of recovery of strategic minerals, this book brings knowledge of this field up-to-date. Well-drawn diagrams illustrate the modes of excavation and the geological formations from which the ores are recovered. Although useful lists of active companies are included, there is no bibliography. M.O'D.

LAUDISE (R. A.). *The growth of single crystals.* Prentice-Hall, Inc., Englewood Cliffs, 1970. pp. xv, 352. £9·25.

This excellent introductory work, the best by far that I have seen in monograph form on this subject, forms part of the *Solid state physical electronics* series. Each form of crystal manufacture is related and illustrated by well-drawn diagrams in the text; there are subject and author indexes in addition to references given at the end of each chapter. M.O'D.

LOBACHEV (A. N.), editor. *Crystallization processes under hydrothermal conditions.* Translated from the Russian. Consultants Bureau, New York, 1973. pp. viii, 255. £17·25.

This work froms part of the series *Studies in Soviet Science.* The experiments described took place in the Hydrothermal Synthesis Laboratory of the Institute

of Crystallography, Academy of Sciences of the USSR. It includes accounts of the synthesis of zincite, the oxides of titanium, sodalite and the lithium silicates. Each chapter includes a bibliography. M.O'D.

MEGAW (Helen D.). *Crystal structures: a working approach.* W. B. Saunders Co., Philadelphia, 1973. pp. xviii, 563. £9·30.

This book forms part of the series *Studies in physics and chemistry* and sets out to cover the crystallographic concepts and to include accounts of representative structures with additional notes on thermal effects, treated from the geometrical rather than the thermodynamic viewpoint. There is a classified bibliography, an authors' index and a formula index as well as a list of references pertaining to each chapter; this is placed at the end, perhaps not the ideal position. Altogether this is a first-class book and is directed at readers with no first-hand knowledge of crystallography but with some general physical background. M.O'D.

SCHOON (Theo). *Jade Country.* Jade Arts, Sydney, 1973. Illustrated in colour. pp. 143. $5·95.

The author has studied Maori art for many years and this book is described as an episode in his life. It is lucidly written, and, for the price, very well illustrated with coloured plates of most types of New Zealand jade. There is an account of the jade trade in Hong Kong, and some of the author's designs are shown. M.O'D.

SMITH (Norman R.). *Users' guide to industrial diamonds.* Hutchinson Benham, London, 1974. pp. 352. £4·50.

Although the greater part of this well-illustrated book deals with the employment of diamond in such works as the construction of grinding tools, borers, glass and stone tools, much of the information is more easily assimilated here than in other larger books; indeed, comparatively little has been brought together in monograph form previously. The chapter on "diamond cut diamond" contains some information on the use of diamond in the watchmaking and jewellery industries. M.O'D.

VILLIARD (Paul). *Gemstones and minerals.* Winchester Press, New York, 1974. pp. xi, 228. Illustrated in black-and-white and in colour. £3·95.

Subtitled a guide for the amateur collector and cutter, this book, which is quite cheaply priced, is quite accurate and useful. The section on the fashioning of gemstones appears to be lucidly written and that on the materials themselves comprehensive. For readers in North America the details of mine availability will prove valuable. M.O'D.

ASSOCIATION NOTICES

MEMBERS' MEETINGS

London

A talk was given at Goldsmiths' Hall on the 9th October, 1974, by Mr B. W. Anderson entitled "Twenty-Five Years". A full report of this talk and the Reunion of Members and Presentation of Awards held on the 25th November, will appear in a future issue of the *Journal.*

Scottish Branch

A lecture entitled "The Uniqueness of Diamond" was given by Mr Henry Whitehead, F.G.A., on the 8th November, 1974, at the Station Hotel, Aberdeen.

Midlands Branch

An all-day gem-testing meeting was held at the Jewellers' School, Birmingham, on the 13th October, 1974.

Nottingham Branch

Mr Robert Webster, F.G.A., gave a "teach-in" dealing with new aspects of gemmology and new testing methods on the 14th October, 1974, at the Trent Polytechnic, Nottingham. Among other topics he covered new types of doublets, synthetic opals, ultra-violet screening, testing for the organics, and the Tisdall method of direct R.I. measurement.

A meeting was also held at the Trent Polytechnic on the 11th November, 1974, when Mr Eric Bruton, F.G.A., gave an illustrated talk on his visit to South Africa.

ACTIVITIES BY FELLOWS

Mr Herbert Tillander, F.G.A., (Tully medallist 1935) was admitted as an Associate of the Worshipful Company of Goldsmiths in London on the 2nd October, 1974.

Mr Michael O'Donoghue, M.A., F.G.A., gave a talk at the Imperial College on the 27th November, 1974, entitled "Recent Developments in Synthetic Gemstones", to the British Association for Crystal Growth.

GEMMOLOGICAL ASSOCIATION OF AUSTRALIA

The Annual General Meeting and Gemmological Symposium of the Gemmological Association of Australia is to be held on 18th-20th April, 1975, at the Australian Mineral Foundation, Adelaide, South Australia. Symposium theme —non-destructive analysis methods and the occurrence and geology of opal.

All members and interested visitors are welcome. Programme: Federal Publicity, G.A.A., Box 1532, G.P.O. Sydney 2001, N.S.W., Australia.

GEM DIAMOND EXAMINATION

Forty-one candidates entered for the Association's 1974 Gem Diamond Examination, of whom thirty-six qualified, one with distinction. The following is a list of successful candidates, arranged alphabetically.

QUALIFIED WITH DISTINCTION

Daly, Patrick Joseph Edward, Chelmsford

QUALIFIED

Andreu Griera, Juan, Barcelona, Spain
Backshall, Henry George Robert, Hainault
Bayarri Bosch, Federico, Barcelona, Spain
Blanco Artiques, Jose Ma., Barcelona, Spain
Bonet Coll, Jose, Barcelona, Spain
Butterworth, Joan Louise, Rochdale
Canals Cadafalch, Ma. Montserrat, Barcelona, Spain
Comely, Christopher Norman, London
Costa Ramon, Maria, Barcelona, Spain
Culi Perarnau, Jose, Barcelona, Spain
Dewhirst, Stephen Clive, Stockport
Doman, Eleanor Margaret, Ilford
Esquerra-Torrescasana Llobet, Jose-eloy, Barcelona, Spain
Esteve Vila, Vicente, Barcelona, Spain
Farreny Riera, Andres, Barcelona, Spain
Frampton, Derek Nigel, Bognor Regis
Frost, Frank Roger, London
Frost, Julia Josephine, Cambridge
Gardner, Wilfred Charles, Reading
Jeffries, Colin Levi, Newport
Juan Prevosti, Leopoldo, Barcelona, Spain
Leek, Janet Sylvia, Alcester
Lopez Perez, Oceano, Barcelona, Spain
Marshall, Terence, Nottingham
Maymo Mas, Jaime, Barcelona, Spain
Mones Mendoza, Luis, Barcelona, Spain
More Andujar, Francisco, Barcelona, Spain
Mozolowski Horczyczak, Barbara, Barcelona, Spain
Poultney, Sidney Augustus, Salisbury, Rhodesia
Salloway, Mary Adene, Lichfield
Scarratt, Kenneth Vincent Granville, Ilford
Solans Huguet, Joaquin, Oviedo, Spain
White, Paul John, Nuneaton
Winter, Colin Howard, Dorking
Yamaguchi, Takashi, London

EXAMINATIONS IN GEMMOLOGY 1974

In the 1974 examinations in gemmology organized by the Gemmological Association of Great Britain, 637 candidates sat for the preliminary examination and 315 for the diploma examination. Centres were again established in many parts of the world.

Upon the recommendation of the examiners the Tully Memorial Medal has been awarded to Helen Muller, M.Sc., Leeds, and the Diploma Rayner Prize to Edith Daras, London.

The Preliminary Rayner Prize has been awarded to Kalevi Roine, Jarvenpaa, Finland.

The following is a list of successful candidates, arranged alphabetically.

DIPLOMA EXAMINATION

TULLY MEMORIAL MEDAL
Muller, Helen, Leeds

DIPLOMA RAYNER PRIZE
Daras, Edith, London

QUALIFIED WITH DISTINCTION

Alvarez Fernandez, Manuel, Grado-Oviedo, Spain
Amoros Angel, Julio, Valencia, Spain
Ballin, Peter Edward, Birmingham
Campon Fernandez, Enrique, Oviedo, Spain
Clewlow, Alan Joseph, London
Daras, Edith, London
Ferrer Arbona, Santiago, Mislata, Valencia, Spain
Garcia Igual, Arturo, Valencia, Spain
Gill, Robert, Boston
Gimenez Torro, Vicente, Valencia, Spain
Goynshor Frederick Jay, Chicago, Ill., U.S.A.
Hahn, Eckhart J., Idar-Oberstein, W. Germany
Haupt, Inge, Idar-Oberstein, W. Germany
Heintzberger, C. P., Bilthoven, Holland
Holt, Paul G., Tuckahoe, N.Y., U.S.A.
Kaku, Baikei, Kobe, Japan
Kammerling, Manfred, Idar-Oberstein, W. Germany
Jose, Latre David, Valencia, Spain
Lopez Van, Ma. Carmen, Valencia, Spain
Maes, Jurgen, Idar-Oberstein, W. Germany
Manser, Jutta Elisabeth, Southampton
Muller, Helen, M.Sc., Leeds
Palomares Carbonell, Remedios, Valencia, Spain
Parkinson, Joanna May, Salisbury, Rhodesia
Sanchez Cabello, Antonio, Valencia, Spain
Sevdermish, Menaham, Tel Aviv, Israel
Smalley, David Francis, Nottingham
Sow, Hock Guan, Selangor, Malaysia
Thomas, Geoffrey Andrew, Hertford
Turner, Michael James, Stockton-on-Tees
Wailes, Rosemary Margaret, Chertsey

Allin, Frederick Garner,
Port Elizabeth, S. Africa
Alvarez Fernandez, Laurentino,
Grado-Oviedo, Spain
Anderson, Susan Margaret,
Salisbury, Rhodesia
Asano, Seigo, Tokyo, Japan
Ayache, Nicholas, Beirut, Lebanon
Barker, Margaret Mary, Southport
Bates, Andrew, Nottingham
Berkowitz, Rosa,
Toronto, Ont., Canada
Birtley, George, Hull
Blasi Casal, Juan, Barcelona, Spain
Booker, Peter Edward,
Melton Mowbray
Bravo Agudelo, Ma. Luisa,
Barcelona, Spain
Buijs, F. J., Schoonhoven, Holland
Canals Cadafalch, Ma. Montserrat,
Barcelona, Spain
Carbonell Alos, Concepcion,
Valencia, Spain
Carlsen, Gunnar J., Jr,
Haugesund, Norway
Chiba, Taigen, Tokyo, Japan
Clark, Stuart Duncan, Sale
Clayton, Rosamund Susan,
Hong Kong
Cooper, Elizabeth Ashley, London
Costa Ramon, Maria,
Barcelona, Spain
Davidner, Gail Ruth, London
Din, Richard Aziz, Edgware
Duyvendyk, Pieke v.,
Krimpen g/d Yssel, Holland
Dwyer-Hickey, Peter Robin, Ilford
Eagleton, David, Sheffield
Engel, Gerhard,
Idar-Oberstein, W. Germany
Fearnside, Gerald Michael,
Sutton Coldfield
Findlay, Kenneth William,
Johannesburg, S. Africa
Fish, Lorraine Alison,
Cape Town, S. Africa
Folch Soler, Mercedes,
Barcelona, Spain
French, Frank Geoffrey, Purley
Galofre Munne, Ma. Rita,
Barcelona, Spain
Gayton, Mildred Prudence,
Southport
Goerlitz, Rolf,
Idar-Oberstein, W. Germany
Gonzalez Gimenez, Anastasio,
Barcelona, Spain
Gonzalez Sanchez, Juan Manuel,
Valencia, Spain
Haefner, Dr Richard,
New Paltz, N.Y., U.S.A.
Handley, Michael, Plumers Plain
Heaviside, Desmond,
Middlesbrough
Hettema, Jan Anton Hyacint Maria,
Silvolde, Holland
Hill, Roger Colin, Whitecraigs
Hofelt, Joris Corneliis,
Utrecht, Holland
Howell, Philip Edward, Worthing
Howell, Timothy Joseph,
Cirencester
Hulse, Kenneth, Sale
Ishikawa, Taeko, London
Jamieson, Vivienne, Shefford
Jayasinhji, Prince of Dhrangadhra,
New Delhi, India
Klar, Michael,
Idar-Oberstein, W. Germany
Koike, Kiyokatsu, London
Laing, Michael Neilson, Troon
Langthon, Kjell-Odvar,
Oslo, Norway
Larah, Howard Anthony,
Manchester
Lewis, Sheila Judith, Kenton
Leyser, Karl-Georg,
Kirschweiler, W. Germany
Lopez Perez, Oceano,
Barcelona, Spain
Lorenz, Dagmar,
Idar-Oberstein, W. Germany

Lyall-Grant, Mary Jennifer, London
MacGregor, Elizabeth Jane, Lourenço Marques, Moçambique
Majo Llopart, Miguel, Barcelona, Spain
Marshall, John Michael, South Bend, Ind., U.S.A.
Martorell Gisbert, Ma. Isabel, Valencia, Spain
Matsumoto, Kikuo, Gunma-Ken, Japan
Maymo Mas, Jaime, Barcelona, Spain
Möller, Gerd, Pirmasens, W. Germany
Montane, Miguel Bard, Andorra La Vieja
Munne Cardona, Ana Ma., Barcelona, Spain
Nelson, Keith Elwin, Arvada, Colo., U.S.A.
Nohara, Koichi, London
Nowak, W., Bexley
Ohhashi, Naoko, Tokyo, Japan
O'Donnell, Ann, Leeds
O'Rourke, Edward Thomas, Brisbane, Queens., Australia
Palmer, Eileen Marion, Liverpool
Palmer, John Redvers, Hitchin
Pearson, Barry Earle, Southport
Piccione, Amedeo, San Remo, Italy
Quitllet Pou, Guillermo, Barcelona, Spain
Richards, Haik, London
Richardson, Paul Leslie, Nottingham
Riche Feliu, Susana, Barcelona, Spain
Rosenberg, Joya, Chevy Chase, Md, U.S.A.
Rovira Rabell, Manuel, Barcelona, Spain
Rowe, Leonard James, Hanworth
Sato, Ikuo, Los Angeles, Cal., U.S.A.
Schwartzman, Sonja S., Bethesda, Md, U.S.A.
Scrymgeour, David John, Newton Abbot
Sluis, Jan, Vlaardingen, Holland
Snyder, Julia Truitt, Philadelphia, Pa, U.S.A.
Stappenbacher, Joseph J., Bamberg, W. Germany
Stevens, Eric Leslie, French's Forest, N.S.W. Australia
Swart, Willem Roux, Stellenbosch, S. Africa
Tasker, Glenn Vincent, Worthing
Tatiwala, Nawal Kishore, Jaipur, India
Thum, Koh Teik, Penang, Malaysia
Tormo Cruanes, Delia, Gandia, Valencia, Spain
Townsend, Michael John, Wakefield
Uden, Penelope Alison, Seaford
Upchurch, David Ward, Colchester
Van Gogh, Mieneke, Epe (Gld.), Holland
Van Thiel, Carolina Josephina Sophia Maria, Helmond, Holland
Villar Lopez, Luis Fernando, La Coruña, Spain
Waterhouse, Philip Arthur, Auckland, N.Z.
Watkins, Sandra, Bouldon
Weeks, Milton D., Annandale, Va, U.S.A.
Wicks, Sylvia Beryl, London
Will, R. A. F., Salisbury, Rhodesia
Woodhouse, Neville, Inkersall
Yabsley, Anthony John, St Sampson's, Guernsey
Yao, Gladys, Hong Kong

PRELIMINARY EXAMINATION

RAYNER PRIZE

Roine, Kalevi, Jarvenpaa, Finland

QUALIFIED

Agee, Carl Bernard, Rotterdam, Holland
Ahmad, Masud, London
Aklin-Zieseniss, Maria-Luisa, Zurich, Switzerland
Allen, David, Blachly, Oreg., U.S.A.
Amerasinghe, Amarsinghe Gamaethige Bodhipala, Colombo, Sri Lanka
Angell, John V., Dover
Arquer Pocell, Pedro, Barcelona, Spain
Asano, Seigo, Tokyo, Japan
Atapattu, Savinda Buweneka, Colombo, Sri Lanka
Baird, Ian Newton, Glasgow
Baker, Brian Dennis, Birmingham
Ballin, Juliet, Birmingham
Barbier, Michel, Lucerne, Switzerland
Bartoli, Anne Marie, Gex, France
Bates, Adrian John, Birmingham
Beale, Arthur Malcolm, Southampton
Beck Kaiser, Margit, Barcelona, Spain
Benito Lizarralde, Eduardo, Barcelona, Spain
Benjamin, John Circus, Wembley Park
Berkowitz, Roza, Toronto, Canada
Besse Desbiolles, Françoise, Geneva, Switzerland
Bettis, Amanda E., London
Beya Colomer, Ma Antonia, Barcelona, Spain
Bickers, O. Martin, Welling
Blampied, Richard Eric, St Helier, Jersey
Bloom, André David, Streetly
Bolli, Bruno, St Gallen, Switzerland
Bootz-Verbunt, G. H. H., Hilversum, Holland
Bosch Senao, Fco. Javier, Barcelona, Spain
Brauns, Sandra M., Hong Kong
Brewer, Peter Charles, Scarborough
Bristol, Anthony Paul, Aberdeen
Brown, Grahame, Brisbane, Queens., Australia
Bryan, John Charles, Kriens, Switzerland
Buhler, Stefan Sugar, Geneva, Switzerland
Burr, Kevin F., Leatherhead
Caffoor, Ali Allapitchai, Yundum, The Gambia
Camble, Elaine, Petts Wood
Canet Vez, Ma Lourdes, Barcelona, Spain
Capell, Elaine, Port Elizabeth, South Africa
Carey, David Alan, Haxby
Carnaghan, John, Purley
Carrera Poblet, Jaime, Barcelona, Spain
Cartwright, Donald Roy, Little Bookham
Castle, Graeme Robert William, Timaru, New Zealand
Chandrasena, Kaluthantrige Nimal Ravindra, Panadura, Sri Lanka
Charron, Joseph Francis Anthony, Toronto, Ont., Canada
Chiba, Taigen, Tokyo, Japan
Choi, Kim Chow Peter, Hong Kong
Cidoncha Castellote, Christine, Valencia, Spain
Cidoncha Castellote, Reyes, Valencia, Spain
Cidoncha Garcia, Miguel Angel, Valencia, Spain

Clapperton, Elizabeth Morag, Aberdeen
Clewlow, Alan Joseph, London
Cohen, Michael John, Stanmore
Collie, Ann Elizabeth, Cape Town, S. Africa
Connolly, T. J., London
Contretas Ros, Manuel, Barcelona, Spain
Cook, Judith Anne, Northwood
Cookson, Margaret Gillian, London
Cooper, Roy, Disley
Cooper, Sean, Disley
Cornelius, Richard Alan, London
Cornford, Carol Rae, Crowborough
Cornford, Richard, Crowborough
Cottrill, Robin Stephen, Cheadle
Crossland, Julie Hall, Horbury
Danianaryana, Malinie, Colombo, Sri Lanka
Daras, Edith, London
Dash, Anthony Lanyon, Manchester
Dave, Mayur, London
Davey, J. W., Hartlepool
Davidson, Geraldine Ann, Skene
De Gier, Johannes-Willem, Krimpen a/d Lek, Holland
De Hey, W. C. M., Schoonhoven, Holland
De Silva, Lindamulage Mohan Lal, Nawala, Sri Lanka
De Silva, Noeline, Colombo, Sri Lanka
Dharmage, Irandathi, Matugama, Sri Lanka
Dharmage, Prasad Manabharana, Matugama, Sri Lanka
Dissanayake, Jayasinghe Munandiram Ernest, Hounslow West
Domaas, Odin, Trondheim, Norway
Domenech Casellas, Ma Victoria, Oviedo, Spain
Dorrepaal, Carla Vvonne, Gouda, Holland
Douglass, James, Stockton
Dowling, W. A., Liverpool
Duckworth, Andrew Sinclair, Bolton
Duyvendyk, Pieke v., Krimpen g/d Yssel, Holland
Edwards, Randall, London
Edmonds, W. P., Salisbury, Rhodesia
Eklad, Henry, Joensuu, Finland
Engel, Corinne Frances, London
Engel, Gerhard, Idar-Oberstein, W. Germany
Erling, Patricia Britt, Helsinki, Finland
Evans, Martine Jayne, London
Fabregas Guardiola, Virginia, Barcelona, Spain
Fernando, Unagamdadige Findlay Collin Sinclair, Panadura, Sri Lanka
Finlayson, James Cameron, Stevenage
Fisher, Peter Norman, London
Forshaw, Edward David John, Newcastle-upon-Tyne
Forsyth, James Perry, Norfolk, Va., U.S.A.
Franco Aradas, Jose Manuel, Bilbao, Spain
Fransz, Frederique, Arnham, Holland
Franz, Rudolf Siegmar, Paarl, S. Africa
Freeman, Michael John, Enfield
Freijser-Ligthart, Maria Wilhelmina, Voorburg, Holland
Fritzsh, Anja, Helsinki, Finland
Frowein, Carl Richard, Stellenbosch, S. Africa
Fujihara, Shigeru, Yamanashi-Ken, Japan
Fujimoto, Naomi, Osaka, Japan
Gabrielle, L. T. M., West Hill, Ont., Canada
Galotta, Ted, Niagara Falls, Ont., Canada
Garcia Abril, Ana Ma, Valencia, Spain

Giercke, Nicolaus, London
Goerlitz, Rolf,
Idar-Oberstein, W. Germany
Goldberg, Richard,
Canberra, Australia
Gomez Perez, Pilar, Valencia, Spain
Graham, Anthony Francis,
Salisbury, Rhodesia
Grant, Malcolm John
Fordingbridge
Griffiths, Cedric Mills,
Rowlands Gill
Haefner, Dr Richard,
New Paltz, N.Y., U.S.A.
Hahn, Eckhart J.,
Idar-Oberstein, W. Germany
Hakulinen, Maija, Helsinki, Finland
Hammett, Roger Stewart, Southall
Haupt, Inge,
Idar-Oberstein, W. Germany
Hebbard, Christopher Roy,
Fareham
Heckman, Hayo Willem,
The Hague, Holland
Hegarty, T. M., Leatherhead
Hemachandra, Vidyapathi
Indraratne Wijesurendra,
Colombo, Sri Lanka
Hendrickson, James Edward,
Los Altos, Cal., U.S.A.
Heuser, Max, Hilversum, Holland
Hewitt, Leonard Eric, Lincoln
Hidellarachchi, Sujatha,
Pannipittya, Sri Lanka
Holness, Malcolm Henry, Effingham
Holt, Paul G.,
Tuckahoe, N.Y., U.S.A.
Honeker, Vera Mary, Esher
Hopkins, Gwyneth Margaret,
Salford
Horder, Heather Aileen, Windsor
Horn, David Ernest, Ripon
Houghton, John Anthony,
New Malden
Hughes, Charles James,
St. John's, Newfoundland
Hulse, Kenneth, Sale
Hummel, Frank August,
Weiser, Ida., U.S.A.
Hutchinson, Janice, Plymouth
Imai, Takayasu, London
Ishikawa, Koki, Tokyo, Japan
Iwahori, Mitsuo, London
Jaatinen, Markku,
Myyrmaki, Finland
Jackson, Marilyn E.,
Willowdale, Ont., Canada
James, Alan Roy, Walsall
Javeri, Kishan, Kobe, Japan
Jefferson, Barbara Janet, London
Jhaveri, Ravindra J., Bombay, India
Jones, Alison, Woking
Jousmaa, Toivo Juhani (Jussi),
Lahti, Finland
Jubany Socas, Jose Ma.,
Barcelona, Spain
Jucker, Ronald Werner,
Salisbury, Rhodesia
Kaduruwewa, I. M. P. B.,
Panadura, Sri Lanka
Kaku, Eishu, Kobe, Japan
Kallioniemi, Seppo, Helsinki, Finland
Kammerling, Manfred,
Idar-Oberstein, W. Germany
Kanai, Seiji,
Yokohama-City, Japan
Karasik, Morris,
Downsview, Ont., Canada
Karna, Outi, Oulu, Finland
Keckman, Markku Tapio,
Helsinki, Finland
Keeley, Helen Christine Maud,
London
Kelso, Roger Joseph,
Christchurch, N.Z.
Kitano, Keiko,
Yokohama-City, Japan
Kitch, Stephen Charles, Nottingham
Kitcher, John, Burford
Kitson, Malcolm, Rustington
Kiviluoto, Pekka, Helsinki, Finland
Kiviluoto, Raija, Helsinki, Finland
Klar, Michael,
Idar-Oberstein, W. Germany

Kleinendorst, Trudy, Edinburgh
Kojima, Mieko,
Yokohama-City, Japan
Kortelainen, Sirpa, Helsinki, Finland
Kortman, Caj, Helsinki, Finland
Koskipirtti, Eila Marjaana,
Helsinki, Finland
Krasner, Harold,
Johannesburg, S. Africa
Kulatileke, Semage Arnold Allen,
Rathmalana, Sri Lanka
Laguarda Mestres, Joaquin,
Barcelona, Spain
Laine, Simo E. W., Helsinki, Finland
Laurila, Riitta Marketta,
Hyvaneula, Finland
Law, Peter, Sheffield
Lawson, Wendy Angela,
Nottingham
Lee, Po Chu Helen, Hong Kong
Leewis, P. E.,
Schoonhoven, Holland
Legg, Veronica, Hong Kong
Leow, Yong-Siew, Singapore
Leslie, Elisabeth, Hong Kong
Lewis, Ian Rhys Morien, Sheffield
Lewis, Leonard Roy, Bristol
Leyser, Gerarda Sebilla,
Arnhem, Holland
Leyser, Karl-Georg,
Kirschweiter, W. Germany
Li, Sheung Shun, Hong Kong
Lincoln, Anthony David,
Waltham Abbey
Lintott, Diana Cherrill, Aberdeen
Lintunen, Viktor,
Kuusankoski, Finland
Lipscomb, Edward Martin, London
Lo, Wing Yat Sunny, Hong Kong
Logsdon, Maxon Andrew,
Wethersfield, Conn., U.S.A.
Lopez Hijos, Ma Carmen,
Barcelona, Spain
Lorenz, Dagmar,
Idar-Oberstein, W. Germany
Lyall, Angus C., Dundee
McCartney, Robert Martin,
Atlanta, Ga, U.S.A.
McGill, Fiona Macleod, Edinburgh
McIlroy, Isabella McCallum,
Romford
McKell, Letitia, Glasgow
Maeda, Kikuko, Tokyo, Japan
Maes, Jurgen,
Idar-Oberstein, W. Germany
Mahendrarajah, Maureen,
Colombo, Sri Lanka
Mahuroof, Fahmi Noor, London
Malamed, M. R.,
Cape Town, S. Africa
Manzke, Lothar, Geneva, Switzerland
Marsal Astort, Montserrat,
Barcelona, Spain
Marshall, John Michael,
South Bend, Ind., U.S.A.
Marttila, Anne-Maija,
Angelniemi, Finland
Matthesius, Johannes Gerardus,
Amstelveen, Holland
Matthews, Bernard Roy,
West Wickham
Maurer, Robert John, Brentwood
Mayer, Marianne,
Vaud, Switzerland
Mayor Giner, Juan Enrique,
Vinaroz-Castellon, Spain
Meintjes, Arthur Harry,
Stellenbosch, S. Africa
Merriman, Timothy, Northampton
Merritt, Joan, Richmond
Miles, Christopher Robert, Poole
Miller, Charles Robert,
Southfield, Mich., U.S.A.
Miller, Wilda H., Hong Kong
Mingo, Jose-Marie,
Geneva, Switzerland
Möller, Gerd,
Pirmasens, W. Germany
Mones Mendoza, Jose,
Barcelona, Spain
Mora Roses, Eduardo,
Valencia, Spain
Morrill, Christine, Witherley
Moule, Alexander John,
Brisbane, Queens., Australia

Mtuye, Riessen Saliel,
Moshi, Tanzania
Muchmore, Leslie Robert, Liskeard
Muris, Simon Christopher, London
Mustonen, Rauni,
Raanujarvi, Finland
Navaratne, Kiriporunage Gamini,
Colombo, Sri Lanka
Need, Mary, Lelant Downs
Noble, Patrick, Heckmondwike
Nogradi, Maria Irene, Deeside
Nohara, Koichi, London
O'Clee, Caroline Harriet, Hythe
O'Connell, William,
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GEMMOLOGICAL ASSOCIATION OF GREAT BRITAIN

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TWENTY-FIVE YEARS

By B. W. ANDERSON, B.Sc., F.G.A.
(being the substance of a talk given to the Gemmological Association of Great Britain at Goldsmiths' Hall on 9th October, 1974.)

THIS evening I am going to continue the history of the Precious Stone Laboratory from the point where I left it in my two previous talks,* that is, at the end of the Second World War. Twenty-five years is a long period to review in the space of an hour, so I will plunge straight in with my story.

On the 3rd September, 1945, almost exactly six years after being called to serve as a gunner, my old colleague, C. J. Payne, returned to work in the Laboratory. I was mighty glad to have him again at my side—partly, of course, for personal reasons, since for those six long years I had ploughed a lonely furrow in the Lab., with no one to share my gemmological problems and excitements, but also because I was by then a tired man and finding it impossible to cope with the thousands of pearls and other work which was coming in for testing. Working all day at the Endoscope may not be most people's idea of heaven, but for James Payne, after the uncongenial life of the army, it was a thoroughly welcome change, and with his vigorous assistance the back-log of pearls was soon brought under control and I was even able to take a short holiday.

Before many months elapsed, however, the Laboratory was called upon to face a new and formidable challenge. As most of

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you realize, the well-being of our trade depends upon the chain of confidence which exists all along the line from the rough gemstone to the finished jewel. If the first link in this chain were found to be faulty, the seeds of chaos were sown. In my first talk I recounted how in 1925 it was the infiltration of cultured pearls into the hitherto sacrosanct "Bombay bunches" which had forced the pearl traders of London and Paris to devise special apparatus and establish special laboratories to check on the purity of their supplies. Now, 21 years later, it had become increasingly apparent that parcels of rubies and sapphires—particularly those in small calibré sizes—which were imported from Burma from sources hitherto completely reliable were likely to contain anything up to about 10% of synthetic stones. This unwelcome truth had become established beyond doubt when eternity rings, bracelets, bar brooches and the like utilizing such stones were found again and again to contain the odd synthetic stone or two, which then had to be winkled out and replaced, and the customer placated. Obviously the only remedy for this dire situation was to have *all* stones in this category tested before they were released into the trade. Equally clearly this was a task beyond the capacity of a war-battered, ill-equipped laboratory, staffed by only two gemmologists (already fully occupied with the ordinary routine testing of pearls, stones and jewellery which formed the bread and butter of the trade) and a commissionaire.

Accordingly, I was approached by Mr Fred Ward on behalf of the Standing Committee of the Diamond, Pearl, and Precious Stone Trade Section of the London Chamber of Commerce, and asked whether, given the extra staff and any necessary apparatus, I thought the job could be done? Obviously this was a challenge that had to be met, and the answer just had to be "yes". A re-equipment fund was launched and generously supported, and I was free to seek out and purchase the instruments most urgently needed. Microscopes, of course, were the first essential. Until that time we had subsisted, incredible though it now seems, on two venerable Swift instruments, one a Wenham binocular and the other a petrological microscope. Luckily in those days one was in the happy position (which was taken entirely for granted) of being able to walk into any of several microscope makers' showrooms and make one's choice, with the able and willing help of a senior assistant. Our most favoured firm happened to be R. & J. Beck, then flourishing in Mortimer Street, W.1, who had already provided

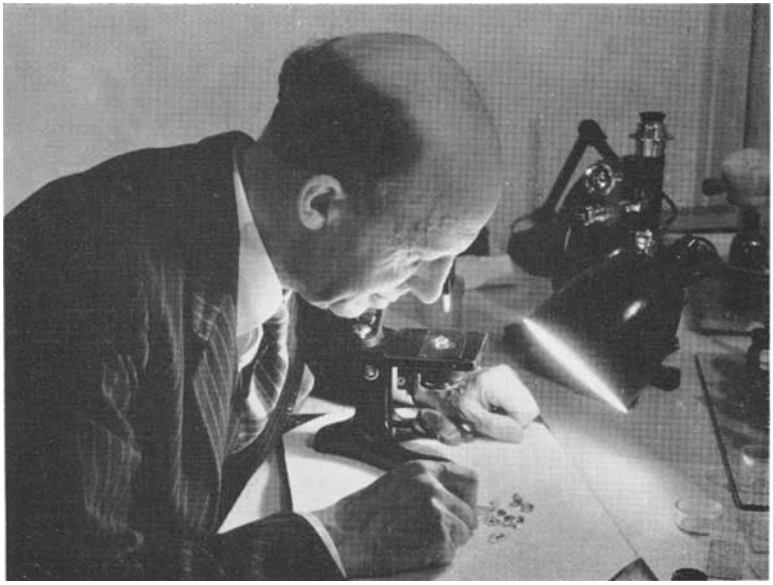

FIG. 1. B. W. Anderson sorting a parcel of stones. (Photo by courtesy of *The Times*.)

us with an excellent table spectrometer and several types of spectroscope. From them we now acquired four splendid "Greenough" type binocular microscopes with large square stages, inclined eyepieces and adjustable substage condensers. Three paired objectives, rapidly interchangeable, gave us the choice between 25 ×—the most generally useful—and higher magnifications. Special advantages of these instruments compared with monocular microscopes were the unreversed image (making the handling of small stones while under observation infinitely easier); the large working distance between objective and stage, enabling sizeable pieces of jewellery to be examined; stereoscopic vision; and the inclined eyepieces which made long sessions at the microscope bench possible without undue fatigue.

Even more important than choosing apparatus, and far more difficult, was the task of finding two gemmologists not only able but willing to tackle the arduous, skilled, and responsible work to be undertaken. Here I was fortunate indeed in being able to persuade Robert Webster, who had already made his mark as gemmologist, teacher, and author, to join us in the Laboratory—a step which

was mutually beneficial. And by a happy chance A. E. Farn, one of my former students who had recently been demobbed, came to see me at just the right moment in search of a job entailing more gemmology than he could expect with his old firm, the jewellers Jay, Richard Attenborough & Co. This completed a team which was before long to become a well-balanced and powerful force in gem-testing and research.

Robert Webster joined us in April 1946, and Alec Farn in May. These were relatively easy months, enabling the newcomers to some extent to play themselves in. The real crunch came in June of that year, when we all had to go through a baptism of fire since, in addition to having 6,126 stones to test, we had also to cope with 10,800 pearls, mostly taken from bunches. These were small and with drill-holes full of pearl-dust, so that much of Farn and Webster's time was taken up with cleaning these tiresome beads to enable Payne to make good progress on the endoscope.

To gemmologists accustomed to testing stones in ones and twos, or perhaps in some multi-stone jewel, to be faced with the problem of coping with parcels of a thousand or more very small rubies or sapphires was a formidable adventure. One realized, of course, that it was vitally important that no mistakes be made and that, so far as humanly possible, no stones be lost in the process. After toying with various ingenious ideas on how best to tackle the problem, a very simple system was evolved which proved (after some weeks of practice) to be both speedy and safe. Stripped photographic quarter-plates provided bases of convenient size to rest on the square microscope stages, and on these some fifty of the stones to be tested were spaced in line, and each stone examined in turn under 25 × magnification, sliding the plate slowly across the stage by hand. Stones which were clearly genuine were left *in situ*; synthetics which revealed themselves at first glance were removed with the tongs and placed in a separate container, whilst those specimens which did not at once show their nature were pushed out of line and eventually examined carefully immersed in methylene iodide. At first the number of these "X" specimens (as we called them) was considerable, but as our expertise grew they became remarkably few. The stones in each consignment were carefully weighed at the outset, as this provided a more rapid and certain check on any stones lost than counting, though after each test was completed both natural and synthetic stones had of course to be

counted as well as weighed. Here again, experience in handling very small stones reduced the time spent in hunting for stray specimens, which at first had seemed an inevitable concluding chore with each parcel tested. When stones were missing, the operator's trouser-cuffs were the first focus for investigation, followed by the work-bench and finally the floor. This was of brown lino, against which small rubies did not readily show up. In serious cases the whole staff would be groping on the floor, lamp or torch in hand, examining the "concentrates" after sweeping a wide area with a soft broom.

In the course of viewing under the microscope so many thousands of Burma rubies (sapphires were in smaller demand) one grew to appreciate to the full the manifold beauty of their colour

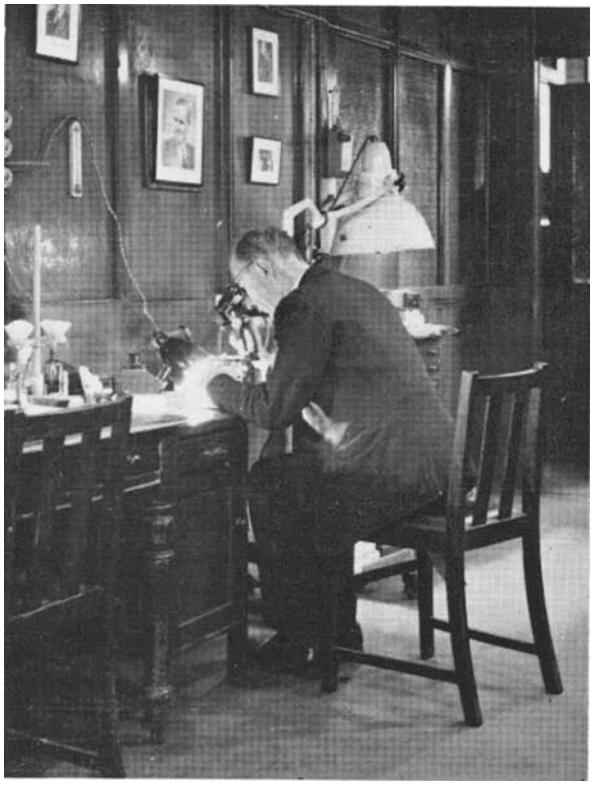

FIG. 2. C. J. Payne in the old lab. at 55 Hatton Garden.

and inclusions, and became extraordinarily perceptive of the smallest traces of "silk" or of the curious syrupy colour-breaks which we nick-named "treacle". As to synthetics: however free from bubbles they might be, one had the comforting knowledge that in the correct orientation and with lowered condenser or tilted mirror the curved striae would inevitably make their appearance. In each case, so distinctive were these features that there was absolutely no need for further testing. Only three or four times did a red spinel appear as an intruder, and these created no problem, since both their colour and inclusions were so distinct from those of ruby that each stood out like the proverbial sore thumb.

Usually a parcel of around a thousand stones would take one of us about a day and a half to complete, allowing for the inevitable interruptions to meet the needs of customers with short-term tests. Faster times were possible when a clear run could be achieved and when the stones concerned were rather larger than the fiddling little five or ten pointers which were our most frequent fodder. To quote one example from my notes of this period (I kept a record of every test), I was able to complete the examination of a parcel of 201 rubies containing six synthetics in a matter of 45 minutes.

In that year of 1946 we tested more than 104,000 stones, of which 100,000 were concentrated into the last seven months. Most of these were rubies, but there were a considerable number of sapphires too. One parcel consisted of 2,005 Kashmir stones, in which the 4500Å absorption band proved of great value as an additional test in those cases where a stone was exceptionally clean. In 1947 the stone total dropped to 40,000, and thereafter political factors altered trading conditions, and London lost for ever its supreme position as the world market-place for the highest class of precious stones. The annual figure eventually levelled off at around fifteen to twenty thousand, but these actually represented far more individual tests, and the majority of the stones examined were mounted, which was liable to make their inspection and identification much more awkward and time-consuming.

I have always regarded the number of reports issued by the Laboratory as the truest indicator of the amount of work done during a given year. Before the war, when Payne and I were without help of any kind, we issued 898 reports in our peak year of 1937. During the war the lowest ebb was in 1941, when I issued only 290 reports. But by 1944, though still on my own, the number

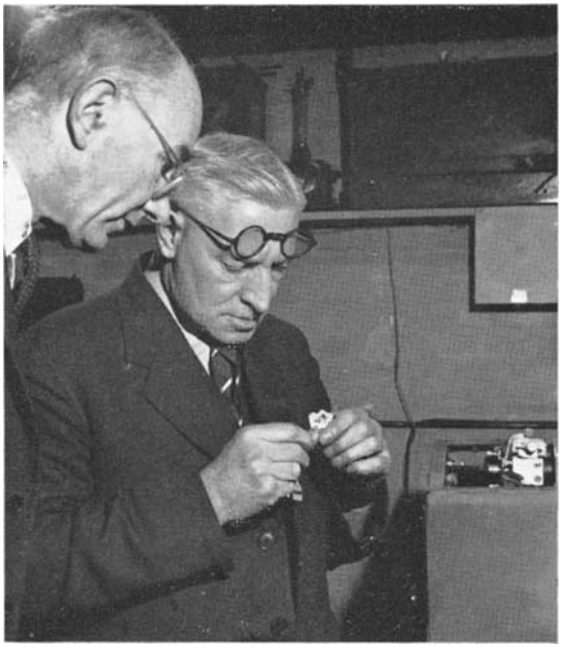

FIG. 3. C. J. Payne and Robert Webster discussing an x-ray report. (Photo by courtesy of Gordon McLeish & Associates Ltd.)

had increased to 782. In 1946, the big year for stones of which I have just been talking, the reports totalled 1,677, while the all-time record so far is held by the year 1970 when no fewer than 4,005 reports were written. Report numbers have been consecutive from the time the first was issued in 1925. At the present time the grand total stands near 90,000, so that I feel there is a fair chance that I may live to see the 100,000th written, and perhaps be allowed to append my signature!

A major reason for the increased use of the Laboratory was, of course, the advent of a succession of new types of synthetic stone. During the first forty years of the century, the field of man-made gemstones had hardly extended beyond corundums and spinels in a wide variety of colours. Then, after the war, beginning with Carroll Chatham's emeralds, factory-made gemstones made their appearance in rapid succession—a trend which has continued to the present day, so that even apparently inimitable products of nature such as opal are no longer safe from reproduction by the

scientist. Nor has it been only synthetic stones which have caused headaches for those who trade in gems: irradiated diamonds, treated opals, stained jade, impregnated turquoise, ingenious doublets, all tended, as they made their appearance, to make life difficult—in fact, not only difficult but quite impossible for the trade, were it not for the protection of an efficient testing Laboratory.

Another important and welcome factor which led to more work for the Laboratory was the increasing flow of tests from the retail jewellery trade through the National Association of Goldsmiths, by agreement with the London Chamber. A similar arrangement was later made with the British Jewellers Association.

Something more, perhaps, should be said about the new apparatus other than microscopes which we acquired soon after the war. Of prime importance was the new x-ray equipment designed by our friend C. G. Osment, who had already provided us (through his firm of General Radiological Ltd) with our previous two sets. The earlier models were intended purely for testing pearls by the sure but very slow process of x-ray diffraction—drilled pearls, of course, being dealt with much more rapidly by the endoscope. The new equipment gave us the choice of employing either diffraction or direct radiography, which before long was developed by Robert Webster into our standard method. More than this, the fluorescence of pearls and of gemstones under x-rays could now be closely and safely studied, and this proved to be of very great practical value. An aperiodic balance weighing to a tenth of a milligram helped the accuracy of our density determinations, and an Abbé-Pulfrich refractometer made possible refractive index readings to four places of decimals in the special cases where this was desirable, though for most purposes our standard Rayner and special spinel refractometers were perfectly adequate. For high readings we were lucky in having the unique diamond refractometer which Rayner had made for us in the 'thirties, the diamond surface of which remains unblemished to the present day.

A small electric furnace giving temperatures up to nearly 1000°C was found to be valuable for research and also enabled us to give reports on the purity of samples of diamond powder or grit, often found to be contaminated with silicon carbide, sand, iron filings, and a whole range of odd substances. A micrometer eyepiece enabled us also to report on average grain-size, where this was required.

The scope of our testing was indeed continually growing, our opinion being increasingly sought on carvings, snuff-bottles, etc., made from jade and other hardstones, turquoise, ivory and the like. Amber and its plastic imitations were other substances on which advice was frequently needed. Both Robert Webster and I gradually accumulated a collection of almost all gem materials and their substitutes, and these were of enormous value for comparison tests in the Laboratory and for teaching purposes. From his close friend, the late Harold Lee, who was an industrial chemist of exceptional skill, Webster assimilated the know-how for some very useful micro-chemical tests, and his specialized knowledge of ivory and bone, work on which had gained him a Research Diploma, was another useful asset.

As the Laboratory in the course of time settled down to a fairly steady routine, it became convenient for each one of us (though ready to tackle *any* of the work if necessary) to specialize to a certain extent, and this often saved argument as to who should do what. Thus, all the drilled pearls (except obvious cultured pearl necklaces) were passed to C. J. Payne, while partly drilled or undrilled pearls were Robert Webster's special province, using mainly direct radiography, at which he had acquired great skill. Stone-testing, unless it became excessive or entailed something quite out of the ordinary, was the province of Alec Farn, whom we all came to acknowledge as "the tops" when it came to finding the necessary evidence with lens or microscope to condemn a difficult synthetic. As for me, I saw to the administrative side, filled in with any necessary testing, and kept a record of every job we did. The tedious and time-consuming work of book-keeping was covered with great efficiency by Robert Webster. Ideally, of course, such chores, and others such as answering the door and telephone, should have been looked after by a purely clerical member of the staff, as they were matters which were continually bedevilling our concentration.

The Move to 15 Hatton Garden

Our premises on the second floor at 55 Hatton Garden were spacious, but by no means ideal. The dark-room, for instance, was a boarded-up cubby-hole some five feet square, two steps up on the way to the lavatory and wash-basin. Descending from this without due care the taller amongst us were apt to suffer a severe blow on the head as it met the lintel of the door. When our lease expired, the resultant move to the basement of 15 Hatton Garden had much

to commend it, not least being the fact that we were closer to the premises of our most frequent users. For many dealers a walk of fifty yards to have a stone checked seemed reasonable whereas a journey of three hundred yards to the far north end of the Garden was not. It should be said that in both situations we were fortunate in having neighbours who were not only friendly but useful. At 55, the Austen sisters were handy for restringing pearls on the floor below, the manufacturing jewellers Joseph & Pearce were on the ground floor, while Arco Electrical, skilled in electrical repairs, were in the basement. Again, at No. 15 we could have our eyes tested at Sharlands on the floor above, stones removed or replaced by Fryer on the first floor, while next door were Mathews Lapidaries under Bull Diamond, the best cutters in Hatton Garden.

The actual move, on a bitterly cold Saturday morning at the end of January, 1954, will be remembered by us all for its sheer discomfort. The gallimaufry of apparatus, books, furniture and accumulated junk of years past looked so unpromising that our hoped-for cleaner, after one look at it, threw in the sponge. And in the midst of this muddle we had to stand for hours with the window removed from its frame waiting for the arrival of our 2¾ ton safe, which finally arrived at 2 p.m. breaking, as a final gesture, the heavy sleeper down which it was being slid into position. However, after a week or two's hard work, things began to look quite ship-shape. We had at last a properly equipped and spacious dark-room, with running water and shelves for all our chemicals, and there were a number of alcoves in the back rooms which proved ideal "stations" for our spectroscope set-up, for ultra-violet lamps, and so-on. Daylight admittedly was only available in the front room, but a combination of fluorescent strip and tungsten lighting, together with the white walls and ceilings made the place look bright and cheerful, while Webster's talent for assembling electrical points on to conveniently accessible panels was exploited fully, and we began to feel at home. The stairs leading from the ground floor to our dungeon were rather steep, but the sound of descending foot-steps at least gave us ample warning of the approach of customers, postmen, or whatever. In the course of time we learned to recognize most of our most frequent visitors by their speed and style of descent, which varied from the rapid tumbling sound of our favourite pearl-merchant to the portentous tread of the two "Weights and Measures" officials whose haughty behaviour in checking the

FIG. 4. A. E. Farn weighing stones on an Oertling aperiodic balance. (Photo by courtesy of Gordon McLeish & Associates Ltd.)

accuracy of our meticulously maintained balance we found very difficult to take.

Unfortunately the comfort of our quarters was badly disturbed some years later when the building next door was demolished and rebuilt in the modern manner. After suffering for weeks the earth-shaking impact of giant digging machinery, clouds of penetrating dust, and obstructive scaffolding, our rooms were invaded one day by quantities of rubble which poured down our chimney. Eventually this had to be sealed off (the builders assured us), which deprived us of our main ventilation shaft. Such are the penalties of "progress", which continues, alas, to transform Hatton Garden from a street of history and character into an ordinary City road full of office blocks.

Looking back over the years and skimming through old records one can recall scores of amusing incidents and gemmologically interesting experiences with which I could entertain you if time allowed. Any worth-while discoveries or invention of new techniques were usually written up by one or other of us in the

Gemmologist or *Journal of Gemmology*; but there were a number of occurrences which naturally enough were too confidential or personal to be put on record at the time, as well as being of insufficient scientific importance. The three tests I am going to describe to you now are chosen as being good examples of cases where the sheer numbers involved constituted a challenge, and as examples of how much can be accomplished by unconventional methods, given expertise and ingenuity, where standard procedures would be far too time-consuming.

One of these cases concerned a parcel of some 5,000 industrial diamonds weighing 4,720 carats which had been purchased cheaply at 21/- per carat but which were rightly suspected of harbouring a certain number of "strangers". After preliminary inspection we decided that the highly characteristic appearance of the rough diamonds, even where their crystal form was not well developed, offered the most rapid means of carrying out a preliminary sorting, and moreover that this procedure was perfectly safe provided we submitted anything about which we had the slightest doubt to further tests. Payne and I accordingly set to work in turns, using a head loupe under the strong light from a desk lamp, putting on one side the undoubted diamonds. The remaining stones weighed some 200 carats, and on these we made use of the unique transparency to x-rays of diamond: in the final result 130 carats of non-diamonds were segregated. Fortunately for us the dealer was not interested in knowing the exact nature of these! Incidentally, x-ray transparency tests proved very useful in checking parcels of the once highly prized coke-like variety of industrial diamond known as carbonado. Not only their nature but the degree of impurity contained could be clearly checked by this method.

On another occasion a member had been asked to guarantee the authenticity of the small white zircons in which he traded, and asked for a parcel of 1,500 of these, cut as brilliants, and 600 baguettes to be checked. Here the spectroscope provided the quickest certain answer, the narrow 6535Å line and its weaker companion at 6590Å being picked up in each by a rapid survey in reflected light. The yellow glow of these stones under long-wave ultra-violet light was used as a double check. Unfortunately I became so interested in studying the bright-line rare-earth fluorescence spectrum of some of these stones that I kept them too long under the u.v. rays for their health, and found to my horror that they had assumed an unpleasant

brownish tinge. Luckily for me a spell on the hot-plate of our domestic Aga stove put things right, and I had the undeserved added pleasure, in the pitch-dark kitchen, of observing the thermo-luminescence which persisted while the change-back in colour was proceeding.

The third large-scale challenge I want to mention concerned pearls and was important for its long-term effect on our testing methods. A consignment of mostly natural but old and low-quality drilled pearls contained in a small sack was dumped on us, with a request that they should be tested as cheaply as possible. There was no question here of testing them on the endoscope. Their drill-holes were so large that one could almost walk inside and look around, and being old pearls they showed the seasonal growth-layers and dark, conchiolin-rich centres very clearly in most cases, so that lens inspection was all that was necessary to prove their natural origin. We could not allow such an influx to interfere with our more urgent day-to-day testing, so Payne, Webster and myself formed the practice of taking turns to test batches of these ancient relics in our back room where there was a convenient baize-covered table. The whole job took several months to complete, and the final tally revealed that of the 89,739 pearls tested, 1,460 were cultured. This quite unusual "extra" task which we undertook in the winter of 1955/56 had an important influence on our pearl-testing methods. After 30 years of use and damage by blast during air-raids, our three endoscopes were patched-up relics of their former selves, and the replacement needles made for us by a friendly craftsman had not the brilliance of the original French-made products. It was thus natural that we were glad to take advantage of our now increased skill and confidence in testing by lens and reserve the endoscope for difficult cases only.

Teaching and Publications

In addition to our daily work in the Laboratory, Webster, Farn and myself were all doing evening teaching, first at Chelsea Polytechnic (the original home of these classes in gemmology to which all who knew it will look back in affection) and later at Northern Poly where the neighbourhood was far less salubrious. And the results of our experiences in the Laboratory were being shaped into numerous articles, published chiefly in the *Gemmologist*—that valuable monthly journal which covered the span 1931 to 1962—and in the *Journal of Gemmology*, brain-child of G. F. Andrews, which

first appeared in 1947. The most permanently useful of these papers were probably a series of twelve articles by Robert Webster giving a complete review of luminescent effects in gems under long and short-wave ultra-violet light and under x-rays, and 39 articles on the use of the spectroscope in gemmology, in which I gave a full account of the pioneer work which C. J. Payne and I had started way back in the early 'thirties.

Even for those people who take their gemmology seriously enough not only to read such articles as they appear, but keep bound copies of the relevant journals on their shelves, their content all too quickly becomes lost in the mists of time unless it is included in the more easily accessible form of a book. Fortunately this was done in a very thorough fashion by Robert Webster in his great book *Gems*, first published in 1962, of which the third edition is soon to appear. In its more limited field, my own book *Gem Testing*, now in its eighth edition, has made available the most useful fruits of our Laboratory experience throughout the years.

The lack of spare time in these twenty-five post-war years prohibited prolonged and leisurely research on the scale possible in the quiet 'thirties, but quite a respectable body of work was done in connexion with new gem minerals, as described in detail in my last talk, and as a matter of urgency we had to learn to cope with each new synthetic product and each new "treated" or irradiated gemstone as it appeared. In this important matter of keeping abreast of new developments we were helped considerably by being provided with samples of the stones concerned by certain public-spirited firms, and by a valuable and close liaison with Robert Crowningshield and Richard Liddicoat, of the Gem Testing Laboratories in New York and Los Angeles, who so often were ahead of the rest of the world in being able to handle the latest synthetic or illegitimately "improved" gemstones.

Before I end, I should like to mention two valuable additions to the gem-testing armoury which we developed in the Laboratory, each of which is easy and inexpensive to apply. One was the use of a copper sulphate solution to act as a filter in front of the power light employed in connexion with the spectroscope, which not only made observation of absorption bands in the blue and violet parts of the spectrum far more feasible but, in conjunction with a suitable red or orange complementary filter, provided a powerful means of stimulating and viewing fluorescence. It would be a mistake to

regard this "crossed filter" technique as merely a sort of "poor man's ultra-violet", since the effects observed can often not be seen under any other conditions of stimulation.

The other concerns new and effective immersion techniques which have very wide applications. It has, of course, long been recognized that the degree of "relief" shown by a stone immersed in a liquid or of an inclusion imbedded in a crystal is greater for substances having a refractive index markedly different from that of the imbedding medium, and the so-called "Becke line" effect which enables the mineralogist to determine under the microscope which of two media in optical contact has the higher refractive index is well known to students of gemmology, if only by name. When it comes to cut gemstones immersed in liquid, the movement of the bright Becke line at the edge of the stone is difficult to see and still more difficult to interpret with absolute certainty. In 1951, a laboratory experiment in which I used a contact photograph of a blue synthetic spinel immersed in monobromonaphthalene to record the unusual curved colour-bands seen in the stone led to further experiments in immersion contact photography of gemstones which yielded spectacular pictures not only demonstrating beyond peradventure whether the stones involved had higher or lower refractive indices than the fluid in which they were immersed, but also by how much lower or higher. It also provided a very simple and rapid photographic record of the size, outline, facet-pattern and included features of a gemstone (including curved striae in synthetic corundums) all without benefit of a camera. Some years earlier, we had found both synthetic rubies and synthetic emeralds to be notably more transparent in the ultra-violet region than their natural counterparts, and a suggestion by Norman Day enabled immersion contact photography to display this difference in the simplest possible manner. One has to realize, of course, that testing methods involving even the simplest forms of photography are hardly practical politics for the majority of jeweller-gemmologists, and I was happy to devise a very simple set-up which showed immersion contrast effects in all their spectacular beauty with the aid of only a piece of ground-glass and a pocket mirror. These techniques are now described in several text-books, but I still feel that their simplicity, beauty and power are not sufficiently recognized.

Owing to the Trade Descriptions Act of 1968, which is excellent in principle but sometimes a nuisance in practice when enforced in

too heavy-handed a manner by officials who don't sufficiently understand the trade, the Laboratory had latterly to face a great increase in awkward little tests to decide such things as the exact nature of the subsidiary stones (either diamonds or representing diamonds) mounted on the shoulders or as surrounds of stones set as rings, etc. Doing this fiddling if necessary work made us very conscious of the filthy state of the backs of stones in their settings which obtains in jewellery if it is frequently worn. A small pot of water containing a mild liquid detergent, and a small soft tooth-brush became an essential feature of the work-bench. It was found well worth while to spend time in cleaning a jewel thoroughly before attempting to examine it under the microscope. While one might think it a good thing to advise the owners of jewellery to have it cleaned periodically, as this so greatly enhances its appearance, particularly where diamonds are concerned, there may be considerable risks when the now fashionable ultra-sonic cleaners are employed. Deleterious effects have been reported in the case of blue zoisite (tanzanite), which may develop flaws under this ordeal. And emeralds, which unfortunately nowadays so often have their appearance up-graded by soaking in oil to diminish the effect of any surface-reaching flaws, will emerge with the oil leached out of them and looking very much the worse.

In my three talks on London's gem-testing laboratory, I hope I have been able to convince you of the absolute necessity for the health, reputation and prosperity of the trade that such a reliable, independent, specialized laboratory should be maintained in this country, and indeed in all countries which trade in gems. In the course of my narrative I may not have made it sufficiently clear how much of the success of the Lab. has been due to the work of my three gifted and loyal colleagues. Their talents, I am sure, could have earned them higher material rewards, but certainly not a more interesting life, gemmologically speaking.

Our Laboratory, I am glad to say, continues to flourish in its new quarters in 36 Greville Street, E.C.1, which is only a stone's throw from the hole in the ground which at the moment marks our former home. It is now in the experienced hands of Alec Farn, who is assisted by three promising young gemmologists. Though the old hands have had to leave the Laboratory, they remain in the wings, ready and available should help or advice be needed.

INCLUSIONS IN GEM ALMANDINE FROM IDAHO AND NEW YORK

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Introduction

Gem almandine has been mined since the turn of the century at the Barton mine, North Creek, New York, and at Emerald Creek, Clarkia, Idaho. These two localities have produced prodigious amounts of almandine which, although only a small percentage thereof is faceting quality, has been widely disseminated and is now frequently encountered as cut gems. The present study was initiated to determine the nature of the abundant inclusions in these two almandines.

Methods of Investigation

The almandines and inclusions were x-rayed utilizing a Gandolfi 114·6 mm powder camera and CuKα nickel-filtered radiation. The almandines were ground and polished until the inclusion to be studied was exposed and the inclusion scratched with a sharply pointed diamond chip. The resulting powder was gathered on the tip of a glass capillary and exposed in the Gandolfi camera. The Gandolfi powder camera is ideally suited to the x-ray study of inclusions because it employs two axes of simultaneous rotation, which eliminate preferred orientation problems, and because it affords accurate powder data from a very minute sample. The Gandolfi camera can also give powder data from a single crystal with careful manipulation.

Density determinations were made on a Berman microbalance with toluene as the liquid and employing a temperature correction factor. Optical determinations were made in sodium light using a polarizing microscope and the Rayner Dialdex refractometer.

The almandines and the inclusions were chemically analysed on an ARL electron microprobe, using an operating voltage of 15KV and a sample current of 0·15 Ma. The standards used were NMNH microprobe standards of high reliability. The intensities were corrected for absorption, fluorescence, backscatter and stopping power with the ABFAN computer programme of The Geophysical Laboratory, Washington, D.C. The analyses are presented in Tables 1, 2 and 3.

TABLE I

ALMANDINE, LABRADORITE AND ILMENITE ANALYSES

	Gore Mtn, N.Y. Almandine #90518	Gore Mtn, N.Y. Almandine (Miers 1926)	Emerald Creek, Idaho Almandine #128192	Labradorite in #90518	Ilmenite in #128192
SiO_2	40·1	40·24	37·9	55·47	
TiO_2	tr		tr	0·00	52·0
Al_2O_3	22·8	20·66	21·6	28·34	
Cr_2O_3	tr		tr		
Fe_2O_3		4·65			
FeO**	25·0	18·58	36·9	0·0	46·7
MgO	9·8	11·18	4·4	0·0	·56
MnO	0·4	·25	0·6	0·0	·21
CaO	4·1	5·3	·4	10·80	
Na_2O	0·0		tr	5·39	
K_2O	tr		tr	0·0	
Total	102·2	100·26	101·8	100·00*	99·53

*Normalized to 100%.

**All iron analyses of this study expressed as FeO.

Specimen numbers are from the National Museum of Natural History, Smithsonian Institution collections.

NEW YORK ALMANDINE

The Barton mine (formerly known as the Rogers mine) on Gore mountain, North Creek, New York, is a source of gem-quality almandine. The Gore mountain garnet is mined for use as an abrasive. Crystals from this mine sometimes attain a diameter of 60 cm. The garnet is intimately associated with hornblende, hypersthene and plagioclase. The genesis of the deposit has been studied by Miller (1912, 1938) and by Shaub (1949). The garnet has a pronounced parting, parallel to {110}, yielding rectangular fragments well suited to emerald and oval cuts. Pyrite is frequently formed on the parting planes and was noted by Shaub (1949).

The Gore mountain almandine is deep red in colour, has a refractive index of nD = 1·764 and a specific gravity of 3·84. The characteristic almandine absorption spectrum was observed.

The analysis of this almandine is presented in Table 1. The analysis of Miers (1926) is also included to demonstrate the compositional variance of the material at this locality. The unit cell edge of this garnet is 11·54 Å, in good agreement with the observed physical and optical properties and the composition. The analysis of this study indicates that this garnet is comprised of 58% of the almandine component.

Solid inclusions are common in this material and are dominantly pyrrhotite, apatite, plagioclase, and chalcopyrite. All inclusions were initially identified by x-ray diffraction.

PYRRHOTITE is the most abundant inclusion and occurs as discrete, spherical grains, occasionally discoid, which are usually rather randomly distributed in the host garnet. The maximum size of these pyrrhotite grains in gem-grade material is about 0·2 mm and most are considerably smaller. In darkfield illumination the pyrrhotite appears as opaque blebs with red haloes due to reflection of light from the pyrrhotite. The pyrrhotite grains sometimes occur in swarms. Under very

TABLE II

PYRRHOTITE ANALYSIS

Fe	59·87
S	38·09
Ni	·61
Co	·12
	98·69

high magnification (286 ×) the pyrrhotite-garnet contact is seen to be very rough and this is likely responsible for the tendency of these grains to adhere tightly to the garnet and not pop out when exposed in the cutting and polishing of the gem. An analysis of this pyrrhotite is presented in Table 2.

CHALCOPYRITE occurs as very small crystals, usually attached to pyrrhotite grains and is quite uncommon. This mineral is not distinguished from pyrrhotite in the usual darkfield illumination.

PLAGIOCLASE occurs as anhedral colourless blebs (≈ 0·1 mm in size). The plagioclase is usually arranged in a three-dimensional array of very tiny micro-crystals surrounding pyrrhotite grains. Some pyrrhotite grains are completely enveloped by plagioclase and Figure 1 shows a pyrrhotite grain enveloped by plagioclase. This enveloping of pyrrhotite by plagioclase causes the pyrrhotite to appear blurred. This plagioclase has a composition of An 50 (Table 1) and is thus labradorite. No compositional zoning was observed.

APATITE is abundant as an inclusion and forms resorbed hexagonal crystals which are readily recognizable by their obvious hexagonal cross section. The crystals are colourless and usually isolated (Fig. 2). Apatite is more abundant in the lower quality almandine which has many acicular canals. Although the apatite has a deficiency of chlorine (Table 3), there is insufficient fluorine to classify it as a fluorapatite. Hydroxyl could not be determined due to the limitations of the microprobe and the paucity of material, but it is assumed from the fluorine and chlorine content, that this apatite is probably a fluorine-rich hydroxylapatite.

TABLE III
APATITE ANALYSES

	From Gore Mtn Almandine (#90518)	From Emerald Creek Almandine (#128192)
MnO	0·20	0·19
CaO	55·39	54·61
P_2O_5	42·79	42·68
F	1·12	2·17
Cl	·29	·21
Ce_2O_3	·05	·04
	Total 99·84	99·90

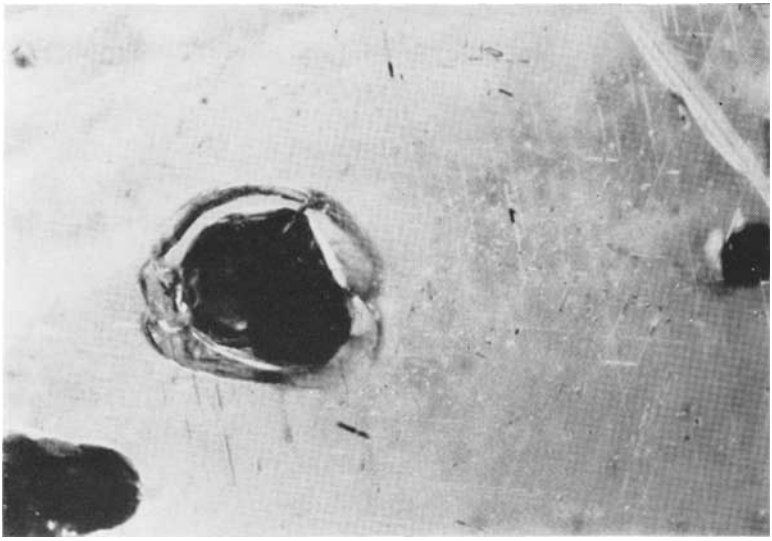

FIG. 1. Pyrrhotite bleb enveloped by labradorite. (60 ×)

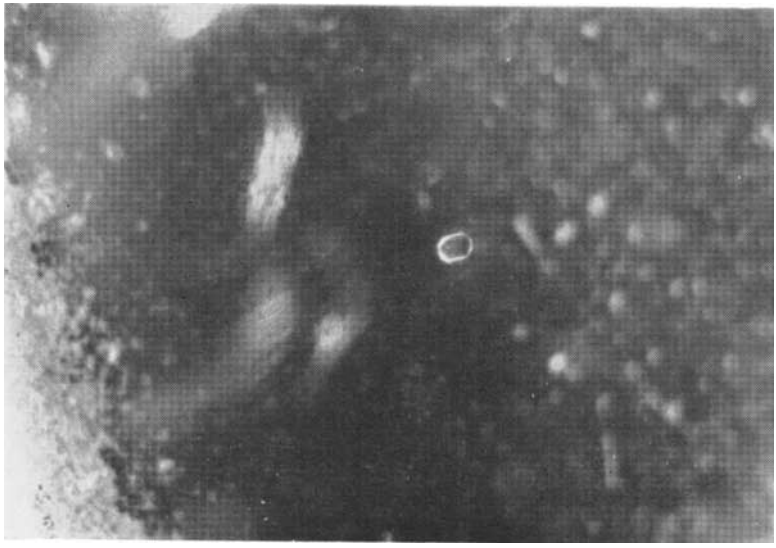

FIG. 2. Isolated apatite crystal in New York almandine. (70 ×)

ACICULAR CAVITIES are observed in this almandine but are too small to permit the determination of their contents. The majority of the cavities appear to be hollow, elongated 10 : 1 and, under very high magnification (400 ×), it can be observed that some unidentified opaque crystals occupy part of the cavities. These cavities are arranged in a three dimensional pattern suggesting they are parallel to {110}. Pyrrhotite grains are also included within the labradorite and apatite. Hence, pyrrhotite appears to have been the first of the inclusions to form.

IDAHO ALMANDINE

Gem almandine from Emerald Creek, Idaho, is best known as the opaque asteriated material from which very nice star-stones are cut. These star garnets grace many gem collections, public and private. Less well known, but equally interesting, is the clear almandine from the same locality, which is of faceting quality. The material examined in this study is from the east fork of Emerald Creek, Clarkia Ranger district, in St Joe National Forest, between Clarkia and Fernwood, Idaho. It was collected in the summer of 1971 by Donald G. Wyman and Leo C. Vaught, two noted and extremely capable New England mineral collectors and friends of the author. It is obtained as water-worn subhedral crystals in alluvium.

The Emerald Creek almandine is medium pinkish-violet in colour, has a refractive index of nD = 1·808 and a specific gravity of 4·07. The specific gravity increases to 4·11 in material with a moderate amount of included ilmenite and to 4·16 when opaque due to abundant ilmenite. The characteristic almandine absorption spectrum was observed.

The analysis of this garnet is presented in Table 1 and shows it to be almandine. The unit cell edge of this almandine is 11·52 Å and is in good agreement with the composition and observed properties. The analysis of this garnet indicates it is comprised of 85% of the almandine component and 15% of the pyrope component.

Inclusions of fluorapatite and ilmenite are abundant in the Emerald Creek almandine.

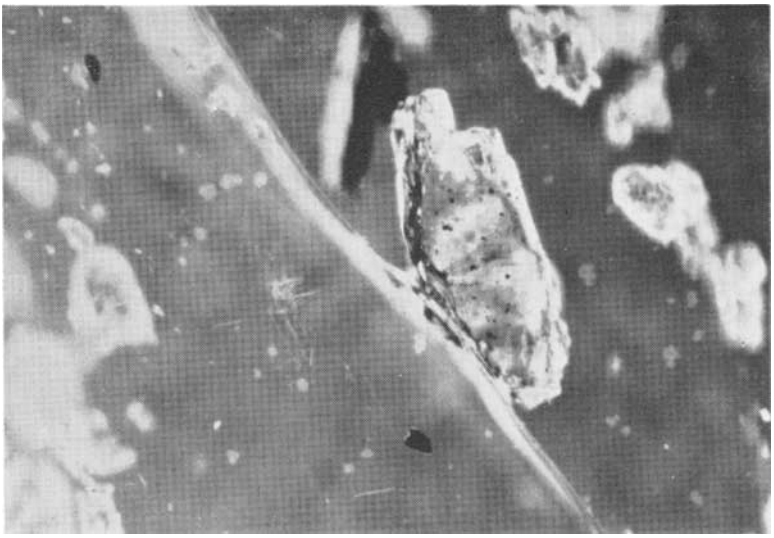

FIG. 3. Blocky fluorapatite in Emerald Creek almandine showing ilmenite included in fluorapatite. (30 ×)

FLUORAPATITE occurs in two distinct habits, both habits frequently seen in the same gemstone.

a—as parallel swarms of minute (<0·1 mm) highly resorbed hexagonal crystals which resemble colourless cylinders as the resorption of crystal edges is severe.

b—as large (0·2 to 1·0 mm) irregular blocky blebs which frequently enclose ilmenite (Fig. 3). These blebs have noticeable pleochroism.

Separate analyses of these two fluorapatites are identical. The analysis is given in Table 3.

ILMENITE occurs as distinct, euhedral crystals, tabular in habit (Fig. 4). They are frequently concentrated in swarms with a galactic appearance and are randomly oriented within the swarms. Ilmenite crystals are also observed as inclusions within the large, blocky fluorapatite crystal inclusions. It is obvious that ilmenite was the first included mineral to form and was followed in the formation sequence by apatite. The analysis of this ilmenite is presented in Table 1.

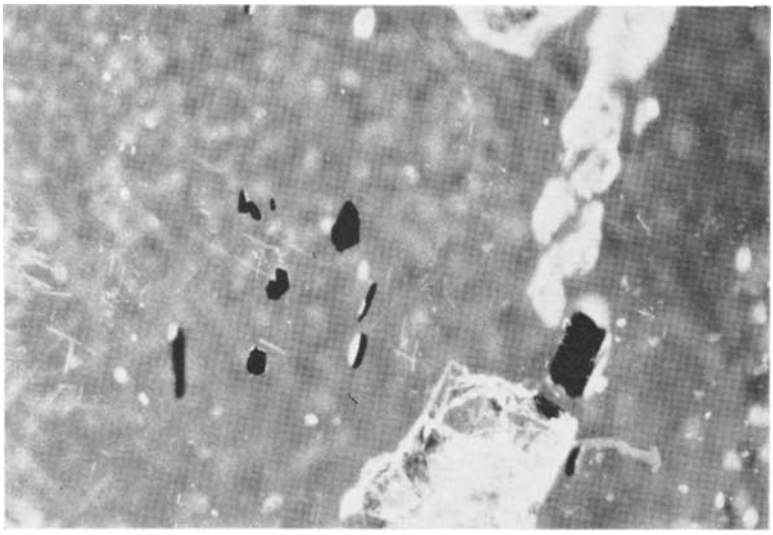

FIG. 4. Ilmenite and fluorapatite in Emerald Creek almandine. (35 ×)

The author is indebted to Mr Richard Johnson for the painstaking preparation of microprobe samples of the gems in this study. His contribution to the success of this study was invaluable. The author is also indebted to Mr John S. White, Jr, for proof-reading and suggestions for improvement in format.

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REPORT ON A NEW ELECTRONIC REFRACTOMETER

By ROBERT WEBSTER, F.G.A.

WITH the advent of so many new synthetic (man-made) stones which are now used as simulants of diamond, the news that a new refractometer working with electronic devices would read refractive indices up to 2·7, seemed a welcome advance. The writer has had the privilege to examine one of these instruments, which are made by Sarasota Instruments Inc., of Sarasota, Florida, U.S.A.

The instrument consists of a metal box 9 inches wide, 7½ inches deep and 8 inches high overall. Finished in mottled grey enamel, the instrument weighs about 4 lb. On the flat top is a circular black plastic examination disc, which can be covered by a black plastic cup to provide a dust cover and a light trap when testing stones. The examination disc has a raised "nipple", at the centre of which is a small hole over which the stone to be tested is placed.

On the inclined top front of the instrument is mounted a meter marked in refractive indices and divided in the range 1·40 to 1·80 into divisions of 0·02, and in the higher range from 1·80 to 2·7 the divisions are 0·05. On the left of the meter panel is a push-button to activate the electronic system, while below the meter there is an adjusting screw to allow the meter to be calibrated with stones of known refractive index.

At the back of the case there is a removable half panel which when unscrewed and removed has, internally, the clip for holding the 1·5 volt alkali dry cell which supplies the necessary electric current. Figure 1 shows a picture of the "Gemeter", as the instrument has been named.

The literature sent with the instrument is careful to state that the facet of the stone to be tested must be scrupulously clean and not less than ⅛th of an inch across. The facet, too, must be flat and well polished and should be carefully centred on the examination disc which, like the stone, must be dust free. Other operating instructions are given, as well as the means to calibrate the Gemeter. It is also suggested that several readings be taken and the mean of these readings taken for the final result.

A further clip of eight pages tells much about bi-refringence, although the Gemeter will not measure this constant. The write-

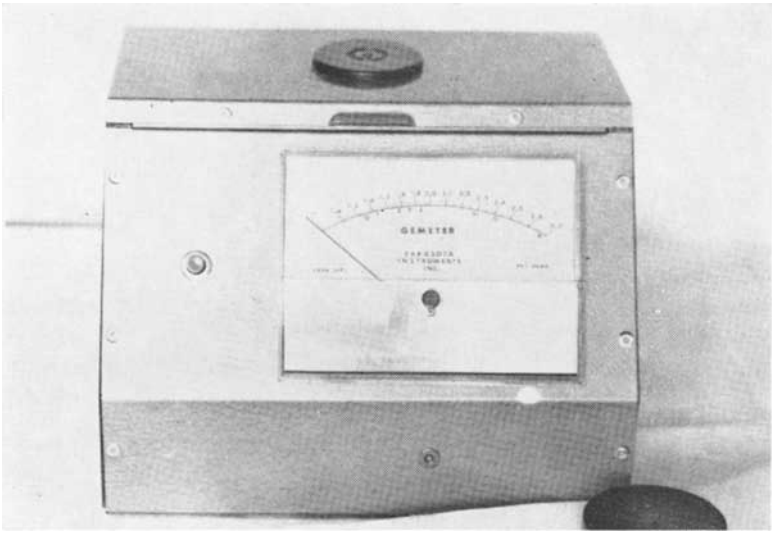

FIG. 1. The Gemeter (Top of plastic cup to cover examination disc is in partial view at lower right hand of picture).

up in these pages is largely inaccurate and leaves much to be desired. Certain facts of interest are given and these give food for thought. The makers have found that the Gemeter shows that the Y.A.G. stones seem to fall into two common values at approximately 1·82 and 1·87, and that the value for strontium titanate is 2·3 and not 2·4 as given in gem literature. These papers conclude with two sheets of graphs showing the refractive indices of stones. The system used for these graphs is that used by Karl Chudoba for the density of ornamental stones[1] and also currently used in *Edelsteinkundliches Handbuch* written by Chudoba and Gübelin[2]. No information whatsoever is given on the principle upon which the instrument works.

Before any estimation is made of the performance of the Gemeter it may be as well to discuss what the writer feels may be the principle upon which the instrument works, using for the assessment the facts elucidated by experiment.

Bearing in mind the various techniques which have been, and are, used to obtain the refractive index of transparent materials, it seems that none fit the features of the Gemeter. One has, therefore, to consider some technique which has hitherto been scarcely men-

tioned in gem literature. One of these, and in the writer's view the most likely, is by measuring the reflecting power of the stone to a light ray at normal (perpendicular) incidence. This may well be the answer.

Anderson[3] mentions that the proportion of reflected light to refracted light in transparent substances increases with the refractive index of the substance. However Anderson does not make any suggestion that the effect could be used to measure the refractive index of a stone.* From the above reference to Anderson's note it may be inferred that a source of visible light would be needed. No visible light source could be found in the Gemeter, either by visible observation or by a photoelectric cell placed against the examination disc; and nor, to clear up any other possibilities, was it found to affect a compass needle.

Infra-red "light" is said to obey the same laws as ordinary visible light and this could conceivably supply an answer to the problem of how the Gemeter operates. For normal incidence the reflectance, denoted as r (the reflectance being the ratio of the reflected to the incident intensity) of a transmitting material is determined by the expression

$$r = \left(\frac{n-1}{n+1} \right)^2$$

where n is the index of refraction, and this formula is true both for visible and for infra-red light. It has been pointed out by Vaško[4] that reflectance of a material depends *to a great extent*, but not wholly, on its refractive index, and he further states that these values are only true for optically flat surfaces and any roughness of the surface will reduce the percentage of reflection.

At the present time it seems far from impossible for infra-red radiations to be so used, as currently small electronic devices are made both to produce and to detect infra-red rays. To probe this notion further, the wiring inside the Gemeter was examined and

*Following a similar statement by Mr Anderson to a meeting in Salisbury early in 1958, the late L. C. Trumper, B.Sc., F.G.A., constructed a "differential reflectometer", designed to enable the refractive indices of gemstones up to 3·00 to be read off a calibrated dial and operating with white light from a 4·5 volt miniature bulb, and in 1959 was awarded a Research Diploma for his thesis on the measurement of refractive index by reflection: and according to an article by Roy Wilkins in the *Lapidary Journal*, 1972, 26, 432–434 (abstracted in *J.Gemm.*, 1973, XIII, 6, 232), a prototype instrument for determining refractive index by measuring reflectivity with a photocell and amplifier was made by R. H. Long in Oregon, U.S.A., but few constructional details were given.—Ed.

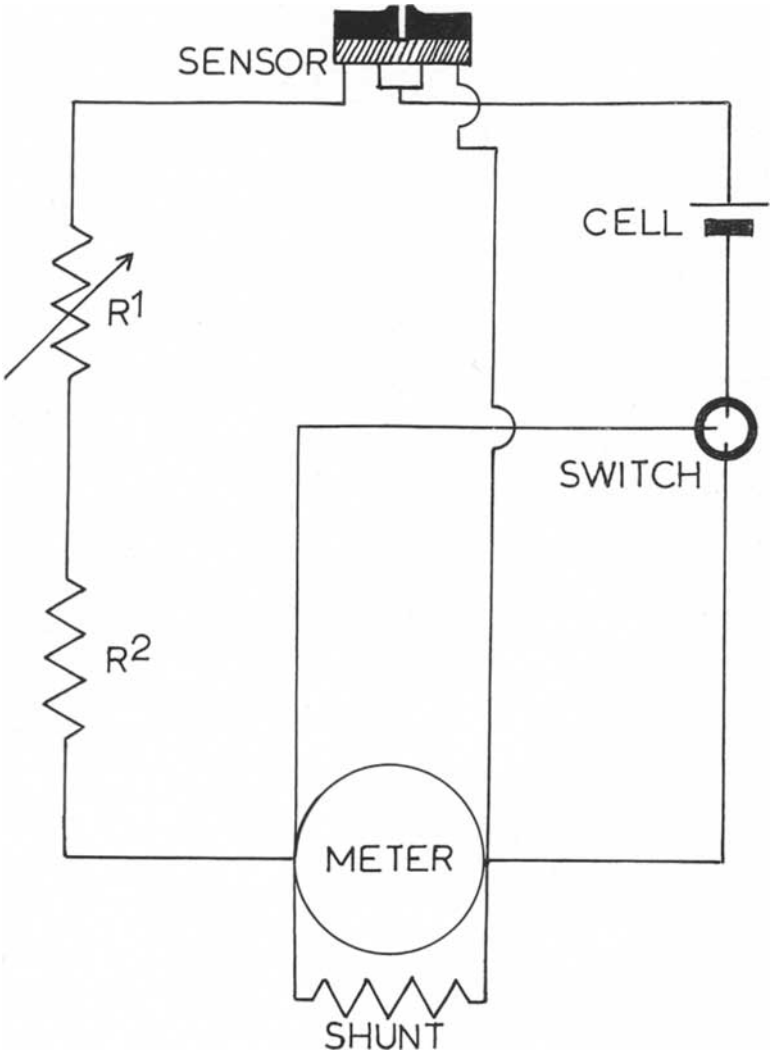

FIG. 2. Circuit drawing of the Gemeter wiring. (R^1 is an adjustable resistance used to calibrate the meter. R^2 is a fixed balancing resistance).

a circuit diagram prepared (Figure 2). This seems to show a balanced circuit in which any change in resistance would show on a suitable meter. There are semi-conductors of very small size which will alter an electrical resistance when irradiated with either visible light or infra-red radiations.

To test this idea further, the bulb of a finely graduated mercury thermometer was clamped over the hole in the examination disc and a rise of temperature at the rate of approximately 0·15°C per minute was seen to occur. It is by reason of these observations and other features displayed during the actual operation of the machine that the writer feels that infra-red reflectance is the method used in the Gemeter.

Some 300 faceted gemstones of various species and refractive indices, from fluorite (1·43) to rutile (2·90), were examined on the Gemeter, and records were made of some 1,000 observations. The stones used were "run of the mill" stones from commercial suppliers and stones from the writer's personal collection. No selection was made as to the style of cutting or the perfection of the polish, this being in keeping with the view that the instrument is to be marketed for the use of jewellers and not trained gemmologists.

The values registered on the Gemeter were found to be nearly always much lower than the known refractive index of the species, and in only a few species were indices recorded anywhere near what they should have been. Quartz and beryl and, of course, diamond, which usually has such a superb polish and is normally used for calibration, were exceptions. In no case could the birefringence be estimated even by turning those stones which had known optical directions. Stones with large double refraction, such as peridot, zircon and rutile, failed to display any marked differences in readings which could be ascribed to double refraction.

Two frustrating aspects were that the instrument would not always "repeat" itself even when the position of the stone had not been altered on the examination disc, and, secondly, that any different degree, or angle, of pressure on the activating button resulted in different readings being obtained. There is some evidence, too, that the electronic system may suffer from "fatigue", from which it may later recover. Although the instruction sheets suggest that temperature may cause a difference in readings—the instruments are said to be set for 72°F, which may be a useful value for Florida, but for England 60°F to 65°F would be a better value—

experiments have shown that there is little difference with temperature changes.

The makers claim that the refractive index of strontium titanate is, on the Gemeter, 2·3 and not 2·4 as given in gem literature. The values found on the few stones of this type tested were nearer to 2·2 than 2·3 in most cases. There seems to be some justification for the makers suggesting two values for Y.A.G. stones. Personal but not extensive observations of the behaviour of yttrium aluminate on the Gemeter seem to show that there may be something in this notion.

Most of the paste stones examined on the Gemeter seemed to give a reading about 1·50, even with pastes known to have an index of refraction of 1·65. Certain iridescent pastes, which have a true refractive index of 1·57, gave readings of 2·1 to 2·3, while another stone with similar characters gave a reading of only 1·40.

Much more startling was the result obtained on a faceted Burma red spinel, which had a true refractive index of 1·714 but gave on the Gemeter readings, of which many were taken, of anything between 2·5 and 2·7. Another Burma crystal gave a reading of 1·80 from an unpolished natural crystal face.

Large awkward-shaped stones, such as pendeloques and long trap-cut stones, do not balance well on the raised "nipple" of the examination disc, nor could mounted jewellery be easily accommodated; such stones and jewellery tend to fall over after the plastic cup is placed over them, with the consequence that one gets false readings or none at all.

To sum up: although at first sight the instrument appears to have some potential, experiments have shown that this is not as hoped. Up to a reading of 1·80 this electronic instrument cannot match the standard refractometers which operate on the projection of the shadow edge of the critical angle on to a scale or screen as in the Dialdex instrument. These jewellers' refractometers are far more accurate and do allow measurement of the bi-refringence. Over a refractive index of 1·80 there seemed more likelihood of a break-through, but as far as the instrument examined is concerned its seeming inaccuracies would make it dangerous to use except in the hands of an expert who could detect irregularities.

On a more constructive note, the writer might say that, mechanically, the examination disc would be more effective if the surface had been plane and had no raised "nipple". A simple hole

at the centre of a flat disc engraved with concentric circles as an aid to centering would be more effective. Electrically, the push-button switch seems to be somewhat faulty; it could be replaced with something more robust and could with advantage be placed on the top of the instrument, which would allow a more even distribution of pressure on the button. It might be more advantageous to confine the Gemeter to the ranges of 1·80 to 2·70 coupled with improvements to its performance.

What are the most important factors which, if the operation of the instrument is, as surmised, the reflectance of infra-red light, lead to the inaccuracies in such an instrument? Firstly, the measurement of the reflecting power of a transparent medium depends upon the reflecting surface being optically flat, and, except perhaps for well polished diamonds, this is not so with the normal polish given to gemstones, which therefore show "irregular reflections", producing a "scattered" type of reflection all of which does not reach the sensor, and hence a lower reading is shown on the meter. Secondly, not enough "homework" appears to have been done on the characteristics of gem materials under infra-red radiations.

It might be suggested that some of the irregularities in the meter readings shown by the Gemeter may be due to absorption of certain wavelengths of the incident infra-red beam, and this could well account for the lowering of the value of strontium titanate as shown on a "reflectance" instrument, and also some other "freak" low results. The reason for the higher readings, and in particular the anomalous effect of the Burma red spinel, is less easily explained. However, one might suggest that it could be due to a "fluorescent" effect in the infra-red producing a "characteristic" emission. A consideration of the effects of infra-red radiation on gem materials requires much further study and such an investigation may well be profitable, and, if the Gemeter does work on the principle outlined, further work may well iron out some of the faults.

In fairness it must be pointed out that the instrument examined had travelled some 4,000 miles and could conceivably have suffered some "shake-up" which could have impaired its working conditions, although no observable damage was noticed. The writer has

now been informed that a new model is being marketed which is said to "iron-out" some of the faults mentioned above. This new model has not as yet been evaluated.

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STAINED WALRUS IVORY*

By E. A. JOBBINS, B.Sc., F.G.A. and Miss P. M. STATHAM, B.Sc., F.G.A.

THE exhibition "Ivory Carvings in Early Medieval Sculpture" mounted at the Victoria and Albert Museum, London, during May-July 1974, showed a number of beautiful and remarkably preserved carvings attributed to walrus ivory. They were produced during the period 700-1200 A.D. and reminded the authors that this material is little known in this country except for a few experts on medieval sculpture. Carvings in walrus ivory by Eskimo artists, mostly simple in form, have been reported from Scandinavia, Canada and other countries bordering the Arctic.

Some time ago a spinach-green necklace was submitted for examination with the comment that it had been offered to the enquirer as jade, which it clearly was not. Subsequent examination showed it to be fashioned from *walrus ivory.* Initial examination with a hand lens showed a generally nodular structure with many small cavities. The distribution of the colouring was very uneven and suggested that the beads had been dyed. Scrapings immersed in oil showed a generally fibrous appearance with tabby extinction, low birefringence and a mean refractive index just above 1·55. The beads were sectile with a hardness between 2 and 3 on Mohs' scale. The specific gravity was 1·99. Minute parings blackened on heating with a smell of burning protein—this virtually confirmed

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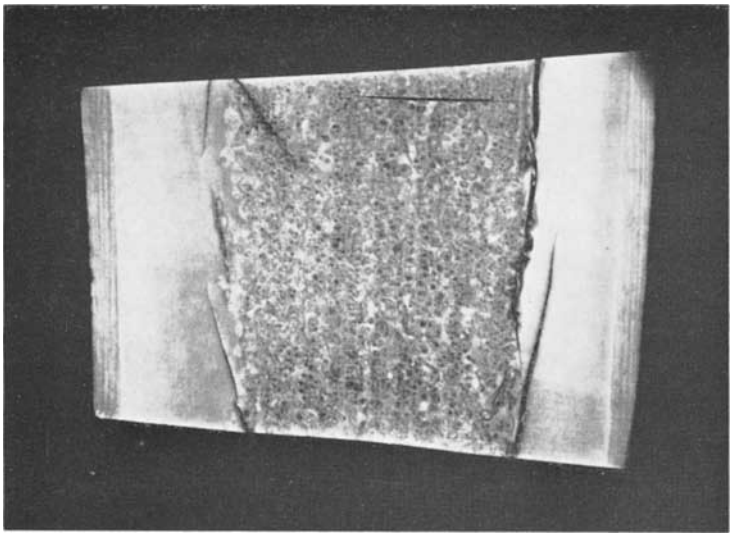

FIG. 1. Ivory: longitudinal section through walrus tooth. Magnification × 2. Photo No. MN 18426.

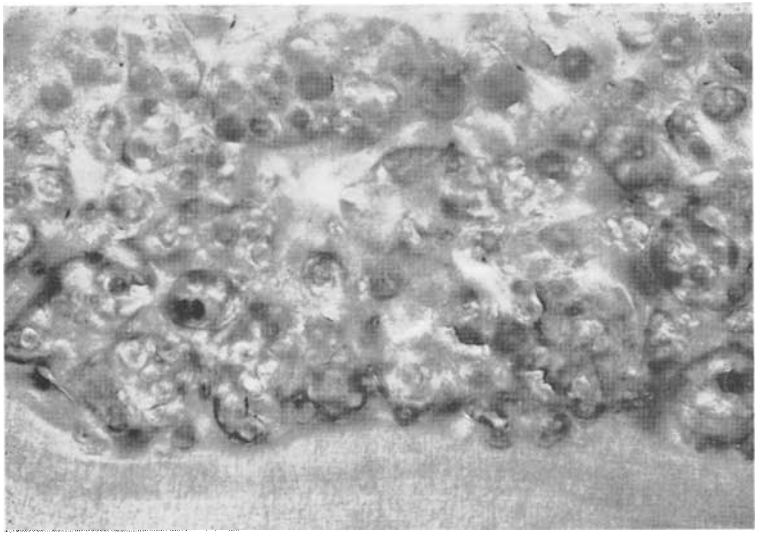

FIG. 2. Ivory: longitudinal section of walrus tooth showing finer outer and coarse inner parts. Magnification × 12. Photo No. MN 18424.

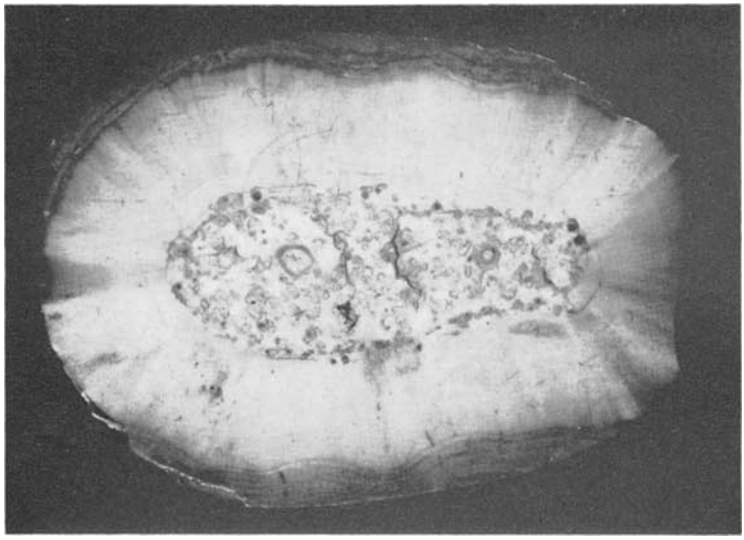

FIG. 3. Ivory: cross-section of walrus tooth showing fine outer and coarse inner parts. Magnification × 3. Photo No. MN 18425.

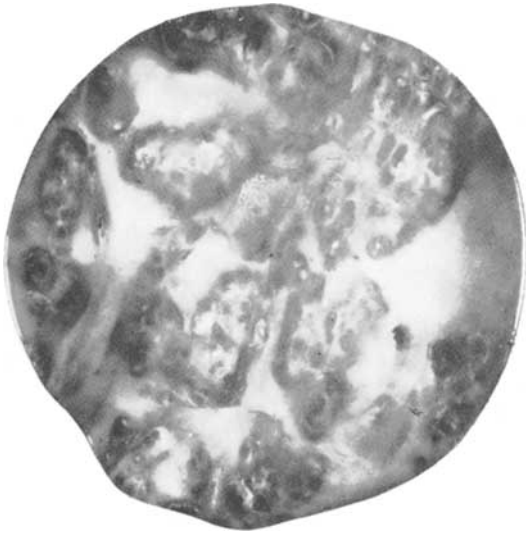

FIG. 4. Stained Ivory bead: polished section showing nodules and the darkening due to surface staining. Magnification × 12. Photo No. MN 18460.

an organic origin. Microchemical tests showed the phosphate radical, and spectrographic analysis showed major calcium (Ca) with minor magnesium (Mg) and copper (Cu). The presence of calcium and phosphate together with the smell on heating and the Cu suggested teeth or bones which had been stained green by a copper salt.

By courtesy of officers of the Zoology Dept at the British Museum (Natural History) the beads were then compared with the more unusual forms of ivory and were identified as being fashioned from walrus teeth. Walrus teeth are enlarged canines from the upper jaw of the animal and are said to reach two or even three feet in length. In cross section the teeth may be broadly oval or circular but often take a deformed "figure of eight" shape. The outer part of the tooth is fine-textured and may show a concentric graining, but the inner "core" is coarser with abundant nodules or "whorls". These structures differ markedly from those in elephant ivory, which usually shows the parallel or intersecting "lines of Retzius". The necklace is fashioned from the inner part of the teeth. It is displayed in the Geological Museum, London, along with a sectioned bead and a sectioned walrus tooth, together with other types of ivory.

The photographs, taken by Mr J. M. Pulsford, show transverse and longitudinal sections of walrus ivory and the stained sectioned bead from the necklace. Photographic techniques have been used to increase the contrast in these pictures, but in unstained specimens the structures will need to be sought for with some care.

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LARGE ASIAN YELLOW CAT'S-EYES

By HELEN L. MACLEOD, F.G.A.

TWO large yellow cat's-eyes, each over 30 carats, were bought in the Orient as chrysoberyl cat's-eyes for some thousands of dollars. One, which had been badly scratched and worn, had been repolished in New York, by a dealer who at one time had it on memorandum. These stones were shown to Antonio C. Bonanno, F.G.A. (National Gem Appraising Laboratory, Silver Spring, Maryland) with the object of selling one of them.

Mr Bonanno had the feeling that one stone (the one that had had the polishing job) didn't look right, although a perfect match in colour. Sure enough, when the two were dropped in methylene iodide, this one floated and so could not be chrysoberyl. The owner was shocked and asked for identification.

Its specific gravity, by hydrostatic method, proved to be 3·18, a trifle heavy if it was a tourmaline, but narrow metallic-type needle inclusions in parallel orientation would account for this. The cabochon had a rough back, and the spot method for determining refractive index gave a reading of 1·63, of course within the tourmaline range. An electrostatic test by rubbing gave negative results for the top of the stone, but positive on the side or lateral portions. Yellow cat's-eye tourmaline was therefore a good guess *but tourmaline it was not.*

A check with a spectroscope had revealed none of the significant lines (didymium) that most people associate with apatite, which has, of course, a refractive index and specific gravity very close to tourmaline under the test conditions applied in this case. Mr Bonanno had examined yellow cat's-eye apatites with the spectroscope before: he had found the rare earth lines in specimens from Mexico, but *not* in those from Asia. For a definite answer, a careful hardness test was carried out.

The gem, which was apatite, *must have been unduly easy to polish.* No discussion or testing could have taken place at the time it was offered to the trade. It is important to bring out these details for the reason that many chatoyant apatites, though seldom this large, are appearing on the market. They are of minimal value, but may be bought and sold by the ignorant as chrysoberyl, and even the fairly knowledgeable might think they had yellow tourmaline, a fairly rare material in its own right.

Gemmological Abstracts

BANK (H.). *Durchsichtiger farbloser bis blaeulicher Sillimanit aus Kenya.* (Transparent colourless to bluish sillimanite from Kenya). Z. Dt. Gemmol. Ges., 1974, 23, 4, 281–282.

The mineral sillimanite is found quite frequently in metamorphous rocks. It is usually found in thin, long, or ray-like or fibre-like crystals and can only seldom be used for cutting. Some specimens found in Burma have long been known to be cuttable: now Kenya has yielded further cuttable silimanite. E.S.

BANK (H.). *Durchsichtiger saphirblauer Sodalith von SW Afrika.* (Transparent sapphire-blue sodalite from S.W. Africa). Z. Dt. Gemmol. Ges., 1974, 23, 4, 279–280.

Sodalite, which is chemically $Na_8[Cl_2(Al\ Si\ O_4)_6]$, was said to be glass because of its $n = 1{\cdot}486$ singly refractive index. However, this has now been found to be sodalite from the northern part of S.W. Africa. E.S.

BANK (H.). *Über Brechungsindizes brasilianischer Smaragde.* (About refractive indices of Brazilian emeralds). Z. Dt. Gemmol. Ges., 1974, 23, 4, 297–298.

The author shows that the values of the refractive indices of Brazilian emeralds are not as low as usually given in gemmological tables, but that the commercially available emeralds from Brazil on the market today show high values. E.S.

BASTOS (FRANCISCO MULLER). *Maxixe type Beryl.* Lapidary Journal, 1975, 28, 10, 1540–1542.

Stones examined in Brazil were of varying colours, some being similar to aquamarine, others being a cobalt blue closer to blue zoisite. Some stones were such an unusually fine dark blue that they at first resembled the stones first found at Maxixe, Piauhy, Brazil. An unstated process was used to change the colour of light pink beryls to the dark blue; the light pink stones altered to a cobalt blue, though two other stones of a similar colour from the Barra de Salinas area did not alter. The duration of the experiment was 9 days. No deterioration of the colour was experienced after a period of exposure to light lasting one month. This alteration of colour is only possible with pink beryls from a certain area and the commonest change is to a light blue. Some stones on heating returned to their original light pink; on being subjected to the experimental technique once more they again altered but to a less fine blue than formerly. No report of any kind of irradiation is mentioned. M.O.D.

BROUGHTON (P. L.). *Emerald deposits of Western North Carolina.* Earth Science, 1974, 27, 4, 222–228. 2 illus; 1 map.

An article giving a good account of the emerald mines of North Carolina, and in particular the Rist and Ellis mines of Alexander County. These mines are open to the public who, for a fee, can search for emeralds. Much is told of the history and the type of occurrences. An interestingly written factual article. R.W.

CASSEDANNE (JACQUES P. and JEANNINE O.). *Note sur la mine d'émeraude de Carnaiba.* (Note on the Carnaiba emerald mine.) Bulletin de l'Association Française de Gemmologie, 1974, 40, 4–8.

The mine, in the state of Bahia, lies south-west of Senhor de Bonfim, which is south of Juazeiro and west of Aracaju. The regional geology consists of quartzites with schists with some occurrence of gold and diamond. Close to Carnaiba there is a granite intrusion and the emeralds are found in a rock composed of phlogopite, with quartz, apatite and biotite. This is known as "sludite". The emeralds have a hardness of 7·5, a density of 2·72, a refractive index of 1·572 and 1·566. No change is observable through the colour filter and there is no fluorescence. Inclusions consist of mica plates, with two-phase inclusions. M.O'D.

DERN (H.). *Der Billiansche Wirbelschliff.* (The Billian spinal cut). Z. Dt. Gemmol. Ges., 1974, 23, 4, 319.

A new cut for gems described by Otto Verbasius Billian from Brazil, variable with material, can be used to produce octagons, or even 10- or 12-cornered stones. The angles are optimal. E.S.

DERN (H.). *Ein neuer synthetischer Sternkorund.* (A new synthetic star-corundum). Z. Dt. Gemmol. Ges., 1974, 23, 4, 294–296.

J. C. Smith and J. M. J. Watts of the United Carbide Corporation of New York have patented in 1973 in Munich a new method of producing synthetic star corundums. The titanium dioxide which produces the asterism and the colouring material are regularly distributed throughout the stone, by pulling a seed crystal out of the melt while rotating it round its c-axis. The crystal is then heat-treated, overshooting the solubility limit of the titanium solution, thus forming an aluminium titanate which produces the asterism. This synthetic material can be distinguished from the natural corundum by its growth lines, which in the natural stone are hexagonal, while concentric circles can be seen in the synthetic product. E.S.

DERN (H.). *Das Reiben von Diamanten.* (Bruting of diamonds). Z. Dt. Gemmol. Ges., 1974, 23, 4, 308–315.

This is part I of an article written for the amateur lapidary who would like to try his hand with diamonds. It explains the crystallographic growth of the stone, as well mentioning some of the tools used in the process: various dops are described, as are also a couple of bruting machines. E.S.

DOEPEL (E. H.). *Rhodonite and bustamite from Daghazeta/Tanzania.* Z. Dt. Gemmol. Ges., 1974, 23, 4, 283–285.

Recently Bank, Berdesinski and Diehl published a paper on rhodonite found in Broken Hill, Australia, which led to this investigation of the joint occurrence of rhodonite and bustamite in Tanzania, Daghazeta. The formation of quartz and spessartite next to bustamite seems to be connected with the decomposition of rhodonite, which appears to be controlled by interlacing fissures and fracture zones. The Daghazeta deposit seems to have been formed firstly by the formation of rhodonite and granulite as a result of regional metamorphism and secondly by the alteration of rhodonite and the augite-containing host rock under special conditions. E.S.

DUNN (PETE J.). *Emeralds in the Smithsonian Gem Collection.* Lapidary Journal, 1975, 28, 10, 1572–1575.

Some recent acquisitions by the Gem Collection, including the Spanish Inquisition necklace and other pieces of Persian design, are described and illustrated. M.O'D.

DUNN (PETE J.). *Elbaite from Newry, Maine.* Mineralogical Record, 1975, 6, 22–25.

Gem quality tourmaline has been rediscovered at the Dunton pegmatite on Newry Hill, Maine. The crystals are mostly zoned parallel to the prism and show a light green rind over a red core. Lengths of up to 27 cm have been recorded. M.O'D.

DUNN (PETE J.). *Chromian spinel inclusions in American peridots.* Z. Dt. Gemmol. Ges., 1974, 23, 4, 304–307.

The peridots examined were found in Arizona and New Mexico. The purpose of the examination was to study the euhedral, equant, dark inclusions often found in stones from these localities. Method of preparation and examination is described in detail: the inclusions were found to be chromian spinel. E.S.

EPPLER (W. F.). *Einschlüsse im Vanadium-Beryll.* (Inclusions in vanadium beryl). Z. Dt. Gemmol. Ges., 1974, 23, 4, 300–303.

The inclusions in the new light green vanadium beryl consist mainly of greyish-white spots and streaks distributed in large numbers throughout the stone. Occasionally they are accompanied by small black spots which are ore. Some parts of the stone can be full of very fine 'dust' giving the stone a matt, sleepy appearance. These various inclusions are illustrated by photomicrographs. E.S.

EPPLER (W. F.). *Synthetischer Alexandrit und synthetischer Opal.* (Synthetic alexandrite and synthetic opal). Z. Dt. Gemmol. Ges., 1974, 23, 4, 286–293.

Synthetic alexandrite was first manufactured commercially in 1972 and was then described by Liddicoat (*Gems & Gemology*, 1972/73, XIV, 4, 102–104). Hardness was 8½, S.G. 3·71 and R.I. 1·75 and 1·76. The same firm has now made a new synthetic alexandrite, which shows a good green in daylight, at night being definitely red, perhaps a little violet. The physical characteristics are the same as before. The inclusions, however, are quite different, showing now arched growth lines which consist of net-like liquid inclusions. These alexandrites also show irregularly formed and irregularly placed black spots and some fine thin needles. Photomicrographs are shown. The prices for these synthetics are very high ($300 to $500 per ct). The author describes his own experiments of alexandrite synthesis, and also describes shortly the synthetic Gilson opal first seen in about 1972 in U.S.A. These synthetic opals consist of regularly arranged 'balls' of cristobalite which produce the opalization. In the case of black opals the matrix is not black or grey, but definitely brown-black. E.S.

HASSAN (F.) and COHEN (A. J.). *Biaxial color centers in amethyst quartz.* American Mineralog., 1974, 59, 7/8, 709-718.

Anisotropy of the characteristic absorption bands in a natural Brazilian amethyst is demonstrated. The biaxiality and pleochroism of amethyst is explained

as due to the existence of strongly anisotropic colour centres, related to iron, of orthorhombic or lower symmetry. When the colour is bleached optically or thermally, the biaxiality also disappears. This anomalous biaxiality and pleochroism in amethyst is a property of the colour centre and not of the quartz crystal structure. R.A.H.

JENKINS (WILLIAM J.). *A photographic method of observing striae in corundum.* Lapidary Journal, 1974, 28, 8, 1258–1260.

A penpoint flashlight using a bulb with a built-in lens is substituted for the stopped-down enlarger as the light source. The converging rays are virtually parallel so that contact prints can be made from negatives which are not actually in contact with the printing paper. There is no need to use an immersion cell or liquid. Exposure time should be $\frac{1}{4}$–$\frac{1}{2}$ second and film sensitive below 4000Å is used. M.O'D.

LESTER (J. G.). *Gem minerals of Georgia.* Rocks & Minerals, 1974, 49, 131–135.

A comprehensive list is given of gems which have been reported in Georgia. Special emphasis is placed on occurrences of diamond, ruby, topaz, aquamarine, golden beryl, almandine, gahnite, apatite, lazulite, kyanite, and quartz (amethyst, smoky, agate, jaspar). R.S.M.

MALTBY (LAWRENCE J.). *Photography for the rockhound. Part 1.* Lapidary Journal, 1975, 28, 10, 1526–1530.

The author uses a 55 mm Micro-Nikkor-P lens for close-up photography; the aperture ranges from F 3·5 to F 32 and the photographs accompanying the article were taken at F 32. The camera body used is a Nikon F with a Photomic FTN finder. Kodachrome II film is useful since the grain is fine; as it is now being phased out of production, the Kodachrome 25 should be a satisfactory replacement. Flash equipment used for the illustrations to the article was the Honeywell Auto/Strobonar 770. M.O'D.

MERTENS (R.). *Die Achate Idar-Obersteins zum gegenwaertigen Zeitpunkt.* (The agates of Idar-Oberstein at the present time). Z. Dt. Gemmol. Ges., 1974, 23, 4, 316–318.

The industry in Idar-Oberstein was originally founded on the local agates. Today the finds are not of commercial value but of great interest to collectors. Details of local occurrences are given. The article is illustrated by 3 photographs of 3 attractive local finds. E.S.

MCCRILLIS (DEAN A.). *Gem tourmaline rediscovered at Newry.* Mineralogical Record, 1975, 6, 15–21.

An account of the events leading to the discovery and notes on the working of the gem tourmaline from Newry, Maine. M.O'D.

NASSAU (K.). *The effect of gamma rays on tourmaline, greenish-yellow quartz, pearls, kunzite and jade.* Lapidary Journal, 1974, 28, 7, 1064–1084.

Colours induced in tourmaline by gamma radiation include pale colours to deep pink, medium pinks to deep pink or yellow, blue to purple and pale green

to a bicoloured pink and green. Some of the new colours are light- and heat-resistant, others are not. A bright greenish-yellow has been produced by irradiating some Brazilian quartz and then gently heating it. This colour is unstable. Pearls may be turned grey, bluish-grey or blue, and this colour is stable. Kunzite, turned to a deep green, is bleached by light exposure or heating. No major colour change can be detected in irradiated jadeite or opal. M.O'D.

POIROT (J. P.). *Une application ancienne de l'observation des inclusions en bijouterie-joaillerie.* (An old application of the observation of inclusions in jewellery). Fend. Soc. Italiana Min. Petr., 1974, 30, 417–422. 7 figs.

The author points out the importance in jewellery of the observation of inclusions for distinguishing natural gems from artificial ones. F.M.

ROSSMAN (G. R.). *Lavender jade. The optical spectrum of Fe^{3+} and $Fe^{2+} \rightarrow Fe^{3+}$ intervalence charge transfer in jadeite from Burma.* American Mineralog., 1974, 59, 7/8, 868–870.

The optical spectra of green, white and lavender jadeite have been studied. Ferric iron is responsible for the colour in the green jadeite. It is suggested that ferrous-ferric iron intervalence charge transfer is responsible for the lavender colour of jadeite. Material sold as 'colour-enhanced lavender jade' has the same spectral features as genuine lavender jadeite and has probably undergone heat treatment which would affect the oxidation state of a small proportion of the iron present. R.A.H.

SCHMETZER (K.), MEDENBACH (O.) and KRUPP (N.). *Das Mineral Kornerupin unter besonderer Berücksichtigung eines neuen Vorkommens in Kwale Distrikt, Kenya.* (About the mineral kornerupine with special reference to a new find in the Kwale district in Kenya). Z. Dt. Gemmol. Ges., 1974, 23, 4, 258–278.

The article describes in detail the cuttable light green kornerupine recently found in the Kwale district in Kenya. This kornerupine is found in prismatic crystals, which are up to 10 cm long, next to crystalline micas, quartz, sillimanite, disthene, tourmaline, muscovite and biotite. The optical data at 589 nm are $n\alpha = 1{\cdot}660$, $n\beta = 1{\cdot}673$–$1{\cdot}674$, $n\gamma = 1{\cdot}675$. The lattice constants are $a_o = 15{,}998$, $b_o = 13{,}698$, $c_o = 6{,}704$. In microanalyses the V_2O_3 content was found to be 0·22%. By spectroscopic examination it was established that the green colour was caused by the V^{3+} content. The new data are compared with previously published data in an extensive bibliography of 51 items. Various photomicrographs, including interference figures, illustrate the article, which also has tables giving the various occurrences of kornerupine, optical and chemical data, d-values and lattice constants and absorption bands. E.S.

TINSLEY (T. C.). *Jet from Colorado.* Earth Science, 1974, 27, 2, 106–108. 2 illus.

Originally written as an academic thesis, this article introduces the reader to a little known source of jet found at El Paso County, Colorado in the United States of America. Considerable work has been shown to have been done on the scientific side and on the comparison with the jet found in Utah. Some historical facts are given which include the fact that the material was shipped to England in the 1870s and 1880s and then sold as 'Whitby jet'. There was a local industry

in Colorado for this jet during the 1920s. The Colorado locality for jet has often been mentioned in the past; that at Trinchera Mesa is said not to be factual.

R.W.

YEREMENKO (G. K.) and POLKANOV (YU. A.). *Luminescence of small diamonds from sandy sediments of the Ukraine.* Dokl. Acad. Sci. USSR, Earth Sci. Sect., 1969, 188, 149–151. 2 figs. Transl. from Dokl. Akad. Nauk SSSR, 1969, 188, 905–908.

Many of the Ukrainian diamonds show orange-red photo-, x-ray-, and cathodo-luminescence. Most of the crystals are cubes and most are coloured. Filtered radiation from a mercury-quartz lamp was used to excite the radiation at room temperature and at 77°K. Their spectrogram consists of a broad yellow line at 575·5 mμ accompanied by a continuous band extending to 650 mμ. Microphotometer curves and a table of the spectrum are given. T.B.

ZEITNER (JUNE CULP). *Feldspar gems in the United States.* Lapidary Journal, 1974, 28, 8, 1204–1216.

The various occurrences of feldspar in the United States are reviewed.

M.O'D.

ZEITNER (JUNE CULP). *The world's most expensive minerals.* Lapidary Journal, 1975, 28, 10, 1532–1538.

Coloured illustrations and a description of the David Wilber collection of minerals, including a phosphophyllite from Potosi, Bolivia, and a proustite from Chanarcillo, Chile. M.O'D.

BOOK REVIEWS

ARGENZIO (VICTOR). *Diamonds eternal.* David McKay Co., New York, 1974. pp. xii, 290. Illustrated in black-and-white. $12·50.

Written in an easy style, this book deals with all aspects of the diamond trade from mining to the care of stones in jewellery. There are some sensible remarks on synthetic gem diamonds, though no account of their manufacture and identification, and the chapter on investment is also clear and informed. There is a short bibliography, rather annoyingly linked with the chapters so that it becomes unnecessarily repetitious. M.O'D.

BANCROFT (PETER). *The world's finest minerals and crystals.* Thames & Hudson, London, 1973. pp. 176. Illustrated in colour. £8·50.

Seventy-two minerals are illustrated in full-page, high-quality photographs. Each has been selected by the curator of a notable collection and facing the plate is a page of description. Introductory matter includes a map of mineral deposits, on too small a scale to be really useful, but then this is not intended as anything other than a book to lift the spirits, which it does. M.O'D.

BAUER (JAROSLAV). *A field guide in colour to minerals, rocks and precious stones.* Octopus Books, London, 1974. pp. 208. Illustrated in black-and-white and in colour. £1·50.

Translated from the Czech and printed in Czechoslovakia, the most remarkable feature of this useful if unexciting book is its price. Introductory chapters lead to an encyclopaedic section in which the specimens are arranged by colour. Good features include the presentation of illustration and text on the same opening: less welcome ones are the arrangement of the gems in order of value and the statement that microscopic examination of synthetic emerald does not provide reliable proof of its origin. M.O'D.

BURNS (ROGER G.). *Mineralogical applications of crystal field theory.* Cambridge University Press, Cambridge, 1970. pp. xii, 224. £4·50.

Crystal field theory has application to elements of the first transition series and this book relates the theory to geochemical and mineralogical work. Of particular interest are the data on absorption spectroscopy and the methods used for determining cation distributions in silicate crystal structures. There is a good bibliography. M.O'D.

EVANS (D. EMLYN). *Investigating minerals.* Reprinted from the Bulletin of the National Museum of Wales, no. 10, Spring 1972. pp. 15. Illustrated in black-and-white. £0·24.

A simple guide to basic mineralogical techniques designed for children and visitors to the mineral galleries of the National Museum of Wales. M.O'D.

ROBERTSON (MARIAN). *Diamond fever. South African diamond history 1866–9 from primary sources.* Oxford University Press, Cape Town, 1974. pp. 250. Illustrated in black-and-white. £5·00.

Much of the material included in this book is taken from letters in the Cape Archives and from material recently deposited in the De Beers Old Mine Museum; new light is shed on the discovery and sale of the first South African diamond. Those interested in the early marketing of diamond will find this book useful. There is a bibliography. M.O'D.

SADANAGA (RYOICHI) and BUNNO (MICHIAKI). *The Wakabayashi mineral collection.* University of Tokyo Press, Tokyo, 1974. pp. 177. Illustrated in black-and-white and in colour. £11·20.

This collection, made by Dr Yaichiro Wakabayashi from 1889 to 1943, is housed at the University Museum at the University of Tokyo. 182 species are

represented by 1,932 specimens and classification is in Dana order. Almost all are from Japanese locations and the mines themselves are given in the descriptions.
M.O'D.

SCHAWLOW (ARTHUR L.). *Lasers and light. Readings from Scientific American.* W. H. Freeman & Co., San Francisco, 1969. pp. vi, 376. Illustrated in colour. £2·80.

A series of papers from *Scientific American*, this excellent book is a basic introduction to lasers and their properties. More important, it introduces concepts in optics which are vital to the understanding of the operation of present-day optical devices and which provide useful and colourful revision notes on original studies. M.O'D.

TENNISSEN (ANTHONY C.). *Colorful mineral identifier.* Oak Tree Press, London, 1973. pp. 224. Illustrated in colour. £1·95.

This handy field guide is designed for the pocket and is a translation of *Bunte Welt der schönen Steine* first published in 1969. Specimens are grouped in Dana order and descriptions face the photographs. The standard of illustration is quite high for such a cheaply-priced book. M.O'D.

Compilation of crystal growers and crystal growth projects. Research Materials Information Center, Oak Ridge National Laboratory, Tennessee, U.S.A., 1972. pp. v, 142. Price on application.

A most useful directory and guide to the synthetic crystal scene in the United States, this book should alert scientists to the possibilities of man-made materials. This also applies to the gemmologist. Entries are alphabetical under company or other organization concerned and contain the names of the people actually involved and the telephone number; also details, with chemical compositions given, of the products under current research. M.O'D.

Journal of the Gemmological Society of Japan. Vol.1, no. 1, Oct. 1974. Address: c/o Institute of Mineralogy, Petrology and Economic Geology, Tohoku University, Aoba, Sendai, 980 Japan. Foreign subscription, U.S.$10·00.

This excellent new journal is in Japanese with English abstracts which could well be amplified to extend the coverage. Articles in this first issue include Jadeite from the Kotaki-Omi area, Niigata Prefecture, Japan; biomineralogy and pearl culture; synthetic gemstones; natural and synthetic gemstones newly appeared after the second world war; gem news in the form of short notes; abstracts and society notes. M O'D.

ASSOCIATION NOTICES

OBITUARY

DR E. H. RUTLAND, F.G.A.

The sudden and utterly unexpected death of Dr E. H. Rutland on 16th January came as a great shock and a great sorrow to his many friends both inside and outside the field of gemmology.

Ernest Hugo Charles Rutland was born in Czechoslovakia 67 years ago and came to England at the age of 14. He was educated at Manchester Grammar School and later at Cambridge University. After taking his M.A. he lived for a while at Toynbee Hall and from there took his Ph.D. degree in the field of statistics —giving him a specialized knowledge of this subject which he put to good use in his subsequent professional life. While at Toynbee Hall, he served as one of the counsellors in the wonderful Samaritan organization—an indication, at that early age, of the breadth of his humanity.

For most of his professional life Ernest Rutland was a Civil Servant in the Ministry of Town and Country Planning and lived for many years with his wife Jill in Hampstead Garden Suburb. In 1948 he took over from his close friend Eric Levett the small but specialized jewellers shop in Hampstead known as Frances Harling after its originator, and Jill Rutland ran the business for some years while Levett was in Rhodesia.

I first came to know Ernest Rutland as an outstanding student in the 1946/47 second-year gemmology classes at Chelsea Polytechnic, when he showed his calibre by sharing the Tully Medal award with another enthusiastic amateur, Lieut-Col. G. M. Sprague, who was still in the Army and took the course by correspondence. In this same post-war class, it is interesting to recall, such well-known personalities as A. E. Farn, Werner Stern and Harry Wheeler also obtained their Diplomas with Distinction. Rutland continued to attend Chelsea Poly in the Post-Diploma class until 1950. Then, when Thorold Jones left teaching to take up an appointment with the A.E.R.E. at Harwell, Rutland's talents were put to good use as a lecturer for the first-year classes at Chelsea. At that time the numbers enrolling in these had swollen to some 80 students, who could only be accommodated by splitting the class between two evenings. Rutland was immediately successful and popular as a teacher, and his knowledge of gemmology became enriched by the experience. Whenever I dropped in to his lecture-room after finishing with my Post-Diploma class he was always still at the lecture bench, surrounded by interested students. During the ensuing years he wrote a number of articles for the Journal, and in 1953 Rayner made to his design the useful vest-pocket polariscope which bears his name.

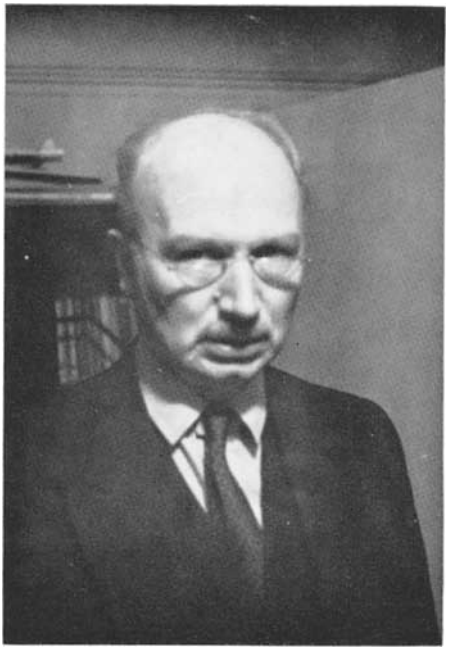

E. H. Rutland in the Laboratory at 15 Hatton Garden
(Photo B.W.A.)

Such was his knowledge and standing as a gemmologist that, after retiring from the Civil Service, he was able to stand in for Mr Alan Jobbins at the Institute of Geological Sciences in 1968 when the latter was doing a very useful spell of duty in Rangoon in organizing the gemmological training in Burma, and he continued as a Principal Scientific Officer in the Mineral Resources Department of the Institute until the end of November, 1969, when he and his wife made their home in Swanage.

This, however, by no means terminated the usefulness of Rutland's career in gemmology. When, at the end of 1970, Dr Claringbull ended his long spell of 42 years as an examiner for the Gemmological Association, Ernest agreed to join John Chisholm and myself as an examiner for the Diploma course.

Rutland was a long-standing member of the Mineralogical Society and of the Deutschen Gemmologischen Gesellschaft, whose meetings in Idar-Oberstein he often attended. His knowledge of German enabled him to translate very successfully Prof. Hermann Bank's superbly illustrated book, "From the World of Gemstones", the English edition of which was published in 1971. This considerable task was, one felt, not adequately acknowledged, but fortunately not long afterwards Hamlyns were in search for an author who would undertake to write a popular book on gemstones for them at rather short notice, and Rutland, at my suggestion, agreed to meet their needs. The result was a very attra ctive and lavishly

illustrated book, "An Introduction to the Gemstones of the World", which duly appeared in the summer of last year. This was brilliantly and succinctly written and should achieve lasting popularity. One can be very thankful that Ernest saw this crowning contribution of his to gemmology reach completion and received from his friends the congratulations he deserved.

In all his walks of life, of which I have only been able to give an outline, he gathered firm friends. This was true even in his last few years when, though relatively a newcomer in Swanage, he had already begun to play an active part in the local community. And of course it is as a friend that we shall miss him most—remembering his unfailing kindliness, his tolerance, his humour and his unshakeable reliability. Ernest Rutland was a big man: big physically, big mentally, and big in spirit. It is hard indeed to have to say farewell.

B.W.A.

Mr J. M. B. McWilliam, Glasgow, who gained the Association's Diploma in 1938, died on 27th December, 1974. He was a member of Council from 1968 and assisted a great deal with the evening classes in gemmology in Glasgow and the setting up of a gem-diamond class in that City.

Mr Leslie Payne, Southampton, who gained the Association's Diploma with Distinction in 1952, died on the 12th January, 1975. For a number of years Mr Payne had been an instructor for the Retail Jewellers' Correspondence Courses conducted by the National Association of Goldsmiths.

PRESENTATION OF AWARDS

There was a record attendance at the Presentation of Awards which followed the Members' Reunion at Goldsmiths' Hall on 25th November, 1974, including candidates from many different parts of the world.

Mr Norman Harper, the Chairman, said that in 1974 the candidates for the Preliminary and Diploma Examinations numbered 994, which was yet another record, and there were some present who had come from as far afield as Japan and South Africa, as well as others from Holland, Germany, Finland, Spain and, of course, the United Kingdom. After extending a welcome to Gordon Andrews, F.G.A., the former Secretary, and to the National Association of Goldsmiths' Chairman, Richard Cope, F.G.A. and Vice-Chairman, David Callaghan, F.G.A., Mr Harper said that Dr Eduard Gübelin, whose new book he praised, needed no introduction and asked him to present the awards to the successful candidates.

Professor Dr Eduard Gübelin, Ph.D., F.G.A., C.G., then presented the prizes, diplomas and certificates won in the gemmological and gem-diamond examinations and gave an address which is recorded in full below.

Dr Claringbull, the President, thanking Dr Gübelin, welcomed the presence of one of the Association's Honorary Fellows, Dr W. Campbell Smith, who was formerly Keeper of Minerals at the British Museum (Natural History): "in addition," he continued, "few would dispute that we have in the Hall this evening the two most eminent gemmologists in Europe—Eduard Gübelin and Basil Anderson." Both of them had made most valuable contributions to gemmology,

Mr Anderson in the field of absorption-spectroscopy, to which Church had pointed the path, and Dr Gübelin in the study of inclusions, following Michel. Dr Gübelin's recent book, *The Internal World of Gemstones*, was not only a wonderful book for the student of gemstones, but its superb colour photomicrographs were an inspiration to the artist and the industrial designer.

DR EDUARD GÜBELIN'S ADDRESS

In his address, following the presentation of awards, Dr Gübelin said:

What is happening on our planet today? I do not mean the belligerent tensions in the near East nor the failure to adopt a common energy policy nor the world-wide monetary crisis—no, what happens in this world as an entity, what happens at the present for the first time uniquely and so thoroughly that it will be remembered in the centuries to come, just as we still acknowledge and appreciate today the invention of the wheel, of the alphabet, the development of the great religions of the world, or from a geological point of view the folding up of the Alps, as an outstanding and irrevocable phenomenon. Well, what is happening in front of our eyes today? It is a tremendous and in its kind certainly a unique metamorphosis, which could at best compare with the change which mankind underwent during the dark ages and then again at the beginning of the Renaissance. The world happens to be in the midst of a fundamental change of structure with biological, physiological, sociological and even theological effects, and these are of such profundity that we cannot escape them.

To a certain extent we have been experiencing drastic changes also in our profession. Until recently, our ideas of sales promotion moved along perspectives which had already been fixed in medieval times and which were almost exclusively limited to the mere action of selling, and at best to a successful sales talk, while today after a short time of transition (calculating just a few years) great value is being placed in an extensive professional erudition, profound psychology, sound argumentation and efficient advice. While previously the old Roman warning *Caveat Emptor*, which originated from distrust, alerted the buyer to be careful, it now has the meaning that the client wishes to be well informed and accurately advised about the goods he is interested in purchasing. This desire may only be fulfilled by the salesman if he masters a fundamental professional knowledge. Science reigns today over all sequences of our life, medicine as well as commerce, production as well as communication, and the last consumer wishes to share in this professional science.

It is the aim of the gemmological courses, which you have so successfully completed, to offer this specialized knowledge which will give you greater self-assurance and consequently increase well founded trust to assist your clients in such a way as to justify the confidence they place in your hands. The relatively broad spectrum of knowledge taught in the condensed form of, say, 25 or 30 assignments distributed over two courses challenged your capability to understand connexions and relationships which exist between different disciplines of the science of nature as well as between different properties of gemstones. The capacity of thinking in relationships and coordinations as well as the readiness to engage yourselves and to take responsibility and to accept solidarity should, apart

from your technical achievement, be the human or spiritual benefit of your gemmological study. In this sense I wish to congratulate you most cordially on your successful attainment, which is the well deserved result of your perseverence and brave sacrifice during two years of intensive study. Not only your personal interest in gemmology has led you to this award but also your thirst for knowledge and education, that marvellous, growing, aching process, whereby the mind develops into a usable instrument with a collection of proved experiences from which to function.

Some of you may consider the diploma examination as the climax of your gemmological studies. Yet, may I bring to mind that this is rather the first "rung of the ladder"—that you have merely just crossed the threshold of a space spreading before you with no visible horizon, and the "heady" sensation you may feel now is only the beginning of further studies combined with unexpected experiences which perhaps are more closely linked with your practical everyday life in future. Therefore I recommend you to remain abreast of future developments by joining the advanced post diploma courses and subscribing to gemmological periodicals.

Your diploma should not mislead you to consider yourselves as infallible experts. Your *status quo* is comparable to the situation of a young B.Sc. or Ph.D. who has just received his academic title, which does not attest him yet as a fully fledged scientist but merely that he has learnt to think and act independently and—as is to be hoped—with a sense of responsibility.

In a specified course, like the one you have successfully accomplished, it is not possible to include everything relevant. It may set forth an optic, a direction, a theory or methods coupled with practical experience from which the student may think and act further, and we must remain aware of the limitations that we may properly use our own vocables only for the resources at our disposal.

Among the resources offered to the modern Science of Nature gemmology assumes a prominent place. Unfortunately it was considered a superfluous appendage and hardly acknowledged for almost a generation, and gemmological publications only appeared as foot-notes to mineralogical literature. Yet, indeed, as an independent basis, gemmology has often supplied mineralogy with fundamental data and proved to be of invaluable assistance. Gemmology was lacking professionalism for a long time and for far too long gemmology was merely a trade accessory. Gemmological degrees at present are still no more than school degrees, either awarded by trade associations or by private institutes affiliated with the trade. An academic degree course would help in upgrading the profession's standing similarly as university training would facilitate gemmology and gemmologists to meet the increasing technology and standard of investigation.

However, thanks to numerous outstanding achievements in highly scientific gemmological research, today gemmology is fully recognized as a science. As a matter of fact, gemmology is today rightly entitled to claim the merit of having essentially contributed towards the astonishing progress of mineralogical research. The endeavour to expand as far as possible the boundaries within which we human beings are placed, and the curiosity for the means by which this may be possible, is a central motive of technical and scientific development. It is the same force which led our progenitors to master the use of fire and which drives us to-day to investigate outer space without knowing where this may lead us to. This intense desire of mankind to question all boundaries again and again is already grappled

in the Genesis of the Old Testament by the words "Conquer the Earth with all that is within" and thus deprived of any further argumentation. However, if man conquers the Earth, then he must corroborate by his mental disposition as well as by his moral conduct that he is indeed legitimized for this role—not only as a scientist but also in his quality as a human being.

By this I mean to emphasize that we have a right to profit from our knowledge to our own personal advantage, yet never to use it to the harm of others. A French philosopher expressed this thought with the following words: "Science sans conscience n'est que ruine de l'âme"—science without conscience is the undoing of one's soul. Scientific research means searching for the truth. Consequently, we are obliged to be honest and always tell the truth, and if we happen to make a mistake we should summon the courage to admit it.

Irrevocable laws do not only exist in the field of the sciences of nature but also in the sphere of human life and co-existence. In this connexion I may refer to the problematics of liberty and restraint, to all the tensions which occur because man is a personality who must develop in freedom, yet according to the laws of nature he is also a social being, who can only completely unfold himself in a society. It may not be superfluous to remind ourselves of this fact today, when sometimes righteously, but more often with no right whatsoever, scientific or social achievements are assaulted and when the behaviour of certain unscrupulous people assumes a most aggressive character. The essence of the intrinsic virtue of the thing stipulates a much more positive and courageous mind, in social, public, religious and scientific domains, in order to defend all these accomplishments of mankind and save them for future generations.

In this sense I bid you a successful future resulting from your freshly acquired gemmological knowledge; may many interesting tests be the source of personal satisfaction and happiness to you and the reason of increasing confidence placed in you by your clientele.

MEMBERS' MEETING

Midlands Branch

Mr George C. Walter, B.Sc., F.G.A., F.B.H.I., gave an illustrated talk on his experiences of diamond prospecting in Africa to members of the Branch on the 31st January, 1975, at the Auctioneers Institute, Birmingham.

GIFTS TO THE ASSOCIATION

The Council of the Association is indebted to the following for their gifts: Mr Joseph Best, F.G.A., of Santa Barbara, Cal., U.S.A., who, before emigrating to the U.S.A., worked in the retail trade in Birmingham, for an excellent and comprehensive collection of synthetic materials including some cut specimens. Amongst the collection are white and purple apatite, lithium-niobate, barium sodium niobate, lithium tantalate, lanthanum aluminate, cadmium tungstate, and potassium tantalum niobate.

Mrs Susan M. Warner, B.Sc., Salisbury, Rhodesia, for a copy of her "Check List of the Minerals of Rhodesia", Rhodesia Geological Survey, Bulletin No. 69 (published 1972).

STOLEN GOODS

Among stolen goods recovered by the police in Brighton are a Beck prism hand-spectroscope, a Rayner refractometer and a Herbert Smith refractometer in a box on which the name "Walford" is written. Anyone identifying these goods should communicate with the Letchworth Police Station, Hertfordshire.

GEMMOLOGISTS' VISIT TO IDAR OBERSTEIN

A party of forty-seven jewellers and gemmologists visited Idar Oberstein at the end of October, 1974, on a conducted tour organized by *Watchmaker Jeweller & Silversmith* in collaboration with the Gemmological Association and the National Association of Goldsmiths. The party first visited the new bourse, where they were welcomed by the President, Konrad Wild. Then they spent some time on the buying floor, before touring the standing exhibition and the museum, where exhibits contributed by the local dealers and cutters are on display. The party visited Konrad Wild's factory in the afternoon, where they saw the automated cutting of coloured stones "up to beryl". The stones are pre-cut to identical size and shape, travelling up to the cutter on a moving belt. The stones are then mounted in "combs" and facets cut and then polished in computer-controlled automatic machines.

On the second day the party visited the famous showrooms of Ruppenthal, which have aptly been described as Aladdin's cave. The third morning was given over to buying, members of the party revisiting the buying floor of the bourse or calling upon individual firms in the town. After lunch the party went to the warehouse of Julius Petsch, F.G.A., who has an interest in seventeen mines in Africa and South America, and imports rough. Here the party saw how gems arrive in Idar—oil drums full of amethysts, sacks of run-of-the-mine rubies and emeralds. They also saw the rough crystals being hammered to remove unwanted material and sorted for quality before being offered to the cutters in the town.

During the visit both Professor Dr Hermann Bank, F.G.A., and Julius Petsch, gave talks about the current situation in the gem trade and some of the problems which face those who deal in stones. Professor Bank explained the gemmological exhibition which was being set up in the Gewerbehalle, now the headquarters of the Gemmological Association in Idar Oberstein. He then gave a brief history of the industry in the twin towns. He said that the fact that the Romans in the second century A.D. had obtained stones from the area was proved by the existence in Roman jewellery of stones which according to their colour and their structure could only have come from that region. There was, however, no positive proof that stones were cut there at this date. They were certain, however, that from the twelfth century stones were both being found and cut in Idar Oberstein. And up to 1820 only stones found in the region had been cut there. Since 1834, though, the town had obtained the material for cutting from Brazil. Later, harder stones from other places were cut in the town, and the old sandstone-wheel-cutting which the town had developed could not be used for these. In 1875 therefore lapidary cutting had been introduced from Bohemia, where it had been practised since 1600 at latest. In 1884 diamond cutting also was introduced to

Idar Oberstein, and between 1960 and 1970 a lot of people had gone to Paris to learn stone engraving. Professor Bank then showed a series of slides illustrating the various types of gemstones and their physical characteristics.

Julius Petsch spoke next and said that Idar Oberstein was a place where in a relatively small geographical area you could find the biggest selection of stones from the very cheapest agates to the best diamonds. You could travel all over the world and not find the variety of cuts and colours that could be found in this town. It was not only in the town of Idar Oberstein that stones were cut, but also in all the surrounding villages. Most of the firms were small three-, four- or five-men businesses: and already they called themselves a factory when they had three men: these men were artists: they took the best out of the rough stone.

Because the industry was not concentrated it had been decided, he continued, that it was necessary to do something more to attract buyers from all over the world. This was why the industry had built the exchange buildings, in which over a hundred companies from all over the world had offices. The bourse was the only place where one could go from table to table and compare prices and make purchases on the spot.

He went on to explain that there were three types of cutter in Idar Oberstein. There were those who cut the ornamental stones, then there were those who faceted the coloured stones, and then there were the diamond cutters. Incidentally there were not so many diamond cutters at the present time because they could cut diamonds more cheaply elsewhere.

The fact that there was something of a falling off in demand for the cheaper to medium priced stones at the present time was not being reflected in the price of these, he said. The new mines still had to prove that they would give good production: and there were still big buyers at the mines in Brazil and in Africa and Afghanistan, who bought big lots and made them disappear, bringing them on the market again at a later date. This kept prices at a certain level.

Silver jewellery was, as they all knew, in fashion at the moment, he said; and for this there was a big demand for ornamental stones. Besides agates, many other stones were now being used such as the jaspers, the obsidians, rhodonite and sodalite. Such was the demand that the cutters who cut these stones had delivery times of three, four, five and six months. Also, stones were being cut to form bangles and rings, which made further demands on the cutters. At the present time too they were cutting a lot of beads in Idar Oberstein and the drillers of beads were hopelessly behind in their delivery dates. The orders were there: the beads were there: but they lacked their holes. The stone-drillers were specialists: not everyone could drill beads—it was very delicate work and was done by ultrasonic machines nowadays.

What he thought would particularly interest the party, Mr Petsch went on, were some of the rumours that were currently going around. The South African government had for some time placed a restriction on the export of uncut tiger's-eye. They had opened cutting factories there, but these could not produce enough. Everybody still came to Idar Oberstein asking for tiger's-eye, but it wasn't there any more. He thought they would have to look round and replace tiger's-eye with another yellow stone in the near future. Dealers were also facing the same problem with malachite. This came from the Congo, and it was very difficult to get hold of good quality material. He then went on to talk about the

supply of tanzanite. The tanzanite mine in Tanzania no longer produced the same quantities. He had heard that the government-owned company responsible for producing stones in Tanzania had gone bankrupt and was no longer able to pay the workers. As a result fewer stones and smaller sizes were coming to Idar Oberstein, and this mine was the only source in the world.

Stones which they had been seeing in Idar Oberstein, he then said, were wonderful almost emerald-green tourmalines from Afghanistan or Pakistan, probably from the border between the two areas. Unfortunately these often had imperfections, but they were better in colour than either the Brazilian or the African stones. Then there were the chrome grossular garnets from Kenya, which were still arriving, though the stones were in general not so big any more, a common size now being from half to one carat or even smaller.

Another stone he wanted to mention was the ruby from Kenya. Early in the year they had discovered in Kenya between Nairobi and Mombasa, near the Tanzanian border, a very large deposit of rubies. These stones had Burmese colour. An area of about fifty square miles had been prospected. In one place John Saul had found stones in considerable quantities. Ninety per cent of the stones found so far were only suitable for cabochon cutting, however, and only ten per cent were suitable for faceting. He felt that stones of four or five, or even eight to ten carats, would come out of this area. He didn't think that there was any fear that prices would tumble down as a result of this find, though, because the people who dealt in fine rubies had plenty of money to buy up the good stones and would regulate the price. But cabochon quality stones were coming out in quantity and he thought that in future it would be possible to buy for a good price stones from one to twenty carats.

He was convinced that stones for faceting other than cheap citrines would not in future be as readily available as they were in the past. Every time he sold stones, it was more difficult to replace them, even from his own mines. The demand was growing. Even the Chinese were beginning to buy stones. Prices would go up and deliveries would be more difficult. As a result, in his opinion people should look more to cabochon material in tourmaline, aquamarine, amethyst, ruby and emerald. The jeweller would have to persuade the customer to buy these stones for their colour, because of course one did not produce clean cabochons. If a stone was clean it was faceted.

He went on to talk about some wonderful aquamarines that had appeared on the market about a year ago, of a wonderful tanzanite blue. A lot of dealers had purchased these and paid 500 marks a carat for them. After some time exposed to the daylight—as little as eight to ten days—these aquamarines lost their colour. Jewellers who had bought them and put them in their windows found that they turned white. Tests were made and it was found that colourless beryls placed under x-rays could be changed from white to this wonderful blue colour.

Another stone they had seen recently in Idar Oberstein was blue precious topaz, cut stones up to 20 carats of good colour without blemishes. Suddenly they appeared at the bourse in large quantities, a thousand to two thousand carats. Nobody knew the rough stone source of these, so rumours were rife that these stones also had been treated by x-rays or nuclear rays to change a colourless topaz to the beautiful blue. But up to now, he said, nobody could prove whether these stones were treated or not. But he said the retailers bought a lot of aquamarines

and tourmalines that had been heat-treated. One could often turn dirty brown beryl into a very fine blue stone by heat-treatment. If in the twentieth century they could use modern technology to turn colourless stones into blue precious topaz, and the colour would remain, why should they not use this method also? The heat-treatment of aquamarine and tourmaline had been practised for over a hundred years and nobody objected. Eighty per cent of all aquamarines are heat-treated, he added.

Julius Petsch then went on to show a series of slides he had taken at various mines, including those he had taken when he visited the new ruby mines in Kenya. This mine, he said, had been found by the geologist John Saul who had been looking for chrome tourmalines. He had found tourmalines, but as he had dug down he came to gneiss rock, and here he had found the rubies.

FURTHER VISIT TO IDAR OBERSTEIN

The *Watchmaker Jeweller & Silversmith* will be arranging a second trip to Idar Oberstein for early October, 1975, and the dates will be announced shortly.

COUNCIL MEETING

At the meeting of the Council held on Wednesday, 5th February, 1975, the following were elected to membership:

Fellowship

Alvarez Fernandez, Laurentino, Grado-Oviedo, Spain. D. 1974
Alvarez Fernandez, Manuel, Grado-Oviedo, Spain. D. 1974
Amoros Angel, Julio, Valencia, Spain. D. 1974
Anderson, Susan M., Salisbury, Rhodesia. D. 1974
Ashley-Cooper, Elizabeth J., London. D. 1974
Berkowitz, Rosa, Toronto, Ont., Canada. D. 1974
Booker, Peter E., Melton Mowbray. D. 1974
Campon Fernandez, Enrique, Oviedo, Spain. D. 1974
Carlsen, Gunnar J., Jr, Haugesund, Norway. D. 1974
Clewlow, Alan J., Braintree. D. 1974
Eagleton, David, Sheffield. D. 1974
Engel, Gerhard, Idar-Oberstein, W. Germany. D. 1974
Ferrer Arbona, Santiago, Valencia, Spain. D. 1974
Garcia Igual, Arturo, Valencia, Spain. D. 1974
Goerlitz, Rolf M., Idar-Oberstein, W. Germany. D. 1974
Heaviside, Desmond, Great Ayton, Cleveland. D. 1974
Heintzberger, Cornelis P., Bilthoven, Holland. D. 1974
Hettema, Jan A. H. M., Silvolde, Holland. D. 1974
Hill, Roger C., Whitecraigs. D. 1974
Hofelt, Joris C., Utrecht, Holland. D. 1974
Holt, Paul, Tuckahoe, N.Y., U.S.A. D. 1974
Hulse, Kenneth M., Sale. D. 1974
Ishikawa, Taeko, London. D. 1974
Jayasinhji, Prince of Dhrangadhra, Dhrangadhra, India. D. 1974
Jimenez Torro, Vicente, Valencia, Spain. D. 1974
Kammerling, Manfred, Idar-Oberstein, W. Germany. D. 1974
Klar, Michael A., Idar-Oberstein, W. Germany. D. 1974
Langthon, Kjell-Odvar, Oslo, Norway. D. 1974

Larah, Howard A., Manchester. D. 1974
Latre David, Jose, Valencia, Spain. D. 1974
Leyser, Karl-Georg, Kirschweiler, W. Germany. D. 1974
Lopez Perez, Oceano, Barcelona, Spain. D. 1974
Maes, Jurgen, Kirschweiler, W. Germany. D. 1974
Manser, Jutta E., Southampton. D. 1974
Matsumoto, Kikuo, Gunma-ken, Japan. D. 1974
Maymo Mas, Jaime, Barcelona, Spain. D. 1974
O'Rourke, Edward T., Brisbane, Queens., Australia. D. 1974
Pearson, Barry E., Southport, Merseyside. D. 1974
Rosenberg, Joya, Chevy Chase, Md, U.S.A. D. 1974
Rovira Rabell, Manuel, Barcelona, Spain. D. 1974
Salloway, Mary A., Lichfield. D. 1951
Sanchez Cabello, A., Valencia, Spain. D. 1974
Sato, Ikuo, Miyagi-ken, Japan. D. 1974
Scrymgeour, David J., Newton Abbot. D. 1974
Snyder, Julia T., Philadelphia, Pa., U.S.A. D. 1974
Tatiwala, Nawal K., Jaipur, India. D. 1974
Thum, Koh Teik, Penang, Malaysia. D. 1974
Turner, Michael J., Stockton-on-Tees. D. 1974
Van Duyvendijk, Pieke, Krimpen g/d Yssel, Holland. D. 1974
Van Gogh, Mieneke, Epe (Gld.) Holland. D. 1974
Van Thiel, Carolina J. S. M., Helmond, Holland. D. 1974
Villar Lopez, Luis Fernando, La Coruña, Spain. D. 1974
Weeks, Milton D., Annandale, Va, U.S.A. D. 1974
Wicks, Sylvia B., London. D. 1974
Woodhouse, Neville, Inkersall. D. 1974

ORDINARY

Aleksander, Michael, Kloten, Switzerland.
Allen, John William, Hornchurch.
Archbold, David, Hartlepool.
Bates, Sandra H., Fareham.
Bettis, Amanda E., London.
Bloch, David H., San Francisco, Cal., U.S.A.
Boileau, John A., Chermside Nth, Queens., Australia.
Borg, Raine, Helsinki, Finland.
Bouch, Nancy E., Franklin, N.C., U.S.A.
Brandenburg, W. M., Schoonhoven, Holland.
Bromley, Ivy May, London.
Brown, Hartley R., London.
Burford, Murray Lyle, Toronto, Ont., Canada.
Carmichael, Michael L., Castle Donington.
Clarke, Michael D. H., Kirchzarten, W. Germany.
Collett, Jessica M. F., London.
Cornelius, Richard A., London.
Cooper, Roy, Disley.
Dale, Christopher M., Bordon.
Darragh, Peter J., Wembley, W. Australia.
Davis, Frederick W., Chislehurst.
Daws, Bernard Stephen, Worcester Park.
De Silva, G. P. M., Singapore.
Dominguez, Joseph, Carcassonne, France.
Ekanayake, Wilmot J. E., Colombo, Sri Lanka.

Eliahoo, Miriam F. M., London.
Fava, Ralph M., Paterson, N.J., U.S.A.
Giercke, Nicolaus, Hamburg, Germany.
Grelick, Gary R., New York, U.S.A.
Haraguchi, Yozo, Fukuoka City, Japan.
Hayes, Martine N., London.
Hill, Anthony C., Blackpool.
Holness, Malcolm H., Effingham.
Hughes, John S., Reigate.
Karasik, Morris, Downsview, Ont., Canada.
Kelham, Heather M., Bromley.
Kern, Anita, London.
Kleiner, Peter H., London.
Krysler, Clement, London.
Lewis, Leonard R., Bristol.
Li, Sheung Shun, Hong Kong.
Locke, Frank, London.
Lopez Gutierrez, Luis, Mexico.
Malamed, Mervyn R., Cape Town, S. Africa.
Margel, Guy, Antwerp, Belgium.
Mayer, Maurice, Parkview, Transvaal, S. Africa.
Meek, Kerrie, Vancouver, B.C., Canada.
Mitchell, Joyce P., London.
Molten, Camille P., Richmond, Va, U.S.A.
Moses, Heather, London.
Nakase, Akio, Tokyo, Japan.
Obolewicz, Nicholas A. W., Norwich.
Patel, Natakerbhai P., Nairobi, Kenya.
Peace, Reginald J., Beverley.
Pender, Harold, Kenilworth.
Phillipe, Waveney M., Georgetown, Guyana.
Quispe, Vicente R., Lima, Peru.
Read, John V., Randburg, S. Africa.
Richards, Rolph, London.
Ridge, James B., Kidderminster.
Sato, Takayuki, Tokyo, Japan.
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CORRIGENDA

On page 186 *ante* in lines 4–5 for "rich in copper but not in zinc" read "rich in zinc but not in copper" and in line 6 for "an yttrium copper" read "an yttrium copper analogue of prosopite". On page 235 *ante* in lines 2–3 for "the Mountains" read "the Cascade Mountains".

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THE JOURNAL OF GEMMOLOGY

and

PROCEEDINGS OF THE GEMMOLOGICAL ASSOCIATION OF GREAT BRITAIN

GEMMOLOGICAL ASSOCIATION
OF GREAT BRITAIN
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THE JOURNAL OF GEMMOLOGY
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ON JEWELLERY FIT FOR A QUEEN

By PETE J. DUNN, M.A., F.G.A.

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THE acquisition of a major gem or a piece of significant jewellery is always a source of excitement to those who curate major gem collections. Imagine then the great excitement when the Smithsonian Gem Collection recently acquired not one but many truly significant pieces of Royal jewellery. Both the amount of new material and the quality were overwhelming. Five new exhibits were designed and installed, swiftly becoming a major attraction in the Hall of Gems. Some of these exciting recent acquisitions, and others, are herein described.

The Marie Antoinette Earrings

Among the last gifts of Louis XVI to Marie Antoinette was the pair of diamond earrings shown in Figure 1. These gems are approximately 36 carats each and, although not quite a matched set, one being more tapered than the other, they are fine, brilliant, colourless, and of very high quality. These elegant pendeloques have large culets and were obviously cut to effectuate maximum yield. Each 36 carat diamond is suspended from a smaller trapeze-cut stone of approximately two carats. Inasmuch as the African diamond fields were not yet discovered, these diamonds are likely of Indian origin. The gems were originally set in silver and are now set in platinum with small accessory diamonds. The original settings

FIG. 1. The Diamond Earrings of Marie Antoinette (NMNH Gem #5018) (Photograph by Lee Boltin, Smithsonion Institution).

are preserved as objects of historical interest. These earrings were treasured by Marie Antoinette and were found on her person after the arrest of the Royal Family at Varennes while they were fleeing the Revolution in 1791. The earrings then passed through the Youssoupoff Family, were purchased by Cartier Ltd, and were eventually donated to the Smithsonian by Eleanor Close Barzin, of Paris. They presently reside in the Hall of Gems where they are a major attraction.

THE RUSSIAN NUPTIAL CROWN

This beautiful crown, shown in Figure 2, was designed and constructed about 1840 from a diamond belt that belonged to Catherine the Great. It was created for, and first worn at, the wedding of Marie Alexandrovna and Alexander II; then it was worn at the subsequent wedding of Marie Feodorovna and Alexander III, and also at that of Alexandra Feodorovna and

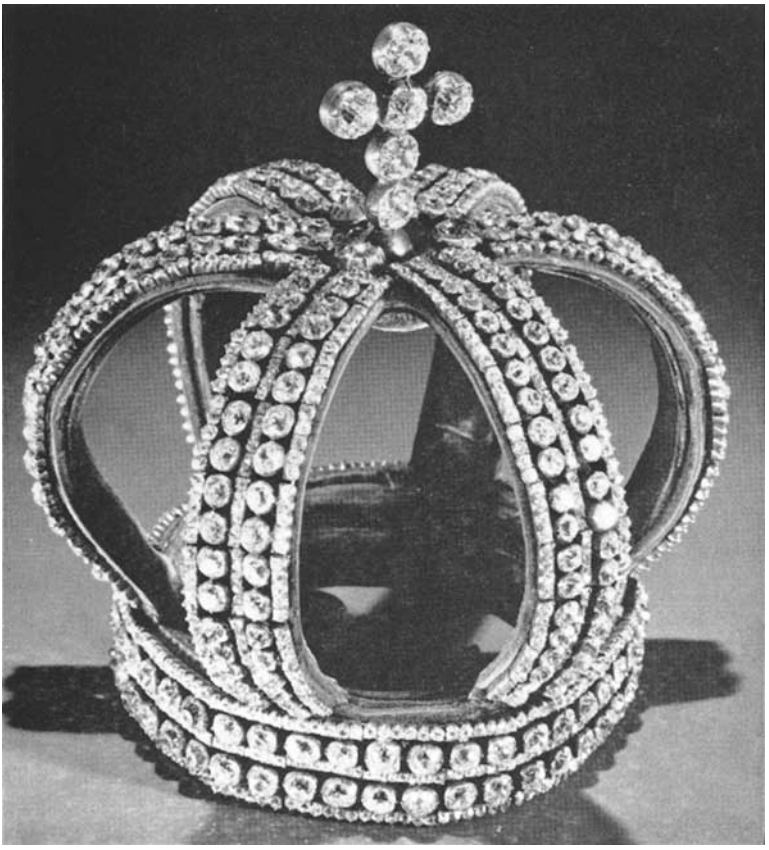

FIG. 2. The Russian Nuptial Crown of Marie Alexandrovna (Photograph by Lee Boltin, Smithsonian Institution).

Nicholas II. The crown has a spectacular total of 1,535 diamonds weighing a composite 283 carats. Upon the apex of the crown is a cross with 5 large antique cushion-cut solitaire diamonds of high quality. The crown is small, about 4½ inches in diameter at the base and approximately 5½ inches tall. The large diamonds in the cross (about 15 carats total) are mounted with girdle circlets so that the gems are also seen from the rear. Not obvious are three rose-cut diamonds of about 2 carats each, which are on the top of the tiara at the base of the cross. The pleasant lavender colour of the fabric is in good balance and heightens the aesthetic appeal of the whole

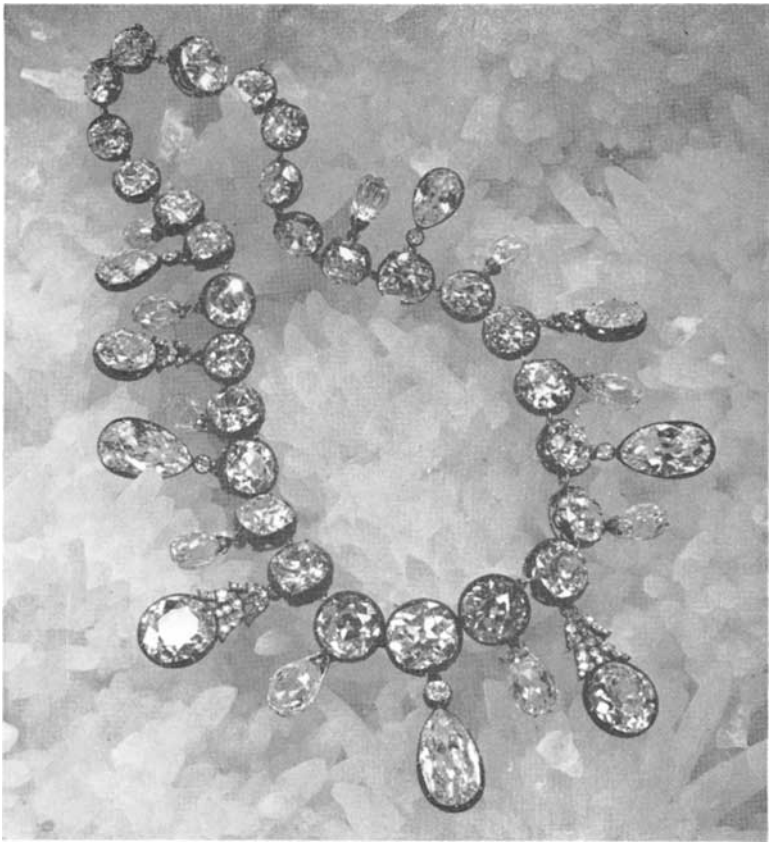

FIG. 3. The Napoleon Necklace (NMNH Gem #5019) on a background of quartz crystals. (Photograph by Lee Boltin, Smithsonian Institution).

piece. The crown was sold at Christie's in London in 1927 for £6,100! It was eventually purchased by the late Marjorie Merriweather Post who bequeathed it to the Smithsonian.

THE NAPOLEON NECKLACE

Joyous at the birth of a son, Napoleon I bestowed many fine gifts on his wife, the Empress Marie Louise. To mark the birth of their son, the King of Rome, Napoleon gave Marie Louise a beautiful necklace of colourless diamonds set in silver and gold (Fig. 3). Most prominent are the thirty-two cushion-cut diamonds, twenty-eight of which form the framework of the necklace, and five

FIG. 4. The Turquoise and Diamond Tiara of Empress Marie Louise (NMNH Gem #5021). (Photograph by Lee Boltin, Smithsonian Institution).

FIG. 5. The Bismarck Sapphire (NMNH Gem #4753) (Photograph by Lee Boltin, Smithsonian Institution).

elegant pendeloques, the largest of which is almost an inch in length. These thirty-seven magnificent stones are mounted with girdle circlets of silver. Ten briolettes are symmetrically spaced and hung in silver-wire baskets. The total assemblage of 167 Indian diamonds weighs 275 carats. The necklace, which was loaned to France for the Napoleon Bicentennial Exhibition in 1969, was originally created, at a cost of 376,274 francs, by Nitot et Fils, jewellers who made most of Napoleon's jewellery. After the death of Marie Louise, the necklace passed to the Hapsburgs of Austria and was sold in 1948 by Prince Francis Joseph of Liechtenstein. The necklace was later acquired by Mrs Post who generously donated it to the Smithsonian.

Marie Louise Diadem

This beautiful headpiece, shown in Figure 4, was another gift from Napoleon to Marie Louise in 1811 when their son was born. This high-symmetry diadem is comprised of about 950 Indian diamonds with a total weight of 700 carats, setting off 79 cabochons of high quality Persian turquoise weighing 540 carats. There is some difference in colour-grade among the turquoises, but the workmanship is excellent. As beautiful as the tiara is in its present state, it nonetheless must have been even more enthralling in 1811, as the original tiara was replete with emeralds which have since been replaced by the turquoise. Accompanying papers indicate only that the original emeralds were replaced by turquoise "a few years ago". The liberal use of brilliant diamonds is in good taste and adds to the very high symmetry of the piece. The diadem is set off by a base row of well-matched diamonds, and large diamonds are also used to accent the visual impact of the turquoise. It was willed by Marie Louise to the Archduke Leopold of Austria, became the property of the Imperial Family of Austria, and was later acquired by Mrs Post, who donated it to the Smithsonian.

The Bismarck Sapphire

This exquisite sapphire from the gem gravels of Sri Lanka (Ceylon), shown in Figure 5, has an exceedingly fine deep royal blue colour. There is no noticeable unsightly colour-zoning, and the colour is well distributed throughout the gem. The refractive indices, measured in sodium light, are $\varepsilon = 1{\cdot}759$, $\omega = 1{\cdot}767$, with a birefringence of 0·008. The gem is cut as a squarish oval and measures 27 × 21·7 mm by 15·5 mm in depth.

FIG. 6. Bracelet of 31 Burmese rubies and African Diamonds (NMNH Gem #5020) (Photograph by Lee Boltin, Smithsonian Institution).

The gem is set in a diamond and platinum mounting and surrounded by eight smaller sapphires. The setting is designed in such a way that the sapphire can be worn as a pendant, or the necklace can be removed and the gem worn as a separate brooch. The sapphire is ensconced in a platinum framework encrusted with tiny diamonds and is nicely set off by rows of baguette diamonds, in sets of five on the long edge of the gem and sets of three on the short edge.

The attendant necklace is comprised of 70 baguette and 142 half brilliant-cut diamonds, arranged in alternating rows of two brilliants and one baguette, and set in platinum.

This magnificent gem, the second largest faceted sapphire in the Hall of Gems, was donated by Countess Mona Bismarck.

The above-described items constitute but a part of the recent additions to the Hall of Gems. Other notable pieces include:

1. A magnificent contemporary ruby and diamond bracelet (Fig. 6) comprised of thirty-one well matched Burmese rubies and 86 marquise and brilliant African diamonds, set in platinum.

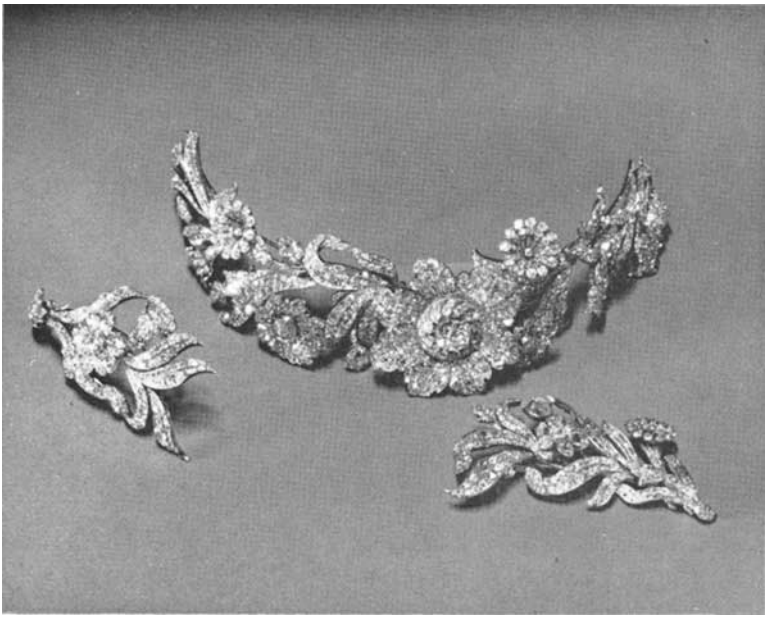

FIG. 7. Floral Diadem with Matching Brooches (NMNH Gem #5026) (Photograph by Lee Boltin, Smithsonion Institution).

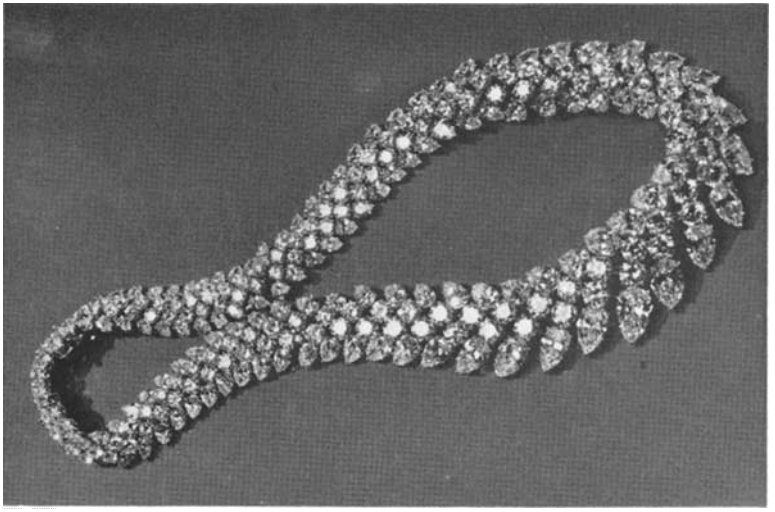

FIG. 8. Contemporary diamond necklace designed by Harry Winston, Inc. (NMNH Gem #5022) (Photograph by Lee Boltin, Smithsonian Institution).

Small emerald-cut diamonds separate the central rubies, while brilliant and marquise-cut diamonds serve to fill out the balance of the bracelet.

2. A lovely floral diadem, mounted on gold-wire spring-work. It is encrusted with diamonds, and some of the floral leaves may be removed and worn separately. Shown in Figure 7, this head-piece was in the hands of the Saxon Royal Family until the end of the 18th century and was eventually donated to the Smithsonian Gem Collection by Mrs Eleanor Close Barzin, of Paris.
3. The contemporary diamond necklace shown in Figure 8 is comprised of 128 pendeloques weighing 66·85 carats and 134 brilliants weighing 42·67 carats. Designed by Harry Winston, Inc., it effectively combines two central rows of brilliant-cut stones with two outer rows of pendeloques, giving the resultant necklace an inherent brilliance while making it appear more lavish than it really is. Estimations on the carat-weight of this necklace are invariably higher than the 110 carat real total.

This assemblage of new and old jewellery has provided a stimulating addition to the Hall of Gems where the National Gem Collection is on exhibit.

The author is indebted to Mr Lee Boltin for the excellent photography and to Paul E. Desautels for assistance with the historical background. Special thanks are due John S. White, Jr, for a critical reading of the manuscript.

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EMERALDS AND BERYLS

By A. E. FARN, F.G.A.

AN article by Ian C. C. Campbell, F.G.A., in the October issue of the *Journal of Gemmology** needs an answer. I do not normally rush into print, but feel compelled to deal with the question mooted by Mr Campbell. He asks where is the dividing line between emerald and green beryl? This is not an original question: it has been adequately dealt with before by other authorities. Certainly green beryl, whose colour is due to chromium, is correctly termed "emerald". Green beryl that does not owe its colour to chromium is not emerald.

In his article, first read to the Gemmological Association of Rhodesia in 1971, Mr Campbell made considerable use of an article by A. M. Taylor, Ph.D., F.G.A., on Synthetic Vanadium Emerald† (in itself a contradiction, since his opening lines state that this new synthetic has no chromium). In a number of analyses of emerald he (Taylor) states vanadium was present, but so too was chromium. No one doubts the presence of vanadium, which is usually swamped by chromium, but it is the ubiquitous chromium which keeps turning up. Campbell quotes Taylor's definition of emerald as "a bright green variety of beryl" adding on his (Campbell's) own account "no matter what the cause of the colour is—as long as it is the acceptable(?) hue of green. (The question-mark in brackets is mine)." By his question-mark Mr Campbell admits that "acceptable hue" is ambiguous, to say the least.

The use of the Chelsea colour-filter is no longer of great diagnostic power: it is well known among practising gemmologists that many natural emeralds remain green when so viewed but have in fact a good clear sharp chromium spectrum. I should like to point out here that the use of the spectroscope is in itself an art, when one considers that inadvertently some people have an optical deficiency in resolving lines in the red end of the spectrum. Although my eyes are not so good as once they were, I find that by expertise and judicious use of the spectroscope (handling, focusing and hosing) I can see lines which have escaped my younger colleagues until skill has been placed at their disposal—*then* they are seen.

J. Gemm.*, 1974, **XIV 4, 177-180.—Ed.

†*J. Gemm.*, 1967, **X**, 7 211-217.—Ed.

I digress however, since I am in print for the sole purpose of stating that emeralds *must* have chromium in their content such that with skill, expertise and knowledge, it can be detected by use of a hand-spectroscope—preferably a Beck prism model. The beauty of the spectroscope is that it is indeed a non-destructive test and saves what Mr Campbell touched upon, the destruction of a stone to find traces of chromium! !

Because this spectroscope test is so positive and sensitive it is unique in fixing the determination of emerald, whether it be a poor thing or a superb example of emerald at its best. The merits of the stone, be they commercial or not, are decided by appearance. The example of a poor emerald being mounted and *thought* to be merely green beryl only affords one the obvious knowledge that the stone had no great merit and no gemmologist had tested it (we hope!).

One cannot but feel sorry for the poor hapless people in Rhodesia being "unwittingly legally at fault for dealing with uncut emeralds while genuinely thinking the stones are ordinary beryl". (Mr Campbell's words, not mine). Dr Taylor does not have a valid point when he advocates that "emerald should apply to a bright green variety of beryl". The trade does *not* accept this suggestion and in this country is zealous, if not anxious, to have its emeralds tested to know that they confirm to "trade regulations and usages", as published and displayed by all members of the London Chamber of Commerce and Industry's Precious Stone Trade Section. These state:—"According to the custom of the trade the word Emerald not preceded by a qualification is applied exclusively to natural grass-green beryl with colour due to chromium". The writer respectfully refers all readers to "Chromium as a criterion for Emerald", by B. W. Anderson, *Journal of Gemmology*, Vol. X, No. 2, April, 1966.

TOURMALINES: MULTIPLE INDICES ON THE REFRACTOMETER: A FURTHER NOTE

By C. A. SCHIFFMANN, F.G.A., G.G.

REFERENCE is made to an article submitted for publication by the author in spring, 1972, and printed in the *Journal of Gemmology*, Vol. 13, No. 4, October 1972. The contents offered a detailed description of the appearance of certain cut tourmalines showing satellite shadows of the basic refractive indices on the refractometer, together with a microscopic examination of superficial features present in some of these tourmalines. With the intention of contributing an interesting exchange of experience the author gave a short summary of this subject as an "avant-première" in his talk before the members of the 14th Gemmological Conference at Vitznau, in September 1972. In the following discussions, Professor H. Bank mentioned having observed a similar phenomenon of indices with several shadows in fired tourmalines, and submitted the hypothesis that the reason might be a kind of dissociation.

In private communications following the publication of the article an Australian correspondent, J. R. Jones, wrote to the author mentioning that he had occasionally observed a similar appearance of shadows on the refractometer with certain tourmalines. Mr Jones suggested the hypothesis that agents used during the cutting process might cause a temporary alteration of the surface structure but that this might after a time disappear.

In the 1972 article the author suggested that heat-treatment of the tourmalines would play a role in this phenomenon, but it was not yet clear whether heat alone, or heat as developed in the course of the cutting process through grinding and friction on the polishing lap, would be responsible. According to M. D. S. Lewis and Mrs. G. Parry a modification of the surface of crystals, through the heat of the cutting process resulting in the existence of a Beilby layer, was not conspicuous when testing the indices on a refractometer—the layer being too shallow. "The fully amorphous layer where it exists is far too thin for effect on refractive index".(3) This concurs with the observations reported where the tourmalines did not show the reaction of a superficially amorphous substance, but the indices of a crystalline one, exposing the usual birefringence of tourmaline at their point of maximum separation.

The next step foreseen was to check whether the phenomenon was superficial or present throughout the stones. However, prior to the drastic step of recutting the specimens, in order to avoid uncontrolled modifications, it was preferred to verify the permanence of the phenomenon on the most typical of the tourmalines previously examined, exhibiting 4-fold indices, the data of which are as follows:

Tourmaline of S.W. Africa, cut, with "record" 8-shadow effect on the refractometer

Colour of the stone	dark green				
Weight of the stone	over 13 carats				
Specific gravity	3·11 (hydrostatic method)				
Indices		basic shadow	satellite shadows		
	o	1·645	1·647	1·652	1·660
	e	1·623 +	1·624	1·625	1·629

This specimen was placed at one side at room temperature for about two years and checked from time to time—lastly in 1974. The same satellite indices were obtained on different facets, under the same testing conditions as previously. Consequently, the phenomenon is considered as being permanent at room temperature without further treatment.

The next step was now attempted through carefully recutting to assess whether this appearance would be only superficial (as the shallow fissures observed previously on some specimens and described in 1972 suggested) or whether the modification existed throughout. To verify this, the same tourmaline was slightly recut in 1974, paying particular attention in

(*a*) taking great care to avoid any excessive heating of the stone by settling it especially gently onto the lap, and

(*b*) grinding away only a thin layer of substance, about 0·1 to 0·2 mm in thickness. The result, after partial recutting, is shown in Figures 1 and 2.

On the larger resulting facet of the pavilion side (Fig. 1) the indices measured on the refractometer consisted of two single shadows without satellite lines, as is usual for normal tourmaline, situated at

o	1·645
e	1·623 +

whereas on the other unmodified facets the multiple indices were always present with the same intervals, without any modification due to the time lapse, as the latest check has proved.

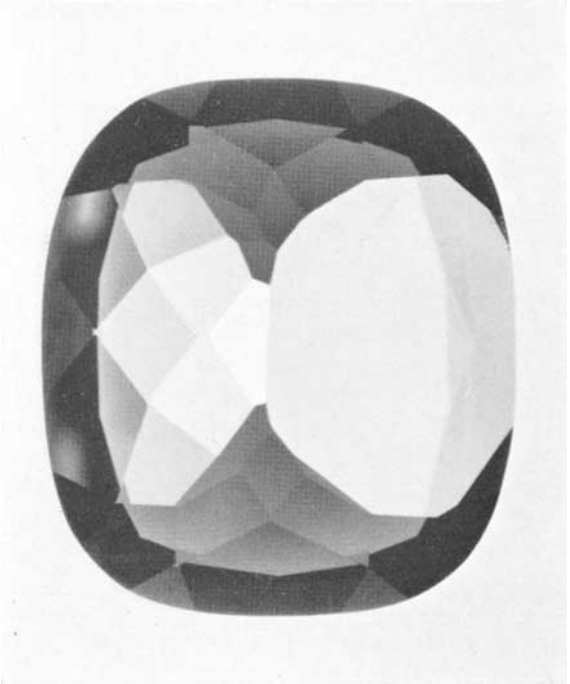

Fig. 1.

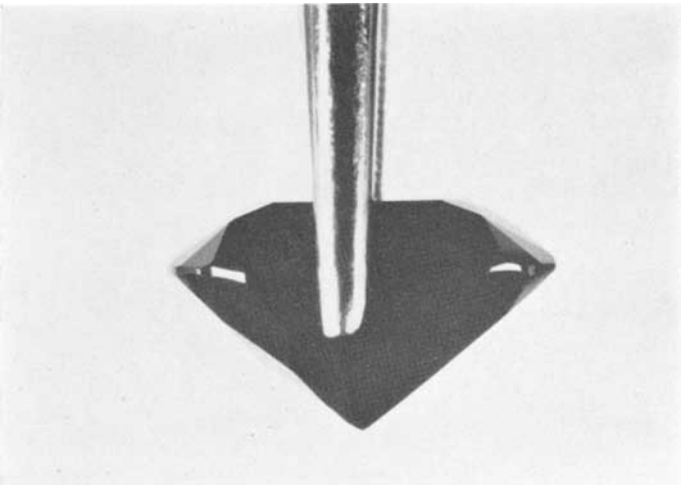

Fig. 2.

The following factors influencing the phenomenon were ascertained:

(*a*) it is limited to a shallow, superficial layer;

(*b*) cutting without development of excessive heat is not the cause;

(*c*) lubricating and grinding agents used had no action of re-establishing it.

The next sample worth noting is a "record" cut tourmaline weighing over 25 carats, showing a 4-fold effect of the refractive indices on the refractometer; this is the largest showing this effect met with up to date. The shape is rectangular with cut corners, the colour green: compared with the colour samples of the DIN 6164 system, the lighter zones correspond approximately to the master colour 21·5 : 4 : 2, the prevalent wavelength being situated between the master colour 21 at 502·4 nm and the master colour 22 at 529·5 nm. Further details of this sample are as follows:

Dichroic colours	:	o dark green
		e lighter green
Specific gravity	:	3·08

Aspect of the indices as observed on a spinel prism refractometer (Anderson-Payne model by Rayner)

	Basic shadow as observed on 9 of the larger facets	Satellite shadows as observed on 14 of the larger facets		
o	1·642	1·643	1·645	1·648
e	1·622	1·6225	1·623	1·625

True Birefringence 0·020.

The prominent feature was that amongst the 25 larger facets, 14 gave the 4-fold readings, i.e. two basic indices with a true birefringence of 0·020 each accompanied by three satellites, whereas

FIG. 1. Base view of a dark green, cut tourmaline, weighing over 13 carats, showing 4-fold indices on the table and on the smaller facets when tested on the refractometer. Slight recutting of some of the pavilion side facets resulted in one large facet (right side of figure) on the centre edge of which only two single, basic indices were observed.
Original length of the sample: 16 mm.
Combined lighting—transmitted light to show the transparency of the specimen, reflected light to demonstrate the shape of the facets. (*Photograph C. A. Schiffmann*)

FIG. 2. Side view of above tourmaline—to show how little material was cut away on the right side of the pavilion: at the formerly prominent spot only approximately 0·1 to 0·2 mm thickness. On the left side of the pavilion the facets were left in their original condition. Original size of the sample: width 14·1 mm, height 8·4 mm.
(*Photograph C. A. Schiffmann*)

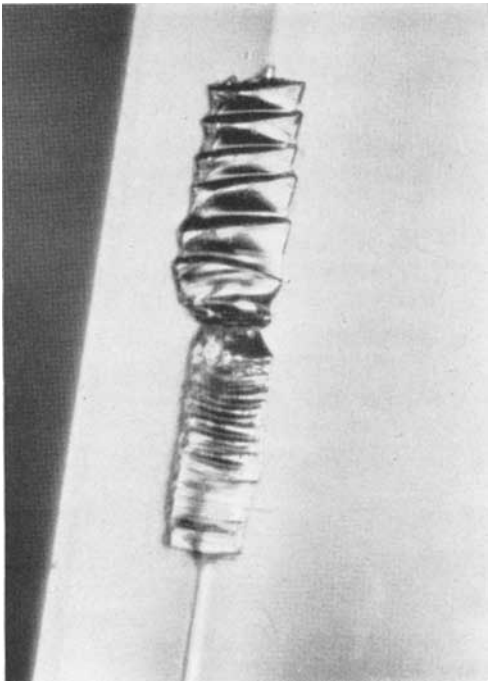

FIG. 3. Microphotograph of dark green, cut tourmaline, showing 4-fold indices, weighing over 25 carats—the largest met with to date. At the girdle on the common edge of two long side facets (orientated parallel to the direction of the optic axis) fracture surface was not caused by a knock but presumably through thermal shock. The roughly similarly orientated, cyclic arranged grooves at the surface give testimony of relieving internal strain. Original length of the fracture: approx. 1 mm.
(*Photograph C. A. Schiffmann*)

the nine of the remaining larger facets showed only the two single readings, usually situated at the same values as the basic indices above; the corner facets were too small to yield valid readings.

Through examination between crossed polarizers, tourmalines often exhibit strain resulting in irregular extinction in a direction parallel to the optic axis; another effect of strain is a good example, showing a small splintered place spotted on a common edge of two long facets. Under convenient magnification, the fractured place is seen to have quite a remarkable surface configuration worth showing as in Figure 3; the cyclic arrangement of the nearly parallel grooves confirms the repeated zones of internal strain.

There are several reasons why the presumable releasing factor induced was a thermal shock when heating the tourmaline—the

localization on a facet edge, the shape, the recessed aspect which is not the one of a fracture through damage caused by a mechanical knock. The fact that the multiple indices are absent in a certain number of facets proves that these have been recut after heating; consequently damaged places at the surface must have been more significant necessitating repolishing with the exception of a small spot.

It should be stressed that among all the tourmalines tested, a few were of a dark green colour still usable for jewellery, whereas the majority of them fortunately showed a very pleasant, saturated green colour which, together with good cutting proportions, made fine bright gems of them.

The absolute largest of all these green cut tourmalines showing the phenomenon (in this case a doubling of the two basic indices, i.e. two basic indices with each one a satellite line, as observed on the table and on the back facets sides) is a splendid gem of 156·04 carats, rectangularly shaped. The colour is a bright, saturated green (dominant wavelength 552·7nm) which compares with colour sample 23 : 4 : 6 of the DIN 6164 Colour Card for the brighter spots, whereas the darker ones have no equivalent on the DIN Card in its present version, and are presumably located at 23 : 6 : 8. This gem is undoubtedly a collector's item with a particular scientific interest. It is part of a private collection.

Up to now, only green tourmalines have been met with showing the multiple indices on the refractometer, but as green tourmalines are more numerous on the market than tourmalines of other colours, there is of course less chance of meeting this feature in the less frequent red, pink, yellow, brown, blue tourmalines.

In a further stage of study, it is foreseen to determine under which conditions the phenomenon is taking place.

In a recent short note, illustrated by a reproduction of the Figures 1, 3 and 4 of the 1972 article presented by the author, Professor Bank describes experiments made independently from those of this study, in an attempt to solve the problem.(4)

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TOPCON DIAMOND PROPORTION HAND SCOPE

By ERIC BRUTON, F.G.A.

THE Japanese, justifiably noted for their optical systems, have introduced a "diamond proportion hand scope" of Topcon make that is different from the three other systems available. The object of any such instrument is to gauge the quality of cut of a diamond by comparing it with a drawing or image of an ideal cut. The accuracy of cutting, or make of the stone, is becoming increasingly important as prices rise and has in any case been a factor in the value of stones of otherwise high quality on the American market in particular for some years.

For this reason, the Gemological Institute of America introduced their "ProportionScope" early in 1967, based on the optical comparator used in industry for quality control, in the hobbing and milling of gear wheels for example. The principle is to project an enlarged and accurate shadow of the part, in this case the diamond, on to a screen with the ideal proportions and the tolerances drawn on it. The magnification of the diamond is adjustable to make the shadow fit the drawing as nearly as possible. The ProportionScope is easy to use, has a wide range but is not easily portable, needs a plug-point and is expensive in the U.K.

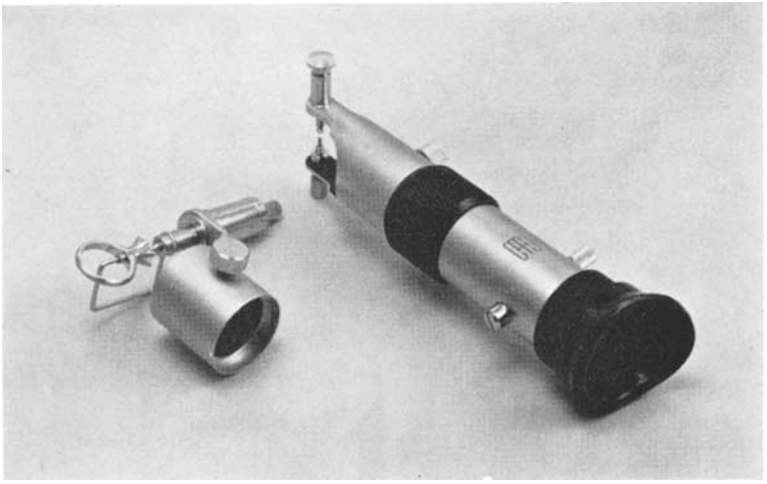

Subsequently, for those owning the binocular diamond-grading microscope known as the "Gemolite", with a zoom lens, the GIA introduced a simpler and, to my mind after using both, better alternative called the "diamond proportion reticule". It is an eyepiece containing the same diagram of ideal cut which replaces one of the microscope eyepieces. With it comes a special holder for the diamond which enables it to be placed in the field of vision and to be turned and rotated. It also makes the culet visible. The silhouette of the diamond seen through the eyepiece is made to fit the diagram as nearly as possible by moving the magnetic stone holder and increasing or decreasing the size by the zoom lens.

The third system referred to is a simple one devised by U. J. Pettersson, F.G.A., in which the stone is held in a special holder and its shadow projected by an orthodox projector on to an enlarged drawing of an ideal cut. I have not tried it, but wonder how many modern projectors would have a slide slit width sufficient to admit more than quite small diamonds.

The Japanese instrument looks at first glimpse like a hand-spectroscope with a gadget on one end to hold the stone. Its principal advantage is certainly its portability, because using the GIA eyepiece with their microscope still needs a power-point and the Gemolite is not an easily portable instrument. The Topcon hand scope can be used anywhere as long as there is reasonable light. The stone is clipped between a screwed piece which presses against the table and a spring-loaded one with a tubular end into which the culet fits. It is held centrally, and by means of the screwed part the image of the stone can be centralized vertically in the eyepiece diagram. A screw in the body of the instrument centralizes it horizontally. It is varied in size to fit the diagram by a central knurled band which operates a zoom system. In addition there is another attachment to hold a single stone diamond ring so that the diamond can be examined in the setting.

The instrument works well and is a pleasure to use. Judging the proportions of a stone in relation to pavilion and crown angles, table diameter ratio to total diameter, girdle width, and so on is quick and easy. The only point on which I would criticize it is that the diagram is more complicated than in the GIA's instruments. Without going into detail, it gives actual proportions in percentages and actual angles in degrees and minutes showing the ideals and certain limits, together with scales for table width and girdle thick-

ness. The GIA diagram on the other hand provides scales for all the parameters (except angles, as the angles relate directly to other proportions): this makes the diagram simpler and easier to read.

A more serious omission in the Japanese instrument is a circle on which to gauge the roundness of the stone. To provide one would also need a modified stone holder, of course. Roundness (and centralization of the culet) is an important factor in gauging the quality of make. It is also a factor in another use to which proportion instruments can be put—estimating the weight of stones that are to be recut. For old-mine cuts with cushion-shaped outlines and for earlier European cuts with high crowns and deep pavilions, a Leveridge or Moe gauge can be used to estimate the weight when recut to ideal proportions. If the stone is out of round, or asymmetrical because of an off-centre culet, is too deep in the pavilion, or broken, a proportion instrument can be used to estimate the new weight.

There is one major difference between the two scale diagrams, however. The Japanese one is based on the ideal cut according to the SCAN.D.N. standard, which are the general proportions considered ideal in Europe. The GIA scale diagram is based on the revised Tolkowsky proportions considered ideal in the U.S.A. The main difference is in the size of the table, 53 per cent of the girdle diameter in the modified Tolkowsky ideal cut and 57·5 per cent in the SCAN.D.N. figures. The table height is also slightly less in SCAN.D.N., 14·6 per cent of the total depth (not including girdle) compared with 16·2 per cent as favoured in the U.S.A.

The range of the ProportionScope is 0·18 to 8·00 carats (two screens are provided), and of the diamond proportion reticule from 0·10 to 5·50 ct with the Mark V *de luxe* Gemolite, but only from 0·25 to 1·80 with the non *de luxe* model. The Topcon diamond proportion hand scope has a range from 0·25 ct to 2 ct.

Cost in the U.K. approx. £150.

A JEWEL STONE OR A SCIENTIFIC TOY?

By ROBERT WEBSTER, F.G.A.

THE writer has been privileged to examine an unusual necklet and pendant which has been presented to the Gemmological Association. This piece of jewellery, made of gilt metal, is set with an oval cabochon stone having unusual properties, for when warmed, even by just the heat of the hand, the stone is seen to change colour. The stone, which comes from Japan, owes its colour-change properties to "liquid crystals" sealed into the base.

Examination of this cabochon stone, approximately 17 mm by 12 mm and mounted in a closed-back rolled-over setting, showed the colour at ambient temperature to be blue-grey, which on slight warming first turned to a speckled reddish-yellow, then to a bright green and finally to a bright blue.

The cabochon itself is apparently colourless, and by the "distant-vision" method the refractive index was found to be about 1·57. The hardness is less than 7 as the stone could be scratched by rock crystal. Under the short-wave ultra-violet lamp the cabochon glowed a uniform bluish light, and under the long-wave ultra-violet lamp a somewhat similar glow was seen, but this was not uniform and seemed to come more from the edges, from which it could be inferred that the glow emanated from the base. Mounted on its side on the stage of a petrological microscope, so that light could be transmitted through the stone, and with the "polars" in the "crossed" position, the stone was found to be isotropic. A fair presumption, despite no definite bubbles being seen, is that the stone is glass.

On examining the stone through the microscope, using top lighting, the base was seen to show a mosaic of colours, which were more or less predominantly the colour of the stone at a given temperature. What was more interesting was the quite strong dichroism which could be seen when a hand-dichroscope was used, the "twin-colours" being light and dark shades of the hue of the stone at the given temperature. This is considered to be an optical effect from the encapsulated liquid crystals. No diagnostic absorption spectrum could be seen, although, maybe, there was an absorption of the blue-violet which moved to shorter wave-length as the stone turned to a blue colour.

An experiment to determine the temperatures at which the liquid crystals turned to different colours was carried out by placing the pendant, metal surface downwards, on the flat surface of the asbestos housing of a sodium lamp. This supplied a slow-heating warm plate. Placed in juxtaposition with the metal of the pendant was set the bulb of a mercury thermometer which was graduated in fifths of a degree Celsius. The following results were established:—

17·3°C Ambient temperature colour of the stone blue grey.
22·3°C Stone started to turn to a reddish-yellow.
23·0°C Stone completely reddish-yellow.
23·5°C Stone started to turn green.
23·8°C Stone became a bright green.
24·4°C Stone had a blue-green colour.
25·0°C Stone turned to a bright blue.

This colour remained till about 28·5°C when the stone appeared to start to turn to its original blue-grey colour. At this stage the lamp was switched off—in fact when the temperature was at 30·0°C. On cooling, the stone changed colour in reverse order and at similar temperatures.

Liquid crystals do not appear to have entered the field of gemmology until now, although they have been used in digital displays in watches. What are liquid crystals? The short statement by Julius Grant(1) that "they are a liquid which have the optical properties of a crystal" gives a start to the answer. The report of a lecture given to The British Horological Institute at the Royal Society of Arts by Richard Elliott(2) puts it another way as the lecturer states "The action of a liquid crystal is rather complex. Briefly, it can be described as a re-alignment of molecules when a voltage is applied causing the crystal to become cloudy and light-reflective". Later the writer was credibly informed that there is a mirror or reflective surface placed below the crystal and the normal incident light is reflected and "lights-up" the cloudy crystals. This may well be due to a "Tyndall effect". It is clear from this that the liquid crystals used in watches operate by electrical or magnetic stimulation. This jewel stone operates by temperature, so it was necessary to "dig further".

A scientific encyclopaedia was then consulted(3) and further information was obtained from this reference. This told much more and stated that liquid crystals are viscous with viscosities extending from that of a light glue to a glassy solid and that they have very

definite evidence of structure. There is a three-fold classification of liquid crystals, depending upon the arrangement of the molecules. These are *smectic* crystals, *nematic* crystals, and lastly the *cholesteric* liquid crystals which exhibit the phenomenon of *circular dichroism:* that is, they break a beam of ordinary light into two components, one with the electric vector rotating clockwise and the other rotating counter-clockwise. The first is usually transmitted and the second reflected. This is a property which gives these liquid crystals an iridescent light when illuminated with white light. Some liquid crystals of cholesteric type behave as liquid crystals and produce colour change only in a certain temperature range. It seems that the liquid crystals in this jewel stone are of this category.

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1. Grant (J). *Hackh's Chemical Dictionary*, 1969, McGraw-Hill, London. p.185.
2. *Horological Journal*, November 1972, **115**, 4, 10.
3. *Van Nostrand's Scientific Encyclopedia*, 4th Edition, 1968, New Jersey, pp. 1024-1025.

NOTES ON INCLUSIONS IN TANZANITE AND TOURMALINATED QUARTZ

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Helvite in Quartz

Tourmalinated (schorl) quartz from Governador Valadares, Minas Gerais, Brazil, is frequently encountered as cabochon-cut or faceted gems. Gems of clear, colourless, quartz with the black needles of tourmaline are quite striking. Interspersed through this material are exceedingly thin filaments of an unknown mineral (perhaps tourmaline). Perched on these filaments are euhedral light yellowish-green tetrahedra (Fig. 1). These tetrahedra are usually isolated and quite obvious under a magnification of 10 × and

FIG. 1. Tetrahedra of helvite impaled on unknown filamentary crystal in Brazilian tourmalinated quartz. (60 ×).

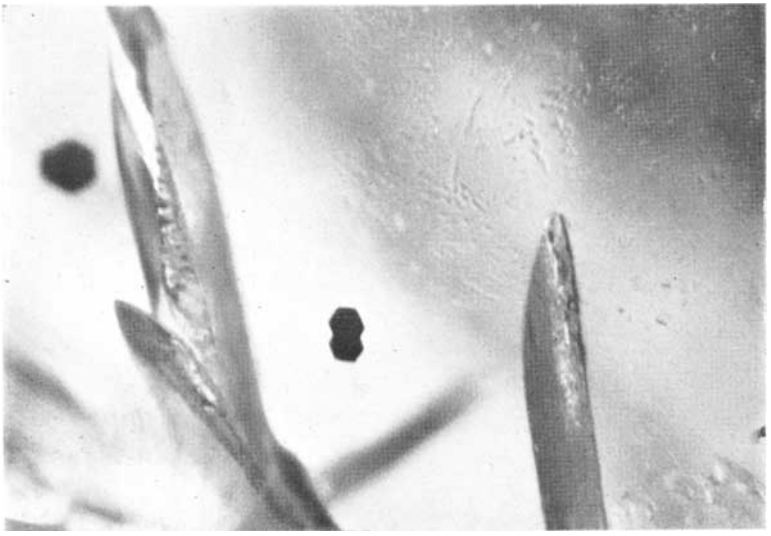

FIG. 2. Graphite inclusions in tanzanite. (40 ×).

they are about 1 mm in maximum dimension. Optical examination of these green tetrahedra indicated that they are isotropic, with a refractive index of $\sim nD = 1{\cdot}73$. Examination by x-ray diffraction indicated that these crystals were in the helvite group. Microprobe analysis of this helvite group mineral indicates that Mn > Fe > Zn and thus the yellowish-green included crystals are helvite, $Mn_4Be_3(SiO_4)_3S$. This analysis is presented as Table 1.

Graphite in Tanzanite

Blue gem zoisite (tanzanite) was discovered in Tanzania in 1967 and was described by Hurlbut (1969). Inclusions of black hexagonal crystals in this material were noted by Eppler (1969) and by Liddicoat (1967). The identity of these black crystals was not determined by either Eppler or Liddicoat. The hexagonal euhedrons occur both as discrete crystals and in parallel growth (Fig. 2). X-ray diffraction indicates that they are graphite. In one of the specimens in the Smithsonian collections, there appears to be an epitaxial relationship with {0001} of graphite parallel to {010} of tanzanite. Since there also is abundant randomly oriented graphite in some specimens, this possible epitaxy is not at all certain and confirmation must await repeated observations.

Most tanzanite is cut with the table of the stone parallel to {010} to avoid the less pleasing red-violet colour of the X-vibration direction. Gems cut with this orientation will have the strongest and most pleasing blue colour. If the above noted possible epitaxial relationship is substantiated by repeated observations, this presents a dilemma for the lapidary in the cutting of a stone with these graphite inclusions. In order to produce a stone with the strongest blue colour, he will be compelled to cut the gem in such a manner that the graphite crystals will be most obvious. By cutting the gem with the table parallel to {100}, the lapidary can orient the graphite so that it is seen edge-on when looking through the table of the stone, but he will be cutting a gem in which the less pleasing red-violet colour of the X-vibration direction will be observed. This also will hold true for heat-treated tanzanite, although the effect is less troublesome as the X-vibration direction colour is changed to violet-red after heat-treatment. It is indeed fortunate that the graphite inclusions are not too common. For a detailed discussion of the effects of heat-treatment of tanzanite, the reader is referred to Dr C. S. Hurlbut's paper.

TABLE 1

ANALYSIS OF HELVITE FROM BRAZIL

MnO	47·67%
FeO	1·46
ZnO	0·24
CaO	0·60
BeO*	13·51
Al_2O_3	0·71
SiO_2	31·90
S	5·17
TOTAL	101·26
LESS O = S	2·58
	98·68

*BeO content estimated from calculation from pure end-member components.

TABLE 2

OPTICAL PROPERTIES OF ZOISITE

(Reprinted from the *American Mineralogist* with Dr Hurlbut's permission.)

Indices (Na light — ± 0·0001)	Orientation and Pleochroism	
α = 1·6925	X = b red-violet	Opt (+)
β = 1·6943	Y = c deep blue	2V = 53°
γ = 1·7015	Z = a yellow-green	$r > v$

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Eppler, W. F. (1969), *Einschlüsse im blauen zoisite.* Z. Dt. Gemmol. Ges., **18,** 2, 56-60.

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EMERALD FROM NORTH CAROLINA

By M. J. O'DONOGHUE, M.A., F.G.A.

THE Big Crabtree emerald mine is situated near the Great Smoky National Park in Mitchell County, near to the town of Asheville. It is operated commercially and had reached a depth of 210 feet in 1968. I am greatly indebted to Mr William Collins, operator and part owner of the mine, for sending me two crystals, of good hexagonal form and of a fine colour, and a piece of quartz with feldspar, bearing tourmaline and emerald crystals. I am most grateful to Professor William J. Furbish, of Duke University, Durham, North Carolina, for introducing me to Mr Collins.

The mine contains quartz, feldspar (albite), tourmaline of a dark colour, and mica schist. The emeralds are found in a pegmatite and are growing deeper in colour as the mine goes deeper. Most of the emerald is so intimately associated with the feldspar that the two are recovered and slabbed and polished together, being sold under the name of "emerald matrix". Mr Collins was kind enough to send me a slab of this material.

The two crystals in my possession show a medium red under the Chelsea filter and display a chromium absorption spectrum. It was not possible to obtain a clear refractive index reading since there were no faces sufficiently flat, but a rough "bright line" reading indicated approximately 1·58.

Professor Furbish, who refers to the location as "Little Switzerland" in an article in *Gems and Gemology*, Summer 1972,* showed that inclusions of quartz crystals were found in emeralds recovered from all depths of the mine, though they occurred in few individual crystals. The quartz crystals did not appear to follow any crystallographic orientation. Mica crystals could be seen in the quartz inclusions, though I was unable to distinguish either mineral in my specimens. G. F. Kunz, in "History of the gems found in North Carolina", published in 1907, states that the emerald crystals varied in length from minute up to one inch, and were $\frac{1}{8}''$ to $1\frac{1}{4}''$ in diameter. My two crystals are $\frac{1}{4}''$ long by $\frac{1}{4}''$ wide.

The other major emerald location in North Carolina is the Rist Mine, near the town of Hiddenite. At this mine work takes place in surface levels, which are bulldozed to facilitate access.

**Gems Gemol.*, XIV, 2, 34-37. — Ed.

There is no tunnelling as at the Big Crabtree mine. In 1969 the largest crystal of emerald found in North America was unearthed; it measured $3\frac{1}{16}''$ long by $2\frac{1}{8}''$ wide. Many of the emeralds from this area are a good chrome-green on the outside but have colourless cores. The surrounding material is a micaceous red sandy clay in which the emeralds occur in pockets. Muscovite mica flakes and quartz crystals appear to be an indication of the possible whereabouts of emerald.

William Earl Hidden, after whom the green chrome-coloured spodumene was named, was sent to this area by Edison to look for platinum. This was not found, although hiddenite was. In 1881 he started the Emerald and Hiddenite Mining Company; operation of the mine was sporadic and ceased in 1927. To-day the property is owned and worked by American Gems, Inc., who allow visitors to dig for emerald.

Gemmological Abstracts

ANDERSON (B. W.). *Short cuts to certainty.* Australian Gemmologist, 1974, 12, 3, 71–74.

First printed in *Z. Dt. Gemmol. Ges.*, and abstracted in *J. Gemm.*, 1974, XIV, 4, 181. R.W.

BALL (R. A.). *Liesegang rings.* Australian Gemmologist, 1974, 12, 3, 89–91. 1 illus.

A discussion on the formation of Liesegang rings and the theories for them that have been propounded. There is a good list of references. R.W.

BANK (H.). *Gelblich-grünlicher durchsichtiger Prehnit aus Australien.* (Yellow-green transparent prehnite from Australia.) Z. Dt. Gemmol. Ges., 1975, 24, 4-7.

Prehnite has long been known as usable as a gemstone. It has now been found in a transparent or nearly transparent state; the refractive indices of these stones can easily be read and their R.I.s and their relationship with their chemical composition are presented in diagram form. The prehnite under discussion came from Australia. Bibliography. E.S.

BANK (H.). *Durchsichtiger schleifwürdiger roter Cuprit von der Onganja Mine.* (Transparent cuttable red cuprite from the Onganja mine.) Z. Dt. Gemmol. Ges., 1975, 24, 8-9.

The author discusses this cubic crystal from a new find in S.W. Africa. Chemically the stone is Cu_2O, D = 6·0 ± 0·2, the hardness is $3\frac{1}{2}$–4 and the R.I. 2·848. Bibliography. E.S.

BANK (H.). *Grüner durchsichtiger schleifwürdiger Phosphophyllit von Cerro Rico de Posito/Bolivien.* (Green transparent cuttable phosphophyllite from Cerro Rico de Posito in Bolivia.) Z. Dt. Gemmol. Ges., 1975, 24, 10-12.

This phosphophyllite was found in the silver and tin mines in Bolivia. It has a hardness of 3-4, density 3·081-3·0825, crystallization is monoclinic-prismatic, R.I. = 1·599-1·621, D.R. = 0·022. The colour is light green. E.S.

BANK (H.). *Grüne chrom- und vanadiumhaltige Granate (Grossulare) aus Kenya: Tsavolith—Moeglichkeit einer neuen Benennung?* (Green grossularites containing chromium and vanadium from Kenya: Tsavolite—possibility of a new name?) Z. Dt. Gemmol. Ges., 1975, 24, 13-15.

There have been various finds in Kenya of green grossularites which occur in various colour intensities. The trade has suggested a new name for these stones, i.e. Tsavolite, as the Tsavo Park is near the occurrences and lithos = stone. E.S.

BANK (H.) and BERDESINSKI (W.). *Über Phänomene bei der Refraktometerablesung gewisser Turmaline.* (Phenomena when taking the refractometer reading of certain tourmalines.) Z. Gemmol. Ges., 1975, 24, 20-22.

The authors will continue to research into the cause of the phenomena shown when reading R.I. of tourmalines first described by R. K. Mitchell in 1967 and later noted by various other gemmologists. After some experiments in which stones showing these phenomena were halved and one half repolished, the authors conclude that these deviations from the norm could be classed as surface phenomena caused by overheating during the heating process. E.S.

BOLTON (H. C.). *Synthetic diamonds.* Australian Gemmologist, 1974, 12, 3, 81–83.

The report of a lecture given at the Federal Conference of the Gemmological Association of Australia. The article contains much useful data and there is a good list of references. R.W.

BRIDGES (C. R.). *Green grossularite garnets ("Tsavorites") in East Africa.* Gems & Gemology, 1974, XIV, 10, 290–295. 1 illus. 2 maps.

A very good geologically oriented survey of the green grossularite garnet found in Kenya. This stone has been called "Tsavorite" by Tiffany & Co. Much is told of the possible formation of the mineral and the elements which may be the cause of the colour. A seemingly unnecessary comparison with emerald is made. R.W.

BROOKES (N.). *Jade.* The Guilder (Johannesburg), 1975, 1, 4, 1–5. 3 illus.

A short and concise article which is factually correct. R.W.

BUECHE (ARTHUR M.). *Diamond Synthesis—A Continuing Exploration.* Proceedings of the Royal Institution of Great Britain, 1974, 47, 287-302.

This is an account of Dr Bueche's Discourse given at the Royal Institution on 2nd May, 1974, during the course of which he not only demonstrated the burning of a diamond by heating it to about 800°C and dropping it into liquid oxygen but also actually made some diamonds by the General Electric process—"the first time we have ever made a public demonstration of this type". Success was first achieved by General Electric using a metal catalyst, and now by using different metal catalysts a variety of shapes, sizes and types can be produced to meet customers' requirements. At pressures nearing 3 million p.s.i. and simultaneous temperatures of nearly 5000°C graphite can now be directly converted to diamond without a catalyst, but using catalysts at lower temperatures and pressures remains most cost-effective. "Hexagonal diamond" has been created, which in nature has been found only in meteorites ("Lonsdaleite"): and semiconducting diamonds can be made, as well as diamonds of gem quality. Still in the future, it is suggested that, under sufficient pressure, diamond, like silicon and germanium, should have a metallic form. J.R.H.C.

CASSEDANNE (Jacques P. and Jeannine O.). *Le gîte d'améthyste de Cabeludos.* (The home of Cabeludos amethyst). Bulletin de l'Association Française de Gemmologie, 1975, 42, 22-24.

An account of the occurrence of amethyst in the state of Bahia, Brazil. The crystals are found as hexagonal prisms with pyramids and are more deeply

coloured towards the termination. S.G. given as 2·67, R.I. as 1·553, 1·544, D.R. 0·009, H. 7. M.O'D.

CROWNINGSHIELD (R.). *Developments and Highlights at the GIA's Lab in New York.* Gems & Gemology, 1974, XIV, 10, 298–305; 11, 327–336. 40 illus.

There is the report of another taaffeite, said to be the largest on record, but no present weight is given (although it is stated to have weighed more than 9 carats before recutting), and there are further reports on a cat's-eye kornerupine weighing 7·57 carats and of a grey-green cat's-eye zircon. A bright green and some yellow sapphires brought back from the Orient were found to be synthetic. Quartz crystals suitably cut and painted green found inserted into matrix rock form a new fake to puzzle the mineral buyer. Proposed to be marketed under the name "captured emerald" is a new composite stone which consists of a hollow-backed rock crystal in the hollow of which are embedded pieces of beryl or emerald in a green cement (plastic). A pendant of fluorite of some age, but well protected by the setting, is mentioned. A black and white vase which was found to be nephrite and a carved dagger in stained jadeite are two other items recorded. A number of fake lapis lazuli pieces are mentioned and these include dyed howlite and plastic bonded lapis-lazuli types. Other items reported are surface-stained and plastic-coated turquoise, an imitation opal on matrix, inclusions in an emerald which probably came from the Lake Manyara source in Tanzania, the inclusions being emeralds of a deeper colour. Reference is made to modifications to the brilliant-cut and inclusions in diamond. A star-sapphire damaged by a loose diamond shoulder stone and damage to a diamond by burning are reported. The name "blue morganite" is mentioned as being used for treated "Maxixe type" beryl. There are reports on the rubies from Tsavo National Park, Kenya, and some notes on the Uncle Sam diamond and on a visit to the Maine tourmaline mine. R.W.

CURTIS (George E.). *Venezuela's valley of diamonds.* Lapidary Journal, 1975, 28, 11, 1708-1718.

Diamonds obtained from the Rio Guaniamo amounted to almost 700,000 carats in 1973, the location being near the Guaniamo river, reference 7° 50′ north, 65° 80′ west. M.O'D.

DEGENHARD (W. E.). *The measurement of the brilliance of diamond.* Also EULITZ (W. R.). *The optical brilliancy of two different brilliants—a comparative investigation.* Gems & Gemology, 1974, XIV, 9, 259–269 and 273–282. 11 illus. 5 tables.

These two articles are respectively a complaint and a rebuttal, giving two different interpretations of the brilliance of a brilliant-cut diamond with 106 or (supplemented by 38 additional girdle facets) 144 facets compared with the normal brilliant cut of 58 facets, Degenhard claiming that it shows more, and Eulitz that it shows less, brilliance. In Figure 1 of the Degenhard article there seems to be a lack of clarity and understanding of the optics of light rays. R.W.

DUNN (P. J.). *Inclusions of albite and phenakite in gem topaz from the Tarryall Mountains, Colorado.* Gems & Gemology, 1974, XIV, 11, 337–339. 2 illus.

The deposit of blue topaz crystals at this locality was first worked about 1909 and consists of well-formed crystals in the loose debris formed from the weathering

of pegmatites. The refractive indices are about 1·61–1·62, but the birefringence is said to be only 0·008, which is rather low for the fluorine-rich type of topaz. The density is 3·56. The crystals darken to a murky brown after a ten-hour x-radiation using CuKα radiation, but this gradually fades after several days exposure to sunlight. Two types of inclusion were found—by using x-ray powder photographic method and by electron microprobe—and were broad platy crystals of albite either as single platelets or twinned multiple crystals and clear colourless phenakite crystals. R.W.

EPPLER (W. F.). *Nochmals: Synthetischer Opal.* (Again: synthetic opal.) Z. Dt. Gemmol. Ges., 1975, 24, 23-25.

In December 1974 the author described in the *Z. Dt. Gemmol. Ges.* the black synthetic opal produced by the firm Gilson in France*. This firm also manufactures white opal with specific gravity and R.I. as in the natural stones. The easiest way to differentiate between the natural and synthetic white opal is again by microscopic examination. The synthetic product shows a cobble-like structure made up of fairly regular blocks. These synthetic stones are made from sodium silicate (water glass) or a silicon ester which is then slowly dehydrated. The tiny particles are similar to the cristobalite balls in natural opal and have a diameter of 0·0002 mm. The synthetic product has a hardness of 4½ as opposed to 5½-6½ for the natural stone. The commercial value is £10-£300 p. ct. E.S.

GELLIE (G. J.). *Industrial diamonds.* Australian Gemmologist, 1974, 12, 3, 84–89.

A general survey of the types of diamond and a very good exposition of the various uses to which diamonds have been put in industry and science. R.W.

GRAINDORGE (J. M.). *A gemmological study of emerald from Poona, Western Australia.* Australian Gemmologist, 1974, 12, 3, 75–80. 10 illus.

A very good survey of the emeralds first found during 1914 in the Poona district of Western Australia. The geology of the emerald formation and the properties of the emeralds found at this locality are given. It is said that three-phase inclusions are found in Poona emeralds. A useful article. R.W.

HUDSON (D. R.). *"Pilbara jade".* Australian Gemmologist, 1974, 12, 4, 127–133. 3 illus.

"Pilbara jade", or "Marble Bar Jade", is found to be a serpentine mineral. The article deals with the different types of serpentine and tells of other green minerals in the Pilbara region. R.W.

LEITHNER (H.). *Seltene Lasuritkristalle aus Afghanistan—Ein Beitrag zum Farbproblem Lapis-lazuli.* (Rare lazurite crystals from Afghanistan—a contribution to the colour problem of lapis-lazuli.) Z. Gemmol. Ges., 1975, 24, 26-36.

Survey of history and characteristics of lapis-lazuli, found mainly in Hindu-Kush and specifically in Badakhshan: also gives details of rare rhombic dodecahedral crystals of lazurite, roughly 5 cm diameter, found in white marble from

*Abstracted in J. Gemm., 1975, XIV, 6 295.—Ed.

Afghanistan. The author discusses chemical composition, crystal structure and habit, colour and how it is produced, R.I. density, and fluorescence and especially details of occurrence of the Badakhshan finds. E.S.

LIDDICOAT (R. T.). *Developments and Highlights at the GIA's Lab in Los Angeles.* Gems & Gemology, 1974, XIV, 10, 309–316; 11, 340–351. 44 illus.

A very full report on the examination of Gilson synthetic opals is given, which includes the effects seen by transmitted light and by ultra-violet transparency. A new synthetic white star-sapphire and cameos in hessonite garnet and in quartz are mentioned. A colour-change natural spinel, a ruby with unusual inclusions, sodalite, and black spinel are items discussed. Various inclusions seen in diamond as well as a diamond which had cleaved in two are referred to, and damage to a red garnet-topped doublet is described. Concentric growth lines in a synthetic star-sapphire, and unusual inclusions in glass and in hessonite garnet, as well as unevenly dyed jade, are mentioned. A tortoiseshell snuff-bottle, which showed the layering where the material had been pressed together, is another item referred to. R.W.

LINDSTEN (Don E.). *The emerald.* Lapidary Journal, 1975, 28, 11, 1694-1700.

A general account of the emerald with particular reference to the manufacture of synthetic stones. M.O'D.

MALES (P. A.). "*Mexican onyx and other marbles*". Australian Gemmologist, 1974, 12, 3, 92–94. (Reprinted from Australian Lapidary Magazine).

A general article on "onyx marbles" with much consideration of the nomenclature with overtones on Consumer Protection. R.W.

NASSAU (K.). *Natural, treated, synthetic and imitation gems.* Gems & Gemology, 1974, XIV, 11, 322–326. 5 illus.

This article puts into perspective the various groups implied by the title but with the main emphasis on treatment. The terms synthetic and imitation are discussed. There is a good list of references. An article which must be read. R.W.

OUGHTON (J. H.). *Treated stones.* Australian Gemmologist, 1974, 12, 4, 111–118.

A general survey of the stones said to have had their colour changed or enhanced by irradiation or by sub-atomic bombardment, methods which have reached considerable importance in the last decade. The stones mainly considered are topaz and beryl. There are some notes on the treatment of amethyst, spodumene and sapphire. The type of wording to be used on certificates for these stones and the legal aspects of nomenclature are discussed. R.W.

PETROV (I.) and BERDESINSKI (W.). *Untersuchungen künstlich farbveraenderter blauer Topase.* (Examinations of blue topazes with induced colour-change.) Z. Dt. Gemmol. Ges., 1975, 24, 16-19.

This report is only preliminary. The authors report on the blue topazes which have recently been sold in Europe and which could not be distinguished from the natural blue topazes. The method of differentiating between the natural and synthetic colour is a thermo-luminescence one. Bibliography. E.S.

POIROT (J.-P.). *Les principaux substituts de lapis-lazuli.* (The principal substitutes for lapis-lazuli). Bulletin de l'Association Française de Gemmologie, 1975, 42, 25-26.

Sodalite, lazulite, dumortierite, azurite, glass, synthetic spinel, stained jasper and other imitations are described. M.O'D.

POST (George). *Blue magic: turquoise Indian jewellery.* Lapidary Journal, 1975, 28, 11, 1670-1676.

An account, illustrated in colour, of the history of the use of turquoise as an ornamental stone with illustrations of Indian jewellery from the Navajo tribe of the U.S.A. M.O'D.

ROSE (W. A.). *Treating matrix opal.* Gems & Gemology, 1974, XIV, 10, 306–308. 2 illus.

Precious opal embedded in a kaolinite clay matrix does not show the play of colour effectively owing to the white reflections from the clay which dilute the play of colour. When the clay is dyed black the play of colour is much enhanced. The stones need to be cut before treatment, which consists of soaking the stone for about two weeks in a sugar solution of which various types are used; the stones are then placed in a glass container and covered with sulphuric acid and left for twenty-four hours or more, after which they are well washed in a strong solution of sodium bicarbonate: the stones are then lightly polished. R.W.

SCALA (C. M.). *A survey of some research work on impurities in gems.* Australian Gemmologist, 1974, 12, 4, 119–124. 6 illus.

This erudite article describes the estimation of impurities in gemstones by the use of Mossbauer spectra (which concern the resonant absorption of gamma rays in crystals containing impurities which can be produced by radioactive decay), and further investigation was made by using Electron Paramagnetic Resonance (E. P. R., sometimes referred to as "electron spin"). R.W.

SCHMETZER (K.), TRAUB (I.) and MEDENBACH (O.). *Demantoid aus Korea.* (Demantoid from Korea.) Z. Dt. Gemmol. Ges., 1975, 24, 1-3.

A green garnet coloured by Cr^3 from a new occurrence is described. For the crystals of gem quality $a_o = 12{\cdot}0597$Å, $n_D = 1{\cdot}8889$, $D = 3{\cdot}82$-$3{\cdot}83$. A microprobe analysis gave a composition of 36·6% SiO_2, 30·3% Fe_2O_3, 33·9% CaO and traces of Al_2O_3, Cr_2O_3, MgO and MnO. E.S.

STEINERT (H.). *Das Volksfest der Strahler—Mineralbörse der Schweiz in Brig.* (The fête of the rockhounds—a mineral bourse in Brig in Switzerland. Z. Dt. Gemmol. Ges., 1975, 24, 37-39.

The author reports on an annual event taking place in Brig in Switzerland. The rockhounds of all ages meet, eat and exchange views and specimens. E.S.

STEYN (E.). *Unakite.* The Guilder (Johannesburg), 1975, 1, 4, 12.

A short but interesting article on the rock called unakite. While no mention is made of the origin of the name unakite and its occurrence in the Unaka Mountains in North Carolina, this article does give a new locality for this ornamental rock—the Limpopo valley bordering South Africa and Rhodesia and mainly in the Beit Bridge area near Messina. Some notes are given on the polishing of the material. R.W.

SWITZER (G. S.). *Composition of green garnet from Tanzania and Kenya.* Gems & Gemology, 1974, XIV, 10, 296–297.

Using a microprobe analyser the author has produced an analysis of four green grossular garnets from Kenya and Tanzania. The compositions are tabled and it is stated that the correct mineralogical nomenclature for the green gem-quality garnet from Kenya is *vanadian grossular.* R.W.

WILSON (A. T.), HENDY (C. H.) and TAYLOR (A. M.). *Peridot on Ross Island—Antarctica.* Australian Gemmologist, 1974, 12, 4, 124–125. 1 map.

Peridot crystals of gem quality have been found in the Cape Bird area of Ross Island. The facet-grade material is yellowish-green in colour and in sizes one to three grammes, from which stones fairly free from inclusions and up to a carat in size can be faceted. The inclusions seen in these peridots are brown mica platelets and minute melt inclusions of a glassy nature. The refractive indices were found to be $\alpha = 1{\cdot}653$, $\gamma = 1{\cdot}689$, the double refraction being 0·036, and the density was found to be 3·34 to 3·35. R.W.

YAKOVLEVA (M. YO). *Variegated garnet-bearing jasper of the southern Urals.* Dokl. Acad. Sci., U.S.S.R., Earth Sci. Sect., 1970, 191, 134-137, 3 figs. Trans. from Dokl. Akad. Nauk S.S.S.R., 1970, 191, 1134-1137.

Variegated jasper containing dispersed garnet occurs as lenses 0·2 to 3 m thick and 5 to 40 m long in Lower Devonian greenstone. Hematite is the pigment in red jasper, magnetite in black jasper, and both hematite and magnetite in violet jasper. The garnet, mainly andradite, occurs as minute globular granules 1 to 5 μm dispersed in jasper. X-ray peaks are given for garnet; chemical and mineralogical analyses for 3 types of jasper. R.B.H.

Le salon des minéraux. (The hall of minerals). Bulletin de l'Association Française de Gemmologie, 1975, 42, 2-16.

An account with coloured illustrations of some of the finest pieces in the recently re-arranged galleries of the Muséum National d'Histoire Naturelle, Paris. M.O'D.

BOOK REVIEWS

COOPER (Diana) and BATTERSHILL (Norman). *Victorian sentimental jewellery.* David and Charles, Newton Abbot, 1972. pp. 127. Illustrated in black-and-white. £2·95.

The two parts of this book deal with mourning jewellery and with love brooches respectively. A number of jet pieces are illustrated. The meaning of the various devices found on love brooches is listed and there is a short bibliography.

M.O'D.

FAKTOR (M. M.) and GARRETT (I.). *Growth of crystals from the vapour.* Chapman and Hall, London, 1974. pp. x, 300. £7·00.

Chemical vapour transport is one of the cheapest and most versatile methods of growing crystals and is widely used in the production of material for the electronics industry. The basic science, thermodynamics of crystal growth, elementary crystallography and chemistry are treated before the actual growth processes are described. There is a useful bibliography. M.O'D.

GOODMAN (C. H. L.). *Crystal growth theory and techniques.* Vol. I. Plenum Press, New York, 1974. pp. ix, 300. £10.

Four topics of crystal growth are treated by different contributors—mechanism in vapour epitaxy of semiconductors: principles of the vapour growth of single crystals: travelling solvent techniques: refractory metal crystal growth techniques. There is a subject index and a materials index. References are given at the end of each chapter. M.O'D.

KUSHNER (Ervan F.). *A guide to mineral collecting at Franklin and Sterling Hill, New Jersey.* Ervan F. Kushner Books, Paterson, New Jersey, U.S.A., 1974. pp. 91. Illustrated in black-and-white. $4·50.

An excellent guide to this fascinating area, this book is particularly valuable for its up-to-date notes on the luminescence of the minerals of the district, which contradict some earlier reports. Also of value are the maps and historical notes.

M.O'D.

MACDONALD (Barbara). *Gemstones as amulets, talismans and healing stones.* M.O.S. Publishing Co., Ringoes, New Jersey, U.S.A., 1974. pp. ii, 11. Price on application.

A short guide listing 14 gemstones, 3 symbols and 6 colours with the magical, healing or occult powers attributed to them. M.O'D.

MARTYNOVA (M. V.). *Precious stones in Russian jewelry art in XIIth–XVIIIth centuries.* Iskusstvo, Moscow, 1973. pp. 51. Illustrated in black-and-white and in colour. £4·90.

A general introduction precedes the very fine coloured reproductions of Russian jewellery. Each piece is described in Russian and English, giving size, details of the metal and stones used, provenance and present location. M.O'D.

MAXWELL-HYSLOP (K. R.). *Western Asiatic jewellery c.*3000–612 B.C. Methuen, London, 1974. (University paperbacks 525). pp. lxvi, 286. Illustrated in black-and-white and in colour. £4·90.

This book covers the period from the Early Dynasties in Mesopotamia to the capture of Nineveh in 612 B.C. Line drawings and photographs are of high quality. There is a bibliography. M.O'D.

MYATT (Bill). *The Paul Hamlyn dictionary of Australian gemstones.* Paul Hamlyn, Dee Why West, N.S.W., Australia, 1974. pp. 191. Illustrated in black-and-white and in colour. Price on application.

An abridged edition of the same editor's *Australian and New Zealand Gemstones,* published in 1972, this book includes such unlikely gems as selwynite and zeolite, which is a mineral class. There are some mis-spellings, such as Burchester for Buchester, in the bibliography, which does not include B. W. Anderson's *Gem Testing;* some of the colour plates are out of focus and the typography is indifferent. M.O'D.

PAMPLIN (Brian). *Crystal Growth.* Pergamon Press, Oxford, 1975. pp. xiv, 672. £21.

A compilation of current papers dealing with all aspects of crystal growth, including comprehensive bibliographies and tables. All techniques are described in considerable detail. An invaluable contribution to a study whose literature is still scarce and largely theoretical. M.O'D.

SATALOFF (Joseph) and RICHARDS (Alison). *The pleasure of jewelry and gemstones.* Octopus Press, London, 1975. pp. 96. Illustrated in colour. £2·50.

A popular introduction to jewellery, this well-illustrated book contains a section on gems, illustrations for which are taken from the photographs prepared by the Geological Museum. The matter seems unexceptionable. M.O'D.

SIMPSON (Brian). *Minerals and rocks.* Octopus Books, London, 1974. pp. 128. Illustrated in black-and-white and in colour. £2·95.

A general popular guide to minerals and rocks with a special chapter on gemstones. This appears unexceptionable, though the statement that the blue variety of topaz is the most valuable seems open to question. M.O'D.

WAINWRIGHT (John). *Discovering lapidary work.* 2nd edn. Mills and Boon Ltd, London, 1973. pp. 216. Illustrated in black-and-white and in colour. £3·60.

This book is intended for use in schools and much of it is devoted to step-by-step explanations of the tumbling and faceting processes. An early chapter introducing simple gemmological theory and testing contains some loose writing, including the statement that sinhalite is a common gemstone. The bibliography is unhelpfully compiled by title and no publication dates are given. Nothing raises the book above the common run. M.O'D.

WEBSTER (R.) *Gems.* Third edition. Newnes-Butterworths, London, 1975. pp. xviii, 931. Illustrated in black-and-white and in colour. £15·50.

The third edition of such an accepted work as *Gems* provides a convenient point from which to review the enterprise as a whole and to consider the shape

that might be taken by future editions. The book has reached the largest size possible for a single-volume and the weight of paper on a binding not apparently mounted on tapes arouses misgivings for the condition in a year or two of books subjected to heavy use.

The most notable feature of the book to anyone who uses it frequently is the difficulty of locating some of the information which is nevertheless known to be included. Large sections which might have been expected to occur in the gem-testing part of the book lurk among the individual gem materials; an example is the lengthy note on asterism in the chapter on corundum. In this note reference is made to Alice Tait's work, but this is not mentioned in the bibliography. Again, the reader may seek the topic 'alteration of colour'; it will not be found in the index under colour but under colour change—quite a different conception. Here again some details are given with the stones and the rest lumped together in the testing section—in this case the painting of emerald. All this should have been tidied up by the publishers' editor in previous editions. Presuming that later editions will once more appear in more than one volume or even in sections that can be separately purchased, it should not be too difficult to bring appropriate sections together.

The details of the occurrence of some of the gems are very uneven; there is no account of the paragenesis of demantoid garnet, although a theory regarding that of hydrogrossular is given; this information is also absent from the sections on less well-known gemstones but could well be included.

The section on the testing of stones is excellent as readers will know by now. Here again there could be more on inclusions, although this would naturally increase the size of the book; there could be more on the use of x-rays—much more, since the work of the American Society for Testing Materials and its powder diffraction files should certainly be included. However, if so much more information goes into later editions, either the book will become unusable by reason of size or other parts may have to be sacrificed. I suggest that neither of these two courses need be followed. Much of the book is written in an essay form which could, often with advantage, be altered to a simpler style. This would incidentally cut out some phrases which become tedious with repetition. It would also be easier for readers to find what they want and for the editors to ensure that all material on one topic is placed together.

A new edition must have an adequate bibliography—this one is too small, gives insufficient detail, includes works of no merit and excludes periodical articles. (The writer must set his teeth and include them in a work of this magnitude!) The index is also inadequate and needs professional handling. The illustrations are almost all good, but those of jewellery should be left out of later editions or else replaced; the details of the stones are too small and the general appearance of the models dated (these are not and never can have been examples of top-class fashion photography). The illustrations of gem stones are much better, but perhaps a less wooden arrangement could be adopted for later editions, as in Gübelin's Edelsteine. The few misprints (Eicholz for Eickhorst is a bad one since it occurs in the preface to this edition) and the one out-of-focus photograph (the coloured plate of diamonds, plate IV) can easily be corrected.

The foregoing remarks are offered as suggestions on the ways in which a superb book may be made unrivalled. They involve a great deal of work, but

Mr Webster's innumerable excellencies fortunately include an infinite capacity for taking pains—said to be an attribute of that indefinable quality, genius.

M.O'D.

WILKINSON (Alix). *Ancient Egyptian jewellery.* Methuen, London, 1975. (University Paperbacks, 524). pp. lxi, 266. Illustrated in black-and-white and in colour. £4·90.

A reprint of a book first published in 1971, this is a comprehensive and lucid account of jewellery from predynastic times to 525 B.C. Many examples are illustrated by line drawings and the finest pieces by photographs. There is a museum index and a bibliography. M.O'D.

Gemstone fossicking in New South Wales. Published by the Department of Tourism of New South Wales, 1974. Freely distributed.

A well-illustrated pamphlet introducing the gemstones of the State and including particulars of mining and prospecting laws. M.O'D.

Turquoise annual. Vol. 1. Published by Longart Corporation, Reno, Nevada, U.S.A. $2·95.

A well-written and illustrated first number, this publication contains articles on the identification and marketing of turquoise, on its use in American Indian jewellery and on treatment and substitutes; one of these of unstated composition is called "Turquite". There are articles on variscite and on United States locations.

M.O'D.

Gem World.

This periodical is the official journal of the Jewellers' Association of Jaipur, India. It appears monthly and the annual subscription is Rs 50.00. The issue examined, Vol. II, No. 3, 1975, contains articles on diamond simulants, in which an immersion technique is incorrectly described, and details of trade visits from West Germany. Considerable space is devoted to the Indian diamond trade.

M.O'D.

ASSOCIATION NOTICES

DR G. F. CLARINGBULL

In the Birthday Honours published in mid-June the honour of knighthood was conferred on the Association's President, Dr G. F. Claringbull, for services as Director of the British Museum (Natural History).

Mr F. E. LAWSON CLARKE

The Association's Treasurer, Mr F. E. Lawson Clarke, celebrated 50 years in the jewellery trade in December 1974 and in May 1975 he was elected President of the National Association of Goldsmiths. This organization represents retail jewellers in the U.K.

EXAMINERS

At the meeting of the Council held on 5th February, 1975, Mr A. E. Farn, F.G.A., and Mr E. A. Jobbins, B.Sc., F.G.A., were appointed as examiners in gemmology.

ANNUAL GENERAL MEETING

The 45th Annual General Meeting of the Association was held at Saint Dunstan's House, Carey Lane, London E.C.2 on the 28th April, 1975.

The Chairman, Mr Norman Harper, welcomed members and commented:

"I should first of all like to say how pleased we are that Dr G. F. Claringbull is continuing as our President and his interest in the Association is much appreciated.

"It is with regret that we heard of the death of Mr McWilliam who although having to travel a long way was a regular attender at meetings of the Council. He represented the interests of members in Scotland in an admirable way. I would also say how very sorry we were to lose Dr Ernest Rutland in January this year.

"Once again the Branches were very active and arranged a number of interesting meetings and also social events, and I should like to say thank you to the Branch Secretaries who carry out such a useful job. Mr Basil Anderson completed his trilogy of talks about his work at the Gem Testing Laboratory and in November Dr Gübelin was good enough to come specially from Switzerland to present the 1974 Awards.

"Entries in the 1974 examinations were again very high and our thanks are due to the Examiners and the staff for the way the work was carried out. The Association's diploma is still held in very high esteem in places overseas.

"The Association lost its Registrar at the end of 1974 with the result that the staff were placed in a very difficult position, especially with the arrangements for the 1975 examinations. I am pleased to say that through a lot of extra work by the staff everything should be satisfactory for the forthcoming examinations. In this respect our thanks are due to the N.A.G. for allowing staff to spend so much time on this vital G.A. work."

The Chairman then proposed the adoption of the Annual Report and Accounts, which was seconded by Mr Robert Webster and duly carried.

Dr G. F. Claringbull was re-elected President, Mr N. A. Harper re-elected Chairman, Mr D. King re-elected Vice-Chairman and Mr F. E. Lawson Clarke re-elected Treasurer. Messrs E. Bruton, D. Kent and M. O'Donoghue were re-elected and Mrs S. Hiscox and Messrs D. Callaghan and P. Daly were elected to serve on the Council.

The Chairman announced that Messrs Hard Dowdy, Watson Collin & Co., chartered accountants, had signified their willingness to continue as Auditors.

Finally the Chairman expressed the Association's thanks to the Goldsmiths' Company: the Wardens make various rooms at the Hall available for meetings whenever it is convenient and the Association is greatly indebted to them.

MEMBERS' MEETINGS

London

A talk was given at Goldsmiths' Hall on the 19th March, 1975, by Mr A. E. Farn, F.G.A., on "Pearls". The substance of his talk will be given in a future issue of the *Journal*.

Midlands Branch

Members of the Branch attended a Mediaeval Banquet on the 26th February, 1975, at Coombe Abbey, Coventry.

On the 11th June, 1975, Mr E. A. Jobbins, B.Sc., F.G.A., gave a lecture on one of his recent trips abroad, illustrated by slides.

Nottingham Branch

On the 12th May, 1975, Mr J. W. Farrell, Keeper of Textiles at the Castle Museum, Nottingham, gave a talk and exhibited the antique jewellery in his keeping at the Museum.

A buffet dance was held on the 2nd June, 1975, at the Bridgford Hotel, Trent Bridge, Nottingham.

Scottish Branch

Mr H. J. Whitehead gave talks in Glasgow and Edinburgh on the 12th and 19th March, 1975, respectively, entitled "The Sri Lankan Gem Scene". The talks were illustrated by colour slides and specimens.

The Annual General Meeting of the Branch was held on the 23rd April, 1975, at the North British Hotel, Glasgow. Mr H. Whitehead and Mr A. Tait were re-elected Chairman and Secretary respectively, and Mrs C. Kilpatrick and Messrs D. Hill, A. McRae, I. McKenzie, A. Armstrong and M. Turner were elected to serve on the Committee.

GIFTS TO THE ASSOCIATION

The Council of the Association is grateful to the following for their gifts:

Mr James G. Gosling, F.G.A., a number of concretionary formation on laterite core-layers of goethite and concretionary limonite known as "Black Pearls of Guyana" found at Aranka River.

Mr F. W. Maiwurm, Newark, Delaware, U.S.A. for a copy of the book "Man-made Crystals" by Joel E. Arem.

TALKS BY FELLOWS

Mr Pete J. Dunn gave a talk to the Baltimore Mineral Society on the subject of "New Gem Acquisitions at the Smithsonian Institution" on the 21st February, 1975.

BOOKS

"Gems" by Robert Webster. Third edition, revised, now available. Price £15.50. Postage extra. U.K. 54p. Overseas charged at cost. Net weight 5 lb.

LABORATORY—GOLDEN JUBILEE

The Gem Testing Laboratory of the Diamond, Pearl and Precious Stone Trade Section of the London Chamber of Commerce celebrated its Golden Jubilee in March. A luncheon was held at Goldsmiths' Hall, London, to mark the occasion when Messrs Basil W. Anderson, Alec E. Farn, Cecil J. Payne and Robert Webster were present. This team of four ran the laboratory for over a quarter of a century.

COURSES FOR F.G.A.s

Two special courses for Fellows of the Gemmological Association are being organized by *Retail Jeweller* in September.

The course lecturers will be Alan Hodgkinson, F.G.A. and Michael O'Donoghue, M.A., F.G.A., and the number of students will be limited so that individual attention can be given to them.

Objects of the courses are to show experienced gemmologists the many new synthetics and some 'new' gemstones they may not have encountered and to give them practice in identification of these materials.

Dates for the two-day courses are Thursday and Friday, 11th and 12th September and 25th and 26th September. The venue is Elm House, Elm Street, off Gray's Inn Road, London WC1X 0BP (training room, seventh floor). Bookings should be made with Miss Ann Williamson at the address above or phone 01-278 2345, ext. 246/203.

COUNCIL MEETING

At the meeting of the Council held on Monday, 28th April, 1975, the following were elected to membership:

FELLOWSHIP

Boruszak, John K., Blackpool. D. 1966

Smalley, David F., Nottingham. D. 1974

Alcock, Ann, Toowoomba, Australia.
Ayres, Thomas D., Farnham.
Baker, Irene M., Brisbane, Australia.
Balakumaran, Sivasubramaniam, Colombo, Sri Lanka.
Barker, Cyril H., Southampton.
Beste, Achim, Hanau/Main, W. Germany.
Boileau, Joyce M., Brisbane, Australia.
Breeze, John A., Francistown, Botswana.
Bressel, Heinz L., Milwaukee, Wis., U.S.A.
Candel, J. L. G., Boskamp, Netherlands.
Chikano, Hirokazu, Kobe, Japan.
Chikano, Takane, Kobe, Japan.
Colcs, Christopher J., Childrey, nr Wantage.
De Jong, Ype P., Krimpen Aan Den Ijssel, Netherlands.
De Silva, Pandigamage D. A., Colombo, Sri Lanka.
Dias, Ahauda A. P. R., Angoda, Sri Lanka.
Gamble, Joan A., Brisbane, Australia.
Gautier, A. E., Newton.
Gerhardt, Willem C., Ede, Netherlands.
Gorinsky, Peter D., Idar Oberstein, W. Germany.
Goto, Tetsuya, Okayama-Ken, Japan.
Gujjar, Arthur, Limerick, Eire.
Hallford, Dianna O., Hong Kong.
Hansen, Lynette C., Johannesburg, S. Africa.
Hargreaves, Raymond J., Brisbane, Australia.
Hegi, Michel A., Geneva, Switzerland.
Henrich, Francis J., Lower Hutt, New Zealand.
Ikonen, Hilkka, Colombo, Sri Lanka.
Inukai, Nobuhiro, Okayama-Ken, Japan.
Jager, Edith E., Schoonhoven, Holland.
Jayawardene, Lt. Jayadeva P. A., Nugegoda, Sri Lanka.
Johnston, Rae, Brisbane, Australia.
Kaasschieter, Huig C., Barneveld, Holland.
Kanamitsu, Takako, Okayama-Ken, Japan.
Keeley, Helen C. M., London.
Kothari, Deepak T., London.
Kropman, Caroline A-M., Schoonhoven, Holland.
Kuff, David J., Washington D.C., U.S.A.
Lake, Thomas R., Cuychoga Falls, Ohio, U.S.A.
Langaard, Conrad, Hanau/Main, W. Germany.
Langton, Adrian, London.
Laurence, Carol M., Lourenço Marques, Moçambique.
Legein, Patrick C. J. M., Rotterdam, Holland.
Legg, Veronica, Hong Kong.
Longbottom, Jane, Colchester.
Los, Rembrandt J., Voorhaven, Netherlands.
Mayer, Marianne, Cully, Vaud, Switzerland.
Mayling, Clifford G., Slough.
Mayur, Dave, London
Middleton, Beryl A. M., Winchester.
Mishima, Yoji, Hiroshima-Ken, Japan.
Papanicolaou, Michael D., Athens, Greece.
Pearce, Mary M., Mousehole.
Rush, Jerome B., London.
Rustage, Donald A., Cuddington.
Sanchez, Sabeena T., Reading.
Scells, Gerald V., Collinsville, Australia.

Silva, Senaka W., Katana, Sri Lanka.
Smith, James D., Riverton, Ill., U.S.A.
Soni, Shashikant V., Wembley.
Summers, Adele E., Orpington.
Tanaka, Shigenori, Okayama-Ken, Japan.
Thomas, Ian, Lawnton, Australia.
Toshima, Tetsuo, Fukuoka City, Japan.
Turner, Christopher F., Hertford.
Van Berkel, Sylvia M., Amersfoort, Holland.
Van Den Hoven, Alexander N., Ede, Holland.
Van Ginneke, Vincentius H. M., Woerden, Holland.
Van Hoogenhuizen, Julia H., Schoonhoven, Holland.
Van Rooyen, Irma E., Schoonhoven, Holland.
Verkerk, Ruud, Stolwyk, Holland.
Vest, Kenneth N., Bangkok, Thailand.
Victorsen, Monica A., Brisbane, Australia.
Walter, Letty, Vlist, Holland.
Walter, P. A., Dordrecht, Holland.
Warburton, Alan J., Leigh-on-Sea.
Watson, John L., Bulawayo, Rhodesia.
Westaway, Joyce, Brisbane, Australia.
Willemsen, Francine, Utrecht, Holland.
Wong, George, San Francisco, Cal., U.S.A.
Yamamoto, Kazui, Fukuoka City, Japan.

1974 Examinations

It is regretted that the name of Mrs F. Brooks, of Hong Kong, was omitted from the list of successful candidates in the 1974 Preliminary Examination.

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THE JOURNAL OF GEMMOLOGY

and

PROCEEDINGS OF THE
GEMMOLOGICAL
ASSOCIATION
OF GREAT BRITAIN

GEMMOLOGICAL ASSOCIATION
OF GREAT BRITAIN
SAINT DUNSTAN'S HOUSE, CAREY LANE
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THE JOURNAL OF GEMMOLOGY
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ON GEM ELBAITE FROM NEWRY, MAINE, U.S.A.

By PETE J. DUNN, M.A., F.G.A.
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IN August of 1972, a very significant find of gem quality elbaite (lithium tourmaline) was made at the Dunton gem mine, Newry, Maine, U.S.A. The narrative of discovery was related by McCrillis (1975) and the description of the elbaite was given by Dunn (1975).

The elbaite occurs in a lenticular pegmatite atop Newry Hill. The pegmatite had long been noted for elbaite and many of the finest examples of New England "watermelon" tourmaline had come from this mine in years gone by, although most of it was not facet-grade. Some gem pockets had been found in recent years, but the yield of gem material was small. This rediscovery at Newry, which has produced a prodigious amount of facet-grade rubellite, is truly one of the most significant tourmaline discoveries of all time.

The elbaite occurs as prismatic, hemimorphic, crystals, from 27 cm in length to very small. The vast bulk of the crystals are broken sections averaging 5 cm in width by 10-15 cm in length. It is apparent from the partially rehealed surfaces of the broken ends that these crystals were broken in past geologic time when mineralizing solutions were still active. The terminations of the crystals are complex and consist of several trigonal pyramids modified by several ditrigonal pyramids.

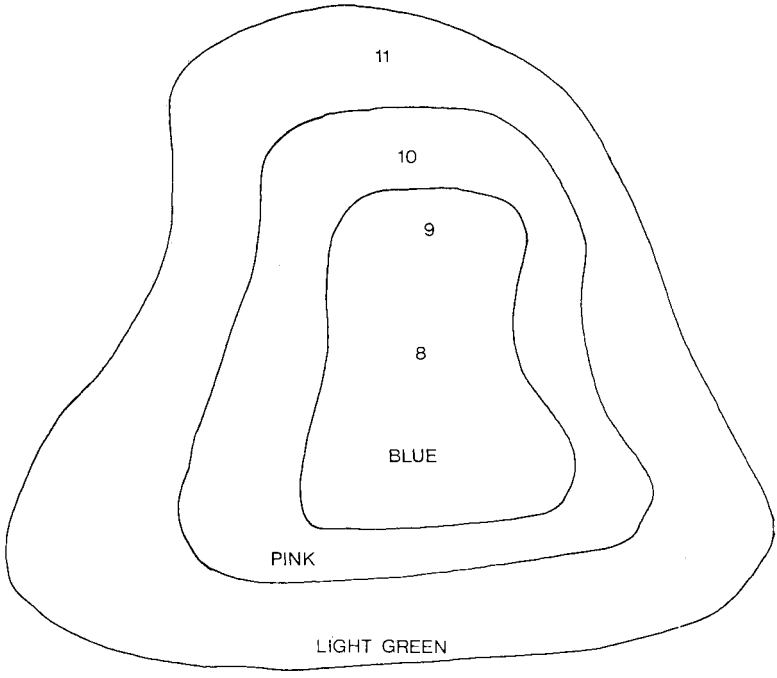

FIGURE 1. Cross-section (40 mm radius) of "watermelon" tourmaline crystal zoned parallel to the prism. Section is parallel to a axes. (NMNH #128157).

Much of the new Newry elbaite is zoned, creating the beautiful "watermelon" effect. This type of zoning, parallel to the prism of the crystals, is the most common type at Newry. (See Figures 1 and 4). Most of the crystals are rubellite which has been grown over by a thin layer of green elbaite, which is badly fractured. This fracturing does not continue into the rubellite core, however, and only serves to give the beautiful red gem material a crackled green coat! The thin outer green rind can be easily removed to reveal the frequently flawless rubellite underneath. Those few crystals which exhibit three colours indicate that a dark blue formed first and was then subsequently covered by rubellite and finally by green elbaite. Most samples, however, show only red and green.

Zoning is also noted which is parallel to the pedion $\{000\bar{1}\}$ and has produced a few "bicolour" gems. This zoning is usually sharp and distinct. Many of the crystals have a red core, which is oddly shaped in that the upper surface of the red core is not perpendicular to the prisms but is canted at a non-constant angle.

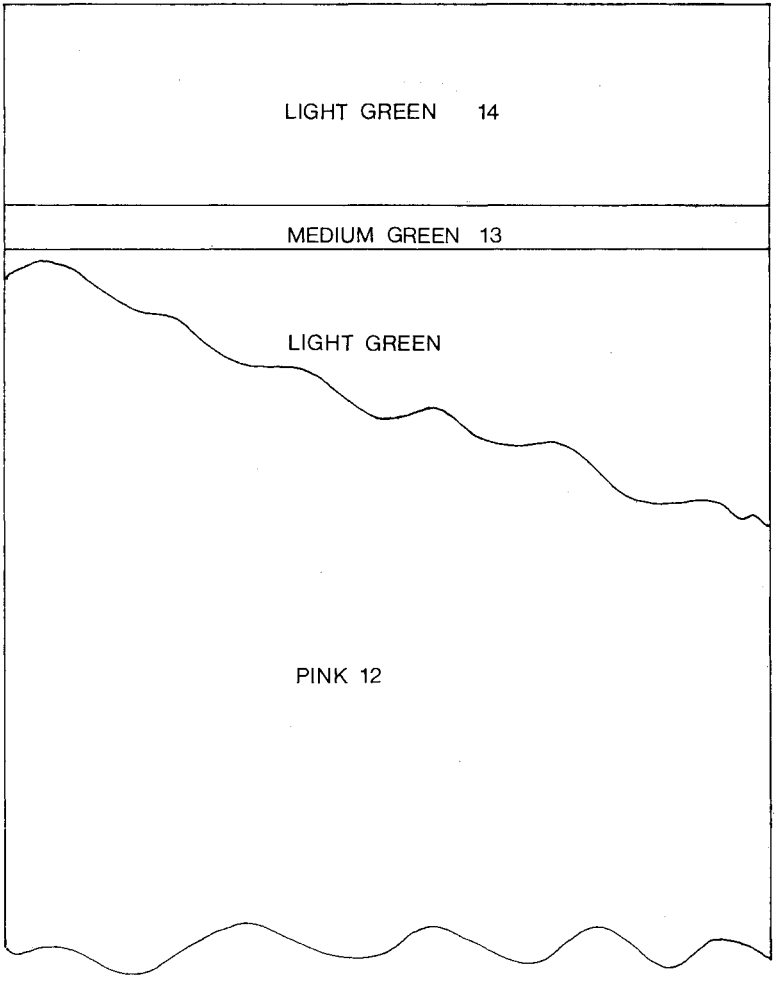

FIGURE 2. Length-section (10 × 18 mm) of a crystal which is zoned parallel to the pedion. Section is parallel to the *c* axis. (NMNH #133814).

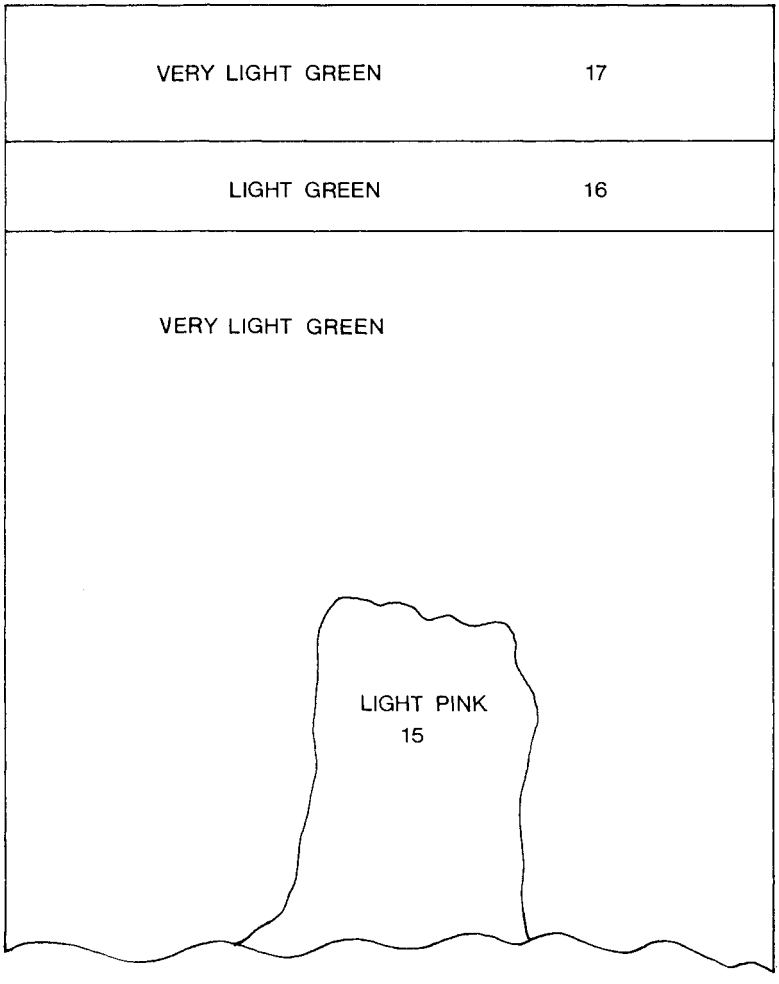

FIGURE 3. Length-section (10 × 8 mm) of a crystal which is zoned parallel to the pedion. Section is parallel to the *c* axis. NMNH #133815).

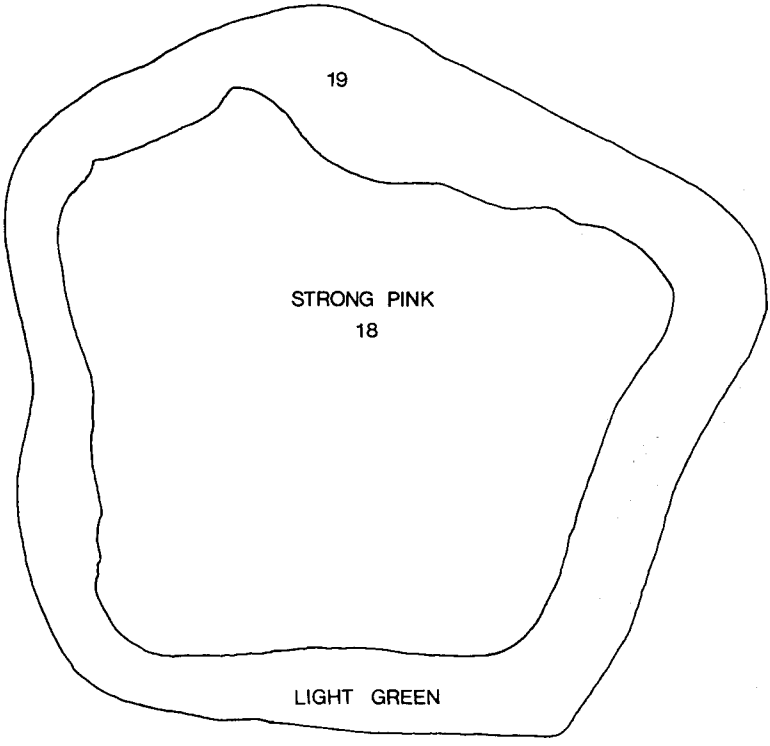

FIGURE 4. Cross-section (7 cm radius) of a "watermelon" tourmaline crystal zoned parallel to the prism. Section is parallel to the a axes. (NMNH #133816).

(See Figures 2 and 3). This is likely due to a peculiar resorption of the original rubellite by subsequent mineralizing solutions or by a sudden explosive event which fractured the still-growing crystals. The obvious zoning of the pedial type is seen only in the green material, and is always parallel to the pedion, regardless of the shape of the "termination" of the previously formed rubellite. (See Figure 2).

Many of these pedially zoned crystals have sharp zones of medium green colour, which have been preceded in growth by light green and followed in the deposition sequence by more light green. Because of the sharpness of this medium green zone and the relative thinness of it, few fine-quality bicolour gems have been cut from this material, and most of the gems are cut as mono-coloured stones. Clean stones of 78 carats have been cut from the finest rubellite.

This discovery of gem material is still continuing after two years of semi-continuous operation of the mine. The elbaite is being mined from collapsed gem pockets and an extraordinary amount of gem-quality material has been recovered.

Through the courtesy of Mr Dean McCrillis, of Plumbago Mining Corporation, Rumford, Maine, the author was permitted to examine several hundred faceted stones. This study was initiated because there are very few such opportunities to examine a large number of cut stones from a single locality, where there is absolutely no doubt that all the stones are from one site.

The Newry gem elbaite comes in a wide variety of colours. The most abundant of these, in decreasing order of relative abundance in faceting quality, are noted in Table 1 with their pleochroic colours.

The most beautiful and stunning colour is the rich burgundy rubellite, which grades through all shades of pink to a very light pink. It occurs in sizeable pieces and fine, large brilliant gems have been cut up to 100 ct. Next in terms of visual appeal (author's opinion) is a medium green, which is a pure green, without the yellow component which so frequently diminishes the beauty of green tourmaline. Much of the green material is this good clean green colour, although some yellowish-green is also found, as well as a very beautiful soft blue-green.

An expected consistency in the refractive indices of the pink and green gems was not observed. There was considerable latitude in the variation of the indices (0·014), and the only observed correlation between refractive indices and colour was that the lightest pink stones had the lowest indices and the deepest burgundy-red stones had the highest. Thanks to the foresight of Mr McCrillis, several boxes of stones were available which had all come from the same pocket. The variation in refractive indices of these stones was the same as that of the entire lot. The high, low, and most common refractive indices for each of the major colour-groups are presented in Table 1.

The density of the Newry elbaite varies from 3·04 to 3·09, the stones with darkest colours having the higher densities.

The absorption spectrum of the dark red elbaite has two distinct lines of 4560 and 4650 Å. These lines are also present, although not easily observed, in the pink elbaite.

The pink and red elbaite does fluoresce a weak violet colour under short-wave ultraviolet radiation, although the green material does not fluoresce at all. This observation was first noted by Mr Beesley, of the GIA in New York. Neither the red nor the green material responds to x-radiation.

TABLE I

OPTICAL DATA FOR NEWRY TOURMALINE

APPARENT COLOUR	PLEOCHROIC COLOURS	
	ε	ω
Deep burgundy red	Light pink	Deep red
Medium pink	Light pink	Medium pink
Light pink	Colourless	Light pink
Light green	Green	Yellow-green
Greenish-blue	Light green	Blue-green

COLOUR	REFRACTIVE INDICES*					
	HIGHEST INDICES		LOWEST INDICES		MOST COMMON INDICES	
	ε	ω	ε	ω	ε	ω
Deep red	1·626	1·644	1·617	1·635	1·620	1·638
Medium pink	1·626	1·643	1·612	1·629	1·620	1·638
Light pink	1·621	1·637	1·617	1·635	1·621	1·636
Light green	1·625	1·642	1·616	1·633	1·620	1·638
Blue-green	1·622	1·640	1·617	1·634	1·620	1·638

*Determined in sodium light (± 0·002) on several hundred gems.

CHEMISTRY

Three samples of Newry elbaite were semi-quantitatively analysed by emission spectroscopy to determine the presence and relative concentration of minor and trace elements. The results of these analyses are presented as Table II. These figures represent a single determination on 2·5 mg of sample. They are valid within a range of 50% of the reported value, i.e., a concentration reported as 0·05 per cent might range between 0·025 and 0·075 per cent.

Semi-quantitative comparison was made using the Spex Industries graphite standards and Spex mix.

TABLE II

SPECTROGRAPHIC ANALYSES

ELBAITE, NEWRY, MAINE

	#128157 (BLUE)	#133812 (GREEN)	#133811 (PINK)
Ag	·0001	·0001	·0001
Al	M	M	M
B	> 1·0	> 1·0	> 1·0
Ba	·0005	·0005	·0003
Be	·03	·003	·003
Ca	·007	·005	·005
Cr	·005	·001	·0001
Cu	·03	·03	·03
Fe	> 1·0	·30	·005
Ga	·03	·01	·007
Hg	·003	·001	·003
K	·03	·01	·01
Li	·50	·65	·50
Mg	·007	·003	·0003
Mn	·50	·07	·05
Mo	·003	·0005	·0007
Na	> 1·0	> 1·0	> 1·0
Ni	·01	·001	·0001
P	·07	·05	·05
Pb	·01	·05	·07
Si	M	M	M
Sn	·03	·007	·03
Sr	·0005	·0003	·0003
Ti	·0005	·0005	·0005

Symbols M —Major element
> —Greater than

Samples of all the principal colour-varieties of Newry elbaite were analysed with an ARL Electron Microprobe, using an operating voltage of 15 kV, a sample current of 0·15 Ma, and NMNH microprobe standards of high reliability. Boron, lithium and oxygen cannot be detected with the microprobe and, therefore, the analyses are partial. All specimens are from the collection of the National Museum of Natural History and the sample numbers refer to catalogue numbers in the mineral collection.

The analyses of the elbaite are given in Table III, and notes about each analysed sample are in Table IV. Where pertinent, analysis numbers have been noted on Figures 1, 2, 3, and 4 to indicate the approximate area analysed.

TABLE III

ANALYSES OF NEWRY ELBAITE

NMNH #	Analysis #	SiO_2	Al_2O_3	FeO	MnO	MgO	CaO	K_2O	Na_2O	TiO_2	Cr_2O_3	F
133809	1	37·37	42·96	0·11	1·30	0·03	0·77	0·00	2·00	0·00	0·00	0·84
133810	2	38·21	44·97	0·00	0·04	0·01	0·14	0·00	2·08	0·00	0·00	0·72
133807	3	38·78	n.d.	0·00	0·14	0·04	0·44	0·02	1·92	0·00	0·00	0·67
133811	4	38·56	45·31	0·00	0·24	0·03	0·48	0·02	1·95	0·00	0·00	0·62
133812	5	37·79	43·14	1·18	0·67	0·06	0·35	0·01	2·13	0·00	0·00	0·73
133808	6	38·26	n.d.	0·86	0·22	0·04	0·22	0·05	2·10	0·01	0·00	0·65
133813	7	37·77	44·23	1·21	0·20	0·06	0·20	0·02	2·20	0·00	0·00	0·75
128157	8	37·00	40·42	4·40	0·90	0·03	0·22	0·03	2·80	0·02	0·01	1·08
128157	9	37·25	40·56	4·10	1·05	0·07	0·22	0·05	2·70	0·01	0·00	0·96
128157	10	37·66	45·03	0·00	0·13	0·05	0·21	0·02	1·93	0·00	0·00	0·63
128157	11	37·43	43·28	0·73	0·16	0·06	0·12	0·01	2·00	0·00	0·00	0·57
133814	12	38·43	44·59	0·00	0·13	0·00	0·31	0·00	1·91	0·00	0·00	0·81
133814	13	37·90	42·20	1·70	0·66	0·04	0·30	0·02	2·14	0·00	0·00	0·89
133814	14	38·17	42·50	0·57	0·45	0·02	0·05	0·01	2·03	0·00	0·00	0·69
133815	15	38·03	43·68	0·00	0·47	0·02	0·18	0·02	2·01	0·00	0·01	0·63
133815	16	39·20	39·82	2·03	0·61	0·06	0·25	0·02	2·23	0·00	0·00	0·83
133815	17	37·70	43·44	0·30	0·37	0·02	0·03	0·00	2·16	0·00	0·00	0·46
133816	18	38·38	43·22	0·31	0·09	0·02	0·17	0·02	1·92	0·00	0·00	0·70
133816	19	38·10	44·02	0·91	0·18	0·04	0·16	0·00	2·17	0·00	0·00	0·75

Accuracy of data—± 2% of the amount present

Of special interest to the gemmologist are the relative concentrations of iron and manganese. Many investigators have searched for the cause of the colour in pink and green elbaite, and have generally concluded that Fe^{+2} is primarily responsible for the cause of the green colour, and Mn^{+2} or Mn^{+3} for the cause of the pink colour. For more information on this topic, the reader is referred to the work of Quensel and Gabrielson (1939) who investigated the elbaites of the Varutrask pegmatite, Carobbi and Pieruccini (1947) who examined the Elba tourmaline, and Bradley and Bradley

TABLE IV

LIST OF ANALYSED SAMPLES OF NEWRY ELBAITE

ANALYSIS #	NMNH #	REMARKS
1	133809	Random core fragment—very light pink
2	133810	Random core fragment—brownish pink
3	133807	Random core fragment—strong pink
4	133811	Random core fragment—strong pink
5	133812	Single crystal—light medium green
6	133808	Single crystal—light medium green
7	133813	Single crystal—yellowish-green
8	128157	Crystal section parallel to *a* (Fig. 1)—blue inner core
9	128157	Crystal section parallel to *a* (Fig. 1)—blue outer core
10	128157	Crystal section parallel to *a* (Fig. 1)—pink middle zone
11	128157	Crystal section parallel to *a* (Fig. 1)—light green outer zone
12	133814	Crystal section parallel to *c* (Fig. 2)—inner pink zone
13	133814	Crystal section parallel to *c* (Fig. 2)—medium green thin zone
14	133814	Crystal section parallel to *c* (Fig. 2)—very light green outermost zone
15	133815	Crystal section parallel to *c* (Fig. 3)—light pink core
16	133815	Crystal section parallel to *c* (Fig. 3)—light green thin zone
17	133815	Crystal section parallel to *c* (Fig. 3)—very light green outer zone
18	133816	Crystal section parallel to *a* (Fig. 4)—strong pink core
19	133816	Crystal section parallel to *a* (Fig. 4)—light green outer zone

(1953) who studied Pala, California, elbaite. More recent investigations have indicated that the colour is very likely due to the oxidation state of part or all of the manganese or iron content (Manning (1969); Darragh *et al.* (1967); Voskrensenskaya *et al.* (1967)).

The microprobe cannot determine the oxidation state of elements. The iron and manganese content of the Newry elbaites has been calculated as divalent oxides, but it may actually be in part or all trivalent.

The Newry elbaite analyses indicate that the dark blue elbaite has the highest iron and manganese content, the green elbaite the next highest, and the pink elbaite the lowest. Analysis #1 is anomalous and will be discussed later. The iron content of the green elbaite is proportional to the intensity of the colour, the darker green gems having a higher iron content than the lighter ones. However, the manganese content of the rubellite samples is not proportional to the intensity of the pink colour. Deer, Howie and Zussman (1962) have noted that pink tourmalines have a very low iron content rather than a significant manganese content. This observation has been substantiated by the present study. Most pink elbaite from Newry has no appreciable iron and a relatively small amount of manganese. It is possible, as noted by Bradley *et al.*, that the pink colour is produced by very small amounts of manganese, but is masked when iron is present.

The relatively high manganese content of analysis #1 is somewhat puzzling at first glance, inasmuch as the material is very light pink. However, Bradley *et al.* (1953) have noted a colourless crystal with 1·38% each of MnO and FeO and suggested that iron content may be adequate to mask the pink colour induced by manganese but insufficient to produce a green colour. It is possible that the crystal in analysis #1 is similarly affected by the iron content, or that the light colour is due to the oxidation of the manganese.

In Table 3, analyses #8-19 are zoned "watermelon" and "bicolour" crystals. Freehand sketches of these zoned crystals are shown in Figures 1, 2, 3, and 4. All four crystals were cut across the direction of colour-zoning, either parallel or perpendicular to *c*. Analyses of the separate zones show that compositional changes, evidenced by colour-change, are abrupt and not gradual. Both light green sections of the crystals shown in Figure 2, although separated by a relatively iron-rich zone, have identical compositions (analysis #14). The outermost green rind of "watermelon" sections is enriched in iron.

Due to the high quality of this elbaite, and the prodigious amounts in which it is being recovered at this date (August 1974), this gem material will undoubtedly be encountered by the practising gemmologist with increasing frequency in coming years.

The author is indebted to Mr Dean McCrillis and Mr John Marshall, of Plumbago Mining Corporation, for their invaluable

assistance during the course of this study, and to George Switzer, Daniel Appleman and John S. White for suggestions for improvement of the manuscript. The spectrographic analysis was obtained from the Conservation Analytical Laboratory of the Smithsonian Institution.

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MAGNESIOAXINITE, A NEW MINERAL FOUND AS A BLUE GEMSTONE FROM TANZANIA*

By E. A. JOBBINS, ANNE E. TRESHAM AND B. R. YOUNG

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A PALE BLUE circular mixed-cut gemstone, weighing 0·1577 grams (0·78 carats), was submitted for detailed examination by Mr R. K. Mitchell, who had received it from Mr C. R. Bridges, a mineral dealer operating in East Africa. The rough

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material had been obtained from a prospector in Tanzania, and there had been no distinct crystal faces or form. The stone did not identify with any of the usual gem minerals and was later shown to be a new member of the axinite group. It was acquired for the Institute collections (registered number MI 34610), and is now on display in the Geological Museum, London.

The cut stone is of brilliant appearance with a vitreous lustre; pale blue in daylight but pale violet under tungsten lighting. The refractive indices, obtained on a Rayner Dialdex refractometer using sodium light, are α 1·656, β 1·660, γ 1·668 (all $\pm$0·001), giving a birefringence of 0·012. In contrast, a specimen of the well-known axinite from Bourg d'Oisans, Dauphiné, France gave values of α 1·672, β 1·679, γ 1·682 (all $\pm$0·001). For a pale coloured stone the pleochroism is notable—from pale blue to pale violet to pale grey. The mineral is optically positive in contrast to most axinites which are biaxial negative; it has not yet been possible to determine 2V or the optical orientation.

The specific gravity of the gemstone is 3·178, whereas that of the Bourg d'Oisans axinite used for analysis and x-ray work is 3·288. The streak (powder) is white and the hardness is greater than 6 but less than 7. Under the binocular microscope very fine cleavage traces were seen in one plane, but no other inclusions were noted.

Under ultra-violet light the stone fluoresces a distinct orange-red by long-wave radiation (3650Å), but appears a duller red by short-wave radiation (2357Å); the Bourg d'Oisans material is inert. The stone appears pink through the Chelsea colour filter. Viewed between crossed filters (of copper sulphate solution and red glass) the stone fluoresces bright red. When viewed through the spectroscope, using the copper sulphate solution as a filter, it shows a faint, broad fluorescent band in the orange-red (5900-6500Å region) but no bright lines. These properties might be taken to indicate the presence of chromium, but possibly only in trace amounts since chromium is known to give similar fluorescent effects in concentrations as low as 100 parts per million. Examination of the absorption spectrum of the stone using white light, did not reveal any chromium lines in the red, but there was a faintly perceptible general absorption of the green, and of the deep violet.

TABLE 1

OBSERVED AND CALCULATED X-RAY POWDER DIFFRACTION DATA FOR MAGNESIOAXINITE (1) AND FERROAXINITE FROM FRANCE (2).

(1)				(2)			
I/I_1	d_{obs}	d_{calc}	hkl	I/I_1	d_{obs}	d_{calc}	hkl
15	8·95Å	8·935Å	010				
25	6·29	6·290	110	20	6·30Å	6·308Å	110
		6·278	$1\bar{1}0$			6·305	$1\bar{1}0$
				1	5·85	5·851	$10\bar{1}$
				1	5·11	5·116	101
4	4·96	4·959	011	2	4·97	4·976	011
8	4·76	4·762	$1\bar{1}1$	4	4·78	4·787	$1\bar{1}1$
2	4·51	4·522	$1\bar{1}\bar{1}$	6	4·54	4·535	$1\bar{1}\bar{1}$
10	3·97	3·981	$20\bar{1}$	4	3·99	3·987	$20\bar{1}$
5	3·66	3·659	$1\bar{2}1$	10	3·68	3·678	$1\bar{2}1$
65	3·440	3·441	002	80	3·451	3·452	002
20	3·269	3·270	$1\bar{2}\bar{1}$	20	3·277	3·281	$1\bar{2}\bar{1}$
65	3·139	3·139	$2\bar{2}0$	85	3·148	3·154	220
						3·153	$2\bar{2}0$
8	3·069	3·064	$0\bar{2}2$	10	3·077	3·077	$0\bar{2}2$
		3·064	102			3·077	102
20VB	2·985	3·001	012	20VB	3·000	3·011	012
		2·978	030			2·992	030
		2·977	$0\bar{3}1$			2.991	$0\bar{3}1$
				12	2·957	2·961	$1\bar{1}\bar{2}$
				4	2·923	2·925	$20\bar{2}$
20	2·877	2·877	$13\bar{1}$	18	2·886	2·887	$13\bar{1}$
				2	2·839	2·834	$1\bar{3}0$
						2·835	$13\bar{0}$
100	2·796	2·797	$31\bar{1}$	100	2·799	2·801	$31\bar{1}$
5B	2·753	2·770	$1\bar{3}1$	2	2·783	2·784	$1\bar{3}1$
		2·742	112	4	2·753	2·752	112
5	2·633	2·636	$2\bar{1}\bar{2}$	6VB	2·647	2·658	$3\bar{1}\bar{1}$
						2·642	$2\bar{1}\bar{2}$
25	2·556	2·559	$2\bar{1}2$	25B	2·562	2·571	$2\bar{1}2$
						2·558	$20\bar{2}$
				2	2·521	2·520	$13\bar{2}$
				1	2·477	2·480	230
						2·479	$2\bar{3}0$
18	2·429	2·429	$31\bar{1}$	20	2·440	2·437	311
18	2·415	2·411	$30\bar{2}$	20	2·416	2·419	131
		2·410	131			2·415	$30\bar{2}$
				1	2·391	2.393	$2\bar{2}2$
						2·387	$13\bar{2}$
8	2·352	2·354	$11\bar{3}$	20	2·361	2·362	$21\bar{2}$
		2·353	212			2·360	$11\bar{3}$
1	2·305	2·309	$23\bar{2}$	1	2·319	2·320	$3\bar{2}\bar{1}$
						2·315	$23\bar{2}$
1	2·252	2·253	$12\bar{3}$	3	2·261	2·261	$2\bar{3}1$
		2·252	$2\bar{3}1$			2·260	$12\bar{3}$
28	2·176	2·176	$14\bar{1}$	28	2.185	2·188	$14\bar{1}$
32	2·150	2.148	103	32	2.154	2·156	103
4	2·121	2·119	$1\bar{1}3$	5	2.125	2·125	$1\bar{1}3$
14	2·048	2·048	$13\bar{3}$	20	2·055	2·055	$13\bar{3}$
14	2·028	2·0285	$13\bar{2}$	14	2·035	2·0356	$13\bar{2}$

The intensities were estimated visually by comparison with an intensity scale. B=broad, VB=very broad.

1. Magnesioaxinite, Tanzania (Registered No. M.I. 34610). CuKα radiation ($\lambda = 1{\cdot}54178$Å) *a* 8·933Å, *b* 9·155Å, *c* 7·121Å, α 102·59°, β 98·28°, γ 88·09° (cell volume 562·4Å^3).

2. Ferroaxinite, Bourg d'Oisans, Dauphiné, France (Registered No. M.I. 34509), CoKα radiation ($\lambda = 1{\cdot}79021$Å). *a* 8·953Å, *b* 9·197Å, *c* 7·143Å, α 102·63°, β 98·10°, γ 88·21° (cell volume 568·2Å^3).

Comparison of x-ray powder data (Table 1), obtained from films taken with an 11·46 cm camera, of the gem mineral and axinite from Bourg d'Oisans shows the gem to be an axinite. The powder data were provisionally indexed by comparison with published data and were refined using the least squares program (BA1·0) developed by Dr R. J. Davis, Department of Mineralogy, British Museum (Natural History), for the refinement of cell dimensions and enumeration of all possible d-spacings. This refinement gave cell dimensions *a* 8·933Å, *b* 9·155Å, *c* 7·121Å, α 102·59°, β 98·28°, γ88·09° (cell volume 562·4Å^3) for the Tanzanian axinite and *a* 8·953Å, *b* 9·197Å, *c* 7·143Å, α 102·63°, β 98·10°, γ 88·21° (cell volume 568·2Å^3) for the axinite from Bourg d'Oisans. The Tanzanian axinite gives slightly smaller d-spacings than the French material and gives an additional spacing at 8·95Å which is also given by the manganese-rich axinite known as tinzenite (Milton *et al.*, 1953).

In view of the unusual colour for an axinite and the low physical constants, it was decided to carry out a chemical analysis by electron microprobe (Geoscan microanalyser) despite its limitations on elements with an atomic number below 11 (sodium), and the consequent omission of boron and water from the results. A small fragment of axinite from Bourg d'Oisans was also analysed for comparison. Analyses were made of the various elements using appropriate silicates, oxides, sulphides and pure metals as standards. The analyses were made at an accelerating potential of 20kV and the results have been corrected for x-ray absorption, atomic number effect and secondary fluorescence using the computer program written by Mason, Frost and Reed.

TABLE 2

SHOWING ANALYSES OF MAGNESIOAXINITE (1) MAGNESIUM RICH AXINITE FROM AUSTRALIA (2) AND FERROAXINITE FROM FRANCE (3)

	(1)	(2)	(3)
SiO_2	44·0	42·39	42·2
TiO_2	0·03	—	0·03
B_2O_3	*	5·52	*
Al_2O_3	17·9	17·10	17·5
Cr_2O_3	nt.fd.	—	nt.fd.
V_2O_3	0·13	—	nt.fd.
Fe_2O_3	nt.fd.	1·68	†
FeO	nt.fd.	5·18	6·1†
MnO	0·4	1·38	3·3
MgO	6·9	4·20	1·6
CaO	21·7	20·31	20·1
ZnO	0·06	—	nt.fd.
NiO	nt.fd.	—	nt.fd.
CoO	nt.fd.	—	nt.fd.
Na_2O	nt.fd.	0·06	0·04
K_2O	0·01	0·03	0·02
$H_2O > 105°$	n.d	1·67	n.d
$H_2O < 105°$	n.d	0·31	n.d
	91·13	99·83	90·89

n.d. = not determined, nt.fd. = not found. *The presence of boron was confirmed by chemical tests. †Assuming that all the iron is in the divalent state.

α	1·656	1·659	1·672
β	1·660	1·665	1·679
γ	1·668	1·668	1·682
δ	0·012	0·009	0·010
D	3·178	3·19	3·288

NUMBERS OF IONS ON THE BASIS OF 28(0) (COLUMNS 1, 2a, AND 3), ON THE BASIS OF 32 (O,OH) (COLUMN 2b).

	(1)		(2a)		(2b)		(3)	
B	—		1·772		1·789		—	
Si	8·012		7·885	8·00	7·961	8.00	8·025	
Al^{iv}	—		0·015		0·039		—	
Al^{vi}	3·842	3·87	3·634	3·87	3·746	3.98	3·923	3·93
Fe^{3+}	—		0·235		0·237		—	
Ti	0·004		—		—		0·004	
V	0·019		—		—		—	
Mg	1·872	6·18	1·165	6·27	1·176	6·33	0·454	6·07
Fe^{2+}	—		0·806		0·814		0·970	
Mn	0·061		0·217		0·220		0·531	
Zn	0·008		—		—		—	
Ca	4·234		4·049		4·088		4·095	
Na	—		0·021		4·021		0·015	
K	0·002		0·007		0·007		0·005	
OH	—		2·072		2·092		—	

The number of ions has been given to three places of decimals to avoid rounding up errors.

1. Magnesioaxinite, Tanzania (Registered No. M.I. 34610). Microprobe anal. A. E. Tresham.
2. Magnesium-rich axinite associated with epidote, tremolite and calcite; London Bridge, near Queanbeyan, New South Wales, Australia. Anal. T. G. Vallance.
3. Ferroaxinite, Bourg d'Oisans, Dauphiné, France (Registered No. M.I. 34509). Microprobe anal. A. E. Tresham.

The results of these analyses and that of the magnesium-rich axinite described by Vallance (1966) are shown in Table 2. Since the microprobe analyses do not show B_2O_3 or H_2O we have calculated the number of ions in the unit cell on the basis of 28 oxygens, but the full analysis of Vallance has been calculated on a 32 oxygen basis (column 2b). We also show the Vallance analysis calculated on a 28 (0) basis (column 2a) for direct comparison with the microprobe analyses.

Analyses for chromium using the microprobe are complicated by the overlap of the chromium $K\alpha$ peak by the vanadium $K\beta$ peak, and it was not possible to make a satisfactory count for chromium. It may be that traces of chromium are the cause of the red fluorescence, but one cannot exclude the possibility that the 0·13% V_2O_3 is responsible. A synthetic corundum simulating alexandrite and coloured by vanadium (probably > 1%V) showed the characteristic sharp line at 4750Å (not seen in the axinite gemstone) through the spectroscope using copper sulphate solution as a filter, but there was no fluoresence in the red part of the spectrum, although the fluorescent effects in UV light and between crossed filters are similar to the gemstone. However, the fluorescent effects of vanadium in axinite do not necessarily follow a precisely similar pattern to that when it is used as a colouring agent in synthetic corundum. The presence of manganese and vanadium interfere with some sensitive microchemical tests for chromium, and we were unable to confirm the presence of the element by this means. Accordingly, we record chromium as 'not found'.

Since boron and water cannot be detected with the microprobe used it was deemed desirable to confirm these constituents of the axinite by other tests. A scraping from the gemstone mixed with potassium bisulphate and fluorite was fused on a platinum

wire and the presence of boron was confirmed by the green coloration imparted to the flame. It was hoped to confirm the presence of water by heating in a dried tube and observing the condensation in the cooler part of the tube, but the results were not sufficiently conclusive and further material could not be spared from the gemstone.

The chemical formula of axinite has been given as 2 [(Ca, Fe^{2+}, Mn, Mg)$_3Al_2BSi_4O_{15}OH$] and there is considerable variation in the proportions of Fe and Mn, and also Ca, in different axinites. Sanero and Gottardi (1968) proposed the names ferroaxinite and manganaxinite for the calcium iron (Ca, Fe) and the calcium manganese (Ca, Mn) end members of the series. Vallance (1966) described an axinite from London Bridge, near Queanbeyan, New South Wales containing 4·2% MgO, 5·18% FeO, 1·68% Fe_2O_3 and 1·38% MnO (the only other axinite previously described with such a high Mg content seems to have been that of Steinwachs (1929), which had 4·13% MgO) and with this significant percentage of magnesium it appears that mutual substitution is possible between Fe, Mn and Mg. The refractive indices of the London Bridge material α 1·659 (1·656), β 1·665 (1·660) and γ 1·668 (1·668) approach those of the present gemstone (shown in brackets) and the specific gravity is also reduced 3·19 (3·178). It would seem that the increase in magnesium, at the expense of Fe and Mn, is responsible for the lowering of the physical constants (including the cell dimensions) compared with the Bourg d'Oisans and most other axinites. However, the physical constants of the present axinite (with 6·9% MgO) are not as low as might have been expected compared with those of the Australian material (4·2% MgO).

The composition of the gemstone now described closely approaches the theoretical calcium magnesium (CaMg) end member, with 6·9% MgO and only 0·4% MnO, and we now propose that the name *magnesioaxinite* should be applied to it. Fromme (1909) proposed the name magnesium-axinite for a theoretical end member of the series, but the mineral had not then been found in nature, nor was artificial material known. The name magnesioaxinite (following the style of Sanero and Gottardi) has been submitted for approval to the Commission on New Minerals and Mineral Names of the International Mineralogical Association.

In the course of preparation of this paper the authors have had much constructive discussion with their colleagues in the Petro-

graphical Department of the Institute, and with friends at the Gem Testing Laboratory of the London Chamber of Commerce, Mr R. K. Mitchell and others—their assistance is gratefully acknowledged. We are especially indebted to Dr R. J. Davis and Mr J. G. Francis of the British Museum (Natural History) for their collaboration in making available the computer program for the refinement of the x-ray data. Prof. R. A. Howie kindly allowed us to see the revised typescript for the axinite section of Deer, Howie and Zussman, *Rock Forming Minerals*, 2nd edition.

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INFRA-RED REFLECTION SPECTRA OF TURQUOISE (NATURAL AND SYNTHETIC) AND ITS SUBSTITUTES

By M. ARNOULD and J.-P. POIROT

Abstract: Studies are reported of the 800-1200 cm^{-1} reflection spectra of natural and synthetic turquoise and some of its substitutes. Resulting curves permit an easy identification of the different stones.

Infra-red reflection spectroscopy is a non-destructive method of investigation, which can be applied to gemstones, even if they are

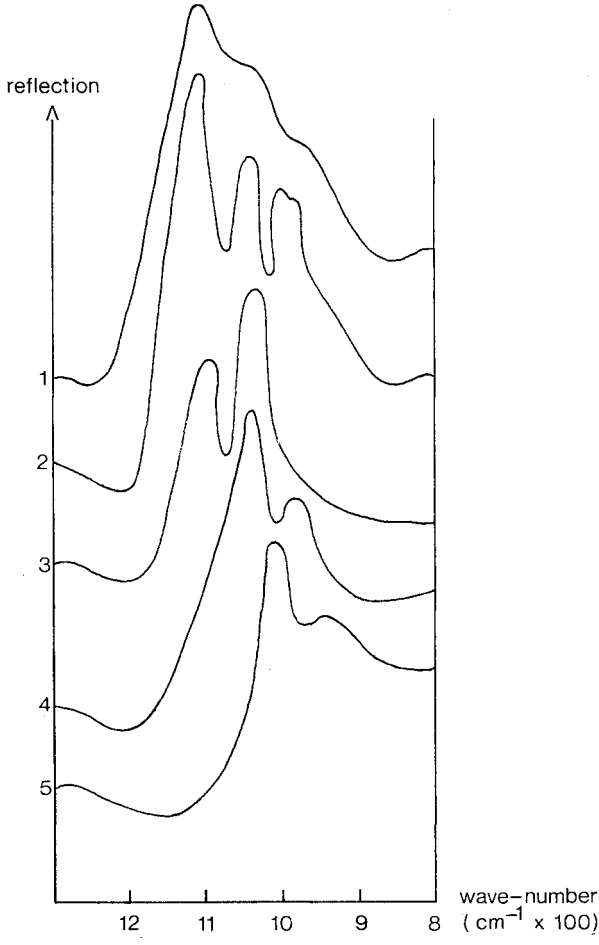

FIGURE 1

Infra-red reflection spectra of turquoise and its substitutes (ordinate origins of the curves are displaced for clarity):

1—Synthetic turquoise
2—Natural turquoise
3—Odontolite
4—Turquoise-imitation "Vienna"
5—Turquoise-imitation "Reese"

in settings, in order to identify them. It seemed interesting to compare some samples by this method:

—natural turquoise, from various localities

—synthetic turquoise, of Gilson manufacture

—several species of stones occasionally used in jewellery as substitutes for turquoise: odontolite, "neolite" and other compressed phosphates.

Turquoise is a complex aluminium-copper-phosphate. Infra-red spectroscopy is used to display the transitions of $(PO_4)^{3-}$ radicals, the energy of which depend on their cationic environment in the crystal structure. One of these transitions is characterized by a strong reflection peak in the 1000 cm^{-1} band (10μm). Therefore we have limited the investigation field to the wave-numbers between 800 and 1200 cm^{-1} (approx. 12 to 8μm).

Figure 1 shows some characteristic spectra; the spectrum of natural turquoise is quite constant, for all the samples studied; it should be observed that this sampling includes some stained and some plastic-impregnated stones. Three sharp peaks are obvious, at 950, 1030 and 1120 cm^{-1}. The same energy values, but with wide peaks, are observed on the spectrum of synthetic turquoise: natural and synthetic stones can be easily differentiated from the aspect of the spectrum curve (see Figure 1).

Several phosphates, natural or man-made, can be employed instead of turquoise. We have recorded in Figure 1 three spectra corresponding to such substitutes: odontolite, turquoise-imitation "Vienna", turquoise-imitation "Reese". The difference between them is large, and infra-red reflection spectroscopy can be considered as bringing an additional technique to the identification of various turquoise-looking stones in jewellery.

A REPORT ON THE GEMETER '75

By ROBERT WEBSTER, F.G.A.

THE report published in the *Journal of Gemmology*[1] of the writer's assessment of the earlier type *Gemeter* has, as shown by the personal communications received, aroused a great deal of interest. Indeed much more information was obtained from the observations of other workers who kindly wrote to me.

Before it was published, a copy of my report was sent to Sarasota Instruments Inc., and a kindly reply was received by the Secretary of the Gemmological Association from Mr Wallace L. Minto, the President of the Company[2]. In this letter Mr Minto agreed that I was substantially correct in my assessment as to how the instrument operated, and he gave the added information that the wavelength of infra-red radiation used was 0·98 microns (9800Å or 980·0 nm). Mr Minto also agreed that several of my comments were valid and said that these were expected to be overcome in later models.

Much information was sent to the writer by Dr E. Gübelin[3], in which he described his own findings on the behaviour of the *Gemeter*, and these tended to confirm my own findings. Dr Gübelin also mentioned that Dr Godehard Lenzen was to speak on the instrument at the German Gemmological Conference at Idar-Oberstein. It is understood that this talk was given, but no written report seems to have been published as yet.

A letter from Herr M. Eickhorst, of Hamburg,[4] added to the knowledge of the working of the *Gemeter* by the information that the "sensor" consists of a combination of a LED (light emitting diode) and a photo-transistor placed adjacent to each other at an angle of 30°. Such a piece of equipment is said to be well known to electricians and is mainly used as a light barrier and for scanning perforated cards. Figure 1 shows a photo-print enclosed in the letter received from Herr Eickhorst, which shows the sensor unit and path of the rays.

The writer is indebted to Mr P. E. Paulin, of Sweden,[5] for the mass of results he has recorded using the *Gemeter*, and, further, his experiments with the power-supply to such an instrument. This worker found that the major fault seemed to lie with the power-supply and removed the battery and connected the instrument to a

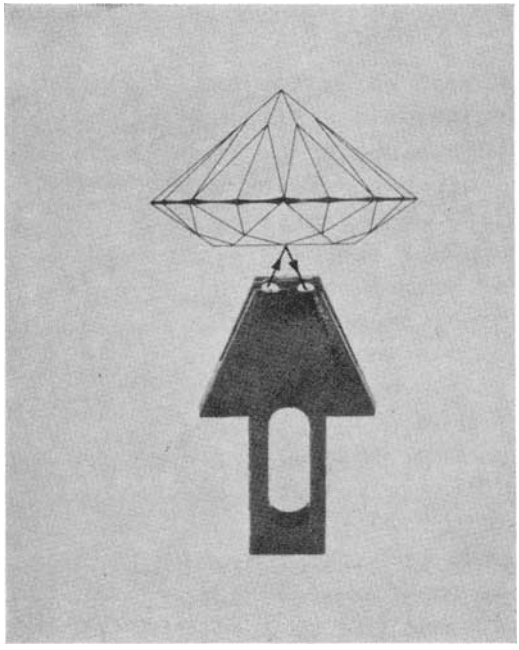

FIG. 1. The sensor as described by Herr Eickhorst.

stabilized direct-current supply at 1·45 volts. This increased the constancy of the readings, and further experiments confirmed that differences in readings occurred when the voltage is altered by only 0·05 volt. This tends to confirm the writer's own findings that constant use drains the battery and thus leads to inaccuracies. Mr Paulin also had the sight of a similar type of instrument produced by another maker. This is the RE-DEX and is powered by a 9 volt cell. From accounts received, this instrument apparently gives more stable readings.

The writer must appear to the reader to have digressed from the original title, but it was felt necessary to give some information on the experiments known to have been carried out by other workers and to correlate their findings so as to complete the picture.

The "*Gemeter* '75" is housed in a fawn-coloured plastic case of a completely new design (Fig. 2). On a horizontal platform is placed the press-button switch, the adjustment screw and the examination disc: the meter is conveniently placed on an inclined

panel behind the horizontal platform and has a clear scale marked from 1·4 to 2·7, with, as in the old instrument, the more important stones marked by letters. The alkaline dry battery fixes in clips in a recess in the base plate, which itself is secured by screws through rubber grummets which provide "feet" for the instrument. The press-button switch is of much better construction and is more positive in action. It does not "slip" like the switch used in the earlier model.

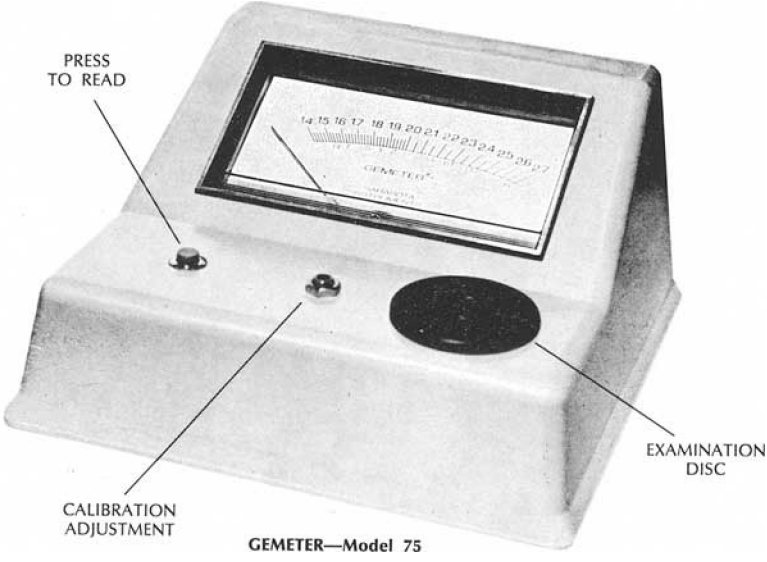

FIG. 2. The Gemeter '75.

The examination disc is similar to the one used in the original model except that it has radial bars at 45° marked on it as well as the concentric circles. The "nipple" is still present and is, if anything, of a smaller diameter than the "nipple" on the original instrument. To set a stone correctly is therefore much less easy, especially if it be a long trap-cut or a pendeloque stone of any size. With a stone set off-centre in a piece of jewellery the balancing feat necessary would call for some ingenuity. Mr Minto's view that the "nipple" allows a stone to be tested where the setting is "proud" of the stone, while a valid answer, seems to the writer to be using a minority case and ignoring the general run of normal tests. Give me a flat working surface every time.

Testing out the new model showed the performance to be superior to that shown by the earlier instrument examined: even so, the repeatability does not appear to be all that could be desired. For the general test the instrument was calibrated on synthetic spinel at 1·73: unknown to each other, Mr Paulin and the writer both used synthetic spinel as a calibration point. With the *Gemeter* so set, the values recorded were, in general, not unduly out. This is especially so with the lower ranges below 1·80. The value of the instrument must undoubtedly lie in the range over 1·80 where the normal optical refractometer does not readily function. In this higher range the instrument was found to be useful but not always reliable, for the readings, often quite good, were at times widely off the mark, even with the same stone. One could reasonably understand low readings and attribute them to bad surface polish, unclean stone or extraneous dirt, but quite often the readings obtained were exceptionally high, a diamond or a stone of lower refractive index indicating in the range of rutile.

The reason for these high readings is puzzling and the writer can offer no solution. Other workers too have found this effect and have so far provided no answer. It is this defect which nullifies the suggestion that even a counter-hand can use the instrument, for, unless he was a competent gemmologist who could spot such errors, misidentification could easily occur and this, in England with its present consumer protection legislation would be dangerous.

With all the experimental work now being carried out on this type of instrument something satisfactory must eventually be evolved, but the Fresnel stipulation that a well-polished surface is essential must prevail. This limits the accuracy of this type of instrument, which can never surpass the performance of the optical refractometer in the range below 1·80. Above this the *Gemeter* does have a distinct value, if handled by a knowledgeable person.

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PEARLS

By ALEC E. FARN, F.G.A.

(being the substance of a talk given to the Gemmological Association of Great Britain at Goldsmiths' Hall, London, on 19th March, 1975.)

IT was a happy coincidence, when I was asked to give a talk to the Gemmological Association in London at the Goldsmiths' Hall, that the subject should be Pearls. This year is the golden jubilee of the laboratory of the London Chamber of Commerce, which was founded solely as a pearl testing station in 1925. Pearl testing to combat the very serious threat of Japanese cultured pearls was undertaken by B. W. Anderson, B.Sc., who was later joined by fellow graduate of King's College, C. J. Payne, B.Sc. Pearl testing by early lucidoscope and eventually the endoscope soon proved a fast and efficient method of testing drilled pearls, and Anderson and Payne became extremely proficient workers.

Unfortunately for many traders the world slump of *circa* 1931 caused a cessation in trading and virtual collapse of the pearl market. Fortunately for gemmologists time was available and opportunity for research presented itself to Anderson and Payne. We are fortunate that we had these two young men of education and intelligence gifted with probing minds. Data for gemmologists flowed from their work and today's gemmologists and instructors alike owe much to the work of these two pearl testers. Had it not been for the cultured pearl threat we would not have had Anderson and Payne. Without these two gemmology would not have achieved its present standard in this country. I confess we owe it all to the Japanese (albeit indirectly)! So then I come to gemmologists of today, who possibly consider gemmology to be about gemstones when in fact it really owes much to pearls. My idea was to talk about x-rays and results seen when jewellery such as pearl-set pieces were under test and the various results and reactions seen. However, it seems appropriate in this our fiftieth year to deal with pearls and x-rays.

The first use of x-rays was to check thin-shelled oysters for possible pearls and avoid opening masses of oysters and leaving the rotting flesh to decompose under a hot sun. Raphael Dubois[1] first mooted this method to detect (not to test) pearls in 1901and it was put into practice in 1906: it was not very successful since labour was cheap and plentiful. Dauvillier in 1924 found upon

investigation that nacre (mother-of-pearl) gave a six-spot hexagonal or ring-structure when penetrated by x-rays normal to the mother-of-pearl layer and a four-spot pattern at right angles to it: he published his paper in 1926.[2]

Shaxby (1924)[3] followed Dauvillier and proved that the thin-layered structures of nacre in the concentric structure of pearl were platelets of aragonite whose *C* axis was normal to the plane of the layers. These calculations were agreed by Prof. W. L. Bragg (later to become President of the Gemmological Association).

Galibourg and Ryziger (1926–1927)[4] followed and put to use the lauegram method of testing. It follows that if a beam of x-rays is passed through a real pearl a six-spot pattern will result and that if the pearl is turned through 90° a second six-spot pattern will be obtained—proving emphatically a natural pearl. A mother-of-pearl nucleus in a cultured pearl will give a six-spot pattern through the pearl skin and layers of mother of pearl and a four-spot pattern at 90° when the beam of x-rays travels along the layers of mother-of-pearl. If a first x-ray diffraction picture shows a four-spot pattern no further testing is necessary. The pearl is cultured.

The knowledge of the concentric and radial structure of natural pearls is utilized in the endoscope method of testing. In this method a beam of concentrated light (usually from a carbon arc source) is focused through a hollow platinum needle which has one end of the tube polished at 45° as a miniature mirror and a short distance away a second mirror is placed inversely at 45°. The pearl is threaded upon the needle to a position such that its centre is poised mid-way between the two mirrors. Light from the carbon arc source impinges upon the second mirror, shoots up into the pearl, travels round concentrically until (through an aperture) it meets the end mirror and is emitted through an eyepiece (which is the end-scope!) Cultured pearls so tested allow the light to travel along a mother-of-pearl layer and escape through to the exterior surface of the cultured pearl.

This knowledge, gained by testing tens of thousands of pearls and consequent examination of their interiors via drill holes, enabled a speeding up of the use of x-rays in radiographs of pearl necklaces. Dog-leg drill holes, thin skins and conchiolin gaps were very easily recognized signs of a cultured pearl. With natural pearls a radiograph serves to indicate very accurately the nature of the pearls and subsequent optical examination lends speed to expertise. No

anomalies are allowed—any doubtful cases are again x-rayed and fluoresced. We think we have the best of both methods, both endoscope and radiographs. The mother-of-pearl used for bead nuclei comes from the Mississipi River mussel: it contains traces of manganese, which fluoresces under x-ray excitation. It is a cold candle-wax colour when viewed down the drill hole, whereas most natural pearls have a warm light-yellow to honey colour and a ringed structure when so viewed. Cultured pearls generally have larger drill holes than natural pearls: this is because natural pearls are sold by weight and cultured pearls by size (small holes conserve weight).

Following mother-of-pearl-nucleated cultured pearls from sea-water oysters, the Japanese now grow cultured pearls without a nucleus in fresh water mussels. In Lake Biwa, the largest freshwater inland lake in Japan, they dredge the mussel *hyriopsis-schlegeli* which grows to 9 inches in length and lives for 13 years. The mussel has no room internally to accept a bead nucleus. It is opened up and 10 slits are cut into each side of its body and pieces of tissue are inserted into each incision. The mussel is then lowered in a cage from rafts as in normal cultivation routine. In three years the mussels produced 60% successfully, i.e. 20 baroque pearls to each mussel, very regularly irregular, having a soft white waxy brilliance akin to river pearls. The mussels are not discarded but are returned to the lake and produce a second crop without further insertion of tissue nuclei. The pearls of this second crop are rounded and buttony in shape—a step further than the first baroques. Sometimes a third crop is formed which is flatter in shape. Radiographs of first-crop non-nucleated cultured pearls show a distinctive pattern of slight wispy nature likened by a former and young colleague to potato crisps, which when viewed from a side elevation do have this vague thin structure. When a whole necklace of pearls shows such a structure—nebulous it may be—it is further proved by the very typical strong white/greenish fluorescence and distinct phosphorescence seen under x-ray excitation. The last figures of production I received of non-nucleated cultured pearls was approximately 2 million momme annually: one momme = 3·75 grammes. 70% of the production was sold to Beirut.

In Australian waters much larger sea-water oysters are found: this is *pinctada maxima*, which can produce (and does) pearls naturally. Japanese workers and methods are used to insert much larger

spherical mother of pearl nuclei for cultivation. After three months the seeded oysters are checked and it is found that 50% of the oysters have failed to accept the nucleus and in fact the mother of pearl lustrous lining of the very large oyster has become erupted and made useless for its normal commercial use. Since the seeding and consequent spoiling of large oysters is expensive, a method is used to recoup at least the cost of the spoiled oysters. A half-sphere shape or slightly less (usually steatite) is inserted and this it seems is "acceptable". The oyster isolates the hemisphere by attaching it to the inner wall of its shell and coating it with nacre. This cultured pearl blister is subsequently sawn off as a disc from the shell proper and sent to Japan to be worked. The nucleus is removed, the pearl is bleached and cleaned, the hollow interior filled with resin and a mother of pearl cap or disc seals the base of the now termed "mabe cultured blister pearl".

In the Japanese language "mabe" is synonymous with half-pearl. Half a million "mabe pearls" are produced annually and are sold principally to Spain, Mexico and Hong Kong. Now the Japanese or their colleagues are cultivating the large *pinctada maxima* with tissue inserts as in non-nucleated cultured Biwa fresh-water mussels. These produce large baroque natural-looking cultured pearls. Since sea-water oyster products such as these do not fluoresce under x-ray excitation radiography is an absolute essential.

I am grateful to my friend and colleague, Robert Webster, for use of some of his work and references in "X-ray Focus", an Ilford production, Vol. 7, No. 1, 1966.

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RED DRAVITE FROM KENYA

By PETE J. DUNN, M.A., F.G.A., JOEL E. AREM, Ph.D. and JOHN SAUL, Ph.D.

OCCASIONALLY it will happen that gemmologists in diverse parts of the world will be investigating the same problem, each unaware of the other's efforts. Such was the case in the matter of a red tourmaline recently described by H. Bank (1974). A parallel effort was under way at the Smithsonian Institution, and the following short paper is offered as it contributes further knowledge to the understanding of this uncommon material.

A dark red tourmaline was discovered several years ago by one of the authors (J.S.) at Osarara, Narok District, Kenya. The deposit is located at 1° 34′ S, 35° 46′ E, in the heart of Masailand. Saul's field notes follow:

> "In a high sloping meadow I found small outcrops of massive-bedded iron-stained quartzites of the Basement System (part of the Mozambique Belt of Eastern Africa) which in places contained dark tourmaline. In a position that appeared to be stratigraphically between two such outcroppings was found red tourmaline float. Digging at this point through the black soil which covered much of the hillside exposed a friable, weathered quartz muscovite schist (also of the Basement System) with tourmalines which were distinctly smaller, redder, gemmier, and more numerous than the tourmalines seen in either quartzite. Despite appearances, it would be imprudent to make any assertions concerning the stratigraphic relationships, since several pieces of quartzite float found on the hillside exhibited slickensides."

This tourmaline (NMNH # 126030) occurs as euhedral, equant, hemimorphic crystals from 3 to 25 mm in size. The crystals are lustrous and partially transparent. The forms present, in order of decreasing dominance, are the trigonal prism $\{1120\}$, modified by the hexagonal prism $\{1010\}$, and another trigonal prism $\{0110\}$. The crystals are terminated by the pedion $\{0001\}$, and the trigonal pyramids $\{h0\bar{h}\bar{1}\}$, $\{0h\bar{h}\bar{1}\}$, and $\{h0\bar{h}1\}$.

A partial analysis of this tourmaline indicates that it is a dravite with a high iron content. This analysis is presented as Table 1. The oxidation state of the iron was not determined. The ratio of Mg : Fe is 4 : 1. The material is probably a ferrous

dravite as the aluminium content is too high to allow any extensive substitution of Fe^{+3} for Al^{+3}, such as was noted by Frondel *et al.* (1966). This dravite has some gem potential, and it is dark red, of a hue similar to good quality almandine. The specific gravity, determined by use of a Berman balance and employing a temperature correction factor, varies from 3·07 to 3·08.

The refractive indices, determined in sodium light on a Rayner Dialdex refractometer, vary from $\varepsilon = 1{\cdot}623$, $\omega = 1{\cdot}654$ to $\varepsilon = 1{\cdot}626$, $\omega = 1{\cdot}657$. Attempts to lighten the colour of the material by irradiation with CuKα x-radiation and ultraviolet radiation were unsuccessful. Heat treatments of eight hours duration at 200°, 400°, and 600° C also were non-productive in terms of lightening the colour of the material.

The authors are indebted to Mr Richard Johnson for the preparation of polished samples, and to Gail L. Dunn for assistance in the heat-treatment of this material.

TABLE 1

PARTIAL ANALYSIS OF KENYAN DRAVITE

K_2O	0·06%
Na_2O	2·7 %
CaO	0·06%
MgO	9·4 %
MnO	0·03%
FeO	4·4 %
TiO_2	0·3 %
SiO_2	37·9 %
Al_2O_3	31·1 %

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Frondel, C., Bield, A., Ito, J. (1966). *New Type of Ferric Iron Tourmaline.* Am. Miner. **51**, 1501-1505.

Gemmological Abstracts

ADDAMIANO (ARRIGO). *Silicon carbide—artificial and natural.* Lapidary Journal, 1975, 29, 3, 674-678.

An informative account with a useful bibliography. M.O'D.

AKIZUKI (MIZUHIKO). *Opal, history and science, Part 2.* Journal of the Gemmological Society of Japan, 1975, 2, 1, 11-24.

Three types of lamellae of silica spheres have been identified with the electron microscope; those with no voids, those with a unit layer without voids and with three voids encircling spheres of silica and those with a unit layer and six or three voids. Illustrations of opal from the various fields are included. There is a discussion of the formation of opal in igneous and sedimentary environments.

M.O'D.

AMTHAUER (G.). *Zur Kristallchemie und Farbe grüner und brauner Grossulare aus Tansania.* (Crystal chemistry and colour of green and brown grossularites from Tanzania). Z. Dt. Gemmol. Ges., 1975, 24, 2, 61-72.

Detailed article with 3 tables, 4 graphs and bibliography of 25 items. Green and brown garnets from Tanzania are nearly pure grossularites with small contents of transition elements. The colour of the green grossularites is mainly due to absorption bands of Cr^{3+} and V^{3+} in octahedral position, the colour of the brown grossularites to absorption bands of Fe^{3+} in octahedral and Mn^{2+} in the garnet structure. E.S.

BANK (H.). Z. Dt. Gemmol. Ges., 1975, 24, 2, 88-93.

Three short articles by Dr Bank:

(1) Transparent colourless to yellow cuttable augelite from the White Mountains in California. Description of the first specimen of augelite from California seen by the author. The double refraction was measured and found to be 0·020 which is higher than previously mentioned as 0·014.

(2) Transparent green gahnite from Brazil. The author described the rare example of gahnite or zinc spinel from Brazil.

(3) A short discussion on the value for determination of specimen by publishing exact data of up-to-then unknown values for R.I. and double refraction, density, lattice constants, spectra. The value of publishing details of trace elements and descriptions of inclusions is mentioned. E.S.

BEESLEY (C. R.). *Dunton mine tourmaline: an analysis.* Gems & Gemology, 1975, XV, 1, 19-24. 4 illus; 2 Tables.

A survey of the tourmalines found at the newly re-opened Dunton mine at Newry, Maine. This mine has intermittently produced small amounts of tourmaline since the turn of the century, but it was not until 1972 that a group of amateurs stumbled on a rich find of tourmaline in this mine. This find has been

exploited and the mine re-opened. Two of the features of the tourmalines found at this mine are said to be the exceptional brilliance of the stones, said to be due to a trace of caesium, and the wide range of colours produced: these vary from pink to red and light yellowish green to dark blue, and there is a "water-melon" type. The constants of these Dunton mine tourmalines are recorded, together with the fact that they tend to fluoresce under short-wave ultra-violet light, and something is told of the inclusions seen in these stones. R.W.

BERAN (K.). *Das Absorptionspektrum des Benitoits im nahen Ultrarot.* (The infra-red absorption spectrum of benitoite). Tschermaks Min. Petr. Mitteilungen, 1974, 21, 47-51.

In colourless benitoite crystals a broad pleochroic band is found at 3030 cm^{-1}. It disappears on heating the crystal to 400°C and is thought to indicate the presence of H_2O molecules. M.O'D.

BUURMAN (P.). *Wood opals from Yakuplu, Turkey: their properties and genesis.* Scripta Geologica, 1975, 30, 1-19. 15 figs. Price Dfl 6·50.

Lignitic to opaline fossil driftwood occurs in Late Miocene gravel near Yakuplu, west of Istanbul. Opalization took place at various stages of decay; the stage of decay and admixture of detrital clay influenced the crystallinity and dehydration characteristics of the opals. X-ray diffraction, DTA, TG, and XRF investigations are reported. Opalization was probably the result of the weathering of volcanic ash in the overlying strata. The geological setting is comparable to that of some Hungarian wood opals. R.A.H.

CARREL (R.-P.). *Les pierres precieuses du Pakistan.* (The precious stones of Pakistan). Bulletin de l'Association Française de Gemmologie, 1974, 41, 7.

Aquamarine, garnet and tourmaline are mentioned and a further note promised on emerald. M.O'D.

COHEN (A. J.) and HASSAN (F.). *Ferrous and ferric iron in synthetic α-quartz and natural amethyst.* American Mineralogist, 1974, 59, 719-728.

Positive rhombohedral growth regions of synthetic α-quartz containing Fe^{3+} is related to the generation of the amethyst colour on treatment with ionizing radiation. It is thought that interstitial Fe^{3+} ions in voids perpendicular to positive rhombohedral faces give charge compensation for substitutional Fe^{3+} ions. M.O'D.

CROWNINGSHIELD (R.). *Developments and highlights at GIA's lab in New York.* Gems & Gemology, 1974/75, XIV, 12, 362-366; 1975, XV, 1, 12-18. 29 illus.

A new imitation opal is discussed. These objects have a density which varies from 2·41 to 2·50 and have a refractive index of 1·50 to 1·52 and the hardness is about 5 on Mohs's scale. Some comparison is made of these fake opals with the Gilson synthetic opals. An opal doublet consisting of a white opal top cemented to an ironstone base by a thick layer of epoxy resin and ground-up particles of ironstone, and a similar composite stone with a top of carved white opal and mounted in a brooch are also mentioned. A carved nephrite horse weighing

180 lb, a hololith bangle in calcite which had areas selectively dyed green, a brooch with three crackled synthetic rubies and a dark blue lazulite of 0·48 carat, which was negative biaxial with refractive indices of 1·616-1·646 showing an absorption spectrum resembling that of turquoise, are some of the items seen in the New York laboratory. A hololith ring with white and yellow metal insets was found to be made of what was probably water-buffalo horn. Serious damage to a tanzanite by overheating during repair and damage to peridots probably by an acid cleaning bath are reported. The articles conclude with mention of a true canary coloured diamond and that flux grown synthetic rubies are now more frequently seen.

R.W.

DRYSDALE (D. J.). *Hydrothermal synthesis of various spodumenes.* American Mineralogist, 1975, 60, 105-110.

Elements substituting for aluminium include iron, chromium, vanadium, indium and scandium. Cell dimensions are given. α-spodumene has not yet been successfully synthesized. M.O'D.

GÜBELIN (E.) and Weibel (M.). *Vanadium-Grossular von Lualenyi bei Voi, Kenya.* (Vanadium–grossular from Lualenyi, near Voi, Kenya). Neues Jahrb. Min., Abhdl., 1975, 123, 194-197, 1 fig., 1 coloured map. (Also a more extensive version in English under the title *Green vanadium grossular garnet from Lualenyi, near Voi, Kenya.* Lapidary Journal, 1975, 29, 2, 402-426.)

A dark green vanadian grossular of gem quality is discovered in a clinopyroxene rock in Lualenyi, Mgama Hills, Taita District, Kenya, with nearly 10% graphite and nearly 30% of different alteration products of unknown origin. The green grossular forms porphyroblasts or sometimes idiomorphic crystals; it is always surrounded by a kelyphitic alteration shell consisting of fine-grained epidote and scapolite. For Na-light, *n* 1·739-1·744, increasing with increasing V content; the typically green variety has $1{\cdot}743 \pm 0{\cdot}001$; sp. gr. 3·57-3·65, mean 3·61; *a* 11·863 Å. Composition CaO 35·1, $Na_2O + MgO + MnO + FeO$ 1·4, Al_2O_3 20·9, V_2O_3 3·3, Cr_2O_3 0·19, TiO_2 0·25, SiO_2 38·7, = 99·84. I.Kb.

HUBER (M. V.). *Pink copper-bearing prehnite from Isle Royale National Park, Michigan.* Lapidary Journal, 1975, 29, 3, 666-673.

Prehnite occurs as amygdales in Keweenawan lava floors and has frequently been mistaken for thomsonite. The pink colour arises from reflections from disseminated inclusions of native copper. M.O'D.

LAGERWEY (A. A. F.). *Detection of structural varieties of red gem spinels from Ratnapura, Sabaragamuwa province of Sri Lanka.* Scripta geologica, 1974, 27, 1-27, 1 pl. (in pocket). Price Dfl 10·50.

A new instrumental method for the spectrographic detection of particularities of crystal fields around optically active ions, e.g. Cr^{3+}, was applied to a study of red spinels from the Ratnapura gem gravels and other sources. The method analyses the luminescence spectra in the red and near-IR ranges excited by concentrated flux of blue radiation. The spectrograms reveal multiplet structures and the intensity distributions of component lines. Systematic study of these red spinels revealed one grain (0·45 carats) of an unknown variety here termed a spineloid: this is "mallow purple" with sp. gr. 3·61, *a* 8·082 Å; it shows cracks on

{111} and is practically isotropic. Although the spineloid shows the same wavelenght pattern in the 6500-7600 Å range, it gives a completely different intensity distribution of the spectral lines, and in particular a very intense broad luminescent band at 6876 Å. From various models, it is concluded that the spineloid is a near-stoichiometric spinel ($MgO.Al_2O_3$) in which Cr^{3+} ions appear in pairs in regular polyhedral configuration; the spectrum is modified by the presence of Mn ions of different valencies. R.A.H.

LEHMANN (G.). *On the color centers of iron in amethyst and synthetic quartz: a discussion.* American Mineralogist, 1975, 60, 335-337.

The band at 5·6eV (46000cm^{-1}) is concluded to arise from Fe^{3+} on lattice sites in quartz. The absorption spectrum of Fe^{2+} in green synthetic quartz proved that the iron occupies interstitial sites of distorted octahedral symmetry. A band at 6·2eV (51000cm^{-1}) is found in iron-doped synthetic quartz with a shoulder near 41000cm^{-1} and these are consistent with Fe^{3+} in interstitial sites of distorted tetrahedral symmetry. The visible coloration of amethyst is dominated by Fe^{4+}. The biaxial nature seen in amethyst is thought to be due to unequal substitution of the three lattice sites by Fe^{3+} M.O'D.

LIDDICOAT (R. T.). *Developments and Highlights at GIA's Lab in Los Angeles.* Gems & Gemology, 1974/75, XIV, 12, 367-371; 1975, XV, 1, 26-30. 19 illus.

Report of a new synthetic alexandrite grown by the Czochralski "pulling" technique. The colour of the stones is more reminiscent of the well-known synthetic "alexandrite colour" sapphire than of natural alexandrite. These stones have a refractive index of 1·740-1·749 ± 0·005. The fluorescence was strong red under long- and short-wave ultra-violet light and under x-rays. Transparency tests to both long- and short-wave ultra-violet light gave interesting results. These experiments showed that the "pulled" alexandrite was much more transparent to both long- and short-wave ultra-violet rays than the natural or the flux-grown alexandrites. A blue coral which was found to be calcareous and not, as is the black coral, composed of conchiolin is described and a black coral which showed a sub-surface sheen is mentioned. The strange case of a supposedly Australian white opal which after twelve months became non-transparent in the centre, and which was to some extent corrected when immersed in hot water was finally considered to be a porous type of Mexican opal. Mention is made of the rare case of a natural blue sapphire so devoid of iron that it fluoresced blue under short-wave ultra-violet light as does the synthetic sapphire. Other interesting items seen in this laboratory were a cabochon of rock material consisting of grains of red ruby and green tourmaline; a glass of "metajade" type which showed a jadeite spectrum; a nephrite bangle which fluoresced orange under ultra-violet light and two carved rubies in zoisite matrix. Helical inclusions in an emerald and a variscite with the high refractive index of 1·60 are mentioned. A Montana blue sapphire mounted in a ring produced an unexplained problem, for over twelve months wear the stone gradually lost its polish. R.W.

MARSHALL (M.) and RUNCIMAN (W. A.). *The absorption spectrum of rhodonite.* American Mineralogist, 1975, 60, 88-97.

The specimen tested was rich in calcium and iron. A table of the bands per-

taining to both high- and low-iron rhodonite is given; most non-vibrational bands can be assigned to Fe or Mn. M.O'D.

NAESER (C. W.) and SAUL (J. M.). *Fission track dating of tanzanite.* American Mineralogist, 1974, 59, 613-614.

The average fission track age established from 7 crystals from the Ally and d'Souza mines, Tanzania, was 585 ± 28 million years. M.O'D.

NASSAU (K.). *The origins of color in gems and minerals.* Gems & Gemology. 1974/5, XIV, 12, 354-361; 1975, XV, 1, 2-11. 7 illus. 5 Tables.

These are the first two instalments of a three-part article on the causes of colour in gemstones. In the introduction the general mineralogical aspect of colour in gemstones is briefly discussed, i.e. idiochromatism, allochromatism and pseudochromatism, the latter originating from physical causes such as the diffraction grating effect in opal. Although twelve different types of colour-causing mechanisms are to be described, only four distinct theories cover the whole range of colours in gemstones. These are the "crystal field theory", "molecular orbital theory", "band theory" and "physical optics theory". A short explanation is given of each of these. A section on "light, energy, and quantum considerations" deals with colour as a wavelength of light, and energy as electron volts. The colour and fluorescence of ruby and emerald are explained by reference to paired and unpaired electrons and energy levels. Pleochroism is discussed as well as the twelve specific causes of colour. In part two there is a discussion of idiochromatic and allochromatic colorations which are caused by transition metals. Colour centres are described as a defect in a crystal in which an electron can be "trapped", or a "hole" which is explained as the absence of one electron from a pair leaving behind an unpaired electron which then may cause colour. These colorations by colour centres are discussed and the instability of the colour in the case of irradiated stones is mentioned. This second part concludes with a discussion of molecular orbital causes of colour and some information is given on the treatments, such as heat and radiation, used to alter the colour of gemstones. Part three of this series, which must not be missed, is to follow in the next issue of this American journal. R.W.

PETROV (I.) and BERDESINSKI (W.). *Thermolumineszenz als Untersuchungsmethode der Farbursachen von Topasen.* (The use of thermoluminescence in examining the causes of colour in topazes.) Z. Dt. Gemmol. Ges., 1975, 24, 2, 73-80.

Various tables; bibliography of 18 items. The article describes the thermoluminescence method as a possibility in examining the causes of colour in minerals, especially in topazes. Besides an introduction to the theory of luminescence, there is a discussion over possible colour-centres and chromophores found in topazes. The results of these thermoluminescent measurements in colourless, pink and blue topazes are discussed. E.S.

PIAT (D.). *Le rubis himalayen d'Hunza.* (Himalayan ruby from Hunza.) Bulletin de l'Association Française de Gemmologie, 1974, 41, 5.

Hunza Province is in the north of Pakistan; rubies are found in calcite. M.O'D.

RAO (K. M.). *The first Indian cultured pearl.* Gem World, 1975, 2, 5, 31-34. 2 illus.

This article appears to be based on a group discussion at the Central Marine Fisheries Research Institute (India) at which Dr K. Alagarswami gave a description of the first experiments to produce cultured pearls in Indian waters. It was suggested that both the Gujarat coast which lies just south of Pakistan and the coast of Tamil Nadu in the Gulf of Manaar would be suitable sites for pearl cultivation. Neither the name Tamil Nadu nor Veppalodai, which is named as the location for the Pearl Culture Laboratory of the Central Marine Fisheries Research Institute, could be found on the map in the abstracter's possession (Times Atlas 1968) and it can only be assumed to be the coastline around Tuticorin. It is said that the oysters are grown for about six months in the sea and then brought to the laboratory for conditioning after which they are anaesthetized using chemicals. Nucleus insertion operations are then performed using dice of mantle and bead nuclei of either imported or indigenously produced shell beads of 3 to 6mm diameter. Both the bead nucleus and the graft tissue are manipulated to obtain the correct orientation. They are then returned to the sea water to allow recovery from the operation and then kept in a running water system in the laboratory for a week. They are then returned to the rafts on the oyster farm. The first experiments were carried out during May to August 1973 and the first cultured pearl was produced on the 25th of July 1973, just 43 days after the date of the operation. Much is made of this quick growth and it is compared with the three years necessary with Japanese culture. It would have been expected that with this quick growth commercialization would have gone ahead, but there seems to be no report of these objects coming on the market. Indeed Dr Alagarswami's talk was not made until early this year, so that there may well have been "snags" which have delayed things. It will be interesting to see what comes out of this endeavour. R.W.

SANTOS MUNSURI (A.). *Koh-i-Noor.* Boletin del Instituto Gemológico Español, 1975, 11, 27-33.

A historical account of the celebrated diamond forming part of the British Crown jewels. M.O'D.

SANTOS MUNSURI (A.). *Tabaqueras de rapé chinas.* (Chinese snuff-bottles). Boletin del Instituto Gemológico Español, 1975, 11, 19-26.

An account, illustrated in colour, of the snuff-bottles used in pre-1912 China, often including gemstones as ornamentation or as the stopper. M.O'D.

SCHMETZER (K.), BERDESINSKI (W.) and BANK (H.). *Farbveränderungen von Edelsteinen der Beryllgruppe.* (Colour-changes of various gems in the beryl group). Z. Dt. Gemmol. Ges. 1975, 24, 2, 81-87.

Apart from three graphs and a bibliography of 6 items, the article contains a table showing the colour-changes in variously coloured beryls with and without iron, with chromium, with vanadium, with iron and chromium, with manganese and various other types of beryls. These stones are listed and their colour-changes described after first irradiation with x-rays, γ-rays and electrons and then heat treatment, and also after heat treatment and with following irradiation. E.S.

SHAUB (BENJAMIN M.). *Dunton gem mine and its remarkable tourmalines.* Mineral Digest, 1975, 6, 20-28.

An account with high-quality illustrations in colour of the occurrence of tourmaline at Dunton, Maine, U.S.A. M.O'D.

STEYN (EDDIE). *South African agates.* The Guilder, 1975, 1, 5, 11-14.

An account of the formation of agates and their occurrence in the Vaal River and other areas associated with diamond digging. M.O'D.

SWINDLE (LEWIS J.). *Digging for pegmatite pockets in the Pikes Peak region of Colorado.* Lapidary Journal, 1975, 29, 3, 682-702.

The author found topaz, goethite, quartz, feldspar, epidote, fluorite and other minerals. M.O'D.

TAKENOUCHI (SUKUNE). *Basic knowledge on studies of fluid inclusions in minerals. Pt. 1.* Journal of the Gemmological Society of Japan, 1975, 2, 1, 25-33.

Inclusions are grouped for the purposes of discussion into gaseous, liquid, multi-phase fluid, CO_2 fluid and petroleum-bearing fluid. Microphotographs illustrate some typical forms. M.O'D.

WADA (KOJI). *Biomineralogy and pearl culture. Part 2.* Journal of the Gemmological Society of Japan. 1975, 1, 3-10.

Discusses the mineralization of pearl and the chemical composition of mollusc secretions. M.O'D.

WEBSTER (R.). *The London Gem Testing Laboratory.* Lapidary Journal, 1975, 29, 3, 646-651.

A short history of the laboratory from its inception in 1925, illustrated with photographs of the various premises and types of equipment used. M.O'D.

WOODS (G. S.) and LANG (A. R.). *Cathodoluminescence, optical absorption and x-ray topographic studies of synthetic diamonds.* Journal of Crystal Growth, 1975, 28, 215-226.

Under cathodoluminescence polished sections of synthetic diamonds show distribution of growth sectors belonging to the forms {100}, {111}, {110} and {113}. These sections can be distinguished by their colour and the brightness of their cathodoluminescence. Crystals tested had diameters in the range 0·75-1mm; others were larger. M.O'D.

WYART (J.) and BARIAND (P.). *Lapis-lazuli: le gisement de Sar-e-Sang couche, Badakhchan, Afghanistan.* (Lapis-lazuli: the Sar-e-Sang bed, Badakhchan, Afghanistan.) Bulletin de l'Association Française de Gemmologie, 1974, 41, 2-4.

An account with a coloured illustration of the classic locality for lapis-lazuli. M.O'D.

Cutting soft stones. Rocks & Minerals, 1974, 49, 62-63.

Notes on the cutting of variscite, obsidian, malachite, lazurite, serpentine and ulexite. M.O'D.

Short gemmological notes. Z. Dt. Gemmol. Ges., 1975, 24, 2, 94-98.

K. Schmetzer and J. Brezina publish physical constants of emeralds from Ghana. H. Bank and W. Berdesinski describe a kornerupine occurrence in Tanzania, H. Bank also an occurrence of ruby in Kenya. A contact liquid with n=1·84 produced by R. P. Laboratories in Cedar Grove, U.S.A., is mentioned by H. Bank. M. Schulz describes an adaption to the new carat scales 430CM by Sauter to make density determination even simpler. There is also an article dealing with 40 years education in gemmology in Idar-Oberstein, comparing courses then and now. E.S.

BOOK REVIEWS

ASSCHER (S.). *Diamant, wonderlijk Kristal.* (Diamond, crystal extraordinary.) Fibula-van Dishoeck, Bussum, 1975. pp. 164. Dfl 37·50.

An account by a member of one of the most famous Dutch diamond firms of the commercial aspects of the diamond trade. It provides interesting historical notes on the Dutch diamond scene and there are lucid descriptions of the current systems of grading. There is a short bibliography. M.O'D.

BAWDEN (Sharman N.). *Australian gemstones.* Golden Press, Gladesville, N.S.W., Australia, 1972. pp. 109 Illustrated in colour. Price on application.

A simple but well-written guide to the commoner Australian gem materials, this pocket-sized book deserves wide circulation. Each illustration is faced by the appropriate text and an outline map of the continent with localities pinpointed. Simple tables and a bibliography would have been useful. M.O'D.

BÜHLER (H. -P.). *Antike Gefässe aus Edelsteinnen.* (Antique fashioning of gemstones). Verlag Philipp von Zabern, Mainz, 1973. pp. vii, 85. Illustrated in black-and-white and in colour. DM 98.

An account of the use of ornamental materials in the manufacture of artefacts in classical and later periods, concentrating particularly on the quartz family. References to classical sources are given in separate tables and there is a bibliography. The standard of illustration is high. M.O'D.

COLAHAN (John). *Australian opal safari.* White Lion Publishers, London, 1975. pp. 127. Illustrated in black-and-white and in colour. £4·50.

A well-illustrated guide to the Australian opal fields, this book makes pleasant reading and contains some useful information. M.O'D.

DEL CALDO (Ambrogio) and others. *Minerale bestimmen.* (Identifying minerals). Franckh'sche Verlagshandlung, Stuttgart, 1974. pp. 152. Illustrated in colour. DM 24·00.

A beautifully illustrated pocket-sized guide to minerals, this book includes simple field identification methods, tables and examples of storage methods as well as an account of the better-known minerals. There is a short bibliography. M.O'D.

FIRSOFF (V.A.) and (G.I.). *The Rockhound's Handbook.* David & Charles, Newton Abbot, 1975. pp. 210. £4·95.

Although the conception of the book is good its usefulness is vitiated by numerous erros which could have been avoided by someone more familiar with mineralogy. The section on spinel contains, apart from the inevitable old names (and some new—sapphire spinel) which seem essential in books of this class, a strange typographical arrangement which suggests that zeolites are members of the spinel group; chrysotile and chrysolite have been confused; no mention is made of the cleavage of topaz; the important Mexican locations for sphene are omitted. All these are the type of error we have come to expect from this hurriedly produced area of mineralogical literature. There are better books and it is to be hoped that they are the ones which will sell. The abbreviations used in the text and in the tables can only be described as ludicrous. M.O'D.

GARBE (Richard). *Die indischen Mineralien, ihre Namen und die ihnen zugeschriebenen Kräfte.* (Indian minerals; their names and the art of writing on them.). Verlag Dr H. A. Gerstenberg, Hildesheim, Germany, 1974. pp. x, 104. DM 19·00.

A reprint of a work first published in Leipzig in 1882, this book is a translation from the Sanskrit of Narahari's Râǵanighantu Varga XIII. One of the four sections deals with the occurrence and working of gems. M.O'D.

HARTIG (Herbert). *Edle Steine Schleifen.* (Cutting gemstones). Verlag Frech, Stuttgart, 1974. pp. 120. Illustrated in black-and-white. Price on application.

A revised and enlarged edition of *Mineralien und Edlesteine selbst schleifen.* M.O'D.

HARTMANN (K.). *Edelsteine.* (Gemstones). Franckh'sche Verlagshandlung, Stuttgart, 1975. pp. 71. Illustrated in colour. DM 8·80.

A good short guide to gemstones, beautifully illustrated in colour and including the better-known species. M.O'D.

KIPFER (A.). *Ein neues Hobby: Kleinmineralien.* (A new hobby: micromounts). Franchk'sche Verlagshandlung, Stuttgart, 1974. pp. 64. Illustrated in colour. DM 5·80.

Introduces micromounts with many excellent illustrations and a discussion of storage methods. M.O'D.

LIEBER (W.). *Leuchtende Kristalle.* (Fluorescent crystals). Vetter K. G., Wiesloch, 1974. pp. 48. Illustrated in black-and-white and in colour. About 60p.

A short guide to commoner fluorescent minerals with notes on some light sources currently available. There is a short bibliography, and many helpful references are contained in the text. M.O'D.

LUZZATTO-BILITZ (Oscar). *Antike Jaden.* (Archaic Jades). Schuler Verlagsgesellschaft, Munich, 1974. pp. 160. Illustrated in colour. DM 14·80.

Originally published in 1966, this is a well-illustrated short guide to the archaic jades of China, America and New Zealand. M.O'D.

PETER (Mary). *Collecting Victorian Jewellery.* Macgibbon & Kee, London, 1970. pp. 100. Illustrated in black-and-white. £2·00.

This short book is directed at the collector who specializes in small pieces which may be found in out-of-the-way places. Most forms are discussed and designers such as Giuliano and Castellani are mentioned. There is no bibliography. M.O'D.

ROGERS (C.). *Forming a mineral collection.* Lapidary Publications, Broadstairs, 1975. pp. 48. 60p.

A well-written and illustrated booklet on mineral collecting aimed at the beginner, this praiseworthy set of articles avoids serious error and should be most useful. The price is very reasonable for today. M.O'D.

ROGERS (C.). *More of Britain's gems.* Lapidary Publications, Broadstairs, 1975. Not paginated. 60p.

Intended as a companion to the author's earlier *Finding Britain's Gems*, this pocket-sized book contains chapters by a number of authors. The common theme is the occurrence of minerals (gems in the title is something of a misnomer) in the British Isles; the material included is reasonable and most if not all of the items listed should be found. M.O'D.

STEINBACH (Kurt P.). *Ein Strauss Edler Steine.* (A bouquet of gemstones). Alles Brillant, Friedrichsdorf, 1969. pp. 148. Illustrated in colour. DM 19·80.

A beautifully-illustrated introduction to gemstones printed with an elegant type-face on a brown paper. Constants of the stones are quoted on the verso of the plates and there is a short bibliography. M.O'D.

TINDALL (James R.) and THORNHILL (R.). *The Blandford rock and mineral guide.* Blandford Press, London, 1975. pp. 256. Illustrated in colour. £6·95.

Designed for the collector of rocks and minerals, this book is written in a simple style and has well-chosen and balanced illustrations. The quality of these is less good, and one purporting to depict zircon looks more like peridot. In the discussion of mineral classes, silicates are given a disproportionate amount of room; some of the other classes yield collectable specimens. Tables are reproduced from Deeson *et al.*, *The collectors' Encyclopaedia of Rocks and Minerals*—not a recommendation. The habits in these tables are reduced to one word or phrase, which hardly reflects the true state of affairs. The bibliography is inadequate for so large a book. M.O'D.

WAGNER (P. A.). *The Diamond Fields of Southern Africa.* C. Struik (Pty), Cape Town, 1971. pp. 355. Illustrated in black-and-white. R12·50.

This large and interesting book is a re-issue of a work first published in 1914. Its pull-out maps and other illustrations, as well as an informative text, make it well worth buying. M.O'D.

Crystal Growth 1974. Proceedings of the fourth International Conference on Crystal Growth, Tokyo, Japan, 24-29 March 1974. Edited by K. A. Jackson, N. Kato and J. B. Mullin. North-Holland Publishing Co., Amsterdam, 1974. pp. xvi, 707. £56·00.

The original publication of *Crystal Growth 1974* formed a special issue of the *Journal of Crystal Growth* (24/25, 1974). In this very large and expensive hardcover book there are a number of articles of interest to the scientific gemmologist. One paper, by A. R. Lang, of the University of Bristol, deals with the growth of natural diamonds. Whereas most diamonds grow with concentric octahedral growth layers, some show stacking faults and some coated stones show a sharp transition between normal and fibrous growth modes. Other papers deal with the synthesis of chrysoberyl single crystals, the synthesis of serpentine minerals and the perfection of flux-grown crystals. A variety of topics with the rare-earth garnets are included. M.O'D.

ASSOCIATION NOTICES

NEW BRANCH

It is proposed to start a branch of the Association for Merseyside and the North West, taking in the Manchester area. An inaugural meeting is being held on Monday, 27th October, 1975, at 6.30 p.m. in the premises of Pyke & Sons Ltd., 30 Exchange Street, Liverpool. Anyone who is interested and wishes to attend should communicate with Mr John G. Roach—telephone 051-647 7444 (business) or 051-652 3458 (home).

All Fellows and Members of the Association in the area are eligible to become a member of the branch without payment of any extra subscription.

OBITUARY

Mr H. Cecil Diss, M.B.E., F.B.H.I., died in his 88th year. Mr Diss was one of the six successful candidates in the first Gemmological Examination held in 1913.

Mr Fred E. Ullmann, London, who gained the Association's Diploma with Distinction in 1938, died on the 20th August, 1975.

Notice has been received of the death of Mrs Martha J. (Jean) La Due, of Jensen, Kentucky, U.S.A., a Fellow of the Association who attained her Diploma with Distinction in 1972. Mrs La Due died on 9th March, 1975.

MEMBERS' MEETINGS

Midlands Branch

The Annual General Meeting of the Midlands Branch was held on the 11th June, 1975.

Mr John Marshall was re-elected Chairman and Mr C. Hundy elected Secretary.

Nottingham Branch

At the Annual General Meeting of the Nottingham Branch, held on the 17th February, 1975, Mr D. T. K. Lewis and Mrs B. Crutchley Smith were re-elected Chairman and Secretary respectively.

SOME ASPECTS OF THE SCIENCE OF GEMS AND MINERALS

The Harrow College of Technology and Art, Northwick Park, Harrow, Middlesex, started a course on 30th September, 1975, entitled "Some Aspects of the Science of Gems and Minerals". The Course tutor is Mr Frederick A. Fryer, B.Sc., F.G.A., A.R.I.C., Lecturer in Inorganic Chemistry, Harrow College of Technology and Art, Faculty of Science and Engineering, Northwick Park, Harrow, HA1 3TP, from whom further details can be obtained.

GIFTS TO THE ASSOCIATION

The Council of the Association is indebted to Mr R. H. Outerbridge, India, for a sphene weighing 1·49ct, which shows quadrupling of back facets.

EXAMINATIONS 1976

Examinations next year will be held as follows:

Preliminary (Theory only)—Tuesday, 29th June
Diploma (Theory only)—Wednesday, 30th June
Diploma (Practical) —London—1st and 2nd July.
Other U.K. Centres and Overseas as arranged. *The Diploma* (*theory*) examination must be taken on the 30th June.

Please note *final* date for receipt of completed examination entry form is 1st March, 1976.

ACCREDITED GEMOLOGISTS ASSOCIATION

First official meeting held January 31, 1975

Formation of Accredited Gemologists Association

Intent: Endeavour to keep up with new developments in gemmology (new gemstones, new finds, meetings of interest, etc.) and for purposes of open discussions of new equipment and procedures in gemtesting; new books; advancements in educational matters; get to know other American FF.G.A. who may just be neighbours.

Meetings will be held quarterly—January, April, July and October.

Membership will be composed of Fellows of the Gemmological Association of Great Britain and Accredited Gemologists of the Gemological Institute of America. Anyone who is interested in membership of this new organization should communicate with the *Acting Secretary:* Mrs Sonja S. Schwartzman, F.G.A., 8717 Bradmoor Drive, Bethesda, Maryland 20034, U.S.A.

INSTRUCTORS

At the meeting of the Council held on 5th February, 1975, the appointment of G. Pratt, F.G.A. and J. Edwards, F.G.A., as instructors was approved.

EXAMINERS

At the meeting of the Council held on 6th October, 1975, Dr G. H. Jones, B.Sc. Ph.D., F.G.A., was appointed as an examiner in gemmology.

LETTER TO THE EDITOR

Dear Sir,

The late Dr E. H. Rutland

Mrs Jill Rutland has pointed out to me that in the obituary notice of Ernest Rutland published in your April issue* I was incorrectly informed on two points.

Firstly, Rutland's Ph.D. thesis was not concerned with statistics but was entitled "The Decentralization of Industry and Population from London", and secondly, though he was a trained statistician and used statistics in some of his work, his true bent lay in the field of sociology.

I hope that this note will help to keep the record straight.

Yours sincerely,
BASIL W. ANDERSON

22nd July, 1975.

CORRIGENDA

On page 183 *ante* in line 19 for "The Natural Collection of Gems" read "The National Collection of Gems".

On page 341 *ante* in lines 11–13 from the bottom of the page for "Cerro Rico de Posito" read "Cerro Rico de Potosi".

*J. Gemm., 1975, XIV, 6, 301–303. —Ed.

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OF GREAT BRITAIN
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NEGATIVE CRYSTALS IN RUBY FROM BURMA

By PROFESSOR DR W. F. EPPLER

NEGATIVE crystals are not seldom mistaken for solid inclusions, particularly if they exhibit crystal faces of the same kind as those of a real crystal. In corundum, notably in ruby, the planes of negative crystals often show numerous steps, as can be seen in Fig. 1. They result from the alternating development of the base plane and the pyramid faces respectively. They are identical with the steps on the outside of ruby crystals, as may be seen in Fig. 2. Here, some of the edges or steps are roughened, due to the abrading of the crystals during their transport to the secondary deposits.

In other cases, the negative crystals show flat faces combined with rounded forms, significant of naturally rolled material. A convincing example is presented in Fig. 3. Sometimes, the cavities have well defined corners, edges and planes, the latter showing irregularities which are quite common with natural crystal faces (Fig. 4).

Flat forms of negative crystals also can be observed and two of them are shown in Fig. 5. They are reminiscent of waterworn crystals. The inclusion on the left side of the picture shows numerous "steps" as already mentioned above. The background of the

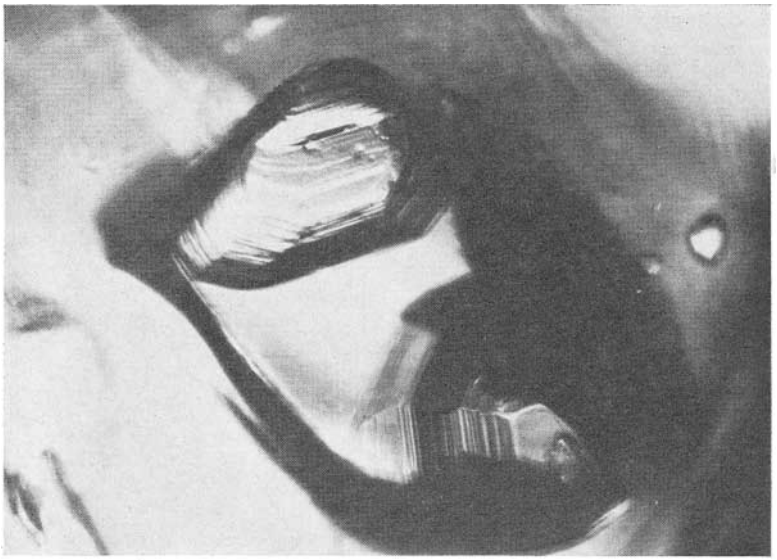

FIG. 1. A negative crystal in ruby with two elevations and numerous "steps" on its sides. 118 ×

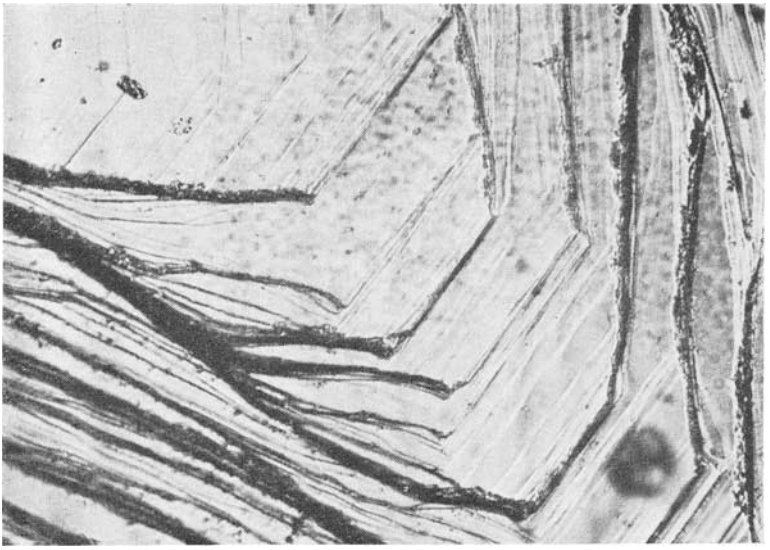

FIG. 2. Steps on the outside of a ruby crystal from Burma. 118 ×

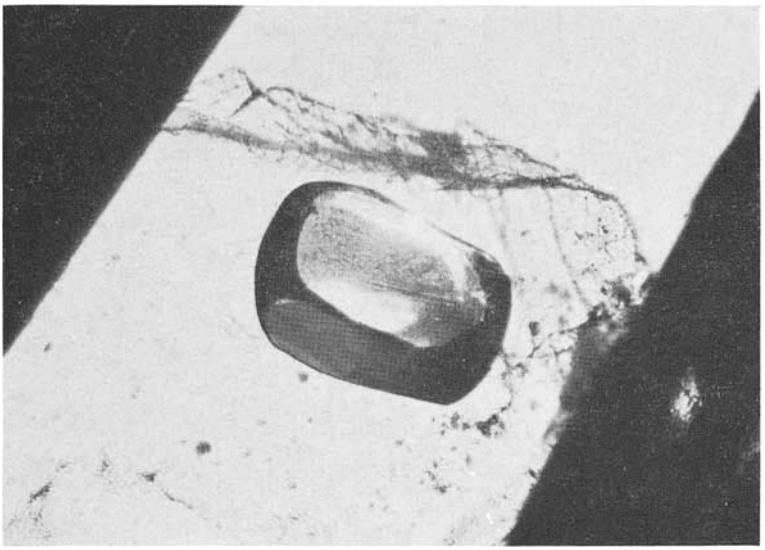

FIG. 3. Ruby from Burma with a rounded negative crystal showing also flat crystal faces; combined reflected and transmitted light. 62 ×

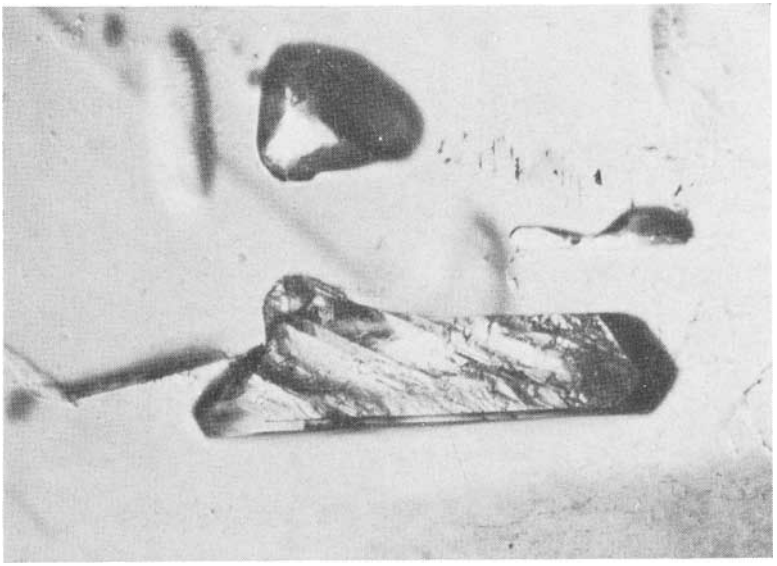

FIG. 4. An elongated negative crystal in a Burma ruby. Above, a doubly refractive crystal with a refractive index lower than 1·764. 118 ×

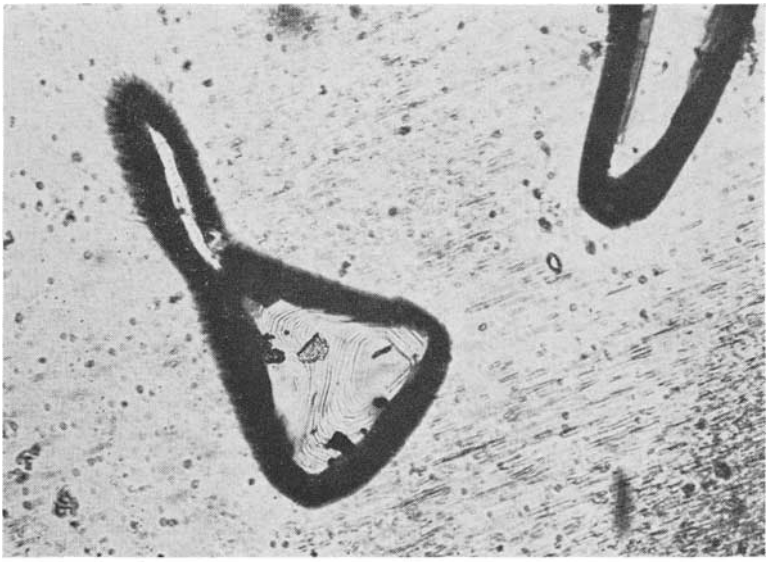

FIG. 5. A Burma ruby with two flat negative crystals, one of them showing fine steps. 118 ×

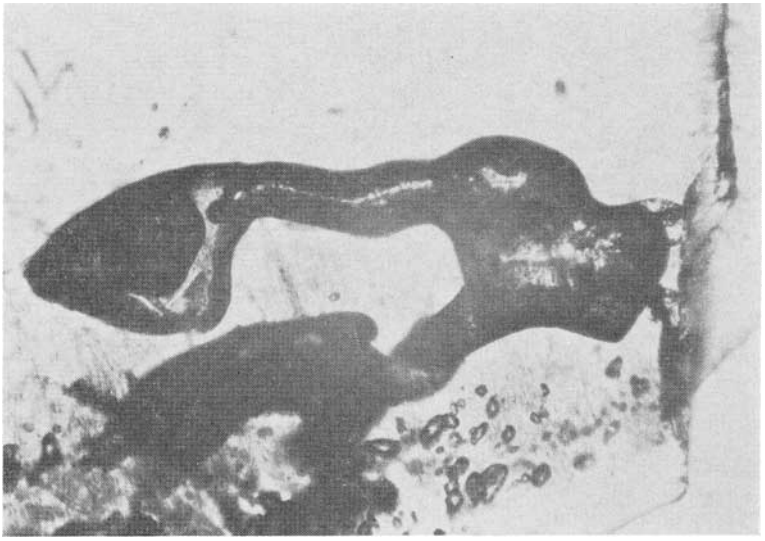

FIG. 6. A Burma ruby with a great cavity. 62 ×

picture, particularly on the right side, reveals needles of rutile, the orientation of which indicates that these negative crystals are situated parallel to a plane of the second order prism. Besides this, a facet has opened the negative crystal and a few particles of dust have been deposited. They can be recognized by their irregular forms. They also demonstrate that this negative crystal is really grown as an empty cavity.

Fig. 6 exhibits a strange inclusion in a ruby from Burma. It is a great cavity with two elongated arms. In reflected light, some crystal faces can be observed. This formation is about 1·4 mm long and can be seen with the naked eye.

The origin of these hollow spaces is not easy to explain. It may be possible that the growing ruby had to undergo a disturbance of its surface tension, which could be due, for example, to local differences in temperature or to some other cause. In any case, an obstacle for the growth front was present which partially stopped the growth of the crystal and caused these multiformed cavities with more or less well developed crystal faces.

The negative crystals are not totally empty, but they contain gases among which hydrogen sulphide must be present in a predominant amount. It could be recognized by its characteristic smell when the stones were crushed and the gas-filled cavities thus opened. There exists here a similarity to the newly found "vanadium-garnet", which, according to E. Gübelin and M. Weibel (1975),* also contains perceptible quantities of this particular gas. It is also most probable that during the growth of the ruby the gas was already present in the form of bubbles and that these "obstacles" have been another cause for the origin of the negative crystals.

*Lapidary Journal, 1975, 29, 2, 406.—Ed.

NOTES FROM THE LABORATORY

By A. E. FARN, F.G.A.

The Gem Testing Laboratory, London Chamber of Commerce and Industry.

FIGURES arrived at recently during a test on a suspect amber/casein necklace were rather amusing. They reminded me forcibly of attempts seen sometimes in examination papers, where the result is guessed accurately and the characteristics made to fit, hoping the examiner would not notice! A similarity of numbers caught my eye (figuratively speaking) and having a penchant for word-play I wondered whether they were worth noting. These figures were taken from carbon copies and have *not* been adjusted. Normally when carrying out tests on amber-like products we use a large container of salt solution, such that amber is readily floated away from its near neighbours, except copal resin. A touch of ether will reveal tackiness of copal resin: other subtle tests are used for casein, etc. However, in this case the necklace was of large beads very tightly strung, so that it was too stiff to coil and immerse in our salt solution. We had therefore to resort to useful practical weighing in air and then in water and to divide the loss in weight into the weight in air to arrive at a relative density. The weight in air was 108 grammes and weight in water was 8 grammes, thus a loss in weight of 100, which when divided into weight in air showed an exact figure for amber as follows:

$$108 - 8 = 100 \qquad 108 \div 100 = 1{\cdot}08$$

* * *

A necklace of spherical, deep green, subtranslucent, mottled beads was a recent test. Williamsite, a green form of serpentine, had been mooted and almost accepted as the result, since chromium had been detected in the spectrum, albeit weakly. Black octahedral inclusions, which williamsite has, plus a poor distant-vision reading of 1·57, *seemed* to clinch matters. At each drill-hole white powdery deposits seemed to indicate softness of abraded material, caused by close contact rubbing as the beads were not knotted. However, having been taught to accept facts which seem to fit, though loosely, and in fact never having seen such a fine colour of Williamsite cut specifically into a graduated necklace, I decided to unstring and take a density. I was pleased to get a good density figure for nephrite. Nephrite too has black octahedra and weak chromium

spectra. The apparent abrasion was not rubbing traces, as imagined, since the drill-hole edges were sharp—the powder was probably drilling-residue worked out by the stringing or polishing-powder incompletely washed away. The distant-vision reading was due to a poorish surface on the beads. The result—nephrite instead of williamsite—was, I believe, due to experience plus gemmology!

* * *

Among a parcel of jewellery sent in for test was a finely carved grey cameo in an antique mount. The owner, one of our more erudite and gemmologically-aware members, takes pride, when sending his goods for testing, in having them accurately described on his order note. He had requested "please test agate cameo", and, since it was beautifully carved, it presented a little difficulty in regard to a test. Close examination with a lens gave information of structure *not* that of agate. A simple test for a carbonate reaction, discreetly carried out, proved positive. It was in fact a very fine shell carving and still looked like agate.

* * *

Every now and then we are presented with a pink-red stone to decide: Is it pink sapphire or pale ruby? Although one can often arrive at a conclusion by simply asking several people to describe the colour of the stone and taking the majority verdict as visual evidence, it still presents a problem. When corundum is of such a colour as to be on the border-line between deep pink/red and pale red/pink, no harm can be done by allowing either name to be employed. Contrary to the usual request—from someone who has a pink sapphire which *is* pink and wants a ruby certificate—we had the other day the unusual. A customer with a definite ruby asked us to condemn it (his words) as pink sapphire, which of course we could not.

* * *

A very fine intaglio carved pendant of soft rich yellow transparent material presented a problem recently. A good distant-vision reading indicated opal, but our customer didn't think it could be, such was the quality of the carving. The pendant looked like a mid-nineteenth century piece, and it would have been sacrilege to cut through the very fine gold mount, which fully enclosed the edge and prohibited much of a view. Examination over a white matt reflecting surface with a 10 × lens showed natural features not in themselves diagnostic. To our relief and pleasure it was found by

the jeweller that the stone could in fact be lifted out bodily, due to the exquisite nature of the workmanship leaving a very firmly flush-fitting band of metal which allowed the stone to be extracted. We had moved warily in the matter, since our methods are non-destructive and the material, which was probably opal, was frangible to say the least. A matching density liquid with known S.G. comparison stone established the stone to be opal.

* * *

Another opal, which caused me a lot of trouble customerwise, not gemmologically, was a black opal purchased as such, mounted in a ring and offered for sale. All of the jeweller's customers condemned it as a doublet, due to a fairly straight band of potch running parallel to the girdle of the stone. Using a flexible light-source, I followed the potch around the stone and found the opal colour lipped slightly into the potch and again where potch merged into opal colour. This made it impossible to be a doublet. Our provincial member still had difficulty in accepting our findings. However by calling in a consultant we finally read the lesson and doubled our charges.

* * *

A parcel of 25 grossular garnets recently submitted for our interest varied in colour from colourless to pale yellow to brown and cinnamon, from pale light green to very deep green. The refractive index measurement ranged from 1·739 to 1·750, and there were various reactions under x-ray, long-wave and short-wave ultra-violet light stimulation. The first seventeen stones were marked from Laletema, Tanzania, and the second two batches from Kenya, from Bridges Mine and Morgans Mine, C. R. Bridges and P. R. Morgan being geologists. The absorption spectra seen in some of the green grossulars did not seem to be chromium, but possibly vanadium, and on the blue end of the spectrum were vague lines or indications of what could be manganese bands as seen in spessartite garnets. All 25 stones were fairly small—some very small—and all were loaned by E. F. W. Wolff, of 1 Hatton Garden. The tabulation (see page 9) gives a better idea of colours and reaction under filter, x-ray and U.V. light than does a worded article.

One other very fine garnet also sent in for our information (and pleasure) was a beautiful oval faceted deep yellow grossular garnet weighing 13·89 ct. The stone had a refractive index of 1·738 and a

No.	*Colour*	*R.I.*	*C.C.F.*	*X-ray*	*S.W.*	*L.W.*	*ABSP.*	*Province*
1.	Colourless	1·7395	Inert	Bright Apricot	Bright Yellow	Deep Apricot	—	Lalatema,
2.	Pale Yellow	1·740	,,	Apricot	Dull Apricot	Apricot	—	Tanzania
3.	,, ,,	1·7405	,,	,,	,, ,,	Pale Brown	MN ?	,,
4.	Yellow Brown	1·7415	P. Yellow	,,	Deep Brown/Red	Inert	,, ?	,,
5.	Golden Yellow	1·7415	,,	,,	,, ,,	,,	,, ?	,,
6.	,, ,,	1·742	,,	Apr./Yellow	,, ,,	,,	Hint MN	,,
7.	Cinnamon	1·746	Brown	Deep Yellow	,, ,,	,,	MN ?	,,
8.	Brown	1·750	,,	Inert	,, ,,	,,	—	,,
9.	Lime Green	1·740	Light Green	Bright Apricot	Dull Yellow	Feeble Brown	—	,,
10.	Yellow Green	1·7405	Yellow Green	Apricot	,, ,,	Inert	—	,,
11.	Light Emerald	1·740	Near C/less	V. Bright Apricot	Bright Yellow	Apricot	—	Lalatema,
12.	,, ,,	1·740	,, ,,	,,	Apricot	Dull Apricot	Hint VA	Tanzania
13.	,, ,,	1·740	,, ,,	Apricot	,,	Light Apricot	Hint MN	,,
14.	,, ,,	1·740	,, ,,	V. Bright Apricot	V. Bright Yellow	Apricot	—	,,
15.	Light Tourm. Green	1·740	Light Pink	Apricot	Dull Apricot	Poor Apricot	Hint MN	,,
16.	Bright Green	1·740	V. Pale Pink	Dull Apricot	Brown Apricot	Inert	—	,,
17.	,, ,,	1·7405	Pale Pink	V. Poor Dull Apricot	Inert	Dull Green	Hint MN	,,
18.	Emerald Green	1·7405	Pink	Apricot	Deep Apricot	Inert	—	Teita Province
19.	,, ,,	1·741	,,	V. Pale Yellow	Inert	,,	—	Bridges Mine
20.	Grossular Green	1·741	Light Pink	Apricot	V. Deep Apricot	,,	—	Kenya
21.	Deep Gross. Green	1·740	Pink	V. Dull Yellow	Inert	,,	—	
22.	Deep Green	1·742	Pink/Red	Inert	,,	,,	VA & MN ?	Teita Province
23.	V. Deep Green	1·742	Brown/Red	,,	,,	,,	,, ,,	Morgans Mine
24.	,, ,,	1·749	,, ,,	,,	,,	,,	,, ,,	Kenya
25.	,, ,,	1·750	,, ,,	,,	,,	,,	,, ,,	

MN ? = Hint of band in blue indistinct
VA = Hint in red of obscure band not chromium
VA & MN = Vanadium and Manganese?

specific gravity of 3·625: it fluoresced with an apricot fluorescence under x-ray excitation, a duller hue under S.W. U.V. and an even deeper tone under L.W. U.V. Considering the well known isomorphous character of garnets, one wonders what new varieties lie in store for us?

It is interesting to note from the list that the stone with the least colour behaved or reacted most strongly under excitation, and as body colour increased and refractive index ascended the reactions were slightly inhibited. One wonders whether the optimum amount of manganese and/or vanadium causes beauty of colour in like manner as a trace of chromium affects the colour of Burma rubies?

* * *

Among the variety of tests carried out in the laboratory are those on large and unusual pearls. One tends to miss the obvious in "Notes from the Laboratory". Although we write most frequently upon the stones and jewellery we see and abstracts published are on every possible aspect of jewellery, pearls do not receive the attention they deserve. Obviously—as I have stressed in one or two talks—gemmologists usually have a 10 × loupe, possibly a refractometer or spectroscope at their disposal, but seldom an x-ray set! Since the laboratory was founded to test pearls (and coloured stones came second) it seems only reasonable in this our fiftieth year to give pride of place to *pearls*. Like all precious gems they have their imitators, cultivators and propagators. The basic theme of a large mother-of-pearl bead and a very thin skin of nacre is well understood. The diagrams so expressively drawn of cross sections of cultured pearls, the endoscope needle, the radiographs and lauegrams—all excellent examples, chosen especially to portray how to test pearls—make laboratory procedure appear simple. Probably the simplest test of all is an obvious poor-quality Jap pearl necklace. This photographs well and leaves no doubt in the mind or eye of the radiographer. Natural pearls of very fine quality strung as a necklace do not in general show sharply demarcated structures. The finer the pearl growth, the less one sees, if x-ray techniques are used.

The really difficult one is a large rounded slightly baroque pearl in a ring. One such pearl gave us considerable trouble recently. On first sight the pearl looked natural, being a rounded button shape: its colour was not too good: and for these reasons we hoped for a

radiograph to show, as they usually do, several overlapping concentric arcs of structure. Unfortunately, such lines were seen *plus* the very faintest of suggestions—dead centre—of a spherical nature, not strong and slightly evanescent, with no typical conchiolin gap, no fluorescence, no phosphorescence. Opinions varied upon the interpretation of apparently fine structure so faint in the centre as to leave one thinking "Did I see it or is it imagination?"—such conditions do occur if one looks too long and too hard. Fortunately for us our customer was a gemmological enthusiast. Most of our customers are commercially concerned and in a hurry typical of Hatton Garden, wanting the results yesterday or at latest today! After several unhappy radiographs we decided to resort to lauegrams. These did clinch the result, but only after several shots. It was obvious towards the end that the "pearl", which was 109·28 grains, was at least 80 grains natural exterior and 20 grains mother-of-pearl bead nucleus. This of course gave a rounded hexagonal structure with undertones of four spots merging into the six-fold pattern. Not a piece of cake—not as per textbook. Most tests which finally arrive at our door, apart from mechanical or mundane valuation tests, are those which are difficult. The customer in this case was interested since an earlier valuation had been as of an *imitation pearl*—and what an imitation!

Another and far larger undrilled pearl of a round button shape also gave some trouble. This pearl was of a very fine interesting creamy colour and weighed 134·16 grains. We had poor success at first, using exposures of 25 minutes to try to get sufficient strength of structure revealed. Finally we ordered some *new* film and found the results were excellent as they should be. Doubtless we shall keep an eye on film stock and ensure rotation of stock turn-over. We use at least six types of film of varying speeds for radiography and lauegrams.

* * *

Among other stones tested, remarkable for their range in value and/or interest, we have had recently a very large alexandrite indeed, a small glass bead from a thirteenth century collection, pink marble beads looking like coral, a large star-diopside of magnetic attraction, a bracelet of williamsite-like green stones which weren't, and a specimen of "cultured amber", which is not.

The alexandrite was a very fair example of its type and weighed just over 40 ct. The glass bead was sent in for its antiquity and

interest alone. It was very coarsely made, had a very large drill-hole, and the swirl-striae were concentric about the drill-hole. It sank in methylene iodide, but the gas bubbles so easily seen should have floated it. Whilst no great problem and of no great merit, it was interesting to see something so very obviously hand-made so long ago—one could weave tales to fit about its wearer. Gemmology in a laboratory, though, does not permit of flights of fancy: science and facts keep us down to earth. The star-diopside was not physically attractive in appearance, but, as has been reported earlier by R. Webster and D. G. Kent,* they do react to a magnet; that is to say, a star-diopside—placed, polished cabochon surface down, on a clean glass slide—will react to the pull exerted by a pocket magnet. Just for the fun of it we reversed the order. We spun the diopside briskly and used a magnet to brake its speed of spinning. The pink baroque opaque beads were a pleasant colour but had a saccharoidal to granular structure totally divorced from coral structure. A strong reaction to acid proved the probable calcium carbonate nature, backed up by a density of the whole necklace in the region of 2·69–2·70.

The bracelet of nine oval translucent/transparent pale green cabochons was very attractive. Examination showed decided octahedra and cubic black inclusions as seen in williamsite (serpentine). The quality of polish and surface lustre seemed too good for a serpentine, however, and a distant-vision showed a good reading, just above 1·70. Final confirmation that they were grossular garnets came from the yellow fluorescence under x-ray excitation. From Harry Wheeler we received our piece of "cultured amber". This was ostensibly a cigarette-holder on which, being broken, we were permitted to use methods not usually employed. Normally all testing is of a non-destructive nature—our customers seem to regard this as essential! The golden amber-coloured holder had crowded, squeezed and whorl-like structures reminiscent of pressed amber but markedly more so. The specimen had a density of 1·239 and a refractive index, quite sharp for this material, at 1·56. We took a scraping and heated it in a test tube. It melted fairly readily, and the fumes, which had a very itchy, fatty smell, left a condensed brownish yellow sticky liquid to congeal plus quite attractive radiating crystals which formed as a "frosting" on the test tube walls. Using R. Webster's *Gems* (third edition) we carried out his test for

*J. Gemm., 1973 XIII 8,308.—Ed.

an alkyd resin. This test is described under turquoise impregnation.† The chemical test carried out by my colleague, Alan Clewlow, B.Sc., F.G.A., proved conclusively that an alkyd resin was present. The radiating crystals of phthalic anhydride were proved by addition of resorcinol and adding concentrated sulphuric acid (H_2SO_4) and warming the solution. The addition of sodium hydroxide produced a yellow solution, which gave a very strong fluorescent glow under long-wave ultra-violet excitation.

Alkyd resins, formerly termed glyptal resins, are a condensation product derived from glycerol and phthalic anhydride. The term covers dyallic esters used as resin binders in alkyd moulding materials. Needless to say the term "cultured amber" can now be safely dropped by the firm marketing this product.

* * *

The job of a laboratory trade gemmologist is an interesting occupation—we seldom see the same thing twice and feel constantly the challenge or possibility of something new, unusual or demanding. I enjoy the job very much even though at times things get a bit hectic.

The careful wording of reports or certificates, using words or phrases which cannot be misinterpreted and are not in themselves ambiguous, tends to the consideration of and correct use of words. Nomenclature, terminology, trade terms and phrases, all have an aspect and bearing such that, apart from giving or putting a label upon a stone, the very use of certain phrases is itself indicative of a person. Certain trade phrases give a clue to a person's age and/or experience. If a customer calls at the Laboratory for a test and asks conversationally of his stone "Is it Brazilian?" I know he means "Is it a sherry-colour topaz from Brazil?" Again, if a customer, speaking of his diamond, says, "Is it a three grainer?" I know he is a little long in the tooth and means "Is it a three-quarters of a carat stone?" Similarly, if he talks in grains and the "once" of a pearl, he is fairly experienced in the trade and not one of the younger merchants. But not all terms are indicative of age: well-known phrases, such as "a them there" or "plonk testing", are the products of the literate world of B. W. Anderson and the late Dr Ernest Rutland—both eminent gemmologists who have coined words and phrases which have found their niche in our world of gemmology.

A fairly recent new word would have caused them some

†op.cit. pp. 217 sq.—Ed.

hilarity and with their crossword-clue training might have afforded them a little gemmological exercise. A customer called and was tended at the door by one of my colleagues. The conversation seemed to be upon whether or not he was a member of ours or an affiliated trade association and so entitled to use the Laboratory facilities. He gave the name of ARABELLA, which to me was proof enough of his non-membership, since we know most of our firms by memory. I told him we had no member firm of that name. "That is not the name of a firm," he replied, "it is the name of this stone." Intrigued by 'Arabella' and what it might portend, I asked, "What stone?" "This one," he replied, producing a bar brooch with an obvious quartz cat's-eye in a border cluster surround. Then the psychological penny dropped—"Do you mean, is it a CHRYSOBERYL?" I asked. "That is right", he brightly responded, "Arabella or Chrysoberyl, that sounds like it!"

A modern tendency is "name-dropping": whether or not this was gemmological probing for a clue, it served no useful purpose, apart from inducing a mental note on the use of speech therapy. We duly accepted the test in all commercial seriousness and found it to be neither Chrysoberyl nor Arabella and duly reported upon it unambiguously as a *Quartz* cat's-eye. Other aspects of the misuse of words or even misspelling can be cited without trying to be superior. Doubtless the examiners when checking exam papers come across many such instances. I think, though, that in our own trade, whether wholesale dealer, retail, etc., we should spell the names of well-known gemstones correctly. Literally (or illiterally) not a stone's throw from our Laboratory one can read such 'gems' as "ametheist" and "saphire". I do not say the following was written by a West End shop manager, but it *did* come from a West End address. A stone in a ring was carved in intaglio style and we had to determine the nature of the stone: the note enclosed, with instructions from the West End address, said "Please test Englio ring". One can assume that a messenger perhaps was asked to make out an order to "test intaglio in ring," and being a little hard of hearing did not get the message! Thus, not liking to ask for the details to be repeated, he allowed this peculiar word to find its way into the journals of the trade.

* * *

When calling, some of our more vociferous customers (not necessarily all gemmologists) ask breezily "What is new?" as if we

are constantly turning up new gemstones but probably really want to know only what is new in synthetics or what to look out for. Certainly our routine testing is concerned primarily with the better-known gemstones used in jewellery, and, when an apparently normal stone does not quite respond to routine checks or where there is an anomaly, this is the juncture at which laboratory gemmology swings into action. No deviation, no slight differing from basic characteristics, no anomaly in fact should be allowed to escape full investigation until a satisfactory result or reason is found or afforded for the difference. *Vive la différence* has subtle innuendoes! Sometimes, when routine is disturbed by unusual occurrences, or when pressure builds up for a result to be found for an important item for an impatient customer needing our report to enable a purchase "subject to test" to be completed, then life in the laboratory becomes a bit hectic. I used the same phrase earlier in these notes, mentioning that I enjoy the job although things sometimes become a bit hectic—well, here we have yet another example of the use of words and their meaning. Hectic is often used to describe events which become tremendously busy or involved, and for myself I always used to associate "hectic" with "frantic", which is probably a more suitable word. Hectic is defined in Chambers Twentieth Century dictionary as: "Pertaining to the constitution or habit of body". One can see the link between a flushed hectic fever and "feverish". It took gemmology in the laboratory plus etymological guidance from B. W. Anderson for me to realise early on the frequent misuse of words—not exactly malapropisms, but close relatives.

* * *

Anomalies or even nuances of difference can cause quite a lot of bother gemmologically. One such case recently covered a routine test on an amber cigarette-holder. The item in question satisfied all the requirements for natural amber, S.G., R.I., frangibility, inert to ether, blue patch on freshly scraped surface when viewed under short-wave ultra-violet light, *no* signs of reconstruction by pressure, burning evenly with aromatic smell (we had permission to destroy), even the inclusions satisfied me; the exception being not so much an exception as an addition—there were several of these holders and they practically matched with each other. The merchant concerned said there were still more, all identical—which worried me (and still does). Although I cannot prove it, I feel

that someone has devised a method of reconstructing amber, in vacuum possibly, leaving no tell-tale traces or signs. I have also seen a slim bottle in "amber", about 6 inches high 2½ inches wide and about 1 inch thick, absolutely without any inclusion, feather, striae, etc., in fact so utterly clean as to look plastic beyond belief—this sort of thing I find hard to accept. Among the very normal tests we do, we are enlivened every now and then with not so much a variety as a "variation on a theme". One such item recently was a square emerald-cut green stone mounted fairly importantly in a heavy gold brooch. It was passed to me by my colleague for observation on the rather curled nature of the feather inclusion. The feather at first glance seemed to be of the hydrothermal type of 2-phase droplets and when viewed through the Chelsea filter was a poor brownish-red. The stone looked wrong for emerald and too poor for synthetic emerald. It had a straight-line colour-break, which could have been part of hexagonal structure zoning. The feather and colour decided me to take its R.I., which was 1·434. All factors added up precisely and accurately for fluorspar. A very nice fluorspar—just a little different to mundane emerald.

* * *

We had a solid hoop ring of mottled opaque green and white colour. It looked like jadeite, it had a density of 3·221 and a faint chromium spectrum with a faint band in the blue, a hardness (or softness) *easily* scratched by a steel broacher, and a fluorescence colour of a light honeyish yellow/green under x-ray excitation. We feel it could well be included under the umbrella name of Saussurite. Perhaps one day we shall be really proficient in the use of our own soon-to-be-installed powder-diffraction camera. We hope to be that much more positive in the identification of rocks and mixtures of minerals.

* * *

These few items may seem small beer, but they are the little pieces of cake which make bread and butter routine that much more palatable. There would seem to be room in these last few lines for afterwords on apatite, but perhaps I am making too much of a meal of it?

R.I. ANOMALIES IN TOURMALINE AND A STRANGE ZIRCON

By R. KEITH MITCHELL, F.G.A.

PAPERS by Chas. Schiffmann[1] and Prof. Dr Hermann Bank[2] have reported on experiments which appear to prove that the strange multiplicity of refractometer readings in certain tourmalines, first reported by me in 1967[3], is no more than skin deep. Areas on stones giving four or more R.I. readings, when repolished or recut, were found to give only the normal two readings, and in each case these were the lowest of those obtained before repolishing. These findings deserve further comment.

First, the suggestion by J. R. Jones reported in Schiffmann's paper cannot be accepted. Tourmalines, and indeed most other minerals, cannot undergo temporary alterations to their refraction which will go away in time. The suggestion that a Beilby layer was responsible for the anomalous effects is also rightly dismissed. Sir George Beilby postulated that heat and friction in polishing produced an amorphous layer which only in some instances re-crystallized on cooling. This layer is far too thin to influence any refractometer readings. Assuming that, in these cases, the Beilby layer were thick enough to register on the refractometer scale, the result would be either the single reading for an amorphous substance, or *three* values; two for the normal R.I. of the stone and a *lower* one for the amorphous layer, which would be thin enough to allow the crystalline R.I.s to be determined.

The writers mentioned above seem to have established with reasonable certainty that the anomalous multiple indices must be due in some way to the effects of heat. The chemical composition of tourmaline is well known for its complexity. The hydroxyl radical is a conspicuous item in the formula, while fluorine is a possible constituent element. In the case of topaz, fluorine leads to lower R.I.s than are found in those containing the OH radical. It seems to me probable that over-heating the tourmalines in some way alters the balance of these two factors in the outer layer of the stone, possibly by oxidation, and that a surface layer develops with higher refractive indices than the main body of the stone but still doubly refracting and thin enough to allow the true values to register through it on the refractometer.

A suggestion for further experiment occurs to me. Having restored an abnormal stone to normality by repolishing, I feel that an attempt should be made to return it to the multi-reading state by reheating. Success in this would prove beyond reasonable doubt that the initial effect was due to careless heating.

I think I was the first to report this strange phenomenon in print. However, the multiple R.I.s were brought to my attention by Dr C. J. Kerez, F.G.A., who, in 1965, was an exceptional student of mine, then living in Brazil. Credit where credit is due—I suggest the multiple R.I. effect be henceforth known as the Kerez Effect.

Much more recently I have encountered another strange stone, a drop-shaped zircon of 14·33 carats which, when taken from its stone paper, is a golden, almost orange-brown colour. About ten minutes exposure to sunlight reduces it to a dull brown, more nearly resembling that of cairngorm quartz. Several weeks of total darkness are needed to bring it back to its original colour. So far the phenomenon seems to be reversible *ad infinitum*. Obviously such phenomena must be due to changes in the stone's absorption of light. But the colour of a gem is due to the light it transmits and only in a negative way to the absorption lines which are the easily observed aspects of a spectrum. This zircon shows no apparent changes in its absorption spectrum, while any changes in the transmitted regions are too subtle to be observable in the normal use of the hand spectroscope. The absorption spectrum is in fact limited to a single very faint line at 6535Å, typical of most reddish brown zircons.

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THE "JEWELER'S EYE": A REPORT

By ROBERT WEBSTER, F.G.A.

HAVING discussed and evaluated the *Gemeter* and the *Gemeter* '75, [1, 2] the writer, through the courtesy of Dr W. W. Hanneman, of Hanneman Lapidary Specialties, Castro Valley, California, has been allowed to examine the electronic gem-tester called the *Jeweler's Eye*.

This instrument, which was designed by Dr Hanneman, is comparatively small, being approximately 4½ inches (11 cm) in width, 2¼ inches (5·5 cm) in depth and 2 inches (5 cm) in height. The whole instrument fits into a durable soft case made of "Nangahyde", a material used extensively in the United States for high-class upholstery. The whole (instrument and case) is of such a small size as to fit into a standard U.S.A. shirt pocket, or most certainly in a brief or executive case. (Fig. 1).

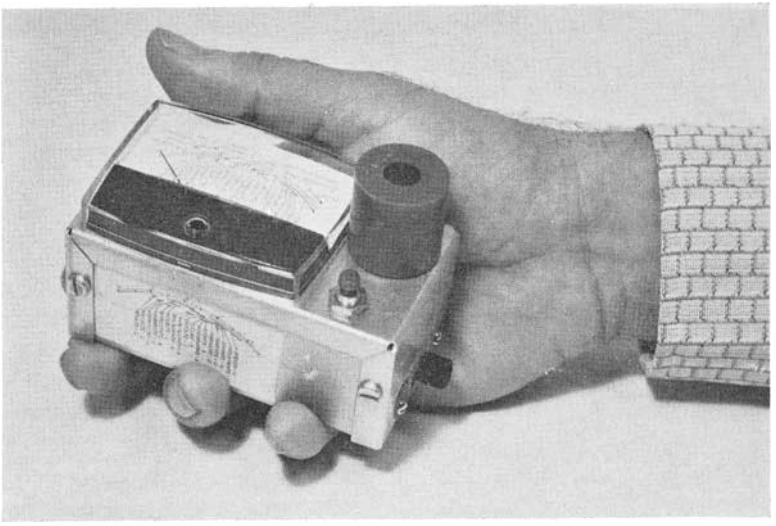

FIG. 1. The *Jeweler's Eye*.

As with the *Gemeter*, the *Jeweler's Eye* operates on a beam of infra-red rays and probably uses a similar "sensor".[2]

The instrument is most compact, with the meter, examination disc and push-button switch all mounted on the top of the box-like casing. However, on one end face there is a two-way switch, which allows either of two ranges marked on the meter to be used. (Fig. 2). The general layout of the circuitry is shown by Fig. 3. The instrument is powered by a nine volt dry cell and this may contribute to the more consistent performance shown by the *Jeweler's Eye*. Before discussing the performance of the instrument, it may be as well to give some consideration to the maker's literature.

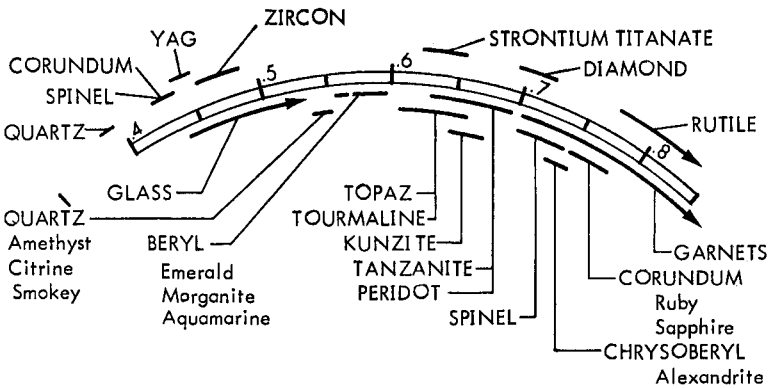

FIG. 2. The meter scale used in the *Jeweler's Eye*.

In the literature the maker makes no pretentions that his instrument will replace the refractometer which measures the critical angle of total internal reflection: indeed he is careful to point out that refractive indices, as given in gem textbooks, are based on the index as measured using the D line of sodium, but the electronic instruments are using a band in the infra-red with a wavelength of getting on for a micron—anyway somewhere about 900 nm. Dr Hanneman states that one cannot call these electronic instruments gem refractometers because a gem refractometer measures the refractive index for the wavelength of the sodium line (n_D), which the electronic instruments cannot do. For each gem there is a different *index of refraction* (n) for every wavelength, but there is only one *refractive index* and that is by definition the index of refraction obtained by using sodium light (n_D). There are also pointed out

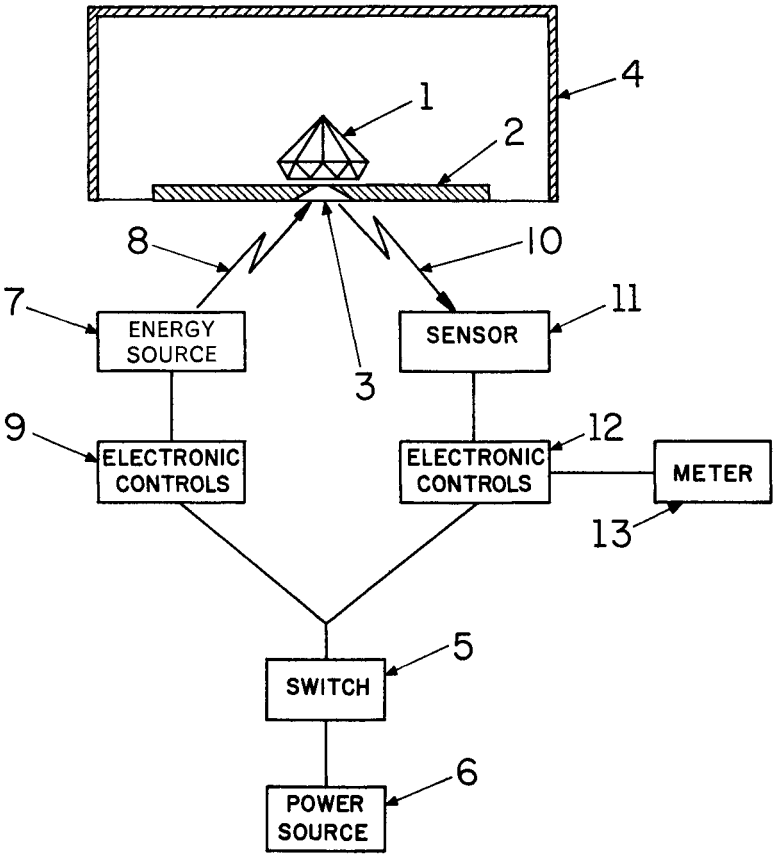

FIG. 3. Schematic diagram showing general layout of the circuitry of the *Jeweler's Eye*. Polished gem (1), placed on baseplate (2), with hole (3) in baseplate completely covered. Opaque cover (4) to eliminate external light. Closing of switch (5) provides energy from power source (6) and causes energy source (7) to radiate energy (8) in direction of hole (3). Intensity of energy is regulated by electronic resistors and circuits (9). Reflected rays (10) are intercepted by sensor (11) whose response is converted by electronic circuits (12) into visual response on the meter (13).

the deficiencies inherent in using Fresnel's reflectivity in the infrared. It is emphasized that a clean well-polished surface is essential, which many gemstones do not have, although they may appear to have such surfaces, and it is also mentioned that the instrument will *not* read birefringence or optic sign. Dr Hanneman is careful to point out that the *Jeweler's Eye* is not a precision instrument but is a useful tool.

In personal communications Dr Hanneman explains the reasons for some of the anomalies found by various workers who have used these instruments and have found high- and low-reading results. Low results are mainly due to badly polished or unclean stones, high readings being due to internal reflections inside the stones. The reason for the lower reading for strontium titanate than for diamond as shown by these electronic instruments may be explained by reference to Fig. 4. This graph shows the relationship between the index of refraction (n) and the wavelength of light used to determine it. The graph shows that the change of index of

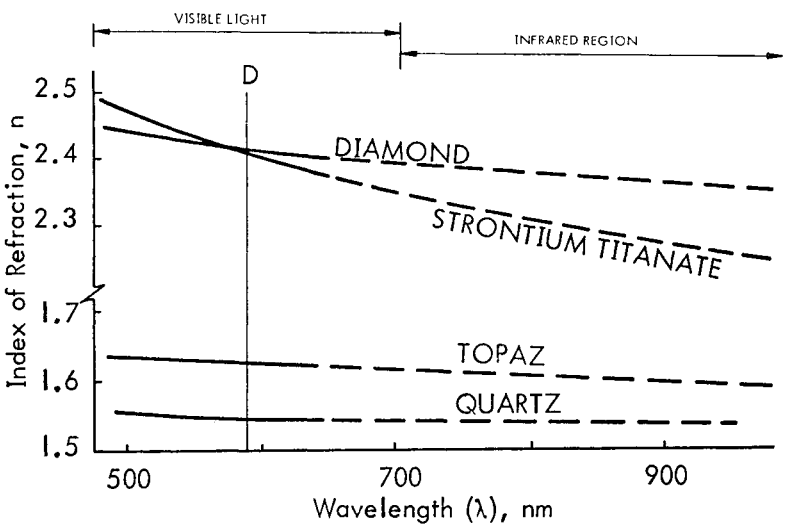

FIG. 4. Dependence of Index of Refraction upon wavelength of Energy.

refraction (n) over a range of wavelengths (λ) is different for diamond and strontium titanate. Mathematically this can be

expressed as follows:

$$\frac{\Delta \text{ n (diamond)}}{\Delta \lambda} \neq \frac{\Delta \text{ n (strontium titanate)}}{\Delta \lambda} ;$$

dispersion being defined as $\frac{\Delta \text{ n}}{\Delta \lambda}$ = dispersion.

Experiments to ascertain the performance of the *Jeweler's Eye* showed that the claims of the makers were valid and in the main the readings obtained were fairly consistent. Some anomalous readings were found to occur, but these were most probably due to the factors mentioned above, and in this connexion Dr Hanneman is wise in stating that the instrument is more safely handled by a trained gemmologist than by an untrained assistant, as the former is more likely to spot any inaccuracies of readings due to a badly polished stone or to internal reflections of a secondary nature.

The examination disc is much smaller and has a smaller diameter aperture than in the *Gemeter* and this allows readings to be taken with stones having fairly small table facets. The disc has a flat surface with no markings, and, thankfully, there is no "nipple". The nearness of the examination disc to the meter and the push-button switch rather precludes the stones in a fairly large piece of jewellery from being tested with ease. This of course must be accepted with an instrument designed on the small side. If the disc could be raised above the meter glass and the switch, this might be an answer, but it might entail manufacturing problems. The small cylindrical covers for the examination disc seem to have a tendency to pick up fluff by electrostatic attraction and it might have a deleterious effect if fluff gets into the "sensor" hole.

The results obtained with some Y.A.G.s seem to read higher than the scale on the meter indicates. It might be mentioned that printed subsidiary scales pasted on the base and back of the instrument indicate the meter positions for the more unusual stones, and in one of these the Y.A.G. line slightly overlaps that of zircon and this seems to be a truer version for Y.A.G. The line on the meter itself needs to be similarly extended—it is a minor criticism.

To sum up: these electronic instruments may, to some extent, be said to be still in their infancy, but they could have reached their potential, as the limiting factor is still the polish on the gem and no improvement in the instrument will overcome this. What these

electronic instruments will do is to give some satisfactory means of identifying the newer man-made (synthetic) stones which have a refractive index above the "threshold" of the ordinary refractometer. In conclusion, it can be said that the *Jeweler's Eye* is the best of these "reflectivity" instruments which the writer has so far seen.

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PERIDOT — THE GREEN STONE

By S. B. NIKON COOPER, B.D., F.G.A.

ACCORDING to the Oxford Dictionary of English Etymology (1) the name "peridot" derives from the Old French, can be traced back to the XIVth century, but is "of unknown origin". The Encyclopaedia Britannica (2) agrees with this: "the word peridot is an old trade-term, of unknown origin, used by French jewellers and introduced into science by J. R. Haüy."

Of unknown origin? The writer of this article believes in words; believes that they have a meaning; and, as a general rule, the more ancient the word the more literal its meaning. Let us consider the evidence available from early sources.

In Peterborough 33,(3) a MS from the late XVth century, we have the following entry: "Periot is a stone that is lygt grene"; and, obligingly, a footnote: "apparently the same as the peridon of The Second Lapidary of Engraved Gems". Turning to this source (4) we have a (mainly prose but partly verse) MS—Gonville and Caius Coll. Camb. 435—of the XIIIth century, where we read: "Peridon est piere verz". Not much is known of it ("De ses vertuz ne sui pas cerz") but at least the colour is there—green.

Also from the XIIIth century, Albertus Magnus: in his Book

of Minerals[5] II, ii, 14, under "perithe, or peridonius" we read: "there is said to be another variety of this which is similar to chrysolitus, except that it is greener." And again, another entry under "virites" (II, ii, 19): "virites is the gem which we have called peririte above" (referring to the II, ii, 14 entry). The point is made that this may be merely a copyist's error for "pirites" (pyrites)—inserting "V" instead of "P"—or may be a confusion with viridis—green.

A confusion? It would give a clear and exact meaning for describing this "new" gem—the one point on which all the authorities agree: its colour. The progression would seem to be: Virites→Pirites→Peririte = Peridonius→Peridon→Peridot.

But why was there a need in the XIIIth century for a new name? The stone was already known. We can recognize it easily enough in Pliny's excellent description of "topaz"[6], the stone which "yields to the action of the file", and which "admits, too, of being worn by use". It is beyond doubt that his "topaz" is our modern peridot. As additional proof, he classes "topaz" among his "green" stones. Why not keep the name "topaz" then? Why this need for a new name?

The answer would seem to lie in the gradual change of meaning which the name "topaz" had undergone. From Pliny (Ist century): a green stone, of low hardness (our peridot); through to Isidore[7] (VIIth century)—again under "green" gems ("de viridioribus gemmis. . . Topazion ex virenti genere est. . ."), an account which follows Pliny—including the famous story of how it was discovered, by accident, when the stranded Trogodyte pirates ("troglodytae" in Pliny) dug up the gem in their frantic search for edible roots. . .; but by the time of Bishop Marbode[8] (XIth century), there is a change. Topaz now has a golden colour ("alterius puro color est vicinior auro").

Again, from the MS Cotton Tiberius AIII:[3] "Topaz, which is like gold". Albertus Magnus (XIIIth century), in his "Book of Minerals"[5] II, ii, 18, cites two varieties: "one of them is entirely similar to gold, and this is the more precious. The other is yellow, but more transparent than the colour of gold, and this is less valuable." Again, MS Douce 291[3] (XVth century): "Topace is of yelowe colour. . ." And finally, Peterborough again[3] (the same source that gives us "periot"): "Topaces is a stone that hath a yelowe color."

From this we can see that from the XIth century onwards "topaz" has changed colour—to become the golden yellow stone we know today (and incidentally, how many people now would classify as "topaz" the more common colourless or light blue varieties? No, "topaz" is a yellow stone—everyone knows that!)

It only remains to ask where was "topaz" before the XIth century? This is a matter of conjecture, but the most likely claimant would seem to be "chrysolithos" (literally "golden stone")—the "chrysolite", which in some countries still, unfortunately, persists even today as a name for "peridot". If we accept this, we have the apparent paradox of Pliny's "chrysolithos" becoming our "topaz", and his "topaz" becoming our "chrysolite" (or, more correctly, our "peridot")!

I submit, though, that we have a plausible root-source for "peridot". . .that it stems from "virites"—the "green stone".

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(8) *Marbode (Marbodus Redonensis), Liber lapidum seu de gemmis* ed. J. P. Migne, Patrologiae Latinae, Paris, 1893, Vol. 171.

GREEN GEM HERDERITE FROM BRAZIL

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A BEAUTIFUL green Brazilian gem weighing 5·90 ct (NMNH Gem #4948) and reported to be herderite was acquired by the U.S. National Gem Collection in 1973. During a routine verification of this gem, prior to a computer indexing of the Gem Collection, abnormally low refractive indices were noted by one of the authors (W. W.), and the following investigation was initiated.

Herderite, $CaBe(PO_4)(F,OH)$, and the analogue hydroxyl-herderite, $CaBe(PO_4)(OH,F)$, are seldom encountered as gem materials. Crystallizing in the monoclinic system, it has a hardness of 5–5½. As a late-stage hydrothermal mineral in granite pegmatites, herderite is most frequently encountered as brown or grey, thin botryoidal masses, occasionally coating beryllonite. Crystals are found in micro sizes, and large non-gemmy light brown crystals up to 5 × 12 cm have been found in Brazil and at the Fletcher mine, Groton, New Hampshire. Herderite and hydroxyl-herderite are similar, if not identical, in appearance, and available optical data for analysed members of this series are scarce in the literature, compounding the difficulties of investigators who wish to characterize a gem of this series accurately.

The gem herein described is light green, oval brilliant-cut, with the hue and intensity of the Tanzanian green grossular. It is free from visible imperfections, and no diagnostic inclusions were noted. There was no apparent absorption spectrum. Refractive indices measured in sodium light with the Rayner Dialdex refractometer are $\alpha = 1{\cdot}581$, $\beta = 1{\cdot}601$, and $\gamma = 1{\cdot}610$ ($\pm 0{\cdot}002$), with birefringence of 0·029, optically negative. The indices were determined on a number of facets to insure that the maximum and minimum values were obtained.

The pleochroism is very weak. The dispersion is moderate, $r > v$, 0·017 (B-G), measured with the Dialdex refractometer for the X-vibration direction (α–index).

Previously published refractive indices for gem herderite (Webster, 1970) of $\alpha = 1{\cdot}594$, $\beta = 1{\cdot}613$, and $\gamma = 1{\cdot}624$ are considerably higher than the values for our gem. Since fluorine substituting for hydroxyl in other phosphate minerals such as amblygonite and

apatite causes a lowering of the refractive indices (Switzer *et al.*, 1965), it was thought that the gem in question could be fluorine rich, and that the indices given by Webster might be for a hydroxyl-rich member.

Analysis for fluorine content was carried out with an ARL Electron Microprobe operating at 15kV, with a sample current of 0·15μA. The fluorine content was determined to be 7·01%, indicating that the gem is indeed herderite with F > OH, but near a midpoint in the series.

When exposed to ultraviolet radiation, the gem fluoresces a pale violet in short-wave and a stronger violet in long-wave. No phosphorescence was noted. The stone fluoresces strongly in CuKα x-radiation with a pinkish-orange colour. After a thirty second exposure to x-rays, there is a very persistent phosphorescence lasting 30 minutes. Webster (1970) noted an orange glow with persistent phosphorescence under x-rays, but this material fluoresced pale green under ultraviolet.

The specific gravity, determined on a modified Berman-type balance, is 3·02 ($\pm$0·01). This is somewhat higher than the calculated value for herderite (2·98), but within acceptable limits. Powder scraped from the girdle of the gem was x-rayed and gave the pattern of herderite. Although the x-ray powder patterns of herderite and datolite are very similar, the higher optical constants of datolite, combined with the absence of silicon, as proven by the microprobe, remove all doubt. Therefore, we are able to confirm that the green gem is herderite.

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ON THE OCCURRENCE OF GEM CORUNDUM IN KOLONNÉ

By HERBERT S. GUNARATNE, F.G.A.
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IN early 1973 my colleagues and I of the State Gem Corporation, Sri Lanka, were confronted with a flood of rough blue sapphires, quite unlike the ones hitherto found among the gem gravels of Sri Lanka. These were of a very good colour. The majority of the stones bore their original crystal shapes and more often than not the stones were fissured. The stones came from regions around Kolonné, a place about 15 miles north west of Embilipitiya, in the Ratnapura District—the most famous gem district in Sri Lanka. Very soon these stones were popularly dubbed "the Kolonné Stones". However, not long afterwards the Kolonné stones disappeared from the market and it was not till the latter half of the year 1974 that these stones made their re-appearance. The gem deposits of Kolonné had been rediscovered. The earlier stones were predominantly blue sapphires, whereas the stones that reached us later were predominantly blue star (asteriated) sapphires.

General Observations

The majority of Kolonné stones bear their original crystal shapes and the stones are essentially blue corundums. The crystals are large and well developed (euhedral). These crystals have a cementation or encrustation around them and all are characteristically fissured. The blue sapphires are real quality stones. On the other hand the "silky stones" which should produce asterias proved to be rather disappointing, in the sense that a majority of them failed to produce the expected result on fashioning. In a large number of cases the stars did not show up although the colours remained good. Rubies had not been known to occur in this region.

Problems

Occurrences of this nature pose a fair amount of questions and problems, some of which, of course, may not find ready answers. To my mind there are three salient issues that need explanation, two of which could be settled with field data, while the third remains a problem for the laboratory. Firstly, it is the question regarding the nature of the occurrence—is it an "in situ" occurrence where the gems are found in the parent rock itself, or is it secondary in nature? Secondly, an explanation is necessary for the characteristically fissured nature of the crystals. Thirdly, why is it that

most of the "silky stones" of the nature which should normally produce asterias do not show up the effect as expected when fashioned? This last problem no doubt needs detailed analysis in the laboratory and in due course will receive attention.

It was with these issues in mind that a team of gemmologists from the State Gem Corporation of Sri Lanka set off for the site in late September, 1974. From Kolonné it is a trek of about four miles to this site, through undulating scrubland terrain. The effort involved and the energies spent were certainly rewarded. A typical area is Opalla, a region characterized by calcic rocks and isolated pegmatite outcrops. It is these pegmatites that are significant in relation to the gem occurrence at Kolonné. The pegmatite outcrops are large and isolated and consist of large crystals. A characteristic mineral seems to be diopside, the crystals of wh'ch are sometimes as long as 6 inches. It is from the periphery of these pegmatite outcrops (where a fair amount of weathering and decay is noticeable) that the gemstones are retrieved from the parent rock. Blasting is sometimes resorted to.

The occurrence of isolated pegmatite outcrops too call for an answer—its answer ties up well with the nature and occurrence of gemstones in the area. The pegmatites appear to be the result of a cooling phase of residual magmas, apparently isolated in reservoirs which had defied solidification for long periods. It follows that the surrounding rock magma did solidify leaving behind the residual magma-filled pockets to solidify at some later phase. These pockets, owing to some phenomena, solidified and crystallized extremely slowly, providing ample opportunity for the free floating chemical atoms to aggregate to form large and well developed crystals of the nature that are typical of the Kolonné pegmatites. As a consequence of delayed cooling, fissuring of crystals—particularly the larger ones —is a likely result. While cooling, gases and vapours are released, thereby decreasing the prevailing pressures within the reservoirs. These areas were immediately acted upon by pressures from the surrounding areas—compressional forces from the already solidified surrounding regions converged on the reservoirs and this naturally resulted in the fissuring of minerals that had already crystallized within. It is this fissuring of minerals that is quite evident and is even typical of the Kolonné stones.

While this region may be considered a type area in Sri Lanka where gem corundums occur in parent rocks, it is also an area where secondary deposits could be located.

Gemmological Abstracts

ARNOULD (M.) and POIROT (J.-P.) *Spectrographie infrarouge par réflexion de la turquoise et de quelques-uns de ses substituts.* (Infra-red reflection spectroscopy of turquoise and some of its substitutes). Bulletin de l'Association Française de Gemmologie, 1975, 44, 9-10.

A polished surface of the material is subjected to a beam of polychromatic infra-red light and the reflection analysed by an apparatus which measures the reflective power of the surface. It was found that natural turquoise even when its colour was altered or if it had been impregnated with coloured plastic, gave predictable readings but that the synthetic material gave an appreciably different picture. M.O'D.

BALL (R. A.) and BURNS (R. L.). *Agate.* Australian Gemmologist, 1975, 12, 5, 143-150. 12 illustrations.

Although complete in itself this article is only part 1 of a series. This first part examines critically the various theories which have been put forward to account for the composition and formation of chalcedony. There is a full discussion of the cause of the rings in agate. Amygdales with unusual features are discussed, as are also the probable conditions under which silica forms opal, chalcedony and quartz. There is an excellent list of references. This is a most useful article, which gives a very good survey of the problems of the formation of silica minerals. R.W.

BARRINGTON (E. N.). *Electromagnetic resonance in yellow sapphires.* Australian Gemmologist, 1975, 12, 5, 159-160.

Tells of a visit to Monash University in order to see the working of the equipment used for experiments using electro-magnetic spectroscopy and to carry out some research with reference to yellow sapphires. The equipment consists of a source of constant radio-frequency which is passed down a hollow rectangular tube "wave-guide" so as to bombard the object under test. The test object is located within a controllable electromagnet, which allows orientation of the specimen, alteration of the direction of the magnetic field and its strength, the radio-frequency all the time being constant. After bombarding the test piece, the emergent radio waves are captured and fed into an oscilloscope which shows amplitudes of the signal in response to any resonance that occurred within the test piece. The results of some experiments are detailed. R.W.

BECHBERGER (PAUL). *Franklin fluorescents.* Mineral Digest, 1975, 6, 6-19.

An account profusely illustrated in colour of the fluorescent minerals of Franklin, New Jersey. M.O'D.

BROOKES (C. A.) and MOXLEY (B.). *A pentagonal indenter for hardness measurements.* Journal of Physics, E: Scientific Instruments, 1975, 8, 456-60.

Most indentation tests for hardness are affected by anisotropy on single

crystals. The new pentagonal indenter gives results which are not affected by the orientation of the facets of the indenter and the crystallographic nature of the surface tested. The indenter takes the form of a regular pentagon-based pyramid with angles of 65° between each face and its geometric axis. M.O'D.

BROWN (R. E.). *The discovery of cap-quartz in northern New South Wales, Australia.* Australian Gemmologist, 1975, 12, 5, 156-159. (Reprinted from the Lapidary Journal of October 1974). 4 illus.

Cap-quartz is a quartz crystal which is made up of separable layers or caps due to the deposition of a little clayey material being deposited at intervals during the growth of the crystal. The New South Wales deposit occurs in a quartz pod in a host rock of kaolin pegmatite. The crystals lining the inside of the pod are short and stumpy. The cap crystals, however, form the base of the pod and are composed of kaolin-rich quartz and are a grey-blue in colour. Some crystallographic characters are considered. R.W.

CASSEDANNE (J. P.) and (J. O.). *Les opales du Rio Corrente (Pedro II, Piaui, Bresil).* (Opals of Rio Corrente (Pedro II) Piaui, Brazil). Bulletin de l'Association Française de Gemmologie, 1975, 44, 1-4.

An earlier account of opal from Brazil appeared in no. 16 of this journal; the localities presently discussed are at Fazenda Roça and Fazenda da Barra. Together with the location at Boi Morto already discussed these two sites are the main opal producers at the present time. They are situated in the north of Piaui state between Fortaleza and Terezina, close to the frontier with the state of Ceara. At Fazenda Roça the rocks are Devonian and there are some occurrences of laterite. Opal is found both in rock and alluvially. At Fazenda da Barra the opal is found in boulders of diabase. Constants of the opal from Fazenda Roça are S.G. 2·09, H.6, R.I. 1·458, no luminescence. Opal from Fazenda da Barra has S.G. 2·10-2·11, R.I. 1·458. Hematite is closely associated with the opal. M.O'D.

CLAYTON (N. A.). *Classification & nomenclature of precious opal.* Australian Gemmologist, 1975, 12, 5, 152-154.

A compilation of the data amassed by the late Jack Oughton on the subject of opal classification and nomenclature, his notes having finally been drafted into an article by the author. R.W.

FLAMINI (A.), GRAZIANI (G.) and GRUBESSI (O.). *Inorganic inclusions in amber.* Archaeometry, 1975, 17, 1, 110-112. 8 illus.

Examination of inorganic inclusions (which are described) in reddish Sicilian and yellow Baltic ambers using a scanning electron microscope with a Si/Li solid state non-dispersive detector (simultaneously allowing a stereoscopic view and a semi-quantitative analysis)—the only sample preparation being metalization of the specimen with a 50Å graphite layer and superposition of an exceedingly thin gold layer on the graphite layer—is claimed to show that the method adopted contributes effectively to the differentiation of ambers from different sources. J.R.H.C.

FRANCO (R. Ribeiro). *A síntese de minerais e de outras substâncias de interesse gemológico.* (Synthesis of minerals and other substances of gemmological interest). Gemologia, 1974, 20, 40, 21-32.

A survey brought up-to-date from an article published in the same journal (Vol. 10, No. 34) in 1966. Some comments on YAG not included in the original article appear here. M.O'D.

SCALA (C. M.) and HUTTON (D. R.). *A definitive test for golden sapphires.* Australian Gemmologist, 1975, 12, 5, 160-161. 1 table; 1 graph.

This article is really a carry on from Barrington's article abstracted above. The article reports the results of the examination of natural and synthetic yellow, blue and brown sapphires, and a synthetic ruby by microwave magnetic resonance spectra. The spectra due to iron were stronger in the natural sapphires, while the spectra for chromium were weak or not present. In the case of the synthetic stones the reverse was true, for the iron spectra were weak and the chromium spectra strong. In the synthetic ruby there was no trace of iron. R.W.

SENIOR (B. R.). *Precious opal in Queensland.* Australian Gemmologist, 1975, 12, 5, 155. (Reprinted from an unpublished report in Bur. Miner. Resour. Rec. 1974/35).

A short article on precious opal deposits of Queensland. It tells of the alteration of the area rocks during the late Cretaceous period, which subsequently produced faults and cracks and voids in the ironstone which allowed percolating silica solutions to deposit opal. R.W.

SVISERO (D. P.). *O diamante das regioes centroleste de Mato Grosso e sudoeste de Goias. Pt. 3. Inclusoes minerais.* (Diamond from the east-central regions of Mato Grosso and south-west Goias). Gemologia, 1974, 20, 40, 33-42.

The third part of a survey on diamond from Mato Grosso and Goias, dealing with inclusions of olivine, pyroxene, garnet, chromite and diamond. M.O'D.

WHITFIELD (G. B.). *Emerald occurrence near Menzies, Western Australia.* Australian Gemmologist, 1975, 12, 5, 150-152. 1 map.

Reports the finding of gem-quality emeralds at a new source in Western Australia. The area consists of an ultramafic body which had metamorphosed to a chlorite schist. Across this body run two pegmatite veins, which contain quartz, feldspar and randomly scattered pale green and opaque beryl crystals. At two places on the pegmatite veins the chlorite schist outside the vein for a distance of some 6 metres has been enriched by quartz, and to a lesser extent by emerald crystals which are up to 2 cm in length. The reason given for the formation of emerald within the chlorite schist instead of beryl, which occurs in the pegmatite, is that there is an excess of chromium in the schist. R.W.

BOOK REVIEWS

FALK (Fritz). *Edelsteinschliff und Fassungsformen.* (Gem cutting and setting). Verlag Wilhelm Kempter KG, Ulm, 1975. pp. 150. Illustrated in black-and-white. DM 48.

An account of the use of gemstones in jewellery from the late Middle Ages to the 16th century, this book, at a reasonable price, illustrates some fine pieces mostly from German and Austrian collections. Footnotes refer to the literature and there is an extensive bibliography. M.O'D.

GÖTZ (Friedrich). *Diamanten und Diamantwerkzeuge zum Abrichten von Schleifkörpern.* (Diamonds and diamond working with the cutting of rough). VDI-Verlag, Düsseldorf, 1968. pp. 108. Illustrated in black-and-white. DM 18.

A well-illustrated account of the diamond fashioning process with notes on the tools currently in use. Particularly valuable are the photographs of diamond crystals indicating the various faces and hardness directions. There is a short bibliography. M.O'D.

KIPFER (Alex). *Der Micromounter.* (The micromounter). Ott Verlag, Thun, Switzerland, 1972. pp. 212. Illustrated in black-and-white and in colour. Sw.fr 33·80.

A concise guide to the hobby of micromounting, this is the earliest book I have seen on this subject in a European language. It is well illustrated and contains advice on the preparation of specimens with details of those which necessitate special treatment. There is a section on the choice and use of a microscope. M.O'D.

KIPFER (Alex). *Mineralindex.* (Mineral index). Ott Verlag, Thun, Switzerland, 1974. pp. 206. DM 12·80.

Lists of names of minerals or connected with minerals make up the bulk of this pocket-sized book. English and other foreign names are given their equivalents in German, the main language used. Some obsolete names are unfortunately perpetuated; these would be much better abandoned altogether. Instead almost all gem and mineral books continue to include them while excusing their presence on the grounds of common usage. In most examples this is simply not the case and greater concentration on original rather than second-hand sources would quickly relegate these names to oblivion. M.O'D.

KÜHNEL (Walter). *Nutzbare Mineralien.* (Useful minerals). Wilhelm Goldmann Verlag, Munich, 1972. pp. 232. DM 36.

An account of the use of minerals in pharmaceutics, cosmetics, chemical technology, paper-making and other industries. The minerals are described in alphabetical order and their constants and occurrences are also given. Each entry also has references to the relevant literature; there is a general bibliography and an index. A most useful and well-written book. M.O'D.

LOCHMÜLLER (Walter). *100 Jahre Schmuck Design.* (100 years of jewellery design). Verlag Hans Schöner, Konigsbach-Pforzheim, 1973. pp. 207. Illustrated in colour. Price on application.

All the illustrations are photographs of the original designs and the reproduction of the colour is especially faithful. All the designs illustrated are German and there is a short introduction. M.O'D.

MÜLLER (G.) and RAITH (M.). *Methoden der Dünnschliffmikroskopie.* (Thin-section microscopical methods). Geologisches Institut der Technischen Universität Clausthal, Clausthal-Zellerfeld, Germany (Clausthalen Tektonische Hefte. no. 14), 1973. pp. 131. Illustrations in the text. Price on application.

A well-illustrated account of the cutting of rock sections to obtain various optical properties. Each chapter has its own extensive bibliography. M.O'D.

PAPE (Hansgeorge). *Der Gesteinssammler.* (The mineral collector). Second edn. Ott Verlag, Thun, Switzerland, 1974. pp. 100. Illustrated in black-and-white and in colour. DM 19·80.

A well-written and illustrated guide to the occurrence of various rocks and minerals, with useful information on geological maps and a comprehensive bibliography. M.O'D.

VISSER (J. M.). *Bijdrage tot de kennis van het medische, para-medische en occulte gebruik van edelstenen en mineralen.* (A compendium of knowledge on the medical, alchemical and magical use of gemstones and minerals). The Hague, Uitgave Mineralen Bulletin, 1967. In three parts, only parts 2 and 3 of which are reviewed here. Reproduced from typewriting.

A most interesting compilation of data covering not only the legendary properties of gemstones but also a number of practical points of identification. Mineralen Bulletin appears to be a newsletter consisting of a single bifolium and in its 36th year in 1972. M.O'D.

VRINDTS (Jozef). *Diamantbewerking.* (Diamond fashioning). Standaard Wetenschappelijke Uitgeverij, Antwerp, 1974. pp. 180. Illustrated in black-and-white and in colour. Price on application.

The main feature of this short book is the provision of diagrams illustrating the fashioning of a cut stone from various types of crystal. All the well-known varieties of cut are illustrated, although some of the more recent cuts making use of thin crystals are not included. There is a chapter on the uses of diamond in industry. A bibliography would have been useful and an index more so.

M.O'D.

ASSOCIATION NOTICES

MR B. W. ANDERSON

A formal document, signed by Professor H. Bank and Dr. G. Lenzen on behalf of the German Gemmological Association, was recently sent to Mr B. W. Anderson. Translated, the citation reads as follows:—

Mr B. W. Anderson, B.Sc., F.G.A. was, by a resolution of the Deutsche Gemmologische Gesellschaft on 27th September, 1975, proclaimed an Honorary Member of the Society, in recognition of his exceptional contributions to the furtherance of gemmological knowledge and his success in arousing interest in gemmology by means of publications and lectures during many successful years as teacher and research worker.

MEMBERS' MEETINGS

London

A talk was given at Goldsmiths' Hall on the 8th October, 1975, by Mr M. J. O'Donoghue, M.A., F.G.A., on "Recent Developments in the Synthesis of Possible Gem Materials". The substance of his talk will be given in a future issue of the *Journal*.

A report of the Presentation of Awards held at Goldsmiths' Hall on the 17th November, 1975, will appear in the April issue of the *Journal*.

North West Branch

At a meeting held on the 27th October, 1975, the North West Branch of the Gemmological Association was formed with the following officials:

Chairman:	Mr John G. Roach, F.G.A.
Hon. Secretary:	Mrs Doreen M. Brook, F.G.A.
Committee Members:	Mrs Mary Doughty, F.G.A.
	Mr Harry Eakins
	Mrs P. Gayton, F.G.A.
	Mr F. E. J. Hewitt, F.G.A.
	Mr S. Hill, F.G.A.
	Mrs Joan Kendall, F.G.A.
	Mr Barry Pearson, F.G.A. (Co-opted)

Any member who did not attend the first meeting of the Branch and who wishes to be informed of its activities should communicate with Mrs D. M. Brook, F.G.A., 22 Moorcroft Road, Allerton, Liverpool, L8 9UG. (Telephone: 051-427 5096.)

Nottingham Branch

A meeting was held on the 13th October, 1975, at the Mechanics Institute, Nottingham, when Mr E. A. Jobbins, B.Sc., F.G.A., gave an illustrated lecture entitled "The Gemstones of South-East Asia".

Scottish Branch

On the 7th November, 1975, Mr H. J. Whitehead, F.G.A., repeated his lecture "The Sri-Lankan Gem Scene" at the Station Hotel, Aberdeen.

Dr Jeff Harris gave an illustrated talk on "Diamond Inclusions" on the 25th November, 1975, at the North British Hotel, Glasgow. Dr Harris, an authority on diamonds, has done research into various aspects of diamond morphology both in South Africa and in Britain.

CONSULTANT GEMMOLOGIST

The United Nations Technical Assistance Recruitment Service wish to recruit a Consultant Gemmologist for a period of four months starting approximately April 1976. This person will be stationed at Kathmandu (Nepal). He will work under the general direction of the Project Manager and in co-operation with the Project Economic Geologist and Mineralogist and will be required to assess the possibilities for exploration and extraction of gemstones in Nepal.

Full particulars of this post are available from the Association at Saint Dunstan's House, Carey Lane, London, E.C.2.

GEM DIAMOND EXAMINATION 1975

Forty candidates entered for the Association's 1975 Gem Diamond Examination, of whom thirty-one qualified. The following is a list of successful candidates arranged alphabetically.

Qualified

Amor Cubeiro, Carmen, Barcelona, Spain.
Anton Martinez, Miguel, Valencia, Spain.
Ballin, Peter Edward, Birmingham.
Blasi Casal, Juan, Barcelona, Spain.
Carbonell Alós, Concepción, Valencia, Spain.
Clayton, Rosamond Susan, Hong Kong.
Cooke, Victoria Jane, London.
Cranton, Keir, New Malden.
Daras, Edith, London.
Din, Richard Aziz, Edgware.
Dwyer-Hickey, Peter Robin, Ilford.
Ferrer Arbona, Santiago, Valencia, Spain.
Garcia Igual, Arturo, Valencia, Spain.
Gonzalez Sanchez, Juan Manuel, Valencia, Spain.
Green, Arnold, Wembley.
Handley, Michael, Horsham.
Ishikawa, Taeko, London.
Latre David, Jose, Valencia, Spain.
Lopez Vaño, Maria Carmen, Valencia, Spain.
Manser, Jutta Elisabeth, Southampton.
Martorell Gisbert, Maria Isabel, Valencia, Spain.

Munne Cardona, Ana Maria, Barcelona, Spain.
Nohara, Koichi, London
Palmer, John Redvers, Hitchin.
Palomares Carbonell, Remedios, Valencia, Spain.
Proctor, V., London.
Sanchez Cabello, Antonio, Valencia, Spain.
Shindler, Albert, Kenton.
Upchurch, David Ward, Colchester.
Vendrell Saz, Mario, Barcelona, Spain.
Villar Lopez, Luis-Fernando, Barcelona, Spain.

EXAMINATIONS IN GEMMOLOGY 1975

In the 1975 examinations in gemmology organized by the Gemmological Association of Great Britain, 728 candidates sat for the preliminary examination and 385 for the diploma examination. Overseas centres were established again in many parts of the world.

Upon the recommendation of the examiners, the Tully Memorial Medal and the Diploma Rayner Prize have been awarded to Mr Michael John Freeman, of Bulawayo, Rhodesia.

The Rayner Prize in the preliminary examination has been awarded to Mr Sten Rundkvist, of Frolunda, Sweden.

The following is a list of successful candidates, arranged alphabetically.

DIPLOMA EXAMINATION

TULLY MEMORIAL MEDAL AND DIPLOMA RAYNER PRIZE

Freeman, Michael John, Bulawayo, Rhodesia

QUALIFIED WITH DISTINCTION

Aguilar Casamayor, Carlos, Zaragoza, Spain.
Brown, Grahame, Brisbane, Australia.
Buhler, Stefan, London.
Domenech Casellas, Maria Victoria, Oviedo, Spain.
Freeman, Michael John, Bulawayo, Rhodesia.
Garcia Abril, Ana Maria, Valencia,
Gomez Perez, Pilar, Valencia, Spain.
Hammett, Roger Stewart, Southall.
Harris, Janet Elizabeth Anne, Stafford.
Jhaveri, Ravindra Jayantilal, Bombay, India.
Lo, Wing Yat Sunny, Hong Kong.
Logsdon, Maxon Andrew, Wethersfield, Conn., U.S.A.
Mayor Giner, Juan Enrique, Vinaroz, Spain.
Noble, Patrick, Heckmondwike.
Ripley, Evelyn, Stockton.
Sanchez Garcia, Paloma, Valencia, Spain.
Tarazona Almenar, Federico, Valencia, Spain.

QUALIFIED

Agee, Carl B., Rotterdam, Holland.
Ahmad, Masud, Wimbledon.
Alvarez Perez, Aurelio, Barcelona, Spain.
Aparisi Miguel, Rafael, Valencia, Spain.
Bartoli, Anne-Marie, Gex, France.
Bassett, Allen M., La Jolla, Cal., U.S.A.
Benjamin, John Circus, Wembley Park.
Bloom, André David, Streetly.
Bootz-Verbunt, Emilie Henri Hélène, Hilversum, Holland.
Bosch Senao, Javier, Barcelona, Spain.
Brauns, Sandra Maureen, Hong Kong.
Bredebusch, E., Hong Kong.
Brooks, Ferriel, Hong Kong.
Burr, Kevin Francis, Guildford.
Capell, E., Port Elizabeth, S. Africa.
Carey, David Alan, York.
Carrera Poblet, Jaime, Barcelona, Spain.
Cartwright, Donald Roy, Little Bookham.
Chandrasena, Kaluthantrige Nimal Ravindra, Panadura, Sri Lanka.
Cidoncha Castellote, Reyes, Valencia, Spain.
Cidoncha Garcia, Miguel Angel, Valencia, Spain.
Clapperton, Elizabeth Morag, Aberdeen.
Cornelius, Richard Alan, London.
Cornford, Carol Rae, East Grinstead.
Cornford, Richard, East Grinstead.
Crawley, Annette, Liverpool.
Dissanayake, Jayasinghe Muhandiram Ernest, Hounslow West.
Diniz, David C., Hong Kong.
Erling, Patricia, Helsinki, Finland.
Frowein, Carl Richard, Stellenbosch, S. Africa.
Grant, Malcolm John, Fordingbridge.
Haddy, H. J., Melville, W. Australia.
Hewitt, Leonard Eric, Lincoln.
Holness, Malcolm Henry, Effingham.
Horder, Heather Aileen, Windsor
Houghton, John Anthony, New Malden.
Hoyos Guerrero, Miguel Angel, Madrid, Spain.
Hughes, Charles James, Newfoundland, Canada.
Hummel, Frank August, Weiser, Ida., U.S.A.
Hutchinson, Janice, Plymouth.
Imai, Takayasu, London.
Iwahori, Mitsuo, London.
Jackson, Brian, Edinburgh.
James, Alan Roy, Walsall.
Javeri, Kishan B., Kobe, Japan.
Jones, Alison Rena, Woking.
Jucker, R. W., Idar-Oberstein, W. Germany.
Kalevi, Roine Usko, Jarvenpaa, Finland.
Kan, Eishi, Tokyo, Japan.
Kennedy, Esther I., Charlotte, N. C., U.S.A.
Kortelainen, Sirpa, Helsinki, Finland.
Kuo, Jung Chou (Eishu Kaku), Los Angeles, Cal., U.S.A.
Laine, Simo E. W., Helsinki, Finland.
Langaard, Conrad, Hanau, W. Germany.
Leewis, P. E., Schoonhoven, Holland.
Leslie, C. Elisabeth, Hong Kong.
Leyser, Gerarda Sebilla Margot, Arnhem, Holland.
Lowe, Peter Eric, Windhoek, S. W. Africa.
Marsal Astort, Montserrat, Barcelona, Spain.
Matthesius, Johannes Gerardus, Amstelveen, Holland.

Maurer, Robert J., Brentwood.
Miller, Charles Robert, Southfield, Mich., U.S.A.
Miller, Wilda L., Pretoria, S. Africa.
Mones Mendoza, Jose, Barcelona, Spain.
Morrill, Christine, Cambridge.
Moule, Alexander John, Brisbane, Australia.
Obiols Mundet, Agustin, Barcelona, Spain.
Padro Tortajada, Angeles, Barcelona, Spain.
Paul, Anne Carse, Hong Kong.
Paulin, Per Philip Elon, Uppsala, Sweden.
Petersen, Graeme Edward, Lower Hutt, N. Z.
Phillipson, Erica, Boxmoor.
Rappitt, Toby James, Maidenhead.
Read, Peter George, London.
Rossetti, Luigi, Idar-Oberstein, W. Germany.
Round. Anthony William Reginald, Epsom.
Rowe, Elaine, Brierley Hill.
Sandberg, Dag, Kjeller, Norway.
Scavia, Fulvio, Milan, Italy.
Schulze, Heinz, Austin, Tex., U.S.A.
Shida, Junko, Kanagawa Pref., Japan.
Stanford, Paul L., Guernsey.
Strachan, Anne R. N., Hong Kong
Sweeting, Penny J., London.
Sze, Yeong-Miin, São Paulo, Brasil.
Tenkate, Iris, Schoonhoven, Holland.
Teske, Jan, Lisse, Holland.
Tester, Robert Edward, Gibraltar.
Tolmie, Andrea Joan, Stonnall.
Tolmie, Nigel Lester, Stonnall.
Vainio, Erkki, Helsinki, Finland.
Van, Bodil Ann-Catrin, Hong Kong.
Van Westen, Linda Justina Louisa, Eindhoven, Holland.
Vander-Heyden, Eveline, Barcelona, Spain.
Warr, David Arthur, Hardwicke.
Williams, Jack Daniel, Philadelphia, Pa, U.S.A.
Wisdom, Terence Roy, Chorleywood.
Wong, Leung Kim Po, Joanna Hong Kong.
Yano, Kiyoko, Kobe, Japan.
Yoda, Mitsuhiro, Tokyo, Japan.
Young, Martin J. P., Aberdeen.
Zoppi, Marco, Flims-Dorf, Switzerland.

PRELIMINARY EXAMINATION

RAYNER PRIZE

Rundkvist, Sten, Frolunda, Sweden

QUALIFIED

Aaby, Jens-Erik, Oslo, Norway.
Abeyesinge, Roland Gomis, Colombo, Sri Lanka.
Abeyratna, Nayana Savitri Sudharshana Kumari, Colombo, Sri Lanka.
Abeywardena, Hettiaratchige
Adamally, Duraiya, Colombo, Sri Lanka.
Akthar, Abdul Sather, Beruwela, Sri Lanka.
Allen, Michael John, Truro.
Aloy, Richard N., Bromley.
Alston, Evelyn Jetta, Pretoria, S. Africa.
Alvarez Perez, Aurelio, Barcelona, Spain.
Ambalavanar, D., Colombo, Sri Lanka.

Ambros Perez, Jaime, Barcelona, Spain.
Anandavadivel, Kumarasamy, Ratmalana, Sri Lanka.
Andersson, Arild, Oslo, Norway.
Arguijo Lopez, Antonio, Barcelona, Spain.
Armitage, Kevin Paul, Rotorua, N. Z.
Arseculeratne, Raphael Barnes, Colombo, Sri Lanka.
Asano, Shinichi, Sendai-City, Japan.
Asano, Yoshio, Tokyo, Japan.
Ashton, Michael, Luton.
Asokaudayamitta, Ekanayake Mudiyanselage, Moratuwa, Sri Lanka.
Aspinall, Paul, Higher Bebington.
Atapattu, Niruala Kumari, Mount Lavinia, Sri Lanka.
Atukorala, D. P. K., Boralasganuwa, Sri Lanka.
Aunon Armero, Pascual, Valencia, Spain.
Ayres, Thomas David, Farnham.
Baird, Donald Douglas, London.
Baker, Elaine C., Lihue, Hawaii
Bakker, Elizabeth, Delft, Holland.
Balasubramaniam, Mylvaganam, Mount Lavinia, Sri Lanka.
Baldock, Lynette, Neston.
Balendra, Kailasapillai, Colombo, Sri Lanka.
Bapat, Suresh Balaji, Bombay, India.
Barclay, William H., Quebec, Canada.
Barlow, Clifford Maurice, Coventry.
Bassett, Allen M., La Jolla, Cal. U.S.A.
Bastinsz, Maxwell Anthony, Colombo, Sri Lanka.
Beal, David William, North Watford.
Bedford, Richard John, Sheffield.
Behennah, Frank Ernest, West Moors.
Bell, Howard Hershey, Hanover, Canada.
Beng, Goh Kong, Petaling Jaya, W. Malaysia.
Bennett, Lise Christine, Gillingham.
Bhaskaran, G., Bombay, India.
Biggs, Margaret Irene, London.
Bingham, Edward Dean, Nevada, Ia, U.S.A.
Birtley, Robert, South Shields.
Boerman, Hendrik, Rotterdam, Holland.
Booker, Martin, Chester.
Borgen, Jennifer Averel, Fredrikstad, Norway.
Bosch, Fontcuberta, Luis Felix, Barcelona, Spain.
Bratton, Timothy James, Sidcup.
Brennan, Henry Joseph, Bolton.
Brown, Hartley Raymond, London.
Butler, Russell Trevor, Birkenhead.
Byfleet, Anne Patricia, Haxey.
Callaghan, Christopher Claude, Port Elizabeth, S. Africa.
Calonge Flores, Nieves, Berga, Spain.
Canas Carballido, Miguel, Madrid, Spain.
Carrillo Farnandez, Jose Angel, Barcelona, Spain.
Casseer, Noble Jenita, Nugegoda, Sri Lanka.
Catafau Riera, Jaime, Barcelona, Spain.
Cavagna, Sergio, Milan, Italy.
Chandraratna, Balasuriya Arachchilage, Wahakula, Sri Lanka.
Chown, Ronald, Lincoln.
Christoffersen, Brian Dudley, San Leandro, Cal., U.S.A.
Clarke, Kathleen Daphne, London.
Clarke, Nigel Kenneth, Marple Bridge.
Clayton, Keith M., Alfold.
Clements, Jennifer Margaret, London.
Cohen, Charles Stewart Sydney, London.

Colacicco, Lia Giovanna Lawton, Poole.
Collett, Jessica Mary, London.
Comin Vilajosana, Luis, Barcelona, Spain.
Cooke, David Orton, Hastings.
Cooper, Marjorie, South Elmsall.
Cooper, Malcolm David, Hoddesdon.
Costa Florit, Maria Luisa, Barcelona, Spain.
Coswatte, Bertie, Colombo, Sri Lanka.
Cowling, Denise Elizabeth, Northampton.
Crout, Stephen James, Wellington, New Zealand.
Cusco Ezquerra, Jose-Oriol, Barcelona, Spain.
Dayalji, Ghaghada Jayantilal, Wembley.
De Kock, H. M., Gouda, Holland.
De Rubeis, B., Nottingham.
Diaz Valcarcel, Maria Teresa, Barcelona, Spain.
Dick, Julie Ellen, Hastings, N. Z.
Diment, Paul Edwin, Battle Ground, Wash., U.S.A.
Diniz, David C., Hong Kong.
Dodson, John Sidney, Cobham.
Dominguez Mondelo, Segundo, Oviedo, Spain.
Doncel Corte, Jose, Oviedo, Spain.
Drost, Kristina R., Brummen, Holland.
Duckworth, Neil Frank, Bolton.
Duque Munoz, Marta Isabel, Madrid, Spain.
Edmunds, Sheila Margaret, Transvaal, S. Africa.
Edward, D. R., Colombo, Sri Lanka.
Egi, Shigeo, Tokyo, Japan.
Egi, Yoshi, Tokyo, Japan.
Eldridge, Maurice William, Sheffield.
Engelbrecht, Greta Anne, Pretoria, S. Africa.
Engelbrecht, Johann Pieter, Pretoria, S. Africa.
Engineer, Thrity P., Bombay, India.
Eno, Takatuko, Tokyo, Japan.
Escola Gabriel, Carina, San Cugat, Barcelona, Spain.
Evans, Karen Standish, East Horsley.
Evans, Linda Ann Elizabeth, Chester.
Evans, Mark, London.
Ewen, Edward Spence, Pinner.
Fabregat Sarro, Manuel, Barcelona, Spain.
Falomir Penarrocha, Amadeo, Liria, Valencia, Spain.
Faura Oriol, Regina, Barcelona, Spain.
Fenoll Hach-Ali, Purificacion, Granada, Spain.
Fernandez Goula Pfaff, Antonio, Barcelona, Spain.
Fernando, Bathiya Dhammika, Colombo, Sri Lanka.
Ferrandis Recatala, Juan Vicente, Valencia, Spain.
Ferrando Laric, Salvador, Valencia, Spain.
Fitzgerald, Leslie Edmund, Stanmore.
Fitzgerald, Patrick, Orpington.
Flewelling, Arthur Gary, Arthur, Canada.
Foster, Constance D., Sarasota, Fla, U.S.A.
Fotheringham, Noelle Anne, Johannesburg, S. Africa.
Freyer, Nina, Hong Kong.
Friedlaender, Lilly-Luise, Dusseldorf, W. Germany.
Fuentes Lopez, Jose Javier, La Coruña, Spain.
Gade, Fredrik Georg, Snaroya, Norway.
Gancedo Morera, Margarita, Barcelona, Spain.
Garcia Girones, Antonio, Barcelona, Spain.
Garcia Pilan, Alfonso, Albuixech, Valencia, Spain.
Garfat, Joe H., Peterborough, Canada.

Gausa Castro, Enrique, Barcelona, Spain.
Ghaswala, Sudhir R., Bombay, India.
Gifford, Thomas Leslie Noel, Alexandria, Va, U.S.A.
Goda, Motoyuki, Tokyo, Japan.
Godamanna, Thilak, Colombo, Sri Lanka.
Gonzalez Suarez, Maria Amparo, Gijon, Oviedo, Spain.
Goonatilake, Deepal, Colombo, Sri Lanka.
Goonawarna, C. L. W. P., Ratnapura, Sri Lanka.
Gorinsky, Peter Denis, Idar-Oberstein, W. Germany.
Goto, Midori, London.
Gould, Maurice Henry, Brunei.
Grant, William John Corrie, South Shields.
Grelick, Gary R., Buffalo, N. Y., U.S.A.
Grimbly, Margaret Susan, Plymouth.
Gunasekera, Aluthdura Anslem Winston Fernado, Kalutara, Sri Lanka.
Gunatilleke, G. A. E., Colombo, Sri Lanka.
Hacking, Peter Dennis, Accrington.
Hacquebord, Ronald Tjerk, Pretoria, S. Africa.
Haddy, H. J., Melville, W. Australia.
Hallauer, Rainer, Los Angeles, Cal., U.S.A.
Hallford, Dianna O., Hong Kong.
Hanni, Henry A., Basel, Switzerland.
Hansen, Lynette Carol, Johannesburg, S. Africa.
Harcourt-Wood, Ivan, Cape Town, S. Africa.
Hargreaves, Roy Compton, Sapphire, Australia.
Harris, Janet Elizabeth Anne, Adelaide, Australia.
Harris, Nancy Campbell, Bowie, Md, U.S.A.
Hatharasinghe, Swarnamali, Colombo, Sri Lanka.
Hayata, Yoshitoshi, Tokyo, Japan.
Hayes, Elizabeth Anne, Sheffield.
Henocq, James, South Croydon.
Henocq, Rosemary Shirley, South Croydon.
Hill, Orvin G., Malvern.
Hing, Tan Teong, Kuala Lumpur, Malaysia.
Holdroyd, Donna, Oslo, Norway.
Hori, Nagao, Tokyo, Japan.
Hornytzkij, Seppo, Helsinki, Finland.
Houghton, Linda Anne, Burnley.
Hoyos Guerrero, Miguel Angel, Madrid, Spain.
Huddlestone, Maria, Cape Town, S. Africa.
Hudspith, James Walter, Leatherhead.
Hughes, John Stanley, Reigate.
Hutson, Douglas Robert, Hornchurch.
Ikonen, Hilkka, Colombo, Sri Lanka.
Indra, Ratnasabapathy Maha, Colombo, Sri Lanka.
Indra, Srimevan Mohanraj Maha, Colombo, Sri Lanka.
Innes, Kenneth Raymond, Salisbury, Rhodesia.
Ip, Iau Tchum, Hong Kong.
Iqbal, Yath Mohamed, Colombo, Sri Lanka.
Ishak, Mohamed Mohideen Mohamed, Colombo, Sri Lanka.
Iyne, Tuan Fareeth, Colombo, Sri Lanka.
Jamous, Ezra Moise, Beirut, Lebanon.
Johnson, Frances Dorothea, Dallas, Tex., U.S.A.
Judez Martinez, Gregorio, Valencia, Spain.
Junquero Abellan, Ramon, Valencia, Spain.
Kandiah, Asokavathy Puivithavathy, Colombo, Sri Lanka.
Kavunanayake, Kodagoda Gam Acharige, Colombo, Sri Lanka.
Knowles-Brown, Andrew, Chesham.

Koivula, John Ilmarii, Seattle, Wash., U.S.A.
Koot, M. E., Schoonhoven, Holland.
Kothari, Navin, Jaipur, India.
Krol, James R., Troy, Mich., U.S.A.
Kull, Christian, Geneva, Switzerland.
Kull, Manfred W., Bonn, W. Germany.
Kume, Hiromao, Osaka, Japan.
Kuokkanen, Eune, Joensuu, Finland.
Kurata, Yukiko, Tokyo, Japan.
Langaard, Conrad, Hanau, W. Germany.
Lappalainen, Jorma, Lahti, Finland.
Lathpandura, Polgawage Don Gamini Gunasiri, Moratuloa, Sri Lanka.
Laurence, Carol May, Lourenço Marques, Mozambique.
Leach, Jane, London.
Lewis, Robert George, London.
Lezana Dominguez, Florentina, Barcelona, Spain.
Lezana Dominguez, Javier, Barcelona, Spain.
Lindstrom, Magnus, Stockholm, Sweden.
Lund, Gorm G., Oslo, Norway.
MacDonald, James Hartley, Herberton, Australia.
McLeod Gordon, Helen, London.
McRitchie Griffin, Bruce, Ashley Green.
Manchanayake, Sasanapala Kumaranatunga, Lunawila, Sri Lanka.
Manthregratna, Mallika Chandra, Mandawala, Sri Lanka.
Marchand, Hummer, Northampton, Mass., U.S.A.
Martinez Canales, Jaime, Barcelona, Spain.
Martinez Gamarra, Pilar, Barcelona, Spain.
Martorell Prat, Ramon, Barcelona, Spain.
Maryan, Mark, Northampton.
Mathiaparanam, Mathi Kumari, Colombo, Sri Lanka.
Mathiaparanam, Mathi Vathani, Colombo, Sri Lanka.
Mathiaparanam, Mailvaganam, Colombo, Sri Lanka.
Matsui, Reiko, Tokyo, Japan.
Mayling, Clifford George, Slough.
Mendis, Rowena, Colombo, Sri Lanka.
Miki, Kazuko, Osaka, Japan.
Mindry, Ernest Roy, Salisbury, Rhodesia.
Mitchell, Joyce Patricia, London.
Moline Sala, Agustin, Barcelona, Spain.
Moller, Peter John, Queensland, Australia.
Mollfulleda Buesa, Antonio, Barcelona, Spain.
Molten, Camille, Richmond, Va, U.S.A.
Montero Guerra, Ana Maria, Oviedo, Spain.
Montoliu Ferrer, Maria Carmen, Valencia, Spain.
Montserrat Nebot, Alfredo, Barcelona, Spain.
Mora, Carbonell, Antonio R., Valencia, Spain.
Moreno Garcia, Roberto, Madrid, Spain.
Moreno Humet, Luis, Barcelona, Spain.
Moses, Heather, London.
Munell Casini, Juan, Barcelona, Spain.
Murga Chivite, Miguel Angel, Lerida, Spain.
Nandalal, Ranasinghe Liyanage Upali, Angoda, Sri Lanka.
Naotunna, Ananda Sirisena, Kelaniya, Sri Lanka.
Narangoda, Shanaka, Ratnupura, Sri Lanka.
Nazeer, Mohamed Hussain Mohamed, Colombo, Sri Lanka.

Nightingale, Graham Jeffrey, Manchester.
Nisbet, Alistair Scott, Salisbury, Rhodesia.
Noor Deen, Mohamed, Colombo, Sri Lanka.
Nootenboom, Winnie Lee-Bing, Hong Kong.
Oliveiro, Esther Paola Marguerite, Curacao, Holland.
Olsen, Ole, Wimbourne.
O'Neil, Robert Lincoln, Brisbane, Australia.
Orford, Carl Victor, Broadstairs.
Oria, Albero, Isabel J., Valencia, Spain.
Oria Albero, Maria Paz, Valencia, Spain.
Osawa, Yukihiro, Tokyo, Japan.
Oyaguez Martinez, Domingo, Madrid, Spain.
Paddock, Orlando S., Dallas, Tex., U.S.A.
Padro Vers, Ramon, Manresa, Barcelona, Spain.
Palencia Fernandez, Carlos, Madrid, Spain.
Paulin, Per Philip Elon, Uppsala, Sweden.
Paulsen, Marie, Oslo, Norway.
Peace, Reginald Jewitt, Beverley.
Pedemonte Gonzalez, Maria Dolores, Barcelona, Spain.
Perceval, Gregor C., Fremont, Cal., U.S.A.
Perera, Ambagapathirige Mervyn Terrence, Panadura, Sri Lanka.
Perera, Nihal Kirihi Marinus, Hendela, Sri Lanka.
Perry, Charles John, Marple.
Phillips, Ian, Nottingham.
Pickering, Horace Ensor, Burton-on-Trent.
Pilley, Brian, London.
Pino Panades, Jose, Barcelona, Spain.
Pitigala, Chandra Rohan Wasanthakumar, Angoda, Sri Lanka.
Piyasundara, Pitigala Kankanange, Pelawatte, Sri Lanka.
Poel, Melvin Christopher, Solihull.
Pozas Ashton, Carlos, Barcelona, Spain.
Prat Moya, Maria Sagrado C., Barcelona, Spain.
Prickett, John Davidson, Auckland, New Zealand.
Puerta Semprum, Carmen Dela, Madrid, Spain.
Puiggali Fabregas, Jose Maria, Barcelona, Spain.
Punchihewa, Ranjith Susantha, Nugegoda, Sri Lanka.
Purushottam, Zaveri Rupesh, Bombay, India.
Quaak, E. P., Kraggenburg, Holland.
Rademaker, Elizabeth Johanna, Soest, Holland.
Rae, John Allan, Hong Kong.
Ralston, Jonathon Barry, London.
Ramalingham, A. S., Kandy, Sri Lanka.
Ramchandran, K. T., Bombay, India.
Ramos Rodriguez, Pedro, Madrid, Spain.
Ranasinghe, Mahesha, Yogoyans, Sri Lanka.
Ratmalana, Arthur, Sri Lanka.
Read, John Vernon, Transvaal, S. Africa.
Richards, Nancy Ann, New Brunswick, Canada.
Rimmer, Robert James, Southport.
Ripley, Evelyn, Stockton.
Robertson, Valerie Patricia, Sheffield.
Rodes Sole, Maria Dolores, Barcelona, Spain.
Rodrigo, Warnakulasuriya Richard Felix, Colombo, Sri Lanka.
Rodriguez Rodriguez, Julio C., Gijon, Oviedo, Spain.
Rooms, Paul Anthony, Florence, Italy.
Roye, Ann, Bolton.

Ruiz Roca, Jose Vicente, Valencia, Spain.
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Suriyawansa, Priyanthi Nerupamal De Silva, Galle, Sri Lanka.
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Valls Fontanals, Jose-Oriol, Barcelona, Spain.
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Zacher, Martin Paul, Crawley.
Zoppi, Marco, Flims-Dorf, Switzerland.

COUNCIL MEETING

At a meeting of the Council of the Association held on Monday, 6th October, 1975, the Council agreed to accept the "Rules of Application for the Diamond Trade", drawn up by CIBJO (Confédération Internationale de Bijouterie, Joaillerie et Orfèvrerie), which is the international organization for the jewellery trade in Europe, and these Rules will be observed in the Association's Courses and Examination Syllabuses.

At the same meeting the following were elected to membership:

Fellowship

Blasi Casal, Juan, Barcelona, Spain. D. 1974
Borgen, Per Otto, Krakeray, Norway. D. 1962
Canals Cadafalch, Montserrat, Barcelona, Spain. D. 1974
Carbonell Pujol, Rafael, Barcelona, Spain. D. 1972
Chantara, Kem, London. D. 1973
Costa Ramon, Maria, Llis de Vall, Spain. D. 1974
Crawley, Annette, Liverpool. D. 1975
Esquerra-Torrescasana Llobet, Jose, Barcelona, Spain. D. 1973
Gonzalez Gimenez, Anastasio, Barcelona, Spain. D. 1974
Majo Llopart, Miguel, Barcelona, Spain. D. 1974
Read, Peter George, London. D. 1975
Sidoli, Julien, London. D. 1959
Sweeting, Penny, London. D. 1975
Warr, David A., Gloucester. D. 1975

Transfers from Ordinary Membership to Fellowship

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Benjamin, John C., Wembley Park.
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Brooks, Ferriel M., Hong Kong.
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Yamazaki, Midori, Tokyo, Japan.
Yonekura, Eiko, Toyonaka-shi, Japan.
Yu-Yun Yue, Monica, Taipei, Taiwan.
Zdanowicz, Stanislaus, Warsaw, Poland.

GEM DIAMOND EXAMINATION 1976

The Association's post-diploma examination in Gem Diamonds will be held on 7th and 8th June in London and in Birmingham.

Prospective candidates for the examination should apply to the Association's Registrar for an entry form in January and the final enrolment date is 1st March, 1976.

Candidates are reminded that they should have passed the Association's Diploma examination before applying for the Gem Diamond examination.

CORRIGENDA

In J. Gemm., 1975, XIV, 8—

(1) on p. 364, sixth line from bottom of page, for "a sample current of 0·15 Ma" read "a sample current of 0·15μA":
(2) on p. 395, sixth and seventh lines from bottom of page, for "Antique fashioning of gemstones" read "Antique gemstone vessels":
(3) on p. 396, fifteenth line from bottom of page, for "the art of writing on them" read "the powers ascribed to them".

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and

PROCEEDINGS OF THE
GEMMOLOGICAL
ASSOCIATION
OF GREAT BRITAIN

GEMMOLOGICAL ASSOCIATION
OF GREAT BRITAIN
SAINT DUNSTAN'S HOUSE, CAREY LANE
LONDON, EC2V 8AB

GEMMOLOGICAL ASSOCIATION OF GREAT BRITAIN

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THE JOURNAL OF GEMMOLOGY
AND PROCEEDINGS OF THE GEMMOLOGICAL ASSOCIATION OF GREAT BRITAIN

Vol. XV No. 2 APRIL 1976

THE TWENTY-FIVE LARGEST DIAMONDS IN THE CROWN JEWELS OF IRAN

By G. G. WAITE, B.A.Sc.,

Research Associate, Royal Ontario Museum, Toronto, Canada.

TWENTY-FIVE DIAMONDS, each exceeding fifty metric carats in weight, are listed and described in the accompanying table, which was prepared so as to clarify certain descriptive errors which have appeared in recent literature. Each diamond is illustrated and the number on each photograph is keyed to the table. This information has been abstracted from data accumulated in 1966, when the team from the Royal Ontario Museum made their protracted study of the Crown Jewels of Iran (Meen and Tushingham, 1968).

To Nasir ud-Din Shah (1848–1896) is due the acquisition and fabrication of most of the large diamonds of South African origin. In fact the cutting was done in the Golestan Palace by European cutters imported for that purpose. The diamonds of Indian origin were acquired by Nadir Shah in 1739.

The Table follows on pages 54 and 55, and the photographs are on pages 56 to 61.

Item	*Photo No.*	*Weight (metric carats)*	*Dimensions (mm)*	*Cut*	*Colour*	*Fluorescence*	*Source*	*Remarks*
1	79	51·90	31·67 × 24·19 × 6·55	Mogul	colourless	bluish	India	large flat back, worn slightly
2	130	53·50	21·75 × 22·92 × 15·00	Cushion brilliant	silver cape	medium blue	S. Africa	several inclusions
3	41	54·35	22·30 × 20·04 × 14·40	Rectangular brilliant	slightly peach	none	India	resembles "Cairo Cut" but of 8-fold symmetry
4	39	54·58	24·69 × 21·83 × 12·27	Mogul	colourless	none	India	quite clean
5	57	55·67	21·00 × 21·50 × 15·75	Cushion brilliant	cape	very slight	Africa	very clean, very brilliant
6	56	56·19	21·78 × 22·87 × 15·52	Cushion brilliant	silver cape	very slight	S. Africa	very clean
7	47	57·15	22·20 × 22·50 × 14·90	Cushion brilliant	silver cape	faint blue	S. Africa	small table, very clean
8	121	57·85	23·41 × 23·86 × 15·77	Brilliant	silver cape	slightly blue	Africa	modern proportions, clean
9	R9N4	60 (est.)	*c.*25·80 × 14	Square brilliant	yellow	—	?	very clean
10	R16N22A	60 to 65	31·50 × 27	Oval brilliant	pink	—	India	The Nur ul-Ain, believed part of Tavernier's Great Table, very limpid
11	46	65·65	25·43 × 22·67 × 16·75	Rectangular brilliant	cape	very slight bluish	S. Africa	very clean
12	38	72·84	25·90 × 22·03 × 13·97	Mogul	slightly champagne	greenish blue	India	clarity exceptional

13	R16N25A (right)	75 (est.)	32·80 × 23·80	Pendeloque brilliant	silver cape	—	S. Africa	nearly clean
14	R16N25A (left)	75 (est.)	32·80 × 24·80					
15	45	75·29	23·43 × 23·33 × 17·70	Cushion brilliant	cape	faint blue	S. Africa	very clean
16	44	78·96	25·40 × 22·65 × 17·92	Rectangular brilliant	cape	very slight bluish	S. Africa	very clean
17	66	86·28	24·50 × 26·00 × 16·10	Mogul	silver cape	strong blue	?	quite clean, large natural at girdle
18	43	86·61	30·92 × 13·34	Triangular brilliant	cape	slight blue	Africa	12-fold symmetry
19	52	114·28	27·80 × 27·94 × 20·62	Rectangular brilliant	silver cape	very faint	S. Africa	slight feathers & chips at girdle
20	37	115·06	32·03 × 24·28 × 14·74	Mogul	colourless	blue	India	very clean. The Taj-i Mah
21	53a & b	121·90	29·0 & 29·10 (point to point measurements)	Overall faceted octahedron	cape	very slight	S. Africa	symmetrical octahedron very clean
22	54	123·93	27·10 × 25·32 × 21·44	Rectangular brilliant	silver cape	very slight blue	S. Africa	very clean, naturals on girdle
23	42	135·45	31·67 × 26·70 × 21·00	Rectangular brilliant	cape	none	S. Africa	extra culet facets, very brilliant
24	51	152·16	31·75 × 28·10 × 20·40	Rectangular brilliant	silver cape	very slight	S. Africa	elaborately faceted girdle
25	R9N1	185 (est.)	41·40 × 29·50 × 12·15	Step Tablet	pink	blue	India	flawless. The Darya-i Nur

J. Gemm., 1976, XV, 2

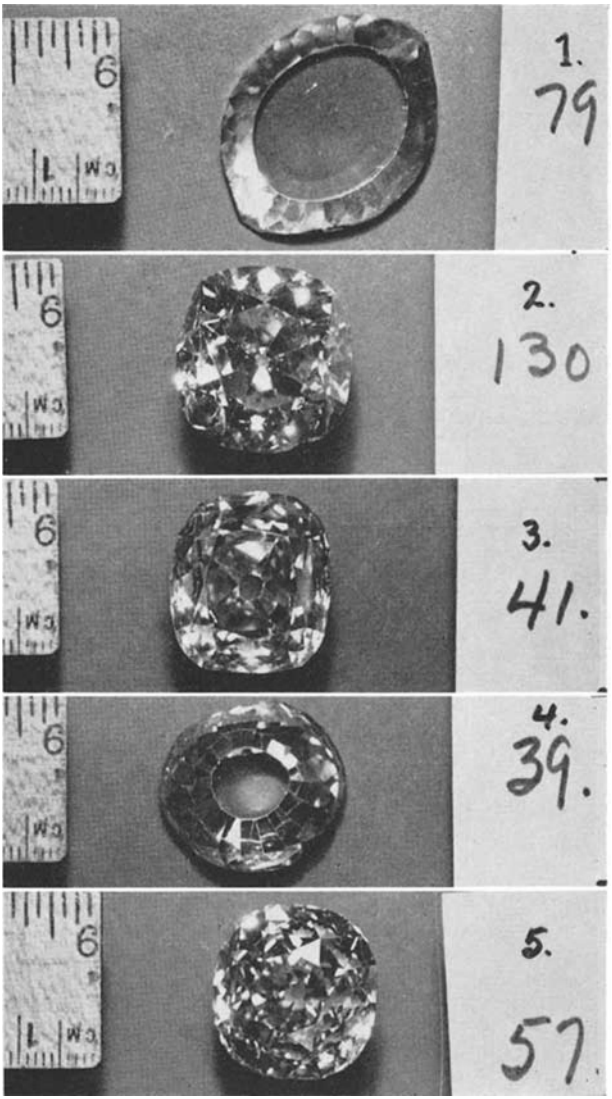

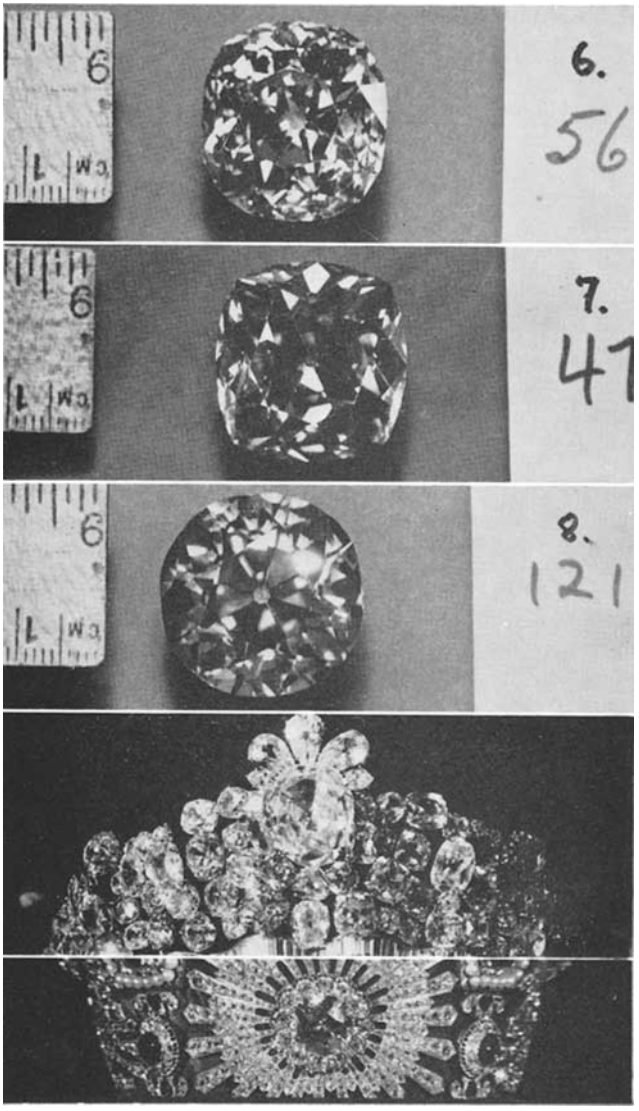

9.
R9N4

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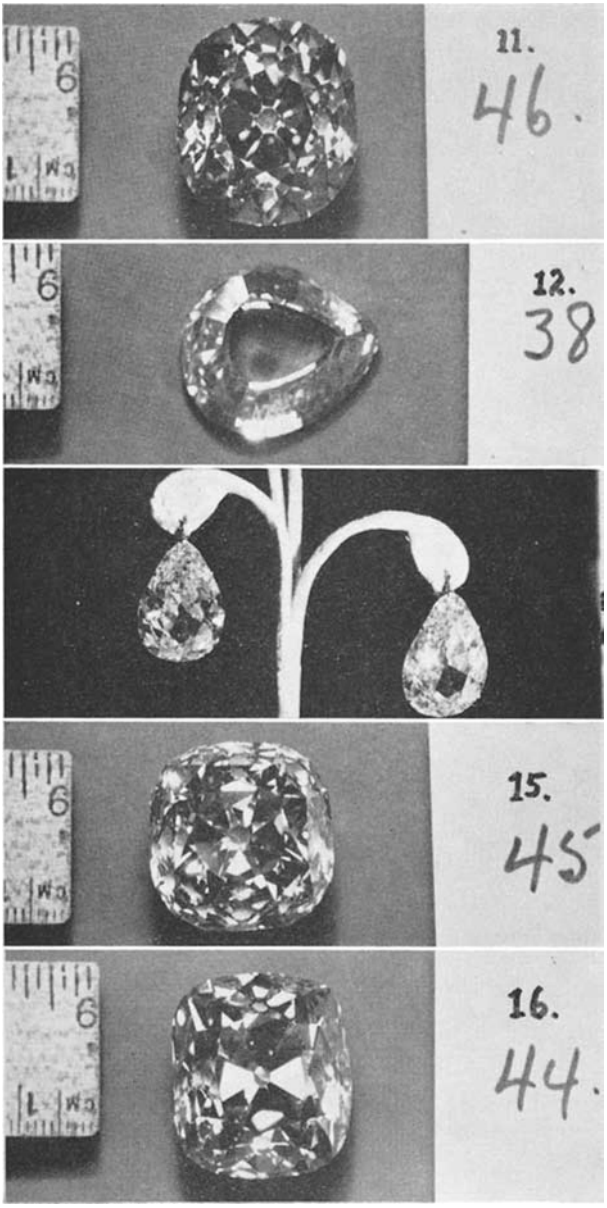

13 (right)
14 (left)
R16N25A

17.
66

18.
43

19.
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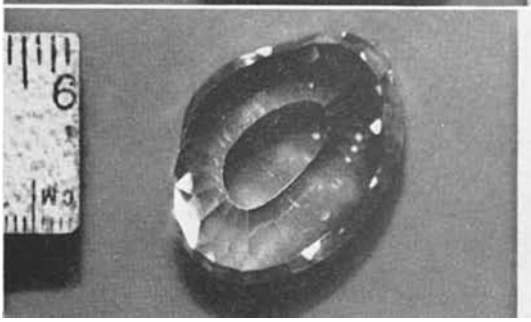

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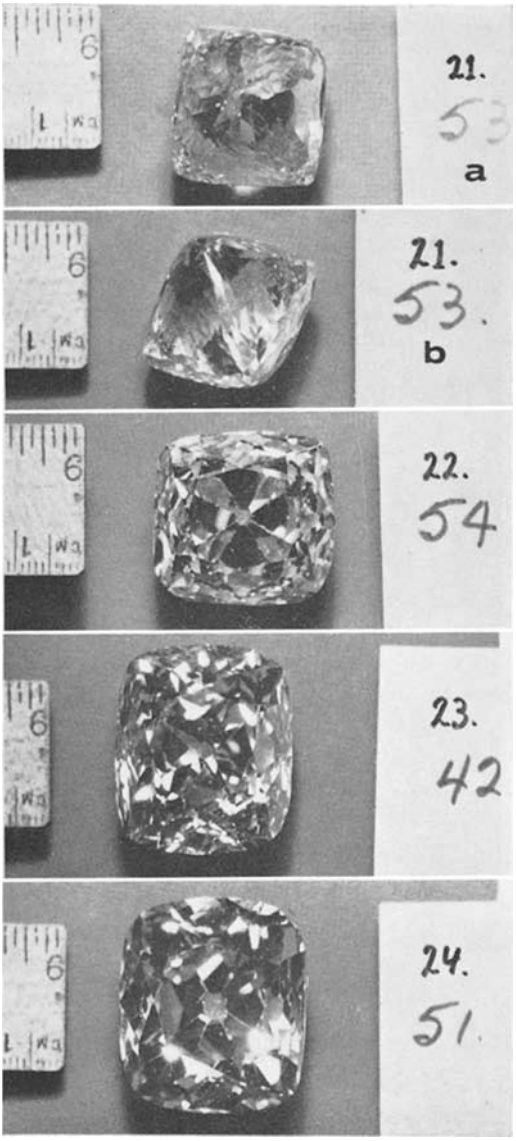
21.
53
a
21.
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b
22.
54
23.
42
24.
51.

Item 25. Photo No. R9N1. The Darya-i Nur.

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(Evidence is provided for a possible resolution of the weight discrepancy of Tavernier's Great Table and the Darya-i Nur together with that of the Orloff and the Great Mogul.)

NOTES ON GILSON SYNTHETIC WHITE OPAL (September 1975)

By KENNETH SCARRATT, F.G.A.
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RECENTLY the Laboratory received on loan from a well-known Hatton Garden stone-merchant a Gilson synthetic opal and another synthetic opal said to be of a new type also manufactured by Monsieur Gilson. Both stones were of the white variety with a good play of colour.

To see if the structure lines of the new opal differed in any way from what we have come to regard as the diagnostic structure lines for Gilson opals, I examined it at first on low-power magnification under the Gemolite microscope with the diaphragm partially closed, ensuring that all light passed through the stone. I observed that the main colours of the stone with transmitted light were green, of a matt texture, and a strong red and orange (by reflected light some of the red and orange areas changed to blue and green, and some of the green areas changed to a greyish-blue). The overall structure of the stone looked similar to the "diagnostic" structure: however, a difference was revealed when I used a high-power magnification. The difference lay in the structure lines within each colour segment. Figure 1 shows the structure lines seen within a yellow segment of the original Gilson synthetic white opal. As can be seen, these resemble skin stretching around a healing scar. Figure 2 shows the structure lines within an orange segment of the new synthetic opal. I think that these structure lines may be described as resembling crazy paving.

Having noted this difference, I continued my examination of the stone. Visible from the back of the stone was a central white core. The core had a perimeter similar to the banding seen in agate, and, although it had a play of colour, it was weak in comparison to the rest of the stone. Because of this, I felt further investigation into this new stone was necessary. I approached another leading Hatton Garden stone merchant who very kindly loaned me six natural white opals of the same quality and colour as the two synthetics.

I then proceeded to see if there was any difference in the long wave or short wave ultra-violet transparency of these eight stones.

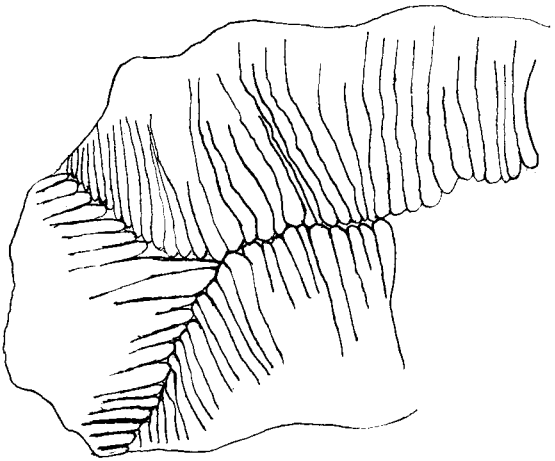

FIG. 1. The structure lines observed in a yellow segment of the original Gilson synthetic white opal.

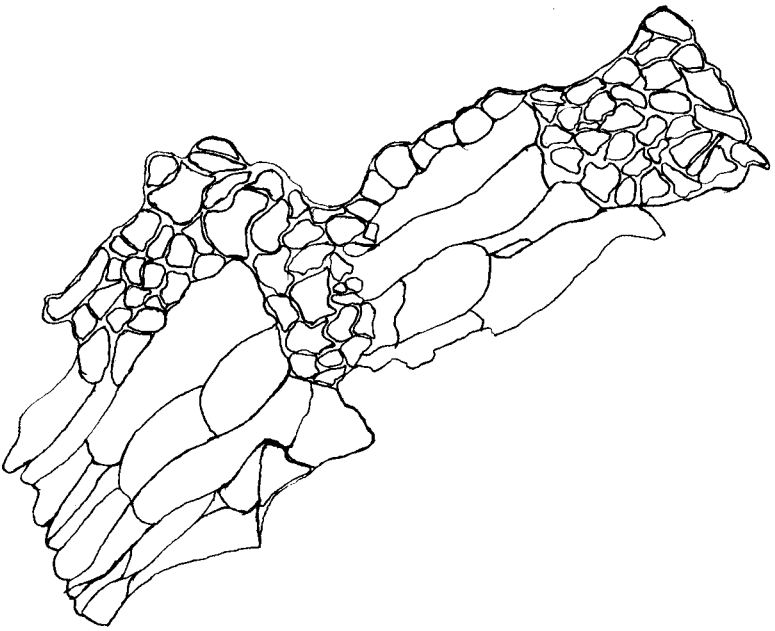

FIG. 2. The structure lines observed in an orange segment of the new synthetic white opal.

I tried 4, 6 and 8 second exposures on each wavelength at a height of 12 inches, the stones immersed in ordinary tap-water. The resulting photographs revealed that they all had the same degree of transparency.

To see if there was any difference in the specific gravities of the two synthetic opals, I made up a liquid consisting of methylene iodide and toluene in which the six natural opals sank slowly. I then put in the original Gilson opal—it floated. The new type Gilson synthetic, however, when placed in this liquid, floated for approximately 30 seconds, gradually absorbed the liquid, and then sank. Realizing that this stone had obviously taken in a considerable amount of the liquid, I removed it immediately and placed it once again under the Gemolite microscope. There was a substantial loss of colour from all colour segments and the structure as previously described had been enhanced. Over a period of approximately 2½–3 minutes, because of the heat emitted by the Gemolite light source, the colours and the structures gradually returned to their original strengths. I then examined all seven other opals to see if they had a similar reaction after being immersed in this liquid—they had not. Because of the difference in specific gravity between the original Gilson synthetic and the six natural opals, and the curious behaviour of the new synthetic, I decided to take hydrostatic measurements of their specific gravities. The Gilson had a specific gravity of 2·05 and the natural stones 2·07. The new type of synthetic, as is understandable, was rather more difficult because of its absorption properties: however, a calculation taken from its lowest weight in water revealed a specific gravity of 1·97. The increase in weight while in water over a period of 2½ minutes was 0·022 carats, which is considerable in a stone with a total weight of only 1·28 carats.

I left the stone for a period of 24 hours and then decided to see if its absorption in the heavy liquid had affected its transparency to short wave ultra-violet light. An exposure of 4 seconds at a height of 12 inches revealed, as can be seen in (Fig. 3), that the new opal was now opaque to this wavelength. Obviously some of the heavy liquid had remained within its structure. At this point, the quality of the stone had not been affected, but I felt, however, that further examination along these lines could do some damage. As the stone was not the property of the Laboratory I terminated my examination. My reasoning for this decision may be amply explained by

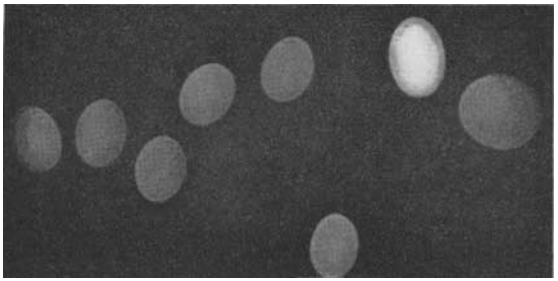

FIG. 3

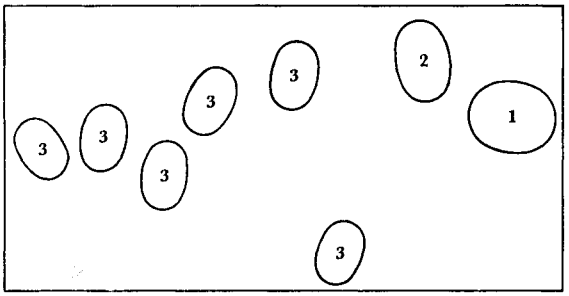

1—Gilson synthetic Opal
2—New type synthetic Opal
3—Natural Opals

drawing attention to an article in *Gems and Gemmology*, Spring 1975, * by Richard T. Liddicoat, Jr, in which a permanent colour loss is recorded in what was assumed to be a porous Mexican white opal.

In conclusion, if this stone is typical in its absorption properties of the new type of synthetic, it can be said that extreme caution must be observed by all merchants dealing in it, and of course a warning must be given to anyone attempting to clean an item of jewellery in which this stone is set.

*Gems Gemol., **XV**, 1, 26.—Ed.

INTERNAL STRUCTURES AND IDENTIFICATION OF GILSON SYNTHETIC OPALS

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THE French chemist, Pierre Gilson, has been synthesizing gemstones for some years now, and we have recently had the opportunity to examine a number of his synthetic opals. His latest opals, both black and white, were so convincing—almost too good to be true—that we felt it desirable that some of their internal structural features should be more generally known. Our survey includes Gilson synthetic opal cabochons obtained in London from early 1974 until December 1975.

FIG. 1. Synthetic black opal (Gilson, early 1974) showing longitudinal banding, with some "herring-bone" structure; note "equigranular" appearance near bottom of photograph. ×4·5, reflected light.

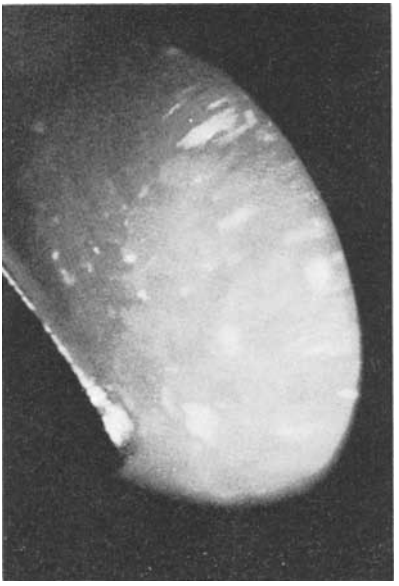

FIG. 2. Synthetic white opal (Gilson, late 1974) showing columnar structure extending from girdle; note "equigranular" texture on top of stone. ×8, reflected light.

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FIG. 3. Synthetic white opal (Gilson, late 1974) showing "equigranular" mosaic. ×5, transmitted light.

FIG. 4. Synthetic white opal (Gilson, Nov. 1974) showing "dendritic" line structure or "healed-scar" effect. ×13, transmitted light.

FIG. 5. Synthetic white opal (Gilson, Sept. 1975) showing broadly "equigranular" texture, overall milkiness, and turbid central patch. ×5 reflected light.

FIG. 6. Synthetic white opal (Gilson, Nov. 1975) showing pinkish-buff matrix colour, pale pink, blue and yellow patches and "dried leaves" effect. ×4, transmitted light.

FIG. 7. Synthetic white opal (Gilson, Nov. 1975) showing "lizard skin" effect. × 12, transmitted light.

FIG. 8. Synthetic black opal (Gilson, Dec. 1975) showing "lizard skin" effect and crenulate margins. × 12, reflected light.

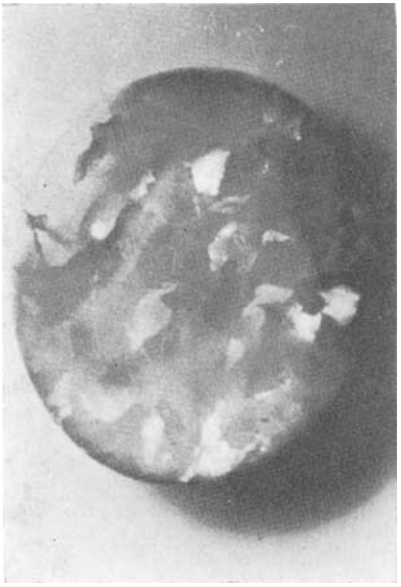

FIG. 9. Synthetic white opal (Gilson, Nov. 1975) immersed in chloroform showing transparency spreading from girdle at top left. × 5, reflected light.

FIG. 10. Synthetic white opal (Gilson, Nov. 1975) immersed in chloroform for 2 minutes showing transparent margin and turbid central patch; note iridescent areas (showing as light patches). × 5, reflected light.

The synthetic black opal (early 1974) is quite characteristic, showing well-defined longitudinal bands with some fine striae along their length and some at oblique angles giving rise to "herring-bone" patterns between adjacent bands (see Fig. 1). The transverse section of the longitudinal bands (where it can be seen near the girdle) shows an equidimensional mosaic similar to the overall appearance of the later Gilson opals. Surface blemishes resemble evaporated drops of water on glass. These opals are transparent to some degree and show a dark brown body colour.

Seen by transmitted light the white opal cabochons (late 1974) display a pronounced "equigranular" texture (many "grains" are around 0·75 mm across, but generally in the range 0·5—1·5 mm) resembling a quartzite in thin section if viewed from above or below (see Fig. 3). However, the side elevation (Fig. 2) shows the columnar structure which seems to be characteristic of opals of this date. The general colour effect by transmitted light is produced by the pinkish-buff matrix, but patches of "washed-out" pale pink, greenish-blue and yellow are also evident (see Fig. 3). Natural opals that we have examined recently usually do not show this colour variation, but range from shades of very pale yellow to brownish-orange in transmitted light. By reflected light the earlier synthetic opals show patches of colour in a turbid matrix. In these and later synthetic opals the mosaic pattern appears to remain static with changing viewpoint and at certain angles almost the whole area of the base shows one colour by suitable reflected light. In contrast, in many natural opals the iridescent pattern appears to change shape and depth to a varying degree as the viewpoint is altered.

Synthetic white opals obtained in November 1974 also show an equidimensional aspect, but with coarser "grains" generally in the range 0·5—2·5 mm, many around 1·5 mm across. The general appearance by transmitted light is again of a pinkish-buff matrix with pale bluish and yellow areas; however, the overall appearance gives the impression of dried leaves, caused by the twisted shadows at "grain" interfaces. Greater magnification (see Fig. 4) of the material reveals the "dendritic" pattern resembling rivers with their many tributaries in hill and valley country—a feature described by Scarratt (1976). The columnar structures previously described are still present, and it is possible to identify a characteristically shaped "grain" on the top of the stone and to recognize a similarly shaped

FIG. 11. Synthetic white opal (Gilson, Nov. 1975) showing mosaic, "lizard skin" effect and overall iridescence in yellow-green. ×4, reflected light.

FIG. 12. Synthetic black opal (Gilson, Dec. 1975) showing mosaic with distinctly crenulate boundaries and "lizard skin" effect. ×4, reflected light.

FIG. 13. Synthetic black opal (Gilson, Dec. 1975) showing mosaic with distinctly crenulate boundaries and "lizard skin" effect. ×4, reflected light.

FIG. 14. Synthetic black opal (Gilson, Dec. 1975) showing "lizard skin" effect and crenulate margins. ×12, reflected light.

"grain" on the under-surface, a reasonable indication that the column extended from top to bottom of the cabochon.

Specimens of synthetic white opal obtained in September 1975 also appear generally equidimensional, but with more irregular boundaries to the mosaic. One stone (see Fig. 5) has a very turbid centre patch (see Scarratt 1976). At higher magnification fine lines are evident in the reflected coloured surfaces, sets of lines sometimes intersecting at angles reminiscent of amphibole, pyroxene or calcite cleavage traces.

The latest white opals (obtained in November 1975) also show an equidimensional aspect with a mosaic to 3 mm across or more, and with finely crenulate boundaries to the "grains" (see Fig. 11). On magnification (by reflected and transmitted light) the "grains" show a distinctive pattern resembling lizard skin or fish scales (see Fig. 7). The columnar structure seen in earlier white opals is still discernible but greatly reduced in its impact. By transmitted light the overall pale pinkish-orange colour and the pale bluish and yellow patches are still apparent, as is the "dried leaves" effect (see Fig. 6). An overall milkiness or turbidity is discernible by transmitted light, but becomes very noticeable by reflected light, adjacent "grains" often displaying different degrees of turbidity with the "lizard skin" effect apparently superimposed.

The latest (December 1975) synthetic black opals are very striking in appearance. In contrast to earlier material they are almost opaque and only transmit light (a very dark brown) on the thinnest of edges. By reflected light (see Figs. 12 and 13) they show a generally equidimensional mosaic with distinctly crenulate margins to the "grains" (cf. the white opals of November 1975). Magnification reveals the presence of the distinct "lizard skin" effect (see Fig. 14). By reflected light, areas which are not orientated to show a play of colour, show a milky effect "superimposed" on the general dark matrix colour.

Many, if not most, gemmologists will have convinced themselves that they can recognize natural opal at a glance, but nevertheless, they may not be familiar with the detailed appearance of the iridescent patches when magnified. Therefore, we show patterns seen in several natural opals at our disposal, but these patterns are but a small fraction of the various possibilities (see Figs. 15 to 18).

The synthetic white opals examined showed a very weak off-white (often bluish-white) fluorescence under short-wave (2357Å)

FIG. 15. Natural opal, showing mosaic with some "albite twinning" structures. × 7·5 reflected light.

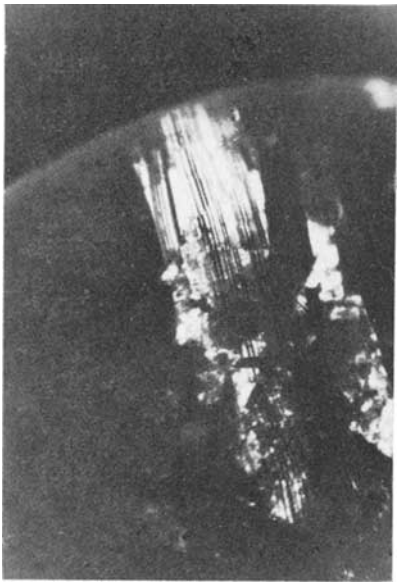

FIG. 16. Natural opal, enlarged view of "albite twinning" structure. × 30, reflected light.

FIG. 17. Natural black opal showing iridescent areas with intersecting sets of parallel lines. × 6·5, reflected light.

FIG. 18. Natural white opal showing typical irregular ragged iridescent areas. × 12 reflected light.

UV light; a stronger, generally whitish, fluorescence was observed under long-wave (3650Å) UV radiation, with a short greenish phosphorescence which could only be seen after the eyes had become dark adapted. The synthetic black opals examined were inert. Not all the natural opals examined fluoresced, but others showed a strong (usually whitish) fluorescence, brighter under long- than short-wave radiation, and a strong, readily visible, persistent phosphorescence following long-wave irradiation.

In view of the known porosity of some opal we were reluctant to carry out refractive index measurements using the normal dark coloured, halogen-bearing contact liquids; instead we used the colourless liquid benzyl benzoate (R.I.1.567) and obtained a series of readings by direct and distant vision techniques. However, since there were no really plane surfaces good results were not forthcoming but were within the range 1·45 to 1·47 for the synthetic opals tested.

To remove quickly the small residual mark caused by the benzyl benzoate it was decided to wash one opal in pure chloroform, which has a similar refractive index (1·45) to opal. On immersion the test stone immediately appeared to lose some iridescence and became more milky. Within 30 seconds the girdle of the stone became transparent (see Fig. 9), showing only iridescent patches and resembling water opal. The transparency spread quickly towards the centre of the stone and within 2 minutes one half the width of the stone was transparent (see Fig. 10), showing an extremely pale yellowish body colour. These changes were accompanied by the vigorous emission of tiny bubbles. After 15 minutes the transparent area extended across two thirds of the width of the stone, but the central turbid patch did not diminish further after 30 minutes immersion.

On removal from the chloroform the stone immediately regained a milky appearance, and the base seemed normal within 2 minutes, although it took 14 minutes to dissipate all traces of transparency from the curved top of the stone, the joints in the mosaic pattern being outlined in white at one stage during the drying out process. The original appearance of the stone was completely restored after evaporation of the chloroform.

The other synthetic opals examined also became transparent on immersion in chloroform, but the size and shape of the residual milky patch and the rate of change were somewhat variable. Black synthetic opals immediately lost iridescence on immersion followed

by some loss of turbidity, and then appeared as sombre, dark brown, translucent cabochons sometimes with black spots or other markings. They quickly regained their beauty on removal from the chloroform.

The use of chloroform as an immersion liquid with similar refractive index to opal obviously helps to achieve transparency and it appears that the abundant pores of the synthetics rapidly fill with chloroform—the air being dispersed as bubbles. It would seem that the milky appearance of these opals is directly related to the high porosity, light being reflected or diffused at the surfaces of the minute pores.

For comparison, a series of both black and white natural opals was then immersed in chloroform. In general there was a slight loss of iridescence with an apparent increase in turbidity, and the margins of the stones were, of course, less well-defined when viewed in the chloroform. In the stones examined we saw no spread of transparency as seen in the synthetics and it would appear that in the stones tested the solvent penetrates to a more limited extent or not at all, indicating that the Gilson synthetics are more porous than their natural counterparts which were tested. The fact that the synthetics adhere to the tongue (indicating high porosity) whereas the natural stones tested did not, bears out the differences in porosity.

It is tempting to suggest that behaviour on immersion in chloroform is a useful guide in the testing for Gilson synthetics, but considerable caution should be exercised since chloroform is a very powerful solvent (and anaesthetic!) and could damage the cement of any doublet (its true nature possibly concealed by a setting) subjected to this treatment, and could carry any surface contaminant into the pores of the opals.

Summary

The following properties of Gilson synthetic opals appear to be worthy of note, and taken together should assist in their identification:

1. The stones show a broadly equidimensional mosaic viewed from above or below.
2. Many white synthetic opals show a pronounced columnar structure viewed from the side.
3. Some white synthetic opals show a distinct "dendritic" structure at higher magnifications by transmitted light.

4. By transmitted light the overall pale pinkish-buff matrix colour is interspersed by patches of pale pink, greenish-blue and yellow.
5. By transmitted light there is often a "dried leaves" effect caused by discontinuities between adjacent "grains".
6. In later black and white synthetic opals a "lizard skin" or "fish scale" effect is seen on magnification, both by transmitted and reflected light.
7. Many Gilson opals have high porosity and tend to absorb liquids rapidly, and in this connexion it has been noted that the synthetics tend to stick to the tongue, whereas many natural stones do not to the same extent.
8. Many Gilson opals become transparent on immersion in chloroform (and possibly other solvents also).

It is a pleasure to acknowledge the ready help and co-operation of our colleagues in the Institute and at the Gem Testing Laboratory during this work. We are particularly indebted also to Mr J. A. Fleming, Mr E. A. Thomson and to Mr M. O'Donoghue for the loan of specimens.

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ON GEM RHODONITE FROM MASSACHUSETTS, U.S.A.

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INTRODUCTION

Rhodonite, $MnSiO_3$, occurs as massive gem material, well suited to carving and the cutting of cabochons, at many places in the U.S.A. Foremost among these are the deposits of Rosamond, California, and Plainfield, Massachusetts. The present paper discusses the Massachusetts occurrence of this beautiful gem material.

Fine gem-quality rhodonite was discovered in Cummington, Massachusetts, about 1825, has been recovered from the area steadily for the last 150 years, and is still available at this writing. For early descriptions of the deposit, the reader is referred to the works of Hitchcock (1825) and Nash (1827).

LOCATION

The deposit is located in a small village, Plainfield (population 562), which snuggles in the gentle foothills of the Berkshire Hills of Hampshire County, in western Massachusetts. Plainfield is about 24 miles north-west of Northampton. The deposit is located on the property of the Betts family, and is known locally as the Betts manganese mine.

The rhodonite is found here at the contact of the Hawley and Savoy schists and has been recovered as a by-product of the bedrock mining of rhodochrosite and from glacially-distributed boulders strewn through the adjacent town of Cummington, where the material was first found in glacial boulders. The material, both in the boulders and at the outcrop, is black in surface colour due to oxidation of the manganese.

Kunz (1891) describes the removal of blocks of rhodonite weighing several hundred pounds each, which "were equal in quality and beauty to the Russian rhodonite."

The name rhodonite is from the Greek *rhodon* (*ῥόδον*), in allusion to its beautiful pink colour. Older specimens sometimes bear the local name "Cummingtonite," but this name should be dropped. Cummingtonite is a legitimate species name for a magnesium amphibole $(Mg,Fe)_7Si_8O_{22}(OH)_2$, first described from Cummington, Massachusetts, which is the type locality.

MINERALOGY

The Plainfield rhodonite is intimately associated with quartz, rhodochrosite, kutnohorite, secondary manganese oxides (chiefly pyrolusite), and minor amounts of pyrite and galena. The black manganese oxides coat all natural exposures of the material and large boulders of rhodonite may have up to several inches of black-coloured material on the surfaces. The black areas run in veinlets throughout much of the pink rhodonite, giving a very pleasing visual effect and adding to the appeal of the material. Although this dense outer rind of black material appears to be a separate phase, it is, in fact, oxidized rhodonite and gives an x-ray powder pattern of rhodonite with no extraneous lines. Very thin black coatings of manganese oxides are usually found on the outermost surface of this black rhodonite.

The colour of the Plainfield rhodonite varies from a deep reddish pink to very light pink. More rarely encountered are zones of orangish material, which resemble the spessartine associated with rhodonites from Madagascar, but these are zones of orange rhodonite. The variation is noted above only for completeness. Actually, most Plainfield rhodonite is a very uniform pink colour. Also attractive are veins of rhodonite ($\sim 1{\cdot}0$ cm wide) in the surrounding quartz. White spots as irregular segregations are encountered but are not abundant in the material. The majority of these white areas are fine-grained kutnohorite, $Ca(Mn,Mg,Fe)(CO_3)_2$, and are easily distinguished from the white quartz by the inferior polishing hardness of the kutnohorite, which has a relatively dull lustre, both in rough and polished samples.

The texture of this rhodonite varies slightly. Most of the material is a dense intergrowth of microcrystals, but some less dense, friable material is also found. In general, the Plainfield material conforms to the observation of Sinkankas (1959) in that both the richness of colour and the transparency go hand-in-hand with the compactness of the material. The more friable rhodonite has a much lighter colour and a higher degree of opacity. Rhodonite is a very tough material, due to the intergrowth of microscopic crystals, and this high tenacity adds to the gem potential of the material. Due to this toughness (approaching that of jadeite in some samples), the Plainfield rhodonite lends itself well to carving. According to Kunz, some "polished specimens of thin-cut stones and a vase were shown in Tiffany's exhibition of gems at the Exposition in Paris" (Emerson, 1895, Pers. Comm. from Kunz).

TABLE I. ANALYSES OF RHODONITE

NMNH #	SiO_2	Al_2O_3	FeO**	MgO	CaO	ZnO	MnO	Total	Colour
67950–2	46·25	0·00	6·34	0·43	2·75	0·25	43·67	99·69	Light pink
67950–1	46·21	0·03	4·74	0·26	2·72	0·27	45·45	99·68	Light pink
121258	47·21	0·04	4·72	0·52	3·10	0·28	44·50	100·37	Light pink
103735	46·07	0·02	3·98	0·30	4·06	0·26	44·56	99·25	Pink
44774	46·22	0·01	3·90	0·28	4·23	0·19	44·26	99·09	Pink
45004	46·26	0·03	3·85	0·34	3·72	0·24	44·67	99·11	Pink
82439–1	45·98	0·01	3·45	0·23	3·55	0·22	45·55	98·99	Pink
132707	46·60	0·02	3·43	0·35	4·24	0·26	45·16	100·06	Light pink*
R14464	46·98	0·04	3·39	0·29	3·67	0·32	45·62	100·31	Pink
82439	45·36	1·88	2·93	0·26	3·72	0·24	44·84	99·23	Pink
105214	46·84	0·02	2·72	0·22	2·37	0·30	48·02	100·49	Light pink
105214	45·76	0·02	1·71	0·19	3·90	0·24	47·23	99·05	Orange
105214	47·04	0·03	1·67	0·14	4·07	0·20	46·93	100·08	Black
Theoretical	45·90						54·10	100·00	
Hermann (1849)***	48·91		tr	2·35	2·00		46·74	100·00	
Schlieper (1850)	51·21		4·34	tr	2·93		42·65	101·13	

Analyses accurate to ± 2% of the amount present.
All samples have less than 0·20 Na_2O and K_2O.
*—Partially decomposed.
**—Total iron calculated as FeO.
***—Calcium and magnesium values were accidentally reversed in Dana (1850).

Chemistry

Two previous analyses of the Plainfield rhodonite exist and are shown in Table I. Inasmuch as the analysis of Schlieper (1850) indicated iron was present, but Hermann (1849) found only a trace of iron and considerable magnesium, it was decided to analyse some samples of this gemmy rhodonite to determine the limits of variation in the composition.

Thirteen samples were analysed using an ARL-SEMQ electron microprobe utilizing an operating voltage of 15 kV and a beam current of 0·15 μA. Standards used were analysed rhodonites in the collection of the Smithsonian Institution. A tabulation of these analyses is given as Table I.

The compositional variation in Plainfield rhodonite is minor, with the major fluctuation being the amount of iron substituting for manganese. Iron varies from 1·67% to 6·34% FeO. In general, the colour of the pink rhodonite does not vary consistently with the iron content. Calcium substitution is limited and varies between 2·37% and 4·24% CaO. Those rhodonites with the lighter hues of pink do have a lower calcium content, but there is no firm evidence of relationships between colour and composition for this gem rhodonite. The analysis of Hermann (1849) is not representative of the Plainfield rhodonite. The presence of magnesium in his analysis suggests that there may have been admixed kutnohorite in his sample.

Not abundant, but occasionally encountered, are lenses within the rhodonite. They have a distinctly zoned structure; black to grey in the centre and surrounded by an orange phase. Both the black and the orange phases are rhodonite but do vary in composition from the common pink material. Both the black and orange zones of these lenses are relatively low in iron (1·67% and 1·71% respectively) when compared with the pink material. One sample with a lens as described above (# 105214) was analysed in the present study, and the analyses of the separate zones are given in Table I.

Summary

Rhodonite from Plainfield, Massachusetts, is a very beautiful ornamental gem material, with a relatively uniform colour. It is ideally suited to carving due to its toughness and is a superb cabochon material. The black veining provides a very attractive

contrast to the pink body-colour and heightens the visual appeal of the mineral.

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A NOTE ON THE OCCURRENCE OF EMERALD AT MAYFIELD FARM, FORT VICTORIA, RHODESIA*

By SUSAN ANDERSON, B.Sc., F.G.A.

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EMERALD is currently being produced from a new locality in Rhodesia. The beryl claims are situated in the north-west corner of Mayfield Farm, approximately 12 km north-east of the town of Fort Victoria. The Mayfield Beryl Block was first pegged and registered in 1970 and is now owned and operated by Callock (Pvt.) Limited, who kindly loaned the material discussed in this report.

Geology

The beryl at Mayfield was apparently formed in a hydrothermally emplaced glassy quartz reef that is conformable with the country rocks. Pale green euhedral beryl and kaolinized feldspar occur in the reef quartz. The material of gem interest is found in a rubble zone and the hanging and foot-wall ultramafic schists contacting the quartz. These country rock schists were formed by potassium metasomatism of serpentinite as a result of the hydro-

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thermal activity. On average the rocks contain 0·15% chromium and vary mineralogically from predominantly biotite-phlogopite schists to rocks that additionally contain tremolite, hornblende, talc and chlorite. Apart from outcrops of serpentinite and granite near the mine, exposure is poor, and is limited to the main open-cut and several trenches. The group as a whole is an ultramafic remnant of the Precambrian Basement Complex enveloped as inclusions in granite from which emanated the beryllium-bearing quartz vein material.

Mineralogy

Refractive index determinations were made by the oil immersion method in monochromatic sodium light using a Leitz-Jelly refractometer. The refractive indices are:

extraordinary ray—1·589 (±0·001)
ordinary ray—1·584 (±0·001)

Birefringence is 0·005.

Insufficient material was available for confident specific gravity determinations: however, one reading obtained using a pycnometer is 2·72.

Spectrographic analysis of the emerald shows:

Nickel %	*Chromium* %	*Copper* %	*Iron* %
0·02	0·20—0·25	0·02	0·5
		(Analyst: I. H. Green)	

No absorption spectrum was noted with a hand spectroscope, although strong bands centred at 5202, 5206 and 5208 ångströms, weaker bands at 5345, 5348 and 5409 ångströms and a strong band at 4289 ångströms were present on the large quartz emission spectrograph.

The emerald shows marked pleochroism, the colour-change being:

extraordinary ray—blue/green
ordinary ray—yellow/green.

Colour-banding is present, the zones being parallel to the basal plane.

INCLUSIONS

Mineral inclusions are rare, and in the specimens examined only small groups of phlogopite platelets were noted. These averaged 0·15 mm in diameter and are presumably of protogenetic origin. In contrast, liquid inclusions are common and may be distinguished on the basis of the containing-cavities into three types:

(*a*) Minute rounded or drop-shaped cavities that occur in linear trails and dense aggregations giving the beryl a "peppered" appearance. These aggregations are formed into twisted planes randomly orientated, and at low magnifications they appear to be particles of an opaque mineral. The average size of these cavities is 0·02 mm, and, in addition to containing liquid, each has a gas bubble.

(*b*) Tubular cavities or negative crystals aligned parallel to the vertical crystallographic axis are also present. Some examples are more than 1 mm long, and, in most, an elliptical gas bubble is present. Some tubular cavities are stained with iron-oxide, and in others a brown mica with spherulitic habit is present.

(*c*) Other cavities with variable shape in section are present. Some polygonal ones may be square, rectangular or triangular, whilst others are rounded or tadpole-shaped. These cavities invariably contain a gas bubble, spherical in form, and, in some, a mineral inclusion as well. The alignment of these cavities is variable, but crystallographically controlled.

These liquid-filled cavities with a gas inclusion—two-phase inclusions—are characteristic, and, in combination with optical constants, may serve to distinguish the Mayfield emerald from material originating elsewhere.

IMPROVED U.V. TECHNIQUE FOR DETECTION OF "SUSPECT" STONES

By T. F. ZOOK, M.A., F.G A.

EXPERIMENTATION has shown that the following technique which was developed using U.V. light can aid the gemmologist in detecting "suspect" stones from among those which react to irradiation with ultra violet light. An electric long- and short-wave *Mineralight Ultra-Violet Lamp* which was supported in a metal stand (and thus converted to appear similar to a desk lamp) was used to perform the tests in a room devoid of all other light than that from the U.V. source. The U.V. lamp transmitted long wave at 365 millimicrons or short wave at 254 millimicrons. Room temperature at the time of the experiments was in the region of 70°F or 21°C. The base of the lamp-stand was covered by a piece of black non-reflective paper for the first step, and in the second step a 72mm by 55mm mirror (whose layer of "silver" lay 2mm below the top surface of the mirror) was placed over the black paper to provide a reflective surface.

In *Step Number 1*, the stone to be tested was held in tweezers with the culet pointing up toward the U.V. light source and was held at a distance from that light of about two inches or 5 centimetres. First long-wave irradiation was used and then short-wave irradiation was tried. If the stone fluoresced, the extent and the colour of the reaction were noted. Paste imitation stones usually betrayed their presence by showing a pavilion which appeared to have a dark cone covered by an etched or frosted surface. Synthetic spinels tested also responded to U.V. light with a brightly coloured fluorescent ring in the girdle area and with a dark pavilion—a reaction akin to that of imitation paste stones except that the spinels showed a much lighter frosted surface over a dark pavilion, particularly under short-wave U.V. light. Synthetic corundums and YAGs which reacted to U.V. irradiation in this step showed a dark cone in the pavilion area over which there appeared to be a transparent glassy glaze, again surrounded by a brightly coloured fluorescent ring in the girdle area. Some composite stones also betrayed their presence by one or the other of the above reactions (depending upon whether the pavilion was a paste or a synthetic material). The above reactions were accepted only as indicators of composition and were not taken as conclusive evidence. It was found that stones of

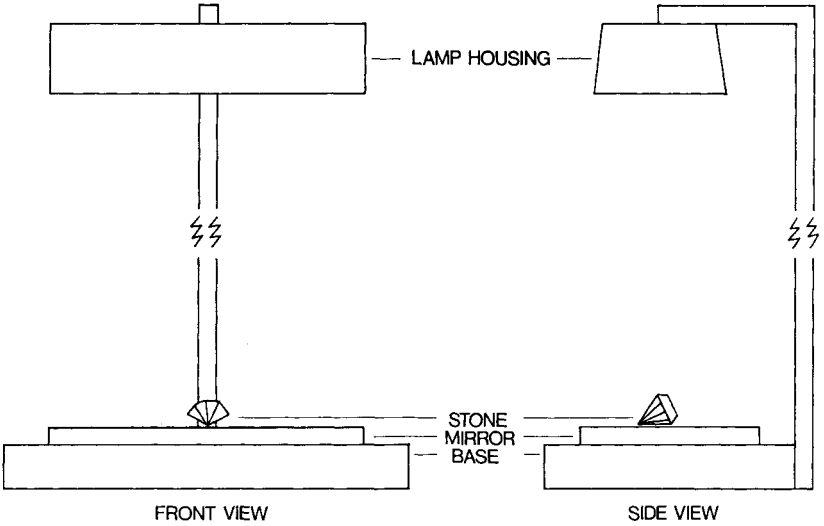

FIG. 1. Diagrams (not to scale) to show position of stone on mirror in Step No. 2.

a natural origin, which were either heavily included, or which had large inclusions or which had colour-zoning, also often appeared to have a darkening in the pavilion area due to a differential U.V. irradiation reaction from that of the host stone.[1]

In *Step Number 2*, the unmounted stone was placed on the mirror surface in such a way that it rested on part of its girdle edge (see Fig. 1). Tweezers were used to nudge it so that it revolved slowly around its complete perimeter, and while this was happening the mirror image was constantly checked by the observer from a distance of 4 to 8 inches (10–20 cm) from the stone and on an oblique angle of 40 to 60 degrees above the horizontal desk surface. Both long- and short-wave U.V. light were used. The mirror image clearly revealed the areas which were fluorescent and those which were non-responsive or inert.[2] A fluorescent ring around the girdle area with a dark pavilion was a "suspect" stone. Likewise a bright fluorescent area within a stone which appeared inert was a warning signal of a possible composite stone in which the cement was fluorescing. Any image reflected which showed a different reaction to U.V. light within different areas of the stone became a "suspect" stone.

At the conclusion of both steps 1 and 2, either a decision was made to subject the "suspect" stones to further tests or in the case of stones under consideration for purchase the stone was closely examined by either a 10 × loupe or the microscope to determine whether it had inclusions or colour-zoning which may have caused it to react differentially within itself to U.V. radiation. Since this technique takes but a short time to complete, and since it effectively alerts the gemmologist to "suspect" stones, it can be a good preliminary tool. However, caution must be used during its performance not to work with the hand under the lamp and never to look directly into the U.V. lamp itself.[3] In the case of composite stones[4] which are colourless, or which are red, it is a distinct aid to the investigator who finds it difficult to detect a composite red or colourless stone by differences in lustre and alerts the investigator to the necessity of further careful testing.

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2. In *Step Number 2,* positioning of the gemstone on the mirror permits observation of the luminescent pattern in two aspects: one in the direct view, and the other by its reflection in the mirror. Experience has shown that the latter view is most revealing with respect to the detection of a composite, synthetic or paste nature of a stone.

3. Tweezers and not the hand should be used for work under the U.V. lamp because of reactions in the skin: see Wurtman, Richard J., *Scientific American.* 1975, 233 (1), 69-74, The Effects of Light on the Human Body.

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Gemmological Abstracts

ALEXANDER (A. E.). *The jewels of Fortunato Pio Castellani and Carlo Giuliano.* Gems & Gemology, 1975, XV, 2, 50-56. 6 illus.

Discusses some of the pieces of jewellery produced by these two Italian goldsmiths. 18 pieces made by Giuliano are described and 12 made by Castellani. Some personal details of these two artist-craftsmen are given.

R.W.

BALL (R. A.). *Opal from Coolgardie, Western Australia.* Australian Gemmologist, 1975, 12, 6, 171-173. 3 illus.

A report on the opal found at Coolgardie in Western Australia. The occurrence is in a network of veins in Precambrian sediments, both precious opal and potch being found in the cobweb-like network of veins, usually of very small width. Some five specimens were examined by the scanning electron microscope, one specimen of which consisted of a quartz crystal coated with iridescent opal. The occurrence appears to have little commercial significance.

R.W.

BALL (R. A.) and CLAYTON (N.). *Opal references and abstracts.* Australian Gemmologist, 1975, 12, 6, 181-189. 1 map.

A very useful compilation of references to the literature on opal. These are set out in sections, such as "Occurrence", which is further sub-divided into countries; Formation; Structure; Synthetic Opal; Treated Opal, etc. Each section is prefaced by a survey which is of importance in itself.

R.W.

BOSCH-FIGUEROA (J. M.), and MONÉS ROBERDEAU (Y. L.). *Processo de la talla brillante del diamante: clasificación e importancia de la calidad de talla en el brillante.* (The process of cutting a diamond as a brilliant: classification and importance of the quality of cutting in a brilliant.) Gemologia, 1975, 5, 19/20, 15-33.

A description of the diamond-polishing process with photographs and diagrams illustrating ideal proportions.

M.O'D.

BOSCH-FIGUEROA (J. M.) and MONÉS ROBERDEAU (Y. L.). *El color de las gemas.* (Gemstone coloration). Gemologia, 1975, 5, 19/20, 35-41.

A general survey dealing chiefly with the role played by the transition elements in the coloration of gemstones.

M.O'D.

CASSEDANNE (J. P.) and (J. O.). *L'opale verte de la fazenda brejinho (Brésil).* (Green opal of Fazenda Brejinho, Brazil.) Bulletin de l'Association Française de Gemmologie, 1975, 45, 6-7.

A green opal with a S.G. of 2.07, hardness of 5½ and R.I. of 1.450, which is neither fluorescent nor radioactive, has been found in the south of the state of

Bahia. The green opal fills fissures in a chalcedony and forms veins which turn at times into larger blocks. The colour resembles that of peridot.

M.O'D.

CROWNINGSHIELD (R.). *Developments and highlights at GIA's Lab in New York.* Gems & Gemology, 1975, XV, 2, 57-62. 12 illus.

A number of diamonds are mentioned, including a "chameleon" stone, a diamond which had been badly burnt during repair and a diamond which contained a patch of stocky needles running in one direction. There is a discussion on the electro-conductivity of some diamonds particularly with respect to any semi-conducting diamonds which were subsequently treated. The durability of G.G.G. stones was the subject of experiment and there is a considerable write-up on "mood stones". There is a report on a new gem material from the U.S.S.R. This is a rock-like material which has a violet coloured part said to be the new mineral canasite (or *kanasite* according to Min. Abs.). Some information is given on "Imori stone" ("meta jade").

R.W.

LIDDICOAT (R. T.). *Developments and highlights at GIA's Lab in Los Angeles.* Gems & Gemology, 1975, XV, 2, 44-49. 15 illus.

An unusual faceted tablet was found to have a central hexagonal crystal of sapphire surrounded by pinite. A number of articles of "scrimshaw" on whale teeth are illustrated. The teeth are coarse ivory. A difference in quality of polish of a diamond on each side of a twin plane was ascribed to poor polishing. A large spinel inclusion in a spinel, an unusual large synthetic pink sapphire, an unusual black diamond and a hornbill snuff bottle are other items mentioned.

R.W.

LÓPEZ-SOLER (M.), VENDRELL-SAZ (M.) and BOSCH-FIGUEROA (J. M.). *Medición de la refringencia de las gemas.* (Measurement of gemstone birefringence.) Gemologia, 1975, 5, 19/20, 7-12.

Methods described include the use of a polarizing microscope, immersion techniques and that of the measurement of minimum deviation.

M.O'D.

MACFALL (R. P.). *The story beyond the story of the great tourmaline discovery.* Lapidary Journal, 1975, 29, 5, 994-1001.

Tourmaline has been found at the Dunton Mine, Plumbago Mountain, near Newry, Maine, U.S.A., in the celebrated pegmatite area of Oxford County. Some stones of high quality, including one green specimen measuring 10″ × 4″ have been recovered, and a regular supply to lapidaries has been maintained.

M.O'D.

MUMME (I. A.). *Rocks, gems and minerals of Olary.* Australian Gemmologist, 1975, 12, 6, 173-178. 1 map.

A very well-written report on the minerals found in this area, which stretches from the Peterborough district of South Australia to Broken Hill in New South

Wales. The article mostly details the occurrence of gold and other economic minerals. There is much interesting information on the recovery of uranium deposits found in the Olary, and the geology of the area is also discussed. The gem materials discussed seem to be only suitable for cutting into cabochons, and such are andalusite, chiastolite, beryl, feldspar, cornelian, chrysocolla and haematite. Some quartz in the yellow and brown varities, citrine and cairngorm, and some epidote are suitable for faceting.

R.W.

NASSAU (K.). *The origins of color in gems and minerals (Part 3).* Gems & Gemology, 1975, XV, 2, 34-43. 7 illus. and 2 tables.

This part of the series concludes the valuable and authoritative article on colour. The text covers the "band theory" which is well explained, and refers also to semi-conductors. Much is told about Type Ia and Ib diamonds as well as Type IIb where the cause of semi-conduction and the blue colour of such diamonds are explained. The concluding sections of this important series of articles refer to colour produced by dispersion, scattering, interference and diffraction.

R.W.

REAM (L.). *Nephrite in Washington.* Lapidary Journal, 1975, 29, 9, 1748-57.

Nephrite deposits have been found in the serpentinites of Washington state and in particular from alluvial deposits in Snohomish and Skagit counties. Much of the nephrite is not good quality and most has a grey tinge.

M.O'D.

SCAVIA (F. M.). *Cenni di propedeutica alla gemmologia.* (Notes for an introductory course in gemmology). L'orafo italiano, August 1975, 48-50; Sept. 1975, 90-92.

The first article covers birefringence and optic sign, the second dispersion.

M.O'D.

SCHUBNEL (H. -J.). *Excursion à la mine de saphir de Bo-phloï, Thailande.* (Visit to the sapphire mine of Bo-Phloï, Thailand). Bulletin de l'Association Française de Gemmologie, 1975, 45, 8-10.

The mine is situated north of Kanchanaburi, which is about 170km from Bangkok. Pits are dug to recover the sapphire which is associated with black spinel and some of the colour is good. Most is cut locally or in Bangkok.

M.O'D.

SKALICHY (J.). *The Czechoslovak moldavites.* Lapidary Journal, 1975, 29, 8, 1560-62.

Moldavites occur in two parts of Czechoslovakia, in the area of České Budějovice in southern Bohemia and in the Trebic area of Moravia. Some bicoloured specimens exist, but in general the colour is deep green from Bohemia and a brownish-green from Moravia.

M.O'D.

TOMBS (G. A.). *Notes on identification of Gilson synthetic opals.* Australian Gemmologist, 1975, 12, 6, 179-180. 3 illus.

The author gives the findings of his examination of the Gilson synthetic opal, which may be of assistance in distinguishing the natural opal from the synthetic stone. Natural opal may or may not fluoresce under long-wave ultra-violet light, but if it does fluoresce, usually in a cream or white colour, it will also phosphoresce for some seconds. The synthetic opal was found not to fluoresce under long-wave ultra-violet light, but under short-wave ultra-violet rays fluoresced a dusty green with only a short phosphorescence of about a half second. The synthetic opal showed high transparency and a pattern of colour stacking is visable which forms "chimneys" which are so rarely seen in natural opal. Under the microscope at 60 times magnification the colour zones were seen to be a series of distinct hexagons. Examination of the colour patches of both natural and synthetic opals showed zonal type colour stripes in the synthetic stone not present in the natural stone. It is unfortunate that the text does not make this quite clear and does not quite agree with the illustrations.

R.W.

WEBSTER (R.). *More notes on turquoise.* Lapidary Journal, 1975, 29, 8, 1428-1456.

Covers synthetic turquoise, Eilat stone and faustite.

M.O'D.

ZEITNER (J. C.). *The legend and lore of turquoise.* Lapidary Journal, 1975, 29, 8, 1430-1450.

An account of the derivation of the various names used for turquoise and of the legends associated with it from the earliest times. Illustrated in colour.

M.O'D.

BOOK REVIEWS

ANDERSON (B. W.). *Gemstones for Everyman.* Faber and Faber Ltd. 1976. pp. 368. Illustrated in black-and-white and in colour. £15·00.

Another book from the pen of B. W. Anderson can scarcely fail to be important. "Gemstones for Everyman", in spite of being intended for a wider public than that provided by the gem trade, is gemmologically both important and valuable. It is over thirty years since this author's first book, "Gem Testing", appeared, although that can scarcely be regarded as a single work, having run through eight editions (a ninth is even now in preparation) and grown, with much revision, addition and re-writing, from a modest and slender volume to a substantial tome which has been a standard work for many years.

With "Everyman" in mind the present book simplifies the scientific approach considerably. Instruments other than lens and colour filter are described with no attempt to involve the reader in their construction or in the theoretical optics behind their working.

Crystallography is discussed quite briefly and the cubic system is used to explain the bare essentials of crystal morphology. No gemmological textbook deals with more than very elementary crystallography, and it has been, I think, somewhat difficult to draw the line even closer in this book. Axial definitions of the other six systems are given, but that for the monoclinic system is inaccurate and revives one which the reviewer battled for years to have eliminated in another well-known textbook.

The author was, for 46 years, Director of the "Hatton Garden Gem Testing Laboratory". He uses this name in preference to the more cumbersome official name. This was the first full-time laboratory anywhere specifically engaged solely in gem-testing and Anderson was almost certainly the first full-time gemmologist. Gemmology as we know it today is very largely based on his personal work over the years and such things as the 1.81 liquid, absorption spectroscopy as applied to gems, the crossed filter technique, immersion contrast photography and a host of other testing methods have resulted directly from his investigations. With others he has explored new gem problems and constantly surmounted the apparently insurmountable. With such a fund of gemmological "know-how" on which to draw one is left wondering how the writer decided what to leave out.

In spite of the broad aims of the book the text on individual gem species, arranged for the most part in a very practical order of comparative hardness, is crammed with extremely valuable information and is perhaps even more useful to the serious gemmologist than to the layman.

Personally I take pleasure in the fact that this is a "book-sized" book. Far too many publications of recent years are in a larger and often unconventional format and apparently intended to lie carelessly on coffee tables as evidence of the erudition of their owners. A book intended to be read and re-read should, in my opinion, fit comfortably into a bookcase without requiring a major disruption of shelves to accommodate it.

The 17 colour plates are mostly of outstandingly fine specimens in the collection of the Geological Museum, plus one or two fine stones belonging to the author and his wife. They are from fine transparencies prepared by E. A. Jobbins and J. Martin Pulsford of the Institute of Geological Sciences. Reproduction is good, but the colour printing process cannot capture the full effect of the original photograph. Black-and-white plates have less impact but are well produced.

A black-and-white drawing of the absorption spectrum of a (Burmese?) zircon needs some indication of colour, or at least of which end is which. A line diagram of four different faceted cuts has its captions in reverse order to the drawings. The text refers to line drawings of right- and left-handed quartz crystals when only right-handed is actually shown. These could be confusing to the layman. A glossary definition of Ångstrom Unit, given quite correctly in another form in the text, is given as "1 ten-millionth of a metre", instead of "-millimetre". An effort was made to correct this by telephone but, between the knowledgeable author in Devon and the less informed publisher's staff in

London, the correction was not made. I feel that Post Office telecommunications could take some of the blame for this.

In the case of sapphires and some other stones the author has rather unwisely quoted prices. Even accurate figures quoted in times of economic stability can rapidly date a book. In times of rampant inflation values quoted can be wildly out long before the book is in print. In the present work such figures can be taken only as broad indications of trend and not as valid values.

Seen from a gemmological viewpoint this is a valuable contribution to the current literature and well worth a place on every gemmological bookshelf. It is more difficult for me to assess it from the point of view of the layman. But the explicit and careful writing, so characteristic of this author, seems to me to result in a book which is both interesting and intelligible enough to live up to its title.

R.K.M.

AREM (Joel E.). *Gems and Jewelry.* Bantam Books, New York, 1975. pp. 159. Illustrated in colour. $1·95.

A very simple but lucid introduction to gemstones with (on the whole) adequate coloured illustrations, at least for this price range of book. The photographs of synthetics are particularly good; many of the specimens are from the Smithsonian Institution. A longer bibliography would have been useful, especially in so short a book. Some of the captions seem odd, particularly that describing a stone purporting to be chrome fluorite and another which mis-spells Malagasy.

M.O'D.

AREM (Joel E.). *Rocks and Minerals.* Bantam Books, New York, 1973. pp. 145. Illustrated in colour. $1·95.

A well-illustrated guide in simple terms outlining mineralogy. The information on simple crystallography is well presented and most of the book describes the better-known minerals and rocks.

M.O'D.

DRAGSTED (Ove). *Gems and Jewellery in Colour.* Blandford Press, Poole, 1975. pp. 232. Illustrated in black-and-white and in colour. £3·25.

In the course of his brief introduction, Mr Dragsted writes: "Like the craftsmen of ancient cultures, contemporary jewellers create ornaments from snail-shells and fossils, from wood and fruits, and they set conventional stones in imaginative, new, and sophisticated ways." And it is this very wide acceptance of what constitutes a gem material that sets this little book apart from any other, though, as may be seen below, it contains many other original features.

The book opens with a series of short introductory chapters. Most of these are too brief to be of much consequence, but the section on crystals includes a useful series of drawings of the idealized forms shown by crystals of the various systems, and the "Gem Trade" chapter has similar drawings of the different styles of cutting and of the most commonly used settings.

Then come the coloured plates, which occupy nearly a hundred pages, and upon which the popularity of the book must chiefly depend. The plates are from a series of coloured drawings by Otto Frello, of which there are no fewer than 820 shown. To assemble all the necessary materials and to make the drawings

constitute a major piece of work. The aim has been where possible to show the rough gem material, the cut and polished version of this, and finally the gem set in some form of jewellery. Amorphous materials are dealt with first, then cubic, tetragonal, hexagonal, trigonal, orthorhombic, monoclinic and triclinic stones. A final series is shown of synthetic gem materials. Each of these drawings is numbered and a key printed on the same page. The remainder of the book is taken up with extended descriptions of the stones and other gems shown in the plates.

To modern eyes, which by now have become accustomed to the very accurate representations of gemstones made possible by colour photography, these plates appear rather crude, and the crowded assemblage of a number of stones and jewels on the same page gives a somewhat jumbled effect. As is always the case with drawings of gemstones, the opaque materials are represented more realistically than the transparent, faceted gems. But the vast range of materials covered by the plates is certainly impressive, and one can agree at once with the author's contention that so varied a collection can be found in no other book, however large.

In the non-crystalline and organic section we get not only the expected pearls, coral, amber, ivory, tortoiseshell and so on, but shells, beetles, fossils, and a substance quite new to the reviewer called bezoar. This is a stony concretion found in the stomach or intestines of the bezoar goat, and though quite unattractive was apparently often mounted in the form of an expensive jewel in the Middle Ages because of its high reputation as an antidote to poisons and even the plague. When it comes to the crystalline gems, all the minerals which have been used as gems or even occasionally faceted by ardent amateur lapidaries are included. It was somewhat startling to see three cut specimens of painite depicted: one was aware of no record that any cut stones have been fashioned from this rarest of Burma minerals.

The descriptions of the stones and other materials shown on the plates, which occupy the last eighty pages of the book, contain a large amount of interesting detail with a slant reflecting the historical and antiquarian interests of the distinguished author. A curious but obviously intended omission in these descriptions is any reference to the physical properties (hardness, density, refractive index) of the materials, though methods of measuring these had been briefly described in Chapter 10 under "Identification of Gems." Inclusion of such data would occupy very little space and could hardly offend the eye of the non-scientific collector, while it would add considerably to the value of the book as a guide. This would be particularly helpful in the case of the out-of-the-way minerals which are not included in any standard work on gemstones.

Very few errors or misprints were noticed: in future editions, "trigonal" should replace "tetragonal" at the bottom of page 18, and the oxygen and hydrogen inlets should be reversed in the drawing of the Verneuil furnace on page 220.

B.W.A.

FERNIE (W. T.). *The occult and curative powers of precious stones.* Rudolf Steiner Publications, Blauvelt, New York, 1973. pp. 486. $3·95.

A reissue of the text first published in 1907 under the title Precious stones: for curative wear, etc.

M.O'D.

GÜBELIN (E. J.). *The colour treasury of gemstones.* Elsevier-Phaidon, London, 1975. pp. 137. Illustrated in colour. £4·50.

This is a translation of "Edelsteine" by the same author, published in German, French* and Italian in 1969. It covers the more important commercial stones and each coloured plate, of very high quality, includes both mounted and unmounted specimens, some of the latter in their rough state. There is quite a lot of information on mining techniques and some of these are illustrated. Details of the stones are confined to general scientific points only—this is not a textbook, but one designed to please, as the lyric style suggests. There is a glossary in which a large number of technical terms are explained. A most pleasing book.

M.O'D.

LIDDICOAT (Richard T.). *Handbook of gem identification.* 10th edn. G.I.A., Los Angeles, 1975. pp. xv, 440. Illustrated in black-and-white. Price on application.

The latest edition of this standard and justly celebrated work includes new materials in the synthetic field, including Gilson opal and stones subjected to gamma-ray irradiation. The preface suggests that a new synthetic alexandrite made by the pulling method may soon appear, though the reviewer has not yet seen it. GGG and other fairly new materials are included in the various tables which are so useful a feature of this first-class book.

M.O'D.

PAPE (Hansgeorg). *Leitfaden zur Gesteinsbestimmung.* (Guide to stone testing). 3rd edn. Ferdinand Enke Verlag, Stuttgart, 1975. pp. 152. Illustrations in the text. DM 11.80.

A useful pocket-sized guide to the finding of minerals. Only the commoner species are included; there is a short bibliography.

M.O'D.

PURTELL (Joseph). *The Tiffany touch.* Pocket Books, New York, 1973. pp. 390. Black-and-white illustrations. $1·50.

A lightly-written history of the celebrated firm of New York jewellers—especially interesting on the history of design in the nineteenth and early twentieth centuries.

M.O'D.

RANSOM (Jay Ellis). *Gems and minerals of America.* Harper & Row, New York, 1974. pp. xxiii, 705. Illustrated in black-and-white and in colour. $17·50.

By "America" the author means "the United States", and at first sight this would seem to be a most useful guide to gemstone localities, since they are arranged alphabetically under state and county. This section appears to be correct, but some of the other matter needs revision. The cause of the play of colour in precious opal is stated to be due to interference of light from cracks within the stone: corundum is seldom found in scalenohedral form: and Professor Strunz's first name is Hugo, not James. Mineralogical Record is missing from the bibliography, as is Webster's "Gems". The colour plates are quite wretched.

*Reviewed in J. Gemm., 1970, XII (3), 91.—Ed.

A disappointing book, though a careful revision would work wonders. The sections on conservation and lapidary say nothing that has not been said—frequently —before.

M.O'D.

RODGERS (Peter R.). *Agate collecting in Britian.* B. T. Batsford, London, 1975. pp. 96. Illustrated in black-and-white and in colour. £4·95.

The price of this small book is not in keeping with its standard of production, which is indifferent; there is insufficient differentiation between the specimens illustrated in colour, and those shown in black-and-white are not really very clear. The introduction is carelessly written (or derived); the statement that agate cannot be marked with a file will surely lead many collectors astray, and emerald is not the rarest of gemstones. The notes on quartz are also not very clear, and the termination of a quartz crystal shows rhombohedral, not pyramidal form. I was also surprised to see amethyst classed as coarsely crystalline. The note on the colour of opal is rubbish; the author must surely have access to up-to-date textbooks, most of which carry correct statements on this phenomenon. In the tables at the end of the book some lapidary societies are incorrectly named and those beginning with the definite article are amusingly listed alphabetically under the letter T: this is scarcely flattering to the potential reader. Points in favour include the provision of O.S. map references for localities and the maps in the text.

M.O'D.

SCARFE (H.). *The lapidary manual.* Batsford, London, 1975. pp. 172. Illustrated in black-and-white and in colour. £5·50.

Quite a well-written and certainly a well-illustrated book—the colour plates depict specimens from the collections of the Geological Museum in London. The bibliography is perversely arranged in alphabetical order of titles. In other respects the book is similar to many others on the market.

M.O'D.

WEBSTER (Robert). *Gems in Jewellery.* NAG Press Ltd, London, 1975. pp. viii, 136. 35 black-and-white and 6 coloured photographs. £3·90.

Gemmologists throughout the world have long known the late Robert Webster (whose death is reported on another page) as an indefatigable worker: many of them cut their gemmological teeth on his "Practical Gemmology" (now in its 5th edition) and his "Gemmologist's Compendium" (also now in its 5th), and to-day when in need refer to his monumental "Gems", meanwhile being kept up to date by articles from his pen in this *Journal*, *Gems & Gemology* and elsewhere. In 1975 he not only produced the third edition of "Gems" (and no doubt was already collecting additional material for the fourth!) but also found time to offer this wholly new work, which is addressed to a slightly different public. It is intended as a book not for the specialist but for the general reader who is interested in jewellery. It is not, however, a book about jewellery. The information conveyed by book-titles, as by newspaper headlines, is limited by the need for compression, and in this case the title is elliptical and might be more fully expressed as "Gems [normally to be seen] in Jewellery": there is no discussion of

jewellery as such—though there are seven photographs of interesting pieces—but all the gem-materials commonly met with in jewellery are described—their appearance, properties, provenance, treatment (cutting, polishing, heating, staining, etc.) up to but not including setting. Rarities like taaffeite and painite and minerals which are cut and polished only for collectors are quite rightly omitted, but a number of not-so-usual stones are covered by a chapter on "Some lesser-known gemstones."

The book consists of twenty chapters dealing with individual gem-materials —from diamond (two chapters) through ruby and sapphire (one), the beryls (one), and other gemstones grouped together in chapters, to pearl (one), cultured pearl (one) and organic gems (one), including one chapter on ornamental stones and one on synthetics. These are followed by a short chapter on testing methods, tables of physical features of stones classified by colour (10pp.), a page of "wedding anniversaries" ("silver wedding", "diamond wedding", etc.—many of the earlier ones having no connexion with jewellery), the NAG list of birthstones and colours, a short list of books for further reading and an index.

As I wrote in reviewing the first edition of "Gems" nearly fourteen years ago, it is the business of the critic to criticize. The publishers' blurb says that the text is "absolutely authoritative in the facts provided", but, while nobody would dispute that, *quandoque bonus dormitat Homerus*—even Mr Webster sometimes had a lapse! I was surprised to find Alexander II (born in 1818, the eponym of alexandrite and assassinated in St Petersburg in 1881) described as the last of the Russian Tsars and murdered at Ekaterinburg, for Mr Webster must have remembered as well as I do the shocking news of the massacre of Nicholas II and the Imperial Family in 1917: and I cannot accept the statement (p. 25) that aquamarine shows *blue* through the Chelsea filter! The chapter sub-headings ("The Garnets: *they are not always red*") coupled with unhelpful quotations ("*Red hyacinths of antiquity. Rev. C. W. King. 'Antique Gems'* ") seem sadly out of character, and there are many misprints and mis-spellings which proper proof-reading should have eliminated—mostly not affecting the sense, though the printing of "Andamooka" for "Amberooka" (p. 58) and of part of the table of green stones on the wrong page (p. 128) as a continuation of the table of red and pink stones may well cause some confusion. The colour photographs are not satisfactory: although opals—surprisingly—are quite well shown, the diamonds are very poor—more dark than bright: almandine, hessonite, rhodolite and spessartine all look the same colour, and the star-garnet is near-black with two white spots but no star, and the hiddenites are not green! As already mentioned, Mr Webster's previous books have all run into numerous editions, and I see no reason why with proper corrections this one should not follow suit: these criticisms are offered in the hope that they may be of some assistance in preparing a second edition.

In general, this is a nicely produced and attractive volume, and, for these inflationary days, not unreasonably priced.

J.R.H.C.

ASSOCIATION NOTICES

OBITUARY

GEORG O. WILD

On 23rd November, 1975, one of the world's outstanding gemmologists, Georg O. Wild, died suddenly at his home in Idar. He was born in January, 1894, and was thus approaching his eighty-second birthday. After his schooling in Idar he was sent to New York at the early age of fifteen to continue his education, and eventually was able to earn his living as a dealer in precious stones both in New York and in Idar. As a young man he also travelled widely, visiting most of the major gem deposits, and eventually acquired a knowledge of gemstones in all their practical aspects more intimate and profound than that of most academically trained scientists.

Though Wild was a dealer all his life, he was endowed with a curiosity which was essentially scientific. He established a small research laboratory in Idar, and there, working either alone or in collaboration with friends who were trained scientists, he tackled various problems in gemmology which interested him, his chief preoccupation for many years being the cause of colour in gemstones.

The earliest of his papers on this subject was published in the *Zentralblatt für Mineralogie* in 1922, his collaborator being R. E. Liesegang, who became famous for his theories on the growth of agate, and after whom a street is named in Idar town. Nine years later (August 1931) the very first issue of the British journal, *The Gemmologist*, contained an article by G. O. Wild on "The colour of precious stones", which was soon to be followed by others on the same topic and later by papers on other aspects of our science. His upbringing enabled him to speak and write excellent English, which helped him to become good friends with fellow enthusiasts in Britain. Our mutual appreciation of each other's work was also helped by the fact that, partly due to financial stringency and partly to a natural austerity of outlook, we each preferred to use the simplest forms of apparatus, often improvised, with which to carry out our investigations. The quartz spectrograph, for instance, with which Wild and his co-workers carried out their search for trace-elements influencing colour, was a very small and simple affair.

This propensity for simple and improvised testing methods remained with Wild all his life. His delightful and original short book "*Praktikum der Edelsteinkunde*" (1936) was followed fourteen years later by a slim paper-backed volume, written with K. H. Biegel, with a long explanatory title which in English

would read "Small signposts for the identification of gemstones by the simplest means."

In 1932, Georg Wild furthered the cause of gemmology in his native Idar by founding the German Gemmological Association (Gesellschaft für Edelsteinkunde), which was thus one of the earliest of such national Associations to be formed. His skill as an artist-craftsman should also not be forgotten. Following the Fabergé tradition, but in a more realistic fashion, he produced delightful carvings of animals and birds from pieces of rough ornamental stones, exploiting their colour-variations and characteristic markings to very happy effect.

All told, Wild published nearly one hundred scientific papers. These were for the most part quite short, reflecting the laconic nature of his conversation; but each one was apt to contain some really original observation which became before long embodied in our growing science.

In commemoration of his 75th birthday in 1969, the Deutsche Gemmologische Gesellschaft paid Georg Wild a truly remarkable compliment in the preparation of a special issue of their *Zeitschrift* in his honour. This contained articles and tributes from all quarters of the globe, and apart from these a list of more than four hundred names of individuals or Societies who sent congratulatory messages. It is doubtful whether any other gemmologist could call forth such an amazing display of affection and respect. It is sad that our present tribute must be paid, not to the living, but to the dead.

B. W. A.

It is with great regret that we announce the death of Mr Robert Webster on 22nd February, 1976, in his 77th year. A full obituary notice will appear in the July *Journal.*

GIFTS TO THE ASSOCIATION

The Council of the Association is grateful to the following for their gifts:

Mr John R. Fuhrbach, F.G.A., G.G., of Amarillo, U.S.A., for an oval cabochon of golden coral from Maui, Hawaii, U.S.A., "deep water" location.

Mr and Mrs Kennedy, of Charlotte, N. Carolina, for a collection of green spodumene crystals from Alexander County, N. Carolina.

Mr Arthur Kermeth, F.G.A., of Sutton, for specimens of crystals including topaz, emerald, ruby, quartz, red and green tourmaline and zoisite.

Mr Albert Ruppenthal for a copy of his book "Edle Stein und Mineralien."

MEMBERS' MEETINGS

London

A meeting of members was held at Goldsmiths' Hall on Tuesday, 10th February, 1976, when two films were shown. One was entitled "Arum" and included many fine examples of the goldsmith's craft throughout the ages and also dealt with the mining and refining of gold. The second film had been sponsored by the State Gem Corporation of Sri Lanka and was called the "Island of Gems". There were some excellent aerial views of the countryside where

gemstones are found and the film covered the recovery of gems from alluvial sources as well as methods of mining.

Midlands Branch

Mr James Parke, ex-President of the Mid-Warwickshire Antique Collectors Circle, gave a lecture on antiques on the 14th January, 1976, at the Auctioneers' Institute, Birmingham.

North-West Branch

The official inaugural meeting of the North-West Branch was held on the 4th February, 1976, at the Royal Institution, Liverpool. The guest speaker was Mr B. W. Anderson, B.Sc., F.G.A., who gave a talk on the Recollections of a Veteran Gemmologist.

Scottish Branch

On the 13th February, 1976, at the North British Hotel, Edinburgh, a talk was given by Mr E. A. Jobbins, B.Sc., F.G.A., of the Institute of Geological Sciences, South Kensington, entitled "Gem Surveys in Brazil and Guyana." This extensively illustrated lecture described the search for diamond, opal, amethyst and rutile in Piaui State, Brazil, also for agate and jasper in Guyana, and the setting up of a lapidary training scheme in Georgetown. Other aspects of the local natural history were also considered.

PRESENTATION OF AWARDS

The Annual Reunion and Presentation of Awards was held at Goldsmiths' Hall on 17th November, when the Chairman, Mr Norman Harper, noted that the large gathering included members from France, Holland, Italy, Spain, Switzerland and the United States. Since last year the President had been knighted and become Sir Frank Claringbull and the Treasurer, Mr F. E. Lawson Clarke, had become President of the National Association of Goldsmiths.

Every year saw new records broken in the number of candidates who sat for the examinations throughout the world. Last year's total of 994 had risen to 1,153, though only 532 had passed.

Mr Richard Cope, F.G.A., Chairman of the National Association of Goldsmiths, after presenting the awards, recalled that when he received his diploma in 1957 he did not think for one moment, at that time, that one day he would be presenting diplomas to other successful candidates. In congratulating them on receiving the "seal of your labours", he added that it really marked the start of a long hard road at a time of great changes and problems in gemmology. The progress in the manufacture of synthetic gem material had been astonishing.

"In every area where scientific strides are being made (and these include both gemmology and horology in the retail trade)," he said, "there is the demand for more knowledge and better understanding of the subjects."

Jewellers using these subjects required professional knowledge, for consumers were hungry for technical detail and advice, even demanding it. Their qualification was a platform on which to build, and they should never stop learning. To keep abreast of change and progress they should have an enquiring mind, a thirst for further knowledge and a deep and genuine interest in gemmology.

For those who were jewellers, gemmology had great value for valuation work, in the buying of the right stock—both right gemmologically and right commercially—and in selling the stock to the customer. The manufacturer also needed to select his gem materials for his merchandise with sound knowledge of the gemmological trade. But gemmology had also grown up from being product knowledge in the jewellery trade to become an expanding and fascinating science. It had contributed to progress in mineralogical research.

Finally, Mr Cope said, their qualification admitted them to a happy world-family. They should take pride in possessing their qualification, not be afraid to ask advice if they were unsure, and derive pleasure in using it.

Mr Lawson Clarke, in thanking Mr Cope, pointed out that he was greatly interested in trade education, being a former Chairman of the N.A.G. Education Committee and a trade representative on the Distributive Industry Training Board.

COURSE INSTRUCTOR

The Association requires an Assistant Correspondance Course Instructor to undertake part-time assessment of papers during the period October to May. Only persons resident in the U.K. should apply. Applications should be addressed to the Secretary, Gemmological Association of Great Britain, Saint Dunstan's House, Carey Lane, London, EC2V 8AB, and should give full details of qualifications.

COUNCIL MEETING

At the meeting of the Council held on Tuesday, 10th February, 1976, the following were elected to membership:

Fellowship

Agee, Carl B., Rotterdam, Holland. D. 1975

Bassett, Allen M., Paris, France. D. 1975

Bloom, André D., Streetly. D. 1975

Brown, Grahame, Brisbane, Australia. D. 1975

Buhler, Stefan, Geneva, Switzerland. D. 1975

Cartwright, Donald R., Little Bookham. D. 1975

Cornford, Carol R., East Grinstead. D. 1975

Cornford, Richard, East Grinstead. D. 1975

Domenech Casellas, Maria V., Oviedo, Spain. D. 1975

Garcia Abril, Ana M., Valencia, Spain. D. 1975

Grant, Malcolm J., Fordingbridge. D. 1975

Hammett, Roger S., Southall. D. 1975
Hutchinson, Janice, Plymouth. D. 1975
Iwahori, Mitsuo, London. D. 1975
Jackson, Brian, Edinburgh. D. 1975
James, Alan R., Pelsall D. 1975
Jhaveri, Ravindra J., Bombay, India. D. 1975
Jones, Alison R., Woking. D. 1975
Kan, Eishi, Tokyo, Japan. D. 1975
Kortelainen, Sirpa, Helsinki, Finland. D. 1975
Laine, Simo E. W., Helsinki, Finland. D. 1975
Lo, Wing Yat Sunny, Hong Kong. D. 1975
Marti Girona, Maria M., Barcelona, Spain. D. 1970
Matthesius, Johannes G., Amstelveen, Holland. D. 1975
Mayor Giner, Juan E., Vinaroz, Spain. D. 1975
Miller, Wilda L., Pretoria, S. Africa. D. 1975
Morrill, Christine, Cambridge. D. 1975
Moule, Alexander J., Toowong, Qld, Australia. D. 1975
Noble, Patrick, Heckmondwike. D. 1975
Padro, Angel, Barcelona, Spain. D. 1975
Phillipson, Erica K., Richmond. D. 1975
Ripley, Evelyn, Stockton. D. 1975
Schulze, Heinz, Austin, Tex., U.S.A. D. 1975
Vainio, Y. Erkki, Leppakoski, Finland. D. 1975
Van Westen, Linda J. L., Eindhoven, Holland. D. 1975
Wong Leung Kim Po, Joanna, Kowloon, Hong Kong. D. 1975
Yoda, Mitsuhiro, Tokyo, Japan. D. 1975

Ordinary

Ali, Syed J. A., London.
Amunugama, R. T. R., Morapitiya, Sri Lanka.
Anderson, Martin, Ft Monmouth, N. J., U.S.A.
Armstrong, Declan R., Hollywood, Cal., U.S.A.
Asano, Shinichi, Sendai City, Japan.
Azizollahoff, Henry, London.
Bagdasarian, Aram, River Edge, N. J., U.S.A.
Barea, Manuel P., Lyon, France.
Barea, Odette T., Lyon, France.
Bhuta, Kishore, Nadi, Fiji.
Bobe, Bernard, Paris, France.
Bourdon Destrem, H., Paris, France.
Brown, Ronald, Frankston, Vic., Australia.
Buckner, Richard A., Clinton, Tenn., U.S.A.
Burgess, John R., Southampton.
Campos, Joao P. R., São Paulo, Brazil.
Cartmel, Edna, Liverpool.
Caspi, Daniel, Stanmore.
Conrad, Donald B., East Islip, N. Y., U.S.A.
Croydon, Charles E. J., New York, U.S.A.
D'Amour, Hedwig, Bauerbach, W. Germany.
Dodson, John S., Cobham.
Doughty, Robert R., Newark, Cal., U.S.A.
Drost, Kristina R., Brummen, Gld, Holland.
Egi, Shigeo, Tokyo, Japan.
Egi, Yoshi, Tokyo, Japan.
Eldridge, Maurice W., Sheffield.
Elms, Kenneth G., London.
Eno, Takahiko, Tokyo, Japan.
Estavillo, William, San Francisco, Cal., U.S.A.

Etchen, E., Toronto, Canada.
Feld, Rainer, Marburg, W. Germany.
Fernando, Dilrukshi Y., Colombo, Sri Lanka.
Fik, Margaret M., Birkenhead.
Fitzgerald, Leslie E., Stanmore.
Fitzgerald, Patrick H., Orpington.
Fookes, Mark H., Brentwood.
Ford, Hermione D., Hereford.
Fujise, Noboru, Tokyo, Japan.
Gadot, Arnona, Tel-Aviv, Israel.
Gianforte, Carmen A., Columbia, Md, U.S.A.
Goldberg, Esther, Sun Valley, Ida., U.S.A.
Goonesekere, Premalal N. W., Lusaka, Zambia.
Graham, Peter D., Liverpool.
Gryg, Bessie, Hilton, W. Australia.
Hanley, William B., Menorca, Baleares.
Haseyama, Hiroyuki, Yokohama, Japan.
Hatanaka, Toshiaki, Kanagawa, Japan.
Heng, Tiaw B., Singapore.
Holgate, David E., Oxton.
Hori, Nagao, Tokyo, Japan.
Hotson, Roy H., Tuakau, N. Z.
Hutson, Douglas R., Hornchurch.
Ishii, Hajime, Kyoto, Japan.
Ishii, Jinko, Kyoto, Japan.
Iwabuti, Setsuko, Tokyo, Japan.
Jones, Terence G. M., Ruislip.
Kato, Kumao, Tokyo, Japan.
Katoo, Koichi, Chiba, Japan.
Kawaguchi, Masato, Fukuoka-Shi Fukuoka-ken, Japan.
Kikuchi, Isao, Tokyo, Japan.
Kinoshita, Ichiro, Kobe, Japan.
Kirinde, Harischandra W., London.
Kobayashi, Yaeko, Kanagawa, Japan.
Kodituwakku, Sugath, Colombo, Sri Lanka.
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XVth INTERNATIONAL GEMMOLOGICAL CONFERENCE

The Fifteenth International Gemmological Conference was held in Washington, D.C., U.S.A., from the 5th to the 9th October, 1975. Twenty-six speakers in all gave talks upon various matters of gemmological interest. One or two husbands were accompanied by their wives, and three women gemmologists were present, but only one spoke, Mlle Dina Level, formerly of the Paris laboratory.

On Tuesday, 7th October, there was a reception and dinner at the Smithsonian Institution*, which was followed on Wednesday, 8th October, by a behind-the-scenes tour: and a farewell luncheon terminated the proceedings on Thursday, 9th October.

The working sessions began on Monday, 6th October, with an introductory talk by Mr Richard T. Liddicoat, Jr, President of the Gemological Institute of

* The Smithsonian Institution was founded by act of Congress in 1846 to use the endowment provided for the purpose by the residuary bequest of James Smithson, F.R.S., (1765-1829), a natural son of the 1st Duke of Northumberland.—Ed.

America and director of the GIA Los Angeles laboratory. Mr P. E. Desautels, of the Smithsonian Institution, followed with a description of the collection and policy of the museum, which houses the National Collection of Gems.

Dr H. J. Nairis, F.G.A., (Sweden) gave a short illustrated talk upon possible diamond occurrence in Sweden.

Professor Dr H. Bank, F.G.A., (Idar Oberstein, W. Germany) showed selections of some very rare gemstones and gave a second talk mainly illustrative of Tanzanian gem deposits.

Mr H. M. Forth (Ontario Gem Lab) provided samples and colour-slides of gem apatite from Canada. He also gave an account of a previously abandoned mine being re-opened forty years later—originally a mine for phosphates used as fertilizers, but now a gem deposit. Mr Forth described the first cut stone as a deep blue-green apatite of 65 carats.

Mlle Dina Level (Paris) gave a description of some antique items in the Louvre collection. Prase, a quartz-family mineral containing chromium, was her chief talking-point.

Dr K. Nassau (Bell Laboratories, New Jersey) gave a masterly summation of the causes of colour in gemstones. He also stated that Maxixe-type beryls which have masqueraded as aquamarines *all* fade to some extent—some more quickly than others.

Mr X. Salier, F.G.A., (Munich, W. Germany) gave warnings on dyed jadeite and the continuing struggle over nomenclature of jade, jadeite and nephrite. (In the London Chamber of Commerce Laboratory the terms "nephrite-jade" and "jadeite-jade" are used.)

Mr E. B. Tiffany (Canada) spoke of his visit to attempt to value the Iranian Crown Jewels. A series of colour slides served to emphasize the amazing variety of this fantastic collection of jewels and jewelled ornaments, gemstones, pearls and precious metals.

Dr P. C. Zwaan, F.G.A., (Leiden University, Holland) described with colour photography visits to Sri Lanka, Thailand and India.

Dr K. Nassau followed with a second discourse on "irradiation-induced colours in gem materials." Neutrons, gamma-rays, electrons, x-rays and ultra-violet short waves were discussed.

Mr Pete J. Dunn, F.G.A., (Smithsonian Institution) gave a talk upon tourmalines from Newry (Maine), a very exciting find in type locality.

Professor R. Franco (Brazil) spoke on morganites from Barra de Salinas and the variation of quality of change in pink beryls from varying localities.

Dr H.-J. Schubnel (Paris) spoke on Abbé Haüy, the "father of gemmology" —Haüy was an early worker on the geometry of crystallization.

Mr A. E. Farn, F.G.A., Manager of the Gem Laboratory of the London Chamber of Commerce and Industry, followed with a talk on pearls. After mentioning the strong milky greenish fluorescence (and perceptible phosphorescence) of non-nucleated cultured pearls from Lake Biwa (a fresh water product) and the fluorescence of normal cultured pearls due to a trace of manganese in the m.o.p. nucleus made from the non-iridescent shell of a Mississippi mussel (fresh

water again), he pointed out that the real difficulty for to-day's laboratories lies in the production of cultured pearls from large oysters—such as Pinctada Maxima —from mainly Australian waters: we now have these large oysters from sea waters producing huge very thick-skinned round cultured pearls and large somewhat smooth baroque non-nucleated cultured pearls, both types being non-fluorescent, the former because the thick outer skin of natural pearl masks what fluorescence there is and the latter because it is a product of sea-water with no trace of manganese.

Dr E. H. Gübelin, F.G.A., (Switzerland) spoke on recent conflicts over famous—or infamous—diamonds which have been treated. He also referred to a difficult stone which had been handled also by the London Chamber of Commerce Laboratory and invited comments from Mr Farn: London lab's findings were supported by Dr W. F. Eppler and Mr C. Schiffmann, F.G.A., (Switzerland).

Mr H. Tillander, F.G.A., (Finland) gave a concise history of the Hope Blue Diamond and provided a specially printed pamphlet.

Mr G. R. Crowningshield, F.G.A., director of the GIA New York laboratory spoke on "observations from the Gem Trade Laboratories," and referred to the exchange of information and the accord which exist between the laboratories.

M. J.-P. Poirot, director of the Service Public du Contrôle des Diamants, Perles Fines et Pierres Précieuses (Chambre de Commerce et d'Industrie de Paris), gave a useful account of some curiosities seen in the Paris laboratory and the dangers in interpreting short-wave effects seen in synthetic blue sapphires.

Mr Richard T. Liddicoat, Jr, also showed photomicrographs of synthetic and imitation gemstones.

Mr E. Sasaki, F.G.A., (Japan) spoke on the use of x-ray diffraction equipment in gem testing.

Mr H. S. Pienaar, F.G.A., (Stellenbosch, S. Africa) talked about a new cut for diamond, which seems to consist of a round stone with an emerald-cut top and brilliant base. The new cut is called the "Barion Cut."

Dr J. Kanis (Rhodesia) gave a talk on "Gemstone News of Southern Africa," comparing various mining districts, rock faults, emerald mines and the terrifying background dangers in places such as Angola.

The last "lecture" was in fact a film, depicting readings obtained from investigations on jade substitutes by powder analysis.

A. E. F.

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Although a number of books on gemstones have been published in the past decade or two, they have tended to be either handsomely produced picture books containing little worthwhile information, or technical works designed for the student and specialist that are too demanding for the general reader who wants to widen his knowledge of precious stones but doesn't relish a great deal of hard work.

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and

PROCEEDINGS OF THE GEMMOLOGICAL ASSOCIATION OF GREAT BRITAIN

GEMMOLOGICAL ASSOCIATION
OF GREAT BRITAIN
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THE JOURNAL OF GEMMOLOGY
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Vol. XV No. 3 JULY 1976

A NEW TYPE OF SYNTHETIC RUBY

By C. A. SCHIFFMANN, F.G.A., G.G.

Gübelin Gemmological Laboratory, Lucerne, Switzerland.

DURING the summer of 1975 a puzzling ruby, which lacked obvious characteristics for accurate identification, was presented for our examination. This faceted ruby weighed approximately 3 carats, cut in a modified brilliant-cut, with an 8-sided outline, the colour being a saturated violetish red of bright appearance and the dichroic colours showing violetish red and orange.

Other data include:

R.I. 1·772–1·764, birefringence 0·008
Optic axis direction perpendicular to the plane of the table.
S.G. approx. 4·02 (hydrostatic method)
Abs. spectrum: typical Cr spectrum of ruby
Fluorescence under UV 265nm: medium red
Fluorescence under UV 254nm: medium red
Fluorescence under x-rays : strong, red, slightly weaker than that of a Verneuil synthetic ruby of similar size, and as strong as that of a flux-fusion synthetic ruby.
Phosphorescence under x-rays : not noticeable to eyes adapted to the dark.

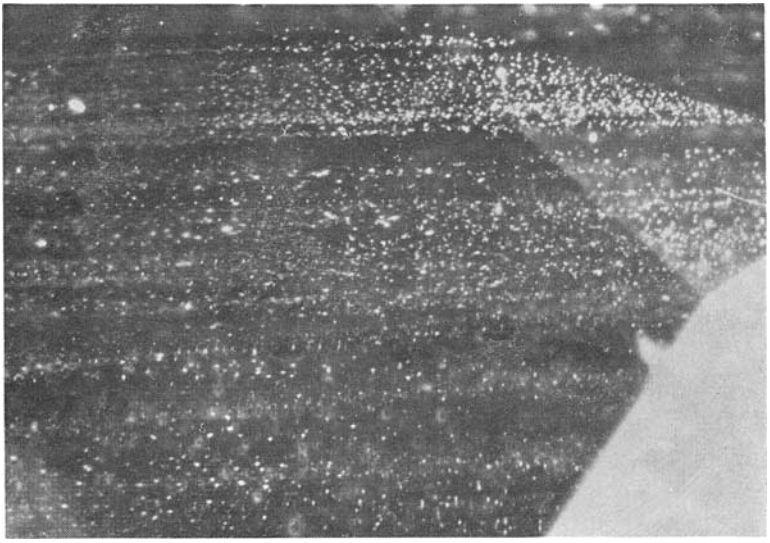

FIG. 1. Synthetic ruby of a new type: dense concentration of tiny particles arranged along roughly parallel-lying planes. Micro. magn. 40 ×, figure magn. approx. 120 ×. *(Photo. C. A. Schiffmann)*

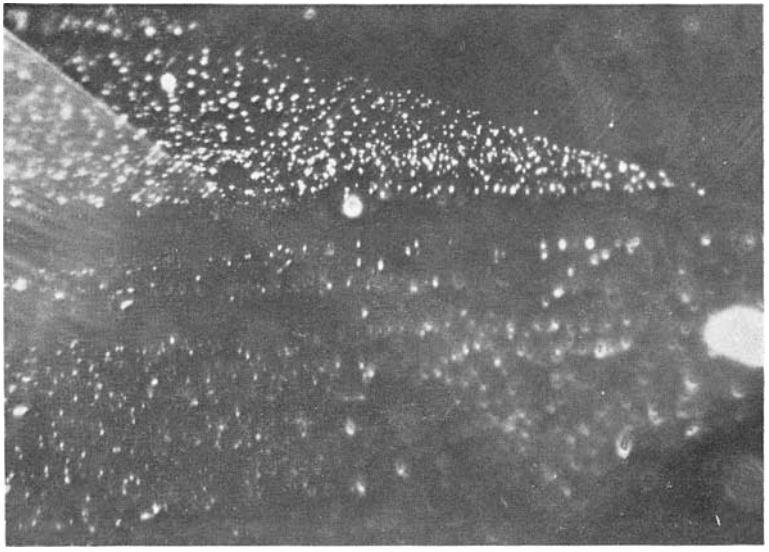

FIG. 2. Synthetic ruby of a new type: same features as in Fig. 1 at a higher micro. magn. of 80 ×, figure magn. approx. 240 ×. *(Photo. C. A. Schiffmann)*

Degree of transparency under UV 254 lamp: intermediate between the degrees of transparency of natural and flux-fusion synthetic rubies. A spectrometric curve was not conclusive about the UV absorption edge, because the strong colour saturation of this cut stone and its improper geometry resulted in too much absorption for the instrument used, to be precisely put forward.

As these data failed to reveal conclusive facts for an identification of the nature of the ruby, the stone was then thoroughly scrutinized under the microscope. At first sight and low power, it appeared to be exceptionally clear. Under higher magnification and special illumination conditions, the following features were discovered:

1. Within the sample tiny particles could be seen, somewhat irregularly distributed along roughly parallel-looking planes—they appear bright under light reflection and are probably minute cavities (Figs. 1 and 2).
2. Some of these cavities were opened during the cutting process and give a dotted aspect of tiny holes to some of the facets. This is best seen under light reflected from the facet's surface (see Fig. 3). The straight, parallel-lying lines on the facet are cutting grooves.

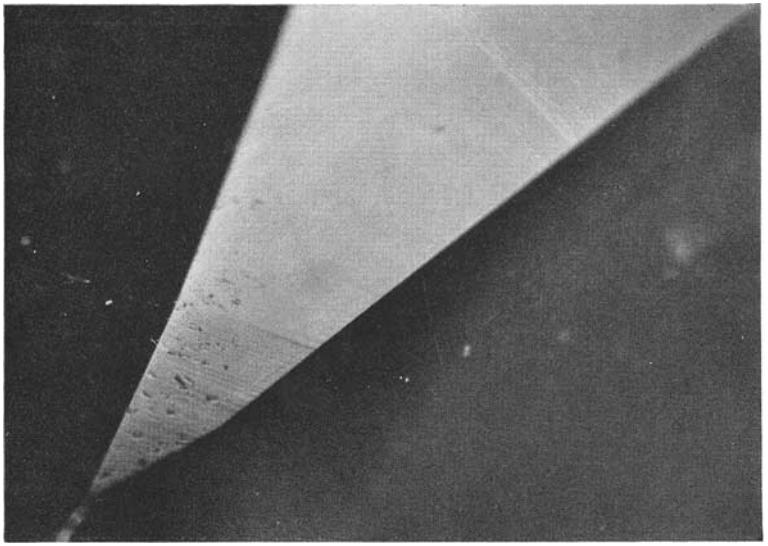

FIG. 3. Synthetic ruby of a new type: surface of a facet seen in reflected light. Dotted effect through tiny cavities. Parallel straight lines across the facet are traces of cutting grooves. Micro. magn. 40 ×, figure magn. approx. 120 ×. (*Photo. C. A. Schiffmann*)

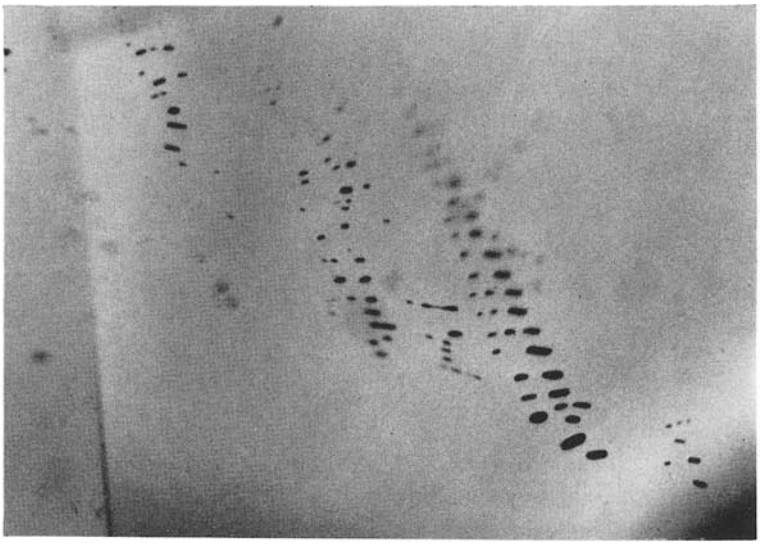

FIG. 4. Synthetic ruby of a new type: coarser type of grouped cavities, having rounded ends, one with dumb-bell shape. Micro. magn. 40 ×, figure magn. approx. 120 ×. (*Photo. C. A. Schiffmann*)

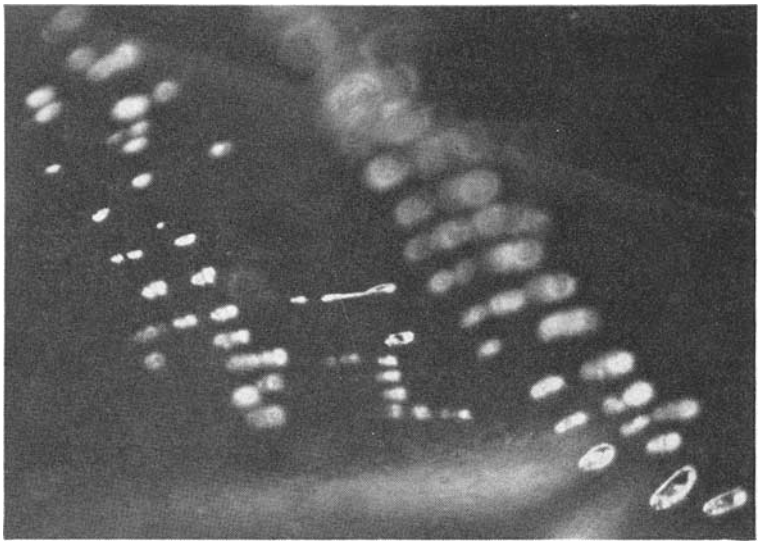

FIG. 5. Synthetic ruby of a new type: same features as in Fig. 4, at higher micro. magn. of 100 ×, figure magn. approx. 300 ×. Dumb-bell like cavity is clearly noticed. (*Photo. C. A. Schiffmann*)

3. Groups of coarser cavities, seeming roughly orientated, having rounded ends, some with a dumb-bell shape (see Figs. 4 and 5).
4. Few isolated cavities, in groups of two, one sometimes larger than its companion, visible at over 100 × magnification.
5. Few, narrow straight needles, one of them ending in a fork shape, observed at over 60 × microscopic magnification.
6. Examination in immersion liquid: seen in a direction perpendicular to that of the optic axis, growth features form a wavy plane of irregular colour saturation, the trace of which appears as a garland in Fig. 6.
7. Traces of parallel-lying growth planes through the whole sample, looking like fine straight lines, only to be seen in immersion, under proper light conditions and sight angle, not to be confused with straight colour in natural rubies.
8. At one place, the tiny particles described under §1 above are concentrated in a comet-like, flowing pattern, the trace of which starts from a rounded head, and expands like diverging arms of irregular concentration. Where the flowing lines join together, they form a hairpin-like pattern. (Fig. 7).

   These features were only observed under a particular sight angle and specially arranged illumination conditions.

The properties described were not in accordance with those of natural or artificial rubies of known sources, and accordingly on the basis of the inclusions described a new artificial product was suspected. Particularly, features mentioned in §8 above are met with only in artificial rubies.

Coming across this for the first time, we considered it necessary to inform the members of the Gemmological Conference of our findings and during the October 1975 meeting in Washington the matter was opened to discussion.* Among our colleagues from other laboratories, Mr Farn, of London, had also met this item but did not issue a final statement due to lack of time for a thorough examination. However, he suspected that the stone might be synthetic. The history of this specimen is worth mentioning: it was sold in Africa as a genuine stone and stated afterwards in a mineralogical examination report to be natural. In the course of discussion during the Gemmological Conference, Messrs Liddicoat and Crowningshield, from the G.I.A., reported having met rubies with

*see J. Gemm., 1976, XV, 2, 104.—Ed.

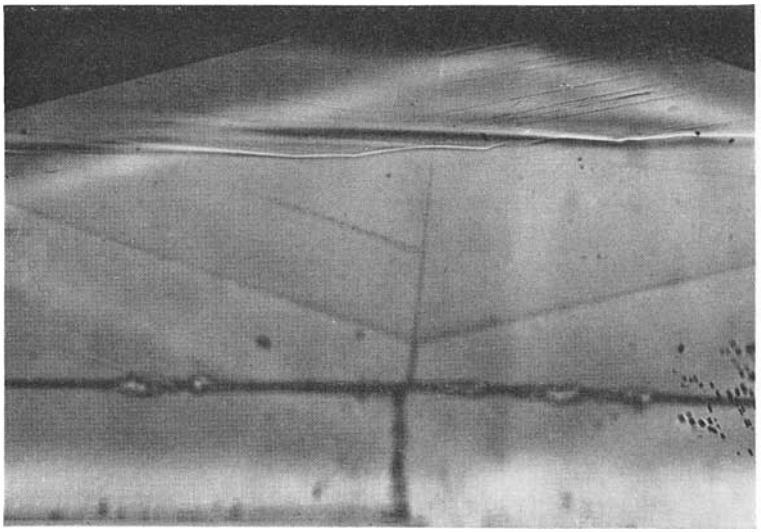

FIG. 6. Synthetic ruby of a new type: view perpendicular to the optic axis direction: wavy trace of irregular growth zone shows as a narrow light garland on the figure. Right lower part: group of cavities as in Fig. 4. Straight, black lines in the lower half of the photograph are facet junctions; narrow, thin black lines in the upper part of the photograph are cutting grooves left by insufficient polishing. Micro. magn. 32 ×, figure magn. approx. 100 ×. (*Photo. C. A. Schiffmann*)

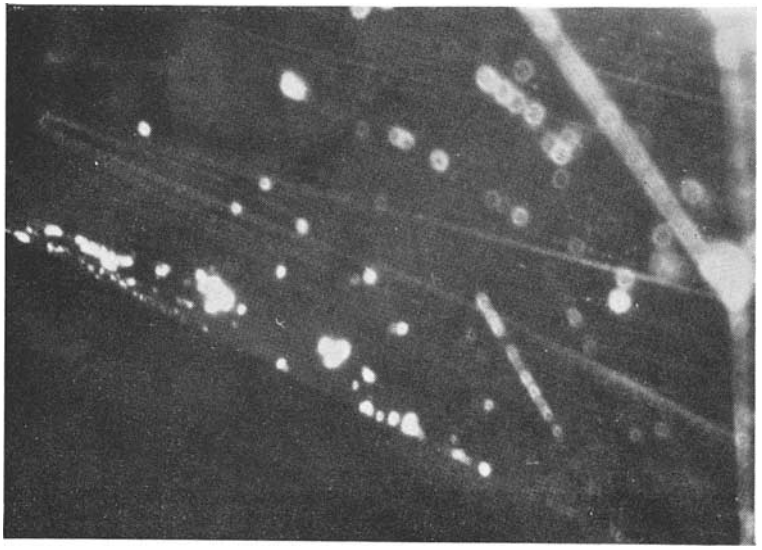

FIG. 7. Synthetic ruby of a new type: comet-like and hairpin-like pattern of diverging flow lines, through irregular concentration of tiny particles. Micro. magn. 40 ×, photog. magn. approx. 120 ×. (*Photo. C. A. Schiffmann*)

similar features and after enquiries Mr Liddicoat was convinced that these are manufactured in the U.S.A.

Summarizing: we have met a new kind of synthetic ruby, gemmologically described here in detail. To avoid inaccurate identification of similar samples in the future, this article is illustrated with clear, large-size photographs of the inclusions for the information of the reader. However, looking at the Figures above does not provide a key to automatically solving identification problems, and, in consideration of the high value of rubies today, and of the commercial consequences involved, we would expressly warn gemmologists not to judge on the grounds of resembling clues only and not to go beyond the limits of their own experience but when in doubt to submit the difficult cases for a reliable laboratory examination.

The author wishes to thank Dr E. Gübelin for his enlightening discussion of this problem and for allowing the release of this information paper, and also Mr G. O. Brunner for registering the absorption spectrum of the sample.

[*Manuscript received 26th February, 1976.*]

HELVITE AND TOURMALINE ACCOMPANIED BY GRUNERITE IN QUARTZ

By E. J. GÜBELIN, Ph.D., C.G., F.G.A.
Lucerne, Switzerland.

WHEN I read P. J. Dunn's description of helvite as an inclusion in tourmalinated quartz from Governador Valadares, Brazil, in the July 1975 issue of this *Journal**, I remembered having observed this same variety of mineral inclusion in quartz some 20 years ago. However, in those days we gemmologists did not enjoy the convenience of easy access to such

*J. Gemm., 1975, XIV, 7, 335–338.—Ed.

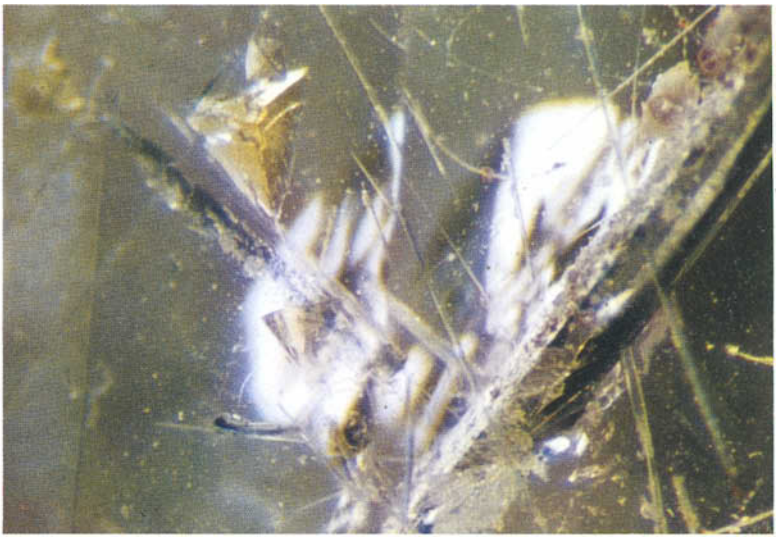

Interesting internal paragenesis of three different minerals in a rock crystal from Governador Valadares, Brazil, consists of yellow tetrahedra of helvite, dark rods of tourmaline and fine fibres of grunerite. (50 ×)

elaborate apparatus as the electron microscope, the electron microprobe or the Gandolfi x-ray camera, let alone to such an excellent reference book as the recently published 'Encyclopaedia of Minerals' by W. L. Roberts *et al.*, which thanks to its marvellous colour illustrations may at least give us valuable information as to the possible appearance of an obscure or rare mineral occurring as a guest in a gemstone. Consequently, and since I could not definitely identify these beautifully shaped greenish-yellow tetrahedra, I stowed away my cut rock crystals containing these attractive inclusions among the unsolved cases in my sample collection. Thus I was delighted to find them there again after their long slumber and a renewed observation under the microscope revealed an exact concurrence with P. J. Dunn's description. Furthermore, it seemed possible that those fine filaments mentioned by P. J. Dunn could be analysed by the microprobe since some of them appeared to be large enough and were exposed in the polished surface of the cut quartzes for such an investigation.

Of the various fibrous or acicular filaments in the four quartz specimens investigated by the electron microprobe *all* revealed the

following elements: Fe, Al, Si, (Mg), (Mn), no Ca (which could however substitute Mg and Mn). We know several possibilities amongst the silicates for this combination of elements. A representative of the inosilicates of the amphibole group would just as well agree with the chemical composition as a phyllosilicate of the asbestos group. However, the low content of Mg appears to be rather uncommon for the inosilicate of serpentine-asbestos. This consideration and the presence of traces of manganese lead to the conviction that these needles are grunerite. A certain prolificacy is also attested by the presence of the yellowish helvite tetrahedra which are manganese-rich beryllium nesosilicates.

Grunerite is the almost pure iron-hydroxyl amphibole ($Fe_7[OH\ Si_4O_{11}]_2$) with only little MgO and Al_2O_3, but usually with MnO. It varies from colourless via green to brown with a silky lustre and forms asbestos-like, fibrous and divergent aggregates. Its presence as a guest mineral is not uncommon within rock crystal.

May this short communication act as a further contribution towards the search for knowledge on mineral inclusions in gemstones.

[*Manuscript received 17th February, 1976.*]

GEMMOLOGICAL NOTES

By PETE J. DUNN, M.A., F.G.A.

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CUPRITE

Very large crystals of cuprite (up to 5 cm) have been found at the Onganja mine, near Seeis, Southwest Africa, about 68 miles from Windhoek. The rough crystals, comprised of the octahedron {111}, the dodecahedron {011}, and the cube {001}, are equant and euhedral, and are altered on the surface to a thin coating of malachite.

The cuprite itself is quite gemmy, and can be faceted into fine gems. Due to its low hardness (4) and brittleness, and the semi-metallic lustre produced by the high refractive index ($\sim$2·85), and

very dark red colour, cuprite is rarely cut as a gem, and then only for collectors and museums. The material is, in some sections, quite flawless, and from these portions dark red gems of surprising clarity have been produced. The largest known cut stone is in the Smithsonian collections and is a round modified brilliant of 172 carats. The stone has a deep dark blood-red colour and is a magnificent brilliant gem.

Opaque Inclusions in Ornamental Serpentines

Opaque inclusions, both euhedral and anhedral, are frequently observed in serpentines used in the carving of ornamental objects and cabochons. These opaque minerals in gem-quality ornamental serpentines from 7 localities were x-rayed utilizing CuKα x-radiation and Gandolfi cameras. The opaque inclusions were found to be magnetite, haematite, and pyrrhotite, and only one phase was present in any given serpentine specimen. The samples, all from the collections of the National Museum of Natural History, Smithsonian Institution, Washington, D.C., are listed in Table 1 with the identity of the opaque inclusions.

Table 1
List of Serpentines with Opaque Inclusions

NMNH #	LOCALITY	OPAQUE INCLUSION
94998	Lime Pit Mine, Cecil Co., Maryland, U.S.A.	Magnetite
16049	Tasmania, Australia	Magnetite
114953	Dypingdal, Modum, Norway	Haematite
118473	Devil's Den, Newbury, Massachusetts, U.S.A.	Pyrrhotite
B17970	Snarum, Norway	Haematite
108302	Delight, Maryland, U.S.A.	Magnetite
47167	Musashi Province, Japan	Magnetite

Aikinite Inclusions in Phenakite

Fine gemmy phenakite crystals, up to several cm, have been found for some years at San Miguel Di Piricicaba, Brazil. Occasionally noted in this gem phenakite are acicular crystals of a black mineral with deeply striated prisms. These crystals were x-rayed utilizing CuKα x-radiation and found to be aikinite, $PbCuBiS_3$, a very rare sulphosalt. The aikinite crystal inclusions are often doubly terminated and frequently adjacent to a gas or vacuum

bubble. No epitaxy with the host phenakite was observed. Also noted as inclusions in the phenakite are colourless clear to light green crystals of an unidentified member of the mica group.

Alexandrite from Tanzania

A crystal recently received at the U.S. National Museum is worthy of note. This chrysoberyl, $BeAl_2O_4$, is from the area of Lake Manyara in Tanzania. The crystal is $25 \times 20 \times 12$ mm in size, is pseudohexagonal in habit, elongated on [001] and flattened on [100]. It is a twinned crystal, comprised of three individuals, and the dominant forms are the prism {110} and the pinacoids {100} and {001}.

The alexandrite is opaque. There is a chatoyancy, which is due to a fibrous layer about 0·5 mm below the surface, which is overgrown by a clear zone. The colour-change of this material is quite striking: it is a beautiful blue-green in white fluorescent light, a rich green in daylight, and reddish-violet with bluish overtones in incandescent light.

The crystal fluoresces a deep magenta red in long-wave ultraviolet radiation, but does not respond to short-wave. There was no luminescent response to x-radiation. Optical constants could not be determined, as the crystal is not to be cut but will be for exhibit as gem rough. The x-ray powder pattern of the material matches that of chrysoberyl.

New Jersey Natrolite

Gem natrolite, $Na_2Al_2Si_3O_{10}.2H_2O$, was discovered in the Bound Brook quarry, at Bound Brook, New Jersey in late 1972. The crystals recovered were notable for their large size, which varied from microscopic to $1{\cdot}5 \times 17$ cm megacrystals.

The crystals are orthorhombic with the usual natrolite morphology, are prismatic in habit, and have a square cross-section. Although the crystals occur coated with a micro-crystalline druse of heulandite, this can be easily removed by scraping to expose the gemmy natrolite within. The terminal ends of many of these natrolite crystals are facetable, and some fine stones have been cut, among them two step-cut gems of superb quality weighing 9·31 ct and 7·9 ct. These gems are in the Smithsonian Institution collection (NMNH Gem Numbers 5111 and 5116).

The natrolite is not fluorescent in either long or short-wave

ultraviolet radiation, and is transparent to both. No fluorescence was observed in x-radiation. The refractive indices, determined in sodium light with the Rayner Dialdex refractometer are: $\alpha = 1{\cdot}478$, $\beta = 1{\cdot}480$, $\gamma = 1{\cdot}490$, with a distinct birefringence of 0·012. The optic sign is positive.

Inclusions noted in this material consist of thin, parallel, chevron-like zones of tiny white crystals resembling breadcrumbs. These unevenly spaced chevron-like bands of included matter are parallel to the pyramidal termination of the crystals and obviously represent prior growth surfaces.

Natrolite is, due to its low hardness of 5-5½, useful only as a gem for collectors of the unusual and for museum gem collections.

The natrolite was analysed on an ARL Electron Microprobe utilizing an operating voltage of 15 kV and a sample current of 0·15μA with a beam diameter of 50 microns. Standards used were Department of Mineral Sciences microprobe standards of high reliability. The analysis is presented as Table 2. No zoning was noted in the crystals.

The author is indebted to Joseph Nelen for the chemical analysis and to Dr George Switzer for a critical reading of the manuscript.

TABLE 2

ANALYSIS OF BOUND BROOK NATROLITE

		1	2
	SiO_2	48·5	47·4
	Al_2O_3	27·2	26·8
	Fe_2O_3	—	
	MgO	< 0·1	
	CaO	—	
	Na_2O	16·2	16·3
	K_2O	< 0·1	
ASSUMED——	H_2O =	8·0	9·5
	TOTAL		100·0

1. Microprobe analysis of Bound Brook natrolite; H_2O assumed by difference.

2. Theoretical composition of natrolite, $Na_2Al_2Si_3O_{10}.2H_2O$.

A Special Grey Glass

A light greyish glass was offered for sale as cordierite (iolite) at a mineral sale held recently in Switzerland. Although offered as cordierite, the gem had no pleochroism, the most obvious characteristic of cordierite. One gem, weighing 15·6 carats, was offered for $100·00.

The gem is poorly cut, with abundant scratches, poor polish, rounded facet-edges, and an over-large coarsely-ground girdle. It is quite soft. It has a refractive index of nD = 1·516 (±0·003), a specific gravity of 2·64 (±0·02) and is isotropic, with a weak anomalous birefringence, possibly due to strain. Although quite obviously a glass, the fact that the specific gravity was close to, but slightly higher than that of cordierite, combined with a refractive index close to, but lower than those of cordierite, prompted a more detailed investigation of the material. Powder from the girdle was x-rayed and gave no diffraction pattern, confirming the amorphous nature of the material.

The gem was analysed on an ARL-SEMQ electron microprobe using an operating voltage of 15 kV and a beam current of 0·15 μA. A preliminary analysis indicated a high barium and silicon content, with smaller amounts of aluminium, potassium, and sodium. A more detailed analysis was warranted, and this analysis of the gem is presented as Table 3. The BaO content of 12·67% is quite high and suggests that the barium may have been introduced to raise the density of the glass to near the limits of the density variation of cordierite. The potassium and sodium content may have been

Table 3

Analysis of Special Grey Glass

SiO_2	69·99%
Al_2O_3	3·43
FeO	0·11
MgO	0·08
CaO	0·07
K_2O	6·05
Na_2O	6·56
TiO_2	0·09
BaO	12·67
Total	99·05

Accuracy of data ± 2% of the amount present.

selected to adjust the refractive index of the material to be near that of cordierite. The possibility exists that other elements, not detected by the microprobe, are present.

Detection of this glass imitation is quite easy. The complete lack of pleochroism obviates the possibility of cordierite (iolite). The material is isotropic with a weak anomalous birefringence. The glass does respond to ultraviolet radiation, unlike cordierite which does not. Under long-wave it fluoresces an extremely weak light green, and under short-wave it fluoresces a stronger greenish-cream colour and becomes almost opaque in appearance. There is no phosphorescence in either wavelength, and no response to x-radiation. The refractive index of nD = 1·516 is lower than that of gem cordierite, and the absence of any birefringence confirms the isotropicity of the material. No absorption spectra were observed, using the G.I.A. absorption spectroscope. No inclusions were noted, nor were the schlieren, so common in glasses, seen in this material. The colour was very evenly distributed, with no patches or concentrations. No bubbles were observed.

In summary, this grey glass is a most interesting imitation gem material, but the trained gemmologist should have no difficulty in ascertaining its true identity.

The author is indebted to John Saul for the opportunity to study the gem, and to John S. White, Jr, for bringing it to his attention.

RECENT DEVELOPMENTS IN THE SYNTHESIS OF POSSIBLE GEM MATERIALS

By M. J. O'DONOGHUE, M.A., F.G.S., F.G.A.

(being the substance of a talk given to the Gemmological Association of Great Britain at Goldsmiths' Hall, London, on 8th October, 1975.)

FOR many years scientists have been developing crystalline materials for the furtherance of research in the fields of optics, electronics and communications. Work on the laser alone has led to the creation of many new materials, including, of course, rubies of high quality. Almost all crystalline substances produced for research purposes are useless if flawed or if they show various types of twinning. There is, therefore, a high degree of wastage and this can be seen reflected in the number of such substances which appear on the gem market. Much crystalline material finds its way into the waste basket, and, where there are staff members who have a lapidary interest, we are likely to find some faceted stone which at first defies identification. These stones may be unusual in colour or behave in ways not previously described in the gem literature when subjected to ultraviolet light or x-rays. So far many substances which from their colour and hardness would seem to have possible gem applications have been manufactured in small sizes only, but there is no reason why one or a number of them should not suddenly appear in larger and faceted forms.

Blue β-spodumene has been synthesized and resembles a pale aquamarine or blue topaz in colour. Both flux-melt and hydrothermal methods have been successfully employed and the temperatures needed are not particularly high. The α-form does not easily yield to synthesis, but an iron-bearing type has been obtained at temperatures between 550°–600°C and using pressures of 2,000–3,000 atmospheres. A chromium-bearing green spodumene (cf. hiddenite) has been made, and various other colours can be obtained by the addition of suitable dopants. The lithium compounds were synthesized in solutions of LiCl or LiOH using a combination of the oxides Al_2O_3 and SiO_2. Alkalinity of the solutions was varied by adding HCl to the original LiCl or LiOH. Results obtained by Kuznetsov[1] indicated that in pure solutions of LiCl and at temperatures of 400°–700°C and pressures of 750–3,000 atmospheres

α-eucryptite, β-spodumene and petalite can be obtained. The β-spodumene is found as bipyramids and also as concretions. During the experimental production of the green chromium-bearing spodumene an overgrowth of colour formed on the natural crystal at 3,000 atmospheres and at 700°C. This occurred when Al_2O_3 was partly replaced by Cr_2O_3.

Dr D. J. Drysdale, of the University of Queensland, tells me[2, 3] that he has made $LiCr_3Si_2O_6$ using silica gel, LiOH solution and $Cr(NO_3)_3$ and Li_2CO_3—this crystallizes at around 500°C under 2 bars pH20 to produce a very fine-grained powder of chrome spodumene. Dr Drysdale states that the synthesis of a true hiddenite (i.e. with a few per cent Cr_2O_3 replacing Al_2O_3) would be more difficult and would need much higher pressures, up to 6kb. He suggests that part of the difficulty in synthesizing the α-spodumene lies in the dense hexagonal structure with Al in 6-fold co-ordination. The β-spodumenes have lower density phases with Al in 4-fold co-ordination. Dr Drysdale has synthesized spodumenes with iron, vanadium, indium and scandium substituting for aluminium as well as chromium.

Sodalite cannot be grown from a melt, since this method invariably produces a glass with the sodalite composition. Hydrothermal methods produce single crystals using a solvent of an aqueous solution of NaOH and a charge of the sulphur-bearing sodalite, hackmanite. Seeds have been obtained by growing artificial material on natural hackmanite. Weights up to 70g have been manufactured and the colour is a fine dark blue. Sodalite crystals are grown for their interesting optical properties, and although the period of growth may be as long as six months some crystals could very well appear on the gem scene.

Lithium tantalate is $LiTaO_3$, has a S.G. of 7·3 and quite a high degree of hardness. It is optically positive and uniaxial, with R.I. 2·175 and 2·180. The birefringence is 0·006. It is similar to lithium niobate in its optical transmission, since it transmits from 0·3 to 6 microns. It is grown by the flux-melt method and also with the Czochralski technique. It is insoluble in dilute acids and with a fairly high dispersion could make a diamond simulant.

Bismuth germanium oxide (BGO): two stoichiometric compositions of this material are known, $Bi_{12}GeO_{20}$ with a molar ratio of $6Bi_2O_3$:1GeO, and $Bi_4Ge_3O_{12}$ with a ratio of $2Bi_2O_3$:$3GeO_2$.

The material crystallizes in the cubic system and is used for electro-optic research. It is manufactured using the Czochralski technique, and, since its melting point is relatively low, it is quite easy to obtain crystals with a high degree of mechanical soundness. $Bi_{12}GeO_{20}$ has a S.G. of 9·23, a R.I. of 2·55 and a hardness of 4·5. The colour is bright yellow to orange. $Bi_4Ge_3O_{12}$ has a S.G. of 7·12, a R.I. of 2·07 and a hardness of about 4. Both materials are transparent, and $Bi_{12}GeO_{20}$ shows photoluminescence spectra at 6358Å and 9537Å; on doping with various elements the peaks of the luminescence can be shifted further into the infrared.

Spinel has been grown by flux evaporation; crystals of spinel have been grown from solution in PbF_2 and have reached quite large sizes. Green colours have been obtained by doping with cobalt, yellow from the addition of iron (or nickel?) and red from the addition of chromium. The octahedral form is prominent and shows triangular trigonal pyramids on well-formed faces. Crystals doped with Ni and Co show a highly coloured central region with a colourless periphery. Crystals in which Zn replaces Mg and Ga replaces Al have also been grown: colours include red (from chromium) and other colours from other dopants, as in the Mg spinels. Only {111} faces are present; there is a uniform growth rate and no preferential absorption of dopant on different faces. In the red crystals there is a strong emission line in the red part of the spectrum but no group of emission lines as shown by some natural red stones.

Nickel-olivine was synthesized by Grigoriev in 1937, using a fusion of NiO and SiO_2 with 3% CaF_2. Ringwood[4] in 1956 showed that Mg_2SiO_4 and Ni_2SiO_4 form a complete series of solid solutions. It may be that the nickel enters the olivine structure in excess of the magmatic Mg:Ni ratio because iron in the natural material lowers the thermal stability. Stones made by Ito at the University of Chicago are coloured a fine bright green. The S.G. has been calculated at 4·09. Another reported method combines $NiCO_3$ with $Mg(OH)_2$ and H_2SiO_4 with a flux of $NaWO_4.2H_2O$. The process runs for 72 hours at 1280°C to produce $NiMgSiO_4$.

Phenakite doped with vanadium is an interesting bright blue-green. The natural mineral has a hardness of 7½, R.I. of 1·670 and 1·654, with no pronounced cleavage. The crystals examined were made at the University of Chicago: a larger crystal made at Bell Laboratories shows the typical crystalline characteristics of phenakite.

Recent progress in the synthesis of corundum has led to the production of a red corundum that is not ruby since it contains no chromium (using the analogy of emerald). The colour, from doping with manganese, is an orange-red and the flattened plate-like crystals have a brown edge, due to the presence of magnesium. There is no noticeably prominent band in the absorption spectrum. These stones were manufactured by White, of Imperial College, London.

Yttrium ortho-aluminate, $YAlO_3$, was developed by the Raytheon Co. in about 1969 for use as a possible laser material, for which purpose it was doped with neodymium. Apparently it was not completely successful in this role and may now be on the market as a diamond simulant. It has a S.G. of 5·35, and R.I. of 1·97. The dispersion is 0·033 and the hardness $8\frac{3}{4}$. The melting point is 1875°C and it is made by the Czochralski technique.[5]

Rare-earth silicate apatites have been made in a wide variety of colours. Vasilieva (1958)[6] showed that the intensity of the colour obtained was due to the amount of Mn in the mineral but that the nature of the colour depended on the degree of oxidation of the Mn. Mn^{2+} gives pale pink and blue, Mn^{3+} blue and Mn^{7+} violet. The combination of ferrous and ferric iron gives green. Ito, of the University of Chicago, has synthesized some apatite-like minerals[7], including Na-Nd-F silicate, coloured purple; $NaLa_8Si_6O_{24}F_2$, colourless; Na-Pr silicate, bright green; and Na-Sm silicate, yellow. Cobalt and nickel produce violet and pale green colours respectively. RE^{3+}, $RE^{3+}:Si^{4+}$ and $RE^{3+}:O^{2-}$ charge-coupled substitutions and defects are quite easily incorporated into the apatite structure.[8]

Investigations of the possibilities of the use of Nd-doped fluorapatite for laser work has shown that $\sim$1wt% Nd doping of FAp crystals by adding Nd_2O_3 to the melt makes a laser body with more than twice the efficiency of yttrium aluminium garnet, since the emission is concentrated in a narrow line, due to the occurrence of nearly all the active Nd in a single site. Doping with NdF_3 produced larger crystals of high optical quality but with impaired laser characteristics. Work in this field shows that Nd substitutes at both Ca(1) and Ca(2) sites in approximately equal atomic fractions in the NdF_3-doped material and that Nd substitutes only at the Ca(2) site in the Nd_2O_3-doped material.[9]

Professor E. Kostiner, of the Institute of Materials Science of

the University of Connecticut, has recently published an account of the synthesis of azurite and malachite. Small crystals of azurite that I have examined show well-developed crystal form and are of a fine dark blue. So far they are of approximately 2mm size only; I have not yet seen the synthetic malachite.

Gadolinite has the chemical composition $Be_2FeY_2Si_2O_{10}$. A form with the composition $CuPr_2Be_2Si_2O_{10}$ has been synthesized (Ito, University of Chicago) and is a very bright green. The natural mineral has a hardness of $6\frac{1}{2}$–7, a S.G. of 4·0–4·6 and R.I. 1·7–1·8. In nature the colour is dark green to black; the synthesis is probably hydrothermal.

Lithium niobate has been known as a diamond simulant for some time, although it does not often seem to occur. Through the kindness of Dr R. Diehl[10] I have recently examined a set of coloured crystals. These include one undoped crystal which is virtually colourless; one coloured brown (due, it is thought, to a reduction in the amount of niobium); one, doped with 0·1 mole% Co_2O_3, which is a dark blue colour and which gives a clear cobalt absorption spectrum; one doped with 0·05 mole % NiO which is yellowish; and one doped with 0·05 mole % CuO which is golden brown to yellow. None of these, other than the cobalt-doped crystal, shows an absorption spectrum and none shows any luminescence under ultraviolet radiations. Interesting surface dendrites have been observed by Singh and Deshmukh in lithium niobate crystals grown perpendicularly to the c-axis. This phenomenon only seems to occur when there is a fairly large amount of the melt in the crucible and when there is a slow rate of cooling.[11]

Zincite, the zinc oxide, is only known from one locality in its natural state (Franklin, New Jersey). It takes its attractive orange-red colour from manganese, and this can now be repeated in the laboratory since the mineral has been grown hydrothermally. It is formed in aqueous solutions of NaOH or KOH and the temperature of the dissolution zone has been reported as 380°–410°C and that of the growth zone as 350°–380°C. The initial charge is a zinc oxide chemical reagent or a fine crystalline charge of previously crystallized ZnO. Growth is improved by the addition of mineralizers usually LiOH or LiF. The crystals obtained are hexagonal prisms, hexagonal pyramids and monohedra. The rate of growth of the {0001} face is about 8–10 times greater than that of the prism and

pyramid faces. Red is obtained by the addition of manganese, green by the addition of nickel.

We are by now quite familiar with the diamond simulant gadolinium gallium garnet (GGG). A little less well-known are the coloured forms, red coloured by manganese and green by cobalt. Even more interesting are the crystals, which (in the examples in my collection) take on forms typical of the cubic crystal system, dodecahedra combined with icositetrahedra. The red crystal shows some form of two-phase inclusion and it will be interesting to see whether cut stones appear on the market.

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NOTES FROM THE LABORATORY

By A. E. FARN, F.G.A.
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IN this trade, and certainly as a trade gemmologist in a laboratory serving commerce, one never stops learning. A very large baroque pearl of about 50/60 grain size in a brooch (set with baguette and brilliant-cut diamonds) of quite reasonable importance proved very interesting and to me unusual. A radiograph of the brooch with pearl still mounted showed a mabe effect in a very strong and striking manner. In fact the centre of the mabe looked remarkably opaque, much more than is usual, and the exterior much more transparent (to x-rays) than usual. I decided to unset

the "pearl". I found it very simply pegged and secured by pearl cement and removed it quite easily. The base had a cap of mother-of-pearl in the manner of a mabe, and the sides had been worked as is usual with a large baroque to fit snugly into a mount. The heft seemed very great and to my surprise it scaled 142 grains, whereas it looked about 50/60 grains. In print this may sound rather tame, but in fact it was quite interesting. The texture was now very thoroughly examined. I found it, to my surprise, to be fine matt glass of an exceptionally fine orient. I took a density and found it to be 4·21—much too heavy for pearl! The customer, a well-known F.G.A., was equally interested, having intended to purchase it (subject to test). He described a firm who, pre-War, made "pearls" to order to match a pearl in a suite, etc. These he said were usually filled glass beads and were termed "de meisner pearls".

* * *

Heft is a useful rough and ready guide, or at least indication, to preliminary testing of a gemstone. If an apparent aquamarine of reasonable size—say above 7 carats—is handed in for testing, one can sometimes tell in the hand by heft that it is too heavy for aquamarine. Reasonable chances are it is a blue topaz or synthetic blue spinel.

Thus very recently when Harry Wheeler, Secretary of the Gemmological Association, sent to me for my interest and observation a golden coral, I was surprised at its extreme lightness in the hand. In fact it felt like a thin piece of plastic. I read of golden coral in *Gems and Gemology*, 1974/5, 14, 12, 369–370, which contains photographs showing good examples of the peculiar surface structure. At best it can be described as resinous or lacquered (treacly perhaps), which when examined by reasonably high-power magnification (50 × upwards) shows some signs of overlapping or tears, as seen when too much paint is applied to a vertical panel. The most striking feature, however, structurewise is the dotted or circular pattern which—to coin a phrase—is regularly irregular. Since heft was my first impact and impression, I took a density of the stone and found it to be 1·27, and a distant vision method refractive index of 1·54. I am continually impressed by the number of items often tested by this method which show a mean figure of 1·54, without counting the quartz family. We have reported earlier on the characteristics of black coral. I must confess that I

had never really liked the term black coral, neither did I feel happy with golden coral. To my shame I had always thought of coral as being, to quote Webster,* "almost wholly calcium carbonate ($CaCo_3$) . . ." [with] "a density of between 2·6 and 2·7". Here I was faced with a non-calcareous substance with a density of 1·27.

Resorting to Chambers's Encyclopaedia, I found that coral belongs to the Madreporaria, an order of marine animals which form the true or stony corals, but the hydrocorallines, the horny corals, are also embraced under the general title of coral. I feel at least relieved that, when I did report recently on a black coral hoop ring as such, I did not either upset the Trade Descriptions Act or impinge upon the already overstretched nomenclature division of gemmological references. Incidentally, the golden coral examined came from Maui divers in Hawaii. Since our first testing of golden coral we have had a further piece of black coral in to test, brought to us by a local jeweller's daughter. She had the pendant sent to her by her boy-friend who is diving for black coral in Hawaii. Father, the jeweller, condemned it as plastic because he said it was "too light for coral": which proves that heft is a *rough* guide, not to be used lightly.

I have re-examined a large specimen of black coral, previously and amply reported upon by Robert Webster in this *Journal*, 1954, IV, 5, 197–199. One quick density gave a figure of 1·33. Webster quotes 1·32 and 1·35. I felt pleased to be not only in the target area but well bracketed by Webster. One characteristic of black coral—having immersed it and dried it by placing it on top of a convector, I noted that whilst warm it bends. Black coral is probably a form of conchiolin, a horny substance.

* * *

Synthetic gemstone manufacturers seldom produce inferior looking goods as does nature. Since there is no logical reason to perpetuate mediocrity, it follows that most synthetics seen in jewellery are good in size, sometimes well cut, if a modern hydrothermal or flux-fusion product, and exhibiting colours which to the trained eye *look* wrong. These strong colours, particularly in Verneuil flame-fusion products, are usually due to random cutting, as opposed to correct cutting from a crystal for a natural stone.

*"Gems", 3rd edn, 1975, p.502.—Ed.

Gemmologically one can admire the knowledge, expertise and research required to arrive at a new synthetic. Sometimes one wonders on reading of the new synthetics or of the synthesis of yet another gemstone if it is really worthwhile. We have had recent information of synthetic sodalite, and it doesn't seem too far removed to hear of synthetic lapis lazuli, synthetic turquoise, synthetic opal and synthetic quartz. Gemmologically this is fascinating if one only has to read the journals, attend classes or give talks. Equally, if one is in doubt as a dealer or merchant, one can opt out of a purchase and deal only in goods one is familiar with, or those which already bear a certificate. After all, if stones are bought and sold "subject to test", a merchant is fairly well covered. This of course presumes he is buying in the market.

Recently we have been given two samples of "synthetic lapis lazuli", the product of that master of synthesis, Pierre Gilson. I wrote to him to thank him for his gesture and generosity and asked him if it were a bonded product by plastic or other cementation. I was told that *no* plastic bonding occurred in his opal, turquoise or lapis lazuli. The chief ingredient in his lapis he states is lazurite, which can be checked by x-ray powder diffraction method. One of the constituents of natural lapis lazuli is of course lazurite, which cancels out lazurite as a test for a synthetic! However, the pieces I received were of sufficient size to afford a density-test, and I found it to be extremely low for such apparently pure material, namely 2·33 to 2·35 plain and 2·36 with some pyrites. On doing a second check of specific gravity I found my weights were wrong, or so it at first appeared. Further checking proved that the discrepancy was due to porous material soaking up water.

I decided to crush a portion and burn a sample. I would not do this to jewellery set with lapis lazuli in a routine test. Just simply crushing a small piece of synthetic lapis lazuli gave off a smell of fireworks similar to sulphurous smoke. The porous synthetic lapis lazuli, when placed against or with known natural lapis lazuli, is inert when viewed through the Chelsea filter, whereas most natural lapis lazuli appears a brown red to dull liver-red colour. The test is best conducted with side by side comparison. Checking lapis lazuli and its imitations in Robert Webster's third edition, I found that the test he gives† for natural lapis lazuli as against

†"Gems", 3rd edn, 1975, p.222.—Ed.

imitations is that a drop of dilute hydrochloric acid upon natural lapis lazuli gives off a smell of hydrogen sulphide. I tried a drop of hydrochloric on the Gilson synthetic lapis lazuli which produced a fierce reaction of foaming effervescence. I tried the same acid test on various specimens of known natural lapis lazuli with no effervescence and no smell.

To sum up: to check lapis lazuli one should be suspicious (always) of fine superb colours, including finely disseminated pyrites. If possible, a check density should be taken, or, failing this, a very careful weight in air to three places of decimals, followed by a soak in water (which can do no harm) for ten minutes and a further weighing to note any increase in weight. Follow on by observation (with comparison piece) with a Chelsea filter and a discreet touch on the back of the piece using a glass dipstick, so that only a microscopic dot of acid is dropped. Viewing with a watchmaker's glass in the eye, one can see the positive reaction leap from the stone. This has a bleaching effect and leaves a dull somewhat faded mark, which won't matter on the back of a stone. With the stone suspended in a wire cage and the balance freely poised, I was able to watch the illuminated scale of the balance move as water was absorbed and weight gained in well under a minute.

Since the S.G. is so low and the material so porous, one wonders whether the term "synthetic" is incorrectly applied. In this case it should be *imitation.* The modern tendency is to apply the word "synthetic" broadly to almost any man-made product. Doubtless there will be further debate in the future about the use of the word "synthetic", which I previously discussed in April 1960 in this *Journal* (VII, 6, 209–210).

STUDIES OF NUCLEATION AND PROPAGATION OF CRACKS IN NATURAL QUARTZ

By M. S. JOSHI, Ph.D., M.Sc., and B. K. PAUL, Ph.D., M.Sc.,

Department of Physics, Sardar Patel University, Gujarat, India.

ABSTRACT

Evidence is given for existence of pile-up of dislocations against some impurities on rhombohedral cleavages. Nucleation of cracks due to pile-up of dislocations on rhombohedral cleavages is dealt with. Initiation of cracks due to intersection of glide bands with a grain boundary on basal cleavages are illustrated and discussed. Also described are the intergranular cracks, viz. wedge-type (w) and round-type (r). Their formation and growth are discussed and interpreted.

INTRODUCTION

Plastic deformation and nucleation of cracks are two closely related phenomena. Influence of plastic deformation on nucleation of cracks has been investigated by several workers both in metallic and nonmetallic crystals [1-4].

Dislocation etching experiments carried out on fracture surfaces of natural quartz crystals gave evidence for the nucleation of cracks due to pile-up of dislocations and also due to intersection of glide bands with a grain boundary. Cracks are found to be nucleated also at grain corners as well as along grain boundaries on subjecting the crystals to thermal stresses. The authors contribute evidences of such cavitation fracture.

OBSERVATIONS

Cracks at the head of dislocation pile-ups

A noteworthy observation on a rhombohedral cleavage $\{10\bar{1}1\}$ after etching the cleavage in steam in an autoclave at 280°C for 12 hours is illustrated in Fig. 1. The row of triangular etch pits represents a pile-up of dislocations in a direction parallel to the r-m edge. This is one of the possible directions of glide in quartz, the glide plane being {0001}. No visible boundary is observed at the tip of the pile-up. Therefore it would be reasonable to assume that the pile-up had taken place against some obstacle such as an

impurity. It may also be noted that the direction of propagation of crack coincides with the r-z and r-m edges of the crystal.

Nucleation of cracks at the intersection of glide bands with a grain boundary

There are two general types of crack nucleation sites:

(i) at the intersection of glide bands;

(ii) at the intersection of glide bands with a boundary.

A large number of fracture surfaces were examined, but no evidence for the first type of nucleation mechanism was obtained. Nucleation of microcracks at the intersection of glide bands with a grain boundary has been observed on the $\{10\bar{1}1\}$ cleavages of quartz. A typical example is illustrated in Fig. 2. It was obtained after etching the cleavage in fused KOH (6 gm of KOH + 3 cc of distilled water) for 1 hour at 250°C. The two sets of rows of pits are oriented along r-m and r-z edges of the crystal. This means that the two sets of glide bands are formed as a result of glide on $\{0001\}$ and $\{01\bar{1}1\}$ planes along r-m and r-z directions respectively. As observed earlier, here also the microcrack P is found to be oriented along one of the glide directions (r-z edge direction).

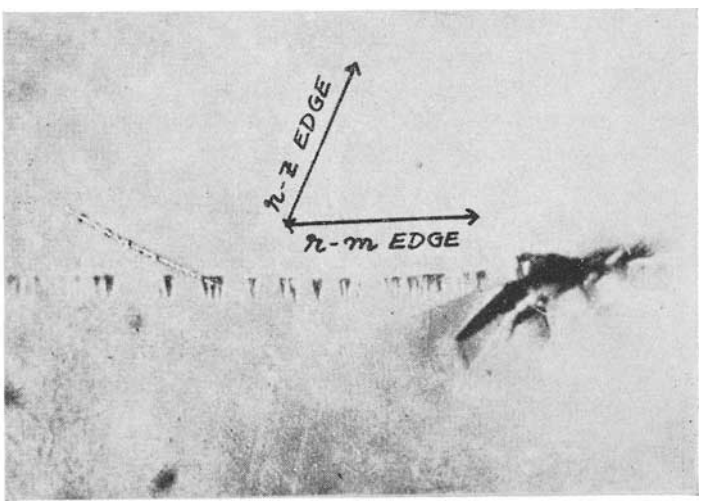

FIG. 1. Nucleation of cracks at the tip of dislocation pile-up; direction of pile-up along r—m edge; crack propagation along r—z and r—m edge directions. (×90)

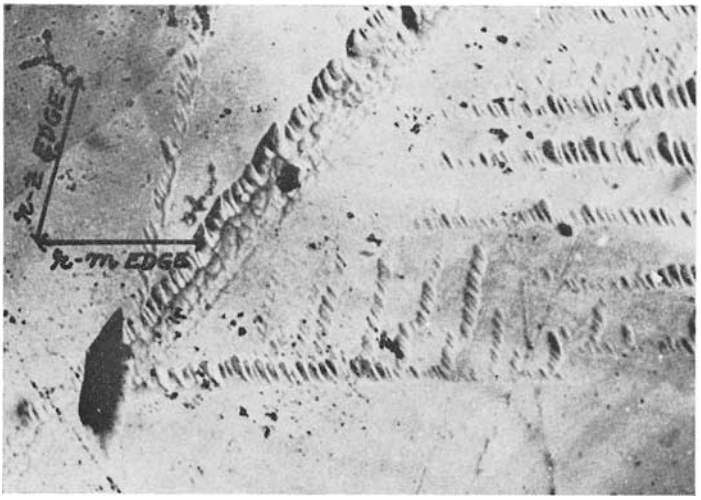

FIG. 2. Nucleation of microcrack at the intersection of glide bands with a grain boundary. Major axis of the crack along r—m edge direction. (× 170)

Intergranular cracks

During the microscopic investigations of heated fracture surfaces, the authors obtained two varieties of cavities associated with grain boundaries:

(i) wedge type cavities (w-type);

(ii) round type cavities (r-type).

The wedge cracks are formed at grain corners, whereas the spherical cavities are distributed all along grain boundaries. It was also noted that the above types of cavities appear only on the fracture surfaces of annealed samples of quartz. A typical example of a w-type crack observed at a corner of an s-bend grain boundary on a {0001} fracture surface is illustrated in Fig. 3. This observation was obtained on a fracture surface subjected to air-annealing at 500°C for about 2 hours.

One case of the second variety of cavities distributed along a grain boundary on a {0001} fracture surface is shown in Fig. 4. The cavities are almost spherical in shape and well isolated (the heat-treatment is the same as before). In order to understand whether a further heating has any effect on the growth of these spherical cavities, successive annealing treatments were given to the

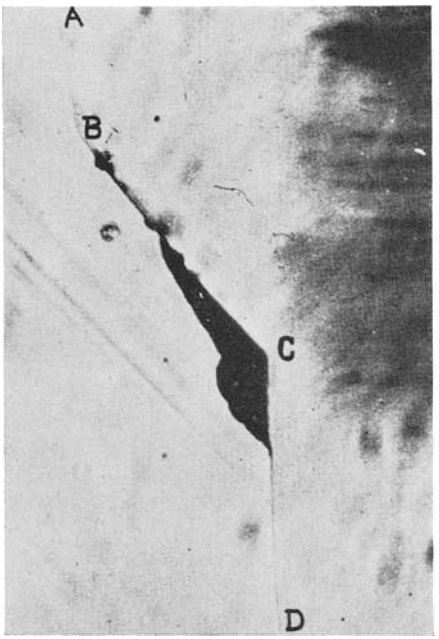

FIG. 3. An example of wedge (w) type crack at the corner of an s-bend grain boundary observed on a {0001} fracture surface after heating the specimen for 2 hours at 500°C. (×360)

specimen of Fig. 4. Figure 5 illustrates the region of Fig. 4 resulting from a further annealing for a period of three hours at the same temperature. Evidently the heat-treatment resulted in the growth and linking of the spherical cavities along the boundary leading to a continuous grain boundary crack. (Fig. 5).

DISCUSSION AND CONCLUSIONS

Observations presented in this paper suggest that plastic deformation assists the nucleation of cracks in brittle materials like quartz. The string of piled up dislocations terminated by obstructions forms a macroscopic stress concentration and the relaxation of this stress concentration takes place by the coalescence of the leading dislocations to nucleate a crack. Theoretical possibilities of such coalescence due to such piled up dislocations have been suggested

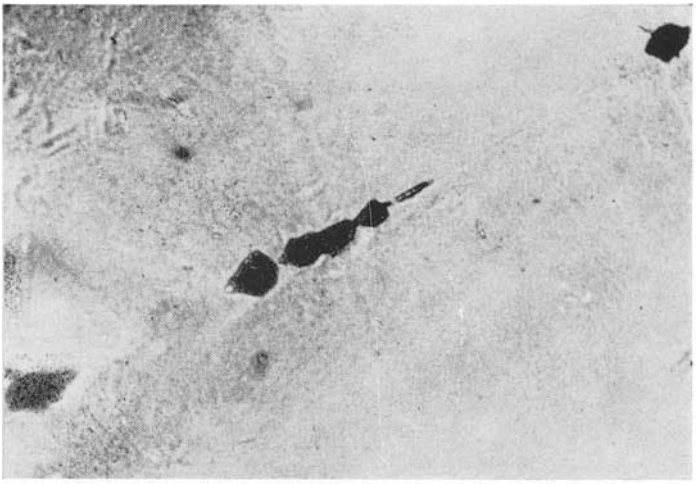

FIG. 4. Example of cavitation fracture along a grain boundary; heat treatment the same as that given to the specimen of Fig. 3. (×90)

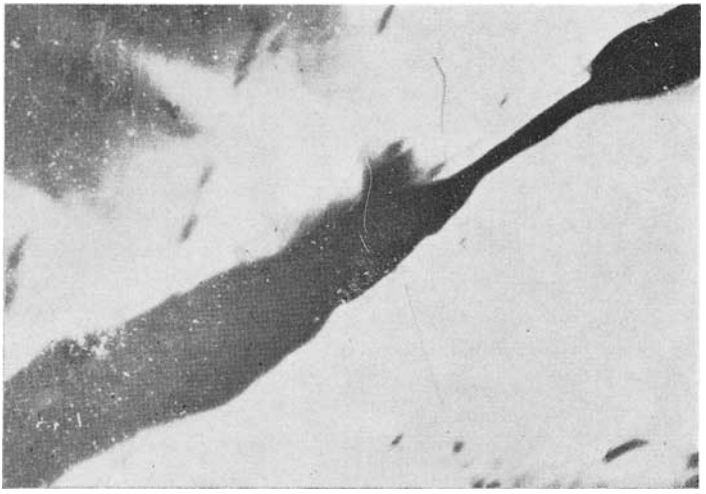

FIG. 5. Same region as Fig. 4 after heating for another 3 hours at the same temperature; this region was also etched in KOH afterwards. (×90)

by Stroh[5]. An interesting fact observed is the tendency of the crack to propagate along glide directions. Taking into consideration the observation of Fig. 1, it may be noted that the cracks begin to propagate exactly in the r-z and r-m edge directions, which are two possible directions of glide in quartz with gliding on $\{01\bar{1}1\}$ and $\{0001\}$ planes.

A number of instances of intersecting glide bands were obtained in the present investigation but without any evidence of crack nucleation at such points. However, the presence of grain boundaries alters this condition. Grain boundaries are effective barriers to slip. Nucleation of cracks is to be expected to occur in polycrystalline materials when slip is hindered by grain boundaries as observed in the present study (Fig. 2). The cause of the nucleation of such microcracks is the superimposition of the stress concentration of the two glide bands on each side of the boundary as suggested by Westwood[6] and due to subsequent coalescence of dislocations. The stress concentration occurs by blockage of dislocations at the boundary so that dislocation motion will be highly difficult. As observed earlier, here also the major axis of the microcrack is oriented in one of the glide directions (r-z edge). The above observations strongly suggest an anisotropic propagation of cracks along easy directions of glide in brittle materials like quartz.

Intergranular cracks (both w- and r-types) have hitherto been reported only in metals and alloys. This is the first report of such cracks in brittle crystals like quartz. These types of cracks are often associated with grain boundary sliding [7] which is a consequence of slip[8]. The thermal stresses resulting from the annealing treatments are responsible for plastic deformation in this crystal at such high temperatures. Since grain boundary sliding is a result of slip, plastic deformation occurring at such high temperatures should be responsible for grain boundary sliding and hence for the formation of cracks at grain boundaries. When such sliding gets blocked at grain boundary junctions, a crack nucleated thereby leads to the formation of w-type cracks.

Several suggestions to nucleate cavities (of the second type) in grain boundaries have been made. The essence of each was that sliding should take place in a grain boundary containing a jog or ledge. On the other hand, Greenwood *et al.* [9, 10] suggested that it is possible to form cavities by the condensation of vacancies at the grain boundary. Since in the present investigation no evidence of

such a ledge or jog is obtained at the boundary it would be reasonable to rule out the first possibility. Vacancies may be originally present in these crystals or may be created at high temperatures due to lattice expansion and annihilation of dislocations. These vacancies can be supplied to the boundary by diffusion along the dislocations[11]. It is therefore suggested that voids at elevated temperatures are produced due to the agglomeration of diffused vacancies at the boundary.

ACKNOWLEDGEMENT

The second author gratefully acknowledges CSIR Govt of India's financial assistance.

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BRIEF NOTE ON A NEW SPECTROSCOPE ASSEMBLY

By M. J. O'DONOGHUE, M.A., F.G.S., F.G.A.

THE Eickhorst "Kaltlicht" spectroscope assembly forms part of the series of gemmological instruments manufactured by the firm of Eickhorst & Co., Hans-Henny-Jahnn Weg, Hamburg, West Germany. The light, both transmitted and reflected, is brought from its source by fibre-optic guides, one of which is movable so that the specimen can be viewed to the greatest advantage. The specimen stands on a rotatable mount and the spectroscope is arranged to move in an arc above it. So far the spectroscope used is that made by Zeiss of Jena, East Germany; it has a built-in wavelength scale and this is separately illuminated on the assembled instrument. Both the main light and the scale illumination are adjustable for brightness and a fan cools the light source. Trials on the two-day course for F.G.A.s last September and on subsequent courses elicited widespread satisfaction, and the instrument also was most useful for showing spectra to students who had never seen them before. Altogether a first-class instrument.

Gemmological Abstracts

AKIZUKI (M.). *Gemstones with optical effect.* (In Japanese). Journal of the Gemmological Society of Japan, 1975, 2, 4, 150-164.

Explanations are given on lustre, reflection and refraction, diffraction and dispersion.

M.O'D.

ANDERSEN (H.). *Synthetischer Lapis lazuli aus der Herstellung Gilson.* (Synthetic Gilson lapis lazuli). Z.Dt.Gemmol.Ges., 1976, 25, 1, 42-43.

Hints for recognizing the Gilson product include very good violet-blue colour comparable with the finest lapis lazuli, a better lustre than the natural stone, more like sodalite; the pyritic inclusions can be scratched with a needle; density of 2·38 is also nearer to sodalite; the white inclusions are like longish clouds, not comparable to the natural stone inclusions; the streak is dark blue instead of light blue; and the x-ray shows as amorphous substance.

E.S.

ARBUNIÉS-ANDREU (M.), BOSCH-FIGUEROA (J. M.), FONT-ALTABA (M.), and TRAVERIA-CROS (A.). *Physical and optical properties of garnets of gem quqlity.* Fortschr. Min., 1975, 52 (Spec. Vol.; Papers & Proc. 9th Gen. Meeting I.M.A., Berlin (West)—Regensburg, 1974) 531-538. 6 figs.

Values of *n*, S.G. and microhardness have been measured for gem-quality purple-red almandines, light green grossulars, and yellow hessonites. The dispersion curves of transmittance are given, but no data on the chemical compositions of the specimens.

R.A.H.

ASMUS (B.). *Buying emeralds in Colombia.* Lapidary Journal, 1976, 29, 12, 2288-9.

A large rough crystal purporting to be emerald proved to be colourless beryl sawn into five sections and recemented with a green cement. It was then dipped at the ends into a molten slag to give the appearance of natural matrix.

M.O'D.

CAVENEY (R. J.). *The hardness of diamond and gem diamond "substitutes".* Industr. Diamond Rev., 1976, 45-47. 2 figs.

The use of Mohs's scale to compare the hardness of diamond with that of the various simulants, several of which are currently marketed under different trade names, can be very misleading. Yttrium aluminium garnet (YAG), one such material, has H. 8-8½ but will wear 3000 times more readily. Using the pentagonal indenter developed by Brookes and Moxley [Journ. Phys. E., Sci. Instr., 1975, 8, 456*], diamond has an indentation hardness of 10000 kg/mm^2; equivalent values are sapphire 1200, spinel 1730, YAG 1600, strontium titanate 500.

R.A.H.

*Abstracted in J.Gemm., 1976, XV, 1, 31.—Ed.

CHIKAYAMA (A.). *New localities of gemstones in Eastern Africa.* (In Japanese). Journal of the Gemmological Society of Japan, 1975, 2, 4, 147-158.

Countries covered include Kenya, Tanzania and Uganda; the gem materials are described and illustrated.

M.O'D.

COLLINS (A. T.). *The Hannay Diamonds.* Industrial Diamond Review, December 1975, 434-437.

This fair, well-reasoned and informative paper should provide a fitting conclusion to the long series of investigations undertaken by physicists on the famous Hannay diamonds with the modern knowledge and techniques at their command. Dr Collins has re-examined nine of the original diamond fragments which were found in the residues of the three possibly successful attempts by J. B. Hannay to manufacture diamonds by heating in a furnace mixtures of bone oil, paraffin and lithium in iron tubes four inches thick.

Originally there were 12 such fragments, mounted on a slide and labelled "Hannay's artificial diamonds" in the collections of the Mineral Department of the British Museum, and the specimens accorded well with the description of those examined by the mineralogist Story-Maskelyne in 1880, and accepted by him as diamond. In 1943 the matter was re-opened when the pieces were re-examined by F. A. Bannister and Kathleen Lonsdale using x-ray crystal analysis, who found that 11 of the 12 pieces were indubitably diamond.

In 1955, when for the first time the conditions necessary for the synthesis of diamond were firmly established, it seemed certain that the necessary enormous pressures and temperatures just could not have been attained in Hannay's experiments. In 1959 and in 1962 the Hannay specimens were again examined by x-ray methods by Professor Lonsdale and her colleagues, and they now became convinced that the fragments consisted of *natural* diamond. Dr M. Seal, on the basis of electron microscope studies, is the only modern worker who has expressed belief that the diamonds recovered from Hannay's apparatus could have been formed by his process.

For the present investigation, Dr Collins examined the cathodoluminescence of the fragments, and compared this with the luminescence produced by synthetic and by natural diamonds under these conditions. Electrons from a heated tungsten filament were accelerated by a voltage of 50 kV and focused into a tiny spot which impinged on the diamond in question, and the luminescence was analysed by a Hilger Monospec spectrometer. The results were highly characteristic of natural diamond in which the blue glow is apparently due to donor-acceptor pair recombination of boron and nitrogen impurities which have aggregated together. Such aggregates have not been found to occur in any synthetic diamond.

These latest results thus reinforce the generally held judgement that Hannay's diamond fragments could not have been synthesised as the results of his experiments. It is good to have Dr Collins's opinion that despite these conclusions Hannay's scientific integrity is no longer impugned. The most probable explanation of the mystery seems to be that the starting materials were accidentally contaminated with particles of diamond dust.

B.W.A.

DIEHL (R.). *Herstellung und Laseranwendung von Rubineinkristallen.* (Production of ruby single crystals and their application as lasers). Z.Dt.Gemmol.Ges., 1975, 24, 3, 148-152.

Since the first synthesis of rubies by the Verneuil methods, a whole series of alternative crystal production methods have been used to produce homogeneous and stress-free ruby crystals for use as lasers. The more economic methods start with an Al_2O_3 melt with a chrome oxide content of 0·035 mol %. Various methods are described and the laser application explained. In medicine it is used mainly for optical and tumour treatments. Laser treatment of the retina can save complicated eye operations, while, in the treatment of cancer, especially skin cancer can be thus treated. In dentistry, the ruby laser can be applied to fight caries.

E.S.

DIEHL (R.) and BANK (H.). *Eigenschaften, Herstellung und Charakterisierung von Lithiumniobat-Einkristallen und ihre mögliche gemmologische Verwendung.* (The properties, production and characteristics of lithiumniobate single crystals and their possible use in gemmology). Z.Dt.Gemmol.Ges., 1975, 24, 3, 118-129. 9 illustrations, bibl.

Lithiumniobate, $LiNbO_3$ has many interesting properties and because of its possible technical application many laboratories work on this substance. It crystallizes in the trigonal class, is piezo-, pyro- and ferro- electric and can be used as an optical store. The production of large single crystals with these properties is of great importance in technology. The authors suggest the application of this material in gemmology mainly because of its optical storing capacity.

E.S.

DE MICHELE (V.). *Réné Just d'Haüy e l'inizio della gemmologia scientifica.* (Réné Just Haüy and the beginning of scientific gemmology). La Gemmologia, 1975, 1, 2, 20-21.

Quotations from "Trattato dei caratteri fisici delle pietre preziose per determinarle quando siano lavorate", published as a translation from the French in Milan, 1819.

M.O'D.

EPPLER (W. F.). *Totalreflexion an Rissen in Edelsteinen.* (Total reflection of fissures in gems). Z.Dt.Gemmol.Ges., 1975, 24, 4, 237-9. 3 photomicrographs.

Professor Eppler discusses Professor Schlossmacher's statement in his book that air-filled fissures in gems appear as dark areas due to the total light reflection. This seems to depend on the angle of the fissure, which has to be fairly vertical to appear dark.

E.S.

EPPLER (W. F.). *Wachstumsröhren im Kunzit.* (Growth tubes in kunzite.) Z.Dt.Gemmol.Ges., 1975, 24, 3, 115-117.

Article with four photomicrographs showing long thin needle-like inclusions in kunzite, most probably from Brazil. These hollow needles or tubes contain snake-like lines, which proved to be growth phenomena and not inclusions. They

are parallel to the c-axis and seem to have been formed by the alternative growth of two neighbouring vertical planes.

E.S.

FONTANA (M.). *Zoisite blu (varietà "tanzanite")*. (Blue zoisite—variety "tanzanite"). La Gemmologia, 1975, 1, 2, 17-19.

A review of the occurrence and properties of blue zoisite with diagrams of the crystals.

M.O'D.

GLAZUNOV (O. M.), SUTURIN (A. N.) and ZAMALETDINOV (R.S.). *(Gem-type chrysolite from ultrabasic rocks of eastern Sayan.)* Nemet. Polezn. Iskop. Giperbazitov, 1973, 248-254 (in Russian). (Edited by Yu K. Andreev and V. P. Petrov, "Nauka", Moscow.)

This chrysolite (olivine) has a composition Fo_{93} and is similar to that from kimberlite pipes. EPR spectra show that Mn^{2+} ions are present replacing some of the Mg^{2+}. The chrysolite occurs in asbestos-like, chrysolite-sepiolite shells and as crystalline inclusions in talc veins intersecting serpentinized, carbonaceous peridotites of Cambrian age.

R.A.H.

GRAMACCIOLI (C. M.). *Una gemma insolita: la benitoite.* (An unusual gem: benitoite). La Gemmologia, 1975, 1, 2, 14-16.

A review of the occurrence and properties of benitoite with the additional comment that pabstite, $BaSnSi_3O_9$, is also only found in California.

M.O'D.

GÜBELIN (E. J.). *Where gemstone research stands today.* Fortschr. Min., 1975, 52, (Spec. Vol.: Papers & Proc. 9th Gen. Meeting I.M.A., Berlin (West)—Regensburg, 1974), 501-513.

New gemstones discovered during the last 30 years include taaffeite, sinhalite, painite, ekanite, and brazilianite, as well as gem varieties of long-established species such as amblygonite and zoisite. In gem testing, absorption spectroscopy and microscopy have become important and the study of infrared absorption spectra of polarized radiation appears to be becoming important for distinguishing between certain simulants or treated stones and their natural counterparts. The study of inclusions in gemstones by x-ray fluorescence and electron microprobe also helps in this distinction and in recognizing diagnostic features typical of certain sources. Gemmology is now being commercially applied to give more accurate grading methods of gemstones.

R.A.H.

GÜBELIN (E.). *Die neuen Katzenaugen-Schmucksteine von Taiwan.* (The new cat's-eye gems from Taiwan). Z.Dt.Gemmol.Ges., 1975, 24, 4, 234-236.

The author refers to H. Bank's note in Z.Dt.Gemmol.Ges., 1975, 24, 3, 167 (see Short Gemmological Notes *infra*). These stones are marketed under the name of nephrite cat's-eye, have a very strong chatoyancy and have been shown to be actinolite. The difference between actinolite and tremolite can be decided by the

colour, the former being the iron-rich variety, the latter poor in iron and nearly colourless.

E.S.

GÜBELIN (E.) and WEIBEL (M.). *Neue Untersuchungen am blauen Zoisit (Tansanit).* (New examinations of blue zoisite (tanzanite)). Z.Dt.Gemmol.Ges., 1976, 25, 1, 23-31. Bibl.

The natural colour of this mineral is usually yellow-brown and trichroic (violet-red, dark blue, yellow-green), rarely blue. This colour is usually produced by firing (about 400°C?). By the heating process the trichroism is converted into dichroism (violet-red, dark blue, dark blue) and the colour becomes more intense. The colour seems to be caused by vanadium. The authors mention work done on the colour change by various people and give details of chemical composition and trace elements. The fired stones were re-heated and were unchanged at 900°, but at 1000° gave off some water and became dirty-yellow in colour. Details of mineral inclusions are given; there are five black-and-white photomicrographs and three coloured ones, the latter showing actinolite inclusions, an included graphite table and two staurolite prisms, the brown colour of which can be easily seen against the blue tanzanite.

E.S.

GÜBELIN (E.). *Skorodit-ein neuer Edelstein aus Tsumeb, S.W. Afrika.* (Scorodite—a new gem from Tsumeb in South-West Africa). Z.Dt.Gemmol.Ges., 1976, 25, 1, 33-39. Bibl., 5 photomicrographs.

Scorodite is an iron-containing arsenate, is orthorhombic and has a density of 3·29. It can be nearly colourless to grey-green, green, yellow, blue to violet. It is strongly pleochroic (violet blue and blue-green, similar to the fired tanzanite). R.I. and birefringence vary according to Fe and Al content between 1·785 and 1·812. Tsumeb in S.W. Africa yielded a few single crystals up to 25mm length and some very good geodes with many larger and smaller crystals. The stone will be of interest to collectors but not suitable for jewellery purposes, as the hardness is only 3½-4 and too rare.

E.S.

HOCKLEY (J. J.). *Nephrite (jade) occurrence in the Great Serpentine Belt of New South Wales, Australia.* Nature, 1974, 247, 364. 1 fig.

A lensoid-shaped occurrence 24 km SE. of Tamworth yielding gem quality material is reported. Its size, overall grade, and economic potential are under investigation.

F.B.A.

JAIN (S. K.). *Tourmaline, a gemstone packed with many peculiarities.* Gem World, 1975, 2, 9, 31-36.

A summary of the properties of tourmaline.

M.O'D.

JONES (R. W.). *Arizona's green gem, peridot.* Gem World, 1975, 2, 9, 33-35. (Reprinted from Alaska Highways).

In the San Carlos Indian reservation peridot is collected and much is sold to the Peridot Mining and Marketing Project, who cut and sell the stones. Some peridot is also fashioned and made into jewellery on the reservation by trained Indian workers.

M.O'D.

LANG (A. R.) and WOODS (G. S.). *Fingerprinting diamonds by x-ray topography.* Industr. Diamond Rev., 1976, 96-103. 4 figs.

Successful tests have demonstrated the effectiveness of x-ray topographic maps of internal crystal lattice defects as "fingerprints" which unambiguously identify a given cut gem with its parent rough stone, or identify the gem even though it may have been recut. The technique could be used with other gemstones, such as ruby, sapphire or emerald.

R.A.H.

LEHMANN (G.). *Bemerkungen zu der Arbeit "Thermolumineszenz als Untersuchungsmethode der Farbursach von Topasen".* (Notes to the article on thermoluminescence as method for examining causes of the colour in topazes). Z.Dt. Gemmol.Ges., 1975, 24, 4, 242-244.

Lehmann discusses an article* by I. Petrov and W. Berdesinski in Z.Dt.Gemmol. Ges., 1975, 24, 2, 73, about thermoluminescence as testing method of the cause of colour in topaz. He maintains that the article is not detailed enough and the authors answer shortly that it was only designed as an introduction.

E.S.

MANUTCHEHR-DANAI (M.). *Zur Geologie und Mineralogie der Türkis Lagerstätte Baghu.* (On the geology and mineralogy of the Baghu turquoise deposit). Z.Dt.Gemmol.Ges., 1976, 25, 1, 15-22. Bibl., maps.

Baghu lies in north Iran: the deposits are historically known. The turquoise deposit is connected with an eocene intermediate magmatic rock formation in which granodiorite can be found. The clay minerals as weathering products of the feldspars react with copper-bearing aqueous solutions and form turquoise. The area also yields gold, copper and lead.

E.S.

MATHUR (S. M.). *Exploration for diamonds in India.* Gem World, 1975, 2, 9, 21-28.

Most of the current Indian production of about 20,000ct per year comes from the Panna area of Madhya Pradesh. Since over Rs 600 million was spent on importing diamonds in 1973 more effort is needed to be devoted to prospecting in India; a reserve of about 1·2 million ct is estimated for the Majhgawan mine in the Panna district. No diamonds are mined at present in southern India, the historically important area.

M.O'D.

*Abstracted in J.Gemm., 1975, XIV, 8, 392—Ed.

MERTENS (R.). *Peridot von beachtilicher Grösse aus der Eifel.* (Sizeable peridots from the Eifel). Z.Dt.Gemmol.Ges., 1975, 24, 4, 240-241.

Olivine pebbles up to the size of a head have always been found in the Eifel (German mountain range on the left side of the middle Mosel), but the material was mostly not of cuttable quality. Now some material has been cut—some peridots of good gem quality, some over 1 ct. The mineral haüyne in good blue colour has also been found.

E.S.

MONÉS-ROBERDEAU (L.), BOSCH-FIGUEROA (J. M.), and FONT-ALTABA (M.). *Quantitative study of fluorescence of brilliant-cut diamonds.* Fortschr. Min., 1975, 52 (Spec. Vol.; Papers & Proc. 9th Gen. Meeting I.M.A., Berlin (West)—Regensburg, 1974), 521-529. 9 figs.

The fluorescence of 52 specimens of commercial white and top silver Cape diamonds, weighing 0·35–0·75 carats, in UV light at 365 nm was measured using a specially designed camera with photomultiplier and a running interference filter monochromator. A practical classification of the colour can be established from the intensity of the fluorescence. The dispersion curves of the relative intensity of fluorescence are given.

R.A.H.

NASSAU (K.). *Radiation-induced colors in gem materials.* Guilds, (published by the American Gem Society), 1975, 6-7, 15-16.

A survey of the effects of various types of radiation on gemstones.

M.O'D.

NASSAU (K.) and PRESCOTT (B. E.). *A reinterpretation of smoky quartz.* Phys. Stat. Sol. (a), 1975, 29, 659.

In some specimens of quartz optical absorption bands A_1 and A_2 which are characteristic of smoky quartz have been found, although the colour of the specimens does not show this type of coloration. If these specimens are further irradiated the smoky colour becomes apparent, a new absorption band appears at 2.9eV (designated A_3) and an EPR signal develops due to the substitutional Al centre. The smoky colour is therefore due to this A_3 band.

M.O'D.

NASSAU (K.), PRESCOTT (B. E.) and WOOD (D. L.). *The deep blue Maxixe-type color center in beryl.* Amer. Mineral., 1976, 61, 1 & 2, 100-107.

A deep blue colour is produced in beryl by a variety of penetrating radiations. If the original beryl is yellow or green, the resulting colour can be green or blue-green, though this colour centre cannot be produced in just any beryl. Both light and heat can cause fading of the blue component of the colour, and it can be restored by γ-ray, x-ray or neutron irradiation in the Maxixe-type material. In the case of the original blue material found about 1917 in the Maxixe mine, Brazil, irradiation of bleached material produces a green colour, indicating that the Maxixe colour was not due to irradiation.

R.A.H.

RÖSCH (S.). *Versuch einer Geschichte der Reflektographie.* (Sketch of the history of reflectography). Z.Dt.Gemmol.Ges., 1976, 25, 1, 1-14.

This article, which has a bibliography of 35 items, tries to construct the story of the reflectograph. The idea of a reflex picture is explained, and it is seen how this is applied in photography. The first work done in this subject was published around the turn of the century and about 20 years later a reflectograph was built The author concludes with details of its non-crystallographic applications and of its importance to gemmology by providing a "passport" for each stone.

E.S.

SANDERS (J. V.). *Microstructure and crystallinity of gem opals.* Amer. Min., 1975, 60, 749-757. 8 figs.

Gem opals from various volcanic host rocks have been examined by electron microscopy and diffraction. They are generally a mixture of amorphous and crystalline silica, the extent of crystallinity varying between samples from different sources. Tridymite has been identified in some samples. The microstructures are compared with those of gem opals from sedimentary rocks and with specimens heated in the laboratory. Changes in morphology produced by sintering occur at around 400°C and crystallization at around 1100°C. Both tridymite and cristobalite were identified in material crystallized by heating.

A.P.

SANDERS (J. V.). *Star opal from Idaho.* Lapidary Journal, 1976, 29, 11, 1986-2010.

Opal from the Spencer mine in Idaho is brilliantly coloured, commercially valuable and may show a star. The stones are sold as triplets capped by quartz. One type of star resembles a cat's-eye in that a single streak of dispersed colours moves across the surface at a given angle; other types show three rays and six points. Some stars were examined with the aid of an optical diffractometer and the patterns obtained differed from those seen in Australian stones. These usually give a set of six parallel streaks and two spots, the layers of silica particles being arranged on a hexagonal net but arranged in a random order, being neither face-centred cubic nor hexagonal in sequence. The star opals on the other hand show the layers parallel to the base to have a face-centred cubic stacking sequence. In addition there are stacking faults and twins on the three $\{111\}$ planes inclined to the base and it is diffraction from these faults which gives rise to the star effect. It is thought that the opal showing the star was laid down in bands of particles separated by an interfacial layer of silica which gave a smooth surface on to which the particles in the next band could settle. The opal occurs in a volcanic rock.

M.O'D.

SANTOS MUNSURI (A.). *Tabaqueras de rapé chinas.* (Chinese snuff-bottles). Boletin del Instituto Gemológico Español, 1975, 12, 17-23. Coloured illustrations.

The second part of a survey of Chinese snuff-bottles dealing mainly with those fashioned from quartz-family minerals.

M.O'D.

SCHMETZER (K.), BERDESINSKI (W.) and TRAUB (I.). *Vanadiumhaltiger Grossular aus Kenya.* (Vanadium-containing grossularites from Kenya). Z.Dt. Gemmol.Ges., 1975, 24, 4, 230-233. Bibl.

The chemical and physical properties of grossular-spessartite are described. This stone is light green in colour and coloured by V^{3+} vanadium.

E.S.

SCHMETZER (K.) and GÄRTNER (H. R.). *Über Kurnakovit und Inderit, zwei wasserhaltige Magnesiumborate gleicher chemischer Zusammensetzung.* (About kurnakovite and inderite, two water-containing magnesium borates of the same chemical composition). Z.Dt.Gemmol.Ges., 1975, 24, 3, 130-137. Bibl. of 28 items.

Kurnakovite occurs in colourless and perfectly transparent crystals of up to 2 cm long, density 1·833, R.I. 1·488-1·520. Kurnakovite and inderite are two (respectively triclinic and monoclinic) modifications of $(B_3O_3(OH)_5).5H_2O$. In several cases the two types have been mixed up and various physical properties of both crystals are described.

E.S.

SINKANKAS (J.). *Beryl in Brazil: Part I.* Lapidary Journal, 1975, 28, 324-332, 1 sketch-map: *Part II.* Ibid., 1975, 506-515, 1 sketch-map: *Part III.* Ibid., 1975, 646-655, 2 sketch-maps.

Details are given of Brazilian beryl and emerald production figures followed by locality details of beryl-bearing pegmatites in the states of Ceará, Rio Grande do Norte, Paraiba, Bahia, Minas Gerais, and Espirito Santo.

R.A.H.

STRACK (E.). *Die Diamantvorkommen der Elfenbeinküste.* (The diamond occurrences in the Ivory Coast). Z.Dt.Gemmol.Ges., 1975, 24, 4, 199-229. Bibl.

A very detailed report on two diamond occurrences, in Tortiya and in Séguela. The geographical situation and its geology is described and the production compared to world production. The sorting and separating is explained. The occurrences seem to produce some colourless or slightly coloured crystals for gem purposes (55-65%), some industrials (34-45%) and boart (1-2%). Purity is good (clean to VS) and average size seems to be 8-12 stones per carat. The two occurrences are compared and the other occurrences in West Africa are described.

E.S.

STRÜBEL (G.). *Neue Methoden der Hydrothermalsynthese.* (New methods of hydrothermal synthesis). Z.Dt.Gemmol.Ges., 1975, 24, 3, 138-147.

Various new methods are discussed, the apparatus used schematically illustrated. There are photographs of recrystallized gold crystals and of some silver crystals produced from an alkaline hydrothermal solution.

E.S.

SUNAGAWA (I.). *Surface microtopography as a tool of distinguishing natural and synthetic emeralds.* Fortschr. Min., 1975, 52 (Spec. Vol.: Papers & Proc. 9th Gen. Meeting I.M.A., Berlin (West)–Regensburg, 1974), 515-520, 4 figs.

Surface microtopographs of crystal faces reflect very sensitively the differences in growth conditions and in growth seeds and thus can be used as a tool to distinguish natural from synthetic crystals or even to identify different localities or manufacturers. Examples are given of natural, flux and hydrothermal synthesized emeralds to show the marked differences in the surface microtopographs of their crystal faces.

R.A.H.

SUZUKI (S.). *Further comments on the double dispersion design.* Australian Gemmologist, 1974, 12, 95-97.

A revised description is given of the Suzuki brilliant cut designed to give enhanced dispersion, without loss of brilliance, in stones of medium to low refractive index.

D.R.H.

TAKENOUCHI (S.). *Basic knowledge on studies of fluid inclusions in minerals.* (In Japanese). Journal of the Gemmological Society of Japan, 1975, 2, 4, 165-172.

Destructive methods of analysis are considered. Contamination is a problem when such small amounts are to be studied and apparatus needs to be carefully checked in this regard. Notes are given on the mixing of waters in the earth's crust.

M.O'D.

TOMBS (G.). *Synthetic-like fluorescence in a natural sapphire.* Australian Gemmologist, 1974, 12, 94.

A cut Ceylon sapphire with strong colour zonation from colourless to blue has fluorescence similar to Verneuil synthetic blue corundum. The colourless portion fluoresces apricot pink in long wavelength UV and weak red under short UV, and the blue portion is inert under long UV and fluoresces pale bluish under short UV.

D.R.H.

WILSON (A. C.). *An occurrence of sapphire in the Land's End granite, Cornwall.* Bull. Geol. Surv. Gr. Britain, 1975, 52, 61-63. 1 coloured plate.

Clusters of mid-blue sapphires are distributed over an area of one square metre in megacrystic coarse granite at Trencrom Hill, in the north-eastern part of the Land's End pluton about 0·5 km from the margin of the intrusion. The sapphire is associated with coarse-grained pink andalusite, and it is considered that this association represents digested, highly aluminous inclusions derived from the surrounding pelitic rocks. There are no replacement textures between the sapphires and the quartz andalusite.

R.A.H.

ZANCAMELLA (R.). *Considerazioni sul taglio delle gemme, in particolare, del diamente.* (Considerations on the fashioning of gemstones, especially of diamond). La Gemmologia, 1975, 1, 2, 6-13.

A summary of ideas on proportion postulated at various times with particular attention to those of Tolkowsky.

M.O'D.

ZOIS (A.). *Extract from a letter to Dr E. Gübelin dated 22.1.1976.* Z.Dt.Gemmol. Ges., 1976, 25, 1, 32.

This letter explains the history of the Zois family, which originated in Crete and then came via Spain and Italy to Egg (Switzerland), where they worked an iron mine. Amongst the minerals found there was one called locally "saualpite" but later re-named zoisite. The title Freiherr Zois von Edelstein (Baron Zois of Gemstone) was granted by the Empress Maria Theresa.

E.S.

SHORT GEMMOLOGICAL NOTES. Z.Dt.Gemmol.Ges., 1975, 24, 3, 154-172.

Various short articles of gemmological interest. Firstly, H. Bank talks about the importance of publishing as quickly as possible characteristics of new synthetics. The two examples he mentions are synthetic ruby and synthetic alexandrite. In the case of the first, new production methods show that straight growth lines also can occur in synthetic rubies: in the second case, the synthesis of actual alexandrites is fairly new. H. Bank and W. Berdesinski report on translucent, nearly transparent antigorite (serpentine) from Pakistan. The faceted green-yellowish stones had an R.I. of 1·559-1·561, with a double refraction of 0·001-0·002. H. Bank discusses low refractive indices and double refraction of nearly transparent rhodochrosite from Argentina. The stones came from Las Capillitas and the R.I. was as low as 1·6 and 1·8. H. Krupp and K. Schmetzer researched into scapolite from Tanzania with very high R.I. (1·579-1·553; 0·026). A. Frere warns against aventurine quartz (slightly transparent, faceted, dark green to emerald green, porous surface) which is being marketed as emerald and jade. H. Dern talks about the artificial colour-effect of originally colourless gems. According to a U.S. patent, the stone is given a small hollow at the bottom of the culet, which is filled with colour which is then reflected to the table. The last three notes are by H. Bank. The first deals with light brown and yellow as well as green tourmalines with low R.I. and medium double refraction from Kenya, which are of cuttable quality. The second discusses cat's-eyes of tremolite, actinolite and nephrite; the third deals with ortho-pyroxide cat's-eyes; these are offered commercially as enstatite cat's-eyes but have been shown to be ortho-pyroxide.

E.S.

SHORT GEMMOLOGICAL NOTES. Z.Dt.Gemmol.Ges., 1975, 24, 4, 245-256.

K. Schmetzer and H. Bank describe cut grossularite-chlorite-epidote hornfels from Pakistan. H. Bank talks about precious green apatite from Canada, with relatively low R.I. and occurring in large pieces. H. Bank also writes about transparent violet stones shown to be tremolite according to R.I., birefringence, S.G. and x-ray powder diagram. A blue gemmy willemite from Mount St Hilaire near Montreal in Canada is described also by H. Bank. The same author also

contributes a small article dealing with nomenclature, suggesting the use of tsavorite instead of tsavolith for transparent emerald-green grossularite. He also deals with treated yellow topazes: these stones were originally white with low R.I. (1·61-1·62) and are now commercially available as heat-treated yellow topazes with high R.I. (1·63-1·64). H. Dern contributes a note on a synthetic gem with chatoyancy. These are produced by a patented process by the Queensbury Opal Co. Ltd in Cleveland, Ohio, from a molten block of light-conducting fibres of boron silicate glass, hardness 6·5, S.G. 3·25-3·93. The effects of a star-stone can also be produced. The material is also used in doublets together with amethysts, rose quartz, garnet, topaz, opals, etc. to produce the chatoyancy effect. The last two notes deal with observations from the laboratory. One is a short article by H. Bank and W. Berdesinski on the possibility of mistaking paste ($CaSO_4.2H_2O$) cat's-eyes for ulexite cat's-eyes. H. Bank, K. G. Leyser and J. Maes mention a case where amblygonite was thought to be tourmaline.

E.S.

SHORT GEMMOLOGICAL NOTES. Z.Dt.Gemmol.Ges., 1976, 25, 1, 40-57.

H. Bank describes an apatite cat's-eye which can be mistaken for a yellow-green tourmaline cat's-eye or a yellow or green beryl cat's-eye. He also describes pink transparent topazes from Pakistan; they come from the Mardan district, have a R.I. of 1·632-1·641, double refraction 0·009 or 0·011, density 3·53. H. Bank also examined several cut apatites of various colours from various localities, recording their R.I. and birefringence. These vary according to their F and OH content between 1·628 and 1·642 for the extraordinary and 1·632 and 1·649 for the ordinary ray. Birefringence varies between 0·003 and 0·007. Bibl. The same author deals also with cuttable epidotes with low R.I. and birefringence from Minas Gerais in Brazil, density 3·3 to 3·5. The crystals had been offered as tourmalines, but were suspicious because of their trichroism and were shown to be epidotes. Poor in Fe-content, their low R.I. was $1·724 \pm 0·002$ and $1·745 \pm 0·002$. H. Bank also describes some cut vivianites; these are of interest only to collectors—their hardness is 2 and because of their perfect cleavage they are difficult to cut. Another short article by H. Bank deals with the R.I. and birefringence of cuttable datolite, which is a monoclinic prismatic tecto-silicate.

E.S.

BOOK REVIEWS

ANDERSON (B. W.). Trans. SCHIFFMANN (C. A.). *Identification des Pierres Précieuses.* Hugo Buchser S. A., Geneva, 1975. pp. XXV, 422. Illustrated in black-and-white and in colour. Sw. fr 120.

This is a fatter volume than my latest English "Gem Testing", due not so much to the slightly different format (with longer lines of print and one less line to a page) as to added matter. Indeed at first glance I thought it must be a translation of the yet unpublished 9th edition: but on further reading—beginning at the beginning—I found it to be a translation *and adaptation* of the 8th edition. The main changes are the addition of descriptions of the Dialdex refractometer and of a number of recently introduced man-made gem materials: some of the original black-and-white illustrations have been changed and some have been added. The original colour-plates are omitted and instead the book is "enriched" (the publisher's word) by 176 colour-photographs taken by Mr Schiffmann of different gem materials: these are perhaps more suitable to a work titled as in the French version than in one strictly confined to gem *testing*, but with some exceptions—for instance, I am not happy about the alexandrite (shown green in artificial light, mauvish in daylight) or the notably different pinks of the rhodonite and the rhodochrosite—they give a fair indication of the appearance of the stones illustrated.

Misprints are not only to be found in English publications. They do not catch the eye of this reviewer so painfully in French as in English, but a number were observed: to mention a few, "sciure de bois" on p.5 should surely be ". . de buis": chrysoberyl is printed instead of orthoclase in a sub-heading on p.167, and Eric Bruton appears as Burton (twice): also, surprisingly, the "Erratum" only succeeds in replacing one error by another. They are, however, of little consequence.

Mr Schiffmann has done his work well. This book will be an invaluable aid to French-speaking gemmologists, and for those English-speakers with sufficient French will bridge the gap between the 8th edition of "Gem Testing" and the eagerly awaited 9th edition.

J.R.H.C.

COURT (A.) and CAMPBELL (I.). *Minerals: nature's fabulous jewels.* Harry N. Abrams, Inc., New York, 1974. pp. 318. Illustrated in black-and-white and in colour. Price on application.

Although there is a short introduction, the bulk of this book is given over to high-quality illustrations of mineral specimens, most of these emanating from North and Central America. Some of the statements in the opening chapters are incorrect; the R.I. of water is 1·33, not 1·00; quartz crystals are said to be terminated by pyramids, not rhombohedra. In the caption to the orthorhombic crystal illustrated the name of the system is misspelt. In general the authors seem unhappy with the crystal systems and the text is not lucid at these points. Elsewhere they seem to be uncertain about the type of audience they are addressing. However, the illustrations are good, some very good. The bibliography includes

some out-dated and worthless works; the name Sinkankas is misspelt. The index is far too short and does not cover the introductory chapters.

M.O'D.

DE MICHELE (V.). *Guida mineralogica d'Italia.* (Mineral guide of Italy). Istituto Geografico de Agostini, Novara, Italy. 2 volumes. pp. 216 and 192. Illustrated in colour. Price on application.

One hopes that this superb production might be a forerunner of similar guides to other well-mineralized countries; arranged by location, each entry covers at least two facing pages and includes a map, general photograph of the working area and photographs of one or more of the mineral species found there. Descriptions include general geology, specific details of the minerals encountered and details of associated minerals. One might perhaps cavil at the publicity given to classic sites, but this is a world-wide problem.

M.O'D.

GILL (J. O.). *Origins of gemology in pictures.* J. & S. S. De Young, Inc., Boston, Mass., 1976. pp. 50. Illustrated in black-and-white. Price on application.

Illustrations and title-pages from early books are reproduced with captions almost long enough to serve as a separate text. The books are chosen from the author's large private library of books on gemmology.

M.O'D.

POIROT (J. P.). *Éléments de Gemmologie.* (Elements of Gemmology). Institut National de Gemmologie, Paris. pp. 350 (in two loose-leaf volumes). Fr 165.

In the international literature of gemmology, which is by now quite extensive, we have had surprisingly few contributions from French authors. This new publication, written by no less an authority than the Director of the Precious Stone Laboratory in Paris, should therefore be of special interest to serious gemmologists, since it provides for the first time a clear insight into recent French thought and teaching on the subject.

It seems more appropriate to refer to "Éléments de Gemmologie" as a "publication" rather than as a "book", since it is issued in the shape of two slim loose-leaf volumes in plain red covers, each containing some 170 foolscap pages. There are diagrams in great abundance and some drawings, but no other concessions in the form of photographic illustrations or coloured plates. The work can in fact be fairly described as notes for a course in gemmology, but a course more thorough and notes more detailed than any previously attempted.

It is in two sections: "General gemmology" and "Descriptive gemmology". There are a few concluding pages on legislation in connexion with gemstones, a table of contents and an index which, in the reviewer's copy, was added as a typed sheet, but will presumably be incorporated into the text. To level up the contents of each folder, the first 42 pages of Section II are included in the first volume.

The first chapter, as might be expected, deals with crystals, with diagrams of the unit cells appropriate to the seven systems and of the common habits of some of the gem minerals. One surprise comes in an illustration of "sceptre quartz", which shows crystals in parallel growth in place of the more usually accepted form

of a crystal head on a more slender prismatic "stem". Next follow chapters on light and its behaviour in gemstones, on refractive index and its measurement, and lustre. A short discussion on the influence of the proportions of a cut stone on its reflecting power is followed by a chapter giving a very detailed treatment of dispersion and fire, where, not content with the determination of dispersion as $n_G—n_B$ (here given as $n_B—n_G$, which would be a minus quantity), there is a table where figures are given for "fire", "dispersive power" and "constringence", which will mean little to the practising gemmologist. "Fire" is defined as $n_G—n_B/n_D \times 1000$, which leads to a figure of 20 for zircon which is higher than the 18 calculated for diamond.

It would take too long to comment on, or even enumerate, each one of the chapters in Section I, but a few points may usefully be mentioned. The importance of the "doubling" of the back facet edges of a cut birefringent stone as observed with a lens is well understood by any practising gemmologist, but it is seldom accorded more than passing reference in text-books. In M. Poirot's work, however, an entire chapter is devoted to this effect, and the important observation is made (and explained mathematically) that the doubling effect for stones of comparable birefringence is less for stones of high index than for those of low, so that the effect in rutile, for example, is less than that to be seen in calcite. A complete table is given showing the birefringence and a figure for the actual "doubling" effect, based on the formula birefringence/$(R.I.)^2$ for every gem species.

Chapter 12, on absorption spectra, was naturally of particular interest to the reviewer. A clear account of the techniques for observing the spectra is given, but the reader is left with the impression that the chief value of the method lies in its providing a means of identifying trace elements in gemstones, rather than being, as it is, an indispensable means for the identification of numerous species regardless of whether the elements causing the absorption bands are known or not. Diagrams indicating the positions of all the important absorption bands in gemstones are given, as seen through a prism spectroscope in which the red end of the spectrum is on the observer's right. In the drawing of the spectrum for Cape diamond the 4780Å absorption band is strongly delineated, while the more powerful and fundamental band at 4155Å is omitted.

Chapters 22 and 23, dealing with the principal counterfeits of natural gems and on inclusions seen in natural and synthetic stones are, from a practical point of view, the most valuable in the whole work. Clear descriptions of glass, porcelain and plastics of various kinds are provided and also some of the many unpleasantly clever doublets which may nowadays be encountered.

In the descriptive part of the work, a great deal of emphasis is laid on the atomic structure of the gem minerals as revealed by x-ray crystal analysis, and to enable the student to understand the nature of the covalent and electrovalent forces by which the atoms in a crystal are bound together a good deal of general discussion and explanation has been undertaken in an introductory section before proceeding with a description of diamond—the only gemstone whose atoms are held together by covalent forces. Once launched on actual description, the author gives diamond the full treatment in 13 (admittedly short) chapters. The remaining gemstones (all classed as essentially electrovalent in structure) are naturally described far more briefly. In the accounts given of all the more important species there are diagrams showing the internal crystal structure,

common habit and (on a sketched Mercator projection) the world distribution of their major sources.

There is a special section on pearl and other gems of organic origin, and the book concludes with a brief summary of legislation in connexion with the terminology of gems—a matter which concerns the author in his official capacity.

Despite its austerity, M. Poirot's text should prove fascinating and rewarding reading for the serious student of the subject. There is much therein which is not to be found elsewhere. The amount of work which has gone into the preparation of the innumerable diagrams and tables is truly formidable, and the author is to be congratulated on having provided a major contribution to our science.

B.W.A.

SCHIFFMANN (C. A.). See ANDERSON (B. W.) above.

SHAUB (B. M.). *Treasures from the earth: the world of rocks and minerals.* Crown Publishers, New York, 1975. pp. 223. Illustrated in colour. Price on application.

A guide to minerals directed at the general public, this book deals in the main with and illustrates almost totally the minerals from the North American continent. It is welcome on that score and for the quite good quality of the illustrations. Appendices list museums of mineralogical interest, confined to the U.S.A. and Canada, a glossary, bibliography (in which Dana's Textbook of Mineralogy is listed as an advanced work), mineral habits and simple chemical tests. A useful book for those living in North America and also of interest to those interested in minerals from that area.

M.O'D.

The International Turquoise Annual, Vol. 2. Impart Corporation, Reno, Nevada, U.S.A., 1976. pp. 112. $2·95.

This issue, as well illustrated as its predecessor, contains articles on turquoise from Australia, various chapters on the manufacture of turquoise jewellery and a special feature on tourmaline. The general standard is high.

M.O'D.

Queensland's gem fields. (Leaflet). Queensland Government Tourist Bureau, Brisbane. Undated. Free of charge.

A list of locations with a map and general information on mining.

M.O'D.

ASSOCIATION NOTICES

OBITUARY

ROBERT WEBSTER

An Appreciation by B. W. Anderson

So manifold and varied were the activities of Robert Webster in the field of gemmology that the gap left in our ranks by his death can never adequately be filled—not, at least, by any one person. It is but natural that we who were his friends should mourn his loss, but there is much to be said for the practice followed by Quakers who, following the death of one belonging to their group, gather together not so much to lament his passing as to give thanks for his life and work—spontaneous tributes being paid by several speakers covering different aspects of their lost Friend. In the case of Robert Webster I feel that we should indeed be grateful that he was able to exercise his activities as teacher, writer, and consultant until quite a short time before the end of his long and busy life. To him idleness was misery: work at a chosen task, a pleasure. And he was able, some months before he left us, to hold in his hands and to distribute with his accustomed generosity the third enlarged edition of his 900-page book, "Gems", and to receive the acclamations of many gemmologists at home and abroad for his achievement in completing this massive contribution to our science.

Robert Webster was born on 29th September, 1899, and his formal education was interrupted at the age of fifteen by the necessity to earn a living to support his widowed mother. His father had been a master pawnbroker and it was natural for young Robert to follow the same calling. This branch of the trade, at least to one so intelligent and eager to learn as Webster, provided a rough but valuable training ground for a practical gemmologist, since success in the business must depend so largely on the ability to assess the nature and value of both metal and gems in pieces of jewellery of all kinds.

In the First World War Robert was just old enough to serve in the Army: his courage in carrying messages under fire was recognized by the award of the Military Medal.

I first came to know him when, newly appointed as evening lecturer in gemmology at Chelsea Polytechnic, I had the good fortune to number him amongst my second-year students. He had already received a good grounding in the elements of gemmology under Mr I. G. Jardine, to whom the organization of these classes had up till then been due. This was in the autumn of 1933 and came at a period when gemmology was advancing on all fronts. The Paris Laboratory, the

German Gemmological Association and the Gemological Institute of America were all just getting into their stride, while here in Britain the Gemmological Association had become independent of its parent, the National Association of Goldsmiths, of which it had been the Educational branch. Moreover, an important stimulus for the keen students of that time was the *Gemmologist*, which was launched in August 1931 by Mr Arthur Tremayne, director of the N.A.G. Press. This little monthly journal was devoted entirely to gemmology, and was the first of its kind in the world. It served admirably as a vehicle for the exchange of news and ideas, and encouraged young gemmologists to contribute accounts of any original work on which they were engaged. An added attraction, especially to those like Robert Webster, who had a wife and family to support, was the fact that fees were paid for any contributions published. He soon became one of Arthur Tremayne's "stable", and found plenty to write about, as, after obtaining his Diploma with distinction in 1934, he continued to attend Chelsea, together with a few other gifted students, and was able to carry out some useful research work.

A year or two later he compiled the collection of gemmological tables, data, and glossary, originally known as "The Gemmologist's Pocket Compendium", which was published by Tremayne and soon became the constant companion of most students and of gemmologically-minded jewellers. Enlarged and revised editions of this work have continued to be published to the present day. In 1941, Webster's second book, "Practical Gemmology", made its appearance. This was a useful and easily comprehended course on the subject which has also been revised from time to time.

Although still earning his living in the pawnbroking trade, Webster was now definitely marked for a gemmological career. In 1942, Thorold Jones, who had been an assistant lecturer at Chelsea, was called to take up a special war-time job in Wales; Robert succeeded him in teaching the first-year students, and he continued to lecture when the powers that framed the policy of the L.C.C. decided to banish gemmology from its long-established home in Chelsea Poly. and we were shifted first to Northern Polytechnic, and later to the Sir John Cass School of Art. Throughout the Second World War R.W. served with enthusiasm and efficiency in the Home Guard, and eventually took a Commission. Fortunately he, together with a few others of us who were home-based, kept skeleton classes in gemmology going, despite interruptions and alarms by Goering's bombers.

Quite soon after the war, we in the Precious Stone Laboratory of the London Chamber of Commerce were faced with a formidable problem—that of preventing the infiltration of calibré synthetic rubies and sapphires, which were being imported into the country from hitherto reliable sources, each parcel of the native stones containing five or even up to ten per cent of Verneuil synthetics. The need became urgent to test each and every imported stone: an impossible task in a Laboratory with a staff of only two scientists, a lack of good microscopes, and already fully occupied in testing pearls. More staff and new microscopes were urgently needed. The most experienced gemmologist then available was clearly Robert Webster, and I persuaded him to join us: A. E. Farn (another fortunate choice) completing a team which was to endure for the next quarter century.

After a year in which no fewer than 105,000 stones were tested, the flow of calibré corundums subsided somewhat, as, for political and other reasons, London ceased to be the chief world centre for marketing these goods, and we in the

Laboratory settled to a routine of more varied tasks. Without definitely planning a demarcation of our respective labours, it became convenient for each of us to undertake the main responsibility for testing in one particular field. Robert Webster became interested in the radiography of pearls, for which a specially designed x-ray set had recently been installed, and he quickly acquired a particular skill in producing good negatives and a flair for their interpretation. He also assumed responsibility for the burdensome task of bookkeeping, which he carried on for many years with great efficiency. His powers of concentration in this and in all the tasks he undertook were formidable, and one of the prime reasons why he could get through so much work.

He explored so many fields in gemmology—in particular those neglected by other workers—that it is difficult even to enumerate them. While still a student he had investigated the properties and structure of Corozo nuts—the source of "vegetable ivory", and was able to continue in this line of country while assembling a paper on Ivory and its Substitutes, which was to earn him the coveted Research Diploma of the Gemmological Association. One consequence of thus drawing attention to ivory as a suitable subject for gemmological study was rather amusing to the onlooker. Dr Herbert Smith, who had not considered the substance worthy of inclusion in the 1940 edition of his classic "Gemstones", over-reacted to Webster's work by incorporating no fewer than sixteen pages on the subject in the text of his next (1949) edition—not to mention a plate illustrating the ivory-bearing animals.

Possibly the most useful of all Webster's long-term and completed researches lay in the field of luminescence. Over the years he investigated with characteristic patience and thoroughness the luminescent responses of all gem materials to long and short ultraviolet light and to x-rays, and recorded his results in systematic alphabetic sequence in a series of papers published in the *Gemmologist*. Other noteworthy investigations included those on turquoise and its substitutes, on the serpentines, and on different types of imitation pearl. Though his results were fully published in the appropriate journals, they might be difficult of access to gemmologists of to-day had they not been eventually included in his all-embracing book, "Gems", which first made its appearance as a two-volume work in 1962, and which also incorporated the accurate determinations on stones of special interest which had been tested by C. J. Payne and myself throughout years of work in the Laboratory.

Though he relied largely upon others for niceties of optics, Webster, with his relish for hard work, probably carried out a greater number of hydrostatic density determinations on "fringe" gem materials than any other worker. In establishing the range shown, shall we say, by the massive grossular (hydrogrossular) garnets, where most investigators would be content with half-a-dozen S.G. measurements, Robert would carry out fifty to ensure covering the complete range!

As time progressed, Robert Webster's techniques began to include some very effective micro-chemical tests, which held for him a special fascination. In this trend he was greatly helped and influenced by his close friendship with an exceptionally gifted industrial chemist, the late Mr Harold Lee, who lived a bachelor existence near Robert's home in Wimbledon, and whom he initially met as a fellow-member of the local Conservative Club.

Another growing interest in his life became the work of the police in its detective branches, and in the Courts of law, where so often gemmology played a leading role in the correct identification of goods which had been stolen or which were the subjects of some kind of fraud. Witnesses who could properly be termed "expert" in this field were few and hard to find, in police experience. The busy jeweller who really knew his job was naturally reluctant to sacrifice his time and risk being the butt of clever Counsel in matters which did not concern him personally. Where the Lab. was in some degree involved, or when our aid was sought by the police, R.W. was less unwilling than the rest of us to undertake the job of acting as an expert witness—in fact he usually thoroughly enjoyed himself in the witness box. He gradually became "known to the police" in a favourable sense, and over a period of nine years was an honorary visiting lecturer to the Detective Training School in London. The lectures were very popular, being copiously illustrated by lantern slides, not all of which were strictly technical. Eventually Webster was to become a member of the British Academy of Forensic Sciences, and then of the Forensic Science Society, serving on the Committee of the former body. He also recently completed a term on the Committee of the Mineralogical Society, of which he had been a member for many years in common with several others of Britain's more serious gemmologists.

Although not a "collector" in the field of either rough or cut gemstones in the usually accepted sense, where showmanship and detailed cataloguing play a major rôle in the hobby, Webster accumulated throughout his life a vast and valuable assemblage of (chiefly uncut) gem materials from well authenticated sources, which were of enormous value in his teaching work, in his researches, and also to the Gemmological Association, and to his friends on appropriate occasions.

His kindness to those who sought his help was quite exceptional, and he was almost absurdly lavish with his time and trouble, tending sometimes to embarrass the recipient. When monitoring students or protégés by correspondence, for instance, he was very liable to write several pages in long-hand in the form of a "model answer", if he felt it would help the student.

He had a useful working knowledge of electrical circuits, and rigged up many effective and robust (if crudely finished) pieces of electrical equipment for use in the laboratory or in Poly. classes in gemmology. As an invigilator in the practical examinations held by the Gemmological Association he was without peer and will here be particularly missed—this because he knew so well how the testing equipment could best be laid out in the appointed room, and could vet the equipment to ensure that it was working properly. Moreover he was generally capable of putting right the minor breakdowns which are always apt to occur during the course of an exam., and which can have a devastating effect on the students' morale.

In 1968 Webster was invited by the Canadian G.A. and the Gemological Institute of America to cross the Atlantic and give a series of lectures, in Toronto, New York, and Los Angeles, where he spent some days in the G.I.A. headquarters. And on another occasion he was able to visit the main diamond mines and other gem localities of South Africa by acting as assistant courier and gemmologist to a group of people on a tour organized and financed by the *Illustrated London News*.

Though I have written only of Robert Webster's public life and work, before concluding it should be put on record that he was fortunate and happy in his

family life. He and his wife Margaret had three daughters, all of them now married. Though his wife has had the misfortune for many years of being unable to move more than a few paces, her grave disability has been borne with amazing cheerfulness and courage. Only the fact that she was well cared for by their daughter Jean and her husband, who shared their household, enabled Robert to spend such long hours away from home on his manifold gemmological activities.

Mr J. D. S. Wade, F.G.A., Tully Medallist 1951, died in January 1976.

GIFTS TO THE ASSOCIATION

The Council of the Association is grateful to the following for their gifts:

Mr J. R. Briggs, F.G.A., Cromer, for a nodule of amber picked up on the Norfolk coast (eastern England).

Mr H. B. Crawford, F.G.A., Borgue, Scotland, for a 34 ct blue synthetic quartz, together with a piece of original material from which it was cut.

Mr Yoshio Nemoto, F.G.A., Japan, for a donation to the funds of the Association, in appreciation of help received.

Professor Jose C. Precklet, Brazil, for six golden topaz crystals.

Mr E. A. Thomson, London, for an oval, faceted, rare purple colour scapolite weighing 0·60 ct.

ANNUAL GENERAL MEETING

The 46th Annual General Meeting of the Association was held at Saint Dunstan's House, Carey Lane, London E.C.2. on the 28th April 1976.

The Chairman, Mr Norman Harper, welcomed members and commented: "I should first of all like to mention the honour given to our President and express our thanks that despite all of his other commitments he has agreed to continue as our President.

"The Association suffered a sad loss in the sudden death of Mr Robert Webster earlier this year and I would like to thank all of those interested in gemmology both at home and overseas who wrote and expressed their condolences.

"During the year, through Mrs Jill Rutland (widow of Dr Ernest Rutland), the Association was able to acquire some very useful crystal specimens and cut stones to supplement its collection which is constantly in use for teaching purposes and for illustrating talks given by members.

"I would like to thank those members who during the year donated specimens and books. Members may remember the G.A. of Australia donated a large collection of Australian mineral specimens in 1974 and during a recent visit to Sydney, Australia, Mr D. J. Ewing attended a meeting of the Australian G.A. Council and personally expressed our thanks for their very kind gesture. I would like to mention the very useful work done by Mr John Chisholm as Editor of the *Journal of Gemmology* and the way that he continues to maintain such a high standard. I would also like to thank the many contributors to the *Journal*, in particular those who do book reviews and abstracts."

The Chairman then proposed the adoption of the Annual Report and Accounts which was seconded by the Rev. Nikon Cooper and duly carried.

Sir Frank Claringbull was re-elected President, Mr N. A. Harper re-elected

Chairman, Mr D. King re-elected Vice-Chairman and Mr F. E. Lawson Clarke re-elected Treasurer.

The Secretary then read the nomination of the Council putting forward Mr Basil W. Anderson for election as Vice-President. The Chairman said that the Council had never lightly made nominations for Vice-Presidents, but the work that Mr Anderson had done for so many years for gemmology certainly warranted his election and it was a great pity that he was not present to hear the well deserved remarks that had been made. Mr Anderson had done a great deal of pioneering work in establishing gemmology as the important subject that it is today; his work as an examiner is of untold benefit and we still continue to have his excellent services in this respect; and his books, which are published in more than one language, are known and respected world-wide.

In declaring Mr Anderson elected as Vice-President Mr Harper said that this gave him a great deal of pleasure.

Miss I. Hopkins and Mr P. Riley were re-elected and Messrs M. Carr, N. Deeks, D. Frampton and C. Winter were elected to the Council. The Chairman thanked Mr T. H. Bevis-Smith, who did not seek re-election, for all the hard work he had done in the past.

The Chairman announced that Messrs Hard Howdy, Watson Collin & Co., Chartered Accountants, had signified their willingness to continue as Auditors.

Finally the Chairman expressed the Association's thanks both to the N.A.G. and also to the Goldsmiths' Company for the ready willingness of the Wardens to place various rooms at the Goldsmiths' Hall at its disposal for meetings whenever convenient: "the Association is greatly indebted to them".

MEMBERS' MEETINGS

London

A talk was given at Goldsmiths' Hall, London, on 12th April, 1976, by Mr J. D. C. Wood, Manager of the Crystal Growth Laboratory, Imperial College of Science and Technology, entitled "Methods of Crystal Growth". The substance of his talk will be given in a future issue of the *Journal*.

Midlands Branch

On the 6th May, 1976, at the Royal Institution of Chartered Surveyors, Birmingham, Mr M. J. O'Donoghue, M.A., F.G.S., F.G.A., gave a talk on synthetics.

North-West Branch

A meeting of the Branch was held at Church House, Liverpool, on the 6th May, 1976, when a selection of gemstones and crystals, together with synthetics, were available for examination.

On the 12th June, 1976, a party visited the Museum in Liverpool, where they were shown the Museum's collection of gemstones and crystals by Dr Trezise.

Scottish Branch

A meeting was held on the 24th March, 1976, in the North British Hotel, Glasgow, when films entitled "Aurum" and "The Island of Gems—Sri Lanka" were shown.

The Annual General Meeting of the Branch was held on the 5th May, 1976, at the North British Hotel, Glasgow. Mr M. Turner and Mr A. W. Tait were elected Chairman and Secretary respectively, and Messrs B. Jackson, H. Whitehead, C. Wade, A. Armstrong, I. McKenzie, A. McRae and Mrs C. Kilpatrick, elected to serve on the Committee.

The Summer Outing was held on the 13th June when members of the Branch visited the Leadhills area. A demonstration of gold panning was given in one of the local burns and a visit to a lead mine was arranged.

GEMMOLOGISTS' VISIT TO IDAR OBERSTEIN

A second trip for jewellers and gemmologists was organized by the *Watchmaker, Jeweller and Silversmith* in collaboration with the Gemmological Association and the National Association of Goldsmiths, and a group of members of the G.A. and of the N.A.G. visited Idar Oberstein from 5th to 8th October, 1975.

On the first morning the party was welcomed to the Diamond and Precious Stone Exchange by Julius Petsch, Jr, F.G.A., who recounted some of the history of Idar Oberstein and of the Diamond Exchange Building—finished three years previously and functioning as a Diamond Exchange since October 1973, with 123 offices occupied by people dealing in stones from 23 different countries: there are also 500 members who, having no offices in the building, are entitled to show their stones and carry on business in the hall. The Exchange also houses a museum, which Mr Petsch claimed is rivalled only by the Smithsonian Institution in Washington, D.C., and on the second floor there is a permanent samples exhibition open to trade buyers only, where 200 show-cases display the ranges of 130 local companies.

Mr H. Wheeler, F.G.A., Secretary of the Association, thanked Mr Petsch on behalf of the group and emphasized that they would be seeing a remarkable collection of gemstones and mineral specimens which the ordinary visitor would not have the opportunity to see.

Later in the tour Mr Petsch gave a talk, and began by pointing out the reasons behind the new fashion in gemstones, and the reasons why the cutters in Idar Oberstein were now cutting such a wide variety of gem minerals.

"Before the war we, in Idar Oberstein," he said, "were mainly faceting gemstones. Now, though we are still faceting many fine stones, rubies, tourmalines, aquamarines and so on, we are also cutting a great many cabochons from many types of material—rhodonite, rhodochrosite, onyx, jade, chrysoprase, sodalite, lapis, and of course, agates. We discovered long ago that one can dye agate to produce many different colours, every shade of green, blue, red and black, producing stones with or without striations. Besides agates, we are cutting those other chalcedonies, the jaspers. We get a wonderful variety of these from India in shades from green to yellow and red. Then we get jaspers from Australia in brownish, rose and orange colours as well as those from Africa. Indeed we get jaspers from all over the world today. Every cabochon cut today from the jaspers and the other decorative gem minerals is a work of art in itself. Each stone is a unique single piece cut from natural stones, for of course nature never repeats herself. The reason why we are cutting all these stones in such quantities

today is that people do not just wear jewellery set with stones to go to special celebrations. Young people wear jeans and want to wear jewellery with them, not jewellery set with diamonds or aquamarines, but something which also looks nice but is not so expensive.

"The cutters in Idar Oberstein all have big orders to cut this cheaper material and do not foresee any decrease in the demand. Good companies, which previously made only diamond-set jewellery are now starting to make the new everyday jewellery. They are forced to do this. I know the stone trade from the mining aspect in particular, and today when you visit the mines in Africa or Brazil you meet a lot of competition. The Japanese and people from Hong Kong and India are going to the mines wanting to buy good stones. As a result there is insufficient fine material suitable for faceting any more. It is for this reason that we have to use other materials in order to fulfil the wishes of our customers. It is also a question of price. Five years ago, a good aquamarine in Idar Oberstein cost approximately 300 marks a carat. Today the same stone costs 650 to 700 marks a carat. If you look at the price of cheap stones, five years ago a cheap aquamarine cost 8, 10 or 12 marks a carat while today the same stone costs 24 to 36 marks a carat. Prices are going up, so fewer and fewer people can afford a fine faceted stone or even a medium quality one. So more and more of the non-transparent stones are being cut.

"As well as facing a lot of competition from people who buy the rough directly from the mines and distribute it throughout the world, a lot of nationalization has been going on in Africa. The African nations seem to think that the Europeans who come to buy are stealing their national wealth and so they nationalize the mines. The governments try to run the mines themselves and the end result is usually that no further supplies are available. This happened in Tanzania. The mines there were nationalized and then the stones were no longer available on the market in any quantity. At the present time we are facing the same problem in Mozambique. I have just come back from Mozambique, and it is now very difficult to get an export licence for any kind of stones. Then a lot of infighting is going on in Kenya concerning the nationalization of the mines and the same thing is going on in Madagascar. My firm unfortunately has a mine there, and the latest news is that the government of Madagascar are also thinking of nationalizing the mines, and this means again that no more stones are coming onto the market. Many years will pass before these people start producing systematically. All this explains why fine material is increasing so much in value, and why bulk materials from Australia and other countries which allow free export are now being used increasingly."

Mr Petsch then referred to the increasing amount of treated stones coming on the market, mentioning particularly topaz, tourmaline, aquamarine and citrine, and continued: "The agate which comes from Brazil or Madagascar is almost always a grey colour. By processing this and dying it they can produce blue, green, red or black agate. Black agate simulating onyx is very easy to make. The stone slabs are put into sugar-water and left for three or four weeks, and then the slab is treated with sulphuric acid, causing oxidation. As a result the sugar carbonizes, producing the fashionable black onyx. Making a cornelian out of a grey agate is a similar process. The stone is left in the liquid and heat-treated,

cooked in certain acids and turned into red cornelian colour. Agates can be dyed green or blue in a similar way.

"Most of the tanzanite crystals found in Tanzania are a brownish colour, as I have seen myself at the mines. Once the brown crystals are heat-treated, however, they take on an attractive mauve blue colour. If these stones were not treated, only ten per cent of tanzanites would in fact be blue. As I have said before, far fewer tanzanites are coming out of Africa since the nationalization of the mines. Also the Tanzanian government are asking very high prices for what they do release, more than 1,000 marks a carat. It is possible to buy medium-colour sapphires for this price.

"New rubies are coming out of Kenya from the Tsavo area between Mombasa and Nairobi. The Tsavo park is situated by a little place called Voi, and here very good quality rubies are found, which are the colour of Burmese rubies. Quite a lot of these have come onto the market in the last few years, but now the Kenyan government has prohibited the mining there.

"Not far from the area where the rubies have been found, they have also found blue sapphires which are better than the Australian stones, which usually have a greenish colour on one side. The sapphires from Kenya are blue on both sides and are very fine. In the next three or four months a lot of these stones should be coming on the market, but I hope that the dealers will regulate the price so that nobody makes a loss on his sapphires."

Mr Petsch then showed a number of slides he had taken himself during his regular visits to the Brazilian gem mines, and talked about the mining methods employed there. The biggest discovery of emeralds ever made, he said, had been made, not in Colombia or Russia, but in Brazil in 1965. Thanks to this discovery the price of emeralds had been kept down to half or a third of what they would otherwise cost by this time. Ninety per cent of these emeralds coming out of Brazil were only of cabochon quality but the ten per cent of facetable stones were enough to keep down the price.

Up to the present time Brazil was still the biggest producer of gemstones. What tended to come out of Africa were new stones like tanzanite or stones which were now coming into fashion such as scapolite. Of the traditional stones such as tourmalines, aquamarine, amethyst, topaz, agate and the jaspers, the bulk were still mined in Brazil. And because of nationalization in Africa, the Brazilian deliveries of stones were becoming even more interesting than they had been in the past. "Stones mostly come", he said, "from three areas in Brazil, the south, the state of Minas Gerais and Bahía. Stones are also mined in the north of Brazil. Opals and aquamarines are both found in Rio Grande do Norte for instance. From Rio Grande do Sul, a hilly mountainous area twice the size of West Germany, come agates and amethysts which can be heat-treated and turned into citrine. Five hundred miles into the interior is the harbour of Porto Leigo in the Palmeria area, where the biggest finds are made. The small stone-diggers and miners bring their goods to the local restaurants to sell them to the buyers and dealers. You can do business in the back yards of these small restaurants. The miners bring along citrine. They have already burned the amethyst by putting it on the ground, covering it with sand and lighting a big fire over it. They know instinctively how long to leave the fire until the stones have become a reddish yellow colour.

"Most of the agate dealers in this area are poor farmers and they often have twenty to fifty tons of agate in their yards, which they find in their fields. The buyer can either pick out individual stones or buy in bulk. As I mentioned before, these Brazilian agates are ninety-eight per cent grey coloured with a white skin outside.

"Rio do Sul in the south of Brazil is interesting only for amethysts and agates. Going north of Rio de Janeiro one comes to the little town of Teofilo Otoni, which is the centre of mining in the state of Minas Gerais. Here one finds German and Japanese buyers from São Paolo and exporters from Rio de Janeiro and Bahía, who either live in the town or go there every four or five weeks to buy their stones.

"Going from Teofilo Otoni into the mining area of Marambaía one notices that all the hills contain pegmatites in which tourmalines, aquamarines and kunzites are found. At the side of every road you can see where the miners have staked their claims and dug for stones. The mine of Machadão, in this area, is a very famous one with feldspar outcrops in which tourmalines and aquamarines are found. Mining is done by tunnelling ,and the mines are very primitive and very dangerous. Inside the mine, pockets of tourmalines of various colours are found in mica, and in one pocket the colour of the stones can vary from black to a fine green.

"A mine such as this is owned by several miners. The normal system in Brazil is that one man discovers a claim, another man registers it, and together they form a company of five or six partners. They do not draw up any written agreements. The group who own the mine also work it. One man is appointed to sell the stones that they find, and once they have been sold in the nearest town or city the partners divide the profits amongst themselves. The mines are worked not with machines but entirely by hand.

"At this mine, one can see large and well crystallized white non-transparent quartz crystals containing tourmalines outside the manager's house. Tourmalines are found every day, but not in large quantities. Half a kilo or three hundred grams a day add up to ten or fifteen kilos by the end of a month, which may have a value of anything between £10,000 and £100,000 depending on the quality of the stones. Today really fine rough tourmaline is sold in Brazil for between £20,000 and £22,000 a kilo.

"A lot of kunzites and aquamarines are found at the mine of Galileia, together with rutilated quartz. Most of the mining here is done in underground tunnels and caves. Where traces of a pegmatite are found the miners follow this into the hill. Miners continue working even in the rainy season when the tunnels are full of water. The stones coming out of this mine are very good and much in demand. The typical Brazilian buyer lives at the mine and carries a suitcase of money with him, as the miners always want cash and do not trust cheques. A few years ago a lot of very large aquamarines were found in mines like this weighing about 14 or 15 kilos apiece. Each stone was sold for about £50,000 or £60,000. When a stone such as this is found, some of the miners who divide the profits buy land and farm, but most of them run through their money in a matter of weeks. Then they return to the mines and try their luck once more.

"It is in the area of Carnaíba that the largest known deposits of emeralds in Brazil have been found. In fact these are probably the largest emerald deposits anywhere in the world. Along a stretch of ten kilometres there are claims every

two or three kilometres. There are thousands of small miners digging there because the Brazilian government has declared this area a free mining area. Anyone who goes there can start working a claim. The main centre is in Campo Formoso. Here the miners work on the hillside erecting small huts over their claims. In the rainy season the huts are often swept into the valley and the miners have to rebuild them again. The claims here have been worked for the past ten years, and large areas of the hillside have been removed. The miners are now working in holes they have dug reaching down for twenty or thirty metres, which lead into underground caves where emeralds are found.

"Brazil exports rough and cut emeralds to the value of several million dollars, some say $80 million worth a year, whereas others believe the gems are exported to the value of only $10 million. My feeling is that the export of rough and cut emeralds must average out at between $60 to $70 million, all the stones being mined in this one area completely by hand.

"With ten thousand miners living close together, as they do in this area, it's every man for himself. Every man carries a gun, and law and order are established by the miners in their own fashion. They are proud people and expect to be treated with respect. A well-known Indian buyer from Bombay, who bought millions of American dollars' worth of rough material, recently had an account to settle with a local miner for only £40. He told the man that he would have to wait for his money until next week. To a small miner £40 is a lot of money, however. So the miner said, 'I'll show you how I get my money', drew his gun and shot the buyer dead. Four or five times a year a man is killed because of a minor dispute of this kind.

"When the miners have found the mica which contains the emeralds, they throw it in a small river bed at the end of the mine to wash the stones free of mica and mud. The buyers and miners then cluster round to see the stones being washed in the hope of finding perhaps a large stone of 50 carats, though so far no stone of that size had been discovered.

"Even in the abandoned parts of an emerald mine, one can sometimes see a lone miner searching through the tailings the others have abandoned looking for stones. In a week such a man might find one or two stones. This is just enough to keep him going. It is only the few among all the miners who are lucky enough to find big deposits of stones. The majority spend their whole life digging, often ruining their health, and when they are old they have nothing to show for it. Even the few who do make a good find think the money will go on forever, spend it and end up perhaps searching for small overlooked stones in an old tip at the mouth of an abandoned mine shaft."

Mr R. W. Yeo thanked Mr Petsch on behalf of the party for his fascinating talk.

The party visited the gem-testing laboratory, which is affiliated to the University of Mainz. From there they passed into the exchange hall, where local stone-dealers offer their merchandise for sale. Here they saw not only a wide range of familiar faceted and cabochon stones, but also stones from the new finds in Kenya and Tanzania—the newly discovered Kenyan rubies and the beautiful green chrome garnets from Kenya and Tanzania. Most of these green garnets are small, from 0·3 to 1 carat. Larger stones are rare and expensive—for example, Albert Ruppenthal had a very fine 2 carat stone, for which the firm was

asking £400. Besides the natural material, a wide range of synthetics were being offered for sale. One firm had a box of Gilson synthetic opals, the white synthetic opals in this collection being the most convincing. There was also reconstituted material on display. Besides powdered and compressed turquoise both clean and veined, there was compressed lapis lazuli complete with specks of iron pyrites, and also compressed coral. Those who inspected these reconstituted stones felt they would be very difficult to detect when mounted. The group also visited the museum and the permanent sample exhibition.

A visit was arranged to the firm of Julius Petsch where the party saw how rough minerals and gemstones arrived in crates, sacks and drums from all parts of the world. Mr Petsch conducted the group round his showrooms, describing the gems on display and indicating the price of the rough. Among the many unusual specimens on show was one enormous aquamarine crystal of gem quality from one of his mines. The next morning the group was conducted by Albert Ruppenthal round the Ruppenthal showrooms, perhaps the largest and most diverse collection of gems and minerals in the world.

The final morning of the trip was left open for private visits to firms. Some of the group, however, participated in a visit to the factory of Johann Wild and saw the automated gem-cutting controlled by computer. Another party visited a small gem-engraving workshop and had the opportunity to talk to two of the last practitioners of this disappearing craft.

THE JOURNAL OF GEMMOLOGY

The Editor wishes to call the attention of readers and contributors to *Quantities, Units and Symbols*, published by the Royal Society last year. This is a report of the Symbols Committee and was approved by the Council of the Royal Society on 6th March, 1975. It aims at providing "an authoritative and convenient statement of the best up-to-date practice for the use of procedures, symbols and units by scientists in general." It will be editorial policy to bring the usages of the *Journal* in respect of matters covered by this Report (including the printing of numbers and symbols) into line with the Royal Society's recommendations as soon as reasonably practicable.

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and

PROCEEDINGS OF THE GEMMOLOGICAL ASSOCIATION OF GREAT BRITAIN

GEMMOLOGICAL ASSOCIATION
OF GREAT BRITAIN
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NOTES ON MONO- AND BI-PHASE INCLUSIONS IN AMETHYST

By E. J. GÜBELIN, Ph.D., C.G., F.G.A.
Lucerne, Switzerland.

THE striking beauty of a throng of euhedral negative crystals in a small amethyst crystal stirred my curiosity to investigate their mono- and bi-phase fillings in order to determine their chemical composition. Apart from the conventional crystallographic shape of some of these negative crystals I was greatly intrigued by the conspicuous distortions (viz. elongations parallel to the horizontal axes of the amethyst crystal) of the majority of these inclusions. They were all neatly arranged in two parallel arrays on two planes parallel to the narrower prism m of the first order $(10\bar{1}0)$ lying below the smaller rhombohedron z $(01\bar{1}1)$ at a distance of 1 or 2 mm inside the surface of these three prisms, and they were large enough to be visible to the unaided eye. (Figs 1 and 2).

The microscope revealed that these inclusions mainly contained a mono-phase of some fluid or gas, while only a few were bi-phase inclusions embracing a liquid and a vesicle. In order to disclose the chemical composition of these fillings it was necessary to

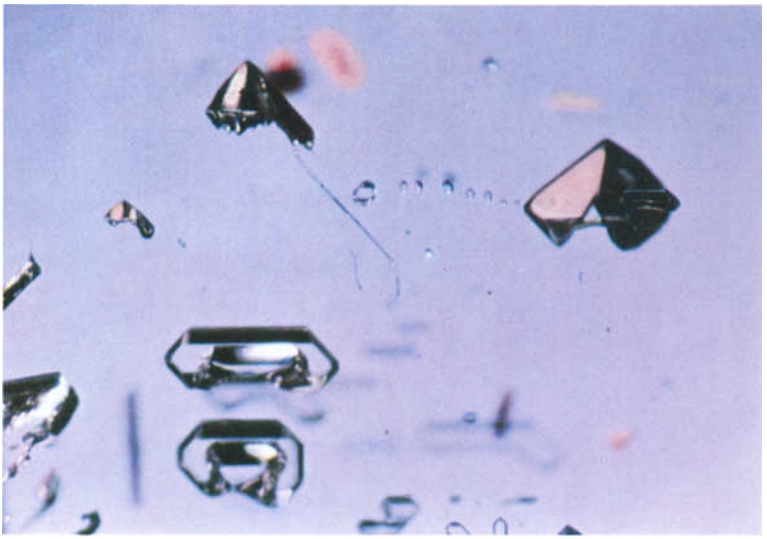

FIG. 1. The c-axis runs vertically through this picture. In the upper half the negative crystals in the shape of rhombohedral pyramids are in the right position, while the negative crystals in the lower half are extended along the horizontal axes. 10 ×

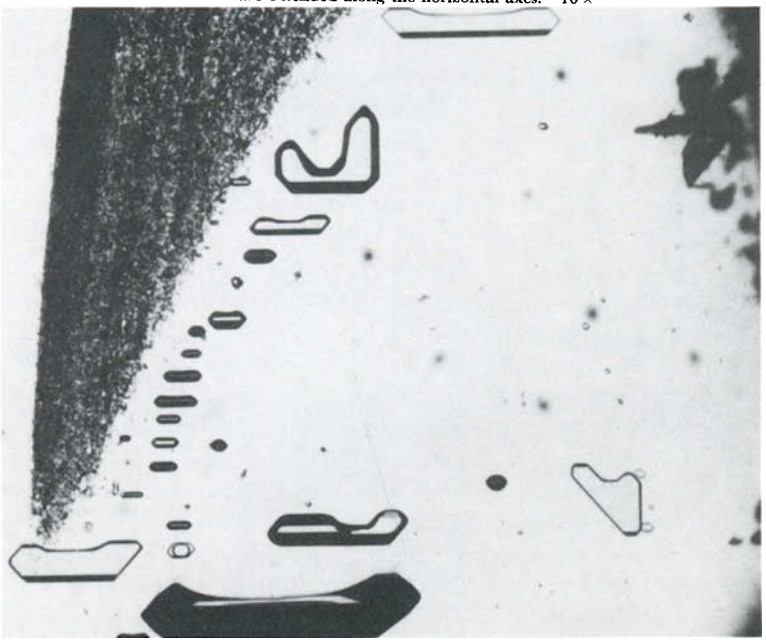

FIG. 2. Another combination of negative crystals lying parallel to one of the prisms of the first order. Almost all of them are extended along the horizontal axes of the host amethyst. 16 ×

take recourse either to the freezing or to the heating stage. Since the application of this method of analysing fluid and gaseous inclusions has not yet been explained in English gemmological literature this occasion might be a welcome opportunity. The classical method, which was already used by H. C. Sorby more than 100 years ago, makes use of the heating-stage microscope. By means of slowly heating up the gemstone, that is to say its inclusions, the temperature of homogenization, i.e. the temperature at which the bubble disappears, is determined. This method actually reverses the course of events which took place in nature, when an inclusion slowly cooled in its host mineral. In the laboratory the specimen is heated until the content of an inclusion has reverted to its homogeneous fluid phase, i.e. until the vesicle has vanished and until the salt crystals, which might be present, have completely dissolved again. The temperature at which total homogenization is reached corresponds with the possibly minimal temperature of formation of the host crystal. In fact it does not lie much below the actual temperature of formation, particularly if the pressure of a hydrothermal mineral formation was relatively small. Matters are different if the pressure was great—then greater corrections for the temperature become necessary. Quartz is excellently suited as experimental material. It is an ubiquitous mineral which exceeds most other minerals in that it can preserve inclusions unaltered for long geological eons and in addition does not leak easily during experimentation.

As long as the inclusions essentially contain aqueous solutions there are no particular problems of investigation. However, conditions change whenever considerable carbon dioxide CO_2 (or methane CH_4) occurs simultaneously. Liquid carbon dioxide has already a pressure of 60 atm at room temperature. This pressure increases very rapidly with slight warming and consequently most specimens with CO_2-inclusions burst upon heating long before the homogenization temperature is reached, unless a strong external pressure in the experimental cell counters the internal pressure of the inclusions. This method of research has for the last few years provided a vast amount of valuable data on liquid and gaseous inclusions in minerals.

When applying the freezing-stage microscope the host mineral is very rapidly cooled down to say $-100°C$ and then slowly warmed up again. This procedure permits observation of quite different

physical and chemical alterations—e.g. the melting point of a watery solution and hence the reducing of the melting point which enables a conclusion to be reached with regard to the salt content of the solution. Or the homogenization temperature of gaseous and liquid carbon dioxide may be determined, which again allows one to draw a conclusion concerning the density of the CO_2, and furthermore the temperature of decomposition of hydrates or the melting point of carbon dioxide etc. may be found.

The freezing and heating methods offer the eminent advantage that each inclusion may be investigated individually. Other methods, such as the mass-spectrometer or gas chromatography, can only scan the total number of inclusions in a mineral. The trapped liquids are in most cases aqueous solutions with relatively large portions of mineral matter like sodium, potassium, calcium, magnesium and others on one side (cations) and chloride, carbonate, sulphate etc. on the other side (anions). It has become possible to determine these different cations and anions, though merely in relative amounts of each other and not in percentages of the filling of the inclusion. However, just these relative amounts—for instance the ratio of K/Na—are very important for the petrologist, because under certain circumstances they may serve as geological thermometers, in that they permit a conclusion as to the conditions of temperature prevailing at the time of formation. This is possible, because for instance the ratio potassium/sodium is being regulated during the growth of a host mineral by the two types of feldspar which occur simultaneously and because the ratio differs with changing temperatures. Yet, apart from this somewhat hypothetical application of a geological thermometer, the identification of the cations and anions supplies valuable information on the geochemistry of a mineral—or ore deposit—as well as about the pressure/temperature conditions predominant during the formation of a mineral.

These were the questions of interest which were aroused by the mono- and bi-phase inclusions of the amethyst.

The cooling down to $-155°C$ on the refrigeration stage produced the following observations:

(*a*) the sublimation of a solid body took place at the temperature of $-99°C$ (Fig. 3) in one case, and in another case at $-90°C$ (Fig. 4):

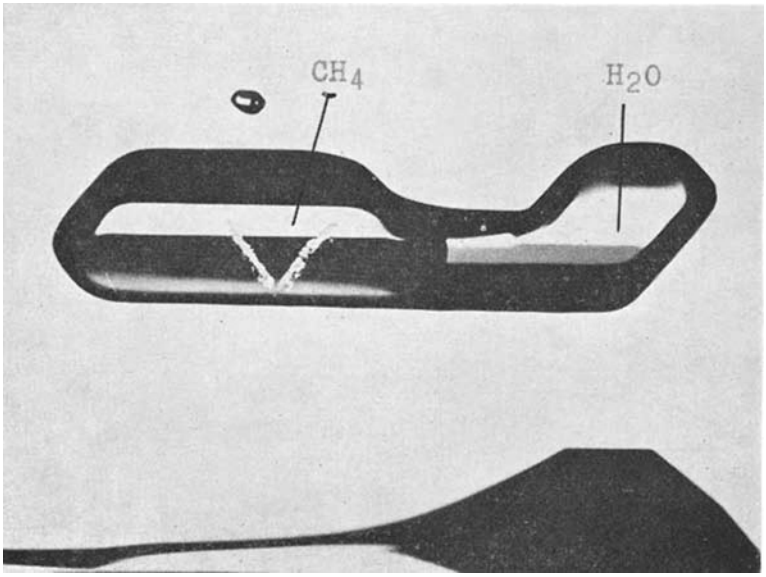

FIG. 3. In one of the negative crystals depicted in Fig. 2 a solid V-shaped body developed first in the gaseous CH_4 phase upon cooling and disappeared at −99°C. The melting point of the aqueous phase was −0·6°C. 100 ×

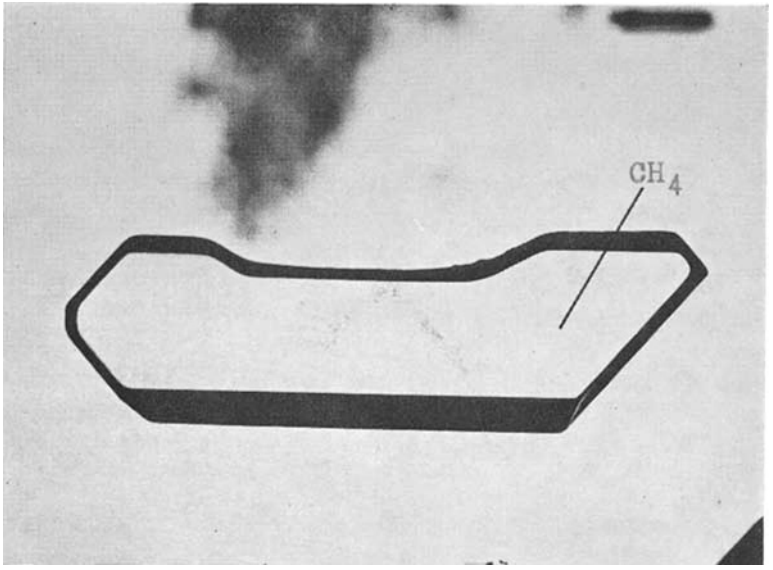

FIG. 4. In another negative crystal filled with gaseous CH_4 a similar V-shaped solid substance formed and vanished at −90°C. 100 ×

(*b*) melting of the ice at the temperature of −0·4°C (another inclusion at −0·6°C). This behaviour corresponds with a saline content of 0·7 wt% of NaCl (1·0 wt% for the second inclusion) (Fig. 5).

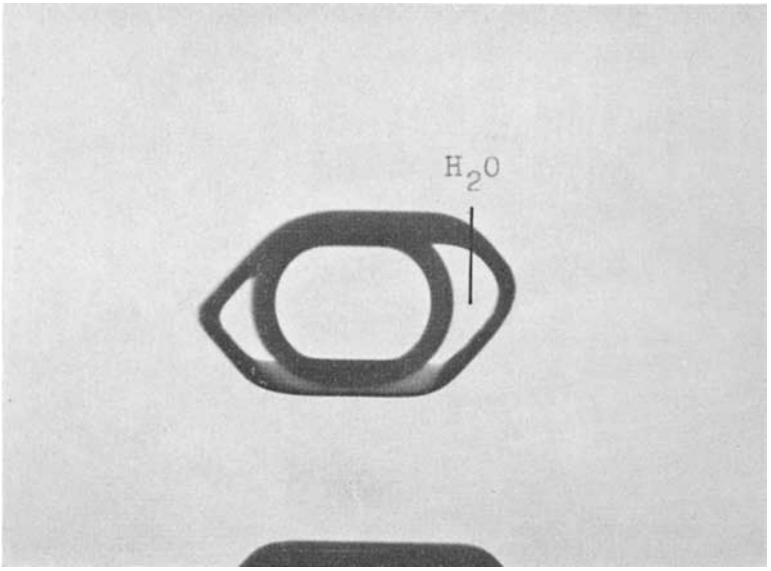

FIG. 5. Two-phase filling consisting of a saline watery solution and its vapour bubble in a negative crystal. The melting point of the ice was −0·4°C. 100 ×

No other alterations of phases could be determined. Unfortunately, the interpretation of these observations is not quite definite. The liquid phase is doubtless a watery solution with a low salt content. The problem lies in the composition of the gaseous phase. It was not possible to liquefy it even at −155°C. The solid phase, which formed directly out of the gaseous phase at approx. −110°C could not be identified. However, it is a well-known fact that when methane is cooled down a morphologically identical solid phase always emerges from the liquid methane. The solid matter, however, was not possible to analyse. If the gas is methane—and this is highly probable—then it was trapped at a very low pressure. However, if the gaseous phase is not methane then only nitrogen (i.e. air) comes into consideration because all the other possible gases would, in view of the low refrigeration, have been subjected to typical phase alteration. Hence, methane is definitely much more plausible than nitrogen.

I favour methane because of the conspicuous elongation of the negative crystals along two completely different crystallographic directions, i.e. euhedral negative crystals aligned to the crystal habit of the amethyst and distorted negative crystals which are extended along the horizontal axes. It has been observed that the presence of methane may exert a strong influence on the development of the crystal forms of growing quartzes and consequently on the shaping of their negative crystals. Stalder and Touray (1970) noticed that methane played an important role during the formation of transparent, dipyramidal quartz crystals from the western limestone rocks of the Swiss Alps. They distinguished four different types of habit, of which the differences of the first three may be explained by the dynamic co-operation of crystal growth and breaking the aperture of a fault, and they held the small amount of CH_4 responsible for the formation of the habit types 2 and 3 as well as for the absence of the x-faces on these crystals. On the other hand, they were convinced that methane was responsible for the development of the fourth habit.

Under these conditions the various shapes and the different directions of the extensions of these inclusions need not be surprising. Very similar formations and orientations of negative crystals have been observed in quartzes of the Helveticum containing methane. Negative crystals elongated along their C-axis and shapes severely distorted along the horizontal axes—all occurring on the same plane—do not even seem to be a rarity.

The different fillings in the inclusions of the amethyst dealt with in the present discussion, i.e. mono-phase and bi-phase (H_2O and CH_4), reveal that the amethyst did not grow in a pure methane environment. It would seem more feasible that at the time of the crystal growth and after a rapid reduction of the temperature and the pressure an exsolved watery solution and methane (in a supercritical state) must have been present in the birth chamber of the amethyst. As a concluding remark it may be emphasized that methane and higher hydrocarbons may in present times still exist in a free state in deposits where quartzes were formed.

Acknowledgement: I wish to extend my best thanks to Dr H. A. Stalder, Natural History Museum, Berne, for his efficient assistance and valuable advice.

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[*Manuscript received 17th February, 1976.*]

COMPARATIVE GEMMOLOGICAL STUDY OF LAPIS LAZULI AND OF ITS NEW SUBSTITUTE

By C. A. SCHIFFMANN, F.G.A., G.G.

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THIS is a report of a series of tests made with the first samples of a new substitute for lapis lazuli[1]. A complementary paper is intended at a future date. The colour of the new substitute is of a pleasant intense ultramarine blue, of an even shade. Compared with samples of the DIN 6164 Colour Chart the closest standard is sample no. 16:4:5, with a corresponding wavelength of 469 nm. To aid gemmologists without knowledge of this colour description system, we may describe the colour tone as approximately the colour of the binding of the 1962 (two volumes) edition of "Gems" by R. Webster.

Aspect

Under magnification, the regular and fine structure includes some tiny elongated particles with rounded ends. Tiny metallic particles with metallic lustre are incorporated, having a rather evenly elongated shape and size, quite unlike the irregularly sized, unexpected, sometimes dendritic, inclusions (occasionally with re-entrant angles) seen in natural lapis. The samples under examination did not show the irregular colour distribution so peculiar to most of the natural lapis with the so-called Chile lapis as an extreme case with its random distribution of light blue or white phases.

Under the Chelsea filter, as well as under ultraviolet radiation, no specific reaction of the samples was observed.

Under the powerful beam of a fibre glass conductor lamp which was shone directly upon the flat surfaces of the samples, they revealed no light transmission, as against pieces of natural lapis that may exhibit a distinct translucency as an intensely blue light around the end of the beam of light, where some natural lapis may be opaque. Henceforth, a definite translucency of a blue colour is a clue to genuine lapis. Furthermore natural lapis exhibits often (but not always) a spotted ultraviolet fluorescent reaction made of irregularly distributed small spots of orange, yellow or whitish colours corresponding to the inhomogeneous mixture of phases of this rock.

Hardness

One would expect that in his effort to surpass nature the manufacturer might have succeeded in duplicating the properties of natural lapis. All the greater was the surprise to ascertain the lower hardness of about 4½ for the artificial product, which is scratched by apatite (which has 5 Mohs hardness degree), whereas trade gem-quality lapis scratches apatite, showing a hardness of about 5½. The difference in hardness expresses itself in the streak left by samples on a rough porcelain plate. Natural lapis has no streak, or leaves a very faint bluish grey mark; the state of cohesion is such that it resists abrasion and releases no odour; on the contrary, presumably because of its lower cohesion state, the substitute has a strong blue streak, leaving a powdered residue, when rubbed on the plate with similar pressure applied (see Fig. 1), because it crumbles fairly easily, while, due to this action, a definite smell of sulphur compound develops. This alternative reaction seems to be convincing, all the more as, under more strenuous conditions, viz. touched with the rotating, small carborundum abrasive disc on a

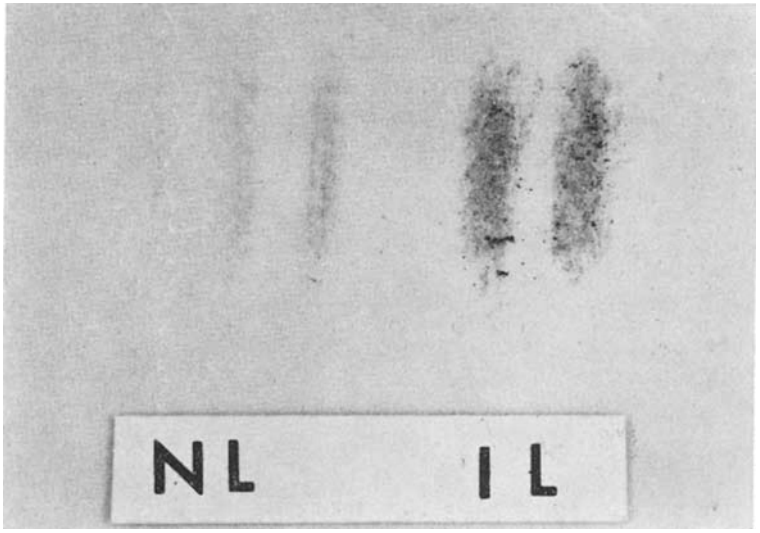

Fig. 1. Compared hardness. Streak left by natural lapis (NL) and new substitute (IL). (*Photo. C. A. Schiffmann*)

flexible motored arm used by jewellers, both natural lapis and the substitute give off the similar sulphur odour. The detection of smell is rarely practised by the average gemmologist but in this case offers a hint towards a definite identification.

In order to analyse the structure of the substitute, an x-ray powder diagram was carried out thanks to Dr W. Oberholzer, of the Zürich Institute of Crystallography, whose first results confirm that some of the phases are in a crystalline state. The aggregation state of these phases is being studied in further detail.[3]

REFRACTIVE INDEX: non-typical, vague edge at about 1·5.

SPECIFIC GRAVITY

Gemmological literature gives only a range of S.G. for lapis lazuli qualities as used for jewellery. In order to obtain more precise data on different types and so to bridge this literary gap, we made a series of determinations by the hydrostatic weighing method, on samples of average jewellery types. Determinations of S.G. of more irregular or extreme types are intended to be reported at a later date. The hydrostatic method enabled us to verify a possible porosity of natural lapis by leaving all the specimens immersed for a duration of 6–15 minutes and then weighing again.

The table below is a summary of our new S.G. data (at 4°C) for natural lapis in jewellery qualities.

Lot No.	*Colour*	*Inclusions or Phases*	*S.G.*	*Porosity*
1	Blue, intense, dark, (resembling sodalite shade)	without pyrite	2·83	None
2	Blue, intense	without pyrite few white spots	2·51	None
3	Blue, less intense	without pyrite	2·73	None
4	Blue, ultramarine, homogeneous	without pyrite	2·85	None
5	Blue, ultramarine, homogeneous	without pyrite	2·77	None
6	Blue, ultramarine, homogeneous	without pyrite	2·89	None
7	Blue, ultramarine, homogeneous	few, tiny pyrite grains	2·88	None
8	Blue, ultramarine, homogeneous	few, tiny pyrite grains	2·90	None
9	Blue, ultramarine, homogeneous	few, tiny pyrite grains	2·79	None

Lot No.	*Colour*	*Inclusions or Phases*	*S.G.*	*Porosity*
10	Blue, ultramarine, homogeneous	few, tiny pyrite grains	2·86	None
11	Blue, ultramarine, homogeneous	few, tiny pyrite grains	2·77	None
12	Blue, spotted, "Chile lapis"	approx. $\frac{1}{4}$ of surface having paler blue or white phases	2·96	None

A trifling porosity resulting in a S.G. increase of 0·003 came out with no. 3 and 11, and is negligible within the precision limits of the method used, the results being rounded up to the second decimal point.

S.G. of 1 to 12, extreme values 2·51 and 2·96

S.G. of 1 to 12, average value 2·81

To enable comparison, the S.G. of samples of lapis substitute was determined using the same method:

Lot No.	*Colour*	*Approx. S.G. at immersion time*	*S.G. after 6–15 mins. immersion*	*Apparent porosity in vol%*
1	Blue, ultramarine	2·41	2·53	4·8
2	Blue, ultramarine	2·33	2·47	5·7
3	Blue, ultramarine	2·34	2·39	2·2

Extreme S.G. values 2·39 and 2·53

Average S.G. value 2·46

Just after immersion the evident porosity manifests itself by a quick shift of the balance dial which stabilized visually after 6 to 15 minutes.

With its distinct porosity the lapis substitute has an obviously different behaviour from that of natural lapis without porosity; together with the considerably lower S.G. at an average of 2·46 against 2·81, this way of separating them is very convincing.

Gemmologists working hastily with heavy liquids might be led to error, as the substitute falls within the S.G. range for sodalite, which lies in average at 2·3 with a possible variation. However, sodalite has no porosity: and, by the way, the lapis substitute would soak up quite an amount of chemicals, a reason why heavy liquids are not necessarily a recommendable method for testing porous

materials. Furthermore, the colour of sodalite is on the average of a more violetish blue (colour tone 15 of DN 6164 Colour Chart), and its R.I. lies lower, towards 1·48. Under the strong direct beam of light as mentioned before, sodalite further exhibits a distinct translucency in the form of a beautiful violet blue colour.

In a search for other possible testing methods a trial was undertaken with infrared spectrophotometry, a method which gave us interesting results in a number of cases. The first results obtained in working between 2·5 and 40 mm were not conclusive, since the respective absorption curves of both the natural and the artificial lapis materials were not diverging enough to differentiate them safely.

However, the method gave a positive result in another regard, identifying sodalite mentioned above by well defined typical absorptions at 980, 740, 710, 670, 470, 440 cm^{-1} against the one broad absorption of lapis of 1420 and 1030 cm^{-1} and weaker lines between 900 and 300 cm^{-1} (Fig. 2). The advantage of this procedure being that by means of an instrument recorded results are available for future reference when written proof is required.

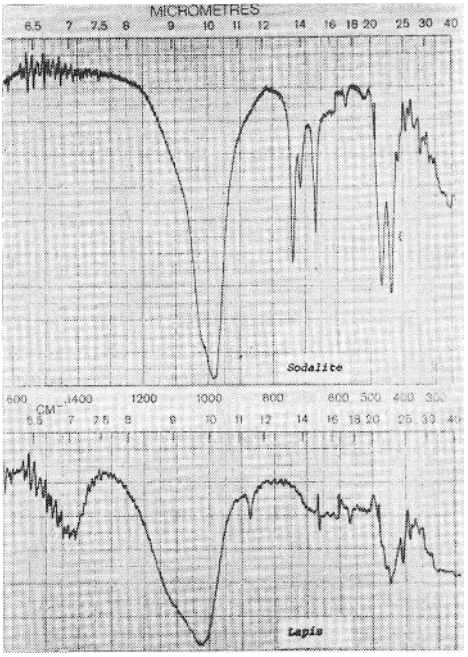

FIG. 2. Differentiation between natural lapis and sodalite by means of their infrared spectra between 9 and 40 μm.

Finally, some chemical reaction tests were included on pieces of natural and artificial lapis in order to search for their different reactions. It should be known, that due to being a rock of inhomogeneous structure and because of its components, lapis is sensitive to acid and when set in jewellery should be treated with caution. An unconsidered drop in the diluted acid bath in use with jewellers may ruin the surface of lapis. This destructive test was performed in applying a drop of 3 acids and observing the development and the result of the reaction under the microscope as in the table below.

Chemical tests and reaction at room temperature on cut pieces:

Diluted Industrial Acids	*Natural lapis*	*New lapis substitute*
Sulphuric	Reaction not very rapid. Sulphur fumes slow to develop, not very strong. Irregular white residue.	Rapid attack. Immediate effervescence. Strong, sulphurous fumes.
Nitric	Reaction slower, not very strong. After evaporation, trace of the drop hardly visible. Fumes weak.	Attack irregular. Fumes less pronounced than above, but developing rapidly.
Hydrochloric	Reaction quicker than no. 1. Gas bubbles arise much less rapidly than on the substitute surface. Formation of a colourless jelly.	Reaction and fumes immediate. Drop keeps round shape.

The photographs (Figs 3 and 4) will enable the reader to grasp a better idea of the relative intensity of the reactions. It is intended to discuss these reactions in more detail at a later date.

Altogether, the new substitute has properties sufficiently unlike the ones of natural lapis to distinguish them quite easily. For the gemmologist in this case care in testing and knowledge are the necessities. On the whole, at least some of the properties of this substitute are strikingly similar to those of a lapis imitation made

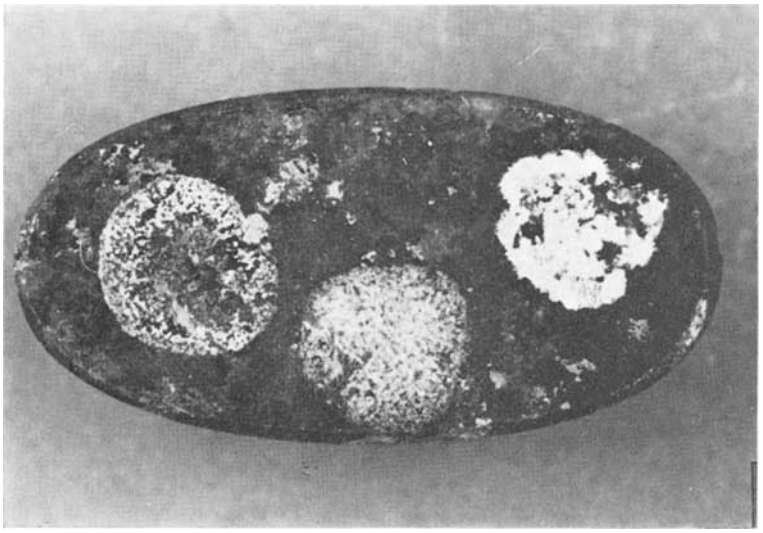

FIG. 3. Natural lapis, action of diluted acids on the surface of an oval-shaped stone.
right: drop of sulphuric acid, strongest reaction with white residue
left: drop of nitric acid, weak reaction
below: drop of hydrochloric acid, medium reaction
(*Photo. C. A. Schiffmann*)

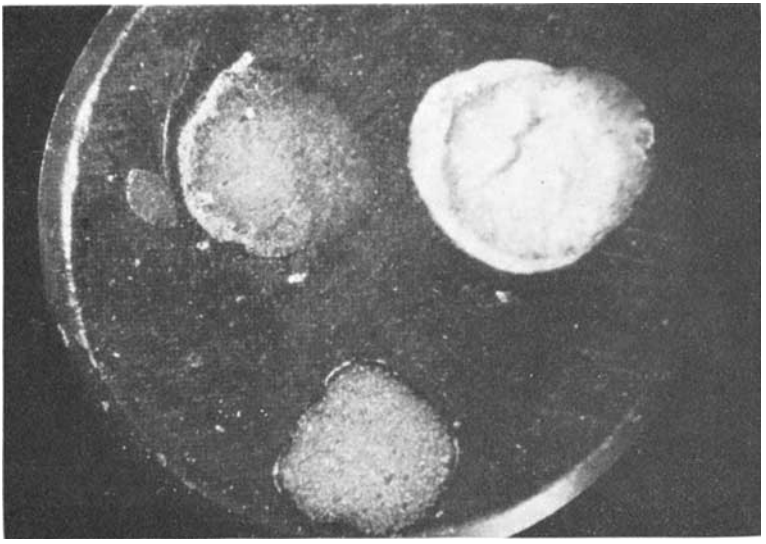

FIG. 4. Lapis substitute, action of diluted acids on the surface of a round stone
right: drop of sulphuric acid, very strong reaction
left: drop of nitric acid, medium reaction
below: drop of hydrochloric acid, fairly strong reaction; on this sample the reaction was immediate and stronger than on natural lapis. (*Photo. C. A. Schiffmann*)

already in 1957 by Reese and reported upon by W. F. Eppler[2] As far as we know, the present material is marketed by the firm of Gilem.

We should like to express our appreciation to Dr W. Oberholzer, of the Institute of Crystallography, Zürich, for his kind assistance in arranging the Gandolfi x-ray analysis and Mr K. Kunz, Reiden, for his careful preparation and carrying out of the infrared spectra.

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[*Manuscript received 8th March, 1976.*]

MOLDAVITES AND A SURVEY OF OTHER NATURALLY OCCURRING GLASSES

By PROFESSOR JIRI KONTA,
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JOHN M. SAUL, Ph.D.,
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INTRODUCTION

This paper surveys the occurrences of glass in nature with an emphasis placed on those materials which may be of interest to the gemmologist. The first section discusses tektites and, in particular, gem varieties of moldavites, with new information given on their geology and on their gemmological applications. The second part of the paper gives an inventory of all those natural or possibly natural glasses known to the authors. Some unusual materials are discussed, but emphasis is again placed on those substances of greatest interest to the gemmologist and it is pointed out that some attractive glasses have not found their way into jewellery due to the fact that there is at present no way to determine whether they are of natural origin.

TEKTITES

Tektites are enigmatic bits of natural glass which in many cases exhibit attractive sculptured forms. They are known from only a few areas or strewnfields and their varietal names have usually been taken from the regions in which they were found. *Moldavite* is the variety of tektite most commonly encountered by gemmologists, and moldavites were the first tektites to be studied scientifically. They were described by Professor Joseph Mayer in 1787, some fifteen years before the true nature of meteorites was recognized by the scientific community. The moldavites take their name from the river Moldau which is called the Vltava in Czech and the term *vltavite* shows up in some older publications. Moldavites occur in a scenic area approximately 100–150 miles north-west of Vienna and 60–100 miles south of Prague. About sixty years after Mayer's original publication, tektites were discovered in Australia (*australites*), and at the end of the 19th century discoveries were made in south-east Asia (*philippinites*, *javanites*, *billitonites*, *etc.*). Other discoveries followed.

Tektites can be divided into four groups in accordance with their potassium-argon ages: the oldest are *bediasites* from Texas and Georgia (with two unique specimens attributed to Martha's Vineyard, Massachusetts, and to Cuba) with a K/Ar age of about 35 million years. The name bediasite comes from Bedias, a proper name in Grimes County, Texas. The moldavites are the second oldest group of tektites at about 14·5 m.y., then *Ivory Coast tektites* which are dated at approximately 1·3 m.y. The youngest are the south-east Asian varieties and the australites with an age of about 700,000 years. It is interesting to note that these last two dates refer to periods when man or man-like beings were already in existence. A unique natural material from western Egypt is called *Libyan Desert Glass* and has a K/Ar age of about 35 m.y. It should almost certainly be classed with the tektites but, because of its high viscosity in a molten form, its physical appearance is quite different and it has been treated separately by many authors.

Origin—Hundreds of papers have dealt with the origin of tektites. Most of them can be summarized in the following table:

TABLE 1

Summarized hypotheses of the origin of tektites (after Mason, 1962).

A. Tektites have been formed from terrestrial materials by:

1. Impact (*a*) of meteorites; (*b*) of comets.
2. Lightning (*a*) fusing soil; (*b*) fusing dust particles in the atmosphere.
3. Natural fires: burning straw, forest fires, burning coal seams, etc.
4. Volcanic activity.
5. Human activity: furnace slags, glassworks, etc.

B. Tektites are of extra-terrestrial origin; they came from:

1. The moon, from (*a*) lunar volcanoes; (*b*) splashes from meteorite impact.
2. Comets.
3. A disrupted planetary body having a glassy surface layer.
4. Meteorites consisting of free Si, Al, Mg, etc.
5. Stony meteorites by fusion in the earth's atmosphere.

It is clear from the few facts already presented that many of these ideas are untenable; others are so speculative that they are exceedingly difficult to prove or to disprove. During the past two decades evidence has accumulated that indicates rather strongly that the tektites must have originated from impacts of large meteorites or other cosmic bodies. These impacts caused the rock on the ground at the site of impact to melt and material was ejected in some special manner that permitted the formation of the tektites. Scientists still argue whether the original impacts took place on the earth or on the moon, but almost all experimental data support a terrestrial impact site. Any theorizing along these lines must, however, take into account a troublesome aerodynamic consideration, namely, that tektites are invariably small and the earth's atmosphere is large, and the launching, splashing or throwing of the tektites in a liquid or solid form presents a problem analagous to throwing a feather a considerable distance. Somehow, the air resistance built up in front of the projectile of low mass must be removed or greatly attenuated in order to satisfy the aerodynamicists. Any successful theory of tektite formation at the surface of the earth must resolve this problem and most of the ways suggested to date entail extremely energetic events. Expressions such as

"blowing a hole in the earth's atmosphere" are bandied about regularly.

According to Konta and Mraz (1975) many authors are wrong in postulating that tektites originated by a direct melting of terrestrial silicates to glass. At the 34th Annual Meeting of the Meteoritical Society, held at Tübingen, Germany, Gentner (1971) and Konta (1971) presented, independently of one another, a hypothesis based on experimental data in which it was suggested that the moldavite substance originated when terrestrial silicate material evaporated during the thermal shock which followed the impact of a large cosmic body. During the explosive ejection, the gaseous silicate phase seized some of the solid and liquid phases and quartz grains, in particular, were melted to lechatelierite. In the opinion of both authors moldavites were formed by the condensation of silicate vapours during their passage through the atmosphere. According to Konta and Mraz (1975) all the experimental data hitherto obtained indicate that the evaporated and condensed material in moldavites prevails over the material that passed directly from a solid state to a liquid one. The discrepancy emphasized by some authors between the chemical composition of impact glasses at the craters and that of the tektites assumed to be genetically related to them can now be understood better. The enrichment of silicate vapours in silica, in total FeO, and in Na_2O and the impoverishment of these vapours in CaO, MgO, K_2O, and Al_2O_3 which apparently took place during thermal shock can attain such a degree that the chemical composition of the glass condensed from the hot silicate vapour (e.g. the tektites) will differ substantially from the chemical composition of the original rock, as well as from glasses generated from it by direct melting.

A lunar site for the initial meteoritic impact now seems highly unlikely due to aerodynamic considerations which are as imposing as those involving a terrestrial site, plus a complete lack of chemical or isotopic similarity between tektites and the lunar rocks recovered by the Apollo program. An additional constraint is imposed by the fact that during their initial cooling, tektites were in a magnetic field comparable to that of the earth's (De Gasparis, Fuller and Cassidy, 1975).

Many researchers suppose that the well-known Ries crater in West Germany has been the source impact crater for the moldavites. Likewise, the Ivory Coast tektites are referred to the Lake Bosumtwi

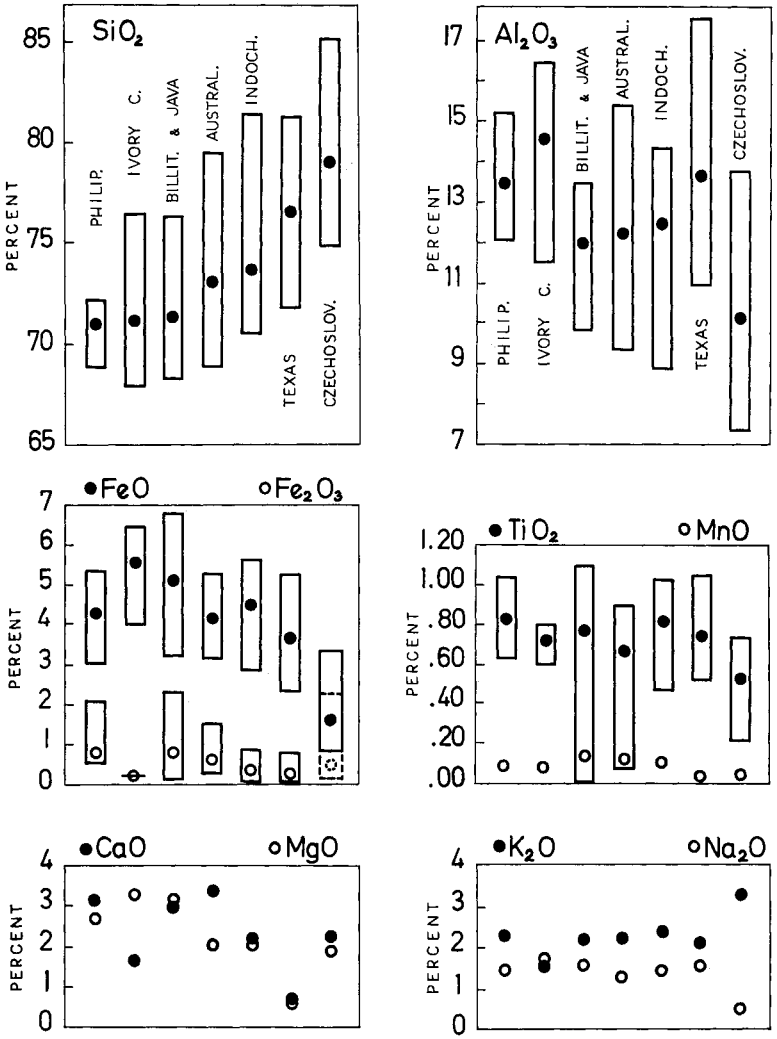

FIG. 1. Chemical composition of tektites from different areas.

crater in Ghana and in Libya there are two relatively unknown craters in a quartz sandstone, one of which, the "Oasis site", appears to explain the Libyan Desert Glass (Martin, 1969: French, Underwood and Fisk, 1972). The lack of any suitable impact site associated with the North American tektites or a definite site or sites related to the Australasian tektite strewnfields is evidence that the origin of tektites is still an unsolved problem.

Chemical composition—Fig. 1 shows the variation in chemical compositions of tektites from different areas. Silica is seen to be the major constituent in every case. On the vertical axes are plotted weight percentages of the respective oxides and the horizontal is used to show groups of tektites from different strewnfields. The size of the columns shows the known ranges of percentages of some oxides, and the circles indicate average values. The ranges and average values given for moldavites were calculated from more than fifty published chemical analyses. All tektites have a very high silica content and alumina ranks second in all cases. The prevalence of bivalent iron over trivalent iron and the absence of volatiles are also characteristic of all tektites.

Colour—In hand specimens, tektites from most localities are black or almost black and non-translucent. In thin sections they are translucent and usually brown or greenish brown. On the other hand, most Czechoslovakian moldavites and some specimens from the United States are translucent or transparent and many moldavites are greyish green or green, in various shades from deep to light; rarely, moldavites of bluish green colour can be found. The translucency of relatively thick specimens is due to the favourable chemical composition of particular moldavites. These contain the lowest amounts of iron oxides and of other colouring oxides (TiO_2, MnO) and the highest amounts of silica and potassium oxide of all tektites, the Libyan Desert Glass excluded.

Bouška, Faul and Naeser, 1968, p. 282–3, have studied 15,576 moldavites from 21 localities and report that: "In Bohemia 79% of the moldavites are bottle green; the percentage for individual localities varies from fifty-four to ninety-three. Olive green and light and pale green are the next most important Bohemian colours, with brown and intensive green ('poisonous' green) each being usually less than two per cent at each locality . . . Two colours predominate in Moravia; 89% of the moldavites are olive green and brown.

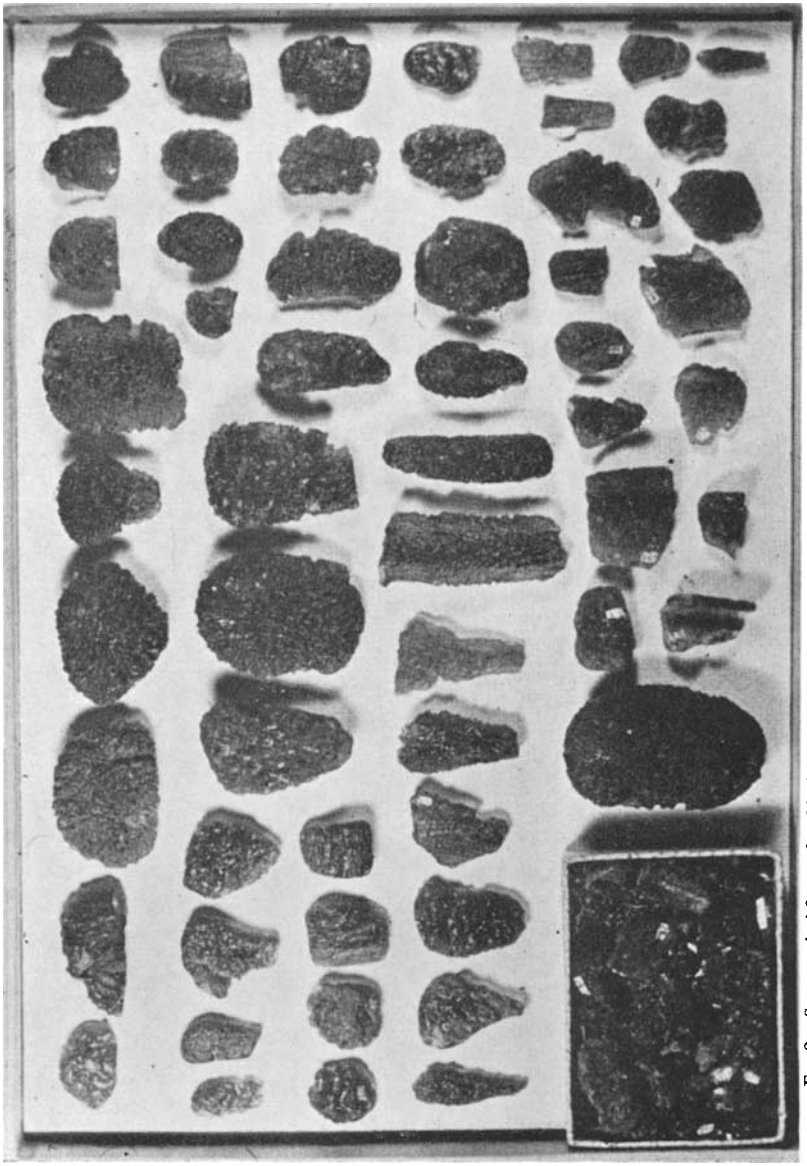

FIG. 2. Some typical forms of moldavites from southern Bohemia. Some of them are of gem quality. (Half natural size).

Bottle green, the dominant colour in Bohemia, is the colour of only five per cent of the Moravian moldavites, light and pale green accounts for five per cent, and the remaining one per cent is made up of intensive ('poisonous') green." Bicoloured, green and brown moldavites are known but are exceedingly rare. The translucency, bright colours, diversified shapes and surface features, along with their mysterious origin, are the main reasons why Czechoslovak tektites have become a material in wide demand for jewellery. Not all moldavites, however, can meet gem standards. One top-quality moldavite may be selected from as many as fifty to seventy specimens found in the field.

The number of areas from which tektites are known is very small and a gemmologist will note that deposits of sapphire and emerald, not to mention tourmaline or garnet, are much more numerous.

Physical properties of tektites—Size and shape of moldavites—Moldavites usually occur as irregular fragments ranging from ten to fifty millimetres in size. We can reconstruct the original shape of most of them, partly because original whole forms have been found, and partly because matching fragments occur in some localities (Fig. 2). The most frequent whole forms of moldavites from southern Bohemia are drops (Fig. 3), flat discs, and rod-like forms. In

FIG. 3. The most frequent complete forms of moldavites from southern Bohemia. (Nearly natural size).

Moravian localities the shapes are more spherical and the drops are short and thick. All of these forms are the result of aerodynamic forces. Tektites from other localities, australites in particular, show even more dramatic evidence of aerodynamic shaping. These aerodynamic forms should not be confused with the secondary surface features which result from weathering and which are discussed below.

Bulk density varies in a direct relationship with the refractive index. Both of these properties show an inverse relationship to silica content; that is, the lower the silica content, the higher the bulk density and refractive index. Javanites have the highest average bulk density of all tektite groups (between 2·40–2·55), followed closely by australites and philippinites. Bediasites have a lower bulk density and the moldavites are lower still with figures between 2·30 and 2·40. Within the moldavites, the mean bulk density of those from Moravia is slightly lower than of those from Bohemia. The refractive index of moldavites is low, ranging from 1·475 to 1·500. Libyan Desert Glass, which in common with other tektites may contain voids, has a bulk density of about 2·21 and a refractive index of 1·459 to 1·465. The hardness of tektites ranges from 6 to 7.

FIG. 4. Deeply grooved moldavites with very sharp surfaces, Besednice (left) and Nesmen (right) southern Bohemia. (Nearly natural size). First photo taken in incident light, the second one by transmitted light.

Secondary surface features of moldavites—A terrestrial sculpturing of the surfaces of moldavites has taken place through the action of weak aqueous solutions which percolated through the clay sediments in which the moldavites were originally deposited. This corrosive activity formed deep grooves and depressions, the peculiar character of which is a result of the chemically and physically inhomogeneous nature of the moldavites. The vast majority of moldavites contain grains and elongated schlieren of lechatelierite, a pure silica glass. The remaining portions of the moldavites have an increased content of the oxides of Fe, Al, Ca, Mg, K, Na and Ti, and a correspondingly lower percentage of the predominant silica.

Moldavites which have been buried in a fine-grained sediment such as the gravelly-sandy clay at Besednice and other localities, for the better part of fifteen million years (from the Upper Miocene until comparatively recent times), were deeply grooved and their surfaces contain sharp points (Fig. 4). The surfaces of most of these moldavites are dull and without glassy lustre even after all the clay material has been washed away (Fig. 5). Some of the moldavites

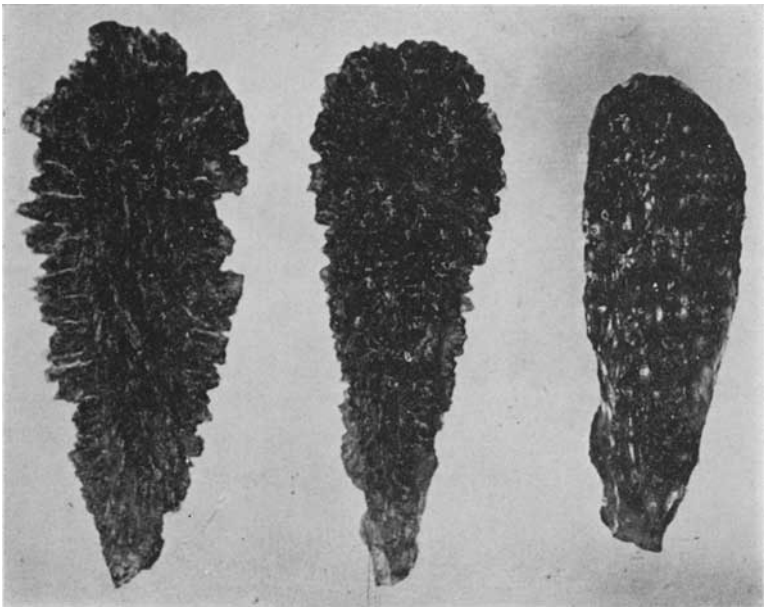

FIG. 5. The surfaces of moldavite drops after stream transport over various distances. Southern Bohemia.

were later transported after the Upper-Miocene clay had been denuded and were abraded to various extents during this transport. Together with gravel fragments and sand grains they were redeposited in younger Miocene, and in Pliocene to Quaternary strata. Most of the clay material was transported by streams into other areas and only a small portion of the clay material was deposited together with the sand and gravel. The surfaces of moldavites that were transported approximately five miles or more are subrounded or rounded (see the drop-shaped moldavite on the right in Fig. 5). If the moldavites were transported over a distance of only several hundred metres, however, their surfaces remained rough, and only the sharpest points and edges were rounded as is shown by the drop in the middle of Fig. 5.

In order to become glossy and to retain its deeply grooved surface, a moldavite had to lie in a clay sediment for several million years, and then after corrosion the moldavite had to be freed from the clay material and redeposited with gravel fragments and sand grains not far from its original sedimentary position. In the new sedimentary environment where there are relatively sizeable pores enabling an easy percolation of water and in which there is an insignificant admixture of clay matter, the moldavites are washed for hundreds of thousands or millions of years. The dull and rough surfaces turn smoother and lustrous. Seeping rain-water contains some aggressive compounds and it penetrates thoroughly into all the grooves and depressions, uniformly treating the entire surfaces.

Searching for moldavites—Moldavites can be found most easily in the fields after the spring thaw or in late fall after strong rains, when the surfaces of the fields are mostly free of vegetation. This seasonal water washes out the finest soil material; loam lumps and clods are elutriated, and all bigger solid fragments remain on the surface of the fields. The moldavites are well washed, as are other stones, and are found thinly scattered over the surface. Moldavites are recognized because of their green-black colour and their distinctive grooved sculpture. The best conditions for moldavite hunting are immediately after the rain or the morning dew, at which times the surfaces of the washed moldavites exhibit a glassy lustre. Under optimum conditions and in the richest localities an experienced collector can obtain as many as 30 to 60 pieces in one day from an area of approximately 300 × 900 metres. In other localities, however,

the search may be unsuccessful for several years. Of 30–60 moldavites, usually only one is suitable for jewellery as a gem variety. All collected specimens do, however, represent valuable material for scientific purposes, especially if details of the find are recorded. Why are the gem moldavites so rare? The reason is that the gravelly sands that contain moldavites also contain quartz, feldspars, and fragments of acid igneous rocks. As a result of the weathering of the feldspars a soil profile is formed which contains an increased portion of clay particles and humus. These fine particles retard the percolation of water and form a clay environment somewhat similar to the Upper-Miocene clay sediment environment. The surfaces of the moldavites from such soils thus become dull again. In addition, a not inconsiderable number of moldavites get scratched or broken in the course of agricultural work on the fields.

The finding of gem varieties of moldavites—A reliable, although time-consuming, way of finding gem varieties of moldavites is digging in sand pits. The gem varieties of moldavites occur in those layers which are rich in gravel fragments. They are relatively little worn in those localities in which the gravel fragments of quartz, rocks, and feldspars are themselves but little rounded. Fig. 6 shows a section

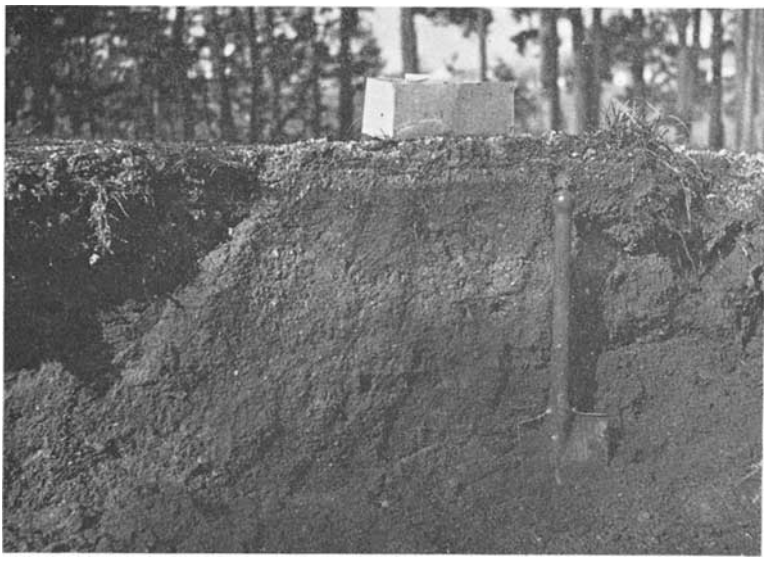

FIG. 6. A section of tektite-bearing sediments in the sand pit at Nesmen, southern Bohemia.

from the well-known sand pit at Nesmen in southern Bohemia. Moldavites are accumulated in those horizons which contain high amounts of gravel. All moldavite-bearing sediments are rusty brown in colour except those with a considerable content of clay, which are deep brown.

The sedimentary profile at Ločenice, about one mile from Nesměň is comparatively rich in moldavites, and yields one to three moldavites per 30 cubic feet. A group from Charles University (Prague) studied the section at Nesměň and Ločenice and searched for moldavites several years ago. Several beautiful moldavites were found in each of these sand pits. Twelve people digging in three pits for eight days found 43 moldavites. A total of 600 cubic feet of gravelly sand and 240 cubic feet of gravelly clay were dug and carefully examined. Forty-three moldavites weighing 118 grams were found and, of these, 30 specimens were of gem quality and weighed a total of 98 grams. The weight of the heaviest one was 13·276 grams and its size was 26·3 × 21·9 × 18·8 millimetres; the weight of the lightest one was 0·391 gram.

Gem moldavites as gemstones—Most varieties of gemstones undergo cutting and polishing in one manner or another in order to take full advantage of their colour, lustre, or internal reflections. Pearls typify another class of gems in which the raw material is not cut or polished and in which the jeweller makes use of the natural lustre and the original form of his raw material.

The Czech gem-cutters and jewellers feel that moldavites, in common with pearls, should be used in their original forms with their naturally appealing surface characteristics. Particularly popular in Czechoslovakia are the flat sword-like shapes, which represent the blades of elongated drops (Fig. 7). These occur mainly in the southernmost part of the Bohemian moldavite strewnfield. The blade-like shapes and similar forms displaying high translucency or transparency are usually incorporated in pieces of jewellery whose structure and form make use of transmitted light. Crosses, ear-rings, necklaces, and brooches are particularly popular. Thick and dark-coloured moldavites are often set with a reflecting metal placed behind them.

Cutting and polishing of moldavites are not advisable because they deprive the stones of their original surface features and charm. Polishing cannot achieve a more beautiful surface than a high

I.
Ueber die
Böhmischen Gallmeyarten,
die grüne Erde der Mineralogen, die Chrysolithen von Thein, und die Steinart von Kuchel.
Vom Professor
Joseph Mayer.

§. 1.
Böhmische Gallmeyarten.

Gallmey, oder Zink, in kalkigter Gestalt, wird zwar an verschiedenen Orten in Böhmen gefunden, aber man hat es kaum die Mühe geachtet, seine Aufmerksamkeit darauf zu wenden. Das Bedürfniß des Zinks hat man mit den verhandenen häufigen Blendenarten ersetzt, besonders bey den Messingwerken, und nur sehr wenig von den verschiedenen Minern desselben wird benutzet, um es in metallischer Gestalt zu erhalten. Tscheren und Lipohausen, wo Gallmey in beträchtlicher Menge gefunden wird, wird gar nicht gebaut. Von beyden Orten habe ich gute Arten erhalten.

Kk 2

FIG. 7. Flat, sword-like shapes or elongated drops of gem moldavites, southern Bohemia. The text is the first recorded description of tektites (Mayer, 1788). (Half natural size).

quality moldavite has already acquired by chemical corrosion during its many hundreds of thousands of years of burial in gravelly sand. Facets or polished free-form depressions are suitable only for those moldavites whose surfaces are dull or have a very rough relief, or for those whose excessive thickness causes a very low transmittal of light. Two additional considerations play a role in our suggestion that moldavites be mounted in their natural state rather than as faceted stones. One of these is the low index of refraction of moldavites (and of all other tektites) which will cause any faceted stone to have no more than a minimum of appeal. The other consideration is of quite a different nature. As outlined in previous sections, the origin of tektites is still an open question and much research is still going on. The definitive answers to our questions may come from any one of several possible lines of enquiry and it may be that there are rare classes or categories of tektites, as yet unstudied or undefined, which will be of great scientific value. By mounting tektites as undamaged whole pieces, we also preserve them for possible

future research, especially in those cases where the locality of the place of find is still known. This may appear far-fetched, but an example will show that it is not. As an example of a truly unusual physical property, we note that about one gem moldavite in two hundred has such great internal strain that it will ring like a coin when dropped, a unique property amongst gems. A greater knowledge of the specific origins of these rare specimens might throw light on the entire tektite problem. The high-strain specimens cannot be faceted in any case; they shatter immediately when cut into. The bicoloured moldavites also constitute a special class of particular scientific potential.

Some other minor gem applications have been made of tektites. Tektites from south-east Asia have been cut into black cabochons, difficult to distinguish from cabochoned obsidian. Libyan Desert Glass has been faceted, but with its very low refractive index, its unattractive colour, and its potential scientific value, this can scarcely be recommended. Libyan Desert Glass does not exhibit moldavite-like surface features, although sand blasting by the desert wind has given rise to some curious surface features and textures.

Other names for tektites which have appeared in various publications include: "*Agni Mani*", *Fire Pearl*, *glass meteorites*, "*Bouteillenstein*" (especially for moldavite), *bottle stone* (for moldavite), *water-chrysolite*, *pseudo-chrysolite*, *obsidian buttons*, *Blackfellows' buttons* (for australites), and, no doubt, other unfortunate terms as well. Valid names for tektites in other languages, including "*buga*" (in the language of the Ifugaos people of northern Luzon) and "*agna*" (in the Agni and Baoulé languages of the Ivory Coast), have also found their way into print and are of great use in carrying out field work.

Other Classes of Natural and Supposedly Natural Glasses

In the years preceding the landing of men on the moon there was considerable activity in scientific circles to determine whether tektites or any other material found on earth might have come from the moon. None was found and recognized as such. The search concentrated on ash-like and tektite-like (glassy) substances. Some of the materials that turned up during this period may have come to the attention of gemmologists and a brief and probably incomplete survey is given below. A few of the materials noted have the potential of eventually becoming gemstones in their own right, but most are either curiosities or materials on which more research is

required to determine whether or not they are natural in origin. In the same listing we have thought it appropriate to include all other natural glasses or possibly natural glasses and to comment on the gemmological potential of some of them.

Any theory relating to the origin of tektites must also be consistent with the existence of *microtektites*, small (under 1 mm) glassy objects discovered in deep-sea sediments in 1968 by B. P. Glass. Microtektites are known from sediments off the coast of the Ivory Coast and also in and to the west of the Australasian tektite strewnfield.

Bentonite is a clay mineral which is formed as a decomposition product of volcanic ashes and glasses. In 1970 Storzer and Gentner suggested that bentonite glasses which they studied in Bavaria and which they had dated at 14·5 million years were in fact identifiable as corroded relics of *micromoldavites*.

Impactites or *impact glasses* are known from the sites of several recognized meteorite impact craters. They are usually very heterogeneous, vesicular and mixed with crystalline fragments. Although massive brown and black specimens have been recorded, impactites are in no way suitable for lapidary purposes. *Darwin Glass*, from Mt Darwin in Australia, and the closely related *Macedon Glass* are impactites which are being extensively studied to see if they shed any light on the problem of the place of origin of the Australian tektites. The Darwin Glass is a dark brown, black, colourless or pale green, slaggy vesicular material with a very high SiO_2 content. It may well be related to a sizeable impact crater whose symmetrical form has been obscured by erosion (Ford, 1972). *Queenstownite* is a former name used for Darwin Glass. Impactites exhibit a range of refractive index from 1·46 to 1·55 and have a bulk specific gravity of "generally less than 2·3" according to Chao (in O'Keefe, 1963). Our own experience has included specimens with bulk specific gravity values up to 2·5 but any specimens that might come to the attention of a gemmologist would be unusual and might exceed even this higher figure.

Of no direct professional interest to the gemmologist are the glass minerals such as *lechatelierite* (with the composition of quartz) and *maskelynite* (with the composition of plagioclase) which are products of shock metamorphism and which are found in meteorites, tektites and impactites, and at nuclear test sites. These materials will not be encountered on their own.

The *Sakato* or *Sakado Glass*, said to have fallen from the sky over Tokyo in 1910, has been identified as a glass-coated albite-quartz schist which had been greatly heated by a process that was never identified (Okashi, 1936). It is not classed with either the meteorites or the tektites and its formation is most probably related to human activity. It is amusing to note that this object "fell" at a time when there was great excitement relating to the return of Halley's Comet, that it was subsequently buried in the scientific literature and was only revived, and very briefly at that, when the first explorations of the space age commenced.

Schonite is reported as a unique glassy material from Sweden. Although it has made its way into the literature concerning tektites, it is probably man-made, possibly part of a bottle, and is of no interest in the field of gemmology. The unique specimen has, in any case, disappeared (Wiman, 1941 and Zenzén, 1940).

Fulgurites are small-diameter tubes of glassy rock formed as a result of lightning striking rock or sand. Some fulgurites formed by lightning striking a sand dune may be over five metres in length but the inner fused portion appears never to contain clear glass fragments much greater than 3 mm in thickness. The refractive index of this glass is around 1·46. Certain mountain peaks exhibit unusual clinker-like altered rocks that contain even smaller bits of glass and these may be due to multiple lightning strokes, ball lightning or other electrical phenomena. (Bruce, 1958 and Lacroix, 1942).

Obsidian is volcanic glass and is usually black, although red, green and brown varieties are known. These have minor gem uses as cabochons, faceted stones, and as "*Apache teardrops*". The dark colours, low refractive index and usually unattractive natural shapes make obsidian in small demand as a gem material. In a few deposits attractive shapes, not unlike tektites, are known. The term *Valverdite* was applied to one attractively shaped variety of Texas obsidian which had been mistaken for a tektite. Neither the term nor the material it referred to were properly defined and confusion and acrimony resulted (La Paz, 1948). *Pitchstone* is a volcanic glass with a pitchy rather than a glassy lustre.

Macusanite, formerly known as *americanite* or *amerikanite*, is a green-grey to nearly colourless variety of obsidian known from Macusani and Paucartambo in Peru, and probably also from the Philippines and perhaps from other localities in western South America. A red-brown variety is also known from a Peruvian

locality. A somewhat different obsidian exists near Popayan, Colombia. Macusanite is an unusual material, certainly facetable as a collector's stone, but with no attributes that would commend it to the trade.

Bruce (1958) gives analyses, refractive index, and specific gravity data for two types of "pseudo-tektites" from the Philippines which are reproduced in part below in a combined table with partial data from Barnes *et al.* (1970) for Macusani and Paucartambo. Barnes *et al.* state that the obsidian pebbles from near Popayan, Colombia, differ from Macusanite in chemical composition, absence of inclusions of high-alumina minerals and the general absence of the typical macusanite etched surface. It thus appears as though there are at least two, and probably three, four or five different unusual obsidians which have been reported in the literature. The term *obsidianite* which is sometimes encountered in the older literature as a synonym for tektites or other unusual glasses would appear to be a usable term in describing members of this poorly understood subgroup of igneous glasses.

TABLE 2

	Philippine "Pseudo-Tektites"		Macusanite from Peru	
	Type I	Type II	Macusani	Paucartambo
	(Bruce, 1958)		(Barnes *et al.*, 1970)	
S.G.	2·323–2·59	2·77–2·912	2·345–2·361	
R.I.	1·53	1·57–1·61	1·4831–1·4862	
SiO_2	73·56%	50·12%	70·67–72·8%	70·56%
Al_2O_3	14·11%	14·02%	16·12–16·93%	20·54%
Fe_2O_3	1·65%	5·85%	0·29–1·33%	—
FeO	1·18%	7·20%	0·30–0·6%	0·96%
MgO	0·55%	6·27%	0·00–0·19%	0·11%
CaO	1·33%	10·39%	0·16–2·07%	0·78%
K/Ar age			4·2 m.y.	

The reader is referred to the original references for more detailed data. Dr Charles W. Naeser, of the United States Geological Survey, has made nine fission-track age determinations of macusanite and gives a best estimate for the age of this material as 4·39 ± 0·07 million years.

Pele's Hair, a filamentous glass of volcanic origin, may be several metres long but almost never exceeds 0·1 millimetre in diameter.

"*Pit glass*" is a name applied to glass pebbles reported from the gem pits of Sri Lanka. Many specimens of pit glass are surely

manufactured objects which were salted in fields in order to enhance their value in the eyes of prospective fee miners. There are many reasons to believe that pit glass pebbles are man-made, but there are also several reasons to believe that some specimens may be natural, that the term "pit glass" is an uninformative catch-all term, and that more work should be carried out. Unfortunately, there seems to be no set of criteria to make the general distinction between natural and man-made glasses and it is doubtful that there will be until some more thought is given to just what materials can fall into the category of "natural glasses". For the moment, fission-track age dating is the most promising but fission-track dates on glasses can only give a minimum age date. Obsidians which have been collected from a desert environment show definite indications of annealing and therefore give a reduced age. Apparently hot sunny days can cause track annealing in glass and obsidians collected from underground give older ages than identical materials collected from outcrop. (C. W. Naeser, personal communication, October 1975). Heating, possibly even heating in the course of cutting and polishing, would cause a reduction in track density and apparent age.

Information is given on pages 198-199 (Table 3) in a consolidated form on seventeen specimens of pit glass which have been reported in the literature or obtained by one of us (J.M.S.). The information is confusing and to some extent internally contradictory but it should be appreciated that glasses, whether man-made or natural, may exhibit a great range in properties. All the specimens listed were gemmy or described as gemmy.

An uncertain reference to a pit glass specimen with a specific gravity of 2·34 also exists. It is possibly significant that some of the colours of stones listed in Table 3 are very unattractive and would do little to attract a gem digger unless he made the assumption that the unattractive stones and the marketable colours would be found together. Specimens W5 and W6 have an indicated melting point of 1500–1600°C, higher than that of normal man-made glass.

Geological Setting:—In an appendix to an article entitled "Aspects of the fauna of Ceylon", Dr P. E. P. Deraniyagala, a highly respected scientist, reports:" It is probable that natural glass which is proof of former volcanic activity occurs in Ceylon. Sinhala gem miners recognize seven varieties of Ceylon's natural glass which they term *Bim viduru* = earth-glass. Their colors may be either dull red, yellow, light green, faint green, dark blue or luminous cornflower

TABLE 3

"PIT GLASS" SRI LANKA

Specimen Number	S.G.	R.I.	Wt grams*	Colour	Bubbles	Additional data and comments
W1	2·459	1·511	(0·524)	pale turquoise blue	One large and some very small	1·83% K_2O, 10·06% Na_2O. No strain birefringence. No absorption spectrum with direct vision hand spectroscope. Greenish glow under long wavelength UV. Very weak greenish glow under short wavelength UV. Bright green under x-ray.
W2	2·570	1·533	(0·651)	dark green	None seen	1·70% K_2O, 7·20% Na_2O. No strain birefringence. No absorption spectrum with direct vision hand spectroscope. Dull orange under long wavelength UV. Very weak orange under short wavelength UV. Weak misty glow under x-ray. No fission-tracks after 5 sec. and 10 sec. exposures to 40% HF.
W3	2·664	1·567	(0·466)	pale green	scattered small spherical	1·79% K_2O, 3·00% Na_2O. No strain birefringence. No absorption spectrum with direct vision hand spectroscope. Reaction to UV and x-ray identical to specimen W2 but slightly less weak with short wavelength UV.
W4	2·695	1·569	(0·609)	green	scattered spherical and ellipsoidal	0·43% K_2O, 4·94% Na_2O. Other observations identical to those made on specimen W3.
B1	2·735+	1·5751 –	(0·785)	dark olive green	absent or very small	Cut stone. H = 5½.

*Figures in brackets are for incomplete specimens.

Specimen Number	S.G.	R.I.	Wt grams*	Colour	Bubbles	Additional data and comments
B2	2·746	1·585	(0·821)	dark olive green	absent or very small	Cut stone. H = 5½.
W5	2·61			green		(One of these specimens was the one with a liquidus at 1260–1280°C. Both specimens are rough pebbles.
W6	2·817			green		
P1			7·9	green	several scattered	1·20% K_2O, 5·50% Na_2O. No fission-tracks after 1 sec. and 5 sec. exposures to 40% HF. Rounded pebble.
P2			20–40	bright blue	One very large; probably others also	Rounded pebble. Colour said not to be due to cobalt.
P3				light green	scattered and small	Incomplete pebble with abraded surface. No fission-tracks after 2 sec., 5 sec. and 10 sec. exposures to 40% HF.
P4				very pale green		Almost colourless incomplete (?) pebble.
P5	2·6	1·54	(0·905)	olive brown	none	Cut stone. Exhibits some streaks or spicules.
P6				greenish	scattered and small	Pebble.
P7				greenish	scattered and small	Pebble.
AM1				blue		Blue beads recognized by K. Parkinson as identical to specimen P2. Anuradhapura Museum label indicates provenance from a dagoba with 2000 + years before present date.
AM2				green		Green beads in Anuradhapura Museum. Doubtful if pit glass.

*Figures in brackets are for incomplete specimens.

blue. It occurs in the gem sand at about 15 feet below the surface and in association with fossils of extinct mammals of late middle Pleistocene and upper Pleistocene age. This glass contains spheroid gas vesicles and spicule-like structures. All are more or less transparent when fractured. Four specimens, two of which were considered to be natural glass and one a tektite by me were secured from gem miners. . . ." (Deraniyagala, 1965).

Dr Deraniyagala informed one of us (J.M.S.) that the supposed tektite was in fact an agate and so it is difficult to know just what weight to place on the rest of his statement which may in fact refer to information that reached him second or third hand.

Pit glass is referred to by Smith (1913) but was not mentioned in recent editions of the same work. Church (1924) makes a brief reference to the rolled glass pebbles from Ceylon to strengthen his opinion that moldavites are natural in origin! Webster (1962) expands somewhat on Church's comments and concludes that the question is unresolved. Vorobiev (1965) refers to a dark green glass found in matrix in Ceylon which was discarded by either the miners or the lapidary. Other tangential references to pit glass exist. Deraniyagala in a 1958 publication referred to a strongly water-worn paleolithic pebble artifact from the gem gravel forming part of the Ratnapura Phase II. A gemmologist who examined this specimen through a display case was convinced that it was in fact an object made of glass. Dr S. Cavenago-Bignami Moneta, author of the encyclopedic "Gemmologia", has mentioned in a discussion of pit glass that she has seen a red specimen, apparently similar in nature, in an Indonesian museum.

Pit glass specimens W1, W3 and W4 have been dated by the fission track method by Dr Charles W. Naeser and no tracks were found. This indicates a very young age, and a man-made origin seems likely.

East African Glass, in several varieties, has been brought into Nairobi by African prospectors from the bush. All specimens obtained were massive chunks in attractive shades of bright blue or bright green. A pale yellow-brown variety with long, hair-like inclusions was seen on several occasions but not obtained from the prospectors. Many of the bright-coloured specimens exhibited fractures which contained a white powdery substance which was moist to the touch when the glass was broken open, but which dried within seconds. The SiO_2 contents of these glasses as determined by

Dr T. Bunch fall into two groups clustered around 56% and 67%, indicating that at least two different types of material are probably present. These glasses are stated to come from both Kenya and Tanzania and are often stated to come from areas rich in marble but not far from recent volcanic centres. The glasses might be man-made, or volcanic, or possibly some sort of immiscibility product at the contact between a marble and a lava. If this glass, or these glasses, proved to be natural, they would certainly be of interest to both hobbyists and commercial gemstone traders, with their low refractive index and relative softness being amply compensated for by their very bright and attractive colours.

An interesting parallel can be suggested between the East African glasses and the pit glass of Sri Lanka. The general geology of the gem areas in Sri Lanka and those of Kenya/Tanzania is extremely similar, with the major geological difference being that the gem area in Sri Lanka is peneplaned and weathered to a much greater depth. As a consequence, the gems in Sri Lanka appear as rounded pebbles as a constituent of gravels. In East Africa the gemstones are usually known from a host rock, which may or may not have an alluvial deposit associated with it. Since the glasses in Sri Lanka appear as pebbles and those in Kenya and Tanzania as massive chunks, we can at least note that there is a certain consistency with the weathering histories of the two areas.

Seven samples of various East African glasses were selected by Dr Charles W. Naeser for fission-track dating. Three showed no tracks and are therefore of very recent age and four specimens could not be dated because of their extreme solubility and very low etching efficiencies. Natural glasses have not been reported with such characteristics and a man-made origin does seem likely. The young age and unusual chemistry are, however, also consistent with a natural origin at the contact between a marble and a recent lava. Recent lavas are numerous in the areas in question.

Malawi Glass is a glass obtained under similar circumstances to the East African glass. It is a totally different material however, almost colourless, full of bubbles and with a SiO_2 content ranging as high as 93% (partial analysis by Dr T. Bunch). Dr C. W. Naeser's fission-track work also covered one specimen of Malawi glass which was of very recent age and most probably man-made.

Specimen of *Glass from South West Africa:* This interesting glass is represented by a single specimen which weighed about a

hundred grams. It was picked up off the surface by a knowledgeable mineral collector (Jerry Rossouw, of Florida, Transvaal) several decades ago, before much industry, aside from mining, had come to the area. The locality of the find was "100 miles north of Uppington", an area far from any known volcanism. The material is an attractive brown, much like the darkest of smoky quartzes. A light dirt-brown weathering crust, a fraction of a millimetre in thickness, covered the specimen and, although it was angular, it presented no edges sharp enough to cut a person handling it. A shard of this glass was tested by heating with a blowtorch but it melted without evolving any gases; in this respect the specimen behaved like a tektite rather than like a man-made glass or an obsidian. The material, however, has no other tektite-like features. Work is continuing on this specimen which does not seem to fall in the same class as any of the glasses enumerated above. If a natural supply of this material came on the gem market it would be traded commercially, but not at high prices.

Fission-track dating by Dr C. W. Naeser on a fragment of the glass from South West Africa gave an age of 4·1 million years, with a standard deviation of $\pm 0{\cdot}6$ million years. This specimen with its date is not relatable to any geological formation or geological event indicated on the 1963 Geological Map of South West Africa.

A purist might want to consider the glass which can be generated from the burning of a haystack as a potentially natural substance if the hay was set afire by lightning. Such material is normally slaglike in nature but smoky-grey and brownish pieces have been faceted. Glassy materials may also have their origins from the burning of termite nests, bamboo thickets, forests, underground coal seams, etc. and it is possible that some of these fires could be natural in origin.

An object was reported to have fallen from the sky over Igast, Estonia, in 1855 which may have been of a glassy or, more likely, a slaggy nature. Very little can be said about it inasmuch as there was a mix-up amongst different specimens or perhaps a mislabelling at an early date and various studies reportedly made on this object were evidently carried out on totally different materials. An informal study of the Igast object carried out by O'Keefe and Lowman led to the suggestion that museum collections of "pseudometeorites" might shed light on the tektite problem. The present authors would like to conclude with the suggestion that readers of

this article with access to museum collections around the world might be able to find glassy objects which can throw some light on the nature of some of the poorly understood glassy materials mentioned in our review.

The authors are grateful to William A. Cassidy, P. E. P. Deraniyagala, L. J. D. Fernando, Kenneth Parkinson, John B. Southard and the late Robert Webster for useful correspondence and discussion. We are additionally indebted to Mr Parkinson and Mr Webster for the generous donation of their specimens. Paul Pellas was kind enough to etch the pit glass specimens for us and we are particularly indebted to Theodore E. Bunch who determined the silica content of several of the glasses. Charles W. Naeser added much to our review by his active interest in the subject and his determination of the fission-track ages of several of the less well-known glasses. We are very grateful to him for his work and for permission to use his results freely. We thank Ruth L. Saul for a meticulous job of proof-reading and editing.

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PROSOPITE, AN EFFECTIVE TURQUOISE SUBSTITUTE

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Introduction

Prosopite, a calcium aluminium hydroxide fluoride, is not often thought of as a gem material, inasmuch as it is an uncommon mineral, usually occurring in a light grey colour, and with no distinctive properties to give it any gemmological status.

Blue prosopite, however, has been found associated with azurite near Santa Rosa, Zacatecas, Mexico, and a preliminary report on this material was made by Liddicoat and Fryer (1974). A similar prosopite, but more greenish in colour, was discovered in 1895 in the Dugway mining district, Torvel County, Utah, and was described by Hillebrand (1899). Hillebrand's analysis indicated the presence of 0·17% Cu and the bluish-green colour of this Utah prosopite may have been due to this small amount of copper.

The intimate association of the Santa Rosa prosopite with azurite prompted a detailed chemical investigation of this material to ascertain if there was copper present which might explain the beautiful turquoise-blue colour of the material. Also, since hydroxyl and fluorine substitute mutually in many minerals, it was also desirable to examine the material in light of the possibility of the existence of a hydroxyl analogue of prosopite. The association with azurite, $Cu_3(CO_3)_2(OH)_2$, also suggested this possibility.

Physical Properties

Inasmuch as the density of prosopite ($\sim$2·88) is very close to the higher limits of turquoise's variable density (2·6–2·8), routine specific gravity measurements are not alone sufficient for the detection of prosopite. The density of Santa Rosa prosopite varied from 2·69 to 2·85. Prosopite (H = 4½) is slightly softer than turquoise (H = 5–6), but the difference is not too useful in gemmological testing.

Refractive index determinations, even though the gemmologist may use the distant-vision method on this opaque material, remain

TABLE I

ANALYSES OF PROSOPITE

	Ca	Al	F	H_2O	Mg	Cu	Na_2O	Y_2O_3	O	Total	Remarks
Theoretical	16·84	22·66	31·92	15·14					13·44	100·00	F:OH = 1:1
Santa Rosa, Zacatecas, Mexico**	15·37	20·65	30·16	16·78*	tr	1·39	tr	0·00			Partial analysis
Dugway district, Torvel County, Utah Hillebrand (1899)	16·85	22·74	29·95	16·12		0·17			14·34	100·17	Recalculated analysis
St. Peter's Dome, Colorado Cross & Hillebrand (1885)	17·28	22·02	33·18	13·46	0·17		0·48		13·41	100·00	Mean analysis

*Average of two analyses for H_2O of 16·88% and 16·69%.

**Partial microprobe analysis; average of four closely agreeing analyses.
Accuracy of data—±2% of the amount present.
Copper content is an approximation.

the most reliable gemmological detection method. The mean refractive index for prosopite is ~1·50, and for turquoise the mean index is ~1·62.

X-ray Diffraction

X-ray powder patterns were obtained, using Cu Kα x-radiation and Gandolfi powder cameras, of three samples of the Santa Rosa prosopite, which were all identical and also identical with those of prosopite from the Eureka Tunnel, St Peter's Dome, El Paso County, Colorado, and the Dugway, Utah, material described by Hillebrand (1899). There was no noticeable difference in the cell-edge of these prosopites, as revealed by x-ray powder patterns.

Chemistry

The Santa Rosa prosopite was analysed with an ARL-SEMQ electron microprobe utilizing an operating voltage of 15kV and a sample current of 0·15 μA. Standards used included the Colorado prosopite and pachnolite described and analysed by Cross and Hillebrand (1885), and other NMNH microprobe standards of high reliability. Total water was determined using the standard Penfield method by Miss Julie Norberg, of the Chemical Laboratory, Department of Mineral Sciences, Smithsonian Institution, Washington, D.C.

A partial microprobe analysis for the Santa Rosa prosopite is given in Table I, together with analyses of the bluish-green Utah prosopite, and the Colorado prosopite used as a standard in this work. The Santa Rosa analysis is an average of four closely agreeing analyses.

The Santa Rosa material is lower in calcium than the other cited analyses, and higher in total H_2O. The anticipated low fluorine content of this prosopite was not confirmed, and the mineral has a "normal" amount of fluorine. Copper was present in small amounts and the given figure of 1·39% CuO is an approximation. The copper may be responsible for the coloration of the material. Yttrium, previously noted as a possible constituent, is absent.

In summary, blue prosopite from Santa Rosa is an effective turquoise substitute and a very attractive, uniformly coloured gem material. No significant compositional variations were observed, and the material appears to be a rather normal prosopite. The original designation of the name prosopite was from the Greek for

"mask" in allusion to its deceptive character. Although its use as a turquoise substitute could not have been foreseen, the name is still quite fully appropriate!

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THE "BLACK PEARL" OF GUYANA

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DURING 1973 the author was privileged to be asked to set up a lapidary workshop in South America and train a substantial number of students in Georgetown, Guyana, under a British Government Technical Assistance project. During the field surveys for the collection of suitable rough specimens for cutting and polishing, a number of interesting new materials were brought to light.

One of these was the "Black Pearl of Guyana." The origin of the name has not been discovered, but it is reported that when the first European explorers came to Guyana they were met by Amerindians wearing black stones around their necks. The Indians believed that each stone had an individual shape which contained its own spirit. Thus a stone with the shape of a bird contained the spirit and power of a bird—a stone the shape of a reptile contained the spirit, wisdom and power of a reptile—the stone which resembled the male genitalia possessed the power of bestowing virility on the one who was fortunate enough to possess such a stone!

One of the areas in which these stones are found is Aranka, one of the richest of the old gold-fields of the former British Guiana, and for this reason it was selected in 1963 for a copper—lead—zinc prospecting programme. Some fifty square miles were covered by the preliminary sediment-sampling programme, in the course of which a few rounded pieces of "Black Pearl" were picked up in the concentrates of Consolation Creek, a branch of the Aranka River, some four miles from its junction with the Cuyuni River.

Aranka may be reached from Bartica by a powered boat in about three to four days, but on our visit we used a small amphibious aircraft and then cut our way into the jungle for about two to three miles. At this point and as far as Consolation Creek to the north, rounded nodules of "Black Pearl" (2 mm—20 mm) are found embedded in a light yellowish clay along with subangular quartz pebbles. These "pearls" are more abundant on the gently sloping banks of the creeks but are more concentrated at the heads of the smaller creeks. It would appear that these nodules are only found to a depth of some fourteen inches from the surface, although some large fragments of quartz partly encrusted with limonite were found

at a lower level. The method of extraction is to dig out the yellowish clay containing the "pearls" and place it on a set of Brazilian sieves and wash out the clay. My companion, S. W. Nerine, and I found the extraction and washing comparatively easy, but carrying all the raw material back to the aircraft seemed far more exhausting, as we had to surmount a number of natural hazards in the jungle.

Polished sections (Fig. 1), for which I am indebted to E. A. Jobbins, of the Institute of Geological Sciences, reveal concentric bands of limonite around a nucleus of clayey material. It has been suggested that these concretionary nodules of limonite (or more precisely goethite FeO(OH)) are formed as a result of changes of the water table during the heavy rainy seasons and shrinkage cracks are also prominent. When this material was tested, it was found that the hardness varied between 5 and 6 according to the composition of the nucleus. Likewise the specific gravity was found to vary between 2·64 and 3·52; the polished surface appeared to be a very dark brown (Fig. 2), but on scratching, the streak was orange-yellow.

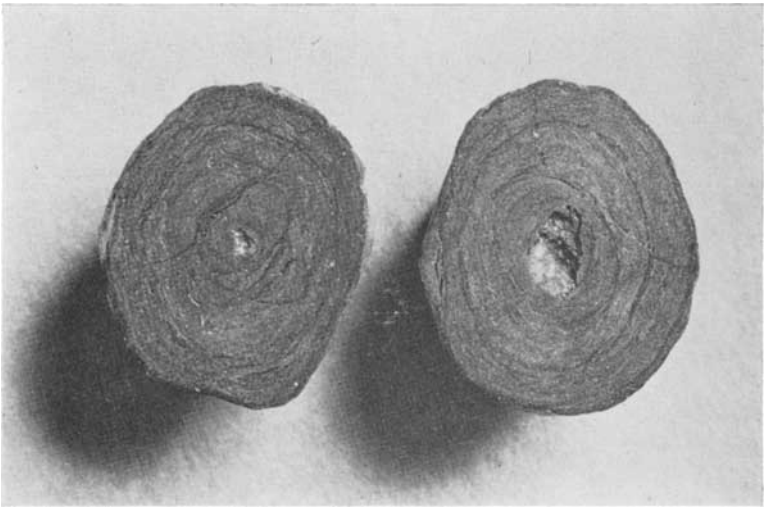

Institute of Geological Sciences Photo.

FIG. 1. Sections of "Black Pearl" concretions showing concentric layered structure and hollow centres originally filled with clayey material.

Institute of Geological Sciences Photo.

FIG. 2. "Black Pearls of Guyana" showing 'raw' concretions and partly polished, polished and sectioned examples.

Thus we have a new material that should give our more *avant-garde* jewellery designers a fresh source of inspiration. Although not a true black pearl, of course, it appears an attractive lustrous black when polished, but the difficulty of obtaining good specimens means that this material is not likely to become plentiful for some time.

When "Black Pearls" were first discovered, a few were polished and the resulting "pearls" with their black lustre looked so attractive that it was suggested to the Prime Minister of Guyana, who was about to embark on a tour of the East African countries, that some should be mounted on pendants, ear-rings, tie clips etc. and presented to the heads of the African countries he visited. After this a small commercial enterprise was set up to supply items of jewellery for sale in Georgetown.

[*Manuscript received 4th September, 1975.*]

Gemmological Abstracts

AKIZUKI (M.). *Gemstones with optical effect: pt. 2.* Journal of the Gemmological Society of Japan, 1976, 3, 1, 3–13. (In Japanese).

The phenomenon of schiller in feldspar is examined and attributed to the dispersion of light from the lamellar texture. Where the dispersion is strong the colour is reddish and where it is weak the colour is more inclined to blue. Electron micrography has been used to examine thin plates of moonstone. M.O'D.

ANDERSEN (H.). *A study of Gilson synthetic lapis lazuli.* Lapidary Journal, 1976, 30, 1, 412–413.

The colour is very dark blue and close to that of the best quality natural material and the supposed pyrite inclusions may be scratched with a needle. The S.G. at 2·38 is closer to that of sodalite and an x-ray diffraction test showed the presence of a quantity of amorphous material. M.O'D.

BROUGHTON (P. L.). *Robin's Buchanan thundereggs, a new Oregon mining venture.* Rocks & Min., 1975, 50, 75–79. 6 figs.

"Thunder-egg" agates occur in a rhyolitic flow that crops out along the east side of the Harney Basin near Buchanan, Harney County, Oregon. The specimens usually weigh 1–80 lbs, although some weigh several hundred pounds. Hollow specimens are lined with quartz crystals. Those which are solid are filled with agate (black, blue, white, brown) and opal (yellow to blue) in banded, swirl, and brecciated patterns. Cinnabar and manganese oxide stains are in some of the specimens. The site is described in detail. R.S.M.

CASSEDANNE (J. P.) and (J. O.). *Quelques gîtes d'améthyste à l'ouest de Vitoria da Conquista (Brésil).* (Some sources of amethyst to the west of Vitoria da Conquista, Brazil.) Revue de Gemmologie, 1976, 47, 6–9.

The area described lies in the state of Bahia and contains the mines Fazenda Joanina, Coruja, Baixinha and Montezuma. Typical crystals from these mines are illustrated; in general those from Montezuma make the best gems, most production from the other mines being pale in colour. M.O'D.

CHERMETTE (A.). *L'améthyste d'Auvergne.* (Amethyst from Auvergne.) Revue de Gemmologie, 1976, 47, 2–5.

Amethyst from this region has been known since Roman times, although production only got under way in 1860–70. The area in question lies in the south of the Département of Puy-de-Dôme and forms part of the Livradois mountains. These are granitic formations in which the amethyst veins may attain several metres in length. The colour is normally inhomogeneous and is best in small stones. M.O'D.

CROWNINGSHIELD (R.). *Developments and highlights at GIA's Lab in New York.* Gems and Gemology, 1975, XV, 3, 89–94. 13 illus.

Flux-grown synthetic rubies cut in Thailand are described. A quench-crackled Verneuil synthetic ruby with a heavily scratched pavilion looked natural. Another showing curved striae running "in opposite directions from the centre of the stone" is described but not clearly illustrated. Bubble-like negative crystals in a natural sapphire are illustrated; healed crack feathers in the same stone confirm it as natural beyond doubt. A light brownish-orange gem with R.I. 1·755–1·763 proved to be a low reading (!) synthetic corundum; while a melon-cut (ribbed oval cabochon) "chalcedony" proved to be a Ceylon sapphire. Green enamel baked onto pale green beryl crystals is reported sold as "uncut emerald". A sky-blue YAG with a cobalt-like spectrum is reported with the comment that few coloured YAGs are seen. Cat's-eye and faceted vanadium green kornerupine from Kenya and a brown kornerupine cat's-eye from Ceylon are reported. Prosopite resembling turquoise is described with R.I. 1·51, S.G. 2·65 and no absorption spectrum. It appears to be absorbant since it became mottled during testing. A suspect deep red "cuprite" proved to be an almandite (almandine) garnet which had been sputtered with a metallic coating. R.K.M.

CROWNINGSH.ELD (R.). *Developments and highlights at GIA's Lab in New York* Gems and Gemology, XV, 4, 123–127. 12 illus.

Diamonds with interesting inclusions are again described. One with an "insect-like" cloud; another with two included octahedra, one with trigons to be seen on its faces; a third with green (chrome enstatite or diopside) and brown (garnet) crystals in the same stone. Yet another diamond was found to have seventeen laser holes (drilled to reduce the effect of natural inclusions)—scarcely worth the expense, since in addition to the multiple reflections of the natural inclusions the stone now has 17 white drill holes to reflect around it. A large blue diamond proved to be non-conductive and had a Cape spectrum. It was a painted stone. Gadolinium gallium oxide (the garnet-structured synthetic GGG) is said to be perhaps the most convincing diamond imitation yet marketed. Although brownish in colour and inclined to darken under UV exposure, this is already appearing fraudulently. An instance where a setter damaged a GGG in the belief it was diamond and capable of withstanding heavy pressure is cited and illustrated. Hexagonal colour patches and porosity in Gilson synthetic opal are mentioned with the comment that the porosity would render the material unsuitable for use in jewellery. The writer recognizes that this fault may be confined to one particular run or batch of stones. Flux-grown rubies were found which looked very natural but showed the characteristic seed crystal and bluish separation layer on closer examination. Colour generally was dark red and oversaturated. One instance of apparent fraudulent use is cited. (The stone was in "an old platinum lady's" ring; which conjures up an amusing picture!) R.K.M.

DUNN (P. J.). *On gem orthopyroxenes.* Gems and Gemology, 1975, XV, 4, 118–122.

An investigation of stones sold as "hypersthene" establishes that this gem is more correctly named bronzite. Their relationship to the enstatite-hypersthene isomorphous group is discussed in detail. R.K.M.

EULITZ (W. R.). *The variable effects of faceted gemstones.* Gems and Gemology, XV, 4, 98–112. 9 diagrams.

In some ways a sequel to Harding's paper in the previous issue, this examines the theory and facts behind the complex matters of brilliance, reflection and dispersion in a multifacet gem exhaustively and in depth. Diagrams are complex and lack clarity for the less erudite reader. The usefulness of this dissertation to either the ordinary cutter or gemmologist is questionable. R.K.M.

FESQ (H. W.), BIDDY (D. M.), ERASMUS (C. S.), KABLE (E. J. D.) and SELLSCHOP (J. P. F.). *A comparative trace element study of diamonds from Premier, Finsch and Jagersfontein mines, South Africa.* Physics and Chemistry of the Earth, 1975, 9, 817–836. 7 figs.

Neutron activation studies of the trace elements in 1500 diamonds from these three kimberlite sources provide evidence for the presence of sub-microscopic inclusions of a quenched or temperature-re-equilibrated melt from which these diamonds crystallized. These micro-inclusions of parental magma contain variable amounts of H_2O-CO_2-rich fluids and Fe-Ni-Cu-Co sulphides in addition to a major silicate phase which is relatively constant in composition irrespective of the source of the diamonds and the age of emplacement of their host kimberlite. R.A.H.

HARDING (B. L.). *Faceting limits.* Gems and Gemology, 1975, XV, 3, 78–87.

An exhaustive and complex attempt to define optimum angles and proportions for gem faceting and to grade other angles according to their effectiveness. The text is backed up by 24 graphs of some complexity. R.K.M.

HARRIS (J. W.), HAWTHORNE (J. B. X.), OOSTERVELD (M. M.) and WEHMEYER (E.). *A classification scheme for diamond and a comparative study of South African diamond characteristics.* Physics and Chemistry of the Earth, 1975, 9, 765–783. 5 figs.

A diamond classification system based on the physical features of uncut diamond as a function of size is described; crystal form, crystal angularity, and crystal regularity determine the major divisions, but transparency, colour, number of inclusions, and surface features allow further subdivision. The system has been used to define uniquely samples of diamonds from three kimberlite diatremes, Premier, Finsch, and Koffyfontein, and an alluvial source, Dreyers Pan, based on a study of over 68000 crystals. For the kimberlite sources, variations in crystal shape versus size are considered in terms of a primary crystal population of octahedra and twinned crystals (macles) subsequently altered by secondary processes in the kimberlite magma. Variations in colour are discussed in terms of aggregation of nitrogen into platelets in the crystal lattice as the diamond grew. Characteristic features of the Dreyers Pan alluvial diamonds give indications of the nature of the original source from which these diamonds were derived. R.A.H.

HIROSE (M.). *Early stage of Verneuil method.* Journal of the Gemmological Society of Japan, 1976, 3, 1, 17–24. (In Japanese).

The flame-fusion method perfected by Verneuil is traced through its applications in Europe, the U.S.A. and Japan. Plants in the U.S.A. are reported to have virtually ceased production. M.O'D.

HURLBUT (C. S.). *A device for obtaining interference figures for gemstones.* Gems and Gemology, 1975, XV, 3, 66–71. 5 illus.

Describes a simple "crystal orienter" which allows rotation of a cut gem about two axes mutually at right angles and discusses its use with convergent polarized light to obtain interference figures. R.K.M.

JENSEN (D. E.). *Minerals and gem materials from New York State.* Lapidary Journal, 1976, 30, 1, 82–94. Illus. in colour.

Reviewed are Herkimer diamonds (rock crystal), fluorite, rose quartz, celestine, diopside from Dekalb, and a chatoyant labradorite. M.O'D.

KHORASSANI (A.) and ABEDINI (M.). *A new study of turquoise from Iran.* Min. Mag., 1976, 40, 640–642. 1 fig.

Four new chemical analyses are given for sky-blue and apple-green turquoise from the classical localities of Nishapur and Damghan, north-east Iran. The finest sky blue turquoise is lowest in iron. DTA results are given and IR spectra are figured for unheated material and for material after heating to 400 and 800°C. The latter sample gave the x-ray pattern of phosphocristobalite. R.A.H.

LIDDICOAT (R. T.). *Developments and highlights at GIA's Lab in Los Angeles.* Gems and Gemology, 1975, XV, 3, 72–77. 17 illus.

A brown cyclotron-treated diamond looked natural, but sharp colour zones showed that it had been treated unusually from one side only with light-weight particles which had penetrated only fractionally. An attractively coloured emerald showed sharp zoning with zig-zag margins to colourless areas visible from the pavilion direction. An extraordinary "ravelled thread" cloud inclusion in topaz is illustrated without giving colour of the stone. A faceted semi-transparent grey jadeite, a carved marble "sword" or knife and a moldavite are briefly described and illustrated. Rhombohedrally oriented two-phase channels seen in a natural amethyst are likened to inclusions seen in flux-grown synthetic material (without indicating which synthetic). White "cottony" inclusions outlined a Maltese Cross shape in a dark green nuclear treated diamond. A white acicular inclusion sprouting from a square cluster of sugary inclusions in a colourless diamond is described and illustrated (no magnification quoted). A dark brown baroque "gem" proved to be limonite. R.K.M.

LIDDICOAT (R. T.). *Developments and highlights at GIA's Lab in Los Angeles.* Gems and Gemology, 1975, XV, 4, 113–117. 11 illus.

A somewhat gruesome testing of blue tesserae overlaid on the front half of a human skull showed them to be plastic (type?). A "two-phase" inclusion in

diamond (liquid with bubble) was shown to be a natural cavity which was open to the surface of the stone in which liquid had become trapped fortuitously. A needle- or graver-like inclusion and another shaped like a horse's head were also seen in diamonds and illustrated. Opal cemented to irregular surfaced iron-stone to simulate boulder opal is also depicted. Heavily banded and speckled grey-green material used in a carving of a horse and foal looked like aventurine or quartzite but proved to be nephrite. R.K.M.

MacFall (R. P.). *Wyoming jade.* Lapidary Journal, 1976, 30, 1, 182–193.

A history of the discovery and exploitation of the various Wyoming jade fields. All the occurrences are of nephrite, though unconfirmed reports suggest that jadeite might be available in one or two places. Most of the nephrite originated in the Granite Mountains area. The best colours are an apple green and a black, though most of the material recovered is a darker olive-green. A bibliography concludes the article. M.O'D.

Meyer (H. O. A.) and Svisero (D. P.). *Mineral inclusions in Brazilian diamonds.* Physics and Chemistry of the Earth, 1975, 9, 785–795. 3 figs.

Microprobe analyses are reported for olivine (5), enstatite (5), garnet (8), rutile (2), ilmenite (3), zircon (1), and pyrrhotite (2) found as inclusions in diamonds from several localities in Brazil; this is the first record of ilmenite and zircon in natural diamond. The ilmenite differs from that of most kimberlites in that it contains no appreciable Mg. R.A.H.

Nassau (K.). *Synthetic emerald: the confusing history and the current technologies. Part 1.* Lapidary Journal, 1976, 30, 1, 196–202.

In the past there has been confusion between the flux growth and the hydrothermal methods of growing synthetic emeralds. A number of early products, once ascribed to the hydrothermal method, are in fact flux-growth pieces. Those emeralds made by Nacken are an example; examination of the specimens and of the literature proves that his emeralds are made with a lithium molybdate or potassium vanadate flux and that the lack of indications of water in the infrared spectrum shows their true origin. Much of the confusion springs from a misreading of a post-war intelligence report dealing with the German crystal growth industry. A table summarizes the various growth methods and the workers concerned, and there is a bibliography. The article will be continued in a later issue. M.O'D.

Poirot (J.-P.). *Amblygonite ou montebrasite?* (Amblygonite or montebrasite?). Revue de Gemmologie, 1976, 40, 12–13.

A faceted stone of about 5 ct was submitted to the Paris laboratory for identification. The following features were observed: R.I. n_m 1·625; n_p 1·615–1·618; n_o 1·642–1·645: D.R. 0·024–0·030. Biaxial positive. Dichroism in two shades of yellow; no perceptible absorption spectrum; no fluorescence under either form of ultraviolet light, but a slight greenish-blue fluorescence under x-rays. S.G. 3·0. H. 5½–6. Two-phase inclusions and indications of perfect cleavage could be seen. These constants agree with those published for amblygonite. However, montebrasite from Creuse, France, with similar constants, is biaxial negative. Tables

give relative constants for amblygonite from Utö, Sweden, montebrasite from Karibib, South Africa, and montebrasite from Kimito, Finland. Optic axial angle alters with change in hydroxyl content. M.O'D.

PRINZ (M.), MANSON (D. V.), HLAVA (P. F.) and KEIL (K.). *Inclusions in diamonds: garnet lherzolite and eclogite assemblages.* Physics and Chemistry of the Earth, 1975, 9, 797–815. 2 figs.

Inclusions from 29 diamonds, mainly African, were studied with the aid of electron microprobe analyses of garnet (15), calcic pyroxene (11), Ca-poor pyroxene (4), olivine (6), magnetite (6), rutile (2), chromite, kyanite, hornblende, actinolite, phlogopite, muscovite, sanidine, pentlandite, and chalcopyrite. Those interpreted as syngenetic with diamond (e.g. garnet, pyroxene, olivine) frequently have crystal faces related to the diamond rather than to their own structure and are termed xenohedral. Ten diamonds contain minerals comparable to those in garnet lherzolite assemblages and 15 diamonds have minerals comparable to those in eclogites enclosed in kimberlites. In the garnet lherzolite suite, subcalcic diopside assemblages may have formed in the sheared lherzolite zone at 1200–1400°C, and re-equilibrated in the granular lherzolite zone at 1000°C, of the upper mantle. Three of the clinopyroxene inclusions analysed are omphacite unusually rich in K_2O (0·62–0·87%). The presence of kyanite is the first record of this eclogite mineral in diamond. R.A.H.

ZIEGLER (M.). *Sunstones—out where the desert sparkles.* Rocks & Min., 1975, 50, 59.

Clear to pink and green plagioclase phenocrysts ("sunstone") occur in lava north of Plush, Oregon. These shiny crystals, less than an inch across, are used as gems. R.S.M.

BOOK REVIEWS

ACCORD (W. J. and J. P.). *Main Trails to Maine minerals.* Revised. Published from RFD 2, Litchfield, Maine, U.S.A. Undated and unpaginated. Price on application.

A typewritten guide with freehand sketches of some of the more important Maine mineral collecting areas. M.O'D.

BOND (W. L.). *Crystal technology.* John Wiley & Sons, New York, 1976. pp. xi, 342. Price on application.

Although this book is intended to show how to cut plates from crystals for electric and electronic use, there is a large amount of information on allied topics such as crystal growth and symmetry. Particularly useful are the sections on etching and polarization of light. M.O'D.

ELWELL (D.) and SCHEEL (H.-J.). *Crystal growth from high-temperature solutions.* Academic Press, London, 1975. pp. xi, 634. £19·80.

This is altogether an exceptional book. No previous work has brought together so large an amount of information on crystal growth theory and techniques and there is in fact no monograph solely devoted to the growth of crystals from molten salt and metallic solutions. Each individual chapter has its own very extensive bibliography, and there is a general index. Although a certain acquaintance with crystal growth concepts is assumed, there is no reason why the educated gemmologist should not attempt this book. Those engaged on actual growth will find complete reviews of experimental techniques and those dealing with synthetic gemstones will find (at last) correct versions of the apparatus and methods of flux growth so frequently and inadequately covered by the average gemmology textbook. Although some previous knowledge is assumed, this does not need to be exhaustive, since such basic topics as dislocations are mentioned and illustrated. Especially valuable is the chapter on characterization (the full description of a material based on the widest possible variety of appraisal techniques). These include chemical analysis, coulometry, polarography, optical emission spectrography, atomic absorption spectrometry, x-ray fluorescence analysis and electron probe microanalysis. Each of these methods is briefly described. Diagrams illustrating theoretical points and growth apparatus are to be found in profusion and the photographs are of very high quality. The final chapter lists all the materials so far known to have been grown from high-temperature solutions with references to the literature in each case. Earlier tabulations by Laurent (1969), Wanklyn (1974) and Wilke (1973) are included. M.O'D.

FARMER (V. C.), ed. *The infrared spectra of minerals.* Mineralogical Society, London, 1974. pp. x, 539. Price to non-members of the Society, £16·00.

The first chapters of this large and important book describe the theoretical aspects and instrumentation of infrared and Raman spectroscopy. They are followed by chapters covering different mineral groups in which are described the various effects observable in the infrared range. Later chapters include such topics as cements and glasses. Each chapter includes its own bibliography and there is cross-referencing between chapters. One of the most important features of infrared spectroscopy is its ability to reveal the presence of water and this subject may be studied exhaustively here. Approximately 100 pages are devoted to the silicates and there are interesting points made on the presence of water in beryl and cordierite. There is an adequate index; the binding is a little flimsy for so large a book and one could wish that it had been taped to the text. M.O'D.

PATCH (Susanne Steinem). *Blue mystery: the story of the Hope diamond.* Smithsonian Institution Press, Washington, D.C., 1976. pp. 64. Illustrated in black-and-white and in colour. Price on application.

An excellent short guide which explodes some of the less reputable stories about this celebrated stone and gives as much as is known about its provenance, which is well worked out. The stone was tested free from its setting in November 1975, when it was found to weigh 45·52 ct and to phosphoresce red after illumination with ultraviolet radiation of less than 3,500 Å. The colour is described as dark or steel blue, and this comes over well in the photograph. M.O'D.

PSCHICHHOLZ (D.). *Schedule of ornamental and gem stones.* Rühle-Diebener-Verlag, Stuttgart, 1976. pp. 30. Price on application.

This handy book consists largely of identification tables in which 14 different properties are enumerated. Although the tables are in German the introductory matter is in English; absorption bands and lines are quoted in nm (according to the now standard practice) and the whole arrangement is in ascending order of refractive index. At the end are coloured drawings of the commoner absorption spectra, in which that of high zircon does not show all the possible regions of absorption, although, in fairness, sufficient of them to identify the stone. One or two illustrations of the absorption spectra of the rare-earth-doped synthetics would be a useful addition to later editions, information for which is solicited and for which application cards are included. There is a short bibliography. Altogether an excellent production. M.O'D.

SHEFTAL' (N. N.) and GIVARGIZOV (E. I.). *Growth of crystals: vol. 9.* Consultants Bureau, New York and London, 1975. pp. x, 329. Illustrated in black-and-white. £18·55.

Although published in an English translation last year, this volume of Growth of Crystals represents the proceedings of the E. S. Fedorov All-Union Symposium on Crystal Growth held in May 1969, so that some of the papers, although revised by the editors in 1972, may be somewhat out-of-date. None the less, many of them contain basic information for the time, which is now lost in more recent developments or submerged in chapter bibliographies in Russian monographs. Papers are grouped into sections covering hydrothermal growth, growth from solution, growth from molten solutions, growth from melts, growth from vapour, and theory of crystal growth. Each chapter includes a short bibliography in which most but not all of the works cited are in Russian. Most papers are short and deal with specific aspects of crystal growth. Of some interest is the growth of scheelite-group tungstate and molybdate single crystals from molten solutions; these crystals cannot easily be grown from pure melts, since there are difficulties in association with the need to maintain high temperatures; nor can they easily be made hydrothermally, since the vessel needs to be thermally stable and uncorroded. Crystals grown at atmospheric pressures and quite low temperatures have been successfully synthesized from solution, making use of temperature difference methods. A large number of dopants can be accepted by the crystals but need to be introduced as chlorides rather than as oxides. Beta-spodumene has been made by crystallization from fluxes in platinum crucibles by programmed temperature reductions; using seeds, crystals up to 15 mm in length were obtained during the manufacture of beta-eucryptite and up to 6 mm for beta-spodumene. The latter was grown in lithium vanadate, spectral analysis showing that 0·2–0·3 wt% vanadium had entered the crystal; only 0·01 wt% Fe^{3+} was accepted and the authors hazard that the presence of a relatively large amount of vanadium hindered acceptance.

The topics quoted above illustrate the range contained in this excellent book; other volumes in the series are still in print. M.O'D.

ASSOCIATION NOTICES

SIR FRANK CLARINGBULL

Sir Frank Claringbull, President of the Association, has recently retired as Director of the British Museum (Natural History), a position which he had held since December, 1968.

ACTIVITIES BY FELLOWS

Mr Norman Harper, F.G.A., Chairman of the Council of the Association, was elected to the Management Committee of the Birmingham Assay Office at their annual meeting on 16th July, 1976.

Mr M. J. O'Donoghue, M.A., F.G.S., F.G.A., a member of the Council of the Association, has been elected to the Beirat (Council) of the Deutsche Gemmologische Gesellschaft in Idar-Oberstein.

FINCH LECTURE

The Finch Lecture, an annual lecture since 1506 of the Clothworkers' Company, will be delivered this year by the Rev. S. B. Nikon Cooper, B.D., F.G.A., at St Margaret Pattens, Eastcheap, at 1.10 p.m. on Tuesday, 23rd November. The subject will be: "Precious Stones of the Bible, and their significance". Visitors will be welcome.

SECRETARY'S VISIT TO JAPAN

The Gemmological Association of All Japan celebrated its tenth anniversary in June, 1976. During its formation Mr Harry Wheeler had given a great deal of help, and he was personally invited to go to Japan as a guest. During his eight days in that country he invigilated at our own examinations at the Tokyo Centre and saw the excellent conditions available there for the practical examination.

During the visit, the Officers of the G.A. of All Japan arranged a special dinner at which Mr Wheeler was the principal guest. A silver dish engraved with the Association's Crest and Coat of Arms and bearing the inscription "Presented by the Gemmological Association of Great Britain to commemorate the 10th Anniversary of the Gemmological Association of All Japan" was given to Mr A. Yamada, Chairman of the Japanese Association. On behalf of the Association Mr Wheeler was presented with a Diamond Proportion Hand Scope and a book containing many excellent coloured illustrations of gems and jewellery. In a talk given

during the visit Mr Wheeler referred to the history of gemmology and suggested that it was due to Mr Kokichi Mikimoto having produced cultured pearls that a testing laboratory was set up in London in 1925 and we were fortunate enough to have Mr B. W. Anderson appointed as the Director: that laboratory extended its work to include the testing of gemstones and considerably helped to put gemmology in the strong position in which it finds itself today.

A day visit was made to Kofu to the Yamanashi Lapidary and Gem Research Institute, followed by a tour of a local gem-carving workshop and a jewellery-making factory. Then the Yamanashi Jewellery Museum was visited, where some excellent crystal specimens were exhibited, many of them mined locally. A meeting also took place with senior local government officials who wished to know more about training facilities in the U.K.

Three days were spent on a visit to the Toba Bay area—the centre for Japanese cultured pearls. There was a first class exhibition for tourists on Mikimoto Pearl Island and the Ama girls were seen diving for pearl oysters. A special visit to the Cultured Pearl Research Institute at Kashikojima, which was most interesting, was arranged, followed by a trip in a small boat around the bay to get a close-up view of the rafts. The cages in which the treated oysters are placed before being lowered into the sea and suspended from the rafts are now made of nylon net with a metal wire framework: this construction saves a considerable amount of weight and makes for easier handling.

After leaving the Toba Bay area there was a full day sight-seeing visit to Kyoto, the ancient capital of Japan. The return train journey to Tokyo afforded a view of Lake Biwa, where freshwater cultured pearls are produced. Before leaving Tokyo a press conference was held at which most interest was shown in the CIBJO grading scales for gem diamonds and the issue of grading certificates.

A stop at Hong Kong provided the opportunity for a tour of what is claimed to be the largest diamond cutting and polishing factory in the Far East. Automatic machinery was in use for small stones and some female labour was employed for the cutting and polishing of larger stones. The last trip of the homeward journey included a stop over at Bangkok.

MEMBERS' MEETINGS

Midlands Branch

The Annual General Meeting of the Branch was held on the 9th June, 1976, at the Royal Institution of Chartered Surveyors Headquarters, Birmingham.

On the proposal of Mr M. Kirkpatrick, seconded by Mrs S. Hiscox, Rule 5 was amended and now reads as follows: "An Annual General Meeting of the Branch Members shall be held to elect a Chairman, Chairman-elect, Honorary Secretary and Committee for the year. A Chairman shall not be eligible for re-election within a period of three years after completing his term of office."

The A.G.M. was followed by a talk by Mr B. W. Anderson, B.Sc., F.G.A.

North-West Branch

A meeting of the Branch was held on 16th September, 1976, at The Royal Institute, Liverpool, when Mr A. E. Farn, F.G.A., Head of the Gem Testing Laboratory of the London Chamber of Commerce, gave a talk entitled "Jade and Jadeite".

COUNCIL MEETING

At the meeting of the Council held on Tuesday, 22nd June, 1976, at Saint Dunstan's House, the following were elected to membership:

Fellowship

Roine, Kalevi U., Jarvenpaa, Finland. D. 1975
Sanchez Garcia, Paloma, Valencia, Spain. D. 1975
Van der Heyden, Eveline L., Barcelona, Spain. D. 1975
Warren, Lois F., Sacramento, Cal., U.S.A. D. 1965

Ordinary

Arnold, Thomas E., Memphis, Tenn., U.S.A.
Bagnato, Ugo, Milan, Italy.
Bartlett, Jennifer, Hong Kong.
Bin Ibrahim, Mamat Mukhtar, Kuala Lumpur, Malaysia.
Birch, Walter J.De-G., Port of Spain, Trinidad.
Boraston, Peter George, Kenley, Surrey.
Brenton-Coward, Richard I., Otford, nr Sevenoaks.
Campbell, S., Hong Kong.
Chou, Elizabeth, Hong Kong.
Clarke, Donald Hugh, Northcliff, Transvaal, S. Africa.
Clarke, David R., Camperdown, Natal, S. Africa.
Cox, Harold M., Ahwaz, Iran.
Danker, Joy L., Dublin, Eire.
Dennis, Jillian A., Sandown.
D'Esterno, Guek N., Repulse Bay, Hong Kong.
Fearn, Barry J., Billericay.
Flewelling, Arthur G., Arthur, Ont., Canada.
Fritsche-Haberle, Margret, Rorschach, Switzerland.
Furniss, Ronald A., Sutton-cum-Lound, Retford.
Gant, Richard D., Orpington.
Gorg, Ulrike, Idar-Oberstein, W. Germany.
Grant, William T., Salisbury, Rhodesia.
Gray, Robert I., Edinburgh.
Green, Colin R., Evington.
Green, Michael, Kuala Lumpur, Malaysia.
Hamilton, Christopher N., Edinburgh.
Harding, Bruce L., Holden, Mass., U.S.A.
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Zandstra, Ilse, Surbiton.
Zimmermann, Michel, Paris, France.

OBITUARY

We regret to record the death of the distinguished mineralogist and gemmologist, Dr Karl Chudoba, on 14th March, 1976, in his 79th year. An appreciation of his work for gemmology will be published in a later issue of the *Journal*.

GIFTS TO THE ASSOCIATION

The Council of the Association is grateful to the following for their gifts:

Professor A. Chikayama, F.G.A., Gemmological Association of All Japan, for an oval cabochon green jade, weighing 7·04 ct, showing chatoyancy.

Mr B. D. Fernando, F.G.A., Sri Lanka, for first-day cover with four new postage stamps depicting a blue sapphire, ruby, cat's-eye and star sapphire.

Mr Norman Harper, F.G.A., Chairman of the Association, for a cabochon almandine garnet showing asterism, weighing 141·5 ct.

Mr R. Holt, F.G.A., London, for a large thin slice of banded agate (first piece to be cut and polished in the new workshop of R. Holt & Co.).

Mrs Jill Rutland, Dorset, for a silver dish, which had been presented to her husband, the late Dr Ernest Rutland, on his retirement as a lecturer from the Sir John Cass College, and also the Tully Medal which he had received in 1947.

GEMMOLOGICAL INSTITUTE OF INDIA

The Gemmological Institute of India, founded in 1971 as a trust for the promotion and encouragement of study and research in gemmology, established in that year the first gem-testing laboratory in India, which now tests on average 1,200 stones a year. It has also built up the nucleus of a museum, where rough

gemstones of various species are displayed, and formed a library in which foreign and Indian periodicals as well as authoritative textbooks are available and freely made use of by the trade. The Institute has now decided to provide short (three months) courses in gemmology to give theoretical knowledge to those who have acquired practical experience of gemstones in the trade. The training is designed to cover the origin, forms, characteristics and special properties of gemstones and the use of modern appliances and equipment for their identification. Applications for admission to the courses should be made to the Secretary, Gemmological Institute of India, 29/30 Gurukul Chambers, 187/189 Mumbadevi Road, Bombay–2.

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An Association tie is available for Fellows. The tie is dark blue and bears the crest of the Association in golden yellow.

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ERRATUM

In line 12 of page 157 *ante*, Mr H. B. Crawford was wrongly described as F.G.A.

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October, 1976

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PROCEEDINGS OF THE
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ASSOCIATION
OF GREAT BRITAIN

GEMMOLOGICAL ASSOCIATION
OF GREAT BRITAIN
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THE JOURNAL OF GEMMOLOGY
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KORNERUPINE CAT'S-EYES FROM SRI LANKA (CEYLON)

By H. J. KOREVAAR, F.G.A.,
Ter Aar, Netherlands,

and

P. C. ZWAAN., Ph.D, F.G.A.,
National Museum of Geology and Mineralogy, Leyden, Netherlands

INTRODUCTION

Last year one of the authors (Korevaar), visiting Sri Lanka, bought a parcel of 125 cat's-eyes from a gem dealer in Galle. Although he knew that these stones could not possibly be chrysoberyls, he was not able to identify them with the naked eye only. The dealer gave the information that the cutters are not much interested in this type of cat's-eye because it is not hard enough to compete with "real cat's-eye", which, of course, is chrysoberyl. Anyway, according to the dealer, these stones originate from the Weligama gem gravels in the Matara district.

Back in Holland, Korevaar contacted the Dutch Gem Laboratory, which is housed in the National Museum of Geology and Mineralogy in Leyden, to identify these cat's-eyes, since this type of gemstone cannot easily be identified by the usual testing methods only. The authors, therefore, worked together and the results of their investigations seemed interesting enough to publish.

PROPERTIES

The total weight of the whole parcel was 99·47 carats. This meant that the average weight of one stone was under one carat. All the stones were oval cabochon cut, the average size being approximately 6 × 5 × 3 millimetres.

Their colour was greenish to dark yellowish green. All the stones showed a good cat's-eye effect and were translucent to transparent. In Fig. 1 three stones, now in the collection of the National Museum of Geology and Mineralogy in Leyden, are shown. They have the registration numbers RGM 151 780 to RGM 151 782. Their weights are 0·77, 0·62 and 0·65 carats respectively.

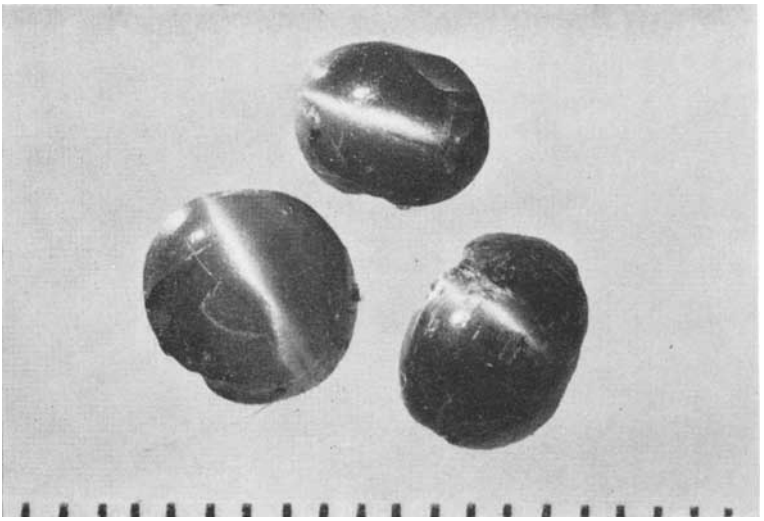

FIG. 1. Some kornerupine cat's-eyes out of a parcel of 125 stones (with millimetre scale).

All these cat's-eyes behaved in the same way in methylene iodide, viz. they just sank in this liquid. Ten stones, weighing 11·69 carats all together, were selected to measure their specific gravity. This was found to be 3·337 for all stones together, while the density of the stones individually varied from 3·329 to 3·350, with an average of 3·338 It should be noticed that the smallest of these stones was 0·79 carats, while the biggest one was 1·43 carats. Although ethylene dibromide was used as an immersion liquid, together with a very accurate hydrostatic balance, it is known from

experience that with such small stones accurate results may hardly be obtained.

To measure the refractive indices, six stones were provided with a flat polished base. They all gave readings at 1·680 and 1·668 for the highest and lowest refractive index respectively.

All these cat's-eyes had a strong pleochroism in tones of yellow-green and reddish. Their absorption spectra, however, were not very distinct. Some weak bands in the green and the blue part of the spectrum were observed.

X-ray powder photographs of two stones gave a pattern of diffraction lines, characteristic for kornerupine. The x-ray data of photograph RGM 201 952, taken from cat's-eye RGM 151 782, are as follows:

d (*in* Å)	*Intensity*	*d*	*I*	*d*	*I*
10·51	8	2·40	3	1·490	7
8·07	4	2·29	4	1·440	4
6·89	6	2·12	4	1·412	6
4·10	1	2·09	8	1·373	3
4·02	6	2·07	4	1·320	3
3·42	7	1·992	3	1·298	3
3·36	8	1·878	3	1·274	4
3·01	10	1·767	4	1·209	3
2·84	2	1·677	6	1·150	3
2·77	4	1·598	3	1·035	2
2·70	4	1·543	5	1·026	2
2·62	10				

Inclusions

The cat's-eye effect is apparently due to a needle-like structure or to oriented needle-shaped inclusions (Fig. 2), the composition of them being unknown.

Distinct inclusions found amongst others in cat's-eye RGM 151 781 are blackish grains with a metallic high lustre and a short prismatic habit (Fig. 3). They were found to be rutile by means of x-ray powder photograph RGM 201 942.

Some of the cat's-eyes contain black submetallic flakes (Fig. 4). Those included in sample RGM 151 782 have been identified as graphite by x-ray powder photographs RGM 201 941 and RGM 201 949.

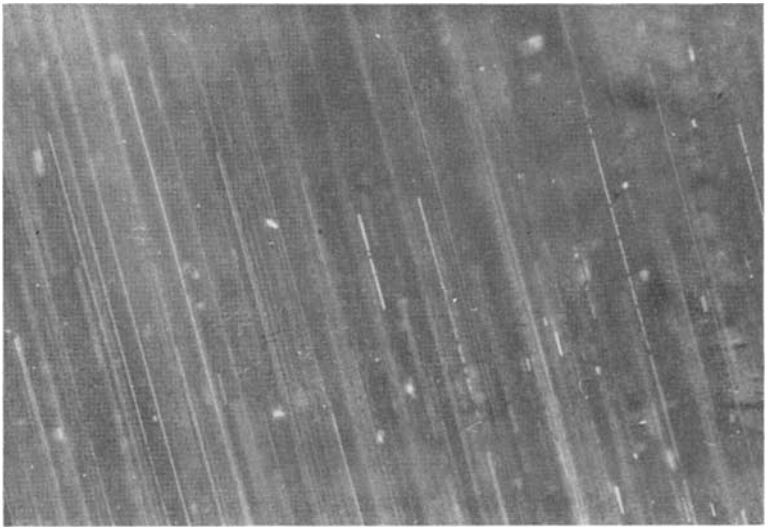

FIG. 2. Needle-like structure in kornerupine cat's-eye RGM 151 780. (60 ×)

FIG. 3. Rutile included in kornerupine cat's-eye RGM 151 781. (Reflected light; 60 ×)

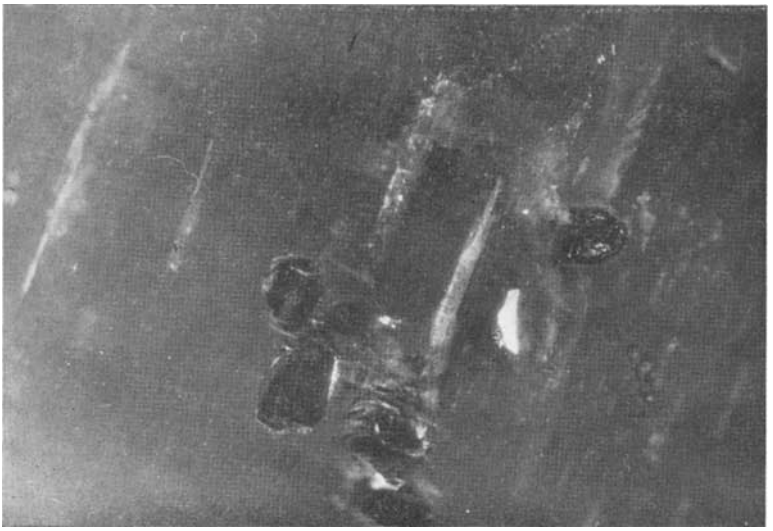

FIG. 4. Graphite flakes in kornerupine cat's-eye RGM 151 782. (Reflected light; 60 ×)

DISCUSSION OF THE RESULTS

Cat's-eyes of kornerupine are only mentioned very briefly in the literature. Recently, however, Crowningshield (1974) described a kornerupine cat's-eye of 7·57 carats. He considered it to be a rarity. The authors, however, ask themselves whether it is right to call them rare when 125 of such stones can be obtained at the same time, though they are all small. Moreover, on a recent trip to Sri Lanka in February 1976, the authors noticed a lot of these stones in the Ratnapura Gem Museum as well as in parcels of stones offered for sale by people in the street in Ratnapura. It is very likely, therefore, that in the near future kornerupine cat's-eyes will come on the market in large quantities.

With regard to the inclusions, one of the authors (Zwaan, 1974) has found the same type of rutile crystals as mentioned above in rhodolite garnet and almandine garnet from Umba, Tanzania, as well as in an almandine garnet from Sri Lanka (Zwaan, 1967). He has also found similar graphite inclusions in deep violet corundums from Umba, Tanzania (Zwaan, 1974), but not before in Ceylon gems. This is, however, not particularly strange, because both graphite and kornerupine may occur in the same type of rock,

namely in cordierite-gneiss. This type of rock is very common in Sri Lanka, graphite being a very important economic mineral in the island. It is very likely, therefore, that in the future included graphite will turn out to be as normal as included apatite in Ceylon gems.

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[*Manuscript received 9th April, 1976.*]

NOTES FROM THE LABORATORY

By A. E. FARN, F.G.A.,
The Gem Testing Laboratory, London Chamber of Commerce and Industry

At the beginning of 1975—or even a little earlier, in late 1974—we commenced movements towards obtaining and installing a powder diffraction camera. Almost immediately we were beset with problems, which may or may not have been gemmological but certainly affected our gemmology in the laboratory. The laboratory, of course, began as a pearl testing station for the trade, and gems (i.e. stones) followed as an ancillary study. So when our x-ray generating set broke down *several* times in quick succession we were put out! This, as well as the interior upheaval due to heated ventilation being installed (plus exterior pavement lighting to our basement), made life infinitely variable between frustration and despair. Needless to say, on each occasion when the x-ray set broke down we had plenty of undrilled and part-drilled pearls needing to be tested by the x-ray method. Our important pearl customers were reasonable and patient, appreciating our predicament, but some of the non-pearl merchants (i.e. those who dabble in all jewellery) were not so understanding

and gave us an extra half hour in which to x-ray their pearls with a non functioning set!

It was during this period of pearl pause that we were also negotiating the installation of the x-ray powder diffraction camera. Each time I was asked to report upon progress to our patient Trades Section Committee I had to reply in the negative—appropriate enough on the subject of cameras, but I should have been happier had my replies been more positive. As the year developed, however, we were able finally to fix the day and at the end of our financial year (terminating our fiftieth anniversary) we had in fact a powder camera installed.

As with all new presents (for it was partly subscribed for by the Diamond Trading Company) we were very keen to try it out. The equipment itself is expensive and so are the special films and the large amounts of developer, fixer, and electricity used in obtaining one negative. As a commercial laboratory testing gems for the trade we need to earn our keep, and obviously testing by such sophisticated methods will be expensive and reserved for very particular items, where customer requirements are imperative and costs will be agreed, incurred and met! Universities and museums are fortunate in being geared for such work, with funds usually available or allocated.

* * *

We were asked to look at some material said to be from a new source in a new colour, consisting of three small, faceted, mauve stones. They ultimately proved to be scapolite. Gemmological circles are very small, and just one day later we saw another and larger specimen, reputedly mauve scapolite and stated to come from Tanzania. We were subsequently told that the first three stones also came from Tanzania. Usually mauve or pinkish scapolite is fibrous chatoyant and comes from Burma. This material was optically clean and clearly of faceting quality. There were some (not diagnostic) inclusions (see Figs. 1, 2 and 3).

On the first three small stones we did routine tests, i.e. density, refractive indices, hardness, fluorescence and/or phosphorescence under long- and short-wave ultraviolet light. We asked and received permission to bombard them with x-rays, since we believed a colour change could occur (and it did). The largest stone (received the second day) received the same treatment (less x-ray fluorescence, etc.)

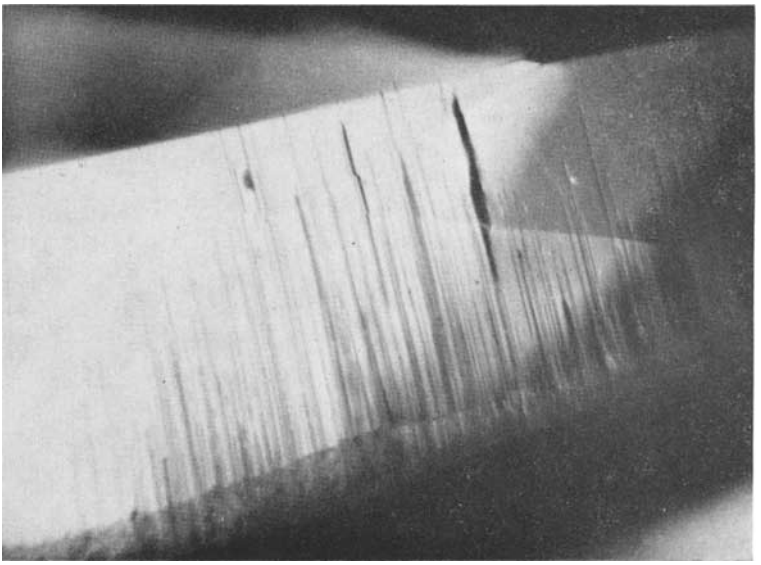

Fig. 1.

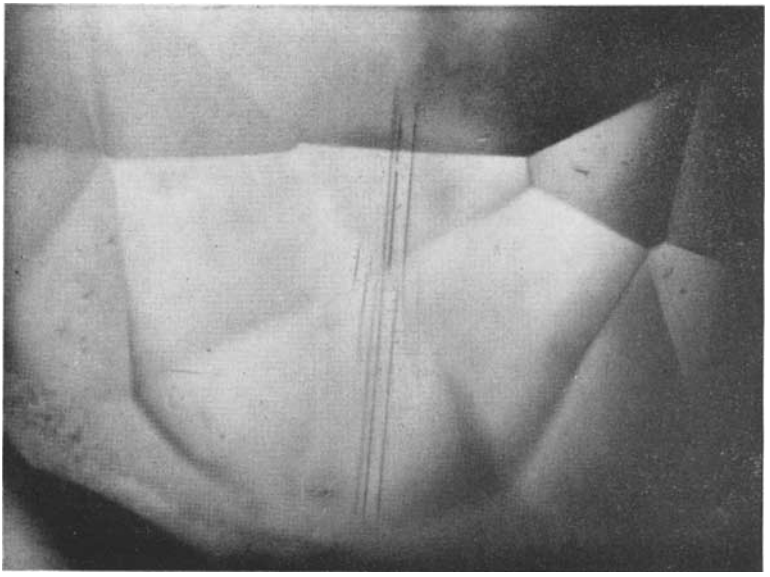

Fig. 2

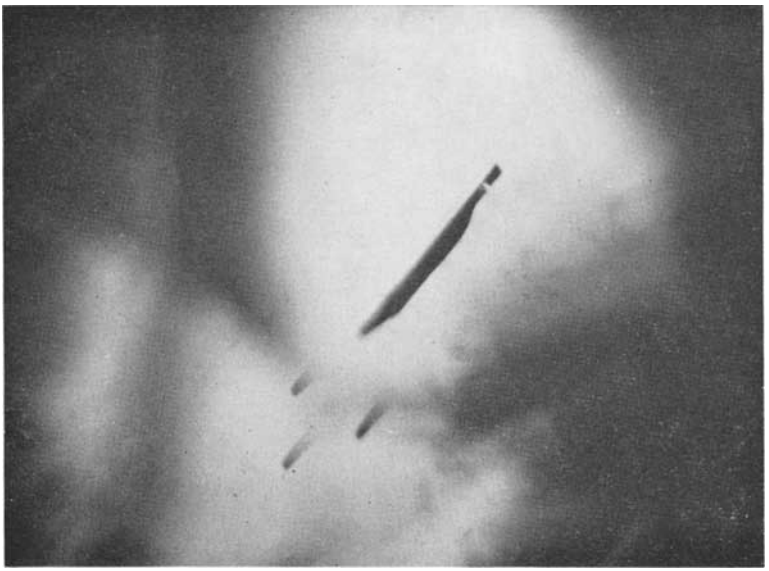

Fig. 3
FIGS 1, 2 and 3. Inclusions in mauve scapolites. (*Photo. K. Scarratt*)

When we did our routine tests we decided that since we were dealing with an apparently new material we should try out our powder camera. Alan Clewlow, who had a broad outline understanding of its characteristics, did our very first powder scraping and achieved a fine clear negative on 35 mm film showing a pattern of concentric lines of varying strengths, looking rather like the cross-section of a pearl. We now had to decide just what these lines represented. To an expert in this technique it was simple, to us an exciting beginning. Our very good friends at the Institute of Geological Sciences, with whom we have established a good working accord, read the picture for us and identified it as *Scapolite*. To each his own specialization: had it been a spectrum or a radiograph of a pearl, we would have been the experts!

The first three small scapolites were oval, faceted and mauve, looking somewhat like amethyst or synthetic sapphire imitating alexandrite or perhaps a natural spinel. One needs to see a colour to appreciate it, rather than form an opinion based upon someone else's description. Beauty is in the eye of the beholder, colour likewise. The three small stones were collectively checked for density with a result of 2·58. The largest (second day) stone was

found to have a density at first of 2·59 and later on of 2·61: perhaps the higher density is the more acceptable. The refractive indices of the stones showed them to be uniaxial, negative in sign. The table facets of the first three were very small, and some parallax occurred, the readings being 1·535–1·540, with only the smallest perceptible movement of the lower reading—in fact it looked like form birefringence as seen in agates. The largest stone gave readings of 1·537–1·542, which caused us some concern at the disparity. Possibly this was caused by the small table facets, but scapolite is like garnet in being a member or part of an isomorphous series, the terminal members being marialite (a sodium aluminium silicate) and meionite (a calcium aluminium silicate), and this could be an explanation of the variation in the optical figures. The smallest stone was checked for fluorescence under x-ray excitation: it fluoresced an orange colour and suffered a change of colour to a deeper hue. This coloration faded after a few hours and the stone is now back to normal. All of the scapolites were inert under long- and short-wave ultraviolet light. They had a hardness between 5 and 6.

Obviously with new source material we could carry out only non-destructive tests—especially as the stones were on loan for our investigation for the benefit of the trade. We have since been donated one stone for the laboratory's collection by Mr E. A. Thomson, of Thomson Gems, to whom our most grateful thanks are due. The largest of the mauve scapolites was sent to Mr B. W. Anderson for his information and appreciation: he states that the high density material of 2·61 is possibly 80% marialite and 20% meionite. The variations possible in scapolite impress the need for careful checking of refractive indices and densities. Photo-coloration by x-ray could be disconcerting, but mercifully most readers do not possess such equipment in their home laboratories. Stones which colour quickly by low heat and/or bombardment equally lose it fairly quickly.

* * *

Since that first exciting use of the powder camera, we have built up a series of *known* examples for our film library. We have been supplied with standard patterns by our friends in the Gemological Institute of America (Los Angeles laboratory) and some more by Pete Dunn, of the Smithsonian Institution, Washington, D.C.

We have also received as a gift a book of reference entitled "Inorganic Index to the Powder Diffraction File"; this too came from Los Angeles—a typically friendly American gesture. Although I have formally on behalf of the London Chamber of Commerce Gem Testing Laboratory written an official letter of thanks, it is perhaps opportune here and now in the *Journal of Gemmology* to say "Thank you" to our American counterparts for their many friendly gestures.

* * *

Another stone sent to us for examination by the owner of the largest of the mauve scapolites was a blue transparent faceted stone in a packet marked "Azurite". This proved to be blue apatite, giving a uniaxial negative reading of 1·635–1·639 and a density of 3·22. It fluoresced blue under x-ray excitation and a "dusty" green under short-wave ultraviolet and was practically inert under long-wave ultraviolet. The colours seen as viewed through the dichroscope were blue and greenish blue, of not too wide a disparity. Viewed by microscope some long thin needle-like cavities were seen, but are not diagnostic—also black hexagonal crystals (see Fig. 4).

* * *

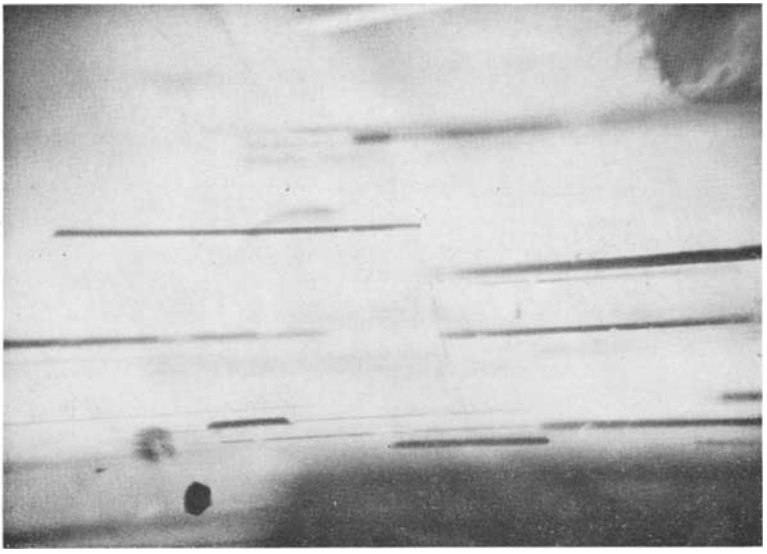

FIG. 4. Needle-like cavities and black hexagonal crystals in blue apatite. (*Photo. K. Scarratt*)

Another new stone (new, that is, to us) came in a ring. The customer paid us the usual compliment of expecting us to do an on-the-spot test under "while you wait" conditions. Since we have always fancied ourselves at speedy testing we are hoist with our own petard by such a request. Is it a challenge we can seldom fail to rise to, or is it some sort of gemmological masochism which allows pride to reply promptly "Send it along"? Well, the oval red stone mounted in a not too difficult-to-view setting arrived with the potential purchaser and the standard Hatton Garden story of a customer waiting in his office, etc., etc. The red stone did not look like a ruby, a spinel or a garnet, nor for that matter did it look like a red tourmaline.

I always use a 10 × lens before I do any formal instrument test, since I fully believe one can extract much early information from this type of examination. Very often to fly to flexible fibre optics and a powerful microscope or to cheat a little by taking a quick absorption spectrum spoils the pleasure of real gemmology. Mlle Dina Level, the now retired inclusions expert of the Paris laboratory, speaks of the 10 × lens as the jeweller's "third eye". The 10 × lens detected crystalline inclusions plus dichroism (or was it dichromatism?) or at any rate two tones of red. The girdle of the stone was bordered by the setting, but crown and base were both fully on view. The colour could have been that of an East African ruby with just too much iron damping the exuberance of chromium. Having tested in earlier days many tens of thousands of rubies (calibré sizes mostly) one develops a feeling for knowing when a synthetic is on parade, even though one does not immediately see curved lines and/or bubbles. Random cutting of a synthetic causes incorrect colour or, as we say, "it looks wrong". It was the base of the stone which looked wrong: the top was O.K. So, with doubts aroused by the 10 × lens, I could now proceed formally.

Immersion, although messy, is the quickest way to determine difficult inclusions. However, no particular trouble occurred in this instance: curved structure lines of a flame fusion Verneuil synthetic ruby gave the answer, but the upper portion yielded no refractive index at first sight. This could have been due to poor polish on the table facet, but such was not in fact the case. A high-reading almandine garnet of just over 1·81 was found by the use of phenyldi-iodoarsine—a nasty liquid, but useful. Carefully placing the stone across the small beryllium window of our x-ray set, we

saw the base of the stone fluoresce and phosphoresce, whilst the top half remained inert. With the spectroscope, light transmitted through the stone gave only a strong ruby absorption spectrum. This could be dangerous, if one took crystalline inclusions plus absorption spectrum of ruby as sufficient (and they are) to prove a natural ruby. This brings me back to the good old 10 × lens. Slick sophisticated methods could have caused some trouble for an unwary gemmologist.

A glancing beam of light played across the table of the stone enabled a grazing incidence absorption spectrum to be obtained. This gave faint indications of the familiar three bands in the green as part of an almandine spectrum. Thus we finished by 100% complete proof of an unfamiliar unusual doublet, undoubtedly devised to deceive.

* * *

A customer brought us a parcel of mixed rough stones, thirty pieces all told. "Please identify" were the words on the advice note. Gemmologically it was a piece of cake, except that perhaps one portion caused a little indigestion.

There were twenty-seven almandine pyropes, two rough peridots and one yellow rough. The yellow rough almost suspended in density liquid in which quartz slowly sank. It matched ethylene dibromide (R.I. = 1·54) and was doubly refracting, somewhat lack-lustre. It had quite a few inclusions (see Fig. 5), but the hackly surface prevented a proper view of its interior. A little discussion followed upon the worth of following it further—it seemed to be quartz. However, one factor stood out—quartz is remarkably steadfast in its density but this seemed fractionally less dense: could it be the inclusions, etc., etc.?

The matching liquid of ethylene dibromide was not really 100%. As I have often been warned, cajoled and coaxed by Mr B. W. Anderson, we decided we could not let this anomaly pass. A careful density established it as 2·63, too low for quartz and perhaps a little too high for feldspar. The refractive indices of this doubly refracting stone would possibly settle the matter but so far we had not had recourse to asking our customer (a lapidary) to have a flat polished on the rough. We decided that if it were feldspar we could check its absorption spectrum and effects under short- and long-wave ultraviolet light. Yellow orthoclase from Madagascar shows a reddish/orange glow under both long- and short-wave

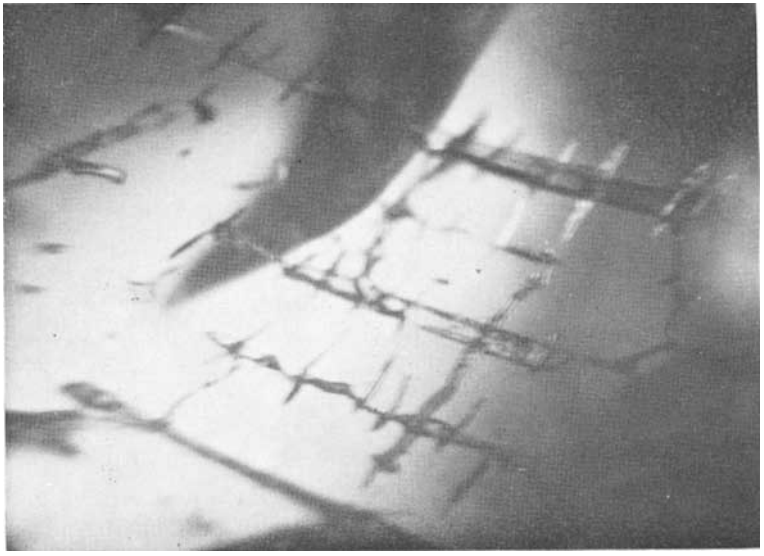

FIG. 5. Inclusions seen in yellow scapolite. (*Photo. K. Scarratt*)

ultraviolet light and a stronger effect under x-ray excitation. This we checked, and as is not unusual in our laboratory we could not agree upon the interpretation of the colours seen.

This sort of testing takes place in a busy day during which we may well be dealing with pearls by x-ray, stones set in jewellery, a carving or two and lately powder diffraction photography with our new camera. Sometimes three people at the same time need the dark-room to develop a film, to load a cassette or to view fluorescence with ultraviolet light. When these situations occur and the dark-room is occupied, we diversify in modern manner and carry out other tests meantime: this is necessary to keep work up-to-date and avoid queueing. This combination of testing and flitting from pillar to post has its hazards and its rewards. We have a mixed variety of skills, ages and techniques, and so what one may miss another will see, and what I forget my colleagues will diplomatically recall to my memory. In this particular case we had proceeded thus far with our yellow rough and stopped for more pressing and profitable testing. On a return to discussion of our yellow stone, K. Scarratt noticed a faint hint of violet on one rough edge. Had

we missed this before? Had it been there all the time? Or, more exciting, had it photocoloured by x-ray irradiation? Secondly, what yellow stone would or could photocolour? Scapolite seemed to fit the bill. Now we had moved from probable quartz to possible feldspar to potential scapolite.

Would the customer play ball? We telephoned, giving details of the rest of the parcel, and by dint of full explanation not only obtained permission to go ahead but also an optical flat was polished. On the spinel refractometer the stone had refractive indices of 1·544–1·556, uniaxial, negative in sign. We then placed the stone optical flat down on the beryllium window of the x-ray generating set and gave it a good dose of x-rays for two minutes. To our great pleasure we found a neat circular patch of pinkish violet hue which penetrated probably a millimetre. We now felt fairly happy that we had a yellow scapolite. Hindsight, of course, helps, but we agreed that had we not had a discussion on colour by x-ray excitation and had not four of us taken a long look, we might not—or K. Scarratt might not—have seen that first touch of violet on a rough stone. We also agreed that if this stone were cut and mounted in ring or brooch it could easily pass a quick refractometer check as quartz. It is a somewhat sobering thought that, did we not at times *not* fully agree, or if we failed to query a stone merely because of a small isolated anomaly, we could easily fall down on the job.

A BRIEF LOOK AT THE SANCY DIAMOND

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IN January 1976 we were invited to examine the Sancy Diamond in the Institute laboratories, but for security reasons the stone was available for a short time only. Famous historical diamonds of this calibre are rarely removed from safes, and it seemed appropriate that our good fortune should be shared by two professional gemmologists, A. E. Farn of the London Chamber of Commerce Gem Testing Laboratory and the late Robert Webster, their gemmological consultant. Little did we know, during that short time in the laboratory, that this was the last time that we should be able to discuss gemmology with Robert Webster and draw upon his great fund of knowledge which was always so generously shared with others.

The Sancy diamond is pear-shaped and approximates to a double rose cut, with mostly triangular facets but with a central

FIG. 1. General view of the Sancy Diamond, as seen in January 1976 (×3 approx).

*Published by permission of the Director, Institute of Geological Sciences.

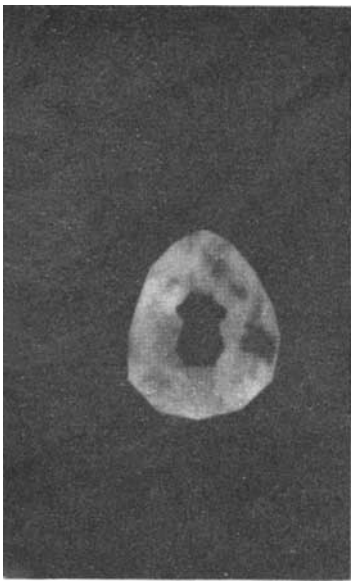

FIG. 2. Contact immersion photograph taken by short-wave ultraviolet light, showing the total light transmission through the two parallel facets (above and below), but only partial transmission elswhere due to internal reflections by the many other facets. Same size.

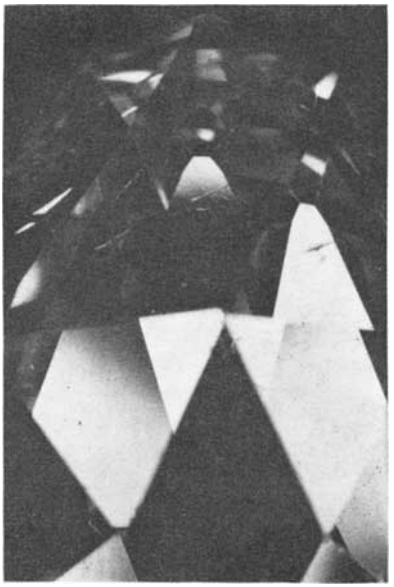

FIG. 3. Enlarged photograph (×4·5 approx.) showing small flaw near surface (repeated by reflection in the facets) on right hand side.

pentagonal facet on each side, the latter facets being roughly parallel to each other. There are slight scratches on one of the pentagonal facets. The maximum dimensions of the stone are 25·7 mm long, 20·6 mm wide and 14·3 mm deep. The weight is 11·0464 grams or 55·23 metric carats, and the specific gravity (determined in toluene) is 3·519.

The stone is reasonably clean, apart from a small flaw near the surface (repeated by reflection in the facets) which is shown in Figure 3. Comparison stones were not available to us and we were, therefore, unable to colour-grade the stone, but the general appearance suggests a good colour. The stone is lively and the fire (dispersion) is well displayed. The general appearance of the stone is shown in Figure 1; unfortunately there was not sufficient time to take a series of views from different angles.

The fluorescences of the stone by ultraviolet light are extremely interesting. By short-wave (235·7 nm) UV light the stone

fluoresces a distinct yellow, but we saw no phosphorescence on cutting off the radiation. By contrast, under long-wave (365 nm) radiation the stone fluoresces a pale salmon-pink, with a very noticeable greenish-yellow phosphorescence. This behaviour is not common and, in itself, would serve as a good identification test for the stone. We were unable to detect any absorption spectrum when white light was passed through the stone.

Contact immersion photographs (by exposing photographic paper upon which the stone rests in water to short-wave UV light) reveal that the stone is transparent to this radiation (235·7 nm) and would appear, therefore, to be a Type II diamond, as are many other large diamonds. This transparency is well demonstrated in Figure 2, which shows the total UV light transmission through the two parallel central facets (above and below), but only partial transmission elsewhere due to internal reflections by the many other facets.

In conclusion we should like to thank the owners of the Sancy diamond for allowing us the opportunity of examining the stone. The assistance of our colleagues in various ways is gratefully acknowledged.

THE INTERNATIONAL SYSTEM OF UNITS AND ITS APPLICATION TO GEMMOLOGY

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WITH the continuing trend of conversion to the metric system, we can foresee a time in the not too distant future when all the sciences and technologies of the world will use the same set of units. Undoubtedly, this will be "SI"—the Système International*. The following is an outline of this system and a brief discussion of its relevance to the field of gemmology, particularly with respect to the varied units used in spectroscopy.

The International Bureau of Weights and Measures (BIPM) has been studying the problem of units and their names for many years. Based on a series of resolutions and recommendations of the General Conference on Weights and Measures (CGPM), BIPM has published "SI Le Système International d'Unités", OFFILIB, 48 rue Gay-Lussac, F 75005 Paris (revised edition 1973). An official English translation has been prepared jointly by the National Physical Laboratory, U.K., and the National Bureau of Standards, U.S.A., and published in the U.K. by Her Majesty's Stationery Office, London, 1973, under the title "SI The International System of Units".

The base units of SI are given in Table 1, and the SI prefixes to be used with these and other derived units in Table 2. There are also many derived units with special names, e.g. newton N for force, pascal P for pressure, etc., but the majority of these has little relevance to gemmology.

TABLE 1. SI BASE UNITS

Quantity	*Name*	*Symbol*
length	metre	m
mass	kilogram	kg
time	second	s
electric current	ampere	A
thermodynamic temperature†	kelvin	K
amount of substance	mole	mol
luminous intensity	candela	cd

†Celsius temperature is expressed in degrees Celsius (symbol °C)

*Use of the SI units as mentioned in this article is included among the recommendations of the Royal Society (see J. Gemm., 1976, XV, 3, 164), which, however, do not specifically refer to the metric carat.—Ed.

TABLE 2. SI PREFIXES

Factor	*Prefix*	*Symbol*
10^{18}	exa	E
10^{15}	peta	P
10^{12}	tera	T
10^{9}	giga	G
10^{6}	mega	M
10^{3}	kilo	k
10^{2}	hecto	h
10^{1}	deca	da
10^{-1}	deci	d
10^{-2}	centi	c
10^{-3}	milli	m
10^{-6}	micro	μ
10^{-9}	nano	n
10^{-12}	pico	p
10^{-15}	femto	f
10^{-18}	atto	a

It may be noted that temperature °C = "degrees Celsius" is the same as "degrees centigrade". The absolute temperature K (note the absence of the degree sign) is obtained by adding 273·15 to the °C value. Both K and °C units are the same size, differing only in the starting point of the two scales (absolute zero and the freezing point of water, respectively).

Refractive index and other optical constants as well as specific gravity are all ratios and therefore have no units. Length and mass units are the ordinary metric ones, with the following exceptions:

(i) Since μ is a prefix, as listed in Table 2, the length micron μ is not permitted and now becomes micrometre, abbreviation μm; similarly millimicron mμ becomes nanometre, abbreviation nm.

(ii) For volume litre l, ml, etc., may continue to be used, although the cubic metre m^3, dm^3, cm^3, etc., are the SI units. The use of the ångström unit Å (=0·1 nm) is discouraged.

(iii) The use of the metric carat is "deprecated". (It does, however, seem unlikely that gemmologists will soon surrender this unit for the gram!)

The frequency, previously given in cycles per second or sec^{-1}, becomes hertz, abbreviation Hz.

Absorption and emission (fluorescence) features in spectra are described in many different ways, and conversion from one to

TABLE 3. VARIOUS WAYS OF SPECIFYING THE COLOUR SPECTRUM

Name and Symbol	Wavelength Descriptions			Energy Descriptions		
	Wavelength λ			Frequency ν	Wave-number $\tilde{\nu}$	Energy E
Unit and Symbol	ångström Å	nanometre nm	micrometre μm	hertz Hz	cm^{-1}	electron-volt eV
Colour*						
Infrared	300,000	30,000	30	$1{\cdot}00 \times 10^{13}$	333	0·041
Infrared (near)	10,000	1,000	1·0	$3{\cdot}00 \times 10^{14}$	10,000	1·24
Red	7,000	700	0·70	$4{\cdot}29 \times 10^{14}$	14,300	1·77
Orange	6,500	650	0·65	$4{\cdot}62 \times 10^{14}$	15,400	1·91
Yellow	6,000	600	0·60	$5{\cdot}00 \times 10^{14}$	16,700	2·06
Green	5,500	550	0·55	$5{\cdot}45 \times 10^{14}$	18,200	2·25
Blue	4,500	450	0·45	$6{\cdot}66 \times 10^{14}$	22,200	2·75
Violet	4,000	400	0·40	$7{\cdot}50 \times 10^{14}$	25,000	3·10
Ultraviolet (lw)	3,660	366	0·366	$8{\cdot}19 \times 10^{14}$	27,300	3·39
Ultraviolet (sw)	2,537	254	0·254	$1{\cdot}18 \times 10^{15}$	39,400	4·89

*Typical values only.

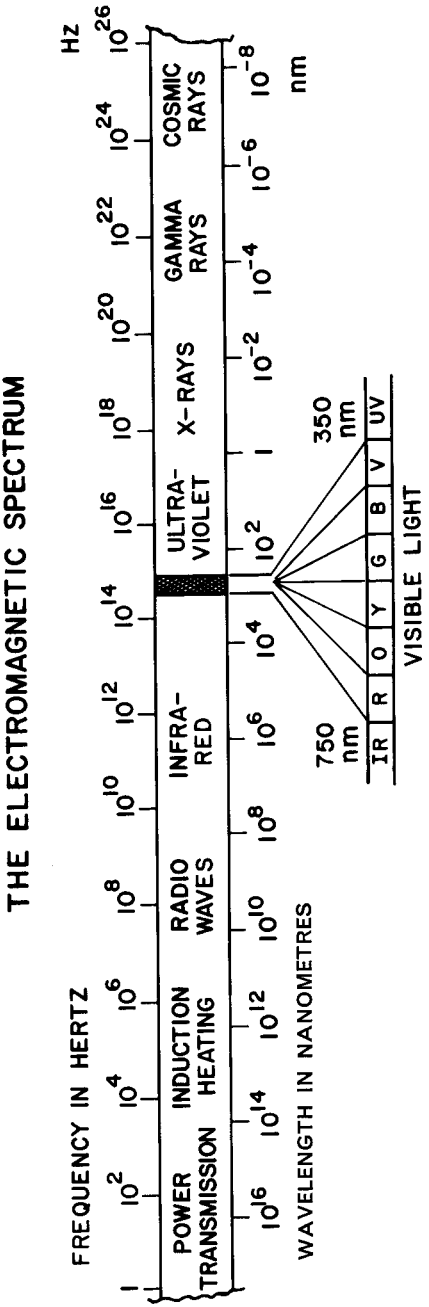
THE ELECTROMAGNETIC SPECTRUM
FREQUENCY IN HERTZ
Hz
1
10^2
10^4
10^6
10^8
10^{10}
10^{12}
10^{14}
10^{16}
10^{18}
10^{20}
10^{22}
10^{24}
10^{26}
POWER TRANSMISSION
INDUCTION HEATING
RADIO WAVES
INFRA-RED
ULTRA-VIOLET
X-RAYS
GAMMA RAYS
COSMIC RAYS
WAVELENGTH IN NANOMETRES
10^{16}
10^{14}
10^{12}
10^{10}
10^8
10^6
10^4
10^2
1
10^{-2}
10^{-4}
10^{-6}
10^{-8}
nm
750 nm
350 nm
IR
R
O
Y
G
B
V
UV
VISIBLE LIGHT

Fig. 1.

another may be needed, particularly when consulting the results of physicists who best like additive energy units (such as cm^{-1} for wavenumbers (usually designated $\tilde{\nu}$) and eV (electron volts), both accepted as SI units). The most commonly used units are assembled in Table 3. Of these units only the ångström is not a recommended SI unit; for general use nm is probably most convenient. The whole electromagnetic spectrum is shown in Fig. 1.

The relationships of Table 4 are given to assist in accurate conversions. Also included here are the less frequently encountered energy units cals/mole and ergs, neither of which are SI units.

TABLE 4. SOME DEFINITIONS AND USEFUL RELATIONSHIPS CONNECTED WITH LIGHT

1. Velocity of light $c = 3{\cdot}0 \times 10^{10}$ cm/sec.
2. Wavelength λ is the distance between two repeating parts of the light wave (in cm, micrometres μm, nanometres nm, or ångströms Å).
3. Wavenumber $\tilde{\nu}$ is the number of waves in 1 cm length (in cm^{-1}):

$$\tilde{\nu} = \frac{1}{\lambda(\text{cm})} = \frac{10{,}000}{\lambda(\mu\text{m})} = \frac{10{,}000{,}000}{\lambda(\text{nm})} = \frac{100{,}000{,}000}{\lambda(\text{Å})}$$

4. Frequency ν is the number of waves passing in one second (in $sec^{-1} = Hz$):

$$\nu = \tilde{\nu} \times 3 \times 10^{10} \text{ Hz.}$$

5. Energy $E = \nu \times 1{\cdot}99 \times 10^{-16}$ ergs,
$= \nu \times 1{\cdot}24 \times 10^{-4}$ eV,
$= \tilde{\nu} \times 2{\cdot}86$ cals/mole.

Usage of the SI system of units, with the help of the National Physical Laboratory publication cited, should be encouraged, both at the national as well as at the international level.

THE USE OF THE ELECTRON MICROPROBE IN GEMMOLOGY

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Introduction

Although technology has made much of the older instrumentation in other disciplines obsolete, the tools of the gemmologist have changed but little since the development of the optical refractometer for gems by Smith in 1905. Density balances, refractometers, and microscopes are still the primary tools of the gemmologist and are not likely to be rendered obsolete in the near future.

New advances in electrical engineering have, however, greatly improved the resources available to the research gemmologist in her/his quest for the "reasons why" and the ever-continuing accretion of the tiny bits of knowledge upon which the practising gemmologist makes judgements and decisions. Foremost among these new tools is the electron microprobe. This paper is written to acquaint the gemmologist with this instrument, and the operation, methods, techniques, and special advantages of the electron microprobe in the study of gems.

The Electron Microprobe

The electron microprobe is a relatively recent instrument and was first patented by Hillier in 1947. The further development of the basic concepts which governed its use were proposed by Castaing in 1951 and by 1956 microprobes were being produced commercially (Wilson, 1972).

The microprobe operates on the principle that an element, when bombarded by high-energy electrons, emits x-radiation of specific characteristic wavelengths. The amount of radiation emitted is roughly proportional to the amount of the element in the sample. The microprobe consists of four basic components, together with an impressive array of accessories. These four basic components are: the electron gun, the electromagnetic focusing lenses, the spectrometers and the associated electronic recording system, and a microscope.

The electron gun is located in the topmost conical section of the microprobe (see Fig. 1) and it contains a tungsten filament. With high voltage (15–20kV), electrons leave the filament surface These

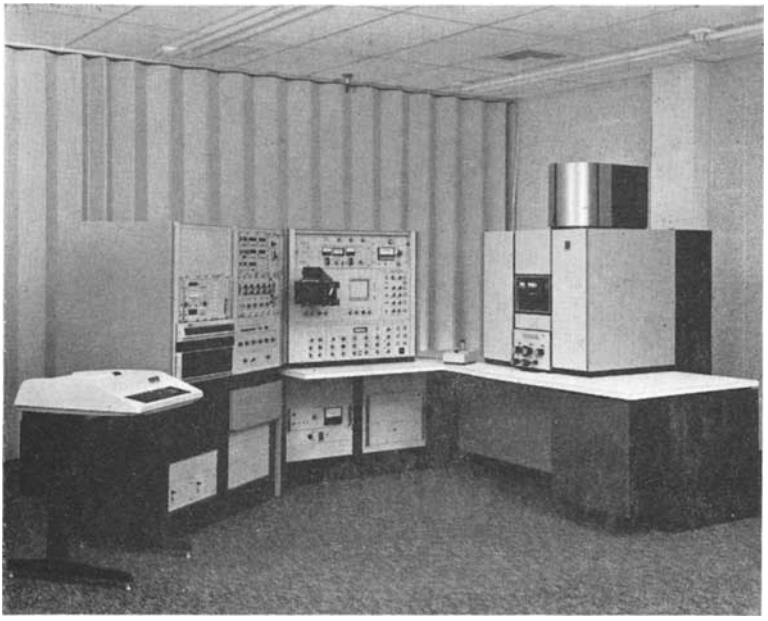

FIG. 1. The ARL-SEMQ electron microprobe. The large rectangular module on the right houses the actual electron gun, lenses, and microscope and sample chamber. The white module to the left is the print-out component of the on-line computer.

electrons are emitted through an aperture and then pass through a series of electromagnetic "lenses" which serve to focus the beam of electrons to whatever beam width is selected by the analyst. With modern microprobes, this beam can be focused to one micrometre (0·001 mm) and inclusions of very small size can be studied in detail.

The gem to be analysed is positioned in this now-focused beam of electrons, using the microscope to observe the sample, and as the electrons bombard the polished surface of the gem, x-radiation is given off, each element within the gem emitting its characteristic radiation. This x-radiation is detected and measured by a counting device and diffracting crystals such as ADP (ammonium dihydrogen phosphate) and LiF (lithium fluoride) whose "d" spacings are well known. These counters and crystals are mounted on spectrometers.

The spectrometers can be set to detect only one element (calcium, for example), or they can be tuned manually or by motors to scan all the x-ray radiation given off by the gem. The elements which are present can be observed by recording the wavelength at

which radiation is detected. The detectors count x-rays and this information is passed as an electronic impulse to a teletype and/or a cardpunch or computer link-up terminal, for further processing.

When scanning the x-rays emitted by an unknown, we make use of Bragg's law $n\lambda = 2d \sin\theta$. Since we know the "d" of the specific crystal in our spectrometer, and know θ which is the angle of incidence at which the x-rays are received by the crystal, we can determine λ, the wavelength at which a given element in our gem is emitting x-rays. Tables of emission spectra lead us to the element known to produce x-radiation in this wavelength. By scanning the full spectrometer range, and recording all the detected radiation, we can perform a qualitative analysis of our sample.

Analysis Procedure

For quantitative analysis, our unanalysed gem is compared with standards which are natural minerals or synthetic compounds whose composition is well-known. The selection of which standard to use in our analysis is a critical one. It is best if the proportion of the element we are analysing for is similar in both our standard and our unknown. In analysing some gems, tourmaline for example, it is also best if the atomic structure of our standard is similar to that of our unknown. If we were analysing an almandine garnet, for example, we would choose a standard for iron which contained about 30% FeO and was a silicate with a structure similar to the garnets. Ideally, we would like to use as a standard another analysed member of the garnet group with an iron content comparable to that noted above.

A sample procedure for analysing a peridot (forsterite) would be as follows. First, we would choose standard(s) for iron, magnesium, and silicon, the primary constituents of peridot. Since peridot has a low-iron and high magnesium content, we would choose an analysed forsterite with comparable constituents. In this laboratory, we would use MARJALAHTI forsterite (named for the Marjahlati meteorite, Viipuri, Finland in which the forsterite occurs), which has a composition very close to that of good, green, gem-quality peridot. Next we would set the spectrometers to analyse for iron, magnesium, and silicon. If we were using a microprobe with more than three spectrometers or an automated microprobe, we would also set others to detect the minor elements found in forsterite, (e.g. calcium, aluminium, chromium, manganese, and

titanium) so as to analyse the gem completely. Next we would have to determine the x-ray intensities for each element on our standard(s) and then determine x-ray intensities emitted from our gems under identical conditions. Such counting periods might range from 10 to 100 seconds on each point on a sample, and 10 or 15 points on our sample or more may be used to insure an accurate analysis. Finally, the intensities on our standards could be read again, and then the spectrometers could be moved off-peak so as to read the ever-present "background" radiation (due to scattered x-rays).

After subtracting these "background" counts from both the standard counts and our sample counts, we could then set up a simple linear ratio, to obtain an approximate estimate of the composition of our gems.

For a precise analysis, it is necessary to submit the rough data to a number of corrections, for example for backscatter, fluorescence, and absorption due to the presence of other elements in the sample. These corrections are complicated and very tedious mathematical procedures and are quite laborious when done by hand. Fortunately, computers can perform these corrections quite quickly and so most microprobe laboratories are equipped with hook-ups for card-punching or direct terminals for computers. Also, microprobes can be set-up with an on-line computer which can calculate final analyses within minutes. Computer data reduction programs are quite varied, and large, flexible ones such as the ones in operation at the Smithsonian Institution can handle a large number of samples, perform all necessary calculations and corrections, and also possess a number of options which allow the analyst to select in what format he would like his analyses.

Figure 1 is a photograph of the new ARL-SEMQ electron microprobe in the Department of Mineral Sciences, National Museum of Natural History, Smithsonian Institution, Washington, D.C. This microprobe, one of the most modern anywhere, is capable of analysing for nine elements simultaneously. Six of the nine spectrometers (all concealed within the instrument) are fixed in position to always analyse for silicon, aluminium, iron, magnesium, calcium, and potassium. The remaining three can be used for scanning and can be set for any three additional elements the analyst wishes to examine.

This microprobe is hooked-up to an on-line computer which performs all corrections and permits the analyst to have a complete,

final analysis within minutes of completing the actual bombardment of the sample gem with electrons!

Limitations of the Microprobe

In spite of its many advantages, the microprobe does have some limiting factors and the gemmologist should be aware of them. The microprobe cannot detect with reliability the presence of elements with an atomic number below 9. Hence we do not analyse for beryllium, boron, lithium and oxygen in our samples. This can be most frustrating since so many of our gem minerals do contain substantial amounts of these elements.

Secondly, the microprobe cannot detect the oxidation state of the elements, and so elements which occur frequently in several oxidation states must be reported as total element content, without a specific designation of the degree of oxidation. Iron, in a garnet or tourmaline, for example, is usually reported as total iron (usually calculated as FeO) without any sure indication from the instrument as to whether it is ferrous or ferric.

When using well-analysed standards, of similar composition and structure to our unknown, and exercising good judgement, the accuracy of the microprobe is about $\pm 2\%$ of the amount present. For example, a peridot with a reported iron content of 10·00% FeO (7·77% Fe) could have an error of $\pm 0{\cdot}15\%$ Fe.

The extremely high cost of a microprobe—a modern one with on-line computation and other advanced features can cost about $150,000—is also an extreme limitation.

Advantages of the Microprobe

The chief advantage of the electron microprobe and a most important one to a gemmologist is that it is completely non-destructive. Hundreds of analyses can be performed on a gem with no trace of mark remaining thereafter. A second advantage is that we can perform complete analyses (partial analyses if elements with atomic number below 9 are present) of minute inclusions only micrometres in width, if they are exposed at the surface of the gem, or can be exposed through the grinding down of rough. A third advantage is the extremely short time required for analysis when compared with classical wet-chemical methods.

When working with gems, the stone is illuminated in vertical incident illumination, which can be polarized. This has advant-

ages in that the gemmologist can observe phase changes in opaque mineral inclusions and twinning and exsolution phenomena in both inclusions and the host gem.

Another notable advantage is that the gemmologist can analyse small portions of gems, or select certain coloured zones for separate analysis to seek clues as to the cause of the coloration where the colour-change is directly related to compositional variation in the gem. It might be noted here that because we are working in vertical, reflected illumination, there are no colours observed. Hence, the analyst must mark such designated colour-areas with paint or ink on the surface of the gem before placing the gem in the microprobe.

At the same time, hardness can be observed. Due to the high magnification (300 ×), one is able to observe subtle differences in hardness between host gems and inclusions. This is evidenced by a differential resistance to polishing, wherein mineral inclusions softer than the host gem show negative relief features (depressions), and inclusions harder than the host appear as positive relief features (small bumps) on the gem surface.

Procedures for Sample Preparation

1. In the study of gem rough, in this laboratory, when chips are available and non-destructive procedures are not required, the samples are usually mounted in a bakelite disc impregnated with epoxy. This task requires consummate skill at polishing and a familiarity with a broad array of techniques and mounting media. Hence the individuals who perform this work are highly trained specialists.

   The usual procedure with gem rough is to drill a number of holes in a 25 mm bakelite disc, and insert each sample into one of these holes. The entire disc is then impregnated with epoxy, and, after curing, the disc is ground down to expose the gem grains. They are then highly polished to a mirror-finish with diamond abrasives. (Fig. 2)

   In the case of inclusion studies, the task is infinitely more time consuming. Each piece of rough is mounted in a separate disc, polished so that the inclusion can be observed, and then laboriously ground down to expose the selected inclusion. This work takes much skill, and more patience.

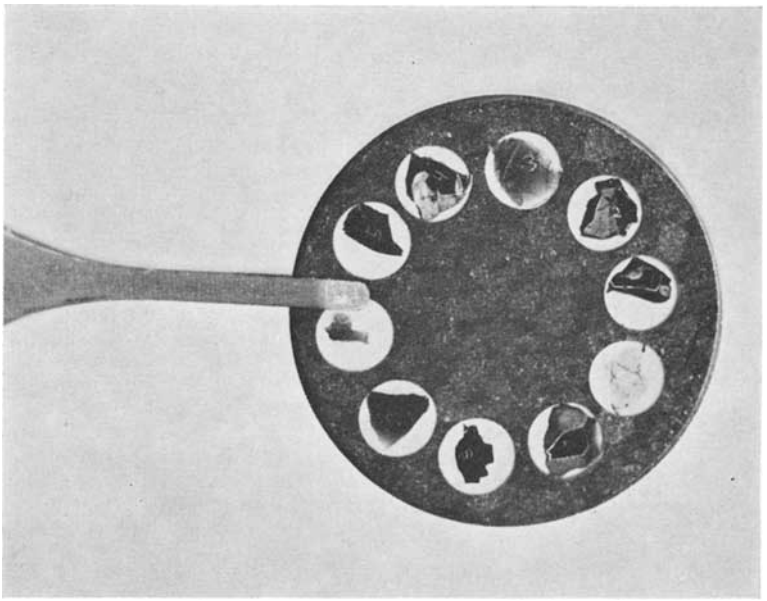

FIG. 2. A sample-disc containing ten fragments of tourmaline. Small numbers scratched on the surface of each grain aid in identifying the specimen within the microprobe.

2. In cases where we desire to analyse a faceted gem, different procedures are followed. The gem is mounted by hand in a sample holder (Fig. 3), using a high-vacuum clay (APIEZON is a good one) to hold the gem rigid in the sample holder. Since it is absolutely necessary that the surface that is to be analysed is horizontal, the gem-in-clay-in-sample-holder is then pressed in a levelling press (Fig. 4) so as to bring the surface to be analysed (usually the table of a gem) into horizontality and flush with the top edge of the sample holder.
3. Whether the sample to be analysed is in the form of a disc of rough fragments or a finished gem, it must then be carbon-coated to give a conducting surface for the removal of electrons, since most gems are non-conductive. For this purpose, the samples are placed in a carbon-coating instrument and a thin layer ($\sim$400 Å thick) of carbon is deposited on the gem. This thin layer is not noticeable on most gems, but it should be wiped off, after the analysis is complete, with a very soft abrasive to ensure maximum brilliance in the gem. Because the carbon-coating is thin, there may be breaks in the conducting surface at

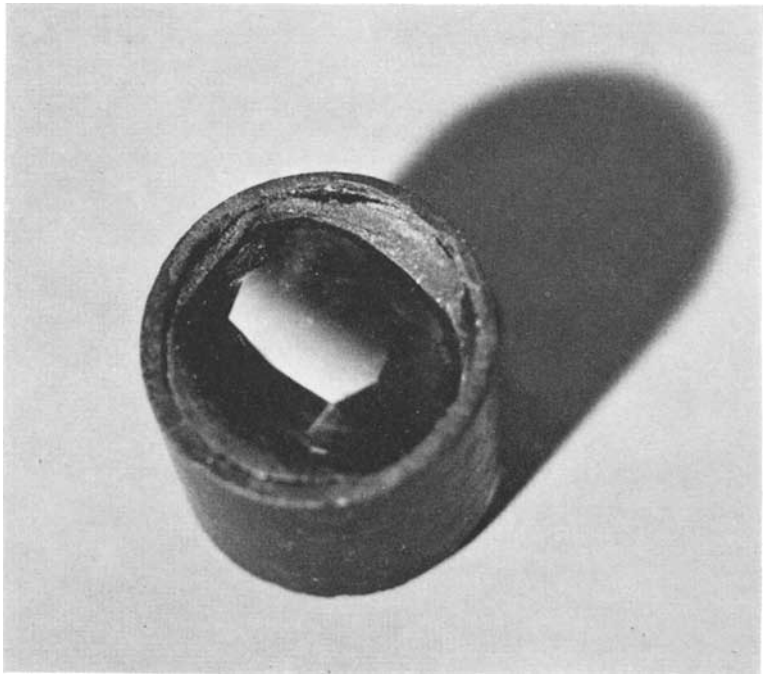

FIG. 3. A faceted amethyst mounted in clay within a sample-holder.

the juncture with the sample holder, and to avoid this break in the conducting surface, the samples are usually daubed with silver or gold paint (Fig. 5), especially at the contact with the sample holder.

4. The gems are now ready for analysis and are placed in the brass module depicted in Fig. 6. This module has five holes (the centre one is reserved for the standard disc) and thus can hold four faceted gems or four discs with up to 19 chips of gem in each disc (Fig. 7).

One additional advantage of the microprobe is that it can accommodate sizeable gems. Figure 8 is a photograph of a 911 carat aquamarine mounted on a module and ready for insertion into the microprobe. Mounted jewellery could also be placed directly in the microprobe, if the need arose.

Due to the essential requirement that the samples have a flat polished surface lying horizontal in the microprobe to insure an

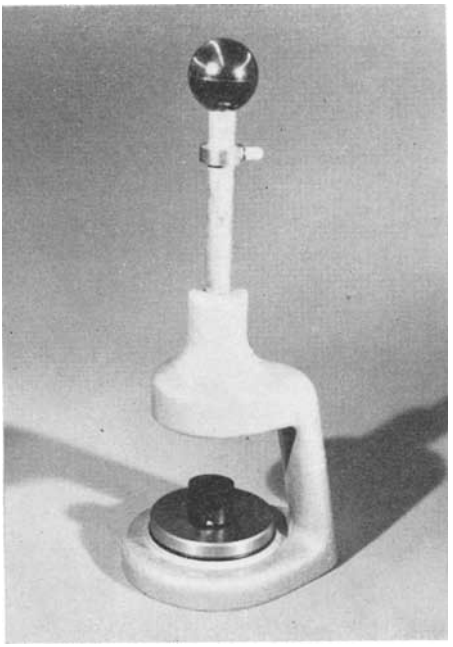

FIG. 4. A levelling press used to obtain horizontality of the surface to be analysed.

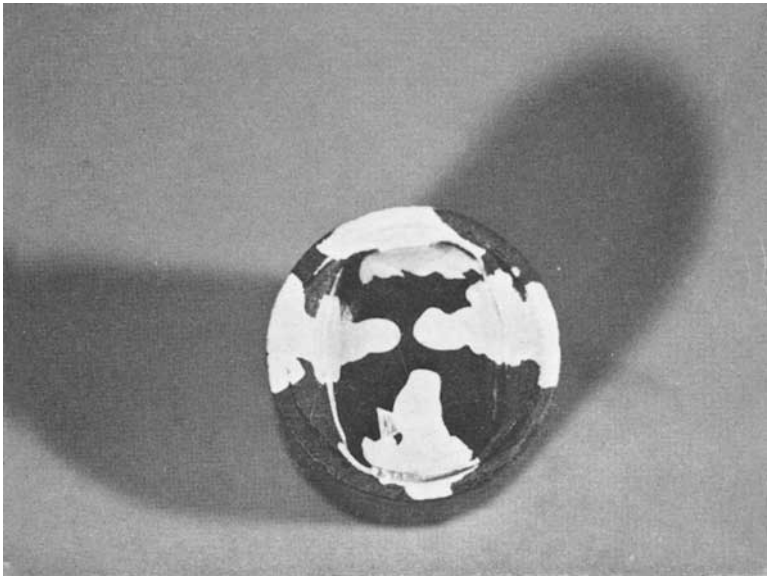

FIG. 5. The faceted amethyst of Figure 3, coated with silver paint to ensure electrical conductivity. The gem will be analysed on the clear, non-painted areas.

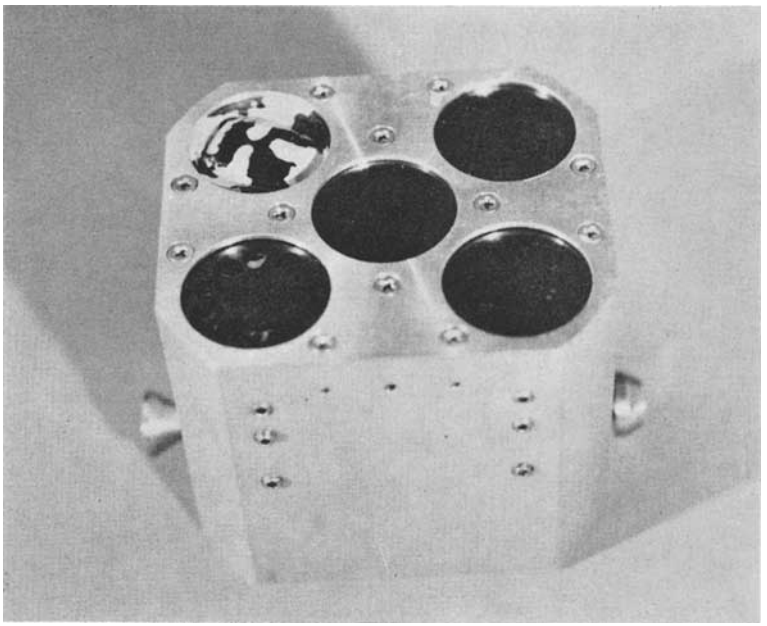

FIG. 6. A module for holding sample discs and gems.

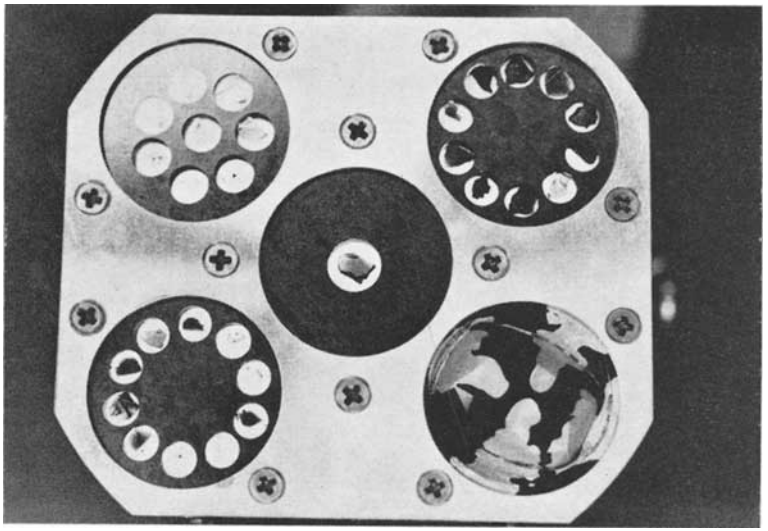

FIG. 7. Top-view of the module of Figure 6. The single fragment mounted in the centre is for analysis of an exposed inclusion of apatite. The amethyst shown in Figures 3 and 5 is mounted in the lower right position.

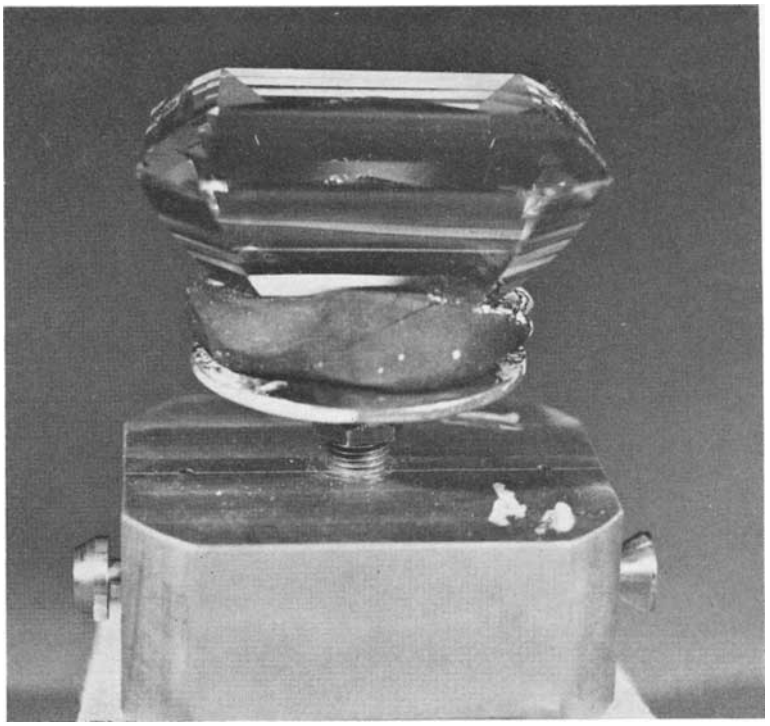

FIG. 8. A 911 carat aquamarine mounted on a module for insertion into the microprobe.

accurate analysis, cabochons cannot be analysed easily in the probe. To analyse a cabochon, it would be necessary to polish a flat on the bottom of the stone. Qualitative results could be obtained without this flat facet, but a really accurate analysis would necessitate it.

In summary, the electron microprobe is a most useful tool to the research gemmologist or mineralogist, and its full potential in gemmology might not yet be realized. More so than any other instrument, it has allowed us to omit the over-qualified "maybe" from the identification of gemstone inclusions and allowed us to define and characterize such inclusions with certainty.

The author is indebted to Mr Eugene Jarosewich, Supervisor of the chemical laboratory in the Department of Mineral Sciences, Smithsonian Institution, for a critical reading of the manuscript and helpful suggestions for improvement.

REFERENCE

Wilson, W. E. (1972). *The State of the art: the electron microscopes and electron microprobe.* Min. Record, 3, 4, 151–164.

Gemmological Abstracts

AKIZUKI (M.). *Gemstones with optical effect: pt 3.* Journal of the Gemmological Society of Japan, 1976, 3, 2, 51-56. (In Japanese, summary in English.)

Recent studies in this area include some on aventurine feldspars but no cause for the origin of hematite in the feldspar has yet been discovered. Flakes of hematite in labradorite from Labrador, which are arranged in straight lines, may be following dislocation lines in the host. Chatoyancy and asterism are also discussed. M.O'D.

BANK (H.). *Gemmologische Kurznachrichten.* (Gemmological short notes). Z.Dt. Gemmol. Ges., 1976, 25, 2, 106-112.

Six short notes by the author. (1) Cuttable villiaumite from Los Island (Guinea). This cut reddish stone has n=1·328, density 2·79, hardness only 2. (2) Natural colourless beryls covered with synthetic emerald after Lechleitner; constants are given, as also of (3) colourless topaz covered with synthetic emerald according to Lechleitner: the "kernel" of topaz has been determined by x-ray diffraction. (4) In this case a reputed synthetic emerald with beryl kernel was shown to be a doublet using topaz. (5) A case is described where zoisite was mistaken for vesuvianite and lastly (6) a reputed synthetic spinel was shown to be a pale green grossularite from Kenya. E.S.

BANK (H.) and OKRUSCH (M.). *Über Rubin Vorkommen in Marmoren von Hunza-Pakistan.* (About occurrences of rubies in the marbles of Hunza, in Pakistan.) Z.Dt.Gemmol.Ges., 1976, 25, 2, 67-85. 12 illus., bibl.

Gem quality, cuttable rubies and well coloured spinels which were not of cuttable quality have been found in the marbles in the Hunza valley in Pakistan, north-west of the Karakoram mountains of Kashmir. The marble forms concordant intercalations within sillimanite-bearing garnet-biotite-plagioclase gneisses and mica schists. The metamorphic sequence is cut by discordant aplite and pegmatite dykes. Details are given of the micro-analysis showing quantities of chromium and iron contents in the rubies and in three colour varieties of spinel. The Hunza rubies have the same purity, transparency and colour as those from Burma, while the spinels found so far are not of gem quality. The formation of corundum in the Hunza marbles was caused by an enrichment of alumina in the parent material. The uncommon rock chemistry is best explained by lateritic weathering of impure limestone. Metamorphic conditions are estimated from experimental data as about 600-620°C at a total fluid pressure of 7 kilobars. The CO_2/H_2O ratio in the fluid phase should have been roughly 20:80. E.S.

BOATWRIGHT (C.). *Unusual jade-like quartz from Georgia.* Rocks & Min., 1976, 51, 20-21. 1 fig.

Green quartz, of lapidary quality, occurs in veins east of Marietta, Cobb County, Georgia. The colour is caused by unidentified green inclusions. R.S.M.

BOSCARDIN (M.), DE MICHELE (V.) and MATTIOLI (V.). *Lo smeraldo della Val Vigezzo (Ossola).* (Emerald from Val Vigezzo, Ossola). La Gemmologia, 1976 II, 1, 21-26.

Emerald from this locality in Ticino, Italy, was discovered as recently as 1974. It occurs with albite and is semi-transparent, with inclusions which may be bertrandite, chlorite or cookeite. Accessory minerals include a blue tourmaline, zircon and clinochlore. Chromium content was estimated at up to 0·05%. Specific gravity was between 2·69 and 2·72, the latter value being for a crystal of good colour. The R.I. for the ordinary ray was measured as 1·5905 and for the extraordinary ray as 1·5834. This gives a birefringence of 0·0071. Pleochroism was distinct but no absorption spectrum was seen. However, the infrared spectrum closely resembled that of stones from Muzo, Colombia. M.O'D.

BROWN (G.), MOULE (A. J.) and O'NEAL (R. L.). *The radiopacity of some common gem minerals.* Australian Gemmologist, 12, 8, 241-247. 5 illus.

An attempt to use the varying opacity of different gems to x-rays as a testing factor. An x-ray source and a densitometer are needed and it is evident that the method is slow and demonstrably vague unless one is authenticating diamond. No mention is made of colour changes, temporary or otherwise, produced in some species (e.g. corundum) when exposed to x-rays. The authors come to conclusions which are already well established. R.K.M.

DIEHL (R.) and BANK (H.). *Einige neuere Synthesen und künstliche Produkte in durchsichtigschleifwurdiger Form.* (Some new syntheses and artificial products in transparent and cuttable form). Z.Dt.Gemmol.Ges., 1976, 25, 2, 104-106.

The article deals with six products which are usable as gems. (1) Zinc blende and wurtzite, ZnS, both colourless imitations of diamond: R.I. 1·81 (thus higher R.I. than normal refractometer reading); very soft, Mohs scale 3–4; zinc blende is cubic, wurtzite hexagonal; both can be coloured green with cobalt, yellow with nickel and pale green with copper. (2) $RbMnF_3$, rubidium manganese fluoride, is a synthetic product which can be produced in long pink single crystals with a diameter of 10·15 mm by drawing out of the melt, hardness 4; S.G. 4·31; R.I. $1{\cdot}428 \pm 0{\cdot}001$. (3) LiF, cubic lithium fluoride, used in the optical industry because of its low R.I., colourless but can be coloured yellow with chromium. (4) MnF_2: this manganese fluoride is brown/pink, tetragonal; D.R. 0·030; hardness 4; density 3·93. (5) $YA10_3$, yttrium aluminium garnet (YAG), orthorhombic; density 5·36; R.I. $1{\cdot}90 \pm 0{\cdot}05$; hardness $8\frac{1}{2}$; colourless, but can easily be coloured; of importance to gemmology and for laser work. (6) Greenockite, CdS: crystallization hexagonal, similar to wurtzite; density 4·79; hardness 3–4; doubly refractive, $n = 2{\cdot}50$; used for its photoelectric properties. E.S.

DITCBURN (R. W.), TABOR (D.), FRANK (F. C.), MITCHELL (E. W. J.), EVANS (T.), LOUBSER (J. H. N.) and ROSENBERG (H. M.). *The future of diamond research.* Diamond Research 1976 (Industr. Diamond Inform. Bur.), 4-6.

Each of these authors offers individual thoughts on what results future research may bring. In addition to work giving a better understanding of present results or which represents extension or completion of work now in progress, new and unexpected discoveries may be concerned with studies of the phases of carbon

at very high P and T, the behaviour of diamond under very high densities of UV or x-radiation, the electrical properties of He-doped diamond, the petrogenesis of diamond-bearing rocks, the solubility and diffusion of nitrogen at very high P and T, bonding at diamond surfaces, the surface chemistry of diamond, the production of synthetic diamonds for maser use, and the high velocity of sound waves in diamond. R.A.H.

DOLENC (M.). *Das Tansanitvorkommen Merelani in Tansanien.* (The Merelani deposit of tanzanite in Tanzania). Z.Dt.Gemmol.Ges., 1976, 25, 2, 86-95. 5 illus. bibl.

The tanzanite deposit at Merelani, south-west of Moshi, is connected to the marble and gneiss complex of the Usagaran system of Late Archaean. Zoisite appears as a fissure-filling mineral in the graphite gneiss, amongst quartz boudins. Quartz and gneiss must relate in such a manner that conditions are right for the formation of fissure-filling material. A part of the zoisite is formed as tanzanite. Amongst accompanying minerals are green tourmaline and vanadian grossularite. E.S.

FAYAZ (H.) and FORGHANI (A.-H.). *The turquoise of Iran.* Rocks & Min., 1975, 50, 526-528. 3 figs.

Blue, bluish-green, and green cryptocrystalline turquoise occurs in nodules and veinlets in volcanic rocks near Neishabur, Khorassan Province, north-eastern Iran. The mine has a 1,000 year history. The petrography of the associated trachyte is given. R.S.M.

GLOBOVITCH (B. A.). *Les richesses de Leningrad.* (The riches of Leningrad). Revue de Gemmologie, 1976, 47, 14-15.

A short account of the gem materials displayed in the museums of the city and in particular that of the School of Mines. M.O'D.

GRAMACCIOLI (C. M.). *Lo zircone: una pietra interessante.* (Zircon: an interesting stone). La Gemmologia, 1976, II, 1, 16-20.

An account of the types and occurrences of zircon, some of which are illustrated in colour. M.O'D.

GÜBELIN (E.). *Zum Problem des Farbwechsels im Alexandrit.* (The problem of colour-change in alexandrite). Z.Dt.Gemmol.Ges., 1976, 25, 2, 96-102. 3 illus., bibl.

The colour-change in alexandrites seems to be brought about by chromophore chrome-atoms taking the place of Cr^{3+}ions in the octahedric co-ordination which is usually taken up by Al^{3+}ions: this replacement takes place twice, once in the normally-sized lattice and once in the "small" lattice. In order to push sufficient numbers of Cr^{3+}ions into the small lattice either high temperature/low pressure or extremely high pressure/low temperature is necessary. These rare conditions occur very infrequently in the formation process of chrysoberyls, so that specimens with good colour-change are very rare. E.S.

HUDSON (P.R.W.). *A review of the thermal properties of natural gem diamond.* Australian Gemmologist, 1975, 12, 9, 286-290. 3 figs.

A résumé of papers on this essentially industrial attribute of diamond. Heat conductivity is five times that of pure copper, and diamond, apart from the very rare type IIb, is an electrical insulator. Presence of nitrogen, and unidentified "platelets" parallel to the cube form, in type Ia, and nitrogen in type Ib, reduce the thermal conductivity. Type II diamonds, the purest material, are the best thermal conductors but IIb is electrically a semi-conductor. Because of these facts diamond is an excellent abrasive not only because of its extreme hardness but also because it conducts heat away from the point of friction with sufficient speed to avoid graphitization. More importantly diamond, apart from type IIb, is extremely useful as an electrically insulated heat-sink in present day miniaturized electronics. Although only a precis of available information this is a highly technical paper and is not easily understood in detail. Such expressions as "10^4W m^{-1} c^{-1}" are meaningless to the average gemmologist and need explanation. Some of the data refer to the performance at $-173°C$, the optimum temperature for thermal conductivity. Generally, the facts given are either of purely scientific or of industrial importance rather than gemmological. The Editor attempts to simplify one definition but in so doing reduces its accuracy. R.K.M.

JONES (D. A.). *Stockbarger crystal growth, optical assessment and laser performance of holmium-doped yttrium erbium lithium fluoride.* Journal of Crystal Growth, 1975, 30, 21-26.

Single crystals of this material have previously been grown by the top-seeded solution growth method. Growth by the Stockbarger technique has been shown to produce crystals with an improved laser performance and with a high degree of optical homogeneity. No light scattering centres occur in the visible region of the electromagnetic spectrum. The method cannot, however, produce crystals oriented along a definite crystallographic direction. M.O'D.

KOSEL (G. E.). *The prairie agate—Nebraska's state rock.* Rocks & Min., 1975, 50, 613-614.

The "prairie agate" described is a banded chert of red, yellow, tan, blue, and grey colour. It occurs in the north-western and central western parts of the state, although its original source is Wyoming. Colourful chalcedony also occurs in Dawes and Sioux Counties, Nebraska. R.S.M.

LAPWORTH (P.). *Jet.* Australian Gemmologist, 1975, 12, 8, 248-250.

An account of jet and jet mining particularly from a historical viewpoint. R.K.M.

MOORE (P. B.) and ARAKI (T.). *Painite, $CaZrB[Al_9O_{18}]$: its crystal structure and relation to jeremejevite $B_5[\square_3Al_6(OH)_3O_{15}]$ and fluoborite, $B_3(Mg_9(F,OH)_9O_9)$.* Amer. Min., 1976, 61, 1/2, 88-94.

Painite was found to possess a rigid and dense octahedral framework topologically identical to that of jeremejevite and fluoborite. The chemical composition, obtained from electron probe analysis, is proposed as $CaZrBAl_9O_{18}$. M.O'D.

NICHOL (D.). *Nephrite jade deposits.* Australian Gemmologist, 1975, 12, 7, 220-221.

An account of nephrite deposits at Cowell, S. Australia. Material is said to be similar to that found in New Zealand and other places. An estimated 45,000 tonnes is thought to be available. R.K.M.

ONOTAKE (H.). *Historical development of cultured pearl industry in Japan.* Journal of the Gemmological Society of Japan, 1976, 3, 1, 14–16. (In Japanese).

A chronological review of the cultured pearl industry in Japan begins with this article. M.O'D.

OUGHTON (J. H.). *New synthetic gems set a problem.* Australian Gemmologist, 1975, 12, 7, 222-226.

A general account of synthetics which have appeared in recent years, including synthetic alexandrite, opal, YAG "garnet" imitations of diamond, hydrothermal and flux-fusion rubies and emeralds, synthetic turquoise, synthetic quartz and a synthetic purple zircon (not available commercially). Laser drilling and irradiation of natural diamond to improve clarity and colour, and various doublets are also discussed although outside the subject of the paper. R.K.M.

POULLEN (J.-F.). *Un gisement exceptionnel : le grenat demantoide de Sferlun, Val Malenco, Italie.* (An exceptional location: demantoid garnet from Sferlun, Val Malenco, Italy). Revue de Gemmologie, 1976, 40, 2-6.

Val Malenco lies about 130 km north of Milan and has long been known for its fine demantoid garnets. Artinite and perovskite are found in association, and melanite is also found. Chemical analyses and comparative absorption spectra are given. M.O'D.

POVARENNYKH (A. S.), PLATONOV (A. N.), TARASHCHAN (A. N.) and BELICHENKO (V. P.). *The colour and luminescence of tugtupite (beryllosodalite) from Ilímaussaq, South Greenland. (Contributions to the mineralogy of Ilímaussaq, no. 21)* Grønlands Geologiske Undersøgelse, 1971, Bulletin no. 95 (II).

The cause of the luminescence of tugtupite was established as S_2^- molecular ions taking up the position of Cl ions in the structure. These ions may also be the cause of the colour, together with other radiation centres of lower thermal stability. M.O'D.

SØRENSEN (H.), DANØ (M.) and PETERSEN (D.). *On the mineralogy and paragenesis of tugtupite. (Contributions to the mineralogy of Ilímaussaq, no. 20).* Grønlands Geologiske Undersøgelse, 1971, Bulletin no. 95 (I).

Tugtupite is $Na_8Al_2Be_2Si_8O_{24}(Cl,S)_2$ and is a member of the tetragonal crystal system. It forms triplet twins on {101}. Data on the mineral include c:a 1·0269 ± 0·0003, d = 2·33 gm/cm³, n_e 1·499 ± 0·001, n_w 1·495 ± 0·001, a_o = 8·637–8·643, c_o = 8·867–8·870, V_o = 662A³. It occurs in hydrothermal veins in the Ilímaussaq alkaline intrusion, South Greenland, and in the Lovozero alkaline intrusion, Kola Peninsula. It is associated with albite, analcime and lithium mica. M.O'D.

SUTTON (J. & P.). *Crystallography is fun.* Australian Gemmologist, 1975, 12, 7, 210-220. 16 figs.

A detailed account of the method of making a model of the atomic structure of the diamond unit cell and of methods of producing cubic crystal models from cubes of expanded polystyrene. Deals with cubic system only and, by implication, erroneously includes the icositetrahedral form among those of diamond. The double unit-cell model illustrated would be better if the atom bonds were differentiated from the cubic framework by colouring them differently. Ideally the cube outline should not be included in the model. Diagrams relating the eight basic forms to the cube and to each other are well drawn and helpful in identifying Miller indices. R.K.M.

TAKENOUCHI (S.). *Basic knowledge on studies of fluid inclusions in minerals: part 5.* Journal of the Gemmological Society of Japan, 1976, 3, 1, 25–31. (In Japanese).

Inclusions typical of pegmatite minerals, especially quartz and beryl, are studied; they are compared with inclusions from hydrothermal minerals. Gases from diamond crystals have been analysed. M.O'D.

TROSSARELLI (C.). *Il rifrattometro.* (The refractometer). La Gemmologia, 1976, II, 1, 5-13.

A summary of the use of the refractometer and the various types available. The principle of total internal reflection is described. M.O'D.

VANDENBERGE (G.). *Blauw Zoisiet of Tanzaniet.* (Blue zoisite of Tanzania). Bulletin, Société Belge de Gemmologie, 1976, 2, 1-4.

A summary account, with two photographs, of the blue variety of zoisite found in Tanzania. M.O'D.

VAN DE WALLE (P.). *Le filtre à émeraude.* (The emerald filter). Bulletin, Société Belge de Gemmologie, 1976, 1, 2-3.

A list of the uses of the Chelsea colour-filter with a number of stones and their appearance specified. M.O'D.

WANKLYN (B. M.), GARRARD (B. J.) and WONDLE (F.). *Flux growth of some fluoride crystals under reducing conditions* (VF_2,$K_5V_3F_{14}$,$KTiF_4$)*: pt 3.* Journal of Crystal Growth, 1976, 33, 165-8.

Crystals of some fluorides were grown in strongly reducing conditions with a vertical tube furnace. An atmosphere of hydrogen and nitrogen gave the required reduction. M.O'D.

WATANABE (J.), YOSHINO (F.) and HASEGAWA (T.). *Structure of etch pits and light figures developed on diamond surfaces.* Journal of the Gemmological Society of Japan, 1976, 3, 2, 57-63. (In Japanese, summary in English).

Two methods of etching are described. The {111} surface is covered with etch pits of triangular pyramidal shape surrounded by side faces inclined at 11·5°

against the {111} plane. The {100} surface etched by one of the methods shows tetragonal-pyramidal etch pits with side faces at an angle of 28·5° against the {100} plane. M.O'D.

YOSHIMURA (J.) and KOHRA (K.). *Studies on growth defects in synthetic quartz by x-ray topography.* Journal of Crystal Growth, 1975, 33, 311-23.

Characteristic patterns of lattice disturbance due to 2-dimensional impurity distributions showed in Z-growth sectors. M.O'D.

ZAPATERO (L.). *Inclusiones fluorescentes en cuarzo.* (Fluorescent inclusions in quartz). Boletin del Instituto Gemologico Español, 1976, 13, 15–21. Illus. in colour.

These include negative crystals, two-phase inclusions, polyphase inclusions with bituminous solid matter and liquid and gas; some liquid inclusions are paraffin, which may fluoresce. M.O'D.

ZEITNER (J. C.). *The southwest: a mineral rich land.* Lapidary Journal, 1976, 30, 1, 50–62. Illus. in colour.

A review by state of the ornamental minerals of the area. M.O'D.

ZEITNER (J.). *False names, real names, trade names.* Lapidary Journal, 1976, 30, 4, 1070-75.

A list of undesirable names applied to minerals and gemstones. M.O'D.

NOTE.—*Bulletin, Société Belge de Gemmologie* (Belgische Vereniging voor Edelseenkunde) is a new journal, reproduced from typewriting but containing some interesting articles. It is published from 118, rue du Midi, Brussels, and the annual subscription is B fr 400.

Revue de Gemmologie is the new title of the former *Bulletin de l'Association Française de Gemmologie;* the numeration continues without a break. M.O'D.

BOOK REVIEWS

CAVENAGO-BIGNAMI (S.). *Manuale di gemmologia.* Ulrico Hoepli, Milan, 1973. pp. xix, 193. Illus. in colour. L 4000.

A beautifully-illustrated small guide to the commoner gemstones, this book is well worth obtaining for the photographs alone. Preceded by a short section on basic gemmology, most of the book consists of short descriptions of gems in rough order of accepted value. An illustration of an elephant carved from Tanzanian ruby is particularly impressive—that of ruby in zoisite from the same country is out-of-focus. Crystal system, chemical composition, hardness, specific gravity and refractive index are given for each species. M.O'D.

MACINTOSH (E. K.). *A guide to the rocks, minerals and gemstones of Southern Africa.* C. Struik, Cape Town, 1976. pp. 96. Illus. in colour. £4·00.

This book is presumably intended for the amateur collector and deals almost exclusively with the Republic of South Africa and with South-West Africa. A short introduction to the crystal systems is followed by a descriptive section making up most of the remainder of the book and arranged by major and minor rock-forming minerals, the major rock groups, minerals of economic importance; despite the title gem materials are fitted into appropriate sections and are not awarded a section on their own. Specific gravity is perversely abbreviated as relative density; there are some misconceptions on the colouring of quartz varieties which are attributed to the hexagonal system although the trigonal system is separately treated in the introduction; none of the representations of water-melon tourmaline actually depict this species; the section on garnet is useless as an introduction. No doubt the rest of the book is equally rich in errors and slack writing; like many other works aimed at the amateur, this book shows up the insufficient critical apparatus possessed by the author, who must seek the aid of a guide to his sources before he writes another book. M.O'D.

PEARL (Richard M.). *Garnet, gem and mineral.* Earth Science Publishing Co., Colorado Springs, Colorado, U.S.A., 1975. pp. 24. Illus. $1·00.

A general introduction to the garnet group of minerals with notes on their crystallization and other relevant data. Some undesirable names are included in the glossary but marked by quotes. M.O'D.

PEARL (Richard M.). *Turquoise.* Earth Science Publishing Co., Colorado Springs, Colorado, U.S.A., 1976. pp. 32. Illus. $1·35.

A well-written short guide with special reference to North American deposits and fashioning of turquoise. The material was and is of great importance to the North American Indians and some references to their superstitions are included. M.O'D.

SINKANKAS (John). *Gemstones of North America in two volumes. Vol. 2.* Van Nostrand Reinhold Co., New York, 1976. pp. xv, 494. Illus. in black-and white and in colour. $30·00.

Volume one of this standard work was first published in 1959*; in this second volume some earlier material is included where the author felt it was needed, but in the main all the information here is new. As in the earlier volume the materials are listed in general order of importance and within this category by area of deposit. A large number of quoted personal communications are especially valuable and when taken with the superb bibliography (by far the most exhaustive to appear on the subject and an enticing forerunner of the same author's projected general gemstone bibliography) make this book as authoritative as it is possible to be. This reviewer laments the paucity of information given in most gemmological texts (do most authors merely read books similar to their own?) and wishes that the general standard of writing on the subject was improved by a greater familiarity with material in other languages and from sources other than monographs which have the same readership. However this state of affairs may change in the future, this book shows the way that a country guide should be written. Each mine is briefly described with notes on its origin and ownership, with records of finds of particular importance and mention of their destination and present location. Information is as up-to-date as January 1975: the Tourmaline Queen mine at Pala, California, is now in operation once more—at least it was in December, 1975, when the author and the present reviewer were present and a fine crystal-bearing pocket was opened. The tourmalines from Newry, Maine, are given 13 pages of description, which is proportional to their importance. It is interesting to learn that the manganese-bearing red beryl from the Wah Wah Mountains in Utah has yielded some small cut stones: this material has the varietal name of bixbite. With regard to one of the minerals peculiar to the U.S.A., benitoite, it appears that the supply may be exhausted, since no accessory minerals are found in the lowest glaucophane schists and their altered phases. Willemite from Franklin is also exhausted and the mine flooded. A great deal of information is given on nephrite jade deposits (unfortunately the running head "Nephrite jade production in British Columbia" is allowed to run over into sections dealing with other areas) and these have been greatly developed since publication of the earlier volume. Alaska has alone produced some fine-quality nephrite.

As in the earlier volume, North America includes Mexico, Canada, parts of Central America and, by geographical convention, Greenland, so that some notes on tugtupite are included. The last chapter covers the history of North American gemmological literature—the only place where this information can be found. The bibliography itself is exhaustive; dates are given before volume and page numbers so that the reader can see quickly how current the information is.

This book is a model for a country guide and is quite essential for anyone with an interest in North American materials, indeed for anyone with any gemmological interests in any country. The price is quite reasonable for these days.

M.O'D.

*Reviewed in J. Gemm., 1960, VII, 5, 197–8.—*Ed.*

UEDA (R.) and MULLIN (J. B.). *Crystal growth and characterization. Proceedings of the ISSCG2 Spring School, Japan, 1974.* North-Holland Publishing Co., Amsterdam, 1975. pp. vii, 419. £16·15.

The second International Spring School on Crystal Growth was organized by the committees associated with the International Organization of Crystal Growth and the International Union of Crystallography; it was linked to the 4th International Conference on Crystal Growth held one week later in 1974. Proceedings of the first International Spring School (Hartman, ed.) dealt with nucleation theory and experimental techniques; this volume covers crystal growth and characterization. Early chapters include material on the practical growth of device-quality crystals and the basic science associated with the techniques used. Vapour phase, melt and solution growth are considered. A large number of illustrations in the text include excellent-quality reproductions of crystal dislocation effects. Each chapter includes its own bibliography, and there are subject and author indexes. M.O'D.

WENK (H.-R.). *Electron microscopy in mineralogy.* Spring-Verlag, Berlin, 1976. pp. xiv, 564. U.S. $39·40.

This book consists of a series of papers by various authorities on the uses of electron microscopy as applied to mineralogical topics. Many of the subjects treated are most interesting to the gemmologist with mineralogical leanings, and there are many excellent photographs. Each chapter includes its own bibliography and there is a general subject index. M.O'D.

Guidebook I to mineral collecting in the Maine pegmatite belt. Federation of Maine Mineral and Gem Clubs, 1974. pp. vi, 22. Price on application.

Complete directions and maps are given for a number of the classic localities, including Mt Mica and Newry. Owners are mentioned where appropriate. M.O'D.

Jahrbuch der Edelsteinkunde, 1976. (Gemstone Yearbook, 1976). Verlag Edelsteinlabor Dieter Pschichholz, 87 Würzburg, Domstrasse 13, West Germany. Price on application.

An excellent new venture containing accounts of new developments in gemmology over the year. Included are articles on inclusions in the new Lechleitner synthetic emerald, reviews of new instruments, including the Eickhorst Gemmodul-Kaltlichtspektroskop* and the Diamant-Photometer by the same manufacturer. The theme of diamond grading is prominent in the book, reflecting present interest throughout the trade. Other articles cover a variety of minerals and phenomena with a note on some synthetic materials by the present reviewer. M.O'D.

Treasures of the U.S.S.R. Diamond Fund. The Diamond Fund, Moscow, 1975. Unpaginated. Illus. in colour. Price about £11·50.

Each piece of jewellery is given brief captions in English and French, but the main descriptions are in Russian. The standard of reproduction of the photographs is fairly high, though not up to modern Western standards. The pieces illustrated are a selection only from the great wealth of the Fund. M.O'D.

*See J. Gemm., 1976, XV, 3, 136.—Ed.

ASSOCIATION NOTICES

OBITUARY

Professor Dr KARL F. CHUDOBA—A TRIBUTE

Professor Dr Karl F. Chudoba, whose death on 14th March last was briefly recorded in the October *Journal*, was one of a formidable series of German mineralogists who have given to our science a solidity and academic prestige it might have lacked without their aid. Bauer, Brauns, Schlossmacher, and Eppler, each in turn became so fascinated by gemmology that it is by their work in this special aspect of mineralogy that they will be chiefly remembered. Karl Chudoba, retired Professor of Mineralogy at the University of Göttingen, may be included in the same category, though mineralogists may reasonably maintain that his most important contribution to science lay in his continued scholarly series of additions to that most complete of all descriptive texts on minerals—Hintze's "Handbuch der Mineralogie", which first appeared in the eighteen eighties, and has since spread like some coral reef along the shelves of our largest libraries.

Chudoba's first impact on gemmology resulted from research work carried out with M. von Stackelberg in 1936—just forty years ago—in which for the first time a satisfactory explanation was discovered for the great variations in the density and refractive index of gem zircons from the Ceylon gravels, which had puzzled two generations of scientists. I had been able to lend him for this investigation a green zircon of exceptionally low density (3·97), in which x-ray analysis showed that the tetragonal lattice had broken down, leaving amorphous silica and zirconium oxide, partly crystallized in the cubic modification.

This important disclosure of what we now refer to as the metamict state (later fully exemplified in the radioactive gem mineral, ekanite) was presented by Chudoba in a simplified form in an article which appeared in the *Gemmologist* for November 1937.

This was followed by another article on the low hardness of metamict zircon. Soon the advent of war imposed a gap of about ten years before the work of German scientists became once more known to us in this country. But from 1952 onwards many of Chudoba's papers (chiefly on the causes of colour in gemstones) became available, being published either as abstracts or in full in this *Journal*. Already the author of a textbook of mineralogy, Prof. Chudoba, in collaboration with Dr E. Gübelin, also published two useful gemmological books, "Echt oder synthetisch?" and "Edelsteinkundliches Handbuch", the latter rather in the style

of Webster's "Compendium". The third edition of this appeared as recently as 1974. Professor Chudoba joined Professor Eppler in representing Germany in meetings of the International Gemmological Conferences held in many of the capital cities of Europe, and he and his wife Lotte were popular figures at these gatherings, until his health became too precarious for such activities. But his bibliographical work continued to the end, particularly as an Editor of "Hintze". In this field it seems unlikely that his thoroughness and assiduity will ever be matched. Those who knew him will remember with gratitude his gift for warm-hearted friendship. B.W.A.

GIFTS TO THE ASSOCIATION

The Council of the Association is grateful to the following for their gifts:

Mr D. M. Arandara, Seven Kings, Ilford, for 90 ct of rough Sri Lankan gem materials, including some crystals.

Dr Donald L. Marchbanks, Salina, Kansas, U.S.A., for specimens of Gilson synthetic lapis lazuli and Gilson synthetic turquoise with matrix streaks.

Mr J. M. Marshall, F.G.A., South Bend, Indiana, U.S.A., for a collection of coloured slides of inclusions in diamonds and other gemstones suitable for use for study purposes.

Mr E. A. Thomson, London, for a very dark, almost black, small round iron-rich cut spinel having a R.I. of about 1·78 with S.G. in the region of 3·90 from Thailand.

During the early part of 1975 Mr Joseph Best, F.G.A., Santa Barbara, California, U.S.A., presented the Association with a comprehensive collection of synthetic materials. Since then Mr F. G. French, F.G.A., Purley, Surrey, has very kindly produced cut and polished specimens from most of that synthetic material, so that the Association now has an excellent collection of rough and cut specimens of less common synthetic materials.

MEMBERS' MEETINGS

London

A talk was given at Goldsmiths' Hall, London, on 11th October, 1976, by Mr P. G. Read, C.Eng., M.I.E.E., M.I.E.R.E., F.G.A., Technical Manager for the Diamond Trading Co. Ltd., entitled "Automation in sorting of rough diamonds". The substance of his talk will be given in a future issue of the *Journal*.

Midlands Branch

On the 30th September, 1976, at the Royal Institution of Chartered Surveyors, Birmingham, a talk was given by Mr R. Huddlestone entitled "An approach to diamond colour-grading".

Mr P. G. Read gave a repeat of his London lecture, "Automation in sorting of rough diamonds", on the 17th November, 1976, at the Royal Institution of Chartered Surveyors, Birmingham.

North-West Branch

The Annual General Meeting of the Branch was held on the 14th October, 1976, at Church House, Liverpool. Mr J. G. Roach and Mrs D. M. Brook were

re-elected Chairman and Secretary respectively. During the evening Mr J. L. Pyke, F.G.A., gave an illustrated talk on his visits to the emerald mines of Colombia and various Far Eastern gem mining deposits.

Scottish Branch

On the 24th November, 1976, at the Royal British Hotel, Edinburgh, Mr Alastair Cairncross, F.G.A., gave a talk entitled "Scottish pearls", accompanied by two films on the same subject. Members were also able to examine specimens.

GEM DIAMOND EXAMINATION 1976

Thirty-four candidates entered for the Association's 1976 Gem Diamond Examination, of whom twenty-eight qualified, three with distinction. The following is a list of successful candidates arranged alphabetically.

Qualified with Distinction

Benjamin, John C., Wembley Park.
Garcia Abril, Ana, Valencia, Spain.
Gomez Perez, Pila, Valencia, Spain.

Qualified

Alvarado Moro, Odorico, Barcelona, Spain.
Cartwright, Donald R., Little Bookham.
Carrera Poblet, Jaime, Barcelona, Spain.
Cidoncha Garcia, Miguel, Valencia, Spain.
Clarkson, Roland N., Chessington.
Harding, J. L., London.
Hewson, Robin J., Crowthorne.
Horder, Heather A., Windsor.
Iwahori, Mitsuo, London.
James, Alan R., Walsall.
Jones, Alison R., Woking.
Lewis, Sheila J., Kenton.
Marsal Astort, Montserrat, Barcelona, Spain.
Maurer, Robert J., Brentwood.
Mayor Giner, Enrique, Vinaroz, Castellon, Spain.
Morrill, Christine, Cambridge.
Padro Tortajada, Angeles, Barcelona, Spain.
Read, Peter G., London.
Sanchez Almer, Javier, Castellon, Spain.
Sanchez Garcia, Paloma, Valencia, Spain.
Thomas, Geoffrey A., Hertford.
Tolmie, Andrea J., Lynn Stonnall.
Wharton, Stuart, St. Albans.
Wisdom, Terence R., Chorleywood.

EXAMINATIONS IN GEMMOLOGY 1976

In the 1976 examinations in gemmology, organized by the Gemmological Association of Great Britain, 755 candidates sat for the preliminary examination and 413 for the diploma examination. Overseas centres were established again in many parts of the world.

Upon the recommendation of the Examiners, the Tully Memorial Medal has been awarded to Dr Joel E. Arem, of New Carrollton, Maryland, U.S.A.

Mme Genevieve Bourdon Destrem, of Paris, France, was commended by the Examiners for her excellent work.

The Rayner Prize, in the preliminary examination, has been awarded to Mr Aarne Alhonen, of Salpakangas, Finland.

The following is a list of successful candidates, arranged alphabetically.

DIPLOMA EXAMINATION

Tully Memorial Medal

Arem, Joel E., New Carrollton, Md, U.S.A.

Qualified with Distinction

Arem, Joel E., New Carrollton, Md, U.S.A.
Baker, Elaine C., Lihue, Hawaii, U.S.A.
Bourdon Destrem, Genevieve M. C., Paris, France.
Fenoll Hachi-Ali, P., Barcelona, Spain.

Qualified

Abraham, Robert, Amsterdam, Holland.
Alabaster, Stephen P., Birmingham.
Aloy, Richard N., Allhallows.
Alvarado Moro, Odorico, Barcelona, Spain.
Ambjornsen, Truls P., Fredrikstad, Norway.
Anandavadivel, Kumarasamy, Ratmalana, Sri Lanka.
Asano, Yoshio, Kyoto, Japan.
Baird, Donald D., London
Baldock, Lynette, Weston.
Beck Kaiser, Margrit, Barcelona, Spain.
Blackley, Robert, London.
Bolli, Bruno, St Gallen, Switzerland.
Borscho, Shirley J., Plymouth.
Bratton, Timothy J., Sidcup.
Byfleet, Anne P., Doncaster.
Callaghan, Christopher C., Port Elizabeth, S. Africa.
Chapellier, Dominique M. B., Lausanne, Switzerland.
Collier, John M. B., Fordingbridge.
Comin Vilajosana, Luis, Barcelona, Spain.
Cook, Judith A., Northwood.
Elliott, Douglas H., Nairobi, Kenya.
Eldridge, Maurice W., Sheffield.
Engelbrecht, Johann P., Pretoria, S. Africa.
Engineer, Thrity P., Bombay, India.
Evans, Mark, London.
Fabregas Guardiola, Virginia, Barcelona, Spain.
Falomir Penarrocha, Amadeo, Valencia, Spain.
Ferrandis Recatala, Juan V., Valencia, Spain.
Ferrando Lario, Salvador, Valencia, Spain.
Flewelling, Arthur G., Arthur, Ont., Canada.
Furuya, Masashi, Tokyo, Japan.
Gaarder, Kierstin, Voyenenga, Norway.
Garcia Pilan, Alfonso, Valencia, Spain.
Giereke, Nicolaus, Hamburg, Germany.
Goh, Kong B., Petaling Jaya, W. Malaysia.
Goto, Midori London.
Gulliksen, Gunnar B., Gol, Norway.
Hanni, Henry A., Basel, Switzerland.
Hayes, Elizabeth A., Ossett.
Heckman, Hayo W., The Hague, Holland.
Hendrickson, James E., Los Altos, Cal., U.S.A.
Holdroyd, Donna J., Oslo, Norway.
Hornytzkyj, Seppo, Helsinki, Finland.
Hudspith, James W., Leatherhead.

Jayakody, Don F., Ja-Ela, Sri Lanka.
Jefferson, Barbara J., London.
Judez Martinez, Gregorio, Valencia, Spain.
Junquero Abellan, Ramon, Valencia, Spain.
Koivula, John I., Seattle, Wash., U.S.A.
Kurata, Yukiko, Tokyo, Japan.
Leach, Jane, London.
Lewis, Ian R. M., Sheffield.
Lo, Louis Y., Hong Kong.
Maeda, Kikuko, Tokyo, Japan.
Mahendrarajah, Maureen, Colombo, Sri Lanka.
Matsui, Reiko, Tokyo, Japan.
Miller, Duncan E., Cape Town, S. Africa
Mills-Owens, Paul, London.
Moline Sala, Agustin, Barcelona, Spain.
Moller, Peter J., Tully, N. Qld, Australia.
Mollfulleda Buesa, Antonio, Barcelona, Spain.
Monche Maristany, Alicia, Barcelona, Spain.
Montserrat Nebot, Alfredo, Barcelona, Spain.
Mora Carbonell, Antonio R., Valencia, Spain.
Moses, Heather, London.
Need, Mary, Lelant Downs.
Oclee, Caroline H., Hythe.
Oliver, Peter J., Wellington, New Zealand.
Oria Albero, Isabel J., Valencia, Spain.
Oria Albero, Maria P., Valencia, Spain.
Pandithakoralege, Don R. M., Nugegoda, Sri Lanka,
Pender, Harold, Kenilworth.
Piech, Olwen, Bushey Heath.
Pinder, William R., Cairne, Qld, Australia.
Poel, Melvin C., Solihull.
Pons Gomez Joaquin, Barcelona, Spain.
Prat Moya, Sagrado C., Barcelona, Spain.
Pratt, John C., Toronto, Ont., Canada.
Ralston, Jonathan B., London.
Ranasinghe, Mahesha, Yogiyana, Sri Lanka.
Read, John V., Randburg, Transvaal, S. Africa.
Ribes Cudinach, Emilio, Barcelona, Spain.
Richards, Nancy A., Fredericton, N.Br., Canada.
Richards, Patsy-Ruth, Brisbane, Australia.
Rider, Stephen G., Leatherhead.
Ruiz Roca, Jose V., Valencia, Spain.
San Juan Ribes, Antonio, Valencia, Spain.
Sant' Angelo, Louis, London.
Sieders, Margaretha E. Den Haag, Hollan d
Sigl, Berta, Sargans, Switzerland.
Simonin, Daniel, St Gallen, Switzerland.
Snow, John J., Brisbane, Australia.
Speekenbrink, Wilhelmus A. M., Den Haag, Holland.
Staver, John, Virginia, Minn., U.S.A.
Storr, Jonathan, Lincoln.
Stromnaes, Bjorn, Oslo, Norway.
Suzuki, Yusaku, Tokyo, Japan.
Tanner, Eileen M., Amersham.
Tilling, Julian G., Dunstable.
Tomita, Koichi, Tokyo, Japan.
Tschudin, Francoise F., Lausanne, Switzerland.
van den Hoven, Alexander N., Ede, Holland.
van Iwaarden-Bender, Maria M.A., Delft, Holland.
van der Meer, Bastiaan, Schiedam, Holland.
Verkerk, Ruud, Stolwyk, Holland.

Vilá Perales, Vicente, Barcelona, Spain.
Vivo Ibanez, Jose, Valencia, Spain.
Vleeschhouwer, Willy A., Schoonhoven, Holland.
Vuorijarvi, Terhikki, Leppakoski, Finland.
Wilson, Anthony A., Bromborough.
Winstone, Harry, Durban, S. Africa.
Wennell, Susan D., Hazel Grove.
Yamada, Masahiro, Tokyo, Japan.
Zaveri, Rupesh P., Bombay, India.

PRELIMINARY EXAMINATION

RAYNER PRIZE

Alhonen, Aarne, Salpakangas, Finland.

QUALIFIED

Abraham Robert, Amsterdam Netherlands.
Abril Sirvent, Inmaculada, Barcelona, Spain.
Alabaster, Stephen P., Birmingham.
Allen, Darold C., Santa Monica, Cal., U.S.A.
Almirall Elizalde, Marta, Barcelona, Spain.
Alvarez Bringas, Jose A., Oviedo, Spain.
Amendra, Don H., Maharagama, Sri Lanka.
Andersen, Brit N., Horten, Norway.
Andersen, Oddvar F., Horten, Norway.
Anderson, Martin G., Fort Monmouth, N.J., U.S.A.
Anderson, Neil, Dover.
Antony, Mary R. R., Negombo, Sri Lanka.
Anttila, Kristiina, Helsinki, Finland.
Arandara, Don M., Ilford.
Arem, Joel E., New Carrollton, Md, U.S.A.
Arla Peris, Francisco, Barcelona, Spain.
Arla Pont, Enrique, Barcelona, Spain.
Arnold, Alan P., Metairie, La, U.S.A.
Aron, Mass K. Mass, Nugegoda, Sri Lanka.
Asquith, Lynn C., Bradford.
Attanayake, Walter, Ratnapura, Sri Lanka.
Ayuso Estanol, Juan, Barcelona, Spain.
Ayling, John C., Portsmouth.
Bailey, Paul S., Corsham.
Badenas Perez, Jorge, Barcelona, Spain.
Balachandran, Kanagaratham, Los Angeles, Cal., U.S.A.
Baldock, Edward J., Neston.
Banfill, Paul D. T., Sutton.
Barker, William G., Sutton Coldfield.
Barnatt, Robert W., Northampton.
Barnett, Paul A., Johannesburg, S. Africa.
Barrella, Lydia, Sea Point, S. Africa.
Basnayake, Gerard S., Colombo, Sri Lanka.
Bastiampillai, Mary N., Colombo, Sri Lanka.
Beard, Paul, Nottingham.
Beeks, Johannes F. M., Valkenswaard, Netherlands.
Bennett, Russell K., Aylesbury.
Berger Eva, London.
Bienert Albaladejo, Rosario, Barcelona, Spain.
Blackman, Margit C., Port Elizabeth, S. Africa.
Bloom, Leon K., Walsall.
Bolin, Anita M. H., Stockholm, Sweden.
Bolin, J. M. J., Stockholm, Sweden.

Bourdon Destrem, Genevieve M. C., Paris, France.
Bowskill, Alan P., Mansfield.
Brady, Michael F., Salisbury.
Brenton-Coward, Richard I., Otford.
Bressel, Heinz L., Milwaukee, Wis., U.S.A.
Briant, Richard A. C., Fleet.
Bromley, Ivy M., London.
Brookhuis, Harry, Schoonhoven, Netherlands.
Brown, Harold G., Glasgow.
Buckner, Richard A., Clinton, Tenn., U.S.A.
Buhary, Tuan D., Colombo, Sri Lanka.
Burford, Murray L., Ottawa, Ont., Canada.
Burlage, Ingeborg C., Schoonhoven, Netherlands.
Buxeda Corbera, Pilar, Barcelona, Spain.
Bylander. Liliane D., Bangkok, Thailand.
Cabrera Lagunilla, Pilar, Madrid, Spain.
Campbell, Susan H., Hong Kong.
Campo de Quevedo, Juan, Madrid, Spain.
Caparros Reyes, Victor, Barcelona, Spain.
Carry, Peter D., Aberdeen.
Cassidy, David F. F., Worcester.
Cassidy, John, Birmingham.
Castanera Rodriguez, Luis, Barcelona, Spain.
Cavey, Christopher R., London.
Cawdron, Margaret A. F., Aberdeen.
Chadderton, Yvonne E., Royton.
Chambers, Gareth, Harrow.
Chan, Sow C., Penang, Malaysia.
Chandrasena, Sooriya H. M., Colombo, Sri Lanka.
Chang, He O., Rio de Janeiro, Brazil.
Chapellier, Dominique M. B., Lausanne, Switzerland.
Clarke, Donald H. Johannesburg S. Africa.
Clarke, Elizabeth A., Barking.
Clarke, Tristan R., Wendover.
Close, Keith J., Liverpool.
Cobbald, Catherine J., Islington, Ont., Canada.
Coebergh, Henricus M. A., Montfoort, Netherlands.
Coleman, Kevin J., Huntingdon.
Collier, John M. B., Fordingbridge.
Conrad, Donald B., East Islip, N. Y., U.S.A.
Consolacion Montseny, Alredo, Barcelona, Spain.
Cooper, Dorothy A., Stockport.
Cooper, John D., Manchester.
Cooray, Harindra T., Moratuwa, Sri Lanka.
Cotes Mediavilla, Eusebio, Barcelona, Spain.
Crawford, Hugh B., Kirkcudbright.
Crossley, Anne D.. Oldham.
Croydon, Charles, Ipswich.
Cullman, Peter, Johannesburg, S. Africa.
Curran, Wilma, Weston-Super-Mare.
Daniel, Janice B., Plymouth.
Davies, Mark A. P., Hereford.
Davies, Robert I., Coventry.
Davis, Howard A., Toronto, Ont., Canada.
de Boer, K. J., Schoonhoven, Netherlands.
de Knecht, Petrus-Bernardus, Strijen, Netherlands.
Denton, Gillian M., Clacton-on-Sea.
de Silva, Denise M., Colombo, Sri Lanka.
de Silva, Nirmali Priyani, Ambalangoda, Sri Lanka.
de Silva, Pandigamage D. A., Colombo, Sri Lanka.
de Tong, Ype P., Krimpen a/d Issel, Netherlands.
Devereux, Maureen, Hong Kong.
Devji, Praful G., London.

de Waele, Carine-Ghislaine, Gent, Belgium.
Dewendra, Rekha, Panadura, Sri Lanka.
Dharmadasa, Sooriya H. M. S. P., Colombo, Sri Lanka.
Dick, Brigitte M., Great Billing.
Dissanayake, Akuranawattage B., Colombo, Sri Lanka.
Domenech Plo, Juan, Valencia, Spain.
Drummond, John R., London.
Dunlop, Helen R., Maybole.
Duroc-Danner, Jean-Marie, Geneva, Switzerland.
Edwards, Peter M., Aberystwyth.
Elkington, Mary, Solihull.
Ellis, Paul A., Colchester.
Elms, Kenneth G., London.
Elizinga, Vivienne, Durbanville, S. Africa.
Emmanuel, Michael R., St. Helier, Jersey, C.I.
Enger, Antoinette C. A., Voorburg, Netherlands.
Enrique Aranda, Laura, Barcelona, Spain.
Essery, Martin H., Feltham.
Etchen, Elsie J., Toronto, Ont., Canada.
Farnham, Julian R., Haslemere.
Farweez, Shabdeen M., Nawalapitiya, Sri Lanka.
Feingold, Sidney D., Manchester.
Feldman, Trevor M., London.
Fernando, Dilrutshi Y., Colombo, Sri Lanka.
Fernando, Joseph S. B., Toronto, Ont., Canada.
Fernando, Rambukkanage A. N., Colombo, Sri Lanka.
Fernando, Regina T. B., Colombo, Sri Lanka.
Fillmore, Robert W., Bromley.
Fonseka, Rita J., Colombo, Sri Lanka.
Fonseka, Ruwan K. M., Colombo, Sri Lanka.
Fonseka, Wanniachchige A., Dehiwala, Sri Lanka.
Fookes, Mark H., Brentwood
Fores Domper, Nieves, Barcelona, Spain
Funaro, Stella B., Livorno, Italy.
Gadot, Arnona, Tel-Aviv, Israel.
Galasko, Gail T. F. Johannesburg, S. Africa.
Gamage, Deegodagamage S. de S., Sri Lanka.
Gammidge Michael G., Sheffield.
Ganesen, Ganga-Devi, Colombo, Sri Lanka.
Garcia Blasco, Jose, Barcelona, Spain.
Garland, David J., Sheerness.
Gerard, Anthonypillai, Kayts, Sri Lanka.
Gianforte, Carmen A., Ellicott City, Md, U.S.A.
Gill, Stephen H., East Horsley.
Gion, Hirotaka, Toyohira-ku, Sapporo, Japan.
Girbes Faba, Adolfo, Valencia, Spain.
Gleeson, Derek B., East Leake.
Goicoechea Utrillo. Luisa, Barcelona, Spain.
Goldsmith, Philip E., Preston.
Goldwyn, Peter G., London.
Gotoh Takeshi, Amsterdam, Netherlands.
Gower, Wendy, Brisbane, Australia.
Grater, Jane, Fordingbridge.
Gray, Peter J. G., Plymouth.
Gray, Philip, Hessle.
Green, James E. W., Albrighton.
Green, Kenneth Farnham.
Grigg, Andrew J., Norwich.
Groves, Jane M., Bulawayo, Rhodesia.
Grunberg, Emanuel, Hertzlia, Israel.
Gulwer, Mats K., Karlstad, Sweden.
Gunaratna, Don L., Ratnapura, Sri Lanka.
Gunaratna, Mapatunage S., Colombo, Sri Lanka.

Gunasakara, Sirimevan P., Ratmalana, Sri Lanka.
Gunasekera, Ajit I., Colombo, Sri Lanka.
Gunathilake, Kenneth D., Nugegoda, Sri Lanka.
Gunatilaka, Hemamala, Kandy. Sri Lanka.
Gunawardena, Manel S., Colombo, Sri Lanka.
Gunawardene, Mahinda, Colombo, Sri Lanka.
Hailey, Robert J., London.
Hamilton, Sheilah E., Hong Kong.
Harper, Ian R., Sutton Coldfield.
Harre, Hendrik, Schoten, Belgium.
Harris, Philip, Bradford.
Haseyama, Hiroyuki, Tsurumi-Ku, Yokohama, Japan.
Haugh, Breda, London.
Havlik, Jan C. London.
Hebratski, Kazimierz F., Boston.
Hellman, Knut, Asker, Norway.
Hemaratne, Suraweera A., Colombo, Sri Lanka.
Hemphill, Craig L., Pacific Grove, Cal., U.S.A.
Hemphill, Sheri T., Pacific Grove, Cal.. U.S.A.
Henrich Francis J., Lower Hutt, New Zealand.
Herbert, Janet E., Northampton.
Hewitt, Nigel F. Amersham.
Hibberd, Nigel J., Ipswich.
Higuma, Teruo, Tokyo, Japan.
Hirotsune, Masanori, London.
Hiscox, Peter C., Solihull.
Hitchen, Alan, Walsall.
Ho, Kennedy, Bangkok, Thailand.
Hodges, Caroline F., Lowdham.
Hodges, Cherryl A., Bridgend.
Hoskins, Robert C., Mobile, Ala, U.S.A.
Hoskins, Tonja R., Mobile, Ala, U.S.A.
Houghton, John Manchester.
Hoyle, Elizabeth M., Huddersfield.
Huang, Hsing Y., Singapore.
Huddart, Alastair C. D., London.
Hudson, Robert J., Bradford.
Hughes, Steven B., Manchester.
Hurst, Adam K., Solihull.
Iborra Garcia, Juan C., Valencia,
Ilukkumbure, Parakrama M. J., Nuwara Eliya, Sri Lanka
Innala, Harri, Hameenlinna, Finland.
Irving, Antony J., Bradford.
Ismail, Mohamed H., Colombo, Sri Lanka.
Jackson, Christopher P., Gosport.
Jackson, Paula R., London.
Jacobs, Marie F. T., Colombo, Sri Lanka.
Jaliwala, Firoz A., Bombay, India.
Jayasingha, William H., Nugegoda, Sri Lanka.
Jayasuriya, Ranjit L., Colombo, Sri Lanka.
Jayawardena, Dennis A., Dehiwela, Sri Lanka.
Jimenez-Diaz Jorrin, Teresa, Madrid, Spain.
Jimenez Montoya, Angel, Bogota, Colombia.
Jinadasa, Sybil T., Colombo, Sri Lanka.
Jobin, Marc P. B., Beaconsfield.
Joel, Thomas, Waterloo, Belgium.
Johansen, Kare M., Lillehammer, Norway.
Johns, Alan T., Exeter.
Johnson, David S., Stoke-on-Trent.
Jothimani, Rajanawamani, Badulla, Sri Lanka.
Kallioniemi, Erkki, Helsinki, Finland.
Kan, Neville Y. C., Kew.
Kandasamy, Srimathi, Colombo, Sri Lanka.
Kangasvuori, Matti, Hameenlinna, Finland.
Kannangara, Vishwakanthie W., Colombo, Sri Lanka.
Kapukotuwa, Senerath L. B., Rajagiriya, Sri Lanka.

Kat, Amanda, Hadley Wood.
Kattan, Jacob, London.
Kawecki, Julian M., Maidstone.
Kaye, Ian D., London.
Kearney Garrett D. A , Manchester.
Keenan, James, Glasgow.
Keller, Joseph R., Concord, Cal., U.S.A.
Kennedy, Padraic J. T., North Vancouver, B.C., Canada.
Kim, Young C., Seoul, Korea.
Kimura, Tokao, Kodaira-City, Japan.
Kinch, John C., Morden.
King, Marie C., Seattle, Wash., U.S.A.
Kinsey, John D., Cape Town, S. Africa.
Kipps, Maurice J. D., Cape Town, S. Africa.
Kizawa, Masakatsu, Ibaraki-Ken, Japan.
Kleibrink Marion Amsterdam, Holland.
Knedler, Karin E., Lower Hutt, New Zealand.
Knight, David J. R. E. A., London.
Knight, Ronald C., Stockton-on-Tees.
Koetter, Marthlina H. M., Cape Town, S. Africa.
Kortenaar, Francois L. Schagen, Holland.
Kossick, Martin, Enfield.
Kotagama, Leslie S., Harlow.
Krishnarajah, Dev R., Colombo, Sri Lanka.
Krogfoss, Odd R., Tarnasen, Norway.
Kropman, Caroline A., Schoonhoven, Netherlands.
Kubica, Jack, Vaxjo, Sweden.
Kulanayagam, Karthigesu K., Point Pedro, Sri Lanka.
Kumburagedera, Wijeratne, Nugegoda, Sri Lanka.
Laking, Brian G., Newlands, S. Africa.
Lame, Elizabeth H. G., Schoonhoven, Netherlands.
Lammi, Lauri, Hameenlinna, Finland.
Lander, Charmian E. M., London.
Lea, Thomas, Maidenhead.
Leppanen, Virpi, Helsinki, Finland.
Leslie, Phyllis Sylvia, Bournemouth.
Leslie, Steven C., London.
Lewis, Keith, Liverpool.
Lind, Rolf, Raisio, Finland.
London, Phil, Melrose Park, Pa, U.S.A.
Ludlow, Lynda J., Orpington.
Lyly, Anne, Hameenlinna, Finland.
Mack, Jerrold F., Los Angeles, Cal., U.S.A.
Mackie, Mohamed I. S., Colombo, Sri Lanka.
Magudia, Ratilal H., Ilford.
Malkamaki, Hilkka, Helsinki, Finland.
Manthri, Anthony P., Colombo, Sri Lanka.
Margetts, William J., Sherborne.
Marti Calvo, Victoria, Valencia, Spain.
Martin, Denham D., Wellington, New Zealand.
Mastenbroek, Caroline H., Breda, Netherlands.
Mathieson, Cynthia J. G., Hong Kong.
Matugama, Don C. J. Migoda, Sri Lanka.
Mead, Valerie S., Leicester.
Mendis, Harold G. S., Panawala, Sri Lanka.
Mendis, Sarath D. A., Devinuwara, Sri Lanka.
Mennie, Ruth, Wallasey.
Mercado, Brian R., Braamfontein, Transvaal, S. Africa.
Mewes, Richard R., Salisbury.
Micheli Bellera, Francisco, Barcelona, Spain.
Micilotta, Francesco, Port Elizabeth, S. Africa.

Middleton, Michael S., Swansea.
Miles, Patricia A. J., Barton-on-Sea.
Miller, Duncan E., Cape Town, S. Africa.
Mills-Owens, Paul, London.
Mitchell, Ann V., Nairobi, Kenya.
Miyokawa, Yoshinori, Kodaira-City, Tokyo, Japan.
Mohideen, Mohamed F., Kelaniya, Sri Lanka.
Molamure, Atma H., Colombo, Sri Lanka.
Monras Montells, Jorge, Barcelona, Spain.
Moor, David, London.
Moriuchi, Masana, Niigata City, Japan.
Morris, Jane D., London.
Moser, Martin I., Edgware.
Mott, Junko, Strood.
Muhsin, Aftab R., Mount Lavinia, Sri Lanka.
Muije, Cornelius S., Louisville, Ky, U.S.A.
Muije, Lilian E., Louisville, Ky, U.S.A.
Muller, Jennifer A., Mt Gravatt, Brisbane, Australia.
Mundin, Kenneth W., Leicester.
Muraishi, Kunio, Ohta-Ku, Tokyo, Japan.
Murray, Gillian M. S., London.
Murray, Graeme D., Perth.
Muthulingam, Yaithianathan, Colombo, Sri Lanka.
Myer, Richard D., Auckland, New Zealand.
Mylius, Maren-Ann, Alle, Norway.
Nachimson-Palacci, Rosy, Geneva, Switzerland.
Nakazato, Tetuo, Taito-Ku, Tokyo, Japan.
Nanayakkara, Vajira, Nugegoda, Sri Lanka.
Narros Martin, Gabriel, Madrid, Spain.
Nation, Peter L., St. Helier, Jersey, C.I.
Nelson, James B., London.
Nessim, Barry, London.
Ng, Edward B. G., Singapore.
Ng, Kevin K., Singapore.
Nilsen, Tore, Oslo, Norway.
Nimalasuria, Lakshmie S., Colombo, Sri Lanka.
Nithiyananthasothy, Vallipuram, Ratmalana, Sri Lanka.
Noakes, David E., Chelmsford.
Odaka, Etsuko, Inba-Gun, Chiba-Pref., Japan.
O'Donoghue, Mary E., Brooklyn, N.Y., U.S.A.
Ogawa, Kenji, Nerima-Ku, Tokyo, Japan.
Oliver, Peter J., Wellington, New Zealand.
Onnink, Jannie A. P., Barendrecht, Netherlands.
Oono, Kunihiro, Shinagama-Ku, Tokyo, Japan.
Opsal, Kjell A., Oslo, Norway.
Paillard, Eva E., Paris, France.
Pandya, Praful J., Welwyn Garden City.
Pardo Marques, Jorge, La Bisbal-Gerona, Spain.
Pares Vinals, Candelaria, Barcelona, Spain.
Patel, Natvarlal, Bradford.
Pathirana, Hetti P. D. P., Ratnapura, Sri Lanka.
Patterson, Mark S., Merion Station, Pa, U.S.A.
Pattni, Ashok, Luton.
Pattni, Harish R., Nairobi, Kenya.
Pender, Harold, Kenilworth.
Perera, Gardi H. A. P., Mount Lavinia, Sri Lanka.
Perera, Kamala S. M., Kelaniya, Sri Lanka.
Perera, Kukulage A. P., Colombo, Sri Lanka.
Perrett, Roy, Swinton.
Petrasthuk, Juli M., Burlington, Ont,, Canada.
Peuri, Pertti, Hameenlinna. Finland.

Pfersich, Francois A., London.
Phillipe, Waveney H., Georgetown, Guyana.
Pillai, Sinnathamby K., Colombo, Sri Lanka.
Pomar Llado, Antonia, Barcelona, Spain.
Pothuwila, Indraseela S., Rajagiriya, Sri Lanka.
Pounds, James R. W., Horsham.
Rahuman, Sheriff A., Idar-Oberstein, W. Germany.
Ramesh, Alwani U., Bombay, India.
Ramm, Wendy E., Dereham.
Ranaweera, Viraj K., Narammala, Sri Lanka.
Rankin, Sandra, Glasgow.
Ratnavira, Ronald, Colombo, Sri Lanka.
Ratnayake, Mudiyamselage W., Ratnapura, Sri Lanka.
Richard, Gil, Chigny, Switzerland.
Richards, Patsey-Ruth, Brisbane, Australia.
Rivera Escamilla, Antonio, Barcelona, Spain.
Roberts-Mason, Anthony M., Capetown, S. Africa.
Robins, Henry, Liverpool.
Robinson, Kenneth W., Milton Keynes.
Rodriguez Rodriguez, Rosa, Barcelona, Spain.
Rodriguez Rosado, Luis, Madrid, Spain.
Rolfe, Dilys A., Hove.
Ropka, Christopher, Bradford.
Rubesinghe, Patricia S. K., Kosgama, Sri Lanka.
Rupasinghe, Indrani, West Harrow.
Rupasinghe, Lancelot, West Harrow.
Salminen, Mirja, Pori, Finland.
Salt, G. L. Graham, Wolverhampton.
Samarasinghe, Sarath C., Colombo, Sri Lanka.
Samaratunga, Edith K., Maharagama, Sri Lanka.
Sanchez, Sabeena T., London.
Sanchez Chercoles, Javier, Oveido, Spain.
Sanchez-Lafuente Mariol, Jose, Barcelona, Spain.
Sanz Balague, Joaquin, Barcelona, Spain.
Sayer, David J., Weston-super-Mare.
Scott, Eugene W., Apo, N.Y., U.S.A.
Selsky, Daphne B., London.
Selvarajah, Kulaveerasingam, Dehiwala, Sri Lanka.
Semmes, Granville M., New Orleans, La, U.S.A.
Senaratne, Amal C., Nugegoda, Sri Lanka.
Seneviratne, Anoma D., Colombo, Sri Lanka.
Seneviratne, Digodagamage S. S., Colombo, Sri Lanka.
Seoane Garcia, Encarnacion. Valencia, Spain.
Shaikh, Leela, London.
Shand, Dolores M., Colombo, Sri Lanka.
Shariff, Saaila A., Ambalangoda, Sri Lanka.
Sigl, Berta, Sargans, Switzerland.
Simpson, Caroline A., Middlesbrough.
Smart, Denis O., Kettering.
Smookler, Michael, Kenton.
Snow, John J., Brisbane, Australia.
Sopena Dasi, Gloria, Valencia, Spain.
Spaeti, Susanna, Lucerne, Switzerland.
Speller, Richard A., Surbiton.
Staggenborg, Laurie M., Santa Monica, Cal., U.S.A.
Stevens, Marion, Maroubra, N.S.W., Australia.
Stewart, Christopher J., London.
Stewart, Susan K., Kenyon.
Stone, Frederick J., Carshalton.
Stonebanks, Judith M., Hong Kong.
Stromnaes, Bjorn, Oslo, Norway.

Subasinhage, Gunapala O., Horana, Sri Lanka.
Takigawa, Junko, Kita-Ku, Kyoto-City, Japan.
Talgeri, Jayshree G., Poona, India.
Tan, Grace J., Singapore.
Tanaka, Toshio, London.
Tanyaviriya, Sayree, London.
Tarjan, Andre, Toronto, Ont., Canada.
Taylor, John A., Scarborough, Ont., Canada.
Teakle, Simon J., Lewes.
Tellez Mir, Jose, Barcelona, Spain.
Terrades Villsan, Carmen, Barcelona, Spain.
Thangaraj, Ponnusamy, Colombo, Sri Lanka.
Thenuwara, Sarojini R., Colombo, Sri Lanka.
Theobald, Robert. Leighton Buzzard.
Thomas, Richard N. C., Redcar.
Thornton, Simon J., Kettering.
Tilling, Julian G., Dunstable.
Tlush, Betty M., Meadow Brook, Pa, U.S.A.
Torvany Carole L.. Aberdeen.
Tose, Christin, Middlesbrough.
Truelove, Stephen R., Bradford.
Tuokila, Raija, Helsinki, Finland.
Turner, Reginald, Loughton.
Upali, Kasthuri A. D. K., Mount Lavinia, Sri Lanka.
Vainer, Richard L., London.
van Binsbergen, Karel G. C., Ouderker a/d Amstel, Netherlands.
van der Maden, Pieter, Vlissingen, Netherlands.
van Dissel, Sijtje M., Rhoon, Netherlands.
van Kerrebrouck, Alex J. C., Schoten, Belgium.
van Weenen, Gysbrecht de Leeuw, Nederwetten, Netherlands.
Velasco Llano, Daniel, Oveido, Spain.
Verch, Ulla, London.
Vinten, Christopher J., Leigh-on-Sea.
Voorn, Cornelius M. A., Amsterdam, Netherlands.
Vuorinen, Jorma, Hameenlinna, Finland.
Waadenoijen Kernekamp, Madelon v., Ulvenhout, Netherlands.
Wakefield, Raymond S., Durban, S. Africa.
Walikanne, Gunawardene, Ratnapura, Sri Lanka.
Walker, Andrew G., Guildford.
Wallis, Keith, Surbiton.
Walpitagama, Karunapala, Colombo, Sri Lanka.
Watson, Timothy L., Bulawayo, Rhodesia.
Weber, Aeldred B. M., Kuranegala, Sri Lanka.
Weeresinghe, Nedra P. O., Ratmalana, Sri Lanka.
Weissler, Chaggai H., London.
Weldon, Martin M. J., Dublin.
Wellinghoff, John J., Miami, Fla, U.S.A.
White, Paul T., Seattle, Wash., U.S.A.
Whittaker, Kenneth R., Cronton.
Wightman, Janice T., Hinckley.
Wijayanathan, Sashika, Colombo, Sri Lanka.
Wijayasingha, Kumarasena M., Colombo, Sri Lanka.
Wijemanne, Anura, Colombo, Sri Lanka.
Wijenayake, Tissa P., Ratnapura, Sri Lanka.
Wijeratna, Ashok S., Dusseldorf, W. Germany.
Wijeratne, Chakkrawarthiege H. R., Colombo, Sri Lanka.
Wijesinghe, Singappuli A., Homagama, Sri Lanka.
Wijesuriya, Guthila, Colombo, Sri Lanka.
Williams, Terence E., Birmingham.
Willis, Edward R., Saltburn.

Wilson, Philip, Newcastle-upon-Tyne.
Winslade, Harold, London.
Withana, Ajantha S., Ambalangoda, Sri Lanka.
Wood, Roger D., London.
Woodhall, Jon W., Home Hill, Qld, Australia.
Wright, Nigel A., Laleham-on-Thames.
Yamada, Masahiro, Japan.
Yamajo, Shuichi, Hiratsuka, Kanagawa-Pref., Japan.
Yamato, Kenzo, Setagaya-Ku, Tokyo, Japan.
Yamaya, Sachiko, Funchu-Shi, Tokyo, Japan.
Zdanowicz, Stanislaw J., Warsaw, Poland.

COUNCIL MEETING

At a meeting of the Council held on Monday, 1st November, 1976, the appointment of Mr F. A. Fryer, F.G.A., Mrs S. J. Lewis, F.G.A. and Mrs H. Muller, F.G.A., as course instructors was approved.

At the same meeting the following were elected to membership:

Fellowship

Alabaster, Stephen P., Birmingham. D. 1976
Aloy, Richard N., Allhallows. D. 1976
Ambjornsen, Truls P., Fredrikstad, Norway. D. 1976
Arem, Joel E., New Carrollton, Md, U.S.A. D. 1976
Baird, Donald D., East Sheen. D. 1976
Borscho, Shirley J., Plymouth. D. 1976
Bratton, Timothy J., Sidcup. D. 1976
Byfleet, Anne P., Doncaster. D. 1976
Collier, John M. B., Fordingbridge. D. 1976
Eldridge, Maurice W., Sheffield. D. 1976
Evans, Mark, London. D. 1976
Goto, Midori, Kitayusyu-City, Japan. D. 1976
Gulliksen, Gunnar B., Gol, Norway. D. 1976
Hanni, Henry A., Basel, Switzerland. D. 1976
Hayes, Elizabeth A., Ossett. D. 1976
Holdroyd, Donna J., Oslo, Norway. D. 1976
Leach, Jane, London. D. 1976
Monche Maristany, Alicia, Barcelona, Spain. D. 1976
Oclee, Caroline H., Hythe. D. 1976
Piech, Olwen, Bushey Heath. D. 1976
Poel, Melvin C., Solihull. D. 1976
Sieders, Margaretha E., Den Haag, Holland. D. 1976
Sigl, Berta, Sargans, Switzerland. D. 1976
Snow, John J., Brisbane, Australia. D. 1976
Storr, Jonathan, Lincoln. D. 1976
Stromnaes, Bjorn, Oslo, Norway. D. 1976
van der Meer, Bastiaan, Schiedam, Holland. D. 1976
van Iwaarden-Bender, Maria M. A., Delft, Holland. D. 1976
Vuorijarvi, Terhikki, Leppakoski, Finland. D. 1976

Transfers from Ordinary Membership to Fellowship

Anandavadivel, Kumarasamy, Ratmalana, Sri Lanka.
Asano, Yoshio, Kyoto, Japan.
Baker, Elaine, Lihue, Hawaii, U.S.A.
Blackley, Robert, London.
Bolli, Bruno, St Gallen, Switzerland.
Bourdon Destrem, Genevieve, Paris, France.
Engineer, Thrity P., Bombay, India.
Fenoll Hachi-Ali, Purificacion, Granada, Spain.
Flewelling, Arthur G., Arthur, Ont., Canada.
Furuya, Masashi, Tokyo, Japan.
Goh, Kong B., Petaling Jaya, W. Malaysia.
Heckman, Hayo W., The Hague, Holland.
Hendrickson, James E., Los Altos, Cal., U.S.A.
Jayakody, D. F., Jaela, Sri Lanka.
Kurata, Yukiko, Tokyo, Japan.
Lo, Louis Y., Hong Kong.
Maeda, Kikuko, Tokyo, Japan.
Mahendrarajah, Maureen, Colombo, Sri Lanka.
Matsui, Reiko, Tokyo, Japan.
Miller, Duncan E., Cape Town, S. Africa.
Mills-Owen, Paul, London.
Moller, Peter J., Tully, N. Qld, Australia.
Moses, Heather, London.
Need, Mary, Lelant Downs.
Oliver, Peter J., Eastbourne, New Zealand.
Pandithakoralege, Don R. M., Nugegoda, Sri Lanka.
Pender, Harold, Kenilworth.
Pinder, William R., Earlville, Qld, Australia.
Pratt, John C., Toronto, Ont., Canada.
Ralston, Jonathan B., London.
Read, John V., Randburg, Transvaal, S. Africa.
Richards, Nancy A., Fredericton, N.Br., Canada.
Sant' Angelo, Louis, Hamrun, Malta.
Simonin, Daniel, St Gallen, Switzerland.
Staver, John, Virginia, Minn., U.S.A.
Suzuki, Yusaku, Tokyo, Japan.
Tanner, Eileen M., Amersham.
Tilling, Julian G., Dunstable.
Tomita, Koichi, Tokyo, Japan.
Tschudin, Francoise, Lausanne, Switzerland.
van den Hoven, Alexander N., Ede, Holland.
Verkerk, Ruud, Stolwyk, Holland.
Wilson, Anthony A., Bromborough.
Winstone, Harry, Durban, S. Africa.

Ordinary Membership

Adams, Audley V., Cranbrook, Qld, Australia.
Adams, Ian A., Townsville, Qld, Australia.
Adler, Jacques H., Honolulu, Hawaii, U.S.A.
Aikawa, Kiyoharu, Takasaki-City, Gunma-Ken, Japan.
Allingham, William G., Belfast.
A'Logann, Charles, S. San Francisco, Cal., U.S.A.
Alvarez-Prado, Marcelo, London.
Amasaki, Tetsuya, Osaka, Japan.
Anantaprakorn, Tongchai, Bangkok, Thailand.
Arnold, Elizabeth, Opfikon, Switzerland.
Ashby-Crane, Paul R., Sidmouth.

Baba, Hiromi, Tokyo, Japan.
Barcham, Kathryn L., Hong Kong.
Bartholomew, Peter, Rio de Janeiro, Brazil.
Birkett, Joan, Ingham, Qld, Australia.
Brennan, Gwendoline L., Albion Park Rail, N.S.W., Australia.
Bryant, Kevin C., Bath.
Budding, Peter J., Guildford.
Chalmers, Maureen C., Salisbury, Rhodesia.
Chan, Charles H. C., Singapore.
Chan, Sow Chee, Penang, Malaysia.
Chou, Elizabeth, Hong Kong.
Clarke, Tristan, R., Wendover.
Colucci, Thomas R., Broomall, Pa, U.S.A.
Constantinides, Theodoros N., Nicosia, Cyprus.
Cooper, Geoffrey L., Manchester.
Crossley, Anne D., Oldham.
Cunning, John J. B., Bundaberg, Qld, Australia.
Danker, Joy L., Dublin, Eire.
Devereux, Clare L., London.
Dharmadasa, S. H. M. Sunil P., Colombo, Sri Lanka.
Dokiya, Tetsuo, Yokohama-Shi, Kanagawa-Ken, Japan.
Dunn, David L., Guildford.
Ebihara, Koichi, Omiya-City, Saitama-Pref., Japan.
Ellis, Martyn J., Budleigh Salterton.
El Sirgany, Adel, Jeddah, Saudi Arabia.
Emmanuel, Michael R., St Helier, Jersey, C.I.
Faiz, M. H. M., Colombo, Sri Lanka.
Farrugia, George J., Rexdale, Ont., Canada.
Fennessy, Sean, Wellington, New Zealand.
Fernando, Nairabaduge B. S., Ratmalana, Sri Lanka.
Fleeman, Geoffrey A., Underwood, Qld, Australia.
Fleisch, Percy R., Bulawayo, Rhodesia.
Forcat Ycardo, Maria A., Madrid, Spain.
Fujii, Terutoshi, Richmond.
Fujikawa, Takao, Maebashi-Shi, Gumma, Japan.
Fukami, Yukio, Tokyo, Japan.
Fukita, Eiitu, Aomoli-City, Japan.
Furuya, Noboru, Tokyo, Japan.
Gidoomal, Chandan, Nairobi, Kenya.
Gillen, Richard D., Coral Gables, Fla, U.S.A.
Gion, Hirotaka, Sapporo, Japan.
Gordon, Norman A., Oklahoma, U.S.A.
Gower, Wendy, Brisbane, Australia.
Grant, John W., Milledgeville, Ga, U.S.A.
Green, Kenneth, Farnham.
Green, Michael, Kuala Lumpur, Malaysia.
Hallauer, Rainer, Brugg, Switzerland.
Hamamoto, Kouichi, Osaka, Japan.
Harding, Jeremy L., Christchurch, New Zealand.
Hasieber, Francis G., Natal, S. Africa.
Hayashi, Takeshi, Tokyo, Japan.
Healy, Janice M., Aloha, Oreg., U.S.A.
Heathfield, Kenneth A., South Woodham Ferrers.
Heng, Kheng B., Singapore.
Herrmann, Giampaolo, Schoten, Belgium.
Hiramatsu, Setsuko, Kitashitaragun, Aichi-Ken, Japan.
Hitchman, Michael J., Wigston.
Honma, Tadashi, Tokyo, Japan.
Horley, Anna C., Salisbury, Rhodesia.
Houten, H. Ten, Laren-N-H, Holland.
Howe, Peter R., Christchurch, New Zealand.
Howells, Grace W., Waterloo, Ont., Canada.

Ho Yoong Long, Michael, Singapore.
Hughes, Susan M., Kowloon, Hong Kong.
Humphrey, George, Newcastle-under-Lyme.
Hussain, Muhammad Y., Karachi, Pakistan.
Huxley, Peter M., Wellington, New Zealand.
Isaac, Melvin, Phoenix, Ariz., U.S.A.
Ishibashi, Yoshimitsu, Miyakonojo City, Miyazaki Pref., Japan.
Itaya, Eiki, Morioko-City, Iwate-Pref., Japan.
Ito, Mamoru, Yokohama, Kanagawa-Ken, Japan.
Ivers-Read, Ronald, London.
Iwakiri, Mineo, Tokyo, Japan.
Jain, S. Chandra, Ilford.
Jayasuriya, Ranjit L., Colombo, Sri Lanka.
Jogia, Suresh, London.
Jones, John, Bristol.
Jones, Richard, London.
Kaleel, Ameena, Colombo, Sri Lanka.
Kaneko, Mamoru, Tokyo, Japan.
Karfunkel, Joachim, Belo Horizonte, M.G., Brazil.
Karpinas, Francis, Glenrothes.
Kastan, Alvin, Ashland, Ohio, U.S.A.
Kawaguchi, Yoshimasa, Tokyo, Japan.
Kawakami, Masanori, Hokkaido, Japan.
Keegan, Michael J., Townsville, Qld, Australia.
Kennedy, Padraic J. T., North Vancouver, B.C., Canada.
Kimura, Takao, Tokyo, Japan.
Kitahara, Nobuko, Kobe, Japan.
Kitajima, Akinoki, Tokyo, Japan.
Kobayashi Masaki, Hiratuka, Kanagawa, Japan.
Krakowiak, Czeslaw, Chlopska, Poland.
Krapenc, Terry S., Painesville, Ohio, U.S.A.
Krauss, Richard L., Springfield, Ohio, U.S.A.
Kubica, Jack, Vaxjo, Sweden.
Lander, Charmian E. M., London.
LeDuce, Eleanor, Miami, Fla, U.S.A.
Lee, Chun-Sang R., Hong Kong.
Lee, Robert J., Georgetown, Guyana.
Leng, Yeo H., Singapore.
Lennard, Jack K., Pewport Beach, Cal., U.S.A.
Leung, Elaine S. L., Kowloon, Hong Kong.
Levi, Henry T., Nanticoke, Pa, U.S.A.
Logan, Joan A., Hounslow.
Lu, Milton R., Taipei, Taiwan.
Luton, Kevin S., Ganges, B.C., Canada.
Mackenzie, Ranald W. K., Salisbury, Rhodesia.
Makino, Fumiko, Tokyo, Japan.
Maldonado, Irina M., Philadelphia, Pa, U.S.A.
Manabe, Sukehiko, Tokyo, Japan.
Marchbanks, Donald L., Salina, Kan., U.S.A.
Marsh, Kendall C., Holdew, Mass., U.S.A.
Marshall, Michael G., Manchester.
Mathu, Sidney K., London.
Matthews, Guy, Woking.
Maughan, Raymond J., Townsville, Qld, Australia.
McBeth, Lee R., Sacramento, Cal., U.S.A.
McDonald, Ian R., Dundee.
Mian, Chen C., Singapore.
Miles, Stanley W., Broadstone.
Mimastu, Nobuo, Tokyo, Japan.
Ming, Cheung K., Kowloon, Hong Kong.
Ming, Chow K., Hong Kong.
Miyazawa, Fumitaka, Tokyo, Japan.

Morris, Philip, Wembley.
Moyersoen, Yeon F., Brussels, Belgium.
Muller, Liz R., Roskilde, Denmark.
Muller, Peter L., Cardiff.
Munro, Ewen S., Glencarse.
Murase, Fujio, Kyoto, Japan.
Nagasawa, Susumu, Tokyo, Japan.
Nakagawa, Hideki, Yokohama-Shi, Kanagawa-Ken, Japan.
Nakashima, Kozo, Okayama City, Okayama Pref., Japan.
Negishi, Kimiko, Tokyo, Japan.
Ng, Kevin K. F., Singapore.
Noe, James A., New Orleans, La, U.S.A.
Norberg, Rolf B., Drammen, Norway.
Notton, William J., Bristol.
Oda, Kosaku, Tokyo, Japan.
Odaka, Etsuko, Inba-Gun, Chiba-Ken, Japan.
Ogawa, Kenji, Tokyo, Japan.
Ogi, Michiko, Washington, D.C., U.S.A.
Ohmi, Morihiro, Tokyo, Japan.
Ohno, Hiroko, Kurume-Shi, Fukuoka-Ken, Japan.
Okamoto, Ichiro, Tokyo, Japan.
Okaro, Chizuru, Tokyo, Japan.
Okuno, Mitsuji, Kobe-City, Japan.
Onnink, Fannie A. P., Barendrecht, Netherlands.
Oomi, Kumiko, Yuki-City, Ibaragi-Ken, Japan.
Oomori, Masahori, Tokyo, Japan.
Parkin, Ian T., Wakefield.
Perchtold, Werner J., Roodepoort, Transvaal, S. Africa.
Phillips, Martin J., Camberwell.
Potter, Matthew S., Bangkok, Thailand.
Powell, Colin V., Cheltenham.
Preager, Joyce D., Los Angeles, Cal., U.S.A.
Preager, Ronald S., Los Angeles, Cal., U.S.A.
Rajendran, Vythilingampillai, Kandy, Sri Lanka.
Raphay, Haji M., Kuala Lumpur, Malaysia.
Rasborn, Jeannine M., Hong Kong.
Robbins, Gerald, Philadelphia, Pa, U.S.A.
Rubin, Howard, New York, U.S.A.
Salakian, Silva, Salisbury, Rhodesia.
Sakai, Mithuo, Tokyo, Japan.
Sakamoto, Masayuki, Tokyo, Japan.
Sano, Toshiro, Saitama-Ken, Japan.
Sasaki, Futaba, Tokyo, Japan.
Sato, Akira, Oomiya-Shi, Saitama-Ken, Japan.
Sato, Kastunori, Yono-Shi, Saitama-Ken, Japan.
Sawaragi, Machiko, Richmond.
Schroder, Rosemary J. S., Oslo, Norway.
Sekizawa, Fujio, Tokyo, Japan.
Selkirk, James R., M. S. O. Box, Australia.
Shem-Tov, Daniel, London.
Shioguchi, Kyoko, Kobe, Japan.
Simon, Claudette S., Encino, Cal., U.S.A.
Siu, Liao Kun, São Paulo, Brazil.
Sjoberg, Eric J., Wembley.
Skeate, Denis S., Johannesburg, S. Africa.
Sonekawa, Noriko, Tokyo, Japan.
Stanfield, Peter B., Townsville, Qld, Australia.
Stanley, Geoffrey, Accrington.
Stoch, Naomi D., Johannesburg, S. Africa.
Suter, Philip, Croydon.
Suzuki, Yukio, Tokyo, Japan.
Tada, Yoko, Funabashi-City, Chiba, Japan.
Takashi, Toshikuni, Tokyo, Japan.
Takeguchi, Machiko, Bangkok, Thailand.
Tam Ho Che, Nelson, Hong Kong.
Tan, Huang Tai P., Singapore.
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Zullu, Alli S., Dar es Salaam, Tanzania.

Research Diploma

The Council upon the recommendation of the Examiners awarded a Research Diploma to Pete J. Dunn, M.A., F.G.A., for his work on gem tourmaline: his thesis entitled "Uvite: A Newly Classified Gem Tourmaline" will be published in a future issue of the *Journal*.

LETTER TO THE EDITOR

From Dr E. Gübelin, C.G., F.G.A.

Dear Sir,

A recent opportunity to acquire several small hessonites from Ceylon, all excelling in that well-known granular look caused by a dense dissemination of minute guest minerals, offered the welcome chance of carrying out a more careful and accurate examination of these mineral inclusions. Several of the guest minerals in each hessonite were subjected to an electron microprobe analysis, and in each case the mineral inclusions were identified as being *apatite*. This result causes an amendment to be necessary in my book, "Internal World of Gemstones", and I wish to invite readers to alter the caption of the *centre right* illustration on *page 166* so that it reads: "Hessonites from Ceylon are recognizable by their 'granular' appearance which is provided by grains of apatite" (instead of "diopside or zircon" as thought previously).

Yours sincerely,

13th September, 1976. E. Gübelin

GIA's NEW HEADQUARTERS

After twenty years in San Vicente Boulevard, Los Angeles, the Gemological Institute of America has recently completed its move to new headquarters at 1660, Stewart Street, Santa Monica, California, which were built specifically for GIA needs and incorporate the most modern equipment and teaching aids available.

The new training centre is more than twice the size of the old one and contains more than 50,000 square feet of space situated on a 3½ acre campus-like setting: the building also includes the Gem Trade Laboratory, Instrument Manufacturing Division and Publishing Division, of which the Laboratory offers the services of a fully equipped laboratory and a staff of highly skilled professional gemmologists, while the Instrument Manufacturing Division is engaged in the research, design and manufacture of gem-testing and grading instruments, and the publications for which the Institute is responsible include dictionaries, texts, pamphlets and other articles of interest to gemmologists and jewellers: it also, of course, publishes the quarterly *Gems & Gemology*.

The address of the new GIA Headquarters for correspondence is Post Office Box 2110, Santa Monica, CA 90406, U.S.A.

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FURTHER NOTES ON MONO- AND BI-PHASE INCLUSIONS IN AMETHYST AND TOPAZ

By E. J. GÜBELIN, Ph.D., C.G., F.G.A.,

Lucerne

SINCE writing my paper on mono- and bi-phase filled negative crystals in an amethyst (J. Gemm., 1976, XV, 4, 165–171) I have been favoured by a welcome opportunity to examine another amethyst of unknown origin and a blue topaz from the St Anne's Mine, Miami, Rhodesia, the inclusions in which were large and clear enough for an exact investigation (Figs 1 and 2). The experimental process was the same as with the previously described amethyst, namely an interpretation of the results obtained from microthermometry.

The more recently explored AMETHYST contained two types of inclusions, (*a*) primary cavities, i.e. negative crystals which were aligned parallel to the c-axis of the host crystal and (*b*) pseudo-secondary inclusions with highly irregular shapes and predominantly filled with two phases (fluid and gaseous) (Fig. 3).

The amethyst was first cooled to −150°C. During annealing and heating which ensued the following alterations were observed:

FIG. 1. Amethyst with a large distorted negative crystal containing a liquid and a gas vesicle. 30 ×

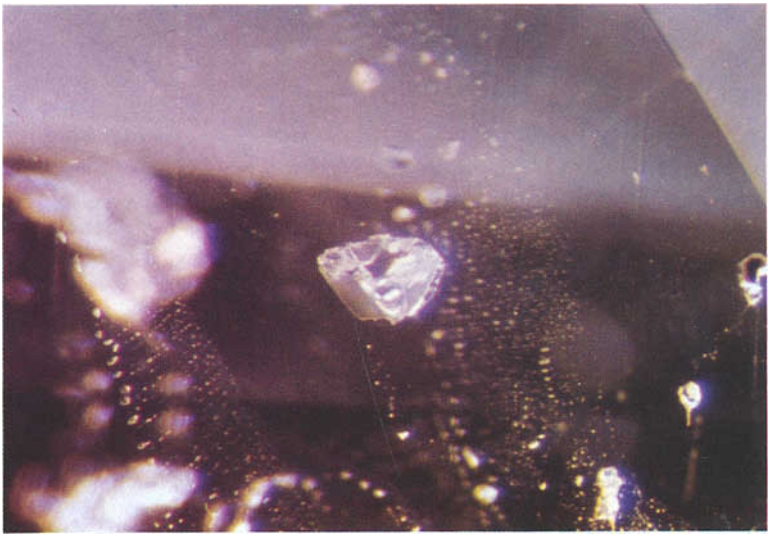

FIG. 2. Blue topaz from St Anne's Mine with a large negative distorted crystal accompanied by numerous tiny two-phase inclusions. 45 ×

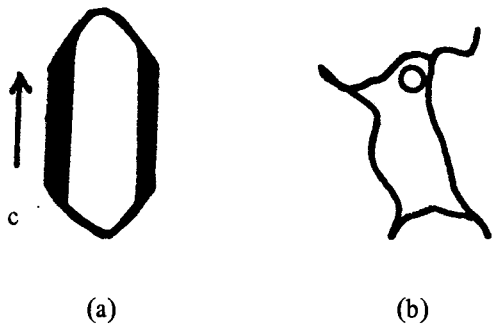

FIG. 3. Sketches of a primary negative crystal = type (*a*) and an irregular pseudo-secondary two-phase inclusion = type (*b*).

(1) the first sublimation occurred in the inclusions of type (*a*) at a temperature of −108°C;
(2) in the type (*a*) inclusions the ice melted at −1·6°C, in the type (*b*) inclusions at −0·2°C;
(3) homogenization took place in the pseudo-secondary inclusions at temperatures of +153 to 170°C.

The following table offers a comparison of the behaviour of analogous inclusions in the previous and the more recent amethyst:

Amethyst	*First sublimation*	*Melting (or sublimation)*	*Homogenization*
Previous a_1	−99°C	−0·6°C	
sample *a*	−90°C	−0·4°C	
New sample *a*	−108°C	−1·6°C	
New sample *b*		−0·2°C	+153 to 170°C

From this it is obvious that the phase alterations in both amethysts are analogous. Hence one may rightly conclude that both amethysts occur from identical sources. Although microthermal observations are not entirely foolproof and cannot be interpreted with absolute certainty without accessory examinations, with reference to the (*a*) inclusions two deductions may today however be accepted with great probability:

(1) the inclusions contain some water;
(2) the pressure in the inclusions is very weak.

The (*b*) inclusions contain water, which is distinguished by a low content of some kind of salt, i.e. the water is but weakly saline. The temperature of homogenization corresponds approximately to the temperature of formation of the inclusions; yet, because the phenomenon of the "necking down" appears to have taken place, no exact temperature but merely an approximation can be indicated (viz. +153 to 170°C).

It is highly likely that both amethysts originated from a volcanic deposit, i.e. from druse-like cavities in lava flows. Their formation is due to a hydrothermal process: they crystallized from an aqueous solution at temperatures between +150 and 200°C and under low pressures varying from 20 to 30 bar. The slightly saline water in the type (*b*) inclusions was—at least for some time—at boiling point, so that a vapour bubble could separate which was later partly trapped in characteristic cavities (distorted negative crystals, i.e. type (*a*) inclusions) by the growing crystal. In the gaseous phase there was not only water vapour but also a second gas (perhaps CO_2), which sublimated between −90 and −110°C.

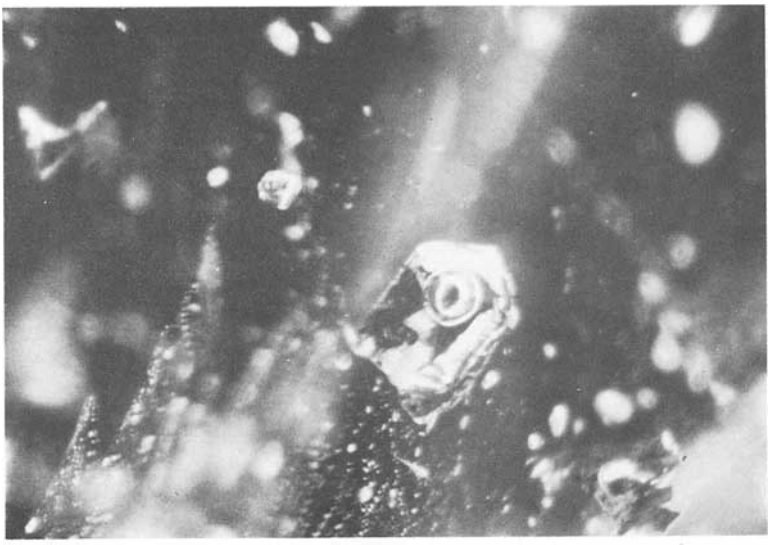

FIG. 4. Well shaped negative crystal with two-phase filling accompanied by minute pseudo-secondary two-phase inclusions. 45 ×

FIG. 5. Adjacent occurrence of primary and pseudo-secondary mono- and bi-phase inclusions in blue topaz. 45 ×

In consulting the literature it became evident that apparently no one has heretofore systematically investigated the inclusions in amethysts from volcanic deposits, so that comparison with other results of research are at present not possible.

In the blue TOPAZ from Rhodesia the inclusions betray a turbulent evolution of the host gem which is rich in two-phase inclusions. They either belong to the type (*a*) of negative crystals or to the pseudo-secondary type (*b*) with highly irregular shapes (Figs 4 and 5). Their investigation by means of microthermometry yielded equally informative results.

During the annealing process the following changes were noticed after the inclusions had been cooled down to −180°C:

(1) at the temperature of −2°C: the ice started melting;

(2) from +20°C to +100°C: daughter crystals, which had partially formed during the previous cooling, yet to some degree had already existed, dissolved completely;

(3) at +232°C: the majority of the solid phases in many inclusions dissolved, while, however, in other inclusions solid phases remained prominent (the topaz was not heated to over 232°C to avoid cracking);

(4) at approximately +250°C: the critical point of homogenization of the gaseous and fluid phase would most probably have been reached.

Repeated annealing and refrigeration allowed the observation of several recrystallizations within the inclusions. Strong as well as weak undercooling resulted in spontaneous nucleation as well as slow growth on existing seed crystals. Similarly, as in the case of the amethysts, the interpretation of these observations is rather difficult. The topaz seems to have sprouted from a hydrothermal formation—a conclusion which concurs with geological field observations at St Anne's Mine. The surmised temperature of homogenization (+250°C) would appear to be very low for topaz, especially so because in the literature values between 300 and 800°C are mentioned. The saline content is extraordinarily high; yet it was not possible to identify the nature of the salt. The solid crystals which precipitated and which were optically birefringent could be sulphates. In any case they were salts which caused only a very slight reduction of the melting point of the water content. Consequently they could not be chlorides.

Although these explanations may not perhaps yet be definite they may however serve as a plausible working hypothesis as well as a challenge to other workers to continue this research with more abundant material.

Acknowledgement: I wish to express my best thanks to Prof. H. A. Stalder of the Natural History Museum, Berne, for his technical assistance and valuable commentary.

[*Manuscript received 28th October, 1976.*]

GEM MONAZITE FROM SRI LANKA*

By E. A. JOBBINS, ANNE E. TRESHAM, B. R. YOUNG,

Institute of Geological Sciences, London, SW7 2DE.

DURING the latter part of 1974 Miss G. Sri Nissanka, a keen Colombo gemmologist, was sorting through gem gravels from Sri Lanka and noted a reddish-orange pebble of gem-quality material of unusual appearance. The absorption spectrum was impressive and since there were strong bands in the red she assumed it was probably an unusual zircon. The specimen was brought to England by Mr H. J. Whitehead and shown to Mr R. K. Mitchell, who passed it to the Institute of Geological Sciences for further testing once he realized it was not zircon as was assumed originally.

The specimen is a small flattened pebble of rounded outline, approximately 6mm in diameter and weighing 0·2818 grams (1·41 carats). It is completely transparent, has a hardness approaching 6 on Mohs's scale and has a white streak (powder). The almost adamantine, but resinous lustre (seen on a small polished flat) is reminiscent of zircon, but the specific gravity of 5·247 is greater than that of high zircon (4·68). Seen through the dichroscope the pebble displays pleochroism from reddish-orange (colour 7B8) to golden-yellow (colour 5B7), the figures in brackets referring to standard colours shown in the *Methuen Handbook of Colour* (Kornerup & Wanscher, 1967). The refractive indices, determined on a Rayner sphalerite refractometer using sodium light, were α 1·795, γ 1·845 (both $\pm$0·003) and the extinction between crossed polars was sharp. The clear, transparent material was almost free from inclusions but a few "healed feathers" were present. The pebble showed no fluorescent effects under ultraviolet light or between crossed filters. The mineral was noticeably radioactive when tested under a Geiger counter.

An x-ray diffraction film (X 7196) of powder scraped from the pebble showed that it was a member of the monazite group. The x-ray powder data set out in Table I were obtained from films taken with an 11·46cm diameter camera. The powder data were provisionally indexed by comparison with published data and were refined using the least squares program (BA1·0) developed by Dr

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TABLE I

Observed and calculated x-ray powder diffraction data for a gem monazite from Sri Lanka. CoKα radiation (λ=1·790207Å) *a* 6·761Å, *b* 6·966Å, *c* 6·478Å, β 103° 35′ (cell volume 296·5Å^3). Space group $P2_1/n$.

I/I_1	*d* obs	*d* calc	*hkl*	I/I_1	*d* obs	*d* calc	*hkl*
10	5·17Å	5·197Å	$10\bar{1}$	4	2·335Å	2·336Å	022
6	4·75	4·780	110	25	2·182	2·179	031
16	4·64	4·671	011	40	2·151	2·151	$10\bar{3}$
20	4·15	4·165	$11\bar{1}$				
14	4·08	4·092	101	25	2·123	2·120	$13\bar{1}$
						2·118	221
20VB	3·50	3·528	111				
		3·483	020	50	1·963	1·963	212
35	3·285	3·286	200	6	1·896	1·896	230
80	3·078	3·078	120	30	1·876	1·876	103
12	2·973	2·972	210	18	1·798	1·798	023
				8	1·764	1·764	222
100	2·862	2·864	$11\bar{2}$	40B	1·738	1·741	040
18	2·598	2·598	$20\bar{2}$			1·735	132
25B	2·440	2·444	112	12	1·691	1·690	321
		2·435	$21\bar{2}$				

The intensities were estimated visually by comparison with an intensity scale.
B = broad, VB = very broad.

R. J. Davis, Department of Mineralogy, British Museum (Natural History), for the refinement of cell dimensions and enumeration of all possible d-spacings. This refinement gave cell dimensions *a* 6·761Å, *b* 6·966Å, *c* 6·478Å, β 103°35′.

A quantitative analysis (Table II) using a "Geoscan" electron microprobe was then carried out using silicates, oxides and phosphates of known composition as standards for Mg, Al, P, Ca, La, Ce, Pr and Nd. Pure metal standards were used for the elements V, Cr, Fe, Y, Sm, Gd, Dy, Ho, Er, Pb, Th and U. All the elements were analysed using an accelerating potential of 20kV and the results were corrected for x-ray absorption, atomic number effect and secondary fluorescence using the computer program written by Mason, Frost and Reed. Analyses for silicon using the microprobe are complicated by the overlap of the third order neodymium Lα peak, for phosphorus by the third order cerium Lγ peak, for chromium by the lanthanum Lβ_2 and third order thorium Lβ peaks, and

for gadolinium by the cerium Lγ peak. The contribution of the neodymium Lα peak was calculated and subtracted from the silicon Kα peak before computing. Likewise, allowance was made for the cerium Lγ peak under the phosphorus Kα peak and for the lanthanum Lβ_2 and third order thorium Lβ peaks under the chromium Kα peak. Gadolinium Lα and cerium Lγ peaks were distinguished using pulse height analysis. The data in Table II are the averages of three analyses. The numbers of cations on the basis of 16 oxygen ions have been calculated. The specific gravity calculated from the x-ray data is 5·496, compared with 5·247 as determined by hydrostatic weighing; calculated densities are commonly greater than the observed values, but a fine crack in the stone could account for some of the discrepancy.

TABLE II

ELECTRON MICROPROBE ANALYSIS OF GEM MONAZITE FROM SRI LANKA

		Number of ions on the basis of 16 (0).		
SiO_2	0·4			
ThO_2	11·6			
U_3O_8	0·4			
Ce_2O_3	28·7	P	3·783	3·849
La_2O_3	21·7	Si	0·066	
Nd_2O_3	6·0	Al	0·004	4·157
Pr_6O_{11}	1·9	Th	0·430	
Sm_2O_3	0·6	U	0·014	
Gd_2O_3	0·09	Ca	0·174	
Dy_2O_3	0·2	Ce	1·714	
Ho_2O_3	0·05	La	1·305	
Er_2O_3	nt fd.	Nd	0·350	
Y_2O_3	nt fd.	Pr	0·110	
Al_2O_3	0·02	Sm	0·033	
Fe_2O_3	nt fd.	Gd	0·005	
Cr_2O_3	nt fd.	Dy	0·011	
V_2O_3	nt fd.	Ho	0·003	
CaO	1·0	Pb	0·004	
MgO	nt fd.			
Pb_3O_4	0·1			
P_2O_5	27·4			
	100·16			

nt fd. = not found.

The spectacular absorption spectrum of the gem monazite was the cause of its discovery in gem gravels by Miss Sri Nissanka in Sri Lanka, and when seen by Mr R. K. Mitchell it immediately reminded him of the very strong spectrum displayed by a tiny parisite crystal inclusion in a Colombian emerald discovered by Sir James Walton in 1950 (Walton, 1950). Parisite is a fluocarbonate of calcium and the cerium group of rare earths, $(Ce, La)_2 Ca (CO_3)_3 F_2$, usually with some didymium (neodymium and praseodymium). There are similarities between the monazite, parisite and some gem apatite spectra and the spectrum of didymium glass (MI 33205) in the IGS collections. The latter was qualitatively analysed by Dr M. T. Styles and contains cerium and neodymium with silicon, calcium and potassium as major constituents; lanthanum, samarium and sodium as minor constituents with traces of magnesium, aluminium, scandium, together with praseodymium, europium and terbium in some of the fragments analysed on an energy dispersive x-ray analyser attached to a scanning electron microscope. As will be seen from Table II this qualitative analysis bears a considerable resemblance in its constituent elements to the analysis of the gem monazite. However, the lines in the glass absorption spectrum are relatively fuzzy compared with the sharp lines displayed by the monazite.

The monazite and the didymium glass (the Institute has two cut stones) are reddish-orange and orange-brown respectively as seen in daylight; both show a bright green by mercury vapour lamp or fluorescent tubes and both take on a pinkish-brown appearance in tungsten lighting. These remarkable colour changes would appear to be related to the strong absorption bands in the yellow part of the spectrum, with the residual light energy adding up to different colours (as seen by the eye) when viewed under the various light sources. Incidentally the green colour of monazite by mercury vapour lamps has been utilized in the petrological study of monazite sands (Murata and Bastron, 1956).

Comparison of the three absorption spectra shown in Figure 1 shows the expected broad correspondence of the lines in the yellow and green parts of the spectrum caused by the rare earths, but there appear to be additional lines in the monazite spectrum in the orange and red; it seems possible that these lines may be caused by the uranium shown in the analysis and akin to the lines produced in the absorption spectrum of zircon by small amounts of uranium.

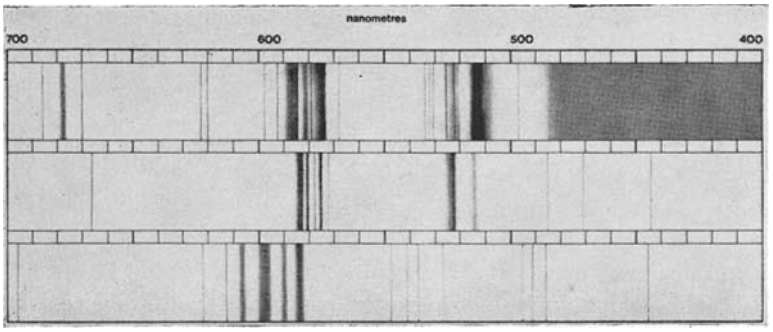

FIG. 1. Absorption spectra as seen through grating spectroscope:
Monazite gem material, Sri Lanka. (above).
Parisite, cf. material from Mineral County, Montana, U.S.A. (IGS registration number MI 35288).
Didymium glass. (IGS registration number MI 33205). (below).

The specimen has now been returned to Miss Sri Nissanka in Sri Lanka. It was earlier suggested that it should be fashioned into a gem stone since it appears to be the first cuttable specimen to be found. However, Miss Sri Nissanka preferred that it should remain as a rough stone. So yet another species is added to the long list of interesting gem minerals found in Sri Lanka.

It is a pleasure to acknowledge the ready help and assistance given by colleagues in the Petrographical Department of the Institute, Dr R. J. Davis and Mr J. G. Francis of the British Museum (Natural History) and Messrs R. K. Mitchell, H. J. Whitehead and others during the course of this work; and, of course, to thank Miss G. Sri Nissanka for allowing us to work upon this unusual specimen.

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UVITE, A NEWLY CLASSIFIED GEM TOURMALINE

By PETE J. DUNN, M.A., F.G.A.,
Department of Mineral Sciences, Smithsonian Institution, Washington, D.C., 20560, U.S.A.

TOURMALINE is a group name applied to several species. These are schorl, ferrous iron tourmaline; dravite, magnesium tourmaline; elbaite, lithium aluminium tourmaline and buergerite, ferric iron tourmaline.

The gemmologist is primarily concerned with elbaite, the lithium aluminium tourmaline which occurs in so many pleasing colours. Of lesser gemmological significance is dravite.

The occurrence of gemmy brown tourmaline in the Uva Region of Ceylon (Sri Lanka) and several fine brown gem tourmalines from Brazil prompted the author's interest in examining the heretofore unknown nature of these gem tourmalines, to determine their correct species designation.

Five cut gems and 28 rounded pebbles were examined in the first run of analyses. Some non-gemmy pebbles were included but the majority were of gem potential. It was immediately apparent that the brown gem tourmalines were magnesium tourmalines and would be termed dravite by the conventional classification system, using the four known species cited above.

However, it was also apparent that these gemmy magnesium tourmalines were different from most dravite, for they had a very high calcium content, and, in some cases, almost no sodium!

Dravite has the chemical formula $NaMg_3Al_6B_3Si_6O_{27}(OH)_4$. The position of magnesium (Mg) in the formula is sometimes filled by other cations. For example, if the Mg position in the above formula were filled by Fe^{+2}, it would be schorl; if it were filled by (Li,Al) it would be elbaite, etc.

What made the composition of these gemmy magnesium tourmalines so unique is that there was a substitution of calcium for sodium in the first site of the formula. A theoretical molecule had been proposed by Kunitz (1929) to explain the then-known calcium-rich magnesium tourmalines and he named this hypothetical molecule uvite, but it was never accepted as a valid mineral species name.

A detailed study of the calcium-sodium ratio in magnesium tourmalines was in order and has been published (Dunn *et al*, 1977).

The species uvite was proposed to the International Mineralogical Association Commission on New Minerals and New Mineral Names, and it was the judgement of the Chairman of the Commission that uvite was already established in the literature and thus out of the Commission's jurisdiction. This paper will treat uvite in brief general terms, with the emphasis on gem material.

The chemical formula of uvite is $CaMg_3[Mg,Al_5]B_3Si_6O_{27}(OH)_4$. This is a departure from the general formula of the tourmaline group $(X)_1(Y)_3Al_6B_3Si_6O_{27}(OH)_4$ in that the substitution of Ca^{2+} for Na^{1+} in the (X) position of the formula requires a compensation elsewhere in the formula to ensure electrostatic charge balance. This is accomplished by the substitution of one Mg^{+2} for one Al^{+3} to generate an electrically neutral structure.

Uvite is not distinguishable from dravite by standard gemmological techniques. Although calcium (atomic weight 40·08) is heavier than sodium (atomic weight 22·99), as calcium increases there is a concomitant increase in magnesium (atomic weight 24·31) substituting for aluminium (atomic weight 26·98) which serves to decrease the total atomic weight of uvite as calcium is increasing it. Hence, the densities of these two species are very similar. In addition, the presence of iron in these specimens also increases the density. The density of the examined uvites and dravites varied from 2·97 to 3·06.

The refractive indices are likewise of no use in distinguishing between uvite and dravite. The refractive indices of tourmaline are known to depend on the content of Fe^{+2}, Fe^{+3}, and Mn^{+2}, and excellent graphs have been prepared to demonstrate this relationship (Deer *et al*, 1962). Eight non-gemmy samples with extremely low iron content (less than 0·25% FeO) were examined. Their refractive indices were indistinguishable from dravite, and neither the indices nor the birefringence increased or decreased with increasing calcium content. Pleochroism is distinct in uvite, as in all tourmaline, with absorption $\omega > \varepsilon$. Optical data for the purest (most calcium-rich) gem uvites from each known locality are presented as Table I.

The Ceylon gem material is uniformly slightly turbid and lacks the brilliance of Burmese and Brazilian uvites.

Both uvites and dravites fluoresce a weak mustard-yellow under short-wave ultraviolet. There is no response to long-wave ultraviolet and no phosphorescence. The dispersion, always low for

TABLE I

OPTICAL DATA FOR UVITES

NMNH#	LOCALITY	ε	ω	BIREFRINGENCE	PLEOCHROIC COLOURS	
					ε	ω
C5212	Ceylon	1·619	1·638	0·019	light brown	dark brown
G2154	Brazil	1·619	1·638	0·019	light yellowish brown	medium brown
R18119	Burma	1·621	1·642	0·021	light yellowish brown	medium brown
G1107-1	Macomb, New York	1·612	1·632	0·020	light brown	medium brown

All determinations with Rayner Dialdex refractometer in sodium light ($\pm$0·003)

TABLE II

PARTIAL MICROPROBE ANALYSES OF UVITES AND DRAVITES FROM CEYLON

	NMNH #	SiO_2	Al_2O_3	FeO	MgO	CaO	Na_2O	TiO_2	Total	% Uvite	Locality
Uvite	134437	36·01	26·36	0·49	14·90	5·09	0·35	0·55	83·75	91	Ceylon
Uvite	134438	36·27	25·73	0·47	14·96	4·69	0·52	1·03	84·28	84	Ceylon
Uvite	B20712	35·57	28·18	1·01	13·16	4·40	0·62	0·69	83·63	79	Ceylon
Uvite	B20701	35·91	26·29	0·81	14·21	4·33	0·72	1·04	83·31	77	Ceylon
Uvite	B20709	35·64	27·82	1·31	13·22	4·23	0·70	0·92	83·84	75	Ceylon
Uvite	B14814	36·22	28·46	0·44	13·81	4·01	0·85	0·13	83·92	72	Ceylon
Uvite	B20708	35·28	28·50	1·76	12·27	3·98	0·82	0·50	83·11	71	Ceylon
Uvite	B20716	35·87	26·59	3·50	11·91	3·91	0·78	0·57	83·13	70	Ceylon
Uvite	B20718	36·54	26·34	0·47	14·26	3·87	0·90	1·57	83·95	69	Ceylon
Uvite	B20713	35·70	29·05	1·25	12·38	3·82	0·81	0·84	83·85	68	Ceylon
Uvite	B20717	36·00	28·17	1·27	12·91	3·77	0·90	0·42	83·44	67	Ceylon
Uvite	B20704	36·16	29·01	0·61	13·37	3·49	0·95	0·42	84·01	62	Ceylon
Uvite	B20702	34·86	29·33	3·99	10·21	3·33	0·89	0·61	83·22	59	Ceylon
Uvite	134436	35·28	28·42	1·27	12·52	3·25	1·15	1·16	83·05	58	Ceylon
Uvite	B20710	36·22	29·75	0·48	12·43	3·24	1·14	0·65	83·91	58	Ceylon
Uvite	B20705	35·33	30·96	0·23	12·51	3·16	1·27	0·26	83·72	56	Ceylon
Uvite	B20703	36·17	28·87	1·65	12·23	2·81	1·26	0·66	83·65	50	Ceylon
Uvite	B20698	36·18	29·67	0·39	12·13	2·63	1·21	0·92	83·13	47	Ratnapura, Ceylon
Uvite	B20700	35·95	28·74	0·77	12·43	2·58	1·38	0·88	82·73	46	Ceylon
Dravite	B14657	35·63	28·10	1·21	11·93	2·49	1·40	1·29	82·05	44	Ratnapura, Ceylon
Dravite	B20707	36·35	28·68	0·82	12·06	2·32	1·51	1·10	82·84	41	Ceylon
Dravite	B20699	35·06	26·65	5·50	9·52	2·25	1·46	2·05	82·49	40	Ratnapura, Ceylon
Dravite	B20706	35·90	30·10	0·33	11·71	2·25	1·36	0·35	82·00	40	Ceylon
Dravite	B20697	36·07	27·65	0·65	12·39	2·17	1·49	1·77	82·19	39	Ratnapura, Ceylon

Accuracy of data: ± 2% relative.

All samples have less than 0·05% K_2O, 0·03% Cr_2O_3.

TABLE III

ANALYSES OF UVITE FROM MOGOK, BURMA

NMNH#	SiO_2	Al_2O_3	FeO	MgO	CaO	Na_2O	TiO_2	Total	% Uvite
R18119	36·03	28·60	0·21	14·21	4·16	0·92	0·71	84·84	74
R18121	35·09	28·36	0·21	13·64	3·97	1·11	0·74	83·12	71
R18120	35·27	28·91	0·20	13·53	3·97	0 98	0 82	83·68	71
R18123	36·19	28·85	0·24	13·74	3·87	1·21	0·70	84·80	69
R18125	36·27	29·59	0·22	13·76	3·86	1·15	0·73	85·58	69
R18126	35·45	28·86	0·25	13·97	3·77	1·24	0·75	83·29	67
R18122	36·13	29·09	0·24	13·74	3·75	1·21	0·71	84·87	67
R18127	35·83	29·54	0·30	13·52	3·73	1·20	0·73	84·85	66
R18124	35·22	28·71	0·78	12·75	3·16	1·14	0·55	82·31	56

Accuracy of data: ±2% relative.

All samples have less than 0·05% K_2O, 0·03% Cr_2O_3.

magnesium tourmalines, varied from 0·019 to 0·018 (B-G) for both the uvites and the dravites examined.

Thirty-three specimens of brown tourmaline were analysed with the electron microprobe utilizing an operating voltage of 15kV and a sample current of 0·15 μA. Standards used were NMNH microprobe standards of high reliability. The analyses are partial, since the microprobe cannot detect boron, hydrogen, oxygen, and lithium.

Analyses of gem uvites and dravites from Ceylon are presented as Table II, in order of decreasing calcium content. Analyses of gem uvites from Mogok, Burma, are presented as Table III, in the same order.

The most sodium-deficient uvite found, among 170 analyses, is a magnificent 17·80 carat rectangular Brazilian gem on exhibit in the Hall of Gems at the Smithsonian Institution (Gem #2154). It was the extremely high calcium content of this gem that initiated the study of these uvites.

Next in relative purity was a Ceylon uvite of 20·05 carats (#C5212). This gem had reposed in our vaults for some time because it had been cut in two pieces many years ago. The bottom quarter of the gem had been sliced off roughly parallel to the table.

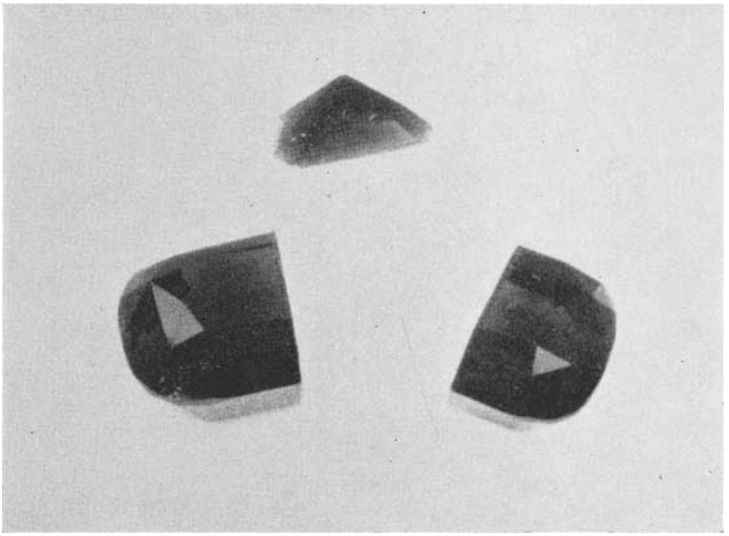

FIG. 1. Uvite from Ceylon: this gem, already marred, was sectioned for gemmological research. (NMNH C5212)

Inasmuch as there was no "type" material for uvite (type material is the very specimen used in the original mineralogical description of the species), one of the samples, this Ceylon gem, already marred by being sawn in two, was chosen to be the neotype material and is so designated. Since a wet-chemical analysis of this material would be necessary for the complete description of a new end-member, the gem was further subdivided (Fig. 1) and half of the larger fragment was subjected to wet-chemical analysis by Mr Joseph Nelen and Miss Julie Norberg, of the Chemical Laboratory, Department of Mineral Sciences, at the Smithsonian Institution. The results of this analysis are presented as Table IV.

TABLE IV

Analysis of Gem Uvite, NMNH #C5212

SiO_2	35·96%
Al_2O_3	26·80%
FeO	0·41%
MgO	15·20%
CaO	5·50%
Na_2O	0·13%
K_2O	0·00%
H_2O^+	2·70%
H_2O^-	0·04%
TiO_2	0·62%
Li_2O	0·00%
B_2O_3	11·49%
F	1·49%
TOTAL	100·34%
less O = F	0·63%
	99·71%

analysts: J. Nelen, J. Norberg.

It is obvious, from Table II, that brown gem tourmalines from Ceylon have varying compositions. Nineteen of the 24 samples from this locality have Ca > Na and are thus uvites. The statement Ca > Na refers to the number of atoms. Since the analyses in

Table II are given in terms of oxides, the calcium: sodium ratio is not immediately apparent.

Nine gemmy brown tourmalines from Mogok, Burma, were examined, and all are uvite. The compositions of these Burmese uvites, separated from boxes of gem gravel by Dr Brian Mason, are quite uniform, and allow the assumption that most, if not all, brown tourmalines from Mogok, Burma, are uvite.

Four of the 24 Ceylon samples were labelled as being from Ratnapura. . These four gems have a TiO_2 content in excess of 0·92% and are all dravite, which might suggest a compositional identifying factor for Ratnapura stones. Since most Ceylon brown tourmalines are reported to be from the Uva Region in south-eastern Ceylon, and Ratnapura is in the south-western section, these gems may indeed be from separate localities. But given the status of Ratnapura as a gem-trading centre, such an assumption is very weak indeed.

No diagnostic absorption spectra were found for either gem uvite or dravite from Ceylon or Burma. Inclusions were not noted in the examined Ceylon stones, but many non-gemmy samples from other localities, not noted here, were seen to have rutile inclusions. Inclusions in the Burmese uvites will be the subject of a subsequent investigation.

Although it is less than satisfying to present a new gem species to the gemmological community without also presenting methods of detection and distinguishing characteristics, in this case there do not appear to be any of the usual gemmological techniques which can be employed.

Uvite is a legitimate species name and may be safely applied to Burmese brown tourmalines. It might be noted that only five of the 33 analysed brown tourmalines were dravite, and that none of these five had any gem potential. Hence, although it may be only circumstantial evidence, all gem-grade facetable brown tourmalines examined in this study are uvite.

ACKNOWLEDGEMENTS

The author is indebted to Mr Joseph A. Nelen and Miss Julie Norberg, of the Chemical Laboratory, Department of Mineral Sciences, Smithsonian Institution, for the wet-chemical analysis of sample C5212. Thanks are also due to Mr Mike Laskin for the preparation of the final manuscript.

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ANOMALOUS OPTICAL CHARACTERISTICS SEEN IN CALCIC PLAGIOCLASE FELDSPARS

By A. J. CLEWLOW, B.Sc., F.G.S., F.G.A.

Introduction

Labradorite is an intermediate member of the isomorphous plagioclase feldspar series with the anorthite content falling within the range An_{50} to An_{70}. It often shows a characteristic play of colour sometimes referred to as labradorescence or schiller. However, in recent years a gem-quality transparent yellow variety of this mineral has been obtained from several localities. The author recently had occasion to identify a faceted stone of this type at the London Chamber of Commerce Gem Testing Laboratory.

Calcium-rich labradorite has a specific gravity and refractive indices which also coincide with the range for yellow beryl. Therefore a careful study of the refractive indices was made to determine whether the stone was uniaxial (as would be the case with beryl) or biaxial (as in plagioclase feldspar). The results obtained showed the stone to be biaxial negative. All references consulted referred to labradorite as optically positive, although the optic sign of plagioclase feldspar changes at several points with increasing anorthite content (see Fig. 1). It was therefore decided to investigate the cause of this apparent anomaly, and ten specimens reputed to be

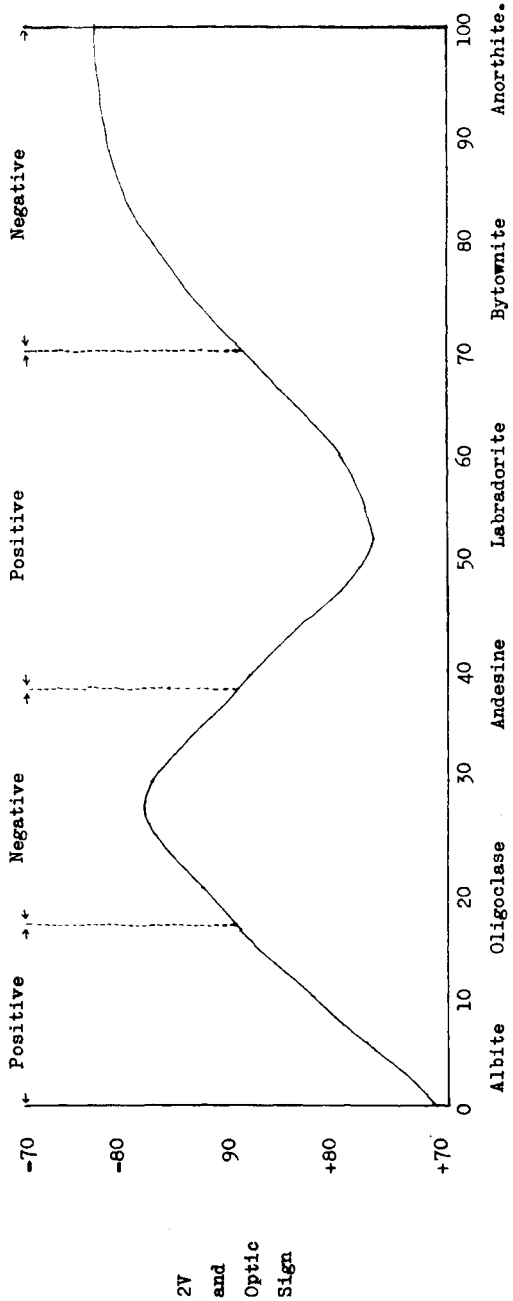

FIG. 1. The Plagioclase Feldspar series with a plot of percentage Anorthite content against 2V and Optic Sign. (After Dana).

TABLE I

Specimen Number	Presumed Origin	Weight and Cut	α	β	γ	Optic Sign	Specific Gravity
1	Canada	1·1679gm oval	1·563	1·569	1·572	Neg.	2·70
2	Hogarth Range N.S.W./Queensland border	0·9192gm rectangular	1·554	1·559	1·563	Neg.	2·68
3	Unknown	0·628gm round	1·563	1·568 –1·570	1·572	Neg.	2·71
4	S. Queensland	0·484gm round	1·559	1·562	1·568	Pos.	2·70
5	Millard Co. Utah, U.S.A.	0·544gm trapeze-cut	1·562	1·567 –1·568	1·570	Neg.	2·71
6	Malagasy Rep.	3·610gm fancy-cut	1·561	1·565 –1·566	1·570	Pos. or Neg.	2·71
7	Millard Co. Utah, U.S.A.	0·338gm rough	1·561	1·566	1·570	Neg.	2·70
8	Malagasy Rep.	0·872gm rough (with labradorescence)	1·555	1·559	1·562 +	Pos. or Neg.	2·69
9	Millard Co. Utah, U.S.A.	0·272gm rough	1·561 +	1·567 + –1·569	1·571 +	Neg.	2·72
10	Millard Co. Utah, U.S.A.	0·572gm rough	1·561	1·567 –1·568	1·570	Neg.	—

labradorite were obtained, originating from localities in North America, Australia, and the Malagasy Republic. Results obtained are outlined in Table I.

Refractive Index Determinations

Measurements of the refractive indices of the stones were made using a Rayner refractometer (Spinel model). On faceted stones, readings were taken on the table facet and one other, and on the rough crystalline samples two optically flat surfaces were polished. This enabled a fairly accurate calculation of β to be obtained, using the method described by Anderson. Readings for α and γ were straightforward to obtain, taking the lowest point of the lower reading, and the highest point of the higher reading respectively. Then $\beta 1_1$ (highest point of lower reading) and $\beta 2_1$ (lowest point of higher reading) were obtained. Readings on another face gave $\beta 1_2$ and $\beta 2_2$, and thus in most cases β could be calculated either within very narrow limits or precisely. Only on two samples was the position of β fixed within limits such that the stone could be either optically positive or negative. Results obtained from the ten samples showed seven to be optically negative, one stone to be optically positive and two indeterminate.

Behaviour in Cross-Polarized Light

Of the six faceted stones examined closely between crossed polarizers, five of the stones clearly showed curved bands of light passing through with a spectral play of colour (see Fig. 2). The only stone which did not show such an effect was specimen No. 4. In addition, twin planes were observed in four of the six faceted specimens. However, these tended to take the form of isolated planes crossing the stone, rather than the strong lamellar twinning under the Albite Law, which might have seriously affected the refractive index determinations.

The four specimens of rough material were also examined between crossed polarizers and all showed good extinction, although their uneven surfaces precluded the observation of strain bands or twinning very clearly (specimen No. 10 however did clearly show a twin plane running through the stone).

Specific Gravity Determinations

The specific gravity of nine of the ten specimens was determined. Specimen number 10 had some other material adhering to the

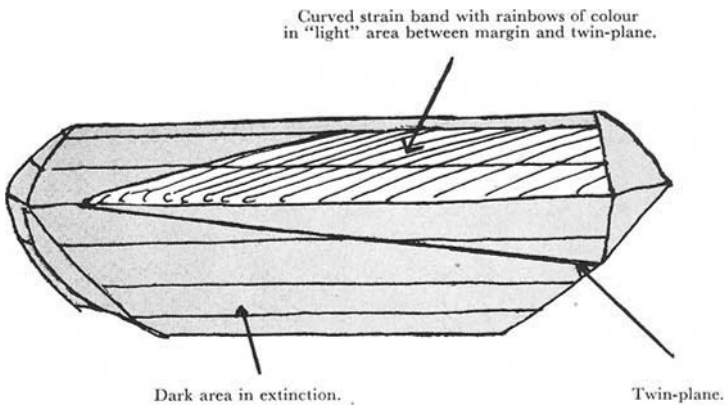

FIG. 2. Sketch illustrating appearance of specimen No. 6, in cross-polarized light.

crystal and therefore no determination of the feldspar alone was possible. The method used was by hydrostatic weighing in air and 1,2-Dibromoethane. Results obtained (to 2 decimal places) showed all specimens to fall into the range from 2·68 to 2·72, the specific gravity generally rising in proportion with the refractive index of α. However, when the values for specific gravity and α were plotted against one another (see Fig. 3), there did appear to be more scattering than expected and a simple line linking the two with increasing Anorthite content could not be drawn. Similar plots of specific gravity against values for the refractive indices of β and γ gave the same result.

CONCLUSION

It has been known for many years that zoning is common in plagioclase feldspar. A eutectic melt containing, for example, plagioclase of the composition An_{50} would first produce high-calcium plagioclase crystals of approximately An_{82}. Crystallization with further cooling causes both liquid and crystals to change composition until at 1285°C the crystals reach a composition of An_{50}

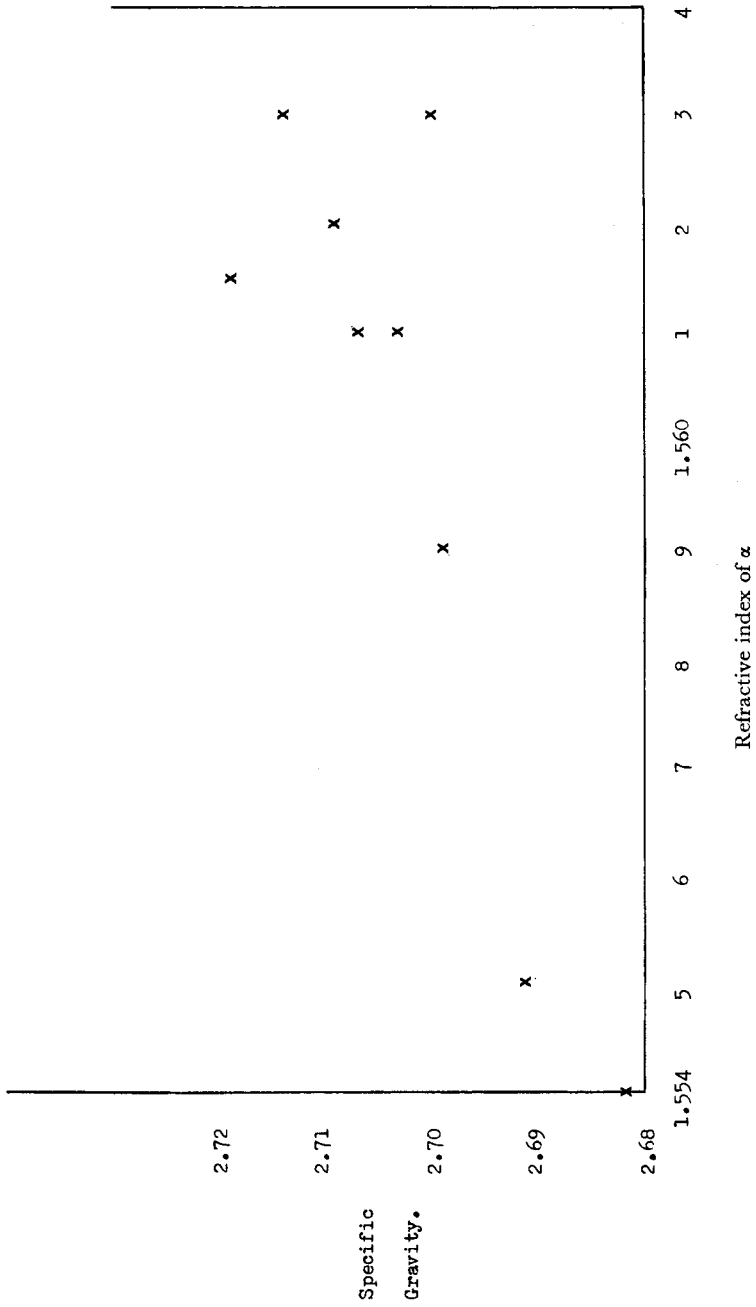

FIG. 3. Plot of the determined Specific Gravities of samples against the observed refractive index of α.

as the last of the liquid is used up. If the crystals have formed with time to react with the liquid and change their composition accordingly, they will be homogeneous. If there has been insufficient time to react, the composition of the crystals will be zoned, having a calcium-rich core with progressively more sodium-rich outer layers.

Zoning of this type in plagioclase will produce differing refractive indices and densities with lowering of anorthite content in each succeeding layer (the refractive indices and density becoming progressively lower). Since the refractometer measures the refractive index of the surface in contact with it, all measurements taken will be of the outer, less calcic, zones of the plagioclase crystals. However, the optic sign of the crystal will be a function of the optical character of the whole crystal. Furthermore, the effect of the zoning on the optics will be correspondingly much greater than on the density, which is dependent upon the relative volume taken up by each zone. The scattering produced when the specific gravities of the specimens were plotted against α readings is thought to be due to the differential effect on refractive indices and density caused by zoning in plagioclase feldspars.

Since the boundary between the labradorite and bytownite at An_{70} composition is also a boundary between optically positive (labradorite) and optically negative (bytownite) it seems likely that zoning in such stones would be more liable to result in a negative optic sign than positive, especially in crystals whose surface compositions give refractive indices in the high-labradorite range (An_{65+}), and whose inner zones would all be in the bytownite range or higher.

The presence of strain in nearly all of the faceted stones when viewed between crossed polarizers is indicative of zoning within these specimens. It should be noted that the only faceted stone which did not display this internal strain (specimen No. 4) was the only stone which was found to be optically positive. These facts indicate that specimen No. 4 was not zoned and thus composed wholly of labradorite, whereas the remainder were zoned and contained an appreciable proportion of plagioclase feldspar with a more calcic composition than the An maximum of labradorite.

It should be possible to obtain more evidence of this critical relationship between optical characteristics and zonal composition by an electron-probe study of calcium content together with optical

determinations, and it is hoped that someone with facilities to undertake this study will do so. The question which now remains is as to the nomenclature of such stones. Although they are of little importance commercially, many stones are being sold as "Labradorite Feldspar" which from this study would indicate that the description may be an over-simplification, especially where the average percentage composition is likely to fall well into the bytownite range. The author suggests that the term "Labradorite/Bytownite Feldspar" or "Calcic Plagioclase Feldspar" would be more appropriate.

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NOTES ON SOME OF THE CAUSES OF COLOUR IN GEMSTONES

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THE word "colour" signifies a different concept for different disciplines: to the artist it means pigment, to the psychologist it means perception, to the physiologist it means a response by the optic cones and rods: it means an electromagnetic radiation to the physicist and splendour to the gemmologist.

Of all the physical constants, the velocity of light in free space is the most accurately known, determined by Michelson and Morley in 1933 to be $2{\cdot}997925 \times 10^8$ metres per second, a figure which is the product of the frequency times the wavelength. Visible light is a narrow band in the continuous series of electromagnetic radiation ranging from over 10 megametres (10^7 m) in wavelength and 30 Hz in frequency to less than 1 femtometre (10^{-15} m) in wavelength and greater than 3×10^{23} Hz in frequency. The frequency range of visible light is from 4×10^{14} Hz at the red end to $7{\cdot}5 \times 10^{14}$ Hz at the violet end. When light passes from an optically rare medium, such as air, to an optically dense medium, such as glass, its wavelength is reduced, the ratio of reduction being the refractive index of the dense medium and because the frequency remains the same the velocity is reduced by the same ratio. Our eyes perceive the frequency or oscillations of light and not the wavelength, as has been customarily regarded.

In air our flesh appears pinkish, an optical phenomenon produced by a combination of colours resulting in a blend of wavelengths about 600 nanometres (600×10^{-9} m) and frequency about 5×10^{14} Hz. When our eyes are immersed in water the light reaching them is slowed down by a factor of 1·3 so that while the frequency of the light from our flesh remains the same at 5×10^{14} Hz, the wavelength would be about 460 nanometres. Thus, if we perceived by wavelength, our flesh would appear blue: this not being so confirms that our optic nerves respond to the frequency of light and not the wavelength. It is therefore incorrect to say that we see colours of a certain wavelength or group of wavelengths unless we specify the medium in which we make the observation, but it would be scientific to say we perceive colours of certain frequencies regardless of the medium.

Each frequency of light produces a different colour sensation and although monochromatic light is never truly attained in practice it is virtually produced by several light sources. Our eyes cannot distinguish whether the light perceived is monochromatic or consists of certain frequency combinations that produce colour sensations indistinguishable from monochromatic light. When our eyes are stimulated by the frequencies of all the colours simultaneously we are conscious of white light, but this effect may be produced by specific combinations of only two or three bands of frequencies. Red, green and blue-violet are the three colours that combine to form white light and are therefore called the primary colours and when combined in suitable proportions are capable of producing light of any colour.

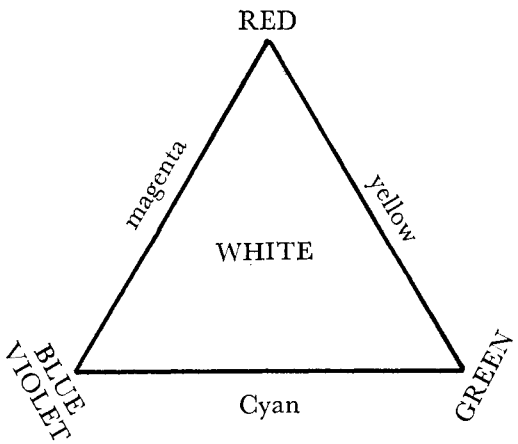

The diagram is a simplified concept of colour by addition, the corners of the triangle representing the three primary colours and the sides joining each pair of corners representing the colour produced by that pair of primary colours, for example red and green produce yellow. The sides also represent the complementary colour of the primary shown at the respectively opposite corner, for example yellow is the complementary of blue.

The three complementary colours yellow, cyan and magenta form an efficient set for colour by absorption.

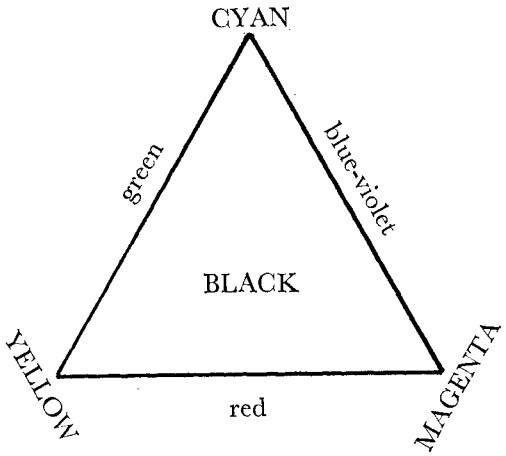

The corners of the triangle represent the three complementary colours and the sides joining them show the colour produced by the absorption of one respective complementary by the other, for example cyan absorbed by magenta produces blue-violet which on absorption by yellow leaves no visible light.

In general, when white light falls upon a gemstone, the result would be one or other of the following four principal effects or combinations thereof:

1. The light is completely reflected, that is to say there is no transmission and no absorption of any of the frequencies—the gem is then white and opaque, e.g. carrara marble.

2. The light is completely transmitted, there is no reflection and no absorption of any of the frequencies—the gem is colourless and transparent, e.g. diamond.

3. Some frequencies of light are absorbed at the surface and the remainder reflected—the gem is coloured and opaque, e.g. turquoise.

4. Some frequencies of light are absorbed in transmission—the gem is coloured and transparent, e.g. ruby.

Diaphaneity or transparency is a feature of a gemstone dependent on the quantity of light transmitted and ranges from transparent to opaque. A gem is described as:

(*a*) Transparent, when the outline of an object seen through the gem is perfectly distinct.

(*b*) Semi-transparent, when considerable light penetrates the gem but an object seen through it would appear blurred.

(*c*) Translucent, when some light passes through but no object can be seen.

(*d*) Semi-translucent, when there is a slight transmission of light through the thin edges of the gem.

(*e*) Opaque, when no light passes through the gem.

These descriptions refer to ordinary thicknesses, because in very thin sections practically all substances transmit some light; for example, gold-leaf appears translucent green.

Apart from the play-of-colour in opals and iridescence in some feldspars caused by the interference of light, the majority of gemstones would be colourless, were it not for the presence in the crystal lattice of ions which are non-essential for the chemical and structural identity of the mineral. Those which owe their colour to the presence of such impurities are known as allochromatic gems to distinguish them from a smaller group which are self-coloured (that is, in which the colour is due to an element forming part of the molecular structure); such gems are referred to as being idiochromatic. There are only four elements of the ninety-two that give rise to colour in the idiochromatic gems. They are:

Chromium	—	green	e.g. uvarovite
Copper	—	green	e.g. dioptase
Copper	—	blue	e.g. azurite
Iron	—	green	e.g. peridot
Iron	—	red	e.g. almandine
Manganese	—	pink	e.g. rhodochrosite

The elements causing colour in the allochromatic gems as impurities are:

Chromium	—	red	e.g. ruby
Chromium	—	green	e.g. emerald
Nickel	—	green	e.g. chrysoprase
Titanium	—	blue	e.g. sapphire
Vanadium	—	is known to influence the green colour in certain emeralds and in transparent green grossular garnet.	

A further element, cobalt, does not appear in natural gemstones, but is a well-known blue colouring agent in synthetic spinel and in glass.

These eight elements, titanium atomic number 22, vanadium 23, chromium 24, manganese 25, iron 26, cobalt 27, nickel 28 and copper 29 are part of a group called the transition elements. All are metals and have two or more unpaired electrons in their 3d orbitals with the exception of copper which has one unpaired electron in its 4s orbital. The five 3d orbitals are split into two high energy levels and three low energy levels and it is this energy difference ΔE that an electron absorbs on promotion from a lower level to a higher level. In the case of the transition metal compounds ΔE corresponds to a quantum in or near the visible region of the spectrum. The Crystal Field Theory offers an explanation of the source and interactions of the electrostatic fields originating from the negatively charged anions and dipolar groups or ligands situated on the lattice surrounding the transition metal ions. ΔE is mainly dependent on the symmetry and intensity of the field and thus explains why the energy differs for the different cations of the same transition metal, as examples the metal oxides Ti_2O_3 is purple; TiO is bronze; V_2O_5 is yellow; VO_2 is blue; Cr_2O_3 is emerald green; CrO_3 is red. This means that certain specific frequencies of light are absorbed by the energy change of electron promotion. The transmitted or reflected light that characterizes a gemstone is the complementary colour of that absorbed by the atom of the particular transition element. By noting the nature and position of the absorption bands when reflected or transmitted light is observed through a spectroscope, one can, in most cases with confidence, name the element causing the absorption. A more important fact for the gemmologist is that the disposition and nature of the absorption bands caused by a given element vary considerably according to the crystal lattice of the host mineral. It is the characteristic pattern of absorption bands shown by many gemstones which enables the gemmologist to identify the stones by means of the spectroscope.

The author gratefully acknowledges the encouragement and assistance given by Professor J. R. McIver.

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PORTABLE POLARISCOPE

By HAMILTON STITT, F.G.A.

THE identification of a cut stone, or piece of rough, in a well equipped laboratory is usually a matter of a few minutes routine inspection. However, we have all been confronted with the necessity of an educated guess, when examining a stone in some situation with a hand lens our only resource. The polariscope is a valuable aid in these circumstances. With it, we can differentiate between amorphous or isometric and doubly refractive materials, detect strain in glass, tabby extinction in synthetic spinel, indicate cryptocrystalline materials, find the optic axis in uniaxial materials, with a 10 × hand lens develop the optic figure of doubly refractive stones, and, not the least important, provide illumination for examination under a hand lens.

A simple polariscope can be constructed, in a few minutes, from a pair of polaroid sun glasses (or clip-ons) and a small flashlight. Many of the polaroid glasses come with a tag, comprising a small piece of polaroid material in a paper mount. This tag can easily be trimmed to fit firmly into the front of the flashlight and simply pushed into place. If the tag is not supplied, a piece of material can be cut from a second pair of polaroid glasses. It is important to place the polaroid material (polarizer) over the plastic flashlight lens, not under it. The type of flashlight is, of course, not critical, but the model illustrated is convenient for several reasons. It has a well in the nose which holds the stone in a relatively spill-proof manner. The single cell type fits easily into the pocket. The base is flat, so that the flashlight will sit in a vertical position. It should be powered by an alkaline cell; this is considerably more expensive, but much more reliable than an ordinary AA dry cell.

In use, the polaroid glasses or clip-ons (analyser) are worn normally. The flashlight is held in the vertical position with the switch on. It is then rotated in the fingers, until the extinction position is reached. The use of the polariscope is too well explained in the standard texts to require repetition here. There is however, one slight deviation. If, when examining a doubly refractive stone, the interference colours appear, then in order to develop the optic figure, with the flashlight in the crossed polar position, rotate the stone to achieve the maximum intensity of colours: hold the 10 × lens about 18 inches from the eye, and manipulate it above the

specimen until the figure is seen. It is not always possible to develop a full perfect figure. Very often a portion only can be seen. The device can also provide the illumination needed to examine the interior of a stone with a hand lens. It is most useful when used with a doubly refractive gem; the interior can be examined, brilliantly illuminated against the dark field of the crossed polarizers. But with any stone, it is a portable variable intensity source of (often much needed) illumination.

With pockets bulging only slightly, but with a great deal more confidence, I now carry stone tongs, a 10 × lens, and my portable polariscope.

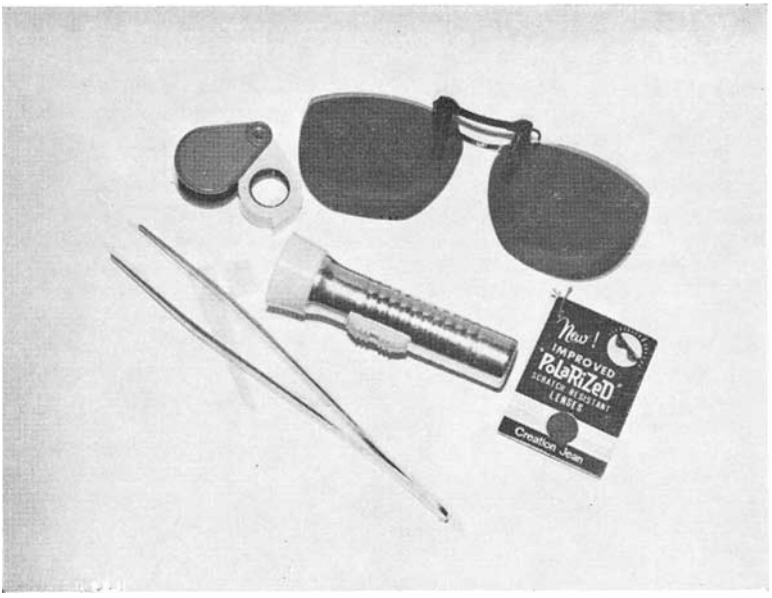

Gemmological Abstracts

ALEXANDER (A. E.). *Jade—China's contribution to the fine arts.* Gems and Gemology, 1976, XV, 5, 145-152. 10 figs.

A brief discussion of Chinese fine jade carvings both ancient and modern, with dynasties listed. The author's account of the dealer who bid for the Four Seasons screens, each 25″ × 13½″ × ½″ in size, with the intention of cutting them into ring-sized cabochons is a horror story in its own right. He also reports a necklace of beads showing intense green and colourless crystals of jadeite alternating. R.K.M.

BANK (H.). *Ein Jahrhundert Lapidärie in Idar-Oberstein.* (A century of lapidary in Idar-Oberstein). Z.Dt.Gemmol.Ges., 1976, 25, 3, 125-129. Bibl.

An interesting little article on the history of the lapidaries in Idar-Oberstein. Although it seems that stones were already worked in Idar-Oberstein during Roman times, but certainly at the latest in 1521, it is just over 100 years ago, in June 1875, that minutes of a meeting give details of a lapidary school and its board. One of the founder members was Wilhelm Purper. The school went through some difficult times: even towards the end of 1875 there was some talk of closing it down. E.S.

BANK (H.). *Citrin.* (Citrines). Z.Dt.Gemmol.Ges., 1976, 25, 4, 189-194. Bibl.

Citrine is a variety of quartz; the name derives from the French *citron* (lemon) because of its colour, which is produced by iron. It is found in its natural yellow-brown colour in varying intensities and shades; it is produced by heating brown smoky quartz, by heating amethyst to 420-560°C and by irradiating rock crystal and subsequent heating. The natural-coloured stone is found in Brazil (Goyaz, Bahia, Rio Grande do Sul), Madagascar, Russia, Spain, Scotland (Cairngorms) and France. It is often imitated by cheaper stones or glass, made into doublets or triplets and has been synthesized hydrothermally and sometimes imitated by other synthetic products, such as lithium niobate. Towards the end of the last century the heated product was called "topaz" and it is difficult to get rid of this wrong nomenclature. Heated and natural citrines can be distinguished one from another, but only with great difficulties. E.S.

BANK (H.). *Euklase von Santana do Encoberto, Minas Gerais, Brasilien.* (Euclase from Santana do Encoberto, M.G., Brazil). Aufschluss, 1974, 9, 445-448.

Euclase is found with feldspar, quartz, calcite, apatite and other minerals near the town of São Sebastião do Maranhão in Minas Gerais. The S.G. was 3·09 and the R.I. 1·649, 1·656, 1·674, with a D.R. of 0·025. M.O'D.

BANK (H.) and GÜBELIN (E.). *Das Smaragd-Alexandritvorkommen von Lake Manyara, Tansania.* (The emerald-alexandrite deposit near Lake Manyara in Tanzania). Z.Dt.Gemmol.Ges., 1976, 25, 3, 130-147. 22 illus. Bibl.

Deposits of emerald and alexandrite found in the metamorphic rocks of the crystalline mother-rocks in East Africa, near Lake Manyara in Tanzania, are now being worked. A plan of the mine as well as its location is shown and the geological,

mineralogical and petrological aspects discussed. During the visit of the authors about 50 workers were employed: there were bulldozers, compressors, washing and sorting facilities. Some veins were very thin (1-10 cm) in places. Emeralds varied from pin-head size to 20 mm length. Some examples of 20 and 150 g weight had been found. Colour of the emeralds varied. Chrysoberyl was found as well as alexandrite. Details of crystallographic, physical, optical, R.I., colour, absorption, inclusion and luminescence characteristics of emeralds and alexandrites described as are also the parageneses. E.S.

BANK (H.) and SCHMETZER (K.). *Geschliffener Bronzit aus Ceylon.* (Cut bronzite from Ceylon). Z.Dt.Gemmol.Ges., 1976, 25, 3, 153-155. Bibl.

For the crystal series enstatite-bronzite-hypersthene various R.I.s are known; the iron content for bronzite should be between 5 and 13%. A bronzite from Ceylon is tested and details given. E.S.

BASTOS (F. M.). *Imperial topaz from Brazil.* Lapidary Journal, 1976, 30, 8, 1836-38.

Pink, peach and red-orange coloured topaz crystals have been found in the Ouro Preto area of the state of Minas Gerais, Brazil. Especially fine stones have been found near Saramenha where they occur with limonite and specular haematite; there is no mica nor kaolin in this deposit as there is in most others in the Ouro Preto area. Nine crystals of exceptional colour and clarity, the largest weighing 333 grams, are illustrated in colour. All stones from the area are deeply striated. M.O'D.

BROWN (G.). *Horn—some aspects of interest to the gemmologist.* Australian Gemmologist, 1976, 12, 11, 331-338. 10 figs.

Rhinoceros horn, deer antlers and bovine horns are dealt with in detail together with a number of simulants and methods of distinguishing between them. Misprints and misspellings (e.g. longditudinal) mar an otherwise good paper. R.K.M.

CARLSON (E. H.) and KIRCHER (M. A.). *A pleochroic variety of gem labradorite from the Rabbit Hills area, Lake County, Oregon.* Gems and Gemology, 1976, XV, 6, 162-167. 8 figs.

Pleochroic transparent plagioclase labradorite occurs in the area in yellow, red-orange, blue-green (and combinations of the last two), yellowish-green, orange and parti-coloured bluish-green/violet all in varying depths of colour. R.I.s average α 1·562, γ 1·570, S.G. 2·713, suggesting a two to one anorthite/albite ratio. No U.V. fluorescence or absorption spectrum seen. R.K.M.

CARBONNEL (J. P.). *A visit to the Mingaora emerald mine, Swat, Pakistan.* Lapidary Journal, 1976, 30, 5, 1236-38.

The mine was discovered in 1958 and lies about 1km north-east of the town of Mingaora. It consists of a trench lying north-east at an altitude of about 3,000 feet. Emeralds occur at the contact of talc-schist and calc-schist and the presence of fuchsite is a guide to their presence. Lenses of quartz associated with calcite, hydrothermal in origin, may also contain emeralds in the form of fine needles, often cracked. Emeralds also occur in fissures cutting serpentine and talc-schists. Between 450 and 900 ct a month have been recovered from the mine during part of 1973. M.O'D.

CASSEDANNE (J. P. and J. O.). *La cordierite de Virgolândia, Bresil.* (Cordierite from Virgolandia, Brazil). Revue de Gemmologie, 1976, 48, 4-5.

Stones from this locality were at first believed to be blue sapphires and there was a rush to the area which lies north-west of Governador Valadares, about 500 km north-north-east of Rio de Janeiro. Cordierite is found in nodules ranging in size from a few centimetres to 0·4 metre; they are covered by a micaceous skin; the cordierite has a hardness of 7, S.G. of 2·57, R.I. 1·532, 1·540, 1·545, with a double refraction of 0·013. Above 400°C the cordierite became grey in colour but the blue reappeared on cooling. M.O'D.

CROWNINGSHIELD (R.). *Developments and highlights of GIA's Lab in New York.* Gems and Gemology, 1976, XV, 5, 153-157. 8 figs.

An opal-like glass showed swirls and spherules of other glass. R.I. 1·456, S.G. 2·25; probably a slag glass. A natural sapphire with a curved "veil of needles" is illustrated. Carroll Chatham is reported to have said that his flux-grown synthetic sapphires will soon be available. Jade-like green stones proved to be the Rhodesian (cryptocrystalline) quartz "mtorolite". Among gifts acknowledged was a granite, stained turquoise-blue by the process used for the howlite imitation, and a small crystal of red beryl from Utah. R.K.M.

CROWNINGSHIELD (R.). *Developments and highlights at GIA's Lab in New York.* Gems and Gemology, 1976, XV, 6, 181-189. 24 figs.

A cut bevelled cube of diamond, 8·55ct, containing a cube-shaped dark cloud of inclusions forming a cross is rightly described as intriguing. A fancy brown diamond with a roughly hexagonal white cloud, another with bright green inclusion (chrome diopside or enstatite?) are also described. Another inclusion is said to be "indescribable". A range of red spinels fine enough to look like synthetic rubies was seen and the term "soft rubies" heard for such stones. GGG diamond simulant is reported used in the classic "broken engagement" confidence trick, the word "diamond" not mentioned in the transaction. A diamond, turned yellow by deposits from well-water, was cleared by hydrochloric acid when all else failed. Small, apparently spherical, bubbles seen in a diamond. A circular spiral scratch running round the table of a brilliant-cut diamond defies explanation. A moss-like inclusion in dyed agate is thought to have been electrically induced. Slocum opal-imitations reported in pink, blue and orange body colours, some faceted; colour seems to come from thin flakes within the body of the material. Dyed green quartzite cabochons gave an absorption band centred at 6700Å, no fluorescence. Hot hydrochloric acid turned these black. A brilliant-cut diamond notched to form a six sided star shape and another, green treated, notched to give a Christmas tree shape are described and illustrated. Comments on frangibility of diamond are illustrated by several pictures; one stone shattered as cutting was being finished. Unusual cuts consisting of from one to five facets polished onto natural octahedra of diamond are shown with a reminder that American Federal Trade Commission rules state that there must be 17 or more symmetrically placed facets on a diamond before it can be called "diamond" without other qualifying terms.

R.K.M.

DANNER (W. R.). *Gem materials of British Columbia.* Montana Bureau of Mines and Geology, Special publication 74 of 1976.

Nephrite is the most important of the gem materials found in the Province and rhodonite is also found. Argillite from the Queen Charlotte Islands is used for Indian carvings. Some fire opals and gold nuggets are also found. Pegmatite minerals are rare. M.O'D.

DARRAGH (P. J.), GASKIN (A. J.) and SANDERS (J. V.). *Opals.* Scientific American, 1976, 234, 4, 84-95.

An expanded version, illustrated in colour, of articles by the same authors published in other journals. Reference is made to the use of tetraethyl orthosilicate to give spheres of the required size for diffraction of light to take place. Sodium/sols, also used for this purpose, in the form of aqueous solutions of sodium silicate by treatment with ion-exchange resins, proved much longer in settling into the ordered layers needed. M.O'D.

DE MATTEI (R.), HUGGINS (R. A.) and FEIGELSON (R. S.). *Crystal growth by the electrochemical Czochralski technique (ECT).* Journal of Crystal Growth, 1976, 34, 1, 1-10.

Large single crystals of sodium tungsten bronze, Na_xWO_3, up to 2·5 cm in diameter and 11 cm in length have been grown by electrochemical crystallization from molten salt solutions combined with crystal pulling. M.O'D.

ELBE (M.). *Brillianten-Krieg?* (War around brilliants?) Z.Dt.Gemmol.Ges., 1976, 25, 3, 148-152. 1 illus. Bibl.

Pros and cons of an argument about maximum brilliance in brilliant-cut diamonds. Table illustrates tolerances of the angles of the crown facets as compared with the angles of the pavillion facets of the various types of brilliant cuts. The author advocates not cutting the stone on the traditional octagon principle, but using an odd number of corners in the table. E.S.

ENGLAND (B. M.). *Quartz polyhedroids in Australia.* Australian Gemmologist, 1976, 12, 10, 303-306. 5 figs.

Multi-sided agate nodules found in S. Australia. Thought to be quartz infilling of spaces between blades of tabular calcite which later weathered out. R.K.M.

FUJISAKI (Y.). *Glass made imitation jade and its inclusions.* Journal of the Gemmological Society of Japan, 1976, 3, 3, 99-105. (In Japanese.)

Material circulating in Japan under the name of Siberian or reformed jade is made from glass. It is dark green, translucent to opaque, with a hardness of between 5 and 5½; the S.G. is 2·67 and the R.I. 1·523 ±0·005. Broad absorption bands are seen at 4600-4000Å and 7000-6000Å. Three types of inclusion have been distinguished; one type consists of needle-like structures identified as hydroxyl apatite; another type, in dendritic form, is believed to be either vapour or liquid and the third type consists of four groups of structures none of which have so far been identified. The material shows pseudo-optical anisotropy. M.O'D.

GAINES (A. M.) and HANDY (J. L.). *Mineralogical alteration of Chinese tomb jades.* Nature, 1975, 253, 433-434. 3 figs.

White chalky areas on nephrite tomb jades from the period 1766 B.C. to A.D. 220 are caused by leaching along grain boundaries by ammoniacal solutions of high PH produced during decay of the corpses with which the jade was buried. There is no change in mineralogical composition. F.B.A.

GAINES (R. V.). *Beryl—a review.* Mineralogical Record, 1976, 7, 5, 211-23. Illus. in colour.

The beryl minerals are described with illustrations and geochemical data. The red variety, bixbite, has recently been found in the Wah Wah Mountains of Utah, making four locations in all. The beryl structure is illustrated. M.O'D.

GAINES (R. V.). *Los berilos.* (The beryls). Boletin del Instituto Gemologico Español, 1976, 15, 23-34. Illus. in colour.

This article deals with emerald, other green beryls, aquamarine, heliodor, morganite, goshenite, red beryls and synthetic productions. M.O'D.

GILL (J. G.). *An easy method of measuring the depth of a mounted transparent stone in a closed-back setting.* Gems and Gemology, 1976, XV, 6, 178-180. 2 figs.

The old "real and apparent depth" R.I. method adapted by multiplying the apparent depth by the known R.I. of the stone to obtain a close approximation to its actual depth. Describes adding millimetre scale to microscope not equipped with one. R.K.M.

GÜBELIN (E.). *Scorodite—a new gemstone from Tsumeb, South-West Africa.* Gems and Gemology, 1976, XV, 5, 130-136. 6 figs.

A full account of a strongly pleochroic dark blue gem mineral which has been reported before in this journal. A hydrated ferric arsenate with R.I. α 1·785, γ 1·816, birefringence 0·031 positive, S.G. 3·29, H. 3½ to 4, this is a rare orthorhombic mineral known so far in about five world localities. A collector's gem rather than commercial owing to extreme softness and to rarity of gem material. This paper is prepared with all the great care and scientific detail one has come to expect from one of the world's foremost gemmological scientists. R.K.M.

GÜBELIN (E.). *Über eine neue Opal-imitation.* (About a new opal imitation.) Z.Dt.Gemmol.Ges., 1976, 25, 4, 199-203. 3 illus. Bibl.

The author describes the Slocum-stones (produced by John Slocum, of Royal Oak, Michigan) which give a very good first impression, but when viewed with a loupe one can see thin, variously coloured, irregularly shaped splinters which reflect the light. Lustre is vitreous and fracture conchoidal. The white imitations contain elements of Na, Si, Mag (Al) and (Ti), the black specimen is a mixture of two phases which are intergrown consisting of Na, Si, Ca, Mag and (Al) and are also silicate glasses. The coloured splinters seem to be very thin pieces of heated and metal-covered silica gel. R.I. 1·49 to 1·52; S.G. 2·41 to 2·51 and Mohs hardness 5·5 to 6·5. Sizes of produced material allow production of cabochons and use in doublets and triplets. E.S.

GÜBELIN (E.). *Djevalith—eine neue Diamant-Imitation.* (Djevalite—a new diamond imitation.) Z.Dt.Gemmol.Ges., 1976, 25, 4, 204-210. 2 illus. 1 graph. 2 tables. Bibl.

The author describes a new diamond imitation produced by Hrand Djevahirdjian in Monthey, Kanton Wallis, Switzerland. It is colourless, transparent, cubic and has the chemical composition $ZrO_2 + CaO$ and is very difficult to distinguish from diamond. R.I. $2{\cdot}1775 \pm 0{\cdot}005$, no birefringence. The material is completely isotropic. Dispersion 0·0627 (higher than diamond), adamantine lustre; Brewster's angle = 65°20′; the critical angle of total reflection = 27°20′. The spectrum shows no absorption lines or bands. Mohs hardness about 8-8½, i.e. harder than most diamond imitations. Under x-rays the djevalite is opaque, as opposed to diamond which is transparent. Table compares the new product with diamond and other diamond imitations. E.S.

HORIUCHI (N.). *Relation between proportion and yield of brilliant diamond.* Journal of the Gemmological Society of Japan, 1976, 3, 3, 106-113. (In Japanese.)

Various calculations were employed to assess the possible yield from the following cases: off-centred and centred brilliant-cut diamond from ideal octahedron; brilliant from ideal dodecahedron; re-polish of brilliant into Tolkowsky cut. M.O'D.

KHORASSANI (A.) and ABEDINI (M.). *A new study of turquoise from Iran.* Min. Mag., 1976, 40, 640-2.

Specimens from various locations in Iran have been analysed on a powder diffractometer and agree in general with the formula $Cu(Al,Fe)_6(PO_4)_4(OH)_8 \cdot 4H_2O$. The finest sky-blue coloured specimens are the lowest in iron content. Turquoise from Nishapur and Damghan shows strong absorption bands in the range 3560–3000cm^{-1}, characteristic of OH, and strong bands in the range 1180–1000cm^{-1}, characteristic of PO. A sample heated to 800°C showed a new absorption band at 715cm^{-1}, perhaps due to the formation of a pyrophosphate. M.O'D.

KRAUS (P. D.). *Topaz and citrine, birthstones for November.* Lapidary Journal, 1976, 30, 8, 1841-1852.

A review of the occurrence, properties and legendary accounts of topaz and citrine. M.O'D.

LAL (K.). *Characterization of dislocations in gadolinium gallium garnet single crystals by transmission x-ray topography.* Journal of Crystal Growth, 1976, 32, 357-362.

Growth bands due to thermal variations were found in almost all specimens examined and growth facets observed were found to be the traces of (211), (121) and (112) lattice planes. Some wafers cut parallel to (111) showed dislocation loops of dodecagon shape and these are associated with iridium inclusions. M.O'D.

LAL (K. P.). *Corundum deposits in India.* Gem World, 1976, 3, 3, 31-36.

Corundum has been found recently near Janwali in Rajasthan. The rubies are found in a cordierite rock lacking in quartz, and other varieties are found as

disseminated crystals in Aravali schist intruded by aplitic and pegmatitic rocks. Corundum of a variety of colours is found in Madhya Pradesh at Pipra in Sidhi district, where it occurs in a sillimanite schist associated with hornblende and intrusive granite gneiss. Corundum also occurs in Tamil Nadu at Coimbatore, where it is found in syenite in the Sivamalai hills. In Assam corundum occurs in a sillimanite rock at Sonapahar. At Soomjam, in Jammu and Kashmir state, ruby and sapphire are obtained from a kaolinized pegmatite intruding into garnetiferous biotite and other rocks. M.O'D.

LIDDICOAT (R. T.). *Developments and highlights of GIA's Lab in Los Angeles.* Gems and Gemology, 1976, XV, 5, 138-142. 8 figs.

An 0·20ct jeremejevite, a 3·73ct eosphorite are recorded as resembling aquamarine and topaz respectively, and a supposed synthetic powellite turned out to be synthetic scheelite; testing details are not given. A white cabochon pectolite gave R.I. 1·59-1·62 by the spot (distant vision) method; S.G. 2·8. It was confirmed by x-ray powder diffraction. A sinhalite in an old bracelet was identified (although recognized as a separate mineral only in 1952, sinhalite has been cut probably for as long as Ceylon has been producing gems). A new synthetic emerald with veil-like healed cracks, flux inclusions and phenakite crystals, R.I. 1·560-1·565, birefringence 0·005, S.G. 2·65, medium red fluorescence, is described and illustrated. Treated turquoise of poor quality tested for paraffin (wax) by hot point test proved to have been treated with some type of plastic. A large light green beryl showed growth features characteristic of trapiche emeralds but colour was due to green dye. Cultured pearls are sometimes drilled eccentrically and additionally via the stringing hole to reach backs of dark conchiolin blisters so that these may be bleached. A radiograph is illustrated showing pearls with up to three or more drillings through the M.O.P. bead for this purpose. A cluster of blue sapphire "crystals" proved to be synthetic sapphire cut to simulate natural hexagonal crystals and cemented together with blue plastic. The latter showed bubbles and a cobalt absorption spectrum. R.K.M.

LIDDICOAT (R. T.). *Developments and highlights at GIA's Lab in Santa Monica.* Gems and Gemology, 1976, XV, 6, 170-177. 16 figs.

A chrysoberyl showing a four-rayed star, two-phase irregular inclusions in natural ruby and natural-looking inclusions in synthetic ruby and sapphire are described and illustrated. A cyclotron-treated emerald-cut green diamond is described with comment that such a stone is rarely seen today. It showed colour zoning due to directional irradiation. A reddish-purple diamond, 0·44ct, showed characteristic spectrum for treated pink; absorption is described. A cicada "in amber" proved to be entombed in plastic. A Mabe pearl (half-cultured, or "Jap" pearl) with an imitation pearl centre, large rutile needles in emerald, monoclinic crystal inclusions in Mexican opals and a combined flux-melt and flame-fushion synthetic ruby are also described and illustrated. R.K.M.

MAGRYN (H.). *Calculating radiopacity.* Australian Gemmologist, 1976, 12, 11, 323-326. 1 fig. 2 tables.

An explanation of a mathematical method of predicting the probable degree of opacity to x-rays in mineral and other substances. R.K.M.

MALES (P. A.). *Ruby corundum from the Harts Range, N.T.* Australian Gemmologist, 1976, 12, 10, 310-312. 1 illus.

Red material originally thought to be ruby has been identified as garnet. This area, north-east of Alice Springs, has now produced pink corundum similar to Madagascan material. (Corundum formula is incorrectly quoted). R.K.M.

MATHUR (S. M.). *Shallow diamond mines of Panna (India).* Gem World, 1976, 3, 6, 13-20.

The mines are in conglomerates or in gravels, diamond-bearing conglomerates occurring towards the top of the Upper Rewa sandstone, the Lower Rewa sandstone and towards the base of the Jhiri shale formation. The gravels exist either on the top of the Kaimur and Rewa plateaus, as detritus caught in fissures in the Kaimur quartzite, in the stream gorges cutting the Kaimur and Rewa scarps or as recent detritus in stream beds. All working is manual, quantities recovered being very variable. M.O'D.

MATHUR (S. M.). *The historical background of Koh-I-Noor.* Gem World, 1976, 3, 10, 21-32.

The history of the diamond is told with illustrations of sketches by Tavernier of the Great Moghul diamond, believed to be the Koh-I-Noor. M.O'D.

MEYER (H. O. A.) and TSAI (H.-M.). *The nature and significance of mineral inclusions in natural diamond: a review.* Min.Sci.Eng., 1976, 8, 242-261. 6 figs,. 12 colour photos.

The history of the identification and realization of the significance of inclusions in natural diamonds are reviewed, together with a discussion of their detailed mineralogy and major-element chemistry. The categorization of inclusions into primary (pre- or syngenetic) and secondary (epigenetic) is considered, as well as the subdivision of primary inclusions into those representing ultramafic and eclogitic suites. The contribution of work on diamond inclusions to the problems of the genesis of diamond and the formation of kimberlite and associated xenoliths, and to the mineralogy of the upper mantle, is reviewed. Data presented include new analyses of olivine (2), enstatite (2), clinopyroxene (3), chrome-pyrope (2), pyrope-almandine, and chromite (2). R.A.H.

MOREAU (M.). *Nong Bon ou le rubis de Thailande.* (Nong Bon or ruby from Thailand). Revue de Gemmologie, 1976, 47, 10-12.

Nong Bon lies in the extreme south of Thailand, close to the Cambodian frontier. Production of cuttable stones amounts to approximately 300ct a year; stones are frequently included, fassaite being the commonest intruder. M.O'D.

MORNARD (H.). *De la biologie . . . à la gemmologie.* (From biology to gemmology.) Bulletin, Société Belge de Gemmologie, 1976, 3, 5-8.

Contains notes on coral, amber, petrified wood and opal. M.O'D.

MUMME (I. A.), SEIBRIGHT (L.) and BALL (R.). *The origin of volcanic opal from Houghlahan's Creek (near Teven).* Australian Gemmologist, 1975, 12, 8, 235-240. 2 figs. 2 maps.

Deals in detail with an occurrence of opal in New South Wales. Some of the gem material is said to resemble Mexican opal. R.K.M.

NARASIMHAN (V. K.). *Sparkling sales. The Times* newspaper, 26th January, 1977, no. 59917 (India Supplement, XIII).

This report gives figures of exports of Indian-made jewellery and ornaments, rising from Rs 224 m in 1963/4 to Rs 718·8 m in 1972/3 and to Rs 1300 m in 1975/6. Diamond exports constitute more than 80% of gems and jewellery exports, and other gemstones about 15%. Exports of cut diamonds rose from Rs 24·3 m in 1963/4 to Rs 990 m in 1975/6, principally to the U.S., Japan, Belgium, Hong Kong and Holland. A gem-testing laboratory has been set up in Jaipur (Rajasthan) by the Gem and Jewelry Export Promotion Council, and another will be set up in Delhi. J.R.H.C.

NASSAU (K.). *A new diamond imitation: cubic zirconia.* Gems and Gemology, 1976, XV, 5, 143-144. 2 figs.

Two stones were examined. S.G. determined at 5·7, H. between 8 and 9. R.I. quoted by manufacturer, 2·15. Dispersion 0·060. Cubic zirconium oxide is a high temperature polymorph of zirconia known in nature, so this is a true synthetic. X-ray testing turned it yellow. One stone showed lines of bubble-like flux-filled negative crystal inclusions. Trade name "Djevalite". Another, with 15% yttrium oxide, made in U.S.S.R. by a melt technique called "skull melting", is sold as "Phianite". Commercial viability in competition with YAG and GGG is questioned. R.K.M.

NASSAU (K.). *On the naming of new man-made crystals.* Gems and Gemology, 1976, XV, 6, 168.

Some manufactured gem materials are being made with two or more possible chemical compositions. $Y_3Al_5O_{12}$ and $Y_4Al_2O_9$ are both yttrium aluminate and sold as "YAG", "diamonaire", etc. Strontium titanate ("fabulite") is one form of four possible chemical substances each of which could be called by the same name. Dr Nassau suggests that the chemical formula should be added after the name at all times for these isoidiomorphous substances. Polymorphs (same formula but different crystal system) should have the system appended. R.K.M.

NASSAU (K.). *Synthetic emerald: the confusing history and the current technologies. Part 2—Conclusion.* Lapidary Journal, 1976, 30, 2, 468-492.

Hydrothermal growth of emerald has been confined in recent years to the productions of Lechleitner and the Linde Division of the Union Carbide Corporation. This latter production changed slightly during the period of manufacture (1965-1975). Production as distinct from distribution ceased in 1970. Both Chatham and Gilson processes use acid lithium molybdate as a flux though full details of the processes are not available. M.O'D.

NASSAU (K.), PRESCOTT (B. E.) and WOOD (D. L.). *The deep blue Maxixe-type color center in beryl.* Amer. Min., 1976, 61, 100-107. 8 figs.

A deep blue colour centre is produced in beryl by a variety of penetrating radiations. If the original beryl is yellow or green, the resulting colour can be green or blue-green. This colour centre cannot be produced in just any beryl, and the nature of the required precursor is unknown. Apparently it does not involve transition metals, alkalis, or water. Both light and heat can cause fading of the blue component of the colour, and it can be restored by γ-ray, x-ray, or neutron

irradiation in the Maxixe-type material. In the case of the originally blue 1917 Maxixe material, irradiation of bleached material produces a green colour, indicating that the Maxixe colour was not due to irradiation. A.P.

NASSAU (K.). *D'où provient la couleur des gemmes et des mineraux?* (Where does the colour of gems and minerals come from?) Revue de Gemmologie, 1976, 40, 7–10.

French translation of an article first published in *Gems & Gemology*, 1974/5, 14, 12, 354-361; 1975, 15, 1, 2-11; 1975, 15, 2, 34-43. M.O'D.

NEWBURN (J. M.). *The electropolishing of the precious metals and their alloys.* (Part I.) Australian Gemmologist, 1976, 12, 11, 339-346.

This is essentially electro-plating in reverse, the article to be polished being connected to the positive (anode) terminal in what is effectively a plating bath. (In plating it would be on the cathode side). "Asperities" (roughnesses) are removed as the current flows and with care and attention to details of current, electrolite composition, and temperature a very good polish can be obtained in a very short time. The process, properly applied, provides a fine scratch-free finish on good quality single piece items, but tends to accentuate solder lines in joined pieces and porosity or pitting in castings. R.K.M.

O'LEARY (B.) and BALL (R. A.). *Indonesian opal.* Australian Gemmologist, 1976, 12, 11, 327-328. 4 figs.

A report on opal found in a remote but un-named locality in Java. Jelly opal, similar to Mexican opal, some called "tea" opal, or "black tea" opal, and white opal are found. "Crystal opal . . . with intense actinic irisisations" seems a strange misuse of terminology. Opal from this source tends to crack or craze easily, possibly due to unusual micro-structure. R.K.M.

PAVITT (J. A. L.). *Thailand—gem cutting and trading.* Australian Gemmologist, 1976, 12, 10, 307-309, 318-319. 1 map.

Deals mainly with the economics of the Thai gem industry based on available Customs figures. Movement of material across the Cambodian border is not recorded. R.K.M.

PHILLIPS (F. C.). A *letter* referring to paper *Crystallography is fun* (see Abstract in J.Gemm., 1977, XV, 5, 264, s.v. Sutton, J. & P.). Australian Gemmologist, 1976, 12, 11, 329.

Professor Phillips straightens out some misconceptions in the original paper. Erroneous printing of signs, or their complete omission, when dealing with crystallographic angles makes part of this kindly and explicit letter difficult to follow. R.K.M.

PRADESH (S.). *Jade in Salarjung Museum.* Gem World, 1976, 3, 7, 32-35.

The Museum is in Hyderabad and contains such celebrated treasures as Emperor Jehangir's hunting knife, together with other artefacts. M.O'D.

RAAL (F. A.). *The Special Research Project—25 years later.* Diamond Research 1976 (Industr. Diamond Inform. Bur.), 2-3.

Some of the results from co-operation between De Beers and British Universi-

ties are reviewed. They include ion implantation, studies of mechanical properties of diamond, surface chemistry, and studies relating to kimberlite and diamond genesis. R.A.H.

RICHARD (H. M.). *Arizona's rainbow gems.* Lapidary Journal, 1976, 30, 1, 22–48. Illus. in colour.

Minerals able to be fashioned include azurite, turquoise, dioptase, cuprite and wulfenite. Gold is also found and has been used for ornament. Peridot and pyrope garnet are found in Indian reservations in the south-east of the state. M.O'D.

RODGERS (J. R.). *Classic Oregon localities.* Lapidary Journal, 1976, 30, 1, 116–128. Illus. in colour.

Oregon is celebrated for its "thunder eggs" and opalized wood. Transparent sunstones are also found. M.O'D.

ROLFF (A.). *A trip to the famous citrine areas of Brazil.* Lapidary Journal, 1976, 30, 8, 1986-95.

Reprint of an article first published in the issue for November 1969. M.O'D.

ROSENTHAL (J.). *Les perles: pt 1.* (Pearls: pt 1). Revue de Gemmologie, 1976, 48, 11-12.

Outline of the use of pearls in antiquity and of their composition. M.O'D.

SANDERS (J. V.). *The structure of star opals.* Acta Cryst., 1976, A32, 334-338. 9 figs.

Optical diffraction patterns have been obtained from a set of unusual gem opals from Idaho, U.S.A. The formation of star patterns in them is described, and the structure producing the stars is deduced from optical diffraction. The arrangement of particles is different from that found previously for Australian opals. (Author's abstract). D.T.

SCHMETZER (K.), BANK (H.), BERDESINSKI (W.) and KROUŽEK (E.). *Coeruleit—ein neuer Schmuckstein.* (Ceruleite—a new gem). Z.Dt.Gemmol.Ges., 1976, 25, 4, 195-198. 2 illus.

Rough and cut stones were offered on the market which were similar to turquoises, but found to be ceruleite. The colour is sky-blue. The aggregates look homogeneous, but under the Raster electron microscope (10000 × mag) crystals could be seen to have a length of 5 microns and a thickness of 2 microns. Chemical formula: $Cu_2Al_7(OH_{13}(AsO_4)_4 \cdot H_2O$; R.I. 1·60; S.G. 2·70 ± 0·02. E.S.

SCHOWALTER (M.). *Slocum stone—a new man-made material.* Lapidary Journal, 1976, 30, 1370-1374. 1 coloured plate.

A brief description is given of imitation opal made by J. L. Slocum of Michigan and guaranteed against crazing, cracking, or colour loss in normal procedures. These stones have H. 5½-6½, sp. gr. 2·41-2·50, *n* 1·49-1·51. R.A.H.

SCHWALM (J.). *Von der Heilkraft der Edelsteine.* (On the healing-power of gemstones). Aufschluss, 1975, 26, 355-67.

The medicinal properties of the better-known gemstones are reviewed with references to the literature. M.O'D.

SHEENS (K. A.). *Chinaman's hats.* Australian Gemmologist, 1975, 12, 7, 208-209, 5 figs.

Shallow conical opal masses occurring at Lightning Ridge. "Hats" form either apex-up, or -down, usually at end of vertical opal pipe. Some are all potch. Others have "colour" on upper side, regardless of which way up the "hat" has formed. R.K.M.

SHODA (T.). *Basic knowledge on studies of gemstone by the use of polarized light. (Part 1).* Journal of the Gemmological Society of Japan, 1976, 3, 3, 123-131. (In Japanese).

General survey with diagrams. M.O'D.

SPEER (J. A.) and GIBBS (G. V.). *The crystal structure of synthetic titanite, $CaTiOSiO_4$, and the domain textures of natural titanites.* Amer. Min., 1976, 61, 3/4, 238-247.

Specimens of synthetic titanite (sphene) proved the space group symmetry to be $P2_1/a$, not $A2/a$ as previously reported for the natural material. Octahedra of TiO_6, corner-sharing and in chains, run parallel to the a-cell edge and are linked by silicate tetrahedra to form a $TiOSiO_4$ framework accommodating Ca in irregular 7-coordination polyhedra. Crystals were manufactured from a mix of composition $CaCO_3.TiO_2.SiO_2$. CO_2 was driven off before melting in a platinum crucible at about 1400°C and 1 atm. Material was homogenized by repeated crushing, remelting and quenching, then crystallized at about 1200°C for several weeks, before cooling. M.O'D.

STERNS (M.). *Gemology—Now you see it, now you don't.* Gems and Gemology, 1976, XV, 6, 169.

Tries to trace the history of the name. "Gemmology" was used as early as 1811. Encyclopedias Americana (1960) and Britannica (1974) ignore it in both its spellings. On evidence provided it seems that the British spelling is etymologically correct and that the American orthography arrived with the G.I.A. R.K.M.

STRUNZ (H.) and WILK (H.). *Cuprit von Onganja, SW-Afrika.* (Cuprite from Onganja, S.W. Africa.) Aufschluss, 1975, 1, 1-4.

Cuprite crystallizes in the isometric system and typical crystals are illustrated. Notes on other localities are given. M.O'D.

SUNAGAWA (I.). *10th General Meeting of the International Mineralogical Association.* Journal of the Gemmological Society of Japan, 1976, 3, 3, 117-122. (In Japanese).

Reviews of some of the papers presented. M.O'D.

SUZUKI (S.) and LANG (A. R.). *Occurrence of facetted re-entrants on rounded growth surfaces of natural diamonds.* Journal of Crystal Growth, 1976, 34, 1, 29–37.

Faceted re-entrants are initiated at particular growth horizons at which an episode of strong inhibition of growth on {111} commences. It is believed that they occur at dislocation outcrops as preferential locations. M.O'D.

SWINDLE (L.). *Amazonite—a specimen from the Centennial state, Colorado.* Lapidary Journal, 1976, 30, 1, 96–98. Illus. in colour.

The microcline feldspar amazonite was first shown in the U.S.A. about 100 years ago, at the World's Fair of 1876. The material came from the Pike's Peak region. M.O'D.

WILD (H. W.). *Die deutsche Edelsteinstrasse.* (The German Gem-Street). Aufschluss, 1976, 27, 2, 83-86.

The "Deutsche Edelsteinstrasse" is the name given to the villages surrounding the West German town of Idar-Oberstein. A map shows the extent of the area devoted to the trade in and working of gemstones. M.O'D.

WILSON (M. M.). *Montana's treasure. Part 1.* Lapidary Journal, 1976, 30, 1, 100–114.

Some sapphire locations are open for collecting on a fee basis, notably that south of York. Sizes are small. M.O'D.

WILSON (W. E.). *Saint John's Island, Egypt.* Mineralogical Record, 1976, 7. 6, 310-14.

An account, illustrated in colour, of the peridot and associated minerals of the island of St John in the Red Sea. Notes on the history and geology of the island are given together with a table of references. M.O'D.

ZIEGERLI (Karl). Z.Dt.Gemmol.Ges., 1976, 25, 4, 222-225.

The Swiss gemmologist, Mr Karl Ziegerli has prepared an index of host crystals and substances and also of inclusions shown in Dr Gübelin's book "Innenwelt der Edelsteine" ("Internal World of Gemstones"). E.S.

Short Gemmological Notes. Z.Dt.Gemmol.Ges., 1976, 25, 3, 156-160.

H. Bank publishes a short note on the R.I. of vivianite from Cameroun and also discusses the high R.I. of colourless topaz from Pakistan. H. Dern has patented a new cut suitable for diamonds based on a triangle and also publishes a short note on synthetic amethyst crystals. E.S.

Short Gemmological Notes. Z.Dt.Gemmol.Ges., 1976, 25, 4, 214-221.

H. Bank describes cuttable green diopside from Minas Gerais in Brazil, especially pointing out differences between enstatite, which crystallizes in the orthorhombic system, and diopside, which is monoclinic. H. Bank also describes some transparent, cuttable, pale brown pollucite, which originally was found on the island of Elba together with petalite (formerly known as "Castor" to the "Pollux" of pollucite as both were found together in lithium-rich pegmatites). Pollucite yields caesium, but cuttable qualities are only found in Maine, U.S.A. H. Bank also reports on a transparent chambersite, a manganese borate, which is orthorhombic and has a hardness of 7; it is doubly refractive, colourless to dark red, and is called after Chambers County in Texas, U.S.A. H. Dern reports on a method introduced by the firm Ernst Winter & Sohn in Hamburg, in which transparent (natural or synthetic) gemstones are covered with a thin layer of synthetic diamond, in order to improve optical properties and durability. E.S.

BOOK REVIEWS

ANDERSON (B. W.). Trans. BOSCH FIGUEROA (J. M.). *Gemas—Descripcion Identificacion.* Entasa (Publicaciones Tecnicas), Madrid, 1976. pp. 471. Illustrated in black-and-white, with 1 coloured plate. Price on application.

A straight translation of the 8th edition of "Gem Testing".

BOSCH FIGUEROA (J. M.). See ANDERSON (B. W.) above.

FRANK (Joan). *All gemstones are precious.* Argus Books, King's Langley, 1976. pp. 48. Illus. in colour. £1·95.

A simple guide presumably intended to introduce gemstones to the general public. To this end it contains notes on birthstones and the legendary powers possessed by gems, together with some coloured illustrations rather awkwardly captioned. Some attractive models display the latest designs in jewellery. M.O'D.

O'DONOGHUE (M.). *Synthetic Gem Materials.* Worshipful Company of Goldsmiths, London, 1976. pp. 215. £12.

This book is a review of the literature of man-made gemstones, mainly consisting of annotated references to the growth of gem materials, including the important properties of the various stones. There are roughly 2,000 entries, for example nearly 100 on ruby, referring to syntheses of historic interest as well as those relating to gemstones which might now appear over the jewellery counter. The introductory section lists trade names of well-known synthetics and the main journals and books which might contain articles or sections pertaining to the growth of synthetic gemstones. There are a few notable omissions from the list of monographs, such as J. C. Brice's "The Growth of Crystals from Liquids" (North Holland, 1973).

The title of the book might be slightly misleading since the compilation includes references to imitations, including doublets using only natural gemstones, rather than referring only to materials which have been synthesized. The author's rather derogatory use of the term "synthetic" is, of course, not uncommon in gemmology, but "man-made" would be more accurate.

It is interesting to note that no example of synthetic corundum or spinel can be attributed to Djevahirdjian, who are the largest manufacturers of such materials in Europe and possibly in the world.

There are a few inconsistencies, such as entries under "beryllia" and "bromellite" for the same material, BeO, and the use of "yttrium aluminium garnet" and "yttrium aluminate" to refer to the material of formula $Y_3Al_5O_{12}$. Some materials, such as the metals cadmium and copper and the water-soluble salts like aluminium ammonium sulphate, would perhaps have been best omitted, since they are not normally considered gem materials.

In general, however, any quibbles are minor and the main impression left by the book is one of admiration for the author's diligence and patience in compiling so extensive a reference work. There is no doubt that "Synthetic Gem Materials" will be greatly welcomed by anyone interested in gem synthesis and identification, and Mr O'Donoghue has performed an invaluable task in bringing together in one volume such a vast compilation of literature on known types of man-made gemstones. The book will be continuously up-dated by means of entries which

will appear in the *Journal of Gemmology**, so that it will constitute the first part of an on-going and unique service. D.E.

PECH (Heinrich). *Smaragde-Gauner und Phantasten.* (Emerald, rogue and visionary). Pinguin Verlag, Innsbruck, 1976. pp. 124. Illus. in colour. DM 28·50.

A description of the emerald locality of the Habachtal, Austria, with notes on other occurrences of emerald, this is a lightly-written book with attractive photographs, largely anectdoal in tone. M.O'D.

SCHUMANN (W.). *Edelsteine und Schmucksteine.* (Precious and ornamental stones). BLV Verlagsgesellschaft, Munich, 1976, pp. 255. Illus. in colour. DM 28.

A beautifully-produced guide to the wider range of gem materials, this pocket-sized book contains brief descriptions facing whole-page colour illustrations of high quality. Identification tables are also provided and there are production statistics for diamond. Photographs are by the firm of Hartmann and some of them have covered some mileage, notably that of rutilated quartz on page 47: but, in fairness, the previous appearances have been in larger books designed for a less discriminating market. A first-class guide and worth a translation into English. M.O'D.

TRÖGER (W. E.). *Optische Bestimmung der gesteinsbildenden Minerale. Teil 1, Bestimmungs tabellen.* (Optical properties of rock-forming minerals: Part 1, Tables of Properties). 4th edn, revised by H. U. Bambauer and others. E. Schweizerbart'sche Verlagsbuchhandlung, Stuttgart, 1971. pp. 188. Price on application.

This first volume of a complete work in two parts contains diagrams of the crystals of rock-forming minerals with illustrations of their optic properties. Tables are arranged in order of optical properties, crystal systems and chemical groups; diagrams on pages following the relevant parts of the tables. Pleochroic colours are included with the crystal diagrams and there is a table of interference colours at the end of the text. A table lists the minerals under their strongest x-ray interference lines and references to the literature are given with this table; other tables include birefringence and specific gravity. The whole book is extremely well printed. M.O'D.

VOLLSTADT (H.). *Einheimische Minerale.* (Native minerals). 4th revised edn. Steinkopff, Dresden, 1976. pp. xii, 399. Illus. in black-and-white and in colour. M 26·00.

A general introduction to the commoner minerals precedes accounts of East German localities which are in some cases illustrated by sketch-maps. M.O'D.

ZIMMER (S. H.) and METZ (W.). *Mineralfundorte in Frankreich.* (Mineral locations in France). Werner Noltemeyer Verlag, Dossenheim/Heidelberg, 1976. pp. xviii, 228, 37.

A pocket-sized guide arranged alphabetically by location, this handy book should lead the mineral collector fairly close at least to the sites where specimens can be found. In an appendix are sites listed under Departments and notes on the crystal systems with illustrations. Further guides to other European countries are promised. M.O'D.

*In "Gemmological Abstracts".—Ed.

International Mineralogical Association. *Papers and proceedings of the ninth general meeting, Berlin (West)—Regensburg, September 12-18, 1974.* Special issue to vol. 52 of Fortschritte der Mineralogie, 1975. pp. xxxiv, 629. Price on application.

Includes: Gübelin (E. J.), *Where gemstone research stands today:* Sunagawa (I.), *Surface microtopography as a tool of distinguishing natural and synthetic emeralds:* Monés Roberdeau (L.) et al., *Quantitative study of fluorescence of brilliant-cut diamonds:* Arbuniés-Andreu (M.) et al., *Physical and optical properties of garnets of gem quality.*

M.O'D.

Mineralienfreund. Zeitschrift der Urner Mineralienfreunde. Published bi-monthly by UMF at Herrengasse 2,6460 Altdorf, Uri, Switzerland. Annual subscription Sw.fr. 23.

The issue examined (14, 3) contained articles on bazzite from the Alps (bazzite is the scandium analogue of beryl) and on the phosphate minerals from the pegmatite at Hagendorf in the Oberpfalz. There are illustrations in colour and the text is authoritative.

M.O'D.

ASSOCIATION NOTICES

PRESENTATION OF AWARDS

The annual Reunion and Presentation of Awards was held at the Goldsmiths' Hall on 15th November, 1976, when the Chairman, Mr Norman Harper, remarked that the number of entries for the examinations had, at 1,201, once again exceeded all previous records. He said the Tully Memorial medallist came from America, the Raynor Prize-winner from Finland, and specially commended for her papers was a candidate from Paris: others in the gathering came from France, Germany, Holland and Spain. During the past year their Secretary, Mr Harry Wheeler, had visited Japan and Hong Kong to meet gemmologists, many of whom had taken the Association's examinations.

The Chairman continued that whereas when he took the examination in 1934 all his class of 21 had passed and in 1949 with 104 sitting 81 passed, 21 with distinction, the percentage rate of successes had been falling. This year 413 sat for the diploma but only 116 passed.

The Chairman extended a warm welcome to Professor Dr Hermann Bank, F.G.A., President of the German Gemmological Association (Deutsche Gemmologische Gesellschaft) and a member of the Board of the Diamond and Gemstone Exchange in Idar-Oberstein (Diamant-und Edelsteinbörse), who then presented the prizes, diplomas and certificates won in the gemmological and gem diamond examinations and delivered an address, which is recorded in full below.

Mr Douglas King, the Vice-Chairman, in thanking Dr Bank, congratulated him on two counts, not only on mkaing such an excellent speech following a difficult flight to this country—his plane had been diverted to Bournemouth because of fog and a dash by train had brought him to the ceremony with little time to spare—but also on being accompanied by his charming wife, a veritable gem from Brazil, of which she was a native. Mr King added that he hoped the newly qualified members would draw together to strengthen the Association and to benefit themselves.

PROFESSOR DR HERMANN BANK'S ADDRESS

Ihre Einladung ist für mich eine grosse Ehre und ich möchte mich sehr herzlich dafür bedanken. However, I think that you prefer that I speak in your language and beg you to excuse my poor English.

I feel it a great honour to have been invited to present the awards of the Gemmological Association of Great Britain to the successful examination candidates this year, and I should like to thank you very much for this invitation. I have been asked to address you after having fulfilled my first obligation, and I should like especially to speak to the candidates.

As many other parts of our daily life have undergone an enormous revolution and unforeseen developments in the last few years, our special field of gemmology has also experienced many changes. On the one hand new minerals have been discovered; on the other, old minerals have been found in better quality—and therefore worth cutting. Likewise we have invented new synthetic and artificial products as well as new colour manipulations which are not easy to diagnose.

For many years gemmology has been regarded as an appendix to mineralogy—more technical and commercial than scientific. However the discovery of new mineral species in cut stones (taaffeite and sinhalite) and the adoption of scientific methods by gemmologists have caused people to regard it as a new and special science. Every day mineralogists and gemmologists all over the world are trying to discover new gem minerals—their properties, genesis and special distinguishing characteristics. Comprehensive information is nowadays increasingly important in all fields; thus the customers of jewellers expect more information and this places additional demands upon the jeweller. The Gemmological Association of Great Britain recognized this demand at an early stage and started the gemmological courses many years ago which have become an example for many Gemmological Associations in other countries and the title "F.G.A." is highly esteemed throughout the world—hence the enormous number of students taking part in the courses and in the examinations.

The Gemmological Association tries to give the students a general idea of mineralogical science in the preliminary course and special theoretical and practical knowledge in gemmology in the diploma course. However it can only give instruction until the date of the examination. So, if a student—as I was nearly 25 years ago—should remain on the level of knowledge of that day, he would be lost among the present synthetics as well as the new methods of treating gemstones and the new methods of examining them. Therefore it is necessary not only to have good fundamental education but also to keep up-to-date by continuous study. Goethe says: "What is written in black and white you can confidently bring home". But I hope that most of you have not been interested only in obtaining a diploma but that you really have been interested in educating yourselves—so that you will have the knowledge and information to pass on, and learning to examine and determine a given stone as real, synthetic or imitation.

You have been successful—and perhaps ingenious—in convincing your examiners that you have collected enough practical and theoretical knowledge to pass successfully the examinations of the Gemmological Association of Great Britain. But this is only the beginning of your career—now daily examinations will follow in your gemmological life and you must prove that you can use what you have learned. And—most important—you should be aware that you should never mention the result of a test if you are not sure—if you have even the slightest suspicion of the result. Ask somebody who knows it better than you do, who has more practice and more experience in gemmology. You should never be too proud to ask since you can easily lose your good name as a gemmologist if you are careless. The great philosopher Immanuel Kant said: "Act always in such a manner that the principle of your acting can at any time be used as a general law".

As a practical matter you are fortunate to have available the facilities of the London laboratory and you should make use of it. The field in which you and we labour is so elegant, so aesthetic, that it is a great pleasure to work with gemstones

in which, according to the great roman writer Pliny, "the whole majesty of nature is encompassed in minute space and a single one suffices to demonstrate the excellence of creation".

You have to test carefully, you have to use several methods as you have learnt during your studies and you have the obligation to keep your knowledge up-to-date. Doctors can bury their mistakes: your mistakes can bury you. Everyone makes mistakes: try to keep them small. You need not say with Socrates "Scio, nescio, I know that I do not know anything", and you also need not say with a kind of conceited scientist "I know that I know much, but I should like to know everything". It is not necessary that you know everything, but it is important that you have the right brain-wave in the right moment, and I wish that you and we all will always have the right idea at the right moment.

You must also not become too great experts, because, as you probably have heard, the definition of an expert is that he knows more and more about less and less, until he knows everything about nearly nothing. I think it quite adequate that you become gemmologists who do their investigations carefully and who know their limits. Perhaps one or more of you will also become outstanding scientists or practicians, who will help to develop gemmology and make it an ever more widely recognized distinct science in itself as well as a means to assist the gem trade.

A Chinese poet once said:

I lay in the garden and dreamed that life would be joy;
I awoke and saw life is duty;
I began to work and recognized duty is joy.

Successful candidates, I congratulate you on your diplomas, I welcome you among the gemmologists and I wish you much success in your gemmological future. Perhaps you will find a new gemstone, perhaps not, but I hope that after a while you will find out that this is not the most important thing in the world but that doing your duty is most enjoyable. You may perhaps have heard the story of an old lady who approached a professor after his lecture and said: "Oh, Professor, before your lecture I was so confused, and now I am even more confused, but on a much higher level". I wish that you may never get confused—even on a higher level—when you are testing gemstones and their substitutes. I wish you, as the miners say, good luck on your way!

ANNUAL GENERAL MEETING

The Association's Annual General Meeting will be held at Saint Dunstan's House, Carey Lane, London E.C.2 on Monday, 23rd May, 1977, at 6.00 p.m.

MEMBERS' MEETINGS

London

On the 9th February, 1977, at Goldsmiths' Hall, London, Mr A. E. Farn, F.G.A., Manager of the London Gem Testing Laboratory, gave a talk entitled "Gemprint—identification method for diamonds".

Midlands Branch

A talk was given on the 17th February, 1977, at the Royal Institution of Chartered Surveyors, Birmingham, by Mr P. Cook, of the Diamond Trading Company, London. Mr Cook spoke on the "Automation of Cutting in Diamond Rough".

North-West Branch

A buffet dance was held on the 22nd January, 1977, at the Shaftesbury Hotel, Liverpool.

On the 10th February, 1977, at the Royal Institution, Liverpool, Mr M. J. O'Donoghue, M.A., F.G.S., F.G.A., gave a talk on the subject "Some Recent Developments in Synthetic Crystals".

South Yorkshire and District Branch

The inaugural meeting of the Branch was held at the Sheffield Polytechnic, Sheffield, on the 17th January, 1977. Dr M. W. Eldridge, F.G.A. and Mr D. M. Larcher, F.G.A., were elected Chairman and Secretary respectively.

ACTIVITIES BY FELLOWS

Mr Norman Harper, F.G.A., Chairman of the Council of the Association, conducted two N.A.G. seminars in the theory and practice of appraisals at Goldsmiths' Hall, London, on 14th and 15th March, 1977.

In January, February and March, 1977, at the Geological Museum, London, Mr E. A. Jobbins, B.Sc., F.G.A., gave ten out of a series of twelve evening lectures on "The Geology of Gemstones", arranged jointly by the Institute of Geological Sciences and the University of London Department of Extra-Mural Studies.

GIFTS TO THE ASSOCIATION

The Council of the Association is grateful to the following for their gifts:

Mr David Callaghan, F.G.A., London, and Mr Peter Truman, F.G.A., London, for two garnet-topped doublets having a good resemblance to demantoid garnet.

Mr Alan Hodgkinson, F.G.A., Glasgow, for Microscope Demonstration–Viewing Attachment which allows two persons to view at the same time.

Mr E. A. Thomson, London, for a fine faceted specimen of oval tektite, weighing 4·90 ct.

Mr Chr. Zachariades, Cyprus, for four pieces of analcite. Thanks are also due to Mr R. Holt, of Hatton Garden, London, who has kindly arranged for two of the pieces to be cut and polished *en cabochon.*

"OPAL THE RAINBOW GEM"

There is to be a joint exhibition, devised by the artist Laurence Hope in collaboration with the Geological Museum and the Institute of Contemporary Arts, opening on 12th May, 1977.

Opals and colour photographs of highly magnified opal surfaces will be on display at the Geological Museum, South Kensington, London SW7, with paintings and photographs on view at the Institute, N.A.S.H. House, The Mall, London SW1.

EXAMINATIONS 1977

The Gemmological Examinations will be held as follows:

Preliminary (Theory) —Tuesday, 28th June
Diploma (Theory) —Wednesday, 29th June
Diploma (Practical) —Thursday, 30th June, or Friday, 1st July, or as notified for local centres.
Gem Diamond Examination: Theory—Monday afternoon, 13th June
Practical—Morning monday, 13th June or Tuesday morning, 14th June.

GEM TESTING LABORATORY FOR HONG KONG

Hong Kong has recently opened its own gemmological laboratory for the testing of precious stones and metals. The new laboratory has been set up by the Hong Kong Standards and Testing Centre, a branch of the Federation of Hong Kong Industries. The gemmological laboratory will work closely with the chemical laboratory of the Centre. It will provide a wide range of testing services, which include assaying precious metals used in the jewellery trade as well as testing stones for authenticity.

INDEX—"INTERNAL WORLD OF GEMSTONES"

Mr D. N. Frampton, F.G.A., has compiled an Index of the photo-micrographs in Dr Gübelin's book *Internal World of Gemstones*. A copy of the printed index can be obtained from the Gemmological Association.

Price is as follows: 1 copy—17p including postage in U.K.
1 copy—30p including airmail postage overseas.

Please send payment with order.

EASIBINDERS FOR THE JOURNAL

Easibinders which will take one volume (8 issues) of the *Journal of Gemmology* are now available. Colour of binding—grey, gold blocked on spine with title.

Price per binder, including postage—U.K. £1·60 (includes V.A.T.)
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LETTER TO THE EDITOR

From Dr E. Gübelin, C.G., F.G.A., and Mr M. J. O'Donoghue, M.A., F.G.S., F.G.A.

Dear Sir,

The undersigned wish to congratulate Drs M. S. Joshi and B. K. Paul for their excellent "Studies of Nucleation and Propagation of Cracks in Natural Quartz", which was published in the July 1976 issue of the Journal*. In our opinion this paper represents the first absolutely clear and profound explanation of the mechanisms involved in the formation of cracks in a natural mineral.

* *J. Gemm.* 1976, XV, 3, 129-135.—Ed.

Yet we rather feel that the term "nucleation" was wrongly chosen in connexion with the cause of releasing a crack. According to Van Nostrand's Scientific Dictionary nucleation is (1) "the formation of condensation nuclei which are the first structurally stable particles of a new phase in a phase transformation" and (2) "a process of phase transformation from a less to a more condensed state when initiated by particles of the condensed state". In simpler words, nucleation is the process by which a nucleus, a seed, is formed which is a minute particle of solid matter. In all these definitions the formation of a particle or particles is of paramount importance. Contrary to this the initiation of a crack does not create particles but rather a void. Consequently it would perhaps be more appropriate to substitute either "initiation", "formation" or "development" for the term "nucleation". Of course, the formation (=nucleation) of an alien particle (for instance by exsolution) or its extension (for instance by thermal expansion) inside a crystal could also be the cause of a crack but this case was not considered in the above mentioned paper.

Although a linguistic authority once warned his audience that "Language criticism is a ticklish affair and the person following it gets under fire in the twinkling of an eye", the undersigned felt that in the interest of pure scientific expression the above remarks should be made. In times like ours, when traditional values are dethroned and the etymological significance of words dialectically misused, it is imperative to watch our words and preclude them from impure elements—especially so the language of science.

E. Gübelin
25th November, 1976. M. J. O'Donoghue

CORRIGENDA

On p. 260 *ante*—

(1) in the 21st line from bottom of page, for "R.I. 1·81" read "R.I. > 1·81":
(2) in the 16th line from bottom of page, for "10·15 mm" read "10-15 mm":
(3) in the 12th line from bottom of page, for "YA 10_3" read "Y Al O_3" and for "garnet (YAG)" read "oxide":
(4) in the 7th line from bottom of page, for "Ditcburn" read "Ditchburn".

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THE JOURNAL OF GEMMOLOGY

and

PROCEEDINGS OF THE GEMMOLOGICAL ASSOCIATION OF GREAT BRITAIN

GEMMOLOGICAL ASSOCIATION
OF GREAT BRITAIN
SAINT DUNSTAN'S HOUSE, CAREY LANE
LONDON, EC2V 8AB

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THE JOURNAL OF GEMMOLOGY
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Vol. XV No. 7 JULY 1977

A FEW MORE "REWARDS"

By B. W. ANDERSON, B.Sc., F.G.A.

EACH year, in the process of toiling through exam papers, the tedium is a little lightened for the examiners by student "howlers" which for one reason or another tickle their fancy. Some years ago I collected a small anthology of those which seemed worthy of a wider audience, which was published in the *Journal* for July, 1970. This was so well received that the exercise appeared worth while, and I now venture to offer a smaller selection gathered since that time.

To begin with, here are some examples of stones which, from the student's account, behaved in a curious manner. There was a chatoyant stone, for instance, which had "an eye that opened and closed, but poorly", and another stone which "showed no turning on and off when used by the polariscope"; yet another which "floated to the bottom of the 3·05 liquid", and an obviously polite stone which "sicks with some restraint in 3·33 liquid".

Then there were those which had an odd appearance. These included a corundum crystal which was "an oblong hexagonal cube" in shape, another crystal which was "slightly terminated at one end", a stone which suffered from "grobular inclusions", and a hessonite garnet, presumably wet to the touch, since it had "trickly

inclusions". One specimen showed "a strong flourescence suggesting an overdose of some ingredient", while another was less fortunate, having "no flourlicence".

Ordinary spelling mistakes are, as Mr Callaghan knows, more a rule than an exception, but one had to admire the young lady candidate who managed to separate the "q" from the "u" in stating that a zircon crystal had a "sqaurish shape". Another described the same crystal as a "tetrangol praymarid". A beryl crystal was said to have "longatudinal strea", while a white topaz crystal was a "dome-toped pinaquoid", reminding one of Prospero's famous utterance "our revels now are ended . . ." in "The Tempest". Rather than quote the passage, I will allow the interested reader the pleasure of looking it up. One other stone is worth mention because it had a refractive index "larger than the refractometer".

Some of the crazy mis-identifications in the practical exam betrayed the complete ignorance of the students of quite common gem materials which happen to be outside the very limited range of goods which they handle in the course of business. Examples were the identifications of aventurine glass as "turquoise", of an andalusite as "amber", a quartz crystal as "plastic", while a blue jade was thought to be an "apapalite".

This may seem a rather meagre gleaning of "rewards" compared with the harvest of six years ago, but it must be realized that the former collection took some twenty years to accumulate.

[*Manuscript received 30th November, 1976.*]

A STUDY OF RECENT CHATHAM SYNTHETIC RUBY AND SYNTHETIC BLUE SAPPHIRE CRYSTALS WITH A VIEW TO THE IDENTIFICATION OF POSSIBLE FACETED MATERIAL

By KENNETH SCARRATT, F.G.A.,
The Gem Testing Laboratory, London Chamber of Commerce and Industry

ONCE again we in the Laboratory find ourselves fortunate in having such good friends in the trade. Merchants often bring interesting specimens in for our observations. Often we may only have minutes or maybe an hour to examine and note their main characteristics but sometimes, as in this case, specimens are left with us for a more detailed examination without a time limit. This is particularly useful at the present time because research work is having to take second place, due to the pressure of normal day to day testing.

Our first brief encounter with the new synthetic blue sapphire crystals was when a well-known gemmologist paid a flying visit to the Laboratory. On this occasion not a great deal of information was gained about the crystals but at least we were now aware of their presence on the market and for this we are grateful. A few enquiries around the trade brought the offer of a loan of a group of the sapphire crystals and a group of the latest Chatham synthetic ruby crystals for an indefinite period. Within a few days of receiving these first two, a further three groups of sapphire crystals and three groups of ruby crystals were forthcoming from Mr H. Wheeler of the Gemmological Association. Now with a reasonable number of specimens we began to observe and note their properties.

The individual crystals in the case both of the sapphires and of the rubies are tabular/platey in habit and randomly orientated in the groups. The first two groups obtained measured approximately: length 17 mm, width 15 mm, height 10 mm, with average individual crystal measurements of depth 2 mm, width 8 mm for the sapphires, and length 18 mm, width 14 mm, height 12 mm, with average individual crystal measurements of depth 2 mm, width 10 mm for the rubies. The later six groups (three ruby and three sapphire) were smaller but in the case of the rubies had a greater number of individual crystals. The average measurements of these groups were as follows: rubies—length 15 mm, width 9 mm,

height 4 mm; average crystal size, depth 0·5 mm, width 4 mm: sapphires—length 12 mm, width 11 mm, height 7 mm; average crystal size, depth 2 mm, width 7 mm.

The colour in the case of the first sapphire group was located mainly in the tips of the crystals and covered about one-third of their mass, the remainder being colourless. In the three other smaller sapphire groups the colour was a little better, covering up to three-quarters of the individual crystals. The blue in all cases varied from medium-dark to very pale. For the rubies the colour was a good strong carmine red when seen in depth and a very pale pinkish-red otherwise. The colour in general was not patchy although there was in some cases the odd blue area.

Under a low power microscopic examination (10× to 30×) of the surfaces of both the sapphire and the ruby groups there could be seen on the base of the groups frosted areas (Fig. 1) and in a layer which showed no crystal form, where crystals met, a plane of gas bubbles (Figs 2 and 3). In two of the smaller ruby groups there were large areas on their bases which may best be described as looking like a residual covering of clear liquid—almost like water which has not been completely shaken off. These surface observations would be of little or no use in the identification of a faceted specimen. However the included material in both varieties should,

FIG. 1 A frosted area seen on the base of a group of Chatham blue synthetic sapphire crystals.

FIG. 2. Gas bubbles at the junction of two Chatham synthetic sapphire crystals and fine-line angular zoning.

FIG. 3. A plane of bubbles at the junction of two Chatham synthetic ruby crystals.

FIG. 4. Two-phase inclusions, veil-like feathers and a few small angular platelets in the Chatham synthetic sapphire.

FIG. 5. A U-shaped inclusion, angular platelets, and a few needle-like inclusions in a Chatham synthetic sapphire.

FIG. 6. Angular platelets in the Chatham synthetic sapphire.

at the very least, point the examiner in the right direction. Figs 4 to 8 show some of the inclusions seen in the sapphire and Figs 9 and 10 show some of the inclusions seen in the ruby.

The dark angular platelets (possibly metallic) are common to both the ruby and the sapphire and in both cases are present in

FIG. 7. Angular platelets in the Chatham synthetic sapphire.

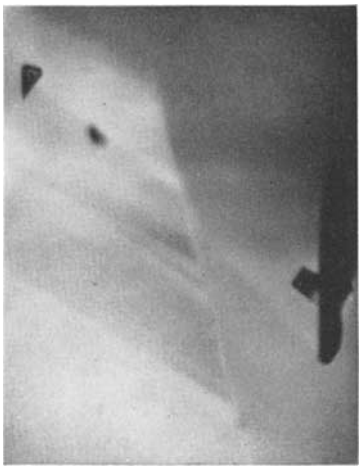

FIG. 8. Angular zoning and platelets in the Chatham synthetic sapphire.

FIG. 9. Angular platelets and two-phase inclusions in a Chatham synthetic ruby.

FIG. 10. Angular platelets in a Chatham synthetic ruby.

great numbers (Figs 6, 7, 8, 9 and 10). Many of the feathers observed, but by no means all, were twisted or veil-like; an example is included in Fig. 4. The U-shaped inclusion in Fig. 5 was only seen in one sapphire crystal. Two-phase inclusions were seen in

both varieties (Figs 4 and 9). Angular colour zoning, hitherto unknown in synthetic blue sapphires, could be seen easily in both varieties even with the naked eye. Fine line angular zoning could be seen with the aid of the 10× lens or microscope (Figs 2 and 8).

The absorption spectrum of the ruby variety is normal as described by B. W. Anderson*. However the spectrum for the sapphire is a little surprising in that unlike the Verneuil synthetic there is an easily seen absorption band at 4500Å (450 nm) when the deeper blue areas are analysed with a hand spectroscope. The other two bands of the sapphire complex at 4600Å (460 nm) and 4710Å (471 nm) are also present but are very weak and in all probability will only be seen by observers well versed in the use of the hand spectroscope.

It was not possible to take the refractive indices of the ruby crystals. A large reasonably flat surface on a sapphire crystal gave readings normal for corundum, 1·760–1·768, D.R. 0·008 on the dialdex refractometer, but the optical character and sign could not be obtained from this face.

The fluorescence colours under long-wave ultraviolet light—3650Å (365 nm), short-wave ultraviolet light—2537Å (253·7 nm), crossed filters red/blue and x-ray excitation for both varieties are listed in Table 1. The following is an expansion of that table.

In one instance part of the colourless area of a sapphire crystal turned a pale greenish-brown after exposure to short-wave ultraviolet light. We could not repeat this discoloration on the colourless areas of other crystals when we tried under controlled conditions.

In the case of the first ruby group, after observing its long-wave and short-wave ultraviolet fluorescence in the dark-room we turned on the light only to find that it had changed its depth of colour from a carmine red to a deep purple-red. With Mr Wheeler's permission, one of the other ruby groups was broken into several pieces so that we could try to discover, without risking the other two groups, which wavelength caused the discoloration. We subjected the pieces individually to long and short exposures of long-wave and short-wave ultraviolet light, and in a few cases a combination of both wavelengths. At no time did any of the pieces discolour. We then decided to risk subjecting the remaining two ruby groups to both long-wave and short-wave ultraviolet light and once again

*"Gem Testing", Eighth Edition, p. 147.

TABLE 1

THE FLUORESCENCE OF CHATHAM SYNTHETIC BLUE SAPPHIRES AND SYNTHETIC RUBIES

Wave-length	*Chatham Synthetic Blue Sapphire*	*Chatham Synthetic Ruby*
Long-wave ultraviolet light 3650Å (365 nm)	Overall yellow with dark blue and greenish patches.	Strong red. One or two small areas were inert.
Short-wave ultraviolet light 2537Å (253·7 nm)	Overall blue. Parts of the surface frosted areas and where some of the crystals meet fluoresce yellow.	A strong pinkish-red. Pale bluish in crevices on the bases of the groups.
Crossed filters Red/blue	Red.	A strong flame red.
X-rays	Yellow with a hint of green, some dark blue patches. Colourless and some pale blue areas photocolour to a deep green or yellow.	Very strong red with a strong persistent phosphorescence.

neither group discoloured. Returning to the discoloured group, we found we could not return the crystals to their original colour.

The x-ray fluorescence, as can be seen in the table, proved to be very interesting. The ruby had a very strong fluorescence and strong persistent phosphorescence. The length of exposure varied from 10 seconds to 10 minutes after which the length of phosphorescence varied from 2 to 20 minutes. A small area photocoloured to an orange-red after a 4 minute exposure. This was only just perceptible.

The sapphire after fluorescing on this wavelength had no perceptible phosphorescence. However, it was found that the colourless and some of the pale blue areas of the crystals photocoloured to varying depths of green or yellow, depending on the length of exposure (the longer the exposure, the deeper the colour). These induced colours are not permanent. A deep green irradiated crystal after close exposure to the heat and light of a 40 watt bulb for 5 minutes lightened to a medium green. After 25 minutes the

colour changed to a light green and after a further 8½ hours the green had almost disappeared. A yellow irradiated crystal also faded after being similarly treated. Throughout the exposure to x-rays and the 40 watt bulb the deeper blue areas of the crystal remained unchanged.

Conclusions

Up to the time of writing we have not seen any faceted stones produced from these crystals. When they do appear on the market we feel that identification in the majority of cases should not be too difficult. For the rubies, the inclusions should be enough to arouse suspicion, for although similar angular platelets have been observed in some natural rubies, never have they been in such profusion. This, coupled with their pronounced x-ray phosphorescence, which is as strong as (or in many cases stronger than) that seen in the Verneuil type synthetic, should be enough for their identification. It should be mentioned that to this date no natural ruby, with the exception of some East African stones, has phosphoresced after excitation with x-rays. In the case of the East African stones, their inclusions are quite distinctive, i.e. long needles resembling "grasshopper legs", arranged in many cases in a scaffold formation, and to date their x-ray phosphorescence has never been as strong and persistent as this new Chatham ruby. There will be the occasional clean synthetic or natural East African stone which will be difficult, but we think not impossible, to identify. The most useful identifying feature to look for in the synthetic sapphires must be their distinctive patchy yellow fluorescence under long-wave ultraviolet light. No natural blue sapphire fluoresces in this way. Great care must be taken if exposure to x-rays is necessary.

It is with pleasure that the author acknowledges the ready help given by his colleagues and friends in the Gem Testing Laboratory and at the Institute of Geological Sciences. We are indebted to Mr M. O'Donoghue for giving us our first look at the crystal groups and to Mr J. A. Fleming and Mr H. Wheeler for the loan of specimens.

[*Manuscript received 18th March, 1977.*]

AFRICAN GROSSULAR GARNETS; BLUE TOPAZ; COBALT SPINEL; and GRANDIDIERITE

By R. KEITH MITCHELL, F.G.A.

African Grossular Garnets

Although they have been on the market in this country for the past two or three years the important and attractively coloured grossular garnets from Tanzania and Kenya have been featured in this *Journal* so far, apart from brief references by Axon (1974) and Petch (1976) and a few abstracts, only in a short note accompanied by a list of R.I.s and fluorescent reactions in a paper by A. E. Farn in the issue for January 1976.* For many of the Trade the green varieties are appearing in jewellery under the names "Tsavorite" or "chrome-grossular" with little indication of their gemmological significance.

The stones found vary from colourless to a fine clean yellow or orange-brown hessonite, lacking the sugary inclusions usually associated with this best known grossular garnet, and from a pale lime green to the rich dark green usually associated with chrome- or vanadian-tourmaline. Some of the garnets approach the colour of emerald and this fact appears to be influencing the prices.

The great majority of the green stones are small in size, averaging under one carat. This is probably due to the fragmentary nature of the rough and, at least in part, to the very deep colour. Large cut stones would tend to be too dark. A very fine four carat stone I handled recently could be regarded as exceptional. This is now in the collection of the Geological Museum.

There appear to be three sources; two in the Tsavo National Park, near Mount Kilimanjaro (hence "Tsavorite", a somewhat misleading name since it does nothing to identify the stone as garnet), which produce green stones, and another at Lalatema in Tanzania which provides green as well as the colourless, yellow and brown varieties. The testing constants are those expected for grossular garnet, R.I. 1·740, S.G. 3·68, with slight variation around these values for individual specimens. Hardness is about $7\frac{1}{4}$. Perhaps the most obvious immediate testing feature is the pink to red residual colour seen through the Chelsea emerald filter. Although this has

*J. Gemm., 1976, XV, 1, 8-10.—Ed.

been assumed to be due to chromium which is present in small amounts (hence the names "chrome-grossular" and "chrome-garnet"), vanadium is known to be present in an appreciably larger percentage and the intense greens are almost certainly due to this element. A parallel can be drawn with the fine green "chrome-tourmaline" marketed a few years back, which gives a very similar residual colour through the Chelsea filter. This stone was also found to owe its colour to vanadium. The darker greens of these two minerals are very similar and a refractometer test, or at least one for birefringence, is probably advisable to distinguish between them. Strictly speaking both should be called "vanadian-" stones rather than "chrome-".

Blue Topaz

Another gem which is now quite widely known, particularly in better class jewellery using large stones, is a deep blue topaz which has been available for the past several years.

I first heard of this material from a Rhodesian source quite a while before it was marketed here, but since then it has been reported as coming from South Africa and from Brazil. No exact locations are given. The colour is almost that of a fine medium blue sapphire, far finer than the best aquamarine generally available today. Yet the price stays comparatively low.

I believe the reason for this lies in the fact that this is a treated gem. Dr Kurt Nassau, of Bell Laboratories, New Jersey, is reported to have produced this colour by irradiation. (I have a cinnamon brown topaz crystal which has been produced from white by similar means and it is known that *this* colour is subject to fading on prolonged exposure to strong light. So far the deep blue stones have not shown a similar tendency. A German laboratory claims to have found a method of detecting the treated blues, but a promised further report is still awaited.)

Testing constants of these stones are apparently those to be expected from fluo-topaz. In one specimen tested they were R.I. 1·615–1·623 and S.G. 3·56, showing a slight move towards the values for hydroxyl-topaz. The low birefringence, 0·008, ties in with this.

One valuable test between these fine blue topazes and fine aquamarines lies once more in the careful use of the Chelsea filter.

Most aquamarines give a distinctive greenish residual colour which is almost entirely absent in the case of the topaz.

A Rare Spinel

My third stone is one which first came to my notice a good many years ago. An old friend in Ceylon sent me a bright Reckitt's blue stone with the question "What do you make of this?" The colour was similar to that of deep blue synthetic spinel, although the small native-cut stone seemed strange for this material. But one glance through the Chelsea filter showed a magnificent residual red such as one would expect from the cobalt-rich synthetic. So I wrote back saying that it was an obvious synthetic spinel. Back came the reply "What about the inclusions?"

This time I stopped jumping to conclusions and really examined the stone. It did have natural crystal inclusions and its R.I. was 1·717. Synthetic blue spinels normally have a very stable R.I. of 1·727. So, here was a natural spinel in a most unusually beautiful shade of blue. Since the normal blue colour in spinel is due to iron which suppresses fluorescence in the red, the suggestion was that in this stone the colour must be due to cobalt. The absorption spectrum showed two quite marked bands centred at 6500Å and 5400Å respectively, with a broad but vague absorption between them. The deep red was quite strongly transmitted, which accounted for the emerald filter red. The over-all spectrum was that of a faint iron absorption combined with a rather more marked cobalt one. Subsequently the original stone was analysed by the electron probe technique by Mr Brian Young, of the Institute of Geological Sciences, who found about 0·25% of cobalt together with a larger percentage of iron.

Now this gives more than one anomaly. B. W. Anderson has said that cobalt in natural minerals gives pink colours. In synthetic spinel this impurity gives a blue colour and, since this synthetic is not an exact copy of the natural stone (it contains more aluminium oxide) it was thought that the difference in colour was due to the resultant difference in atomic structure. (There is a possible analogy with colours caused by chromium. When chrome atoms are tightly packed in the lattice, as in ruby, red spinel and pyrope garnet, the colour is red; when they are in less tightly packed situations, in emerald or demantoid garnet, the colour is green. Alexandrite provides an intermediate case).

However, in the natural spinel under discussion we have cobalt apparently giving a blue colour, albeit assisted by a generous helping of iron. The resultant shade of blue is not the inky one normally expected from iron coloration and the red is not suppressed by the iron. Since the R.I. is normal for natural spinel and substantially lower than that for the synthetic material, I feel that it can be assumed that, impurities aside, the composition and hence the structure, are those of normal $MgAl_2O_4$ spinel and that cobalt in this situation overcomes the usual quenching effect of iron on the colour.

Since this first stone I have seen only two others of this fine blue colour in some twenty years. The largest of these was about 2½ carats. The two smaller stones, both under one carat in weight, are still in my own collection. I think I can safely say that they are a rare type of blue spinel.

Grandidierite

My last stone is in no way commercial, being an example of a rare mineral faceted for the sake of providing yet another "gem" for the collector of the "rare, the rarer and the down-right impossible."

Grandidierite is a slatey-blue mineral originating from southern Malagasy (Madagascar). It is, in the stones examined, only semi-transparent, due to fissures and inclusions, and the small parcel I have consists of five faceted stones and a number of cabochons. Superficially the latter are a little jade-like in appearance, if one accepts what would be very rare colour in jadeite.

Dana Ford, 1932 edition, gives the chemical composition as "a basic silicate of aluminium, ferric and ferrous irons, magnesium *etc.*". It has orthorhombic symmetry but good crystals are rare.

The R.I. of the specimens tested were α1·583, γ1·622, with β close to γ, making the sign optically negative. S.G. was 2·85. Pleochroism is marked, giving light and dark shades of the body colour. Birefringence is 0·039. These constants are low compared with those quoted in Dana but probably correspond with values obtained in more recent work on the mineral. One stone tested gave three R.I.s at one reading, suggesting a twinned structure which was presenting more than one crystal in differing optical aspect on the one surface tested.

A fragment of the original rough was finally confirmed as grandidierite by Mr E. A. Jobbins, of the Institute of Geological Sciences, who very kindly had powder x-ray diffraction tests carried out for me.

[*Manuscript received 3rd February, 1977.*]

NOTES FROM THE LABORATORY

By A. E. FARN, F.G.A.,
The Gem Testing Laboratory, London Chamber of Commerce and Industry

WE are fortunate in the Laboratory in that our members are both forward-thinking and trade-protection-minded. Whilst we occasionally pen notes upon new synthetics, new stones, new trickery, we can only do so if we are supplied with the stones to test. Whilst our function is to test gemstones and pearls for members of our trade section of the London Chamber of Commerce, we are often sent stones by members who *tell us* what the stone is or that it is from a new source or a new example of an established stone, etc. We are grateful for the opportunities and specimens provided and shown to us, which result in added protection and education for the trade in general. Thus does the trade provide the work and material for the benefit of its members and our science of gemmology.

We are now termed the "Gem Testing Laboratory of the London Chamber of Commerce and Industry". I feel that our older and longer title perhaps more adequately described our function and our role. Our old title was "The Laboratory of the Diamond, Pearl and Precious Stone Trade Section of the London Chamber of Commerce". In it we have "The Laboratory" (which is what we are), "The diamond, pearl and precious stone trade section" (which sums up gemmology), "London" (which is where we are), and finally "Chamber of Commerce" (and where would any of us be without commerce?).

* * *

Among the many items forming a routine week's work we have recently had pink opals; these look like pale pink coral without any signs of structure and are subtranslucent at the edges, with no play of colour, looking like glass imitations—in fact extremely unimpressive-looking stones. We found that they had a S.G. of 2·083 and R.I. of 1·45. Their fluorescence colour was a violet blue under long- and short-wave ultraviolet light with a green phosphorescence under long-wave ultraviolet.

* * *

A member showed us aznac stone from Peru: it is basically a deep green opaque cabochon-quality stone with small patches of blue and overall brown veins. The suppliers of the stones state that they are from the old mineral beds which supplied the Incas with their jewellery and are a mixture of chrysocolla, malachite, turquoise and azurite. They have a pleasing appearance, looking like a good green verdite: the densities of two tested were 3·29 and 3·24 respectively, and both reacted to dilute hydrochloric acid. They should make attractive suites of jewellery in silver or gold.

* * *

Another green stone was a diamond in a handsome diamond marquise cluster ring. It was quite a fair size and a tourmaline-green in colour. As any good gemmologist knows green diamonds of decent size and strong colour almost *have* to be irradiated. This one was no exception. It had the umbrella shaded culet, hallmark of a cyclotroned diamond—proof positive.

* * *

Not long ago on testing an alexandrite I should have written a certificate saying—"found to be an alexandrite chrysoberyl". Last week we wrote one—"found to be a *natural* alexandrite chrysoberyl". The synthetic alexandrites produced in America by Creative Gems force one nowadays to add *natural* to alexandrite if the case warrants. To decide whether it is a *synthetic* alexandrite is not so simple. Ideally text-books show only the strong, good and clear examples of synthesis, whether it be of emerald, ruby, sapphire, alexandrite, etc., flux fusion or hydrothermal. The synthetic alexandrite we borrowed from the Gemmological Association was used in comparison tests on a pale green alexandrite sent in for test. The owner—a capable merchant and competent gemmologist—having obtained a few sent one in for test. He was surprised at the

FIG. 1. Structures in natural alexandrite. (*Photo. K. Scarratt*)

FIG. 2. Structures in synthetic alexandrite. (*Photo. K. Scarratt*)

fairly close parallels between characteristics of natural and synthetic alexandrites. Examples of these structures suitably captioned were photographed by K. Scarratt (see Figs. 1 and 2).

Natural alexandrites have a better daylight green colour. Synthetic alexandrites show both colours in daylight but *not* markedly so. Under ultraviolet light, both appear dull red under long-wave, but the natural is a mustardy green under short-wave, whereas the synthetic is a very dull red. X-ray fluorescence shows the natural to be a pale milky-white, whereas the synthetic has a red fluorescence with no phosphorescence. The flux inclusions, depending upon the angle from which they are viewed, have a very worrying natural appearance. I am told that very clean synthetic alexandrites are causing concern and that comparison of transparency to ultraviolet light has to be an added weapon in our hands.

* * *

Recently at Liverpool a discussion on the umbrella-term "jade", which covers both nephrite-jade and jadeite-jade, elicited a statement that an apricot fluorescence under x-ray excitation would help to identify green grossular garnet (one of the jade-like minerals). Almost immediately (the following day in fact) we had to check an oriental carving, which could have been jade (or not), and dis-

covered that *some* nephrites fluoresced in a like manner to green grossular garnet. This really brings home the fact that fluorescence can never be accepted as a basic test, but only to afford about 1% added value to a series of tests which on their own are sufficient and adequate to determine a stone without a shadow or penumbra of doubt.

Since most gemmologists are fortunate (?) enough not to possess x-ray generating equipment with a viewing chamber, this danger of relying on x-ray fluorescence will not often arise. Nevertheless the fluorescence effect even under both long- and short-wave ultraviolet light should be regarded with considerable caution and accepted only as an extra and not a fundamental characteristic. Fluorescence followed by phosphorescence is a much stronger combination as a diagnostic than fluorescence alone. A blue fluorescencing diamond with a yellow after-glow is unique (but I would still apply a boule test).

* * *

Included here is a picture of the surface structure seen on pink (conch) pearls (Fig. 3). With a 10× lens this structure is easily seen—it might be lost under a high magnification. This is one of

FIG. 3. Pink (conch) pearl "flame structure". (*Photo. K. Scarratt*)

the tests where it is not really possible to do much else except to look at it and decide that the structure, termed "flame structure", is sufficient. (Of course one could prove it to be a carbonate by adding a spot of acid, but this does not come within our non-destructive tests.) Pink pearl can be distinguished merely by structure from pale pink coral. Pink pearl, of course, has a density range of 2·83–2·86, whereas coral is about 2·70.

* * *

The 10× lens in the hands of an experienced gemmologist is a very powerful and flexible weapon. Indeed it is the most flexible and convenient of all instruments, being a pocket microscope. Double refraction even in a rubbed-facet specimen can often be detected. If it is used over white mat paper as a reflector, faint curved structures can be seen using any table lamp of 60–100 watts: these faint structures will tend to be magnified out of sight by a microscope. Garnet-topped doublets' demarcation, soft facet edges in pastes, demarcations in cultured pearl drill-holes—all can be exposed with judicious use of a lens. Its constant use makes one a better practical gemmologist in the same way that I feel one is a better motorist if one is brought up using a manual gear-change rather than starting with an automatic gear-box: after all, many an old model can be revived with a push start—which is more than can be done with a posh automatic! Double refraction and the amount of double refraction can be very useful guides when using a lens only. We had in recently a half-hoop ring, set with three blue stones, deeper than aquamarines in colour but not a sapphire blue. Examination with a lens showed easily observed D.R., much more than in quartz, and slightly rubbed facet edges. The slightly fuzzy, "out of focus", look of the stone was characteristic of zircon. Whilst it is true that as a laboratory gemmologist I also took their absorption spectra for record purposes, I would have confidently stuck to my decision without the spectroscope's help.

* * *

Simple or plain gemmology using basic instruments, such as microscope, spectroscope, dichroscope, 10× lens, Chelsea filter, refractometer, density liquids, immersion liquids and known samples of gemstones, plus the all important factor of a good grounding in gemmology and trade experience, will fit most people

for gem-testing in trade terms. Whilst it has been mooted that with the advent of man-made gems based very often on spin-offs from space research programmes sophisticated equipment such as electron probes, photospectrometers, etc., in the hands of physicists will be necessary in the final event to prove a man-made stone, I find it rather science-fiction stuff. We do need and do appreciate the help of physicists at times with something quite new and usually not of jewellery potential. This jewellery-potential point surely is a key factor in our kind of gemmology. Almost 100% of our customers are tradespeople needing quick positive results. We used to be rather keen to provide a while-you-wait service for genuine cases, but in the end we had to take a stand against such speed, which could be dangerous in generating a decision to beat the clock. We know that when it comes to real sophistication we have to wait our turn and it can be weeks, not days. Normal gemmology is still the perquisite of the trade gemmologist using basic principles, instruments and know-how: an ounce of practice is worth a deal of theory—even practice with a 10× lens!

* * *

Some items which arrive at the Laboratory for testing are so interesting and gemmologically rewarding that we feel we should pay the customer for being so forthcoming in sending such intriguing specimens! However, our sense of duty overcomes our gemmophile inclinations and we carry on testing for financial reward!

One such item recently was a piece of green subtranslucent rough, with a very hackly surface offering no chance of a distant vision refractive index measurement nor any easy view of the interior (inclusions in green material could be quite a help). It seemed obvious that a specific gravity determination would be a logical next step, after an obvious check with the Chelsea filter and an absorption spectrum examination. The specimen was green through the filter and showed a rare earth spectrum. Next came the density at 3·15, which pointed to fluorspar and/or apatite. Viewed between crossed polaroids a feeble sign of D.R. (or was it strain?) did not help much. Fluor is singly refracting and apatite is notorious for having a very small D.R. Apatite has a rare earth spectrum, as does fluorspar. The density was closer to apatite, so we decided to have an optical flat put upon it to decide the issue.

One should be able to see signs of D.R. when carefully scrutinizing

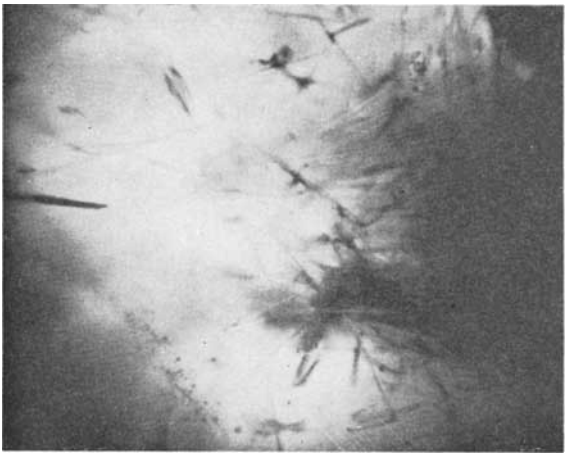

FIG. 4. Actinolite/tremolite-like needles in green apatite rough. (*Photo. K. Scarratt*)

inclusions, flaws, feathers, etc.—along an edge or back facet (if faceted) one should see doubling. So the specimen was immersed in benzyl-benzoate, and an interesting pattern of criss-crossing slender actinolite/tremolite-like needles or crystals, somewhat like Sandawana emerald inclusions, were seen (see Fig. 4). These to me were not reminiscent of fluorspar, and, frankly, I had not looked into many green apatites—usually refractive indices being obtainable and spectra would be sufficient identification. It still seemed probable that it would have to be taken to a lapidary.

We decided, however, in the interests of gemmology and practice for our staff, to obtain an x-ray powder diffraction pattern on our still new camera. Toby Rappitt and Ken Scarratt prepared the samples and took the diffraction picture. We obtained a good diffraction pattern and compared it line by line with a known recorded sample picture of apatite. (The original comparison film was of green apatite taken by Chuck Fryer of the G.I.A. Los Angeles (now Santa Monica) laboratory.) The two patterns were identical.

So the specimen was indubitably apatite. It afforded us a little gemmological ploy, a little photography, a lot of interest and considerable satisfaction in obtaining a positive result. (We never did get that optical flat put on.)

* * *

Recently we were asked (not to test) for our opinions on an opal which had faded, literally to near colourless with only a dismal remainder of the play of colour present. Most of these cases of faded stones, whether they be opals, quartz, emerald or whatever, we see only *after* the so-called fading—never, of course, before. This stone was so bad it was impossible to tell whether it had been a white opal or a water opal or a fire opal with some play of colour.

My first reaction, of course, was to look at it with a lens. I was really pleased on my first quick routine look to see a pattern described as lizard-skin, shagreen, etc., this pattern having been very well shown by photographs and drawings of K. Scarratt in his articles on synthetic opals, written in two parts, one by himself, and the other in co-operation with E. A. Jobbins and Pat Statham of the Institute of Geological Sciences (J. Gemm., 1976, XV, 2, 62-75). The typical structures portrayed were those I saw in this terribly faded synthetic (heated?) opal.

Upon mentioning this fact of (not a faded opal but) a faded *synthetic* opal to our customer, he was delighted to be able to report our findings to the owner of the ring. Obviously one doesn't worry so much over a faded synthetic opal as a faded natural—least of all if one supplied a natural!

The reason for the fading was never followed up, but I should imagine heat could be a factor, if a ring were sized without removing

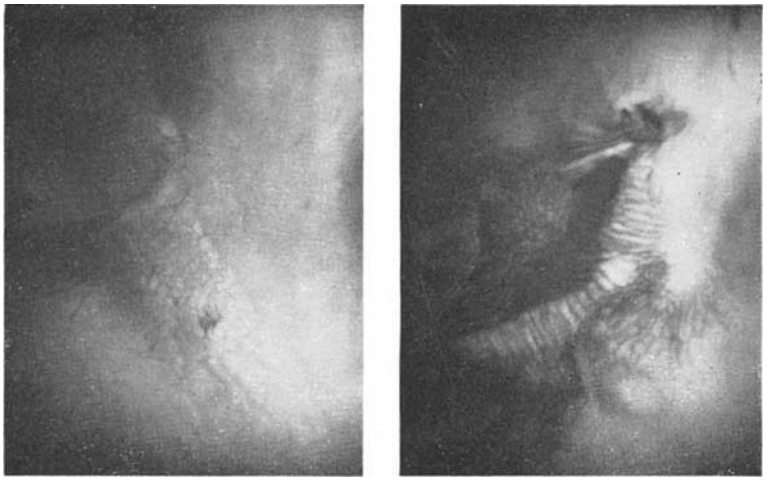

FIG. 5 (a) and (b). Structures seen in faded synthetic opal. (*Photo. K. Scarratt*)

the opal. It was also quite pleasing to think that one could spot a faded synthetic opal with a 10× lens. We were so pleased we had a look through a conventional microscope and took photographs (Fig. 5) of the structures seen just for the fun of it, if not for the record!

* * *

Once upon a time all synthetic rubies had curved structure-lines and clouds of included gas bubbles. They were usually a garish red colour and due to cheap cutting had chatter-marks almost as hallmarks. If one had *any* difficulty in proving them, they could be vetted by exposing them to x-ray excitation, which would produce a strong fluorescence followed by a prolonged phosphorescence. If for any reason this should not be practicable owing to the proximity of other natural or synthetic rubies in the mount, then a transparency test with short-wave ultraviolet light would eliminate the sheep from the goats. Failing all this, there was the knowledge of rubies and their *look* which had been built up over years of testing many thousands of rubies in which about 8–10% synthetics were found.

That, of course, was once upon a time. Nowadays we have the flux-fusion and hydrothermal rubies to contend with. A little learning is a dangerous thing and perhaps a lot of learning further clouds the horizons with possibilities which might never enter the heads—or curricula—of happier gemmologists. It is indeed humbling to be faced with a ruby which one feels one should deal with in a matter of minutes (thinking the paper work will take longer!) and then be halted by indecision.

Among some items of jewellery not long ago we had a cushion-shaped red stone in a three-stone ring to test. In its mount it was not very forthcoming. What little we could see were crystals (?), a feather, and, at an acute angle, a very restricted view of what looked like looped structures. We asked to have the stone unset and never saw the customer again! Some weeks later we saw the same ring—from another source. It was very easy to recognize and just as awkward! This time, when we asked to have the stone unset, it was promptly done. It *should* have been easy after unsetting but it only served to add to our feeling that it was not natural. The crystal-like inclusions were of a two-phase type not necessarily usual in rubies from Burma, Siam or East Africa. The feather on the girdle looked just such a feather as can be seen in both natural

and synthetic specimens. The loop-like structures emanated from a series of crystal-like inclusions and looked peculiar, but not necessarily typical of a synthetic—nor for that matter of a natural stone. They could have been acceptable if other stronger features had predominated but they were the few inclusions seen in a fairly clean ruby which had the body colour of a Burma or *fine* East African ruby.

The ruby fluoresced moderately under x-ray excitation with a following phosphorescence of such a weak nature that one wondered whether it was there or an effect upon the retina following fluorescence? This poor phosphorescent effect was corroborated by the younger and keen eyes of Ken Scarratt who had first had the stone to test in the ring. We then used filtered methylene iodide to obtain a close optical match for the stone and viewed it immersed, using low-, medium- and high-power objectives. We all studied the inclusions which were somewhat of an angular (two-phase?) crystalline appearance. On the girdle was what I would have been happy in earlier days to accept as natural—a feather of an oval-shape, looking quite natural. Under high power Ken Scarratt felt the looped links were of a dash-dot nature as seen in some Kashan synthetics. Having earlier on in 1975* encountered a very peculiar ruby and enlisted the opinion of Dr Edward Gübelin's laboratory, I felt a second opinion would be very helpful from the same source. We sent the stone unset with transparency photographs and drawings indicating our interests. We received corroboration once again from both Mr C. E. Schiffmann and Dr Gübelin that the stone was to be considered of synthetic origin. Together with informative, friendly and interested letters from both Mr Schiffmann and Dr Gübelin I received details of a paper written by Professor Dr W. F. Eppler on "Synthetic ruby produced by the hydrothermal method and grown from a melt",† which contained photographs of inclusions particularly of the two-phase type which were identical in shape with those noted in our problem stone. After the stone had been returned to us and our opinions strengthened and morale boosted, we decided to photograph it for record purposes. This proved to be most difficult. The photographs by Ken Scarratt show the feather on the girdle, the two-phase crystals and the looped

*See J. Gemm., 1976, XV, 2, 104; 3, 109.—Ed.

†Z. Dt. Gemmol. Ges., 1971, 20, 1, 1-5: abstracted in J. Gemm., 1971, XII, 8, 357.—Ed.

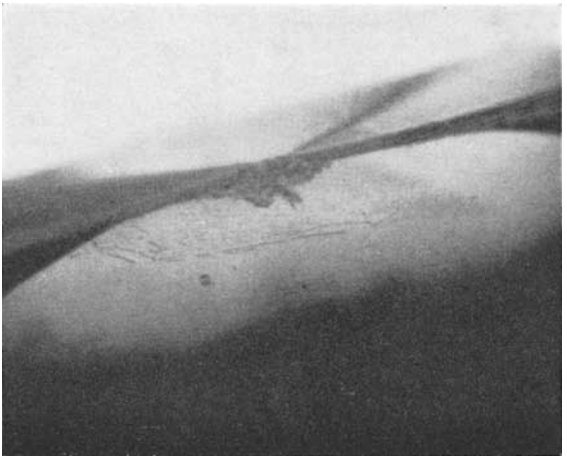

FIG. 6. Liquid feather on girdle of synthetic ruby. (*Photo. K. Scarratt*)

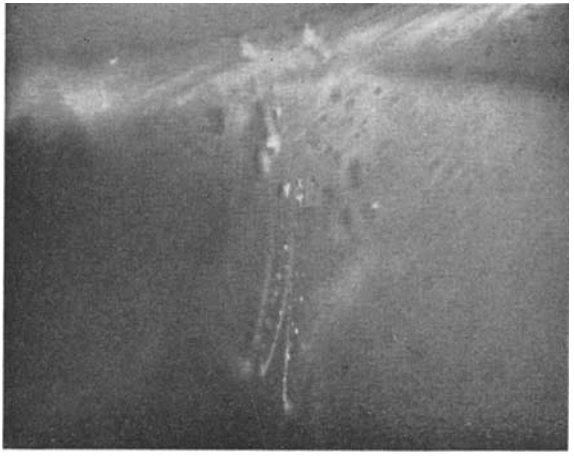

FIG. 7. Looped structures and two-phase crystalline inclusions in synthetic ruby. (*Photo. K. Scarratt*)

dash-dot links (Figs. 6, 7, and 8). Further we decided to take a short-wave ultraviolet light transparency photograph, using various synthetics of somewhat similar size plus one natural ruby as a

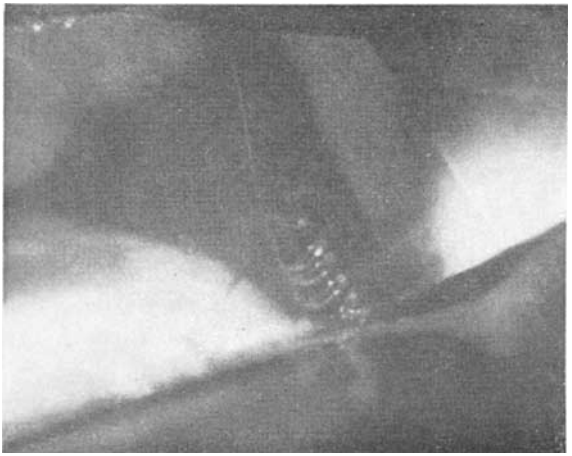

FIG. 8. Same looped structures and inclusions in synthetic ruby as in Fig. 7 viewed from position at right angles. (*Photo. K. Scarratt*)

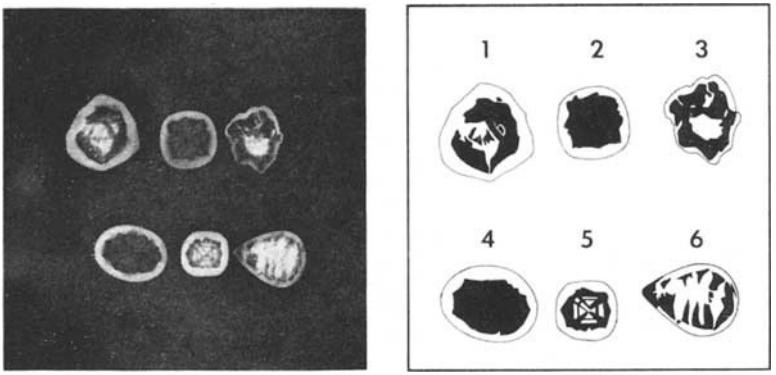

FIG. 9. Ultraviolet transparency photograph of 5 synthetic and one natural rubies. (*Photo. K. Scarratt*)

control (Fig. 9). The stones are as follows:

(1) Siam seed with hydrothermal overgrowth, 3·48 ct.
(2) Verneuil flame fusion synthetic ruby, 2·12 ct.
(3) Hydrothermal synthetic ruby (early Chatham), 1·68 ct.
(4) Kashan flux-fusion synthetic ruby, 3·09 ct.
(5) The problem (synthetic) ruby, 1·37 ct.
(6) Natural ruby from E. Africa, 1·91 ct.

How well the transparency photograph conveys the similarity of opacity of the natural and the problem stone I do not know: what I do know is that the stone in question looks natural to an experienced eye, and in a setting it could fool many people. We with quite a bit of experience didn't like it, and it took quite a time for a consensus of opinion to be reached. I should like to say "thank you" to both Dr E. Gübelin and Mr Chas. A. Schiffmann for their help and gemmological enthusiasm.

Only a few days later we had a further three Kashan-type flux-fusion rubies in to test. One matched our own Kashan for short-wave ultraviolet light transparency, two nearly matched our natural stone and previous problem stone. Two fluoresced and phosphoresced quite strongly, and one did not phosphoresce but did have "hallmark" Kashan flux inclusions. So it seems that the amount of chromium and iron are variable, causing variations of luminescence and also affecting the transparency to short-wave ultraviolet light. Inclusions, transparency and luminescence, plus a background of knowledge, with known stones as comparisons, seem necessary in testing rubies which were so easy once upon a time.

* * *

"The umbrella term jade"—which I mentioned a few pages back—was the title of a lecture given some years ago at Northern Polytechnic to the Post-diploma Class run by B. W. Anderson, assisted by A. E. Farn. This was one of many very enjoyable lectures given to that class. I have always had a very keen interest in the varieties of green materials which have at times arrived at the Laboratory to be examined—purporting to be jade. I always feel the challenge when something jade-like comes through our portals and like to have a stab at it before routine tests set in. We have been fortunate lately in receiving quite a few specimens of vases, dishes, figures, etc., in (mostly) nephrite-jade of varying colours.

One such item very recently was a very pleasing (to me) variegated green subtranslucent to transparent bowl. It was not quite eggshell in thickness or fragility but certainly very thin for a wide-mouthed bowl weighing 219g and measuring 14 cm in diameter (approx.). The variety of greens in patches, linked by transparent almost colourless patches, with some black inclusions of irregular shape made me feel instinctively it was a mixture—

more of a rock than nephrite. I did not do the test myself but kept an interested eye on the bowl as it was handled. The density was found to be 2·62 and refractive index 1·56 (in several places), *plus* a good strong band at 4650Å and a weaker one at 4970Å.

I was asked what I thought it could be, and because of the absorption band I felt flummoxed. It did not "tie in" with the colour in this thin material. The only material I could place without reference to books was a noble serpentine which has such a band, but I had not seen it with this variety of colours. A little checking with Webster confirmed the absorption bands, density and refractive index. Just a little additional detail was gathered by a discreet touch of dilute hydrochloric acid: this caused an effervescence. So then our bowl was proved to be ophicalcite, sometimes termed Connemara marble—a variety of serpentine. Because it was such a fine quality both in material and workmanship, the fragility of it gave the colours a nuance not normally seen in the more solid examples of the serpentine family. It had attained a finish and appearance not recognizable as serpentine. It did not come under the "umbrella of jade", but personally I should be very happy to provide it with shelter.

* * *

An interesting item came into the Laboratory recently in the form of an Egyptian deity's head carved in lapis lazuli. The piece looked old: or was it perhaps the association of ideas of a link with the past producing the appearance of a patina to the mind's eye?

By using the "jeweller's third eye" (to use Mlle Dina Level's expression which I have mentioned before*) pyrites and calcite inclusions were noted. The calcite was less profuse than seen in some Chile lapis, the pyrites looking softer and a hint more golden than usual. Perhaps the blue colour looked a little tired—certainly the piece looked old—a little worn—soft looking as if it had been handled a lot. Its original lines were somewhat dulled, rather in the manner of some Chinese jades which have been reverently handled and have developed a smoothness unobtainable by mechanical abrasion. The "third eye" (or 10× lens) probed meticulously around, the mind meanwhile pacing it with thoughts—"the pyrites looks more like gold and very soft, the calcite does not 'sit' naturally in the host material, and a funny look to the apparent distribution—

*J. Gemm. 1977, XV, 5, 236.—Ed.

looks like attempted random distribution which has the mark of man".

Then the lens picked up little round blow-holes rather like woodworm exits—but surely not in lapis lazuli. Now the 10 × lens fairly zoomed around all the little nooks, depressions and reliefs. Sure enough the blow-holes were found rather like blow-holes in castings. We took a density and found it to be 2·168. We checked the calcite for a carbonate reaction—positive. It was in fact an artefact, very very cleverly made—to my mind the best I have seen —not garish, not overdone, not too blue, with pyrites and calcite looking fairly normal in a *worn* piece. It was intended to deceive—in a difficult mount or setting it could well have done so if only a cursory examination had been made. I considered it to be a case of "Ten out of ten for the 10 × lens"!

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EMERALDS AND EMERALDS

By ALLAN M. TAYLOR, Ph.D., F.G.A.,
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I HAVE read with interest the recent short article in the Journal by Mr Farn[1] concerning the correct usage of the term emerald. There is no doubt that a problem exists and it is to be hoped that a suitable solution agreeable to all can be evolved. In an earlier article where I described the properties of synthetic vanadium emerald[2], I suggested that a definition of emerald that was non-committal with regard to the chromophore present might be appropriate, i.e. "that emerald is a bright green variety of beryl". Indeed, emerald has been just that for several thousands of years. With the appearance on the gem-testing scene of the pocket spectroscope, during the latter part of last century, it became possible for gemmologists to positively identify with ease the presence of chromium in emerald, even at concentration levels below 0·1 wt% in many cases. Since then, the continual detection of chromium as a chromophore in emeralds has led to the gradual conclusion that all

emeralds contain chromium, and eventually, that emeralds must have detectable chromium otherwise they should not be called emeralds. This latter view has been developed and expounded by Anderson[3], who has pioneered the use of the pocket spectroscope as an essential tool in gem testing.

During the last decade, the essentiality of chromium in emeralds, and hence the definition of emerald, has come under question due to the discovery and marketing of natural emerald-coloured beryls[3] lacking in chromium, and new data being available on synthetic vanadium-doped beryls or vanadium emeralds[2]. Continuing developments in the chemical analysis of emeralds and of other gemstones (e.g. garnet[4, 5, 6], axinite[7], tourmaline[8], zoisite[9]) have shown that the presence of vanadium as a chromophore in gemstones, including some emeralds, can no longer be ignored. This demonstrates that things are not always as simple as they might at first appear. Just as Mr Farn informs us that the Chelsea filter is no longer of great diagnostic power in distinguishing emeralds from green paste and other imitations, it is now apparent that sole reliance on the pocket spectroscope for proving the existence of emerald may in some cases produce an equivocal result.

I was interested to read at the end of Mr Farn's article about the trade regulations and usages as formulated by the London Chamber of Commerce & Industry's Precious Stone Trade Section viz., "According to the custom of the trade the word Emerald not preceded by a qualification is applied exclusively to natural grass-green beryl with colour due to chromium." If one accepts this statement in full, then the title of my article, "Synthetic Vanadium Emerald" is perfectly in accordance with the regulations, and not a contradiction of terms, as suggested by Mr Farn.

I have been informed by Mr Chisholm[10] that the regulation was formulated in order to distinguish between natural emeralds coloured by chromium and natural green beryls from Salininha, which were claimed to be emeralds but contained only the merest trace of chromium. Whether or not the regulation was formulated with the knowledge that vanadium as a chromophore in beryl may produce a grassy-green colour equally as attractive as that due to chromium I do not know. Colour comparisons are very subjective exercises and easily open to manipulation one way or the other. I have no doubt that there are similar high proportions of poorly coloured chromium emeralds and vanadium emeralds.

In the case of "synthetic vanadium emerald", I do not see what objection there can be to the use of this term, unless it is that in subsequent descriptive writing about them, they are loosely referred to as emeralds, just as in the same manner one may loosely describe Chatham synthetic emeralds, simply as emeralds.

The real problem, however, is not with the few synthetic stones that may be in existence, but with the natural ones that do not contain any significant chromium. These have emanated mainly from certain localities in Brazil. Some analytical data on them have been published by Wood and Nassau[11]. The stones from Salininha, which they call Chrome-Free Emeralds, all contain V and Fe in the range 0·1 to 3%, Mn 0·01 to 0·3%, and have only a slight trace of chromium, $<0{\cdot}001\%$. An analysis of a chrome-free emerald from Bahia is similar. From a scientific point of view it would be bad policy to label these stones as vanadium emeralds as there is no easy way to prove that they do in fact all contain appreciable vanadium, except by individual destructive chemical analysis. The further a non-chromium emerald ventures from the point of origin (whether synthetic or natural), the more doubt and suspicion is aroused—particularly if it is a good quality stone. I am not enthusiastic about the label "Chrome-Free Emerald", as it implies a certain deficiency in a gemstone which has every right to be considered on the same plane as any chromium emerald. Such a label is an unintentional and, I believe, undeserved stigma for the element vanadium, whose name is appropriately derived from that of the Scandinavian goddess of beauty.

The problem has arisen, as mentioned previously[2], because of the distinctive nature of the chromium absorption spectrum, compared to that of vanadium. This has resulted in gemmologists raising the element chromium to such a great height of excellence, that everything else is hopefully ignored. From a chemist's point of view, the importance of such a phenomenon is considered in its proper perspective. For the gem collector, the important thing is whether a stone is an object of beauty, attractive and desirable. Gemstones are the flowers of the mineral kingdom and, like flowers, they are here for us all to enjoy. Collectors may admire a gorgeous golden topaz without being concerned over whether or not it may contain detectable trace amounts of chromium or some other chromophore.

However, to return to a more constructive line of thought, I would like to throw into the ring, so to speak, the following suggestion: that emeralds be defined as "grass-green" or "bright green" (since grass-green is rather variable from place to place) variety of beryl, and are of two types, viz.

Type I: Those that contain sufficient chromium to have an absorption spectrum detectable by a pocket spectroscope.

Type II: Those that do not contain sufficient chromium to be detectable by the spectroscope. Thus emeralds-II would probably include all presently known vanadium emeralds, or any other bright green emerald-like beryls which may contain other chromophores or combination of chromophores, e.g. Fe, V; V, Mn; Ni, V; Fe, Ni, V, Mn etc.

This type of classification would mean that the merits of a particular emerald are considered on its aesthetic value. One does not have to resort to a destructive chemical test to decide what a particular stone may be—if it is a beryl and the colour is acceptable for emerald, then emerald it is; if chromium is not detectable with the spectroscope, then it would be labelled a Type II emerald. The possible case of when V > Cr and yet Cr is still detectable would be emerald Type I. An example may be the Muzo trapiche-type emerald[12], for which an XRF analysis has shown the presence of 0·10% Cr and 0·12% V. It is stated that a noticeable vanadium absorption in addition to the chromium absorption was observed in the clear outer material.

The precedent for naming of gemstones according to their colour is well established, and one does not have to leave the beryl group to find examples. Morganite, heliodor and aquamarine varieties of beryl have their distinctive colours, and yet nobody is greatly concerned about whether or not their absorption spectra are distinctive or even detectable, or due to one, two or a multiple of chromophores existing in a variety of different crystallographic sites. I think that gemmologists should be thankful that of all the chromophores found in the beryl group of gemstones, it is chromium which has a readily detectable absorption spectrum—and not say iron! If the latter were the case, the ubiquitous iron would result in nearly all beryl gemstones being named aquamarines, if one allowed the naming of gemstones to be determined solely on the criteria

of having detectable and distinctive absorption spectra.

The importance of vanadium as a chromophore, whether dominant or subordinate, in many emeralds, is now fairly well established. The initial discovery was made about 1920 by the celebrated geochemist V. M. Goldschmidt[13] who found that the emeralds from the southern end of Lake Mjösen, Norway, contained 0·9% V_2O_3 and only 0·1% Cr_2O_3. This particular emerald locality, it seems, is the one described in Webster's book[14] "Gems"; however, he does not mention that these emeralds may perhaps be more correctly called vanadium emeralds. If, in this case, vanadium is the predominant chromophore, why should vanadium be ignored? Surely not because one element has a more distinctive absorption spectrum than the other!

So it would seem that at least one natural vanadium emerald occurrence, albeit unimportant commercially, has been masquerading simply as emerald in our foremost gemstone reference book for some considerable time. We may also wonder just how many fine Muzo emeralds have vanadium as the predominant chromophore.

My thanks are due to Mr J. R. H. Chisholm, whose constructive criticism of this article I found of considerable assistance.

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TRENDS IN DIAMOND SYNTHESIS

By DENNIS ELWELL, B.Sc., Ph.D.

Growth of Diamond at High Pressure

In spite of the ever-growing family of simulants, diamond retains its unique position as the outstanding gemstone in terms of hardness and optical properties. For the materials scientist, diamond presents a challenge since it is the stable form of carbon at high temperature and very high pressure. The great pioneer of high pressure physics and technology, P. W. Bridgman, is said to have attempted the graphite→diamond transformation as the first experiment whenever he had developed some new technique to obtain higher pressures than those possible in his earlier apparatus.

The first reproducible synthesis of diamond was achieved not simply by the attainment of temperature and pressure conditions in the diamond-stable region but by the addition of a "catalyst". It has now been recognized that the formation of diamond by the process first reported in 1955 by General Electric involves crystallization from a solution of carbon in a molten metal. A wide range of solvents has been found to yield diamond, and a study of the solvent action has been reported by Wentorf (1966). Fig. 1 shows the phase diagram of carbon, with the shaded region indicating the area which has been used for the growth of diamond from a metallic solution.

The possibility of diamond crystals of gem size and quality was investigated only in the last few years. Wentorf (1971) reported successful experiments in which small diamond crystallites were heated at about 1450°C in contact with a molten nickel solvent and transported in the solution to deposit on a diamond "seed" crystal at 1420°C. The maximum rate at which diamonds could be grown was found to decrease as the crystals got larger, and a diamond 5 mm in diameter took a week to grow. This necessity to decrease the growth rate as the crystal gets larger is a normal phenomenon in crystal growth from solution and the theory behind this effect is discussed by Elwell and Scheel (1975). Gemmologists may take comfort from this phenomenon of "supersaturation inhomogeneity", which has the consequence that, although synthetic diamonds of high quality and weighing over 1 carat may be produced, their cost is at present uneconomic. Only the development of new equipment to permit large volumes of solution to be

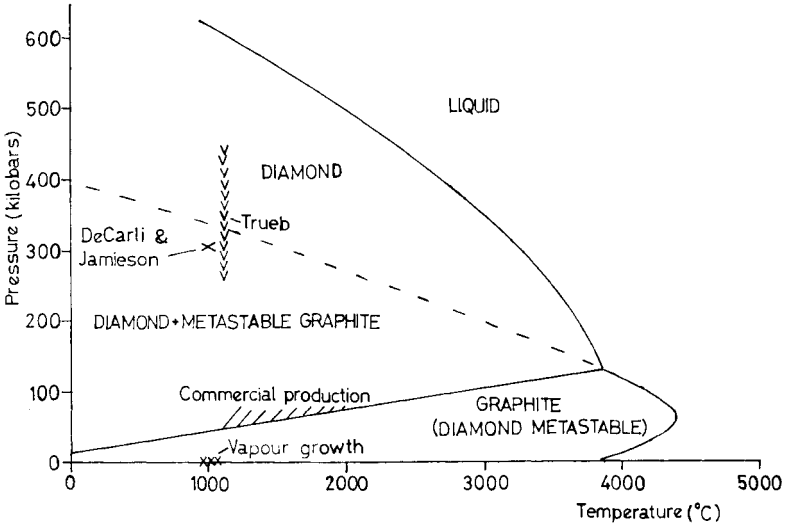

FIG. 1. Phase diagram of carbon (after Bundy *et al.*, 1973) showing approximate regions of experiments discussed.

maintained under a pressure of about 55 kbar* over long periods at relatively low cost would change this situation.

Crystallization of industrial diamond from metal solution is, of course, a major industry and roughly half of the diamond grit for cutting and polishing is produced synthetically. Production occurs in Czechoslovakia, Ireland, Japan, the Netherlands, South Africa, Sweden, and the Soviet Union as well as in the U.S.A., and it is possible that China is also a producer. At least 30 tons of graphite have been converted into diamond, and the actual figure may be several times this amount.

USE OF SHOCK WAVES

In the absence of a solvent ("catalyst") the pressure required to transform graphite into diamond greatly exceeds the minimum value expected from the phase diagram. The earliest attempts at producing diamond, by Hannay in 1880, made use of a chemical reaction to generate a high pressure and temperature. The

*that is, 55000× atmospheric pressure, approx. a 350-ton load on each square inch. (1 bar = 10^5 pascals, and 1 Pa = $1 m^{-1} kg s^{-2}$.)

authenticity of Hannay's experiments has been questioned, and the first proved synthesis of diamond by shock compression was reported by De Carli and Jamieson (1961). They used a charge of high explosive to generate a pressure estimated at 300 kbar for about 1 microsecond. The presence of diamond in the graphite sample to which this pressure was applied was confirmed, but the particles were very small, comparable with "carbonado" in meteorites. The graphite which was transformed to diamond was in the rhombohedral form, and its transformation occurred by compression along a particular crystallographic axis (the so-called c-axis). The approximate region of the phase diagram reached in these experiments is shown in Fig. 1, and is clearly well removed from the graphite-diamond boundary. The pressures and temperatures are still not sufficient, however, to ensure 100% transformation to the diamond phase.

A more recent study by Trueb (1971) involved pressures of 250–450 kbar for 10–30 microseconds, and produced a post-shock temperature of 1100°C. The graphite used was in the form of platelets 0·5–5 μm in diameter and the diamonds produced were of similar size, up to 36 μm. However, these particles were found to be made up of aggregates of much smaller cubic diamonds, in the size ranges 10–40 Å and 100–1600 Å. (1 Å $= 10^{-10}$m $= 10^{-4}$μm.) The suitability of these diamonds for industrial application will depend on the behaviour of these particles during use for cutting or grinding. The use of explosives could reduce the cost of industrial diamonds, but the tiny particle size would be a deterrent except perhaps for resin-bonded wheels where some wear of the diamond is acceptable. At present, however, shock-produced diamond does not appear to have been used commercially.

A related method which has produced commercial diamond involves shock-compression of metal blocks, for example of cast iron, containing small inclusions of graphite. Patents for this process were granted in 1966 to G. R. Cowan, B. W. Dunnington and A. H. Holtzman of DuPont de Nemours & Co. The pressures generated are above one million atmospheres and the metal, since it is less compressible than the graphite, serves the function of cooling the carbon inclusions very rapidly. This prevents the tendency of the diamond formed during compression to revert back to graphite after the passage of a pressure wave. The diamond formed by the DuPont process is partly of the hexagonal type (lonsdaleite), which

forms under conditions of very high pressure and relatively low temperature.

Ion Beam

Alternative means of producing diamond are frequently under investigation. The general principle is that the energy required for the growth of diamond-like carbon may be obtained by some technique other than compression, and in the method of Aisenberg and Chabot (1971) this energy is obtained by accelerating a beam of carbon ions by an electric field. Positive ions of carbon were produced in an electrical discharge at low gas pressures, and accelerated to high energies so that the carbon atoms incident on the surface of a diamond seed crystal (or perhaps a metal needle to be coated with diamond for use in a record player) have high effective surface temperatures. A detailed evaluation of the results of this experiment has not yet appeared, but the layers were probably amorphous. No information is available on the maximum thickness of the diamond films.

Growth from the Vapour

Perhaps the most interesting development in diamond synthesis in recent years has been the deposition onto diamond seed crystals from the vapour phase under conditions well inside the graphite-stable region. The process of diamond deposition by the decomposition of a carbon-containing gas at low pressure was developed independently by B. V. Derjaguin and B. V. Spitsyn in the U.S.S.R. and by W. G. Eversole in the U.S.A. The early Russian study used carbon tetraiodide, CI_4, while Eversole used methane, CH_4.

Since graphite normally co-deposits with diamond in this method, conclusive proof that diamond is, in fact, deposited was not easy and there has been scepticism at the validity of the various claims. Scepticism was certainly the general mood of delegates at the 1968 International Conference on Crystal Growth (see Elwell and Robertson, 1968), but it is now widely accepted that diamond does deposit. To understand this phenomenon we must consider the relative probability of deposition onto a diamond surface of new diamond or of graphite as carbon atoms arrive from the vapour phase. The growth of diamond is possible because the arrangement of new carbon atoms on the surface replicates that in the

existing crystal lattice, and it is possible for the probability of nucleation of new diamond layers to exceed that of graphite clusters. However, graphite clusters do tend to form in the vapour and these are deposited with the diamond on the crystal surface.

In order to remove this graphite, the growth process is interrupted at intervals and the material heated in hydrogen at 50–200 atmospheres pressure. Hydrogen reacts more readily with the graphite and so the diamond crystals are cleaned. Alternatively the graphite is removed by oxidation at atmospheric pressure, which is clearly more convenient.

For growth of diamond, the Russians now use typical conditions of 1020°C and a methane pressure of 0·07 torr (about 10^{-5} of an atmosphere)* and claim that the fastest growth rates are about 0·1 μm per hour, with about 1 carat deposited per hour in the whole reactor (Derjaguin and Fedoseev, 1975). The highest growth rate mentioned is of several μm per hour, under conditions of pulsed heating by a xenon discharge tube.

It has recently been reported (Derjaguin *et al.*, 1975) that the crystallographic cell dimension of the diamond layers is about 1% lower than that of the natural diamond crystals on which growth occurred, so that the film grows under compression.

The American work (now mainly at Case Western Reserve University) uses similar growth conditions (1000°C, 0·2 torr pressure of methane) to give an increase in weight typically of 6% in 20 hours, corresponding only to 0·001 μm per day linear growth rate. Much higher growth rates are found during the initial stage, possibly because of the strain which occurs because the film and crystal are of slightly different lattice dimension. Perhaps the most interesting observation from a gemmological viewpoint is the colour change from grey or off-white to light blue, which was reported to occur after several deposition and cleaning cycles (Poferl *et al.*, 1973).

This treatment may enhance the appearance of cut stones of poor colour, and it may well be that diamonds treated in this way will appear in some future series of "Notes from the Gem Testing Laboratory" or "Highlights at GIA's Lab", although it does not yet appear possible to deposit diamond layers uniformly on relatively large stones.

*1 atm = 101 325 Pa, and 1 Torr = (101 325/760) Pa.

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THE AGATES OF THE MIDLAND VALLEY OF SCOTLAND

(An appraisal of the work of Dr M. Forster Heddle)

By ALISTIR TAIT, F.G.A.

THERE can be few stones of gemmological interest that receive as little attention as the agate. Perhaps its relatively common abundance has had much to do with its underrated position amongst the popular gems. However, it is my opinion that this beautiful stone merits much attention from the serious gemmologist. Popular literature on gemmology affords little space to the many individual varieties of agate or their particular genesis.

As a Scottish student of gemmology one is very aware of the natural abundance of this intriguing stone occurring in a belt of andesites and basalts of mostly Devonian age across the Midland Valley of Scotland. Since Victorian times these stones have been collected from fields, rivers and *in situ* from their parent rock as "Scotch Pebbles" and mounted in traditional jewellery.

One of the first mineralogists to concern himself seriously with the formation of the Scottish agates was Matthew Forster Heddle,

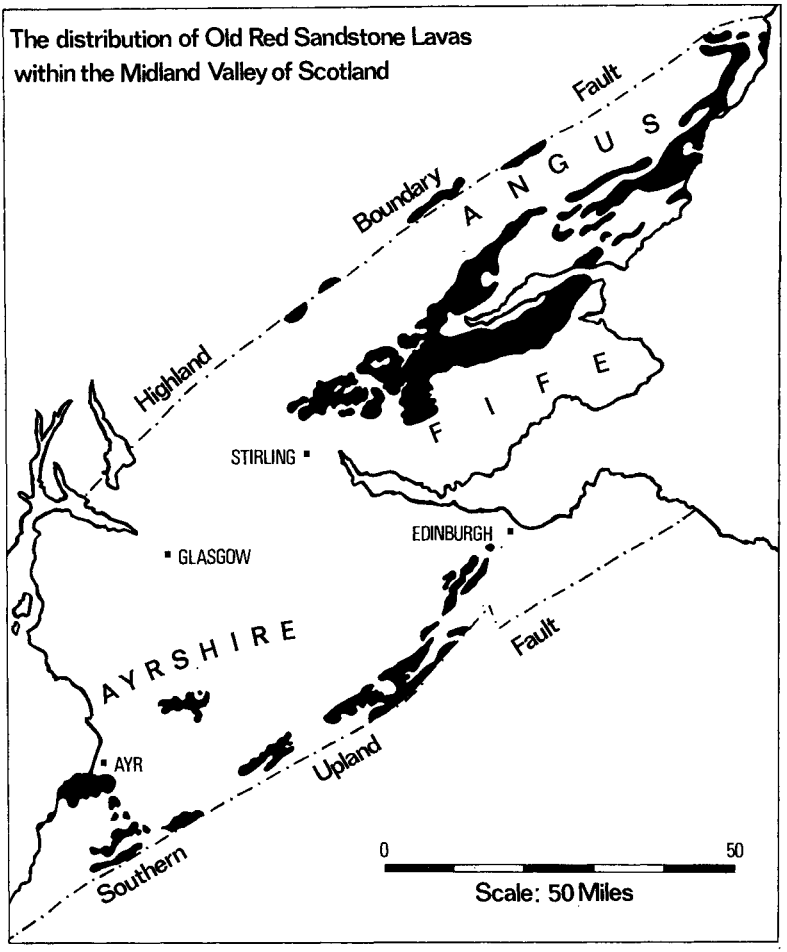

1828–97. Professor of Chemistry at Saint Andrew's University, he amassed a unique collection of Scottish minerals, said to be the most complete collection of a country's minerals ever made. In 1858 he revised and partly edited Greg and Lettsom's "Mineralogy of Great Britain and Ireland" and in 1879 was elected President of the Mineralogical Society of Great Britain. However, it is his work into the formation of agate that concerns us here. Most of his research was done on specimens collected by himself in the Midland Valley of Scotland and from these he derived his theory of their

formation. His splendid collection of minerals and agates now resides in the Royal Scottish Museum, Edinburgh.

The belt of agate-bearing lava was erupted from a number of volcanic vents during the Devonian, Old Red Sandstone, age. The existence of only a few can be traced today from a number of volcanic centres which have been obscured by subsequent geological activity, and some may lie under the North Sea off the Angus coast. Briefly this area extends in patchy exposures from Kincardineshire, Angus and Fife in the north-east of the Midland Valley, south-westwards to Ayrshire on the opposite coast. Basically the agates occur in an andesite which is a fine-grained intermediate igneous rock, although the exact composition will tend to vary between different flows. These lavas due to their once semi-liquid state, are, particularly near their surface, riddled with masses of air bubbles caused by the expansion of gases formerly compressed in the magma. These are commonly known as amygdules or amygdales from the Greek "amygdalos", an almond shape which these vesicles resemble. These exist in vast numbers and vary in size from pinheads to several feet in length. One observed at Dunure, Ayrshire, measured 3 feet by 12 feet. It is within these vapour cavities that the majority of agates form and from the shape of this cavity there is much we can tell about the condition of the lava before cooling. The agate nodule will cleanly "pop" out of its cavity, like a pea out of its shell, when the rock is split.

Amygdales are found in most lava flows. In a very static flow with little forward motion they will be roughly circular in shape. In a fast moving stream, however, amygdales will assume various shapes depending on the character of the flow. In a very viscous lava where gas bubbles rose upwards only with great difficulty while the flow continued to move forward, rod-shaped forms occur often lying virtually at the horizontal with their blunted noses like tadpoles facing the direction of flow. If, on the other hand, there has been little forward motion and a great deal of fluidity then the cavity will be pear or balloon-shaped. When mobile and very fluid, then characteristic axe-shaped nodules occur which are well known to collectors of the agate. When a lava has been moving forward rapidly with considerable speed and fluidity, then Dr Heddle described the resultant shape as lanceolate. With very large cavities there is often an elevation in the centre of the floor rather similar to that in a wine bottle. Agates with a flat

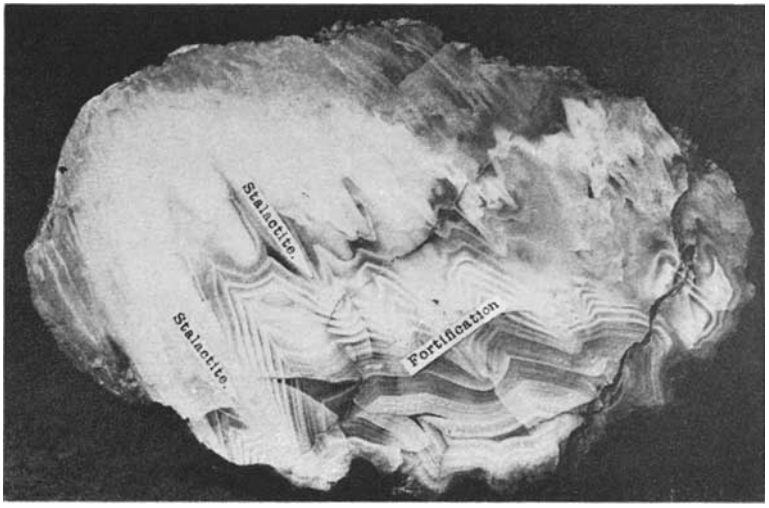

FIG. 1. Stalactitic agate (Norman's Law, Fife).

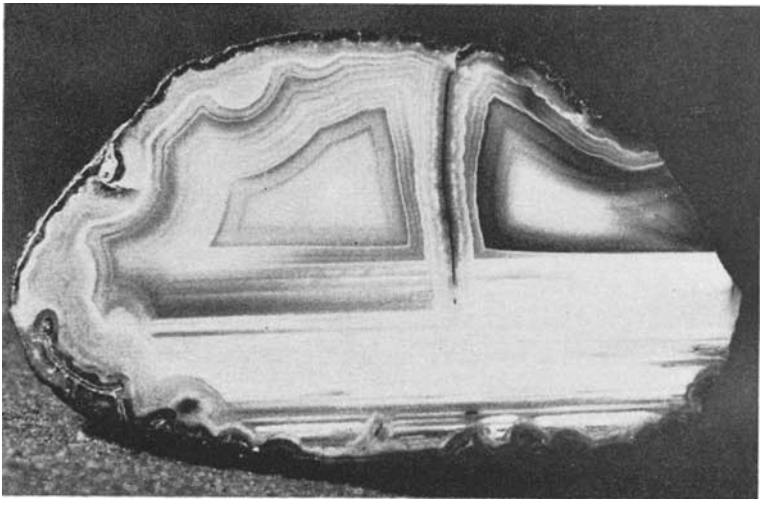

FIG. 2. Fortification agate (Usan, Montrose).

underside, Heddle observes, are almost invariably onyx-agates, although the parallel layers may not necessarily accord with the flat surface of the amygdale.

Where there is a high degree of excess silica in the lava an agate infilling will occur although often other minerals will crystallize out. In close proximity to agates vesicles may contain various other forms of silica such as crystalline amethyst, smoky quartz, rock crystal or the amorphous cacholong, opal or hornstone. In areas where the composition of the rock contains less silica other minerals may occur. The most notable group is the zeolites. Natrolite, stilbite, thomsonite and heulandite are commonly found as well as the closely related pectolite and prehnite. However, it is mostly the hydrous and anhydrous modifications of silica which concern us, along with the zeolites which occur with them.

Heddle found that in the majority of Scottish agates the first two outer layers are remarkably consistent. The first is the skin which completely coats the inside of the vesicle and usually consists of one of the following materials: celadonite which imparts a characteristic green colour to the skin and is soft, often earthy, formed by the decomposition of augite in the rock matrix: the other may be natrolite or stilbite which is red in colour. After the skin a uniform layer of colourless chalcedony is deposited which is often totally uncharacteristic of the subsequent colouring and banding in the stone. These subsequent layers of differing materials can be deposited in almost any order although usually the hydrated silicas form first.

Numerous theories have been proposed as explanation of the origin of the concentric ringed structure of agate. Perhaps the most significant contribution came from Raphael Liesegang, a German photographer who in 1896 observed that a crystal of silver nitrate placed in potassium dichromate in gelatin diffused outwards to form a concentric banding not dissimilar to that seen in agate. Whether this similarity is purely superficial or the key to the genesis of agate has been debated ever since. More recent experiments in the laboratory by Copisarow and Copisarow (1942) and Christamanos (1950) have attempted to reconstruct an environment where the effects of this rhythmic precipitation could be studied. It is my personal belief that although this form of rhythmic precipitation may have had some bearing on agate formation their structures are too complex and varied to be satisfactorily explained in this way.

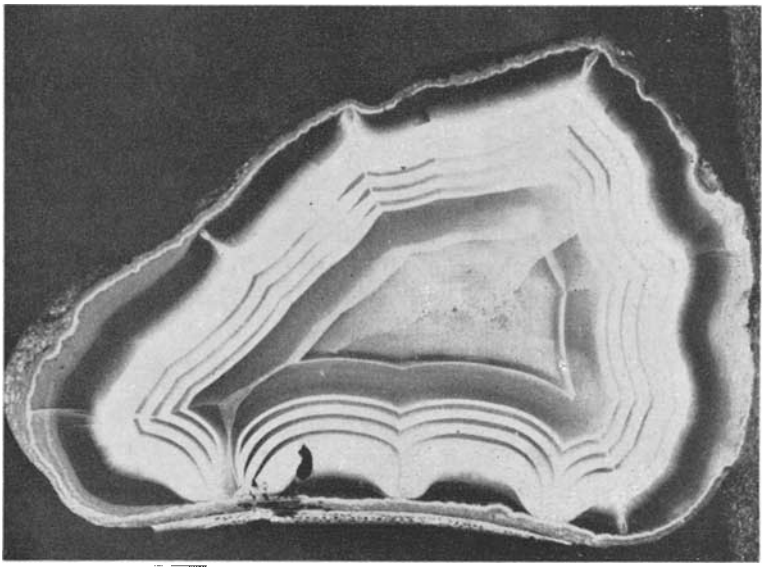

FIG. 3. Agate showing a multitude of expulsion tubes (Balmeadowside, Fife).

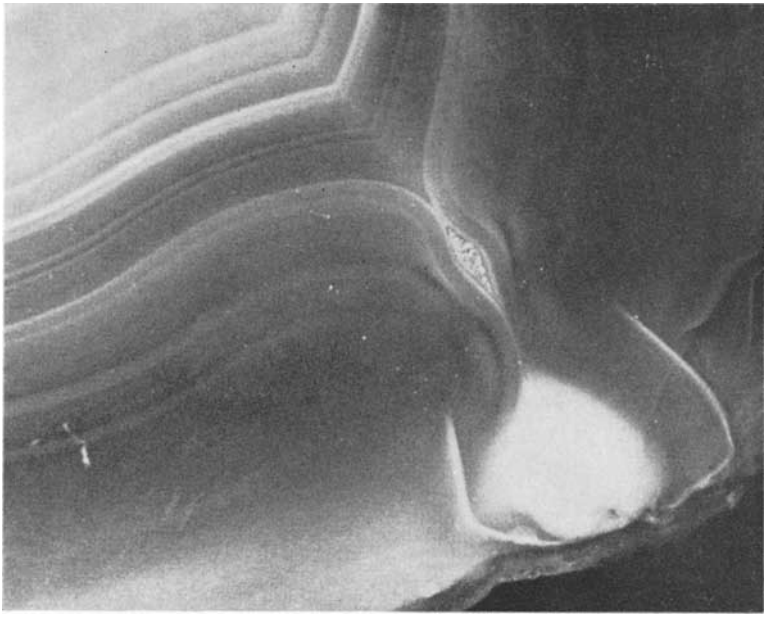

FIG. 4. Detail of dilatation in tube of escape.

Sim (1973) suggested that the banding was caused by seasonal fluctuations in the water-table generating successive depositions of silica, and Knoll (1942) attributed the rhythm to climatic variations and volcanic activity affecting the availability of siliceous material.

Fundamental to any theory of the formation of agates is an explanation of the so-called tube of escape. Such tubes exist in virtually all agates if examined in sufficient detail, and it is not uncommon to find several. One specimen showed as many as twenty. Dr Heddle supposed that chalcedonic material in solution is forced by endosmosis through the layers of chalcedony along the divergent fibres of tridymite into the semi-filled cavity. Here the solution deposits its silica and is subsequently forced out via one or many of the escape tubes by a further influx of solution. Heddle found many of these openings to the surface not round but linear in form easily mistaken for a rent. On the surface of the agate nodule these can often be traced as slight ridges traversing the agate's skin. Each layer deposited diminishes in thickness as it nears this tube of

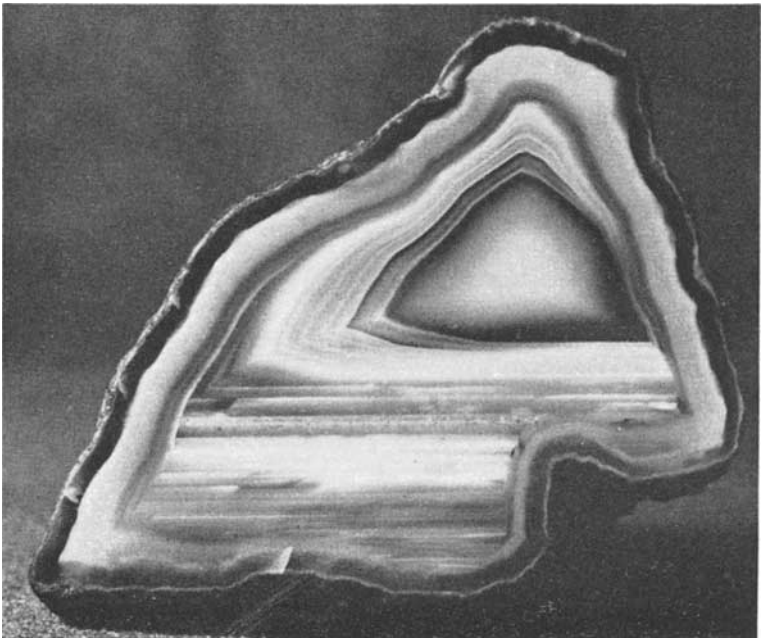

Fig. 5. Onyx-agate (Montrose).

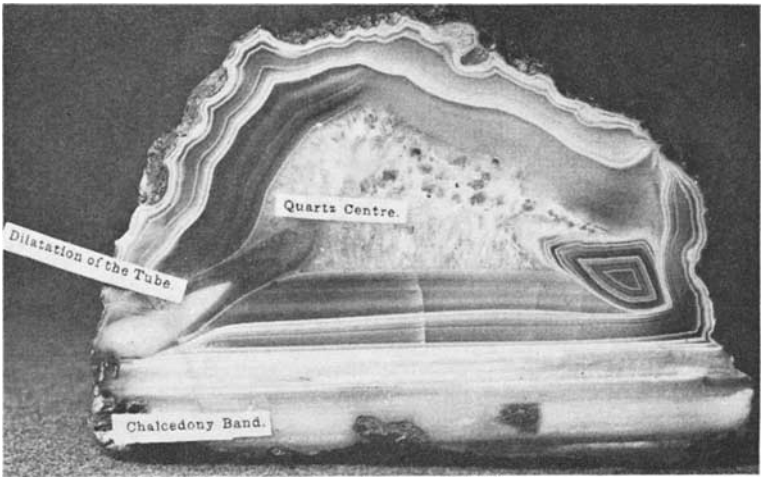

FIG. 6. Onyx-agate with quartz centre and tube of escape.

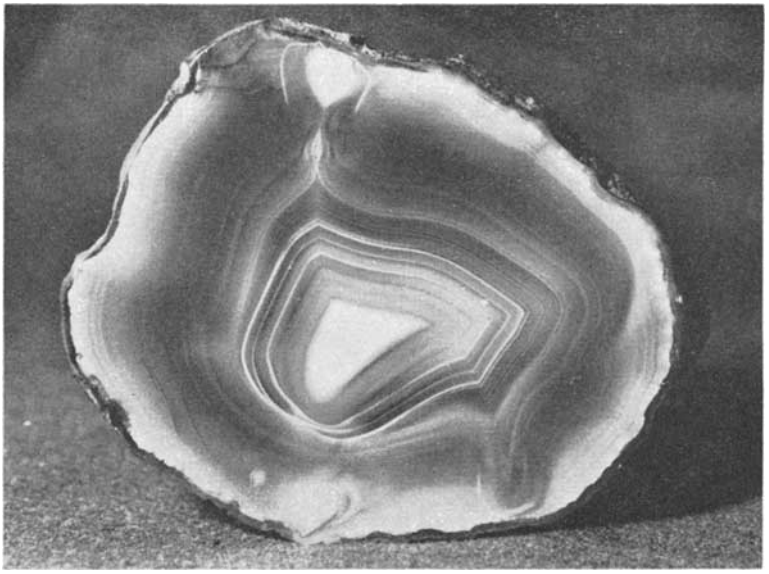

FIG. 7. Agate with tube of escape (Montrose).

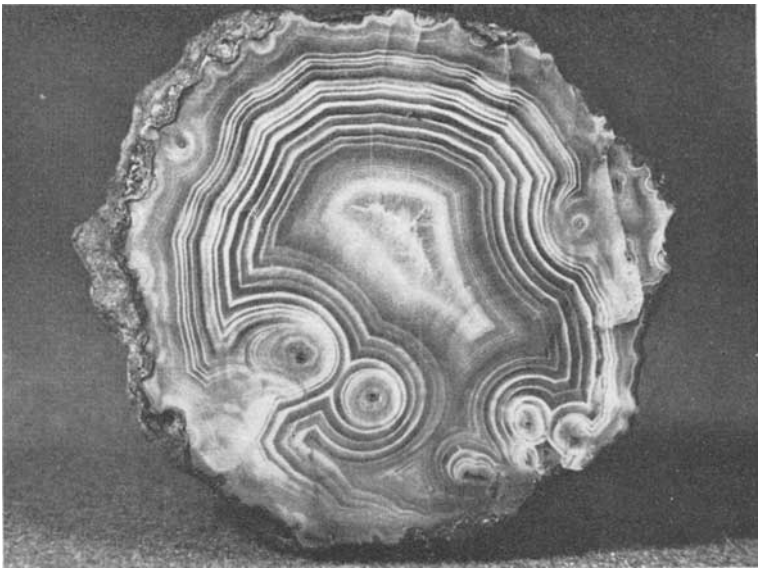

FIG. 8. Fortification agate.

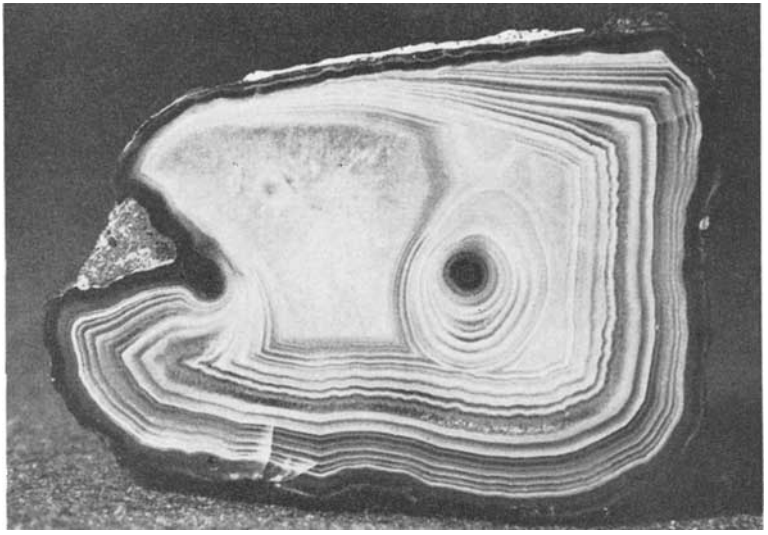

FIG. 9. Agate with quartz centre.

escape, it being the last portion of the cavity to be filled. The tube reaching the skin may be of virtually microscopic dimensions. In almost all cases there is a large dilatation at the end of the tube of escape at the point where the first clear layer of chalcedony has been deposited. It resembles a congestion such as when a moving stream of people is arrested at a narrow exit. Although doubtless significant, Dr Heddle could not explain what has caused this curious feature other than it being pressure outwards of the silica solution. This is an interesting point, as some authorities maintain that this tube is the means by which solutions entered and others that it is irrelevant to the formation of agate at all.

Onyx is common either partly or completely filling the amygdale. Heddle explained onyx as the silica gel whilst in solution being less viscous than normal and so instead of adhering equally to all the sides of the amygdale it settles by the laws of gravity in the lowest part of the cavity. In some instances, due to localized earth movements, the solidified lava has been tilted causing a disruption in the deposition of the banding, i.e. the bands are not parallel but inclined to one another. Such occurrences are, however, uncommon.

The work of Dr Heddle poses a number of intriguing questions regarding agate and its formation. Many of the features he observed are peculiar to specific localities or regions and more recent theories on agate are not satisfactory in explaining their origins.

ACKNOWLEDGEMENT

The Author wishes to acknowledge the valuable assistance of Mr R. J. Gillanders in photographing specimens, also of Dr H. Macpherson and his staff at the Royal Scottish Museum for making available specimens from the Heddle collection.

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[*Manuscript received 26th February, 1976: revised 21st June, 1976.*]

Gemmological Abstracts

BERDESINSKI (W.), SCHMETZER (K.) and MÜLLER (E.). *Palygorskit aus Peru und Mexico.* (Palygorskite from Peru and Mexico.) Z.Gt.Gemmol.Ges., 1977, 26, 1, 6-8. 2 illus. Bibl.

This material is pink or grey-pink, a comparatively rare clay mineral formed by erosion of Mg-rich rocks, also found in sedimentary deposits. Physical properties vary according to chemical composition, i.e. amount of Mg and Ca present. Can be orthorhombic or monoclinic. The authors compare material from Peru and from Mexico, the first being more intensive pink, with density 2·18, R.I. 1·55, the latter being paler, with density 2·10, R.I. 1·55. The editor adds that this material is marketed in Germany under the name "pink opal" and the rough is imported as "angel-skin opal". E.S.

BROWN (G.). *Two new precious corals from Hawaii.* Australian Gemmologist, 1976, 12, 12, 371-377. 6 figs.

Deals in detail with pink coral (C. secundum) and gold coral (Parazoanthus sp.), both occurring at 300 to 500 metre depths off Hawaii. The pink coral appears to be similar to other pink corals occurring in other localities. It is affected by hydrochloric acid. Gold coral, on the other hand, although apparently growing in symbiotic association with the pink, is much more like black coral in its nature and properties, i.e. the substance is similar to conchyolin and does not react with hydrochloric acid. There is some suggestion that it is a parasitic growth on bamboo coral. This seems to be the most complete paper on these corals so far published in gemmological literature and, as such, is important. R.K.M.

CASSEDANNE (J. P. and J. O.). *La turquoise de Pau à Pique (Brésil).* (Turquoise from Pau à Pique, Brazil). Revue de Gemmologie, 1976, 49, 3-6.

The location of the deposit is in the north-west of the State of Bahia and the main rock is a biotitic gneiss. Much of the turquoise occurs in veins cutting quartzite and also in a cement of iron-bearing variscite. S.G. of the turquoise was approximately 2·65 (blue cryptocrystalline fragments), 2·40 (greenish-blue porous material); hardness varied between 5·5 for compact material and 4 for porous stones. Mean refractive index was approximately 1·618. Mining is now thought to have been abandoned. M.O'D.

CHALMERS (B.). *Emeralds—three for* $150. Australian Gemmologist, 1976, 12, 12, 365-370. 6 figs.

An account of a visit to Bogota with some historical background to the country and the emerald sources. The $150 (Australian) of the title becomes $1.50 in the text. R.K.M.

CROWNINGSHIELD (R.). *Developments & highlights in GIA's Lab in New York.* Gems & Gemology, 1976, XV, 7, 218-224. 17 figs.

Several examples of serious laser damage to diamonds are illustrated, including one with a brown burn on the table. The tilt or light-spillage test for diamond simulants is described but illustration is too small to be clearly interpreted. Aventurine quartz and realistic "paste" emeralds and yet another fake emerald crystal are also described. Random fibres in chatoyant chrysoberyl, simulated ivory "engine-turning" in a plastic copy of a netsuke, and a partially dyed monolith jade ring are described, while a dyed marble bangle proved to be easily frangible. R.K.M.

CZYGAN (W.). *Die schwarze Varietät.* (The black variety). Lapis, 1977, 2, 3, 20-21.

Melanite, the black variety of garnet, is found in the Kaiserstuhl area of Germany; common forms encountered are the rhombic dodecahedron and a combination of this form with the icositetrahedron. M.O'D.

DUNN (P. J.). *Gem Notes.* Gems and Gemology, 1976, XV, 7, 199-202. 3 figs.

Notes on Madagascan hambergite; inclusions in Yogo Gulch (Montana) sapphires; green fluorite from New Hampshire; opalescent sandstone from Louisiana; and inclusions in Brazilian andalusite; presumably based on specimens in the Smithsonian collections. R.K.M.

FISCHER (K.). *Sphen.* (Sphene). Lapis, 1977, 2, 1, 27-29.

The characteristics and localities for sphene are reviewed with two illustrations in colour. M.O'D.

GIRGIS (K.), GÜBELIN (E.) and WEIBEL (M.). *Vanadiumhaltiger grüner Kornerupin vom Kwale-Distrikt, Kenya.* (Vanadium-containing green kornerupine from Kwale District, Kenya). Schweiz. Min. Petr. Mitt., 1976, 56, 65-68.

New detailed chemical data are given on the green iron-free vanadian kornerupine of gem quality in southern Kenya. The analysis presented by Schmetzer *et al.* (in their paper abstracted in J. Gemm., 1975, XIV, 6, 297) seems to be erroneous in the determination of boron and water. M.W.

GODEFROY (G.), LOMPRÉ (P.) and DUMAS (C.). *Pure and doped barium titanate; crystal growth and composition.* Materials Research Bulletin, 1977, 12, 2, 165-9.

Single crystals of barium titanate have been grown by the Czochralski and Remeika methods and have been doped with Fe, Cu and Co. M.O'D.

GRAMACCIOLI (C. M.). *Grüne Samen in Asbest.* (Green offspring in asbestos). Lapis, 1977, 2, 3, 10-13.

An account, illustrated in colour, of the occurrence of the demantoid variety of andradite garnet in the Malenco-Tal, Italy. The garnets occur in a chrysotile asbestos with magnetite. M.O'D.

GRICE (J. D.) and WILLIAMS (R.). *Jeffrey Mine, Asbestos.* Lapis, 1977, 2, 3, 14.

An account, illustrated in colour, of the occurrence of hessonite and a green variety of grossular garnet at the Jeffrey Mine, Asbestos, Quebec, Canada. M.O'D.

GÜBELIN (E.). *Alexandrite from Lake Manyara, Tanzania.* Gems and Gemology, 1976, XV, 7, 202-209. 7 figs, 3 in colour.

An excellent and very full account of the sparse occurrence of alexandrite in the emerald deposits of this comparatively newly opened gem area. The Manyara material contains less iron than does alexandrite from other known areas and in luminescence and transparency to long U.V. light resembles synthetic material to some extent. Colour plates are rather garish. R.K.M.

KOCH (S.). *Granatfels aus den Karpaten.* (Garnet in the Carpathians). Lapis, 1977, 2, 3, 25.

Good garnet crystals are found in the Banat area of Romania; andradite is the commonest variety encountered, but the colour inclines to dark brown or brownish-red rather than green. M.O'D.

LEAVENS (P. B.). *The hall of minerals and gems at the American Museum.* Mineralogical Record, 1977, 8, 1, 28-31.

The new display at the American Museum (of Natural History, New York City) opened in 1976 and consists of a cluster of rooms, carpeted and dimly lit except for the cases themselves. The gemstone display is fine in quality but cramped, and some of the larger minerals are not in the best condition. One notable exhibit is a made-up pegmatite pocket. M.O'D.

LIDDICOAT (R. T.). *Developments & highlights at GIA's Lab in Santa Monica.* Gems and Gemology, 1976, XV, 7, 210-215. 18 figs.

A hornbill snuff-bottle proved to be composite, not one piece. A spodumene cat's-eye (no colour given), African alexandrites, quartz inclusion in emerald, and knots (naarts) in a fancy diamond, are illustrated and described. Inclusions and striations in botryoidal opal from a North Mexican locality, a spodumene-like inclusion in synthetic emerald, and devitrification around a bubble in a paste stone, are also reported and illustrated. R.K.M.

MEIXNER (H.). *Aus der Gamsjagd entdeckt.* (Found in the Gamsjagd). Lapis, 1977, 2, 3, 6-7.

A short account of the occurrence of garnet in the Tirol with illustrations taken from an early work. The garnets are pyropes. M.O'D.

MERTENS (R.). *Beitrag zur Erkennung synthetischer Opale.* (Contribution to the recognition of synthetic opals.) Z.Dt.Gemmol.Ges., 1977, 26, 1, 28-29. 4 illus.

Article based on one by Jobbins, Statham and Scarratt in J. Gemm., 1976, XV, 2, 66-75. The author points out that when viewed sideways layers of varying colour can be observed. Another effect is the formation of "scales" in individual colour-zones. These scales are irregular and nearer to lizard scales than fish scales. The colour-zones are clearly defined as opposed to those in natural opals. E.S.

NASSAU (K.). *How to define non-single-crystal synthetics.* Gems and Gemology, 1976, XV, 7, 194-198.

Dr Nassau proposes scientific requirements for the use of the term "synthetic" in connexion with such substances as man-made opal, lapis lazuli and turquoise. He considers that they should be congruent with the natural product at four out of five levels, i.e. chemical composition, crystal structure at x-ray diffraction level, sub-micro structure at electron microscope level, and at macro-structure (visual) level. Only micro-structure may vary to some extent, as it does in the natural stone. R.K.M.

NASSAU (K.). *Zur Bestimmung von "nicht-einkristallinen Synthesen".* (Definition of non-single-crystal synthetics.) Z.Dt.Gemmol.Ges., 1977, 26, 1, 19-23.

This article is a translation by B. Günther from the English (*v.sup.*). E.S.

NASSAU (K.). *Das internationale System der Einheiten in Messwesen und seine Anwendung in der Gemmologie.* (The international system of units and its application in gemmology.) Z.Dt.Gemmol.Ges., 1977, 26, 1, 24-27.

German translation of Dr Nassau's article in J.Gemm., 1977, XV, 5, 243-247. E.S.

O'DONOGHUE (M. J.). *Two interesting zinc minerals.* Australian Gemmologist, 1976, 12, 12, 364.

An account of the zinc spinel, gahnite, and of the zinc tungstate, sanmartinite, with brief reference to their synthesis. Confused by a mass of mineralogical data much of which is academic and of little consequence to the gemmologist. Reference to "cubic oxygen", vagueness about gahno-spinel and a printer manifestly out of his depth add to this confusion. Sanmartinite does not appear to have been cut as a gem. R.K.M.

OKRUSCH (M.), BUNCH (T. E.) and BANK (H.). *Paragenesis and petrogenesis of a corundum-bearing marble at Hunza (Kashmir).* Mineralium Deposita, 1976, 11, 278-297.

A calcite marble containing gem-quality ruby is exposed in the Hunza Valley, in north-western part of the Karakoram mountains, Pakistan zone of Kashmir. Electronprobe microanalyses are reported for two rubies and for claret-red, greyish red-violet, and cornflower-blue spinels (and also for garnet, biotite, phlogopite, chlorite and plagioclase). The rubies have a maximum size of 15 mm; only a few of them are of gem quality but they are reported to compare in colour and clarity with Burma rubies; they have ε1·762, ω1·770; sp.gr. 3·99. The two ruby analyses show Cr_2O_3 0·14, 0·17, total iron as FeO 0·01, 0·01%. The cornflower-blue spinel has Cr_2O_3 0·19, total iron as FeO 1·88%; the claret-red spinel has Cr_2O_3 0·41, FeO 0·39%. R.A.H.

O'LEARY (B.). *Opals of Indonesia.* Lapidary Journal, 1977, 30, 11, 2484-2500.

The material, found on Java, is said to be volcanic in origin and both white and black varieties are found, as well as a jelly opal (i.e. fire opal). A jet-black variety is said to display a garnet-red colour. Pseudomorphs after various fossils and a variety resembling boulder opal are also found. Security considerations prevent further disclosures at the present time. M.O'D.

PENSE (J.), SCHNEIDER (W.) and SCHRADER (H. W.). *Magnesit als Türkis Imitation.* (Magnesite as turquoise imitation.) Z.Dt.Gemmol.Ges., 1977, 26, 1, 17-18. Bibl.

Various pieces had been offered as turquoise and were examined and shown to be coloured magnesite gel, which has similar density to turquoise. (Dr Lenzen has added a note to the above, giving details. The examples were baroque pieces which had been used for necklaces. The magnesite can be dissolved at room temperature in 25% hydrochloric acid; however, care should be taken not to immerse real turquoise in such solution as the colour can change.) E.S.

SANDERS (J. V.). *Precious opal in the Warrumbungles.* Australian Min., 1976. 3, 9-11, 5 figs. (in Australian Gems & Crafts Mag., no. 16).

Precious opal and white potch opal occur in vesicular lavas in north-western N.S.W. The precious opal has the normal structure of regular equal-sized spheres of diameter 0·15-0·3μ with cusp-shaped interstitial holes, whereas the potch consists of spherical particles of variable size up to 10μ. Curved boundary surfaces between particles are due to void-filling after the irregular-sized spheres had settled together. D.R.H.

SCHMETZER (K.), BERDESINSKI (W.) and KRUPP (H.). *Grüner Opal aus Tansania.* (Green opal from Tanzania). Aufschluss, 1976, 27, 381-384. 2 figs.

Green opal from Tanzania can be structurally placed into the cristobalite-tridymite-opal group. As in chrysoprase, the colour is due to a small amount of Ni. The Ni^{2+} ions are probably situated in Mg^{2+} positions in clay minerals which are present in green opal as admixtures. The bands of the absorption spectrum of the opal, which is reproduced together with one of chrysoprase from Australia, are assigned to Ni^{2+} transitions in octahedral coordination. A.P.

SCHMETZER (K.), GÜBELIN (E.), MEDENBACH (O.) and KRUPP (H.). *Skapolith-Katzenauge und Sternskapolith aus Zentral Tansania.* (Scapolite cat's-eye and star scapolite from central Tanzania.) Z.Dt.Gemmol.Ges., 1977, 26, 1, 3-5. 7 illus. Bibl.

The authors examined yellow scapolites from central Tanzania which were cut en cabochon and showed a cat's-eye effect; in one example a four-rayed star was observed. Under the microscope leaf-like, tabular and needle-shaped inclusions of reddish-brown and orange-red colouring were seen to have higher R.I. and are thought to be iron oxides or iron hydroxides (haematite, goethite, lepidocrocite). The inclusions are quite different from those found by Anderson and Payne in 1934 in scapolite cat's-eyes from Mogok in Burma. E.S.

SCHMETZER (K.), OTTEMANN (J.) and KRUPP (H.). *Skapolith aus Zentral-Tansania,* (Scapolite from Central Tanzania). Aufschluss, 1976, 27, 341-346. 3 figs.

Yellow scapolite of gem quality from the region between Dodoma and Singida in central Tanzania is described. The microprobe analysis reported indicates 26% meionite. The cell dimensions are *a* 12·06, *c* 7·56 Å, space group $P4_2/n$. Refractive indices and dispersion are reported in detail. On 199 crystals that have been studied 10 forms in 19 different combinations have been recorded and are fully tabulated. {100}, {110} and {101} are invariably present; next most common is {301}, recorded on 131 crystals. A.P.

SINGHEE (A.). *Ivory carving in India.* Gem World, 1976, 3, 11, 23-25.

The ivory carving trade in India is in a very healthy state and during 1975/76 exports reached a record level. Ivory used comes from Mysore, Tamil Nadu, Kerala and Assam in India, though this material is only suitable for small pieces. African ivory is used for the larger carvings. Cutting is carried out by hacksaw; hydrogen peroxide is used for bleaching and marble powder for polishing.

M.O'D.

STRUNZ (H.). *Djevalith-Kristallstruktur und Chemismus.* (Crystal structure and chemistry of Djevalite.) Z.Dt.Gemmol.Ges., 1977, 26, 1, 9.

The author measured the cubic crystal with a =5·12Å, and gives further crystallographic details. He reads the density as 5·62 (5·60 and 5·71 according to Gübelin). The author also mentions electrical conductivity of the material.

In a footnote on p. 10 Dr Gübelin corrects an error in his article in Z.Dt. Gemmol.Ges., 1976, 25, 4, 204-210 (abstracted on page 328 *ante*). The right value for dispersion is G-B 0·0653, i.e. nearly 50% higher than diamond. E.S.

STRUNZ (H.) and WILK (H.). *Violetter Skapolith von Edelsteinqualität aus Ostafrika.* (Violet scapolite in gem quality from East Africa). Aufschluss, 1976, 27, 389-391. 2 figs. 1 coloured pl.

Violet scapolite of gem quality is found in a modern placer deposit near Dodoma, Tanzania. Morphology, cell dimensions, and optical properties are fully reported. The crystals are markedly pleochroic, colourless parallel to *c*, intense violet normal to *c*. A full chemical analysis shows that this scapolite is a marialite with a substantial magnesium content (MgO 1·60 wt%). The Ti and Mn content is less than 0·01%; Cr was spectrographically detected. A.P.

SUHNER (B.). *Eine einfache Methode zur Messung der Dispersion.* (A simple method of measuring dispersion.) Z.Dt.Gemmol.Ges., 1977, 26, 1, 11-16. Bibl.

The author uses two interference filters: blue 480 nm and red 654 nm together with a good light source on a Japanese Topcon refractometer. He claims that it is possible to obtain values to within 0·001. Various gems are given as examples.

E.S.

WANKLYN (B. M.). *Growth of silicate and germanate crystals from PbO-SiO_2 (GeO_2) fluxes.* Journal of Crystal Growth, 1977, 37, 1, 51-56.

Zircon has been grown from several flux systems and its possible use as a laser material has been suggested. Deep blue crystals were produced when a flux of V_2O_5 was used. Crystals doped with Tb were yellow, those doped with Cr were green. M.O'D.

WILKE (H. J.). *Outokumpu.* Lapis, 1977, 2, 3, 16-19.

An account, illustrated in colour, of the occurrence of uvarovite at Outokumpu, Finland. Pyrrhotine and chrome diopside are also found in this locality.

M.O'D.

ZEITNER (J. C.). *The turquoise blues.* Lapidary Journal, 1977, 30, 11, 2460-2472.

Reviews the types of turquoise currently available with particular reference to Indian jewellery. M.O'D.

ZEITNER (J. C.). *Agates around the world.* Lapidary Journal, 1977, 30, 12, 2668-82.

The nature and occurrences of agate are reviewed by country; chrysocolla is erroneously grouped with quartz. M.O'D.

Joyaux et objets d'art de Louis XIV. (Louis XIV's jewels and *objets d'art*). Revue de Gemmologie, 1976, 49, 9-16.

In the recently re-opened Collection National de Gemmologie, housed in the Museum d'Histoire Naturelle, Paris, are a number of celebrated historical objects which are described, some being illustrated in colour. M.O'D.

Man-made gem diamonds have exclusive properties. Retail Jeweller, 20th January 1977, p. 6.

A report was released by Diamond Grading Laboratories Limited on two synthetic gem diamonds made by the General Electric Company. One stone, weighing 0·28 ct, was brilliant-cut and greyish in colour. No absorption was seen as 4155Å nor at any other position. Under long-wave ultraviolet light there was a yellowish fluorescence with no phosphorescence; under short-wave irradiation the fluorescence was similar in colour but with a bluish-green phosphorescence lasting several minutes. Under x-rays a strong light blue fluorescence with a light blue phosphorescence was seen. In the other stone, rod-like inclusions could be seen with a 10 × lens and were thought to be voids, carbon not taken into the diamond structure or catalyst. The first stone was graded SI by SCANDN but colour grading was not applied. M.O'D.

Pearls. Gem World, 1976, 3, 11, 26-33.

The Indian pearl trade has suffered a decline in recent years, especially in the last two decades. Large-scale pearl farming in off-shore shallow bays has been started with a view to offsetting this situation. M.O'D.

Türkis. (Turquoise). Lapis, 1977, 2, 2, 5-18.

Accounts by various authors with illustrations in colour of the occurrence, properties and use of turquoise. M.O'D.

BOOK REVIEWS

AXON (G. V.). *The California gold rush.* Mason/Charter, New York, 1976. pp. vi, 136. Illus. in black-and-white. $6·95.

The gold rush began with the discovery of gold at Coloma, California, in 1848. This short book traces the development of the state of California and shows why its acquisition was so vital to the expanding Union; since prospecting attracted many men of initiative, the area soon prospered and even without gold would eventually have done so; contemporary illustrations show some original settlements and typical figures of the time. M.O'D.

BALTĂ (P.) and BALTĂ (E.). *Introduction to the physical chemistry of the vitreous state.* Abacus Press, Tunbridge Wells, 1976. pp. 287. £14·65.

Readers interested in the formation and properties of the various types of glasses will find some chapters in this book useful, in particular those on oxide glasses, the behaviour of ionic colouring agents in glasses and light absorption by charge transfer. The style of the book (a translation from Roumanian) is a little heavy but the matter is worth scanning. 671 references are given but there is no index. M.O'D.

BARIAND (P.). *Marvellous world of minerals.* Abbey Library, London, 1976. pp. 126. Illus. in colour. U.S. $12·50.

Those familiar with the world of minerals will know Nelly Bariand's superb photographs. Here they accompany a brief text translated from the French by David Macrae. The book is printed in West Germany and the standard of reproduction is as high as one would expect. But the specimens themselves provide the magic which fills the book; among many delights are sphalerite from Tenagh, Ireland, erythrite from the classic locality of Bou Azzer, Morocco, cyanotrichite from Grandview, Arizona. Arrangement is simple and there is a short introduction. As in Roberts *et al.*, "Encyclopedia of minerals" (reviewed on p. 401), the specimens are small, sometimes of micromount size; this ensures the presentation of the finest possible crystal. The scale is given for each illustration. At the price (or at almost any price) a superb book. M.O'D.

KOUŘIMSKÝ (Jiří). *A colour guide to familiar minerals and rocks.* Octopus Books, London, 1975. pp. 190. Illus. in colour. £0·99.

Faults in this remarkably cheap and handy-sized book chiefly spring from mistranslations, the original language being Czech. Many of the minerals described are given outdated and unnecessary synonyms and much important detail is omitted. As one comes to expect, the nature of the cause of colour in precious opal is incorrectly given; it is odd to see the cleavage of fluorite given as "difficult". The crystal system of arsenopyrite is monoclinic, not orthorhombic (the crystals are pseudo-orthorhombic); argentite is classed as orthorhombic (pseudo-cubic) and no mention is made of its relationship to acanthite (cubic crystals of Ag_2S are paramorphs of acanthite after argentite). The quality of the coloured illustrations is not high and certainly unflattering to many of the species described. Although the price is low readers will be much better served, within the same size and range and in nearly the same price range, by Hamilton *et el.* "The Hamlyn book of minerals, rocks and fossils" (reviewed in J.Gemm., 1974, XIV, 4, 194). M.O'D.

ROBERTS (W. L.), RAPP (G. R.) and WEBER (J.). *Encyclopedia of minerals.* Van Nostrand Reinhold, New York and London, 1974. pp. xxv, 693. Illus. in colour. £41·00.

This is in every way a magnificent production and serves immediately as a most welcome standard reference work. All known minerals are listed alphabetically and in addition to the expected constants much more information is given, including the three strongest diffraction lines, lattice constants and best reference in English (this is frequently Palache *et al.*, "Dana's System of Mineralogy", 7th edition, lamentably still incomplete; the present work goes far towards alleviating this sorry state of affairs). As this review (by oversight) is written rather a long time after publication the present reviewer has had the advantage of reading other appraisals; all are favourable, and very few errors and omissions have been noted. One or two species have been listed under names now relegated to synonym status by the International Mineralogical Association (sphene, now titanite, and cobaltocalcite, now spherocobaltite; less alarming are celestite for celestine and niccolite for niccoline). There are some other errors and inconsistencies, which can no doubt be cleared-up in a second edition.

The coloured illustrations are arranged in eight groups of 16 pages; they are of very high quality. Although there are 16 of diamond and eight of these are Nomarski phase-contrast photographs, the other minerals illustrated include many rarities and some have not been shown in colour before. Most of those illustrated are micromounts, which helps to ensure that the crystals are beautifully formed, since larger ones are more frequently distorted.

Some points of description are explained in the introduction and there is a glossary. Altogether this is a book which the serious mineralogist must have; there is not likely to be anything else of this quality available for many years, if ever, and, although the price is high, it is not exaggerated. M.O'D.

TANNER (B. K.). *X-ray diffraction topography.* Pergamon Press, Oxford, 1976. pp. xiii, 174. £6·25.

This interesting and lucid work includes chapters on crystal growth from solution, from the melt and from the solid state. Each chapter includes a bibliography. M.O'D.

ZUCKER (B.). *How to invest in gems.* Quadrangle & the New York Times Book Co., New York, 1976. pp. 120. $12·50.

This book purports to show that cut gemstones can show a profit on outlay and supports this thesis with a table of prices. Remarks on colour and quality are vague and ill-informed; the whole subject is sketchily treated. This reviewer does not believe that gemstones can be regarded in this light. M.O'D.

Lapis. Die aktuelle Monatsschrift für Liebhaber & Sammler von Mineralien & Edelsteinen. (Lapis. A topical monthly magazine for lovers and collectors of minerals and gemstones). Christian Weise Verlag, Munich. Annual subscription DM 48.

A beautifully illustrated new journal covering rocks, minerals and gemstones with the emphasis on minerals. In the issue examined (Jahrg. 1 no. 2) were articles on hauyne, the mines of Panasqueira and Alpine minerals. M.O'D.

ASSOCIATION NOTICES

MEMBERS' MEETINGS

Midlands Branch

On the 12th May, 1977, at the R.I.C.S. Headquarters, Birmingham, a talk was given by Mr A. Monnickendam entitled "The CIBJO Grading System". The Annual General Meeting of the Branch was also held during the evening, and Mr D. Morgan, F.G.A. was elected Chairman and Mr C. L. Hundy, F.G.A., re-elected Secretary.

North-West Branch

A talk was given on the 20th April, 1977, at the Royal Institution, Liverpool, by Mr B. W. Anderson, B.Sc., F.G.A., on "Liquids in the Service of Gemmology".

On the 19th May, 1977, at Church House, Liverpool, Mr R. Huddlestone, of Diamond Grading Laboratories Limited, gave a talk on the subject "Diamond Fingerprinting and Diamond Colour Grading, the State of the Art Today".

The collection of jewellery at the Liverpool Museum was viewed by a group of members on the 26th May, 1977.

Scottish Branch

The West of Scotland Mineral and Lapidary Society was visited on the 15th March, 1977, when members were able to see the cutting and setting of stones.

Following the Branch A.G.M. held on 13th April, 1977, when it appeared that the expense of travelling long distances had the effect of severely reducing the numbers attending meetings, it was announced with regret that no further meetings would be arranged for the time being. Mr G. M. Turner, "Kimberley", 39 Grahamshill Street, Airdrie, Lanarkshire, ML6 7EN, has taken over all the records in the hope that in the not too distant future it will be possible to activate the branch again.

South Yorkshire and District Branch

At a meeting held on the 14th March, 1977, at the University of Sheffield, Dr D. A. Carswell gave a talk entitled "Geology of Diamonds". This covered the latest thinking on the origin of diamonds and the analysis of the various minerals found in the kimberlite pipes, as well as the various minerals found in the xenoliths which had been carried along with the pipe material. Dr Carswell illustrated his talk with slides and samples, many of which he had gathered himself.

COUNCIL MEETING

At the meeting of the Council held on Monday, 14th March, 1977, the following were elected to membership.

Fellowship

Abraham, Robert, Amsterdam, Holland. D. 1976
Alvarado Moro, Odorico, Barcelona, Spain. D. 1976
Baldock, Lynette, Neston, Wirral. D. 1976
Beck Kaiser, Margrit, Barcelona, Spain. D. 1976
Callaghan, Christopher C., Port Elizabeth, S. Africa. D. 1976
Chapellier, Dominique M. B., Lausanne, Switzerland. D. 1976
Cook, Judith A., Northwood. D. 1976
Cottrill, Susan D., Stockport. D. 1976
Elliott, Douglas H., Nairobi, Kenya. D. 1976
Engelbrecht, Johann P., Pretoria, S. Africa. D. 1976
Fabregas Guardiola, Virginia, Barcelona, Spain. D. 1976
Gaarder, Kierstin, Vöyenenga, Norway. D. 1976
Hornytzkyj, Seppo, Helsinki, Finland. D. 1976
Lewis, Ian R. M., Sheffield. D. 1976
Moline, Sala A., Barcelona, Spain. D. 1976
Mollfulleda Buesa, Antonio, Barcelona, Spain. D. 1976
Montserrat Nebot, Alfredo, Barcelona, Spain. D. 1976
Oria Albero, Maria P., Valencia, Spain. D. 1976
Pons Gomez, Joaquin, Barcelona, Spain. D. 1976
Ranasinghe, Mahesha, Yogiyana, Sri Lanka. D. 1976
Ribes Cudinach, Emilio, Barcelona, Spain. D. 1976
Richards, Patsey-Ruth, Brisbane, Qld, Australia. D. 1976
Rider, Stephen G., Chelmsford. D. 1976
San Juan Ribes, Antonio, Valencia, Spain. D. 1976
Speekenbrink, Wilhelmus A. M., Den Haag, Holland. D. 1976
Vilá Perales, Vicente, Barcelona, Spain. D. 1976
Vleeschhouwer, Willy A., Schoonhoven, Holland. D. 1976
Zaveri, Rupesh P., Bombay, India. D. 1976

Ordinary Membership

Aksoy, Ayhan, Istanbul, Turkey.
Ando, Taiichiro, Wembley Park.
Aron, Mass K., Nugegoda, Sri Lanka
Bandara, Ranasinghe M. K., Colombo, Sri Lanka
Barrella, Lydia, Cape Town, S. Africa
Bayley, Adrian, Kowloon, Hong Kong
Beach, Wendy, Twickenham.
Beg, Mirza Z., Woking.
Bennett, Russell K., Aylesbury.
Bram, Carol B., North Melbourne, Va, Australia.
Burk, Ralph, Pforzheim, W. Germany.
Carr, William F. Hyannis, Mass., U.S.A.

Carter, Maurice, London
Chamberlain, Colin S., Leicester.
Choi, Yat H., Kowloon, Hong Kong.
Chong-Keun Lee, Joseph, Seoul, Korea.
Coffin, David G., Highbridge.
Cole, Arthur G., London
Cooray, Harindra T., Moratuwa, Sri Lanka.
Costet, Louis, Walnut Creek, Cal., U.S.A.
Culverwell, James C., London.
Daniels, Brian R., Dunedin, New Zealand.
Davis, Jonathan V., Stanmore.
Demouthe Smith, Jean, San Francisco, Cal., U.S.A.
Dharmawardene, Kahanawita G.E.R.W., Southall.
Dickson, Dorothy S., Harrisburg, N.C., U.S.A.
Driscoll, Richard F., Washington, D.C., U.S.A.
Eldridge, W. Randle, Kerrville, Tex., U.S.A.
Ellis, Paul A., Colchester.
Ereira, Jack, North Wembley.
Fernando, Bathiya D., Colombo, Sri Lanka.
Fielding, Evelyn, Klemzig, S. Australia.
Gadda, Fabrizio, Milan, Italy.
Gallant, Sherry L., Grand Island, N.Y., U.S.A.
Giorgetti, Pierangelo, Milan, Italy.
Golding, Ian A., London.
Harte, Partrick J., Whitstable.
Henniker-Heaton, Gay D. A., Cape Town, S. Africa.
Hein Dessing, Johan H. P., Gouda, Zuid, Holland.
Hitchen, Alan, Aldridge.
Holgeth, Jean, Grimsby.
Hood, Glynis M., Johannesburg, S. Africa.
Horata, Yoshihiro, Shibuya-Ku, Tokyo, Japan.
Hornstein, Sydney, Montreal, Que., Canada.
Hubbard, Audrey L., New Malden.
Hurst, Adam K., Solihull.
Inparajan, Athanas B., London.
James, Paulette V., Bognor Regis.
Jayanetti, Don C., Colombo, Sri Lanka.
Jayanetti, Prema, Colombo, Sri Lanka.
Kalra, Om P., London.
Katz, Raphael D., London.
Kaye, Ian D., London.
Kinch, John C., Morden.
Kuehn, Robert L., Dallas, Tex., U.S.A.
Landvik, Jan, Djursholm, Sweden.
Langoulant, Peter B., Salisbury, Rhodesia.
Lee, Dennis P., Leatherhead.
Leong, Lee-Wah, Singapore.
Lindsay, K. Sharon, Salisbury, Rhodesia.
Liu, Kin-Shun, Hong Kong.
Loh, Swee K., Singapore.
Maeda, Kiseko, Shibuya-ku, Tokyo, Japan.
Mahinda, Balasingham, Colombo, Sri Lanka.
Martin, William J., Nairobi, Kenya.
Matsuo, Harumitsu, Shibuya-ku, Tokyo, Japan.
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Muruganantham, Katherval, Colombo, Sri Lanka.
Oetter, Leroy P., Phoenix, Ariz., U.S.A.
Oka, Hirobumi, Shibuya-ku, Tokyo, Japan.
Pantelli, Andrew, London.
Parry, Julie, Pewsey, Wirral.
Patney, M. L., Lusaka, Zambia.
Payne, Philip, London.
Perrett, Roy, Manchester.
Pierce, Alan L., Los Alamitos, Cal., U.S.A.

Plomp, Jan, Alkmaar, Netherlands.
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Quick, Rodney J. A., Torquay.
Rafi, Mohamed, Colombo, Sri Lanka.
Reeves, A. Smith, San Francisco, Cal., U.S.A.
Roberts, Edward A., Kowloon, Hong Kong.
Robertson, Thomas B., Bundaberg, Qld, Australia.
Ros-Jones, Catherine A., South Ascot.
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Sarna, Rajesh, Nairobi, Kenya.
Sasaki, Shizuo, Yokosuka-Shi, Kanagawa-ken, Japan.
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Spencer, Bernard J. C., Marlow.
Stayte, Philip A. J., Leicester.
Takayama, Naoyuki, Shibuya-ku, Tokyo, Japan.
Tanaka, Kiyofumi, Yokohama-Shi, Kanagawa-ken, Japan.
Towler, Eric A., Kowloon, Hong Kong.
Tsukagoshi, Hideaki, Bunkyo-ku, Tokyo, Japan.
Turelli, Manuel L., São Paulo, Brazil.
Tyson, Jeffrey G., Carmarthen.
Ueda, Yoriaki, Ikeda-city, Osaka, Japan.
Veo, Luana, Vanderbijlpark, S. Africa.
Vickers, William, Beer.
Yokoyama, Kiyoshi, Shibuya-ku, Tokyo, Japan.

ACTIVITIES BY FELLOWS

The following Fellows of the Association have recently been granted the freedom of the Worshipful Company of Goldsmiths—Miss Judith Banister, Mr Eric Bruton, Mr A. E. Farn and Mr Alan Hodgkinson.

On the 6th May, 1977, Mr E. A. Jobbins, B.Sc., F.G.A., gave a talk on "Gemmological Survey" to the Wessex Branch of the N.A.G. in Bournemouth.

THE SHAPES OF PEARLS

The Japan Pearl Promotion Society has recently promulgated a set of expressions to specify the shapes of pearls, having reclassified all terms hitherto used in Japan and elsewhere in describing the shapes of pearls and selected those considered most appropriate, including those most widespread in English. In the past, confusion has been caused by the various different descriptions of some shapes of pearls and this has led the Society to take action to promote uniformity of phraseology. The new list of expressions covers virtually all shapes of the seawater species and the Society intends gradually to adopt new terms to designate such new and unusual shapes of freshwater pearls as may occur in the future. The shapes of pearls with their authorized names are set out in the accompanying Figs 1 and 2: a "Pearl Chart" showing them in colour may be obtained from the Gemmological Association of All Japan, Tokyo Bihokaikan Building, 1-24 Akashi-cho, Chuo-ku, Tokyo, Japan.

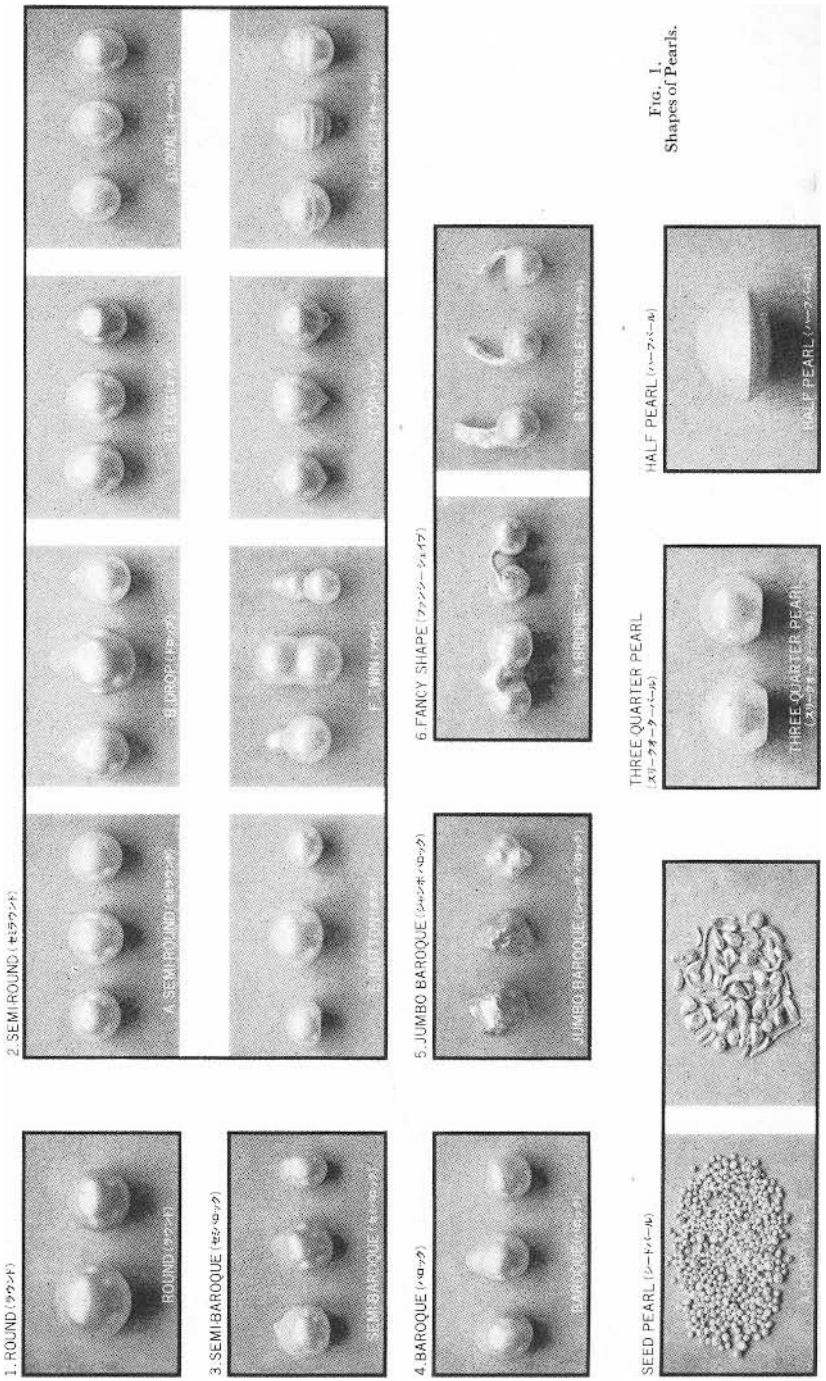

Fig. 1.
Shapes of Pearls.

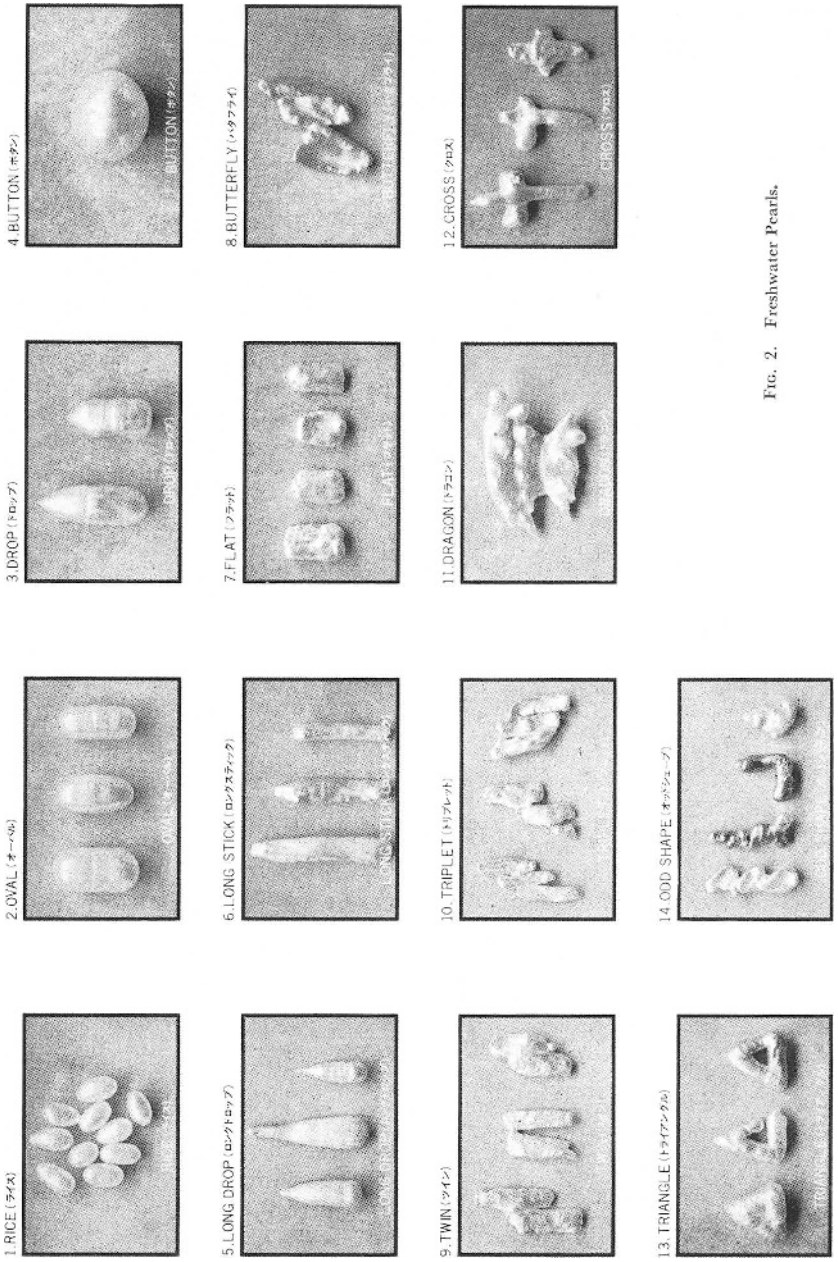

Fig. 2. Freshwater Pearls.

OBITUARY

Mr A. T. Kemp, F.G.A. (D.1936), London, died on the 2nd October, 1976.

GIFTS TO THE ASSOCIATION

Arising from a bequest by the late Mr A. T. Kemp, F.G.A., the Association has been presented with bound volumes of The Gemmologist and Journal of Gemmology, and various instruments including a microscope, refractometer, dichroscope and spectroscope.

PRESENTATION OF AWARDS

The Reunion of Members and Presentation of Awards is to be held at Goldsmiths' Hall, London, on Monday, 24th October, 1977, and NOT as originally arranged in November.

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No. 7
July, 1977

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THE JOURNAL OF GEMMOLOGY

and

PROCEEDINGS OF THE GEMMOLOGICAL ASSOCIATION OF GREAT BRITAIN

GEMMOLOGICAL ASSOCIATION
OF GREAT BRITAIN
SAINT DUNSTAN'S HOUSE, CAREY LANE
LONDON, EC2V 8AB

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THE JOURNAL OF GEMMOLOGY
AND PROCEEDINGS OF THE GEMMOLOGICAL ASSOCIATION OF GREAT BRITAIN

Vol. XV No. 8 OCTOBER 1977

AUTOMATION IN THE SORTING AND SIZING OF ROUGH GEM DIAMONDS

By P. G. READ, C.Eng., M.I.E.E., M.I.E.R.E., F.G.A., F.I.S.T.C.,
Technical Manager of the Diamond Trading Company

(being the substance of a talk given to the Gemmological Association of Great Britain at Goldsmiths' Hall on 11th October, 1976)

APPROXIMATELY 80% of the world's production of rough gem diamonds are marketed by the De Beers Central Selling Organisation. Before these diamonds can be valued and offered for sale, they must be separated into categories of shape, quality, colour and size, and it is the Diamond Trading Company, a principal member of the C.S.O., which performs this task. Until about ten years ago, the entire operation was done by hand. Today, partly because of the shortage of skilled labour, and partly because of the increase in the production and sales of rough diamonds, several of the simpler tasks have been successfully automated by D.T.C.'s Research and Development department. This department, which was formed seven years ago, consists of a team of electronic and mechanical development engineers who have all had previous experience of similar work in industry.

The word automation often conjures up visions of machines ousting the human operator from his skilled work, and, at best, relegating him to the task of machine minder. In the diamond business, however, both the economics of sorting and the practical limitations of what can be achieved with electronics and mechanics combine to make the use of automation and automatic sorting aids

particularly applicable to the less skilled and more monotonous tasks. This leaves the Sorter free to concentrate on the more interesting aspects of his work.

D.T.C.'s Research and Development department first becomes involved with a new project when the need for a specific sorting aid has been determined by the development co-ordinator, who acts as an information link between the department and the diamond floors. Once an outline specification for such an aid has been agreed with the appropriate diamond department, and authorization for the new project has been obtained from the Executive Committee, a search is made of all commercial equipments to see if there exists a product which either directly, or after modification, fits the specification. This is because it is much more expensive to design and build a new machine than to purchase and adapt an existing one. The new project will then pass through the stages of drawing office design, feasibility tests on a "mock-up", prototype assembly and test, and finally, when all engineering drawings are completed, manufacture of the production version. The time taken to progress from the initial request to the finished product is normally between one and two years, depending on the complexity of the project.

The four main operations in which automatic or semi-automatic equipment is currently being used are:

Sieving Shape Sorting Colour Sorting Sizing (weighing)

To these can be added an extra operation which occurs at intervals during the sorting sequences, that of counting. In Figure 1, the sequence in which these operations occur during the five-week work cycle that precedes a "sight" is indicated in a generalized flow chart. This flow chart shows in simplified form one sequence for goods under 1·2 carats in size.

The automatic machines which will now be described have been chosen to illustrate both modified commercial equipments, and those equipments designed entirely within D.T.C.'s R. and D. department.

First of all on the flow chart we have sieving, which is initially used to divide the incoming "run-of-mine" shipments of diamonds into two groups called smalls (diamonds smaller than 1·2 ct) and sizes (diamonds greater than 1·2 ct). The sizes are then again divided by sieving into a further series of weight groups. Although sieving is not a precise method of separating diamonds into weight categories, it is used at this initial stage for reasons of speed. The

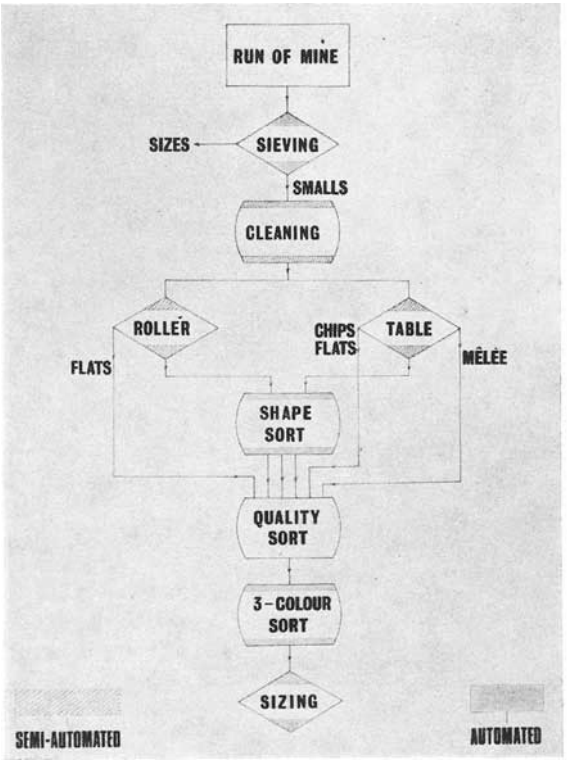

FIG. 1. Generalized flow chart showing a simplified sequence of operations for "Smalls" (diamonds less than 1·2 carats).

accurate weighing of the diamonds into precise weight categories finally takes place at the end of the various sorting operations. Hand sieving used to be one of the least attractive jobs for a sorter, and as the quantity of diamonds increased over the years it also became a very arduous task.

Some years ago, motorized cam-driven sieving machines were introduced which roughly copied the type of motion used when hand-sieving. More recently these have been replaced by the simpler and more robust version which is shown in Figure 2. The new machine is a good example of a commercial equipment which has been modified to make it more suitable for use with diamonds. It consists of a sieving frame to which can be clamped a range of sieves. The frame is mounted resiliently onto a baseplate by means

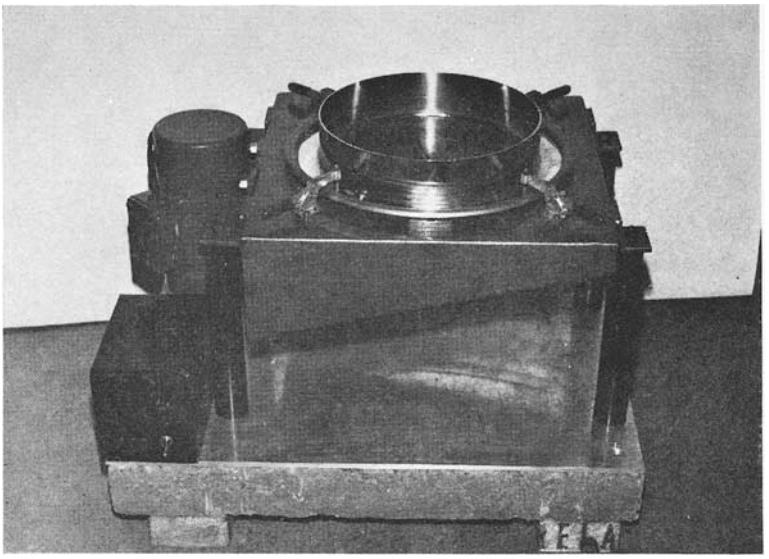

FIG. 2. Motorized sieving machine. Interchangeable ten-inch sieve plates are clamped under a hopper assembly.

of rubber blocks. Bolted to the sieving frame is an electric motor. On the top and bottom shafts of the motor are adjustable eccentric weights. When the motor is running, these weights cause the motor, and hence the sieving frame, to vibrate. Adjustment of the position of these weights allows the vibration to be set for correct sieving operation. In order to encourage a flow of diamonds across the sieve plate, the motor is switched off and on every ten seconds. This makes the motor speed pass through resonances in the frame assembly to give a stirring motion to the diamonds.

The sieving machine is basically a very simple design, and, as it has no complicated mechanical linkages between the source of the vibration and the sieve plate, it requires the minimum of maintenance. The sieve plates are our design. They are approximately ten inches in diameter, and are manufactured from stainless steel. The holes in the plate are punched out on a numerically controlled machine tool to very high dimensional tolerances. The holes are made two thousandths of an inch larger in diameter than required, and a final plating process reduces these holes to correct size and also puts a hard protective surface on the plate. The plating of the sieve plates is necessary not only to reduce wear on the plates, but

also to prevent the diamonds from becoming dirty during sieving. If it does become necessary to clean the diamonds between the various sorting operations, this is done by the use of ultrasonic baths and centrifuge driers.

In complete contrast to sieving, we have automatic shape sorting. This is a project still under development, but experimental results indicate that it is feasible to sort diamonds automatically into their basic shape categories of Stones, Shapes, Cleavages, and Flats. So far, the prototype shape sorter (Figure 3) consists of a modified commercial particle analyser, comprising a high-definition television camera with associated shape determining computers, and a D.T.C.-designed and built diamond feeder and sorter.

The diamonds to be sorted are contained in a hopper which is shaped like a hollow inverted pyramid. At the bottom of the hopper are four holes, and through these holes pass four pickup rods with small recessed cups on their ends. Both the cups and the rods are hollow and have vacuum applied to them. As the rods are driven up through the diamonds in the hopper, they pick up one diamond in each cup. A transfer plate above the hopper receives the four diamonds from the rods and holds them by vacuum. Vacuum is

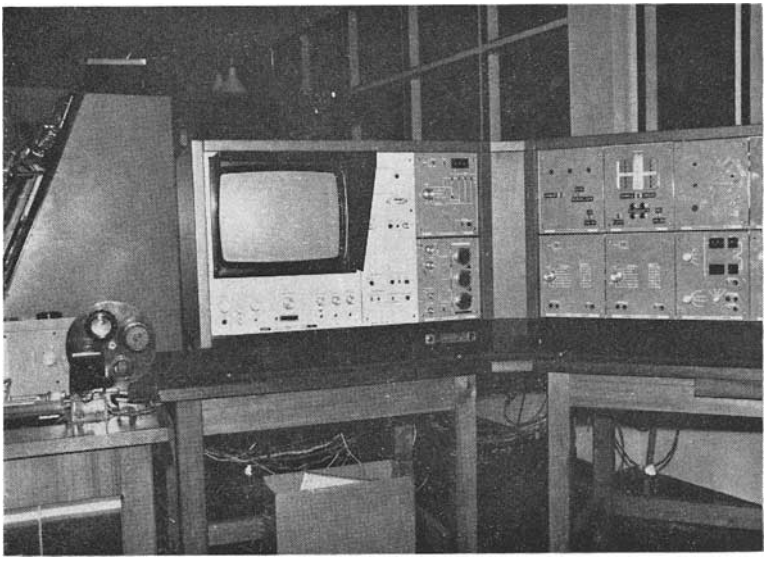

FIG. 3. Shape-sorting using an Imanco particle analyser to identify the basic shapes of diamonds which are fed automatically to a high-definition television camera (extreme left).

then switched off the rods and they are retracted into the hopper ready to pick up four more diamonds for the next feed cycle.

The vacuum transfer plate then moves horizontally to the television camera position, and deposits the four diamonds in a precise pattern on the flat surface formed by the two side-illuminated prisms. When the television camera has passed its video information on the diamonds to the shape determining computers and they have identified the shape of each of the four diamonds, the two prisms are pivoted to allow the diamonds to drop into four sorting channels, one for each diamond. In these channels are gates which are set by the computers to sort the diamonds by shape into the appropriate output boxes.

The mechanism of shape determination is as follows. The computers are fed with the video output of the television camera in digital form. From this they measure both the perimeter of each diamond image and its total area. They then divide the area by the perimeter squared (A/p^2) to produce a dimensionless shape factor (i.e. a factor which is independent of the size of the diamond). This shape factor can be, typically, 3×10^{-2} for a triangular shape, 7×10^{-2} for an octahedron, or 9×10^{-2} for a spheroid. By setting acceptance limits for the shape factor it is possible to make a simple sort between triangular flats and octahedra. By using more sophisticated shape factor formulae and greater computing power, it is hoped that the shape recognition capability of this machine can be extended to cover all shape categories.

While machines of the complexity of the television shape sorter are very exciting engineering concepts, there also exist much simpler machines which are capable of doing a limited degree of shape sorting. One of these, the roller sorter (Figure 4a), is very useful for extracting flats and maccles from a batch of mixed diamonds. It consists of two contra-rotating steel rolls, the gap between the rolls being adjusted so that it is small at one end and large at the other. The rolls are inclined so that the end with the wide gap is the lowest. Diamonds are fed, in single line, to the top end of the rolls, and as they pass down the rolls under gravity they fall through into containers at the point where their minimum dimension is just less than the gap between the rolls.

Another simple shape sorter is the vibratory table (Figure 4b). This can make a progressive sort between the rounder shapes and the flatter ones. The table works on the principle that those diam-

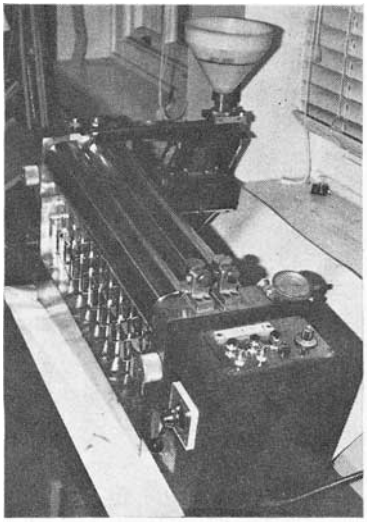

FIG. 4a. Roller Sorter separates flats from stones and shapes by sensing smallest dimension.

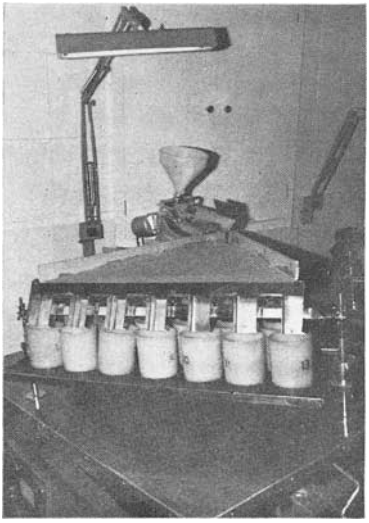

FIG. 4b. Vibratory table used for simple shape-sorting uses difference in surface contact.

onds having flatter surfaces, and therefore more contact area, will travel further across an inclined vibratory surface than diamonds with a more rounded shape, which will tend to roll off. The co-efficient of friction of the table surface is important, and various surfaces are used for specific sorting requirements.

Sorting diamonds for colour is one of the more exacting and interesting tasks, but even this can lose its attraction when it is necessary to sort tens of thousands of diamonds in sizes ranging from 1 ct down to twenty or forty to the carat. This is another area where automation is the only sensible way to sort enormous quantities of diamonds within the allocated time.

Some years ago, long before the Diamond Trading Company had a Research and Development department, a member of the staff saw a press release which described a colour sorter designed by Gunson's Sortex Ltd to separate discoloured peas from green ones. He contacted the Company and put our problem to them. The result was a machine which was able to sort diamonds into two broad colour categories. Although this still meant that for a three-colour smalls sort a considerable amount of hand sorting had to be done, the work load was considerably reduced.

The latest colour sorter (Figure 5) is the result of further liaison

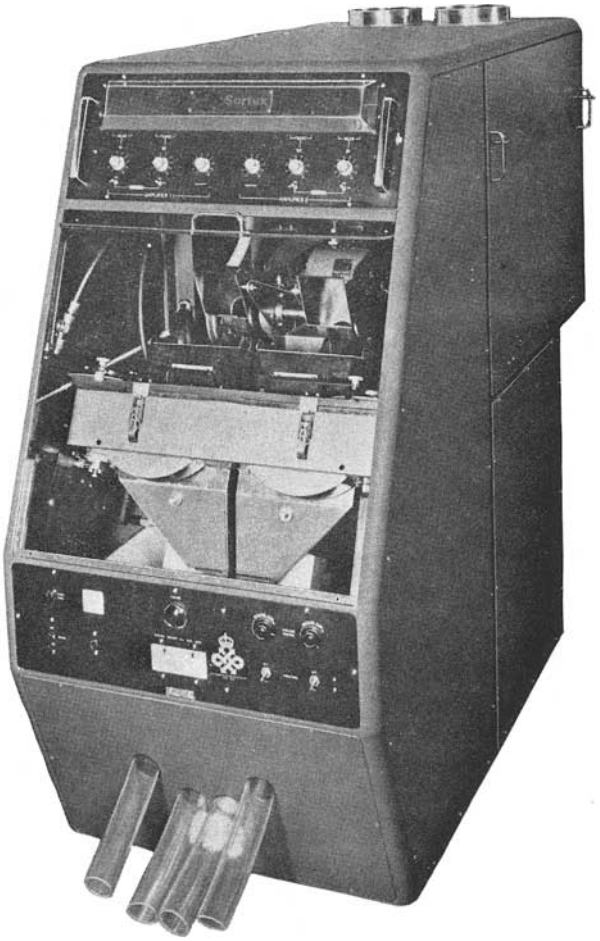

FIG. 5. Gunson's Sortex twin-channel colour-sorter for diamonds.

between my department and this Company, and represents a considerable advance on those first early machines. As with the majority of automatic sorters, the diamonds start off in a hopper, from which they are extracted by a linear vibratory feeder. The feeder drops the diamonds into a "V"-belt feeder which accelerates and separates them before allowing them to fall through an optical "box". This box contains quartz halogen lamps and photo-multipliers, which measure the degree of colour in the diamond. If the diamond's colour is above a certain pre-set limit a tiny jet of air is released to deflect the diamond into a separate sorting channel.

Before dealing with the fourth area of operation, that of sizing, I will describe a diamond counter which was designed in my department. Although in this instance there were commercial equipments available, none of these had a specification which met our needs. In particular, we required a very high accuracy of count, giving a maximum error of plus or minus one in 100,000 at a count rate of 600/minute. In addition we needed to be able to count diamonds over a large range of sizes, from 0·5 ct to 10 ct.

The counter (Figure 6) consists basically of a vibratory bowl feeder, and a detector. The bowl feeder acts as both a hopper and as

FIG. 6. Counter and batcher for rough diamonds uses a twin infrared light-curtain as detector.

a means of delivering the diamonds one at a time to the detector. The diamonds are constrained into a single line by the output chute of the bowl, and are velocity separated as they fall from the chute. To prevent overloading the output chute, a section of the final part of the feed track can be adjusted in width to pass only a single line of diamonds.

The detector consists of a light-curtain formed by "bouncing" an infrared beam between two parallel mirrors. The angle between the mirrors and the infrared source is adjusted to increase the number of reflections between the mirrors to a point where there is just enough infrared energy left in the final beam to be detected by a photocell. Two such curtains are placed one beneath the other in the detector. The first one is used to count the diamonds as they break the beam, and the other is used to check this count. This enables any malfunction in the feeding or in the photo-optics to be detected. Provision is also made for counting out pre-set numbers of diamonds by means of a batching switch.

Finally, we come to the need for weighing individual diamonds so that they can be accurately separated by weight. Rough gem diamonds are sized into a series of weight categories. From 1·81 carats upwards these categories span one carat intervals, that is 1·81 to 2·80, from 2·81 to 3·80 and so on. Below 1·81 carats, there are smaller subdivisions.

Outside the confines of each one carat weight category, the price of the diamonds is not linearly related to weight, but tends to follow a square law. For example, a two carat diamond is approximately four times the price of a one carat diamond of similar colour and quality. For this reason, each of the individual weight categories into which the diamonds are sorted has its own price per carat. As there may be large differences in the price per carat between adjacent weight categories, it is essential that each diamond is weighed accurately. This need for accuracy is not only a requirement for the individual weighings, but, as I will explain later, is also important when considering the cumulative error in totalling the individual weighings of a batch of several thousand diamonds.

D.T.C.'s experience of automatic weighing started eight years ago when we commissioned a system consisting of twenty balances and a D.E.C. PDP8I computer. The balances were designed to work either independently, when they used a built-in program, or

under the control of a computer, which collected the weighing data from each machine and directly controlled the sizing. The computer used the weighing data it collected to produce a print-out of the weighings for each machine. This print-out gave the number of stones, total weight and average weight for each weight category, and after they were checked by the operator, the data was stored on magnetic tape ready for further processing by the Company's main computer. As it was probably the first computer controlled weighing system of this complexity that had ever been built, we inevitably discovered many problems when it was put into operation. Over the following years we made a variety of modifications to both the balance and the computer program. Despite the difficulties in operating and maintaining this first system, it became an indispensable part of the Company's operation.

Finally, with over five years experience of operating an automatic weighing system behind us, we obtained authorization to start work on the design of our own automatic weigher, to act as a replacement for the original machines. The new design project was started two years ago and the resulting production machine can be seen in Figure 7a. The original operating specification was adhered to

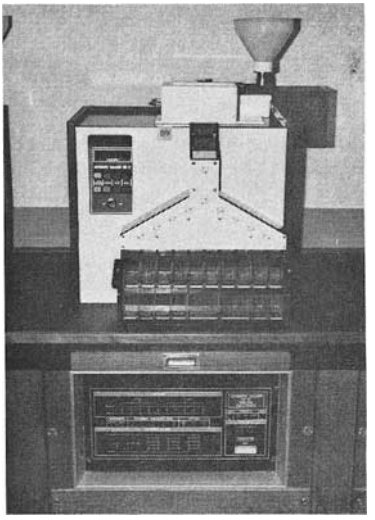

FIG. 7a. Automatic diamond weigher. The top unit contains the weigh head, feeder and sorting mechanisms. The bottom drawer unit contains the control electronics.

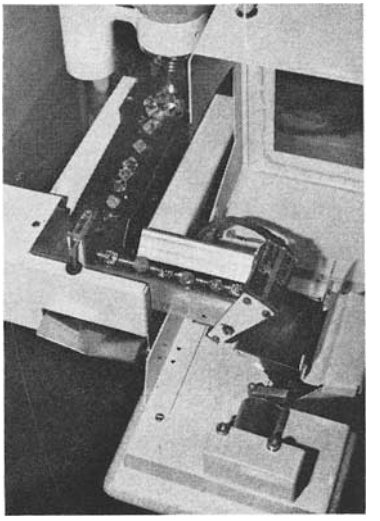

FIG. 7b. Two-stage feeder of auto-weigher. Diamonds are extracted from the conical hopper by the black vibratory track and fed to the screw feeder.

in that the new balance can weigh on-line, or off-line, to the computer, but we have uprated the specification with regard to accuracy and speed of operation, and have given priority to operating simplicity, reliability and ease of maintenance.

As with our television shape sorter, the mechanical handling part of the design was the most difficult. By mechanical handling, I mean the delivery of one diamond at a time from a bulk hopper to a weigh pan, followed by its placement in the appropriate sortbox. This problem is made more acute by the fact that a typical batch of diamonds may contain sizes ranging from one carat up to fifteen carats.

The central part of the problem, that of removing the diamond from the weigh pan, was solved by the decision to purchase a Mettler tablet balance to form the heart of our machine, as this balance has its own pan unload mechanism. The last part of the mechanical handling problem, that of placing the diamond, following its ejection from the weigh pan, into the correct sortbox was the simplest as this had already been done successfully in the previous design. We simply saved space by arranging our sortboxes in two stacked tiers.

The delivery of one diamond at a time from the hopper to the weigh pan was, as we knew from experience, to be the biggest problem. Our solution is part mechanical and part electronic. We use a hybrid two-stage feeder in conjunction with some sophisticated photo-electric logic circuitry (Figure. 7b).

The first stage of the feeder is a linear vibrator, which moves the diamonds out from the bottom of the hopper, and feeds them along a track which constrains them into a single line. The angles of the tracks are carefully chosen to achieve the desired single-line separation without jamming or flooding.

At the output end of the track, the diamonds are dropped one-at-a-time onto the start of a screw-feeder, which consists of a pair of contra-rotating rolls. These rolls have a screw-thread cut into them whose pitch has been carefully chosen to provide a means of both driving the diamonds forward and keeping them separated. A stepping motor is used to drive the screw-feeder rolls to ensure that they stop precisely, with the minimum of overrun, when controlled by the photo logic. Separation of the diamonds is achieved by means of two sets of photo-electric detectors, one at the start of the screw feeder and one at its end.

The operation of the Mettler pan eject mechanism is initiated by the weight signals from the weigh head. When no diamonds are fed to the weighpan, the eject mechanism does not operate. An electronic zero circuit is operated automatically by the machine once every fifteen weighings to take care of any drift in the balance zero, and to relieve the operator of this task. Error circuits are built in to give warning of the failure of the photo-electric circuits, or to warn if any of the lower sortboxes (which are not completely visible to the operator) become full.

When used on-line to the computer, the weight information is fed out by digitally coded electric signals to the computer. The information is processed by the computer, which then sends back digitally coded sortgate signals to operate the appropriate sortgate. Two PDP8E computers are used in the new installation to service thirty auto-weighers. When using the system on-line, the operator types in the information on the diamonds she is about to weigh together with the code number of the machine she is going to use. She then loads the diamonds into the hopper of that machine and presses the feeder start button. When all of the diamonds have been fed and weighed, the operator then returns to the teletype and requests from the computer a tabulated print-out of the weighings. The known total weight of the batch of diamonds is fed to the computer before weighing commences; the difference between this and the sum of individual weighings represents the cumulative error. In a batch of 1,000 diamonds, the maximum permitted error would be ± 1 carat, representing a worst case of 1,000 weighings multiplied by $\pm 0{\cdot}001$ carat. Normally, however, this error would not exceed 0·2 carat.

The front panel of the electronics drawer unit (Figure 7a) carries 51 engineering lamps, which enable the correct functioning of the machine to be checked and act as an aid to fault diagnosis. Also contained on the panel are the photo-electric pre-sets, and a switch which enables weighings to be simulated so that the sortgate functions and limits can be checked.

Like all completed systems, the equipments I have desscribed in this article are already technically dated. The scope of what can be achieved is constantly being enlarged by new techniques and components, a recent example being the solid state microprocessor. This device, which packs the heart of a computer into a single integrated circuit, now makes it possible to build power-

ful computing capabilities directly into an equipment, this bringing the era of the intelligent machine one step closer.

Like the American space program, it would seem that almost any technical feat can be accomplished, given sufficient funds. In the commercial world however, the cost of automating a process must be balanced against the expected advantages. Using this criterion, the automation of diamond shape sorting and sizing, as described in this article, can be justified. However, the cost of automating an operation such as the sorting of rough diamonds for quality would be prohibitive and could not be justified. This is because of the number of variables involved (i.e. size and position of inclusions, naats, internal and external fissures, etc.), and also the need for assessing the optimum yield from a diamond. The solution here would probably be to develop improved handling and inspection aids. These could take the form of automatic feeding of diamonds to an inspection position, provision for holding and turning the diamond for all-round viewing, and a means of placing the diamond after assessment into the appropriate sortbox. Such an approach would use to full advantage that most versatile and adaptive of all information processors, the skilled diamond sorter.

OBSERVATIONS ON SOME RHODESIAN EMERALD OCCURRENCES

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DURING the summer of 1974 one of the authors (A.M.T.) was fortunate to inspect the emerald occurrences near Fort Victoria, Rhodesia. This was made possible through the assistance of Dr J. W. Wiles, the Director of the Geological Survey, Salisbury. Dr Wiles and Mrs S. Anderson, of the Geological Survey, kindly reviewed this article. Considerable thanks are due to Mr Cyril Gurr of the Mines Department, Fort Victoria, for his valuable assistance as guide to the area and for providing additional emerald samples for analysis.

The object of the investigation was to try and further our understanding of emerald formation in Nature by studying in particular the trace element geochemistry of emerald and associated country-rock. A summary of certain aspects of this investigation that may be of gemmological interest are given, and other data or details may be referred to in the report by Metson (1975). An account of the visit to the area is related in the U.S. *Lapidary Journal* (Taylor, 1976).

The emerald occurrences visited were the Novello Prospect and the abandoned Twin Star Mine, both of which are located about 17 km NW. of Fort Victoria. Some samples of Chikwanda emerald were kindly provided by Mr Cyril Gurr. This claim was not visited, but is located some 6 km north of the famous Bikita lithium mine about 80 km east of Fort Victoria. Details of the local geology, together with spectrographic analyses of the emeralds and enclosing country rock, are admirably recorded by Martin (1962). The trace element geochemistry that particularly interested us was the following:

(1) What elements are responsible for the colour of emerald? Besides Cr and Fe, very few emerald analyses report whether or not other transition metals were analysed for, in particular, V, Ni, Mn, all of which can give various green shades to synthetic beryls when grown by the hydrothermal method (Emel'yanova *et al.*, 1965).

(2) Similarly, one needs to know whether these potential colouring elements are present in the host rock.

(3) The alkali content of the emeralds is of interest for two important reasons. Because of their comparatively large size (Li excepted) they locate themselves within the channel sites of the emerald structure, together with varying amounts of water molecules, and so directly increase the density of the crystal as the unit cell size is not significantly increased by these substitutions; also increase in density goes hand in hand with increase in refractive index. The R.I. and S.G. of gem quality emeralds have long been used as a pointer to their place of origin and, combined with information on the nature of the inclusions present, it is very often that one can make such a pronouncement with a degree of certainty. Thus it would be reasonable to conclude that all gem-quality emeralds from a particular deposit would have closely similar amounts of

alkali and water substitution.

Secondly, the type of alkali present in emerald may be an indication of the chemical nature of the hydrothermal fluid responsible for the crystallization. This is particularly the case if the alkali concentration in the emerald represents an increase over what is present in the host rock. Ideally, to obtain this information one should analyse the fluid inclusions present in emerald, but this is a rather difficult task to perform satisfactorily even with present-day technology.

(4) The relationship and/or distinction between beryl-producing pegmatites and emerald-producing pegmatites is of special interest and will be speculated upon later.

Geological Setting

According to Martin (1962) the geological setting of the three emerald occurrences (viz. Novello, Twin Star, Chikwanda) is very similar. There is an older basement complex consisting of greenstones, banded ironstones and ultramafics which has been intruded by granite or granodiorite. At the Novello and Chikwanda areas the serpentine is thought to be of Shamvaian age (2,650 m. years). The Twin Star mine is only 6 or 7 km distant from the Novello Prospect and within the same serpentine belt. The Chikwanda claims, however, are located about 90 km eastward, near the Bikita pegmatite mine.

Novello Prospect: The discovery of emerald and alexandrite in this area was made by Mrs C. Girdlestone in 1960. The occurrences lie in a narrow belt of serpentine that traverses the Girdlestone ranch. Considerable lateral shearing has taken place and some transverse faulting. Large lens-shaped bodies of quartz and pegmatite extend along the shear zones over a distance of about 5 km through the pegged area. The pegmatites contain spasmodic minor amounts of beryl and the lithium minerals, petalite and lepidolite. There are two emerald occurrences, both associated with pegmatites, which are located close to either side of the Chipopoteke River, the course of which follows a transverse fault across the serpentine belt. The abandoned workings consist of a number of prospect pits, some 2 to 4 metres deep and 4 to 10 metres across (Figure 1b). The workings are in an area of mica-rock intruded by numerous pegmatite stringers. Useful samples for study were recovered from the dumps. Thin sections of the country-rock showed it to consist essentially of

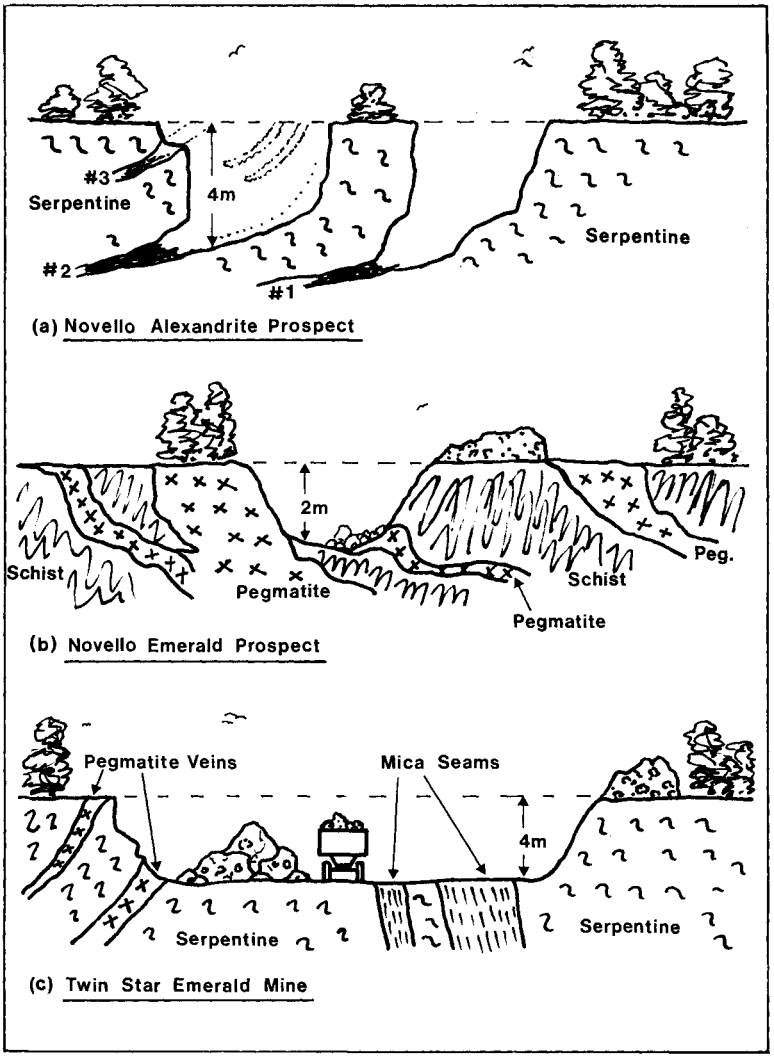

FIG. 1. Idealized cross-sections of the mine-workings investigated.

phlogopite mica, but graduations exist from phlogopite to chloritized phlogopite to chlorite rock. The groundmass consisted of minor sericitized plagioclase feldspar, muscovite, quartz and opaque minerals. Samples of mica-rock were found containing pegmatite stringers 2 to 3 cm wide carrying quartz, mica and euhedral beryl

as grey-coloured hexagonal prisms of 1 to 5 mm diameter. Opaque and fractured emerald crystals of similar size were found in the mica-rock, but confined to within 20 cm of a beryl-containing pegmatite stringer. They were especially abundant in very contorted mica-rock and tended to concentrate along minor fold axes. The non-contorted mica-rock appeared barren of emeralds. Emerald crystals were recovered only from material found on the dumps, hence their true distribution would be best evaluated by the original prospectors.

The Novello alexandrite-chrysoberyl prospect is located a little over 1 km distant NE., but still within the same serpentine belt. No pegmatites are apparent in the immediate vicinity. Two pits about 4 m deep had been excavated in the serpentine in order to follow three gently dipping phlogopite mica seams of 10 to 100 cm thickness. The prospecting operation was being conducted by four African workmen and the mine manager. Two smaller mica seams that did not extend to any depth had already been worked out, but excavation was continuing on three well-defined seams (Figure 1a).

Twin Star Mine: The excavations here are considerably more extensive than what had been done at Novello. A derelict treatment-plant stands nearly surrounded by huge piles of tailings. The main workings are developed in serpentine and consist of a shallow elongated pit, some 4 to 5 m deep and extending approximately 200 m long and up to 50 m wide, with various offshoots. Several steeply dipping quartz-pegmatite veins 10 to 30 cm wide are exposed in the walls of the excavation (Figure 1c). The mine was operational over the period 1965-69 when it was recorded that rough and cut stones to the value of £2650 were produced.

Active mining of emeralds had been undertaken from seams of mica rock enclosed in the serpentine. A few samples taken from the stock piles at the old treatment-plant showed glassy quartz studded with radiating clusters of slender beryls and pale emerald prisms, 1 to 2 mm diameter and 1 to 2 cm long. Clusters of darker, extensively flawed emerald prisms, 1 to 2 cm size, in parallel growth, partially coated with mica, were obtained for chemical analysis. At the time of the visit (1974) a new lease had been taken out over the property by a Salisbury-based gem dealer and some prospecting work was being done on a mica seam at the far end of the old open-cut.

Physical Properties of the Emeralds

Samples of emerald crystal were selected from each locality (viz., Novello, Twin Star, Chikwanda) and cleared of any adhering mica. The specific gravity range for samples from each locality was determined by a heavy-liquid dilution method. The refractive indices were determined by using a Rayner spinel-type refractometer after a flat surface was ground and polished on each crystal. The data obtained are presented in Table 1.

TABLE 1

PHYSICAL PROPERTIES OF EMERALDS AND BERYL

Type	*Specific Gravity Range*	*Refractive Index*		*Double Refraction*
		ω	ε	ω-ε
Novello beryl*	2·66-2·67	1·576	1·570	0·006
Novello emerald	2·68-2·74	1·581	1·576	0·005
Twin Star emerald	2·67-2·71	1·586	1·580	0·006
Chikwanda emerald	2·72-2·74	1·590	1·583	0·007
Chatham, synthetic	2·65	1·563	1·560	0·003
Chivor, Columbia	2·68-2·69	1·577	1·572	0·005
Sandawana	2·74-2·76	1·593	1·586	0·007

*An off-white beryl taken from an adjacent pegmatite vein.

The somewhat higher and variable values of S.G. and R.I. of natural emeralds compared to those recorded for Chatham synthetic emeralds are due to more extensive ionic and molecular substitutions existing in the former. Chatham synthetic emerald can be taken as a convenient standard "pure emerald", essentially lacking in iron, alkali and water substitution. Thus the higher the S.G. or R.I. found for emerald, the more of these substitutions can be expected, particularly of the larger alkali ions and of water molecules, both of which go to take up channel lattice sites in the structure. For example, the Miku emerald reported by Hickman (1972) has an S.G. of ~ 2·75 and is analysed as having 5·8 wt % potential channel ion components (viz. Na_2O+K_2O+CaO, which includes cations of ~ 1Å radius or greater) and a high water content of 2·6%. Of the Rhodesian emerald samples examined, that from Chikwanda had the highest S.G., averaging 2·73, and the alkalis (Na_2O+K_2O) totalled 4·7 wt %; water was present but the amount not determined. The physical properties obtained for the Chikwanda emerald agree closely with those determined by Martin

(1962), but somewhat higher values, compared to Martin's, were found for the refractive indices of the Novello emerald.

Chemical Composition

Host rock and representative emerald samples were analysed by atomic absorption for the following elements: Na, K, Mg, Ca, Fe, Mn, Li, Ni, Cr and V. The glass fusion technique was used to get the samples into solution, except for Li (as the fusion mixture consisted of lithium tetraborate 60 parts, lithium carbonate 10 parts, rubidium iodide 1 part). Samples for Li analysis were prepared by the $HF/HNO_3/H_3BO_3$ method. Analyses for the host rocks at Novello and Twin Star are shown in Table 2, which includes, for comparative purposes, two analyses by Martin (1962). The emerald analyses are shown in Table 3, as weight % oxides and as atom weight %.

TABLE 2

EMERALD HOST-ROCK ANALYSES

wt%		1		2		3	4
Cr_2O_3	(Cr)	0·39	(0·27)	0·13	(0·09)	(0·2)	(0·1)
FeO	(Fe)	9·97	(7·8)	5·96	(4·6)	M	M
NiO	(Ni)	0·10	(0·08)	0·12	(0·09)	(0·1)	(tr)
MnO	(Mn)	0·08	(0·06)	0·04	(0·03)	(0·1)	(0·1)
MgO	(Mg)	M	(M)	M	(M)	(M)	(M)
CaO	(Ca)	tr	(tr)	vst	(vst)	(0·5)	(–)
Li_2O	(Li)	0·5	(0·2)	0·31	(0·15)	(–)	(0·5)
Na_2O	(Na)	0·16	(0·1)	0·87	(0·6)	(–)	(0·5)
K_2O	(K)	8·98	(7·4)	7·88	(6·5)	(–)	(–)

M = Major; tr = trace, < 0·03%; vst = very slight trace, < 0·001%

(1) Phlogopite rock, Novello
(2) Phlogopite rock, Twin Star
(3) Serpentine, Novello (Martin, 1962)
(4) Biotite rock, Chikwanda (Martin, 1962)

Spectroscopic Analysis

Thin polished plates of emerald were examined with a recording-type spectrophotometer over the wavelength range 300-700 nm. All the emeralds gave the characteristic chromium spectrum having two broad bands centred near 430 and 600 nm and sharp (but weak

TABLE 3

EMERALD ANALYSES

wt%	1		2		3		4		5	
Cr_2O_3 (Cr)	0·59	(0·41)	0·08	(0·05)	0·28	(0·19)	0·05	(0·04)	0·55	(0·38)
FeO (Fe)	0·79	(0·61)	0·39	(0·30)	0·33	(0·25)	0·15	(0·12)	0·51	(0·40)
NiO (Ni)	0·02	(tr)	tr	(tr)	tr	(tr)	tr	(tr)	0·01	(tr)
MnO (Mn)	tr	(tr)	tr	(vst)	tr	(vst)	tr	(vst)	tr	(tr)
MgO (Mg)	0·80	(0·48)	0·17	(0·10)	0·25	(0·15)	0·05	(0·03)	0·28	(0·17)
CaO (Ca)	vst	(–)	–	(–)	–	(–)	vst	(–)	–	(–)
Li_2O (Li)	tr	(tr)	0·01	(vst)	0·01	(vst)	tr	(tr)	0·02	(tr)
Na_2O (Na)	4·04	(3·0)	1·45	(1·08)	1·97	(1·46)	1·14	(0·84)	2·24	(1·66)
K_2O (K)	0·65	(0·54)	0·01	(tr)	0·06	(0·05)	0·19	(0·16)	0·28	(0·24)

tr = trace, $< 0·03\%$; vst = very small trace, $< 0·001\%$

1. Dark green emerald, Chikwanda
2. Pale green emerald, Twin Star
3. Dark green emerald, Twin Star
4. Pale green emerald, Novello
5. Dark green emerald, Novello.

intensity) peaks at 470 nm in the blue and at 680 and 683 nm in the red. There was no evidence of any absorption that could be attributed to vanadium and subsequent chemical analysis did not reveal the presence of this element.

Infrared spectra obtained on powder samples showed that water molecules were present in the emeralds from the three localities. Analysis of the data indicated that they were of the type II variety described by Wood and Nassau (1968); that is, the water molecules are located in channel sites adjacent to an alkali ion which influences their orientation.

Inclusions

The inclusions present in a crystal may provide some information as to the environment in which it grew. Emeralds are of particular interest in this respect, as both natural and man-made stones always contain inclusions which are often definitive of their origin—whether that be due to perhaps a contact metasomatic event or a carefully attended growth in a crucible.

Examination of the emerald samples available did not reveal anything in the way of inclusions that was unexpected. The most abundant inclusions present in samples from all three localities were flakes of the host-rock material, i.e. brown phlogopite-biotite mica. The flakes averaged in size about 0·2 mm across and showed some tendency to be orientated more or less parallel to the prism faces. In some cases the mica flakes followed fracture lines and often they were broken or resorbed. Martin (1962) noted the presence of considerable muscovite "veining" and fine muscovite aggregates in Chikwanda emerald. In the present study, fine mica aggregates were also observed, but the type of mica could not be identified with certainty. Some of the coarser mica flakes showed occasional pleochroic haloes.

Next in abundance to the mica inclusions, but seen only in the Twin Star and Chikwanda emeralds, were "negative crystal" inclusions. These appeared to consist of both liquid only and liquid-vapour (two phase) inclusions. Such inclusions have been reported in emeralds from other world localities, such as India (Anderson, 1971) and Tanzania (Thurm, 1972). The "negative crystals" generally occurred in clusters and were always orientated parallel to the c-axis of the crystal. They were often very elongate or tubular and divided into sections.

Black opaque material, possibly chromite, was observed in several of the Novello samples. An attempt to isolate this material by magnetic methods proved unsuccessful. Fissuring occurred in all samples, it being more prevalent in the Novello emeralds and least so in the Chikwanda stones. Feathers were uncommon.

In summary, the major inclusions in the Novello, Twin Star and Chikwanda emeralds clearly reflect the nature of the host-rock material. The absence of any noticeable liquid or liquid-vapour inclusions in the Novello samples make them somewhat distinctive from those of Chikwanda and Twin Star.* The presence of fine mica aggregate in the Chikwanda stones allows them to be distinguished from those of Twin Star. The Chikwanda and Twin Star emeralds, with their abundance of mica and "negative crystal" inclusions are reasonably distinctive on the world scene.

Discussion

The rather intriguing geochemical coincidences associated with the formation of emeralds in Nature were first revealed by the famous Norwegian geochemist V. M. Goldschmidt, around about the year 1920. A readily available summary of this work can be consulted in his textbook entitled "Geochemistry" (Clarendon Press, 1954). The formation of these Rhodesian emerald deposits conforms with the predicted state of affairs. The associated pegmatites carry a little beryl and the host rocks consist of chrome-bearing mica-rock or "schist", if this term may be used without necessarily implying a sedimentary origin.

In Table 3 it can be seen that the chrome content of the emerald samples ranges from 0·04% (pale-green) up to 0·59% (dark-green), and in all but one of the five analyses the iron content is slightly greater (i.e. FeO range 0·15 to 0·79 wt%). The pale emeralds having low chrome also tend to have low iron values. Of other possible chromophores, we see that both nickel and manganese were detectable, but in trace amounts (i.e. NiO 0·00X to 0·02%; MnO 0·00X%); however at this concentration level they would have no effect on the overall colour of the stone. Vanadium was analysed for but not detected.

Turning attention now to the host-rock analyses, we see that the phlogopite rock at Twin Star contained 0·39 wt% Cr_2O_3, and at

*A recent communication from Mrs S. Anderson, Geological Survey Department, Salisbury, states that certain samples of emerald-beryl from Novello do possess prominent negative crystals and two-phase inclusions.

Novello 0·13%, which are chrome values of similar magnitude as for the emeralds found in them. Thus no appreciable concentration of chromium would be required locally for emeralds to form, assuming ideally, that what chromium is present is readily available for the growing beryl crystal; that is, it can all be at least temporarily mobilized from its initial state and transferred to its final state in the emerald. Unfortunately we were not able to produce any concrete evidence as to the initial state of the chromium. Perhaps the two most likely possibilities are:

(*a*) finely disseminated chromite and

(*b*) ionic substitution within the phlogopite mica.

Whether or not any appreciable ionic substitution actually occurs while a natural emerald crystal is growing depends on the local availability of the element in question, as well as whether it can be mobilized, at least temporarily, while emerald growth is under way. Another factor of importance is the acceptability to the beryl crystal lattice of the ion (or combination of ions) on crystal chemical grounds. Some insight into the latter problem may be had by examining the data gathered by Feklichev (1963) who lists the maximum concentrations reported for various elements in beryl analyses. (See Table 4.).

TABLE 4

SELECTED MAXIMUM OXIDE CONCENTRATIONS REPORTED IN BERYL ANALYSES (Feklichev 1963)

Cr_2O_3	2·00 wt%	MgO	3·37 wt%
V_2O_3	0·90	CaO	3·98
Fe_2O_3	2·83	Li_2O	1·39
FeO	1·2	Na_2O	4·22
NiO	0·10	K_2O	2·25
MnO	0·74	H_2O+	3·00

If one uses the data simply as a guide to the acceptability of chromophoric ions by the beryl lattice, then it would seem that chromium and iron are almost equally acceptable and nickel the least so. Of the four chromophoric elements detected in the Rhodesian emeralds (viz. Cr, Fe, Ni, Mn) it likewise seems that chromium is the one most readily accepted. It was a little disappointing that no data on vanadium was forthcoming from this investigation. Campbell (1975) has reported emeralds or pale-green beryl of

ambiguous colour from the Filabusi area, Rhodesia, but we have not examined any samples.

The alkali substitution in these emeralds is of interest. In all cases the order of abundance is Na > K > Li, whereas for the host rock, it is K ≫ Li ≃ Na. The Na_2O levels for the emeralds are quite high, ranging from 1·14 to 4·04 wt%, the latter value being for a Chikwanda stone and close to the maximum value reported for any beryl (see Table 4). Alkali substitutions in beryl are necessarily coupled substitutions involving other ions in order to maintain charge balance. This is most likely achieved by concurrent substitution of a divalent ion for Al^{3+}, or by the leaving out of an occasional beryllium ion to form a vacant lattice site, e.g.,

(*a*) $Be_3.Al_{2-x}(MgFe^{2+})_x.Si_6O_{18}.(Na_x,nH_2O)$

or (*b*) $Be_{3-\frac{x}{2}}.Al_2.Si_6O_{18}(Na_x,nH_2O)$

Since the emerald analyses given are only partial analyses, with no data on beryllium content or iron valence, it would be hazardous to suggest which type of substitution might be predominant. Both would cause an increase in specific gravity compared to ideal emerald, with the former type more so.

The origin of emerald and the differences from that of beryl have been discussed by Martin (1962), from observations made on the same Rhodesian occurrences. Of particular importance is the small size and irregular nature of the pegmatites and the ability of the beryllium to diffuse out into the country rock. In the case of the Twin Star emerald locality and the Novello alexandrite occurrence, this migration of beryllium-containing fluid has been over considerable distances and has resulted in crystallization of beryllium minerals within seams of phlogopite rock, enclosed within the serpentine. Martin has suggested that the ultramafic host-rock (i.e. serpentine or dunite) has a natural "tightness" and plasticity which results in intrusion of only small and irregular-shaped pegmatitic bodies, which are in contrast to the large, linear pegmatites found in the more fractured rocks, such as greenstone and granite, from which the bulk of industrial beryl is mined. Certainly the smaller or thinner the pegmatitic vein, the more chance there might have been for beryllium to diffuse into the country-rock. However, there are in other parts of the world instances of narrow pegmatite veins carrying beryl, which show no evidence of adjacent emerald or beryl crystallization in the country rock. A suitable

example would be the Mica Creek Pegmatite near Mt Isa, Australia. Here, a near-vertical pegmatite outcrops in schistose rocks over several hundred metres and ranges from 0·5 to 3 metres wide and in places contains beryl crystals up to 20 cm in size together with quartz, feldspar and muscovite. In order to try and explain these field observations perhaps a little speculation may be permissible.

During the pegmatitic stage of crystallization, which is defined as when crystals coexist with a silicate magma and an aqueous-rich fluid, any beryllium present may itself be immobile and confined to the pegmatite vein, i.e. beryl crystallizes within the pegmatite. On the other hand, in the hydrothermal stage of crystallization, which is defined as when crystals coexist only with an aqueous fluid (or aqueous liquid and vapour), i.e the silicate magma has been exhausted or crystallized, any beryllium remaining is now much more mobile and may be transported via a hydrothermal fluid along shear zones in the country-rock. It is suggested that emerald crystallization tends to be associated with that very hazy "in between" period of mineralization whereby pegmatites grade in hydrothermal veins. This may explain why the Rhodesian emeralds are associated with very small pegmatites and quartz veins.

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EPIPHANIUS ON GEMSTONES

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EPIPHANIUS, Bishop of Salamis in Cyprus, was born in Palestine at the beginning of the 4th century A.D. His reputation for both erudition and piety grew and impressed deeply all who knew him, including Jerome who called him "five-tongued" in allusion to his command of Greek, Syriac, Hebrew, Coptic, and Latin. But although his learning and reputation for honesty protected him to some extent from persecution by the Arian Emperor Valens, they were not sufficient to prevent his becoming embroiled in a quarrel over Origen's orthodoxy, which involved not only himself but also Theophilus of Alexandria and John Chrysostom. In fact, a strain of naïveté runs through his work. A myriad facts and ficta have been acquired but not assimilated, and Photius had no hesitation in criticizing his style as "low and careless".

The pamphlet on the twelve stones of Aaron's breastplate has come down to us in different versions, the Greek *Peri Lithōn* (ΠΕΡΙ ΛΙΘΩΝ) being an abbreviation of a much longer work. It is a description of and commentary on the Septuagint version of *Exodus* 28.17-20, (3rd century B.C.). We have Jerome's assurance that Epiphanius himself had given him a copy of the work and indeed he quotes from it in his commentary on Isaiah.[1] This original version, however, has been lost, and what we have are two parallel epitomes of the section which described the stones. There are also versions in Latin, Georgian, Syriac, Coptic and Armenian.[2] The Greek text is to be found in Migne: P.G. 43.294-302, and what follows is a translation (printed in italic) of and brief commentary (printed in roman) on the Greek epitomes.

De Gemmis[3]

1. The first stone is called a Babylonian sard. It is flame coloured and blood red, like a pickled sardion fish which derives its name from the colour. It is translucent and doctors use its therapeutic power to heal swellings and wounds inflicted with iron. There is another stone called sardonyx, also

[1] *In Isaiam* 15.54— Migne: P.L.24.525.

[2] For a full account see H. de Vis: *Epiphanius de Gemmis*, (London, 1934).

[3] Written just before 394 A.D.

known as molochite, which can soften sebaceous tumours. Both these stones are greenish. The sard is very influential, especially during the first days of Spring when these illnesses begin.

Sard is a brownish form of chalcedony, but Epiphanius's stone sounds more like cornelian. Theophrastus (*De Lapidibus* 30) says that the translucent, redder kind of sard was the "female" of the species. Both it and the darker "male" variety were extensively used for seals, especially in the Aegean area, as Pliny tells us [*Historia Naturalis* 37.31 (106)]. Exactly what was the sardion fish I do not know. Sarda became a very general name not only for pickled Tunny and Pelamyd but for a great variety of other potted fish, as D'Arcy Thompson says.[4] Molochite simply means "fibrous" and probably refers to the laminate structure of sardonyx. "Greenish" is a puzzle, unless Epiphanius is referring to another type of chalcedony which is grey or greyish-blue, fibrous to crypto-crystalline, found in fissures and cavities in basaltic rocks.[5]

2. *The topaz is bright red, even more than an* anthrax. *It is found in Topaz, a city of India. Some masons once were quarrying stones there when it appeared in the middle of another stone they were cutting. They saw how brilliant it was, told certain [Theban] buyers it was alabaster,*[6] *and sold it to them for a small sum of money. The Thebans then approached the Queen who was ruling [Egypt] at that time. She took the stone and placed it in her crown, right in the middle of her forehead. The gem has the following property when tested. When it is rubbed on a doctor's whetstone the liquid it exudes is not bright red like itself but milky, and fills as many drinking bowls as the grinder wishes. Moreover, it remains the same weight as when he started. The juice from it is used to anoint diseased eyes, and drinking it is good against dropsy and for those dying from [eating] "sea-grape".*[7]

The topaz described by Pliny was green, almost certainly the modern peridot, though in medieval authors the word is used for a yellow stone. It is true that nowadays a red topaz is known, but this is because the name topaz has been restricted to aluminium fluosilicate. Natural red stones from Brazil have been found occasionally and it is possible to produce a rose-pink shade in some of the brownish-yellow Brazilian stones by the application of heat. But it

4 *A Glossary of Greek Fishes*, (London, 1947), 229.

5 Pliny, however, describes molochite (malachite?) as a green stone, [37.36 (114)], as does Isidore: *Etymologiarum Libri* 16.7.11.

6 The Greek here is corrupt. Presumably "Thebes" refers to the city in Egypt.

7 Probably a kind of fish. See Pliny: 32.49 (138).

seems fairly clear that Epiphanius's topaz is not the same as our stone. Perhaps his reference to the *anthrax* is not fortuitous and indicates that his topaz is actually a kind of almandine. The name almandine is a corruption of albandine from Alabanda in Asia Minor—hence the curious reference to alabaster, which otherwise does not make sense. Almandine is very brittle and therefore would grind easily to a powder.[8] Epiphanius's account, however, may be a remarkably garbled version of a passage from Juba [apud Pliny: 37.32 (108)] which recounts a tale about the peridot (topaz). "Juba states that Topazos is the name of an island situated in the Red Sea . . . Juba records that the stone was first brought from here as a gift for Queen Berenice, the mother of Ptolemy II . . . The stone is found also near Alabastrum, a town in the Thebaid". Here we have "Topazum" and "in rubro mari" close together, as well as references to an Egyptian Queen, and Alabastrum, a Thebaid city. Confused tradition may well have turned the topaz into a piece of red alabaster sold in Egypt by Thebans—hence Epiphanius's version.

3. The smaragdus, *also called* prasinus [*leek-green*].[9] *It also*[10] *is green and there are various kinds. Some are called Neronian or Domitian. The Neronian is sharp in colour,*[11] *very green, transparent and brilliant. They say it is called a Neronian (or Domitian) for the following reason. Nero (or Domitian) poured oil into the appropriate vessels and after a while the oil turned green on account of the verdigris. A rock which was liberally soaked with this oil turned yellowish-brown. Some people say that Nero discovered an ancient worker in mother-of-pearl, or a gem-cutter, or the most effective way to deal with* smaragdus, *and therefore it was called Neronian. Others [prefer to use the term] Domitian. But there are other types of* smaragdus. *One, which is found in Judaea, is very like the Neronian. Another is found in Aethiopia by the River Phison.*[12] *The Greeks call this river the Indus; the natives call it the Ganges. The* anthrax *can also be found in the*

8 The *New English Bible* translates topazion as chrysolite, but it is obviously not Epiphanius's stone. It is unfortunate that the NEB translators have chosen "chrysolite" because the name has been used at different times for different stones, and should really be used these days only to refer to olivine. Besides, both the Septuagint and the Vulgate, as well as Epiphanius, have chrysolite as a tenth stone, so it is unnecessarily confusing to use it as a name for the second.

9 Cf. Theophrastus: *De Lapidibus* 37. Pliny: 37.34 (113).

10 The Greek implies that the preceding item was green too, as the topaz of Pliny almost certainly was.

11 I.e. an acid green. The text, however, is doubtful. Another reading could be "small in size."

12 Aethiopia often referred vaguely either to North Africa or to India. Phison is referred to in *Genesis* 2.11.

same river. "There are found the anthrax *and* prasinus".[13] *They say that this gem [obviously the* smaragdus*] has the ability to reflect one's face as in a mirror. Novelists maintain it gives one power to foretell the future.*

Smaragdus is a word which covers various types of beryl, including aquamarine and emerald. *Prasinus* refers to prase, a dark leek-green chalcedony or, possibly, to quartz coloured by actinolite fibres inside it. The name Neronian almost certainly arises from Pliny's story that Nero looked at a green stone to relieve his eyes from the glare of the arena.[14] Pliny also says (*ibid.*) that certain *smaragdi* have the power to reflect objects just as mirrors do. "Aethiopian" *smaragdi*, according to Juba, were bright green but usually had flaws and were not uniformly tinted.[15] These stones actually came from Egypt. Theophrastus (23) says that the *smaragdus* turns water green and he may be right, since if the stone is placed in an opaque white vessel and illuminated obliquely from above the water may well take on a greenish cast.

4. The anthrax *is a bright, sharp red and is found in Libyan Carthage in Africa. Some people, however, say that the gem is to be found like this. It cannot be seen during the day, but at night it shines from afar like a lamp or sparking ember and so gives light from a great distance. Those who look for the stone know this and so it is easily discovered. Anyone who wishes to steal it cannot walk off with it unnoticed, because if he conceals it inside his clothes, the glow shines out through the folds. This is why it is called a carbuncle. For a while the heliotrope, which is called "wine-faced", was supposed to be similar. There is a chalcedony quite like it which is found in the same place.*

Epiphanius's evidence is contradictory here. If the stone is bright red it cannot be like a darker, more violet-coloured stone (the heliotrope). The word *anthrax*, however, was used to cover a

13 *Genesis* 2.12. Epiphanius gives the Septuagint version. The Hebrew refers to bdellium and onyx (*bedholah* and *shoham*), a version followed by Jerome (*bdellium et lapis onychius*), as well as later translators. The discrepancy simply means that there were different Greek versions available in ancient times and that Epiphanius used one rather than another. Even the Hebrew can vary. See F. Wurthwein's comments on Jeremiah in *The Text of the Old Testament*, trans. P. R. Ackroyd, (Oxford, 1957), 37.

14 37.16 (64). He did *not* use the stone as an eye-glass. This suggestion was made by C. W. King in *The Natural History . . . of Precious Stones*, etc., (London, 1865), 322-3, based upon an inferior MS. reading. In his Loeb edition of Pliny's *Historia Naturalis* (1962), D. E. Eichholz suggests that Nero looked at the stone to relieve his eyes from the glare of the arena. Cf. Pliny: 37.16 (62-3). J. W. Meadows noted that "the green mineral found in copper deposits [is] good for the eyes," and ground malachite was certainly used as a cosmetic. "Thus the beneficial properties of malachite would be attributed to all the stones that were called by the same name," and so *smaragdus* which had begun by referring to crystals of green malachite was later restricted to the finest varieties of green stone and so to the emerald. the best of all. Thus the emerald inherited not only the name but also the properties of *smaragdus;* "Pliny on the Smaragdus," *Classical Review* 59 (1945), 50-51.

15 Quoted by Pliny: 37.18 (69).

wide variety of crimson-red stones and here it may refer to *pyrope* which is blood-red but can deepen to purplish if its constitution approaches that of almandine. Theophrastus (18) also describes the *anthrax* and correctly implies that Carthage was simply a port of export and not the locality where the stone was to be found. Archelaus observed that Carthaginian stones were rather dark, appearing dark red or violet indoors and flame red in the open air.[16] Perhaps this accounts for their being likened to heliotrope.[17]

5. The sapphire is a deep crimson, like the colour of dark purple [porphyry].[18] *Many varieties of this can be found. One is "basiliscus", stippled with gold. This stone is not admired quite as much as that which is completely crimson. Apparently "basiliscus" is found in India and Aethiopia. It is said that in India there is a temple of Dionysus which has 365 steps made of sapphire leading up to it, though most people do not believe it. It is a marvellous stone, very beautiful and elegant,*[19] *and is often made up into anklets and small necklaces, especially for Kings. It can ward off pain. Ground up with milk, it heals the scabs from pimples and tumours when smoothed on the sore places. It is written in the Law that when Moses beheld his vision on the mountain and was given the Ten Commandments, he stood upon sapphire stone.*[20]

This is an extraordinary passage because "sapphire" in the ancient world referred to lapis lazuli—almost certainly the stone in *Exodus*[21]—and the gemstone is, of course, blue. *Porphyrizōn*, Epiphanius's adjective, is a tricky word to translate because its meaning is much disputed, but there can be little doubt that some shade of deep red is always meant by the term.[22] Imperial porphyry from Egypt, so Pliny tells us, was red, mottled with white dots, [36.11 (57)]. In the same place he describes the properties of two other stones, *ophite*, a light green marble, and *mephis*,[23] which leads me to

16 Quoted by Pliny: 37.25 (95).

17 A stone which must have been violet or purple in colour. The *heliotrope* described by Pliny [37.60 (165)] was a green stone extensively streaked with red, not in the least wine-faced or carbuncular.

18 This word may have slipped into the text from a marginal note.

19 Or, "very finely coloured and very beautiful".

20 *Exodus* 24.10.

21 The NEB translates *Exodus* 28.18 by "lapis lazuli".

22 There is a very full discussion by H. Gipper: "Purpur," *Glotta*, 42 (1964), 39-69. He supplies a colour example of "purple" which is a shade of crimson. One may compare with this the frontispiece to L. M. Wilson: *The Clothing of the Ancient Romans*, (Baltimore, 1938), which shows seven different shades of "purple" obtained from recipes in the *Papyrus Graecus Holmiensis*. Only one has the slightest blue tinge to it. All are obviously variations upon red. Cf. F. E. Wallace: "Colour in Homer and in Ancient Art," [Smith College Classical Studies, 9 (1927), frontispiece], which shows the reddish shade for "purple."

23 Possibly Dolomite.

wonder if Epiphanius (or his epitomizer) has not vaguely remembered this passage and attributed the qualities of very different stones to lapis lazuli. How the discussion became attached to sapphire is a mystery.[24]

6. The iaspis *is similar in colour to the* smaragdus. *It is found near the banks of the River Thermodon and round Amathus, a city in Cyprus. There are many varieties of "Amathusian" stone. Its colour is greenish, like that of* smaragdus, *but duller and more cloudy. Inside it glows green like copper rust, with four rows of veins. I have heard (and novelists also say this) that it disperses hallucinations. Another kind is bluer than the sea,*[25] *deeper than flower or dye.*[26] *Another is found in the caves of Mount Ida in Phrygia, similar in shade to shell-fish blood, but brighter (like wine), or deeper*[27] *than amethyst. You see,* iaspis *has more than one colour or potency. A fourth is more porous, lighter in colour, does not shine at all, yet is not altogether devoid of [power]. A fifth is like frozen water; novelists say it is a cure for hallucinations.*[28] *It is found in Iberia and among Hyrcanian shepherds who live in Caspia. There is another* iaspis *called "antique" which is like snow or sea-foam. Novelists say it frightens off wild beasts from one's land, and ghosts.*

It is fairly clear that Epiphanius is not describing what we mean by *jasper*. The term obviously covered what are now regarded as a number of separate gem materials. including many varieties of quartz, (prase, blue chalcedony, cornelian, rose quartz, rock crystal, etc.) and quite possibly malachite, azurite, and even jade, although this is not likely to have been common in the Mediterranean area. Pliny refers to Orientals preferring green *iaspis* which they wore as an amulet, [37.37 (118)] and this seems to indicate jade. Galen says that the most powerful *iaspis*, a pale yellowish-green colour, came from Aethiopia and that the light-green variety was a good charm against ailments of the stomach.[29] This green variety could be

24 The word I have translated as " crimson" (*porphyrizōn*) is given as "purple" or "purplish" in the Lexicons, but this is very misleading, as it conjures up an impression of dark reddish blue which is not the shade intended by ancient usage. Pliny says that lapis lazuli (*sappiri*) is also light blue and only rarely tinged with crimson (*purpura*), [37.39 (120)]. This is repeated, in garbled fashion, by Isidore, who omits the word "rarely", [*Etymologiarum Libri* 16.9.2.]

25 *Glaukos* always refers to blue-grey.

26 The alchemist pseudo-Democritus tells us that *anthos thalassion* was a dye made from sea-weed. *Glaukos* dye was also made from woad, and therefore blue.

27 The text is confused. It actually reads, "'more yellowish-brown", but this is nonsense when referred to amethyst, though it would describe a form of agate. "Deeper" is an alternative MS. reading.

28 Perhaps for DT's, since amethysts—with which the *iaspis* is compared—were worn to counteract the effects of drunkenness.

29 Quoted by Aetius of Amida: *Libri Medicinales* 2.18. Cf. *Ibid.* 2.36.

malachite or jadeite, which agrees with Pliny's description of its having white lines running through it, and Epiphanius's mention of "veins".[30] The blue was probably common blue chalcedony or azurite; the white, milky quartz; the colourless, rock crystal. I suspect that the red-violet variety may well have been amethyst itself.[31] "Sea-foam" *iaspis* could, perhaps, be meerschaum or pumice. Theophrastus's *malōdēs* suggests *mēlōdēs*, as Caley-Richards point out, ("Theophrastus on Stones", Ohio, 1956, page 49, note 19), whose colour would be pale yellow, like the *hypochloros* of Galen's Aethiopian *iaspis*. Could the pumice "from the foam of the sea" have been incorporated into the general term *iaspis*, too?[32]

7. *The* ligyrion. *I cannot discover at all where this stone is to be found, though I have consulted both natural scientists and ancient authorities who keep the history of such things. There is a stone "lankurion" which is called "lagurion" in a particular dialect, and I am convinced that this is* ligyrion *since the Scriptures transpose names—for example,* smaragdus *for* prasinus. *Among the names of gemstones they do not mention "hyacinthus", and yet it is an outstanding and valuable stone. Thus we have come to believe that there is no stone called* ligyrion *in Holy Scripture. Well now,* hyacinthus *has several forms. The more deeply coloured the variety, the more valuable it is regarded as being. It is similar in colour to wool which has been dyed crimson*[33] *a number of times. Holy Scripture says that the High Priest's vestments were dyed with hyacinth and crimson,* (porphyra)[34]. *One variety is called "sea-shade"; a second, "rose"; a third, "natural";*[35] *a fourth, "sea-perch";*[36] *a fifth, "part-white". They are found in the wild interior of Scythia, are highly prized, and have the following magical properties. If you throw them into a fire, they are not spoiled but put the embers out. Not only that, if anyone carries the stone wrapped in linen and puts it on to the hot coals, the linen wrapping does not catch fire either, but remains undamaged. The stone is said to be good for women in labour who want an easy birth. It also drives away ghosts.*

According to modern authorities, *ligyrion* was probably

30 37.37 (118). The NEB also translates *iaspis* as "jade", *Exodus* 28.18.

31 See Pliny: 37.40 (121).

32 Theophrastus: 22.

33 The awkward word *hypoporphyrizōn*, again.

34 *Exodus* 28.5.

35 Literally, "native", presumably meaning it was the natural colour of the hyacinth.

36 *Channiaeus*. The derivation is uncertain. "Spongy" could be an alternative.

amber.[37] Epiphanius obviously thinks that the stone is more likely to have been a form of hyacinth (or jacinth), which may, indeed, be yellow, but it is unlikely that the varieties of hyacinth refer to types of zircon, as the *Encyclopaedia Britannica* (11th edn) [14, 25] suggests, because zircons come mainly from south-east Asia, and as far as I know, no ancient examples have been found. The tale that it could be thrown into fire without being damaged suggests remarkable hardness.[38] Pliny's hyacinth is probably blue corundum [37.41 (125)], a stone he compares with amethyst and finds wanting. Sapphire could well be what Epiphanius means by "sea-shade". "Sea-perch" could be yellowish-grey or silvery-blue.[39] Pink ("rose") and colourless ("part-white") stones are rare, but can be found. The main puzzle, however, is his reference to the hyacinth's being the colour of crimson wool. "Blue-john", the finest material, was violet or purple in colour, but came from Derbyshire in England. Trade with the Middle East might well have taken specimens as far as Cyprus or Palestine, but I do not know of any examples being found.[40] Theophrastus (16 and 29) mentions that amber was dug up in Liguria. It is possible that *ligyrion* originally denoted Ligurian amber, a more plausible etymology than "lynx-urine" which Theophrastus assumes (28).[41]

8. Agate.[42] *This is supposed to be the gem called "white-edged" which I mentioned in my discussion of the hyacinth.*[43] *It is an amazing stone, a rather dark blue, with a white circle round the outside, like marble or ivory. It is found round about Scythia. There is a type of agate which is the colour of a lion. When ground up with water and smeared on bites or stings it drives away the poison of a scorpion, or of vipers and such-like creatures.*

Pliny's description of agate [37.52 (139-143)] mentions a large number of stones which might or might not be classified nowadays as agates. Both the blue and the "lion-coloured" varieties described by Epiphanius are almost certainly true agates. Pliny, too,

37 E.g. D. E. Eichholz: *Theophrastus de lapidibus*, (Oxford 1965), 108-9.

38 Hyacinth or jacinth are terms now used only for red-brown zircon or hessonite garnet.

39 See D'Arcy Thompson: *A Glossary of Greek Fishes*, 284.

40 NEB translates *ligyrion* as "turquoise" which is unlikely to be right.

41 The Old Georgian version of Epiphanius describes an animal called *lygyron*, "which is of the colour of the wild cow, like a red heifer, and on the tip of its tail it has a bunch of hair which gives off a greenish reflection. It is called *lyngos ouros*, i.e. "lyngos-tail", (de Vis.).

42 *Achatēs*. See E. Sarofim, "Origin of the name Agate," *J. Gemm.* 1969, XI, 6: 203. Over the centuries the spelling of the word has varied. It appears first in English in the *Ancren Riwle* (c.1230).

43 He called it "part-white" before, but the text could be faulty.

mentions the agate's supernatural power (*sacra*) over the bites of spiders and scorpions (*loc. cit.* 139).

9. Amethyst. This has a deep flame-coloured band around it. It is rather pale[44] *in the middle and emits a "wine-like" colour. It also has various forms and probably comes from the mountains of Libya.*[45] *One variety is rather like a pure hyacinth; another is similar to the murex-fish. It can be found on the sea-banks of Libya.*

Pliny's description is well-known. "The reason for its name is said to be that it approaches the colour of wine but shades off into violet before it reaches this colour," [37.40 (121)]. He also mentions a variety in which the purple fades into white (*ibid.* 123) and that is probably the impression Epiphanius wishes to convey about his first stone which reminds one of the reddish-violet colour of "Siberian amethyst". The "hyacinthine" is the ordinary purple variety; the "murex", a purplish or deep crimson stone. The *New English Bible* translates "amethyst" as "jasper"[46] and this may well be correct for Epiphanius's gem, since his word *amphicochlos* describes the shell of the murex-fish and hints at bands in the colour.

10. Chrysolith. Some people call this stone chrysophyllon. *It has a fairly golden colour and is found in the two faces of rock on the reservoir near the walls of Persian Babylon. Both Babylon and the reservoir are called Persian (Achaemenid) because that was the name of Cyrus the Great's father. There is also* chrysopastus *which doctors grind up and give their patients to drink to cure ailments of the stomach and bowels.*

The chrysolith is probably yellow corundum, for example, yellow sapphire,[47] a fairly pale variety. "Chrysopastus" simply means "shot through with gold". The *New English Bible* translates chrysolith as "topaz", and it may be that citrine, which for many years was not distinguished from topaz, is the stone described by both Pliny and Epiphanius.

11. The beryl is bluish,[48] *the colour of the sea or of a rather watery hyacinth-stone. It is found round the base of Mt Taurus. If you hold up the stone to the sun and peer through it, it appears to shine like glass, with brilliant millet-grains within. Another beryl is like the pupils of a dragon's eyes, and another like wax. This one is found about the mouth of the Euphrates.*

44 Various other translations are possible, paler, whitish, rather white, whiter.

45 Horace mentions the African purple industry: *Odes* 2.16[36] and so does Propertius: 4.3[51].

46 *Exodus* 28.19.

47 Cf. Pliny: 37.42 (126).

48 *Glauki-zōn*. See above, note 25. Pliny calls this type green, 37.20 (76).

There is no difficulty in identifying both the blue and greyish-white stones, as both are indeed common varieties of beryl.[49] Beryls were then probably not free from impurities, and I presume it is these Epiphanius means by "millet-grains".[50]

12. The onychion *is very yellow-brown.*[51] *They say that girls who wed royalty or money particularly like this stone because they can have it made into drinking-cups. Other stones, ambiguously called* onychia, *are like the colour of a honey-comb, and some people say that they have been created out of disordered water.*[52] *They also say that* onychitae *are named from their natural colour since onyx is blood-red, like the marble used by the Smart Set.*[53] *Others, without investigation, inaccurately call the marble "onychite" in view of its being pure white colour.*

Various types of stone are mentioned here. *Onychion* is perhaps some form of banded chalcedony, though I suspect that since it can be worked into cups it is more likely to be another type of *onychia*—stalagmitic calcite, which is sometimes commercially still called "oriental alabaster" and "onyx marble". This was extensively quarried in ancient Egypt and much used for vases, statues, and the ornamentation of buildings. Pliny calls it *alabastrites.*[54] He warmly recommends honey-coloured onyx but does not at all approve the gleaming white or "glassy" look. It is the latter which Epiphanius probably means by his frozen stone. Red marble may be red granite from Egypt and the stone which is like it, sardonyx.

I am very grateful to Mr J. R. H. Chisholm for reading and commenting upon an earlier draft of this article.

[*Manuscript received 26th June, 1975: revised 30th April, 1976*]

49 NEB translates "cornelian".

50 Modern aquamarines are almost certainly free of impurities, but that is because they come mainly from sources, such as Brazil and Madagascar, which are unlikely to have been available in ancient times. Pliny says that all beryls have flaws or inclusions and that those without them are pale and lifeless, 37.20 (77).

51 See also Theophrastus: 31 and Pliny: 37.24 (90-91).

52 This does not make sense and the text needs emendation. The verb can mean "to freeze" and it looks as though Epiphanius means that the marble has the appearance of frozen or petrified liquid. Rock crystal was believed to be frozen water, frozen so hard that it would not melt again, and it looks as though Epiphanius is recording a similar belief about some onychia. Could the idea refer to frozen Nile water? This would be yellow because of the river's alluvial content.

53 Literally, "elegant, charming, witty men."

54 36.12 (61) and 37.54 (143).

A GEOLOGICAL CURIOSITY*

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ACCORDING to the saying, "history never repeats itself". One could say the same of the problems met by the jeweller-gemmologist. Their variety is illustrated by a problem on the border of gemmology, which at the same time is a geological enigma whose subject was revealed to the Lucerne Geological Congress in 1968 by Dr U. P. Büchi.

We are sometimes indebted to the daily press for a great many surprises: a news item written hurriedly and with a lack of knowledge of the subjects tackled and in emphatic stop-press style often envelopes the various facts in a cloak of mystery which makes them attractive in the readers' eyes. This has happened with the fact described below. A number of newspaper articles published towards 1965 in Switzerland and Germany have announced the discovery of "fossil black pearls" of great beauty and great value. Their quality has been compared to that of the most beautiful oriental pearls. The man who made the discovery is an amateur of geological curiosities who seems to have quite a flair for the discovery of rarities: Mr E. Glanzmann lives near Langenthal: he is a farmer, and long contact with nature has developed his inborn gifts of observation. Whilst studying the geological make-up of his land he observed, in a quarry of building-stone, some strange opaque black spherular objects embedded in the rock. By digging, he freed them from their matrix. They are illustrated in Figure 1.

If you would believe the journalist, you would become excited over "the precious formations of inestimable value showing the same quality as oriental pearls". If, however, these little black balls are held in the hollow of your hand, their blackish colour, their lack-lustre surface and their unassuming appearance leave you with a much poorer impression. It seems, however, to be truly a new discovery. Such ball-like formations seem to be a unique case. What is their origin? To find out, I suggest a journey to Switzerland.

The place where they were found is on the Swiss Plateau about 30 km north-west of Berne. It was at Oschwand (known as having

*First published (in German and French) in *Schweizer Goldschmied*, August, 1969, pp. 16-25: see Mr Schiffmann's "Letter to the Editor", p. 463 *infra*.—Ed.

been the residence of the painter, Cuno Amiet), in an isolated and peaceful part of the Bernese countryside, that in rural calm and quiet I met Mr E. Glanzmann, who did me the honours of his lands and showed me the place of the discovery, which can be seen in Figures 2 and 3. After having found the black balls he had an identification problem to solve. The unusual nature of the case made it a

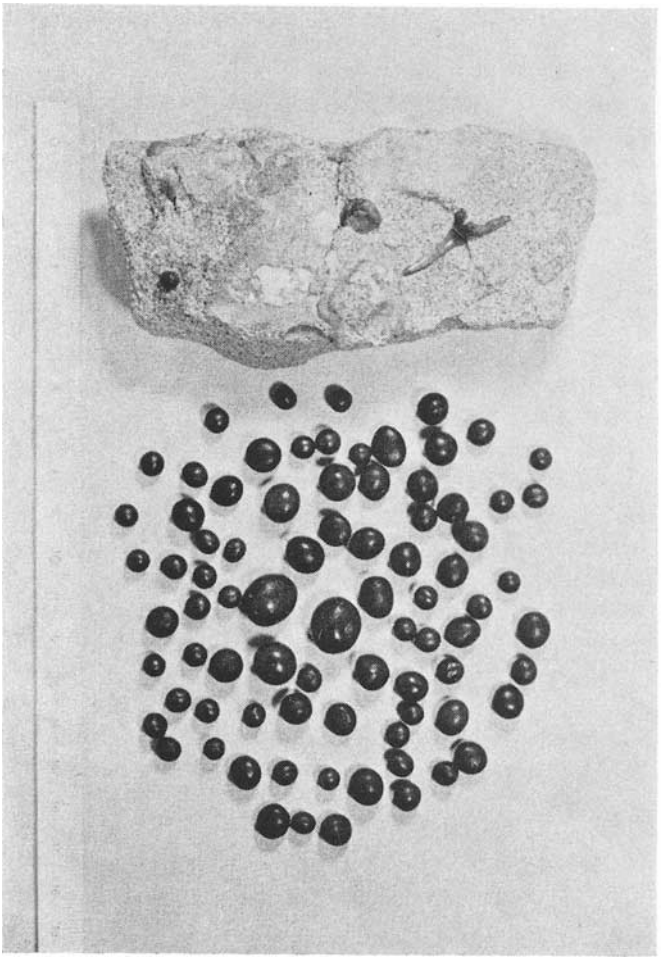

FIG. 1. Piece of grey-brown sandstone, with two spheres *in situ*, as well as a fossil, at right, and a *scutella* (convex part slightly darker grey than the colour of the sandstone). Below, a number of balls taken out of their matrix and cleaned.

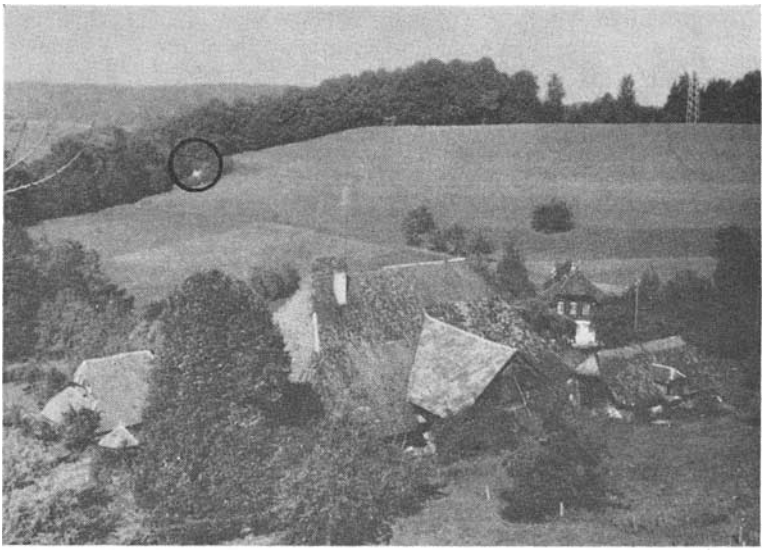

FIG. 2. General view of Oschwand: the quarry is high on the left, at the edge of the trees. The spot is marked by a circle.

FIG. 3. Oschwand: the building-stone quarry.

problem for a geologist, and Mr Glanzmann sought the explanation among several geologists. But, as there were no precedents, they have not so far been able to pronounce a final judgment on the origins of these objects. Towards 1965, however, contrary to the journalists' imagination, Professor F. Rutsch, of Berne University, declared that there was no question of their being fossil pearls, without propounding any other hypothesis for their provenance. Some of the savants with whom Mr Glanzmann had made contact have taken an interest in the question and tackled it systematically. The results of their research have been embodied in a paper by Messrs U. P. Büchi and G. Wiener.* Before reporting the main features of this study, let us first consider the more modest results of a routine gemmological examination.

Colour: black, sometimes a little greenish, opaque.

Shape: generally spherical, sometimes ovoid or slightly flattened. Some specimens have a slight surface depression.

Dimensions: diameter varies from 3 to 10 mm: a single ovoid specimen is 18 mm long.

Specific gravity: rather variable: 8 specimens, measured by hydrostatic weighing, using dibromoethane, gave results of 2·01 to 2·59, which probably indicate their irregular compositions. There was no obvious porosity.

Refractive index: the irregular surface does not allow a precise reading to be obtained on the refractometer, even by the distant-vision method: a vague shadow-edge may be seen at about 1·55.

Fluorescence: under x-rays, inert: under long-wave ultraviolet, inert: under short-wave ultraviolet, inert.

Microscopic examination: the surface is granular in texture: small colourless crystals are sometimes visible at the surface: the outer layer of the spheres is harder than the interior.

Radiography: radiographs of 5 specimens showed more or less great permeability, evidenced by a spotted appearance of the film, but with no regular structure recognizable.

The limitations of gemmological methods did not permit a definite conclusion to be reached on the identity of these spherules and from now on we have recourse to other disciplines. The following account is based on the work of Messrs Büchi and Wiener, which it summarizes.

*Bull. Ver. Schweiz. Petrol. Geol. Ing., 1967, 34, 85, 17-28.

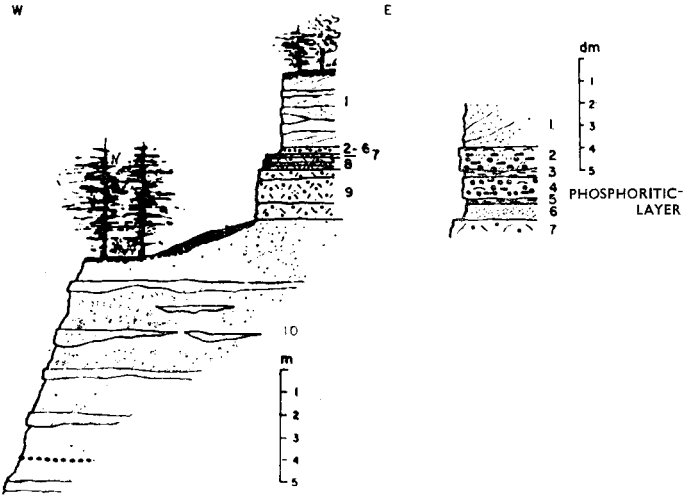

FIG. 4. Geological profile of the Oschwand quarry.

1. Medium to coarse calcareous sandstone, carbonized remains of plants and drift-wood: minimum thickness 3·00 m.
2. Medium calcareous sandstone with rolled pebbles and numerous marly pebbles, fossils, shells and *scutellae:* thickness 0·08-0·12m.
3. Brown and beige marl: thickness 0·01-0·03m.
4. Phosphoritic layer in which the black spherules were found: medium and grey-beige calcareous sandstone, numerous alpine pebbles, marly vesicles: various fossils, in particular *scutellae*, to whose presence the black balls are related: thickness 0·01-0·12m.
5. Light beige marl: thickness 0·02-0·03m.
6. Calcareous sandstone, medium, grey-blue, small alpine pebbles: thickness 0·07-0·15m.
7. Shelly calcareous sandstone, grey-blue, hard, alpine pebbles: thickness 0·22m.
8. Shelly sandstone, calcareous, grey-blue, hard, pebbles: thickness 0·70m.
9. Shelly sandstone, calcareous, grey-blue, pebbles in banks of 0·30-1·00m., thickness 2·00m.
10. Coarse to medium sandstone, grey, with strong calcareous deposits: at about 11m under the base of the sandstone, a band of pebbles: gradient of the bed about 8° towards SE.: thickness 13·00- + Xm.

GEOLOGY OF THE REGION

The two places where black spheres were found (Oschwand and Stouffenbach) are situated in the shelly sandstone of the upper marine molasse. The profile of the building-stone quarry at Oschwand is illustrated by Figure 4. The most interesting part of this sectioned view is the phosphoritic bed No. 4, rich in alpine shingle and locally in fossils, in particular large *scutellae* up to 80 mm in diameter. This is the bed in which the black spheres were found. They lie sparsely in the sandstone, with some local concentrations.

PETROGRAPHICAL EXAMINATION

In thin section under the microscope the spheres have a fine structure, which is irregular and without any sign of concentric

growth-zones. The chemical composition is largely phosphatic (fine skeleton of colophony slowly soluble in HCl but not in organic acids). This calcium phosphate is practically amorphous and impregnated with microcrystalline calcite. The components of the host-rock (sandstone) are not present, or only in minimal quantity. On the surface, the balls are partly impregnated with glauconite. The sand grains have penetrated the material, from which it follows that the spheres were relatively soft at the time of their deposition in the sand. This latter has a different composition: in the compacted parts, about 35% carbonates and about 5% dolomite, with glauconite quite frequent.

Examination in the light of sedimentary petrography shows that there is no question of their being fossil pearls: the chemical composition excludes this possibility and, moreover, the concentric structure of a pearl is lacking. The phosphate content and the other peculiarities show that we must rather consider whether they may be coprolites.

Micropalaeontological Findings

In thin sections the black spheres are characterized by the presence of fossilized micro-organisms, some of which Professor Reichel, of Basle, has been able to identify (Figures 5, 6 and 7). By way of comparison, Fig. 8 is a photograph of a thin section across a clayey nodule from the surrounding phosphoritic bed showing numerous remains of micro-fossils. The difficulties in identifying the micro-fossils found and their small number did not permit of the black spherules' age being determined by palaeontological methods.

Origin of the Phosphated Balls

In principle, the objects may be of either organic or inorganic origin. J. Schadler (1932, 1934, 1944) has described larger objects, of irregular shapes, found in the Austrian oligocene and miocene, which are partly of inorganic origin. It seems, however, that some organisms have contributed to the phosphatic enrichment.

The products of the Oschwand and Stouffenbach localities, however, are very different from the Austrian objects, in respect both of shape (spherical) and of size (maximum diameter about 10 mm). The Austrian finds have been partly designated as being coprolites of terrestrial mammals.

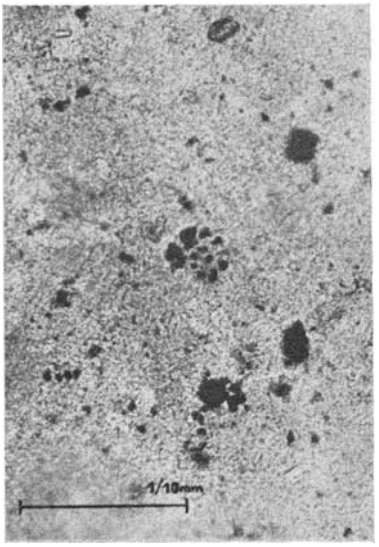

FIG. 5.

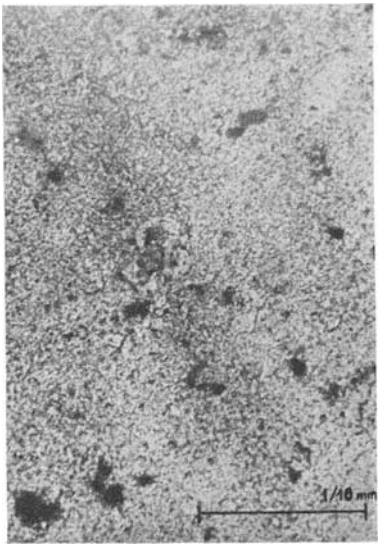

FIG. 6.

FIG. 7.

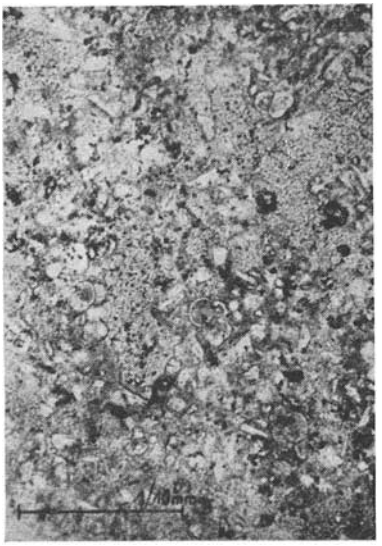

FIG. 8.

FIGS. 5, 6, 7. Thin sections across the phosphatic balls. Note the fine grain and the remains of microfossils, particularly in Fig. 7.

FIG. 8. Thin section across a marly nodule from the phosphoritic bed.

For those of the Bernese shelly sandstone it seems that the origin could equally be animal, because near to the black spheres have been found echinids in important quantities and the presence of excrementary balls of these latter is known. The fossil remains of small organisms found in the phosphoritic layer do not correspond with the age when the *scutellae* existed: they could, however, be part of the food which these latter failed to digest. This group of animals, algae-eaters, also swallow sand and mud, but retain only the digestible parts. The *scutellae* are in such a good state of preservation that important geographical displacements cannot have taken place: so the formation of the black spheres could be due to the coprolitic waste-matter of the *scutellae*. As these residues have not been transported, it seems that it is a matter of a primary bed, for the balls have only been found in the phosphoritic horizon of the shelly sandstone. Other horizons, also containing the same rounded pebbles of alpine origin, do not contain the phosphatic balls. Moreover, the black balls are marked by the imprint of sand-grains, which show that they have not been rolled and must originally have been soft. The spherules seem to have been permeated by the calcium phosphate during or after their deposition. The necessary conditions for the formation and concentration of phosphate are likewise fulfilled in this region (marine basin, proximity of glauconitic formations, phosphate-producing fauna and fishes). The discovery has been made in two places only, for systematic search has not so far been undertaken. It seems that other kinds could be expected in the same stratigraphic surroundings, according to the regional distribution of the *scutellae* in the shelly sandstones of neighbouring districts.

Conclusion

The resulting solution of the problem of the nature and origin of the black spherules is both unexpected and rather unromantic! Nature's oddities and curiosities are numberless, and the contrast between the real nature of these geological finds and the eulogistic descriptions quoted at the beginning of this article will no doubt raise a smile on the lips of more than one reader. The mistake arises from the erroneous idea that rarity alone raises an object to the rank of an article of finery or adornment. But other factors hallowed by tradition are of just as great importance as rarity: more than rarity, it is beauty—in shape, orient, lustre—and also fashion, which have

given to the pearls used in jewellery the privileged position they occupy nowadays among articles of adornment.

ACKNOWLEDGMENTS

The author here records his thanks to Mr E. Glanzmann for the information kindly provided and for having made available the photographs reproduced as Figures 2 and 3, as well as his lively gratitude to Dr U. P. Büchi, who kindly made Figures 4, 5, 6, 7 and 8 (originally published in *Bulletin des Ver. Schweiz. Petrol. Geol. Ing.*,) available and permitted their reproduction: of these, the excellent thin-section photographs (Figures 5, 6, 7, 8) were taken by Miss L. Eymann.

Gemmological Abstracts

ACCORD (J. P.). *Tourmaline.* Lapidary Journal, 1977, 31, 1, 216-229.
An account of the rediscovery of gem-quality tourmaline in Maine. M.O'D.

ACCORD (J. P.). *Tourmaline.* Lapidary Journal, 1977, 31, 2, 512-525.
Continues the article begun in vol. 31, no. 1 (v. sup.). Outlines further discoveries in Maine and reviews the use of tourmaline in jewellery. M.O'D.

ALEXANDER (A. E.) and ZARA (L.). *Garnets, legend, lore and facts.* Mineral Digest, 1977, 8, 6-16.
A general review, superbly illustrated in colour, of the gem members of the garnet family of minerals. M.O'D.

ALTHAUS (E.). *Farbe aus Fehlern.* (Colour from defects.) Lapis, 1977, 2, 5, 8-9.
Describes the operation of colour centres in fluorite. M.O'D.

BLAIR (G.). *Pyrite-collectors' delight.* Lapidary Journal, 1977, 31, 1, 46-50.
An illustrated account of the formation and occurrence of pyrite. M.O'D.

BOWER (C. E.). *Digging for black opals at the Royal Peacock opal mines, Virgin Valley, Nevada.* Lapidary Journal, 1977, 31, 2, 526-533.
Opal from this region has been stabilized by a process not described; on mining, the stones are immediately placed in mineral oil to preserve the water content. After the stabilization has been carried out the stones may be fashioned without fear of crazing. The water content of stabilized opal is stated to be less than 1%. M.O'D.

BRIDGE (P. J.), DANIELS (J. L.) and PRYCE (M. W.). *The dravite crystal bonanza of Yinnietharra, Western Australia.* Mineralogical Record, 1977, 8, 2, 109-110.
Dravite is found enclosed in a phlogopite-plagioclase schist, the plagioclase being a calcic oligoclase. The crystals of dravite are almost equant and resemble garnets, with which they are frequently confused. The colour is a golden brown (Ridgway colour blister 15″m). M.O'D.

BÜRGER (H.). *Was ist Azurlapis?* (What is "azurlapis"?) Lapis, 1977, 2, 4, 22-23.
This mixture contains about 60% quartz and 40% azurite/malachite. The concretions, either dark blue or green, are found in the U.S.A. and have a specific gravity of 2·88-2·99 with a yellowish-blue or yellowish-green streak. M.O'D.

COURTER (W. E.). *Michigan's favorite gemstone.* Lapidary Journal, 1977, 31, 1, 150-158.
A description of Petoskey stone with references to datolite and agates. M.O'D.

DANIELS (A.) and BALL (R. A.). *Opal in South West Queensland.* Australian Gemmologist, 1976, 12, 12, 359-363. 5 figs.
Gives a short summary of historical background (opal discovered 1872-3) and

geology of the area (deposits are in early tertiary and cretaceous beds of freshwater and marine origin; common opal widespread, gem opal very localized). The paper then deals with Yowah nuts which are siliceous almond-shaped nodules of ironstone occurring in the Cunnamulla Mining District, some of which contain precious opal. They are up to 2 cm in diameter. Considerable details of locality, opal occurrence and structure are given but the paper is beset by the printers' errors which so often plague this journal. R.K.M.

DOUGLAS (I. N.) and RUNCIMAN (W. A.). *Application of magnetic circular dichroism spectroscopy to the optical spectra of natural and irradiated diamonds.* Physics and Chemistry of Minerals, 1977, 1, 129-136.

MCD spectra of natural Type Ia and electron-irradiated Type Ia and Type IIa diamonds show that there are at least four different defect centres occurring in diamonds. M.O'D.

DUNN (P. J.). *Apatite: a guide to species nomenclature.* Mineralogical Record, 1977, 8, 2, 78-82.

The general formula for the apatite group of minerals can be expressed as $Ca_5(XO_4)_3(F,Cl,OH)$. The (XO_4) position is most commonly filled by the phosphate radical (PO_4) and there is some substitution by the carbonate radical (CO_3) in some varieties. The most common apatites are fluorapatite, $Ca_5(PO_4)_3F$. hydroxylapatite, $Ca_5(PO_4)_3(OH)$ and chlorapatite, $Ca_5(PO_4)_3Cl$. M.O'D.

DUNN (P. J.), APPLEMAN (D. E.), NELEN (J.) and NORBERG (J.). *Uvite, a new (old) common member of the tourmaline group and its implications for collectors.* Mineralogical Record, 1977, 8, 2, 100-108.

The general formula of the tourmaline group may be written $Na(R)_3 Al_6B_3Si_6O_{27}(OH,F)_4$. Where the R position is occupied by lithium/aluminium the variety is elbaite, where R is ferrous iron the variety is schorl, ferric iron is buergerite and where magnesium, dravite. Many tourmalines are mixtures of two or more species since there is extensive substitution in the group. The variety in which calcium replaces sodium may be described as $CaMg_3(MgAl_5)B_3Si_6O_{27}(OH)_4$ and specimens have been found in Sri Lanka, DeKalb (New York) and Gouverneur (in the same State). They have been given the name uvite after the province of Uva (Sri Lanka) and the name has been confirmed by the IMA Commission on New Minerals and New Mineral Names. The crystals show no outward difference from other varieties of tourmaline; the specific gravity ranges from 2·96-3·06, the hardness is about $7\frac{1}{2}$, comparable with dravite. Most specimens are brown though some from DeKalb are colourless and some from Franklin, New Jersey, are light green. The refractive indices are the same as those of dravite and provide no means of distinguishing the species. Examination with the electron microprobe at the National Museum of Natural History (Smithsonian Institution) proved the identity of uvite and dravite in 80 specimens. Generally speaking dravite is the magnesium tourmaline with sodium greater than calcium and uvite is the magnesium tourmaline with calcium greater than sodium. Most brown tourmaline associated with calcium minerals is uvite and most brown tourmaline associated with schist and non-pegmatite micas is dravite. M.O'D.

EDGAR (A.) and VANCE (E. R.). *Electron paramagnetic resonance, optical absorption and magnetic circular dichroism studies of the CO_3^- molecular ion in irradiated natural beryl.* Physics and Chemistry of Minerals, 1977, 1, 165-178.

X-irradiation of some natural beryls at room temperature showed some new absorption lines in the EPR spectrum, some known optical absorption lines in the 500-700nm range and a shift of the absorption edge to lower energies. Two of the paramagnetic centres responsible for the new lines have been identified as atomic hydrogen and methyl, CH_3. The third is thought to be the CO_3 molecular ion located in the widest part of the structural channel. The "Maxixe" centre is attributed to this ion. M.O'D.

FERGUSON (R. W.). *California's cuttable serpentines.* Lapidary Journal, 1977, 31, 1, 174-180.

Serpentines found in the State include antigorite, soapstone, chrysotile and various locally-named varieties. M.O'D.

FUJISAKI (Y.). *Inclusions in emerald from Muzo, Colombia.* J. Gemm. Soc. Japan, 1976, 3, 4, 147-156.

Inclusions in an emerald from Muzo were studied by means of microscopic and electron microprobe analysis. Solid inclusions were found to be pyrite, pyrrhotite, pentlandite and rutile. Characteristic 3-phase inclusions were smaller than those commonly encountered in Colombian material. M.O'D.

GÜBELIN (E. J.) and WEIBEL (M.). *Grüner Vanadium-Grossular, Kenya.* (Green vanadium-grossular, Kenya.). Lapis, 1977, 2, 4, 17-21.

Vanadium-bearing green grossular has been found in the Lalatemi Hills and, as an accessory mineral with blue zoisite, at Miralani, south of Moshi, Tanzania. It has now been found in Kenya in the Taita district and the mine at which it is found is known as the Lualenyi mine. About 3% V_2O_3 causes the green colour. Among the minerals included are byssolite (probably) and lines composed of minute liquid droplets are also found. M.O'D.

GÜBELIN (E.). *Einschlüsse im Fluorit.* (Inclusions in fluorite.) Lapis, 1977, 2, 5, 16-19.

Typical inclusions are illustrated in colour, including green crystals of chlorite, secondary liquid inclusions, 3-phase inclusions and euhedral pyrite crystals. M.O'D.

HOPKINS (R. H.), STEINBRUGGE (K. B.) and STEWART (A. M.). *Laser damage-initiating inclusions in $CaLa_4(SiO_4)_3O:Nd$ crystals.* Journal of Crystal Growth, 1977, 38, 255-261.

Laser damage in rods of this material arises from iridium particles trapped in the material during growth. They appear to enter during fluctuations in growth rate but can be minimized by using a slightly oxidizing growth atmosphere with automatic control of crystal diameter, together with control of the thermal geometry of the growth station. M.O'D.

VAN DE WALLE (P.). *Les bulles gazeuses.* (Gas bubbles.) Bulletin, Société Belge de Gemmologie, 1976, 4, 2-6.

Includes black-and-white photographs of some common gem inclusions. M.O'D.

WATANABE (K.) and SUMIYOSHI (Y.). *Synthesis of corundum single cyrstals by the flux method.* J. Gemm. Soc. Japan, 1976, 13, 4, 147-156.

Corundum crystals were grown by various methods including seeding, top-seeding and temperature rotation. The flux was cryolite (Na_3AlF_6) and a number of dopants were tried including Cr^{3+}, Fe^{3+}, Ti^{4+}, La^{3+}, Nd^{3+}, Dy^{3+}, Yb^{3+}. Good crystals were obtained and alteration of habit according to dopant was observed. M.O'D.

WEIBEL (M.). *Rosafluorit.* (Rose fluorite.). Lapis, 1977, 2, 5, 6-7. Illus. in colour.

The finest pink fluorite is found in Switzerland and occurs as octahedra often in association with quartz, calcite and chlorite; apatite and hematite are also occasionally found as neighbours. The colour is thought to be due to the operation of a colour centre. The Gotthard area produces the best pink fluorite. M.O'D.

WEINER (K. L.). *Thermoluminesszenz.* (Thermoluminescence.) Lapis, 1977, 2, 5, 20-21. Illus. in colour.

Two types of fluorite displaying thermoluminescence are illustrated in colour. M.O'D.

WILD (K. E.). *Das Schatzkästchen von Idar-Oberstein.* (The jewel-box of Idar-Oberstein.) Lapis, 1977, 2, 6, 11-13.

Gives an account of the Heimatmuseum in Idar-Oberstein and a brief history of gemmological activity in the area. M.O'D.

WILSON (M. M.). *Sapphire blue.* Lapidary Journal, 1977, 31, 1, 32-44. Illus. in colour.

An account of the various locations of corundum in the United States. M.O'D.

WILSON (W. R.). *Famous mineral localities: the Pulsifer quarry.* Mineralogical Record, 1977, 8, 2, 72-77.

The Pulsifier quarry is situated in Androscoggin County, Maine, and is especially celebrated for purple apatite which owes its colour to Mn^{2+}. The mineral is found in pockets in the pegmatite which runs through the district, and tourmaline is also found. An especially fine specimen of the purple variety of apatite, now in the Smithsonian Institution, forms the cover photograph for the issue. M.O'D.

WRIGHT (C.). *Arkansas, land of quartz.* Lapidary Journal, 1977, 31, 1, 188-196.

The article describes and illustrates the variety of quartz crystal types found in the State. M.O'D.

ZAPATERO (L.). *Estudio de inclusiones por el método de los tres granos.* (Study of inclusions by the three grain method.) Boletin del Instituto Gemológico Español, 1977, 16, 21-25. Illus. in colour.

Inclusions are pin-pointed and examined under drops of Canada balsam; they can be permanently mounted, presumably in thin section. M.O'D.

ZEITNER (J. C.). *Our American gems.* Lapidary Journal, 1977, 31, 2, 468-478.

A general survey of gem materials found in the United States and hints on visiting gem-producing areas. M.O'D.

Gem mining in Sri Lanka. Facets, 1977, 1, 4, 2/5. 2 illus.

A description of the methods used for recovery of gemstones from the "illam", of which there may be more than one layer in some pits. J.R.H.C.

Mohs, Brewster, Carlyle and the table of hardness. Mineral Digest, 1977, 8, 82-86.

An account of the life of Friedrich Mohs and the table of hardness bearing his name. M.O'D.

Turquoise. Mineral Digest, 1977, 8, 64-68.

A general review showing artefacts made with turquoise. M.O'D.

Why the CSO is a diamond's best friend. Gem World, 1977, 4, 1, 16-22.

Reviews the work of the Central Selling Organization and its effects on world diamond prices. M.O'D.

NOTE.—*Facets* is a new periodical published by the State Gem Corporation of Sri Lanka (24, York Street, Colombo, Sri Lanka); though called a "Quarterly Newsletter" it has so far been published at irregular intervals – Vol. 1, No. 1 in July 1975, No. 2 in December 1975, No. 3 in July 1976, No. 4 in February 1977.

BOOK REVIEWS

O'DONOGHUE (Michael), ed. *The Encyclopedia of Minerals and Gemstones.* Orbis Publishing Co., London, 1976. pp. 304. Numerous illustrations in colour and many diagrams. £7·95.

The importance and value of this handsomely produced book are hard to assess. It consists of a series of chapters by different authors, entitled The Chemistry of Minerals (Robert Thompson); The Crystalline State (John Bradley); Geology for the Collector (Alan Woolley); Minerals Valuable to Man (Robert Symes); Identifying Minerals (Michael O'Donoghue); The Fashioning of Stones (Colin Winter); Conserving and Displaying Minerals (Michael O'Donoghue); ending with the most important and by far the longest section of the book – The Mineral Kingdom, by Michael O'Donoghue, who also edited the whole work. The concluding pages contain a lot of useful information: identification tables, a full bibliography, a list of useful addresses, and an excellent index.

The book is superbly illustrated throughout, with clear and instructive diagrams in the earlier chapters and a wealth of photographs in colour of mineral specimens, which make the book a delight to browse through and should assist the collector considerably in the identification of unknown specimens. It is interesting to note that the one plate representing faceted gemstones is probably the least successful in the book, indicating the intrinsic vulgarity of over-large cut stones compared with crystals which maintain their dignity and impressiveness under any enlargement. Some of the "blown up" pictures of minerals in their natural state to be found in this book are indeed quite awe-inspiring. We have in recent years admittedly become somewhat blasé when faced with photographs of this sort of quality, so many are the "picture-books" dealing with gem materials which have been published. But here the illustrations both large and small are skilfully used to enhance and assist the text, which without their aid might make rather dry reading, at least for the layman.

As the book is weighted rather more on the natural minerals than on the limited number which can legitimately be used for human ornament, we are pleasingly reminded that these islands of ours, so weak in true gem materials, have produced many mineral specimens of the finest quality. The attractive display made by typically radiating crystals of wavellite which have emanated from a quarry near Barnstaple, for instance, are honoured by being reproduced in three places in the book.

Only the last – descriptive – half of the book corresponds at all closely to the usual conception of an encyclopaedia: but the editor of the whole assemblage, and its chief contributor, would probably claim that its all-embracing scope, which aims to inform the budding mineralogist, amateur lapidary and gemmologist, warrants such a title. Certainly it would be difficult to think of another.

The late Sir James Walton was the first to conceive the idea, in his "Physical Gemmology", that the subject should be taught by beginning with the atom, continue with the grouping of atoms or ions into crystals, and so on, in logical sequence. Much the same basic approach has been adopted in this "Encyclopedia", and quite difficult concepts have been made plain by the skilful use of diagrams. These early chapters certainly make more attractive reading for the beginner than the traditional form of textbook, and the average collector and amateur lapidary does not need more than can be conveyed by this "easy" treatment.

The chapter on fashioning stones covers a lot of ground in its forty-odd pages, starting with details of the increasingly popular pastime of tumble-polishing, which requires the minimum of skill but a good deal of care and know-how for really good results. Practical details, with clear diagrams to assist the reader, are given to enable the keen do-it-yourself man to construct his own tumbling machine or even a vertical or horizontally running lapidary bench for sawing, grinding and polishing gems. The same chapter includes quite a useful description of minerals suitable for cutting, arranged in alphabetical order. There has been an extraordinary outburst of enthusiasm in this country for collecting, polishing and even mounting ornamental stones, with two specialist magazines, numerous clubs, and commercial suppliers. The pity of it is that "gem collecting" in the field so far as Britain is concerned is limited almost entirely to various ornamental forms of chalcedony.

In writing the chapter on identifying minerals, the editor (M. O'Donoghue) has allowed himself far too small a space (only seven pages) to do more than write a pleasing essay on this complex subject. This is more suited to an article for a large general encyclopaedia than in a specialized one. It may gratify "rockhounds" by making the subject seem easy, but will disappoint the budding gemmologist, who will have expected something more specific from one who has become well-known for his energetic study and reporting of the subject.

As against this, the meatiest part of the book and by far the longest is the section entitled "The Mineral Kingdom" for which O'Donoghue is also responsible. Here, the most essential data are given for some 1,000 minerals, which comprise all those likely to be met by the amateur in the field or from popular suppliers, and many more besides. The information is necessarily given in a condensed form. Following the name of the mineral, the composition, crystal system, physical properties, appearance, type of occurrence and appearance are listed, as well as

the more important occurrences. The order followed is a chemical one, as in the Chemical Index of Minerals compiled by Dr M. H. Hey and issued by the Mineral Department of the British Museum (Natural History). The non-specialist will find it difficult with such an arrangement to find a mineral of which he knows only the name, but he will be aided in this by reference to the index. The appearance of a large number of the minerals is made clear by provision of coloured photographs of typical specimens. An unusual feature of these brief descriptions is that in many cases a directive is given for the cleaning of specimens of the mineral concerned. Water, and not just water but *distilled* water, is often recommended as the safest cleaning agent. This seems unnecessarily fussy, and becomes really amusing when suggested for so chemically tough a mineral as painite, which, despite its extreme rarity, has found its way into the text as it has, for some curious reason, into several other recent books on gemstones. Only two crystals of painite are as yet in captivity, and it may interest readers to know that a recent analysis has led to the revised formula for the mineral – Ca Zr B (Al_9O_{18}) – and to the establishment of its crystal structure (hexagonal) being related to another rare mineral recently claimed as a gemstone by American workers – jeremejevite.

A tremendous amount of work and thought has gone into the making of this book and it is undoubtedly full of good things as well as being very reasonably priced. Its weakness lies perhaps in its attempt to be of universal appeal to anyone attracted to the mineral kingdom for one reason or another. The earlier chapters if expanded and filled in with more detail (especially the one on identification) would have formed a very pleasant text for the instruction of the collector of minerals and amateur lapidary. And the last, descriptive part, if given more expanded treatment in the case of the hundred or so really important minerals would have provided a very acceptable reference book. Though admittedly some of the impressive illustrations of fine mineral specimens would lose a little of their grandeur by being diminished in size, the volume would have been made far easier to handle, hold, and house by being reduced somewhat from its 12 x 9 inch dimensions. It could be given more pages, slightly smaller type, and then not require a lectern to read from in comfort.

A reviewer is expected to point out misprints or more serious errors when a book such as this is under notice, if only to show that he has studied the text with the requisite thoroughness. There are admittedly and inevitably some mistakes to be found in this "Encyclopedia", such as the occasional misplacing of captions in the coloured photographs, the description of Clerici solution, and so on, but these small points are of more interest to the editor of the work than to the reader. One's main feeling should be one of gratitude for a book which is not only full of fine pictures but also full of useful information. B.W.A.

SÖHNGE (G.). *Tsumeb, a historical sketch.* 2nd edn. Committee of the S.W.A. Scientific Society, Windhoek, 1976. pp. 92. (Scientific Research in South West Africa, 5th series.) Price on application.

The Tsumeb area, long celebrated among mineralogists, produces copper, lead, zinc, cadmium, silver and germanium. Mining began in the 1870's but the main construction of pit gear and larger exploitation did not begin until the early 1900's. To the mineralogist the minerals resulting from oxidation of the primary ore deposits are of the greatest interest. Exploitation still continues and further deposits should be found. M.O'D.

ASSOCIATION NOTICES

MR B. W. ANDERSON

Mr B. W. Anderson, B.Sc., F.G.A., Vice-President of the Association, is to be congratulated on having been elected a Fellow of King's College, London.

FELLOWS' ACTIVITIES

On the 8th June, 1977, Mr M. J. O'Donoghue, M.A., F.G.S., F.G.A., gave a demonstration of some of the recently produced synthetic crystalline materials to the Swiss Gemmological Association at Villars-sur-Ollon, Vaud, Switzerland: many specimens were available for individual microscopic examination.

The Rev. S. B. Nikon Cooper, B.D., F.G.A., and Mrs Nikon Cooper had the honour of being presented to H.M. the Queen Mother at the Buckingham Palace Garden Party on Tuesday, 26th July, 1977, when they enjoyed some minutes' conversation with Her Majesty.

GIFTS TO THE ASSOCIATION

The Council of the Association is grateful to the following for their gifts:

Mr B. D. Fernando, Colombo, Sri Lanka, for First Day Cover stamps – Special Issue – 7th April, 1977, handicrafts of Sri Lanka – with gemmological interest, one with a jewellery box and the other with a caparisoned elephant in ivory.

Mr Michael van Moppes, of Wessex Impex Ltd, for one fine specimen of "potato stone" from Dulcote, Somerset, together with four other good specimens of the material being mined.

MEMBERS' MEETINGS

North-West Branch

On the 26th June, 1977, a visit was made to Castleton, Derbyshire, the interesting old mining area where specimens of calcite, fluorite and barytes may be found.

South Yorkshire Branch

A joint field trip with the Sheffield Amateur Geological and Lapidary Society was held on the 3rd July, 1977, to Dirtlow Rake and Pindale. Pink banded barytes, fluor, galena and calcite may be found at Dirtlow Rake, and fluor crystals, calcite crystals, hydrocarbons and various fossils at Pindale.

OBITUARY

Mrs Alix Stewart (D. 1956), Scotland, died on the 24th June, 1977.

EXAMINATIONS 1978

The dates for the 1978 Gemmological Examinations are as follows:

Preliminary: Theory, Tuesday, 27th June

Diploma: Theory, Wednesday, 28th June
Practical, Tuesday, 27th June, Thursday, 29th June or Friday, 30th June (London). Other centres as arranged.
Gem Diamond Examination: Monday, 12th June.

The *final* date for entry is the 1st March.

Entry forms available from the Association.

DIALDEX REFRACTOMETER

We are pleased to announce that the Dialdex Refractometer is now available from stock.

ANNUAL GENERAL MEETING

The 47th Annual General Meeting of the Association was held at Saint Dunstan's House, Carey Lane, London, E.C.2. on the 23rd May, 1977.

The Chairman, Mr Norman Harper, welcomed members and expressed particular thanks for the work that the Examiners undertook, especially with the large increase of entrants and the fact that it had to be done during the summer period. He also mentioned that because of the large number of failures in the Diploma Examination it seemed essential to raise the standard required for a pass in the Preliminary Examination and stated that the Council had decided to raise the pass standard in the Preliminary Examination to the same as that required in the Diploma. The Chairman also thanked members of Council, Branch Representatives and Instructors for the time that they gave up for the Association.

The Chairman then proposed the adoption of the Annual Report and Accounts which was seconded by Mr John Roach and duly carried.

Sir Frank Claringbull was re-elected President, Mr N. A. Harper re-elected Chairman, Mr D. King re-elected Vice-Chairman and Mr F. E. Lawson Clarke re-elected Treasurer.

Mrs S. Hiscox and Messrs E. M. Bruton, D. J. Ewing, and M. J. O'Donoghue were re-elected to the Council.

The Chairman announced that Messrs Hard Dowdy, Watson Collin & Co., Chartered Accountants, had signified their willingness to continue as Auditors.

Finally the Chairman expressed the Association's thanks to the Goldsmiths' Company for the ready willingness of the Wardens to place various rooms at the Hall at its disposal for meetings whenever convenient, saying "we are greatly indebted to them."

COUNCIL MEETING

At a meeting of the Council held on Monday, 23rd May, 1977, at Saint Dunstan's House, the following were elected to membership:

FELLOWSHIP

Douglas, David N., Market Drayton. D. 1966
Heyerdahl, Sten S., Oslo, Norway. D. 1969
Jucker, Ronald W., Urdorf, Switzerland. D. 1975
Penn, Leslie, Birmingham. D. 1949

ORDINARY MEMBERSHIP

Aiyadurai, William K., Seattle, Wash., U.S.A.
Ariyaratna Bandara, Panik M., Colombo, Sri Lanka.
Asquith, Lynn C., Bradford.
Carlsson, Gosta, Stockholm, Sweden.
Cheung, Kai Yuen, Happy Valley, Hong Kong.
Clarke, Kathleen D., London.
Coghlan, James, London.
D'Arcy, John P., Kitwe, Zambia.
de Souza, Ceclia M., Tokyo, Japan.
Douglas, John J., Cardiff, N.S.W., Australia.
Duroc-Danner, Jean-Maric, Geneva, Switzerland.
Fernando, Ivor S. M., Manchester.
Ford, Robert, Birmingham.
Foucart, Daniel, De Pinte, Belgium.
Harada, Naeo, Hyogo-Pref., Japan.
Harrington, Christine M., Seattle, Wash., U.S.A.
Hill, Ronald H., Welwyn.
Hoffmeister, Martha, Spokane, Wash., U.S.A.
Ito, Mamoru, Kanagawa-Ken, Japan.
Kemp, Philip M., Stoke Bishop, Bristol.
Knight, David J. R. E., London.
Kobayashi, Hideharu, Tokyo, Japan.
Koller, Robert W., Cherry Tree, Pa, U.S.A.
Mackenzie, Elizabeth A. D., Salisbury, Rhodesia.
Mallawarachchi, Lakshman M., Nyeri, Kenya.
Murray-Jones, Pauline A., Hong Kong.
Niyaz, M. Fareed, Dharga Town, Sri Lanka.
Ranasinghe, Jayampathy P., Kuruwita, Sri Lanka.
Ransom, Hugh M., London.
Sanchez, Bridget E., London.
Seal, Paul S., Cardiff.
Spiro Adnoes, Linda, Jakarta, Indonesia.
Spiro Haccou, Joyce G., Jakarta, Indonesia.
Streep, Norbert A., London.
Takagi, Nobumistu, Kanagawa-Ken, Japan.
Takaki, Shizuo, Sendai-City, Japan.
Tanayaviriya, Sayree, London.
Van Den Bergh, Joseph W., Salisbury, Rhodesia.
Van Der Maden, Pieter, Vlissingen, Netherlands.
Wijesuriya, Lal, Singapore.
Wilson, Hiroko, Hong Kong.
Withycombe, Darroch B., St. John's, Nfd, Canada.
Zimmer, Alvin F., Tucson, Ariz., U.S.A.

LETTERS TO THE EDITOR

From Mr C. A. Schiffmann, F.G.A., G.G.

With reference to "The 'Black Pearls' of Guyana" by Mr Gosling in the *Journal of Gemmology*, 1976, XV, 4, 209, the mode of formation of these items seems to be not known with certainty. May I suggest a possible hypothesis?

Considering the size, the shapes of the items illustrated, and the local conditions under which they have been found, in my opinion there is a striking analogy

with similar items described by U. Büchi, Zürich, 1968, at the International Geological Congress in Lucerne. I had myself the opportunity of getting quite a number of these pieces on their spot of occurrence in the Canton of Berne, Switzerland, from the man who discovered them, and I reported on them at the XIIth International Gemmological Conference in Stockholm, 1968. Similar objects have been mentioned already in 1932, 1934 and 1944. From the former studies, it seems quite evident that these are coprolites from long extinct animal species.

As I expect this is not generally known, I enclose a reprint of the corresponding paper I wrote for the *Schweizer Goldschmied* (August 1969) – a journal little known outside Switzerland and, since then, merged into the *Schweizer Uhrmacher– und Goldschmiede-Zeitung*. If you would deem it interesting for your readers to have this paper published in an English version, I should gladly agree to it.*

From the irregular shapes in Fig. 2 of Mr Gosling's article, the items appear somewhat flattened. Consequently it is probable that they were soft originally and have hardened in the course of time, together with partial replacement which might make for the limonite (goethite) stated. My suggestion would be to investigate them for remains of fossilized micro-organisms and for the presence of phosphate. The measurements mentioned (2 to 20 mm) are partly larger than the ones of the items found in Switzerland (3 to 10 mm) and might be accounted for by a larger species producing them. As these cases demonstrate, all items contemplated for jewellery purposes do not necessarily have a very noble origin!

I hope to have contributed something to clear up the question posed by Mr Gosling's article.

Yours sincerely,
C. A. SCHIFFMANN

11th January 1977. Gübelin Gemmological Laboratory, Lucerne.

From Mr E. A. Jobbins, B.Sc., F.G.A. and Dr M. T. Styles, B.Sc., Ph.D.

Dear Sir,

"Black Pearls" and Coprolites

You have very kindly drawn our attention to the letter from Mr C. A. Schiffmann concerning the origin of the "Black Pearls from Guyana" described by Gosling (Gosling 1976).

We have now re-examined the Guyanese "black pearl" specimens presented by Mr Gosling to the IGS collections (MI 35396) and a spherical black coprolite from Switzerland supplied by Mr Schiffmann, using the energy-dispersive x-ray analyser on the Geoscan electron microprobe. Approximate concentrations of major elements have been calculated from raw data by direct comparison of measured intensities with known standards. Relative errors could be significant but the results are nonetheless useful for the purposes of this investigation.

The outer surface of the coprolite "pearl" from Switzerland was analysed and consists of major Ca, P and Si, minor Al, Fe and K and traces of Mg, Na, Ti, Cl and S. The approximate composition is 32% CaO, 25% P_2O_5 and 10% SiO_2 with the minor and trace elements possibly accounting for 10% by weight; the remainder is probably accounted for by OH, organic and other constituents with

*A slightly shortened version, translated into English, appears on pp. 445-453 *supra*. – Ed.

atomic numbers below 11 which are not detectable using this analyser. The concentrations of Si and the minor elements varied within the outer surface of the specimen. The concentrations of Ca and P are consistent with the specimen being largely composed of apatite, which accords with a coprolitic origin as suggested by Mr Schiffmann.

Three "black pearls" from Guyana were sectioned. Two had the concentric structure illustrated in Gosling's paper, whilst a third consisted of quartz grains cemented by a brown ferruginous (limonitic) material with a very dark brown continuous outer surface coating. The specimen illustrated by Gosling was semi-quantitatively analysed by the electron microprobe and an area scan gave major Fe, Al, minor Si, Ti and trace (less than 1% by weight) Mg, P, S, Cl, K and Ca. This gives an approximate composition of 65% Fe_2O_3, 8% Al_2O_3, 4% SiO_2 by weight. The outer 'skin' is richer in Fe (approx 75%) and in Al (approx 12%) and lower in Si (approx 1%) with a trace of Cr. Near the centre and elsewhere are distinct quartz grains. The dark layers which accentuate the concentric structure are slightly richer in Si, Al, K and S which possibly indicates the presence of fine-grained clay minerals and pyrite.

The "pearls" from Guyana are thus essentially composed of an iron mineral – limonite (goethite). Much of the Al is probably present as bauxitic mineral(s) such as gibbsite, some Si as quartz grains, and some Si with Al as clay minerals in clayey layers. Neither phosphorus nor calcium was detected in concentrations greater than 1% – both elements are commonly found in coprolitic material. Taking into account the concentric growth structure and the chemical composition it appears most unlikely that the "black pearls of Guyana" are coprolitic in origin.

Gosling describes the occurrence of the 'black pearls' in light yellowish clay with some subangular quartz pebbles and comments that they are more abundant on the gently sloping banks of creeks and are concentrated at the heads of similar creeks; Bleackley (1964) notes that bauxites in Guyana are frequently underlain by kaolinitic clays. Pisoliths comparable with the "pearls" are a common constituent of many laterites which have been formed as surface or sub-surface deposits in tropical areas with oscillating water tables (see MacFarlane 1976, p. 70) and it seems probable that the "black pearls" formed as pisoliths in laterite deposits which are now being eroded by river action.

Yours sincerely,

E. A. Jobbins
M. T. Styles

7th July 1977. Institute of Geological Sciences, London, SW1 2DE.

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CORRIGENDA

In the printing of each of the penultimate and antepenultimate lines of Table 4 on p. 247 *supra* the tilde was unfortunately omitted over the ν, and the last three lines of the Table should read as follows:

5. Energy $E = \tilde{\nu} \times 1{\cdot}99 \times 10^{-16}$ ergs,
$= \tilde{\nu} \times 1{\cdot}24 \times 10^{-4}$ eV,
$= \tilde{\nu} \times 2{\cdot}86$ cals/mole.

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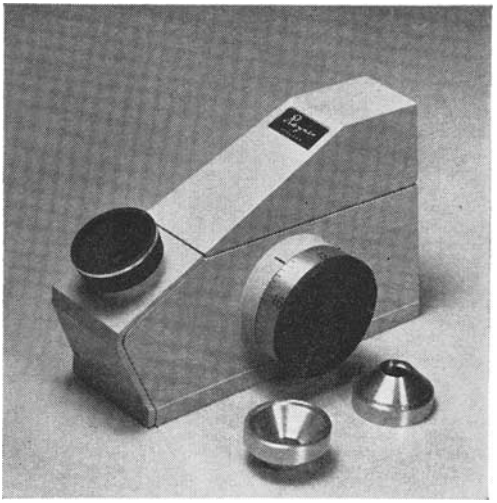

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THE JOURNAL OF GEMMOLOGY

and

PROCEEDINGS OF THE GEMMOLOGICAL ASSOCIATION OF GREAT BRITAIN

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CHAROITE, A SPECTACULAR, NEW, PURPLE MINERAL*

By E.A. JOBBINS, R.J. MERRIMAN and M.T. STYLES

Institute of Geological Sciences, London, SW7 2DE

In June 1977 a spectacular purple vase was brought to the Institute for investigation by Mr C.R. Cavey, of Roughgems Ltd. The vase was a forerunner of other material to be imported, possibly in some quantity, from the Charo river area in the Murun Massif, north-west Aldan, Yakutsk ASSR, USSR. The importers were told that the material was known as charoite.

As will be seen from the colour plate the charoite is of varying shades of vivid purple; on the Munsell System of colour notation the hues are between 2.5P and 5P, the values between 4 and 6 and the chroma between 6 and 10; a typical colour is 2.5P 5/10. It has a distinct fibrous appearance and wraps around subordinate masses of a greenish black mineral some of which appears to have been corroded during some episode in its history, but other areas show stellate acicular development. The vase also shows 'pools' of a pale greenish-grey translucent mineral, a prismatic orange mineral and small specks of a silvery metallic mineral with dark green haloes. The overall mineral assemblage is most unusual.

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Specific gravity measurement on the vase and a small slab both gave a value of 2.68. Refractive index determinations from the flatter surfaces gave values around 1.55 for the charoite and 1.52-1.53 for the areas of greenish-grey mineral. A scraping of the charoite from the base gave an x-ray powder diffraction pattern, which could not be matched in the Powder Diffraction File (JCPDS), with strong lines at 32Å, 12.42Å, 3.34Å, 3.20Å, 3.12Å, 2.97Å, and 2.79Å. Spacings as large as 32Å are not commonly recorded from minerals and this line is easily missed without the use of a low-angle collimator and beam trap. A semi-quantitative analysis was then obtained using the Energy-dispersive x-ray analyser on the Geoscan electron microprobe. The results indicated approximately 55% SiO_2, 20% CaO, 8-10% K_2O; 2-3% of BaO and Na_2O by weight and traces (less than 1%) of Fe, Al and Mn. Thus the charoite is essentially a calcium potassium silicate.

From x-ray and optical examination we were able to identify in the rock, greenish-black aegirine-augite, pale greenish-grey potash-feldspar (microcline), prismatic orange tinaksite (a titanium, sodium, potassium silicate described from the same area, (Rogov *et al.,* 1965)). The rock is dominated by the fibous purple charoite which has low birefringence, positive elongation, with an extinction angle of only a few degrees.

We have since learned that the purple mineral has now been fully investigated by the Russians (Rogova *et al.,* in press), who propose a formula of $(Ca,Na)_2KSi_4O_{10}(OH,F).H_2O$. The name charoite, which was first published in October 1976 (Nikol'skaya *et al.,* 1976), has been approved by the International Mineralogical Association and since a full mineralogical account is in press it was inappropriate that we should pursue our studies further. However, material is now becoming available commercially and it seems desirable that sufficient information should be presented to allow identification.

In conclusion, charoite occurs as a fibrous purple mineral (but also appears in a fine grained form) which dominates a spectacular metasomatic rock formed at limestone contacts from the Murun massif, north-west Aldan, USSR. Refractive indices on polished charoite surfaces are around 1.55, and the specific gravity of the rock is 2.68. Charoite appears inert under both UV radiations (but its purple colour and the visible violet radiation from the lamps makes accurate observation difficult); the associated feldspar glows

Vase (18.5 cm high) showing fibrous purple charoite wrapping around black aegirine-augite, with 'pools' of greenish-grey microcline and orange tinaksite, Charo River, north-west Aldan, Yakutsk, USSR.

a dull red under long wave (365 nm) radiation. There is no distinctive absorption spectrum apart from partial general absorption of the green. The hardness is between 5 and 6 on Mohs' scale.

A fine vase of charoite is now on display in the Geological Museum, London, kindly lent by Roughgems Ltd, London. Finally we should like to thank colleagues in the IGS for assistance in many ways.

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ON THE COMPOSITION OF GEM SCAPOLITES

By PETE J. DUNN, JOSEPH E. NELEN and JULIE NORBERG

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INTRODUCTION

Scapolite is a group name applied to a solid solution series between two end-members. The end-members are marialite, $Na_4Al_3Si_9O_{24}Cl$, and meionite, $Ca_4Al_6Si_6O_{24}CO_3$. Petrologists frequently subdivide the group further using the names mizzonite and dipyre for intermediate compositions, but since the scapolite group is a two-member series, the gemmologist uses but two names. Scapolites with appreciable sulphate content are known, but have not yet been encountered as gem material.

Hence, scapolites with Ca>Na (in atom per cent) are meionite, and those with Na>Ca (in atom per cent) are marialite. Since few

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gem scapolites have been chemically analysed, this effort was initiated to determine as precisely as possible the compositions of gem scapolites from different localities, and to determine whether or not gem material is limited to any given composition.

PREVIOUS WORK

For an overview of gem scapolite, the reader is referred to Webster (1975). Scapolites from Espirito Santo, Brazil, and Madagascar were examined by Perizonius (1966) and found to be meionite, adopting the nomenclature discussed previously. The yellow scapolites from Umba, Tanzania, were described in detail in an excellent paper by Zwaan (1971), who also noted and photographed the inclusions present in the material. Bank and Nuber (1970) described the scapolites from Entre Rios, Mozambique. For a more detailed explanation of scapolite chemistry, the reader is referred to the work of Evans *et al.* (1969).

PHYSICAL PROPERTIES

Meionites have a higher density than marialites, but the density is not a reliable indicator of composition due to the complex ionic substitutions prevalent in most scapolite. The refractive indices of this uniaxial negative gem are far more reliable as an indicator of composition. Both the refractive indices and the birefringence increase with increasing calcium content, and reliable charts have been prepared which correlate the refractive indices with composition (Deer *et al.*, 1963 and Bank, 1970). The refractive indices for the four faceted gems examined in this study are given in Table 1. The determinations were made using sodium light and a

TABLE 1

OPTICAL DATA FOR SELECTED GEM SCAPOLITES

NMNH#	*Locality*	*Colour*	*Species*	ε	ω	*Birefringence*
G1819	Madagascar	Colourless	Marialite	1.552	1.569	0.017
G1818	Madagascar	Colourless	Marialite	1.546	1.562	0.016
G3674	Burma	Pink	Marialite	1.545	1.558	0.013
G3783	Burma	Lt Yellow	Meionite	1.554	1.587	0.033

all measurements ± 0.003

Rayner Dialdex refractometer. All of the examined gems and gem rough were also examined with ultraviolet, since most scapolites exhibit fluorescence in ultraviolet radiation. The results of these observations are noted, together with the chemical analyses, in Table 3.

CHEMISTRY — WET CHEMISTRY

A gem-quality scapolite from Brazil weighing about 20 carats was subjected to a full wet-chemical analysis. The sample was crushed to 60-80 mesh size for use as an electron microprobe standard. The sample portion <80 mesh was ground in a boron carbide mortar for chemical analysis.

The general scheme of analysis followed methods described in the literature: Peck (1964), Jarosewich (1966), Hillebrand *et al.* (1953). Silica was filtered off after double dehydration with HCl, followed by ignition and volatilization with HF. Further recovery of silica was made in the R_2O_3 precipitate. The iron was determined

TABLE 2

WET-CHEMICAL ANALYSIS OF BRAZILIAN MEIONITE

SiO_2	49.78%
Al_2O_3	25.05
FeO	0.17
CaO	13.58
Na_2O	5.20
K_2O	0.94
CO_2*	2.5
SO_3	1.32
Cl	1.43
H_2O^+**	0.21
	100.18
O = Cl	0.32
TOTAL	99.86

Specimen # R6600
analyst: J. Nelen
*J. Norberg

colorimetrically as the *o*-phenanthroline complex. The aluminium was weighed as the 8-hydroxyquinolate. Calcium was precipitated as the oxalate and ignited to CaO. Separate samples were used for CO_2—volatilization with an HCl/HF mixture and absorption on ascarite; the alkalies—flame photometrically; H_2O^+ by the Penfield method; chlorine—as silver chloride; and sulphur—as barium sulphate. Appropriate blanks were carried through the various steps and corrections made accordingly. The analysis is given in Table 2.

CHEMISTRY—MICROPROBE ANALYSES

Nineteen gemmy scapolites from the collections of the Smithsonian Institution were analysed. All the samples were of facetable quality except one from Canada. The lot was comprised of 7 cut gems from the exhibit hall, and 12 uncut gemmy crystals. The samples were analysed using an electron microprobe with an operating voltage of 15 kV, and a sample current of 0.15μA. The data were corrected by computer using Bence-Albee correction factors. The standard used for all elements was the Brazilian scapolite cited in Table 2. The microprobe analyses of seventeen of these samples are given in Table 3, in order of decreasing calcium content.

CHEMISTRY—GENERAL COMMENTS

The gem scapolites examined in this study are all mixtures between marialite, $Na_4Al_3Si_9O_{24}Cl$, and meionite, $Ca_4Al_6Si_6O_{24}CO_3$. None of the samples examined were pure end-members. The ionic substitutions involved in the series are complex; in mixtures between marialite and meionite, aluminium increases and silicon decreases as calcium increases. Further, calcium-rich members of the series have substantial $CO_3^=$ (carbonate) and sodium-rich members contain chlorine. Hence, only end-member marialite and meionite have simple compositions. It is obvious from an examination of the summations of the analyses in Table 3, that calcium-rich members have low summations. This is due, for the most part, to the presence of carbon which is not detectable by microprobe analysis. Small amounts of water (>1.00% in some meionite analyses) are also not detectable by microprobe and lower the summations slightly.

TABLE 3

MICROPROBE ANALYSES OF GEM SCAPOLITES

LOCALITY	NMNH#	SiO_2	Al_2O_3	FeO**	CaO	K_2O	Na_2O	Cl	SO_3	O=Cl	TOTAL	%Me*	body colour	Ultraviolet luminescence short-wave	Ultraviolet luminescence long-wave	Species
Burma	G3783	45.33	27.15	0.31	17.38	1.10	2.82	0.64	0.00	0.15	94.58	72	colourless	medium pink	weak pink	Meionite
Quebec, Canada	R13120	47.07	25.67	0.04	15.99	0.50	3.95	0.41	1.22	0.09	94.76	67	yellow-green	medium yellow	strong yellow	Meionite
Tanzania	136405	48.39	25.57	0.01	15.47	1.08	3.63	0.56	0.66	0.13	95.54	64	yellow	medium yellow	strong yellow	Meionite
Madagascar (?)	R6570	50.04	25.25	0.16	13.80	0.94	5.13	1.41	1.54	0.32	97.95	57	colourless	medium pink	weak pink	Meionite
Minas Gerais, Brazil	B16098	49.39	25.00	0.22	13.79	1.03	4.80	1.32	1.61	0.30	96.86	57	light yellow	medium pink	weak pink	Meionite
Mogok, Burma	R11157	49.02	24.95	0.21	13.71	1.03	4.94	1.37	1.64	0.31	96.56	57	light yellow	medium pink	weak pink	Meionite
Minas Gerais, Brazil	133041	49.88	24.97	0.20	13.45	0.99	5.17	1.37	1.53	0.31	97.25	56	light yellow	medium pink	weak pink	Meionite
Minas Gerais, Brazil§	R6623	49.24	24.75	0.13	13.06	0.90	5.43	1.48	1.05	0.34	95.70	54	light yellow	medium pink	weak pink	Meionite
Brazil	123502	50.86	24.37	0.10	11.93	0.91	6.18	1.78	0.66	0.41	96.38	50	light yellow	medium pink	none	Meionite
Sri Lanka	G3238	51.53	24.31	0.07	11.59	0.95	6.22	1.59	0.20	0.37	96.09	49	light pink	light orange	medium orange	Marialite
Madagascar	G1819	51.21	23.62	0.13	11.22	0.60	6.79	1.76	0.76	0.40	95.69	47	colourless	medium pink	light pink	Marialite
Madagascar	G1818	51.77	23.66	0.14	10.90	0.57	6.80	1.90	0.76	0.44	96.06	45	colourless	medium pink	light pink	Marialite
Betroka, Madagascar	117358	54.80	22.64	0.36	8.60	1.70	7.69	2.85	0.43	0.65	98.42	36	colourless	medium pink	light pink	Marialite
Tanzania	.....	55.79	22.23	0.21	7.89	1.32	8.37	2.69	0.55	0.62	98.43	33	light yellow	medium pink	light pink	Marialite
Tanzania	134794	55.32	22.21	0.20	7.30	1.59	8.64	2.93	0.79	0.67	98.31	30	brown-yellow	medium pink	none	Marialite
Entre Rios, Mozambique	132483	55.91	22.41	0.08	7.30	1.38	8.85	3.11	0.16	0.71	98.49	30	colourless	medium pink	none	Marialite
Burma	G3674	55.02	22.62	0.05	7.25	1.82	8.66	2.90	0.29	0.69	97.92	30	pink	light orange	medium orange	Marialite

§ - from Rio Pardo, Minas Gerais, Brazil
* - percentage of the meionite end-member
** - total iron calculated as FeO
accuracy of data ± 3% relative
all samples have less than 0.10% MgO

DISCUSSION

It is apparent from the analyses presented in Table 3 that the compositions of the gem material examined in the study vary from meionite $_{72}$-marialite$_{28}$ to meionite$_{30}$-marialite$_{70}$. All four specimens from Brazil are meionite, the calcium-rich end-member, and are quite similar in composition. The examined Madagascar gems, however, are marialite, the sodium-rich end-member. One sample, #R6570 is of questionable locality and the (Madagascar?) designation indicates this uncertainty of its provenance. Given the fact that the other Madagascar scapolites are marialite, this may very well be a Brazilian specimen.

Unlike the Brazilian meionites, the Madagascar marialites do vary widely in composition. Burmese scapolites also have widely varying compositions and it is noteworthy that the most sodium-rich and most calcium-rich gems examined in this study do come from Burma. The sample numbered G3783 is a superb 288 carat colourless gem and may be the largest cut scapolite in existence, in addition to being the most calcium-rich. Also of Burmese origin are some white or grey chatoyant gems, which yield very fine cat's-eyes. Due to the cabochon-cut and the requirement that we must have a flat surface for accurate microprobe analyses, only semi-quantitative analyses could be performed on these two gems. The resultant analyses (not given here) indicate these Burmese chatoyant scapolites have compositions near a mid-point in the series. The light yellow material from Tanzania, studied by Zwaan (1971), is marialite, as Zwaan noted in his excellent description of the material.

The most unusual scapolite the authors have seen was brought to their attention by Mr Herb Obodda, a noted American gem merchant. This scapolite, reportedly from Tanzania, has a very strong yellow body colour and the piece examined is facetable. The fluorescence of this material in ultraviolet radiation is remarkable for a gem mineral. The fluorescent colours are a strong yellow in short wavelength ultraviolet and an extremely intense strong yellow in long wavelength ultraviolet. There is no phosphorescence. Only a tiny chip of the material was available for analysis and the optical properties were not measured. However, the material does come in pieces large enough to cut gems of several carats. This yellow scapolite is very weakly fluorescent in x-radiation with a light yellow fluorescence and phosphorescence. This yellow gem

material is a meionite, unlike the other Tanzanian gems examined, and has a composition very close to the opaque Canadian material (#R13120), which has a similar if somewhat less intense fluorescence.

In summary, gem scapolites have varying compositions. The Brazilian gems examined are meionite and the Madagascar gems examined are marialite. Light yellow Tanzanian scapolites are marialite, and the composition of Burmese material varies widely.

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AN INSIGHT INTO CRYSTAL GROWTH TECHNIQUES

By J.D.C. WOOD, B.Sc.

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1. INTRODUCTION

What are single crystals and why are they important?

A crystal is an ordered structure on an atomic scale; in a single crystal this order persists in three dimensions to the external boundaries, unlike a polycrystalline or ceramic solid which is composed of many smaller crystals, often of random orientation.

For the physicist interested in measuring the properties of materials, or the technologist making devices, an ordered assembly of atoms provides the ideal or optimum arrangement for the production of useful physical properties, in particular co-operative phenomena, e.g. lasers, oscillators. This is in contrast to a polycrystalline solid, where the grain boundaries between the crystallites not only interfere with physical processes but even dominate the bulk properties. Unfortunately, perfect single crystals do not exist in nature, and the scientist has to accept the fact that even in the laboratory as-grown crystals will contain imperfections on a micro- or macro-scale.

From the viewpoint of the crystal grower the role of imperfections also has important implications. To understand the reason why, we must examine how real crystals grow. The underlying theme throughout will be the control of growth processes, since only by understanding and control of the underlying mechanisms can the crystal grower hope to achieve an acceptable product.

2. THE BASIC GROWTH PROCESS

To produce an ordered solid (crystal) from relative disorder, e.g. gas, liquid or solid, involves a phase transformation and a change in the volume free energy—thus some *driving force* is necessary. The most common driving forces in crystal growth processes are produced via a concentration gradient (ΔC) or a

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temperature gradient (ΔT), though others are possible, e.g. electrochemical potential via an applied voltage.

It is usual to analyse a growth system theoretically in terms of a single driving force—but invariably several operate in parallel with one dominating.

The overall driving force causes a net flow of atoms down the gradient to the solid interface and the subsequent removal of evolved latent heat. It is obvious that surface processes at this *growth interface* play a vital role. It is here that atoms finally become incorporated into the crystal, possibly after diffusion across the surface, and the manner in which they do so determines the final ordering in the crystal. The growth rate and the subsequent perfection of the bulk crystal lattice will depend on (a) the magnitude of the driving force and (b) the physical nature of the interface.

Two extreme types of interface will be mentioned here and denoted *rough* and *smooth.* A comparison of the two (Fig. 1)

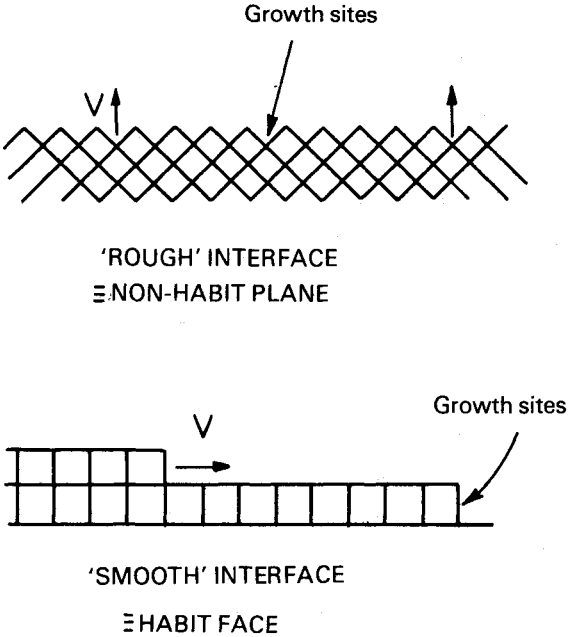

FIG. 1

reveals a fundamental difference: a rough interface always has available growth sites over the whole surface, while a smooth interface only offers growth sites at steps and growth must proceed by lateral spreading of layers. In this case, to grow at low supersaturations, i.e. small driving force, it is necessary to have a continuous source of new layers, and the existence of spiral sources, or other defects due to slipped planes of atoms, does provide these in practice. It is thus interesting to note that the presence of defects can actually aid the growth process. A practical demonstration of this is that under identical conditions damaged crystals will grow faster than perfect ones.

In general, for a given magnitude of driving force, growth is easier on a rough interface as there is no surface diffusion process to be driven. Put another way, we expect faces corresponding to rough faces to grow at lower supersaturations. Since a smooth interface corresponds to one face of a faceted crystal, while a rough face is generally a non-equilibrium face, which tends to grow out and disappear, it is not surprising to find that slow growth processes such as solution or gel growth produce faceted crystals and vice-versa.

3. Control of Growth Processes

Qualitatively, we can see that the magnitude of the driving force controls the growth process by determining the growth rate. This implies that we should have means to control ΔC, dominant in solution growth, or ΔT in melt growth. A typical practical method would be to use a temperature sensing element with some feedback loop to the input heating source.

Problems in controlling the interface via growth rate arise if there are fluctuations in the latter caused by

(i) temperature fluctuations—external cause:

(ii) non-steady flow—internal cause (hydrodynamic).

In the presence of impurities, or in a multi-component system, either too fast a growth rate or lack of affinity of the impurity for the lattice can cause a 'pile-up' of atoms ahead of the interface, leading to a local reduction of liquidus temperature. This is a condition known as constitutional supercooling (CSC) and the presence of this renders the interface unstable with the possibility of breakdown and gross inclusions under adverse conditions (Fig. 2).

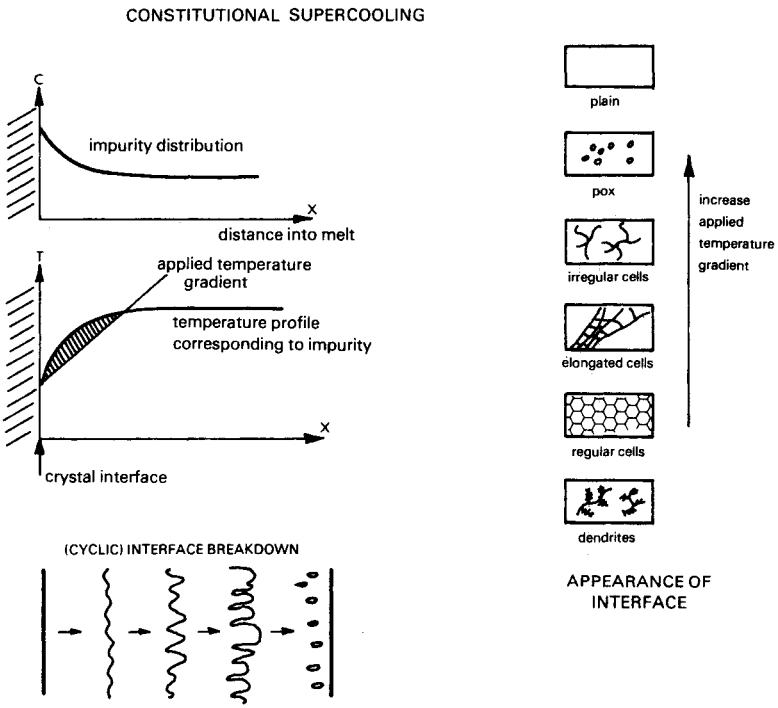

FIG.2

The effect of this can be seen in natural crystals as included bubbles, 'veils' of solution and foreign particles.

In general, the onset of breakdown can be minimized by (a) reducing growth rate, (b) improving temperature control, (c) altering geometry, (d) use of steep temperature gradient at interface etc., depending on the particular case involved.

The crystal orientation—and hence the nature of the growing interface—can be controlled, *a priori,* by the use of appropriate seeds, the 'quality' and preparation of which play a vital role in the subsequent growth, e.g. certain defects may be propagated. Seeds need not be of identical material, but must be chemically compatible and usually a close match in lattice parameter.

4. Doping and Hydrodynamics

It might be thought surprising that hydrodynamics should be at all relevant to crystal growth. However this can be made clear by

a general example, i.e. in any liquid system (also gaseous) where there is a temperature gradient not aligned with g, the force of gravity, then convection can occur. Convection, being a random fluid flow process is undesirable for a crystal growth situation as it represents a process which cannot be controlled. Convection can be used in certain cases to aid homogenization prior to growth, but its occurrence during growth leads to fluctuations at the interface which affect both stability (via CSC) and the momentum boundary layer width, δ, due to the relative motion between solid and liquid which must be zero at the solid. Let us see how this happens.

We can define a segregation coefficient k_o which is simply the ratio of dopant in the crystal to that in solution (Fig. 3). Analysis for a moving (i.e. growing) interface gives

$$k_o = \frac{k^*}{k^* + (1-k^*)\exp(-f\delta/D)}$$

Here f is the growth rate, D is the diffusion coefficient of dopant and k^* is the segregation coefficient at the interface, differing from k_o due to the concentration drop due to diffusion across the interface, i.e. if δ small $k_o \rightarrow k^*$, or if f large (fast growth) $k_o \rightarrow$ unity.

Additionally the dopant concentration in the crystal will reflect variations in both f, e.g. due to temperature fluctuations, and in δ due to the fluid flow effects under discussion.

5. Classification of Growth Processes

Before considering any process in detail, it is worthwhile to consider a classification scheme which covers all growth processes. This provides insight and understanding of how various processes are related.

Firstly, a word regarding purity. It is to be understood that *all* systems contain some impurity, i.e. even semiconductor materials are seldom better than 99.9999% purity. We define a *pure* system as one which contains no deliberately added impurity. Examples of *impure* systems would be

(i) solvent in solution growth;
(ii) dopant to modify properties, e.g. semiconductors, lasers, phosphors;
(iii) halide to provide volatile species in vapour growth.

We shall also distinguish between *Batch* and *Continuous* processes.

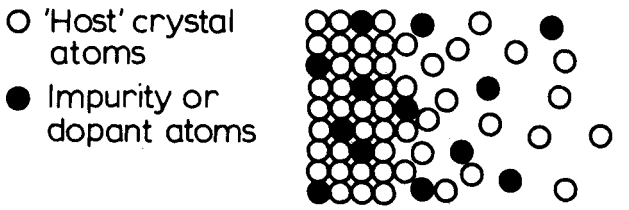

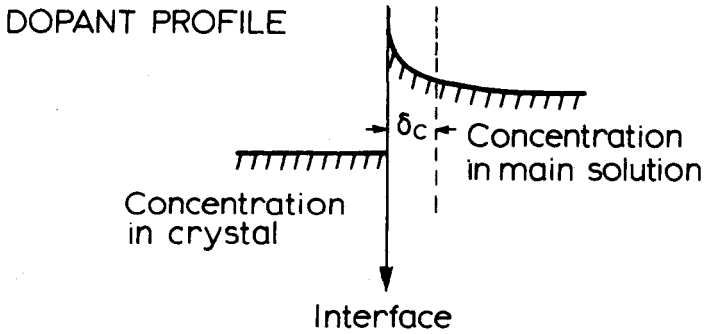

$$\text{SEGREGATION COEFFICIENT} = \frac{\text{AMOUNT IMPURITY IN CRYSTAL}}{\text{AMOUNT IMPURITY IN SOLUTION}}$$

If S.C. < 1 impurity <u>rejected</u> at interface.

For a growing crystal under steady-state conditions

$$k_{eff} = \frac{k^*}{k^* + (1 - k^*)\exp(-V\,\delta_c/D)}$$

k_{eff} is effective S.C.

k^* is S.C. at interface

FIG. 3

CLASSIFICATION OF GROWTH PROCESSES

A. BATCH PROCESSES

Transformation	*Pure System*	*Impure System*
S→S	Strain Anneal	—
L→S	Directional Freeze§	Solution Growth
V→S	Condensation	—

B. CONTINUOUS PROCESSES

Feed	*Growth Zone*	*Pure*	*Impure*
S→	S→S	Phase Transformation	—
L→	S→S	CuCl Growth	Gel Growth
V→	S→S	—	—
S→	L→S	Zone Melting§ - Verneuil§	Travelling Solvent§
L→	L→S	—	Monotectic Growth
V→	L→S	Volatile Feed - Verneuil	VLS Process
S→	V→S	Evaporation →Condensation	Chem. Vap. Transport§ (or Carrier Gas)
L→	V→S		
V→	V→S	—	—

§Most Important Industrial Processes

FIG. 4

CHOICE OF GROWTH TECHNIQUE

(1)	Melting Point?	0—1200°C	Bridgman
		0—2200°C	Pulling or Verneuil
		>2200°C	Fluxed Melt
(2)	Water Soluble?		
	(a) Near Ambient	0—60°C	Water Solution
	(a) Higher Temp./Press	0—600°C	Hydrothermal
(3)	High Vapour Press?		Vapour Transport
	Stable on heating in		Fluxed Melt
	Vacuo, Air, Inert Gas?		Sealed Bridgman
(4)	High Viscosity when Molten →Glassy?		Solution, Flux, CVT
(5)	Melts Congruently?	Yes -	Bridgman Pulling
		No -	Solution, Flux, CVT

Purity	—	Containerless techniques Vapour Phase
Orientation	—	Seeding and Control
Size	—	Relate to time for Diffusion Lim. Process, or Melt Growth
Perfection	—	Slower Growth Technique Unconfined Process
Toxicity	—	Sealing, Fume extraction, Solution

FIG. 5

i.e. *Batch*—a fixed amount of material is processed:
Continuous—new material is added during growth process.

Then, for a single stage (batch) process, there are three transformations,

i.e. $\left.\begin{array}{l}\text{(solid) S}\\ \text{(liquid) L}\\ \text{(vapour) V}\end{array}\right\} \rightarrow \text{S(crystal)}$

and for a two-stage process, nine are possible (see Fig. 4). It should not be expected that all of these will correspond to *practical* growth processes, and in fact, several are either not found or are quite rare in practice.

It is not intended here to describe growth processes in detail; rather we shall compare some of the most important industrial processes to illustrate important similarities and differences and show a few examples of other processes which are used in the laboratory to grow important technological crystals. The factors influencing the choice of a particular technique are indicated in Fig. 5.

6. Directional Freezing Techniques

These are all melt growth processes and heat flow controlled. In the diagram (Fig. 6) the directions of heat flow are indicated. There will usually be some degree of fluid motion, initially laminar, which may become turbulent in extreme conditions. Where there is also relative motion between growth interface and fluid, the flow may more easily become complex and adversely alter the interface shape (Fig. 7), e.g. change from rough to smooth. Conversely, without rotation, flexibility in control would be lost. Thus, the pulling technique is the most versatile of these processes. The crystal diameter is controlled by the rotation speed and the undercooling, while the growth rate is controlled by the pulling speed with a theoretical upper limit set by the rate at which latent heat can be extracted.

They are all important industrial batch processes except that under special circumstances the Czochralski can be made continuous.

Examples of materials grown:-

Kyropoulos : alkali halides
Bridgman : rare earth fluorides
Czochralski : YAG, ruby, silicon

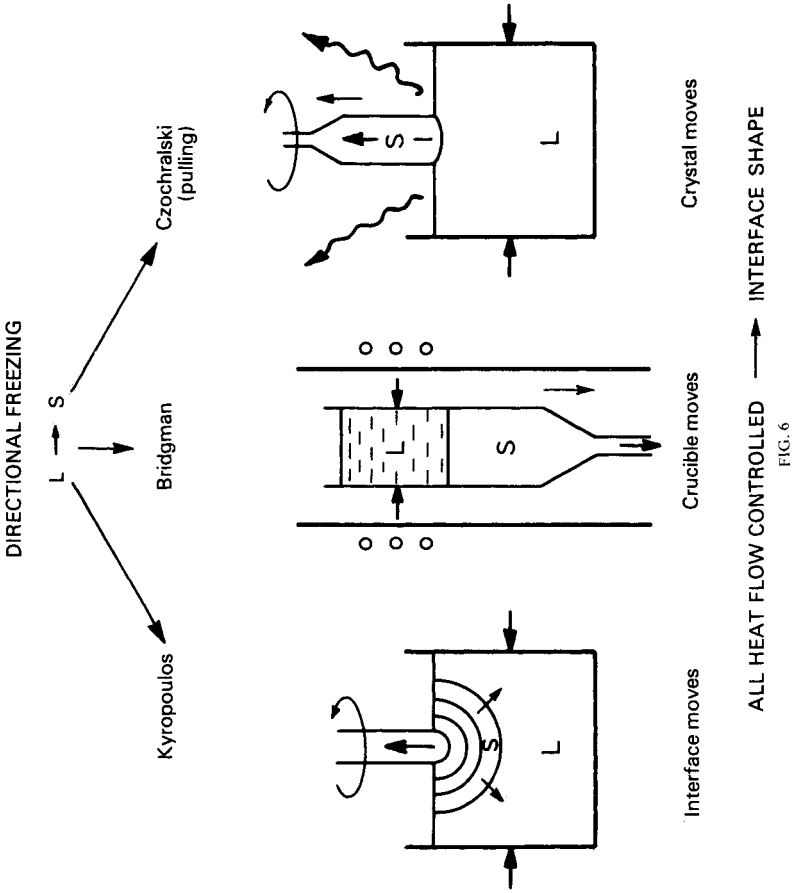
DIRECTIONAL FREEZING
L → S
Czochralski (pulling)
Bridgman
Kyropoulos
S
L
Crystal moves
L
S
Crucible moves
S
L
Interface moves
ALL HEAT FLOW CONTROLLED → INTERFACE SHAPE

FIG. 6

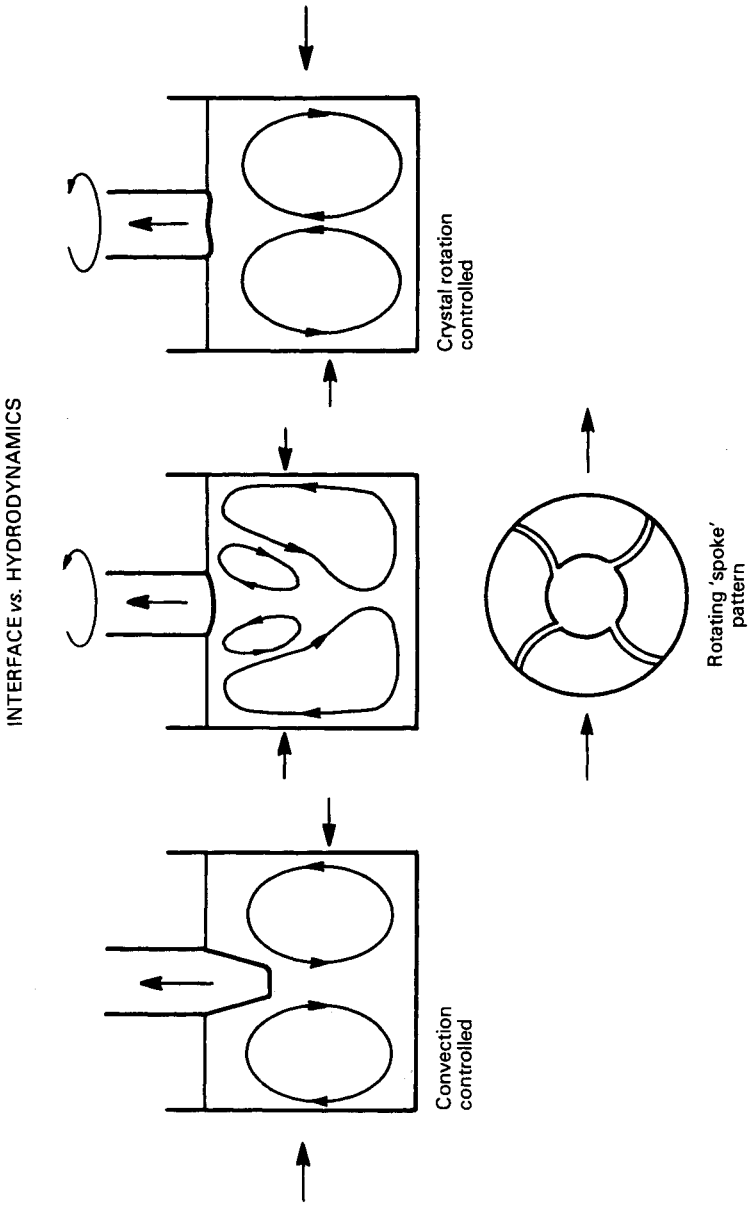
INTERFACE vs. HYDRODYNAMICS
Convection controlled
Crystal rotation controlled
Rotating 'spoke' pattern

FIG. 7

7. Solution Growth Techniques

The major techniques are illustrated schematically in Fig. 8. Apart from the different temperature and/or pressure regimes in which these operate, the methods of growth are quite similar.

Supersaturation, (ΔC), is generated by solvent evaporation, slow cooling or temperature gradient transfer of some source material. Water solution or hydrothermal processes are invariably seeded, while the fluxed melt process usually relies on spontaneous nucleation for the growth of new crystalline materials for research. Seeds can be used, e.g. for growth of larger YIG crystals, although this is more difficult to achieve in practice.

Good fluid mixing is necessary to obtain good growth. Mechanical stirring is used in water solution growth, while the presence of lateral or vertical temperature gradients promotes convective mixing in the other techniques.

Referring to the solubility diagram, the means by which supersaturation arises in the various cases is illustrated, where the solid line is the solubility curve, the dotted line represents the 'growth curve' and the lower curve the metastable limit. XY represents the cyclic process (solvent circulation). It should also be noted that for isothermal evaporation the system remains essentially at B, at a fixed ΔC for growth; while (slow) cooling causes the system to move down the growth curve where ΔC may gradually vary. This has implications for control of surface kinetic processes which are activated processes, varying with the driving force.

For the growth of large crystals, growing three-dimensionally, linear cooling leads to a linear growth rate which falls off $\propto$ (time)^3. The effect of this can be seen when growing doped (transparent) crystals in which doping varies over the cross-section. This can be particularly marked in cases of spontaneous nucleation; when the nuclei form initially, the growth rate is very rapid before the system returns to the growth curve, and such crystals while of good appearance contain highly dendritic centres. With a knowledge of the solubility curve a suitable cooling programme can be devised which maintains the growth rate linear, and in the presence of seed crystals good control over the properties may be achieved.

An important practical consideration is that, generally, melt growth techniques provide the fastest growth rates, of the order of

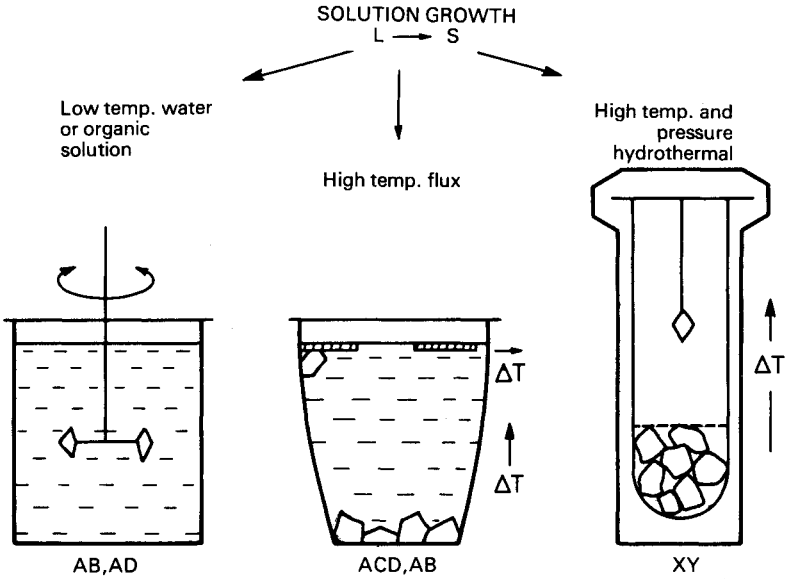
SOLUTION GROWTH
L → S
Low temp. water or organic solution
High temp. flux
High temp. and pressure hydrothermal
ΔT
ΔT
ΔT
AB,AD
ACD,AB
XY

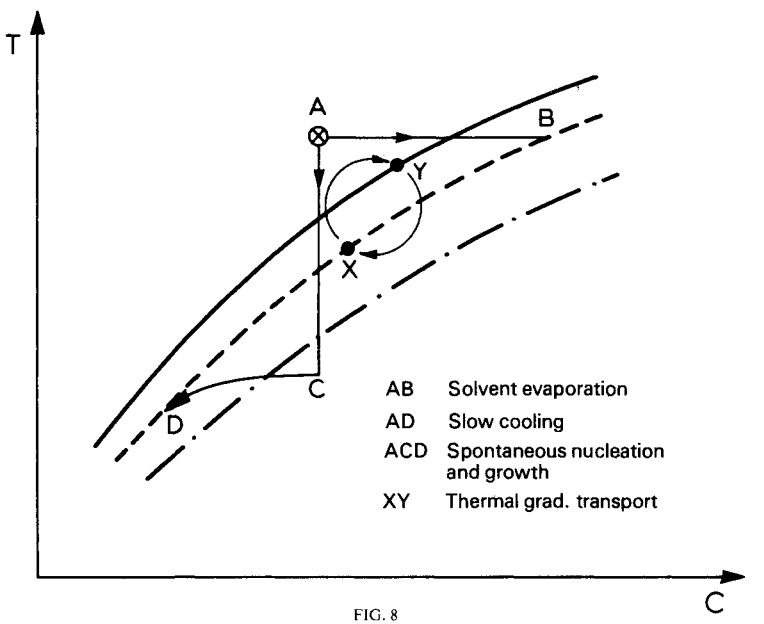
T
C
A
B
Y
X
C
D
AB Solvent evaporation
AD Slow cooling
ACD Spontaneous nucleation and growth
XY Thermal grad. transport

FIG. 8

GROWTH PROCESSES

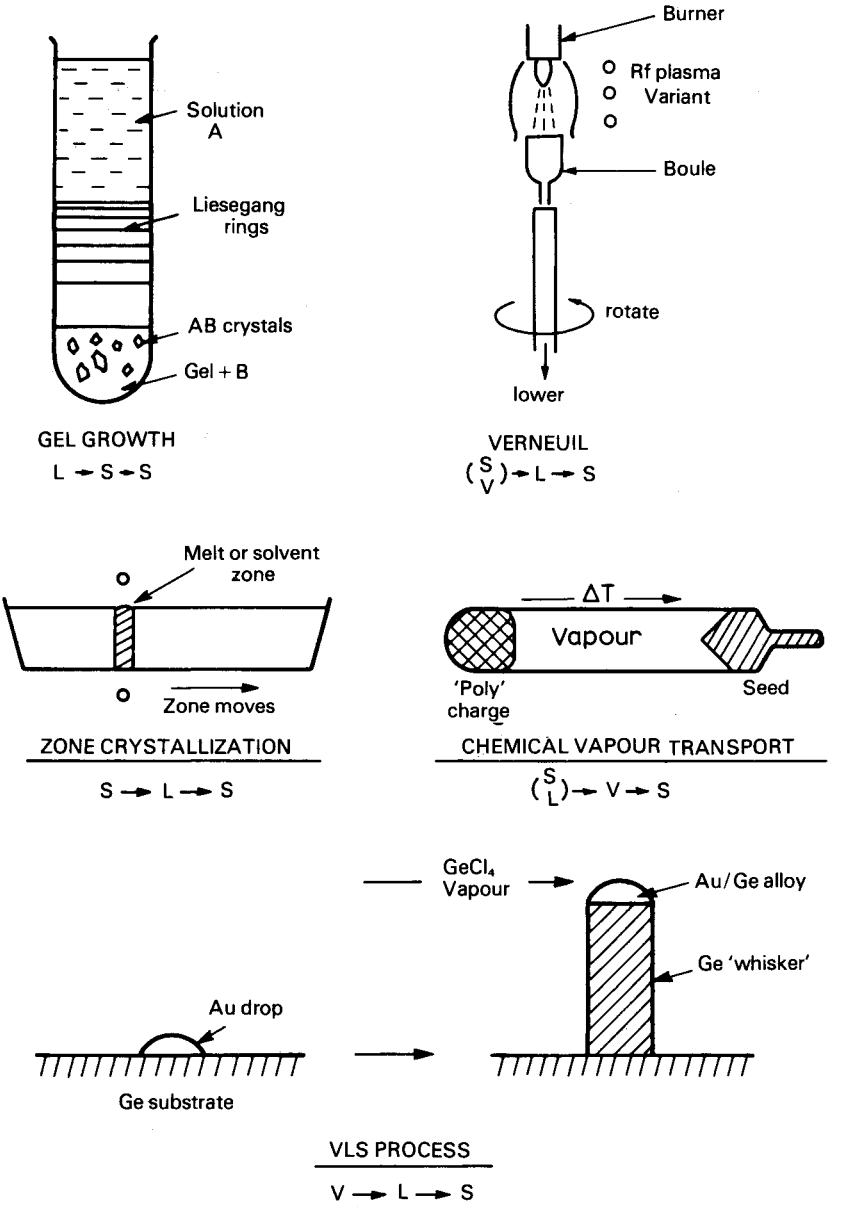

FIG. 9

cms/hour or more, whereas in solution techniques growth rates are diffusion limited to ∿mms/day, a difference of 1000:1. Thus it would be expected that the former would be preferred for production processes, apart from the fact that when growth has to take place over weeks or months there are many more chances for 'control failures', e.g. due to power cuts!

Despite this, solution techniques are notable for the production of large crystals (> 100 grams) of certain classes of materials—particularly for ferroelectric and electrooptic applications.

Water solution—ferroelectric and electrooptic; TGS, KDP, etc.
Fluxed melt —magnetic oxides; YIG, ferrites, etc.
Hydrothermal —quartz, etc.

8. Other Important Techniques

In Fig. 9 are illustrated a selection of other important and/or interesting growth techniques we shall describe briefly:—

(a) Gel growth

Can be used to grow certain sparingly soluble materials when one component is contained in a gel, while the second diffuses slowly from a solution in contact with the gel. This is a very slow process but requires little apparatus, e.g. large test tubes or simple glass geometries can be used. Materials grown include calcium tartrate, lead iodide, cuprous chloride.

(b) Verneuil process

This is still used to provide alumina etc. for watch bearings and 'sapphire' styli (though the former usage may decrease somewhat with the current advent of digital quartz watches!): a drawback, however, is that the feed powder must be capable of being prepared sufficiently free-flowing.

As a technique it can be considered akin to an inverted pulling process—the important difference is that here the molten zone is a thin layer ∿ 20μm thick and is sensitive to temperature fluctuations caused by variations in gas flow and powder feed. It is not then surprising that Verneuil grown material tends to have many defects such as microscopic inclusions of bubbles and unfused powder together with dopant 'banding', e.g. in ruby, as a result of periodic onsets of CSC.

As a result, the technique is not used for the production of electronic materials but is still a valuable research tool as its range can be extended to high temperatures by use of tricone burners or gas plasma and refractory crystals can be grown, e.g. rare earth oxides.

(c) Zone crystallization

An important process, mainly used for purification and doping of semiconductors and metal alloys when multi-pass, multi-zones are used. In particular cases, if the rate of zone passage is slow, preferential crystallization results. For oxide materials a molten solvent zone can be used; other geometries are possible, e.g. 'sandwich' or spot diffusion.

A vertical geometry is used in electron beam float zoning for the production of pure silicon.

(d) Chemical Vapour Transport (CVT)

Vapour transport processes are important for the production of (semiconductor junction) electronic devices by diffusion of various dopants from the vapour. This is mostly carried out in a flow system with inert carrier gas. CVT, in contrast, is a sealed tube process in which a second component is added to a solid so that entirely gaseous species are formed at the growth temperature. In a temperature gradient a cyclic process occurs via a reversible reaction, e.g.

$$Y_2O_{3(g)} + 3Cl_{2(g)} \rightleftarrows 2YCl_{3(g)} + 3/2\ O_{2(g)},$$

somewhat analogous to the transfer process involved in hydrothermal growth.

For the growth of many oxides and chalcogenides, ampoules are usually constructed from silica and located in a suitable temperature gradient inside a tube furnace typically in the range 1150 °C→900 °C.

The ampoule tip can be constricted in such a way that, in conjunction with pulling the ampoule through a reverse gradient, this tip is first cleaned and then the site for preferential nucleation. In a similar manner to crystallite selection in unseeded Czochralski growth, a dominant crystallite usually will emerge to grow into a small boule.

From the viewpoint of control, an inert gas, e.g. argon, can be introduced to limit transport and stabilize the interface against breakdown.

The VLS process is an interesting variant of the flow system and in a way resembles vapour-fed miniature Verneuil growth. At one time it was hoped that by suitable deposition of gold overlays on germanium complex structures could be grown which would avoid masking and etching techniques but it proved too difficult to control growth and composition.

9. New Developments

It seems unlikely that any radically new growth method remains to be invented, though variations on existing themes are many and some novel applications do occur. We list below some interesting developments as illustrative examples which are shown in Fig. 10.

(1.) Flux/vapour technique: a combination of two techniques (L→V→S), i.e. material transport in PbF_2 vapour at 1200 °C to produce highly perfect alumina crystals with ratio of surface area: thickness of 1000:1.

(2.) EFG process. *E*dge-defined *F*ilm-fed *G*rowth is a variant of the Czochralski process in which a shaped die is used in the melt to control crystal cross-section. Growth of Si, Al_2O_3, $MgAl_2O_4$ is possible at high speeds (cms/sec) to produce cheap substrates and solar cells. The melt interface is replenished by capillarity and the crystal strip or fibre is wound onto a drum. This offers a semi-continuous process but it is difficult to control ST effects which lead to breakdown of the interface and cause strings of bubble inclusions.

(3.) LPE process. *L*iquid *P*hase *E*pitaxy. This is used for the growth of thin magnetic layers from fluxed melts for magnetic bubble layers. The novelty is the use of a horizontal rotating disc substrate to give control of the boundary layer. Thin (~10μm) single crystal films can be grown in about 5 or 10 minutes. Growth is isothermal, hence compositional control is good, due to the fact that the addition of 10% B_2O_3 to PbO melt allows a supercooled state to persist for periods up to 20 hours.

(4.) Capillary growth. Certain organic crystals can now be crystallized (as single crystals) in lengths of hollow optical glass fibre. The orientation is controlled by temperature gradients as the freezing interface is traversed along the core of the material filled fibre. These will be important 'active elements', i.e. light modulators, in the new generation of optical fibres.

NOVEL GROWTH TECHNIQUES

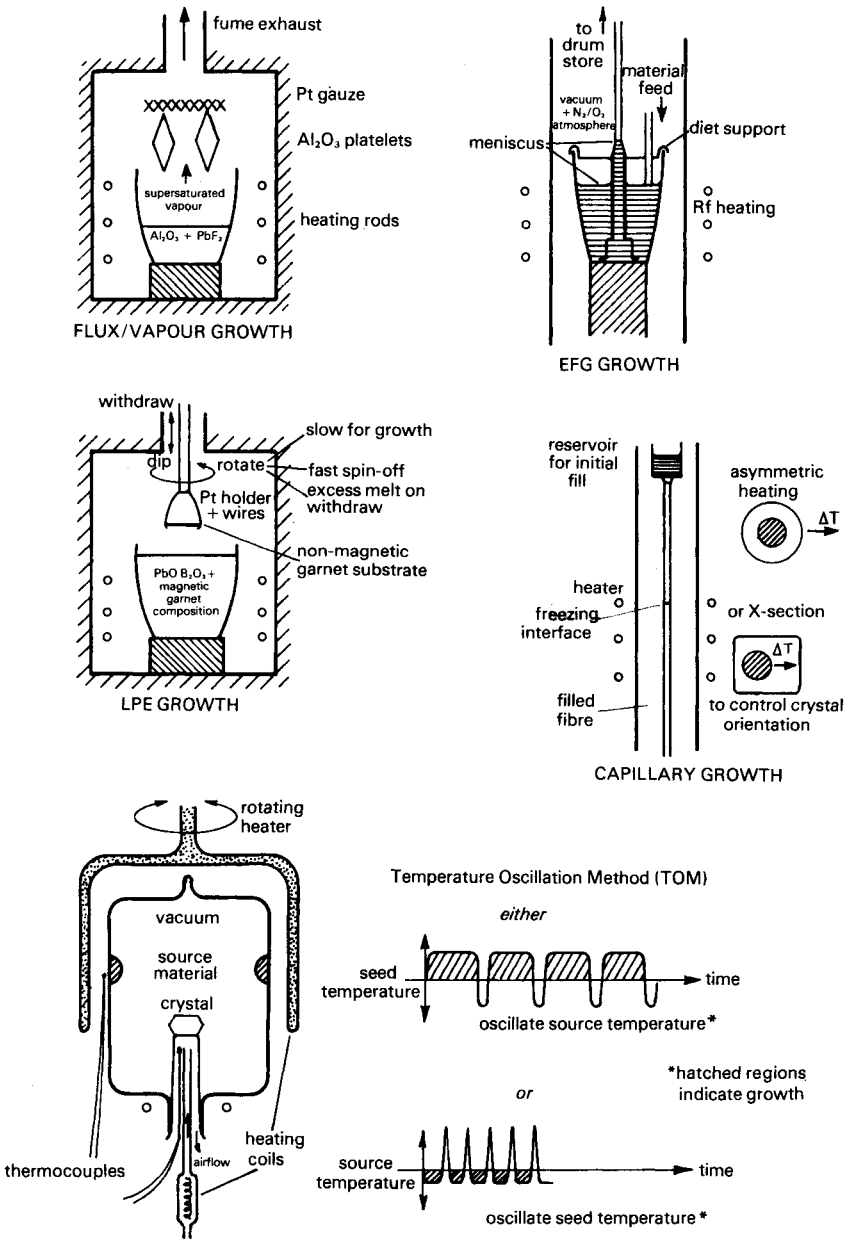

FIG. 10

*(5.) TOM. T*emperature *O*scillation *M*ethod. Here advantage is taken of the fact that if the growth temperature is cycled about a mean value—due to surface-to-volume free energy differences—small crystal nuclei evaporate faster than large ones. This principle is used to control vapour growth processes in which even a small supersaturation produces multiple nucleation. By adjusting conditions single nuclei can be selected and then, by altering the relative evaporation/cooling periods, grown into large single crystals.

(6.) Space processing. The Space-Lab project offers the possibility of material processing in zero-g conditions. The most obvious benefit might be thought to be absence of convection leading to striation-free crystals, but evidence from key experiments suggests that surface tension effects may predominate in zero-g. Certainly there are interesting transport effects occurring in these conditions, but in general the proposals for exploitation do not seem to match up to the opportunity. It needs perhaps the idea of actual *space* processing, i.e. the ultimate crucible-less technique would be a molten spherical charge in orbit round the space-shuttle, heated by giant parabolic mirrors. The details of multiple access, manipulation and method of freezing the melt is left to the imagination of the reader!

Whatever the context, it is hoped that this article will help the reader to follow future developments of crystal growth processes with more understanding.

ACKNOWLEDGEMENT

I should like to express my thanks to Dr E.A.D. White for my introduction to crystal growth and much subsequent encouragement.

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FURTHER DEVELOPMENTS IN SYNTHETIC MATERIALS

By M.J. O'DONOGHUE, M.A., F.G.S., F.G.A.

(based on a lecture delivered to the North-West Branch of the Gemmological Association on 10th February, 1977)

Zinc sulphide (ZnS) has a hexagonal variety as well as the cubic one well-known to mineralogists as zinc blende or sphalerite. The hexagonal variety is wurtzite and it is this which has been prepared by Diehl[1] at the University of Freiburg, West Germany. Doped with Co^{2+} the crystals are a magnificent bright green; those doped with Ni^{2+} are yellow and those with Cu^{1+} are blue. The crystals I have examined show prism and pyramid forms with some parallel growth. Diehl measured the refractive index of this material on the Gemeter and found it to be 2.30 ± 0.005. Hardness was 3-4 on Mohs's scale and the specific gravity 4.06 g cm^{-3}. The crystals are made by the chemical transport method; this involves vaporizing the required compound from a polycrystalline or amorphous source at a high local temperature, transporting it down a temperature or pressure gradient and depositing it on a substrate or seed crystals at a lower temperature. It is interesting to note that wurtzite is generally found associated with sphalerite in nature; it is the high-temperature modification of ZnS and is formed by heating sphalerite above 1020 °.

Although yttrium ortho-aluminate, $YAlO_3$, has been known for some years and regarded in some quarters as a possible diamond simulant, it is not easy to obtain and has never come close to rivalling YAG in the simulant field. It has a hardness of about 8½, refractive index of about 1.90 and a specific gravity of 5.36 g cm^{-3}. Grown by the Czochralski process, it was intended for laser use after doping with Nd. For laser use a material must have sharp fluorescent lines (cf. the emission lines in ruby), strong absorption bands and a high quantum efficiency for the fluorescent transition required. Such qualities are best shown in solids which can incorporate small amounts of elements in which optical transitions can be made between states on inner and incomplete electron shells. This is why the transition metals and the rare-earth

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or lanthanide series, with the actinides, are so important. Rare earths give sharp absorption lines (cf. the absorption spectrum of some apatites in which Nd occurs): they are sharp because the electrons involved in the transition from one shell to another are shielded by outer shells from the surrounding crystal lattice. Rare earths are elements in which the differentiating electrons lie in the third highest energy level: in the transition elements they lie in the second highest energy level, and those elements in which the outermost or highest energy level is the area of electronic differentiation are the most stable of the elements and combine unwillingly (though some fluorides such as XeF_4 have been synthesized). To act as a suitable laser host, a crystal or glass needs to have good optical, mechanical and thermal properties to stand up to operating conditions, so a high degree of hardness, high refractive index, lack of internal strain and resistance to radiation-induced colour centres are all important. Corundum, which fulfils these criteria, was naturally one of the first laser hosts to be tested. It acts as an excellent host for chromium, since the Al site is about the ideal size for incorporation of Cr: Nd-doped corundum cannot be made, since the Al site is too small for rare earths.

With these points in mind we can examine yttrium orthoaluminate further. It has high conductivity and hardness: it is anisotropic and grows faster than YAG. Distribution coefficients for rare-earth dopants are nearly ideal. In addition the anisotropic character of $YAlO_3$ means that particular directions of the rod can be selected for particular properties. Most of the material has been doped with Nd and the fluorescence occurs in three strong lines at 1.0645, 1.0725 and 1.0795 μm. Laser action has been achieved with Er^{3+}, Ho^{3+} and Tm^{3+} as well as with Nd^{3+}.

However, during the growth process Fe^{3+} was found to have entered the crystals; it appears to have arisen from volatilization of some part of the ceramic insulation used; the identity of the impurity was ascertained by checking the EPR spectra of all possible elements involved in the crystal growth process; only that of Fe^{3+} resembled that of the crystal in which the impurity was observed. Naturally the presence of iron as an inhibitor of fluorescence renders the material unsuitable for laser use, and for this reason it no longer appears in this connexion on the market. So far no way of growing the material free from Fe has been discovered.[2]

Three fluorides have been synthesized by Diehl[1]; $RbMnF_3$, LiF and MnF_2. $RbMnF_3$ is grown by the Czochralski method and has a hardness of 4, specific gravity of 4.31 g cm^{-3} and refractive index of 1.428. It is a pinkish-brown in colour. LiF, also grown by the Czochralski process, has a hardness of between 3 and 4, specific gravity of 2.64 g cm^{-3} and refractive index of 1.392. Together with $RbMnF_3$, it crystallizes in the cubic system; when doped with chromium, a yellow colour is obtained. MnF_2 is a member of the tetragonal system and has a hardness of 4, specific gravity of 3.93 g cm^{-3} and refractive indices of n_o 1.475, n_e 1.505. The birefringence is 0.030. The colour is reddish or brownish pink.

It is interesting to note that with the divalent fluorides charge compensation is necessary when trivalent rare earths such as U are used as dopants. Trivalent uranium in CaF_2 gives a fine bright red, while divalent samarium in the same host gives green. Charge compensation can occur in a number of ways; one is where a mineral contains ions in both oxidized and reduced oxidation states. An electron can be transferred between the states so that one is oxidized and the other reduced. Similar transfer can occur between ions of different transition elements; Nassau[3] quotes $Fe^{2+}-Ti^{4+}$ to give the blue in sapphire. The energy which arises from the movement of the electrons causes absorption of light.

The zinc tungstate, sanmartinite (Zn, Fe, Ca, Mn)WO_4, occurs with tungsten ores in a quartz vein at Los Cerrillos in the Argentine Republic. A member of the monoclinic crystal system it has a specific gravity of 6.70, but the refractive index has not been adequately measured. It should be possible to do so before very long, since sanmartinite has been synthesized using the Czochralski process. The colour is a purplish-brown.

Proustite,Ag_3AsS_3, might very well be mistaken for cuprite if both were encountered as cut stones. Both are very red with a metallic lustre. Proustite has been made by the hydrothermal method; it is a member of the hexagonal crystal system and is used for laser modulator and semiconductor work. It is soft, 2½-3 on Mohs's scale; the specific gravity is approximately 5.55-5.64 and the refractive index n_o 3.08, n_e 2.79. Surface alteration occurs on prolonged exposure to light: this also occurs with cuprite.

In a previous paper on synthetic materials I mentioned* the flux-melt growth of spinel, quoting the examples of red from doping with chromium and green from cobalt, together with yellow from the addition of iron or nickel. Through the kindness of Mr J.D.C. Wood, of Imperial College, I have recently obtained specimens of a dark blue spinel, like the previous examples octahedral in form: these are coloured by Cu.

Zirconium oxide, ZrO_2, has appeared as a diamond simulant and may be quite successful in this role, although, as in the case of gadolinium gallium garnet, early production was prone to discoloration. It crystallizes in the cubic system and has a hardness of between 8 and 9 on Mohs's scale; the specific gravity is 5.7 g cm^{-3} and the refractive index is 2.15. The dispersion is 0.060. Gübelin[4] has recently produced a paper on this material. A product, known as 'Djevalith' after the Swiss manufacturer Djevahirdjan, is described in this paper, in which the properties are given as RI 2.17, dispersion 0.06, SG 5.65, hardness 8½.

A recent material first tested for laser use is lanthanum beryllate, $La_2Be_2O_5$; for laser work it is doped with Nd. La^{3+} is the largest of the rare-earth ions and so has the largest distribution coefficients for other trivalent rare-earth ions. Known as BEL, boules of this material are more easily grown than YAG and other materials based on the yttrium ion. BEL has a thermal conductivity less than half that of YAG. The patent specification[5] for the material (there described as beryllium lanthanate) states that the crystals may contain up to 50 atomic % dopant substituted for the lanthanum. Preferred crystals of the invention are those with the formula $Be_2La_{2-2x}Z_{2x}O_5$, where Z is a dopant from the group Pr,Nd,Sm,Eu,Gd,Tb,Dy,Ho,Er,Tm and Yb; mixtures from elements in the group are also used. X represents the fraction of lanthanum sites in the crystal which are occupied by the Z ions and has a positive value not greater than about 0.2 and preferably about 0.007 to 0.015. During growth it is essential to avoid contamination with such impurities as strontium and mercury, which have ionic radii similar to that of lanthanum^{3+}. Such impurities create colour centres which interfere with laser action either by dissipating energy as heat or by radiating it at wavelengths which do not persist.

*J.Gemm., 1976, XV, 3, 121.—Ed.

Czochralski growth is preferred for this material; La_2O_3, BeO and dopant being placed in a crucible and heated until molten. Z (the desired dopant) is added as a compound from the group Z_2O_3, $Z_2(CO_3)_3$ or $Z(NO_3)_3$. Iridium is preferred as crucible material and an oxygen-free atmosphere is maintained around the apparatus by the introduction of an inert gas such as argon or helium. The seed crystal which is brought into contact with the surface of the melt is usually also beryllium lanthanate.[6]

So far very few vanadates have been synthesized; yttrium ortho-vanadate, however, is now frequently grown by the Czochralski process after earlier melt-grown production proved unsuitable for laser work through problems encountered during this method of growth. The material was phased out for a time, until new growth methods were found to be more successful. YVO_4 crystallizes in the tetragonal system and resembles zircon in its crystallographic structure; all rare-earth vanadates have this structure and form solid solutions with YVO_4. Pure YVO_4 is colourless; a yellow form reported by Rubin and Van Uitert[7] is thought to have been grown in a slightly reduced atmosphere. This material has a broad absorption peak near 420 nm: SG has been calculated at 4.30[8].

The growth of zircon has been reported by a number of workers and crystals suitable for gem use were mentioned by the present writer in the previous paper[9]. Wanklyn[10] has recently reported the growth of zircon from flux systems, including PbO-V_2O_5, this method giving deep blue crystals where the proportion of V_2O_5 was sufficiently large. Yellow crystals were obtained by doping with Tb and green by doping with Cr.

Laser action in silicate oxyapatites has been noted, particularly in CaLa SOAP(calcium lanthanum silicate oxyapatite)—the formula is $CaLa_4(SiO_3)_3O$.[11] When doped with Nd the storage of energy is about five times that of YAG, and a further advantage is that large crystals can be grown relatively cheaply. Low thermal conductivity and a low laser damage threshold may militate against its frequent use.[12] In recent years synthetic scheelite (calcium tungstate, $CaWO_4$) has been proposed as a diamond simulant. Like so many others it has never been seriously used in this connexion because its research and industrial use was found to be limited. The reason for this was the proneness of the boules to fracture even

when well annealed, and when rods were made from the boules many had to be discarded. When doped with Nd^3 the absorption spectrum shows a large number of fine lines. The rare earth substitutes for Ca but is in a trivalent oxidation state so that charge compensation is needed; for laser work substitution of Na^+ for Ca^{2+} was found to be best.[13]

It is worth noting that although from time to time new substances with possible gem application are reported the industrial or research potential of the material can rarely be followed up by gemmologists; the result is that textbooks are overloaded with uncritical listings of interesting but irrelevant substances. The materials discussed above may in some cases be suitable for gem use: others are now discarded for reasons which I hope are apparent. The reasons for the neglect of some materials are also relevant for others not discussed above.

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DID PROFESSOR NACKEN EVER GROW HYDROTHERMAL EMERALD?

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ABSTRACT

Gemmology sources state that Professor Nacken grew hydrothermal emerald. Detailed examination of the original literature sources usually cited, of the technical problems involved, and of three different lots of surviving Nacken emeralds leads to the conclusion that Nacken grew emeralds only from the flux. Some conclusions can be drawn as to the nature of the technique employed and the composition of the flux. The two-phase inclusions in Nacken emerald are shown to consist of a flux-composition glass and a gas bubble.

A. INTRODUCTION

Professor Richard Nacken (b. Rheidt, Germany, 4th May, 1884, d. 8th April, 1971) is well known for his pioneering work on the hydrothermal growth of quartz crystals.[1, 2, 3] In the field of gemmology, he is best known for his early work on synthetic emeralds.

In gemmological sources (e.g. Webster[4]) and elsewhere[5] it is stated that Nacken's emeralds were grown by the hydrothermal technique. This conclusion was based on two types of evidence: reports of interviews with Nacken by Sawyer[2] and Van Praagh;[3] and the occurrence in Nacken emeralds of two-phase inclusions apparently composed of a fluid and gas-bubble.

Work for a detailed report on 'Synthetic Emerald: The Confusing History and the Current Technologies'[6] led to a re-examination of the Nacken emerald problem. Study of the primary references, of the known technology of hydrothermal emerald growth, and of some surviving Nacken emeralds indicates that a hydrothermal origin for Nacken emerald cannot be supported.

B. THE PRIMARY REFERENCES

Two primary accounts are usually quoted as evidence that Nacken grew hydrothermal emerald. The first is the post-war

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C. Experimental

Three lots of Nacken emeralds were studied, designated A, B, and C, shown in Figure 1 (this figure appears in colour in Ref. 6.):

A. Three crystals, shown on the left in Figure 1, obtained via F.H. Pough from G.O. Wild of Idar-Oberstein.

B. Five crystals, three of which are shown in the centre of Figure 1, were loaned by the British Museum (Natural History), number BM 1958, 541 'made by Professor Nacken in 1926', courtesy of Mr P. Embrey.

C. Eleven crystals, four of which are shown at the right of Figure 1, were loaned by the British Museum (Natural History), number BM 1946, 87 'see Min. Abs. **10**, p. 104', courtesy of Mr P. Embrey.

Examination techniques included microscopy, scanning electron microscopy (SEM) in both x-ray energy dispersive and element mapping modes, and infrared absorption spectroscopy (IR). The SEM work was performed on an ETEC Autoscan, operated at 20 kV, and a KEVEX model 5100C x-ray energy spectrometer. IR data were taken from a Cary Model 14 double beam spectrophotometer at room temperature.

D. Results

The crystals examined were generally well formed prisms showing both first order and second order prism faces, usually from seven to ten in number. Typical outlines are shown in Figures 2A to D. Some crystals had perfectly developed basal pinacoids, but these were accompanied in many of the crystals by adjacent curved surfaces showing fine striations as indicated in Figure 2A. The morphological feature that was most surprising was the complete absence of any evidence of attachment points, indicating that the crystals had grown as 'floaters'.

Infrared spectra were taken on crystals from each group. Those from groups A and B showed complete absence of water in their spectra, giving curves such as those of Figure 3D and thus confirming flux growth for these crystals.[10, 11] Group C crystals however showed spectra of the Figure 3B type, indicative of both Type I and Type II water as shown in Figure 4. This indicates the presence of a low to medium amount of alkali in these crystals, and such spectra had been observed previously only in natural beryl and emerald.[10, 11]

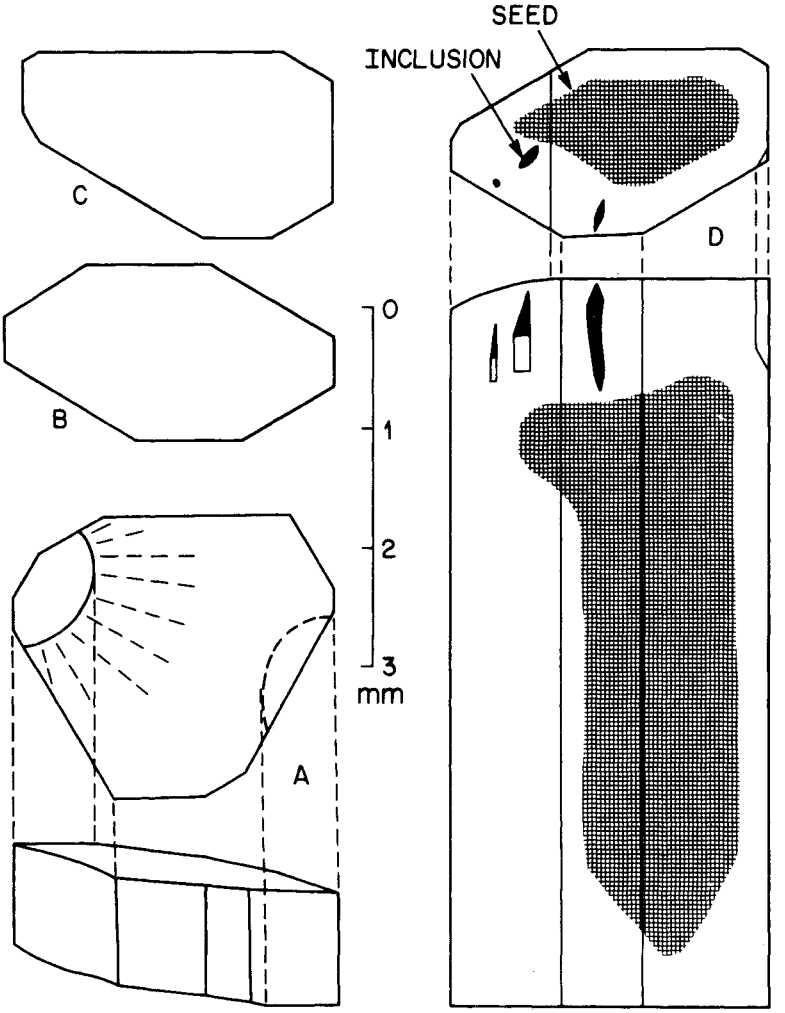

FIG. 2. Drawings of some Nacken emeralds; A and C from Group B, B from Group A, and D from Group C showing pale seed crystal.

intelligence report on Nacken's work by G.B. Sawyer.[2] Reporting on his discussion with Nacken, Sawyer wrote: '. . . He referred to an old research originally on beryl *or* emerald and corundum for watch bearings. The general procedure used by Nacken . . . made *quartz* crystals 1″ in diameter by the hydrothermal method . . .' (There follow details of *quartz* growth conditions; then some biographical data.) '. . . In the evening, we visited Professor Nacken again and he showed us emerald crystals which he had grown in 6 to 8 days . . .' (Further details on *quartz* growth follow; parenthetical comments and emphasis added). Note the absence of a statement as to how the emerald crystals had been grown.

The second source usually quoted for a Nacken hydrothermal emerald is Van Praagh.[3] This is an article on Nacken's hydrothermal quartz work based on his intelligence interview. Near the end he includes this paragraph: 'Although outside the scope of this article, it is interesting to note that Nacken used with success a similar hydrothermal method for the synthesis of other minerals, including felspars, micas, and beryl. *He made large numbers of synthetic emeralds, using a trace of chromium to produce the colour. Hexagonal prisms weighing about 0.2g were grown in a few days. A number have been sent to the Mineral Department of the British Museum for full examination'* (emphasis added). Note that none of these hydrothermal felspars, micas, or beryl (not 'emerald') has ever been reported elsewhere. Also note that once again the technique used to grow the emeralds in the last three sentences is not explicitly stated.

As against these two rather equivocal reports must be ranged more positive evidence that Nacken did grow emerald from the flux ('flux-melt' growth in Great Britain). Merker, based on yet another intelligence interview, mentions both lithium molybdate[7] and potassium vanadate;[8] and lithium molybdate flux growth is also ascribed to Nacken by Fischer.[9] As part of a study on the role of water in emerald, Wood and Nassau[10, 11] found water to be absent in a Nacken emerald, accordingly indicating a flux origin. No reports appear to exist which demonstrate the presence of water in any Nacken emerald.

This evidence thus indicates that Nacken did grow flux emerald, but is indefinite as to the existence of any Nacken hydrothermal emerald.

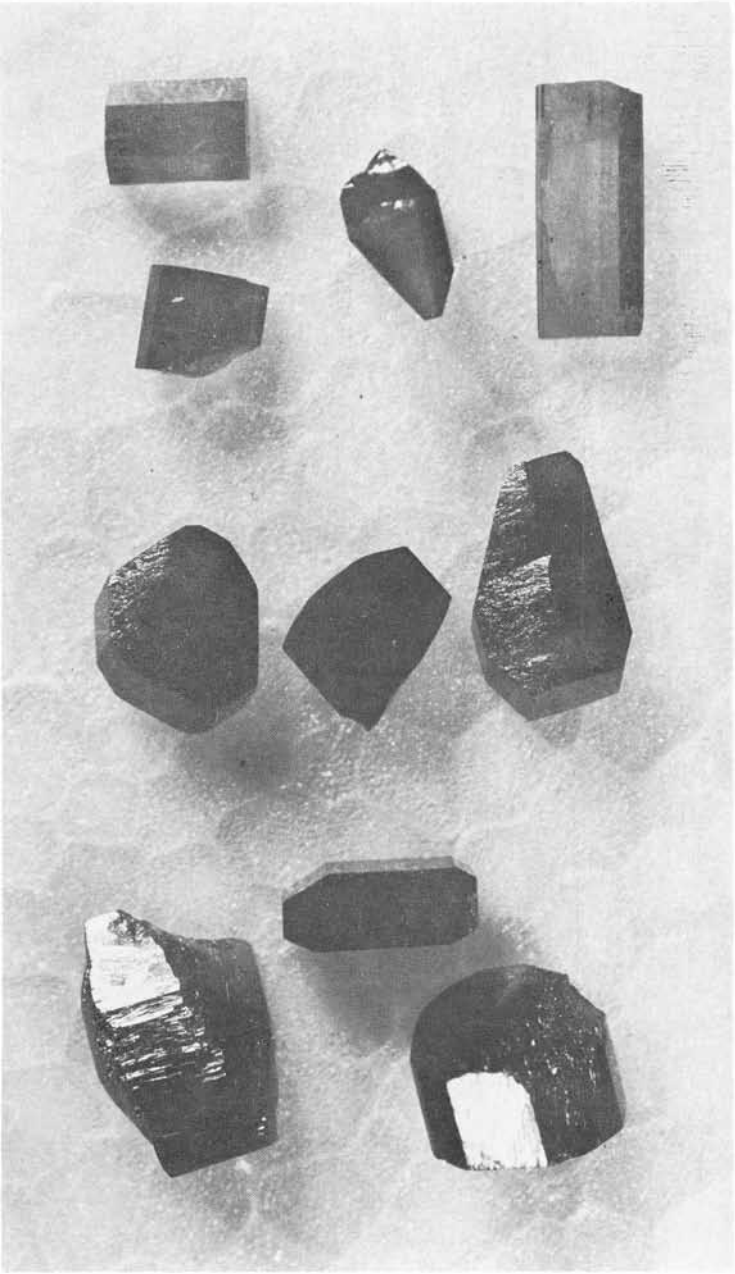

FIG. 1. Three lots of Nacken emeralds; largest is 5 mm across and weighs 0.51 ct. Left to right Groups A, B, and C.

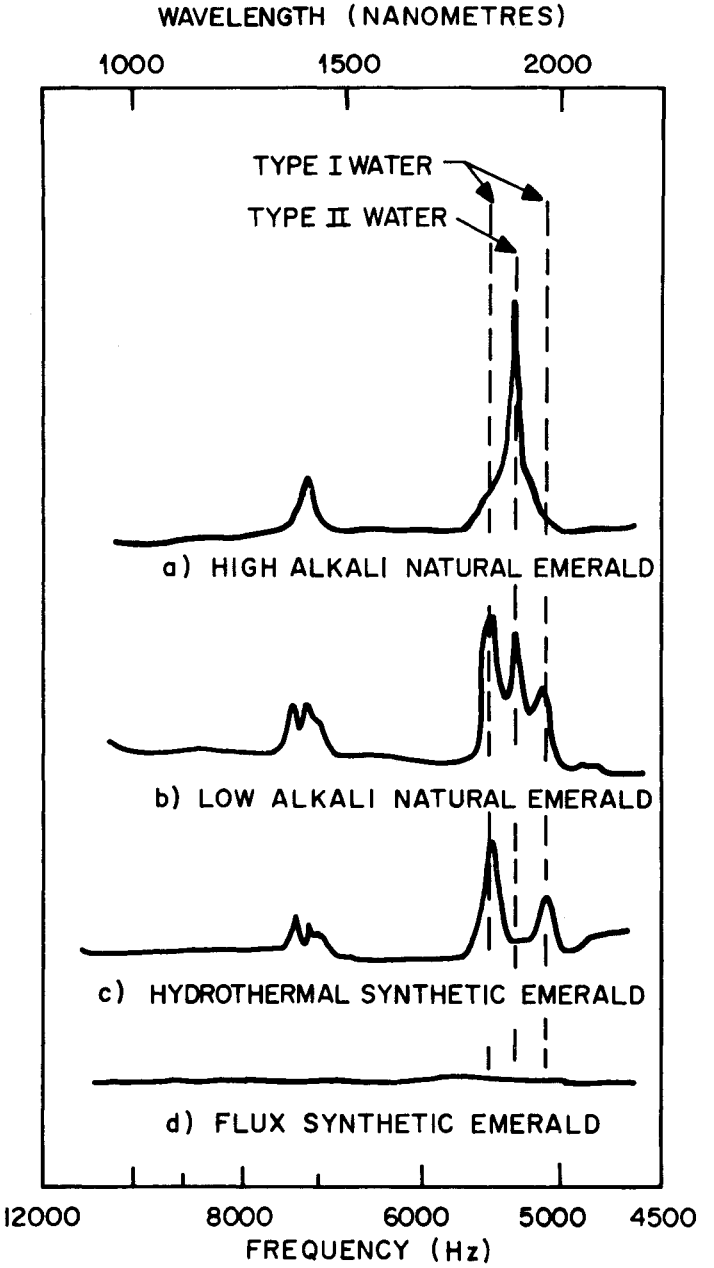

FIG. 3. Infrared water absorption bands in emeralds: natural (a) and (b), hydrothermal (c), and flux (d).

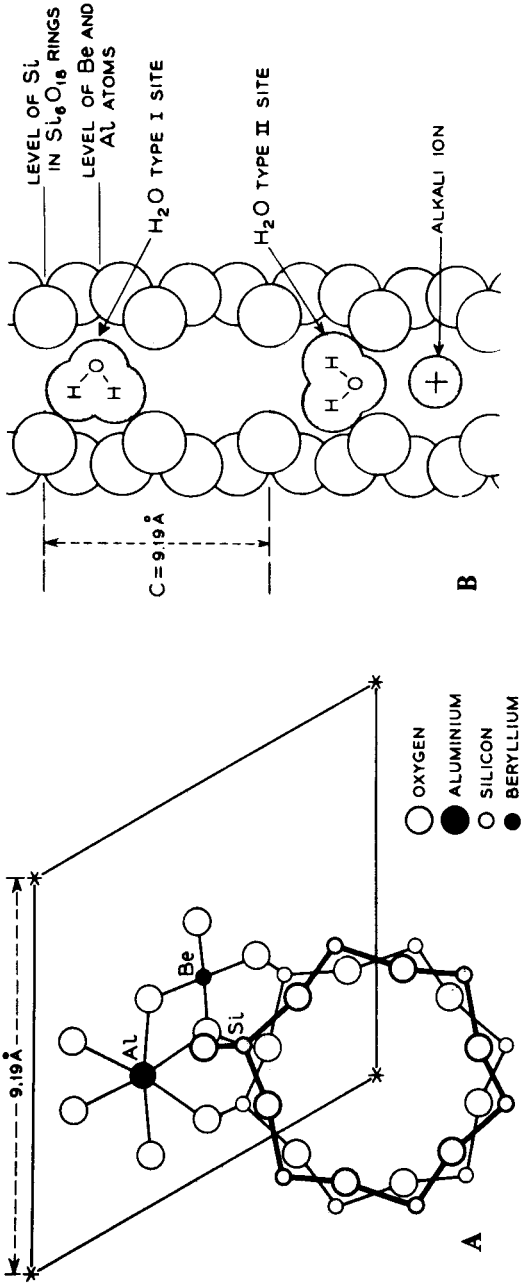

FIG. 4. The structure of beryl (A) showing the channels as seen looking down the optic axis and the two types of water in the channels (B).

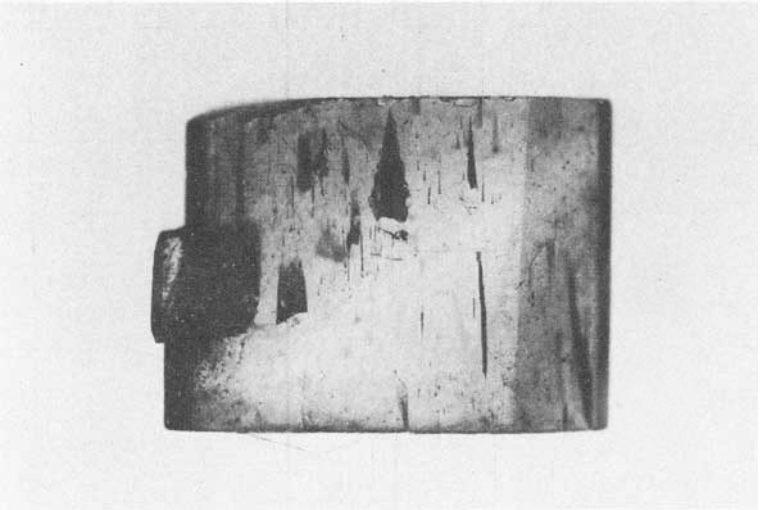

FIG. 5. Nacken emerald crystal from Group C polished down to the triangular flux inclusion, also showing pale central seed region (crystal is 2½ × 3½ mm).

Close examination of these crystals indicated that colourless (or close to colourless) natural beryl seeds had in fact been used in growing the group C crystals. The pale centres of these crystals can be seen in the crystals on the right in Figure 1 and also in Figure 5, a partly polished crystal slice from Group C photographed in transmitted light. Another crystal from this group is shown in Figure 2D. The deeply coloured emerald regions surrounding the seeds showed the same inclusion characteristics as were found in crystals of Groups A and B.

Inclusions in the Group A and B emeralds and in the emerald regions of the Group C crystals were of five types:

(i) Curved veil-like or wisp-like feather inclusions of the type usually associated with flux-grown emerald. Some of these occurred in irregularly oriented twisted networks, Figure 6A, others in flat sheets, oriented perpendicular to the optic axis, Figure 6B;

(ii) Cuneiform nail-type inclusions, Figure 6C, which in emerald are generally caused by the nucleation of a crystal of phenakite followed by a tapering inclusion. In all instances these inclusions pointed towards the surface of the nearest basal pinacoid, suggesting a more rapid growth parallel to the optic axis than in other directions;

(iii) Two-phase inclusions giving the appearance of a fluid-filled cavity with a gas bubble as shown in Figures 6D and E, sometimes also occurring in the tapering section of large nail-type inclusions, Figure 6F;

(iv) Small clusters of crystals, Figure 6G, probably phenakite; and

(v) Rare large tapered inclusions of a dark-brown colour and polycrystalline in appearance.

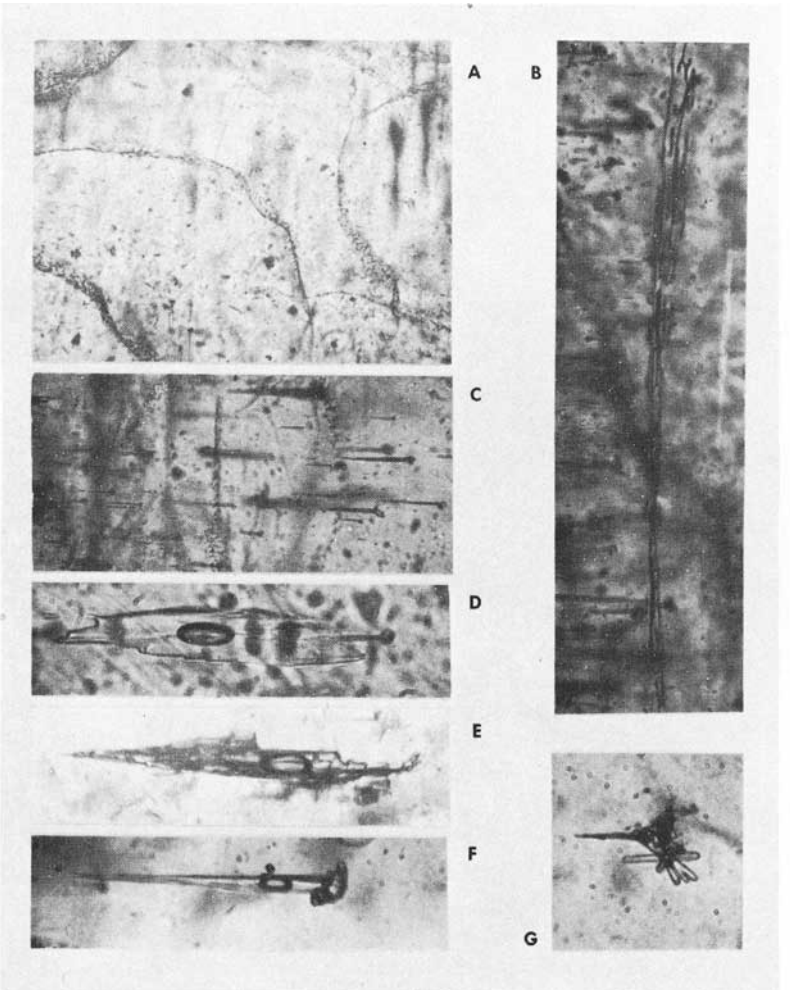

FIG. 6. Inclusions in Nacken emeralds: A and B 'veils'; C 'nails'; D to F two-phase inclusions; and G crystals of phenakite(?). Magnifications: A50 ×; B,D, and E100 ×; C 200 ×; F and G 300 ×.

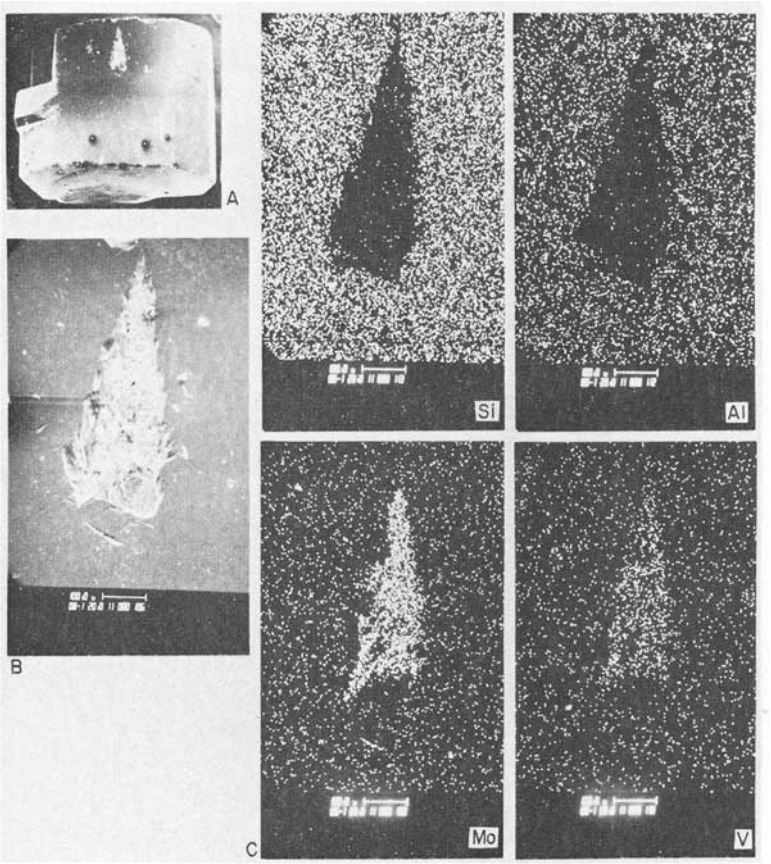

FIG. 7. Scanning electron microscope examination of the crystal of Fig. 5: A and B secondary electron images, C elemental mapping using x-ray emission from the elements shown. Scale bars are 100 μm long.

In general, these inclusions were similar to flux-grown emerald inclusions shown in gemmology texts.[4, 12, 13, 14]

A crystal of Group C containing the largest inclusion of Type (v), triangular in shape and approximately 1 mm × 1/3 mm, was ground and polished so as to expose the inclusion. This crystal is seen in transmitted light in Figure 5 and as a scanning electron photomicrograph in Figure 7A. Energy dispersive analysis of the emitted x-rays in the emerald region of this crystal gave the spectrum of Figure 8A, showing the expected aluminium, silicon, and trace of chromium (beryllium and oxygen cannot be detected in this examination). Several other crystals gave similar curves.

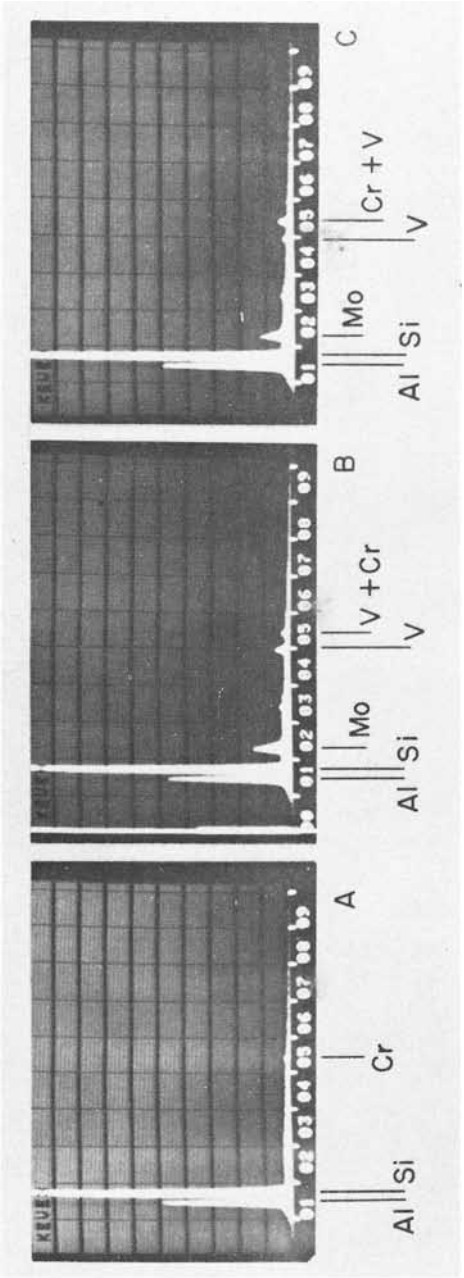

FIG. 8. Energy dispersive x-rays from emerald (A) and from Emerald plus flux inclusion (B) in the crystal of Fig. 5, and (C) from an inclusion such as that of Fig. 6D in a crystal from Group B.

When the exposed inclusion, shown in Figure 7B was included, both molybdenum and vanadium were now seen as in Figure 8B, but no potassium (lithium cannot be detected). In the element mapping mode of Figure 7C it can be seen that Al and Si are essentially absent in the inclusion contents, but much Mo and somewhat less V are present in the inclusion only. Outside the inclusions, Figure 7C shows only background for Mo and V. This indicates a flux composition of MoO_3 and V_2O_5, in all probability combined with Li_2O.

Attempts to move the bubble in two-phase inclusions with heat were unsuccessful. A crystal of Group B showing a two-phase inclusion similar to those of Figure 6D and E was thinned down to expose some of the inclusion filling, which gave the spectrum of Figure 8C. This resembled Figure 8B, except that the chromium peak was significantly higher. Coupled with the fact that the inclusion filling appears to be transparent, isotropic, and solid, this leads to the conclusion that such two-phase inclusions involve trapped flux containing the ingredients of beryl with extra chromium, but in a vitreous state. This glass apparently did not crystallize and also did not completely solidify until enough cooling had occurred to produce a shrinkage bubble, probably containing some oxygen which such a melt would be expected to emit on cooling.

E. Discussion

A careful analysis of the equivocal wording of the Sawyer[2] and Van Praagh[3] reports leads to the conclusion that neither specified the emerald growth technique used by Nacken. The reports of the use of flux by Merker[7, 8] and of Fischer[9] are confirmed by the analyses of the flux inclusion of Figure 7C and Figures 8B and C. The demonstration that the apparent 'fluid' in the two-phase inclusions is in fact a glass removes the only other evidence pointing to a hydrothermal origin. Additional confusion may have been caused by the presence of natural beryl seeds in some of Nacken's emeralds.

Quite decisive is the fact that growth in an alkaline hydrothermal medium, such as that used by Nacken for quartz[1, 2, 3] can yield beryl and aquamarine, but not emerald[15] (the chromium precipitates in all but acid media). This has been discussed elsewhere.[6]

It is interesting to place Nacken's emerald work in the historical context of other early emerald growth investigators.[6] Hautefeuille and Perrey had originally described fluxes based on lithium molybdate and lithium vanadate,[16, 17] and Espig and others at I.G.-Farben had worked from 1911 until 1942 to perfect the lithium molybdate process to produce their 'Igmeralds'. Details of this process were not published until 1960,[18] however, while Nacken discontinued his emerald work in 1927 or 1928.[7]

Despite the apparent independence of these two investigations we can nevertheless deduce that almost exactly the same process was used, based on the absence of attachment points discussed in section D above. For the I.G.-Farben process, as described by Espig[18] and shown schematically in Figure 9, employed the growth of floating emerald crystals as described previously.[6] The only difference appears to be that Nacken added some vanadium oxide to the flux.

This leads to two rather intriguing speculations which suggest themselves. Could it be that Nacken was a consultant to I.G.-Farben? This might explain his reticence in revealing growth details

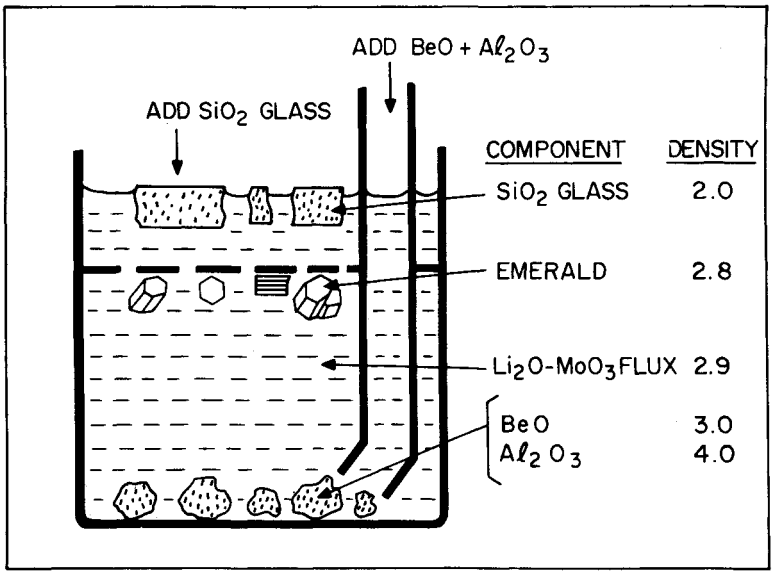

FIG. 9. Schematic diagram of emerald flux-growth apparatus made of platinum as used by Espig at I.G.–Farben.

even although he himself does not appear to have made any attempt to commercialize. From this we could then suggest that the 'secret' ingredient to which Espig alludes[18] as being necessary to produce a good colour in flux emerald in addition to chromium may in fact have been the vanadium present in Nacken's flux.

Quite apart from these speculations we can conclude with certainty that Nacken grew emeralds from a molybdate-vanadate flux (probably lithium-containing), using a floating growth technique similar to Espig's as shown in Figure 9. There is no shred of evidence for any hydrothermal emerald growth by Nacken, so that the question posed in the title of this article can be answered simply as 'No'.

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[*Manuscript received 10th June, 1976*]

THE MARTIN MGA-1 GEM ANALYSER: A REPORT

By P.G. READ, C.Eng., M.I.E.E., M.I.E.R.E., F.G.A., F.I.S.T.C.

This instrument, like the Gemeter and the Jeweler's Eye, enables a faceted gemstone to be identified by measuring the amount of infrared energy reflected from its surface. The intensity of the incident infrared energy is assumed to be constant, and the intensity of the reflected beam, although not an absolute measure of reflectivity, is used to indicate the relative reflectivity of the gem.

The Gem Analyser (Figure 1) has two ranges, the lower one covering glass to corundum, and the upper one YAG to rutile. The meter scales are calibrated directly in the names of the more common gem minerals and synthetics. Unlike the Gemeter and the Jeweler's Eye, which contain few electronic components, the Gem Analyser employs six transistors, a zener diode and two integrated circuits. These components are mounted on a fibre-glass printed circuit board (Figure 2) together with two range switches and the sealed infrared lamp/detector assembly.

The function of the electronic components is to maintain the accuracy of the readings over a wide range of battery voltages and ambient temperatures. This is effected by means of a voltage regulator in series with the battery supply (Figure 3) and a stabilized supply to the infrared emitting diode (LED). To minimize the effects of extraneous light, the current supply to the LED is modulated by a timing generator. The output from the detector is then demodulated to extract the electrical information on the intensity of the reflected beam, which is amplified and fed to the meter.

The manufacturers, Martin Precision Instrument Inc., P.O. Box 829, Saratoga, CA 95070, U.S.A., claim that the instrument will operate satisfactorily from 0 to 55 degrees centigrade, and from 0 to 95% relative humidity. The nine volt battery is said to have a life in excess of 100 000 operations (without the need for recalibration).

When using the Analyser, it is necessary (as with all reflectivity meters) to ensure that the surface of the gemstone under test is clean and that there is no dust in the aperture of the test platform.

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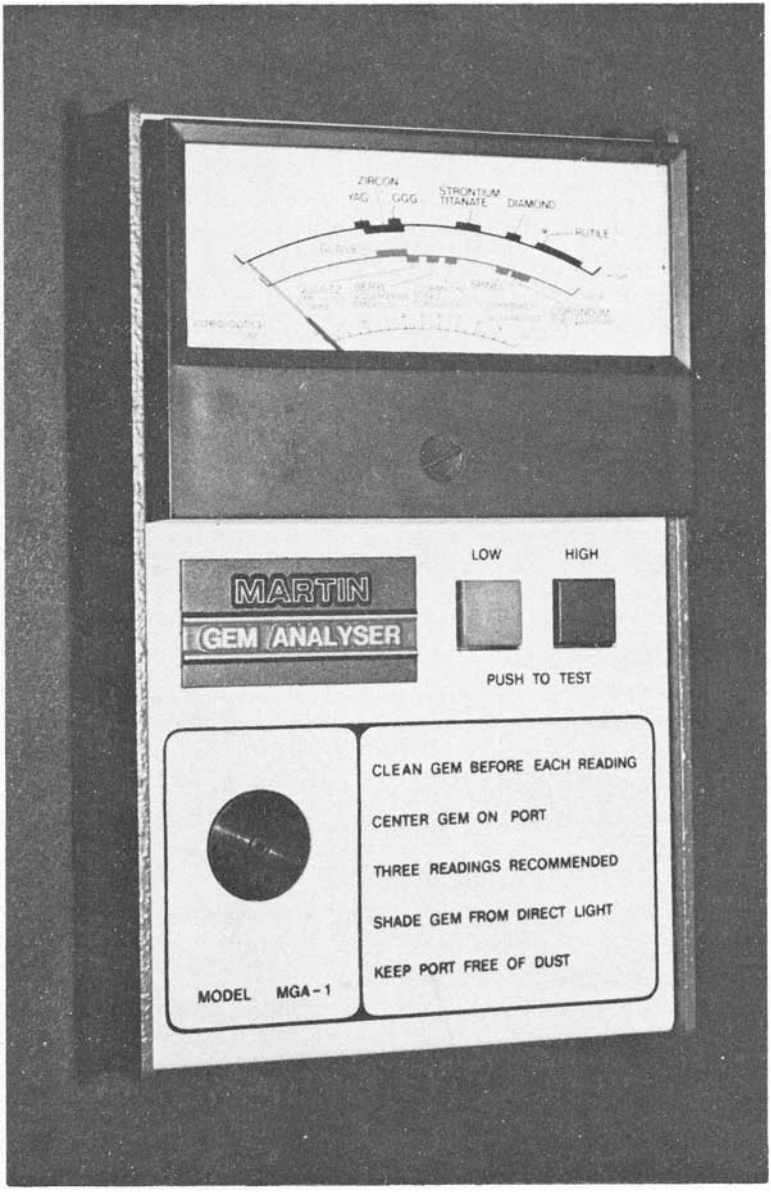

Figure 1. The Martin Gem Analyser, showing the circular test platform at the lower left corner.

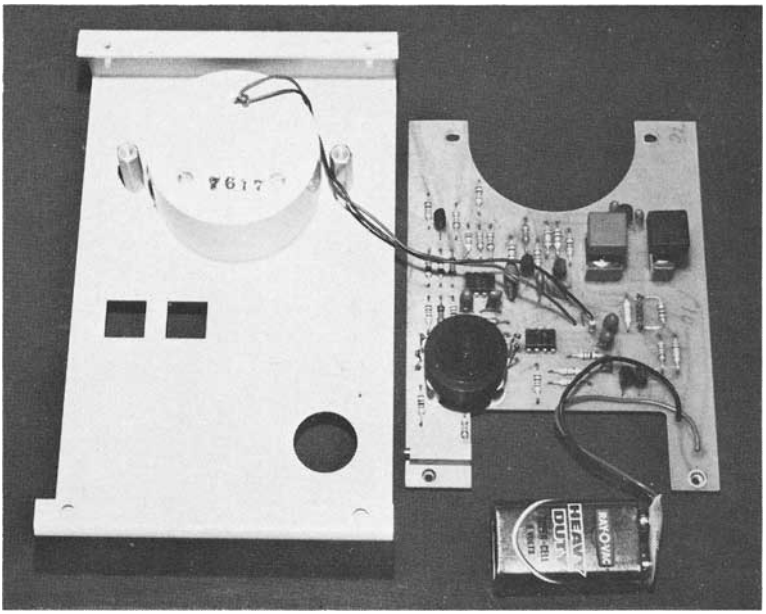

Figure 2. The dismantled Analyser with the front panel and meter on the left and the printed circuit board on the right.

The stone is placed on the raised rim of the test platform aperture and the appropriate range button is pressed. The aperture rim is provided so that mounted stones, having claws which protrude beyond the plane of the table facet, can be accommodated. Unfortunately, it can sometimes be difficult to ensure that the gem is sitting squarely on the rim. This requirement is most important as any tilting will cause a large error in the reading. In practice, it was found that this problem could be best resolved by making sure that the stone was placed symmetrically over the aperture so that there was no tendency for it to over-balance.

When taking a reading, it is also advisable to shield the stone from any strong external light. This can be done by covering the stone with the cupped left hand while operating the range test button with the right one. Failure to shield the gemstone results in a slightly increased meter reading. The degree of error depends on the level of ambient light, but usually does not exceed 1/16 inch on the scale. As is normal with this type of instrument, any surface scratches or grease/dirt on the tested facet lowers the reading appreciably.

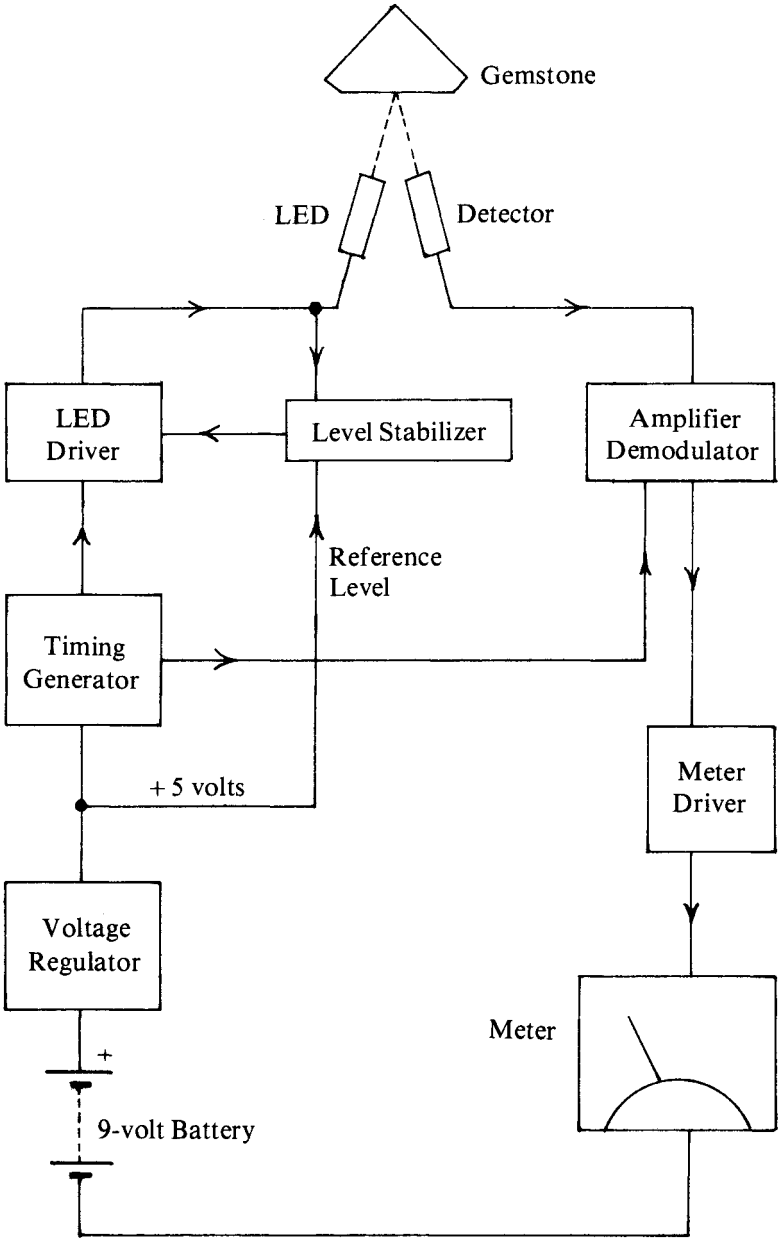

Figure 3. Block diagram of the electronic circuit.

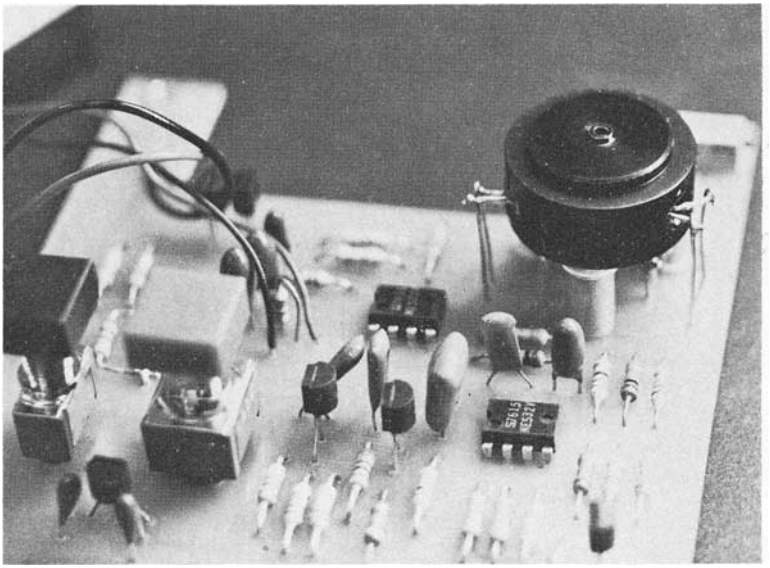

Figure 4. View of the printed circuit board showing the sealed lamp/detector assembly at the top right corner.

The lamp/detector assembly (Figure 4) appears to contain four active elements instead of the normal two (LED and photo detector). These probably comprise a dual LED/detector array, but as the assembly is sealed it was not possible to check either the identity or orientation of these elements.

The Gem Analyser was tested with polished diamonds, and with a selection of polished diamond simulants. The simulants included white synthetic spinel, white zircon, strontium titanate, YAG, synthetic rutile and GGG. In all cases the readings were well within the appropriate calibrated bands on the meter scales. Repeatability for individual stones was also very good. Even the octahedral faces of an unpolished diamond crystal gave the correct reading.

While the Martin Gem Analyser is more expensive at $400 than either the Gemeter or the Jeweler's Eye, it is virtually unaffected by wide fluctuations in ambient temperature and by falling battery voltage, and should never need recalibrating under normal circumstances. The dimensions of the Analyser are 165 × 108 × 45 mm (6.5 × 4.25 × 1.75 inches) and its weight is 600 grams (21 ounces).

[*Manuscript received 14th October, 1977*]

GEMMOLOGICAL ABSTRACTS

IGEA (J.). *Identificación espectrográfica del ámbar.* (Spectrographic identification of amber.) Boletin del Instituto Gemologico Español, **16**, 13-19, 1977.

Examination of the region between 9.5 and 11.5 μm shows interesting differences between types of amber and some of its imitations. The spectrum of ambroid is far less complex than that shown by the natural material. Graphs (not giving figures) illustrate the paper. M.O'D.

JONES (R.W.). *Arizona: heartland of gems.* Lapidary Journal, **31**, 1, 90-112, 1977.

An account, illustrated in colour, of the more important gem materials found in Arizona. These include agate, cordierite, azurite, malachite, cuprite, feldspars and turquoise. M.O'D.

LAREIDA (S.). *Die Mineralien-Fundgebiete im Bergell.* (Mineral sources in Bergell.) Lapis, **2**, 5, 25-31, 1977.

The Bergell, better known by the Italian name of Val Bregaglia, lies in the south-eastern part of Switzerland and extends into Italy. The country rock is granite and some pegmatites are found. The area has been divided into three zones, the second lying roughly to the south and east of the first and the third in the extreme east. Minerals of the first zone include chalcopyrite, pyrite, green to greenish-black spinel, aragonite, scheelite,bismuthinite, chrysoberyl (rare and in association with beryl), beryl in the yellow and aquamarine varieties, very small zircon crystals and black tourmaline. Minerals of the third zone include fluorite, quartz, titanite, prehnite, lazurite and stilbite. M.O'D.

LARSON (P.), HONERT (J.). *Rose quartz of the Black Hills.* Lapidary Journal, **31**, 2, 534-8, 1977.

Rose quartz occurs in granitic pegmatites; some stones display asterism and others dendrites of pyrolusite. The main mines are described. M.O'D.

LIEBER (W.). *Leuchtende Kristalle.* (Luminescent crystals.)Lapis, **2**, 5, 10-13, illus. in colour, 1977.

A brief account of the history of work on mineral fluorescence with particular reference to fluorite. M.O'D.

NASSAU (K.). *The non-single-crystal synthetics: turquoise, opal, etc.* Lapidary Journal, **31**, 1, 18-31, 1977.

A copy of Dr Nassau's article 'How to define non-single-crystal synthetics' which appeared in Gems and Gemology, 1976, XV, 7, 194-8, with the addition of colour plates. The original article was abstracted in J.Gemm., 1977, XV, 7, 396. M.O'D.

OWENS (V.S.). *Unakite.* Lapidary Journal, **31**, 1, 182-4, 1977.

Unakite is a mixture of quartz, feldspars and epidote and shows a wide variety of colours. The main localities in the United States are in Virginia, North Carolina and Tennessee. M.O'D.

PFEFER (J.). *Pala, a 'jewel' of a name.* Lapidary Journal, **31**, 1, 202-10, 1977.

The Pala Valley in southern California is described and illustrated, with particular reference to the tourmaline mines of the area. M.O'D.

POUGH (F.H.). *Alexandrite.* Mineral Digest, **8**, 69-73, illus. in colour, 1977.

A general review of the alexandrite variety of chrysoberyl. M.O'D.

RIEDERER (J.). *Der Edelsteinbergbau in Ceylon.* (Gemstone-mining in Ceylon.) Aufschluss, **28**, 41-7, 1977.

Reviews the occurrence and price ranges of Ceylon gemstones. M.O'D.

SCHIFFMANN (C.A.). *Un nouveau substitut du diamant: l'oxyde de zirconium artificiel.* (A new diamond substitute—artificial zirconium oxide.) Revue de Gemmologie, **51**, 9-11, 1977.

Diamond and some of its simulants, including zirconium oxide, are illustrated in colour. Constants are $n_D = 2.177$, reflective power 0.137 (compared to 0.172 for diamond), dispersion 0.065, hardness 8½, specific gravity 5.66. M.O'D.

SHAUB (B.M.). *Thomsonite.* Mineral Digest, **8**, 24-30, 1977.

The attractive banded zeolite was named for the Scottish chemist, Thomson, in 1820; it occurs in fibrous masses showing schiller or chatoyancy or as nodules with a radial structure of fine acicular grains. Distinct orthorhombic crystals are rare. It is a hydrous silicate of sodium, calcium and aluminium with the formula $NaCa_2(Al_5Si_5O_{20}).6H_2O$. Specific gravity is 2.3-2.4 and the hardness 5-5½. The commoner colours are shades of yellow, brown, red and green, though snow-white specimens have been found. Most thomsonite is found in the basalt rocks of the Lake Superior region and especially round Isle Royale, Michigan. M.O'D.

TAKAGI (K.), IKEDA (T.), FUKAZAWA (T.), ISHII (M.). *Growth striae in single crystals of gadolinium gallium garnet grown by automatic diameter control.* Journal of Crystal Growth, **38**, 206-12, 1977.

Crystals of $Gd_3Ga_5O_{12}$ grown by automatic diameter control show periodic growth striae whose spacing depends on the period of RF power fluctuation. They can be eliminated by decreasing the amplitude of fluctuation to less than 1%.

M.O'D.

TERRILL (B.). *Field trips in the Baltimore, Maryland area.* Lapidary Journal, **31**, 1, 82-140, 1977.

Accounts of amateur prospecting in various areas including the State Line Pits on the Maryland-Pennsylvania border (for the williamsite variety of serpentine) and Little Switzerland, North Carolina (for emerald). M.O'D.

TRUEBE (H.A.). *Lapis lazuli in the Italian Mountain area of Colorado.* Lapidary Journal, **31**, 1, 54-80, illus. in colour, 1977.

Two notable sources of lapis lazuli have been found on Italian Mountain in western Colorado; the mountain is located at the intersection of the Elk Mountain fold-belt and the Castle Creek fault zone. Lapis lazuli is formed in a particular

stratigraphic horizon in the Pennsylvanian age Belden formation near intrusive bodies. Sodalite, calcite, pyroxene and pyrite group minerals are discussed. The quality of the material found is quite high, second grade on the GIA scale. M.O'D.

VACHER (A.). *Étude sommaire des cavités tubulaires dans des aigues-marines.* (Summary study of tubular cavities in aquamarines.) Revue de Gemmologie, **50**, 4-6, 1977.

Some aquamarine crystals from Brazil were observed to contain cavities arranged in various crystallographic directions. The contents of the cavities include water and carbon dioxide and some are corroded by the contact of foreign bodies.

M.O'D.

BOOK REVIEWS

BÖGEL (H.), SCHMIDT (K.). *Kleine Geologie der Ostalpen.* (Little geology of the Eastern Alps.) Ott Verlag, Thun, Switzerland, 1976. pp.231. Illus. in black-and-white. Fr 39.

This well-produced text is intended as a general coverage of the Alpine geology covering approximately the area running eastwards from Vaduz up to Graz and Eisenstadt. This area is shown in a pull-out map and a number of illustrations in the text depict specific areas. An extensive bibliography includes references to articles in journals and there is a name- but no subject-index. Illustrations are of a high quality and the book as a whole is clear and authoritative. It should be read in conjunction with its companion 'Kleine Geologie der Schweiz' published by the same firm.

M.O'D.

BRANSON (O.T.). *Turquoise, the gem of the centuries.* Treasure Chest Publications, Santa Fé, New Mexico, 1975. pp.62. Illus. in colour. £9.00.

This book is composed entirely of coloured illustrations of turquoise from mines in the United States. These are exhaustively covered and the standard of the reproduction is high. An invaluable book for those wishing to distinguish pieces from specific locations and also treated material. M.O'D.

WENINGER (HANS). *Die alpinen Kluftmineralien der österreichischen Ostalpen.* (The alpine cleft-minerals of the eastern Alps of Austria.) 25 Sonderschrift der Zeitschrift Der Aufschluss, Heidelberg, 1974. pp. 168. Illus. in black-and-white and in colour. DM 20.00.

Eleven maps accompany this authoritative work, which covers the main mineralized areas of Austria. The book is arranged in alphabetical order of minerals and each entry shows chemical composition, crystal system and habit with the main localities of occurrence. There is a comprehensive bibliography, index of minerals, list of major localities and, most interestingly, a list of Strahler (crystal collectors), who can, no doubt, be contacted by those wishing to acquire specimens. M.O'D.

ASSOCIATION NOTICES

NEWS OF FELLOWS

On the 24th September, 1977, Mr M.J. O'Donoghue, M.A., F.G.S., F.G.A., attended the conference of the Deutsche Gemmologische Gesellschaft at Idar-Oberstein and read a paper entitled 'The pegmatites of the Pala District of San Diego, California'.

On the 22nd October, 1977, Mr A.E. Farn, F.G.A., gave a lecture entitled 'The Jade Umbrella' to the Wessex Branch of the National Association of Goldsmiths.

On the 5th November, 1977, Mr D. Wilkins, F.G.A., gave a talk on 'Findings and Keepings' to the Wessex Branch of the N.A.G.

MEMBERS' MEETINGS

London

A meeting was held on 10th October, 1977, at the Central Electricity Generating Board Cinema, Newgate Street, London E.C.2, when two films were shown. The first film, entitled 'World of Diamonds', illustrated the passage of diamonds from the mines through the various stages of sorting, valuation and sales, and in addition, showed the services provided by the C.S.O. to support its basic function. The second film, 'It's all done with minerals', showed the excitement, the muscle and brain and the movement in man's endeavours to recover the minerals and metals the world must have.

Midlands Branch

On the 21st October, 1977, a meeting was held at the Imperial Hotel, Temple Street, Birmingham, which marked the 25th anniversary of the Branch. A talk was given by Mr T. Solomon, F.G.A., entitled '25 years as a gemmologist'.

North-West Branch

A meeting was held on 21st September, 1977, at Church House, Hanover Street, Liverpool 1, when Mr E.A. Jobbins, B.Sc., F.G.A., spoke on 'Gem surveys in Brazil and Guyana'.

The second Annual General Meeting of the Branch was held on the 26th October, 1977, when Mr H. Eakins, F.G.A., was elected Chairman and Mrs D.M. Brook, F.G.A., Secretary. This was followed by a slide-show depicting the 'Exotic forms and colours of the mineral world'. which included precious and base metal ores and gemstones.

South Yorkshire Branch

At a meeting held on the 31st October, 1977, at Sheffield City Polytechnic, Mr M.J. O'Donoghue, M.A., F.G.S., F.G.A., gave a talk on 'Minerals of Central and East Africa'.

COUNCIL MEETING

At a meeting of the Council held on Wednesday, 5th October, 1977, the following were elected to membership.

FELLOWSHIP

Baldock, Edward J., Neston, Cheshire. D. 1977
Bapat, Suresh B., Bombay, India. D. 1977
Beard, Paul, Nottingham. D. 1977
Bennett, Lise C., Rochester. D. 1977
Borgen, Jennifer A., Fredrikstad, Norway. D. 1977
Brewer, Peter C., Scarborough. D. 1977
Chadderton, Yvonne E., Royton, Lancs. D. 1977
Clayton, Keith M., Cranleigh. D. 1977
Collier, Alan, Preston. D. 1967
Cooper, Dorothy A., Reddish, Stockport. D. 1977
De Waele, Carine G., Ghent, Belgium. D. 1977
Elkington, Mary, Solihull. D. 1977
Gade, Fredrik G., Snarøya, Norway. D. 1977
Gotch, Takeshi, Amsterdam, Holland. D. 1977
Grater, Jane, Salisbury. D. 1977
Grimbly, Margaret S., Plymouth. D. 1977
Henocq, James E.R., Croydon. D. 1977
Henocq, Rosemary S., Croydon. D. 1977
Horn, David E., Ripon. D. 1977
Kortenaar, Francois L., Schagen, Holland. D. 1977
Lancaster, David J., Johannesburg, S. Africa. D. 1977
Lawson, Wendy A., Nottingham. D. 1977
Litchfield, Jeane, Hahnbach, W. Germany. D. 1977
Main, Arthur M., Southport, Qld, Australia. D. 1977
Manzke, Lothar, Geneva, Switzerland. D. 1977
Meintjes, Arthur H., Stellenbosch, S. Africa. D. 1977
Mennie, Ruth, New Ferry. D. 1977
Muije, Cornelius S., Louisville, Ky, U.S.A. D. 1977
Norström, Stig E., Skärholmen, Sweden. D. 1977
Price, Grenville J., Nottingham. D. 1977
Rimmer, Robert J., Southport. D. 1977
Schinkel, Anthony, Southport. D. 1977
Semmes, Granville M., New Orleans, La, U.S.A. D. 1977
Sepp, Arne, Cape Town, S. Africa. D. 1977

Sierstorpff, John v. Francken, Rheinbrohl, W. Germany. D. 1977
Sukumaran, T.M., Colombo, Sri Lanka. D. 1977
Tillander, Paula, Helsinki, Finland. D. 1977
Tose, Christine, Middlesbrough. D. 1977
van der Meulen, Anne W., London. D. 1977
Walz, Sylvia E., Langenhagenl, W. Germany. D. 1977

TRANSFERS FROM ORDINARY MEMBERSHIP TO FELLOWSHIP

Aron, Mass K., Nugegoda, Sri Lanka. D. 1977
Ayres, Thomas D., Farnham. D. 1977
Cavey, Christopher R., London. D. 1977
Clarke, Kathleen D., London. D. 1977
Conrad, Donald B., N.Y., U.S.A. D. 1977
Cooper, Roy, Disley. D. 1977
Duroc-Danner, Jean M., Geneva, Switzerland. D. 1977
French, Anthony J., Brockenhurst. D. 1977
Haskings, Theresa M., Wollaton. D. 1977
Hemphill, S.I., Pacific Grove, Ca, U.S.A. D. 1977
Henrich, Francis J., Normandale, Lower Hutt, N.Z. D. 1977
Hood, Glynis M., Melville, Johannesburg, S. Africa. D. 1977
Kapukotuwa, Senerath L.B., Rajagiriya, Sri Lanka. D. 1977
Kaye, Ian D., London. D. 1977
Kennedy, Padraic J.T., B.C., Canada. D. 1977
Kim, Young C., Seoul, Korea. D. 1977
Kizawa, Masakatsu, Santa Monica, U.S.A. D. 1977
Knight, David J.R.E., London. D. 1977
Mayur, Dave, London. D. 1977
Moriuchi, Masana, Niigata-Pref., Japan. D. 1977
Nachimson-Palacci, Rosy, Geneva, Switzerland. D. 1977
Ng, Kevin K.F., Singapore. D. 1977
Paillard, Eva, Paris, France. D. 1977
Peace, Reginald J., Beverley. D. 1977
Pfersich, François A., London. D. 1977
Prickett, John D., Auckland, N.Z. D. 1977
Robinson, Kenneth W., Milton Keynes. D. 1977
Simon, Horace, (Jnr), Shreveport, La, U.S.A. D. 1977
Stonebanks, Judith M., Maidenhead Thicket. D. 1977
Talgeri, Jayshree G., Poona, India. D. 1977
Thomson, Paul R., Hobart, Tasmania. D. 1977
van der Maden, Pieter, Vlissingen, Holland. D. 1977
White, Paul T., Seattle, Wash., U.S.A. D. 1977
Woodhall, Jon W., Qld, Australia. D. 1977

ORDINARY MEMBERSHIP

Acheson, Jeffrey D., Johannesburg, S. Africa.
Acuna, Olinto, Tunbridge Wells.
Adachi, Mitsujo, Saitama, Japan.
Akiyama, Masashi, Hokkaido, Japan.
Amendra, Don H., Colombo, Sri Lanka.

Amoroso, Robert E., Boston, Mass., U.S.A.
Asagai, Osamu, Osaka, Japan.
Asano, Osamu, Yokohama-City, Japan.
Barker, Maxwell, Salisbury, Rhodesia.
Basich, Marco, Ca, U.S.A.
Bastiampillai, Sauarimuthu B., Woodford Bridge.
Bell, Lloyd M., Kan., U.S.A.
Black, Lewis C., London.
Boast, William E., Cheadle.
Boyd, Warren F., Toronto, Ont., Canada.
Brown, Harold G., Glossop.
Brunner, Ernst, Vienna, Austria.
Busaracome, Suwin, Wellington, N.Z.
Callow, Russell D., Brentwood.
Campbell, Donene N., North Auckland, N.Z.
Cannon, Robert, Cheshire.
Catley, Reginald A.J., Salisbury, Rhodesia.
Chadwick, John H., Clacton-on-Sea.
Charlton, Mary Ellen, Hexham.
Cheng, Ricky K.M., Birmingham.
Cheung, Kai Y.E., Hong Kong.
Cheung, Li Yau, Hong Kong.
Cheung, Shu W., Tokyo, Japan.
Chisholm, George T., Bradford-on-Avon.
Chosokabe, Yukuto, Nagoya-City, Japan.
Clare, Alan A., Tehran, Iran.
Coulson, Juliet L., Oxted, Surrey.
Crane, Alison R., Ill., U.S.A.
Davies, Clive H., London.
De Silva, G. Ranjan J., Singapore.
Dirk Hurchalla, Robert, Singapore.
Doo, Suen Hoi D., Tokyo, Japan.
Douglas, James S., Auckland, N.Z.
Ebrahimjee, Mustanseir, Harrow.
Elias, Abdul A., Mombasa, Kenya.
Endo, Tadashi, Sendai-City, Japan.
Evans, How M., Qld, Australia.
Fernandez, Michel, Vitry-sur-Seine, France.
Fernandez, Peter, Bangalore, India.
Foucart, Micheline, De Pinte, Belgium.
Franklyn, Rodney L., Liversedge.
Frey, Robert L., London.
Fung, Tsee Hung, London.
Geikler, Patricia, Tehran, Iran.
Gnanam, Janaki M., Colombo, Sri Lanka.
Goldfarb, Lawrence S., Ohio, U.S.A.
Gryska, Stephanie M., Worksop.
Haentjens Dekker, Gerardus R.J., Amsterdam, Holland.
Harris, Vernor G., Tex., U.S.A.
Hartgrove, Patricia M., London.
Hartstone, Jeremy L., London.
Hashimoto, Masaki, Chiba-ken, Japan.
Hattori, Toshikazu, Osaka-City, Japan.
Healey, David, Hong Kong.
Heatlie, James W.M., Edinburgh.
Hirayama, Hiroji, Nigata-City, Japan.
Hirosawa, Kenji, Kobe, Japan.
Ho, Chow Kee, Singapore.
Ho, Kennedy, Bangkok, Thailand.
Huby, Michael, Hutton Cranswick.
Hussain, Surajul H., Mountlavinia, Sri Lanka.
Ide, Takemi, Tokyo, Japan.
Ikeda, Koichiro, Nagoya-City, Japan.
Imaizumi, Yoshihiro, Kanzaki-District, Japan.
Inoue, Yoshiaki, Tokyo, Japan.
Jibiki, Emiko, Nagoya-City, Japan.
Ipekdjian, Denise V., Antwerp, Belgium.
Janiak, Jerzy, Poznan, Poland.
Jasinski, Jozef, Poznan, Poland.
Jenkins, Philip T., Groote Eylandt, Australia.
Jibiki, Emiko, Nagoya-City, Japan.
Jivraj, Hussein A., London.
Kahn, Adrianne H., Pine Bluff, Ark., U.S.A.

Kanako, Watabiki, Chiba-ken, Japan.
Kanegae, Yoko, Tokyo, Japan.
Kato, Mitsuru, Tokyo, Japan.
Kawakami, Sumiyo, Osaka, Japan.
Keiko, Nakanishi, Tottori-ken, Japan.
Kijo, Chiyoko, Tokyo, Japan.
King, Larry G., Texas, U.S.A.
Kipps, M.J.D., Cape Town, S. Africa.
Kita, Keiko, Osaka, Japan.
Kiyama, Tsutomu, Kyoto, Japan.
Kleijn-Jonker, Heleen, Hong Kong.
Kobayashi, Shigeki, Ishikawa-District, Japan.
Kobayashi, Yoshikazu, Long Beach, U.S.A.
Kodama, Mariko S., Tokyo, Japan.
Kohara, Sachiko, Tokyo, Japan.
Kojima, Machinaka, Tokyo, Japan.
Koni, Kazuhiro, Kanazawa-City, Japan.
Konrad, Jerry, Edinburgh.
Kun-Siu, Liao, São Paulo, Brazil.
Kuriyama, Kazuo, Tokyo, Japan.
Kurotaki, Akira, Tokyo, Japan.
Larson, Robert M., Rio de Janeiro, Brazil.
Lasley, Stanley R., Oreg., U.S.A.
Lee, Horace, Staines.
Leith-Smith, Jean E., Hong Kong.
Levine, Carolyn E., Hong Kong.
Lieu, Mai V., Brussels, Belgium.
Maeno, Yoshiyuki, Matto-City, Japan.
Mahoney, Stephen, London.
Makita, Haruaki, Hanno-City, Japan.
Mannai, Mohamed, Bahrain.
Marriott-Smith, Richard L., Horam.
Marsh, Charles E., Fla, U.S.A.
Matheson, James D., Cal., U.S.A.
Mato, Kazuyoshi, Tokyo, Japan.
Miura, Hiroyuki, Sagamihara-City, Japan.
Miyazaki, Shuji, Tokyo, Japan.
Mizuno, Yuzi, Nagoya-City, Japan.
Montoya, Angel J., Bogota, Colombia.
Morimoto, Towa, Kyoto, Japan.
Mui Siu-Ching, Joanna, Kowloon, Hong Kong.
Nakamura, Makoto, Tokyo, Japan.
Nathanson, Daniel P., London.
Neall, Patricia A., Romford.
Neo, Nobushige, Osaka-City, Japan.
Nishino, Tomoji, Tokyo, Japan.
Nobumisto, Takagi, Kanagawa Ken, Japan.
Norkin, Mark M., Ca, U.S.A.
Nose, Yoshishige, Matsumoto-City, Japan.
Ogata, Norihiko, Kanagawa, Japan.
Ohno, Hiroshi, Suginami-ku, Tokyo, Japan.
Oishi, Hirohisa, Nagoya-City, Japan.
Onozawa, Katsumi, Tokyo, Japan.
Osborne, Annie, Hong Kong.
Ozaki, Wakatsu, Kawanishi-City, Japan.
Pathak, Kit, Salford.
Pawson, Peter, Findon.
Probst, Nicholas J., Sarisbury Green, Hants.
Punshon, Clayton R., Regina, Canada.
Ranger, David E.A., St Albans.
Ratilal, Chandrakant, Northolt.
Rehak, Karel, Wakefield.
Richardson, Kay E., Mildenhall.
Roucan, Jean-Pierre, Le Vesinet, France.
Salahudeen, Mohamed F., Kelempong, Sri Lanka.
Saleh, Victor, Wembley.
Sanchez, Sabina, London.
Sato, Eisaku, Saitama-ken, Japan.
Semmes, Granville M., New Orleans, U.S.A.
Shams, Mohammad, Dubai.
Shand, Dolores M., Ontario, Canada.
Shima, Tatsuhito, Toyama-City, Japan.

Shimada, Masahiro, Kanazawa-City, Japan.
Shimaoka, Mitsuaki, Osaka-City, Japan.
Shimomura, Michiko, Tokyo, Japan.
Shum, Helen Y. S., Kowloon, Hong Kong.
Sibtsen, Johannes C., Heerjansdam, Holland.
Silverberg, Donald A., Fla, U.S.A.
Simkin, Michael B., Blackpool.
Singleton, Graham S., Cardigan.
Smith, Cyril R., Durban, S.Africa.
Stiever, Arthur J., Minn., U.S.A.
Sussman, Murray H., Ga, U.S.A.
Takahashi, Junko, Urawa City, Japan.
Takasu, Takitaro, Tokyo, Japan.
Taki, Chikako, Fuji-City, Japan.
Tamaya, Teruhisa, Tokyo, Japan.
Taoka, Hideki, Tokyo, Japan.
Taylor, Richard P., Liverpool.
Teramae, Kiyomi, Shibuya-ku, Tokyo, Japan.
Thelin, Jan, Umea, Sweden.
Thirumavukarasu, Velauthapillai, Colombo, Sri Lanka.
Tormino, Frederick J., N.J., U.S.A.
Tripp, Julia M., Hong Kong.
Tripp, Reginald U.G.H., Hong Kong.
Trowbridge, Rex A., Oreg., U.S.A.
Turner, Richard, Woking.
Ty Vicente, William, Manila, Philippines.
Uchida, Tatsuhiro, Nakakoma-District, Japan.
Van Baaren, Ralph, Zwijndrecht, Holland.
Vouilloux, Annie J., Kowloon, Hong Kong.
Vuyk-Welp, Walthera, Amersfoort, Holland.
Walker-Smith, Michael A., London.
Wills, Derek George, Swanage.
Wilson, Eunice K., Salisbury, Rhodesia.
Wong, Tak Chiu, Kowloon, Hong Kong.
Wood, Margo E., Vt, U.S.A.
Wood, Roger H., Bournemouth.
Wu, Jacob C.Y., Md, U.S.A.
Yano, Hajimu, Osaka, Japan.
Yokoo, Naoya, Tokyo, Japan.
Yoshinaga, Kyoichi, Tokyo, Japan.

GEM DIAMOND EXAMINATION 1977

Thirty-eight candidates entered for the Association's 1977 Gem Diamond Examination, of whom thirty-four qualified, four with distinction. The following is a list of successful candidates arranged alphabetically.

QUALIFIED WITH DISTINCTION

Collier, John M.B., Fordingbridge.
Prat Moya, Sagrado C., Barcelona, Spain.
Tarazona Almenar, Federico, Valencia, Spain.
Vilá Perales, Vicente, Barcelona, Spain.

QUALIFIED

Aloy, Richard N., Gillingham.
Aparici Miguel, Rafael, Valencia, Spain.
Blackley, Robert, Ilford.
Bratton, Timothy J., Sidcup.
Comin Vilajosana, Luis, Barcelona, Spain.
Davidner, Gail R., Wembley.
Fabregas Guardiola, Virginia, Barcelona, Spain.
Falomir Penarrocha, Amadeo, Liria, Spain.
Ferrandis Recatala, Juan V., Valencia, Spain.

Garcia Pilan, Alfonso, Albuixech, Spain.
Hudspith, James W., Leatherhead.
Jamieson, Vivienne, Southgate.
Leach, Jane, London.
Mills-Owens, Paul, London.
Moline Sala, Agustin, Barcelona, Spain.
Mollfulleda Buesa, Antonio, Barcelona, Spain.
Mora Carbonell, Antonio R., Valencia, Spain.
Obiols Mundet, Agustin, Barcelona, Spain.
Oria Albero, Isabel J., Valencia, Spain.
Oria Albero, Paz, Valencia, Spain.
Pons Gomez, Joaquin, Barcelona, Spain.
Ralston, Jonathan B., Stoke Newington.
Rappitt, Toby J., Maidenhead.
Ribes Cudinach, Emilio, Barcelona, Spain.
Rider, Stephen G., Chelmsford.
Ruiz Roca, José V., Valencia, Spain.
San Juan Ribes, Antonio, Valencia, Spain.
Statham, Patricia M., London.
Tilling, Julian G., Dunstable.
Vivo Ibanez, José, Valencia, Spain.

EXAMINATIONS IN GEMMOLOGY 1977

In the Association's 1977 Examinations in Gemmology, 691 candidates sat for the Preliminary Examination (370 passed), and 490 for the Diploma Examination (121 passed). Overseas centres were established again in many parts of the world.

In the opinion of the Examiners no candidate attained the standard required for the Tully Memorial Medal.

The Rayner Prize, in the Preliminary Examination, has been awarded to Mr Michael Allchin, of Altrincham, Cheshire.

The following are lists of successful candidates, arranged alphabetically.

DIPLOMA EXAMINATION

QUALIFIED WITH DISTINCTION

Canas Carballido, Miguel, Madrid, Spain.
Havlik, Jan C., London.

QUALIFIED

Abeyratna, Nayana S.S.K., Colombo, Sri Lanka.
Abril Sirvent, Inmaculada, Mataro, Spain.
Arla Pont, Antonio, Barcelona, Spain.
Ayres, Thomas D., Farnham.
Baldock, Edward J., Wirral.
Bapat, Suresh B., Bombay, India.
Beard, Paul, Nottingham.
Bennett, Lise C., Rochester.
Bhaskaran, Gopalan, Bombay, India.
Bienert Albaladejo, Rosario, Barcelona, Spain.
Borgen, Jennifer A., Fredrikstad, Norway.
Brewer, Peter C., Scarborough.
Bruce, James T., Salisbury, Rhodesia.
Campos De Quevedo, Juan N., Madrid, Spain.
Castanera Rodriguez, Luis, Barcelona, Spain.
Cavey, Christopher R., Ealing.
Chadderton, Yvonne E., Oldham.

Clarke, Kathleen D., London.
Clayton, Keith M., Alford.
Clements, Jennifer M., London.
Conrad, Donald B., East Islip, N.Y., U.S.A.
Cooper, Dorothy A., Stockport.
Cooper, Roy, Disley.
Dantanarayana, Malinie, Colombo, Sri Lanka.
Dave, Mayur, London.
De Silva, Nirmali P., Ambalangoda, Sri Lanka.
De Waele, Carine G., Ghent, Belgium.
Diaz Valcarcel, Teresa, Barcelona, Spain.
Dominguez Mondelo, Segundo, Oviedo, Spain.
Duroc-Danner, Jean M., Geneva, Switzerland.
Elkington, Mary, Solihull.
French, Anthony J., Brockenhurst.
Gade, Fredrik G., Skjetten, Norway.
Ghaswala, Sudhir R., Bombay, India.
Gill, Stephen H., East Horsley.
Goonawarna, Carl L.W.P., Ratnapura, Sri Lanka.
Gotch, Takeshi, Amsterdam, Holland.
Grater, Jane, Salisbury.
Grimbly, Margaret S., Plymouth.
Gunaratna, Mapatunage S., Colombo, Sri Lanka.
Gunawardene, Mahinda, Colombo, Sri Lanka.
Hamamoto, Kouichi H., Osaka, Japan.
Haskings, Theresa M., Wollaton.
Hemphill, Sheri T., Pacific Grove, Ca, U.S.A.
Henocq, James E.R., South Croydon.
Henocq, Rosemary S., South Croydon.
Henrich, Francis J., Lower Hutt, N.Z.
Hood, Glynis M., Johannesburg, S. Africa.
Horn, David E., Ripon.
Hughes, Steven B., Manchester.
Innala, Harri T., Hämeenlinna, Finland.
Kandiah, Asokavathy P., Colombo, Sri Lanka.
Kapukotuwa, Senerath L.B., Rajagiriya, Sri Lanka.
Kaye, Ian D., London.
Kennedy, Padraic J.T., North Vancouver, B.C., Canada.
Kim, Young Chool, Seoul, Korea.
Kizawa, Masakatsu, Ibaraki-ken, Japan.
Knight, David J.R.E., London.
Kortenaar, François L., Schagen, Holland.
Kubica, Jack, Växjö, Sweden.
Lancaster, David J., Johannesburg, S. Africa.
Lawson, Wendy A., Nottingham.
Lewis, Robert G., London.
Lintunen, Viktor, Kuusonkoski, Finland.
Litchfield, Jeane, Albuquerque, N. Mex., U.S.A.
Main, Arthur M., Southport, Qld, Australia.
Manzke, Lothar, Geneva, Switzerland.
Massaron, Mass K., Nugegoda, Sri Lanka.
Meintjes, Arthur H., Stellenbosch, S. Africa.
Mendis, Rowena, Colombo, Sri Lanka.
Mennie, Ruth, New Ferry.
Monras Montells, Jorge, Barcelona, Spain.
Moriuchi, Masana, Niigata City, Japan.
Muije, Cornelius S., Louisville, Ky, U.S.A.
Murga Chivite, Miguel A., Barcelona, Spain.
Mylius, Maren-Ann, Oslo, Norway.
Nachimson-Palacci, Rosy, Troinex, Switzerland.
Narros Martin, Gabriel, Madrid, Spain.

Ng, Kevin K.F., Singapore.
Nootenboom, Poppy Z.L.-B., Kowloon, Hong Kong.
Norström, Stig E., Skärholmen, Sweden.
Paillard, Eva E.S., Paris, France.
Peace, Reginald J., Beverley.
Perez Alberdi, Felix, San Sebastian, Spain.
Pethe, Dilip M., Bombay, India.
Pfersich, François A., London.
Pounds, James R.W., Horsham.
Price, Grenville J., Nottingham.
Prickett, John D., Auckland, N.Z.
Rademaker, Elizabeth J.M., Soest, Holland.
Ramchandran, K.T., Bombay, India.
Rimmer, Robert J., Southport.
Robinson, Kenneth W., Milton Keynes.
Salminen, Mirja L., Pori, Finland.
Sanchez-Lafuento Mariol, José, Barcelona, Spain.
Sanz Balague, Joaquin, Barcelona, Spain.
Sayer, David J., Weston-super-Mare.
Schinkel, Anthony, Southport.
Semmes, Granville M., New Orleans, La, U.S.A.
Sepp, Arne, Cape Town, S. Africa.
Sierstorpff, John v. Francken, Rheinbrohl, W. Germany.
Simon, Horace S., Shreveport, La, U.S.A.
Stonebanks, Judith M., Maidenhead.
Sukumaran, Tharayil M., Wimbledon.
Talgeri, Jayshree G., Poona, India.
Thomson, Paul R., Hobart, Tas., Australia.
Tillander, Paula, Helsinki, Finland.
Timonen, Esko T., Hämeenlinna, Finland.
Tose, Christine, Middlesbrough.
Truelove, Stephen R., Bradford.
Uchihara, Ichiro, Tokyo, Japan.
van der Maden, Pieter, Vlissingen, Holland.
van der Meulen, Anne W., London.
Walker, Andrew G., Guildford.
Wallis, Keith, Surbiton.
Walz, Sylvia E., Langerhagen, W. Germany.
White, Paul T., Seattle, Wash., U.S.A.
Woodhall, Jon. W., Home Hill, Qld, Australia.
Yamaya, Sachiko, Tokyo, Japan.

PRELIMINARY EXAMINATION

RAYNER PRIZE

Allchin, Michael, Altrincham.

QUALIFIED

Abeysinghe, Pushpa K., Colombo, Sri Lanka.
Addinsell, Claire L., Warrington.
Airey, Philip J., Plymouth.
Ali, Syed J.A., London.
Alltree, Derek D., Manchester.
A'Logann, Charles, San Francisco, Ca, U.S.A.
Alos Vidal, Elena, Barcelona, Spain.
Anverally, Fahemida Z., Colombo, Sri Lanka.
Arevalo Gilbert, José, Madrid, Spain.
Arla Matas, Esteban, Barcelona, Spain.
Ashra, Harish B., London.
Athiniotakis, Vassiliki, Athens, Greece.
Aznar Molla, del Dulce N., Valencia, Spain.
Bantekoe, Marijke, Steenwijk, Holland.

Barcham, Kathryn L., Peak, Hong Kong.
Barker, Cyril Henry, Nieder Sachsen, W. Germany.
Barot, Nandkishor R., Nairobi, Kenya.
Barthe Arias, Antonio-R., Oviedo, Spain.
Beach, Wendy L., Twickenham.
Beg, Mirza Z., Woking.
Berggren, U.B. Marie, Oslo, Norway.
Biles, Earl F., Charlotte, N.C., U.S.A.
Birch, Walter J. de Gray, Amarillo, Tex., U.S.A.
Black, John H., Christchurch, N.Z.
Blake, Jeannette A., London.
Blondel, Nigel G., St Martins, C.I.
Bogollagama, Chandresekara R.B., Colombo, Sri Lanka.
Boles, Julian D., London.
Bou Castillo, Angel D., Barcelona, Spain.
Brandon, Jane, Hyde.
Britton, Stephen J., Crawley.
Bromwich, Graham S., Reigate.
Bruce, James T., Salisbury, Rhodesia.
Budding, Peter J., Guildford.
Bürk, Ralph, Pforzheim, W. Germany.
Burns, Lynn D., Birmingham.
Callaghan, Gerard J., Moreton.
Cameron, John S., Auckland, N.Z.
Cannon, Howard T., Joliet, Ill., U.S.A.
Cardenal Gandaras, Francisco, Valencia, Spain.
Carus Mayo, del Pilar, Oviedo, Spain.
Catala Marti, Joaquin, Gandia, Spain.
Catteau, Michel, Sens, France.
Celades Colom, Roberto, Barcelona, Spain.
Chan, Peter K.O., Kowloon, Hong Kong.
Chang, He O., London.
Charlesworth, Anthony R., Southport.
Chiu Mei, Ouyang, Hong Kong.
Clark, Alan J., Croydon.
Clark, Keith D., Ipswich.
Collado Gil, Tomas, Valencia, Spain.
Cook, Robert V., Sale.
Cooray, Bulathsinhalage P.C., Katugaspopa, Sri Lanka.
Corrigan, Bernard J., Walsall.
Costell Ibanez, Manuel, Valencia, Spain.
Cousins, Jonathan, Deal.
Cunning, John J.B., North Bundaberg, Qld, Australia.
Currie, Spencer J.A., Auckland, N.Z.
Daniels, Brian R., Dunedin, N.Z.
Dantanarayana, Ananda S., Panadura, Sri Lanka.
Davies, Clive H., London.
Davies, Garry, Hyde.
Davis, Jonathan V., Stanmore.
Dekker, Gerardus R.J. Haentjens, Amsterdam, Holland.
Dennis, Jillian A., Sandown, I.O.W.
De Regt, Marcus N., Gaes, Holland.
D'Esterno, Guek N., Repulse Bay, Hong Kong.
Dias, Athauda A.R.L., Pannipitiya, Sri Lanka.
Diaz Esnal, Ana, Oviedo, Spain.
Dicker, Johanna A.M., Castricum, Holland.
Docker, Paul B., Birmingham.
Domenech Navarro, Manuel, Barcelona, Spain.
Dougan, Patricia M.S., Nairobi, Kenya.
Doyle, Charlotte T., London.
Dunn, Brian R., Crawley.
Ebina, Tsuneo, London.
Eddy, Donald B., Bethel, Me, U.S.A.
Edirisinghe, Kapila L., Ratnapura, Sri Lanka.
Eijgensleijn, Adriaan J.H., Amstelveen, Holland.
Emden, Norman W., Guildford.
Emslie, Iain A., Walsall.
Ergis, Aflal M., Hamburg, W. Germany.

Evans, Herbert I., Wirral.
Evans, Hilary M.A., Wirral.
Eves, Ian A., Godalming.
Fagleman, Frank I., Newcastle-upon-Tyne.
Faiz, Mohammed H.M., Colombo, Sri Lanka.
Farrow, Karen A., Gt Yarmouth.
Farrugia, George J., Rexdale, Ont., Canada.
Faulder, John A., Purley.
Fennessy, Sean F., Louisville, Ky, U.S.A.
Fernandez Cappellan, José R., Oviedo, Spain.
Fernando, Ivor S.M., Manchester.
Fernando, Marie C.H., Colombo, Sri Lanka.
Fleeman, Geoffrey A., Underwood, Qld, Australia.
Forner Monros, Socorro, Valencia, Spain.
Fox, Irene J., Salisbury, Rhodesia.
Francey, Donald T., Edinburgh.
Franquet, John J., London.
Fritscho – Häberle, Margret, Rorschach, Switzerland.
Fung, Tsee H., London.
Fuster Casas, Miguel, Barcelona, Spain.
Gaastra, Bauke G., Leiden, Holland.
Garcia Dehesa, Felix, Valencia, Spain.
Gerhardt, Willem C., Rotterdam, Holland.
Gil Garcia-Miguel, Jorge, Barcelona, Spain.
Gillen, Richard D., Coral Gables, Fla, U.S.A.
Glaze, Barbara, San Diego, Ca, U.S.A.
Glenister, David A., Port Elizabeth, S. Africa.
Goby, Jaqueline A., Nairobi, Kenya.
Golbey, Terence M., Harrow.
Gomez Echevarria, José, Barcelona, Spain.
Goût, Ralph G., Johannesburg, S. Africa.
Graham, Peter D., Liverpool.
Grant, John W., Milledgeville, Ga, U.S.A.
Greus, Riitta M., Lahti, Finland.
Groenenboom, Peter, Vlaardingen, Holland.
Gryg, Bessie, Hilton, W. Australia.
Gudel Serrano, Antonio, Barcelona, Spain.
Gulu Clua, José L., Reus, Spain.
Gunatilake, Abaya G., Colombo, Sri Lanka.
Hakimian, Michael, London.
Hamamoto, Kouichi, Osaka, Japan.
Hamblin, Nigel H.L., Ringwood.
Hameed Ali, Mohamed S., Colombo, Sri Lanka.
Hammond, Glenys M., Barnet.
Harding, Jayne, Cheadle.
Hasieber, Francis G., Durban, S. Africa.
Hasler, Aileen M., Nairobi, Kenya.
Hindshaw, Judith L., Nairobi, Kenya.
Heathfield, Kenneth A., Chelmsford.
Heatlie, James W.M., Edinburgh.
Heng, Michael K.B., Singapore.
Henniker – Heaton, Gay D.A., Cape Town, S. Africa.
Hewson, Margaret A., Crowthorne.
Heys, Maddi J.M., Limburg, Holland.
Hitchman, Michael J., Wigston.
Hodne, Jan P., Kristiansand, Norway.
Hodson, Steven T., Shaftesbury.
Hoover, Donald B., Lakewood, Colo., U.S.A.
Horley, Anna C., Salisbury, Rhodesia.
Horvath, Elsa, St Julie, Que., Canada.
Howard, David, Longridge.
Hughes, Susan M., Kowloon, Hong Kong.
Hysted, Anne E., New Eltham.
Iber, Beverly, Peoria, Ill., U.S.A.
Ibrahim, Mamat M.B., Kuala Lumpur, W. Malaysia.

Ingamells, Roy, Barnsley.
In't Hout, Guus, Haarlem, Holland.
Israel, Nigel B., London.
Jackson, John G., Sunderland.
Javeri, Suresh H., Bombay, India.
Jerome, Philip, Woodford Green.
Johnson, Marilyn E., Poole.
Jones, Michael D., Flyford Flavel.
Julia Miralles, Nuria, Reus, Spain.
Junquera Sanchez Del Rio, Mercedes, Oviedo, Spain.
Kaleel, Ameena, Colombo, Sri Lanka.
Kalgutkar, Ranchandra S., Bombay, India.
Kanagawa, Kaeko, Osaka, Japan.
Karlgard, Helge, Jakobsli, Norway.
Karunaratna, Austin G., Negmbo, Sri Lanka.
Katz, Raphael D., London.
Keech, June, Stockport.
Keegan, Michael J., Wulguru, Qld, Australia.
Kelly, Robert B., Brisbane, Qld, Australia.
King, Larry G., Grand Prairie, Tex., U.S.A.
Kitahara, Nobuko, Kobe, Japan.
Kiyota, Yumiko, London.
Kjos, Hilde S., Oslo, Norway.
Klein, Hans H., Basle, Switzerland.
Koehli, Ursula, Geneva, Switzerland.
Kraak, Adrianus C., Zuid-Beyerland, Holland.
Krakowiak, Czeslaw, Gdansk Oliwa, Poland.
Krapenc, Terry S., Painesville, Ohio, U.S.A.
Kundanmal, Nitu, Colombo, Sri Lanka.
Lam, To H.K., Hong Kong.
Langoulant, Margaret J., Salisbury, Rhodesia.
Langoulant, Peter B., Salisbury, Rhodesia.
Lappi, Vappu I., Riipila, Finland.
Larson, Robert M., Rio de Janeiro, Brazil.
Leach, Annette, Birmingham.
Leach, David T., Nairobi, Kenya.
Le Duce, Eleanor, Miami, Fla, U.S.A.
Lee, Robert J., Georgetown, Guyana.
Leong, Lee-Wah, Singapore.
Levi, Henry T., Nanticoke, Pa, U.S.A.
Levy, David W.P., Wimbledon.
Litchfield, Jeane, Albuquerque, N. Mex., U.S.A.
Litjens, Rosalia C., Leiden, Holland.
Liu, Kin-Shun, Hong Kong.
Lloveras Bech, Conrado, Gerona, Spain.
Loh, Swee K., Singapore.
Long, Gabrielle E.M., Swanage.
Lopez Paga, Francisca, Barcelona, Spain.
Lopez Garcia, Marisa, Barcelona, Spain.
Low, Bin T., Kuala Lumpur, W. Malaysia.
Lowe, Sylvia J., Harrow.
Lundholm, Carolyn L., Stockholm, Sweden.
Lyall Grant, Ian H., Dartmouth.
Main, Arthur M., Southport, Qld, Australia.
Mallawarachichi, Lakshman M., Nyeri, Kenya.
Manley, Frank R., Lymm.
Marrie, Gordon W., Goroka, Papua – New Guinea.
Marsh, Charles E., Dunedin, Fla, U.S.A.
Martin, William J., Nairobi, Kenya.
Masuda, Hideyo, Shizuoka-Shi, Japan.
McCready, Ann, Nairobi, Kenya.
Midgley, Ronald C., Leeds.
Miller, Harry T., Rio de Janeiro, Brazil.
Miller, Neil, London.
Moller Duran, Rodolfo, Barcelona, Spain.
Monclus Aspero, del Carmen, Barcelona, Spain.

Moody, Kenneth O., Cheltenham.
Moreno Aymerich, Pilar, Barcelona, Spain.
Mortimer, David J., Sale.
Moyersoen, Jean-François, Brussels, Belgium.
Mulase Solana, Mercedes, Barcelona, Spain.
Munuera Quiñonero, Eduardo, Gerona, Spain.
Nau, Pak-Sun, Hong Kong.
Ngugi, Elizabeth P.N., Nairobi, Kenya.
Nieto Reynoso, Luis, Guadalajara, Mexico
Noble, George E., London.
Noblom Salvat, Laura, Barcelona, Spain.
Norberg, Rolf B., Drammen, Norway.
Norström, Stig E., Skärholmen, Sweden.
O'Grady, Gabriel F., Dublin, Ireland.
Okano, Chizuru, Tokyo, Japan.
Orr, William E., Pointe Claire, Que., Canada.
Ovitigala, Mangalika S., Kadawata, Sri Lanka.
Page, David A.L., Mitcham.
Pamies Sole, Santiago, Reus, Spain.
Pastor Alapont, Juan J., Valencia, Spain.
Pathak, Kit, Salford.
Patni, Minakshi J., Nairobi, Kenya.
Penfold, Reginald C., Maidstone.
Pepper, Diana E., Aylesford.
Perera, Pinnagoda L.D.P., Nawala-Rajagiriya, Sri Lanka.
Peterson, Anna W., London.
Pettersen, Sverre, Fredrikstad, Norway.
Pethiyagoda, Upali K., Nugegoda, Sri Lanka.
Phang, Malcolm J., Kingston.
Piercy, Alison, Poynton.
Platt, Carol A., Sale.
Potter, Matthew S., Bangkok, Thailand.
Poyser, Crispin J., Woodborough.
Proctor, Sarah-Jane L., London.
Puig Romero, Dolores, Barcelona, Spain.
Puig-Doria Pala, José, Barcelona, Spain.
Pulle, Amara N.S., London.
Pulle, Bernard T.B., London.
Puolakka, Hannu M., Ji, Finland.
Price, David H., Plymouth.
Purcell, Jeremy C.P., Hove.
Quiles Tarazona, Francisco, Valencia, Spain.
Rainford, David A., Liverpool.
Rajapaksa, Mahinda A.L., Henegama, Sri Lanka.
Rajaratnam, Evelyne V., Ratnapura, Sri Lanka.
Rajivan, Sathyanandan, Colombo, Sri Lanka.
Rakke, Brit, Oslo, Norway.
Rance Jordana, Francisco, Barcelona, Spain.
Rasborn, Jeannine M., Jardine's Lookout, Hong Kong.
Rastall, Mark P., Halifax.
Rastall, Philip, London.
Raymakers, Marina M.E., Mook, Holland.
Raymond, Don S.G.K., Kelaniya, Sri Lanka.
Rise, Ingrid A., Oslo, Norway.
Rissanen, Jukka T., Lahti, Finland.
Roberts, Atie, Cwmbran.
Roberts, Ian P., Northampton.
Roper, Thomas C., Glenorchy, Tas., Australia.
Ros-Jones, Catherine A., South Ascot.
Ross, Johan J., Johannesburg, S. Africa.
Russell, Kenneth M., Bethesda, Md, U.S.A.
Ryan, Thomas G., Limbe, Malawi.
Rydfors, Anne, Nairobi, Kenya.
Saez Perez, Alicia, Reus, Spain.
Saito, Andrea L., Santa Monica, Ca, U.S.A.

Salakian, Silva, Salisbury, Rhodesia.
Sales Csonka, Alicia, Barcelona, Spain.
Salgado, Eric G.A., Solihull.
Salvador Moll, Angel L., London.
Sanchez Berros, Teresa, Valencia, Spain.
Scells, Gerald V., Collinsville, Qld, Australia.
Schippers, Maria J.C., Velp, Holland.
Schofield, John, Leeds.
Schotborgh, Ilse H., Curaçao, Netherlands Antilles.
Seal, Richard M.P., Bridlington.
Searle, Julia M., Sutton Coldfield.
Seevaratnam, Nagalingam, Colombo, Sri Lanka.
Senenayake, A.M.A.S.P., Gampaha, Sri Lanka.
Sever, Katherine M., Altrincham.
Shackley, Ian W., New Brighton, Christchurch, N.Z.
Shah, Nikunj V., Bombay, India.
Shiek, Swun K., Colombo, Sri Lanka.
Sideras, Chris S., London.
Sierstorpff, John v.Francken, Rheinbrohl, W. Germany.
Simpson, Carol A., London.
Skeate, Claire M., Johannesburg, S. Africa.
Snowden, Robert F., San Marino, Ca, U.S.A.
Soler Moradell, Nieves, Barcelona, Spain.
Solves Llorens, Vicente, Valencia, Spain.
Sosna, Boris, Wembley Park.
Soteras Torrella, Emilia, Barcelona, Spain.
Spurr, Rosemary A.E., Johannesburg, S. Africa.
Sugathadasa, Deweligoda G., London.
Sukumaran, Tharayil M., London.
Sunde, Elisabeth M.H., Oslo, Norway.
Suriyaarachchi, Gamini S., Kotte, Sri Lanka.
Swan, David G., London.
Symons, Marion H., Sai Kung, Hong Kong.
Tamarit Garcia, Pedro A., Valencia, Spain.
Tan, Chow-Ng, London.
Tate, Julia F., Hong Kong.
Tattersall, Simon R., Radlett.
Taylor, Ernest B., Warrington.
Taylor, John B., Brisbane, Qld, Australia.
Taylor, Richard P., Liverpool.
Thompson, Hugh D.R., Mount Royal, Que., Canada.
Tilley, Melinda V., Kowloon, Hong Kong.
Tindall, Anthony P., Otley.
Tolley, Ian P., Brisbane, Qld, Australia.
Törnroos, Gunilla A.V., Helsinki, Finland.
Towler, Eric A., Kowloon, Hong Kong.
Townsend, Nigel D., Wakefield.
Truman, Raymond H., Ilford.
Tunnicliffe, Dorothy H., Wallasey.
Turner, Michael J., Sheffield.
Turtiainen, Arja A., Eura, Finland.
Teraura, S., Osaka, Japan.
Uchihara, Ichiro, Tokyo, Japan.
Ueta, Kouji, Osaka, Japan.
Vale, Shelagh V., Limuru, Kenya.
Valero Martinez, José F., Barcelona, Spain.
Valonen, Anne I., Kalhonkylä, Finland.
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The Council of the Association is grateful to the following for their gifts:

The Gemmological Association of All Japan for a large framed collage depicting a typical Japanese vase and floral arrangement. This picture is made up of opals, agates and sapphires.

Mr A. Hardy for calcite crystals from Eyam, Derbyshire.

Mr P.P.E. Paulin, B.Sc., F.G.A., Uppsala, Sweden, for a collection of hessonite garnet, small crystal groups and pieces of idocrase, some of which show a typical spectrum—all from Quebec Province, Canada.

Mr J.L. Slocum, Rochester, Mich., U.S.A., for an excellent collection of 'Slocum' stones—man-made material simulating opal. In the collection are four pieces of rough material and 36 cut and polished stones together with one doublet and two triplets.

Mr M. van Moppes, of Wessex Impex Ltd, for an excellent red agate and amethyst geode from Dulcote Mine, Somerset.

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An exhibition (organized by Gem Craft Magazine) of 'gems, minerals, silvercraft, lapidary machinery, jewellery, enamelling, treasure-hunting and allied crafts' is to be held at Grosvenor House Hotel, Park Lane, London, W.1. on 25th, 26th and 27th March, 1978. (Open 10 a.m.–7 p.m. Admission adults 60p., children 30p.)

"GEMPRINT"

The Gemprint is an instrument, simple in principle, which provides a means of obtaining a permanent record of reflections from polished gemstones—a 'fingerprint' from which the individual gemstone can always be recognized (unless it is repolished or recut). It consists (see Fig. 1) of:

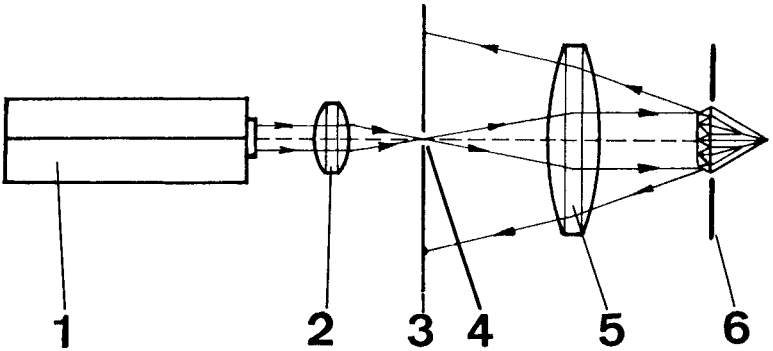

Fig. 1

(1) A laser beam light source
(2) Lens
(3) Polaroid film holder
(4) Holding screen with pin-hole in the centre
(5) A second lens
(6) Mobile holder to position the gem

In operation the laser beam from the light source (1) is focused by the lens (2) onto the screen plane and passes through the pin-hole (4). The second lens (5), which is placed at its focal length from the pin-hole, provides a parallel light beam. When the gemstone is placed in this beam, reflections of the polished surfaces return through the lens and focus on the screen (4). The gem is positioned in its holder (6) so that the reflections of the gem table are directed into the pin-hole. There is only one position in which the light reflected from the table of the gem can be brought to focus on the pin-hole. This provides an orientation point so that subsequent reflection patterns of the same gem will be identical with the original. When the gemstone is positioned in its exact location, recording of the reflection is than made on film at the screen plane.

Shown in Fig. 2 is a pattern of light spots produced by a particular diamond. There is only one position where this diamond will reflect light back from its table through the pin-hole so that subsequent Gemprints of the same stone will be identical, though when comparing negatives or prints it may be necessary to revolve them in order to match the patterns.

The Gemprint will accommodate stones of almost any size when unmounted

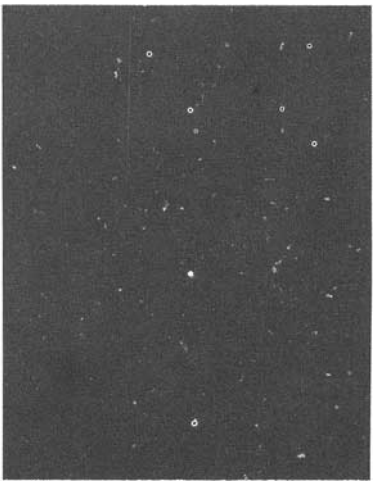

Fig. 2. Diamond.

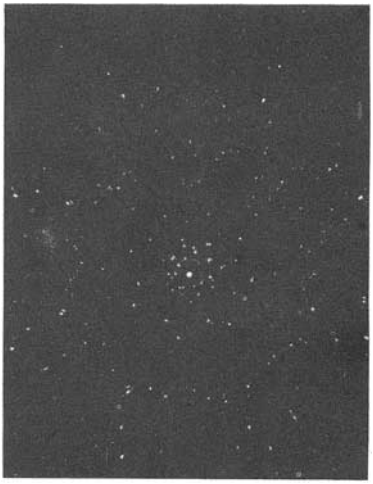

Fig. 3. Y.A.G.

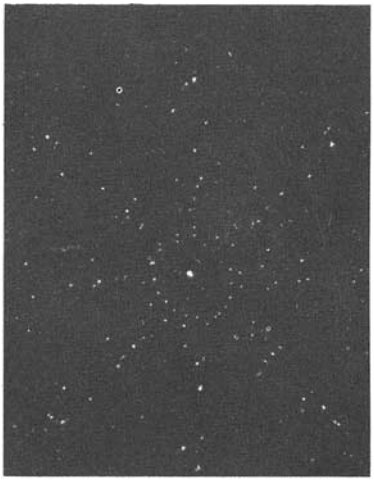

Fig. 4. G.G.G.

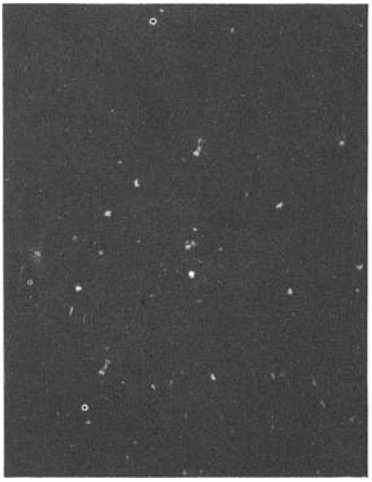

Fig. 5. Strontium titanate.

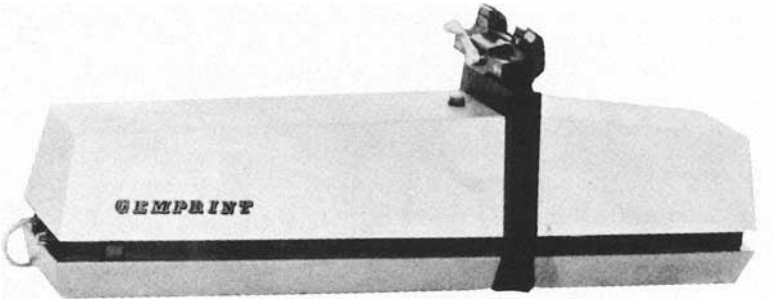

Fig. 6

and also many mounted stones as well. The prints are unique for each brilliant-cut diamond, provided it is not repolished.

The machine can also be used for brilliant-cut simulants of diamond (or indeed for any faceted stone with a flat table facet) because each individual gives a different pattern on the Polaroid film (see Figs 3, 4 and 5). When a stone is machine cut and polished as in the case of Y.A.G., G.G.G. and strontium titanate, shown in the illustrations, it will produce a more symmetrical pattern than a hand-cut stone.

The appearance of the instrument is shown in Fig. 6, and it was demonstrated by Mr A.E. Farn, F.G.A. to members of the Gemmological Association at a meeting in Goldsmith's Hall on 9th February, 1977.

The Gemprint would cost approximately £1,500 in the U.K. Further details are available from Gemmological Instruments Limited, Saint Dunstan's House, Carey Lane, London, EC2V 8AB (Tel. 01-606 5025).

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THE JOURNAL OF GEMMOLOGY

The Editor apologizes for the late appearance of this number of the *Journal* owing to unavoidable delays due to a change of the processes and typefaces used by the printers from letterpress to photolithography and from 'Baskerville' to 'Times' respectively.

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Vol. XVI No. 2 April, 1978

THE JOURNAL OF GEMMOLOGY

and

PROCEEDINGS OF THE GEMMOLOGICAL ASSOCIATION OF GREAT BRITAIN

GEMMOLOGICAL ASSOCIATION
OF GREAT BRITAIN
SAINT DUNSTAN'S HOUSE, CAREY LANE
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THE JOURNAL OF GEMMOLOGY
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Vol. XVI No. 2 APRIL, 1978

THE GEOLOGICAL SETTING OF THE NODULES AT DULCOTE, SOMERSET*

By R.R. HARDING, B.Sc., D.Phil.,
Institute of Geological Sciences, London SW7 2DE

Nodules and geodes from the Mendip Hills in Somerset have been known to mineral collectors for a few hundred years, but recently material of this kind from Dulcote, near Wells, has made a noticeable impact on the lapidary and gemstone market, due to the exploitation of a rich deposit in a quarry primarily worked for road and concrete aggregate. Various articles have appeared in the popular and scientific press describing the nodules and this article is an attempt to outline their geological setting and to summarize the latest ideas on their origin. Quartz nodules from the Mendips have been given different names at different times, being known variously as 'potato stones', 'Bristol Diamonds' or 'Bristol Stones', the diamond allusion having been firmly fixed in the sixteenth century. The 'diamonds' were subsequently correctly identified as quartz, but the controversy surrounding the nodules merely switched from their identification to their mode of origin.

Nodules and geodes occur in the conglomerate and marls of Keuper or Upper Triassic age (190 to 200 million years old) over an

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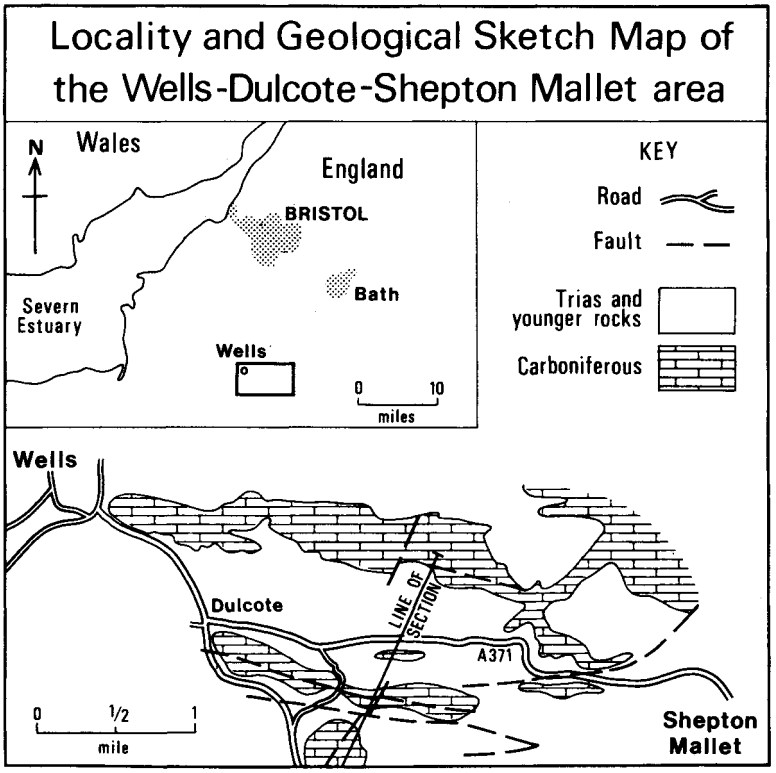

Fig. 1.

area extending from Bristol to Wells. In this region the conglomerates and marls rest unconformably on an uneven surface of folded and eroded rocks of Silurian, Devonian and Carboniferous age (i.e. on rocks formed between 420 and 280 million years ago). Figure 1 shows the areal extent of the Trias and younger rocks between Wells and Shepton Mallet, and Figure 2 shows how patchy and variable in thickness the Trias is on the limestone basement. The Keuper rocks consist mainly of red marls (calcareous and dolomitic mudstone and siltstone) with sporadic thin bands of greenish grey sandstone and marl, between 150 and 400 feet (50-130 m) thick north of the Mendips, but attaining up to 1500 feet (460 m) or more some way south of the Mendips. Between these two sedimentary areas the marls pass laterally into conglomerates and breccias (the Dolomitic Conglomerate) which are banked against the older rocks and represent a massive blanket

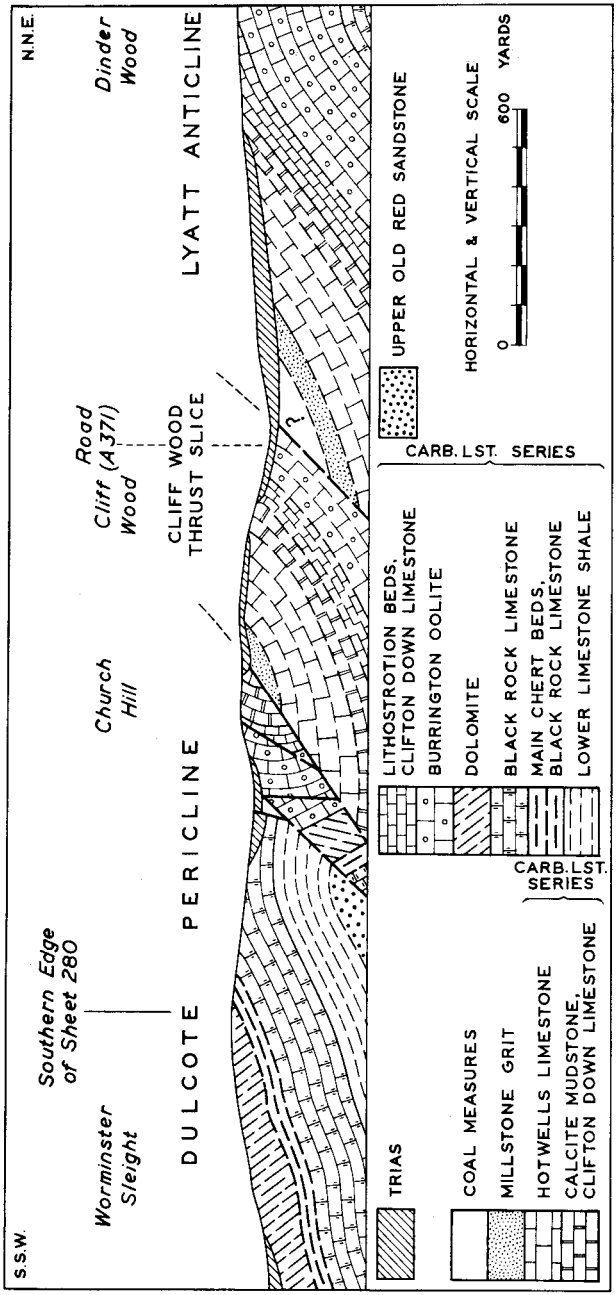

Fig. 2. Section through Carboniferous and Trias rocks near Dulcote (after Green and Welch, 1965).

of scree locally up to 350 feet (91 m) or more thick around the Mendips in a form strongly suggestive of an old shoreline or cliffline. The Dolomitic conglomerate is largely composed of ill-sorted fragments of Carboniferous limestone with some Old Red Sandstone and Quartzitic Sandstone Group (Millstone Grit) detritus set in a sandy marl or fine-grained calcareous matrix. Its calcareous nature has been modified over a large area by the introduction of magnesium and formation of dolomite, and in more localized patches it has suffered varying degrees of silicification and haematitization. The dolomitization affects both pebbles and matrix and is commonly accompanied by hydration processes, the results of which are most obvious in the hand specimen where dark red haematite (Fe_2O_3) has been converted into ochreous yellow limonite ($FeO(OH)$). Near the old shoreline of Palaeozoic rocks the conglomerate is very coarse-grained but farther away from the ancient land mass it passes into finer varieties with beds of marl intercalated with the pebble horizons until ultimately the succession consists of marl and minor fine pebbly calcareous sandstones. The local succession in the Trias below the Rhaetic is divided into the Keuper Marl (predominantly red-brown) and above it the Tea Green Marl (mainly grey-green). Both are affected, like the conglomerate, by dolomitization with $MgCa(CO_3)_2$ replacing the detrital and recrystallized calcite, and by hydrous fluids altering the iron oxides so that the rocks take on a yellow or pale brown hue. In addition to the carbonate and water components a wider variety of replacing fluids containing chloride and sulphate ions is indicated by the occurrence of halite, celestine, anhydrite and gypsum which occur both as matrix replacement minerals and as nodules.

In this wide range of sediment type and associated chemical variation occur the siliceous nodules (see Plates 1 and 2). Some are composed of medium to large quartz crystals with an inner layer of much smaller grains, while others consist of fibrous quartz with or without prismatic quartz. Both types of nodules are found with internal voids or with cores of quartz, calcite or celestine. Recent work on the structures and inclusions in the nodules by Tucker (1976) has confirmed that the silica grew from the outside inwards, but perhaps the most significant of his observations about the inclusions concerns anhydrite. This mineral is no longer found in any quantity in the hand specimen but occurs with carbonates and hydroxides as micron-sized inclusions in the milky parts of the

quartz nodules and as even smaller inclusions in the chalcedonic ones. Tucker interpreted these textures (1976, p.571) to show that the siliceous nodules had formed by replacement of anhydrite—already in nodular form—and quotes examples of similar anhydrite textures in present day nodules in the Persian Gulf. Shearman (1966) has described in detail the environments in the Persian Gulf and the sediments in which anhydrite nodules are forming and suggests that ancient sulphate-bearing sedimentary rock sequences with nodular anhydrite were also formed in supratidal conditions in a desert tropical or subtropical climate. In this connexion Van der Voo and French (1974) have shown that the British Isles were also probably on the edge of the tropics in late Triassic times. A similar arid tidal-flat environment has been invoked for the formation of anhydrite concretions, subsequently silicified, in the Mississippian (about 340 million years old) of Tennessee by Chowns and Elkins (1974). They postulate that ground waters became saturated with $CaSO_4$ and deposited anhydrite in the tidal sediments, and say (op. cit., p.896) that the uncompacted nature of the nodules strongly indicates that silicification commenced before much sediment had been deposited above them. They are uncertain as to the origin of the silica but think it likely that most of it came from the breakdown of siliceous sponge spicules with perhaps later silica coming from the weathering of clay minerals. To account for both solid and hollow nodules Chowns and Elkins (op. cit.) and Tucker (op. cit.) favour the idea of different rates of solution of the anhydrite; in cases where the speed at which silica replaced the sulphate equalled the speed of sulphate solution, the resulting nodule would most likely be solid (Plate 2), but where the rate of solution exceeded that of silica growth, there would come a point when all the anhydrite had dissolved away and the silica would grow into a void (Plate 1). Solid nodules of chalcedony or jasper showing textures similar to the Dulcote stones have been described from an anhydrite bed of Upper Permian age (235 million years) by Harrison (1975). He considers that these nodules started as colloidal masses of silica, resting in anhydrite-rich groundwater, that coalesced and then solidified by rhythmic precipitation of chalcedony, incorporating varying amounts of haematite (giving colour banding) and also small amounts of fluorite and barite.

Little lead-zinc mineralization occurs either in the nodules or in the marls around Dulcote, although in the general area rocks as

PLATE 1. Four red and white geodes showing a variety of minerals in the cavities. In the upper specimen, yellowish calcite is the main cavity mineral with clear quartz and black specks of goethite evident in the top section. Pale grey-blue celestine in thin blades is well developed in two cavities in the left hand geode, providing a fine contrast with the amethystine blue of the quartz in the geode on the right. The lower specimen illustrates the transition from red silica to very clear massive quartz to discretely crystalline quartz - which gives the specular reflections in the picture. The upper specimen is 20 cm long.

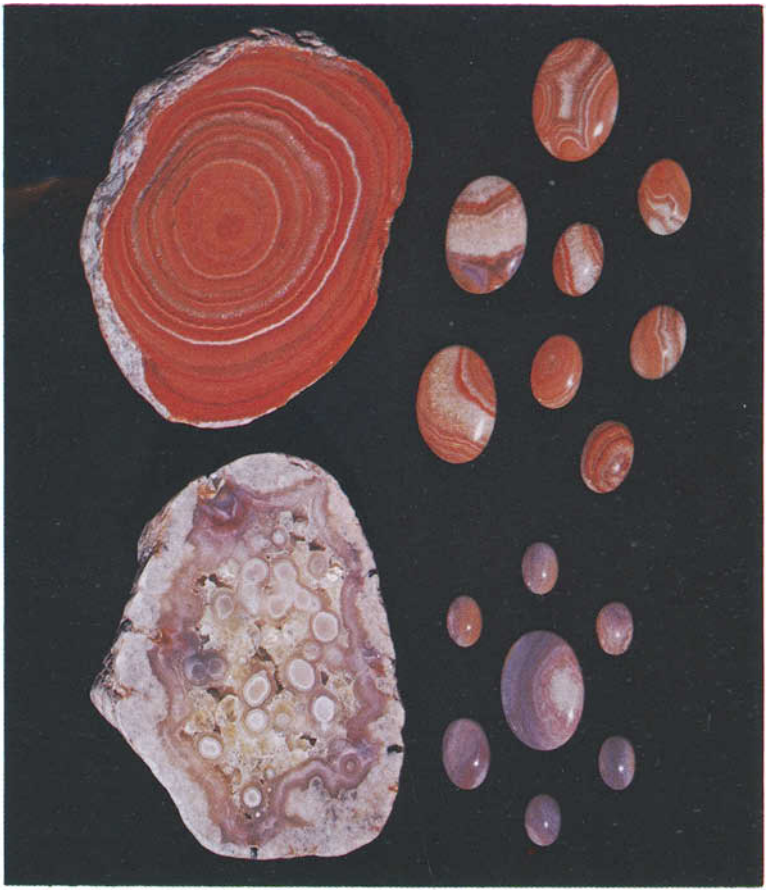

PLATE 2. The left hand nodule consists of white, grey and mauve chalcedony with crystalline quartz mantling the rounded masses of chalcedony in the core. At two spots on the bottom of the specimen and one spot on each side, black veins of galena can be seen to have penetrated up to 5 mm into the chalcedony. The right hand nodule is a beautiful example of concentric banded red and white agate. A selection of cabochons cut from mauve and from red and white material is shown.

young as the Lower Lias (about 170 million years old) are in places cut by fissures which are lined with galena (see Plate 2) and sphalerite. Again iron ore mainly in the form of limonite or goethite is widespread in pipes or fissures cutting the Carboniferous Limestone and Dolomitic Conglomerate but in the latter it also occurs as a metasomatic replacement along certain beds and is present as haematite or goethite in the nodules. It is likely that in some places at least iron mineralization predates the introduction of lead and zinc, for it lines some fissures bearing these ores, but it would be unwise to apply this conclusion to the whole mineral field as much secondary solution of the minerals has occurred.

At Dulcote the nodules occur in red and green marls above the Carboniferous Limestone, which here consists of part of the Burrington Oolite and part of the Clifton Down Limestone (see Fig. 2). Nodules are now extracted from the predominantly red marly clays from above the eroded limestones by a combined Foster Yeoman Ltd—Wessex Impex Ltd operation, and Van Moppes (of Wessex Impex Ltd) has carried out identifications of nodule types on 7100 lb (3220 kg) of material which he characterized thus:

Geodes:	red agate geodes with various minerals in the cavities:	11%
	white quartz-rimmed:	6%
Lapidary grade agate:	purple and red:	33%
Tumbling grade:	nodules containing some agate:	30%
Other grades:		20%

The general proportions are consistent with those found in a previous sample of 2400 lb (1088 kg), and it appears that from this particular area the majority of nodules are composed of red and white cryptocrystalline silica—falling into the fibrous quartz group of Tucker (1976, p.570), with only a small percentage showing good crystal terminations into central cavities. These proportions are not likely to be constant throughout the marls and conglomerates, for conditions of silicification, carbonate development and iron impregnation all vary markedly over distances of a few metres; it will be of interest to see what proportions emerge from future development of the deposits.

ACKNOWLEDGEMENTS

I am most grateful to Mr E.A. Jobbins for suggesting the topic and for his help, to Mr M. van Moppes for demonstrating the range of nodules found, to Mr Ted Airey, of Foster Yeoman Ltd, for guidance round Dulcote Quarry, to Mr G.W. Green and Mr R.F. Symes, who reviewed the text and suggested many improvements, and to Mr H.J. Evans for producing the colour plates.

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[*Manuscript received 19th January, 1978.*]

CERULEITE—A NEW GEMSTONE

By K. SCHMETZER, H. BANK, W. BERDESINSKI and E. KROUŽEK

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INTRODUCTION

Some time ago one of the authors got some rough and cut blue stones which in colour were very close to turquoise and which were offered as ceruleite. Ceruleite is not mentioned at all in some mineralogical textbooks or only with the sign '?' as a 'not exactly defined mineral' in the index; in others it is described in detail, but not in the appearance which will be described hereafter. Therefore in the beginning the authors thought that it might be a 'not exactly known mineral species'.

If one tries to determine samples of such a not exactly known or even unknown mineral, one first determines in the laboratory the chemical and physical properties and compares them with the properties of well known minerals. If one finds no satisfying congruence—naturally within the limits of error—but certain similarities with a known mineral, it is not easy to decide whether it is really a new mineral or whether there are only varying measuring properties (perhaps caused by impurities). If, furthermore, there are only few properties of the 'similar' mineral known and if the locality of the sample-material is not certain, the only possibility is a comparison with samples from the original locality of the 'similar' mineral to confirm the identity of both materials.

This was exactly the problem of our investigations with the Cu-Al-arsenate ceruleite. That the material in question indeed is the mineral ceruleite, could only be confirmed by comparison with an original sample of material from the originally described locality which we received by courtesy of the British Museum of Natural History, London, for which we acknowledge here our thanks.

H. Dufet (1900) described for the first time a Cu-Al-arsenate containing H_2O and called it ceruleite (céruléite) because of its sky-blue colour. The mineral had been discovered in several samples in Chile and came from the Emma Luisa goldmine near Huanaco in the Taltal Province. This first description by Dufet contains the only known data of ceruleite (chemical analysis, specific gravity,

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FIG. 1. Ceruleite from Bolivia—natural and cut.

solubility in acids). To our knowledge, no later supplementary investigations exist or at least are published. This fact has led to the varying position of ceruleite in the different systematic mineralogical textbooks and index tables. In some of them—Dana (1922), Doelter (1918), Fleischer (1975), Hey (1955), Hintze (1933)—the mineral is mentioned in the text part; Strunz (1970) mentions it in the index only with the sign '?' for 'not exactly defined minerals'.

The samples, which we got, come from Southern Bolivia, and it was not possible to get an exact locality though we tried our best. Since the ceruleite samples are in part at least worth cutting, the mineral is also worth describing in this *Journal.* Details have been published elsewhere (Schmetzer *et al.,* 1976).

RESULTS

The samples consist of concretions ranging up to 10 cm in diameter, macroscopically blue in colour (Fig. 1). Single individuals of the very tiny crystals, which form polycrystalline aggregates, cannot be distinguished. With a SEM micrograph, it was possible to recognize rod-shaped crystals up to 5 μm in length and up to 2 μm in thickness (Fig. 2). The concretions are coated on the surface partly by a crust of idiomorphic quartz crystals with inclusions of rutile and fine crystalline barite and goethite. On cutting the concretions, there have been found, in some pieces,

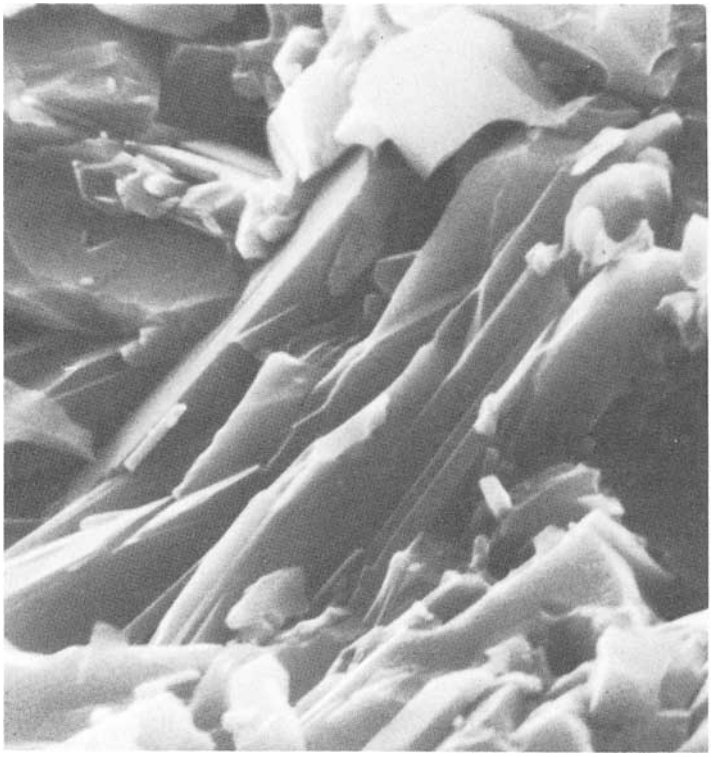

FIG. 2. Ceruleite crystals. SEM micrograph, 10 000 ×.

parts of white mansfieldite, which can range up to 1 cm in diameter. The specific gravity of the polycrystalline aggregates has been experimentally determined at 2.70±0.02 g/cm³. The refraction averages ≈ 1.60; more precise values could not be received either for refraction or for birefringence.

Ceruleite is not soluble in water, but it is attacked by HCl, HNO_3 and KOH. Wet chemical analysis of seven different samples show an average composition of:

CuO	11.8%
Al_2O_3	26.9%
As_2O_5	38.0%
H_2O	23.3%
	100.0%

This furnishes the crystal chemical formula

$$Cu_2Al_7\left[(OH)_{13}\middle|(AsO_4)_4\right].11.5\,H_2O$$

which differs from the formula and the analysis of Dufet (1900) by a lower content of Al_2O_3. We cannot exclude a small impurity perhaps of mansfieldite in our samples.

Since no single crystals of sufficient size have been available, the x-ray investigations were done by powder diffraction analysis. The strongest d-values are:

7.296	(75)
5.926	(70)
5.650	(100)
4.760	(70)
3.545	(60)
2.650	(60)

They can be indexed (supposing a triclinic unit cell) with the lattice parameters:

$a_o = 14.36$Å; $b_o = 14.69$Å; $c_o = 7.44$Å
$\alpha = 96.1°$; $\beta = 93.2°$; $\gamma = 91.6°$

A comparison of this blue investigation material from Bolivia with the ceruleite of the original locality in Chile has furnished an identical x-ray diffraction pattern for the blue, greenish-blue and colourless parts of the sample available. Thus the identity of the mineral from Bolivia with ceruleite has been confirmed.

Ceruleite is stable up to ≈ 230°C and at ≈ 250°C inverts to a blue-green crystalline phase losing 14.7% H_2O. This arsenate is stable up to ≈ 290°C. At higher temperature, there is formed a green substance, amorphous to x-rays.

For the commercial evaluation of a gemstone there are of importance colour, colour intensity or colour optimum. So far, ceruleite could be regarded, with its colour shades similar to those of turquoise, as a gemstone. Since it is similar to turquoise in hardness also, ceruleite may reach an important position on the world market if the occurrence furnishes enough material.

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GEMMOLOGICAL NOTES

By PETE J. DUNN, M.A., F.G.A.,
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THE STAR OF INDEPENDENCE

The Smithsonian Institution was recently given the opportunity to have on loan, for a period of two weeks, a new and superbly cut diamond, named 'The Star of Independence'. The gem was exhibited in the Hall of Gems at the Smithsonian from 17th to 30th November, 1976.

The rough diamond weighed 204.10 carats and was found early in 1976 in Sierra Leone. It was then purchased by Harry Winston, the noted New York diamond merchant. The diamond was cut by Winston's diamond cutters and as the cutting progressed, it became apparent that the largest stone to be cut from the rough would weigh about 76 carats. The actual weight of the finished gem is 75.52 carats. However, rounding this figure gives an approximate weight of 76 carats and hence the gem was named 'The Star of Independence' in honour of the United States Bicentenary (1776-1976).

The author had an opportunity to briefly examine the gem. It

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is cut as a superb pendeloque with a faceted girdle. The most striking feature of the stone is the placement of 8-10 extra facets on the pavilion which does away with the 'black bow-tie' so common in pendeloque-cut diamonds. The finished product is a strikingly brilliant pendeloque worthy of its name. The gem has now been sold to an anonymous owner at an undisclosed price.

PHOSPHOPHYLLITE FROM BOLIVIA

Gem phosphophyllite was found in the Krause vein, Potosi, Bolivia, in the late 1950s. Little of the material has been cut. Owing to its softness 3-3½ and three cleavages on {100}, {010}, and {$\bar{1}$02}, this is a gem material more suited to museum care than to street wear. Bank (1975) noted the refractive indices of the material to be $\alpha = 1.599$, $\beta = 1.621$ with a density of 3.09 g/cm^3. Subsequent analysis of this material has shown that the Bolivian phosphophyllite, unlike the material from Hagendorf, Germany, is manganese-free and approaches the end-member composition of $Zn_2Fe(PO_4)_2.4H_2O$.

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ZEKTZERITE

A new mineral, zektzerite, has been found in a granite in Washington, U.S.A. The mineral was described by Dunn *et al.* (1977) as an orthorhombic lithium sodium zirconium silicate, $LiNaZrSi_6O_{15}$. The gem potential of the material is quite low, although gems up to 5-10 carats might be cut. Since several stones have been cut, it seems useful to set down the constants for the files of the practising gemmologist.

Zektzerite is orthorhombic, with a density of 2.79 g/cm^3 (±0.02). Refractive indices, in sodium light, for this biaxial negative gem are: $\alpha = 1.582$, $\beta = 1.584$, and $\gamma = 1.585$ (±0.003). The material is colourless to very light pink and has very low dispersion. It fluoresces a light yellow colour in short-wave ultraviolet radiation. There is no response to long wave ultraviolet and no phosphorescence. The Mohs hardness is about 6, and there are two perfect cleavages, at right angles to each other, which are parallel to

{100} and {010}. The material takes a good polish and, due to the two perfect cleavages, is best suited to rectangular cuts. It will probably only be encountered by the connoisseur of rare gems and museum curators.

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Blue-green Gem Dravite from East Africa

A stream-worn pebble of tourmaline was found in East Africa and is quite notable in that its colour, bluish-green, is unlike any of the hues normally associated with the common gem tourmaline, elbaite.

A small section of the waterworn single crystal was removed for analysis and the sample was analysed with an electron microprobe operating at 15 kV and utilizing a sample current of 0.15 μA. The resultant partial analysis is presented as Table I. The material is obviously dravite, a sodium magnesium tourmaline. Iron is present as a minor constituent, perhaps in substitution for magnesium. The dravite is uniaxial negative with $\varepsilon = 1.616$, $\omega = 1.637$, birefringence 0.021. The absorption is $\omega > \varepsilon$, ω = bluish-green, ε = light yellowish-green. No inclusions were observed.

The author is indebted to John Saul for calling his attention to the material.

TABLE I

PARTIAL ANALYSIS OF DRAVITE FROM EAST AFRICA

SiO_2	36.27
TiO_2	0.04
Al_2O_3	31.12
Na_2O	2.74
K_2O	0.02
MgO	11.89
CaO	1.43
FeO*	0.39
MnO	0.00
total	83.90

*total iron calculated as FeO

BLUE PECTOLITE FROM SANTO DOMINGO

Many tourists returning from Santo Domingo have purchased a gem called *'larimar'*. This gem material is comprised of radiating spherules of a fibrous mineral. The mineral has been x-rayed and found to be pectolite, $NaCa_2Si_3O_8(OH)$. The spherules vary from 2 to 8 mm in diameter. They are light blue at their centres and the colour changes to white at the exterior of the spherules. Due to the extreme toughness of the material and its attractiveness to tourists, it is likely to prevail as a gem material, but should be labelled pectolite, its true mineral name.

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A STUDY OF EMERALDS FROM AN UNSUBSTANTIATED AFRICAN SOURCE OF ORIGIN

By I.C.C. CAMPBELL, F.G.A.

Upon one of my recent visits to Johannesburg to visit a personal friend of mine, Michael Sutherland, F.G.A. (who is also a practising gemmologist), I had the opportunity of seeing for the first time two comparatively large faceted emeralds of a fine deep bluish-green colour. One was temporarily made available to me after I had indicated my interest in its origin. Mr Sutherland and I spent some time examining this stone. The inclusions, apparent clarity, and hue of colour appeared initially to have some similarity to recorded data in relation to some synthetics—particularly modern ones. Such suspicions were not altogether unfounded because the colour and quality also appeared to be exceptional and the cut unusually good. Initially there were no, or very little, aspects of the inclusions in this particular stone which seemed clearly to indicate natural origin—other than perhaps the physical

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and optical constants which were high and at the top bracket of a few other varieties of natural emeralds. The other large stone was also eventually examined and found to have similar characteristics. Although the inclusions appeared similar to those in Indian emeralds, there were basic differences. A number of smaller stones which were said to be from the same source of origin were then obtained, and in fact covered a colour range from almost that of the two large stones mentioned above down to what may be described as medium shades and qualities. At a later date some additional medium to pale shades were also made available. All these, with a few variations, contained similar inclusions to the two above-mentioned large stones—however, other solid mineral inclusions were also observed in some of the smaller stones *together* with these types originally seen in the two large ones. These additional internal features confirmed that the stones were of natural origin, with the result that I decided to make the following study of the stones. This necessitated a number of visits to Johannesburg over the period concerned, as I did not have any similar emeralds at my disposal in Rhodesia at the time. A limited number of crystals in the rough were also seen which were of various qualities. They also contained similar inclusions to those seen in the other cut stones constituting this study. The uncut crystals were suitably immersed, thus making the internal examination much easier.

Regarding Possible Origin

Questions regarding origin were rather vaguely answered (maybe for trade reasons) and it would appear at this stage that a reliable answer is not to hand. All that could be finally learned was that they were from 'an African country somewhere to the north of Rhodesia and South Africa'. Rumours of Tanzania being the origin were also heard, but I think this is unlikely. Zambia should not be ruled out and may well be the source of origin. Other than limited mica flakes and some inclusions with the appearance of biotite, inclusions in these stones are *not* typical of emeralds from the Miku claims in Zambia. However, the refractive indices and specific gravity range are in part similar. I do not think Moçambique should be ruled out either, although (from a consideration of the circumstances) Zambia seems the probable source. Three emeralds from the Maria Mine (approximately 17 miles north-west of Marvë—in the north Quelimane district of Moçambique) were

examined by me. They were of a poor colour although a good bluish-green is in fact mined. They do not fluoresce. The Refractive Indices were 1.577-1.584 (DR 0.007) and the SG was 2.70 to 2.71. Some inclusions were two-phase, but the general picture did not, in my opinion, reconcile with those seen in the test stones used in this study.

Finally, there is a possibilty that Zaire could also be the source of origin—information has been heard to this effect. The two serious choices are in my opinion either Zambia or Zaire. (I have since received several unconnected statements that Zambia is in fact the source, the new claims apparently being in the district in which the Miku claims are situated).

Colour

From what was seen, the colour appears somewhat similar to some good quality bluish-green stones from Zambia (Miku claims), but with what appears to be more brilliance (no doubt due to good cutting). This obviously grades down through the colour range to an insipid, almost slightly tinted bluish-green colour of ordinary beryl. Another comparison of some of the deeper coloured stones can be made to that of better quality Lechleitner synthetic emerald-coated beryl, except that the test stones are much brighter, coupled with a more full-bodied hue than the Lechleitner. Yet again, stones half the size of the two large ones appeared a slightly more grass green, although still having the bluish tinge to them. Possibly the differences in physical size had at least something to do with this. (In any case, a variation of shades has also been seen in most other emeralds from one source or another.) One could even say that the large spectrum of green shades that were seen were welcomed from a scientific point of view, especially when initially we had doubts as to the identity of the two fine coloured stones. One does not expect to see synthetics with this sort of colour range—not on the market, anyway.

Marketing Aspects and the Requirement of Additional Research

These stones are apparently being cut in a number of Western countries. This has apparently been initiated only relatively recently. Just to what extent the stones have been released on to the market to date is a matter of conjecture, but the writer has not as

yet seen anything in print about them—at least from a gemmological point of view. It is for this reason that the following details are given. It would, however, be of obvious advantage if other gemmologists were in a position to obtain similar stones (which must happen in due course) and enlarge upon what is reported here. Whatever additional results are achieved, such a contribution would benefit all concerned with gemmology. This was amply demonstrated by my original article 'Emeralds Reputed to be of Zambian Origin' (1973)[1] being followed up by the report 'The Emerald Occurrence of Miku, Zambia,' by Professor Dr Hermann Bank, F.G.A., (1974);[2] in which the source of origin was confirmed.

Regarding the Computation of Specific Gravity

These were computed hydrostatically with the use of a Mettler H 800C balance. The liquid medium used was absolute alcohol, the SG of which was determined with a Westphal balance at the time of the exercise. Thereafter, the stones were re-tested against the computed figures with the aid of specially mixed heavy liquids on a comparative basis. As a result of this, one SG was found to be incorrect and re-computed after another weighing. The second figure proved correct.

Short-wave Ultraviolet Transmission Tests

Short-wave ultraviolet light was used (253.7 nm being the main activating radiation) with the two large test stones and some control stones together resting table facet down on photographic paper, the UV light being situated approximately 24 cm above. The exposure was for a duration of 2 seconds and another of 3 seconds. The former one gave better results. The two stones appeared to be opaque, or nearly so, to these rays, whereas two Zambian emeralds and a Lechleitner (except around the area designated by the crown facets) transmitted quite freely. It is also interesting to note that a Gilson synthetic was also opaque to these waves, and slightly more so than the two test stones which were much larger. It is acknowledged that this type of test no longer applies from a diagnostic point of view due to the incorporation of iron into the formula of more recent synthetic emeralds[3] and some natural ones as well.

Test Specimen Reference Number	*Wt Cts*	*Whether Faceted or Rough*	*Colour*	*Refractive Index & Birefringence*	*Specific Gravity*	*Photomicrograph Reference*
1	2.61	Faceted (emerald cut)	Fine deep bluish green	1.583—1.590 0.007	2.76	Figs 1-6 inclusive
2	2.48	Faceted (baguette)	Fine deep bluish green Bright	1.583—1.590 0.007	2.76	Figs 7-12 inclusive
3	1.12	Faceted	Fine moderately deep bluish green Bright	1.584—1.591 0.007	2.76	—
4	1.31	Faceted	Deep bluish green Somewhat dull Moderately heavily included	1.583—1.590 0.007	2.74	Figures 13, 14 and 15
5	0.68	Faceted	Very good moderately deep bluish green Fairly bright	1.583—1.590 0.007	2.75	—
6	0.46	Faceted	Very good moderately deep bluish green Suggestion of leaf green Bright	1.583—1.590 0.007	2.76	Figures 16, 17 and 18
7	0.31	Faceted	As per 6 above	1.583—1.590 0.007	2.76	Figures 19 and 20
8	0.61	Semi-faceted Part-crystal	A good medium bluish green	1.582—1.589 0.007	2.73	—
9	0.648	Small uncut crystal	Somewhat pale bluish green	—	2.73	—
10	0.919	Faceted	Moderately deep bluish green Bright	1.583—1.590 0.007	2.73	Figure 21
11	0.538	Faceted	Pale bluish green More like ordinary beryl than emerald	1.582—1.589 0.007	2.73	—

Refractive Index: 1 stone—1.584—1.591
7 stones—1.583—1.590
2 stones—1.582—1.589
Birefringence: All stones—0.007
Specific Gravity: From 2.73 to 2.76

FLUORESCENCE

The fluorescence, under the Chelsea colour filter, of the two largest stones (Nos 1 and 2) was in the first instance not noticed. However, after paying more attention to this it was noticed that there was a visible darkening of the stones. This applied to specimens referenced 3, 4 and 10 in the above schedule as well. Specimen No. 11 did not react at all and stayed a yellowish-green colour under the filter. However, the others, numbered 5 to 8 inclusive, showed a very slight tinge of reddish colour coupled with a similar dark appearance as described above. The remaining specimen (the uncut crystal of a somewhat pale bluish-green colour) showed a very slight darkening affect. The iron content (see

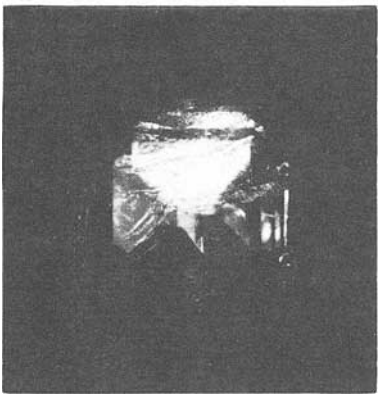

FIG. 1

FIG. 2

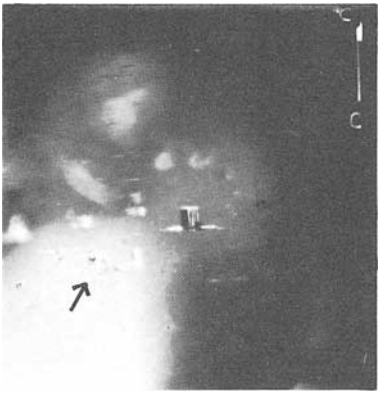

FIG. 3

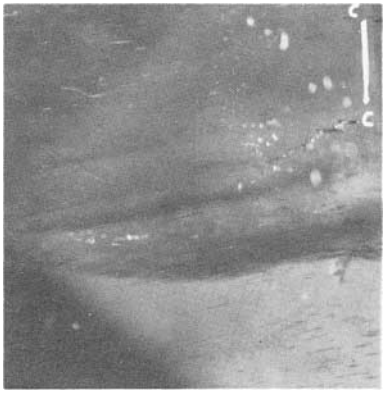

FIG. 4

FIG. 5

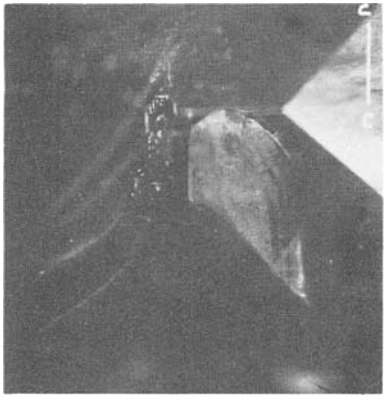

FIG. 6

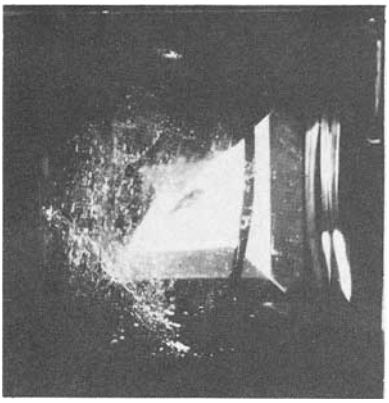

FIG. 7

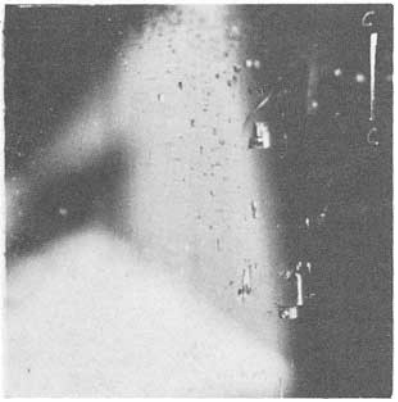

FIG. 8

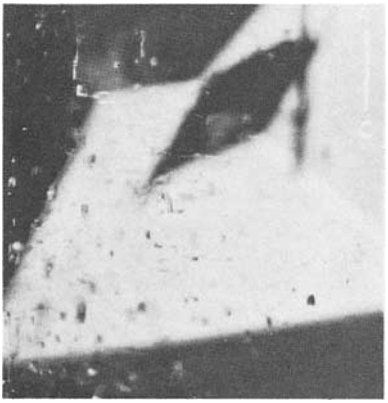

FIG. 9

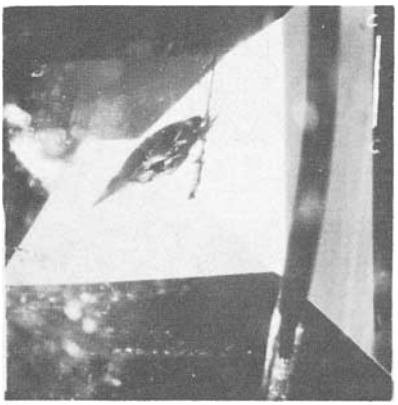

FIG. 10

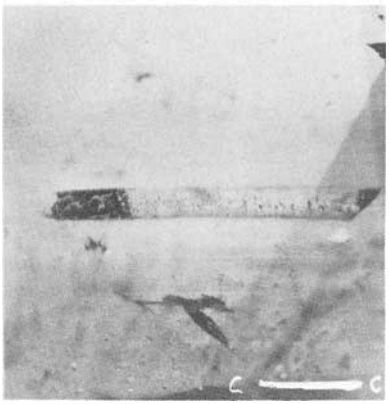

FIG. 11

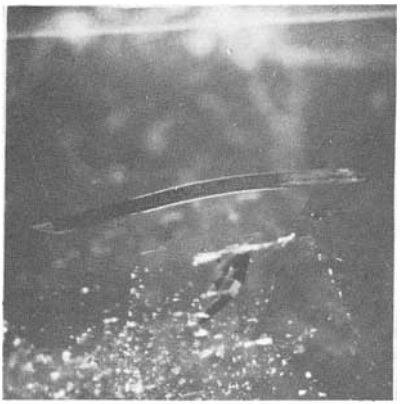

FIG. 12

FIG. 14

FIG. 16

FIG. 13

FIG. 15

FIG. 18

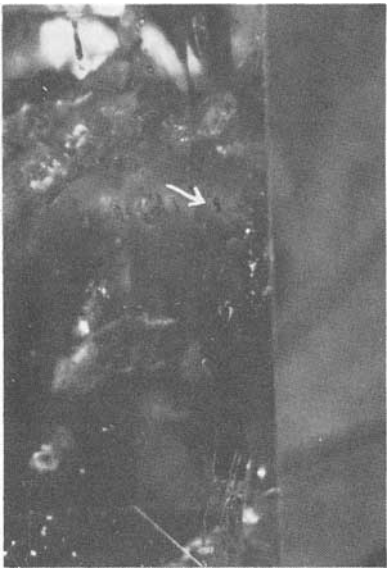

FIG. 20

FIG. 17

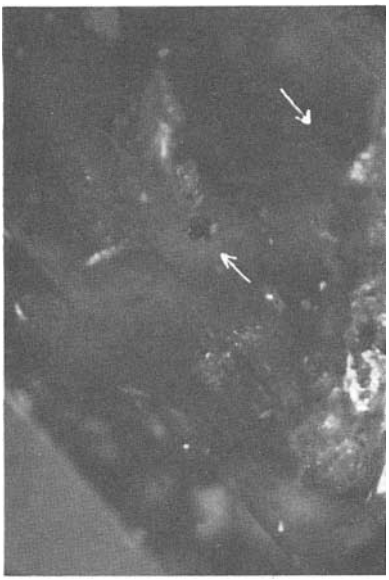

FIG. 19

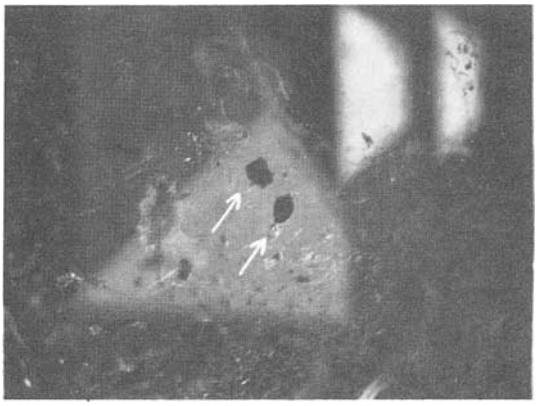

FIG. 21

under paragraph re absorption spectrum) has obviously had an effect on this property.

ABSORPTION SPECTRUM

Absorption for chromic oxide was noticed in all cases, with the intensity appearing to increase in step with the intensity of colour. It was strong in specimens 1 to 7 inclusive, less intense but still obvious in 8 and 10. However, the lines in the red were not at all obvious in the pale stone and could only be seen with difficulty. In all cases an absorption occurred for iron in the medium to lower part of the blue wavelengths when the stones were examined in direct lighting from below the microscope stage (with the spectroscope fitted in place of one ocular). In the paler stones transmitted light was used, which high-lighted the iron absorption bands more clearly. In some cases it appeared as though part of the violet was absorbed as well. In all cases the bands in the blue appeared somewhat diffuse without an obvious demarcation on either side. As the spectroscope (Rayner prism type) was not calibrated, it is not possible to write in terms of wavelengths.

ORIENTATION OF THE TWO LARGE STONES IN RELATION TO THE INCLUSIONS SHOWN IN THE PHOTOMICROGRAPHS, AND THE INCLUSIONS IN THE OTHER STONES

As was inferred earlier in this study, the general picture presented by the inclusions in the two (first seen) larger stones gave

one the impression that perhaps they were of synthetic manufacture. Not until the other stones were examined did it become apparent that they were of, in my opinion, natural origin. The first two seen, really beautiful gems, contained what could be misleading inclusions to the average gemmologist. There were no other inclusions in either of these stones except the two-phase ones (and a rudder-like inclusion in each) which when coupled with other doubtful aspects gave food for thought. However, when the other stones were obtained and tested for similar properties the same type of inclusions were evident in all the stones (except the rudder-like inclusions), with the addition of other foreign crystals (which do not appear to have been seen in synthetics to date, as far as I am aware), thus bridging the gap between the two 'unsure' stones and what are now taken by the writer to be the other natural stones. (The writer has since been told that limited quantities have been obtained to date in South Africa as virtually 'mine-run' material. It has apparently been from these parcels that a limited number of good to fine quality stones have been sorted out, resulting in a good financial return on the amount paid for the parcel. This can, of course, only be accepted at face value until it is actually established that this is so). Another interesting thing about the rough material is that it appears to be abnormally difficult to orientate in relation to obtaining the best cuts from the material.

As the two larger stones gave some problems initially (in spite of the high RI and SG) the results of the photomicrography are given in detail. The remaining photomicrographs of the inclusions in the other stones, much more limited in this context, serve as visual evidence of the common association of all the stones and an indication of their natural origin. The photomicrographs of the larger stones are numbered 1 to 12 inclusive. In numerous cases considerably enlarged prints from the negatives give much clearer indications in relation to the comments below. The optic axis (hence the *C*-axis) of each of the two large stones was orientated with the combined aid of a polariscope and refractometer. Each photomicrograph is marked accordingly where applicable. Magnifications are listed in the schedule as well as under each photomicrograph. Attention is drawn to the following features:

Figure No.	*Magnification (Contact prints)*	*COMMENTS Relating to Specimen No. 1 (Wt—2.61 ct)*
1	6 ×	Overall view of stone with table up. Note curved feathers. (As opposed to 'twisted' veils generally seen in the majority of synthetics.) For large inclusion near culet (or wedge) see No. 6
2 and 3	Both 60 ×	*TABLE FACET UP* These two views are exactly the same in all respects but for one exception. It was noted that the bubble in the left hand inclusion behaved somewhat strangely, while the test specimen remained untouched. It moved 'up' and 'down' with the change of temperature as a result of the substage illumination being reduced or increased—introducing an obvious temperature change. It was difficult to substantiate whether or not the inclusion was actually slightly tilted to the horizontal plane; however, tilted or not, it looked odd to see a bubble with a reciprocating action when its host remained stationary. In order to maintain the light intensity for the purpose of photography, the test specimen was fanned until the bubble moved 'downwards' and the negative thus exposed—(Fig. 2). The fanning was stopped, the bubble travelled 'upwards' (Fig. 3), and the next negative then exposed. It would seem to indicate a critical balance between gas and liquid.
4	40 ×	*TABLE FACET UP* Brush-stroke type inclusions. Other coarser inclusions are also apparent and are approx. parallel to and at right angles to the main *C*-axis (two directions).
5	40 ×	*TABLE FACET DOWN* A clear view of 2-phase inclusions accompanied by other inclusions butting up to one extremity in each case and at right angles to them. Again, one will be seen to have a vaguely striated appearance which is parallel to the length of the inclusion.
6	24 ×	*TABLE FACET UP* A clear view of a rudder-like inclusion protruding into the stone near the culet (or wedge). An interesting observation here is that this inclusion is similar in appearance to that in the other test stone shown in Figs 7, 9, 10 and 12—and also similarly positioned in the host. Nothing like this was observed in specimens examined later. (There is the possibility that the two gems could have been cut from the same piece of rough.) As can be clearly seen in this view, this internal 'protrudence' exhibits curved 'striations', is basically curved at its extremity, and has what appears to be possible external faces along the curved edge. It is more or less aligned to the *C*-axis of the host. Note curved feathers again.
Figure No.	*Magnification*	*COMMENTS relating to Specimen No. 2 (Wt—2.48 ct)*
7	10 ×	*TABLE FACET UP* The concentration of feathers at the right—particularly the upper right—have a curved appearance, not entirely unlike those seen in most synthetic emeralds—although more recently made synthetics show curved veils much less than their older counterparts. See relative photomicrographs below in relation to the two obviously large features shown here—the internal 'protrudence' near the culet (or wedge) and the 'black' curved one across the stone.
8	40 ×	*TABLE FACET UP* A clear view of more two-phase inclusions under higher magnification. There appears to be a tapering affect in some. Note again, the striations on the one two-phase inclusion which gives it the appearance of a piston (the bubble inclusion giving the illusion of the hole that accommodates the gudgeon pin). The orientation in two planes is still obvious. An interesting aspect of this view is the obvious zoning, parallel to the *C*-axis. In fact, both stones showed a broad, slightly paler, colour zone more or less through the centre of the stones and visible end on—i.e. when observing the stone from the side in the direction of the optic axis. The one large stone (the emerald-cut one) showed a similar band—which was less visible than the one in this specimen and at a slight oblique angle to the table facet. This zoning was *not* accommodated with demarcation lines when the stone was examined with the unaided eye under suitable lighting.

9	40 ×	*TABLE FACET UP* Larger inclusion at centre of photomicrograph (which was much clearer when viewed under the microscope) appears to have an irregular (negative?) crystal form. The existence of this particular inclusion as being a two-phase one was not at all apparent.
10	24 ×	*TABLE FACET UP* View of a rudder-like inclusion similar to that in Fig. 6 (in the other stone). The surprising thing about this is the remarkable similarity not only in overall shape but in their position in each stone. It is not known what the ragged 'inclusion' near it is. The curved, dark inclusion (seen obliquely here) is shown in Figs 11 and 12.
11 and 12	Both 16 ×	*STONE RESTING ON A PAVILION FACET AND IMMERSED.* (Fig. 11) The first reaction here is that this inclusion is a seed plate, which it is not. The inclusion itself takes the form of a 'ribbon' which is comparatively thin in section and curved. The view shown here is an oblique end one (i.e. this is not its thickness). The angled end corresponds to the surface of a pavilion facet. Also note the zoning parallel to the *C*-axis. In this view demarcation lines are obvious. This type of zoning was noticed in numerous other stones as well.
		STONE AGAIN IMMERSED: TABLE FACET DOWN. (Fig. 12) Another oblique view (other way round) of the curved inclusion. Curvature even more obvious. This looks very much like a fracture. *NOTE:* Both these exposures were taken in overhead transmitted light. In substage lighting (see other prints) this inclusion showed as black.

NO OTHER FOREIGN MINERAL INCLUSIONS WERE SEEN, OTHER THAN TWO RUDDER-LIKE (SOLID?) ONES IN THESE TWO LARGEST STONES.

Figure No.	*Specimen No.* *Magnification*	*SOME OF THE OTHER STONES* (Specimens 4, 6, 7 &10)
13 and 14	*SPECIMEN* *No. 4* 40 × 60 ×	Fig. 13 shows similar inclusions to the two largest specimens, except in greater abundance. Also a 'black' looking crystal (Fig. 14) of unknown identity at the centre of the view. What appeared to be yellowish-brown iron stains were present in flaws well within the stone. Although appearing like part of a mica flake, this is not so. ('Terminated' both ends). Another view, which prevented successful photography, showed this to have the appearance of a terminated (black) crystal. Another, similar in colour, inclusion seen (which could not be successfully recorded because of its location) looked very much like a well terminated magnetite of octahedron form but this could well be another mineral species.
15	*SPECIMEN* *No. 4* 40 ×	Lozenge shaped, flat inclusion. Transparent. Rounded corners. Slightly deeper green in colour than body colour of stone. Location close to black inclusion mentioned above.
16	*SPECIMEN* *No. 6* 40 ×	Showing two-phase inclusions typical of all the specimens. Diagonally opposite this are fractures a little out of focus, but re-focused as shown below in Fig. 17.
17 and 18	*SPECIMEN* *No. 6* 40 × 60 ×	Iron stained fracture with hair-like inclusions orientated at approximately right angles to the fracture planes. Also (Fig. 18) ragged, apparently tapered, hollow inclusion.
19	*SPECIMEN* *No. 7* 60 ×	An oblique view of an inclusion which appears to be similar in appearance to the striated ones clearly shown in Fig. 2 and Fig. 8. Also irregular, black (biotite?) inclusions (bottom right).
20	*SPECIMEN* *No. 7* 40 ×	Black, geometric shaped, inclusion near edge of specimen and just below the surface. Other black inclusions of irregular shape also present. (Transmitted light). In substage light the inclusion of geometric shape reflects light, giving the inclusion a transparent quality as noticed in mica under similar conditions. Other black, thin (some partly geometric, others irregular shaped) inclusions also seen but not shown here. (Black in both transmitted and substage lighting). Not seen in this photograph, were also numerous hair-like inclusions in circumstances similar to those described in Specimen No. 6 (Fig. 17) above.
21	*SPECIMEN* *No. 10* 40 ×	Thin, irregular and geometric shaped inclusions of a pale brownish colour. Appear to be limited in quantity. Only a few were seen in three stones. Possibly a form of mica (similar to that seen in Zambian emeralds from the Miku claims).

IN CORRELATION OF THE FOREGOING FINDINGS (INCLUSIONS)

(i) As already stated, before the other specimens were seen the writer's thoughts were that a possibility existed that the two initially examined largest specimens were synthetics. This was in spite of the high physical and optical constants. This view was also held by Michael Sutherland who, as I said, examined one of them with me in the initial stages. (He also examined others later). Only Indian emeralds bear any resemblance to the type of inclusions seen in these test stones—and then Indian stones at least have some indication of biotite or fuchsite in them. The 'comma' type negative twin crystals of Indian emeralds have been reported as negative twin crystallites that have grown on one side of a mica flake.[4] Pakistan emeralds contain two-phase inclusions and thin films, of the details of which not a great deal appears to have been printed![5] The constants of Pakistan emeralds are similar to these test stones. However, in view of unconnected sources of information that the test stones are of African origin, it is considered reasonable to accept that they are not of Pakistan origin. Other than the similar physical and optical constants (and colour in many cases) of Zambian stones of Miku origin, there is no relationship with presently known facts insofar as the inclusions are concerned. This does not of course, rule out the possibility of a new Zambian discovery. One thing seems apparent—these stones are from a newly discovered source of origin in or about central Africa.

(ii) Notwithstanding stones of this species which contain the additional type of inclusions as found later in the smaller test stones, future ones of a rich bluish-green colour which contain *only* the inclusions seen in the two larger test stones could, in the writer's opinion, be somewhat misleading—resulting in a possible misidentification. Inclusions and descriptions given by Gübelin (including photomicrographs) appear to have, in part, a similarity to the two large test specimens![4] The high constants of the original two test stones did, however, give food for thought at the time—although it has been reported that recent synthetics have constants well into the natural range (many being quoted, but none as high as these test stones). The addition of larger quantities of iron into the basic formula in recent synthetics is responsible for this. The test stones also have a significant iron content. Quite apart from this, the curved nature of the feathers in the test stones—many being of

a coarse nature, however—can lead to a possible misinterpretation of origin if this is not accompanied by other mineral inclusions.

(iii) The additional inclusions in the smaller stones gave a different outlook and, in the opinion of the writer, support the view that these are natural stones. The identity of the inclusions is not known. Mr Sutherland, who also saw thin rounded 'flake-like' inclusions of a pale brownish hue of colour, wondered if perhaps they were oil. Fluorescent tests conducted under the microscope showed no fluorescence—then again, as the stones have a significant iron content this may have affected the results. Having seen similar flakes, though sparsely situated, which have definite geometric outlines (hexagonal in some cases, or part of a hexagonal form) the writer is of the opinion that it is one of the micas. (Since then, a similar type of flake of a rounded nature was noticed in another similar variety of emerald to that of these test stones by both Sutherland and myself. It was at the crown surface and, with the aid of a probe, we established it as one of the micas.)

(iv) A summary of the inclusions found in the test stones is as follows:

(a) Two-phase, comprising two parts, orientated at right angles to each other with the main component parallel to the *C*-axis. These inclusions appear to be part of curved feathers.

(b) Both coarse and fine feathers. Many of a curved nature.

(c) Brush-stroke type formation of what appear to be densely packed thin tubes more or less orientated in the same direction to each other.

(d) One component of the double inclusion (the bubble-included one) often of a striated nature and orientated parallel to the *C*-axis of the test stone.

(e) An odd rudder-shaped internal growth in the two largest stones but not appearing in any of the others.

(f) Colour zoning parallel to the *C*-axis of the host stone.

(g) Tubular, two-phase inclusions parallel to the *C*-axis of the host stone and other tubular inclusions at right angles to this.

(h) Flat, 'plate-like' inclusions upon which stand the principal two-phase ones.

(i) Crystals, limited in quantity, which resemble black or blackish solid crystals. One *looked* like an octahedron of magnetite. Others did not.

(j) Lozenge shaped, thin transparent 'flakes', which are almost certainly one of the micas.

(k) Yellowish-brownish stained internal fractures (iron stains?) and coarse-looking cotton-wool type clouds in one stone with the same stains in and around the localized area well within the stone.

(l) Black geometric and irregular shaped inclusions. (Biotite and/or some iron compounds).

(m) Hair-like growths extending from fractures within two stones.

CONCLUSION

From the foregoing data, it appears that these stones are in fact from a new unconfirmed source—probably Zambia. The information given here should help to identify them from other varieties. There is an overlap or coincidence of refractive indices and specific gravities in relation to limited numbers of emeralds from other origins, but the inclusions are distinctive and coupled with the physical and optical constants they should serve their purpose as a means of identification of this species—of whatever origin they turn out to be.

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THE ROLE OF REFLECTIVITY IN GEMMOLOGY

By W. WILLIAM HANNEMAN, Ph.D.

PART I. FRESNEL REFRACTOMETERS

A Fresnel refractometer operates on the principle that the quantity of light reflected from the polished surface of a gem can be related to the Refractive Index (RI) of that gem. The equation developed by Fresnel in the early 19th century is shown in the Appendix (on page 113).

The index of refraction, n, by definition equals the ratio of the velocity of light in air to the velocity through the medium.

However, the velocity of a light ray through a gem varies with the wavelength of the ray. It therefore follows that for any gem, the value of n is different for each different wavelength of light. Indeed, the magnitude of the change in n between two selected wavelengths is, by definition, the gemmologist's dispersion.

Because of this variation of n, confusion would be sure to reign, if some standard wavelength were not agreed upon for making measurements of n. As a result, 589 nm was chosen, because essentially monochromatic light of this wavelength can be readily created in the laboratory. This corresponds to the D line of Fraunhofer in the spectrum of the sun and is due to sodium. These values were designated by the symbol n_D and it is these values which are now known to gemmologists by the term Refractive Index (RI).

Although it has been known since the time of Fresnel that one could construct a refractometer if one could only devise a means of determining the fraction of light reflected from the surface, it is only recently that technology has made this feasible.* Does this mean that the Fresnel Refractometer will now become a significant gemmological instrument? For the reasons set out below, I do not think so.

Long ago, scientists recognized the usefulness of RI (n_D) values and the critical angle refractometer was developed and has become an indispensable tool of the gemmologist. Using sodium light, he

*It should be acknowledged that a great deal of work has been done on this principle in the past and can be found referenced in any text on optical mineralogy. While useful for characterizing ore samples, the difficulty of making accurate absolute measurements precluded the development of a practical gemmological instrument.

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can easily measure the refractive index or indices of a gem to three decimal places. The value of double refraction (birefringence) can also be determined as well as optic character. He can even make a good estimate of dispersion by using white light. As a laboratory tool, the critical angle refractometer leaves little to be desired except that its range is limited so that it cannot be used to differentiate the high RI gems, including the modern simulated diamonds.

The Fresnel Refractometer is not so limited and now such a 'universal' instrument can be, and in fact has been, constructed. However, the practical question is whether such an instrument will be useful enough to justify the expense of its construction. The answer to this question would undoubtedly be 'Yes', if the Fresnel Refractometer could duplicate all the functions of the critical angle refractometer and replace it: but it cannot. In spite of its 'unlimited' range, the Fresnel Refractometer cannot either (1) detect double refraction (much less measure its value), or (2) determine optic character, or (3) indicate dispersion. Therefore the only really useful function it can perform is to determine the RI of gems above 1.8, and it really cannot do this too well, as explained below.

The operation of the critical angle refractometer is based on determining the point of total internal reflection of a beam passing from a medium of higher n (the prism) into one of lower n (the gem). This manifests itself in the instrument as a discrete division between a light and dark area. It is easy to observe, easy to measure accurately and if a reading can be made at all (i.e. if the specimen is within the instrument's range) it will be the correct value. Small scratches or imperfections on the gem surface are of no consequence.

The Fresnel Refractometer operates by determining the percentage of light reflected when a beam passing through a medium of lower n (air) strikes the polished surface of a material of higher n (the gem). There is a gradual change in the quantity reflected as the angle of incidence changes and there is a different quantity reflected by different gems at the same angle. The Fresnel Refractometer must be constructed to record these differences and this can only be done, practically, by electronic means.* The only

*The late L.C. Trumper, B.Sc., F.G.A., using visible light and no electronics, constructed an optical Fresnel-principle reflectometer (claimed to provide direct readings of refractive index between 1.40 and 3.20), which he described in *The Measurement of Refractive Index by Reflection,* J.Gemm., 1959, **VII**, 4, 129-38: but there appears to have been no follow-up.

observation by the operator is merely that of reading an electronic meter.

This might be perfectly acceptable if the index of refraction (n) were the only factor which determined the quantity of light reflected. However, any imperfection in the gem surface in the form of poor polish, scratches, dirt, etc., may drastically affect that value and the resulting meter-reading will be low. Also, 90% or more of the incident beam actually passes into the gem and may be reflected again from a back facet. This could lead to high meter-readings.

All of the identification schemes of gemmology depending on the index of refraction are based on the premise that the RI value obtained from a refractometer is indeed the correct value. Consequently, any refractometer capable of providing an erroneous value must be looked upon as an instrument capable of doing more harm than good. The Fresnel Refractometer is such an instrument. The Fresnel Refractometer is not inherently limited by its own design: it is limited by the condition of the gem.

In order to build a Fresnel Refractometer, one must construct an electronic instrument containing a light source, a focusing system, a light detector and a read-out meter. Let us examine these components separately.

Light Source: Since this is going to be a gemmological refractometer, it is imperative that the value it determines is n_D and this means that a sodium light source is required. This is a relatively expensive component and I have yet to see anyone attempting to make a commercial instrument of this design. However, by using a white light source, one can obtain values approximating n_D. Such an instrument has been patented by Long.[1] It is a very complex and expensive instrument and is not currently available commercially.

However, from a practical gemmological viewpoint, there is another insurmountable problem facing the Fresnel refractometer. Diamond and strontium titanate have n_D values which are so close together that they cannot be differentiated on an electronic meter scale. This severely limits the usefulness of the instrument for differentiating the simulated diamonds.

Several commercial instruments (Gemeter and Redex)* have been constructed using infrared light sources. These can indeed

*Redex is understood to be no longer commercially available and Gemeter is now spelt with a J.

separate diamond from strontium titanate, because in this energy range the values of n for these two substances are significantly different from each other (and also from their n_D values). It would appear that the manufacturers of these infrared instruments either did not appreciate the fact that the instruments were not determining n_D or else ignored it in an attempt to create a 'Fresnel Gem Refractometer'. In any event, diamond reads 2.41 on their RI scales and this left R. Webster[2] and other gemmologists wondering whatever had happened to the RI of strontium titanate which appeared on the scale at about 2.2 to 2.3. It seems, also, that these instruments were plagued with detector linearity problems which created calibration difficulties. As a result, they were not widely acclaimed by the critics.

Focusing System: Fresnel's equation relates n to the ratio of the reflected light to the incident light. Therefore, in order to determine this ratio, one must accomplish one of two things, namely either (1) devise a system to measure the total light impinging on the gem surface and another system to measure the total light reflected from the gem surface, or (2) devise a means of focusing and shielding, so that all the light falls only on the gem surface or that only light reflected from the gem surface strikes the detector. Either approach results in a complex instrument with the associated high manufacturing costs.

Detector and Read-out Systems: If Fresnel's equation is to be used, the detector response must be linear with respect to the amount of light striking it. This response is then displayed on a meter. Being a manufactured item, each meter has a specification as to its accuracy. The more accurate the meter, the more costly it is and the best meters are usually no better than ±0.5% of full scale. This can result in a variation of about ±0.01 in the RI value and this is due solely to the meter. When the other sources of error are considered, it is readily apparent that the determination of RI with a Fresnel refractometer can be a very risky business.

Tatsumi[3] also acknowledged the shortcomings of the Fresnel Refractometer when he wrote, 'Measurements on several gemstones with higher refractive index by this instrument showed that we could identify them, provided that stones have a refractive index of over 1.81'. A key word in that sentence is 'several': as the data in Table I which lists some gemstones having RI values between 1.9 and 2 indicates, identification is impossible with a refractometer

which cannot determine double refraction. Unfortunately, the practising gemmologist does not have the luxury of specifying which gems he is going to accept for identification.

TABLE I
Expected RI Range of Fresnel Refractometer Reading

Zircon	1.92—1.98
Scheelite	1.92—1.94
Sphene	1.88—2.05
Yttrium Aluminate	1.93—1.96

All the preceding may leave the reader with the idea that reflectivity has no significant role to play in gemmology. This is not at all true and I shall explain just what that role is in Part II—Relative Reflectivity.

Appendix

Reflection of light by a transparent medium in air (Fresnel's formulae). If i is the angle of incidence, r the angle of refraction, n_1 the index of refraction for air (nearly equal to unity), n_2 index of refraction for a medium, than the ratio of the reflected light to the incident light is,

$$R = \tfrac{1}{2}\left(\frac{\sin^2(i-r)}{\sin^2(i+r)} + \frac{\tan^2(i-r)}{\tan^2(i+r)}\right)$$

If $i = 0$ (normal incidence), and $n_1 = 1$ (approximate for air),

$$R = \left(\frac{n_2-1}{n_2+1}\right)^2$$

PART II. RELATIVE REFLECTIVITY—THE JEWELER'S EYE AND LUSTERMETER

Anyone having the slightest association with gems is well aware that some gems have a greater lustre (i.e. reflect more light) than others. In Part I it was shown that Fresnel mathematically related the fraction of light reflected to the index of refraction of the substance (providing the surface was clean and well polished). As a consequence, today many believe that it is the RI of a gem

which *determines* its lustre. This is not true. The RI is nothing more than a pure number expressing the ratio of the speed of light through air to its speed through a material. It is true that the RI value may be used to calculate the reflecting *potential* of a gem; however, it is the *chemical composition* and the *atomic structure* of that gem which govern the stone's optical and physical characteristics and consequently control its *theoretical* potential reflectivity and in addition its maximum degree of polish and therefore its *practical* potential reflectivity.

It follows, therefore, that one should be able to construct an instrument which relates the quantity of light reflected by a gem surface (i.e. the meter-reading of a reflectometer) to the chemical composition and atomic structure of a gem, which in combination are adequately defined by its name.

Such an instrument, the *relative* reflectometer, has been developed and is marketed under the name 'The Jeweler's Eye'. The late Robert Webster, F.G.A., has previously discussed the mechanics of this instrument in this *Journal*[4].

The relative reflectometer differs from a Fresnel reflectometer in that all of the reflected energy striking the sensor is not reflected from the gem surface. Some comes from the back of the plate on which the gem rests. This configuration simplifies construction to some extent, allows for the use of a smaller hole and makes possible the examination of smaller gems. However, it precludes the use of a standard precalibrated scale for all instruments.

In recognition of the effects of different components comprising each instrument and of the fact that there will be a spread in readings due to birefringence, strain and isomorphous substitution, each instrument is individually calibrated to show a series of regions of expected response for different gems (Figure 1).

The Jeweler's Eye was conceived and designed as a tool to help confirm the identity of gemstones offered for sale in circumstances where there is no access to the full array of gemmological instruments. The philosophy behind the successful operation of 'The Eye' can be summed up as follows. Given a gem which appears to be well polished and clean, and is indeed what the seller claims it to be, then the response on the Jeweler's Eye should fall in the region designated for that gem. If it doesn't, there is something amiss—the gem may not be what the seller claims it is or the surface may

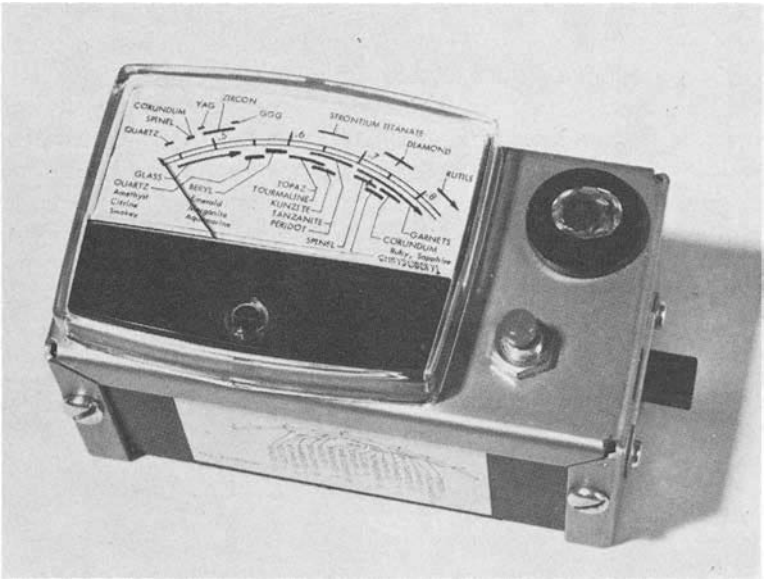

FIG. 1. The Jeweler's Eye, calibrated to show regions of expected response for different gems.

actually be flawed or dirty. Find out before you purchase it. Consider yourself warned!

The Jeweler's Eye can only be understood, appreciated and properly utilized when the user completely removes the concept of RI from his mind and does not try to impose on the Jeweler's Eye any of the attributes, capabilities or functions of a refractometer. This may be a very difficult thing for a G.G. or F.G.A. to accomplish. However, it is a very simple thing for many untrained individuals to do. Consequently, this instrument has found wide acceptance and is proving to be a most useful tool in their hands.

The Jeweler's Eye does nothing more than measure the quantity of energy reflected from the surface of a gem relative to the quantity reflected from a reference gem. The Jeweler's Eye represents a type of instrument which, like the microscope but not like the refractometer, provides information but does not produce a number. Consequently, useful as it is, some gemmologists find it difficult to accept the Jeweler's Eye.

Historically, determinative gemmology has been largely based upon using an instrument to determine a value for one of the in-

trinsic physical properties (e.g. RI, SG, etc.) of a gem and then comparing that value with a table of reference values. Repetition of the test on similar gems will always produce the same results. This is not necessarily true with the Jeweler's Eye, for this instrument does not measure an intrinsic property. The Jeweler's Eye measures reflectivity, and reflectivity depends partly upon the condition of the surface. If the surface condition and cleanliness of the stone to be tested and that of a reference gem of the same type are significantly different then neither will they give the same meter response nor should they be expected to do so. Although the Jeweler's Eye is admirably suited for confirming the identity of gems for which it is has been calibrated, reflectivity instruments must provide useful numerical values, if reflectivity is to play an important role in determinative gemmology: and here I may quote Lord Kelvin—'When you cannot measure it, when you cannot express it in numbers, your knowledge is of a meagre and unsatisfactory kind'.

However, before useful numerical values could be obtained, it was necessary to determine exactly what it was that a reflectometer measured. If one accepts as a definition of lustre—'the appearance of a surface by reflected energy'—then the Jeweler's Eye, using an infrared energy source, actually senses the infrared lustre of the gem surface. Now, by placing a numerical scale on a relative reflectometer, an entirely new gemmological instrument, 'The Lustermeter' was created, which is capable of producing relative numerical values of infrared lustre. Since relative numerical values of infrared lustre had never been determined before, it was necessary to devise a suitable scale. Values are designated by the term L_H indicating the use of a gallium arsenide LED energy source. A thorough treatment of the concept L_H, a table of L_H values and the application of this approach to the characterization of simulated diamonds have been published in American Journals.[5, 6]

The scale is an arbitrary one reflecting relative differences in energy reflecting properties. The overall scale is not linear and is similar in concept to the Mohs scale of hardness, i.e. L_H5 is more reflective than L_H4, L_H4 than L_H3, etc.

Since surface condition is a dominant factor in determining the lustre of a gem, the values on the scale represent the maximum

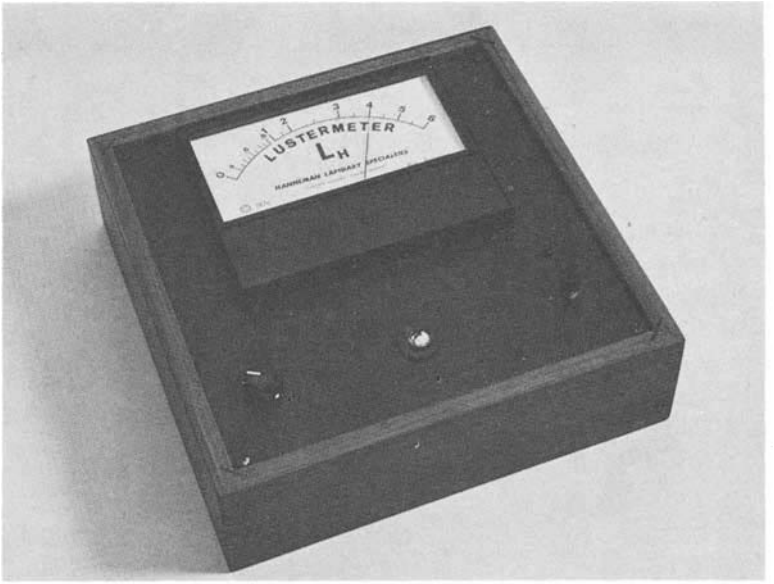

FIG. 2. The Lustermeter, showing a typical scale.

responses shown by the following reference gems: Diamond = 4, Strontium titanate = 3, GGG = 2, and YAG = 1. The positions of 5 and 6 are determined by extrapolation. The scale below 1 is discontinuous from that above and a typical Lustermeter scale is shown in Figure 2.

To use, the numerical L_H value is determined for the unknown gem and compared with a Table of L_H values in the same manner as RI, SG, or hardness values. A higher-than-expected measured lustre value would indicate that an assumed identification was incorrect. A lower value would not positively rule out the purported identity unless it could be shown that the surface condition was not significantly lowering the reading.

I firmly believe that the true role of reflectivity in determinative gemmology is that of measuring the lustre of gems which are above the range of the critical angle refractometer. To be sure, the lustre of the lower RI gems can be measured, but for these gems the ability of the refractometer to determine birefringence values makes it a far more useful instrument.

In order to utilize reflectivity measurements properly, it is imperative that one understands the limitations of this technique. The Lustermeter is by no means the ultimate instrument for the identification of the high RI gems. That instrument is, of course, a refractometer capable of determining their RI values to three or more decimal places as well as birefringence. However, until the day when such an instrument is developed, the Lustermeter appears to represent the best alternative.

Fortunately, there are few scratch-resistant natural high RI gems and a trained gemmologist can easily identify them if he is given but a crude RI value. The Lustermeter can provide a value which, although it is not the same, is equivalent in usefulness to that crude RI value. The Table of L_H values in effect substitutes for the Table of RI values for gems above 1.80.

However, there are problems associated with determining the 'true' L_H value of a specimen. A properly operating and calibrated Lustermeter will always give a steady reading for a gem placed upon it. If the gem is moved slightly, the reading may or may not change. If it changes, it is because the quantity of reflected energy (lustre) changes. This may be a result of a change in surface polish or cleanliness of the new area or it may be due to the effect of energy reflected from within the gem. The Lustermeter is giving the *correct* value for L_H of the *area exposed* over the hole in the examination disc. However, this value may or may not represent the 'true' value of L_H for the specimen and it is this 'true' value which must be compared with the values in the L_H Table.

This concept is illustrated in the example below. Since meaningful L_H values cannot be obtained on poorly polished gems or those with chipped tables, we shall assume the gem surface appears well polished and is clean. If the gem is placed on the examination disc but not over the hole, the Lustermeter will show a small reading representing the background reflection. As the gem is moved across the hole, the readings will change. Figure 3 shows a plot of the different readings obtained related to the position of the area exposed over the hole. The initial low readings are due to the hole not being completely covered. At the edge of the table (and sometimes in other unique spots) high readings will result from internal reflections from the pavilion facets. Across the centre of the table the gem gives relatively stable readings, but the presence of a small scratch or speck of dirt will produce a low reading.

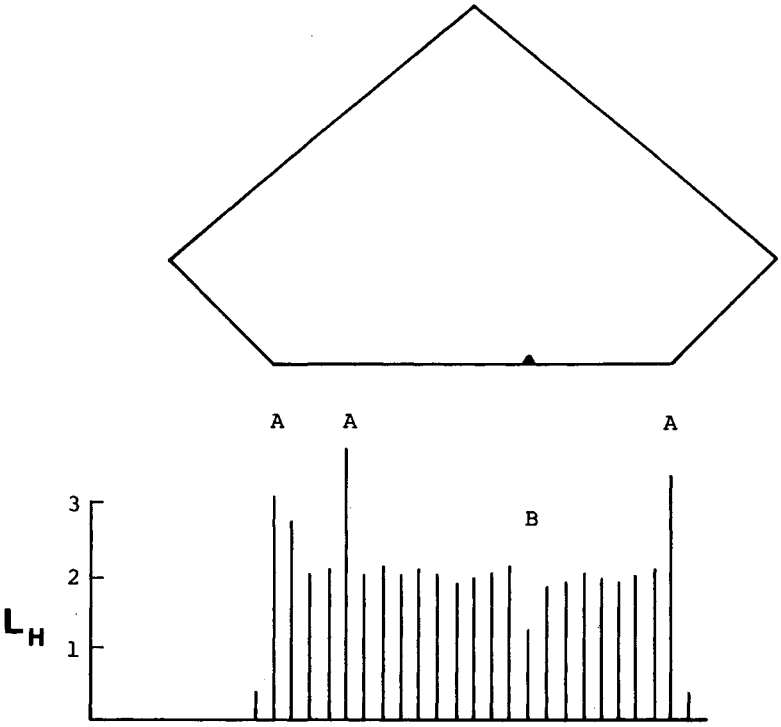

FIG. 3. Typical L_H values measured relative to position of exposed area. A = internal reflections. B = scratch or dirt.

This points out the danger of taking a single measurement. An overall view of Figure 3 indicates that most readings are relatively 'constant' and fall between 1.9 and a shade over 2.0. The 'true' value of L_H to be used for that gem should be 2.0. One must take several readings of different areas in order to determine that 'constant' value. One must also recognize that it is folly to attempt to attach any significance to the second decimal place of any L_H value above 1. The technique of reflectivity is simply not that precise and there is nothing to be gained by lamenting that fact. Nevertheless gemmologists have recognized that while L_H values cannot always tell what a gem *is,* it quite often is the easiest method of telling what it *is not*.

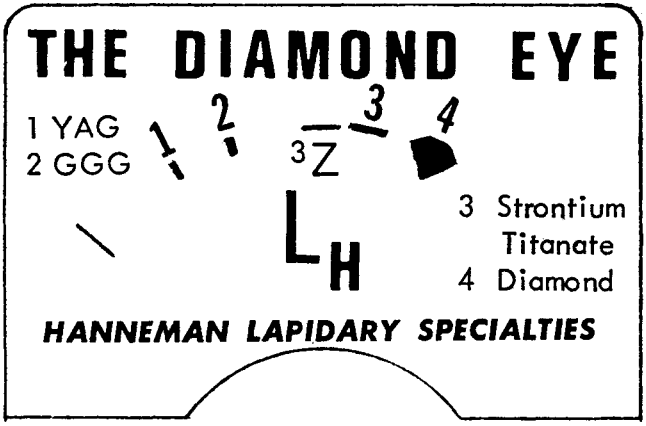

FIG. 4. Typical scale of the Diamond Eye, showing ³Z = cubic zirconia. (× 2)

EPILOGUE—THE DIAMOND EYE

The manufacturers of simulated diamonds are continually creating more realistic products. While synthetic spinel could be detected by the refractometer, YAG, GGG and strontium titanate progressively taxed the skills of the diamond merchants.

Now cubic zirconia has emerged and without a doubt it is going to cause problems in the jewellery trade. Fortunately diamond has a unique L_H value of 4 and can be easily separated from its simulants (L_H of cubic zirconia is ~2.7).

In recognition of this, a new instrument—The Diamond Eye—has been developed. It can serve not only as a tool of determinative gemmology but also as an inexpensive form of insurance for the diamond merchant and/or jeweller. It is smaller in size even than The Jeweler's Eye. A typical scale of this instrument is shown in Figure 4 and is recognizable as being a combination of that of the Jeweler's Eye and the Lustermeter. The use of bands of response serves to mask to some extent the imprecision of reflectivity measurements and the L_H calibration allows for obtaining determinative information on unknowns of all types.

The author would like to express his appreciation for the assistance of Mr J.R.H. Chisholm in the preparation of this article.

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ON COLOUR

By R.M. YU, B.Sc., Ph.D., M.Inst.P.

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Recently a clear and concise account of some of the causes of colour in gemstones was published.[1] In that paper the author explained that 'our eyes perceive the frequency or oscillations of light and not the wavelength, as has been customarily regarded'. The fact that the colour of our flesh remained the same whether observed in air or under water was quoted as evidence. He argued that since the wavelength of light in water was equal to that in air divided by the refractive index of water (1.33), our flesh would appear to have a different colour when observed under water if our colour sensations were associated with the wavelength of light. This happens to be an ambiguous example if we probe deeper into the problem.

Let us consider the anatomy of the human eye, a schematic diagram of which is shown in Figure 1. The reader is referred to any

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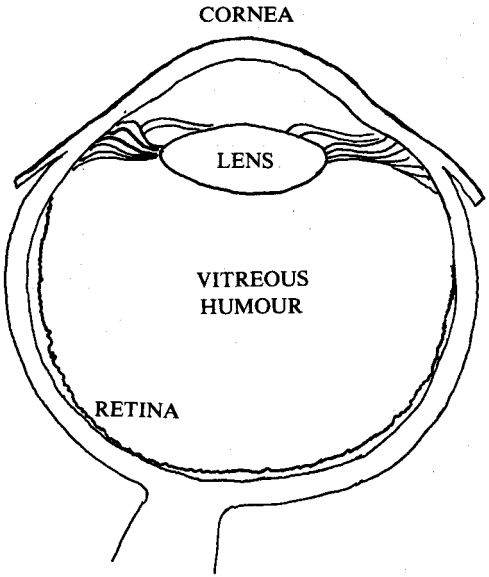

Fig. 1. Cross-section of human eye.

standard textbook on visual optics[2, 3, 4] for a detailed description of the structures and functions of the eye. For the present discussion we are concerned with the light-receiving part known as the retina. It contains two kinds of photo-sensitive cells, the rods and cones. The rods are highly sensitive to light, but are unable to distinguish colour. Thus they give us high speed black and white pictures. The cones are less sensitive, yet they are able to give a coloured view of the object. The rods and cones are always immersed in the transparent gelatinous substance called vitreous humour. The light received by the cones will have a wavelength determined by the refractive index of vitreous humour (about 1.336). Whether the light has passed through air or water does not matter, since eventually it must pass through the vitreous humour before arriving at the retina. In other words, the wavelength of light detected by the cones is independent of the refractive index of the medium in which the object is immersed. The fact that an object appears to have the same colour in water as in air does not

prove that the sensations of colours are associated with the frequency of light rather than the wavelength. However, from a conceptual point of view frequency does have more physical meaning than wavelength, since the latter changes with the refractive index of the propagating medium while the former does not.

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[*Manuscript received 29th July, 1977*]

GEMMOLOGICAL ABSTRACTS

AMSTUTZ (G.C.), BANK (H.). *Geologische, petrographische und mineralogische Beobachtungen in einigen Minen von Smaragd, Tansanit, Tsavorit und Rubin in Tansania und Kenya.* (Geological, petrographic and mineralogical notes on some emerald, tanzanite, tsavorite and ruby mines in Tanzania and Kenya.) Z. Dt. Gemmol. Ges., **26**, 3, 118-27, 12 illus., bibl., 1977.

The authors describe the tectonic structure, the petrographic-stratigraphic position and construction as well as the content of usable gem material from six mines, (1) the emerald-alexandrite mine near Lake Manyara in Tanzania, (2) the Merelani zoisite finds in Tanzania, (3) the grossularite and zoisite finds in Komolo, also in Tanzania, (4) Ol Bill, which is an alluvial find of tanzanite, (5) the vanadium and grossular finds in Mgama in Kenya, and (6) the ruby mines in the Tsavo national park. E.S.

ANDEEN (C.), FONTANELLA (J.). *The dielectric spectrum of Europium doped CaF_2.* Journal of the Physics and Chemistry of Solids, **38**, 237-41, 1977.

The dielectric constant has been measured at 5 audio-frequencies over the temperature range 4.2-400 K for europium-doped CaF_2. Three strong relaxations are noted which indicate large amounts of the Eu^{3+} ion. M.O'D.

ARBUNIÉS ANDREU (M.). *Estudio físico y óptico de variedades gemológicas del granate.* (Physical and optical study of the gem varieties of garnet.) Gemmologia, **6**, 23/24, 23-54, 1974.

Reviews the gem varieties of the garnet group with tables of constants, diagrams and a bibliography. M.O'D.

ARBUNIÉS ANDREU (M.). *Estudio bibliografico y análisis crítico de los trabajos sobre relaciones entre color y composicion quimica de los granates, aparecidos en la última década.* (Biblographical study and analysis of work on the relationship between colour and chemical composition of garnets appearing in the last 10 years.) Gemmologia, **6**, 23/24, 60-63, 1974.

Illustrates absorption spectra, colour figures and relevant publications. M.O'D.

BANK (H.). *Sinhalit und Diopsid aus Ceylon.* (Sinhalite and diopside from Ceylon.) Z.Dt.Gemmol.Ges., **26**, 2, 78-9, 1 graph, bibl., 1977.

The author looked through a parcel of 12 sinhalites and took their RI and found one diopside among them. He shows the difference in the RI of two stones in graph form. E.S.

BANK (H.). *Mit dem Schmelzdiffusionsverfahren hergestellte synthetische Korunde (Rubine und Saphire nach Chatham).* (Synthetic corundums produced by the melt-diffusion method (rubies and sapphires according to Chatham.)) Z. Dt. Gemmol. Ges., **26**, 3, 170-2, 3 illus., bibl., 1977.

Short survey of corundum synthesis with illustration of typical Chatham inclusion and rough crystals grown by Chatham (one ruby and one sapphire). The author describes a group of synthetic sapphires recently received, but does not know whether these will be commercially available in the near future. E.S.

BANK (H.). *Schleifwürdiger gelbbrauner Coelestin.* (Cuttable yellow-brown celestine.) Z. Dt. Gemmol. Ges., **26**, 3, 168-9, bibl., 1977.

Celestine is chemically $SrSO_4$ and named after *coelestis* (i.e. blue). The author had previously described colourless or light blue celestine from Madagascar; this browny material comes from Namibia. Physical properties are given. E.S.

BANK (H.). BECKER (G.). *Klar durchsichtiger Schleifwürdiger Rhodochrosit aus Hotazell in Süd-Afrika.* (Clear transparent cuttable rhodochrosite from Hotazell in South Africa.) Z. Dt. Gemmol. Ges., **26**, 3, 157-60, 4 illus., bibl, 1977.

The crystals from the manganese district Hotazell in South Africa are exceptionally clear, partly macrocrystalline, partly corroded crystals and partly botryoidal and reniform. Physical properties are given. E.S.

BANK (H.), BECKER (G.). *Blauer schleifwürdiger Jeremejewit aus S.W. Afrika.* (Blue cuttable jeremejevite from South West Africa.) Z. Dt. Gemmol. Ges., **26**, 3, 161-5, 7 illus., bibl., 1977.

The mine is near Swakopmund and belongs to the Val-Tourmaline-Mines Company. The original finds were in Transbaikalia in U.S.S.R. The crystals vary from colourless to cornflower blue, even dark blue; some are completely transparent and a few cuttable. The composition is $AlBO_3$, hexagonal or pseudohexagonal, density 3.33, RI 1.653-1.640, DR -0.008. E.S.

BANK (H.), BECKER (G.). *Farbloser und Blau-violetter schleifwürdiger Herderit aus Brasilien.* (Colourless and blue-violet cuttable herderite from Brazil.) Z. Dt. Gemmol. Ges., **26**, 3, 166-7, 1 illus., bibl., 1977.

Physical properties are given. E.S.

BANK (H.), MAES (J.). *Über farblose Spodumene und Farbveränderungen bei Spodumenen.* (About colourless spodumenes and colour changes in spodumenes.) Z.Dt.Gemmol.Ges., **26**, 2, 76-7, bibl., 1977.

Pleochroic spodumene is found as hiddenite and kunzite, but also in yellow and colourless. The colours can be altered by heat treatment and bombardment, the latter being usually reversible. Spodumene made colourless by heating can easily be confused with sillimanite. E.S.

BARIĆ (L.). *Im weissen Marmor.* (In white marble.) Lapis, **2**, 8, 10-12, 1977.

Describes the pink to reddish rubies found at Prilep, Yugoslavia, where the occurrence is in a dolomitic marble. Crystal diagrams and coloured illustrations are given. M.O'D.

BERKOWITZ (R.). *Gem characterized by refractive index.* Canadian Gemmologist, **2**, 1, 9-12, 1977.

Describes the spinel and garnet families, chrysoberyl, corundum, kyanite, rhodonite, azurite, epidote and benitoite. M.O'D.

BIANCONI (F.). *Campolungo, Tessin.* (Campolungo, Ticino.) Lapis, **2**, 8, 14-18, 1977.

Small rubies and sapphires have been found in the dolomite of the Campolungo region of Canton Ticino, southern Switzerland. The dolomite is a marble type and associated minerals include grammatite, scapolite, green tourmaline, chrysoberyl and fluorite. Coloured illustrations, a map and crystal diagrams are given. M.O'D.

BOSCARDIN (M.), MICHELE (V. de), MATTIOLI (V.). *Lo smeraldo della Val Vigezzo (Ossola).* (The emeralds of the Val Vigezzo, Ossola.) La Gemmologia, **2**, 1, 21-6, 1976.

Val Vigezzo runs from Domodossola on the Swiss-Italian border towards Locarno. Emerald is found with albitite and is semi-transparent with inclusions of some albite, chlorite, scheelite and other minerals. Cr^{3+} is found as 0.05% of weight. Refractive index is calculated as 1.5834 and 1.5905 for the extraordinary and ordinary rays respectively. The infrared spectrum was measured, but no absorption bands were seen in the visible spectrum. M.O'D.

BROWN (G.). *Black coral - true or false.* Australian Gemmologist, **13**, 2, 35-41, 9 figs, 1977.

A detailed study of 'true', Antipatharian or thorny black coral and of the 'false', Gorgonian or horny black coral. They are identical in appearance when polished but are readily differentiated when the surfaces are in their natural state, the 'true' coral having an abrasive surface of short black spines while the 'false' black coral is smooth and horn-like. Both are non-calcareous. The 'true' material is a protein, while the 'false' is a collagen. Gemmological testing constants are identical, but the 'false' material softens below 150 °C while 'true' black coral needs temperatures above that figure to become pliable.

Abstractor feels that the use of the 'false' and 'true' prefixes is misleading. Author is dealing with two different species of coral, both of which produce black axial skeletons which are indistinguishable when worked. To designate them in this way only panders to commercial interests. R.K.M.

BROWN (G.), MOULE (A.J.). *The structural characteristics of elephant ivory.* Australian Gemmologist, **13**, 1, 13-17, 13 figs, 1977.

An authoritative account of the structure of ivory of the elephant, mammoth and mastodon. 'Engine-turned' appearance of polished lateral sections of ivory, incorrectly called 'Striae of Retzius', is due to reflection from minute fibres of a dental protein called collagen, not to reflection from dentinal tubes as had been previously thought. The effect is seen only in the three types of elephant ivory, including all fossil forms. Several of the excellent photo-micrographs are lettered but the lettering is not explained in the text. This paper is free from the misprints which usually plague this otherwise excellent journal. R.K.M.

BROWN (G.), MOULE (A.W.). *The structural characteristics of various ivories.* Australian Gemmologist, **13**, 2, 47-60, 9 figs, 1977.

Part two to authors' paper on elephant ivory abstracted above. This deals with less common ivories of wild boar, hippopotamus, walrus and the even rarer ivories of the sperm whale and the long spiral horn of the narwhal. The latter beast is on the verge of extinction. (In fact almost no ivory is obtained from any animal without killing it first, so there are several cases for conservationists here.) Distinction between ivories is difficult in solid pieces (apart from the 'engine-turned' appearance of elephant ivory in cross section and the obvious spiral of the narwhal tusk), but authors show that in thin section micro-differences are distinct. R.K.M.

CECCUZZI (B.). *Il metodo della misurazione diretta dell'indice di rifrazione.* (The direct measurement method of obtaining refractive index.) La Gemmologia, **2**, 3/4, 31-6, 1976.

Describes the real and apparent depth method of obtaining refractive index.

M.O'D.

CHERMETTE (A.). *Bresil 1976 - le Minas Gerais.* (Brazil 1976 - Minas Gerais.) Revue de Gemmologie, **51**, 2-4, 1977.

A general geographical and economic survey of the state of Minas Gerais with some reference to its gemstones. M.O'D.

CHESTERMAN (C.W.). *California jade; a collection of reprints.* Special Publ., Calif. Divn. Mines & Geol., **49**, 53pp, 1976. Price $2.00.

Five earlier reports are here reprinted: R.A. Crippen, *Nephrite jade and associated rocks of the Cape San Martin region, Monterey County, California,* 14 figs., 1951; C.W. Chesterman, *Nephrite in Marin County, California,* 11 figs., 1951; H.S. Yoder & C.W. Chesterman, *Jadeite of San Benito County, California,* 6 figs., 1951; C.W. Chesterman, *Intrusive ultrabasic rocks and their metamorphic relationships at Leech Lake Mountain, Mendocino County, California,* 4 figs., 1963; J.R. Evans, *Nephrite jade in Mariposa County,* 9 figs., 1966. A.P.

CROWNINGSHIELD (R.). *Developments and highlights at GIA's Lab in New York.* Gems and Gemology, **XV**, 8, 245-52, 20 figs, 1976.

Colour banding in natural brown diamond and a single inclusion reflected in almost every facet of another are illustrated. Writer says early irradiated diamonds also showed banding. Another diamond graded flawless but faulted on bad shape after a girdle flaw detected in an earlier grading had been removed. Brilliants cut with crown angles of 30 ° or less noted adversely in reports. Such angles combined with thin girdles account for 75% of damaged stones examined. Natural green diamonds are rare but crystals have brownish skin which may remain if a natural surface is left on the girdle. Laser beam finger-printing of diamonds mentioned and criticized. Strain patterns between crossed polaroids suggested as another finger-print procedure. Coated diamonds not often seen today but are still about. Cloud-like central inclusion in an orange diamond said to be characteristic. Ethics of describing clean diamonds as internally flawless when marked surface graining is present are raised.

A natural ruby with marked strain (shatter) cracks at facet edges due to rapid polishing and another in which apparent bubbles proved to be haloed are described and illustrated. A third one had angular metallic crystals and was a flux synthetic. Indian carved 'rubies' proved to be dyed quartz. 'Venetian blind' banding in Gilson synthetic emerald is well illustrated and mention of similar banding in synthetic alexandrite is made. Insects in amber and in modern plastic are shown. Gift of fibre-glass cat's-eyes acknowledged. R.K.M.

DE CAMARGO (W.G.R.), BRUDER (J.). *Random layer structure of autunite by grinding.* An.Acad.Brasil.Ciênc., **48**, 2, 249-53, 1976.

Grinding may precipitate disorders such as stacking faults, which are naturally found in minerals with preferential cleavage. This has been observed in autunite.

M.O'D.

DE CAMARGO (W.G.R.), FILHO (J.B. de Madureira). *New diagrams for physical determination of garnets.* An.Acad.Brasil.Ciênc., **48**, 1, 57-68, 1976.

A means of identification of individual members of the garnet group is proposed. Triangle diagrams given an approximate idea of the chemical composition and the properties $\Delta 2\theta$, n and D are all that are needed to identify the species. Since the linearity of $\Delta 2\theta$ is a function of chemical composition the use of triangle charts is valid. M.O'D.

DE CAMARGO (W.G.R.), LEITE (C.R.). *Olivine epitaxy in Brazilian diamonds.* An.Acad.Brasil.Ciênc., **48**, 2, 240-4, 1976.

Olivine has been identified as an inclusion in Brazilian diamond and the crystals have been shown to be oriented specifically with respect to the host. The diamonds examined came from secondary deposits at Abadia dos Dourados, Minas Gerais. It is thought that the inclusions might show a relationship between diamonds and basic or ultrabasic magmas. M.O'D.

DIEHL (R.). *Neues zum Thema 'Synthetischer Smaragd': Besuch bei Pierre Gilson.* (New additions to the subject of synthetic emerald: visit to Pierre Gilson.) Z.Dt.Gemmol.Ges., **26**, 2, 61-75, 17 illus., bibl., 1977.

Pierre Gilson lives about 40 km south-west of Calais in a village called Campagne-lez-Wardrecques manufacturing ceramics and for many years synthetic emeralds. Single crystals of beryl are not only used as gem material but also in scientific research to study the channelling of ions in crystals. In beryls the Si_6O_{18}-rings are stacked along the c-axis forming wide channels into which accelerated ions can penetrate. Natural beryls are unsuitable for this purpose because the channels contain water and carbon dioxide, but the Gilson synthetic beryls are useful for these experiments. They are produced by a flux fusion (rather than flux reaction) technique. Therefore the Gilson material is being investigated thoroughly using microscopy, x-ray topography and infrared spectroscopy. These unusual methods may produce interesting results also for the gemmologist. The author closes with remarks on P. Gilson as crystal grower. E.S.

DIEHL (R.). *Diamantsynthese bei Temperaturen unter 1300°C und Drucken unter einer Atmosphäre.* (Synthesis of diamond with temperatures under 1300°C and pressure under one atmosphere.) Z. Dt. Gemmol. Ges., **26**, 3, 128-34, 1977.

This deals not with a synthesis in its strictest sense, but with a crystal growth based on the idea of a metastable synthesis. It is mainly a laboratory method, not suitable for larger commercial output, using diamond powder or small diamonds as starting material. It might be of interest in healing fissures or growing together of canals in diamonds caused by laser beams. The growth rate seems to be 3% in four hours. E.S.

DUNN (P.J.). *Observations on the Slocum stone.* Gems and Gemology, **XV**, 8, 252-6, 7 figs., 1 table, 1976.

A careful examination of a comparatively new glass imitation of opal. Colours change with angle of viewing as in natural opal. SG 2.47, RI 1.514, H 5-5½. Between crossed polaroids colour effect is kaleidoscopic. X-ray diffraction pattern is incoherent, proving it to be glass. Composition is sodium calcium magnesium

potassium aluminium silicate. Very tough, fractures with difficulty. Opalescence possibly due to textural dissimilarity of adjacent layers. No intergranular material, organic or otherwise, was found. R.K.M.

DUNN (P.J.). *Chromium in dravite.* Mineralogical Magazine, **41**, 408-10, 1977.

Shows that chromium can substitute for both aluminium and magnesium in dravite. These dravites have Na>Ca; high chromian dravite is compositionally zoned as light and dark green material, the depth of colour varying with Cr content. The name chrome tourmaline should be abandoned in favour of chromian dravite.

M.O'D.

EPPLER (W.F.). *Amazonit.* (Amazonite,) Z. Dt. Gemmol. Ges., **26**, 3, 109-10, 3 illus., 1977.

Amazonite is an opaque, triclinic potash feldspar, a microcline. The green colour is caused by a trace of copper. The author describes a 'green feldspar' which was found to be amazonite and came from Broken Hill, New South Wales. This stone is found in rock consisting mainly of quartz, garnet and various ores, mainly copper. The quartz contains some rutile needles. In section this amazonite shows a definite perthite (exclusion) structure, more finely developed than usual in amazonite. E.S.

FISCHER (K.). *Edelstein Epidot.* (Epidote the gemstone.) Lapis, **2**, 7, 10-13, 1977.

Reviews and illustrates in colour the gem varieties of the mineral epidote. Details are given of the occurrences in Europe, particularly those in Austria.

M.O'D.

FISCHER (K.). *Die Zweifache Kraft Fundorte und Verarbeitung von Cyanit (Disthen).* (Two-fold hardness, origin and working of kyanite.) Lapis, **2**, 8, 31-5, 1977.

Reviews the properties and occurrences of kyanite, especially those found in the Ticino area of Switzerland and other parts of Europe. Crystal diagrams and coloured illustrations are provided. M.O'D.

GAAL (R.A.P.) *Cathodoluminescence of gem materials.* Gems and Gemology, **XV**, 8, 238-41 (240 = 5pp), 4 figs, 16 colour figs, 1 table, 1976.

Describes results obtained with an 'inexpensive' Nuclide Luminoscope ELM-2A, recently acquired by the GIA, when attached to an ordinary binocular microscope or to a scanning micro-spectrophotometer. The effect is analogous to the luminosity of a television screen. A stream of high velocity electrons bombards the specimen in a vacuum chamber on the stage of the microscope. Impurities, defects, distortions or intrinsic elements cause the specimen to emit visible light. Spectrophotometry provides further identifying features. Cathodoluminescence (CL) in gemmology is only in its early stages and should be regarded as a further sophistication of the fluorescence under UV light or x-rays type of test. Irradiation for 10 seconds or more was found to change the colour of the luminescence in some cases, probably due to heating. It is not stated whether this form of radiation causes temporary or permanent changes in the intrinsic colour of the material examined: cf. corundum temporarily yellowed by x-rays, zircons faded by UV. A helium gas supply is shown in one figure but is not explained in the text. R.K.M.

GLEADOW (A.J.W.). *The geology of the moon.* Australian Gemmologist, **13**, 1, 22-7, 5 figs., 1977.

A brief account of the fascinating lunar geology as revealed by examination of rock samples brought back from the several Apollo landings. Most are basalts or breccias of very great age. Some new minerals, unknown on Earth, were found. Lack of atmosphere and of water has meant that almost all geological evolution on the moon ceased more than 3000 million years ago. By contrast the Earth is still geologically extremely active. Most rocks were fine grained with minute crystals. No gem minerals reported. R.K.M.

GRAMACCIOLI (C.M.). *Lo zircone: una pietra interessante.* (Zircon, an interesting stone.) La Gemmologia, **2**, 1, 16-20, 1976.

Describes and illustrates in colour the members of the zircon family with particular attention to crystals found in Alpine regions. M.O'D.

GÜBELIN (E.). *Im Tal der Rubine.* (In the valley of Rubies.) Lapis, **2**, 8, 19-26, 1977.

Describes with a coloured geological map and other illustrations the Mogok area of Burma with notes on the occurrence and mining of the rubies found there. Typical inclusions are illustrated in colour. M.O'D.

GÜBELIN (E.), WEIBEL (M.), GIRGIS (K.), WESSICKEN (R.). *Die Struktur der Sterne.* (The structure of stars.) Lapis, **2**, 8, 27-30, 1977.

Illustrates, with the aid of electron microscope photographs, the way in which asterism forms in minerals; special attention is given to a very dark form of star-sapphire from Bang-kha-cha, south-east Thailand. M.O'D.

HARDING (B.L.). *Crazy corundum.* Rocks & Min., **51**, 180-2, 2 figs, 1976.

This paper discussed the cutting of gem corundum, and the ways polysynthetic twinning and parting affect this. R.S.M.

HASSIB (A.), BECKMAN (O.), ANNERSTEN (H.). *Photochromic properties of natural sodalite.* Journal of Physics D:Applied Physics, **10**, 771-7, 1977.

The authors postulate the presence of colloidal metal clusters as the cause of the blue colour of sodalite. A pink colour can be obtained by the production of F-centres by ionizing radiations. It is thought that these centres can be eliminated by visible light and that this process may be the cause of the establishment of the colloidal clusters. A number of colour and bleach cycles will impart a deep blue colour to the material. M.O'D.

HOGARTH (D.D.), GRIFFIN (W.L.). *New data on lazurite.* Lithos, **9**, 39-54, 1976.

Non-cubic lazurite was found to be common and may be caused by S_3^- ions in parallel orientation. Dark lazurite contains more S_2^- than pale varieties. M.O'D.

ITO (J.). *High temperature solvent growth of orthoenstatite, $MgSiO_3$, in air.* Geophysical Research Letters, **2**, 533-6, 1975.

Crystals up to $5 \times 2 \times 1$ mm size were obtained by the primary crystallization of a melt in the system MgO-SiO_2-lithium vanado-molybdate. Crystals are stoichiometric, transparent and often euhedral. M.O'D.

ITO (J.). *Crystal synthesis of a new cesium aluminosilicate, $CsAlSi_5O_{12}$.* American Mineralogist, **61**, 170-1, 1976.

Crystals of a substance ideally $CsAlSi_5O_{12}$ have been grown by slow cooling of the melt containing Ba-, Cs-vanadate flux. It is orthorhombic, space group Bbm2. M.O'D.

ITO (J.). *Crystal synthesis of a new olivine, $LiScSiO_4$.* American Mineralogist, **62**, 356-61, 1977.

$LiScSiO_4$ has been synthesized by both oxide mixes in air and by high-temperature solvent growth with lithium molybdo-vanadate. It is orthorhombic, space group Pbnm. M.O'D.

JAHNS (R.H.). *Gem materials.* Industrial minerals and rocks (ed. S.J. Lefond *et al.*), American Institute of Mining, Metallurgical and Petroleum Engineers Inc., New York, 271-326, bibl., 1975.

Gives market prices for rough gem material together with comparative retail values. Short scientific summaries of the different materials are included. M.O'D.

KOLOMITSEV (A.I.), YAKUBOVA (S.A.). *Columnar mechanism of growth of natural diamond crystals of cubic habit.* (In Russian.) Zapiski Vsesoyuznyi Mineral. Obshchestva, **105**, 469-72, 1976.

Columnar growth of natural diamond crystals with a cubic habit proceeds along the [111] axis. This results in the development of coherent single crystals and is proved by Laue patterns. M.O'D.

KRESTEN (P.). *Chrome pyrope from the Alnö complex.* Geologisk Föreningen Förhandlinger, **98**, 179-80, 1976.

This example shows 64.8% of the pyrope molecule and is similar to garnets found with diamonds and in ultrabasic nodules in kimberlite. M.O'D.

KUSTOV (E.F.), PETROV (V.P.), PETROV (D.S.), UDALOV (J.P.). *Absorption and luminescence spectra of Nd^{3+} and Er^{3+} ions in monocrystals of $CaYAlO_4$.* Physica Status Solidi, **41**, 379-83, 1977.

Crystals are grown by the optical melting method; the absorption and luminescence spectra were investigated at 77 and 300 K. M.O'D.

LEHMANN (G.). *Über die Färbungsursachen natürlicher Citrine.* (About the causes of colour in natural citrines.) Z.Dt.Gemmol.Ges., **26**, 2, 53-60, 5 graphs, bibl., 1977.

Citrine has been chosen as gem for 1977 and the author shows that the gem chosen is not the natural citrine but the burnt amethyst, as this has a much more attractive colour than the natural citrine. Natural citrines often contain smoky quartz 'centres' in varying degrees - these centres are conductor defects in non-conductors. The author compares the absorption spectra of smoky quartz, citrines and burnt amethysts, the spectrum of the latter being isotropic. It is shown that it is easy to differentiate between natural citrines and the burnt amethysts. E.S.

LIDDICOAT (R.T.). *Developments and highlights at GIA's Lab in Santa Monica.* Gems and Gemology, **XV**, 8, 233-7, 13 figs., 1976.

A diamond with up to thirty laser-drilled holes, a paste imitation bloodstone cameo (writer suggests it is carved but it looks moulded) and plastic repairs to jades are mentioned and illustrated. A canary yellow diamond lacking 'normal' Cape

spectrum (note: a yellow *with* a Cape spectrum is *not* a canary stone), a 6ct sinhalite, blue and colourless jeremejevite crystals described and a possible new diamond simulant (SG 5.57, singly refractive, H 6-6½, inert to UV) structurally close to dysprosium gallium oxide recognized as a rare-earth garnet-structured synthetic. Gilson opal used in triplet had glass top. Various inclusions in diamond are described, while a 'spherical' bubble in natural sapphire proved to be a drumshaped inclusion. R.K.M.

LIEBER (W.). *Peridot—Arizonas Staatsjuwel.* (Peridot, state gem of Arizona.) Lapis, **1**, 1, 14-17, 7 figs, 1976.

Describes and illustrates the occurrence of gem-quality peridot in the State of Arizona; most of it is mined by Indians of the Apache tribe and used in Indian-style jewellery. M.O'D.

LOEFFLER (B.M.), BURNS (R.G.). *Shedding light on the color of gems and minerals.* Amer. Scientist, **64**, 636-47, 11 figs (2 in colour), 1976.

Colours in minerals depend upon the selective absorption of light according to wavelength. The responsible electronic processes fall into four main categories: crystal field transitions, molecular orbital transitions - e.g. oxygen→metal charge transfer or metal→metal charge transfer, colour centres, and band gap transitions. Several examples of each type are given. R.V.D.

LOUGHLIN (John). *Australian opals.* Rocks & Minerals, **52**, 139-40, 1 fig, 1977.

A general review is given of the mining and marketing of opal. The mine fields are at Coober Pedy and Andamooka, in far inland South Australia, and Lightning Ridge, in western New South Wales. R.S.M.

MEIXNER (H.). *Rubin von Longido Tansania.* (Rubies from Longido, Tanzania.) Lapis, **2**, 8, 12, 1977.

Describes the occurrence of ruby in the Longido region of Tanzania, lying approximately 100 km north-west of Kilimanjaro. The rubies are found in a zoisite-bearing amphibolite and are associated with hornblende, the bytownite variety of plagioclase, a greenish zoisite and tremolite. Refractive index is measured at 1.764, 1.772, with a birefringence of 0.008; specific gravity is 3.99 g/cm^3. M.O'D.

MICHELE (V.de). *Ametista di Osilo.* (Amethyst from Osilo.) La Gemmologia, **2**, 3/4, 5-8, 1976.

Osilo is a commune in Sassari province, north Sardinia. Crystals are heavily striated and some contain two-phase inclusions. Colour occurs in typical bands. Heating to 400°C drives the colour off temporarily, heating to 1000°C permanently. Some Brazilian twins have been noted. Specific gravity, somewhat low at 2.63, is probably affected by small voids. M.O'D.

MITCHELL (R.S.). *A turquoise-like mixture of chalcedony and celadonite from Conejos County, Colorado.* Rocks & Min., **51**, 394-5, 1976.

Specimens resembling turquoise, from the Blue Sky mine, Conejos Canyon, Conejos County, Colorado, are actually a mixture of chalcedony and celadonite. The material is bluish-green to emerald green, waxy to dull, and has a conchoidal fracture. The veins and masses of chalcedony-celadonite occur in a fine-grained, brownish-grey basalt porphyry. Natrojarosite and clays are also present. R.S.M.

MOMOI (H.). *Hydrothermal crystallization of $MnSiO_3$ polymorphs.* Mineralogical Journal of Japan, **7**, 359-73, 1974.

Pyroxmangite was synthesized at temperatures lower than 700 °C and rhodonite above this figure. M.O'D.

MONES ROBERDEAU (L.). *Estudio cuantitativo de la fluorescencia provocadas por la radiación ultravioleta en diamantes tallados en estilo brillante.* (Quantitative study of fluorescence stimulated by ultraviolet radiation in brilliant-cut diamonds.) Gemmologia, **6**, 23/24, 5-12, 1974.

Surveys the fluorescence emitted by cut diamonds on irradiation and gives tables and diagrams. M.O'D.

NASSAU (K.). *Cubic zirconia, the latest diamond imitation and skull melting.* Lapidary Journal, **31**, 4, 900-26, 1977.

This material is the cubic modification of ZrO_2, whose monoclinic form is known as baddeleyite. Constants are refractive index 2.15-2.18, dispersion 0.060-0.063 and hardness 7½ to 8½ (these are provisional figures).The material has been grown by the skull-melting technique in which a skull-shaped container holds the melt in a crust of its own powder. RF energy passes through the skull to heat the contents. Small bubbles, cloudiness and striations have been noted in the material, but good quality stones should not show them. The absence of typical diamond features forms a reasonable test. M.O'D.

NASSAU (K.), PRESCOTT (B.E.). *Smoky, blue, greenish-yellow and other irradiation-related colors in quartz.* Mineralogical Magazine, **41**, 302-12, 1977.

Blue was found to originate from absorption by the A_1 and A_2 bands at 1.85 and 2.55 eV. The cause of the colour in smoky quartz is now believed to be a previously unreported absorption band at 2.90 eV. Greenish-yellow colours were seen after irradiation with gamma rays both in natural and synthetic quartz, the colour originating from the tail of an absorption band in the ultraviolet. The variation in colour of natural and irradiated smoky quartz is attributed to the combination of the A_3 (smoky) with the A_1 and A_2 (blue) and the greenish-yellow absorption features. M.O'D.

NASSAU (K.), PRESCOTT (B.E.). *A unique green quartz.* American Mineralogist, **62**, 589-90, 1977.

Green quartz collected in Brazil by Dana was found to be coloured by a broad absorption band at 2 eV and a strong band extending from 2.5 eV into the ultraviolet. This is lost by heating to 500 °C and cannot be recovered by heating under reducing conditions or by irradiation. Some amethyst colour is also present with the green. The origin of the green is so far unestablished. M.O'D.

NICHOL (D.) *Opal occurrences near Granite Downs Homestead.* Min. Resrcs Rev., South Australia, **139**, 99-101, 2 figs, 1975.

A brief inspection of workings in the vicinity of Granite Downs homestead showed that both precious and common opal occur in deeply weathered gneiss of the Precambrian crystalline basement at one group of workings, 4 km east of Mount Chandler. At a second group of workings, also in weathered gneiss, 3 km south-east of Granite Downs homestead no evidence of the occurrence of opal was found.

D.C.W.

NICHOL (D.). *Amethyst deposit, hundred of Kelly.* Min. Resrcs Rev., South Australia, **138,** 99-102, 1975.

Semi-precious amethystine quartz fills fractures and cavities in a discordant quartzite development which cuts Cleve Metamorphics of Lower Proterozoic age. The amethyst is purple in colour and ranges from light to dusky tones. Crystal form is poor due to deformation during crystal growth. The portion of gem quality material is less than 5%. It is estimated that over 250 m^3 of amethyst are available in the deposit. D.C.W.

O'LEARY (B.). *Black opal.* Australian Gemmologist, **13,** 1, 3-11, 1977.

A largely historical account of this gem, including theories that earlier black opals were treated stones. Writer suggests, incorrectly, that play of colour is due to micro-faulting of opal structure. Explanation of black body-colour is inadequate and P.J. Darragh is credited with saying that it is due to carbon (this surely referred to *stained* blacks and not to the natural stones). Named large opals are listed, and a further list suggests that the practice has been extended *ad absurdum* to quite small stones (e.g. 'Eros', 2.31 carats). R.K.M.

PELLÉ (F.), DENIS (J.-P.), BLANZAT (B.). *Crystallographic and spectroscopic studies of europium trivalent doped garnet type germanates.* Materials Research Bulletin, **12,** 511-17, 1977.

Polycrystalline calcium-yttrium germanate doped with trivalent europium at different concentrations has been prepared for research purposes which include study of the spectroscopic properties of the trivalent europium ion. M.O'D.

PETROV (I.), BERDESINSKI (W.), BANK (H.). *Bestrahlte gelbe und rotbraune Topase und ihre Erkennung.* (Treated yellow and red-brown topazes and their identification.) Z. Dt. Gemmol. Ges., **26,** 3, 148-51, 3 graphs, bibl., 1977.

Topaz colours based on a colour centre (blue, red-brown, yellow and orange) can easily be caused by radiation treatment; the colour can be deepened or altered. Also the more stable violet caused by chrome can be altered to yellow or red. All topazes where the colour has been formed by radiation cannot be distinguished from naturally coloured topazes by the absorption spectra; the only method of differentiation is thermoluminescence. E.S.

PETROV (I.), SCHMETZER (K.), BANK (H.). *Chromhaltige violette und orangefarbige Topase—Ein Vergleich.* (Chrome-containing violet and orange-coloured topazes—a comparison.) Z. Dt. Gemmol. Ges., **26,** 3, 152-6, 5 illus., bibl., 1977.

Orange-coloured topazes are found near Ouro Preto in Minas Gerais, Brazil. When heated these topazes turn violet and are similar to those natural topazes found in Sanarka in the Soviet Union. There is very little cuttable material available from these Russian sources, but recently violet topazes have been found in Pakistan, the colour apparently being caused by traces of chrome in the crystal lattice. The orange colour is shown to be a mixture of yellow and violet. E.S.

POIROT (J.-P.). *Quelques aspects de l'oxyde de zirconium cubique synthétique: fabrication de la 'djévalite', apparence de cette probable zirkelite synthétique.* (Some aspects of synthetic cubic zirconium oxide: manufacture of 'djevalite' and appearance of this probable synthetic zirkelite.) Revue de Gemmologie, **51**, 11-12, 1977.

Constants agree with those of Schiffmann (p.56 above) and some notes on the preparation of the substance are given. The material is made by the Bridgman process and the zirconium oxide is stabilized by the addition of calcium and yttrium oxides. M.O'D.

RISLING (M.). *The diagnostic inclusions of beryl and topaz.* Canadian Gemmologist, **2**, 1, 2-8, 1977.

Describes and illustrates the typical inclusions in topaz and in the beryl family. Parisite is misspelt throughout. M.O'D.

SCHIFFMANN (C.A.). *Gemmologische Studie an einem Original Maxixe Beryll.* (Gemmological study of an original maxixe beryl.) Z. Dt. Gemmol. Ges., **26**, 3, 135-41, 7 illus., bibl., 1977.

The original maxixe beryls were mined in the Maxixe mine in the west of the Minas Gerais in Brazil about 1917 and described during the thirties by Schlossmacher, Klang and Wild. The beryls had an intensely blue colour, which was somewhat unstable when exposed to light and production was stopped. Beryl of similar colour and behaviour came onto the market about 1972 and interest was aroused again. Strong pleochroism, density and RI as for heavy beryl (2.801 and 1.594-1.596). Microscopic examination shows layered phases of growth and resolution. E.S.

SCHMELTZER (H.). *Katzeldonien und gut Rötelstein.* (Katzeldonia and good red stones.) Lapis, **2**, 6, 6-10, 1977.

Lists and illustrates the minerals of the Rhineland-Pfalz. M.O'D.

SCHMETZER (K.). *Chrom, Eisen & Titan: Ursachen für die Farben von Rubin und Saphir.* (Chromium, iron and titanium: cause of the colour of ruby and sapphire.) Lapis, **2**, 8, 8-9, 1977.

Explains, with coloured illustrations and a diagram in the text, the work of the colouring elements in ruby and sapphire. M.O'D.

SCHMETZER (K.), MEDENBACH (O.), BANK (H.), KRUPP (H.). *Kristalle mit aussergewöhnlichen Einschlussen—Turmalin aus Tansania und Beryll aus Brasilien.* (Crystals with exceptional inclusions—tourmaline from Tanzania and beryl from Brazil.) Z. Dt. Gemmol. Ges., **26**, 3, 145-7, 4 illus., bibl., 1977.

Well illustrated note on two different crystals. The brown tourmaline from Tanzania shows a spiral inclusion consisting of 18 regular spirals parallel to the c-axis with a distance between each spiral of about 0.5 mm. The 5.7 kg aquamarine from Brazil also shows a spiral inclusion, but not of the same regularity. E.S.

SCHREIBER (H.D.). *On the nature of synthetic blue diopside crystals: the stabilization of tetravalent chromium.* American Mineralogist, **62**, 522-7, 1977.

Crystals were synthesized in air from silicate melts and some were found to be blue rather than green. This is attributed to the stabilization of a small portion of the total Cr as Cr(IV). This is not present initially in the melts but forms from the reduction of Cr(VI) during crystallization. M.O'D.

STOCK (H.D.), LEHMANN (G.). *Phenomena associated with diffusion of trivalent iron in amethyst quartz.* Journal of the Physics and Chemistry of Solids, **38**, 243-6, 1977.

Changes in the EPR, optical and infrared spectra were measured as a function of annealing temperature in natural amethyst crystals from different locations. After heating to 650 °C for two hours the concentration of Fe(III) on substitutional sites with alkali ions as charge compensators is equal in all crystals irrespective of initial concentration. M.O'D.

STRUNZ (H.). *Dichroskop, Polariskop, Kristall-Refraktometer—Drei vereinfachte bzw. verbesserte Hilfsmittel zur Edelsteinbestimmung.* (Dichroscope, polariscope, crystal-refractometer—three simplified, i.e. improved, instruments for gem identification.) Z. Dt. Gemmol.Ges., **26**, 3, 111-17, 7 illus., bibl., 1977.

The author suggests the use of a filter-dichroscope, polarization tweezers and a semi-cylindrical crystal refractometer. E.S.

SUHNER (B.). *Zur Messung der Dispersion an geschliffenen Steinen.* (Measuring dispersion of cut stones.) Z. Dt. Gemmol. Ges., **26**, 3, 142-4, bibl., 1977.

The author compares results obtained with refractometer and goniometer, naming some feldspars, tanzanite, vesuvianite, grossularite and hessonite. E.S.

TROSSARELLI (C.). *Il polariscopio-conoscopio.* (The polariscope-conoscope.) La Gemmologia, **2**, 3/4, 9-24, 1976.

Introduces and illustrates the use of polarized light in gem testing with photographs and diagrams. Interference figures are explained. M.O'D.

VILLEDIEU (M.), DEVISMES (N.), DE GOER (A.M.). *A study of valency changes of vanadium ions in Al_2O_3 by γ-irradiation.* Journal of the Physics and Chemistry of Solids, **38**, 1063-70, 1977.

The effect of γ-irradiation at 300 K on the concentration of V^{3+}, V^{4+} and V^{2+} in Al_2O_3 is studied quantitatively. M.O'D.

VOLOSHIN (A.V.), DAVIDENKO (I.V.). *Andalusite in granite pegmatites of the Kola peninsula.* (Translated into English.) Doklady Acad. Sci. USSR, Earth Sci. Section, **203**, 116-17, 1972.

Prismatic crystals up to 3 cm long and 0.5 mm across and coloured orange, pink or brownish-pink with a faint pink to lilac-pink pleochroism are found in granite pegmatites in gneisses of the Kola series. Some of the andalusite is replaced in the pegmatite by sillimanite. M.O'D.

WILLIAMS (J.D.), NASSAU (K.). *A critical examination of synthetic turquoise.* Gems and Gemology, **XV**, 8, 226-32, 6 figs, 1976.

A detailed report of the sophisticated scientific examination of Gilson synthetic turquoise and Adco, Syntho and Turquite simulations, with natural Nevada turquoise. Scanning electron microscope, x-ray diffraction and tests for possible binding substances, together with conventional gemmological tests were used. This established the Gilson product as a true synthetic and the other three manufactured substances as simulants or imitations. This determined, the important comment was that normal gemmological procedures should clearly distinguish the imitations; while the Gilson synthetic was identifiable under magnification. R.K.M.

Gemmologische Kurzinformation. (Short Gemmological Notes.) Z.Dt.Gemmol.Ges., **26**, 2, 82-5, 1977.

H. Bank examined a parcel of sinhalites and found a peridot amongst them—the RI and DR being very similar, but the peridot having a lower density was separated from the denser sinhalites. H. Bank also contributes a small article on the colour changes of topaz, and mentions the following: (1) heating from brown or yellow to pink, (2) bombardment from colourless to brown, (3) bombardment and subsequent heating from colourless to blue (low RI), and (4) bombardment from yellow to intensive yellow (high RI): he heated yellow-brown topazes which became salmon-brown at about 420 °C and colourless at a higher temperature without obtaining the desired pink colour. Lastly, G. Lenzen mentions the fact that Gilson's synthetic opals also are used in opal triplets. E.S.

Materials of electrical and magnetic interest. One-day meeting of the Crystallography Group of the Institute of Physics, 22 November 1974.

Reviews the electrical and magnetic properties of spinel, lithium tantalate, corundum and other crystals. M.O'D.

Tsumeb. Mineralogical Record, **8**, 3, pp. 128, illus. in colour, 1977.

Although not separate from the numeration of the series, this issue ranks as a special item, since it is devoted completely to the mineralogy of Tsumeb in south-west Africa. Chapters cover the history and the individual mines of the area and a particularly noteworthy feature is the number of new minerals mentioned (they are not fully described). A good general bibliography is provided. M.O'D.

BOOK REVIEWS

ANTHONY (J.W.), WILLIAMS (S.A.), BIDEAUX (R.A.). *Mineralogy of Arizona.* University of Arizona Press, Tucson, 1977. pp.255. Some coloured illustrations. $22.50 (hardback).

A major work in which the minerals to be found in the state of Arizona are listed alphabetically. The bulk of each descriptive entry is given over to an account of the various localities in which the mineral is found, details of the mineral itself being restricted to chemical composition. Some crystals are shown in diagrammatic form, but there is no description accompanying them nor is there a table which could be consulted. This is the deliberate policy of the authors as stated in the introduction; serious students of mineralogy will possess Roberts *et al.*, 'Enclyclopedia of Minerals' (see J. Gemm., 1977, XV, 7, 401) and 'Dana's System of Mineralogy', 7th edition, or at least have access to them. This book does provide detailed descriptions of the mode of occurrence of the minerals to be encountered in the State and also good-quality maps. Arizona contains uranium and vanadium deposits as well as the perhaps better-known copper ones, such as Bisbee and Tiger;

48 minerals were first found in the State; over 200 have been discovered since 1959, which pays tribute to the amount and depth of mineralogical study taking place in the area.

The quality of printing and of the coloured illustrations is very high; the authors have included an extensive bibliography and also, where applicable and desirable, catalogue numbers denoting important type materials in museum and other collections. At the price, this is well worth buying, even if a trip to Arizona is not imminent. M.O'D.

BLAKEY (G.G.). *The diamond.* Paddington Press, New York and London, 1977. pp.280. Illus. in black-and-white and in colour. £10.95.

This large and handsome book is not aimed at the specialist though he will be pleased to acquire such obscure scraps of information as the whereabouts of celebrated stones and illustrations of contemporary scenes obtained during the early years of diamond mining in South Africa. Notes on the properties of diamond are given; there is a very short bibliography and a glossary in which the description of kimberlite is inadequate. M.O'D.

EVANS (J.). *Magical jewels of the Middle Ages and the Renaissance.* Dover Books, New York, 1977. pp. 264. £2.15.

Reprint of a classic of the genre; first published in 1922. Its greatest value lies in its treatment of original manuscript and early printed material. M.O'D.

GREG (R.P.), LETTSOM (W.G.). (1858). *Manual of the Mineralogy of Great Britain and Ireland.* A Facsimile Reprint with Supplementary Lists of British Minerals by L.J. Spencer, F.R.S. and a Fourth Supplementary List (1977) together with a Foreword by Peter G. Embrey. Lapidary Publications, Broadstairs, Kent, 1977. pp. lxvii, 483. £10.

For many years now and particularly since the expansion in interest in all aspects of mineralogy since World War II, curators of mineral collections have been inundated with requests for information on British mineral localities. The Mineral Resources Memoirs of the Geological Survey have been available in specialized libraries or could sometimes be bought from the Stationery Office, but they were confined, in general, to the somewhat specialized treatment of limited areas and with mineral deposits of economic or potential strategic importance. There has been no *general* British mineralogy since Greg and Lettsom was published in 1858 and it has long been out of print. In recent years a number of articles on British regional mineralogy have appeared in magazines catering for the amateur, and it seems wholly appropriate that this reprinting of Greg & Lettsom should be carried out by publishers catering mainly for the amateur fraternity who have contributed so much to British mineralogy.

It has been argued that the ideal would be a *new* British Mineralogy, but this is a truly mammoth task and those few individuals with the expertise and necessary encyclopedic knowledge are often burdened with administrative and/or teaching duties. The late Sir Arthur Russell, a gifted amateur, planned such a mineralogy as did L.J. Spencer, formerly Keeper of Minerals of the British Museum (Natural History), but neither had the time to attack the problem in the necessary single-minded manner.

For this reprint, Peter Embrey has persuaded the publisher that this volume would be so much more valuable if the lists of minerals new to Britain since 1858

produced by L.J. Spencer in 1898 and 1931 (combined in this volume) and in 1958 were to be appended. Spencer's 1958 list went further than listing the mineral name with the reporter and date (as in the first and second lists) and included the chemical formula, crystal system, locality, and the reference to the original paper. Embrey has followed the latter arrangement in his 4th supplementary list which was specially compiled for this reprint edition, and mentions all additional species new to Britain and Ireland that had come to his notice by late summer 1977.

The new Foreword to the reprint by Peter Embrey gives much detail on the history of mineral collecting and of some of its personalities during the 'classical era' of its development during the late 18th and 19th centuries. References are freely appended and the amateur mineralogist will find this section of more than passing interest and even an inspiration for the future.

In the original work the primary classification is into *metallic* and *non-metallic* minerals, and these are then divided into chemical and element groupings with further chemical sub-divisions. This arrangement seems to have no modern counterpart, but it is not difficult to find one's way around the book—there is a useful alphabetical index, but no locality index. The principal merit of the book is the reasonably detailed locality information which is provided for each species, and this will be its main appeal to the amateur mineralogist.

With its lucid, plump foreword and biographical notes, supplementary lists and good locality information in the original manual this *new* Greg and Lettsom is a volume which no enthusiastic British or visiting mineralogist, amateur or professional, can afford to ignore, more especially since the binding and photo-lithography are well executed and the price reasonable. Criticisms are few; the modern type face and the layout of the title page appear out of sympathy with the original 1858 printing and the facsimile of the entry in the Allan-Greg catalogue is placed too high on the page. On the other hand the dust jacket shows an excellent colour reproduction of Weardale fluorite fluorescing. E.A.J.

POYNDER (M.). *The price guide to jewellery, 3000 B.C. to 1950 A.D.* Antique Collectors' Club, Woodbridge, 1976. pp. 385. Illus. in black-and-white and in colour. £15.00.

This large and expensive book attempts to give an indication of the price range of a variety of jewellery types. Many of these are illustrated in colour quite adequately and black-and-white photographs depict the more commonplace pieces. Prices are based on those obtaining in the saleroom and in some of the more important specialist shops. It is hoped to provide an annual updating service for a small extra cost. There is a bibliography, some notes on cutting, a glossary and a small section on gemstone identification. By and large the material is well chosen and accurate, although one or two undesirable names (which this reviewer will not perpetuate by quoting) have crept in. Though everyone has his own idea of price, this book will be invaluable for those who do not see antique jewellery every day and for the student. M.O'D.

RYKART (R.). *Bergkristall.* (Rock-crystal.) 2nd edn. Ott Verlag, Thun, Switzerland, 1977. pp. 248. Illus. in black-and-white and in colour. Fr 39.

This is the second edition of a work first published in 1971. The previous edition was not illustrated in colour, as this one is, and the later bibliography is much more extensive. M.O'D.

SCHNEER (C.J.). *Crystal form and structure.* (Benchmark papers in geology, no. 34.) Dowden, Hutchinson & Ross, Stroudsburg, Pa, 1977. pp.xiii, 368. $33.50.

The Benchmark papers are collections of major papers on a variety of scientific subjects edited by an acknowledged authority in the field. They cover the subject back to early papers (in this instance the 17th century) and endeavour to present the landmarks in the subject with some connecting editorial comment. This volume begins with some papers on the conception of internal periodicity and also includes items on vectorial surface energy, Bravais's rule and its extensions, the applicability of thermodynamics, periodic bond chains and surface energy as a function of structure. Since it is now quite difficult either to obtain the earlier papers or to separate basic theory from its applications with which most current papers are concerned, this book will prove invaluable to students of crystallography and crystal growth. M.O'D.

SCHUMANN (W.). *Gemstones of the world.* English trans. by Evelyne Stern. N.A.G. Press, London, 1977. pp. 256. Illus. in colour. £8.95.

This is a concise, almost pocket-sized survey of gems, chiefly notable for its 70 pages of quite superb colour plates illustrating some 1500 specimens. Mrs Evelyne Stern has used her own very considerable gemmological knowledge to good purpose in preparing this careful translation.

Exhaustive tables are provided, but gemmological facts and methods are glossed over, or totally omitted, in the cause of brevity. Crystallography is dealt with inadequately in a couple of pages. Synthetics are dismissed in less than a page, imitations in half a page, doublets in seven lines, and no procedure for the recognition of any of these is given. The microscope, polariscope and dichroscope are not mentioned.

The main part of the book consists of brief descriptions of gem species divided into five sections: traditional trade gems, usable collectors' gems, rare gems for collectors, rocks (decorative minerals), and organic gems. Gem minerals are arranged in order of decreasing hardness in each group and one is surprised to find beryl between sapphire and chrysoberyl and to be told that it is a trigonal mineral. (I have been asked to point out that this error does not occur in the original German version, nor was it in Mrs Stern's translation. However, the joint publishers in New York, with an eye to the American sales, employed Professor Anthony C. Tennisen, of Lamar University, as a consultant and the unconventional classification seems to have crept in at this point. Is this another divergence between American mineralogy and that of the rest of the world?). Each description has its own superb coloured illustration on the opposite page. A few rarer gems are named but described by colour and hardness only and are not illustrated. In most cases, but not all, the deficient physical constants can be found in the tables. RIs and SGs are generally quoted only as overall ranges.

One is surprised to find sulphur included as a gem. Gaylussite, also in the third section, tends to lose water and become opaque.

Final tables combine hardness, refractive indices and specific gravities and suggest a gemmological procedure for testing individual stones. One of the tests postulated is hardness. Professor Schumann is a mineralogist, and this is evident in his approach to gem testing.

The book is called a complete survey of gemstones. A survey is not necessarily a detailed study. This one is aimed at the lay public rather than at the gemmologist. Its chief merit must be in its fine colour plates. R.K.M.

SCHUMANN (Walter). *Mineralien und Gesteine.* (Minerals and stones.) 5th edn. BLV Verlagsgesellschaft, Munich, 1977. pp.256. Illus. in colour. DM 25.

Available in both hard- and flexi-cover copies, this forms a companion to the author's *Edelsteine und Schmucksteine* (reviewed in J.Gemm., 1977, XV, 6, 337). Some Hartmann photographs appear, but the majority are new and welcome on that account as well as for their general excellence. Some rocks are included, but the space devoted to them is only about one quarter of the book. There is no bibliography, though (in the flexicover copy) advertisements from the publisher suggest further reading in the subject. Each specimen is described opposite its illustration and the quality of reproduction is high. An English edition is promised. M.O'D.

STERN (Evelyne). See SCHUMANN (W.). *Gemstones of the world,* above.

STONE (D.M.), BUTT (R.A.). *Australian precious opal.* (Revised edn.) Periwinkle books, Dee Why West, N.S.W., 1977. pp. 110. Illus. in colour. $2.95.

A well-illustrated book which gives some good shots of various opal mines, together with good quality colour-plates illustrating the types of material associated with different areas. Hints on prospecting and maps make this a promising guide for the collector in the field. M.O'D.

STRÜBEL (G.). *Mineralogie. Grundlagen und Methoden.* (Mineralogy: foundations and methods.) Ferdinand Enke, Stuttgart, 1977. pp. viii, 472. DM 24.80.

This pocket-size book presents an exhaustive survey of mineralogy with a good deal of reference to modern techniques. Up-to-date instruments are illustrated by photographs and the results obtained from them by clear diagrams. Each chapter includes its own bibliography and there is also a general list of relevant periodicals. Knowing this author's particular interests, it is not surprising to find particularly good treatment of crystallography and crystal-growth techniques. A feature which makes the book particularly suitable for student use is the section of question and answer accompanying each chapter. M.O'D.

VARGAS (G.), VARGAS (M.). *Faceting for amateurs.* 2nd edn. Vargas, Thermal, Ca. 92274, U.S.A., 1977. pp.xii, 345. 122 figs (black-and-white). Price on application.

This large book contains much more than instructions for faceting techniques, though these form the major part and are very well done. The rest is devoted to descriptions of gem materials, both natural and synthetic, and the range of materials included is very wide (painite is there, together with villiaumite, wardite and mellite). Among the synthetic materials are bromellite and tellurium oxide, both of which produce toxic dust, and tourmaline, which has only been manufactured in minute sizes. Natural zirconium oxide (baddeleyite) is wrongly stated to be hexagonal (it is monoclinic). These are, however, small points in an otherwise excellent work. Especially valuable to the student of gemmology are the directions given to the faceter when examining rough material with a view to fashioning it; diagrams illustrate all the important styles of cutting; there is a short bibliography and an extensive glossary. The book can be highly recommended. M.O'D.

VOLLSTÄDT (H.), BAUMGÄRTEL (R.). *Einheimische Edelsteine.* (Native gemstones.) 2nd edn. Steinkopff, Dresden, 1977. pp. x, 232. Illus. in black-and-white and in colour. Price on application (about DM 19).

This is a manual of gemmology in the sense of an introduction to the world of gemstones; crystal symmetry is discussed and, unlike many (or most) gemmological textbooks, the geological origin of the gem minerals is described. The gem materials themselves are listed in traditional mineralogical order (elements, oxides, etc.) and some unlikely candidates such as painite make their appearance. Many of the listed species are shown diagrammatically in their crystalline state, though some important ones (fluorite, brazilianite) are not so treated. By now the origin of the cause of colour in precious opal is common knowledge and it is treated correctly here.

Probably the most serious omission is a detailed review of the use of the spectroscope in gem testing; although the instrument is described, there is no list of important lines and bands apart from a small list of the significant features in the absorption spectra of some red stones. The chapter on synthetic materials lacks the important illustrations of inclusions in synthetic emerald and additional discussion of this important topic would have been welcome. A fairly large section of the book is devoted to the fashioning of stones and there is a short bibliography and a table of constants. Altogether quite a workmanlike book, evidently aimed at readers in the German Democratic Republic since that country and its mineral locations are shown on the back end-paper. M.O'D.

ZUCKER (B.). *How to invest in gems.* Blandford Press, Poole, 1977. pp. 128. Illus. in colour. £3.95.

The English version of the American text already reviewed (J.Gemm., 1977, XV, 7, 401), with appropriate changes in currency. M.O'D.

Guide to Australian gemstones. Reader's Digest Services Pty, Sydney, 1976. pp. 52. Illus. in colour. $1.10.

A beautifully illustrated booklet which covers the gem materials found in Australia, this useful guide includes maps and brief lapidary information and is substantially accurate. M.O'D.

Inventaire minéralogique de la Françe. (Mineralogical inventory of France.) Bureau de Recherches Géologiques et Minières, Service Géologique National, Orléans. Price on application.

These guides are prepared for each Department of France and so far the following have been covered: Hautes-Alpes, Alpes-Maritimes, Aveyron, Cantal, Côtes-du-Nord, Finistère, Tarn. Locations are pinpointed within each area and sketch maps are provided. Indexes are included for places and minerals and there are bibliographies. M.O'D.

Mineral Fundstellen. (Mineral Sources.) Christian Weise Verlag, Munich, 1975–

This series, as yet incomplete, is highly recommended and is easily the best of its type so far seen. The volumes published up to now are as follows:

1. FRUTH (L.). *Tirol, Salzburg, Südtirol.* (Tyrol, Salzburg, South Tyrol.) 1975. 2nd edn. pp. 207. Illus. in colour. DM 28.50.

   This area of Austria includes the Habachtal, where emeralds are found in a

mica schist. In this volume the bibliography is very short, but the coloured illustrations are well up to standard.

3. GLAS (M.), SCHMELTZER (H.). *Baden-Württemberg.* (Baden-Württemberg, W. Germany.) 1977. 2nd edn. pp. 197. Illus. in black-and-white and in colour. Price on application.

Baden-Wüttemberg is rich in minerals due to its varied geology and these are illustrated in high-quality colour plates. Each mineral location is depicted by a sketch-map and there is a very comprehensive bibliography. Well-known regions included are Pforzheim and the Kaiserstuhl.

4. WILKE (H.-J.). *Skandinavien.* (Scandinavia.) 1976. pp. 370. Illus. in colour. DM 48.

There is no other guide comparable to this one which deals with the minerals of the whole of Scandinavia (i.e. Sweden, Norway, Finland). Since there are so many important locations in these countries, such a guide has long been a desideratum, but now we have a handy form of reference to such places as Outokumpu (Finland), celebrated for uvarovite and chrome-diopside, Langesundfjord (Norway) with its suites of rare minerals, and Långban and its vicinity in Sweden, also famous for rarities. As in the other guides of this series, there is a superb bibliography extending over 14 pages (of small print): this is arranged by country, locality and then alphabetically.

5. WENINGER (H.). *Steiermark und Kärnten.* (Styria and Carinthia, in Austria.) 1976. pp. 231. Illus. in colour. DM 32.

This volume follows the pattern of this excellent series in listing the major mineral sources of the country or portion concerned. The bibliography contains 200 entries, which gives some guide to the depth of the work. The area around Graz is well covered, as might be expected, since there is a wide range of minerals in that region. Titanite, fire opal and fluorite are found widely in the area and are beautifully illustrated in colour.

6. SCHMELTZER (H.). *Rheinland-Pfalz.* (Rhineland-Palatinate, W. Germany.) 1977. pp. 189. Illus. in black-and-white and in colour. Price on application.

This area includes Idar-Oberstein and the Hunsrück as well as the Saarland. Other features are similar to the volumes reviewed above.

8. HUBER (S.), HUBER (P.). *Oberösterreich, Niederösterreich und Burgenland.* (Upper and Lower Austria and Burgenland.) 1977. pp. 270. Illus. in black-and-white and in colour. Price on application.

Similar to the volumes mentioned above and of equally high quality.

M.O'D.

ASSOCIATION NOTICES

PRESENTATION OF AWARDS

The Chairman, Mr Norman Harper, presiding over the annual Reunion and Presentation of Awards, held at Goldsmiths' Hall on 24th October, 1977, described the results of the year's examinations as regrettably below those of previous years. Only 53% of those taking the Preliminary and only 24% of those taking the Diploma had passed. He described this as 'terrible'.

The Prime Warden of the Goldsmiths' Company, Mr Algernon Asprey, made the presentation of the awards to successful candidates, who had come from all over Britain as well as from Sri Lanka, Finland, Spain, the Netherlands and Belgium. In addressing the assembled students, he drew a parallel between the Worshipful Company and the Association in that they both cared for the integrity and stability of the trade. 'Your success is the stepping-stone to experience', he said, 'because to be expert in gems requires constant handling of them. People push rings under my nose and say "What are they worth?"' he added, and to illustrate that this was an impossible task he instanced as a case of experts disagreeing over value the yellow diamond which was to have been auctioned in Switzerland as naturally coloured but was then pronounced to have been artificially coloured by irradiation. He had seen such disasters happen on a smaller scale where people had bought goods abroad thinking them bargains and he had to explain to them that the knowledge of stones was world-wide—a dealer in Bangkok was just as aware of their value as was one in London. 'I have often told such people that they should have known better, and should have gone to a well-known firm to buy. An individual may or may not be honest, but a firm with a famous name cannot afford to be dishonest: the integrity of a business must be sustained.'

He quoted a passage from Samuel Pepys where the diarist had recorded that his wife had increased her stock of jewellery by getting a ring made with a turkey stone (turquoise) set with diamonds. She had chosen the gift. No one just *bought* such things, they were eventually *given,* no matter how fantastic they might appear as part of a stock: giving was a fact of life, which brought much pleasure.

As members of the Gemmological Association they were not alone, because they had a world fellowship. Mr Asprey recalled a meeting with the jeweller to the Imperial Household in Ethiopia, who said that he was not alone where diamonds were concerned because he was in touch with dealers in Hatton Garden, but he was

on his own where coloured stones were concerned. That meeting led to an embarrassing experience. 'We went to the Palace to examine the gifts of a wealthy Arab ruler. Looking at the rubies, we realized that they were reconstructed.'

Mr Asprey had recently visited Teheran, where they had been holding a British Cultural Festival at which treasures from London had been an important exhibit presented by the Goldsmiths' Company after touring the U.S. and Canada. He had planned to buy turquoises there but was interested to note that the dealer had some magnificent diamonds and was backing them with a gemmological certification. So, though he was in a remote country, he was not alone.

MEMBERS' MEETINGS

London

On the 1st February, 1978, at the Geological Museum, London, Mr E.A. Jobbins, B.Sc., F.G.A., gave a lecture on 'The Ruby and Sapphire Gem Fields, Cambodia', based on a three months' visit in late 1974. Mr Jobbins dealt with the methods of working, the gemstones and the basic geology, as well as proposals for future working; and his lecture was illustrated by maps and a large number of colour-transparencies. The lecture-theatre of the Geological Museum proved a most attractive and comfortable venue and it is hoped that the substance of the lecture will be published in a future issue of the *Journal.*

On the 4th April, 1978, at the Central Electricity Generating Board Cinema, London E.C.1., a talk was given by Mr P.H. Read, C.Eng., M.I.E.E., M.I.E.R.E., F.G.A., Head of Electronics, De Beers Central Selling Organization, entitled 'New Gemmological Instruments and Techniques'.

Midlands Branch

A meeting was held on the 26th January, 1978, at the Royal Institute of Chartered Surveyors, Birmingham, when Mr R. Punnell gave a talk on 'The Art of Stone Cutting'.

North-West Branch

On the 24th November, 1977, at the Royal Institution, Liverpool, films were shown entitled 'Aurum' and 'Its All Done with Minerals'.

On the 28th January, 1978, a Buffet Dance was held at the Shaftesbury Hotel, Liverpool.

On the 22nd February, 1978, at Church House, Liverpool 3, Mr Alan Hodgkinson, F.G.A., gave a lecture entitled 'Gemmological Insight'.

South Yorkshire and District Branch

A 'Practical Evening' was held on the 16th January, 1978, at the Sheffield City Polytechnic, when members were able to examine a selection of specimens.

The Annual General Meeting of the Branch was held on the 11th February, 1978, at Tapton Hall, Sheffield 10, followed by a dinner for members and guests.

ANNUAL GENERAL MEETING

The Association's Annual General Meeting will be held at Saint Dunstan's House, Carey Lane, London EC2V 8AB on Thursday, 11th May, 1978, at 6.00 p.m.

COUNCIL MEETING

At a meeting of the Council held on Monday, 13th February, 1978, the following were elected to membership.

Fellowship

Alexander, Frank E., London. D. 1955
Bhaskaran, G., Bombay, India. D. 1977
Bruce, James T., Transvaal, S. Africa. D. 1977
Campos de Quevedo, Juan N., Madrid, Spain. D. 1977
Cañas Carballido, Miguel, Madrid, Spain. D. 1977
Clements, Jennifer M., London. D. 1977
de Silva, Nirmali P., Ambalangoda, Sri Lanka. D. 1977
Gill, Stephen H., East Horsley. D. 1977
Goonawarna, C. L. W. P., Ratnapura, Sri Lanka. D. 1977
Gunaratna, M. S., Colombo, Sri Lanka. D. 1977
Gunawardene, Mahinda, Colombo, Sri Lanka. D. 1977
Havlik, Jan C., London. D. 1977
Innala, Harri T., Toijala, Finland. D. 1977
Lintunen, Viktor, Kuusonkoski, Finland. D. 1977
Mendis, Rowena, Colombo, Sri Lanka. D. 1977
Murga Chivite, Miguel A., Barcelona, Spain. D. 1977
Mylius, Maren-Ann, Oslo, Norway. D. 1977
Narros Martin, Gabriel, Madrid, Spain. D. 1977
Nootenboom, Poppy Z. L-B., Hong Kong. D. 1977
Perez-Alberdi Manzano, Felix, San Sebastian, Spain. D. 1977
Pethe, Dilip M., Bombay, India. D. 1977
Pounds, James R. W., Horsham. D. 1977
Rademaker, Elizabeth J. M., Soest, Holland. D. 1977
Ramchandran, K. T., Bombay, India. D. 1977
Salminen, Mirja L., Pori, Finland. D. 1977
Sayer, David J., Weston-super-Mare. D. 1977
Timonen, Esko Tapio, Hameenlinna, Finland. D. 1977
Truelove, Stephen R., Bradford. D. 1977
Uchihara, Ichiro, Osaka, Japan. D. 1977
Walker, Andrew G., Guildford. D. 1977

Ordinary Membership

Abasolo, Aranguren, Ander, London.
Abeyakoon, Sudanta, London.
Abeysinghe, Pushpa K. de S., Colombo, Sri Lanka.
Akizuki, Haruo, Nairobi, Kenya.
Alidina, S. A., London.
Anderson, Charles, Va, U.S.A.
Andrews, Sheila M., Dalkeith, W. Australia.
Aresh, Gordafrid T., Tehran, Iran.
Ashra, Harish, London.
Atiqalam, Farooqi, Rawalpindi, Pakistan.
Bartram, Garry D., Perth, W. Australia.
Bass, Joan J. A., Deal.
Baxendale, John F., Shipley.
Blake, Jeannette A., London.
Blanckenberg, Antoinette, Southampton.

Bodenham, Kenneth E., Newcastle-upon-Tyne.
Bogues, Patrick M., Omagh, N. Ireland.
Bolsover, Shirley, Hong Kong.
Bonham, Frank C., Ca, U.S.A.
Borg, Stefan, Charlottenlund, Denmark.
Borthwick, George W., Klerksdorp, S. Africa.
Bradoch, Robert, Tokyo, Japan.
Bramwell, Peter, Durham.
Brierley, Hugh, Invercargill, New Zealand.
Bromwich, Graham S., Reigate.
Brownlow, Arthur H., Mass, U.S.A.
Burgan, Shirley E. M., Bristol.
Burns, Lynn D., Birmingham.
Carrel, Gerard, Geneva, Switzerland.
Chadwick, John S., Todmorden.
Chodanowicz, Janina T., Bradford.
Christensen, Curtis J., London.
Clampitt, Marjorie, Abingdon.
Curtis, Malcolm D., Fareham.
de Almeida Prado, Joao B., São Paulo, Brazil.
de Camargo, William G. R., São Paulo, Brazil.
Deeley, Peter J., Birmingham.
de Grado, Joseph, La, U.S.A.
Deuell, C. Francis, Oreg., U.S.A.
Dobb, George H., Ca, U.S.A.
Dominguez Mondelo, Segundo, Oviedo, Spain.
Donald, Robert J., Ont., Canada.
Dougan, Patricia M. S., Nairobi, Kenya.
Dups, Kennerley C., London.
Emslie, Iain A., Bromyard.
Fainzilber, Misha, Dar es Salaam, Tanzania.
Fenton, John, Dartford.
Folgueras Dominguez, Servule, Madrid, Spain.
Foster, Stephen V., Ohio, U.S.A.
Furse, Anna A., London.
Furuya, Hitomi, Tokyo, Japan.
Garson, Magnus S., Kerala, India.
Gold, Andrew D., Ilford.
Green, James E. W., Wolverhampton.
Griffiths, Geoffrey E., Grimsby.
Groenenboom, Hans K., Spykenisse, Holland.
Hameed, Abul H. M. S., Hong Kong.
Harding, Roger R., London.
Hashiguchi, Masahiro, Tokyo, Japan.
Hassen, Naufan W., Dharga Town, Sri Lanka.
Henson, Ian J. D., Hillingdon.
High, Lawrence R., Salisbury, Rhodesia.
Horvath, Elsa, Que., Canada.
Howard, David, Longridge.
Huang, C. K., Taipei, Taiwan.
Huo, Bonnie K., Hong Kong.
Ichimura, Yoshino, Aichi Pref., Japan.
Ishida, Toshio, Kyoto, Japan.
Israel, Nigel B., London.
Jealouse, Roy G., Crewe.
Jibiki, Emiko, Aichi Pref., Japan.
Johnson, Arthur George, Ill., U.S.A.
Jones, Edith W., Peppermint Grove, W. Australia.
Kasahara, Yuriko, Yokohama-City, Japan.
Kato, Takenori, Osaka, Japan.
Kayman, Shelley, London.
Kenner, George F., Ca, U.S.A.
Keydar, Susan, London.
Khan, Humayun Y., South Ruislip.
Kimura, Shinichi, Kyoto, Japan.
Klaver, G. J., Jeppestown, S. Africa.
Kojima, Mieko H., Yokohama, Japan.
Lakdawalla, Noshir J., Bombay, India.
Lam, Kenneth T. H., Hong Kong.
Lee, Richard S. K., Hong Kong.
Li, Woon So, Hong Kong.
Lurie, Joseph, Randburg, S. Africa.
McCready, Ann, London.
McNeel, Day P., Tex., U.S.A.
Mavromati, Yiota, Nicosia, Cyprus.
Minster, David, Pretoria, S. Africa.
Murphy, Mary M., New York, U.S.A.

Nakama, Toshiro, Okinawa Pref., Japan.
Nakagawa, Masateru, Hyogo Pref., Japan.
Narita, Kazuaki, Tokyo, Japan.
Nobumisto, Takagi, Kanagawa Ken, Japan.
Nosaka, Yoshiko, Tokyo, Japan.
O'Donnell, Francis X. D., Liverpool.
Ohkura, Keiko, Tokyo, Japan.
Okimoto, Yoshiyuki, Tokyo, Japan.
Okimoto, Youko, Tokyo, Japan.
Pagoulatos, Elias, Athens, Greece.
Palmer, Joanna G., Guildford.
Pattni, Pravin, London.
Pendlebury, Marguerite D., Hove, S. Australia.
Perera, G. M. Beatrice, Nivitigala, Sri Lanka.
Pierson, Robert C., Deale, Md, U.S.A.
Pillay, Subbiah V., Isipingo Hills, S. Africa.
Pollard, James F., Glen Waverley, Australia.
Pollard, Jilly, Dorking.
Qami, Kiyoshi, Tokyo, Japan.
Quinn, Robert C., Dublin, Ireland.
Raniga, Harish B., Ilford.
Richardson, Malcolm F., Cleethorpes.
Roditi, Maurice, New York, U.S.A.
Sadamatsu, Toyojiro, Nagasaki Pref., Japan.
Salgado, Eric G. A., Solihull.
Schofield, John, Leeds.
Selbey, Sheelagh F., Newcastle-upon-Tyne.
Senda, Katuniko, London.
Sever, Katherine M., Altrincham.
Shepherd, Richard B., Aylesbury.
Shirai, Saijiro, Tokyo, Japan.
Shore, Barry F., Ca, U.S.A.
Sin, Gwang S., Seoul, Korea.
Skai, Eve, Oslo, Norway.
Spivack, Hyman, Harrow.
Spooner, David J., Merstham.
Stears, Trevor W., Bromley.
Streight, Stewart G., Ont., Canada.
Sugawara, Tadashi, Tokyo, Japan.
Sugiyama, Yoshie, Yamaguchi Pref., Japan.
Suhner, Bertold, Herisau, Switzerland.
Suzuki, Takayoshi, Tokyo, Japan.
Takahashi, Ikuo, Kyoto, Japan.
Tarjan, Andrew, Toronto, Canada.
Tate, Julia F., Hong Kong.
Timms-Hackworthy, David, London.
Tollefson, Terry W., Minn., U.S.A.
Tongi, Aurora, Bouira, Algeria.
Uppard, John E., Westcliff-on-Sea.
Vale, Shelagh V., Dundee.
Vidal, Nessio V., Eastbourne.
Vollom, Paul A., Oreg., U.S.A.
Vose, James, Me, U.S.A.
Watson, Joy S., Cottingham.
Watts, Terrence J., Newcastle-upon-Tyne.
Weeresinghe, N. P. O., Ratmalana, Sri Lanka.
West, Clive G., London.
Winarto, Arief, Jabar, Indonesia.
Winn, Neelia, London.
Woodford, Trevor A., Windsor.
Worthington, Sally L., Bingley.
Yamashita, Junko, Tokyo, Japan.
Yoshikawa, Kazuhiko, Wakayama Pref., Japan.
Zahir, Sheik, Oberwil, Basel, Switzerland.
Zala, Marga, Hong Kong.
Ziff, Harold, Ariz., U.S.A.

NEWS OF FELLOWS

On the 4th December, 1977, Mr E.A. Jobbins, B.Sc., F.G.A., gave a talk entitled 'The Gentle Art of Gemstone Faking' at the Geological Museum, London.

Mr E.A. Jobbins also took part in a program entitled 'The Mountain of Light: the Story of the Koh-i-Noor Diamond', which was broadcast by the BBC on Radio

4 at 11.05 a.m. on Monday, 19th December, 1977, and repeated at 8 p.m. on Thursday, 22nd December.

On the 14th January, 1978, Mr J.A. Fleming, F.G.A., gave a talk on unusual gemstones to the Wessex Branch of the N.A.G.

The classes in gemmology started by the Gemmological Institute of India two years ago (J.Gemm., 1976, XV, 4, 224) are in charge of Shri Ravindra J. Jhaveri, B.Sc., F.G.A.

OBITUARY

Mr Norman de Berry Noakes (D.1970), Auckland, New Zealand, died on the 31st December, 1977.

GIFT TO THE ASSOCIATION

The Council of the Association is indebted to Mrs Janet Harris, F.G.A., Adelaide, Australia, for a fine oval greenish/brown sphene weighing 6.91 ct.

DIAMOND TRAINING CLASSES (INDIA)

To meet an insistent demand from the trade, the Gemmological Institute of India has now arranged for training classes in diamond grading and sorting. The first trainees started training on 12th December, 1977. The classes are in charge of Shri Sudhir Ghaswalla, B.Sc.

VIENNA NATURAL HISTORY MUSEUM

The Natural History Museum (Naturhistorisches Museum) in Vienna has opened a new room for a mineralogical-petrographic collection which includes rocks and gemstones. The gem part of the exhibition forms about one third of the collection. New safety measures have been introduced, and these enable some specimens to be exhibited which had not been on show since 1848.

Roughly 3000 gemstones are exhibited. The collection of emeralds from Colombia may be one of the best in the world; it contains a piece of rough consisting of 15 large crystals of gem quality, which was a present from Montezuma to Ferdinand Cortez.

The diamond collection is mainly from South Africa; it contains a crystal of 82.5 ct, as well as various rough pieces weighing from 10 to 40 ct each. Some coloured diamonds are set in rings. There are also some Golconda pieces, one beautiful blue of 5 ct, some pink, some yellow-green and a particularly beautiful yellow stone.

The largest European precious opal weighs 584 ct, is of finest quality, was found at the time of Maria Theresa in Czerwenica, now in Slovakia, but then in Hungary. There is also a good collection of precious metal objects and many other gemstones, such as a very fine cut alexandrite of 13 ct, many rubies, a giant precious topaz and tourmaline crystals from Pala in California.

A well produced card on sale at the Museum depicts a bunch of flowers which Maria Theresa presented to her husband in 1760. Made by the Viennese jeweller Grosser, it consists of 1500 coloured gemstones and 1200 diamonds, all of the best quality.

XVIth INTERNATIONAL GEMMOLOGICAL CONFERENCE

(Report received from Mr A.E. Farn, F.G.A., Manager of the London Chamber of Commerce Gem Testing Laboratory)

The Sixteenth International Gemmological Conference was held at The Hague from 9th to 13th October, 1977. Thirty-nine people, four of them women, participated, and the Conference was chaired by Dr P.C. Zwaan, F.G.A., (National Museum of Geology and Mineralogy, Leiden). At the commencement of the proceedings all stood in silence as a tribute to the late Robert Webster, F.G.A.

Mr B.W. Anderson, B.Sc., F.G.A., gave an elegant and informative talk upon 'Experiences with Industrial Diamond', speaking of carbonado, boart and industrial crystals, plus the purity-testing of powders and grits.

Dr C.E.S. Arps, F.G.A., (Leiden) demonstrated an immersion-contrast polariscope.

At an evening meeting at Oud-Wassenaar Castle, 'Fancy-colour Diamonds' were covered by Mr E. Asscher (a relative of Joseph Asscher, of Cullinan fame).

Professor Dr H. Bank, F.G.A., (Idar-Oberstein) gave a rapid resumé of some recent additions to the world of gemstones, and promised to send a complete list with properties to all participants.

Dr J.M. Bosch-Figueroa (Barcelona University) described accessories for photographing with a microscope the surface structure of diamonds.

Professor A. Chikayama, F.G.A., (Tokyo) gave a talk illustrated with colour slides of gem mines in the Far East.

Mr Robert Crowningshield, F.G.A., (GIA New York Laboratory) spoke upon the growth of diamond grading under the GIA since about 1955.

Mr A.E. Farn, F.G.A., after commenting on the wide range of gem materials encountered (from diamonds and sapphires to such materials as tortoiseshell, shagreen and even dung-beetles), spoke of the carbonates and calcium carbonate itself in its various forms, particularly of calcite—beautiful as a crystal, as a cut stone a rarity (owing to cleavage and softness), the basis of the dichroscope (now an underrated instrument) and nicol prisms, the standard 3 on the Mohs hardness scale and a useful indicator in density determination liquids—and various forms of pearl and shell, but also of bonamite (rivalling both jade and emerald in colour): his talk was illustrated by fine colour slides from the Institute of Geological Sciences and from Mr R.K. Mitchell, F.G.A.

Professor Dr M. Font-Altaba (Barcelona University) described crystallographic applications in gemmology with some wonderful slides.

Mr H.M. Forth (Toronto Gem Lab) spoke of some minute diamond finds in a Kimberlite pipe covering an area of 90 acres in Somerset Island, N.W. Territory, Canada.

Mr E.A. Jobbins, B.Sc., F.G.A, (Institute of Geological Sciences, London) gave a coloured-slide lecture on the origin of the Pailin ruby and sapphire deposits: he had actively participated in surveying the area.

Dr J. Kanis (Rhodesia) gave a potted discourse upon the various gemstones from southern Africa with informed observations upon the physical scene and its latent troubles.

Mlle Dina Level (late of the Paris Laboratory) produced a series of slides and observations which were both beautiful and practical.

Mr Richard T. Liddicoat, Jr, (President of the Gemological Institute of America) described the new headquarters of the GIA in Santa Monica, California. Briefly, they have 17 classrooms (1 research), 215 full-time resident students, 11-12 000 correspondence students, craft classes and department-store management classes. Their equipment includes instruments such as a scanning electron microscope with an energy-dispersant magnification of 5-150 000 ×.

Dr H. Nairis, F.G.A., (Geological Survey, Sweden) gave a short talk on diamond substitutes.

Mr P.P.E. Paulin, B.Sc., F.G.A., (Uppsala University, Sweden) gave details of investigations into the causes of colour-centres in sodalite.

A lecture on 'The Optical Refractoid' by Mr H.S. Pienaar, F.G.A., (Stellenbosch University) described a method of teaching uniaxial and biaxial measurements on a practical refractometer extension.

M. J.-P. Poirot (Paris Laboratory) talked upon the same subject as Mr Pienaar, which caused some overlapping of ideas.

Dr F.H. Pough described cut dumortierite and a new man-made fibrous cat's-eye material.

Mr Hans Reymer (Toronto) accented the difficulties of Canadian gemmologists due to the great distances separating them.

Dr J. Saul gave an exposition on an unusual suite of garnets from the Umba River, Tanzania, which have a colour-change effect.

Mr C.A. Schiffmann, F.G.A., (Gübelin Laboratory, Lucerne) spoke of alexandrite-like garnets and mentioned the powerful influence of chromium on colour.

Dr H.-J. Schubnel (Paris) gave a talk on gem mining methods in Thailand with beautiful colour-slides.

Mr E.B. Tiffany (Ontario) gave a shrewd summation of the impact of gemmology (post- and pre-war effectiveness), commenting on the improvement of quality, standards, techniques and grading and the order emerging from these concepts and emphasizing the principle 'No consumer—no gemmology'.

Mr G. Tombs, F.G.A.A., (Sydney, Australia) spoke of the lack of technical information available on heat treatment and described his own experiments to lighten the colour of dark Australian sapphires.

CORRIGENDA

On page 28 *ante*, in Figure 10, (1) in the top right-hand diagram (EFG Growth) 'diet support' should read 'die support', and (2) in the middle left-hand diagram (LPE Growth) there should be no rule joining 'rotate' to 'excess ...' (viz. slow rotation for growth, fast rotation for spin-off of excess melt on withdrawal).

GEM TESTING EQUIPMENT

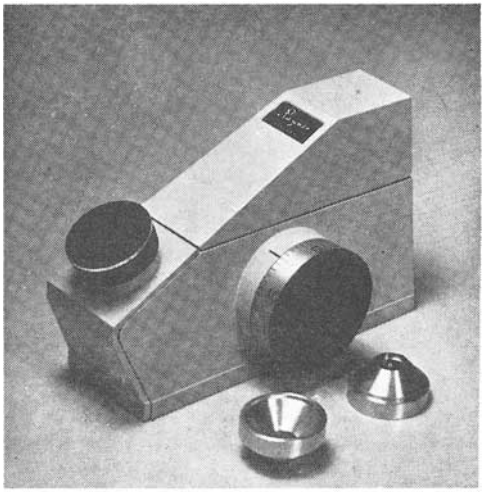

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and

PROCEEDINGS OF THE GEMMOLOGICAL ASSOCIATION OF GREAT BRITAIN

GEMMOLOGICAL ASSOCIATION
OF GREAT BRITAIN
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Vol. XVI No. 3 JULY, 1978

CHARACTERIZATION OF TWO SAMPLES OF TAIWAN'S JADE

By Dr A. FLAMINI, Prof. Dr G. GRAZIANI* and Dr M. MARTINI†,*

*Institute of Mineralogy, University of Rome.

†Laboratory of Physical Analysis, Cassa di Risparmio di Roma.

SUMMARY

Two samples of Taiwan's jade, one of them with a clear cat's-eye effect, have been studied by optical, x-ray, thermal and electron microprobe analyses and SEM investigations. They showed that both samples are tremolitic members of the tremolite-actinolite-ferroactinolite series, with identical chemical and mineralogical composition. The diverse shades of green colour and cat's-eye effect are related to different arrangements of the fibres.

INTRODUCTION

Two samples of jade from Taiwan‡ were analysed by microscopy, x-ray diffraction, thermoanalytical, SEM and electron microprobe techniques to ascertain their nature. Both samples are cabochon cut, 15 × 10 × 5 mm in size and derive from the same

‡The samples were supplied by Messrs Frank and Company, of Taipei, Republic of China (Taiwan), by kind recommendation of Dr E. Gübelin, of Lucerne, Switzerland.

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Fig. 1—Jade of Taiwan : Sample A. (1: 0.75)

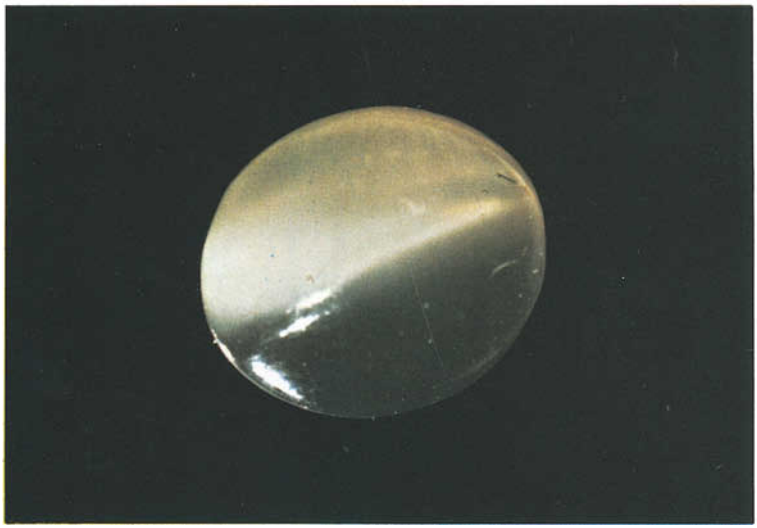

Fig. 2—Jade of Taiwan : Sample B. Evident cat's-eye effect (1: 0.5)

deposit. One of them (sample A) has the typical colour of jade with rare and very slender veins of different shade, whereas the other (sample B) is lighter in colour and with an uncommon cat's-eye effect (Figures 1 and 2).

EXPERIMENTAL RESULTS

Optical investigations were carried out on fracture surfaces and on three polished oriented sections, one parallel to the cabochon basal ellipse and the other two orthogonal and containing respectively the major and minor axes of the basal ellipse. They showed that sample A is constituted by fibrous bunches without a clear preferential arrangement, whereas sample B is constituted by very thin parallel fibres.

The values of the birefringence, for sample B, measured by spinel refractometer, agree with those reported by E. Gübelin[3] for three samples of cat's-eye Taiwan jade. The values are:

$$n_x = 1.616 \qquad n_z = 1.632 \quad = \quad 0.016$$

The values for sample A are very similar, even if they have a larger approximation due to the randomly arranged and distorted fibres. Also the densities of the two samples are similar: 3.01±0.005.

Morphological features of the two samples were investigated by SEM on sections parallel to the cabochon basal plane.

On sample A the fracture surfaces are constituted by bunches of fibres variously arranged and distorted (Figure 3). The polished surfaces generally show a marked compactness; but on them we can see some discontinuities, in which have been observed some fibres with a loose arrangement (Figures 4 and 5). From the investigations performed on fracture surfaces of sample B it appeared that the material is composed of fibres with a perfect parallel texture (Figure 6). This observation is confirmed by investigations carried out on polished surfaces, which also reveal that the material is highly compact and fit for polishing.

Chemical quantitative analyses were carried out by electron microprobe*. Two tremolite crystals, respectively from Malga Mont and Sas dell'Anel, analysed by R. Pirani[5, 6], were used as standards. All iron has been calculated as FeO_{tot}, H_2O^- and loss on ignition were determined by thermogravimetric analysis. Results

*Electron microprobe : Jeol JXA50A. Operative conditions : Accelerating potential, 15 kV; Beam current, 5×10^{-8} A; Sample current, 3×10^{-8}A. Analytical conditions : Beam diameter, 20μm; Sodium volatilization test, <1%; Statistical error, <1%.

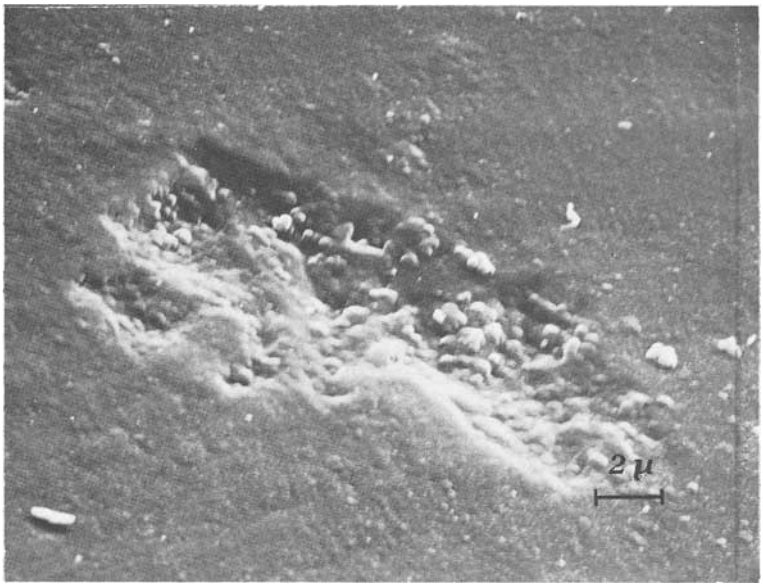

Fig. 3—Jade of Taiwan : Sample A. Randomly arranged tremolite fibrous crystals.

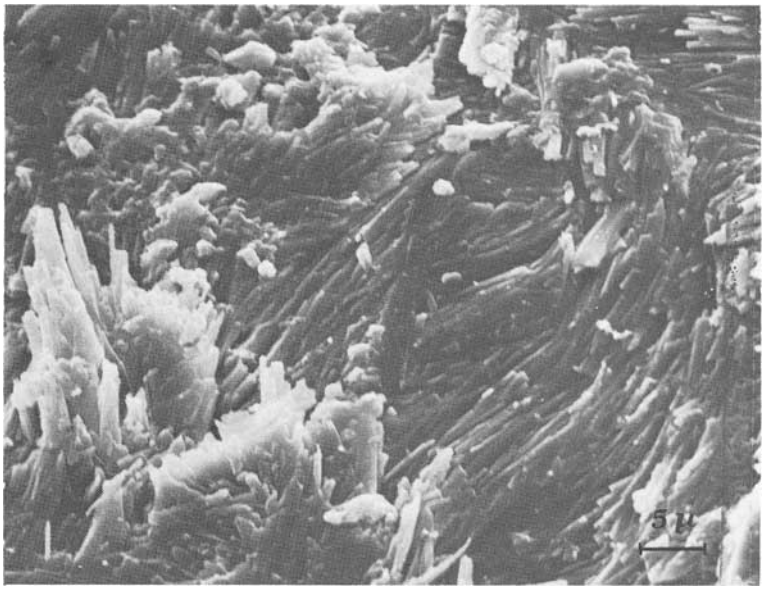

Fig. 4—Jade of Taiwan : Sample A. Example of superficial discontinuity.

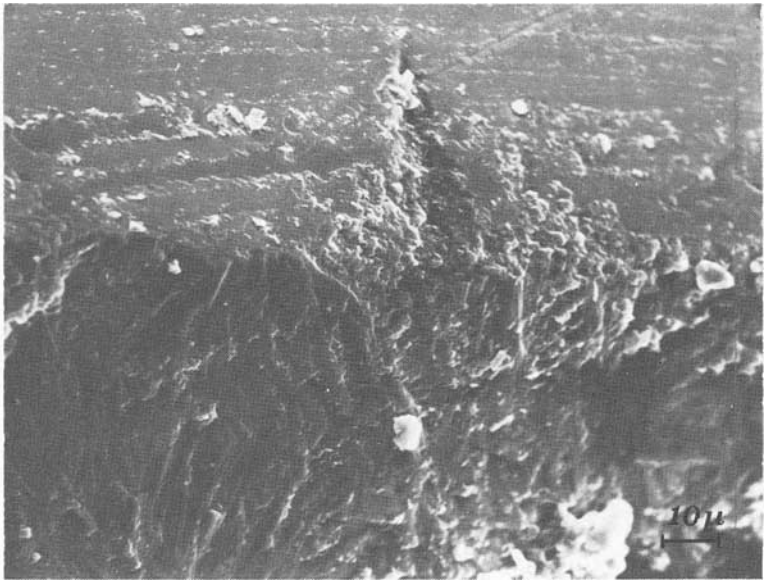

Fig. 5—Jade of Taiwan : Sample A. A discontinuity's image observed both on the polished plane (a) and on a fractured surface (b).

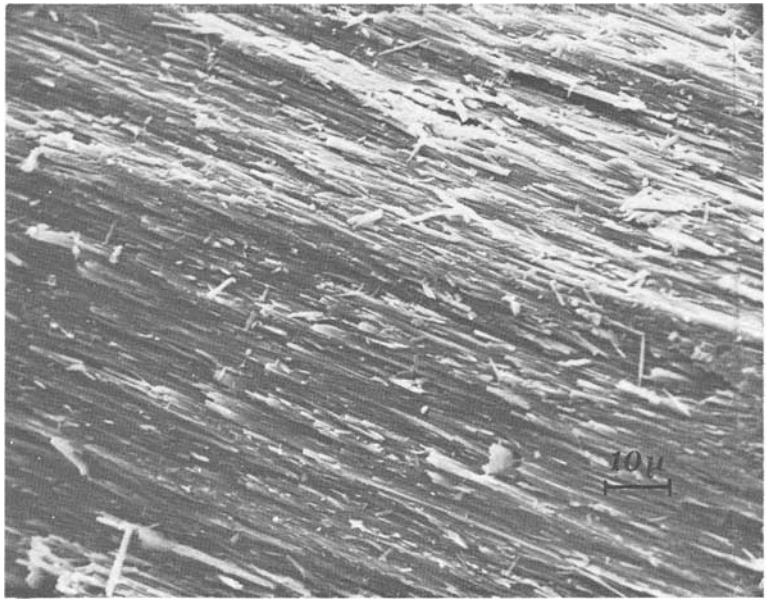

Fig. 6—Jade of Taiwan : Sample B. Fibrous crystals with a perfect parallel arrangement.

(Table I) were corrected, with an IBM 30/40 computer program, for background, electronic dead time, instrumental shift for small and long time, atomic number, absorption, continuous and characteristic fluorescence.

Chemical composition of the two samples is nearly identical.

TABLE I

	Sample A	Sample B
SiO_2	55.76	56.15
TiO_2	0.18	0.18
Al_2O_3	1.76	1.82
FeO_{tot}	2.71	2.71
Cr_2O_3	0.28	0.26
MnO	0.35	0.32
MgO	21.90	21.95
CaO	13.05	13.08
Na_2O	0.61	0.64
K_2O	0.28	0.26
L.O.I.	1.98	2.05
H_2O^-	0.28	0.35
F	—	—
	99.14	99.77

NUMBERS OF IONS ON THE BASIS OF 24 (O, OH, F)

Si	7.791	8.08	7.792	8.09
Al	0.290		0.298	
Ti	0.019	4.97	0.019	4.94
Fe_{tot}	0.317		0.314	
Cr	0.031		0.029	
Mg	4.558		4.537	
Mn	0.041		0.038	
Na	0.165	2.17	0.172	2.16
Ca	1.953		1.944	
K	0.050		0.046	
OH	1.845	1.84	1.897	1.90
F	—		—	
100Mg : (Mg + Fe_{tot} + Mn)	92.72		92.78	

TABLE II

Tremolite ASTM—13—437			Sample A		Sample B	
d Å	I/I_o	hkl	d Å	I/I_o	d Å	I/I_o
8.98	16	020	9.025	11	8.889	9
8.38	100	110	8.425	33	8.268	28
5.07	16	130,001	5.088	13	5.067	9
4.87	10	$\bar{1}11$	4.887	8	4.874	2
4.76	20	200	4.783	8	4.720	5
4.51	20	040	4.518	20	4.495	19
4.20	35	220	4.220	13	4.191	8
3.870	16	$\bar{1}31$	3.875	12	3.867	3
3.376	40	150,041	3.388	23	3.388	4
3.268	75	240	3.267	44	3.267	55
3.121	100	310	3.126	100	3.110	100
3.028	10	$31\bar{1},24\bar{1}$	3.043	8	2.988	3
2.938	40	$\bar{1}51$	2.945	33	2.935	6
			2.876	8		
2.805	45	330	2.814	31	2.805	13
2.730	16	$42\bar{1}$	2.738	23	2.722	12
2.705	90	151	2.710	75	2.702	12
2.592	30	$\bar{1}12,061$	2.596	30	2.589	5
2.529	40	$\bar{2}02,002$	2.540	30	2.535	5
2.407	8	$\bar{1}32$	2.414	8	2.404	3
2.380	30	350,400	2.386	13	2.380	11
2.335	30	$35\bar{1}$	2.341	31	2.338	6
2.321	40	$42\bar{1}$	2.320	22	2.315	5
2.298	12	420,071	2.300	29	2.295	5
2.273	16	112	2.276	13	2.276	2
2.206	6	$\bar{2}42,042$	2.212	6	2.243	2
2.181	6	$44\bar{1}$		34	2.161	7
2.163	35	171,261	2.166	14		
2.042	18	081,280	2.047	22	2.036	2
2.015	45	202	2.014	14	2.014	5
2.002	16	351,370	2.004	9	2.000	11
1.963	6	$28\bar{1},190$	1.967	5	1.961	7
1.929	6	152	1.924	17	1.939	2
1.892	50	510	1.891	14	1.890	15
1.864	16	$460,\bar{1}91$	1.864	8	1.861	5
			1.843			
1.814	16	530	1.817	8	1.848	2
1.746	6	$\bar{2}03$	1.751	5	1.814	9
1.686	10	$003,\bar{2}82$	1.886	10	1.748	2
1.649	40	$210\bar{1}$	1.651	33	1.686	3
1.639	10	$48\bar{0},\bar{5}11$	1.639	13	1.650	11

Also it has been noticed that inside the discontinuities on polished surface of sample A there is a slight increase of iron content.

X-ray powder patterns, obtained from the two samples, A and B, are nearly identical and are typical of tremolite (Table II).

Differential thermal analyses were carried out by a microthermodifferential apparatus (type BDL), working in a dry air stream (5 cc/min) and with a furnace gradient of 10 °C/min. The DTA curves also of the two samples are nearly identical. An endothermic effect at about 960 °C, due to recrystallization, is evident. The absence of the small exothermic effect at about 830 °C, reported for other tremolites [1, 2, 7], is probably due to the low iron content of samples A and B.

CONCLUSIONS

We may conclude that the two samples of jade, A and B, are tremolitic and mineralogically and chemically identical.

The values of birefringence and density are in agreement with the chemical composition of the two minerals, and using the diagram of Deer *et al.*, [1] where the refractive index and density are plotted against the chemical composition of the members of the tremolite-actinolite-ferroactinolite series, the two samples of jade appear to have a ferroactinolitic content of 10%.

The cat's-eye effect is confirmed to be mainly due to the perfect parallel arrangement of the fibres.

Regarding sample A, it has been observed that where the material is less compact there is a slight increase of iron content and the green shade becomes darker.

ACKNOWLEDGEMENT

The authors are indebted to Dr E. Gübelin for his valuable advice and criticism, Prof. R. Pirani for supply of the standards and G. Guidi and R. Tecchia for their collaboration in the analytical work.

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[*Manuscript received 14th April, 1977.*]

STUDIES OF A GEM GARNET SUITE FROM THE UMBA RIVER, TANZANIA*

By E. A. JOBBINS, J. M. SAUL, PATRICIA M. STATHAM and B. R. YOUNG

INTRODUCTION

A series of 204 variously coloured garnet pebbles was acquired by J. Saul during 1974 from the same alluvial area along the Umba River as the blue colour-change garnet described by Jobbins *et al.* 1975. The garnets were shown to us at the Institute and it was suggested that they would form an ideal subject for a detailed study of a large sample from a known and relatively restricted provenance.

A small polished flat was placed on each pebble to facilitate optical determinations. After cleaning in an ultrasonic cleaner the pebbles were sorted into thirteen groups on a colour basis by one author (P.M.S.) and a second author (E.A.J.) checked and agreed with this grouping, which greatly assisted the subsequent handling. At this stage it was noted that the stones in groups 12 and 13 showed marked colour changes (greys to pinks) from daylight to tungsten illumination, that those in group 11 appeared khaki by transmitted daylight but pale orange-brown by reflected daylight, and that there was more variation within the suite than had been apparent to any of us at first inspection.

PHYSICAL AND CHEMICAL PROPERTIES

The refractive index of each specimen was determined (±0.002) using sodium light and a standard Rayner refractometer.

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The specific gravities were determined by hydrostatic weighing in pure toluene. The plot of refractive indices against specific gravities is shown in Fig. 1, and it will be seen that the points form a broad straight band despite the wide range of constants and colours. Two

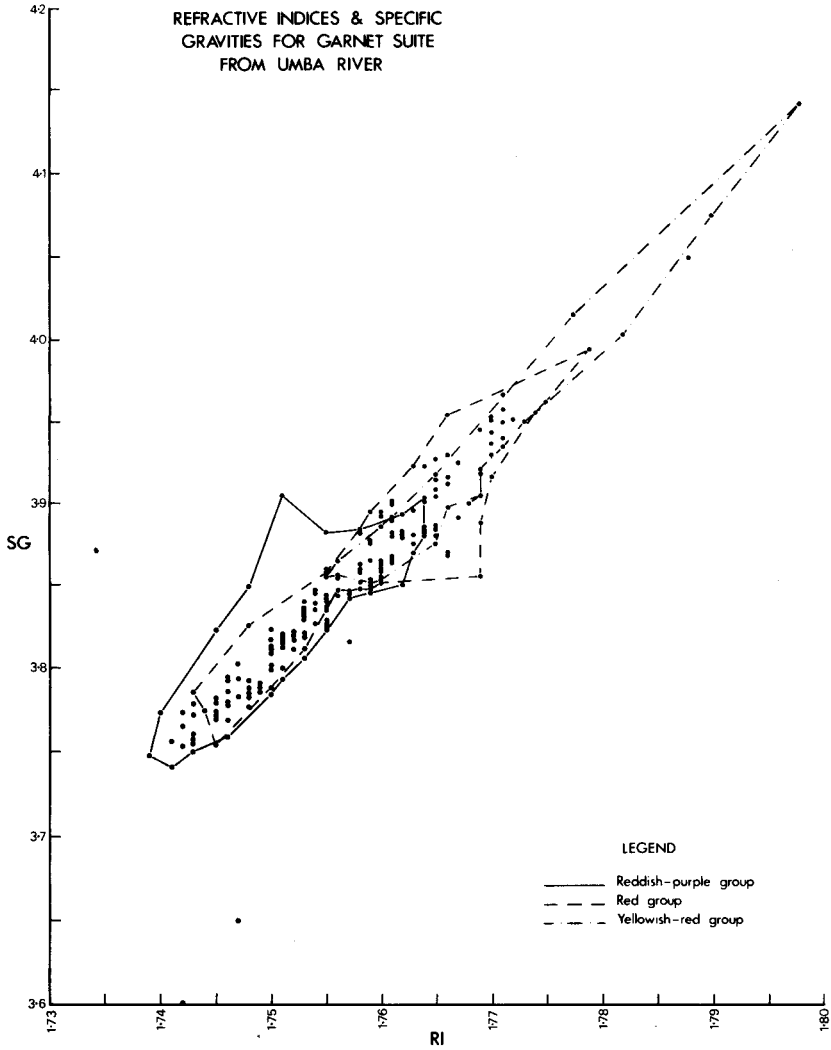

FIG. 1

stones 9/27 and 10/43 fall well below the main band and are rich in the grossular molecule (see Table I) with a low manganese content; they may originate from a different provenance.

Eight of the garnets (four chosen at roughly equal intervals on the main band on the RI/SG plot plus three garnets away from the band and one colour-change specimen from group 11) were analysed for the elements shown in Table I using a 'Geoscan' electron microprobe. Silicates and oxides of known composition and pure metals were used as standards. All elements were analysed using an accelerating voltage of 20 kV. The results have been corrected for absorption, atomic number effect and fluorescence using the Mark V version of the BM-IC-NPL computer program written by Mason, Frost and Reed.

With the electron microprobe it is not possible to distinguish the valency states of iron. For samples 1/3 and 1/26 it has been assumed that all the iron is in the divalent state. For the other samples the FeO and Fe_2O_3 contents have been calculated from the total Fe by assuming that the number of cations in the tetrahedral, octahedral and eight-fold co-ordination sites are in the ratio 3:2:3 as they would be in the theoretical garnet structure. Titanium is here considered as substituting as a trivalent cation in the octahedral sites and is grouped with the Al^{3+}, Fe^{3+}, Cr^{3+} and V^{3+}. However the position of titanium in the garnet structure is in doubt and it is likely that it can substitute in both the octahedral and tetrahedral sites (see Hartman 1969, Dowty 1971 and Huggins *et al.* 1977). Titanium has been ignored in calculating the molecular percentage of the end members.

Three x-ray powder films of each analysed garnet were taken in an 11.46 cm camera at room temperature (*c.*23°C) using filtered copper ($\lambda K\alpha_1 = 1.54051$Å), cobalt ($\lambda K\alpha_1 = 1.78892$Å) and iron ($\lambda K\alpha_1 = 1.93597$Å) radiations, and the most suitable films were selected for measurement. The unit cell dimensions a(Å), which are accurate to ±0.001Å, were obtained by plotting the values obtained from the high angle lines against the Nelson and Riley function

$$\tfrac{1}{2}\left(\frac{\cos^2\theta}{\sin\theta} + \frac{\cos^2\theta}{\theta}\right)$$

and extrapolating to $\theta = 90°$.

The absorption spectra of the whole sample were determined using transmitted light through water-immersed specimens on a microscope stage and a Beck prism spectroscope. As expected we

TABLE I

ELECTRON MICROPROBE ANALYSES OF GEM GARNETS FROM UMBA RIVER AREA

Specimen No.	1/15	9/27	1/3	CCG	11/1	1/26	9/14	10/40	10/42
SiO_2	41.94	38.4	41.7	40.3	39.51	40.5	38.0	37.5	36.6
TiO_2	0.03	0.37	0.04	0.05	0.23	0.01	0.27	0.20	0.22
Al_2O_3	23.98	20.6	23.1	21.8	22.13	22.7	21.5	20.5	20.7
Fe_2O_3	0.59*	2.74*		1.16*			1.21*	1.25*	0.55*
FeO	7.40*	1.54*	16.5⁺	0.16*	3.27⁺	17.7⁺	4.41*	2.27*	2.01*
MnO	4.14	1.3	1.1	18.2	18.27	2.2	25.4	30.5	37.6
MgO	20.78	nt.fd.	16.6	12.9	9.31	13.5	6.3	2.7	1.2
CaO	1.62	34.0	1.2	5.3	6.85	2.7	3.6	5.2	1.5
Cr_2O_3	0.04	nt.fd.	0.01	nt.fd.	0.03	0.10	nt.fd.	nt.fd.	0.01
V_2O_3	nt.fd.	0.05	0.01	0.75	0.26	0.04	0.18	0.04	0.01
CoO	nt.fd.	0.12	0.18	0.03	nt.fd.	0.01	nt.fd.	0.04	nt.fd.
NiO	nt.fd.	nt.fd.	nt.fd.	nt.fd.	nt.fd.	nt.fd.	nt.fd.	0.06	nt.fd.
ZnO	0.04	0.04	0.01	0.03	nt.fd.	0.03	0.05	0.05	0.01
Na_2O	nt.fd.	0.04	nt.fd.	nt.fd.	nt.fd.	nt.fd.	0.12	0.11	nt.fd.
K_2O	nt.fd.	0.01	nt.fd.	nt.fd.	nt.fd.	nt.fd.	0.03	0.02	0.02
	100.56	99.21	100.45	100.68	99.86	99.49	101.07	100.44	100.43

Specimens 11/1 and 1/15, analyst P.H.A. Nancarrow, the remainder, Anne E. Tresham.
nt.fd. = not found. *FeO and Fe_2O_3 are calculated from total Fe by assuming that the number of cations in the tetravalent, trivalent and divalent positions are in the ratio 3: 2:3.
⁺Assuming that all the iron is in the divalent state. CCG = Blue colour-change garnet.

n	1.739	1.747	1.753	1.757	1.760	1.761	1.779	1.788	1.798
D_{obs}	3.745	3.650	3.823	3.816	3.855	3.863	3.995	4.049	4.141
D_{calc}	3.735	3.663_5	3.836	3.837	3.863	3.872	4.016	4.059	4.157
a(Å)	11.502	11.848_5	11.493	11.578	11.609	11.519	11.595	11.633	11.614

NUMBERS OF IONS ON THE BASIS OF 24(O)§

Si	5.940	6.01	5.911	6.01	6.057		5.973	6.00	5.992		6.036		5.898	6.02	5.977	6.01	5.947	6.00
Al	0.068		0.097		—		0.029		—		—		0.118		0.028		0.057	
Al	3.935	4.01	3.640	4.01	3.955	3.96	3.779	4.00	3.956	4.02	3.988	4.01	3.815	4.01	3.824	4.00	3.907	4.00
Fe^{3+}	0.063		0.317		—		0.129		—		—		0.141		0.150		0.067	
Ti	0.003		0.042		0.004		0.005		0.026		0.001		0.032		0.024		0.027	
Cr	0.004		—		0.001		—		0.004		0.012		—		—		0.001	
V^{3+}	—		0.006		0.001		0.089		0.032		0.005		0.022		0.006		0.001	
Fe^{2+}	0.876	6.01	0.198	6.01	2.004	5.94	0.020	6.00	0.415	5.98	2.206	5.92	0.573	6.02	0.302	6.01	0.273	6.00
Mn	0.496		0.169		0.135		2.285		2.347		0.278		3.339		4.117		5.174	
Mg	4.386		—		3.593		2.849		2.104		2.998		1.457		0.642		0.291	
Ca	0.246		5.609		0.187		0.842		1.113		0.432		0.599		0.888		0.261	
Co	—		0.015		0.021		0.004		—		0.001		—		0.005		—	
Ni	—		—		—		—		—		—		—		0.008		—	
Zn	0.004		0.005		0.001		0.004		—		0.004		0.006		0.006		0.001	
Na	—		0.011		—		—		—		—		0.037		0.034		—	
K	—		0.002		—		—		—		—		0.006		0.004		0.004	

§The numbers of ions have been calculated to three places of decimals to minimize rounding errors in the summations.

MOLECULAR PERCENTAGE OF END-MEMBERS

Almandine	14.6	3.3	33.8	0.3	6.9	37.3	9.6	5.1	4.6
Andradite	1.6	8.0	—	3.2	—	—	3.5	3.8	1.7
Grossular	2.4	85.7	3.1	8.6	17.7	6.8	5.9	11.3	2.6
Pyrope	73.0	—	60.7	47.5	35.2	50.7	24.4	10.7	4.8
Spessartine	8.3	2.8	2.3	38.1	39.3	4.7	56.0	69.0	86.2
Uvarovite	0.1	—	0.02	—	0.1	0.3	—	—	0.03
Goldmanite	—	0.2	0.02	2.2	0.8	0.1	0.6	0.1	0.03

were dealing essentially with two reasonably distinct spectra—almandine and spessartine, the intensities of which are shown in Table II; the grossular molecule provided no spectrum. A number of stones with a very weak almandine spectrum showed additional absorption of the green and/or blue, but chromium lines in the red were not seen. In some cases chromium lines may have been inhibited by iron, but chromium is certainly present in analyses for specimens 1/3, 1/15, 1/27 and 10/42 shown in Table I. It would seem, for instance, that in specimen 1/26 the 0.1% Cr_2O_3 is being completely inhibited by the 0.04% V_2O_3. Vanadium, which showed in all the analyses except 1/15, may well account for some of this general absorption and masking of the chromium, but it was not possible to recognize any specific vanadium lines. This behaviour accords well with that of the blue colour-change garnet from the same area described earlier (Jobbins *et al.* 1975) and these stones also show no fluorescence when copper sulphate solution is used as a filter. In contrast the present stones are not fluorescent under long or short wave UV radiation or under the Chelsea filter, as was the blue garnet which showed red under the filter.

Groups 12 and 4 which exhibit less colourful pinkish-greys and greyish-purples respectively show notable colour changes to deep pinks by tungsten lighting. Both groups are characterized by strong spessartine and weaker almandine spectra. In group 11 there is a marked increase in redness by tungsten lighting (an alexandrite type effect), and the same stones also appear different colours by transmitted and reflected daylight, khaki and orange-brown respectively. This latter colour change was similar to that shown by didymium glass (MI 33205) in the IGS collections and raised the possibility that rare-earth elements might be the cause. To investigate this behaviour specimen 11/1 was analysed, but rare earths were not found by the microprobe, although they may be present in concentrations below detection limits of the instrument. Gallium, which is known to be present in some unusually coloured corundums from the Umba River area and Australia, was not detected in any of the analysed specimens.

Colour Grading

At a later stage in the study it was decided to colour-grade the series using one of the standard systems of colour charts, and the American Munsell system, which has previously been used for

colour-grading of rocks, was selected. A broad correlation between this system and the Methuen Book of Colour, a British system, is possible.

The *Munsell Book of Color* provides an orderly arrangement of standard paper charts which serve as guides for the measurement and notation of all colours. These standards represent equally spaced divisions of the three attributes of colour defined in the Munsell system as *hue, value* and *chroma* (see Figure 2). The *hue* notation of a colour indicates its relation to red, yellow, green, blue and purple; the *value* notation indicates its lightness; and the *chroma* notation indicates its strength (or departure from neutral).

In recording a colour by Munsell notation the symbol for *hue* is written first and is followed by a symbol written in fraction form, the numerator indicating the *value* and the denominator indicating the *chroma* (H V/C). For instance, a sample which is 2.5 Red in hue, 5 in value and 8 in chroma is written 2.5R 5/8. A colour having neither hue nor chroma is known as a neutral.

Our reasons for this exercise were: (1) to try to provide colour

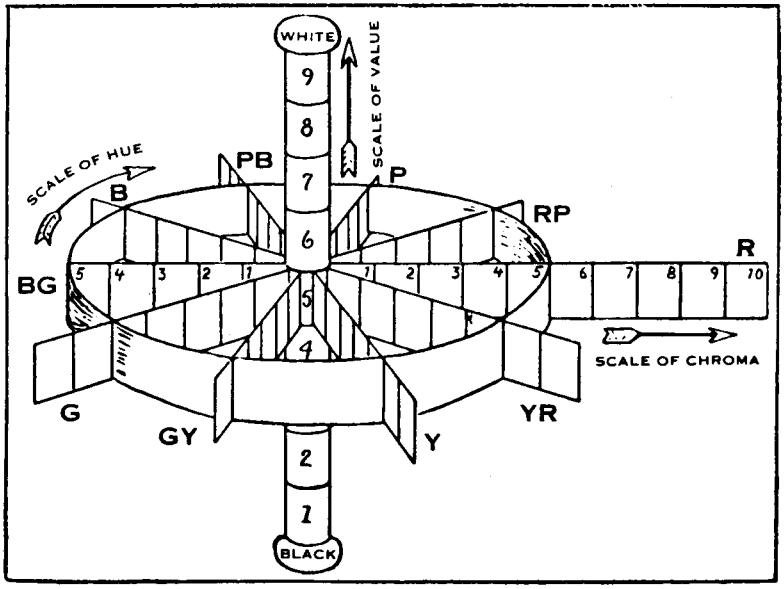

from the Munsell Book of Color

FIG. 2. HUE, VALUE and CHROMA in their relation to one another. The circular band represents the HUES in their proper sequences. The upright centre axis is the scale of VALUE. The paths pointing outward from the centre show the steps of CHROMA, increasing in strength as indicated by the numerals.

descriptions on a scientific basis which could easily be recalled and compared by workers elsewhere and which were not dependent upon subjective colour descriptions based on flowers, fruit and other variable objects; (2) to see if there was any correlation between colour and other physical properties, and (3) to see how practicable such a grading exercise would be on a sample of this size. More complicated grading systems dependent upon spectrophotometry were not considered in this study.

There were many problems in the colour grading among which were (a) the fact that the gemstones were transparent and the colour matching charts opaque; (b) some gems appeared as different colours in transmitted and reflected light despite the fact that, as garnets, they are essentially isotropic and daylight was the only illumination. We determined the colour gradings by transmitted light. The colour gradings for the series are shown in Table II and can be compared there with the absorption spectra intensities, refractive indices and specific gravities. In Figure 1 the outlines formed by areas of reddish-purple (RP), red (R) and yellowish-red (YR) Munsell hue notations respectively are plotted on the refractive index/specific gravity graph of the series and the gradation from reddish-purple to yellowish-red (equivalent to brown in the lower *values*) is seen to correspond broadly with increase in the content of the spessartine molecule.

GEOLOGY

The garnet suite consists of stones found during prospecting in the Umba River Valley area of north-eastern Tanzania. Although the stones probably came from the same group of secondary deposits, it is certain that they did not originate in one primary deposit. This is reflected in the range of colours and in the various external morphologies exhibited by the garnets. In order of frequency these are:

(1) stream-rounded pebbles,

(2) naturally sub-rounded grains which appear to be the fresh cores of larger grains that underwent conchoidal fracturing upon weathering,

(3) sub-rounded grains showing bright surfaces possibly due to resorption,

(4) sharp sub-rectangular fragments, usually with two dimensions substantially greater than the third,

TABLE II. OPTICAL AND PHYSICAL PROPERTIES OF GARNET SUITE, UMBA RIVER, TANZANIA

GROUP 1 PURPLE

No.	Colour Grade			A/S Al	A/S Sp	R I	S G
1	2.5	RP	5/8	5	4	1.743	3.772
2	5	RP	5/10	5	2	1.743	3.750
3	2.5	RP	5/10	5	1	1.753	3.822
4	5	RP	5/10	5	1	1.746	3.795
5	7.5	RP	5/10	4	1	1.748	3.783
6	5	RP	5/10	5	1	1.753	3.833
8	5	RP	6/10	4	0	1.751	3.794
9	5	RP	5/10	6	0	1.760	3.861
10	2.5	RP	5/10	3	3	1.742	3.753
11	5	RP	6/10	3	0	1.750	3.809
12	7.5	RP	5/10	3	0	1.755	3.860
13	2.5	RP	5/10	4	0	1.753	3.806
14	5	RP	6/10	4	0	1.745	3.772
15	7.5	RP	6/8	2	0	1.739	3.748
16	5	RP	5/10	2	0	1.762	3.884
17	2.5	RP	7/6	3	0	1.741	3.741
18	5	RP	5/10	3	0	1.747	3.783
19	5	RP	6/10	3	0	1.750	3.812
20	5	RP	6/10	3	0	1.747	3.794
21	5	RP	5/10	3	0	1.752	3.822
22	5	RP	6/10	3	0	1.745	3.771
23	5	RP	5/10	3	0	1.758	3.857
24	7.5	RP	5/10	3	0	1.748	3.793
25	7.5	RP	6/10	3	0	1.757	3.842
26	7.5	RP	5/10	3	0	1.761	3.880
27	2.5	RP	5/10	3	0	1.746	3.759

GROUP 2 REDDISH PURPLE

No.	Colour Grade			A/S Al	A/S Sp	R I	S G
1	10	RP	6/10	4	5	1.743	3.761
2	5	RP	6/10	4	4	1.741	3.757
3	7.5	RP	7/8	3	3	1.742	3.766
4	7.5	RP	7/8	1	4	1.746	3.786
5	10	RP	7/8	2	4	1.744	3.774
6	7.5	RP	7/8	3	4	1.750	3.784
7	5	RP	6/8	4	4	1.753	3.841
8	7.5	RP	6/8	4	4	1.753	3.823
9	10	RP	8/6	1	5	1.755	3.827
10	5	RP	7/8	4	4	1.740	3.773
11	5	RP	8/6	1	4	1.743	3.755
12	5	RP	8/4	1	4	1.743	3.779
13	5	RP	8/4	1	4	1.745	3.823
14	5	RP	8/6	2	4	1.742	3.773
15	5	RP	7/6	2	3	1.745	3.779
16	5	RP	7/6	2	4	1.754	3.835
17	7.5	RP	7/8	4	5	1.745	3.773
18	7.5	RP	7/8	4	3	1.748	3.783

GROUP 3 BROWNISH PURPLE

No.	Colour Grade			A/S Al	A/S Sp	R I	S G
1	7.5	RP	5/10	5	4	1.750	3.813
2	7.5	RP	6/10	4	3	1.751	3.813
3	10	RP	4/8	5	3	1.764	3.903
4	7.5	RP	6/10	4	3	1.755	3.829
5	7.5	RP	6/10	4	2	1.755	3.843
6	10	RP	6/10	4	2	1.762	3.882
7	7.5	RP	6/8	4	4	1.749	3.791
8	5	RP	6/10	4	3	1.755	3.825
9	10	RP	6/8	4	4	1.760	3.865
10	7.5	RP	5/8	4	3	1.759	3.852
11	10	RP	5/6	3	5	1.755	3.882
12	7.5	RP	5/8	4	2	1.763	3.880
13	7.5	RP	5/10	4	2	1.759	3.847
14	7.5	RP	6/8	4	3	1.758	3.852
15	7.5	RP	6/8	2	2	1.757	3.845
16	7.5	RP	5/8	2	0	1.761	3.867
17	7.5	RP	6/8	2	2	1.747	3.802
18	7.5	RP	5/8	2	3	1.764	3.881
19	7.5	RP	6/10	4	4	1.755	3.836
20	10	RP	6/8	3	5	1.751	3.905
21	10	RP	4/8	5	3	1.748	3.849
22	10	RP	5/8	4	3	1.756	3.857
23	10	RP	4/8	4	3	1.760	3.860
24	7.5	RP	5/8	4	3	1.764	3.885
25	7.5	RP	5/8	4	3	1.752	3.817
26	7.5	RP	7/8	4	4	1.751	3.817
27	7.5	RP	5/8	4	3	1.761	3.867
28	7.5	RP	6/8	4	3	1.746	3.793
29	5	RP	6/8	2	5	1.758	3.883
30	7.5	RP	7/8	4	4	1.750	3.799
31	7.5	RP	7/6	3	3	1.753	3.840
32	5	RP	6/8	4	4	1.748	3.783
33	10	RP	6/8	3	3	1.743	3.757
34	10	RP	6/8	3	3	1.758	3.881

KEY

ABSORPTION SPECTRA (A/S)

Al Almandine
Sp Spessartine

INTENSITIES

1. Very faint
2. Faint
3. Weak
4. Medium
5. Strong
6. Very strong

COLOUR GRADING

RP Reddish-purple
R Red
YR Yellowish-red
Y Yellow

GROUP 4 GREYISH PURPLE

No.	Colour Grade			A/S Al	A/S Sp	R I	S G
1	10	RP	7/6	2	6	1.753	3.839
2	7.5	RP	7/6	1	5	1.740	3.749
3	10	RP	7/8	1	6	1.758	3.860
4	7.5	RP	7/6	1	6	1.753	3.833
5	10	RP	8/4	2	6	1.754	3.847
6	10	RP	6/8	3	5	1.763	3.869

GROUP 5 BROWNISH PINK

No.	Colour Grade			A/S Al	A/S Sp	R I	S G
1	2.5	R	5/10	6	6	1.752	3.811
2	7.5	RP	6/10	4	6	1.762	3.893
3	7.5	RP	6/10	4	6	1.746	3.778
4	10	RP	5/10	4	6	1.762	3.850
5	2.5	R	5/10	5	3	1.753	3.812
6	2.5	R	5/10	4	4	1.749	3.789
7	2.5	R	5/10	4	3	1.753	3.818
8	2.5	R	5/8	3	5	1.771	3.934
9	10	RP	6/10	3	4	1.753	3.833
10	2.5	R	6/10	4	4	1.750	3.801
11	7.5	RP	6/10	4	0	1.751	3.800
12	7.5	RP	6/10	4	4	1.754	3.848
13	10	RP	7/8	3	3	1.749	3.787
14	7.5	RP	6/10	5	2	1.763	3.875
15	10	RP	7/8	4	4	1.751	3.816
16	10	RP	5/10	5	3	1.756	3.843
17	2.5	R	5/10	3	4	1.766	3.868

GROUP 6 PALE BROWNISH RED

No.	Colour Grade			A/S Al	A/S Sp	R I	S G
1	10	R	8/4	1	6	1.748	3.788
2	5	R	7/8	4	6	1.750	3.918
3	10	R	8/4	2	6	1.769	3.948
4	5	R	8/4	1	6	1.757	3.846
5	5	R	6/8	2	6	1.760	3.892
6	7.5	R	5/10	4	4	1.752	3.820
7	5	R	7/6	4	6	1.751	3.820
8	7.5	R	7/8	4	6	1.753	3.835
9	2.5	R	7/8	3	6	1.751	3.817

GROUP 7 BROWNISH RED

No.	Colour Grade			A/S Al	A/S Sp	R I	S G
1	10	R	6/8	4	5	1.755	3.858
2	10	R	6/8	4	5	1.764	3.924
3	10	R	7/8	4	5	1.760	3.895
4	7.5	R	7/8	4	4	1.746	3.780
5	5	R	7/6	4	1	1.748	3.776
6	10	R	6/10	4	5	1.764	3.902
7	10	R	6/6	3	5	1.769	3.855
8	10	R	6/6	2	5	1.748	3.826
9	5	R	6/8	4	6	1.759	3.894
10	10	R	7/6	3	6	1.761	3.901
11	10	R	7/8	3	5	1.755	3.827
12	10	R	5/8	4	5	1.759	3.848
13	10	R	6/8	3	5	1.760	3.851
14	5	R	6/8	4	3	1.746	3.769
15	5	R	5/10	2	5	1.774	3.958
16	7.5	R	7/8	2	5	1.743	3.786
17	5	R	5/12	4	4	1.761	3.866
18	7.5	R	6/10	4	2	1.745	3.782
19	5	R	6/10	4	5	1.772	3.952
20	10	R	5/8	3	4	1.758	3.848
21	7.5	R	6/10	1	5	1.770	3.930
22	10	R	7/6	2	5	1.759	3.873

GROUP 8 PINKISH ORANGE

No.	Colour Grade			A/S Al	A/S Sp	R I	S G
1	10	R	7/8	1	6	1.761	3.901
2	10	R	7/8	2	5	1.762	3.879
3	10	R	6/8	2	6	1.770	3.937
4	10	R	6/10	2	6	1.766	3.930
5	10	R	7/8	2	5	1.750	3.813
6	10	R	7/8	2	6	1.755	3.844
7	10	R	7/8	1	6	1.753	3.835
8	10	R	6/10	2	6	1.771	3.958
9	10	R	6/10	1	5	1.763	3.924
10	2.5	YR	8/4	1	6	1.756	3.868

GROUP 9 REDDISH BROWN

No.	Colour Grade			A/S Al	A/S Sp	R I	S G
1	10	R	4/10	5	5	1.765	3.928
2	10	R	4/10	3	5	1.754	3.827
3	10	R	4/10	3	5	1.761	3.891
4	10	R	4/10	2	4	1.770	3.917
5	10	R	4/10	3	5	1.770	3.951
7	10	R	4/10	1	5	1.775	3.963
8	10	R	5/10	2	5	1.770	3.953
10	10	R	4/10	3	4	1.764	3.882
11	10	R	4/10	2	5	1.766	3.913
13	10	R	4/10	1	5	1.771	3.940
14	10	R	5/10	1	4	1.779	3.995
15	10	R	5/10	4	3	1.750	3.786
17	10	R	5/10	3	6	1.756	3.847
18	10	R	4/10	3	5	1.764	3.881
20	10	R	4/10	4	6	1.769	3.888
21	10	R	4/10	4	6	1.765	3.886
25	7.5	R	5/12	4	3	1.745	3.754
27	10	R	4/10	0	1	1.747	3.650
28	10	R	5/10	2	4	1.759	3.866
29	10	R	6/10	2	6	1.771	3.967
30	7.5	R	4/12	5	3	1.749	3.791
32	10	R	5/10	2	6	1.764	3.885
34	10	R	5/10	2	6	1.768	3.900
35	10	R	5/10	2	5	1.766	3.954
36	10	R	5/10	2	6	1.766	3.869
37	10	R	5/10	4	6	1.767	3.891
39	10	R	5/10	2	6	1.763	3.896

KEY

ABSORPTION SPECTRA (A/S)

Al Almandine
Sp Spessartine

INTENSITIES

1. Very faint
2. Faint
3. Weak
4. Medium
5. Strong
6. Very strong

COLOUR GRADING

RP Reddish-purple
R Red
YR Yellowish-red
Y Yellow

GROUP 10 REDDISH BROWN

No.	Colour Grade			A/S Al	A/S Sp	R I	S G
6	2.5	YR	6/10	2	6	1.765	3.915
9	2.5	YR	5/10	2	6	1.766	3.917
12	2.5	YR	6/10	2	6	1.773	3.950
16	2.5	YR	6/10	2	6	1.758	3.863
19	2.5	YR	6/12	1	6	1.790	4.074
22	2.5	YR	6/12	4	6	1.769	3.921
23	2.5	YR	6/10	2	6	1.765	3.905
24	2.5	YR	6/10	3	6	1.771	3.950
26	2.5	YR	6/12	2	6	1.782	4.003
31	2.5	YR	6/10	2	6	1.778	4.015
33	2.5	YR	6/12	1	6	1.767	3.926
38	5	YR	6/10	1	6	1.765	3.884
40	2.5	YR	5/10	1	5	1.788	4.049
41	5	YR	7/10	0	5	1.761	3.882
42	2.5	YR	6/10	1	5	1.798	4.141
43	2.5	YR	6/12	0	0	1.742	3.601
44	5	YR	7/8	0	6	1.765	3.909

GROUP 11 GREENISH/ORANGE BROWN

No.	Colour Grade			A/S Al	A/S Sp	R I	S G
1	2.5	Y	7/6	1	5	1.760	3.855
2	2.5	Y	6/8	2	5	1.769	3.905
3	10	YR	7/4	2	5	1.760	3.854
4	5	Y	7/4	1	6	1.770	3.943
5	5	YR	7/6	2	5	1.759	3.851
6	10	YR	7/4	2	6	1.766	3.894
7	5	Y	7/4	3	5	1.765	3.875
8	5	YR	7/6	2	6	1.764	3.885
9	7.5	YR	8/2	1	6	1.759	3.877

GROUP 12 PINKISH GREY

No.	Colour Grade			A/S Al	A/S Sp	R I	S G
1	10	YR	7/2	1	5	1.761	3.889
2	10	YR	7/2	1	5	1.765	3.918
3	10	YR	8/2	1	5	1.750	3.824
4	10	YR	7/2	2	5	1.755	3.855
5	2.5	Y	8/2	2	5	1.765	3.915
6	2.5	Y	7/2	2	6	1.760	3.886

GROUP 13

No.	Colour Grade	A/S Al	A/S Sp	R I	S G
1	Colour grading not feasible	3	5	1.755	3.838
2		3	4	1.756	3.856
3		2	5	1.769	3.919

(5) irregular forms.

It is likely that a number of primary deposits of gem garnet were formed simultaneously under similar but not identical conditions, and that the gems thus formed were and are being concentrated in the valley of the Umba.

The regional geology is complicated and has not been mapped on a scale useful to the gem prospector. Metamorphosed sedimentary rocks predominate in the area and are intruded by numerous pegmatites and ultrabasic bodies. The metasediments themselves give ages of around 550 million years (Ma), the age of the Pan-African Event. By analogy with other areas within the same belt of rocks, the Mozambique Mobile Belt, the pegmatites and ultrabasics may also be of similar age.

The 550 Ma event appears to have been of an unusual nature and determined the physical conditions necessary for the gemmy crystallization of the garnets. The unusual range of chemistries probably resulted from the different lithologies (and therefore chemical environments) provided within the metasediments themselves and in the contact zones between metasediments, pegmatites and ultrabasics. Some of the African prospectors prefer to explore areas in which ultrabasics are in contact with particular beds within the metasedimentary sequence. The metasediments are themselves complex with a repetition of lithologies due to cyclic sedimentation within the original depositional basin. There is also later structural repetition of the beds.

Gem almandine (frequently the rhodolite variety) and spessartine have been reported to exist in primary deposits in the valley, but these deposits were not particularly valuable because of the generally poor quality of the crystallization and the high degree of breakage during extraction. On the other hand, the great majority of garnets found in the secondary environments were of gem quality although many of them were small, spotted or of non-commercial shades. The Umba River area thus provides one more demonstration of the general superiority of weathered rough.

It is possible that some of the garnets were recovered from very deeply weathered primary deposits, 'rotten rock', but that the prospectors thought they were digging in a gravelly soil. Some rhodolites from the area have also been recovered from hard secondary deposits, either silcrete or calcrete, but we do not believe that any of these were in our sample of 204 stones.

Other gems found in the valley include pale and subtle coloured sapphires as well as those of the more usual shades (primary deposit known), brown zircon (primary deposit known), kornerupine (primary deposit known) and pebbles of sillimanite (fibrolite), scapolite, actinolite, tourmaline (several varieties including chromian and vanadian), smoky quartz, sphene (?) and both clino- and ortho-pyroxenes.

CONCLUSIONS

We must emphasize the wide range of composition, colour and colour-change seen in this sample from a limited provenance. Vanadium and chromium appear to be involved in these colour-change effects, but we cannot discount the possibility that cobalt or zinc (both of which we have found in Sri Lanka blue colour-change spinels) have some effect. Rare-earth elements, which are known to cause colour-change in other materials, were not detected, but they may be present at concentrations below the detection limit of the microprobe.

The colour-grading presented many problems and in any similar exercise with pleochroic gem minerals, especially those cut and set in jewellery, there would be considerable difficulties.

It is a pleasure to acknowledge ready assistance from our colleagues in the Institute and discussions with them and with other good friends.

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LIDDICOATITE, A NEW GEM TOURMALINE SPECIES FROM MADAGASCAR

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INTRODUCTION

Tourmaline is a group name for six individual species. The general formula can be written as:

$$(X)_1(Y)_3Al_6B_3Si_6O_{27}\,(O,OH)_3\,(OH,F)$$

wherein sodium, Na^{1+}, usually occupies the 'X' position in the formula.

Four of the six species are defined on the basis of the dominant cation in the 'Y' position of the formula. For example, if the 'Y' position is occupied by ferric iron, Fe^{3+}, the species is buergerite which has little gem significance. If the 'Y' position is occupied by ferrous iron, Fe^{2+}, the species is schorl, which is of little gem use but is rarely encountered as mourning jewellery. If the 'Y' position is occupied by aluminium and lithium (Al,Li), the species is elbaite, and this is the gem tourmaline most often encountered as green and pink gems. If magnesium, Mg^{2+}, occupies the 'Y' position, two species are possible: dravite in which sodium, Na^{1+}, occupies the 'X' position, and uvite, in which Ca^{2+} occupies the 'X' position

The discovery of the substitution of calcium for sodium in the magnesium tourmalines led logically to a systematic search for calcium analogues of the other tourmaline species. The calcium analogue of schorl was sought for but not found (Dunn *et al.* 1977*a*.). The possibility for a calcium analogue of elbaite did still exist but was unlikely inasmuch as lithium/aluminium tourmalines are almost always found in sodium-rich pegmatites. This paper is written to report on the discovery of this sought-for calcium lithium/aluminium tourmaline. A more technical description of this new tourmaline is given by Dunn *et al.* (1977*b*).

LOCALITY

The new tourmaline is found in Madagascar. The exact locality cannot be stated with precision since the material did not

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come from a particular mine or deposit but was found as detritus in the soils near Antsirabe, in Madagascar. For detailed descriptions of the pegmatites of the area and the tourmaline crystals, the reader is referred to the work of Lacroix (1893, 1922) and Duparc *et al.* (1910).

We have named this new tourmaline liddicoatite in honour of Richard T. Liddicoat, the President of the Gemological Institute of America. Mr Liddicoat's contributions to gem knowledge and gemmological education have been enormous, and we are most happy to take this humble step and name this new tourmaline in his honour.

CHEMISTRY

Liddicoatite is ideally

$$Ca(Li,Al)_3Al_6B_3Si_6O_{27}(O,OH)_3(OH,F),$$

being the calcium analogue of elbaite,

$$Na(Al,Li)_3Al_6B_3Si_6O_{27}(O,OH)_3(OH,F).$$

Calcium, Ca^{2+}, substitutes for sodium, Na^{1+}, in this mineral and the charge balance is accomplished through adjustment in the lithium/aluminium ratio. Wet chemical analyses of gem liddicoatite and gem elbaite from Madagascar are given in Table 1. Sample #135815 is the purest liddicoatite found in this study and is the type specimen which is in the collection of the Smithsonian Institution. The other samples are of gemmy crystals intermediate in composition between liddicoatite and elbaite, as is readily seen by comparison of their calcium/sodium content.

PHYSICAL AND OPTICAL PROPERTIES

The density of liddicoatite varies from 3.00 to 3.07 g/cm^3. The density of the type specimen, #135815, is 3.02 g/cm^3. Liddicoatite, like elbaite, is uniaxial (—). The refractive indices, determined in sodium light are $\varepsilon = 1.621$, $\omega = 1.637 \pm 0.003$, with a birefringence of 0.019. The mineral has strong pleochroism with $\omega > \varepsilon$. Liddicoatite specimens examined to date do not exhibit any response to ultra-violet or x-radiation. The hardness of liddicoatite is 7-7½ (Mohs). The above refractive indices apply only to the type specimen. The refractive indices of tourmalines depend on the amount of iron, manganese and chromium in the crystal (Deer *et al.* 1962) and thus are of little use in determining the composition of gem tourmalines. In summary, liddicoatite, like uvite, cannot be

Table 1

Wet Chemical Analyses of Liddicoatite and Elbaite from Madagascar

	#135815 Brown	#136517 Pink	#136518 Green
SiO_2	37.7	37.0	37.9
Al_2O_3	37.9	37.3	39.5
TiO_2	0.38	0.01	0.05
FeO	0.83	0.05	2.25
MnO	0.27	4.58	0.67
MgO	0.11	0.02	0.03
CaO	4.21	2.15	0.45
Na_2O	0.88	1.44	2.02
Li_2O	2.48	1.82	1.83
F	1.72	1.47	1.34
B_2O_3	10.89	10.69	10.38
H_2O+	2.69	2.54	2.46
Total	100.06	99.07	98.88
O=F	0.72	0.62	0.56
Total	99.34	98.45	98.32

J. Nelen
Chemist

determined on the basis of physical or optical properties. This is somewhat frustrating inasmuch as both gem elbaite and gem liddicoatite come from Madagascar. It is with some regret that the authors must present a new gem species which cannot be differentiated from elbaite using standard gemmological techniques. At the present time, only chemical analytical methods suffice for characterization of the species. It is hoped that in the future there will be other techniques which will be available to the gemmologist for differentiation between the species.

Zoned Madagascar Liddicoatite

The Madagascar tourmalines have long been noted for their beautiful colour zoning. This zoning (Figure 1) is further notable in that it is parallel to a pyramid of the crystal instead of the more common colour zoning in tourmalines, which is parallel to the pedion or prism. One drawback of this type of zoning is that zone

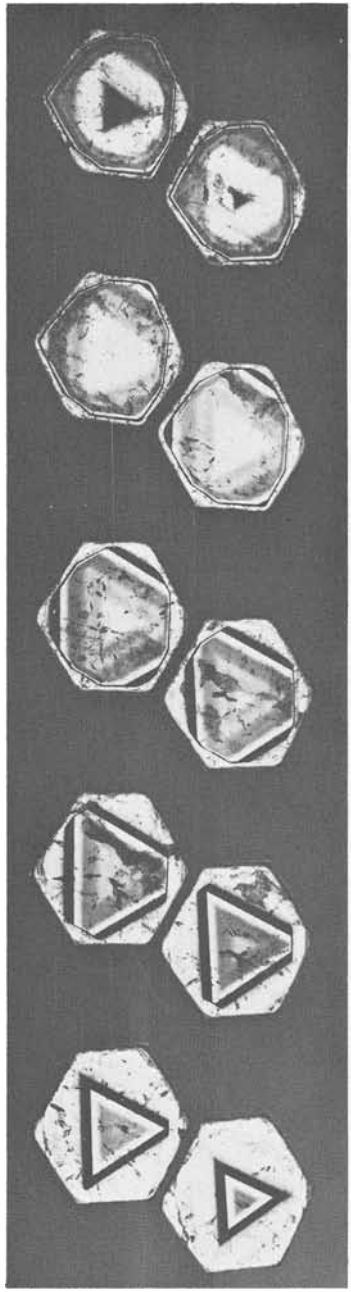

Fig. 1. Zoned Madagascar Liddicoatite sections cut parallel to the basal pinacoid.

margins appear fuzzy when a cross-section normal to the *c* axis is viewed parallel to the *c* axis. Nonetheless, the effect is quite striking and the specimens are very beautiful. A large number of such zoned sections were analysed using an electron microprobe and wet chemically analysed tourmalines as standards. The results of this analytical study indicate two points of interest.

Firstly, the sodium/calcium ratio, or one might as well state the elbaite/liddicoatite ratio, does not vary appreciably from colour zone to colour zone. Hence the crystals are usually one species throughout.

Secondly, the colour zoning is related to the amounts of iron and manganese in the respective zones. Hence, the species cannot be determined on the basis of colour. The preponderance of the analytical data suggests that most of these zoned Madagascar tourmalines are liddicoatite. Hence, it is best to call all these zoned crystals liddicoatite.

Further research on these crystals is now under way and may result in more knowledge about the nature of this beautiful tourmaline.

ACKNOWLEDGEMENT

Special thanks are due Mr Richard T. Liddicoat for permitting us to name this species in his honour and for his outstanding contributions to the great store of gem knowledge.

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NOTES ON THE OCCURRENCE AND MINERALOGY OF EMERALDS IN RHODESIA

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I INTRODUCTION

Emeralds were first discovered in Rhodesia in October, 1956, in the southern part of the Archaean Craton on the south side of the Mweza Greenstone Belt, Belingwe District, 5.2 km west-south-west of the confluence of the Nuanetsi and Sungai Rivers (Martin 1963). This material, marketed under the name 'Sandawana', is from the Zeus Claims now owned and operated by Rio Tinto (Rhodesia) Ltd. The emeralds tend to be small but have earned a world-wide reputation for their superior colour and quality. In 1958 emeralds were discovered in the Filabusi Greenstone Belt, and in 1960 emeralds were found associated with chrysoberyl in an extension of the Greenstone Belt north-west of Fort Victoria. These three greenstone belts have produced the only stones of marketable quality, and numerous claims are held in each area. Emerald occurs in other parts of the country, but the stones are of poor quality and at present are only of academic interest.

Many claims that produced emeralds are now only of historical interest whereas others are being currently investigated, but from geological evidence there is every reason to anticipate further significant discoveries. None of the abandoned or current claims have produced stones of the quality of the Zeus material.

II GENERAL GEOLOGY

Emerald, a chromiferous variety of beryl, is found in a restricted geological environment where beryllium-bearing pegmatites intrude rocks of ultramafic composition. It occurs as euhedral, pale green, hexagonal prisms in pegmatites, aplites, quartz stringers, quartz-feldspar and feldspar veins and as deep green porphyroblasts in the altered ultramafic rocks surrounding the veins. The ultramafic rocks are serpentinites or schists consisting predominantly of tremolite-actinolite, chlorite or talc derived by regional metamorphism from peridotitic intrusions and lavas believed to belong to the lower part of the Archaean Bulawayan Group.

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The beryllium-bearing pegmatites in the emerald localities are derived from the 'younger', intrusive granites dated at 2 650 m.y. (Phaup 1973). They are the Chilimanzi and Chibi adamellites in the Victoria and Belingwe Districts respectively and a small porphyritic adamellite which intrudes the southern margin of the Filabusi Greenstone Belt. The fluids produced during the pneumatolitic phase of pegmatite formation are predicted to have had temperatures of between 750 and 580°C and were intruded under pressure into the ultramafic schists causing local metasomatism.

The incorporation of chromic oxide from the ultramafic host rock into the crystallizing beryl resulted in the deep green emerald colour. Tremolite may have recrystallized during the injection phase but the most common metasomatic effect is an alteration of the ultramafic schists to phlogopite-biotite schists.

From the limited amount of observation on the emerald matrix material it can be determined that a sequence of alteration events affecting the host rock is dependent upon the chemistry of the invading fluid. If it is potassium rich the tremolite-actinolite rocks in the vicinity of the resulting veins are altered to phlogopite-biotite schists. The deposit then consists of thin pegmatite or quartz veins and lenses surrounded by black micaceous schist which grades outwards into less altered greenish-coloured ultramafic schists.

At Coen's Luck Claims (Filabusi) the potassic phase was followed by the introduction of boron, which led to the formation of zoned tourmaline prisms which grew across the foliation of the mica schists. The final phase was the introduction of beryllium-bearing fluids and the ultimate crystallization of beryl in both pegmatite and the surrounding schist. During this process the first-formed and pre-existing (protogenetic) minerals are usually included syngenetically in the beryl crystals.

Potassium metasomatism of the host rocks is well-developed in all three districts but in the Belingwe District emeralds are not confined to the phlogopite zones. Tremolite and tremolite-chlorite schists are reported to be the host rocks at the Zeus Claims (Phaup 1959, unpublished report) and at the Kanya Hlaza Claims emerald occurs in a tremolite-plagioclase rock. Potassium metasomatism was therefore not a controlling factor in the location of emeralds in these deposits although many other deposits in the district are characterized by phlogopite schist. It is possible that the fluids were soda-rich and as such have no marked metasomatic effect on the

ultramafic rocks. In the emeralds from the Belingwe District inclusions of phlogopite are rare or absent, whereas in the stones from Filabusi they are more common and from the Victoria District are abundant.

The crystallization of beryl in the schists away from the pegmatites implies that beryllium fluids were mobile and the degree of molecular migration from the fluid channels was considerable. The beryl which formed within the pegmatite or quartz veins may be a very pale emerald green and only the porphyroblasts enclosed by the phlogopite schist (or tremolite schist in the case of the Zeus Claims) have the deep green emerald colour and are potentially of gem quality.

III INCLUSIONS

The study of emerald inclusions is in its infancy, but it can be demonstrated that every stone is unique in the form and content of its inclusions. Mineral inclusions are similar in emeralds originating from the same geological province but are different from those in deposits from other areas. The identification of mineral inclusions, their form and abundance, considered in conjunction with optical constants, which vary from area to area, forms the basis for the distinction of one emerald province from another.

The most important occurrences of emerald in Rhodesia originate from the Mweza, Victoria and Filabusi Greenstone Belts and material examined from these areas is listed as follows:-

Mweza Greenstone Belt (Belingwe District)—Zeus (Sandawana); Kanya Hlaza and Athens; Maharani and Vidan Claims.

Victoria Greenstone Belt—Novello; Twin Star; Chikwanda; Popoteke; Mayfield and Renders Claims.

Filabusi Greenstone Belt—Flame Lily; Mustard and Coen's Luck Claims.

For comparative purposes the properties of emerald beryl of academic interest only from the I Wonder Claims (Karoi), Makanga Claims (Salisbury), Sabtri Claims (Buhera) and Mush Claims (Soti Source) are included.

The classification of the inclusions in emeralds is a genetic one and is based on that used by Gübelin (1974). Three classes of inclusions are recognized: protogenetic, syngenetic and epigenetic. Protogenetic inclusions are all pre-existing minerals that were

included in the emerald during crystallization. Syngenetic inclusions are predominantly liquid which is contained in cavities (vacuoles) that form during, or after, the growth of the emerald. Other syngenetic features are colour zoning and the crystallographic control of the inclusions of protogenetic minerals. Epigenetic features, which include twinning and exsolution phenomena, are of no significance in Rhodesian emeralds.

PROTOGENETIC INCLUSIONS

These are all mineral inclusions and they may be further subdivided into (a) minerals formed by earlier regional metamorphism unrelated to the introduction of beryllium fluids, (b) minerals formed during metasomatism immediately prior to the crystallization of beryl.

Although some recrystallization of tremolite is postulated (Phaup 1959, unpublished report) the majority of the tremolite-actinolite was probably formed by regional metamorphism of the ultramafic rocks prior to the introduction of the beryl. These amphiboles are the most common protogenetic inclusion and exist as bundles of acicular and columnar crystals within the emerald porphyroblasts in all the material examined from the Belingwe and Filabusi provinces. It is therefore not a diagnostic mineral inclusion of Sandawana material as suggested in published reports of that material (Gübelin 1956). Colourless micas, chlorite and talc are also likely to belong to an earlier phase of regional metamorphism.

Phlogopite and biotite micas are the most common inclusions of minerals formed during the metasomatic alteration immediately before the introduction of beryl. They are therefore regarded as being related genetically to the same phase of events that introduced the beryl into the ultramafic rocks. The micas occur as ragged and corroded platelets and usually show a random distribution within the emerald. They are a common feature of Victoria emeralds, are less common in the Filabusi emeralds and occur only rarely in the Belingwe material (Kanya Hlaza and Vidan only). Rare euhedral booklets of mica occur in the emerald from Kanya Hlaza. Apart from the metasomatic development of the mica, the following minerals are considered to be related to this generation of protogenetic inclusions:- garnet (Zeus), haematite and other iron oxide minerals (Zeus, Mustard, Kanya Hlaza), plagioclase euhedra (Zeus, Vidan, Kanya Hlaza), tourmaline (Coen's Luck, Mustard), and rutile (Coen's Luck, Mustard, Zeus, and Kanya Hlaza).

SYNGENETIC INCLUSIONS

Syngenetic features are those that occurred during the crystallization of the beryl and are predominantly liquid in nature. The liquid is contained in vacuoles of varying shape and size that formed at different stages of the crystal's growth. The liquid inclusions may be further subdivided into primary and secondary inclusions depending upon the age of the containing cavity. The incorporation of protogenetic minerals into the crystal is a syngenetic feature and occasionally there is some crystallographic control, although more frequently the protogenetic minerals show a random habit within the host crystal. Colour zoning, a rare feature in Rhodesian emerald, was observed in the Mayfield, Zeus and Kanya Hlaza material. Pale and deep-green zones, forming alternating bands parallel to the hexagonal prism faces, imply fluctuations in the availability of the colouring pigment, chromic oxide.

Primary Syngenetic Cavities

'Fissuring' is the development of tubular cavities, also termed 'negative crystals', parallel to the principal crystallographic axis (C), giving the crystals a striated appearance. This feature is also common in the aquamarine variety of beryl. During the development of the crystals, there were fluctuations in the supply of the requisite molecules to the growing crystal faces, and in place of a planar surface being formed, a skeletal face with subtraction structure faults develops. These growth tubules remain as cavities and enclose a liquid (primary liquid inclusions) from which a gaseous phase may separate out and remain as a gas libella within the tubule, producing what is termed a two-phase inclusion. The tubules sometimes run the entire length of a crystal and may therefore be several millimetres long. They are of primary origin and are a feature of most Rhodesian emeralds particularly those from Mustard and Novello Claims.

Cavities with square or rectangular outline, are also a common feature in Rhodesian emeralds and are regarded as having the same origin as the tubules. They are crystallographically controlled and are smaller in dimensions than the tubules, being of the order of 20-30 μm in length. The longest cavity measured was 40 μm, containing a gas libella of 25 μm diameter.

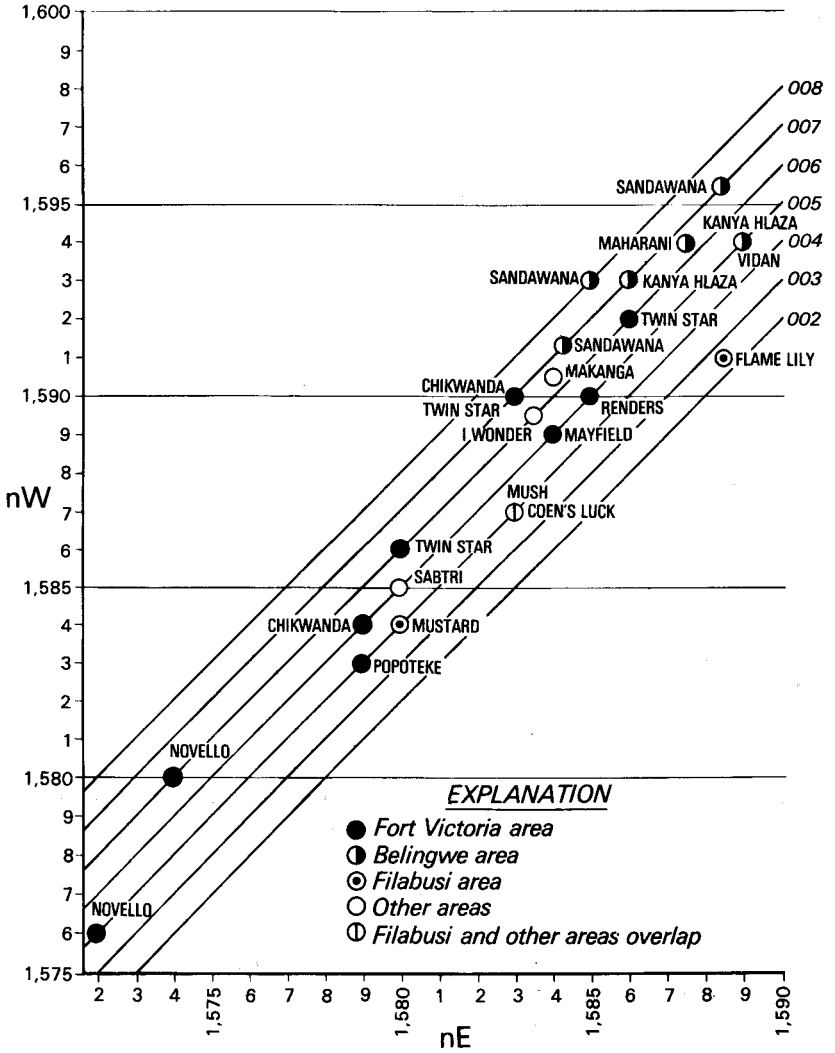

Fig. 1 *REFRACTIVE INDICES OF RHODESIAN EMERALDS*

Secondary Syngenetic Cavities

'Healing fissures', 'feathers' and 'peppering' are features usually showing little or no crystallographic control in their development. During the growth of the host crystal flaws develop where tensions exist: in some emeralds there is a tendency for these flaws to develop parallel to the basal plane (0001), but generally they exist as twisted and random planes. Coupled with the formation of the flaws is the healing process whereby the flaw is bathed in the mother-fluid by capillarity some time after its development. The flaw becomes partially healed, the crystal continues to grow, but some residual fluid remains trapped in the crack and manifests itself in a variety of forms producing (a) 'feathers'—fimbricated liquid droplets, (b) 'healed fissures'—lacey and fan-like liquid patterns, (c) 'peppering'—droplets of ultramicroscopic dimensions showing rounded or tadpole-like forms usually containing a gas libella. The size of the 'peppering' cavities is very small, 20μm and less, and in their aggregated habit they give an impression of dust. They are regarded as the most advanced state of the healing of the flaws whereby the smallest amount of residual liquid remains in the form of isolated droplets. All emeralds so far examined from Rhodesia contain liquid inclusions, and 'peppering' is common to all. The intermediate healing stage is represented by the feathers or fingerprint variety, and where minimum healing has occurred the healed fissure structure is formed. Healed fissures were observed in emeralds from Zeus, Kanya Hlaza, Chikwanda, Popoteke and Flame Lily Claims. 'Peppering' is observed around garnet inclusions in the Zeus emerald, and it is suggested that the inclusion resulted in crystal tension and the formation of a flaw, that was later partially healed.

IV Optical Properties

Table 1 shows the optical constants of the emeralds examined and a description of their inclusions. The refractive indices were determined by oil immersion techniques, utilizing sodium light and the readings were made on a Leitz-Jelley refractometer.

The optical constants are plotted graphically in Fig. 1, and it may be seen that material originating from the Belingwe province has the highest optical constants of all the emeralds examined.

TABLE 1

REFRACTIVE INDICES AND CHARACTERISTICS OF RHODESIAN EMERALDS

Province	Claim	nE	nW	DR	Inclusions
Victoria	Novello	1.572	1.576	0.004	'Peppering'—dense aggregations of minute cavities (5-8μm), some of which contain a gas libella. Brown mica platelets. Polygonal, square and rectangular cavities with two-phase inclusions arranged in trails. Fine negative crystals (tubules). SG 2.71-2.74 (Martin 1963).
Victoria	Novello	1.574	1.580	0.006	As above.
Filabusi	Mustard	1.580	1.584	0.004	Mineral inclusions:- muscovite and phlogopite platelets plentiful. Rutile and profuse peppering of an opaque, euhedral mineral. Rare acicular mineral—possibly amphibole, appears to be hollow, unlike the amphibole from Belingwe material. Tourmaline occurs very rarely. Ilmenite platelets.
Victoria	Popoteke	1.579	1.583	0.004	Typical Fort Victoria material—'peppering'—profuse in planes and trails. Parallel 'fissuring' and at right angles—liquid fingerprints. Larger tabular and irregular liquid-filled cavities—some with gas libellae.
Victoria	Chikwanda	1.579	1.584	0.005	'Peppering' by minute liquid inclusions as in Novello material. Fan-shaped healed fissures. Ragged colourless mica. (Martin 1963).
Buhera	Sabtri	1.580	1.585	0.005	Material not of gem quality. Phlogopite platelets common. 'Peppering' by liquid droplets. The peppering is crystallographically controlled—more or less parallel to (0001). Healed fissures.
Soti Source	Mush	1.583	1.587	0.004	'Peppering' and tubular negative crystals parallel to the prismatic faces. Colour zoning evident. Fort Victoria characteristics. No mineral inclusions noted. The material is not of gem quality.
Filabusi	Coen's Luck	1.583	1.587	0.004	'Peppering' and 'feathers' with two-phase inclusions. Amphibole is common as an inclusion; unlike the material from Mustard. Some amphibole is curved and acicular in form. Rare colourless mica. No euhedral opaque material that is found in the Mustard stones. Tourmaline occurs in matrix but rarely as an inclusion. Phlogopite inclusions are common.
Karoi	I Wonder	1.5835	1.5895	0.006	Prominent two-phase inclusions (20-30μm) each cavity containing a gas libella. The cavities are usually square or rectangular in outline and they are arranged in trails-reminiscent of Nihame (Mozambique) material. No gem quality material.
Victoria	Chikwanda	1.583	1.590	0.007	As for above Chikwanda.
Victoria	Mayfield	1.584	1.589	0.005	'Peppering'. Larger two-phase inclusions with irregular (tadpole-shaped) and polygonal forms. Rare brown mica platelets. Rare needle-like mineral not identified. Healed cracks and fan-shaped liquid inclusions. Colour zoning.
Belingwe	Sandawana	1.5843	1.5913	0.007	Acicular tremolite in dense bundles and masses, sometimes curved. It is finer in form than the Habachtal (Austria) material. Other mineral inclusions are:- limonitized garnet, haematite tablets, rutile, decomposed feldspar and magnetite. Parallel pattern of 'shadows' caused by 'fissure' system parallel to (0001). Two-phase inclusions with geometrical form are present and tabular negative crystals. 'Peppering' is present. 'Resorbed garnet'—clusters of opaque material and liquid droplets around the garnet. SG 2.7436. (Gübelin 1958).
Shamva	Makanga	1.584	1.5905	0.007	No gem quality material. 'Peppering'; the cavities are rounded or irregular in form.
Victoria	Renders	1.585	1.590	0.005	'Peppering' very conspicuous. No mineral inclusions seen. No gem quality material.

Victoria	**Twin Star**	1.586	1.592	0.006	'Peppering' and 'fissuring'. Opaque rounded platelets. Colourless mica inclusions.
Belingwe	**Kanya Hlaza**	1.586	1.593	0.007	Myriads of tremolite needles, very characteristic, somewhat broad and blade-like although some are hair-like. 'Peppering' roughly parallel to (0001). Lacey, healed fissures. Fine 'fissuring'. Phlogopite platelets in some material, often with lozenge form. Feldspar euhedra common in samples containing mica. Rare rutile euhedra.
Belingwe	**Maharani**	1.5875	1.5940	0.006	Very prominent amphibole inclusions, as with all Belingwe material. Variable in size up to 0.53 mm in length and 0.09 mm wide, often opaque material is present within the amphibole. Patches of liquid droplets, some of which are two-phase-'peppering'. No other mineral inclusions were seen other than the amphibole.
Belingwe	**Sandawana**	1.5884	1.5955	0.007	As for above Sandawana.
Filabusi	**Flame-Lily**	1.5885	1.5910	0.004	Amphibole needles are fairly common, the form varies from acicular to stumpy. Phlogopite present in some material. The amphibole is usually fairly densely aggregated. Two-phase inclusions in rectangular and square outline cavities arranged in planar manner. Feathers of liquid inclusions. Iron-stained, healed fissures. Anhedral opaque material.
Belingwe	**Vidan**	1.589	1.594	0.005	To the author's knowledge, no material has been cut from these claims. The colour and inclusions are typical of Belingwe material. 'Peppering'. Tremolite needles are common and phlogopite platelets were noted but are rare. Iron-stained healed fissures. Rare feldspar euhedra were noted.

V CONCLUSIONS

From this preliminary examination of emeralds from Rhodesia, although only a limited amount of material was available for comparative purposes, it is considered that a basis does exist for identifying the stones from a particular geological province. Local variations in optical constants and mineral inclusions are not considered valid for distinctions to be made about individual deposits within the geological province.

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COPPER BEARING AVENTURINE ZEOLITE: AN OCCURRENCE IN INDIA

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In 1969 Mr M. G. Brahmbhatt, then Assistant Geologist, reported a native copper occurrence near Jalampura (23°22′47″N: 73°9′30″E) and reported as under:

'Copper occurs as native copper near Jalampura village. In a well section about 0.5km N. 60° of Jalampura village the presence of native copper is noticed in excavated material. Between two different lava flows there is a loose formation in which such mineralization is observed at a depth of about 18 metres (approximately).'

The present author visited the area and found that the native copper occurrence occurring at the above area has the significance that, for the first time in India, cuttable transparent zeolite with native copper inclusions is reported. Similar occurrences are also rare; perhaps as a spangled gem this may be a unique occurrence. Some of the zeolites which contained more copper inclusions and showed a spangled appearance were cut as cabochons. A spangled effect similar to aventurine structure was noticed in them.

Zeolite crystals occur as cavity fillings and veins in loose intraformational pyroclastic material. Thin blebs and wires of native copper are found in fully transparent to somewhat fractured whitish crystals of analcime associated with above rocks. Brahmbhatt states that copper mineralization evolved during the time of crystallization and native copper occurs as hydrothermal and metasomatic deposits filling cracks, fractures, and as replacement in basic flows.

The transparent oily-looking zeolite posed identification problems. Earlier the mineral was presumed to be a variety of quartz (cristobalite). Later on work at the Institute of Geological Sciences in London by E. A. Jobbins showed that the enclosing material has RI≈1.487 with some grains showing anomalous birefringence of the order of 0.001, and he reported that it was analcime. Further work on samples in India showed that the almost

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copper-free transparent host mineral has the following chemical composition and has given the following x-ray data:

Chemical Composition (Host Mineral)		*X-ray Data Host Mineral*		
		Peaks in order of their intensity d values in Å	Intensity	Remarks
SiO_2 -	54.52			
Fe_2O_3 -	0.55	1. 3.42	8.3	Sharp peak
AL_2O_3-	22.25	2. 5.60	5.1	,,
TiO_2 -	0.15	3. 2.91	4.1	,,
CaO -	2.67	4. 9.8	2.6	diffused composite peaks at less than 9.8
MgO -	0.25	5. 1.74	1.35	Sharp peak
L.O.I. -	8.04	6. 2.68	1.38	,,
Na_2O -	10.96	7. 4.82	1.2	,,
K_2O -	0.06	8. 1.901	1.15	,,
Cu -	0.81			
Total -	100.26			

(Analyst: Mr H. K. Navadia under guidance of Mr V. G. Malkan)

Thus the copper-bearing mineral is Analcime.

DISCUSSION ON THE WORD 'AVENTURINE'

A discussion on whether to call these stones 'aventurine zeolite (analcime)' is perhaps necessary. Herbert Smith (1958) indicates that aventurine structure is reminiscent of a glass containing copper crystals. While describing the aventurine structure in quartz he states that when the included substance consists of mica, haematite or other flaky mineral the result is a vivid spangled appearance.

In the market it is freely available as an artificially created

stone of glass in which copper filings appear to have been added.* Natural aventurine quartz and feldspars are encountered frequently. The vivid spangled appearence is often caused by haematite or mica.

Possibly the term aventurine is restricted to these two minerals only (Ostwald 1955). Sinkankas (1959) however gives aventurine willemite occurrence in U.S.A. and uses the term aventurescence in the same sense, defining the term as 'Reflections of light from numerous small wafer-like inclusions of foreign minerals within a host gemstone, which act like tiny mirrors and give rise to the effect known as aventurescence, and such stones are called aventurines. The minute brilliant spangles are usually exceedingly thin crystals of haematite, goethite, or mica.'‡

In the present sample the spangled effect is evident in the samples which are rich in copper. The effect is mainly caused by flat sided 'veinlets' of copper acting in a manner similar to flakes: less commonly reflections by flakes are also noticed. The present author and Mr Sinkankas prefer the term 'aventurine zeolite' for the above gem. Hence the term aventurine is used realizing that this sample may not be termed as aventurine *in sensu stricto.* The reason for use of the term is the spangled effect seen in the sample.

OTHER OCCURRENCES

Looking for similar occurrences, we find that

(1) Native copper occurrences have been reported from Keweenaw peninsula in North Michigan and also at White Pine, Michigan (Lake Superior), Arizona, and New Mexico in the U.S.A., Chile, Bolivia, Mexico, etc.

(2) Pinkish prehnite, pink colour being imparted by finely disseminated blebs of native copper, has been reported by Surdam (1968) from Vancouver Island. Stoiber and Davidson also reported a similar occurrence in the Michigan copper district.

(3) Recently in the peninsula of Saurashtra, Gujarat State, India, the Directorate of Geology and Mining has reported native copper occurrences at villages:

*The copper inclusions are usually produced by reduction in the glass-making process.

‡Dr Joel Arem in his *Encyclopedia of Gemstones* (Van Nostrand, 1977) refers to 'aventurescence' as 'sparkly effect due to reflection off parallel included flakes'.

(i) Raipur 21°25′48″N: 70°26′0″E

(ii) Isharpur 21°30′10″N: 70°33′0″E and

(iii) Choklu 21°36′25″N: 70°32′05″E

all in Junagadh district. The available information on these occurrences shows that they are all similar and the common factors are as follows:

(a) The occurrence of copper is confined to a depth of approximately 50′-60′ beneath the surface. These have been confined from the debris of well cuttings in the area.

(b) The occurrence is associated with compact, grey, amygdaloidal, highly weathered basalt.

At the occurrence near Raipur small disseminations of the native copper in infillings of zeolites can be seen. (The author wishes to take up work on these at an early date).

(4) Roy (1953 a and b) states that a native copper occurrence near Mojdam contains copper infillings in minor calcite veins and infillings of various types of zeolites. It is noted that so far fully transparent cuttable material has not been reported. (Sinkankas, personal communication).

CONCLUSIONS

For the first time in India, a copper-bearing zeolite is cut as a gem which resembles aventurine in structure. If fully transparent zeolites are encountered with sizable native copper they can be cut as cabochons resembling 'goldstone' (artifically created stone of glass with included copper). Other possible occurrences in India and U.S.A. are also pointed out. The author has noticed that samples having more copper are more pleasing and give a spangled appearance similar to aventurescence.

ACKNOWLEDGMENTS

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It is a pleasure to acknowledge the generous assistance received from Shri K. S. Patel and Shri B. K. Jhaveri for general help during the work.

Thanks are also due to Mr E. A. Jobbins, of the Institute of Geological Sciences, London, and Mr John Sinkankas, of U.S.A., for correct identification and discussion of the paper.

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[*Manuscript received 15th April, 1977.*]

A VISIT TO SRI LANKA, TAIWAN AND THAILAND

By K. W. FINDLAY, B.Sc(Eng.), C.Eng., F.I.Chem.E., F.I.Mech.E., F.G.A.

Some three thousand years ago the Queen of Sheba is alleged to have been adorned with jewels from Sri Lanka given to her by King Solomon when his trading ships returned from the East. Later Ptolemy, twenty-one centuries ago, mentions beryl, sapphires and gold from that island, and Marco Polo (thirteenth century A.D.) describes a fantastic ruby possessed by the King of Sri Lanka.

There seems no doubt that Sri Lanka, (previously Ceylon, formerly Taprobane and also Serendip) has been a source of some of the finest gems for three thousand years, and today it is still a source of an enormous variety — andalusite, beryl (aquamarine), chrysoberyl (alexandrite and cymophane), cordierite, corundum (ruby and sapphire), feldspar (moonstone), garnet (almandine, hessonite and pyrope), kornerupine, quartz (amethyst and cat's-eye), sinhalite, spinel, topaz, tourmaline, zircon.

It would appear that the method of recovery has changed little over the millenia. There are three types of gem-bearing alluvial deposits or 'illam'—those in which the gems occur in relatively shallow soils, those in river course gravels and those in the lower gravels lying on bed rock. Pits or shafts up to 30m deep are sunk to the gem-bearing layers and these are excavated by a type of hoe and hoisted to a surface dump in a wicker basket by using a windlass. The mining and hoisting are done in the morning and after lunch the same team carries out the washing, concentration and sorting. Using the hoe, batches from the dump are scraped into a hemispherical basket, which is handed to the washers who stand waist deep in muddy water, contained in a trench. The basket is given a rotary and jigging motion so that the higher specific gravity minerals settle to the bottom of the basket, whilst the lighter gangue can be flicked over the edge of the basket into a waste dump. When the concentrating process has eliminated a large proportion of waste the basket is taken out of the water and the contents raked over by hand to pick out the potential gem material, by a sorter with an experienced and uncanny eye. One of the few

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Fig. 1. Washing gem gravel, Sri Lanka.

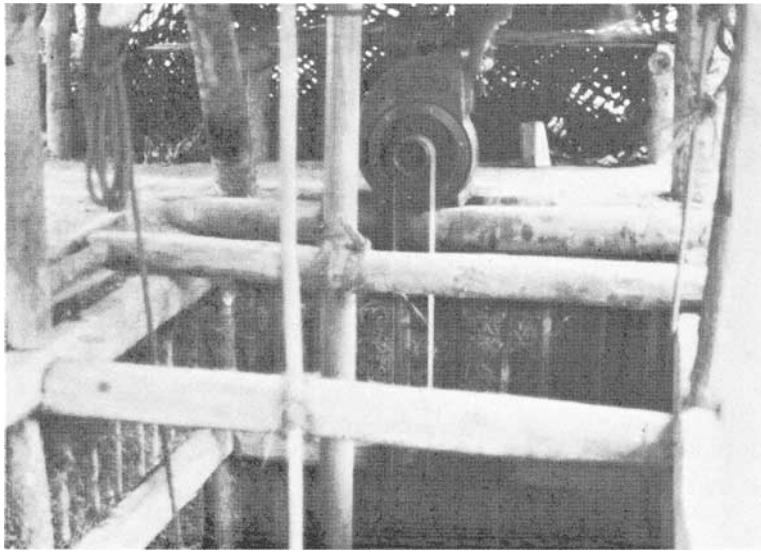

Fig. 2. Pit head, Rakwan river area, Sri Lanka. Lister engine for driving pump.

Fig. 3. Ancient method of polishing, Sri Lanka.

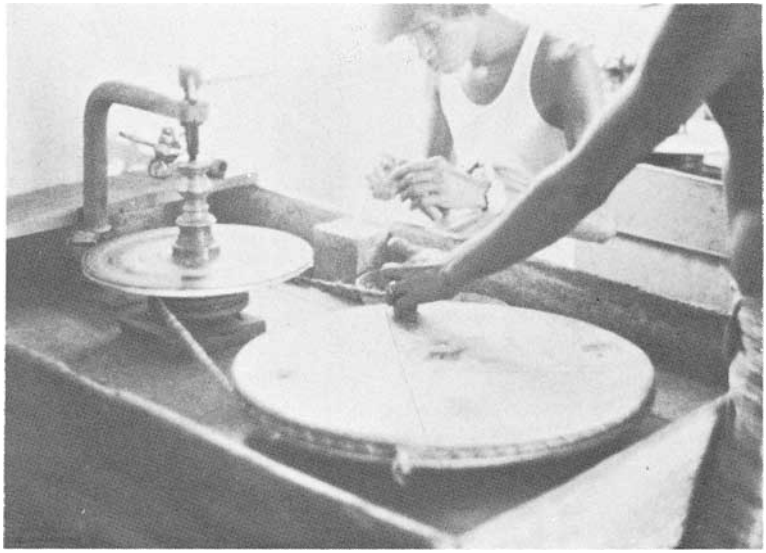

Fig. 4. Polishing lap, Sri Lanka.

modern improvements is the dewatering system. Today a centrifugal pump, driven by a petrol or diesel engine, is used.

Some gems are still polished by ancient methods—the stone being held in the left hand against a leather pad mounted on an oscillatory-rotating wooden disc, attached to one end of a horizontal shaft over which an affixed concentric wooden cylinder is rotated by a bowstring reciprocated by the right hand. An improvement used today is a vertical spindle lap hand-powered by an assistant.

All gem lands are under control of the State and leases are awarded by the tender system. The lessee pays the lease fee, and provides all the equipment and the consumable stores and takes half the proceeds of sale of rough gems as his share, whilst the team of workers who provide the labour divide the other half amongst themselves. Restrictions do not allow for the export of any rough stone which could be faceted and be of commercial value. Certain mineral specimens for study purposes or collectors' items may be granted an export clearance.

Buddhism is almost universal in Thailand whereas only two thirds of Sri Lankans are adherents. In Bangkok, Thailand, there are two images of Buddha which are rather outstanding.

One called the Emerald Buddha has been described as being 61 cm high of translucent green jasper, but another more comprehensive and probably more reliable description is that it has a lap width of 48.3 cm and its height from the base to the top of its head is 66 cm and the crystal belongs to the monoclinic system in the pyroxene group, its hardness is between 6.5 and 6.7 and its specific gravity is between 3.33 and 3.35.* That is the strongest indication that it is Jadeite.

Then there is the Gold Buddha which is reputed to have a mass of 5000 kg of pure gold. This statue is some 2.44 m high and about 1 m across the lap. The remarkable aspect is that it is housed in a very small temple just off the road and is unguarded: the value at the present gold price would be nearly 22 million U.S. dollars.

Taiwan Jade, which is really nephrite, is becoming an increasingly important minor industry. Carvings, figurines, statuettes, bead necklaces and bangles are all processed in small factories, some adapted from residential flats which are still used

*Printed on the back of a picture-postcard of the Emerald Buddha, in winter attire, sold at the Grand Palace, in the grounds of which the Wat (temple) Phra Keo is located.

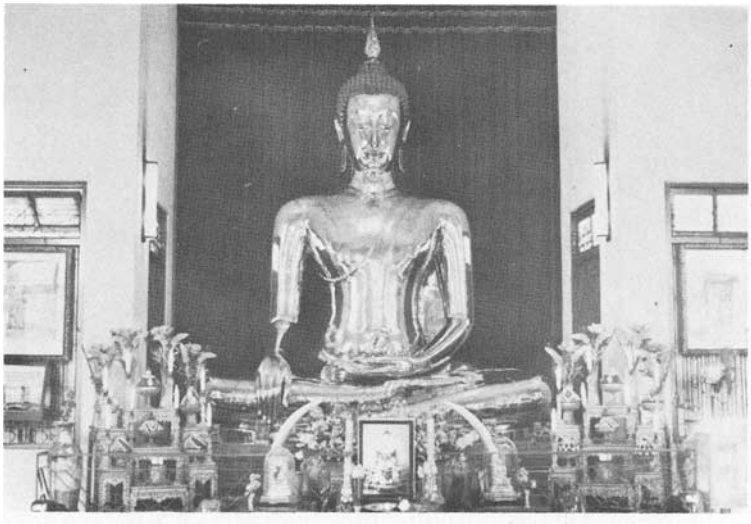

Fig. 5. Gold Buddha, Wat trimit, Bangkok.

for sleeping as noted by the beds in cubicles or against a wall. Large slabbing is carried out on a circular saw in a lean-to shelter, while the finer cuts are made indoors. Cabochon grinding and carving is done by small groups in very low-intensity artificial illumination, using the old type of cord-driven dentist's drill. Modern electric vibro-polishers are in use, and, although still a cottage-type industry, there is considerable technical progress.

The Taiwan coral industry has been long established, since they have considerable reefs of coral along the shore. Because the pink coral is sparse and more beautiful than the white, the white variety is stained pink. No amount of enquiring could elucidate the nature and ingredient of the dying process, even from I.C.I. (China) Ltd's Taipei branch, who carry large stocks of dyes for the textile industry. The coral processing units appear well illuminated and equipped with modern machines. Many females are employed, particularly in drilling and stringing the beads.

Silver-smithing both at Kandy in Sri Lanka and Chiang Mai in Thailand is aimed at tourist merchandise, and naturally the rice-bowls, platters etc. are embossed in oriental designs. Being unable to purchase silver sheet, bar or wire and not having rolls, they have to hammer ingots into sheet or bar from which they raise the hollow-ware or flatware. Embossing is carried out on all items and

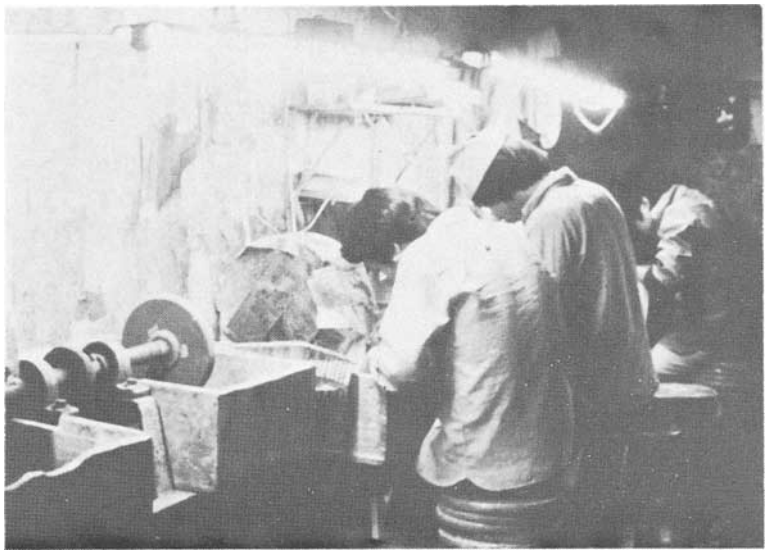

Fig. 6. Polishing nephrite, Taipei, Taiwan.

Fig. 7. Assembling nephrite necklace, Taipei, Taiwan.

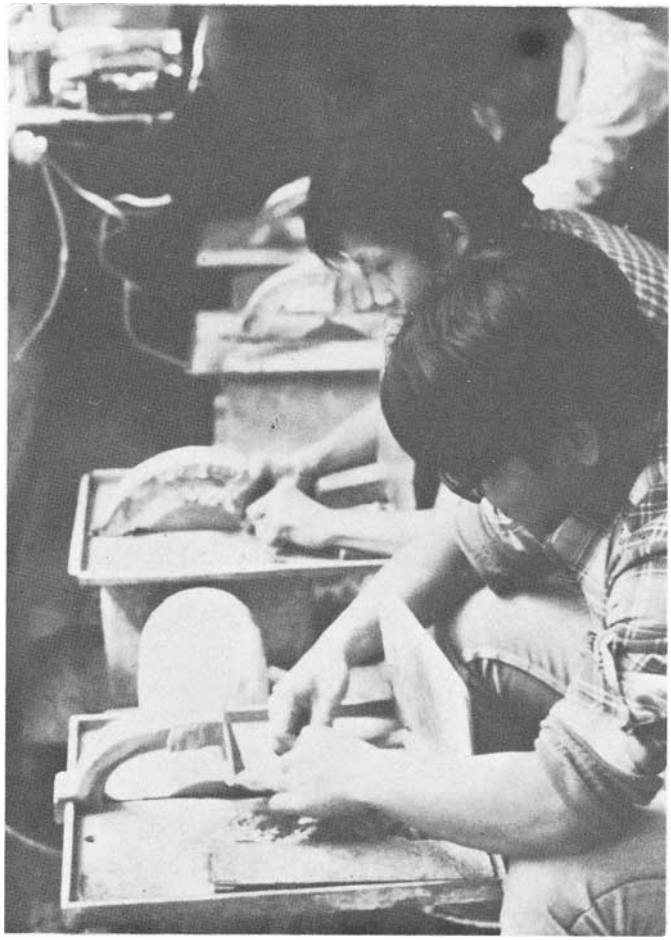

Fig. 8. Cutting coral, Taipei, Taiwan.

no polishing. Hall-marking is unknown—the name Thai Silver is supposed to be enough. The starting material is thought to be silver coins from India, but many details of the craft are held secret.

As usual a first trip is too short to delve into all the mysteries of the East, so a second visit is desired to seek the answers.

[*Manuscript received 15th February, 1977.*]

GEMMOLOGICAL ABSTRACTS

ALEKSEYEVKIY (K. M.), NIKOLAYEVA (T. T.). (New data on the possible primary sources of Timan diamonds.) Doklady Acad. Sci. USSR (Earth Science Section), **204**, 925-6, 1972.

Kimberlite is indicated from the northern Timans by the presence of pyrope which in the circumstances most favourable for diamond occurrence are coloured lilac and green. Orange and red pyropes are not thought to be indicators of possible diamond occurrence. M.O'D.

ANDERSON (B. W.). See *Diamond Lectures* below (p. 210).

ANDRYCHUK (D.). *On the light dispersion by faceted YAG gemstone.* Lapidary Journal, **31**, 8, 1850-6, 1977.

Shows mathematically that dispersion can be enhanced to some extent by the lapidary, but that it also depends upon the physical nature of the material. M.O'D.

ASSCHER (E.). See *Diamond Lectures* below (p. 210).

BAGSHAW (A. N.). *Diverse structures based on the Fd3m space group.* Zeitschrift für Kristallographie, **144**, 53-63, 7 figs, 1976.

Examines 19 types of structure, including those of diamond, spinel, fluorite and cuprite. M.O'D.

BANCROFT (P.). *A new 'Lady' is born.* Lapidary Journal, **31**, 8, 1702-4, 8 figs, 3 colour plates, 1977.

Describes the cutting of the world's largest faceted gemstone, a Brazilian topaz of 21327 ct. The colour is light blue. M.O'D.

BANK (H.). *Durchsichtige, schleifwürdige, Hell-gelb-braune Enstatite aus Tansania.* (Transparent cuttable light yellow to brown enstatites from Tanzania.) Z. Dt. Gemmol. Ges., **26**, 4, 206, 1977.

The new material was found amongst some scapolites, mainly because of its definite cleavage. It was shown to be enstatite, very clear, cuttable, but difficult to cut because of strong cleavage. E.S.

BANK (H.). *Durchsichtiger, schleifwürdiger Hauyn aus der Eifel.* (Transparent, cuttable Hauynite from the Eifel.) Z. Dt. Gemmol. Ges., **26**, 4, 207, 1977.

Hauynite is found in Italy and the Eifel, a district west of the Moselle—the piece described was found by the author in a basalt quarry. E.S.

BANK (H.), MAES (J.). *Blau-rot und blaugrün-rot changierende Granate aus Ostafrika und Ceylon (I).* (Blue to red and blue-green to red colour changing garnets from East Africa and Sri Lanka. Pt. 1.) Börsenbulletin, Idar Oberstein, **12**, 1977.

To be continued in next issue. This introductory article deals mainly with the

alexandrite-garnet described by Crowningshield in 1970, giving chemical analysis, and a similar garnet described in 1975 by Jobbins giving details of absorption spectra. E.S.

BANK (H.), OKRUSCH (M.). *Über die Entstehung von Rubin und seine Vorkommen.* (On the genesis and origin of rubies.) Börsenbulletin, Idar Oberstein, **12**, 57-9, 8 illus., 1977.

Article in German and English giving a short explanation of the genesis of rubies and shortly describing various occurrences, such as Burma, Siam, Afghanistan, Campolungo, Ceylon, Pakistan, Kenya and Tanzania, mainly the Ngorongoro crater and the Umba valley in Tanzania and the Tsavo National Park in Kenya. E.S.

BANK (H.), SCHMETZER (K.), POUGH (F.). *Blauer durchsichtiger Dumortierit aus Brasilien.* (Blue transparent dumortierite from Brazil.) Z. Dt. Gemmol. Ges., **26**, 4, 205, 1977.

The authors compare the blue orthorhombic dumortierite from Brazil with a brown crystal from Ceylon, the data for pleochroism, RI, DR and optimum angle of axes being different for each variety. E.S.

BARINSKY (R. L.), KULIKOVA (I. M.). *Metamict transformations in some niobates and zircons according to x-ray absorption spectra.* Physics and Chemistry of Minerals, **1**, 325-33, 4 figs, 1977.

It is concluded that the nature of the first coordination sphere changes in zircons (though not in niobates) during metamict decay. Difference in decay processes is probably due to different types of chemical bonds between oxygen and niobium and oxygen and zirconium atoms. In niobates directional covalent bonds are formed between niobium (an anion) and oxygen which do not disintegrate during decay; zirconium, a cation in zircon, forms mainly ionic bonds with oxygen, which do disintegrate. M.O'D.

BEDNORZ (J. G.), SCHEEL (H. J.). *Flame-fusion growth of $SrTiO_3$.* Journal of Crystal Growth, **41**, 5-12, 1977.

Exact growth conditions for the production of optical quality crystals are discussed. Overflow problems previously encountered when the crystal had reached a certain size can be adjusted by controlling the $SrCO_3$ excess in the starting powder. M.O'D.

BLOCKLEY (J. G.). *The Ord Range tiger-eye deposits.* Geol. Surv. Western Australia Ann. Rept for 1975, 108-12, 3 figs, 1976.

Attractive tiger-eye opal formed from crocidolite and set in red, brown and black jaspilite is mined from Archaean iron formation in the Ord Range near Mt Goldsworthy. The deposits appear to be the only recorded occurrences of crocidolite in Archaean iron formation. J.D.L.

BLOUNT (A.), SHULMAN (W.). *Twinning in minerals.* Mineralogical Record, **8**, 5, 350-61, 1977.

Reviews the phenomenon of twinning by crystal system, with illustrations. M.O'D.

BORNMANN (S.), HERGT (R.). *Präparation und Charakterisierung von Granatkristalloberflächen.* (Preparation of single crystal garnet substrates.) Kristall

und Technik, **12**, 1, 47-57, 15 figs, 1977.

Describes the growth of gadolinium gallium garnet as a substrate and its nature as a brittle material. Polishing with iron oxide and diamond are investigated as is damage evidence to which x-ray topographic, double crystal spectrometry and selective etching techniques are applied. M.O'D.

BOSCARDIN (M.), MOSELE (G.). *Zircone del Vicentino.* (Zircon from Vicentino.) La Gemmologia, **3**, 2, 13-17, 2 figs, 1977.

The locality described is referred to Tav.top.IGM 1:25000,F°37,III SO Thiene, III NO Caltrano (grid references to the Italian geological survey). Typical crystal forms are illustrated. Corundum, colourless beryl, spinel, topaz and olivine are also found in the area. M.O'D.

BOSSHART (G.). *Kubisch stabilisierte Zirkonoxide.* (Cubic stabilized zircon oxides). Z. Dt. Gemmol. Ges., **26**, 4, 210-20. 3 tables, 1 graph, bibl., 1977.

Cubic stabilized zircon oxides are one of the newer diamond imitations with high refractive index and of medium price range. The author deals with the crystallization method which is a type of 'melt method' and describes physical properties such as inclusions, scratch hardness and wear resistance, absorption, chemical and crystal structure. Hints are given on recognizing this material even if set in rings. The polish of the examined stones did not come up to the polish of a diamond, and the author suggests that the pavilion angles and the width of the girdle should be decreased. It seems likely that in the future zircon oxides with other stabilizers than Y_2O_3 and CaO will come on the market, thus increasing the diamond imitation varieties. E.S.

CANNON (M. C.). *Diamond discovered along Colorado-Wyoming border.* Lapidary Journal, **31**, 5, 1220-4, 1977.

A kimberlite pipe with diamonds has been located on the Colorado-Wyoming border. The largest crystal so far recovered measures 1.0 mm by 1.5 mm. M.O'D.

CASSEDANNE (J.-P.), (J.-O.). *Les améthystes d'Irai.* (Amethyst from Irai.) Revue de Gemmologie, **53**, 12-15, 10 figs, 2 colour plates, 1977.

Describes a location for amethyst in the state of Rio Grande do Sul, Brazil. Irai lies north-west of Porto Alegre and south-west of São Paulo, close to the Uruguayan border. Amethyst occurs in a mineralized basalt and is recovered as geodes. M.O'D.

CASSEDANNE (J.-P.), (J.-O.). *Axinite, hydromagnesite, amethyst and other minerals from near Vitória de Conquista (Brazil).* Mineralogical Record, **8**, 5, 382-7, 1977.

The area described is in southern Bahia, the geology consisting of a gneissic basement rock with mica schists and quartzites, amphibolic lenses and pegmatitic and ultrabasic intrusions. Axinite is recovered from an amphibolitic zone lying on quartzite. Crystals are usually found as flat aggregates on a hornblende matrix; some parts are of gem quality. The colour is chestnut with a tinge of light purple; specific gravity is 3.26, hardness 6.5, refractive indices 1.676, 1.684, 1.687, with a birefringence of 0.011. Emerald, of poor quality, is found in the area at Açude Socêgo, north-west of Vitória da Conquista; it is found in contact with a pegmatite and in association with quartz, feldspar and black tourmaline. Density and refractive indices (2.80; 1.576, 1.658) are slightly higher than those shown by

emerald from Carnaiba in the same state. A green opal, thought to be coloured by nickel, is found in the Fazenda Brejinho, north-east of Vitória da Conquista. Quartz, both in the rose and amethyst varieties, are found in the area. Amethyst from Montezuma is heated to give a green colour and is then known as 'peridine'; amethyst from Coruja is heated to an orange or a yellow-brown and such stones are traded as 'Bahia topaz'. M.O'D.

CASSEDANNE (J.-P.), (J.-O.). *Les grenats de Poaia/Bresil.* (Garnets from Poaia, Brazil.) Revue de Gemmologie, **52**, 2-4, 1977.

The area is situated north-north-west of Governador Valadares in the state of Minas Gerais. The location is in a lenticular pegmatite and the garnet occurs in irregular lumps, mingled with some tourmaline and albite. The colour ranges from brown through rose and orange. Refractive index is 1.810, hardness about 7, density 4.24. Material is sold at around 40 cruzeiros a gram. M.O'D.

CROWNINGSHIELD (R.). *Developments and highlights at GIA's Lab in New York.* Gems & Gemology, **XV**, 10, 306-14, 17 figs, 1977.

Some additions to recorded facts about treated diamonds are made. A number of pinks showed the Cape spectrum line at 4155Å. In Brazilian rough this line was found in all stones which fluoresced blue in long UV. Some comments on black diamonds—any showing green 'windows' or reflections from cracks are treated stones. A brown diamond was found to be type IIB, apparently laminated with a non-conducting type in alternation. Other anomalous spectra of diamond mentioned—a valuable up-dating of data on this subject.

An insect-like inclusion in diamond; comments on the dichotomy of meaning in the term 'opalescent'; strange natural-looking inclusions in an orange synthetic spinel; further unusual inclusions; a conchoidal fracture and an over-large natural extending from girdle to cutlet in diamond are described and illustrated. 'Snow-cloud' inclusions in emerald and surface 'tarnish' on another beryl; two star quartz cabochons with brilliant multiple stars (abstractor described such a stone in 1951*); a Russian synthetic quartz which is half yellow and half green and a 'hauntingly beautiful' opal-like triplet of aragonite fossil capped with quartz, known as Calcentine, are all illustrated and described. 'Emerald Nova' proved to be stained quartzite. R.K.M.

CROWNINGSHIELD (R.). *Developments and highlights of GIA's Lab in New York.* Gems & Gemology, **XV**, 11, 345-9, 15 figs, 1977.

Cubic zirconia, as the latest and probably the best diamond imitation, is discussed. A light transmission effect which shows pavilion facets clearly in dispersed yellow, orange or red colour, is illustrated and suggests a possible testing factor. A GGG simulant of diamond, which had been worn in a ring for three years, showed considerable wear and is considered unsuitable for daily use. Wear and inclusions in diamond are illustrated and mossy patches seen on surface of radium treated green diamonds described. Unusual cultured pearls described and illustrated, including non-nucleated sea-water cultured and also un-stained black cultured pearls from a Pacific source. A yellow diamond crystal from the States only known pipe mine at Murfreesboro, Arkansas, weighed 4.23 carats. Another weighing over 16 carats has been reported. R.K.M.

*Gemmologist, 1951, XX, 235, 28-30.—Ed.

CROWNINGSHIELD (G. R.). See *Diamond Lectures* below (p. 210).

DAVIES (G.). *The H3 centre.* Diamond Research, 15-24, 16 figs, 1977.

Discusses the properties of the H3 centre which if present in a colourless diamond will turn it yellow. Green light is emitted on irradiation with UV or charged particles. The H3 centre is the defect formed when radiation damage centres are trapped by the A form of nitrogen. M.O'D.

DHAMELINCOURT (P.), SCHUBNEL (H.-J.). *La microsonde moleculaire à laser et son application à la mineralogie et la gemmologie.* (The laser molecular microprobe and its application to mineralogy and gemmology.) Revue de Gemmologie, **52**, 11-14, 1977.

This is part one of a series of articles. The use of the laser to generate photons and the investigation of their behaviour by Raman methods represents an advance on previous work using electronic and ionic microprobes. Several characteristic Raman spectra (including one of a phlogopite inclusion in a Madagascan sapphire) are illustrated together with a schematic diagram of the apparatus used. M.O'D.

FARINA (M. S.). *Nota su una perla cresciuta nelle acque del fiume Po.* Note on a pearl formed in the waters of the river Po.) La Gemmologia, **3**, 1, 25-35, 1977.

The pearl was found in a mollusc of the Lamellibranchae class of the order Heterodontae, group Integripalleatae of the Unionidae family genus Unio. The pearl weighed 2.7440 g and fluoresced dark violet under long-wave ultraviolet light, yellowish under short-wave. Surface structures were observed and radiographs are shown. M.O'D.

FUENTES (J. C.), TUCCILLO (R.). *Contribution to the gemological analyses of Argentine fluorite.* Gems & Gemology, **XV**, 10, 290-4, 4 figs, 1977.

A general survey of RI, SG, x-ray and UV fluorescence and spectroscopic analyses of fluorite from seven central Argentine sources and comparisons with Co. Durham and Blue John material in England. A very convincing green plastic carved imitation is mentioned. R.K.M.

FUJISAKI (Y.). *Changes of the concept of gemstones in future.* Journ. Gemm. Soc. Japan, **4**, 2, 60-7, 1977. (In Japanese.)

The supply of gemstones is gradually declining and it may be necessary to modify the conception of gem material in future. Gem diamonds are shown to be less easily recovered than a few years previously. Inclusions in diamond are especially important in grading, since it is by their presence that serious differences in evaluation arise. M.O'D.

GARRETT (J. D.), IYER (M. N.), GREEDAN (J. E.). *The Czochralski growth of $LiBO_2$ and $Li_2B_4O_7$.* Journal of Crystal Growth, **41**, 2, 225-7, 2 figs, 1977.

Large single crystals of $LiBO_2$ and $Li_2B_4O_7$ have been grown using the Czochralski pulling technique. $Li_2B_4O_7$ boules are prone to severe cracking. Preferential growth along (010) was observed in $LiBO_2$. M.O'D.

GRAMACCIOLI (C. M.). *Die Mineralien von Baveno.* (The minerals of Baveno.) Lapis, **3**, 2, 5-10, 9 figs (5 colour), 1978.

Describes the mineral locality of Baveno in northern Italy with a list of the

minerals found there; these include the well-known twinned crystals of orthoclase as well as gadolinite, fluorite, babingtonite and epidote. A map is included. M.O'D.

GÜBELIN (E. J.). *Analytical results of poly-mineralic sulfide inclusions in diamond.* Gems & Gemology, **XV**, 11, 322-7, 9 figs, 1977.

Electron probe investigations of bright colourless crystals surrounded by black inclusions in Ghana diamonds reveal them to be olivine, while the black material is shown to be of mixed mineral content, chiefly sulphides plus, in one instance, a silicate. Bearing on diamond origins and outer mantle evolution is discussed. Analysis by probe of elements in two inclusions is confused by printing *three* lists. R.K.M.

GÜBELIN (E. J.). *Djevalite-una nuova imitazione del diamante.* (Djevalite, a new diamond imitation.) La Gemmologia, **3**, 2, 5-12, 3 figs, 1977.

Gives the outstanding features of djevalite, a trade name for zirconia in its cubic form, with a table of other diamond-imitating materials and illustrations of typical inclusions of minute gas bubbles. M.O'D.

HAMMOND (B. R.). *The Hixon Collection.* Gems & Gemology, **XV**, 9, 288, 1977.

See *The Hixon Collection* below (p. 211).

HANNEMAN (W. W.). *L_H—a new gemological property.* Gems & Gemology, **XV**, 10, 302-5, 4 figs, 1977.

This is effectively an account of the Jeweler's Eye reflectometer adapted to determine a numerical value for lustre. The claim that lustre itself is a new property is not tenable, but the arbitrary scale of values for lustre given by the instrument does provide a new gemmological constant. Among high-lustre gem materials the L_H range runs from silicon carbide 5 to YAG 1, with diamond at 4. Gems with vitreous lustre are accommodated on a separate section of the scale. Any reading must depend upon the degree of polish on the surface tested, so a poorly polished stone may read low. The scale shown in Figure 1 is that of the Jeweler's Eye reflectometer: that of the Lustermeter (Figure 2) is far simpler. R.K.M.

HEWITT (C. G.). *Adventures with Virgin Valley opals.* Lapidary Journal, **31**, 9, 1994-8, 1977.

Account of prospecting in the Virgin Valley region of Navada with details of a process said to halt crazing in some specimens. M.O'D.

HUDSON (P. R. W.), TSONG (I. S. T.). *Hydrogen impurity in natural gem diamond.* Journal of Materials Science, **12**, 2389-95, 2 figs, 1977.

Five natural gem diamonds including types 1A, 1B and 2A were investigated by ion beam spectrochemical analysis to determine total hydrogen impurity concentration. Hydrogen was found in all the specimens, but the concentration did not correlate with any defects observed. M.O'D.

HUDSON (S.). *Hunting the hexagons: in search of Georgia beryl.* Lapidary Journal, **31**, 5, 1116-28, 1977.

Beryl is found in the Mountain and Piedmont regions of the state and is usually associated with mica pegmatites. They occur in the feldspar or quartz near the

central core of the pegmatite. Colours found include green, yellow and blue. Some blue is of gem quality. A history of beryl mining and a bibliography are included.

M.O'D.

JENKINS (W .J.). *A soudé emerald from Colombia.* Lapidary Journal, **31**, 7, 1630-2, 2 figs, 1977.

Describes a cut stone fashioned from an aquamarine crystal cut in two places and cemented together again with green cement. The stone was said to have been purchased in Colombia. M.O'D.

LIDDICOAT (R. T.). *Developments and highlights at GIA's Lab in Santa Monica.* Gems & Gemology, **XV**, 10, 295-301, 12 figs, 1977.

Specimens of colourless phosgenite, a 41.7 carat 'exceedingly radio-active' ekanite and a reddish brown cat's-eye which proved to be anthophyllite are reported. A dyed green stone looking like jadeite was found to be wollastonite. Diamonds with a macle inclusion, purple banding, various 'naturals', a stone 'inked' to improve colour and another with quite exceptionally abraded facet edges are described. The effect of grain lines on clarity is discussed. R.K.M.

LIDDICOAT (R. T.). *Developments and highlights of GIA's Lab in Santa Monica.* Gems & Gemology, **XV**, 11, 328-33, 9 figs, 1977.

An apparently fine-coloured emerald crystal proved to have been core-drilled; space between core and outer crystal filled with green cement. A genuine emerald cabochon found to have strong zoning between fine green and colourless areas. A green cameo head was found to have been carved from a synthetic spinel triplet so that colour cement was retained only behind carved head. Green glass with strong swirling reminiscent of byssolite fibres in demantoid is illustrated. Scratch test to prove diamond demonstrably dangerous if diamond point is used, since diamond *will* scratch diamond. Early flame fusion synthetic ruby showed angular inclusions as well as curved striae. A multi-crystalline semi-fibrous green stone with tourmaline indices but no dichroism still proved to be tourmaline. A deep amethyst-coloured spodumene is described but it is not certain that it is a natural colour. R.K.M.

LIDDICOAT (R. T.). *Comments on the Hixon collection.* Gems & Gemology, **XV**, 9, (2pp.-front and back flyleaves), 1977.

See *The Hixon Collection* below (p. 211).

LIEBER (W.). *Worin sich Kristalle miteinander messen; die Härte von Mineralien.* (Wherein crystals contest with each other—mineral hardness.) Mineralien Magazin, **1**, 2, 134-7, 1977.

Reviews Mohs's scale and the physical basis for the hardness of crystals.

M.O'D.

LOWER (J. N.), WELBOURN (C. M.). *EPR studies of irradiated diamonds.* Diamond Research, 5-10, 7 figs, 1977.

Discusses the room-temperature EPR spectrum of irradiated type IIa diamonds with special reference to impurity interstitial complexes. M.O'D.

MANUTCHEHR-DANAI (M.). *On the turquoise deposits of Nishabur (N.E. Iran).* Gems & Gemology, **XV**, 10, 315-19, 2 figs, 1977.

A historical and geological account of this extremely important source of fine gem turquoise, first worked well over two thousand years ago and still in production today. R.K.M.

MATEIKA (D.), FLISIKOWSKI (P.), KOHLER (H.), KILIAN (R.). *Automatisierte Kristallziehanlage für das Czochralski-Verfahren.* (Automatic crystal-pulling equipment for Czochralski growth.) Journal of Crystal Growth, **41**, 2, 262-74, 12 figs, 1977.

An adaptation of the Czochralski pulling technique for automatic crystal production is described and illustrated. Gadolinium gallium garnet has been successfully grown with this apparatus. M.O'D.

MIR-MOHAMMEDI (A.), PILGER (A.). *Türkis, Stein des Himmels.* (Turquoise, stone of Heaven.) Mineralien Magazin, **2**, 108-13, 11 colour figs, 1978.

Describes the occurrence of turquoise in Iran, illustrating cut and rough specimens of varying colours. A map covers the area. M.O'D.

MITCHELL (R. S.), GIARDINI (A. A.). *Some mineral inclusions from African and Brazilian diamonds: their nature and significance.* Amer. Mineral., **62**, 756-62, 1977.

Inclusions of forsterite, enstatite and quartz from well-crystallized diamonds from Brazil and inclusions of barite, biotite with chlorite, chlorite with biotite with garnet, chlorite with calcite, omphacite, pyrrhotite and pyrrhotite with chalcopyrite from well-crystallized African diamonds have been noted. M.O'D.

NASSAU (K.). *Irradiation colours in topaz, quartz and beryl.* Gems & Gemology, **XV**, 11, 350-1, 1977.

A short but important paper since it establishes authoritatively that irradiated blue topaz is colour stable, while the so-called Maxixe type deep blue beryl, which is probably also irradiated, is by no means stable and will fade on prolonged exposure to light. R.K.M.

NASSAU (K.). *Anmerkung zu 'Über die Färbungsursachen Natürlicher Citrine'.* (Note on 'About the causes of colour in natural citrines'.) Z. Dt. Gemmol. Ges., **26**, 4, 222, 1977.

The author refers to an article by Lehmann (abstracted on p.131 above) in which citrine is called 'burnt amethyst' and the greenish-yellow variety is called 'citrine', which seem contrary to gemmological usage. E.S.

NIKOL'SKAYA (L. V.), NOVOZHILOV (A. I.), SAMIOILOVICH (M. I.). (The nature and colour of a new alkali calcium silicate from eastern Transbaikal.) (In Russian—from a translation by M. Fleischer.) Izvest.Akad.Nauk SSSR, Ser. Geol., **10**, 116-20. 5 figs, 1976.

A deep violet alkali silicate has been given the name charoite. It occurs in conjunction with another new mineral, tinaksite. Mn and Fe have been found by spectroscopic analysis. Colour may be due to Mn^{3+} occurring in deformed 6-fold coordination although Mn^{2+} and Fe^{3+} may also influence it. M.O'D.

O'LEARY (B.). *Fire forever.* Lapidary Journal, **31**, 7, 1498-510, 22 figs (21 colour), 1977.

A history of opal mining in Australia with coloured illustrations of notable stones. Particular reference is made to opal mining near the town of Ballina on the northern coast of New South Wales: opal in this locality is of volcanic origin and when first mined was believed to be unstable. Some opal from this area is stated to have been found in liquid form. M.O'D.

PARKIN (K. M.), LOEFFLER (B. M.), BURNS (R. G.). *Mössbauer spectra of kyanite, aquamarine and cordierite showing intervalence charge transfer.* Physics and Chemistry of Minerals, **1**, 301-11, 4 figs, 1977.

Blue kyanite from Elovyi Klavoloke, ASSR, has been shown by Mössbauer spectroscopy to contain both Fe^{2+} and Fe^{3+}; green kyanite from Kenya contains mostly Fe^{3+}. Both Fe^{2+} and Fe^{3+} are found in blue beryl from Colorado. No Fe^{3+} could be found by this method in either cordierite from the Malagasy Republic or high-iron cordierite from Dolni Bory, Velke, W. Moravia. The blue colour of aquamarine and cordierite had previously been attributed to charge transfer between adjacent Fe^{2+} and Fe^{3+} ions, that in blue kyanite to transfer between Fe^{2+} and Ti^{4+}. M.O'D.

PETROV (I.). *Farbuntersuchungen an Topas.* (Colour investigation of topaz.) N. Jb. Miner. Abh., **130**, 3, 288-302, 1977.

Colour in topazes was investigated by means of polarized absorption spectra within ultraviolet and visible light. Yellow topaz is characterized by colour centres, reddish-brown stones by two centres (red and yellow). Violet-coloured stones show absorption bands (three each in two groups) which can be correlated to Cr^{3+} occupying Al positions. Orange stones obtain their colour from a mixture of yellow and violet, and blue stones from a mixture of green and yellow, the colour in each case being that derived from the operation of a colour centre. M.O'D.

PETROV (I.), SCHMETZER (K.), BANK (H.). *Orangefarbene Topaskristalle bei Ouro Preto, Minas Gerais, Brasilien.* (Orange-coloured topaz crystals from Ouro Preto, Minas Gerais, Brazil.) Aufschluss, **28**, 219-20, 1977.

Illustrates crystals on which the {001}, {112}, {011} and {113} forms are prominent. M.O'D.

PETROV (I.), SCHMETZER (K.), BANK (H.). *Violette Topase aus Pakistan.* (Purple topaz from Pakistan.) N. Jb. Miner. Mh., **10**, 483-4, 1977.

Transparent crystals of purple topaz, associated with quartz and calcite, have been found in the Mardan district of Pakistan. Crystals display prismatic habit and show (110) and (120), with (011), (012) and (112); sizes range up to 2cm × 0.5cm. Refractive index is 1.632, 1.633 and 1.641, suggesting an OH-rich stone with about 15% F. M.O'D.

PETROV (I.), SCHMETZER (K.), EYSEL (H. H.). *Absorptionsspektren von Chrom in Topas.* (The chromium absorption spectrum in topaz.) N. Jb. Miner. Mh., **8**, 365-72, 1977.

The absorption spectrum of purple topaz results from d-d transitions of Cr^{3+} in Al lattice positions. Two strong bands are each split into three components and

this is explained by the symmetry of the (Al,Cr)-O_4-F_2 coordination polyhedron.
M.O'D.

QUIGLEY (D.). *Botswana elevation in diamond league.* The Times newspaper, no. 60274, p.26, 12th April, 1978.

Botswana is to become the third largest diamond producer in the world. De Beers Consolidated Diamond Mines is to develop a new mine at Jwaneng in the Kalahari region, which is to begin producing at the rate of 3.5×10^6 ct a year from 1982, increasing to 6×10^6 ct a year. Production from existing mines at Orapa and Letlhakane should reach 4.8×10^6 ct this year. Indications are that Jwaneng will have a higher proportion of gemstones to industrials than Orapa (*ca.* 14%) but lower than Letlhakane (*ca.* 40%). J.R.H.C.

RADCLIFFE (D.), PEACOCK (S.). *Fire agate.* Lapidary Journal, **31**, 5, 1096-108, 1977.

Fire agate is mined in the Central Mesa of Mexico and most is found in chalcedony in a fine-grained rhyolitic rock. Coloured illustrations are given. M.O'D.

RAGER (H.). *Electron spin resonance of trivalent chromium in forsterite, Mg_2SiO_4.* Physics and Chemistry of Minerals, **1**, 371-8, 4 figs, 1977.

A forsterite crystal was grown and doped with Cr_2O_3 in different concentrations. Spin resonance showed that the chromium ions are located at both the M1 and M2 positions. M.O'D.

RIBBE (P. H.), GIBBS (G. V.), HAMIL (M. M.). *A refinement of the structure of dioptase.* Amer. Mineral., **62**, 807-11, 6 figs, 1977.

A crystal from Renéville, Zaire, was used for analysis and was shown to consist of puckered trigonal rings of six water molecules between puckered rings of six silicate tetrahedra bonded laterally and vertically by Cu. M.O'D.

ROWCLIFFE (D. J.), FRÜHAUF (V.). *The fracture of jade.* Journal of Materials Science, **12**, 35-42, 11 figs, 1977.

The high resistance of jade to crack propagation is due to the fibrous microstructure in which individual fibres are intermeshed. SEM photographs are included. M.O'D.

SCELLS (G.). *Some north Queensland gem fields visited.* Lapidary Journal, **31**, 10, 2228-34, b14 figs, 1978.

Describes with maps the localities for topaz, peridot, moonstone and agate in north Queensland. M.O'D.

SCHÄFER (W.). *Wo man die grünen Steine findet. Zwei europäische Smaragdvorkommen.* (Where you can find green stones. Two European emerald locations.) Mineralien Magazin, **5**, 207-16, 1977.

Describes with coloured illustrations and maps, the locations for emerald in the Habachthal (Austria) and Eidsvoll (Norway). M.O'D.

SCHMETZER (K.), BANK (H.). *Zur Nomenklatur ostafrikanischer Turmaline.* (Towards an East African tourmaline nomenclature.) Z. Dt. Gemmol. Ges.,

26, 4, 208-9, 1977.

Green tourmalines from East Africa are often described as chrome-tourmalines but are to a large extent coloured by vanadium. It is easy to differentiate between these by a simple spectroscopic examination. Dravite and uvite are magnesium-aluminium tourmalines. E.S.

SCHMETZER (K.), OTTEMANN (J.), BANK (H.), KRUPP (H.). *Blaugrüne Kornerupine aus Kenia und Tansania.* (Blue-green kornerupines from Kenya and Tanzania.) Z. Dt. Gemmol. Ges., **26**, 4, 202-4, 1977.

This is a preliminary report on the green, blue-green and blue kornerupines from Kenya and Tanzania which vary in their optical properties considerably from those found in the Kwale district in Kenya. The stones are mostly cut and polished but recently a rough lot reached the European market. The Kwale kornerupines are distinctly green and show different pleochroism from the newer stones. E.S.

SCHUBNEL (H.-J.). *Les diamants d'Indonésie; notes de voyage.* (Indonesian diamonds: notes of a visit.) Revue de Gemmologie, **53**, 9-11, 7 figs, 3 colour plates, 1977.

An account of diamond workings in the vicinity of the town of Bandjarmasin, Borneo. M.O'D.

SCHUBNEL (H. J.). *World map of gemstone deposits: explanatory note.* Bur. Rech. Géol. Minières, Orléans, 2pp, 1 coloured map (1:40 000 000), 1975. Fr 31.30.

On the equi-areal map, the symbols indicate both the gem material and the geological nature of the deposit. R.A.H.

SCHWARZMANN (S.). *Familie Feldspat.* (Feldspar family.) Lapis, **2**, 10, 20-23, 1977; **2**, 12, 28-31, 14 figs, 1977.

Includes illustrations of lunar rock formations as well as coloured photographs of orthoclase, adularia and microcline. Illustrates twinning in the feldspar group of minerals; some types are illustrated in colour. M.O'D.

SELLSCHOP (J. P. F.), ANNEGARN (H. J.), MADIBA (C.), KEDDY (R. J.), RENAN (M.J.). *Hydrogen in diamond.* Diamond Research, 2-4, 7 figs, 1977.

Infrared studies show two very sharp lines in some natural diamonds. In synthetic stones there is no evidence for hydrogen. M.O'D.

SHAW (J. L.). *The Royal Ontario Museum in Toronto, Ontario, Canada.* Lapidary Journal, **31**, 7, 1512-22, 13 figs, 1977.

Describes the gem and mineral collections of the Museum with brief notes on its history. M.O'D.

SHIMADA (S.), KODAIRA (K.), MATSUSHITA (T.). *Crystal growth of bismuth titanates and titanium oxide from melts in the system Bi_2O_3-V_2O_5-TiO_2.* Journal of Crystal Growth, **41**, 2, 317-20, 4 figs, 1977.

Single crystals of $Bi_4Ti_3O_{12}$, $Bi_2Ti_3O_{12}$, $Bi_2Ti_4O_{11}$ and TiO_2 have been grown from the melt with various compositions in the system Bi_2O_3-V_2O_5-TiO_2. M.O'D.

SINKANKAS (J.). *Historical notes on South American gemstones.* Gems & Gemology, **XV**, 11, 334-44, 1977.

A general review of the gem mining history of the South American continent

with some interesting side-lights on the historic Spanish attitude to the vast wealth of emeralds plundered from the natives by the conquistadores. Diamonds and other gems are delt with in some detail. R.K.M.

SOBOLEV (N. V.) *et al.* (Coesite, garnet and omphacite inclusions in Yakut diamonds — first finding of coesite paragenesis.) Doklady Academia Nauk SSSR, **230**, 1442-4, 1976.

Coesite with garnet and omphacite have been encountered as inclusions in diamonds from the Anabar deposits, Yakutia. M.O'D.

SOBOLEV (N. V.), BOTKUNOV (A. I.), BAKUMENKO (I. T.), SOBOLEV (V. S.). (Crystalline inclusions with octahedral faces in diamonds.) Doklady Acad. Sci. USSR (Earth Science Section), **204**, 117-20, 4 figs, 1972.

Diamonds from the Mir kimberlite pipe show pyrope, pyrope-almandine, chrome diopside, olivine, chromite, enstatite and ilmenite as inclusions. These have been thought to be the fillings of growth pits on the faces of diamond crystals by syngenetic materials. Nuclei of these materials appear to fall into the pits and since they grow faster than diamond fill the pits giving inclusions with the morphology of diamond. M.O'D.

SUGITANI (Y.), TAGAWA (K.), KATO (K.). *Optical absorption spectra of iron (III) and chromium (III) doped in synthetic yttrium-aluminium garnet (YAG).* Mineralogical Journal (Japan), **7**, 445-55, 4 figs, 1974.

Peaks noted from Fe^{3+} and Cr^{3+} have been assigned to d-d transitions of the metal ions in octahedral and tetrahedral sites in YAG. M.O'D.

TROSSARELLI (C.). *Confronto fra il rubino naturale, il rubino Verneuil e un nuovo rubino cristallizato in fondente.* (Comparison between natural, Verneuil and a new flux-melt-grown ruby.) La Gemmologia, **3**, 1, 9-24, 1977.

Typical inclusions of all three types of ruby are illustrated; the flux-melt-grown stone had RI 1.762 and 1.770 with a DR of 0.008; specific gravity was 4.00. Opaque inclusions with a metallic lustre were noticed, but their true nature was not established. Platinum was thought to be a possibility. M.O'D.

VAN DEN BERGE (G.). *Spectroscopie.* (Spectroscopy.) Bull. Soc. Belge Gemm., **3**, 1-2, 1977.

General survey, in Flemish, of the spectroscope and its applications. M.O'D.

VARSHAVSKII (A. V.). *Stacking faults in natural diamonds.* Soviet Physics-Crystallography, **22**, 3, 376-7, 1977.

Development of a fine zonal structure along the {111} planes in natural diamond is thought to be at least one of the causes of anomalous birefringence. The structure also appears in luminescence and optical density. M.O'D.

VOGT (H.-H.). *Nicht nur Amethyst Edelsteinparadies Brasilien.* (Not only amethyst comes from the paradise of gemstones, Brazil.) Mineralien Magazin, **2**, 1, 40-43, 13 figs (6 colour), 1978.

Describes with a small-scale map the main gem-producing areas of Brazil. Topaz, aquamarine and other stones are mentioned. M.O'D.

WATANABE (K.), SUMIYOSHI (Y.). *Growth of corundum single crystals from $Na_3AlF_{6-x}Li_xAlF_6$ system fluxes.* Journal of Crystal Growth, **41**, 1-4, 1977.

Corundum crystals were manufactured by the temperature gradient method giving the habit c(0001), n(22$\bar{4}$3) and r(10$\bar{1}$1). Growth rate decreased with increase of Li_3AlF_6. M.O'D.

WEININGER (H.). *Ein bemerkenswerter Scheelit-Fund von der Rauris, Salzburg.* (A notable scheelite discovery in the Rauris, Salzburg.) Lapis, **2**, 9, 26-27, 1977.

Crystals of scheelite have been found in the Rauris area of Austria in association with pericline. M.O'D.

WILSON (M. M.). *Brazil, paradise of gems.* Lapidary Journal, **31**, 6, 1302-16, 1977.

Gives a general description of the gem materials to be found in Brazil with a map and illustrations in colour. M.O'D.

ZWAAN (P. C.), KOREVAAR (H. J.). *Cordierit-Katzenaugen—vermutlich aus Indien.* (Cordierite cat's-eyes, probably from India.) Z. Dt. Gemmol. Ges., **26**, 4, 197-201, 5 illus., bibl., 1977.

Four cordierite cat's-eyes are described. The origin is probably India, although they were bought in Indonesia. All four have the typical grey-violet/blue colour, like the Ceylonese star corundums, but show no asterism but a very definite cat's-eye effect. It seems that this effect is caused by the fibrous structure which is probably built up by a series of microscopic tubes. E.S.

Diamond Lectures (XVI International Gemmological Conference, the Netherlands, 1977). The Hague, Dutch Diamond Publicity Committee. Unpaginated and undated.

This leaflet of 8 pages contains three talks given at the Conference in October, 1977, as follows:

(1) CROWNINGSHIELD (G. R.). *Diamond quality grading in the U.S.A.*

Describes the development of diamond grading by the GIA from 1949: they were much concerned with artificially coloured diamonds, particularly after treated yellow diamonds appeared in 1952: they made formalized reports to an Italian dealer from 1955 and later offered their services across the board: also describes in considerable detail how the GIA laboratories deal with the '4Cs'.

(2) ANDERSON (B. W.). *Some experiences with industrial diamond.*

Describes procedures used in the London Laboratory, (1) shortly after World War II when asked to analyse and report on a number of different so-called diamond powders (sometimes derived from floor-sweepings of diamond workshops) and (2) in modern times to check purity/grain-size of a diamond powder from an unestablished source. Synthetic diamond grits are easily recognizable, consisting of tiny complete crystals, usually brownish and with traces of magnetism. A note is added on carbonado and another describes the testing of a consignment of low quality boart weighing 4585ct and consisting of over 5000 pieces.

(3) ASSCHER (Edward). *Fancy colour diamonds.* 3 coloured illus.

Recounts the history of the French Blue (or Hope): discusses the 104.52ct yellow cushion-shaped diamond sold in 1971 for Fr(S) 1 900 000 (the sale later being

cancelled following Dr Gübelin's judgement that its colour was due to cyclotron treatment): considers the green marquise of 1.22ct, finally submitted to B. W. Anderson and by him to Reading University where it was shown to be irradiated: tells the story of the Goudvis, a deep ruby-red emerald-cut diamond of 5.05ct: denies that Joseph Asscher fainted when he cleaved the Cullinan. J.R.H.C.

Die Diamantvorkommen der Elfenfeinküste, IV. (Diamond locations in the Ivory Coast.) Goldschmiede Zeitung, **75**, 1, 57-78, 1977.

Describes diamonds from the Seguela district of the Ivory Coast and compares them, with their properties, with those from other deposits in West Africa. Diamonds from the Tortiya deposit are also discussed. M.O'D.

Gemmologische Untersuchungspraxis. (Gemmological practice.) Z. Dt. Gemmol. Ges., **26**, 4, 224-7, 1977.

This includes four short notes. The first by H. Bank and K.-G. Leyser reports on an apatite which was sold as a herderite. The second by H. Bank and J. Maes gives an example of blue to red changing garnet from East Africa being accepted as spinel: it was mixed crystal of pyrope and spessartite. The third also by H. Bank and J. Maes, reports a similar mistake in which greenish-blue to red changing garnet from Ceylon was thought to be alexandrite. The last, fourth, note by H. Bank reports on rough and cut glass offered by a dealer from Moçambique as tourmaline. E.S.

The Hixon Collection. Gems & Gemology, **XV**, 9, 258-87 (272 = 5 pp.), 17 colour plates, 1977.

A special issue of this journal consisting of 187 coloured illustrations of gems which have been presented to the Natural History Museum of Los Angeles County by Mr F.C. Hixon, a finance expert of that city, with details of size, weight and specimen number of each on the facing page. Twelve of the specimens appear twice so there are upwards of 25 stones in the full collection (more than 200) which are not illustrated. The issue bears signs of hurried preparation and colours are often unconvincing and sometimes strange for the stones depicted. The collection (valued at $1 million plus) is apparently intended as a working collection with access for the G.I.A. and others (?) in a special laboratory area within the museum. There is a stated attempt to cover 'as complete a colour spectrum as possible . . . for each species'. The stones illustrated scarcely do this. Abstractor knew, in bygone years, a collector who worked on this basis and reached over nine hundred specimens without exhausting its possibilities. However there are several outstanding specimens in the collection in spite of it having apparently been conceived and collected in a short space of time. There is much to be said for the American system of taxation which allows such donations to major public collections to be off-set against tax due. R.K.M.

Künstlerfarbe und Schmuck Lasurstein oder Lapislazuli. (Artist's colour and jewel; azure stone or lapis lazuli.) Mineralien Magazin, **1**, 2, 82-3, 1977.

Includes coloured photographs of lapis lazuli with an account of its properties and uses. M.O'D.

Opal as an investment. Lapidary Journal, **31**, 7, 1492-3, 14 colour illus, 1977.

A brief account of the present-day prices obtaining for fine-quality opal with illustrations of celebrated pieces and mining scenes. M.O'D.

NOTE: *Mineralien Magazin* (ISSN 0341-907X) is a new periodical published by Kosmos-Verlag, Postfach 640, Stuttgart, West Germany. Annual subscription DM 40.80.

BOOK REVIEWS

AREM (Joel E.). *Colour encyclopedia of gemstones.* Van Nostrand Reinhold, New York and London, 1977. pp. xxvii, 147. 64 pages of colour plates. $35.00.

This eagerly-awaited book resembles in format Roberts *et al.*, 'Encyclopedia of minerals', although it is, of course, a smaller work. Over 220 mineral specimens are reviewed and more than 185 of these are illustrated in colour. Preliminary matter covers gemstone origin, crystallography, types of rock, methods of identification, sources of data, explanation of technical terms, a short bibliography, a single page indicating mineral groups (pyroxene, amphibole, zeolite, etc.), a table of the elements and an index. The major portion of the book is taken up by descriptions of the individual species, which contain, as well as the expected constants, sizes of stone likely to be encountered, 'comments' in which the author includes details of usage, historical notes and other matters of interest and a note on the derivation of the name. Amongst these pages of description lie the colour plate sections, four in number, with each page holding at least four pictures and often more. Naturally pictures cannot face the descriptions of the materials to which they pertain but it would be unreasonable to expect this in a work of this kind. Some of the reproduction (in my copy) is a trifle blurred but in all other respects the standard of production is excellent.

What we have is a book in which the gemmologist can turn to the material in question and see virtually at a glance any important feature he needs. It cannot be used as an identification book pure and simple, since there are no tables, but this was not, in any case, the intention of the author and publishers. The sheer amount of information given is likely to make the enthusiast intoxicated with the riches contained in it; the information is accurate and, particularly in the case of the important stones, up-to-date. Just over three whole pages are devoted to beryl and details of the latest reported occurrences are given; as with other important stones, notes on important known specimens are given with size and present whereabouts. Many notes are given on species scarcely ever seen outside museums; these include chondrodite (from the Tilly Foster mine, Brewster, New York), chiolite (from Greenland and the U.S.S.R.), dickinsonite (from two localities in the United States) and so on. Many of these rarities are illustrated, and so we can see, often for the first time, what they look like.

Dr Arem's introductory matter is typical of the whole of his writing; quick and with no wasted words, it encourages the reader to think ahead, and the details are prominent rather than lost in verbiage. No doubt a meticulous sifting would produce the odd error or misprint but to do this would prevent this reviewer, at least, from

devouring the whole book as all readers will wish to do. In this case the 'fool's gold' so often retrieved by the reviewer can safely be cast aside in favour of the true merit of the work as a whole.

The section on diamond is missing from the first printing; intending purchasers should check. M.O'D.

GALL (Robert A. P.). *The Diamond Dictionary.* 2nd edn. Gemological Institute of America, Santa Monica, Cal. 90404, U.S.A., 1977. pp.342. $16.95.

The second edition of this reference book, although physically thinner than the first—which appeared a suprising 17 years earlier—has in fact 27 more pages. There is a different 'flavour' to the text because the author is a research scientist, whereas the first edition was a *compôte* of the work of several members of the G.I.A. staff, based on their courses. The new writing is concise and objective, and fortunately the author has resisted any temptation he might have had to be too academic and has retained the strong gemmological flavour, enhanced with microscope polaroid pictures from the New York and Californian laboratories, as well as some commercial content. The dictionary is also a useful reference source for famous (and some not so famous) diamonds. In all, it remains a unique and even more valuable production. E.B.

HUNGER (Rosa). *The Magic of Amber.* N.A.G. Press Ltd, London, 1977. pp.131. 16 colour plates, 47 black-and-white illustrations. £5.95.

'The Magic of Amber' is a very personal record of a lifetime spent in the trade against a background of centuries of history, rather than a factual and gemmological account of the red-gold fossil resin. Mrs Rosa Hunger was virtually born into the world of amber, and at her own request, it is said, joined her father Arthur Charatan at Sac Frères when she was only fourteen. Her approach to the subject is one of affection rather than one of scientific investigation. One can look in vain for specific gravities, hardness, chemical properties and the other vital statistics beloved of gemmologists, other than the most obvious notes on amber and its imitators. This is rather a pity, for 'The Magic of Amber' is one of the few books on the subject to have been written for many years.

Indeed, in relating the early history of the gem material, Mrs Hunger's rather awed view of science makes her contradict herself more than once. Having stated that the 'scientific study of the zoology and botany of amber has only begun within the last fifty or sixty years', a couple of paragraphs later she reports on the investigations made as long ago as 1830 by German naturalists and later follows it with suggestions that Pliny knew a good deal about 'electrum'. She also has the amateur writer's rather naive habit of referring back to previous chapters, as though the reader might have missed a point or an argument—though unfortunately she does not describe the cogent illustrations in detail or give owner or provenance, except in a short list of acknowledgements, so that the enquiring reader is unlikely to discover where the best collections are to be seen. The colour plates are, however, very fine, though the rest are very smudgily reproduced. Likewise, the index is sketchy and not very helpful, while the large type, comforting to tired and ageing eyes, really seems designed to pad out a slim volume into one of more substance than it in fact contains. Why, for example, should not amber have been used for 'sewing and crocheting implements' in the 19th century? And what were they like? A list of

museums abroad where fine amber can be seen and studied would have been a welcome addition to the book—but perhaps one is quibbling to ask for more opportunity to judge the Baltic gem material by its practical being rather than by the rather sugary alchemy of its magic in fable and poetry. J.B.

KUEHN (R. L.). *The guide to colored gems.* R. Lary Kuehn Productions, Dallas, (Tex., U.S.A.), 1977. 90 leaves. Price on application.

This is a simple guide to the commoner gemstones prepared with the jeweller in mind. Information is given on the colour and durability of gemstones, their availability and legends surrounding them; 'selling keys' (points of general interest) are also included. Blue zoisite is said to be unaffected by ultrasonic cleaning,which is not the case. M.O'D.

LEWIS (D.). *Practical gem testing.* N.A.G. Press Ltd, London, 1977. pp.149. About 180 figs and 50 spectra. £7.50.

In an effort to present the subject for those 'who do not have time or inclination to make a fuller study' much basic gemmological theory has been omitted. Such a work needs to be written with care if possible costly errors of identification are to be avoided.

The general format relegates most of the illustrations to the inside column of each page. This leaves quite a lot of blank paper and results in a rather awkwardly shaped volume.

The first section of the book describes instruments, including some exotic and perhaps unnecessarily expensive items, and gives simple information on their use. The second part deals with testing procedures for each gem. These are occasionally inadequate, e.g. stained turquoise is ignored; irradiated diamonds are not mentioned; synthetic alexandrite is glossed over too briefly. The alphabetic gem order eliminates the need for indexing but separates aquamarine, emerald and morganite (heliodor is missing).

Some of the many illustrations suffer from a generally sooty quality of reproduction. One picture of a 'Garnet-topped ruby doublet' (which it quite evidently is not) is inverted and used again on the next page with a different description. On the same page an obvious garnet-topped doublet is titled 'synthetic ruby' although further description puts the matter right. A red spinel spectrum is described as 'showing copper sulphate'.

The author misuses some terms. 'Loupe' simply means a lens and should not be reserved for the type held in the eye. Observation of absorption spectra is not 'spectrum (or spectroscopic) analysis'. Similarly 'microscopic analysis' is a misnomer for the examination of gem inclusions. Cotton should not be advocated for gem suspension in hydrostatic weighing: it absorbs water and vitiates the result. The text on distant vision RI refers to a wrong diagram. The use of 'physical features' when 'physical constants' are meant; of 'intermediary' for 'intermediate'; 'alternatively' for 'alternately'; 'interesting' for 'intersecting' and such misspellings as 'monobromonapthalene' and 'sausserite' are part of a tendency to lax expression which might have been corrected by more careful proof reading or editing.

Opal doublets and the effect seen in rose quartz stars are inaccurately described. The doublet is a slice of transparent opal cemented to a black onyx base (it simply would not pay to slice *black* opal) or to potch or other material using a black

adhesive. The star stones show an image of the light source at the centre of the star, not 'at the centre of the stone'.

The dichroscope and Chelsea filter are disparaged, yet each, in intelligent hands, can be a valuable aid even today. R.K.M.

NITSCHE (R.), RÄUBER (A.). *Information Über Kristallzuchtung.* (Crystal growth information.) Deutsche Gesellschaft für Kristallwachstum und Kristallzuchtung, Heidelberg, 1976. Various pagings. Price on application.

Gives details of crystal growth enterprises in the Federal Republic of Germany with lists of materials, growers, sizes, etc. M.O'D.

O'LEARY (B.). *A field guide to Australian opals.* Rigby, Adelaide, S. Australia, 1977. pp.159. All figs in colour. $12.95.

The major part of this most attractive book consists of a listing of the various types of white and black opal, each type being illustrated in colour, sometimes with several examples. This is most useful to the interested reader, who will have often encountered such terms as 'contra luz' without being able quickly to find out their meaning. Around this section is a general account of the history of Australian opal mining, an attempt to place the types and colours of opal according to their value and a section of maps of the main opal-bearing locations. The text is clear and quite free from the common anecdotes and legends which quickly become wearisome; anyone starting to collect opal would do well to obtain this book, which is very low-priced. M.O'D.

PEARL (R. M.). *Atlas of crystal stereograms.* Earth Science Publishing Co., Colorado Springs, Col., U.S.A., 1976. pp.80. Diagrams in text. $1.25.

This book is supplied with a pair of stereoscopic lenses mounted in a cardboard viewer and each of the crystal diagrams is repeated so that a stereoscopic image can be obtained by the reader. All crystal systems are represented and arranged in descending order of symmetry; they are not necessarily labelled to represent actual minerals but this is not the purpose of the excellent small book. M.O'D.

VERGNOUX (A. M.). *Documentation sur les synthèses cristallines, Belgique, Espagne, France, Italie.* (Documentation on synthetic crystals, Belgium, Spain, France, Italy.) A. M. Vergnoux, Limoges, 1976. Various pagings. Free (except for postage).

A directory of crystal growers and the materials they produce covering the countries listed. Materials and growers are separately indexed. M.O'D.

First European Conference on Crystal Growth, Zürich, 1976. North Holland Publishing Co., Amsterdam, 1977. pp.xvi, 916. £68.49.

Forming Vol. 2 of 'Current topics in materials science', this volume contains important chapters on developments in the melt-growth of laser materials; $LiYF_4$ doped with Nd^{3+} with the scheelite structure is a fairly recent arrival on this scene, as well as the garnet types $Gd_3Sc_2Al_2O_{12}$, $Lu_3Al_5O_{12}$, $Gd_3Sc_2Ga_3O_{12}$. YAG and $YAlO_3$ have also been doped with Ho^{3+}. A chapter on new experimental developments in flux growth outlines how this and the Czochralski methods have been combined. In general the basic problem with flux growth is the slow rate and the consequent frequent crystal imperfection, together with container problems aggravated by corrosive contents. M.O'D.

ASSOCIATION NOTICES

GIFTS TO THE ASSOCIATION

The Council of the Association is indebted to the following for their gifts:

Mr Murray Burford, G.G., Mississauga, Ontario, Canada, for a copy of the paper *Diamond U.S.S.R. and North America. A Target for Exploration in Ontario,* by J. Satterly.

Mr R. Holt, F.G.A., London, for a copy of *Gem Cutters Craft,* by Leopold Claremont (dated 1906).

Mr J. Alan Fleming, F.G.A., of Roughgems Ltd, London, for a slab (155 × 105 mm) of charoite from the Charo River area in the Murun Massif, north-west Aldan, Yakutsk, U.S.S.R. (it is deep purple material of first class quality—see pp. 1-4 above), and also for a diamond crystal embedded in mother-rock, which comes from the Mir Pipe, Yakutia area, Siberia, U.S.S.R.

NEWS OF FELLOWS

Professor Dr Karl Schlossmacher, Hon. F.G.A., attained the age of 90 on the 10th July, 1977, when a special issue of *Gold Silber Uhren Schmuck* was published in his honour.

Mr Michael O'Donoghue, M.A., F.G.S., F.G.A., gave a talk to the Gemmological Society of Denmark in Copenhagen on 8th April, 1978; a variety of topics were introduced and specimens displayed.

MEMBER'S MEETINGS

London

At the meeting held on 4th April, 1978, at the Central Electricity Board Cinema, Newgate Street, London E.C.2. at which Mr Peter Read, C.Eng., M.I.E.E., M.I.E.R.E., F.G.A., F.I.S.T.C., gave a talk on 'New Gemmological Instruments and Techniques', the talk included a review of electronic reflectivity meters, colorimeters, horizontal-format microscopes and methods of diamond 'finger-printing'. It also covered the application of research techniques such as E.S.R. spectrometry, x-ray topography, electron microprobe analysis and cathodoluminescence. The talk was illustrated with slides and a number of instruments were

displayed including the new Hanneman 'Diamond Eye' (which is very useful for detecting stones such as YAG, GGG, cubic zirconia and strontium titanate). Looking to the future, Mr Read referred to the possible use of a small computer (using a microprocessor) which could compare test-readings fed into it with information stored in its memory-bank and read out an identification.

This talk will be published in the *Journal* in full at a later date.

North-West Branch

On the 15th March, 1978, members viewed the private collection of gemstones of Mr John Pyke, F.G.A.

A visit to the Liverpool Museum to see the Jewellery Collection was arranged on the 27th April, 1978.

South Yorkshire & District Branch

A meeting was held on the 17th April, 1978, in the Sheffield City Polytechnic, when Mr E. A. Jobbins, B.Sc., F.G.A., gave an illustrated talk entitled 'The Gemstones of South East Asia'.

ANNUAL GENERAL MEETING

The 45th Annual General Meeting was held at Saint Dunstan's House, Carey Lane, London EC2V 8AB on the 11th May, 1978.

The Chairman, Mr Norman Harper, welcomed members and said how pleased he was that the Association had completed yet another successful year and that the number of entries for the examinations surpassed previous years. However, the poor results in the 1977 examinations had caused the Council to give serious consideration to this matter and a special sub-committee under the chairmanship of the President, Sir Frank Claringbull, had been set up. Its object was to review the examinations and related educational work in the light of the current situation. The committee will be reporting to the Council later in 1978.

Mr Harper expressed his thanks to the members of Council, Branch Chairmen, Examiners and Instructors, all of whom give up a lot of time for the Association. There was a special thank you to Mr Chisholm who did such an excellent job in producing the *Journal,* also to Mrs Mary Burland who did the work behind the scenes preparing copy for the printers.

Reference was made to the many members who had made gifts of various kinds to the Association. The Chairman also mentioned the excellent opal picture given by the Gemmological Association of All Japan and invited members to look at the picture after the meeting.

There was a special mention for Mr F. S. H. Tisdall who had done so much for gemmology in the Midlands area and who had now retired from class teaching.

The Chairman then proposed the adoption of the Annual Report and Accounts which was seconded by Dr G. Harrison Jones and duly carried.

Mr Harper then said that due to ill health he felt the time had come when he should vacate the Chair. He had enjoyed his thirteen years as Chairman but hoped that he would continue to be closely involved with the work of the Council and would continue to do his utmost for the benefit of the Association. He had pleasure in announcing that Sir Frank Claringbull had offered to continue as President, and

he was re-elected. Mr Douglas N. King was elected Chairman and Mr David J. Callaghan, Vice-Chairman, and Mr F. E. Lawson Clarke re-elected as Treasurer.

Mr King expressed his thanks on being elected Chairman and said he would have a very difficult task to follow in the footsteps of Norman Harper. He extolled the many attributes of Norman and all that he had done for the Association and for gemmology, and he had the greatest pleasure in declaring him elected as a Vice-President. He said this honour was not lightly given and Mr Harper well and truly deserved this appointment.

Mr Callaghan expressed his appreciation of election as Vice-Chairman and said he would do his best to uphold the good name of the Association.

Messrs. M. Carr, P. Daly, N. W. Deeks and D. G. Kent were re-elected to the Council and Messrs. A. J. French, D. Inkersole and D. M. Larcher were elected.

The Chairman announced that Messrs. Hard Dowdy, Watson Collin & Co., Chartered Accountants, had signified their willingness to continue as auditors.

Finally the Chairman expressed his thanks to the National Association of Goldsmiths, and to the Worshipful Company of Goldsmiths for the assistance given by the Wardens in placing rooms in Goldsmiths' Hall at the disposal of the Association for meetings.

LETTERS TO THE EDITOR

From Mr A. E. Farn, F.G.A., Manager of the Gem Testing Laboratory of the London Chamber of Commerce and Industry.

Dear Sir,

Through the channels of the *Journal* I should like to say how sorry I am to hear of the retirement from office as our Chairman of Norman Harper through ill health.

I have been present at many meetings at which his delightful style and manner have carried the proceedings along in a most enjoyable manner. His pleasant *bonhomie* and general affability at these extremely friendly meetings are paralleled by his considerable concern for gemmology and our trade. He has worked very hard in his official capacity and achieved a distinction in launching the Gem Diamond course. We in the jewellery trade should be proud to have been represented and chaired by Norman Harper.

I do not think it would be fitting to allow Norman Harper's retirement to pass in silence. Speaking personally as a trade gemmologist, knowing how much work has to be accomplished in trade promotion and honorary office, I feel that Norman Harper has served us all well. I hope that he benefits from his retirement and that his health improves. I should like to conclude by saying a very sincere 'Thank you Norman Harper'.

Yours sincerely,
A. E. FARN

30th March, 1978. 36 Greville Street, London EC1N 8AU.

From Mr I. C. C. Campbell, F.G.A., Chairman of the Gemmological Association of Rhodesia.

Dear Sir,

An interesting article by M. J. O'Donoghue appeared in the *Journal* of July

1973 (XIII, 7, 263-4), titled 'Synthetic Quartz from the United States'. He covered numerous aspects in terms of the identification of such synthetics against their natural counterparts. This is based on possible inclusions that may exist in the synthetics (physical and optical constants being similar to those of the natural species, of course). The conclusion reached was—'As far as can be seen, the inclusions furnish the only possible clue to the origin, and as these can be found in some natural stones they cannot be completely diagnostic'. O'Donoghue very kindly forwarded to me a slabbed section of a crystal of yellow synthetic quartz (citrine) of the type spoken about. This section showed quite clearly the seed plate, which was of a colourless nature. The inclusions were also typical of those mentioned in his study.

Initially I did some simple comparison tests with this specimen and a number of natural quartz specimens to see what visual results could be obtained after subjecting the test pieces to short-wave ultraviolet (SW UV) irradiation under controlled conditions and with the use of a variable diaphragm (see sketch).

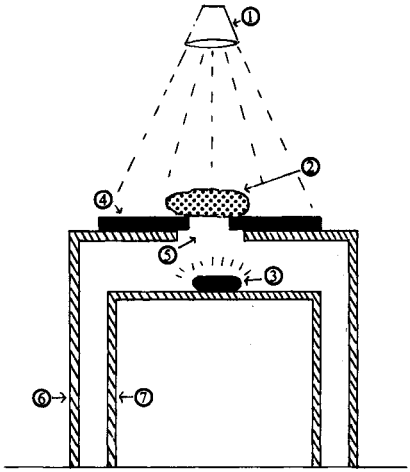

SCHEMATIC LAY-OUT

① SW UV light.
② Test specimen.
③ Scheelite.
④ Diaphragm. (Adjustable).
⑤ Hole in outer cylinder (approx. ½″ diameter).
⑥ Outer cylinder.
⑦ Inner cylinder (note that black (flat) colour was used on the inner surfaces of the outer cylinder and the outer surfaces of the inner cylinder).
⑧ Not shown in sketch: A suitably sized viewing hole cut out of the outer cylinder wall opposite the level of the scheelite. (The whole experiment being conducted in complete darkness).

The UV light was situated approximately ten inches above the specimen which, in turn, rested on a diaphragm; the latter was arranged on a closed-off unit (with a central hole punched through the top of it to allow the rays through). The side of the unit was open to observation of a piece of scheelite which rested directly below the punched hole. Scheelite, of course, fluoresces a whitish-bluish colour under SW UV. Experiments were carried out in complete darkness. It was observed that the natural quartz (colourless, brown, yellow and amethyst) allowed the SW UV rays through, and this was made evident by the fluorescing scheelite. The synthetized quartz did not, or if it did it was only very slight, because the reaction of the scheelite was nil. As I thought this was an interesting result and offered a potential form of identification of synthetic quartz, I repeated the experiment using transmission tests on slow

photographic paper. The results confirmed the initial tests—the difference in transmission of the SW UV being noticeable.

At that stage I wrote to Robert Webster, with whom I had often corresponded on numerous subjects, telling him of the results of my tests. He replied with interest (correspondence on record) and offered to do more conclusive tests along similar lines. (I had no more examples of synthetic quartz for additional tests).

In due course I received a number of photographs of results together with comments from him. The details are as follows, the words in quotation marks being from Webster's letter to me: 'I fixed up a small short-wave UV lamp with filter about 17 inches above a dish of water and with selected stones of comparable size tried out the photo technique (pp. 310-11, Gems, Vol. 1, 1962).' At first the technique was disappointing, as an exposure of about 12 seconds was overexposed and a 4 second exposure was underdeveloped; but other similar exposures were more fully developed, and 'all these tended to show that your supposition was correct and at this stage I had hoped that a test for synthetic quartz had been found.' But further tests on cut stones did not give clear results. The next try was with a slow-acting bromide paper, which 'in all cases got clear results, with one exception.' This was supported by the photographic results which he sent to me. Nine stones were used—5 synthetic (two colourless of different cuts, one cobalt blue, one showing a seed-plate of unknown colour, one green) and four natural (one oval-cut citrine, two brilliant-cut brown, and one pale yellow which was flawed).

The photographic results showed the synthetic quartz, with one exception, in dark relief. The natural quartzes were all in pale (whitish to white) relief. The one exception was the synthetic green quartz which gave the same results as the natural stones. However, this shade of green colour, according to Webster, was not found in natural quartz. The stones were of various shapes and sizes and ranged (when looking at the photograph) from the smallest which measured 8×8 mm square to the largest (a slab) of dimensions 44×30 mm. Thicknesses are not known.

As the synthetic green quartz was an exception, one cannot say that these tests were conclusive and further tests with numerous other specimens (including amethyst) should be done. Nevertheless, it does suggest that this method may well be useful in such identifications.

It should be said also that obviously the photographic technique is rather critical. Webster died before he could finalize the matter. He also stated that he wanted to use my original technique as well—presumably on a more refined basis.

It is suggested that gemmologists who have a full range of synthetic quartz available could follow up this technique and see if anything more substantial will result. I should, of course, have liked to do the work myself, but I have tried for a considerable time (over 18 months to date) to get a *range* of synthetic quartz—but no joy! Synthetic quartz seems to be practically non-existent here—citrine being the only colour-variety seen.

Yours etc.

IAN CAMPBELL

9th May, 1978. Bulawayo, Rhodesia.

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and

PROCEEDINGS OF THE GEMMOLOGICAL ASSOCIATION OF GREAT BRITAIN

GEMMOLOGICAL ASSOCIATION OF GREAT BRITAIN
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ANOTHER BRIEF LOOK AT THE SANCY DIAMOND

By HERBERT TILLANDER, F.G.A., C.G.
Scandinavian Diamond Institute

Historical diamonds are not often available for examination. Most unfortunately the Sancy diamond was at the Institute of Geological Sciences for a very short time only. However, during an exhibition arranged by the Tillander jewellers both the Sancy diamonds, 'Le Grand et Le Beau Sancy',[A] were available for inspection at night in a bank safe. Some additional information may therefore be added to E. A. Jobbins's article in this *Journal* of January 1977.[B]

The stone was then still in its setting and the assessed colour-grade can therefore not be considered as exact and reliable. It compared with the GIA-Master J in our collection and was thought to lie between I and J with a slight brownish, not a yellowish tinge. The colour of the golden setting possibly influenced the judgement. The numerous abraded facet edges were found to disturb the splendour of the fine brilliancy and fire, and it was felt that this should eventually be corrected by a slight repolishing operation in order to restore the original beauty of the diamond. Table and culet

[A] Sometimes called 'the Great Sancy' and 'the Little Sancy'.
[B] XV, 5, 240-242.—Ed.

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FIGS. 1 and 2. Two photographs of the Sancy diamond in its setting.

FIG. 3. Photograph of the Sancy diamond showing inclusion and abraded facet edges.

are not absolutely parallel and the inclusion is rather visible (see Figures 1, 2 and 3). The fluorescence appeared to be a clear yellow.

Germain Bapst[1] described this gem in 1889 approximately as follows: 'Its shape is a flattened pear, almost round, a pendeloque, but the pronounced convexity does not permit the design to be called "Fer de lance" or "Larme." It is faceted both above and below the girdle with a tiny table above. The light-rays entering from above through the various facets are reflected from the bottom facets and irradiate through the top facets exhibiting a fine dispersion (fire).' Bapst further cites Babinet, who believes this shape—often called the Sancy-cut—to be exceptionally economic (weight-saving).

It is surprising how exactly the Sancy diamond has been described and sketched—earliest probably by Thomas Cletscher (1598-1668). The weight, now known to be 55.232 ct (with three decimals) has been given in various old carats, thus 53 ct at 208.4 milligrams, 53¾ ct at 205.5 mg and 54 ct at 204.55 mg. De Sancy himself offered his stone in a letter dated 16th October, 1599, with a weight indication of 60 ct, obviously including the weight of the setting, since in 1604 it was sold to James I with a weight of 214¾ grains = $53^{11}/_{16}$ ct (at 205.75 milligrams). This detail may explain

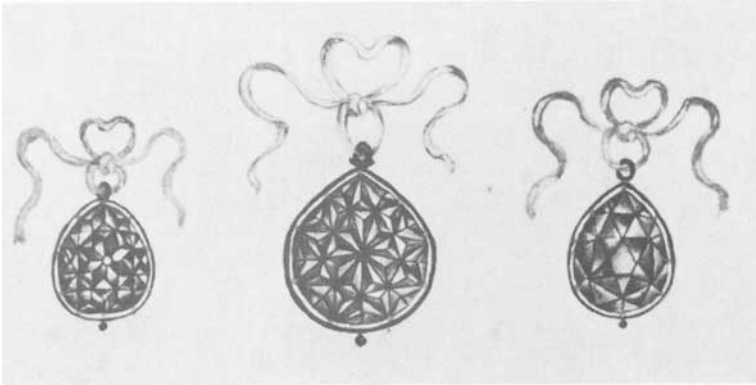

FIG. 4. The Beau Sancy, Florentine and Grand Sancy (from Cletscher, p.2r).

as it was customary in those days, the presumption that the similar stone (weighing 60 ct), once in the possession of the Maharajah of Patiala, was the Grand Sancy. It has been confirmed by the Maharajah's son.

In this connexion I cannot resist the temptation to quote some interesting historical facts regarding this famous diamond.

It has been definitely proved that it never was the property of Charles the Bold, and it seems certain that the stone came from India in its present shape. However, nothing else is known about its travels to Paris, where it was first documented in the hands of Nicolas de Harlay, Sieur de Sancy (1546-1629). He may have brought it from Constantinople, but he was never ambassador there. However, his son was. Further, it was never lost in connexion with the great robbery in 1792, but pawned by the French authorities to the Marquis of Iranda in Madrid and finally sold in Paris legally to a member of the Demidoff family, owners of large industries and silvermines in Russia. Nicholas Demidoff was a resident of Tuscany, where his son Anatol became accredited as chargé d'affaires to the Duke and later received the title of Prince of San Donato. Nicholas died in 1829, a year after he had purchased the Sancy. Anatol did not however, as is generally believed, receive the diamond. His brother Paul did, who in 1836 married a Finnish lady, Aurora Stjernvall, maid of honour at the Russian court. She received the Sancy—as is customary in the Nordic countries—as a 'morning gift' presented to the bride on the morning after the wedding ceremonies. Paul Demidoff died in

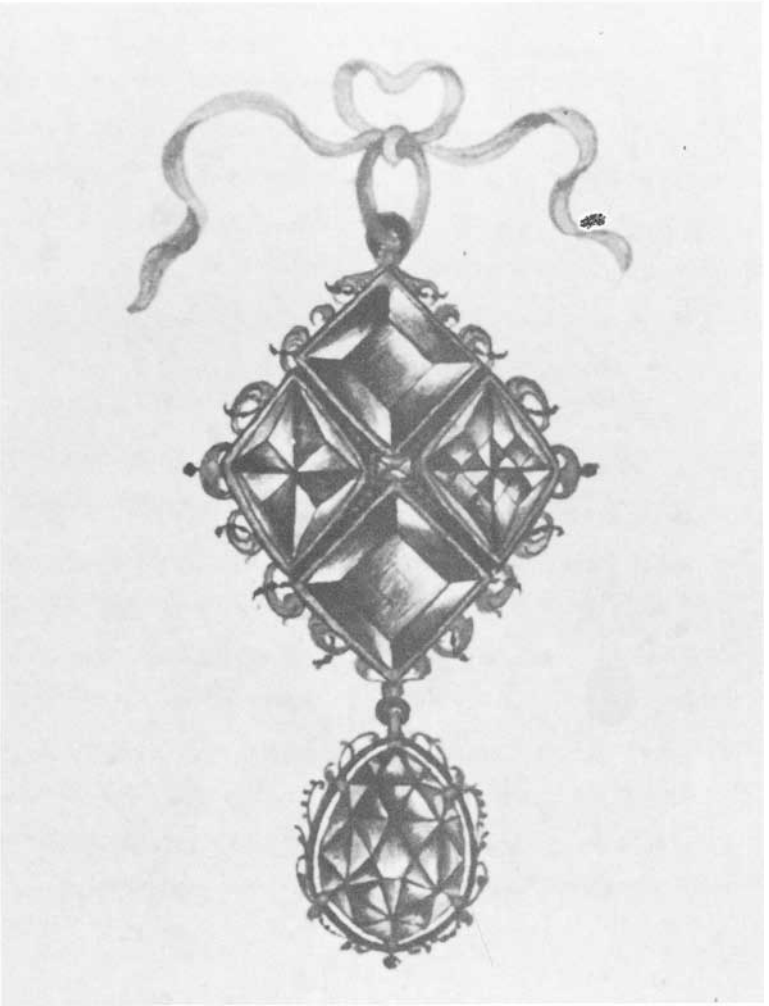

FIG. 5. Very similar to the 'Myrror of Greate Brytayne,' with the Sancy pendant (from Cletscher, p.3r).

FIG. 6. Head ornament with the Sancy and (?) the Mirror of Portugal (from Cletscher, p.34).

1840 and in 1846 Aurora married Andrew Karamsin, captain of the guards, and she was again a widow in 1854, when she finally settled in Helsinki.

In 1865 the Sancy was disposed of through a jeweller in London (Garrards or Oulman) and found its way back to India to Sir Jamsetjee Jeejeebhoy. Since 1906 it was in the possession of the Astor family. The 4th Viscount Astor was the last inheritor. The Sancy is now reported to be on display in the Louvre Museum, possibly on permanent loan.[C]

Historical Ornaments with the Sancy Diamond

Before the sale to James I with the assistance of De Sancy's cousin De Montglat, then French ambassador in London, the setting was very simple. The King had it reset into 'a greate and ryche jewell of golde, called the "Myrror of Greate Brytayne," conteyninge one verie fayre table dyamonde, one verie fayre table rubye, twoe other lardge dyamondes, cut lozengewyse, the one of

[C] Subsequently reported to have been sold to France. The French weekly, *L'Express,* no. 1386, (1978), confirmed that the Banque de France and Musées de France had bought the jewel and it would take its place with the Regent and others in the Gallerie d'Apollon in the Louvre Museum.

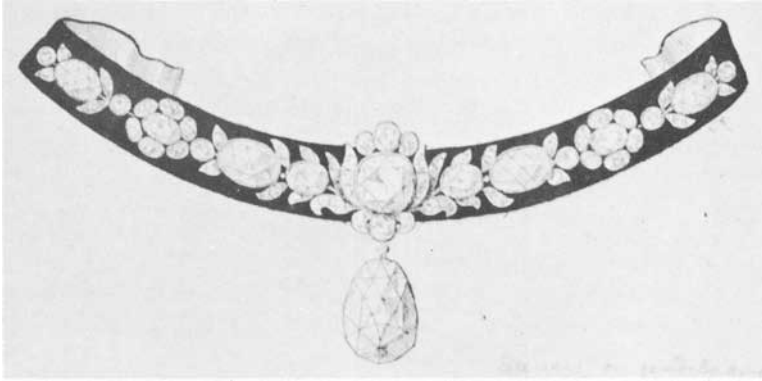

FIG. 7. Queen Marie Leczinska's necklet with the Sancy pendant (from Bapst, p.417).

them called the "Stone of the letter H of Scotlande" [the Great Harry], garnyshed wyth smalle dyamondes, twoe rounde perles, fixed, and *one fayre dyamonde, cutt in fawcetts, bought of Sauncey.'* (Calendar of State Papers—Domestic—James I—Of the Treasury of the Exchequer, p. 305, No. 51.)

Charles I, who inherited the jewels of his father, disposed of this ornament during the first year of his reign, but retained the Sancy. Thomas Cletscher, crown jeweller and Mayor in the Hague, must have been involved in the purchase, since in his famous Sketchbook[D] this diamond is illustrated in three different settings—on page 2 with a simple frame together with the Beau Sancy and the Austrian Yellow sometimes called 'the Florentine', on page 3 in an ornament very similar to the above mentioned 'myrror', and finally on page 34 in a rich head-ornament together with a huge table-cut diamond, probably the Mirror of Portugal (see Figures 4, 5 and 6).

The piece of jewellery on page 3 is accompanied with the following text—translated from the Dutch: 'This jewel was made for King James, who wore it on his hat. The two thick-stones weigh each 36 ct, one of the faceted stones (roses) has a flat base and weighs 12 ct, the other one probably 20 ct, the pendant weighs 54 ct. The jewel is exquisite and was acquired at a cost of some 70 000 pounds sterling.' In this connexion it remains to find out if the original ruby had been exchanged for a diamond, which of the

[D] Produced between 1625 and 1647 and now in the Museum Boymans van Beuningen in Rotterdam: Cletscher was jeweller by appointment to Frederick Henry, Prince of Orange (1584-1647) and his wife Amalia von Solms.

faceted stones was the 'Great Harry' and where the two pearls and small diamonds had been fixed. A further question is posed by the appearance of a very similar pendant—a gift to Charles I's and Henrietta Maria's daughter on her marriage with Prince William II of Orange. This jewel may be seen in a picture painted in 1641 by Sir Antony van Dyck of the Princess Royal (Mary, daughter of Charles I) and Prince William of Orange on that occasion. The original painting is in the Amsterdam Rijksmuseum and a detail showing the jewel is illustrated in a book by M. H. Gans.[2] The ornament is described as being composed of four faceted diamonds joined together in such a way that they appeared as one single huge diamond.

When again a French Crown jewel—bequeathed in the will of Mazarin—it was in the crown 'du sacre' of Louis XV (pictured in Bapst's book[1] on p.411 and in Twining's[3] in Plate 84) and in the collar of his Queen, Marie Leczinska (see Figure 7). Strangely enough we have not been able to recognize the Sancy in other ornaments in portraits of the many owners during this diamond's next to 400 years history. A challenge to art students!

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[*Manuscript received 11th November, 1977.*]

NOTES FROM THE LABORATORY

By A. E. FARN, F.G.A.

The Gem Testing Laboratory, London Chamber of Commerce and Industry

AN UNUSUAL CHRYSOBERYL

I am guilty of having quite a few failings, among them proneness to flogging well known phrases to suit my own particular point of view. Most used and truthful in description of intent is that which I now employ most sincerely in apology for delay to a very keen gemmologist in Australia, Mr R. Chapman, F.G.A. 'The road to Hell is paved with good intentions'.

I received a long time ago two specimens, one rough and one cut, of a green material. They were described as green, but to me they had a brown tinge as well. The rough had been found *'in situ'* by Mr Chapman. He states it was found in a pegmatite with beryl in the Harts Range area of Central Australia, some 150 miles north-east of Alice Springs. Mr Chapman did his own testing upon the cut specimen and obtained the following refractive indices: 1.761-1.771, 1.772-1.779; DR = 0.018 biaxial negative. He also gave a density of 3.7, a hardness in excess of 8, and a broad absorption band in the blue/violet.

Having had two different results given him by two distinct authorities in Australia, he felt considerable interest to find out what his stone really was. Actually his own figures seem to me to be sufficient and he is to be congratulated as a true gemmologist in finding, cutting and polishing his own material and assessing its nature. We at the Laboratory were sent the material, both rough and cut, and promptly did a test upon it and found refractive indices, density and absorption spectrum falling fairly well in line with Mr Chapman. We took a powder scraping and used our diffraction camera. Ken Scarratt did this work and obtained a good chrysoberyl result.

Since two other authorities had said (1) chrysoberyl and (2) corundum, and bearing in mind that a poor surface can play havoc with RI readings, and that corundum has an absorption complex around the area of absorption in chrysoberyl, we decided to ask the co-operation of our consultant, B. W. Anderson. We sent him our

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data and our densities of 3.72 and 3.74 and we received the following report from him.

Report on Cut and Uncut Specimens of an Unusual Green Material

A step-cut transparent green stone weighing 1.52 ct, and a thin slab of supposedly the same material, weighing 3.65 ct, were carefully examined, to provide data to compare with those already established in the Gem Testing Laboratory of the London Chamber of Commerce and Industry, and Mr R. Chapman, F.G.A., of Ayr, Queensland, who originally discovered the mineral in the Hart's Range area of Central Australia.

The rough piece was found to scratch a cleavage plane of white topaz and the basal plane of a beryl crystal. The hardness can be assessed as 8½ on Mohs's scale, a figure only equalled by chrysoberyl and excelled by corundum and diamond amongst natural minerals.

The density of the cut stone was found to be 3.73 (average of two determinations) and 3.78 for the rough stone.

The refractive indices of the cut stone, as determined on a Rayner 'Dialdex' refractometer, were found to be 1.765, 1.772 and 1.777. The birefringence being 0.012, biaxial negative.

The chief feature of the absorption spectrum was an intense broad band in the violet, centred near 4470Å, with a weaker narrow band near 5080Å in the blue-green.

This absorption spectrum, together with the extreme hardness of the mineral, seem to prove that the specimens consist of a variety of chrysoberyl, or possibly a sub-species of chrysoberyl not so far recorded in literature. Normal refractive indices for gem chrysoberyl are 1.747, 1.748 and 1.756, the birefringence being 0.009 and optically strongly positive. The density is near 3.72.

In the samples here reported the density is distinctly higher than normal; but the most surprising features are the higher refractive indices, higher birefringence, and negative optical sign.

One possible explanation of these differences would seem to be the presence of ferric iron in larger quantity than usual. Both the colour and absorption spectrum are thought to be due to traces of this element in normal green and brown chrysoberyl.

B. W. Anderson. 1st May 1977
(Consultant to the Laboratory)

In his letter to me anent the chrysoberyl, B. W. Anderson gave

details of how he was able to use sunlight as his light source via a wavelength-measuring Beck spectroscope. We think Mr Chapman is to be congratulated and envied for this gemmological exercise.

I have at last achieved my intention to write on these chrysoberyls and append here a table of the findings.

	R. Chapman	B. W. Anderson	Laboratory
S.G.	3.70	3.73	3.72
Hardness	Exceeds 8	8½	8½
RI	1.761-1.771 1.772-1.779	1.765-1.772- 1.777	1.765-1.772 1.772-1.778
DR	0.018	0.012	0.013
			Powder diffraction finding: Chrysoberyl

* * *

I have mentioned before a predilection for useful phrases and since they seem to spring readily to mind I think I can comfortably continue their use—particularly following our recent chrysoberyls! I too possess a high-reading brown/golden chrysoberyl, which in post-diploma days at Chelsea Polytechnic used to catch most people out—they all placed it as brown sapphire. 'It never rains but it pours.' In the Laboratory we tested for a customer an alexandrite in a ring. The stone, which later we asked to be unset, weighed 20.12 ct, which is an important size for an equally important stone. Here we were again at the chrysoberyl stakes. In daylight this particular stone was a greenish brown, carrying a nuance of red or that peculiar colour where a gemmologist looks twice or three times before he can really make up his mind. When chromium proliferates, I often find in a mixed lighting such as ours we get warning signals—or is it because we look *into* stones rather than *at* the jewellery? However, we double checked using a spectroscope and received quite a surprise: chromium—yes, signalled in the red end of the spectrum—and three bands at 4500Å, 4600Å and 4700Å typical of sapphire!

We took the refractive indices and found them to be 1.766-1.774 uniaxial negative. In artificial light the stone was a sort of brownish red, looking like a smoky quartz, but reddish. It looked, for all the world, like an alexandrite—a large poor one, but very interesting. So here we had a natural sapphire looking very much more like an alexandrite chrysoberyl: previously we had a chrysoberyl looking to some like a sapphire.

The alexandrite-like sapphire was very clean indeed, except for one long lath-like inclusion which offered no clue to identity. We took the density of the stone and found it to be 4.005.

* * *

Advances in techniques are always welcome and applauded. Mechanization, automation, stereo-zoom, transistors, printed circuits, electronic calculators—all play a part in smoothing the stony path of today's gemmologists. We used to *stand* to use a monocular microscope to test calibré stones by the hundreds and thousands. We used to do our densities by old fashioned use of multiplication, subtraction and division. We have progressed. We now have a calculator. We have a stereo-zoom lens microscope plus four stereo binocular microscopes (non-zoom—old fashioned?). Each has its strong points and some weaker ones—none are perfect—not even the simplest and most manoeuvrable of them all, the 10× lens.

I was fortunate in being taught by an enthusiast who was also an expert. Among many enjoyable evenings at Chelsea and Northern Polytechnics in B. W. Anderson's Post-Diploma class I practised and propagated the use of the 10× lens. We used to have an evening session devoted to identification by 10× lens and heft. No other instruments were allowed. Simple basic tests included finding DR by seeing the doubling of the back facets or doubling of the edge of inclusions. (I bought one or two rock crystal spheres quite cheaply by examining a sheet of paper through the sphere and noting doubling effect on the edge of the page.) The use of the 10× lens cannot be over-stressed as a sound basic beginning to further investigation. Although during my army service I was frequently told that a soldier's best friend is his rifle—I found it hard to appreciate. I do earnestly advise the 10× lens as a gemmologist's best friend.

In the laboratory, of course, we do have other equipment, our latest being a powder diffraction camera which is being appreciated by our younger staff members. We have our old faithful and unique one-off x-ray generating set, purpose-built for radiography and diffraction pattern photography of pearls, with its viewing chamber for observation of luminescence effects. When presented with undrilled pearls we automatically use our x-ray set. We take a radiograph (shadowgraph) or Laue diffraction pattern, depending upon the item—whether it is mounted, whether metal will interfere,

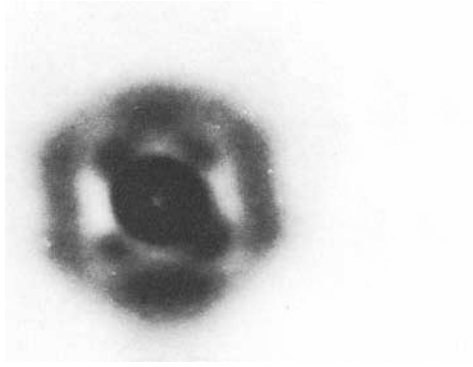

Fig. 1 X-ray 4-spot lauegram of lacquered m.o.p. bead (imitation cultured pearl?)

whether it can be unset or isolated by lead-foil, etc. From one of our customers who sends us quite a lot of pearls to test we recently received a very insignificant small round undrilled pearl weighing 1.19 ct = 4.76 grains. It was a poor-looking whitish pearl, which a quick first look by 10× lens did nothing to improve! Rather it afforded the mental observation, 'poor quality, rubbishy-looking pearl - shocking skin to it.' I took a radiograph on a dentist-size film. The result was negative (no pun intended). For want of a better phrase, it showed nothing—no skin, no core, no structures—nothing. I used the viewing chamber and it fluoresced and phosphoresced strongly as *all* cultured pearls do. Being called away I handed over to my younger colleague and asked for a diffraction lauegram to be taken in my absence. On my return I asked the result and was shown an excellent negative with a strong four spot pattern (Figure 1) characteristic of cultured pearl. This is accepted as proof positive when dealing with suspect cultured pearls.

There being no substitue for experience and remembering many an admonishment to let no anomaly slip by however small, I took another look at our pearl or cultured pearl with the 10× lens. I hadn't liked it in the first place and now less so—normally in pearl testing one looks for shape, subcutaneous markings and general 'look' of the pearl to guide one. We seldom study the actual skin structure to see if in fact it is of the ultra fine overlapping platelets of nacreous pearl. It is always there in pearl and in cultured pearl. This particular pearl was lacking any such structure (although ostensibly a pearl colour). It was in fact a plastic coating over a

mother of pearl bead. The bead showed zonal structure as is seen in thin-skin cultured pearls—it fluoresced and phosphoresced as do all cultured pearls and the x-ray diffraction picture gave a four-spot pattern typical of cultured pearl.

The 10× lens gave a strong lead, which was not immediately followed, but it did prevent us from reporting a cultured pearl, on the basis of an x-ray examination, when in fact it was technically an *imitation* cultured pearl. The reliability and manoeuvrability of the 10× lens were thus graphically proved when one considers the extensive equipment employed in arriving at a slightly awry conclusion. When one moves in certain circles—i.e. dealing with pearls which basically will be natural, cultured, non-nucleated cultured, or imitation (usually glass)—one tends to expect certain precise results. In this particular case preconceived expectations allied to expensive x-ray equipment plus films and cassettes added to knowledge of patterns given by certain structures led us slightly astray. More attention to basics—more and constant use of a 10× lens—can be rewarding and time (and face) saving.

* * *

Talking of pearls, 10× lenses, experience, etc., reminds me of yet another case of x-rays not being so revealing as one would hope. Recently we received from a customer several items of jewellery, all set with pearls as centres to cluster rings and brooches, etc. We often try to obtain results from such items without unsetting the pearls, hoping that in some cases the major portion of the mounted pearl will yield sufficient information from a side-shot radiograph. One case in particular was a very steep *bouton* pearl mounted in a diamond border cluster ring. It looked as if a good picture could be obtained without unsetting. The result was as expected—definitely the structure of natural pearl (several concentric layers showing quite well). The remainder of the jewellery responded to x-ray tests.

Looking again at the ring, I was struck by the size of the pearl diameter set in the cluster surround compared with the small amount of pearl I could see underneath through the pierced basket setting. Some little warning bell rang to tell me that the shape or curvature of the base did not marry with the curve of the steeper upper portion. Using an alcohol lamp, I unset it to find I had two portions of pearl—the upper portion, a sawn pearl with flat base sitting nicely in the surround of diamonds and gold setting, and the lower portion, a smaller, shallower piece of a pearl plugging up the

rear so that a natural rounded pearl base could be seen when examined by lens. The x-ray beam proved correctly that the top portion was natural pearl, but it could not penetrate the metal setting to show a flat base, and insufficient of the lower portion protruded to afford any further clues.

* * *

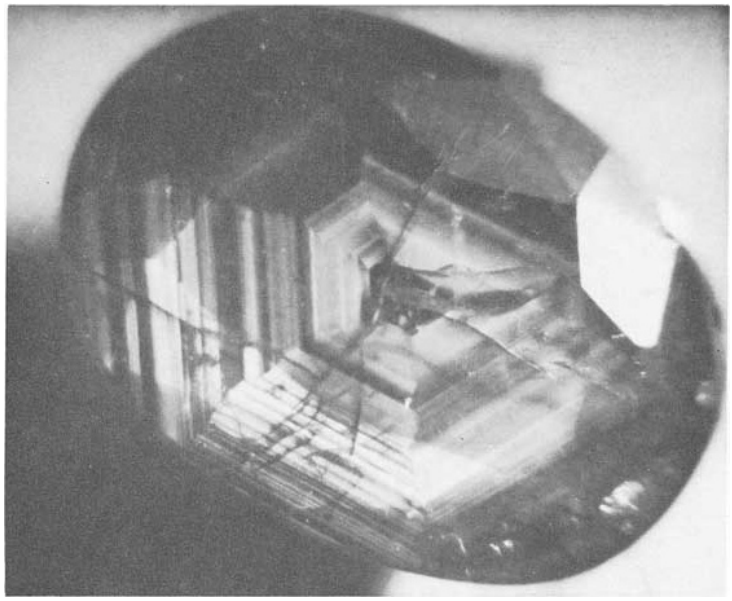

Fig. 2 Zoning in ruby.

ZONING IN RUBY

The zoning in the ruby photographed here by K. V. Scarratt (Figure 2) was so immediately impressive that the original owners, Levy Gem Co. of Hatton Garden, presented it to the Laboratory as of gemmological interest. We were impressed by its obvious self-determination and thought it might interest other gemmologists. From time to time we are presented with samples of new gems and/or synthetics, artefacts, etc. Most are recorded in 'Notes from the Laboratory'. It is refreshing to find this kind of spontaneous enjoyment of basic gemmology. Even a 10× lens was hardly necessary to decide whether natural or not.

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GEM PERIDOT AND ENSTATITE WITH SPINEL INCLUSIONS FROM CHIHUAHUA, MEXICO

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INTRODUCTION

An occurrence of light green and light brown peridot and enstatite in Mexico prompted an examination of the material and the associated minerals to ascertain their compositions and to compare these Mexican gems with the material from the San Carlos Indian Reservation described by Dunn (1974). The peridot and enstatite occur at the Chavira peridot-olivine mines, near Kamargo, Chihuahua, Mexico. The specimens described herein were obtained from Mr Randy Shepard through the courtesy of Mr John Sinkankas, the noted American gemmologist and author.

DESCRIPTION

The peridot occurs as granular aggregates associated with enstatite of a light brown colour, bright-green chromian diopside, and chromian spinel. The massive material is attractive but serves little purpose other than as a source for the gem rough. For a description of the origin of similar deposits, the reader is referred to the work of Ross *et al.* (1954). The peridot occurs in both light green and light greenish brown colours, and stones up to 2 carats can easily be cut from the material. The refractive indices for the light green peridot, measured on two stones in sodium light, are: $\alpha = 1.651$, $\beta = 1.669$, $\gamma = 1.684$, and $\alpha = 1.652$, $\beta = 1.668$, $\gamma = 1.685$. The refractive indices of the brown peridot are $\alpha = 1.655$, $\beta = 1.673$, $\gamma = 1.690$, all ± 0.003. The material is sufficiently abundant at the locality to support a local mining operation, and will very likely influence the jewellery of northern Mexico.

CHEMISTRY

The samples were analysed using an ARL-SEMQ electron microprobe, utilizing an operating voltage of 15 kV and a beam current of 0.15 μA. Standards used were forsterite for olivine, enstatite for enstatite, diopside for diopside, and spinel for spinel.

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In addition, chromite was used for chromium, manganite for manganese, and hornblende for aluminium in all samples. The data were corrected for absorption, backscatter, background and fluorescence using a computer program. The analyses of the gem peridot, gem enstatite, and associated minerals are given in Table 1.

TABLE 1
Microprobe analyses of gem peridot, gem enstatite, and spinel inclusions.

	PERIDOT			*ENSTATITE*		*SPINEL*	
	NMNH 137044			*NMNH 137045*		*NMNH 137046*	
	green	*green*	*brown*				
SiO_2	41.78	41.32	40.35	53.63	53.44	0.00	0.00
TiO_2	0.02	0.01	0.00	0.05	0.04	0.12	0.11
Al_2O_3	0.00	0.00	0.00	4.92	3.94	47.38	46.34
Cr_2O_3	0.00	0.00	0.07	0.90	0.54	20.79	21.60
FeO*	8.58	8.62	11.04	6.07	6.02	11.78	12.38
MnO	0.15	0.14	0.17	0.16	0.12	0.20	0.23
MgO	49.77	49.80	48.26	33.41	33.51	18.84	18.67
CaO	0.08	0.06	0.10	0.97	0.97	0.00	0.00
TOTAL	100.38	99.95	99.99	100.11	98.58	98.81	99.33

*total iron calculated as FeO
Accuracy of data—±2% relative.

Peridot

The green peridot contains about 8.6% FeO, and is similar in composition to the San Carlos peridot. This similarity in composition further supports the observation of Webster (1970) that the iron content of good, green peridot varies little.

The brown peridot, however, has a higher iron content (11.04% FeO) and a correspondingly lower magnesium content. The other elements present do not vary significantly with colour, and it is likely that the brown colour of this peridot is related to the greater amount of iron. This Mexican peridot has between 89 and 91% of the forsterite end-member.

Enstatite

The gem enstatite is markedly less abundant than the peridot at this locality. Several samples were analysed. The analyses indicate that this Mexican enstatite is very close to the enstatite/bronzite composition borderline (Dunn, 1975), but is clearly enstatite. The composition of these enstatites is very similar to that of the San Carlos material; differing in that this material has a higher aluminium content, which is larger than commonly found in mafic rocks.

Spinel Inclusions

Spinel is found in the peridot as dark brown, almost black, anhedral inclusions. The composition of these spinel inclusions, given in Table 1, indicates that they are chromian spinels with an average Al:Cr ratio of 3:1. These Mexican spinel inclusions differ from those of the peridot from San Carlos in that they contain less chromium and more aluminium. The San Carlos spinel inclusions contained 22.62 to 34.79% Cr_2O_3.

SUMMARY

In summation, the gem peridot and gem enstatite from the Chavira peridot-olivine mines in Chihuahua, Mexico, are very similar to those from the San Carlos Indian Reservation in Arizona, U.S.A. The deposit will very likely produce an abundance of material which may be encountered by the practising gemmologist.

ACKNOWLEDGEMENT

The author is indebted to Mr John Sinkankas for initiating this study.

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THE 'DIAMOND EYE' AND THE 'LUSTERMETER': A REVIEW*

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Since the Second World War many diamond simulants have been synthesized and marketed; they have also misled many unsuspecting buyers. The latest and most effective yet produced, cubic zirconium oxide (zirconia), has deceived, among others, a leading diamond cutter and a very experienced London jeweller who bought a three-stone zirconia ring as diamond. Detection of zirconia has become a matter of some urgency for jewellers and gemmologists alike. The material is produced in Switzerland (djevalite), U.S.A. (diamonesque), U.S.S.R. (phianite) and elsewhere.

Modern reflectivity meters using infrared emitting diodes and suitable sensors might well be the answer if they are reliable. Earlier examples have been described in this journal and elsewhere (references 1 to 6), and it seems to be unnecessary to repeat detailed descriptions of the (internal) circuitry. Some of these earlier instruments show named species on the scale whilst others are calibrated on a numerical scale. Both types have their adherents. In the opinion of colleagues and of the author the identities of gemstones with refractive indices below 1.81 can, in general, be determined more effectively using refractometers and other techniques. Diamonds and most of the effective simulants have higher refractive indices and, coupled with these, normally have higher reflectivities, so that only the higher part of the scale of the reflectivity meter is normally necessary for the identification of doubtful stones. Loose diamond simulants can often be identified by careful appraisal of their physical properties. Mounted stones are more difficult and here reflectivity meters are very useful.

The 'Diamond Eye' is a small reflectivity meter measuring approximately 11 cm long, 6 cm wide and 4 cm deep recently introduced by Dr Hanneman, of California. The instrument is calibrated in Hanneman luster values (L_H) (an arbitrary scale) from

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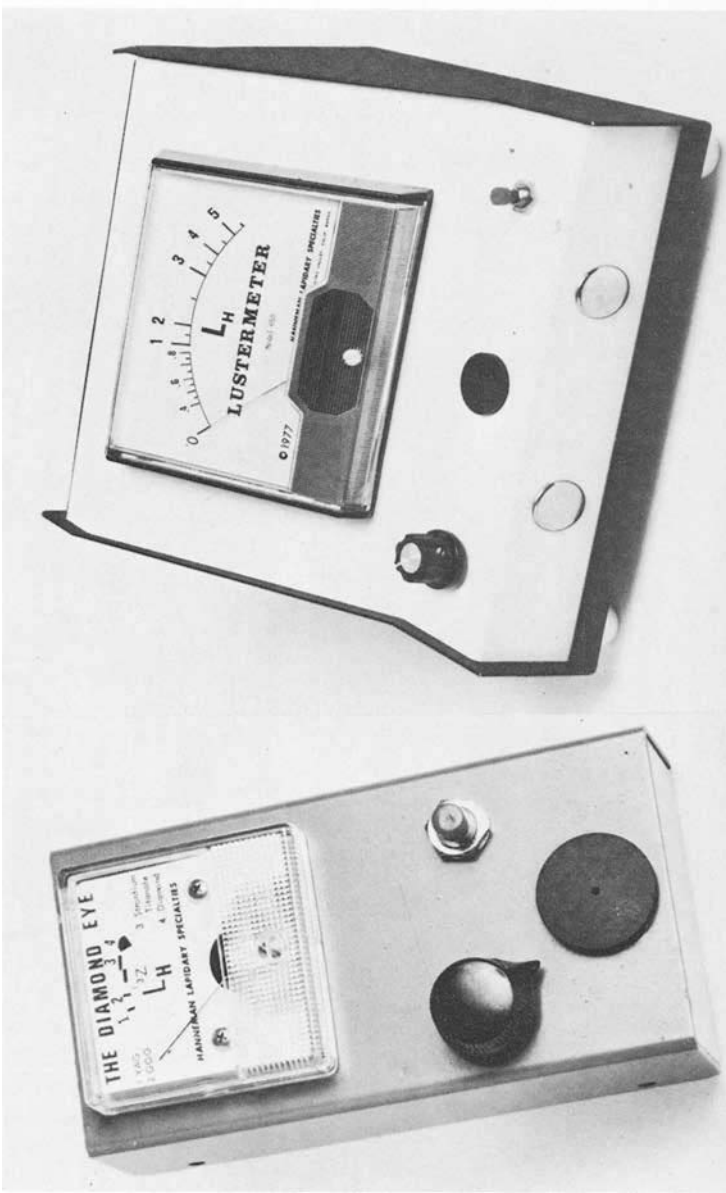

The 'Diamond Eye' and 'Lustermeter' reflectivity meters.
Controls: left—calibration knob, centre—sample platform, right—on/off switch.

1 to 4 and Table I shows the refractive indices, luster values (L_H), hardness, dispersions and specific gravities for diamond and some simulants. The value for cubic zirconia is shown as ^3Z on the meter scale.

TABLE I

	Luster value (L_H)	H	RI	SG	Dispersion
YAG	1	8—8½	1.83	4.65	0.028
GGG	2	6½—7	2.03	7.05	0.038
Strontium titanate	3	5	2.41	5.15	0.190
Diamond	4	10	2.42	3.52	0.044
Cubic zirconia	2.7	7½—8½	2.16	near 6	*c.* 0.060
Synthetic Rutile	4.5—5.5	6—6½	2.8	4.26	0.28

In the use of all reflectivity meters there are several cardinal points which it is essential to observe for meaningful results to be obtained. (1) The instrument must be carefully zeroed using one of the standard stones—diamonds are probably preferable and more generally available. (2) The stones under test must be well polished and clean—scratched or greasy stones will *not* give true readings. (3) Several readings must be taken on each stone with very slight movement between each so as to avoid the occasional high reading caused by internal reflections from within the stone. (4) The stone must be covered by the light-excluding cap provided so as to avoid extraneous light entering the stone from outside. The 'Diamond Eye' under test was demonstrated to gemmology students and was tested by several co-workers using the standard gems (marked 1 to 4 on the scale) and in all cases gave positive and reproducible readings. It was later tested in the laboratory under more controlled conditions and this testing is described below.

The instrument was first zeroed on mark 4 using a 0.25 carat diamond brilliant (4 mm diameter). A series of six yttrium aluminium garnets (YAG) ranging from 1 to 1.5 carats (6.0-6.6 mm) indicated the standard 1 on the scale varying by only the thickness of the pointer on each side of the graduation mark. A brilliant cut (7.9 mm) gadolinium gallium garnet (GGG) gave a reading only very slightly above the standard 2, but a polished 90°, 45°, 45° prism gave correct readings on the smaller polished faces, but a low reading (*c.* 1.5) on the hypotenuse face. A brilliant cut (10.1 mm) strontium titanate gave the standard reading of 3. A

series of brilliant cut synthetic rutiles (recognizable at sight with their gaudy fire!) gave readings well off the scale. Lithium niobates, both brilliant (4.9 mm) and step cut (7.1 × 5.3 mm) gave consistent readings near 3. Six brilliant cut cubic zirconias ranging from 0.47 to 1.08 carats (4.15 to 5.6 mm) all gave readings within the ^{3}Z mark on the scale.

A series of twenty cut diamonds was then checked. These stones varied in weight from 0.13 to 0.90 carats, in cut from modern brilliants to old mine cuts and roses, and from colourless through greenish-blue, yellow, orange to brown, grey and black. Two stones gave high readings, and the smallest stone with an even smaller table facet read to mark 3 only; the majority gave standard readings (4). Diamond octahedra with naturally smooth faces gave standard readings. A thin diamond plate (0.56 ct) measuring approximately 8 × 6 mm and 1 mm thick gave an anomalous reading with the pointer going off the scale. It was not possible to get normal readings from this plate, and it seems likely that reflections from the upper and lower surfaces reinforced each other to give high values. The testing described above took 61 minutes and the meter was tested with the standard 0.25 carat diamond for correct zeroing at approximately 5 minute intervals through the period. It registered correctly throughout, and no drift was observed. The temperature remained constant at 20°C throughout.

Of the stones tested it appeared that brilliant cut stones gave more consistent readings than other cuts and that readings from unusual prisms and plates could be erratic. However, since the average jeweller is unlikely to be testing these unusual shapes this would not seem to be a great disadvantage.

Prior to testing the 'Diamond Eye' the author had examined the earlier and larger 'Lustermeter' reflectivity meter (approximately 18 cm wide, 16 cm deep and 11 cm high) which works on the same principle. This instrument gives values below the L_H1 which is the starting point on the smaller instrument, and is designed to be used for all gemstones—not just those of high refractive index and reflectivity.

Twenty diamonds (brilliant, baguette and marquise cut) were tested on this instrument with reasonably consistent results. Apart from one stone the readings obtained were mostly in the 3.8 to 4.2 range although a few were in the 3.5 to 4.5 range—the instrument was standardized at 4 on a 0.82 carat diamond. One brilliant

cut stone (0.27 carat), apparently well polished, gave many readings in the 2.7 to 3.7 range, but eventually some were obtained in the 4.1 to 4.2 range.

A series of other stones including GGG, YAG, strontium titanate, synthetic rutile, lithium niobate, zircon, synthetic scheelite and synthetic spinel was also tested on the 'Lustermeter'. The values obtained were occasionally up to 0.5 on either side of the values quoted by Hanneman (*Lapidary Journal,* June 1977) but were usually much nearer. However, they were very clearly *not* the values to be expected from diamond and the important function of identifying simulants was fulfilled. During the testing of the 'Lustermeter' it proved necessary to re-standardize the instrument twice within the first 40 minutes period but in subsequent 15 to 50 minute sessions this was not necessary.

In summary both instruments fulfilled their essential function from the jewellers' and gemmologists' point of view—they enabled the user to distinguish rapidly between diamonds and simulants. The 'Diamond Eye' with the restricted scale gave more constant results and more closely matched the quoted L_H values. It is a much smaller instrument, is readily portable, and would appear to be perfectly adequate for the main need of the jeweller—the detection of diamond simulants.

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CUBIC STABILIZED ZIRCONIAS

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ABSTRACT

This article contains a short survey on the stability of zirconias and their growth as stable cubic single crystals, followed by physical and crystallographic data on transparent rough and brilliant-cut material. The chemical composition of yttria-stabilized zirconias is verified by means of rarely used formulas. The results of Vickers and Mohs hardness tests on $(Zr,Y)O_{2-x}$ are compared to the wearing characteristics of other synthetic crystals and diamond, cited in literature. Data of gemmological import are summarized in Table 1 and in Section 5 (Conclusion) which also gives instructions on the positive identification of this efficient new diamond imitation mounted in jewellery.

For the past two decades, the standards for imitating genuine diamonds have been set: their production was successfully achieved by several laboratories. This does not mean that all the other recently grown crystals are essentially less effective 'duplicates'. In general, it can be said that substances with chemical properties similar to those of the diamond (BN, B_4C, SiC, etc.) and many oxides could be very good diamond imitations (e.g. those of the pyrochlore $M^{II}_2M^{V}_2O_7$ and perovskite type $M^{II}M^{IV}O_3$ as well as oxides with garnet structure $M^{III}_3M^{III}_5O_{12}$).

1. PROPERTIES OF ZIRCONIA PHASES

In gemmology, cubic stabilized zirconias are new (chemically zirconium dioxides, in ceramics abbreviated as CSZ). Polycrystalline ZrO_2 phases already were known before 1940, single crystals for about ten years. Zirconias have very high melting points and particular ceramic, electrooptical and metallurgical properties (very small expansion coefficients and thermal conductivity). On the other hand, their technical use is limited because of the instability of the non-monoclinic phases. In the chemically pure cubic form, the substance ZrO_2 is stable only at high temperatures. Without the addition of other oxides, it changes into the tetragonal modification below approx. 2300°C and into the monoclinic polymorph below approx. 1100°C, accompanied by considerable decrease in volume. The pure, synthetic material, therefore, exists at room temperature in the same phase as the mineral Baddeleyite, which is

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merely stable monoclinic ZrO_2. A possible explanation for the existence of cubic zirconia in certain metamict zircons, along with variable proportions of cryptocrystalline SiO_2 and monoclinic ZrO_2 (baddeleyite), is the presence of small amounts of impurities (ref. 1, 2).

Improvements in the structural stability are obtained by additions of about 15 mol.% metallic oxide (p, MO_y), usually in the form of CaO, MgO, Y_2O_3, or Yb_2O_3. These stabilized $(Zr,M)O_{2-x}$ mixed-crystals remain cubic and single-phased. They display a face-centred crystal structure with 4 formula units in the elementary cell, closely related to the fluorite structure, but with oxygen vacancies in the lattice. The oxygen deficiency, $x = p(2-y)$, e.g. amounts to 0.15 O for the divalent metals and decreases to 0.075 O for the trivalent metals. The vacancies are responsible for the efficient electrical conductivity at higher temperatures. The metal ions Mn^{2+}, Sc^{3+}, La^{3+}, Ce^{3+}, Sm^{3+}; Ti^{4+}, Nb^{5+} and Ta^{5+} offer further possibilities of partial Zr^{4+} substitution on the lattice sites of ZrO_2. It is important that the radius of the metal ion be similar to that of Zr^{4+} and that the divalent or trivalent cation be less electronegative than Zr^{4+}, thus possessing a more ionic bonding. Foreign radicals such as OH^- or SO_4^{2-} ions also are conducive to the stabilization of the lattice. Adding two metallic oxides of different valences to the cubic high-temperature modification of zirconia, instead of only one, has the same effect. Thus, through the admixture of titanium-, niobium-, or tantalum-oxide, ternary mixed-crystals develop from binary compounds. They are also stable from room temperature to more than 2000°C because these metals uniformly fix the eight-, seven- and six-fold oxygen-coordination of Zr^{4+} to a coordination number of 8. Some of the aforementioned cubic zirconias, e.g. $(Zr,Mg)O_{2-x}$, become metastable at annealing temperatures as a result of the significant oxygen deficiency which apparently initiates a slow movement of oxygen ions from a disordered, random distribution inside the anion lattice to the ordered lattice sites. Monoclinic ZrO_2 exsolves. At lower temperatures, the non-stoichiometric, that is the non-integer, composition of the mixed-crystals causes a physical hardening, probably the result of oxygen immobilization (ref. 3, 4, 5, 6).

2. The Growth of Stabilized ZrO_2 Crystals

Zirconia crystal growth by the known techniques is not

successful. Thus, taking advantage of the difference in electrical conductivity of ZrO_2 (insulator at room temperature and conductor at high temperatures) by applying the high frequency of an induction coil, the powder can be melted in an open cylindrical crucible. Addition of lower-melting zirconium metal grains and stabilizer powder initiates the process. Simultaneously, a thin layer of the zirconia powder is kept below the melting point at its contact with the wall of the cold crucible, so named because of the palisade of thin water-cooled vertical copper tubes. Upon slowly lowering the temperature, skull or geode shapes crystallize which consist of closely packed, columnar single-crystals measuring $25 \times 15 \times 10$ mm or more. This process, therefore, is called the skull melting method and has just been presented in detail by Nassau (ref. 7). In his article, he states that the properties of the synthetic material now reaching the market vary with chemical composition and are yet to be investigated.

3. The Physical Properties of Stabilized ZrO_2

Durafourg & Co., cutters in Lausanne (Switzerland), kindly placed at our disposal rough and brilliant-cut material of yttria-doped zirconia for examination purposes. As expected, it displays small but definite differences from the already characterized zirconia, stabilized with CaO (ref. 8, 9).

3(a) Inclusions

The fragment of a columnar crystal, almost 70 ct in weight, consists of a white crust on the base and subconchoidal lateral faces. According to the direction of the breaks, conchoidal faces result, having either a concentric cascade or a radial feather structure. These are accompanied by razor-like edges that will splinter to some extent. The inclusions are confined to the crust, which represents the contact zone of the melting oxide powders in the centre of the crucible and the cold, thermally insulating layer of powder at the innermost wall of the crucible. The polycrystalline crust is terminated by irregular pyramidal surfaces from which run tubelike and dumbbell-shaped cavities toward the centre. These internal growth characteristics continue through the 3 to 4 mm thick crust, becoming subparallel rows of isometric negative crystals. All inclusions are colourless and semitransparent. Their interfaces are lined with ZrO_2 powder which had been prevented

TABLE 1

Identification of Cubic Stabilized Zirconias

Properties	$(Zr, Y)O_{2-x}$		$(Zr, Ca)O_{2-x}$ (ref. 8)
Cut	round brilliant 32/24		brilliant 32/24(?)
Weight	3.86 ct	1.38 ct	—
Proportions			
Table	58%	60%	
Crown	15½%	14%	
Girdle	6%	6%	
Pavilion	45½%	47%	
Symmetry	good	good	
Polish	medium	insufficient	
Colour	weak yellowish	very weak pink (almost colourless)	colourless; according to pigmentation also various hues and degrees of saturation
Refractive Index n_D	2.1712 (±0.0005)	2.1651 (±0.0005)	2.1775 (±0.005)
Dispersion $n_F—n_C$	0.0338	0.0336	(0.0376)
$n_G—n_B$	0.0591	0.0587	0.0653
Reflectivity $R_{meas.}$	13.0% (polish)	12.3% (polish)	—
$R_{calc.}$	13.6%	13.5%	13.7%
Fluorescence			
UV-A	none	vw, reddish	none
UV-C	vw, greenish-yellow	w, greenish-yellow	distinct, yellow
Absorption total in the VIS	below 370 nm	below 340 nm	below 310 resp. 360 nm
	no lines or bands		no lines or bands
Inclusions	parallel rows of small, semitransparent, isometric crystal-like cavities extending into hazy stripes of tiny particles	none	in the experimental stage of growth small gas bubbles and individual large ones; in the new cuttable material no inclusions remain
Spec. Gravity (4°C)	5.950 (±0.005)	5.947 (±0.005)	5.65 (5.60 to 5.71)
Cleavage	none	none	—
Vickers Hardness V (500 g test load)	1250 to 1570 kg/mm² (indentation not oriented)		1407 and 1437 kg/mm² (oriented?)
Mohs Hardness			
$M_{det.}$	approximately 8¼		8½
$M_{calc.}$	approximately 8.2 (8.0 to 8.5)		(8.2 and 8.3)
Brittleness	more brittle than synthetic corundum but less than $Y_3Al_5O_{12}$		analogous
External characteristics	roundish facet edges, percussion marks, small chips		analogous
Magnetism	indifferent (diamagnetic?)		
Conductivity	electrical insulator (room temp.)		

from melting by the insulating action of a liquid or air trapped in the crust. These cavities, therefore, are of two phases, i.e. of the sl- or sg-type (solid, liquid, gaseous, ref. 6).

At the experimental stage of crystal growth, the subparallel rows of isometric negative crystals extended beyond the crust in the

form of hazy stripes. The yellowish brilliant-cut $(Zr,Y)O_{2-x}$ of 3.86 ct obviously came from the crust area of a crystal grown in that stage. The new refined material is essentially colourless and the inclusions do not extend into the clear columnar part of the crystal. The 70 ct crystal fragment only possesses a faint orange tinge and is completely transparent. But its surface consists of small, finely chiselled faces which form a weak growth striation parallel to the crust. When compared to each other, the aforementioned striations are perpendicular and leave the impression of 'frozen-in' interference patterns produced by standing mechanical waves.

The crystal fragment rather resembles the smaller brilliant-cut $(Zr,Y)O_{2-x}$ in its properties. The specific gravity, 5.966, is actually slightly higher and the fluorescence is somewhat stronger: UV-A weak, orange; UV-C medium, yellow. The scratch hardness is about 8¼. Material from the crust area manifests specific gravities as low as 5.80.

3(b) Scratch Hardness and Indentation Resistances

The investigation on the resistance to mechanical impact is more important when characterizing new synthetics than during subsequent gemmological identification, which in every normal case must be effected with non-destructive techniques. Which hardness test should be relevant is difficult to determine. The Mohs scratch-hardness values, a purely qualitative sequence of numerals, give a picture of the scratching rather than the cutting strength and general stability. A better measure for the velocity of wear of solids is the resistance to penetration, as determined by the Vickers and Knoop tests, both permitting an estimation of the barely measurable brittleness. Other tests deal with cutting or impact resistance qualities. As is to be expected from the atomic bonding, specific for each substance, these properties have a certain relationship to each other. The relationship of Mohs hardness (M) to any indentation hardness (IH) can be expressed by the following empirical, non-linear formula:

$$log\,(IH) = 0.2M + 1.5\ .$$

With the Vickers test, a square impression is formed by a diamond pyramid with 136° interfacial angle, under a given test load (P) and during a penetration period of normally 30 seconds.

The average diagonal length (d) of the square is then measured and used to calculate the Vickers hardness as follows:

$$V = \frac{1.8543\,P}{d^2} \left[\mathrm{kg/mm^2} \right] .$$

In general, the size of the indentation depends on the test load, the shape of the indentor (sphere, cone; rhomboidal, square or pentagonal pyramid), its crystallographic orientation relative to that of the specimen and the test temperature. Experimentation has proved the Brookes method of indenting hard solids to be the best. Its pentagonal diamond pyramid has a longer life expectancy than other indentors and diminishes the distorting influence of hardness anisotropy on the shape of the impression (ref. 10, 11).

The Vickers hardness of $(Zr,Y)O_{2-x}$, as measured under the Leitz-Microhardness instrument, lies between 1250 and 1570 kg/mm². Applied to the first formula, these values place the Mohs hardness at 8 to 8.5 which coincides with the actual scratch result of 8¼. Interestingly, tests with a 1 kg load on a universal indentation apparatus (industrial model OM 250 of Gnehm & Co. in Horgen, Switzerland) resulted in Vickers hardness figures in the same range. The average of 1400 kg/mm² is slightly lower than the specifications for $(Zr,Ca)O_{2-x}$, but this may not be a real difference since the indentations were not oriented (Table 1). Under the same conditions, resistances to penetration were found to be about 1570 kg/mm² for $Y_3Al_5O_{12}$ and 2290 kg/mm² for synthetic ruby. These orders of magnitude correspond to the data in the literature (1550 kg/mm² for YAG, and 2200 kg/mm² for sapphire). Calculated Mohs hardness values are approximately 8.5 and 9.3. So, the new zirconias are not harder than their predecessor, YAG, but less brittle, for they show less tendency to splinter at the edges of the impression produced by the diamond. The synthetic ruby is tougher and considerably harder, though maybe not quite as hard as suggested by the calculation ($M \approx 9.3$). However, for $M > 9$ the given relation with V is not quite certain.

The hardness anisotropy of stabilized zirconia samples is possibly a bit higher than indicated, yet in no way extreme. For diamond, hardness differences strongly depend on cleavage directions. Indentation resistances are known to range from 5700 to 10 400 kg/mm², with averages near 9000 to 10 000 kg/mm². These

values illustrate the demands placed on a convincing diamond imitation. With a hardness near 4500 or 4750 kg/mm^2, cubic boron nitride (BN), among all known substances, comes closest to the diamond in this respect. The great hardness of both materials originates from the same type of strongly covalent, oriented bonding. It differs only in the atomic spacing which measures 1.57Å in boron nitride and 1.545Å in diamond and in the absence of any ionic bonding character of the diamond (ref. 12).

3(c) Absorption

The spectral diagram (see Figure 1) reflects the typical course of different nearly colourless synthetic materials and diamond. The relationship among the curves is not real. In each case, however, they display good transparency of the solids in the visible range (VIS) and gradual to steep decrease of transmission (increase of absorption) toward the ultraviolet region. The absence of absorption lines and bands in the VIS causes the weak body colours. The absorption edges of strontium titanate and synthetic rutile have virtually no influence on colour. The human eye is quite insensitive to the violet wavelengths and would not detect their absence. Gadolinium gallium oxide (GGG) demonstrates interesting absorption lines in the UV and emission lines in the VIS, under the stimulation of short-wave UV radiation (medium strong 595 nm and weak 614 nm, not recorded here).

4. The Structure and Composition of $(Zr,Y)O_{2-x}$

The microprobe analysis showed Zr and Y as metal constituents. Semiquantitatively, proportions of ≈15.8 mol% $YO_{3/2}$ for the crystal fragment and of ≈18.3 mol% $YO_{3/2}$ for the round $(Zr,Y)O_{2-x}$-rough were detected. Ca, Mg, and Ti are not present in these samples. Because of line interferences (even from higher electron orbits), rare earth elements could be ascertained only with considerably refined mathematical corrections. It is very likely that trace elements, e.g. Nd, Ce, Er, cause the very weak pink colour of the small brilliant-cut $(Zr,Y)O_{2-x}$. Hafnium, in the form of hafnia, with its chemical affinity to zirconium, is a permanent companion of zircons ($ZrSiO_4$), suppliers of the raw materials. Separation of the two oxides, HfO_2 and ZrO_2, is both difficult and costly. It is only done for special purposes and for the extraction of hafnia which does not form independent minerals. A HfO_2 content

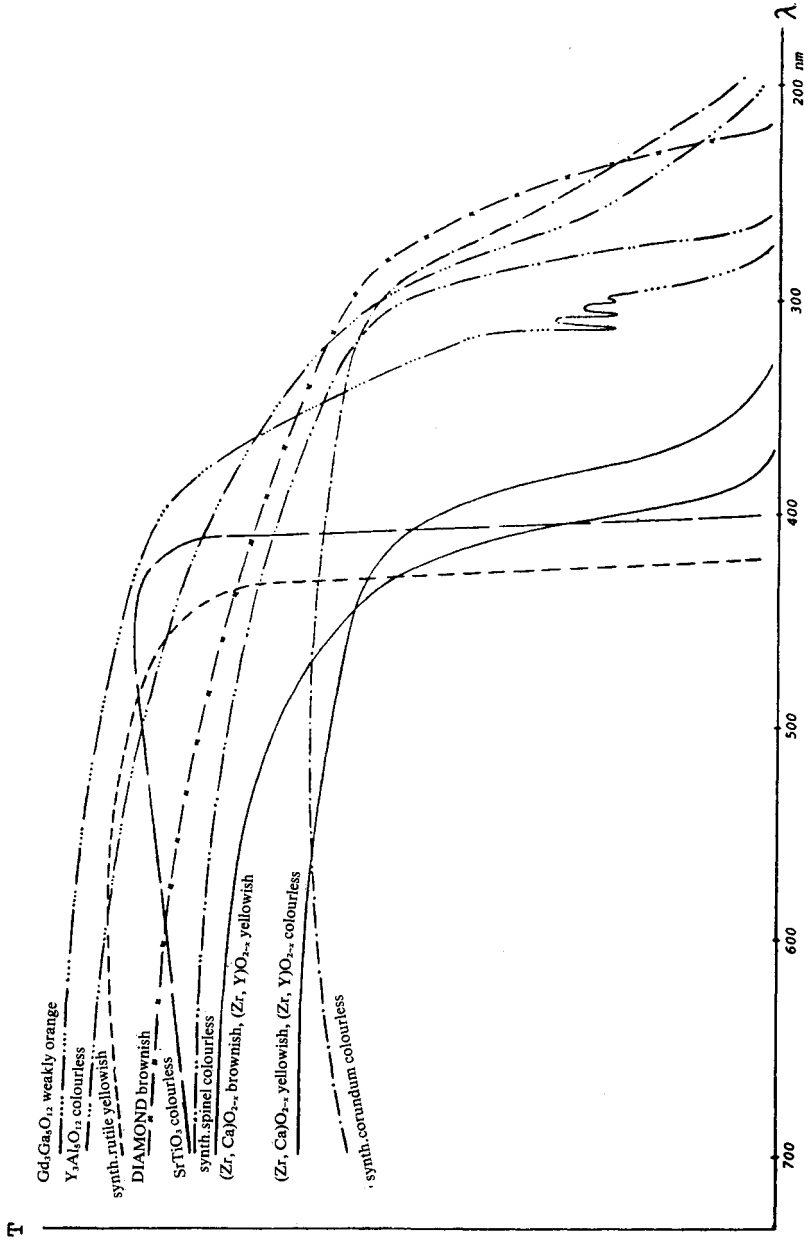

Fig. 1 Schematic presentation of the spectial transmission behaviour of diamond and its most important imitations at ambient temperatures.

in the magnitude of 0.5 to 1 mol% cannot be ruled out although in the present synthetic crystals no significant quantities were discovered.

4(a) Crystal Structure

The specification of crystallographic data is also required for the characterization of a new solid. Together with optical values, it allows verification of the chemical composition which, in the present cases, cannot be considered completely reliable. From the x-ray diffraction pattern of powdered $(Zr,Y)O_{2-x}$, a close relationship to cubic ZrO_2 of the crystal-class O_h can be deduced. This is especially so with respect to the stabilized binary phase $(Zr_{0.85}Ca_{0.15})O_{1.85}$ (ref. 13). An evacuated, self-focusing x-ray camera of the Guinier-de Wolff type was used.

The lattice constant (a_o) can also be established. From this, the specific gravity is calculated for the cubic case and in the

TABLE 2

Interplanar Spacings d_{hkl} of Stabilized Zirconias

$(Zr_{0.84}Y_{0.16})O_{1.92}$ $\lambda(CuK\alpha/Ni) = 1.5418$ Å silicon standard			$(Zr_{0.85}Ca_{0.15})O_{1.85}$ $\lambda(CuK\alpha_1/Ni) = 1.54056$ Å ASTM card 26-341		
d [Å]	hkl	$I_{estim.}$	d [Å]	hkl	I/I_1
2.97_5	111	100	2.961	111	100
2.58	200	15	2.565	200	20
1.820	220	50	1.815	220	45
1.552	311	40	1.548	311	25
1.484	222	5	1.4823	222	4
1.286	400	5	1.2837	400	4
1.180	331	10	1.1781	331	6
1.149	420	5	1.1482	420	4
cubic system space group Fm3m $a_0 = d\sqrt{h^2+k^2+l^2}$			1.0484	422	5
			0.9884	511 333	4
			0.9080	440	1
$a_0 \cong 5.145$ Å (weighted)			$a_0 = 5.135$ Å (weighted)		

CGS-system (cm,g,sec) according to the formula:

$$SG = \frac{z\,M}{N\,V} = 1.6602\,\frac{z\,M}{(a_o)^3},$$

where z represents the number of formula units in the elementary cell (= 4 molecules). V is the unit cell volume and M the molecular weight of the mixed-crystal. N represents the Avogadro number of molecules per mole (= 6.023×10^{23} mole^{-1}; ref. 14).

4(b) Verification of the Chemical Composition

The specific gravity gives a clue to the chemical composition and to impurities such as inclusions and other perturbations of the real crystal. The specific gravity (5.966±0.003) as well as the lattice constant (5.145±0.005Å) of the crystal fragment are known. So the equation can be resolved for the molecular weight. It follows that M = 122.35. This coincides with the molecular weight of 122.4 from the analysis, if a trace of hafnium oxide is taken into account. On the basis of 4 (Zr + Y), the approximate non-stoichiometric, that is the non-integer, structural formula can be given as $(Zr_{3.37}Y_{0.63})O_{7.68}$. The formula for the round rough approximately is $(Zr_{3.27}Y_{0.73})O_{7.63}$. Alternatively, these formulas can be expressed as $(Zr,Y)O_{1.92}$ and $(Zr,Y)O_{1.91}$ or, in dualistic writing, 3.37 ZrO_2. 0.63 Y_2O_3 and 3.27 ZrO_2. 0.73 Y_2O_3 (ref. 15).

Gladstone and Dale's rule offers another means of verification. The specific refractivity (or specific refractive power, K) of a material is related to its specific gravity (SG) and refractive index (n) through the following equation:

$$K = \frac{n-1}{SG}$$

The specific refractivity can be cross-checked with the partial refractive powers (k) and weight proportions (q) of the constituent oxides by the formula:

$$K = k_1q_1 + k_2q_2 \ldots\ldots k_nq_n$$

For most minerals, the two results of K differ by less than 5% (ref. 16).

The results lie within the expected limits, especially if a small amount of HfO_2 would be taken into consideration. Calculations with lattice constants from precise x-ray data lead to reliable values for the specific gravity (and molecular weight). This second, physical method is only appropriate for verifying the overall

TABLE 3

Verification of the Chemical Compositions

Specimen	$K = \frac{n-1}{SG}$	$K = k_1q_1 + k_2q_2$
$(Zr, Y)_4O_{7.68}$	0.197	0.193
$(Zr, Y)_4O_{7.63}$	0.196	0.191
$(Zr, Ca)_4O_{7.44}$	0.209	0.203
$k(ZrO_2) = 0.201$, $k(Y_2O_3) = 0.144$, $k(CaO) = 0.225$, $k(HfO_2) = 0.3$		

chemistry because of the relatively uncertain partial refractive power values. A systematic inadequacy of the formula cannot be excluded since it was developed for liquids and gases.

Nevertheless, when the weight proportions of a compound are varied or constituents substituted, the qualitative behaviour of its refractive index and specific gravity can be predicted by means of the two equations for K. Thus, $(Zr,Ca)_4O_{7.44}$ should show a similar refractive index, but a distinctly lower specific gravity than the two $(Zr,Y)_4O_{8-4x}$. Table 1 confirms this. The partial refractive power of the CaO stabilizer is higher and the molecular weight lower than that of the yttria additive, with lattice constants of the binary zirconias being almost identical (5.07 to 5.15 Å). For cubic stabilized hafnia, theoretically being cuttable material, essentially higher refractive index and specific gravity values must be expected than for each stabilized zirconia, since its lattice constant also is near 5.2 Å (ref. 9, 3).

5. Conclusion

The stabilized zirconias are the latest products in the jewellery trade. For the time being, they may be considered as the most convincing of medium expensive, highly refractive diamond imitations. The gemmologist has no reason for anxiety if he remains alert and is able to effect a determination of the specific gravity and light refraction, e.g. by the apparent depth method. As many tests have demonstrated, the refractive index (n = measured depth: apparent depth) can be established, by means of a microscope and competent measurement, with an accuracy better than 1% (n for $(Zr,Y)O_{2-x}$ = 2.17±0.02 to 2.16±0.02). This technique has the advantage of being independent from the quality of the surface

(polish and flatness) and of being more precise than the approximation of n based on the principle of reflection, e.g. with a Gemeter or micro-spectrophotometer (R in Table 1).

Usually, not the real but the diamond weight corresponding to the size of the mounted synthetic stone is stated, and this creates additional confusion. It therefore is not possible to determine or estimate the specific gravity of the fake diamond. For positive identification, a value in addition to the refractive index figure would be useful in this case. Here dispersion becomes important. It can be approximated by the microscopic technique mentioned above, applying interference filters. Most likely the differentiation between yttria- and calcia-stabilized zirconias would not be possible. However, this has little significance.

The variations of the gemmologically important values, recently published by Nassau (ref. 7), are: refractive index n_D = 2.15 to 2.18, dispersion $n_G - n_B$ = 0.060 to 0.063, Mohs hardness M = 7½ to 8½ and specific gravity about 6. For jewellery material they have to be slightly altered. The variation of n remains the same. The dispersion range must be extended to $\leqslant 0.059$ for $(Zr,Y)O_{2-x}$ and to $\geqslant 0.065$ for $(Zr,Ca)O_{2-x}$. Mohs hardness has not been found inferior to M = 8. The specific gravity enables the unequivocal separation of $(Zr,Y)O_{2-x}$ and $(Zr,Ca)O_{2-x}$. Their ranges are 5.94 to 5.97, and 5.60 to 5.71 respectively (values for CaO-stabilized zirconia by Gübelin, ref. 8). Stabilized zirconias may be coloured by pigmentation. Almost colourless specimens transmit the visible radiation freely, but absorb totally below about 340 nm. Inclusions are absent in the newest products. At room temperature, zirconias are structurally stable, physically resistant and chemically inert.

It is conceivable that zirconias will appear containing stabilizers other than yttria or calcia. The indicated variations, therefore, may again increase in future.

To verify Mohs hardness values and the chemical composition of solids, rarely used mathematical formulas have been presented. The rule of Gladstone and Dale should be pointed out. It permits a qualitative prediction of the refractive index and specific gravity of materials with identical crystal structure and variable composition. The x-ray data of Table 2 demonstrate that the interplanar spacings and lattice constants, on the other hand, are fairly insensitive to chemical variations.

Reflection patterns of the two brilliant-cut $(Zr,Y)O_{2-x}$ with mediocre polish, recorded by means of a Gemprint instrument, did not differ greatly from those of the predecessors $Y_3Al_5O_{12}$, synthetic spinel, synthetic rutile, and $SrTiO_3$. The patterns display a limited number of large multipartite black spots on the film negative. They cannot be confused with the configurations of numerous small but intense reflections produced by diamonds and zircons. However, an approximate matching would be possible by improving the polish and reducing the pavilion angle and girdle thickness of the latest diamond imitations.

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BRIEF NOTES ON SOME NEW SYNTHETICS

By M. J. O'DONOGHUE, M.A., F.G.S., F.G.A.

Two amethysts, both cut and of large size and good colour, have been examined recently. They were obtained through the good offices of Dr L. Baumgartner, of the firm of Swarovski in Austria, one stone being in the author's collection and the other belonging to the Worshipful Company of Goldsmiths. I am informed by Dr Baumgartner that the stones are manufactured in the U.S.S.R. and other reports have been made which seem to indicate that similar stones are reaching the American market.[1] Neither stone showed any noticeable inclusions under 10× magnification or under the microscope (about 40×). Though the stone is presumably manufactured by the hydrothermal process with the use of a seed, there is no sign of the usual discontinuity in the region where seed and overgrowth meet (the area in which 'heat-shimmer' or 'breadcrumbs' are frequently seen). Refractive index and specific gravity are typical for quartz; there is no trace of luminescence nor any absorption in the visible spectrum. Neither stone transmitted short-wave ultraviolet light. One feature only strikes the observer: the colour, although dark and quite pleasing, contains a degree of mauve-brown which can be seen in the stones under discussion when tilted slightly away from the light source; this is not shown with the dichroscope and, although quite easy to see, would not be noticed by the layman, although the experienced dealer or gemmologist might be put on his guard. Generally speaking, there is no way to identify synthetic quartz if cut from a region well away from the seed; fortunately there seems to be little chance of this material making a commercial success. Recent studies seem to show that some synthetic quartz is opaque, or at least far less transparent, to short-wave ultraviolet radiation. More tests on a wider range of synthetic material need to be carried out before this can be said to be useful—green synthetic material, for example, appears to behave in this respect very much the same as natural quartz*.

Two white opals made by the firm of Pierre Gilson have recently been examined. Although magnification reveals the customary hexagonal 'honeycomb' structure, the stones are translucent to a much greater degree than some of the earlier

*See J. Gemm., 1978, XVI, 3, 218-220.—Ed.

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products from this firm, and could be confused with water opal at first sight. No luminescence or phosphorescence was observed.

I have recently received from the manufacturer (Djévahirdjan) two specimens of coloured zirconia. The manufacturer states that they will not at present market coloured material but concentrate on perfecting the colourless crystals which have potential as diamond simulants. One of the coloured pieces (both are crystal sections) is violet and resembles the scapolite from East Africa as far as colour goes; the presence of a heavy didymium absorption spectrum at once reveals its true nature, or at least its artificial genesis. In the stone examined the doping had been so heavy that the two groups of fine lines had each coalesced into a band-like structure. The other piece, brownish-pink in colour, showed no absorption in the visible region and the colour may be due to Ti or Ni.

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GEMMOLOGICAL COLORIMETRY

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ABSTRACT
The necessity and advantages of a system of colorimetry for gemmological use are first propounded. Various scientific methods of specifying colours are then described. Transparent cabochons are chosen as examples for the application of these methods.

§1 INTRODUCTION

The value of a gem is dependent on factors such as its weight, perfection, cutting and colour. Among its various attributes only the weight can be easily measured and unambiguously quoted. So far there has not been any objective means of specifying a colour. A gem dealer in London cannot describe accurately the colour of a gem to his client in New York without actually sending the stone. Yet the price of a ruby or sapphire can change by several hundred per cent as a result of a slight variation in colour.

Whether the colour of a gem is natural or artificially induced, it is liable to fade or change over a period of years. Chemical and physical transformations take place slowly as a result of heat, moisture, radiation or simply aging. (Findlay 1977, O'Donoghue 1974, Hutton 1974). Lacking any objective quantitative measurement of colours it is impossible to detect slight colour changes that take place very gradually. Hence posterity several centuries from now will not be able to visualize the colour of a crown jewel as it appears today.

The above considerations indicate clearly a real need for a scientific method of measuring and defining colours in gemstones. In other words, we should develop a new branch of science called gemmological colorimetry.

As far as their colour-rendering properties are concerned, gems may be classified into the following three categories:

(1) Transparent cabochons; e.g. ruby and sapphire cabochons.

(2) Opaque, translucent or iridescent cabochons; e.g. turquoise, jade and opal cabochons.

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(3) Transparent faceted stones; e.g. diamond and emerald in round brilliant or emerald cuts.

In the second category several shades of colours are usually present on one cabochon surface, so that it is necessary to describe the distribution pattern as well as the varieties of colours. In the third category the faceted stones disperse the incident white light into all the colours of a rainbow, giving 'fire' to the stone. As a first step in the development of gemmological colorimetry we shall deal with the first category exclusively in the present discussion.

§2 Specification of Colours

§2.1 *Hue, Saturation and Lightness*

Any colour is completely described by its hue, saturation and lightness. Hue is the attribute of visual sensation according to which the observer distinguishes light of different spectral compositions. A hue is denoted as red, yellow, green and so on, depending on the wavelength of the light. An achromatic colour is one not possessing a hue. It can be roughly described as 'white' in layman's language.

The saturation of a colour is the degree of its difference from the achromatic colour most resembling it. Saturation can be pictured as the 'strength' of a hue. For example, two drops of red ink dispersed in water would give a colour of higher saturation than one drop of red ink dispersed in the same amount of water. The lightness of a colour is the attribute of visual sensation ranging from black to white for achromatic light diffusing objects, and from black to perfectly 'colourless' for achromatic transparent objects.

The visual perception of the lightness of a colour is a subjective experience depending on the observer as well as on the incident light. The capacity of light to evoke lightness sensation is called the luminous flux. Equal amounts of radiant energy of different wavelengths do not produce visual sensations having equal lightness. A luminous efficiency curve shows as ordinates the capacities (reciprocals of the required amounts of energy) of light of various wavelengths to evoke sensations of equal lightness. The luminous efficiency curve of the standard observer for photopic vision as adopted by the International Commission on Illumination (Commission Internationale de l'Eclairage, abbreviated CIE) is shown in Figure 2.1 (CIE Proc. 1924). It is assumed to be valid for

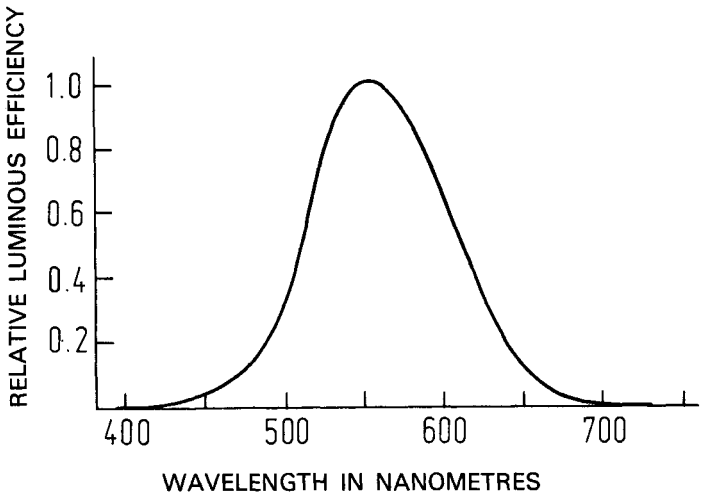

Fig. 2.1 Luminous efficiency function for photopic vision.

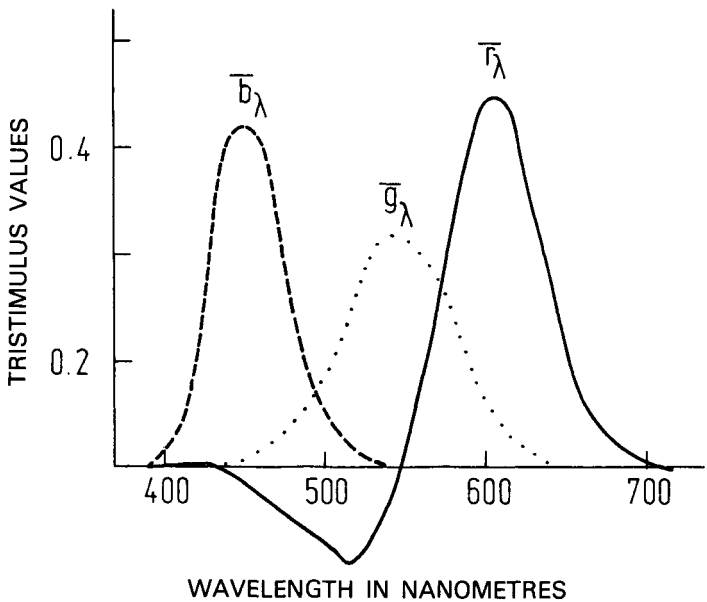

Fig. 2.2 Colour-matching functions in *R, G, B* system.

about 95% of the total population, i.e. for people having normal colour vision.

§2.2 *Trichromatic Colour-matching*

Any colour can be precisely specified by the method of 3-colour matching. The colour to be specified (hereafter called the sample colour) is visually compared with a mixture of three primary colours, usually red, green and blue. The amounts of the three primary colours are adjusted so that the resultant mixture appears to have identical colour with the sample. Suppose $\boldsymbol{S}_1$ is a vector representing the sample colour and $\boldsymbol{R}$, $\boldsymbol{G}$, $\boldsymbol{B}$ are vectors representing unit amounts of the three primary colours, then the vector equation

$$\boldsymbol{S}_1 = \mathrm{R}_1\boldsymbol{R} + \mathrm{G}_1\boldsymbol{G} + \mathrm{B}_1\boldsymbol{B} \tag{2.1}$$

indicates that the sample colour $\boldsymbol{S}_1$ is matched by an additive mixture of quantities R_1, G_1, B_1 of the respective primary colours $\boldsymbol{R}$, $\boldsymbol{G}$ and $\boldsymbol{B}$. The scalar quantities R_1, G_1 and B_1 are called the tristimulus values of the sample colour $\boldsymbol{S}_1$ with respect to the chosen set of primary colours $\boldsymbol{R}$, $\boldsymbol{G}$ and $\boldsymbol{B}$.

There are some colours which cannot be matched by a direct mixture of $\boldsymbol{R}$, $\boldsymbol{G}$ and $\boldsymbol{B}$ as indicated by Eq. (2.1). Such a colour has to be mixed first with a suitable amount of one of the primary colours before it can be matched with a mixture of the remaining two primary colours. Eq. (2.2) shows the matching equation for such a colour $\boldsymbol{S}_2$:

$$\boldsymbol{S}_2 + \mathrm{r}_2\boldsymbol{R} = \mathrm{g}_2\boldsymbol{G} + \mathrm{b}_2\boldsymbol{B} \tag{2.2a}$$

$$\boldsymbol{S}_2 = -\mathrm{r}_2\boldsymbol{R} + \mathrm{g}_2\boldsymbol{G} + \mathrm{b}_2\boldsymbol{B} \tag{2.2b}$$

Note that Eq. (2.2b) has the same form as Eq. (2.1) if we allow negative values of tristimulus values. Thus all colours can be specified by their tristimulus values.

Suppose the three primary colours are chosen to be monochromatic light of wavelength 700 nm ***(R)***, 564.1nm ***(G)*** and 435.8nm ***(B)***. If equal amounts of light from narrow regions of the entire visible spectrum are successively employed as the sample colour, the amounts of the $\boldsymbol{R}$ primary colour necessary for the colour match is shown in the solid curve of Figure 2.2. It is known as the colour-matching function $\bar{\mathrm{r}}_\lambda$ in the primary system $\boldsymbol{R}$, $\boldsymbol{G}$, $\boldsymbol{B}$. Similarly the amounts of $\boldsymbol{G}$ & $\boldsymbol{B}$ primary colours required for colour-matching are shown as functions $\bar{\mathrm{g}}_\lambda$ and $\bar{\mathrm{b}}_\lambda$ in Figure 2.2. In

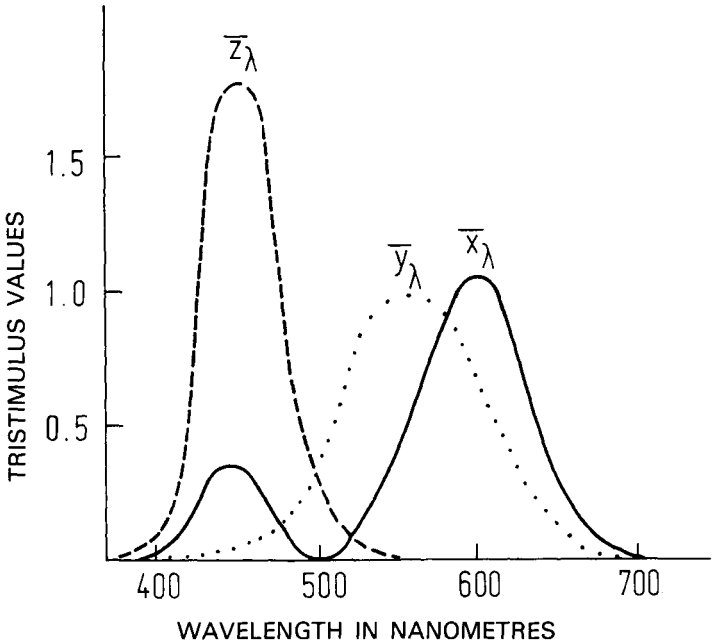

Fig. 2.3 CIE colour-matching functions $\bar{x}_\lambda$, $\bar{y}_\lambda$, $\bar{z}_\lambda$.

the ***R, G, B*** system defined above the colour-matching function $\bar{r}_\lambda$ has negative values for wavelengths around 500nm. In order to facilitate computation in colorimetric work the International Commission on Illumination adopted the ***X, Y, Z*** system in which the colour matching functions $\bar{x}_\lambda$, $\bar{y}_\lambda$, $\bar{z}_\lambda$ have no negative values, as shown in Figure 2.3 (CIE Proc. 1931).

Consider a sample colour ***S*** with tristimulus values X, Y, Z in the ***X, Y, Z*** system. We define its chromaticity coordinates by

$$x = \frac{X}{X+Y+Z}$$

$$y = \frac{Y}{X+Y+Z} \qquad (2.3)$$

$$z = \frac{Z}{X+Y+Z}$$

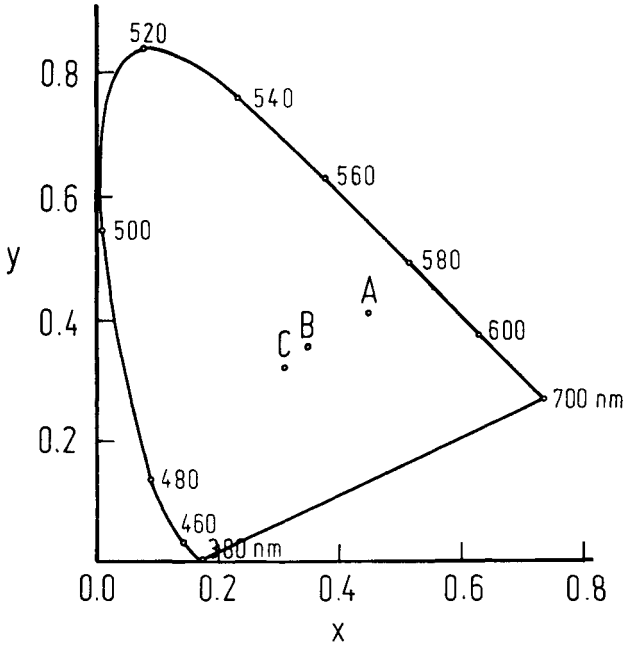

Fig. 2.4 CIE (x, y) chomaticity diagram.

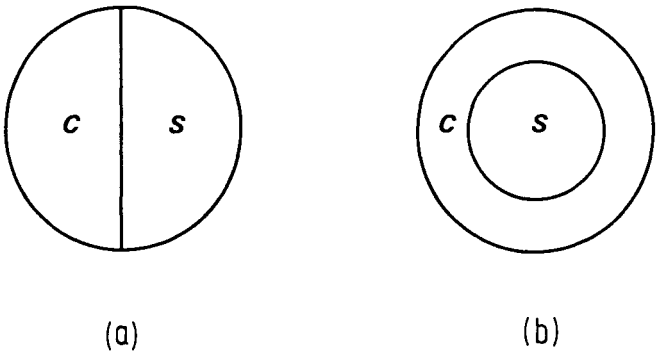

Fig. 2.5 Field of view in visual colorimeters.

Since the sum of x, y and z is always unity, the chromaticity of a colour is completely defined by any two of its three chromaticity coordinates. Two such coordinates fix the position of a point on the chromaticity diagram. The chromaticity coordinates of each spectrum colour are calculated from Eq. (2.3) and plotted on a chromaticity diagram (Figure 2.4). The locus is a smooth continuous curve. The points A, B, C on the diagram correspond to the CIE standard light sources A, B, C to be described in §3.

§2.3 *Colorimeters*

A visual colorimeter is a device by which a sample colour ***S*** can be matched visually with another adjustable comparison colour ***C***. The field of view consists of the sample and comparison colours, as shown in Figure 2.5. The observer adjusts the comparison colour until it matches the sample colour. Various types of visual colorimeters are available (Judd & Wyezecki 1963, Committee on Colorimetry of the Optical Society of America 1963). In Stiles trichromator or Wright colorimeter the comparison colour is formed by a mixture of lights of three primary colours. The tristimulus values of the sample colour with respect to the instrumental primary colours are convertible to the CIE (X, Y, Z) tristimulus values. In this way they provide absolute quantitative specification of colours.

§3 Illumination and Colour Measurement

The colour of a transparent cabochon arises from reflection of the incident light by its top and bottom surfaces. The reflected light depends not only upon the nature of the reflecting surfaces but also upon the spectral distribution of the incident light. It is well known that the colour of a gem can vary markedly with the illumination. Alexandrite appears green in daylight but red under a lamp. A yellow diamond that displays intense blue fluorescence will look bluish under strong daylight. Therefore consistent and meaningful data on the colour of gemstones can only be obtained by using standard light sources and adopting standard conditions of illumination and measurement. Natural daylight is obviously unsuitable as a standard light source since it is subject to great fluctuations in both intensity and spectral composition. The International Commission on Illumination recommends the following

three standard light sources for colorimetry (CIE 1931, Davis *et al.* 1953):

(1) Source A—an incandescent tungsten lamp operated at a colour temperature of 2854 K (K stands for degree Kelvin—see Nassau 1977).

(2) Source B—the source A combined with a two-cell Davis-Gibson liquid filter B, the composition of which is given in Table 3.1 (Davis & Gibson 1931). Source B is a simulation of direct sunlight at noon. Its correlated colour temperature is about 4870 K.

(3) Source C—Source A combined with a two-cell Davis-Gibson liquid filter C. It is an approximation to the average daylight. The correlated colour temperature is about 6770 K.

Table 3.1

Composition of Davis-Gibson Liquid Filters B & C

	Filter B	Filter C
Cell 1 (1 cm)		
Copper sulphate ($CuSO_4.5H_2O$)	2.452g	3.412g
Mannite ($C_6H_8(OH)_6$)	2.452g	3.412g
Pyridine (C_5H_5N)	30 cm^3	30 cm^3
Distilled water to make	1000 cm^3	1000 cm^3
Cell 2 (1 cm)		
Cobalt ammonium sulphate ($CoSO_4(NH_4)_2SO_4.6H_2O$)	21.71g	30.58g
Copper sulphate ($CuSO_4.5H_2O$)	16.11g	22.52g
Sulphuric acid (density 1.835)	10 cm^3	10 cm^3
Distilled water to make	1000 cm^3	1000 cm^3

Figure 3.1 shows the spectral distributions of these three standard light sources. In the diamond trade the northern-sky light has been the standard light source. Since CIE source C has a spectral distribution very similar to the northern-sky light (Taylor & Kerr 1941), it is ideal as a standard light source for gemmological colorimetry. It will provide stable standard illumination day and night under all weather conditions.

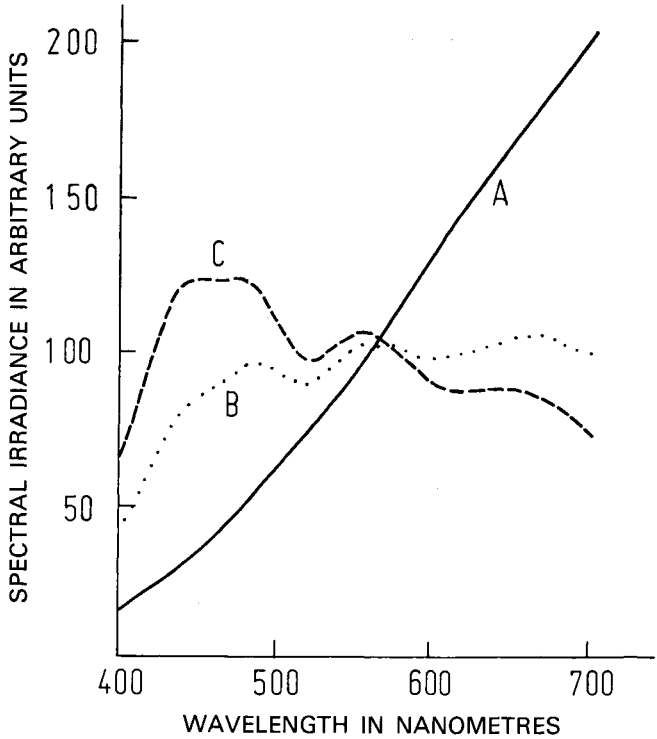

Fig. 3.1 Spectral distributions of standard light sources A, B & C.

The colour of a gem is dependent on its position relative to the light source and the observer. For measurement of the spectral reflectance of surfaces the International Commission on Illumination (CIE Proc. 1931) recommends the (45°, 0°) arrangement in which the reflecting surface is illuminated at 45° and viewed perpendicularly to the surface. This arrangement has already been widely used in jewellery shops. (Figure 3.2). We propose that for gemmological colorimetry the distance of the gem from the observer be fixed at 25 cm, the nearest distance of clear vision for normal eyes.

§4 Other Colour Systems

Material standards are often selected to represent scales of hue, saturation and lightness. A sample colour may be specified by

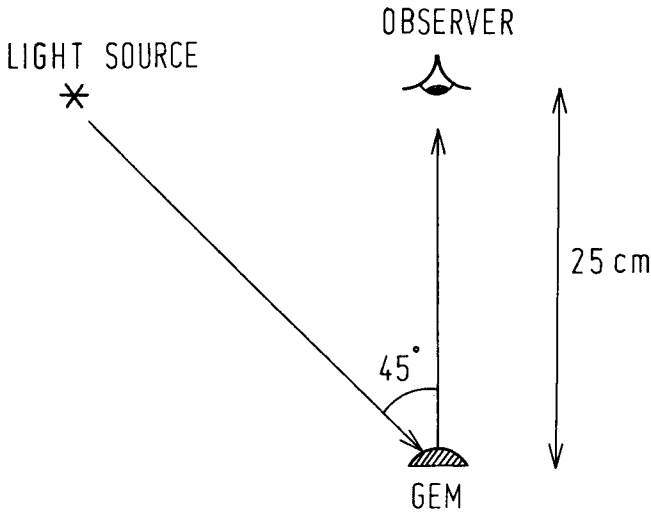

Fig. 3.2 The (45°, 0°) arrangement of illumination and observation.

identifying it with a particular member of such a material colour system. The DIN Colour System (DIN 6164) has been realized in the form of painted rectangular paper chips with a matt finish. The chips are arranged in terms of hue (DIN- Farbton), saturation (DIN- Sättigung), relative lightness (DIN- Dunkelstufe) and specified accordingly. The Munsell Colour System (Davidson *et al.* 1957) is realized in the form of 1225 different colours painted on high-gloss surfaces. The Inter-Society Color Council and the National Bureau of Standards have developed a systematic set of colour names (Kelly & Judd 1955). The ISCC-NBS publication includes equivalent ISCC-NBS designations for 7500 colour names previously published in eleven different colour systems, among which are the Munsell Colour System, the Maerz and Paul Dictionary of Color (Maerz and Paul 1951), the British Colour Council Dictionary of Colour Standards (British Colour Council 1934).

Provided the necessary precautions are taken the colour of a gem can be accurately recorded on a colour slide. If the light source and the magnification of the slide viewer are correctly chosen, an actual-size, true-colour image of the gem can be readily observed. Colour slides of a precious stone can be sent to potential buyers all

over the world at the same time. This would effect considerable saving in time as well as in insurance costs. As holographic techniques improve we shall soon be able to record 3-dimensional colour pictures of gems and jewellery in colour holograms.

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[*Manuscript received 16th September, 1977.*]

GEMMOLOGICAL ABSTRACTS

ALTHAUS (E.). *Fehler in der Struktur.* (Defects in structure.) Lapis, **3**, 4, 12-15, 5 figs (3 in colour), 1978.

Discusses the cause of colour in the varieties of beryl with reference to absorption spectra and irradiation. M.O'D.

ANDERSON (M.). *Brazil—nature's mineral treasure chest.* Lapidary Journal, **31**, 11, 2303-12, 23 figs (10 in colour), 1978.

Describes and illustrates the gem-bearing areas of Brazil with particular reference to Ouro Preto in the state of Minas Gerais. Topaz from this region is depicted in colour and a map of the area is included. M.O'D.

ANDRES-GAYON (J. I.). *Una nueva síntesis.* (A new synthesis.) Boletin del Instituto Gemológico Español, **17**, 37-38, 1978.

Describes a new synthetic emerald with RI 1.547-1.552, DR 0.005. It shows a medium red through the colour filter. Very small sizes made so far; name of maker not given. M.O'D.

BAKER (W. E.). *Some exotic minerals of Western Tasmania.* Australian Gemmologist, **13**, 4, 99-103, 4 figs, 1 map, 1977.

Accounts of anglesite, cerussite, crocoite, dundasite, pyromorphite and stichtite occurring around Dundas and Zeehan in an area chiefly noted for gold and cassiterite. Not of gem significance. R.K.M.

BALL (R. A.). *Identification of synthetic opal—a review.* Australian Gemmologist, **13**, 5, 131-3, 3 figs, 1978.

A summary of the findings of several writers. R.K.M.

BALL (R. A.). *Imitation opal.* Australian Gemmologist, **13**, 5, 156-8, 5 figs, 1978.

A paper on Slocum stone which confirms the layered structure of included films but throws doubt on Darragh and Sanders' suggestion that they are alternating layers of silica and alumina. R.K.M.

BALL (R. A.). *Natural or synthetic opal.* Australian Gemmologist, **13**, 4, 104-5, 2 figs, 1977.

A short paper on structural differences revealed by electron-micrographs at 5000×. Author doubts infallibility of this test. Synthetic opal showed tendency to disintegrate when etched and under electron beam. R.K.M.

BANCROFT (P.). *Royal gem azurite.* Lapidary Journal, **32**, 1, 66-129, 15 figs (12 in colour), 1978.

Describes an azurite noted for hardness and toughness found on the Copper World mining property between Barstow and Las Vegas. M.O'D.

BANK (H.). *Gelber schleifwürdiger Skapolith mit hoher Licht- und Doppelbrechung aus Ostafrika.* (Yellow cuttable scapolite with high RI and double refraction from East Africa.) Z.Dt.Gemmol.Ges., **27**, 1, 23-25, bibl., 1978.

Various scapolites examined in the last few years are described and some additional high value R.I.s and double refractions mentioned. Further details to follow. E.S.

BANK (H.). *Skapolithe, orange-gelb avanturisierend.* (Orange-yellow aventurized scapolites.) Z.Dt.Gemmol.Ges., **27**, 1, 26, 1978.

The author describes two scapolites from Kenya showing an aventurine-like effect caused by needle-like inclusions of iron oxide. The stones were orange-yellow. E.S.

BANK (H.). *Topas als Danburit bestimmt.* (Topaz determined as danburite.) Z.Dt.Gemmol.Ges., **27**, 1, 41, 1978.

A number of gemmologists diagnosed a simple topaz as danburite. Dr Bank compares the physical and optical values of the two stones. E.S.

BASTOS (F. M.). *Occurrence of cordierite in the state of Minas Gerais, Brazil.* Lapidary Journal, **31**, 11, 2336-8, 3 figs, 1978.

Cordierite is found in the district of Virgolandia, close to the cities of Pecanha and Governador Valadares. It occurs with quartz and biotite mica. Some stones were sufficiently transparent to allow them to be faceted as gemstones. Details of the properties of cordierite are given. M.O'D.

BERKOWITZ (R.). *Report on microscopes.* Canadian Gemmologist, **2**, 2, 10-13, 1978.

Discusses the relative merits of the De Luxe Mark V Gemolite, the Custom Mark V Gemolite B, the Custom Mark V Gemolite A, the Nikon SMZ3, the Olympus model JM, the Zeiss Jena Citoval and the Carl Zeiss stereo-microscope DV4. This last was found to be the best optically, though the best all-round value was thought to be the Custom Mark V Gemolite B. The Nikon gave best performance for a low price. M.O'D.

BROWN (G.). *The Burinut.* Australian Gemmologist, **13**, 5, 134-40, 6 figs, 1978.

The buri nut, the seed of the talipot or corypha palm of SE. Asia, is being used as a source of vegetable ivory in Australia. The naturally spherical seeds are tumbled to give beads with either dark brown, mottled or off-white finish according to the degree to which the outer surface is removed. Resultant beads are porous cellulose and white ones can be bleached to a better ivory hue, or stained to other colours with aniline dyes. R.K.M.

CALAS (G.). *Le chrome et la couleur des minéraux: un exemple 'pédagogique'.* (Chromium and colour in minerals: a study for students.) Revue de Gemmologie, **54**, 6-8, 6 figs, 1978.

Shows by means of graphs the absorption spectra of chromium in synthetic green diopside, ruby from Mogok (Burma), red spinel from Mogok, synthetic emerald and Norwegian garnet; the part played by chromium in these materials is discussed. M.O'D.

CHERMETTE (A.). *La bonne aventure ou l'histoire d'un placer.* (Good luck or the story of a placer.) Revue de Gemmologie, **54**, 2-5, 8 figs, 1978.

Describes the author's experiences as a gold prospector in the Republic of Bénin (formerly Dahomey). M.O'D.

COCKAYNE (B.). *The melt growth of oxide and related single crystals.* Journal of Crystal Growth, **42**, 413-26, 2 figs, 1977.

Describes some of the new methods devised over the past three years in the growth of crystals from the melt. More importance is attached to the atmosphere in which a crystal grows, and crystals are now examined with greater resolution. M.O'D.

COZAR (J. S.). *Estudio de las proporciones de talla en el diamante.* (Study of the proportions of the cut of diamond.) Instituto Gemológico Español, **17**, 27-31, 6 coloured figs, 1978.

Examines the use of the various instruments which estimate the nearness of a particular cut stone to an ideal proportion. M.O'D.

CROWNINGSHIELD (R.). *Developments & highlights at GIA's Lab in New York.* Gems & Gemology, **XV**, 12, 361-70, 25 figs, 1977.

Cubic zirconia is discussed at length as a very close imitation of diamond which presents a considerable problem to the gem trade. It is appearing in a fraudulent context in the States. A pale pink one has been seen. Brown type IIb electrically conductive diamond is reported. A grey IIb lost its conductivity when irradiated to a blue colour. Hence conductivity still indicates a natural blue diamond. A 25 carat natural green diamond of type IIa was transparent to short UV. A pair of light green-blue diamonds showed the 4155Å line of a Cape stone, but origin of the colour was not determined. A diamond with a twin-plane (grain) line in the girdle plane was at first suspected of being a doublet. An intense fancy yellow-brown diamond had a fluorescent line at 5400Å. Worm-like inclusions in a diamond are illustrated. A 204 carat multi-star blue-grey quartz resembled corundum. Quartz triplets made to resemble red/blue-green tourmaline are reported. Tahiti black cultured pearls are described as unstained and reacting as for natural black pearls to long UV. Synthetic amethyst from USSR described as generally brownish purple and not fine in colour. An emerald resembling a swirled 'Ferrer'-type paste is illustrated: also a collection of ambers from the Dominican Republic, ranging from pale yellow to almost black-brown, many with insect fossils, none with stress spangles. Quench-fractured synthetic sapphires and a Mexican opal with negative crystal inclusions are also illustrated. A visitor to Russia expected to buy demantoid garnets but was disappointed: best source today said to be in secondhand and antique jewellery. R.K.M.

DARRAGH (P. J.), GASKIN (A. J.), SANDERS (J. V.). *Synthetic opals.* Australian Gemmologist, **13**, 4, 7pp. (insert between p.108 and p.117) 11 figs (5 in colour), 1977.

A careful account of visual, structural and other differences between synthetic and natural opals. At electron-micro level synthetics show some particulate choking

of interstitial spaces as well as concentric structure in the spheres of silica gel which are absent from natural opal. At visual level under magnification synthetic opal shows identifiable columnar grain and sub-grain structure which are seen much less frequently in natural opal. Spherule size so far produced has generally given synthetics with exceptionally fine red flash predominating. Any of these visual features could be changed in future batches. Gilson synthetics appear to be more porous than natural opal, especially when sliced to make triplets. In solid opal this may become more apparent on repolishing. R.K.M.

DARRAGH (P. J.), SANDERS (J. V.). *Slocum stone.* Australian Gemmologist, **13**, 5, 146-8, 4 figs (2 in colour), 1978.

A short paper on this spectacular glass simulation of opal. Obvious visual differences are mentioned. Colour flakes are thought to be due to alternating layers of silica and alumina suspended in a featureless transparent glass. Electron micrographs show the regular structure of these flakes which is responsible for the diffraction colours. R.K.M.

DIEHL (R.). *Künstliche Produkte mit Granat-Kristallstruktur.* (Synthetic products with garnet structure.) Z.Dt.Gemmol.Ges., **27**, 1, 12-21, bibl., 1978.

The rare earth garnets YAG and GGG have been introduced as diamond imitations, but are only two of a whole series of synthesized garnets. Oxide compounds which crystallize in the garnet structure have the general chemical formula $A_3B_2C_3O_{12}$—A, B and C being symbols for the vast number of chemical elements having a garnet structure, the A element being a rare earth, the B and C aluminium, gallium or iron. Since the Al and Ga garnets are transparent, have high value hardness and high RI and can be coloured by chromium, cobalt or nickel or some rare-earth elements, they can make attractive gem materials. Some yellow and pink-red uncut gemstone material was identified as mixed crystals of yttrium and holmium aluminium garnet and yttrium and erbium aluminium garnet. Both materials are grown as new laser material for eye-secure lasers. E.S.

DUNN (P. J.), APPLEMAN (D. E.), NELEN (J.). *Liddicoatite, a new calcium end-member of the tourmaline group.* American Mineralogist, **62**, 1121-4, 1 fig, 1977.

Many large multi-coloured tourmalines from the Malagasy Republic were found to have a high Ca content. A new calcium analogue of elbaite has been named after Richard T. Liddicoat, President of the Gemological Institute of America. Ideal formula is given as $Ca(Li,Al)_3Al_6B_3Si_6O_{27}(O,OH)_3(OH,F)$. Space group is R3m, cell dimensions a = 15.867 (4); c = 7.135 (4)Å. Zoning is usually parallel to a pyramid; in elbaite it is usually parallel to $\{0001\}$ or $\{10\bar{1}0\}$, $\{11\bar{2}0\}$ or both. M.O'D.

FOORD (E. E.). *The Himalaya dike system, Mesa Grande district, San Diego County, California.* Min. Record, **8**, 6, 461-74, 22 figs (4 in colour), 1977.

Describes the pegmatite-aplite dike system of the Mesa Grande district in north-central San Diego County. The area is especially celebrated for its fine tourmaline crystals, which are found together with beryl and quartz; some gem quality apatite is found. The beryl (morganite) ranges in colour from peach-orange to strawberry-pink. M.O'D.

GALAS (C. A.). *Thomas Range, Utah, U.S.A.* Lapis, **3**, 4, 28-31, 15 figs (4 in colour) 1978.

Describes the occurrence of manganese-bearing beryl with topaz and pseudobrookite in the Thomas Mountains of Utah, U.S.A. M.O'D.

GALIA (W.). *Zufällig entdeckt.* (Chance discovery.) Lapis, **3**, 4, 34-5, 4 coloured figs, 1978.

Discusses the cause of colour in aquamarine, golden beryl and non-emerald green beryl with remarks on absorption spectra and luminescence. M.O'D.

GLAS (M.). *Beryll Fundorte.* (Occurrence of beryl.) Lapis, **3**, 4, 10-11, 3 coloured figs, 1978.

Describes the mode of occurrence of beryl with particular reference to and illustration of materials from Bavaria and Austria. M.O'D.

GÜBELIN (E.). *Charakteristische Einschlüsse in Aquamarin und Smaragd.* (Typical inclusions in aquamarine and emerald.) Lapis, **3**, 4, 18-19, 13 coloured figs, 1978.

Photographs illustrating inclusions in emerald and aquamarine. Magnification ranges from 20× to 400×. M.O'D.

GÜBELIN (E. J.). *Jadeite, der grüne Schatz aus Burma.* (Jadeite, green treasure of Burma.) Lapis, **3**, 2, 17-28, 12 figs in colour, 1978.

Describes the jadeite occurrences of Burma and illustrates mining scenes. A map is included. Methods of recovery, fashioning and selling procedures are outlined. M.O'D.

GÜBELIN (E.), SCHIFFMANN (C. A.). *Aus der Untersuchungspraxis.* (From the testing practice.) Z.Dt.Gemmol.Ges., **27**, 1, 33-40, bibl., 1978.

The authors describe various interesting stones they encountered in their laboratory work, a sapphire, various quartzes, emeralds, synthetic and genuine, with beautiful photomicrographs. E.S.

GUILLEN (P.). *Vuelven las perlas.* (Returning to pearls.) Boletin del Instituto Gemológico Español, **17**, 9-25, 6 coloured figs, 1978.

A review of the history of the use of pearl as an ornamental material. M.O'D.

GUNARATNE (H. S.). *Blue sapphires and rubies—precious commodities of investment.* Facets, **2**, 1, (1), 1 illus., n.d. (1978?).

Advises fine quality blue sapphires and rubies as investments as good as diamonds. While production of coloured stones has been increasing and demand dropped as a result of the oil crisis, there has been no fluctuation in the prices of quality blue sapphires and rubies of bigger sizes, which may be regarded as suitable for investment. J.R.H.C.

HANNEMAN (W. W.). *Gemological instruments—which should I buy?* Lapidary Journal, **32**, 1, 422-9, 11 figs, 1978.

Reviews the instruments made or supplied by the Gem Instruments Corporation (GIA), Gemmological Instruments Ltd (Gemmological Association of Great

Britain) and Hanneman Gemological Instruments (Hanneman Lapidary Specialties). Also recommends books for gemmological study. M.O'D.

HANNEMAN (W. W.). *Water as a gemological tool.* Lapidary Journal, **31**, 12, 2576-8, 1978.

Attempts to show how the shape and behaviour of a drop of water placed on a polished stone may determine its identity. M.O'D.

HARTFORD (W. H.). *Color and the chromium minerals.* Rocks & Minerals, **52**, 169-75, 5 figs, 1977.

Discusses the minerals in which chromium acts as a colouring agent and gives a special account of crocoite from Beresov, Urals, USSR. M.O'D.

HERTING (S.), STRUNZ (H.). *Jeremejewit von Cape Cross in SW-Afrika.* (Jeremejevite from Cape Cross, SW Africa.) Aufschluss, **29**, 43-53, 7 figs, 1978.

Jeremejevite is found in a pegmatite at Cape Cross, 100 km north of Swakopmund in South-West Africa. Crystals are described and illustrated and their characteristics are compared with those of the occurrence in Transbaikalia, U.S.S.R. Specific gravity is given as 3.313, RI as 1.641 (ε), 1.649 (ω), with a DR of 0.008. M.O'D.

HOCHLEITNER (R.). *Die Berylliumpegmatite von Tittling im Bayerischen Wald.* (The beryllium pegmatite at Tittling in the Bayerischen Wald.) Lapis, **3**, 2, 4-16, 15 figs (4 in colour), 1978.

Describes the pegmatite in which milarite, epidote, monazite, samarskite, bertrandite, albite and, more rarely, crystals of purple fluorite and other minerals are found. M.O'D.

HUTTON (D. R.), BARRINGTON (E. N.). *Electron spin resonance of emeralds.* Australian Gemmologist, **13**, 4, 107-8 and 117-8, 4 figs, 1977.

A technique which measures magnetic fields to detect minute percentages of transition metals in beryl, allowing distinction to be made between (a) natural and synthetic emerald, (b) Chatham and Gilson synthetics, (c) emerald and green beryl. No detail of procedure or apparatus given. Printer has converted Gilson to 'Gibson' throughout. R.K.M.

KELLER (P. C.), KAMPF (A. R.). *The Natural History Museum of Los Angeles County.* Min. Record, **8**, 6, 487-93, 10 figs (5 in colour), 1977.

The Natural History Museum of Los Angeles County is about to open a new display area for minerals and gemstones, some of the finest of which are illustrated. The recently-acquired Hixon collection has made the Museum's gem collection one of the most important in the U.S.A. M.O'D.

LARSON (B.). *The best of San Diego County.* Min. Record, **8**, 6, 507-15, 12 figs (6 in colour), 1977.

Describes San Diego County, California, with particular reference to the main pegmatite districts, Chihuahua Valley, Aguanga, Pala, Rincon, Mesa Grande, Ramond and Jacumba. Pala is probably the best-known of these areas, since the production of tourmaline and to a lesser extent morganite, spessartine and

spodumene is important commercially. More tourmaline comes from the Himalaya mine in Mesa Grande district and fine quality spessartine from the Hercules mine, Ramona district. The Beebe Hole mine in Jacumba district has recently yielded crystals of yellow, blue and purple spodumene. M.O'D.

MATEIKA (D.), RUSCHE (Ch.). *Coupled substitution of gallium by magnesium and zirconium in single crystals of gadolinium gallium garnet.* Journal of Crystal Growth, **42**, 440-4, 6 figs, 1977.

Crystals with magnesium and zirconium substituting for gallium show less tendency to form cracks during growth. Growth is by the Czochralski process; substituting ions occupy octahedral sites. M.O'D.

MICHEL (D.), PEREZ Y JORBA (M.), COLLONGUES (R.). *Growth from skull-melting of zirconia rare-earth oxide crystals.* Journal of Crystal Growth, **43**, 546-8, 3 figs, 1978.

Describes the use of the so-called skull-melting technique to produce crystals of zirconia with different compositions. Lanthanide oxides were used in stabilization experiments. M.O'D.

MITCHELL (R. S.). *'Odell diamonds', barite crystals from Gage County, Nebraska.* Rocks and Minerals, **52**, 357-9, 3 figs, 1977.

'Odell diamonds' are transparent to translucent pink barite crystals found in a Cretaceous shale near Odell, Gage Co., Nebraska. Some colour-zoning can be seen. M.O'D.

MORTEANI (G.), GRUNDMANN (G.). *The emerald porphyroblasts in the penninic rocks of the central Tauern Window.* Neues Jahrbuch der Mineralogie (Mönatschefte), 509-16, 3 figs, 1977.

Discusses the emeralds found in the Leckbachscharte, Habachthal, Austria. They are found to be porphyroblasts which have grown in biotite-epidote-plagioclase gneisses and in metasomatically altered serpentinites. Zoning observed in the emeralds is thought to be due to a change in metamorphic conditions. The origin of the Be is assumed to be volcanic. M.O'D.

NASSAU (K.). *Wie Mahlwerke für Zuokerrohr.* (Like millstones for sugar-cane.) Lapis, **3**, 4, 20-3, 7 figs (4 in colour), 1978.

An account of the so-called trapiche emerald found in Colombia. In some examples emerald is intergrown with albite. M.O'D.

NASSAU (K.), SCHONHORN (H.). *The contact angle of water on gems.* Gems & Gemology, **XV**, 12, 354-60, 3 figs, 1977.

A paper which puts into scientific perspective the water spot test, previously thought of as an indicator of hardness. Contrary to the thinking of other writers it was found that soft imitations such as YAG, GGG, and cubic zirconia, together with corundum, zircon and other natural stones, all give higher contact angles than diamond and hence more spherical water spots. A test to be used with great care, but

not to be discarded if it helps with the worrying cubic zirconia, djevalite. Irradiated diamonds and other stones do not respond normally to this test and must be specially cleaned with Linde A to remove an extraneous layer of altered oil resulting from the irradiation. R.K.M.

NICHOL (D.). *The colour of nephrite jade from Cowell.* Quarterly Notes, Geological Survey of South Australia, **53**, 9-12, 2 figs, 1975.

Nephrite from this area is not so vivid a green as that from New Zealand; this is attributed to the lower chrome content (less than 0.1% compared to 0.4%). M.O'D.

O'DONOGHUE (M.). *Aquamarin und Morganit.* (Aquamarine and morganite.) Lapis, **3**, 4, 16-17, 3 figs, 1978.

Describes the aquamarine and morganite varieties of beryl with reference to the Maxixe stones and to the general occurrence and properties of the two varieties. (Author's abstract) M.O'D.

O'DONOGHUE (M.). *Crystal structures.* Gemmological Newsletter, **7**, 13-17, 1978.

An introduction to the basic structures of crystals with an explanation of co-ordination numbers, the various types of ionic packing and description of the structures of some well-known minerals with particular reference to the silicates. (Author's abstract) M.O'D.

O'DONOGHUE (M.). *Russian minerals.* Gems, **10**, 2, 9-12, 1 fig, 1978.

A survey of the better-known minerals recorded from the U.S.S.R. with particular reference to those with gem application. Most of the finest gem species come from the Ural Mountains, though Siberia has produced a number of important minerals, especially diamonds. Chrome diopside is also found in Siberia and nephrite is well-known from the shores of Lake Baikal.

(Author's abstract) M.O'D.

PETROV (I.). Farbe, Farbursache und Farbveränderungen bei Topasen. (Colour, causes of colour and colour changes in topazes.) Z.Dt.Gemmol.Ges., **27**, 1, 3-11, bibl., 1978.

More than 1500 topaz crystals from different localities were tested as to their absorption spectrum. Other tests included thermoluminescence tests and systematic radiation and heating experiments and the comparison of the absorption spectra before and after radiation and heating. Thus a connexion between the colour of the topazes, the content of trace elements and the formation of colour-centres was found. The results were shown in (A) topazes coloured by chromium (these included only the violet-coloured topazes) and (B) topazes coloured by colour-centres, which were subdivided into (1) those without chromium and with colour-centres and (2) those with chromium and colour-centres. B(1) topazes were again subdivided into (a) red-brown and yellow topazes (the red-brown colour is caused by red and yellow colour-centres, while the yellow colour is caused by yellow colour-centres alone) and (b) blue and green topazes (the blue colour is caused by blue colour-centres, the green by blue and yellow colour-centres). The second group of topazes (B(2)—with chromium and colour-centres) includes yellow, orange-coloured and violet stones. The colours produced by colour-centres can be destroyed by heating and reconstructed by radiation. The blue colour can be obtained by radiation with succeeding heating. Orange-coloured topazes (from Ouro Preto) were changed to violet by heating (the yellow colour-centres were destroyed, only the Cr stayed effective). E.S.

PETROV (I.). *Farbuntersuchungen an Topas.* (Colour investigation of topaz.) Neues Jahrbuch der Mineralogie (Abhandlungen), **130**, 288-302, 3 figs, 1977.

The colour of violet topaz is ascribed to an absorption spectrum with two groups each with three absorption bands correlated with Cr^{3+} substituting for Al^{3+}. Orange topaz is coloured by the addition of yellow and violet; blue by colour-centre operation and also by an absorption band in the direction of oscillation X. Green is formed by the addition of blue and yellow. Change of colour by radiation and heating is discussed. M.O'D.

PETROV (I.), SCHMETZER (K.), BANK (H.). *Violette Topase aus Pakistan.* Neues Jahrbuch der Mineralogie (Mönatshefte), 483-4, 1977.

Violet-coloured crystals of topaz from Katland in the Mardan district of Pakistan show {110} {120} and {011} {012} and {112}. Refractive indices are 1.632, 1.633 and 1.641; pleochroism yellow, violet with red and violet with blue. X-ray examination shows the stones to be OH-rich with around 15% F. The violet colour is due to Cr^{3+}. M.O'D.

POIROT (J.-P.). *La lecture de l'indice de réfraction au réfractomètre à prisme.* (Reading refractive index with the prism refractometer.) Revue de Gemmologie, **54**, 14-16, 9 figs, 1978.

An account of the theory of refractive index illustrated with diagrams. M.O'D.

RECKER (K.). *Smaragd-Synthesen.* (Synthesis of emerald.) Lapis, **3**, 4, 24-7, 5 figs (1 in colour), 1978.

The process of manufacture is described and characteristics of the crystals given. M.O'D.

REED (T. B.), FAHEY (R. E.), MOULTON (P. F.). *Growth of Ni-doped MgF_2 crystals in self-sealing graphite crucibles.* Journal of Crystal Growth, **42**, 569-73, 4 figs, 1977.

Optical quality MgF_2 crystals doped with Ni are light green in colour. Growth by a vertical gradient freeze technique may be appropriate for other materials of a volatile nature. M.O'D.

SAUL (J. M.), JOBBINS (E. A.), STATHAM (P. M.), YOUNG (B. R.). *Un essai d'établissement d'une échelle de couleurs pour des grenats de la vallée de l'Umba, Tanzanie.* (An attempt to establish a colour range for garnet from the Umba Valley, Tanzania.) Revue de Gemmologie, **54**, 9, 2 figs, 1978.

In a graph on which refractive index is plotted against specific gravity garnets are found to be grouped by colours. Three groups have been identified, reddish-purple, red and yellowish-red. M.O'D.

SKINNER-NIXON (E.). *The alteration of colour of gemstones.* Australian Gemmologist, **13**, 3, 85-8, 1977.

A summary of methods under headings: 1, irradiation; 2, heat-treatment; 3, staining. R.K.M.

SMITH (D.). *That looks interesting let's put it under the microscope.* Australian Gemmologist, **13**, 4, 121-126, 5 figs, 1977.

Describes various types of microscope and advises on purchasing one. But power of a microscope is incorrectly stated as being the sum of the power of the objective and the eyepiece. R.K.M.

SNOW (J.). *Paste or glass.* Australian Gemmologist, **13**, 3, 71-4, 1977.

An account of artificial and natural glasses reprinted from Wahroongai News. Marred by many printer's errors. R.K.M.

SUHNER (B.). *Zur Diagnose der Zirkone.* (The diagnosis of zircons.) Z.Dt.Gemmol.Ges., **27**, 1, 27-32, 1978.

The diagnosis of zircons is more difficult than that of many stones because of its RI of 1.8 being above those measurable by ordinary refractometers. A characteristic of zircons is their radioactivity caused by uranium and thorium; it is suggested that this should be used for their identification. Only a few zircons show no radioactivity. By measuring the radioactivity, the stones could also automatically be identified as high, normal or low zircons. Ekanite is also radioactive, but has about a ten times higher radiation intensity as compared with the low zircon and can also be differentiated from zircon by its sp. gr. (3.28) and its RI (1.595). E.S.

TENNYSON (C.). *Gerüste aus Ketten und Schichten.* (Framework of chains and layers.) Lapis, **3**, 4, 6-9, 6 figs (1 in colour), 1978.

Illustrates with diagrams the atomic structure of beryl. M.O'D.

THORSSON (H.). *The Zeiss slit lamp microscope.* Canadian Gemmologist, **2**, 2, 14-16, 1978.

This instrument was designed for ophthalmological work but can be adapted for use in gem testing. M.O'D.

WISE (W. S.), GILL (R. H.). *Minerals of the benitoite gem mine.* Min. Record, **8**, 6, 442-52, 31 figs (6 in colour), 1977.

The most important minerals from this mine are benitoite, neptunite and joaquinite, but these occur in a number of interesting forms. Although most neptunite appears black, a red crystal is illustrated. M.O'D.

WRIGHT (Pearce). *Doubt thrown on tests of diamond pedigrees.* The Times newspaper, No. 60337, p.2, 26th June, 1978.

Spectroscopic analysis has been recognized by the G.I.A. as providing a test for distinguishing between natural yellow diamond and diamond whose yellow colour is due to irradiation and heating to 700-800°C. But Dr Alan Collins (King's College, London) has found that when treated yellow diamonds are heated to 1000°C the anomaly between them and the natural yellow diamonds disappears, while the colour remains unchanged: this throws doubt on the reliability of the test. J.R.H.C.

Manufacture of ornaments. Facets, 2, 1, (2-3), 4 illus., n.d. (1978?)

Among ornamental stones to be found in Sri Lanka, including spodumene, apatite, cassiterite, fluorspar, crystalline limestone, quartzites and rose quartz,

particulars are given of serpentine (including Bowenite) - approximating to the formula $MG_6(OH)_6Si_4O_{11}$, RI 1.49 to 1.57, SG 2.5 to 2.6, H 2½ to 4 - which is cut into chessmen, eggs, ashtrays, boxes, clock dials and bases, as well as pendants, earrings, necklaces and cufflinks. J.R.H.C.

Stones seen... Australian Gemmologist, **13**, 5, 154, 1978.

Reports a cubic zirconia, other than djevalite, showing a sharp absorption line at 5125Å. R.K.M.

The collector's library. Min. Record, **9**, 1, 5-13, 1978.

A number of specialists have listed the books that they consider most necessary for a study of minerals and gemstones. Items are given with bibliography details, excluding prices. M.O'D.

BOOK REVIEWS

BRAZEAU (E. G.), BRAZEAU (L. S.). *Standard mineralogical catalogue, mid 1977 to mid 1978.* No publisher or place of publication given in book; available from the authors (address: Mineralogical Studies, 7805 Division Drive, Battle Creek, Michigan, 49017, U.S.A.); dealers only; unpriced.

Lists minerals in alphabetical order with prices for ½", 1", 2", 3"and 4" specimens.Introductory notes provided. M.O'D.

HURLBUT (C. S.), KLEIN (C.). *Manual of mineralogy, after James D. Dana.* 19th edn. Wiley, New York, 1977. pp.xi, 532. Illus. in black-and-white. £7.95.

This is the mineralogy students' friend in a new format with new material of petrology and morphology and more species described. An interesting feature is the treatment of the crystal systems; the authors begin with the triclinic (the system of lowest symmetry) and end with the isometric; in each of the systems the classes are arranged in decreasing symmetry order. The aim is to be able to describe lower symmetry classes as special cases of the higher classes. The typography is very pleasing and with a reasonably low price the book can be highly recommended. M.O'D.

SCHMETZER (K.). *Vanadium III als Farbträger bei naturlichen Silikaten und Oxidenein Beitrag zur Kristallchemie des Vanadiums.* (Vanadium III as a colouring agent in natural silicates and oxides—a contribution to the crystal chemistry of vanadium.) Inaugural-Dissertation zur Erlangung der Doktorwürde der Naturwissenschaftlichen Gesamtfakultät der Ruprecht-Karl-Universität, Heidelberg, 1978. pp.277, 71 figs. Apply to the University for copies.

Dr Schmetzer illustrates the role played by vanadium in the colouring of silicates and oxides; in particular he discusses emerald, tourmaline, corundum, kornerupine, zoisite, kyanite, epidote, topaz, axinite, diopside, chrysoberyl amongst other minerals not of gemmological importance. There is a very detailed survey of the relevant literature. M.O'D.

WANKLYN (B. M. R.). *Sources of single crystals in the United Kingdom and Scandinavia.* Clarendon Laboratory, University of Oxford, 1978. pp.78. Available to scientists only on application.

This compilation takes its place with similar ones from other European countries and the U.S.A. It lists the various organizations engaged in crystal growth with the materials that they manufacture. General availability of the materials is shown. M.O'D.

WOOLLEY (A.), ed. *The illustrated encyclopedia of the mineral kingdom.* Hamlyn, London, 1978. pp.240. 150 figs in colour, many in black-and-white. £5.95.

The present reviewer had a sense of *déja vu* when seeing this book for the first time. Like his own (O'Donoghue, ed., The encyclopedia of minerals and gemstones, Orbis, 1976), this book introduces the unlearned reader to the world of minerals and describes some of the better-known species (300 in this case as against over 1,000). There are chapters on crystals, the geological environment of minerals and rocks, mineral properties and study, gemstones and economic minerals, building a collection and a guide to the literature on minerals. All are written by a team of professional workers in mineralogy and each is illustrated by appropriate photographs. Study of the earth and the planets leads to a consideration of the internal structure of the earth, the elements to be found on it and their chemistry. A good deal of attention is paid to the types of rocks and to the mineral assemblages which accompany them and this part of the book should be especially useful.

The chapter or section describing 300 mineral species is called 'The mineral kingdom'—surely an overworked phrase by now and eerily familiar to this reviewer. Minerals are arranged in crystallochemical order, so that the index is needed to locate a particular item if its nature is unknown. Each description includes chemical composition, crystal system, physical and optical properties, formation and occurrence. Many entries do not give localities, which, in a book aimed at the general reader, is surely a blunder. Dimensions of specimens are omitted so that one has no idea how large (micromount or cabinet size) a particular mineral is.

A short chapter on gemstones ends rather suddenly and is disappointingly dull but includes some interesting data (e.g. on saussurite) not always found in books of this type. A chapter on economic minerals, much like similar chapters in other books, is followed by notes on building a collection, again with nothing to make it stand out in the memory. Bibliography and index are adequate.

The standard of illustration, bearing in mind the indifferent quality of the paper, is quite acceptable but scarcely exciting by today's standards. This is the main impression left by the book; it is certainly workmanlike, free from serious error and very cheap, but it is so like other books that there is nothing to distinguish it. Style ranges from the didactic (properties and study of minerals) to the pedestrian (gemstones); it would be good to see at least some of the excitement over the beauty of minerals (as in some papers in Mineralogical Record) coming across to the reader. But perhaps such transports are beyond the reach of British workers! M.O'D.

ASSOCIATION NOTICES

GIFTS TO THE ASSOCIATION

The Council of the Association is indebted to the following for their gifts:

Mr Don Demarray, London, Ontario, Canada, for a packet of small green fluorite crystals with mauve centres from Faraday Mine, Bancroft, Ontario.

Mr R. I. Gait, Assistant Curator of Mineralogy, Royal Ontario Museum, Toronto, Canada, for two booklets entitled *A General Guide to the Gallery of Mineralogy* and *A Guide to the Teaching Section.*

Mr B. Krijger, F.G.A., The Hague, Netherlands, for a book entitled *Edelstenen in Kleur* revised and translated into Dutch from the German original.

Mr Alec Pickett, F.G.A., London, for a copy of *Investing in Diamonds* by David H. Wolf, F.G.A., South Africa.

Dr D. J. Talati, Ahmedabad, India, for two cabochons and 25 pieces of rough copper-bearing aventurine zeolite, mined in Jalampura, Gujarat, India.

Mr Grant W. Waite, Toronto, Canada, for three pieces of ruby corundum in matrix from the Fiskenaesset area, South West Greenland, one piece of thomsonite in matrix and four pieces of green agate from Lake Superior, U.S.A.

Mr Benjamin Zucker, New York, U.S.A., for a copy of his book *How to Invest in Gems: Everyone's Guide to Buying Rubies, Sapphires, Emeralds and Diamonds,* published by the New York Times Book Company in New York and by the Blandford Press in England.

MEMBER'S MEETINGS

Midlands Branch

The Annual General Meeting of the Branch was held on the 15th June, 1978, at the Royal Institute of Chartered Surveyors, Birmingham, and was followed by a talk by Mr Alan Hodgkinson, F.G.A., entitled 'Visual Optics'. Mr Hodgkinson brought along several specimens and a Diamond Eye (one of the new diamond testing instruments), and a practical demonstration was given.

North-West Branch

On the 9th July, 1978, branch members joined with the Wirral Mineral and Lapidary Society for a field trip. The venue was Dyserth and two further quarries nearby. Travertine, chert and galena were collected.

SECRETARY'S VISIT TO CANADA

During a holiday visit to Canada Mr Harry Wheeler met officials of the Canadian Gemmological Association in Toronto. He gave an evening talk at the Sheraton Centre on Wednesday, 12th July, 1978, to members of the Canadian Association. The talk mainly concerned the history of the Gemmological Association of Great Britain, its educational activities, including examinations, and the instruments handled by Gemmological Instruments Ltd. During the period he spent in Toronto he was entertained by Officers of the Canadian Association.

HARROW COLLEGE OF TECHNOLOGY AND ART

A short course of nine weekly two-hour lecture demonstrations on 'The Science of Minerals and Gems' starting on Wednesday, 17th January, 1979, is being organized by Mr F. A. Fryer, B.Sc., C.Chem., M.R.I.C., F.G.A., (senior Lecturer in Inorganic Chemistry). It is expected that the lectures will be given by Mr Fryer, Dr Paul Madget (Geology Lecturer), Mr James Harding, F.G.A. (Senior Lecturer in Silversmithing) and Mrs Sheila Lewis, F.G.A. Enquiries should be addressed to Mr Fryer at Harrow College of Technology and Art, Northwick Park, Harrow, HA1 3TP. (Telephone 01-864 4411).

COUNCIL MEETING

At a recent meeting of the Council it was agreed that with effect from 1st January, 1979, the annual subscription for Fellows and Ordinary Members shall be £6.00. The annual subscription for the *Journal* for non-members is increased to £8.00.

BACK ISSUES OF THE JOURNAL

The Association is interested in aquiring from members copies of the previous issues of the Journal listed below in order to supplement our stock.

Vol. 1, No. 1, 1947.	Vol. 2, No. 2, 1949.	Vol. 11, No. 5, 1969.
Vol. 1, No. 2, 1947.	Vol. 2, No. 3, 1949.	Vol. 12, No. 2, 1970.
Vol. 1, No. 3, 1947.	Vol. 2, No. 4, 1949.	Vol. 13, No. 1, 1972.
Vol. 1, No. 4, 1947.	Vol. 2, No. 5, 1950.	Vol. 13, No. 2, 1972.
Vol. 1, No. 5, 1948.	Vol. 3, No. 1, 1951.	Vol. 13, No. 5, 1973.
Vol. 1, No. 6, 1948.	Vol. 3, No. 4, 1951.	Vol. 13, No. 8, 1973.
Vol. 1, No. 8, 1948.	Vol. 9, No. 12, 1965.	Vol. 15, No. 2, 1976.
Vol. 2, No. 1, 1949.	Vol. 11, No. 4, 1968.	Vol. 15, No. 7, 1977.

Members are requested to write with details to the G.A. office.

EXAMINATIONS 1979

The dates for the 1979 Gemmological Examinations are as follows:

Preliminary: Theory, Tuesday, 26th June.

Diploma: Theory, Wednesday, 27th June.
Practical, Tuesday, 26th June, Thursday, 28th June, Friday, 29th June (London). Other centres as arranged.

Gem Diamond Examination: Monday, 11th June.

The *final* date for entry is the 1st March. Entry forms available from the Association.

CORRIGENDUM

On page 213 (line 6), for 'GALL (Robert A. P.)' read 'GAAL (Robert A. P.)'.

GEM TESTING EQUIPMENT

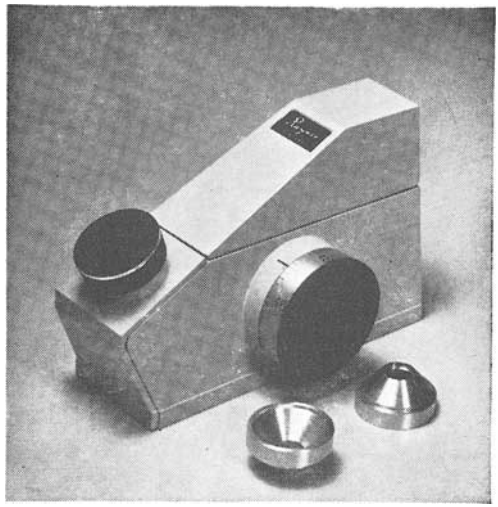

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THE JOURNAL OF GEMMOLOGY

and

PROCEEDINGS OF THE GEMMOLOGICAL ASSOCIATION OF GREAT BRITAIN

GEMMOLOGICAL ASSOCIATION OF GREAT BRITAIN
SAINT DUNSTAN'S HOUSE, CAREY LANE
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THE JOURNAL OF GEMMOLOGY
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Vol. XVI No. 5 JANUARY, 1979

THE LATE ROBERT M. SHIPLEY AN APPRECIATION

By B. W. ANDERSON

Robert M. Shipley, the undisputed founder of organized gemmology in America, died last April at the great age of 91, and it is only fitting that some account of the life story of this remarkable man should be given in this *Journal.* The details in what follows have been largely culled from an extensive article by Mitchell Gilbert in the *Jewelers' Circular-Keystone* which appeared two years ago.

Shipley was born in south-west Missouri on February 21st, 1887, the son of a railroad man, and had a very varied upbringing—being educated first by the family's negro maid (who was a college graduate) and then (to 'harden him up') at a military academy in Wisconsin, where he showed athletic talent as a long-distance runner and as an oarsman. His subsequent education at college was interrupted early by his father's death, and he returned to the family home (then at Wichita, Kansas) in search of work. By this time Robert Shipley was a strikingly handsome youth, six feet six inches in height and something of a ladies' man. After working as a switchboard operator, type-setter, and at other jobs, he married (in 1912) a local girl, Jeanette Vail, whose wealthy father

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owned a well-established jewellery store. Two years later the store manager left, and Shipley was persuaded, rather reluctantly, to join the business, which entailed an extensive silver-cleaning routine which he detested. When, after some years, he inherited full responsibility for the store his main interest was in extending it to incorporate new departments for fine china, giftware, and even an art gallery. By the early twenties he had gained a sufficient local reputation to be elected as President of the Kansas Retail Jewelers' Association, and subsequently became a member of a National Retail Jewelers' Research Group, through which he struck up friendships with nationally important jewellers—friendships which some years hence were to be his salvation when struggling to 'sell' gemmology. He also became involved in one or two really big deals in supplying stones to wealthy customers, which in two cases at least made him humiliatingly aware of his ignorance in judging the quality of emeralds and diamonds.

There then followed a black period in Shipley's life, involving nervous prostration and a sense of failure both in his marriage and his business, which he sold, passing the assets to his wife. After a period in a 'health farm' he made some money by writing movie scenarios for Hollywood. This enabled him to travel to Paris, where he learned all he could about ceramics and the arts generally by visiting museums and factories and taking courses at the Louvre. Then two things happened which vitally affected his future: he met Beatrice Bell, who eventually became his second wife—'the luckiest thing that ever happened to me in my life' as he often said in later years, and he decided to enrol in the correspondence course in gemmology then being offered by the N.A.G. in London. His money was running out, but Beatrice was able to introduce him to museum jobs as lecturer on porcelain, and in this way he discovered that he had an ability and liking for teaching.

With more money saved, Robert Shipley next went to London to take the necessary practical classes leading to his sitting and passing the Diploma* examination. This was in May 1929, and in the following December Shipley returned to the States, armed with what was only the second refractometer to reach America, intent on earning his living and on regaining touch with his beloved Bea.

*When the Gemmological Association was formally inaugurated in 1931, holders of diplomas awarded by the N.A.G. became automatically eligible for fellowship.—Ed.

In terms of job-seeking his timing could hardly have been more unlucky, as at that very time when he was on the boat home the first frightening stages of the great Wall Street crash were shaking the foundations of the business world. Shipley sought out Beatrice Bell in California and for a while they lived together on the proceeds of a small art gallery. The first tiny indicator of the shape of things to come was the result of an invitation by an old jeweller friend, Armand Jessup, to give a series of lectures on gemmology to members of the California Jewelers Association under the aegis of the University of Southern California. This he did, as many as eighty turning up for his first lecture. But some of those attending had to motor hundreds of miles to get to and from the lectures, and by one jeweller on the Mexican border he was pressed to type out his lectures and send them by mail.

Here was the germ of an important idea: to sell his typed courses to 'ethically minded' jewellers throughout the States, leading to a form of degree gained by examination, and through this to membership of an enlightened and informed Guild of jewellers. The educational side of this enormous one-man ambition Shipley styled the 'Gemological Institute of America', having as 'laboratory' Bea's kitchen, while the Guild-type group of educated jewellers was termed, when the time came, the 'American Gem Society'. Very broadly speaking, the American Gem Society corresponds to the N.A.G. in Great Britain, while the G.I.A. corresponds to our Gemmological Association. But whereas the N.A.G. is greatly senior to the G.A., in the case of Shipley's brain-children it was the educational side of his ambitious project that had a three years' start.

What is difficult to realize is the enormous effort that this one man put into selling his ideas, at the age of forty plus, with practically no capital, and at that early stage without even the moral support of his wife Beatrice, who thought his chances of success were nil. Shipley pawned his last piece of jewellery, bought an old A model Ford for 52 dollars, rented a typewriter, and 'set out across the country to sell a course that was still being written'. As can be imagined, he met with a great deal of opposition from old-fashioned jewellers who did very well despite frequent mistakes and misrepresentations and resented the idea of their junior employees knowing more about precious stones than they did. But here the mysterious 'spirit of the age' was fighting on Shipley's side—an

awareness of the *necessity* for gemmological knowledge in the jewellery trades of the world, threatened by the advent and rapid spread of cultured pearls and the Verneuil synthetics. London's Laboratory had been inaugurated in 1925 and was now going strong: by 1931 similar laboratories were being established in Paris and in Idar; the *Gemmologist,* first of the specialized journals, made its appearance in 1931, and our own Gemmological Association was established. In addition to the knowledge gained from his N.A.G. course, Shipley was avidly seeking information by means of long questionnaires sent to prominent gemmologists in London and in Germany.

By the time the first course was completed, Robert Shipley Jr, already an inventive young scientist, joined his father and was able to give valuable help in the design and production of instruments specifically designed for the needs of the gemmologist, who had previously been expected to 'make do' with microscopes etc. intended for the pure mineralogist. The Shipley instruments made possible 'table-top' laboratories with which the qualified jewellers could impress their clients. The binocular microscope employing dark field illumination was one of the Shipley ideas that undoubtedly aided the study of diamond imperfections and the tell-tale signs of synthesis in the coloured corundums. Shipley Junior also helped his father write the advanced courses on coloured stones which superseded the first completed series.

During all those early formative years of the G.I.A. and the A.G.S. the administration of the organizations was in the capable hands of Shipley's wife Beatrice, assisted by Dorothy Jasper Smith, who gave dedicated service for over thirty years. Invaluable help was also forthcoming from friends amongst the big jewellers who appreciated the ideals behind the Shipley drive to educate the trade in terms of gemmology. The organization also gained some much needed academic muscle from one or two trained mineralogists who had become attracted to the scientific study of gem materials. In some cases these 'outside' attachments were short-lived—an episode, merely, in a career devoted mainly to mineralogy in its wider sense. In others, the attachment was more lasting, as in the case of Dr Edward Wigglesworth, Curator of Gems and Minerals at Boston Museum, whom Shipley persuaded to become President of the G.I.A. shortly before the war, while he himself assumed the title of Executive Director.

In 1938 the Institute moved to an apartment building in Los Angeles which was capable of expansion if needed. The coming of the war interrupted Shipley's forward-looking plans and caused him some anxiety as to the future of his Institute. Robert Junior, who was an officer in the Air Force Reserve, was called up in 1941, and Richard T. Liddicoat Jr (now President of the G.I.A.) was appointed Director of Education. This important assignment was on the advice of Dean Edward H. Kraus and Professor Chester B. Slawson of the University of Michigan, who were well known as authors of the standard textbook *Gems and Gem Materials.* Other valuable long-term appointments about that time included Robert Shipley's nephew, Alfred L. Woodill, who later became Executive Director of the A.G.S., and Virginia Hinton, on the educational side.

After the war there came an unexpectedly vast increase in student enrolment as the result of the G.I. Bill, and from then on the prosperity of both the G.I.A. and the A.G.S. was assured. George Switzer and Mark Bandy each served for a while on the G.I.A. staff and greatly enhanced its reputation on the scientific side, while of more permanent importance were Lester Benson and Robert Crowningshield—the former influential in instrument design, and the latter to become probably the world's finest and most experienced laboratory gemmologist as Director of the New York Gem Trade Laboratory.

In 1952, at the age of 65, and after 21 years of hard and continued work in directing the G.I.A., Robert M. Shipley retired, and he and his much-loved wife were able to enjoy well-earned leisure in their lovely home in South Laguna Beach, California, till Bea's death in 1973. Robert himself lived on, in full possession of his faculties, and on the eve of his 90th birthday he was able to visit the impressive new headquarters of the G.I.A. in Santa Monica and delight the assembled staff and students with racy accounts of his early struggles.

If, in the above appreciation of his work for gemmology and honourable dealing in the jewellery trade, the emphasis has been placed more on the formative years of struggle than on the later prosperity of the two organizations which Shipley founded, it is because it is the enormous tenacity and capacity for unrelenting hard work in pursuit of his ideals which chiefly excite our admiration in remembering this remarkable man.

THE TOURMALINES OF THE PALA VALLEY, SAN DIEGO COUNTY, CALIFORNIA, U.S.A.

By M. J. O'DONOGHUE, M.A., F.G.S., F.G.A.

In December 1975 I was able to visit this area through the courtesy of the Worshipful Company of Goldsmiths of London, who had provided funds for me to travel over the United States surveying methods of crystal growth and the production of new man-made crystalline materials with possible gemmological application. At the American Museum of Natural History in New York City I met (quite unexpectedly) Mr Bill Larson, of Pala Properties International, one of the owners of several mines in the Pala District. He very kindly invited me to see something of the working of the mines when I arrived at San Diego and when I arrived there a few days later I was able, with John Sinkankas, to spend a whole day inspecting two of the more important Pala mines and a good deal of their typical production of tourmaline.

Pala is in north-west San Diego County, about 45 miles north of San Diego and 80 miles south-east of Los Angeles. It forms part of the Peninsular Range province, mountain masses extending from the Los Angeles area to Baja California in northern Mexico; many pegmatites are found in this range, which has a characteristic igneous rock basis. Pala itself is a mission village on the San Luis Rey river and is surrounded by hills rising to 1500 feet; close by are even higher hills including Queen Mountain, Hiriart Mountain and Chief Mountain, all over 1500 feet. Pegmatites in the Pala district occupy an area of about 13 square miles; on Queen Mountain they are well known as a source of lithium, tourmaline and quartz. On Chief Mountain the Pala Chief mine is one of the world's largest producers of gem quality spodumene, together with beryl and some tourmaline. There are also pegmatite dikes on Hiriart Mountain, where they can be seen as projections on the slopes; gem quality spodumene and beryl with some quartz and green tourmaline occur here.

Generally speaking the pegmatites are confined to areas underlain by gabbroic rocks; they are quite well exposed, even though much of the area is covered by a dense brush. Since they resist

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erosion better than much of the country rock, they can be recognized as knobs and ribs on hillsides and this leads to their relatively easy discovery in what is rather a harsh area.

Graphic granite is the commonest rock type in the pegmatites of the Pala area. This consists of large crystals of microcline in which rodlike grains of quartz lie parallel to one another; it is easily recognized since the material is fairly resistant to erosion. Some very coarse-grained pegmatites with little graphic granite content are also found and include some of those which give commercially viable minerals. They are largely of quartz or perthite or both and many contain spodumene. Local usage gives the name 'pocket zone' or 'gem seam' to a gem-bearing portion of a pegmatite dike. This type of pegmatite occurs most commonly in the central parts of the dikes and contains for the most part fine- to coarse-grained minerals, including quartz, albite, tourmaline, lepidolite, orthoclase and microcline. Many pockets are filled with a muddy clay which is typical of this area; quartz crystals, often quite well-formed, are frequent in this type of pegmatite. Gem quality crystals of tourmaline, beryl and spodumene are often attached to quartz minerals, although the finest quality material is free within the muddy clay.

Although the principal minerals of the pegmatites of this region are quartz and potassium feldspars, tourmaline is present in quite a number of the dikes—the occurrence growing less frequent as one proceeds eastwards. In the easternmost areas the colour is largely green or yellow-green. Most colours of tourmaline are found in the area, black (schorl) being by far the commonest. This appears blue to deep violet under the microscope although in hand specimen it appears black. This type of tourmaline occurs most frequently in the upper part of the pegmatite and the crystals grow more numerous as the horizon of the pocket zone is neared. If a very concentrated area of schorl crystals is observed, it may be a sign of the presence of a pocket immediately below (which may also contain schorl crystals). Colour varieties include rubellite (often of a raspberry or 'shocking pink' colour), blue (indicolite), green and colourless. It is common for two or more colours to be present in a single crystal, although the arrangement of the colours may be random or regular.

Some crystals show a deep blue to black core with a rim of green, red, blue or pink; others with a similarly coloured core may

show a number of variously coloured rims. Those with a core coloured pink and with rims successively colourless and green are well known by the name of 'water-melon' tourmaline, and this name has been extended to cover similarly coloured material from other tourmaline-producing areas of the world. Some very fine pink crystals have a very thin black or dark blue rim. Quite another group of crystals show colours in varying layers perpendicular to their long axes; some may show up to five colours in the length of the crystal but the majority are pink at one end and green at the other; some pass from black to colourless. In the case of many schorl crystals the end of the crystal nearest the pegmatite wall is black but the other end (that nearest the inner portion of the pocket) may be pink or green.

The crystals are prismatic and may occur as isolated individuals or as columnar groups or as parallel groups. They are most commonly clear and lustrous, though many contain very minute inclusions which lend a milkiness to their overall appearance. Some large fractures are healed with quartz and some crystals are altered with a decrease in transparency, loss of toughness and colour. This alteration is most noticeable in crystals from the Stewart mine. From this mine comes the lepidolite-tourmaline rock in which pink tourmaline crystals form rosettes in fine-grained lepidolite. Green tourmaline usually occurs with quartz and cleavelandite and may occur as inclusions in books of muscovite. Blue and colourless tourmalines occur in pocket-bearing parts of the pegmatites and are associated with concentrations of lepidolite.

Economically the tourmaline mines of this area have had a chequered career. Although in the early part of the century much red tourmaline was sent to China (where it is especially prized), this trade collapsed with the fall of the dynasty in 1912; the presence of the material is said to have been known as far back as 1876. In 1968 Ed Swoboda, a Los Angeles jeweller, re-opened the mines on Tourmaline Queen Mountain and formed at the same time the company Pala Properties International. This company acquired both the Stewart and the Tourmaline Queen mines and the road leading up to them was repaired. This is a very steep and difficult road, the worst part (as I can witness) being the section leading down from the Queen to the Stewart mine. In December 1968 work began to press forward to reach a section of the pegmatite in the Stewart mine ignored by the original miners, who were seeking

lepidolite as a source of lithium, rather than gem tourmalines. By October 1969 pockets of gem quality tourmaline had been found, all filled with the ubiquitous pinkish clay. Most of the crystals were broken along basal planes and about 95% were pink. This pink is not quite so purple as in crystals from the Tourmaline Queen mine; with the dichroscope the colours observed are yellowish-pink and fine deep pink. Sinkankas (1976)[1] states on information received from the company that 295 kg of tourmaline were mined of which 2.25 kg were of faceting grade. In 1973, in a new work area, some green crystals were found in the Stewart mine and some of these have zones of other colours. A good account of work in this mine is that by Szenics (1970);[2] Although Sinkankas (1976) states that work had halted at that point to await completion of work at the Tourmaline Queen mine, this has now occurred and the Stewart mine is being further explored.

Pala Properties began to re-open the Queen mine in 1971, when the crystals found in the pockets were seen to be in better condition than their counterparts in the Stewart mine. Many matrix specimens were discovered and some of these have been the finest ever found in the United States. Sides of the crystals are usually striated and terminated by (0001). A purple tinge to the pink distinguishes them from Stewart crystals. As with the Stewart mine, 95% of the crystals are pink; up to the end of 1974, 363 kg of tourmaline recovered included 4.5 kg of facet-grade material and 213 kg of matrix specimens. Morganite crystals attached to tourmaline were a feature of this deposit. The work of Jahns and Wright (1951);[3] on which some of this account is based, suggested further areas for prospecting.

On the occasion of my visit in 1975 little was taking place at the Stewart mine, but at the Tourmaline Queen mine the manager, John McLean, with the assistance of two Mexican miners, was working on a suspected pocket at the time John Sinkankas and I arrived with Bill Larson. We examined the area inside the mine where the edge of a quartz core met the lower half of the pegmatite, as this type of formation is where pockets occur. As we were inside the mine nothing much happened, and we went outside to have some beer and sit in the bright sun. We had not been there long before an excited cry from inside the mine sent us scurrying back to find that a pocket had been located and opened. Bill Larson took charge at once, John Sinkankas gave advice and I held the lamp.

The pocket was filled with the expected clay, but the cause of the excitement was the end of a large crystal protruding from one of the pocket walls—it was clear that the crystal was a large one or part of a large one, and it was necessary for Bill Larson to use a screwdriver to prise it loose from the pocket. This took about 20 minutes, but on recovery it was found to be of very fine quality, partly dark blue, partly pink and some green. This was a specially fortunate day, since there had been no crystals found of this quality for the previous few months. I am unable to say what happened to it eventually, but it would certainly have been of facet grade. Interestingly and typically it was found to have fractured at some time in its history, but the other sections were not found at the time of my visit, although they may subsequently have been discovered. Later on at the Fallbrook shop 'The Collector', one of the retail outlets of Pala Properties International, I was able to see a large number of specimens from the Pala area, some cut (of which I have an example).

The future of Pala tourmaline seems to be quite bright, as work is proceeding at the Stewart mine; it may be possible to open the Pala Chief mine which was at one time famous for its crystals of kunzite; at the time of the original working some large coloured tourmaline crystals were found there. From time to time the Indians of the Pala reservation make representations (by shotgun) concerning their possible ownership of the mining area but this, together with the occasional raid on the workings (before there was a regular armed guard) does not appear to be too serious. The demand for first-class faceting material has never been greater, and if supplies can be maintained things look good in Pala.

Much useful material has been written about the area; the best geological account is that by Jahns and Wright in Special Report 7A of the Department of Natural Resources of the State of California.[3] This is issued with maps, and tourmalines are shown in colour. Accounts of early mines and miners can be found in Rynerson *Exploring and Mining for Gems and Gold in the West*.[4] Sinkankas's *Gemstones of North America*,[1] volume 2, contains personal communications from Pala Properties International to the author and is invaluable on this and other points.

For those wishing to obtain materials from the area the address of Pala Properties International is: 912, South Live Oak Park Road, Fallbrook, California 92028, U.S.A. (Telephone 714-728-9121.)

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IMITATION OPAL—SLOCUM STONE

By A. E. FARN, F.G.A.

The Gem Testing Laboratory, London Chamber of Commerce and Industry

How one regards innovation seems always a question of age. Since change is ever with us, it is necessary to accept that what is a stable concept now may be almost a forgotten myth tomorrow. After the first commercially successful synthetic emeralds appeared upon the market not long after the war we felt (in the Lab) fairly happy that we could easily detect those new and somewhat wonderful stones. In retrospect, life then was pleasant. Quite frankly we thought that at least star-stones were beyond the bounds of feasibility. Since then, of course, we have had not merely the hydrothermal and flux-fusion products, syntheses of corundums and beryls, but synthetic opal as well.

The products of Verneuil, Chatham and Gilson—ruby, sapphire, emerald, alexandrite, opal—are what I call true synthetics. They are artefacts but nevertheless are a synthesis of something which occurs in nature. Such products as strontium titanate, YIG, YAG, GG, and GGG—to name a few spin-off products of space research—do not seem to me to warrant the use

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of the adjective synthetic. They are just simply artefacts—man-made stones. However, I am not now proceeding to exercise that particular hobby-horse of mine but rather to arrive at what is clearly a satisfactory conclusion—that in the Slocum stone we have an *imitation,* not a synthetic—an imitation opal in fact.

Apart from the fantastic achievement of producing a harder-than-opal, workable substance of considerable attraction, John Slocum began by producing a true synthetic opal of outstanding beauty!

I am late in coming round to describing Slocum stone—it was well written up in the *Lapidary Journal* of September, 1976.* John Slocum decided to have a go at producing synthetic opal, since this remained a barrier which had not yet been surmounted and seemed to offer him a challenge. It took him many years of patient work and a small gravel-pit filled with his rejects and waste material before he achieved a beautiful synthetic opal. Unfortunately it inherited the faults of true (natural) opal—cracks, porosity, etc. Having achieved his goal, he was dissatisfied.

So he then decided to produce a gem of opal quality which was more durable, and he has succeeded. He has produced a very pretty and attractive material which has a play of colour closely resembling opal (see Figure 1). Looked at with the unaided eye (as most jewellery is when worn) it looks like opal of very attractive quality, whether it be black opal, water opal or white harlequin opal. The range of colours is wide. I have had a few to look at, and while I think I can claim to be a reasonably critical person and not unused to handling a 10× lens, I do not want to go on record as someone damning a very fine achievement and (as I should imagine from reading recent brochures) a commercially successful venture. Opals, of course, have all the faults: nature seldom bestows favours plenteously (this results in rarity). One thing which always strikes me about synthetics, artefacts and imitations, is their endless reproduction. I still take off my gemmological hat to John Slocum for his achievement in first perfecting a true synthetic opal and *then* proceeding to seek perfection in an imitation opal.

I must say that to me, using a 10× lens, they present no problem—perhaps none was intended. Their structures are very interesting (Figures 2, 3 and 4). I measured the densities of some of

*Schowalter (M.). *Slocum stone—a new man-made material.* Lapidary J., 1976, 30, 1370-4.—Ed.

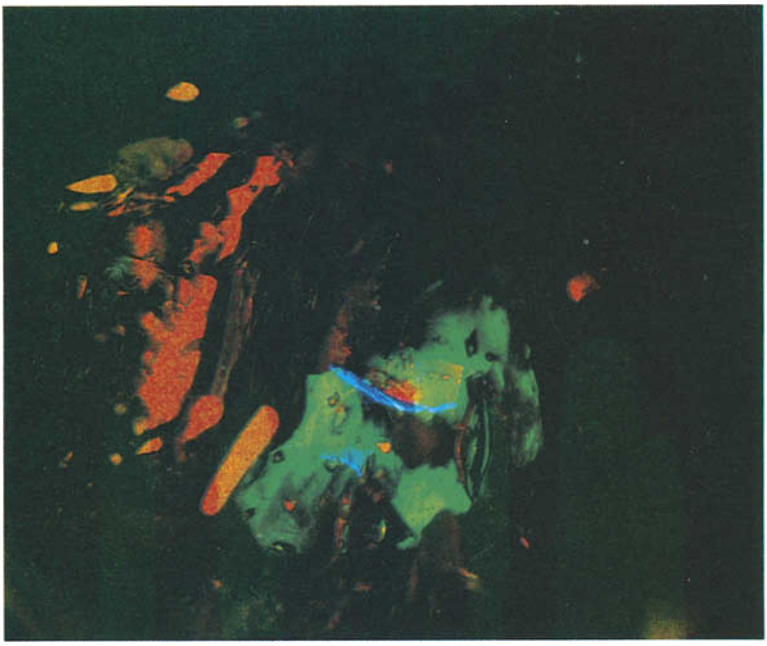

Fig. 1. Slocum stone.

the specimens. First I took a bulk SG of six stones which gave me a density of 2.49 and then I took the three largest and most strongly coloured and also the smallest which was water opal in colour. These stones, being a fair cross-section of depth of colour and size, also varied slightly in their respective RIs, as set out below:

Weight in grams	SG	RI
33	2.505	1.53
13	2.500	1.52/3
12	2.500	1.52/3
5.70	2.450	1.51

The refractive indices, taken by the distant vision method, were fairly sharp, due to a good polished surface. Under both long and short wave ultraviolet light the stones varied with no apparent clue or pattern between long or short or parallels between stones under each wavelength. With a 10× lens looking through and at the stones one could easily see bubbles and at times signs of layered

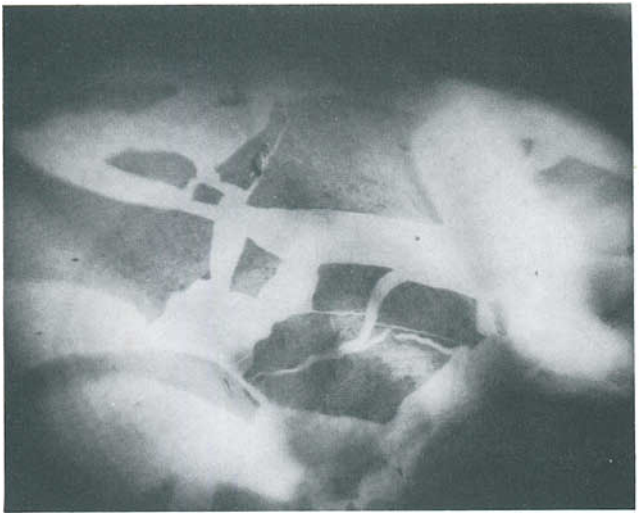

Fig. 2. Structures in Slocum stone.

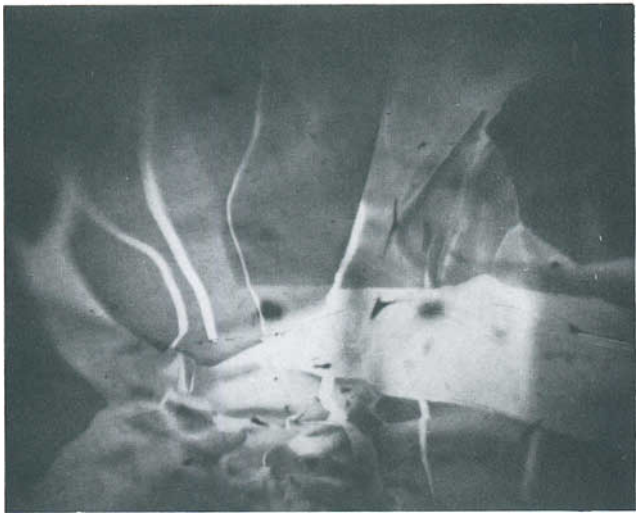

Fig. 3. Structures in Slocum stone.

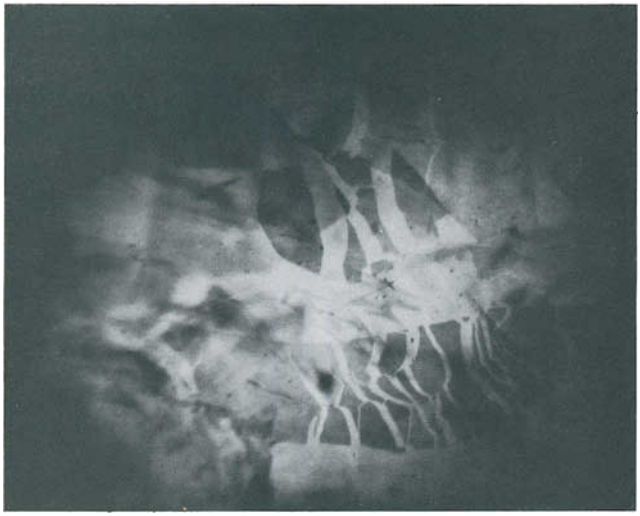

Fig. 4. Structures in Slocum stone.

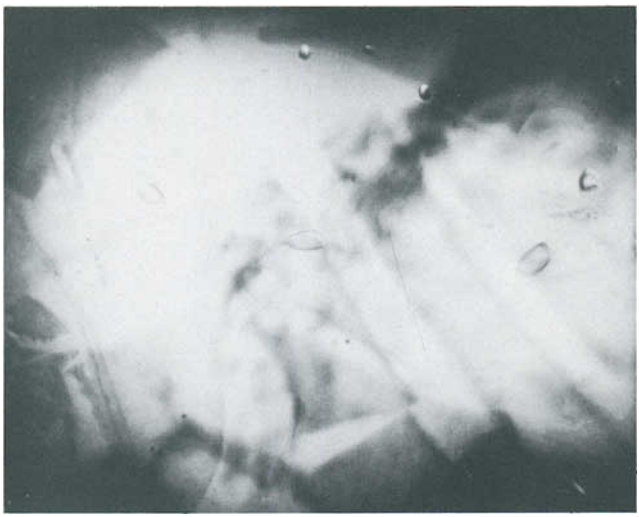

Fig. 5. Structures and bubbles in Slocum stone.

Fig. 6. Structures and bubbles in Slocum stone.

structure (Figures 5 and 6). The black opal types looked more realistic on their unpolished backs.

Slocum stone is obviously very successful. A small brochure recently published describes it as 'opal-essence: a step beyond opal'. The advantages of Slocum stone imitation opal are that it is tougher than real opal, is not porous and has no included water content to shrink or expand. It is said to be easy to cut, polish and slice. By all standards it is an intriguing, attractive, successful accomplishment.

The beautiful colour photograph was taken by B. W. Anderson and the photographs of internal structures (which are difficult to depict in black and white) were taken by K. V. Scarratt, to both of whom, and also to Harry Wheeler for the loan of the specimens, my thanks are due.

[*Manuscript received 18th February, 1978.*]

VISUAL OPTICS

By ALAN HODGKINSON, F.G.A.

This is a technique for visually observing the optical phenomena of faceted gems, set or unset. By mentally noting and combining the various phenomena which form on the retina and assessing their relative measurement, one has a method of eliminating many gem possibilities, if not always of identifying the gem in question. The technique should be seen as a supplement to instrumental gemmology, of more benefit to the gemmologist at the counter than the one in a gem laboratory.

The best introduction to Visual Optics is in a dark room with a sole light source. With practice, one can cope well in any situation, provided there is a unique light source to provide the virtual images seen. A clear bulb with 'C' shaped filament is a most useful starting point, but the normal line filament will suffice and most torch bulbs reproduce this effect and offer a practical portable light, in pocket form.

Figure 1 shows my assistant, Mrs L. Ferguson, F.G.A., demonstrating the technique, which involves closing the non-seeing eye, and virtually closing the seeing eye (the more closed the better) and placing the table facet of the gem to be observed so that it touches the eyelashes, the view being directed toward the bulb source which may be 10 or 20 feet away or more.

Proof that the eye is suitably controlled is gained by the appearance of a number of spectral reproductions of the filament image. It is advisable to start with a lower refractive gem, as the virtual images are easier to locate; the number of images being relative to the number of main pavilion facets.

The spectral images, their relative position and their optical nature, provide us with an approximate measure of all the optical phenomena. With practice this becomes a useful and competent method of gem identification, when instruments are not immediately accessible, although in no way does it pretend to compete with the instrumental approach.

Figure 2. Refraction and Double Refraction. The top diagram is a simple illustration of the various light paths taken by a light ray, as it slows through gems with varying degrees of refraction.

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Fig. 1. Mrs. L. Ferguson, F.G.A., demonstrating the technique.

Fig. 2. Refraction diagram.

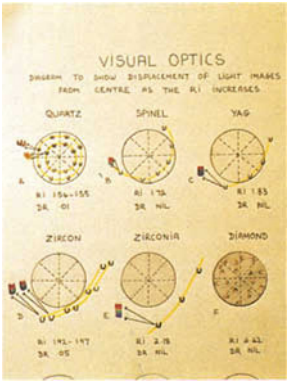

Fig. 3. Refractive phenomena—from through-the-eye position.

Fig. 4. Dichroism.

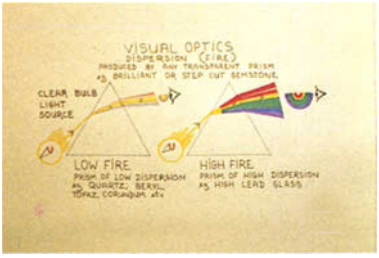

Fig. 5. Dispersion diagram.

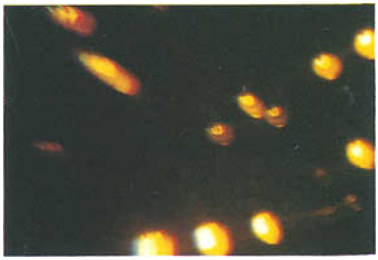

Fig. 6. Golden quartz.

The lower diagram illustrates how the eye sees these refractive variations using the 'visual optics' technique, though no attempt has been made to show the light mechanics within the eye itself. The lower the RI of the gem, the closer the image pattern occurs in relation to the culet position. The higher the refractive medium, the nearer the image occurs to the girdle and beyond, which is better shown by Figure 3.

Figure 3 shows the same refractive phenomena, but from a through-the-eye position. Low refractive gems such as quartz, bring the inner ring of light images well into the centre. Please note—the images will appear closer to the central area, the shallower the stone is cut, whilst deeper cut gems will have the opposite effect. The relative cut and proportion of each gem should be observed before employing the technique, in order to make due allowance for its virtual image positions, each of which is the product of an individual main back facet. As the different gemstones rise in their refractive power, the innermost images are located further and further from the centre.

Double refraction, being present in the quartz specimen, shows itself by the virtual images becoming doubled. The extent of the doubling will depend on the angle of viewing, whilst those corresponding with the optic axial directions, will appear only single, making it necessary to rotate the ring, bracelet, or other, in order to perceive the doubled images, and to give the gem a chance to show its maximum birefringence.

It is not possible to observe the image phenomena in a cabochon stone, and poorly polished facets also lead to difficulty because of blurring of the images—a common complaint against quartz and ruby today.

In gems of low birefringence, the slight separation of the 'C' shaped filament images may occur in any direction, though consistent in the one gem, and a series of 'M's, 'W's, '3's may be seen or, more difficult to detect, the 'C's wrapped round each other, when a 'C' filament is used.

With blurring or small separation of the images, it is useful to introduce a polarizing device between the stone and the light source, rotating the filter through 45°, which will enable the double nature of the images to be established distinctly. Occasionally one encounters rogue images superimposed on other images by reflection. There will be no regular pattern of such twinnings, and it is

Fig. 7. Glass.

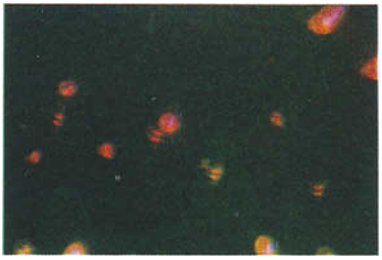

Fig. 8. Ruby.

Fig. 9. Tourmaline.

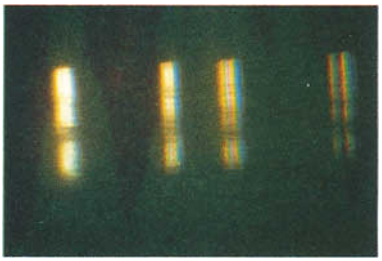

Fig. 10. Tourmaline.

Fig. 11. Peridot.

Fig. 12. Zircon.

Fig. 13. Cubic Zirconia.

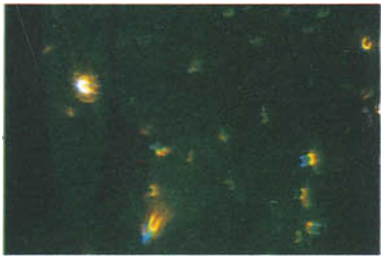

Fig. 14. Diamond.

therefore always a useful proof to find two or three consistent pairings to establish double refraction.

With low refractive gems, it is normal to see two or more patterns of lights, the images from the outer facets having a strengthening effect on the property of double refraction and dispersion, the light having travelled a further distance. In consequence, the twin images move further apart from each other. A good example is shown in the peridot (Figure 11).

In assessing a gem's refraction, double refraction and dispersion, one uses the primary images which are nearest the centre of the stone. Gems with higher RIs push the image pattern further from the centre, and by 1.73 (spinel) or 1.83 (YAG), the pattern is pushed so far from direct view, that only part of the perimeter of the inner image pattern is seen. To see the total perimeter, the stone must be rotated.

By a refractive index of 1.9 or more, e.g., zircon, then, provided the back facets are cut acceptably deep to make the stone lively in appearance, it will be found difficult to locate an image or two from the inner perimeter. The image can be found, either by slightly tilting the stone back or forth toward the light source, or by slightly raising or lowering the eye.

Another graduated effect is that the higher the refraction of the gem, the darker the stone interior becomes, until with high RIs, such as those for zircon and zirconia, etc., there is a blackout effect, which gives added accent to the spectral images when located.

Figure 4. Dichroism. Once the virtual images have been located (a task more difficult, the smaller the stone and the higher the RI), a polarizing device may be inserted between the stone and the light source, which will, if birefringent images are observed, produce dichroism in the stone, if this is one of the gem's optical products. Simply rotate the polarizer through 45° and on to 90°. In strongly dichroic stones the individual virtual images of each twin will often show this without recourse to a polarizer. The dichroism is sometimes helpful with the smallest of stones—in an eternity ring, for example—for the pleochroic effect establishes anisotropism where it may be difficult to locate any separation of the images which would establish doubling.

Figure 5. Dispersion. The diagram shows the contrasting images of the 'C' filament, when observed through transparent

quartz family members, aquamarine, topaz, etc., with their feeble dispersive images. In contrast, the normal glass gems, with their high lead content, produce striking spectra with each colour spread relatively wide. Being low in refraction, all the varieties mentioned will show the images formed up in the plan pattern of the gem, viz., a circle of images in a round cut gem.

If there is an outer pattern (or patterns) of the light images, due to the extra row (or rows) of main pavilion facets, the longer distance travelled by the light through the gem from those facets nearer the girdle causes the dispersive effect to increase, so that in a larger round amethyst, for example, the outer ring of images will achieve a spectral effect far greater than the dispersive product of quartz. It is necessary, therfore, to use the innermost row of images as an indicator of the power of dispersion. The same exaggerated effect is observed in the double refraction *(v. sup.)*.

The following photographs (Figures 6 to 14) were taken by removing the lens unit from an Olympus O.M.1., S.L.R., camera and substituting the gemstones one by one, blacking out all the extraneous light by embedding the stone in a flat circle of 'Blu-Tack', which was then plastered across the lens orifice. The images could be observed through the eyepiece and photographed when best displaying the inherent properties. The only optical factor which cannot be measured on the photograph, is the refractive power, because of the angling of the gem involved in producing the best effect for the camera. In actual practice, one gauges the refraction by establishing a straight line from eye to light source, with the table facet at right angles to this line. Point one's unused arm down, or up, to the first row of images (or the first image found in a highly refractive gem); the angle between one's pointing arm and the line of eye to light is the measure of refraction, remembering to allow for the cut being shallow or deep.

Figure 6 shows various virtual images seen in a golden quartz. Some of these primary images have overexposed, although the doubling is just evident in one corner.

In the centre are two doubled image pairs, faithfully reproducing the 'C' filament. These are what I call secondary images, which come from the smaller girdle facets and then reflect off the main pavilion facet, hence the loss of light intensity and correct exposure on the film.

Figure 7. In contrast to Figure 6, this 16mm glass produces

exaggerated spectral images, enabling the spectrum to be analysed for all its colour components. The images form close into the central area, indicating low refraction, and this combination of factors indicates a glass identity.

Figure 8. Ruby. Again, the secondary images come to the rescue by displaying birefringence. Note how there is no green in the spectral image—the green, of course, being absorbed, as witness the absorption spectrum. The blue and violet have also not appeared, as the exposure time was not long enough for them to register, though in practice these short wave colours are seen.

Figure 9. Tourmaline. This hemimorphic mineral makes an interesting subject for 'visual optic' study. The birefringence is usually found instantly, and, if not so, try looking through the back of the setting; while in smaller tourmalines, an across-the-girdle direction may be productive. The dichroism also readily shows itself, but particularly in the green to brown tourmaline's colour range. One of the images will be distinctly more intense than the other, due to the strong differential absorption involved, the faint image being the projection of the ordinary ray, and a unique feature of tourmaline.

The tourmaline in the photograph displays the phenomenon of four images in the centre—two strongly absorbed and two slightly absorbed, making up an image quartet. The effect was observed in several greenish brown stones, and would seem to illustrate the phenomenon written up by Keith Mitchell, F.G.A., in his report on a tourmaline's four shadow readings on the refractometer, which appeared in this *Journal.* *

Figure 10. Tourmaline. Sometimes the facet edges on larger step-cut stones light up, and are observed as doubled facet lines. This photograph shows the central facet line has allowed more light through, with consequent overexposed blurring. The succeeding three facet lines move further away from the centre and one observes that both the birefringence and dispersion increase at each facet stage, a factor described earlier.

Figure 11. Peridot is a useful stone to begin with, as its low refraction allows easy capture of the image field, the general image pattern showing the facet formation of the stone. Birefringence is at once visible, and the outer twinned images give an instant pointer to higher double refraction, approximately twice that of

*J. Gemm., 1967, **X**, 6, 194, and 1976, **XV**, 1, 17.—Ed.

tourmaline, whilst the 0.020 dispersion is unable to raise any sign of spectral behaviour other than in the outermost images.

Figure 12. Although at first it is difficult to locate the images in a well proportioned zircon due to the high refraction, once located, the powerful spectral twin images, emphatically separated, give the whole guide to a zircon's identity—high refraction, high double refraction and high dispersion.

The technique instantly distinguishes blue zircon from aquamarine, blue topaz and synthetic spinel of that colour. In brown stones, tourmaline and sinhalite are readily distinguished from zircon, whilst in white gems, even in small stone-set eternity rings, one can pick up the unique nature of zircon from the other diamond simulants, merely by looking up at the strip lights in a normal shop, though it is stressed the single clear bulb filament in a room is much safer to work with.

Lastly, white zircon and lithium niobate, with their strong optical properties can be separated by no more than lifting the stone to the eye, that is, provided one has practised 'visual optics', and, equally, is aware of the relative constants of the two stones.

Figure 13. Cubic Zirconia. Suffice it to say that in the 'Two-day Practical Gem Identification Course' which I ran in May 1978 for *Retail Jeweller* magazine, the whole group were able to distinguish between diamond and cubic zirconia. What gives the test more credibility, is that the two stones were emerald-cut, of the same size, and were handed to the group in a dark room.

With both stones, the first reaction is of blackness, but as the zirconia is tilted, or the eyes are lifted, the extravagant primary spectra are located, each colour spreading out into a long continuous spectrum. Many tiny secondary images are seen, but these are blurred compared with diamond.

Figure 14. Diamond. In the normal range of proportions of cut for diamond, the high refraction excludes the light from the eye by its total internal reflection, the result being a blackout effect, indicative of the high optical power. One does, however, see a swarm of tiny secondary images, proof of their secondary origin being their haphazard display—the 'C's pointing in all directions, unlike the formal pattern of primary images which are directly related to the symmetry of the main back facets and are the sole criteria for an estimate of refraction. The sharp focus of the secondaries is unique to diamond.

With the more shallow cut diamonds, one is able to angle the stone sufficiently to draw in one or two primary images, but their spectral display can in no way compare with that of zirconia.

Dispersion being a cone effect, the larger stone will always produce a larger spectral image and one must make due allowance for size.

'Visual Optics' has been a feature of the 'Two-day Practical Gem Identification Courses' for the last eight years, but only now have I attempted to put the concept on paper. It was, therefore, sobering to be sent a copy of *Gems and Gemology,* dated 1951, in which Robert Crowningshield* covered the ground from a different angle—literally. His article concluded—'It is hoped that the information given will prompt others to investigate this method of observing gemstones, and that perhaps other uses for the method will be reported.' I trust this is in accord with those hopes.

Gemmology is now developing a certain awesome aspect, as it reaches the level of computer identification. Much identification, however, must still be attempted at shop-counter level, falling back to the instrument section when necessary. Perhaps Visual Optics will give some help in these initial areas of investigation and may help save some time and effort by its immediacy of approach, apart from astonishing some of your gemmological colleagues.

Practice makes for improved technique in all things, but time, of course, is a commodity we all have trouble in affording, so, with tongue in cheek, may I suggest you place the light source on top of the television set, and, with one eye on the programme, the other eye can learn to decipher the identity of a gem via the visual assessment of its various optical properties, which, in combination, make each gem a unique optical phenomenom.

[*Manuscript received 26th August, 1978.*]

*Gems Gemol., 1951, **VII**, 4, 120-4.—Ed.

EAST AFRICAN TOURMALINES AND THEIR NOMENCLATURE

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In the past years, increasingly larger quantities of green tourmalines have come on the gem market from various localities in East Africa which meanwhile have reached a certain importance. The intensely green-coloured tourmalines are generally called chromium tourmalines. Green-coloured tourmalines from East Africa have been described as vanadium tourmalines from the Gerevi Hills, Tanzania, by Bassett (1953), McKie (1955) and Webster (1961). Chromium tourmalines of unknown locality in East Africa have been mentioned by Bank and Berdesinski (1967), and vanadium (chromium) tourmalines from the Umba Valley, Tanzania, by Zwaan (1974).

Though the lots which generally come on the market often contain stones from different mines, we have been able to separate stones from six localities by crystallographic, analytic and spectroscopic investigations. These samples are dravites and uvites of five different localities in Kenya and Tanzania, coloured by vanadium. Only one locality has furnished samples which show a higher chromium than vanadium content, but they are generally not of gemstone quality. Besides the green ones there are yellow and brown colour shades available which are caused by additional contents of iron.

Dravite and uvite are Mg-Al-tourmalines with the generalized formulae

$NaMg_3Al_6[(OH)_4|(BO_3)_3|Si_6O_{18}]$ for dravite

and $CaMg_3(Al_5Mg)[(OH)_4|(BO_3)_3|Si_6O_{18}]$ for uvite.

The significant difference is a coupled substitution of (Ca,Mg) and (Na,Al) in the structure of tourmaline. The distinguishing feature between chromium and vanadium bearing tourmalines is a sharp absorption line of Cr^{3+} at 684nm (14 600 cm^{-1}), which is not present in the case of vanadium tourmalines. This absorption line can be found by spectroscopic investigations.

In summary, green tourmalines from East Africa, which are

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often called chromium tourmalines, are mainly not coloured by chromium but by vanadium and therefore should be named vanadium tourmalines (dravites and uvites). By a simple spectroscopic test, they can be distinguished.

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[*Manuscript received 8th March, 1978.*]

A NOTE ON COLOUR

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In his recent article, K. W. Findlay[1] discussed some aspects of colour. He suggested that the eye would perceive different colour sensations, depending on the medium of transmission (air, water, etc.). His postulate was that, since the refractive index of the medium is different, so would be the velocity of the light and hence the wavelength would change, resulting in a changed colour.

In a subsequent note Dr R. M. Yu[2] pointed out appropriately that the intermediate medium does not matter since the light is perceived within the eye where conditions are always the same. Both authors claim that the frequency of light has more meaning than the wavelength, since the latter changes with the propagating medium while the former does not.

In my article on the International System of Units[3] I discussed the meaning and conversion of the various units used to specify the colour spectrum. In the interests of brevity I did not

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there mention a fact, well known in the field of optics, which neither of the cited authors mentioned. When wavelengths, frequencies, etc. are measured by instruments, the value read and quoted is *that which would have been obtained if the measurement had been performed in vacuum.*

This convention is always followed and has several important consequences. All measurements on a given beam of light, in whatever medium, performed by any technique and on any instrument, will always give the same answer. Results will be independent of laboratory variables such as temperature and humidity. Different experimenters in the different laboratories can compare their results with the assurance that they are using the same standards. And, finally, both wavelengths and frequencies are equally meaningful, since the conversion between[3] them is the velocity of light in vacuum which is a constant.

It might be mentioned that my comprehensive survey on the twelve causes of colour in gems and minerals[4] has also recently appeared in an abbreviated but more technical version.[5]

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[*Manuscript received 9th August, 1978.*]

THE DIFFERENCE BETWEEN MAXIXE BERYL AND MAXIXE-TYPE BERYL: AN ELECTRON PARAMAGNETIC RESONANCE INVESTIGATION

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A deep blue beryl was discovered in 1917 in the Maxixe mine in Minas Gerais, Brazil[1]. Unfortunately, the colour was not stable in daylight. A similar beryl appeared on the gemstone market in 1972/1973 and also lost its colour after being exposed to light for an extended period of time. This beryl was thoroughly investigated by Drs Nassau and Wood[2,3] and called Maxixe-type beryl. They found a slight difference in the optical spectrum of this stone and the original Maxixe beryl. The present investigation shows that the colour arises from different impurity ions which have lost one electron, probably by irradiation, to form CO_3^- colour centres in the Maxixe-type beryl and NO_3 colour centres in the Maxixe beryl.

*Electron Paramagnetic Resonance (EPR)**. This type of spectroscopy uses microwaves, which are orders of magnitude weaker than light waves and therefore truly non-destructive to the sample. The sample, normally of dimensions between 1 mm and 1 cm, is put into a microwave cavity which is placed in a strong magnetic field. The microwave frequency is determined by the spectrometer design and resonances are observed by sweeping the magnetic field. The observed transitions correspond to energy differences much smaller than in optical spectra and are related to the energy states of unpaired electrons.

Electrons are normally paired in ions and in chemical bonds. When an electron is removed, e.g. by irradiation, the remaining entity (often a colour centre) contains an unpaired electron and can be detected by EPR. Transition-metal ions often have unpaired electrons in their inner shells and can therefore be detected by EPR in unirradiated materials. An example of this is the determination of Cr^{3+} as the impurity in synthetic yellow sapphire[4] while the natural impurity giving the colour is Fe^{3+}. Diamonds and other gem

*also called Electron Spin Resonance (ESR)

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stones have also been investigated by EPR. The interpretation of the EPR spectra not only yields the nature of the colour centre, but often also its position and orientation in the crystal lattice. Since the electrons are used as probes, effects on the atomic and molecular level are observed.

Measurements. I am very grateful to Prof. E. Gübelin, Lucerne, for lending me the Maxixe beryl[5] and to Mr J. B. Schaffroth, Zürich, for lending me the Maxixe-type 'indigo beryl' (later also called 'Halbanita aquamarine') for this study. The beryl crystals were investigated with a Varian E-109 EPR spectrometer.

The EPR spectra of the two crystals are shown in Figure 1. These spectra were obtained with the magnetic field perpendicular to the *c* axis of the crystals. The magnetic field, measured in gauss, increases from the left to the right. Since the microwave frequency of different spectrometers may be different, the frequency is divided by the resonance field (and multiplied by a constant) to give a characteristic value for the resonance, the g-value, which is independent of the spectrometer used.

The g-values for the strong EPR signals are 2.021 in Maxixe

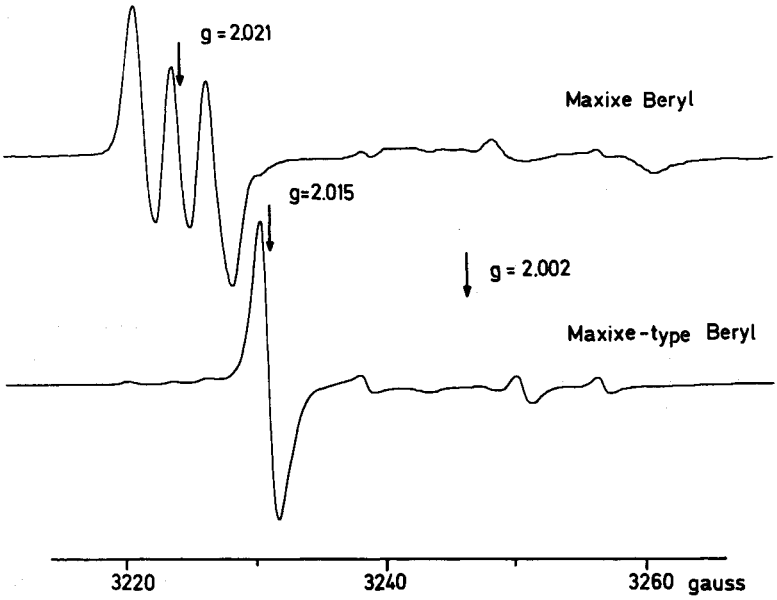

Fig. 1. EPR spectra of Maxixe and Maxixe-type beryl at a frequency of 9.1 GHz with the magnetic field perpendicular to the *c*-axis direction. These spectra were obtained at −180°C, where the lines are narrower than at room temperature. The small lines in the spectra arise from CH_3 and other radiation damage centres.

beryl and 2.015 in Maxixe-type beryl when the magnetic field is perpendicular to the *c* axis. When the field is parallel to the *c* axis the g-values are 2.004 and 2.005 respectively. The difference of the g-values from the g-value (2.002) of the free electron gives an indication of the species with which the unpaired electron is associated. Similar g-values to those observed here have been found for NO_3 (g = 2.023 and 2.003) in irradiated KNO_3 [6] and for CO_3^- (g = 2.016 and 2.005) in irradiated calcite[7]. (These irradiated crystals are also blue.)

The EPR spectra of the 'Halbanita' stone[8] and of Maxixe-type beryl obtained from morganite by x-irradiation[9] have already been interpreted. In both cases the blue colour was found to arise from a CO_3^- ion oriented with its plane normal to the *c*-axis direction and situated at the largest section of the empty channel in beryl.

In the top trace of Figure 1 the EPR signal is split into three lines. This is characteristic of a nucleus with spin = 1 like ^{14}N, while nuclei which have spin = 0 like ^{16}O and ^{12}C do not split the EPR line. The orientation dependence and the comparison with the results (g-values and size of splitting) for NO_3 in irradiated KNO_3 lead to the conclusion that the colour centre in Maxixe beryl is NO_3, positioned in the same way as CO_3^- in Maxixe-type beryl.

Discussion. It has been established by EPR that the colour centres in Maxixe beryl and Maxixe-type beryl are NO_3 and CO_3^- respectively. These centres may be created when NO_3^- and CO_3^{2-} impurity ions lose one electron or when a hydrogen atom is removed from HNO_3 and HCO_3^-. Such processes occur when crystals are exposed to x-rays or gamma rays. In certain cases electrons can also be removed by ultraviolet irradiation.

It has been demonstrated[2, 3, 9] that a deep blue colour can be produced by irradiation of certain pale beryl stones with neutrons, x-rays and gamma rays. In a report[10] on the 'Halbanita' beryl, it is stated that this Maxixe-type beryl has not been exposed to any of these energetic types of irradiation. It was admitted that a non-defined method was used to create the deep blue colour in about 10 days. Since the energy of ultraviolet radiation sometimes is sufficient to create colour centres, a test was made with a thermally bleached 'Halbanita' stone. After a few minutes of ultraviolet irradiation in the 230 to 330 nm range, one could already observe the CO_3^- signal in the EPR spectrum. After two hours of irradia-

tion, a weak blue colour could be observed and the EPR signal was much stronger. This shows that it is possible to produce Maxixe-type beryl by ultraviolet irradiation. Since the EPR method is much more sensitive than the eye, it could be used to select those stones (after an initial short period of irradiation) which may become coloured by prolonged irradiation.

Cosmic rays or irradiation from radioactive nuclei in the surrounding minerals may have built up the NO_3 concentration in the Maxixe beryl.

Not all beryls can be coloured deep blue (or green) by gamma irradiation[3]. The present results show the necessity that the beryl contain CO_3^{2-} or NO_3^- impurities. This is, however, not sufficient. In order for the colour to remain, the lost electrons have to be strongly trapped. Otherwise they will return to the original ion, as they do under the influence of heat or light, causing the colour to bleach. The extent to which a stone can be coloured depends on the concentration of the necessary impurities (and electron traps). This explains the large variations observed[3]. (A small concentration of NO_3 is also present in the Maxixe-type beryl studied, as can be seen by the very weak NO_3 lines in the spectrum of this crystal in Figure 1.) The stability of the colour under the influence of heat and light may also vary considerably. This depends on the nature and the stability of the electron traps in the different stones.

Since the trapped electrons are unpaired, they can also be investigated by EPR. It has been found that most electrons in the Maxixe-type beryl are trapped together with protons to form hydrogen atoms[11]. This was also found to be the case in the Maxixe beryl. Many electrons in the Maxixe-type beryl are also trapped by centres which are preliminarily interpreted to be CO_2 impurities forming CO_2^- associated with different alkali metal ions. EPR signals of NO_2 are observed in the Maxixe beryl.

Heat treatment experiments show that the CO_2^- type signals are the least stable and disappear with a rate corresponding to the fast decay of the colour in Nassau's experiment[3]. The hydrogen signal disappears with a rate corresponding to the slow decay. The electrons released by the heat are caught by the CO_3^- ion and cause its EPR signal to disappear at the same rate as the colour[8, 9].

I wish to thank Mr J. B. Schaffroth for initiating the investigation of the 'indigo beryl'. I also thank Professor E. Gübelin and Mr J. B. Schaffroth for valuable comments on the manuscript.

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ECONOMIC GEOLOGY OF THE ANAKIE SAPPHIRE MINING DISTRICT, QUEENSLAND

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ABSTRACT

The Anakie district in east-central Queensland is the largest of the two major Australian sapphire-bearing gem gravel mining areas. The fields were established in the late 19th century for marketing distinctive royal blue hued stones to the Imperial Russian court. Since the decline in competitiveness of south-east Asian gem gravels over the last fifteen years, the Anakie sapphires have dominated the commercial gem markets. Sapphires and zircons are the major gemstones associated with the shallow Tertiary gravels of the district. Source of the sapphires has not been conclusively demonstrated. The largest commercial field is the Rubyvale-Sapphire trend, which is famed for its blue hues. The Willows field is noted for the golden yellow sapphires, as well as large green specimens, but production of blue stones is limited and of poor colour. The Tomahawk Creek field produces the finest green coloured sapphires. Commercial mining utilizes a bulldozer trenching system. Only a few commercial claims are hand-operated vertical shafts, an approach generally associated with the casual prospector. Up to 60 feet of overburden may be excavated. Commercial recovery of the sapphires involves trummel screening, sluice washing and gravity separating with a riffled pulsating jigger.

INTRODUCTION

Australia has two major commercial sapphire mining districts: the Anakie area of east-central Queensland and the New England area of north-central New South Wales. The production from these mining districts has substantially replaced the classic Asian sources on the world gem markets.

The ruby and sapphire mines near Mandalay, Myitkyina and Mogok in Burma have been in operation for centuries, probably predating the historical records. Thailand also ranks as a classic producer of fine gem quality sapphires from a coarse gravel belt that extends into Cambodia. The widespread sapphire bearing gravels of Ceylon and India are similarly famed, though their production has considerably paler hues. The primitive mining methods within relatively small claims, exhaustion of the gravels from centuries of excavation and political upheavals over the last several decades have resulted in a steadily declining production. This decline, however, has assured the economic survival of the two

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major Australian sapphire mining districts. Nevertheless, Australian sapphires, while in abundant supply, are somewhat less desirable than their Asian counterparts. They have a tendency towards a less brilliant inky blue hue rather than the more favoured, lighter 'cornflower' shades.

This is the first of two papers on the economic geology of the Australian mining district of central Queensland, and the Glen-Innes (New England) district of New South Wales with comments on the commercial marketing system and notable sapphire gems.

THE AUSTRALIAN SAPPHIRE DISTRICTS

There are two major sapphire mining districts: the Anakie district of central Queensland and the New England district of north-central New South Wales. Non-commercial sapphire occurrences are reported elsewhere over widespread areas of Australia.

The discovery of the Anakie fields is attributed to a Mr Richardson, employed as a railroad right-of-way surveyor. In 1875 he collected some red zircons on Retreat Creek, 13 miles west-south-west of Anakie. Thinking they were rubies, he shipped the zircons and their gravel concentrate for gemmological testing. He failed to notice the small sapphires with the red zircons, but upon identification, Mr Richardson became one of the partners in a company to work the field for the sapphires. This original discovery site was commercially worked in 1891 by the Withersfield Sapphire Company. The company's operations soon expanded from central Queensland to beyond Armidale in New South Wales, exploring almost every creek and river gravel bed for the gemstones. By the end of the century the commercially viable zone had been extended across 28 square miles.

Sapphires have been recovered from a number of localities in the state of Victoria. They are associated with heavy mineral concentrates recovered during gold mining. Tasmania has produced small specimens associated with its tin gravels. Gem quality sapphires are rare in Western Australia, but extensive corundum and emery deposits are recognized.

The occurrence of ruby in Australia is very rare. A number of reports are on record from the early years of this century, but the validity of their identification is questionable. It is likely that most

of the specimens are actually spinel or garnet. Occasional small crystal fragments of pale pink corundum occur in the Queensland gem gravels near Sapphire, Tumberumba and Burmah. Isolated recoveries of reported ruby in Queensland have been at the Jordan Creek goldfield in the Little Beatrice River, the Henrietta Creek area, the Rocky Tate River of the Chillagoe district, Campbell Creek of the Palmer goldfield and in the Anakie sapphire district. Ruby discoveries in New South Wales and elsewhere in Australia are virtually unknown.

ANAKIE SAPPHIRE DISTRICT: PRODUCTION HISTORY

The Anakie area in central Queensland is the major producing Australian sapphire district. It was here that the sapphire bearing district had been shown by the end of the century to extend eastward for 12 miles, westward for 14 miles and northward for 16 miles. The small village of Sapphire (Figure 1) was the only business centre in the early years of the twentieth century, but by 1907 the influx of miners from the nearby worked out Black Bridge placer gold field settled and worked the gem gravels in Policeman Creek, 4 miles from Sapphire, and founded the township of Rubyvale. Today, the main workings cluster around Rubyvale, Sapphire, The Willows and Tomahawk Creek (Figure 1). These fields constitute the 'Anakie' district, although no sapphires are found in and around the town of Anakie itself. Rubyvale is but 12 miles north of Anakie. Anakie is approximately 200 miles west of Rockhampton.

The Anakie field was proclaimed on 3rd September, 1902, as a recognized mineral field subject to the state mining laws. The area was defined to cover 18000 acres or approximately 28 square miles. This has now been expanded to over 80 square miles within a potential area of over 400 square miles.

Initial nineteenth century production was minimal because of the lack of incentives related to low prices. Many of the smaller mines and prospects ceased production by the close of the nineteenth century, only to be revived with the establishment of regular markets for the gemstones by late in the first decade of this century. Virtually all of the Australian sapphire production in the 15 years prior to World War I was controlled by German gem merchants. Many of the early immigrant prospectors were German. The

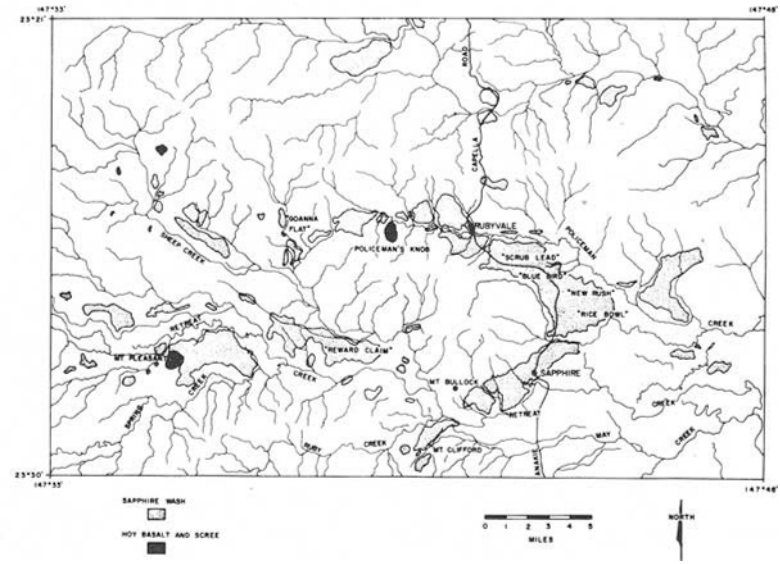

Fig. 1. Distribution of the gemmiferous gravels, the sapphire wash, in the central Anakie mining district, east-central Queensland. The most productive fields of the district are excavations of buried alluvium trends between the towns of Rubyvale and Sapphire.

sapphires were exported to Germany to be sorted, graded and cut, and finally sold to the lucrative Imperial Russian Court market. The very deep royal blue hues favoured by the Anakie fields held a fascination for the Russian nobility unmatched elsewhere in the world. Although the Australian (the Anakie and Glen-Innes fields) sapphires are predominantly deep blues, yellows and greens, only the blue hues were commercially viable as gemstones prior to World War I. The unsellable yellows and greens, as well as the discarded grades of blue, were marketed to the watch-bearing industry.

World War I eliminated the German control of the marketing but also brought about the collapse of the Imperial demand. After the end of the hostilities, however, the Anakie fields experienced a new boom that continued until the Great Depression, when western European and the new North American markets filled the vacuum left by the Russian Revolution.

Popularity and production of the Anakie sapphires was at an all time low in the decade following the Great Depression and World War II. The entire production from the Anakie district

during 1957, for example, was only a hundred dollars worth of stones. The Anakie stones are a blue-black shade that is so dark as to be 'dull' when compared to the rival southern Asian sapphires. Yet the near exhaustion of the Asian gem gravels since the mid-1960s has seen a revival of the Australian production, not only for the blue hues but also for the 'fancy' colours.

GEOLOGY OF THE ANAKIE SAPPHIRE DEPOSITS

The Anakie fields are extensive, sapphire-bearing alluvial sands and gravels overlying a bedrock of granite, slate, clay and sandstone sequences.

The oldest geological unit in the area is the Anakie Metamorphics, a succession of quartz-mica schists, banded phyllites, quartzites and slates. Interbedded basic volcanics occur in the northern part of the field, south of Mount Ball, and limestones outcrop between Mount Clifford and Rubyvale. The Anakie Metamorphics are generally accepted as pre-Devonian, and potassium-argon dating by Webb and McDougall (1968) indicates an Ordovician age. The Anakie Metamorphic complex is intruded by the Retreat Granite (Devonian), which in the mining district consists of sheared granites, adamellites, granodiorites and diorites, and underlies the sapphire-bearing gravels, especially on Bedford's Hill and the Scrub Lead area.

A major source for quartzitic clasts of the sapphire bearing gravels is the 'Kettle Beds', an informal sequence of orthoconglomerates and gritty sandstone recognized by Robertson (1974). The unit is well exposed in the bend of Policeman Creek north of the New Rush area. The thickness of the sequence is unknown, but is estimated to exceed 150 feet (Robertson, 1974). The beds are overlain by the Hoy Basalt to the north of the New Rush area, and over widespread areas they are unconformably deposited on the Retreat Granite. Although the Hoy Basalt is postulated to be the primary source of the Anakie district sapphires, *in situ* discovery has never been confirmed. It is predominantly a porphyritic olivine basalt that emanates as a series of volcanic vents intruding the Retreat Granite.

Policeman's Knob and Mount Pleasant are the only volcanic neck structures known within the mining district (Figure 1). Corundum has been identified in the basalt on Policeman's Knob

(Robertson, 1974). It is widely advocated that the predominant portion of the sapphires and corundum associated with the mining district is derived from eroded volcanic necks somewhere, yet unknown, in the Drummond Ranges over a hundred miles to the west. Many local miners note a general tendency for the size of their recovered sapphire crystals to increase towards the west and a few small isolated sapphire discoveries have been made on the slopes of the ranges. Infrequently, cobble-sized pieces of basalt containing embedded fragments of corundum are recovered from the district's mines, but probably represent a secondary envelopment.

The sapphire-bearing alluvial deposits are termed 'wash' by the local miners, in particular reference to the stream-washed nature of the component boulders ('billy'). The wash varies in thickness from the surface to 60 or more feet in depth locally, but over most areas it is perhaps only two to four feet thick and usually under a foot or more of topsoil. Wash near the surface tends to be mainly of quartzite pebbles, while the deeper and richer deposits are generally larger boulders amid clays. In several localities, notably the New Rush area, a second wash has been found below the wash that was thought, incorrectly, to rest on basement.

The predominant colours of sapphires throughout the Anakie district are blue and green. Blue sapphire, the commercially viable commodity, is confined to a very limited area embracing the valley of Retreat Creek, but only north of the Creek itself. The fields north of Retreat Creek, especially Freehold, Reward and Sapphire, have a high proportion of blue gems, as well as considerable green-hued stones. The blue stones predominate in the Scrub Lead area. Blue stones are also found in Boot and Kettle Creek, although Carbine Creek, the next digging area to the north, only has sapphires lacking this desirable hue. Fields immediately to the south of Retreat Creek are void of blue sapphires; the green shades predominate. The fields are Zircon Gully, Washpool, Big Poverty and Subera. They have very marginal or no commercial interest.

THE MAJOR FIELDS

The gem gravels that comprise the Anakie district are distributed into three major fields. The main field is an area between and surrounding the towns of Sapphire and Rubyvale, 6 and 10 miles respectively north of Anakie (Figure 1). The Willows

field is approximately 25 miles south-west, by road, of Anakie. Another major area is the Tomahawk Creek field, about 24 miles from Rubyvale in the direction of the Zig Zag Range.

The sapphire wash of the Anakie district rests unconformably on the bedrock units discussed. The gem-bearing gravels are widespread: north as far as the Clermont gold fields, east to Capalla and Taroborah, south towards Springsure and west to Alpha. They are concentrated north and south of the Anakie Range in what is called the Anakie district fields, centring around the townships of Rubyvale, Willows and surrounding creeks.

THE RUBYVALE SAPPHIRE FIELDS

There are five main runs of gem gravel in the greater Rubyvale and Sapphire area. These are the catchment areas of Central, Tomahawk, Boot and Kettle, Policeman and Retreat Creeks (Figure 1). Most of the early commercial production and subsequent production was confined to the wash associated with the gravel deposits of Policeman and Retreat Creeks, and especially the area within a few miles of Sapphire and Rubyvale townships.

The sapphire-bearing gravels of the Sapphire township extend from near Mount Bullock to the Rice Bowl. They are within six feet of the surface along the Sapphire-Rubyvale Road near Sapphire and to the east of the Rice Bowl area. This area, known as the Sapphire field (or Retreat Creek field) is responsible for the bulk of modern commercial production.

The Cainozoic gravels in the Sapphire area appear to lie mainly on the Anakie Metamorphics. There are three types of sapphire-bearing washes known (Robertson, 1974). The most widespread type consists of ferruginous quartzite 'billy' emplaced within a reddish clayey matrix. A more restricted second type consists of three feet of reddish gravel soil above six feet of a gravel consisting of clasts of quartzite 'billy', basalt and metamorphics within a red feldspathic sand matrix. This wash variety is the shallowest and has the nearest proximity to the Sapphire township. A third wash variety is along the southern margin of the field to the west of Sapphire, and is similar to that found in the Freehold area on Retreat Creek to the west of Sapphire. This lithology consists of up to 25 feet of 'billy' and metamorphic boulders as a densely packed framework with a matrix of clayey feldspathic sand.

The Retreat Creek area is considered among the greatest producers of the district and was one of the first areas to achieve

significant commercial attention. The main concentrates of wash, termed a 'lead', centres around the town of Sapphire, hence 'the Town Lead'. It is shallow, and its variable thickness averages only three feet. It has been extensively worked, but short-term prospecting has frequently yielded substantial results from virgin patches amid the older abandoned workings. The deep wash that occurs about a mile west of the old township has workings averaging 20 foot depths. Substantial quantities of blue, yellow and green sapphire are still being recovered from isolated unworked patches in this area as well. Prior to World War I, during the major mining boom period, the main production zone on Retreat Creek was the Town Lead at Sapphire passing eastwards into Fighting Ridge and westwards into the Deep and Bessie Leads. Nevertheless, important zones of wash were worked on the southern side of the Retreat, areas called Grave Hill, Croker and Black Soil. Above the confluence of Sheep Station Creek were Elwood's Grave (5 miles south-west of Rubyvale), the Reward Claim and the Freehold, which are sites of the initial sapphire discoveries in the district. On the northern side of Sheep Station Creek were the deposits worked at Iguana Flat and the Granite Waterholes.

The Reward and Freehold claims reached their commercial peak at the turn of the century. They were considered the largest and most valuable deposits associated with the Retreat Creek gravels.

The Reward Claim is about seven miles from Rubyvale on a road trending south-west. It is situated but a couple of hundred yards from the road about a mile after crossing Sheep Station Creek. This site was worked by the Withersfield Sapphire Company from 1891 on the site of the first discovery of the district's sapphires in 1875. The main sapphire wash is on top of the ridge, extending down both sides and trends along some of the smaller spurs. It rests on a bedrock of weathered granite. The wash has abundant 'billy boulders' that are considered by the miners to be a favourable indicator for sapphires. The original claim workings, now abandoned, cover two hundred acres of extensively excavated ground. However, it is widely recognized that considerable portions of this claim remain unmined, since the gravels under the original dumps have never been worked. A mile further down the road is the old Freehold claim of about 100 acres. The geology of the deposit is similar to the Reward.

The Rubyvale field is the extensively worked ground approximately one to four miles north of the Sapphire field (Figure 1). Modern commercial sapphire production in the immediate vicinity of Rubyvale is from a series of gravel deposits to the east of the town along both sides of the Rubyvale-Sapphire road. The mining areas are named: Scrub Lead, Blue Bird, New Rush and the Rice Bowl. Sapphires are recovered from deposits to the north-west and west of Rubyvale on Bedford's Hill, Norman's Hill and Shotgun Hill, and Policeman's Knob and Policeman's Creek.

The wash to the east of the Policeman's Knob is composed of 'billy' boulders and basalt with minor metamorphics in a clay and black soil matrix, but to the west large 'billy' boulders predominate in the clayey matrix. These wash deposits are unconformably deposited on the Anakie Metamorphics. The wash at Shotgun Hill is similar, and is also underlain by the Anakie Metamorphics. A lithologically similar wash on Norman's Hill and Bedford's Hill overlies the Retreat Granite. Sapphires were extensively mined from these deposits around the turn of the century, especially from 60 foot deep shafts on Bedford's Hill.

The wash in the immediate vicinity of Rubyvale is generally shallow between 10 and 25 feet. Along the Keilambete road to the south of the township, the depth to the wash locally exceeds 50 feet. The wash is a clay matrix generally with 'billy' boulders, angular metamorphic clasts and quartz pebbles derived from the Kettle Beds.

The composition of the wash changes significantly to the east of Rubyvale. The gravel is an assemblage of pebbles, cobbles and boulders of quartz, basalt and metamorphics within a feldspathic sand matrix. The wash is upwards of 10 feet thick and is comparatively shallow. This commercial field includes the Scrub Lead and the New Rush area, and has yielded some of the finest quality blue sapphires in the state. The wash throughout this area is underlain by the Retreat Granite, where commercial concentrations of sapphires in the wash have been trapped within the irregular surfaces of the igneous subcrop. Depth to the bedrock surface varies widely between 3 and 60 feet, but generally is within 40 feet of the surface. The basal 3 feet of wash usually has the greatest gemstone concentration.

The most important commercial sapphire-mining pursuits for the last decade have been associated with the Scrub Lead (Figure 1).

Extensive workings can be observed from the road about a mile before reaching Rubyvale on the road from Sapphire. These mines form a mile long and a quarter-mile wide belt of several dozen open-cut mines on the south-western banks of Policeman's Creek. The Scrub Lead mines monopolize the commercial production of the district because of the relatively high recovery percentage of the most desirable deep blue-hued sapphires from workings as much as 50 feet deep. The grade of stone is immediately recognizable as the 'Scrub blues', the shades of blue that are a little lighter than the Retreat Valley average. Almost the total production is a shade of blue—yellows and green being relatively rare. An infrequent sapphire specimen recovered may reach an ounce or more.

THE WILLOWS FIELD

The second most important field in the Anakie district is the Willows field. This area is approximately 20 miles north-west of Anakie via the Capricorn Highway, then 7 miles south-east of the highway on a posted access road into the Willows township.

The Willows field was discovered in 1918. It has been since the scene of only intermittent mining for the commercial market. Heavy mining machinery is generally restricted to the major areas of the Rubyvale-Sapphire fields to the north and is not permitted (with a few exceptions) in the Willows area. The field is presently reserved for the casual prospector and 'tourist' digger without the use of mechanized recovery methods. The field has supported earlier in the century, however, a number of professional miners with hand-dug shafts.

The Willows field does not produce the commercially valuable blue-hued gemstones, and what blue stones are found are generally too dark to be marketable. Nevertheless, the area is widely recognized as a productive field for greens, fine yellows and parti-colours. The green-colour hues do not approach perfection. Regardless of this the generally large and flawless gem material, particularly in desirable golden yellows, provides incentive for continued prospecting.

The Willows field provides the best opportunity for success for the casual digger with but few days or weeks excavating a pit by hand (Figure 2). The average casual prospector with only a pick and shovel can excavate and process about two cubic yards of wash a day. The yield may be minimal, but a reasonable expectation is

the recovery of a dozen or two small sapphires, ranging from a half to as much as 3 to 5 carats. Some collectors have dug for a week with only a third to a half ounce yield, but 20 feet away, an excavation pit may strike a small run and recover an ounce within hours.

Frequent finds of 10, 20 to 30 carat stones in green to yellow hues are notable for this field. The area is particularly famed for its golden yellow gems of a hue recognized as without rival elsewhere in the world. Such stones tend to be flawless, brilliant, evenly coloured and sizeable as well. Blue sapphires are rare at the Willows and, when found, are mostly small and with a decidedly inferior greenish shade.

There are several digging areas within the two-mile diameter Willows field. Access to the area generally initiates from the general store and caravan park within the central portion of the field, adjacent to the dam and water supply tanks. From the general store the road winds less than a mile north circumventing the dam and eastward past the Yukon claim to a large clearing several miles across. Between the Yukon claim and the clearing are several hundred yards of partially excavated ground that is popular with the casual visitor because the wash is shallow and in the shade of surrounding trees and brush (Figure 2). It is but one of a half dozen workings in the area. The sapphire bearing wash continues, as far as is known, hundreds of yards, perhaps thousands, into the cleared area. Only a few scattered wild-cat holes have been dug there, however, because of the increased overburden thickness, and also because of the lack of shade.

There are six commercial claims on the Willows field. These are permitted to utilize heavy machinery. These are still outstanding old leases, but new restrictions prohibit any more from being issued. Only the Yukon claim has any serious, though intermittent, attempt at production. Commercial success has not been encouraging because of the lack of marketable blue stones.

The Willows field is attractive to hand excavation techniques because of the thin overburden. Brown, boulder-strewn topsoil generally is 1 to 6 feet thick, generally closer to 2 feet. It overlies about a foot thickness of sapphire-bearing wash. The wash is sometimes absent or only a few inches thick, but has been observed as much as three feet thick. It is stained white by decomposed granite. Under the wash is a yellowish to brownish grey clay that persists downward to bedrock. Thickness of the underclay varies widely,

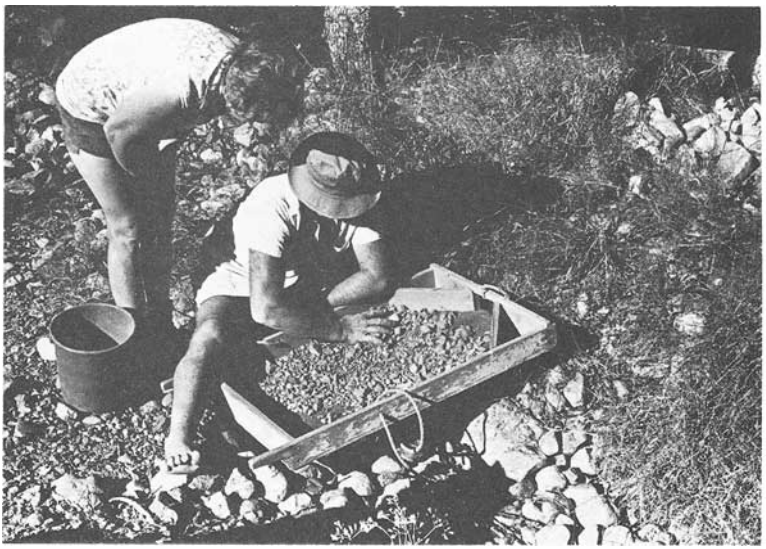

Fig. 2. Prospecting for green sapphires on the Willows field. Limited water favours the use of dry screening procedures and hand sorting at the numerous prospect pits on the field.

between 3 and 20 feet. Some prospectors excavate deeply into the underclay for a second gravel horizon, 6 to 20 feet below. This lower wash is not always present and often barren of sapphires. Most prospectors follow the wash horizons along their east-west trends, always careful to examine thoroughly the eastward (downstream) sides of any large boulders uncovered and to process a few inches of the clayey sand under the gravel for any sapphires that may have worked downward into softer sediments.

The bedrock is generally weathered basalt, but sometimes is an overlying sandstone bed as in the caravan park area and at Steptoe Hill two miles to the north.

Quality yellow and green sapphires have been found on the sandstone ridges north of Willows, particularly the Glenalva rise about 5 miles north of Willows. The Glenalva field has a potential sapphire bearing zone approximately three miles long and a mile wide. It has a few active prospects with a limited production.

THE TOMAHAWK CREEK FIELD

The Tomahawk Creek field is an important field in the Anakie district but is largely undeveloped. The field, like the Willows, does not have commercially viable quantities of blue coloured gems. Its green stones, like the yellows from the Willows, are reported to be the finest shade possible and are known throughout the world as 'Tomahawk greens'. Many feel that Tomahawk Creek, some 24 miles by road north-west of Rubyvale, offers the most encouraging opportunity for the newcomer to the sapphire fields. The topsoil is only inches thich and in many places the wash is exposed at the surface. The sapphire-bearing wash along Tomahawk Creek extends to Hut Creek, a distance of approximately 2 miles. Some of the best stones that have been found are associated with the Hut Creek and Costie Creek gravels. This field is relatively remote, and accessibility is difficult. Supplies must be brought in with difficulty from Sapphire or Rubyvale across a number of sharp, narrow creek crossings.

Black spinel (pleonaste, var. ceylonite) and zircon are abundant in the Tomahawk Creek gravels. Occasionally, some attractive zircons are cut from rough of this area.

The Tomahawk Creek field is accessible with difficulty and the potential is poorly known but considered significant. Undoubtedly it remains the major, but as yet unproven, sapphire reserve for future decades.

MINING METHODOLOGY

During 1975 field studies in the Rubyvale area, most of the commercial production was from a cluster of claims a half-mile south-east of town. Virtually all of the mines are bulldozed trenching operations (Figure 3). Only a few are hand-operated underground shafts associated with the casual prospector (Figure 2).

A typical Scrub Lead commercial sapphire mine is generally a two or three man partnership. The claim operators regularly contract-hire a bulldozer and operator to trench their claim area and stockpile the wash. It is considered economical to contract-hire when needed, generally every two weeks, since bulldozers are a relatively expensive investment and not in daily use. Several bulldozer owner-operators make a reasonable income from neighbouring claims by excavating and stockpiling their wash. Each mine operator, however, has his own mechanical backhoe or front-end loader to move portions of the stockpile to the processing plant.

Fig. 3. Excavation and processing the gravel from the Scrub Lead field south-east of Rubyvale. The sapphire-bearing gravel is excavated from the pits and dumped into a sieve, sluice and pulsating jig sequence to gravity-separate the heavy gemstones.

The Scrub Lead bedrock ranges from 6 to 50 or 60 feet below the surface. The open-cut miners process this entire section from surface downward. The independent, hand-dug shaft operator, on the other hand, preferentially mines only the several feet of rich concentrate overlying the bedrock.

The stockpiles are covered with extensive sheets of plastic to insure that the gravel wash remains dry until processing. The methodology is to dry or wet screen the wash to remove the silt and sand fraction, as well as the cobbles and boulders (Figure 4). The retention size for most plants is usually between an eighth-inch and seven-eighths inch to an inch. Since the mines are generally operated as a two man partnership, one miner operates the back-how or front-end loader to move the stockpile to the screening machinery and the screened concentrate to the wash plant, while the partner processes the gravel in the wash plant. The screening operation may be either a flat bed or a rotary mechanism. A couple of cubic yards of gravel are typically dumped into a 12 foot long, 5 foot diameter, pair of rotating drums, called a 'trummel', with a system of the desired screen mesh. Some claims use a flat-bed screen shaker mechanism for separating out the large gravel and

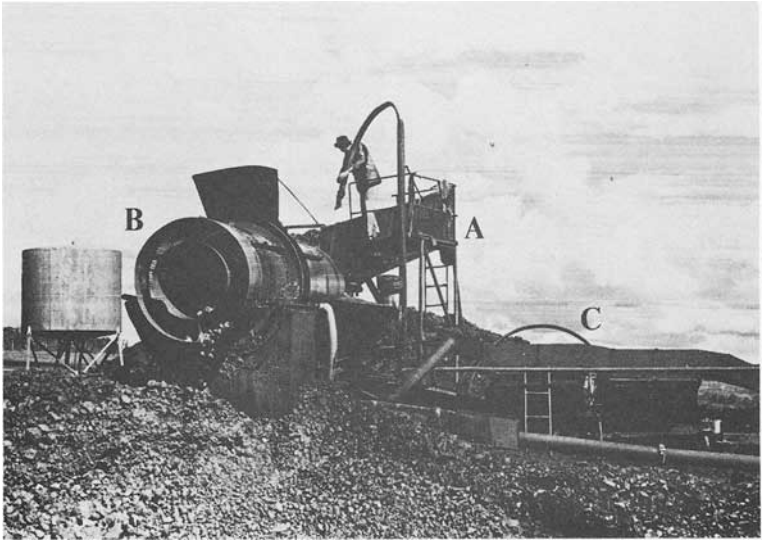

Fig. 4. Wash plant procedure to separate the sapphire-corundum-zircon concentrate.
A. The gemmiferous gravel is dumped into a wide box, and hosed into a trummel (B).
B. The trummel screens the gravel and rejects the sand and very fine gravel as well as the cobbles and boulders. The retention size is generally between a quarter and an inch or two.
C. The slurry is then conveyed into a gravity separator. The sluice and pulsating jig mechanism traps the sapphires, zircons, corundums and other heavy minerals behind riffles.

cobble clasts. Many of the mills do not have a fines separation step, but send the gem gravel directly into the washing plant. It is only essential to eliminate the large rocks and boulders in excess of an inch or two diameter. Some plants utilize a conveyor belt to direct the gem gravel from the dry screen 'trummel' into the washing plant, but most other mines use a front-end loader to move the gravel (see Figures 3 and 4).

Washing plants in the commercial mines are essentially similar in design and only vary in size. They consist of three essential components: an open tank, a sluice and a pulsating jigger. A front-end loader at a typical Scrub Lead plant dumps a couple of cubic yards of gem-bearing gravel into a flat-bottomed steel trough, 20 feet long and nearly as wide, that is tilted forward into a 20 foot long sluice. This guides the gravel slurry into the pulsating jig (Figure 4). The jig circulates the gravel up and down in a water stream to concentrate the heavier minerals, including sapphires, towards the bottom, trapped behind riffles. A jig usually has five circulation cells but recovers most of the larger gems in the first cell and only the very small ones in the fourth or fifth.

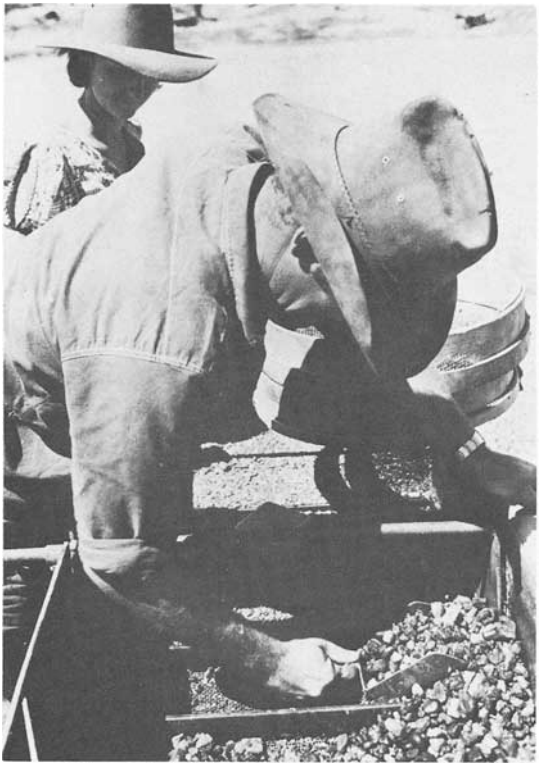

Fig. 5. The pulsating jigs on the Scrub Lead field are cleaned twice daily to recover the trapped sapphire-corundum-zircon concentrate.

The pulsator is cleaned twice a day for the concentrate by scraping the accumulated gravel with a hand trowel into buckets (Figure 5). This concentrate is hand-screened and further concentrated in a water trough and then picked through for saleable gems (Figure 6). The quantity of daily recovered sapphires varies widely throughout the Anakie district. A small two or three man claim will recover an average of an ounce or two of sapphire a day. Most of the gem sapphires are the 'Scrub Blues', a desirable light-hued royal blue, generally free of silky inclusions, as well as a smaller percentage of green and yellow sapphires. Quantities of corundum, black spinel, and considerable gem quality zircon are associated with the sapphires. The zircon portion recovered varies widely on the fields, from one ounce of zircon to four ounces of

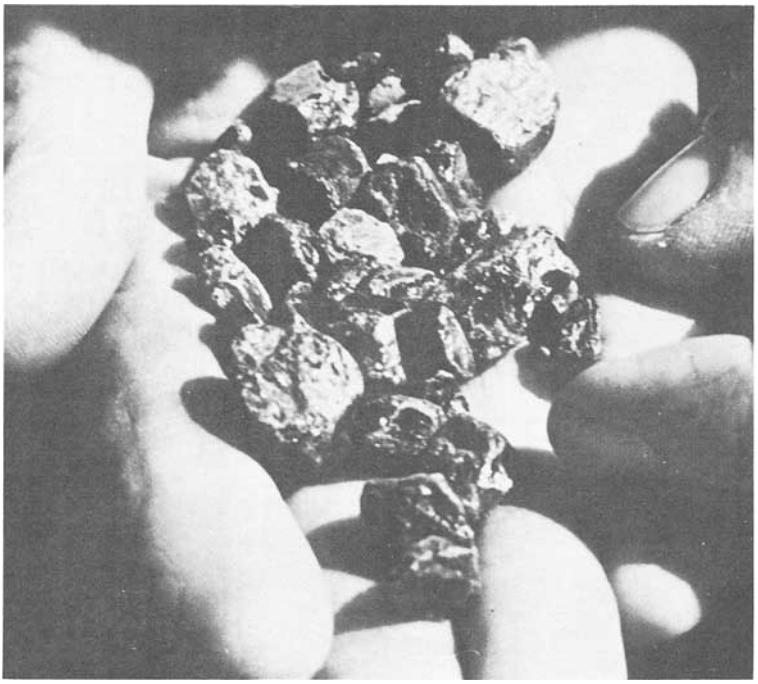

Fig. 6. An ounce of mine-run blue sapphires from the Scrub Lead. Note the angular shapes and poorly preserved crystal and cleavage faces.

sapphire recovered to as much as equal proportions. The zircon is generally flawless, water clear to light buff brown. Large pieces, 5 to 20 carats weight, are relatively common. The zircon, however, lacks a viable commercial market. Diamonds are only rarely recovered, but not unknown.

Notable Sapphire Gems Recovered from the Anakie District

Notable sapphire specimens have been associated only with the Anakie fields, virtually none with the New South Wales deposits. Sizeable gems, those in excess of 20 carats to as much as several ounces, usually have the non-blue colours, especially yellow and green hues. Many of these have been recovered from the Willows field. Two of the earliest known sizeable Anakie stones were found by W. Dyer: a gem of 20 grams rough in 1920 and a 1925 discovery of an orange-yellow stone that was cut to 31 carats. A notable

orange-yellow sapphire of 13 grams was found by E. Russell in 1924 on the Freehold claim, and a fine quality 14 gram golden-yellow stone was recovered in 1949 from the Policeman's Creek alluvium. *Anderson's Yellow* was a 21 gram golden-yellow sapphire found in 1949 on the Willows field by J. Anderson. The stone was first cut to a finished weight of 70 carats with an 'off cross-table' style making it the largest gem of its kind in existence. However, the cutting failed to display the gem's proper brilliance and it was subsequently recut into several stones, the largest being a double oval brilliant weighing 35.75 carats.

The *Golden Willow,* renamed the *Golden Queen,* was found in 1951 on the Willows Field by H. Clifton-Parr. It weighed 322 carats in the rough, or approximately 2 ounces. It was sold to J. McSweeney, of Toowoomba, for cutting into a 91.35 carat finished stone.

Mr Stonebridge, of Rubyvale, has recovered from his claim a particoloured sapphire of 18.4 grams. This crystal fragment, approximately two inches long and an inch thick, is a dichroic deep bottle green and a lighter greenish yellow. The gem remains in the rough but would be suitable for two sizeable finished stones, one green and one yellow. A sizeable particoloured stone weighing 78 carats, approximately a half ounce, was found by P. Robertson and P. Tanzik from a claim near Sapphire. It was nicknamed the 'Bootmaker's Foot'.

The Willows field has produced a number of sizeable, unnamed yellow-green gems between 50 and 100 carats during the last decade. An 84 carat yellow stone was recovered in 1966; a 73 carat green stone was recovered in 1975. Dozens of equally sizeable gems have also been found, many of them simply picked from the surface. Other Anakie fields also have had large stones uncovered in recent years. The Scrub Lead produced a 4 ounce yellow sapphire in 1973 and the small Divide field, upstream from the Scrub, yielded in 1975 a 4 ounce blue-yellow particolour and a 10 ounce, partly gemmy, blue sapphire.

The black star sapphires are a class of gems usually associated with the Anakie district. There have been a number of famous specimens discovered over the years. The best known of these is the *Queensland,* an enormous 1156 carat mass that was thought at first to be a 12 troy ounce piece of nearly worthless corundum. A young boy named Roy Spencer, later in life a noted gem dealer, was visit-

ing the Reward Claim near Rubyvale in 1934. He picked up the specimen and kept it at home as a door stop for many years. Black star corundum was not readily distinguished at this time from ordinary massive corundum and was considered essentially worthless. A visiting Sydney buyer to the Anakie fields later offered a few pounds for it but was refused. The specimen was later sold to the Kazanijian Brothers Lapidary firm in Los Angeles. The rough mass was cut into a 733 carat black star sapphire, more than 200 carats heavier than the famed *Star of India.*

The most renowned group of Australian star sapphires is undoubtedly the carved 'Heads of Presidents' series undertaken by N. Maness and H. Derian under the supervision of the Kazanijian lapidary firm. The four rough pieces of blue to black star sapphire utilized in the carving project averaged about 2.5 inches long, 2 inches wide and as deep. Three of these giant stones came from the Scrub Lead, and the fourth from the Iguana Flat field. The head of Abraham Lincoln is a blue star stone weighing 2302 carats rough and 1318 carats finished weight. The head of Dwight Eisenhower is a black star stone, weighing 2097 carats rough and 1444 carats finished. The head of Thomas Jefferson is a blue star-stone weighing 1743 carats rough and 1381 carats finished. The head of George Washington is a blue star stone weighing 1997 carats rough and 1056 carats finished. The most recent sizeable asteriated sapphire was found in 1973, which weighed in excess of 11 ounces.

The Willows field will undoubtedly remain the most prolific producer of unusually large stones for the near future, especially for those of yellow and yellow-green hues. With the future development of the Tomahawk Creek area, it would not be suprising to find a number of very large deep green gems on the world markets.

Economic Viability of the Anakie District: A Comment

The Australian sapphire mining industry faces two serious economic crises. The mining claims in Queensland are restricted in size to limit the viable operations to a two or three man partnership. The Scrub Lead claims, for example, are limited to a maximum of three acres. This normally contains enough reserves for three of four years of production. The laws are designed to favour the 'independent' mine operator and to prevent the monopoly of the industry by large, well-financed syndicates employing dozens of men and innumerable pieces of mechanized

equipment. This latter approach dominates the fields in New South Wales. Neither approach seems satisfactory. The small producer in Queensland is rapidly facing a land squeeze. There is considerable sapphire bearing land, more than 100 000 acres, remaining largely unworked in Queensland, but most of it is either too isolated or patchy to permit effective mechanized mining, or the land is restricted against mechanized mining in favour of hand-excavated trenches and shafts for the 'tourists' or casual prospectors, who are loath to see the areas declared commercial districts. New regulations (1976) would allow hand operators to confine their excavation to about one-quarter acres, while the machinery operators would be restricted to a four acre area, but open up grounds previously zoned against commercial development. Nevertheless, the over-mechanization in adjacent New South Wales is frequently responsible for flooding the market with an oversupply of gem material and promoting frequent recessions in the industry. Many of the large syndicates operations at best are being utilized at only partial capacity or at worst have been forced into only intermittent production.

REFERENCES

Robertson, A. (1974). Preliminary geological report on the Anakie mining field. *Geol. Surv. Queensland. Rec.*, **18**, 1-11.

Webb, A., McDougall, I. (1968), The geochemistry of the igneous rocks of eastern Queensland. *Jour. Geol. Soc. Aust.*, **15**, 313-46.

[*Manuscript received 30th October, 1977.*]

ASSOCIATION NOTICES

GIFTS TO THE ASSOCIATION

The Council of the Association is indebted to the following for their gifts:

Mr H. Alexanian, Cairo, Egypt, for a parcel of rough pieces of peridot from the Isle of St John.

Mrs Joan Bass, Deal, Kent, for a piece of amber containing a number of interesting inclusions with attractive shapes.

Mr D.B. Hoover, F.G.A., Denver, Colorado, U.S.A., for three pieces of uncut material and one cut and polished stone weighing 1.90 ct of anorthite from Great Silkin Islands, Alaska, U.S.A.

Mr R.W.K. Mackenzie, Salisbury, Rhodesia, for one set of Rhodesian stamps (1c, 3c, 4c, 5c and 7c) featuring gemstones—morganite, amethyst, citrine, blue topaz and garnet.

Mr E.A. Thomson, London, for one GGG cut stone weighing 2.12 ct.

NEWS OF FELLOWS

On the 16th September, 1978, Mr Peter G. Read, C.Eng., F.G.A., gave a talk on 'New Gemmological Instruments and Techniques' to the Wessex Branch of the N.A.G. in Bournemouth, followed by a demonstration of a selection of reflectivity meters, and on 1st October, 1978, he gave a talk on 'Automatic Weighing and Sorting of Rough Gem Diamonds' to the Deutsche Gemmologische Gesellschaft during their Second Technical Meeting 1978 at Idar-Oberstein.

Dr Stanley Holgate, F.G.A., is again taking classes in the 1978/79 diamond course at Central Liverpool College of Further Education.

Mrs Sheila J. Lewis, F.G.A. and Mr Michael J. O'Donoghue, M.A., F.G.S., F.G.A., gave a course entitled 'Synthetics Simplified' at Harrow College of Further Education on 10th November, 1978. A wide variety of set pieces was shown and members were invited not only to identify the stones but also to value the pieces. In some cases they were asked to estimate weight and value loss in re-cutting. Materials just entering or about to enter the jewellery area (including a crystal of synthetic gem-quality diamond) were also shown, along with a set of slides depicting important features of man-made stones.

Mr M.J. O'Donoghue spoke to the Tunbridge Wells and Tonbridge Branch of the N.A.G. on the 19th October, 1978. The subject was 'Exploration for gem materials' and the talk was illustrated by specimens.

MEMBER'S MEETINGS

London

On Wednesday, 11th October, 1978, M. Pierre Gilson gave a talk at the Geological Museum Cinema Theatre, South Kensington, entitled 'Precious Stones of the future from the Laboratory'. A full report of the talk will appear in a future issue of the *Journal.*

Midlands Branch

On the 22nd September, 1978, Mr Alec Farn, F.G.A., gave a talk on carbonate gems.

On Friday, 20th October, 1978, Mrs Mary Salloway, F.G.A., gave an illustrated talk entitled 'Gemmological Travels'.

On Friday, 17th November, 1978, Mr Sid Tisdall, F.G.A., gave a talk entitled 'Tisdall on Gems'.

All three talks were given at the Royal Institute of Chartered Surveyors Headquarters, Birmingham.

North-West Branch

On Thursday, 7th September, 1978, at Church House, Hanover Street, Liverpool, 1, Mr Roy Reid gave an illustrated talk on the subject of pearls.

The third Annual General Meeting of the Branch was held at Church House, Hanover Street, Liverpool, on 12th October, 1978. The following officers were re-elected: Mr H. Eakins, F.G.A., Chairman; Mrs D.M. Brook, F.G.A., Secretary.

South Yorkshire and District Branch

A meeting was held on the 2nd November, 1978, at the Sheffield City Polytechnic, when Mr Peter G. Read, C.Eng., F.G.A., gave a talk on 'Diamonds', covering formation, mining and recovery, sorting, polishing and grading of gem diamonds.

COUNCIL MEETINGS

At a meeting of the Council held on Wednesday, 20th September, 1978, at Saint Dunstan's House, the following were elected to membership.

FELLOWSHIP

Athiniotaki, Vassiliki, Athens, Greece. 1978
Beach, Rowan M., London. 1978
Berry, Elizabeth K., Melbourne, Vict., Australia. 1978
Bogollagama, Rarindra C. B., Kurunegala, Sri Lanka. 1978
Boles, Julian D., London. 1978
Dillmann, Rolf, Berne, Switzerland. 1978
Dunn, Brian R., Crawley. 1978
Faulder, John A., Purley. 1978
Ghaswala, Sudhir R., Bombay, India. 1977
Golbey, Terence M., Harrow. 1978
Hammond, Glenys M., Barnet. 1978
Hailey, Robert J., New Malden. 1978
Haugh, Breda M., London. 1978
Hiscox, Peter C., Solihull. 1978
Houlgrave, Peter B., Rickmansworth. 1978
Jamieson (née Fish), Lorraine A., London. 1974
Jerome, Philip, Woodford Green. 1978

Jobin, Marc P. B., Henley. 1978
Keast (née Jefferson), Barbara J., Lower Kingswood. 1976
Lyall Grant, Ian H., Dartmouth. 1978
Miller, Neil, London. 1978
Turner, Michael J., Sheffield. 1978
Weissler, Chaggai, London. 1978
Wilson, Philip, Newcastle-upon-Tyne. 1978

TRANSFERS FROM ORDINARY MEMBERSHIP TO FELLOWSHIP

Barcham, Kathryn L., Hong Kong. 1978
Bennett, Russell K., Winchcombe. 1978
Bramwell, Peter, Durham. 1978
Busaracome, Suwin, Khon Kean, Thailand. 1978
Chang, He O., London. 1978
Crawford, Hugh B., Kirkcudbright. 1978
Daniels, Brian R., Dunedin, N.Z. 1978
Davis, Jonathan V., Edgware. 1978
Dominguez Mondelo, Segundo, Oviedo, Spain. 1977
Dougan, Patricia M. S., Nairobi, Kenya. 1978
Duckworth, Andrew S., Bolton. 1978
Emslie, Iain A., Bromyard. 1978
Faiz, M. H. M., Colombo, Sri Lanka. 1978
Fennessy, Sean, Paris, Tex., U.S.A. 1978
Gianforte, Carmen A., Sarasota, Fla, U.S.A. 1978
Grant, John W., Milledgeville, Ga, U.S.A. 1978
Gryg, Bessie, Hilton, W. Australia. 1978
Hashimoto, Mieko K., Yokohama, Japan. 1978
Healey, David, Hong Kong. 1978
Heatlie, James W. M., Edinburgh. 1978
Henniker-Heaton, Gay D. A., Cape Town, S. Africa. 1978
Hitchen, Alan, Aldridge. 1978
Hitchman, Michael J., Leicester. 1978
Hoover, Donald B., Lakewood, Colo., U.S.A. 1978
Hughes, Susan M., Kowloon, Hong Kong. 1978
Israel, Nigel B., London. 1978
Jayasuriya, Ranjit L., Colombo, Sri Lanka. 1978
Kinch, John C., Morden. 1978
Krakowiak, Czeslaw, Ul. Chlopska, Poland. 1978
Lakdawalla, Noshir J., Bombay, India. 1978
Lander, Charmian E. M., London. 1978
Langoulant, Peter B., Welkom, O.F.S., S. Africa. 1978
Lowe, Sylvia J., Harrow. 1978
Martin, William J., Nairobi, Kenya. 1978
Mayling, Clifford G., Slough. 1978
Megel, Gary E., Colorado Springs, Colo., U.S.A. 1978
Moyersoen, Jean-François, London. 1978
Okano, Chizuru, Tokyo, Japan. 1978
Perrett, Roy, Manchester. 1978
Pope, Lesley J., Lymington. 1978
Ros-Jones, Catherine A., South Ascot. 1978
Seal, Richard M. P., Bridlington. 1978
Shaikh, Leela, London. 1978
Shimomura, Michiko, Tokyo, Japan. 1978
Takigawa, Junko, Kyoto, Japan. 1978
Teakle, Simon J., Lewes. 1978
Thomas, Ian, Duffy, A.C.T., Australia. 1978
Visser-Bonnmann, Maria I. A., Delft, Holland. 1978
Vollom, Paul A., Eugene, Oreg., U.S.A. 1978

Watson, John L., Bulawayo, Rhodesia. 1978

Weeresinghe, N. P. O., Ratmalana, Sri Lanka. 1978

Wong, Tak C., Kowloon, Hong Kong. 1978

Yoshikawa, Kazuhiko, Wakayama Pref., Japan. 1978

Yu, Robert M., Hong Kong. 1978

ORDINARY MEMBERSHIP

Agapiou, Andreas C., Nicosia, Cyprus.
Allen, Darold C. A., Portland, Oreg., U.S.A.
Amarasinghe, A. G. B., Ratnapura, Sri Lanka.
Angelo, Luiz, Rio de Janeiro, Brazil.
Archer, Kenneth A. G., London.
Arla Pont, Antonio, Barcelona, Spain.
Ascher, Claude D., Montreal, Que., Canada.
Atlas, David S., Philadelphia, Pa, U.S.A.
Attanayake, Asoka, Pasyala, Sri Lanka.
Austin, Kenneth N., Sumter, S.C., U.S.A.
Barbosa, Jose E. C. A., Madrid, Spain.
Bargilis, Christos, Limassol, Cyprus.
Barkir Marikar, Mohamed, Harrow.
Behne, Bernhard H., Ottawa, Ont., Canada.
Berent, Stephen V., Geneva, Switzerland.
Berjaud, Philippe, Abidjan, Ivory Coast, W. Africa.
Bradstock, Anne M., Newbury.
Bramley, Charles H. V., Nottingham.
Brown, Douglas R., St Helier, Jersey.
Bryant, John R., Scottsdale, Ariz., U.S.A.
Bucolt, Christine, Milwaukee, Wis., U.S.A.
Buhl, Robert A., West Vancouver, B.C., Canada.
Burns, Karen F., Albuquerque, N. Mex., U.S.A.
Butterfield, Ernest B., Albuquerque, N. Mex., U.S.A.
Bylander, Liliane D., Sigtuna, Sweden.
Carpenter, Linda S., Durango, Colo, U.S.A.
Castanera Rodriguez, Luis, Barcelona, Spain.
Cattni, Naginchendra J., Nairobi, Kenya.
Chan, Bun Yuen, Kowloon, Hong Kong.
Chan, Chung Chee G., Hong Kong.
Chan, Therese K. S. C., Hong Kong.
Chappel, Sharon, Salisbury, Rhodesia.
Charlesworth, Anthony R., Southport.
Cheng, Kwan To R., Hong Kong.
Chilvers, Anthony C., Chigwell Row.
Chin, Chong-Meng, Singapore.
Chow, Peter S. C., Hong Kong.
Colonica, Nancy L., Santa Monica, Cal., U.S.A.
Cousins, Nigel T., Deal.
Currie, Spencer J. A., Manurewa, N.Z.
Curry, Sonia, North Battleford, Sask., Canada.
De Graaf, Lambertus, Bristol.
Dugar, Kanak M., Bombay, India.
Dupuis, Ronald J. R., Toronto, Ont., Canada.
Durham, Dennis, Hull.
Dwyer, Michael G., New Town, Tas., Australia.
Ebrahim, Bilquis H., Hong Kong.
Eckermalm, Hjordis, Tumba, Sweden.
Edwards, Peter M., Aberystwyth.
Eliezri, Israel Z., Ramat Hasharon, Israel.
Epstein, Mario, Porto Alegre, Brazil.

Fagg, Primrose M., Wallington.
Fernandez, Ixidro, Madrid, Spain.
Flusser, Peter, Culver City, Cal., U.S.A.
Foakes, Margaret A., Birmingham.
French, Yuko, Bangkok, Thailand.
Furber, John M., Sydney, N.S.W., Australia.
Gabella, Laurent P., London.
Garfinkel, Derek A., Pretoria, S. Africa.
Gerber, Rolland D., Challenge, Cal., U.S.A.
Giacone, Anna G., Norwich.
Gibson, David, Scarborough.
Gleizes, Michel, The Hague, Holland.
Goby, Jacqueline A., Nairobi, Kenya.
Gomm, Elizabeth A., London.
Gordon, Clement R. I., Brisbane, Qld, Australia.
Grant, William J. C., South Shields.
Green, Richard D., Sedgley.
Greeson, Gordon, Carmel, Cal., U.S.A.
Guinn, Mack F., Houston, Tex., U.S.A.
Haagensen, Kathryn, Medway, Mass., U.S.A.
Hadden, Myra, Carlow, Ireland.
Hanosh, Pamela A., Batavia, Ill., U.S.A.
Harada, Shigeo, London.
Hardewall, Per-E, Geneva, Switzerland.
Harding, Keith J., Holden, Mass., U.S.A.
Heath, John A., Grand Bahama, Bahamas.
Hedd, Harold S. A., Washington, D.C., U.S.A.
Heeney, Barbara A., Hong Kong.
Helne, Mary K., Rome, Italy.
Henwood, Glyn A., Basingstoke.
Ho, Antonio C. J., Cebu City, Philippines.
Holcombe, Neil S., Purley.
Hung Chuan-An, John A., Taiwan.
Jeffery, Robert G., Jakarta, Indonesia.
Jennings, Harold F., Roanoke, Va, U.S.A.
Joly, François J., Champeix, France.
Jørgensen, Svend E., Nordborg, Denmark.
Kaminski, Peter E., Dollard des Ormeaux, Que., Canada.
Katsuta, Yuu, Yokohama-shi, Japan.
Keller, Peter C., Los Angeles, Cal., U.S.A.
Kelson, Anthony P., Santa Monica, Cal., U.S.A.
Kenyon, Robert V., Gladstone, Qld, Australia.
Kim, Yong K., San Francisco, Cal., U.S.A.
Khairallah, Hafez, London.
Kirkeby, Laurits, Haderslev, Denmark.
Klages, Helen, Orlando, Fla, U.S.A.
Kuranuki, Yoshinori, Tokyo, Japan.
Larcombe, David B., Wincanton.
Lau, Theodora A., Hong Kong.
Leeds, Paul, Highland Park, Ill., U.S.A.
Le Mon, Marie, Denver, Colo, U.S.A.
Levine, Leona R. B., Norwich.
Liberatore, Paolo, Rome, Italy.
Lien, Jan P., Norrkoping, Sweden.
Lim, Boon C., Malacca, Malaysia.
Lim, Kathleen A. L., Perak, W. Malaysia.
Lindley, Michael P., Edgware.
Liu, Chie M. M., Den Bosch, Netherlands.
Lum, Koke C., Kuala Lumpur, Malaysia.
Marques da Silva, Francisco, Lisbon, Portugal.
Marques da Silva, Nair, Lisbon, Portugal.
Matsuda, Haruyoshi, Kobe, Japan.
May, James W., Greenford.
Meacham, John F., Sooke, B.C., Canada.
Moffatt, Kathleen G., Ottawa, Ont., Canada.
Moore, Paul R., Frimley.

Morse, Robert A., Enfield.
Mozaffarian, Simin, New York, U.S.A.
McCallum, Marcus A., Newbury.
McKenzie, Alastair J., Paisley.
McMordie, Ken R., N.E. Calgary, Alta, Canada.
Nicita, Domenico, Milan, Italy.
Nieto Reynoso, Luis, Barcelona, Spain.
Oakley, Norman S., Salisbury, Rhodesia.
Obayashi, June T., Hong Kong.
Olpherts-Forrester, Richard W. G., Brighton.
Osborne, John, Canterbury.
Ovitigala, Mangalika S., Kadawata, Sri Lanka.
Ow, Yue Heong, Singapore.
Packman, Joseph A., Willowdale, Toronto, Canada.
Padley, David J., Chester.
Pantos, Konstantin, Eskilstuna, Sweden.
Pattni, Aruindkumar, London.
Pattni, Shashikant, Loughborough.
Peattie, Andrew, Singapore.
Penwell, G. Norman, Dowell, Mass., U.S.A.
Perrella, Antonio, Benevento, Italy.
Peyronel, Giorgio, Milan, Italy.
Pilbrow, Ian J., Gisborne, N.Z.
Pittock, Hugh R., Colorado Springs, Colo, U.S.A.
Poff, Stephen G., Invercargill, N.Z.
Potgieter, Sandra L., Pietermaritzburg, S. Africa.
Pridan, Gad, Antwerp, Belgium.
Quinn, Kathryn, Dublin, Ireland.
Rajab, Jehan S., Kuwait.
Raniga, Dilip R., Nairobi, Kenya.
Raniga, Umesh C. G., Sigatoka, Fiji.
Rastall, Mirhane, Southwell.
Reinhardt, Annie, Geneva, Switzerland.
Renel, Ronald J., Bishopstoke.
Rhoades, Emily M., Calgary, Alta, Canada.
Ricci, Sandro, Rome, Italy.
Ridding, Michael J., Banff, Alta, Canada.
Rimmer, Peter, Harrogate.
Roos, Raimo H., Nairobi, Kenya.
Sakata, Taketoshi, Tokyo, Japan.
Sandefer, George H., Gainesville, Fla, U.S.A.
Sanders, Mark J., Wellington, N.Z.
Sanz Balague, Joaquin, Barcelona, Spain.
Schwieger, Rolf, Ratnapura, Sri Lanka.
Shamdasani, Ramchandra H., Hong Kong.
Shami, Farouk Y., Jeddah, Saudi Arabia.
Shams, Dunia M., Banbury.
Shelemay, Aviva, London.
Sherwood, Stephen L., Nottingham.
Sito, Wah, Singapore.
Smith, Brandon C., Karlsruhe-Durlach, W. Germany.
Spence, Lynette M., Hong Kong.
Stevens, Graham W., Hambledon.
Stone, Frederick J., Carshalton.
Stratford, Helen M., Forrestfield, W. Australia.
Styles, Sidney B., Kenilworth.
Subky, Thaha A. M., Colombo, Sri Lanka.
Subramaniam, Manoharan, Virginia Water.
Sweeney, Patrick J., Amsterdam, Holland.
Thomas, Michael A., Salisbury, Rhodesia.
Tinkler, Wilfred, Toronto, Ont., Canada.
Ueda, Kokichi, Osaka, Japan.
Uvenhoven, Elvira, Nairobi, Kenya.
Warren, E. William, Leesburg, Fla, U.S.A.
Weinberg, Joan, London.
Welmerink, Edith C., Aadorp, Holland.
Whibley, Alan K., Tonbridge.

Williams, Michael, Ryde.
Wood, Barbara A., Amersham.
Yee Yung Shing, Jimmy, Singapore.
Yeung, Raymond K-K., Kowloon, Hong Kong.
Young, Gerald G., Dunedin, N.Z.
Young, Helen D., Dunedin, N.Z.
Zimmermann, Ursula T., Kowloon, Hong Kong.
Zoll, Harry F., Medford, N.J., U.S.A.

At a meeting of the Council held on Wednesday, 1st November, 1978, at Saint Dunstan's House, the following were elected to membership.

FELLOWSHIP

Andersen, Henrik, Copenhagen, Denmark. 1978
Anverally, Fahemida Z., Colombo, Sri Lanka. 1978
Cassidy, David F.F., Alfrick. 1978
Davies, Robert I., Coventry. 1978
Diggle, Anna S., London. 1978
Galasko, Gail T.F., Johannesburg, S.Africa. 1978
Glaze, Barbara C., San Diego, Cal, U.S.A. 1978
Guiu Clua, Jose L., Tarragona, Spain. 1978
Gunawardena, Manel S., Colombo, Sri Lanka. 1978
Hkimian, Michael, London. 1978
Hindshaw, Judith L., Nairobi, Kenya. 1978
Houghton, Linda A., Burnley. 1978
Hysted, Anne E., London. 1978
Johnson, Marilyn E., Poole. 1978
Kanagawa, Kaeko, Osaka, Japan. 1978
Kangaasvuori, Matti J., Hameenlinna, Finland. 1978
Lammi, Lauri V., Hameenlinna, Finland. 1978
Mahaindra, Mohanraj S. Colombo, Sri Lanka. 1978
Mathiaparanam, Mathi V., Colombo, Sri Lanka. 1978
Meckoni, Harshad R., Bombay, India. 1978
Micilotta, Francesco C., Port Elizabeth, S.Africa. 1978
Moller Duran, Rodolfo, Barcelona, Spain. 1978
Moll, Salvador A.L., Calvia, Mallorca, Spain. 1978
Mouat, Susan G., Lower Hutt, N.Z. 1978
Murray, Gillian M. St.C., Inverclyde. 1978
Proctor, Sarah-Jane L., London. 1978
Rajaratnam, Evelyne V., Ratnapura, Sri Lanka. 1978
Richard, Gil Y., Chigny, Switzerland. 1978
Robins, Henry, Liverpool. 1978
Saez Perez, Maria A. Tarragona, Spain. 1978
Saito, Andrea L., Santa Monica, Cal., U.S.A. 1978
Shah, Nikunj V., Bombay, India. 1978
Shiek, Swun-Kou, Colombo, Sri Lanka. 1978
Sosna, Boris J., Wembley Park. 1978
Suren, Jane L.L., Edenbridge. 1978
Tashey, Thomas E., Santa Monica, Cal., U.S.A. 1978
Tattersall, Simon R., London. 1978
Taylor, Barbara J., Los Angeles, Cal., U.S.A. 1978
Taylor, John A., Ontario, Canada. 1978
Truman, Raymond H., Ilford. 1978
White, John P., Mansfield. 1978
Whiting, Peter J., Auckland, N.Z. 1978
Wood, Roger D., Bristol. 1978
Young, Helen M., Waltham Abbey. 1978

TRANSFERS FROM ORDINARY MEMBERSHIP TO FELLOWSHIP

Amarasinghe, Bodhipala G., Ratnapura, Sri Lanka. 1978
Currie, Spencer J.A., Manurewa, N.Z. 1978
Hallauer, Rainer, Nussbaumen, Switzerland. 1978
Mackenzie, Ronald W.K., Salisbury, Rhodesia. 1978

ORDINARY MEMBERSHIP

Aiiso, Miki, Tokyo, Japan.
Arrate Segura, Juan, Canary Islands, Spain.
Asakawa, Mamoru, Fukuoka Pref., Japan.
Axelsen, Timothy J. London.
Azimullah, Ahmad B., Singapore.
Bannon, Lewis A., Baton Rouge, La., U.S.A.
Bein, Steven, Los Angeles, Cal., U.S.A.
Bonisoli, Giovanna, Torino, Italy.
Booth, Neil, Alyangula Groote Eylandt, N. Territ., Australia.
Brazell, Kenneth B., Norwich.
Brereton, John F., Malahide, Co. Dublin, Ireland.
Celades Colom, Robert, Barcelona, Spain.
Chapman, Ernest J., Exeter.
Chesney, Hazel, Portglenone.
Chesney, William, Portglenone.
Chulani, Resham L.H., London.
Cornwell, Michael W., Hemel Hempstead.
Cracknell, John, Ryde.
Dougan, David A., Dublin, Ireland.
Douglas, Ian B., Wellington, N.Z.
Eastaugh, Roberta M.H., Kowloon, Hong Kong.
Errera, Michel G.L., Brussels, Belgium.
Gion, Yasuko O., Hokkaido, Japan.
Hanataka, Jitsuo, Hyogo Pref., Japan.
Hata, Kenichi, Koto-fu, Japan.
Hatane, Nobuo, Osaka, Japan.
Hayakawa, Chieko, Osaka, Japan.
Hinde, Rosemary J., Hong Kong.
Hiraoka, Satoshi, Tokushima Pref., Japan.
Horii, Toshiji, Hogo Pref., Japan.
Inatsugi, Shiko, Osaka, Japan.
Inenaga, Atsushi, Fukuoka Pref., Japan.
Ishiguro, Osamu, Tokyo, Japan.
Ito, Eiko, Kanagawa Pref., Japan.
Iwaguchi, Seichi, Osaka, Japan.
Joshi, Mangala V., Panaji-Goa, India.
Kagami, Kimiko, Tokyo, Japan.
Kagita, Mayumi, Kyoto, Japan.
Kajita, Motoyoshi, Shizuoka Pref., Japan.
Kajita, Yukio, Tokyo, Japan.
Kaneko, Isamu, Tokyo, Japan.
Kanesaka, Masatoshi, Chiba Pref., Japan.
Kanzaki, Ichiro, Tokyo, Japan.
Kermoal, Violette H., Buntingford.
Kibas, Masataka, Tokyo, Japan.
Kita, Masako, Fukuoka, Japan.
Kodama, Mariko S., Melbourne, Australia.
Kogai, Shozabruro, Tokyo, Japan.
Kuki, Tohru, Kanagawa Pref., Japan.
Kuroiwa, Satomi, Paris, France.
Lilley, Derek J., Windsor.
Mackechnie, Valerie J., St Albans.
Maeda, Setuko, Tokyo, Japan.
Matsubara, Hiroshi, Hyogo Pref., Japan.
Matsunobu, Hiroshi, Tokushima Pref., Japan.
Miki, Machiko, Osaka, Japan.
Mitchell, Ann V., Limuru, Kenya.
Miyahara, Reiko, Tokyo, Japan.

Miyake, Yasuhiro, Kyoto-Fu, Japan.
Mizoguchi, Toshizumi, Osaka, Japan.
Morishima, Katsusuke, Hokkaido, Japan.
Mukai, Yujiro, Yamanashi Pref., Japan.
Nakayama, Anako, Tokyo, Japan.
Ng, Shirley S-Y, Hong Kong.
Nojiri, Masatomi, Fukuoka Pref., Japan.
Nonaka, Masayuki, Kanagawa Pref., Japan.
Nozawa, Hidekazu, Shiga Pref., Japan.
Ochiai, Nobusuke, Tokyo, Japan.
Ohta, Kazou, Hyogo Pref., Japan.
Oono, Hideki, Hokkaido, Japan.
Ozaki, Naoko, Hokkaido, Japan.
Partridge, Raymond O., Wellington, N.Z.
Pattani, Narendra V., Leicester.
Pattani, Versha N., Leicester.
Reeks, Graham W., Johannesburg, S.Africa.
Ryan, Margaret E., Hong Kong.
Sacher, Leonhard K., Sinsheim, West Germany.
Saito, Masahiko, Hokkaido, Japan.
Sato, Atsuko, Tokyo, Japan.
Sato, Koji, Miyagi Pref., Japan.
Sato, Kuniko, Tokyo, Japan.
Sima, Takehiko, Tokyo, Japan.
Sugita, Tadashi, Chiba Pref., Japan.
Suzuki, Kimio, Hokkaido, Japan.
Tajika, Kazutaka, Tokyo, Japan.
Telford, Robert A., Southampton.
Tohyama, Akiko, Tokyo, Japan.
Toti, Patricia A., Cape Town, S.Africa.
Tsekouras, Dimitrios, Athens, Greece.
Tsuji, Takao, Tokyo, Japan.
Wacker, Penny Sue, Hong Kong.
Weber, Rudiger G., London.
White, Anthony F.J., Enfield.
Woodward, Paul R., Burnley.
Yamasita, Hisao, Yamanashi Pref., Japan.
Yeo, David S.C., Singapore.
Yoshida, Jyunitiro, Wakayama Pref., Japan.
Yoshida, Katsuji, Wakayama Pref., Japan.
Young, Laurie P., Auckland, N.Z.

GEM DIAMOND EXAMINATION 1978

Twenty-six candidates entered for the Association's 1978 Gem Diamond Examination, of whom fourteen qualified, one with distinction. The following is a list of successful candidates arranged alphabetically.

QUALIFIED WITH DISTINCTION

Castanera Rodriguez, Luis, Barcelona, Spain.

QUALIFIED

Alabaster, Stephen P., Birmingham.
Arla Pont, Antonio, Barcelona, Spain.
Baldock, Lynette, Neston.
Chadderton, Yvonne E., Oldham.
Clarke, Kathleen D., London.
Eakins, Harry, Heswall.
Emmanuel, Peter J., Croydon.
Gayton, Mildred P., Southport.
Havlik, Jan C., London.
Henocq, James E. R., S. Croydon.
Henocq, Rosemary S., S. Croydon.
Prats Ballester, Juana, Barcelona, Spain.
van der Meulen, Anne W., London.

EXAMINATIONS IN GEMMOLOGY 1978

In the 1978 Examinations in Gemmology, 711 candidates sat for the Preliminary Examination (420 passed), and 450 candidates for the Diploma Examination (155 passed, including 10 with Distinction).

In the opinion of the Examiners no candidate attained the standard required for the Tully Memorial Medal. The highest marks were gained by Mr Rowan M. Beach of Twickenham who deserves commendation for an excellent set of papers.

The Rayner Prize, in the Preliminary Examination has not been awarded.

The following are lists of successful candidates, arranged alphabetically.

DIPLOMA EXAMINATION

QUALIFIED WITH DISTINCTION

Beach, Rowan M., Twickenham.
Boles, Julian D., Cattistock.
Dillmann, Rolf, Berne, Switzerland.
Hallauer, Rainer, Nussbaumen, Switzerland.
Israel, Nigel B., London.
Littman, Esther P. M., Curaçao, Neth. Antilles.
Moyersoen, Jean-Francois, Brussels.
Taylor, Barbara Jean, Clinton, Iowa, U.S.A.
Whiting, Peter J., Auckland, N.Z.
Wong, Tak-Chiu, Kowloon, Hong Kong.

QUALIFIED

Amarasinghe, Bodhipala G., Ratnapura, Sri Lanka.
Andersen, Henrik, Copenhagen, Denmark.
Anverally, Fahemida Z., Colombo, Sri Lanka.
Armitage, Kevin P., Rotorua, N.Z.
Atapattu, Nirmala K., Mount Lavinia, Sri Lanka.
Athiniotaki, Vassiliki, M., London.
Attanayake, Walter, Ratnapura, Sri Lanka.
Barcham, Kathryn L., Peak, Hong Kong.
Bates, Adrian J., Sutton Coldfield.
Bennett, Russell K., Aylesbury, Bucks.
Berry, Elizabeth K., Melbourne, Australia.
Birch, John W. de Gray, Mexico.
Bogollagama, Ravindra C. B., Kurunegala, Sri Lanka.
Bou Castillo, Angel D., Almazora, Spain.
Bramwell, Peter, Durham.
Busaracome, Suwin, Thailand.
Cassidy, David F. F., Worcester.
Catala Marti, Joaquin, Gandia, Spain.
Celades Colom, Roberto, Barcelona, Spain.
Chang, He Ok, London.
Collado Gil, Tomas, Valencia, Spain.
Currie, Spencer J. A., Manurewa, N.Z.
Crawford, Hugh B., Kirkcudbright.
Daniels, Brian R., Dunedin, N.Z.
Davies, Robert I., Coventry
Davis, Jonathan V., London.
Diggle, Anna Sylvia, London.
Dillimuni, Dayananda, Colombo, Sri Lanka.
Domenech Plo, Juan, Valencia, Spain.
Dougan, Patricia M. S., Nairobi, Kenya.
Duckworth, Andrew S., Bolton.
Dunn, Brian R., Crawley.
Emslie, Iain A., Bromyard.
Faiz, M. H. M., Colombo, Sri Lanka.

Faulder, John A., Purley.
Fennessy, Sean F., Paris, Tex., U.S.A.
Fookes, Mark H., Brentwood.
Fuster Casas, Miguel, Badalona, Spain.
Galasko, Gail T. F., Johannesburg, S. Africa.
Gianforte, Carmen A., Florida, U.S.A.
Gil Garcia-Miguel, Jorge, Barcelona, Spain.
Girbes Faba, Adolfo, Valencia, Spain.
Glaze, Barbara C., San Diego, Cal., U.S.A.
Golbey, Terence M., Harrow.
Grant III, John W., Milledgeville, Ga, U.S.A.
Gryg, Bessie, Perth, W. Australia.
Guiu Clua, José L., Reus, Spain.
Gunatilake, Abaya Geetha, Moratuwa, Sri Lanka.
Gunawardena, Manuel S., Colombo, Sri Lanka.
Hailey, Robert J., New Malden.
Hakimian, Michael, London.
Hammond, Glenys M., Cockfosters.
Hashimoto, Mieko Kojima, Yokohama, Japan.
Haugh, Breda M., London.
Healey, David, Loughborough.
Heatlie, James W. M., Edinburgh.
Henniker-Heaton, Gay D. A., London.
Hindshaw, Judith L., Nairobi, Kenya.
Hiscox, Peter C., Knowle.
Hitchen, Alan, Aldridge.
Hitchman, Michael J., Leicester.
Hoover, Donald B., Lakewood, Colo., U.S.A.
Horkel, Dorothea, Vienna, Austria.
Houghton, Linda A., Burnley.
Houlgrave, Peter B., Rickmansworth.
Hughes, Susan M., Hong Kong.
Hysted, Anne E., New Eltham.
Jayasuriya, Ranjit L., Colombo, Sri Lanka.
Jerome, Philip S., London.
Jobin, Marc Paul B., London
Johnson, Marilyn E., Poole.
Kan, Neville Y. C., London.
Kanagawa, Kaeko, Osaka, Japan.
Kangasvuori, Matti J., Hameenlinna, Finland.
Kinch, John A. C., Morden.
Krakowiak, Czeslaw J., Gdansk Oliwa, Poland.
Lakdawalla, Noshir J., Bombay, India.
Lammi, Lauri V., Hameenlinna, Finland.
Lander, Charmian E. M., London.
Langoulant, Margaret J., Salisbury, Rhodesia.
Langoulant, Peter B., Perth.
Lowe, Sylvia J., Harrow.
Lyall Grant, Ian H., Kingswear.
Mackenzie, Ranald W. K., Salisbury, Rhodesia.
Mahaindra, Mohanraj S., Colombo, Sri Lanka.
Martin, William J., Nairobi, Kenya.
Mathiaparanam, Mathi Vathani, Colombo, Sri Lanka.
Mayling, Clifford G., Slough.
Meckoni, Harshad R., Bombay, India.
Megel, Gary E., Colorado Springs, U.S.A.
Micilotta, Francesco C., Port Elizabeth, S. Africa.
Miller, Neil, London.
Moll, Salvador A. L., Mallorca, Spain.
Moller Duran, Rodolfo, Barcelona, Spain.
Mouat, Susan G., Lower Hutt, N.Z.
Murray, Gillian M. St. C., London.
Okano, Chizuru, Tokyo, Japan.
Perrett, Roy, Swinton.
Pethiyagoda, Upali Kumarasane, Kandy, Sri Lanka.
Pope, Lesley J., Lymington.
Proctor, Sarah-Jane L., Guildford.
Rajaratnam, Evelyne V., Ratnapura, Sri Lanka.

Richard, Gil Y., Chigny, Switzerland.
Robins, Henry, Liverpool.
Ros-Jones, Catherine A., Ascot.
Rubesinghe, Savithri P. K., Mount-Lavinia, Sri Lanka.
Saez Perez, Maria A., Reus, Spain.
Saito, Andrea L., Santa Monica, Cal., U.S.A.
Seal, Richard M. P., Bridlington.
Seevaratnam, Nagalingam, Colombo, Sri Lanka.
Seoane Garcia, Maria E., Valencia, Spain.
Shah, Nikunj V., Bombay, India.
Shaikh, Leela, London.
Shiek, Swun-Kou, Colombo, Sri Lanka.
Shimomura, Michiko, Tokyo, Japan.
Sosna, Boris, Wembley Park.
Stanislaus, Saverimuttu J. L., Colombo, Sri Lanka.
Suren, Jane L. L., London.
Takigawa, Junko, Kyoto, Japan.
Tashey, Thomas E., Santa Monica, Cal., U.S.A.
Tattersall, Simon R., Radlett.
Taylor, John A., Toronto, Canada.
Teakle, Simon J., Lewes.
Thomas, Ian W., Brisbane, Australia.
Truman, Raymond H., Ilford.
Tubella Llurba, Carlos, Reus, Spain.
Turner, Michael J., Sheffield.
Ueta, Kouji, Osaka, Japan.
Van Den Berge, Diane M., Niedernhausen, W. Germany.
Vargas Perez, Manuel de, Barcelona, Spain.
(Verduyn) Walter, Laetitia, The Hague, Holland.
Virtanen, Anne M., Helsinki, Finland.
Visser-Bonnmann, Maria I. A., Delft, Holland.
Vollom, Paul A., Eugene, Oreg., U.S.A.
Watson, J. Lincoln, Bulawayo, Rhodesia.
Webster, Pamela R., Middlesbrough.
Weeresinghe, Nedra P. O., Kandy, Sri Lanka.
Weissler, Chaggai C. A., London.
White, John P., Mansfield.
Wilson, Philip, Newcastle-upon-Tyne.
Wood, Roger D., London.
Yamaguchi, Takashi, Osaka, Japan.
Yoshikawa, Kazuhiko, Gobo, Japan.
Young, Helen M., Waltham Abbey.
Yu, Robert M., Hong Kong.

PRELIMINARY EXAMINATION

QUALIFIED

Aasen, Signe Louise, Oslo, Norway.
Abasolo, Ander, Bilbao, Spain.
Abayasingha, Amaranath, Colombo, Sri Lanka.
Abels, Jan L., Schermerhorn, Holland.
Acheson, Jeffrey Duncan, Blairgowrie, S. Africa.
Adams, Audley Vivian, Cranbrook, Qld, Australia.
Akiyama, Masashi, Hokkaido, Japan.
Alva, Shyamala, Bombay, India.
Amoroso, Robert E., Boston, Mass, U.S.A.
Andersen, Henrik, Copenhagen, Denmark.
Andrews, Sheila Marjorie, Dalkeith, Australia.
Arnold, Martin John, Edgware.
Asagai, Osamu, Osaka, Japan.
Aspero Fageda, Carlos, Barcelona, Spain.
Aubertin-Watson, Kunigunde, London.
Auma, Richard Aol Henry, Nairobi, Kenya.
Austin, Kenneth Neil, Sumter, S.C., U.S.A.

Avasia, Rohinton Kersasp, Bombay, India.
Aye, Htun, Birmingham.
Bada-Marzo, Daniel Vicente, Valencia, Spain.
Bae, Hyung Soon, Seoul, Korea.
Bahl, Neela, Bombay, India.
Bahl, Sujata, Bombay, India.
Bailey, Rosemary Jane, Solihull.
Balague Lopez, Leonor, Barcelona, Spain.
Barker, Maxwell, Sandton, S. Africa.
Barrett, Louise A., Bowmanville, Ont., Canada.
Barthau, David Stephen, Markham, Ont., Canada.
Bawa, Mohamed Shah Nawaz Marikar, Colombo, Sri Lanka.
Beech, Trevor Alan, Blackpool.
Beevers, Jacintha Mary, Hong Kong.
Behne, Bernhard Heinz, Ottawa, Ont. Canada.
Bell, Robert Douglas, Durban, S. Africa.
Bernus Altes, Agustin, Barcelona, Spain.
Berry, Elizabeth Kate, Melbourne, Australia.
Bertrand, Sarah, Lancing.
Betterton, Natalie Ann, Chatham.
Bird, Victor Paul, London.
Blanckenberg, Antoinette, Southampton.
Boast, William Ernest, Cheadle.
Bogues, Patrick Martin, Omagh, N. Ireland.
Bokhobza, Robert, London.
Borras Torra, Ignacio, Barcelona, Spain.
Borreda Perez, Federico, Valencia, Spain.
Bouman, Els, Utrecht, Holland.
Bower, John Cyril, Singapore.
Boyd, Warren Frederick, Toronto, Ont., Canada.
Boyes, Richard William, Haydock.
Bradoch, Robert V., Tokyo, Japan.
Bradshaw, Barbara Ann, Preston.
Braine, Margaret Joan, Nedlands, Australia.
Brennan, Ranee Lilamani, Seria, Brunei.
Bresco Pont, Florencio, Barcelona, Spain.
Bridgwater, Mark, Brierley Hill.
Britland, Trevor, Johannesburg, S. Africa.
Brohier, Kenneth Gordon, West Kirby, Wirral.
Brown, Valerie Jane, Bognor Regis.
Brownlow, Arthur Hume, Needham, Mass, U.S.A.
Bucciarelli, Robert, Downsview, Ont., Canada.
Busaracome, Suwin, Khon Kean, Thailand.
Butler, Adrian Christopher, Tamworth.
Carlsson, Björn, Täby, Sweden.
Carson, Constance, Wanstead.
Cartier, Richard Harvey, Toronto, Ont., Canada.
Castello Torres, Maria Dolores, Valencia, Spain.
Chadwick, John Harlow, Clacton on Sea.
Chamberlain, Timothy Mark, Bolton.
Champaneria, Deepti Sharad, Thana, Maharashtra, India.
Chappell, David Andrew, Goole.
Charatan, Ivan Louis, Northolt.
Chawla, Gulzari, Downsview, Ont., Canada.
Cheung, Kai Yuen, Happy Valley, Hong Kong.
Chosokabe, Yukuto, Nagoya-City, Japan.
Chuc, Ruby Carrera Lowe, Hong Kong.
Chulani, Resham Lachman Hariram, Hong Kong.
Claeys, Olivia Elvira Eugenie, Schoonhoven, Holland.
Clarke, Francis Brian, Upminster.
Coffin, David George, Highbridge.
Collett, Richard, Cassington.

Condom Rovira, Maria Lourdes, Barcelona, Spain.
Cooper, Nicholas Tyson, Croydon.
Cornwell, Michael William, Hemel Hempstead.
Costa Campos, Ana Maria, Barcelona, Spain.
Cracknell, John, Ryde.
Cukier, Gerard, London.
Curry, Sonia A. N. Battleford, Sask., Canada.
Curtis, Malcolm David, Gosport.
DaCosta, Michael Stuart, Toronto, Ont., Canada.
D'Arcy, John Patrick, Dunlaoire, Ireland.
De La Rue, Nigel Peter, Vale, Guernsey.
Dickson, Dorothy S., Harrisburg, N.C., U.S.A.
Diggle, Anna-Sylvia, London.
Dillimuni, Dayananda, Colombo, Sri Lanka.
Dillmann, Rolf, Berne, Switzerland.
Dimtrio, Maria, Eskkstuna, Sweden.
Dolz Adell, Maria del Carmen, Valencia, Spain.
Donald, Robert Johnston, Willowdale, Ont., Canada.
Douglas, Brian Sydney, Downsview, Ont., Canada.
Douglas, Ian Barry, Wellington, N.Z.
Douglas, John James, Cardiff, N.S.W., Australia.
Dupuis, Ronald R.J., Toronto, Ont., Canada.
Ebrahimjee, Mustanseir, Harrow.
Echarri Zapiain, Maria José, Barcelona, Spain.
Eckermalm, Hjördis Margareta Eleonora, Tumba, Sweden.
Edmunds, Roger Alan, Accrington.
Eldridge, William Randle, Kerrville, Tex., U.S.A.
Escursell Pujol, Maria del Carmen, Barcelona, Spain.
Esteve Bosch, José, Prat de Llobregat, Barcelona.
Esteve Fernandez, Jaime, Barcelona, Spain.
Evans, Huw Mercer, Townsville, Qld, Australia.
Eves, Michael Sydney Harold, Nairobi, Kenya.

Fagg, Primrose Mary, Wallington.
Fairweather, Robin John, Brisbane, Australia.
Farooqi, Muhammad Atiq Alam, Rawalpindi, Pakistan.
Felani Rodriguez, Jaime, Barcelona, Spain.
Feria Aguilera, Francisco, Barcelona, Spain.
Fernandez Montiel de Prado, Oscar, Pamplona, Navarra, Spain.
Fitzmaurice, Gabrielle Mary, Roscommon, Ireland.
Foakes, Margaret Ann, Birmingham.
Franks, John Wilson, Altrincham.
Fraquet, Helen Rosemary, Frinton on Sea.
Fulwiler, Jack Henry, Abilene, Tex., U.S.A.
Furuya, Shuji, Tokyo, Japan.

Gabella, Laurent Pierre, London.
Garrigos Fernandez, Ma Asuncion, Valencia, Spain.
Garrigos Fernandez, Ma José, Valencia, Spain.
Gaudy, Monica Elisabet, Solna, Sweden.
Geikler, Patricia Jean, Richmond, Va, U.S.A.
Gillett, Christopher, Bexhill on Sea.
Glen, Jillian, London.
Gonzalez Fernandes, Inmaculada, Barcelona, Spain.
Gonzalez-Quiros Corujo, Ma Angeles, Oviedo, Spain.
Gonzalez-Quiros Corujo, Ma Pilar, Oviedo, Spain.
Good, Amanda Grahame, London.
Goonesekera, Shantilal Sudirikku J., Colombo, Sri Lanka.
Green, Edward Maurice, London.

Griffin, Catherine Elizabeth, Silver Spring, Md, U.S.A.
Griffiths, Geoffrey Edward, Grimsby.
Groenenboom, Hans Karel, Spykenisse, Holland.
Gryska, Stephanie Margaret, Worksop.
Guiu Clua, Mariano, Lerida, Spain.
Hakamada, Tetsuo, London.
Hall, Clive Denis, Edgware.
Hall, Michael D., Derby.
Hamid, Mohammed Rizavi, Colombo, Sri Lanka.
Hamilton, Hamish Donald, Burntisland.
Harada, Shigeo, London.
Harding, Roger Robertson, London.
Harker, Judith Margaret, Bradford.
Harkins, Charles Francis, Glasgow.
Harris, Barbara, Toronto, Ont., Canada.
Harris, David Kenneth, Gloucester.
Hart, Judith Elizabeth, Denby.
Hartzman, Mark Jeffrey, New York, U.S.A.
Hayashi, Hidenori, Tokyo, Japan.
Hayes, Thomas William, Sidcup.
Healey, David, Hong Kong.
Heapy, Timothy Maurice, Macclesfield.
Hemsted, Simon Garnet, Plymouth.
Hernandez Ordonez, Arturo, Valencia, Spain.
Hidaka, Masano, Silver Spring, Md, U.S.A.
Hills, Albert Edward, Leeds.
Hirst, Rosalind, Johannesburg, S. Africa.
Hochstrasser, Beat, Zurich, Switzerland.
Holdsworth, Ian, Stafford.
Hopkins, Philip Keith, St Albans.
Hopkinson, Barbara Joyce, Nottingham.
Hordyk, Robert Ernst, Schoonhoven, Holland.
Horkel, Dorothea Elizabeth Irma, Nairobi, Kenya.
Horstead, Brian Thomas, Coventry.
Howarth, Janet, Bolton.
Huby, Michael, Nafferton.
Hudyma, Robert William, Don Mills, Ont., Canada.
Hughes, Brian Richard, Nairobi, Kenya.
Huo, Bonnie Tin-Wing Kwan, Hong Kong.
Hurrell, Joanna Louise, Erdington.
Hussain, Surajul Hilmy, Mount Lavinia, Sri Lanka.

Inamdar, Geeta, Newmarket, Ont., Canada.
Ingram, Ian Stephen, Bridgwater.
Ipekdjian, Denise Virginia, Antwerp, Belgium.
Izquierdo Grasas, Jorge, Barcelona, Spain.

Jägerstig, Björn Olof, Saltsjöbaden, Sweden.
Jalaldeen, Mohamed Roshan, Dehiwela, Sri Lanka.
Janse, Robin, Toronto, Ont., Canada.
Jayawardena, Palihawadana Arachchige J.L.P., Colombo, Sri Lanka.
Jealouse, Roy George, Crewe.
Jensen, Edna, Huddinge, Sweden.
Jhaveri, Mahendra Manmohandas, Bombay, India.
Jibiki, Emiko, Tokyo, Japan.
Jonani, Jacob Evans Ondeuo, Nairobi, Kenya.
Jones, Edith Winifred, Peppermint Grove, Australia.
Jones, Gordon, Hounslow.
Jones, Jeffrey Malcolm, London.
Jonestrand, Helene, Johanneshov, Sweden.
Jovanovic, Tomislav, Birmingham.
Joynt, James, Hereford.

Kämäri, Arvi Nestori, Alvettula, Finland.
Kawakami, Sumiyo, Osaka, Japan.
Kayman, Shelley Naomi, London.

Keating, Molly Imelda, Nairobi, Kenya.
Kemp, Roy E.H., Farnham.
Kendall-Smith, Stephen, Beaconsfield.
Kessler, Paul, London.
Keydar, Susan, London.
Kimura, Shinichi, Kyoto, Japan.
Kimura, Takashi, Tokyo, Japan.
Kita, Keiko, Osaka, Japan.
Klaver, Gerardus Johannes, Johannesburg, S. Africa.
Ko, Yiu Wai Richard, Hong Kong.
Kohara, Sachiko, Tokyo, Japan.
Kojima, Michinaka, Tokyo, Japan.
Kowalewsky, Adrian Paul, Hereford.
Kristensen, Jorgen Anton, London.
Kuehn, Robert Lary, Dallas, Tex, U.S.A.
Kurotaki, Akira, Tokyo, Japan.
Kuruppu Achchige, Don Edward, Pelmadulla, Sri Lanka.
Kyriacou, Mamas, London.

Lainé, Paul David, Vale, Guernsey.
Lakdawalla, Noshir Jamshed, Bombay, India.
Lane, Mark John, Mansfield.
Latham, William Gary, Manchester.
Laucher, Frank Andrew, London.
Lee, Dennis Philip, Leatherhead.
Leith-Smith, Jean Elizabeth, Sai Kung, Hong Kong.
Lemar, Desiree Racheal Bridgette, Hyattsville, Md, U.S.A.
Lemire, Flora Marianne, Toronto, Ont., Canada.
Li, Woon So, Wanchi, Hong Kong.
Lien, Jan Peter, Norrköping, Sweden.
Lilley, Derek John, Windsor.
Lindsay, Kathryn Sharon, Salisbury, Rhodesia.
Llado Badia, Carlos, Barcelona, Spain.
Low, Teck Khoon, Bombay, India.
Lurie, Joseph, Randburg, S. Africa.
McAteer, Alice, London.
McCubbin, Diane Frances, Sutton Coldfield.
Machlup, Peter Mark, Johannesburg, S. Africa.
Mackenzie, Ranald William Kenneth, Salisbury, Rhodesia.
MacKichan, Brian Somerled, London.
Mc Millan, Grace Margaret, St Lucia, Australia.
Madrenys Mur, José Oriol, Barcelona, Spain.
Madrid Safont, Isabel, Prat de Llobregat, Barcelona.
Mai, Van Lieu, Brussels, Belgium.
Martel Vilaplana, Ma Mercedes, Barcelona, Spain.
Martin, John Patrick, Nairobi, Kenya.
Mathu, Sidney Kamau, London.
Meckoni, Harshad Ramniklal, Bombay, India.
Megel, Gary Edward, Colorado, Springs, U.S.A.
Melhus, Per Kristian, Bekkestua, Norway.
Mimica, Stefano, Rome, Italy.
Minster, David, Pretoria, S. Africa.
Miura, Hiroyuki, Kanagawa, Japan.
Miyumo, Julius Blasio, Nairobi, Kenya.
Mizoguchi, Toshizumi, Osaka, Japan.
Moesker, Anneke Antje Geke Elisabeth, Schoonhoven, Holland.
Monner Dieguez, Jaime, Barcelona, Spain.
Montagu, Christopher Robert, Bournemouth.
Moore, Roderich Rudiger, Solihull.
Morimoto, Towa, Kyoto-City, Japan.
Mortimer, Paul, Harrow.
Moscrop, Laurence Brent, Kandy, Sri Lanka.
Moxon, Michael David, Palmerston North, N.Z.
Munas, Carmel Leonte, Morden.
Mungania, Charles Ndegwa, Nairobi, Kenya.
Munro, Lesly, Cowbridge.
Murphy, Mary Margaret, New York, U.S.A.

Murray-Jones, Pauline Ann, Hong Kong.
Narukawa, Yoshiko, Tokyo, Japan.
Nasser, Sahera, Northwood.
Nathanson, Daniel Philip, London.
Neo, Nobushiga, Osaka, Japan.
Nicholson, Edgar Irving, Port Elizabeth, S. Africa.
Nishino, Tomoji, Tokyo, Japan.
Nosé, Yoshishige, Nagano, Japan.

O'Donnell, Francis Xavier Desmond, Liverpool.
Ogombo, John Joel, Nairobi, Kenya.
O'Hare, Jane Kathleen, Liverpool.
Okamoto, Ichiro, Tokyo, Japan.
Okayasu, Kuni, London.
Ong, Kim Chin, Birmingham.
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RESIDENTIAL GEMMOLOGY COURSES AT CHICHESTER

Mr Peter G. Read, C.Eng., M.I.E.E., M.I.E.R.E., F.G.A., F.I.S.T.C., is tutoring weekend residential courses in gemmology at the West Dean College, Chichester. The new gemmology course is an extension to the College's existing jewellery and lapidary courses and includes the principles and methods of use of gem testing instruments, the identification and testing of gemstones, the identification of diamond and diamond simulants, and related topics. Details of the course can be obtained from Miss Susan Overman, West Dean College, West Dean, Chichester, West Sussex, PO18 0QZ (telephone Singleton 301).

ROCK AND GEM HUNTING IN CORNWALL

'Yonder Towan Cornish Purpose Holidays' for 1979 (3rd March—3rd November) include nine one-week (Saturday to Saturday) 'Rock, Gem and Mineral Hunting' holiday courses, combining daily field collecting trips and museum visits, with evening lectures given by qualified visiting tutors. Full particulars may be obtained from Yonder Towan (Field Holiday) Centre, Newquay, Cornwall. (Telephone: Newquay (STD 063 73) 2756).

OBITUARY

It is with great regret that we announce the death of Mr Gordon F. Andrews, F.G.A., former Secretary of the Association, on 5th January, 1979. A full obituary notice will appear in the April issue of the *Journal*.

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No. 5
January, 1979

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and

PROCEEDINGS OF THE GEMMOLOGICAL ASSOCIATION OF GREAT BRITAIN

GEMMOLOGICAL ASSOCIATION OF GREAT BRITAIN
SAINT DUNSTAN'S HOUSE, CAREY LANE
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TELL-TALE INCLUSIONS IN A PHENAKITE FROM BRAZIL

By E. GÜBELIN, Ph.D., C.G., F.G.A.

The following report on a detailed investigation of fluid inclusions in a phenakite from Brazil is intended as an additional contribution following two previous publications[2, 3] about the determination of fluid inclusions and the conclusions to be drawn from their analyses.

Always greatly inspired by any new inclusion found in a gemstone I became vividly interested by Pete Dunn's description[1] of acicular aikinite inclusions in some phenakites from San Miguel Di Piricicaba in Brazil (Figure 1). As I had never seen aikinite inclusions before and also since this combination appeared to be extremely rare, I summoned the courage to ask Mr Dunn to send me a specimen for inspection. He not only responded positively to my request but most generously sent me three different phenakite crystals—all containing aikinite needles. I am sincerely grateful for his courteous cooperation. The largest crystal proved to be extraordinarily interesting in that one of two adjacent and well-shaped, pencil-like aikinite crystals was part of a multiphase inclusion (Figure 2). This aikinite jutted into a slender cavity filling it

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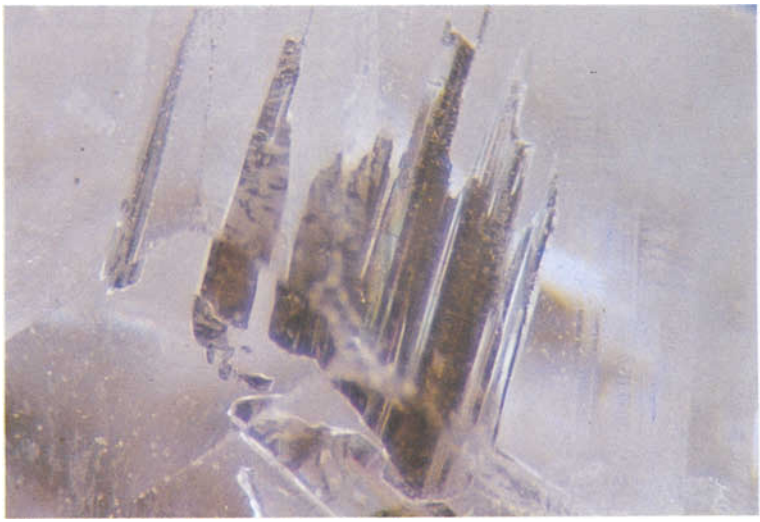

FIG. 1. Group of slender to broad stalks of aikinite crystals in a phenakite. Note the characteristic striation parallel to the long crystal axis and the interference colours of the tarnish. (Bright field, 20 ×).

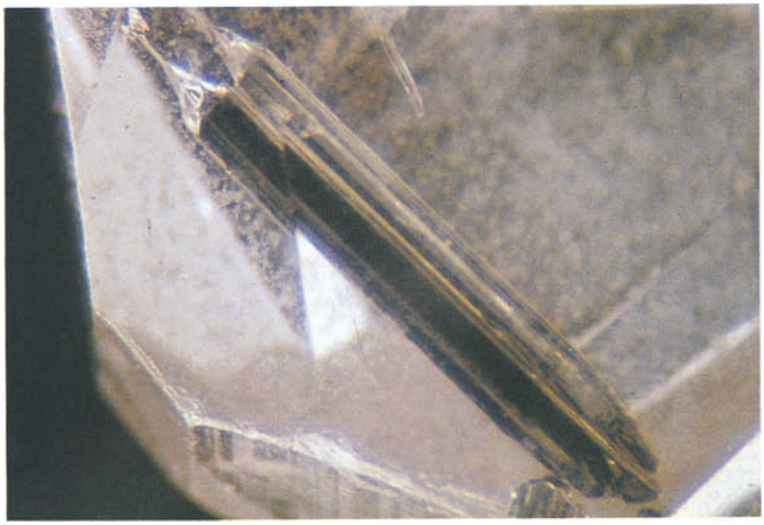

FIG. 2. Two adjacent, pencil-shaped aikinite crystals in parallel position, each one jutting into a slender cavity. Note the copper-brown tarnish colours and the liquid-filled cavity at the head of the darker aikinite. (Dark field, 40 ×).

to about 98% of its volume, while the remaining space was filled by a liquid and a gas bubble (Figure 3). Indubitably, this inclusion was a *primary* multiphase inclusion. Besides, the cavity contained another solid phase which was anisotropic, yet could not be determined.

Since aikinite normally occurs together with gold on quartz veins and thus suggests hydrothermal descent, this unusual existence in a liquid inclusion in phenakite justified the hope of gaining some increased knowledge about the conditions of formation—not only of the inclusions but also of the host crystal itself. Further very close examination of the phenakite crystal disclosed that apart from the above-mentioned multiphase inclusion there were a few minute acicular crystals of greenish colour as well as numerous syngenetic liquid inclusions of secondary origin (named pseudosecondary inclusions) (Figure 4).

A careful electron microprobe analysis of the tiny green needles indicated the presence of the elements Pb, Cu, Bi and S, thus pointing to aikinite again. In disintegrated state aikinite turns green. We may therefore assume that these green aikinite crystals had existed and disintegrated before they were enclosed by the growing phenakite crystal and consequently represent protogenetic inclusions.

The primary syngenetic as well as the secondary syngenetic fluid inclusions were then subjected to the same method of microthermometry as previously described in detail in this *Journal.*[2] The primary fluid inclusion at the top of one of the fresh aikinite needles consisting of a liquid and a large gas bubble (Figure 3) was first cooled down to −140°C and then slowly warmed up to +60°C. This process was repeated twice, and the following alterations of phases could be observed:

at a temperature of −2.5°C the ice started melting,

at approximately +8°C dissociation of a hydrate (= CO_2–hydrate) occurred,

and between +20°C and +50°C some minute solid grains disappeared.

The anisotropic phase did not dissolve when heated up to +60°C.

These incidents lead to the interpretation that the liquid in this particular inclusion was a relatively weak, watery but saline solution with 4.2 equivalent weight per cent of NaCl. A content of

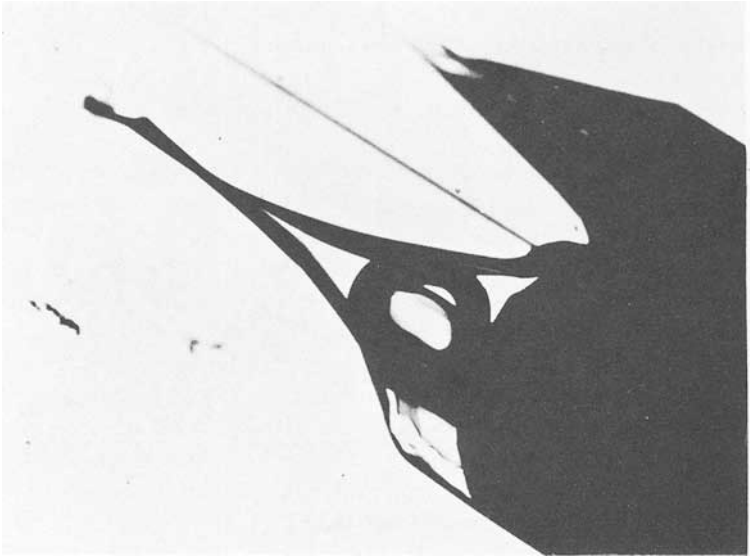

FIG. 3. Strong magnification (250 ×) of the head part of the darker aikinite crystal clearly depicting the large gas bubble in the fluid of the triangular cavity. (The anisotropic body is concealed behind the broad relief of the vesicle).

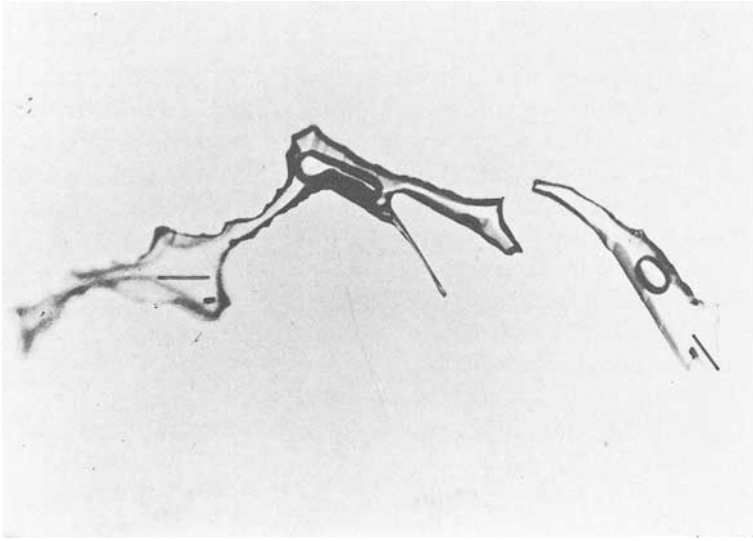

FIG. 4. The two largest and complexest of the pseudosecondary fluid inclusions. The anisotropic phase is situated at the right end of the larger gas bubble. The black needles and the black grains (inked in)* are probably sulphosalts (aikinite?). (250 ×).

*Inked in because, though perfectly clear when viewed under the microscope, they were out of focus in the photograph when the more important details were sharp.

CO_2 was just detectable (below 6 wt % of CO_2). The nature of the minute grains, which slowly disappeared between +20° and +50°C, could not be identified.

The *pseudosecondary* inclusions constituted the 'undigested' fluid drops on the curved plane of a partially-healed fracture. In size they measured between 5 and 350μm, and they all appeared to be of the same composition as the primary inclusion in that they comprised a liquid with a gas vesicle and three different solid precipitations. The gas bubbles totalled up to about 5 vol % (Figure 4).

The method of investigation was the same as applied to the primary inclusion, i.e. first they were cooled down to −140°C and then annealed to +30°C. The process was repeated just once. The course of events was very similar to that with the primary inclusion:

at a temperature of −2.1°C the ice began to melt,

at approximately +9°C dissociation of the CO_2–hydrate took place (liquid or solid CO_2 could not be observed during the cooling process).

Here too, the anisotropic phase did not dissolve when heated up to +60°C.

The result gained from this treatment reveals that the liquid is a weak watery but saline solution with 3.5 equivalent weight per cent of NaCl, while the content of CO_2 is exactly the same as in the primary inclusion. This interesting piece of new knowledge manifests that no great difference intervened in chemical composition of the mother liquor—and perhaps also in time—between the formation of the primary and the secondary inclusions.

The hydrothermal solution from which the phenakite crystal formed presents itself today in these residual inclusions as a relatively weak saline solution. The original composition of the mother liquor must have been of a very complex nature, which is indicated by the minute daughter grains, some of which disappeared while others remained inert at higher temperatures. The exact composition of these daughter crystals was unfortunately not possible to ascertain.

Apart from this informative investigation of the fluid inclusions it was interesting to observe three generations of inclusions in this phenakite crystal, namely:

(a) protogenetic green disintegrated aikinite needles which must have existed before the phenakite formed,

(b) syngenetic primary inclusions of two kinds:
  (b.1) primary mineral inclusions represented by fresh aikinite needles (Figures 1& 2),
  (b.2) primary fluid inclusion floating round the head of one of the primary pencil-shaped aikinite needles (Figure 3),

(c) syngenetic secondary (so-called pseudosecondary) fluid inclusions also containing mother liquor because the fissure occurred during the growth—at least before the growing process of the phenakite crystal had come to an end, yet not as an immediate consequence of the actual formation (Figure 4).

This exciting examination of protogenetic, syngenetic primary and secondary (pseudosecondary) inclusions in one and the same phenakite crystal—yet formed during three distinctly different periods—has enabled us to collect valuable information about the growth phases as well as about conditions and environment of the host mineral during its growth; also to acquire the definite corroboration of what the aikinite inclusions already told us—namely that the host phenakite was of hydrothermal origin.

ACKNOWLEDGMENT

I am indebted to Prof. Dr A. H. Stalder, of the Museum of Natural History in Berne, without whose technical help and reliable comment this study could not have been completed.

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[*Manuscript received 27th July, 1978.*]

OBSERVATIONS ON GEM MANGANOTANTALITE FROM MORRUA, MOZAMBIQUE

By S. HORNYTZKYJ, F.G.A., and K. T. KORHONEN, M.Sc.

Although a red transparent variety of manganotantalite (ideal formula $MnTa_2O_6$) is reported from a number of localities,[1] all the material that has been cut, mainly for collectors, has presumably come from Morrua mine, Zambesia, Mozambique. Some time ago we had an opportunity to examine three specimens from this source, two transparent prismatic crystals weighing 2.458 grams (12.29 carats) and 2.722 grams (13.61 carats) and a small brilliant-cut stone weighing 0.116 grams (0.58 carats).

At first one of the crystals was studied by means of x-ray diffraction. A cleavage fragment from the crystal of dimensions $1.5 \times 0.5 \times 0.4$ mm was subjected to x-ray analysis using nickel-filtered CuKα-radiation ($\lambda = 1.5418$ Å) and operating voltage of 35kV and 13mA. From the oscillation x-ray diffraction photographs we determined one of the three dimensions of the unit cell. The crystal system and other cell dimensions were determined from equi-inclination Weissenberg photographs. The crystal system was orthorhombic with cell dimensions, a 14.450 Å, b 5.772 Å, c 5.098 Å. These cell dimensions agree well with those previously mentioned in mineralogical literature concerning manganotantalite from Morrua.[1, 2] The formula of manganotantalite from Morrua is $Mn_{0.97}(Ta_{1.72}Nb_{0.29}Ti_{0.01})_{2.02}O_6$.[2] It is found there together with tantalite in a pegmatite.

The habit of the examined crystals was prismatic. One of the crystals had an obvious resemblance to the cross-shaped interpenetrate twin in which the crystals cross one another at nearly 60 degrees. The cleavage was perfect, the cleavage plane being parallel to the plane at which the *a* and *c* axes are located, {010} plane. The fracture seemed subconchoidal. The hardness is 5½-6 on the Mohs scale.[2] Hydrostatic weighing of the examined crystals in carbon tetrachloride using a Mettler H10-balance (accuracy±0.001 carat) gave us the specific gravity 7.73-7.97. The specific gravity according to literature is 7.52-7.92.[1, 2]

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Because the refractive index of the cut specimen was over the scale of the standard refractometer we employed the real depth/apparent depth method to get a rough idea of the refractive index. This was done with a Leitz SM-Pol petrological microscope. The average of several measurements was 2.16. The refractive indices according to Knorring *et al.*[1] are $\alpha = 2.14$, $\beta = 2.15$, $\gamma = 2.22$, the biaxial positive birefringence being 0.08. However, the refractive indices may be as high as 2.17-2.25.[2]

The colour of the examined specimens was scarlet red, the dispersion was strong and the lustre somewhat metallic. The colour was red under the Chelsea colour filter but dark green under the light coming through a saturated copper sulphate solution. The pleochroism observed with a Rayner dichroscope was weak, the main colours being deep red and pale pink. The absorption spectrum seen through a Rayner prism spectroscope showed a broad absorption band in the yellow green and in the violet. All the three examined stones were inert under long-wave and short-wave ultraviolet light and under x-rays. The microscope investigation of the cut specimen revealed a group of negative crystals with two-phase fillings parallel to the *c* axis. This orientation was determined by using the same petrological microscope as mentioned before.

We should like to offer our sincere thanks to Professor Th. G. Sahama for his valuable advice and to Mr Rurik Peura, Koru-Kivi Co. Ltd, Helsinki, for his kindness in allowing us to examine the specimens described.

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[*Manuscript received 13th February, 1978.*]

NOTES FROM THE LABORATORY: ENJOYING GEMMOLOGY

By A. E. FARN, F.G.A.

The Gem Testing Laboratory, London Chamber of Commerce and Industry

I was listening recently to a discussion of the standards (low) of examinees in gemmology and to discussions of the merits and demerits of teaching parrot-fashion and non-essay-type answers to questions and the (apparent) unimportance of correct spelling. I found this somewhat depressing, but was fairly promptly wafted into the upper echelons of gemmology by some excellent articles in our *Journal of Gemmology,* including an impressive discussion of a new type of gem-testing equipment. However, much modern technology does tend to lack the charm of some rule-of-thumb methods.

Equally recently (and much seems to happen in landslide conditions) we have had some very enjoyable practical gemmology, needing experience and basic skills—some learning and a memory for structures, etc. I always find the positive identification of a gemmological item by means of heft and lens plus basic gemmological knowledge very satisfying and rewarding. As an instance (no affront meant to the much respected customer) we had a large, clear, colourless sphere, 4 inches in diameter, to test. As I took it in my hand, it clouded over (the sphere). I wiped it and saw the edge of my thumb doubled in outline. On that evidence I would have written a certificate to state 'a colourless quartz sphere', my reasoning being that it was a colourless doubly refracting material of suitable heft and size and *stone cold.* (In the Laboratory, of course, I would take a distant vision reading plus a density.) A possibility that it could be topaz was discounted by reason of topaz's ready cleavage. We have a topaz crystal about 25 lb in weight which has developed a cleavage crack just lying flat in a display cabinet!

That, of course, was comparatively obvious and easy gemmology, but isn't it nice to steer clear of those dreadful formulae and equations? This week we were requested to determine a series of densities by the hydrostatic method, using balance, ethylene dibromide and temperature correction. This is basic stuff but very

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enjoyable work—three of us agreed figures (without comparison of workings—strictly individual efforts) to three places of decimals. This pleased us all—me particularly, because SG work is so fundamental. Having the equipment helps a lot, it is true. Because of the number of workings involved we used a small calculator, but I feel pleased to think I can still rapidly work out problems by old-fashioned methods. Computers, of course, are only as accurate as the information fed into them. It pleased me to do one or two samples by old fashioned methods to find if the little electronic gadget was accurate (it was).

In the last few days the telephone has rung and callers have called, all with a sudden surge of interest in a problem far from new but in a fresh guise. It seems that surges of interest come and go, fashion providing the *diktat.* And now pearls are back with a flourish—although flourish is hardly the word for that perfection of sheen arising from those microscopically thin overlapping platelets of nacre which form the 'orient' of pearl.

We had a stone dealer in with a fine cameo, difficult to decide by eye. Was it superb shell finely polished or banded agate? No marks were awarded for this particular determination: since we employ only non-destructive methods, I defy anyone to find the imprint of a dot of acid or the abrasion of a hardness point. These tests, using a microscope, are quite precise, practical gemmology.

The subject of shells, pearls and pearly products, nacreous and non-nacreous, reminds me of a most useful book I am pleased to have purchased. In it I found adequate answers to back up findings recently on two slightly unusual 'pearls'.

One was what looked like a white clam pearl with a red band of colour, looking as if a pink conch pearl had been drained of colour except for one band of pink on a white background. This was found to be a bead turned from conch *shell.* Until you have seen one, you just don't know.

The second item—much more intriguing—was what at first sight looked like a bluish grey 'mabe' pearl in an old-style pendant. The 'pearl' was in a close-backed setting, probably late Victorian/Edwardian. By using the ubiquitous 10× lens an interesting curved banded exterior structure fanning outwards could be seen faintly. It was a difficult proposition to x-ray since it had to be done sideways. This meant the pearl was very proud of the film, leaving only a small chance of determination, since over-

exposure to allow for depth would mean a very darkened negative. We were pleased to find that, using only a small permissible portion of the edge of a film slipped under and supported, we were able to obtain sufficient evidence in structure to identify what is termed a pearly nautilus, *Nautilus pompilius.* This is briefly but adequately described in *Gems and Jewellery,* by Ove Dragsted, F.G.A., Crown Jeweller to the Danish Court. This is the book I have found so fascinating and rewarding: it describes some very unusual gem materials, especially among the ornamentals—from dried beetle wing-cases to bronze-pearl-like squids' eyes!

To return, however, to the pearly nautilus, it was memory which helped hold the door. Many years ago I purchased from a street market stall a very pretty nacreous shell of distinctive shape which my old friend and colleague Robert Webster instantly recognized as a nautilus shell. It was seldom that he was ever stumped by being presented with an 'unusual' to identify. He took an x-ray photograph of it and made a print which hangs close to our x-ray set, showing the structure very sharply (see Figure 1). It vividly prompted my memory on seeing this particular item which

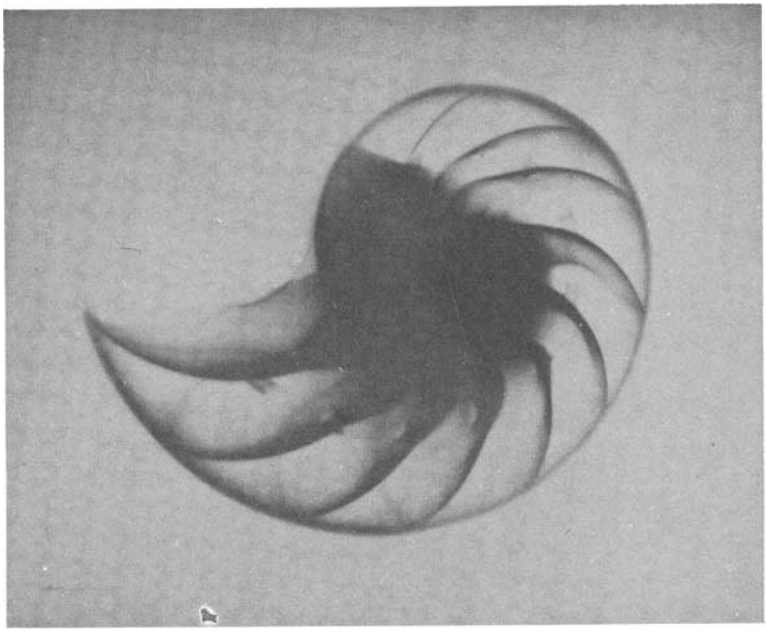

FIG. 1. X-ray photograph of Pearly Nautilus *(Nautilus pompilius)*—from negative by R. Webster.

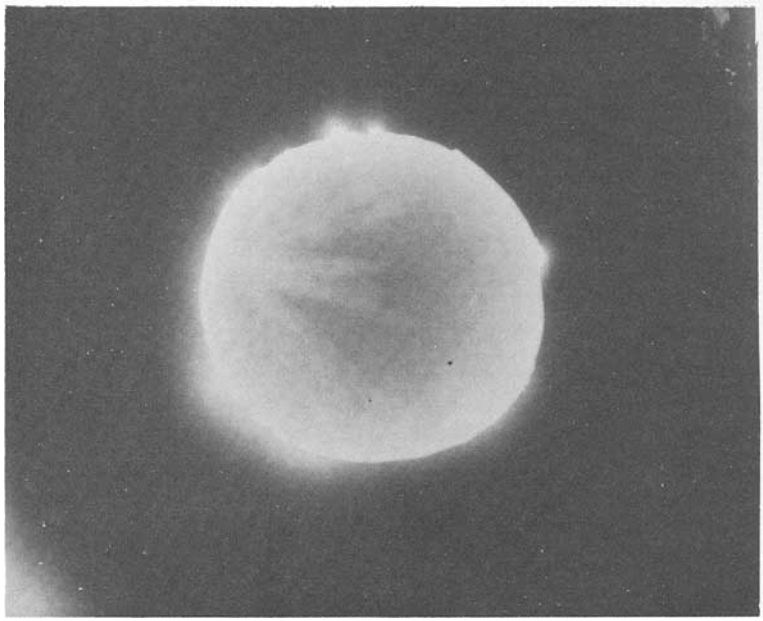

FIG. 2. Eight drill-holes in a cultured pearl taken from a ring.

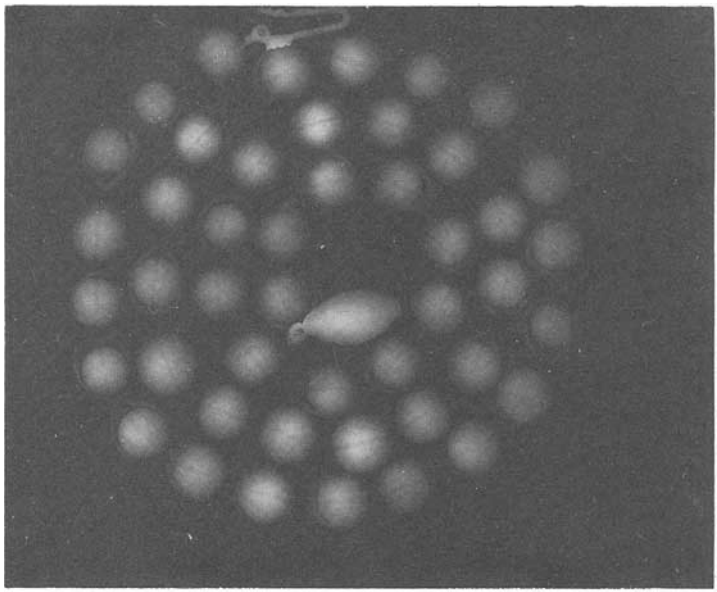

FIG. 3. A necklace of extremely baroque cultured pearls, showing large drill holes and huge gaps between m.o.p. bead and nacreous outer layers.

we were currently examining. Certainly it was the first time for all of our staff and the second time for me. The memory made me search for Ove Dragsted's book, in which it is depicted. He gives the Indian Ocean, off Indonesia and the Philippines as being the provenance. Further reading of *Molluscs and Brachiopods* by Cooke, Shipley and Reed, added to my knowledge. Under the heading 'Order Tetrabranchiata' they state 'Cephalopoda (the highest class of mollusc exclusively marine) with four branchia and four kidneys; animal inhabiting the last chamber of an external multilocular shell: found consisting of two separate lobes; tentacles numerous, without suckers or hooks; no ink sac'. Not exactly a selling *spiel* for a keen salesman!

The outer shell of the nautilus is porcellanous. This is stripped to reveal the beautiful nacreous layer of the large inner chamber and *septa,* the *septa* being a series of chambers or divisions all having a nacreous layer. These *septa* are often removed and engraved as jewellery. An adequate reproduction of *our* x-ray photograph cannot be produced, but it is worth looking up Ove Dragsted's book just to refresh one's knowledge of some very enjoyable gemmology. As Thomas Gray might have had it, 'far from the madding crowd [of erudite gemmologists] they keep the noiseless tenour of their way'.

The concentric and radial structure of a natural pearl necklace is evidenced by the fine precision of the drill holes which meet dead centre with geometric precision. The banded structure of the spherical bead of mother of pearl which is the huge nucleus of most cultured pearls has a diverting effect on the direction of the pearl drill—usually the drill tries to take the line of least resistance, as is seen in the various attempts at drilling in or at the drill holes of many cultured pearls (see Figures 2 and 3). Reading an x-ray negative of a cultured-pearl necklace which shows no apparent bead or skin outer layer can be assisted in determination by the 'dog leg' nature of the string canals which is repeatedly seen—this being just plain basic gemmological knowledge of the structure of natural and cultured pearls. Basic gemmology and a 10× lens will still be detecting when the batteries run out in the calculators.

[*Manuscript received 21st March, 1978.*]

DIAMOND NOTES

By P. G. READ, F.G.A.

There have been several occasions in the past when controversy has arisen over the question of whether the colour of a particular diamond was natural or whether it was the result of electron or neutron irradiation of the stone followed by heat treatment.

One of the diagnostic indications of this type of artificial coloration has been the presence of a line at 595nm[1] in the diamond's absorption spectrum. While this indication still remains valid, work carried out by Dr A. T. Collins, of King's College, London, has shown that the absence of this line does not necessarily mean that the diamond's colour is natural.

In a paper read at the De Beers annual Diamond Conference in July 1978 (and in a previous letter published in *Nature*[2]), Dr Collins has revealed that if the annealing temperature of electron-irradiated Type I diamond is raised above the normal range of 800-900°C, the 595nm absorption line begins to weaken, finally disappearing completely and permanently at 1000°C.

The presence of the original 415.5 line system (if the stone was originally of the Cape series) together with lines associated with the new colour at 504nm and 498nm, would in combination still, however, provide evidence of artificial coloration. Although these lines are faint, A. E. Farn has indicated that they can be enhanced by cooling the diamond with the aid of liquid nitrogen, and he is currently using these techniques in the Gem Testing Laboratory of the London Chamber of Commerce and Industry.

The improvement of a diamond's colour by means of nuclear irradiation generally depends on the modification of the initial radiation-induced colour by subsequent heat treatment. In effect, the heat treatment increases the mobility of the radiation defects in the diamond, enabling them to regroup within the lattice.

A similar mobility effect is a feature of another possible colour enhancement technique reported by R. M. Chrenko, R. E. Tuft

(1) This is given as 594nm by E. Bruton in his book *Diamonds*, and as 592nm in R. T. Liddicoat's book *Handbook of Gem Identification*.

(2) 'Investigating artificially coloured diamonds', *Nature*, Vol. 273, No. 5664, 1st June, 1978.

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and H. M. Strong, of General Electric, in an article in *Nature*[3]. Their work showed that the high temperature/high pressure annealing of diamond can be used to increase the mobility of the dispersed nitrogen in a yellow Type Ib diamond, allowing it to aggregate into the nitrogen platelets which are the main feature of Type Ia diamonds.

Unlike dispersed nitrogen, which is responsible for the yellow tints of Cape series diamonds, nitrogen platelets only absorb light at the UV end of the spectrum. Significantly, the General Electric team reported that after heat treatment[4], which was for periods ranging from hours to days, the deep yellow colour of a Type Ib crystal had faded considerably. They also suggested that large yellow Type Ib synthetic diamonds, which are grown slowly to obtain gem quality stones, could be turned into colourless crystals by proper annealing at high pressure.

While it may not be possible in future to identify diamonds whose colour has been 'improved' in this way, the technique does imitate the natural geological process of nitrogen migration in diamond, and as it appears to be equally permanent, perhaps the question of identification is, after all, irrelevant.

[*Manuscript received 5th September, 1978.*]

(3) 'Transformation of the state of nitrogen in diamond', *Nature*, Vol. 270, No. 5633, 10th November, 1977.

(4) 2000°C (2273K) at 55-65 kilobar.

MAGNETIC RESONANCE— A NON-DESTRUCTIVE PROBE OF GEMSTONES

By D. R. HUTTON, B.A., M.Sc., Ph.D.
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INTRODUCTION

The basic instruments of the gemmologist have changed little over the last 50 years. However, modern technology has recently made available a number of new instruments, e.g. the electron microprobe (Dunn 1977), the x-ray and electron microscopes, the Mössbauer spectrometer and magnetic resonance spectrometers, which although primarily designed for research purposes to determine 'the reasons why', are becoming increasingly available to the practising gemmologist for diagnostic and identification purposes.

This article aims to outline the principles and techniques associated with the phenomena of magnetic resonance and to show how the information of this newer spectroscopy can help solve the problems of today's practising gemmologist.

MAGNETISM IN GEMS

Many gems show magnetic effects, in that they may affect a compass needle or be attracted by a magnet, and Anderson (1971) has shown how these effects may be used to differentiate between more or less magnetic stones of similar appearance. His method, shown in Figure 1, relies upon measuring with a sensitive balance the magnetic force on a gem sitting in a non-uniform magnetic field.

Five kinds of magnetism are well known, each kind depending on the interactions between the atoms or ions of the solid with the magnetic field and with each other.

Diamagnetism (or negative magnetism) is due to the tendency of electrical charges (e.g. atomic electrons) partially to shield the interior of a body (e.g. the atom) from an applied magnetic field. With Anderson's balance it would show up as a weak repulsion or downwards force. Diamagnetism occurs in all materials including gems.

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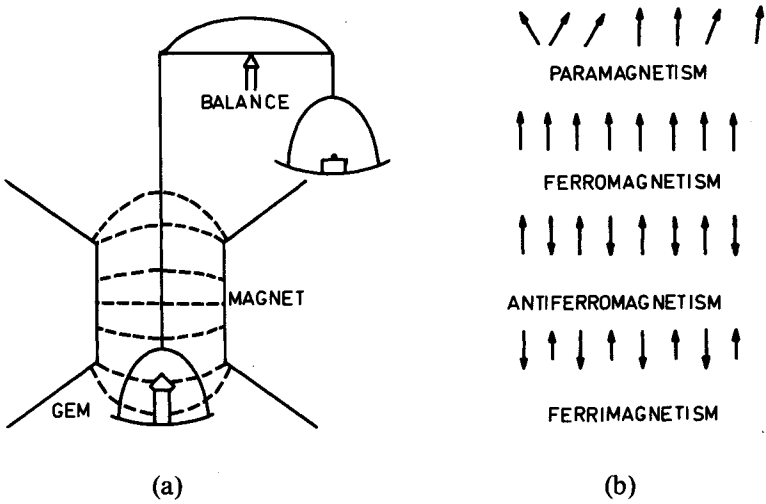

FIG.1. (a) Gouy balance for measuring magnetic susceptibility.
(b) Spin ordering in various magnetic materials.

Paramagnetism (or positive magnetism) shows up as an attraction into the magnetic field and hence a loss of weight due to an upwards force. It only occurs in atoms, ions of molecules with unpaired or odd numbers of electrons (or in nuclei with odd numbers of neutrons and protons) and is of particular importance for atoms and ions with partly filled inner electron shells, i.e. the transition elements. All these atoms or ions have a resultant spin angular momentum and so, being charged, they act like little magnets and therefore in turn interact with a magnetic field. Thus this magnetism is induced by the applied magnetic field, is proportional to it, and disappears when the field is turned off. It also increases at low temperatures. Many gems are paramagnetic due to the inclusion of transition metal or rare-earth ions in their structures, e.g. ruby which has Cr^{3+} ions in Al_2O_3.

Then there are two kinds of magnetism which depend on an internal interaction between neighbouring paramagnetic atoms or ions in the material. *Ferromagnetism,* e.g. as found in some garnets, arises when the internal interaction tends to line up the spins of, for example, the iron ions in the same direction, as shown in Figure 1b, giving a very strong positive effect, which may even be spontaneously present in zero applied field and hence capable of affecting a sensitive compass needle. *Antiferromagnetism* and

ferrimagnetism arise, e.g. in spinels, when the internal interaction between neighbouring spins tends to align them in opposite directions (Figure 1b). The magnitude and direction of the resultant magnetism depends on the relative magnitude of the oppositely directed coupled ionic spins; if they are equal we have antiferromagnetism and if different ferrimagnetism, which like ferromagnetism also is a strong positive magnetism.

All of these different kinds of magnetism exist in various gems and have resonance phenomena associated with them. The most useful experiments are associated with paramagnetism of the electrons (Electron Paramagnetic Resonance—EPR; or Electron Spin Resonance—ESR) or of the nucleus (Nuclear Magnetic Resonance—NMR).

PARAMAGNETIC RESONANCE

A gem material containing paramagnetic ions (or nuclei) and magnetized by placing it in a magnetic field, is found to strongly absorb certain wavelengths (or frequencies) of electromagnetic radiation. For normal laboratory-sized magnetic fields of about one tesla* these resonant absorptions are found to occur at microwave frequencies for ESR and at short-wave radio frequencies for NMR. Figure 2 illustrates the basic arrangement needed to observe such magnetic resonant absorption. In it the gem sample sits in a strong magnetic field usually generated by an electromagnet and is at the same time subjected to a strong alternating radio frequency (RF) field at right angles to the strong steady field.

The resonance phenomenon may be viewed in two ways, each of which helps us understand different aspects of it. First of all, classically, it is found that the magnetism of the tiny para-magnets

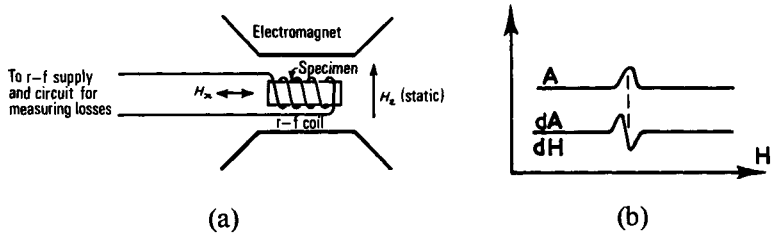

FIG. 2. (a) Schematic arrangement for spin resonance absorption experiments.
(b) The observed spectrum is a plot of absorption (or more often rate of change of absorption) versus frequency or magnetic field.

*The S.I. unit for magnetic flux density is the 'tesla' (symbol 'T'), which is defined as kg s^{-2} A^{-1}.—Ed.

in the gem precesses or rotates at an angle to the magnetic field at a frequency f which is proportional to the steady magnetic field H, i.e. $2\pi f = \gamma H$, where γ is a constant called the gyromagnetic ratio. If now the rotating RF field is tuned into the same frequency as the precession (this is called resonance) then the magnetism will change direction and energy will be absorbed by the sample from the RF field. The magnetic resonance spectrometer measures this absorption and at the same time measures f and H, which allows γ, a characteristic of the spins, to be calculated.

The second, or quantum, way of viewing magnetic resonance may be even more readily understood by the gemmologist since it is akin to the familiar view of optical absorption spectroscopy (Troup 1969). As in the optical case, the energies of the magnetic spin states of the material are calculated, and then resonant absorption occurs when the energy gaps ΔE between the levels equal the quantum energy hf of the incoming radiation, i.e. $\Delta E = hf$ at resonance. And since the magnetization and hence the magnetic energy gaps are usually proportional to applied magnetic field then the result is the same as above

$$f = \frac{\Delta E}{h} = \frac{\gamma}{2\pi} H$$

Nuclear Magnetic Resonance, NMR

Nuclear paramagnetism is due to the presence in the gem of nuclei which have odd numbers of nucleons (neutrons and protons). Since each nucleon has a half unit of spin then the total nuclear spin depends on how many unpaired nucleons there are. Table 1 lists some nuclei and their resultant spins.

TABLE 1 Magnetic nuclei often found in gem minerals.

Nucleus	*Spin I*	*Resonant frequency in 1 tesla Field*	*Gems*
H^1	$\frac{1}{2}$	42.6 MHz	Zoisite, Topaz, Beryl
Be^9	$\frac{3}{2}$	6.0 MHz	Beryl, Chrysoberyl
B^{11}	$\frac{3}{2}$	13.7 MHz	Tourmaline
F^{19}	$\frac{1}{2}$	40.1 MHz	Topaz
Al^{27}	$\frac{5}{2}$	11.1 MHz	Corundum, Spinel, etc.

To determine the spectrum of a given gem we need to know the magnetic energy levels of the nuclei and these are calculated using the equation

$$E = -M_I \frac{h\gamma}{2\pi} H$$

where M_I is given in turn all the values between $+I$ and $-I$ differing by unity. Let us illustrate by considering the energies of H or F nuclei. Here $I = \frac{1}{2}$, and so M_I can be $+\frac{1}{2}$ or $-\frac{1}{2}$ and the possible energies are therefore $+\frac{1}{2}\frac{h\gamma}{2\pi}H$ and $-\frac{1}{2}\frac{h\gamma}{2\pi}H$. These values are graphed in Figure 3a. Now resonant absorption occurs between these two levels when

$$hf = E_2 - E_1 = +\frac{1}{2}\frac{h\gamma}{2\pi}H - (-\frac{1}{2}\frac{h\gamma}{2\pi}H)$$

i.e. if $$f = \frac{\gamma}{2\pi}H \quad \text{as before.}$$

The NMR experiment is done with equipment somewhat more complex (Varian staff 1960) than, but similar in principle to, Figure 2. Usually the field is held constant and the frequency scanned until resonant absorption is found, but alternatively the frequency may be held constant and the field scanned. In either case the frequency and field need to be measured accurately.

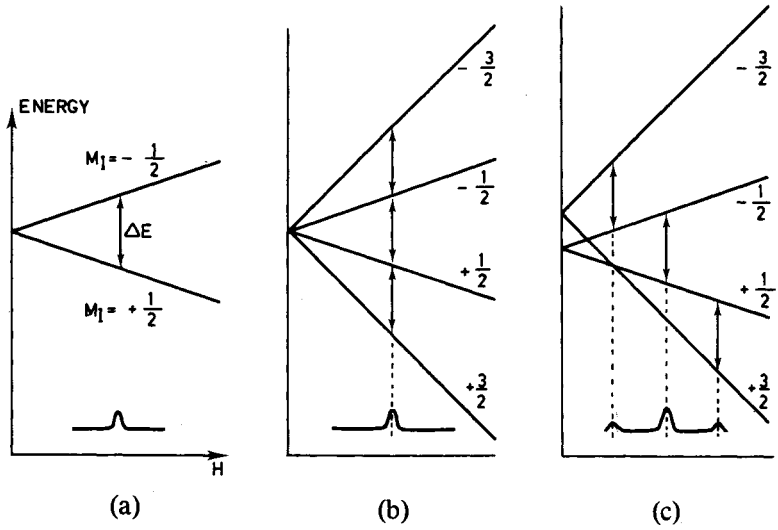

FIG. 3. Magnetic energy levels and resulting spectra for
(a) I = 1/2
(b) I = 3/2
(c) I = 3/2 with quadrupole interaction.

For H and F nuclei a single line will be observed in the scan for each crystallographic site and rather subtle interpretation is needed to deduce information about the surrounding gem material.

For nuclei with more unpaired spins I will be larger and the situation more complex but as a consequence of greater value to mineralogy. For example consider the beryllium nucleus. This has $I = \frac{3}{2}$. Therefore $2I + 1 = 4$ energy levels are now possible, i.e. $\frac{h\gamma}{2\pi}$ H multiplied by $+\frac{3}{2}$, $+\frac{1}{2}$, $-\frac{1}{2}$, $-\frac{3}{2}$, as shown in Figure 3b. If the magnetic interaction was the only one present we would once again get only a single resonance line 6 MHz in 1 tesla field as shown in Figure 3b, but fortunately there is another and more important interaction also present as illustrated in Figure 3c. This is the interaction between the nuclear quadrupole moment or the 'out of roundness' of the nucleus and the electric field gradient generated by the gem's internal structure. This results in a splitting between the $\pm\frac{3}{2}$ levels and the $\pm\frac{1}{2}$ levels in zero magnetic field, and the consequent formation of a $2I = 3$ line spectrum, instead of 1 line. The outer lines (Figure 3c) are called quadrupolar satellites and a gem NMR study would normally be most concerned with seeing how the quadrupolar splittings vary with the angle between the magnetic field and the crystal axes. For example Figure 4 illustrates the results obtained by Brown and Williams (1956) for beryllium and aluminium in beryl. For aluminium $I = \frac{5}{2}$ so we have $2I + 1 = 6$ energy levels $2I = 5$ lines in the spectrum including two pairs of quadrupolar satellites. Detailed study of such satellites gives much information about the gem mineral such as the location of the magnetic nuclei in, and the symmetry of, the crystal structure.

Electron Paramagnetic or Spin Resonance, EPR, ESR

Many atoms and ions have unpaired electrons in their outer electron shells and because the electron mass is so much smaller than that of nucleons the associated electron spin precesses at a much higher frequency in the same magnetic field. Thus the associated gyromagnetic ratio is much greater and electron resonance absorption occurs at microwave frequencies 10 000 MHz. So that although the spectrometer principle is the same as that shown in Figure 2, the mechanical appearance is different because instead of wires and cables, waveguides are used to convey the RF field to and from the gem sample which is now placed in a

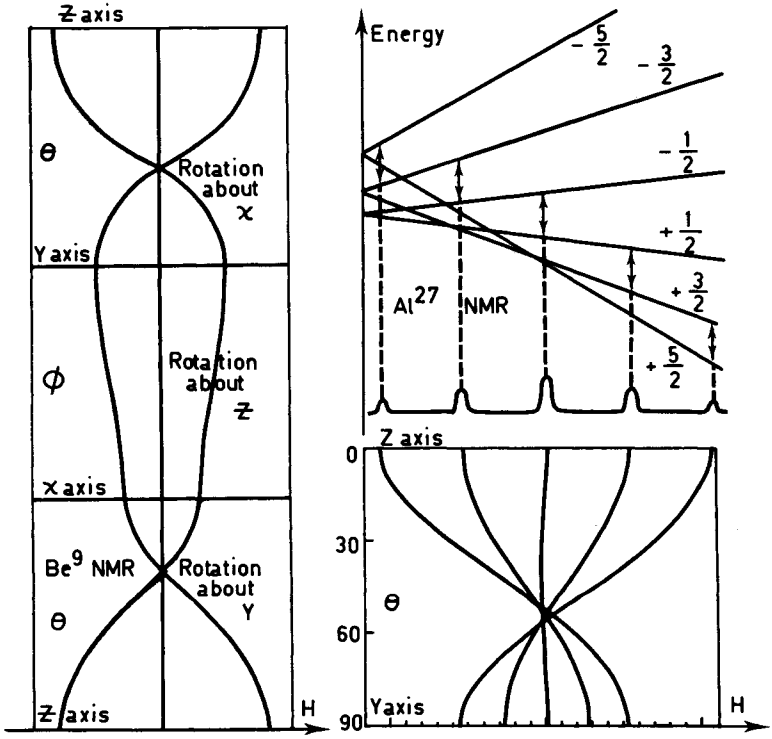

(a) (b)

FIG. 4. NMR energy levels and spectral variations with angle for
(a) Be^9 in beryl.
(b) Al^{27} in beryl.

resonant microwave cavity instead of a coil. Figure 5 (after Varian 1960) is a block diagram of an ESR spectrometer capable of giving out recorded spectra, Figure 6 shows a typical machine's layout and Figure 7 shows how a small sample (approx size 0.1 cc or 1 carat) is mounted for the experiment which will in no way destroy or otherwise affect it. Since it is difficult to tune microwave systems it is normal experimental practice to use a fixed frequency or wavelength and to vary the magnetic field to find the resonance lines, cooling the sample to 77K or 4K to improve the sensitivity if necessary.

Such high frequency ESR is very sensitive, about 10^{14} magnetic centres with spin $= \frac{1}{2}$ being detectable at room temperatures; thus ESR is distinguished by many valuable features (Low 1968):—

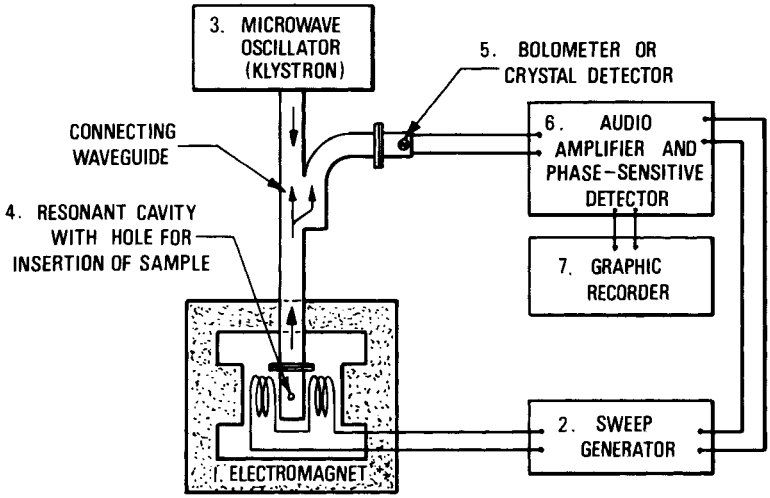

FIG. 5. Block diagram of EPR spectrometer. At resonance the power absorbed by the sample increases and so that detected by the crystal detector decreases. The output is displayed on a CRO or can be recorded graphically.

a. It detects minor impurities in diamagnetic minerals; in many cases, picogram* impurities can be detected.
b. It determines the point symmetry of the paramagnetic ion, in particular whether this ion is in a substitutional or interstitial position.
c. It discriminates easily between different paramagnetic ions.
d. It determines the valence state of the ion.
e. It measures the abundance of the paramagnetic impurities as well as the relative abundance of different paramagnetic impurities or different valence states of a given impurity, in a given mineral.
f. In many cases, one can establish the degree of order and disorder in the mineral, the effects of strains in the crystal.

Now since paramagnetic ions and defects (particularly ions of the transition metal series) are responsible for most colouring of allochromatic gems it can be seen that ESR should greatly help the gemmologist's 'why coloured?' questions of the various gem varieties.

*pg = 10^{-12}g.—Ed.

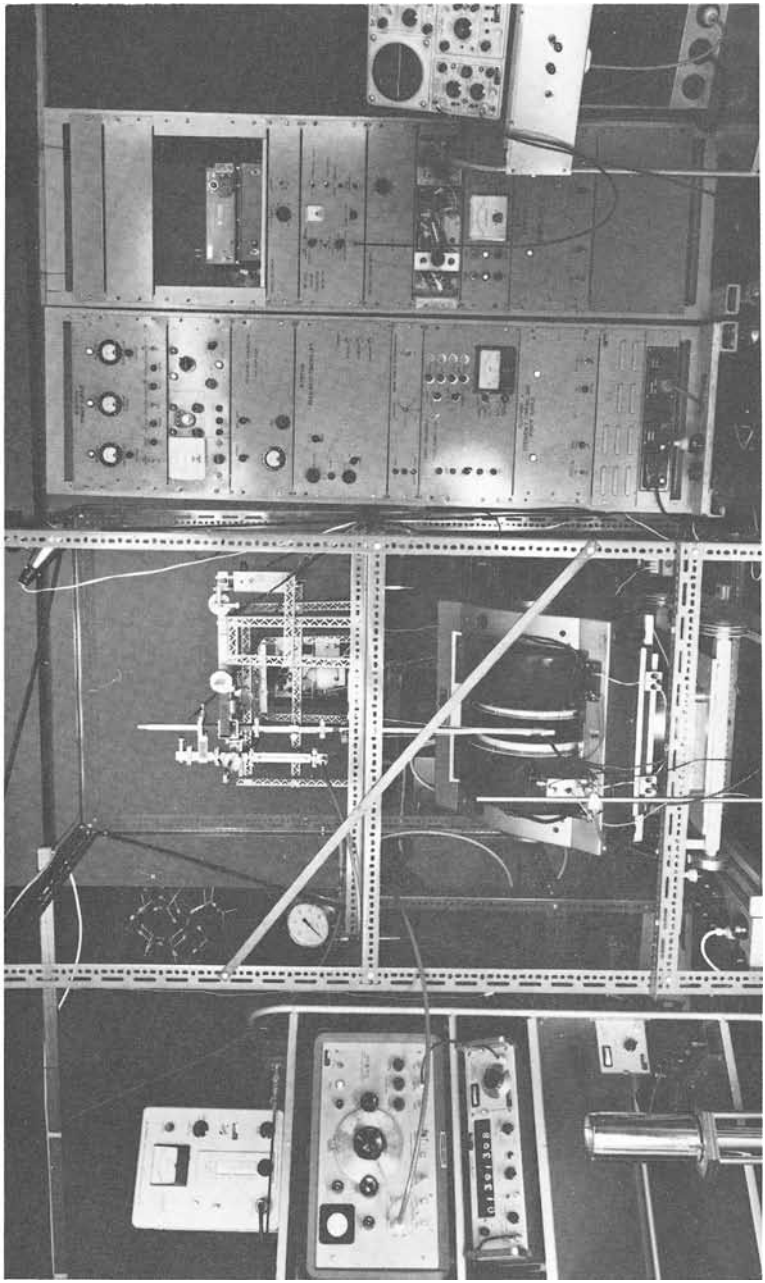

FIG. 6. Photograph of Monash University X band (10 000 MHz) ESR spectrometer. The microwave cavity can be seen between the magnet pole tips and the microwave generator and bridge above the magnet. Frequency measuring equipment is to the left and on the right are the detecting, recording and display systems. A dewar flask at lower left allows the sample to be cooled if necessary.

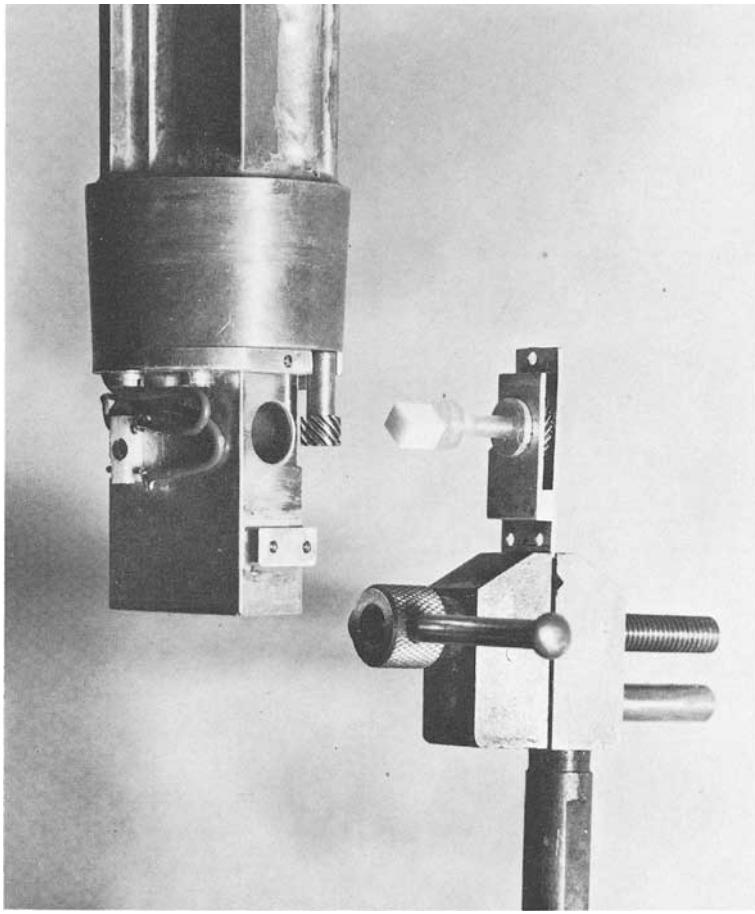

FIG. 7. A block of feldspar mounted on a perspex holder ready for insertion into the microwave cavity of the ESR spectrometer.

The interpretation of ESR spectra can be a complex process, but some of the features are easily understood. First of all, as with NMR, an ion of spin S gives $2S+1$ energy levels and so 2S spin or fine structure resonance lines. For example if $S = \frac{1}{2}$ then there are 2 levels and 1 resonance line in the spectrum. Secondly, the variation of line positions (so called g value) with angle between magnetic field and the gem crystal axes gives the symmetry properties of the defect site. Thirdly, many lines split into multiple components called hyperfine structure, due to an interaction between the

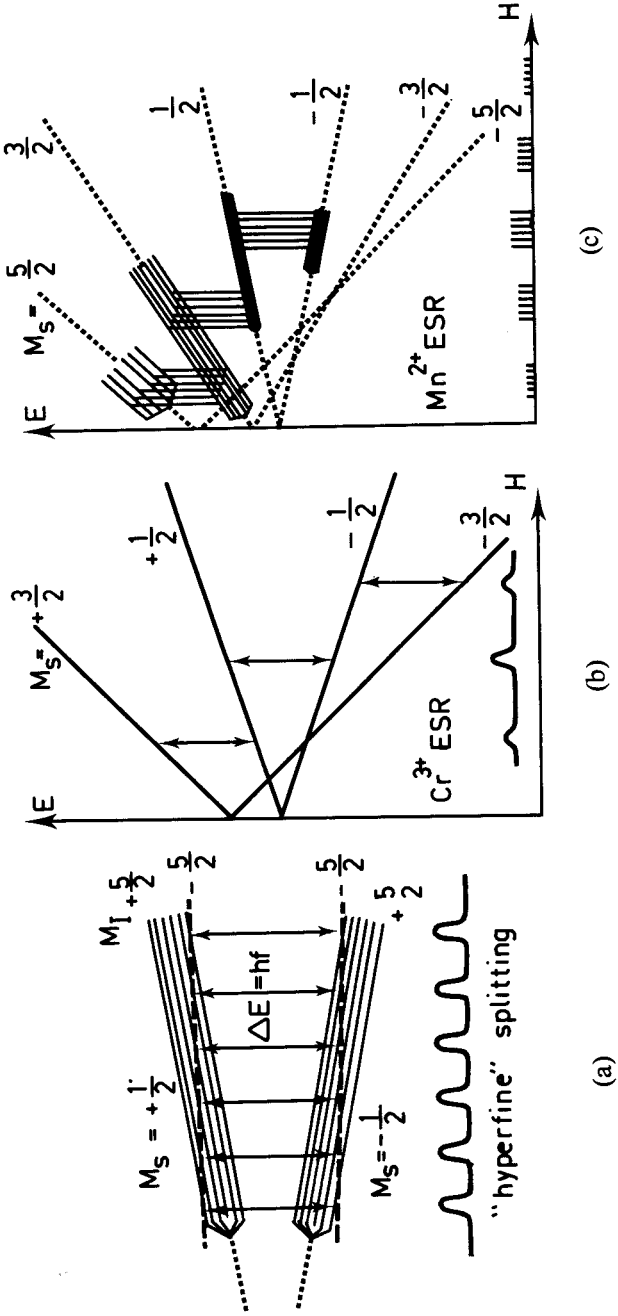

FIG. 8. ESR Energy levels and spectra for
(a) S = 1/2, I = 5/2
(b) S = 3/2
(c) S = 5/2, I = 5/2

spinning electron magnet and a nearby magnetic nucleus. If this nucleus has spin I then there will be $2I + 1$ hyperfine components in each fine structure line.

Figure 8a illustrates the energy levels and spectrum for smoky quartz. ESR shows (O'Brien 1955) that the smoky colour is caused by the absence of an electron from an oxygen ($S = \frac{1}{2}$) which is next to a defect aluminium ($I = \frac{5}{2}$) substituted for silicon in the structure. Similarly nitrogen donor impurities in diamond (Smith *et al.* 1959) give beautiful 3 line spectra since $I = 1$, $2I + 1 = 3$, and substitutional yttrium ($I = \frac{1}{2}$) in irradiated brown zircon (Barker and Hutton 1973) gives doublet lines.

Figure 8b illustrates the energy levels and spectra for the Cr^{3+} ion in a gem. This ion has 3 unpaired electrons ($S = \frac{3}{2}$) and so $2S = 3$ fine structure lines. Notice that the splitting between these lines depends on the difference in energy between the $\pm\frac{1}{2}$ and $\pm\frac{3}{2}$ levels in zero magnetic field, which splitting in turn depends on the strength of the crystal field at the Cr^{3+} site (compare with Figure 3c where the nuclear quadrupole splitting in NMR depends on the electric field gradient). Thus the ESR spectra (Geusic *et al.* 1959) clearly show that the splitting for Cr^{3+} in green beryl (emerald) is very much greater than that in red corundum (ruby).

Similar arguments show that Mn^{2+} and Fe^{3+}, both with 5 unpaired electrons ($S = \frac{5}{2}$), will have a 5 line fine structure spectrum, but still these appear quite different in ESR since the manganese nucleus has $I = \frac{5}{2}$ and this will split each fine structure line into $2I = 6$ hyperfine components as illustrated in Figure 8c.

It should be apparent that many of the valuable features of ESR as listed above arise because of the ease of identifying specific paramagnetic impurities in gems from their characteristic spectra or 'fingerprints'. Also the width of the resonance lines gives information on the order or disorder in the mineral and may give clues as to the conditions during crystal growth. Thus ESR information may be able to differentiate between gems of the same variety but from different localities or sources, due to differences in abundances of paramagnetic impurities or formation conditions. For example the ESR spectra of emeralds (Hutton and Barrington 1977) clearly differentiate the better ordered synthetic emeralds from the natural, and also differentiate between Gilson and Chatham synthetics by the presence of an iron ESR spectrum in the Gilson stones. Yellow and golden corundums have been similarly

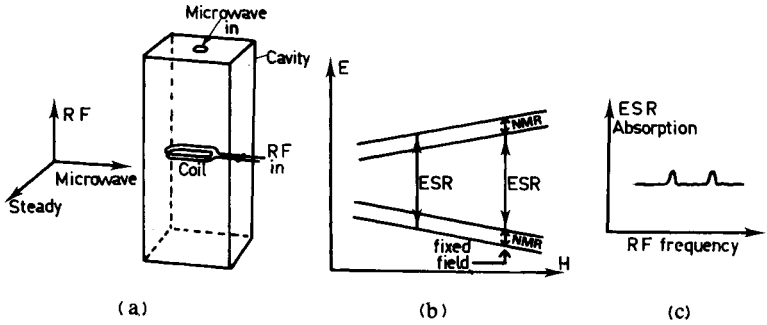

FIG. 9. Electron nuclear double resonance ENDOR
(a) arrangement of fields,
(b) transitions for S = 1/2, I = 1/2 in a fixed field H,
(c) spectrum for S = 1/2, I = 1/2.

differentiated by Scala and Hutton (1975).

The detection and analysis of some spectra may be very difficult, and more advanced techniques may be necessary. Very low temperature measurements are usually necessary for ions with even numbers of electrons since these interact strongly with the diamagnetic gem lattice, and if crystal field effects are large a second higher-frequency spectrometer (e.g. 35 000 MHz) may be needed to resolve the spectra.

Electron Nuclear Double Resonance (ENDOR)

For many ESR spectra the hyperfine effects are very small and unresolved and so little can be deduced from them. ENDOR allows direct, accurate measurements of nuclear moments and hyperfine couplings and hence the identification of nearby nuclei and in many cases the detailed mapping of atomic and defect positions.

An ENDOR spectrometer is really only an ESR spectrometer with an added NMR RF source and RF coil around the sample, Figure 9. In operation the magnetic field is set on an ESR line and the RF frequency is scanned while monitoring the strength of the ESR line. NMR transitions are then seen, with high sensitivity, as changes of ESR absorption.

This technique has been very fruitful in, for example, confirming the nature of the nitrogen defect in type 1b diamonds (Cook and Whiffen 1966), the aluminium defect in smoky quartz (Barker 1975), and in elucidating the nature of the centres in red-brown zircon (Barker and Hutton 1973), and in topaz where the electron spin of the Fe^{3+} ions interacts with many surrounding fluorine nuclei (Barry and Holuj 1973).

These spectrometers are examples of an increasing suite of instruments which are helping to elucidate some of the mysteries of gemmology. We hope this article may help gemmologists to understand magnetic resonance, since they are likely to see increasing numbers of articles which refer to it and soon may even, themselves, be using the techniques in more difficult diagnostic work.

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NEW GEMMOLOGICAL INSTRUMENTS AND TECHNIQUES

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(being the substance of a talk given to the Gemmological Association of Great Britain at the Central Electricity Board Cinema, Newgate Street, London, E.C.2, on the 4th April, 1978)

When the Gemmological Association was founded in 1908 as the Education Committee of the National Association of Goldsmiths, commercial instruments suitable for gem testing were few and far between. The compound microscope had already become a sufficiently versatile tool to require no modification for gemmological use, but probably the first commercial instruments specifically designed for gem testing were the Bertrand and Herbert Smith critical angle refractometers. These were followed by the Tully version in 1925, and, eleven years later, by the first Rayner refractometer.

The initial slow development of gemmological instruments was no doubt due to the very limited demand that existed in those days, the rare new instruments being developed out of necessity rather than for economic reward. Today the growing consumer demand for jewellery has not only increased the number of retail outlets, but has resulted in an increased market for gem testing instruments. This is reflected in the wide range of instruments available; taking the critical angle refractometer as an example, the choice now includes the Rayner Dialdex, the G.I.A. Duplex II, the Japanese Okamo and Topcon models, and various German models marketed by Krüss, Hans-Günter Schneider, and Eickhorst.

In recent years a new class of instrument, the reflectivity meter, has been introduced. This instrument combines optics and electronics to give a quantitive measurement of a gemstone's surface reflectivity or lustre. The usefulness of the reflectivity type instrument in the identification of gemstones depends on the relationship between the reflectivity of a polished gemstone and its refractive index. This relationship is expressed in Fresnel's simplified equation, which shows the reflectivity as being equal to the ratio of the intensity of the reflected ray to that of the incident ray.

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$$R = \frac{Ir}{Ii}$$

This in turn is equal to $$\frac{(n-a)^2}{(n+a)^2}$$

where 'n' is the refractive index of the gemstone and 'a' is the refractive index of the surrounding medium (that is, for air, 1.0). Although the Fresnel relationship between reflectivity and RI was formulated for isotropic substances and for normal incidence of the rays, it works well enough in practice for anisotropic stones and for reflection at angles other than 90 degrees to the surface. However, as it is reflectivity and not refractive index which is being measured on this type of instrument, the surface condition of the stone being measured is all important. This is because the instrument can only measure the stone's *effective* reflectivity or lustre. If dirt or scratches on the gem's surface cause this lustre to be less than the *potential* lustre of the stone, the relationship between reflectivity and RI will break down and a low reading will result.

Because of their high efficiency and convenient size, solid state infrared emitting diodes are used as the source of incident rays in electronic reflectivity meters, and the reflected ray is detected by a photo-diode or photo-transistor. The peak output in the emission of the infrared diodes is in the region of 930nm. This is another reason for not using the readings of the reflectivity meter as a direct indication of a stone's RI, as this is defined in terms of yellow monochromatic light at 589.3nm.

Another difficulty in relating the reflectivity of a gem to its refractive index when using this type of instrument occurs when the gem has an appreciable amount of dispersion, as indicated by the difference in the index of refraction measured at the B and G Fraunhofer wavelengths of 686.7nm and 430.8nm. The refractive index of a gemstone is conventionally given in terms of sodium light at 589.3nm. If a gemstone has very little dispersion, its index of refraction will not be very much different if measured at other wavelengths. However, for gems having appreciable dispersion, the use of wavelengths above or below 589.3nm will modify the measured refractive index considerably. At the infrared wavelength of 930nm, as used in reflectivity meters, the 'RI' readings of strontium titanate (RI = 2.41) and diamond (RI = 2.42), will be found to be well separated, with strontium titanate reading much

lower than diamond because of its greater dispersion. In this case, the separation of two almost identical refractive indices works to advantage when distinguishing strontium titanate from diamond.

There are at least four makes of reflectivity meter on the market, and although they all use infrared light and the same basic measuring techniques, there are several interesting differences between them.

The first instrument to be introduced was the 'Gemeter' by Sarasota Instruments.* This is a single-range desk model, and is the only reflectivity meter whose scale is directly calibrated in RI values. (Figure 1).

The 'Jeweler's Eye' by Hanneman Specialties is a dual range pocket model.† The circuit is similar to that of the 'Gemeter', but the calibration presets are connected in series with the LED and not the meter. (Figure 2).

No attempt is made with any of these instruments to measure absolute reflectivity

$$(\text{i.e. } \frac{Ir}{Ii}).$$

Instead, the intensity of the incident 'light' is assumed to be constant, and that of the reflected ray is displayed as a measure of relative rather than absolute reflectivity. For this reason all reflectivity meters have pre-set adjustments which allow them to be calibrated against standards such as spinel and diamond.

The newer 'Diamond Eye' by Hanneman (Figure 3) is another pocket meter, using the same basic circuit as the 'Jeweler's Eye' but calibrated only for diamond and diamond simulants.

Dr Hanneman has also introduced a meter (Figure 4) calibrated solely in terms of relative reflectivity using a 0 – 6.0 lustre scale of his own devising. This, rather like Mohs scale of hardness, is based on standard gems. In this case YAG, GGG, strontium titanate and diamond are chosen, and have been given lustre values of 1 to 4. This instrument is called a Lustermeter and is also available as a desk model,‡ as is his 'Jeweler's Eye'.

Another relative reflectivity meter of interest is the Martin Gem Analyser.§ In this instrument an attempt is made to make the

* See Fig. 2, J. Gemm., 1975, **XIV**, 8, 380.
† See Fig. 1, J. Gemm., 1976, **XV**, 1, 19.
‡ See Fig., J. Gemm., 1978, **XVI**, 4, 240.
§ See J. Gemm., 1978, **XVI**, 1, 50-54.

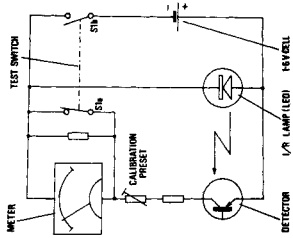

FIG. 1. 'Gemeter' circuit diagram.

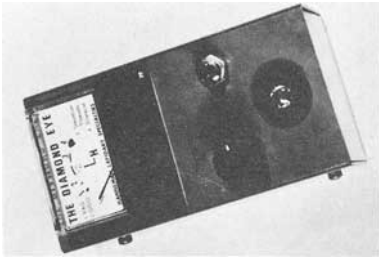

FIG. 3. 'Diamond Eye'.

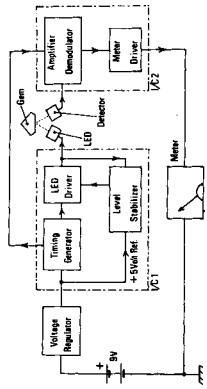

FIG. 5. Martin 'Gem Analyser' circuit diagram.

FIG. 4. 'Lustermeter'.

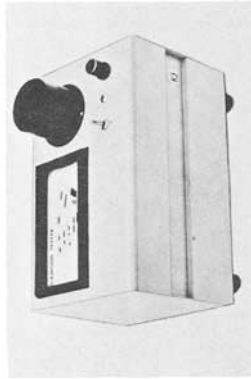

FIG. 6. Tatsumi 'Diamond Tester'.

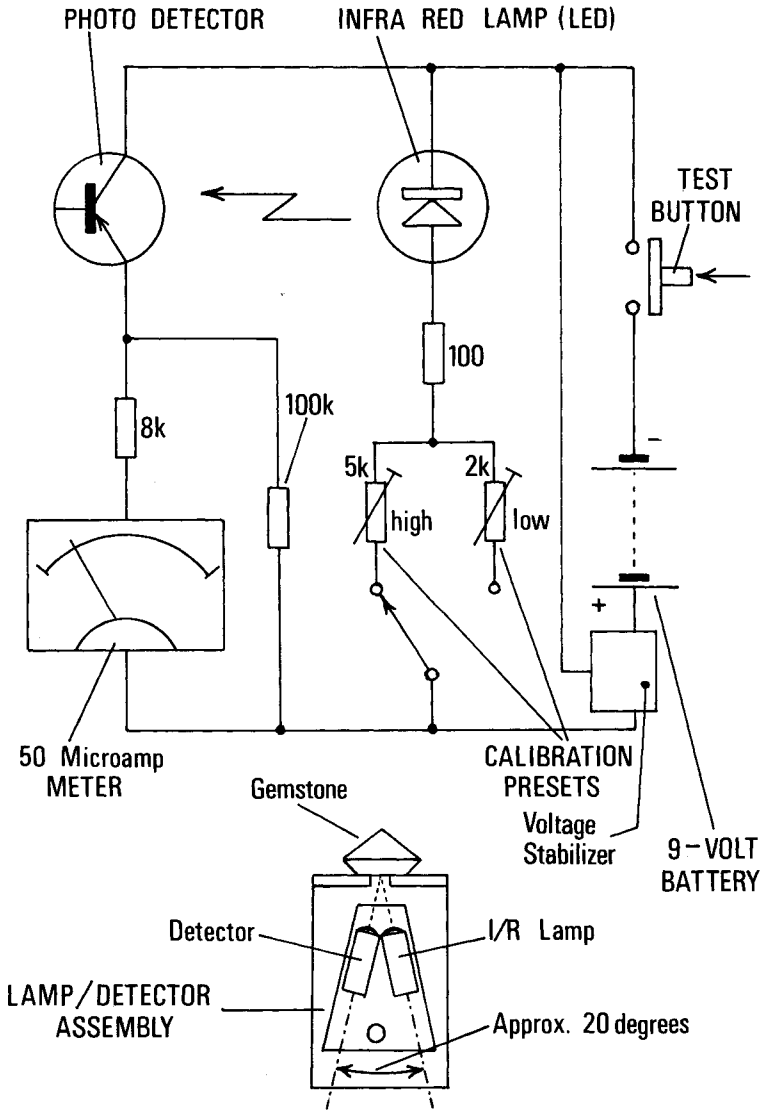

FIG. 2. 'Jeweler's Eye' circuit diagram.

readings independent of both battery voltage level and ambient lighting (Figure 5). This has been done by stabilizing both the voltage fed to the electronic circuits and the current supplied to the infrared source. Protection from the effects of ambient light is achieved by modulating the infrared beam and using the same modulation to decode the output of the detector. Even so, the manufacturer advises that the gemstone under test be shielded from strong light.

The Tatsumi 'Diamond Tester' (Figure 6) is a Japanese reflectivity meter made by the Japan Institute of Gemological Science, and is similar to the Hanneman instruments in design and operation.

While these instruments are very convenient for checking gemstones whose RIs are above the range of the critical angle refractometer, they cannot compete with the accuracy or amount of information that can be extracted from the standard refractometer. It is not possible for instance, to measure double refraction, optical character or optical sign on the reflectivity meter.

Before leaving the subject of reflectivity and refractive index, there are two items of interest which are relevant to the critical angle refractometer. For some years Rayner offered special versions of their refractometer which were fitted with 'glasses' made of synthetic spinel, blende and diamond. The spinel 'glasses' opened up the scale and permitted more accurate readings and the blende and diamond versions allowed higher RI's to be measured. Of these three variants, only the diamond version is now made to special order.

With the appearance of the new diamond simulant, cubic zirconium oxide, having an RI of 2.18 and a hardness of 8.5, it is now theoretically possible to make a refractometer 'glass' which is less expensive than diamond and which would give the refractometer the advantage of both an extended scale and a durable test surface. If such a refractometer is marketed, and if the chemists could be persuaded to produce a non-toxic contact liquid with an RI in the region of 2.2, this would provide a very useful scale extension, enabling readings to be taken on YAG, zircon, sphene and the high-reading garnets.

While it is possible to measure a gem's dispersion on a refractometer by using a monochromator to supply blue and red

light at the B and G Fraunhofer wavelengths, not many gemmologists have such an instrument available. However, the measurement of dispersion has been made to an accuracy of 0.001 using interference filters. Mr Suhner, who reported his work in 1977 in the journal of the German Gemmological Association, used standard interference filters of 480nm and 654nm. Although interference filters are expensive, the size needed for the light port of a standard refractometer is small and the provision of two interchangeable filters would make a useful optional extra. Alternatively, such filters could be inserted sequentially into the light path between the refractometer glass and the eyepiece.

There are now many microscopes, particularly of the stereo zoom variety, which have been developed specifically for the examination of gemstones and the grading of polished diamonds. Recently we have seen a move towards a microscope design which is more convenient for immersion work. When inspecting the interior of a gemstone, particularly when using the higher magnifications, trouble is often experienced because the illuminating light is reflected back from the facets of the stone, thus making it difficult to see into the stone. Dark-field illumination often overcomes this problem, but when difficulties are experienced with facet reflections, these can be eliminated by placing the gemstone in a glass immersion cell and filling the cell with a liquid having a refractive index somewhere near to that of the stone. In some commercial microscopes, the lens assembly has been designed so that the light path of the objective is horizontal. This is done to facilitate the use of a deep immersion cell, which allows the stone holder to be inserted into the cell vertically.

The Eickhorst Gemmoscope (Figure 7) is an example of a microscope which has been developed so that its optical head can be used either with a conventional vertical objective stand or with one designed for horizontal work. In the horizontal-format, the light source can be pivoted radially round the stone holder to give light-field, dark-field or incident illumination. The immersion cell stage is provided with controls for vertical and horizontal alignment and a third control rotates the stone holder. The stage can also be fitted with a polarizing filter attachment. Two controls are positioned at the side of the stand for focus and light intensity adjustment. An adaptor is also available which enables the G.I.A. Gemolite optical head to be fitted to the horizontal stand.

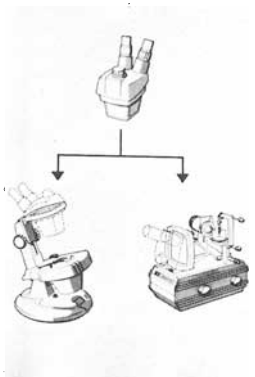

FIG. 7. Eickhorst 'Gemmoscope'.

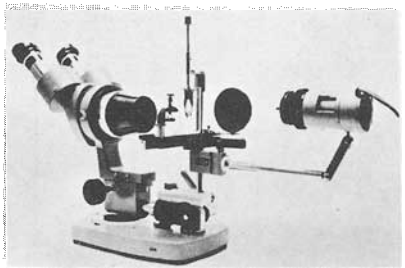

FIG. 8. Krüss model KA8 microscope.

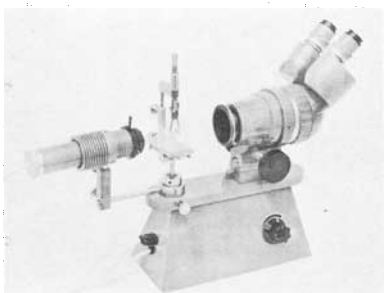

FIG. 9. Hans Günter Schneider model SZ1 microscope.

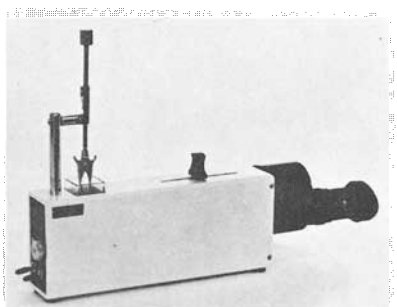

FIG. 10. Krüss portable model KA4 microscope.

FIG. 11. Krüss portable model KA4 microscope.

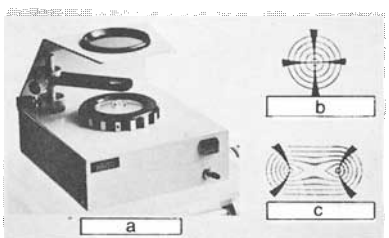

FIG. 12. Krüss combined polariscope and konoscope, and interference patterns.
(a) Polariscope with konoscope attachment
(b) Double refraction, uniaxial
(c) Double refraction, biaxial

Horizontal-format microscopes are also available from Krüss and from Hans-Günter Schneider (Figures 8 and 9). An interesting variant made by Krüss is the portable version KA-4 (Figures 10 and 11). This can be supplied in a carrying case with a full range of accessories including a tripod stand, a dichroscope eyepiece and a selection of immersion fluids. The light source is powered by rechargeable batteries.

Another new instrument by Krüss (Figure 12) is a combined polariscope and konoscope which, in addition to the usual light source and polarizing filters, includes a converging lens. This lens enables the optical axis of gems to be made visible by means of interference patterns.

I want to review now the latest instruments and techniques used in the 'fingerprinting' of diamonds. One of the problems with the buying and selling of diamonds is that the buyer often requires a certificate with his purchase (particularly if it is an unmounted stone bought for investment purposes). Such certificates are issued by many organizations and grading laboratories, and vary from a simple authenticated statement of the diamond's colour and clarity grading and weight, to a dossier of sophisticated tests and measurements. Such a certificate not only acts as an assurance to the buyer of the stone's worth, but, if it contains sufficient detail, can be used as a method of identifying that particular stone should the need ever arise.

Means of irrefutably proving a diamond's identity is also very much in the interest of insurance companies, police, and jewellers themselves, who could become involved in disputes over gems left for re-setting or cleaning. There have been many claims made over the years for special methods of 'fingerprinting' diamonds so that they can be positively identified. One commercial equipment that has reached the market and has been put into use by retail jewellers is the Gemprint (Figure 13). This instrument was invented and developed at the Weizmann Institute of Science in Israel, and is exclusively manufactured by Kulso Ltd, of Haifa. The North American marketing rights for the Gemprint were granted to Mr W. Levine, of Chicago, who founded Gemprint Ltd to establish a central registry of identifications for every gem recorded by Gemprint instruments.

In the Gemprint the scientists and engineers at the Weizmann Institute have used a laser to produce a pattern of reflected and

refracted light spots, which is unique to each gem. The instrument records on film the unique pattern of light spots caused by minute and individualistic differences in symmetry and polish on a stone's facets.

The basic components of the Gemprint machine (Figure 14) are:

1. A small low-power laser
2. Shutter
3. First lens
4. Polaroid film holder
5. Pinhole screen
6. Second lens
7. Adjustable gemstone holder.

Light generated by the laser passes through a polarizing filter and a shutter, and is then focused by the first lens onto the pinhole screen. Laser light passes through the pinhole to the second lens which provides a parallel light beam. When the gemstone is placed in this beam, reflections and refractions from the facets return through the lens and appear on the front (gem) side of the pinhole screen (Figure 15). The gem must be positioned in its holder so that the reflection from the gem's table is directed into the pinhole. As there is only one position in which this reflection can be orientated with the pinhole, this enables subsequent prints of the same gem to be matched with the original. When the gemstone is correctly positioned, a recording of the spot pattern is made using Polaroid film on the pinhole screen.

A fingerprinting technique using a modified version of Nomaski interference contrast has been developed by Diamond Grading Laboratories Ltd, of Hatton Garden. This system uses a special form of microscope illumination in which the surface contrast of a diamond's facets can be enhanced to a point where both its surface features and the underlying crystal structure can be made clearly visible. Photographic records of these unique features are used as a means of identifying individual diamonds.

Another technique which can be included under the heading of fingerprinting has been developed commercially by the Okuda Jewelry Technical Institute Co. Ltd, of Tokyo. It is radically different from the gemprint method in that it identifies a polished diamond by printing an individual code on the table facet of the diamond. This code, which includes the diamond's colour grade,

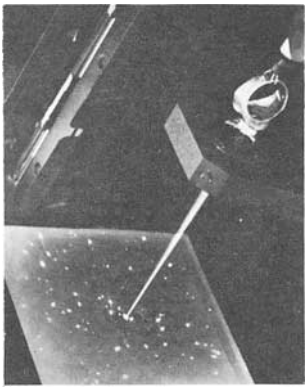

FIG. 15. 'Gemprint'—laserlight returns through lens to screen.

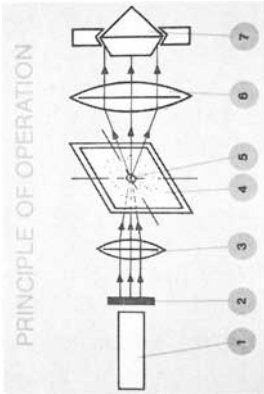

FIG. 14. 'Gemprint'—principle of operation.

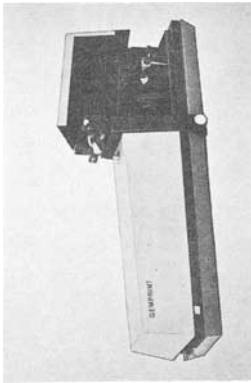

FIG. 13. 'Gemprint'.

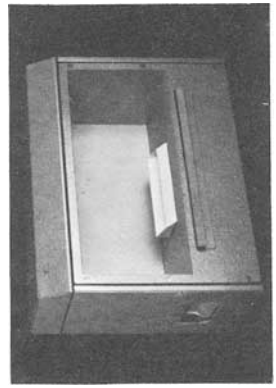

FIG. 18. 'Koloriskop G & S' grading lamp/cabinet.

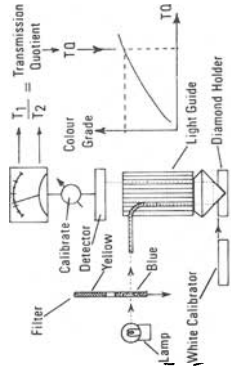

FIG. 17. Eickhorst colorimeter (diagram).

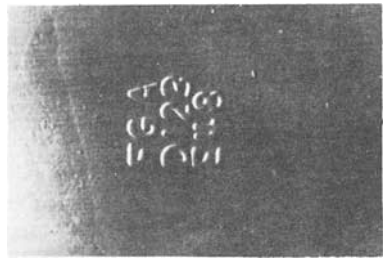

FIG. 16. 'SPD' (Scientifically Printed Diamond).

clarity grade, and carat weight, is printed into the surface of the diamond using a metal fusion process. The printed code can only be made visible by means of a microscope having a 400× magnification and using special illumination. It is applied to the surface of the diamond's table by means of photomask etching techniques as employed in the semiconductor industry. The table is first coated with a photo-sensitive emulsion, and the code characters from a microfilm are exposed onto this surface. Grains of a special metallic preparation are deposited on the exposed area and are fused into the diamond's surface. Finally the emulsion layer is dissolved away, leaving behind the fused metallic code letters. The printing process takes about two hours.

The printed code (Figure 16) is only 1-1.5nm thick, and the width of the printed characters is 500nm. The fingerprinting method is called S P D (Scientifically Printed Diamond) and is backed by a comprehensive group which includes a grading committee, certifying organizations, qualified distributors and affiliated retailers. As the metal fusion process is specific to diamond it cannot be physically applied to simulants, so that its presence on a stone alone proves that it is a diamond. Each diamond bearing the printed code also has a serially numbered diamond card carrying the same identifying information.

As 'fingerprinting' relies on those features and characteristics that are unique to a particular diamond, it is relevant to include the instrumental measurement of colour as one of these features. There are three basic methods of determining the colour of diamond. Two of these rely on the measurement of the light absorption characteristics of diamond, and the third analyses the nitrogen content of Cape series diamonds.

Using one of the two light absorption measuring techniques, the Eickhorst Diamond Photometer and the now obsolete G.I.A. Shipley colorimeter are examples of commercial instruments designed specifically for measuring the degree of yellowness in Cape series stones. The appearance of yellowness in such a diamond is caused by absorption lines at the blue (415.5nm) end of the spectrum.

The Eickhorst colorimeter uses monochromatic yellow and blue light to compare the absorption of the diamond at these wavelengths. As can be seen in the diagram (Figure 17), the yellow and blue light is directed, in turn, into the table facet of the diamond by

means of a glass-fibre light guide. Use is made of the optics of the brilliant-cut stone to achieve total internal reflection of the sampling light, which is then collected as it emerges from the table facet by a second concentric light guide. The output of this second light guide is fed to a photo detector which is connected to a meter to indicate the intensity of the yellow and blue light. These two intensities are called T1 and T2, and the ratio of these two figures is called the transmission quotient (by taking the ratio of T1 and T2, the effects of path length differences in diamonds of different size are cancelled out). The transmission quotient number is then converted to the appropriate diamond colour grade by means of a graph on the front of the instrument. Before each measurement is made, a white calibration plate is placed under the fibre optic head (in place of the diamond), and the calibration controls are adjusted for a 100% transmission reading on the meter. In the MkII version of the Diamond Photometer, the meter is to be replaced by a digital readout.

One of the problems with the measurement of diamond colour by using the yellow/blue absorption ratio is that it takes no account of the bluish fluorescence which may be stimulated in a diamond by the UV content in white light. Diamonds which fluoresce blue in white light will therefore appear to have a whiter body colour than indicated by the instrument. With instruments such as the Eickhorst and the G.I.A. Shipley colorimeter, it is necessary first to check each diamond for fluorescence under a UV lamp before inserting it in the colorimeter. This, however, is more a problem of colour grading than of colour measurement for 'fingerprinting' purposes.

Having touched on the subject of colour grading, I will briefly mention the new Koloriskop grading lamp (Figure 18), originally developed from a specification by Dr Gübelin and Mr Schiffmann. It comprises a colour grading cabinet which is fitted with fluorescent tubes having a colour temperature of 5000K, and meets the ISO Standard 2243 which has been considered by C.I.B.J.O. for the colour grading of diamonds.

The other method of quantifying the body colour of a diamond is to measure its entire absorption spectrum by means of a spectrophotometer. For 'fingerprinting' purposes, this gives a unique set of spectral absorption lines and can be used for diamonds of any colour. The Zeiss PM1D (Figure 19) is an example

of one of the simpler spectrophotometers and covers the range of 320-750nm. The Zeiss PMQ3 (Figure 20) is an example of the more complicated research version. It is capable of measuring absorption characteristics from 180nm to 3000nm with a combination of light sources and monochromators. Its output can also be connected to a computer. An earlier and modified version of the PMQ3 is installed in the Idar-Oberstein laboratory of the German Gemmological Association. An adaptation of a Zeiss spectrophotometer is also used by Diamond Grading Laboratories Ltd to colour-grade Cape series diamonds to very fine limits.

One of the nore unusual research methods of measuring the 'yellowness' of a Cape series diamond is to analyse its nitrogen content. Following research into fundamental diamond characteristics at the Diamond Research Laboratory, Johannesburg, in the 1950s, the Director of Research, Dr J. F. H. Custers, proposed that the existing classification of diamonds into nitrogen-contaminated Type I and the purer nitrogen-free Type II should be further subdivided into Type I, Type IIa and Type IIb, the latter to include nitrogen-free diamonds which contain aluminium in their structure. Because of the aluminium impurity in the Type IIb's these diamonds possess semi-conductor properties and are thus capable of passing an electric current. Subsequent work showed that both nitrogen and aluminium affect the body colour of diamond. Nitrogen absorbs light at the blue end of the spectrum, and causes the yellow tints which are seen in the Cape series, and aluminium in the rare Type IIb diamonds produces the natural blue stones as obtained fron the Premier mine at Cullinan near Pretoria, South Africa.

For a while there appeared to be a conflict of data, as it was known that some Type I diamonds existed which contained relatively large amounts of nitrogen, but which were of top colour and not a deep yellow as experimental results implied. It was then found that there were two ways in which nitrogen atoms are grouped in the diamond lattice. If the nitrogen content of the diamond is low, the nitrogen atoms are dispersed throughout the crystal lattice, and produce a yellowish body colour. However, if the nitrogen content is high, the majority of the nitrogen atoms are not dispersed in this manner but are grouped together in small clusters of atoms called 'platelets'. These have no effect on the diamond's colour as they only absorb light at the ultraviolet end of

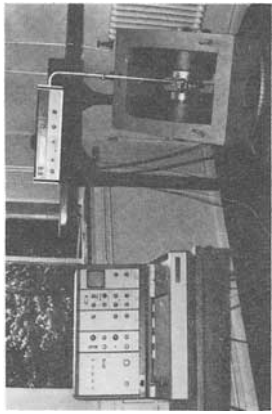

FIG. 21. Varian E109 spectrometer.

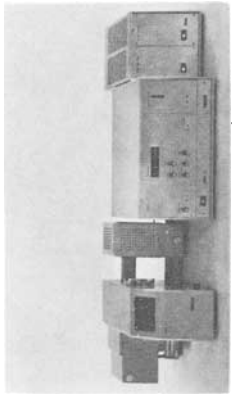

FIG. 20. Zeiss PMQ3 spectrophotometer.

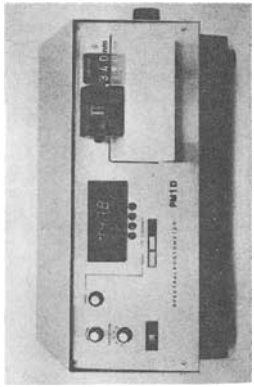

FIG. 19. Zeiss PM1D spectrophotometer.

FIG. 24. 'Luminoscope' vacuum chamber and electron gun.

FIG. 23. 'Luminoscope'.

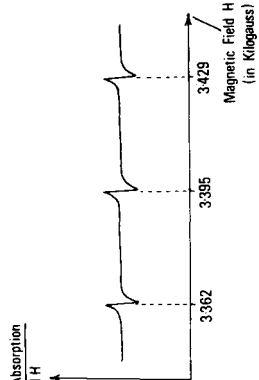

FIG. 22. Typical E.S.R. spectrum for diamond.

the spectrum. The colour of these diamonds is therefore due to the small amount of dispersed nitrogen and not the much larger amount of nitrogen in platelets. From this evidence, it was possible to subdivide Type I diamonds into Type Ia, which contains nitrogen mainly in platelets, and is the category to which the majority of natural diamonds belong, and Type Ib which is a much smaller group of diamonds containing nitrogen only in dispersed form.

The direct relationship between the amount of dispersed nitrogen in a diamond and the yellowness of that diamond was established at the D.R.L. by the use of an electron-spin resonance spectrometer, which provides a non-destructive means of measuring the amount of the dispersed nitrogen atoms in the diamond lattice. The carbon atom in the diamond lattice has a valency of four; that is, it has an electron orbital shell containing four electrons which enables it to link to four other carbon atoms to form a geometric crystal lattice. In Type I diamonds, each dispersed nitrogen atom replaces a carbon atom in the diamond lattice, and as nitrogen has a valency of five, this results in a free uncommitted electron associated with the nitrogen atom. This free electron behaves like a tiny bar magnet and, under the influence of the nitrogen nucleus, has distinguishing magnetic resonances in the 9.5 GHz microwave region of the electromagnetic spectrum. These resonances can be detected and quantified on the E.S.R. spectrometer.[1]

The Varian E109 spectrometer shown in Figure 21 is typical of a modern E.S.R. instrument and consists of three basic parts:

1. A magnet assembly, having a maximum field strength of 10 kilogauss, with a specimen module positioned in a cavity between the pole pieces.
2. A microwave generator/bridge. This contains a tunable klystron valve which generates the microwave energy, and a microwave bridge to detect the absorption of that energy by the specimen. The output of the microwave generator is fed to the specimen cavity in the magnet assembly.
3. A control unit which, among other things, enables the field of the magnetic assembly, and the scanning range over which the field is to be swept, to be adjusted. This unit also contains a chart recorder to plot the microwave absorption spectrum of the specimen and thus reveal (by

the level of absorption) the amount of nitrogen present in its lattice.

The E.S.R. spectrometer analysis is made as follows. First the diamond under test is placed in the specimen module, and the klystron in the microwave bridge is tuned to the resonant frequency of the magnet cavity. The bridge is then adjusted for an exact balance. For work on nitrogen defects in diamond, the resonance is adjusted to 9.5 GHz, the field strength of the magnet assembly is set to approximately 3.4 kilogauss, and the range over which the field is swept is set typically to ±50 gauss. When the test is run, the magnetic resonances in the nitrogen defects result in microwave energy being absorbed at characteristic field strengths as the magnetic field is swept across the scanning range. This absorption unbalances the microwave bridge, the unbalance being recorded as the vertical component on the chart. The amount of absorption, and hence the quantity of nitrogen and degree of yellowness in the diamond, is therefore indicated by the vertical deflexions in the recorded trace.

A typical E.S.R. spectrum for diamond is shown in Figure 22. The single differentiated peak in the centre is due to the spin resonance of the nitrogen electron, while the two outer responses are due to the modifying effect of the nitrogen nucleus on this resonance. The spectrum was taken with the magnetic field parallel with the cubic (100) plane. Spectra taken with the field parallel with the dodecahedral (110) and octahedral (111) planes show twin outer responses.

It is interesting to note that C. A. Schiffmann,[2] of the Gübelin Laboratory, Lucerne, used a prototype E.S.R. spectrometer in the laboratory of Beckman Instruments, Geneva, to distinguish between genuine sea-water pearls and cultured salt-water pearls having mother-of-pearl nuclei. The genuine pearls showed an almost flat E.S.R. trace containing low amplitude high-frequency 'noise', while the cultured pearls showed traces containing peaks of a much higher amplitude and lower frequency. The irregular absorption peaks in the latter were thought to be due to a small content of manganese.

Another research technique, which could have an application not only in diamond fingerprinting but also in the identification of gemstone simulants, uses the phenomenon of cathodoluminescence. This is the visible fluorescence produced when a beam of electrons

strikes the surface of a specimen. The fluorescent display can yield much information about a specimen since both the colour and intensity are dependent on very small changes in the concentration of trace impurities, as well as on the matrix substance and the way in which the impurities are incorporated in the base material.

Cathodoluminescence is used in studies concerning the concentration of rare earths[3, 4] to six parts in one thousand million, the degree of perfection of synthetic crystals, and the identification of minerals in conglomerates.

The Luminoscope (Figure 23) manufactured by the Nuclide Corporation, U.S.A., is a compact instrument designed for use in the microscopic examination of cathodoluminescence. It consists of a specimen vacuum chamber and a control unit. The specimen chamber is flat enough to permit it to be placed on a microscope stage, but is still capable of taking a specimen up to $51 \times 76 \times 13$ mm in overall dimensions. A 3 mm-thick lead glass window in the top and bottom of the chamber permits incident or transmitted illumination of the specimen under observation. A stage is provided for the specimen within the chamber and this can be indexed in the X and Y directions by means of two external controls.

The electron beam is generated by a low work-function cold cathode 'gun' mounted at the right-hand end of the chamber (Figure 24), which is pumped down to the relatively 'soft' vacuum of 15-25 millitorr ($1.5\text{-}2.5 \times 10^{-2}$mm of mercury). The gas ions produced in this soft vacuum leak away any static charges developed on non-conducting specimens. The control unit contains the E.H.T. supply for the gun cathode, which is variable from 0 to 18 kV. A current limit control is provided which can be adjusted from 8 microamps to 2 milliamps to set the current level at which the E.H.T. voltage is tripped off. A push button is provided which switches off the E.H.T. and turns on the microscope light to enable rapid alternate observation of the specimen under visible light or electron bombardment. Provision is also made for the control of a vacuum pump, which can be quite a small one as the pumping capacity and the vacuum requirements are modest. Chamber pressure is displayed on a meter which is fed from a transducer on the chamber.

The gun is fitted with collimating anodes, and an electrostatic lens electrode gives control of the electron beam focus via a knob

on the control unit. The electron beam is guided and deflected downwards onto the specimen by means of a permanent-magnet deflexion assembly which can be moved laterally across the top of the chamber. When in use, the electron beam can either be defocused so as to irradiate a group of specimens, or it can be focused to a spot of approximately $4mm^2$ to energize a single stone.

The luminoscope shown in Figures 23 and 24 is the one in use in the Crystallography Department at University College, London. It is used there to investigate the cathodoluminescence (CL) properties of diamonds, and to act as a selector for diamonds having special features, which are them investigated in detail on a scanning electron microscope. Diamonds appear to be one of the most interesting minerals to be observed in CL. There is an indication that only diamonds with lattice imperfections can radiate visible CL, and that the particular colour produced suggests the type of defect. Natural Type Ia and IIb diamonds often show two contrasting shades of blue. The variation in shade in a specimen indicates a mixture of Type I and II material.

CL colour can be used for the detection and identification of many gem materials. It can also be used in quality control in the growth of synthetic crystals. By using a broad beam, parcels of mixed stones can be examined and sorted.

Finally, I should like to describe a research technique which is particularly relevant to the fingerprinting of diamonds, as it is entirely dependent on the internal crystal structure and lattice defects in the diamond, and is not affected by subsequent surface changes such as repolishing. Work done by Dr A. R. Lang and Dr G. S. Woods[5] in the H. H. Wills Physics Laboratory at Bristol University has demonstrated that x-ray topographic 'maps' of internal defects in a diamond's lattice can be used to identify a polished stone with the rough stone from which it was cut. This work has also shown that an x-ray topographic recording on film can serve to identify a polished gem even though it may have been recut. It is this aspect of x-ray 'fingerprinting' which is of particular interest to anyone who may become involved with disputes over the identification of polished diamonds.

Unfortunately, the equipment used to produce an x-ray topographic photograph of a diamond is both bulky and expensive. In the present state of the technique's development, it is therefore more in the province of the research laboratory than the grading

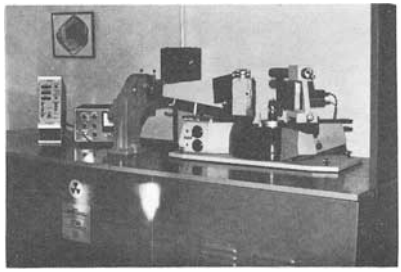

FIG. 25. Bristol-Lang Topography Camera and GX20 Rotating Anode X-ray Generator.

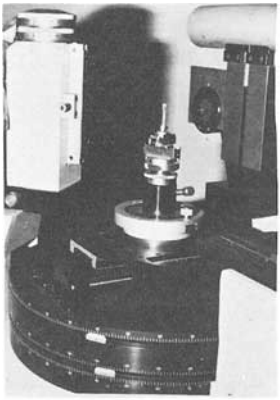

FIG. 26. Bristol-Lang camera in more detail.

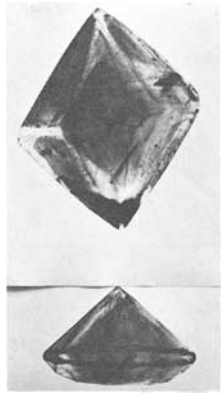

FIG. 27. X-ray topography photographs of a brilliant-cut diamond (below) and 1 ct rough (above) from which it was cut.

laboratory. Depending on the intensity of the x-ray source and the sensitivity of the photographic emulsion, the time taken to produce an x-ray topographic print may be hours rather than minutes. However, it is possible that further development of the equipment and the technique may reduce both the bulk and the time factors to a more practical level.

A suitable equipment for x-ray topography work is shown in Figure 25. The bulk of the equipment comprises a GX20 Rotating Anode X-Ray Generator, manufactured by the Neutron Division of Elliott Bros (London) Ltd, at Borehamwood. On the unit is mounted a Bristol-Lang Topography Camera. Figure 26 shows the Bristol-Lang camera in more detail. The camera consists of a spectrometer type table on which the angular positions of the specimen and the film holder can be adjusted relatively to the

source. The source in this case is a vertical ribbon-like beam of collimated x-rays (10 to 100 microns wide) which emerge from the slit on the left-hand side of the diamond specimen.

The two most important x-ray topographic techniques for use in the fingerprinting of diamonds result in the production of a 'section' topograph and a 'projection' topograph. In the section topograph, the thin ribbon of x-rays is used to penetrate a slice of the diamond. The diamond is orientated so that the x-rays are diffracted by the atomic layers in the crystal lattice and emerge at an angle to the incident beam. The emerging x-rays fall on a photographic plate placed close to the diamond, but shielded from the direct beam. Any defects in the crystal lattice will deflect the beam more strongly and be recorded as darker areas on the photographic plate. A photographic record is therefore produced which reveals a pattern of crystal defects in the slice of the crystal penetrated by the x-rays.

In the projection topograph, the diamond and the frame holding the photographic film or plate are together moved backwards and forwards through the x-ray beam. In effect, the ribbon-like beam scans the whole of the diamond, and the image formed on the photographic plate is a parallel-beam projection of the internal lattice defects of the complete diamond.

Two typical x-ray topography photographs are shown in Figure 27. The upper photograph shows a series of lattice defects in a 1 carat rough diamond crystal of octahedral shape, and having no visible flaws. A large defect is seen in the upper half of the stone, with several needle-like defects crossing the large one and pointing towards the centre. In the centre of the stone is a nail-shaped defect. The lower photograph shows a polished brilliant-cut diamond produced from the rough stone in the top photograph. The brilliant has been cut from the upper part of the octahedron, and the large defect, the lines and the nail-shaped image are still clearly visible. From the photographs it is fairly obvious that no amount of re-polishing of the stone will remove these defects as they are within the body of the stone (this is shown by taking similar x-ray topographs in different directions).

It is fortunate that the refractive index of diamond is virtually unity at the x-ray wavelengths used for fingerprinting, as this removes any problems that might have been caused by irregular shape or surface roughness in the diamond specimen. Refraction of

the x-ray beam may, however, take place if the technique is applied to other gemstones whose RI is considerably lower than that of diamond, and unless x-rays of an appropriate wavelength can be used this may restrict the technique to the fingerprinting of diamonds. Despite this drawback, x-ray topography has been used to distinguish natural from synthetic emerald.[6]

The absorption by diamond of the radiations used in x-ray topography is so low that even very large diamonds can be completely irradiated without the x-ray beam suffering excessive attenuation. Nor is there any damage done to the diamond by the radiation. Some diamonds have in fact been x-rayed so often that their accumulated x-ray dose would be equivalent to several hundred fingerprinting operations, and no detectable colour change has been produced.

I should like to close this review of instruments and techniques by looking to the future. We have already seen the use of electronic devices such as LEDs, photo transistors and integrated circuits in the new reflectivity meters. The most recent milestone in the history of electronics has been the emergence of the microprocessor. As these miniaturized computing elements become cheaper and more versatile, it is possible that an instrument, similar to a small hand-held calculator, could be produced containing a microcomputer which would give diagnostic information on gemstone constants and characteristics.

Already small home computers, built round the micro-processor, can be purchased for under £200. I am working at the moment on a computer program for such a unit which, when presented with a set of test readings, will compare these with the information in its memory and read out an identification. Alternatively, it can be made to read out all available data on a specific gem mineral. Such a diagnostic microcomputer as this can be regarded as an extension to the gemmologist's memory, leaving him (or her) free to apply skills and experience to best advantage.

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GEMMOLOGICAL ABSTRACTS

BANK (H.), BANERJEE (A.), PENSE (J.), SCHNEIDER (W.), SCHRADER H.-W.). *Sogdianite—ein neues Edelsteinmineral?* (Sogdianite—a new gem material?) Z. Dt. Gemmol. Ges., **27**, 2, 104-5, 1978.

The mineral was found in the Wessel mine near Hotazel in the North Cape Province, South Africa. It was a violet centimetre-thick layer grown onto some black material and was shown to be sogdianite. E.S.

BANK (H.), SCHMETZER (K.), MAES (J.). *Durchsichtiger, blau-rot changierender Korund aus Kolumbien.* (Transparent, blue-red changing corundum from Columbia.) Z. Dt. Gemmol. Ges., **27**, 2, 102-3, 1978.

The transparent, cut stone was blue with a trace of red when viewed in daylight, but intensive red in artificial light, i.e. it had a typical alexandrite effect. It was a natural corundum from Columbia. It showed surprisingly little pleochroism (dichroism). E.S.

BILL (H.), CALAS (G.). *Color centers, associated rare-earth ions and the origin of coloration in natural fluorites.* Physics and Chemistry of Minerals, **3**, 117-31. 6 figs, 1978.

Optical absorption and EPR methods were used to study the cause of colour in natural fluorites. The colours observed were attributed to rare-earth ions and/or oxygen with formation of complex colour centres. Yttrium-associated F-centres gave blue, yttrium and cerium associated F-centres acting together gave yellowish-green, the (YO_2) centre gave rose and the O_{-3} molecule ion gave yellow. Colour is also given by divalent rare-earth ions such as Sm^{3+}, which gives green. Eu^{2+} gives a strong fluorescence. M.O'D.

BLÄZEK (M.C.). *Is your amber real?* Rocks & Min., **52**, 315-6, 1977.

In this general discussion of amber, tests are given for distinguishing between the true substance and common substitutes like copal, bakelite, and other plastics. Pressed and heat-treated amber (ambroid) is also considered. R.S.M.

BUKANOV (V.V.), PLATONOV (A.N.), TARAN (M.N.). *The colour of gem spinels from the Kukhilal deposit.* Zap. Vses. Min. Obshch., **106**, 565-71, 5 figs, 1977. (In Russian.)

Gem spinels occur in the Kukhilal deposit in magnesite marbles near their contact with migmatites and granitic gneisses. Mössbauer and optical absorption spectroscopy were used to study the colour of the spinels. They are chromian (rose) and Fe-Cr (rose-violet) varieties containing, respectively, Fe 0.1, 0.6; Cr 0.04, 0.004%. The intensity of colour is attributable to the amount of Fe and Cr present. R.A.H.

CASSEDANNE (J.-P.), CASSEDANNE (J.-O.). *La pétalite de Itinga (Minas Gerais).* (Petalite from Itingá, Minas Gerais.) Revue de Gemmologie, **55**, 14-16, 3 figs, 1978.

Petalite with an S.G. of 2.40, R.I. 1.504, 1.510, 1.516, birefringence 0.012, has

been found in the Itinga district of Minas Gerais, Brazil. This material shows no orange luminescence as has been reported from other places, nor does it show the band at 454.0nm. M.O'D.

CHIKAYAMA (A.). *Natural and synthetic gemstones newly appeared after the 2nd World War.* J. Gemm. Soc. Japan, **1**, 32-42, 27 figs; Ibid, **1**, 65-70, 1974. (In Japanese with English summary.)

Gemmological properties and keys for identification of new gemstones, both natural and synthetic, which have been discovered or appeared in the gem market after the 2nd World War are described briefly, together with short descriptions of the histories of their discovery and syntheses. Descriptions are given of the following: brazilianite, amblygonite, greened amethyst, chrysoberyl cat's-eye and alexandrite from Brazil, Brazilian emerald, Brazilian opal, Brazilian (or Maxixe) aquamarine, taaffeite, sinhalite, ekanite, painite, chrome-diopside, Russian emerald, tugtupite, blue zoisite, grossular, rhodolite, Tanzanian corundum, chrome tourmaline, Manyara emerald and alexandrite, red tourmaline from Kenya, nephrite cat's-eye, green dyed quartzite. Also man-made diamond, synthetic ruby, synthetic red spinel, synthetic emerald, colourless synthetic stones for diamond imitation, Gilson turquoise, Gilson opal, synthetic alexandrite, synthetic blue quartz, synthetic citrine, synthetic amethyst. I.S.

FRIDJHON (Harold). *De Beers' new diamond mine in commission.* The Times newspaper, no. 60792, p.18, 29th August, 1978.

De Beers have commenced production on the Namaqualand coast where 810 000 tons of overburden will be stripped each month to reach the Koingnaas orebody, expected to yield over 500 000 ct yearly of good quality but small diamonds (average 0.25 ct.). Great planned expansion of the group's operations is reported, with increased production at Jwaneng, Letlhakane and Orapa in Botswana.

J.R.H.C.

FUJISAKI (Y.). *Identification of gemstones by means of x-ray transmission (x-radiography).* J. Gemm. Soc. Japan, **4**, 4, 11-23, 15 figs, 1977. (In Japanese with English summary.)

Reviews the use of x-rays in general gem testing and discusses the interpretation of intensity photographs using the Sakura PDA-81 intensity meter. X-lide is the name given to a new apparatus which measures this intensity. The apparatus is claimed to be able to identify diamonds and their imitations, whether mounted or unmounted, imitation and natural coloured stones, natural and cultured pearls and composite stones. M.O'D.

GÜBELIN (E.J.), MEYER (H.O.A.), TSAI (H.-M.). *Natur und Bedeutung der Mineral-Einschlüsse im naturlichen Diamanten.* (Nature and significance of mineral inclusions in natural diamonds.) Z. Dt. Gemmol. Ges., **27**, 2, 61-101, 18 coloured photomicrographs, 6 diagrams, 13 tables, bibl. of 101 items, 1978.

Several minerals occur as inclusions in natural diamond. The historical identification and significance are discussed as well as relevant mineralogy and major element chemistry. Division of inclusions into primary (pre- or syngenetic) and secondary (epigenetic) is considered as is also the subdivision of primary inclusions

into ultramafic and eclogitic suites. The relation of diamond inclusion research to the understanding of the genesis of diamond and the formation of kimberlite and associated xenolites, and to the mineralogy of the upper mantle, is revised. Certain results have been ascertained. (1) Most of the primary mineral inclusions are small, mono-mineral homogeneous crystals whose morphology is dependent on the crystal structure of the host diamond. (2) Many inclusions are similar to those minerals occurring free in the accompanying kimberlite or xenolites, but show in detail to be of different chemical composition. (3) The difference in the chemical composition between the mineral inclusion and the free minerals in the kimberlite is mainly additional chromium in the inclusion mineral. (4) There are two quite definite groups of mineral inclusions, the ultramafic and the eclogitic, and they never occur in the same diamond. (5) Based on the chemical composition of the inclusions and on the values of the trace elements, it could be assumed that the diamond and its mineral inclusions in the primary stage have crystallized from a melt which corresponded either to a lherzolite or an eclogite. (6) Pressures and temperatures of the diamond genesis as calculated from research of the inclusions lie within the field of stability of the diamond and correspond generally with the stability-temperatures of the xenolites in the kimberlite. As proof for this could be mentioned that diamonds crystallize in the upper mantle between 150-200km, and not during the genesis of the kimberlite. (7) Future research should be directed towards the determination of isotope quantities in the inclusion, solving the date of genesis of the inclusion and the host mineral, showing details of the diamond genesis and occurrences in the upper mantle. E.S.

JENSEN (K.E.). *Minerals which look like jade.* Rocks & Min., **52,** 551, 1977.

Among minerals often resembling jade are serpentine ("bowenite"), vesuvianite ("californite"), grossular, amphibole ('smaragdite"), chrome mica ("verdite"), and prehnite. R.S.M.

KAGAYA (B.). *Fingerprint of diamond.* J. Gemm. Soc. Japan, 2, 51-61, 10 figs, 1975. (In Japanese with English summary.)

Two-circle goniometric measurements of many brilliant-cut diamonds have demonstrated that there is not a single stone which gives exactly the same ϱ, ι values of facets. This is naturally expected, since diamonds are cut manually. Probability calculations have shown that the probability of two stones having exactly the same ϱ, ϕ values for 8 bezel facets is 2.13×10^{-27}. Therefore, the ϱ, ϕ values of bezel facets can be used as a method for fingerprinting cut stones. A new reflection theodolite goniometer is designed to diminish time required for goniometric measurements. It is possible to measure a stone with this goniometer in less than 15 minutes. I.S.

KOMATSU (H.), AKAMATSU (S.). *Differentiation of black pearls.* Gems and Gemology, **XVI,** 1, 7-15, 15 figs in colour, 1978.

Title refers to naturally coloured black pearls *cultivated* in the very large black-lipped pearl oysters (pinctada margeritifera) produced with some difficulty on a small scale off the Nipponese Islands of Yaeyama and off Fiji and Tahiti. Authors show that photographing black cultured pearls on infrared colour-film allows these naturally coloured blacks to be differentiated from those made by staining with silver nitrate by their image colours. The stained pearls give a lighter and greener

image while the natural blacks give darker and bluer images on this type of film. Stained pearls are also said to be more brittle than the natural blacks. (Abstracter believes that other stains are also in use to blacken cultured pearls. Have authors investigated these?) R.K.M.

KRAUS (P.D.). *Opal and tourmaline; birthstones for October.* Lapidary Journal, **30**, 7, 1609-24, 1976.

Both stones are reviewed with summaries of their properties, main locations and references to the literature. Tourmaline crystals are illustrated in colour.

M.O'D.

LOWELL (J.), RYBICKI (T.). *Mineralization of the Four Peaks amethyst deposit, Maricopa County, Arizona.* Mineral. Record, **7**, 72-77, 7 figs, 1976.

Large gem-quality crystals of amethyst have been found with colourless and smoky quartz, fluorapatite, and specular hematite in a fault breccia in Mazatzal quartzite, on the southernmost peak of the crest of the Mazatzal Mountains, Maricopa County, Arizona. G.W.R.

MEDENBACH (O.), SCHMETZER (K.), KRUPP (H.). *Spessartin aus den Taita Hills, Kenia.* (Spessartine from the Taita Hills, Kenya.) Aufschluss, **29**, 275-6, 1978.

A spessartine variously coloured yellow, orange-red or reddish brown has been found in the area of Salt Lick Lodge in the Taita Hills of southern Kenya. MnO content was measured at 31.2%. M.O'D.

MEIXNER (H.), PAAR (W.). *Ein Vorkommen von Väyrynenit-Kristallen aus 'Pakistan'.* (An occurrence of väyrynenite crystals in 'Pakistan'). Zeitschrift für Kristallographie, **143**, 309-18, 3 figs, 1976.

Gem quality rose-red crystals of the beryllium manganese phosphate väyrynenite were seen at Chitral, West Pakistan, in a bazaar. Physical and chemical constants agree with those for mineral which was previously known from a pegmatite vein in Finland. M.O'D.

MIURA (Y.). *Labradorescence.* J. Gemm. Soc. Japan, **4**, 4, 3-11, 11 figs, 1977. (In Japanese with English summary.)

The writer has studied the iridescence of labradorite and found that gem-quality material from deep-seated plutonic and metamorphic rocks shows periodic lamellar structure. Colour changes over the range ultraviolet to near infrared depend on anorthite content, according to the Bøggild rule. Labradorescence depends upon this lamellar structure. M.O'D.

MUMME (I.A.). *The Little River Sapphire lease.* Australian Gemmologist, **13**, 6, 177-9, 182-5, 1978.

Abridged report largely concerned with historical notes on an area originally worked for gold. Sapphire interest developed only in past 20 years. Topographic and geological information given. R.K.M.

MUMME (I.A.), BALL (R.A.). *Notes on sapphires from stream gravels at Frazer's Creek in Glen Innes area, New South Wales.* Australian Gemmologist, **13**, 6, 173-6, 5 figs, 1978.

The sapphires are often dark, patchy with strong colour-zoning about the *c* axis. Some stones can be made lighter in colour by heating to 1500°C in an oxidizing atmosphere. Figures show surface structures without explanations. Gallium is present in greater amounts than were found in a previous analysis. A separately headed spectrophotometric list at the end of the paper needs further explanation if it is to substantiate the findings of the text. R.K.M.

NASSAU (K.). *Comment on 'Water as a gemological tool'.* Lapidary Journal, **32**, 2, 580, 1978.

Discredits the reports by Hanneman (Lapidary Journal, **31**, 12, 2576-8, 1978, abstracted J. Gemm., **XVI**, 4, 275, 1978) and Tjwan (Lapidary Journal, **23**, 624, 1969, and J. Gemm., **XI**, 6, 205-10, 1969) on the grounds of carelessness and misapprehension of the nature of the material used. M.O'D.

NASSAU (K.). *The origins of color in minerals.* Am. Miner., **63**, 219-29, 8 figs, 1978.

Discusses crystal field theory, molecular orbital theory, band theory and various operations of physical optics giving colour in minerals; among these are diffraction, scattering, dispersion and interference. M.O'D.

NASSAU (K.), PRESCOTT (B.). *Growth-induced radiation-developed pleochroic anisotropy in smoky quartz.* Am. Miner., **63**, 230-8, 7 figs, 1978.

Anomalous pleochroism has been observed in smoky quartz crystals grown on seeds cut parallel to the face of the minor rhombohedron. Smoky means irradiated in this context. The anomalous pleochroism is attributed to site-selective distribution of Al ions during growth on minor rhombohedral faces. Charge compensation with other ions may also occur. M.O'D.

PABIAN (R.K.). *Inclusions in agate and their origins and significance.* Gems & Gemology, **XVI**, 1, 16-28, 17 figs in colour, 1978.

Author has studied similarities and differences in over 3900 agates from ten New World and one African source. There are similarities between agates from widely different localities but the paper is largely a precis of the various and sometimes conflicting opinions of other authorities on the interesting subject of agate formation. The colour plates are excellent but cannot possibly illustrate the information and pattern variations in so large a sample. Agates are essentially three dimensional and it is not easy to interpret modes of formation from the two dimensional pattern seen at the polished surface of a usually random section.

R.K.M.

PETERSEN (O.V.). *The twin formation of tugtupite; a contribution.* Mineralog. Mag., **42**, 251-4, 4 figs, 1978.

Tugtupite is a member of space group $I\bar{4}$ and belongs to the crystal class 42m. Pseudotrigonal contact triplets are described. M.O'D.

QUIGLEY (Desmond). *Total of 173 diamonds* [sic] *so far in CRA's Australian strike.* The Times newspaper, no. 60 400, p.24, 7th September, 1978.

Conzinc Riotinto of Australia disclosed the discovery (by Ashton Joint Venture group in the Kimberley Region of Western Australia) of 173 ct of diamonds (largest about 3.3 ct), but it was not known to what extent they were of gem quality. They were recovered during the first stage of tests involving taking samples of about $100m^3$ from the surface of each hectare of those kimberlite pipes judged to be of potentially economic size, some $1918m^3$ having been treated so far. J.R.H.C.

SCHUBNEL (H.-J.). *Le diamant en Inde.* (Diamond in India.) Revue de Gemmologie, **55**, 11-13, 7 figs, 1978.

Describes the working of the diamond mine at Majhgawan in the Panna district of India with some remarks on the commercial handling of the production. M.O'D.

SUNAGAWA (I.). *Gem fingerprinter.* J. Gemm. Soc. Japan, **2**, 62-5, 1975. (In Japanese with English summary.)

In connexion with the article by B. Kagaya on gem fingerprinting by means of goniometry, a new apparatus of gem fingerprinting recently devised by the Weizmann Institute, Rehovot, Israel, is critically described. The apparatus is based on the same principle as Kagaya's method, but a laser beam is used and the rotation methods are original. I.S

SUNAGAWA(I.). *Cubic zirconia.* J. Gemm. Soc. Japan, **4**, 3, 14-19, 3 figs, 1977. (In Japanese with English summary.)

Describes physical properties, polymorphism and compares cubic zirconia with diamond. Growth by the skull-melting technique is reviewed. M.O'D.

TAKUBO (J.). *Refractive indices and specific gravities of beryls.* J. Gemm. Soc. Japan, **4**, 3, 3-8, 7 figs, 1977. (In Japanese with English summary.)

Compares constants for natural and synthetic beryls and discusses the effects of high temperatures, high pressures and impurities. Water pressure applied during manufacture has a marked effect on the refractive indices and specific gravity of synthetic beryls. Using a high pressure technique a synthetic emerald with constants as high as those for the natural material can be made. M.O'D.

TAKUBA (H.), KOIZUMI (M.). *Specific gravity, refractive indices and depth of formation of natural emeralds.* J. Gemm. Soc. Japan, **4**, 4, 24-33, 4 figs, 1977. (In Japanese with English summary.)

It was found that specific gravity increased with increase in refractive index and that deviation from the curve (postulated by the Lorentz-Lorentz law) depended upon the amount of inclusions present. Emeralds from schists and some from pegmatite deposits showed higher refractive indices than any synthetic material. Stones from vein deposits and metasomatic-type deposits have constants similar to hydrothermally-grown stones and higher than flux-grown emeralds. Emeralds with high specific gravity and refractive indices occur in those schists and granitic pegmatites where granite and ultrabasic intrusives are found. High-pressure experiments assuming that load pressure and water pressure are equal show that schist-type stones from Pakistan, India, South Africa and Rhodesia are formed in a region

deeper than 60 km, that stones from Colombia and Brazil (vein- and metasomatic-type) are formed in a region shallower than 30 km and that stones from Austria, Tanzania, the Urals and Zambia were formed at an intermediate depth. M.O'D.

TAKASU (S.). *Synthetic gemstones . . . principles and methods.* J. Gemm. Soc. Japan, **1**, 24-31, 10 figs, 1974. (In Japanese with English summary.)

The basic problem of finding an appropriate method to grow synthetic crystals for gem purposes is discussed, using garnet as an example. Representative methods for single-crystal growth are reviewed briefly, which include slow cooling, Bridgman, Verneuil, pulling, zone melting, flux, hydrothermal, vapour growth, and high-temperature-high-pressure methods. The methods for synthesizing polycrystalline gemstones such as opal and jadeite are also discussed. There are many potential gem materials among those which have been originally developed for semiconductor or optoelectronic purposes. I.S.

TATSUMI (T.). *On the refractive and reflective indices in identifying a gemstone.* J. Gemm. Soc. Japan, **2**, 105-9, 5 figs, 1975. (In Japanese with English summary.)

Since the refractive index is a function of reflective index, an instrument has been designed to measure high refractive index using the value of reflectivity. Measurement on several gemstones with high refractive index by this instrument showed that they could be identified, provided that they had a refractive index > 1.81. I.S.

TOMBS (G.A.). *Heat treatment of Australian blue sapphires.* Australian Gemmologist, **13**, 6, 186-8, 4 figs, 1978.

Sapphires sliced in order to have one half as control. The other half raised to white heat (2300°F) for short periods of time. Surfaces tended to melt. Colour became greener and there was some loss of pleochroism and some improvement in clarity in certain stones. Author is more concerned about detection of treated stones than with colour improvement and gives little information on the latter aspect. (The paper is spoiled by characteristic printers' errors, which make nonsense of part of the text.) R.K.M.

WEBER (R.H.). *Turquoise in New Mexico.* Ann. Rept. New Mexico Bur. Mines Min. Resrcs., 1974-1975, 25-8, 1 map, 1975.

The principal deposits of turquoise in New Mexico that have been sources of significant production are the Cerrillos district, Santa Fe County; the Burro Mountains and Eureka (Hachita) districts, Grant County, and the Orogrande (Jarilla) district, Otero County. Minor occurrences have been recognized in the White Signal and Santa Rita districts, Grant County, the Organ district, Dona Ana County, and the Nogal district, Lincoln County. Deposit characteristics, turquoise physical properties, history, and production for each of the above districts are discussed. J.E.T.

WILSON (W.E.), DUNN (P.J.). *The Kalahari manganese field.* Mineral. Record, **9**, 3, 137-53, 38 figs (9 in colour), 1978.

This field lies in the northern part of Cape Province, Republic of South Africa,

and produces, among many varied mineral species, exceptional crystals and crystal groups of rhodochrosite. The mines chiefly concerned with rhodochrosite are the N'Chwaning and Hotazell mines. From the former come fine groups consisting of individual scalenohedrons ranging from rich pink to deep orange-red; from the Hotazell mine rhodochrosite is deep rose-red to yellowish-pink. Stones are fetching from US $30.00 to US $60.00 a carat. M.O'D.

Pitiable condition of Rajasthan emerald mines. Gem World, **4**, 9, 33-4, 1977.

Production is said to be 500 g per year compared with 10 kg some years ago. Kala Guman in the Udaipur district is said to be the best of the mines but is at present filled with water which hinders the open-cast workings. New sources of emerald have been found at Tikhi and Goan Guda in the same district. M.O'D.

BOOK REVIEWS

ALT (D. D.), HYNDMAN (D. W.). *Roadside geology of northern California.* Mountain Press Publishing Co., Missoula, Montana, 1978. pp.xii, 244. Illus. in black-and-white. $6.95.

This is an authoritative and well-produced book which sets out to describe geological features in simple terms. The authors are members of the Department of Geology at the University of Montana and present the subject in areas defined by the main roads of the state—these appear as running heads so that the reader can see at once which area is being discussed. Photographs are good and maps clear. Much of the area described is of interest to gemmologists since many of the beaches yield pebbles of jade and agate. M.O'D.

ALT (D. D.), HYNDMAN (D. W.). *Roadside geology of the northern Rockies.* Mountain Press Publishing Co., Missoula, Montana, 1978. pp.280. Illus. in black-and-white. $6.95.

A companion book to *Roadside geology of northern California,* this includes such interesting areas as the Butte and Coeur d'Alene mining districts, as well as the Yellowstone National Park. Layout is similar to that in the other volume. M.O'D.

BARSANOV (G. P.), YAKOVLEVA (M. E.). *Mineralogiya Yashm SSSR.* (Jasper minerals in the U.S.S.R.) (In Russian.) Akademiya Nauk SSSR, Moscow, 1978. pp.86. 56 figs (15 in colour). 95 copecks.

A short guide which gives the occurrences and composition of the types of jasper found in the U.S.S.R. There is a short bibliography. M.O'D.

BLANKENBURG (H.-J.). and others unspecified. *Quarzrohstoffe.* (Rough quartz.) VEB Deutscher Verlag für Grundstoffindustrie, Leipzig, 1978. pp.243. Illus. in black-and-white. M47.

This book gives a useful survey of the properties and synthesis of quartz with

good illustrations of both the natural and synthetic material. Details of occurrences and methods of recovery are given and there is a bibliography. M.O'D.

BRUTON (E.). *Diamonds.* 2nd edn. N.A.G. Press, London, 1978. pp.xiv, 532. 548 illus. in black-and-white: frontispiece and 16 other pages in colour. £12.50.

In a review (April 1971) of the first edition of 'Diamonds' in this *Journal* it was averred that the book possessed 'the quality and dimensions of a future classic', and in its new and greatly enlarged form that tribute is shown to be fully justified. Bound, as before, in the somewhat unusual Royal octavo format, it now contains no fewer than 160 extra pages as well as a further 218 text illustrations, and with the heavy glazed paper used to ensure good reproductions of the fine range of photographs the volume now weighs more than three pounds avoirdupois. An attractive innovation is the addition of sixteen pages in colour. These are unnumbered and unlisted and presumably derive from photographs taken by the author during his extensive travels in the diamond fields together with several showing very successfully the appearance of fluorescent diamonds under ultraviolet light.

The chapter headings remain the same, though each section contains additional material, except that between the former chapters 19 and 20 a new one has been inserted on 'Famous Diamonds'. Other and useful features are the additional references given at the end of most chapters and a 'Glossary of Terms' at the end of the book.

Much of the new material concerns information on the newly-opened diamond mines and developments in the techniques of prospecting, mining and recovery. The author's personal experiences in visiting so many of the main diamond localities during recent years has added to the authenticity of his descriptions, while the long list of authorities from whom he has sought and obtained information and illustrative material testifies to the immense pains he has taken to make the book both accurate and (for the lazy-minded) attractive to browse through as a picture-book on the subject.

Developments in the grading of cut diamonds have also received full treatment. The international committee conveniently known as C.I.B.J.O., which has replaced the old B.I.B.O.A., has now produced its own grading system, which takes its place beside the very successful G.I.A. and Scan. D systems. Some of the wisest and most helpful pages in Mr Bruton's book concern the valuation of diamonds and their importance to the public as a form of investment. The true perspective provided in these pages has been very much needed. A diagram prepared from data provided by A. Monnickendam Ltd, which is reproduced on page 341, shows the alarmingly steep increase in the selling price of investment quality diamonds even over the short period since 1964.

On the more scientific side, the successful production in Switzerland, America and Russia of cubic zirconia (marketed as 'Djevalite', 'Phainite' etc.) in recent years has provided the most formidable contender so far for the 'similarity to diamond' award, and a full description of its properties and those of other synthetics of high refractive index is naturally to be found in this book, together with suggestions for their detection. Perhaps the most easily applied and most effective means to this end has been provided by a reflectivity meter designed by Dr W. W. Hanneman and named by him the 'Diamond Eye'.While Mr Bruton names and illustrates the 'Diamond Eye', one feels he might have given rather more information about its use

and added some cautionary remarks that the stone surface to be tested must be above a certain minimum diameter and be scrupulously clean if accurate readings are to be obtained. Another Hanneman product, an ingeniously designed beam balance which enables a hydrostatic determination of diamond or its substitutes (provided they are unmounted) to be made quickly and without calculation, is illustrated in a brilliantly conceived line drawing which shows with complete clarity and without the need for descriptive text how the apparatus is put into effect. The author remarks that 'another, but fussier, method is to use heavy liquids'. The reviewer can see nothing very 'fussy' about a trial in Clerici solution, provided this has been mixed to match the density of diamond. In such a solution quite tiny stones can be tested against a known diamond indicator and with an accuracy quite impossible with hydrostatic weighing. Incidentally, Mr Bruton claims that only sphene amongst those stones which resemble diamond at all plausibly in appearance has a density at all close to that mineral. While this is true for cut stones, experience in the Gem Testing Laboratory has shown that rolled pebbles of colourless topaz are not infrequently claimed as diamond by prospectors, who are misled by their considerable hardness and rather similar (3.56) density.

Still on the subject of density, in his chapter on the physical properties of diamond Mr Bruton quotes some interesting determinations on its specific gravity which made an astonishing claim to an accuracy of four of five places of decimals and to have shown that there is a significant difference between the density of Type I and Type II diamonds. Though the three workers concerned have names as Russian as could be wished, the author is wrong in assuming that this delicate work (employing Clerici solution with elaborate precautions) was carried out in the U.S.S.R. The investigation was actually done in the Massachusetts Institute of Technology and reported (in excellent English) in the *Journal of Applied Physics.*

One may be allowed to disagree with another small point, in this case concerning diamonds coloured green by exposure to radium salts or emanations, of which there are very few extant. Mr Bruton remarks that in these stones the residual radioactivity (by which they can readily be detected) 'is not harmful, as after treatment a diamond loses about half its radioactivity every ten minutes'. Such a rapid decay may be true of a diamond after cyclotron treatment, but since some radium treated stones retained appreciable activity after fifty years or more the decay cannot surely have been as rapid as all that.

The index, which of course is an important factor in a book of this kind, contains around 1300 entries and must thus be considered a good and full one. It was probably the law of cussedness that led the reviewer to look up 'density', 'dispersion' and 'lustre' and in each case fail to find an entry.

It will of course be realized that the above criticisms are matters of trivial importance. The fact remains quite clear that this is a book altogether worthy of its great subject. B.W.A.

GOODMAN (C. H. L.), ed. *Crystal growth: theory and techniques.* Vol. 2. Plenum Press, New York, 1978. pp.x, 191. Illus. in black-and-white and in colour. $29.00.

Part 3 of this useful book will appeal to gemmologists with the necessary background knowledge. It deals with the Verneuil process and lists the materials grown, with details of the various snags which have had to be overcome. Of special interest

is the section on mechanisms inducing stress; coloured photographs illustrate isochromatics seen in thin sections of spinel, depicting the operation of stress. Other chapters in the book deal with silicon epitaxy, growth effects in the heteroepitaxy of III-V compounds and an additional note on subsidiary electrical heating for Verneuil furnaces in the U.S.S.R. M.O'D.

GRAMACCIOLI (C. M.). *Die Mineralien der Alpen.* (Minerals of the Alps.) Kosmos, Stuttgart, 1978. 2 vols, pp.503. Illus. in black-and-white and in colour. Dm120.00.

Collectors have long needed an authoritative work covering the whole Alpine region. Although many guides have been produced for various countries none have had the scope and quality of this one, which should be in every collector's library. Several preliminary chapters introduce minerals, their composition and classification, and minerals are then followed through the rest of the book in traditional order, beginning with the elements. Many important species have their typical crystal form illustrated in coloured diagrams; photographs include the size of specimen depicted; species described have constants given down to space groups. Each chapter includes a short bibliography. The quality of the photographs is excellent—all those depicting actual specimens are in colour. M.O'D.

GÜBELIN (E. J.). *Im Edelstein eingeschlossen.* (Trapped in a gemstone.) Kirschgarten-Druckerei AG, Basel, 1978. Unpaged. 12 coloured plates. Price on application.

This set of 12 photographs forms part of a calendar from which it is detachable, enabling it to be used as a book. The photographs are taken from the author's *Innenwelt der Edelsteine (Internal World of Gemstones)* but are on a slightly larger scale. This is indeed a beautiful production and an original conception. M.O'D.

HAMMONS (L.). *Mineral and gem localities in Arizona.* Arizona Maps and Books, Sedona, Arizona, 1977. pp.112. Illus. in colour. $5.95.

The book consists of 30 coloured maps giving details of gem and mineral locations in Arizona. A list of minerals is appended to each map. Introductory notes mention brief details of specimens likely to be found. M.O'D.

HANAUER (E.). *Rocks and minerals of the western United States.* Barnes, New York: Yoseloff, London, 1976. pp.237. Illus. in black and white and in colour. £5.50.

Each state is discussed and the important mineral locations illustrated by a sketch-map. The directions given could possibly lead the searcher directly to the mineral required but they are not really sufficiently precise, nor are the notes on the species themselves. The coloured illustrations are of poor quality. M.O'D.

HOCHLEITNER (R.). *Mineralien Kompass.* (Mineral guide.) Gräfe und Umser Verlag, Munich, 1978. pp.79. Illus. in colour. Dm8.80.

A pocket-sized guide to the commoner minerals, this can be recommended on account of the excellence of the coloured illustrations. Chemical composition, hardness, specific gravity, cleavage, occurrence, locality and colour are given for each example as is the actual size of the specimen shown. There is a short glossary and a bibliography. M.O'D.

HOLFERT (J.). *A field guide to topaz and associated minerals of Topaz Mountain, Utah.* New revised edn. Published by the author, Bountiful, Utah, U.S.A., 1978. pp.66. 10 figs. Price on application.

An excellent pocket-sized guide to one of the well-known U.S. localities for topaz. Maps and photographs illustrate the area; together with topaz Mn-bearing red beryl, pseudobrookite, garnet and bixbyite are found. M.O'D.

KALDIS (E.), ed. *Current topics in materials science.* Vol. 1. North-Holland Publishing Co., Amsterdam, 1978. pp.xi, 761. $(U.S.)115.50.

The opening chapters deal with crystal growth and its associated problems with special reference to alkali halides; chapters 4 and 5 cover semiconducting materials and chapter 6 new work in high-temperature chemistry. Both chapters 7 and 8 deal with lithium niobate and Nb-H alloys and chapters 9 and 10 with non-stoichiometry. References are given after each chapter and there is a materials index. M.O'D.

LIEBER (W.). *Der Mineraliensammler. 7 Auflage.* (The mineral collector. 7th edn.) Ott Verlag, Thun, 1978. pp.314. 112 figs, 24 plates (16 in colour). Price on application.

This seventh edition of an old favourite is enlarged and contains more coloured plates than its predecessors. It covers the same ground, geology, mineralogy, the formation and classification of crystals, fashioning of gemstones and descriptions of the more important minerals and gems. The section dealing with localities (especially West Germany) is amplified by maps and the list of museums and the bibliography have been brought up-to-date. Since the book still remains the only general guide to the mineral localities of the world it would be good to see a translation into English. M.O'D.

MICLEA (I.), BLEAHU (M.). *Cristalele Romaniei.* (Crystals of Romania.) Editura Sport-Turism, Bucharest, 1977. pp.xiv, 33. 89 figs (all in colour). Lei 80.

Coloured illustrations of Romanian minerals include opal, beryl, garnet and amber. Short descriptions are given. M.O'D.

ROBINSON (G.), ALVERSON (S.). *Minerals of the St Lawrence Valley.* Published by the authors, Potsdam, New York, 1971. pp.42. Illus. in black-and-white. $2.50.

This small book describes 25 localities in the state of New York with short notes on 15 others. The important sites of DeKalb (diopside), the St Joseph Lead Mines (fluorescent minerals) and the titanite location at Fine are included. There is a short bibliography. M.O'D.

ROOIJMANS (C. J. M.), ed. *Crystals for magnetic applications.* Springer, Berlin, 1978. pp.139. Illus. in black-and-white. Dm58.00.

This is the first in a new series entitled 'Crystals; growth, properties and applications.' The aim, according to the publishers, is to present critical reviews of recent developments in the field of crystal growth with special reference to techniques, mechanisms and theories. This present volume includes chapters on the growth of magnetic garnets from high-temperature solutions, on the hydrothermal crystallization of magnetic oxides, on the growth of magnetic single crystals by the Bridgman technique and on gadolinium gallium garnet—the first general review of this important substance.

It is interesting to see that the author of this chapter believes that GGG is the most perfect single crystal material currently being grown; earlier difficulties with coloration and with dislocations have been identified and to a great extent eliminated. Since gallium oxide is expensive, other materials have been considered as possible replacements for GGG—the only possible one so far seems to be the compound $Ca_3Ga_2Ge_3O_{12}$. M.O'D.

RUPPENTHAL (A.) *Wunder aus dem Reich der Mineralien.* (Wonders of the mineral Kingdom.) Ruppenthal (KG), Idar-Oberstein, 1973. pp.88. Illus. in colour. £8.50.

The text of this beautifully-produced book is in German but this should not deter the prospective purchaser. Designed to show off the range of minerals sold by this celebrated German firm, it succeeds in presenting fine quality specimens, arranged chemically, with details of composition, hardness, specific gravity and, by no means least, the actual size of the piece shown. M.O'D.

SCHLEE (D.), GLÖCKNER (W.). *Bernstein und Bernstein-Fossilien.* (Amber and amber fossils.) Stuttgarter Beiträge zur Naturkunde, Series C, 8. Staatliche Museum für Naturkunde, Stuttgart, 1978. pp.72. 26 figs. (16 colour). Price on application.

This is the best-illustrated work on amber that this reviewer has seen. The various areas from which the material can be obtained are discussed and the 16 coloured plates illustrate the inclusions, mostly insects, that can be found. Simulants and testing are covered and there is a bibliography. The emphasis is scientific rather than decorative. M.O'D.

SPERO (S.A.). *Diamonds, love and compatibility. (So you think you've got a gem!)* Exposition Press, Hicksville, N.Y., 1977. pp.119. $7.50.

An attractive and amusing book which sets out to link the sale of diamond (cut) to the personality of the female buyer or wearer. Notwithstanding the title there is quite a lot of commonsense in the book, and it is recommended to counter salesmen. M.O'D.

STALDER (H. A.), EMBREY (P.), GRAESER (S.), NOWACKI (W.). *Die Mineralien des Binntales.* (Minerals of the Binntal.) Naturhistorisches Museum der Stadt Bern, Bern, 1978. pp.143. 28 plates (5 in colour), 53 figs. Price on application.

This is an up-to-date account of the minerals of the Binntal, a famous mineralized area of Canton Valais, Switzerland. It is especially noteworthy for the sulpho-salts found at the quarry of Lengenbach and these minerals are given extensive treatment. The arrangement of the book is alphabetical by name of mineral; there is a bibliography and excellent photographs in black-and-white and in colour. M.O'D.

STRASSER (A.). *Salzburger Mineralogisches Taschenbuch.* (Mineralogical pocket-book for the Salzburg area.) Eignverlag Strasser, Salzburg, 1975. pp.85. Maps. Price on application.

The first section lists minerals alphabetically, referring them to their localities which are themselves described in the second section. The third and fourth sections

provide a glossary and list of mineral species arranged alphabetically and giving their chemical composition. Various tables and maps complete the book which should be obtained by those intending to visit the areas described. M.O'D.

TAIT (H.), GERE (C.). *The jeweller's art: an introduction to the Hull Grundy gift to the British Museum.* British Museum Publications, London, 1978. pp.23. 48 figs (16 in colour). £3.95.

The Hull Grundy gift to the British Museum covers the period 1700-1930 and thus includes a number of art nouveau pieces which are illustrated in this short catalogue. The collection also includes some gold boxes of high quality, tortoise-shell, Berlin ironwork, 'botanical jewellery' and toys. The collection formed the subject of an exhibition during the latter part of 1978 and a full catalogue is promised. M.O'D.

TAYLOR (G.), SCARISBRICK (D.). *Finger rings from ancient Egypt to the present day.* Lund Humphries, London, 1978. pp.100. Illus. in black-and-white and in colour. Price on application.

This attractive book is the catalogue to an exhibition of the same title held at the Goldsmiths' Hall and later at the Ashmolean Museum during 1978. Many of the pieces illustrated and described come from two collections, those of Sir John Evans and of Charles Drury Fortnum. The introduction deals with the history of these collections, and notes on the specimens themselves are left to the individual entries. The whole catalogue is excellently produced and the black-and-white reproductions are especially clear. M.O'D.

VAUGHAN (D. J.), CRAIG (J. R.). *Mineral chemistry of metal sulfides.* Cambridge University Press, Cambridge, 1978. pp.xv, 493. £19.50.

The lucidity of this excellent book makes it worth while for the student to consult if not buy it. Students of any type of mineral will profit by reading the chapters on electronic absorption and reflectance spectra in particular, but other chapters are equally interesting. A bibliography is provided at the end of each section, and appendices give mineralogical data for the materials covered in the text and other information on the sulphides. M.O'D.

WADIA (M.D.N.). *Minerals of India.* 3rd rev. edn. National Book Trust, New Delhi, India, 1976. pp.xi, 224. R 11.25.

A general description of the types and whereabouts of minerals in India with a chapter devoted to gemstones, in which diamond, ruby, sapphire, chrysoberyl, garnet and zircon are discussed. M.O'D.

International opal journal. Impart Publishers, Reno, Nevada, U.S.A., 1977. pp.76. Illus. in colour. $2.95.

The first of this attractively-produced journal contains articles on the formation, buying, history and photography of opal. The many coloured illustrations are of high quality. So far this is the only issue produced (as at July 1978) and the publishers, in a communication to the reviewer, state that it is now to be issued annually. M.O'D.

ASSOCIATION NOTICES

GORDON F. ANDREWS—AN APPRECIATION

The sudden death on 5th January 1979, of Gordon Andrews, aged 66, secretary of the Gemmological Association from 1939 until his retirement in 1973, which was reported briefly in the January issue of this *Journal,* will have deeply shocked all who knew him.

I first met Mr Andrews in 1932 when he was introduced to the gemmology class at Chelsea Polytechnic as 'the Tully Medallist for 1931'. He and I were almost exactly the same age, but it was quite a few years before I lost the awe which the phrase inspired at that time, despite acquiring the same award myself two years later.

It was entirely fitting that Gordon should have been among the first to gain gemmology's top honour, for he had started his business career in the Bond Street shop originally owned by B. J. Tully, in whose memory the medal is awarded. Tully died in 1928 and I am not sure whether Mr Andrews ever actually knew him, but he certainly worked for Mrs Tully and with J. H. Stanley, one of the early instructors on the G.A. Correspondence Courses. In 1931 he was with Hunt & Roskell Ltd, of Old Bond Street, part of the J. W. Benson organization.

A serious minded, intelligent, quietly spoken and very personable young man, Gordon Andrews was an obvious choice to succeed E. Trillwood as secretary to the National Association of Goldsmiths in 1939. As most readers will know, the N.A.G. was the parent of the Gemmological Association and they shared offices, staff and secretary from the earliest days. The G.A. was eventually given an entity of its own, but the same arrangement held good in respect of staff and accommodation. Mr Andrews organized this change of emphasis in 1947 and later applied for letters patent and commissioned the designing of a suitable coat of arms for our Association.

After War service with the R.A.F. he returned to run both Associations from a sequence of offices and eventually from neat prefabricated premises on a bomb-site behind Goldsmiths' Hall. In 1955 both Associations moved to their present home at Saint Dunstan's House, Carey Lane, EC2. Meanwhile Gordon Andrews had launched the *Journal of Gemmology* in 1947. He remained its editor until his retirement. Later he formed the marketing company, Gemmological Instruments Ltd, which provides the retail outlet for the Rayner range of instruments. In his N.A.G. capacity he masterminded the big Clearing House Scheme which has proved so beneficial in retail accounting. He became a member of the Institute of Chartered

Secretaries and was even more qualified for the important trade position he was to occupy for so many years. Throughout those years he was ably and loyally assisted by the brothers, Harry and Douglas Wheeler, all three working as a team to bring the various innovations to successful fruition. Mr Harry Wheeler succeeded Mr Andrews as secretary.

Gordon was one of the founders of the Retail Jewellers' Course which was started initially as a rehabilitation measure for service men returning to the Trade after the War. He acted as instructor on this Course from its inception, retaining this interest and an advisory editorial interest in our *Journal* even after he had retired. He was a Liveryman of the Worshipful Company of Goldsmiths.

Taking an early retirement, largely for family reasons, he went to live in Norfolk. It is perhaps the more tragic that his death came at a time when he and Mrs Andrews were literally on the point of going to Australia to join their son, Nigel.

Gordon Frederick Andrews, always a highly respected man, was a good friend to a great many people. He contributed enormously to the well-being and development of the gem trade both here and overseas. I feel proud and, indeed, honoured to have known him for nearly 45 years. He will be greatly missed. I am sure that all readers will join in expressing sincere sympathy to Mrs Margaret Andrews and her family at this sad loss.

R. Keith Mitchell.

OBITUARY

Mr Douglas J. Ewing, F.G.A. (D.1945), Edinburgh, died suddenly on 13th March, 1979. He had been a member of Council for 25 years. Mr Ewing started evening classes in gemmology in Edinburgh in 1947 and was an instructor for many years. He was also responsible for establishing the Edinburgh Branch of the Association.

Mr Clive J. Taylor, F.G.A. (D.1973), Gravesend, died on 29th November, 1978.

Mr Edward R. Robson, F.G.A. (D.1973), Nairobi, Kenya, died on 29th December, 1978.

MEMBERS' MEETINGS

London

On Monday, 12th March, 1979, at the Central Electricity Generating Board Theatre, London E.C.1., Mr Alan Hodgkinson, F.G.A., gave a talk based on his article 'Visual Optics' (J.Gemm., **XVI**, 5, 301, 1979).

Midlands Branch

On Saturday, 27th January, 1979, a dinner and dance was held at the Allesley Hotel, Coventry.

On Friday, 23rd February, 1979, at the R.I.C. Headquarters, Birmingham, Mr E. A. Jobbins, B.Sc., F.G.A., gave an illustrated talk on the ruby and sapphire deposit of Pailin, Cambodia.

On Thursday, 22nd March, 1979, at the R.I.C. Headquarters, Birmingham, a film entitled 'Gem Fun and You' was shown. The film covered an introduction to gem collecting, gem-making tools used in cutting and polishing, and ways in which they are used. Following the film Mr D. Price, F.G.A., a prominent stone cutter,

and Mr D. Morgan, F.G.A., former Branch Chairman and noted lapidary and teacher of gemmology, gave demonstrations and answered questions arising from the film.

North-West Branch

On Saturday, 3rd February, 1979, a buffet supper dance was held at the Shaftesbury Hotel, Liverpool.

On Thursday, 15th March, 1979, at Church House, Hanover Street, Liverpool, a selection of diamond simulants was available for examination by members.

South Yorkshire Branch

On Thursday, 25th January, 1979, the Annual General Meeting of the Branch was held at Sheffield City Polytechnic, Sheffield. Dr M. W. Eldridge, F.G.A., was re-elected Chairman and Mr B. Butler, F.G.A., elected Secretary. This was followed by a practical session when specimens were available for examination and discussion.

NEWS OF FELLOWS

In January, 1979, Mr A. E. Farn, F.G.A., of the London Chamber of Commerce Gem Testing Laboratory, was interviewed in the B.B.C. radio programme 'World at One' on djevalite and asked to compare it with diamond.

On the 12th February, 1979, a seminar was held at the Rudyard Hotel, Manchester, organized by Openshaw Technical College in collaboration with Mr A. Hodgkinson, F.G.A.

During September and October 1978 Mr M. J. O'Donoghue, M.A., F.G.S., F.G.A., led a mineralogical tour to Norway, Sweden, Finland and the U.S.S.R., visiting a number of famous localities (Kongsberg, Iveland, Evje, Långban, Outokumpu, etc.) and meeting museum curators in many places.

PRESENTATION OF AWARDS

Opening the proceedings at the annual Presentation of Awards in Goldsmiths' Hall on 20th November, 1978, the Chairman, Mr D. N. King, congratulated the candidates who had been successful in the Association's examinations, which this year had been held in no less than 32 countries as well as the United Kingdom. He welcomed those who had come to the Hall that evening to receive their awards, including a contingent from Spain, some from other European countries, America, the Middle East and Sri Lanka, and one each from Japan and New Zealand. He also welcomed the Association's distinguished guests, Mr Richard T. Liddicoat, Jr, (President of the Gemological Institute of America—himself a F.G.A.) and Dr W. W. Hanneman (also from the U.S.A.) as well as Miss Margaret Biggs, F.G.A. (President of the National Association of Goldsmiths).

Miss Biggs presented their awards to successful candidates in the Association's examinations and having performed this pleasant duty recalled that this year was for her a golden celebration in gemmology, for she had taken her examinations fifty years ago in that very Hall. At that time there was no Gemmological Association but only a gemmological section of the N.A.G.: the Association had been formed some time later and had since grown into an international organization of high repute.

Miss Margaret Biggs and Mr B. G. Amarasinghe (Sri Lanka).

Sir Frank Claringbull and Mr Norman Harper.

Dr W. W. Hanneman with *(left)* Mrs Jean Smith and *(right)* Mr B. W. Anderson.

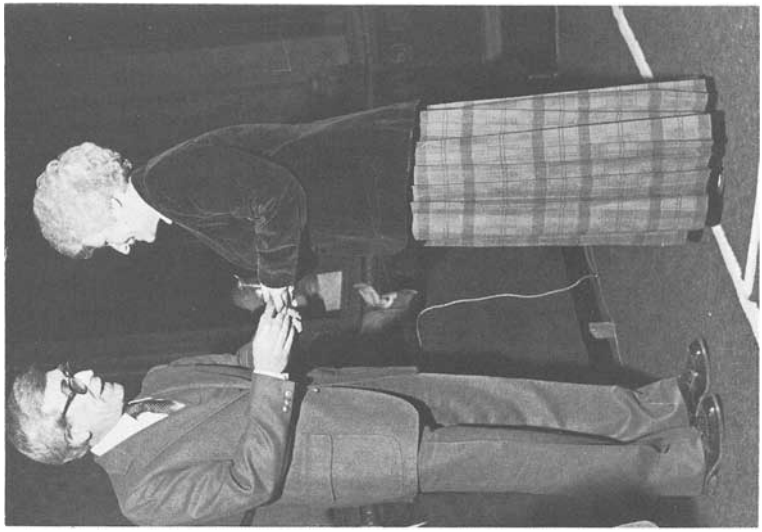

Dr W. W. Hanneman and Mr Richard T. Liddicoat, Jr.

The president, Sir Frank Claringbull, then made a presentation of a silver 'Armada' dish engraved with the Association's coat-of-arms to Mr Norman Harper, recently retired from the Chairmanship for reasons of health. When he first started in gemmology, said the President, one young man's name kept on appearing—that of Norman Harper: he had trained as an artist, was educated in history, adept as a musician, had flown in races with the Royal Aero Club and had interests in many other activities and possessed many other skills, which he had demonstrated not only in the offices he held in the Association and in the N.A.G.—he became Chairman of both—but also in lecturing and promoting the education of their members. He obtained his Fellowship with distinction in 1934 (but was 'pipped at the post' for the Tully medal by Keith Mitchell) and in 1946 was awarded the Greenough Trophy by the N.A.G. At about that time he went to the School for Jewellers in Birmingham to take a refresher course and subsequently found himself appointed the senior lecturer in gemmology. He was a freeman of the Goldsmiths' Company and had made great contributions to raising the standards of the retail jewellery trade.

The Chairman, after explaining that Mr Harper, who was not in good health, had asked to be excused for not expressing his thanks and appreciation in public, then proceeded to the last item on the agenda, the presentation by Dr Hanneman of the Hanneman Awards—which he had instituted and named in memory of his father—for outstanding contributions to the literature of gems and minerals. Eleven trophies—a symbolic prospector's hammer mounted on a slice of agate—had been designed and made for him by a well-known American artist, although Dr Hanneman said he did not yet know who all the recipients would be. The first one was in honour of the work of the late Robert Webster and was received by his daughter, Mrs Jean Smith. The second was presented by Dr Hanneman to Mr B. W.

Anderson and the third to Mr Richard T. Liddicoat, who had made a special effort to be present in London to receive the award from another American!

In closing the proceedings the Chairman expressed the thanks of the Association to the Worshipful Company of Goldsmiths for allowing the use of their magnificent Hall for this notable meeting.

COUNCIL MEETING

At a meeting of the Council held on Wednesday, 31st January, 1979, it was agreed to appoint Mrs Mary Burland as Editorial Assistant, and the following were elected to membership:

FELLOWSHIP

Amendra (née Rubesinghe), Savithri P. K., Mount Lavinia, Sri Lanka. 1978
Armitage, Kevin P., Rotorua, N.Z. 1978
Bates, Adrian J., Sutton Coldfield. 1978
Birch, John W. de Gray, Hillcrest, Natal, S. Africa. 1978
Dillimuni, Dayananda, Colombo, Sri Lanka. 1978
Fuster Casas, Miguel, Barcelona, Spain. 1978
Horkel, Dorothea, Vienna, Austria. 1978
Kan, Neville Y. C., London. 1978
Seevaratnam, Nagalingam, Colombo, Sri Lanka. 1978
Stanislaus, Saverimuttu J. L., Colombo, Sri Lanka. 1978
Ueta, Kouji, Osaka, Japan. 1978
Vargas Perez, Manuel de, Barcelona, Spain. 1978
Yamaguchi, Takashi, Osaka, Japan. 1978

TRANSFERS FROM ORDINARY MEMBERSHIP TO FELLOWSHIP

Celades Colom, Roberto, Barcelona, Spain. 1978
Verduyn-Walter, Laetitia, Capelle, Holland. 1978

ORDINARY MEMBERSHIP

Barlow, Peter C., Kidderminster
Barnett, Paul A., Johannesburg, S. Africa.
Benguira, Daniel, London.
Boreen, Henry I., Rydal, Pa, U.S.A.
Bradley, Ivon, Chesterfield.
Carson, Constance, London.
Chan, Thomas C., Maidstone.
Christensen, Ove G., London.
Clare, Vanessa J., St Albans.
Cotton, Sarah N., Kitwe, Zambia.
Derry, Catherine E., Nottingham.
Dix, Neil R., Opio, France.
Donohoe, Edward, London.
Duke, Paul E., Singapore.
Emms. Eric C., Brentwood.
Fjordgren, Olle, Gothenburg, Sweden.
Fondyga, Eugeniusz W., Sutton Coldfield.
Forbes, Maureen, St Albans.
Freeman, Darlene M., Belmont, Ca, U.S.A.
Giannella, Donata, Rome, Italy.
Gunther, Bernhard, Basel, Switzerland.
Gustine, Richard R., Richmond, Va, U.S.A.
Hakamada, Tetsuo, Hokkaido, Japan.
Harada, Hirotaka, Tokyo, Japan.
Haria, Ashok P. M., Mombasa, Kenya.
Hirst, Rosalind, Johannesburg, S. Africa.

Horwitz, Stephen T., Atlanta, Ga, U.S.A.
Huges, James P., Launceston, Tasmania.
Joynt, James, Hereford.
Kessler, Paul, London.
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Lo, Tung Man, Kettering.
Lodhia, Babulal D., London.
Low, Teck K., Kuala Pilah, N. Sembilan, W. Malaysia.
Mai, Lionel, D'Heres, France.
McLerie, Robin E., London.
Medagoda, Alfred S., Maccesfield.
Metters, George H., Ascot.
Mountfort, Donald, Kingsford, N.S.W., Australia.
Moxon, Michael D., Palmerston North, N.Z.
Newman, Kathryn J., Tahunanui, Nelson, N.Z.
Noach, Louis, London.
Okamoto, Yoshitaka, Osaka, Japan.
Ow, Evelyn, Singapore.
Peel, Charles D., Midland, Tex., U.S.A.
Phillips, Ian, Nottingham.
Pickering, Caroline A., Nairobi, Kenya.
Pickett, David J., Southsea.
Price, Stephen A., Ipswich.
Rankin, Roderick W. G., Whangarei, N.Z.
Rapley, Michael J., Guildford.
Rosen, Elly, Brooklyn, N.Y., U.S.A.
Rumbold, Richard, St Leonards-on-Sea.
Samarajiwa, Eulalie, Reading.
Santiago-Gonzalez, Antonia, Tenerife, Canary Islands.
Sheffield, Martin, Don Mills, Ont., Canada.
Sideras, Triantafilio R., Nairobi, Kenya.
Silvant, John C.M., London.
Siroya, Bakhtawarmac B., Bombay, India.
Sivananthan, Chinniah A., Colombo, Sri Lanka.
Sjostrom, Bjarne J., Vallingby, Sweden.
Soni, Dinesh, Hounslow.
Sutton, Graham G., London.
Takahashi, Narifumi, Hiroshima City, Japan.
Tan, Carmela, Hong Kong.
Tarbuck, William B., Manchester.
Tateishi, Masateru, Tokyo, Japan.
Toughlouian, Gregoire, Chaville, France.
Verdiere, Jo, Kuurne, Belgium.
Wantanabe, Yoko, Hokkaido, Japan.
Win, Min Hla, Cupar.
Wong, Helen, Hong Kong.
Wu, Shun-Tien, Taipei, Taiwan.
Wyant, Harvey C., Lighthouse Point, Fla, U.S.A.
Yui Wai, Richard K., Hong Kong.

ANNUAL GENERAL MEETING

The Annual General Meeting of the Association will be held on Wednesday, 16th May, 1979, at 6.00 p.m. at Saint Dunstan's House, Carey Lane, London EC2V 8AB.

ETHYLENE DIBROMIDE—A WARNING

Ethylene dibromide (sometimes called ethylene bromide, dibromoethane, sym-dibromoethane, 1,2-dibromoethane, glycol dibromide or EDB) is commonly used by gemmologists as a heavy liquid (SG 2.188) or (owing to its low surface tension) in hydrostatic weighing. It is now listed by the National Institute for Occupational Safety and Health of the United States as a suspect carcinogen and rigorous precautions are suggested by the Institute for its use.

quantities are administered direct to the stomach, there is no evidence to date of any cases of cancer in man following exposure to it. Excessive acute or chronic exposure to EDB, however, can produce toxic effects in man, which can result from skin contact, inhalation of vapour, or, of course, swallowing. Care should therefore be taken in using ethylene dibromide (and also Clerici solution, and indeed any liquids other than clean water) to avoid skin contact or inhalation of vapour, and on no account should any of the liquids used by gemmologists for gem testing be swallowed.

In case of contact with the skin, it should be washed off: if in the eyes, they should be well flushed out with running water: if inhaled, move to fresh air: if swallowed, vomiting should be attempted and medical assistance obtained.

DEUTSCHE GEMMOLOGISCHE GESELLSCHAFT
2nd TECHNICAL CONFERENCE OF 1978

(Report received from Mr Peter G. Read, F.G.A.)

The Second 1978 Technical Conference of the German Gemmological Association was opened by the Association's President, Prof. Dr H. Bank, F.G.A., in the Diamond and Gemstone Bourse in Idar-Oberstein on Saturday, 30th September. This was followed by a talk on 'Methods of Geological Dating' given by Dr Klaus Hellmann, of the Nuclear Research Centre, Karlsruhe. In his talk, Dr Hellmann covered the various techniques of radio-active dating and discussed their relevance to the age determination of rocks and minerals.

This initial talk of the Conference was followed by a series of working and discussion meetings which were held in the well-equipped lecture rooms and laboratories of the new DGemG Gemmological Training Centre.

On Sunday, 1st October, Diplomas were presented to the successful graduates of the DGemG study courses by the President Prof. Dr H. Bank, and by Dr G. Lenzen. Dr Diehl then gave a talk on 'Djevalite, Phianite, Zirconia—what are they?' in which he described the Russian skull melting technique and the methods used to stabilize zirconium oxide in its cubic state. This was followed by talks on 'Automatic Weighing' by P. G. Read and on 'Gemstones of East Africa' by Dr K. Schmetzer.

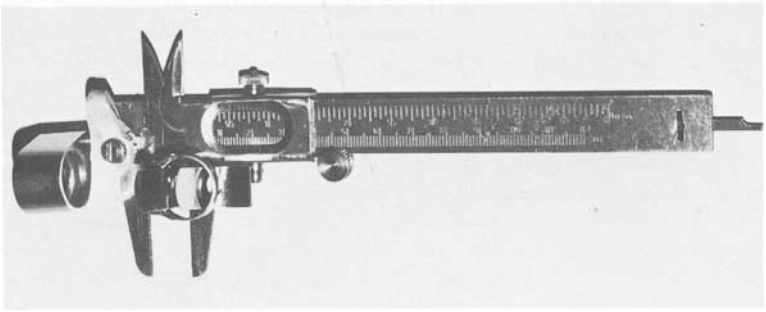

After these three talks, H. Bartmann demonstrated a novel combination of vernier calliper gauge and hand lens which he had constructed to facilitate the measurement of refractive indices of both mounted and unmounted gemstones by the direct reading method. The illustration shows the device with a ring clipped in a spring holder. The apparent depth of the gemstone in the ring is measured by focusing the lens, via the calliper adjustment, first on the surface of the table facet, and then on the culet, and subtracting the two readings. The actual depth of the stone is measured directly, using, in the case of a mounted stone, an extension anvil fitted to the gauge head.

The final series of talks included short reports by W. Schneider on the 'Slocum Stone' and by D. Schwarz on 'Fluorescent properties of new diamond imitations'.

Among the faceted gem minerals on display were amethysts from Russia and Arizona and morganites from Brazil. Also shown were samples of cubic zirconium oxide crystals and several rock crystal specimens containing large pyrite inclusions.

ADDENDA

By way of clarification, Mr G. Bosshart would like to add three notes to his article 'Cubic Stabilized Zirconias' in J. Gemm., XVI, 4, 244-56, namely:

(1) The following to be added at the end of paragraph 3(c) on page 250 above, viz: For obvious reasons a gemmological spectroscope, effective in the wavelength range of 400 to 700 nm, is of little aid in the differentiation between these nearly colourless solids. The yellow type of $(Zr,Ca)O_{2-x}$ absorbs totally below about 310 nm and the brownish-pink type below about 360 nm, which is roughly inverse to the behaviour of yellowish and faint pink $(Zr,Y)O_{2-x}$ as indicated in Table 1. For colourless $(Zr,Ca)O_{2-x}$, manufactured in Switzerland, total absorption starts near 260 nm as it does for $(Zr,Y)O_{2-x}$ of the Russian production, this minimum figure being valid for various hues of the faintest saturations (very weakly greenish, bluish, orangy, etc.).

(2) The label '$(Zr,Y)O_{2-x}$ colourless' in Fig. 1 on page 251 above to be replaced by '$(Zr,Y)O_{2-x}$ faint pink'.

(3) For the interested gemmological reader, the most comprehensive and latest article among modern papers on single crystals of cubic stabilized zirconia and hafnia may be mentioned, namely:

Alexandrov, V. I. *et al.* 1978. 'Synthesis and Crystal Growth of Refractory Materials by Radio-frequency Melting in a Cold Container', in *Current Topics in Materials Science,* vol. 1, pp.421-80. Amsterdam, New York, Oxford: North-Holland Publ. Co.

CORRIGENDA

On p.324 above, line 11, for 'The Rubyvale Sapphire Fields' (sub-heading) read 'The Rubyvale and Sapphire Fields'.

On p.331 above, lines 9 and 8 from foot of page, for 'back-how' read 'back-hoe'.

On p.349 above, second column, line 9, for '(Verduyn) Walter, Laetitia' read 'Verduyn-Walter, Laetitia'.

GEM TESTING EQUIPMENT

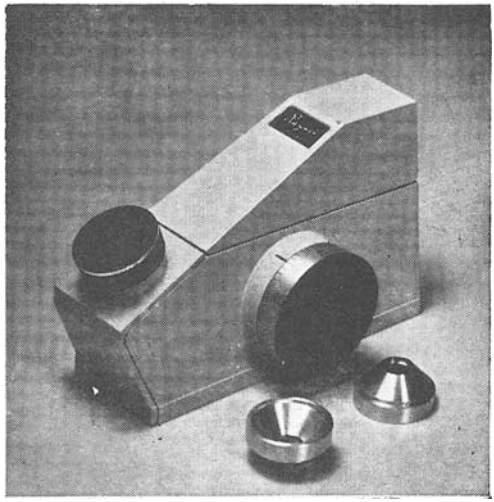

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THE JOURNAL OF GEMMOLOGY

and

PROCEEDINGS OF THE GEMMOLOGICAL ASSOCIATION OF GREAT BRITAIN

GEMMOLOGICAL ASSOCIATION
OF GREAT BRITAIN
SAINT DUNSTAN'S HOUSE, CAREY LANE
LONDON, EC2V 8AB

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THE JOURNAL OF GEMMOLOGY
AND PROCEEDINGS OF THE GEMMOLOGICAL ASSOCIATION OF GREAT BRITAIN

Vol. XVI No. 7 JULY, 1979

INVESTIGATING THE VISIBLE SPECTRA OF COLOURED DIAMONDS

By KENNETH SCARRATT, F.G.A.
The Gem Testing Laboratory, London Chamber of Commerce and Industry

INTRODUCTION

There have been some interesting developments in recent years in the methods used to detect and the information compiled on natural and artificially coloured diamonds. Most of these developments have involved in some way the absorption and/or emission spectra. This paper will deal solely with this aspect. The identification of irradiated diamonds is sometimes a difficult and controversial subject and as such should only be attempted by an experienced spectroscopist with a great deal of background knowledge. It is hoped that the following will provide for some of the latter: the former may only be obtained by hard work on the part of the individual. Some time ago in this laboratory it was decided to initiate a fresh study and to correlate the known facts and problems involved. The investigation is over an extended period of time: stones of all colours have been and are continuing to be examined.

ISSN: 0022-1252 XVI (7) 433 (1979)

We have received a considerable amount of practical help from the solid state physics research group at King's College, London, from the recognized laboratories on the European and North American continents and from the father of gemmological spectroscopy, B. W. Anderson.

THE INVESTIGATION

At the outset the most pressing problem was the positive identification of the very few treated yellow Type Ia diamonds which at room temperature have no indication of the 'diagnostic' absorption line at 594nm. This line is induced into the spectrum of an irradiated diamond after the stone has been annealed, as are the lines at 504 and 497nm and many others. If the stone is annealed at temperatures above 1000 °C the 594nm line, unlike the lines at 504 and 497nm, disappears[1] even when the spectrum is examined with the stone at 77K.* After such treatment all that may remain in the spectrum to give an indication of artificial coloration could be the lines at 504 and 497nm and any 'cape' lines which had been present before irradiation. Neither the 504 nor the 497nm line unfortunately is uncommon in the spectra of naturally coloured yellow or yellow/brown diamonds. It would therefore seem that the answer lies in our ability to differentiate between the naturally occurring 504 and 497nm lines and those induced by artificial irradiation and annealing.

In the past some authorities have noted a difference in the relative strengths of these lines when they occur naturally to when they are induced.[2] We have run a survey on a number of known treated and known naturally coloured yellow and yellow/brown diamonds, paying particular attention to the relative strengths of the 504 and 497nm lines. A sample of 32 known irradiated stones were checked. Figure 1 shows that in ten stones the 504 was the stronger, in thirteen stones the 504 and 497 were of similar strength and in nine stones the 497 was the stronger.

These findings are best explained in a paper by Davies and Summersgill.[3] Briefly—in irradiated and annealed Type Ia diamonds the strengths of the 504 and 497nm lines are dependent upon the strengths of the nitrogen induced A and B absorption bands in the infrared. (The A form with peaks at 1282 and

*K (kelvin): see J. Gemm., 1977, XV, 5, 244.—Ed.

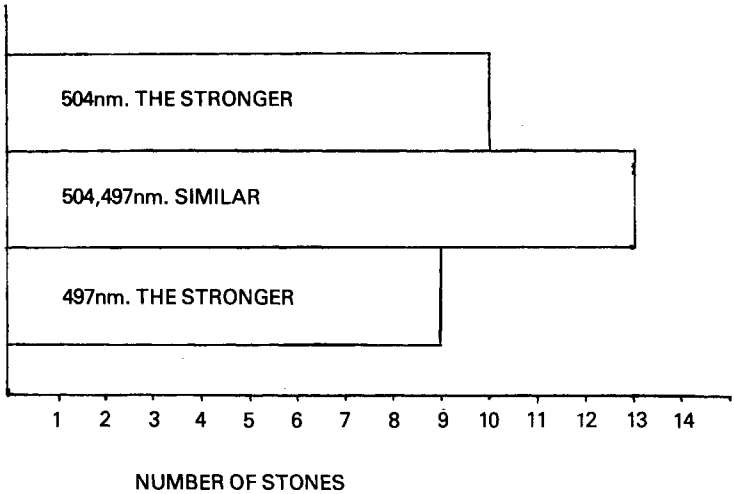

FIG. 1. In a sample of 32 irradiated yellow and yellow/brown diamonds, 10 stones had the 504nm line predominating, 13 stones had the 504 and 497nm lines of similar strength and in 9 stones the 497nm line predominated.

1206 cm^{-1} and the B form at 1172 cm^{-1}).* That is the 497 and 504 line strengths produced in a diamond by irradiation and annealing are present in a ratio proportional to the ratio of the B to A nitrogen. Either one of these infrared bands may predominate or they may be present in roughly equal proportions. It cannot therefore be stated that in a treated diamond either one or the other of the 504 or 497nm lines must predominate.

Davies and Summersgill in the same paper note that generally speaking there is a tendency for the stronger 415nm absorption to be found in a diamond with a strong B band. This confirms our observations. Figure 2 shows that in a sample of thirteen irradiated yellow diamonds in which the 415 system was very strong, the lines were of similar strength in six stones, the 497 predominated in six stones and only in one stone was the 504nm line the stronger. When the 504, 497nm lines have been observed in naturally coloured yellow stones, with strong 415nm systems, albeit very weakly in some cases, we have found the 504 either is the stronger or the lines are of similar strength. In many cases the 497 has been absent. There is a similar situation found with the naturally coloured

*For cm^{-1} see J. Gemm., 1977, XV, 5, 247.—Ed.

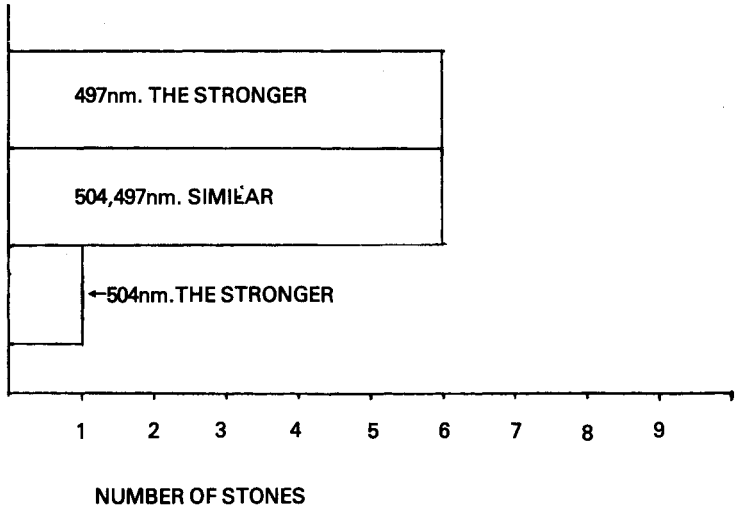

FIG. 2. In a sample of 13 irradiated yellow diamonds in which the 415nm system was very strong, the 504 and 497nm lines were of similar strength in 6 stones, the 497nm line predominated in 6 stones and only in one stone was the 504nm line the stronger.

brownish yellow stones we have examined. Those which have had the 504, 497nm lines visible have the former as the stronger partner.

It appears, as has already been noted by Collins,[1] that the naturally occurring 497, 504nm lines are in general not present in a ratio proportional to the ratio of the B to A nitrogen. This may seem to be the basis of an answer to the problem; however, the difficulties involved in measuring the B to A nitrogen concentrations in most gem diamonds make this line of investigation impracticable.[1] From the foregoing it becomes apparent that with the use of only normal gemmological techniques, the relative strengths of the 504, 497nm lines can only serve as a very general guide.

We know through the teachings of B. W. Anderson that the absorption lines in diamond are often sharpened when the temperature of the stone is lowered. This is very much the case with the 594nm line. If a stone with this line present is allowed to rise much above room temperature during examination, there is a good chance the line will disappear and only return once the stone has cooled. To counter this we have often used ice during an examina-

tion, and it was with considerable gratitude that we readily accepted an offer by Dr A. T. Collins and his colleagues to design and build for us an apparatus which would cool our diamonds to approximately 120K and keep them there during the course of a spectroscopic examination. This apparatus is now built and functioning in the laboratory. It is described in Figure 3. The theory upon which it works is surprisingly simple. Liquid nitrogen in a suitable container is evaporated by an electrical element, and the cold gas given off is then blown over the sample which is held in a glass vessel with evacuated walls.

This method not only sharpens many of the absorption lines, it also makes visible those which are not seen at room temperature. An example of the improvement achieved is produced in Figure 4. Here a known irradiated yellow stone with a very weak 594nm line (by transmitted light) was first examined at room temperature *(a)* and then at approximately 120K *(b)*. This method of observation is now helping us with the problem of the absent 594nm line. If the line has not been completely annealed out, but is not visible under normal conditions, it will be seen at low temperatures. Since the installation of this equipment we have had for examination two irradiated yellow stones in which the 504 was much the stronger of the 504, 497nm partnership. In both stones we noted that the 497 had at low temperatures resolved into a structure most easily described as a doublet, with a strong line at 497nm and a weaker line on its short wave side at approximately 496nm. (Figure 4c.) A similar structure has previously been noted by Gübelin[4] in treated yellow stones.

Collins[9] explains that when the 504nm line is strong and the 497nm line is weaker the 504 first phonon replica is produced on the short wave side of the 497nm line, thereby giving the appearance of a doublet in the area of the 497. When we first observed this structure we had not seen or heard of it recorded in any naturally coloured stones. We have since seen exactly the same structure in a naturally coloured green stone, which is to be described later.

Naturally, as yellow is the most popular and one of the easiest to obtain of the fancy colours, we are asked to examine more of this colour than any other. Following close behind are the browns. These two together make up the majority of coloured diamonds entering the laboratory. With brown Type Ia stones we have not as yet had the same problems concerning the 594nm line. It is worth

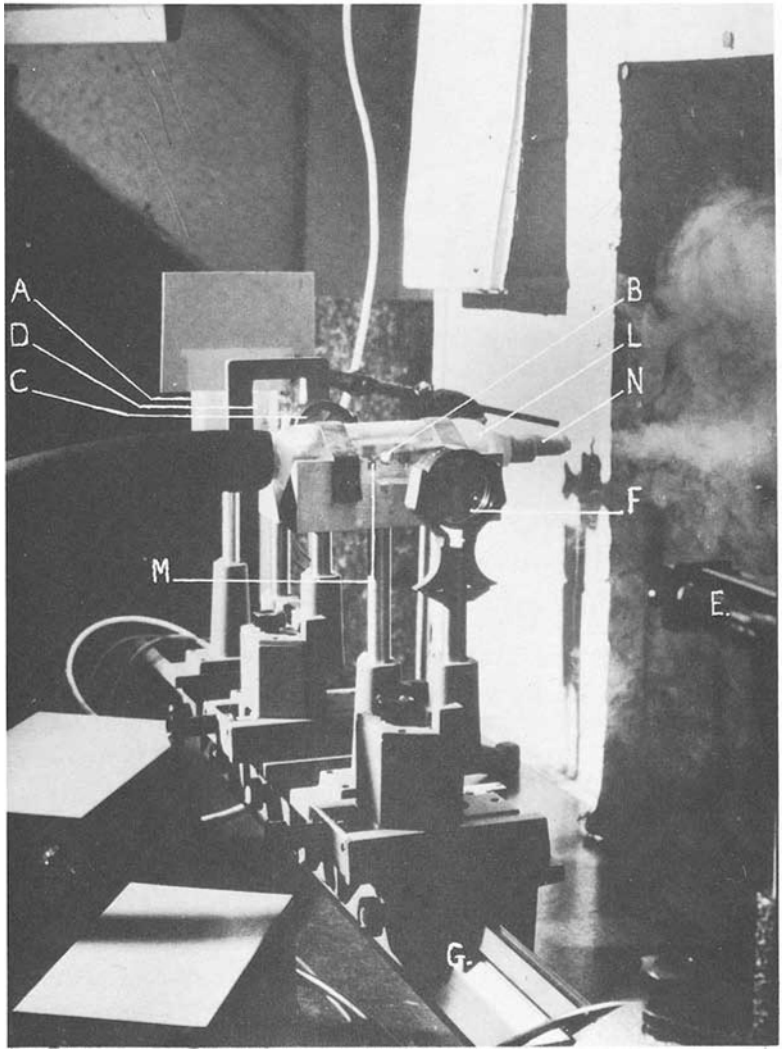

FIG. 3 (1)

FIG. 3. THE EQUIPMENT USED TO LOWER THE TEMPERATURE OF COLOURED DIAMONDS

The light from the 100 watt source *(A)* is focused on the diamond *(B)* by the lens *(C)* after passing through the heat filter *(D)*: the light after passing through the diamond is focused on the spectroscope *(E)* by the lens *(F)*: all of these being mounted on an optical bench *(G)*. The control console *(H)* is a 12 volt lamp supply unit. The liquid nitrogen is stored in the container *(I)*. The console *(J)* controls the electrical element which is inside the liquefied gas container. The cold gas travels along the insulated tube *(K)* into a glass vessel with evacuated walls *(L)* in which the diamond is held bv a specially designed holder *(M)* which incorporates the exhaust *(N)*.

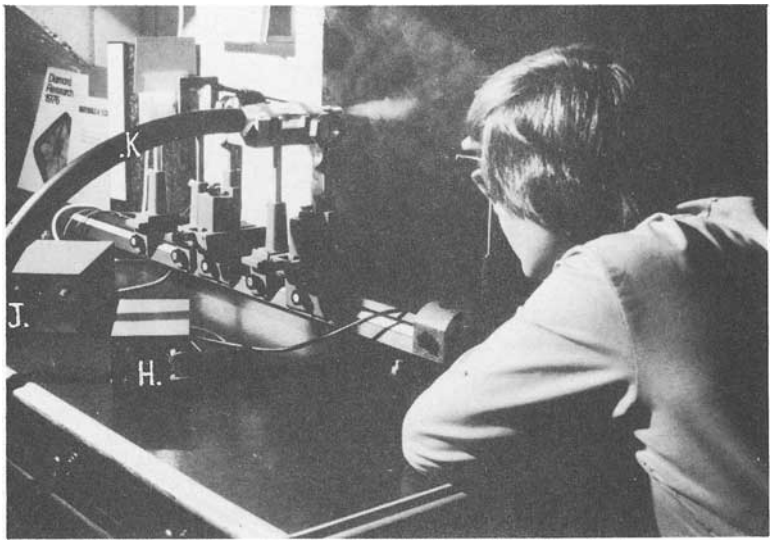

FIG. 3 (2)

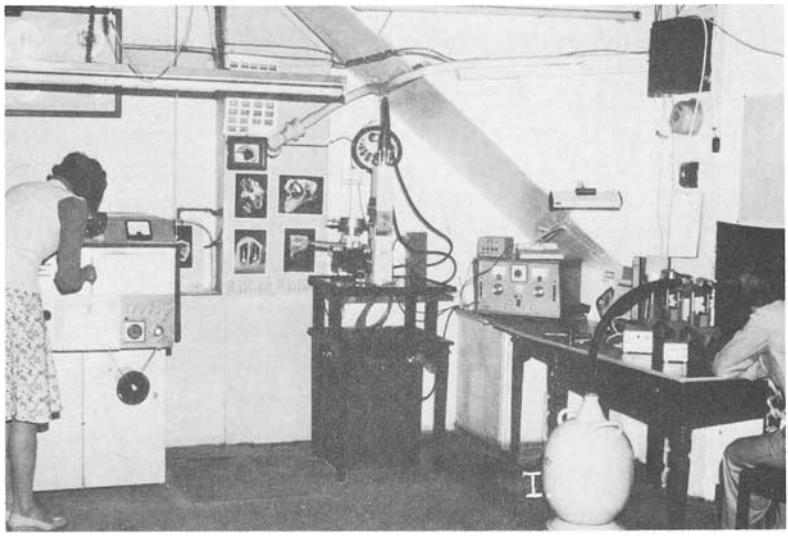

FIG. 3 (3)

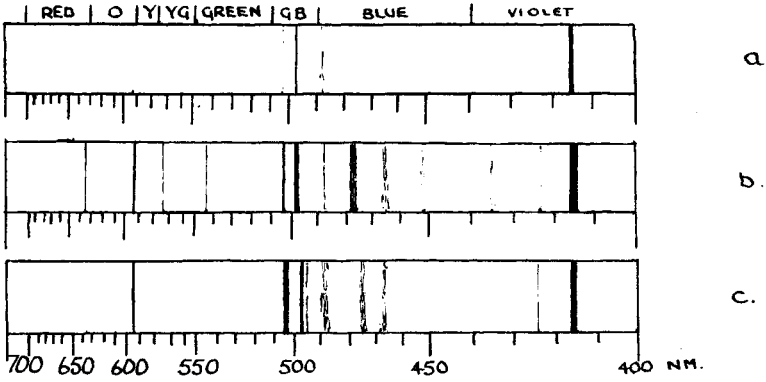

FIG. 4. The room temperature spectrum of an irradiated yellow diamond *(a)* and the low temperature spectrum of the same stone *(b)*. The low temperature spectrum of an irradiated yellow diamond in which an extra line is resolved on the short-wave side of the 497nm line *(c)*.

noting however, that in the natural brown stones so far examined which show the 504, 497nm system, either line may predominate, or they may be of similar intensity, as is found with the treated browns we have examined. We have not had the opportunity at this time to examine at low temperatures a treated brown in which the 504 predominates. Therefore we cannot say if a similar structure to that seen in the treated yellow stone at 497, 496nm exists in this colour. The room *(a)* and low temperature *(b)* spectra of a treated brown diamond are given as another example of the effectiveness of the cooling equipment in Figure 5. The 504, 497nm lines are often referred to as the 'brown lines'. This being because these lines along with those at 512 and 537nm are associated with brown or yellow/brown natural diamonds. They are often very difficult to

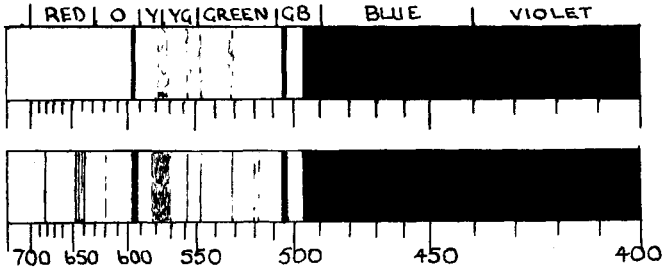

FIG. 5. The room *(a)* and low temperature *(b)* spectra of an irradiated brown diamond.

see at room temperature and are often accompanied by the line at 415nm.

These are not, however, the only lines to be seen in natural brown stones. We have recently recorded unusual spectra in six naturally coloured brown stones, four of which were a strong brown colour and two a dirty yellow/brown. Four of these, including the yellow/brown stones, consisted of two pairs—from the absorption spectra and other properties we have concluded that they were cut from two crystals. Both yellow/brown stones at room temperature recorded a strong full cape spectrum—415, 478nm, etc. At low temperatures the spectra had additional strong sharp lines at 471.8 and 558.5nm and two further very weak lines at approximately 540 and 548nm. At the time the other four stones were examined we did not have the facility for cooling diamonds. At room temperature the first of the single stones had an absorption spectrum with a very strong line at 415, sharp lines at 478 (not the cape series line) and 562nm and two fuzzy lines, one at 546 and the other at approximately 554nm. Note the similarity of the spectra seen in these first three stones. The fluorescence properties are also very similar.

The pair of deep brown stones gave absorption spectra with sharp lines at 504 and 497 plus two further sharp lines at 466 and 471nm. The last of this group revealed a sharp line at 504nm and a weaker but still sharp line at approximately 470nm. There was a very weak fuzzy band in the region of 465nm. The similarity of the spectra of these last three stones is also quite striking. The fluorescence properties are also very similar. It is tempting to assume that if the latter three stones were examined at low temperatures a group of lines in the yellow/green and green similar to those in the first three stones, may be resolved. However, this is speculation and we may never have the opportunity to prove or disprove the theory.

A problem we are currently facing concerns what may be Type Ib brown stones. We have examined three such stones recently and know of one other which is being examined on the continent. The first of the three stones we have examined has at low temperatures a strong sharp line at 637nm and weak diffuse bands at 616 and 596nm approximately. There is also a weak but sharp line at 504nm. The second stone at low temperatures has lines at 635 and 631.5nm and a weak fuzzy area at approximately 592nm. In both these stones the bands at 637 and 635nm respectively are visible at

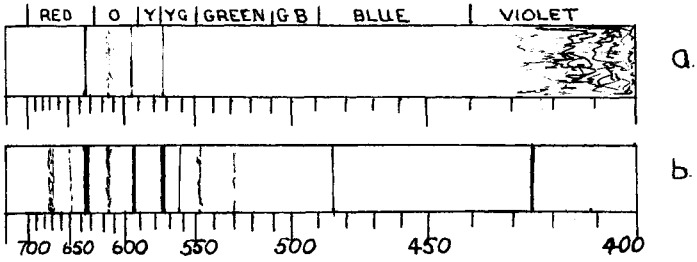

FIG. 6. The room *(a)* and low temperature *(b)* spectra of an irradiated pink diamond. The line at 573.5nm may be seen in absorption or fluorescence. There is a further fluorescent line on the short-wave side of the absorption line at 548.5nm at approximately 548nm.

room temperature. The third stone at room temperature shows only a general absorption of the violet, but at low temperatures a line at 634.5nm, sharp and clear, is resolved.

This is the type of absorption spectrum we would expect to see in Type Ib irradiated and annealed diamond.[3] The treated pink stones have a similar spectrum—the 637nm line is usually very much stronger. There is a strong possibility that this type of spectrum could appear naturally in brown stones but we have found no record of it. Until we are able to examine similar stones with the same spectrum and of a known history, the cause of the colour in these stones must remain in the grey area. The room *(a)* and low temperature *(b)* spectra of a treated pink diamond are recorded in Figure 6. A cursory glance at the low temperature spectrum could lead one to believe that the stone was a Type Ia with a strong 415nm line. This is because the line at 426nm has a similar appearance. Davies and Summersgill[3] have reported that the line at 636 appears to be associated with isolated substitutional nitrogen—Type Ib. Crowningshield has reported[5] a 415nm absorption in treated pinks with the 636nm system. Here the possibility is a mixture of Ia and Ib.

The absorption spectrum of natural pink stones at room temperature seen in the course of this investigation in the main consists of a 415nm line or no absorption lines at all. In one stone the fluorescence spectrum recorded by Anderson[6] was observed, consisting of a strong fluorescent line at 575 and three weaker fluorescent lines at 585, 598 and 620nm approximately. This spectrum was obtained by filtering the incident light through a copper sulphate solution. We have examined three natural pink stones at low temperatures, two showed no absorption. The third,

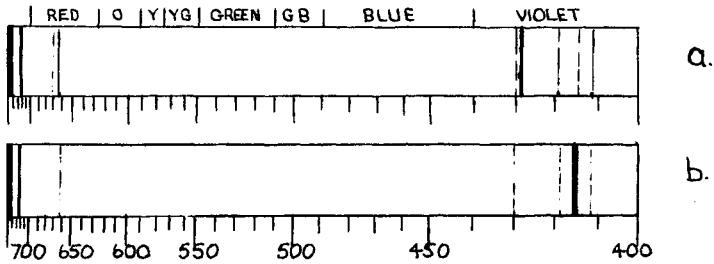

FIG.7. The low temperature spectra of two irradiated blue diamonds.

the same stone which revealed the fluorescence spectrum, had a fine absorption line at 572.6nm, This stone in every way emulated the two reported by Anderson.

We have examined at low temperatures the spectra of two natural and two irradiated blue stones. The natural stones conducted electricity and the treated stones were insulators. This would seem to be a simple enough test to enable us to distinguish between the two. We must however take into account the possibility of a naturally occurring blue stone being other than Type IIb. The natural blue stones showed no absorption in any part of the visible spectrum. At room temperature one of the treated stones had no absorption lines, while the other had a very strong 415nm line. At low temperatures both stones revealed similar spectra (Figures 7a and 7b respectively).

In the violet the spectra differed a little but both formed basically a similar pattern. The first stone (7a) had a strong line at 428.5 and weaker lines at 430, 419, 415 and 413nm. The second stone (7b) had a very strong line at 415 and then weaker lines at 430, 418 and 413nm. The lines in the red end of the spectrum in both stones were very interesting. Both had a fine sharp line at 662nm. One stone (7a) had another line on the long-wave side of this at approximately 670nm.

Both stones had two strong lines in the deep red. There was some difficulty in measuring these two lines, therefore the resulting values can only be considered as approximations. The stronger was at 742nm and the weaker at 720.6nm. The line at 742nm is probably the one referred to by physicists as the GR 1 (general radiation 1). An earlier reference in the gemmological texts to what are probably these lines is given in a paper by Anderson[7]. A similar spectrum is

also reported by Schiffmann[8]. If the line at 742nm is the GR 1, with the aid of the cooling apparatus the problem of identifying irradiated unannealed green stones with only the use of the hand spectroscope would be made that much simpler. The GR 1 band is induced by artificial irradiation and as such is present in all irradiated stones but is destroyed during the annealing process.[1]

Four irradiated green stones have been examined at low temperatures. The absorption observed in the spectrum of one of the four consisted of the full 'cape series' plus a very weak band on the short-wave side of the 415nm line (Figure 8a). The remaining three (8b, c, d), whilst differing in wavelengths shorter than 650nm, had virtually identical patterns in the red and deep red, the two most prominent lines in the deep red having the same values as those in the irradiated blue stones. At room temperature as with the irradiated blue stones only those with the 415nm system revealed any absorption, this consisting of a weaker version of the cape lines recorded at low temperatures and nothing else. All other lines are only visible at low temperatures.

The lines at 471 and 560.8nm recorded in 8c form a pattern very similar to those recorded in the brown stones previously mentioned. This may be taken as yet another warning to step

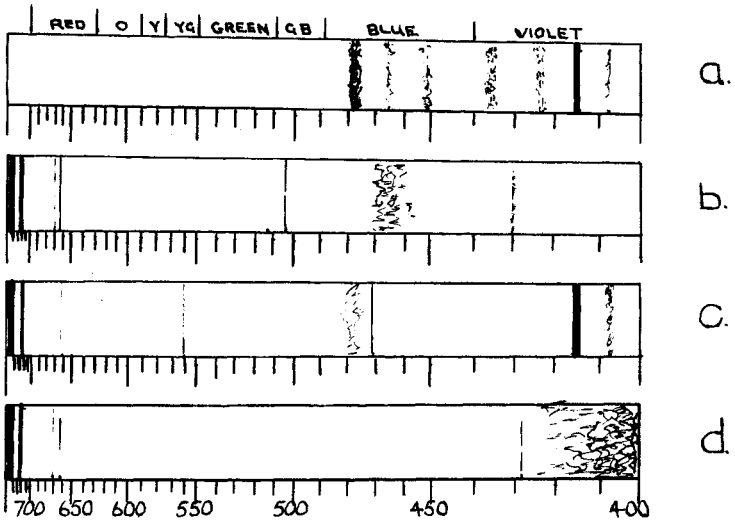

FIG. 8. The low temperature spectra of four irradiated green diamonds.

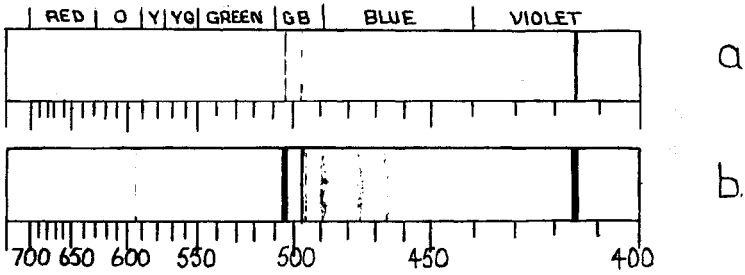

FIG. 9. The room *(a)* and low temperature *(b)* spectra of a *natural* light green faceted diamond. The low temperature spectrum reveals the line at 594nm which is normally indicative of a treated stone.

cautiously when examining coloured diamonds. Many lines which are induced by artificial irradiation may also be produced naturally. Another example is the line often referred to as the 'treated line' at 594nm. Whilst this line is seen in the greater majority of irradiated stones which have been annealed at temperatures between 300 and 900 °C, it has previously only been observed naturally in a very few uncut crystals.[7]

We have during the course of this investigation now seen the 594nm line in a naturally coloured faceted light green stone. There can be no doubt of this stone being naturally coloured. This being a statement of some importance we will record here a full description of the stone concerned.

The room and low temperature spectra may be seen in Figures 9a and 9b respectively. The 594nm line becomes visible only at low temperatures. Three absorption lines are seen at room temperature; they are at 504, 497 and 415nm. The 504 and 497nm lines are fine and sharp, the former being the stronger. The 415nm is strong and sharp. At low temperatures their strength is greatly increased. The 497 is resolved into a kind of doublet and three vague bands are seen on the short-wave side of this. By reflected light at room temperature, in certain directions, three fluorescent lines appear in the region of the blue/green boundary. The stone is old cut and cushion shaped, weighing 0.95 ct. The dimensions are: width 4.9mm, length 5.7mm and depth 4.1mm. Under x-radiation there is a bright fluorescence consisting of a mixture of yellow and blue, with a phosophorescence. Under both long-wave and short-wave ultraviolet radiation the stone is a fluorescent green. The effect is brighter under long-wave.

Five other stones of a similar colour have been examined recently. All were naturally coloured. Four of the stones were examined before the low temperature apparatus was operational. We were able, however, to examine the fifth stone in this manner. No 594nm line was seen. All five stones had absorption spectra similar to that in Figure 9a. In one stone the 504 and 497nm lines were of approximately equal strength with the possibility of the 497 being fractionally stronger. The other four stones had the 504nm line as the prominent member. We have only seen one stone of this exact colour, which has been reported upon by several laboratories as being treated. It has not been examined at low temperatures. The 594 line is seen with difficulty by reflected light only, at room temperature. Other lines noted were a weak 415 and 504, a strong sharp 497 and a weak line on the short-wave side of this in the region of 490nm.

There has been of late some commercial interest shown in black diamonds. It follows that the people concerned have required a laboratory examination of their stones. Those naturally-coloured black diamonds we have examined owe their colour almost entirely to masses of black graphite-like inclusions. The only absorption spectrum seen has consisted of a solitary 415nm line. The irradiated black stones, when a thin section is examined, are in fact very deep green. Obtaining a spectrum from such stones has its difficulties. When it has proved possible the spectrum illustrated in Figure 10 has been the result. The lines at 504 and 497nm are extremely strong.

The foregoing information is but a pin-prick compared to the wealth of information provided by earlier researchers. There is still much to be learnt about the peculiarities of the absorption and emission spectra of diamond. Research is being carried out at all levels and I have no doubt that this will be so for many years. Any

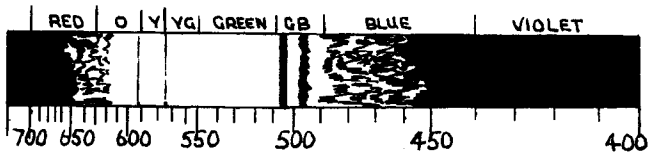

FIG. 10. The room temperature spectrum of an irradiated black (very deep green) diamond.

further developments on the topics discussed in this paper will, we hope, be published at a later date in this *Journal.*

The author acknowledges the ready help given by his colleagues in gathering the information for this paper and the help given by members of the trade in supplying the samples on which the majority of the work was carried out. To Dr A. T. Collins and his colleagues the laboratory owes a special note of thanks. The photography for Figure 3 was kindly carried out by the Institute of Geological Sciences.

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MORE DATA ON VIOLET GEM SCAPOLITE, PROBABLY FROM EASTERN AFRICA

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INTRODUCTION

In the beginning of this year (1978) a parcel of violet cut stones was sent in for identification by a gem-cutter in Holland. The stones were offered to him as scapolites originating from Eastern Africa.

Many papers dealing with scapolites, especially from East African countries, have been published recently. Strunz and Wilk (1976) describe violet Mg-rich marialite with refractive indices ε 1.559 and ω 1.563 and a density of 2.64 to 2.67. In a paper of Dunn *et al.* (1978) the lowest properties mentioned are ε 1.545 and ω 1.558 for a pink marialite from Burma. Zancanella (1977), finally, was surprised to find ε 1.541 and ω 1.550 for a violet scapolite, which could easily be confused with amethyst on the basis of its properties.

We thought it would be of interest to add the results of our investigation to these data as none of them gave the properties of scapolites as we found them with the above mentioned stones.

PROPERTIES

The colour of the stones has some resemblance to that of amethyst and therefore it is conceivable that a wrong conclusion might be drawn after a quick test, as the properties are almost equal to those of amethyst. In Table 1 the properties for ten faceted violet scapolites are given.

The refractive indices have been measured on a refractometer provided with a prism consisting of synthetic Yttrium Aluminium Garnet, as designed by the author. The specific gravity of the stones was measured by using a hydrostatic balance and ethylene dibromide. From these data it may be concluded that these scapolites have extremely low refractive indices. Their densities, too, are low, the average is 2.589. These low properties do already indicate a marialite-rich scapolite.

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TABLE 1
Properties of ten violet scapolites from East Africa.

Sample no.	Weight in carats	Size in mm	ε	ω	D	Remarks
—	4.16	11.5× 9.0×7.0	1.532	1.539	2.586	oval mixed cut
—	3.23	10.1×10.1×5.8	1.534	1.540	2.592	mixed cut
—	2.93	11.9× 7.9×5.3	1.532	1.539	2.587	oval mixed cut
—	2.06	9.7× 7.4×4.8	1.531	1.539	2.587	oval mixed cut
RGM 151802	1.44	7.3× 7.3×5.0	1.534	1.540	2.595	mixed cut
RGM 151803	0.86	6.6× 6.6×3.8	1.534	1.540	2.592	mixed cut
RGM 151804	0.71	5.5× 5.2×3.4	1.534	1.540	2.593	trap cut
RGM 151805	0.46	5.5× 5.5×3.0	1.534	1.540	2.586	mixed cut
RGM 151806	0.60	5.4× 5.4×4.0	1.534	1.540	2.590	mixed cut
RGM 151807	0.49	5.1× 5.1.×3.7	1.534	1.540	2.586	mixed cut

All stones have a strong dichroism with ω colourless and ε violet. The absorption spectrum is not very diagnostic; weak didymium lines in the yellow part may be observed together with faint lines in the blue at 4955, 4880 and 4500Å.

Short-wave ultraviolet light causes a distinct pink fluorescence in all stones. Under long-wave conditions they are inert.

The stones are surprisingly free from inclusions. Some of them contain elongated needles parallel with n_o, that is with the *c*-axis.

Besides these cut stones, two crystal fragments were available for investigation. They were used to prepare x-ray and microprobe analyses.

In all, four x-ray powder photographs were made. In Table 2 the results of photograph RGM 202130, made from scapolite RGM 164268, are given. These data agree best with those from a yellow marialite-rich scapolite RGM 107194, from Tanzania, described by the author (Zwaan, 1971).

Several microprobe analyses were kindly carried out by Dr P. Maaskant of the Institute of Earth Sciences of the Free University at Amsterdam. Dr Maaskant is a member of the WACOM, a working group for analytical geochemistry subsidized by the Netherlands Organization for the Advancement of Pure Research (ZWO) at Amsterdam. Standards used were albite feldspar and jadeite (Na), corundum, albite and jadeite (Al), diopside, albite and jadeite (Si), orthoclase feldspar (K), diopside (Ca), hematite (Fe), barite (S) and halite (Cl). The scapolite was found to be homogeneous, as far as the chemical composition is taken into

TABLE 2

X-ray powder diffraction data for violet scapolite RGM 164268

$d_{obs.}$	I	h k l	$d_{obs.}$	I	h k l
8.50	3	1 1 0	1.741	3	5 0 3
6.44	4	1 0 1	1.700	4	7 1 0
6.07	2	2 0 0	1.671	3	6 4 0
4.42	½	2 1 1	1.610	2	4 0 4
4.25	3	2 2 0	1.555	4	7 1 2
3.80	8	3 1 0	1.507	3	5 4 3
3.56	3	3 0 1	1.459	5	7 3 2
3.45	10	1 1 2	1.417	5	3 0 5
3.05	9	3 2 1	1.397	1	7 2 3
3.00	4	4 0 0	1.379	5	3 2 5
2.83	2	2 2 2	1.363	6	8 2 2
2.72	2	4 2 0	1.343	5	6 2 4
2.68	7	3 1 2	1.327	1	7 5 2
2.54	1	4 2 1	1.313	5	9 2 1
2.36	1	5 1 0	1.282	5	5 0 5
2.29	5	5 0 1	1.179	2	9 5 0
2.20	1	4 2 2	1.167	3	6 3 5
2.13	5	4 4 0	1.156	4	10 0 2
2.07	1	5 3 0	1.146	3	4 2 6
2.01	4	5 1 2	1.123	2	7 2 5
1.948	½	6 1 1	1.081	2	10 4 2
1.907	7	0 0 4	1.061	2	8 8 0
1.813	4	5 3 2	1.031	3	10 6 0
1.776	½	6 0 2			

account. In Table 3 the average of several microprobe analyses is given.

It should be noted that the contents of MgO, MnO, TiO_2, V_2O_3 and CO_2 have been omitted. They were all found to be very low and therefore could be neglected. The total iron was calculated as FeO. The calculation of the marialite content on the basis of

$$\frac{Na}{Na + Ca}$$

gives the result of 89.2%, which is a very high percentage indeed.

TABLE 3

Microprobe analysis of violet scapolite RGM 164268

	ox. %		el. %	numbers of ions on the basis of 24 (O)	
SiO_2	60.64	Si	28.35	Si	8.48
Al_2O_3	19.56	Al	10.35	Al	3.22
Fe O	0.06	Fe	0.05	Fe	0.008
Ca O	2.66	Ca	1.9	Ca	0.40
Na_2O	12.29	Na	9.1	Na	3.32
K_2O	0.90	K	0.75	K	0.16
SO_3	0.18	S	0.07	S	0.02
Cl	3.9	Cl	3.9	Cl	0.92
	100.19				
0 = Cl	0.88				
Total	99.31				

CONCLUSIONS

The scapolites described in this paper have refractive indices and densities lower than ever before measured by the author in members of this group of minerals. The marialite content is higher than ever mentioned in the literature.

In fact this type of scapolite is unique in that it seems to be the purest marialite ever found. It is hoped, therefore, that the origin of this material will become known in due course.

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THE BLUE COLOUR OF SODALITE

By P. E. PAULIN, B.Sc., F.G.A.

During the summer of 1977 I had the great pleasure of meeting Dr Adil Hassib from the University of Khartoum, Sudan. At the time Dr Hassib was doing research on sodalite—work that is still going on—in order to try and establish, among other things, the true cause of the colour in the blue variety. As Dr Hassib is an ESR-expert, Electron Spin Resonance was used as the main instrument in a series of experiments at the University of Uppsala, Sweden, where I had the opportunity of following some of them in detail.

Sodalite, a cubic mineral with the chemical composition $Na_8(Al_6Si_6O_{24})Cl_2$, does mainly appear in nature coloured blue, often with white and darker blue irregular bands. As it had been suggested that the blue colour was due to sulphur, a regular part of the variety hackmanite, the specimens used were carefully analysed for sulphur content but none was found, at least not down to the detection level of 0.01 per cent.

Significant clues as to the nature of the colouring came forward after a series of experiments with heat, x-ray excitation and daylight exposure. Blue sodalite when heated loses its colour and becomes a greyish-white in appearance. Tests showed no structural change after heat treatment. A short (about 3 minutes) x-ray irradiation period caused a fairly strong pink coloration rapidly fading in about the same duration of time in daylight or tungsten light, the pink colour now replaced by a very light blue. Repeating this cycle, x-ray irradiation followed by daylight exposure resulted in a gradually deepening blue colour, until after about 20 cycles no more pink can be induced and the material stays blue of the same hue as the original, i.e. before the heat treatment.

During all phases of this experiment Dr Hassib obtained ESR-spectra as a basis for evaluation of results. First of all, spectra of untreated blue sodalite in single-crystal form show an isotropic centre, i.e. one resonance line that does not shift position with varying orientation of the crystal. Heating sodalite powder in steps shows that this isotropic line gradually diminishes in intensity to

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disappear completely at a temperature slightly above 600 °C. This is also the point where all the blue colour has disappeared. On the other hand transparent, colourless and naturally occurring crystals of sodalite did not show the isotropic feature until after heat treatment and subsequent x-ray and daylight induced blue colour. These crystals did not regain their transparency.

This connexion then—strong blue colour and an isotropic line in the ESR-spectrum—was the first clue. The second clue is rather technical. It has to do with the saturation of the resonance signal when the microwave power is varied, or rather with the non-saturation in the case of sodalite.

Earlier research (Portis 1953) has shown that the non-saturation behaviour of the isotropic line intensity excludes the resonance from being due to trapped electrons i.e. F-centres. Furthermore Hodgson *et al* (1967) and McLaughlan and Marshall (1970) have shown that the pink colour induced by x-ray irradiation

FIG. 1. Thin plate of blue sodalite viewed in transmitted light. (63 ×)

is due to the generation of F-centres. The sequence in the experiment mentioned above—

x-ray irradiation —— pink coloration

Tungsten or daylight exposure —— bleaching of pink colour and gradual deepening of the blue colour with repeated cycles—

indicates that annihilation of the pink F-centres and the immediately following formation of metallic sodium colloidal particles is the mechanism that produces the blue colour of sodalite. Such a sequence is similar to what other researchers have found to be responsible for generating colloids in alkali halides and the well-known silver colloids of photography.

The structure of sodalite may be regarded as Na—Cl units in an alumino-silicate cubic framework with the sodium ions along the cube diagonals and the chlorine ions at the corners and in the centre. This is a probable structure for allowing the formation of colloidal particles of a size necessary to produce the blue colour in sodalite by the Tyndall scattering effect which also explains the blue colour of the sky. Optical examination by microscope of a thin section of blue sodalite did show the Tyndall effect. The presence of clustered matter is quite obvious when a thin plate is viewed in transmitted light (Figure 1). The darker parts are the most intense blue ones and the clustered nature is evident.

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TRANSPARENT BLUISH-GREEN KORNERUPINE FROM EAST AFRICA (KENYA AND TANZANIA)

By Dr K. SCHMETZER, Dr J. OTTEMANN, Prof. Dr H. BANK and Dr H. KRUPP

Since 1972 bluish-green and blue kornerupines (Bank & Berdesinski 1974, 1975; Webster 1974) from Kenya and Tanzania have arrived at gemmological laboratories. These stones are distinctly different in their optical features from the green kornerupine crystals from the Kwale District, Kenya (Schmetzer *et al.* 1974; Girgis *et al.* 1976). The samples which are described here are mainly cut stones which could be partly detected in lots of other minerals (green tourmalines or green garnets). Partly they had been offered as single stones under other names (e.g. sillimanite). In the last few months, we have been able to obtain bigger lots of rough cuttable material of these bluish-green kornerupines for investigations. Therefore we publish here some of our results, though we have not yet been able to clarify comprehensively the especially interesting correlation between their crystal chemistry and colour.

The kornerupines mentioned above differ especially in their expressive pleochroism (Table 1) from those of the Kwale District, Kenya, and also from the brown-green crystals of the historic occurrences in Ceylon and Madagascar. They show, on observation in polarized light parallel to the crystallographic *c*-axis, an intense emerald-green colour. Perpendicular to the *c*-axis, there can be seen

Table 1

Pleochroism of kornerupine from different localities.

	Ceylon and Madagascar	Kwale District, Kenya	Kenya and Tanzania, various localities, somewhat different due to contents of trace elements		
X	yellowish-brown	intensely green	emerald-green	emerald-green	
Y	brown	slightly green	bluish-grey	reddish-purple	Y and Z show only small differences
Z	greenish	greenish-yellow	reddish-purple	bluish-grey	

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a slightly weaker blue colour which may differ from crystal to crystal (sometimes more reddish-purple, sometimes more bluish-grey). The colour itself varies in natural unpolarized light in various stones from green through bluish-green to blue and purple. This colour corresponds to the colours along the directions of X, Y and Z (colours parallel to the crystallographic axes *a, b,* and *c* of the orthorhombic mineral kornerupine) and eventually a mixture of these three colours appears on viewing at any angle other than these directions. A similar pleochroism is present for different colours of all varieties of optically anisotropic minerals, but only in very few minerals are they distinctive. It has been described by Rösch (1970) for blue zoisite as an example.

Though polarized absorption spectra of the kornerupine crystals from Kenya and Tanzania could not yet be interpreted in detail, it can be stated with certainty, as the result of chemical and spectroscopical investigations, that the colour is caused by traces of the elements iron, chromium and vanadium (Table 2). In the case of blue samples, it was possible to determine a distinctive content

Table 2

Chemical analysis of kornerupine (microprobe analysis)

locality	colour	Fe	Cr	V
Madagascar	brown or green	0.83	0.02	0.01
Ceylon	brown or green	3.82	—	0.02
Burma	brown or green	1.05	0.02	0.01
Kwale District, Kenya	green	0.03	0.03	0.15
Kenya and Tanzania, various localities	green	0.08	—	0.04
	green	0.05	0.04	0.17
	bluish-green	0.14	0.06	0.07
	blue	0.11	0.10	0.02
	blue	0.18	0.39	0.53

— = not found

of Cr_2O_3 analytically, whereas chromium-free kornerupines and samples with little chromium and much vanadium showed green colour shades in varying intensity. Chromium will possibly be present as Cr^{3+} in the Mg-Al-silicate kornerupine whereas the valency stated of iron (Fe^{2+} and/or Fe^{3+}) and vanadium (V^{3+} and/or V^{4+}) could not yet be determined. The lattice positions of these ions, which theoretically may occupy five different lattice points in the crystal structure of kornerupine, could also not yet be determined.

The refractive indices of the optically biaxial negative kornerupine crystals vary for the various determined samples within narrow limits. Due to the small optical angles, n_y and n_z do not show big differences.

n_x	1.662-1.663
n_y	1.673-1.674
n_z	1.674-1.675
$2V$	6-11°
n_z-n_x	0.012-0.013

Until now, we have only been able to recognize that the kornerupine crystals come from occurrences in Kenya (district of Namanga) and Tanzania (southern part of the Usambara Mountains or Daluni in the Umba Region). More localities of blue kornerupines will most probably be discovered in Eastern Africa.

We thank Prof. Dr E. Gübelin, Lucerne, Switzerland, and Mr H. W. Lorenz, Idar-Oberstein, Germany, for providing research material from Ceylon, Madagascar and Burma from their collections.

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OPAL—THE UNLUCKY 'LUCKY' STONE

By S. B. NIKON COOPER, B.D., F.G.A.

The early Sanskrit writers were nothing if not straightforward in their approach to gem-names. How better to describe an emerald than by its greenness?—so: marakata to maragda→σμάραγδος (smaragdos)→esmeraude→emeraud, to our emerald. Or, the blood-red colour of a ruby: rudhira (= 'blood') → ἐρεύθρος (ereuthros) → ruber → rubith → rubis → rubie, to our ruby. Even the word meaning 'untameable': adamya (α–privative + 'dam' (= to 'subdue'), the 'unsubdued'), which passed to ἀδάμας (adamas) → adamans → adamant → adyamont → diamonde, to our diamond.

But there was one word they used with a meaning just of 'jewel' alone. A 'precious stone', upala. It is tempting to read more into this than can be justified—that this is, in fact, 'our' opal. However, all that can be said with certainty is that the word was the root-form of the Greek ὀπάλλιον (opallion), which in turn was the source of Pliny's 'opalus' (de Opalis; Book 37, Chs 21, 22).[1] He tells us that the stone comes from India. It would be more correct to say the name came from there. And yet, of all his descriptions, this ties up more completely than any other with a modern gem: '...of all precious stones, it is opal that presents the greatest difficulties of description, it displaying at once the piercing fire of carbunculus (i.e. ruby), the purple brilliancy of amethystos and the sea-green of smaragdus (i.e. emerald), the whole blended together and refulgent with a brightness that is quite incredible...' (Ch. 21). He is surely referring to the play of colour in our opal. But India...? The Romans knew opal well enough. The deposits in what is now Czechoslovakia were already in production. It was a favourite stone with them. Again, with Pliny as our authority (Ch. 23), '...of the highest rank.' Could it be that Pliny is falling into the trap of a practice which obtained until not so long ago of designating all the really 'precious' stones as 'coming from the East' or 'oriental'? An 'oriental' opal must be more precious than the relatively local product... There is a suggestion of this in the first two lines of Ch. 21. 'India, too, is the sole parent of these precious stones (i.e. opals), thus completing her glory as being the great producer of the most costly gems.' As an example of the latter

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point he cites the—then—well-known opal of Nonius, valued at a small fortune of two million sesterces.

One other significant fact: so well known and well loved was this gem that it even had a nickname: 'paederos', poetically translated by Gübelin[2] as 'a child, lovely as Love'. Cross-referencing to the 'paederos' entry (Ch. 46) we learn one more fact: the paederos (opal) was a 'white' stone, named—says Isidore (Lib.XVI:X:2)[3]—for its preeminence of beauty.

The next source to mention opal is Marbode[4], taking us to the Middle Ages, to a time when every really 'precious' gem had its own 'virtue'—the ability to confer this or that benefit on its fortunate owner. That of optallius—his name for opal—is given. It was the stone for all eye-troubles ('Avertens oculis morbos').

One virtue might be thought as good as another, but why would eye-troubles be mentioned specifically? This is answered from a source of the next century: Albertus Magnus;[5] who describes (Book 2, Ch. 13) a gem named ophthalmus, whose 'colour is not stated, perhaps because it is of many colours...' Ophthalmus...? Of course, ὀφθαλμός = the 'eye'; and, if a gem were called after the eye, it follows, parallelism being what it is, that it must be 'good' for the eyes. The only trouble with this is that there was already a stone of virtue for the eyes—the emerald. Right then, to avoid confusion, some extra virtue must be claimed for the new contender. So the assertion (Ch. 13) (the entry stems largely from that of Marbode) that it is said not only to be good for all diseases of the eyes but also to 'dim the sight of those near by. And therefore it is known as the protector of thieves, for those who wear it are, as it were, invisible.'

Truly a remarkable gem indeed! Surely, one of the 'luckiest' of all to possess! We doubt though that it was able to maintain its claim to confer invisibility for long, because no other author after the 13th century repeats the claim. But no matter; it still had the virtue of protecting one from diseases of the eyes. The same stone, with variant spellings (olthamus—13th century; apthalme—15th century) still retains its curative powers. We particularly like the Peterborough[6] (late 15th century) reference: '...he kepeth & saueth yene, & kepeth him cler & scharp & withowte greuance.' Peterborough, by the way, is the one who nearly restores the modern spelling ('Optalio' (elsewhere 'opatallio') 'is a stone that is cleped opalus.')

Turning to Leonardus Camillus[7] (16th century) we see two entries. One, for 'opalus' or 'opal', the other for 'obtalius' or 'obtalmius.' It is obvious that both refer to the same gem. Both are of 'many colours': both have virtue over eye-diseases. Referring to its talismanic nature he says: '...it cannot be improper to attribute to it so many Virtues, since it partakes of the Nature and Colour of so many Stones.' One point, by the way: in retelling Pliny's account of Nonius's opal, the value is now given as twenty thousand sesterces. We are obviously in a period of deflation!

A final entry with Agricola[8](Book 6) gives us not only, once again, Pliny's description of opal's play of colour but, of interest, the current 16th century popularity ratings for gemstones; from which we see the order is: diamond, pearl, emerald and opal—opal in preference, therefore, to ruby and sapphire. Elsewhere he contradicts himself and says opal is more valuable than emerald, putting it third in order of favour.

So, a gem truly to be prized. Both valuable and beautiful; but above all, a stone of 'virtue'—a 'lucky' stone. It had a history, as we have tried to show, all through the Middle Ages of one that could confer desirable gifts on its fortunate owner.

'The belief in the unlucky character of opal is not, I think, earlier than Scott's "Anne of Geierstein"...' So says Joan Evans in her *Magical Gems.*[9] And we cannot even blame Sir Walter Scott for this. It is doubtful that he ever intended to malign the opal; only that its play of colour interested him, and that he made use of it in his plot. In briefest detail, a certain lady named Hermione wore one in her hair (incidentally, a good setting for a gem of such relative softness!) It was a charmed stone and changed colour according to the mood of its wearer. When she was happy, it flashed gay and bright; when she was angry, it glinted redly; and so on. The story goes on to tell how a few drops of Holy Water were sprinkled on the opal—immediately its fire was quenched and Hermione fell in a swoon. Taken to her bed, next day nothing was found save a small heap of ashes. (Incidentally again, we note that 'water' has a deleterious effect on opal!)

That was in 1829, and on such slender grounds are reputations born. So, the opal is 'unlucky'—after all, who wants to suffer the fate of Hermione! It took all of Queen Victoria's judicious patronage, through her gifts, in popularizing the newly-discovered opal fields of Australia, to bring the so-beautiful gem back into

favour. The emergence of the black variety of opal, from Lightning Ridge and Andamooka, has completed the process, until in recent times opal has once again regained the first rank of precious stones that it held in Roman times.

But something of its 'unlucky' character still remains... We are not superstitious, yet we cannot help but recall our feelings after cutting a particular fire opal. Every precaution had been taken; care in dopping the stone; more in its grinding; still more in polishing it. The finished result proved the worth of these measures—a lovely orange-red gem, truly worthy of the care that had been taken in its fashioning. And then the disappointment, on inspecting it again some days later, to see the same gem—but now a travesty of itself, with cracks and surface crazings marring its beauty. Picture the same, seemingly inexplicable, transformation happening a hundred years ago, and we come to what must have seemed a reinforcement of the 'unlucky' tag. Today, it can be explained; in earlier times it would have been proof of undeserved ill-fortune; a stone, therefore, to be avoided; but it is so beautiful...

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NEW FORMS OF SYNTHETIC GEM MATERIALS: TWO BRIEF NOTES

By MICHAEL O'DONOGHUE, M.A., F.G.S., F.G.A.

I

SYNTHETIC OPAL BY GILSON

The black and white opals manufactured by Pierre Gilson S.A. of France are now on the market as preformed rough sections which can be cut by lapidaries to any desired shape. Two pieces in my collection have been examined. The white section measures 11 × 8.5 × 3mm and shows on the top face a fine play of colour, which is echoed to a lesser extent on the other faces due to sawing. Individual colour patches are large and evenly sized; some red, orange and yellow shows quite clearly by transmitted light. As in other products of this firm, dark or neutral patches show at all angles of viewing; at some angles a red blush sweeps across the whole surface. The play of colour is very strong and even in diffused light (daylight) is sufficiently visible to make the gem-potential very high: the pieces examined are presumably first quality, since I have seen many finished stones with a far less prominent play of colour and with a pronounced milkiness. No luminescence or phosphorescence could be seen. The colour patches do not extend over any of the edges, but there is a distinct impression, when looking from the top, that the play of colour begins a little way below the rather glassy surface.

The black opal measures 11 × 11 × 1mm and is also very spectacularly coloured. Colour patches are again large and relatively even in size; the thinness of the piece suggests that its use in a composite stone would be profitable. Viewed at different angles the surface tends to take on various shades, not too different, of the one colour, mostly green or red. No luminescence or phosphorescence could be seen. More interestingly, in this piece, on some of the edges, colour patches visible on the surface can also be seen with the same dimensions, looking as if the patch is distinctly three-dimensional. Viewed at a distance from the light source, glassiness (as in the white piece) can easily be seen and is not at all like natural opal: in fact there should be no possibility of confusion with either piece.

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SYNTHETIC ZIRCONIA

Zirconium oxide has now been on the scene for a little while and is also known in colour as well as in white forms. At least one firm is marketing various coloured varieties and I was fortunate enough to be able to acquire a superbly-coloured crystal section on a recent visit to Moscow. The colour is instantly reminiscent of padparadschah-coloured (orange) sapphire. Examination of the absorption spectrum showed that only the red, orange, yellow and part of the green were unabsorbed—there was no sign of chromium which might just have been expected. Fire opal would not have allowed so much of the green to pass, but there is really very little likeness between the two since fire opals have so low a hardness.

II

'REGENCY EMERALD': A NEW SYNTHETIC FROM THE U.S.A.

Through the kindness of Mr Walter E. Johansen and of Mr John B. Mandle, I have recently received a crystal and a cut stone of 'Regency emerald', produced by Vacuum Ventures, Inc., of Pompton Lakes, New Jersey and of Sunnyvale, California. The cut stone weighs 0.33 ct and the crystal 5.02 ct.

In the hand-out sent with the stones the SG is given as 2.67-2.69, RI as 1.570-1.576 with a birefringence of 0.005-0.006 and dispersion as 0.014. Hardness is 7½-8 and toughness is fair to poor depending on quality. The fluorescence is stated to be bright red, and there is said to be no transparency to x-rays, nor do they cause any luminescence. The stones are said to glow bright red through the colour filter and to have a similar absorption and infra-red spectrum to the natural material.

I examined the two specimens sent by the manufacturers. The presence of platinum wires and a seed of slightly lighter colour, together with typical cuneate growth-tubes with two-phase contents stemming from phenakite crystals, indicate a hydrothermal origin for the product; if this is the case, it may reinforce the manufacturer's statement that the infrared spectrum does not differ from that shown by natural emeralds. Stones manufactured by the hydrothermal (but not flux-melt) process will show bands due to water in the IR spectrum as do many natural stones. It is also possible to see numerous phenakite crystals taking up linear

positions on a previous growth plane, and they can also be seen pointing in the growth direction from the seed. The crystal and the cut stone show wisps (in the cut stone they appear to be in several parallel planes) and several irregularly-shaped structures resembling water-lily leaves with some unidentified spot occupying the centre.

Both specimens show a distinct red under the colour filter and under long-wave ultraviolet light both show a distinct red—this is quite rare for emerald, whether natural or synthetic. The RI is as the makers state—the SG was not tested. The absorption spectrum was most interesting. A sharp and prominent line in the light blue (477.4nm) could be seen in one direction as quoted by Anderson* and the windows beside the lines at 662.0 and 646.0nm were easily seen. Observations were made with the Eickhorst 'Kaltlicht' spectroscope light source with Zeiss spectroscope fitted with blue filter and polarizing attachment for the various readings.

There should be no difficulty in recognizing this product; the colour is a fine bluish-green and is comparable to other stones presently in production. It is possible that this new emerald is a continuation of that commenced and later abandoned by Union Carbide, whose patents they are said to be using under licence. On a visit to San Diego a Union Carbide spokesman told me that the emerald had been discontinued due to the difficulty of obtaining crystals sufficiently thick to be cut as gemstones, and a specimen in my collection seems to bear this out. The present 'Regency' crystal is much thicker and would cut with no difficulty.

**Gem Testing,* 8th edn, 1971, p.156.

[*Manuscripts received 12th December, 1978, and 24th May, 1979.*]

REPORT ON THE GEM DIAMOND PEN

By P. G. READ, C.Eng., M.I.E.E., M.I.E.R.E., F.G.A.

The Gem Diamond Pen, marketed by Gem Instruments Corporation, is the latest in a series of instruments designed to distinguish between diamond and its simulants. Like the grease tables and belts which are still in use at some diamond mines, the Diamond Pen depends for its effectiveness on diamond's unique surface characteristics (i.e., its low water contact angle). The instrument is similar in construction to a draughting pen, and has the same type of dispensing head and ink reservoir. The Diamond Pen, however, uses a specially formulated test liquid. This liquid is a non-drying viscous fluid containing inert chemicals and a blue dye to make it easily visible.

The complete test kit (Figure 1) consists of the pen, a pair of stainless steel locking tweezers, a quantity of polishing powder, a

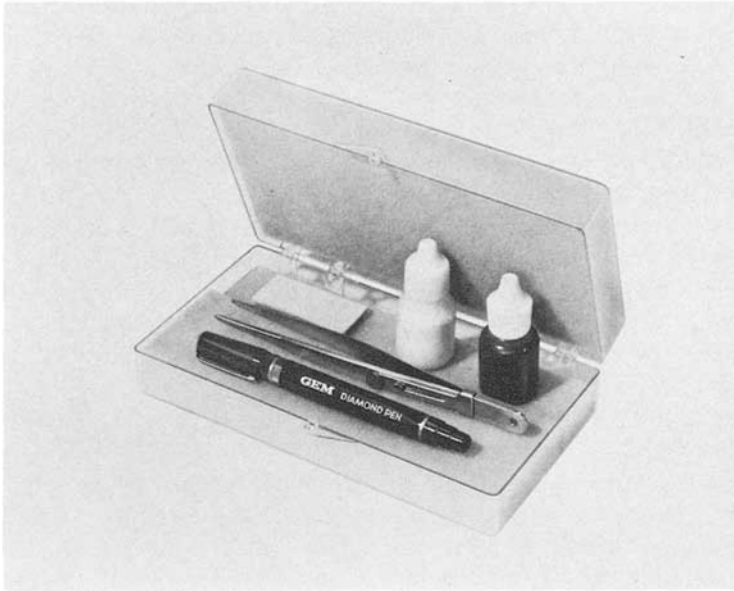

FIG. 1. The Gem Diamond test kit.

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felt cleaning pad and a plastic bottle containing a supply of the test liquid. Detailed instructions for the use of the pen are also included together with explanatory sketches.

The stone to be tested is first cleaned by placing a small quantity of the polishing powder on the felt pad and rubbing the table facet of the stone back and forth on the powder. When cleaning a large unmounted stone the tweezers are used to hold the stone round the girdle. A small unmounted stone can be held by placing the hole in the end of the tweezers over its pavilion. When the stone is thoroughly clean, it is wiped with a tissue to remove any excess powder. The stone is then held table facet uppermost, and the tip of the pen is pressed down vertically onto the facet and drawn slowly across its surface. If the stone is a diamond, the pen will draw a continuous line of test liquid across the facet. However, if the stone is a simulant, the liquid will not flow in a continuous line but will break up into a series of droplets.

During repeated tests with the pen it was possible to identify, without ambiguity, a diamond from a selection of three diamond simulants (cubic zirconium oxide, GGG and strontium titanate). Typical results obtained from these tests can be seen in Figures 2-5. When testing the diamond sample, it was sometimes necessary to make two or three attempts before the test liquid could be persuaded to flow. With the simulants, however, it was even more difficult, and on a few attempts only a single droplet was left on the surface as the pen was lifted off.

Two things were of prime importance to the success of the test; one was the thorough cleaning of the stone (reminiscent of a similar need with reflectivity meters), and the other was the priming of the pen before application. The instruction leaflet advises that the pen should be shaken gently to start the 'ink' flowing after filling. However, it is helpful to repeat this just before each test, and to check for ink flow by touching the tip of the pen on a piece of paper.

A cautionary note in the instructions warns that the test should be regarded as a strong indication rather than a positive identification of diamond. The instruction leaflet also warns that anomalous results can occur with stones whose refractive indices are below 1.80. This was confirmed with further tests on paste, quartz and spinel, all of which resulted in a continuous line of liquid being drawn across the facet. However, the ease with which

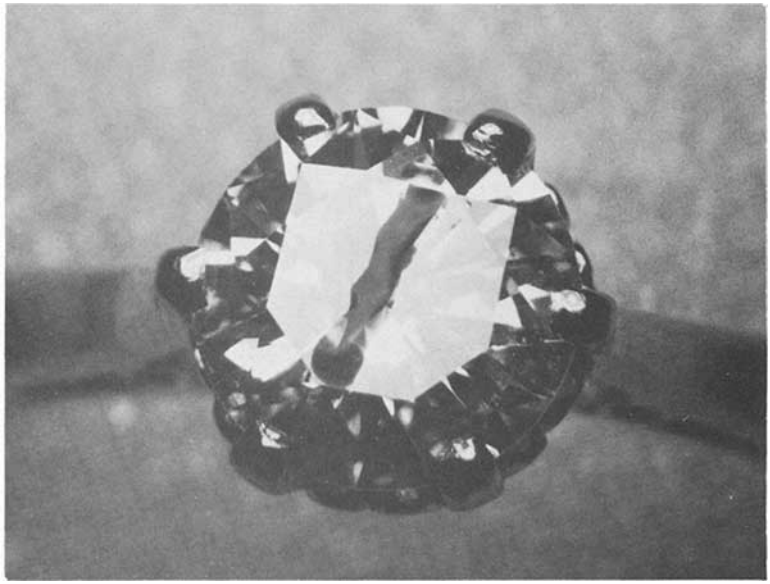

FIG. 2. Diamond.

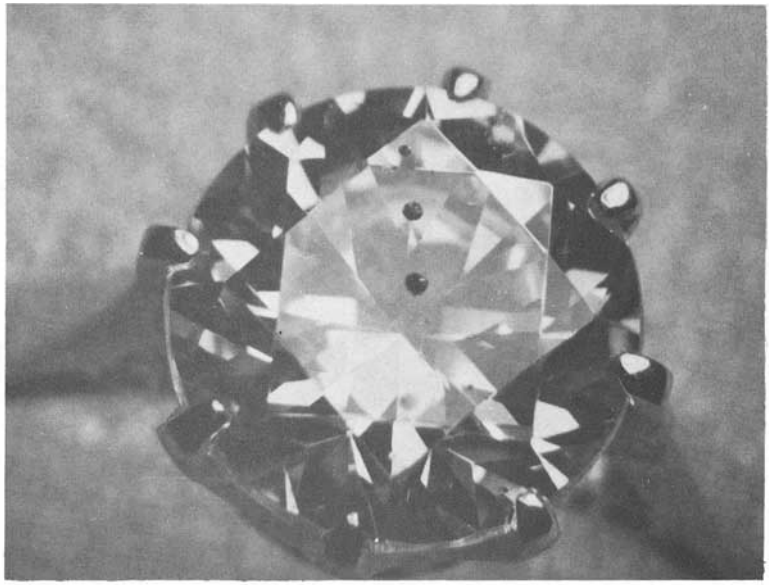

FIG. 3. Cubic zirconium oxide.

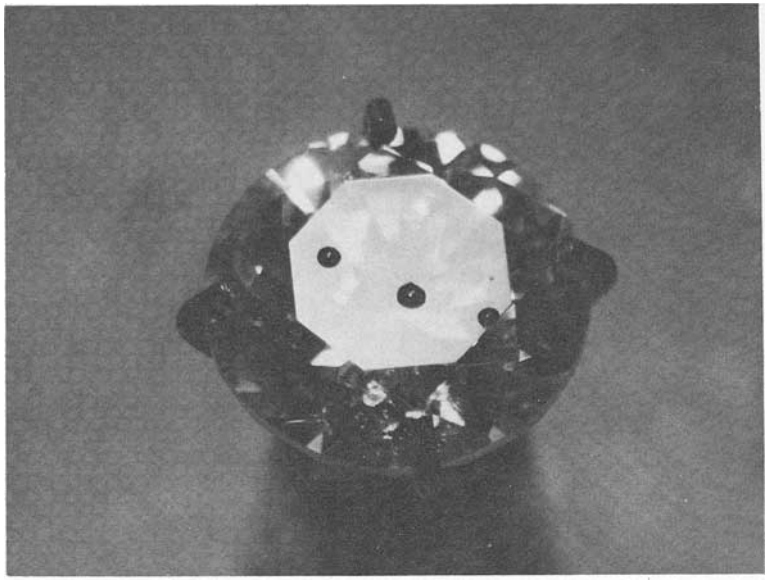

FIG. 4. Strontium titanate.

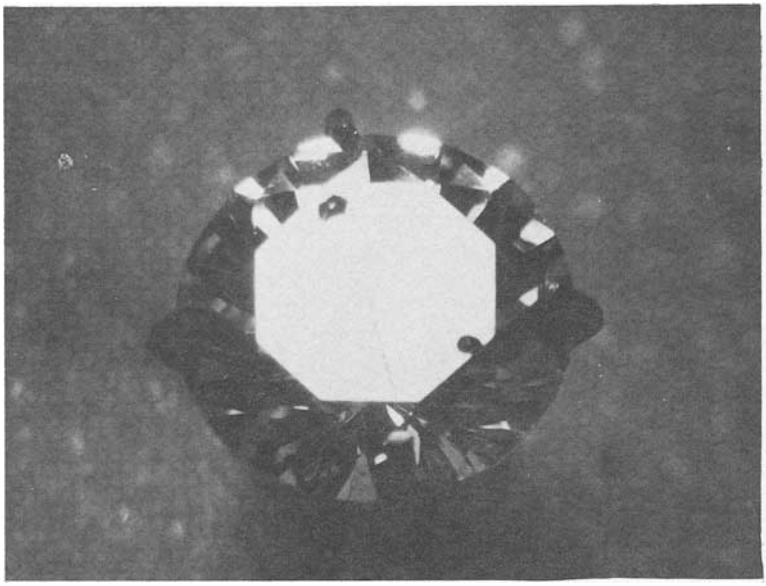

FIG. 5. Gadolinium Gallium Garnet.

the line was started (compared with the slight reluctance encountered when testing diamond) did provide some discrimination even with these stones.

A note on simple tests for detecting cubic zirconium oxide which appeared in the December 1978 issue of the trade magazine 'Canadian Jeweller' suggests using a felt-tip pen in the same way as the Diamond Pen. To verify this possibility, my tests were repeated using three different types of felt-tip pen in place of the Diamond Pen. The results were found to be both unreliable and confusing, and this was probably because of variations in the grease content of the inks and the difficulty in controlling its flow. In comparison, the success of the Diamond Pen is no doubt due to the consistency of the test liquid and the fine degree of control in its application.

With unmounted stones which approximate to the ideal proportions of the brilliant cut, a more conclusive test for diamond is to check the stone's girdle diameter against the weight of the stone. With mounted stones, however, the Gem Diamond Pen could be usefully combined with other simple procedures, such as the 'light spill' test,* to provide a reliable indicator for diamond.

The Gem Diamond Pen is available from Gemmological Instruments Limited. The approximate price in the U.K. is **£21**.

[*Manuscript received 23rd February, 1979*]

*P. G. Read, Close up on C.Z., *Diamond News and S. A. Jeweller.* **44**, 3, 28-30, December 1978.
P. G. Read, The diamond simulants: how to spot them, *Canadian Jeweller,* pp.10-12, September 1978.
E. Bruton, *Diamonds,* 2nd edn, p.472, N.A.G. Press.
P. G. Read, *Gemmological Instruments,* p.154, Newnes-Butterworths.

GEMMOLOGICAL ABSTRACTS

BALL (R. A.). *A note on the structure of fire agate.* Australian Gemmologist, **13**, 7, 210-11, 3 figs, 1978.

A very brief note on the subject, made obscure by use of terminology which will leave the average gemmologist unenlightened. R.K.M.

BANCROFT (P.). *La benitoite, Californie, USA.* (Benitoite from California, U.S.A.) Le Monde et les Minéraux, **11**, 258-61, 7 figs (1 colour), 1976.

A sketch-map of the location, with notes on the mineral and its recovery, is accompanied by a fine colour photograph of benitoite with neptunite on natrolite. M.O'D.

BANCROFT (P.). *La fluorite.* (Fluorite.) Monde et Minéraux, **24**, 746-8, 4 figs (3 in colour), 1978.

Describes the various types and occurrences of fluorite with illustrations in colour. M.O'D.

BARIAND (P.), POULLEN (J. F.). *The pegmatites of Laghman, Nuristan, Afghanistan.* Mineral. Record, **9**, 5, 301-8, 15 figs in colour, 1978.

Minerals of gem quality found in this area include kunzite, green spodumene, elbaite and morganite. Three pegmatite deposits, Nilaw, Mawi and Kurgal, are situated near the Alingar River, the area as a whole lying in the north-east of the country. M.O'D.

BETTETINI (E.). *Au coeur des gemmes.* (In the heart of gemstones.) Le Monde et les Minéraux, **07**, 155-7; **08**, 183-5; **09**, 216-17, 8 figs (4 in colour), 1975.

Illustrates typical inclusions in blue sapphire, demantoid garnet, emerald and ruby. M.O'D.

BROWN (G.). *The identification of some rare organic materials.* Australian Gemmologist, **13**, 7, 238-9, 1978.

Summary of a paper read before the G.A.A. at Perth. Deals briefly with ivories, vegetable ivory, stag horn, corals, copal resins, keratoproteins (various horns, tortoiseshell and hornbill casque) and wood. R.K.M.

BROWN (G.). *Kauri gum.* Australian Gemmologist, **13**, 7, 225-31, 6 figs, 1978.

Attempts to distinguish this recent resin from other copal gums. Kauri-gum is comparatively rare today and occurs only in New Zealand. Author describes early recovery methods and subsequent overproduction leading to present moribund state of the industry. Distinction between kauri and other copals is difficult since they are essentially similar except in the trees from which they come. Distinction from amber, which *is* important, relies largely on the relative insolubility of the latter in ether. Part of the paper seems to be missing. Illustrations have not reproduced well. R.K.M.

BROWN (G.). *Commercial gemstone production in Australia.* Canadian Gemmologist, **2**, **4**, 2-11, 5 figs, 1979.

The commercial importance of the gemstone resources of Australia is steadily growing. Over 22 million dollars' worth of opal and over 13 million dollars' worth of sapphires were traded in 1975. The value of chrysoprase slightly declined compared to previous years. Details of the mining of these materials are given. M.O'D.

CASSEDANNE (J.). *Une exploitation primitive: les gîtes d'améthyste de Brejinho (Bahia-Brésil).* (A primitive working: Brejinho's amethyst deposits in Bahia, Brazil.) Bull. Assoc. Franç. Gemmologie, **31**, 14; **32**, 7-9, 11 figs, 1972.

Brejinho is in the central south-west of the state of Bahia, Brazil, about 430 km west-south-west of Salvador. Amethyst is recovered from galleries and marketing carried out through Idar-Oberstein, West Germany. Citrine is also found. M.O'D.

CASSEDANNE (J.), CASSEDANNE (J.). *Les diamants du Guaniamo (Venezuela).* (Diamonds from Guaniamo, Venezuela.) Le Monde et les Minéraux, **16**, 444-5; **17**, 465-9, 9 figs (2 in colour), 1977.

Guaniamo is 320 km west-south-west of Ciudad Bolivar and 450 km south-south-east of Caracas. The diamond-bearing zone extends over the whole basin of the Cuchivero River. Diamonds are recovered from gravels and frequently contain inclusions of forsterite, enstatite and pyrope. M.O'D.

CASSEDANNE (J.-P.), CASSEDANNE (J.-O.). *La pegmatite à quartz rose du Alto Feio.* (Rose quartz-bearing pegmatite at Alto Feio.) Revue de Gemmologie, **57**, 11-14, 6 figs (2 in colour), 1978.

Alto Feio lies in the north of the Brazilian state of Paraiba, in the north-east of Brazil. Alto Feio is a small hill with a pegmatite carrying beryllium and tantalum, contacting schist and granite. Rose quartz shows no crystal faces; morion and citrine have also been found. Other minerals from the area include tourmaline (black), beryl (pale blue or green), zircon and garnet. M.O'D.

CASSEDANNE (J.), CASSEDANNE (J.). *La pegmatite de Limoeiro et ses minéraux.* (The Limoeiro pegmatite and its minerals.) Le Monde et les Minéraux, **14**, 354-6; **15**, 403-5, 7 figs (1 colour), 1976.

Limoeiro is north-west of Virgem da Lapa in the north-east of Minas Gerais, Brazil. Topaz, either yellow or blue, tourmaline, black, green or red, herderite and apatite are the chief minerals of interest recovered from the pegmatite in the locality. M.O'D.

CECCUZI (B.). *Considerazioni sull'uso del rifrattometro.* (Considerations on the use of the refractometer.) La Gemmologia, **4**, 1, 9-14, 1978.

A general review of refractive index and its measurement with examples of how various authorities differ in published figures. M.O'D.

CHAKRABORTY (D.), LEHMANN (G.). *Infrared studies of x-ray irradiated and heat treated synthetic quartz single crystals.* Neues Jahrbuch für Mineralogie Monatshefte, **7**, 289-98, 1 fig., 1977.

It was found that irradiation produced formation of smoky quartz centres and

rearrangement of hydrogen defects. Destruction of smoky centres by x-ray irradiation is faster than the restoration of the original hydrogen defects. Heat treatment for 24 hours at 550°C caused milkiness but did not alter the infrared spectrum. M.O'D.

DANBOM (E.A.). *Some 'new' angles on faceting.* Gems & Gemology, **xvi**, 3, 88-91, 8 figs, 1978.

Some suggestions for improved cutting angles for coloured stones. Fig 2 is confused in its angles. Author's strange suggestion to off-set crown mains to fall between pavilion mains might produce a 'busier' stone but not one readily acceptable in Western markets. Interestingly, this paper originates from Sri Lanka, not the world's best centre of stone cutting. May the author prevail in his home country! R.K.M.

ESCOBAR (R.). *Geology and geochemical expression of the Gachalá emerald district, Colombia.* Economic Geology, **73**, 7, 1391, 1978.

Features of the area suggest a close relation between evaporitic sequences and the emerald deposit, since the evaporites supply some of the ions needed to give the metasomatic alteration of the host formation and the mineralization. M.O'D.

FALTER (M.), LIEBERTZ (J.). *Rasterelektronenmikroskopische Untersuchungen von synthetischem Opal.* (Raster electron microscopic examination of synthetic opal.) Z.Dt.Gemmol.Ges., **27**, 3, 134-43, 12 figs, 1978.

The article discusses the crystal structure of synthetic opals emphasizing the faults in the lattices. The opals examined were Gilson opals and some produced by the authors. Article is illustrated by 12 beautiful photomicrographs. E.S.

FIEREMANS (C.). *Het voorkomen van diamant langsheen de Kwango-rivier in Angola en Zaïre.* (Diamond occurrences along the Kwango river in Angola and Zaire.) Mém. Acad. Roy. Sci. Outre-Mer, Cl. Sci. Natur. Méd., Brussels, n.ser., **20**, 1, 29, 2 pl., 1 map. French summary.

A historical review is given of diamond exploration along the Kwango river and information provided about the geology, tectonics, diamond deposits, and their origin. A systematic increase of the size of diamond crystals from north to south, related to a variation of accompanying minerals (ilmenite, pyrope, diopside), may indicate an approach to the primary pipes. R.V.T.

FISCHER (J. C.). *L'ambre jaune. Roche biologique.* (Yellow amber—a biological rock.) Monde et Minéraux, **22**, 670-80, 3 figs (2 in colour), 1978.

Gives a general account of the occurrences and types of natural amber with a map of world deposits. M.O'D.

FISCHER (K.). *Verfeinerung der Kristallstruktur von Benitoit.* (Refinement of the crystal structure of benitoite.) Zeitschrift für Kristallographie, **129**, 222-43, 1 fig, 1969.

Discusses the crystal structure of benitoite on the basis of powder and single-crystal diffractometer data. M.O'D.

FRANCESCONI (R.), SVISERO (D. P.), VALARELLI (S. V.). *Minerais de elementos raros no distrito pegmatítico de São João del Rei, Minas Gerais.* (Rare-element minerals from the pegmatite district of São João del Rei, Minas Gerais.) Gemologia, **22**, 43, 53-63, 1 fig, 1978.

Optical microscopy and x-ray diffraction have identified a number of rare-element minerals as well as zircon, beryl and spodumene from the pegmatite at São João del Rei, Minas Gerais, Brazil. M.O'D.

FRUTOS MARTÍNEZ (M. I.). *Características generales de los elementos de transición.* (General characteristics of transition elements.) Boletin del Instituto Gemológico Español, **18**, 5-11, 2 figs, 1978.

An explanation of the importance of transition elements in the coloration of gemstones. M.O'D.

FUJIKI (Y.). *Growth of ZrO_2 single crystals using V_2O_5-NaF flux.* Collected papers of National Institute for Researches in Inorganic Materials (Japan), **3**, 207-8, 2 figs, 1975.

Crystals grown with a flux of V_2O_5-NaF were lemon yellow from V^{5+}. Localized cooling methods were the most successful. M.O'D.

FUJIKI (Y.), ONO (A.). *Growth of ZrO_2 crystals by localized cooling method using $Na_2B_4O_7$-KF flux.* Collected papers of National Institute for Researches in Inorganic Materials (Japan), **3**, 53-4, 1 fig, 1975.

Crystals grown fall into two classes; those showing tabular and those showing prismatic form. Many prismatic crystals are twinned. M.O'D.

FUJIKI (Y.), SUZUKI (Y.). *Flux growth and surface observations of ZrO_2 single crystals.* Journal of Crystal Growth, **24/25**, 661-5, 7 figs, 1974.

Monoclinic ZrO_2 crystals were grown by a localized cooling method with various fluxes. Growth and etch patterns were observed by EPMA on the {100} surfaces and by differential interference microscopy. M.O'D.

FUJIKI (Y.), SUZUKI (Y.). *Growth process of baddeleyite (ZrO_2) in PbF_2 flux.* Mineralogical Journal, **6**, 6, 477-85, 8 figs, 1972.

Crystals show both prismatic and tabular form and polysynthetic twinning is observed. M.O'D.

FUJIKI (Y.), SUZUKI (Y.), ONO (A.). *Preparation of baddeleyite (monoclinic ZrO_2) using PbF_2 flux.* Collected papers of National Institute for Researches in Inorganic Materials (Japan), **2**, 273-7, 5 figs, 1973.

Crystals of high quality were obtained by the localized cooling method using PbF_2 as a flux. Crystals, of tabular form and showing {100}, {110}, {111} and [011] faces are typical of the better qualities obtained; less good quality crystals are twinned with development of {110} with composition planes (100) and (110). Polysynthetic twinning is also found in these crystals. M.O'D.

GILL (J.O.). *A study of colored diamonds.* Jewelers' Circular-Keystone, June, 83-86; July, 131-2; Aug., 71-2, 74; 3 coloured figs, 1978.

This writer is the compiler of a comprehensive index to journals, articles and books related to gems and jewellery and published by the G.I.A. Here he has apparently collected into three papers most of the published gemmological facts on coloured diamonds. The first paper covers naturally coloured stones; the second, foiled, painted and irradiated ones, the latter continuing in the third paper. Despite rather poor colour plates and an unfortunate misprint which converts Abbé Haüy to 'Abbie Haüy', the papers are well written and contain a lot of information on a comparatively rarely considered subject. R.K.M.

GILL (J.O.). *Water melon diamonds.* Jewelers' Circular-Keystone, Aug., 106, 108, 1978.

A further short paper listing such oddities as particoloured natural diamonds and others which change colour in different lights or which change after being stored in the dark. Opalescent (cloudy) diamonds may very occasionally be found with play of colour. R.K.M.

GOLDMAN (D. S.), ROSSMAN (G. R.), PARKIN (K. M.). *Channel constituents in beryl.* Physics and Chemistry of Minerals, **3**, 225-35, 8 figs, 1978.

Examines the electronic absorption spectra in non-Cr beryls with particular reference to the behaviour of Fe^{2+}. Some dark blue beryls have an absorption band at 700 nm which may arise from an Fe^{2+}/Fe^{3+} intervalence interaction. Channel iron strongly influences colour when beryl is subjected to heating or irradiation. M.O'D.

GORELIKOVA (N. V.), PERFIL'EV (Yu. D), BABESHKIN (A. M.). (Distribution of iron ions in the structure of tourmalines according to Mössbauer spectroscopic data.) Zap. Vses. Min. Obshch., **105**, 418-27, 5 figs, 1976. (In Russian; abstract from note by L. Bulgak.)

Mössbauer spectroscopy was used to study the distribution of Fe ions in cation sites in tourmalines. M.O'D.

GRAZIANI (G.), GUIDI (G.). *Hydrous gem magnesian cordierite with inclusions of hydroxyapatite, dolomite and rutile.* Mineralog. Mag., **42**, 481-5, 3 figs, 1978.

Cordierite from Madagascar, pale blue in colour, has RIα1.528, β1.522, γ1.537 with a DR of 0.009. Using a probe, dolomite, hydroxyapatite and rutile inclusions were identified. M.O'D.

GREENSPAN (J.). *Charoite, a spectacular new cutting material.* Lapidary Journal, **32**, 9, 1942-3, 4 figs, 1978.

Charoite's constants are given as SG 2.68, RI 1.55 and hardness 5-6. Hints on fashioning are provided. M.O'D.

GREENSPAN (J.). *Diamond tools in the lapidary arts.* Industrial Diamond Review, Jan., 12-14, 1979.

Amateur lapidaries in the U.S.A. have found that bonded diamond wheels and discs produce better and faster results than the more conventional tools which use

silicon carbide abrasive. These new diamond tools employ nickel plating to bond a single layer of blocky synthetic diamond grit to the working surface of the steel rings and discs. Even diamond compounds have been found to produce a better finish, with less 'undercut' (particularly with gem minerals such as jadeite and nephrite), when used with the appropriate lap. P.G.R.

GÜBELIN (E.). *Saphirblauer Euklas—ein Sammlerstein.* (Sapphire blue euclase—a stone for collectors.) Z.Dt.Gemmol.Ges., **27**, 3, 145-50, 1978.

Up to a year ago euclase was found in pale colours, from colourless to light blue and green to yellow green and green blue. Then sapphire blue euclase was found in Miami in Rhodesia, in the south-west corner of a beryl and muscovite bearing gneiss field (map reproduced). It was shown that trivalent iron was the cause of the blue colour. Physical constants are given. The blue stones are not as clean as the colourless specimens often are, but show irregular flaws. E.S.

GÜBELIN (E.J.). *The tears of the Heliades.* Gems & Gemology, **XVI**, 3, 66-76, 3 maps, 21 figs. in colour, 1978.

An account of amber, its origins and particularly its fossil insect and flora inclusions which are very beautifully illustrated. Text is a little laboured, occasionally obscure and difficult to follow, with some errors, e.g. vertebrae for vertebrates; geni for genera; quiver-flies and day-flies are better known in English as caddis and may-flies or lace-wings, but this is still a serious account of a rather neglected subject. R.K.M.

HASSAN (F.), LABIB (M.). *Induced color centers in a-spodumene called kunzite.* Neues Jahrbuch für Mineralogie, **134**, 1, 104-15, 6 figs, 1978.

Lilac and green colours in kunzite are produced by ionizating radiation acting upon impurity-related precursor centres. Lilac is thought to be due to a hole centre trapped on a Mn^{2+} ion substituting for Si^{4+} in the tetrahedrally coordinated site. With exposure to radiation these centres trap other holes altering the Mn to the Mn^{4+} state. Electrons released in this reaction are trapped by adjacent Fe^{3+} ions in the Al site. The bluish colour acquired by kunzite on irradiation is due to a combination of these activities. On heating crystals up to 500°C all centres were destroyed and the crystals rendered colourless. M.O'D.

HECKMAN (M. W.). *La formation gemmologique en Angleterre et en Allemagne.* (Gemmological structure in England and Germany.) Revue de Gemmologie, **57**, 15, 1978.

Gemmological education in Great Britain and in the Federal Republic of Germany is reviewed; the British system is thought to leave the identification of stones to the initiative of the individual student whereas in Germany all courses are residential and identification is supervised. The German course is expensive. No mention is made of local classes in the U.K. M.O'D.

HOMMA (S.), IWATA (M.). *X-ray topography and EPMA studies of synthetic quartz.* Journal of Crystal Growth, **19**, 125-32, 10 figs, 1973.

Lang diffraction topography and EPMA studies combined to show charac-

teristic growth patterns on as-grown surfaces of hydrothermally grown quartz. Al, Fe and Na were detected as impurities. M.O'D.

KOMATSU (H.), LANG (A. R.). *The growth condition of a natural diamond.* Mineralogical Society of Japan, Special Papers, **1**, 35-41, 6 figs, 1973.

An octahedral diamond from South Africa was studied by surface micro-topographical methods; internal microstructures were also studied. Features observed lead to the conclusions that the crystal grew into octahedral form conserving bundles of dislocations generated at early stages of growth and that it was later subjected to strong shear stress giving an incomplete crack along an octahedral plane, the crack later being filled on further growth. M.O'D.

LALLEMENT (A.). *Fievre à Governador Valadares (Minas-Gerais, Brésil).* (Fever at Governador Valadares, Minas Gerais, Brazil.) Monde et Mineraux, **25**, 804-5, 1 fig in colour, 1978.

Rubellite of exceptional quality has been discovered at the Itataia mine 5 km east of Conselheiro Pena, Minas Gerais, Brazil. A specimen is illustrated. M.O'D.

LIDDICOAT (R. T.), KOIVULA (J. I.). *Synthetic cubic stabilized zirconia.* Gems & Gemology, **XVI**, 2, 58-60, 7 figs (6 in colour), 1978.

A résumé of known facts about, and test for, this comparatively new diamond simulant. Colour plates show inclusions (which are normally avoided in stones cut for market purposes), also the rich colour range available apart from the white stones commonly used as the diamond simulant. R.K.M.

LOKHOVA (G. G.), RIPINEN (O. I.), BUKIN (G. V.), VEIS (M. E.), SOLNTSEV (V. P.). (Quantitative evaluation of the colour characteristics of natural emeralds.) Zap. Vses. Min. Obshch., **106**, 704-7, 3 figs, 1977. (In Russian.)

The spectral transmission characteristics were measured for five specimens of emeralds from the Urals, ranging yellowish green to bluish green in colour. Their contents of Cr (0.04-0.38%), Mn (0.004-0.016%), Fe (0.21-0.50%), and Ti (tr.-0.016%) are tabulated. The greenish colour is caused by Cr^{3+} replacing Al; the presence of active Mn chromophores does not affect the colour. R.A.H.

LÜSCHEN (H.). *Mineralogische Märchen.* (Mineralogical stories.) Mineralien Magazin, **1**, 19-22, 5 figs (4 in colour), 1979.

A general summary of legends connected with minerals includes a fine full-page photograph of rough diamonds in colour. M.O'D.

MCCAULEY (J. W.), GIBBS (G. V.). *Redetermination of the chromium position in ruby.* Zeitschrift für Kristallographie, **135**, 453-5, 1972.

Least-squares refinement using a three-dimensional single crystal x-ray diffraction shows that Cr is disordered in the cation site of the corundum, displaced about 0.03Å toward the nearest cation along c. The displacement is not significant. M.O'D.

McCawley (E. L.). *How, where and why hardness varies in gem minerals.* Lapidary Journal, **32,** 5, 1090-1105, 6 figs, 1978.

A full account of the structure of minerals shows how variation in hardness comes about and how this affects the lapidary. M.O'D.

Manson (D. V.). *Plastic impregnated opal.* Gems & Gemology, **XVI,** 2, 49-57, 22 figs (14 in colour), 1978.

A paper dealing with the broad field of opal and opal simulants introduces two new plastic imitations with sub-microscopic sphere structures similar to those of natural opal. RIs are within natural opal range but SG (1.17) is much lower. Principal information is on plastic-impregnated (stabilized) Brazilian opal, sometimes with added black dye to imitate fine black opal. Specimens from which all opal was dissolved by hydrofluoric acid retained form, polish and some play of colour although they then consisted entirely of a network of the polymer plastic known as *n-butyl methacrylate.* Treated stones said to be undetectable by ordinary gemmological means. R.K.M.

Manson (V.). *Genèse des tourmalines de Pala (California).* (Origin of tourmaline from Pala, California.) Le Monde et les Minéraux, **12,** 302-5, 3 figs, 1976.

General notes are given, with a sketch-map, of the tourmaline-bearing pegmatite located in the Pala Valley, San Diego County, California. M.O'D.

Mehta (K.). *Gemstones of Rajasthan.* Gem World, **5,** 6, 33-6, 1978.

Emerald, garnet (mostly almandine), ruby, aventurine, aquamarine, amethyst, serpentine, tourmaline, rock crystal and chrysoberyl are found in the state. Emeralds from the Kalaguman area are said to be of first class deep green colour: those from Rajgarh are said to excel Colombian stones in colour. M.O'D.

Michele (V. de). *Le collezioni mineralogiche del Museo Civico di Storia Naturale di Milano attraverso 140 anni di storia.* (The mineralogical collections of the Civic Museum of Natural History in Milan over 140 years of its history.) Atti della Società Italiana di Scienze Naturali e del Museo Civico di Storia Naturale di Milano, **119,** 1, 3-58, 18 figs, 1978.

The collections now number 22500 specimens and over the past 15 years considerable reorganization has taken place. Training of amateur mineralogists is carried out by the Museum. Italian type locality material is kept in a special section. M.O'D.

Milashev (V. A.). (Toward a theory of the prediction of bedrock diamond potential.) Geologiya i Geofizika, **18,** 4, 9-17, 1 fig, 1977. (In Russian with English abstract.)

Many geologic and petrographic surveys of possible diamond-bearing deposits have been unreliable owing to uncertain predictions; new criteria are suggested for the study of kimberlite regions. M.O'D.

Miles (E.R.). *Laser reflection patterns in diamond and diamond substitutes.* Gems & Gemology, **XVI,** 3, 77-84, 22 figs, 1978.

Laser reflection 'finger-prints' obtained from diamond and its simulants with

Gemprint, an Israeli invention. Some earlier techniques are outlined. Suggestions made for further uses for this somewhat expensive piece of equipment. Interpretations might present problems in non-scientific circles. (Use of circular transparent film instead of square paper would make matching easier if it is to be used to identify individual stones). R.K.M.

MOSELE (G.). *Una nuova rubrica: gemme e inclusione tipiche.* (A new rule—gems and their typical inclusions.) La Gemmologia, **4**, 1, 18, 4 figs in colour, 1978.

Examples are shown of curved striae in a Verneuil-growth sapphire; elongated gas bubbles in a similar stone; colour zoning in a sapphire from Sri Lanka; and zircon haloes in another Sri Lanka sapphire. M.O'D.

MUMME (I. A.), BALL (R. A.). *On the genesis of volcanic opal at Houghlahan's Creek near Teven-Tintenbar, New South Wales.* Australian Mineralogist, **8**, 33-5, 6 figs, 1977; also Australian Gems & Crafts Mag., **21**, 1977.

Precious opal, together with common opal, chalcedony, and quartz, occurs in amygdales in the upper part of a Tertiary basalt flow. Adjacent and overlying beds of diatomite are belived to have been a source of silica-rich solutions for opal formation. D.R.H.

NASSAU (K.). *The history and present status of synthetic diamond.* Lapidary Journal, **32**, 1, 76-96; **32**, 2, 490-508; 24 figs (9 in colour), 1978.

A description of the processes involved in the manufacture of diamond with notes on the history of the experiments carried out in order to produce it. References to man-made gem-quality diamond show that a blue colour is caused by boron and a yellow colour by nitrogen. Both parts of the paper include a list of references. M.O'D.

NASSAU (K.). *A test of the Ceres diamond probe.* Lapidary Journal, **32**, 9, 1970-3, 2 figs, 1978.

The Ceres diamond probe is able to identify diamond by means of its unique thermal conductivity; the probe, copper tipped, is placed against the stone to be tested for about three seconds; where the stone is diamond an indication is given to the operator. Stones as small as 3 points could be satisfactorily checked and no commonly used materials are likely to cause confusion. M.O'D.

NAUMOV (V.B.), KOVALENKO (V.I.), IVANOVA (G.F.), VLADYKIN (N.V.). *Genesis of topaz according to the data on microinclusions.* Geochemistry International, **14**, 2, 1-8, 2 figs, 1977.

Shows that topaz crystallizes at temperatures in the range 1000-3000°C and that it can form from melts, brines and solutions. Specimens from a number of regions are listed according to the types of inclusion present. M.O'D.

NICHOL (D.). *Amazonite deposit near Koppio.* Min. Resrcs. Rev., South Australia, **141**, 110-14, 2 figs, 1977.

A lensoid amazonite-bearing pegmatite transects Cleve metamorphic rocks of

Lower Proterozoic age near Koppio, South Australia. The amazonite megacrystals are light blue-green coloured, constitute about 30% of the pegmatite, and are associated with quartz and plagioclase. The proportion of gem quality material is less than 5%. The deposit contains at least 400 tonnes of amazonite. W.A.F

NIKOLSKAYA (L. V.), TEREKHOVA (V. M.), SAMOILOVICH (M. I.). *On the origin of natural sapphire color.* Physics and Chemistry of Minerals, **3**, 3, 213-24, 9 figs, 1978.

The optical spectra of natural sapphire, together with EPR and infrared spectra, have been examined to see whether Fe^{2+}/Fe^{3+} ratios could be the cause of colour. Charge compensation in $Fe^{2+} \rightarrow Al^{3+}$ isomorphism is discussed. M.O'D.

O'DONOGHUE (M.). *Scandinavian rock hunt. Part 1.* Gems, **11**, 1, 43-5, 1979.

The author led a party of mineralogists to Norway, Sweden, Finland and the U.S.S.R. in the autumn of 1978. This first part describes visits to various locations in Norway (Landsverk, Flåt, Larvik), Sweden (Långban) and Finland (Outukumpu). At the last-mentioned place very fine uvarovites were obtained.

(Author's abstract) M.O'D.

O'DONOGHUE (M.). *A tour of mineral sites in Eastern Europe.* Lapidary Journal, **32**, 9, 2056-61, 4 figs, 1978.

In 1976 a party left the U.S.A. under the guidance of the author and others to visit sites of mineralogical importance in Poland, Czechoslovakia, Austria, Hungary, Yugoslavia, Greece and Turkey. At several places tour members were able to collect for themselves. Notable places visited included Karlovy Vary (the former Carlsbad), Trepça and Laurium. (Author's abstract) M.O'D.

ONO (A.). *Syntheses of monoclinic and tetragonal ZrO_2 at high temperatures.* Mineralogical Journal, **6**, 6, 442-7, 1 fig, 1972.

Single crystals of ZrO_2 were grown by flux methods; a tetragonal crystal was transformed into a monoclinic twinned phase on cooling. Equilibrium temperature of the monoclinic and the tetragonal phases is $1145 \pm 10°C$. M.O'D.

OTOTAKE (H.). (Historical development of cultured pearl industry in Japan.) J. Gemm. Soc. Japan, **3**, 14-16, 114-16, 165-8, 1976; **4**, 13-15, 1977. (In Japanese with English summary.)

Development of cultured pearl industry in Japan is reviewed chronologically. It is divided into seven stages, and events are described in some detail. I.S.

PERTHUISOT (V.), GUILHAUMOU (N.), TOURAY (J.-C.). *Les inclusions fluides hypersalines et gazeuses des quartz et dolomites du Trias évaporitique Nord-tunisien.* (Hypersaline fluid and gaseous inclusions in quartz and dolomite from the evaporitic Trias of northern Tunisia.) Bulletin de la Société Géologique de France, 73 ser., **20**, 2, 145-55, 9 figs, 1978.

Among various inclusions noted in a study of quartz and dolomite crystals from the Trias of northern Tunisia were halite, sylvine, hematite, various carbonates, liquid CO_2, gaseous CO_2 and nearly fresh water. Study of the inclusions made it possible to distinguish between late quartz of vein crystallization under hydrostatic

conditions in a high geothermal gradient and early quartz and dolomites grown in a lower geothermal gradient. M.O'D.

POVARENNYKH (A. S.), CLARK (A. M.), JONES (G. C.). *The infrared spectrum of painite.* Mineralog. Mag., **42,** 518-19, 1 fig, 1978.

The formula of painite can be written $CaAl_9ZrO_{15}(BO_3)$; this takes into account the very high vibration frequency of the $(BO)^{3-}$ radical; this shows a narrow and intense absorption band at 1360-1310cm^{-1} and bands with maxima at 792 and 760cm^{-1}. M.O'D.

POVONDRA (P.), CECH (F.). *Sodium-beryllium-bearing cordierite from Haddam, Connecticut, U.S.A.* Neues Jahrbuch für Mineralogie, Monatshefte, **5,** 203-9, 1978.

Reports a cordierite found in a pegmatite at Haddam, Connecticut. Some of the cordierite is of gem quality and is dark blue to purple. M.O'D.

PRESCOTT (B. E.), NASSAU (K.). *Black elbaite from Corrego do Urucum, Minas Gerais, Brazil.* Mineralog. Mag., **42,** 357-9, 2 figs, 1978.

A black tourmaline from Corrego do Urucum, Minas Gerais, Brazil, showed blue, green and pink areas when cut into sufficiently thin slices. Two distinct growth stages are postulated. Iron is believed to account for the blue and manganese for the pink coloration. M.O'D.

RANKIN (A. H.). *Macroscopic inclusions of fluid in British fluorites from the mineral collection of the British Museum (Natural History).* Bulletin of the British Museum (Natural History), Geology series, **30,** 4, 297-307, 14 figs (8 in colour), 1978.

Twenty-one specimens of Weardale fluorite from the collections of the British Museum (Natural History) were examined for macroscopic fluid inclusions. All are primary in origin and show no signs of leakage. Further work is needed to establish their chemical nature. M.O'D.

RISLING (M.). *The diagnostic inclusions of quartz.* Canadian Gemmologist, **2,** 3, 2-7, 8 figs, 1978.

Describes and illustrates some of the typical inclusions to be found in amethyst, aventurine and other varieties of quartz. M.O'D.

ROBINSON (D. N.). *The characteristics of natural diamond and their interpretation.* Min. Soc. Eng., **10,** 55-72, 9 figs, 1978.

Consideration of the characteristics of natural and synthetic diamond and current ideas on conditions prevailing in the interior of the Earth, lead to the belief that most terrestrial diamond probably crystallized just within its thermodynamic stability field from the parent liquids of peridotitic and eclogitic rocks. Such diamond has been brought to the surface as xenocrysts in kimberlite, the only igneous rocks originating from sufficient depths (>150 km) to have frequently tapped diamond-bearing regions. All known meteoritic diamonds show characteristics indicating a shock-induced origin. The inclusions and surface textures of diamonds are reviewed briefly and the conditions of crystallization of terrestrial

diamond are discussed; carbonado may have a much lower temperature of origin. R.A.H.

ROGOVA (V. P.), ROGOV (Yu. G.), DRITS (V. A.), KUZNETSOVA (N. N.). (Charoite, a new mineral and jewellery stone.) Zap. Vses. Min. Obshch., **107**, 94-100, 7 figs, 1978. (In Russian; abstract from note by L. Bulgak.)

Charoite is given the formula (Ca, Na, K, Sr, Ba)$_3$Si$_4$O$_{10}$(OH,F) with 0.5-1.0 H_2O. Lilac material is found associated with dark green aegirine and honey-yellow tinaksite in the central part of the course of the Charig River, Siberia. Both charoite and tinaksite, together with other K-Ca minerals are found at the contact between potassium feldspar-bearing metasomatic rocks and limestone. RI is given as 1.550, 1.553 and 1.559. It can be polished and has considerable tenacity. M.O'D.

SACHANBINSKI (M.). *Edelsteinvorkommen in Polen.* (Gem occurrences in Poland.) Z. Dt. Gemmol. Ges., **27**, 3, 156-8, 1978.

The article is a reprint from a monthly magazine 'Polen-illustrierte Monatszeitschrift' (Poland-Illustrated monthly magazine). Chrysoprase is found in large quantities in Silesia; this source has been mined since 1740 and produces very beautiful green stones. Together with these one sometimes finds a milky opal. Before 1906 Jordanow was the only European source of nephrite; in 1899 the American gemmologist Kunz acquired a piece weighing two tons which is to be found in the Metropolitan Museum in New York. A number of beautiful quartzes are found in Silesia, mainly smoky quartz, morion, rock crystal and amethysts; the chalcedony found in Karkonosce is especially colourful and occurs in all rainbow colours. Serpentine is also found and used mainly for vases, ashtrays, etc. In small quantities one can find fluorite, tourmaline, garnet and even ruby and sapphire. E.S.

SAMOILOVICH (M. L.), TSINOBER (L. I.), DUNIN-BARKOVSKII (R. L.), LISITSYNA (E. E.), KHADZHI (V. E.). (The third type of citrine colour of natural quartz.) Zap. Vses.Min.Obshch, **105**, 223-7, 7 figs, 1976. (In Russian; abstract from note by L. Bulgak.)

Dark brown colours in one variety of quartz are caused by interstitial ions of Fe^{2+} and Fe^{3+}. In another a smoky colour is related to hole centres due to radiation effects on oxygen tetrahedra where Si ions are replaced by Al. A third variety can be decolorized by heating at high temperature during gamma-ray irradiation. M.O'D.

SCHMETZER (K.), BANK (H.). *Blaugrüner Zoisit aus Merelani, Tansania.* (Blue-green zoisite from Merelani in Tanzania.) Z.Dt.Gemmol. Ges., **27**, 3, 151-2, bibl, 1978.

The optical and crystallographic data for the blue-green zoisite do not differ from the values for the blue zoisite. The absorption spectrum shows the lines of the vanadium-containing zoisite from Merelani as well as those of the chrome-containing green zoisite from Longido. Chemical analysis confirmed that these zoisites contain roughly the same amount of vanadium as of chromium. E.S.

SCHMIDT (W.), ROSLER (H. J.). *Zur Nutzung der Harteanisotropies des Diamanten am Beispiel von Ritzwerkzeugen.* (Making use of diamond's anisotropic hardness taking as an example a scratch tool.) Z. Geol. Wiss., **6**, 813-20, 9 figs, 1978.

Experimental data are used to demonstrate that there is a relation between the abrasion resistance of industrial diamonds and the anisotropic hardness properties of diamond crystals, with the position of the cleavage surfaces of the diamond towards the abrasive base acting as a controlling factor. The mineralogical properties of diamond crystals exert an influence on the efficiency of industrial diamonds which needs further investigation. P.Br.

SCHUBNEL (H.-J.). *Le diamant et l'URSS.* (Diamond and the U.S.S.R.) Revue de Gemmologie **57**, 7-10, 9 figs (2 in colour), 1978.

Describes and illustrates some of the specimens of diamond, both cut and rough, in the Diamond Fund of the U.S.S.R. in Moscow. The Siberian localities for diamond are shown on a map. M.O'D.

SHAUB (B. M.). *Notes on the origin of the Biggs jasper.* Rocks & Min., **53**, 56-62, 12 figs, 1978.

Jasper, from a locality south of Biggs Junction, Oregon, exhibits intricate configurations of thin dark-brown lines on a lighter brown matrix. Dendritic black manganese stains also often are present. In the field the jasper is sandwiched between two successive basalt lava flows. The quartz rock probably was derived from the hydrothermal alteration of clays formed from volcanic ash. Factors relating to this origin are considered in detail, and associated rocks and fossils are described. Some lapidary uses of the picturesque rock are illustrated. R.S.M.

SHAW (R.). *The new gem diamond pen.* Gems & Gemology, **XVI**, 3, 92-95, 3 figs, 1978.

An introduction to the diamond pen which is claimed to distinguish diamond from its imitations and simulants. Nassau's list of contact angles for water on various gems is quoted and a connexion implied between this and the liquid used in the pen. But the latter is evidently not plain water. On diamond it gives a continuous line; on highly refracting simulants the coloured liquid beads into droplets. Stones must be clean and free from artificial coating before testing. A polishing pad, which could damage softer stones, is provided. The test, although empirical, proves diamond but does not distinguish between the different simulants. R.K.M.

SMITH (G.). *A reassessment of the role of iron in the 5000-30 000cm^{-1} region of the electronic absorption spectra of tourmaline.* Physics and Chemistry of Minerals, **3**, 343-73, 9 figs, 1978.

Polarized optical spectra of blue-green tourmalines were measured at a variety of temperatures. Some green stones were heated at 750-800°C in air and hydrogen. Absorption at 7900 and 13 800cm^{-1} are ascribed to Fe^{2+} in the b-site. Bands at 9000 and 13 400cm^{-1} are ascribed to Fe^{2+} in the c-site. Heat treatment shows that the band at 18 000cm^{-1} can be assigned to the charge transfer $Fe^{2+} + Fe^{3+} \rightarrow Fe^{3+} + Fe^{2+}$. Broad absorptions found in the 22 000 and 25 000cm^{-1} regions in some green and brown

tourmalines are attributed to $Fe^{2+} + Ti^{4+} \rightarrow Fe^{3+} + Ti^{3+}$ charge transfer. It is suggested that on heating green tourmalines in air and hydrogen Fe^{3+} cations in b- and c-sites are reduced. Further heating in air and hydrogen oxidizes $Fe^{2+} \rightarrow Fe^{3+}$ and generates bands near 19 000 and 21 600cm^{-1}. These are assigned to $Fe^{3+}-Fe^{3+}$ pairs. M.O'D.

SMITH (G.). *Evidence for absorption by exchange-coupled Fe^2–Fe^3 pairs in the near infrared spectra of minerals.* Physics and Chemistry of Minerals, **3**, 375-83, 1 fig, 1978.

It was found that by heating tourmaline in hydrogen Fe^{3+} is reduced to Fe^{2+} and that the absorbance of the bands at 9000 and 13 800cm^{-1} is lessened. This appears consistent with the *d-d* origin of the bands; in sapphire spin-forbidden bands are intensified by Fe^{3+} -Fe^{3+} exchange-coupling. Bands at about 10 000 and 11 500cm^{-1} in blue sapphire may be of spin-allowed exchange type. M.O'D.

STEPANOV (I. S.), SYCHKIN (G. N.). (On evaluating the reliability of certain diamond finds.) Geologiya i Geofizika, **18**, 10, 73-9, 1 fig, 1977. (In Russian with English abstract.)

A summary of diamond finds in magmatic rocks and clastic deposits of Paleozoic and Proterozoic age in the Ural Mountains of the U.S.S.R. Much of the existing data is considered unreliable owing to the poor interpretation of results, identification of specimens and disregard for possible contamination of testing devices. M.O'D.

STRUNZ (H.), WACHSEN (G.). *Perlen aus dem Fichtelgebirge.* (Pearls from the Fichtelgebirge.) Aufschluss, **29**, 379-95, 20 figs (2 in colour), 1978.

Freshwater pearls from the Fichtelgebirge (in Bavaria, north-east of Bayreuth) are found in sizes rather less than 1 cm across. The history of their recovery is given, together with notes on their structure and formation. M.O'D.

SUHNER (B.). *Das Goniometer in der Gemmologie-Möglichkeiten und Grenzen.* (The goniometer in gemmology—possibilites and limits.) Z.Dt.Gemmol. Ges., **27**, 3, 121-33, 1978.

The determination of the refractive index and dispersion of faceted stones according to the minimum deviation method is the most accurate and generally accepted method for isotropic stones. In the case of anisotropic minerals it is only an exception when the main indices can be read, with the exception of the ordinary ray. Dispersion can always be determined, especially in the case of weak double refraction, as the dispersion alters only slightly with the direction of the rays. Although limited in the case of anisotropic minerals, the author argues his case for the application of the goniometer. The article is illustrated and examples are given. E.S.

TAKENOUCHI (S.). (Basic knowledge on studies of fluid inclusions in minerals, parts 2, 3 and 4.) Journ. Gemm. Soc. Japan, **2**, 2, 66-73, 14 figs, 1975; **2**, 3, 110-21, 17 figs, 1975; **2**, 4, 21-8, 7 figs, 1975. (In Japanese.)

The second part of the survey introduces principles of fluid inclusion

geothermometry and discusses the relationship of formation temperature and filling temperature of fluid inclusions. Heating-stage microscope and decrepitation methods are described. Part 3 introduces the use of the freezing-stage method in fluid inclusion study. There are discussions of the formation of liquid CO_2 and CO_2hydrate in cooled CO_2-bearing fluid inclusions and the pressure-specific volume-temperature and pressure-composition-temperature relations of binary systems of H_2O-NaCL and H_2O-CO_2 in hydrothermal conditions. Part 4 reviews the destructive methods of analysis of fluid inclusions with particular remarks on possible contaminations of samples. M.O'D.

TAXER (K. J.), BUERGER (M. J.). *The crystal structure of rhodizite.* Zeitschrift für Kristallographie, **125**, 423-36, 4 figs, 1967.

Ideal formula is calculated as $CsBe_4B_{12}Al_4O_{18}$ with space group $P\bar{4}3m$. Cell edge is a = 7.319±0.001Å. M.O'D.

VACHER (A.). *Étude du processus d'étranglement des cavités intracristallines.* (Study of the strangulation process of intracrystalline cavities.) Revue de Gemmologie, **56**, 3-4, 5 figs, 1978.

Epigenetic inclusions in quartz are examined. The formation of two-phase inclusions allows stages of growth to be studied with particular reference to intracrystalline cavities. M.O'D.

VASIL'EV (V. I.), PRUGOVA (I. V.). (New minerals in Siberia and the Soviet Far East.) Geologiya i Geofizika, **18**, 12, 60-72, 1977. (In Russian with English abstract.)

A list, arranged in chemical classification, includes several varieties of garnet, chromiferous kyanite, strontioapatite and pyroxene of the diopside-jadeite-chromochlore series. M.O'D.

VOILEAU (A.). *Thaïlande. Le rubis de Chanthaburi.* (Thailand. Ruby from Chanthaburi.) Le Monde et les Minéraux, **09**, 202-6, 7 figs (1 in colour), 1975.

The recovery of ruby is illustrated and notes given on the commercial aspects of mining in the region. M.O'D.

VOILEAU (A.). *Thaïlande. Le saphir de Kanchanaburi.* (Thailand. Sapphire from Kanchanaburi.) Le Monde et les Minéraux, **10**, 230-3, 6 figs (1 in colour), 1976.

Gives brief but unspecific notes on the region; sapphires are sold locally as well as in Bangkok. M.O'D.

VOILEAU (A.). *Minéraux de Namibe, Afrique du sud-ouest.* (Minerals from Namibia, South-West Africa.) Monde et Minéraux, **26**, 832-6, 1978.

Among the gem minerals to be found in Namibia are red tourmaline, pink smithsonite, rhodochrosite and azurite-malachite. M.O'D.

WACHSEN (G.). *Weisser Opal aus dem Fichtelgebirge.* (White opal from the Fichtel mountains.) Z.Dt.Gemmol. Ges., **27**, 3, 153-5, 1978.

Milky opals were found in the mountains in north-east Bavaria, a well-known occurrence of hyalite. Physical constants are given. E.S.

WERDING (G.), SCHREYER (W.). *Synthesis and crystal chemistry of kornerupine in the system MgO-Al_2O_3-SiO_2-B_2O_3-H_2O.* Contributions to Mineralogy and Petrology, **67**, 247-59, 13 figs, 1978.

Synthesis of micron-sized crystals of kornerupine showed that the total number of cations per formula unit increases beyond the ideal number of 14.0 with increasing boron content. The Mg:Al:Si ratio may remain constant with increasing boron content. M.O'D.

WILKS (E. M.). *Optical methods to select diamonds of very high lattice perfection.* Nature, **262**, 570-1, 1 fig, 1976.

Criteria for selecting strain-free diamonds include minimum birefringence, freedom from trigons on natural faces and from rectangular markings on polished cube faces, and the ability to produce polarized photons when used as a synchrotron target. F.B.A.

WILSON (A. F.). *The refractory metamorphic gemstones of Australia.* Australian Gemmologist, **13**, 7, 203-9, 1978.

A mineralogical account of various infusible (refractory) minerals and their formation. From details of actual occurrences listed it is evident that there are many potential gem sites as yet unexplored. Hopeful parallels are drawn between Australian localities and known gem areas in other parts of the world. The uncertainty of results from prospecting hinders development. R.K.M.

WOOD (M. M.), WEIDLICH (J. E.). *Diopside 'jade' from the Eel River, Mendocino County, California.* Lapidary Journal, **32**, 7, 1532-5, 6 figs, 1978.

Some jade-like boulders found in the Eel River, Mendocino County, California, have proved to contain diopside in whole or in part. Tests are described. M.O'D.

ZEITNER (J. C.). *The big sky sapphire.* Lapidary Journal, **32**, 6, 1244-54, 13 figs, 1978.

A rough blue sapphire from Montana weighed 24ct and yielded a faceted stone of 12½ct. Mining methods in the Missouri River area of Montana are described. M.O'D.

ZEITNER (J. C.). *The gem investment boom.* Lapidary Journal, **32**, 6, 1372-8, 14 figs, 1978.

Gemstones have increased in price so rapidly over the past few years that many species formerly obtainable at low prices now attain price levels that only a few buyers can reach. M.O'D.

ZEITNER (J. C.). *Sri Lanka, isle of gems.* Lapidary Journal, **32**, 8, 1668-98, 16 figs in colour, 1978.

A general survey of Sri Lanka with notes on the gemstones found there and an account of tours made to the island. M.O'D.

Boletim de preços, bens minerais e produtos metalúrgicos. (Bulletin of prices, fin minerals and metallurgical products.) Boletim de Preços, **5**, 25, 1-43, 1978.

This number includes a section giving the prices of rough and cut diamonds and of various Brazilian gemstones; Rio Grande citrine is said to be heat-treated amethyst; green spodumene is labelled hiddenite; emerald is given a separate table. M.O'D.

Lista de preços e demais especificações técnicas de materiais gemológicos. (List of prices and technical details of gem materials.) Gemologia, **22**, 45, 65-78, 1978.

This price list is extracted from the Boletim de Preços of the Departmento Nacional de Produção Mineral, **3**, 14, Sept/Oct 1976, and lists prices asked for rough and cut Brazilian and other gemstones. M.O'D.

The Headley Museum, Lexington, Kentucky. Rocks & Min., **53**, 28-31, 9 figs, 1978.

This private museum was founded in 1968 by artist-designer George Headley. It houses jewelled bibelots, including numerous items made from rare and precious stones. Large faceted gemstones are also exhibited, and there is a Shell Grotto containing rare and unusual specimens. R.S.M.

NOTE: Le Monde et les Minéraux became Monde et Minéraux with issue no. 22.

BOOK REVIEWS

AMELINCKX (S.), GEVERS (R.), VAN LANDUYT (J.). *Diffraction and imaging techniques in material science.* 2nd edn. North-Holland Publishing Co., Amsterdam, 1978. 2 vols, pp.847. Illus. in black-and-white. $(US)109.75.

This new edition of a standard work brings up-to-date the work on various types of surface study, with particular reference to different types of electron microscopy. SEM and TEM are described and examples given of the uses in which they are competent. Those wishing for descriptions of the principles and methods of operation of these instruments are recommended to this book. M.O'D.

BALDOCK (J.W.), HEPWORTH (J.V.), MARENGWA (B.S.I.). *Resources inventory of Botswana: metallic minerals, mineral fuels and diamonds.* Mineral Resources Rept No. 4, Geol. Survey Dept, Botswana, 1977. pp.xi, 69. 3 figs, 7 pls, 8 geol. maps (in pocket). P4.

There is an 8-page section on diamonds, including details on the history of prospecting, geological setting, kimberlite petrology and geochemistry, and the grade and quality of the diamonds. In the Orapa-Letlhakane region 29 kimberlite pipes have been found, the largest in area being Orapa (110 hectares) yielding 2.2-2.5

carats/m^3, of which only 10% are gem quality. Seven pipes have also been discovered in the Jwaneng region. Most of these pipes have a highly altered upper part derived from kimberlite and capable of being worked opencast to a depth of 37 m. R.A.H.

BARIAND (P.), CESBRON (F.), GEFFROY (J.). *Les minéraux, leurs gisements, leurs associations.* (Minerals, their occurrences and associations.) Minéraux et Fossiles, Meung-sur-Loire, France, 1977. 3 vols, pp.489. Illus. in black-and-white and in colour. Price on application.

Although the first part of this book is concerned with didactic mineralogy, the bulk of it deals with the better-known minerals, arranged in order of the main chemical constituent (reminiscent of the Handbook of Geochemistry). The most useful parts are undoubtedly the section for each mineral which give considerable details of occurrence and associated minerals so that the student can get some geological relationships as a background to determinative mineralogy. The photographs (by Nelly Bariand) are of high quality—some have already been published elsewhere. The reviewer noted the lack of a bibliography and, more seriously, of an alphabetical index. Species can only be found from a contents list so that the reader must know the composition of a particular specimen in advance. M.O'D.

BOSCH FIGUEROA (J.M.), MONES ROBERDEAU (L.). *Diamantes.* (Diamonds.) Editorial Entasa, Madrid, 1979. pp.648. Illus. in black-and-white and in colour. 3000 pesetas.

This large and attractively produced book will immediately become the standard Spanish text on the diamond. It deals with the origins of the stone, including a number of maps and photographs of working sites, how it is cut (again with numerous illustrations), how diamonds are classified, identified, synthesized and imitated. Each chapter has its own short bibliography and at the end of the book is a section illustrating (in colour) the grading system used for clarity assessment, the actual system being in this case the Scandinavian Diamond Nomenclature. Highly recommended for those with a fair knowledge of Spanish and even for those without. M.O'D.

DEER (W.A.), HOWIE (R.A.), ZUSSMAN (J.). *Rock-forming minerals.* Vol. 2A. 2nd edn. Longmans, London, 1978. pp.viii, 668. 1 fig. in colour. £25.00.

Since the first edition of this standard series was published in 1963 the amount of information added to the literature has been so great as to necessitate the splitting up of the original volume dealing with the chain silicates into two; this one deals with single-chain silicates. As the authors say in their preface, the growth of electron microprobe work, of crystal structure determination and of experimental petrology, has increased the amount of information available so that the student has, as never before in the earth sciences, to keep constantly in touch with journals. This book will serve for a time to reduce the labour spent in these searches.

The most important minerals covered by the present volume are the pyroxenes; these include augite, the diopside-hedenbergite series, jadeite, rhodonite, bustamite and spodumene among others less likely to be sought by gemmologists. Each mineral has an introduction, diagram of a characteristic crystal, followed by notes on the chemistry, experimental work including synthesis, optical and physical

properties, distingushing features and paragenesis, concluding with a list of references, brought for the most part up-to-date for 1976 and the early months of 1977. There are many more phase diagrams than in the first edition, thus reflecting the work done since then, and many analytical tables. This volume is quite expensive but should find a place in the library of every serious student, most of whom will welcome the appearance of the series in parts! M.O'D.

MEDENBACH (O.), WILK (H.). *Zauberwelt der Mineralien.* (Magic world of minerals.) Sigloch Edition, Künzelsau, W. Germany, 1977. pp.204. Illus. in colour throughout. Dm49.

This is not just another collection of beautiful mineral pictures; although the illustrations are of superb quality, there is also an accompanying text of considerable authority. The introduction to the study of minerals is accompanied by full-page facing pictures so that the reader is impelled to learn just how these beautiful things come about. The introduction is not too complicated, confining itself to a description of the crystal systems, optical properties, hardness and specific gravity. This takes up a few of the early pages. After this, however, the minerals themselves take over, and for the remainder of the book all the text is devoted to descriptions of the specimens illustrated—text and picture face each other as in all good books. Specimen size, too, all too often omitted, is given. But it is the sheer beauty of the pieces which makes this book essential to the private collection of anyone caring for natural beauty. They are quite easily the best that this reviewer has ever seen—readers with an interest in gems should look for the green tourmaline crystal on page 185, the hessonite on page 177, the red beryl from Utah on page 197 and the emerald group on page 193. These are only some of the gem varieties illustrated but are typical of the standard of the rest. There appear to be very few errors—one misprint is the incorrect spelling of the Wah Wah mountains in the caption to the red beryl picture, but even this is of relatively small account. Over the years I have accumulated many hundreds of mineral books but this is easily the best illustrated. M.O'D.

METZ (R.). *Visage des minéraux et des pierres précieuses.* (The face of minerals and gemstones.) Librairie du Muséum, Paris, 1978. pp.187. Illus. in colour. Fr185.

This beautifully illustrated work was first published in 1964; this new issue contains a preface by H.-J. Schubnel. It is possible that an English translation may appear at some time in the future. The book follows a pattern almost traditional with mineral books; early chapters deal with crystals and their symmetry, the physical properties of minerals and some general geology. After this, chapters cover mineral origins and there is a special section on minerals from Alpine clefts. Ten pages of general notes on gemstones are unaccompanied by plates other than those depicting minerals not of gem quality. There is a very short bibliography. M.O'D.

MIKA (J.), TÖRÖK (T.). *Analytical emission spectroscopy.* Butterworths, London, 1974. pp.529. £9.00.

A useful and fairly exhaustive guide to the whole area of emission spectroscopy, this book would be useful for those wishing to learn more about those aspects of the subject pertaining to minerals and gemstones. M.O'D.

MYERS (H.P.). *Colour classification of sapphires from Sri Lanka.* Institute of Physics, Göteborge Universitet Chalmers Tekniska Högskola, Sweden, 1978. pp.16. 6 figs. Price on application.

A method of appraising the value of blue sapphires from Sri Lanka involves comparison of their colour with a series of agreed standards, in this case a set of solutions ranging from dark to light blue. M.O'D.

READ (Peter G.). *Gemmological Instruments.* Newnes-Butterworths, London, 1978, pp.227, 146 figs. £8.50.

It might be supposed that all aspects of gemmology had by now been adequately covered by the literature, which has been particularly prolific during recent years, but Peter Read has shown in his book 'Gemmological Instruments' that the increased production and variety of specifically gemmological instruments has by now created a useful place for a work giving information on these products and where to obtain them. The author was formerly Technical Manager to the Diamond Trading Company and he brings to the subject the skill and knowledge as to 'how things work' gained as a trained engineer and expert in electronics. He has also acquired enough knowledge of gemmology to give very capable and succinct summaries of those properties of gemstones which the instruments are designed to observe and measure.

The book is well organized, and packs a great deal of information into the space of its 227 pages, much of which is taken up with illustrations. After an introductory section on the characteristics and constants of gems the second chapter deals with supersonic baths (whose value is dubious in this context and highly dangerous to many gemstones) and such humble but essential accessories as tweezers, shovels and stone-papers. Chapter 3 covers the enormously important inspection aids ranging from pocket lenses and head-loupes to elaborate binocular microscopes which have been found most suitable for the examination of gems whether mounted or unmounted. Sources of illumination are also included in the same chapter. The next chapter covers colour (including pleochroism) and colorimeters, while Chapter 5 copes with refractive index, refractometers, polarizers and (one is glad to see) table spectrometers.

The new reflectivity meters are the subject of a separate chapter and diagrams of their construction given. These instruments have become available just at a time when the manufacture of high-index diamond substitutes has become a serious nuisance to the legitimate trade. Chapter 7 treats with specific gravity, while the next, entitled 'Spectra', briefly covers the absorption spectra of gemstones and the spectroscopes (both prism and grating types) most suitable for viewing them. It is good to see several spectroscopes here which dispense with the added complication and cost attendant on having a wavelength scale attached. This is followed by a chapter on luminescence and a very short one on hardness.

In the eleventh chapter the author abandons his descriptions of instruments and surveys the pressing problem of identifying synthetic gemstones and other forms of simulant, with potted descriptions of each. Chapter 12 concerns itself with diamond grading—on which Mr Read should write with special authority—and the descriptive part of the book ends with a survey of some of the expensive and elaborate equipment which may be of value in specialized research laboratories.

There are some valuable appendices, in the first of which are given the names and addresses of suppliers of the instruments described in the text. These are listed in alphabetical order and amount to no fewer than 100 names, compilation of which must have cost the author considerable trouble, for which we should be grateful. There follow comprehensive tables of constants (obligatory in any serious book on gem identification), notes on the most typical inclusions in natural and synthetic gemstones, and a good index.

The nature of the subject matter has tempted the publisher to include some relevant advertisements in the end pages of the book. Though slightly 'infra dig', these give in some cases useful information as to the cost of the instruments advertised. This, for most readers, most important matter is, for obvious reasons not even hinted at in the text. What the author might consider doing in a future edition is to indicate groups of items of essential equipment recommended for (*a*) a student, (*b*) a professionally involved or keen amateur F.G.A. and (*c*) a small trade laboratory, with a broad indication as to total cost in each case. A chapter might well be added on photography in the service of gemmology, with suggestions and descriptions of the most useful types of camera.

Where it is not directly concerned with the descriptions of individual instruments Mr Read's text is largely an intelligent condensation of standard works. This is frankly acknowledged by the author giving a list of references at the conclusion of each chapter. In this context it was pleasant to observe in the chapter on the spectroscope a reference going as far back as 1859, to Bunsen's original work on the spectra of the elements.

A few errors were noticed, some of which may be mentioned for the sake of future editions. On page 2 the author maintains that metallic lustre is due to 'the type of very high surface finish associated with metals'. This is quite untenable: a rough piece of galena or pyrites, for instance, needs no polish to reveal itself as having an undoubtedly metallic lustre. Also in the first chapter, 'cabouchon', 'waxey' and 'hackley' are not spellings favoured by the dictionaries. Rose quartz shows a 6-ray, not a 4-ray star: the definition of prism is incorrect, and the terms pinacoid, twinning, and parallel growth should be added to the list of definitions. On page 13 only two of the three pleochroic colours of iolite and zoisite are given, and alexandrite deserves a place in the short list of notables in this connexion, while on page 17 moonstone is for some reason substituted for orthoclase in Mohs's hardness scale.

In Chapter 5 it seems as though the author has perpetuated a common misconception in implying that the dispersion of a gemstone can be measured on a refractometer simply by taking shadow-edge readings in suitably filtered red and blue light and subtracting one from the other, whereas things are much more complicated, readings being dependent on the relative dispersion of the (highly dispersive) lead glass of the refractometer prism and that of the stone being tested. The *higher* the dispersion of the stone, the *narrower* the colour-fringe in white light. Further, in the diagram 5.1, the rays R6 and R7 are surprisingly refracted *towards* instead of *away from* the normal, giving the drawing a very odd appearance!

In Chapter 8, the credit for being the first spectroscopist to employ a collimating lens between the light-source and the prism of the instrument is given to Fraunhofer. This enormously important advance in design is usually ascribed to Zantedeschi in 1846: an exact reference to Fraunhofer's use of the device would be

welcome, and would add yet one more 'Oscar' to those he earned for his wonderful work on the spectroscope.

In the notes on artificially coloured diamonds (page 157), those coloured by neutron bombardment are said to show an umbrella pattern round the culet, whereas this effect is seen only in stones which have been bombarded by charged particles from a cyclotron, and lastly it might be suggested that in the list of gem materials which show characteristic fluorescent effects under x-rays the orange glow shown by grossular should be mentioned.

None of the above points are of radical importance, and they do not seriously detract from the value of what to gemmologists should prove a very useful compilation. B.W.A.

WEBSTER (B.). *Mineral collector's field guide, Connecticut.* B. Webster, Wallingford, Connecticut, 1978. pp.39. Sketch maps in black-and-white. Price on application.

This small guide describes how to get to some of the best known collecting areas in Connecticut. Especially well known is the Haddam area, now closed, which has produced tourmaline and aquamarine, and several other places have pegmatites where interesting minerals may be found. Up-to-date information on access and sketch-maps are given. There is a short bibliography. M.O'D.

YOGEV (Gedalia). *Diamonds and coral.* Leicester University Press, Leicester, and Holmes & Meier Publishers Inc., New York, 1978. pp.360. £8.50.

This well produced book is a scholarly record of research based on the author's Ph.D. thesis. The title, however, may be somewhat misleading: it is not a book about diamonds and coral as such—its subject is better indicated by the subtitle 'Anglo-Dutch Jews and Eighteenth Century Trade'—though indeed many of the merchants participating in the coral-diamond trade were Portuguese Jews driven out of Portugal by the fires of the Inquisition.

After 25 pages taken up by the title page, table of contents, acknowledgments, Foreword and a brief Introduction, the text is divided into three Parts—a 'General Survey' of four chapters (pp.25-77), 'The Diamond and Coral Trade, 1660-1800' (chapters 5-9, pp.81-180) and 'The House of the Prager Brothers (Levin Salomons) and the Anglo-Dutch Trade, 1760-1796' (chapters 10-12, pp.183-274)—followed by a page of Abbreviations, Notes (pp.276-330), eleven Appendices (pp.331-40), a copious Bibliography (pp.341-8) and Index (pp.349-60).

The third part and the appendices have only a minimal connexion with gemmology except for some particulars in Chapter 12 of the Anglo-Dutch diamond trade (London merchants supplying Brazilian and Indian rough diamonds to Amsterdam for cutting), but there is much in the first and second parts and their notes for the gemmologist who takes an interest in the history of the gem trade. Some excerpts follow.

'The jewellery trade between India and Europe has always been a two-way business. India supplied Europe with diamonds, garnets, rubies and eastern pearls, and Europe exported to India coral and amber: later Europe also exported emeralds and western pearls from South and Central America. After the early sixteenth century diamonds were the main item in jewellery exports from India, and coral

took first place in exports to the East . . . . The western Mediterranean was the only source of red coral, the kind needed for the Indian market. Marseilles, Leghorn, Genoa and Naples were centres of coral fishing and coral industries . . .' (pp.102-3), but it was shipped from London. 'The diamond mines were spread over a large area, north and south of Madras. Stones were found in the river beds of the Penner, the Kistna, the Godavari, and the Mahanadi, and in the neighbouring areas. In the middle of the eighteenth century a new source was discovered further north, in the vicinity of Panna in Bundelkhand.'

I was particularly interested to find a number of references to emeralds being supplied from Europe to India but none to any movement of emeralds in the reverse direction and this seems to back up the late Robert Webster's statement[1] that a source of true emerald in India was not known until a much later date (viz. 1943).

The great number of diamonds from Brazil reaching Lisbon from 1728 onwards of course affected the Anglo-Indian diamond trade, but Dr Yogev considers Dr Lenzen's estimate[2] that the discovery of diamonds in Brazil caused an approximate eight-fold increase in the supply to Europe of rough diamonds to be grossly exaggerated (Note 42, p.294): a comparison of the data concerning sales of Brazilian stones during 1775-88 given by W. L. Eschwege[3] with the diamond imports from India[4] for the same period tend to show that the diamond imports from India were generally larger: but smuggling must not be forgotten—the official figures both for Indian and for Brazilian diamonds do not represent the total value of imports.

Towards the end of the eighteenth century import of diamonds from India by way of trade was adversely affected when men who had made great fortunes in India (such as Clive and Warren Hastings) found an easy way to remit their wealth to England was by buying diamonds in India for sale in London: these large purchases in India created a typical sellers' market there, which greatly disadvantaged the merchants engaged in the Anglo-Indian diamond trade, and from the late 1780s the trade was entering the stage of its final decline. By 1823, as reported by Mawe[5] Brazil was almost the only supplier of diamonds to Europe. J.R.H.C.

International directory of micromounters. 9th edn. Baltimore Mineral Society, Balitmore, U.S.A., 1978. pp.34. $1.25.

Lists micromounters by country and state, then alphabetically. M.O'D.

Precious stones newsletter. Precious Stones Newsletter, Thousand Oaks, California 91359, U.S.A., 1978. $104.00.

The first issue of a monthly journal aimed at those intending to obtain gemstones as an investment. Market trends are observed and analysed. M.O'D.

[1] *Gems, their sources, descriptions and identification,* Newnes-Butterworths, London, 3rd edn. 1975, pp.94-5.

[2] *History of Diamond Production and the Diamond Trade,* (1970), p.121.

[3] *Brasilien, die neue Welt,* (Braunschweig, 1830), I, 112.

[4] according to the General Cash Journals of the East India Company.

[5] *Treatise on Diamonds and Precious Stones,* (2nd edn, 1823).

ASSOCIATION NOTICES

NEWS OF FELLOWS

Mrs Sheila J. Lewis, F.G.A., and Mr M. J. O'Donoghue, M.A., F.G.S., F.G.A., gave a second course on 'Synthetics Simplified' at Harrow College of Further Education on 9th March, 1979. As before, a wide variety of set pieces and new possible gem materials were shown, including some rare-earth germanates, synthetic zircon and dysprosium gallium garnet.

On 1st May, 1979, the Worshipful Company of Goldsmiths held a Symposium on 'Synthetic Stones in Jewelry' at Goldsmiths' Hall, with Mr Ivan Tarratt, F.G.A., (past Prime Warden) in the Chair, and Mr M. J. O'Donoghue, M.A., F.G.S., F.G.A., was one of the principal speakers.

On 23rd May, 1979, Vice-President Mr B. W. Anderson, B.Sc., F.G.A., and Mr Alan Hodgkinson, F.G.A., appeared in the third instalment of the BBC2 television series 'The Genuine Article' (dealing with discrimination between the true and the false, the genuine and the fake). Mr Anderson recalled his Laboratory's demonstration of the different transparency to x-rays of zircon and diamond in a Court case where a man was prosecuted for having fraudulently passed off zircons as diamonds, and Mr Hodgkinson with two collaborators showed how to distinguish natural and synthetic rubies by their inclusions and how to recognize doublets by immersion in liquid.

GIFTS TO THE ASSOCIATION

The Council of the Association is indebted to the following for their gifts:

Mr D. Inkersole, F.G.A., London, for a piece of dendritic opal rough, referred to as 'Seascape Opal', from Peru.

Mr M. J. Keegan, Wulguru, Queensland, Australia, for two specimens of prehnite with native copper and chrysocolla inclusions.

MEMBERS' MEETINGS

London

On 3rd April, 1979, at the Central Electricity Generating Board Theatre, London E.C.1., the films 'Gem Fun and You' and '7000 Years of Gold Jewellery' were shown.

Midlands Branch

On 10th May, 1979, at the Society of Friends, Colmore Circus, Birmingham, Mr C. Hicks gave an illustrated talk on crystals and minerals. The meeting also included the Annual General Meeting of the Branch, when Mr C. L. Hundy, F.G.A., and Mrs J. S. Leek, F.G.A., were re-elected Chairman and Secretary respectively.

North-West Branch

On 26th April, 1979, at Church House, Hanover Street, Liverpool, a film show was held, covering an introduction to gem collecting, gem-making tools available for cutting and polishing stones, and how they are used.

South Yorkshire and District Branch

On 3rd May, 1979, at Sheffield Polytechnic, Mr P.G. Read, C.Eng., F.G.A., gave a talk on 'Colour in Diamonds'.

PRECIOUS STONES OF THE FUTURE FROM THE LABORATORY

(A report on M. Pierre Gilson's talk)

On the 11th October, 1978, a talk was given to members of the Association by M. Pierre Gilson on 'Precious Stones of the Future from the Laboratory' in the Geological Museum Cinema Theatre, South Kensington. The theatre was full when the proceedings were opened and the speaker was introduced by the Vice-Chairman, Mr David Callaghan, F.G.A., who said M. Gilson produced the very best that man could produce and was able to do in a relatively short time things which Nature took very much longer to achieve: his talent and the vast range of materials that he was producing were quite fantastic.

M. Gilson's talk then took the form of a running commentary on the hundred or so slides which he showed during the evening and he left few people in doubt about the progress made in the last fifty or sixty years. He reminded the audience that Verneuil was the first to make synthetic ruby and sapphire at the beginning of the century: with his relatively simple method he was able to produce a boule in one of several colours in a matter of three hours or so, and his synthetic corundum was soon used to make the jewels in watches.

In contrast, M. Gilson's company takes as long as nine months to grow synthetic emeralds. They start with a seed—synthetic material of the highest

quality—and grow it as a non-stop process for nine months. A continuous supply of electricity is essential, because it is important to allow crystallization to take place at a constant temperature if good crystals are to be grown. Accordingly arrangements have been made to ensure that the company is guaranteed a supply of electricity privately in case there should be a failure in the public supply due to breakdown or perhaps a strike.

But it is not just a matter of having the right equipment and know-how: experimentation also is necessary. Before success in making synthetic turquoise was achieved, thirty different phosphates had to be crystallized.

The equipment now used in the Gilson laboratories is very sophisticated and quite advanced. In order to study the size and formation of the tiny 'beads' which make up such gemstones as emeralds an electron microscope is used. A spectrophotometer is another essential piece of equipment, because it is important to be able to control absorption to within one part per million.

With synthetic emeralds M. Gilson has found it beneficial to cut at a specific angle in relation to the seed crystal on which the new material has been grown. He used slides to explain that the main difference between synthetic and natural emerald lies in the nature of the inclusions. In the synthetic material the 'veil' is twisted, whereas in the natural stone it is straight. He added that Nature produced only one good emerald for every million crystals formed: in the laboratory it was essential to have a very much higher success-rate. Emerald production in the Gilson laboratory takes precisely nine months, since, if you wait any longer, crystallization may have stopped. A simple—but impractical!—test to distinguish between natural and synthetic emerald was mentioned: if you heat it to one thousand degrees and it turns white when it cools, you know it is natural. He added that the hardness of emerald was affected by the extent of inclusions in a given stone.

Opal was next discussed. Opal is pure silica: it acts like a prism and the colours which can be seen are pure spectral colours. Gilson synthetic opals contain more pure colours than natural material because they contain more pure constituents. Laboratory production of opal calls for a very high temperature: natural opal is no longer being created because temperatures are not high enough. Even in the laboratory it is impossible to produce two identical opals. Production starts with the production of millions of tiny 'beads', each about 0.3 microns in diameter, and these eventually form the finished material. M. Gilson's most recent improvements involve the removal of all traces of water from synthetic opals, and this gets rid of cracks and helps to avoid some of the hazards associated with the natural material. With natural opals, it is interesting to note that material found at a depth of more than six metres is often noticeably better than stones found near the surface.

Natural turquoise contains iron, and in some cases customers are disappointed when the iron turns green after a year or two. 'Our own stones are pure turquoise, so this problem doesn't arise'—but a process has now been developed so that iron can be introduced to the surface of synthetic turquoise.

With lapis, although pyrites (its inclusion) can be synthesized, M. Gilson uses natural pyrites. 'Each day nine hundred tons of natural pyrites are mined: I cannot compete with that!' He is now successfully synthesizing coral and uses calcite which is now being mined in France.

In answer to a question whether he could suggest any methods of testing stones to tell the difference between real and synthetic specimens, he said: 'We work on

FIG. 1. Chinese style carving in Gilson synthetic lapis-lazuli.

Fig. 2. Gilson synthetic emerald—crystal group.

FIG. 3. Gilson synthetic black opal—rough.

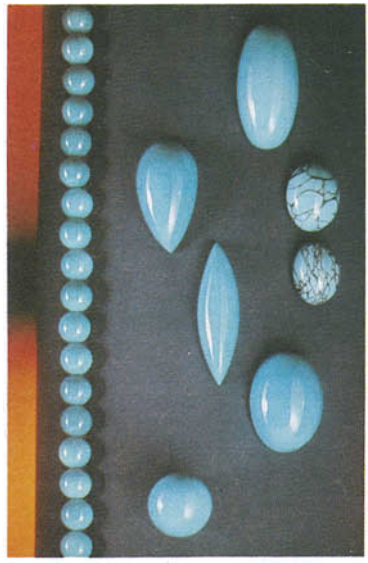

FIG. 4. Gilson synthetic turquoise—beads and cabochons.

FIG. 5. Gilson synthetic emerald crystals being removed from furnace after nine month's growth.

FIG. 6. Gilson synthetic black opals.

FIG. 7. Gilson synthetic turquoise—cabochons and rough.

developing new scientific products, but when it comes to identification you are the experts.' Asked whether it was his intention to produce stones so similar to the natural product that they could not be detected, he replied: 'We are not competing with Nature but merely trying to improve on it by producing more pure stones—more beautiful ones for the jeweller to work with.'

Mr Alec Farn, F.G.A., (L.C.C. Gem Testing Laboratory) asked if M. Gilson had produced any emeralds without chromium but with the additon of vanadium, and M. Gilson replied that he had not—and even if it was done, could the result be described as emerald? 'If people want chromium in emerald, then why shouldn't we give it to them?'

Offering a tip for improving opals, M. Gilson said that if soaked over night in ethyl alcohol all moisture in the stone would be driven out and the colour improved—but it was essential not to do this if the stone was a triplet! And in reply to an enquiry whether he had carried out any experiments on the jadeite family, he smiled and said: 'Yes, we are working on this problem.'

When asked how long he had been trying to make synthetic stones before he had his first success, he said he took fifteen years to succeed with emerald, ten years with opal, and eight years with turquoise: and because of slow reactions and the length of time it took to grow a single crystal before it was known whether or not the experiment was a success, research was becoming more difficult and expensive. Some members of the audience were surprised when M. Gilson mentioned that his main business was not the production of synthetic gemstones but the manufacture of about nine tons of ceramics each month for industrial use.

Mr Alan Jobbins, B.Sc., F. G. A., (Institute of Geological Sciences) proposed a vote of thanks to M. Gilson, which was passed by acclamation.

(Text based on report in the Retail Jeweller by courtesy of the Editor: illustrations reproduced from his slides by permission of M. Gilson)

CORRIGENDA

On p.385 above, in the 'References' *s.v.* Dunn P. J., for 'microbe' read 'microprobe'.

On p.410 above, line 7, for 'show' read 'shown'.

On p.417 above, line 20, for 'four of five' read 'four or five'.

In J.Gemm., 1976, XIV, 3, on p.146, *s.v.* Takenouchi (S.), for '1975, 2, 4, 165' read '1975, 2, 1, 165'.

GEM TESTING EQUIPMENT

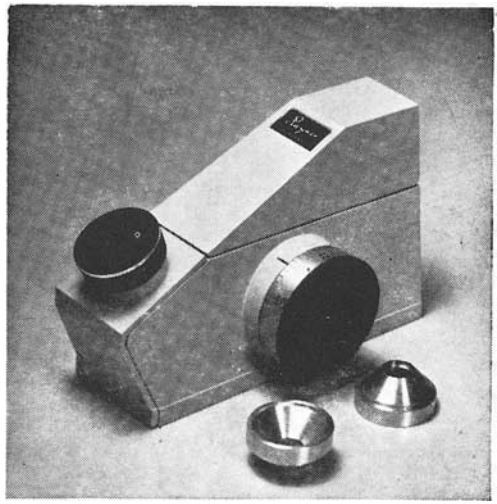

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THE DIAGNOSTIC RADIOGRAPHIC STRUCTURE OF PEARLS

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University of Queensland Dental School

Direct radiography of pearls has been used as a diagnostic technique since the early 1930s. It would appear that the Phillips Metalix Pearl Testing X-ray Unit was a pioneer design specifically produced for jewellers. This unit produced direct radiographs, x-ray diffraction radiographs, and x-ray fluorescence of unknown pearls.

For those gemmologists interested in the historical development of the use of x-rays for pearl testing, Webster [1,2] has published two fine reviews. Most gemmological text books [2,3,4,5] devote some space to a general discussion of the use of x-rays in pearl testing; however, this discussion is seldom given in depth. The neophyte pearl tester frequently finds his literature searches yield few useful details of radiographic technique. This apparent lack of technical information is readily explained, as no universally applicable technique exists which will reproducibly produce direct radiographs of pearls of diagnostic quality.

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Pearl radiography must be conducted in a sequential manner, utilizing a range of exposure times, target-film distances, kilovoltages, shields, film types and development times, until a radiograph of diagnostic quality is produced. General guidelines do exist; these are well documented by Webster.[1,2] If detailed guidance is required by the beginner, the gemmologist could do no better than to seek advice from a major pearl-testing laboratory.

Certainly, the average gemmologist does not possess the training, equipment, or legal authority to involve himself or herself in the radiography of pearls; however, it is important that a competent gemmologist does develop the necessary observational skills that will enable him or her to interpret a well prepared radiograph.

The radiographs and their accompanying diagnostic criteria, which are appended to this paper, aim to assist the interested gemmologist understand the potential diagnostic usefulness that direct radiography possesses for assisting the identification of pearls.

DIAGNOSTIC CRITERIA FOR PEARL RADIOGRAPHS

Type	Figure No.	Radiographic Characteristics
1. NATURAL PEARLS		
(1) WHOLE PEARLS		
(A) Salt Water Pearls		
(i) Oyster Pearl *(Genus Pinctada)*	Figure 1 (undrilled)	Central radiolucent cavity. Irregularly distributed radiolucent arcs and circumferential lamellae of cochyolin.
	Figure 2 (drilled)	Radiolucent drill-holes.
(ii) Abalone Pearl *(Genus Haliotis)*	Figure 3 (undrilled)	Irregular external form. Large irregular radiolucent central cavity. Radiolucent arcs of conchyolin.
(iii) Conch Pearl *(Genus Strombus)*	Figure 4 (undrilled)	Spherical radiopaque mass with no discernible structural characteristics.
(B) Fresh Water Pearls		
(i) Mussel Pearl *(Genus Unio)*	Figure 5 (undrilled)	Predominantly baroque shape. Fine circumferential arcs of radiolucent conchyolin.
(2) BLISTER PEARLS		
(A) Salt Water Pearls		
(i) Oyster Pearl *(Genus Pinctada)*	Figure 6 (undrilled)	Partial radiopaque external form. Regular radiolucent central cavity.

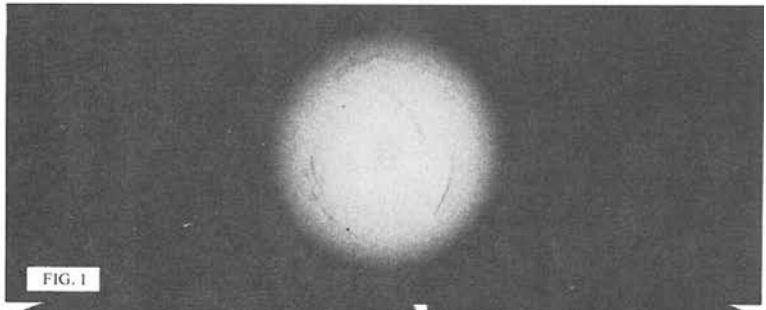

FIG. 1

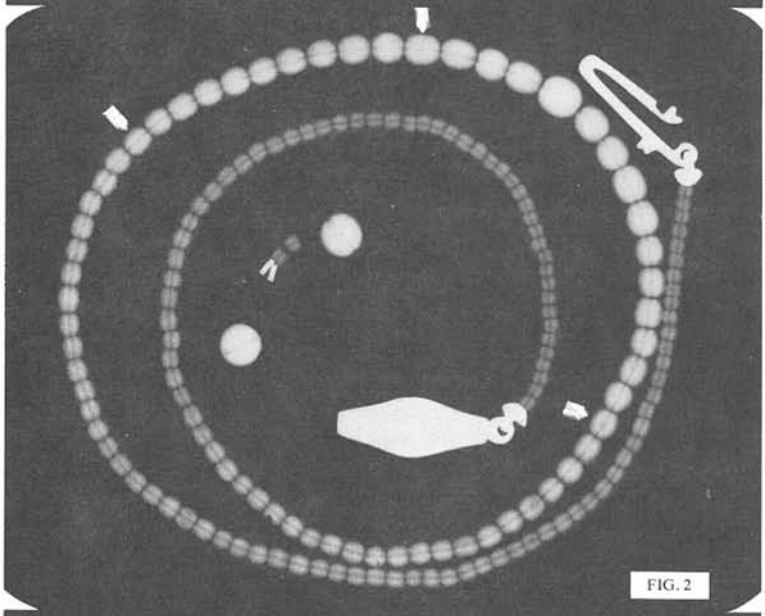

FIG. 2

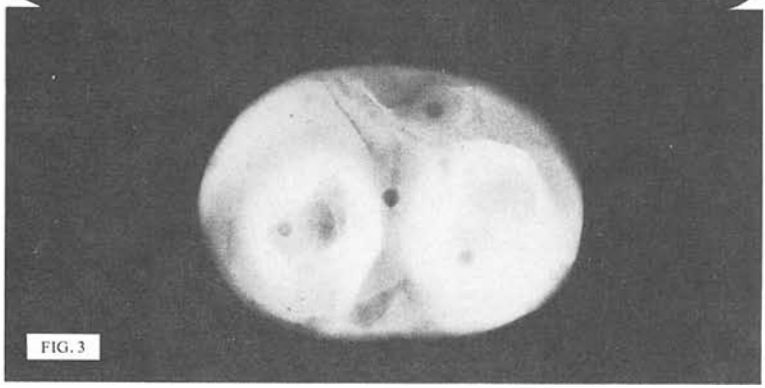

FIG. 3

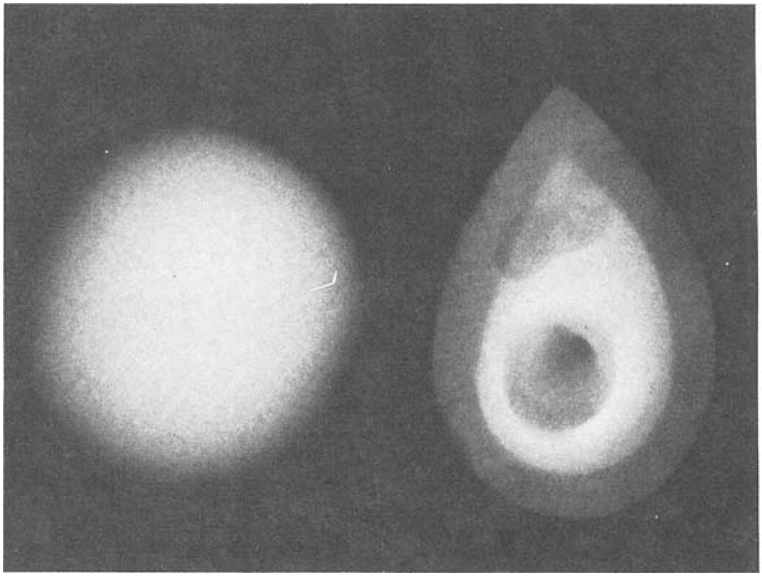

FIG. 4 FIG. 6

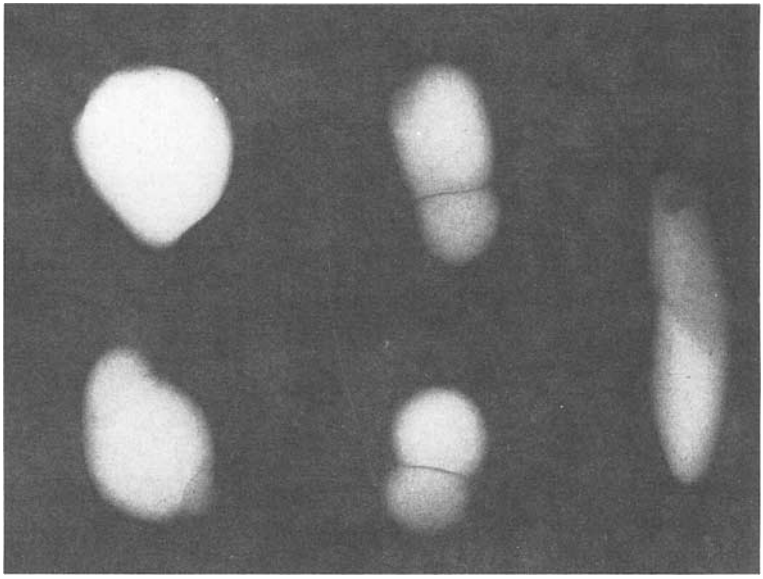

FIG. 5

2. CULTURED PEARLS

(1) WHOLE PEARLS

(A) Salt Water Pearls

(i) Bead Nucleated Pearls

(a) Australian, Silver *(Pinctada maxima)*	Figure 7 (undrilled)	Thin external radiopaque layer of nacre. Thin continuous radiolucent layer of conchyolin (thick if baroque). Large central radiopaque bead of mother of pearl.
(b) Australian, Pale Yellow *(Pinctada maxima)*	Figure 8 (drilled)	Accessory radiolucent drill-holes to facilitate bleaching and dyeing.
(c) Japanese, Rosé *(Pinctada martensi)*	Figure 9 (drilled)	Thin external radiopaque layer of nacre. Thin continuous radiolucent layer of conchyolin. Large central radiopaque bead of mother of pearl.
(d) Cook Is., Black *(Pinctada margaritifera)*	Figure 10 (undrilled)	Mostly baroque shapes. Thick irregular radiopaque external layer of nacre. Thick/thin continuous radiolucent layer of conchyolin. Large central radiopaque bead of mother of pearl.

(B) Fresh Water Pearls

(i) Flesh Nucleated Pearls

(a) Japanese (Lake Biwa) *(Hyriopsis schlegeli)*	Figure 11 (baroque, drilled)	Small baroque shape. Irregular central radiolucent cavity.
	Figure 12 (oval, drilled)	Round/oval shape. Small central radiolucent cavities often removed by the drill hole. Note: fine circumferential lamellae of radiolucent conchyolin could not be detected.
	Figure 13 (undrilled)	Semi-baroque shape. Irregular central radiolucent cavity. Note: fine circumferential lamellae of radiolucent conchyolin could not be detected.

(2) MABE PEARLS

(A) Salt Water Pearls

(i) Australian *(Pinctada maxima)*	Figure 14 (side view, top view)	Thin hemispherical radiopaque layer of nacre. Central radiopaque bead. Radiolucent cement-filled space.

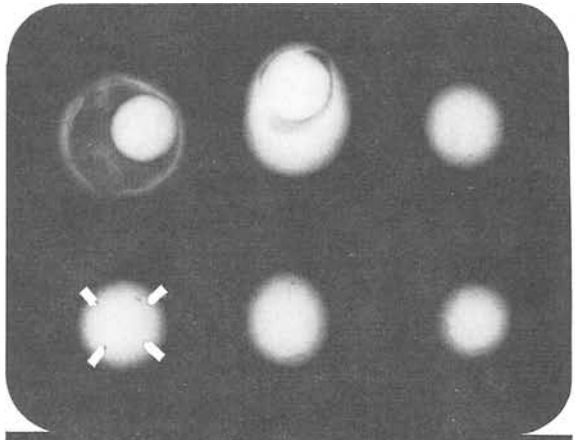

FIG. 7

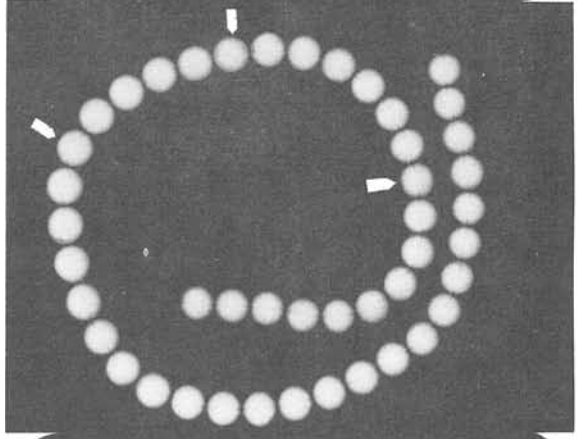

FIG. 8

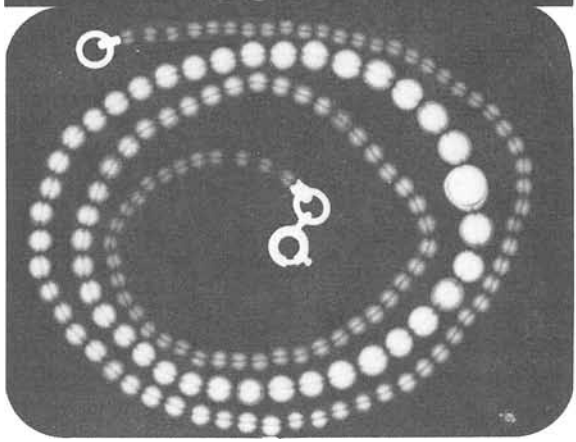

FIG. 9

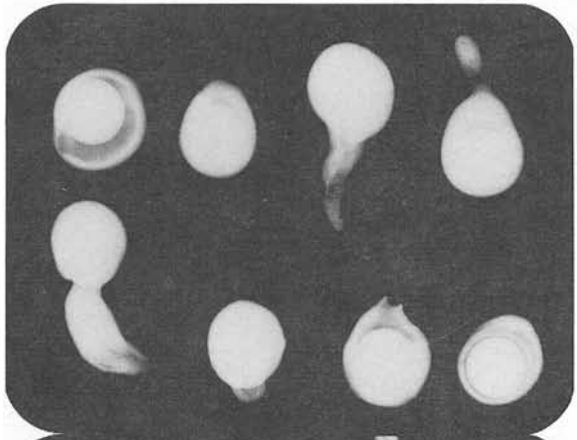

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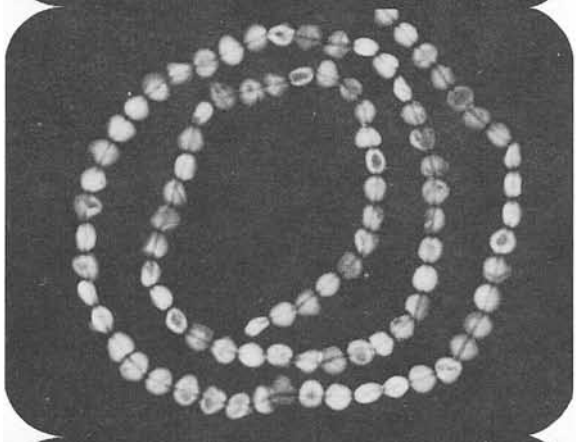

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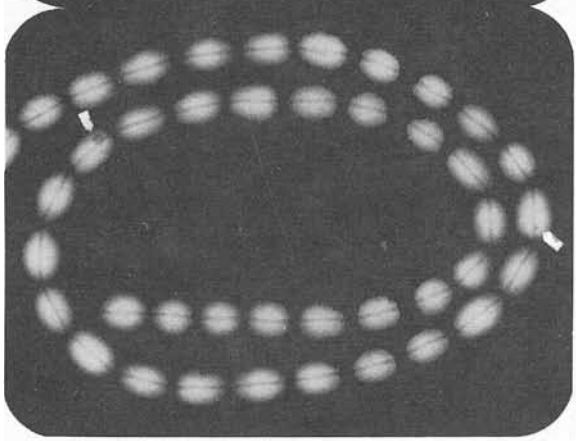

FIG. 12

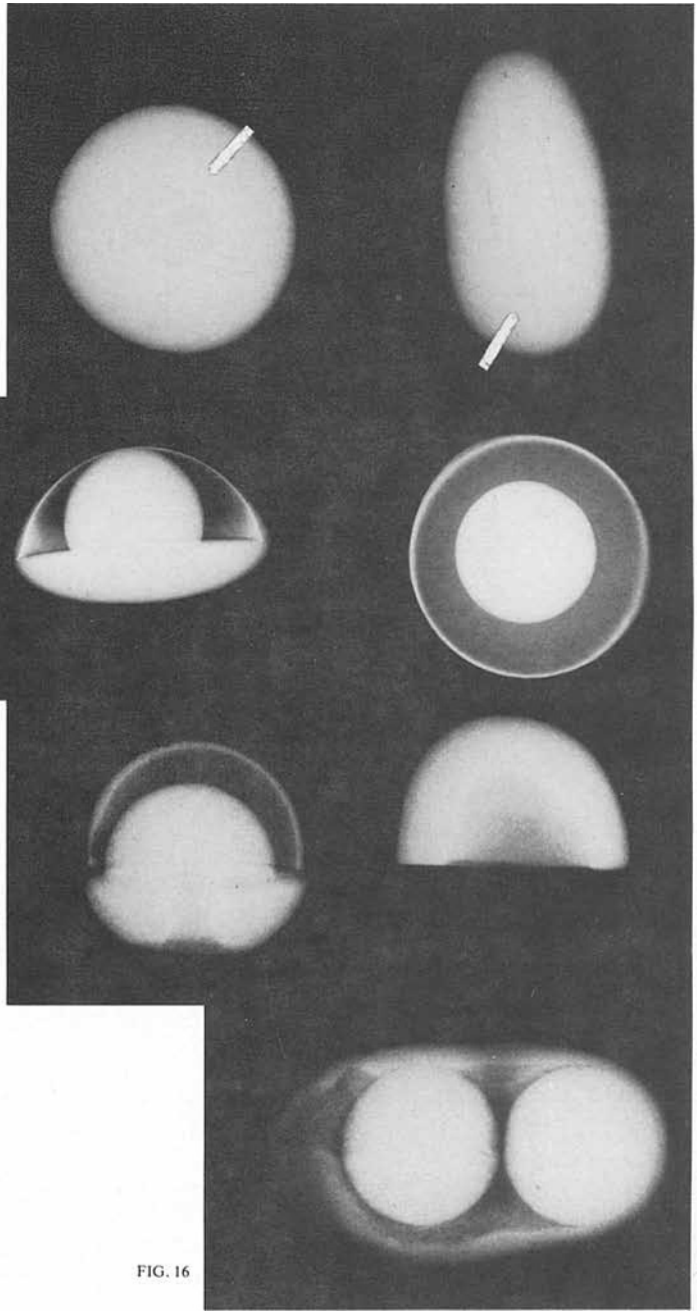

FIG. 13

FIG. 14

FIG. 15

FIG. 16

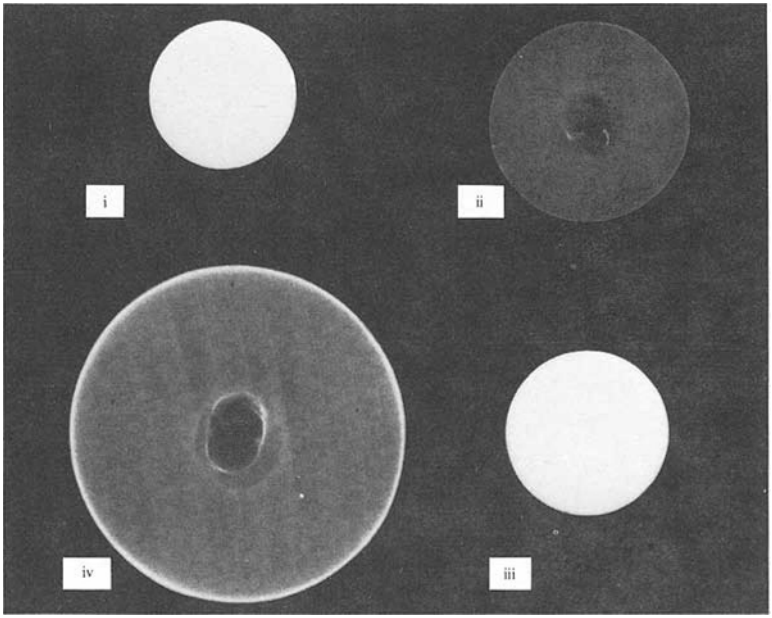

FIG. 17

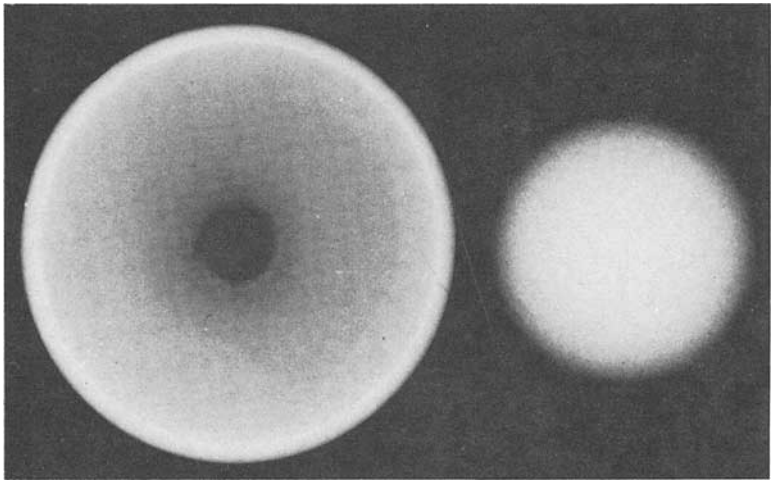

FIG. 18

FIG. 19

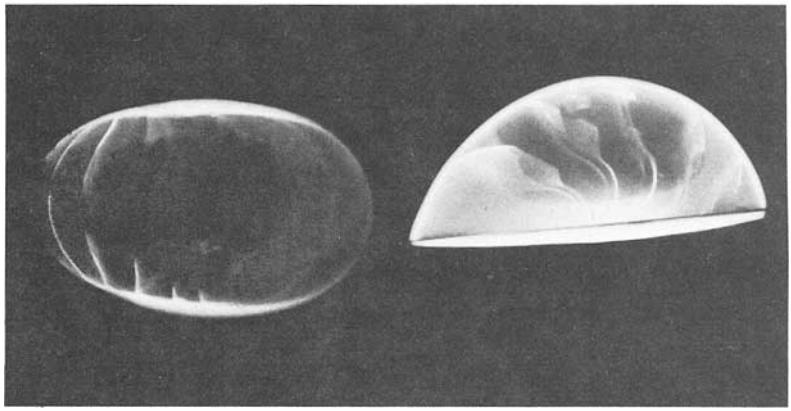

FIG. 20

(ii) Japanese *(Pinctada martensi)*	Figure 15	Thin hemispherical radiopaque layer of nacre. Fitted radiopaque backing of mother of pearl. Thin radiolucent cement-filled space.
(3) CULTURING ACCIDENT	Figure 16 (undrilled)	Two radiopaque beads!

3. IMITATION PEARLS

(1) ESSENCE D'ORIENT COATED BEADS

(A) Solid Glass	Figure 17 (i)	Spherical radiopaque mass.
(B) Solid Plastic	Figure 17 (ii)	Spherical nearly radiolucent mass. Thin continuous external radiopaque layer of essence.
(C) Mother of Pearl	Figure 17 (iii)	Spherical radiopaque mass with no discernible structural characteristics.
(D) Solid Wood	Figure 17 (iv)	Spherical nearly radiolucent mass showing the linear pattern of the wood grain. Thin continuous external radiopaque layer of essence.
(E) Wax-filled Glass	Figure 18	Spherical mass with a densely radiopaque exterior and a much less radiopaque interior.
(2) ANTILLES PEARL (TURNED M.O.P.) *(Conch Shell)*	Figure 19	Radiopaque mass with no discernible structural characteristics.

(3) COQUE DE PERLE *(composite imitation made from the first coil of the internal spiral of the Nautilus shell)*	Figure 20 (top view, side view)	Internal radiopaque spiral whorls.

ACKNOWLEDGEMENTS

I wish to express my appreciation to the following people who have assisted me with this project: for provision of specimens—N. Barnes (Pacific Pearls), H. Mendis (Mendis Gems), R. O'Neil; for radiographic services—L. Street; for photographic services—D. Lund.

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[*Manuscript received 27th July, 1978.*]

BLUISH-GREEN ZOISITE FROM MERELANI, TANZANIA

By Dr K. SCHMETZER and Prof. Dr H. BANK

Since the first publication on the blue variety of zoisite, called tanzanite, from Merelani, Tanzania (Bank *et al.* 1967), this mineral has become an important gemstone. The colour is caused by traces of vanadium, replacing Al^{3+} in the crystal structure of zoisite (Hurlbut 1969). The absorption spectra of this blue zoisite have led various working teams to different interpretations of the absorption bands (Faye & Nickel 1971, Tsang & Ghose 1971). Most probably, the Al^{3+}-positions are occupied by tri- and tetra-valent vanadium ions (Schmetzer 1978). The colour change of the zoisite crystals from Merelani through heat treatment to approximately 500°C is caused by the disappearance of an absorption band in the blue part of the visible spectrum (at 22 000 cm^{-1}). Pleochroism before and after heat treatment is as follows:

	crystals before heating	crystals after heating
X‖*a*	reddish-purple	reddish-purple
Y‖*b*	blue	blue
Z‖*c*	yellowish-brown	blue

Green zoisite from Longido in Tanzania, which is coloured by Cr^{3+}, was first reported by Game (1954). The absorption bands in its spectrum are attributed to Cr^{3+}-ions, which having been already described for vanadium, are located on Al^{3+}-positions in the zoisite lattice (Schmetzer & Berdesinski 1978). Some time ago one of the authors discovered among rough zoisite crystals from Merelani numerous bluish-green stones, showing a pleochroism differing from that of pure blue zoisite. When heated up to 500°C, these stones too changed their colour. The pleochroism of heat-treated and not heat-treated stones of this bluish-green type is as follows:

	crystals before heating	crystals after heating
X‖*a*	reddish-purple	reddish-purple
Y‖*b*	bluish-green	blue
Z‖*c*	greenish-yellow	bluish-green

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The optical and crystallographical values of the bluish-green zoisites do not differ from the respective parameters of the blue zoisites. The absorption spectra of the bluish-green varieties show all bands of the vanadium bearing blue crystals from Merelani and those of the chromium bearing zoisites from Longido. Microprobe analysis confirms the spectroscopic investigation: the bluish-green crystals contain nearly equal contents of vanadium and chromium (0.06% V, 0.07% Cr), whereas the iron contents of bluish-green and blue zoisites from Merelani remain very low (0.001% Fe).

The bluish-green zoisite from Merelani must be regarded as coloured by both vanadium and chromium. We regret that we could not find out in which part of Merelani deposit these bluish-green crystals occur. Therefore there is no possibility to discuss the genesis.

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[*Manuscript received 23rd March, 1979*]

SOGDIANITE

By ROLF DILLMANN, F.G.A.

Gübelin A. G., Berne, Switzerland

In the journal of the German Gemmological Association, 2nd June 1978, I read an article by H. Bank *et al.*[1] about sogdianite as a possible gemstone which I found interesting. As good luck would have it, such a sogdianite was sent to me by a gem-supplier: this was a cabochon-cut stone weighing 6.27 ct and measuring 13.2 mm long by 10.2 mm wide (see Figure 1). Though I cannot be certain of my specimen's provenance, the stone examined by H. Bank *et al.* was said to have originated in the Wessel mine near Hotazel by Karuman, N. Cape Province, S. Africa, and to have been supplied by the firm Weinz-Nebert, of Kirschweiler, and as my stone was supplied by the same firm it may well derive from the same occurrence. As I had never seen such a gemstone before and as I did not find any mention of it in my gemmological library, I decided to investigate it with the gemmological means at my disposal. Here are the data as (apart from chemical composition) I determined them.

Sogdianite	
chemical composition: (after H. Strunz, 1970,[2] following W. D. Dusmatov *et al., 1968*[3])	$(K,Na)_2(Zr,Ti,Fe)_2(Li,Al)_3[Si_{12}O_{30}]$
colour:	lively violet
lustre:	waxy
transparency:	translucent
specific gravity: (by hydrostatic weighing, using distilled water with two or three drops of washing-up liquid, at room temperature)	2.765

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Fig. 1. Cabochon-cut sogdianite weighing 6.27 ct.

hardness: (using a hardness plate and checked with Rayners' hardness pencils)	5-6 (Mohs)	
microscope:	bright veins visible (quartz?) white flakes (accumulation of bright veins)	
refractive index:* (Dialdex refractometer checked by Topcon refractometer)	anisotropic positive	ω 1.606 ε 1.608
luminescence:	UV short UV long	very weak dark red weak violet
absorption spectrum: (by Cool-light Spectroscope with a Zeiss optic, having a wavelength scale: using a blue filter for clear view of lines in the blue)	411 nm 419 nm 437 nm 488—493 nm 630—645 nm	sharp lines (diagnostic) weak bands

Personally, I should be pleased if these data found confirmation.

*The RI was measured on a thin slice taken from one end of my stone and polished. Repeated attempts to obtain the RI from the curved surface of the cabochon by the 'spot method' invariably resulted in a figure of 1.54: I cannot explain this discrepancy.

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[*Manuscript received 18th November, 1978.*]

REPORT FROM THAILAND, 1978

By K. W. FINDLAY, B.Sc.(Eng.), C.Eng., F.I.Chem.E., F.I.Mech.E., F.G.A.

On our second visit to Thailand*, in March, 1978, we wandered through Chantaburi looking for gem dealers—there must be several score but they all had faceted synthetics on offer. A few had garnets and green sapphires. The market in Chantaburi is a highlight tourist attraction; they sell all kinds of tropical vegetables and fruit, also fish, live crabs, eels, frogs and shellfish.

Just opposite the market square we came upon a Lapidary Supply Shop. The counter is shown in Figure 1. They had lapwheels made in Red China, tongs, lubricants in bottles, hard grindstones. The varieties of colour of boules and half-boules from Idar-Oberstein show up very well.

It seems as if the Chantaburi gem areas have dried up as there is very little mining activity and practically nothing coming through from Pailin, Cambodia. Khau Ploy Waen (Figures 2-5) is now a sacred hill; Bo Rai, 48km due East of Chantaburi is a present source of rubies: it is only 7km from the Cambodian border, 12°36′N. 102°30′E. Nong Bar, Bo Waen and Na Wong are stated to be producing rubies in the Chantaburi area but are not shown on the Highway Map 1:10^6.

*For the first, see J.Gemm., 1978, XVI, 3, 194-5.—Ed.

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Fig. 1. The counter of a Lapidary Supply Shop on Market Square in Chantaburi. Faceted synthetics are in the saucers, and boules and half-boules on the lower shelf.

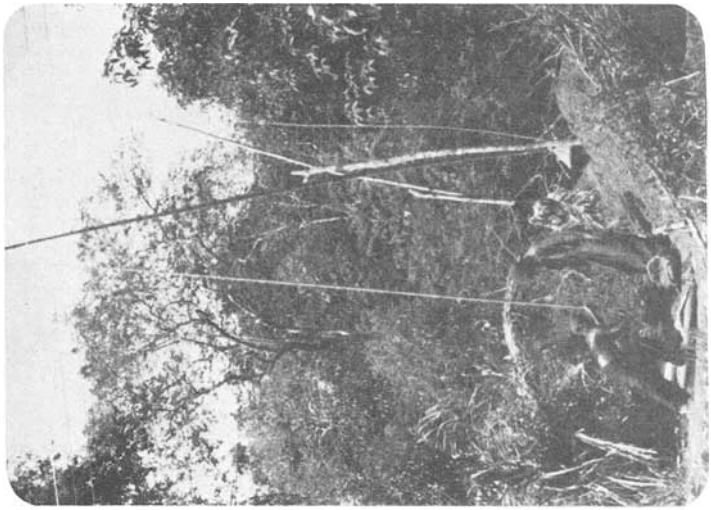

Fig. 3. The bamboo boom and draw-rod for hoisting the gem gravel from the pit. The length of the draw-rod gives some idea of the depth of the pit.

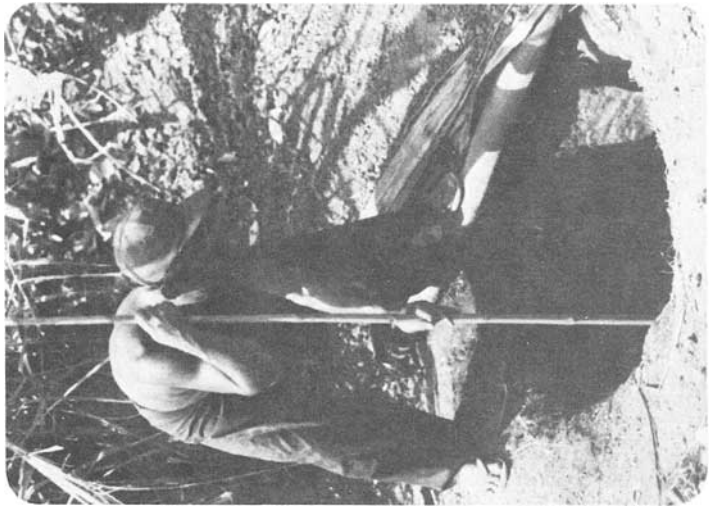

Fig. 2. Fox-hole entrance to the gem-pit—at Khau Ploy Waen, near Chantaburi.

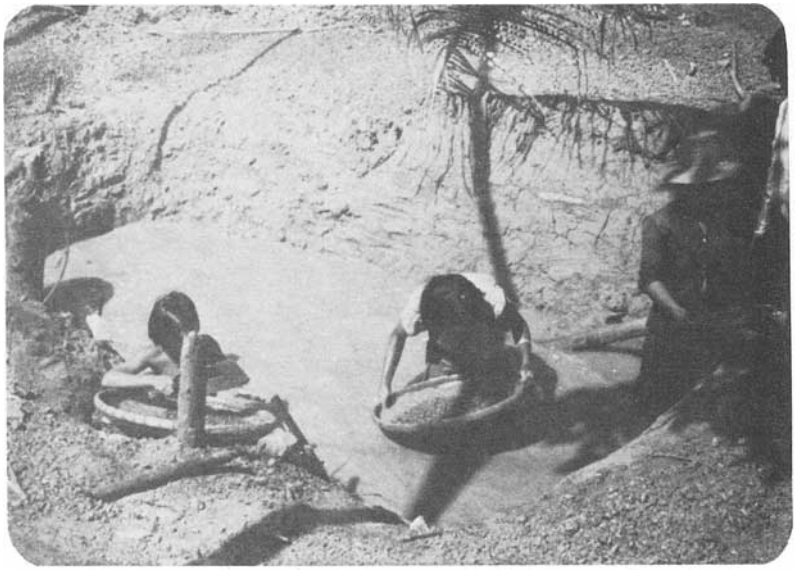

Fig. 4. Young and old female members of the mining family washing the gravel.

Fig. 5. A group of gem (?) vendors at Khau Ploy Waen, near Chantaburi. They have genuine green sapphires, Linde star sapphire and ruby, doublets (sapphire and ruby), also dark red star rubies—synthetic with thin black star backing.

Irrem, Tap Rom and Bang Kaja are sources of sapphire near Chantaburi. I understand Bang Kaja (Ban Cha Cha) is 15km from Chantaburi.

The gem area near Kanchanaburi is Bo Ploy some 40km N. by road, where they recover blue and green sapphires, also in smaller quantities yellow sapphires and chrysoberyl cat's-eye.

There is a local air-conditioned coach service from Bangkok, costing 60 Baht (equal to $(US)3) for the 260km round trip.

Kanchanaburi 14°02′N. 99°30′E.

Bo Ploy 14°20′N. 99°27′E.

Phrae, 744km North by road from Bangkok, 18°10′N. 100°10′E., is stated to be the centre of a new sapphire area where they are finding good royal blue stones. Den Chai, 18°0′N. 100°03′E., is near the railway line to Chieng Mai. The actual mining areas are: Wang Chin, 50km from Den Chai at 17°54′N. 99°33′E., accessible only in dry weather, and Bar Gow, 20km from Den Chai (not on map), and Now Soon near Den Chai (not on map).

Another gem area is said to be near Si Sa Ket (Srisaket) (Srisrkes), 580km from Bangkok East at 15°12′N. 104°20′E.

62km South is the town of Kantaralak, 14°40′N. 104°40′E. The mining area is at Kor Sa Ad nearby.

We were also told by a reputable dealer in Bangkok that zircons were being recovered from Cheom Ksan (Chomkasan), 14°15′N. 104°55′E., in Cambodia.

I understand that no gem material is coming out of Burma because the government has closed the mines and the small miners dare not sell any rough they have, for they would not be able to use the money to buy goods, so they are biding their time.

With 200,000 gem cutters in Thailand, they are faceting stones from all over the world. I saw much from Sri Lanka, Australia and Colombia and Brazil, but what impressed me most was the extent of the synthetic gem industry; it may be for the cheaper oriental jewellery as well as the ignorant tourist who thinks he is getting a bargain.

[*Manuscript received 24th May, 1978.*]

THE AIR-BOUNDARY REFRACTOMETER*

By R. M. Yu, Ph.D., F.G.A., and D. Healey, Ph.D., F.G.A.
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§1 INTRODUCTION

Of all the gemmological instruments, the refractometer is undoubtedly the most useful tool for the identification of gemstones. Unfortunately the common Rayner refractometer measures refractive indices up to 1.81 only, the limitation imposed by the refractive index of the prism material. This makes it useless for a number of natural and synthetic gems having refractive indices above 1.81 (see Table 1†). An ever increasing number of synthetic materials such as YAG, GGG, cubic zirconia and strontium titanate are being placed on the market as diamond simulants. To differentiate these high refractive index synthetics new refractometers have been developed to meet the demand. Some of these new refractometers use infrared light sources, while others measure the relative reflectivity of the gemstones. Dr W. W. Hanneman has pointed out the shortcomings of these new instruments in a most comprehensive review on this subject (Hanneman 1978).

The most fundamental approach to measuring refractive indices is of course to base the method on the very definition of refractive index. Using a monochromatic sodium light source and a precision spectrometer this is a simple and accurate process, if the gem is cut as an equilateral prism. Having measured the apex angle A and the angle of minimum deviation D on the spectrometer, the refractive index of the prism material can be calculated from

$$n = \frac{\sin\left(\frac{A+D}{2}\right)}{\sin\left(\frac{A}{2}\right)} \qquad (1)$$

In practice the gems are usually faceted into round brilliants or trap cuts, so that measuring refractive index by this method is an extremely laborious and painstaking process. To overcome this

*Patent pending.

†see page 535 below.

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difficulty we have devised a new type of refractometer, which is based on the fundamental definition of refractive index and yet is relatively easy to use. Refractive indices up to 2.6 may be measured without the use of any refractive index liquid. With water as a refractive index liquid the upper limit may be extended to 3.4. In the present stage of development it is not as accurate as the Rayner refractometer, being able to measure refractive indices to within ±0.02 only. The instrument's main advantage is its ability to measure refractive indices above 1.81. We feel that the device could become a useful additional piece of equipment in the gemmologists' laboratory, rather than a replacement for the Rayner refractometer.

§2 Principle of the Air-Boundary Refractometer

This new refractometer utilizes the phenomenon of total internal reflection when light travels from an optically denser medium, i.e. the gemstone, into the surrounding air. Total internal reflection occurs at the table facet of a gem when the angle of incidence ∟ABC is greater than or equal to the critical angle θ_c (Figure 1). The critical angle for a gem of refractive index n is given by

$$\theta_c = \sin^{-1}\frac{1}{n} \qquad (2)$$

As a result of total internal reflection the angle of reflection ∟CBD is equal to ∟ABC. The totally reflected ray BD is then refracted at a pavilion facet CDE and viewed by the observer. We shall show that the angle θ_1 between the emergent ray DK and the vertical direction DJ gives a measure of the refractive index of the gem.

According to Snell's law of refraction, the angles of incidence and refraction at the boundary CDE are related by

$$\frac{\sin i}{\sin r} = \frac{1}{n} \qquad (3)$$

From simple geometry:

$$i = \theta_p - \theta_c \qquad (4)$$

where θ_p is the angle subtended by the pavilion facet CDE and the table facet.

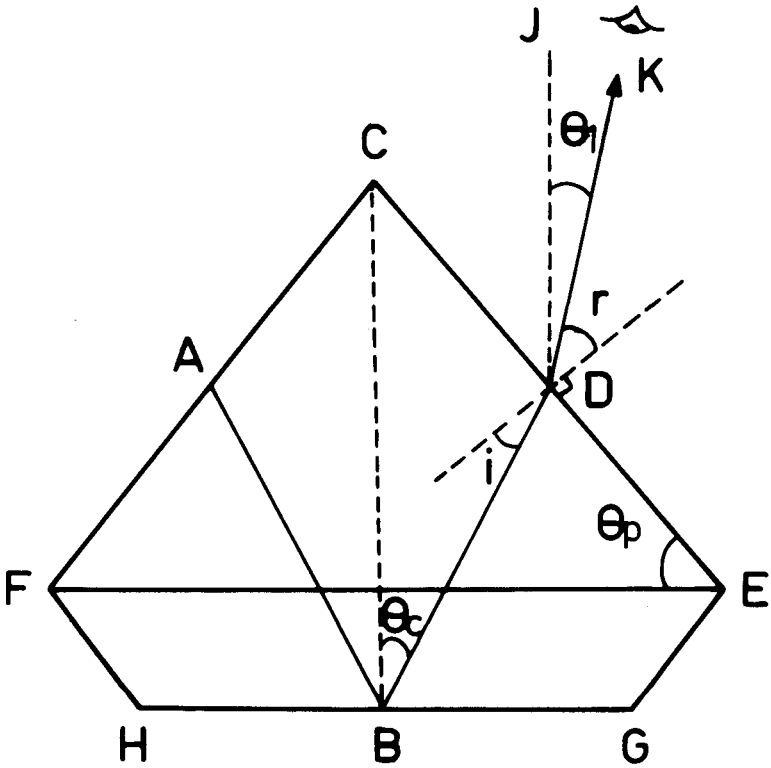

Fig. 1 Total internal reflection at the table facet of a gem.

Also from geometry:

$$r = \theta_p - \theta_1 \tag{5}$$

Therefore

$$\frac{\sin(\theta_p - \theta_c)}{\sin(\theta_p - \theta_1)} = \frac{1}{n} \tag{6}$$

Thus the unknown refractive index n of a gem can be calculated from Eq. (6) if the angles θ_p and θ_1 are measured.

For angle of incidence ∟ABC larger than the critical angle θ_c the light will always be total internally reflected at the table facet HBG, refracted at the pavilion facet CDE and seen by the observer at an angle ∟JDK smaller than θ_1. For angle of incidence ∟ABC

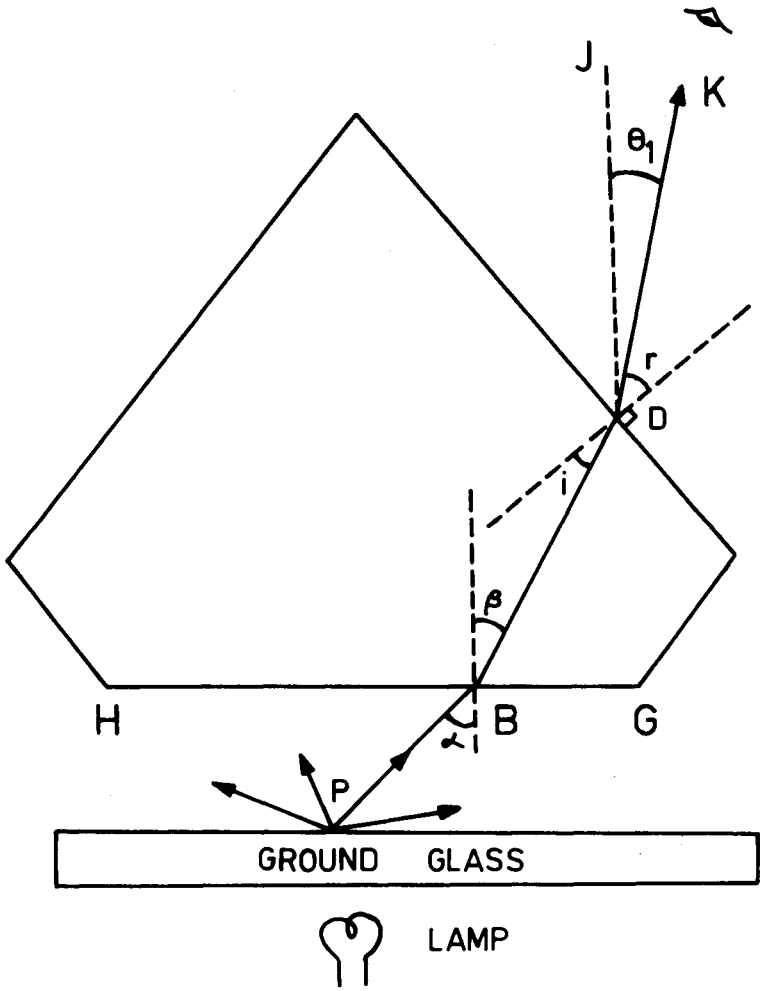

Fig. 1(a) Gem illuminated through a piece of ground glass.

smaller than the critical angle θ_c, the light is not total internally reflected at the table facet HBG and hence never seen by the observer.

As the observer looks down at the gem along the vertical direction JD he sees a brightly lit gem because of the total internally reflected light. As he moves his head away from the vertical direction the gem will remain bright until the angle ∟JDK is equal to θ_1.

For ∟JDK larger than θ_1 the pavilion facet will appear dark because no light comes out of the gem at an angle larger than θ_1. Thus θ_1 can be found by moving the observer's head slowly from the vertical (i.e. varying ∟JDK) until the pavilion facet just turns from bright to dark. This condition corresponds to ∟JDK $= \theta_1$, the angle θ_1 is measured and the refractive index n of the gem can be calculated from Eq. (6).

In the discussion above we have assumed that the light ray enters the gem from above as indicated by ray AB in Figure 1. In practice we find the effect is more pronounced if the gem is illuminated through a piece of ground glass placed underneath the table facet HBG as shown in Figure 1(a). The ground glass scatters light in all directions. Consider a light ray PB incident on the table facet on an angle α. The angle of refraction β is given by Snell's law of refraction:

$$\frac{\sin \alpha}{\sin \beta} = n \qquad (6a)$$

Since the largest possible value of α is 90°, the largest possible value of β is arc sin $(1/n) = \theta_c$. Thus the gem will appear dark when the observer moves his head so that ∟JDK is larger than θ_1.

To measure the pavilion angle θ_p a horizontal beam of light AB is shone on the pavilion facet (Figure 2). The observer moves his head until he sees a mirror image of the light source in the pavilion facet closest to the light source. From the law of reflection and simple geometry we find that θ_p is related to the angle θ_2 between the line of sight BC and the vertical direction BD by

$$\theta_2 = 90° - 2\theta_p \qquad (7)$$

Thus θ_p can be calculated from measured value of θ_2.

A simple technique sometimes used by diamond dealers to distinguish round brilliant cut diamonds from lower refractive

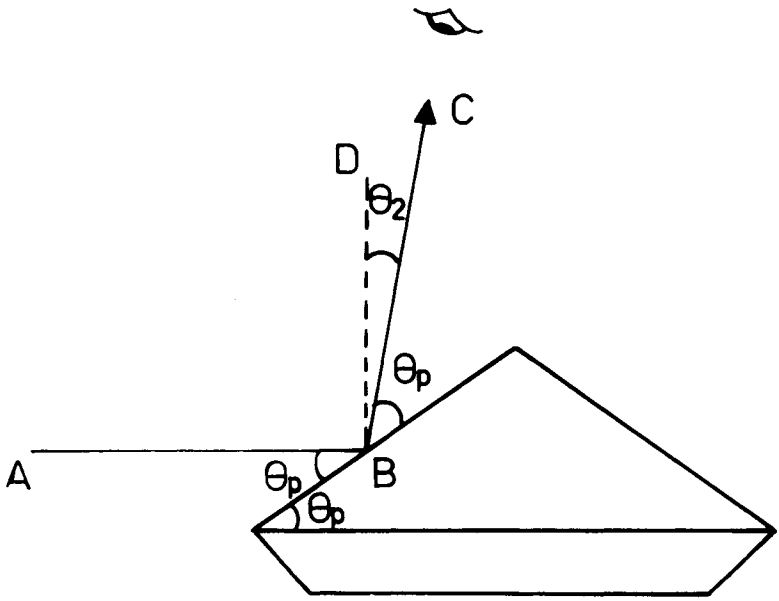

Fig. 2 Specular reflection at a pavilion facet.

index simulants quickly is to place the stones table facet downward and rock the stones back and forth. When observed from above the diamonds look silvery because no light gets out of the pavilion in a vertical direction while the lower refractive index stones look glassy because light can get out of the stones even at large angles away from the vertical. It can be seen that the air-boundary refractometer essentially measures how far away from the vertical one has to look before no light can be observed coming out of the stone.

§3 Construction of the Air-Boundary Refractometer

As explained in §2 the refractive index of a gem can be calculated from Eq. (6) if the two angles θ_p and θ_1 are known. To measure these two angles we have constructed an inexpensive prototype refractometer. The refractometer consists of a black plastic box of inside dimensions shown in Figure 3. ABCD is a sliding door which may be moved sideways to allow the gem to be placed table facet downward on a one centimetre square ground glass stage S. The sliding door is closed to shut off roomlight while

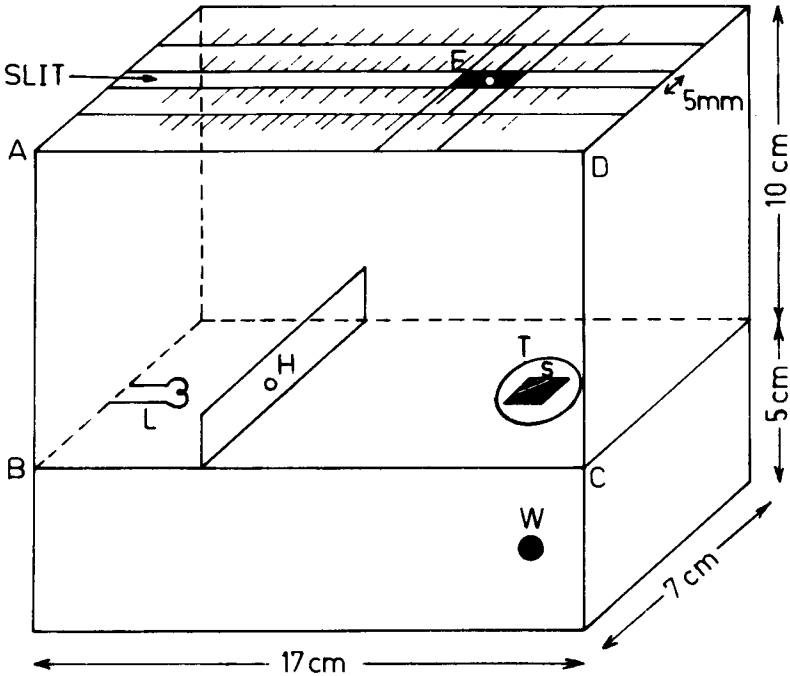

Fig. 3 Sketch of the air-boundary refractometer.

making measurements. To measure θ_p and θ_1 the gem is illuminated with small light bulbs L and M respectively. A metal sheet with a 1 mm diameter hole H at a height 2.5 mm above the base defines the light beam illuminating the pavilion facets of the gem. The height of the illuminated hole H is adjustable by a screw mechanism not shown in Figure 3. Light bulb M is directly underneath the ground glass stage S. Both light bulbs are powered by two UM-1 dry cells and controlled by a 3-way switch W.

The gem is observed through an eyepiece E which consists of a perspex sheet with a 2 mm diameter hole in the centre. The eyepiece slides along a narrow slit 5 mm wide and 17 cm long at the top of the refractometer. Figure 4 shows a cross-sectional view of the refractometer. The angles θ_1 and θ_2 are related to the displacements X_1 and X_2 of the eyepiece by

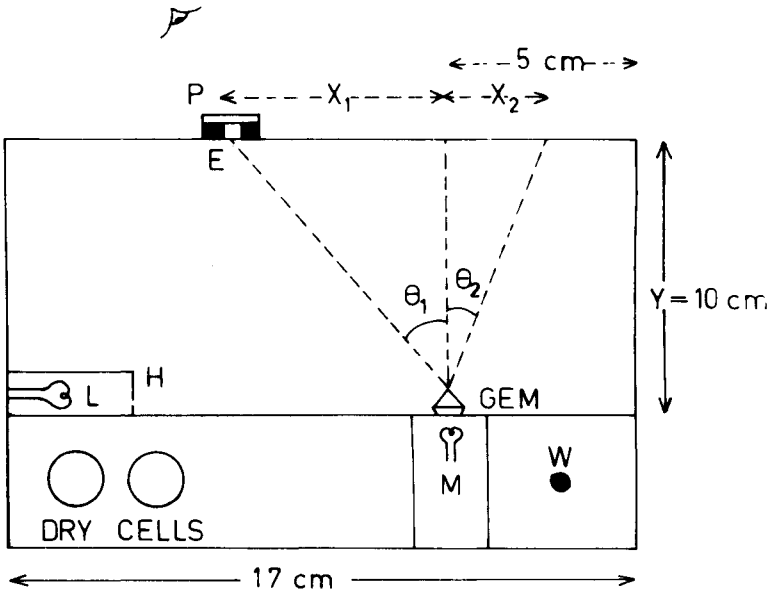

Fig. 4 Cross-sectional view of the air-boundary refractometer.

$$\tan \theta_1 = \frac{X_1}{Y} \tag{8}$$

$$\tan \theta_2 = \frac{X_2}{Y} \tag{9}$$

where the height Y is chosen to be 10 cm for the prototype model.

Using Eq. (9) and Eq. (7) the values of X_2 for various pavilion angles θ_p can be calculated. Thus a scale of θ_p can be marked alongside the viewing slit and θ_p for a particular gem can be read directly from the scale (bottom scale in Figure 5).

Similarly X_1 for various values of θ_p and refractive indices are calculated from Eqs (2), (6) and (8). It should be noted that X_1 depends on θ_p as well as on the refractive index n. Figure 6 plots X_1 as a function of the refractive index for pavilion angle θ_p = 37°, 39°, 41°, 43° and 45° respectively. The refractive index scales for θ_p = 39°, 40°, 41°, 42°, 43°, 44° and 45° are marked alongside the eyepiece slit in Figure 5. The refractive index of a gem with a pavilion angle θ_p in between the integral values can be found by extrapolation. Thus the refractive index for θ_p = 40.5° is the average of the refractive indices for θ_p = 40° and 41° respectively.

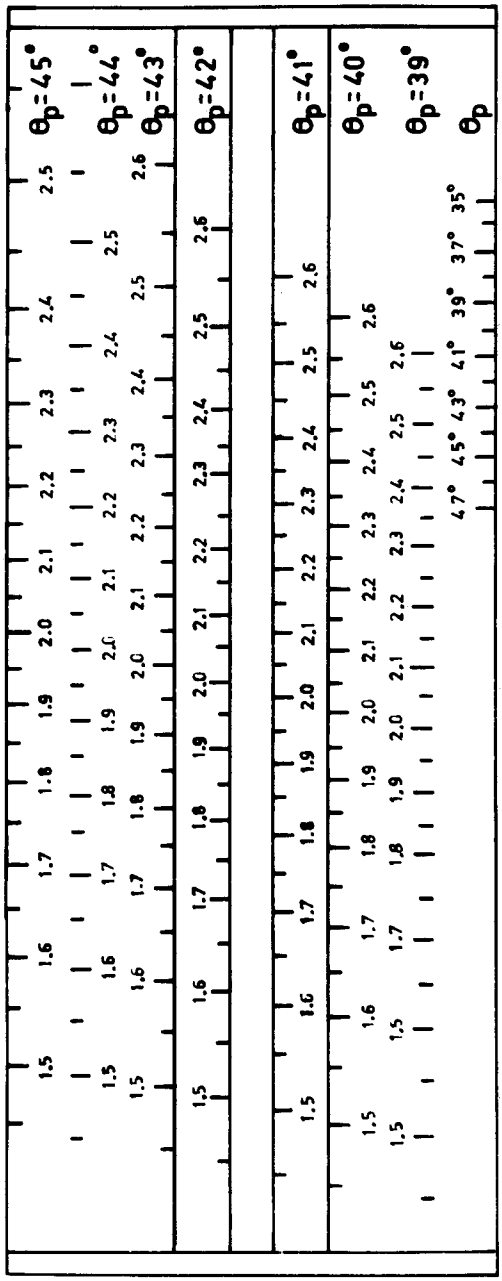

Fig. 5 Scales of refractive index and pavilion facet angle.

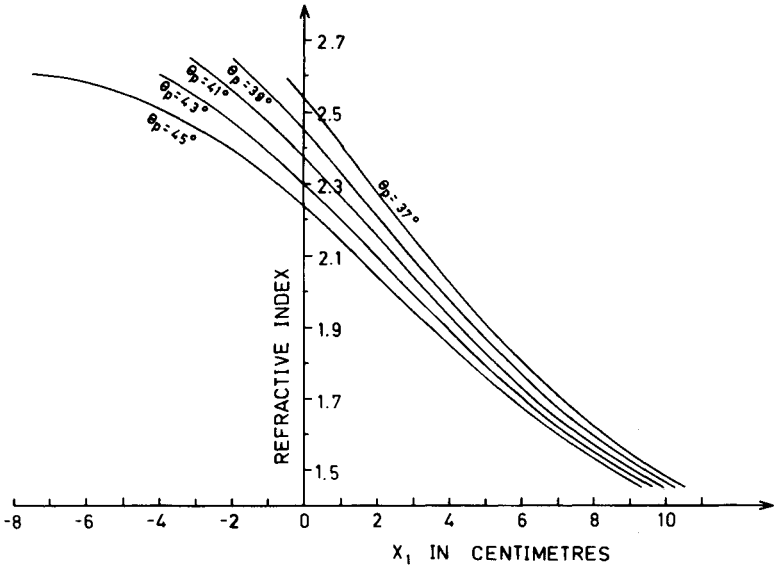

Fig. 6 Variations of X_1 with refractive index and pavilion facet angle

§4 Operation Procedures

(1) Move the sliding door sideways to place the gem table facet downward on the ground glass stage S. No refractive index liquid is required, but the gem should be wiped clean of grease or fingerprints. Move the gem so that the girdle falls on the black line marked on the ground glass stage. This is important, as the value of θ_p measured depends on the position of the gem on the stage S.

(2) Switch on the light bulb L by pressing down the 3-way switch. Look through the viewing slit on top of the refractometer for a reflected image of the illuminated hole H in one of the pavilion facets of the gem. It may be necessary to rotate the gem by a few degrees so that the reflected image of H is seen through the lower girdle facet E or the pavilion main facet F in Figure 7a. To facilitate this operation the stage S is made rotatable by fixing it at the centre of a brass cylindrical table T (Figure 8). The cylindrical table T fits into a cylindrical shell Q and can be rotated through a few degrees by moving the rod R.

(3) After θ_p is measured the 3-way switch is pushed to its

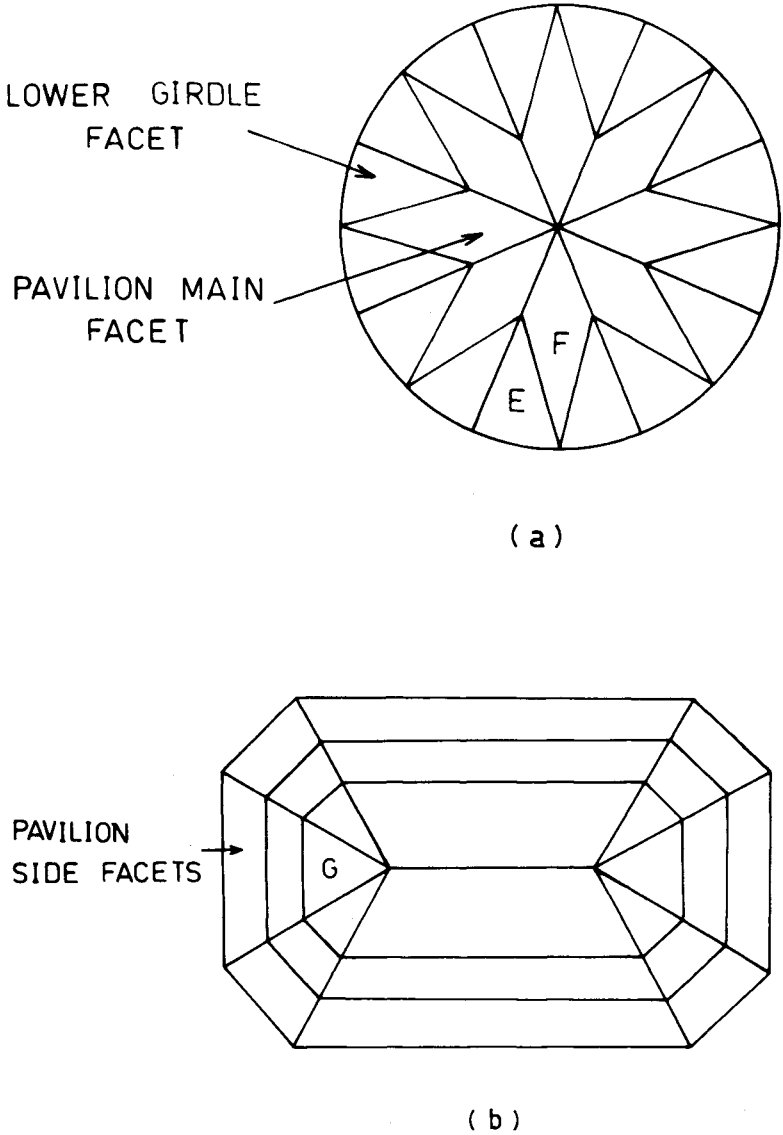

Fig. 7 Pavilion facets of round brilliant and trap cut stones.

upward position to switch on light bulb M underneath the ground glass stage. The eyepiece is first moved so that it is directly above the gem (θ_p = 45° on the θ_p scale). If the RI of the gem is lower than 2.37 it will appear bright, otherwise it will appear dark. For the sake of argument assume the RI of the gem is less than 2.37; move the eyepiece to the left until the lower girdle facet E (Figure 7a) just turns dark. The RI of the gem is read from the position of the eyepiece along the appropriate refractive index scale for θ_p. If θ_p had been measured to be 41°, then the RI is read from the θ_p = 41° scale. It should be noted that as the eyepiece is moved further to the left, the pavilion facet E becomes darker and darker until it becomes quite black. The refractive index of the gem is determined by the eyepiece position when the facet E first darkens.

(4) For argument's sake consider a gem of pavilion angle θ_p = 41°, say. If the refractive index is higher than 2.37 the gem will appear dark when the eyepiece is directly above the ground stage. In this case the eyepiece should be moved to the right until the lower girdle facet E just turns slightly bright. The refractive index of the gem is then read from the θ_p = 41° scale. If the refractive index is higher than 2.86, then total internal reflection occurs also at the pavilion facet CDE (Figure 1) so that the gem looks dark in all directions. In such a rare case the refractive index can be found by placing a drop of water between the gem table facet and the ground glass stage S. Total internal reflection then occurs at the gem-water boundary instead of the gem-air boundary. Hence the refractive index is obtained by multiplying the scale reading by the refractive index of water (1.33). There are few gems of such high refractive indices, the only noteworthy one being rutile (2.616-2.903).

(5) After the measurements the 3-way switch should be returned to its neutral position to conserve battery power.

§5 Refinements in the Air-Boundary Refractometer

(1) For measuring refractive indices of strongly birefringent gems, a rotatable polarizer is attached to the eyepiece (P in Figure 4).

(2) The refractive indices can be measured more accurately by placing an interference filter or coloured glass filter over the light bulb M, so that only yellow light (589 nm) illuminates the ground glass stage S.

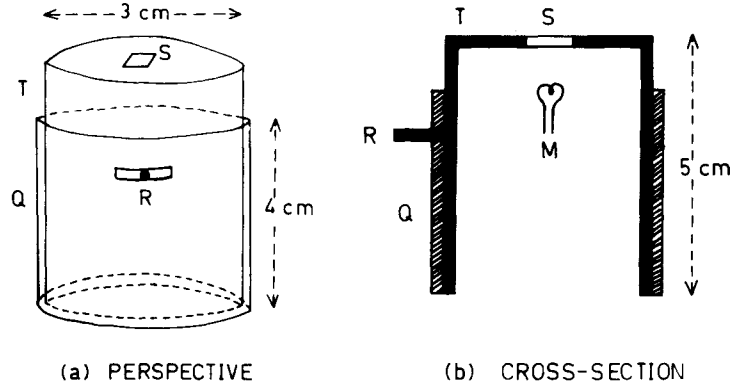

Fig. 8 Perspective and cross-sectional views of the rotatable table.

(3) The θ_p scale and refractive index scales have been calculated assuming the pavilion facets to be 2.5 mm above the ground glass stage S. This assumption is valid for a round brilliant cut stone weighing about 1 carat. For larger stones the pavilion facets will be higher. This increase in height is measured by a scale attached to the refractometer and the height of the illuminated hole H correspondingly increased. This operation maintains the accuracy of the θ_p scale; the errors introduced into the refractive index scales due to the larger size of gems are negligible.

(4) To calibrate the refractometer we place a small right-angle glass prism to simulate a gem. The 45° angle of the prism is measured by the refractometer and the θ_p scale of the refractometer set accordingly. The vertical direction corresponds to $\theta_p = 45°$, hence the refractive index scales are also set. The refractive index of the prism is then measured on the air-boundary refractometer. Since the refractive index of the prism is known from previous measurement on a spectometer or Rayner refractometer, this process demonstrates to a novice what we mean by "the refractive index of the gem is determined by the eyepiece position when the facet E first darkens" (last sentence in paragraph (3) of §4).

§6 Results and Discussions

The air-boundary refractometer has been used to measure the refractive index of a variety of gems and the results compared with those obtained with the Rayner refractometer or literature values

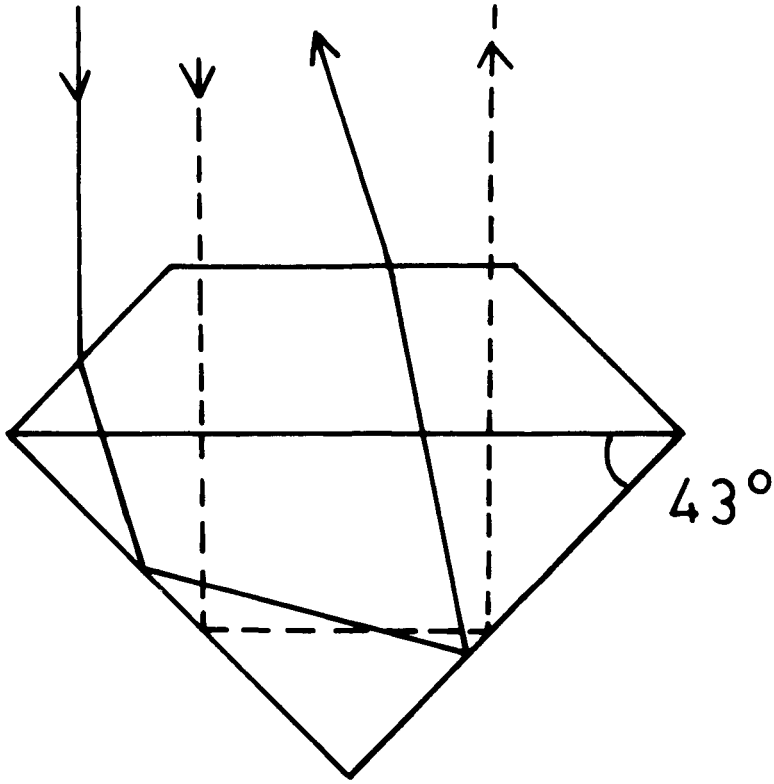

Fig. 9 Total internal reflection in a cut stone.

(Table 2). At the present stage of development we are aware of its shortcomings:-

(1) It is less accurate than the Rayner refractometer. Its accuracy is affected by the measured value of the pavilion facet angle θ_p. In general the refractive index can be measured to ±0.02 by this device as compared to ±0.001 for the Rayner refractometer.

(2) It cannot be used on cabochons or fancy cut stones with pavilion facet angles outside the range 37° to 45°. It can only be used on set stones the pavilion facets of which are left exposed by the setting.

Nevertheless it has the following advantages:-

(1) Most important of all, the air-boundary refractometer can measure refractive indices higher than 1.81. It can measure the refractive index of YAG (1.83), GGG (2.03), cubic zirconia (2.15) and thus distinguish them from diamond (2.418). The refractive index of strontium titanate (2.41) is too close to that of diamond to be differentiated by this method. However it can be easily recognized by its dazzling fire due to the high dispersion.

(2) It is simple and robust in construction. Although the prototype model is made of plastic, it can very well be made of wood, brass or aluminium.

(3) It costs only about £20. No expensive prism is required as in the Rayner refractometer.

(4) It does not require a refractive index liquid.

(5)The angles of the lower girdle facets and the pavilion main facets are measured by this method. This allows us to determine whether the gem is correctly cut or not, a factor which affects the beauty and price of a gem. In a correctly cut gem the pavilion angles are chosen so that light entering from the table facet is total internally reflected inside the pavilion and comes out at the crown to give brilliance and fire to the gem (Figure 9). Table 3 gives the pavilion main facet angle for gems of various refractive index range (Sinkankas 1962). The lower girdle facet angles are usually larger than the pavilion main facet angles by two or three degrees.

In conclusion we feel this new refractometer may prove to be useful for gemmologists interested in high refractive index stones such as diamond and its more recent simulants.

TABLE 1

Gems with Refractive Indices Higher than 1.81

YAG	1.83
Demantoid Garnet	1.89
Zircon (High)	1.93-1.99
Sphene	1.90-2.02
GGG	2.03
Cubic Zirconia	2.15
Strontium Titanate	2.41
Diamond	2.418
Rutile	2.62-2.90

TABLE 2

RI measured by the Air-Boundary Refractometer

Gems	Air-boundary refractometer	Other sources
Amethyst	1.56	1.553-1.544
Topaz	1.61	1.613-1.622
Chrysoberyl	1.75	1.749-1.756
Synthetic ruby	1.77	1.760-1.769
YAG	1.85	1.83
Zircon	1.97-2.03	1.93-1.99
Cubic zirconia	2.16	2.15-2.18
Diamond	2.41	2.418
Strontium titanate	2.42	2.41

TABLE 3

Pavilion Main Facet Angles by RI Range

Refractive Index	Pavilion Main Facet Angles
1.40-1.60	43°
1.60-2.00	40°
2.00-2.50	37° to 40°

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[*Manuscript received 13th January, 1979.*]

AN EXPERIMENTAL BREWSTER-ANGLE REFRACTOMETER

By PETER G. READ, C.Eng., F.G.A.

Over the last ten years, the introduction of convincing man-made diamond simulants having refractive indices above the range of the critical-angle refractometer has emphasized the need for a simple and reliable quantitative method of identifying both diamond and its imitations, particularly when mounted.

The development of the blende and diamond versions of the standard Rayner refractometer[1,2] provided a useful extension to that instrument's range, but even here, the limiting factor was the contact liquid (West's solution, with an RI of 2.05). There are, of course, several alternative ways in which high refractive indices can be measured, and these range from the 'Direct' method which uses a microscope[3] (or a modified vernier caliper gauge[4]), to the derivation of RI via the measurement of facet and minimum deviation angles on a goniometer or table spectrometer.

None of these alternatives, however, has the convenience of a direct-reading instrument, and it was not until the introduction of the first commercial electronic reflectivity meter in 1974[5,6] that an easy method of identifying high RI gems was provided by the measurement of their relative reflectivities.

While the use of this type of instrument enables a rapid check to be made on a gemstone's identity, the accuracy of the result depends on the cleanliness and perfection of polish of the gemstone's surface. In inexperienced hands, the reflectivity meter can provide misleading readings, particularly if the surface condition criteria are disregarded.

During a search through one of the more recent reference works[7] on optics for an alternative technique for the measurement of high refractive indices, the writer came upon a description of the plane polarization of light by reflection. In this connexion, Brewster's law states that complete polarization of a ray reflected from the surface of a denser medium occurs when it is normal (i.e. at right-angles) to its associated refracted ray in that medium (Figure 1.) The Brewster angle of polarization can be related to the medium's refractive index as follows:

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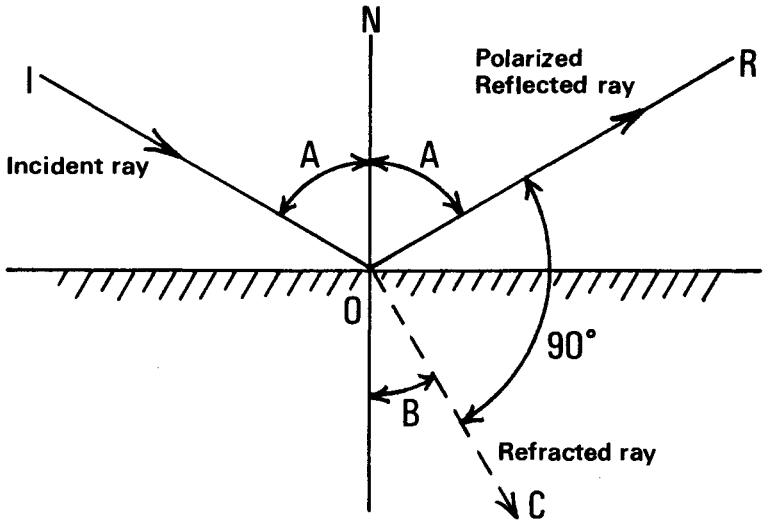

FIG. 1. Showing the 90° relationship between the reflected and refracted rays at the polarization angle A for the denser medium.

If A in Figure 1 = the Brewster angle of polarization (i.e. ROC = 90°)

$$\text{then } A + B = 90°$$

$$\text{As the RI of the denser medium} = \frac{\sin A}{\sin B},$$

$$\text{and } A + B = 90°, \text{ then RI} = \frac{\sin A}{\cos A} = \tan A$$

and Brewster angle of polarization A = arc.tan of the medium's RI.

Taking the extremes of fluorspar and rutile:

Brewster angle for fluorspar = arc.tan 1.43 = 55°

Brewster angle for rutile = arc.tan 2.75 = 70°

Although further investigation showed there had been previous attempts to use the angle of polarization to measure RI, these do not appear to have been pursued seriously because of the mechanical difficulty in rotating a beam of incident light about the surface of a gemstone, and simultaneously following the movement of the reflected ray with a suitable polarization detector[8].

To test the practicality of using the Brewster angle phenomenon as a means of measuring a gemstone's refractive

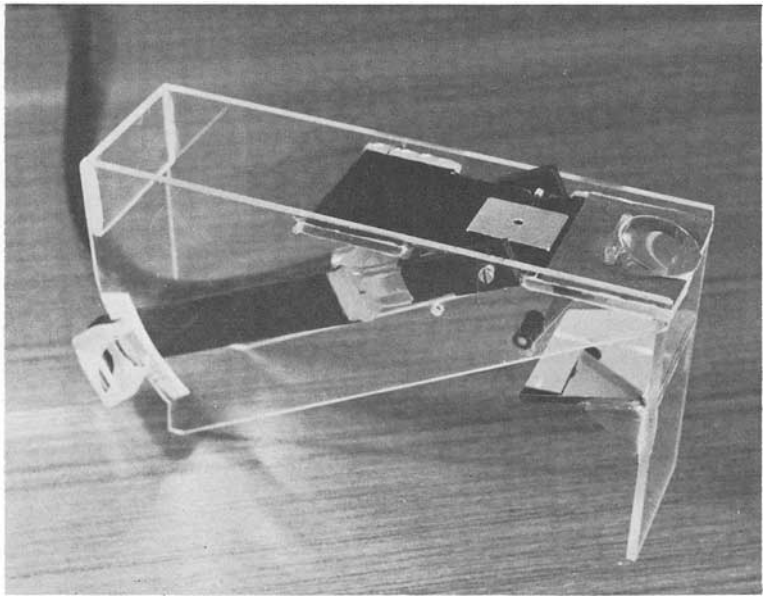

FIG. 2. Experimental Brewster-angle refractometer.

index, the writer constructed a simple optical model (Figure 2) which dispenses with a moving detector and passes the reflected ray through a suitably orientated polarizing filter, imaging the result on a translucent screen (Figure 3). With a gemstone positioned over the test aperture, the angle of the incident light is then adjusted for extinction of the reflected light spot, the extinction or Brewster angle being used as a direct measure of RI.

The experimental model proved the feasibility of the technique. It also showed that a strong source of light was necessary to compensate for the light lost both through the polarizing filter and by the low reflectivity of the gemstone (for a normal incident ray, this light loss is as high as 83% for diamond, and 95% for quartz).

Although a high-intensity white light source was used for the experimental model, ideally a monochromatic source should be used to achieve total extinction of the reflected ray at the Brewster angle.

While not capable of detecting double refraction, the experimental model was (in contrast to the reflectivity meter) relatively insensitive to scratches or dirt on the gemstone's surface,

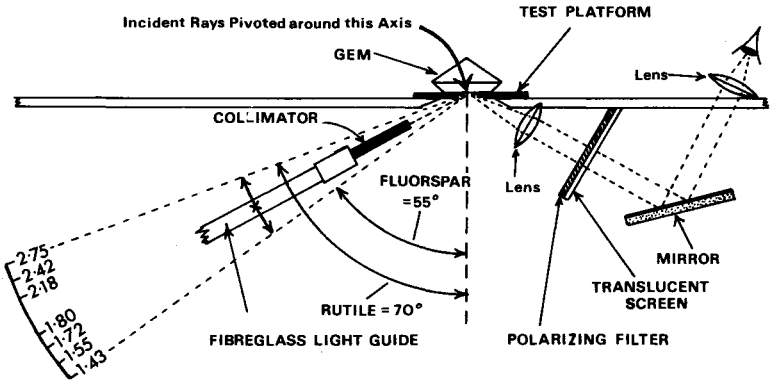

FIG. 3. Sketch showing the construction of an experimental Brewster-angle refractometer. To prevent unwanted light reflections from reaching the screen, a vertical light baffle was fitted beneath the test platform aperture.

which simply reduced the degree of attenuation of the filtered light spot at the polarization angle. Measurement of RI was limited in the model to two significant figures, although this could no doubt be improved by the more efficient use of the light source and by providing a fine adjustment of the incident light angle. However, satisfactory readings were obtained with a range of opaque as well as translucent and transparent gems.

Readings taken on the semi-polished flat bases of cabochons (jasper, tiger's eye, rose quartz, moonstone, sodalite) were more positive than on the standard critical angle refractometer. As with the reflectivity meter, correct registration of the surface of the gem over the test aperture is most important. In the experimental model, this is ensured by first setting the incident beam at an angle which produces a visible light spot on the translucent screen, and then adjusting the position of the gem until this spot is symmetrical and centred on a guide line drawn vertically down the screen. Finally, the angle of the incident light is adjusted until the light spot is either extinguished, or at its weakest, and the RI value of the gemstone then read from a calibrated scale.

In conclusion, the writer hopes that this initial development work will encourage further experiments in the use of polarization by reflection (a phenomenon which is the main source of naturally

occurring polarized light), and that this may eventually lead to the production of a commercial Brewster-angle refractometer.

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GEMMOLOGICAL ABSTRACTS

ALEXANDER (A.E.). *Before the gems came the crystals.* Australian Gemmologist, **13**, 8, 247-50, 6 figs, 1978.

A rambling reminiscence of a specific find of gem crystals in Minas Gerais in 1947 and their subsequent use in part by sculptor Oskar Hansen. Most were unused and found their way to the author for advice and marketing. Other examples of Hansen's work are illustrated. R.K.M.

ALEXANDER (A.E.). *The Far Eastern gem deposits and Dr Edward Gübelin, the Marco Polo of the gemmological profession.* Australian Gemmologist, **13**, 8, 280-4, 4 figs, 1978.

A rather disjointed dip into correspondence from Dr Gübelin on journeys which took him to gem mines in a great many places. Author brings Chas. Murray into the account and finally includes lists of gems found in 'Far East' countries. (It is disconcerting to find Tanzania and Kenya included, but to an American they are eastern lands). R.K.M.

ALEXANDER (A.E.). *Two new mineral specimens enter the New York market.* Australian Gemmologist, **13**, 8, 250, 2 figs, 1978.

Brief mention and photographs of 'angel-skin opal' (pink, from Mexico, carved/cabochoned in Idar-Oberstein), Australian yellow-brown jasper (carved in China) and 'a mixture of quartz and tiger-eye' cut in Idar-Oberstein. J.R.H.C.

ALTHAUS (E.). *Wassermelonen und Mohrenköpfe.* (Watermelons and niggerheads.) Lapis, **4**, 1, 8-11, 12 figs (7 in colour), 1979.

Explains the various theories of the cause of colour in tourmaline with illustrations of absorption spectra and notes on charge transfer. M.O'D.

ANDERSON (H.). *How to feel the difference between a diamond and a cubic zirconia.* Australian Gemmologist, **13**, 8, 285-7, 1978.

This is the 'slippery topaz' of Church brought up to date. Diamond is said to feel sticky due to affinity for natural grease of the skin. Drop test (heft) is also suggested. R.K.M.

BALAKIREV (V.G.), TSINOBER (L.I.), KOVALENKO (V.S.), SVIRIDENKO (A.F.), AYEROV (G.D.). *Electron microscopy of cristobalite-tridymite opal.* Doklady Akademii Nauk SSSR, **233**, 4, 672-4, 1 fig, 1977). (In English.)

Cristobalite-tridymite opals coloured green, reddish-brown and yellow were studied by means of electron microscopy using replicas, diffraction contrast and microdiffraction. Reflections of 4.30Å which are characteristic of tridymite but not of cristobalite showed that all types of particles studied were low-temperature tridymite. M.O'D.

BANK (H.). *Edelsteine aus Kenya.* (Gemstones from Kenya.) Z.Dt.Gemmol.Ges., **27**, 4, 185-95, 1 map, bibl., 1978.

Because of its geology and petrology, Kenya is rich in minerals and gemstones. The author lists alphabetically the various occurrences, adding a few notes to some. Green, as well as blue-green, apatites are found. The beryls are mostly of industrial quality, but aquamarines are found in the Baragoi region; there are some green and blue beryls (but not emeralds) and a few morganites. Kyanite is mentioned, as is also diopside, epidote and various feldspars, mainly amazonite and oligoclase, also gaylussite. The garnet group is represented by almandines, which are found in good crystals, and green garnets, which are transparent vanadium-chromium grossularites. Rarer are the green kornerupines, and even rarer the green kornerupine cat's-eyes. The most valuable gem found in Kenya is undoubtedly corundum, which occurs as ruby, sapphire and in other varieties. Meerschaum of good quality was found in the year 1953; obsidian can be seen in the rift valley near Magadi. Some olivine is present; there is some opal but not of cuttable quality with the exception of some yellow-greenish material. Quartz is represented by amethyst, rock crystal, rose quartz, agate and a variety of green quartz. Sillimanite in gem quality is rare; there is some spinel, sphene and titanite, but not much. Topaz is found in its colourless and yellow variety. Tremolite and tourmaline are mentioned. The vesuvianite from Kenya is yellow-green. There is some zircon. The other gems mentioned are amblygonite, anglesite, augite, azurite, barite, cassiterite, cerussite, magnesite, scheelite, smithsonite and sphalerite. E.S.

BANK (H.). *Rubine aus Alipur, Mysore (India).* (Rubies from Alipur in Mysore, India.) Z.Dt.Gemmol.Ges., **27**, 4, 211, 1978.

Although most rubies are not as good as the Kenyan material, some good quality stones have reached the market. E.S.

BANK (H.), BERDESINSKI (W.), SCHMETZER (K.). *Durchsichtiger rosafarbiger Bustamit aus Australien.* (Transparent pink bustamite from Australia.) Z.Dt.Gemmol.Ges., **27**, 4, 208-10, bibl., 1978.

Data are given of a transparent, pink stone, bustamite, presumed to come from Australia. A table compares the optical data with those of other chain silicates such as wollastonite, rhodonite and pyroxmangite. E.S.

BANK (H.), MAES (J.), DOS SANTOS (A.). *Sillimanit-Cabochons in gemischter Ceylon Partie.* (Sillimanite cabochons in mixed parcel from Ceylon.) Z.Dt.Gemmol.Ges., **27**, 4, 212-13, bibl., 1978.

Sillimanite is very difficult to cut because it is very fibrous; up to the present some examples have been found from Burma, Ceylon and Kenya. Two further stones were diagnosed in a mixed parcel from Ceylon. E.S.

BARIAND (P.), POULLEN (J.F.). *Nicht nur Lapis.* (Not only lapis.) Lapis, **4**, 1, 20-3, 6 figs (4 in colour), 1979.

The areas of Nilaw, Mawi and Korgal in Afghanistan produce a number of important gemstones. Nilaw is a pegmatite with beryl, various feldspars, tourmaline, spodumene and pollucite; Mawi pegmatites give very large kunzite crystals, including green, blue, rose-coloured and colourless, morganite and aquamarine and

multi-coloured tourmaline. At Korgal the pegmatite produces fine elbaite with beryl, muscovite and microcline. Crystals of tourmaline are large and fine-coloured from all three areas. M.O'D.

BERGER (J.). *Kostbare Klippen.* (Rich cliffs.) Lapis, **4**, 1, 28-30, 7 figs (3 in colour), 1979.

Describes the area near Windhoek in South-West Africa where tourmalines and other minerals are found. The individual mines include the Neuschwaben (green tourmalines), the Usakos Tourmaline mine (yellow-green, rose-red, yellow and colourless tourmaline), the Otjimbingwe mine (red and olive-green tourmaline), the Kubas mine (fine quality yellowish-green, red and rose-colour), the Albrechtshöhe mine (emerald-green), the Brandberg Tourmaline mine (dark red, colourless, dark- and yellowish-green). M.O'D.

BEYER (H.). *Ausgesuchte Objekte zum Thema 'Kieselsäure'.* (Choice pieces on the theme of 'silicic acid'.) Aufschluss, **30**, 120-38, 21 figs (2 in colour), 1979.

A survey of the types of quartz with reference to crystal formation and twinning. M.O'D.

BEYER (H.). *Über einflussfaktoren auf Tracht, Habitus, Skelettformen, Verzerrungen, Zwillings und Aggregatbildungen an Kristallen.* (On the influence of inclusions on the form, habit, structure, twinning and aggregate-forming properties of crystals.) Aufschluss, **30**, 33-50, 12 figs, 1979.

An introduction to the ways in which crystal growth can be hindered, altered and re-started due to the presence of impurity inclusions. Diagrams show characteristic modes of growth of apatite and zircon. M.O'D.

BIBBY (D.M.). *Zonal distribution of impurities in diamond.* Geochimica et Cosmochimica Acta, **43**, 415-23, 2 figs, 1979.

Zonal distribution of impurities in several diamonds were studied by neutron activation followed by dissolution of the stones into fractions. All stones were found to contain submicroscopic inclusions, either silicates, carbonates or immiscible sulphides derived from the parent magma. Variations in impurity concentration are thought to reflect changes in growth rate or environment. M.O'D.

BIRCH (W.D.). *Kein Land für Turmaline?* (No country for tourmaline?) Lapis, **4**, 1, 32, 2 figs, 1979.

Describes the dravite from Western Australia. M.O'D.

BROWN (G.). *Gemmological study group report on a new opal imitation.* Australian Gemmologist, **13**, 8, 273, 2 figs, 1978.

Slocum Stone cemented to opal-veined ironstone base. Deception easily detected by preferred direction of play of colour seen in the imitation top (no play of colour from side) and by ironstone characteristics visible through the top of the stone. R.K.M.

DE GROOT (G.E.). *Rijksmuseum van Geologie en Mineralogie, 1878-1978; a retrospect.* Scripta Geologica, **48**, 1-96, illus. in black-and-white and in colour, 1978.

The Museum contains a collection of gemstones which are mentioned in this account of Museum history and reconstruction. M.O'D.

DILLMANN (R.). *Sogdianit.* (Sogdianite.) Z.Dt.Gemmol.Ges., **27**, 4, 214, 1978.

Physical properties are given. E.S.

DUNN (P.J.), WOLFE (C.W.), LEAVENS (P.B.), WILSON (W.E.). *Hydroxyl-herderite from Brazil and a guide to species nomenclature for the herderite/hydroxyl-herderite series.* Mineral. Record, **10**, 1, 5-11, 10 figs, 1979.

Almost all specimens described as herderite are in fact hydroxyl-herderite. These form the end-members of an isomorphous series; fine crystals have recently appeared from Virgem do Lapa and the Golconda mine, both in Brazil. M.O'D.

FISCHER (K.). *Knallerbsen und Katzenaugen.* ('Torpedos' and cat's-eyes.) Lapis, **4**, 1, 43-4, 2 figs, 1979.

Gives instructions for the cutting of tourmalines with particular reference to cat's-eye stones. M.O'D.

FORD (T.D.). *Blue John—Derbyshire's unique gem.* Gems, **11**, 2, 13-23, 9 figs (4 in colour), 1979.

An account of the occurrence and working of the Blue John variety of fluorite in the Peak District of Derbyshire. Historical notes are included and the author states that the material is still available, though not now found on outcrops. The colour is here attributed to hydrocarbons with associated uranium, the radioactive emanations of which give rise to dislocations and colour centres. M.O'D.

FUMEY (P.). *L'apatite.* (Apatite.) Revue de Gemmologie, **58**, 16-17, 3 figs, 1979.

Apatite from various localities is discussed with particular reference to examples found in France. M.O'D.

GRAZIANI (G.). *Rote Bänder in Willemit von Franklin Furnace, N.J., U.S.A.* (Red striations in Willemite from Franklin Furnace, New Jersey, U.S.A.) Z.Dt.Gemmol.Ges., **27**, 4, 201-4, illus., bibl., 1978.

The willemite is of pale green-yellow colour with red striations, which were examined and found to be hematite. E.S.

GRAZIANI (G.), GUIDI (G.). *Mineralogical study of a star-beryl and its inclusions.* Neues Jahrbuch für Mineralogie Monatshefte, **2**, 86-92, 5 figs, 1979.

The beryl was in the form of a thin sheet about 12×6×3mm, green and transparent. Quartz, corundum, pyrrhotite were found as inclusions with less prominent examples of epidote, apatite and pyrite. It is unusual to find quartz and corundum in beryl. The specimen is Brazilian. M.O'D.

GRICE (J.D.), WILLIAMS (R.). *The Jeffrey Mine, Asbestos, Quebec.* Mineral. Record, **10**, 2, 69-80, 20 figs (3 in colour), 1979.

The Jeffrey mine is celebrated for the superb crystals of grossular garnet, some

of which are green with chrome-rich cores, others being the orange hessonite variety. Green stones once reported as uvarovite are now known to be grossular; TiO_2 is also thought to play a part in the green coloration of some of the stones. M.O'D.

GÜBELIN (E.J.). *Einschlüsse im Turmalin.* (Inclusions in tourmaline.) Lapis, **4**, 1, 38-9, 14 figs in colour, 1979.

Coloured illustrations of characteristic inclusions in tourmaline are shown together with a faceted 'water-melon' stone. M.O'D.

GÜBELIN (E.J.). *Fiskenässet: Rubinvorkommen auf Grönland.* (Fiskenässet: ruby location in Greenland.) Lapis, **4**, 3, 19-26, 11 figs (10 in colour), 1979.

Ruby and kornerupine are found at Fiskenässet in the south-west of Greenland. Ruby occurs in mother rock of plagioclase and is accompanied by pargasite. Kornerupine is dark green and transparent with RI 1.662-1.665, 1.673-1.677 and 1.675-1.679, and DR 0.013-0.014. M.O'D.

GÜBELIN (E.J.). *Il punto sulla ricerca in gemmologia.* (The point of research in gemmology.) La Gemmologia, **4**, 2, 5-21, 1978.

Differences in the properties of natural stones and a number of synthetic materials are discussed. There is a short bibliography of up-to-date items. M.O'D.

GÜBELIN (E.J.). *Zwei neue Schmucksteine aus den Vereinigten Staaten.* (Two new gemstones from the United States.) Z.Dt.Gemmol.Ges., **27**, 4, 196-200, 5 figs, 1978.

The two new gem materials described from the States are stellarite and parrot wing, both commercial names. Stellarite is most attractive and consists of blue and dark materials which can be blue to green with metal grey to black veins. The blue component is quartz; the blue colour is produced by the copper matrix. The blue-green component is chrysocolla; the grey to black veins consist of hematite; interference colour can be traced to plancheite, a hydrous copper silicate. Parrot wing consists mainly of cryptocrystalline quartz, similar to agate or jasper. The brown, red and yellow colours are quartz, the second component is chrysocolla, which adds a green-blue hue. The chrysocolla is mixed with limonite, adding brown to the mixture. E.S.

HINTZE (J.). *Die Smaragdlagerstätten Kolumbiens.* (The emerald localities of Colombia.) Aufschluss, **30**, 83-92, 3 figs, 1979.

The mines from which emeralds have been recovered are indicated on maps, two of which illustrate the immediate areas around Muzo and Gachalá respectively. A useful bibliography is included. M.O'D.

HOCHLEITNER (R.). *Dravit von der Drau.* (Dravite from the Drava.) Lapis, **4**, 1, 31, 1 fig in colour, 1979.

Dravite from the classic locality of the Drava in Carinthia is described and illustrated. This brown variety was discovered in 1883; von Kunitz gave the name dravite to the sodium magnesium tourmaline. M.O'D.

HORIUCHI (N.). (New synthetic opal made of plastics.) J. Gemm. Soc. Japan, **5**, 2, 61-65, 9 figs, 1978. (In Japanese.)

The white opal is made from plastic spheres of about 220nm in diameter, bonded by plastic and gives a fine play of colour. M.O'D.

HUDSON(P. R. W.). *Crystal imperfections in natural gem diamond.* Australian Gemmologist, **13**, 8, 253-7, 1978.

An erudite discussion of experimental evidence of the presence or otherwise of nitrogen platelets, and/or discrete or paired N atoms in the diamond lattice. (At such submicroscopic levels their existence appears of little gemmological consequence. They are not defects affecting value except in so far as N can cause colour). R.K.M.

JAMIESON (N. P.). *Recognition of synthetic opal.* Australian Gemmologist, **13**, 8, 259-60, 3 figs, 1978.

A brief account of a talk by Dr J. V. Sanders in 1977. Summarizes probable methods of manufacture and differences between natural and synthetic opal. 'Glueing' of silica spherules either by heat sinter of by organic cement is suggested, also blacks obtained by glucose and acid method mooted. (Author gives a 'synthetic' label to Slocum Stone—which is really a glass imitation). R.K.M.

KOSE (A.). (Artificial opal.) J. Gemm. Soc. Japan, **5**, 2, 66-74, 5 figs, 1978. (In Japanese.)

An irridescent polymeric material simulates precious opal and displays colour in the same manner. Microspheres are obtained from synthetic polymeric monodisperse latex. M.O'D.

LAREIDA (S.). *Man mietet sich einen Esel . . .* (One hires an ass . . .) Lapis, **4**, 1, 14-19, 14 figs (7 in colour), 1979.

An account of the occurrence of tourmaline on the island of Elba with particular reference to 'niggerheads' (crystals with black tops). Notes are also given on other minerals found in the area; these include spessartine, topaz, quartz, cassiterite, beryl (aquamarine and morganite) and orthoclase. M.O'D.

LIEBER (W.). *Diamanten: Bruchstücke der Ewigkeit.* (Diamonds: fragments of eternity.) Lapis, **4**, 3, 4-10, 13 figs (4 in colour), 1979.

A short account of the history of the workings for diamond with especial reference to South Africa. M.O'D.

MUMME (I. A.), SEIBRIGHT (L.). *The colouration Mt Surprise topaz by gamma irradiation.* Australian Gemmologist, **13**, 8, 274-7, 1978.

An account of experiments in colouring topaz from one locality, using cobalt 60 source of gamma rays. (Unfortunately this intelligent report is spoiled by the omission of an unknown length of text between pages 275 and 276. Printing errors frequently mar this ambitious little journal, e.g. elsewhere in this issue, 'chariote' for 'charoite', 'rastite for 'bastite', 'scarolite' for 'scapolite', and once again Monsieur Gilson has been called 'L. Gibson'. Surely something can be done about these unnecessary errors?) R.K.M.

NASSAU (K.). *Distinguishing diamond from cubic zirconia.* Lapidary Journal, **32,** 10, 2136-50, 5 figs (1 in colour), 1979.

Cubic zirconia can be distingushed from diamond by the use of a reflectivity meter, by the use of a recently-devised test of surface wetting and by a thermal conductivity probe. Using a felt-tipped pen a sharp blob will be formed on a cleaned diamond surface while with zirconia the ink forms beads. Room temperature thermal conductivity can be used to give a signal when a particular stone is tested. M.O'D.

NIEDERMAYR (G.). *Phenakit in Edelsteinqualität aus dem Habachtal, Salzburg (Österreich).* (Phenakites in gem quality from the Habach Valley, Salzburg, Austria.) Z.Dt.Gemmol.Ges., **27,** 4, 205-7, 2 figs, bibl., 1978.

Phenakites are found in the well-known emerald deposits in the Habach Valley in Austria. They are generally colourless, transparent to translucent, but can be found with orange-yellow to beige clouds. The material is often free from inclusions and is now used for gemstones. The author mentions stones up to 12 ct. The two illustrations show parallel very fine liquid inclusions as growth lines and irregular two-phase inclusions. E.S.

OBENAUER (K.). *Über den Aufbau des Buntsandstein-Carneols und seiner Achatdrusen.* (On the formation of cornelian in coloured sandstones and their druses.) Aufschluss, **30,** 113-19, 3 figs (2 in colour), 1979.

Discusses three German locations for cornelian with illustrations of thin sections. M.O'D.

O'DONOGHUE (M.J.). *New facets of gems.* New Scientist, **82,** 1153, 373, 1 fig, 1979.

Gives a short review of progress in manufacturing gem materials; written in connexion with an exhibition held at Goldsmiths' Hall, London.

(Author's abstract). M.O'D.

OTTEMANN (J.), SCHMETZER (K.), BANK (H.). *Neue Daten zur Anreicherung des Elements Gallium in Alexandriten.* (New data on the enrichment of gallium in alexandrite.) Neue Jahrbuch für Mineralogie Mönatshefte, **4,** 172-5, 1978.

Ga^3 replaces Al^3 in the crystal lattice of alexandrite chrysoberyl; in some stones from Brazil up to 1200 ppm of Ga were found. M.O'D.

ROST (F.), FUCHS (B.), SADDREDINI (H.). *Über Demantoid aus dem Ural und seine Farbe.* (On demantoid from the Urals and its colour.) Aufschluss, **30,** 51-6, 2 figs, 1979.

Chromium and titanium in demantoid from the Urals are measured and their absorption spectra shown. M.O'D.

RUSKONÉ-PONCET (E.). *Le travail des gemmes jusqu'au début du XXe siècle.* (Fashioning of gemstones up to the beginning of the 20th century.) Revue de Gemmologie, **58,** 13-15, 4 figs (1 in colour), 1979.

Discusses the role and methods of the lapidary with particular reference to those operating in the Jura during the 19th century. M.O'D.

SCHMITZ (H.-H.). *Mineralogie der Kieselsäure.* (Mineralogy of silicic acid.) Aufschluss, **30,** 103-12, 7 figs, 1979.

The mineralogy of silica is discussed with particular reference to and illustration of crystal form. M.O'D.

SCHRADER (E.L.), FURBISH (W.J.). *Hyalite from the Spruce Pine district, North Carolina.* Mineral. Record, **10,** 1, 29-30, 4 figs, 1979.

Hyalite coloured light green, light blue, yellow or translucent white, is found in the Spruce Pine area of North Carolina. RI is 1.445-1.455 and some specimens fluoresce under short-wave ultraviolet light. M.O'D.

SCHUBNEL (H.-J.). *La gemmologie au 11e congrès de l'association internationale de minéralogie.* (Gemmology at the 11th International Mineralogical Conference.) Revue de Gemmologie, **58,** 5-7, 1979.

Summaries of papers dealing with Soviet lazurite, nephrite, charoite, and synthetic emerald and diamond in general are given. M.O'D.

SINKANKAS (J.). *Turmalinreiches Südkalifornien.* (The tourmaline country of southern California.) Lapis, **4,** 1, 33-7, 8 figs (3 in colour), 1979.

Tourmalines are found in five main areas of Southern California; Pala, Mes Grande, Ramond, Palomar Mountain and Rincon. The various occurrences and mines are described. M.O'D.

STRUNZ (H.). *Anjanabonoina, Fundort schönster Turmaline.* (Anjanabonoina, home of the finest tourmaline.) Lapis, **4,** 1, 24-27, 11 figs (9 in colour), 1979.

Anjanabonoina in the Malagasy Republic is celebrated for the high quality of the tourmaline produced there. Especially noteworthy are the zoned sections. Many crystals show complex terminations. Danburite of an orange-yellow colour is also found. M.O'D.

TAN (L.-P.), LEE (C.W.), CHEN (C.-C.), TIEN (P.-L.), TSUI (P.-C.), YUI (T.-F.). *A mineralogical study of the Fengtien nephrite deposits of Hualien, Taiwan.* National Science Council of the Republic of China, NSC Special publication No. 1, pp. v, 81, 77 figs (64 in colour), 1978.

Nephrite from Taiwan is classified into common, cat's-eye and waxy material and occurs in hanging walls and footwalls of serpentinite. Inclusions of serpentine and chromite are found in the nephrite and appear to indicate that the nephrite is a metasomatic product of serpentinite derived from ultramafic rock. Surface textures, thin sections, rough boulders and faceted stones as well as cabochons are illustrated. The value of nephrite sold on the retail market in Taiwan annually is estimated at 10 billion NT dollars. M.O'D.

TENNYSON (C.). *Der Feinbau des Turmalins.* (The elegant structure of tourmaline.) Lapis, **4,** 1, 6-7, 7 figs, 1979.

Diagrams illustrate the chemical composition and the structure of tourmaline and are amplified by brief notes. M.O'D.

WILKS (E.M.). *Remarks on the classification of natural polycrystalline diamond.* Industrial Diamond Review, 156-61, 15 figs, May 1979.

The limitations of descriptive names such as 'carbonado', 'ballas', 'framesite' and 'boart' for natural polycrystalline diamond are explored, and examples of conflicting definitions in existing reference works are quoted. Specimens of carbonado, ballas and framesite were obtained, and their surfaces inspected for coherence and compactness by polishing a facet on each one and viewing it at low magnification on an optical microscope (using Nomarski interference contrast). The specimens were then checked for abrasion resistance using a V-shaped diamond wheel, and for density using hydrostatic weighing. From the results of these tests, a proposal is made (backed up by a series of microphotographs) that future reports on polycrystalline diamonds should include an indication of such essential identification parameters as density, porosity and degree of coherence. P.G.R.

Diamond probes secrets of Venus. Industrial Diamond Review, 115-18, 10 figs, May 1979.

A 205.4 carat Type IIa diamond from the Premier mine at Cullinan was used to produce an 18.2mm diameter by 2.8mm thick window for the NASA Pioneer Venus Multiprobe. The diamond window was used to protect the infrared radiometer sensor fitted to the largest of the probes whose function was to determine how temperatures on Venus varied with altitude and location. Diamond was chosen for the window as it was the only material which could meet the stringent requirements of strength and corrosion resistance and also have good optical transparency in the infrared (hence the use of nitrogen-free Type IIa diamond).

The diamond window was cut and polished from the rough by D. Drukker of Amsterdam. Sawing of the window blank took more that two months, and when completed, the window weighed just under 13 carats. Two windows were produced, one for the flight and one as a spare. The Pioneer Venus Multiprobe was launched on 8th August, 1978, and after a 220 million mile journey, the large probe carrying the diamond window landed on Venus on 9th December, 1978. Although initial data have given more precise details than hitherto on the composition of the Venusian atmosphere, it is said that most of the data from the probes will take at least four years to assess and correlate. P.G.R.

Gemstones and abrasives. Mining Annual Rev., 125 & 127-8, 1978.

A review of the world production of diamonds is presented, including a table of the output of individual countries over the past three years. A brief review is also given of industrial diamond consumption (both natural and synthetic). R.A.H.

Recent prices on coloured stones. Canadian Gemmologist, **2**, 4, 31-2, 1979.

A list gives the retail price per carat (including wholesale price with 30% plus tax plus keystone) of most of the commoner gemstones. Examples given include a medium coloured tanzanite of 3ct at (Canadian) $500 per ct, golden beryl of under 2ct at $200 per ct and pink tourmaline of about 7 ct at $300 per ct. M.O'D.

BOOK REVIEWS

CANNON (B.). *Minerals of Washington.* Cordilleran, Mercer Island, Washington, U.S.A., 1975. pp.iii, 184. Illus. in black-and-white. $4.95.

A well-written and attractively produced guide to minerals found in the state of Washington, this book consists largely of an alphabetical arrangement of the minerals found with their descriptions and in many cases with sketches. Maps are provided with the preliminary material, which also includes descriptions of rocks in general and of the various geologic provinces of the state. M.O'D.

RAMDOHR (P.), STRUNZ (H.). *Klockmann's Lehrbuch der Mineralogie.* (Klockmann's Mineralogy). 16th edn. Enke Verlag, Stuttgart, 1978. pp.xi, 876. Illus. in black-and-white. DM168.

This reviewer has waited a long time for this standard work to be issued once more; since there is no comparable English work at present on the market English-speaking readers have to discover details of many new minerals in a number of works, many of which, though very useful and accurate, have not the convenience of including new data together with notes on occurrence, tests, etc. A quick check shows that material has been added up to 1977 (from items listed in the bibliography) and that such new reports as liddicoatite are included, though the transparent variety of vayrynenite from Pakistan is not listed. However since such out-of-the-way items have to be checked readers can be sure that the rest of the book is of a more than satisfactory completeness.

Early chapters deal with the formation and classification of crystals, with the occurrence of minerals, with geochemistry and with methods of testing. This takes us approximately half-way through the book. The rest of it is devoted to systematic mineralogy in which all details are given for the minerals concerned. Important species have more details given of their occurrence, easily seen since this is printed in italic. Diagrams are beautifully drawn as one expects in a German textbook. Bibliographies are appended to each section; there are subject and species indices and a list, arranged alphabetically, of some of the most important of the world's mineral sites.

'Klockmann' is the standard textbook on the Continent and those who are seriously interested in minerals should not let the language stand in their way of obtaining and using this excellent book. M.O'D.

REAM (L. S.). *Gems and minerals of Washington; a collector's reference.* Jax Products, Renton, Va, 1977. pp.202. 110 Figs. $5.95.

This pocket-sized guide has a pleasing precision of style and is arranged in two sections, gems and minerals, in each of which the species are listed alphabetically. Agates and nephrite are the most important of the ornamental materials found in the State. There is a short bibliography. M.O'D.

ASSOCIATION NOTICES

GIFTS TO THE ASSOCIATION

The Council of the Association is indebted to the following for their gifts:

The Gemmological Association of All Japan for a collection of 28 cabochon and faceted stones produced by Dr S. Iimori, of Tokyo, Japan. They imitate jadeite, sapphire, emerald, amethyst, turquoise and cat's-eyes. These are made of lead glass, but minute pieces of mineral are added to the melt to improve the appearance.

Mr E. A. Thomson, London, for a cut specimen of trilliumite, 2.76ct, from Wilberforce, Ontario, Canada.

NEWS OF FELLOWS

Mr Louis Lo, F.G.A., has been appointed Secretary of a newly-formed organization—The Gemmological Association of Hong Kong. He would be pleased to hear from any members of the Gemmological Association of Great Britain who are interested in joining the local Association. Letters should be sent to Mr Lo c/o G.P.O. Box 2664, Hong Kong.

On the 8th June, 1979, Mr M. J. O'Donoghue, M.A., F.G.S., F.G.A., gave a talk to a general audience at Ightham, Kent, entitled 'An introduction to gemstones'. On the 12th June, Mr O'Donoghue gave a talk to the Essex and London Rock and Mineral Society on the subject of 'Developments in the gem world since 1970' and a number of specimens were shown. On 3rd July Mr O'Donoghue spoke to the Amateur Geological Society, London, on 'The minerals of Scandinavia'.

On 31st July, 1979, at a special dinner at the United Nations Buildings, New York City, Mr John F. Croydon, F.G.A., (this year's President of the National Association of Goldsmiths) and Professor Dr E. Gübelin, F.G.A., received the Retail Jewellers of America International Jewellery Leadership Award.

MEMBERS' MEETINGS

Midlands Branch

A field trip to Derbyshire Peak District was held on the 22nd July, 1979.

North-West Branch

On 15th July, 1979, a field trip was arranged to Crich Quarry, near Matlock, where fluorite and pink and cream banded barite are among the minerals to be found.

On 13th September, 1979, Mr P. G. Read, C.Eng., M.I.E.E., M.I.E.R.E., F.G.A., gave a talk on new gemmological instruments and techniques.

ANNUAL GENERAL MEETING

The 49th Annual General Meeting was held at Saint Dunstan's House, Carey Lane, London EC2V 8AB on the 16th May, 1979.

The Chair was taken by Mr David Callaghan, the Vice-Chairman, who explained that the Chairman, Mr Douglas King, was unfortunately prevented by illness from being present. He also referred to the untimely deaths of the former Secretary, Mr Gordon Andrews (the 1931 Tully Medallist), and of Mr Douglas Ewing, a member of Council who had done a great deal to promote gemmology in Scotland and had been a good ambassador for the Association in his travels around the United Kingdom and to many places abroad.

Special thanks were extended to the Chairmen and Secretaries of Branches as well as to members of Council, Examiners and Instructors, who willingly gave so generously of their time to attend Council Meetings and do other work for the Association. The Examinations Review Committee had met during the year and thanks were due to the President, Sir Frank Claringbull, for acting as its Chairman and to Mr Jonathan Brown as its Secretary. Mr Callaghan then referred to the excellence of the *Journal of Gemmology,* which had such a high standing in the gemmological world, and expressed sincere thanks to the Editor, Mr John Chisholm, for all his work. The Association's thanks were also recorded to the Treasurer, Mr Lawson Clarke, for keeping the accounts in good order and ensuring that there was a satisfactory balance at the end of the year, to the Rayner Optical Company for its continued interest in the Association and for its efforts in improving instrument production (which enabled Gemmological Instruments Ltd to meet the needs of gemmologists throughout the world) and, last but not least to Mr Harry Wheeler, the Secretary, and all his headquarters' staff, who worked so diligently to ensure the smooth running of the gemmology courses, examinations and other activities.

In the absence of the Treasurer, the Secretary reported on the accounts for the year, and the Assistant Secretary, Mr Douglas Wheeler, was thanked for the way in which he had used every opportunity to obtain bank interest on available funds.

The adoption of the Annual Report and Accounts was then proposed from the Chair, seconded by Mr David Larcher and duly passed.

Sir Frank Claringbull was re-elected as President: Messrs Douglas N. King, David J. Callaghan and F. E. Lawson Clarke were re-elected Chairman, Vice-Chairman and Treasurer respectively: Messrs D. Frampton, P. Riley and C. Winter were re-elected and Messrs L. Cole, A. E. Farn, A. Hodgkinson, B. Jones and A. Round were elected members of Council.

It was announced from the Chair that Messrs Hard Dowdy, Watson Collin & Co., Chartered Accountants, had signified their willingness to continue as auditors, and, in closing the meeting Mr Callaghan expressed his thanks to the British Jewellery and Giftware Federation for the use of their Boardroom and to the

Worshipful Company of Goldsmiths for generously continuing to allow the Association to use rooms in Goldsmiths' Hall when convenient.

TSAVOLITE

At a recent meeting of the Coloured Stones Commission of C.I.B.J.O. (International Organization for the Jewellery Trade) it was decided that the green grossular garnet should be known as 'Tsavolite' and not 'Tsavorite' as it was originally called. The original name had no proper etymological basis, whereas the new agreed name, in common with many other minerals, has the termination '-lite', derived from the Greek λίθος (lithos = stone) and so means 'a stone of the Tsavo region'.

'SYNTHETIC JEWELLERY AND GEMS'

An exhibition of 'Synthetic Jewellery and Gems' was held at Goldsmiths' Hall, London, from 1st May to 25th May, 1979. In addition to a display of synthetic and imitation material and cut specimens, there were exhibits of jewellery dated from 1400 BC to 1979 AD and a collection of plastic jewellery. The exhibits were divided into six sections covering ceramics (from Wedgwood's jasper and sandblasted bone china); glass (including paste jewellery and gems); enamels from all over the world; vulcanite (the Victorian substitute for jet); plastics (from before 1939 to modern resins by Susanna Heron and acrylics by David Watkins); and finally a small section on synthetic stones.

REUNION OF MEMBERS AND PRESENTATION OF AWARDS

The Reunion of Members is to be held at Goldsmiths' Hall, Foster Lane, London E.C.2. on Monday, 19th November, 1979, between 6.00 and 7.00 p.m.

Following the Reunion the awards gained in this year's examinations will be presented by Prof. Dr Pieter C. Zwaan, F.G.A., Director of the National Museum of Geology and Mineralogy, Leiden, Holland, at 7.00 p.m.

'THE CRYSTALLINE WORLD OF GEOLOGY'

A course of 12 meetings has been arranged by the Geological Museum and the Department of Extra Mural Studies of the University of London, to be held at the Museum every Monday evening from 7th January to 24th March, 1980, at 6.30-8.30 p.m.

It will be an introductory course for those who wish to know more about the crystalline state and will consist of a series of informal talks, demonstrations and practical sessions. Museum exhibits, films and colour slides, microscopes and optical instruments will be used to investigate rocks, minerals, gem and man-made crystals. The lecturer will be Mr Ian F. Mercer, B.Sc., F.G.A.

For further information and enrolment please contact Mrs Julie Robins, Department of Extra Mural Studies, University of London, 26 Russell Square, London WC1B 5DQ.

FRIENDS OF JADE

A press release has been received regarding the formation of a new non-profit society named 'Friends of Jade', primarily concerned with circulating information about jade for people interested in the subject. For further particulars, write to Friends of Jade, P.O. Box 135, Wallington, Surrey, England.

LETTER TO THE EDITOR

From Mr D. Minster

Dear Sir,

A new concept in the use of closed circuit T.V. for the gemmologist or diamond merchant.

One of the main problems facing the consulting gemmologist today, after a customer has been told that his diamond is not flawless, is showing the customer the flaw under the microscope. The main problems are that (*a*) people's eyes differ, and, if the flaw is relatively small or insignificant, it will (or can) be out of focus for the customer, so that he does not see the flaw (we are now dealing with the higher magnifications): and (*b*) even when the flaw is visible and described, most customers are still 'not sure' about what they are looking for or at. Another problem is that when people are allowed into the laboratory, they start fiddling with the equipment and stones while the gemmologist is busy studying the stone in question under the microscope, and for various security reasons this is not desirable.

After much deliberation on the subject, I came up with a solution to these problems with the aid of a closed-circuit television system. Instead of buying expensive attachments for incorporating the T.V. system into the microscope or buying a special microscope, I decided to use the actual T.V. camera in place of the microscope (*see sketch*).

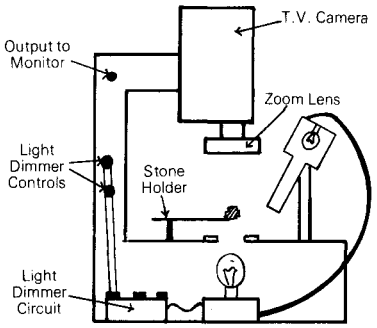

As can be seen in the sketch, the layout is fairly simple and very easy to operate. The stone to be viewed is placed in the holder: it is then manipulated up or down to bring it into the focus of the fixed objective zoom lens. This is easily done by observing the image on the T.V. monitor. The zoom lens is then adjusted to give the desired magnification. It will be noted that the viewer has the choice of variable intensity transmitted or incident light or both. By observing the image on the screen the flaws can be pinpointed and pointed out to the customer. They can then be discussed by the gemmologist with the added advantage of knowing that the customer has seen the same flaws and now knows what he is looking at. The beauty of this system is that a microphone can be placed near the camera and two monitors can be used, thereby allowing the gemmologist in the laboratory to see what he wants to see and the customer, who is situated elsewhere in the shop, to 'examine' the stone with the gemmologist on his monitor. The gemmologist can then describe his progress over the microphone via an intercom and the customer can ask questions as well. One drawback that seems apparent is that the T.V. system used is black-and-white; this is no drawback if the system is used exclusively for diamonds, as they are essentially black-and-white. The cost of the system is a lot less than a high quality microscope and a much higher magnification (approx. 400×) and resolution are obtained than from a standard gemmological microscope.

Other plus factors are that the customer is more impressed and gains something from the experience, and now knows what he or she is buying, and also that the customer is kept out of the laboratory, thus alleviating the problems of security and damage to equipment. This system is also a great educational aid.

Yours etc.,
D. Minster

5th July, 1979. c/o Minster Jewellers, Pretoria, South Africa.

CORRIGENDA

On page 217 above, in line 17, for '45th Annual General Meeting' read '48th Annual General Meeting'.

At foot of page 465 above, the Coded Bibliographic Strip should read 'ISSN:0022-1252 XVI(7) 465 (1979)'.

On page 486 above, at the end of line 1, for 'fin' read 'fine'.

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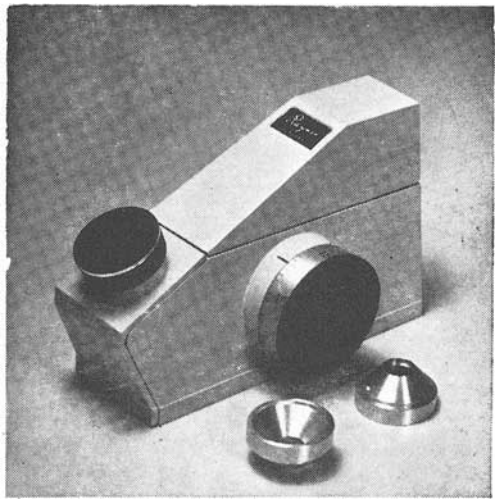

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AN UNUSUAL STAR PERIDOT

By STEFAN BORG, Cand. Scient.
Copenhagen

The purpose of this report is to describe the unusual inclusion pattern in a 1.97 ct brownish-green cabochon-cut peridot from Norway in the author's possession. The refractive indices are measured with a Rayner Dialdex refractometer by the distant-vision method to be $n_a = 1.650$ and $n_g = 1.685$. This corresponds closely to values found for other peridots from Norway (Arem, 1977). Upon examination of the absorption spectra with a Krüss hand spectroscope only a band between the green and the blue is observed. This is perhaps due to the colour of the stone or the density of the inclusion to be described. The stone shows a 6-ray star and a sheen in the centre of the star when observed under a single strong light source (Figure 1a and b).

In the literature only one reference is found to 6-ray star peridots (Cavenago-Bignami, 1972). These, however, are supposed to be from the United States. Another reference mentions only

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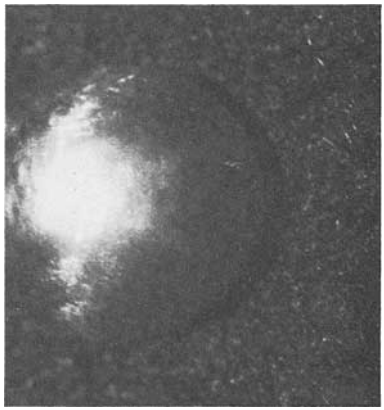

FIG. 1a. Star peridot showing sheen and star under single strong light source.

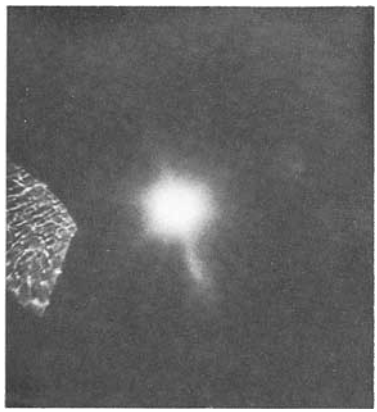

FIG. 1b. Star peridot slightly out of focus. 10×

4-ray star peridots with the rays at right angles to each other (Eppler, 1973). Those few other authors mentioning that peridot occurs as a star stone do not specify how many rays are present. Of the other gem minerals crystallizing in the orthorhombic system not one reference is found describing a cabochon-cut stone with inclusions creating a 6-ray star.

With the aid of a Leitz Ortholux microscope the different inclusions causing these effects are distinguished as seen in Figures 2 and 3. The photographs have been taken through the polished base of the cabochon. Under 100× magnification (Figure 2) a multitude of needles define three axes in a plane separated from each other by 60 degrees causing the 6-ray star. Furthermore strings of brown inclusions are directed along axes perpendicular to those of the needles. These inclusions create the sheen in the centre of the star. When the stone is seen close-up slightly out of focus, two of these perpendicular strings give rise to four additional but weak rays (Figure 1b). Under 250× magnification (Figure 3) the brown inclusions are recognized as many small biotite platelets by their colour and hexagonal habit (Gübelin, 1974) and the sides of the biotite platelets are parallel to the needles in all three directions. It

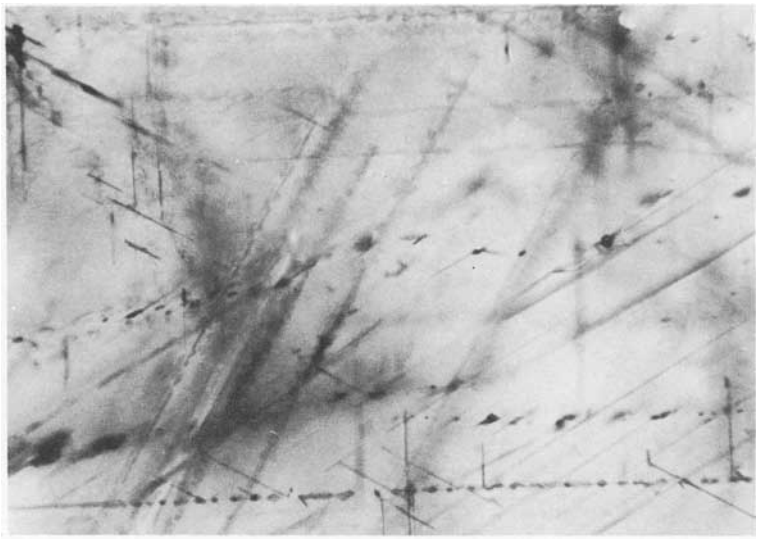

FIG. 2 Inclusions in star peridot. 100×.

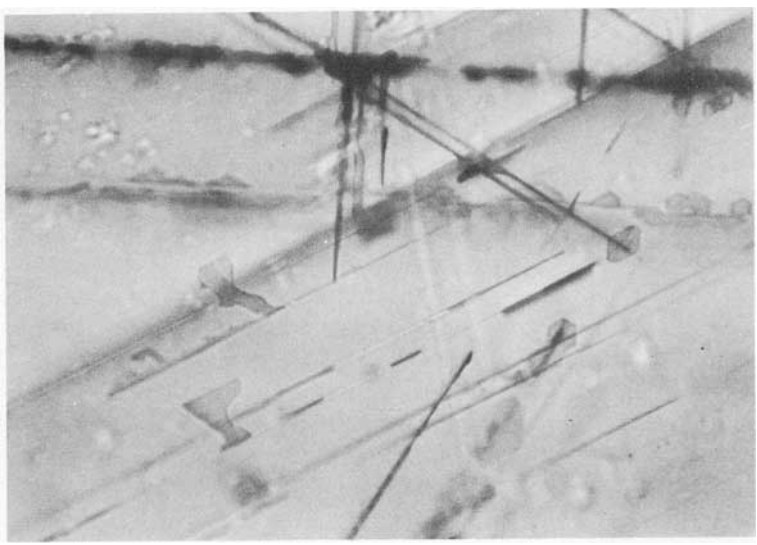

FIG. 3. Inclusions in star peridot. 250×.

is not clear what has caused the biotite to be assembled into long strings. In the same figure the needles are seen to be partly filled channels.

It is hoped that this short description will provide a supplement to the current knowledge on peridots.

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[*Manuscript received 1st August, 1979.*]

AN UNUSUAL TOURMALINE

By STEPHEN R. JONES, F.G.A.

Jewellery Valuation Centre, Sydney, N.S.W., Australia

The Jewellery Valuation Centre (or, to give it its full name, The Jewellery Valuation Centre and Gem Testing Laboratories of Australia) is a commercial laboratory set up in September 1978 to cater both for the trade and for the public. Accordingly the emphasis is not only on accuracy but also on speed, which can be frustrating for a gemmologist, particularly when a known gem is submitted which has uncommon inclusions or properties diverging slightly from the norm: instead of being able to devote many hours immersed in the wonders of research and discovery, the stone is whisked away by an eagerly awaiting client. Recently, however, the writer was able to spend some time examining an unusual gem simply for the love of it.

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A well known local lapidary, while in the laboratory one day, happened to have with him two pieces of unusual rough. At first glance they resembled small pieces of fused glass, misshapen with numerous concoidal fractures, the largest piece measuring approximately 1½″ × 1″ × ½″, and no sign of any crystal morphology. The colour was somewhat unusual, bottle-green with strong red overtones, similar to good green andalusite. Time was at a premium, so that only a cursory inspection was possible. Strong double refraction was noted on looking through the stones, edges of fractures were noticeably doubled, even without a 10× loupe. This, along with the bottle-green colour, suggested tourmaline, but the strong red gleams were confusing. According to the cutter, the stones had been in his possession for many years, and, although not remembering clearly, he was sure that they were originally procured from an African dealer friend.

Many weeks later, to the writer's joy, a stone cut from this material was presented for closer inspection. Details as follows:

Description: Round brilliant cut. Diameter, 9.1 × 9.2mm. Depth, 5.9mm, thick polished girdle. Weight, 2.77ct. The table facet had been placed at an angle of approximately 45° to the optic axis.

Colour: The appearance of this stone altered dramatically with the type of lighting. Under simulated north light (G.I.A. Diamondlite) the colour was a fairly even dark green or yellowish green depending upon direction, a common sight in cut tourmaline. The effect with an incandescent source was interesting. Looking down through the table of the stone an iron-coloured dark green with flashing orange, red and dirty yellowish green was observed. The red colour was less pronounced in this stone than in the rough. Light from a high intensity lamp was then transmitted through the stone with fascinating results. Strong red gleams were displayed, from small sections to almost completely saturating the stone. This colour was not directionally restricted as in the case of dichroism but seemed to envelope the gem under many different angles of lighting. An interesting feature was noted in that when the gem was observed in a direction looking down through the culet, a periphery of red light around a green centre was seen, not unlike the old garnet-topped doublets.

Several tests were carried out on the stone and resulted in the following information:

Refractometer: The refractive index was measured through the table facet and gave values of 1.619-1.64 to 1.623-1.64, showing a negative uniaxial birefringence of 0.017 to 0.021.
Chelsea Colour Filter: Strong red, reminiscent of vanadium coloured colour-change synthetic corundum.
Polariscope: Clear uniaxial interference figure.
Ultra Violet Lamp: Short Wave, Mustard Yellow. Long Wave, Inert.
Dichroscope: Distinct, strong pure green: dirty yellowish green.
Spectroscope: The specimen displayed a strong chromium spectrum. Fine strong line at 675nm, fine but diffuse line 640nm, broad absorption band 570-630nm, general absorption below 470nm.
Microscope: Under 126× magnification the stone (immersed in monobromonaphthalene) appeared clean with the exception of a single crack extending inwards for about 0.2mm from the surface near the culet.
Specific Gravity: Three separate weighings were performed, the mean value equalling 3.054.

Examination by electron microprobe was suggested in order to detect trace elements, particularly vanadium; however, once again shortage of time precluded such arrangements. For such a chrome-rich tourmaline the colour was dull compared to many of the African stones. The colour properties seem to compare with chromium/vanadium tourmalines from Tanzania except for the attendant strong red gleams. Another perplexing issue was the character of the rough. No sign of the normal prismatic striated faces, almost as though the piece had been chiselled out of a larger original crystal.

It would seem that as well as possible new gem finds in the future, and man's incredible hunger for better and better gemstone synthesis, nature has in store many surprises even in 'old timers' such as tourmaline.

[*Manuscript received 6th February, 1979.*]

SOME LESS COMMON GEMSTONES

By MICHAEL O'DONOGHUE, M.A., F.G.S., F.G.A.

The writer has acquired over the past few months a number of faceted stones, in some cases better known as minerals than as gemstones. Readers may be interested to hear about them while bearing in mind that my first thought on seeing a fine crystal is not 'Can it be fashioned?'.

Crocoite, the chromate of lead ($PbCrO_4$), is best known from the occurrence in the Dundas district of Tasmania, where it attains lengths of up to 80cm; no other crystal could easily be confused with it since the bright orange colour, together with the characteristic prismatic shape, is frequently seen in museums and in the stock of the higher-class mineral dealers. The crystal system is monoclinic, and crystals are longer in the direction of the *c*-axis, nearly square in cross section. Many museum specimens show a group of crystals pointing in all directions. The hardness is 2½-3, specific gravity about 6.00 and refractive index 2.29 (α) and 2.66 (γ). Crocoite occurs in oxidized areas of ore deposits (lead or chromium) with cerussite and wulfenite (both have from time to time been faceted) and other associated minerals. The first report of crocoite was from the Sverdlovsk area, Beresov district, in the Ural Mountains of the U.S.S.R.; in 1797 L. N. Vauquelin discovered that chromium was present in material from this area. Supplies from Tasmania are much less plentiful than formerly and collectors would do well to confine their searches to micromount material. Named from the Greek κρόκος (saffron).

Wulfenite, lead molybdate ($PbMoO_4$) is also found in the oxidation zone of ore deposits; it is orange-yellow to brown with a decidedly resinous lustre (most easily seen on the characteristic tabular crystals). It shares with crocoite a low hardness, 2½-3, high specific gravity, 6.5-7.0, and refractive index, 2.40 (ω) and 2.28 (ε). The crystal system is tetragonal. With crocoite, wulfenite shares a high dispersion which gives a very lively appearance to the cut stones, which are usually small. The best-known wulfenite comes from the Red Cloud mine in Arizona, though crystals from this area are generally too thin to facet; thicker crystals have been

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found at Tsumeb, South West Africa. Named after the Austrian mineralogist, Wülfen.

Hexagonite is a variety of tremolite ($Ca_2Mg_5Si_8O_{22}(OH)_2$ with Fe). It is lilac-pink and has only been found in New York State, particularly at Fowler. It is transparent, though crystals would only yield cut stones of 1 ct at the most. Up to 1% MnO has been found in hexagonite and no doubt this accounts for the colour. It is found in metamorphosed calcareous rocks, has a hardness of 5-6, specific gravity of 2.98-3.03 and (according to the literature) refractive index within the range (α) 1.560-1.562 (β) 1.613 (γ) 1.624-1.643 (for the whole series to actinolite); DR is given as 0.019-0.028 (for hexagonite). Pleochroism is strong with colours reddish-blue, violet blue and rose-red. A certain amount of luminescence has been observed; the colour is pink under long-wave and greenish-white under short-wave ultraviolet radiation. The name refers to the misconception that hexagonite belonged to the hexagonal crystal system (it is, in fact, monoclinic).

Pyroxmangite is $(Mn,Fe)SiO_3$ and crystallizes in the triclinic system. The faceted example under discussion is a bright pink, inclining to purple; it comes from Honshu, Japan, where it occurs in metamorphic or metasomatic rocks with rhodochrosite and spessartine. Crystals are always very small and cut stones correspondingly rare. The hardness is 5½-6, specific gravity 3.61-3.80 and refractive index (α) 1.726-1.748 (β) 1.728-1.750, (γ) 1.744-1.764 with a birefringence of 0.016-0.020. Pleochroism is insignificant and there is no luminescence. At one time pyroxmangite was thought to be a pyroxene, hence the name.

Eosphorite is the manganese end-member of a series $(Mn,Fe)AlPO_4(OH)_2.H_2O$. The iron-rich end-member is childrenite. It crystallizes in the monoclinic system forming pseudo-orthorhombic crystals and is pale pink; faceted stones are very bright though never large. The hardness is 5 and the specific gravity 3.05 (for the pure Mn end-member). Refractive index is given as (α) 1.638-1.639 (β) 1.660-1.664 (γ) 1.667-1.671 (for the whole series to childrenite) with a DR ranging from 0.029-0.035 (for eosphorite). A strong line can be seen at 410.0 nm and another at 490.0 nm. There is no significant luminescence but a pronounced pleochroism with yellowish, pale pink and colourless directions. Eosphorite is found in granite pegmatites often with manganese phosphates. Most cuttable material comes from Itinga, Minas

Gerais, Brazil. The name is from the Greek ἠωσφόρος, bringer of the dawn; childrenite from J. G. Children, English mineralogist.

Proustite, Ag_3AsS_3, forming crystals of a magnificent dark red, is found as a low-temperature hydrothermal vein mineral, usually with silver, galena, pyrite, etc. It is a member of the hexagonal crystal system; crystals from Andreasberg, Harz Mountains, Germany, are often scalenohedral and may rarely be sufficiently translucent to facet. Although the colour is so fine, unless proustite is kept away from light a surface tarnish will develop (this is a photochromic effect due to the silver content) so it should be ranked (with the others described above) as a stone for collectors. The hardness is 2-2½, specific gravity 5.5, refractive index (ω) 3.08 (ε) 2.79 with a DR of 0.296. Other features are not of great use in distinguishing proustite from, say, cuprite with which it shares its colour. The name is from the French chemist, J. L. Proust.

Opal variety 'contra luz' comes from Mexico and has the interesting property of displaying a play of colour by both transmitted and reflected light. I have seen only one example of this variety, which, like another illustrated in a book, is faceted; in my example the play of colour is exceptionally fine and the stone resembles a water opal more than any other variety, although it has a slightly bluish milkiness. This variety is said to be rare but would certainly make a most desirable specimen.

[*Manuscript received 25th August, 1978*]

A NOTE ON THE COMPOSITION OF JET

By HELEN MULLER, M.Sc., F.G.A.

SUMMARY

Samples of English, Turkish, Spanish, Russian and North American jet were subjected to x-ray emission spectroscopy. It would appear that the ratio of aluminium to silicon to sulphur is an indication of the provenance of the sample. This finding may be of interest to the archaeologist concerned with ancient trade routes. The significance of the results is limited because only one sample of each foreign jet was available.

INTRODUCTION

The name jet is derived from the ancient name Gagates through the old French Jaiet and old English Gayet. Pliny[1] says it is called Gagates after the town and river Gagae in Lycia (Turkey), where it was found in ancient times. Hagen[2] in her review of Roman jet maintains that the mineral referred to by Pliny was probably a type of lignite.

Jet is also found in Germany in the Poseidon slate of the Swabian and Frankish Alps[3], in the Danish island of Bornholm[3], the Jurassic near Czenstochau in Poland[3], in the greensands of the Upper Chalk formations in the Dept l'Aude in S. France[3] and in northern Spain in Aragon and Asturias[4]. Outside Europe it is found in the U.S.A.[3], Russia (Irkutzk) and in India.

In this country jet is obtained from the area around Whitby in North Yorkshire, where it is found in the Upper Liassic deposits of the Lower Jurassic in the stratum known as the Jet Rock Series. This is a layer of rock about 25 ft thick and composed mainly of a hard black bituminous shale in which the jet occurs in lenticular masses. The hard jet occurs in the upper 10 ft. Above the bituminous shales are the Alum Shales from which alum was manufactured until the late 19th century.

Jet is a form of brown coal which takes a high polish; it has a hardness of 3-4 and a SG ranging from 1.19 to 1.28. It gives a brown streak on porcelain and fractures conchoidally.

Both the ancient and the early 19th century writers thought it was a form of black amber. In 1811 it was referred to by Parkinson[5] as Succinum Nigrum and in spite of all evidence to the

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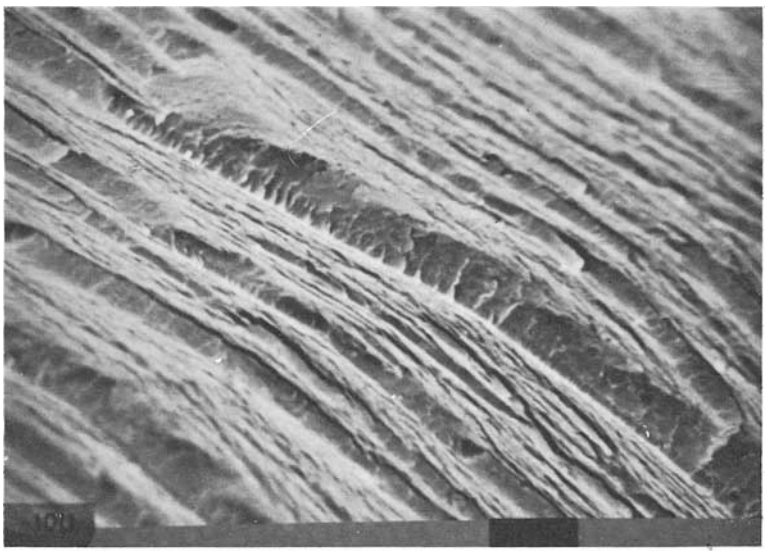

FIG. 1. S.E.M. Photograph of Whitby jet showing woody structure.

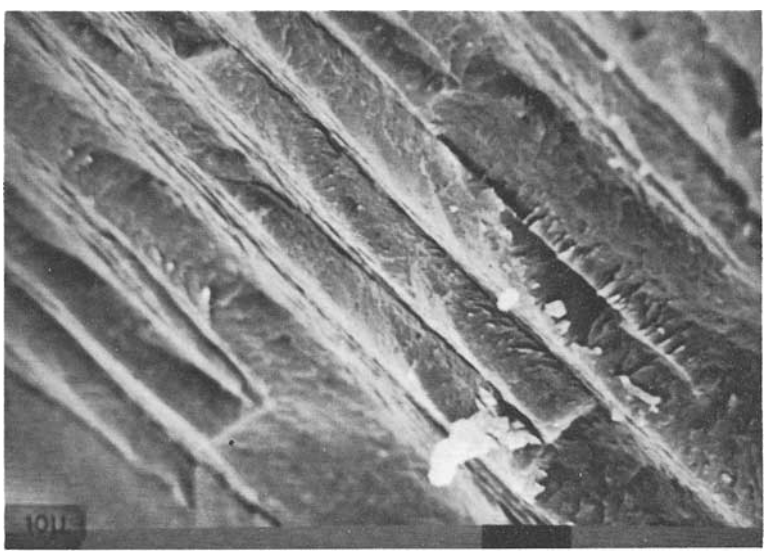

FIG. 2. S.E.M. Photograph of Whitby jet showing woody structure.

contrary the jet workers of Whitby were convinced that it was a form of solidified bituminous matter.

As early as 1904 A. C. Steward[6] produced photomicrographs showing clearly the ligneous nature of jet by the presence of tracheids. It has since been accepted by the scientific world that jet is a form of fossilized Araucaria—like soft wood which has been compressed by long immersion in stagnant water.

The first part of this paper is a confirmation of the ligneous origin of jet by the use of Scanning Electron Microscope (S.E.M) photographs of Whitby jet showing clearly the woody structure. Although large areas of the specimen appeared relatively structureless the spiral arrangement of the original cellulose fibrils on the inner wall of the wood cells can be clearly seen (Figures 1 & 2).

Because of its ability to take a high polish and its velvety black lustre, jet has been used for the manufacture of amulets and jewellery since Neolithic times. Jet beads are frequently found in the tumuli of northern England and Scotland[7] and the Romans made a considerable amount of jewellery in Eburacum (York) much of which is said to have been exported to Germany and Rome[2,8]. Jet was used by the Celts of the Hallstatt and La Téne periods[9] and during the 15th and 16th centuries there was a moderate jet-working industry in Schwäbisch Gmünd in Germany. In Spain the industry flourished in the 14th and 15th centuries and declined in the 16th, although continuing spasmodically until the present day[10]. The height of the Whitby jet industry was in the 19th century.

Archaeologists have expressed an interest in the origins of jet artefacts found both in this country and in Europe, particularly in the Rhineland. For this reason an attempt has been made to determine whether there was any difference in the composition of jet from Whitby and that from other sources.

MATERIALS AND METHODS

Mr E. A. Jobbins, of the Institute of Geological Sciences, kindly provided one specimen of jet from each of the four provenances Turkey, Spain, Russia and the U.S.A., and these were compared with samples of rough Whitby jet obtained locally. The Turkish jet sample consisted of a small bead. Readings for all samples were taken from the freshly broken surface except for the Turkish bead which was mounted as received. A reading was also

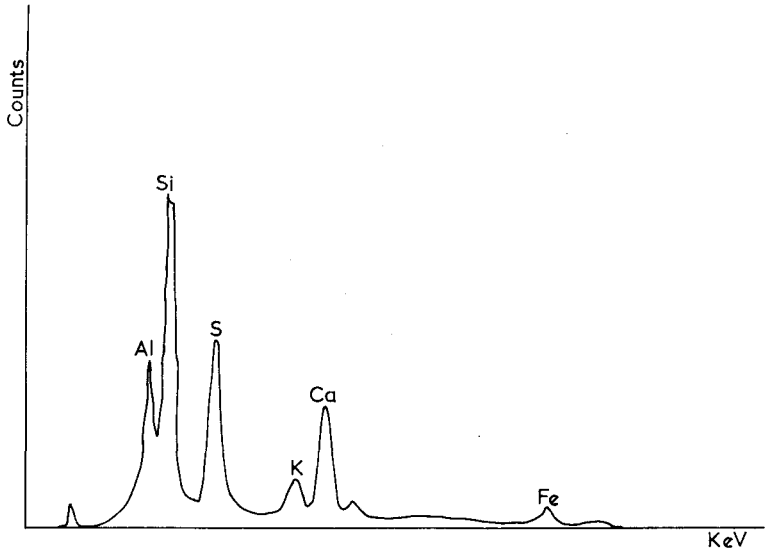

FIG. 3. X-ray emission spectrum of the outer surface of Whitby jet.

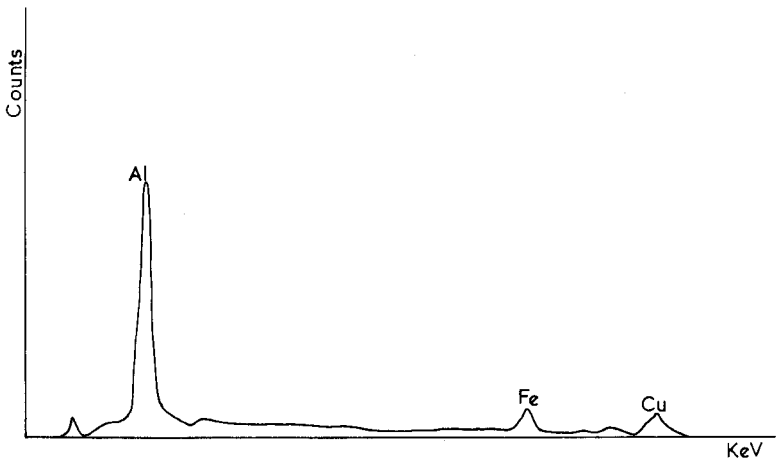

FIG. 4. X-ray emission spectrum of the internal surface of Whitby jet.

taken from the outer layer or 'skin' of the Whitby jet sample. Since the aim of this work was to indicate the provenance of manufactured artefacts from which the 'skin' had been removed during shaping and polishing it is the internal surface which is relevant.

The scanning electron microscope used was a Stereoscan 600 (Cambridge Scientific Instruments Ltd) fitted with a roll-film camera (C.B. 40). Before taking the pictures (Figures 1 and 2) the specimen was gold coated in the usual way, using a Polaron S.E.M. Coating Unit E 5000. For an analysis of the x-ray emission spectra the uncoated specimens were not mounted on the usual aluminium stubs. Since Whitby jet is often associated with alum[11], this stub was undesirable. For this reason all but one of the specimens were mounted on short stainless steel pegs by means of sealing wax. The exception was the Turkish bead. Here the peg was bent near its upper end by 45° and the bead placed upon it. In this way emission from the peg was avoided.

The x-ray data presentation unit (A.E.P. International Ltd) was used with an XY plotter. The areas of the peaks obtained were evaluated by triangulation (Area = Height of peak × width at half height in mm). As reported, the results are not quantitative, but the ratios of the peaks are (within the experimental error) in constant proportion.

RESULTS AND DISCUSSION

1. *X-RAY EMISSION SPECTRA.*

The results are shown in Figures 3 to 8. It appeared that the composition of the surface of the sample was different to the interior.

Whitby jet (Figures 3 and 4)

The surface was high in silicon and showed significant levels of aluminium, sulphur, potassium, calcium and iron. The internal surface contained a good deal of aluminium, very little sulphur and some iron and copper. Silicon, potassium and calcium appeared to be absent.

Spanish jet (Figure 5)

The internal surface showed both aluminium and sulphur as well as silicon, potassium, calcium, iron and copper. It is interesting to note that Bower[12] stated in 1873: 'the Spanish jet contains sulphur and no doubt this fact explains the reason of its breaking up under the influence of sudden changes of temperature.'

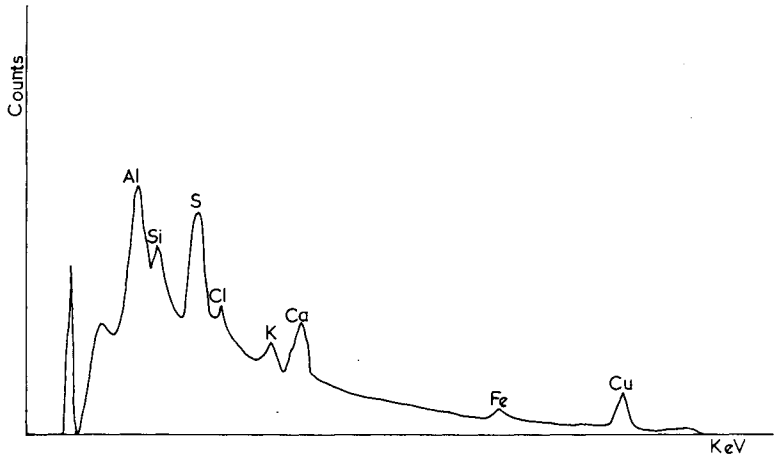

FIG. 5. X-ray emission spectrum of the internal surface of Spanish jet.

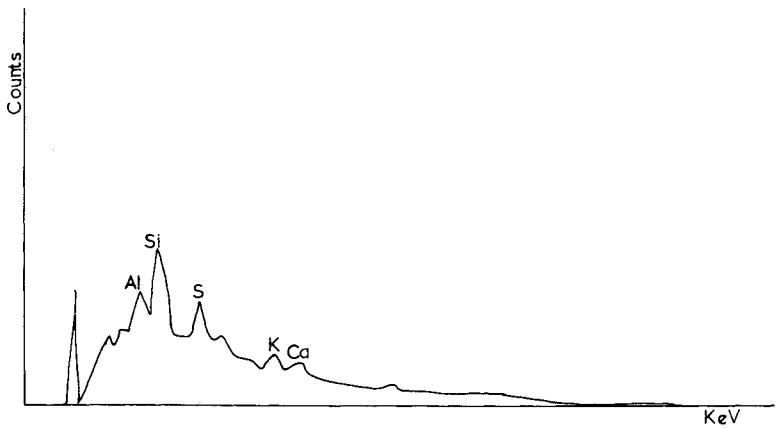

FIG. 6. X-ray emission spectrum of the internal surface of Turkish jet.

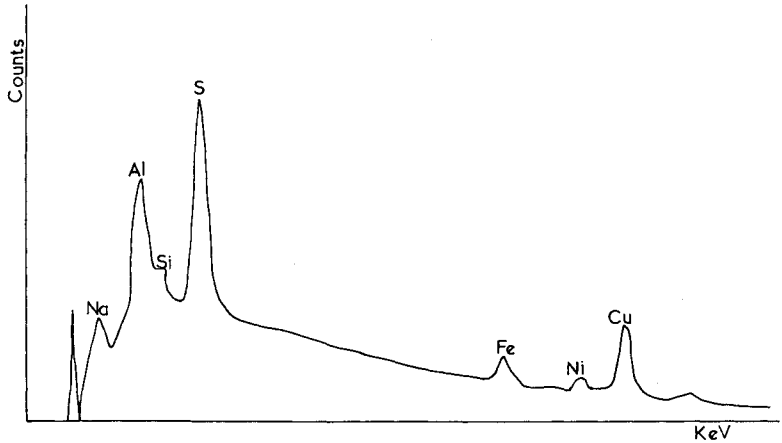

FIG. 7. X-ray emission spectrum of the internal surface of North American jet.

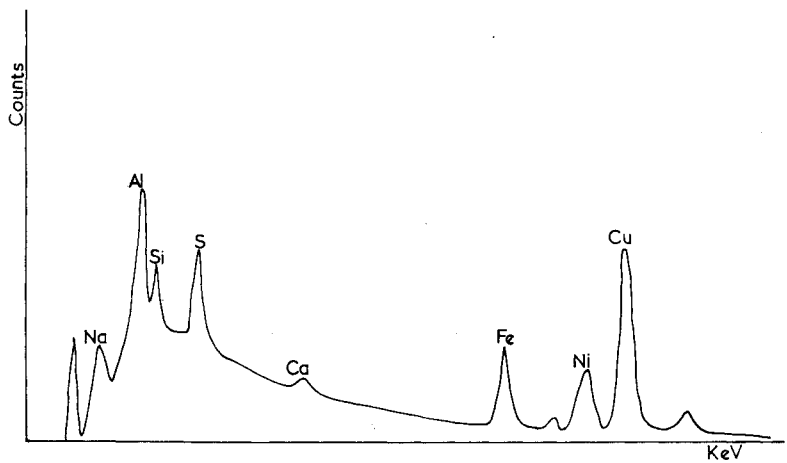

FIG. 8. X-ray emission spectrum of the internal surface of Russian jet.

Turkish jet(Figure 6)
The bead showed significant amounts of aluminium, silicon and sulphur as well as a little potassium and calcium.

2. *A COMPARISON OF ENGLISH, SPANISH AND TURKISH JET.*

Comparing the three types of jet of interest to the archaeologist, it would appear that the Whitby jet is high in aluminium but low in sulphur. The Turkish sample showed relatively high levels of silicon while those of aluminium and sulphur were similar. The Spanish jet contained little silicon and again the levels of aluminium and sulphur were similar. Iron and copper were present in both English and Spanish jet but not in significant amounts in the Turkish specimen.

Using triangulation, the peak surfaces of the jet samples for aluminium, silicon and sulphur appear to be in the following ratios.

	Al	Si	S
Whitby jet	30 :	0 :	0
Turkish jet	3 :	9 :	5
Spanish jet	12 :	2 :	2

This clearly distinguishes the three samples.

The value of these results to the archaeologist is of course limited, as only one sample of each foreign jet was available. No samples of French or German origin could be obtained. Nevertheless it is possible that the Al : Si : S ratio is characteristic of jet of a particular provenance. The author would be interested in testing further samples of jet of known origin.

3. *X-RAY EMISSION SPECTRA OF AMERICAN AND RUSSIAN JET.*

Although of no interest to the archaeologist the results on North American (Figure 7) and Russian (Figure 8) jets are given for the sake of completeness. Both showed significant levels of aluminium and sulphur together with silicon. A characteristic feature of both was significant amounts of iron, copper and nickel. The latter element was particularly noteworthy in the Russian sample.

ACKNOWLEDGMENTS

I wish to thank Mr E. A. Jobbins for kindly supplying some of the jet samples and Mr K. Birkby and Dr H. G. Muller, both of Leeds University, for their technical assistance.

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EUCLASE*

By SUSAN M. ANDERSON, B.Sc.(Geol.), F.G.A.

I INTRODUCTION

The most significant gem-beryl producing area in Rhodesia is the Miami pegmatite field, situated a few kilometres north, east and south-east of the town of Karoi. Here, former argillaceous sediments of the mid-Precambrian Piriwiri Group have been converted, over successive metamorphic events, to sillimanite and staurolite schists with associated sillimanite gneisses. They form the country rock to pegmatites and late-phase quartz veins intruded at various times before and after the *circa* 500 Ma Miami metamorphic event. Economic minerals found in the younger pegmatites in this area include beryl, mica, tantalite and cassiterite; the quartz veins contain wolframite. Late-stage pneumatolytic processes, resulting sometimes in the kaolinization of the feldspar in

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the pegmatites, created an environment suitable for the growth and development of gem quality beryl, tourmaline and topaz (Stagman, 1978, p.56). These processes also appear to be responsible for the formation of euclase, which replaces earlier-formed beryl crystals.

The rarer beryllium minerals are more plentiful in the Miami area than in any other part of Rhodesia, and Wiles (1961, p.193) reports the presence of herderite, hurlbutite, phenacite, chrysoberyl and euclase. Most of these remain of academic interest although chrysoberyl is currently produced and the recently exploited euclase is of potential gem and specimen value.

Euclase has a general formula of $BeSiAlO_4(OH)$ and is a hydrated beryllium-aluminium silicate, with a common habit of stubby prisms terminated by prominent dome faces. Few of the published descriptions indicate its paragenesis, but it reportedly originates in granite pegmatites, quartz-topaz veins and greisens. Two authors (Sharp, 1961, p.1506, and Strand, 1953, p.4) consider its formation to be related to a late stage low-temperature replacement of beryl. This is thought to be the case for the Rhodesian material.

A prominent feature of euclase is the presence of a perfect cleavage (010) and the name derives from this characteristic. It was first introduced into Europe from South America in 1785 (Dana, 1892, p.509) and this first discovery, according to the available information, is today still producing crystal specimens and facetable material. Despite its comparatively early discovery, euclase has remained one of the classic rarities in the mineral kingdom.

II World Occurrences

Euclase has been recorded from the following countries: Brazil, U.S.S.R., Austria and other areas in the Alps, Guiana, East and West Germany, Tanzania, North America, Norway, England and Kashmir. Of these, Brazil, Tanzania and the U.S.S.R. have mined spectacular mineral specimens, including crystals up to 10cm in length (in McKie, 1955, p.86). The remaining occurrences are of academic interest, and crystals, generally of the order of 1-2mm, are usually colourless or pale blue.

Euclase from Brazil originates from the topaz-producing belt of the Ouro Preto, in the Minas Gerais region, and mention is made of occurrences at the Boa Vista and Capao do Lana Mines (Rolf, 1971, pp.1556-1562). It is probably fairly extensively associated

with the topaz, but in its colourless form it is easily overlooked. The euclase, found in kaolinized pockets within phyllites and dolomitic limestones of the Pre-cambrian Minas Series, which lie adjacent to a granite stock, is associated with yellow topaz, smoky and milky quartz, specularite and rutile together with secondary iron, manganese and titanium minerals. Although pegmatites containing beryl and mica are found in the general area, euclase is associated only with these hydrothermal kaolinized offshoots. Fluorite, another hydrothermal mineral, is reported in the limestones.

Euclase is also recorded from Brazil as an alluvial mineral, in diamond-bearing sands (Spencer, 1924, p.188).

Alluvial euclase occurs in the U.S.S.R.; the rolled crystals are found together with topaz, corundum and kyanite in the Orenburg District of the southern Urals (Spencer, 1924, p.188).

In Austria, euclase, together with albite, rutile and quartz, occurs in vugs within mica schists from the Gross-Glockner region of the Alps (Spencer, 1924, p.188), with other localities on the Salzburg and Carinthian sides of the Alps. Of minor interest is the euclase mentioned from granite pegmatites at Dobschutz, near Gorlitz in East Germany, and at Epprechtstein, Fichtelgebirge, Bavaria.

Two distinct habits of alluvial euclase are described from Guiana, as single isolated crystals of clear colourless material and radial aggregates of opaque crystals.

Euclase from Tanzania occurs, together with muscovite, in cavities in an offshoot of the larger Lukangasi pegmatite located in gneisses in the Morogoro District (Spencer, 1934, p.617).

The only record of euclase from North America is in Colorado where it is found in greisen pipes and related quartz-beryl deposits within two granite bodies (Sharp, 1961, pp.1505-8). In the Redskin Gulch area, vugs within greisen contain quartz, encrusted with euclase, associated with fluorite, muscovite and bertrandite. Within the greisen, local lens-shaped zones, composed of quartz, muscovite and bertrandite, contain hexagonal beryl pseudomorphed by fine-grained muscovite and cryptocrystalline bertrandite. In the Boomer Mine area, late-stage euclase, intergrown with quartz and muscovite, appears as clusters and coatings on fluorite crystals in vugs in a quartz-muscovite-fluorite greisen.

The euclase recorded from Norway is of academic interest

only; its paragenesis is similar to that described from Colorado. It occurs in vugs with bertrandite, muscovite and associated minor quartz and albite. The mica and bertrandite totally replace beryl which occurred in a marginal zone of a pegmatite from Iveland, situated about 50km north of Kristiansand in the southernmost part of Norway (Strand, 1953, pp.1-5). According to Strand the presence of cavities is the result of a decrease in volume caused by the replacement of the beryl. Although the bertrandite and rare euclase occupy about a third of the volume of the original beryl crystal no loss of beryllium is indicated. The formation of euclase is considered to be due to insufficient potash being available to convert the residual alumina to muscovite after the conversion of beryl to bertrandite.

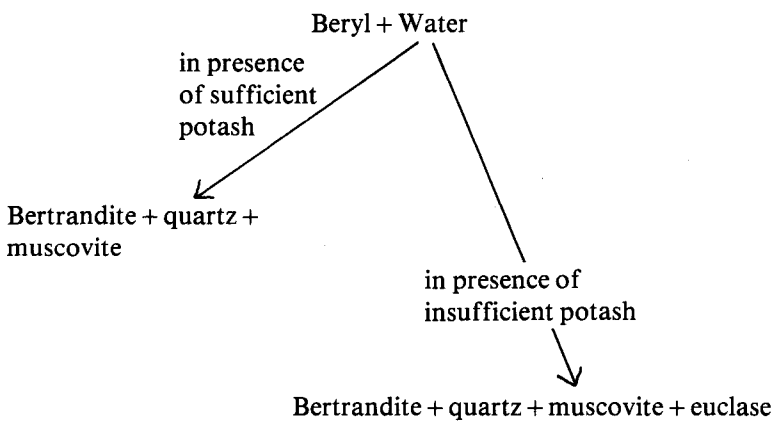

The reaction envisaged by Strand is as follows:

$$12\ Be_3Al_2Si_6O_{18}\ \text{(beryl)} +$$
$$17\ H_2O + K_2O \rightarrow 9\ Be_4Si_2O_7(OH)_2\ \text{(bertrandite)} +$$
$$4\ K_2Al_4Si_6Al_2O_{20}(OH)_4\ \text{(muscovite)} + 30\ SiO_2$$

A crystal of euclase was discovered in a quartz vein within a greisen in the Cligga Head region of western England. This area has produced well-crystallized topaz from quartz-tourmaline veins and greisens and the occurrence of euclase in one sample indicates that the find could be repeated (Kingsbury, 1958, pp.815-16).

Euclase, occurring in a pegmatite vein with tourmaline, garnet and kyanite is reported from the Kanskar range in Kashmir. Associated with the pegmatites are kaolinized pockets which

contain sapphires. The country rocks are lenses of actinolite-tremolite within crystalline limestones (Webster, 1978, p.70).

Although some of these world-wide occurrences of euclase are of minor interest, the mineral association and paragenesis generally indicated is of late-stage, hydrothermal or greisen phase of pegmatite intrusion. A water phase is critical, euclase being a hydrated mineral.

III Rhodesian Occurrences

Some spectacular aggregates of euclase have been produced recently from mining claims held in the Miami area. These are: Last Hope, Last Hope 3 and M.W.M., located on Momba and Haselmere estates; Mishek, The Falls and Trim, all reputed to be in the Mukwichi Tribal area; and Rattis, situated on Farm 142 of Vuti Purchase Land. Disposal of the productions has been small and the bulk stockpiled while investigations to find the most lucrative market continue. Only one claim, the Last Hope, situated 13km north-north-east of Karoi has been examined. This mine formerly produced muscovite and the current excavations lie immediately west of one of the old mine shafts, some 500 metres south-east of Momba Farm homestead (Fey, 1978). The euclase has been extracted from a 2.5m wide pegmatite, striking parallel with the country rock at 088 degrees but dipping more steeply than the enclosing mica schists/gneisses. A crude zoning is recognized within the pegmatite; the marginal areas contain books of fish-tail muscovite, which are developed perpendicular to the strike of the pegmatite and, together with anhedral quartz, occur in iron-stained kaolin. Rare schorlite was also noted. Beryl crystals of a commercial grade are located in the centre, occurring in a matrix of iron-stained kaolin which contains muscovite and quartz. Larger 'blows' of quartz penetrate this zone from the marginal areas. The euclase occurs in association with the beryl and examples have been studied in which the sequence of replacement can be followed. Small aggregates of euclase crystals also occur in the marginal zone in association with quartz.

Some of the euclase crystals are transparent and of potential gem quality. Much of the material is dark indigo or cobalt blue, paling to peacock-blue. The striking coloration, which is intense in the prismatic zone, is often streaky, like that in kyanite. The overall blueness in the crystals is produced by these sharply defined

prismatic coloured zones within an allochromatic mineral. No differences were apparent in the x-ray diffraction patterns for the blue and colourless areas. Green tones are unusual, and attempts to alter the colour by heat treatment were unsuccessful.

Replacement of beryl crystals by euclase aggregates is often incomplete, but pseudomorphs by euclase and subordinate quartz with accompanying muscovite do occur with the hexagonal form of beryl well preserved. These coarse textured replacements are composed of anhedral crystals of euclase (which may attain prismatic lengths of several centimetres) between which cavities containing euhedral euclase and quartz occur. This vuggy texture is similar to the material described from Norway and Colorado. The replacement of the primary beryl is not limited to within the confines of the crystal: it would appear that the process is initiated on the crystal faces as evidenced by coarse-grained irregular encrustations of anhedral quartz, muscovite, and granular euclase. Additionally, a layer of quartz and pearly mica may form on the relict beryl faces. Beryl crystals showing partial replacement contain irregular patches of euclase developed in the angle between the beryl prisms. No other beryllium minerals were identified in the replacement assemblage.

A crystal was sectioned to observe the mineral change from beryl into euclase. The beryl, a single crystal 14cm in diameter, is irregularly fractured with quartz stringers penetrating the breaks. In places the quartz forms branching veinlets isolating areas of beryl which contain only the normal two-phase liquid inclusions. The beryl contact with the euclase patches is irregular and small areas of beryl are penetrated and surrounded by narrow veinlets of euclase originating from a larger euclase crystal. All these veinlets are in optical continuity with the parent crystal and both the parent and its offshoots are crowded with small randomly orientated quartz euhedra (see Figure 1). This form of quartz is not present in the beryl host.

It is proposed that the quartz euhedra are formed from the excess silica released during the replacement of beryl by euclase. Quartz is therefore regarded as forming an integral part of this replacement reaction since it is an early formed phase enclosed by euclase and occurs in the later stages as anhedral encrustations and cavity fillings.

It is possible that a reaction involving beryl, potash and water

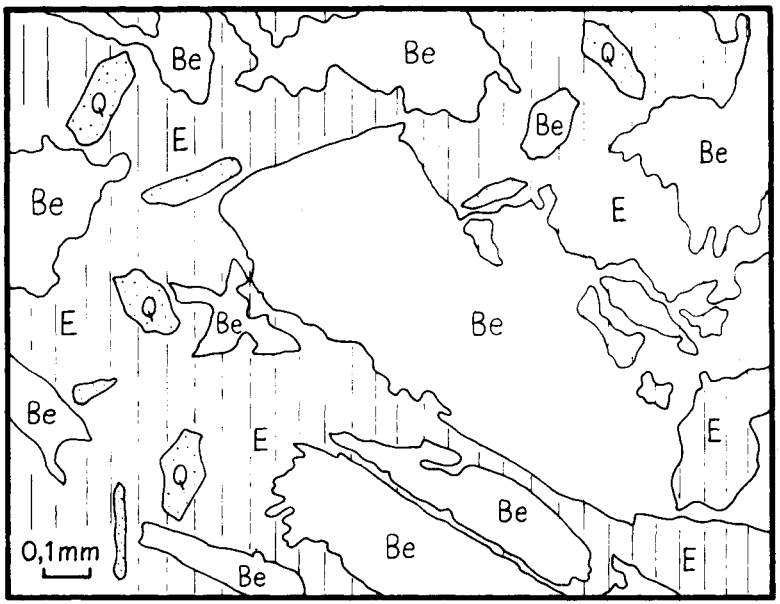

FIG. 1. Replacement of beryl by euclase.
Relict patches of a beryl crystal (Be) enclosed in a single euclase (E) crystal containing quartz (Q) euhedra.
(Drawn from thin section)

could produce euclase, quartz and minor muscovite in a closed chemical system, resulting also in a net volume decrease and hence vuggy texture.

IV Mineralogy of Rhodesian Euclase

Crystallography

A few perfect doubly-terminated crystals of euclase, up to 15mm in length, have recently been produced from Rhodesia. Larger, imperfect crystals showing well-developed faces are more common. Anhedral crystals, attaining prismatic lengths of several centimetres exist in the replacement aggregates.

Euclase crystallizes as stout prisms in the normal class of the Monoclinic System. These crystals are terminated by prominent clinodomes which are conspicuous on all samples examined. Clinopinacoids are prominent and usually well preserved and unmarked. The front and back faces of the crystals show a range in habits

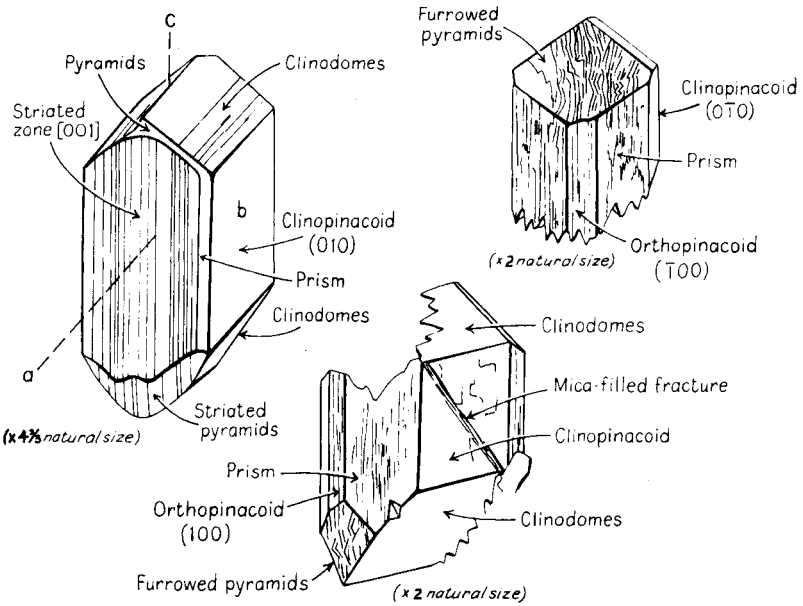

FIG. 2. Sketches of euclase crystal habits.

depending on the relative development of the prisms and orthopinacoids. In combination these faces cause a markedly striated [001] zone. Narrow unstriated orthopinacoids and prisms were observed. Pyramidal faces of the [010] zone are usually not conspicuous, often being small and unpatterned. However, in some examples, orthopyramids are well developed and often deeply furrowed by overlapping forms in a step-like divergent pattern (Figure 2). In contrast to the crystals from Brazil, the Alps and Tanzania, forms are simpler. Sketches showing some of the common habits of euclase from Rhodesia are depicted in Figure 2.

Chemistry

Only one chemical analysis of euclase is published, and it is presented in column A of Table I. The chemical analyses of the associated minerals bertrandite and beryl are also shown. Table II shows spectrographic analyses of euclase from Colorado and Rhodesia.

TABLE I
CHEMICAL ANALYSES OF EUCLASE, BERTRANDITE AND BERYL

	A	B	C
	EUCLASE $BeSiAlO_4(OH)$	BERTRANDITE $Be_4Si_2O_7(OH)_2$	BERYL $Be_3Al_2Si_6O_{18}$
BeO	16.97	42.00	13.39
Al_2O_3	34.07	—	17.99
SiO_2	41.63	49.26	65.23
FeO	1.03	—	0.57
Fe_2O_3	—	1.40	0.96
SnO_2	0.34	—	—
H_2O	6.04	6.90	1.23
K_2O	—	—	0.01
Na_2O	—	—	0.52
CaO	0.14	—	0.03
MgO	—	—	0.06
F	0.38	—	—
TOTAL	100.60	99.56	99.99

Localities: A. Brazil. Dana (1892, p.509)
B. Barbin, France. Dana (1892, p.546)
C. Missouri, U.S.A. Deer *et al.* (1962, p.260)

TABLE II
SPECTROGRAPHIC ANALYSES OF EUCLASE

	COLORADO	RHODESIA
	%	%
Si	major	major
Al	major	major
Be	7	major
Ca	0.005	less than 0.05
Fe	0.003	0.1
Cu	0.003	less than 0.002
Ge	0.15	0.025
Sc	0.003	n/v
Sn	0.015	less than 0.005
Mn	—	0.01
Na	—	—
Mg	—	less than 0.05
As	—	0.08

n/v not visible, less than 0.001%
Localities: Colorado. Sharp (1961, p.1508)
Rhodesia. Analyst, I. H. Green

Optical and Physical Data

The identification of euclase was confirmed by x-ray diffraction analysis. Table III shows data available from world-wide sources on euclase.

TABLE III
OPTICAL PROPERTIES OF EUCLASE

	A	B	C	D	E	F
	BRAZIL	GUIANA	COLORADO	U.S.S.R.	NORWAY	RHODESIA
SG	3.097	3.05	2.987(±005)	3.051	—	3.075
$n\gamma$	1.671	—	1.670(±001)	—	1.675(±003)	1.669
$n\beta$	1.6553	1.655(av)	1.655(±001)	—	1.655	—
$n\alpha$	1.652	—	1.652(±001)	—	—	1.653
2V	49° 37′	—	48°	—	45°	—

References: A. Dana (1892, p.509)
B. Spencer (1924, p.189)
C. Sharp (1961, p.1507)
D. Dana (1892, p.508)
E. Strand (1953, p.3)

V CONCLUSIONS

Insufficient data concerning the mineral stability field and geological environment for euclase were available to give a full understanding of its paragenesis. Euclase does occur as a primary hydrothermal mineral in miarolitic cavities in granites and pegmatites and as a product of greisenization in the late, low-temperature hydrated phase of pegmatite formation. Certainly there is good evidence to show that it forms as a replacement mineral after beryl by some process akin to autometasomatism within the late pneumatolytic stage of pegmatite development as exemplified in the occurrences from Norway, Colorado and Rhodesia. In these examples the presence of primary beryl is a common factor. It would seem that some basic initial chemical difference in the composition of the original pegmatite may be responsible for the preferential formation of bertrandite rather than euclase in the examples for Colorado and Norway.

The phenomemon of kaolinization of pegmatites is mentioned previously as providing an environment suitable for the development of the gem minerals, beryl and topaz. This process could also augment the pneumatolytic conditions in the replacement of primary beryl by euclase yielding kaolinite as a by-product. By

postulating that the original matrix for the primary beryl may have been potassium feldspar, a margin-core mineral for the Miami pegmatites (Wiles, 1961, p.91), it would therefore be possible, by reaction with water, to derive euclase, quartz, kaolin and potash.

$$2\,(Be_3Al_2Si_6O_{18}) + 10\,(KAlSi_3O_8) + 11\,H_2O \rightarrow$$
$$\text{BERYL} + \text{FELDSPAR} + \text{WATER}$$
$$6(BeSiAlO_4(OH)) + 2(Al_4Si_4O_{10}(OH)_8) + 28\,SiO_2 + 5\,K_2O$$
$$\text{EUCLASE} + \text{KAOLINITE} + \text{SILICA} + \text{POTASH}$$

The presence of euclase and quartz as an association has been described. Resultant kaolinite and potash could combine by the following reaction to produce muscovite mica, which is observed in the replacement association, viz:

$$3(Al_4Si_4O_{10}(OH)_8) + 2\,K_2O \rightarrow 2(K_2Al_6Si_6(OH)_4) + 8\,H_2O$$
$$\text{KAOLINITE} + \text{POTASH} \quad \text{MUSCOVITE} + \text{WATER}$$

Given suitable conditions of temperature and pressure the water resulting from the above reaction could enter into reaction again with beryl and feldspar.

Unlike the St Ann's pegmatite where a kaolinitic phase is demonstrable (Grubb, 1976), this cannot be presumed in the case of euclase-bearing pegmatites. Although it is postulated that kaolinite is generated from the above reaction, the clay minerals in the pegmatite matrix may be the result of the present cycle of weathering and not the derivative of the pneumatolytic replacement process.

The suite of pegmatites containing economic minerals is considered by Wiles (1961, p.82) to be a younger group that are largely unaffected by the Miami metamorphism; it could follow therefore that the important pneumatolytic phase is merely a final stage of pegmatite genesis. In this case the replacement phenomenon is considered as occurring within a closed chemical system.

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[*Manuscript received 7th July, 1979.*]

VISUAL COLORIMETRY AND COMPARISON GRADING

By PETER G. READ, C.Eng., F.G.A.

Despite the use of sophisticated spectrophotometers in a few of the specialized diamond grading laboratories, and the introduction of relatively simple commercial instruments such as the Eickhorst Diamond Photometer[1] and the now obsolete Shipley colorimeter, the majority of polished diamonds are still colour graded by eye. A prime example of this can be seen in the international CIBJO colour grading system for diamonds, which is based on subjective comparison grading against a set of seven master stones chosen to define the boundaries between eight colour categories in the Cape series.

While the majority of diamonds cover only a very limited colour span, the grading of coloured gemstones presents the more complex problem of assessing a wide range of hues as well as variations in colour saturation and lightness[2]. In the few instances where this problem has been tackled, the simplest solution has

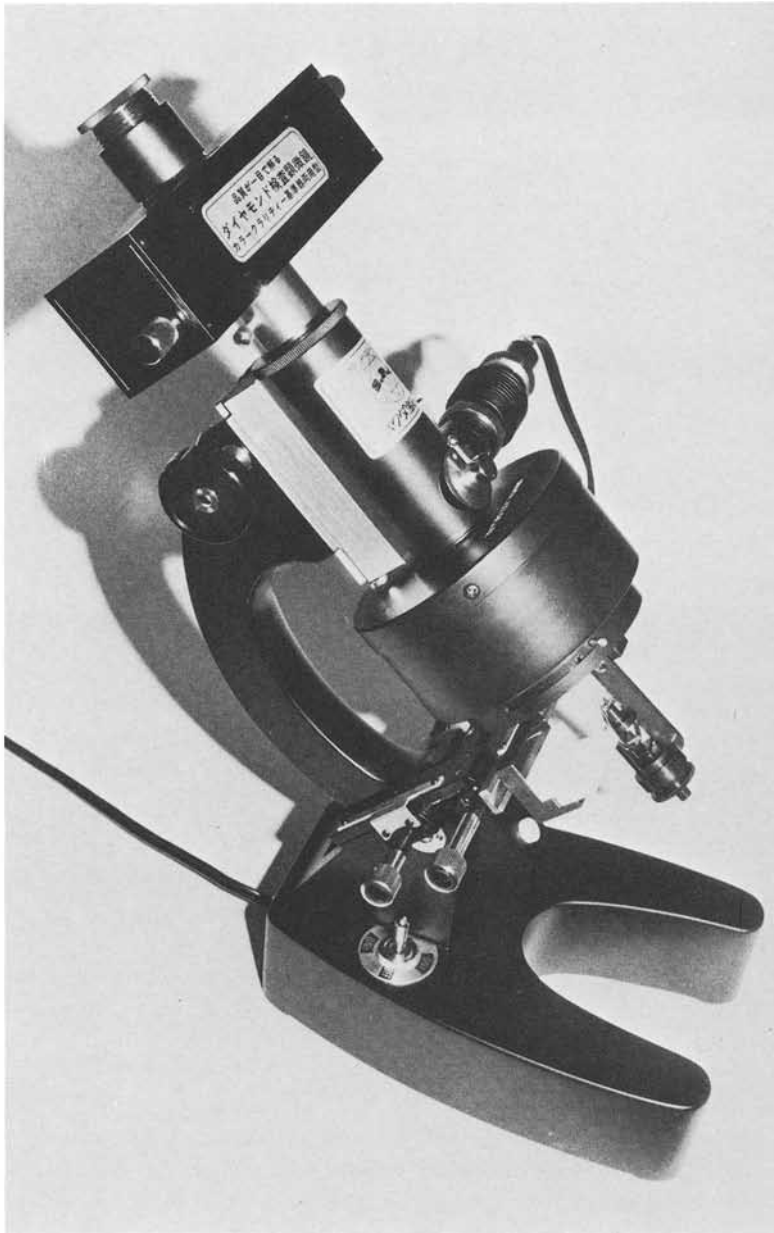

FIG. 1. The Okuda diamond grading microscope.

again been in the use of a set of master comparison stones appropriate to the particular colour variety.

Although comparison grading with the aid of master stones is undoubtedly effective, it can tie up a considerable sum of money in the value of the stones. The establishment of duplicate sets of stones for several grading laboratories can also be very difficult, usually necessitating a time consuming search through many hundreds of stones.

Recently, two instruments have been developed which provide an alternative to the use of comparison stones; one of these is designed for the colour grading of diamonds, and the other for the grading of coloured stones.

The first instrument is a new diamond grading microscope (Figure 1) designed by Okuda, the Japanese company who introduced the SPD printing-on-diamond service[1,3]. For colour grading purposes, the microscope uses a 10× wide-field eyepiece (giving an overall magnification of 20×). This forms an integral part of a simple visual colorimeter, or colour comparator unit. Colour comparison grading of Cape series stones is effected by means of a yellow-tinted glass slide, which is visible in the top

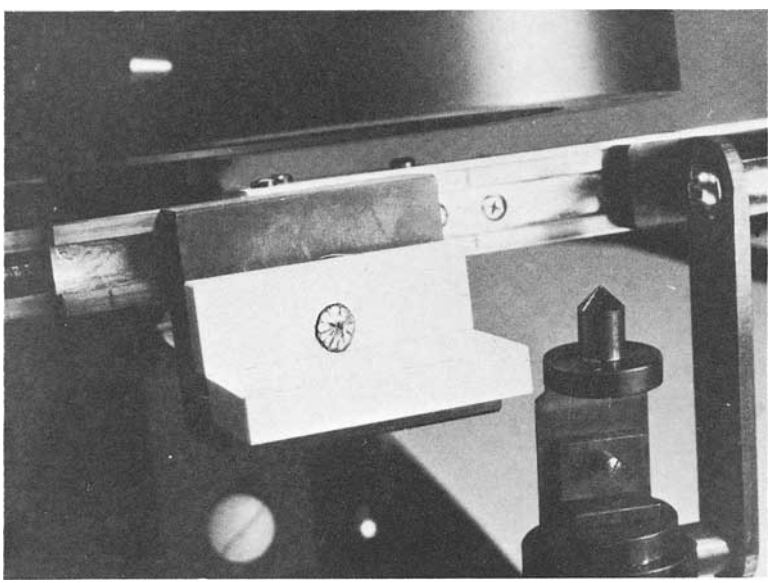

FIG. 2. A diamond positioned on the standard white grading surface.

section of the eyepiece's field of view. The slide is manufactured from a plate of yellow filter glass having a transmission peak at 585nm. This glass is polished into a wedge shape, the depth of the thicker end being adjusted to produce a colour saturation of 12% (equivalent to the G.I.A. grade 'J'), and that of the thinnest end to produce a colour saturation of 2% (equivalent to the G.I.A. grade 'E').

The unmounted diamond is placed on a standard white grading surface (Figure 2), and illuminated by a circular fluorescent grading lamp having a colour temperature and spectral distribution equivalent to the CIE standard illuminant C. The diamond is positioned so that it can be viewed through the side of its pavilion, and the grading surface is moved so as to bring the image of the diamond's table facet adjacent to that of the colour comparison slide. A control at the side of the colour comparator unit enables the slide to be moved laterally across the field of view until a colour match is obtained between it and the diamond.

The diamond's G.I.A. colour code is then read from a scale visible through a circular window immediately above the eyepiece (Figure 3). This scale is also calibrated 0-50. To allow for a more

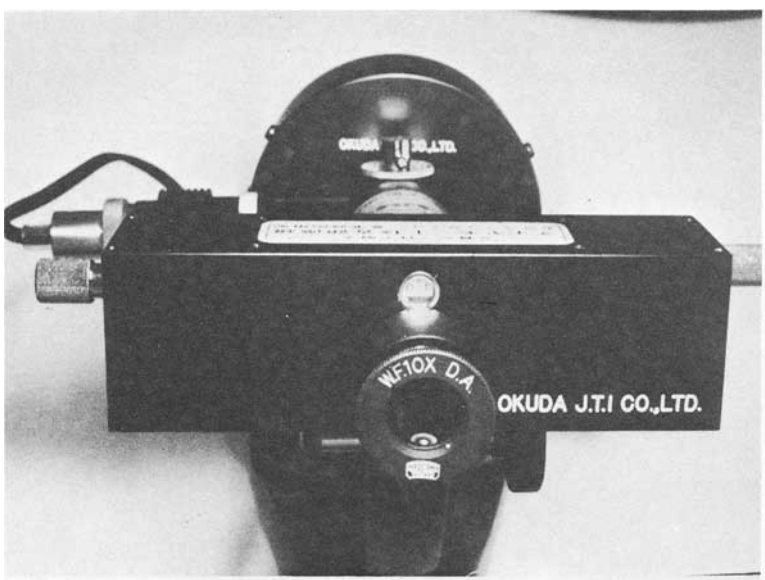

FIG. 3. Colour comparator unit showing colour saturation control (left), hue trimming control (right) and G.I.A. colour grade window (above eyepiece).

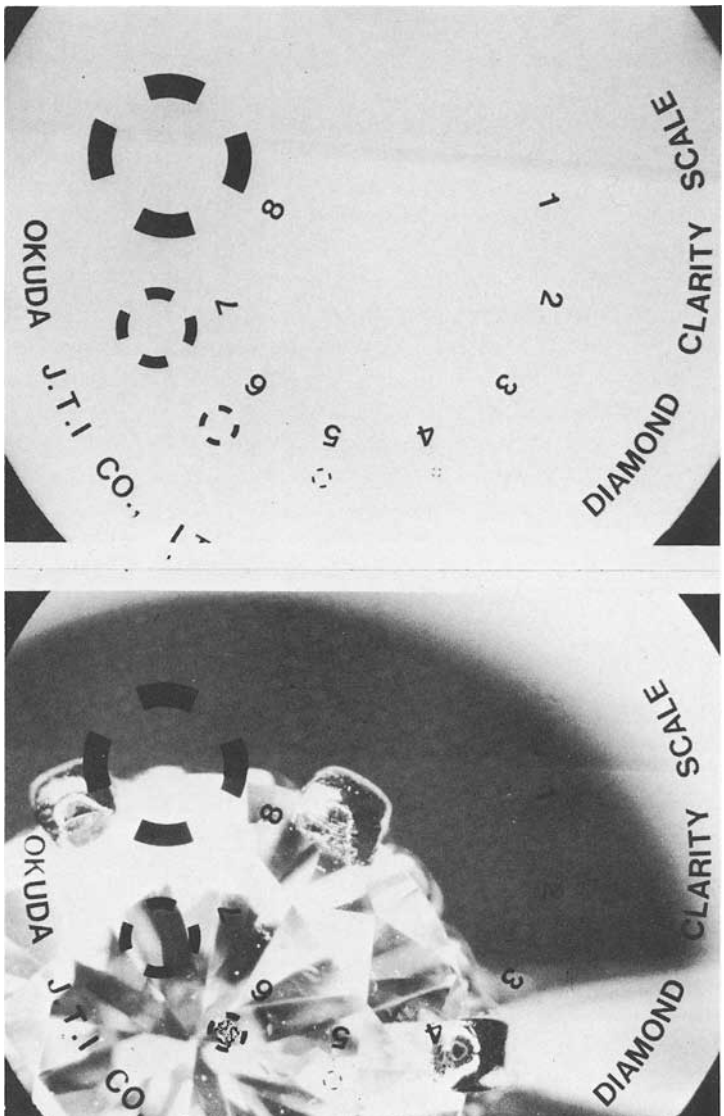

FIG. 4. Two views of the clarity grading graticule. On the left, a group of inclusions has been positioned within the clarity circle 6. No circle appears opposite the figure '1' as this represents a 'flawless' condition.

precise colour match with diamonds whose hue is slightly offset from 585nm, a hue trimming control is provided which allows the peak transmission of the wedge filter to be adjusted between the limits of 580nm and 590nm.

Provision is also made for clarity grading, the eyepiece optics containing a graticule on which is printed six circles numbered from 2 to 8 (Figure 4). Single inclusions, or groups of inclusions, are assessed for grading purposes by first noting the number of the smallest circle which completely encloses the inclusion, and then the number of the largest circle which can be fitted within the area of the inclusion. These two numbers are added together, and the appropriate CIBJO or National clarity grade derived from a table. If there is more than one inclusion or group, the individual numbers are added together. A weighting factor is also applied which depends on the reflecting or absorption properties of the inclusion, and its position within the stone.

To allow for easy inspection of mounted stones, the microscope stage is fitted with a spring-loaded holder (Figure 5), which can be rotated in two directions. An adaptor can be fitted to the

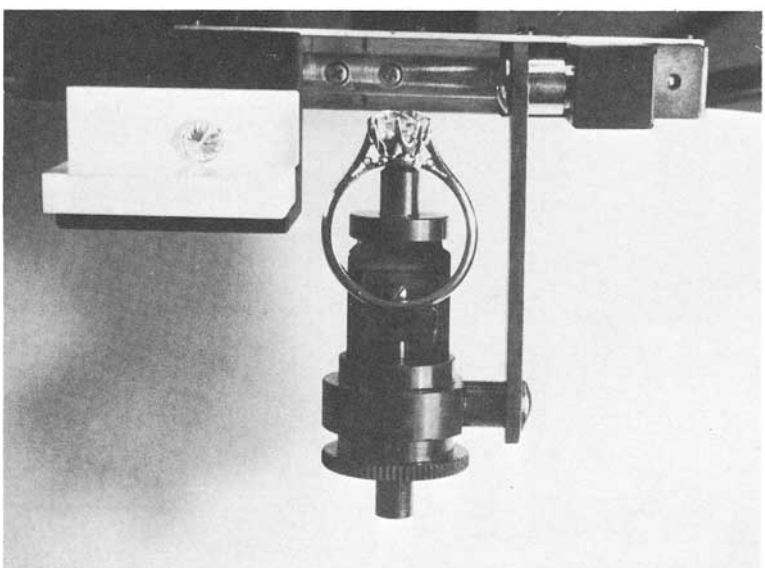

FIG. 5. Right: The spring-loaded ring holder (an adaptor can be fitted to hold unmounted stones). Left: A diamond on the standard colour grading surface.

FIG. 6. The XY stage with vernier scales.

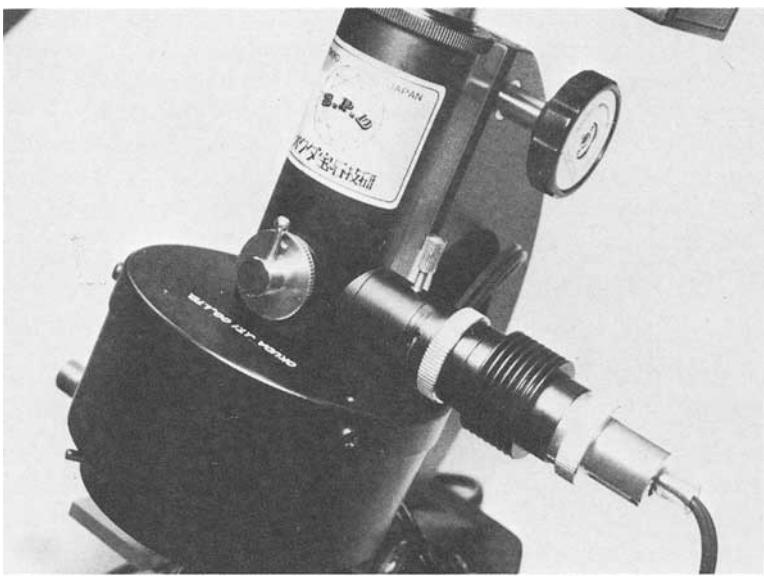

FIG. 7. The SPD illumination lamp is mounted at the side of the body tube alongside the control which adjusts the angle of the glass beam-deflector.

ring holder to provide a mount for loose stones. The stage can be indexed both laterally and vertically by means of two micrometer adjustments, each fitted with a vernier scale (Figure 6), which allow co-ordinate logging of inclusion sites. Both the ring holder and the grading platform can be moved independently along a common key-way cut in the front edge of the stage, and can be easily removed from the stage when necessary. The composite 10× eyepiece and colour comparison unit can be replaced by a 5× eyepiece to provide an overall magnification of 10× for non-grading work.

A three-position (centre-off) switch at the base of the microscope controls the circular fluorescent lamp, and allows an alternative source of illumination to be brought into use for inspecting the Okuda printed code on the table facet of a diamond. This 'SPD' illumination source comprises a small lamp unit (located at the side of the microscope's body tube) which is fitted with a green filter and an iris control (Figure 7). When in use, a rotatable glass beam-deflector in the microscope tube enables the green-filtered light to be set coaxially with the microscope optics, thus providing the increased contrast necessary for viewing the printed code against the mirror surface of the table facet.

The writer experienced two small difficulties when using this otherwise well-engineered instrument; one of these was caused by the inverted eyepiece image, although this was only apparent when it became necessary to position a stone other than by means of the XY controls. The other minor difficulty was associated with the circular lamp housing, which partially obscured the lateral vernier scale. This necessitated raising the microscope tube by means of the focus control in order to take a reading from the scale.

The microscope is designed for 100-volt and 240-volt, 50-60Hz operation, and is marketed by the Okuda Jewelry Technical Institute Co. Ltd, Fuji Bldg 2F, 30 -7 Taito-4-chome Taito-ku, Tokyo 110, Japan.

The second colour grading device[4] was developed in Professor H. P. Myers's Department of Solid State Physics at the Chalmers University of Technology, Gothenburg, Sweden, and is specifically designed for the colour grading of blue Sri Lankan sapphires. The work was carried out for the Sri Lankan State Gem Corporation and Via Star (Lanka) Ltd, both of which organizations required a simple and reproducible method for specifving and

grading sapphires which would not depend on the use of comparison stones.

Sri Lankan sapphires vary in colour saturation from a deep 'Royal' blue to a pale 'Cornflower' blue, the deeper colours containing a trace of red. As the appearance of colour in a sapphire is affected not only by its size, but also (because of dichroism and the way in which the colour is distributed within the stone) by the direction in which it is viewed, its colour is graded subjectively by inspecting it through the table facet.

In a search for a stable and easily available medium whose hue and colour saturation could be adjusted to match those of the Sri Lankan sapphires, the researchers at Chalmers University first measured the spectral response of a pale 2.5mm-thick disc of sapphire using a spectrophotometer (Figure 8). Despite the relative uniformity of this response curve, caused by the paleness of the specimen, two absorption peaks are noticeable at 390nm and 450nm, the latter being one of the iron bands characteristic for sapphire. A third much broader absorption band in the mid spectral range is the one mainly responsible for the colour of blue

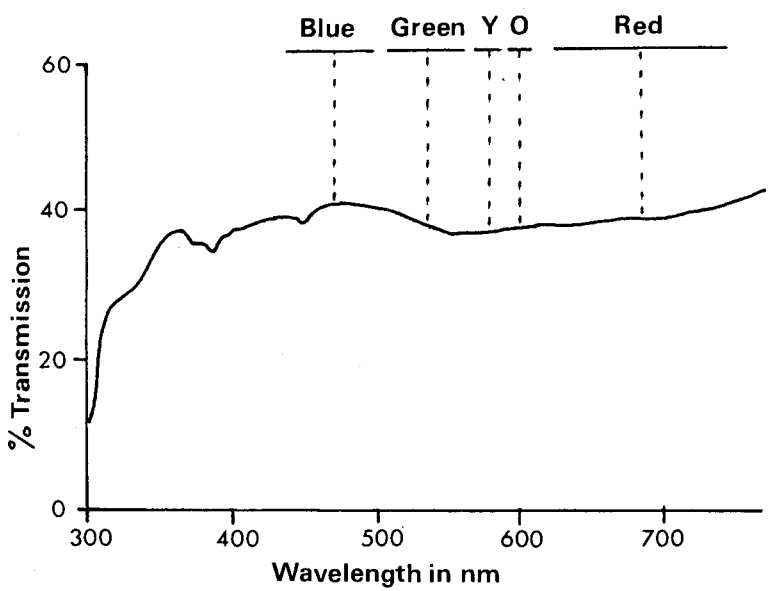

FIG. 8. Spectral transmittance of a 2.5mm-thick disc of pale sapphire.

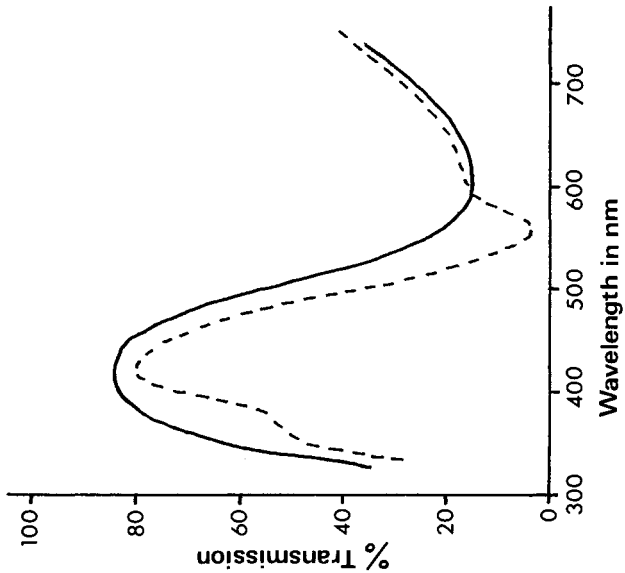

FIG. 10. The effect on the spectral transmission of copper ammonium sulphate (solid line) caused by the addition of a quantity of the standard solution of phenolphthalein is shown in the broken line curve, which has a strong absorption peak in the green at 560nm.

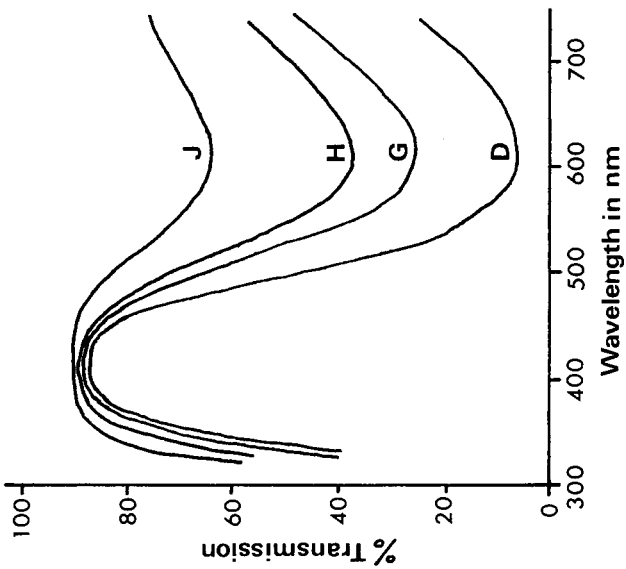

FIG. 9. Spectral transmittance of various strengths of copper ammonium sulphate solution.

sapphire. The response curve confirmed that sapphire transmits green and yellow less well than it does blue and red, and indicated the type of spectral response necessary in a suitable comparison medium.

While investigating various liquids and dyes, it was discovered that the spectral response of blue sapphire was most closely matched by a solution of copper sulphate crystals in 2.5% ammonium hydroxide (Figure 9). With such a solution, the colour saturation could easily be adjusted by controlling the weight of crystals added to the solvent. To match the red tints present in Sri Lankan sapphires, it was found necessary to add to this solution appropriate quantities of a 'standard solution' made up from 50mg of phenolphthalein dissolved in 50ml of ethyl alcohol and 50ml of water. The increase in the red tint of the copper ammonium sulphate solution is due to an absorption band which appears in the green section of its spectra at 560nm (Figure 10).

From the results, it is possible to specify a series of copper ammonium sulphate solutions (doped by the standard phenolphthalein solution) which match the required nine colour standards (see Table). These nine solutions are then made up and placed in small glass cuvettes (Figure 11) having accurately parallel and polished walls. The cuvettes are fitted with extension reservoirs so

TABLE

Colour Grade	Weight of $Cu_2SO_4.5H_2O$ crystals in grams per litre of 2.5% NH_4OH.	Volume of standard phenolphthalein solution as a percentage of undoped solution
B	8.0 grams	13.0%
C	6.67 grams	9.0%
D	5.0 grams	6.0%
E	4.0 grams	3.5%
F	3.33 grams	2.3%
G	2.5 grams	1.4%
H	1.67 grams	0.8%
I	1.25 grams	0.5%
J	0.625 grams	—

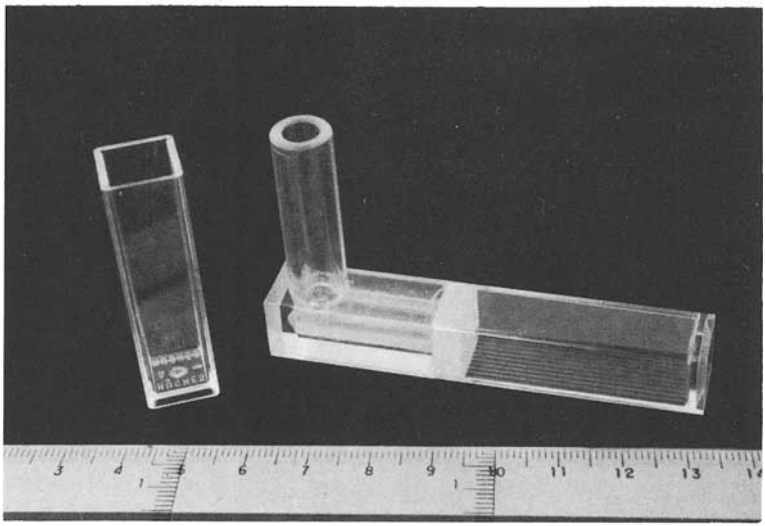

FIG. 11. The standard glass cuvette (left) fitted with a reservoir extension (right).

that they can be positioned horizontally in a light box containing a daylight fluorescent lamp and having fixed illumination geometry (Figure 12).

The colour grading of sapphires is carried out by direct comparison with the uniform colour of the liquid in the horizontal section of the cuvettes, the sapphires being placed in the illuminated area directly in front of the cuvettes (Figure 13).

The cuvettes are arranged and coded as follows:

B	C	D	E	F	G	H	I	J
Deep Blue				Medium Blue			Pale Blue	

For grading purposes, first the nearest and then the second nearest cuvette colours are identified. These are then used in the following way to produce a classification code. If a sapphire is nearest to F in colour, but is paler than E, it is classified as F_G. If a sapphire is nearest to D, but deeper in colour than E, it is classified as D_C.

As the liquids used in the cuvettes have a specific chemical composition, they can be easily duplicated in any grading laboratory which has access to the appropriate chemicals. Use of the light

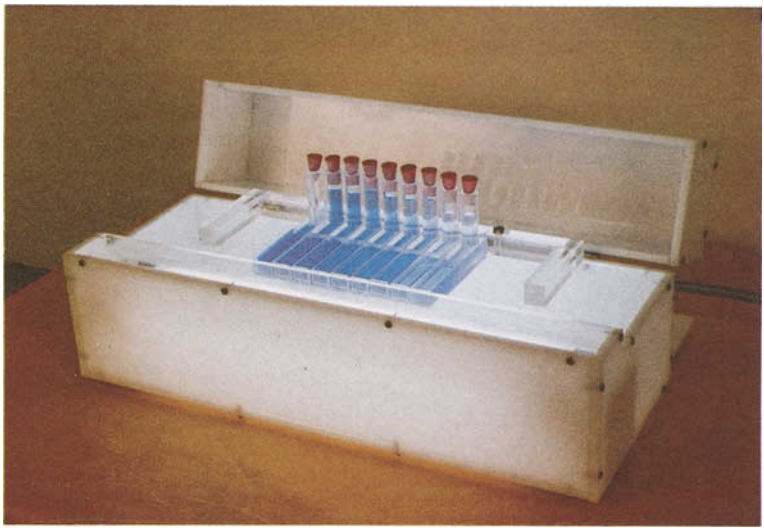

FIG. 12. Colour grading light box showing the nine cuvettes in position.

FIG. 13. Light box with lid closed. Comparison colour grading is effected on the transparent section in front of the cuvettes.

box will permit the colour grading of Sri Lankan sapphires without the need for comparison stones. The derived colour codes will also permit the unambiguous colour description of these sapphires.

The writer found the light box easier to use than a set of comparison stones, and this was probably due to the larger area of colour available for matching purposes. While this particular project was initiated for the colour grading of Sri Lankan sapphires, it is anticipated that with the appropriate solutions it will be possible not only to match the colour range of sapphires from other sources, but also that of rubies, emeralds and diamonds.

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2. Yu, R. M., Gemmological colorimetry, *J. Gemm.*, 1978, **XVI** (4), 259-69.
3. The code is visible under contrast lighting at 20× magnification, but because of the thinness of the printed symbols they are not visible under normal illumination. The original printed code was very much smaller and required a magnification of 400× (see Figure 16 in Reference 1. above).
4. Myers, H. P. *Report on Colour Classification of Sapphires from Sri Lanka,* Chalmers University of Technology, September 1978.

[*Manuscript received 27th July, 1979,*]

GEMMOLOGICAL ABSTRACTS

AKIZUKI(M.), HAMPAR(M. S.), ZUSSMAN (J.). *An explanation of anomalous optical properties of topaz.* Mineralog. Mag., **43**, 237-41, 4 figs, 1979.

Some topaz crystals show a sectorial texture which is related to the growth of the crystal. Fluorine/hydroxyl sites in topaz are symmetrically equivalent in the solid crystal, but this balance is sometimes lost at growth surfaces so that the crystal symmetry is reduced. Topaz heated to about 950°C loses the optical anomalies resulting from the reduction in symmetry. M.O'D.

BANK (H.). *Gemological notes.* Gems & Gemology, **XVI**, 4, 123-5, 1978.

Describes blue gem quality haüyne from Eifel, Germany; demantoid garnet of deltoid-icositetrahedral habit (usually a form found only in combination, according to Dana) from Korea and various blue/red colour-change garnets of the pyrope/spessartite group from Tanzania are reported and compared with similar stones from Sri Lanka. R.K.M.

BARLOW (F. J.). *Red beryl of the Wah Wah's.* Lapidary Journal, **32**, 12, 2540-70, 16 figs (15 in colour), 1979.

Describes the finding and fashioning of a manganese-bearing type of beryl found in the Wah Wah Mountains of Utah. M.O'D.

BECK (R. J.). *Jade and gemstones from Southern New Zealand.* Lapidary Journal, **33**, 1, 186-90, 4 figs, 1979.

Deals mainly with nephrite but mentions some less important ornamental materials including several varieties of quartz. M.O'D.

COLLINGS (A. T.). *Investigating artificially coloured diamonds.* Nature, **273**, 654-5, 1 fig., 1978.

It is suggested that the absence of an absorption line at 595 nm (used by many gem-testing laboratories to decide the pedigree of yellow-coloured diamonds) does not unambiguously categorize a diamond as untreated. This line disappears completely when annealing temperature is increased from the normal range of 700-800°C to 1000°C. R.A.H.

GALWEY (A. K.), JONES (K. A.), REED (R.), DOLLIMORE (D.). *The blue colouration in banded fluorite (Blue John) from Castleton, Derbyshire, England.* Mineralog. Mag., **43**, 243-50, 2 figs, 1979.

Microscopic examination of lightly etched and cleaved (111) surface of Blue John seems to show that coloured lamellae are not associated with dislocations in the lattice. It is suggested that the blue colour is caused by colloidal calcium which results from radiation damage; this may be caused by the intermittent deposition of radioactive material on the surfaces during growth. M.O'D.

GIANNOTA (V. P.). *Precious amber in the Simeto River, Sicily.* Lapidary Journal, **33**, 1, 32-4, 1979.

Amber with a wide variety of colours is found in the Simeto River area of Sicily. Much of the material is fluorescent. Brief details of recovery are given. M.O'D.

GÜBELIN (E. J.). *Sapphire-blue euclase, a new collector's gem.* Gems & Gemology, **XVI**, 4, 104-10, 1 map, 1 fig, 1978.

Euclase, referred to here as the epigone (later generation) of beryl, has been found near Miami in Zimbabwe-Rhodesia. It is in a deep blue colour reminiscent of sapphire. RI 1.652—1.671, DR 0.019 positive. SG 3.06 to 3.13. H 7½. Colour often in bands alternating deep blue and colourless. R.K.M.

HENRY (J. H.). *Pink diamonds.* Lapidary Journal, **33**, 1, 35-54, 4 figs (2 in colour), 1979.

A short account of a number of pink diamonds with historical notes. M.O'D.

HUANG (C. K.), YEH (C. L.). (Taiwan cat's-eye). J. Gemm. Soc. Japan, **5**, 4, 13-20, 3 figs, 1979. (In Japanese with English summary).

Taiwan cat's-eye is found to be a chatoyant tremolite which occurs in veins at the contact of graphite-sericite schist and serpentinite sills in association with nephrite, asbestos, talc and a diopside skarn in the Fengtien area south of Hualien, Taiwan. The colour is greenish-, pale- or honey-yellow, dark green, dark brown or black, translucent to opaque. H6-7, SG 3.045, RI 1.613, 1.626, 1.637. X-ray examination shows that the material is close to that found in the St Gotthard area of Switzerland. M.O'D.

IISHI (K.), SALJE (E.), WERNEKE (Ch.). *Phonon spectra and rigid-ion model calculations on andalusite.* Physics and Chemistry of Minerals, **4**, 173-88, 8 figs, 1979.

Al-O bond strength of about 70% ionic and SiO_4 tetrahedra bonded mostly covalently with about 40% ionicity have been established by polarized Raman and infrared spectra in andalusite. M.O'D.

JONES (R. W.). *Chrysocolla, Arizona's premier gem.* Lapidary Journal, **33**, 1, 6-16, 12 figs (11 in colour), 1979.

Chrysocolla is found at the Cobre Valley, Arizona, close to the towns of Miami and Globe. Specimens are still being recovered. M.O'D.

KOMATSU (H.), AKAMATSU (S.). (Studies on differentiation of true and artificial coloured black and blue pearls). J. Gemm. Soc. Japan, **5**, 4, 3-8, 40 figs (31 in colour), 1979. (In Japanese with English summary).

Black pearls have been cultivated recently in the Ishigaki Islands, Okinawa and in the Tahiti Islands. Blue pearls have also been encountered among ordinary cultivated pearls. True and artificially coloured black pearls can be distinguished by a combination of four different methods or by comparing different colouring on infrared film. Further study is needed on the blue pearls. Methods of cultivation of the black pearl are described. M.O'D.

LEITHNER (H.). *Sherrybraune Topase von Ouro Preto in Brasilien.* (Sherry-brown topaz from Ouro Preto, Brazil). Lapis, **4**, 5, 26-29, 5 figs (3 in colour), 1979.

A brief account with fine illustrations of the topaz found in the classic locality of Ouro Preto, Brazil. An early map of the district is reproduced. M.O'D.

NASSAU (K.). *Distinguishing diamond from cubic zirconia.* Gems & Gemology, **XVI**, 4, 111-17, 3 figs, 1978.

Summarizes in detail the assessment of the two substances by infrared reflectometer, by diamond wetting pen, and by thermal conductivity probe. All three methods are approved, but each has some slight limiting factor. Dr Nassau points out that some felt-tipped pens will also be suitable for the diamond wetting test. R.K.M.

NASSAU (K.). *An examination of the new Gilson 'Coral'.* Lapidary Journal, **33**, 1, 42-49, 4 figs (2 in colour), 1979.

A coral imitation consisting largely of calcite has been made by the firm of Gilson. The density is lower than for the natural material (2.44 as against 2.6-2.7); the material is slightly porous and some extra phases are revealed by x-ray diffraction and thermal analysis. M.O'D.

NASSAU (K.). *A test of the Ceres diamond probe.* Gems & Gemology, **XVI**, 4, 98-103, 2 figs, 1978.

A thorough assessment of a new diamond testing instrument depending on the very high thermal conductivity of diamond when compared with its simulants. Tests down to sizes of about 0.03 ct. In general this is a new test for diamond and works admirably. R.K.M.

O'DONOGHUE (M.). *Scandinavia to Russia.* Gems, **11**, 3, 47-49, 1979.

The second part of an account of a mineralogical tour to Norway, Sweden, Finland and the U.S.S.R.; includes notes of visits to institutions in Moscow and Leningrad. In all museums visited synthetic crystals were on display. The Diamond Fund in Moscow showed very large, well-formed diamond crystals as well as set pieces. (Author's abstract) M.O'D.

ROBERTSON (A. D.). *Lowmea amethyst deposit.* Queensland Govt. Mining J., **79**, 380-1, 1 fig., 1978.

Amethyst occurs in vugs having an outer sheath of milky quartz. These occurrences are found in quartz veins in an adamellite. Radiation from the adamellite is thought to have caused the colour development and colour zoning. Fractures and annealed fractures are common, and rutile rods, feldspar, and magnetite dust have been observed. D.J.D.

SAHAMA (T. G.), KNORRING (O.), TÖRNROOS (R.). *On tourmaline.* Lithos, **12**, 109-14, 4 figs, 1979.

Chemical analyses and physical properties are given for a group of 10 tourmalines from Mozambique, one from Afghanistan and one from Madagascar. The colours of the stones examined vary. Isomorphism in the tourmaline group is reviewed. M.O'D.

TURNER(N.) *et al. Gemstones of New Zealand.* Lapidary Journal, **33**, 1, 116-41, 17 figs, 1979.

A survey of the main ornamental materials to be found in New Zealand, with a map and guides for rockhounds. M.O'D.

VAN LAER (W. C.). *Tourmalines of the Homestake Pass.* Lapidary Journal, **33**, 1, 58-64, 6 figs, 1979.

Tourmaline has been found at the Homestake Pass, Butte, Montana, U.S.A. Crystals are black and found in association with smoky quartz and perthite. M.O'D.

WILL (G.), NOVER (G.). *Influence of oxygen partial pressure on the Mg/Fe distribution in olivines.* Physics and Chemistry of Minerals, **4**, 199-208, 3 figs, 1979.

Mg/Fe ordering in olivines appears to be affected by prevailing pressure of oxygen. Natural crystals of volcanic origin were studied by x-ray diffraction. M.O'D.

WINDISCH (H.). *Polishing material in Southern Africa.* Lapidary Journal, **33**, 1, 18-30, 8 figs, 1979.

A survey of the ornamental material available from the southern part of Africa. Stones described include tiger's-eye, agates, amethyst, rose quartz, petrified wood, hydrogrossular garnet, amazonite, aragonite, sodalite, stichtite and verdite. M.O'D.

YU (R. M.), HEALEY (D.). *A new refractometer.* Lapidary Journal, **33**, 1, 288-91, 6 figs, 1979.

A refractometer using the principle of total internal reflection and involving the movement of the eyepiece is described. Birefringence can also be measured but the RI of cabochon-cut stones cannot. Accuracy to within ±0.02 (Rayner ±0.001) is claimed. M.O'D.

ZEITNER (J. C.). *From Russia—a new gem.* Lapidary Journal, **33**, 1, 208-14, 7 figs, 1979.

The new gem, not (strictly) Russian but Siberian, is charoite, which is described. Some details of the appearance of charoite on the Western market are given. M.O'D.

ZEITNER (J. C.). *Gems of Brazil.* Lapidary Journal, **33**, 1, 142-55, 15 figs, 1979.

A general account of the main gem materials found in Brazil, with a map. M.O'D.

ZEITSCHEL (W.). *Tektite-die rätselhaften Gläser.* (Tektites, the mysterious glasses). Mineralien Magazin, **3**, 172-5, 8 figs in colour, 1979.

A short introduction to tektites with a map and bibliography. M.O'D.

BOOK REVIEWS

ARIYARATNA (D. H.). *Gems of Sri Lanka.* 3rd revised edn. D. H. Ariyaratna, Colombo, 1978. pp.47. Illus. in black-and-white and colour. Price on application.

A pocket-sized and pleasantly-written book whose main value is in the account of gem working in Sri Lanka. A number of Sinhala words are explained and details given of the operation of the State Gem Corporation. Only the more important stones are described but the matter is clear and accurate. M.O'D.

ELWELL (D. H.). *Man-made gemstones.* Horwood, Chichester, 1979. pp.191. Illus. in black-and-white and in colour. £15.00.

This is a badly-needed book in which the emphasis is placed upon the history and development of crystal growth as it affects gem-quality materials. It does not set out to be a student's guide and for this reason does not include notes on or illustrations of inclusions (although they are mentioned where relevant). There is a short table of the major constants of the better-known gemstones, a glossary, a guide to growing your own rubies and a short general bibliography, more detailed papers being listed at the end of the appropriate chapters. The details of the various processes used to grow gem-quality crystals are lucidly described and the information is up-to-date. One weakness of standard gemmology texts is that crystal growth processes are not well described and tend to be dated. This book fills that gap and is very welcome on that account. M.O'D.

FYNN (G. W.), POWELL (W. J. A.). *The cutting and polishing of electro-optic materials.* Hilger, Bristol, 1979. pp.xv, 215. Illus. in black-and-white. £25.00.

Those with an interest in polishing man-made transparent materials will find parts of this book very useful, although it is not intended for the lapidary or gemmological market. Tables at the end of the book list a variety of substances and their behaviour under various conditions of polishing; agents are also listed. M.O'D.

GILL (J. O.). *Gill's index to journals, articles and books relating to gems and jewelry.* Gemological Institute of America, Santa Monica, California, 1979. pp.xiii, 420. $24.50.

This unusual book is divided into four sections covering gems and gem materials, gem locations, gemmology and jewelry. Within each section various topics are listed alphabetically and referred to six journals (*Minerals Yearbook, Gemmologist, Gems and Gemology, Journal of Gemmology, Lapidary Journal* and *Australian Gemmologist*). There is also a section headed 'Gem Library Bibliography' which includes monographs. So far so good. In the section on gems there is little difficulty since the reader would expect to find the materials listed alphabetically; but some parts of this section are a little unexpected, for example 'group gem descriptions' (mostly including works on synthetics) is not referred to from the term 'synthetic' anywhere else in the book (there is no general index). 'Wonderstone' is included but its identity is not given; alternative names for some substances are given in brackets with the main name chosen but again there are no

cross-references. In each journal section references are given in date order; a few include the name of the author but choice of this (and of capitalization) is capricious.

Similar inconsistencies appear in the locality section; South-west Africa is alternatively called German South West Africa rather than Namibia; British Isles is not a recognized geographical name; on the other side Botswana's former name is omitted although that for Lesotho is given. A school atlas would have cleared all this up. Moldavite and its fellows are given at the end of the section under the heading 'Gems from Space'.

Part 3, Gemmology, has the most capricious choice of sub-headings and it is admittedly hard to see how this can be avoided if this particular arrangement is adopted. Thus we find 'assembled stones' with no cross-reference from composites or doublets; 'fraud in gemmology' with no reference from 'forensic'; 'phenomena' (to include chatoyancy, asterism, etc.); 'refractive index' (to include polarized light) and many other inconsistencies and downright annoyances.

Annoyance is the prevailing feeling after using this book, whose conception is good. Like so many amateur productions (for this is quite unprofessionally done) the conception is not assisted by any skill or forethought. Not to include a general index or cross-references is a major blunder (or even cynical cost-cutting) by author and publisher; it would have been better to wait until all loose ends had been tidied up; until the text had been read by someone more familiar with gemmology and publishing and until headings had been agreed by a number of people rather than by just one. None the less many will find the book useful—but why not strive for excellence too? M.O'D.

MARFUNIN (A. S.). *Physics of minerals and inorganic materials: an introduction.* Springer, Berlin, 1979. pp.xii, 340. $(US)53.90.

This is an important book for students of the electronic structure of atoms in minerals and for those with interests in the area where mineralogy and the physics of the solid state meet. This area covers such topics as the effect of chemical bonding on spectroscopy, the energy band theory and the reflectance spectra of minerals, and the origin and nature of mineral coloration Mathematics 'has been kept to a minimum' as almost all books of this nature now seem compelled to say; but it is also true that a number of concepts are not understandable except in mathematical terms. This is particularly true of quantum mechanics, the study of which is vital to an understanding of atomic behaviour.

Readers of the *Journal of Gemmology* would probably find the sections on types of optical absorption spectra and selection rules especially interesting. (Selection rules cover the various transitions theoretically possible for electrons and explain why some transitions are impossible). Although the spectra associated with transition metal ions are explained, those wishing to know more about the spectra associated with rare-earth ions should refer to a work by the same author (*Spectroscopy, luminescence and radiation centres in minerals,* to be reviewed later). The conceptions and their associated observations are especially elegant and show (at least to this reviewer) the beauty of the physical side of mineralogy. M.O'D.

ASSOCIATION NOTICES

GIFTS TO THE ASSOCIATION

The Council of the Association is indebted to the following for their gifts:

Mr J. R. H. Chisholm, M.A., F.G.A., Lytham St Annes, for a book entitled 'A History of Fossils' by John Hill, London, 1747 (being the first volume of that author's 'A General Natural History: or, Descriptions of a knowledge of the Animals, Vegetables, and minerals of the different parts of the World.').

The Gemological Institute of America for a small refractometer which is included in the Gem Instruments Corporation 'Mini-Lab' set.

Mr R. Holt, F.G.A., London, for two step-cut stones—a blue kyanite weighing 2.58ct and a colourless petalite weighing 4.32ct.

Mr Per Paulin, B.Sc., F.G.A., Uppsala, Sweden, for a gift of money for the purchase of specimens for students.

NEWS OF FELLOWS

On 20th September, 1979, Mr F. A. Fryer, B.Sc., F.G.A., gave a lecture entitled 'The Chemistry of Colour' to the Chemical Society of the German Democratic Republic at Wilhelm-Pieck University, Rostock, E. Germany.

On the 5th October, 1979, Mr M. J. O'Donoghue, M.A., F.G.S., F.G.A., gave a talk entitled 'Finding Gemstones' to the Sussex Lapidary and Mineral Society. Mr O'Donoghue also gave a two-day course to Liberty & Co., London, on gem identification with particular reference to synthetics and jade.

MEMBERS' MEETINGS

London

On 12th October, 1979, at the Central Electricity Generating Board Theatre, London E.C.1., Dr Jacques Sabbagh, M.B., B.Ch., M.I.C.S., gave an illustrated talk entitled 'Promoting and Merchandizing Coloured Stones'. A full report will appear in a future issue of the *Journal.*

Midlands Branch

On the 30th September, 1979, a Gem Teach-In was held at the School of Jewellery, Birmingham. Messrs D. Price, D. Morgan and P. Balin gave advice and assistance to members on their personal gemstone collections.

On the 25th October, 1979, at Central Hall, Birmingham, two films were shown entitled 'Diamonds' and 'The Magic of Diamonds'.

North-West Branch

On 11th October, 1979, at Church House, Liverpool, the Annual General Meeting of the Branch was held. Mrs M. P. Gayton, F.G.A., and Mrs D. M. Brook, F.G.A., were elected Chairman and Secretary respectively.

South Yorkshire Branch

On 4th October, 1979, at the Sheffield Polytechnic, the Revd S. B. Nikon Cooper, B.D., F.G.A., gave a talk entitled 'Precious Stones of the Bible and Their Significance'.

FORTHCOMING MEETING

On Wednesday, 26th March, 1980, there is to be a talk in London by Mr P. G. Read, C.Eng., F.G.A., on 'Modern Developments in Gem Testing'.

COUNCIL MEETING

At a Meeting of the Council held on Wednesday, 3rd October, 1979, at Saint Dunstan's House, it was agreed that with effect from 1st January, 1980, the annual subscription for Fellows and Ordinary Members shall be £10.00. The annual subscription for the *Journal* for non-members is increased to £12.00. The following were elected to membership.

FELLOWSHIP

Atapattu, Nirmala K., Mt Lavinia, Sri Lanka. 1978
Beech, Trevor A., Blackpool. 1979
Beeks, Johannes F. M., Valkenswaard, Netherlands. 1979
Breden, Robert J., Liverpool. 1979
Brohier, Kenneth G., Wirral. 1979
Callaghan, Gerard J., Liverpool. 1979
Clark, Alan J., Croydon 1979
Crossland, Julie H., London. 1979
Cukier, Gerard, London 1979
Deste, Roberta A. E., London. 1979
Franks, John W., Altrincham. 1979
Good, Amanda G., London. 1979
Gunatilake, Abaya G., Colombo, Sri Lanka. 1978
Herbert, Janet E., Northampton. 1979
Hidaka, Masano, Silver Spring, Md, U.S.A. 1979
Holdsworth, Ian, Stafford. 1979
Howarth, Janet, Bolton. 1979
Jayawardena, Palihawadana A. J. L. P., Colombo, Sri Lanka. 1979
Jones, Michael D., Flyford Flavel. 1979
Langoulant, Margaret J., Subiaco, W.Australia. 1978
Lewis, Robert G., London. 1977
Mercade Galles, Jamie A., Barcelona, Spain. 1970
Midgley, Ronald C., Leeds. 1979
Mundin, Kenneth W., Leicester. 1979
Okayasu, Kuni, Hokkaido, Japan. 1979
Perry, Charles J., London. 1979
Pethiyagoda, Upali K., Nugegoda, Sri Lanka. 1978
Pietruska, Julia E. J., London. 1979
Pluckrose, William H., Herne Bay. 1979
Pulle, Amara N. S., London. 1979
Pulle, Bernard T. B., London. 1979
Sinclair, Netta, Enfield. 1979
Smit, Neil C., Pietersburg, S.Africa. 1979
Styles, Jonathan A., Enniskillen, N.Ireland. 1979
Taank, Ashok P., London. 1979

Taylor, John B., Brisbane, Qld, Australia. 1979
Theobald, Robert, Leighton Buzzard. 1979
Tindall, Anthony P., Ilkley. 1979
Tubella Llurba, Carlos, Tarragona, Spain. 1978
van der Geest, Eduard E., Heemstede, Netherlands. 1979
van Roojen, Tobias, Amsterdam, Netherlands. 1979
Virtanen, Anne M., Helsinki, Finland. 1978
Whittaker, Kenneth R., Widnes. 1979
Wright, Stephen R., London. 1979
Zelley, Michael J., Great Dunmow. 1979

TRANSFERS FROM ORDINARY MEMBERSHIP TO FELLOWSHIP

Akiyama, Masashi, Hokkaido, Japan. 1979
Ali, Syed J. A., London. 1979
Asagai, Osamu, Osaka, Japan. 1979
Barker, Maxwell, Sandton, S.Africa. 1979
Barot, Nandkishor R., Nairobi, Kenya. 1979
Boyd, Warren F., Willowdale, Ont., Canada. 1979
Bromwich, Graham S., Reigate. 1979
Brownlow, Arthur H., Needham, Mass, U.S.A. 1979
Bürk, Ralph, Pforzheim, W.Germany. 1979
Chadwick, John H., Clacton-on-Sea. 1979
Charlesworth, Anthony R., Southport. 1979
Chosokabe, Yukuto, Aichi Pref., Japan. 1979
Darcy, John P., Dun Laoghaire, Ireland. 1979
de Knecht, Petrus B., Strijen, Netherlands. 1979
Derry, Catherine E., Nottingham. 1979
Douglas, John J., Cardiff, N.S.W., Australia. 1979
Dupuis, Ronald J. R., Toronto, Ont., Canada. 1979
Fagg, Primrose M., Wallington. 1979
Farnham, Julian R., Haslemere. 1979
Fernando, Bathiya D., Colombo, Sri Lanka. 1979
Fookes, Mark H., Brentwood. 1978
Fung, Tsee H., London. 1979
Gion, Hirotaka, Sapporo, Japan. 1979
Glenister, David A., Stellenbosch, S.Africa. 1979
Gower, Wendy, Brisbane, Qld, Australia. 1979
Green, James E. W., Albrighton. 1979
Harding, Roger R., London. 1979
Hirst, Rosalind, Johannesburg, S.Africa. 1979
Jayendran, Ariacutty, Colombo, Sri Lanka. 1979
Jealouse, Roy G., Crewe. 1979
Jennings, Harold F., Jr, Roanoke, Va, U.S.A. 1979
Jibiki, Emiko, Tokyo, Japan. 1979
Jørgensen, Svend E., Nordborg, Denmark. 1979
Kaleel, Ameena, Mt Lavinia, Sri Lanka. 1979
Kimura, Shinichi, Kyoto, Japan. 1979
Kimura, Takashi, Tokyo, Japan. 1979
King, Larry G., Grand Prairie, Tex., U.S.A. 1979
Kitahara, Nobuko, Kobe, Japan. 1979
Kohara, Sachiko, Tokyo, Japan. 1979
Kojima, Michinaka, Tokyo, Japan. 1979

Lee, Dennis P., Leatherhead. 1979
Lien, Jan P., Norrköping, Sweden. 1979
Lindsay, Kathryn S., Salisbury, Zimbabwe-Rhodesia. 1979
Lurie, Joseph, Randburg, S.Africa. 1979
Minster, David, Pretoria, S.Africa. 1979
Morimoto, Towa, Kyoto, Japan. 1979
Murray-Jones, Pauline A., Hong Kong. 1979
Nathanson, Daniel P., London. 1979
Neo, Nobushige, Osaka, Japan. 1979
Nishino, Tomoji, Tokyo, Japan. 1979
Nott, Shelley N., London. 1979
Palmer, Joanna G., London. 1979
Rasborn, Jeannine M., Hong Kong. 1979
Roos, Raimo H., Nairobi, Kenya. 1979
Roper, Thomas C., Glenorchy, Tas., Australia. 1979
Salakian, Silva, Salisbury, Zimbabwe-Rhodesia. 1979
Samarajiwa, Eulalie, Reading. 1979
Smart, Denis O., Kettering. 1979
Streight, Gordon S., Mississauga, Ont., Canada. 1979
Takahashi, Junko, Urawa City, Japan. 1979
Tarbuck, William B., Manchester. 1979
Tateishi, Masateru, Tokyo, Japan. 1979
Tilley, Melinda V., Kowloon, Hong Kong. 1979
Vale, Shelagh V., Exeter. 1979
van Lieu, Mai, Brussels, Belgium. 1979
Verch, Ulla, London. 1979
Watts, Terrence J., Newcastle-upon-Tyne. 1979
West, Clive G., London. 1979
Wilson, Hiroko, Hong Kong. 1979
Winter, Julie, Leatherhead. 1979
Withycombe, Darroch B., St John's, Newf., Canada. 1979
Zimmer, Alvin F., Tucson, Ariz., U.S.A. 1979

ORDINARY MEMBERSHIP

Acheson, Michael A., Geneva, Switzerland.
Ahmad, Zaheer, Nairobi, Kenya.
Akaishi, Shinichi, Chiba Pref., Japan.
Almazan Gurumeta, Francisco J., Madrid, Spain.
Amarasena, Sepala De Silva, London.
Arnold, Martin J., Edgware.
Ashton, Michael, Luton.
Attapattu, Nimal G., Mt Lavinia, Sri Lanka.
Aylward, Peter S., Westonaria, Transvaal, S.Africa.
Bacon, John E. T. S., Cape Town, S.Africa.
Balordi, Corrado, Lusaka, Zambia.
Barker, Janet E., Santa Monica, Ca, U.S.A.
Beard, Thomas E., Jr, Atlanta, Ga, U.S.A.
Bell, Robert F., Honolulu, Hawaii, U.S.A.
Booth, Anna E., Leven.
Bowles, Susan M., London.
Brown, Eric G., Geneva, Switzerland.
Burch, Clive R., Sunderland.
Burns, Kenneth W., Miami, Fa, U.S.A.
Buser III, Charles G., Mechanicsburg, Pa, U.S.A.
Butler, Fredrick W., Tokyo, Japan.
Carno, Dennis, Mount Vernon, N.Y., U.S.A.
Carrera Publet, Jaime, Barcelona, Spain.
Carrette, Philippe, Brussels, Belgium.

Castillo, Ramon G., New York, N.Y., U.S.A.
Cheshire, Carey S., Billericay.
Chiu, Carol C., Hong Kong.
Chooi, Siew-Cheong, London.
Colaprete, Arthur, St Marys, Pa, U.S.A.
Conrad, Robert, Marina Del Rey, Ca, U.S.A.
Cooper, David J., Bedfont.
Cowling, Denise E., Northampton.
Crawford, Douglas J., Betchworth.
Cudworth, Patricia J., Mansfield.
Czarnetzky, Edward M., Springfield, Va, U.S.A.
Czernys, Madeline F., Ottawa, Ont., Canada.
Dassenaike, Alastair C. A., Colombo, Sri Lanka.
Davis, Robert J., Margate, Tas., Australia.
De Rezende, Octavio L., Parana, Brazil.
Devich, Charles A., Milwaukee, Wis., U.S.A.
Dickey, Marlin L., Alta Loma, Ca, U.S.A.
Dolleslager, James T., Houston, Tex., U.S.A.
Donnelly, Bernard, Blackburn.
Doughty, Eva, Wembley.
Dufay, Gail F., Ludlow Castle.
Duque Munoz, Marta I., Madrid, Spain.
Eddelin, Frank H., Southend-on-Sea.
Edmund, Hapuwalanage D., Kadawata, Sri Lanka.
Edwards, Kenneth F., Luton.
Elliott, David, London.
Elzinga, Vivienne, Cape Town, S.Africa.
Evison, Robert A., Pukalani, Hawaii, U.S.A.
Fell, Allan L., New Malden.
Fernandez, Luis, Geneva, Switzerland.
Fiore, Peter W., Aldershot.
Flanagan, Kevin, San Mateo, Ca, U.S.A.
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Forman, Morris, Johannesburg, S.Africa.
Fradkin, Howard E., Huntington Beach, Ca, U.S.A.
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Fujii, Michiru, Yokohama, Japan.
Gailterie, Marie-Claire, Geneva, Switzerland.
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George, Silvester O., London.
Gideon, Lester P., Vandenberg, Ca, U.S.A.
Giermek, Grzegorz M., Skawina, Poland.
Glogowski, Wladyslaw H., Middlesbrough.
Goatly, Andrew M., London.
Good, Phyllis D., Butler, N.J., U.S.A.
Goosen, Heather M., Bulawayo, Zimbabwe-Rhodesia.
Gosswinn, Nicholas S., Newport.
Gough, Raymond G., Bristol.
Gros, Fabrice, New York, U.S.A.
Grundy, Jonathan S., Sheffield.
Gunn, Phyllis, Spokane, Wash., U.S.A.
Hall, Clive D., Edgware.
Hamza, Mohamed C. M., Beruwala, Sri Lanka.
Handoll, Trevor J., Eastbourne.
Heiberg, Axel L., Copenhagen, Denmark.
Hill, Ann F., Fairview Park, S.Australia.
Hirokawa, Sumiko, Tokyo, Japan.
Ho, Alice J., Kowloon, Hong Kong.
Holahan, Michael J., Johannesburg, S.Africa.

Hung, Lillian, Santa Monica, Ca, U.S.A.
Hutchinson, Marjorie E., London.
Ingle, Henriette E., Aberdeen
Irwin, Simon A., Stockport.
Jackson, Robert M., Calgary, Alta, Canada.
Jacobsson, Rolf, Jarfalla, Sweden.
Jain, Yudhvir S., Delhi, India.
Jetha, Akbarali H., Bombay, India.
Jones, Winfield G., Jr, Boise, Idaho, U.S.A.
Joz-Roland, Michel, Sannois, France.
Kalnin, Daniel S., Toronto, Ont., Canada.
Karpel, Geoffrey, London.
Karpel, Lance S., London.
Kawasaki, Shizue, Tokyo, Japan.
Kerr, David J., Northcote, Auckland, New Zealand.
Kimura, Mariko, London.
Kingsley, Ann S., Sidmouth.
Kinoshita, Shigeyoshi, Osaka, Japan.
Kitney, Gordon T. J., Maidstone.
Klener, Kenneth S., Santa Monica, Ca, U.S.A.
Knutson, Donald S., Denver, Colo., U.S.A.
Kodaka, Katuyoshi, Tokyo, Japan.
Kothari. Rajan S., Bombay, India.
Lam, Freddy, Singapore.
Lam, Tat Hong F., Kowloon, Hong Kong.
Lam, Thao Shiou S., Singapore.
Lambley, Jenifer G., Hong Kong.
Langlois, Jean-Guy, Montreal, Que., Canada.
Laurie, Amanda, Bicester.
Lavinder, Ann N. L., Kuala Lumpur, Malaysia.
Lee, Doreen S. S., Singapore.
Lee, Sammy H. Y., Kowloon, Hong Kong.
Leigh, John E., Stockport.
Leong, Daniel K. T., Macau.
Leung, Lap-yan, Kowloon, Hong Kong.
Liccini, Mark L., Laurel, Md, U.S.A.
Lilley, Keith A., Pontllanfraith.
Littlejohn, Gordon H., Tunbridge Wells.
Lo, Philip Hing-Kwong, Hong Kong.
Lueking, Edward N., Costa Mesa, Ca, U.S.A.
Lynch, Mary C., Kildare, Ireland.
MacKellar, Christine H., Stafford.
Maitland-Kimzey, Gretchen, Santa Rosa, Ca, U.S.A.
Marriott, Stuart C., Stanmore.
Mayor, Norah, Diss.
Milne, Nigel P., London.
Miniati, Roberto, Rome, Italy.
Minowa, Shinichi, Gumma, Japan.
Mitchell, Simon J., Leeds.
Mojzes, Igor, Downsview, Ont., Canada.
Moore, Roderich R., Solihull.
Morgan, Richard J., Carlisle.
Morgan, William H., Carlisle.
Morris, Kelsey, Hayling Island.
Mourad, Huguette, Jeddah, Saudi Arabia.
Moury, Armand J., Brussels, Belgium.
Neale, Lorna, Gloucester.
Newton, Kevin S., British Columbia, Canada.
Ngai, Ken, Kowloon, Hong Kong.
Nithianandan Selladurai, Nithianandan, Schwenningen, W.Germany.
Nooten-Boom II, Apollonius, Kingsland.
Okayasu, Tetsuya, Tokyo, Japan.
O'Sullivan, Dennis J., Poole.
O'Sullivan, James, Boca Raton, Fla, U.S.A.
Ozawa, Chikako, Woking.
Pala, Suresh, Birmingham.
Parcel, Rodney F., Jr, Perris, Ca, U.S.A.
Parker, Michael A. J., Old Portsmouth.
Parks, Jeremy J., London.
Parr, Dorothy M., Toronto, Ont., Canada.

Pattni, Narendra P., Leicester.
Paxton, Jeremy M., Fordingbridge.
Peralta Pastor, Miguel, Barcelona, Spain.
Perrella, Loto, Barcelona, Spain.
Perren, Llewellyn J., Worthing.
Philipou, Philip, Byfleet.
Pickford, Michael G., Bicester.
Pitts, Carl C., Huntington Beach, Ca, U.S.A.
Podsiadly, Maria, Birmingham.
Polichar, Grace S., San Francisco, Ca, U.S.A.
Pomphret, Eric W., Salford.
Ponzano, Stefano, Rome, Italy.
Poultney, Alan M., Sandton, Transvaal, S.Africa.
Pouncey, Jean M., Solihull.
Price, Michael H., Sutton.
Pusey, Chikako, London.
Quincey, Mary E., Rugby.
Quinn, Patrick D., Miami, Fla, U.S.A.
Rajapakse, Rajapakse K. N. L., Ratmalana, Sri Lanka.
Riegler, Walter G., McGuire, N.J., U.S.A.
Robertson, Thorington B., Oakhurst, Ca, U.S.A.
Robinson, Stuart A., Norwich.
Robson, Ellen M., Nairobi, Kenya.
Ross, Robert J. C., Sharjah.
Rubin, Leon, Sr, Brussels, Belgium.
Rufli, Lisbet, Sollentuna, Sweden.
Sanchez-Lafuente Mariol, Jose, Barcelona, Spain.
Schlussel, Joseph L., New York, N.Y., U.S.A.
Schmid, Marlene, Rio de Janeiro, Brazil.
Seah, Stephen S. K., Singapore.
Seeger, Peter R., Wirral.
Shaw, Clive M., Odendaalsrus, S.Africa.
Shaw, Josephine N., Aspen, Colo., U.S.A.
Shima, Kiyohiko, Osaka, Japan.
Shimizu, Teruo, Kyoto, Japan.
Shimoura, Seisku, Hiroshima Pref., Japan.
Shiraishi, Makoto, Tokyo, Japan.
Shiwa, Haruki, Fukuoka City, Japan.
Shiwa, Seiichi, Fukuoka City, Japan.
Shone, Nicholas R., Ringwood.
Sinha, Purushottam, Agra, India.
Smith, Robert A., Shoreham-by-Sea.
Smith, Robert R., Westfield, N.J., U.S.A.
Smythe, Richard H., St Catherines, Ont., Canada.
Spence, John D., Thornton Dale.
Sultan, Rukhsana A., London.
Surgeoner, David R. H., Beaconsfield.
Suzuki, Takako, London.
Swain, Anthony P., Llandudno.
Swersky, Ann H., Ramat Hasharon, Israel.
Swersky, Barry R., Ramat Hasharon, Israel.
Taher, Tasneem A., Dubai.
Tanaka, Kentetsu, Tokyo, Japan.
Taylor, Alec E., Port Seton.
Thompson, H. D. R., Town of Mount Royal, Que., Canada.
Thompson, Reginald F., St Charles, Missouri, U.S.A.
Thompson, Reva E., St Charles, Missouri, U.S.A.
Thunas, Richard, Rugby.
Torres, Louis, Rego Park, N.Y., U.S.A.
Tracey, Neil J., London.
Trotter, Stuart M., Edinburgh.
Villars, Uif E., Stockholm, Sweden.
Walford, Michael J., Wickford.
Walker, Doreen M., Leigh-on-Sea.
Weeden, Richard G., Dorking.
Weil, Maurice K., Shreveport, La, U.S.A.
Weishaupt, Ulrich, Clermont, Qld, Australia.
Whitrow, Patricia A., Dunedin, N.Z.
Wickramasinghe, Upasena, Colombo, Sri Lanka.

Williams, Bruce M., Walla Walla, Wash., U.S.A.
Wootton, William J., Goring-by-Sea, Worthing.
Yenson Chu, Mabel, Kowloon, Hong Kong.
Yip, See Yin, Kowloon, Hong Kong.

GEM DIAMOND EXAMINATION 1979

Fifty candidates sat for the 1979 Gem Diamond Examination, of whom forty-two qualified, two with distinction. The following is a list of successful candidates arranged alphabetically.

QUALIFIED WITH DISTINCTION

Seal, Richard MacGregor Park, Bridlington.
Stern, Marion Judith, London.

QUALIFIED

Amoros Angel, Julio, Valencia, Spain.
Baldock, Edward James, South Wirral.
Bates, Adrian John, Sutton Coldfield.
Bennett, Russell K., Cheltenham.
Biernet Albaladejo, Rosario, Barcelona, Spain.
Byfleet, Anne Patricia, Doncaster.
Catala Marti, Joaquin, Valencia, Spain.
Celades Colom, Roberto, Barcelona, Spain.
Chang, He Ok, London.
Davis, Jonathan Vincent, Edgware.
Domenech Plo, Juan, Valencia, Spain.
Faulder, John, Purley.
Girbes Faba, Adolfo, Valencia, Spain.
Haugh, Breda, London.
Hitchen, Alan, Walsall.
Hodgkinson, John Alan William, Glasgow.
Holmes, Graham John, Tenterden.
Houlgrave, Peter Baron, Rickmansworth.
Israel, Nigel Brian, London.
Jerome, Philip S. Woodford Green.
Jimenez Tormo, Vicente, Valencia, Spain.
Lander, Charmian Elizabeth Mary, London.
Lewis, Ian Rhys Morien, Sheffield.
Lyall Grant, Ian Hallam, Dartmouth.
Mayling, Clifford George, Slough.
Moller Duran, Rodolfo, Barcelona, Spain.
Noble, Patrick, Cleckheaton.
Piech, Olwen, Bushey Heath.
Poel, Melvin Christopher, Solihull.
Proctor, Sarah-Jane L., London.
Ros-Jones, Catherine Anne, South Ascot.
Saez Perez, Ma Alicia, Barcelona, Spain.
Seoane Garcia, Ma Encarnacion, Valencia, Spain.
Sosna, Boris, Wembley Park.
Tattersall, Simon, London.
Taylor, John, Chislehurst.
Turner, Michael James, Chester.
Turner, Michael James, Sheffield.
Vargas Perez, Manuel de, Barcelona, Spain.
Weissler, Chaggai, London.

EXAMINATIONS IN GEMMOLOGY 1979

In the 1979 Examinations in Gemmology a total of 1239 candidates entered for the two Examinations.

There were 748 candidates who sat for the Preliminary Examination, of whom 363 passed. The Rayner Prize in the Preliminary Examination was not awarded this year.

For the Diploma Examination, 491 candidates entered (one more than the record number for 1977), of whom 198 passed, including ten with Distinction—a marked improvement on recent years. In the opinion of the Examiners, Dr Roger R. Harding (London) should be congratulated for submitting the best set of papers, but no candidate reached a sufficiently high standard to warrant the award of a Tully Memorial Medal.

The following are lists of successful candidates, arranged alphabetically.

DIPLOMA EXAMINATION

QUALIFIED WITH DISTINCTION

Glorioso, John T., Baltimore, Md, U.S.A.
Harding, Roger Robertson, London.
Hidaka, Masano, Silver Spring, Md, U.S.A.
Kimura, Takashi, Tokyo, Japan.
Leith-Smith, Jean Elizabeth, Hong Kong.
Lindsay, Kathryn Sharon, Salisbury, Rhodesia.
Shimaoka, Mitsuaki, Osaka, Japan.
Sweaney, James Leo, Santa Monica, Ca, U.S.A.
van Lieu, Mai, Brussels, Belgium.
Vashishtha, Shekhar, Delhi, India.

QUALIFIED

Abayasingha, Amaranath, Colombo, Sri Lanka.
Akiyama, Masashi, Hokkaido, Japan.
Ali, Syed J. A., London.
Andersson, Arild, Oslo, Norway.
Asagai, Osamu, Osaka, Japan.
Avasia, Rohinton Kersasp, Bombay, India.
Bahl, Neela, Bombay, India.
Bahl, Sujata, Bombay, India.
Barker, Maxwell, Sandton, S. Africa.
Barot, Nandkishor Raojibhai, Nairobi, Kenya.
Beech, Trevor Alan, Blackpool.
Beeks, Johannes F. M., Valkenswaard, Netherlands.
Berggren, U. B. Marie, Oslo, Norway.
Blondel, Nigel Capener, Guernsey, C.I.
Bontekoe, Maryke, Steenwyk, Netherlands.
Borreda Perez, Federico, Paterna, Spain.
Boyd, Warren Frederick, Willowdale, Ont., Canada.
Bradoch, Robert V., Tokyo, Japan.
Breden, Robert John, Liverpool.
Brohier, Kenneth Gordon, Wirral.
Bromwich, Graham Stanley, Reigate.
Brownlow, Arthur Hume, Needham, Mass, U.S.A.
Bürk, Ralph, Keltern, W.Germany.
Callaghan, Gerard Joseph, Liverpool.
Castello, Torres, Ma Dolores, Valencia, Spain.
Chadwick, John Harlow, Clacton-on-Sea.
Charlesworth, Anthony Robert, Southport.
Cheung, Kai Yuen, Hong Kong.
Chosokabe, Yukuto, Nagoya, Japan.
Clark, Alan Joseph, Croydon.

Clarke, Donald Hugh, Marbella, Spain.
Cleiman, Catherine Griffin, Silver Spring, Md, U.S.A.
Costell Ibanez, Manuel, Valencia, Spain.
Cowling, Denise Elizabeth, Northampton.
Crossland, Julie Hall, London.
Cukier, Gerard, London.
da Costa, Michael Stuart, Toronto, Ont., Canada.
Darcy, John Patrick, Dun Laoghaire, Ireland.
de Knecht, Petrus Bernardus, Strijen, Netherlands.
Derry, Catherine Eleanor, Nottingham.
Deste, Roberta Aline Elissa, London.
Dolz Adell, Carmen, Valencia, Spain.
Douglas, Brian Sydney, Toronto, Ont., Canada.
Douglas, John James, Cardiff, N.S.W., Australia.
Dupuis, Ronald J. R., Toronto, Ont., Canada.
Edmunds, Roger Alan, Accrington.
Esteve Fernandez, Jaime, Barcelona, Spain.
Fägerstig, Björn Olot, Saltsjöbaden, Sweden.
Fagg, Primrose Mary, Wallington.
Farnham, Julian Reginald, Haslemere.
Fernando, Bathıya Dhammika, Colombo, Sri Lanka.
Franks, John Wilson, Altrincham.
Franks, William, Bowdon.
Fung, Tsee Hung, London.
Geikler, Patricia Jean, Sewickley, Pa, U.S.A.
Gion, Hirotaka Zuiho, Sapporo, Japan.
Glenister, David Athol, Stellenbosch, S.Africa.
Good, Amanda Grahame, London.
Gower, Wendy, Brisbane, Qld, Australia.
Green, Edward Maurice, London
Green, James Edward Wooldridge, Albrighton.
Groenenboom, Peter, Arnhem, Netherlands.
Hartzman, Mark J., Bronx, N.Y., U.S.A.
Hayashi, Hidenori, Tokyo, Japan.
Herbert, Janet Elizabeth, Northampton.
Hernandez Ordonez, Arturo, Valencia, Spain.
Hirst, Rosalind, Johannesburg, S.Africa.
Holdsworth, Ian, Stafford.
Howarth, Janet, Bolton.
Ibrahim, Mamat Mukhtar bin, Ipoh, Perak, W.Malaysia.
Inamdar, Geeta, Newmarket, Ont., Canada.
Jayawardena, Palihawadana A. J. L. P., Colombo, Sri Lanka.
Jayendran, Ariacutty, Colombo, Sri Lanka.
Jealouse, Roy George, Woore, Crewe.
Jennings, Harold F., Jr., Roanoke, Va, U.S.A.
Jibiki, Emiko, Tokyo, Japan.
Jones, Michael Derrett, Flyford Flavel, Worcs.
Jørgensen, Svend Erik, Norborg, Denmark.
Julia Miralles, Nuria, Barcelona, Spain.
Kaleel, Ameena, Mt Lavinia, Sri Lanka.
Kimura, Shinichi, Kyoto, Japan.
King, Larry G., Grand Prairie, Tex, U.S.A.
Kita, Keiko, Osaka, Japan.
Kitahara, Nobuko, Kobe, Japan.
Kizirian, Vahe, London.
Kleibrink, Marion, Middelburg, Netherlands.
Ko, Yiu Wai Richard, Hong Kong
Kohara, Sachiko, Tokyo, Japan.
Kojima, Michinaka, Tokyo, Japan.
Lalonde, Ernest Richard, Bangkok, Thailand.

Langeraar, R. C., Oegstgeest, Netherlands.
Lee, Dennis Philip, Leatherhead.
Lien, Jan Peter, Norrköping, Sweden.
Lurie, Joseph, Randburg, S.Africa.
Machlup, Peter Mark, Johannesburg, S.Africa.
Melhus, Per Kristian, Skudeneshavn, Norway.
Midgley, Ronald Charles, Leeds.
Minster, David, Pretoria, S.Africa.
Moody, Kenneth Olaf, Cheltenham.
Moore, Roderich R., Solihull.
Morimoto, Towa, Kyoto, Japan.
Munas, Carmel Leonie, Morden.
Mundin, Kenneth William, Leicester.
Murray-Jones, Pauline Ann, Hong Kong.
Nathanson, Daniel Philip, London.
Neo, Nobushige, Osaka, Japan.
Nieto Reynoso, Luis, Barcelona, Spain.
Nilsen, Tore, Oslo, Norway.
Nisbet, Alistair Scott, London.
Nishino, Tomoji, Tokyo, Japan.
Norberg, Rolf Bernhard, Drammen, Norway.
Nott, Shelley, West Harrow.
O'Donnell, Francis Xavier Desmond, Liverpool.
Okayasu, Kuni, London.
Onozawa, Katsumi, Tokyo, Japan.
Osborne, Annie W. S., Hong Kong.
Ou Yang, Chiu Mei, Hong Kong.
Palmer, Joanna Grace, Guildford.
Pastor Alapont, Juan Jose, Catarroja, Spain.
Perera, Ajith G. H. P., Mt Lavinia, Sri Lanka.
Perry, Charles John, London.
Pietruska, Julia Elizabeth Jane, London.
Pluckrose, William Henry, Herne Bay.
Pomar Llado, Ma Antonia, Barcelona, Spain.
Puiggali Fabregas, Jose Ma, Barcelona, Spain.
Pulle, Amara Nilkamal Sirima, London.
Pulle, Bernard Terence Bastian, London.
Rakke, Brit, Oslo, Norway.
Rasborn, Jeannine Madeleine, Hong Kong.
Roos, Raimo Helmer, Nairobi, Kenya.
Roper, Thomas Charles, Glenorchy, Tas., Australia.
Rowe, Regina, Torquay.
Rufli, Lisbet, Sollentuna, Sweden.
Salakian, Silva, Salisbury, Rhodesia.
Samarajiwa, Eulalie M. S. K., Sri Lanka.
Santos, Americo Sancho Dos, L. Marques, Mozambique.
Scells, Gerald Victor, Collinsville, Qld, Australia.
Schilling, Andreas Georg Wilhelm, Stuttgart, W.Germany.
Schippers, Maria Johanna Carolina, Velp, Netherlands.
Schotborgh, Ilse Hedwig, Willemstad, Curaçao, N.A.
Seed, Moira Jean, Toronto, Ont., Canada.
Senaratne, Upali Nimal, Nugegoda, Sri Lanka.
Shelley, Jessica, Toronto, Ont., Canada.
Shima, Kiyohiko, Osaka, Japan.
Sinclair, Netta, Enfield.
Smart, Denis Owen, Kettering.
Smit, Neil Conrad, Pietersburg, S.Africa.
Sorolla Maupoey, Marinela, Valencia, Spain.
Streight, Stewart Gordon, Mississauga, Ont., Canada.
Styles, Jonathan Appleby, Enniskillen, N.Ireland.
Taank, Ashok P., London.
Takahashi, Ikuo, Kyoto, Japan.
Takahashi, Junko, Saitama, Japan.
Tan, Carmela, Hong Kong.

Tarbuck, William Benjamin, Manchester.
Tateishi, Masateru, Tokyo, Japan.
Taylor, John Bruce, Brisbane, Qld, Australia.
Teraura, Shin, Yoshimo, Japan.
Theobald, Robert, Leighton Buzzard.
Thompson, H. D. R., Mt Royal, Que., Canada.
Thompson, Sharon Elaine, Glendale, Ca, U.S.A.
Thornton, Peter, Newcastle, N.S.W., Australia.
Tilley, Melinda Vera, Hong Kong.
Tindall, Anthony Peter, Burley-in-Wharfedale.
Truyens, Simone Maria Caecilia, Schoonhoven, Netherlands.
Vale, Shelagh Vivienne, Exeter.
van der Geest, Eduard Ernst, Heemstede, Netherlands.
van Roojen, Tobias, Amsterdam, Netherlands.
Vazquez Pavon, Rafael, Valencia, Spain.
Velthoven, Nicolaas, Bergschenhoek, Netherlands.
Verch, Ulla, London.
Verma, Rajiv, Dehra Dun, India.
Vonk, Philippe André Jean, Rotterdam, Netherlands.
Watson, Timothy Lincoln, Cape Town, S.Africa.
Watts, Terrence Joseph, Newcastle-upon-Tyne.
Wechgelaar, Didrich Johannes H., Zaandam, Netherlands.
West, Clive Graham, London.
Wezel, Renée, Maasland, Netherlands.
Whittaker, Kenneth Raymond, Widnes.
Wilson, Hiroko, Hong Kong.
Winter, Julie, Fetcham.
Withycombe, Darroch Blair, St John's, Newf., Canada.
Wright, Stephen Richard, London.
Yamagishi, Shoji, Kanagawa, Japan.
Yokowo, Naoya, Tokyo, Japan.
Yost, Dara Elizabeth, San Diego, Ca, U.S.A.
Zelley, Michael John, Bishop's Stortford.
Zimmer, Alvin F., Tucson, Ariz., U.S.A.

PRELIMINARY EXAMINATION

QUALIFIED

Abdul Majeed, Mohamed Sulltanul A., Colombo, Sri Lanka
Aiiso, Miki, Tokyo, Japan.
Amasaki, Tetsuya, Osaka, Japan.
Ammerlaan, George Martin, Rotterdam, Netherlands.
Anderson, Joseph Maxwell, London.
Anderson, Fred Birger, Oslo, Norway.
Anderson, Mona, Oslo, Norway.
Anver, Mohamed Shibly, Matara, Sri Lanka.
Apall-Olsen, Martha Beate, Lopik, Netherlands.
Archer, Kenneth Argen Goulden, London.
Asakawa, Mamoru, Fukuoka, Japan.
Askew, Mark Alan, Bournemouth.
Askey, Doria Leslie, Burlington, Ont., Canada.
Athauda, Weerasinha A. N. S., Kandy, Sri Lanka.
Attwood, Alan Stuart, Blandford Forum.
Aylward, Peter Seymour, Westonaria, S.Africa.
Bacon, John Edward Thomas S., Cape Town, S.Africa.
Badger, Anthony John Charles, High Wycombe.
Baird, Myra Letricia, Auckland, N.Z.
Balthasar, Greta, Bournemouth.

Bannon, Lewis A., Baton Rouge, La, U.S.A.
Barlow, Peter Charles, Kidderminster.
Benham, Michael Frederick, Chatham.
Bennett, David William, London.
Bennett, Elaine, Stockport.
Berkowitz, Joseph, Toronto, Ont., Canada.
Best, Reina Unita, Liverpool.
Bill, David Nigel, Cannock.
Bjørner, Bo, Bagsværd, Denmark.
Blatch, Kim, Newhaven.
Bongers, Johannes Theodorus H. M., Schoonhoven, Netherlands.
Bonisoli, Giovanna, London.
Bramwell, William John, Durham.
Brown, James Edward, Louth.
Browne, Jess Elizabeth, Dalkeith, W.Australia.
Buhl, Robert Anthony, W.Vancouver, B.C., Canada.
Bullock, Gail Kathleen, Walsall.
Burnett, Julie L., Nottingham.
Butterfield, Ernest B., Albuquerque, N.M., U.S.A.
Camelinat, Valma Mary, Jersey.
Campbell, Sandra, Venice, Ca, U.S.A.
Cannon, Jayne Rosemary, Spalding.
Carre Pan, Gabriel, Barcelona, Spain.
Castellote Mas, Guiliermo Fernando, Barcelona, Spain.
Charlton, Maurine, Scarborough, Ont., Canada.
Chauhan, Rajendra, London.
Cheng, Elaine, Sheffield.
Cheung, Veronica, Hong Kong.
Chin, Chong-Meng, Singapore.
Chiu, Carol C., Hong Kong.
Chu, Miu Hing, Hong Kong.
Clare, Vanessa Jayne, St Albans.
Clements, Julie Ann, Erith.
Clibbens, Peter Christopher, Ruislip.
Coelho, Susan Osborn, Richmond.
Cook, Graham Andrew, Dundee.
Coombes, Martin Lewis, Crewe.
Cooper, Judith Margaret, Colchester.
Cornwell, Russell John, Bury.
Courtliff, Steven Paul, Ford, Liverpool.
Coward, Fiona, Ringwood.
Cramer-Langoha, Monique Marie Edouard, Verviers, Belgium.
Cuadras Pons, Montserrat, Barcelona, Spain.
Cudworth, Patricia June, Mansfield.
Culpin, Ivor David, Weston-super-Mare.
Darracott, Britt-Marie, London.
Dawson, Jane, London.
Deascenti, James Harry, Accrington.
de Bure, Ursula, Hong Kong.
de Grefte, Glaudina Joanna Maria, Tilburg, Netherlands.
de Mey, Nigel Robert, Dordrecht, Netherlands.
Derry, Catherine Eleanor, Nottingham.
Deste, Roberta Aline Elissa, London.
Diack, Adrian Lindsay, Eastbourne.
Dickey, Marlin L., Alta Loma, Ca, U.S.A.
Dickson, Amanda Jane, London.
Dolphin, Margaret, Birmingham.
Donohoe, Edward Groves, London.
Eger, Christine Ryon, London.
Eide, Gry Vibeke, Oslo, Norway.
Emms, Eric Charles, Brentwood.
Fairlie, Alison Helen, Cheltenham.
Faizer, M. S. M. A., Idar-Oberstein, W.Germany.
Falkus, Geoffrey Charles, Woodford Green.
Faux, Teresa Mary Frances Ann, Winslow.
Ferguson, Deborah Anne, Pirbright.
Fernandaz, Patricia, London.
Fernando, Warnakulasooriya Justin, Columbo,Sri Lanka.
Forbes, Maureen Rose, St Albans.
Ford, Hermione Dolores, Hereford.
France, Jeremy Peter, Birkenhead.
Frankel, Markham Joel, London.
Franks, William, Bowdon.

Froeling, Robertus Maria A.G., Schoonhoven, Netherlands.
Fünfschilling, Jakob Heinrich, Rünenberg, Switzerland.
Furse, Anna Antonia, London.
Gabriel Pascual, Jose, Barcelona, Spain.
Gallardo Bravo, Matilde, Barcelona, Spain.
Gajanayake, Don Stanley Dananda, Moratuwa, Sri Lanka.
Garcia Hector, Julia, Barcelona, Spain.
Garcia Nebot, Manuel, Barcelona, Spain.
Garfinkel, Derek Andrew, Pretoria, S.Africa.
Giacone, Anna, Norwich.
Gimple, Michael Dennis, Rochester, N.Y., U.S.A.
Glorioso, John T., Baltimore, Md, U.S.A.
Goatly, Andrew Martin, London.
Goldberg, Reuven, London.
Goldstein, Sam, New York, N.Y., U.S.A.
Gomis Sorribas, Juan, Barcelona, Spain.
Gomis Sorribas, Luis, Barcelona, Spain.
Goodman, Mark, London.
Gordon, C. R. I., Brisbane, Qld, Australia.
Gorham, Josephine Eva, London.
Graus, Jeremy Ze'ev, London.
Gray, John Stephen, Pontefract.
Green, Richard Douglas, Dudley.
Greene, Horace Arthur, Elmhurst, Ill., U.S.A.
Greeson, Gordon, Carmel, Ca, U.S.A.
Groom, Peter John, Dunstable.
Guinot Sierra, Agustin Ignacio, Barcelona, Spain.
Guinot Sierra, Carlos Ma, Barcelona, Spain.
Gupta, Arun Kumar, Toronto, Ont., Canada.
Hall, Michael Geoffrey, Birmingham.
Hammad, Hammad Ahmad, Peshawar, Pakistan.
Hanataka, Jitsuo, Kobe, Japan.
Hardewall, Per, Geneva, Switzerland.
Harding, Bruce L., Holden, Md, U.S.A.
Harris, Edward, Grimsby.
Harrison, Kathryn, Doncaster.
Hata, Kenichi, Kyoto, Japan.
Hausman, Karen, Willowdale, Ont., Canada.
Hayakawa, Chieko, Osaka, Japan.
Heath, David Graham, Worcester.
Heeney, Barbara Ann, Hong Kong.
Helne, Mary K., Rome, Italy.
Herriott, William Alexander, Winchester.
Hetherington, George, Ashton-under-Lyne.
Hettena, Andre, London.
Hinde, Rosemary Gill, Hong Kong.
Hiraoka, Satoshi, Tokushima, Japan.
Hirokawa, Sumiko, Tokyo, Japan.
Ho, Chow Kee, Singapore.
Hodge, Peter, Christchurch, N.Z.
Holahan, Denise Mignon, Johannesburg, S.Africa.
Holahan, Michael John, Johannesburg, S.Africa.
Howden, Mark Frazer, London.
Huizinga, Jeroen, Rotterdam, Netherlands.
Hunger, Giselle Hulda, Lugano, Switzerland.
Inatsugi, Shiko, Osaka, Japan.
Indrebø, Solveig, Oslo, Norway.
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Iobal, Tahir, Peshawar, Pakistan.
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LETTER TO THE EDITOR

From Mr R. KEITH MITCHELL, F.G.A.

Dear Sir,

The paper on Visual Optics in the January issue of the *Journal*[1] contains some fundamental errors of fact which I, as Mr Hodgkinson's instructor in 1960-61, find surprising, and feel should be corrected if and when he again lectures on the subject. Personally, I experimented pretty thoroughly with the method in 1936, but came to the conclusion that, although spectacular, the effects seen were too empirical and unreliable to warrant publication. The January paper does nothing to make me revise that opinion.

There is nothing new in the idea of squinting through a faceted stone held close to the eye. Bauer, Dieulafait, Kluge and Brard[2] all mention it, the latter as early as 1808. It is noticeable that none of these eminent writers claim more for it than the detection of the presence of birefringence.

Mr Hodgkinson's paper contains more than one basic misunderstanding. He twice says that the greater separation of pairs of spectra, and their increased length, seen through facets nearer the girdle, is due to the light travelling a longer distance through the gem. This just is not so. In the majority of stones light entering by facets near the girdle will have a shorter path through the stone than will light entering near the culet. But the important point is that this increase in separation and spectrum length is due entirely to increases in the angle of incidence both at the point of entry and at the underside of the table facet. These changes are directly due to the fact that facets are cut steeper the further they are from the culet. At no point does the author mention an angle of incidence; indeed he ignores Snell's laws of refraction completely.

Later, a quadrilateral arrangement of four images, 'seen' through a tourmaline, is illustrated, and it is assumed that they provide an example of the multiple RI (Kerez) effect which I first reported.[3] One of the two laws of refraction states that

1. J. Gemm., 1979, XVI (5), 301-9.—Ed.
2. Bauer (M. H.), *Edelsteinkunde*, 1896; Dieulafait (L.), *Diamants et Pierres Précieuses*, 1871; Kluge (K. E.), *Handbuch der Edelsteinkunde*, 1860; Brard (C. P.), *Traité des Pierres Précieuses*, 1808.
3. J. Gemm., 1967, X (6), 194.—Ed.

the incident ray, the normal at the point of incidence, and the refracted ray must be in one plane. This precludes the possibility of a rectangular display of images from any one facet. I suggest that the four images illustrated are the result of camera, stone, or light-source movement during exposure. Did Mr Hodgkinson take the elementary precaution of checking this stone (and others) by refractometer? I still have one of my original specimens of tourmaline which shows the multiple RI effect and can assure him that it gives only two spectra for each facet.

Early in the paper we are told that RI can be assessed only from images 'nearest the centre of the stone'. Later he illustrates a peridot in which these facets do not give the required effect, and elects to use the fourth row instead. This is supposed to be a test for an unknown stone. Why on earth should the user suddenly start selecting spectra from a different set of facets to obtain his identification?

Throughout the paper the author has taken *known* stones and tried to prove them by stone-to-eye methods. There are, however, four variables; the unknown RI of the stone, the angle of incidence (controlled by that of the facet in relation to the light source), the position of the optic axis or axes in a birefringent stone, and the size of the stone. With higher RI it is necessary to tilt the stone to see the pairs of spectra. This changes the angle of incidence and must invalidate the result. The Crowningshield & Ellison paper in *Gems & Gemology* for Winter 1951/2[4] falls into the same error of dealing with effects seen through *known* stones. That paper is also a little vague in that it sometimes talks of 'results as expected' instead of describing those results. I find it significant that a gemmologist of Robert Crowningshield's undoubted ability has never followed this close-vision method through.

The authors of neither paper appear to have noticed another phenomenon which I saw more than forty years ago. If a round stone (it works with other shapes, but is more difficult to manipulate) is rolled on its girdle, and a single pair of spectra is watched throughout a complete rotation, it will be found that the two spectra slowly girate around each other. Observing this obviates the need for the use of polaroid to separate closely aligned spectra as suggested in the American paper and as copied by Hodgkinson. Way back before the War I experimented hopefully with the idea that this particular phenomenon might allow me to distinguish between uniaxial and biaxial stones, but unfortunately both spectra of a pair appear to move, even in uniaxial stones.

In the Visual Optics paper the later illustrations of the spectra seen in cubic zirconia and in diamond are not a fair comparison. The ^{3}Z picture is of a 'flared' spectrum obviously obtained by tilting the stone. That of the diamond spectral images is taken without such tilt. It is possible that the method does provide a test between these two stones, but it must be applied identically to both. A similarly flared spectrum can be obtained from diamond if it is tilted enough.

Yours etc.

R. KEITH MITCHELL.

5th October, 1979. Orpington, Kent.

4. Gems Gemol., 1951, VII (4), 120-4.—Ed.

CORRIGENDA

In J.Gemm., 1979, XVI(5), on p.319 (in l. 20) for 'west-south-west' read 'west-north-west', and on p.320 (in l. 17) for 'Black Bridge' read 'Black Ridge'.

GEM TESTING EQUIPMENT

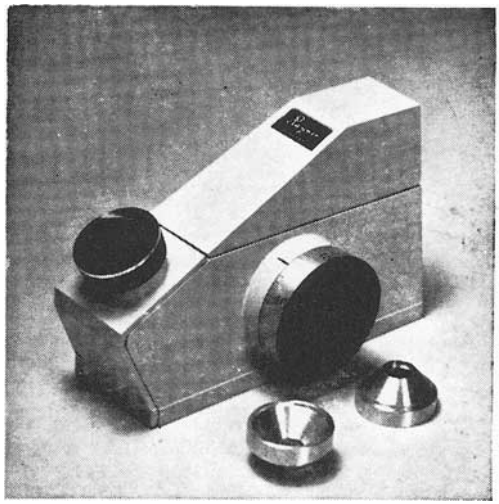

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Notes for Contributors

The Editor is glad to consider original articles shedding new light on subjects of gemmological interest for publication in the *Journal.* Articles are not normally accepted which have already been published elsewhere in English, and an article is accepted only on the understanding that (1) full information as to any previous publication (whether in English or another language) has been given, (2) it is not under consideration for publication elsewhere and (3) it will not be published elsewhere without the consent of the Editor.

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Although not a mandatory requirement, it is most helpful if articles are typed (together with a carbon copy) in double spacing on one side of the paper, with good margins at sides, top and foot of each page. Articles may be of any length, but it should be borne in mind that long articles are more difficult to fit in than short ones: in practice, an article of much more than 10 000 words (unless capable of division into parts or of exceptional importance) is unlikely to be acceptable, while a short note of 400 or 500 words may achieve early publication.

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OF GREAT BRITAIN
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NOTES FROM THE LABORATORY

By A. E. FARN, F.G.A.

The Gem Testing Laboratory, London Chamber of Commerce and Industry

1. A Stone Cold Cert

The late Professor Tolansky, famous for many things, one of them being his dictum that the only rule which can be applied to diamonds is that they are all different, is followed by Dr Gordon Davies, scientist at the Wheatstone Physics Laboratory, King's College, Strand, who agrees basically but does put them into broad categories in his book *The Chemistry and Physics of Carbon* (Vol. 13, 'Optical properties of diamond').

Most of us know that, whilst diamond is a singularly pure substance having very little impurity indeed, that impurity when present is nitrogen. Diamond is unique in its simplicity of chemical composition, hardness and rarity. We all know, from facts recorded in articles, books and films upon the subject, what great expenditure goes to produce 1 carat of gem diamond—probably paralleled only by the enormous output of oysters necessary to produce one round unblemished pearl of fine orient. Millions of

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oysters are destroyed annually by predators (starfish). Most oysters do not produce a pearl at all: those that do, produce a poor-coloured thing of irregular shape. One can see that rarity is indeed an aspect of a gemstone, be it pearl or even diamond.

Diamonds to the lay public mean wealth, glamour and all the trappings which go with wealth and glamour. The public at least know of diamonds and of the consequent value as a status symbol of having one as big as possible (or as your friendly tax man will allow!).

Because of the constant advertising of diamonds being the jeweller's best friend, one-upmanship inevitably follows in achieving even bigger, better and cleaner diamonds for the public to buy; and the demand is for a certificate. There seems to be a sort of magic about the possession of a piece of paper which states degrees of purity and colour. This sort of certification of diamond, however, is *not* gemmology; it is rather a skill acquired by the constant handling and examination in good lighting conditions of one only variety of gem, namely colourless diamond. There is no doubt at all about the absolute skills of some diamond graders. They can see with a 10× lens such minute imperfections that even when they are pointed out and carefully indicated for me I can seldom find them immediately. I have had some very salutory lessons at the hands of these highly skilled people and am left in no doubt that this is a very particular skill indeed and not easily acquired.

This demand for cleanliness, clarity and certification (now termed the three Cs by A. E. Farn) is an increasing symptom of modern demand. Diamonds are always news, particularly large ones, preferably colourless or of a distinct colour.

That imitation is a form of flattery is another oddly apt phrase when considering the gem world. Returning but briefly to pearls, the imitation of real pearls by cultured pearls for a time spoiled the pearl market, but pearls eventually (certainly today) have regained lost ground, because of (possibly) inflation, shortage of cultured pearls due to contaminated waters, etc., and a desire by newly rich people to acquire something rare and natural.

In a like manner diamonds have attracted the synthesizers and the 'improvers'. Laser drilling to remove black spots and bombardment in atomic piles to impart colour are two aspects now faced by the gemmologist in the laboratory. Not too long ago a yellow diamond or a brown diamond was very difficult to sell. When

irradiation was more or less successfully achieved *circa* the 1950s, stronger, harder, colours were produced, and from then onwards (apart from radium-treated stones) we were faced with the detection of treatment in coloured diamonds.

The basis of modern gem testing was firmly laid by the work of B. W. Anderson and C. J. Payne in their early pioneering days, very shortly after the slump years around 1927-31. Until then it is amazing to realize that no precise measurement in Ångström units had been published of gemstones with the exception of the letter from Professor (then, not yet Sir) A. H. Church in 1866 to the editor of the *Intellectual Observer**, upon his findings in the examination of pleochroic minerals and salts. In this Church mentioned seven bands seen in zircons colourless and coloured, heat-treated and natural, as well as the bands seen in almandine garnet. Strangely, he never followed it up, probably being fully engaged upon other activities. The use and *method of use* of the spectroscope, e.g. the attainment of a decisive spectrum in a ruby in gem testing, was first postulated by C. J. Payne, who partnered B. W. Anderson in those early formative days. Practically every gem absorption-spectrum measurement we rely upon today stemmed from the work of these two early gemmologists, who were both qualified scientists as well. There can never be sufficient praise and appreciation by us ordinary gemmologists for the foundations so well and truly laid by these two English pioneers. In this changing shrinking world it is good to look back and take the opportunity in *Notes from the Laboratory* to say again 'Thank you for your work'.

As the new technique of neutron bombardment in an atomic pile and the subsequent annealing by heat of the irradiated stones produced exciting new colours, so the demands grew for such stones. Where there is a lot of money represented in a very small article, so the temptation to obtain some of it opens the path of chicanery and deceit. So too forms the queue to have stones tested and certified—this time the emphasis of the three Cs is on *cleanliness,* and *colour certification*—and the *colour,* is it natural?

We have known for many years that, in brief, the irradiation of diamond and its subsequent annealing causes damage, the damage being signposted by a line at 5920Å, sometimes accompanied by lines at 4980/5040 with 'Cape series' lines at 4780

*Micro spectroscope investigations, *Intellectual Observer,* 1866, 9, 292.—Ed.

and 4155Å. We have known from examination of these lines (in our laboratory and others) that heat at room temperature increased by transmission of light through a diamond undergoing spectroscopic examination drives off the faint but distinct line at 5920Å. In our laboratory B. W. Anderson tried many times to restore/sharpen this fugitive line by cooling the diamond. Given time we would leave a diamond in the safe overnight, come into the lab in the morning with fresh eyesight, rig up the spectroscope and our 500 watt lighting and look quickly to find the line. Usually B. W. A. spotted most quickly: he was uncannily perceptive in the blue end of the spectrum, as well as at 6500-6800Å. He tried purchasing frozen carbon monoxide and carried it in a brief case all frosted up by taxi to our laboratory. We never did get good results, due to insufficiently low temperature, inadequate insulation and lack of technique and know-how on this side (the cold side), and insufficient funds. Kenneth Scarratt has already written of our later achievement of low-temperature spectroscopic examinations (J. Gemm., 1979, XVI (7), 433-47) and these notes are merely by way of filling in some background details.

Much was written by B. W. Anderson on the classsification of diamond and upon line systems in the fluorescence spectra of diamond (J. Gemm., 1962, VIII (5), 193-202, and 1963, IX (2), 44-54). When he retired in 1971, we had a fair understanding of the nature of treated diamonds and the characteristics to look for. Equally, thanks to his early endeavours we enjoy a very strong accord with other world-wide laboratories and exchange notes and information for mutual protection. There have been cases in recent history of coloured diamonds being variously described by experts. Some, of course, are genuine mistakes, due to lack of experience: others we fear can be less happily explained. We have been continually aware of this and not entirely happy at times when we have *not* issued a certificate due to questionable interpretation of the characteristics of a diamond as far as we could obtain them with the facilities then at our disposal.

Fortunately for us we established a happy relationship with workers researching irradiation damage in diamond and made contact with them at University of London King's College (Strand). Their method of cooling diamond was copied by us with their assistance in a fairly simple form. Basically it is a Dewar (thermos) flask holding 25 litres of liquid nitrogen, which is turned into gas by

a 'boil off' system. The cold gas flows through insulated flexible tubing to cool the diamond mounted on a special holder in a vacuum tube—this prevents frost occurring on the diamond, which could impede light transmission. The whole system is built on an optical bench to facilitate focusing in line. One end constitutes a cold light (halogen) light-source and heat shield, with a warm-up rheostat built in to avoid surge. Through a lens the light is focused onto and through the girdle of the diamond, table facet parallel to floor. The emergent light is focused again by an equidistant second lens onto the slit of a Beck 2458 prism spectroscope clamped in line at the far end of the optical train.

This added refinement to gem testing is a most useful addition in the continuing struggle by the gemmologist for truth. We have positive proof in cases of evanescent 5920 lines at room temperature in treated diamonds becoming fine sharp and clear thus proving 100% conclusively a treated stone.

There have in the past year been articles in newspapers based on extracts from erudite papers (quoted out of context) by scientists publishing their new findings, and undoubtedly there will be an occasional treated diamond which causes trouble, but I would think that 99% of treated stones tested will be proved beyond doubt: of the small remaining portion of 1%, I should imagine that most will be detected by cooling methods and, failing that, a print-out chart from an infrared photospectrometer. Despite the heat generated by some diamond dealers' reactions on reading scare headlines in the daily press (and I have suffered their vociferous protestations), I would say that our advice to them is—'Cool it!'.

[*Manuscript received August, 1978: revised October, 1979**]

2. The Lennix Synthetic Emerald

Quite early in 1979 I was paid a courtesy visit by the husband of Mrs C. Bartolo, F.G.A., of Rhodesia. I was shown some small green crystals said to be a new synthetic emerald currently manufactured by a friend, who is a chemical engineer, prospector and something of a mineralogist. Would I like to examine them?

*Although received in 1978 it was most unfortunately mislaid and was slightly adapted for its long-delayed publication.—Ed.

They were offered as specimens for the Laboratory collection. I was both pleased to have them and grateful that we were considered of sufficient merit to warrant the gift and the information. My contacts with fellow gemmologists in Rhodesia have been most cordial since we understand now the position of chromium as a criterion for emerald, and an accord has developed from this matter.

At international gemmological conferences we have had very interesting résumés of the mining and prospecting scenes in both South Africa and Rhodesia by their geologists. The names of the adjoining regions being synonymous to me with rubies, emeralds, grossular garnets, tanzanite, etc., a new *synthetic* emerald emanating from that source seemed unusual, to say the least. In the past I was asked by the editor of the then popular monthly, *The Gemmologist,* to write a series on Verneuil synthetics and the then new to us Carroll Chatham synthetic emerald. I replied that it had all been done before very competently by my own colleagues, B. W. Anderson and Robert Webster. I was told it would always be new and news to some, and that not every budding gemmologist read B. W. Anderson or R. Webster. So let us hope that familiarity has not bred contempt and that some gemmologists will find interest in the details of this new synthetic emerald.

I have not grown blasé towards practical gemmology despite many years of practical application. Because of the many changes taking place in our Laboratory whether of staff, venue, outlook, commitments, etc., I find myself less and less involved in actual practical gemmology except for pearls. I decided to do some gemmology for a change—at least that *was* my intention. Which brings me to the end of this preamble, and a suggestion that above my paper- and pearl-strewn workbench I should have a sampler suitably sewn. It should read 'The road to Hell is paved with good intentions.' Last June I started work on the Lennix stones! (Today is 31.1.1980).

The first thing that struck me about the stones was that they were individual small shapes rather like preformed crystals of tabular habit. They had smaller crystals jutting out haphazardly but not in quantity, rather like a few eruptions or pimples.

I used a 10× lens as my first tool in the examination. I find it quite a challenge to see things with a 10× lens for the first time. I try to establish characteristics, whether surface structures such as

low viscinal faces, striations, double refraction, dichroism, etc., before full testing. Perhaps I should have started off to say that the name of the manufacturer is L. Lens, of France, hence the name for his synthetic emerald *Lennix*. In his correspondence, M. Lens has asked if possible that the details should be published in the *Journal of Gemmology*. A compliment to our *Journal*—I wish I had been able to be speedier in my presentation.

M. Lens is understandingly reticent upon some details of his method of manufacture for commercial reasons, but he states definitely that the growth is by flux fusion, very similar he says to Carroll Chatham and Pierre Gilson. He states, 'One peculiar feature that you will note on the enclosed sample is that while the natural facets of the hexagonal crystal can be easily seen, the general outline of the crystal is rather square or rectangular with cut corners. This is done intentionally by a process I developed, whereby (although crystallizing in the normal hexagonal system) the crystals are forced to adopt these external shapes. This is of great advantage to the lapidary and buyer of rough material, because the usual hexagonal shape of natural crystals is far from being the most advantageous from the point of view of recovery in cut stones. On the contrary, with this synthetic material the stones are 'pre-shaped', which results in the minimum of labour for cutting and the minimum of waste.'

M. Lens continues as follows:

'I thought you might be interested in some background on the research that has been involved. It all started in 1954, when I came across an article in the French edition of the *Readers Digest,* dealing with different achievements in the manufacture of synthetic crystals, and more specially with the work of Chatham. That article was in fact an abstract of a publication in the U.S.A. magazine *Fortune,* no. 42, August 1950, of which I have been able to obtain a copy recently.

'At that time, I was established in ex-Belgian Congo (today Zaïre) and engaged in mining and prospecting with a mining company. I had always had some interest in gemstones, but my work there was much more prosaic and dealt only with tin and tungsten ores. Since I had qualifications as a chemical engineer, and already some experience in mineralogy, the results obtained by Chatham appeared to me as a challenge, and I decided then that to achieve a similar result would be my main hobby. Of course, life in

the middle of the African bush is far from offering the ideal condition for a research work of that kind! Nevertheless, I did not despair, and still managed for some years to do a little work on my 'hobby', sometimes under the most hectic conditions of improvisation. No need to say, I did not reach any positive result at that time.

'Fortunately, I had in 1960 the opportunity to leave the Congo and to establish myself in Johannesburg, South Africa, where I joined the Diamond Research Laboratory, a branch of the Anglo-American Corporation. In addition to being a most interesting job, it gave me access to scientific libraries and to a lot of priceless information. Also I could this time continue on my personal project under much better conditions. It took until 1966 before eventually I could obtain some positive result. Nothing yet very exciting indeed: in the residues of a test run, I at long last spotted some greenish crystals. They could be seen only under the microscope at high magnification, were poorly crystallized, and lacked transparency. Very difficult conditions for an accurate identification!

'These tests were repeated numerous times, under different conditions, until eventually I could produce crystals, still of very poor quality, about ½mm long. That was sufficient to have a determination of SG and refractive index which confirmed that the crystals were beryl. From then on, work has been continued, with very slow but constant progress, up to the latest samples that you have now.

'I feel that more progress still can be done, mostly on the clarity and freedom from defects, and I am still continuing in that direction. So far I have done since the beginning over 8000 runs. . . .'

Proceeding with my tests on the Lennix synthetic emerald, I found it salutory to find my several densities by hydrostatic method to be consistent in result, but consistently low and slightly wrong! Over a series of weighings I had an average density of 2.6409 on specimens averaging 0.607 ct—1.465 ct. To check myself, the balance and the ethylene dibromide, I took a large clear quartz polished piece used by B.W. Anderson as a check on the density of liquids and found the density to be 2.651, which proved the liquid (ethylene dibromide, or dibromoethane if you prefer it) to be correct. The simple aspect of gemmology was to make a new suspension liquid of bromoform and bromonaphthalene with a

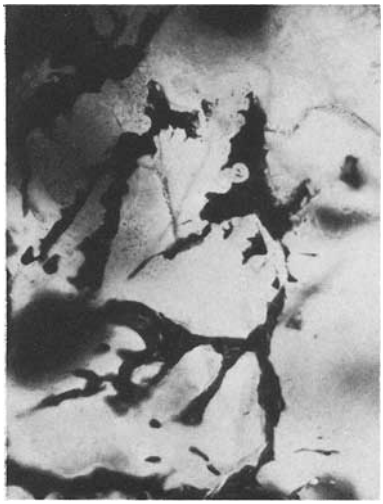

FIG. 1. Flux inclusions

FIG. 2. Three-phase inclusions

in Lennix synthetic emerald.

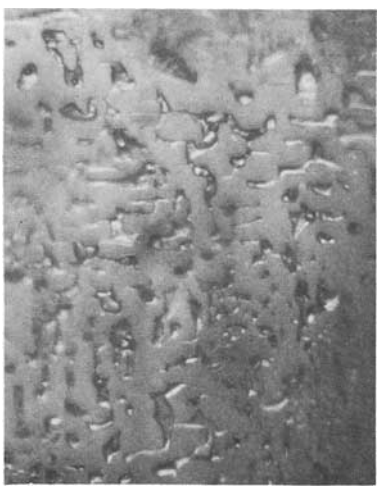

FIG. 3. Two-phase feathers

FIG. 4. Two-phase inclusions

in Lennix synthetic emerald.

doubly terminated Herkimer ordinary quartz crystal finely suspended (very enjoyable). Having obtained this tube of liquid of *known* density I placed in eight specimens of Lennix synthetic emerald. They clustered around, slightly above and slightly below the quartz in suspension, offering a density range of 2.650-2.6515.

I employed a further refinement and enjoyed further pleasure by slightly warming the tube in front of and close to a 60-watt bench lamp. This caused them all to sink in a dignified manner and to recover their poise as the liquid cooled. In fact they behaved as good party members of the quartz group (density branch) exhibiting solidarity with the party leader (Herkimer) and practising their disciplined party piece of 'one up all up', 'one down all down'.

All the Lennix specimens were a very strong glowing coal ember red when viewed through the Chelsea filter. Under long wave ultraviolet light they all had a reddish glow, under short wave ultraviolet (SWUV) they were a lesser more orange red. Under x-ray excitation they were a dull but distinct red. One of the useful tests for synthetic emerald, published long ago in the old *Gemmologist,* is the transparency to SWUV light of synthetic emerald*, whereas natural emeralds are opaque to SWUV. My tests in this manner were somewhat inconclusive (probably due to heavily included material). I appeared to have some opaque to SWUV among the synthetics and a transparent among the natural stones I had borrowed! Fortunately we had polished 'flats' on two specimens and were able to obtain results showing low refractive indices and small birefringence. In fact the low 'text book' SG, RI and fierce red under Chelsea filter plus red glow under long wave ultraviolet light are themselves sufficiently diagnostic.

The photographs of inclusions, feathers, etc. are by K. V. Scarratt, and the exteriors of the single crystals showing protrusions are by R. K. Mitchell. I am indebted to Mr and Mrs Bartolo for their gift to the laboratory and to M. Lens for interesting details of his experiments.

The Lennix synthetics should not deceive the gemmologist, since they are marketed as synthetics, and as we have been given long and full details by M. Lens we should be able to tell them when they arrive (hopefully) at our Laboratory door—even if they are in an antique mount!

*Anderson, B. W. A new test for synthetic emerald, *Gemmologist,* **XXII** (264), 115-17 (1953): *Gem Testing,* 8th edn, pp.86, 101. London, Butterworths (1971).

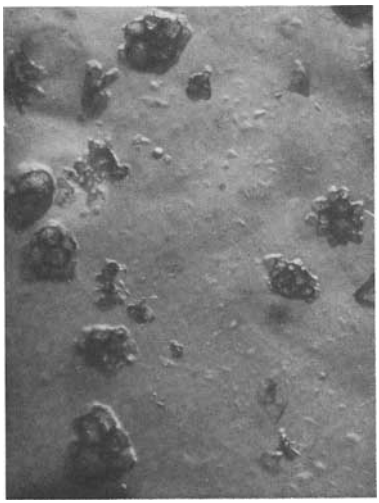

FIG. 5. Crystal groups

FIG. 6. Crystal aggregates

in Lennix synthetic emerald.

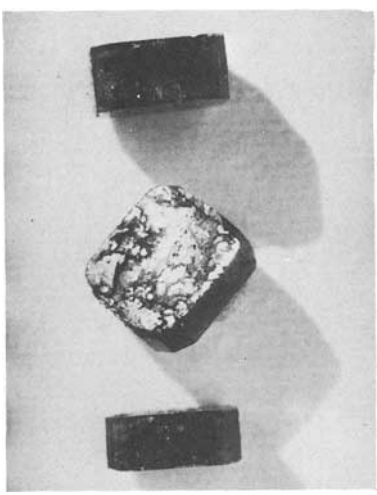

FIG. 7. Exterior of Lennix synthetic emerald crystals.

FIG. 8. Crystals on surface of Lennix synthetic emerald.

SUMMARY

LENNIX SYNTHETIC EMERALDS
A fierce red viewed through the Chelsea Filter.
Red under *long wave* ultraviolet light.
Orangy-red under short wave ultraviolet light.
Refractive Indices 1.562 to 1.566.
Birefringence *small* 0.004.
Specific Gravity 2.65 (quartz matching liquid).
Absorption Spectrum a strong chromium spectrum which is not diagnostic for distinguishing natural from synthetic emerald.
Although fluorescence is useful as a back-up test, it must not be 'leaned upon' for support.
I have noticed that most *natural* emeralds are green or inert under LWUV, but this is not a rule.

[*Manuscript received 9th February, 1980.*]

AN OPAL IMITATION MADE FROM LATEX

By MICHAEL J. O'DONOGHUE, M.A., F.G.S., F.G.A.

Through the kindness of Dr Achira Kose, Institute of Applied Optics, Tokyo, Japan, I have been able to examine two pieces of an opal imitation made from a monodisperse polystyrene latex. Both stones are cut en cabochon; both have a play of colour against a white background and both show a much less regular pattern of colour patches than the opal manufactured by Gilson. Both stones appear to be quite hard and neither was porous—at least there appeared to be no effect when the stones were briefly immersed in methylene iodide. Under long wave ultraviolet light there was a

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weak whitish luminescence. Microscopic examination (20× and 30×) showed quite clearly, in both stones, markings resembling streaks made by a paint brush moved unevenly. These dark markings were not confined to any particular patch of colour but extended over a number of the patches. I have seen no such effect in natural opal nor in the Gilson product; the hexagonal markings seen in the colour patches in Gilson opal were quite absent here. At present it looks as though these markings provide the best clue to the identity of the material, though it should be stressed that with only two stones examined further features may later come to light.

Monodisperse means simply that there is a constant value of the sedimentation coefficient for successive time intervals of growth; the polystyrene latex showed iridescence when sodium polyacrylate was added to it, the iridescence appearing on the surface of the test tube as well as on the subsided sediment.[1] Since the iridescence shows that there must be a regular structure in the tube the affinity with the structure of precious opal is apparent. The process of coagulating the particles into the aggregates which display iridescence is known as 'flocculation' and the aggregate itself as a 'floc'. It was noted[1] that during growth the standard particles were green and that other colours, in particular yellow and orange, were seen when impurity particles of larger size appeared toward the surfaces of the crystallites.

It is fair to say that even without a lens the stones arouse faint suspicion on account of a tendency towards glassiness; in this they have a slight resemblance to the Gilson product. The play of colour appears to begin perceptibly below the surface and at some angles a sheet of colour(blue and green in this case) appears to flood the whole stone. By transmitted light there is a light yellow colour, quite like that seen in other manufactured and in natural opals.

REFERENCE

1. Kose, A., Hachisu, S. Ordered structure in weakly flocculated monodisperse latex. *Journal of Colloid and Interface Science*, **55** (3), 487-98, 1976.

[*Manuscript received 15th October, 1979.*]

TWO REPORTS: (1) ALTERNATIVE REFRACTOMETER LIGHT SOURCES: (2) THERMAL DIAMOND PROBES

By PETER G. READ, C.Eng., F.G.A.

(1) ALTERNATIVE REFRACTOMETER LIGHT SOURCES

A monochromatic light source centred on 589.3nm is an essential requirement for the precise measurement of refractive indices when using a critical angle refractometer. This is particularly the case if there is an appreciable difference between the dispersion of the measuring prism and that of the gemstone under test, as this results in the production of a 'rainbow' fringe to the shadow edge when using a polychromatic light source.

Unfortunately, the production of yellow light at 589.3nm by means of a sodium lamp can be expensive. This is because a lamp of the size convenient for gemmological use has a very limited market and is therefore only produced in small, and correspondingly expensive, batch quantities.

Alternatives to the sodium lamp include the use of a yellow colour filter either between the light source and the refractometer, or over the refractometer eyepiece. In either case the effective emission spectrum of the light source, while centred on 589.3nm, overlaps into the red and green portion of the spectrum. The high transmission loss through the filter also necessitates the use of a high-intensity light source. If an interference type filter is used (as in the latest version of the Krüss ER60 refractometer) this results in a much closer approximation to a monochromatic light source, but because of its narrow pass-band it also requires a high-intensity light source.

A separate refractometer light source, using a quartz-halogen lamp and an interference filter, has been marketed by Orwin Products Ltd, and is called the 'Monolite' (Figure 1). This unit uses an optical system which can be adjusted in height to suit all makes of refractometer. The transmission response of the filter has a bandpass which is centred on 589.3nm, cuts off sharply at the yellow/green boundary and tails off slightly into the red.

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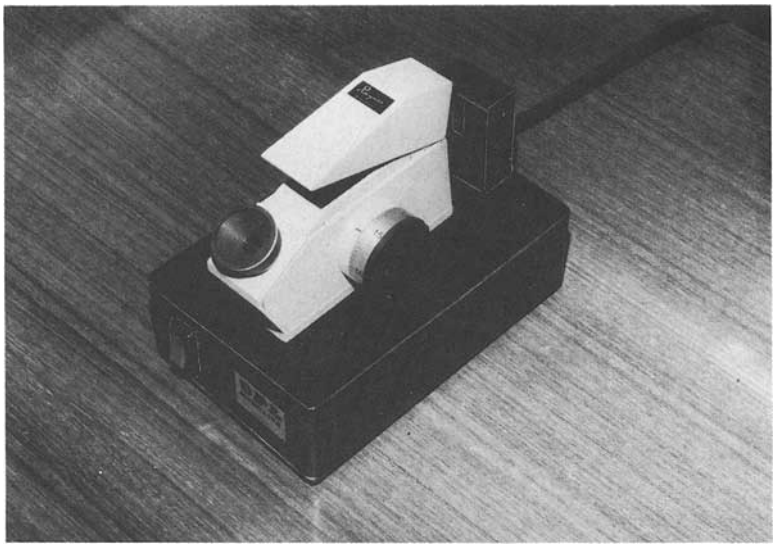

FIG. 1. The 'Monolite' with a Dialdex refractometer.

In a recent letter* to Mr J. R. H. Chisholm, Mr D. Minster† (of Pretoria, South Africa) proposed the use of yellow light-emitting diodes (LEDs) as an alternative light source for the refractometer. His test, using a Beck wavelength spectroscope Type 2522, indicated that the LEDs had a peak emission very close to that of the dominant sodium line and an emission bandwidth of 550-640nm. In a battery-powered unit incorporating six yellow LEDs, constructed by Mr Minster, the LEDs were mounted in an array which fitted the light entry port of his Rayner Dialdex refractometer.

With Mr Minster's approval, Mr Chisholm submitted his letter to me and asked me to test and report on the proposal. Accordingly I obtained a supply of yellow LEDs (Vitality, type CM4-582B) and checked their emission spectra with the aid of a Jena wavelength spectroscope. The LEDs were of the high-brightness GaAsP/GaP type with internal luminized reflectors. Their emission peak was centred on 585nm, with a bandwidth extending from 560-640nm, the latter corresponding closely to the measured transmission response of the Rayner eyepiece filter.

*Posted 5th July, 1979.—Ed.
†Now F.G.A. (D. 1979).—Ed.

The electrical characteristics of LEDs are more variable than those of filament lamps, and for this reason it is difficult to operate them satisfactorily when connected in series. Because of this, D. Minster powered his six LEDs by connecting them in parallel (via individual current-limiting resistors) to a 9-volt battery. While this makes a useful portable unit, the battery current is in the region of 120-200mA, and I considered it more satisfactory to construct a mains-powered unit for evaluation purposes using a bell transformer (see Figures 2 and 3).

I made tests using this LED light source on a Rayner Dialdex refractometer, with a range of gemstones having a dispersion from 0.007 to 0.027. In all cases the shadow edge, while not as sharply defined as with the sodium light source or as bright as with the 'Monolite', was as clear as that obtained with the Rayner eyepiece filter when used with a high-intensity lamp. The cost of the various components was not high, and by choosing a Klingel 4-volt 1-amp bell transformer it was possible to mount the LEDs on the plastic transformer housing. An external mains lead clamp was added as a safety precaution.

The Rayner Optical Company is currently developing a mains-powered LED light source to provide a low cost alternative to their existing sodium lamp unit. This, like the 'Monolite', will be available from Gemmological Instruments Ltd.

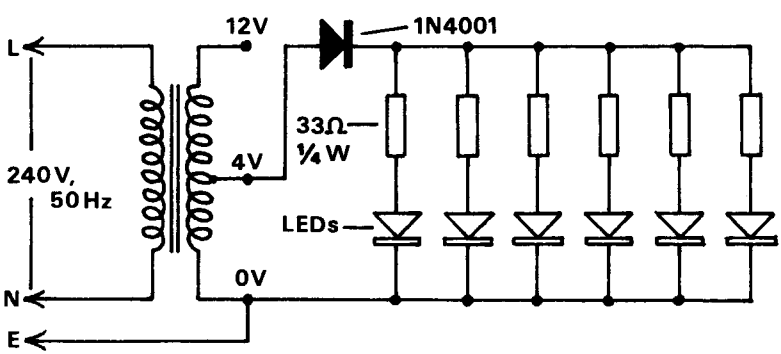

FIG. 2. Circuit diagram of mains-powered LED unit.

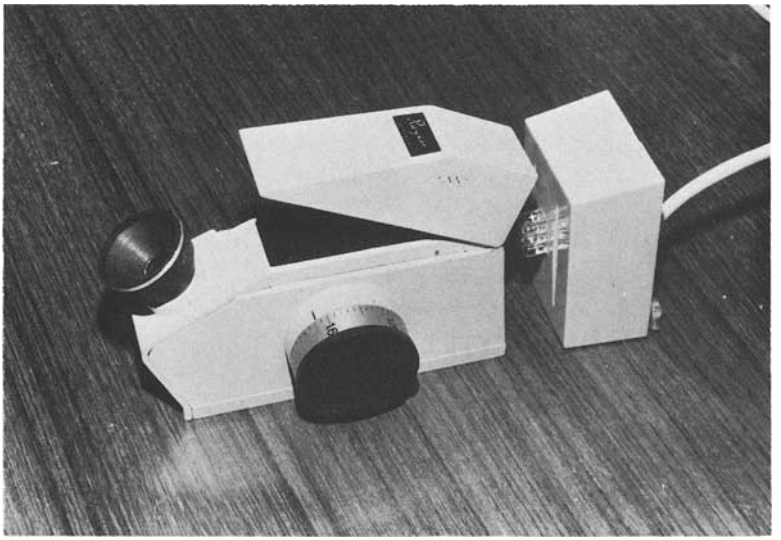

FIG. 3. Unit positioned for use with a Dialdex refractometer. The LEDs are mounted on the plastic case of the bell transformer. The associated rectifier and resistors are mounted inside the case.

(2) THERMAL DIAMOND PROBES

The introduction of a commercial gem-testing instrument using a virtually unexploited phenomenon is a rare and interesting event. Over the last four years the only items of equipment in this category have been the reflectivity meter, the GIA Gem Diamond Pen, and the Ceres Diamond Probe, each of which uses a different and unique gemstone property as an aid to identification.

The reflectivity meter (now manufactured by six firms in the U.S.A., Australia, Japan and Italy) identifies gemstones by measuring their relative reflectivities or lustres. This type of instrument is particularly useful for checking diamond and those diamond simulants whose RI is above the range of the standard critical-angle refractometer. However, it cannot be regarded as a precision instrument, and misleading readings can sometimes be produced by internal reflections and dirty or scratched facets.[1]

The GIA Gem Diamond Pen[2] uses the low water-contact angle of diamond to distinguish it from its simulants. In use, the pen dispenses a special 'ink' which flows relatively easily on the

surface of diamond but breaks up into droplets on all of the high RI diamond simulants. As this test can sometimes be invalidated by the presence of thin surface coatings, which cause a simulant to react in the same way as a diamond, it is necessary for the table facet of the stone under test to be rigorously cleaned (using a 'soft' polishing powder provided with the kit).

Both reflectivity and liquid-flow tests can be difficult with small stones, the practical lower limit being a stone having a 2-3mm girdle diameter (i.e. a 20-50 point diamond). Furthermore, if the mounting claws of a ring-set stone are above the plane of the table facet, it is only possible to obtain a reflectivity reading on those instruments which have either a recessed groove to accommodate the claws, or a raised rim surrounding the test aperture.[3] If the stone is recessed in its mounting, it becomes impossible to take a reading, even on instruments which make provision for claw settings. It is in these situations where the Ceres Diamond Probe can be particularly useful in distinguishing diamond from its simulants.

The prototype of the Ceres Diamond Probe was first made available for evaluation in 1978.[4] Since then several improvements have been made, and these have been incorporated into the production model which was tested for this report.

The instrument (Figure 4) is a thermal conductivity comparator, and comprises a control/indicator unit and a test probe. The thermal conductivity of diamond is unusually high,* and it is this property which is used by the instrument to distinguish diamond from its simulants.†

The test probe contains a copper tip linked to two very small bead-type thermistors (i.e. ceramic elements whose resistance varies with temperature). One of these thermistors is fed with pulses of current at one second intervals, and acts as a miniature heater. The other thermistor is used as a thermal sensor, and its resistance is measured to indicate the temperature of the copper tip of the probe.

When the probe is not in contact with any other material, the temperature of its tip rises a few degrees above ambient because very little heat is being conducted away from it. However, if the tip is pressed against a diamond, each short pulse of heat is conducted

*Typically 1500 Watts/m°C for Type I diamond, compared to 400 Watts/m°C for copper (at room temperature).

†The same property is used in the 'breath' test, where the rapid dispersion of moisture from the surface of a diamond acts as an indicator.

FIG. 4. The Ceres Diamond Probe. On the left of the vertical front panel is the socket for the battery charger and below it the battery warning lamp. (These may be seen better in Fig. 9—but on the right, as the panel is inverted.)

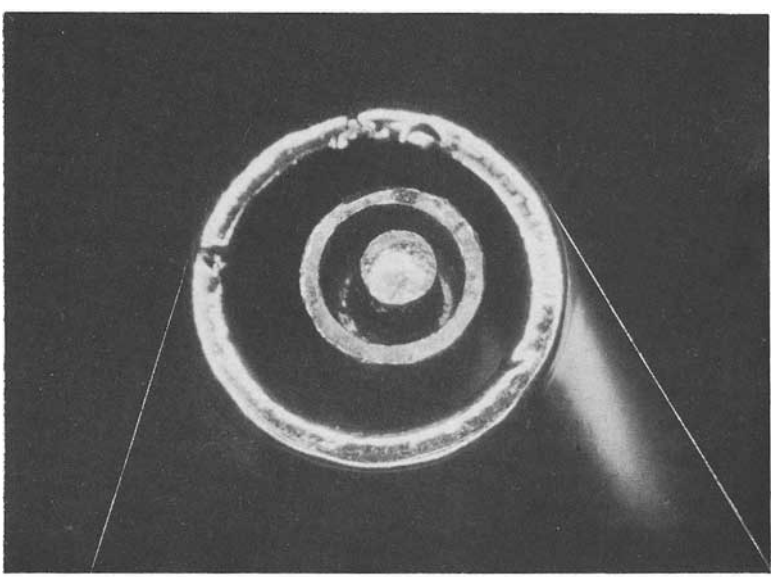

FIG. 5. View of the 0.5 mm diameter copper tip of the probe with its protective guard ring.

away through the diamond, and the temperature of the tip is not able to rise as high. If the tip is pressed against a poor heat conductor such as glass or cubic zirconium oxide, the tip temperature rises to an intermediate value which is significantly higher than that for diamond.

Because the energy content of the heating pulse is very small and occurs in short pulses separated by one second intervals, even a very small diamond is capable of conducting a significant proportion of the heat away from the probe. The temperature of the probe tip is automatically measured by the instrument at one second intervals. The measurement is 'latched' to produce a steady meter-reading, which is then updated at each successive sampling of the probe temperature.

To protect the probe tip and thermistors from damage, the tip assembly and its concentric metal guard ring (Figure 5) are spring-loaded, and retract under pressure into the body of the probe when the tip is pressed against the surface under test. Because of the small dimensions and low thermal mass of the tip assembly it is possible not only to test stones down to 3 points in size, but also to check stones which are recessed in their mounting.

The instrument's meter scale is marked off into three colour-zones. If the meter needle comes to rest within the broad red zone on the left side of the scale, this indicates that the gem under test is a simulant and not a diamond. If the needle moves across into the green zone at the right of the scale, this indicates that the stone has a high thermal conduction, and is therefore most probably a diamond. A narrow amber 'no indentification' zone separates the red and green sections of the scale.

In addition to the meter indication, there are red, green and amber indicator lamps. If the stone is a simulant, the red and amber lamps flash alternately; if a diamond is detected, the amber and green lamps flash. If the meter reading lies in the central amber zone, only the amber light is energized. Although the instrument is capable of testing stones down to 3 points in size, small diamonds (because of their low thermal mass) produce a reading towards the amber end of the green zone, while larger diamonds cause the meter needle to move further into the green zone. With stones having a lower thermal conductivity than diamond, the size of the stone has much less effect on the meter reading.

Two probe test surfaces are provided on the sloping front

panel to allow the instrument's calibration and correct functioning to be checked. The square test surface on the left simulates the thermal conductivity of a mid-range simulant, while the one on the right imitates that of a medium size diamond. A recessed pre-set adjustment is provided in the front vertical panel which allows the calibration of the instrument to be adjusted in conjunction with the test surfaces.

As the instrument is designed to measure very small thermal changes at its probe tip, for best operation it should be used in a constant ambient temperature within the limits of 12-32°C (55-90°F). For the same reason, gemstones which have been in a cold environment must be allowed to warm up to room temperature before being tested. Should the unit be operated outside the specified temperature range, the meter needle will return to the amber zone, and only the amber test lamp will continue to flash.

To check the reliability and range of the instrument, the writer made a series of tests using a variety of natural and synthetic simulants of diamond, together with diamonds of various sizes down to 3 points, and a selection of metals. For convenience of handling, and to achieve comparable conditions, all loose stones were tested in a 4-prong stone holder (hand-holding a stone did not, however, appear to affect results).

Although Type IIa diamonds (as used in heat sinks) would be expected to produce, size-for-size, a larger meter deflection than Type I stones, all diamonds used in the test were unclassified and were assumed to be the normal Cape series combination of Type Ia and Ib material. A summary of the tests is given in Table 1, and Figures 6-8 give an indication of the readings produced during tests on large and small diamonds, and on cubic zirconium oxide.

The overall impression gained from these tests was one of reliability, and once the technique of applying the probe tip at right-angles to the test surface (with just sufficient pressure to cause the tip to retract slightly) was mastered, consistent and repeatable results were obtained down to the specified limit of 3 points. The only problem which occurred was with very small rose-cut diamonds and 'chips,' where it was difficult to locate the probe accurately on a usable facet surface.

During a test, it is important that the probe is held in steady contact with the stone for at least three seconds until a constant reading is obtained. This is to allow for two or more successive

TABLE 1

GEM MATERIAL	CLOCKWISE DEFLECTION OF METER NEEDLE†
Diamond (0.75 ct)	9 mm into Green zone
Diamond (0.20 ct)	6 mm into Green zone
Diamond (0.03 ct)	2 mm into Green zone
Colourless Sapphire*	28 mm into Red zone
Colourless Zircon*	22 mm into Red zone
Colourless synthetic Spinel*	16 mm into Red zone
YAG*	12 mm into Red zone
Strontium Titanate*	11 mm into Red zone
Colourless Quartz (10 ct)	10 mm into Red zone
GGG*	10 mm into Red zone
Rutile*	10 mm into Red zone
Lithium Niobate*	6 mm into Red zone
Cubic Zirconium Oxide (2.5 ct)	5 mm into Red zone
Glass*	2 mm into Red zone
Sterling silver (1 oz ingot)	11 mm into Green zone
Aluminium foil	10 mm into Green zone
Krugerrand/24 carat gold	5 mm into Green zone
22 carat ring shank	Amber/Green boundary
9 and 18 carat ring shanks	Red/Amber boundary
Electroplated nickel-silver	Red/Amber boundary
Rolled gold	33 mm into Red zone

*Between 0.5 and 2.0 ct
†Effective length of Red zone = 35 mm
Effective length of Green zone = 15 mm

samplings by the electronic circuits as the probe temperature stabilizes. The manufacturers warn against using too much force on the probe tip, and also state that it should not be moved or wiped across the surface of the gemstone, as this may damage the soft copper tip.

Surface dirt and thin coatings of grease and oil appeared to have no effect on the accuracy of the readings, although in excess these would undoubtedly contaminate the probe. To test the effect of an insulating coating, a 10mm square of aluminium was sprayed with a thin layer of lacquer. The resulting thermal conductivity as measured by the probe was only marginally lower. Before making the tests detailed in Table 1, all samples were cleaned to conform with normal gem-testing practice.

FIG. 6. Testing an 0.75 carat diamond.

FIG. 7. Testing an 0.03 carat diamond.

FIG. 8. Testing a 2.5 carat cubic zirconium oxide.

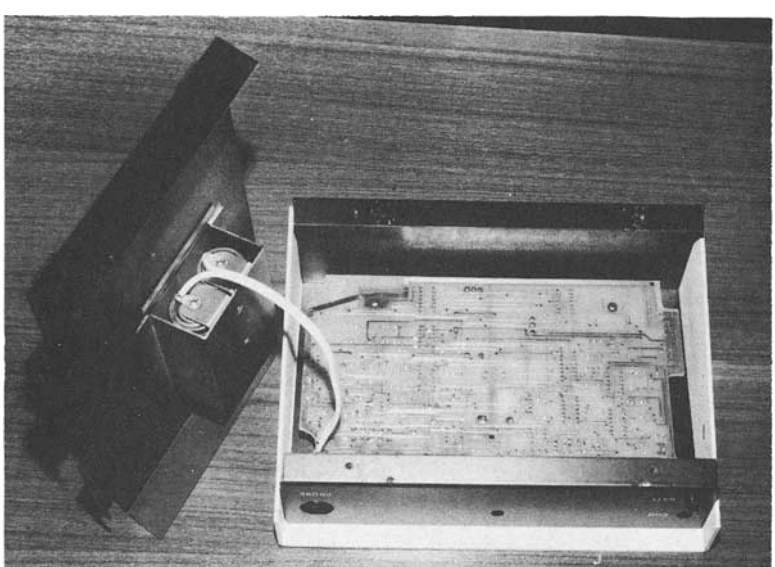

FIG. 9. View of the unit with the base cover/battery holder removed. The electronic components, including twelve integrated circuits, are mounted on the panel side of the large printed-circuit board.

Although no tests were carried out with diamond doublets, these can be expected to produce a 'diamond' reading in the green meter zone (although presumably the deflection would be smaller for a given size than if the stone was 100% diamond). However, if it is possible to make tests on both the crown and pavilion facets of a suspect stone, even this type of 'simulant' can be detected.

The Diamond Probe's electronic components are mounted on a large double-sided printed-circuit board in the control unit (Figure 9), and include twelve integrated circuits. The unit is powered from two 1.2-volt rechargeable nickel-cadmium cells. A separate twin-range (120/240-volt, 50/60 Hz) battery charger is provided, and this can also be used to operate the unit directly from the mains. If the battery voltage falls below a predetermined level, a red battery warning light flashes on the front vertical panel; the instrument will then continue to function accurately for several more minutes before switching itself off (in this condition all the top panel lights are extinguished, and the meter needle returns to the amber zone). The instrument can be operated for 8 to 10 hours from fully charged cells; re-charging time is 14 to 16 hours.

The only maintenance that appears to be necessary concerns the probe tip, which, for reliable readings, must be kept clean and free from dust particles. During tests, the gap between the probe tip and its guard ring tended to collect dust particles, and, although these did not affect the results, the probe tip was cleaned with a fine camel-hair brush between tests. The manufacturers suggest that the probe tip is cleaned by rinsing it in alcohol, and then allowing it to dry out. They also recommend that the tip is polished lightly by wiping it, using a rotary action, on a piece of lint-free paper.

As with the GIA Gem Diamond Pen, the accompanying instruction book carries a warning that test results should be regarded as a strong indication rather than a positive identification of a simulant or a diamond. It should also be remembered that high conductivity metals such as sterling silver and 24 carat gold will produce readings in the green zone (see Table 1). Although gold jewellery settings are usually made from alloy golds, care should still be taken to see that the probe tip is in contact with the surface of the gem and not the metallic mounting. While there are also a few transparent non-diamond materials which could produce readings in the green zone of the meter scale (e.g. silicon carbide, bromellite and cubic boron nitride), these are unlikely to be met

with in jewellery, and are in any case sufficiently different in appearance to prevent them from being confused with diamond.

To summarize, the Ceres Diamond Probe provides a rapid and practical means of distinguishing diamond from its many simulants. Its ability to identify very small diamonds, and diamonds whose table facet is well below the level of the mounting, enables the probe to complement the operation of the reflectivity meter in this respect. However, there are very few tests in gemmology that are 100% confirmative, and results obtained with the instrument should always be checked by means of other techniques such as the inspection of facet edge condition with a hand lens, the 'tilt' test, or, where practical, a reflectivity reading.

The Diamond Probe is manufactured by the Ceres Electronics Corporation, 411 Waverly Oaks Park, Waltham, Mass., 02154, U.S.A. (The parent company, Ceres Corporation, is the American manufacturer of cubic zirconium oxide). The dimensions of the instrument are 230mm × 185mm × 95mm, and its price is approximately $650, plus freight, duty and VAT.

A much simpler thermal comparator for diamond testing has been developed, in conjunction with the Australian Gemmological Association, by Professor J. Goldsmid of the University of New South Wales. This unit is also battery-powered, and uses a temperature indicating galvanometer and a glass probe containing a heating element. In the U.K., the Rayner Optical Company is developing the 'Rayner Diamond Tester' which also uses the high thermal conductivity of diamond and provides an accept or reject indication on three panel lamps. While more sophisticated than the Australian version, the Rayner model will be considerably less expensive than the Ceres Diamond Probe, and will be marketed through Gemmological Instruments Ltd.

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THE GEMMIFEROUS GRAVELS OF THE FRASER AND REDDISTONE CREEKS, INVERELL-GLEN INNES DISTRICT, NEW SOUTH WALES

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ABSTRACT

The gemmiferous gravels associated with the Fraser and Reddistone Creeks in north-eastern New South Wales are the second largest source of commercial sapphire production in Australia. The mining district is centred north-east of Inverell and north-west of Glen Innes. The sapphire, zircon and corundum fraction is extracted from Tertiary buried gravels, which have been partially reworked into the Holocene drainage system. Igneous source of the sapphires is unknown.

The size of the mining operation is dependent upon the width of the alluvium. A 40 to 50 cubic yard daily excavation is typical of the small two man operated leases. These are generally restricted to the narrow entrenched river sections, where filled potholes into irregular bedrock surfaces are excavated with mechanical back-hoes. Wide flood plains support syndicate financed extraction plants processing up to 2000 cubic yards daily.

The Inverell-Glen Innes district, New South Wales, and the Anakie district, Queensland, are the only major commercial production centres for Australian sapphire and zircon gemstones. Australian blue sapphires dominate the world sapphire market, despite unfavourable dichroism and brilliance, because of the declining production from the classic southern and south-eastern Asian sources.

INTRODUCTION

Sapphires are associated with the Quaternary alluvial sediments of New South Wales, usually in stream drainage areas associated with Tertiary basalt cover. They have been recovered in the Oberon, Porters Retreat, Crookwell, Mittagong, Hill End, Wee Jasper and Mundle river alluviums. They are also associated with the buried Tertiary gravels at Mount Werong, Vegetable Creek, Airly Mountain and elsewhere. The Inverell and Glen Innes area of north-eastern New South Wales has sufficient concentration of quality stones to encourage commercial production for the international gem markets. The alluvium of the Fraser and Reddistone Creeks between Inverell and Glen Innes are commercially viable sources of sapphire and zircon gemstones. This mining district is the smaller of Australia's two major sapphire mining areas. The

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economic geology of the rival Anakie sapphire mining district in east-central Queensland was discussed previously in this *Journal*.* The extent of the Inverell-Glen Innes sapphire deposits in the New England district of New South Wales has only been realized since the early 1960s. In the last decade commercial production has expanded to rival the Anakie district in Queensland. Most of the production, historically and at present, has been associated with Fraser's Creek, and its Horse Gully tributary near Inverell, and the Reddistone Creek north of Glen Innes in the vicinity of Bullock Mountain.

Sapphires have been recovered in the district and surrounding regions for more than a century. The placer tin and gold miners recovered the numerous crystals from their heavy concentrates. The first recorded observation of sapphires in New South Wales dates to 1851. A Mr Stutchburry observed their presence in a gold sluicing operation on the Cudgegong and Macquarie Rivers. A few years later, in 1854, a Rev. Mr W. B. Clark noted sapphires in the tin sluicing concentrates of the Inverell mining district (Curran, 1897). The recognition of these New South Wales sapphires predates the discovery of the famed Anakie fields of central Queensland by a couple of decades.

The initial identification of the sapphire crystals was considered valid, but they were dismissed as essentially worthless. Quantities of sapphires were recovered in 1869 and 1870 from the buried gold-bearing gravels (Tertiary) associated with the ancestral Cudgegong River in the vicinity of Gulgong. They were again discovered in the Oberon area on Native Dog Creek in 1878, also incidental to gold prospects and sluices.

The first commercial mining of sapphire deposits in New South Wales was attempted in 1919 on the Fraser Creek claim of C. L. Smith. It is now at the site of the small village of Sapphire, north-east of Inverell (Figure 1). The recorded production for Smith's first year of operation was an uneconomic return of eight ounces of corundum and sapphire. Nevertheless new deposits were delineated for future exploitation. Commercial sapphire mining developed on a larger scale during the 1920s between the towns of Inverell and Glen Innes in the gemmiferous alluvial gravels associated with Fraser's Creek, Horse Gully, Mary Anne Creek in

*J.Gemm., 1979, **XVI** (5), 318-37.

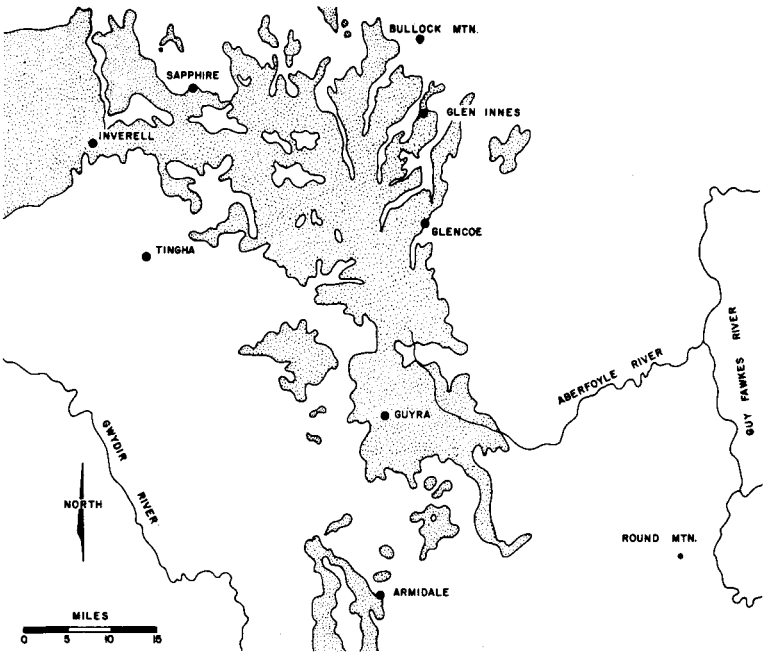

FIG. 1. Generalized distribution of Tertiary basalts and associated sapphire-zircon gemmiferous gravels (stippled) in north-eastern New South Wales. *(Adapted from MacNevin, 1971)*

the vicinity of Inverell and Sapphire townships, and Reddistone Creek near Bullock mountain, north of Glen Innes (see Figures 1 and 2). Minor interest was directed towards Copes Creek near Tingha township. The sapphire mining industry was relatively stable until the Great Depression after which production ceased until the early 1960s.

GEOLOGY OF THE GEMMIFEROUS GRAVELS

North-eastern New South Wales is a region of widespread Tertiary to Holocene sapphire bearing sands and gravels overlying a bedrock of Permian granites, prophyries, volcanics and Permo-Carboniferous metasediments and intercalated Tertiary flood basalts. Dissected Tertiary plateau basalts cap most of the topographic highs (Figure 1). The gemmiferous gravels are generally associated with the modern drainage system. Sapphires

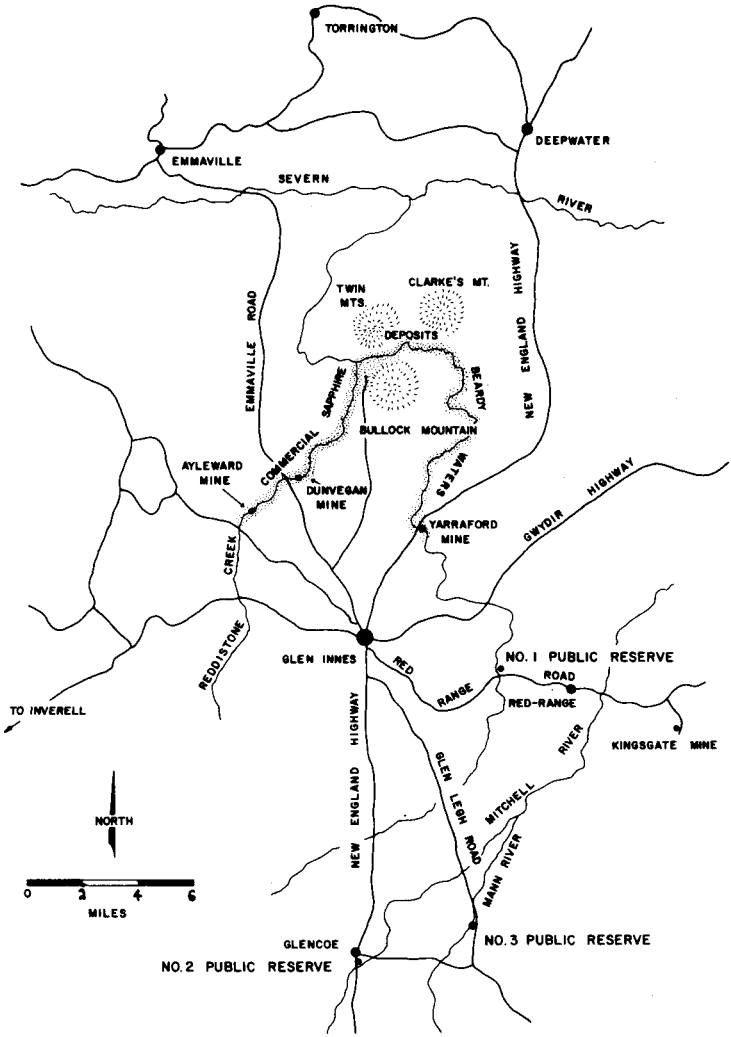

FIG. 2. The Glen Innes sapphire mining district. The commercial sapphire bearing gravels (stippled) are associated with the Reddistone and Beardy Waters alluvium.

are also found in weathered basaltic soils in older sediments, preserved at higher elevations than the modern drainage systems. The streams have locally breached the Tertiary basalts and subsequently reworked the buried Tertiary gem gravels into Palaeozoic basement rocks, which characterizes commercial deposits of the district.

The sapphire deposits are concentrated in irregular zones and reflect the undulating basement subcrop surface. Concentration is favoured within the inside of meander bends of older phases of the drainage system and within trough and pothole traps of the river bottom. The lowermost zones of these sediment traps have the highest concentrations of gem sapphires, especially within 5 feet of the bedrock surface.

The drainage system and associated gem gravels display a regionally distinctive radial pattern about the flood basalt of the district (MacNevin, 1971). These volcanics are associated with two major periods of volcanism: the 'Older Series' of Oligocene to Miocene age and the 'Newer Series' of Pliocene age. They are separated by a widespread laterite-bauxite horizon of late Miocene age. Most of the regional gem gravel trends (termed 'leads') have been deposited in channels that have eroded through the basalt sequences. The aerial distribution of the gravels indicates the source of the sapphires to be these Tertiary basalts, but only as a secondary source. The actual *in situ* mother rock has never been discovered. Pleonaste, the opaque black spinel, is a prolific component of the corundum- and gem-sapphire-bearing gravels. Considering its similar chemistry to sapphire, it is likely that the two species have the same igneous source. However, megascopic sapphires have never been found *in situ*, and only the pleonaste crystals are abundant in the local olivine basalt outcrops. Some sapphire crystal fragments have been observed embedded in basalt erratics worked from the gem gravels. Both the sapphire and pleonaste grains found, independently, in the basalts have very thin chemical reaction rims within the adjacent fine-grained olivine. An alumina-rich reaction halo around these zenocrysts is lacking. There is a total lack of fine-sized corundum grains in the basalt specimens. The size and perfection of the corundum crystals implies a prolonged degree of metamorphism not supported by field and petrological examinations of the basalts. MacNevin (1971) concluded that the basalts acted as an enveloping and trans-

porting mechanism for bringing corundum crystals, formed independently at depth, to the surface. This actual original source horizon has never been recognized in the subsurface nor is, so far as is known, exposed on the surface.

The gemmiferous gravels are composed of angular to well-rounded clasts of granite, porphyry, metasediments and basalt as well as the heavy mineral concentrates. The heavy mineral concentrate fraction includes sapphire, corundum, pleonaste, red and orange-brown to colourless zircon, ilmenite, black tourmaline, enstatite, quartz, garnet, bauxite, hematite and infrequently gold and diamond.

THE MAJOR GEMMIFEROUS GRAVEL TRENDS

The commercially exploited sapphire-zircon bearing gravels are distributed as two major trends, termed 'leads': Fraser's Creek and its tributary, Horse Gully, north-east and east of Inverell; Reddistone Creek and its marginal gravels on Bullock Mountain, north of Glen Innes.

Future commercial sapphire production in the district will likely include the at present marginally uneconomic sediments associated with the Mitchell River, Marowan Creek, Beardy Waters, Wellingrove Creek and Cameron's Creek in the Glen Innes area and the King's Plains, Bingara, and Tingha areas near Inverell. The main drainage courses from watersheds rising in the basaltic regions of the Great Dividing Range all carry sapphires. These rivers include the Severn, MacIntyre, Mitchell (Mann), Gara, and the Bundra (Gydir). Most of the gravels associated with these creeks and rivers have once had localized commercial production. The Mitchell River, Marowan Creek and the Beardy Waters near Glen Innes have exploitable deposits capable of substantial production under improved and stabilized market conditions.

The northern and eastern slopes of Bullock Mountain probably have the best reserves of gemmiferous gravels in the district. This area comprises the Reddistone Creek section downstream from the junction area of the Reddistone with the Beardy Waters on the north slope of Bullock Mountain, west of Twin Mountains, and the section of the Beardy Waters on the eastern slope of Bullock Mountain and south slope of Clarke's Mountain, north of Yarraford (see Figure 2). This is a largely inaccessible area with little or no roads in steep, mountainous terrain. Several small,

'two-man and backhoe operations' are presently engaged in this area. Their success is largely related to world market fluctuations and the localization of rich gravel concentrations.

The Fraser Creek and Horse Gully Deposits

The Fraser Creek and Horse Gully deposits are the main commercial sapphire production zones between Inverell and Glen Innes. Nearly two hundred mines have been operational in the past, about a hundred excavations each on the Fraser Creek and along the Horse Gully valley.

Sapphires are not deposited in the Fraser upstream from its junction with Horse Gully. Miners hypothesize the source of the sapphires to be from the vicinity of Swan Peak at the head of Horse Gully, 4 miles south-east of Sapphire. From this area they were transported into Horse Gully and thence into the Fraser at Sapphire and eventually worked down stream (north-west) in commercial concentrations as far as Nullamanna. Sapphire crystals have also been found in the Swan Creek south of Swan Peak. The Dominion Mining Corporation established one of its several plants on the river bed west of Swanvale, but temporarily suspended production because of economic recession (1975).

Commercial mining of the Horse Gully gravels is the most viable in the Inverell-Glen Innes district. Two mining syndicates essentially control this deposit: the Arrawatta and the Stellar Corporations. Their mines on the Horse Gully are 15 miles north-east from Inverell off the Swanbrook Road towards Wellingrove. A half mile beyond the Sapphire Post Office, the posted turn-off road north-east towards Swan Peak continues about a half mile to the access road into the Arrawatta property. Another two miles distant to the east is the Stellar's access road to their Horse Gully claims.

The mile-long access road into the Stellar claims crosses the largest and richest sapphire grounds of the entire district. The Horse Gully Mine is comprised of two open-cut pits on opposite sides of the mine office and wash plant. Stellar Mining, established in 1969, is one of the few commercial sapphire mines in the country that both mines and retails its own cut and polished gemstones. Most other mines sell directly to foreign buyers that regularly visit the producing fields. Stellar's sustained quantity and quality of production has helped to maintain marketing offices in London,

Amsterdam, Berlin, Florence, Madrid and New York. Most of the mine's commercial sapphire supply have the deep royal blue hues characteristic of the Horse Gully area; there is also a limited production of golden yellow stones. The Stellar operation has two trenches each approximately 300 feet long, 60 to 100 feet wide and averaging 10 to 15 feet deep. Two scrapers at each pit remove 6 to 10 feet of overburden above the white stained clay and gravel wash, and back-fill it into the adjacent, previously excavated trench (Figure 3). Four to seven feet of gemmiferous gravel are removed with backhoes onto trucks for the quarter mile haul to the washing plant. The sapphire-bearing gravel is unconformably deposited on a yellowish green bedrock, the uppermost foot of which is usually decomposed. This friable, weathered bedrock zone is also excavated and processed with the wash to ensure recovery of any sapphires trapped on the irregular bedrock surface. The two trenches are capable of producing between 500 and 600 cubic yards of wash a day for the processing plant.

Adjacent to the Stellar Mining properties are the extensive holdings of the Arrawatta Company. This company has intermittent and limited production depending upon favourable international marketing conditions. The managers utilize unfavourable periods, e.g. the mid-1970s, to intensify exploration for the more economic gravel concentrations that are salient from the Stellar property.

The largest commercial operation on the Fraser Creek is the Dominion Company's plant, 2.5 miles west of the Sapphire Post Office. Two washing plants are constructed on the extensive properties leased from the Norine Martin estate. The larger plant has a capacity to process a voluminous 2000 cubic yards daily while the second plant is very small with approximately 150 cubic yards per day. This is undoubtedly the highest capacity of any sapphire mine in Australia, if not the world. After the large plant was built in early 1974 its volume of production was instrumental in precipitating the collapse of the 1974-75 sapphire price structure on the world gem markets. The overproduction and falling prices forced the plant to be abandoned after only six months operation, and emphasis was shifted to the smaller 150 yard washing plant (Figure 4). The wash is between 5 and 10 feet thick and under but a couple of feet of topsoil. The open-cut mine is more than a thousand feet long and half as wide. These plants were situated at

FIG. 3. Excavation of the sapphire-bearing gravels at the Stellar mine on the Horse Gully.

FIG. 4. A wash plant operated by the Dominion Company on Fraser Creek. The sapphire-bearing gravel is dumped into a flat, open-ended box and washed into a rotating sieve to remove the over-sized gravel and sand. The remaining slurry is sluiced to a pulsating jig where the sapphire-zircon concentrate is trapped behind a series of riffles.

the junction of the Horse Gully and Fraser where significant concentrations of sapphire have been discovered. The gem gravels infill a half mile wide flood plain at this junction which is one of the widest zones of sediment accumulation associated with the Fraser.

The company operates the small plant with but two men, one of whom loads a truck with backhoed gravel and delivers it to the washing plant. The other employee washes the gravel with a hydraulic hose from the dump box and into the plant's trommel and pulsating jig.

The mining leases of the Saunders family and the adjacent leases of Allen Scheb are downstream from the Dominion Company plants, midway on the Fraser between Nullamanna and Sapphire. These claims cover a mile long section of the Fraser, 5 miles upstream from Nullamanna and 6 miles downstream from Stellar mine on Horse Gully. The half mile wide flood plain of the Fraser, characteristic of the Horse Gully junction area, quickly narrows and becomes entrenched within a narrow gorge between Nullamanna and Sapphire. Granite outcrops bank and protrude from the creek bed. The gravel deposits are seldom more than a hundred yards wide on the Fraser from the Scheb mine downstream to Nullamanna and beyond (Figure 5). While the sapphire-bearing wash may be very thick, the narrowness of the deposits and the rugged topography inhibit large-scale open-cut mining by well financed corporations similar to the Dominion or Stellar operations. Consequently this section of the Fraser has been traditionally exploited by two man mining partnerships. Regardless, they are the most sensitive to fluctuations characteristic of the international sapphire market.

The availability of very thick wash in the gorges is a dominating criterion of success or failure for these small independent mines. The number of small mines fluctuates rapidly between one or two dozen and a couple of hundred. The introduction into the district of the mechanical backhoe during the early 1960s provided for efficient and economical excavation of the wash from between the trees and outcrops within a narrow gorge. The backhoe can effectively extract the gravels between outcrops down to bedrock surface, as well as gravel-filled potholes in the river bed. One particular excavation on the Saunders claim was a deep trench between two granite knobs but ten feet apart. The excavation at the time of observation was only 6 feet into a pothole that was proving

to be a rich sapphire concentration. A similar excavation on the claim was a 20 foot wide patch of gravel between two flat outcrops that was but the narrow surface expression of a 30 foot deep pit into the bedrock. Several pounds of fine gem sapphires were eventually recovered.

FIG. 5. Gemmiferous alluvium partially excavated along the Fraser Creek. Note the narrow valley fill suitable only for small scale mining operations.

The Saunders operate two washing plants along the Fraser, and the adjacent Schebs claim only one. The Saunders are sheep and grain ranchers but intermittently utilize the sapphire mines to help themselves through unstable agricultural market conditions. This is a typical approach by local small landholders. Since they do not have sufficient manpower to work both businesses effectively, the mine is operated on the tribute system. The Saunders provide access to the land to a pair of miners who put up the machinery and necessary labour for an equal split of the recovered gemstones.

The Fraser river bed at Nullamanna is worked by the Brown

claim. This is upstream and adjacent to the public sapphire digging area of MacIntyre Shire. The area is north from Inverell towards Ashford, and after 4 miles, the north-east turn-off for Emmaville and Nullamanna is reached. The turn-off is approximately a hundred yards after crossing the Swanbrook Creek bridge. The bridge over the Fraser is reached after 1.6 miles on this turn-off road, past the Nullamanna Post Office. The turn-off into the public digging area is indicated just south-east of the bridge. The area is designated the MacIntyre Shire Sapphire Fossicking Area, but is more commonly known as the Nullamanna public digging area. It was set aside for public recreation in early 1974. Approximately a quarter mile of river section upstream from the bridge is permitted for public digging (Figure 5). The Brown commercial operation is upstream with control over the next mile of creek bed.

The public digging area is overseen by a caretaker during the digging hours of 9.00 a.m. to 5.30 p.m. on Tuesday, Thursday, Saturday and Sunday. A daily collecting fee (1975) of two dollars is charged. There are several other public collecting reserves that have been set aside in the district, and all except this one at Nullamanna require the possession of a prospecting licence. The collecting fee essentially covers the cost of backhoeing a trench in the creek bed and stockpiling the gem-bearing gravel. The casual prospector can either fill a bucket from the stockpile, continue the excavation, or, if desired, start his own trench.

The grey-white to sandy yellow gem gravel is very coarse. Half the volume is boulders upwards of a foot in diameter. The wash lies on a granite bedrock that outcrops along the narrow valley walls throughout the area. The gravel deposits are generally 10 to 20 feet thick and unevenly distributed within the narrow flood plain. The gorge's bottom sediments form a plain generally less than a hundred yards wide. Portions of the public digging area were once commercially worked in the early 1960s, but with inefficient equipment. Sizable patches of unworked ground remain for public access.

The public reserve has three 10 foot diameter water troughs to facilitate screening the gem gravel. Popular screens utilized are the half-inch and sixteenth-inch mesh sizes to eliminate the coarse gravel, fine sand and clay. Sorting is generally done on a burlap cloth. The recovered sapphires tend to be small, generally under a carat, but of a fine blue colour.

The Reddistone Creek Deposits

The gemmiferous gravels of the Reddistone Creek and those on the lower reaches of adjacent Bullock Mountain are second in importance to the Fraser Creek gravels (see Figure 2). The main production area is the section of the creek bed and associated alluvium eight miles north-west of Glen Innes, midway towards Wellingrove.

The Reddistone Creek deposits are similar to the Fraser. The upstream portion of the commercial sapphire mining district is a half-mile wide alluvial flood plain that tends to support large, syndicate financed, mining operations. Downstream, north-eastward, the Reddistone winds between Bullock Mountain and surrounding peaks. And similar to the Fraser, it becomes entrenched eastward into a narrow gorge capable of supporting only limited partnerships.

There are only two major and several small commercial mines excavating the Reddistone Creek gravels. The Graham and Ayleward operations are the largest mining operations on the Reddistone Creek. Most of the creek will be worked out by 1980.

The largest mine is the Ayleward mine on the Reddistone, north of the Glen Innes airport. It is off the road to Emmaville north from Glen Innes, past the bridge over the Reddistone Creek about 2.6 miles north of the airport. The Wellingrove Road turn-off to the west is another 1.6 miles further. One mile west on the Wellingrove road is an unmarked fence gate, which gives access to a two mile long private road southward to the processing plant on the creek. The Ayleward claim controls the three mile valley between the bridge on the Emmaville Road and the Wellingrove Road. The flood plain averages a half mile wide along most of this section.

The processing plant has been operational at this site since 1974 when the company moved the machinery from worked out claims on Bullock Mountain. The new location has relatively rich, although thin, wash deposits. The brown-coloured gemmiferous gravel is but 9 to 12 inches thick and under 4 to 6 feet of topsoil. Effective utilization of mechanized earth moving equipment and reasonably significant concentration of sapphires favours the economic viability of the operation. Six to eight men operate the 200 yard a day mine and wash plant.

The Dunvegan mine (Figure 6) is a small two man partnership

of the Davidson family and is adjacent to the down stream extent of the Ayleward leases on the Reddistone. The two mile long access road to the property is about a quarter mile north of the bridge on the creek, 2.7 miles north of the Glen Innes Airport on the road to

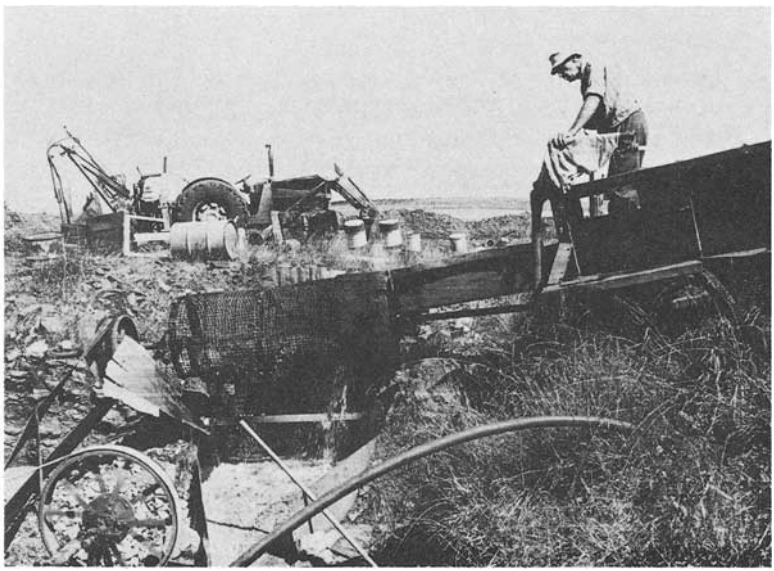

FIG. 6. A typical small wash-plant operated by a single miner. This plant at the Dunvegan Mine on the Reddistone Creek is capable of a daily processing of approximately 40 cubic yards of gemmiferous gravel. It relies on a tractor to power the trommel and pulsating jig.

Emmaville. The Dunvegan Sapphire Company claim is important as a portion of the property reserved for public digging upon payment of a daily fee of three dollars. The public access area is about a thousand feet upstream from the processing plant. Most of the digging area set aside for public use is very marshy and filled with backhoe excavation trenches. How successful individual diggers are on this property is unknown to this writer.

Down stream from the Dunvegan property, the Reddistone Creek has mixed topographic characteristics: steep valley walls with narrow ribbons of gravel as well as wide flood plains capable of supporting larger commercial enterprises. The north-eastern (down stream) limit of major commercial sapphire mining is the Bullock Mountain area, nine miles north of Glen Innes

(Figure 2). Bullock Mountain has the Reddistone Creek gravels on its western slopes and the Beardy Water gravels on the eastern slopes. Both of these areas have been extensively mined in the past. Production of fine quality, sizable, royal blue sapphires is characteristic of this section of the creek alluvium.

The most important of the Bullock Mountain mines is the Graham mining claim on the western slopes. It is reached by the road to Emmaville north from Glen Innes towards the airport. The first gravel road turn-off to the north-east gives access to Bullock Mountain. This turn-off is 2.3 miles south of the airport and 1.1 miles north of a wooden bridge over the Beardy Waters at northern city limits of Glen Innes. The gravel road continues north-eastward for approximately three miles to terminate on the 14 acre leases within the rugged Bullock Mountain slopes.

The alluvial fill on the claims meanders parallel with the course of the entrenched creek—only tens of feet wide in places but often several hundred yards. The property includes a half mile wide section of flood plain at its upstream limits. Most of the mining claim area has three or four feet of gem gravel under only inches of topsoil.

The Graham property was formerly owned and operated by the Stellar Mining Corporation, whose main plant is on Horse Gully near Sapphire. Stellar constructed a poorly designed plant that after six months of operation yielded only meagre returns. Attributing this to low concentration of sapphires in the gravel, Stellar sold the 'barren' ground to Graham in 1970. The new owners redesigned the recovery methods and proceeded to mine the rich sapphire concentrations. The Graham mining methodology is almost unique. It utilizes a power-shovel to excavate, while most other companies have backhoes and/or scrapers. Two men only are required to operate this high volume mine because of the excavation capacity of the power-shovel.

Casual Prospecting Deposits

Most commercial sapphire mines will tolerate private individuals to collect on their property *only* if politely approached well in advance, and then, again, only if no large groups are involved. In addition, the New South Wales Department of Mines

has designated several areas for public prospecting groups. There are four designated ones in the Inverell-Glen Innes district. The MacIntire Shire reserve on the Fraser Creek at Nullamanna in the Inverell area has been discussed previously. The Glen Innes area has three Department of Mines designated public reserves (Figure 2), as well as a privately controlled property available for public use. Public Fossicking Area No. 1 is reached by taking the Red Range Road east from Glen Innes for 8.5 miles to an old wooden bridge. The digging area is a 1000 foot long and 100 foot wide section of flood plain on the east bank. Dozens of two or three foot diameter pits excavated by sapphire prospectors delineate this area.

Public Fossicking Area No. 2 is reached by taking the New England Highway south from Glen Innes for 14 miles to the small town of Glencoe. A bridge over the Marowan River at the south end of town is adjacent to an extensive mile wide flood plain. The designated digging area is north-east of the highway bridge amid a meander bend of the river. The area is about 200 feet long and 100 feet wide. This area has a favourable reputation for availability of sapphires. Dozens of 3 to 5 foot diameter pits scar the area. The alluvial sediment is characterized by a proliferation of 6 to 8 inch boulders, and unfortunately, water seepage.

Public Fossicking Area No. 3 is reached by taking the New England Highway (Highway 15) south from Glen Innes for 1.5 miles and turning east onto the Glen Legh Road towards Blair Hill. The digging area is adjacent to the bridge over the Mann River, 13 miles south of Glen Innes and 2.3 miles past an abandoned commercial sapphire mining property on Blair Hill. The public digging area is the south-east bank of the Mann River. An area of about 500 feet square has been fenced off for this purpose. The area, however, is very overgrown and mostly topsoil and/or very fine gravel. There are very few trenches dug by sapphire prospectors.

These three public digging areas require the possession of a prospecting licence, obtainable for two dollars a year at any court house in the vicinity.

A private claim available for public prospecting upon payment of a daily fee is the Yarraford property (Figure 2). It is adjacent to the New England Highway, 6 miles north of Glen Innes and on the banks of the Beardy Waters.

Extractive Methodology

All producing claims for commercially exploiting the gem gravels in the Inverell-Glen Innes mining district utilize a wash plant to sieve and gravity separate the gemstones from the waste gravel (Figures 4, 6 and 7). The smaller wash-plants process between 40 and 60 cubic yards a day with a labour force of two or three men, whereas the largest syndicate operated plants have daily capacity of 2000 cubic yards and employ as many as 10 to 15 men.

The wash plant of the Stellar Corporation on Horse Gully is typical of the medium-sized plants. The wash is unloaded into one of the pair of 'dump boxes' at the plant: wide, shallow-angled chutes about 20 feet in dimension. Along the side of each chute is a hydraulic hose with 40 lb/inch^2 pressure to sluice the gravel into a series of troughs (Figure 7). The slurry is directed into dual rotating trommels with fine and coarse screens to separate the waste. The trommel's fine size retention mesh is a sixteenth of an inch. The slurry is directed from the trommel's conveyor belts into a jig pulsator, which is a gravity separator. The Stellar plant utilizes a three cell device, each cell about 4 feet deep and 3 feet square. Each

FIG. 7. Washing gemmiferous gravel from the dump box into a rotating trommel, where the fine gravel fraction is separated out for additional processing.

FIG. 8. Cleaning the pulsating jig traps of sapphire-corundum-zircon concentrate on the Reddistone Creek.

water-filled cell has a screen through which water is circulated up and down by an undulating piston. This pulsating water forces the heavier gemstones in the gravel to settle on the screen and be subsequently trapped behind a series of riffles (Figure 8). The lighter, barren waste material continues unobstructed over these and is directed towards a settling pond and waste dump.

The operation at the Graham plant on Bullock Mountain is similar and with only minor variation. The gravel is dumped and washed into a 30 foot long, 8 foot diameter, trommel. The sized gravel, free of sand and boulders, is then split into two pulsating jigs on either side of the trommel. Each jig has three pulsating cells. The plant has a daily capacity of 500 cubic yards. The processing

plant of the Ayleward mine on the Reddistone Creek, on the other hand, uses a pulsating jig with 12 traps built into the bottom of a 12 foot long, 5 foot wide trough. Each trap is 2 feet long and 6 inches wide and deep. The traps are cleaned twice daily and the concentrate is shovelled into five gallon pails.

The smaller claims operated by two or three men normally have a wash plant capable of processing approximately 40 cubic yards a day. Many on these Fraser Creek claims use a tractor as the power source for the trommel, pulsating jig and related machinery (Figure 6). The Brown plant utilizes an 8 foot long, 2.5 foot diameter, trommel with a 0.75 inch boulder reject mesh. A flume feeds the gravel from the trommel into a two cell pulsator.

The processing plant of the Davidson family-operated Dunvegan Mine has a daily capacity of 50 to 60 cubic yards. A tractor is geared to drive the single cell pulsating jig and 8 foot trommel.

Production, Sorting and Marketing of the Sapphire-Zircon Concentrate

The gemmiferous gravels of both the Inverell-Glen Innes district, New South Wales, and the Anakie District, Queensland, are processed for marketable sapphires, corundums, diamonds and zircons. Only the gem quality sapphires, however, have appreciable market value, and the other gemstones are considered by-products that may be stockpiled to await sufficient demand. The diamonds are industrial grade only and relatively rare.

Production of Concentrate

Production of the heavy mineral concentrate (unsorted mine-run gemstones) varies widely throughout the Inverell-Glen Innes district.

At the Stellar Corporation mine on Horse Gully, the gemstone proportion is usually 20 per cent of the jig concentrate. Between 15 and 20 per cent of this, and sometimes as much as 50 per cent, is zircon. The finer quality blue-hued sapphires are associated with the higher percentages of component zircon at the Stellar plant. Some garnet and an occasional industrial diamond are also recovered, as well as the ubiquitous opaque corundum and spinel. The Stellar wash plant utilizes a heavy liquid separation tank for a

finer density separation of the concentrate after removal from the pulsator jig traps. Most other commercial plants bypass this step in favour of direct hand-sorting. The 'Cyclone 60' media separate the hematite and basalt fragments from the gem material in the heavy mineral assemblage. Daily production varies widely, but the Stellar plant averages 250 pounds of mixed gemstone concentrate for direct shipping to the company offices. In Sydney the concentrate is sorted, graded and accordingly finished into marketable faceted gemstones.

Most of the Graham mine concentrate yields an ounce of sapphire to 10 cubic yards. Sometimes, very rich concentrates with as much as an ounce per cubic yard are encountered in depressions of the bedrock surface. The plant produces 20 to 30 gallons of jig concentrate a day. This is shipped to Glen Innes for sorting and grading. The concentrate is fed into a smaller, table-sized version of the pulsating jig for a finer separation, then to a magnetic separator to remove most of the black spinel and finally onto a light table to hand-pick the gem sapphire from the corundum. About 20 per cent of the concentrate is marketable sapphire, mostly deep blue and unusually free from silk. The concentrate fines, less than an eighth inch, are saved and sold for industrial corundum abrasive. Almost no garnets are recovered from the Graham concentrates, but there are sizable quantities of clear to reddish brown zircon. It is common to recover sizable, flawless, zircon crystals upwards of a hundred carats.

Half of the concentrate from the pulsating jig is a non-gem corundum and spinel, and half varying proportions of gem sapphire and zircon. At least half of the gem sapphires from the Saunders and Scheb section of the Fraser is a deep royal blue, about a third green or mixed blue and green, and the remainder mostly light yellow.

The Brown plant recovers an average of three ounces of commercial grade sapphires daily. They have recovered less than an ounce on poor days, but sometimes as much as eight ounces. Half to three-quarters of these stones are blue and the remainder mostly yellow-green. There is considerable zircon. The sapphires produced from these mines are rough fragments of irregular shapes, but infrequently crystal sections with recognizable faces are recovered. Infrequently recovered are elongated, inch-long prisms, pointed to resemble fangs: hence, the local term 'dog's teeth'.

Sorting and Grading

The smaller mines with two or three men in partnership generally sort and grade at the mine site. The larger volume mines, financially backed by major syndicates, ship their concentrate to a central office for sorting and grading.

Procedures of sorting the concentrate vary considerably. The first step is to separate fractions of the concentrate: the ironstone, rock fragments, quartz pebbles, ilmenite and black spinel from the corundum, sapphire, zircon, topaz, garnet and an occasional industrial diamond. This separation involves hand-picking on a light and/or mirror table, although larger volume processes utilize heavy-liquid media and magnetic separators. The gem fraction of the concentrate remaining is then sorted, usually but not always into various size fractions, and then graded. The commercial quality sapphires are separated from the corundum and other associated gemstones. At this point, the entire quality range of sapphires are separated: any corundum crystal reasonably semi-transparent or better. The remaining opaque corundum and zircon may be sorted and graded depending upon existing market conditions.

All sapphires separated out constitute a 'mine run' and sometimes are sold by the ounce by small mine operators to the foreign buyers visiting the fields. The mine run is often graded into 'firsts', 'seconds', and 'thirds' to bring a higher price. These grades refer to quality and may be further subdivided into as many as six or eight size categories by the large mines or two or three by the independent operators.

Size categories for sapphires are designated by number of pieces per ounce, e.g. 100, 50 and 25 pieces per ounce. An individual crystal is rarely sold and must be a particularly valuable stone.

The 'firsts' are those stones with a good, strong light to medium-blue colour and with only minor light coloured silk, if any, present. They are essentially with no visible flaws. The larger size categories, those comprising a parcel of less than 50 pieces per ounce are often termed 'specials'. 'Seconds' have only a fair blue colour without serious flaws or cracks and perhaps minor detrimental silk, or are poorly shaped and required difficult cutting procedures. Some dark blue-black stones may be considered in this category. 'Thirds' are those stones having bad cracks and flaws,

heavy silk concentrations or are off-coloured. A stone in this category can usually be cut but is of poor quality and value. Stones that are a combination of blue and green, or blue and clear are termed the 'parti-colours'. They are usually classified with the 'thirds'. The combination of 'firsts' and 'seconds' constitutes usually around 60 per cent of the mine run.

Comments on the Australian Sapphire Market

Australia supplies approximately eighty per cent of the world market for commercial blue sapphires. Foreign buyers on the Australian fields are generally interested only in the blue hues. Sapphires of yellow and green colours, less so for the parti-coloured, are sold on the local Australian market. There is a substantial international demand, however, for the relatively rare golden yellow sapphires, the values of which may approach the sapphires of 'royal' blue hues.

Australian blue sapphires currently dominate the world sapphire market, but largely because of the rapidly declining production in south-east Asia. Certain optical qualities that characterize Australian stones are considered detrimental: the significant degree of dichroism, and the overall dark blue to blue-black hue that lacks brilliance and in fact is often dubbed as 'dead looking' in artificial light. Most stones display a strong, deep-hued royal blue colour in the direction of the *c*-crystallographic axis and have a blue-green hue on the *a*-axis. This green tint darkens the overall appearance and must be compensated in the cutting by shallower angles yielding a thinner stone. The Anakie (Queensland) district stones are particularly noted for their dichroism, though the 'Scrub blues' from the Scrub Lead of this district tend to be a lighter hue than average and thereby are favoured in commercial markets. The most brilliant Australian sapphires, free from silk and with minimal influence of the green dichroism, are the Reddistone Creek royal blues. However, these crystals are hampered by smaller than average sizes.

Perfection among Australian sapphires is the royal blue hue. It is considered by many to be inferior to the more brilliant, lighter 'cornflower' hues of Kashmir and Cambodia. Recent heat-treating experiments have been very successful in artificially lightening the deep blue-black hues of Australian stones as well as removing some

of the silk. These treated stones are difficult to distinguish from natural shades in a faceted gemstone. The risk is serious that such treatments will partially undermine this sensitive market. Heat treatment of inferior grades of sapphires is widely practised and the process is being introduced as well into the small Australian commercial lapidary industry.

Gem dealers from Thailand dominate the commercial trade in Australian sapphires. Virtually all foreign buyers of the sapphires are Thais, although there are a few infrequent buyers from Hong Kong, Japan and Western Europe. Some of the very largest mines, however, e.g. Stellar mine on Horse Gully, do have their own cutting facilities and marketing outlets throughout Western Europe and North America. It has only been since the early 1960s that the buyers from Bangkok have established a sufficient world marketing system to encourage reasonably continuous production on the fields. Since the onset of the Great Depression in 1929 and up until 1959, there had been only relatively insignificant commercial interest. Australian sapphires were considered too dark and lacking in brilliance to be much favoured on the major European and North American markets. This revitalized market, however, has been the virtual monopoly of the Bangkok gem dealers. This has continued because the Australian rough can be faceted in Asia for only a few cents per carat, compared with 8 to 10 dollars a carat if faceted by commercial cutters in Australia.

The sapphire market conditions are generally unsatisfactory because of the rapid and extreme fluctuations in what the buyers on the fields are willing to pay for rough sapphires. Wholesale prices may decline on the fields as much as 50 per cent over a couple of months, and some of the price depressions may continue for a year or more.

A particularly bad recession in sapphire prices occurred during the 1974-1975 world wide industrial recession. The price for a mine-run ounce of sapphire fell from about 150 dollars (Australian) to less than 80. This decline may have been triggered by voluminous overproduction of some of the giant corporations like Dominions' 2000 yard daily capacity wash plant on the Fraser. Prices in a buoyant market for the finest quality rough have been as high as 4000 dollars an ounce for 'special' grades of 'firsts'. Finished faceted stones of the rich royal-blue will wholesale at 60 to 80 dollars a carat.

Attempts have been made in recent years to stabilize the sapphire market from fluctuation, as well as to assert more control on the world market by the producers. Some miners have tried to form a co-operative marketing system, but such attempts have failed or been only short-lived.

During the early 1970s there was an increased interest in, and value attached to, the fancy coloured sapphires. Nevertheless, it was not sufficient to encourage establishment of systematic markets overseas. Markets for the finer specimens of yellow, green and parti-coloured sapphires are lucrative in Australia, but only to a lesser extent in the United States. The Australian blue may not be perfection to the discriminating gemmologist familiar with the classic Asian sources, but the golden yellow from the Willows field and the green from the Tomahawk Creek areas of Queensland are without equal. The Ceylon yellow is too light and the Thailand yellow is more of an amber shade; Anakie yellow and green sapphires are readily becoming collectors' specials. White sapphires have been found but are extremely rare.

A particularly Australian sapphire is the black star, a dark stone with a copper-coloured asteriated sheen. Star sapphires are generally not widely recognized by the miners during field sorting and hence are not distinguised from the junk corundum. Australian black star sapphires achieved a small degree of desirability on the North American market in the 1960s but have since lost their appeal. They are difficult to sell at present, Opaque corundum will generally sell for 10 to 20 dollars a pound for use in precision instruments and gramophone needles.

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[*Manuscript received 19th November, 1977.*]

GEMMOLOGICAL ABSTRACTS

BALL (R. A.), CLAYTON (N.). *Opal references and abstracts Part II.* Australian Gemmologist, **13**, 9, 307-10: **13**, 10, 334-6: **13**, 10, 363-6, 1979.

An extended bibliography of opal literature, the first part of which was published three years ago. R.K.M.

BANK (H.). *Changierender Granat (Mit Farbwechsel) für Alexandrit ausgegeben.* (Garnet with colour change sold for alexandrite.) Z.Dt.Gemmol.Ges., **28**, 1, 41-2, 1979.

The stone being discussed is blue-green-brown to pink violet. It was easily identified as garnet by its refractive index. E.S.

BANK (H.). *Edelsteine aus Brasilien.* (Gemstones from Brazil.) Z.Dt.Gemmol. Ges., **28**, 1, 21-34, 1979.

Extensive bibliography and map of Brazil showing deposits. Short historical summary; also short geological survey. The gems are listed according to their chemical compositions. E.S.

BANK (H.), LEDIG (R.). *'Honig gelbe' Topaz-Ulexite Dublette als Chrysoberyll Katzenauge ausgegeben.* (Honey-yellow topaz-ulexite doublet sold as chrysoberyl cat's-eye.) Z.Dt.Gemmol.Ges., **28**, 1, 43, 1979.

A cabochon honey-yellow stone showing chatoyancy sold as a chrysoberyl cat's-eye was seen to be topaz-ulexite under the microscope. E.S.

BANK (H.), RODEWALD (H.). *Schleifwürdiger roter durchsichtiger Chlorit: Kämmererit.* (Cuttable red transparent chlorite: kammererite.) Z.Dt. Gemmol.Ges., **28**, 1, 9-40, 1979.

Originally named after a mine director in St Petersburg in 1841—the original crystal came from Bisersk, was red-violet and had a mica-type shimmer. Hardness 2-2½. Very strong cleavage, and is therefore difficult to cut. E.S.

BANK (H.), SCHMETZER (K.), PROBST (S.). *Vanadiumgrossulare mit hoher Lichtbrechung (uber 1.75).* (Vanadium grossularites with high R.I. over 1.75.) Z.Dt.Gemmol.Ges., **28**, 2, 70-2, bibl. 1979.

The very intensive dark green crystal from East Africa shows an RI of 1.758 which is tabulated and compared to other vanadium grossularites, synthetic grossularite and goldmanite. E.S.

BLAK (A. R.), ISOTANI (S.), WATANABE (S.), MORATO (S. P.). *Espectros infravermelho da água e dióxido de carbono em águas marinhas e halbanitas brasileiras.* (The infrared spectrum of water and carbon dioxide in Brazilian aquamarines and halbanites.) Gemologia, **23/24**, 45/46, 61-6, 3 figs, 1978.

Infrared spectra of aquamarines and dark blue irradiated beryl ('halbanite') are discussed and illustrated. M.O'D.

BORELLI (A.). *Diamanti di colore fantasia: techniche per rivelare se la colorazione sia naturale o ottenuta per trattamento con radiazioni.* (Fancy-coloured

diamonds: a technique for testing whether the colour is natural or results from irradiation.) La Gemmologia, **5**, 1/2, 26-35, 12 figs, 1979.

Spectra of diamonds both natural and treated are shown in this study of the effects of irradiation upon colour and testing. M.O'D.

BOSCARDIN (M.), CECUZZI (B.), DE MICHELE (V.). *Osservazioni sui vetri naturali italiani.* (Observations on Italian natural glasses.) La Gemmologia, **4**, 3/4, 13-29, 15 figs, 1978.

Locations of obsidian in Italy are given and tables of constants provided. Specimens in thin section are illustrated. M.O'D.

BROUGHTON (P. L.). *Economic geology of Australian gemstone deposits.* Min. Sci. Eng., **11**, 3-21, 14 figs (7 in colour), 1979.

The diamondiferous and the sapphire-zircon gem gravels of eastern Queensland and New South Wales are buried Tertiary fluvial deposits preserved from erosion by overlying basalt flows; the igneous sources of the gem fraction are unknown. The Cretaceous Great Artesian basin across western New South Wales, Queensland, and northern South Australia is host for the precious opal deposits. In eastern Queensland chrysoprase veins are associated with serpentine; emerald deposits are known in the Precambrian Shield of Western Australia. R.A.H.

BROWN (G.). *The hazards of gemmology.* Australian Gemmologist, **13**, 10, 325-9, 1979.

An unusual paper, but in abstracter's opinion, a necessary one, drawing attention to the dangers of electrical installations, flammable liquids, poisonous nature of most gemmological liquids and radiation hazards from UV and x-rays. Excellent suggestions are made to minimize the risks to health involved, and advice on first aid, including resuscitation procedures for those whose breathing may have stopped following electric shock or other injury, is given. R.K.M.

BROWN (G.). *Turquoise—natural, treated, imitation or synthetic.* Wahroongai News, 21-34, April 1979.

Deals systematically with most aspects of this difficult gem material and gives some account of the formation of the natural material. A useful bringing together of information so far known on the subject. (The journal itself suffers from the same misprint problem as the Australian Gemmologist. Apparently produced by stencil cutting, this could be very easily corrected.) R.K.M.

CASSEDANNE (J.-P.), CASSEDANNE (J.-O.). *La mine d'améthyste de la Grota do Coxó; une merveille inconnue.* (The amethyst mine of La Grota do Coxó; an unknown marvel.) Revue de Gemmologie, **59**, 2-5, 7 figs, 1979.

The location is near Jacobina in the state of Bahia, Brazil. Amethyst is found in geodes with the tips of the crystals providing gem-quality material. M.O'D.

CROWNINGSHIELD (R.). *Developments and highlights at GIA's Lab in New York.* Gems & Gemology, **XVI**, 5, 147-54, 19 figs (some in colour), 1979.

Welcome return of this feature, although illustrations are no longer scattered at relevant points in the text. Deals cautiously with 'heat-treated' blue sapphires.

(Reports of this process have been around for a number of years but always at third hand. Doubt must exist whether there is a successful process even now.) Some stones showed signs of cracking due possibly to heat; greenish fluorescence, no iron absorption band (one stone showed a weak absorption similar to that seen very occasionally in deep-coloured synthetics).

Near-round Biwa-ko tissue cultured pearls, a flawless alexandrite of over 4 carats, red chrysoberyl which had no green daylight colour, also described. A 37 carat cubic zirconia seen. Parcels of this gem received for grading as diamonds, proved by size/weight ratio. Green fluorescence under long UV for pink spinel, and blue fluorescence of fancy brown old-mine cut diamond with 5040Å absorption are described. A blue treated diamond showed bright transmission in place of 5040Å absorption. Orange fluorescing pale pink diamonds have a transmission line at 5750Å, same as in treated pinks. Suggested that all treated pinks start as faint pink with orange fluorescence. Zirconium oxide submitted as diamond for grading responded to ink test as diamond. An obvious diamond responded to the same test as a synthetic imitation. Both stones had been coated; the diamond needed acid to remove coating. Good results reported from freezing techniques to improve absorption spectra (cf. London Laboratory, which has been using this for some time).*

Synthetic amethysts purchased for class use contained about 20% of natural stones. Since prices are similar such mixtures can be expected (did they take opportunity to do an UV transparency test?). A 2.71 taaffeite examined, pinkish grey-purple in colour. Needle-like inclusions seen in Verneuil synthetic ruby. Beryl beads with green plastic coating turned red under enerald filter; while a large 'emerald' crystal from Bogota proved to be a quartz crystal cracked apart and hollowed to take a smaller quartz, the interstices being filled with similar green cement. Large air bubbles included, and epoxy resin revealed by UV test. Green graining seen in natural diamond. R.K.M.

DANIEL (P.). *Gem engraving—a dying art.* Industrial Diamond Review, 400-1, 4 figs, Nov. 1979.

A report on the work of Nicholas Lambrinidis, who is probably now the only living European exponent of Glyptography, the art and science of gem engraving. The engravings are made using diamond electroplated burrs of various sizes and shapes in a modern high-speed dental handpiece. Burr life is typically one week on a sapphire and two weeks on a topaz. The design is either incised as an intaglio, or engraved in relief to form a cameo. Mr Lambrinidis, who was a pupil of the British artist and gem engraving specialist Cecil Thomas, is currently setting up a Glyptic Section in the Goulandris Natural History Museum, Athens. P.G.R.

DIEHL (R.). *Djevalith, Fianit, Zirkonia—Was ist das?* (Djevalite, fianite, zirconia—what is it?) Z.Dt.Gemmol.Ges., **28**, 1, 3-20, 8 diagrams, 5 figs, bibl, 1979.

The following is the author's summary. Cubic stabilized zirconia appears to become the most important material to imitate diamond. The high-temperature cubic phase of ZrO_2 can be stabilized at room temperature via the incorporation of certain stabilizing oxides such as Y_2O_3 or CaO. It is deduced from the pertinent sections of the phase diagrams that the phase transformation temperatures are sub-

*See Scarratt (K.), Investigating the visible spectra of coloured diamonds, J.Gemm., XVI (7), 433,—Ed.

stantially lowered by the stabilizers, whereby transformation into a non-cubic modification is prevented. Single crystals up to 8 × 3 × 3 cm are grown by means of the skull melting method. This technique uses a water-cooled crucible which contains the inductively heated melt. A layer of unmolten material protects the container walls from melt attack. Crystallization is initiated by slow cooling. The crystallized product is marketed by different producers who have given the products special trade names, the best known being djevalite, fianite and zirconia. E.S.

DIRKS (J.). *The renaissance of the art of scrimshaw.* Gems & Gemology, **XVI**, 5, 142-6, 16 figs in colour, 1979.

J. Dirks is an artist of considerable skill who has revived the old whalers' art of engraving on bone and ivory, using, perhaps, more colour than in the antique pieces. In these days of animal conservation it is just as well that she emphasizes that only fossil ivory is used. R.K.M.

DODSON (J. S.). *The brilliance, sparkliness and fire of several diamond simulants.* Optica Acta, **25**, 8, 701-5, 4 figs, 1978.

Using a computer program to assess the optical goodness of a range of diamond simulants, in terms of their brilliance, 'sparkliness' and fire, it is shown that strontium titanate is better than diamond, and that for the round brilliant-cut style, the degree of optical goodness is proportional to the refractive index of the material. It is, however, acknowledged in the article that public opinion favours whiter 'sparkles', and that the sparkle of strontium titanite is considered by many to be vulgar. Cubic zirconium oxide (called ZOC in the article) is claimed to be the best of the more acceptable simulants, although according to the computer analysis its general brilliance, sparkliness and fire are lower than those of strontium titanite and diamond. No comparative constants are given for the hypothetical suite of materials simulated by the computer, which comprised strontium titanate, YAG, GGG, synthetic spinel, plus General Electric's Yttralox and two glasses, TiF6 and BK7, made by the Schott optical company. P.G.R.

DODSON (J. S.). *The brilliance, sparkliness and fire of some modifications to the round brilliant cut diamond style.* Optica Acta, **25**, 8, 693-99, 11 figs, 1978.

The difficulty of polishing 57 facets on a diamond having a girdle diameter in the region of 2mm has prompted the writer to investigate several simplifications of the brilliant-cut design. By using a computer program to assess the brilliance, 'sparkliness' and fire of these modifications, a conclusion is reached which states that diamonds with more than eight crown and pavilion facets are acceptable, but inferior, substitutes for the full brilliant-cut stone. P.G.R.

DODSON (J. S.). *A statistical assessment of brilliance and fire for the round brilliant cut diamond.* Optica Acta, **25**, 8, 681-92, 19 figs, 1978.

In assessing the optical goodness of the diamond brilliant cut, the writer establishes criteria of brilliance, fire and 'sparkliness' (the latter coined term being oddly at variance with the academic language of the article, and referring to the scintillation of the diamond produced by its movement). In order to quantify these qualities, the diamond is assumed to be spinning about its axis and surrounded by a hypothetical sphere, centred on the table facet. The optical qualities of brilliance,

fire and sparkliness are represented by the statistical properties of the intensity distribution of reflected light on the sphere. The representation is purely mathematical, and is derived by calculating the final positions and intensities on the sphere of rays reflected from the diamond's facets. The effect of fire is arrived at by tracing the rays at various refractive indices. Unfortunately, the position of the incident light on the diamond is lost in the approximation process, and it is not therefore possible to take account of visible girdle or dark table effects.

A computer program was written to model the hypothetical spinning diamond and its surrounding sphere, and to permit rapid assessment of the effects on the diamond's brilliance, fire and sparkliness, of varying the pavilion-half factor (i.e. the ratio between the lengths of the pavilion main and half facets), the spread of the table, and the pavilion angle. The results confirm that the traditional ideal brilliant cuts for diamond are satisfatory, but indicate that an equally attractive, if not improved, appearance could be obtained with at least one other set of proportions. To exploit this, a new design is proposed with a table spread of 40-50%, a crown height of 15%, a pavilion angle of 53°, and a pavilion-half factor of 0.5. The article contains no mention of any attempt to test these proportions in practice.

The project was supported by the Diamond Trading Company (Pty) Ltd. P.G.R.

FRANCO (R. R.). *As substâncias naturais e artificiais usadas como imitação do brilhante.* (Natural and artificial substances used as diamond imitations.) Gemologia, **21**, 41/42, 57-63, 1975.

Reviews the 'classic' diamond imitations, including composites, M.O'D.

FUQUAN (W.). *Precious stones found in China.* Lapidary Journal, **33**, 3, 694-6, 2 figs, 1979.

The People's Republic of China is rich in gemstones. These include diamond, ruby, sapphire, chloromelanite, topaz, amber, various kinds of quartz and turquoise. M.O'D.

GEORGE (C. D.). *Cultivation of pearl shell and pearls in the Indopacific region.* Lapidary Journal, *Part 1,* **33**, 1, 72-84, 5 figs (1 in colour); *Part 2,* **33**, 2, 48, 498-517, 5 figs, 1978.

The first two parts of a series intended to cover the history and current workings of pearl and pearl shell in the Indopacific region. The first paper lists the pearl-making oysters, the main shell fisheries and the early production of the various countries in the area. The second part continues the account begun in the previous issue with a special note on the discovery of the spherical pearl technique. M.O'D.

GILSON (P.). *Shop practice for gem cutting.* Lapidary Journal, **33**, 3, 826-8, 1979.

Details are given of the preferred media for polishing and cutting stones manufactured by the author. M.O'D.

GREENSPAN (J.). *A collection of Chinese carved jade.* Lapidary Journal, **33**, 3, 668-90, 8 figs (4 in colour), 1979.

Describes and illustrates specimens from the jade collection of the author. All are carved and dates given. M.O'D.

HANNEMAN (W. W.). *Refractive index determination by the method of B. W. Anderson.* Lapidary Journal, **33**, 3, 800-2, 8 figs, 1979

This involves immersion and observation of the characteristic shadow bordering the stone. Examples are illustrated. M.O'D.

KELLY (R. B.). *Rhodonite or pink jasper.* Australian Gemmologist, **13**, 9, 291-5, 1 map, 1979.

An interesting account of two materials of similar appearance from localities in the Coomera District of Queensland, and of the investigations which identified them respectively as jasper and rhodonite, the latter with high silica content. Of particular interest is the coincidental mineral history revealed quite casually in this and similar Australian papers. The rhodonite sites were first worked as rich gold deposits. Text refers to a second map which is not published. R.K.M.

KERR (B.). *Fashioning cubic zirconia.* Gems & Gemology, **XVI**, 5, 155-7, 3 figs in colour, 1979.

Each new material presents problems to the cutter. This paper suggests solutions to those arising with cubic zirconia. Problems mainly with polishing. Work dry on ceramic lap with 'spray' diamond, at slow speed, wiping cutting residue away to avoid scratching. Helpful paper for amateur and professional lapidary alike. (Here there has been some trouble with cleavage under dopping heat.) R.K.M.

KONNO (H.). (A report of the 11th General Meeting of the International Mineralogical Association.) J. Gemm. Soc. Japan, **6**, 1/2, 29-33, 7 figs, 1979. (Japanese with English summary.)

Describes a visit to Lake Baikal, Siberia, and gives notes on charoite. M.O'D.

LESH (C.). *Quartz: myth and magic, science and sales.* Gems & Gemology, **XVI**, 6, 174-8, 1979.

A strange paper, attempting to apply logic to superstition and to equate the radio frequency crystal with the powers of the medicine man; the helix of quartz structure with the spiral (not helical!) tombs of Celts; and Stonehenge and other megalithic circles with the quartz analogue watch of today. R.K.M.

MALLAS (A. A.). *Kashan—creators of beauty.* Lapidary Journal, **33**, 6, 1302-4, 4 figs, 1979.

Describes the processes used for manufacturing ruby by the flux-melt process and its subsequent placement on the market. M.O'D.

MIÚRA (Y.). (Iridescence in alkali feldspar.) J. Gemm. Soc. Japan, **5**, 3, 15-25, 17 figs, 1978. (Japanese with English summary.)

From analyses made with EPMA and observations with the electron microscope it is seen that iridescent alkali feldspars show exsolution lamellae structures which produce the iridescence with compositions from Or(thoclase)$_{20}$ or Or$_{70}$.The colour changes from blue to yellowish-orange as the orthoclase content increases. A whitish blue colour is produced with compositions from Or$_{25}$ to Or$_{33}$. Iridescence therefore is the result of interference and scattering according to the state of the lamellar boundaries. M.O'D.

MOACYR (J.), COUTINHO (V.), SVISERO (D. P.). *Nota sobre algunas ocorrencias de variscitas brasileiras.* (Note on some Brazilian variscite occurrences.) Gemologia, **21**, 41/42, 52-6, 5 figs (4 in colour), 1975.

Brazilian variscite has been found in Rio São Tomé near the frontiers of Mato Grosso and Amazonas; further specimens have been found in the pegmatite of Proberil, close to Linopolis, Minas Gerais. M.O'D.

MUIJE (P.), (C. S.), (L. E.). *Colourless and green grossularite from Tanzania.* Gems & Gemology, **XVI**, 6, 162-73, 6 figs, 1979.

A thorough investigation of these gems. Colourless is by far the rarer, but of less interest to trade. These were colour-graded against diamond although tints of grossularite were green while those of diamond were yellow. Green stones in a range from near colourless to deep green were analysed by x-ray spectrum analysis, establishing that all conformed closely to the ideal grossularite formula. Increases in V_2O_3, and to a much smaller extent of Cr_2O_3, were noted as the colour deepened, the latter being undetected in near colourless and lighter shades of green, suggesting that this colour is almost entirely due to vanadium. Single RI 1.731; SG 3.62; various inclusions, none of which is characteristic. R.K.M.

NASSAU (K.). *An examination of the new Gilson 'coral'.* Gems & Gemology, **XVI**, 6, 179-85, 5 figs, 1979.

An investigation of Gilson coral, undertaken with Dr Nassau's usual care, which assigns the substance, on several grounds, to an imitation category rather than a synthetic one. About eight shades, from almost white to deep ox-blood are available and four of these were examined in detail. The imitation is less dense (2.44) than natural coral (2.6+), the former proving to be absorbent on prolonged immersion, and more easily breakable that the natural material. Presence of silica and iron noted in Gilson coral, not found in natural. It also lacks normal structural veining often seen in the natural product. R.K.M.

NELIŠEROVÁ (E.). (Evaluation of synthetic diamond quality on the basis of crystallography and dynamic strength.) Zborn. Slov. Nár. Múz., **71**, 29-77, 20 figs, 1977. (In Slovak, with Russian and German summaries.)

The aim of this work is to find out whether a relation (functional dependence) exists between the morphological quality of synthetic diamonds and their dynamic strength. It is possible to compare mutually both these parameters as they characterize a particular physical quality of a representative (complex) of synthetic diamonds, thus both have a statistical character. From comparison of index numbers (characterizing crystallomorphological quality of diamonds) and Friatest numbers (characterizing dynamic strength) by means of regressive analysing methods, logarithmic function dependence has been established. Š.D.

O'DONOGHUE (M.). *A gem tour to Scandinavia and the USSR.* Lapidary Journal, **33**, 6, 1416-22, 4 figs, 1979.

A visit to the major gem and mineral locations in Norway, Sweden and Finland is described with additional notes on visits to museums in the U.S.S.R.

(Author's abstract) M.O'D.

O'DONOGHUE (M.). *A study in crystal structures of gemstones.* Gem World, **6**, 2, 33-46, 1979.

Coordination numbers, close packing, bonding and common structures of some gem materials are described and explained in this compilation by the publishers of *Gem World* from several of the author's *Gemmological Newsletters.* (Author's abstract) M.O'D.

ORLOV (Yu. L.). *Polygenesis and typomorphism of diamond in kimberlite deposits.* International Geology Review, **21**, 8, 975-81, 1979.

Investigation has shown that there are different and classifiable types of diamond crystal occurring in kimberlites and it is suggested that different conditions of crystallization apply to each variety. This study is confined to diamonds from xenoliths in deep-seated rocks. M.O'D.

REAM (L. R.). *The Thomas Range, Wah Wah mountains and vicinity, western Utah.* Mineral. Record, **10**, 5, 261-78, 34 figs (5 in colour), 1979.

The areas described and mapped include sites for red manganiferous beryl and for topaz, both of which are illustrated. Red beryl occurs in rhyolites and is found either as clusters of primatic crystals along fracture-controlled veins or as tabular crystals in vugs. M.O'D.

ROBERTSON (A. C. D.). *Porous Gilson synthetic black opal.* Australian Gemmologist, **13**, 9, 297-9, 6 figs in colour, 1979.

A report on a Gilson stone from an unusually porous batch (cf. findings of Jobbins *et al.*, J. Gemm., 1976, XV, 2, 73-5.). R.K.M.

ROLANDI (V.). *Considerazioni particolari sul sistema DIN 6164.* (Special consideration of the system DIN 6164.) La Gemmologia, **4**, 3/4, 42-8, 2 figs, 1978.

The DIN 6164 system is one of the West German standards; it provides a method of measuring colour and has some application to gem description. M.O'D.

RUSKONÉ-PONCET (E.). *Les principaux centres de taille des pierres précieuses et fines dans le monde.* (The chief cutting centres of fine and precious stones in the world.) Revue de Gemmologie, **59**, 7-9, 3 figs (1 in colour), 1979.

Short notes on Idar-Oberstein, Jaipur and centres in Thailand are given with historical background. M.O'D.

SALA (J. della), TUCCILO (R.). *Two interesting treated diamonds.* Gems & Gemology, **XVI**, 4, 125-6, 2 figs, 1978.

Two dark tourmaline-green diamonds showed no 'umbrella' markings, nor absorption spectra for treated stones. Scintillograph test also negative. They were identified as radium-treated by exposure to light-tight photographic film. (Fig. 1 shows a strangely uncharacteristic sharp eight-spot 'autoradiograph' for such a treated stone and in abstracter's opinion this stone may well have been naturally coloured. Similar sharp images have been seen when a stone has been placed on film while using the wrong safe-light. Autoradiographs are not usually sharply patterned in this way.) R.K.M.

SCHÄFER (W.). *Auf den Spuren der Garimpeiros: Smaragdsuche in Brasilien.* (On the tracks of the garimpeiros—emerald-seeking in Brazil.) Mineralien Magazin, **3**, 4, 213-18, 7 figs in colour, 1979.

Describes the work of emerald miners in the Carnaiba area of Bahia, Brazil. M.O'D.

SCHÄFER (W.). *Glücksstein des November. Auf einer brasilianischen Topasmine.* (November birthstone: from a Brazilian topaz mine.) Mineralien Magazin, **36**, 323-6, 6 figs in colour, 1979

Describes a visit to a number of topaz mines in the Ouro Preto area of Minas Gerais, Brazil. A map is included. M.O'D.

SCHMETZER (K.), BANK (H.). *Bluish-green zoisite from Merelani, Tanzania.* Gems & Gemology, **XVI**, 4, 121-2, 1978.

Mainly concerned with pleochroic changes in blue zoisite under heat treatment. Colour change and reduction of pleochroism is due to the removal of an absorption band in the blue. This causes the Z crystallographic direction to yield blue instead of yellow-brown. Bluish-green zoisite has a different pleochroism but also moves towards blue when heated. R.K.M.

SCHMETZER (K.), BARTELKE (W.). *Schleifwürdiger Diaspor aus der Türkei.* (Cuttable diaspore from Turkey.). Z.Dt.Gemmol.Ges., **28**, 2, 69, 1979.

Diaspore is a small constituent of bauxite; it is a rhombic crystal, leafy or scaly; sometimes also needles occur. The crystals are colourless, sometimes grey, yellow-brown or red (when containing Mn). Larger crystals from Chester, Mass., U.S.A., were described in 1865 by Shephard, in 1886 by Dana and in 1964 by Guillemin; a large crystal 30 × 40cm from this locality is to be found in the Harvard University collection. The diaspore was given to the authors in 1977: tabular, light yellow, transparent and of up to 8cm in length , these cleavage pieces were nearly colourless. The material is very brittle and difficult to cut, but faceted stones of up to 0.25ct were produced. E.S.

SCHMETZER (K.), KRUPP (H). *Neue Beobachtungen en Edelsteinen aus Ostafrika.* (New observations of gemstones from East Africa.) Z.Dt.Gemmol. Ges., **28**, 1, 35-37, bibl., 1979.

Three gemstones are discussed. Especially large and clean spessartines from the Taita Hills in Kenya were up to 5cm large and owe their intensive orange-red to coloration by Mn^{2+}. Smaragdite is chrome-containing actinolite from Tanzania. Finally the authors describe an individual cabochon with strong cat's-eye effect, 3.2ct, light green, which was found to be diopside. E.S.

SCHMETZER (K.), OTTEMANN (J.), BANK (H.), KRUPP (H.). *Transparent bluish-green kornerupine from East Africa (Kenya and Tanzania).* Gems & Gemology, **XVI**, 4, 118-20, 1978.

A report in detail on bluish-green and blue kornerupine from these localities, some of which have been offered as tourmalines, garnets or sillimanites. Colour is due to iron, chromium and vanadium. Blue stones contain more chromium, while vanadium is responsible for the greener specimens. RI can be summarized as 1.662-1.674, DR 0.012, strongly negative in sign. R.K.M.

SCHMETZER (K.), OTTEMANN (J.). *Kristallchemie und Farbe Vanadium-haltiger Granate.* (Crystal chemistry and colour of vanadium-bearing garnets.) Neues Jahrbuch für Mineralogie, **136**, 2, 146-68, 1979.

Absorption spectra of vanadium-bearing garnets, including pyrope, spessartine, grossular and goldmanite, include two strong bands in the visible. These are attributed to crystal field transitions of V^{3+} in octahedrally-coordinated positions in the garnet structure. M.O'D.

SNOW (J. J.). *The use of the Figure-O-Scope in gemmology.* Australian Gemmologist, **13**, 9, 301-6, 10 figs (3 in colour), 1979.

At last a description of this curiously named instrument mentioned more than once in past issues. Basically a much simplified polarizing microscope made specifically to give interference figures with a minimum of trouble, it employs a spherical objective lens and divergent light. It will also detect pleochroism. R.K.M.

SUHNER (B.). *Infrarot-Spektren in der Gemmologie.* (Infrared spectra in gemmology.) Z.Dt.Gemmol.Ges., **28**, 2, 55-68, 8 graphs, bibl., 1979.

The author discusses the uses of infrared spectroscopy as an additional method for the identification of gemstones; the reflection method is especially applicable, as it does not destroy the specimen and can be used for set stones. It is also preferable to the absorption method as the spectra obtained are more definite as shown by the illustrations, which represent graphs obtained for sodalite, quartz, tourmaline, garnet, charoite, rhodonite and pyroxmangite. It is not always easy to compare directly the absorption and reflection spectra. Comparative reflection spectra should be collected as well as the absorption data and it would be of advantage if these data could be added to the results of examination of new materials. E.S.

SUNAGAWA (I.). (Activities in gemmological studies in Socialists' *[sic]* countries.) J. Gemm. Soc. Japan, **6**, 1/2, 3-21, 19 figs, 1979. (In Japanese with English summary.)

An account of some of the proceedings of the 11th General Meeting of the International Mineralogical Association held in Novosibirsk, Siberia, U.S.S.R. Details are given of some synthetic products including emerald, tourmaline and alexandrite. M.O'D.

SUNAGAWA (I.), HAMADA (M.). (Lattice images of synthetic emerald.) J. Gemm. Soc. Japan, 5, 3, 11-14, 2 figs 1978. (In Japanese with English summary).

Two-dimensional lattice images of flux-grown synthetic emerald and two electron micrographs of lattice images on (0001) and $(10\bar{1}0)$ are shown. M.O'D.

SUPERCHI (M.). *Introduzione alla quantificazione del colore.* (Introduction to colour quantification.) La Gemmologia, **4**, 3/4, 31-41, 7 figs, 1978.

The colour measurement systems of DIN, Rösch and others are introduced and compared. M.O'D.

SVISERO (D. P.). *As variedades gemológicas de berilo.* (The gem varieties of beryl.) Gemologia, **23/24**, 45/46, 67-71, 1 fig, 1978.

The types and occurrences of beryl of gem quality in Brazil are discussed. M.O'D.

SVISERO (D. P.), HARALYI (N. L. E.). *O diamante princesa de estrela do sul.* (The diamond 'Princess of Estrela do Sul'.) Gemologia, **23/24,** 45/46, 45-53, 4 figs, 1978.

This diamond weighs 82.25ct and was found in a placer of Bagagem River in south-west Minas Gerais, Brazil. M.O'D.

SVISERO (D. P.), POROLA (A. R. A.). *As mudanças de cor do espodumênio.* (Change of colour in spodumene.) Gemologia, **23/24,** 45/46, 59-60, 1978.

The colour of spodumene can be altered by irradiation; green, pink and colourless varieties are known. M.O'D.

SVISERO (J. B. G.), (D. P.). *Geología de los depositos diamantíferos de la parte noroccidental de la Guayana venezolana.* (Geology of the diamond deposits of the north-western part of Venezuelan Guayana.) Boletin de Geología, Dirección General Sectorial de Minas y Geología, Venezuela, **13,** 24, 3-46, 26 figs, 1978.

Diamond has been discovered at Quebrada Grande, a tributary of the Guaniamo River, district of Cedeño, state of Bolivar, Venezuela. Forsterite, enstatite and chrome pyrope are characteristic inclusions. It is suggested that the diamonds originate in kimberlite-type ultramafic matrices. M.O'D.

SWEANEY (J. L.). *Fire agates in Deer Creek.* Gems & Gemology, **XVI,** 5, 130-41, 19 figs in colour, 1979.

Excellent account of a gem agate little known in Britain. These are translucent botryoidal chalcedonies containing micro-thin opaque layers of iridescent iron oxide. These give rise to colour, due to interference, which can vary through the entire spectrum in different specimens. The layers follow the contours of the host mineral, and cutting consists of grinding away all but a thin protective layer and so calls for considerable skill, each stone being cut as an individual and unique exercise in shaping. Colour photographs by Havstad (M. R.) are particularly attractive. Deer Creek (Arizona), California and Mexico all produce this type of agate, but the writer considers the first of these to be the best source. R.K.M.

TAKUBO (H.), KITAMURA (Y.), NAKAZUMI (Y.), KOIZUMI (M.). (Internal textures and growth conditions of flux-grown emeralds from USSR.) J. Gemm. Soc. Japan, **6,** 1/2, 22-8, 16 figs, 1979. (In Japanese with English summary.)

Emeralds showed veil-like secondary inclusions along the curved surfaces of tension cracks, other veil-like inclusions filling pores in a mosaic structure; silk-like inclusions intersecting the *c*-axis obtusely were also cited. Surface growth markings are illustrated. M.O'D.

TAKUBO (H.), MUGURUMA (A.), KOIZUMI (M.). (Relation between internal textures and growth conditions of flux-grown emerald.) J. Gemm. Soc. Japan, **4,** 3-12, 3 figs, 1977. (In Japanese with English summary.)

Emerald crystals were grown in the melt composed of Li_2O-MoO_3 flux and gel powder of $3BeO.Al_2O_3.6SiO_2$ composition using several temperature programmes. Their internal textures were observed under the polarizing microscope and correlated with the growth conditions such as temperature and degree of supersaturation. Development of zonal structures, optical anomalies and domain structures are

attributed to the temporary fluctuation of temperatures during cultivation. Rapid growth on the non-crystallographic rough surfaces tends to form nail-like inclusions. Prolonged cultivation at a fixed high temperature leads to the formation of feather or lace-like inclusions which are characteristic of the flux-grown emeralds in the market. These results suggest that more perfect crystals of emerald can be obtained from the flux-melt both by slow cooling technique and by strict temperature control. I.S.

USHIO (M.). (Appearance and disappearance of crystal faces of emerald during crystal growth by V_2O_5 flux method.) J. Gemm. Soc. Japan, **4**, 51-9, 5 figs, 1977. (In Japanese with English summary.)

Both spherical seeds and cubic seeds, cut parallel to crystallographic and non-crystallographic orientations were prepared from natural beryl crystals. These were used as seeds in growth of emerald from V_2O_5 flux, to investigate appearance and disappearance of crystal faces during growth. All experiments were carried out at 1050°C for growth temperature and 10°C for Δt. When a spherical seed of 10mm was used, $(10\bar{1}0)$ and (0001) appear at the earliest stage (before 5 h), followed by the appearance of $(11\bar{2}0)$ $(10\bar{1}1)$, $(11\bar{2}2)$, $(11\bar{2}1)$, $(20\bar{2}1)$, $(21\bar{3}1)$, and $(31\bar{4}1)$ after 8 h; after 10 h, *u, v,* and *n* faces disappeared. A small prism face $(31\bar{4}0)$ was observed between *m* and *a* faces, and soon disappeared as growth proceeded; *o, s,* and *p* faces disappeared after 200, 250, and 275 h, respectively. The final morphology after 275 h was hexagonal prism consisting of only (0001) and $(10\bar{1}0)$. In the case of cubic seed of 10mm cut parallel to non-crystallographic orientation, *c*(0001), *m*$(10\bar{1}0)$, and *a*$(11\bar{2}0)$ faces appeared at first (after 5 h), followed by the appearance of *p, s,* and *o* faces after 24 h. The latter two faces disappeared after 165 h and the former face after 270 h; the final form was again hexagonal prism. In the case of cubic seed of the same size cut parallel to crystallographic orientations, the faces parallel to the cut plane appeared and developed well at first, but *u, v,* and *n* faces, which are all inclined at higher angles to the *c* face, disappeared after 100 h; *o* and *s* faces remained after 300 h and *p* face after 500 h. In any case, the final forms were similarly hexagonal prismatic form consisting of *c*(0001) and *m*$(10\bar{1}0)$ faces.

I.S.

VARGAS (G.), VARGAS (M.). *Emeralds on a cow pasture.* Lapidary Journal, **33**, 2, 594-600, 16 figs, 1979.

An account of emeralds and other gemstones found during a trip to Brazil. M.O'D.

VOSKRESENSKAYA (I. E.), IVANOVA (T. N.). *Issledovanie turmalinov polychennykh metodom sinteza.* (Study of synthetically produced tourmaline.) Trudy Mineralogicheskogo Museya A. E. Fersmana, **24**, 20-30, 3 figs, 1975. (In Russian.)

Tourmaline crystals up to a few mm in length have been synthesized at temperatures ranging from 750-800°C and at pressures of 1000-2000 atmospheres. Constituents are Al_2O_3,SiO_2 and $MgCl_2.nH_2O$. Dark blue, brown, black and dark green crystals were obtained with various dopants which included Cr, Fe, Fe-Li, Co and Ni. Drawings of crystals are given. M.O'D.

WILSON (A. F.). *Why sapphires from Sri Lanka differ from those from Australia.* Australian Gemmologist, **13**, 10, 315-17, 1979.

Explains differences in colour, zoning, silk content and mineral and fluid inclusions by the fact that Sri Lankan sapphires are the product of a metamorphic environment, while Australian sapphires occur in basalt, a volcanic igneous rock formed at high temperatures and very great depths. R.K.M.

ZEITNER (J. C.), MILLSON (H. E.). *Another look at agates, part 1.* Lapidary Journal, **33**, 2, 478-86, 15 figs in colour, 1979.

A general introduction to agates with illustrations of some examples from the U.S.A., Brazil and Mexico. M.O'D.

ZEITNER (J. C.). *An exceptional euclase.* Lapidary Jornal, **33**, 6, 1282-8, 7 figs (4 in colour), 1979

A rich green euclase weighing 18.29ct has been discovered in a weathered pegmatite dike in the Ouro Preto area of Minas Gerais, Brazil. It has been faceted and presented to the National Museum of Natural History, Smithsonian Institution. M.O'D.

Aus der Untersuchungspraxis. (From the Laboratory.) Z.Dt.Gemmol.Ges., **28**, 2, 73-81, 1979.

H. Bank discusses the diaspore from Turkey, which in its cut state is pale green; H. Bank and V. Zwetkoff examined a lot of synthetic emeralds, which were colourless or pale pink beryls covered with Lechleitner emerald and showed a relatively wide variation in the RI, depending on the type of beryl used and also the Cr-content of the covering material. H. Bank relates an incident when cordierite and amethyst could not be distinguished as the optical properties are very near to each other. Lastly H. Bank and A. Frere warn about dangers when examining set stones. E.S.

Colección de gemas del I.G.E. (The gem collection of the I.G.E.) Boletin del Instituto Gemológico Español, **19**, 17-20, 6 figs in colour, 1979.

Some stones in the collection of the Instituto Gemológico Español are illustrated with brief comments. M.O'D.

Fake Sri Lankan sapphires cause prices to fall. Retail Jeweller, **17**, 423, 12, 1979.

A report emanating from Sri Lanka on the effect of Thai purchases of so-called Geuda sapphires (described as milky greyish-green stones), which are then smuggled to Thailand and heat-treated to a better blue. This practice is said to be depressing the prices obtained for blue stones of natural origin. These are no doubt stones similar to those discussed by R. Crowningshield in his report from the G.I.A. New York Lab in *Gems & Gemology* (see abstract above). (Such stones are also being offered on the London market but so far their heat-treated nature has been disclosed by the sellers. They are not as pleasing as the natural Sri Lankan sapphire in colour.) R.K.M.

NOTE: *Wahroongai News* is the monthly magazine of the Queensland Branch of the Gemmological Association of Australia: the price (in Australia) is 5c.

BOOK REVIEW

AUBERT (G.), GUILLEMIN (C.), PIERROT (R.). *Précis de Mineralogie.* (Compendium of Mineralogy). Masson, Paris, 1978. pp.xiv, 335. Illus. in black-and-white and in colour. Price on application.

This book is chiefly notable for the fine series of coloured photographs and for simplicity of style. The customary introductory chapters on theoretical and determinative mineralogy are followed by a survey of the commoner minerals and by a final chapter 'Elements of gemmology' by H.-J. Schubnel. M.O'D.

BIXBY (M. A.). *A catalogue of Utah minerals and localities with descriptive notes for collectors.* Reprint no. 60 of Utah Geological and Mineralogical Survey, Salt Lake City, 1959. pp.32. $1.00.

An alphabetical list of the minerals found in the State of Utah, including topaz, the red variety of beryl and several rare minerals. Some historical notes are given and a list of locations by county. M.O'D.

BLATCHEY (W. S.). *Gold and diamonds in Indiana.* Geological Survey of Indiana, Bloomington, Indiana, no date. (Reprinted from the 27th Annual Report of the Indiana Dept of Geology and Natural Resources.) pp.47. Price on application.

The gold and occasional diamonds found in the State of Indiana are detailed in this short county-by-county survey by a distinguished early geologist. Speculations on the origin of the diamonds are included. M.O'D.

DIETRICH (R. V.). *Minerals of Virginia.* Virginia Polytechnic Institute, Blacksburg, 1970. pp.vii, 325. Illus. in black-and-white. $4.00.

Forming Research Division Bulletin 47 of the Institute, this useful guide is the eighth list of Virginia minerals to appear; it is also the first one in which the minerals are listed alphabetically. The standard guide and written by a well-known authority. M.O'D.

FIELD (J. E.), (ed.). *The properties of diamond.* Academic Press, London, 1979. pp.xiv, 674. 1 colour plate. £32.50.

This is intended to be a successor to Berman, *The physical properties of diamond,* published in 1965. Many additions to the science of diamond have been made since that date and are reflected here, notably reports on the synthesis and optical spectra of the stone. The book is divided into parts covering the solid state (including work on absorption spectra, thermal and electrical properties, cathodoluminescence and nuclear properties); theoretical work, surface studies, mechanical experiments including wear strength and fracture, growth, geology and industrial uses. Readers will find most to interest them in the sections on optical properties and colour centres, and it is worth noting that there is still no certainty as to the true nature of the origin of platelets; whether these are all nitrogen or whether they are all the nitrogen is still the subject of study. A most useful chapter deals with diamond inclusions which are related in most cases to particular mines of origin; reports of rutile and kyanite inclusions are mentioned, as they have been in other works. Remarks on diamond synthesis show that two problems have to be overcome before

commercial work is feasible; one is preferential graphite nucleation, the other slow, surface-area-dependent growth rates. M.O'D.

GIRARD (R. M.). *Texas rocks and minerals: an amateur's guide.* Bureau of Economic Geology, University of Texas, Austin, Texas, 1976. pp.vi, 109. Illus. in black-and-white. Price on application. (Bureau of Economic Geology, Guidebook 6.)

Although Texas is not one of the more richly-mineralized states of the U.S.A., there are still some interesting and attractive specimens to be found. They include celestine from the Austin area, gypsum from Terlingua, garnets in central and west Texas and at least one occurrence of opal with a play of colour. Minerals, rocks and rock-types are arranged in one alphabetical sequence. M.O'D.

HARSHAW (M. R.). *In search of the scarce green hiddenite and the emeralds of North Carolina.* Hexagon Company, Asheville, N.C., 1974. Illus. in black-and-white and in colour. $2.25.

This short guide is intended for use by those visiting the famous gem-producing areas in Alexander County, North Carolina. Anecdotes, history and maps accompany details of present-day production and notes on the stones. M.O'D.

HURLBUT (C. S., Jr), SWITZER (G. S.). *Gemology.* John Wiley & Sons, New York, 1979. pp.XIV, 254. 350 Figs, 12 colour plates. $29.25/£13.50.

The authors, both of whom hold mineralogical appointments of importance in America, have undertaken a textbook with 'a concise yet comprehensive and systematic treatment'. In this they have succeeded, with certain reservations, although their publishers' idea of a textbook format is biased a little towards the 'coffee-table' presentation which the authors decry. But the reviewers dispute the claim made on the first page of the preface that this is the first such book produced this century.

Inevitably, parts—particularly those chapters devoted to mineralogy and crystallography—may be thought over-comprehensive, and one wonders at the inclusion of so much basic material in a work which seeks to simplify crystal morphology to the point where the dome form is described as a horizontal prism and triclinic crystals are said to consist entirely of pinacoids. There have been many different classifications of crystals, some too complex, others over-simplified. The present one seems to fall into the latter class. Polyhedral diagrams of atom lattices appear frequently but, without adequate explanations in the text, convey very little.

On the gemmological side the book is concise and occasionally almost dismissive. The microscope and spectroscope are each given a scant five pages; inclusions are dealt with in three. It seems to be implied that an absorption spectrum is always an identical black line reversal of the emission spectrum of a substance. This, of course, is not true if applied to our type of absorption spectrum. The effect of reversal can be seen only when bright lines emitted by an incandescent substance pass through a gas, as in the case of the Fraunhofer lines in the spectrum of sunlight. Otherwise an absorption spectrum bears no relation to the far more complex emission spectrum of a substance. The absorption spectra of gems are not black line versions of their bright line emission spectra.

A diagram of the electromagnetic spectrum follows the conventional practice of

showing long waves to the left and short to the right. But absorption spectra diagrams are reversed, with short to the left and long to the right. Since this is a textbook primarily for American consumption it can hardly avoid conforming with the G.I.A. practice, which results from their early adoption of a Beck spectrometer which, unfortunately, reverses the spectrum in this way. Text references quote long waves first, however, and there is some merit in the fact that these are in Ångström Units and not in the newfangled and scarcely necessary nanometres!

One recognizes that the refractometer is perhaps not a 'mineralogist's instrument', but to say that it is possible to read the dispersion of a stone by using white light with this instrument is an error unworthy of the book. One of the first things one learnt when studying gemmology was that the position of the shadow edge seen when using white light depended on the difference in refraction between the stone and the optically dense glass of the instrument. Because the latter has very high dispersion, violet light gives a substantially *lower* RI reading than that obtained with red light. For this reason all normal refractometers are calibrated for one standard wavelength only, that of the sodium emission line. Any attempt to read for other wavelengths must give false results and it is *not* possible to determine dispersion by direct reading.

Also it is stated that, on rotation of a test stone, both α and γ readings will, at some point in rotation, coincide with the reading for β. Unless the test facet is exactly parallel with the optic axial plane of the crystal, this again is not true. For any other test facet only one of the two medial readings will reach the value for β, and a second series of readings, taken from another facet, must be obtained in order to determine which of the two medial values is the same for both facets. This reading will be the RI value of β.

Contrary to the text, the spinel refractometer and, indeed, all Rayner refractometers for many years, have used an optically dense *prism* in place of the earlier and more expensive hemisphere; a breakthrough in design resulting directly from the work in the 1930s of Anderson and Payne on suitable alternative materials for this essential part of the instrument. They have never used a hemicylinder. Also there is no reason why a contact liquid of RI higher than that of the dense prism should not be used, although the text suggests otherwise.

Chapter 13, Descriptive Gemology, is by far the longest, running to about 100 pages. Gems are divided into Important; Less Important; Others and Ornamentals; Organics and Synthetics. Stones in the first section are dealt with in a somewhat arbitrary order of commercial/scientific importance. In the other sections the order is alphabetic, but species headings, in contrast with half inch high chapter headings (each splendidly isolated in a blank half-page), are scarcely distinguishable from paragraph sub-headings, making the finding of a given species a little difficult.

Synthetic lapis lazuli is omitted, although it appeared on the market before cubic zirconia, which is included in the book. In connexion with the latter, why is the infrared reflectometer omitted? Under dyed jadeite it is not sufficient in a textbook to say 'identification may also be made with the spectroscope' without indicating the absorption spectrum to be looked for. Axinite is said to have 'no symmetry'; it has, in fact, centro-symmetry. We are told that its gem colours are blue, yellow, violet or green. In our long experience of handling rare gems we have seen only clove-brown, plum-red and one solitary aquamarine-blue, which is mentioned separately in the text. Painite, at the time the book was written, 'existed' in *two* crystals, both in the

British Museum (Natural History). Gilson synthetic emeralds are made in France, not in Switzerland.

A final short paragraph on Identification Procedure omits the very valuable use of the absorption spectrum. Its last sentence certainly says 'In certain especially difficult cases use of spectroscopic and x-ray diffraction methods may be required.' But this must refer to emission spectroscopy involving vaporization of material. Absorption spectroscopy is often a very simple and decisive method for use early in an identification procedure.

Extensive and elaborately cross-referenced tables of RI and SG are listed. Some values are at variance with those already well established, e.g. DR of tourmaline (average) 0.025; SG of corundum 4.02. In uniaxial species the variable index is underlined. No indication is given that both RIs vary in biaxial species. It might have been a better idea to underline the invariable index and leave the other values for both uniaxial and biaxial free to vary. Lists of the World's largest Rough and Polished Diamonds seem a little out of place in a book of this kind.

There are two indexes, one by subject, which is occasionally inaccurate in page reference, the other by gem species, which contains a useful summary of the essential facts for each stone.

The authors' manuscript was checked by independent readers who should have noted some of the errors quoted above. Further, Lester B. Benson, the brilliant G.I.A. innovator of the 'spot' or 'distant vision' method of obtaining RI readings from cabochon stones, has become 'Lester Brown'. Lechleitner's name is misspelt throughout. Paste is called 'Stross, after the Austrian Joseph Stross'. All other references we can find call it 'strass' after Josef Strasser. The last three could have been printer's errors for, unfortunately, there are many of these. Mostly minor, they are nevertheless irritating and could have been eliminated by careful proof-reading. One accepts differences between American and English spelling, but these do not extend to 'pehnomenon', 'carbochon', 'oojects', 'larg', 'rutiile', 'aquarmarine', 'celluoid', or 'flourite', to list but a few.

To summarize, this may be a better American book than those which have been published before, but we cannot agree that it is necessarily better gemmologically than the Coles Phillips revision of G. F. Herbert Smith's 'Gemstones', not to mention other works which are recommended by the present authors as 'Suggested Reading' at the end of some of their chapters. They are obviously very much at home in the profound depths of mineralogy, but have occasionally foundered in the comparative shallows of gemmology; largely because our simpler techniques are, for quite good reasons, less familiar to the parent science. In its present form 'Gemology' could be considerably improved by careful reading and correction. We feel, also, that the publishers and proof readers have not done justice to their authors. R.K.M./B.W.A.

KING (E. A.). *Texas gemstones.* Bureau of Economic Geology, University of Texas, Austin, Texas, 1972. pp.42. Illus. in black-and-white. Price on application. (Bureau of Economic Geology, Report of Investigations, 6.)

Minerals with a definite or possible gem application are listed alphabetically in this short guide. They include amber, beryl, garnet, fluorite, one authenticated find of diamond, turquoise and varieties of quartz. M.O'D.

LAGACHE (H.). *Initiation à la gemmologie.* (Initiation in gemmology.) Institut National de Gemmologie, Paris, 1979. pp.88, xxvi. F110.

This is a small-sized, simple introduction to gemmology designed for students, who will find it convenient and undemanding. Diagrams of basic phenomena are illustrated by sketches, for the most part accurate (though the zircon crystal seems to have slipped somewhat) and the accompanying text is free from wordiness. Those wanting details of stones will need to look elsewhere, since this book deals only with the process of testing; it succeeds admirably in its limited purpose. M.O'D.

LEAMING (S. F.). *Jade in Canada.* Geological Survey of Canada (Paper 78-19), Ottawa, 1978. pp.59. Illus. in black-and-white. $8.00 ($4.00 in Canada.)

So far as is known at present only nephrite of the two jade minerals occurs in Canada. Known deposits are described and mapped with some of the material being chemically analysed. Production and geological details are given, with references. Some foreign nephrite is also analysed. M.O'D.

MARFUNIN (A. S.). *Spectroscopy, luminescence and radiation centers in minerals.* Springer, Berlin, 1979. pp.xii, 352. $(US)59.40.

Translated from the Russian, this is a major study of the subjects in its title. Of particular interest to those studying the scientific aspects of gem materials will be the long chapter on luminescence in which basic concepts are explained and a history of developments given. Present-day tests are described and in earlier parts of the book the importance of crystal field theory is well explained. A section describing colour centres in minerals also includes crystal diagrams depicting how the holes arise and lists minerals in which they are important. There is an index and a good bibliography. M.O'D.

MILLER (C. E.), HERMES (O. D.). *Minerals of Rhode Island.* University of Rhode Island, Kingston, Rhode Island, 1972. pp.83. 24 illus. $2.00.

This book is the successor to *Rhode Island minerals and their locations* published in 1971. It is arranged in alphabetical order of mineral names; there are maps and a bibliography. Ornamental species found in the State include titanite, amethyst, the chiastolite variety of andalusite, calcite and bowenite. M.O'D.

MITCHELL (R. S.). *Mineral names—what do they mean?* Van Nostrand Reinhold, New York, 1979. pp.xv, 229. £10.45.

A most useful book in which introductory chapters list mineral names by type (i.e. from persons, places, chemical composition, classical languages) and the rest of the book is devoted to a complete alphabetical list in which I could find no significant errors or omissions (vorobyevite, a name sometimes given to a variety of beryl, was not there). Especially useful is an overall index and a list of names for which no history could be found. M.O'D.

ROOT (F. K.). *Minerals and rocks of Wyoming.* Wyoming Geological Survey (Bulletin 56), Laramie, 1977. pp.84. Illus. in black-and-white and in colour. $3.00.

Wyoming is celebrated for its nephrite and for several varieties of agate, of which Sweetwater agate is probably the best known. This small guide illustrates a

number of minerals and gives directions to important sites, several of which are shown on maps. Introductory chapters discuss the geology of the State. M.O'D.

SCHMELTZER (H.). *Mineral-Fundstellen-Bayern.* (Mineral localities—Bavaria.) Weise, Munich, 1977. Illus. in black-and-white and in colour. pp.227. DM32.

This completes the excellent series of guides to mineral sites in Europe; at least no more are currently advertised. Bavaria contains some important sites, including the pegmatite at Hagendorf and the rose quartz deposit at Kreuzberg near Pleystein. Some attractive green beryl is found at Hühnerkobel near Rabenstein. As usual the book has first-class references and locality maps. M.O'D.

TRÖGER (W. E.). *Optical determination of rock-forming minerals.* Schweizerbart'sche Verlagsbuchhandlung, Stuttgart, 1979. pp.188. DM48.

This is the English version of the book reviewed in the *Journal,* XV, 6, 337, 1977. M.O'D.

WILKE (H.-J.). *Mineral-Fundstellen. Vol. 7. Hessen.* (Mineral locations—Vol. 3—Hesse.) Christian Weise Verlag, Munich, 1979. Illus. in black-and-white and in colour. pp.240. DM36.

This is the latest addition to the well-known and justly celebrated series of guides to European mineral locations. The sites are each exhaustively documented, all the major ones having maps and some have especially fine minerals illustrated in colour. A first-class bibliography is included. The area, in which Frankfurt is roughly central, includes such well-known sites as Aschaffenburg where spessartine and beryl are found; fine micromount material includes titanite, cerussite and apatite. M.O'D.

WILSON (W. F.), MCKENZIE (B. J.). *Mineral collecting sites in North Carolina.* (Information circular 24), North Carolina Department of Natural Resources and Community Development, Geological Survey Section, Raleigh, N.C., 1978. pp.vii, 122. Illus. in colour. Price on application.

This attractive work includes the plates from Kunz's *The history of the gems found in North Carolina,* published in 1907 and now a rare work. Other plates show the range of gem material found in the State; maps cover all the major areas and the constituent minerals are well described with brief detail and historical notes. M.O'D.

Diamond digest. Diamond Selection Ltd, London EC1. Annual subscription £10.00.

This journal began as telexed notes on diamond prices but is now enlarged to include a variety of market reports, abstracts and editorial comment. Very valuable for those with a commercial interest in diamond. M.O'D.

Les gemmes et leur identité. (Identification of gems.) Association Française de Gemmologie, Paris, 1978. Price on application.

This book consists of a number of cards in a ring binder, each card dealing with a particular gemstone and giving its constants, characteristic inclusions, common simulants where applicable and stones with which it may be confused. Not all cards are currently included since there are still some to be published; these include some simulants. The cards are also issued with the *Revue de Gemmologie,* the official organ of the Association. M.O'D.

ASSOCIATION NOTICES

GIFTS TO THE ASSOCIATION

The Council of the Association is indebted to the following for their gifts:

Dr N. R. Barot, F.G.A., Nairobi, Kenya, for a collection of six pieces of rough and seven cut specimens of golden brown garnets (Umba River, Tanzania), green grossular garnets (Lualenyi Voi, Kenya) of different shades of colour and a purple scapolite (Tanzania).

Mr R. Holt, F.G.A., London, for a copy of the book 'The Jewelled Trail', by Louis Kornitzer.

Mr Milton R. K. Lu, of the China Gemmological Association, Taiwan, for a round cubic zirconia of 2.11 ct, with a special cut of 144 facets.

Mr E. A. Thomson, London, for a small round green andradite cut stone of 0.16 ct from Korea, a white round herderite of 0.15 ct from Brazil, and an oblong step-cut, transparent, very pale brown, 0.96 ct specimen of diaspore.

Mr Mai van Lieu, F.G.A., Brussels, Belgium, for a book entitled 'Ivoires de Chine' by Mai van Lieu and Pierre-Jean Schaeffer.

NEWS OF FELLOWS

Mr M. J. O'Donoghue, M.A., F.G.S., F.G.A., attended the third 'Convegno' of the Italian Gemmological Institute in Milan on the 18th November, 1979, and read an illustrated paper on 'New Developments in Man-Made Materials'. Mr O'Donoghue has also taken over the editorship of *Gems,* the bi-monthly mineral, gem and lapidary magazine now in its 12th volume.

On 7th December, 1979, Mr P.G. Read, C.Eng., F.G.A., gave a talk on 'Gem and Industrial Diamonds' to the Bournemouth and Poole Medical Society (the President is Dr W. Cross, F.G.A.). Also, Mr Read will be organizing a Gemmology Weekend Course in Chichester, from 30th May to 1st June, 1980.

OBITUARY

Mr Charles R. Miller, F.G.A. (D.1975), Southfield, Michigan, U.S.A., died on 3rd September, 1979.

Mr Dennis R. Selvon, F.G.A. (D.1962), Woodford Green, Essex, died on 27th December, 1979.

Mrs Joyce M. Thomas-Ferrand, F.G.A. (D.1950), Bury St Edmunds, Suffolk, died on 8th January, 1980.

MEMBERS' MEETINGS

Midlands Branch

On 29th November, 1979, at the Central Hall, Corporation Street, Birmingham, a 'Mastermind Quiz' on gemmology was held, with Mr S. Tisdall, F.G.A., as Quizmaster.

On 25th January, 1980, at the Society of Friends, Dr Johnson's House, Colmore Circus, Birmingham, Mr J. G. Todd, F.G.A., of Lotus Pearls, gave an illustrated talk on 'Real and Cultured Pearls'.

On 22nd February, 1980, also at the Society of Friends, Mr M.J. O'Donoghue, M.A., F.G.S., F.G.A., gave an illustrated talk on 'Gem Locations'.

North-West Branch

On 29th November, 1979, at Church House, Hanover Street, Liverpool, a 'practical evening' was held, when specimens and instruments were available to members for examination and discussion.

On 10th January, 1980, at Church House, Mr John L. Pyke, F.G.A., gave an illustrated talk on 'Mining Operations in Colombia and Thailand'. Members were also able to examine his personal collection of gemstones.

On 7th February, 1980, at Church House, a demonstration of simple silversmithing was given by Mr Jim Hunter.

South Yorkshire Branch

On 6th March, 1980, at the Sheffield City Polytechnic the Annual General Meeting of the Branch was held. Dr M. W. Eldridge, M.B., Ch.B., F.G.A.. was re-elected Chairman and Miss J. I. Platts, F.G.A., elected Secretary.

ANNUAL REUNION OF MEMBERS AND PRESENTATION OF AWARDS

The Annual Reunion of Members was held at Goldsmiths' Hall during the evening of Monday, 19th November, 1979, when a large number of members attended.

The Reunion was followed by the Presentation of Awards and the Chairman, Mr Douglas King, welcomed members and the large number of recipients with their relatives and friends who were present that evening, mentioning that people from twelve countries apart from England had come to receive their awards in person, some of them coming from places far afield. He continued that it was always pleasant to welcome the recipients of awards and it was an added pleasure that the results this year were a little better than in recent years. Yet again a record was set for the numbers taking the Examinations: for this Gem Diamond Examination 55 candidates sat, for the Diploma 491, and for the Preliminary 748, of whom 42 passed in the Gem Diamond Examination (including two distinctions), 198 passed in the Diploma (including 10 distinctions), and 363 passed in the Preliminary. Unfortunately the Examiners had been unable to recommend the award of the Tully Medal or the Rayner Prizes, but Dr Roger Harding was congratulated on submitting the best set of papers in the Diploma Examination. The Examinations were as usual held in many countries overseas and thanks were due to all those persons and

Mr B. W. Anderson and Mrs Ameena Kaleel (Sri Lanka).

Left to right: Mr A. E. Farn, Mrs Zwaan, Professor Dr Pieter Zwaan and Professor Dr M. Font-Altaba.

organizations that gave assistance to make this possible. He referred in addition to the large amount of work done by the Association's Headquarters staff and thanked all concerned for this.

The Chairman then introduced and welcomed Professor Dr Pieter Zwaan, F.G.A., Acting Director of the National Museum of Geology and Mineralogy at Leiden, Netherlands, and called upon him to present the awards.

When the presentations had been made, Dr Zwaan delivered a short address, which is recorded in full below.

After Dr Zwann had concluded his address, the Vice-Chairman, Mr David Callaghan, expressed the thanks of the assembled company to Dr Zwaan, and the Chairman after thanking the Worshipful Company of Goldsmiths for again allowing the use of their fine Hall, then declared the meeting closed.

PROFESSOR DR PIETER ZWAAN'S ADDRESS

Ladies and gentlemen, this day is an important day in your life, because you are considered to be gemmologists from now on and what that means cannot be said in a few words.

Gemmology developed enormously during the last twenty years. This was apparently due to the large amount of new stones, both natural and synthetic, that came on the market. For that reason there is a great difference between the contents of the questions at the examinations I passed myself exactly 25 years ago, and those of this year. Since 1954 new techniques have been developed and new methods have been introduced. Gemmology became more and more independent of mineralogy, due to its own ways of investigation. But, originating from a geological school in which mineralogy played an important part, I still consider gemmology as a very special field in mineralogy. In fact, this is not important: what is of importance is the rapid development of this part of science.

Returning to 1954, the only synthetic emerald known was the one manufactured by Carroll F. Chatham. Stones like blue zoisite and emerald-green grossular garnet were not yet discovered. The rare earth synthetic garnets, if I may use the word like a crystallographer, were not yet produced. At that time only corundums made by the flame-fusion method occurred, together with spinel. Turning over the leaves of a gemmological journal of 1954, papers can be seen on immersion contrast, on taaffeite and sinhalite and, of course, on inclusions in gemstones. Nomenclature problems also existed, as with jade. A new type of heat-treated amethyst, called prasiolite, was mentioned for the first time. But believe me, ladies and gentlemen, gemmologists had difficulties, as we have them now—problems which could hardly be solved.

Coming to 1979, it is needless to tell people who have just passed their examinations how many new problems have appeared in gemmology. In my opinion, in the nearest future, the most important matter will be to find out whether the colour of a gemstone has been changed or not. There are several ways of treatment, amongst which irradiation is very popular nowadays and very effective. In this respect I should like to draw your attention to the most useful work done by one of the greatest gemmologists of this century, Basil W. Anderson. His contribution to absorption spectroscopy has been of great importance in gemmology. He discovered anomalies in the absorption spectra of treated diamonds. He also gave indications how to continue in this special field of gemmology. I am certain that new efforts in absorption spectroscopy will give highly important results as far as the origin of the colour of a gemstone is concerned.

From what I have said up to now it will be clear that you are at the beginning, not at the end. I feel privileged to congratulate you with your success and I want to ask you to be active in this beautiful part of science. I hope with all my heart that you did not take classes in gemmology merely in order to obtain a diploma, but with a firm intention to contribute to this very special science which we all love!

ANNUAL GENERAL MEETING

The Association's Annual General Meeting will be held at Saint Dunstan's House, Carey Lane, London EC2V 8AB on Friday, 16th May, 1980, at 6 p.m.

SPINEL REFRACTOMETERS

The Association would be interested in acquiring one or two spinel refractometers from members who no longer require them. Members are requested to write with details of condition and suggested price to the G.A. office.

CROSSED FILTERS TECHNIQUE

To use the crossed-filters technique with a spectroscope it is usually recommended that a high intensity light source be directed through a flask containing a saturated copper sulphate solution. Some spectroscope units are so constructed that this is not possible, and it is difficult to obtain a thin filter suitable for this purpose.

One member has solved the problem by growing a copper sulphate crystal and sawing this into slab form. The slab was large enough to cover the iris diaphragm area of the instrument, and the top and bottom were lapped flat. This was done by rubbing dry with 400 grit silicon carbide on a glass plate. The resulting filter was 2.5 mm thick.

LETTER TO THE EDITOR

From Mr R. Keith Mitchell, F.G.A.

Dear Sir,

Alas poor Ångström!

The Ångström unit is expected 'to fall into disuse'. It is obsolescent, which means the same thing—*not* that it is already obsolete! It is being replaced in light wave measurements by a new unit called the nanometre in the general metrification imposed by the system known as SI.[1] The relationship between the two measurement units is a simple one since 10 Ångströms equal 1 nanometre. So the Ångström is no less a metric unit than is its replacement.

So, it would seem that this memorial to a great Swedish physicist is to be sacrificed on the altar of change for the sake of change.

Ander Jonas Ångström was born in 1814, the year in which J. Fraunhofer discovered the famous 'lines' in the sun's spectrum, and made the first crude diffraction grating by stretching wire between threads of two screws. Ångström was a founder of spectroscopy and was the man who first discovered hydrogen in the atmosphere of the sun in 1862, introducing the Ångström Unit as a convenient measure of the minute wavelengths involved. In 1868 he published a map of the sun's normal spectrum which remained authoritative for many years. He held the Chair in Physics at Uppsala University from 1858 until his death in 1874. Such a man should continue to be commemorated.

After all, who was Nano? No one, the word is Greek for dwarf or something very small.

1. See J. Gemm., 1977, XV (5), 243.—Ed.

Not to be outdone, certain gemmological writers have started using another physicist's unit and are referring to light wavelengths in terms of frequency or of wavenumber, i.e. the number of waves per centimetre. This is, in effect, the reciprocal of the normal wavelength measurement, so that 16 000 cm^{-1} is equivalent to 6250Å. This is not new. Fraunhofer, too, measured his wavelengths in centimetres.

The SI is keeping the Newton, the Ohm, the Coulomb and has brought back dear old Hertz, so why ditch poor Ångström? Will no one start a movement to 'Keep Ångström's Unit bright!'? If not, then at least let us stick to the nanometre and not introduce yet another method of measurement without good reason.

Yours etc.,
R. KEITH MITCHELL.

30th August, 1979. Orpington, Kent.

CORRIGENDUM

By an unfortunate printer's error on p.2 above only part of Figure 1a (in S. Borg's 'An Unusual Star Peridot') was reproduced, and the full Figure 1a is accordingly printed below.

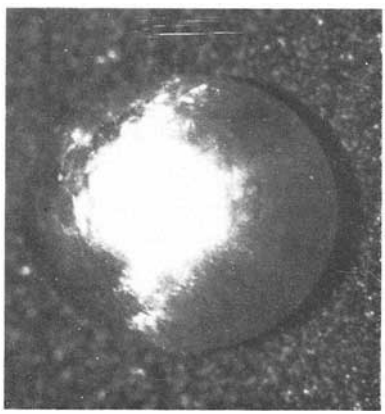

FIG. 1a. Star peridot showing sheen and star under single strong light source.

Historical Note

The Gemmological Association of Great Britain was originally founded in 1908 as the Education Committee of the National Association of Goldsmiths and reconstituted in 1931 as the Gemmological Association. Its name was extended to Gemmological Association of Great Britain in 1938, and finally in 1944 it was incorporated in that name under the Companies Acts as a company limited by guarantee (registered in England, no. 433063).

Affiliated Associations are the Gemmological Association of Australia, the Canadian Gemmological Association and the Rhodesian Gem and Mineral Society.

The *Journal of Gemmology* was first published by the Association in 1947. It is a quarterly, published in January, April, July, and October each year, and is issued free to Fellows and Members of the Association. Opinions expressed by authors are not necessarily endorsed by the Association.

Notes for Contributors

The Editor is glad to consider original articles shedding new light on subjects of gemmological interest for publication in the *Journal.* Articles are not normally accepted which have already been published elsewhere in English, and an article is accepted only on the understanding that (1) full information as to any previous publication (whether in English or another language) has been given, (2) it is not under consideration for publication elsewhere and (3) it will not be published elsewhere without the consent of the Editor.

Articles published are paid for, and any number of prints of individual articles may be supplied to authors provided application is made on or before approval of proofs. Current rates of payment for articles and terms for supply of prints may be obtained on application to the Secretary of the Association.

Although not a mandatory requirement, it is most helpful if articles are typed (together with a carbon copy) in double spacing on one side of the paper, with good margins at sides, top and foot of each page. Articles may be of any length, but it should be borne in mind that long articles are more difficult to fit in than short ones: in practice, an article of much more than 10 000 words (unless capable of division into parts or of exceptional importance) is unlikely to be acceptable, while a short note of 400 or 500 words may achieve early publication.

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THE JOURNAL OF GEMMOLOGY

and

PROCEEDINGS OF THE GEMMOLOGICAL ASSOCIATION OF GREAT BRITAIN

GEMMOLOGICAL ASSOCIATION
OF GREAT BRITAIN
SAINT DUNSTAN'S HOUSE, CAREY LANE
LONDON, EC2V 8AB

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THE JOURNAL OF GEMMOLOGY
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FACETED DIASPORE

By KENNETH SCARRATT, F.G.A.,
The Gem Testing Laboratory, London Chamber of Commerce and Industry

Although a difficult stone to cut, faceted diaspore,* which appeared on the German market two to three year ago[1, 2], is now available in this country. One light greenish brown stone weighing 0.69 ct has been donated to the Laboratory by the firm of E. A. Thomson, who further supplied four others on loan, these ranging from 1.72-6.53 ct. The following is a report upon the examination of these five stones.

Their colour is one of the more interesting aspects. All five have a distinct colour change. The daylight colour is greenish brown, whilst the apparent colour under tungsten lighting is pinkish brown. The change compares favourably with that of a moderate quality alexandrite. The dichroism is also distinct, the distinguishable colours being pinkish brown and green.

The absorption spectra are similar to what one might expect to see in a sapphire. Three broad bands in the middle of the blue at

*Diaspore is aluminium hydroxide, αAlO(OH): orthorhombic; hardness 6½-7, but perfect {010} cleavage.—Ed.

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	Refractive Index			Optic sign & character	Density	Fluorescence			
	α	γ	β			Long-wave ultraviolet	Short-wave ultraviolet	X-rays	Crossed filters
1. Rectangular 0.69 ct.	1.703	1.750	1.722	Positive Biaxial	3.3889	Inert	Green	Green	Red
Birefringence			0.047						
2. Cushion 6.53 ct.	1.701	1.750	1.722	Positive Biaxial	3.3907	Inert	Green	Green	Red
Birefringence			0.049						
3. Oval 1.93 ct.	1.701	1.750	1.722	Positive Biaxial	3.4009	Inert	Green	Green	Red
Birefringence			0.049						
4. Cushion 3.14 ct.	1.702	1.750	1.722	Positive Biaxial	3.3903	Inert	Green	Green	Red
Birefringence			0.048						
5. Rectangular 1.72 ct.	1.702	1.750	1.722	Positive Biaxial	3.3995	Inert	Green	Green	Red
Birefringence			0.048						

TABLE 1.

471, 463 and 454 nm are easily seen. A little more difficult to see is a fine sharp line in the deep red in the region of 701 nm.

Each stone was found to be biaxial positive. The refractive indices (see Table 1.) on the whole concur with those recorded by Larson and Berman[3], 1.702α, 1.722β and 1.750γ, the birefringence ranging from 0.047 to 0.049.

The average density, obtained hydrostatically using ethylene dibromide at temperatures ranging from 14.6 to 18.8°C, was 3.3941, the lowest being 3.3889 and the highest 3.4009. These results differ from those obtained by Bank[1], who records a density of 3.35. They do however fall into the range recorded by Dana[4] of 3.3 to 3.5.

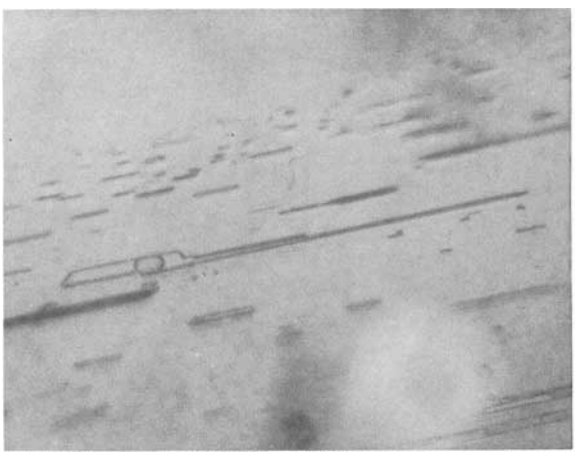

FIG. 1. Elongated two-phase inclusions in diaspore.

The fluorescence under long wave and short wave ultraviolet light and x-rays is of little diagnostic value, but for the sake of completeness we have recorded the effects in Table 1.

We can foresee no problems for the gemmologist in identifying this stone. As a mounted stone the probability is that its facet edges will become worn fairly quickly, inhibiting one's ability to obtain an accurate RI. However the massive doubling of the back facets, as can be seen easily with a 10× lens, and the distinctive absorption spectrum should be enough to ensure that this stone is not confused with any other.

The writer acknowledges with gratitude the assistance given by his colleagues during this investigation and the Laboratory is once again indebted to the firm of E. A. Thomson.

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THE OPTICAL CONSTANTS OF GGG

By K. NASSAU, Ph.D.

Bernardsville, N. J. 07924, U.S.A.

Since it was first used as a diamond imitation in the early 1970s, the optical constants of Gadolinium Gallium Garnet (GGG) have usually been given as RI 2.02 or 2.03 and DISP 0.038. I myself have used these values and am sometimes quoted as the source, but have merely repeated data current in the field.

Recent precision measurements by Dr D. L. Wood of the Bell Telephone Laboratories gave the following values (rounded to five significant figures):

Refractive Index	(sodium light)	1.9698
	(G, 4308Å)	2.0043
	(B, 6870Å)	1.9597
Dispersion	(G - B)	0.0446

Rounded off, the gemmological values that should be used are: RI 1.970, DISP 0.045. There could be a small variability derived from compositional variations.

I am grateful to Dr Wood for permission to use his data.

[*Manuscript received 24th May, 1980.*]

THE FLUORESCENCE OF BENITOITE

By R. KEITH MITCHELL, F.G.A.

When Webster first wrote on the subject of fluorescence of gem minerals*, he said that benitoite fluoresces bright blue under both long and short wave ultraviolet light. In his book, *Gems,* † he corrects this and says that fluorescence is seen only under short wave UV.

Recently I had the opportunity to check a colourless (very faint blue) faceted benitoite, which had been lent to me by Mr C. R. Cavey, of Roughgems Ltd. (There is a faint possibility that I sold the stone to Mr J. A. Fleming of that Company many years ago. I handled a few such cut specimens in about 1960, and Mr Fleming bought from me, when he first arrived here from New Zealand). Colourless benitoite is less commonly cut than the blue variety, but they occur together in the one known locality for the mineral at the head of the San Benito Valley in California.

Mr Cavey had noticed that his faceted stone fluoresced a dull red under long UV wavelengths. The fact that it was benitoite was simple enough to prove since, although the upper RI value is nearly the same as that for the refractometer contact fluid, which may sometimes cause confusion, it needs only a slight turn of the stone to bring that reading for the extraordinary ray down a little so that no confusion can then exist.

Having a quantity of benitoite rough in stock I sorted out a number of colourless and pale blue fragments of crystals and checked their fluorescence. Almost every piece showed the dull red fluorescence seen in the cut stone. Further investigation showed that this effect seen in long wave UV was suppressed more and more as one examined stones with a deeper blue colour. My faceted blues showed no sign of it. The causes of the colour and of the fluorescence is unknown, but it is of interest to note that all stones gave strong light-blue fluorescence under short wave UV. It was not possible to distinguish the colourless stones by this.

[*Manuscript received 12th January, 1980.*]

*Gemmologist, 1953, XXII, 264, 125-6. † 3rd edn. (1975), p.271.

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THE QUEST FOR QUARTZ . . . .

By S. B. NIKON COOPER, B.D., F.G.A.

Although it has the distinction of being the most common of any material used for gems, 'quartz' is an awkward name to assign to a watertight definition. Most books avoid the issue and say simply that it derives from an old German mining term. Those who do attempt to give it a meaning succeed, but with varying degrees of probability.

For instance, one suggestion is from a German root we have been unable to verify: 'quarzen' = 'to crackle'; that quartz 'crackles' when it is crushed . . .[1] Another, from the German 'quer' = 'cross', would make the full name 'querklufterz' = 'cross-grained ore', alluding to the stringers of massive quartz one finds in various country rocks.[2] Or others, taking a more pejorative use of 'quer', i.e. 'contrary' or 'odd', would derive it from 'quer-erz' = 'worthless ore'. This could be more likely, as it would have been the gangue accompanying the pay-vein the miners searched for. Some authorities take this even further and try to establish an ultimate derivation from the German 'zwerg' ('dwarf')[3] on the similar analogy of 'pixilated' cobalt ('kobold') or bedevilled nickel ('nickel'). Seemingly those old mines were inhabited by numerous types of hobgoblin—all rather unpleasant and of no profit to the miner.

And then we came across yet another derivation—this time from Dr Werner Lieber's *Kristalle unter der Lupe*[4]—incidentally above praise for the quality of its illustrations. Under 'quartz', Dr Lieber suggests a derivation from a Slav word 'kwardy', with the root-meaning of 'hard'.

A Slav word . . ? A Czechoslavakian dictionary gave us 'tvrdy', so it was time to enlist Dr Lieber's further help. He supplied his references: Hans Lüschen's *Die Namen der Steine,*[5] which—thankfully—cited most of the derivations quoted above, and with their dates of earliest usage. It also gave this statement: 'Quartz . . . the name first appeared in the mining district of Bohemia in the 14th century, and appears to stem from a Slav root ("kwardy"—a West Slav form similar to the Polish "twardy", Czechoslovak "tvrdy"). The original meaning is "hard". . .'

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From *a posteriori* reasoning this is simple enough to be true. Bear in mind we are considering massive quartz, not rock crystal or amethyst, etc., which had been known generations before; but massive quartz in hard rock mining—the gangue which hampered the miner's progress in the lead/silver veins they followed. Another *possible* derivation then; but why should this one be more acceptable—apart from its earlier date—than any of the others? Here we are fortunate. Unlike most mineral and gem names that evolved over centuries, we can date accurately the first written appearance of the word 'quartz'. It occurs in Agricola's *Bermannus* of 1528.[6] '. . . Ancon: I see several kinds of rocks here. Bermannus: A large number . . .. Another genus is this one which is seen to be transparent at times, at times very white, light yellow or bluish grey. Our people call it quarzum . . ..'

Who was Agricola, and what was his 'quarzum'? First, let us note that both names have been Latinized. 'Agricola' is Georg Bauer, and 'quarzum', a Latinized form of 'quartz' (or 'kwardy').

Georg Bauer—or Agricola—(1490-1555) is deservedly known as the 'Father of Mineralogy'. Until his time we move in almost magical circles—of superstitions little better than old wives' tales; Agricola marks the beginning of a systematic, scientific, approach to minerals. Academics had written of precious stones before; Agricola was the first, though, to leave his 'ivory tower'—writing on other men's writings—and instead go and live and work with the miners themselves. Which, literally, he did—leaving the Rectorship of Leipzig and his studies in Italy—to become a physician in Joachimstal 'partly to test what had been written about mineralogy by careful observations of ores and the methods of their treatment.'[7]

And herein, we believe, lies the clue: he went to Joachimstal—the centre of silver mining at that date. And Joachimstal . . .? The same as the modern Jachymov—in Czechoslovakia. In Agricola's time it would have been the Kingdom of Bohemia. And the language that would have been spoken?—not by German mining officials, but by the miners themselves? A Czechoslovakian/Bohemian dialect. What more natural than that they would use their own Slav terms to describe the minerals they found?

'. . . our people call it "quarzum"'. Again, this is a Latinized

form, as his work was written in Latin. We submit though: 'our people call it "kwardy"' is the original version.

And so a small town in the Czechoslovakian Erz Gebirge gave a new name to the world. Our English 'quartz', Italian 'quarzo', Danish 'quarts', Russian 'kwartz', etc. The older gem names: 'crystal', 'amethyst' and 'citrine' (again, Agricola is the first to apply this to the yellow variety of quartz) will still continue to be used—but now as varieties only of the parent rock: quartz—the 'hard' stone.

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[*Manuscript received 14th September, 1979.*]

NOTES ON THE PROPERTIES AND INCLUSIONS OF GARNETS FROM LAPLAND, FINLAND

By S. HORNYTZKYJ, F.G.A, and K. T. KORHONEN, M.Sc.

INTRODUCTION

In Lapland, northern Finland, red gem quality garnet is obtained as a by-product of goldwashing from river gravels in several areas. The garnet occurs as water-worn pebbles which after cutting mostly yield stones up to 1ct. Some time ago the authors had an opportunity of examining a number of garnets said to have come from these areas. To the authors' knowledge the properties of these garnets have been incompletely recorded in literature; therefore this chance was most welcome. The results of this study are discussed below.

ON THE GEOLOGY OF THE AREA

Geologically the areas where these garnets are found belong to the large granulite area (Figures 1 and 2).[1,1b,2] The granulite complex consists of metamorphic stones formed from sedimentary stones under high temperature and pressure. The main stone of this granulite area is the strongly orientated gneiss, the main minerals of which are quartz, plagioclase feldspar, biotite and pyrope-rich garnet. The granulite complex contains as fine stripes garnet-biotite gneisses, garnet-cordierite gneisses, biotite-plagioclase gneisses, quartzite and hypersthene gneisses. There are also some magma-stones in the granulite complex, such as norites and hypersthene containing quartz diorites.[3]

PHYSICAL AND OPTICAL PROPERTIES

In all, 157 faceted garnets (average weight 0.57ct) were studied. The refractive index of each specimen was determined using sodium light and a standard Rayner refractometer. The values obtained lay within a wide range, 1.764-1.792.

Although garnet is an isotropic mineral, a number of these garnets appeared as different colours in transmitted and reflected light. The colour was finally determined (in daylight) in transmitted light. Two different colours were dominating, brownish red (colour

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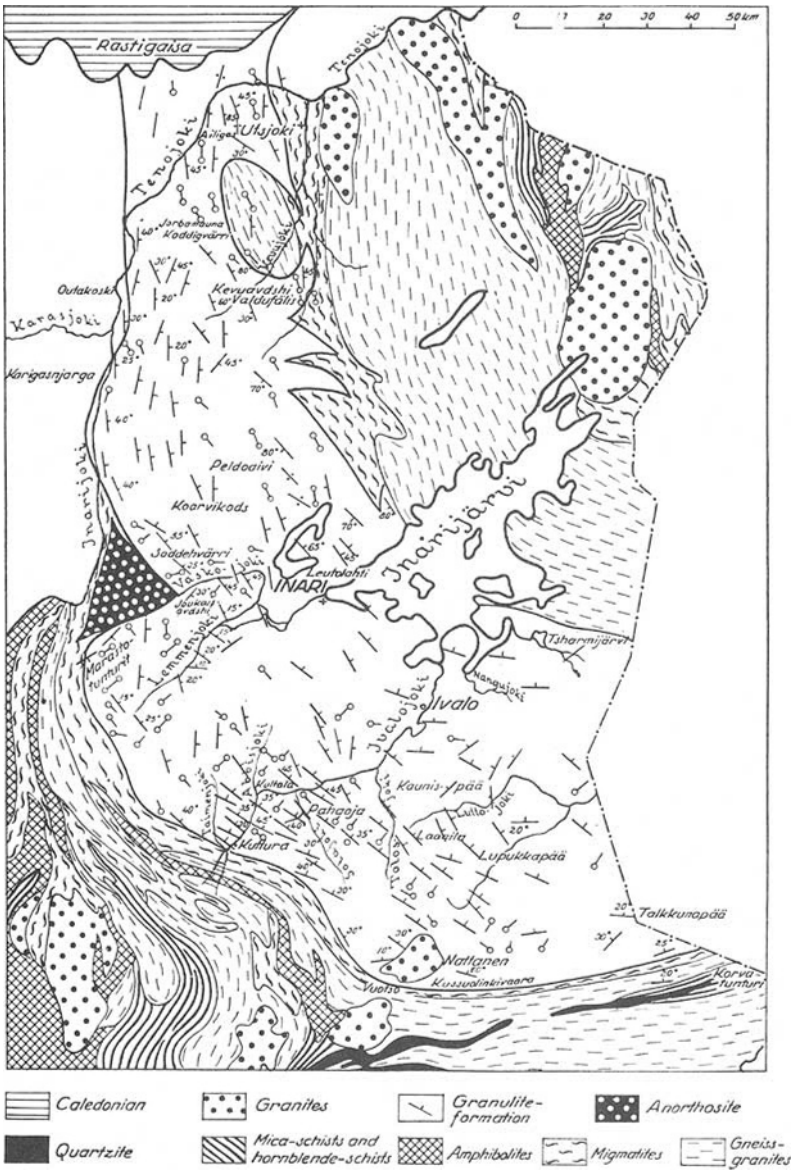

FIG. 1. Geological map of the granulite area of Lapland. *(According to E. Mikkola by P. Eskola*[1,16]*)*

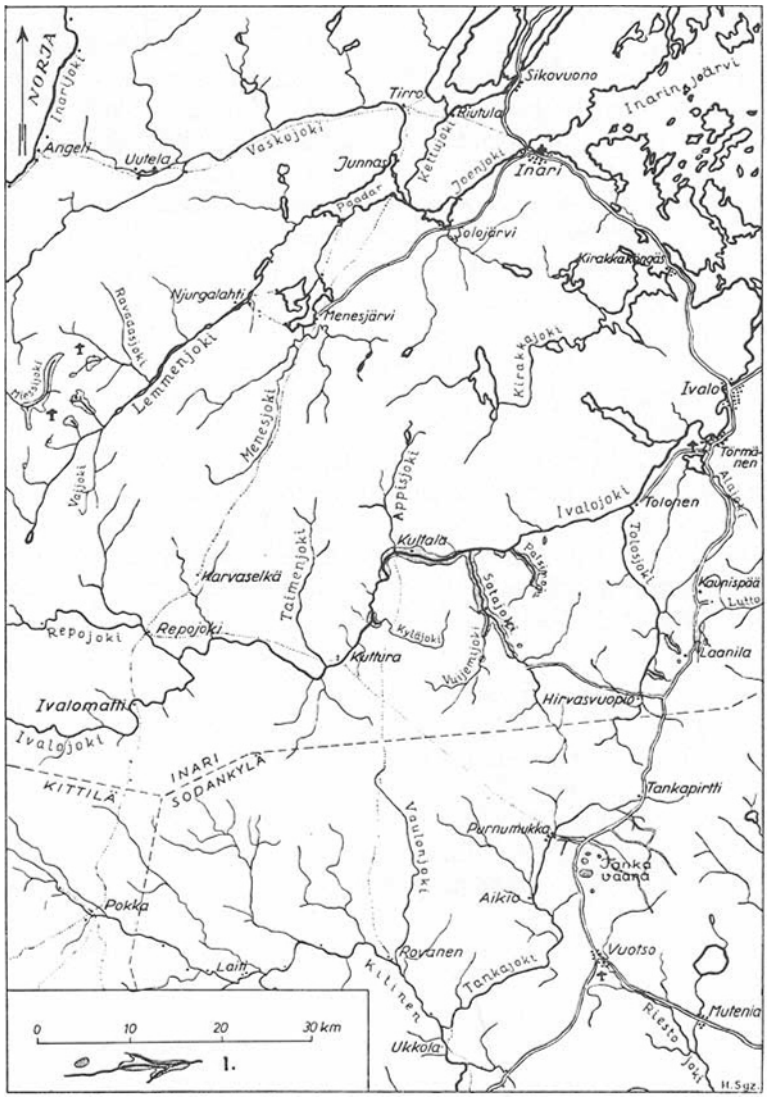

FIG. 2. Placer gold occurrences of Lapland. *(By H. Stigzelius[2])*

1. Gold occurrence

9C8) and greyish rose (colour 12B6), the figures in brackets referring to the standard colour charts shown in the Methuen Handbook of Colour.[4]

The absorption spectra of these stones were determined with a Rayner prism spectroscope. Without exception the three main absorption bands characteristic of almandine, i.e., positioned at 5050, 5270 and 5760Å, and weaker bands at about 6170 and 4620Å were observed.

Between crossed nicols a great number of the stones showed anomalous double refraction which was variable.

Because of the small size of the individual specimens, the specific gravities of these stones were determined by the heavy liquid method. The stones were placed in Clerici solution (they all floated at the surface), and the specific gravity of the liquid was lowered with distilled water until the heaviest stone, and after this the lightest one, remained freely suspended in the liquid. In both cases the refractive index of the liquid was measured and this was repeated several times. The average values of both measurements were then plotted on the specific gravity/refractive index graph of Clerici solution prepared beforehand by testing stones of different known specific gravities.[5] The specific gravities of these garnets were between 3.92-4.17.

Chemical Composition

Owing to the isomorphous replacement of Fe for Mg in the basic chemical composition, a whole series of garnets exists from pyrope to almandine. The garnets lying in the middle of this series, i.e., which can neither be termed pyrope nor almandine but which are intermediate between these two, form a so-called intermediate group of garnets. According to Webster[5] the refractive index of this group may be said to range from 1.75 to 1.78, and the specific gravity from 3.80 to 3.95, but as Webster states these limits are quite arbitrary.

The refractive indices and specific gravities of the examined garnets from Lapland lay within the ranges 1.764-1.792 and 3.92-4.17, respectively. These values correspond well with those ranging from pyrope-almandine intermediate series towards almandine. Our observations are further supported by Meriläinen.[6] According to him, in the coarse-grained garnet-quartz-feldspar gneisses of the granulite complex the garnet is

pyrope-rich almandine (pyrope 30-35%, almandine 60-64%, grossular 1% and andradite 5%), and in the fine-grained garnet-quartz-feldspar gneisses the garnet is also pyrope-rich almandine in composition (pyrope 35-45%, almandine 55-60%, spessartine 1-2%, grossular 1-2% and andradite 2-5%). In the garnetiferous porphyritic potash granites of the granulite complex the garnet contains pyrope 25-30%, almandine 65%, spessartine 2%, grossular 1% and andradite 5%.

Furthermore, on the basis of garnet analyses made from garnets in the granulite complex around some of the goldwashing areas,[1] the mole composition of these garnets was calculated according to the method described by Deer, Howie and Zussman.[7] The average of these calculations gave us the composition: pyrope 41%, almandine 55%, spessartine 1% and grossular + andradite 5%, the variation being: pyrope 39-44%, almandine 50-58%, spessartine 1-2% and grossular + andradite 3-9%.

INCLUSIONS

The microscopic examinations were carried out with both a Wild Heerbrugg stereoscopic microscope and a Leitz SM-pol petrological microscope, and the stones were immersed in methylene iodide (R.I. = 1.742) to facilitate the study. The most typical inclusions observed in these garnets seemed to fall into six distinctive types. They are described hereunder in order of their decreasing abundance:

(1) Long thin or thicker short, sparsely packed needles intersecting each other at certain angles. They showed birefringence between crossed nicols, with bright colour changes (Figures 3 and 4).

(2) Small crystals which lay at random orientation, surrounded by brownish multifold haloes. They were birefringent between crossed nicols, with vivid interference colours (Figures 5 and 6).

(3) Orange brown, thin tabular crystals of random orientation, surrounded by a single halo. A modification of the Becke line test indicated that their refractive index was higher than that of their host. Between crossed nicols they showed birefringence with vivid interference colours. When illuminated with a mercury vapour lamp,[8] they

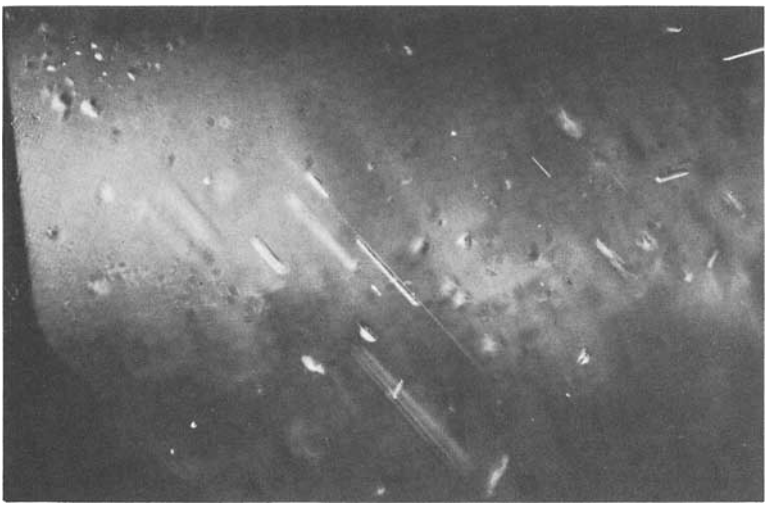

FIG. 3. Sparsely packed needles intersecting each other at certain angles. 140×.

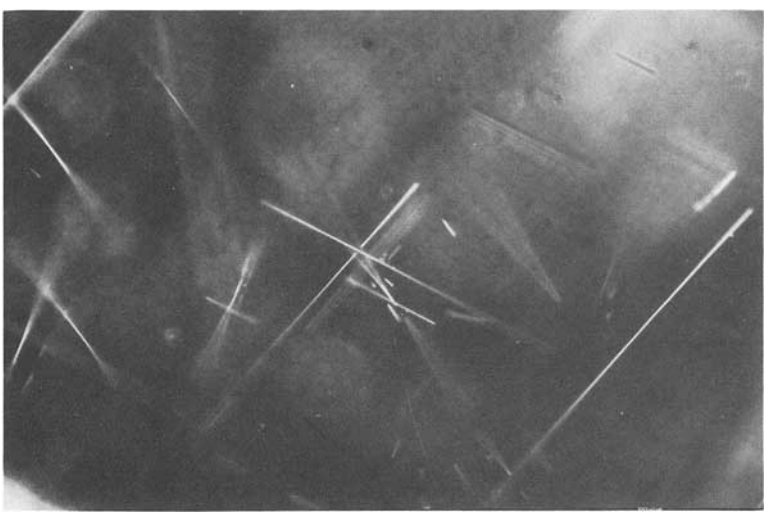

FIG. 4. Sparsely packed needles intersecting each other at certain angles. 140×.

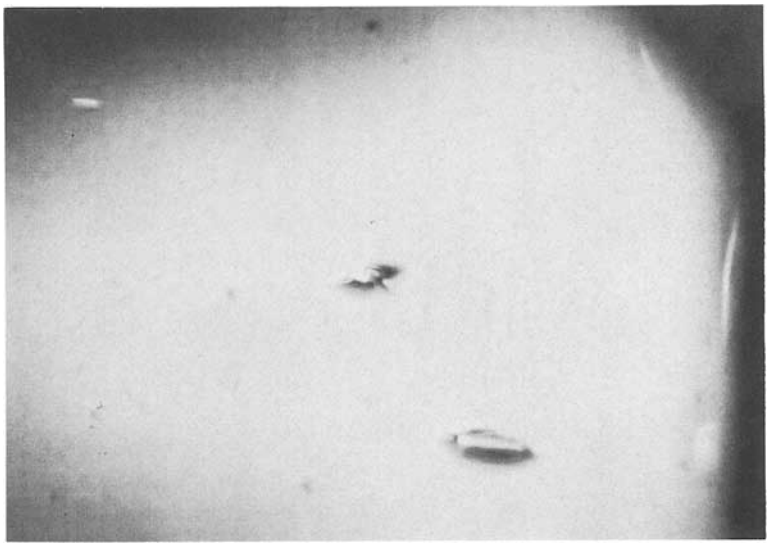

FIG. 5 Small crystals surrounded by brownish multifold haloes. 160×.

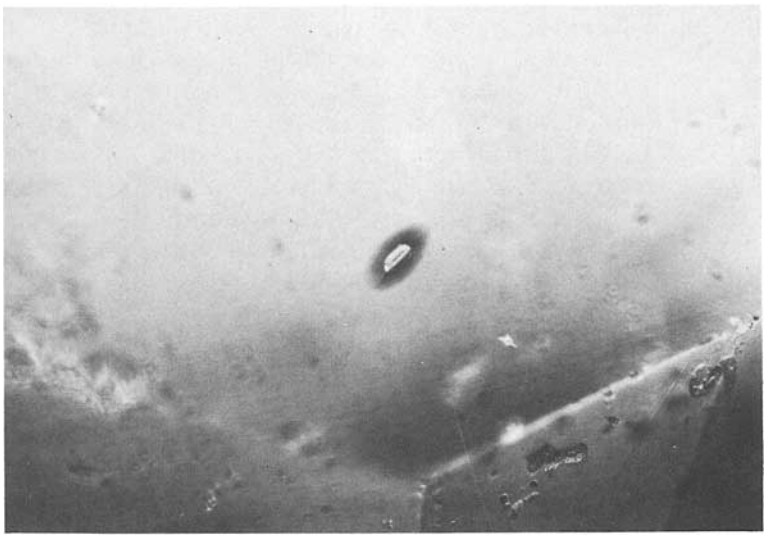

FIG. 6. Small crystals surrounded by brownish multifold haloes. 160×.

FIG. 7. Orange brown thin tabular crystal surrounded by a single halo. 160×.

showed a greenish colour whereas under tungsten illumination the colour was orange brown. These crystals occurred together with the aforementioned small crystals surrounded by brownish multifold haloes (Figure 7).

(4) Tube-like, transparent crystals of random orientation, some of which were slightly curved. Their refractive index was lower than that of their host confirmed by a modification of the Beck line test. They showed birefringence between crossed nicols, with bright colour changes (Figures 8 and 9).

(5) Well formed, doubly terminated, transparent prismatic crystals in which smaller crystals were observed. These prismatic crystals had a six-sided habit and were irregularly orientated. Their facet edges darkened when the focus was raised indicating that their refractive index was lower than that of their host, and this was confirmed by a modification of the Becke line test. Between crossed nicols they showed straight extinction with interference colours ranging from grey of the first order to higher colours (Figures 10 and 11).

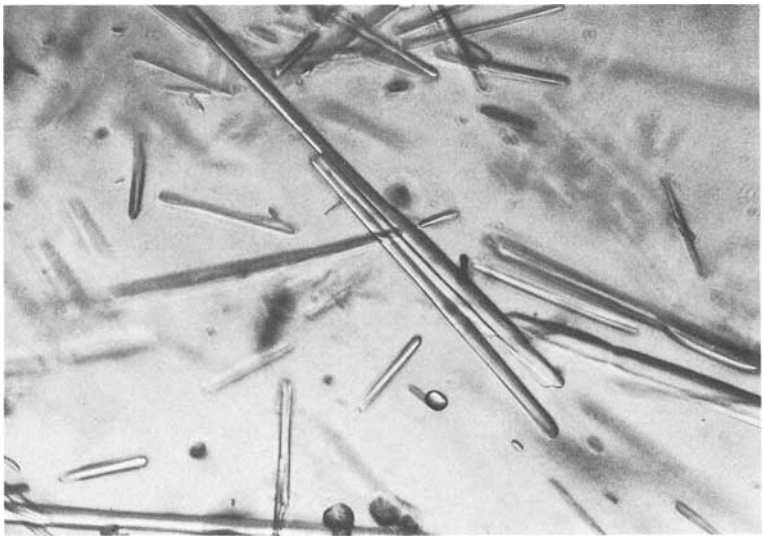

FIG. 8. Tube-like transparent crystals. 175 ×.

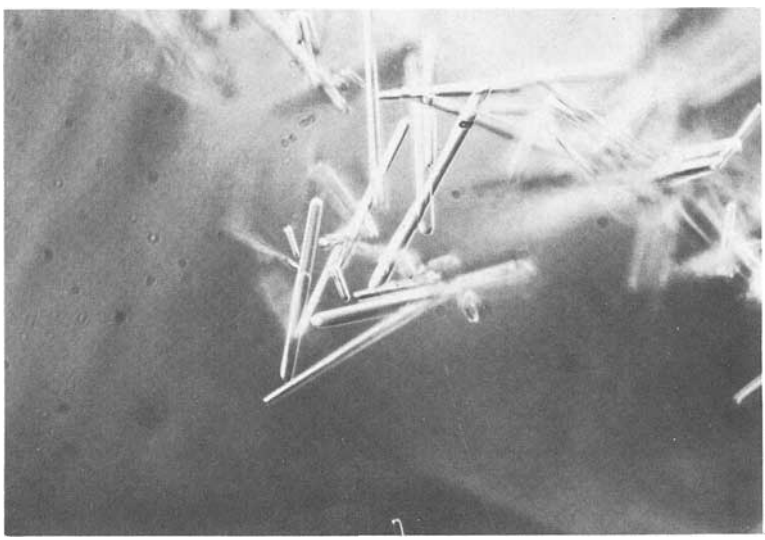

FIG. 9. Tube-like transparent crystals. 175 ×.

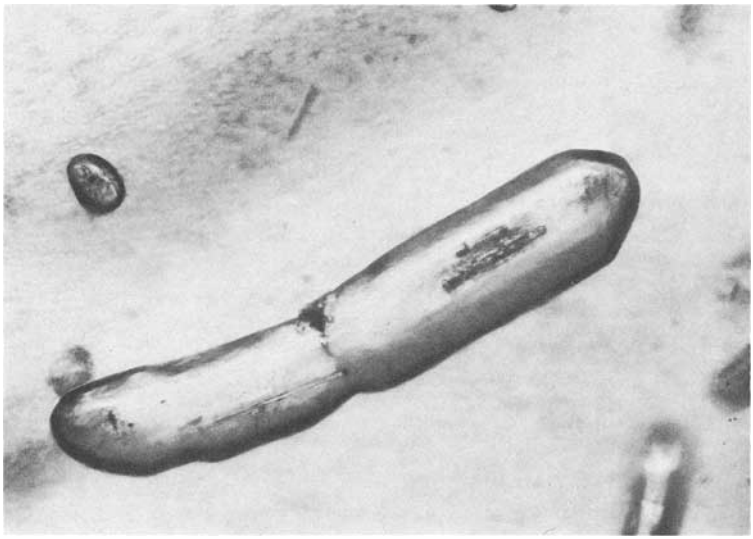

FIG. 10. Doubly terminated transparent prismatic crystal. 200×.

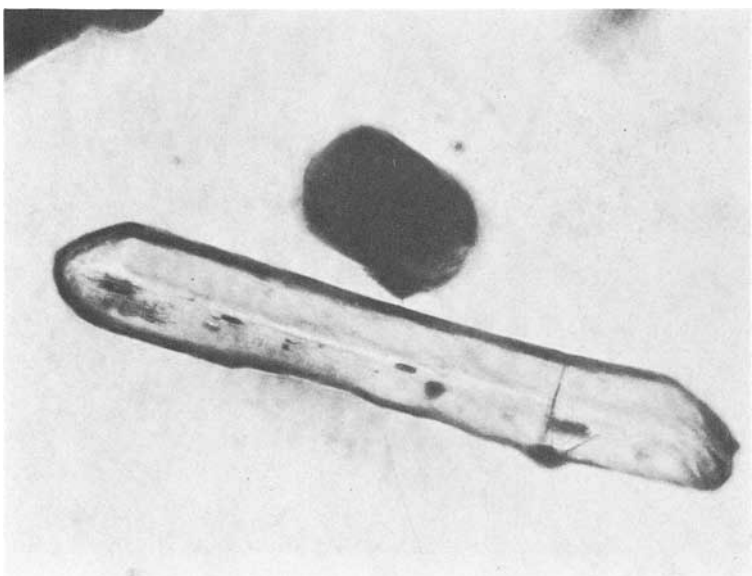

FIG. 11. Doubly terminated transparent prismatic crystal. 200×.

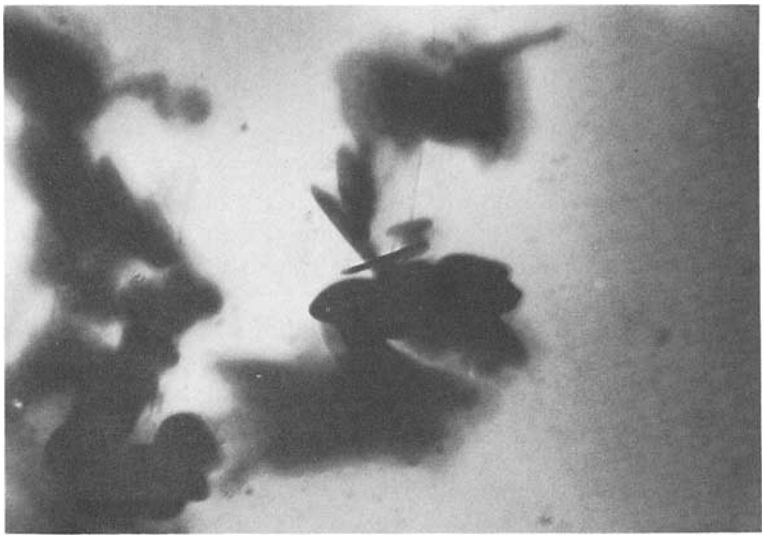

FIG. 12. Black, opaque, thin tabular crystals with a somewhat hexagonal outline. 170×.

FIG. 13. Black, opaque, thin tabular crystals with a somewhat hexagonal outline. 200×.

(6) Black, opaque, thin, irregularly orientated tabular crystals with a somewhat hexagonal outline and metallic lustre (Figures 12 and 13).

CONCLUSIONS

On the basis of the foregoing observations these six types of crystal inclusions are thought to be: 1. rutile (Figures 3 and 4); 2. zircon (Figures 5 and 6); 3. monazite (Figure 7); 4. actinolite (Figures 8 and 9); 5. apatite (Figures 10 and 11); and 6. ilmenite (Figures 12 and 13).

Eskola[1] and Meriläinen[6] have reported all these minerals as common mineral constituents in the granulite area of Lapland. Furthermore, Mellis;[9] Zwaan[10] and Gübelin[11, 12] have proved these minerals to be inclusions in garnets from various localities. However, the precise determination of these inclusions has not yet been possible for want of suitable instruments.

ACKNOWLEDGEMENTS

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PROMOTING AND MERCHANDISING COLOURED STONES

By JACQUES SABBAGH, M.B., B.Ch., M.I.C.S.

(Being the text of a talk given to the Gemmological Association of Great Britain in the Central Electricity Generating Board Cinema, Newgate Street, London, E.C.2., on the 12th October, 1979)

It is a privilege for me to address you this evening on the subject of promoting and merchandising coloured gems, and it would be a pleasure indeed if I am permitted to do so in an informal way. By your leave I shall start, if I may, on a rather personal note. People who happen to know about the story of my life, seventeen years of which were devoted to medical studies and to the practice of medicine, often ask me with astonishment, 'How come you changed horses midstream? What made you quit this most noble, this most essential profession, to get involved in the business of coloured gems?'—these and similar transparent questions thus implying that my present activity in the jewellery trade is a comparatively futile one and that coloured gems are rather superfluous commodities. Well, not only do I immensely enjoy my present occupation, but also I happen to be very proud of it. Indeed, I do not believe that jewels are superfluous commodities. I am convinced that they satisfy one of the basic needs and that jewellers cater for one of the fundamental requirements of human nature.

As Thomas Carlyle, the nineteenth-century Scots essayist and historian said: 'The first spiritual want of barbarous man is decoration.' By this he meant self-adornment, and this is an anthropological fact, substantiated by our observation of the behaviour of primitive man of aboriginal tribes still inhabiting certain recesses of the jungle and isolated areas of our planet, as well as by various archaeological findings. Cave-man, primitive man invariably demonstrates a tendency for self-adornment by using any handy object that lends itself to this purpose. At the same time, he would attribute occult powers to articles he uses for personal decoration, whether they be perishable items such as bird feathers or plant seeds, or non-perishable objects, as for instance sea shells, animal teeth and claws, or mineral crystals. He would pierce them and then string them and wear them for their often inextricably ambivalent functions: the supernatural power of talismans and charms and the

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beautifying property of jewellery. In actual fact, excluding the other members of the genus Homo, none of the components of the animal kingdom, even the higher primates, the anthropoid apes, our closest evolutionary ancestors and collateral relatives, exhibit any marked sign of beauty appreciation. It seems that the emergence of a sense of aesthetics, sufficiently compelling to induce artificial additions to the anatomy of even sometimes minor surgical alterations of it, has occurred more or less parallel to the development of language, tools and culture.

Now, with your permission, I would like to venture a diagnosis. Jewellery enterprises that neglect the field of coloured gems, that to various degrees discard them from their inventory, are—forgive me for saying so—colour-blind. The same way an individual affected by Daltonism, that is colour-blindness, misses out on a lot of the beauty, of the glory, of the colourfulness of life and nature around him, seeing them as it were, in different shades of black and white as though he were watching a telecast on the screen of a non-colour television set, or a black and white movie picture, a jewellery concern that persists in ignoring the field of coloured gems is missing out on incalculable opportunities for profit-making.

Let me sketch out for you a very familiar sequence. When a young woman is considering buying her first piece of jewellery she will, as you know, seek the jeweller almost invariably for a diamond ring. The reason for this is twofold:

1. Diamond, the King of the gem world, is the most prestigious thing to wear, and
2. Diamonds, like pearls, can be used quite indifferently with practically any dress colour or style.

Later on, as and when affluence brings its mixed blessings into her life, this young lady will again look up the jeweller for, probably, a diamond brooch or pendant. Sometime later, she may consider changing her ring for a larger and more important diamond. To cut a not very long story short, she may eventually look for a pair of diamond earrings; and here it will very likely come to an end, the point of saturation being reached.

On the other hand, once this very same lady develops a sophisticated taste for coloured gems, something which requires a certain gratifying dexterousness, some degree of selectiveness in seasonal as well as colour matching of jewel and dress—once she

starts buying and using them, this new sequence will never end. Her desire for coloured gems will prove quite insatiable, due to the enormous variety and the practically endless combinations. The point of saturation in this case is unreachable, it is elusive, unattainable. To put it in a nutshell, coloured gems constitute a dimension that extends far beyond the dimension of diamonds. We can have only one monarch: Diamond. The number of princes and barons on the other hand is theoretically unlimited; consequently, coloured gems offer, literally, a golden opportunity to the jeweller.

Now, we have to face this question: How can the individual jeweller get into the field of coloured gems, or if he is already handling coloured gems as a sideline, or even as a main line, how can he develop this branch to its maximum potentiality? In answer to this question, three factors have to be considered. These are:

1. The Inventory.
2. The point-of-sale merchandising.
3. The sales techniques.

THE INVENTORY

A carefully chosen, well balanced stock of coloured gemstones is logically the starting point. You cannot sell what you do not have—except on the rare occasions where you act as a broker and/or sell from goods consigned to you. Furthermore, sales are in the numbers: the bigger and the wider the choice in your arsenal, the greater are your chances for scoring direct hits.

However, it is not necessary to have all your inventory of gemstones mounted. There is no need to tie up more capital unnecessarily. It is, on the contrary, desirable to leave a substantial part of your stock in the form of loose stones. This way, you will be leaving the door open for the option of custom made, hand tailored pieces of jewellery that would exactly fit the taste and requirements of the eventual buyer.

All right, so you have to build up an inventory of coloured gems. What are these gems? What are the characteristic properties of gemstones? I do not propose to tax your patience or offend your knowledgeability with a detailed dissertation on gemmology; I am sure quite a number of people present are more versed than I in the topic. I intend however, to touch very briefly on certain elements of the subject. I would like first to enumerate the characteristic properties of gemstones. These are:

1. Beauty
2. Durability
3. Rarity

and 4. A property which has been somehow persistently overlooked by gemmologists and consequently its mention in gem books consistently omitted, and this is, Portability.

Beauty

A gem has to be attractive enough in order to trigger the urge to acquire it, in order to stimulate the desire to possess it, in order to incite a willingness to pay for it, to buy it.

Durability

The second property is the resistance to scratching; it is what we commonly call hardness. A gem has to possess hardness enough to retain its beauty. You see, unlike similar luxurious but perishable commodities such as fur coats and precious leather-ware, as for instance crocodile handbags and shoes, jewels are expected to be longlasting, eternal; they are meant to be handed down from generation to generation.

Rarity

The third characteristic of a gemstone, and an exponent of this quality according to the inexorable, all-pervasive, omnipresent law of supply and demand, is price. It must be rare enough in order to fetch a decent price.

Portability

Gemstones constitute value in compact size, they are a form of condensed wealth. One can carry literally in one's pockets tens, or even hundreds, of thousands of pounds in the form of a few tiny parcels of gems. In the course of history, gemstones have surreptitiously or openly crossed borders between countries, they have continuously changed hands, being bought in times of affluence and sold in times of depression. They have repeatedly served to finance a king or a prince to wage war or to buy a peace settlement; they have been used along with precious metals often to appease the appetite of an aggressive imperial power or as ransom for many a crowned head. If gemstones were to disappear overnight from the face of the earth, most people would go on living as usual, practically unaffected; but on the other hand, had gemstones never

existed, many a chapter of human history would have to be rewritten.

Another point I would like to expose is one that has to do with nomenclature. Traditionally, jewels are divided into precious and semi-precious. The members of the precious class are four: first is the universally acknowledged king of them all, diamond. The other three princely members of this class are emerald, ruby and sapphire. The rest of the aristocratic members of the gemworld have been all lumped together under the heading 'semi-precious'. However, over the last few decades, this elementary classification, this simplistic terminology has been increasingly eroded by the gradual realization that the line of demarcation between the precious and the semi-precious gems is indeed a very hazy one.

The dividing line is so blurred that there is in more than one area factual confluence of the two conventional categories; because, what are we to use as a yardstick in order to differentiate between precious and semi-precious stones? Is it the first characteristic of a gem, that is, beauty? But beauty is a dual property: the objective or inherent factor related to form, colour, harmony and symmetry, and the subjective element of assessment and appreciation, which is largely dependant on fashion, taste, the times and geography. To give one example, Pliny tells us that in ancient Rome emeralds were much more appraised that rubies, whereas if we focus on Renaissance Florence some sixteen centuries later, we hear Benvenuto Cellini informing us that rubies were considerably in higher demand than diamonds and were fetching prices eight times as much. Shall we then use as a yardstick the second property of a gem, that is durability, or hardness? But emerald, a notable member of the precious group with a hardness of 7½ on Mohs's scale, is less hard than either chrysoberyl with a hardness of 8½, or topaz with a hardness of 8; both members of the semi-precious group. Is it rarity and its exponent, price, that we shall go by to distinguish between the two categories? We find that this too, does not apply to several cases—for example, a demantoid garnet or an alexandrite chrysoberyl can fetch high prices, both being rarer findings than a rather nice sapphire.

The realization of all these facts has led the participants of an international convention of retail jewellers a few decades ago, to pass the half-measure resolution of arbitrarily shifting the demarcation line between the two groups of gems to the hardness

immediately above that of Quartz—that is 7 on Mohs's scale. They chose the hardness 7 because it is that of silica which is abundantly present in sand as well as in the dust suspended in the air carried by the winds, which would scratch any stone of a hardness of 7 or below, thus prematurely showing the signs of wearing. So, according to this resolution which takes into consideration only the property of hardness, all gems that possess a hardness superior to 7 are precious and all those with a hardness of 7 or below are semi-precious.

It has been quite some years now since the French members of the trade have discarded the illogical term 'semi-precious' to replace it by 'pierres fines' whose closest English equivalent would be 'gemstones'. Quite recently, at the last annual conference of the International Federation of the Jewellery Trade, 'C.I.B.J.O.', in Paris, the use of the term 'semi-precious' was considered at length, it being reported that some Scandinavian countries and West Germany had made progress by getting official acceptance of the term 'precious'. However, there were difficulties for some, it was said, particularly in respect of Customs Authorities, in redefining the expression 'semi-precious'. The U.K. delegation considered that we should do everything possible, in the U.K., to discourage the term, which is a 'down-grading' one. They believe it is better to use 'precious stones' or 'gemstones' . . . . . At long last we can see the light at the end of the tunnel and I trust the day is near when the derogatory expression 'semi-precious' will become obsolescent and the conventional classification of gems will be past history.*

Now let us focus on an important point related to the building up of an inventory of coloured gemstones, namely its investment value to the jeweller. In inflationary times like these, continuous price increases of practically every marketable item of service have become a familiar aspect of the economic landscape. Over the last decade or so, coloured gems have steadily figured among the commodities heading the list of price increases. Between January, 1969 through December, 1978, these gems, in the rough, at the sources—whether in Brazil or Colombia, Africa or Sri Lanka, Australia or Afghanistan—have undergone, across the board, increases in prices by leaps and bounds, so that at present they fetch in terms of Pounds Sterling between nine and a half to

*I had hoped that it was already practically obsolete, except as a matter of history.—Ed.

almost eleven times their prices in the beginning of 1969. Evidently the same has applied to the World gem cutting and jewel manufacturing centres, whether around the mining areas or in such traditional, or recently developed, centres as, for example, London or Birmingham here in the U.K., Idar-Oberstein or Pforzheim in Western Germany, Jaipur in India, or Bangkok in Thailand. What is perhaps even more interesting is the fact that at no point during this last decade, has the curve of price increases ever been deflected downwards, as happened in the fifties and early sixties. It is thus obvious that, even after price indexing against currency depreciation, coloured gemstones have shown a true up-valuation. It follows from this that one should not think twice to invest in coloured stones.

THE POINT-OF-SALE MERCHANDISING

It is all very good to possess an inventory that rapidly scores genuine increases in prices, that gains in value in absolute terms. However, this asset would turn into a liability if such an inventory consists of hard-to-sell items—of articles that go up in replacement price without the need for replacement—of commodities that confine themselves to registering profits on paper. The life-blood of any business is turnover.

An effective catalyst for turnover is point-of-sale merchandising, which actually boils down to proper display techniques, capable of triggering public interest in coloured gemstones with resulting sales. Effective display of the goods is cardinally important for the jewellery shop and the jewellery department in a department store, as well as in the layout at jewellery exhibitions. Space rental costs being what they are in the large City centres of the World, it is vital that every square or cubic foot should be adroitly and efficiently used in order to generate sales and profits that should stretch well beyond the break-even point.

Lighting

The first point in this context I am going to consider with you is the overriding question of lighting. Diamonds, as you know, are shown to their best when bathed in fluorescent or mercury vapour light containing a bluish hue, which would offset any off-coloration present in them. Their cold eternal fire reacts better to a

moonlight type of illumination. Conversely, coloured gemstones are displayed to good advantage under ordinary tungsten spotlights which possess a subtle yellowish hue. Similar to oil paintings, their colours are shown to full glory and striking vividness under a warm solar type lighting. In an art gallery you will never find the strip lamps fitted above the paintings fluorescent, they are invariably ordinary tungsten lights.

In recent years the research work undertaken by optics physicist, Professor O. Erametsa of Helsinki, Finland has resulted in the remarkable invention of the Neochrome electric bulb. The principle of this bulb is that its glass consists of an association of synthetic crystal and of rare mineral salts. This gives it the property of substantially filtering out the yellow component of the spectrum, thus imparting sharper definition to the exposed items and accentuating colour hues and tonality, without denaturing them.

Needless to add that the intensity of the lighting should be adequate. This is especially important in case of street windows facing the sun during part of the day, in order to offset the mirror effect of your window glass whenever the sun is shining their way.

Mixing of Colours

The second point in the proper display techniques is to keep from displaying your jewellery in trays of the same sets of rings, as usually done with diamonds—e.g. a tray containing emerald rings, a tray with aquamarine rings, another of ruby rings, and so on. You have an important asset: Colour! Mix them up, try to find the best combination, the optimum arrangement. Endeavour to compose a chromatic ballad, to produce a symphony of colours. A good practical tip that may help to achieve splendid results is to place complementary colours adjoining each other. Examples of complementary colour pairs are:

Red and greenish blue — Orange and cyan blue
Yellow and indigo blue — Violet and greenish yellow
Purple and green

Complementary colours possess what the physiologists call 'the property of simultaneous contrast', they reciprocally increase their vividness; they enhance each other. Incidentally, this phenomenon is taken advantage of in the street traffic lights.

Not only those already mentioned, but every colour and shade of colour has its complementary, which lies diametrically opposite

it on the colour wheel. At any rate, in your efforts to find the best colour layout, take as often as possible the advice of the ladies in your sales force. I find, as a rule, that members of the gentle sex are blessed with a higher colour sensitivity than myself.

The Hidden Message of Mineral Display

The next recommendation I would like to make in merchandising your coloured gemstones is the wide use of rough crystals as a background for both your windows and in-store displays. Mineral crystals are very decorative; they are an integral part of the display theme; frequently, they can serve as props or in the place of pads for the exhibited jewels; they offer a subject of conversation; furthermore, they are marketable items.

Another suggestion I would like to offer is to spread in the midst of your rings and brooches and necklaces, some loose gems in a way that is in keeping with the general colour harmony. The importance for your image of the presence of both rough crystals and loose stones in your display is not to be slighted. It carries two implied messages: the rough stones hint to a direct link between your concern and the source—the mines, and the loose gems suggest that you are a wholesale gem importer, with contacts with gem cutting centres, who is in a position to offer the best values. In this way two new dimensions are added to the image of your establishment.

Skilful Price Tagging

It is sometimes customary for jewellers to place price tags on certain items on display. There is no harm in this, provided you apply the art of the 'inviting price tag technique'. Every one of you knows perfectly well his best selling price bracket. Put price tags on some of the pieces that fall within this bracket and, if you wish, on some of the items that are below it; but never on any article that lies in a price category above it. This may drive away the shy potential buyer, and you need the traffic. If you are going to price tag some of the loose gems on display, when the stone happens to be a fraction of a carat—say a ¾ carat diamond or a 60 point emerald—it is advisable to mark the tag with the total price of it, which will evidently be inferior to its price per carat. If, on the other hand, the gem is larger than a carat, it is preferable to put

down its price per carat, which will obviously be less than the total price for the stone.

Contagious Use of Jewels

Another helpful procedure in merchandising coloured stones is what I am very fond of calling the 'animated display'. Wear coloured gems yourself; have your wife wear them. Make the members of your sales force wear them. Using coloured jewels imparts to them added life, increased brilliance, intensified fire, because with every movement of the body, they catch the light rays at a different angle, and an alternate corner, another facet springs out from the dark and shines forth in full glory. Confer on them the prestige of being used and of being useful and the compliment will be twice returned—firstly in the form of the privilege of wearing them, and secondly through a vague, inarticulate, yet strongly motivating impression at the border plane between the subconscious and the conscious mind of the potential customer. Translated into the parlance of awareness, this insidious motivation would be the equivalent to an argument along these lines: 'If you, the professional, find them worthy of being used by you, they deserve to be worn by myself.'

Birthstones of the Month

Finally, one of the important topics of the display techniques is the birthstones. The belief in the occult power of birthstones seems to have originated from no less dignified source than the Biblical story of the jewelled breastplate. This was worn by Moses' elder brother Aaron, the High Priest. Clad in vestments wrought with gold and blue, purple and scarlet, Aaron stands before the altar of God, bearing over his heart the jewelled breastplate whose twelve precious stones are each one dedicated to a tribe of Israel. They are mediums whereby God signifies his judgement of the tribes. If He is angry the stones turn dull and colourless, but, if the Israelites have obeyed His Commandments then God makes them shine forth in glorious splendour of light and colour. Later, according to Flavius Josephus in the late first century A.D. and St Jerome in the early fifth century, the twelve gems of the breastplate became linked in association with the twelve signs of the zodiac and the twelve months of the year. Each stone became related to a particular month and endowed with a peculiar virtue for those born in

that particular month. The jeweller intent on developing his business in coloured gemstones must not fail to draw great promotional dividends from such deep seated popular beliefs. He should permanently devote a determined section of his most exposed window, preferably a street window when there is one, to the special display of the stone of the month. After three or four months, he will condition the habitual passer-by to expect a change in this section at the beginning of each successive month. The expectancy in itself will act as a sight-arresting mechanism.

There are two ways of displaying the birthstone. One is the simple method of showing the rough crystals in the background and some loose gems interspersed among the mounted pieces—all consisting of the stone of the month. The other procedure is a rather elaborate one, whereby you propose each month to deliver to the public a sort of graphic lecture on gemmology. It has the advantage of investing your establishment with a kind of academic aura; of heralding it as the gem-headquarters of the vicinity, thus drawing a number of appraisal business and occasionally the good bargain of estate or second-hand jewellery.

(Four slides were then shown to illustrate this technique: they are described below.)

Slide 1. The calendar label is that of February. The birthstone of the month is Amethyst. This gem belongs to the quartz group so, in the central part of the rear of the window, you should show an agglomeration of quartz crystals, clearly labelled: 'The Quartz Group'. On the left side of the front part, occupying a respectable section of the window, you have a largish amethyst geode, quite a few loose amethysts and a good number of set pieces. A label placed nearby is boldly marked 'The stone of the month—Amethyst'. To the right of the window and slightly backward, a citrine geode much smaller than that of the amethyst and three or four loose citrines with a label indicating 'Citrine', the other important member of the group.

Slide 2. The calendar label announces November. The stone of the month is Citrine. The layout is basically the same as in February with the centrally placed label and exhibit of the 'Quartz Group', except that in this month, Citrine is highlighted by the large citrine geode and quite a number of loose and mounted citrines, and its label indicates boldly that it is the stone of the month. Amethyst,

the other member of the group, is pushed back to a secondary plane and is represented by only a smaller geode and three or four loose amethysts.

Slide 3. The month is March. Aquamarine, the birthstone, dominates the picture. The suggested layout is a kind of genealogical tree. The trunk bears the label 'The Beryl Group', from which branch out the following members, each clearly labelled and represented in a background position by a small crystal and two or three loose gems—morganite (pink beryl), heliodor (golden beryl) and emerald; whereas aquamarine is stressed by the presence of a larger crystal and a good number of loose and mounted stones.

Slide 4. It is May and emerald is the birthstone of the month. A few roses in the window symbolize the season and contrast beautifully with the verdant green of the emerald. The scheme is basically the same as that of March, except that emerald has sprung to the forefront with a larger crystal on matrix and more loose and mounted emeralds; whereas aquamarine has receded back to join the rest of the supporting cast that stem from the 'Beryl Group' trunk.

THE SALES TECHNIQUES

As we all know, one of the prominent features of our modern business world is the vast amount of literature and advice proffered by Chartered Accountants concerning tax shelters and methods of tax avoidance. By this, of course, I do not mean illegal practices of tax evasion. In the same vein, though in a different sphere, I now propose to sketch out a few practical points regarding sales induction without, however, infringing on the ethical considerations of consumer protection.

We are going to assume we have reached the stage of being equipped with an adequate inventory of coloured gemstones and we have managed to create the desired interest in them. The points I am about to elucidate are of help to the salesman, whether in the store or on the road. These are:

The Price Ladder

Suppose a lady walks into the shop and asks for say, an aquamarine ring. Unless she asks specifically for a particular ring on display in your window, that is, if her enquiry is vague, it is always a good policy to start by showing her the least expensive of

the aquamarine range in your stock. If she says 'No, I want something better', climb up the price ladder very gradually until you sense you have reached her maximum purchasing capability and stop there! Do not go above this level, because you will be showing her a finer piece, but one which she cannot afford and you may find you have lost a sale.

The Forbidden Expressions

As we all know, quite a number of the natural gemstones have inclusions. Emerald is a notorious example. Other examples are rubellite, ruby, sapphire with its silk, etc., and this common occurrence is tolerated the same way a cloud partially obstructing the sunshine is taken matter-of-factly. This phenomenon is to such degree accepted and sometimes even expected by the relatively knowledgeable consumer, that inclusions are, I am afraid, deliberately implanted in man-reconstituted stones—e.g. the Gilson and Chatham emeralds. However, should a customer ask 'What is this thing I see inside the stone?', never describe it as a 'defect' or an 'impurity' or a 'flaw' or an 'imperfection'. These words should never be used; they are taboo. Use instead the expression 'natural inclusion' and expose the argument that these inclusions are a kind of authenticity certificate delivered by Nature to this particular stone—the visible proof that it is a natural gemstone and not a man-made imitation.

Another danger may arise from a situation like this. Suppose you show a customer a topaz, or a diamond ring, and when you tell her the price, she exclaims: 'Oh no! I cannot afford to pay that much.' Do not snap: 'Let me show you something cheaper'. The terms 'cheap' and 'cheaper' should be crossed out of the salesman's vocabulary, because of their unpleasant connotations and their negative effect on selling persuasiveness. Tell her instead: 'Let me show you something less expensive, but of very good value'. In the sanctum of your Store and by the same token, in the course of door-to-door selling, the anodyne and sometimes enticing expressions 'inexpensive' and 'low priced', 'less expensive' and 'lower priced' are to substitute the offensive adjectives 'cheap' and 'cheaper'. Needless to add that the use of the downgrading expression 'semi-precious' should be at all cost avoided. Who wants to buy a half-anything? The more logical terms 'precious stone' or 'gemstone' are the ones more appropriate and more wisely to be employed.

Knowledgeability is Vital

Know as much as you can about the commodity you want to sell, because you cannot sell what you do not know much about. Once you have established your authority and impressed your customer, across the counter, with your knowledge about the item in transaction, half the battle will be won: you will find him or her less resistant to your arguments, more receptive to your advice.

The necessity of adequate knowledge applies also to the members of your sales force. A good practice is to set the routine of regular weekly meetings of the selling department. These should be kept as informal as possible and limited to 20-30 minutes. The purpose of these meetings is to expose the staff to the items carried in stock, or newly added to it and to exchange selling experiences of the elapsed week and also to comment on impromptu arguments that helped overcome some obstacles met within the course of a sale.

There are two ways I know of to increase your knowledge about coloured gemstones:

(a) The first is to be well read on the subject and to take up a gemmology course, that is, if this has not yet been done. It is important to have at least one qualified gemmologist on the staff.

(b) The second is to take what we may describe as a post-graduate crash course. I mean by this that at least one, preferably several staff members should go to the sources and tap them for first-hand information. Intelligence gathering and/or buying trips to various mining, gem-cutting and jewel manufacturing centres should be organized and/or participated in, as frequently as possible. I know, for example, that in the hierarchically stratified Japanese market quite a few jewellery concerns in different levels of the distribution scale have been organizing for their various customers, and their customers' customers, regular buying tours to production centres, sometimes as often as once a month. In this instance, these visits to the centres represent a good short, medium and long-term investment for the organizing enterprise, as well as for the participants who belong to the trade.

(i) As an immediate dividend the sales are more considerable since they are usually achieved out of a larger stock. There is no clash of interests between supplier on the one hand and organizer or participants from the trade on the other. By prior mutual arrangement, the profits on sales made to the latters'

customers are silently computed into the quoted prices.

(ii) A medium-term benefit is the image boosting effect of word spreading around, concerning the direct contacts that the organizer, and, by the same token, the trade people among the participants, maintain with the producing centres.

(iii) An added bonus is material gathered by them in the course of these visits regarding information, slides and pictures which may be used for Press releases, inserts and articles, and to illustrate public relations talks on various aspects of the jewellery industry.

(iv) Concerning the most important dividend of these gem safaris and study tours to the production centres, I can hardly urge you strongly enough to take part in them. Go to the source. Visit Brazil, Africa. Palpate with your own hands the bare facts concerning coloured gemstones. Get familiar with the amount of work and expertise needed for the mining and cutting of these gems. Back home, you will find that the jewel you offer to the customer across the counter has suddenly acquired a deeper significance, has triggered off an avalanche of memories about rubbing shoulders with the extraction and faceting and polishing processes in the course of such trips. This will find immediate expression in irrepressible enthusiasm colouring your arguments and flowing spontaneously through your selling attitudes; and as everybody knows, sincere enthusiasm is frequently a contagious phenomenon similar to yawning, but conversely, with a positive energizing effect. You will thus find that, more often than not, your enthusiasm has been communicated to your customer with no conscious effort on your part.

To summarize the main points of this talk:

(1) We have seen how coloured gemstones constitute a dimension extending far beyond the dimension of diamonds.

(2) We have found out that the current continuous increases in the price of coloured gemstones is a virtual one, over-reaching currency depreciation to realize a profit in real terms.

(3) We have reviewed various techniques in the display and selling of coloured gemstones that effectively prevent this profit from stagnating on paper and help in converting it into a healthy cash flow.

Finally, I should like to add this. Take a general textbook of gemmology, any textbook, and you will find that only one chapter or section deals with diamonds, whereas the rest of the book is devoted entirely to coloured gemstones. This gives you a gauge as to the scope of the field and an idea of the extent of the potential. According to the old legend, 'There is a pot of gold at the end of the rainbow'; by the pot of gold is meant wealth. In the light of what we have reviewed today, one may most emphatically assert that at the end of the rainbow, there is a pot of colourful, of enjoyable, of profitable gemstones.

GEMMOLOGICAL ABSTRACTS

ALTHAUS (E.). *Achat, Aufbau und Entstehung.* (Agate, structure and growth.) Lapis, **4,** 12, 26-9, 4 figs (2 in colour), 1979.

Details of the structural growth of agate are given with notes on the varying chemical composition. M.O'D.

ALTMANN (J. D.). *Suggestions for nomenclature of opals.* Aust. Gemmol., **13,** 12, 383-5, 1979.

An attempt to clarify the naming of opal, long overdue, not least in Australia. ('Fire opal' is used in the American sense of a light opal with strong play of colour. The European use is for the orange or red body-coloured opal from Mexico, with or without play of colour. The term 'crystal opal' is obscure, since opal is not crystalline. If all opal dealers would use this or a modified version of the nomenclature it would be a much needed step in the right direction.) R.K.M.

BALL (R. A.). *Synthetic opal for natural opal!* Aust. Gemmol., **13,** 12, 386, 2 figs, 1979.

A report by Hylda Bracewall suggests that synthetic opal is being offered as natural opal at mine sites. Mr Ball subsequently received a sand-coated opal from a friend in Lightning Ridge and, by electron microphotographs, proved it synthetic. R.K.M.

BALL (R. A.). *An unusual agate.* Aust. Gemmol., **13,** 12, 390, 3 figs, 1979.

An agate from Tara, Queensland, had a superficially radial structure suggesting a group of crystals, but cut to show normal agate banding. Thought to be an agate pseudomorph after ulexite. R.K.M.

BALL (R. A.), MUMME (I. A.). *Sapphire and silk.* Aust. Gemmol., **13,** 12, 379-81, 1979.

Lists work and theories of ceramicists, crystallographers, mineralogists, geochemists and gemmologists on nature of inclusions causing silk. Rutile and aluminium titanate are both possibles. The influence of gallium on colour and 'silk' formation is queried. (A sprinkling of misprints is to be regretted although the sense is for the most part clear.) R.K.M.

BANK (H.). *Orange (Padparadscha) und andersfarbige Granate aus Ostafrika.* (Orange-coloured (padparadsha) and other-coloured garnets from East Africa.) Z.Dt.Gemmol.Ges., **28,** 3, 146-7, bibl., 1979.

Variously coloured garnets from East Africa, for instance orange coloured ones, show on examination that they contain Mg and Fe as well as Mn and Ca, and are thus mixtures of pyrope, almandine, spessartine and grossular garnets. E.S.

BANK (H.). *Rosaroter durchsichtiger Väyrynenit z. T. in Edelsteinqualität aus Pakistan.* (Pink transparent vayrynenite partly in gem quality from Pakistan.) Z.Dt.Gemmol.Ges., **28,** 3, 163-4, bibl., 1979.

This mineral was first described as being found in Finland in 1954. It now also

comes from Pakistan/Afghanistan; as these minerals are of cuttable quality, some details are given. The mineral is pleochroic (yellow pink/light pink/dark pink), SG 3.230±0.002, RI 1.639-1.667, DR 0.028. E.S.

BANK (H.), SCHMETZER (K.). *Spiralförmige Einschlüsse in Edelsteinen: Spannungsriss in synthetischem Korund.* (Spiral shaped inclusions in gemstones: tension cracks in synthetic corundum.) Z.Dt.Gemmol.Ges., **28**, 3, 148-9, 1979.

A pink boule had its long axis roughly parallel to the *c*-axis. After manufacture the boule was without any cracks, etc., for about 12 hours. Then suddenly cracks appeared, which were seen to be spiral cracks parallel to the *c*-axis; a few other smaller cracks appeared as well. Photographs of the cracks are shown. E.S.

BARABANOV (V. F.). *Géochimie et typomorphisme des aigues-marines zonées.* (Geochemistry and typomorphism of zoned aquamarines.) Bulletin de Minéralogie, **103**, 1, 79-87, 7 figs, 1980.

Zoned aquamarines from Cherlovaya Gora, East Baikal, U.S.S.R., were examined by various techniques. It is shown that zonality is related to tectonic variation during crystal growth. M.O'D.

BASSETT (A. M.). *Hunting for gemstones in the Himalayas of Nepal.* Lapidary Journal, **33**, 7, 1492-1520, 15 figs in colour, 1979.

Good quality tourmalines and aquamarines are found in Nepal; this is an account of travels in the area. M.O'D.

BODE (R.). *Rhodochrosit, Rosenfarbige Schönheit.* (Rhodochrosite, rose-coloured beauty.) Mineralien Magazin, 1, 8-13, 9 figs (8 in colour), 1980.

A well-illustrated introduction to rhodochrosite with particular reference to specimens from South African localities. M.O'D.

BRICE (J. C.). *Crystal growth from liquids at high temperatures.* Progress in Crystal Growth and Characterization, 1, 255-88, 24 figs, 1979.

Growth of crystals from liquids is explained in a simple way and all methods currently used are illustrated. M.O'D.

BROWN (G.). *Corallium precious corals.* Aust. Gemmol., **13**, 12, 391-400, 9 figs, 1979.

Part 1 discusses name origin, history, growth of live corals, composition of calcareous skeleton, harvesting and processing; Part 2, structure and gemmological properties. (Compiled with Mr Brown's characteristic thoroughness, this is unfortunately 'continued next issue' and bibliographic references made here must wait that instalment to connect up. It is hoped that it will not disappear without trace as did another paper in 1976.) R.K.M.

BROWN (G). *Diamond—true of false?* Australian Gemmologist, **13**, 11, 341-51, 354-8, 14 figs, 1979.

Summarizes most of the available tests for diamond, including one or two of doubtful reliability, but omits hardness test on a corundum plate, the one absolutely

positive and instant test for diamond. Reflectometers need to be called infrared reflectometers, since they use radiation in the near infrared and reflectivity in those wavelengths differs from that for visible light. R.K.M

BROWN (G.). *New gem materials—1978.* Wahroongai News, 23-6, January 1979.

Lists 16 'new' gem materials which have 'appeared on the market in 1978'. A later statement that they have been 'presented in detail . . . in gemmological literature' for that year is nearer the truth. Some, e.g. scapolite from Tanzania, are new sources for well-known gems. Others have been known for a long time, e.g. multiple asteriated quartz from Sri Lanka (called 'unique', but the phenomenon is also known in both corundum and spinel) was described by abstracter in 1951.* Kornerupine cat's-eyes, deep blue Maxixe-type beryl (recognition data incomplete; colour stability is not just 'suspect'—it fades rapidly and is scarcely commercially viable) and deep blue topaz are all several years old. Writer discusses synthetic ruby under 'Chatham synthetic sapphire' heading, and neglects to mention that x-ray test for phosphorescence causes corundums to discolour. R.K.M.

BROWN (G.), LUND (D.). *Organic gem materials—what to look for?* Australian Gemmologist, **13,** 11, 352-3, 6 figs in colour, 1979.

Advises what to look for in suspected ivory, tortoiseshell, treated clarified amber, bone, horn and precious coral. J.R.H.C.

BROWN (G.), SNOW (J.). *Gemmology study club report— treated Brazilian opal.* Australian Gemmologist, **13,** 11, 359-61, 4 figs, 1979.

Brazilian opal is structurally different from the material used in Australian treated black opals and investigators found that the distribution of the black colorant was quite dissimilar in the two materials. The three Brazilian stones were poorly oriented and polished; all included potch and the pigment filled dendritic cracks throughout the depth of the stones which were much more translucent than the Australian stones. R.K.M.

CHRISTOPHE (M.), GOUET (G.), WYART (J.). *Synthèse hydrothermale de la bénitoite.* (Hydrothermal synthesis of benitoite.) Bulletin de Minéralogie, **103,** 1, 118-19, 2 figs, 1980.

Benitoite was synthesized from its oxides between 270 and 450°C with water. The only well-crystallized specimens were obtained at a temperature of 300°C in alkaline sodic solutions. M.O'D.

COLLINS (A. T.). *High temperature annealing of colour centres in Type I diamond.* Diamond Research 1979, 7-12, 8 figs, 1979.

A Type Ia diamond that has been irradiated and heat-treated to make it a fancy yellow is impossible to distinguish by eye from the very rare and valuable natural yellow diamond. Testing laboratories have depended on an absorption line at 595nm to identify artificially-coloured stones. It is usually assumed that annealing is carried out at 800°C. (The annealing temperature is between 700 and 800°C.) If the annealing temperature is raised to 1000°C, however, the 595nm line disappears, but the

*Gemmologist, XX, 234, 28-29.

colour is not significantly changed. In some diamonds, high temperature annealing leads to the formation of a 536nm system previously only seen in natural diamonds. E.B.

DE BRODTKORB (A.), (M.). *Rhodochrosit aus Argentinian.* (Rhodochrosite from Argentina.) Lapis, **4**, 10, 19-22, 8 figs (4 in colour), 1979.

Rhodochrosite was first discovered in Argentina in 1885 and the country still remains the chief producer of the material. Details of some varities are given. M.O'D.

DODSON (J.S.). *The statistical brilliance, sparkliness and fire of the round brilliant-cut diamond.* Diamond Research 1979, 13-17, 13 figs, 1979.

In the past, the brilliant cut has been analysed mathematically (by Tolkowsky and others), by appraisal of practical arts (Eppler and Tillander), and recently by computer analysis of light paths (Stern). The author surveys these and concludes that the traditional proportions are correct as far as 'sparkliness' and fire are concerned. Sparkliness is presumably scintillation. His definition of fire is orthodox, but his brilliance is what gemmologists call 'life' or 'liveliness'.

Proportions of a cut depend upon maximizing one of these three qualities at the expense of the others and the mix is a psychological choice. E.B.

FISCHER (K.). *Orientieren und Bearbeitan der Chalcedone und Achate.* (Orientation and fashioning of chalcedony and agate.) Lapis, **4**, 12, 32-6, 8 figs, 1979.

Details of the various patterns shown by the natural mineral are given and advice on fashioning to show details to their best advantage is provided. M.O'D.

FOIT (F. F.), ROSENBERG (P. E.), *The structure of vanadium-bearing tourmaline and its implications regarding tourmaline solid solutions.* Am. Miner., **64**, 788-98, 1979.

Examination of a vanadium-bearing tourmaline showed that the structure was similar to that of other members of the tourmaline group and that the whole system showed a flexibility in response to cation substitution. M.O'D.

FOLGUERAS (S.), RODRÍGUEZ MARTÍNEZ (J.). *Camara de luminiscencia y transparencia de gemas frente a los rayos X.* (Use of the camera in the study of luminescence under and transparency of gemstones to x-rays.) Boletin del Instituto Gemológico Español, **19**, 11-15, 9 figs, 1979.

The Debye-Schirrer camera can be used to observe transparency of gems to x-rays, phosphorescent effects and, with the Gandolfi apparatus, to obtain powder photographs. M.O'D.

FOORD (E. E.), MARTIN (R. F.). *Amazonite from the Pike's Peak batholith.* Mineral. Record, **10**, 6, 373-84, 13 figs (3 in colour), 1979.

Pegmatite-bearing dikes in the Pike's Peak batholith, Colorado, contain fine specimens of amazonite. Crystals show good development of prism, dome and pedion faces, and the colour ranges from very pale blue-green to deep blue-green, turquoise or green-blue. Some of these are illustrated. M.O'D.

GRAZIANI (G.), DI GIULIO (V.). *Some genetic considerations on a Brazilian aquamarine crystal.* Neues Jahrbuch für Mineralogie Abhandlungen, **137**, 2, 198-207, 7 figs, 1979.

The so-called 'rain' effect was found on prism faces and black arborescent structures occupied positions parallel to the basal plane. A sceptre-shaped inclusion was also found. 'Rain' in this context is taken to mean parallel acicular tubes with foreign crystallites; another meaning is a profusion of parallel apatite crystals. Two genetic stages could be recognized in the crystal, the first characterized by inclusions of quartz, apatite, ilmenite, epidote and corundum, with some other minerals; the second by the presence of arborescences due to infiltration of late-magmatic fluids of the hydrothermal type. M.O'D.

GRAZIANI (G.), LUCCHESI (S.). *Einschlüsse und Genese eine Vanadiumberylls von Salininha, Bahia, Brasilien.* (Inclusions and genesis of a vanadium beryl from Salininha, Bahia, Brazil.) Z.Dt.Gemmol.Ges., **28**, 3, 134-45, 6 photomicrographs, diagram, 3 tables, bibl., 1979.

An uncommon crystal of a milky, pale-green Salininha vanadium beryl and its mineral inclusions were examined. Optical tests, x-ray and electron microprobe analyses were undertaken. The inclusions were found to be calcite, talc, potassium feldspar, phlogopite and corundum. The occurrence of these inclusions suggests both the T-P range of this vanadium beryl and the chemical conditions of its environment. E.S.

GÜBELIN (E.). *Feuerachat.* (Fire agate.) Lapis, **4**, 12, 23-5, 7 figs in colour, 1979.

Fire agate which displays a play of colour in some ways similar to that shown by opal is found most commonly in Mexico, although some is mined in southwestern U.S.A. Illustrations show how the colour is arranged in bands. M.O'D.

HARRIS (J. W.). *Physical and chemical constraints in the formation of natural diamond in the Upper mantle.* Diamond Research 1979, 2-6, 3 figs, 1979.

Inclusions in diamonds enable the stones to be separated into two groups, peridotitic and eclogitic. Peridotite is the main component of the upper mantle, whereas eclogites are rare in it. Inclusions from both groups of minerals have never been found in the same diamond. On the other hand, the same kimberlite may contain diamonds of both groups. The two rock types provide clues to the likely chemical environments for diamond formation. E.B.

HEALEY (D.). *The gem scene in Sri Lanka.* J. Gemm. Assoc. Hong Kong, 1, 7-14, 1980.

An interesting description, with much detail, of a trip to Sri Lanka; gems are plentiful, though high quality material is difficult to obtain. M.O'D.

HUBER (O.). *Feueropal aus Mexico.* (Fire opal from Mexico.) Lapis, **4**, 12, 19-20, 4 figs (2 in colour), 1979.

Fire opal is found in a belt running between the states of Guanajuato and Querétaro in Mexico. The mother rock is usually a rhyolite. M.O'D.

JACOBSON (M. I.). *Mount Antero.* Mineral. Record, **10**, 6, 339-46, 15 figs (2 in colour), 1979.

Mount Antero in Chaffee County, Colorado, produces fine quality specimens of aquamarine and phenakite, together with smoky quartz and topaz. M.O'D.

KOCH (S.). *Edelopal aus Ungarn.* (Hungarian precious opal.) Lapis, **4**, 12, 21-2, 3 figs (2 in colour), 1979.

'Hungarian' opal was found in an area which is now politically Czechoslovakia, the main locality being Červenica, formerly Vörösvágás. The material is no longer mined and has historical importance only. M.O'D.

KOSNAR (R. A.). *The Home Sweet Home mine.* Mineral. Record, **10**, 6, 333-8, 9 figs (6 in colour), 1979.

The Home Sweet Home mine is in the Mosquito Range of central Colorado and is celebrated for fine specimens of rhodochrosite and fluorite, which are illustrated. M.O'D.

KUGE (S.), KOIZUMI (M.), MIYAMOTO (Y.), TAKUBO (H.), KUME (S.). *Synthesis of prismatic and tabular diamond crystals.* Mineralog. Mag., **43**, 579-81, 6 figs, 1980.

When diamond is synthesized at conditions of comparatively high T and P, the nucleation rate is high, as is the growth rate of the nuclei; consequently the product is usually an aggregate of crystals with dendritic or skeletal structure. In this study, Au or Ag mixed with a catalyst is reported to have the effect of suppressing nucleation. When a homogeneous mixture of graphite, catalyst, and additive is treated under conditions where skeletal forms and dendrites would form in the absence of additive, euhedral crystals of diamond octahedra are produced. By using a special cell assemblage for high-P experiments (7GPa 1700°C) in which graphite is placed inside a cylinder of catalyst coated with additive, prismatic (400 μm) and tabular (1.5 mm) crystals have been synthesized. R.A.H.

LECKEBUSCH (R.). *Comments on the luminescence of apatite from Panasqueira, Portugal.* Neues Jahrbuch für Mineralogie Mönatschefte, **1**, 17-21, 3 figs, 1979.

Luminescence arises from emission in the blue (Eu^{2+}) and in the yellow (Mn^{2+}) range. A concentric zone structure in a crystal with bright yellow and dark green luminescence showed variations in the incorporation of Mn. M.O'D.

LENZEN (G.). *Diamantengraduierung: die Feinbearbeitung oder das Finish.* (Diamond grading: accurate working or finish.) Z.Dt.Gemmol.Ges., **28**, 3, 150-62, 1979.

This article is a reprint from the newly published book by Lenzen about diamond grading, and deals with the finish of the stone, especially faults in the finish which are measurable, such as deviation from the round (only in the case of brilliants), table not level or eccentric, eccentric facets. These faults can be marked on diagrams when evaluating the stone. Photomicrographs illustrate these main faults. Apart from the measurable faults mentioned, the following must be taken into account: general symmetry faults in the crown, pavilion or girdle also additional or missing facets. The girdle must be marked according to its roughness

and evenness. The culet must be examined and checked whether it is damaged, non-existent or too large. The polish must be judged, whether it has polishing marks, how strong these are and whether they lessen the brilliance. Lastly, the stone must be checked for open, rough or burnt places. All these faults are given points according to their importance and when these are added up the grade of finish can be judged to be very good, good, medium or poor. E.S.

LEVEL (D.). *Le dichroisme photographié.* (Dichroism photographed.) Revue de Gemmologie, **61**, 10-11, 5 figs in colour, 1979.

Dichroism in blue tourmaline and blue sapphire is illustrated to show the use of photography in testing. M.O'D.

LEVINGSTON (K. R.). *Gem diggings—Chudleigh Park.* Queensland Govt Mining J., **80**, 35-8, 2 figs, 1979.

Peridot, sapphire, and spinel occur on the slope of a small Cainozoic cone that produced massive basalt, vesicular flows, and lapilli tuffs. The peridot is associated with cognate mafic nodules, some with spinel which indicates crystallization at pressures of 1.0-1.8 GPa. D.J.D.

LIEBER (W.). *Der versteinerte Wald von Arizona.* (The petrified forest of Arizona.) Lapis, **4**, 12, 30-1, 4 figs (3 in colour), 1979.

Petrified wood in the Petrified Forest National Park, Arizona, is illustrated and described. M.O'D.

LIEBERTZ (J.), FALTER (M.). *Synthese von Edelopal.* (Synthesis of precious opal.) Lapis, **4**, 12, 16-18, 7 figs (4 in colour), 1979.

An account of the development of three-dimensional structures from which diffraction of light could take place, this paper covers the work of Pierre Gilson in the field of opal synthesis. No account of stabilization procedure is given. M.O'D.

MCCOLL (D. H.), WARREN (R. G.). *The first discovery of ruby in Australia.* Australian Gems & Crafts Magazine, **39**, 121-5, 13 figs (10 in colour), 1979.

Ruby has been discovered in the Harts Range of the Northern Territory of Australia. The material has a good colour and is suitable for cutting into cabochons; it occurs as either well-formed tabular crystals or as ovoid masses up to 12cm long. Some smaller crystals are translucent, but very little completely transparent material has been found. Mica flakes and some zircon crystals have been seen as inclusions in the peripheral zones of some crystals. M.O'D.

MADISON (M. E.). *Nephrite occurrences in the Granite Mountains region of Wyoming.* Lapidary Journal, **33**, 9, 2008-13, 1979.

Erratic boulders of jade are found at a number of localities in this region, the most important primary source being the south central portion of the Granite Mountains core. Range of colour extends from very pale green to black (these are seen to be dark green by transmitted light). Chemical analyses are given. Paper reprinted from the 30th Annual Field Conference Guide Book of the Wyoming Geological Association. M.O'D.

MAYO (F.). *Gems of Georgia.* Rocks & Min., **54**, 148-50, 2 figs, 1979.

The following minerals are described and their localities (in Georgia, U.S.A.) are summarized: almandine, apatite, beryl (aquamarine), corundum (ruby), diamond, kyanite, lazulite, nephrite jade, quartz (smoky, clear, amethyst, rose, agate, jasper, chert), rutile, schorl, staurolite, topaz. R.S.M.

MOTEL (B.). *Les joyaux de la couronne de France au XIXe siècle.* (French crown jewels of the 19th century.) Revue de Gemmologie, **60**, 7-13, 11 figs (2 in colour), 1979.

Jewellery of the reigning houses of France is illustrated and described; numbers and weights of the stones are given. M.O'D.

MOTIU (A.). *Rhodochrosit von Cavnic in Rumänien.* (Rhodochrosite of Cavnic, Romania.) Lapis, **4**, 10, 23-4, 5 figs (4 in colour), 1979.

Details and illustrations are given of the occurrence of rhodochrosite at Cavnic, Romania. M.O'D.

MUMME (I. A.), SEIBRIGHT (L.). *The coloration of Mount Surprise topaz by gamma irradiation.* Wahroongai News, 35-9, March 1979.

A reprint of the paper already abstracted* from the Australian Gemmologist, this version contains one and a half paragraphs which were missing from the original paper. It is therefore recorded again. R.K.M.

NASSAU (K.). *An additional note on the new Gilson 'coral'.* Lapidary Journal, **33**, 7, 1504, 3 figs in colour, 1979.

The streak of the Gilson 'ox-blood' coral imitation is red-brown and the wipe after effervescing with acid was also coloured. With natural coral of this colour both these tests would have given a white colour. M.O'D.

NICHOLS (R. A.). *Opal mines of Nevada.* Lapidary Journal, **33**, 7, 1638-44, 4 figs (maps), 1979.

Various mines in the Virgin Valley area of Nevada are described. M.O'D.

NOGUÉS CARULLA (J. M.), DE LA FUENTE CULLELL (C.), MONÉS ROBERDEAU (L.), BOSCH FIGUEROA (J. M.). *Estudio del material de interés gemológica 'Angel Stone'.* (Investigation of 'Angel Stone', a gemmologically interesting material.) Gemologia, **11**, 41/42, 17-29, 9 figs, 1979.

'Angel stone' was offered in a piece of jewellery during 1979; it was a pink massive material, part of which had been fashioned into a cabochon. Investigation proved it to be palygorskite, a silicate of magnesium and aluminium with water. M.O'D.

NUBER (B.), SCHMETZER (K.). *Die Gitterposition des Cr^{3+} im Turmalin: Strukturverfeinerung eines Cr-reichen Mg-Al Turmalins.* (The lattice position of Cr^{3+} in tourmaline: structural refinement of a chromium-rich Mg-Al tourmaline.) Neues Jahrbuch für Mineralogie Abhandlungen, **137**, 2, 184-97, 1 fig, 1979.

A chromium-bearing tourmaline from Nausahi, India, had lattice constants

*J. Gemm., 1979, XVI (8), 547.

$a_o = 15.997$Å, $c_o = 7.287$Å, space group R3m and a composition according to $XY_3Z_6[(O,OH,F)_4|(BO_3)_3|Si_6O_{18}]$, where X = Na, Y = Cr, Mg, and Z = Al, Cr and Mg. Cr^{3+} and Mg^{2+} occupy both of the octahedral positions Y and Z. Cr^{3+} content in the Y-position is higher than that in the Z-position. M.O'D.

OAKLEY (S. A.). *Gems and geology in the Great Rift Valley.* Lapidary Journal, **33**, 9, 2020-3, 1979.

An account of a trip through East Africa with short notes on the geology of the area. Gemstones were more easily obtainable in Kenya than in Tanzania or Zambia. Some current prices are given. M.O'D.

O'DONOGHUE (M.). *Details on how to recognize the latest imitation gemstones.* Retail Jeweller, **17**, 423, 22, 1979.

Short descriptions are given of an opal from Japan in which the diffraction takes place from layers of monodisperse latex; of a synthetic alexandrite with good colour-change and few inclusions; of an orange zirconia from the U.S.S.R. with a padparadschah-like appearance; and of the 'Regency Created Emerald', a hydrothermal product from the United States. (Author's abstract) M.O'D.

O'DONOGHUE (M.). *Rapport sur un laboratoire complet pour l'examen des pierres précieuses.* (Report on a complete laboratory for gem testing.) Revue de Gemmologie, **60**, 4-6, 5 figs, 1979.

Translation of an article first appearing in *Retail Jeweller.*

(Author's abstract) M.O'D.

OSMAN (D.), CAULTON (C.). *Colored gems of East Africa.* Lapidary Journal, **33**, 8, 1768-71, 6 figs, 1979.

Aquamarine from Kenya, orange tourmaline, also from Kenya, and a flame orange garnet from somewhere in East Africa are among the stones reviewed. Prices of coloured stones are expected to double during 1980. M.O'D.

PANTALEO (N. S.), NEWTON (G.), GOGINENI (S. V.), MELTON (C. E.), GIARDINI (A. A.). *Mineral inclusions in four Arkansas diamonds: their nature and significance.* Am. Miner., **64**, 1059-62, 1 fig, 1979.

Enstatite, olivine, pyrrhotite + pentlandite; eclogitic garnet; enstatite + peridotitic garnet + chromite, olivine + pyrrhotite, pyrrhotite, pentlandite, pyrite + pyrrhotite, pentlandite + a nickel sulphide, diamond, are the groups of inclusions found by x-ray diffraction and EDAX analyses from four diamonds found in Arkansas. No nickel sulphide has previously been reported in diamond. M.O'D.

PETSCH (E. J.). *Rough stones.* Lapidary Journal, **33**, 5, 1216-18, 1979.

The writer lists causes explaining why the supply of rough gem-quality stones is much less profuse than in the past. The chief causes are political. M.O'D.

POIROT (J.-P.). *Sur le traitement thermique des gemmes.* (Heat treatment of gemstones.) Revue de Gemmologie, **61**, 16-17, 1979.

Briefly reviews the various techniques used to alter the colour of gemstones by

heating and gives some observations on the ethical and commercial aspects of the practice. M.O'D.

POWELL (R.). *Natural and radiation induced colouration of smoky quartz.* Aust. Gemmol., **13**, 12, 373-8, 3 figs, 1979.

Traces history of theories for this not highly valued colour in quartz, ranging from inclusions of organic hydrocarbons to the now accepted coloration by irradiation, either natural or artificial. Pure silica is not affected, and it is thought that the colour needs the presence of aluminium as an impurity. (Unfortunately some parts of the paper are incomprehensible owing to printers' errors. e.g. 'This absorption colour centre...consists of a hole trapped at an oxygen-ion nearest neighbour of aluminium, the hole spending 97% of its *ime* on the oxygen and 3% of its *lime* on the aluminium.' Printing errors of this kind ruin an otherwise excellent and ambitious journal.) R.K.M.

POWELL (R.). *A note on the serpentine in Lucknow, New South Wales.* Aust. Gemmol., **13**, 12, 387, 2 figs, 1979.

A serpentine found with gold at this site proved unsuitable for gem use or for carving, due to structural weaknesses. R.K.M.

PREST (Michael). *Ashton's diamond find.* The Times Newspaper, No. 60498, p.22. 12th December, 1979.

The Ashton joint venture has announced that one kimberlite sample of about 33m^3 from their Western Australian deposit yielded 47ct (four stones bigger than 1ct 1ct and one of 1.83ct): 11 samples (totalling 250m^3) from alluvial deposits downstream from the Kimberlite pipe yielded 2968ct (167 stones exceeding 1 ct, the biggest being 4.6ct). No professional assessment has been made of the ratio of gemstones to industrials. J.R.H.C.

READ (P.). *Gem testing equipment.* Australian Gems & Crafts Magazine, **39**, 11-16, 12 figs, 1979.

Reviews a number of pieces of equipment used for gem testing with particular reference to reflectivity meters. M.O'D.

RITTER(A.). *Faceting Slocum stone.* Lapidary Journal, **33**, 9, 2038-41, 5 figs, 1979.

Since Slocum stone depends on inclusions for a play of colour there is no need for reflection of light from pavilion facets. Faceting hints are supplied. M.O'D.

ROLANDI (V.), SUPERCHI (M.). *Corindone e berillo: proposta di delimitazione rispettivamente della varietà rubino e della varietà smeraldo.* (Corundum and beryl: proposals for establishing limits on the varieties ruby and emerald.) La Gemmologia, **5**, 1/2, 5-11, 1979.

The paper uses accepted systems of colour grading to establish limits to the use of the names ruby and emerald. M.O'D.

SAMUEL (E. R.). *The invention of diamond polishing.* Industr. Diamond Rev., 5-7, 4 figs, January 1980.

Unlike the softer gemstones, which could be polished by hand, diamond polish-

ing only became possible with the invention of a high-speed lap which could be rotated smoothly on a belt-driven spindle. The author traces the introduction of this version of the belt-driven machine tool back to the small spinning wheel, which came to Northern Italy from China (by way of India, Egypt and Syria) in the 12th century. Italian craftsmen subsequently adapted the principle of the continuous belt drive to grinding and polishing. Spectacle lenses were the first mass-produced results of this adaptation, and soon the technique was used to polish gemstones. Its use in diamond polishing occurred seventy years later with the raising of the lap speed and the use of pulverized diamond for the abrasive, which was mixed with a viscous oil to enable it to remain on the lap in spite of the higher centrifugal force. P.G.R.

SCHÄFER (W.). *Val Vigezzo-Tal der Maler. Neue Smaragdfundstellen.* (Val Vigezzo-Tal der Maler. A new emerald location.) Mineralien Magazin, **3**, 7, 367-72, 11 figs (10 in colour), 1979.

The location lies between Donodossola and Locarno on the Italian side of the Alps. Emerald of a yellowish-green colour and largely opaque is found in a pegmatite. M.O'D.

SCHMETZER (K.), BANK (H.). *Schlossmacherit, ein neues Mineral, benannt nach Prof. Dr Karl Schlossmacher, dem Ehrenvorsitzenden der Deutschen Gemmologischen Gesellschaft.* (Schlossmacherite, a new mineral, named after Prof. Dr Karl Schlossmacher, the Hon. President of the German Gemmological Association.) Z.Dt.Gemmol.Ges., **28**, 3, 131-3, bibl., 1979.

The author was examining a piece of ceruleite from Guanaco in Chila, probably north Chile, and discovered a new mineral with it which he called Schlossmacherite. Details of the new mineral are to be published shortly. The main constituents are H_2O, CaO, Al_2O_3, SO_3 and As_2O_5 as well as small quantities of other oxides. It belongs to the alunite-jerosite series. A photograph shows a piece of ceruleite with chenevixite and green schlossmacherite, the piece being about 70 × 47mm. E.S.

SEGNIT (E. R.). *Australien, Land des Edelopals.* (Australia, land of the precious opal.) Lapis, **4**, 12, 10-12, 5 figs (4 in colour), 1979.

A general review of the opal locations in Australia with notes on the fashioning of opal. M.O'D.

STALLARD (M.). *Florida coral.* Rocks & Min., **54**, 147, 3 figs, 1979.

Coral replaced by chalcedony is found in many parts of Florida. The resulting specimens are usually colourful geodes (blue, yellow, black) which often contain quartz crystals. Specimens occur in Tampa Bay, in the Perry area, and in the Withlacoochee and Suwannee Rivers. R.S.M.

SUPERCHI (M.). *La gemmologia come scienza accademica a sè stante, non una parte della mineralogia.* (Gemmology as an independent science, not as a section of mineralogy.) Rend. Soc. Italiana Min. Pet., **35**, 1, 199-215, 1 fig, 1979.

Gemmology has developed as an independent study and should no longer be considered merely as an appendage to mineralogy. Colour measurement is only one

of the new techniques which will be applied to gemmological studies in the future and the arrangement of gemstones in collections will be undertaken on a unified basis with international agreement. M.O'D.

TENNYSON (C.). *'Struktur' und Farbenspiel des Edelopals.* (Structure and play of colour of precious opal.) Lapis, **4**, 12, 13-15, 8 figs (4 in colour), 1979.

An explanation of the cause of the play of colour in opal is given with illustrations of the cristobalite spheroids responsible. M.O'D.

TENNYSON (C.). *Zwillings strukturen.* (The structure of twinning.) Lapis, **5**, 2, 12-15, 16 figs (3 in colour), 1980.

The atomic structure of twinned crystals is discussed with diagrams. M.O'D.

VENDRELL-SAZ (M.), NOGUÉS CARULLA (J. M.). *Medición directa de los indices de refracción.* (Direct measurement of refractive index.) Gemologia, **11**, 41/42, 35-41, 4 figs, 1979.

Reviews various instruments now on the market which will identify stones with high refractive index. M.O'D.

VERBRAECK (Y.). *Diamant.* (Diamond.) Natuur en Techniek, **47**, 10, 542-59, 16 figs (9 in colour), 1979.

A description of the chemistry, structure, working and mining of diamond for the reader with a scientific background. M.O'D.

VISHWESWAER (M.). *Mining pink corundum crystals.* Lapidary Journal, **33**, 8, 1858-61, 1 fig, 1979.

Describes mining for corundum at a location in Mysore, India. Pink corundum occurs embedded in kyanite. M.O'D.

WEINER (K. L.). *Ein modellar tiger Diamant-Zwilling.* (A type of diamond twinning.) Lapis, **5**, 2, 19, 2 figs in colour, 1980.

A yellow twinned crystal of diamond, weighing 7.36ct and displaying interesting form is illustrated. Twinning gives an overall hexagonal outline. M.O'D.

WEINER (K. L.). *Zwillinge.* (Twinning.) Lapis, **5**, 2, 6-11, 7 figs in colour, 1980.

The various types of twinning are described and illustrated. M.O'D.

WEINER (K. L.), HOCHLEITNER (R.). *Rhodochrosit, Portrait eines Minerals.* (Rhodochrosite, portrait of a mineral). Lapis, **4**, 10, 7-11, 7 figs in colour, 1979.

The crystal structure, properties and main locations for rhodochrosite are discussed. M.O'D.

WILKS (E. M.), (J.). *Light scattering in diamonds and their mechanical reliability.* Industr. Diamond Rev., 8-13, 9 figs, January 1980.

Perfect diamonds should give rise to virtually no scattering of a beam of light in the body of the stone, but most diamonds, in practice, produce readily detectable scattering with an intensity which varies considerably from stone to stone. The

authors' experiments show that the light scattering power of a diamond can be correlated with its mechanical reliability, and, for rounded dodecahedral diamonds, with their natural surface appearance. This scattering of light is thought to be caused by differing concentrations of small inclusions of the order of 1 micrometer (micron) in size. The results of the experiments provide a criterion for selecting rough diamonds for mechanical soundness, the better performance, both for industrial use and for gem polishing, being given by stones producing the least scattering. P.G.R.

ZECCHINI (P.). *Étude de l'absorption infrarouge de quartz d'origine naturelle ou de synthèse.* (Study of the infrared absorption of natural and synthetic quartz.) Revue de Gemmologie, **60**, 14-18, 17 figs, 1979.

Infrared absorption patterns of natural and synthetic quartz differ noticeably and are reproduced. M.O'D.

ZEITNER (J. C.). *Synthetics, imitations and more.* Lapidary Journal, **33**, 8, 1684-90, 5 figs, 1979.

Lists the synthetic and imitation gemstones currently encountered. M.O'D.

Aus der Untersuchungspraxis. (From the gem-testing practice.) Z.Dt.Gemmol.Ges., **28**, 3, 165-70, 1979.

H. Bank describes a highly refractive glass with RI 1.760 which was mistaken for garnet as well as a synthetic emerald which was found to be a colourless quartz covered (after Lechleitner) with synthetic emerald; he also mentions that glass was offered on the market as Gilson synthetic emeralds. H. Bank with J. Maes and A. Dos Santos tested a 'peridot' which turned out to be a garnet-glass doublet. A thin red layer of garnet for the table and crown facets was stuck on a thick layer of green glass. E.S.

BOOK REVIEWS

ANDERSON (B. W.). *Gem Testing.* 9th edn. Butterworths, London and Boston, 1980. pp.(14), 434. 142 figs (black-and-white), frontispiece and 11 plates in colour. £12.00 (U.S. $27.00).

This very well-known textbook, which started life as a slim volume (*Gem Testing for Jewellers*) in 1942, has now reached its ninth edition, still, amazingly, from the pen of its original author. In the intervening 38 years it has grown to become a standard, indeed *the* standard work on Gem Testing. Mr Anderson, himself, emphasizes that it *is* this and not a general work on Gemmology. It is pre-eminently a practical text and is not overweighted with theoretical facts which could destroy its essential usefulness.

If one excepts the very early years, when all was challenging, the years that have elapsed since the eighth edition was published in 1971 have seen more new challenges than any similar previous period. 'The Ninth' has been awaited with considerable

anticipatory interest and pleasure. We all know Mr Anderson's clear and precise prose which seems so effortless, but which, in fact, involves much writing and re-writing, and meticulous research through his own vast store of work-notes accumulated in 46 years of dedicated gemmology as Director of the Gem Testing Laboratory of the London Chamber of Commerce, as well as the work of other gemmologists, world wide, where this is relevant. It is a point of honour to acknowledge fully when his information is from other sources, a gesture which could be reciprocated more often.

He has added to the chapter on 'Refractive Index and its Measurement' a description of the new ER602 Riplus instrument, which, using a strontium titanate prism and a heated 'waxy substance' for contact fluid, can measure refractive indices up to 2.21 and also birefringence. This came on to the market just as the book was going to press.

The new infrared reflectometer is also included in this chapter: it does not measure refractive index or even lustre in the visual sense, but its function justifies its inclusion here rather than in a separate chapter. The spinel refractometer is referred to but is no longer made. (The reviewer understands that using cubic zirconia as its prism is projected, but will lose a major advantage of the spinel model owing to its much higher dispersion. Similarly a recommendation of Velox printing paper for short-wave UV immersion contact photography is out of date since this brand has been off the market for some time.)

The reviewer is relieved, but not surprised, that the author has not followed another writer in denigrating the still extremely useful dichroscope and Chelsea Filter.

'Use of Microscope', quite logically, has been brought forward and now precedes the important and greatly enlarged chapter on 'Detection of Synthetics, Imitation and Composite Stones'. The latter now includes 'skull melt' production of cubic zirconia. Mr Anderson has called my attention to the fact that the O and H entry tubes are unfortunately reversed in the diagram of the Verneuil furnace. Flux-melt corundums from the Chatham and the Kashan Laboratories are described. Rather surprisingly the description of the Gilson emerald, now manifestly a better product than that of Chatham, is not expanded. Yet the statement* of intent to include some iron in this product is by now a fact: to be fair, this is dealt with adequately elsewhere in the book. Dr Kurt Nassau's work in the infrared absorption tests for flux-fusion synthetic emeralds is described. Synthetic green beryl of emerald colour using vanadium in place of chromium is also mentioned. Cubic zirconia, the most successful of the diamond simulants is dealt with in detail. Synthetic alexandrite, turquoise, opal and 'synthetic' lapis lazuli are all additions to this chapter. The author has resisted the temptation to acclaim automatically many substances produced primarily as possible laser materials, or in semiconductor research, as new 'gem' synthetics when these have little hope of acquiring any real gem-trade significance. Slocum stone is included as a clever opal imitation, while some clever and deliberately deceptive new doublets are described in considerable detail. A very valuable chapter!

The spectroscope, which the author, with C. J. Payne, introduced in British gemmology many years before it was adopted by some overseas laboratories, is also an expanded chapter. It is interesting to see that wavelengths are still quoted in

*8th edn, p.103: 9th edn, p.133.

Ångströms, which Mr Anderson prefers to the S.I. nanometres recommended by the Royal Society. The International Bureau of Weights and Measures (BIPM) also wants to see the ending of the metric carat.* The Trade should fight both changes. One welcome innovation in this edition is a concession to the American version of the absorption spectrum which is the reverse of the conventional 'red on the left' used in most other countries (Fraunhofer did label his 'lines' alphabetically from left to right!). Blocks of spectrum illustrations are therefore printed in pairs, with the conventional spectra on the left-hand page and the American version, as an inverted mirror image, on the right-hand page. Regrettably, the publishers have failed to invert the latter on page 189, so that it does not 'tie in' with its numbering or its caption. On the whole the reversed versions, from new drawings, have printed with slightly greater clarity than the conventional ones, possibly due to the risks of off-set printing, on which the error may also be blamed.

The second half of the book deals with the identification of gems, and the main changes here consist of additions either to possible gem species or of imitants and synthetics which have appeared since the eighth edition. Information on testing diamond abrasive powders, although scarcely gemmology, is given here since hardly any literature on the rather special procedures developed by the author has been published. Irradiated coloured diamonds are dealt with, but this is a fast evolving market and it is not easy to keep pace with its developments.

Australian doublets using natural sapphire tops with synthetic sapphire or ruby bases are deliberately made to deceive and are discussed in detail. Deep blue (irradiated) topaz and beryl (Maxixe type and liable to fade) are also added to the chapter on identification of sapphire.

The several Gilson synthetics have been added under appropriate chapters, and new and clever opal doublets are also described. In all cases methods of recognition are given as fully as possible. Kornerupine cat's-eyes are new, while ivory and its imitants have been added to the chapter on organic materials.

Illustrations are good although some of the older black-and-white blocks seem to have suffered slightly in transit from the eighth to the ninth edition. This certainly is the fault of off-set methods. Page proofs were checked with very great care, but these were 'messy' to an extreme and the task a difficult one.

Colour plates are quite good, although Mr Anderson has privately expressed disappointment with some of the new ones by comparison with the brilliant transparencies from which they were taken. Pagination in the table of contents is incorrect for these, again a publishers' error.

The general colour-based lay-out of the book has always lent itself to a degree of repetition. This is largely deliberate and means that essential information for a given stone may be found under more than one possible heading; an advantage, not a failing. In one or two instances constants quoted for given stones vary slightly in another part of the book; very few misprints have been found, and those quite minor.

The author is to be congratulated on personally seeing so many editions of this excellent textbook into print. May he be spared to 'do' a Tenth! It is a book which will never outlive its usefulness.

One sad note; C. J. Payne, to whom every edition has been most faithfully dedicated as collaborator with Anderson in all the earlier research, died a short while after this edition appeared. R.K.M.

*See K. Nassau, *The International System of Units and its Application to Gemmology*, J.Gemm., 1977, **XV** (5), 243.—Ed.

ANDERSON (B. W.). *Gemme al microscopio.* (Gems with the microscope.) Boringhiere, Turin, 1979. pp.433. Illus. in black-and-white and in colour. Price on application.

The title notwithstanding, this is an enlarged translation of the eighth edition of *Gem Testing,* published in 1971. Many illustrations from that work are reproduced, mostly on a larger scale, and there are some full-page illustrations in colour. Illustrations additional to those in the original consist in the main of instruments, crystals and diagrams illustrating the commoner styles of cutting. M.O'D.

AUSTEN (R. L.). *Gems and jewels.* Evans, London, 1979. pp.128. Illus. in colour. £10.50.

A well produced book with illustrations of above average quality (and new), this deserves a wide sale, especially in view of the low price (for these days). Although there are some slight infelicities of style and awkwardness in some of the scientific descriptions, these are of little importance and do not mar a simple and pleasing guide to the gem and jewellery world. M.O'D.

BARDSLEY (W.), HURLE (D. T. J.), MULLIN (J. B.), ed. *Crystal growth: a tutorial approach.* North-Holland Publishing Co., Amsterdam, 1979. pp.ix, 408. Illus. in black-and-white. $(US)53.75.

This compilation represents the proceedings of the third International Summer School on Crystal Growth, held at Durham, N.C., U.S.A. during 1977. Particular interest will be shown by readers of the *Journal* in the paper by Brandle on the Czochralski growth of large oxide crystals (including lithium tantalate, gadolinium gallium garnet, YAG, lithium niobate and corundum). Other papers include notes on the criteria for selecting a particular method of growth and on the latest developments in growth techniques—these include the hydride process and solid-state epitaxy. Papers include questions which readers will enjoy trying. M.O'D.

BOSCARDIN (M.), DE MICHELE (V.), SCAINI (G.). *Itinerari mineralogici della Lombardia.* (Mineralogical journeys in Lombardy.) Museo Civico di Storia Naturale, Milan, 1972. pp.124. Price on application.

Prime place among the minerals of the region (in which over 160 species have been established) must go to the demantoid garnets of the Lanzada commune in Sondrio—the area is better known under its general heading of Val Malenco. Fine pyrite, other forms of garnet, some zircon, topaz and tourmaline also occur in Lombardy. Since the areas are described in alphabetical order of commune, the presence of an adequate index, comprising species and localities, is fortunate. There is also a bibliography. M.O'D.

CAVENAGO-BIGNAMI MONETA (S.). *Gemmologia.* (Gemmology.) 4th edn. Hoepli, Milan, 1980. 3 vols, pp.lxxiv, 1734. Illus. in black-and-white and in colour. L150,000.

Even before the advent of this huge work, previous editions of *Gemmologia* bid fair to be the largest books on gemmology. The previous edition had two volumes; this has three, although one is less that half the size of one of the other two volumes; one could say that the size of the work has increased by roughly 25%. Many of the

plates and much of the text remains unchanged; but the advent of new man-made products and the use of many previously 'non-gem' materials as vehicles for fashioning (manganosite is included, which is always very small) has meant that an increase in size was inevitable, if only to keep pace with the development of the science. The bibliography has been enlarged, though not very extensively and the tables too have been expanded to accommodate new entries.

Almost the whole of the book is devoted to the materials themselves, and their man-made counterparts are included with them, where they exist. Introductory chapters deal with mineral characteristics and testing methods. This area however is but a curtain-raiser to the stones themselves; the material on each is so complete that it would be hard to find fault with it; nearly 300 pages are devoted to diamond alone—including a lengthy table of celebrated stones. An attractive full-page colour plate shows a variety of fluorescence types. Excellent colour photographs show inclusions in various types of synthetic ruby and a particularly good page displays the characteristic structure of Gilson opal. The section on emerald includes so many good photographs of inclusions that it would make a useful monograph on its own—and this is the pattern shown by the other sections. Minor criticisms could (in future) include the strength of the binding (the paper is heavy) and the need for a separate index—but it is hard to see how this could be avoided. Altogether a superb work and relatively cheap for what you get. M.O'D.

CLARK (A.). *Minerals.* Hamlyn, London, 1979. pp.128. Illus. in colour. £1.95.

This small, attractive book represents real value for money. Part of the Hamlyn 'nature guides' series, it depicts about 200 of the commoner minerals and gives composition, common habit, SG and hardness, together with brief details on mode of occurrence. Locations are not given. Introductory matter explains basic crystallography and geology. M.O'D.

COOK (R. B.). *Minerals of Georgia; their properties and occurrences.* Georgia Geologic and Water Resources Division, Atlanta, 1978. pp.vi, 189. $5.00.

Georgia is a richly mineralized state, and apart from important gold deposits there are also fine rutile crystals in the Graves Mountain area, blue sapphires at Hiawassee and aquamarines at La Grange. The book is arranged in chemical order and is written at the level of the mineralogist rather than the amateur mineral collector. M.O'D.

GELDART (G.). *Hand lapidary craft.* Batsford, London, 1980. pp.vii, 144. Illus. in black-and-white and in colour. £6.95.

Quite a pleasant book, re-working some material which will be of interest mainly to the amateur faceter, for whom it is intended. Good illustrations, capricious glossary, shaky science and easily-assimilated empirical craft notes place the book near the top of its class. The colour illustrations are oddly divided between the quite good and the dreadful; the index places orthoclase and feldspar separately with feldspar at both locations but with different references, a feat not unknown with this publisher, whose editors are not nearly critical enough. M.O'D.

GILI (Joan), ed. *Lapidari.* (Lapidary.) Dolphin Book Co., Oxford, 1977. pp.xxiii, 49. £2.50.

This is a 15th-century treatise on precious stones in Catalan. The text is not

difficult to understand for those with some linguistic knowledge; line numeration is provided and there is an introduction as well as a glossary. M.O'D.

HARSHAW (L.). *The rubies of Cowee Valley.* New, revised edn. Hexagon Co., Asheville, N.C., 1978. pp.72. Illus. in black-and-white and in colour. $2.75.

This small book describes the sites in the vicinity of Franklin, North Carolina; they are celebrated for the occurrences of corundum, which is occasionally found in good quality specimens. Details of the individual mines (which are mostly worked for amateur collectors) are given. M.O'D.

LIEBER (W.). *Menschen, Minen, Mineralien.* (Men, mines, minerals.) Christian Weise Verlag, Munich, 1979. pp.224. Illus. in black-and-white and in colour. Price on application.

This book is a general survey of the history of mineralogy, the occurrence and finding of minerals and of testing methods. The history includes biographical notes on some celebrated mineralogists (Haüy, Mohs, Werner, etc.); at the other end of the historical scale there are notes on the electron microscope and similar instruments. Highly recommended as a lucid overview of the subject. M.O'D.

PALACHE (C.). *The minerals of Franklin and Sterling Hill, Sussex County, New Jersey.* Franklin-Ogdensburg Mineralogical Society, Franklin, N.J., 1974. pp.6, VI, 135. Illus. in black-and-white. Price on application.

This mineralogical classic is a reprint of U.S. Geological Survey Professional Paper 180, first issued in 1935. The location is especially famous for fluorescent calcite, willemite and other minerals, as well as for the only translucent facetable zincite found anywhere in the world. M.O'D.

PERRY (N.), PERRY (R.). *Gemstones in Australia.* A. H. & A. W. Read Pty Ltd, Sydney, 1979. pp.158. Illus. in black-and-white and in colour. Price on application.

A most uneven book with some hideous misprints, attractive illustrations and useful locality information, this latest offering from Australia needed expert revision to get it into some logical order. The general impression left is one of the enthusiastic amateur—who else would omit the cause of colour in precious opal (in an Australian book of all places) when explanations are given for asterism in corundum? The account of locations appears good, as does the section on lapidary work. The chapter on synthetics would have been better omitted—existing pages could be stuck together without lessening the value of the book, which, at best, is derivative. It does not need much searching to discover the source of much of the information; this reviewer would prefer writers to describe testing, optical phenomena and similar topics in a fresh and arresting way—or to have the basic sources re-written. Bibliography totally inadequate, index and glossary poor. M.O'D.

ROSENBERGER (F.). *Fundamentals of crystal growth, I.* Springer, Berlin, 1979. pp.x, 530. Illus. in black-and-white. $(US)44.30.

This monograph forms no. 5 in the Springer series in solid-state sciences. Intended to be the first of three volumes on crystal growth, it covers macroscopic equilibrium and transport concepts, the following volume being intended to deal

with morphological and kinetic crystal growth and the last to introduce growth techniques. Based on the theory that crystal growth can be called the science of controlled phase transitions, this book investigates the phase equilibria and diagrams, mass transport and heat transfer, with a section on crystal growth itself. Problems are given, and there is a general review section at the end of the book. M.O'D.

STRUNZ (H.). *Mineralogische Tabellen.* (Mineralogical tables.) Akademische Verlag Geest & Portig K.-G., Leipzig, 1978. pp.vi, 621. 101 figs. M54.

This is by now a standard mineralogical text since the first edition was published in 1941. This issue is described as the seventh edition, but is in fact an unaltered reprint of the sixth, which in turn merely tidied up the fifth edition without substantially altering the text or adding new species. However the book is still very useful, giving necessary data on minerals in a concise and easily-managed form. No details of localities are given, but important references are provided. Serious students will find this fills the gap between Fleischer's list of mineral species and the much more exhaustive treatises such as Dana's *System* or Klockmann. M.O'D.

TAYLOR (R. E.), ed. *Advances in obsidian glass studies.* Noyes Press, Park Ridge, N.J., 1976. pp.viii, 360. Illus. in black-and-white. $32.00.

This comprehensive study covers both archaeological and geochemical aspects of natural glass. Chapters are by different authors and each one includes its own bibliography—the whole book is essential for anyone working in the field. M.O'D.

VAN LIEU (Mai), SCHAEFFER (P.-J.). *Ivoires de chine.* (Ivories from China.) Editions Dereume, Paris, 1978. pp.139. Illus. in black-and-white and in colour. Price on application.

This handsome book surveys the use of ivory in China from the earliest times to the present day. It is not intended as a scientific treatise but rather as a set of examples of fine work in ivory with a commentary rather than a text. This gives a certain breathlessness to the style, but in any case it is to the fine illustrations that the reader will turn. Neither index nor bibliography is provided. M.O'D.

WALENTA (K.). *Mineralien aus dem Schwarzwald.* (Minerals of the Black Forest.) Franckh'sche Verlagshandlung W. Keller & Co., Stuttgart, 1979. pp.127. Illus. in colour. Dm24.00.

A pocket-sized guide, illustrated entirely in colour and reasonably priced, is now becoming as rare as the minerals likely to be described in it. Important species from the area include gold (found in quartz), pale blue apatite, azurite and malachite in attractive forms, with a variety of other minerals of interest especially to the micromounter. Arranged in chemical order but with an index. M.O'D.

Mineralogiya i kristallofizika yuvelirnykh raznvidnostii kremnezema. (Mineralogy and crystal physics of quartz made for jewellery.) Nedra, Moscow, 1979. p.148. 9 colour plates. 90 copecks.

A guide in Russian to the manufacture of the various types of quartz crystals with gemmological application. M.O'D.

ASSOCIATION NOTICES

GIFTS TO THE ASSOCIATION

The Council of the Association is grateful to the following for their gifts:

Mr John R. Fuhrbach, B.Sc., F.G.A., G.G., Amarillo, Tex., U.S.A., for a parcel of peridot material from the Kilbourne Hole, New Mexico, U.S.A.

Mr Milton R. K. Lu, of Taiwan, for a round cubic zirconia, royal brilliant-cut (144 facets), very light brown in colour, weighing 4.28ct.

Mr A. E. Thomas, F.G.A., Johannesburg, S. Africa, for a complete set of Botswana 'Definitive issue' 1974 stamps depicting gem minerals, and a complete set of mint and used South West Africa 1979 and Kenya 1978: also for a sphene crystal found in Kariba area (Zimbabwe) in 1978.

NEWS OF FELLOWS

On 10th March, 1980, Messrs Eric Bruton, John Croydon, David Kent and George Pragnell, FF.G.A., who were visiting China in a study group organized by the *Retail Jeweller,* were entertained to dinner by the officers of the Gemmological Association of Hong Kong, the hosts present being Dr David Healey, F.G.A., Chairman, Mrs Anne Paul, F.G.A., Treasurer, Mrs Katherine Barcham, F.G.A., Assistant Treasurer, Mr Louis Lo, F.G.A., Secretary, Mrs Susan Hughes, F.G.A., Publicity Director (English), Mrs Winnie Nootenboom, F.G.A., Publicity Director (Chinese), and Pieter Nootenboom, Publications Director.

On 8th March, 1980, Mr Peter Read, C.Eng., F.G.A., held a seminar comprising a one-day series of illustrated talks for students of gemmology in Colombo, Sri Lanka, on subjects which included new gem-testing instruments and techniques, colour in diamonds (including artificial coloration), diamond mining and automation in diamond sorting, diamond simulants and computer-aided gem identification.

On 26th April, 1980, Mr Read gave a talk on diamond simulants to the Wessex Branch of the N.A.G. at the Wessex Hotel, Bournemouth.

OBITUARY

Mr Cecil James Payne, F.G.A. (D.1939), London, died on 20th April, 1980. A full obituary notice will appear in a later issue of the *Journal.*

Mrs Eileen R. Riddell, F.G.A., (D.1960), Armagh, N.Ireland, died on 29th March, 1980.

Mr Henry J. Whitehead, F.G.A. (D.1959), Edinburgh, gemmology course instructor, died in March, 1980.

MEMBERS' MEETINGS

London

On 26th March, 1980, at the Central Electricity Generating Board Cinema, Mr Peter Read, C.Eng., F.G.A., gave a talk entitled 'Modern Developments in Gem Testing'. Mr Read exhibited and demonstrated a number of the instruments which have been produced and marketed in recent years. Also displayed was a prototype of a Rayner Diamond Tester, a new instrument to be produced in the near future.

Midlands Branch

On 28th March, 1980, at the Society of Friends, Birmingham, Mr Peter Read, C.Eng., F.G.A., repeated his London talk (see above) under the title 'New Gemmological Instruments and Techniques'.

North-West Branch

On 13th March, 1980, at Church House, Hanover Street, Liverpool, Mr W. Hartshorn and Mr D. Alderson, of Isis Minerals, displayed crystals and minerals and gave a talk on the various sites where some of these have been collected in this country.

On 8th May, 1980, Mr Peter Read, C.Eng., F.G.A., gave a talk on 'Diamond Simulants and Artificial Coloration of Diamonds'. His own complete set of diamond simulants was on display.

COUNCIL MEETING

At a meeting of the Council held on Wednesday, 27th February, 1980, Dr R. R. Harding, B.Sc., D.Phil., F.G.A., was appointed as an Examiner in Gemmology and Mr E. Bruton, F.G.A., was appointed as an Examiner for the Gem Diamond Examination (Practical).

The following were elected to membership:

FELLOWSHIP

Abayasingha, Amaranath, Colombo, Sri Lanka. 1979
Avasia, Rohinton K., Bombay, India. 1979
Berggren, U. B. Marie, Oslo, Norway. 1979
Blondel, Nigel C., Guernsey, C.I. 1979
Bontekoe, Maryke, Steenwyk, Netherlands. 1979
Cleiman, Catherine G., Silver Spring, Md, U.S.A. 1979
da Costa, Michael S., Toronto, Ont., Canada. 1979
Dixon, Stanley C., Horsham. 1927
Douglas, Brian S., Toronto, Ont., Canada. 1979
Edmunds, Roger A., Accrington. 1979
Fagerstig, Björn O., Staltsjöbaden, Sweden. 1979
Franks, William, Bowdon. 1979
Geikler, Patricia J., Sewickley, Pa, U.S.A. 1979
Glorioso, John T., Baltimore, Md, U.S.A. 1979
Groenenboom, Peter, Arnhem, Netherlands. 1979

Hartzman, Mark J., Bronx, N.Y., U.S.A. 1979
Inamdar, Geeta, Newmarket, Ont., Canada. 1979
Kizirian, Vahe A., Pasadena, Ca, U.S.A. 1979
Kleibrink, Marion, Middleburg, Netherlands. 1979
Lalonde, Ernest R., Los Angeles, Ca, U.S.A. 1979
Langeraar-Litjens, Rose C., Leiden, Netherlands. 1979
Moody, Kenneth O., Cheltenham. 1979
Nilsen, Tore, Oslo, Norway. 1979
Ou Yang, Chiu Mei, Hong Kong. 1979
Schippers, Maria J. C., Velp, Netherlands. 1979
Schotborgh, Ilse H., Curaçao, N.A. 1979
Seed, Moira J., Ottowa, Ont., Canada. 1979
Senaratne, Upali N., Nugegoda, Sri Lanka. 1979
Shelley, Jessica, Toronto, Ont., Canada. 1979
Sweaney, James L., Santa Monica, Ca, U.S.A. 1979
Thornton, Peter J., Newcastle, N.S.W., Australia. 1979
Truyens, Simone M. C., Amsterdam, Netherlands. 1979
Velthoven, Nicolaas, Bergschenhoek, Netherlands. 1979
Vonk, Philippe A. J., Rotterdam, Netherlands. 1979
Wechgelaar, Didrich J. H., Gr Driebergen, Netherlands. 1979
Yokowo, Naoya, Tokyo, Japan. 1979
Yost, Dara E., San Diego, Ca, U.S.A. 1979

TRANSFERS FROM ORDINARY MEMBERSHIP TO FELLOWSHIP

Bradoch, Robert V., Tokyo, Japan. 1979
Ibrahim, Mamat Mukhtar bin, Ipoh, Perak. 1979
Moore, Roderich R., Solihull. 1979
Onozawa, Katsumi, Tokyo, Japan. 1979
Thompson, H. D. R., Mt Royal, Que., Canada. 1979

ORDINARY MEMBERSHIP

Absalom, Christine S., Effingham.
Agge, Carl-Arvid, Lerun, Sweden.
Ahamed Hussain, Mohamed J., Beruwela, Sri Lanka.
Andergassen, Willi, Rome, Italy.
Aoshima, Hiroyuki, Shizuoka Pref., Japan.
Baird, Myra, Auckland, N.Z.
Beck, Ian, Scunthorpe.
Beevers, Jacintha M., Hong Kong.
Beligammana, Chandrasena R., London.
Bolin, Jacoba M. J., Stockholm, Sweden.
Boorman, Robert F., Woking.
Boyes, Richard W., Garston.
Bradshaw, Deborah J., Oxford.
Brunton, Thomas A., Miami, Fla, U.S.A.
Bruson, Gerald E., Ft Lauderdale, Fla, U.S.A.
Buchanan, Vera A., Augher, N.I.
Bunge, Julia C. C., London.
Burton, Barry K., Harrogate.
Campbell-Cameron, Clare A. L., Preston.
Caycedo, Miguel J., London.
Charuba, Donald, Detroit, Mich., U.S.A.
Chen, Lee S., Singapore.
Cheung, Paul, London.
Cockrell, Charles E., Lubbock, Tex., U.S.A.
Coelho, Susan O., Richmond.

Corness, Patricia K. V., Auckland, N.Z.
Coward, Fiona, Ringwood.
Dahl, Victor C., jr, Avalon, Ca, U.S.A.
Dodgson, Alan B., Morden.
Ebelthite, Alexander, Twickenham.
Egginton, Roy, Newcastle-Upon-Tyne.
Esmail, Farida, Hong Kong.
Etoh, Tomooki, Fukuoka Pref., Japan.
Faller, Noel P., Londonderry, N.I.
Fujiwara, Osamu, Hyogo Pref., Japan.
Fuller, James E., Waltham Abbey.
Galloway, Leslie R., Perth, W.A., Australia.
Gasecki, Wojciech, Bieruta, Poland.
Grant, Judith M., Carmel, Ca, U.S.A.
Gray, Auriol R., Kidman Park, S.A., Australia.
Gorham, Josephine, London.
Grinyer, Raymond F., Newcastle, Natal, S. Africa.
Hall, Michael G., Builth Wells.
Harada, Akimasa, Tottori Pref., Japan.
Hart, Judith E., Denby.
Hartley, John M., Blackpool.
Hayes, George R., jr, Louisville, Ohio, U.S.A.
Hendrick, Dilli M. S., Kandy, Sri Lanka.
Hendriks, Geertruda M., Durban, S. Africa.
Heffer, William, Cambridge.
Hill, Arthur E., Jersey, C.I.
Herriott, William A., Winchester.
Hobock, Robert L., Tulsa, Okla, U.S.A.
Hoeben, Petrus M., Kidman Park, S.A., Australia.
Hong, Kuong S., Hong Kong.
Howden, Mark F., Tunbridge Wells.
Hurwitz, Jeffrey I., Frederick, Md, U.S.A.
Ichikawa, Shuichi, Akita Pref., Japan.
Ichimura, Seiji, Chiba Pref., Japan.
Iijima, Tsutomu, Nagasaki Pref., Japan.
Imai, Seiichi, Chiba Pref., Japan.
Inako, Tomoko, Hyogo Pref., Japan.
Isaza, Marco A., Bogota, Colombia.
Itoh, Takashi, Kanagawa Pref., Japan.
Itoyama, Emiko, Osaka, Japan.
James, Yvonne A., Sydney, N.S.W., Australia.
Jones, Joyce M., Walsall.
Kambayashi, Minoru, Tokyo, Japan.
Keegan, Dermot, Thika, Kenya.
Kida, Hiroshi, Kanagawa Pref., Japan.
Kikawa, Hiroko, Chiba Pref., Japan.
Kilburn, Kenneth, Shipley.
Kinoshita, Kazuko, Hyogo Pref., Japan.
Kitamura, Seiki, Tokushima Pref., Japan.
Kitano, Yoshimitsu, Yamaguchi Pref., Japan.
Kozawa, Shigeki, Osaka, Japan.
Lam, Peter, Hong Kong.
Landau, Sidney L., Miami Beach, Fla, U.S.A.
Langley, Paul C., Newcastle-Upon-Tyne.
Lifshitz, Issac, Ramat Gan, Israel.
Lo, Chi L., Kowloon, Hong Kong.
McKinney, Earnest C., Chamblee, Ga, U.S.A.
McLaughlin, Edward, Glasgow.
McMurray, Cathy M., Toronto, Ont., Canada.
Maeda, Katsutoshi, Fukuoka Pref., Japan.
Malhar, Lateef, Banstead.
Mamo, Raymond, Msida, Malta.
Matutani, Kei, Tokyo, Japan.
Mikami, Akira, Tokyo, Japan.
Miller, Bronwyn J., London.
Morisima, Katusuke, Kitami-city, Hokkaido, Japan.
Nakagawa, Naka, Tokyo, Japan.
Nakano, Yoshiyuki, Osaka, Japan.

Nakajima, Tetsuya, Chiba Pref., Japan.
Nakamura, Masanori, Osaka, Japan.
Nakayama, Keiiti, Tokushima Pref., Japan.
Nishiyama, Jun, Hyogo Pref., Japan.
Ogata, Hideko, Tokyo, Japan.
Ogintz, Lawrence, Millburn, N.J., U.S.A.
Osmond, Mark E., Salisbury.
Onodera, Noritoshi, Kanagawa Pref., Japan.
Otsuka, Nobuko, Tokyo, Japan.
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Parry, Kevin I., Chester.
Patel, Pramukh, Nairobi, Kenya.
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Petruzalek, Vilma, Anif, Austria.
Piper, Jean A., Carshalton Beeches.
Quintin, Gerard R., Freetown, Sierra Leone.
Rademaker, Jaap, Baarn, Netherlands.
Rainford, James W., Standish.
Root, Edmond, La Jolla, Ca, U.S.A.
Rosenthal, Jay H., Ft Lauderdale, Fla, U.S.A.
Sakai, Suzue, Tokyo, Japan.
Samori, Marco, Bologna, Italy.
Sasaki, Hiroshi, Osaka, Japan.
Sasaki, Kiyoshi, Tokyo, Japan.
Sattar, Ayoob, Mombasa, Kenya.
Seppen, Susan, Pitsford, N.Y., U.S.A.
Seremetis, Katherine, Athens, Greece.
Shibatako, Yashuhiko, Osaka, Japan.
Shono, Roko, Tokyo, Japan.
Smith, Alan J., Birmingham.
Stannard, Prudence A., Hong Kong.
Stillio, Adriano, Andorno Micca, Italy.
Suetugu, Eiichi, Fukuoka Pref., Japan.
Suginome, Hideo, Kitami-city, Hokkaido, Japan.
Sutton, Philip J., Rugeley.
Suzuki, Kumi, Mahdia, Tunisia.
Svec, Charles J., Clayton, Vic., Australia.
Takahashi, Toshio, Tokyo, Japan.
Takai, Toshisuke, Shizuoka Pref., Japan.
Takayama, Tetuo, Ooita Pref., Japan.
Takeshita, Junko, Osaka, Japan.
Tamai, Hideo, Osaka, Japan.
Tanada, Yasuyuki, Osaka, Japan.
Tanaka, Junichi, Kanagawa Pref., Japan.
To, Matthew, Hong Kong.
Tomisaki, Yukiharu, Tokyo, Japan.
Toolin, Maurice J., Hartlepool.
Toy, Joan, Plymouth.
Tsui, Tommy K. W., Kowloon, Hong Kong.
Uehara, Yoshizo, Tokyo, Japan.
Uematsu, Yasuo, Hyogo Pref., Japan.
Van der Ent, Mhairi I., Ruiru, Kenya.
Ward, Nicholas R., Oxford.
Wheeler, Malcolm J., Bishop's Stortford.
Wickramaratna, Pasculhandige D. H., East Croydon.
Wong, Kitty, Kowloon, Hong Kong.
Yamaguchi, Kazuo, Tokyo, Japan.
Yamamoto, Masayosi, Tokyo, Japan.
Yamamoto, Tokuko, Aichi Pref., Japan.
Yasumoto, Akiyo, Hyogo Pref., Japan.
Yoshida, Shingo, Aichi Pref., Japan.
Yoshiyama, Masaru, Chiba Pref., Japan.
Yoshizawa, Atsuko, Tokyo, Japan.
Yoshizawa, Keiko, Tokyo. Japan.
Young, William R., London.
Zawadzki, Antoni, Edinburgh.
Zoysa, Edirimuni G. G., Delft, Netherlands.

PRESENTATION OF AWARDS IN JAPAN

On 28th November, 1979, at a ceremony kindly arranged by the Gemmological Association of All Japan at the Imperial Hotel, Tokyo, Mr R. P. Martin, the Cultural Counsellor and British Council Representative in Japan, presented their Diplomas to those persons who had qualified at the Diploma Examination of the

Mr R. P. Martin presenting a Diploma.

Mr Yamada addressing the company.

Gemmological Association of Great Britain held in Tokyo in 1979. Mr Martin congratulated the recipients on having undertaken their difficult studies and obtained a qualification that was obviously going to benefit them in the future.

Professor I. Sunagawa, of Tohoku University, President of the Gemmological Society of Japan, thanked Mr Martin for his kindness in presenting the Diplomas. He said that 21 candidates had entered for the examination in Tokyo and 16 had qualified. This was a very high proportion and showed how seriously they had undertaken their studies. However, obtaining the Diploma to qualify for the Fellowship of the Gemmological Association of Great Britain should not be regarded as the end, but should rather be considered as the first step on the way to the profound world of gemmology.

Mr W. Yamada, Chairman of the Gemmological Association of All Japan, then expressed his congratulations to the successful examinees on obtaining their Diplomas and said that the knowledge they had acquired could be put into practical use and would be of the greatest help to them in the future.

XVIIth INTERNATIONAL GEMMOLOGICAL CONFERENCE

(Report received from Mr A. E. Farn, F.G.A.
Manager of the London Chamber of Commerce Gem Testing Laboratory)

This conference was held in Idar-Oberstein, the European gemstone and cutting centre, a 'natural' for such a venue. The conference lasted from a reception on Sunday, 23rd September, until the farewell luncheon on Thursday, 27th September, 1979. From first to last it was a smooth running, well organized and enjoyable, friendly conference. We had a tour of the lecture rooms of the German Gemmological Association with practical examples (briefings) of their teaching methods. A conducted geological tour of the immediate countryside under the animated leadership of Professor Dr Herman Bank, F.G.A., our host, made what was in any case a scenically beautiful tour much more interesting, even to non-geologists, because we were shown faults and flows which would normally be looked at casually instead of with interest. It was obvious that a lot of work and preparation had been accomplished by our German hosts and from the commercial side of Idar-Oberstein as well, i.e., Mayoral address and welcome followed by a book presentation and buffet supper. Idar-Oberstein is a single-subject town—the subject, of course, being gemmology in all its stages, rough, cut, polished, stained, carved, organic, amorphous, ornamental, etc., and basically commercial. There are many large and many very small firms and individuals actively engaged in all aspects of gemstone promotion. I still think that the most impressive features of gemmology, arrived at by the requisites of Beauty, Rarity and Durability, are best exhibited by the uncut crystals and crystal groups—nature's art exposition.

The gemmological side of the conference consisted of a series of papers which were read, sometimes accompanied by colour-transparencies and/or photographs, drawings and diagrams exhibited by use of the epidiascope. Speakers from world wide sources gave lectures, most of a short duration with questions following. The whole of the time the lecture room was occupied the outer ante-rooms were set up with modern gem-testing equipment and books from all four corners of the world (which sounds a little square!). To avoid the use of the term 'the broad spectrum' it is easier to describe the talks in alphabetical order of the names of lecturers.

As the assembled gemmologists, mineralogists, geologists, physicists, etc., sat ready to begin this XVIIth series of talks, lectures, etc., the host member, Professor Bank, asked us all to stand and observe a minute's silence in memory of Gordon Frederick Andrews, F.G.A., late Secretary of the Gemmological Association of Great Britain, Tully Medallist, former editor of the *Journal of Gemmology*. Gordon Andrews, like his fellow colleague Robert Webster, left an indelible mark in and on the world of gemmology. Those of us who were privileged to know him remember him for his warmth, friendliness and dry humour.

Dr C. S. E. Arps, F.G.A., collaborated with fellow gemmologist Professor Dr P. C. Zwaan, F.G.A., both of Leiden University (literally A-Z in Netherlands gemmology) in a talk on 'Properties of Gem Scapolites from Different Localities.

Professor Dr J. M. Bosch-Figueroa described methods of observing fluorescence in diamonds.

Professor S. Cavenago-Bignami gave a brief account of black and greenish-black cultured pearls from Tahiti, in which the colour is due to the molusc and not to staining. Diffraction x-rays will prove the cultivation and will not alter the colour.

Professor A. Chikayama, F.G.A., gave a documented map illustrating the present coral industry of Japan.

Mr Robert Crowningshield, F.G.A., of G.I.A. New York Laboratory, spoke with considerable authority on problems and observations in the identification of fancy-coloured diamonds.

Mr P. E. Desautels, of the Smithsonian Museum, Washington, D.C., gave a talk, illustrated with slides showing great dissimilarities in structure of Jadeite. His theme was that Jadeite being a rock makes it difficult to describe specifically in fixed terms. His title was 'Further Studies in Jade'.

Mr A. E. Farn, F.G.A., (following in alphabetical progression) read a paper entitled 'The First Impact of a Gemstone'. (I had a series of very fine colour transparencies illustrating my talk, kindly loaned from the Institute of Geological Sciences.)

Professor Dr E. Gübelin, F.G.A., now retired from commercial life but working just as hard as ever, gave brief descriptions of some new or recent gemstones, comparing them in their positions in the family patterns and links.

Mr Alan Jobbins, B.Sc., F.G.A., gave an illustrated discourse on 'The Opal Deposits of Piaui State, Brazil'.

Dr J. Kanis, of South Africa, gave a review of some of the effects on production of gemstones caused by internal unrest, guerrilla activities, smuggling, etc.

Mlle Dina Level gave a typically animated and enthusiastic talk with some beautiful slides showing the effects of side by side observation of coloured gemstones viewed using polaroid in opposed directions. It is a gemmological treat to listen to this First Lady of French gemmology.

Mr Richard T. Liddicoat, jr, F.G.A., President of the G.I.A., gave a résumé of instruments, ideas and findings currently happening in their new research centre.

Miss Julia Myers, F.G.A., F.G.A.A., of Sydney, Australia, a well-known and much-travelled representative of the Australian scene, showed a series of interesting slides illustrating tough conditions in the search for and recovery of Australian Diamonds.

Dr H. J. Nairis, F.G.A., Geological Survey of Sweden, gave us all a copy of his booklet on 'The International Precious Opal Nomenclature and Grading Standards (IPON)'. This consists of a useful summary and definitions of types, colours, patterns and a point indication system—a very useful general guide to stock control and (although I detest the word) grading.

Mr H. S. Pienaar, F.G.A., of South Africa, gave a very interesting talk on new coral discoveries off the coast of South Africa, these corals having very distinctive structures which hall-mark them. He also told us of inconclusive tests on a greenstone which may yet be a new gem.

M. J.-P. Poirot, (Chambre de Commerce et d'Industrie, Paris), gave a well prepared talk on the heat treatment and detection of treatment in sapphires. M. Poirot deserves credit for his interest and tenacity in following up the challenge of *proving* heat treatment in sapphires.

Dr F. H. Pough talked authoritively upon Obsidian glasses and imitations showing us some interesting examples.

Mr H. Reymer under the heading 'Canadian Gem Report' produced exciting slides and samples of a limited supply of ammonite fossils with a play of colour. They have a natural hard shale backing and are not doublets—a most interesting and very unusual form of gem material. Basically aragonite, it is a collector's item, being very attractive.

Mr J. Roux, well-known personality of De Beers, gave a short, interesting account with maps of diamond re-recovery from working over old dumps with modern methods—an apparently profitable exercise.

Mr X. Saller, F.G.A., of Germany, won universal approval by altering his 'Farewell to Gemmology' and intimating that he hoped to be at the next Conference.

Mr E. Sasaki, F.G.A., of Japan, discussed the heat treatment of corundum in Thailand, whose main produce is tin, and the discovery of diamonds in 1930. An informative talk on aspects of rough coke ovens, cutters and smuggling.

Dr J. M. Saul, of France, gave details of euclase from Morogoro, East Africa, green sphalerites in an emerald parcel, colour-change violet spinels, etc., an intriguing glimpse of the mineral gemstone wealth of East Africa.

Mr Charles A. Schiffmann, F.G.A., of the Gübelin Laboratory, Lucerne showed graphs illustrating the variation in transmission of ultraviolet lamps and the decline in efficiency of their filters over a period. He mentioned the varying strength ratio of 5040/4980 and 4980/5040 (most of this is fully detailed in K. Scarratt's article in *J.Gemm.*, 1979, XVI(7), 433-47). Most gem laboratories are following on similar lines of study of treated diamonds, the spectroscope being the prime reason.

Professor Dr H.-J. Schubnel gave a talk in rather rapid French but, of course, with considerable erudition. His talk was not noted in advance and we had no paper to follow. The lecture was given in a darkened room to accentuate the diapositives. The talk was entitled 'Travaux à la Sonde Laser-Raman'.*

Professor Dr Strunz gave an extremely erudite talk on the morphology and atomic structure of gemstones.

*Sir C. V. Raman, M.A., F.R.S., noted Indian scientist and Nobel laureate in physics, well known for his work on the fluorescence of diamond.

Professor Dr I. Sunagawa, of Japan, gave a most concentrated talk on 'Natural and Synthetic Emerald' and the methods of growth of crystals with hints on crystal surface structures and viscinal faces. He described Japan's Verneuil plants for star stones, the Czochralski process for GGG and YAG, Linobate etc. plus synthetic olivine grown for study and research purposes. A method of infrared heating—by concentrating from two opposing elliptical mirrors, producing 1300-2000°C—can be used to produce alexandrite chrysoberyl doped with vanadium. He showed *plastic* opal based upon the natural structure of opal with characteristics which fortunately miss those of natural opal.

Dr M. Superchi (Italy) did not offer a title or intend to speak but belatedly introduced a paper on the subject of colour grading of gemstones by the use of colour comparison charts—a subject sure to raise gemmological temperatures, particularly for those of the 'Chromium Criterion for Emerald' school.

Mr E. B. Tiffany gave his usual interesting résumé of the gemmological scene by showing slides and talking of some important but little-known historic diamonds which were Golconda stones looted from India by Iran.

Mr Geoffrey Toombs, F.G.A.A., (Sydney, Australia) gave further interesting facts on the heat treatment of sapphires. 1700-1750°C seems to be the optimum region. Thais use ovens of packed coke and forced airfeed for 5 hours and allow 18 hours for cooling. It is said that Ceylon and Thai stones revert after treatment and that Australian stones lose their 4500Å complex. Successful heat treatment of sapphires requires very careful choice of material for the process.

Professor Dr P. C. Zwaan, of Leiden, Netherlands, gave the details of his and fellow researcher Dr C. Arps's work on 'Properties of Gem Scapolites from Different Localities'.

These conferences, which take place every two years, afford opportunities for the reception and interchange of knowledge among gemmologists. We become friendly and human, we realize that F.G.A.s can rub shoulders with Drs and Profs, each profiting from the contacts. Whilst the world becomes smaller and the use of gemmological knowledge is employed in devising new artefacts requiring considerable technique and equipment, we must not lose sight of the fact that we are gemmologists—gemmologists *first*—and that, just as the basic gems are still much with us, it is also the basic equipment which, used with knowledge, continues to score. As a trade gem testing laboratory gemmologist brought up in the trade I continue my advocation of the continual use of the *10× lens.*

TENTERDEN, Kent

An adult education centre in the Tenterden area is considering setting up evening teaching classes in gemmology. An Instructor is required. Will anyone interested please communicate with the Association Secretary at Saint Dunstan's House.

CORRIGENDA

In J.Gemm., 1979, XVI (7), 473, line 4, (reference for abstracted paper by Francesconi *et al.*) for 'Gemologia, **22**, 43, 53-63, 1 fig, 1978.' read 'Gemologia, **22**, 43/44, 53-63, 1 fig., 1976.'

In line 2 on p.119 above (in reference for abstracted paper by Ball *et al.*) for '13, 10, 363-6, 1979.' read '13, 11, 363-6, 1979.'

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DIAMONDS (2nd Edition) By Eric Bruton	£13.50
INTERNAL WORLD OF GEMSTONES By Edward Gübelin	£55.00
HISTORY AND USE OF DIAMOND By S. Tolansky	£3.50
GEMMOLOGICAL INSTRUMENTS By Peter Read	£8.50
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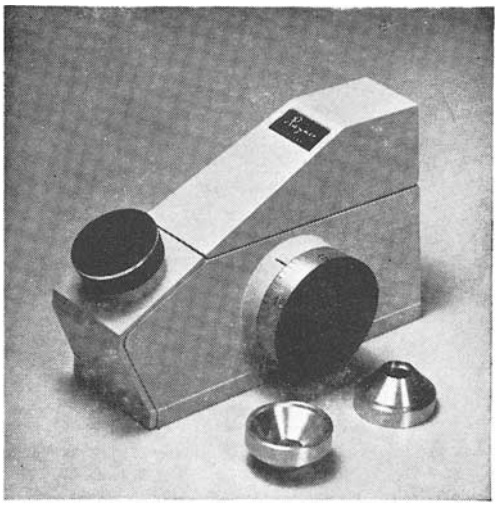

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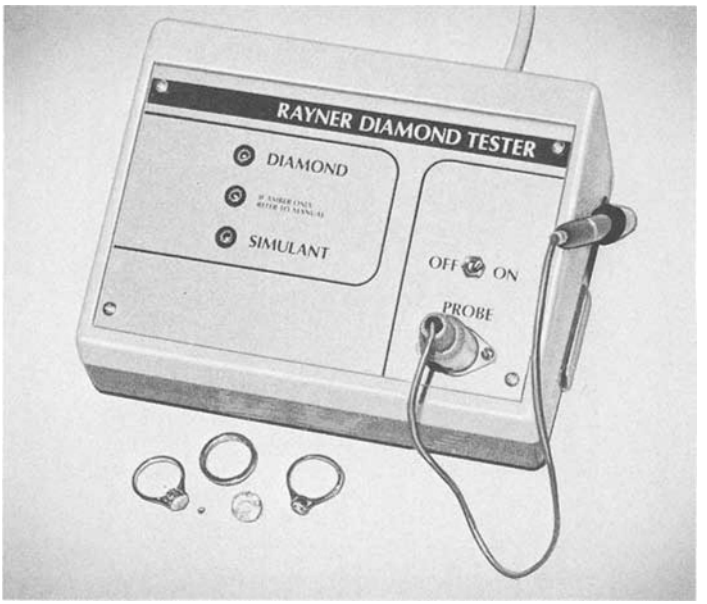

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Although not a mandatory requirement, it is most helpful if articles are typed (together with a carbon copy) in double spacing on one side of the paper, with good margins at sides, top and foot of each page. Articles may be of any length, but it should be borne in mind that long articles are more difficult to fit in than short ones: in practice, an article of much more than 10 000 words (unless capable of division into parts or of exceptional importance) is unlikely to be acceptable, while a short note of 400 or 500 words may achieve early publication.

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and

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THE JOURNAL OF GEMMOLOGY
AND PROCEEDINGS OF THE GEMMOLOGICAL ASSOCIATION OF GREAT BRITAIN

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SPECTROSCOPIC INVESTIGATION OF A CANARY YELLOW DIAMOND

By A. T. COLLINS, B.Sc., Ph.D.

Wheatstone Physics Laboratory, King's College, London

INTRODUCTION

In 1943, Anderson,[1] in the course of a proposed classification of diamonds according to their fluorescent and absorption characteristics, described a certain class of yellow diamonds to which later the term 'canary' was conveniently attached, this being a well-known trade name for fine yellow fancy diamonds. The yellow colour is clearly associated with absorption at the blue end of the visible spectrum, but when examined at room temperature with a hand spectroscope these diamonds show no sharp absorption lines. This is in marked contrast to 'Cape yellow' diamonds which have prominent absorption peaks at 478 and 415 nm.[1] Again, when canary yellow diamonds are illuminated with long wave ultraviolet (365 nm) from a mercury 'black lamp' they emit a yellow or orange luminescence whereas the

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luminescence from Cape yellow diamonds, if present, is blue. No sharp lines are apparent when the luminescence band from a canary yellow diamond at room temperature is examined with a hand spectroscope.[1]

In a later paper (1962) Anderson[2] describes finding an emission line at 575 nm in some diamonds emitting an orange luminescence. Emission lines are often poorly defined when the crystal is excited at room temperature, and the present author has assumed for many years that references in the literature to *featureless* emission bands simply reflected the fact that the diamonds had not been examined at liquid nitrogen temperature. In 1965 Dyer *et al.*[3] had described a new type of diamond which they classified as Type Ib. These diamonds absorb strongly in the blue part of the visible spectrum, giving them an attractive yellow colour, and also have a characteristic absorption band in the infrared spectral region between 7 and 10 μm (1400 to 1000 cm^{-1}). Naturally-occurring luminescence in the 575 and 637 nm systems can sometimes be observed in Type Ib diamonds, and it seemed to the present author that such a diamond would be classified as a canary yellow by gemmologists.

Nitrogen in Diamond

It will probably be useful to summarize here the rôle that nitrogen plays in determining the optical properties of diamond.[4] Natural Type Ib diamonds contain typically 100 parts per million (ppm) of isolated substitutional nitrogen; that is to say the nitrogen is located in the crystal lattice at positions normally occupied by carbon atoms, and no nitrogen atom is close, on an atomic scale, to any other nitrogen atom. Diamonds of this type are very rare in nature—usually the concentration of nitrogen is higher (up to 3000 ppm) and the nitrogen atoms have aggregated to form well defined defects. Diamonds containing aggregated nitrogen are classified as Type Ia, and the two dominant defects appear to be the A-aggregate and the B-aggregate. The A-aggregate is a pair of nearest-neighbour substitutional nitrogen atoms, and the B-aggregate probably consists of 4, 6 or 8 nitrogen atoms in an as yet unknown configuration.

As already noted, Type Ib diamonds have a characteristic infrared absorption with a peak at 1130 cm^{-1} (8.85 μm) and absorb strongly in the blue part of the visible spectrum. Type IaA

diamonds (i.e those with nitrogen in predominantly the A-form) have a different infrared absorption, with a principal peak at 1280 cm^{-1} (7.8 μm), and absorb strongly in the ultraviolet at wavelengths less than 330 nm. The infrared absorption band for Type IaB diamonds is different again, with the principal peak located at 1175 cm^{-1} (8.5 μm). Neither the A-aggregate nor the B-aggregate of nitrogen gives rise directly to any absorption in the visible region and most colourless gem quality diamonds contain substantial concentrations of aggregated nitrogen. However, many diamonds also contain so-called N3 centres. The N3 centre is believed to be a triangle of three nearest-neighbour nitrogen atoms bonded to a common carbon atom, and gives rise to the Cape series of absorption bands. When these bands are strong the diamond has a characteristic straw-yellow colour. There is no correlation between the concentration of N3 centres and the concentration of either the A-aggregates or B-aggregates of nitrogen, but there is a tendency for the Cape absorption bands to be strong in diamonds with a large B-aggregate concentration.

Platelets—extended defects which give rise to anomalous x-ray scattering, and which are sufficiently large to be observed in the electron microscope—were once thought to be the major receptacle of nitrogen in diamond. More recent work suggests that less than 10% of the total nitrogen is incorporated in the platelets; indeed the platelets may not involve nitrogen at all. An infrared absorption peak at 1370 cm^{-1} (7.3 μm) appears to be related to the concentration of platelets, but once again there is no corresponding absorption in the visible region.

Although diamonds which are predominantly Type Ib, Type IaA or Type IaB may be found, most natural diamonds are a mixture of types. Diamonds which have no detectable absorption in the 7-10 μm region contain very little nitrogen and are, of course, classified as Type IIa.

Yellow Fluorescent Diamonds

Recently we have begun an investigation of the optical properties of natural brown and yellow diamonds. During the course of this survey a number of diamonds have been examined which exhibit bright yellow luminescence when excited at 365 nm. No sharp lines are visible in the room temperature spectrum, and when the diamonds are cooled to liquid nitrogen temperature it is

clear that the emission band is not one that has been studied in detail before. These diamonds were not a good yellow colour, and could not be described as canaries, but it was felt desirable that spectra should be obtained from a canary yellow diamond for comparison purposes.

The canary yellow diamond that has been studied is a 0.38 ct step-cut stone kindly loaned by Basil Anderson. The culet on this diamond is not polished to a sharp point, but has a small flat on it, and for the optical absorption measurements the light beam was passed through the culet and out of the table, the thickness of diamond being very close to 3 mm.

Experimental

The spectra shown in this paper have been recorded with the diamonds at either room temperature or liquid nitrogen temperature (77 K) using scanning monochromators. For the absorption spectra the vertical axis is absorption coefficient and this has been calculated point by point using the approximate formula $\alpha = d^{-1} \log_e I_o/I_t$, where I_o and I_t are the intensities of the incident and transmitted light, α is the absorption coefficient and d is the crystal thickness in cm. In practice about 2000-4000 points are used per spectrum, and the absorption coefficient is evaluated and the spectrum plotted using an on-line computer.

Luminescence spectra were excited using a high pressure mercury lamp with an interference filter to select one of the strong lines at 365.0, 404.7, 435.8 or 546.1 nm. The vertical axis on the spectra presented is in arbitrary units—that is, the spectra have not been corrected for the variation in the response of the spectrometer with wavelength.

Results and Discussion

Figure 1 shows the absorption spectrum of the canary yellow diamond in the visible region with the sample at 77 K. For wavelengths shorter than 560 nm the absorption increases smoothly and continuously. This is entirely characteristic of a Type Ib diamond. Although this spectrum confirms the author's previous ideas about the origin of the colour of canaries, it was disappointing in that it showed none of the minor features observed in the series of yellow luminescent diamonds which we are currently studying. (A typical example will be shown in Figure 3).

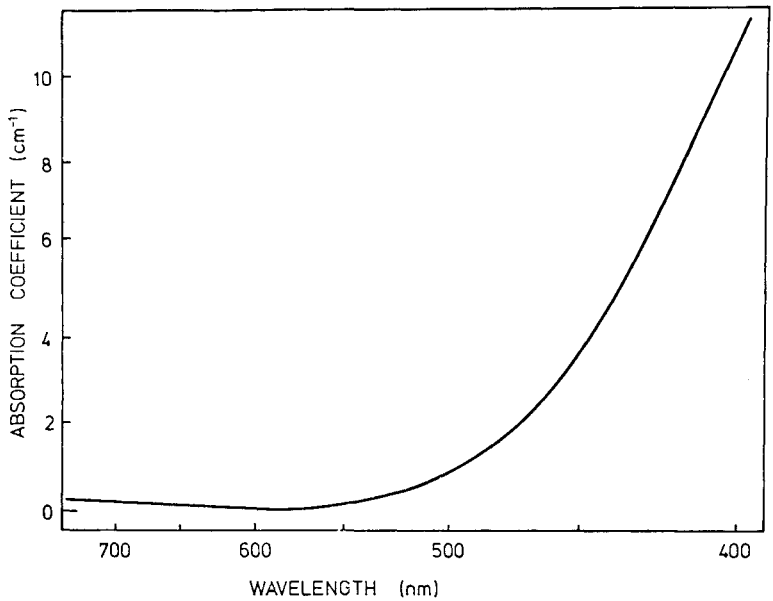

FIG. 1 Absorption spectrum of a canary yellow diamond, in the visible region, recorded with the sample at 77 K.

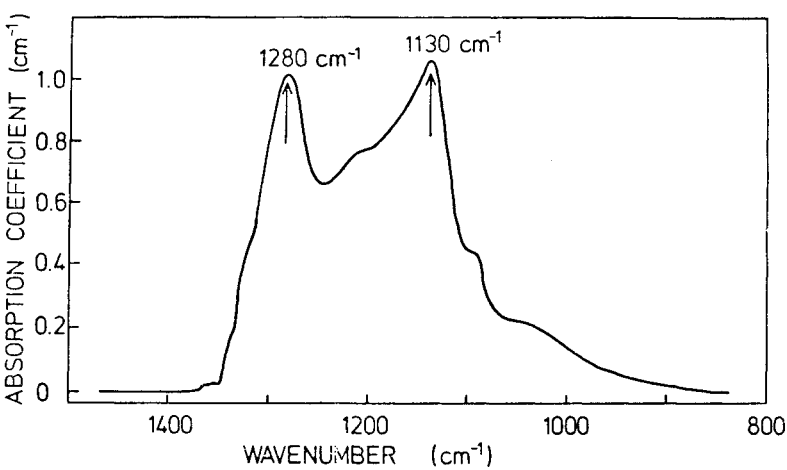

FIG. 2 Absorption spectrum of a canary yellow diamond, in the infrared one-phonon region, recorded with the sample at room temperature. The 1280 and 1130 cm^{-1} peaks are labelled.

Figure 2 shows the absorption spectrum of the canary yellow diamond in the infrared region with the sample at room temperature. The geometry of the sample made these measurements very difficult and a subjective correction has had to be applied to the raw data. The shape of the spectrum may not be exactly correct, therefore, but there is no doubt about the existence of absorption peaks at 1280 and 1130 cm^{-1}. As noted in the introduction, the 1130 cm^{-1} peak is only seen in Type Ib diamonds whereas the 1280 cm^{-1} peak is characteristic of Type IaA diamonds in which the nitrogen is present as A-aggregates. The infrared measurements show, therefore, that the specimen is a mixture of Type IaA and Type Ib material. Many diamonds which have the typical Type Ib absorption in the visible region (as in Figure 1) are found to be a mixture of Types Ib and IaA from the infrared spectra.

Figure 3 shows the absorption spectrum of one of the yellow-luminescing diamonds that we are investigating at present. It will be noted that although there is gradually increasing absorption for wavelengths shorter than 560 nm, as observed in a Type Ib diamond, there is also a broad band centred at around 490 nm and a number of minor peaks at shorter wavelengths. Clearly there is no similarity between that diamond and the canary yellow diamond which is the subject of this report. However, using a hand spectroscope, Kenneth Scarratt of the Gem Testing Laboratory has observed (personal communication) an absorption line at 425 nm in six different natural diamonds. Four of these were yellow stones which exhibited yellow fluorescence under long wave ultraviolet illumination and would properly be described as canaries. It is possible therefore, that some diamonds classified as canaries may also have the 490 nm absorption band and associated structure present.

Luminescence Measurements

During the course of our measurements on diamonds which have an absorption band like that shown in Figure 3 we have observed that bright yellow luminescence is produced by illumination with long wave ultraviolet (365 nm), but if the crystal is irradiated with light of wavelength near the peak of the 490 nm absorption band then the diamond exhibits a red luminescence.[5] As with many optical centres in diamond the luminescence band is

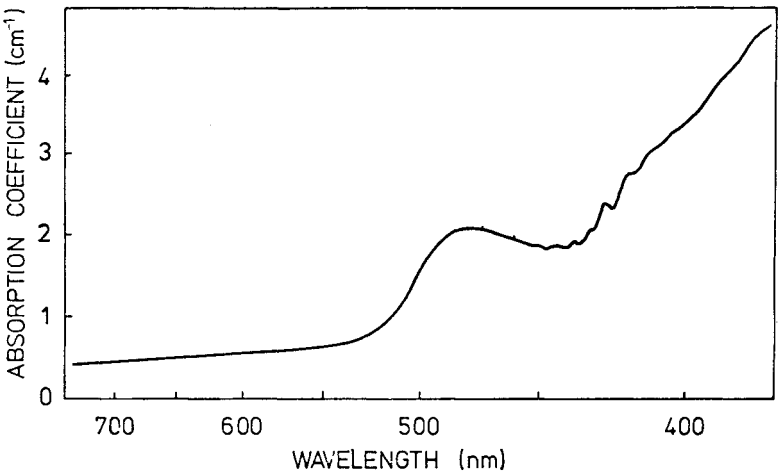

FIG. 3 Absorption spectrum of a yellow-luminescing diamond, in the visible region, recorded with the sample at 77 K.

an approximate mirror-image of the absorption band. With this in mind the luminescence from Anderson's canary yellow diamond has been examined using four different excitation wavelengths. The results with the diamond at room temperature are shown in Figure 4.

With the conventional long wave ultraviolet excitation (curve (a)) the luminescence lies predominantly in the orange region of the spectrum with its maximum near 605 nm; when excited with blue light (curve (c)) the peak of the emission band shifts to about 545 nm in the yellow-green region. Excitation at 404.7 nm (curve (b)) produces an almost equal mixture of these two components, whereas excitation with the green 546.1 nm line (curve (d)) gives rise to a third emission band in the red. Some of the structure on this band is due to luminescence in the 637 nm system, (the zero-phonon line is arrowed).

The picture, then, is an extremely confused one. At least three different components of unknown origin are present in the room temperature luminescence spectrum and these are all quite different to the yellow and red emission bands that we have recorded in diamonds containing the 490 nm absorption band. (Details of the work on these diamonds is to be published separately).[5] The situation becomes even more confusing when the luminescence from the canary yellow specimen is studied with the diamond at 77 K. One example, using 365 nm excitation, is shown in Figure 5.

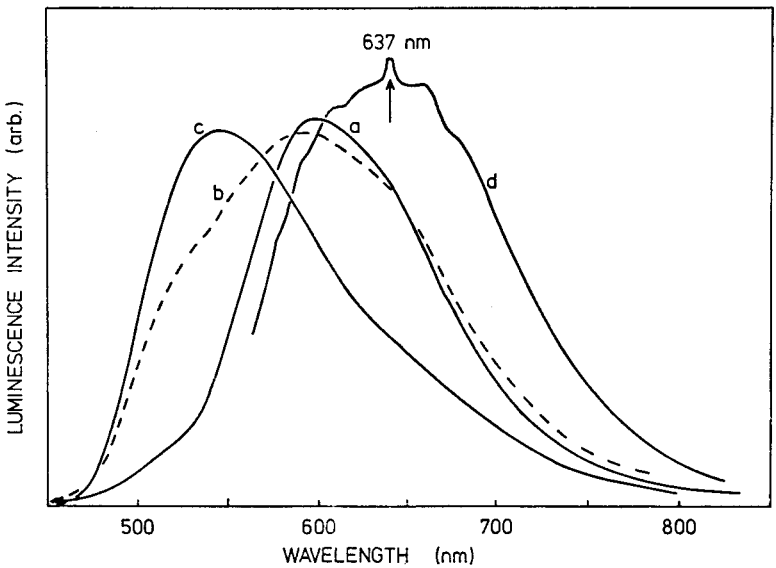

FIG. 4 Luminescence spectra of a canary yellow diamond, recorded with the sample at room temperature. The following mercury lines were used to excite the luminescence: (a) 365.0 nm, (b) 404.7 nm, (c) 435.8 nm and (d) 546.1 nm. The position of the 637 nm zero-phonon line on curve (d) is indicated by an arrow—the peak of the line is well off-scale.

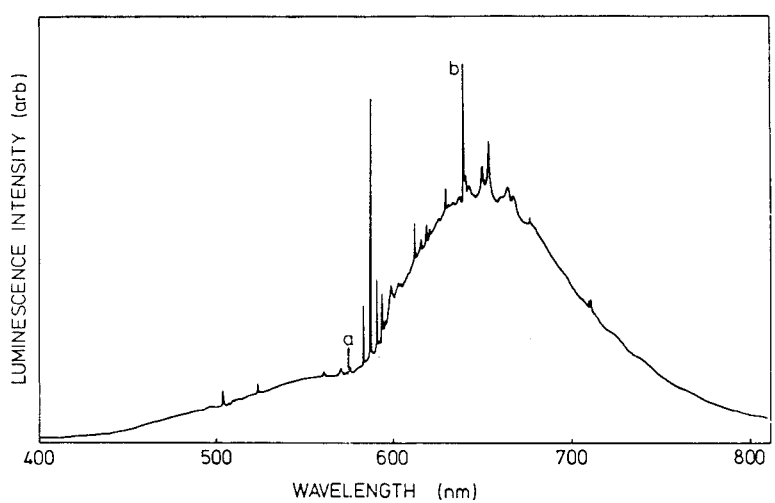

FIG. 5 Luminescence spectrum of a canary yellow diamond, recorded with the sample at 77 K, excited by the 365 nm mercury line. Lines (a) and (b) are very close to the wavelengths of the familiar 575 and 637 nm lines, but are unrelated to them. The wavelengths of all the sharp lines are listed in Table 1.

Anderson had previously noted that the 575 and 637 nm zero-phonon lines are observed in the luminescence spectra of some diamonds.[2] The lines marked (a) and (b) in Figure 5 are at 574.1 and 638.4 nm—deceptively close to the familiar lines at 575.0 and 637.2 nm, but apparently unrelated to them. The very weak line just to the long wavelength side of (a) is in fact the 575.0 nm line, and this is far more prominent in the luminescence spectrum excited by blue light. If green light is used to illuminate the diamond the well-known 637.2 nm line is much stronger than the 638.4 nm line shown in Figure 5, and is, in fact, responsible for the structure in the room-temperature spectrum in Figure 4 curve (d). There are many other sharp lines in Figure 5 which, to the author's knowledge, have not been reported previously, and wavelengths of these 'new lines' are listed in Table 1. It should be mentioned that a qualitative glimpse of sharp line structure in the fluorescence spectrum of a canary yellow specimen was obtained by Anderson[6] in the early sixties. In that investigation the diamond was cooled to about −70 °C by resting it on a block of solid carbon dioxide.

TABLE 1

Sharp lines observed in the luminescence spectrum from a canary yellow diamond excited at 77 K with long wave ultraviolet (365 nm)

S = strong, M = medium, W = weak.

Wavelengths in nm

574.1 (M);	575.2 (W);	582.6 (M);	586.5 (S)
590.2 (M);	591.4 (W);	592.7 (M);	594.5 (W)
611.1 (M);	614.5 (W);	617.5 (W);	619.4 (W)
628.1 (M);	638.4 (S);	639.3 (W);	675.7 (W)
709.4 (W);	710.4 (W).		

SUMMARY

Infrared absorption measurements have shown that the canary yellow diamond studied in this investigation is a mixture of Type Ib and Type IaA material. The absorption in the blue part of the

visible spectrum which gives the stone its yellow colour is entirely characteristic of Type Ib diamond and there is no evidence for the presence of any other absorption systems. The broad luminescence bands observed at room temperature appear to contain at least three different components, and cooling the diamond to 77 K reveals a complex series of sharp lines. The luminescence bands observed in this diamond are not the same as those seen in specimens containing the 490 nm absorption band.

No general conclusion can be reached from studies on one diamond, but it seems probable that all stones classified as canaries are Type Ib or a mixture of Type Ib and Type Ia material. It is also likely that, with so many combinations to choose from, the overall luminescence spectrum will show a marked sample-dependence. There is clearly still a great deal to learn about yellow and red luminescence in diamond, and work is in progress in the author's laboratory aimed at obtaining a better understanding of these emission bands.

ACKNOWLEDGEMENTS

The author is grateful to Basil Anderson for the loan of the canary yellow diamond used in this investigation, made available through Alec Farn of the London Chamber of Commerce Gem Testing Laboratory.I am also grateful to Mr Farn and Kenneth Scarratt of that laboratory, and to Mr Anderson, for their comments on the final manuscript. The absorption spectrum of Figure 3 was obtained by Khalid Mohammed.

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[*Manuscript received 3rd April, 1980.*]

NOTES FROM THE LABORATORY

By A. E. FARN, F.G.A.

The Gem Testing Laboratory of the London Chamber of Commerce and Industry

'Full many a gem of purest ray serene the dark unfathomed caves of ocean bear'. Could it be that Thomas Gray, when writing his *Elegy written in a Country Churchyard,* penned these words knowing that pearls would be the forerunner of our interest in gems as such?

Had it not been for the need for investigation into the internal world and structure of pearls and cultured pearls in the early twenties of this century, *gemstone* investigation would not have reached the position it occupies today. Gemmology, the study of gems, is usually considered by gemmologists as the study of gem *stones.* Gemmology is a science, a learning; much gemmological knowledge is used in gem testing, which is a trade activity affording a service usually from a laboratory such as ours.

Gem testing—particularly that version or variety undertaken in our laboratory—embraces many aspects of gemmological knowledge plus trade experience. To arrive at an accurate conclusion to the test or examination of a gem as a trade requirement we employ the quickest and most economical non-destructive methods to identify specimens sent for test positively.

Routine testing follows standard practice to a certain extent. We are tradespeople and have a certain degree of experience plus rule of thumb knowledge garnered over the years. My own conviction of recognition and consequent routine to follow is based upon the precept that 'the first impact of a gemstone is its colour.' By the impact of colour the course to be followed in testing is decided. I hope that all gemmologists worthy of the name will automatically use their 10× lens for first examination and decide mentally what the stone is or could be. An obvious Verneuil will need microscope and spectroscope. An aquamarine will need the (Anderson-Payne) spinel refractometer.

When it comes to pearls, set or unset or strung as necklaces, they usually find their way to me. Apart from precise requests from customers in the case of pearl testing one knows which method is to be followed. A necklace of pearls of fine graduation, matching in

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colour, possibly a little 'gleaming', will be examined at the drill holes by 10× lens to check for demarcation lines and varicose protuberances. This will dictate usually a radiograph or direct x-ray photograph, in which we should expect to find a typical picture of a cultured pearl necklace. The shapes of some pearls are extremely useful in indicating possible results, i.e. a bouton shape on a bar brooch or ring is much more likely to be a natural pearl than a fine spherical shape. It would be uneconomical to utilize a fine spherical pearl in a bar brooch.

When we have to resort to diffraction-pattern x-ray we obtain a lauegram, so called after Max von Laue, a German physicist awarded the Nobel Prize in 1914. Most gemmologists know the theory of diffraction pattern by x-ray beams. The radial and concentric structure of natural pearl provides six-spot hexagonal patterns from the thin overlapping platelets of aragonite bonded with conchiolin which form the basic structure of the pearls. The layered bonded structure of the mother of pearl bead nucleus in a cultured pearl provides a four-spot pattern in one particular direction. Thus the value of the Laue method for non-drilled or part-drilled pearls. Although we take lauegrams and radiographs of pearls as *routine* we still feel quite a fascination when watching the results emerge in the developing dish. Whilst the x-ray beam does the penetration and the developer and fixer play their parts, it is the interpretation of the film and its content (or lack thereof) which counts. Usually cultured pearl necklace radiographs are easy, because of the regimentation of regularity of nuclei.

The interpretation of a fine quality natural pearl necklace is much less obvious and less rewarding. This is because fine structures regularly developed with no interruption causing conchiolin flow on a coarse growth show little or no positive signs. In fact it is sometimes this *lack* of structure (like the fine quality of the drill holes meeting at the centre) which indicates—but does not prove—a natural pearl.

Pearls like diamonds look alike until you come to examine them. Routine testing therefore is never dull, though it can be tedious when testing individual pearls of less than one grain size (4 grains = 1 carat). The 10× lens is in constant use probing into drill holes and still more in examining radiograph pictures held in front of a 60-watt bench lamp. In the dark-room, as the broad outlines emerge during developing, one gets a general idea or feeling, but it

is not until a little later after washing, fixing and washing again, that full close-up details can be examined.

Recently we tested a drop-shape pearl mounted as a stick-pin. Its shape indicated that it should prove to be a natural pearl; I took a radiograph of it expecting to see one or two overlapping arc structures, a pip nucleus possibly and outer lines following roughly the perimeter of the shape. In the dark-room only the basic outline could be seen. I left the negative to fix and carried on with other items. One good point about x-ray work is that exposure-time or fixing and washing does not impose restrictions, to the exclusion of other testing. Later, sitting with a 60-watt bench lamp and a 10× lens, I began the inspection of a small batch of negatives which

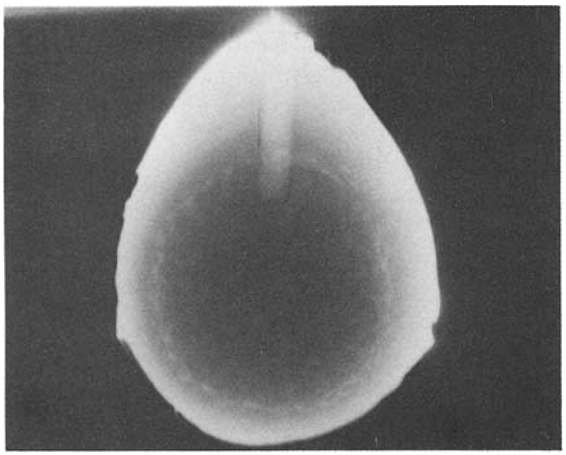

FIG. 1. 'Foraminifera *Stereo-gypsina*'. (Positive print)

were part of the pearl input that morning. They were run-of-the-mill stuff seen on any gem-testing day (except the drop-shape pearl pin). This had a most unusual structure, one that I had never seen before and equally difficult to describe or to reproduce in the *Journal.* The drop shape had one or two line structures following the outer perimeter. Circular in pattern in the centre was a series of regularly irregular dots or small patches, which looked like pewter hammering or the patterns seen on a missel thrush (see Figure 1). The pattern intrigued me. I showed it to Alan Jobbins, of the Institute of Geological Sciences. He thought it could be a variety of foraminifera. His colleagues thought the structure could be a form of foraminifera termed *Gypsina,* sometimes *Stereo-gypsina,* which

has a calcareous skeleton with a complex internal structure. The small intruder is found in warm shallow tropical waters.

To add a little mystery to what should have been a routine pearl testing job, the pearl fluoresced mildly under x-ray excitation. Natural sea-water pearls do not fluoresce; fresh-water pearls do fluoresce, but our pearl did not have sufficient fluorescence to really fit into a fresh-water bracket. It did occur to me that oyster beds could possibly be found in wide estuaries of tidal rivers thus producing some fluorescence from trace manganese? Unusually for us we did a density of our pearl and found it to be 2.684-2.689. We found it gained fractionally and believe in some manner it was slightly absorbent or porous. Unfortunately the pearl had to be returned to the customer (they can be very possessive!). It is intriguing to consider that someone somewhere is wearing a *Stereo-gypsina* stick-pin or maybe it is now a pearl pendant, and they will never know what this 'gem of purest ray serene' has hidden in its unfathomed depths!

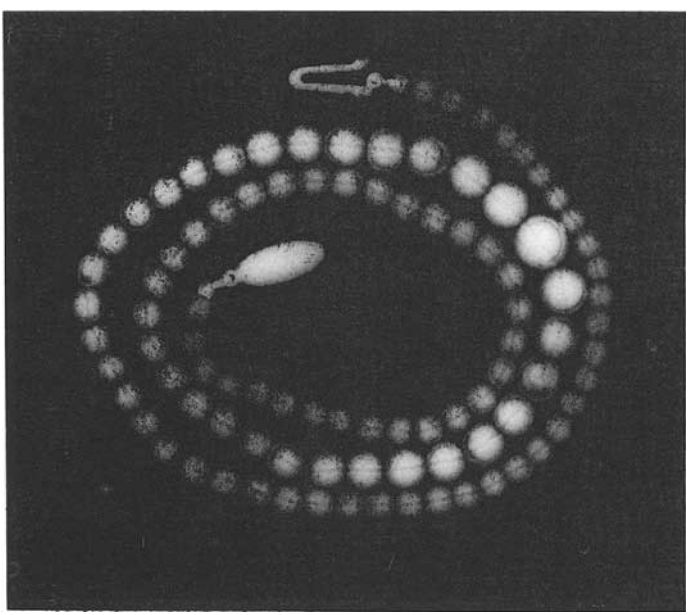

FIG. 2. An easy to spot cultured pearl necklace.

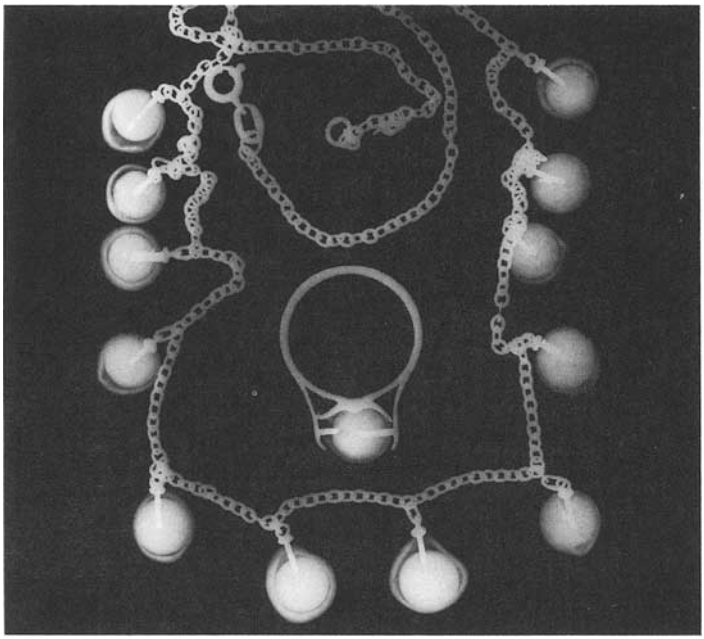

FIG. 3. Cultured (baroque shape) pearls on necklace and ring.

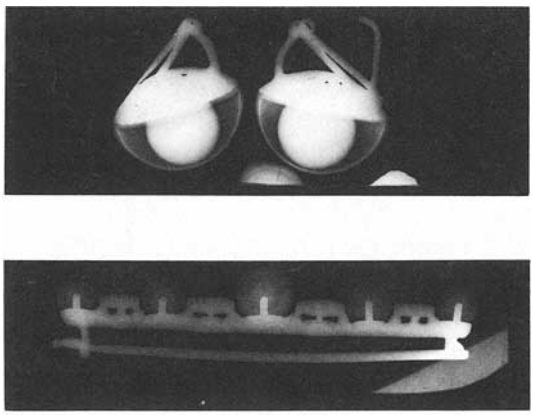

FIG. 4. Above: a pair of cultured blister-pearl ear-rings. Below: five natural pearls and four diamonds (transparent to x-rays) on a bar brooch.

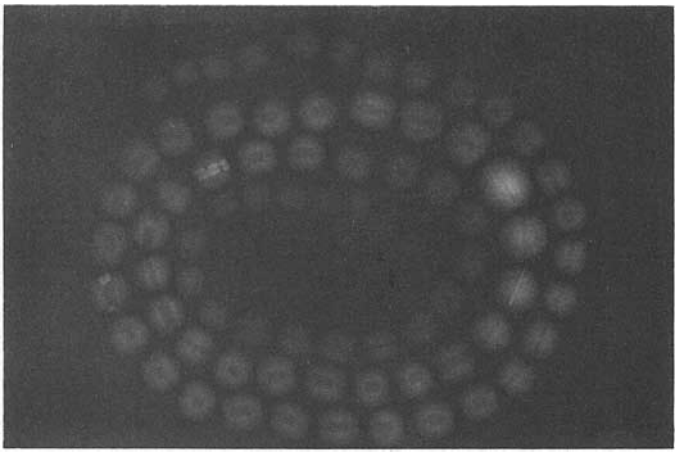

FIG. 5. Worn drill-holes in pearls plugged with m.o.p. and small glass beads.

Inclusions portrayed by x-ray method, i.e. radiographs, can be very interesting. The negatives illustrated (Figures 2-6) with their captions give some examples of the variety in this aspect of gemmology.

If readers feel we have had quite a few pearl articles in the *Journal* recently it *may* be due to bunching in the editorial pipeline.* It is due in part to the resurrected interest in pearls by the trade. It is equally due to the fact that pearls and pearl testing are a major feature in our daily routine and provide our bread and butter.

Continuing along the path of pearl testing brings to mind an allied subject—shell cameos. Most of us know a shell cameo when we see one and equally we all know it is basically our old friend calcium carbonate. Shell cameos are usually white/brown or white/pink as a basis. It was not until I had to answer a customer enquiring for the G.A. that I really looked at and into the structure of a shell cameo. The customer was asking intelligent questions on

*It isn't!—Ed.

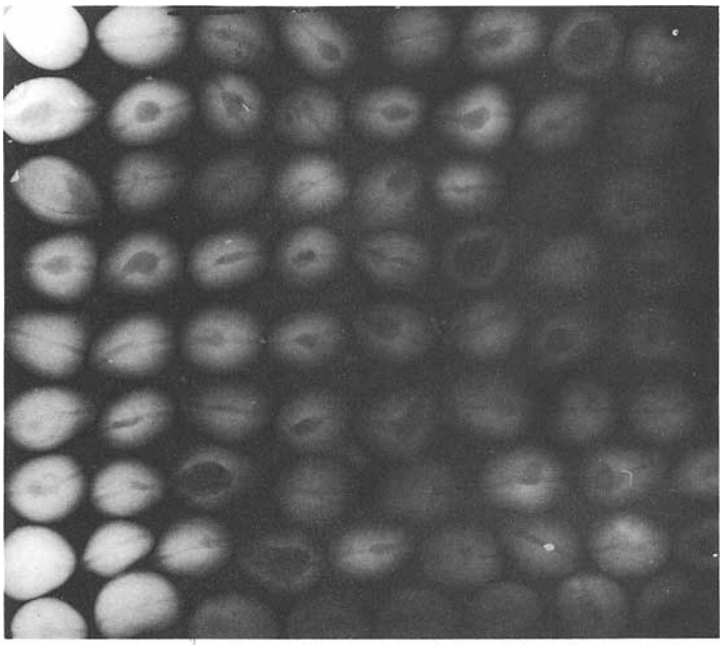

FIG. 6. Non-nucleated cultured pearls (non-phosphorescent—sea-water oyster).

shell cameo *doublets*. I have seen possibly as wide a range of doublets as any gemmologist, from glass on glass (two widely different RI readings) through all the G.T.D.s, soudé 'emeralds', spinel doublets, diamond on synthetic sapphire doublets, sapphire on synthetic ruby doublets, all the versions of opal doublets, beryl on beryl doublets and some I have forgotten, but never shell cameo doublets. The enquirer had noted the different directional structures in some shell cameos, but he couldn't find demarcation lines, bubble layers, etc. Neither could I. Neither had I seriously studied the structure of shell cameos, until this query arrived. When I did so, I was intrigued to find that there were what appeared to be definitely different directional structures in the colour layers carried in some of the cameos I had borrowed. Not that they were doublets, for it would indeed be a skill to superimpose one concave structure upon another!

[*Manuscript received 20th February, 1980.*]

ANDERSON ON HEAVY LIQUIDS

By R. KEITH MITCHELL, F.G.A.

This paper is based on a series of articles, published in the *Retail Jeweller* in 1979 under various titles,* which is important in that it gives a detailed picture of the very precise work that was done with heavy liquids over a very long period of research in the London Chamber of Commerce Laboratory. At the author's suggestion I have attempted to summarize these in order to put the most important of the collected facts on permanent record in this *Journal.*

Mr Anderson, trained as a chemist, with strong mineralogical leanings, was largely responsible for the rationalization of the use of heavy liquids in gemmology. As Director of the Laboratory in 1925 he was primarily concerned with pearl testing, since this was at the height of the cultured pearl 'invasion' which was devastating the trade in oriental pearls.

Using bromoform in various dilutions with monobromonaphthalene to cover the range 2.70 to 2.76, it was found that cultured pearls (SG 2.72-2.78) were almost always perceptibly denser than were oriental pearls (SG 2.68-2.74, av. 2.71) from the Persian Gulf—the main source in those days. This was due to the high density of the Mississippi mussel shell used for the large nucleus in the cultivated pearl. A specially made and very sensitive hydrometer, reading from 2.50 to 3.00, was used to check the densities of the liquids accurately.

Many years later (1946) Robert Webster, having recently joined the Laboratory, carried out a similar series of tests on the normally very obvious imitation pearls which, by an extraordinary coincidence, was later to provide valuable evidence leading to the conviction for murder of the psychopath Neville Heath. Mr Anderson records that a C.I.D. man was susceptible to the fumes from the liquids used and sought fresh air at an open window.

The depression following the Wall Street financial crash in 1929 had repercussions within the laboratory, which had now

*See Abstract on p.259 below.—Ed.

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acquired the services of C. J. Payne, and the exceedingly busy pearl testing, which had kept them fully occupied for several years, slowed considerably. By degrees the work was extended to cover the testing of corundums, since synthetic rubies and sapphires were being used to a disconcerting extent in otherwise fine jewellery.

There was now time for study and research, which resulted in improvements in refractometry (the 1.81 contact liquid, spinel, blende and diamond refractometers), and the recognition that absorption spectra were to provide a powerful third leg to the microscope/refractometer combination of instruments so far relied upon.

The author admits that in those early days they were still essentially 'innocents', assuming without question that all textbook constants were substantially reliable.

The rude awakening came in 1934, when a fine lapis lazuli necklace failed to fit within the 2.38 to 2.45 density range quoted in all standard textbooks then current. Further tests on other lapis—some 500 pieces in all—using pure bromoform, or in various dilutions, showed that 95% fell between 2.75 and 2.90. Never before had Anderson found recorded data so far out, and he researched earlier literature for the reason. After much reading he found that before Breithaupt's *Handbuch der Mineralogie* was published in 1847 the values quoted were generally within the higher range. But Breithaupt had worked on quite pure 'lazurstein' (lazurite) to obtain a figure of 2.406 and thus arrived at a range of 2.38 to 2.42, ignoring the calcite, pyrite and amphibole, all denser minerals, which are also present in the rock we know as lapis lazuli. Other authoritative textbooks copied Breithaupt's figures without query.

This fundamental textbook 'error' started a prolonged investigation of all gem densities which eventually resulted in a general narrowing of the range of values for the comparatively pure gem varieties, from the broader ranges applicable to the less pure specimens of the mineralogical field. The results were published in 1939 and incorporated, with much other work from this author and his colleague, in the greatly revised 1940 edition of Herbert Smith's *Gemstones.*

A third article outlines the history of the search for convenient heavy liquids since Sonstadt's Solution in 1874. Most of the results were impractical, obnoxious, expensive, usually quite poisonous,

and fell into disuse for these reasons.

Methylene iodide, CH_2I_2, provides the exception and is, to this day, the most valuable of the available gemmological liquids, both for its high SG (3.33) and for its RI (1.742). Its pungent smell is acceptable to most and a delight to the dedicated gemmologist!

This liquid was used in a considerable research which culminated in the finding of the first recognized kornerupine from what was then known as Ceylon. Since then many more specimens of this still rare mineral have been found in Ceylon and other localities. Cat's-eye kornerupine was found and marketed in quantity in 1975, again in Sri Lanka (Ceylon).

Clerici's discovery, in 1907,* of the aqueous solution of thallium malonate and formate, which gave a density, at room temperature, of 4.15, had apparently gone unnoticed by the gemmological world. Anderson chanced upon it and, realizing the tremendous value of a liquid as dense as this, introduced it in teaching and eventually in examinations. It still had the disadvantages of the earlier organic acqueous solutions, being expensive, corrosive, highly poisonous and, disastrously, non-miscible with the other, oily, heavy liquids. The latter factor made its use in examinations difficult and it was eventually dropped as a teaching liquid. Its usefulness in laboratory work remained and it was used, among other work, in the eventual investigation of the dense zinc-rich spinel now known as gahnospinel.

It was with this liquid that the straight-line graph relationship between the RI and SG of progressive solutions had been established. This was to be shown to apply equally to mixtures and dilutions of the oily liquids.

In all cases heavy liquid determinations of mineral densities are very accurate, provided that dilutions are carried out to the point of exact suspension. The method is slower than hydrostatic weighing, and can be expensive, but it suffers from none of the inherent inexactitudes which beset the latter, especially when dealing with small specimens. Larger specimens are more difficult only because they require more of the expensive liquids. They are less affected by the snags of hydrostatic weighing and can usually be tested best in this way.

Mr Anderson also recalls the very useful work which was done

*'Preparazione di liquidi per la separazione dei minerali', *Rend. Acad. Lincei, Roma,* **XVI**, 187-95, 1907.—Ed.

on accurate RI determinations at this period, using a Beck table spectrometer and, earlier, an Abbe-Pulfrich refractometer.

The next paper deals with the use of indicators to ensure that the accuracy of the various liquids is maintained. Glass indicators of exact known density were eventually perfected by Rayner. But it was in the course of earlier work on gem mineral densities that it was realized that certain gems with simple chemical compositions were quite remarkably constant in their specific gravities. Quartz, calcite, fluorspar, diamond and corundum were some of the more obvious ones, but their exact densities needed to be obtained primarily by hydrostatic weighing. In the course of this the condition of the balance and indeed the accuracy of the weights themselves were checked with scientific thoroughness.

The question of obtaining a liquid of low surface tension was also a problem and ultimately ethylene dibromide was considered most suitable. Unfortunately this is now suspect as a possible carcinogen.* An improvement in the use of water (high surface-tension) was to boil it, removing dissolved air, and add liquid detergent in small amount. This lowered the surface tension substantially.

For greater accuracy the temperature of the water was taken and the result of the hydrostatic calculation multiplied by the known density of water at that temperature. With other liquids, such as toluene or ethylene dibromide, the fluctuation of density with temperature is far greater and such corrections are always essential.

This paper emphasizes the need to check research against relevant literature and ends with an introduction to the joys of the old Patent Office Library (now part of the British Library and less easy to use since part of the section relating to 'earth sciences' is now in Bayswater).

A further paper records early investigation of densities by a French team which had perfect cubes of quartz made and checked against the cadmium emission line at 6438.4696Å, giving accuracy to one part in half a million. Their result, when reduced to four places of decimals, was 2.6507, a figure varying only slightly in the fourth place from those obtained by Anderson and Payne by far simpler methods. It is noted that amethyst (2.647) is fractionally lower in density than rock-crystal.

*See J.Gemm., 1979, XVI (6), 429.—Ed.

The advent of Chatham's first commercially viable synthetic emeralds caused considerable concern in the gem trade. But it was found that a bromoform liquid diluted to suspend quartz almost exactly matched the synthetic emeralds, while all natural emeralds were denser and sank in this liquid. There was a great advantage in using this method to discriminate between unmounted parcels of synthetic and natural stones since it worked equally well with stones down to the smallest size. The same accuracy could never be obtained by hydrostatic weighing.

A mention is made of a series of experiments by R. W. Yeo, published in the first issue of the *Gemmologist* in 1931, a paper which the present writer remembers well. Yeo used various dilutions and also a diffusion column to establish differences in SG of beryls and tourmalines of various colours. Anderson points out that in the case of beryl the fluctuations in density are due to the presence of alkali metals which have little effect on the colour.

Calcite (2.71), another of the very constant indicator minerals, is only slightly higher than quartz (2.651), but the two together provide a most delicate pair of indicators to regulate bromoform diluted to identify synthetic emeralds.

Next in the ascending scale of constant density minerals is fluorite (3.182) with its anomalously low RI (1.434), due to the influence of fluorine.

Finally, with a note that jadeite (3.33) almost exactly matches methylene iodide (3.34) in density, we come to diamond (3.515), which, with Clerici solution diluted to an exact match, provides a useful top liquid. Another at 3.99 with synthetic corundum could also be useful. But both these latter require the use of the rather messy and unpleasant Clerici solution.

The last of these absorbingly interesting papers summarizes the uses of heavy liquids in testing, underlining again their extreme accuracy when used with proper care. The reader is advised on methods of use, some of which help to eliminate the long and tedious business of retrieving stones individually from a liquid.

As a parting shot the author describes the delight he found in testing pressed amber in the cheapest, cleanest and most simple of all 'heavy' liquids—a solution of salt in water. Such treated amber (1.06) is fractionally less dense than natural amber of similar clarity, and this fact can be proved beyond doubt by this method while hydrostatic weighing could hardly be sufficiently accurate even with large specimens.

While hoping that I have adequately given the gist of this series of papers, I acknowledge that I may have been unable to convey the quite fascinating dedication of Mr Anderson's own version. His total knowledge of his subject is enhanced by the ability to write brilliantly and with great clarity of his personal experiences over so many years.

[*Manuscript received 28th March, revised June, 1980.*]

ADDITIONAL AND CORROBORATIVE DATA ON VIOLET GEM SCAPOLITE PROBABLY FROM EASTERN AFRICA

By BRIAN JACKSON, F.G.A.

Department of Geology, The Royal Scottish Museum, Edinburgh

INTRODUCTION

The composition of gem scapolite has been the subject of papers in this and other journals but of particular interest has been the discovery of violet gem scapolite (from Kenya?) with unusually low refractive indices and density. These low values are indicative of a high sodium content, the scapolite therefore tending towards the sodium end member marialite. Pure marialite is only known in synthesized material but this new violet scapolite represents the highest sodium content so far recorded in natural scapolite giving a marialite component of 89.2% (Zwaan 1979).

PROPERTIES

Four small cut stones of approximately 0.5 ct each were purchased from the Gemmological Association of Great Britain.

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One of these was broken, and part was used for electron probe microanalysis, the remainder being used for conventional bulk analysis of Na_2O and SiO_2, by rock methods, scaled down to suit the sample size. Table 1 shows the average of five probe analyses with corroborative Atomic Absorption Spectroscopy and absorptiometric analysis for Na_2O and SiO_2 respectively.

TABLE 1

	ox%	*el%*	*Number of ions on the basis of 24(0)*
SiO_2	61.6	28.8	8.213
Al_2O_3	19.64	20.4	3.086
FeO	0.1	0.08	0.111
CaO	1.56	1.1	0.223
SrO	0.56	0.48	0.043
MgO	0.00	0.00	0.00
Na_2O	12.9	9.57	3.334
K_2O	0.79	0.66	0.028
Cl	4.36	4.36	0.985
SO_3	0.00	0.00	0.00
	101.51		
O = Cl	0.98		
Total	100.53		

The marialite content of this sample on the basis of

$$\frac{Na}{Na + Ca}$$

as calculated by Zwaan is 93.7%. In this sample, because of the significant minor element substitution for these major constituents the above calculation can be more accurately represented as

$$\frac{(Na + K)}{(Na + K) + (Ca + Fe + Sr)}$$

which gives a marialite content of 89.9%.

The refractive indices were measured on a Rayner Dialdex refractometer and the results obtained (Table 2) corroborated the analytical results when plotted on the approximately linear graph relating chemical composition and mean RI and birefringence

(Deer *et al.* 1963) giving results of 95.3% Ma and 85.5% Ma respectively (uncertainty value ±6.5%).

TABLE 2

Specimen number	ε	ω	*DR*
RSM GY 1979.7.1	1.536	1.541	0.005
RSM GY 1979.7.2	1.536	1.540	0.004
—	1.530	1.540	0.01

The stones all exhibited strong dichroism, varying from a violet colour parallel to the *c* axis to almost colourless perpendicular to the *c* axis. The majority of stones are therefore cut with the table facet more or less at right angles to the *c* axis. This orientation can easily be checked if the stone contains long fine straight tube-like inclusions, as these align themselves parallel to the *c* axis. All stones examined showed these inclusions which sometimes broadened out into what looked more like incipient cleavages (Figure 1).

Establishing the direction of the *c* axis, which for tetragonal minerals is the same as the optic axis, meant that a uniaxial optic

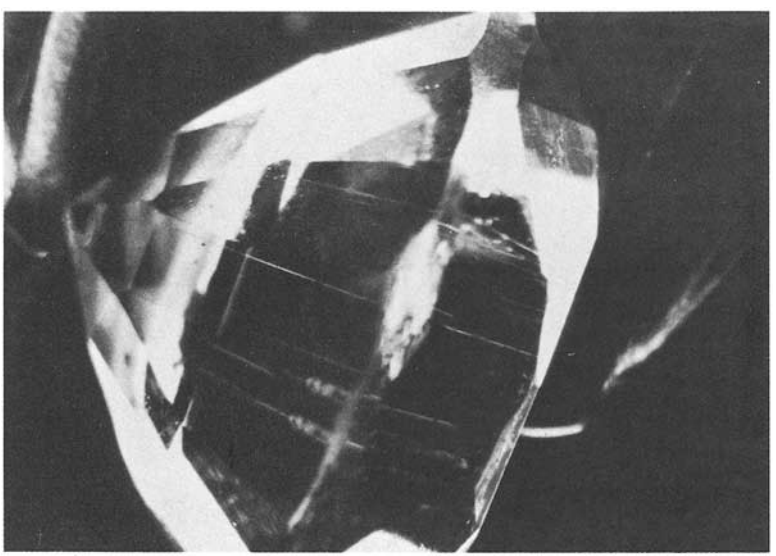

FIG. 1. Inclusions at right angles to the table facet.

axis figure could be obtained using crossed polars and a conoscopic lens. This was very useful in determining the optic sign (−ve) using a quartz wedge or accessory plate. In this orientation stones when rotated through 360° between crossed polars remain dark as the optic axis is a direction of single refraction.

The specific gravity was determined using three stones as a bulk sample. This was to reduce the % error incurred when determining the SG of small stones using the hydrostatic method. Toluene was the liquid used so as to reduce the % error further. The resultant SG of 2.65 also conformed to the trend of reducing SG with increasing sodium content, although this is a less reliable guide to composition because of the complex ionic substitution.

CONCLUSION

Although these stones could be confused with amethyst on the basis of their closely aligned colour and properties, the fact that the orientation of the *c* (optic) axis in the stone can be easily determined makes it a simple matter to determine the optic sign and thus distinguish scapolite (−ve) from amethyst (+ve). However it should be borne in mind, that extrapolation of the relationship of composition against ε and ω (Winchell 1924) indicates that at approximately 90% Ma the scapolite would be isotropic and that pure marialite would be optically positive. The trend is certainly in that direction but this optical sign inversion would not compound the similarity with amethyst for the refractive indices of approximately ε 1.533 and ω 1.528 for pure marialite are much lower than those of quartz.

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[*Manuscript received 14th December, 1979.*]

COMPUTER-AIDED GEM IDENTIFICATION

By PETER READ, C.Eng., M.I.E.E., M.I.E.R.E., F.G.A.

At the end of a talk I gave to the Gemmological Association in 1978 (on the subject of new gemmological instruments and techniques,[1] I referred to the possibility of using a low-cost home computer as a diagnostic aid for gem testing. Although the general use of such an

FIG. 1. The author's installation. On the left of the computer is a small domestic tape recorder which is used to feed in the GEM DATA programs.

aid may not yet be justified, my own experience in computer programming tempted me to prove the viability of the idea. This article describes and evaluates two 'Gem Data' computer programs which I developed to explore the usefulness of the technique.

Computers have already been employed in gemmological research work for handling and assessing test data from

[1]Read, P. G. New Gemmological Instruments and Techniques, *J. Gemm.*, 1979, **XVI** (6), 386-407.

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```
##################
## GEM DATA 1  ##
##################

The GEM DATA 1 program contains
    three separate sections.

      1.  Gem Profiles
      2.  Gem Constants
      3.  Gem Comparisons

Type 1, 2 or 3 for appropriate section.
      (Then press RETURN key)

? -
```

FIG. 2. Title 'page' of the GEM DATA 1 program which contains gem profiles and tables of constants.

```
Section 1. - GEM PROFILES

The following gem profiles are in store -

 1 Almandine     21 GGG          41 Pearl        61 Strontium Ti
 2 Amazonite     22 Grossular    42 Peridot      62 Sunstone
 3 Amber         23 Haematite    43 Phenakite    63 Taaffeite
 4 Andalusite    24 Iolite       44 Pyrite       64 Titanite
 5 Andradite     25 Ivory        45 Pyrope       65 Topaz w,bl.
 6 Apatite       26 Idocrase     46 Quartz       66 Topaz br,y.
 7 Basalt glass  27 Jadeite      47 Rhodonite    67 Tourmaline
 8 Benitoite     28 Jet          48 Rhodochrosite 68 Turquoise
 9 Beryl         29 Kornerupine  49 Rutile       69 Uvarovite
10 Bowenite      30 Labradorite  50 Scapolite bl 70 YAG
11 Chalcedony    31 Lapis lazuli 51 .. pink,y.   71 Zircon, high
12 Chrysoberyl   32 Libyan glass 52 Scheelite    72 Zircon, low
13 Coral         33 Lithium Nio. 53 Sinhalite    73 Zirconia
14 Corundum      34 Malachite    54 Sodalite     74 Zoisite
15 Danburite     35 Moldavite    55 Smithsonite   MISCELLANEOUS
16 Diamond       36 Nephrite     56 Spessartite  75 Gahnospinel
17 Enstatite     37 Obsidian     57 Spinel nat.  76 Emerald, syn
18 Feldspar gp.  38 Oligoclase   58 Spinel syn.  77
19 Fluorspar     39 Opal         59 Spodumene    78
20 Garnet gp.    40 Orthoclase   60 Steatite     79

Type profile No. (or type 99 for list, or 100 to change program)
? -
```

FIG. 3. The index listing the gem profiles held in memory.

instruments such as the electron microprobe.[2,3] However, it was not until the development of the microprocessor that relatively inexpensive and compact computers became available for more general use. This has made the bulk storage of gemstone data economically possible and has provided a practical means of retrieving these data in the most convenient formats for gem identification purposes.

The two programs I have written are intended for use in a small desk top computer,[4] the data input and output being displayed on a video monitor consisting, for reasons of economy, of a modified black-and-white television receiver (Figure 1). The first program is basically a data bank of gem constants and characteristics, while the second one is an interactive version which prints out identifications from keyed-in test figures.

The data bank program, which I call GEM DATA 1, contains three separate sections (Figure 2). The first of these consists of 'Gem Profiles' and contains a numbered index of over seventy gem species or materials (this number being limited only by the size of the existing built-in computer memory). In a manner similar to that used in the 'Viewdata' service, the index can be used to select and display pages of information on individual gemstones by simply keying in the appropriate reference number (Figure 3).

The page of information displayed for each gem species or material commences with a single-line specification giving the refractive index, double refraction, dispersion, specific gravity and hardness. The display then lists the chemical formula, crystal system, optical character and optic sign for the selected gem. This is followed by information on the gem's lustre and cleavage, and by details of its various colour varieties. Finally, where relevant, the gem's pleochroism is listed (Figures 4, 5, 6). Information on absorption spectra, luminescence, habit, occurrence and sources has been omitted so that the program can be contained within the capacity of the existing computer memory. However, these can easily be added as the system is expanded.

The second section of the GEM DATA 1 program contains eight pages of gem constants arranged in tabular form (RI, DR, Disp.,

[2]Dunn, P. J. The use of the Electron Microprobe in Gemmology, *J. Gemm.*, 1977, **XV** (5), 248-58.

[3]Rucklidge, J. and Gasparrini, E. L. Specifications of a Computer Program for Processing Electron Microprobe Analytical Data, 1969, EMPADR VII, Dept. Geology, Toronto University, 1-37.

[4]Exidy 'Sorcerer', with 32k of RAM and 8k of ROM plug-in language (Standard Basic).

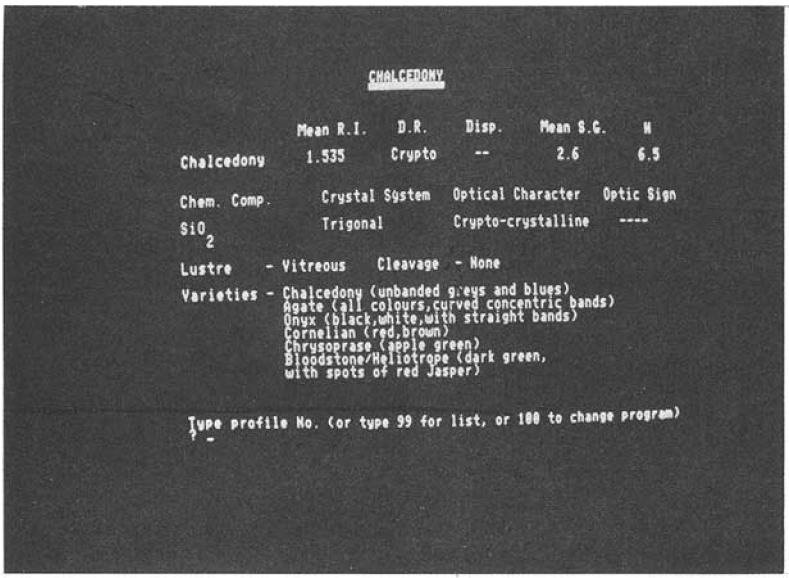

FIG. 4. The gem profile for chalcedony.

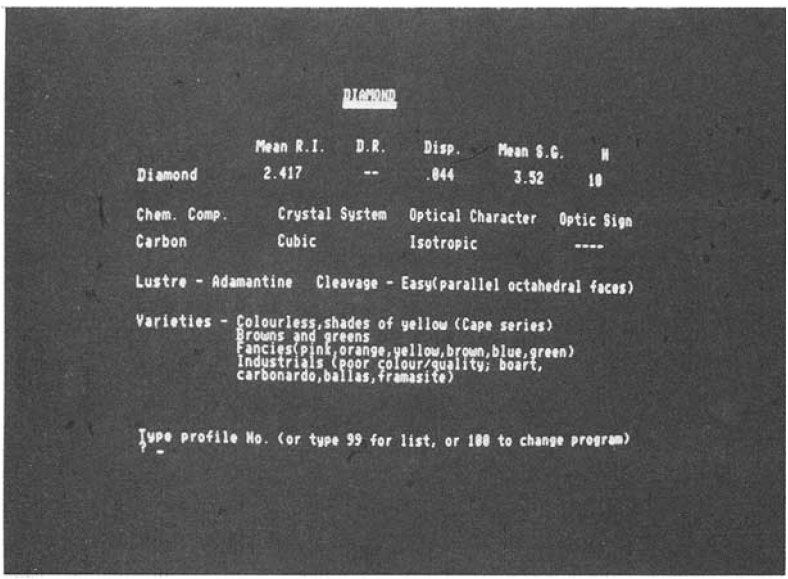

FIG. 5. The gem profile for diamond.

SG, H.). The first four pages list the gems in alphabetical order (Figure 7), while the remaining four pages list them in ascending order of refractive index (Figure 8). The third and final section of the program enables single-line gem specifications to be selected from the gem index and displayed adjacent to each other for comparison purposes (Figure 9).

The second computer program, called GEM DATA 2, is a diagnostic one, and helps to identify a gemstone under test by matching its measured constants (fed in via the keyboard) with data contained in lists of gem constants held in the computer memory (Figure 10). When this program is in use, the computer requests, in sequence, the values of the gem's mean *refractive index, double refraction* and *specific gravity* (Figure 11).

Where it is not possible, for instance, to obtain a reading for refractive index, a '9' is keyed in (Figure 12), and this instructs the program to bypass its lists of RI constants. If it is only possible to detect that the gem is singly-refractive, doubly-refractive or cryptocrystalline (by means of a polariscope), then a '0', a '1' or a '9' is keyed in respectively when the computer requests the value of double refraction. Similarly, if no value is available for specific gravity (e.g. when the gem is mounted) then a '9' is keyed in when the computer requests this value.

Finally, to allow for variations in test measurements, and to accommodate the normal spread of values caused by impurities in the gem, a choice of two 'search tolerance' limits is available. Selection of the appropriate limit is made in response to the computer's request *'Choose Search Limit (type 1 for narrow, 2 for wide)'*. The *narrow* search (input 1) matches the keyed-in data against the stored data over the tolerance limits of ±0.005 for RI, ±0.002 for DR, and ±0.01 for SG. The *wide* search limit broadens these limits to ±0.01, ±0.004 and ±0.03 respectively. Some gem materials such as glass, 'intermediate' zircon and 'low' or metamict zircon have much wider ranges of RI and SG values than are catered for in the search limits, and these are allowed for by means of individual data 'filters' in the program.

If, during a narrow search, the computer is unable to find a match between the keyed-in data and the data in its memory, it will print out the following message:

'For narrow search limits, no match has been found with any gem held in memory. Try wide search limits'.

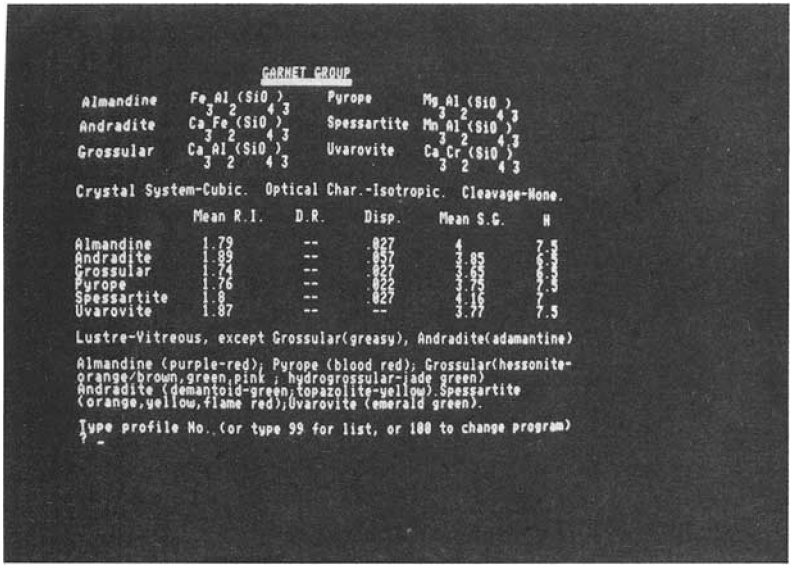

GARNET GROUP

Almandine	$Fe_3Al_2(SiO_4)_3$	Pyrope	$Mg_3Al_2(SiO_4)_3$
Andradite	$Ca_3Fe_2(SiO_4)_3$	Spessartite	$Mn_3Al_2(SiO_4)_3$
Grossular	$Ca_3Al_2(SiO_4)_3$	Uvarovite	$Ca_3Cr_2(SiO_4)_3$

Crystal System-Cubic. Optical Char.-Isotropic. Cleavage-None.

	Mean R.I.	D.R.	Disp.	Mean S.G.	H
Almandine	1.79	--	.027	4	7.5
Andradite	1.89	--	.057	3.85	6.5
Grossular	1.74	--	.027	3.65	6.5
Pyrope	1.76	--	.022	3.75	7.5
Spessartite	1.8	--	.027	4.16	7
Uvarovite	1.87	--	--	3.77	7.5

Lustre-Vitreous, except Grossular(greasy), Andradite(adamantine)

Almandine (purple-red); Pyrope (blood red); Grossular(hessonite-orange/brown,green,pink ; hydrogrossular-jade green) Andradite (demantoid-green;topazolite-yellow).Spessartite (orange,yellow,flame red);Uvarovite (emerald green).

Type profile No. (or type 99 for list, or 100 to change program)
? _

FIG. 6. The gem profile for the garnet group.

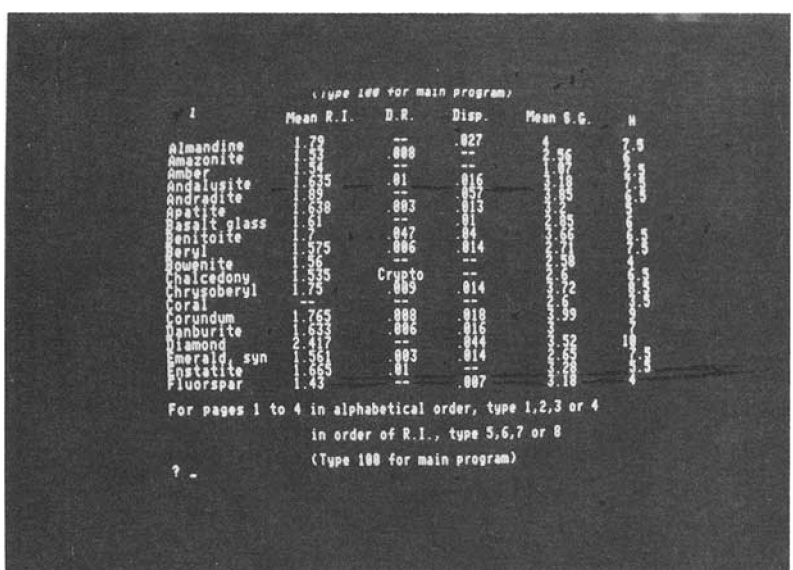

(Type 100 for main program)

I	Mean R.I.	D.R.	Disp.	Mean S.G.	H
Almandine	1.79	--	.027	4	7.5
Amazonite	1.53	.008	--	2.56	6
Amber	1.54	--	--	1.07	2.5
Andalusite	1.635	.01	.016	3.18	7.5
Andradite	1.89	--	.057	3.85	6.5
Apatite	1.638	.003	.013	3.2	5
Basalt glass	1.61	--	.01	2.95	6
Benitoite	1.7	.047	.04	3.66	6.5
Beryl	1.575	.006	.014	2.71	7.5
Bowenite	1.56	--	--	2.58	4
Chalcedony	1.535	Crypto	--	2.6	6.5
Chrysoberyl	1.75	.009	.014	3.72	8.5
Coral	--	--	--	2.6	3.5
Corundum	1.765	.008	.018	3.99	9
Danburite	1.633	.006	.016	3	7
Diamond	2.417	--	.044	3.52	10
Emerald, syn	1.561	.003	.014	2.65	7.5
Enstatite	1.665	.01	--	3.28	5.5
Fluorspar	1.43	--	.007	3.18	4

For pages 1 to 4 in alphabetical order, type 1,2,3 or 4
in order of R.I., type 5,6,7 or 8
(Type 100 for main program)
? _

FIG. 7. The first of four pages of tabular information in alphabetical order of the gemstones.

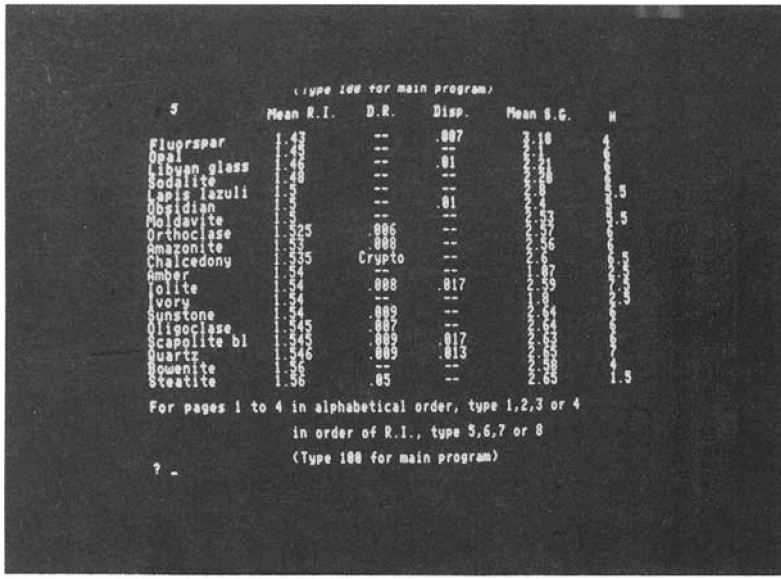

(Type 100 for main program)

5	Mean R.I.	D.R.	Disp.	Mean S.G.	H
Fluorspar	1.43	--	.007	3.18	4
Opal	1.45	--	--	2.1	6
Libyan glass	1.45	--	.01	2.51	6
Sodalite	1.48	--	--	2.28	6
Lapis lazuli	[illegible]	--	--	2.8	5.5
Obsidian	[illegible]	--	.01	2.4	5
Moldavite	[illegible]	--	--	2.53	5.5
Orthoclase	1.525	.006	--	2.57	6
Amazonite	1.53	.008	--	2.56	6
Chalcedony	1.535	Crypto	--	2.6	6.5
Amber	1.54	--	--	1.07	2.5
Iolite	1.54	.008	.017	2.59	7.5
Ivory	1.54	--	--	1.8	2.5
Sunstone	1.54	.009	--	2.64	6
Oligoclase	1.545	.007	--	2.64	6
Scapolite bl	1.545	.009	.017	2.63	6
Quartz	1.546	.009	.013	2.65	7
Bowenite	1.56	--	--	2.58	4
Steatite	1.56	.05	--	2.65	1.5

For pages 1 to 4 in alphabetical order, type 1,2,3 or 4

in order of R.I., type 5,6,7 or 8

(Type 100 for main program)

? -

FIG. 8. The first of four pages of tabular information in ascending order of gemstone RIs.

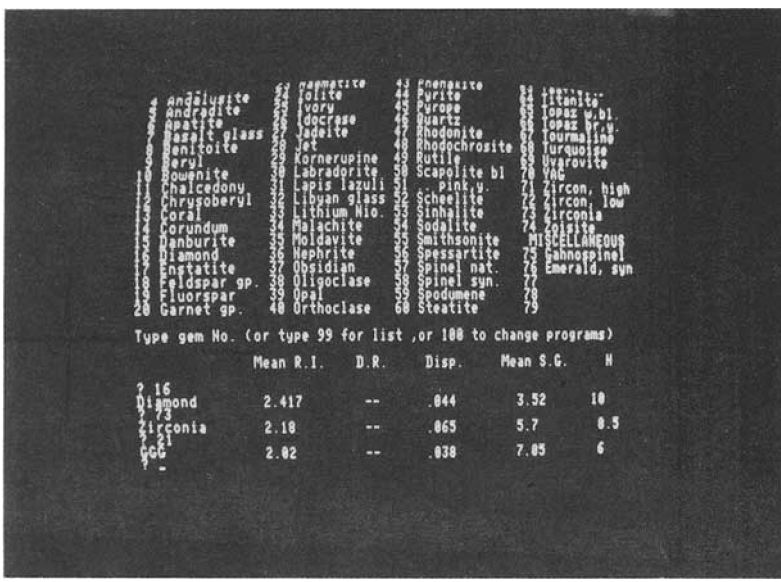

4	Andalusite	43	Hematite	43	Phenakite	43	[illegible]
5	Andradite	44	Iolite	44	Pyrite	44	Titanite
6	Apatite	45	Ivory	45	Pyrope	45	Topaz w.bl.
7	Basalt glass	46	Idocrase	46	Quartz	46	Topaz pr.y.
8	Benitoite	47	Jadeite	47	Rhodonite	47	Tourmaline
9	Beryl	48	Jet	48	Rhodochrosite	48	Turquoise
10	Bowenite	49	Kornerupine	49	Rutile	49	Uvarovite
11	Chalcedony	50	Labradorite	50	Scapolite bl	70	YAG
12	Chrysoberyl	51	Lapis lazuli	51	.. pink,y.	71	Zircon, high
13	Coral	52	Libyan glass	52	Scheelite	72	Zircon, low
14	Corundum	53	Lithium Nio.	53	Sinhalite	73	Zirconia
15	Danburite	54	Malachite	54	Sodalite	74	Zoisite
16	Diamond	55	Moldavite	55	Smithsonite		MISCELLANEOUS
17	Enstatite	56	Nephrite	56	Spessartite	75	Gahnospinel
18	Feldspar gp.	57	Obsidian	57	Spinel nat.	76	Emerald, syn
19	Fluorspar	58	Oligoclase	58	Spinel syn.	77	
20	Garnet gp.	59	Opal	59	Spodumene	78	
		60	Orthoclase	60	Steatite	79	

Type gem No. (or type 99 for list ,or 100 to change programs)

	Mean R.I.	D.R.	Disp.	Mean S.G.	H
? 16					
Diamond	2.417	--	.044	3.52	10
? 73					
Zirconia	2.18	--	.065	5.7	8.5
? 21					
CZ	2.02	--	.038	7.85	6
? -					

FIG. 9. Individual sets of gem constants can be selected and displayed for comparison purposes.

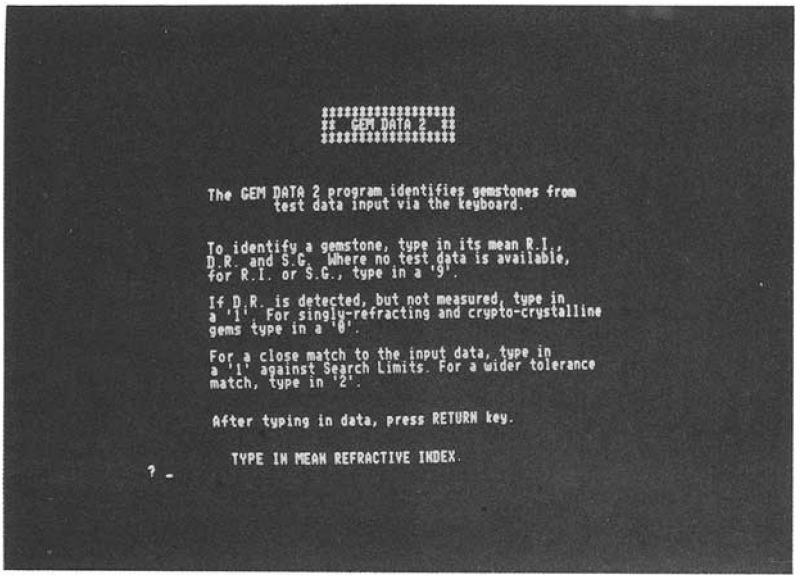

FIG. 10. Title 'page' of the GEM DATA 2 program which identifies gems from keyed-in test data. When the value for DR is requested, a recent modification to the program provides for an input of '9' to indicate that the gem under test is crypto-crystalline.

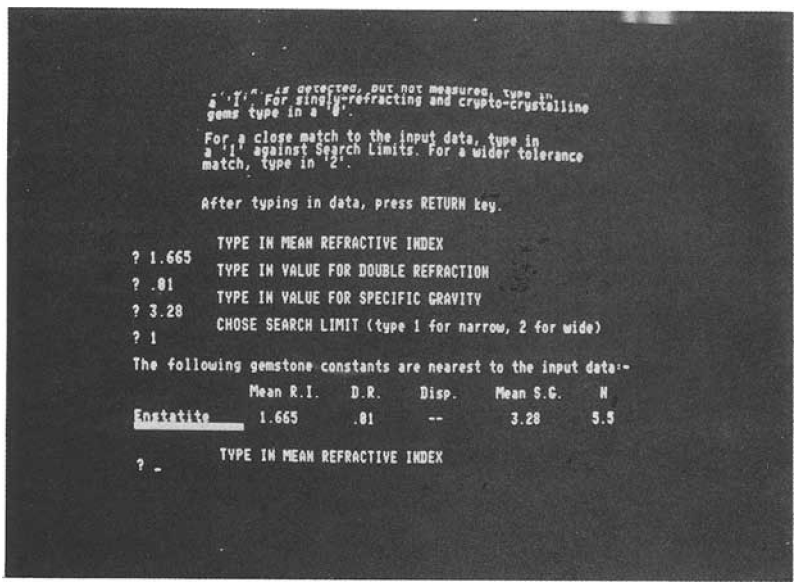

FIG. 11. Data is keyed-in against the computer requests for RI, DR and SG. A narrow search limit has been chosen, and the computer identifies the gemstone as enstatite.

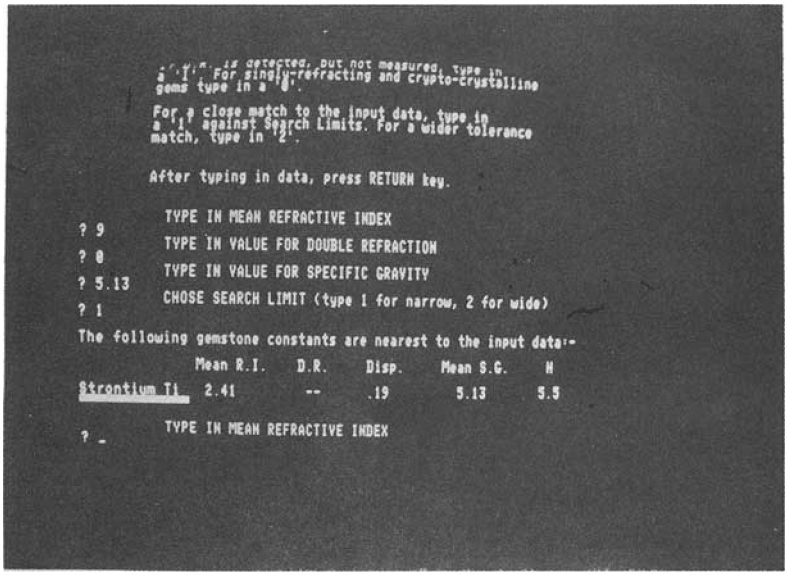

FIG. 12. Here, the RI is not known and strontium titanate is identified from the value keyed-in for SG and the '0' value for DR.

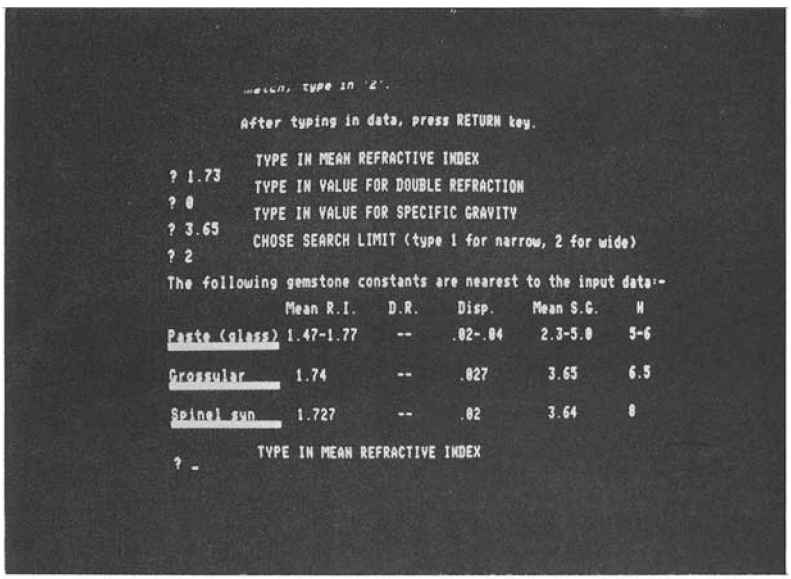

FIG. 13. In providing possible identifications for a gem, the computer program in its present form takes no account of colour or transparency.

If the wide search limits fail to identify the gem, this produces the message:

'For wide search limits, no match has been found with any gem held in memory. Check test results'.

If, in the absence of any measured value for RI, a value for DR is fed in (other than a '0', '1' or '9') the computer responds with the message *'Invalid Data'*, as this is not a logical test situation. As the program takes no account of colour or transparency, the printout occasionally includes unlikely identifications (Figure 13).

Both the GEM DATA 1 and GEM DATA 2 programs are written in 'Standard Basic' computer language and are recorded using Manchester code at 1200 band on a tape cassette. The data bank program occupies the full 32k of computer memory, and the diagnostic program occupies 16k of memory.[5]

After using both programs for several months, I have found that the data bank version provides a very convenient and efficient method of both retrieving and comparing data on gemstones, without relying on one's own memory (or looking up information in textbooks). The diagnostic program also has its uses in reminding one of possible alternatives when attempting a difficult identification with insufficient test data. One can, for instance, ask the computer to display all doubly-refracting gems having a specific gravity close to, say, 3.18 (andalusite, apatite, spodumene). Alternatively, a printout can be obtained of all singly-refracting stones with a refractive index in the region of, say, 1.8 ('low' zircon, almandine, spessartite). By taking the computer through the RI range for isotropic materials (DR input = 0) one can also see the paste 'window' for transparent gems in the region of 1.5-1.7.

If the figures 9, 1, 9, 1 are keyed in (in response to the computer's request for RI, DR, SG and Search Limit) the computer can be made to display sequentially all the doubly-refracting gems held in memory. If 9, 0, 9, 1 is typed in, this will produce a display of all singly-refracting gems in the memory. Similarly, 9, 9, 9, 1 will produce a display of all crypto-crystalline gems. These three inputs form a useful check facility when verifying or amending the memory contents.

Although both programs are viable in principle, in their present limited form they are probably more suited as teaching aids

[5]The size of a computer memory (or a program length) is given in terms of its 'word' capacity. An 8k memory, for example, can hold up to 8000 'words' of program information or instruction. Each computer 'word' is composed typically of 8 'bits' of binary information. The 'baud' is the rate at which data are transferred or transmitted, e.g. 1200 baud = 1200 bits per second.

for students (all of the gems in the Preliminary and Diploma syllabuses are contained in the programs). While current technology has made it possible to reduce the size of the gem data computer installation to that of a hand-held calculator, an alternative use for the full-size version could be as a counter attraction for customers in a jeweller's shop!

The efficiency of all data retrieval systems depends on the accuracy and completeness of the stored data, as well as on the organization of its retrieval techniques (i.e. the programming). When used in an interactive mode for diagnostic purposes the system also depends on the accuracy of the keyed-in test data.

From the results of this work I believe that with a larger memory (perhaps of 64k), and with faster data storage and loading peripherals, both programs can be expanded to a point where they would make a useful contribution to gem identification. If it is to remain effective, however, an essential part of such an information system would be its continual up-dating as new gem materials are discovered or created, and as old data are modified or corrected.

The increasing world-market for gem test instruments is making it economically worth while to develop and market such sophisticated instruments as the pulsed IR reflectivity meter, and the thermal-probe diamond tester (devices which are already making use of integrated circuits, the predecessors of the microcomputer). In other fields, machines and test equipments have been given a degree of intelligence by the exploitation of microcomputer technology. Perhaps the availability of low-cost bulk data storage devices may one day similarly transform our own gem test instruments.

Although the hand lens and the computer may appear to be at opposite ends of the gem testing spectrum, both artefacts have their place in gemmology. The first device has proved its worth over the years, while the second one is just on the threshold of its application.

[*Manuscript received 28th February, 1980.*]

A PHOSPHOROSCOPE

By R. M. YU, Ph.D., F.G.A., and D. HEALEY, Ph.D., F.G.A.
Physics Department, University of Hong Kong

1. INTRODUCTION

The phenomenon of luminescence in gems has been widely used as a quick way of sorting gems. The usual method involves the excitation of gems by long wave (365 nm) or short wave (253.7 nm) ultraviolet light and observing the characteristic luminescent emissions in the visible region. Experience has accumulated a large store of information for distinguishing natural gems from their synthetics by their luminescent properties (Webster 1975, Anderson 1971, Liddicoat 1966). For this purpose ultraviolet lamps are readily available from various commercial suppliers. For example Gemmological Instruments Ltd (U.K.) markets a 'Multispec U.V. Light Source', while the Gem Instruments Corpn (U.S.A.) markets a 'Combination Short & Long Wave Mineral-Light'.

Another use of ultraviolet light in gem identification is to compare the absorptances of the natural and the synthetic stones. Chatham emeralds absorb light of wavelength shorter than 230 nm while natural emeralds start at 300 nm (Anderson 1971). Type II diamonds are distinguished from Type I by the fact that the former start to absorb ultraviolet light at wavelengths shorter than 230 nm while the latter absorbs below 300 nm (Copeland *et al.* 1960).

Mr N. Day* has suggested a method of comparing the ultraviolet absorptances of gemstones (Anderson 1971, p. 86). The stones are placed on a sheet of photographic paper in a dark-room and exposed to ultraviolet light for a short time. The developed photographic paper will show quite clearly the relative absorptances of the gemstones. We have devised a simple phosphoroscope which allows us to observe the ultraviolet absorptance instantly without resorting to a dark-room or tedious photographic process. It also allows us to observe the luminescent emissions of the stones at the same time. The underlying principle of our instrument is similar to the experimental apparatus described by Mr Ian Campbell (Campbell 1978); we have improved

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the design and shown also how the appearance of the gem under transmitted light may be understood in terms of the simple model of a spherical cabochon. The appearance depends essentially on the curvature of the gem and its refractive index.

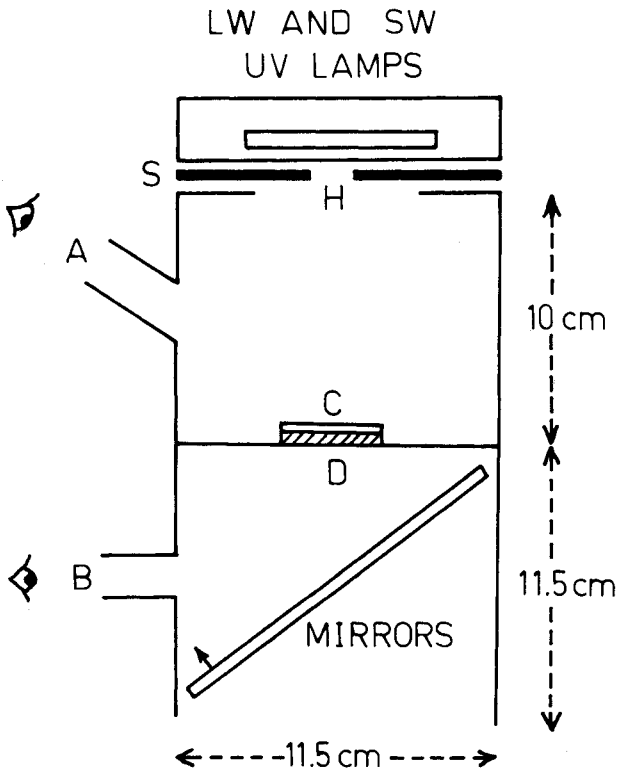

FIG. 1 Cross-sectional diagram of the phosphoroscope.

2. Construction of the Phosphoroscope

The phosphoroscope consists of a wooden box, the cross-section of which is shown in Figure 1. The inside of the box is painted matt black. The side with a viewing port A is a hinged door, which may be opened to allow gems to be placed on a thin sheet of phosphorescent paper C supported on a glass slide D. Any

ultraviolet light transmitted through the gem will reach the phosphorescent paper C. The resulting visible phosphorescent emission is transmitted by the glass slide D, reflected by the mirror and observed through the viewing port B. The ultraviolet absorptance of the gems can thus be observed visually by the naked eye or recorded on photographic film by using a camera. To observe the characteristic luminescent emission of gems, the phosphorescent paper C is covered up with a piece of black cloth and the gems placed on top of the cloth. Visible luminescent emissions from the gems are then observed through the viewing port A.*

To improve the resolution of the picture a screen S with a 1 cm diameter hole H is inserted to reduce the size of the ultraviolet light source.

3. Observations

Our main objective is to compare the short wave ultraviolet (SWUV) absorptances of natural gems and their synthetics. Figure 2a shows a picture that would be observed through the viewport B of the phosphoroscope when an aquamarine cabochon, an oval mixed-cut synthetic ruby and an emerald-cut synthetic corundum (imitating alexandrite) were placed with their flat faces resting on the phosphorescent paper C (see Figure 1). Normally no photography is required, but as illustrations for the present article we have recorded the picture on Kodak Tri-X Pan film with a camera. The SWUV light source was stoppered by the screen S (see Figure 1). The exposure time can be reduced from 60 seconds to 8 seconds if the screen S is dispensed with. Then the resolution of the picture deteriorates somewhat (Figure 2b). Since the resolution of the picture does not affect our study of SWUV absorptance of gems, the succeeding photographs were taken without the screen S.

*It may be noted that—

(i) The areas underneath the gems are stimulated only by UV transmitted by the gems. The areas of the phosphorescent paper C not covered by gems are stimulated by direct UV; this is desirable since it forms a bright background with which the UV transparency of the gems can be compared.

(ii) In the case of luminescent gems, the visible light emitted by the gem also shines on the phosphorescent paper C. We found the effect negligible even in the case of a strongly synthetic ruby.

(iii) As a result of bleaching during the manufacturing process, most white papers are phosphorescent to some degree. By trials we found a paper which was highly phosphorescent; this has worked well for over a year, and we expect it will continue to work for many years. A weakly phosphorescent paper can be made more phosphorescent by smearing with 'invisible pen' made by Besco of Hempstead, N.Y. and marketed by Edmund Scientific at 8985 Edscorp Bldg, Barrington, N.J. 08007, U.S.A. The latter also markets a 'black light spray' which should work well with paper, but we have not tested this product.

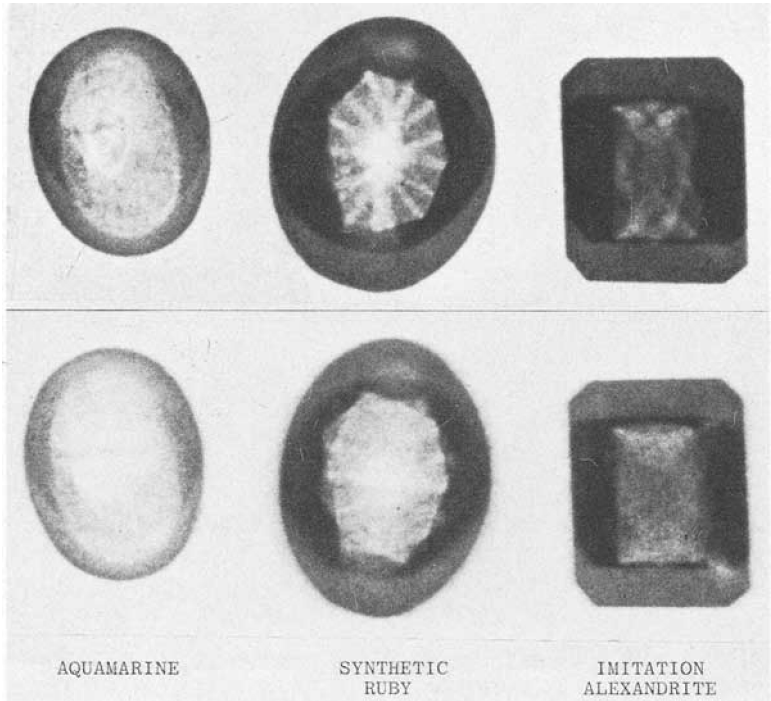

FIG. 2 SWUV absorptance photographs of aquamarine, synthetic ruby and imitation alexandrite: 2a (above) with stopper aperture: 2b (below) without stopper aperture.

In both Figures 2a and 2b a dark rim appears around the edge of the aquamarine cabochon. This dark rim is not due to the higher absorption at the edge of the gem, since aquamarine is transparent to SWUV. Rather it is due to the refractive property of the cabochon. To account for this effect quantitatively we consider a spherical cabochon ABCG of radius of curvature R and centre O as shown in Figure 3.

The cabochon is illuminated with a beam of light perpendicular to its back surface ABC. At a point G on the spherical surface of the cabochon the angle of incidence i is equal to the angle θ betwen the radius vector OG and the vertical direction OB. The incident ray FG is refracted towards the centre of the

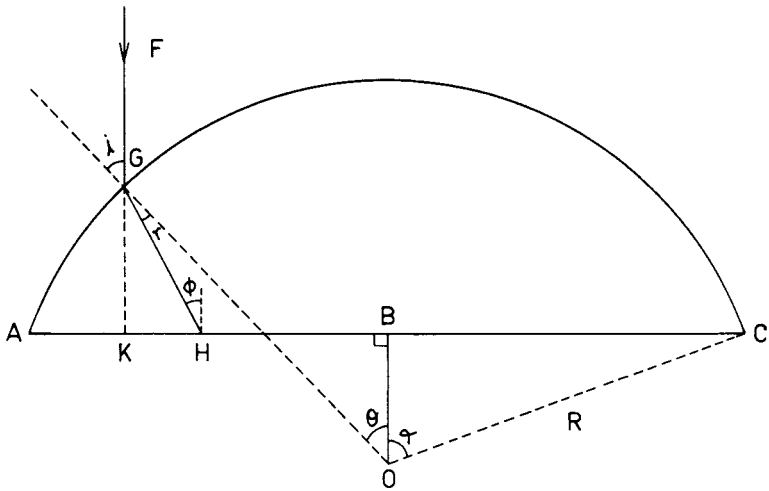

FIG. 3 Ray-tracing in a cabochon.

cabochon, meeting the back surface at H. The angle of incidence ϕ at H is given by

$$\phi = i - r = \theta - r \tag{1}$$

where r is the angle of refraction at G,
Snell's law of refraction gives

$$\frac{\sin i}{\sin r} = n \tag{2}$$

therefore

$$\begin{aligned} \phi &= \theta - \sin^{-1}\left(\frac{\sin i}{n}\right) \\ &= \theta - \sin^{-1}\left(\frac{\sin \theta}{n}\right) \end{aligned} \tag{3}$$

As the point G moves towards the edge A, the angles θ and ϕ increase. When ϕ equals the critical angle ϕ_c the light ray will be totally internally reflected at H rather than transmitted to reach the phosphorescent paper C (see Figure 1). The value of θ corresponding to ϕ_c is denoted by θ_m and calculated from the following equation:—

$$\phi_c = \theta_m - \sin^{-1}\left(\frac{\sin \theta_m}{n}\right) \tag{3a}$$

In other words light entering that part of the gem subtending an angle θ larger than θ_m will not be able to penetrate the back surface of the cabochon. Thus that part of the gem looks opaque through the phosphoroscope, irrespective of the absorptance of the gem.

For aquamarine the refractive index in the UV region is slightly higher than in the visible region. For argument's sake we ignore the birefringence of aquamarine and assume a refractive index of 1.57. The critical angle for total internal reflection is then

$$\phi_c = \sin^{-1}(\frac{1}{n}) = \sin^{-1}(\frac{1}{1.57}) = 39.6° \tag{4}$$

Hence

$$\theta_m = 78.2°$$

A quantitative measure of the dark rim due to the refractive effect is given by the ratio of the lengths BH/BA

where $BA = R \sin\alpha$

and $BH = BK - KH$

$$\begin{aligned} &= R \sin\theta_m - GK \tan\phi_c \\ &= R \sin\theta_m - (R \cos\theta_m - R \cos\alpha) \tan\phi_c \end{aligned} \tag{5}$$

For a hemispherical cabochon $\alpha = 90°$

therefore $$\frac{BH}{BA} = \sin\theta_m - \cos\theta_m \tan\phi_c$$

$$= 0.81$$

The above consideration applies to a hypothetical hemispherical cabochon of aquamarine. It explains qualitatively the occurrence of the dark rim around the aquamarine cabochon shown in Figures 2a and 2b. Similar dark rims are abserved in the oval mixed-cut synthetic ruby and the emerald-cut imitation alexandrite. (Note that the smaller 'extra dark' rims are umbra, the larger darker rims are penumbra.) The calculations are much more complicated but the principle is the same. Figure 4 shows schematically that a light ray PQR entering near the culet of a round brilliant-cut gem is transmitted, while a light ray XYZ entering near the girdle is totally internally reflected. As a result the rim of the gem looks darker compared to the centre as shown in Figures 2a and 2b. By looking at the centres of the gems shown in

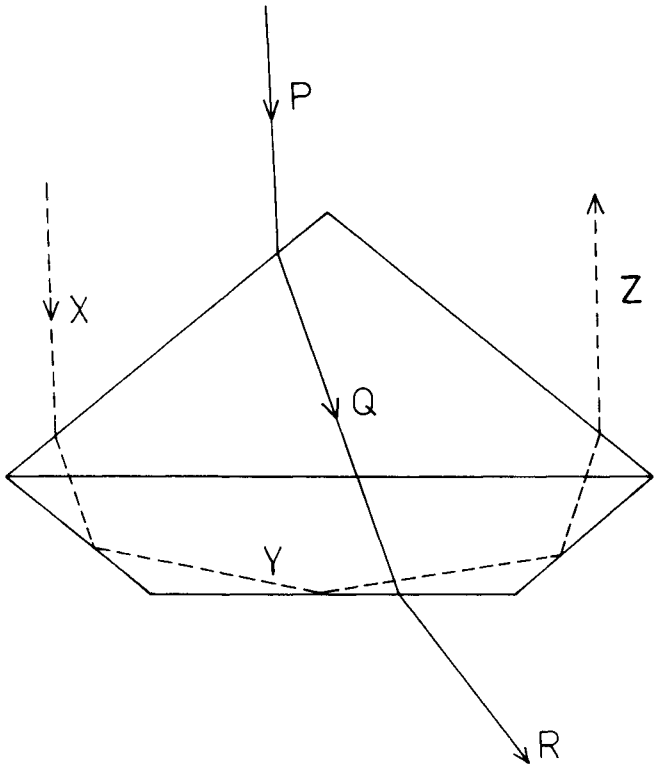

FIG. 4 Transmission and total internal reflection of light rays in a gem.

Figure 2 we can deduce that while the aquamarine cabochon and the oval synthetic ruby are transparent to SWUV, the imitation alexandrite is slightly absorbent.

4. Results and Discussions

Figure 5 is a SWUV absorptance photograph of various types of ruby. The picture shows clearly that the synthetic, Burmese and Sri Lankan rubies are transparent to SWUV while the Thai and Tanzanian rubies are opaque. The absorption of SWUV in the Thai and Tanzanian samples may be attributed to their higher iron content. Using the crossed-filter technique the red fluorescent lines (692.8 nm, 694.2 nm) characteristic of chromium ions are not

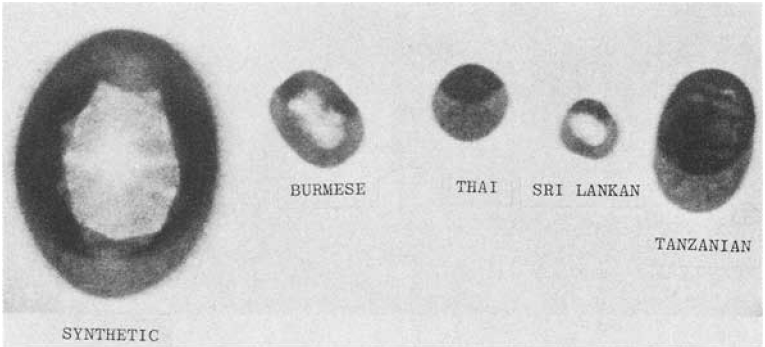

FIG. 5 SWUV absorptance photograph of rubies.

observable in these two stones. This 'quenching' of red fluorescence in ruby can be explained in terms of crystal field theory (Nassau 1978, p.221).

The SWUV absorptance photograph of various types of sapphire is shown in Figure 6. The picture shows that Sri Lankan sapphires are transparent to SWUV, while Thai and Australian sapphires are slightly absorbent. Again this indicates that the latter have higher iron content than the former. The blue colour of sapphires arises from molecular orbital transitions involving the following two valence states: (a) Fe^{2+} and Ti^{4+} (b) Fe^{3+} and Ti^{3+} (Nassau 1978, p.225). Since the optical transition involves both the titanium ion and the iron ion, an excess of iron ions does not make the gems bluer, but renders the gem more absorbent of SWUV radiation.

Figure 7 shows that the Chatham emerald is transparent to SWUV, the natural emeralds are slightly absorbent and the Gilson emeralds are highly absorbent. This phosphoroscopic indication of the iron contents of these types of emeralds agrees with conclusions

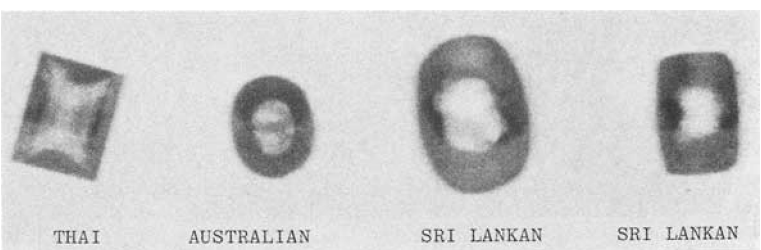

FIG. 6 SWUV absorptance photograph of sapphires.

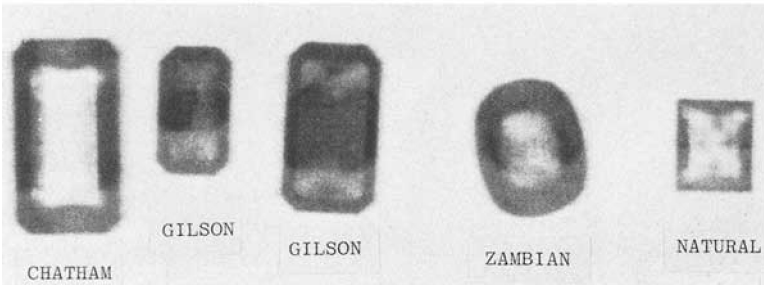

FIG. 7 SWUV absorptance photograph of emeralds.

reached by separate electron spin resonance studies of emeralds (Hutton and Barrington 1977). They found that while both Gilson and Chatham emeralds showed rich chromium electron spin resonance spectra, only Gilson synthetics showed a pronounced iron spectrum. They also found that the concentration of iron ions varied quite markedly in natural emeralds from different sources. Traces of iron were found in emeralds from Poona, Colombia and Minzie but not in samples from Rio Tinto.

In conclusion, the phosphoroscope provides us with a simple and quick way of observing the ultraviolet absorptance of gems. In appropriate cases this instrument may be used to distinguish natural gems from their synthetics. It will become increasingly useful as more and more data of ultraviolet absorptance of gems are collected.

ACKNOWLEDGEMENT

We are most grateful to Mrs Anne C. Paul, F.G.A., Mrs Rosamond Clayton, F.G.A., and Mr S. P. N. de Silva, F.G.A., for allowing us to photograph their fine collection of gems.

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[*Manuscript received 24th May, 1979.*]

GEMMOLOGICAL ABSTRACTS

ANDERSON (B. W.). *Discovering the importance of heavy liquids in gemmology.* Retail Jeweller, **17**, 402, 3: *Errors discovered as gem laboratory branched out.* id., **17**, 403, 21: *More solutions used to test gems.* id., **17**, 404, 8: *The virtues and vices of the Clerici solution.* id., **17**, 406, 36: *Indicators: the search for accuracy.* id., **17**, 408, 15: *Checking the results of new research.* id., **17**, 410, 38: *Using diamond as an indicator.* id., **17**, 413, 18: *Summing up the usefulness of the liquids.* id., **17**, 416, 16-17: January-August, 1979.

An important series of papers on the history and uses of heavy liquids in gem testing, from the pen of this country's most experienced gemmologist.* Abstracter understands that the slightly fatuous titles of the separate articles were the choice of the publishers, not of Mr Anderson. R.K.M.

ARPS (C. E. S.). *The immersion contrast polariscope: an attractive addition to a well known technique.* Z.Dt.Gemmol. Ges., **28**, 4, 184--6, 1 fig, 2 diagrams, 1979.

This is a paper read to the 17th International Gemmological Conference in Idar-Oberstein, September 1979. The instrument is cheap and useful in the laboratory. Based on the principle of immersion of gemstones in liquids to produce RI contrasts and on optical anisotrophy. E.S.

BARKER (B.). *Know your diamonds.* Gems & Gemology, **XVI**, 8, 248-53, 1979.

A bibliography of recent diamond literature. R.K.M.

BLAIR (G.). *Diamonds of the Wyoming outback.* Lapidary Journal, **34**, 2, 496-8, 4 figs, 1980.

Account of the 'salting' with diamonds, emeralds and corundum of an area in the southern Red Desert of Wyoming. M.O'D.

BROWN (G.). *The absorption spectra of beryl.* Wahroongai News, 27-32, Feb. 1980.

An extensively informed paper, apparently based almost entirely on advanced scientific research by Dr Kurt Nassau. Most of the really significant absorption factors which discriminate between natural and synthetic beryls occur at infrared wavelengths well outside the range practical in normal gemmology. Graphs make their point but are crudely drawn. R.K.M.

BROWN (G.). *Gold corals—some thoughts on their discrimination.* Gems & Gemology, **XVI**, 8, 240-4, 5 figs, 1 table, 1979.

A discussion mainly concerned with the differences between 'gold' coral, from Hawaiian waters, and 'golden' coral from the Philippines. Differences, apart from semantics, lie chiefly in the surface structures; gold coral smooth—golden, a bleached or acid-treated whip coral, rough and spiny. Cross sections also differ. R.K.M.

*see *Anderson on Heavy Liquids*, p.230 above.—Ed.

BROWN (G.). *Painite updated.* Wahroongai News, 16, Feb. 1980.

Work by Moore and Araki published in 1976 changes the previously recognized composition of this rare gem, eliminating Si and introducing Zr as constituents, with some changes in the theoretical structure. (Mr Brown still refers to it as a 'single crystal' mineral, but the material for this work was taken from the Natural History Museum's *second* crystal, also found by Pain: and last year the abstracter had information from Mr R. T. Liddicoat to the effect that a third specimen had been found among Burmese rough which had been in the possession of the G.I.A. for many years.) R.K.M.

BUTLER (J. N.). *An attempt to assess the recent popularity of different gems.* Wahroongai News, 33-8, Feb. 1980: *Recent fluctuations in the trade popularity of some gem materials,* id., 3-11, March 1980.

Two articles which try to assess popularity of gem species by counting numbers of articles in the popular press and trade press, and numbers of advertisements. (It is doubtful whether inferences drawn are necessarily correct. Most articles and/or advertisements are written to create interest, and in the latter case there is a tendency for them to increase when supplies are plentiful and demand low.) R.K.M.

CAMPBELL (Ian C. C.). *Personal notes on gems, minerals and related aspects, Zimbabwe Rhodesia.* Lapidary Journal, **33**, 12, 2626-35, 17 figs, 1980.

Special reference is made to emerald, aquamarine, blue topaz, citrine, garnet, alexandrite and serpentine. Authoritative details of finds and commercial potential are not available due to the political situation, but many gemstone species have exciting possibilities. Some have been over-priced in the past, again for political reasons. M.O'D.

CARR (S. G.), OLLIVER (J. G.), CONOR (C. H. H.), SCOTT (D. C.). *Andamooka opal fields—the geology of the precious stones field and the results of the subsidized mining program.* Rept. Invest. Geol.Surv. South Australia, **51**, 68pp, 8 figs, 24 pls, 6 appendices, 1979.

At Andamooka, opal has formed within a bleached profile at the interface of a white, sandy clay or kopi, and an underlying, impermeable, grey-brown montmorillonitic clay or mud in the Cretaceous Marree formation. Generally, this interface or level, is marked by a pebble or conglomerate layer. Precious opal has accumulated in suitable crevices or has been trapped by permeability barriers. Basically, the level undulates gently, reflecting sedimentation on a slightly irregular surface. Small-scale faults or slides, disrupt the level only locally. No structural control of opal has been recognized, but detailed mapping of individual fields is continuing. W.A.F.

CASSEDANNE (J. and J.). *Les grenats de Poço dos Cavalos, Ceará-Brésil.* (Garnets of Poço dos Cavalos, Ceará, Brazil.) Revue de Gemmologie, 62, 5-8, 9 figs, 1980.

The location is in the centre of the State of Ceará; garnets are found in a pegmatitic body. The chemical composition shows that the stones are between almandine and spessartine; the colour is rose-orange. SG 4.15, RI 1.815. M.O'D.

CAVENAGO-BIGNAMI (S.). *New grey-black, greenish-black cultured pearls.* Z.Dt.Gemmol.Ges., **28**, 4, 187, 1979.

Paper read to the 17th International Cemmological Conference in Idar-Oberstein, September 1979. These greenish-black grey-black pearls can grow up to 15mm in diameter and come from Manihi, Tahiti, French Polynesia, produced by the *Pinctada maxima*. Exposure to x-ray for a Lauegram does not influence the colour of the pearls. E.S.

CROWNINGSHIELD (R.). *Developments and highlights at GIA's Lab in New York.* Gems & Gemology, **XVI**, 7, 194-202, 37 figs (36 in colour), 1979.

Yellow and orange-red sapphires unlike any seen before are causing problems. Red colour patchily on surface reminiscent of Lechleitner emerald effect seen when overgrowth is partially polished away. There is reticulation of surface layers, again a feature of Lechleitner emeralds. It is surmised that these are natural stones which have been artificially treated. (Generally the colour plates—photographed by A. Roditti—are an immense improvement over the former monochrome, but occasionally they print dark and detail is lost; one of a 20 ct green sphene ring is too dark to reveal much detail.) 'Emerald' in matrix proved to be green plastic on plastic-bonded grey rock; an unusual self-colour opal, looking like obsidian, is described.

Remaining items include a variety of diamond inclusions and the possibility of using interesting ones as merchandising factors is discussed in view of shortage of clean stones (Gübelin of Switzerland has been doing this for many years). The question of grading a diamond in which a single inclusion reflects in many facets is also discussed. A diamond tested with a diamond point, as a possible cubic zirconia, had been badly scratched—octahedral (hard) point on cubic (softer) facet. (A sapphire point is quite hard enough to reveal cubic zirconia, and will not touch diamond.) Comment is made on the rarity of true cleavage chips of diamond in jewellery. These are fairly common in antique jewellery from India. Finally, an interesting comment on the dearth of fine colour diamonds in smaller sizes, thought to be due to cut, girdle condition, etc., which have more effect on smaller stones. A chance to grade stones of 100 ct plus, down to quite small sizes, all from one crystal, showed that all were grade D (fine on GIA scale) except three which were below 1 ct each and poorer in colour. Recutting can sometimes lower the colour grade of a diamond.

Two new imitations reported by Dr Kurt Nassau: one a microcrystalline cellulose made to resemble ivory (RI 1.5, SG 1.53, H 4½, UV fluorescence medium yellow, no 'engine-turning' pattern). The other a blue glass cabochon with a structural (non-mobile) star built into it, rather like the canes used in glass paper-weights. R.K.M.

CURTIS (C. M.). *'Malaya' lady of the evening.* Lapidary Journal, **33**, 11, 2348-9, 1980.

In the context of the article 'Malaya' is an adjective, for it derives from one of the Bantu group of languages and has the meaning 'out of the family'. It has been given to an orange garnet found near the village of Mwakijembe in the Umba Valley of Tanzania. RI is given as 1.75-1.76. A variety of inclusions have been noted, and the stones are said to belong to a pyrope-spessartine series. M.O'D.

DUYK (F.). *Reflexions sur le diamant.* (Reflections on diamond.) Revue de Gemmologie, 62, 9-11, 2 figs, 1980.

Considers the work done by various writers on diamond from classical times to the present. M.O'D.

FARN (A. E.) *The first impact of a gemstone.* Z.Dt.Gemmol.Ges., **28,** 4, 188-90, 1979.

Paper read to the 17th International Gemmological Conference in Idar-Oberstein, September 1979. Aspects of the work of the London Laboratory are shortly mentioned and the differences in jade-like materials are used to illustrate the work of a gemmologist. E.S.

GRAZIANI (G.). *Crystal inclusions and their implications.* Z.Dt.Gemmol.Ges., **28,** 4, 191-3, 1979.

Paper read to the 17th International Gemmological Conference in Idar-Oberstein, September 1979. Modern methods are applied to find a solution to genetic problems of minerals. Two beryls are taken as examples. E.S.

GÜBELIN (E.). *Neue Edelsteine aus Sri Lanka.* (New gemstones from Sri Lanka.) Z.Dt.Gemmol.Ges., **28,** 4, 194-6, 1979.

Paper read to the 17th International Gemmological Conference in Idar-Oberstein, September 1979. The author discusses and describes four new gemmological minerals from Sri Lanka, giving details of physical properties in each case. The first is a sillimanite, which had previously been found in Sri Lanka in light blue and light green varieties. This sillimanite is a saturated blue, more like a sapphire or a cordierite. The second stone described was a yellow-brown epidote, the colour being caused by iron and the colour intensity being determined by content percentage. The third gem mentioned is an idocrase showing an agreeable warm brown. The stone from Sri Lanka seems to be a little more yellow than its relatives from Canada and Kenya. The last stone was first taken to be a red taaffeite; however, it is now shown to be a new gemstone which the author calls 'taprobanite' (RI 1.177-1.721 [*sic*]*, DR 0.004; SG 3.607±0.005; H 8+. Dichroism yellow red/deep red.) Chromium seems to be responsible for the colour. E.S.

HEALEY (D.). *The gem scene in Sri Lanka.* Lapidary Journal, **33,** 10, 2274-9, 1980.

Already abstracted from J. Gemm. Assoc. Hong Kong at p.185 above.

HEDGES (R. E. M.). *Archaeological evidence from chemical analysis.* Science & Industry, **15,** 12-15, 6 figs, 1 table, 1980.

Chemical analysis techniques can provide information on archaeological artefacts. Some examples are given—pottery, iron, bronze, ceramics and also obsidian. Sources of obsidian (a volcanic glass) in Europe and the Middle East are not common: each lava flow tends to be unique in composition and can generally be differentiated from flows of different eruptions (even from the same volcanic source) on the basis of measurements of concentrations of such trace elements as Ti, Mn, Rb, Ba, Zr. Often the major elements are quite different and it suffices to measure the RI. Usually the analysis of a single subject is sufficient for the

*Probably 1.717-1.721?—Ed.

identification of its source, once a sufficient body of analyses of material from known sources has been built up. J.R.H.C.

HEHAR (W. C.). *The discovery of golden amethyst.* Lapidary Journal, **34,** 2, 582-3, 1 fig, 1980.

A stone in which deep purple alternates with wedges of citrine colour was exhibited in the U.S.A. It is said to emenate from the area of Rio Grande de Sol [*sic-?* Rio Grande do Sul] in southern Brazil. M.O'D.

KANE (R. E.). *Developments and highlights in GIA's lab in Los Angeles.* Gems & Gemology, **XVI,** 7, 205-12, 29 figs in colour, 1979.

An apparently new type of synthetic ruby, which shows intersecting growth lines and others which resemble laminations due to twinning in natural stones, is described. Such lines do not extend through the stone as would be expected of twinning planes. Other rather natural-looking inclusions of flux and veil-like wisps and strings are also seen. Illustrated alongside natural stones in 16 fine photographs. The stones with lines needed careful positioning before the effect was seen, rather as is the case with Verneuil stones. (Query: what was the transparency to short UV and did they phosphoresce after x-rays?) One large cushion antique cut synthetic had poor symmetry reminiscent of native-cut natural rubies. (It is not unknown for synthetics to be native-cut.)

A 13 carat cabochon trapiche emerald had central prism surrounded by six other broad prisms with only narrow areas of opaque material between. (Illustration rather too dark to convey this.)

Other figures are concerned with unusual inclusions in diamond. Strangely, both labs report and illustrate examples of the rarely seen square (cubic face growth pit) naturals on diamond girdles. R.K.M.

KANE (R. E.). *Developments and highlights at GIA's lab in Los Angeles.* Gems & Gemology, **XVI,** 9, 277-82, 19 figs, (Spring) 1980.

Various unusual inclusions in diamond illustrated; an imitation cat's-eye made from optic fibre had exceptionally sharp eye, was transparent from side and showed hexagonal fibre structure under magnification. Random oriented rutile (?) needles reported in emerald; also particoloured, blue and yellow, UV fluorescence in a diamond. Several more unusual inclusions in diamond illustrated and an example of 'lizard-skin' polish on one, due to polishing too close to an octahedral (cleavage) plane. R.K.M.

KIZIYAROV (G. P.), TATARINOV (A. V.), PLATONOV (A. N.), BELICHENKO (V. P.), ZAV'YALOVA (L. A.). *First finds of gem-quality jadeite in West Sayan.* Soviet Geology and Geophysics, **19,** 11, 72-81, 8 figs, 1978.

Three new varieties of jadeite clinopyroxenites have been found on the Kantegir river, West Sayan, U.S.S.R. Some of the jadeite was coloured by chromium and showed a fine green with translucency. The best quality was quite close to Burmese jadeite. Absorption bands are studied and classified. M.O'D.

KOIVULA (J. I.). *Fluid inclusions.* Gems & Gemology, **XVI,** 9, 273-6, 6 figs, (Spring) 1980.

Paper explains dangers of heating stones containing minute fluid or fluid and

gas inclusions. Liquids are incompressible and, once cushion of gas bubble is absorbed, tremendous pressure develops and disaster rapidly follows, either in the form of a bad fissure or in actual explosion of the stone. Point is made that heat applied in repairs, dopping, etc., can exceed that of the stone's formation; it is graphically underlined by the series of photographs of an oil-filled inclusion in quartz at various temperatures. R.K.M.

LEITHNER (H.). *Alexandrit aus dem Ural.* (Alexandrite from the Urals.) Lapis, **5**, 4, 25-8, 11 figs (3 in colour), 1980.

Locations for both alexandrite and emerald are given, with a simple sketch-map. Characteristic crystals are described and illustrated. M.O'D.

LESH (C.). *Gemlure. Opal: smolder of fortune?* Gems & Gemology, **XVI**, 9, 283-8, (Spring) 1980.

Attempts to trace the reputation of opal for ill luck to Scott's *Anne of Geierstein* and for good luck over a period of 3000 years, mentioning Aztecs, Incas, Java, ancient Greece and Rome, Napoleon, the Black Death (plague), Australian aborigines and other primitives: also queries the usual derivation of the name from Sanskrit 'upala' (precious stone), preferring a derivation from two Greek roots, said to mean 'see change'. R.K.M.

LIDDICOAT (R. T.), FRYER (C.). *Developments and highlights at GIA's lab in Santa Monica.* Gems & Gemology, **XVI**, 9, 265-72, 11 figs, (Spring) 1980.

'Sugar cube' and a 'tooth-shaped' inclusions in diamonds are described; a Japanese graded diamond had its report number, weight and grade sintered on the table facet and clearly visible at 10× magnification; a treated grey-green diamond had blue areas. A corundum with badly etched table facet had been damaged by heating with borax or by hot pickle containing borax.* A Va/Cr, green-blue to purplish-red, colour-change garnet proved to be in pyrope-spessartite series with some trace of hessonite and almandine. Problem of testing stones in very large inlaid screen solved by powder x-ray diffraction test proving stone to be serpentine, not nephrite as claimed. An almost colourless stibiotantalite was identified by electron-scan methods. A sapphire-blue taaffeite reported (3.34 ct) found among heat-treated sapphires, and colour may also be the result of heat treatment. Another corundum showed faint colour change reminiscent of alexandrite. Green cabochon was proved by electron probe to be anorthite with brown titanite and green uvarovite inclusions. R.K.M.

MCGLASHAN (I.). *The story of the Hope diamond.* Lapidary Journal, **33**, 10, 2242-9, 1980.

A brief history of the celebrated Hope blue diamond with a number of references to the literature. M.O'D.

MANSON (D. V.). *Recent activities in GIA's research department.* Gems & Gemology, **XVI**, 7, 217-19, 1979.

Reports steady progress in cataloguing some 9000 items now in the reference collection. Specific problems now being tackled include: origin of colour in diamond

*Heat alone can seriously affect colour of corundums, and they need to be unset whenever considerable heat is to be applied to a mount.—Abstracter's Note.

and in lavender jadeite; a review of the gem garnet group; colour permanence, and composition of gem materials. The finding of the 'second' known example of Painite among gem spinels from Mogok is reported (actually the *third* known example since the British Museum, Natural History, has had two specimens for many years). Maw-sit-sit, examined by electron-scan proves to be a combination of ureyite (previously known only in meteorites) and natrolite; not chrome jadeite and albite as previously thought.

Gem garnets from Kenya and Tanzania are proving to be a new spessartite/pyrope/grossular combination hitherto unrecognized. The name Malaya garnet (from Swahili 'Malia') is unfortunately confusing. RI is between 1.74 and 1.76, colour rich golden-orange. Plastic impregnated opal and all-plastic opal imitations are also reported. R.K.M.

NASSAU (K.). *Gemstone imitations made of glass, ceramics, plastic and composites.* Lapidary Journal, **33**, 12, 2528-50, 11 figs (6 in colour), 1980.

Reviews interesting cat's-eye imitations made by two firms in the United States and by Iimori Laboratories, Japan; Slocum stone, products made from ceramics, including a lapis lazuli imitation made from spinel and turquoise imitations; composites and plastics. M.O'D.

NASSAU (K.). *The size and weight of diamond and diamond imitations.* Gems & Gemology, **XVI**, 7, 203-4, 1 graph, 1979.

Graph compares diameter of diamond brilliants of known weight with those of GGG, cubic zirconia and YAG of the same weight. R.K.M.

NASSAU (K.). *The size and weight of diamond and diamond imitations.* Lapidary Journal, **33**, 11, 2350-2, 4 figs, 1980.

Weight and diameter of diamond and some of its imitations are plotted and the warning given that some retailers give the weight of a diamond when selling a substitute. M.O'D.

NASSAU (K.). *Synthetic gemstone developments in the nineteen seventies.* Gems & Gemology, **XVI**, 8, 226-39, 9 figs, 1 table, 1979.

An important summary, largely from author's own papers elsewhere, of progress in all fields of gem synthesis over the period named, giving a better idea of the industry in the United States than is normally available. The Czochralski process is capable of producing high quality 'boules' of corundum in very large sizes; one of 10 kilograms is illustrated. Colour treatments by irradiation of natural stones are included and a forecast of possible developments in the 1980s is made. R.K.M.

NASSAU (K.). *Synthetics in the seventies.* Lapidary Journal, **34**, 1, 50-68, 15 figs (9 in colour), 1980.

Developments in man-made gemstones from 1970-80 include diamond simulants, opal, turquoise and diamond itself. The rate of production of new materials is expected to slacken in the 1980s but perfection of existing materials will be sought. M.O'D.

NASSAU (K.), NASSAU (J.). *The growth of synthetic and imitation gems.* Crystals: Growth, Properties and Applications, **2**, 1-50, 25 figs, 1980.

This is a comprehensive introduction to the growth of gem-quality crystals and

includes a most useful table of 153 references. Growth methods are described with the particular crystals so that all Verneuil products, etc., are reviewed together. A useful feature not generally found in purely gemmological texts is a list of the dopants used for obtaining the colours of corundum. (Since the MS was submitted in 1978, there are no notes on the coloured varieties of cubic zirconia.) Details of the infrared absorption from two types of water in emerald are given, again the first detailed reference easily available. (An offprint of the paper would be most welcome.) M.O'D.

PABIAN (R. K.). *Gem collecting in Nebraska.* Lapidary Journal, **34**, 2, 462-76, 12 figs in colour, 1980.

Agate, jasper and labradorite are among the relatively few gem materials in the State of Nebraska. Blue agate is the official gemstone of the State. M.O'D.

PABIAN (R. K.). *Lake Superior agates; a historical review.* Lapidary Journal, **34**, 1, 110-53, 9 figs, 1980.

Agates from Lake Superior were worked by lapidaries 140 years ago. The article reviews the history of the deposits. M.O'D.

PAYNE (T.). *Shedding light on ultraviolet.* Gems & Gemology, **XVI**, 9, 258-64, 7 figs, (Spring) 1980.

An account of ultraviolet light, its sources, filters, and precautions to be taken when using it. R.K.M.

PERHAM (J.). *New adventures in Maine tourmaline.* Lapidary Journal, **33**, 10, 2114-52, 10 figs (2 in colour), 1980.

Further deposits of tourmaline have been located at the classic Mount Mica site in Maine. M.O'D.

PFAFFL (F.). *Böhmische Granate.* (Bohemian garnet.) Lapis, **5**, 4, 30, 1 fig in colour, 1980.

Location and history of this type of garnet are given. M.O'D.

POUGH (F. H.). *Gemological Update—Part I.* Lapidary Journal, **34**, 1, 154-60, 1980.

Reviews a number of developments and practices, including heating, irradiation and oiling, prevalent today. A number of new finds, extravagantly described, are now known to be less important than was first believed; stones in this category include kunzite from Afghanistan. Opal from Brazil has declined in quantity. The author finds the recent determinations of tourmaline types confusing. M.O'D.

ROSSOVSKII (L. N.), MAKAGON (V. M.), KUZ'MINA (T. M.). *Characteristics of the formation of a kunzite deposit in Afghanistan.* Soviet Geology and Geophysics, **19**, 11, 82-7, 2 figs, 1978.

The deposit is at Kulam, 80km south-east of the centre of Lagman Province, on the right-hand side of the Kulam river belt, a left tributary of the Alingar river. The deposit is in a pegmatite. Kunzite is found in zones and pockets with lepidolite, blue cleavelandite, vorobyevite (pink beryl), pollucite and quartz. Crystals of gem quality range up to $3 \times 15 \times 35$cm and have a well-developed vertical striation. Colours

include pink-violet, red-violet, greenish-lilac, lilac, blue-green, light blue, bluish-green, green, yellow-green and yellow. Combinations of colours are also found. M.O'D.

SCAMBARY (R.). *Australia adds rubies to its mineral riches.* Gems & Gemology, **XVI,** 7, 220-1, 2 figs, 1979.

Australian Information Service reports small quantities of cabochon grade and some facet grade rubies found in Harts Range, north-east of Alice Springs. R.K.M.

SCHAWALLER (W.). *Erstnachweis eines Skorpions in Dominikanischen Bernstein der Stuttgarter Bernsteinsammlung.* (First record of a scorpion from Dominican amber in the Stuttgart amber collection.) Stuttgarter Beiträge zur Naturkunde (Series B), 45, 1-15, 8 figs, 1979.

A new fossil of the family Buthidae, probably genus *Centruroides Marx,* has been found in a specimen of amber from the Dominican Republic in the amber collection of the Staatliches Museum für Naturkunde, Stuttgart. This is the first record of a tertiary amber scorpion from the American continent and the most southern record of a fossil from this group. M.O'D.

SCHAWALLER (W.). *Neue Pseudoskorpione aus dem Baltischen Bernstein der Stuttgarter Bernsteinsammlung.* (New pseudoscorpionidae in the Baltic amber in the Stuttgart amber collection.) Stuttgarter Beiträge zur Naturkunde (Series B), 42, 1-22, 17 figs, 1978.

Pseudoscorpionidae *Chthonius pristinus, Microcreagris* and *Cheiridium sp. (?hartmannii)* have been found in amber specimens from the Baltic in the collections of the Staatliches Museum für Naturkunde in Stuttgart. All three are new or possibly new species. M.O'D.

SCHMETZER (K.), BANK (H.). *Brauner Aktinolith aus Ostafrika—ein Glied der Mischkristallreihe Tremolit-Aktinolith-Ferroaktinolith.* (Brown actinolite from East Africa—a link in the mixed crystal series tremolite-actinolite-ferroactinolite.) Z.Dt.Gemmol.Ges., **28,** 4, 179-83, 1979.

A brown-coloured transparent actinolite from East Africa was described. It had RI n_x 1.633 n_z 1.653 and a density of 3.15. The authors discuss the position of this crystal in the actinolite solid solution series. E.S.

SCOTT (D. C.). *Turquoise occurrence near Mount John.* Min. Resrcs Rev., South Australia, **145,** 69-74, 3 figs, 1979.

An iron-rich zone of silcreted sandstone, near the base of the parachilna formation of Early Cambrian age, near Mount John, in the Flinders Ranges of South Australia, contains small patches of blue-green turquoise. Quartz grains in the turquoise cause pitting, preventing the production of high-quality polished articles. Accessory minerals occurring in the turquoise-cemented silcrete include zircon, rutile, alunite, goethite, and carbonate. W.A.F.

SEAGER (A. F.). *The origin of a tetrahedral diamond.* Mineralog. Mag., **43,** 377-87, 9 figs, 1979.

A tetrahedral crystal of about 4mm edge-length has been examined for evidence relevant to the controversy as to whether the symmetry of diamond is $4/m\bar{3}2/m$ or

$\bar{4}3m$, the rare development of tetrahedral morphology having been cited in favour of the lower symmetry. On this crystal one quadrant containing (111) differs topographically from the other three; the latter have nearly plane faces each surrounded by six curved surfaces of form {*hkl*}, and show coplanar banding of trigons II (III) with striations on the curved surfaces parallel to it. The banding and striations are interpreted as stratigraphic etching of nitrogen-rich layers II (III) in a Type I diamond; slip and apparently polygonization occur in the unique quadrant. The doubt cast on tetrahedral morphology (and the inferred twinning on {100} or about <100> as evidence for lower symmetry) strengthens the case for assigning diamond to class $4/m\bar{3}2/m$. R.A.H.

SENIOR (B. R.), MOND (A.), HARRISON (P. L.). *Geology of the Eromanga Basin.* Bull. Bur. Min. Resrcs, Australia, **167**, 102pp, 16 figs, 18 pls, 3 coloured geol. maps, 1978.

The Eromanga basin is a Jurassic to Cretaceous sedimentary basin. In late Cretaceous time the upper 130 m of the sequence was kaolinized and partly silicified and ferruginized by chemical weathering. Precious opal occurs in the chemically weathered sediments and several large open-cut mines are producing opal from depths of up to 10 m. I.M.H.

STONE (J.). *Coober Pedy—the opal town.* Gems & Gemology, **XVI**, 7, 213-16, 4 figs, 1979.

An Australian Information Service write-up of this desert location. R.K.M.

SUWA (K.), SUZUKI (K.), MIYAKAWA (K.), AGATA (T.). *Vanadian and vanadium grossulars from the Mozambique metamorphic rocks, Mgama Ridge, Kenya.* 4th Preliminary Report of African Studies, Nagoya University, 87-96, 4 figs, 1979.

Vanadium-bearing grossular garnet is found as 'potatoes' (porphyroblasts) in a calc-silicate gneiss at the Lualenyi mine, Mgama Ridge, southern Kenya. Properties and chemistry are given, together with maps of the area. M.O'D.

SVISERO (D. P.). *Piropos cromíferos da mina de diamantes de Romaria: composição química e origem.* (Chrome pyrope from the Romaria diamond mine: chemical composition and origin.) Boletim Mineralogico, 6, 7-14, 3 figs, 1979.

Chrome pyrope has been found associated with diamond at the Romaria mine, Minas Gerais, Brazil. Crystals of up to 1cm have been found. M.O'D.

SZOMOR (I.). *Bernsteinfarbener Opal aus Ungarn.* (Amber-coloured Hungarian opal.) Lapis, **5**, 5, 31, 2 figs in colour, 1980.

An amber-coloured opal without play of colour is found in the Eperjes-Tokajer area of Hungary, close to the Czech border. M.O'D.

WAND (U.), NITZCHE (H.-M.), WETZEL (K.). *Nitrogen isotope composition in natural diamonds—first results.* Chemie der Erde, **39**, 1, 85-7, 1980.

Nitrogen isotope composition was determined from a collection of 13 natural diamonds. The nitrogen was found to be slightly enriched in ^{15}N compared to

atmospheric nitrogen. The method of experimentation proved that the argon content in the samples must have come from the stones themselves and not from atmosphere. M.O'D.

WENTORF (R. H.), DEVRIES (R. C.), BUNDY (F. P.). *Sintered superhard materials.* Science, **208**, 4446, 872-80, 11 figs, 6 tables, 1980.

Diamond or cubic boron nitride particles can be sintered into strong masses at high temperatures and pressure at which the crystalline forms are stable. Hardness and thermal conductivity approach those of large single crystals: resistance to wear and splitting is superior. Produced on commercial scale and increasingly used as cutting tools on hard or abrasive materials. J.R.H.C.

YAMAGUCHI (S.), SETAKA (N.). *Essai de synthése du diamant.* (Experimental synthesis of diamond.) Bull. Min., **103**, 120-1, 1 fig, 1980.

Diamond was produced when a mechanical mixture of carbon monofluoride and copper in the ratio 1:9 was exploded in a closed tube by applying an external shock wave. The pressure and duration of this shock were 0.9 Mbar and 10^{-12} sec, respectively. The diamonds obtained were identified by electron diffraction; their dimensions are $\sim$ 100Å. R.A.H.

YU (R. M.). *The Brewster angle refractometer.* Gems & Gemology, **XVI**, 8, 245-7, 3 figs, 1979.

A refractometer with no upper or lower limits to its capacity. Depends on Brewster's Law which, briefly, states that light reflecting from a polished surface (other than metal) is completely polarized parallel with that surface at an incident angle directly related to the RI of the substance. The instrument, like others based on the same principle, measures the angle approximately and exact RIs are not obtained. Suggests that solid state versions with digital displays might have greater potential. R.K.M.

YU (R. M.), HEALEY (D.). *Practical color systems for gems.* Lapidary Journal, **33**, 10, 2238-41, 1 fig, 1980.

Attempts have been made to match the colour of gemstones with established colour grading systems such as Munsell and the Gem Master Color System. Instrumental measurements were found to possess some advantages over the eye. M.O'D.

NOTE: to avoid confusion, the Spring 1980 number of Gems & Gemology is so described above, because, although in fact part 9 of volume XVI, it carries the number 8.

BOOK REVIEWS

BOSSI (Jorge). *Recursos minerales del Uruguay.* (Mineral resources of Uruguay.) Ediciones Daniel Aljanati, Montevideo, 1978. pp.348. Illus. in black-and-white and in colour. $(US)34.00.

Amethyst and some ornamental marbles are the chief materials of interest to the gemmologist, but this exhaustive book covers many other minerals of economic importance. Maps of deposits are given. M.O'D.

CZARNOWSKI (S.). *Baroque jewellery.* National Museum, Warsaw, n.d. Unpaginated. 9 figs in colour. Zl 20.

A pocket-sized guide for visitors to the galleries of the National Museum, Warsaw. M.O'D.

CZARNOWKSI (S.). *Rock crystal products.* National Museum, Warsaw, n.d. Unpaginated. 9 figs in colour. Zl 20.

A pocket-sized but well-illustrated book for visitors to the galleries of the National Museum, Warsaw. M.O'D.

FUGGER (B.). *Die Mineralien des Herzogthumes Salzburg.* (The minerals of the Duchy of Salzburg.) A. Strasser, Salzburg, 1979. pp. viii, 124. Price on application.

This book is a reprint of a work first published in 1878 and includes all the original text and a map of the area. Minerals are arranged in chemical order. The area is important to gemmologists since it includes the emerald-bearing district of the Habachthal, which is described. M.O'D.

HÄNNI (H. A.). *Mineralogisch und mineralchemische Untersuchungen an Beryll aus alpinen Zerrklüften.* (Mineralogical and mineral-chemical examination of beryl from alpine clefts.) Universität Basel, Basel, 1980. pp.107. Illus. in black-and-white. Price on application.

This close study of the occurrence of beryl in alpine clefts was presented as a Ph.D. thesis. The central alpine regions provide the chief localities for beryl. Chemical analysis of a number of crystals and examination of accessory minerals give a clear range of constants for alpine beryl. M.O'D.

HOWARTH (S.). *The Koh-I-Noor diamond.* Quartet Books, London, 1980. pp.viii, 160. Illus. in black-and-white and in colour. £15.00.

This is an account of the history of the celebrated diamond and does not attempt to discuss the stone itself. It is very readable and contains a wealth of information which would be quite difficult to assemble, and for this the author is to be congratulated. There is an ample bibliography; though it would have been useful for complete references to have been given, this would admittedly have greatly increased the price of the book. The plates are good and those in colour very good—the standard of production is high overall. Those interested in Indian History, religions and legends will find the book good value. M.O'D.

KALDIS (E.), (ed.). *Current topics in materials science.* Vol. 4. North-Holland Publishing Co., Amsterdam, 1980. pp.viii, 596. $(US)102.50.

The fourth* in this excellent series contains papers on the unusual luminescent properties of Eu^{2+}, on phase diagrams of electronic materials (this paper also contains an explanation of phase diagrams with special reference to their importance for crystal growers), on defect structures and growth mechanisms and on the preparation and properties of lanthanide oxides. References to all papers lead the reader with an interest in the properties of crystals to a variety of important sources; those whose business it is to look out for the advent of new materials should familiarize themselves with books such as this, although the price means that a library copy will inevitably be the one consulted. M.O'D.

KUZ'MIN (V. I.), DOBROVOL'SKAIA (N. V.), SOLINTSEVA (P. S.). *Turmalin.* (Tourmaline.) (In Russian.) Nedra, Moscow, 1979. pp.268, 11 figs in colour. R1.60.

This major work on the composition and properties of tourmaline includes work done up to 1976; a bibliography of over 300 entries includes both Slavonic and western works. M.O'D.

LEAMING (S. F.). *Jade in Canada.* Geol. Surv. Canada, Paper No. 78-19, pp.59, 37 figs, 1978. $4.00 (Canada), $4.80 (other countries).

Although dealing chiefly with jadeite and nephrite in Canada, this review includes information on occurrences elsewhere in the world. The physical and chemical properties of jadeite and nephrite are summarized and eight chemical analyses of Canadian nephrite are tabulated. Nephrite is considered to have originated mainly by either metamorphism of calc-silicate rock or metasomatism between serpentine and other rocks. The mineral occurs in alluvial deposits, colluvial deposits (large blocks lying downslope from bedrock occurrences) and *in situ* deposits. The chief Canadian deposits are found in British Columbia, mainly between the coast and Rocky Mountains, associated with serpentinite. Details are given of a number of deposits in British Columbia and Yukon. The largest deposit, in the Cry Lake area of B.C., has a probable reserve of 3600 tonnes. The appendix contains a glossary of technical terms. M.O'D.

LEGRAND (J.). *Diamonds, myth, magic and reality.* Crown Publishers, New York, 1980. pp.287. Illus. in colour. $50.00.

This fine book is divided into sections, each dealing with a particular diamond-producing country. Preliminary material describes and illustrates the use of diamond as shown in early manuscripts, later chapters outline the mining, testing, sale, grading and cutting of diamond. Expensive and somewhat unwieldy, but the text is sound and photographs first-class. M.O'D.

MCCABE (J.). *Opal mining at Lightning Ridge.* Kelly Books, Melbourne, 1979. pp.64. Illus. in colour. Price on application.

A simple guide to mining, this book concentrates on the practical side of obtaining opal. Illustrations in the text are helpful. M.O'D.

*Reviewer advises that Vols 2 and 3 are not in our field: for review of Vol. 1 see J. Gemm., 1979, XVI(6), 419.—Ed.

MATTIOLI (V.). *Minerali Ossolani.* (Minerals of Ossola.) Vittorio Mattioli, Milan, 1979. pp.267. Illus. in colour. £12.00.

This is a first-rate mineralogy of the area of the Val d'Ossola in northern Italy. Minerals are arranged chemically and there is a short bibliography at the end of each section. Introductory matter deals with the geology or the area. Minerals especially noteworthy include emerald, andradite garnet and tourmaline. M.O'D.

MULLER (H.). *Jet jewellery and ornaments.* Shire Publications, Princes Risborough, 1980. pp.32. Illus. in black-and-white. 75p.

This is an admirable little book, very well illustrated and containing all the information those interested in jet are likely to want. It is pleasing to know that several craftsmen are turning to jet and that there is a demand for jet jewellery. This book, which can be read at a single sitting, covers the history and geology of jet, the Whitby jet industry, jet manufacture and imitations. The price is something of a triumph for today. M.O'D.

READ (P. G.). *Beginner's guide to gemmology.* Newnes Technical Books, London, 1980. pp.234. Illus. in black-and-white and in colour. £3.25.

It must be said at the outset that comparison with *Practical Gemmology* is inevitable. Both books aim at the same audience—the student and beginner in gemmology. Accurate comparison must take into account the great change in educational standards since the first appearance of *Practical Gemmology* in 1943. Though many will deplore the apparent decline in standards today, the over-all picture is much more satisfactory, if only in that almost anyone who wants it can obtain higher education. The style of this new book reflects the change in study patterns more than it does anything else (to save the reader time I find it very satisfactory!); *PG* was didactic, and this was understandable, since most readers at that time would have had unimpressive educational backgrounds. It was also wooden and not well arranged; on the other hand it was accurate and had useful questions at the end of the chapters. This book is well written, logically ordered, far better illustrated (the illustrations in *PG* are frequently outdated or irrelevant) and, of course, up-to-date. After an introductory section in which gemmology is defined, the reader is first introduced to colour, then to specific gravity, optical properties, synthetics and simulants, appendices and tables. There are some errors—I am told that a paperback merits only one proof-check, so that if the illustrations are altered the index may be out of step—but all this can easily be corrected in a later edition. In view of the author's background the sections dealing with instruments are especially well done as one would expect. I do find some fault with the arrangement of material toward the end of the book; inclusions in ruby and some other stones are described in the section on synthetics and in the midst of the appendices some more inclusion data are given. This should all be tided up. The bibliography could have been a little extended (journals are not included) and arrangement under the name of the author is *de rigueur* in any book of standing. 'Russia' as a locality is inadequate and inaccurate. The whole section on gemstones could be expanded; 'pyramid' could be added to the glossary of crystallographic terms; the use of 'primary' and 'secondary' in a geological context is dangerous, since confusion with the same terms used for mineralization is possible. It is hard for the present reviewer to put himself into the position of the beginner; I feel that as a textbook it covers the

ground very well indeed but also that it should be used in conjunction with more elementary explanations from instructors; the impression given is that it expects some degree of subject knowledge. M.O'D.

SUPERCHI (M.), ROLANDI (V.). *A proposal for delimiting ruby (from rose and violet corundum) and emerald (from light green and dark green beryl).* Laboratorio di Analisi Gemmologiche, Sezione di Milano, Milan, n.d. Unpaginated and unpriced.

The West German colour standard (DIN 6164 Farbkarte) is used as a basis for distinguishing ruby from close relatives and emerald from other green beryls. M.O'D.

YAVERBAUM (L. H.). *Synthetic gems, production techniques.* Noyes Data Corporation, Park Ridge, N.J., U.S.A., 1980. pp.xi, 353. $39.00.

This book updates and continues a previous publication, *Synthetic gem and allied crystal manufacture,* which like this one, was based on U.S. patents. As in the previous work, the contents are divided into corundum, asteriated gems, rutile, titanates, garnet, miscellaneous crystals (including emerald, zirconia, alexandrite, amethyst, citrine, opal and several others). This takes the reader rather less than half-way through the book, the remainder of which is devoted to diamond.

Each patent is described and most give step-by-step accounts of the manufacture of the materials. It is interesting to note that one manufacturer of synthetic alexandrite states that both chromium and iron are necessary to achieve the colour change; that the orange variety of cubic zirconia owes its colour to cerium oxide; and that there are several ways of stabilizing the array of silica spheroids to obtain workable opal. Readers with an interest in man-made gems should have access to this book. A list of patents is provided together with an index of inventors. M.O'D.

South African Directory of Jewellery and Precious Metals. Thomson Publications S.A.(Pty) Ltd, Johannesburg, 1980. pp.166. Illus. in black-and-white and in colour. Rd 27.

This 1980 edition is the first of what is hoped will be a regular publication. Mostly consisting of advertising material, the book also contains pieces on gemmology (with some horrifying misprints) and on precious metals, prices and retailing. South African dealers will find it most useful. M.O'D.

ASSOCIATION NOTICES

OBITUARY

CECIL JAMES PAYNE—GEMMOLOGIST EXTRAORDINARY

A Tribute by B. W. Anderson

Cecil James Payne was born at Ipoh in the the Malay States (Malaysia) on 5th July, 1905, where his father was an Incorporated Accountant and also Managing Director of the Times Malaysia Press. In 1914 he was sent to England with his sister Joan and lived with four aunts and an uncle in Holland Road, Kensington. He was educated at a Prep. School in Earl's Court and later at Westminster School as a weekly boarder and later dayboy. He finally became a student at King's College, London, where he obtained a B.Sc. in geology

Payne's mother and three younger sisters (Marjorie, Dorothy and Nancy) returned to England in 1920, and he lived with them in Kensington until his father retired and bought the Old Vicarage at Ospringe where the family lived for some years.

It was in October 1928 that he joined me in the Laboratory where I had been working single-handed (with a commissionaire for company) since 1925. As in my case, Payne obtained the job through the good offices of W. T. Gordon, Professor of Geology at King's College. The work at that time was concentrated entirely on pearl testing and for some months I had been working overtime in a vain attempt to cope with the great demand for the elimination of all cultured pearls not only from the bunches as they were imported from Bombay but also from the stocks already held by the big jewellers of the day. I was thus mighty glad to have a team-mate of similar scientific background to work alongside me, and was doubly lucky in that he proved to be a congenial companion. An entry in my diary for 15th October, 1928, reads: 'C. J. Payne, B.Sc., came for the first time today and proved to be a very good sort. Somewhat impetuous but very willing and cheery. He soon was able to weigh and count pearls accurately, which was of considerable help'.

Our work mostly involved cutting the pearls from the bunches in their various sizes, counting, weighing and packeting and eventually testing each pearl on the endoscope. This was a remarkably efficient instrument but not easy to operate without considerable practice. Payne spent some weeks working through pearls I had already tested, but eventually we settled down into an efficient testing team and gained much pleasure from handling such superbly beautiful goods and in winkling out any 'Japs' that had intruded.

Our initiation into the larger world of gemmology was slow in coming, but, when it did, our progress was extremely rapid. The almost complete cessation of routine testing during the great trade depression of the early 'thirties gave us time on our hands which at first we frittered away with such things as chess-playing but soon turned to very good purpose.

The times were propitious for advance. In 1931 the Gemmological Association was founded as an entity separate from its parent N.A.G.; Arthur Tremayne's venture *The Gemmologist,* originally intended as the G.A.'s official journal, made its first monthly appearance in August of that year and acted as an ideal vehicle for reports of any advances; laboratories similar to our own were being established in Paris and in Idar, and Robert Shipley, having obtained his G.A. Diploma, was beginning his giant task of bringing the light of gemmology to the United States jewellery trade.

In our laboratory so much began to happen that it is difficult to place things in their right order, nor, in this context, does this greatly matter. The work that Payne and I carried out in that period on liquids of high refractive index designed to increase the range of the refractometer and on the refractometer itself, on establishing the spectroscope as a major gem-testing instrument, on devising the Chelsea Filter, and on improving the accuracy of the reported constants of the precious stones, etc., has been adequately described in '1925 . . . And All That',[1] and it would be out of place to reiterate it here. We strove together in complete harmony on work which was scientifically serious but also (to us) tremendous fun. We shared a taste for what to an outsider must seem extremely silly jokes. For example, James liked to label our odd assortment of instruments with peculiar Christian names. Ermyntrude (I still remember) was our Tully refractometer, Henry and Henrietta our two pearl shovels, Walter, Eustace and Stubby three of our favoured spectroscopes, and Edgar the 500 watt projection lamp we used with them.

Our most fortunate purchase during this period was a Beck table spectrometer which served us well for the observation and measurement of spectrum emission lines and for the accurate determination of the refractive index of liquids (contained in small hollow prisms) and for the RI and dispersion of gemstones where these were sufficiently well cut. I mention this instrument particularly because it provided the first instance where James became particularly adept[2] and I was well content to be his 'dog's-body'.

I imagine that there are few gemmologists living today who have had the experience of measuring the refractive indices of gems by the beautiful minimum deviation method. There are commonly several spectra visible produced by a

1. *J. Gemm.*, XIII(7), 249-62, 1973: for further details of our research, see 'The Pleasures of Discovery', *id.*, XIV(3), 97-113, 1974, and 'Twenty-five Years', *id.*, XIV(6), 257-72, 1975
2. see his 'Dispersion in Gemstones', *Gemmologist,* IV, 263-5, (April) 1935, and 'Dispersion of Rarer Gemstones', *id.*, IX, 32-5, (October) 1939.

C. J. Payne in gunner's uniform and sporting his Chaplin moustache to which he was addicted for a short time.

succession of facets, so that the correct marrying of facet angles and the minimum deviation observed needs great skill and patience to achieve, involving deft adjustments of the specimen. In this technique C.J.P. showed exceptional aptitude and patience. Later (1937) Payne devoted one of his rare but always well-written papers in the *Gemmologist* to the table spectrometer[3] giving instances of calculations, which were used by Robert Webster in his *Gems.* Another of his special interests was revealed in an earlier paper on 'Interference Figures and Gemstones'[4], showing his excellent grasp of crystal optics. We heard little of his private life, and his marriage in 1933 to Enid Slattery came as a surprise. Enid was clearly devoted to him but, sadly, she had a weak heart which caused her early death in 1941.

Believing strongly that the F.G.A. title should be properly earned both Payne and I entered in turn for the examination in an *hors concours* capacity and thus

3. 'The Table Spectrometer and the Measurement of Refractive Indices', *Gemmologist,* VI, 207-18, (April 1937.
4. *Gemmologist,* VI, 55-61, (October) 1936.

earned our Fellowship title in the regular manner, an example which was followed later by Dr Edward Gübelin.

When, following the capitulation of Münich, the advent of war became imminent, James Payne began his training as a gunner in an anti-aircraft battery operating in Hyde Park, while I joined the London A.F.S. When war was declared in September 1939, James was called up at once and I had to hurry back from holiday to carry out stand-by duty at various fire-posts in the Holborn neighbourhood and keep the Laboratory going. Payne was eventually sent overseas and served with the famous 8th Army for the remainder of the war, mainly in North Africa.

At the beginning of August 1945 he was back in England and almost immediately demobbed. My diary entry for 3rd September reads: 'Almost exactly six years after going forth to war James Payne resumed work in the Laboratory. Tackling all the stack of endoscope work with real determination, he soon got his hand in and whittled it down'. One had the impression that for him the war had been a boring and tiresome episode which had to be gone through before resuming his proper avocation.

In the following year a sudden vastly increased need to test imported rubies and sapphires owing to the infiltration of synthetics, demanded additional staff if we were to fulfil this work in addition to our usual pearl testing. In April 1946 Robert Webster joined the Laboratory, followed a month later by Alec Farn. From then on our team of four was able not only to deal with all the routine testing but to carry out research work in the field of testing methods which enhanced the world reputation of London's Laboratory.

The work of the Lab. eventually became somewhat departmentalized: Robert Webster tackled the x-ray testing of pearls and kept our books, Alec Farn did the bulk of our stone testing and the work of drilled pearls was almost entirely James Payne's reponsibility. My own work was flexibly directed wherever needed. Payne's skill and vast experience with pearls by now enabled him to make decisions by careful lens inspection only, with an x-ray test for anything at all doubtful. The shift from the endoscope was almost a necessity because of the dearth of good needles.

There was no fear, however, of C.J.P. being out of the swim in pure gemmology.[5] We had throughout been fortunate in becoming involved with the discovery of new gem minerals. Before the war we had found hitherto unsuspected zinc-rich gahnospinels in the gem gravels of Sri Lanka and had also been the first to find kornerupine in this same rich source. Soon after the war Count Taaffe had passed to us for investigation the first small spinel-like stone (recovered from a jeweller's junk box) which was eventually proved to be a new mineral and was appropriately named Taaffeite. I feel that Payne's greatest triumph as a gemmologist was the recognition in October 1949 of a second Taaffeite in a parcel of mixed Ceylon stones sent in for routine testing.[6] He was alone in the Lab. when the rest of us were at a Gemmological Exhibition in Goldsmiths' Hall. Our best refractometers were at the exhibition so that Payne had to rely on a uniaxial negative interference figure to confirm his discovery. And there were further new gem

5. 'Sinhalite, a New Mineral and Gemstone', *Gemmologist*, XXI, 177-81, (October) 1952: 'Kornerupine', *id.*, XXIII, 215-19, (December) 1954.
6. 'A New Gemstone', *J. Gemm.*, III(2), 77-80, 1951: 'Further Notes on Taaffeite', *id.*, III(6), 234-5, 1952.

C. J. Payne at his pearl table.

minerals in which he was involved. In August 1952 Chas. Mathews & Son sent to the Laboratory a dark red crystal belonging to A. C. D. Pain, a well-known gem dealer and collector in Mogok, which he had failed to equate with any known mineral. We jointly established its properties, but it was C.J.P. who worked out its hexagonal crystallography and later joined with G. F. Claringbull and M. H. Hey who carried out the necessary x-ray and chemical analysis in the eventual paper, in which the new mineral was named Painite. Only two other crystals have so far been found. In 1950 the purchase from Imperial College of a Zeiss Abbe-Pulfrich refractometer in prime condition gave C.J.P. fresh opportunities for making accurate optical measurements on the rarer gemstones.

Gemmology was by no means the only subject that concerned C. J. Payne: curiously, he seldom bothered to read any gemmological literature. History and anthropology were perhaps his most abiding loves, and his interest in early man led him to undertake a journey to Tanganyika (accompanied by his godson Martin Willis) where L. B. Leakey had recently found the skull of 'Nutcracker Man' reputedly 600 000 years old. The books that he read increasingly obsessed his mind and each in turn became almost his sole topic of conversation. In recent years weather statistics for some reason became almost an obsession and his desk was littered with scraps of paper inscribed with figures for rainfall and recorded hours of sunshine. He did not take holidays in the usual sense but did pay frequent week-end visits to an aunt (who reached the age of 101) and cousin living near Haywards Heath, where he enjoyed working in the garden. He also frequently visited his widowed sister Nancy Hopkins and her two daughters, first in Rye and later Canterbury.

But he was at all times a lonely man by choice and temperament. Unfortunately each of his two closest friends, Maurice Arnold and Leslie Willis (with whose family he used to spend Christmas), predeceased him by many years. These were fellow intellectuals, and when either dropped into the Lab. to share our lunch time the air became thick with learned arguments on this and that. There was for him a rather pleasant short period in his home life when he befriended the small son of a widowed neighbour, and we heard a good deal about the sayings of 'little Gregory' and their visits together to the Royal Tournament and the like.

But after his retirement he had no contacts with people of similar tastes and withdrew more and more into himself with only two cats for company. The last time that the Lab. staff of his day met together was in March 1975—the occasion being a lunch at Goldsmiths' Hall held to mark the 50th anniversary of the Laboratory's inception. James Payne was dressed up for the occasion and appeared to be in good spirits, but his mind seemed more occupied with the new fancy waistcoat he was wearing than with the honour being paid to the Laboratory.

After an illness, the assistance of a social worker was needed to keep an eye on him and later of a kind home help who was very good to him. He had a slight stroke and his mind became unsettled. Eventually he was moved to a Borough Council Home, and there died quite suddenly of heart failure, on 20th April, 1980.

Although he was a very self-centred man, James Payne had a remarkably even temper and inspired affection in all who knew him well. I shall always be glad that each edition of *Gem Testing* contained the dedication: 'To C. J. Payne, with recollections of happy partnership in routine and research'.

* * *

Mr Edwin W. Clifford, F.G.A., (D.1956), Cassington, Oxfordshire, died on 19th April, 1980.

Mr David G. Lennie, F.G.A., (D.1953), West Kilbride, Scotland, died on 25th June, 1980.

Mr Leslie Herbert Tye, F.G.A., (D.1956), Orange, N.S.W., Australia, died on 30th January, 1980.

GIFTS TO THE ASSOCIATION

The Council of the Association is indebted to the following for their gifts:

Mr Christopher Cavey, F.G.A., Greenford, Middlesex, (Roughgems Ltd), for the following: four specimens of rhino hide (one is fashioned as a button, one as a round bead); a copy of 'Ivory' by Geoffrey Wills, published by Arco, London, 1968; a collection of specimens in a presentation box including elephant ivory, wild boar ivory, hippopotamus ivory, walrus ivory, sperm whale ivory, narwhal ivory and corozo vegetable ivory.

Mr W. A. Harris, Exeter, for 'Manual of precious stones and antique gemstones' by H. M. Westropp, published by Sampson Low, Marston, Low & Searle, London, 1874.

Mr R. Holt, F.G.A., London, for parcels of zircon, aquamarine, ruby and sapphire crystals and rough pieces ideal for students' use.

Mr E. A. Thomson, London, for a round cabochon tugtupite from Greenland, weighing 2.24 ct.

NEWS OF FELLOWS

Mr M. J. O'Donoghue, M.A., F.G.S., F.G.A., gave a talk on synthetics on 31st May, 1980, to the Wessex Branch of the N.A.G. Members examined a variety of man-made stones. Mr O'Donoghue also gave a lecture entitled 'The formation of mineral deposits' to the Amateur Geological Society on 1st July, 1980.

In July 1980, the Council of Legal Education announced the results of the Trinity Examinations of students of the Inns of Court, in which Mr Jonathan P. Brown, F.G.A., (Lincoln's Inn) was placed second in Division I of Class II (i.e. fifth overall) and was awarded the Colyer Prize in the law of landlord and tenant.

MEMBERS' MEETINGS

Midlands Branch

The Annual General Meeting of the Branch was held on 24th April, 1980, at the Society of Friends, Dr Johnson's House, Colmore Circus, Birmingham. Mrs S. E. Spence, F.G.A., was elected Chairman and Mrs J. S. Leek, F.G.A., re-elected Secretary. The A.G.M. was followed by an illustrated talk by Dr W. Bardsley, from the Crystal Growth Laboratory of the Royal Radar Establishment at Malvern, on the techniques of growing synthetic crystals. Crystals grown by the laboratory are used for optical purposes (e.g. lasers), and Dr Bardsley discussed the methods of production used.

North-West Branch

On 26th June, 1980, Dr Stanley Holgate, F.G.A., gave a talk on 'Gemmology on a Budget' at Church House, Hanover Street, Liverpool. Dr Holgate demonstrated home-made equipment for the examination of gemstones.

South Yorkshire Branch

On 29th June, 1980, a field trip was organized for members of the South Yorkshire and North-West Branches. The trip commenced at Nettlerdale, about half a mile from Ashford, where specimens of Rosewood Marble were found (the Derbyshire marbles are a black or grey decorative type of carboniferous limestone, which cuts and polishes well and provided a flourishing local industry in the

nineteenth century). After lunch the party proceeded to Friden where pieces of barytes, chalcedony and silicified wood were found.

On the 26th July, 1980, a barbecue was held.

COUNCIL MEETING

At a Meeting of the Council held on Wednesday, 30th April, 1980, Mr D. G. Kent, F.G.A., was appointed as an Examiner in Gemmology. The following were elected to membership:

FELLOWSHIP

Gunn, John F., Brentwood. 1969

Verma, Rajiv, New Delhi, India. 1979

TRANSFERS FROM ORDINARY MEMBERSHIP TO FELLOWSHIP

Sanchez-Lafuente Mariol, José, Barcelona, Spain. 1977

Yamagishi, Shoji, Kanagawa-Ken, Japan. 1979

ORDINARY MEMBERSHIP

Aliprandi, Riccardo, Ostia-Roma, Italy.
Beck, Jennifer S., Rose Bay, N.S.W., Australia.
Boulle, M. J. D., London.
Brookes, Stanley W., Ottery St Mary.
Cook, Duncan J., South Ascot.
Cope, Keith N., West Palm Beach, Fla, U.S.A.
Cottam, Donald L., Jr, Germantown, Tenn., U.S.A.
Craig, Paul N., London.
Crowcroft, Peter J., Bangkok, Thailand.
Dawson, Joan M., London.
Diercks, James S., Gainesville, Fla, U.S.A.
Erickson, Carolee, Billings, Mont., U.S.A.
Fadnes, Jane B., Stavanger, Norway.
Flanagan, Thomas P., Regina, Sask., Canada.
Gimeno Camacho, Vicente, Vina Del Mar, Chile.
Hakomori, Eiko, Tokyo, Japan.
Halley, Eileen D., Palmerston North, N.Z.
Hanneman, W. William, Castro Valley, Ca, U.S.A.
Harris, Ian A., London.
Hauser, Adolf, Zurich, Switzerland.
Hermans, Johannes S., Delft, Netherlands.
Houghton, Carole S., Grantham.
Hui, Yat-Sun, Hong Kong.
Hyman, Alan M., Santa Rosa, Ca, U.S.A.
Johnson, Jeanne L., Vancouver, B.C., Canada.
Jolliff, James V., Edgewater, Md, U.S.A.
Keating, Molly I., Nairobi, Kenya.
Kim, Choo A., Singapore.
Lundholm, Carolyn, Stockholm, Sweden.
Malkin, Stuart J., Van Nuys, Ca, U.S.A.
McDowell, Robert B., Beltsville, Md, U.S.A.
Richards, David, Nottingham.
Robins, Alan P., Bishops Stortford.
Schnider, Jack, Manchester.
Spooner, Carole A., Ruwi, Oman.
Tan Hong Chang, Bernard, Singapore.
Tan Meng Chiang, Francis, Singapore.
Thompson, John E., Elizabeth North, S. Australia.
Walker, John C., Leighton Buzzard.
Williams, Brian E., Stevenage.
Woodward, Christine M., London.

ANNUAL GENERAL MEETING

The Annual General Meeting was held at Saint Dunstan's House, Carey Lane, London, EC2V 8AB, on Friday, 16th May, 1980 at 6.00 p.m.

The Chairman, Mr Douglas King, welcomed those present and then expressed thanks to members of Council, Branch Chairmen, Examiners and Instructors for their assistance during the year and in particular for the work done by the members of the Committee concerned with the review of the Preliminary and Diploma Examinations Syllabuses. He praised the quality of the *Journal,* which had such high standing in the gemmological world and extended thanks to the Editor, Mr John Chisholm, and to his Assistant, Mrs Mary Burland. The Treasurer had once again done a very good job with the result that there was a surplus at the end of the year. In closing, Mr King expressed his regret at having to give up the Chairmanship but felt that he should take heed of medical advice. He had thoroughly enjoyed his short term of office and thanked the Secretary, Harry Wheeler, for all his help and assistance. He felt sure that the younger incoming Chairman would do a first class job for the Association.

There were no questions relating to the Annual Report or Accounts, and Mr Barry Jones seconded the motion, proposed from the Chair, for the adoption of the Audited Accounts and Report of the Council for the year ended 31st December 1979, which was carried unanimously.

Sir Frank Claringbull was re-elected President: Messrs David J. Callaghan and Noel W. Deeks were elected Chairman and Vice-Chairman respectively: and Mr F. E. Lawson Clarke was re-elected Treasurer: Mrs S. Hiscox and Messrs P. Daly and M. J. O'Donoghue were re-elected, and Messrs C. Cavey, A. Hilbourne and P. Read were elected to the Council.

Mr Callaghan in taking Office as Chairman said he would do his utmost for members and for the furtherance of the Association. Mr Deeks expressed his thanks on being elected and said he would give every support to the Chairman.

Messrs Hard Dowdy, Watson Collin & Co., Chartered Accountants, signified their willingness to continue as Auditors and this concluded the business of the meeting.

REUNION OF MEMBERS AND PRESENTATION OF AWARDS

The Reunion of Members is to be held at Goldsmiths' Hall, Foster Lane, London E.C.2., on Monday, 17th November, 1980, between 6.00 and 7.00 p.m.

Following the Reunion the awards gained in this year's examinations will be presented by Sir Edward Ford, K.C.B., K.C.V.O., past Prime Warden of the Worshipful Company of Goldsmiths.

CORRIGENDA

On page 72 above (line 12), for 'carbon monoxide' read 'carbon dioxide'.

On page 160 above (line 8), for 'Beck line' read 'Becke line'.

On page 166 above (line 7), for 'of' read 'or'.

On page 181 above (line 15), for 'Hylda Bracewall' read 'Hylda Bracewell'.

NEW
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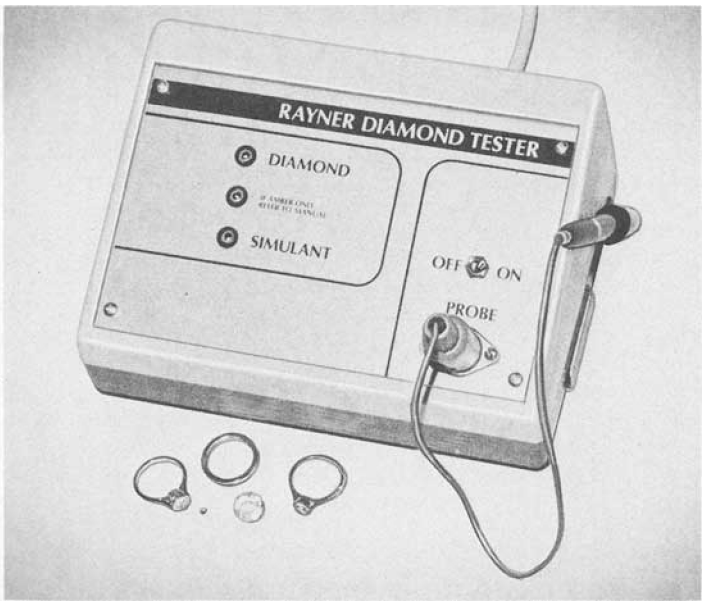

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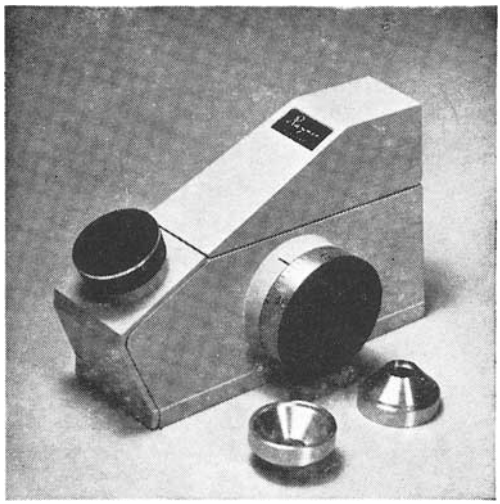

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Historical Note

The Gemmological Association of Great Britain was originally founded in 1908 as the Education Committee of the National Association of Goldsmiths and reconstituted in 1931 as the Gemmological Association. Its name was extended to Gemmological Association of Great Britain in 1938, and finally in 1944 it was incorporated in that name under the Companies Acts as a company limited by guarantee (registered in England, no. 433063).

Affiliated Associations are the Gemmological Association of Australia, the Canadian Gemmological Association and the Rhodesian Gem and Mineral Society.

The *Journal of Gemmology* was first published by the Association in 1947. It is a quarterly, published in January, April, July, and October each year, and is issued free to Fellows and Members of the Association. Opinions expressed by authors are not necessarily endorsed by the Association.

Notes for Contributors

The Editor is glad to consider original articles shedding new light on subjects of gemmological interest for publication in the *Journal.* Articles are not normally accepted which have already been published elsewhere in English, and an article is accepted only on the understanding that (1) full information as to any previous publication (whether in English or another language) has been given, (2) it is not under consideration for publication elsewhere and (3) it will not be published elsewhere without the consent of the Editor.

Articles published are paid for, and any number of prints of individual articles may be supplied to authors provided application is made on or before approval of proofs. Current rates of payment for articles and terms for supply of prints may be obtained on application to the Secretary of the Association.

Although not a mandatory requirement, it is most helpful if articles are typed (together with a carbon copy) in double spacing on one side of the paper, with good margins at sides, top and foot of each page. Articles may be of any length, but it should be borne in mind that long articles are more difficult to fit in than short ones: in practice, an article of much more than 10 000 words (unless capable of division into parts or of exceptional importance) is unlikely to be acceptable, while a short note of 400 or 500 words may achieve early publication.

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No. 4
October, 1980

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THE JOURNAL OF GEMMOLOGY

and

PROCEEDINGS OF THE GEMMOLOGICAL ASSOCIATION OF GREAT BRITAIN

GEMMOLOGICAL ASSOCIATION
OF GREAT BRITAIN
SAINT DUNSTAN'S HOUSE, CAREY LANE
LONDON, EC2V 8AB

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THE JOURNAL OF GEMMOLOGY
AND PROCEEDINGS OF THE GEMMOLOGICAL ASSOCIATION OF GREAT BRITAIN

Vol. XVII No. 5 JANUARY 1981

NOTES FROM THE LABORATORY

By A. E. FARN, F.G.A.
The Gem Testing Laboratory of the London Chamber of Commerce and Industry

Just before starting a talk to one of the Branch meetings of the Gemmological Association we had an informal chat among ourselves. It seemed that an argument or discussion had taken place earlier on the rights and/or wrongs of a decision on a gemstone. One member in particular wanted to know *which* instrument I would first use on testing a sapphire.

Not wishing to be drawn in this instance (since I was fully informed on background details) I answered truthfully that the first test or testing was done automatically by eye upon opening a stone paper and noting the colour of the gemstone. 'The first impact of a gemstone is its colour'.* This, of course, presumes a working knowledge of, or experience in handling, stones and/or pearls. There are many non-F.G.A. merchants and dealers who know when a stone *looks* wrong or the colour is wrong. Frankly not many synthetic sapphires look quite right—certainly by colour alone they

*See A. E. Farn, The First Impact of a Gemstone, *Z.Dt.Gemmol.Ges.*, 1979, 28(4), 188-90.—Ed.

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look wrong, *too* good, or empty centres—something indefinable but enough to arouse one's suspicions. Not many pearl dealers will look too long at a cultured pearl necklace before deciding that it *looks* wrong. An even colour, matching throughout, nuances of sheen influenced by the nuances of mother of pearl serve to arouse suspicions. Perhaps the most dangerous aspect of a gemstone is that betrayer of acumen—the prospect or possibility of a very handsome or quick profit?

Not long ago we had in to test a largish, cushion-cut, native-cut, red stone looking like a possible fine garnet or red spinel. It didn't look like a ruby of Siam or Burma origin or Siam or Burma colour for that matter—but it *did* look like a natural red stone. It did *not* look a synthetic ruby—but it was! First examination with a lens and bench lamp over white mat paper showed distinct curved

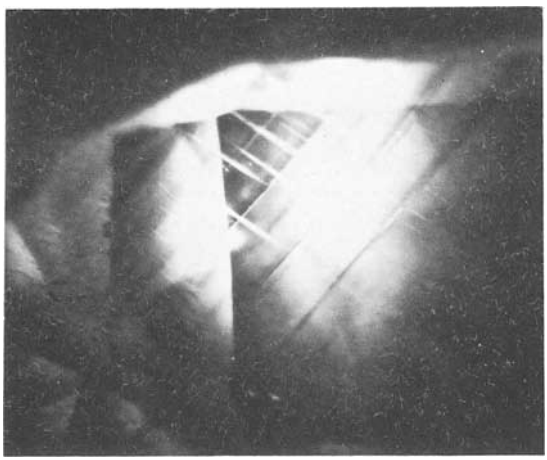

FIG. 1. Twin planes in a synthetic ruby.

lines sideways through the rather heavy belly of the stone. It was carrying quite a lot of weight below the girdle. Through the table one could glimpse an effect of twin planes not just in one direction but crossing each other. Using a microscope, the effect was very strongly seen. Had the stone been mounted as a ring with perhaps a border surround of small diamonds, it would have been very easy indeed to be fooled by the crossing twin planes. The ring setting would have limited the view and what could have been seen would

be sufficient to indicate a natural stone. However the colour did not look quite like ruby and so we decided a photograph would be of interest (see Figure 1—photograph by K. V. Scarratt).

* * *

Very recently we received a Byzantine style necklace to test. It consisted of a flexible flat gold collar adorned with enamelling, supporting a slightly tapering graduated series of baroque (but regularly so) drop-shape, opaque, brown/terra-cotta beads, a few with a pearly lustre—the beads being elegantly mounted with a festoon effect. One of my colleagues undertook the test and after some time took a small dental x-ray film of a section (Figure 2). The result was most rewarding and satisfying. The structures showed (as a radiograph) concentric lines following the shape of the beads with the text-book regularity and repetition of the cross section of an onion only better! I was quite surprised at such a sharp result i.e. such clear definition—particularly since a dental x-film was used. Normally we use a fine grain film, but there was a shortage of this particular film, of which we were awaiting supplies. We decided to use up our dental film to conserve our small stock of fine grain material. The results were those of a fresh-water pearl, because such non-nacreous pearls are usually course in growth and externally are more often than not of a muddy hue,

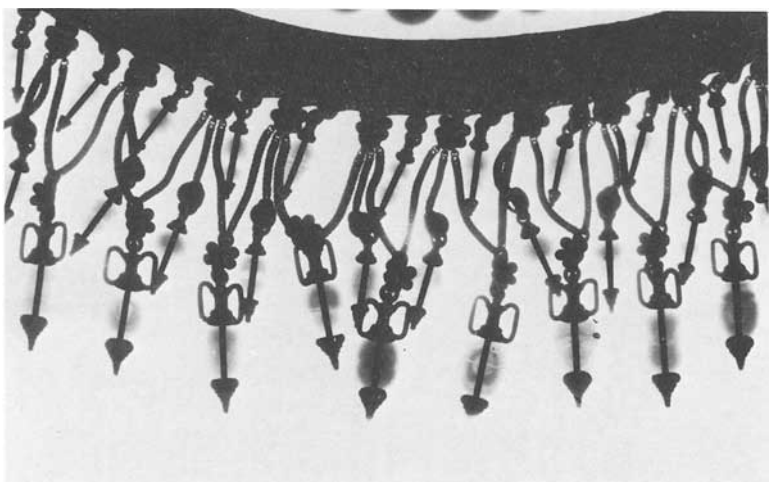

FIG. 2. Byzantine necklace—'cave pearls'. (Positive print)

ranging from dull off-white through to brown. These 'pearls', though, were a terra-cotta colour mostly; one or two had a pearly lustre, albeit non-nacreous, but most were opaque and granular and their shapes were peculiarly drop- or pendant-like, some with a grooved or belted exterior. They were all small 'pearls'; it was the apparent regularity of shape and colour which worried me. Could someone have possibly collected so many poor-quality fresh-water 'pearls' with somewhat similar shapes *and colour?* I doubted it—we did a very very discreet microchemical test to prove a carbonate reaction, which was positive. This didn't help really, because pearls are carbonates. Then we studied the surface structure more carefully, and the penny dropped! Of course they were carbonates! Of course they would show perimeter structure lines. Their shapes added up to stalactitic 'cave pearls'.*

The sharp line structures are, I believe, due to trace iron in the water which passed through the limestone to form stalactites in caverns below.

* * *

I used to have quite a bit of trouble in the 'black-out' during the War. It took me quite a time to become dark-adjusted. Somewhat similar conditions occurred in a 'white-out' recently in the Laboratory. As you will have gathered from previous 'Notes from the Laboratory', on occasions we have members of our section who, upon receiving consignments of (to them) new stones or new sources, invariably ask us to check them. We often receive a specimen for the Laboratory collection in this manner. One of our frequent donors and Laboratory-orientated gemmological members is the firm of E. A. Thomson. Andradite, herderite and diaspore† are among recent welcome gifts. Sometimes it is not necessarily a new stone but a new colour in a range which prompts the gift and the interest.

Ideally certain gemstones are colourless; it is only the imperfections of nature putting in a trace of chromium, iron, manganese, etc., which causes odd colours of ruby in corundum

*Walton, Sir James. (1952) *Physical Gemmology,* p.123 (Inorganic Limestones). Pitman, London.
Webster, R. (1975) *Gems,* 3rd edn, p.260. Newnes-Butterworths, London.

†See Kenneth Scarratt, Faceted Diaspore, *J. Gemm.*, 1980, XVII(3), 145-8.—Ed.

and shades of emerald green in beryl etc. Iron is said to be the impurity causing amethyst colour in quartz. However, when one thinks of opal, it is usually a 'play of colour' which springs to mind, whether basically white or black background or even Gidgee Opal (what an attractive stone!). In this case it is not an impurity causing colour so much as interference effects of light.

When recently we were shewn some specimens of *colourless opal* we were intrigued. These stones (we were shown four specimens) to me *looked* soft. Doubtless they were—we did not apply a hardness test. They were (in gemmological or jewellery terms) colourless, save for the faintest of milky blooms when placed on a black cloth background.

The four stones weighed 7.96 ct, 4.17 ct, 3.32 ct and 2.19 ct respectively. Their densities were taken by hydrostatic method in distilled water (with 0.5% detergent as a 'wetter'). We obtained densities ranging from 2.012-2.047.

Normally we use ethylene dibromide for our hydrostatic weighings, but since we were dealing with opal they would have floated in that liquid, which has a density of about 2.17 depending on temperature. Just for the fun of it I put the colourless opals into a tube of ethylene dibromide in which they floated, then diluted it with monobromonaphthalene so that they slowly sank. This didn't prove or disprove anything, except to demonstrate how closely they were together in their specific gravity. (There *were* fractional differences.) Using a filter-paper in a funnel, I poured off some of the liquid and the opals poured out as well. I didn't *see* them: I *heard* them 'clink' over the lip of the tube. Against the white filter-paper in a liquid nearly matching in refractive index, they disappeared in the 'white-out'' I mentioned earlier. The refractive indices were in fact 1.442, 1.443, 1.443 and 1.445.

I literally had to feel for the stones to find them. With natural opal—the normal type with a play of colour—there is a marked whitish fluorescence and phosphorescence under long-wave ultraviolet light. When these colourless opals were viewed under long-wave UV, they varied in their reactions. Under long-wave UV one was a bright green, two were a much more subdued hue, and one was practically white.

Under short-wave UV three were a very bright green and one was inert. There was no phosphorescence under long- or short-wave ultraviolet light. These were, of course, gemmologically

interesting and will add to collectors' colour ranges of opal. Work (or play) in the laboratory does not have to be all the heavy equipment, electronic calculators, etc.: it can be good gemmological fun, using simple instruments backed by gemmological knowledge. With these colourless opals being such a low density material, one seemed to get a large stone for a few carats.

[*Manuscripts received 23rd February, 1980.*]

JAPANESE SYNTHETIC EMERALDS?

By R. KEITH MITCHELL, F.G.A.

A small parcel of synthetic emeralds, said to be of Japanese origin, offered under the name 'Crescent Vert', recently came to my notice. The small stones in this sample (and there are indications that production is on a fairly large scale) are of very intense colour with the usual tendency to a rather bluish-green. Some stones were apparently clean, while others had a few of the wisp-like veils of healed cracks associated with Gilson and Chatham stones.

The two tiny stones I acquired both gave good chromium absorption spectra, and an RI of 1.568-1.564 was obtained with some difficulty from one of them. This stone was clean but had a dull khaki fluorescence under both long and short ultraviolet light. The second stone had a rounded table and no RI was obtainable on the refractometer. It had a single veil-like healed crack which, at 50×, showed a yellow-green, apparently crystalline, incrustation, possibly of flux material, between the long two-phase tubules over part of its area. Rather unexpectedly the writer could see no apparent fluorescence under UV, although a younger man claimed he could just see a very dull red. Through the Chelsea filter both stones gave a moderately strong, but slightly orange, red. Neither

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was nearly as bright or as orange as was a Chatham synthetic placed alongside them.

In the same week a stone-dealer friend asked my opinion of an exceptionally fine emerald of 1.50 carats which was quite clean under a 10× lens. The residual colour under the Chelsea filter was rather like that seen in the synthetics, and, although the immediate question was rather whether the dealer could afford to buy the stone at a substantial but not excessive price for a genuine emerald of that quality, my reaction was to advise that it should be bought only if it could be proved beyond doubt to be genuine.

The stone was eventually tested and had an RI of 1.574-1.570, so the birefringence was 0.004, the same as for the Japanese synthetics, even though the RI is higher. Birefringence as low as this is a probable indication that an emerald is synthetic, but in the case of a possibly important stone it was necessary to have confirmation. This was obtained by the Gübelin Laboratory, who tested for absorption in the deep infrared which is always present in hydrothermal and natural emeralds. It was absent, and the stone was beyond doubt a flux-fusion synthetic. SG, at 2.66, was also that expected of a synthetic.

Under high-power magnification this stone did show growth lines which were unlike those normally seen in a natural stone, but they were difficult to find and not easy to interpret. It was inert under long-wave ultraviolet light and had a normal strong chromium absorption spectrum.

At a time when new synthetic emeralds seem to be cropping up from a number of sources I feel that these two reports should be noted and fine colour emeralds of exceptional cleanness viewed with suspicion. In neither case did the stone give the bright residual colour normally expected of a synthetic emerald when viewed through the emerald filter.

[*Manuscript received 1st July, 1980.*]

'GEUDA SAPPHIRES'—THEIR COLOURING ELEMENTS AND THEIR REACTION TO HEAT

By HERBERT S. GUNARATNE, F.G.A.
Gemmologist-Chief Valuer, State Gem Corporation, Sri Lanka

The heat-treatment of gemstones has been practised for quite some time to improve the quality of the original colour or to bring out another colour which in such varieties is known or unknown to occur. This treatment is also sometimes meted out to remove turbidity which could be the result of certain inclusions. The detection of such heat-treated gemstones has only been by observation and since this process did not really concern the more expensive gemstones, being confined mainly to less valuable varieties, not much interest was taken to make such detection scientifically. Deducing by observation was good enough and was acceptable. Nevertheless the burning of 'rubies' (purplish red members of the corundum family) was also practised. Such stones were heated (burned) for considerable periods of time to remove the purplish tints present. By this process of heating, very good and favourable results are obtained and the result is deemed permanent and therefore acceptable in the trade. This factor of acceptance has kept the gemmologist and mineral-scientist from making the effort to find out if heat-treated stones could be scientifically detected. Today, it not only becomes more and more necessary to make such distinctions, but it also remains an open challenge to science to determine non-destructive means and ways of detection.

In Sri Lanka the process of burning rubies remains essentially a local adaptation. The stones are burnt embedded in an open charcoal fire, where the blowing is done either entirely by human effort or by mechanical devices. This process is continued for a specified period of time; sometimes it may be as long as forty or fifty hours. Before burning, care is taken to eliminate trapped liquid or gas in crevices or tiny fissures, if any, that may result in cracking up the stone on heating due to expansion. The stones are also given a thick coating of a local paste prior to burning. In this process, two factors are evident—some rubies react readily to the heating and become visibly clear and of a better shade of red, while

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others seem to be more stubborn and do not react to such treatment, or, if at all, the effect is very mild. The purplish tint in rubies is caused by titanium and/or iron in combination with chromic oxide, unlike the blue colour in the sapphire, which is caused by titanium and/or iron only. In instances where the titanium and the chromic oxide are responsible for the colour mixture, the temperature of the local charcoal system is inadequate to bring about any change in colour. On the other hand, where the colour mixture is attributed to chromic oxide and iron, this system readily works, removing the bluish tints and making the red colour caused by the chromic oxide more conspicuous. The theory behind this is the removal from or the concealing of the iron ion (which when present generally causes a dulling or dampening effect on rubies) behind the crystal lattice in the process of heating. The commonly accepted theory that a ruby once heated cannot be re-heated for better results is true on the basis of the above, as much higher temperatures will be required to cause a change in the colour mixture resulting from titanium and chromic oxide. Such high temperatures could produce the adverse effect of causing a purplish colour, as the titanium under such circumstances is most likely to produce a more intense blue, which in combination with the red of the chromic oxide could produce this effect. A further possibility is that such intense heat may cause it to lose its bluish tints altogether and produce the effect of 'geuda' in the ruby, while the reddish tints caused by the chromic oxide will persist. Webster in his book on *Gems** suggests the possibility of titanium producing the colour red on being subject to re-heating. Accordingly, it also remains possible under extremely rare circumstances for 'geuda' rubies to produce a better red on being subject to intense heat, provided the titanium present reacts favourably to produce the colour red rather than blue.

The cooking or baking of particoloured blue sapphires or deep blue sapphires which are very nearly black is also practised in Sri Lanka. These stones are baked for comparatively shorter periods of time, possibly for a few minutes only. The resultant gemstone is either one in which the existing colour patches get dispersed and distributed into regions that had no colour or the stone is made lighter in colour, thereby making it more transparent and pleasing.

**Gems*, by R. Webster, 3rd edn, p.354. London: Newnes-Butterworths, 1975.

Here again the results are permanent. Similarly the cooking of Australian blue sapphires has been practised both in Australia and Thailand, and today this is acceptable in the trade and is commonplace.

Of late an improvement of this process has been extended to the 'geuda' corundum in order to convert the 'geuda' into colour. During the last two or three years this system of burning 'geuda' has been widely carried out in Thailand using Sri Lanka's geuda corundum. Strangely enough, for some reason or other it is still maintained that Sri Lanka 'geuda' corundums are by far the more suited and superior raw material for this purpose. This process is now catching on fast in Sri Lanka and some Sri Lankan merchants are now engaged in this endeavour.

What is a 'geuda'? Not too long ago, buying and selling of 'geuda' stones was only in limited circles. 'Geuda' stones were a 'poor' merchant's merchandise, and these were selling very cheap. Today, however, the situation has taken a complete turn (for the better) and the 'geuda' stone is good business. 'Geuda' in gemstones was a quality that was detested and disliked and was a factor that brought down the value of a gem considerably in relation to accepted standards of evaluation, till such time as the heat-treatment process caught on and changed the standards. 'Geuda' in a gemstone is a milky white opaline character seen within and even outside the stone and is the result of a network of inclusions. In relevance to the text, it is a corundum with an excessive amount of titanium, very often in the form of the mineral rutile, arranged in relation to and conforming to certain crystallographic laws in the crystal structure of the host mineral. This could occur in any variety of the corundum family. The titanium in corundum is the essential ingredient that brings about the colour to such stones on heating. Examination under the microscope, or with other optical aids, or any other relevant analysis will undoubtedly reveal its presence. More sophisticated equipment could even provide a qualitative and quantitative analysis of the guest mineral and this would no doubt help the researcher, who would very much like to delve deeper into the more academic aspects of this problem of geuda heating. The milky white appearance in the texture is only an indication of the presence of the above inclusions, and this is presently the basis for the

selection of the suitable rough. Detailed examinations are not carried out for assessments of this nature.

Among geuda stones are different grades and qualities, and these are in different levels of demand according to how suited these would be for heat treatment. The ideal stones are considered to be the ones which have a very faint powder-blue tint, display a milky white sheen appearance, and which, when held against a light source, give the colour appearance of clean thin honey. Since this colour is similar to a thin flow of diesel oil the local term 'diesel geuda' is now widespread. Freedom from flaws and fissures is a prerequisite. Inclusions, other than geuda, if present should preferably be at a minimum. Liquid and gaseous phases, when present in stones that are to be heated, are detrimental, while completely healed cracks prove to be of little or no risk. Different qualities of rough react differently, and as such these have to be treated differently. Accordingly, in the selection of the rough stones for heat treatment human expertise is vital, as the extent of colour and the degree of success depends largely on the quality of the rough and how it is handled. The judicious examination of some successfully treated stones prompts us to infer that the process in itself is quite a success. Pale, fancy to rich deep blue colours have been obtained by this process. Right now, of course, information on the measure of success in relation to failure is scanty, and it remains impractical to work out the ratio of success in relation to failure.

From the description of the ideal geuda stone (the most suitable for heat treatment) it is evident that it is chemically an oxide of aluminium with a higher than normal (though still negligible) percentage of impurities occurring as titanium, very often in the form of the mineral rutile. Rutile is the guest mineral in corundum crystallized from the chance impurity titanium, which does not in any way alter or affect the chemical formula of corundum nor its crystal lattice, and which during the genesis of corundum has been an associated constituent. The geuda corundum, too, is essentially an allochromatic mineral.

Dr Gübelin records that rutile in corundum could occur syngenetically and epigenetically.* Under the circumstances there is enough reason to think that it is more the syngenetic rutile (that has undergone rapid cooling and consequent crystallization) which is

**Internal World of Gemstones*, ABC Edition, Zurich, 1974, pp.52, 86-8, 112-13.—Ed.

primarily responsible for producing Geuda corundums that are most susceptible to heat and the ones that would invariably react with favourable results. For rutile to be syngenetic in corundum, it has to have its genesis almost simultaneously with that of corundum. To create such a development the growing crystal of corundum during formation engulfs a fair quantity of mother liquid rich in titanium. This quantity of liquid is soon trapped within the solidifying host and is also subject to a rapid drop in temperature. This drop in temperature consequently hastens the process of crystallization, producing microscopic acicular rutile from the titanium-rich mixture. This rapid crystallization process does not promote adequately favourable conditions for the full manifestation of titanium as a colouring agent, but instead these crystals soon fit into place within the host in relation to crystallographic laws. The result is an apparent milky-white geuda corundum. The titanium ions in such stones, if subsequently subject to prolonged intense heat at temperatures close to the melting point of rutile, would invariably re-adjust and re-align themselves within the host. In the process, the titanium ions being true to their function as a colouring element, would even bring out their hidden colouring properties and also impart this colour to the host mineral. This transformation could take place in a metamorphic phase in nature or in the laboratory provided the conditions are right.

In the case of corundum whose rutile inclusions are epigenetic in origin, it is most likely that the guest element has had the greatest possible opportunity to manifest itself in producing the maximum possible colour, once again conditioned by the favourability of the crystallization process. The inference is that if the rutile in corundum, whether of syngenetic or epigenetic origin, is subject to very favourable cooling and crystallization processes in nature, then the colouring process is complete. Such stones could not be re-heated to advantage in the laboratory.

The producing of geuda corundum in nature could be a direct result of a hastened process of crystallization of the guest mineral. Accordingly the revelation of the genetic history of rutile in corundum is of paramount scientific importance for the greater success of treating geuda in the laboratory.

Titanium and iron are both colouring elements to which is attributed responsibility for imparting colour to blue sapphires.

These elements have been found in varying proportions as insignificant impurities which are jointly or by themselves responsible for the colour. In the geuda of the ideal stone the rutile present has remained, so to say, in a state of inactivity, in the sense that its true function as a colouring element has not fully revealed itself. On the other hand, the faint powder-blue tint in such a stone could be attributed to iron present in some form, which, if subject to heat, totally disappears at certain temperatures, making the stone visibly whitish. On being subject to still higher temperatures (temperature closer to the melting point of titanium), the titanium begins to melt within the host while the host is still in a solid state. In this state the atoms of the rapidly melting titanium not only begin to readjust themselves once again in relation to crystallographic laws, but also to bring out its colouring properties which gradually diffuse into the host. This really is the critical temperature—the temperature at which the maximum colour is produced and diffused into the host corundum. At this point, expert handling should control the temperature. Overheating is harmful, as it would tend to destroy the crystal pattern of the host, producing globular and glassy stones of an amorphous form.

In Sri Lanka three methods of heating are adopted with the same object in view, i.e. the imparting of colour to milky-white geuda corundum. The difference in these three methods lies only in the nature of firing. The first is the use of gas, the second the use of dieselene, while the third is heating by electricity. What is common to all three methods is that the stones to be heated are given a thick coating of a local paste. The duration of heating is variable according to the temperatures achieved and the nature of the rough selected for the purpose. The oil and gas furnaces are turned out of metal, locally, and their inner walls are lined with fire-bricks and fire-clay, while the electric furnaces are of foreign design, manufactured to withstand high temperatures. All three methods have invariably achieved the same end result—i.e. the transformation of geuda into colour. Theoretically the results should remain permanent unless and until re-subjected to intense heat.

It now remains a matter for the mineral scientists and gemmologists alike to determine ways and means which are non-destructive to distinguish between a heat-treated geuda corundum and its untreated counterpart. So far only observations have been

made backed with no scientific exactitude. However, with these observations it now seems possible to a very great extent to determine the differences between the heat-treated geuda corundum and its untreated counterpart. A substantial amount of reasoning and shrewd observation are right now the only criteria to make this distinction; some, if not all, have scientific attributes, which should and could be proved positive, it is hoped in the very near future.

In the earlier part of this article I have already theorized on the nature and genesis of rutile in geuda corundum and an attempt was made to tie up certain types to their possible favourable susceptibility to heat. Experimentation in this direction could reveal more about the genetic history of rutile in milky-white geuda corundum. This, though it may sound a little too academic, seems to me the most rational approach towards understanding the problem before offering a solution.

In addition to the burning of milky-white sapphires, the mention of the treatment of two other varieties of corundum seems relevant at this juncture. These are particoloured blue sapphires with even the faintest touch of blue within the stone or outside and the very pale yellow geuda sapphires with scattered streaks of blue. These react very favourably to heat, and the resultant colours are extremely good, being blue and showing uniformity in its distribution. The degree of success in this group of stones in comparison to the milky-white geuda sapphires is very high, and as such these are in greater demand.

The following are the observations made in a representative range of successfully heated geuda corundum for the conversion of geuda into colour.

1. All successfully treated stones have unfailingly indicated the presence of diffused or 'blotchy' colour bands or zones giving the general impression of colour migration within the stone. This colour diffusion has given rise to a tendency to reduce the sharpness of the growth lines seen in these corundums. This is most apparent in deep blue stones, fading out gradually to be less apparent in stones of lighter shades. This could be due to the lack of colour contrast.
2. Certain stones give the appearance of the presence of 'woolly' white isolated patches or small white flaky spots

giving credence to the possible thought that these could be residual titanium that has as yet failed to bring out its blue colour for some reason or the other. It is probably still in a state in the process of conversion.

3. The stones so far examined failed to reveal the presence of zircon crystals which are considered typical in Sri Lanka blue sapphires. It seems very likely that the raw materials so far used have been free from such inclusions.
4. There is a complete absence of any traces of percolation deposits in minute fissures or cracks causing stains in the stone.
5. Completely healed cracks have been observed in several stones. Evidently these could not cause any damage to the stone as a result of different degrees of expansion as the infillings are wholly of corundum material.
6. Exposure to short wave ultraviolet radiation revealed that a large majority of stones were totally inert while a fair amount of still others on exposure to long wave ultraviolet radiation showed a dirty brown to brownish red glow. Of a selected one hundred stones examined (both rough and polished) only four deep blue polished stones displayed a powder-blue glow on exposure to short wave ultraviolet radiation.
7. Tests carried out to determine their optical and physical constants showed nothing different to their untreated counterparts.
8. The colour absorption pattern as determined by the hand spectroscope was found to be identical with the untreated. This however, was expected as no new colouring elements were introduced.

While the above observations could draw a distinction, it should not be expected that a case study of this nature is by any means complete. Many more stones will have to be observed, more so in their rough pre-heated state. If efforts to establish scientific reasoning are concentrated on observations 1 to 5 above, then I feel some conclusive finality could be reached.

An article of this nature undoubtedly leaves behind a series of unanswered questions some of which are:

i. What are the physical changes that are brought about to geuda sapphires on being subject to intense heat and how

could such changes be recognized and distinguished scientifically.

ii. How could one predetermine the critical temperature in relation to the nature and quality of the raw material at which the transformation takes place.

The foregoing conclusions have been arrived at by me under certain limiting circumstances. Most of the examinations were carried out on already treated stones, given to me by courtesy of private organizations that have adopted this heat treating process for strictly commercial purposes and not for scientific research. Further, my observations were confined to a representative collection of successfully treated stones and an adequate amount of rough pre-heated geuda has not yet been subject to such a scrutiny.

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DIRECT RADIOGRAPHY OF DIAMOND JEWELLERY

By A. J. MOULE, Ph.D., F.G.A., F.G.A.A., and G. BROWN, Dip.D.T., F.G.A., F.G.A.A.

Diamond's transparency to a beam of x-radiation has been known since the late nineteenth century (Doetler, 1915). Since that time, it has been demonstrated that diamond is the only gem mineral that is completely transparent to x-radiation (Anderson, 1971; Webster, 1975; Brown, Moule and O'Neil, 1975) and as such will not leave any image on high speed radiographic film exposed to x-radiation. While most gemmological textbooks claim that diamond can be readily discriminated from its imitations by this property, and while several x-ray units have been specifically designed for direct radiography of diamonds and of pearls*, the potential use of x-rays for the detection of mounted and unmounted diamonds has not

*GAAJ Diamond Penetrating X-ray Apparatus (Gemmological Association of All Japan).

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been adequately emphasized. This lack of emphasis has probably occurred because x-radiation sources are usually considered specialized instruments for the exclusive use of research laboratories and the medical and dental fraternity.

Fundamentally, x-radiation obeys the laws of visible light and will affect a photographic film in the same way as visible light. Additionally, x-rays possess some properties not possessed by visible light — short wavelengths (0.01 — 0.05 nm) enabling penetration of materials which would reflect or absorb visible light, and high energy capable of producing biological injury.

Provided proper precautions are taken (Brown, 1979), we would suggest that the use of small x-ray machines, such as routinely used in dentistry, coupled with the utilization of high speed dental x-ray film*, can be simply and effectively used for the positive discrimination between diamond and its imitations and simulants. This technique is equally applicable for both mounted and unmounted stones.

Modern dental x-ray units are manufactured to operate within the 50-90 kV/5-20 mA range and to produce x-radiation with wavelengths which range from 0.01 to 0.05 nm. The x-ray unit used for these studies† operated at a fixed 50 kV/7 mA which could be delivered in single exposures from 0.1 to 5 s. A diaphragm contained within the head of the x-ray unit limited the radiation beam to a diameter of 58 mm at a source-to-film distance of 25 cm. This machine proved to be an effective and reliable source of x-rays for the purpose of demonstrating the radiolucency of diamond. High speed dental x-ray film was chosen as it produced radiographs of good diagnostic quality with extremely short (0.1 to 0.5 s) exposure times. Development and fixation times used for the exposed radiographs were those recommended by the manufacturer.

UNMOUNTED STONES

Unmounted stones could be rapidly examined by placing them face down on a suitably sized x-ray film packet‡ and radiographing them at a source-to-film distance of 25 cm and an exposure time of 0.1 to 0.5 s.

*Kodak DF-58 or DF-54 Ultra-speed Dental Periapical X-ray film: Agfa-Gavaert M2 Ultra-speed Dental Periapical X-ray Film.

† Siemens Heliodent 50 dental x-ray machine.

‡Kodak DF-45.

Even at very low exposure times, e.g. 0.1 s, the radiographic images of diamond always appeared completely radiolucent (dark) whereas its imitations and synthetics were comparatively radio-opaque (light) (Figure 1). While it was not possible to discriminate accurately between the different imitations and simulants, diamonds could always be positively identified. Most diamond imitations and synthetics were completely radio-opaque. Synthetic spinel and synthetic sapphire were two exceptions. While these stones always left an image on the radiographic film, the image they produced was not as distinct as that produced by other diamond imitations and simulants. (Figure 1)

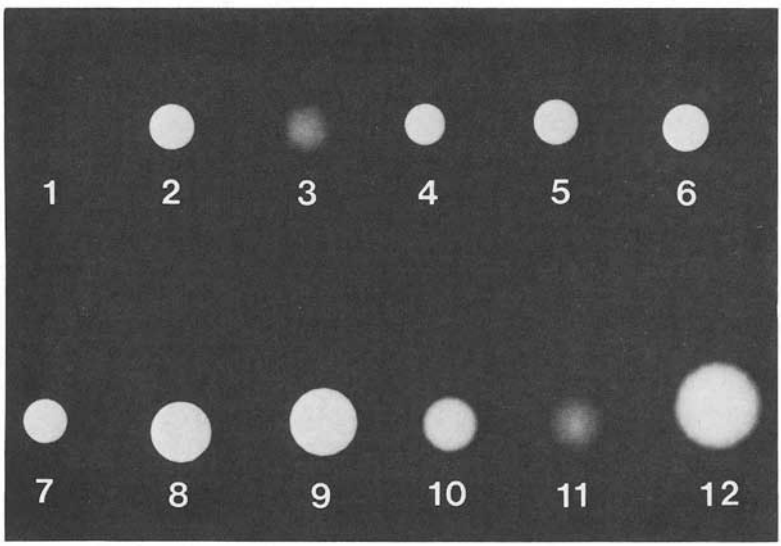

FIG. 1. Radiograph of a diamond and some of its imitations and synthetics demonstrating the comparative radiopacity of (1) Diamond (2) Gadolinium gallium garnet (GGG) (3) Synthetic spinel (4) Yttrium aluminium garnet (YAG) (5) High zircon (6) Cubic zirconia (Yttrium stabilized) (7) Cubic zirconia (Calcium stabilized) (8) Strontium titanate (9) Synthetic rutile (10) Quartz (11) Synthetic sapphire (12) Crown Glass. (Exposure time – 0.2 s)

MOUNTED STONES

A literature search has failed to elucidate a detailed description of any technique suitable for the use of x-rays in the detection of diamonds mounted in jewellery. Most diamonds mounted in jewellery have some portion of their pavilion facets not covered by the metal of the mount. If the film could be so positioned that x-rays could pass uninhibited in a straight line through the stone to

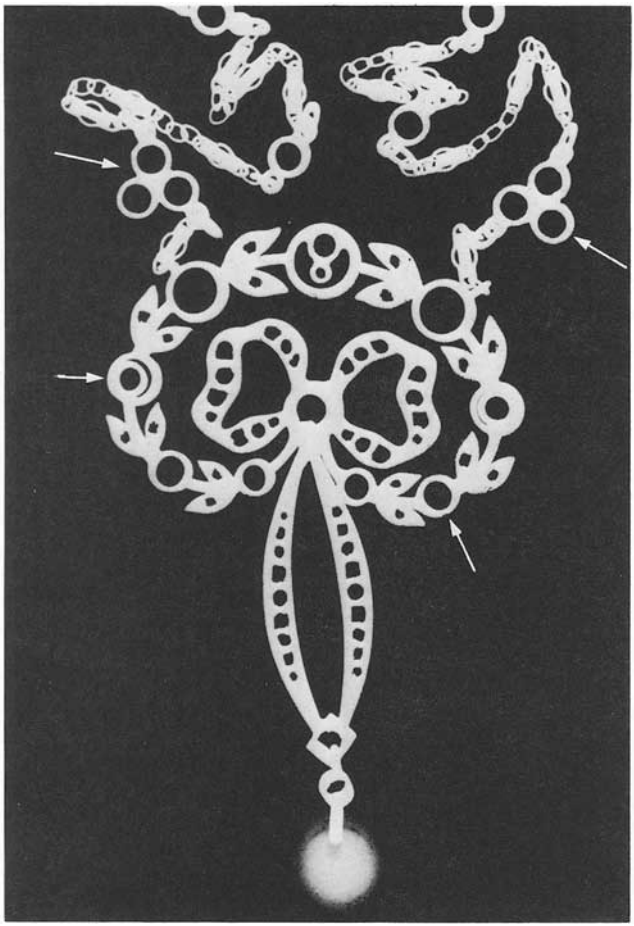

FIG. 2. Radiograph of a pearl and diamond necklace showing the transparency of diamond (arrowed) to x-rays.
NOTE: The radiograph also illustrates the classical radiographic appearance of a nucleated cultured pearl (Brown, 1979).
(Exposure time — 0.5 s)

the film, then a positive identification of the mounted diamond was possible.

(A) *Flat pieces of jewellery,* e.g. pendants and brooches, could be placed directly onto a film of appropriate size and radiographed. On the resulting developed x-ray film diamond appeared completely radiolucent (dark), whereas the mounting metal and the diamond simulants and imitations appeared comparatively radio-opaque (white) (Figure 2).

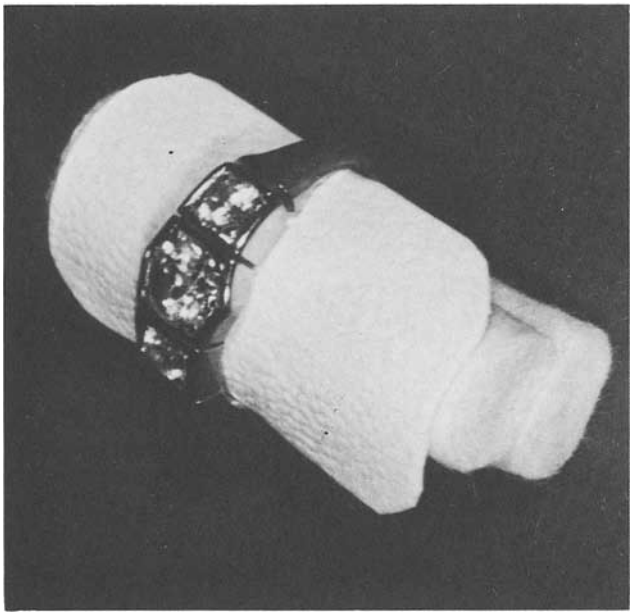

FIG. 3. Photograph of a diamond and cubic zirconia ring in which a small dental periapical film has been positioned inside the ring shank.

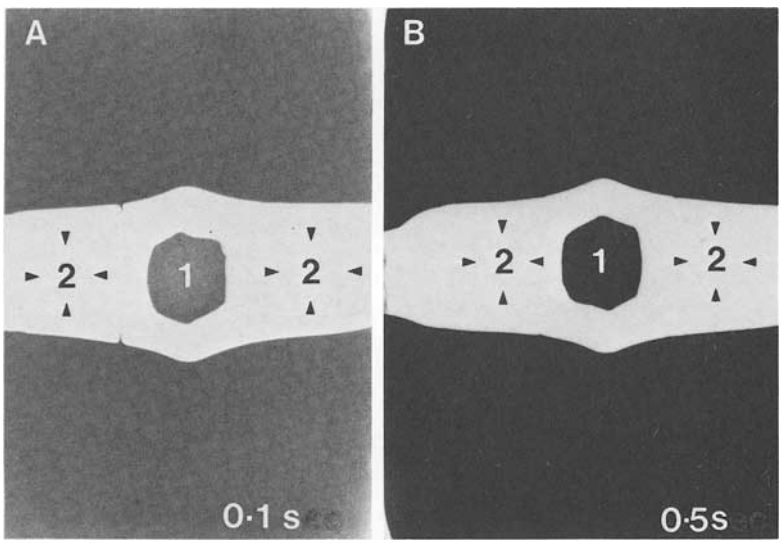

FIG. 4. Radiographs of the ring in Figure 3 illustrating the radiolucent image of diamond (1) and the radio-opaque image of cubic zirconia (2) (arrowed) at different exposure times. (A–0.1 s; B–0.5 s) The metal mounting was completely radio-opaque.

(B) *Diamonds mounted in rings* posed a further problem which could easily be overcome by the use of the smaller periapical type dental x-ray film*. These films are small enough to be curved and placed into a ring and adapted to the undersurface of the mount (Figure 3). Provided the x-rays passed uninhibited through the stone, (i.e. provided the undersurface of the stone was not completely covered by the metal of the mount), a radiographic image was formed which allowed positive identification of the diamond (Figure 4).

SUMMARY AND CONCLUSION

1. A simple technique for the identification of diamond using standard commercially available dental x-ray facilities has been described.
2. While it is not possible to discriminate accurately between the different diamond imitations and simulants by direct radiography, diamonds could always be positively identified.
3. In view of the speed and positive nature of this technique in establishing the identity of diamond, and in view of the advent onto the market of newer and better diamond imitations, it is suggested that direct radiography should be playing an increasingly important role in the positive discrimination of diamond from its imitations and simulants.

ACKNOWLEDGEMENTS

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*Kodak DF-54.

RAMAN SPECTROSCOPY AS A GEMSTONE TEST

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INTRODUCTION

A variety of spectroscopic techniques can be used as non-destructive tests for gemstone identification. Visible and infrared spectroscopy are widely used in technology and can be most helpful, at times, in gemmology. Visible spectroscopy in the form of the hand spectroscope is widely used,(1) and infrared spectroscopy can, as one example, identify the presence, as well as the nature, of the water in emerald.(2) The various magnetic resonance techniques have been recently described in this *Journal*(3) and the full range of all such techniques has been covered in a recent text by Crooks.(4)

With the ready availability of lasers, Raman scattering has now joined the growing list of non-destructive tests which can be applied to gemstones. It has the convenient characteristic that only one surface of a material needs to be accessible to identify the nature of the material. The results depend on the chemical constitution and crystal structure. Even doublets can be identified merely from an examination of the table facet. An outline of the principles behind the technique, the practice, and some typical results are presented.

I wish to thank Dr J. E. Griffiths for permission to use the spectra which we have published elsewhere in an investigation aimed at light-coupling prisms for thin-film studies.[5] For this use a high refractive index and optical transparency are essential; since these are also characteristics of gemstones, in particular diamond imitations, such materials were tested accordingly.

I. THE NATURE OF OPTICAL ABSORPTION AND SCATTERING

The absorption spectrum of an emerald is shown in Figure 1. In the visible (0.4 to 0.7 micrometres)* and adjacent regions of the electromagnetic spectrum are found absorptions due to the chromophores, such as iron and chromium, which cause colour in

*i.e., 400 to 700 nm, or 4000 to 7000Å.—Ed.

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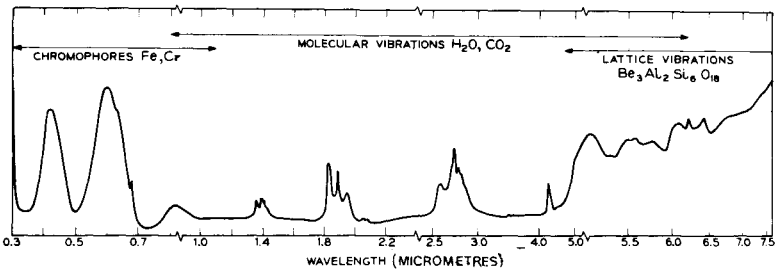

FIG. 1. The visible and infrared spectrum of an emerald.

beryl[2] (the causes of colour in gems and minerals have been described elsewhere[6]).

In the near infrared region there are seen absorptions originating from molecules such as carbon dioxide and water present in channels in the beryl structure. Figure 2 illustrates how these features arise. Consider a light atom attached to a massive structure, with the bond represented by a spring, as in Figure 2(a). Depending on how this bond is stimulated, it can oscillate in a stretching mode *s* or a bending mode *b* as in Figure 2(a). Each of these two modes will have its own oscillating frequency, the exact frequencies depending on the stiffness of the spring, i.e. the strength of the bonding, the masses of the atoms involved, and any constraints arising from adjacent atoms.

In a linear molecule, such as carbon dioxide, CO_2, there are three possible modes: the symmetrical stretching of Figure 2(b), the symmetrical bending of Figure 2(c), and the antisymmetrical stretching of Figure 2(d). Because of subtleties involving the 'polarity' produced by charges on the atoms as well as the 'polarizability', the symmetrical stretch does not absorb in the infrared, but the other two vibrations do absorb, i.e. they are *infrared active.*

In a bent molecule, such as water, H_2O, there are again three modes, but this time all three are infrared active. When infrared radiation falls on a beryl containing such water and carbon dioxide molecules, those frequencies corresponding to the infrared active bond bending and stretching modes will be absorbed, leading to the spectral features seen in the central region of Figure 1.

The features seen at the extreme right of Figure 1 and way beyond, arise in a similar fashion from vibrations in the bonds between the atoms involved in the beryl framework itself, i.e., in

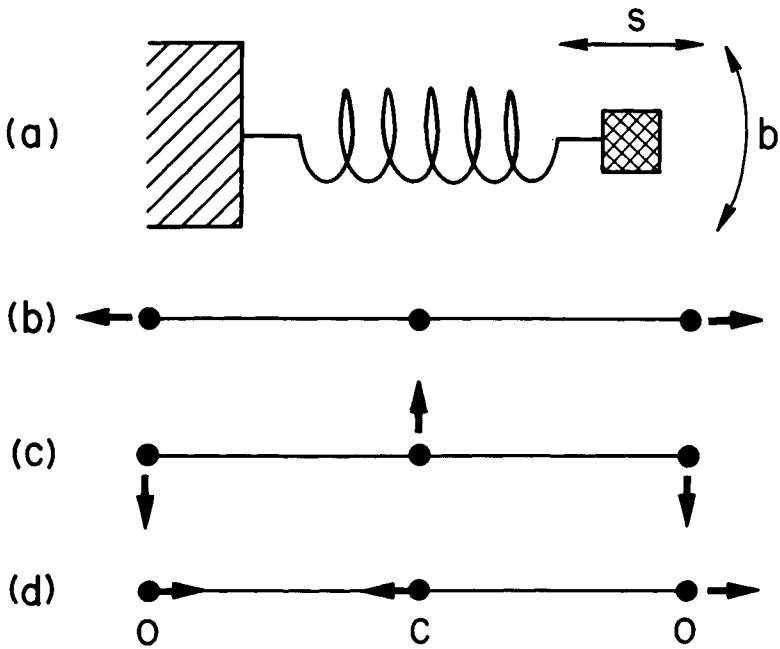

FIG. 2. The stretching mode *s* and the bending mode *b* of a bond represented as a spring at (a) and the three vibration modes of the linear CO_2 molecule: the symmetrical stretch (b), the symmetrical bend (c), and the antisymmetrical stretch (d).

the $Be_3Al_2Si_6O_{18}$. Since this is a large framework with heavier atoms, the vibrations occur at lower frequencies, i.e. longer wavelengths, than do those of the water molecule. Again, it is only the infrared active modes that will absorb light.

The infrared spectrum can be used for identification, but the substance to be tested must be available either as a fine powder or in a thin slab with approximately parallel faces, neither form being convenient for gemstone testing. In addition, measurements in the far infrared region are difficult to make. Collections of spectra have been published for inorganic and mineral substances.[7]

When light of a frequency different from that absorbed falls on a material, a small amount, perhaps one hundred-thousandth of it, is scattered in *Rayleigh scattering*. This is independent of the nature of the scattering material, the intensity depending on the size of the atoms and molecules involved. It is strongly wavelength-dependent and results, e.g., in the scattered blue of the sky.[6]

There is a second type of scattering which is even weaker, perhaps only one ten-millionth of the incoming light, and accordingly is best observed by using the very intense light beam from a laser. This is the *Raman effect,* or *Raman scattering,* first reported[8] in 1928 by Sir Chandrasekhara Venkata Raman (1880-1970) shown in Figure 3. The Raman-scattered light is shifted a little from the frequency of the light beam to a lower frequency, the so-called 'Stokes peaks' ('anti-Stokes peaks', shifted to a higher frequency, are even weaker and are rarely used).

FIG. 3. Sir C. V. Raman, who was awarded the Nobel Prize in 1930. *(Copyright 1980 by the American Chemical Society: used by permission.)*

The process involved in the Raman effect involves the excitation of a vibration, as in the absorption spectrum. In this case, however, the energy is extracted from light having a much higher energy than that corresponding to the excited vibration, and the scattered light has therefore a lower energy; it is the Raman shift, i.e. the difference between exciting and scattered light

energies, that depends on the nature of the atoms and the bonding involved in the structure.

In the case of carbon dioxide, the mode which is not infrared active is *Raman active,* but in the case of water, all three modes are both infrared and Raman active. There are many advanced texts dealing with Raman spectroscopy; a typical one is that by Long.[9]

The laser beam used for producing Raman scattering can be almost any frequency, just as long as it is energetic enough and does not result in fluorescence. Usually, lasers in the visible region are used and a choice of frequencies is desirable. There are polarizing effects in Raman spectroscopy, just as there are with visible light and infrared radiation absorptions (dichroism, etc.); these are controlled by the symmetries of the vibrations involved.

Consider a laser operating in the blue-green at 5145 Å (0.5145μm). This light has a wavenumber of 19 436 cm^{-1}. If we subtract from this up to 2000 cm^{-1}, a typical useful region of interest (corresponding to the infrared region from 5μm on out) we obtain Raman scattered light from the laser light out to 17 436 cm^{-1}, corresponding to 5735 Å (0.5735 μm) in the green. Accordingly, the Raman active vibrations in the infrared are seen in the blue-green to green Raman-scattered region and a good resolution spectrometer is necessary. In this way investigation can be shifted from the relatively difficult infrared to the easier visible region. This only became possible with the ready availability of powerful lasers; typically a laser output power level of 1 watt may be used.

II. Experimental

The various samples tested are summarized in Table 1 and included natural and synthetic diamonds, diamond imitations, a number of beryls, a topaz, and two doublets.

Raman spectra were obtained at room temperature as shown in Figure 4, using a back-scattering geometry in which the beam from a Spectra-physics Model 164 argon ion laser at 5145 Å entered the front face of the various gemstones at near Brewster's angle. The scattered light was focused as shown into the collection optics of an Instruments S. A. Ramanor HG2S spectrometer and detected by a Hammamatsu R928P photomultiplier detector. In general, the crystallographic axes of the samples were not known and therefore the scattered light was not polarization analysed. The spectra are

TABLE 1

Gemstones Examined (Synthetic unless otherwise specified)

Compound	Formula	Source	Comment
Diamond	C	South Africa	Natural, colourless, Type I
		General Electric Co.	Yellow (nitrogen containing)
		General Electric Co.	Blue (boron containing)
		General Electric Co.	Colourless (pure)
Cubic zirconia*	$ZrO_2(Y_2O_3)_x$	Ceres Corp.	Skull melting
	$ZrO_2(CaO)_x$	Djevahirdjian S.A., Switzerland	Skull melting
	$ZrO_2(Y_2O_3)_x$	Lebedev Inst., USSR	Skull melting
Garnet	$Y_3Al_5O_{12}$	Airtron Corp.	'YAG', Czochralski pulling
	$Gd_3Ga_5O_{12}$	Airtron Corp.	'GGG', Czochralski pulling
Strontium titanate	$SrTiO_3$	NL Industries	Verneuil flame fusion
Rutile	TiO_2	NL Industries	Verneuil flame fusion
Sapphire	Al_2O_3	Djevahirdjian S.A., Switzerland	Verneuil flame fusion
Spinel*	$MgO.xAl_2O_3$ $x \sim 2.5$	Djevahirdjian S.A., Switzerland	Verneuil flame fusion
Quartz	SiO_2	Hot Springs, Ark., U.S.A.	Natural
Silicon carbide	SiC	Carborundum Corp.	High temp. furnace, transparent tan colour
Beryls*	$Be_3Al_2Si_6O_{18}.xH_2O$ $0<x<1$	—	—
Aquamarine	$x>0$	Brazil	Natural, contains Fe
Emerald	$x=0$	Chatham Co.	Contains Cr, flux
Emerald	$x>0$	Linde Co.	Contains Cr, hydrothermal
Yttralox*	Y_2O_3(10% ThO_2)	General Electric Co.	Stabilized, hot pressed
Topaz*	$Al_2SiO_4(F,OH)_2$	Unknown	Natural, pale blue
Doublet #1	$C+ZrO_2(Y_2O_3)_x$	Fabricated	Natural diamond crown over cubic ZrO_2 pavilion
Doublet #2	$Al_2O_3+SrTiO_3$	'Nifty Gem'	Sapphire crown over $SrTiO_3$ pavilion

*Composition variable

thus generally 'I_{HU}' where H refers to the horizontal polarization of the incident exciting light and the U refers to the unanalysed scattered light of intensity I.

The one exception to this involves cubic zirconia, where it was important to show that changes in the relative amplitudes of some of the Raman bands as a function of the orientation of the various samples were caused by the effects of polarization and orientation, and not due to compositional changes.

Representative spectra are shown in Figures 5 to 8. Experimental parameters used for Figures 5 to 8 included: laser power at 5145 Å ranged from 50 to 1000 mW, spectral slit widths of

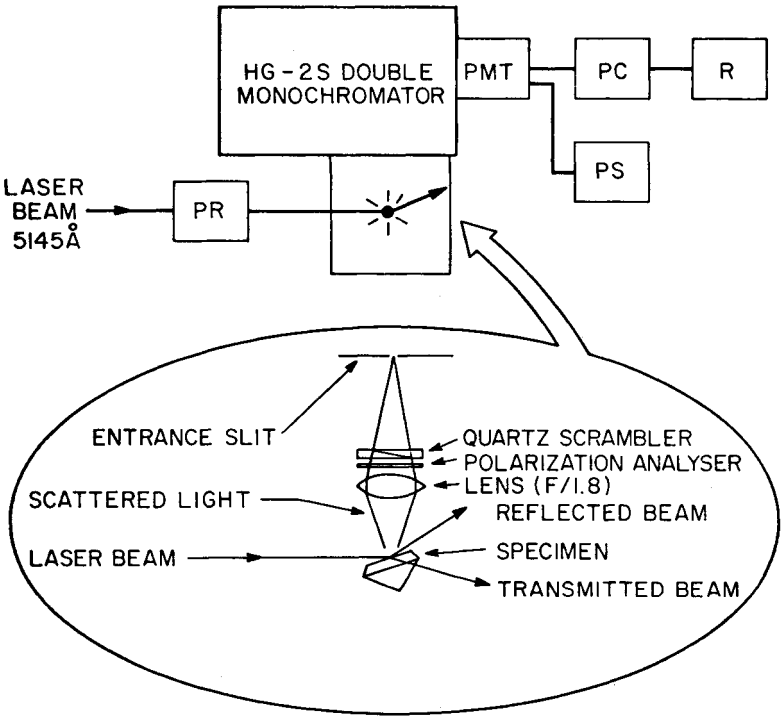

FIG. 4. Raman scattering apparatus. PR = polarization rotator, PMT = photomultiplier tube, PC = photon counter, PS = power supply, R = recorder.

0.9 to 2.6 cm^{-1}, full-scale count rate 10 000 to 100 000 c/s, time constant 0.01 to 0.1 s, and scan rate 50 cm^{-1}/min. Exact details are given elsewhere.[5] The cm^{-1} (wavenumber) scale gives the *Raman Shift* which is the change in frequency between incident and scattered light (conversion factors to other energy or to wavelength units have been given elsewhere[10]).

III. Results and Discussion

Diamond—The Raman spectrum of natural diamond was first observed by Raman[11] and it is indistinguishable from that of the synthetic variety. Both show only a single intense narrow Raman band centred at 1332 cm^{-1}. The spectrum of diamond, shown in Figure 5, is typical for a natural white stone, a synthetic yellow, a synthetic blue and a synthetic white diamond.

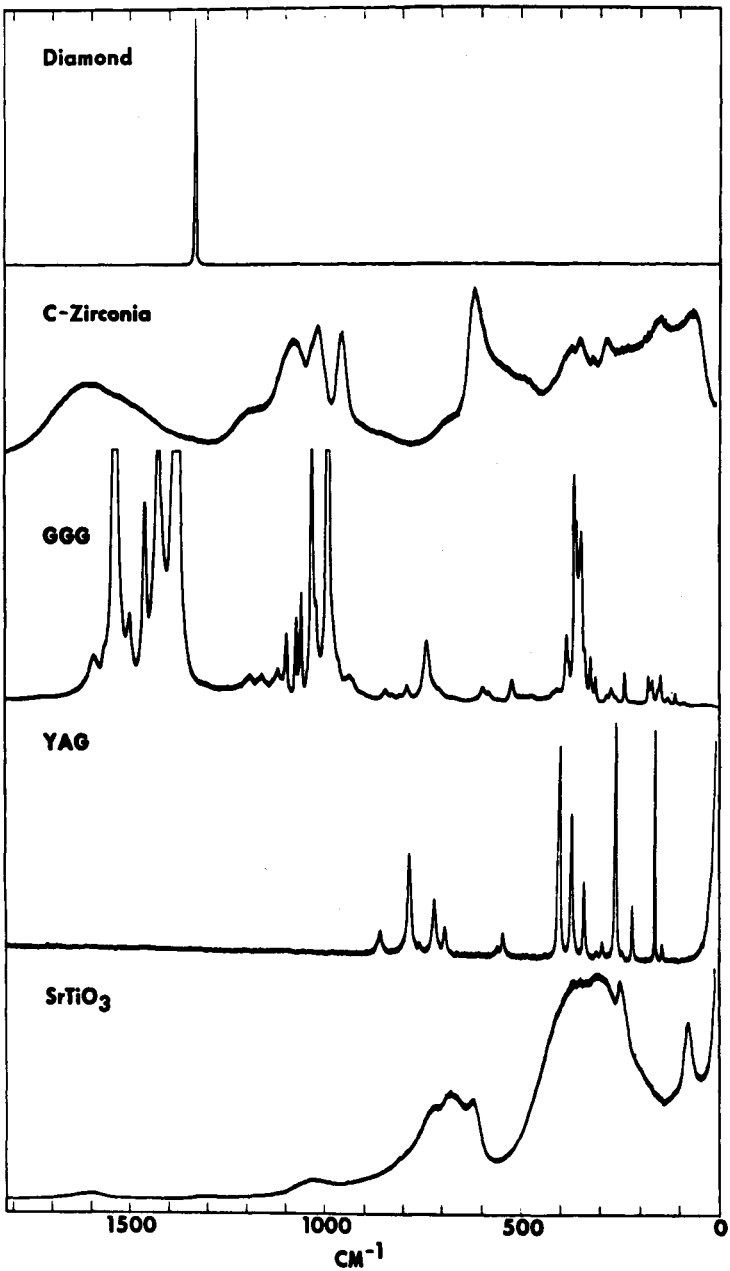

FIG. 5. Raman spectra of diamond and some diamond imitations.

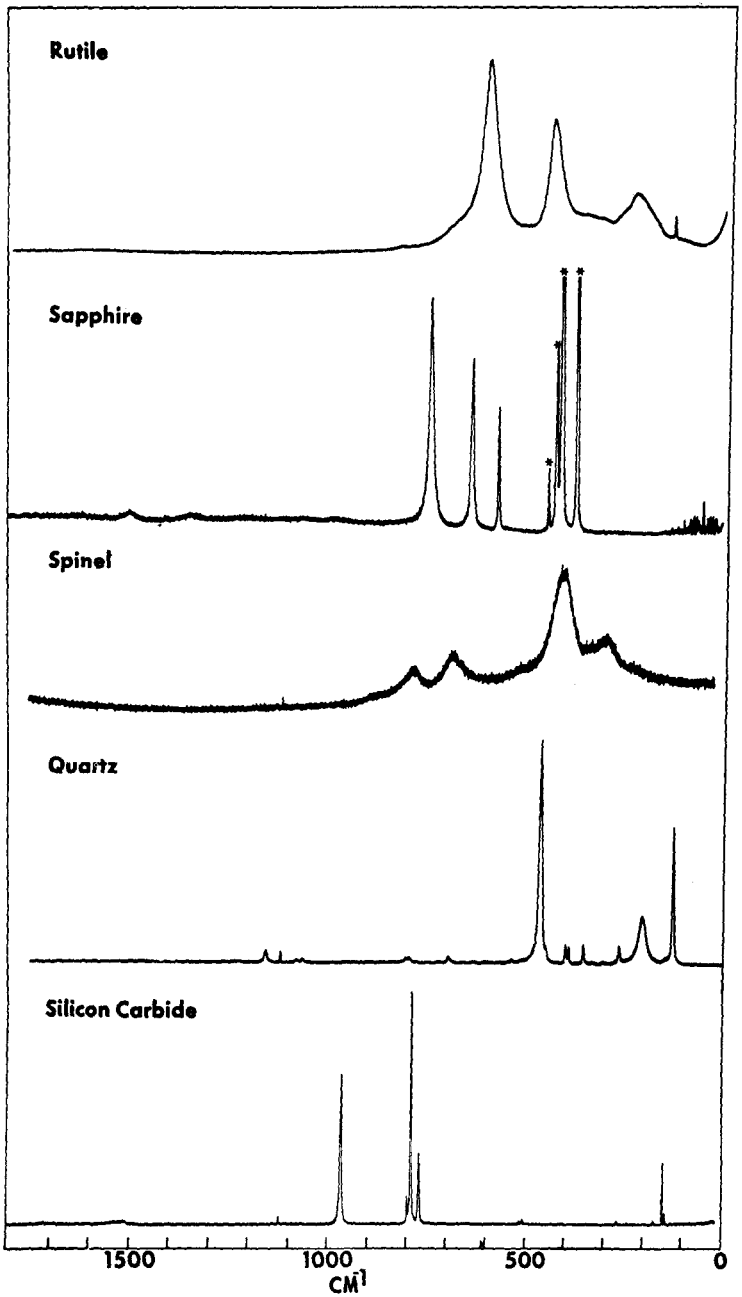

FIG. 6. Raman spectra of some diamond imitations. Lines marked with asterisks originate from light leakage from fluorescent room lighting.

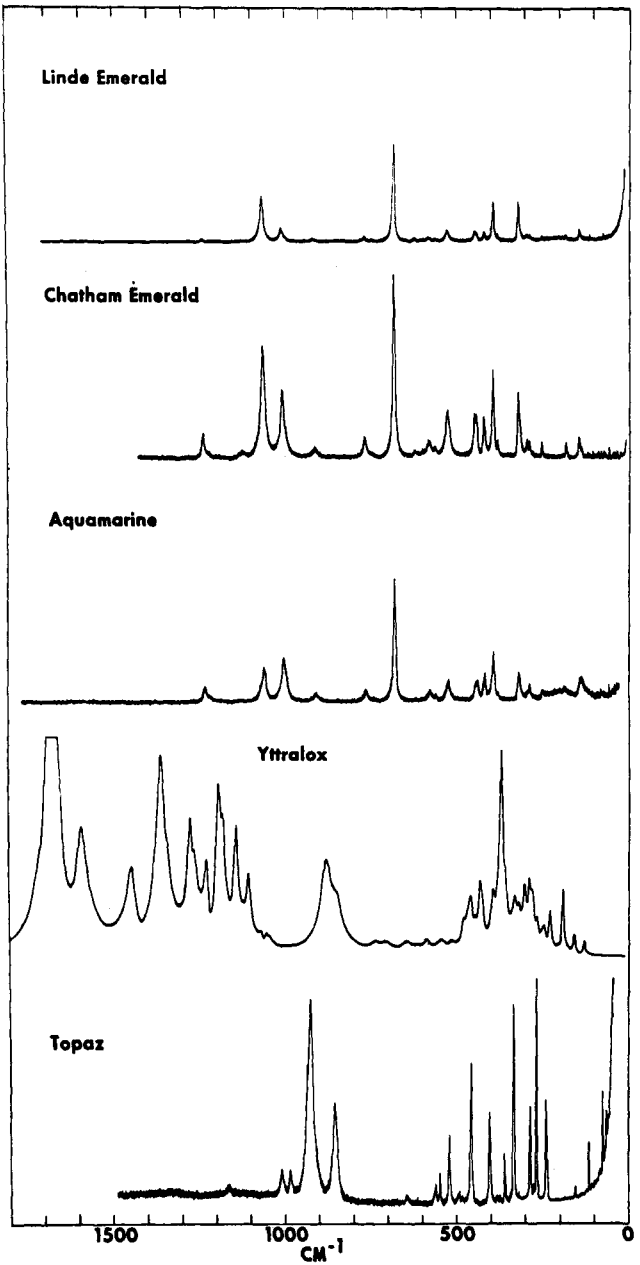

FIG. 7. Raman spectra of three beryls, yttralox, and topaz.

Cubic Zirconia—Zirconia (ZrO_2) commonly exists at room temperature as the monoclinic crystal baddeleyite[12] and its Raman spectrum has been known for some time.[13,14] Stabilization of the high temperature cubic form by addition of various additives has resulted in a room temperature *cubic* form that can be produced readily using a skull melting technique.[15,16] The appearance of cubic zirconia to the untrained eye is so much like that of diamond that it is displacing essentially all other diamond imitations.

The very strong Raman signals that originate in cubic zirconia cover a wide cm^{-1} wavenumber range (Figure 5). Perry *et al.*[17] recently reported spectra of cubic zirconia in which care was taken to study the effect upon the observed spectra of sample and polarization orientation. Accordingly, a crystal was oriented and polarized spectra are shown in Figure 8. Comparison of the cubic zirconia spectrum in Figure 5 with that of a 'Djevalite' spectrum of Figure 8 shows the effect of crystal axis orientation on the relative intensities of the bands. In Figure 5 the bands in the 700-1800 cm^{-1} region are prominent, as they are in the 'Ceres' spectra of Figure 8. The 'Djevalite' spectrum, on the other hand, shows these bands to be significantly reduced. Such variations are dependent on the orientation of the crystal axes with respect to the direction of propagation and polarization of the incident laser beam and to the polarization analysis of the scattered beam. Differences in stabilizer amount or type do not seem to be involved.

'Garnets': GGG and YAG—Gadolinium gallium and yttrium aluminium 'garnets' have been used as reasonably convincing diamond substitutes.[6] Their Raman spectra (Figure 5) are complicated and are significantly different from each other so that identification of these materials by Raman scattering is easy and convincing.

Strontium Titanate. A Raman spectrum of $SrTiO_3$ has been published previously.[18] As a substitute material for diamond in jewellery, $SrTiO_3$ has exceptional optical properties to recommend it but with an unfavourable softness. It is readily distinguishable from diamond without recourse to sophisticated techniques. Its Raman spectrum (Figure 5) is also distinctive and suitable for positive identification.

Other Diamond Imitations—The Raman spectra of rutile (TiO_2), sapphire (Al_2O_3), spinel ($MgO.xAl_2O_3$ with $1<x<5$, usually about 2.5), quartz (SiO_2), and silicon carbide (SiC) are shown in

Figure 6 and it is apparent that identification by Raman spectrum of each is straightforward. Both glass and plastics show variable Raman spectra, and may also show strong fluorescence. None of these materials is a serious contender with cubic zirconia as a substitute for diamond in jewellery at present, nor are these materials likely to emerge as such in the future.

Emerald, Aquamarine, Yttralox, and Topaz*—The Raman spectra, shown in Figure 7, allow easy identification of Yttralox, Topaz, and Beryl, but distinguishing between the various beryls (emerald, aquamarine, etc.) is probably not possible. Their spectra are qualitatively similar, differing only in the relative intensities of a few bands. The intensity ratios of the bands near 1065 and 1002 cm^{-1} are such that I_{1065}/I_{1002} are in the order Linde emerald > Chatham emerald > Aquamarine. For the pair of bands near 395 and 320 cm^{-1}, the intensity ratios I_{395}/I_{320} are in the reverse order, Aquamarine < Chatham emerald < Linde emerald. It is not known whether these trends would remain if a large number of samples were to be studied; it is also possible that these are orientation-polarization effects.

Doublet Structures—When the optical properties of a material mimic those of diamond and the value of this material is very low, the possibility exists for doublets to be made using the lesser valued material as the major component and a thin diamond platelet on the surface. If the fabricator is skilled, such a doublet structure might pass many of the tests for diamond, including the new Ceres 'Diamond probe' thermal conductivity instrument.[19] A doublet of cubic zirconia capped with a diamond platelet for example, would assume an apparent value far in excess of its real worth, and therefore positive identification of these structures is of importance. A gemmologist aware of such a possibility would, of course, recognize a doublet during the usual gem testing routine.[1]

A doublet, made from natural diamond and a 'Ceres' cubic zirconia crystal, was fabricated using a cyanoacrylate adhesive and was subjected to a Raman scattering experiment. The incident light beam entered at the diamond surface, passed through the outer platelet and also through the underlying cubic zirconia. The collection lens of the spectrometer was focused at the point of entry of the laser beam on the first surface. The acceptance cone of this

*According to R. Webster, *Gems*, 3rd edn (1975), p.380, yttralox is an especially sintered polycrystalline product containing about 90% yttrium oxide and 10% thorium oxide.—Ed.

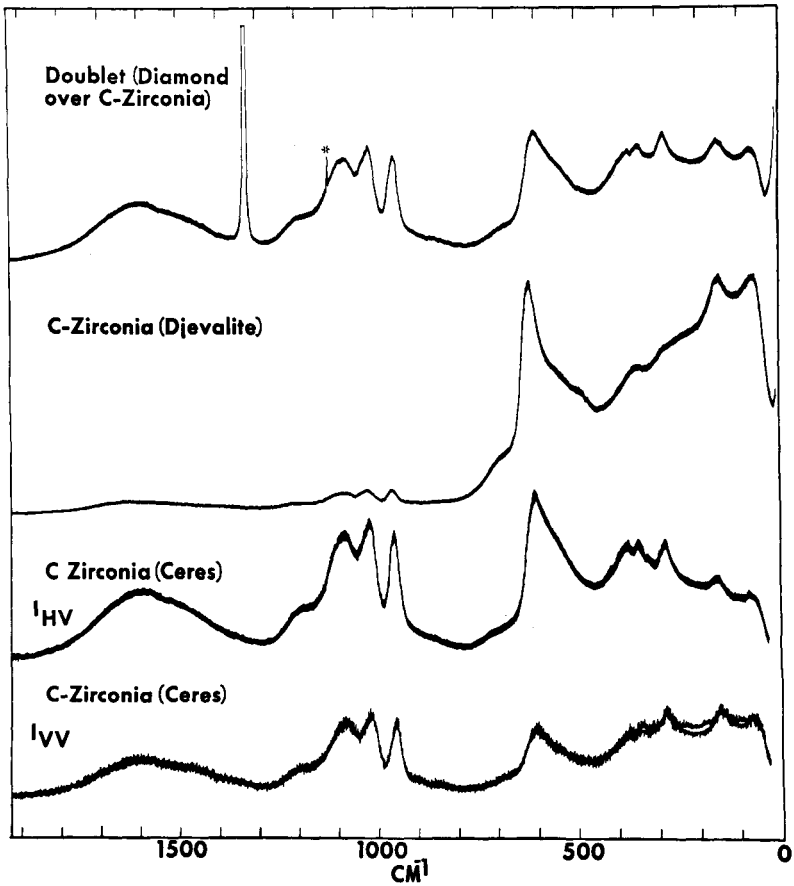

FIG. 8. Raman spectra of three cubic zirconias and of a diamond/cubic zirconia doublet.

lens was sufficient, however, to collect a large fraction of the Raman scattered light originating from both components of the sample. The result is shown in Figure 8 (top) where the observed spectrum, as expected, is a superposition of the spectra of diamond (Figure 5, top) and cubic zirconia (cf. Figures 5 and 8). The very narrow spike-like line at 1122 cm^{-1} that is marked with an asterisk is the 5460Å line of mercury originating from a laboratory fluorescent light. Conventional techniques can certainly be used to detect doublet structures. The Raman method, however, not only

can detect doublet structures and identify the constituent parts, but can do so even when only the table facet is exposed without removing the stone from its setting.(Nevertheless, it still could not identify a 'diamond-air doublet', consisting of a diamond crown over a hollow mounting!)

A 'Nifty Gem' doublet with a sapphire crown (for its hardness) and a strontium titanate pavilion (for its high refractive index and dispersion) was also examined. In this case, the adhesive used in the fabrication fluoresced so strongly under laser excitation that the Raman bands of the crystalline components were completely masked. Thus it was immediately obvious that the specimen was not diamond. If the adhesive were carefully chosen to minimize fluorescence, then the spectra of the crystalline components would be obvious and identification of the components would follow. In either case, the technique is useful in identifying the existence of a multiplet structure.

Summary

A number of natural, synthetic, and imitation gemstone materials were characterized by their Raman spectra. Each was found to be readily identifiable as to its chemical composition and crystal structure, but not usually as to differences of colour or origin. In doublets, both materials can be readily identified even if only the table surface is accessible; if the adhesive fluoresces, then this prevents the identification but, nevertheless, reveals the stone as a doublet. Since Raman testing equipment is comparable in price to a visible-infrared spectrometer, say $(US)20,000 and up, it can hardly be recommended as a routine gemmological test instrument. Nevertheless, it could prove useful for solving some particularly difficult problems.

ACKNOWLEDGEMENTS

I wish to thank Dr J. E. Griffiths for permission to use our results, Doreen DiStefano for some of the Raman measurements and L. Kaplan & Sons, of New York City, for the loan of the diamonds used in this study. Figures 4 to 8 are reproduced with the permission of the *Journal of Applied Spectroscopy* (Reference 5); Figure 3 with permission of the American Chemical Society.

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[*Manuscript received 1st May, 1980.*]

TEST REPORT ON THE RIPLUS ER602 REFRACTOMETER

By PETER READ, C.Eng., F.G.A.

Until recently, the Rayner diamond-table refractometer[1,2] was the only commercially available instrument of this type which could measure refractive indices above 1.81. Even with this version, the top end of the measuring range is limited to 2.03 by the RI of the associated contact fluid.*

Last year, however, an alternative extended-range refractometer was developed by the Swiss mineral and gemstone company, Siber and Siber. This instrument, the Riplus ER602 (Figure 1), is currently being manufactured and marketed by the German optical company Krüss, of Hamburg. The following report is the result of tests made by the writer on two prototype ER602 refractometers.

The new refractometer is fitted with a strontium titanate measuring prism having an RI of 2.41. In order to improve on the limitations of earlier contact liquids, Siber and Siber have also developed a new contact 'fluid' having an RI of 2.22, and this enables the range of the instrument to be extended to 2.21.

The new 'Riplus Kleber' contact fluid is a viscous non-toxic brown paste, which only becomes free-flowing when heated to around 40 °C. To achieve this condition, the paste is contained in a small bottle which is placed in a heated socket in the refractometer's operating plinth.

The paste is maintained in its liquid state, when deposited on the instrument's table, by means of an electrical element (energized from a transformer in the plinth) which heats the strontium titanate prism to 40 °C.

Because of the high dispersion of the prism material (0.19) it is essential to use a monochromatic light source to avoid colour fringing and loss of sharpness in the instrument's shadow line, and for this reason the operating plinth is also fitted with a sodium

*West's solution (a saturated solution of white phosphorus and sulphur in methylene iodide): or Cargille's Series EH1 Index of Refraction liquids (maximum value 2.11). [Cargille liquids, obtainable from McCrone Research Associates Ltd, London, are formulated (in the 1.81 - 2.11 RI range) from arsenic tribromide, arsenic disulphide, sulphur and selenium. They are highly toxic and corrosive: quite unsuitable for general use in a jeweller's shop, they should be used only in strictly controlled laboratory conditions.—Ed.]

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FIG. 1. The Krüss Riplus ER602 refractometer uses a heated strontium titanate prism and a special contact paste. Its measuring range is 1.79 - 2.21

lamp. (For purchasers who already have a sodium light source, the refractometer can be obtained without the plinth unit, but with a separate transformer to supply the prism heater).

When the unit is switched on from cold, it takes approximately fifteen minutes for the paste and the prism to reach their operating temperature. A small quantity of the contact paste can then be applied to the table surface of the prism and spread out to form a 2 - 3mm diameter disc.

The gemstone under test is positioned on the paste and pressed down firmly to squeeze out any surplus material and thus obtain

the thinnest possible contact layer. When moving the gemstone on the instrument's table, this must be done with care to avoid scratching the relatively soft surface of the strontium titanate prism.

The writer chose four brilliant-cut gemstones in the 1-carat size range to test the two prototype refractometers. Readings obtained on the instruments were as follows:

1. YAG, 1.825
2. Colourless zircon, 1.930, 1.990
3. GGG, 1.960
4. Cubic zirconium oxide, 2.175

All four stones gave repeatable readings on both refractometers, although the value measured for GGG's refractive index was lower than expected.[3] However, a reference[4] was later found which suggested that GGG had been manufactured by Bell Telephones with an RI as low as 1.92. A subsequent check on a Rayner diamond-table refractometer gave a reading of 1.965 for this specimen (a reflectivity meter reading and the specimen's orange fluorescence under SWUV confirmed that the stone was in fact a GGG).*

For a stone of a given size, the shadow line appeared to be fainter than that produced by a standard refractometer. However, for very small stones, the writer found that the shadow image could be enhanced by switching off the current supply to the refractometer's heater and allowing the film of contact paste to harden.

After each stone was tested it was necessary to clean the paste remnants from both the stone and the table of the prism by using a swab of cotton wool soaked in a solvent such as methylene chloride or methylene iodide.

Like the Rayner Diamond-table refractometer, the lower end of the ER602's range is somewhat restricted and starts at 1.79 (the Rayner version, with a sliding eyepiece, has a scale calibrated from 1.59), and it is assumed that a standard instrument is available for checking gemstones below this figure.

Although the testing of gemstones is necessarily a slower procedure using the ER602 and its associated contact paste, this was more than compensated for by the advantages of being able to determine the refraction of high RI gemstones to an accuracy of

*See K. Nassau, *The optical constants of GGG*, J.Gemm., 1980, **XVII**(3), 148.—Ed.

three decimal places: and, as it is a critical-angle refractometer, birefringence can be measured in the usual way with the normal degree of accuracy.

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ANALYSIS OF A SIMPLE GEM-TESTING PHENOMENON

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ABSTRACT

A simple gem-testing method is described. An explanation and the critical condition for the occurrence of the phenomenon are presented. The method may be used to distinguish diamond from stones with RI below 2.37. Limitation of the method is discussed.

With the arrival of stabilized cubic zirconia as a diamond simulant, many attempts have been made to distinguish the two.[1,2] Detailed description of its properties has been given by Bossart,[3] and identification of it presents no problem to the gemmologist in the laboratory. Such identification tests, however, involve properties such as specific gravity, refractive index, dispersion, etc., or require instruments making use of thermal or electrical conductivities. Positive identification using conventional refractometers is not possible, since the material has RI above the refractometer value of 1.81. A simple and effective method without the use of special instruments is described by Hodgkinson.[4] This involves looking at

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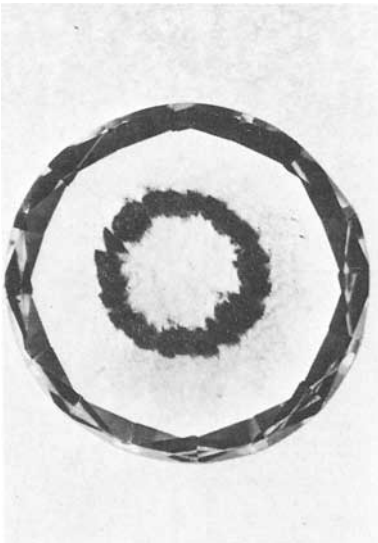

FIG. 1. Dot-ring observed in cubic zirconia.

FIG. 2. Dot-ring absent in diamond.

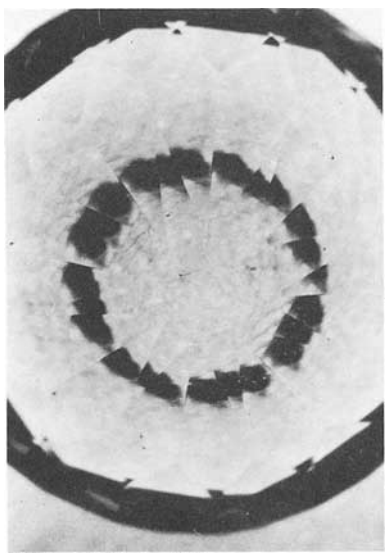

FIG. 3. Dot-ring observed in YAG.

FIG. 4. Dot-ring absent in strontium titanate.

the image of a distant light source through the stone and noting how large the angle is at which one sees the image. In this paper another convenient method is described, which is so simple that probably some jewellers have made use of it one time or another, perhaps in a slightly modified form. The explanation and the understanding of its limitation seem, however, lacking.

If a small dot is made (a pencil would do) on a piece of white paper, and a round brilliant-cut stone, such as synthetic white corundum or YAG, is placed symmetrically with table facet down on top of it, a dark ring can be seen if one looks down vertically on the stone (Figure 3). Actually the ring is made up of images of the dot through the pavilion facets. Depending on the width of the facets, the images may be close enough to appear as a continuous ring to the observer. The ring is very marked and no overhead lamp is required, if the room is properly illuminated. With stones such as diamond and strontium titanate no ring is seen (Figures 2 and 4). This is true only for round brilliant-cut stones which do not deviate appreciably from the ideal cut for diamond (i.e. pavilion angle about 41°). With cubic zirconia, again the ring is unmistakable (Figure 1). It seems, therefore, this simple observation may help to distinguish stones with RI above and below some critical value. The question to answer is: what is the critical refractive index of the stone, cut at a given pavilion angle, which is just about to display the ring? Conversely, with a given transparent gem material what is the critical angle (pavilion) with which it must be cut so that the ring will just appear? The answer lies in the understanding of the optical path taken by the light that reaches the eye of the observer.

For the full ring to be seen, light from the dot (since it is the contrast we see, whether light from the dot or its surroundings is immaterial) must reach the eye in the vertical direction from around the pavilion facets of the stone (Figure 5). This requires the light ray to travel in the stone in a definite direction, i.e. ray V making angle v with the vertical. Light rays in any other direction inside the stone will not emerge vertically. The relationship between v and p, the pavilion angle, is simply:

$$\sin p = n \sin (p - v) , \qquad (1)$$

where n is the refractive index of the stone and is related to the critical angle for total internal reflection, θ_c, by

$$\sin \theta_c = 1/n . \qquad (2)$$

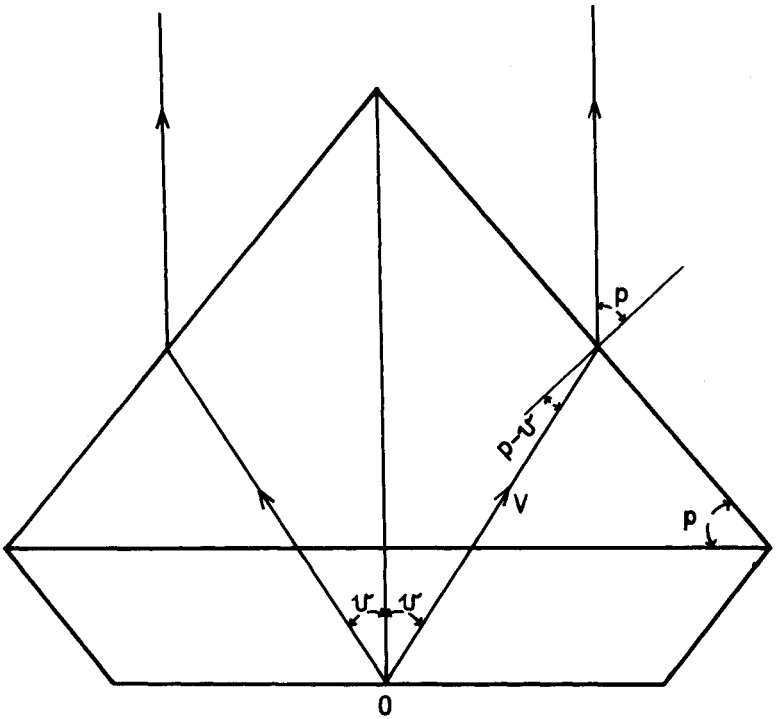

FIG. 5. The light path for observation of the dot-ring.

Since light from the paper is diffused it comes in all directions. For light entering the right hand portion of the stone, Figure 6 shows four such rays. Ray A which enters the stone horizontally is refracted at the critical angle θ_c and emerges from the pavilion facets. Rays B and C will enter the stone and be refracted at angles smaller than the angle θ_c. Ray D enters the stone normally. It does not require much convincing to see that all light upon entering the stone will be confined in directions between the vertical and the critical ray A′. All other directions (except those undergoing reflection within the stone) are not possible.

Now for some stones with low RI and suitable pavilion angle, ray A may emerge from the pavilion facets on that side of the vertical *away* from the culet of the stone. This would be the case if angle θ_c is greater than angle v defined in (1). Such a stone is then ring-positive, i.e., the ring can be seen, because among all the

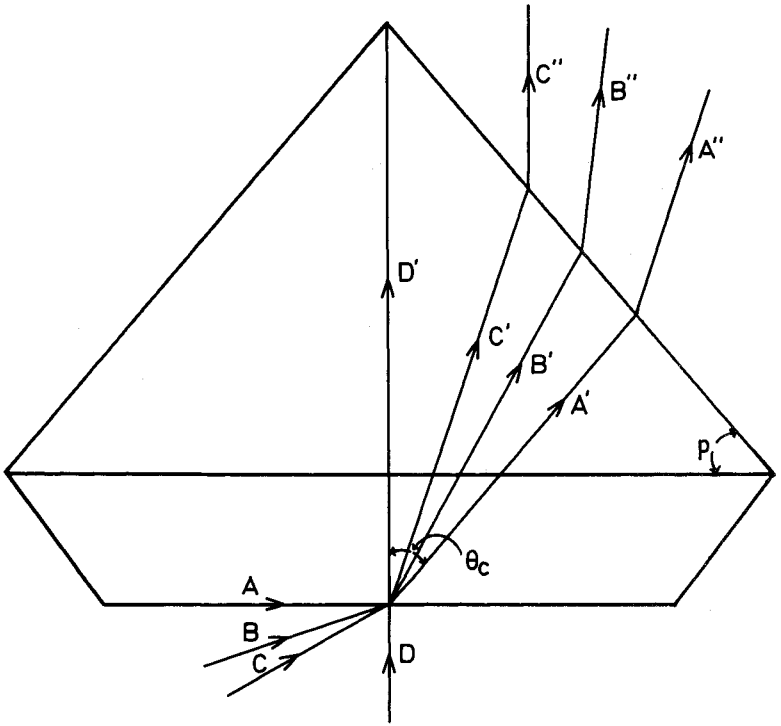

FIG. 6. A dot-ring positive stone. Light rays are confined within angle θ_c inside the stone. $\theta_c > v$.

possible rays there must be one that satisfies condition (1). On the other hand, for stones with higher RI and suitable pavilion angles the critical angle θ_c can be smaller than angle v and the light emerging from the pavilion facets will be directed on that side of the vertical *towards* the culet of the stone (Figure 7), and no light can be seen in the vertical direction.* Such stones must be ring-negative, because no light can emerge vertically. It is appropriate here to point out that it is irrelevant at which point light enters the table facet; it is the directions of the light rays that matter. For convenience the centre of the table facet is taken as the point where light enters the stone in the illustrations.

*For stones of sufficiently high RI it is possible that ray A′ is totally internally-reflected at the pavilion facet and no refracted ray emerges at all. The condition for this to happen is $p - \theta_c > \theta_c$, and for $p = 41°$, the corresponding refractive index must be greater than 2.86.

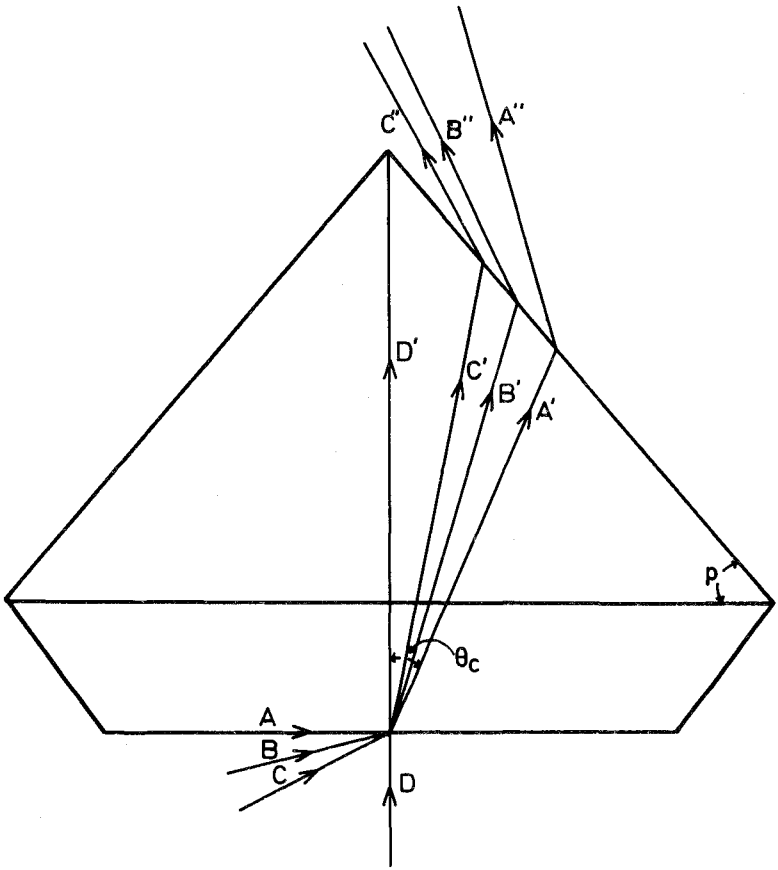

FIG. 7. A dot-ring negative stone. $\theta_c < v$.

To summarize:

$\theta_c > v$ ring-positive

$\theta_c < v$ ring-negative

It is interesting to compare angles θ_c and v for different gems cut at different pavilion angles. Equation (1) has an admissible solution for v:

$$\sin v = \frac{\{n^2\sin^2(2p) + 4n^2(n^2-1)\sin^2 p\}^{1/2} - n\sin(2p)}{2n^2} \qquad (3)$$

Table 1 lists v for different gems cut at pavilion angles p = 39, 40, 41, 43. The critical angles are calculated from (2) with RI values

θ_c \ p	39°	40°	41°	43°
Spinel 35.31°	17.67°	18.19°	18.71°	19.78°
YAG 33.12°	18.89°	19.44°	19.99°	21.12°
Cubic Zirconia 27.44°	22.17°	22.77°	23.40°	24.68°
Strontium Titanate 24.52°	23.86°	24.53°	25.20°	26.56°
Diamond 24.41°	23.93°	24.60°	25.27°	26.63°

Table 1. Angle v (equation 3) for various pavilion angles p and different materials.

1.73, 1.83, 2.17, 2.41, 2.42 for synthetic spinel, YAG, cubic zirconia, strontium titanate and diamond respectively. It can be seen from the table that among the 5 stones only strontium titanate and diamond with p>40° satisfy $\theta_c > v$, i.e. ring-negative. All others are ring-positive. It is interesting to note that at p = 39°, $\theta_c > v$ even for diamond, i.e., the ring appears even for diamond. Hence the dot-ring method (a name proposed for easy reference and to avoid confusion with the red-ring test for garnet-topped doublets) depends on both the RI of the stone and the pavilion angle at which it is cut. Since the majority of the diamond is cut with the pavilion angle close to 41° so as not to lose its brilliance, the method can be useful for those who wish to make a quick judgement.

Following the argument given above, the condition for the dot-ring to be just about to appear is obviously $\theta_c = v$. Combining this with equations (1) and (2) one obtains for the critical condition

$$\sin \theta_c \sin p = \sin (p - \theta_c) \qquad (4)$$

Given p, the critical angle θ_c and hence the critical refractive index n_c can be obtained.

The solution is:

$$n_c = \left\{ \sin \left[\tan^{-1}\left(\frac{\tan p}{1+\tan p}\right) \right] \right\}^{-1} \quad (5)$$

Table 2 lists the critical refractive indices n_c for various angles p. At $p = 41°$, n_c is 2.37. This value lies between the refractive indices of cubic zirconia and diamond and provides therefore a handy and simple test to distinguish the two.

p	39°	40°	41°	42°	43°
n_c	2.45	2.41	2.37	2.34	2.30

Table 2. Critical refractive indices (for the dot-ring to be observed) for different pavilion angles p.

On the other hand, if a transparent gem material is given, the critical pavilion angle p_c which will permit the dot-ring to be seen can be obtained from equation (4). The solution is

$$p_c = \tan^{-1}\left(\frac{\tan \theta_c}{1-\tan \theta_c}\right) \quad (6)$$

For diamond the critical pavilion angle p_c is 39.72° i.e. with p less than 39.72° diamond is dot-ring positive. This is in accord with Table 1 and previous discussions. This implies the dot-ring test fails for such cases. For cubic zirconia the critical angle p_c is 47.20°. Hence if cubic zirconia is cut with a pavilion angle greater than 47.20°, it will be dot-ring negative. Again the test fails in this case. The author, however, has not yet encountered a dot-ring positive diamond or a dot-ring negative cubic zirconia.

In conclusion, for round brilliant-cut stones the dot-ring test is a quick and simple method to distinguish stones with RI above and below a critical value depending on the pavilion angle, and typically about 2.37. If the stone has RI above this critical value, no ring is seen, while for stones with RI below this value, the dot-ring appears. One must be aware, however, of the pavilion angle of the specimen. If the angle can be measured independently, the analysis given in this paper helps one to decide whether the test is valid or not. It should be noted that, strictly speaking, the analysis given in this paper applies to isotropic materials only, i.e. singly refracting stones. Double refraction obviously presents complicating

problems that lie beyond the present discussion, although doubly refracting stones, such as corundum, with RI below the critical value, also display the dot-ring clearly.

Appendix on Equations (3), (5) and (6)

Derivation of equations (3), (5) and (6) requires only a knowledge of elementary trigonometry and simple algebra. The following trigonometric identities for any angles A and B will be used:

$$\sin(A-B) = \sin A \cos B - \sin B \cos A \quad \text{(i)}$$

$$\sin^2 A + \cos^2 A = 1 \quad \text{(ii)}$$

$$2 \sin A \cos A = \sin 2A \quad \text{(iii)}$$

$$\tan A = \frac{\sin A}{\cos A} \quad \text{(iv)}$$

Equation (1) can be rewritten as, using (i) above,

$$\sin p = n(\sin p \cos v - \sin v \cos p).$$

Rearranging and squaring, one gets

$$(\sin p + n \sin v \cos p)^2 = n^2 \sin^2 p \cos^2 v$$
$$= n^2 \sin^2 p(1-\sin^2 v).$$

This reduces easily to

$$n^2 \sin^2 v(\cos^2 p + \sin^2 p) + 2n \sin p \cos p \sin v - (n^2-1) \sin^2 p = 0$$

or,

$$n^2 \sin^2 v + n \sin 2p \sin v - (n^2-1) \sin^2 p = 0.$$

This is a quadratic equation in sin v, identical to

$$ax^2 + bx + c = 0,$$

with $a = n^2$, $b = n \sin 2p$, $c = -(n^2-1) \sin^2 p$, and $x = \sin v$.

The solution to this equation is

$$x = \frac{-b \pm \sqrt{b^2-4ac}}{2a}.$$

Substituting a, b, c from above, one obtains equation (3) for sin v, where the solution with negative sign before the square root has been discarded because it leads to a negative value for sin v, an inadmissible situation.

Equation (4) can be rewritten as

$$\sin \theta_c \sin p = \sin p \cos \theta_c - \sin \theta_c \cos p \quad \text{from (i),}$$

or $\tan \theta_c (\sin p + \cos p) = \sin p$

giving

$$\theta_c = \tan^{-1}\left(\frac{\tan p}{1+\tan p}\right)$$

$$\therefore n_c = \frac{1}{\sin \theta_c} = \frac{1}{\sin\left[\tan^{-1}\left(\frac{\tan p}{1+\tan p}\right)\right]}$$

which is equation (5).

Similarly from (4),

$$\sin\theta_c \sin p = \sin p \cos\theta_c - \sin\theta_c \cos p$$

or $$\frac{\sin p}{\cos p}(\sin\theta_c - \cos\theta_c) = -\sin\theta_c$$

or $$\tan p = \frac{\sin\theta_c}{\cos\theta_c - \sin\theta_c} = \frac{\tan\theta_c}{1-\tan\theta_c}$$

or $$p = \tan^{-1}\left(\frac{\tan\theta_c}{1-\tan\theta_c}\right)$$

which is equation (6), where we have written p_c for p to emphasize that this solution is the *critical* pavilion angle.

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[*Manuscript received 31st October, 1979.*]

NOTE ON THE AIR-BOUNDARY REFRACTOMETER

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Since the publication of our article concerning a new refractometer *(J.Gemm.,* 1979, XVI (8), 521-36) we have received several comments worthy of attention. Much confusion resulted from the fact that the phrase at the bottom of p.523 should have read 'at an angle JDK *larger* than θ_1.' Also the first and second paragraphs of p.525 refer to the situation of Figure 1a of the paper rather than Figure 1 as implied in the text. To clarify the issues here we give a simplified summary of the principles involved in the instrument and discuss the effect of different methods of illuminating the gem.

The basic idea of the instrument is that, with reference to Figure 1 below, a transition from partial reflection (ray R) to total internal reflection (ray R′) occurs for rays striking the table facet from within the gem at incident angle θ_c, the critical angle for total internal reflection. As indicated in the diagram, such a ray incident

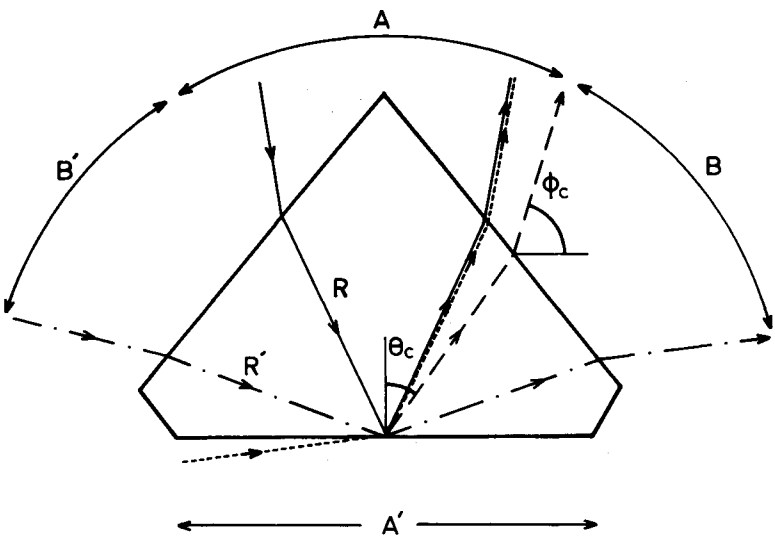

FIG. 1

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at θ_C on the table would leave the pavilion facet at angle ϕ_C to the horizontal. ϕ_C is thus determined by the refractive index of the gem and the pavilion angle (also measured by our instrument). Thus for given (or measured) pavilion angle a measurement of ϕ_C determines the refractive index.

The comments received are of two types. Firstly, as the eye of the observer moves from the region A ($\phi > \phi_C$) to the region B ($\phi < \phi_C$), what change does one observe? Secondly, is this change sharp enough so that ϕ_C and hence the refractive index may be determined with sufficient accuracy?

The first of these comments may easily be dealt with. When observations are made with the eye in region A ($\phi > \phi_C$), one is observing light transmitted from the region A′ below the table (together with any light partially reflected at the table), while for the eye observing from region B ($\phi < \phi_C$) any light observed comes from B′ outside the opposite pavilion facet. In our instrument region A′ is illuminated and region B′ is not, hence as the angle of observation moves from region A to region B a transition occurs from light to dark. It should be noted, however, that if the gem were to be placed table face down on a mat black surface and the pavilion area illuminated the light/dark transition would occur in reverse order. Thus we see that exactly what is observed as the observation angle ϕ passes through ϕ_C is determined by the method of illuminating the gem.

Comments regarding the sharpness of the light/dark transition are difficult to answer in quantitative terms, since ultimately one is involved with the ability of the human eye to distinguish different levels of illuminations, unless, of course, photo-detection of the transition is contemplated. Firstly we would agree with readers who point out that both the absolute reflectivity and the change in reflectivity is small for small variations in angle about the critical angle. However, in our instrument with the gem illuminated from below and the side facets in darkness the reflectivity variation contributes nothing since no light is reflected via the table from B′ to B. By contrast as soon as the eye observes from region A it may receive light, however weak, from the illuminated area A′ underneath the table. We can only emphasize that the transition is sufficiently sharp to enable ϕ_C and hence the refractive index to be determined to the accuracy given in our article, an accuracy somewhat less than that given by (say) the Rayner refractometer,

which incidentally also determines the RI by observing a light/dark transition occurring at total internal reflection.

For readers who still remain sceptical about the sharpness of the transition we can only suggest, failing the construction of the refractometer, the following experiment. Place a brilliant-cut gem (e.g. YAG) table face down on a black cloth, the light/dark transition will now occur in reverse order to that in the instrument. The gem should now be observed from vertically over the pavilion when the black cloth will be observed through the gem. As the angle of observation is lowered, viewing the black cloth through a pavilion facet, a point will come when total internal reflection occurs at the table facet and the black cloth will no longer be 'visible' but rather one will see a bright facet—actually one is observing light coming into the gem through the opposite pavilion facet. This simple experiment should help convince readers both of the nature and the sharpness of the transition. Since in this experimental set-up the illuminated region is viewed by internal reflection at the table facet, the low level of reflectivity near the critical angle reduces the sharpness of the transition, though we would claim that even under these adverse conditions it is still fairly sharp. It should also be noted that with observations made in region A, in principle light can reach the gem from both B′ and A′ whereas for observation made from region B only light from B′ (if any) could be reflected into the eye at the table/air boundary. In our instrument, with the gem illuminated from below the table, the light/dark transition appears to be sharper than in the experimental set up described above and hence enables a reasonably accurate determination of the refractive index.

[*Manuscript received 15th September, 1980.*]

GEMMOLOGICAL ABSTRACTS

ARGUNOV (K. P.), KIRIKILITSA (S. I.), MALOGOLOVETS (V. G.), POLKANOV (Y. A.). (X-ray luminescence of fine natural and synthetic diamonds.) (In Russian.) Mineralogicheskii Zhurnal, 2, 97-101, 1980.

Fine stones of different origin show weak x-ray luminescence. A brighter luminescence is shown by stones from the Yakut ASSR than that shown by stones from the East European platform and from Kazakhstan. M.O'D.

BALL (R. A.) *Letter to the Editor.* Aust. Gemmol., **14**, 1, 23, 2 figs, 1980.

Points out that while sedimentary opals (most colour-play opals) are essentially amorphous, volcanic opals (Mexican fire opal, etc) display disordered cristobalite-tridymite structures and are partially crystalline. [Figs need some explanation and appear to have been cropped, which has partly destroyed the evidence they are supposed to convey.] Reference to a paper in J. Geol. Soc. Aust. (1971) mentions Opal-A, Opal-CT or Opal-C [for which see abstract in J. Gemm., 1972, XIII (3), 107]. A further reference is to a paper by J. V. Sanders in Am. Mineral. (1975) [abstracted in J. Gemm., 1976, XV (3), 145]. R.K.M.

BARNES (V. E.), EDWARDS (G.), MCLAUGHLIN (W. A.), FRIEDMAN (I.), JOENSUU (O.). *Macusanite occurrence, age and composition, Macusani, Peru.* Bull. Geol. Soc. America, **81**, 1539-46, 3 figs, 1970.

The natural glass called macusanite after its location, Macusani, Peru, is to be related to sillar of the same region by K-Ar measurements. These give identical Pliocene ages for sillar and macusanite (4.2 million years) and relate the deposits to ash flows of the southern Andes. Macusani is located 70° 27′ W, 14° 4′ S, on the north-eastern slope of the Andes at about 4300m elevation. M.O'D.

BEDOGNÉ (F.). *Val Malenco.* Lapis, **5**, 6, 9-13, 9 figs (3 in colour), 1980.

The Val Malenco in northern Italy is celebrated for its andradite, which is described here. A map of the area is included. M.O'D.

BOSCH FIGUEROA (J. M.), MONES ROBERDEAU (L.). *Nuevas tecnicas de observación de la luminiscencia en diamantes y en algunos de sus substitutos.* (New techniques for the observation of luminescence in diamond and some of its substitutes.) Gemologia, **11**, 43/44, 7-12, 16 figs (12 in colour), 1980.

Luminescence in diamond and some of its substitutes was examined by the authors with a specially designed luminoscope with accompanying camera. Various temperatures were used for the study and the results illustrated in colour. In addition to diamond, synthetic corundum and spinel, YAG and GGG were examined. M.O'D.

BROWN (G.). *Corallium precious corals. Part two.* Aust. Gemmol., **14,** 1, 14-19, 9 figs, 1980.

This continuation of Part 2 of this paper* (begun in the previous issue) contains the references for the whole paper, and establishes by thin section microscopy that *Corallium rubrum* is composed chiefly of internally secreted calcite spicules rather than the externally secreted aragonite skeletons found in other corals. The spicules move down with age to fuse into the consolidated axis of red coral. Red corals have a diffuse absorption band centred at 495nm and no fluorescence under LWUV. Paler shades fluoresce with increasing strength as the absorption becomes weaker. Conclusions: *Corallium* corals are structurally different from reef-building corals and are modified gorgonian corals. They may be identified by characteristic thin longitudinal striations, RI and SG where necessary. [Thin section microscopy, while interesting, has little practical application in gemmology.] R.K.M.

CASSEDANNE (J.), CASSEDANNE (J.). *Note sur l'andalousite gemme de la Chapada Diamantina.* (Gem andalusite from the Chapada Diamantina.) Revue de Gemmologie, **63,** 15-17, 3 figs (2 in colour), 1980.

The Chapada Diamantina lies in the centre of the state of Bahia, Brazil. Andalusite is found alluvially; the colour is yellow-green to peridot green, hardness 7.5 and SG 3.15. RI is 1.638, 1.642, 1.649, DR 0.011. Pleochroic colours are yellowish-red to orange. Small hematite inclusions were noted. Strong absorption is found between just short of 700nm to 510nm, with other bands at 550-560nm and 520nm. The material is inert under ultra-violet light. M.O'D.

DEINES (P.). *The carbon isotopic composition of diamonds: relationship to diamond shape, color, occurrence and vapor composition.* Geochimica et Cosmochimica Acta, **44,** 7, 943-61, 1980.

330 new ^{13}C analyses of diamonds are presented. Among other conclusions presented is a note that stones from the Premier and Dan Carl mines, South Africa, show that differences in ^{13}C content that can be related to diamond colour and shape are smaller than 1‰ and that the mean ^{13}C content of kimberlite carbonates is 1-2‰ lower than that of associated diamonds. It was also found that there were significant differences in ^{13}C content between the two pipes. M.O'D.

DELE-DUBOIS (M.-L.), DHAMELINCOURT (P.), SCHUBNEL (H.-J.). *Etude par spectroscopie raman d'inclusions dans les diamants, saphirs et émeraudes-1.* (Raman spectroscopic study of inclusions in diamonds, sapphires and emeralds.) Revue de Gemmologie, 63, 11-14, 11 figs (1 in colour), 1980.

Raman spectroscopic techniques are used to examine inclusions in diamond, sapphire and emerald, though only the first two stones are examined in this part of the paper. M.O'D.

GRAZIANI (G.), GUIDI (G.). *Euclase from Santa do Encoberto, Minas Gerais, Brazil.* Am. Miner., **65,** 183-7, 4 figs, 1980.

Euclase from Santa do Encoberto, county of São Sebastião do Maranhão, Minas Gerais, Brazil, contains previously undescribed inclusions of hexagonal

*Abstracted in J.Gemm., 1980, XVII (3), 182.—Ed.

apatite crystals, hematite plates, minute needles of rutile and rounded grains of zircon. The crystals are doubly terminated, milky or transparent, ranging up to several centimetres in length. M.O'D.

HÄFLIGER (I.), SIBER (H.), WEIDERT (W.). *Stein ist nicht gleich Stein. Mineraleigenschaften für den Hobbyschleifer.* (No two stones are alike. Mineral characteristics for the ameteur cutter.) Mineralien Magazin, **4**, 4, 161-4, 7 figs in colour, 1980.

Illustrates and describes Mohs's scale of hardness. M.O'D.

HARDER (H.). *Edelsteine durch Brennen von Korunden.* (A gemstone from heating corundum). Fortschritte der Mineralogie, **58**, 1, 45-6, 1980.

Describes the use of heating as a treatment for alteration of colour in corundum. M.O'D.

HOPPE (R.). *Diamonds from the Kalahari.* Engineering and Mining Journal, **181**, 5, 64-74, 5 figs (4 in colour), 1980.

Describes the operation of the Orapa mine from which 15 000 ct of diamond are recovered daily. About 2300 ct are of gem quality. Recovery methods are based on x-rays. M.O'D.

KVASNITSA (V. N.), MALOGOLOVETS (V. G.), VISHNEVSKY (A. A.), KHARKIV (A. D.). *IR absorption spectra of fine natural diamonds.* Mineralogicheskii Zhurnal, 2, 95-7, 1980.

IR absorption spectra of fine stones from eclogitic xenolith, Yakutian kimberlites and Ukrainian placers show systems of the $A_1B_1B_2$ bands from nitrogen which are common to naturally occurring diamonds. M.O'D.

LIEBER (W.). *Sri Lanka—die strahlende Insel.* (Sri Lanka, the shining island.) Lapis, **5**, 6, 14-19, 10 figs (6 in colour), 1980.

A general review of gemstone recovery in Sri Lanka with a map of the island showing the main gemstone-producing areas. M.O'D.

MOREL (B.). *Les joyaux de la couronne de France à la veille de la revolution.* (The French crown jewels on the eve of the revolution.) Revue de Gemmologie, **63**, 2-8, 6 figs, 1980.

The major items in the French regalia are described with particular reference to the stones contained in them. M.O'D.

NASSAU (K.). *The history and present status of the synthetic quartz family—1.* Lapidary Journal, **34**, 3, 718-26, 10 figs, 1980.

Describes the beginnings of the work on quartz grown by the hydrothermal method with illustrations of the aparatus used. M.O'D.

PLYUSNINA (I. I.). *Infrared spectra of opals.* Sov. Phys. Dokl., **24**, 332-3, 1 fig, 1979 (publ. 1980). Transl. from Dokl. Akad Nauk SSSR, **246**, 606-9, 1979.

Specimens selected to form a transitional series from chalcedony to opal yield IR spectra which vary systematically. The extremes are correlated with chalcedonies

which are cryptocrystalline quartz and with x-ray amorphous opal, intermediate members of the series involving disordered quartz, disordered cristobalite, and, over a short range, some tridymite. In the IR spectra the absorption bands near 510, 560, and 950 are eliminated in this transition, whereas the more prominent bands near 475, 815, and 1120cm^{-1} persist. A.P.

POUGH (F. H.). *Chrysoberyl.* Lapidary Journal, **34**, 3, 792-5, 1980.

Cursory review of the chrysoberyl family with reference to African deposits. M.O'D.

READ (P. G.). *Computer-aided identification of gem diamond simulants.* Industr. Diamond Rev., 167-9, 6 figs, 1980.

The use of data storage and associated diagnostic techniques made possible by present-day low-cost computers is discussed. R.A.H.

SCHMETZER (K.), BANK (H.). *Explanations of the absorption spectra of natural and synthetic Fe- and Ti-containing corundums.* Neues Jahrbuch für Mineralogie Abhandlungen, **139**, 2, 216-25, 3 figs, 1980.

Natural sapphires were heated and their absorption spectra examined before and after treatment. A weakening of the absorption bands at 17 880cm^{-1} and 14 300cm^{-1} was noted after heating and this applied to stones from all the localities studied. From some only of the occurrences fresh bands at 11 500 and/or 20 000cm^{-1} were produced or enhanced. The bands at 20 000cm^{-1} are attributed to Ti^{3+} d-d transitions; bands at 17 880/14 300cm^{-1} and 11 500cm^{-1} are independent from each other and their intensities are ascribed to the respective concentration of Fe^{2+} and Ti^{4+}. M.O'D.

SCHMETZER (K.), BANK (H.), GÜBELIN (E.). *The alexandrite effect in minerals: crysoberyl, garnet, corundum, fluorite.* Neues Jahrbuch für Mineralogie Abhandlungen, **138**, 2, 147-64, 1980.

The article discusses the absorption spectra of alexandrite-like minerals with notes on the cause of the colour change. Alexandrites show strong bands of Fe^{3+} and Cr^{3+} on octahedrally co-ordinated lattice sites. Alexandrite-type garnets fall into two classes: the chromium-rich pyropes and the vanadium- or chromium-bearing spessartine-rich pyropes. Absorption maxima of Cr^{3+} ($^4T_2 \leftarrow {}^4A_2$) and V^{3+} ($^3T_2 \leftarrow {}^3T_1$) in both groups are in the same spectral region, about 17 500cm^{-1}. Alexandrite-like natural corundum shows spectra attributed to superposition of d-d transitions of Cr^{3+}, Fe^{3+} and V^{3+} in addition to charge transfer bands of Fe^{2+}/Ti^{4+} and Fe^{2+}/Fe^{3+}. Alexandrite-like fluorite shows absorption bands of Y^{3+}, Ce^{3+} and Sm^{2+}. All colour changing minerals show absorption minima between 15 000 and 16 000cm^{-1} and between 19 700 and 21 000cm^{-1}, in addition to a strong maximum between 17 300 and 17 800cm^{-1}. M.O'D.

SCHMETZER (K.), GÜBELIN (E.). *Alexandrite-like natural spinel from Sri Lanka.* Neues Jahrbuch für Mineralogie Monatshefte, 9, 428-32, 2 figs, 1980.

A spinel with a colour change from violet in daylight to reddish-violet in artificial light had 2.27% FeO, 0.06% Cr_2O_3 and 0.03% V_2O_3. In the absorption spectrum bands caused by Fe^{2+}, Cr^{3+} and V^{3+} are superimposed. M.O'D.

SCHÖTTLER (G.). *Synthese, Dublette, Imitation.* (Synthetics, doublets, imitations.) Lapis, **5**, 6, 25-7, 5 figs (in colour), 1980.

A general survey of the man-made gemstone field with notes on alteration of colour and simple identification techniques. M.O'D.

SHAUB (B. M.). *Genesis of agates, geodes, septaria and other concretions of sedimentary origin-1.* Lapidary Journal, **34**, 3, 650-62, 7 figs (5 in colour), 1980.

The geological origin of sedimentary bodies is explained with special reference to North American occurrences. M.O'D.

TAYLOR (J. B.). *Pleochroscopes.* Aust. Gemmol., **14**, 1, 3-12, 7 figs, 1980.

A rather elaborate account of monochroscope (single polar?), dichroscope, and a postulated, but as yet uninvented, trichroscope. (Contains some small misconceptions.) R.K.M.

YEFIMOVA (E. S.), SOBOLEV (N. V.). *Abundance of crystalline inclusions in Yakutian diamonds.* Doklady Akad. Nauk SSSR, **237**, 1/6, 231-3, 1980.

Olivine and chromite predominate among the inclusions in diamonds from Yakutia; in the pipes of Aykhal and Udachnaya olivine is more common than chromite, while in the Sytykan and Mir pipes the two minerals are found in roughly equal quantities. In these four pipes crimson garnets are found more commonly than orange ones, while in the pipes of the northern part of the Siberian platform the reverse is the case. M.O'D.

ZEITNER (J. C.). *Notes about blue stones.* Lapidary Journal, **34**, 3, 780-8, 11 figs, 1980.

A brief reviews of blue gem and ornamental stones with particular reference to those found in the United States. M.O'D.

BOOK REVIEWS

BECKER (V.). *Antique and twentieth century jewellery.* NAG Press, London, 1980. pp.301. Illus. in black-and-white and in colour. £15.00.

This is an exceptionally well-produced book, and for the price it is a real bargain—probably the last opportunity this reviewer will have to make this comment, such are the costs in the printing trade today. It can be read through in a (long) sitting, is not too heavy to be carried about with comfort, and the paper is of reasonable quality. For so reasonably-priced a work the colour reproduction is very good, and, since the book depends a good deal on this, it can be counted a great success.

So large a range of possible objects, materials and styles could have been introduced that almost any scheme of arrangement would have been in order. The author has elected to cover a range of subjects and within those confines to treat the matter chronologically. In this way chapters on diamond brooches, coral jewellery, goldwork of the nineteenth century, pique, stick pins, animals in jewellery, find their place. Celebrated figures such as A. L. Liberty and his contemporaries have a chapter to themselves.

There is a bibliography and an index. Students of jewellery should make every effort to buy this book. M.O'D.

EMBREY (P. G.), FULLER (J. P.), ed. *A manual of new mineral names, 1892-1978.* British Museum (Natural History) and Oxford University Press, London and Oxford, 1980. pp.ix, 467. £24.00.

From time to time lists of new mineral names have appeared in Mineralogical Magazine and there have been 30 such lists since 1897. The lists do not include names which are already established but do show a variety of discredited, alternative and trade names, some of the latter being descriptive of gem materials. About 50 new names are accredited each year. Entry is alphabetical with references to the original list and to significant papers being provided. This is in every sense a major reference work and one to be obtained by all serious students of mineralogy; standard of production is high and the price not unreasonable for a reference work today. M.O'D.

HOCHLEITNER (R.). *Fotoatlas der Mineralien und Gesteine.* (Photoatlas of minerals and stones.) Gräfe und Unzer, Munich, 1980. pp.237. Illus. in black-and-white and in colour. DM 68.

This well-produced book includes 400 photographs in colour in addition to 600 diagrams in the text. It is aimed at the 'educated beginner', since a fair knowledge of, or at least interest in, minerals is assumed. The concise specimen descriptions seem to confirm this supposition. Each of the 400 minerals described and illustrated has been well chosen; the quality of the selections is quite high without being too outstanding. The photographs, of the high quality necessary today, are accompanied by brief notes on the hardness, specific gravity, streak, body colour, crystal system and common forms with a note on locations, many of which are German. The order of the photographs is determined by the colour of the streak, an unusual arrangement to say the least. A second set of colour pictures illustrates the commoner rock types. The remainder of the text is workmanlike, though not differing materially from other, similar books. M.O'D.

LÜSCHEN (H.). *Die Namen der Steine.* (The names of stones.) 2nd edn. Ott Verlag, Thun, 1979. pp.380. 25 plates, 7 in colour. Fr 49.50.

This second edition of a most useful book is enlarged and contains an attractive set of colour plates with an especially fine dust-cover, whose magnificent subject is not stated. [It is, however, a proustite from Chanarcillo, Chile.] As in the previous edition, the main part of the book is an alphabetical list of names with their derivations. Not all minerals are included, but there is a wealth of historical information. It forms a useful complement to Mitchell's *Mineral names—what do they mean?* M.O'D.

NASSAU (K.). *Gems made by man.* Chilton Book Company, Radnor, Pennsylvania, 1980. pp.xvii, 364. Illus in black-and-white and in colour. $28.50.

A book by Kurt Nassau on man-made gemstones is the kind of event one encounters during benignant dreams; the reality has just that definition and imagination that characterizes the world of crystal growth. Dr Nassau has arranged his material under the most important gemstone classes; diamond ant its simulants, corundum, emerald, opal, alexandrite, the oxides YAG, GGG and CZ; there are sections on glass and plastic imitations, on the alteration of stones, the techniques of crystal growing and a long section on the cause of colour in gemstones. Most sections are followed by a few references, but there is no general bibliography. It is fair to say that if a bibliography were included to match the rest of the text, it would have to contain many works to which few gemmologists would have easy access. The standard of both the colour illustrations and the black-and-white photographs is good; I have one or two reservations about the paper.

For the gemmologist the main joy of the book is the detailed description of the manufacture of gem-quality crystals. A great deal of information that has not appeared in the standard tests is given (see the section on spinel) and for many processes the historical background is recounted. Trade names are given for many substances, and in passing much useful detail on natural materials creeps in. This is an essential tool for the gemmologist at any level; the gemmological instructor will also accord it a particular welcome. M.O'D.

SMITH (B.), SCHROMM (A.). *Gemcutting, a lapidary handbook.* Prentice-Hall, Englewood Cliffs, N.J., 1980. pp.viii, 184. $6.95.

Illustrated only by diagrams in the text, this book tells the reader nothing that cannot be easily found elsewhere. The book is not recommended; there is no bibliography and the glossary is inadequate, some of the explanations being incorrect and others too general. M.O'D.

WATERMEYER (B.). *Diamond cutting.* Purnell, Cape Town, 1980. pp.387. Illus. in black-and-white and in colour. R15.00.

This is the first book that I have seen which has been entirely devoted to a step-by-step account of diamond polishing. There are 55 chapters, so each one is fairly short; every step is very well illustrated by both diagrams and photographs—the only poor feature in the book is the indifferent reproduction of the colour work, but this is of little importance. A good deal of information on modern fancy cuts is given, and there is sufficient (but not too much) information on famous diamonds, the details of which are easily found elsewhere. The student and the embryo polisher will find this book invaluable. M.O'D.

ASSOCIATION NOTICES

GIFTS TO THE ASSOCIATION

The Council of the Association is indebted to the following for their gifts:

Mr R. Holt, F.G.A., London, for a parcel of crystals and rough material for students' use.

Mr Walter E. Johansen, Morgan Hill, California, U.S.A., for two slices of synthetic corundum produced in Israel, suitable for cutting as star sapphire and star ruby.

Mr Eric Morris, F.G.A.A., Dip.D.T., McLaren Vale, S. Australia, for a copy of the book 'Semiprecious and ornamental stones of South Australia' and six copies of 'Opal in South Australia', both issued by the South Australian Department of Mines and Energy, 1980: also for two excellently formed spessartite garnet crystals from the New Consolidated Mine, Broken Hill, N.S.W., Australia.

Mr Per Paulin, B.Sc., F.G.A., Uppsala, Sweden, for 90 cut pieces of aquamarine weighing 24.9 ct.

Mr Herbert Tillander, F.G.A., C.G., Helsinki, Finland, for a copy of the Scandinavian Diamond Nomenclature and Grading Standards, second edition.

OBITUARY

Major R. F. Cassidy, F.G.A. (D.1950), of Evesham, died on 5th September, 1980.

Mrs Marie-Louise Chisholm, F.G.A. (D.1952), wife of Mr J.R.H. Chisholm, F.G.A., died on 3rd December, 1980.

Miss N. M. N. Coop, F.G.A. (D.1963), died on 11th August, 1980. Former students at Sir John Cass College and many Fellows who have attended the London meetings of the Gemmological Association over the past 17 years will recall the diminutive figure of Miss Nora Coop. With no gem trade connexion, she had spent her business life in printing and publishing. Educated at St Paul's School for Girls, she was trained in music by Gustav Holst, with whom she remained friends until his death. A keen amateur musician, she had a fine voice in her younger days, and had many friends among famous musicians. Gemmology became an interest some years after her retirement, and, with her lively mind, she was an enthusiastic and good gemmologist, lecturing to various organizations up to about a year ago. Although born in York she had actually lived almost all of her very long life in a flat in Barnes, within a stones-throw of the Thames, and died there, very peacefully, at the age of 88. A charming little lady who will be greatly missed by her many friends in the Association. R.K.M.

Mr Henry J. Whitehead, F.G.A., (D.1959), Edinburgh, whose death on 24th March, 1980, was reported briefly on page 201 above, was an instructor on the Gemmological Association Courses for a number of years. A top ranking man in Post Office Telephone engineering, he came originally from Hounslow, transferring to Edinburgh in 1933, where he married in 1938. Both Henry and Helen Whitehead were good students of mine in 1957 to 59. Sadly, Helen died in 1960 without finally qualifying for Fellowship. Up to 1965 Henry was concerned directly with conversion locally to the STD system. Then he took charge of the P.O. Engineers Training Centre at Muirhead. His experience in teaching there helped considerably in his work for the Gemmological Association. Retiring in 1972 he concentrated on this, interrupting it only for two extended visits to Sri Lanka, where he made many friends. At one time he spoke of writing a book on the Gems of Sri Lanka, but his son, Dr Colin Whitehead, tells me that no notes for this have been found. He was active in the affairs of the local branch of the G.A. and gave many lectures on gems and on his experiences in the Far East. He had plans for further extensive travel, but these were thwarted by deteriorating health, which culminated in the stroke from which he eventually died. The Whiteheads were good and kindly people; Henry, a very intelligent and immensely likeable man, had been my good friend for more than twenty years. His passing is greatly mourned. R.K.M.

NEWS OF FELLOWS

On 9th September, 1980, Mr Peter Read, C.Eng., F.G.A., gave a talk on 'Some new gem-testing instruments' to the Bristol and West of England Jewellers Association, in the Royal Hotel, College, Bristol. On 27th September, 1980, he demonstrated his computer gem identification system (see pp.239-249 above) at the D.Gem.G. 2nd Technical Weekend, Idar-Oberstein, West Germany, and on the following day gave an illustrated talk on the two computer programs in the Börse.

On 6th October, 1980, Mr Ivan Tarratt, F.G.A., was installed as President of the Leicester Literary and Philosophical Society.

MEMBERS' MEETINGS

Midlands Branch

On 26th September, 1980, Mr Alan Hodgkinson, F.G.A., gave an illustrated talk on 'Precious Commercial Gemmology' at the Society of Friends, Dr Johnson's House, Colmore Circus, Birmingham. Mr Hodgkinson was unable to show the whole of his collection of slides, and a further meeting was held on the 31st October when the remainder were shown. A panel drawn from the Branch members discussed each slide.

On 27th November, 1980, Mr T. M. Osborne, of Birmingham City Council, gave a talk at the Society of Friends, Dr Johnson's House, Colmore Circus, Birmingham, on plans for the Jewellery Quarter.

North-West Branch

On 18th September, 1980, a visit was organized to Liverpool Museum.

On 6th November, 1980, the Annual General Meeting of the Branch was held at Church House, Hanover Street, Liverpool. Mrs M. P. Gayton, F.G.A., was re-elected Chairman and Mrs E. Cartmel elected Secretary.

South Yorkshire and District Branch

On 21st October, 1980, Dr D. A. Carswell, a specialist in high pressure minerals at the University of Sheffield, gave an illustrated talk on garnets and olivines at Sheffield City Polytechnic.

On 4th December, 1980, the Annual General Meeting of the Branch was held at Sheffield City Polytechnic Mr I. R. Lewis, F.G.A., was elected Chairman and Miss J. I. Platts, F.G.A., was re-elected Secretary.

COUNCIL MEETING

At the meeting of the Council held on Wednesday, 24th September, 1980, at Saint Dunstan's House the following were elected to membership:

FELLOWSHIP

Anderson, Maximillian J., London. 1980
Andersson, Arild, Oslo, Norway. 1979
Bennett, Elaine, Stockport. 1980
Bertrand, Sarah, Worthing. 1980
Coombes, Martin L., Crewe. 1980
Deascenti, James H., Accrington. 1980
Falkus, Geoffrey C., Hainault. 1980
Farrow, Karen A., Great Yarmouth. 1980
Faux, Teresa M. F. A., London. 1980
Glen, Jillian, London. 1980
Gray, John Stephen, Pontefract. 1980
Harrison, Kathryn, Doncaster. 1980
Hetherington, George, Ashton-under-Lyne. 1980
Kemp, Roy E. H., Farnham. 1980
Knight, Antony J., Chippenham. 1980
Lee, Anthony H., London. 1980
Mindry, Ernest R., Manningtree. 1980
Nisbet, Alistair S., Johannesburg, S.Africa. 1979
Payne, Nicholas G., Bournemouth. 1980
Pine, Ann M., Hemel Hempstead. 1980
Rogers, John, Portrush, N.Ireland. 1980
Rowe, Regina, Torquay. 1979
Rutzler, Nigel P., Twickenham. 1980
Smith, Ian J., Aberdeen. 1980
Teraura, Shin, Nara Pref., Japan. 1979
Thomas, Judy, Skipton. 1980
Uren, Derek C., London. 1980
Vashishtha, Shekhar, Delhi, India. 1979
Villars, Irja A. K., Stockholm, Sweden. 1980
Wilson, Andrew R., St Ives. 1980
Wright, Elaine C., Purley. 1980
Wright, Michael W., Redhill. 1980

TRANSFERS FROM ORDINARY MEMBERSHIP TO FELLOWSHIP

Aiiso, Miki, Tokyo, Japan. 1980
Amasaki, Tetsuya, Osaka, Japan. 1980
Asakawa, Mamoru, Fukuoka, Japan. 1980
Aylward, Peter S., Westonaria, Transvaal, S.Africa. 1980
Bacon, John E., Cape Town, S. Africa. 1980
Bannon, Lewis A., Baton Rouge, La, U.S.A. 1980
Blake, Jeannette A., London. 1980
Bogues, Patrick M., Omagh, N. Ireland. 1980

Bolin, Jacoba M., Stockholm, Sweden. 1980
Bonisoli, Giovanne, London. 1980
Butler, Russell T., Wirral. 1980
Bylander, Liliane D., Sigtuna, Sweden. 1980
Chiu, Carol C., Hong Kong. 1980
Coelho, Susan O., Richmond. 1980
Cowling, Denise E., Northampton. 1979
Cudworth, Patricia J., Mansfield. 1980
Dharmadasa, Sunil P., Colombo, Sri Lanka. 1980
Eckermalm, Hjordis, Tumba, Sweden. 1980
Eldridge, W. R., Kerrville, Tex., U.S.A. 1980
Elzinga, Vivienne, Cape Town, S.Africa. 1980
Emms, Eric C., Brentwood. 1980
Etoh, Tomooki, Fukuoka, Japan. 1980
Farooqi, F. M. A., Peshawar, Pakistan. 1980
Fujiwara, Osamu, Hyogo, Japan. 1980
Gabella, Laurent P., St Laurent du Var, France. 1980
Gaudy, Monica E., Stockholm, Sweden. 1980
Goatly, Andrew M., Surbiton. 1980
Goby, Jacqueline A., Castletown. 1980
Gordon, Clement R., Brisbane, Qld, Australia. 1980
Green, Richard D., Sedgley. 1980
Greeson, Gordon, Carmel, Ca, U.S.A. 1980
Hall, Michael G., Builth Wells. 1980
Heeney, Barbara A., Repulse Bay, Hong Kong. 1980
Hiraoka, Satoshi, Tokushima, Japan. 1980
Horvath, Elsa, Ste Julie, Que., Canada. 1980
Hurst, Adam K., Solihull. 1980
Ishii, Hajime, Kyoto, Japan. 1980
Jones, Gwilym M., Abergavenny. 1980
Kajita, Yukio, Tokyo, Japan. 1980
Kerr, D. J., Northcote, Auckland, N.Z. 1980
Kuehn, Robert L., Dallas, Tex., U.S.A. 1980
Larcombe, David B., Wincanton. 1980
Lau, Theodora A., Hong Kong. 1980
Levine, Carolyn E., Hong Kong 1980
Leybourn-Needham, Gerald, Knutsford. 1980
Lundholm, Carolyn, Stockholm, Sweden. 1980
McCallum, Marcus A., London. 1980
Maeda, Kosaku, Fukuoka, Japan. 1980
Mai, Lionel, Brussels, Belgium. 1980
Matsunobu, Hiroshi, Fukuoka, Japan. 1980
Miyaki, Yasuhiro, Kyoto, Japan. 1980
Moury, Armand J., Brussels, Belgium. 1980
Murphy, Mary M., Forest Hills, N.Y., U.S.A. 1980
Nelson, James B., London. 1980
Ng, Shirley S. Y., Hong Kong. 1980
Noach, Louis, London. 1980
Noble, George E., London. 1980
O'Grady, Gabriel F., Dublin, Ireland. 1980
Okuzumi, Hiromi, Tokyo, Japan. 1980
Onnink, Jannie A., Abbotsford, B.C., Canada. 1980
Owen, Neil T., Romford. 1980
Parr, Dorothy M., Toronto, Ont., Canada. 1980
Perrella Estelles, Loto, Barcelona, Spain. 1980
Poff, Stephen G., Invercargill, N.Z. 1980
Potter, Matthew S., Tokyo, Japan. 1980

Rosen, Elly, Brooklyn, N.Y., U.S.A. 1980
Rufli, Lisbet, Sollentuna, Sweden. 1979
Sever, Katherine M., Altrincham. 1980
Shibataka, Yasuhiro, Osaka, Japan. 1980
Sibtsen, Johannes C., Heerjansdam, Netherlands. 1980
Sjöström, Bjarne J., Taby, Sweden. 1980
Smith, Alan J., Birmingham. 1980
Spence, Lynette M., Hong Kong. 1980
Sweeny, Patrick J., London. 1980
Tajika, Kazutaka, Tokyo, Japan. 1980
Takahashi, Toshio, Tokyo, Japan. 1980
Takai, Toshisuke, Shizuoka, Japan. 1980
Takayama, Tetsuo, Ooita, Japan. 1980
Tamai, Hideo, Osaka, Japan. 1980
Taylor, Richard P., Mold. 1980
Timms-Hackworthy, David, Majorca, Balearic Is. 1980
Tormino, Frederick J., North Brunswick, N.J., U.S.A. 1980
Toshima, Tetsuo, Fukuoka, Japan. 1980
Uematsu, Yasuo, Hyogo, Japan. 1980
Wakefield, Raymond S., Durban, S.Africa. 1980
Wickramaratna, H. P. D., East Croydon. 1980
Wieman, Jacob, Amsterdam, Netherlands. 1980
Woodward, Christine M., London. 1980
Zimmermann, Ursula T., Kowloon, Hong Kong. 1980
Zoysa, G. Edirimuni G., Delft, Netherlands. 1980

ORDINARY MEMBERSHIP

Abdulrashid, Harun-Ibrahim, Las Vagas, Nev., U.S.A.
Abi-Habib, Cynthia S., Riyadh, Saudi Arabia.
Aspinall, Anthony, Wigan.
Atlan, Gabriel, Rio de Janeiro, Brazil.
Azeuedo, John F., San Francisco, Ca, U.S.A.
Beduze, William L., Watertown, Wis., U.S.A.
Bell, Robert D., Durban, S.Africa.
Benatar, Samuel, Wembley.
Bengali, Khodi B., London.
Betts, Margaret Y., Bushey.
Bhangu, Gurpal S., Manama, Bahrain.
Bishnu, Sudha, Temple City, Ca, U.S.A.
Blackburn, Mary-Rose, Roodeport, Transvaal, S.Africa.
Boulle, Jean-Raymond, London.
Boulle, Bertrand M. P., London.
Braga, Henrique C., Lisbon, Portugal.
Bridgwood, Corynna W., Seria, Borneo.
Brittain, Mark, Birmingham.
Brown, Linda M., Epsom, Auckland, N.Z.
Buckley, Melville, Paignton.
Bullock Peter H., Fairfield, N.S.W., Australia.
Callahan, Thomas P., Bloomfield, N. J., U.S.A.
Camelinat, Valma M., Jersey, C.I.
Canas, Jose M., Eglin, Fla, U.S.A.
Caouette, Paul A., Washington D.C., U.S.A.
Cestaro, Thomas L, Cheshire, Conn., U.S.A.
Chernichan, Catherine R., Winnipeg, Man., Canada.
Chiang, Yu-Chu A., Taipei, Taiwan.

Chien, Victoria S. L., Scarsdale, N.Y., U.S.A.
Chow, Man H., Kowloon, Hong Kong.
Clark, Richard M., Gibraltar.
Cleanthous, Angela, Nicosia, Cyprus.
Conaway, Jerrold O., Bloomington, Minnesota, U.S.A.
Cottafavi, Aliette, Geneva, Switzerland.
Croydon, Charles E., Ipswich.
Cuellar, Rebecca A., Honolulu, Hawaii, U.S.A.
da Cosse Brissal, Helene, Paris, France.
D'Adamo, Marina, Milan, Italy.
Desai, Suresh M., Chisekesi, Zambia.
Dormer, Joseph L., Barking.
Duke, Paul E., Vancouver, B.C., Canada.
Dykman, Christine S., Hong Kong.
Eisenburger, Sabine F., Thalheim, Austria.
Entremont, Pascal J., Alby sur Cheran, France.
Fickenscher, Rudolf A., Erlangen, W.Germany
Fletcher, Paul M., Dunfermline.
Freeman, Agnes G., London.
Freeman, William D., Fernandina Beach, Fla, U.S.A.
Gabriel, Kevin V., London.
Gertig, Gary K., Froid, Mont., U.S.A.
Gilbert, Charles, New York, N.Y., U.S.A.
Gill, Jogindar S., Kuala Lumpur, Malaya.
Gimpel, Beatrice, London.
Gimpel, Remy F., London.
Glidden, Wilfred, Offenbach, W.Germany.
Glossman, Norton, Walnut Creek, Ca, U.S.A.
Godkin, Paula S., Preston.
Goldsmith, John, Hayle.
Goodman, Diana, Mountsorrel.
Goossens, Pierre J., Trivandrum, Kerala, India.
Gordon, Scott, Oklahoma City, Okla, U.S.A.
Ha, Shek-to, Kowloon, Hong Kong.
Hale, Colin W., Wrexham.
Hammam, Nada S., Riyadh, Saudi Arabia.
Hansson, Henrik L., Bramhult, Sweden.
Harrison, John W., Ballincurra, Ireland.
Hedges, Stephen, Solvang, Ca, U.S.A.
Helm, Charles D., Los Angeles, Ca, U.S.A.
Hill, Allan, Swansea.
Horak, Joseph, Nhulunbuy, N.T., Australia.
Horovitz, Theodore, Geneva, Switzerland.
Hung, Chi-Chuan, Manila, Philippines.
Hurlbut, Cornelius S., Cambridge, Mass, U.S.A.
Hutton, Andrew J., Croydon.
Jacobs, Ronald J., Maldon.
Johnson, Gerald R., San Francisco, Ca, U.S.A.
Joris, William J., Mosman, N.S.W., Australia.
Kalbakjian, Jean, Aleppo, Syria.
Kavanagh, Seamus P., Dublin, Ireland.
Kennedy, James H., Belfast, N.Ireland.
Kimura, Mariko, London.
Klauda, Frank P., Rochester, Minn., U.S.A.
Kong, Suk C., Kowloon, Hong Kong.
Kornis, Elizabeth R., Rio de Janeiro, Brazil.
Kosik, Thomas A., Arlington, Va, U.S.A.
Kotahwala, Vinod, New York, N.Y., U.S.A.

Koy, Bohdan K., Warsaw, Poland.
Kwan, Edward S. M., Kowloon, Hong Kong.
Lau, Kee, Kowloon, Hong Kong.
Laurent, Paul J., Hastings, N.Z.
Lee, Hong G., The Hague, Netherlands.
Lee, Martin Y., London.
Lees, Gordon E., Belize.
Lees, Lilian, Belize.
Leung, Andy W. K., Kowloon, Hong Kong.
Maguire, Brian R., Belfast, N.Ireland.
Matsumoto, Shigeru, Fukuoka, Japan.
Mau, Enoch C., Kowloon, Hong Kong.
Mayer, Stephan P., Schillerstrasse, W.Germany.
Metudi, Mark T., Sherman Oaks, Ca, U.S.A.
Miguel, Hector, Argentina.
Miller, Ian J., Salisbury, Zimbabwe.
Morley, Sandra, Budleigh Salterton.
Murray, Geoffrey P., Maidstone.
McCune, Patrick M., Santa Maria, Ca, U.S.A.
McIntosh, Marsha S., Arlington, Va, U.S.A.
McKenzie-Davidson, Fraser J., Lymington.
Nagata, Misuzu, Yokohama, Japan.
Ng, Allan Y., Singapore.
Nivera, Maridi, Hong Kong.
Parker, David F., Harrogate.
Pattni, Shushil S., Loughborough.
Perillo, Anthony D., Mt Vernon, N.Y., U.S.A.
Phillips, Kathleen-Anne, Carmarthen.
Porto, Marcia E., Belo Horizonte, Brazil.
Prickett, Peter J., Brisbane, Qld, Australia.
Raphay, Jalaldin, Kuala Lumpur, Malaya.
Rees, Gwynfor E., Dundee.
Rolim de Camargo, William G., São Paulo, Brazil.
Ryan, Patrick, Kilkenny, Ireland.
Saeed, Agha M., Ilford.
Saeed, Ahmad, Petaling Jaya, Malaya.
Shauketaly, Asger F., London.
Sharma, Charanjiv L., Cheadle.
Shu, Yau L., Kowloon, Hong Kong.
Siegl, Jörg, St Gallen, Switzerland.
Simon, Christian, St Gallen, Switzerland.
Siow, Chee L., Ipoh, Perak, Malaya.
Singh, Janaki J., Paris, France.
Sivarajasingham, T.S., Ipoh, Perak, Malaya.
Smith, Adrian S., Southsea.
Smith, William B., Ruislip.
Stimler, Harvey J., Wembley Park.
Subramaniam, V.S. Gurusamy, Selangor, Malaya.
Swan, Richard J., Maidstone.
Teo, Tiong W., Singapore.
Tether, John G., Lusaka, Zambia.
Thenuwara, Ananda S., Mt Lavinia, Sri Lanka.
Theodosis, Rallis S., Forest Hills, N.Y., U.S.A.
Tishlias, Jimmy, Houston, Tex., U.S.A.
Tong, Kwong K., Hong Kong.
Trickett, Joyce E., Blandford Forum.
Trickey, Sheila A., Henley-on-Thames.
Tsui, Sunny K., Kowloon, Hong Kong.
Turk, Noriko, Hong Kong.
van Diepen, John W., Germiston, Transvaal, S. Africa.
Wake, Barry A., Snodland.
Waterworth, Michael, Swansea.
Weerasekera, Lampson, New Malden.
Weiss, Amy E., Briarclift Manor, N.Y., U.S.A.
Weller, Mark, Loughton.

Wondergem, Vivienne P., Remuera, Auckland, N.Z.

Wong, Dorothea S., Hong Kong.

Wong, Kin-Wah, Kowloon, Hong Kong.

Wood, James G., Mt Isa, Qld, Australia.

Yenson Chu, Mabel, Kowloon, Hong Kong.

Yuen, Jenny, Bristol.

Zonca, Guido, Rome, Italy.

GEM DIAMOND EXAMINATION 1980

In the Post-Diploma Gem Diamond Examination, 46 candidates sat and all passed, six with Distinction. The following is a list of their names arranged alphabetically.

QUALIFIED WITH DISTINCTION

Brohier, Kenneth Gordon, West Kirby.

Cukier, Gerard, London.

Esteve Fernandez, Jaime, Barcelona, Spain.

Franks, William, Bowdon.

Hysted, Anne Elizabeth, London.

Wright, Stephen Richard, Borehamwood.

QUALIFIED

Alvarez Fernandez, Laurentino, Barcelona, Spain.

Alvarez Fernandez, Manuel, Barcelona, Spain.

Bennett, Frederic, Hazel Grove.

Borreda Perez, Federico, Barcelona, Spain.

Breden, Robert John, Maghull.

Burslem, William Arthur, Liverpool.

Callaghan, Gerard, Liverpool.

Carpenter, Janet Elizabeth, Yelden.

Castello Torres, Ma Dolores, Barcelona, Spain.

Charlesworth, Anthony Robert, Southport.

Clark, Alan Joseph, Croydon.

Connolly, John Patrick, Over Peover.

Costell Ibanez, Manuel, Barcelona, Spain.

Crossland, Julie Hall, London.

Davies, Robert Ian, Coventry.

Derry, Catherine Eleanor, Nottingham.

Dolz Adell, Carmen, Barcelona, Spain.

Fagg, Primrose Mary, Wallington.

Franks, John Wilson, Altrincham.

Green, Edward Maurice, London.

Hernandez Ordonez, Arturo, Barcelona, Spain.

Hinton, Vera Georgina, Farnham.

Howarth, Janet, Bolton.

Jealouse, Roy George, Crewe.

Julia Miralles, Nuria, Barcelona, Spain.

Lewis, Robert George, Dartford.

Moore, Roderich Rüdiger, Solihill.

Nott, Shelley Naomi, West Harrow.

Pomar Llado, Ma Antonia, Barcelona, Spain.

Priestman, Arthur, Wythenshawe.

Puiggali Fabregas, Josep Ma, Barcelona, Spain.

Sanchez-Lafuente Mariol, José, Barcelona, Spain.

Smart, Denis Owen, Kettering.

Sorolla Maupoey, Marinela, Barcelona, Spain.
Stanley, Edward, Denton.
Suren, Jane Lucienne Linzee, London.
Theobald, Robert, Leighton Buzzard.
Vazquez Pavon, Rafael, Barcelona, Spain.
Whatton, Edwin Albert, Sutton Coldfield.
Winter, Julie, Fetcham.

EXAMINATIONS IN GEMMOLOGY 1980

In the 1980 Examinations in Gemmology, 425 candidates completed the Diploma Examination and of these 206 succeeded in passing, twenty of them with Distinction.

The best set of answers was returned by Christine Marie Woodward, of London, who deserves the congratulations of the Examiners for her excellent work.

In the opinion of the Examiners, however, no candidate achieved the high standard needed to warrant the award of a Tully Medal.

In the Preliminary Examination 746 candidates sat and 416 passed. The Rayner prize for the best set of answers in the Preliminary Examination was awarded to Graeme Roy Hogarth.

The following are lists of the successful candidates arranged alphabetically.

DIPLOMA EXAMINATION

QUALIFIED WITH DISTINCTION

Beach, Wendy L., Twickenham.
Bonanno, Kathryn L., Washington, D.C., U.S.A.
Carlsson, Björn O., Täby, Sweden.
Chiu, Carol C., Hong Kong.
Eldridge, W. R., Kerrville, Tex., U.S.A.
Emms, Eric C., Brentwood.
Gray, J. Stephen, Pontefract.
Hunger, Giselle H., Lugano, Switzerland.
Jones, Gwilym M., Abergavenny.
Lakdawalla, Darayus N., Bombay, India.
Leybourn-Needham, Gerald, Knutsford.
Okuzumi, Hiromi, Tokyo, Japan.
Onnink, Jannie A. P., Abbotsford, B.C., Canada.
Reynolds, Roderick H., Montreal, Que., Canada.
Smith, Ian J., Aberdeen.
Takada, Fujio, Osaka, Japan.
van Muyden, Paul P. M. A., Rotterdam, Netherlands.
Villars, Irja A. K., Stockholm, Sweden.
Woodward, Christine M., London.
Wright, Elaine C., Purley.

QUALIFIED

Aiiso, Miki, Tokyo, Japan.
Amasaki, Tetsuya, Osaka, Japan.
Anderson, Maximilian J., Edinburgh.
Asakawa, Mamoru, Fukuoka, Japan.
Aylward, Peter S., Johannesburg, S. Africa.

Bacon, John E. T. S., Wellington, C.P., S.Africa.
Banford, William D., Liverpool.
Bannon, Lewis A., Baton Rouge, La, U.S.A.
Bennett, David W., London.
Bennett, Elaine, Hazel Grove.
Berkowitz, Joseph, Toronto, Ont., Canada.
Bertrand, Sarah, Worthing.
Bill, David N., Hednesford.
Blake, Jeannette A., Ely.
Bogues, Patrick M., Omagh, N.Ireland.
Bolin, J. J. M., Stockholm, Sweden.
Bonisoli, Giovanne, Torino, Italy.
Bramwell, William J., Durham.
Butler, Russell T., Moreton.
Bylander, Liliane D., Sigtuna, Sweden.
Carson, Constance, London.
Cartier, Richard H., Toronto, Ont., Canada.
Castellote Mas, Guillermo F., Barcelona, Spain.
Charlton, Maurine, Scarborough, Ont., Canada.
Chu, Miu Hing, Hong Kong.
Coelho, Susan O., Kew.
Cook, Graham A., Dundee.
Coombes, Martin L., Crewe.
Cooper, Judith M., Colchester.
Cudworth, Patricia J., Mansfield.
Culpin, David I., Weston-super-Mare.
Day, Ghislaine H., Arlington, Va, U.S.A.
Day, William H. L., Arlington, Va, U.S.A.
Deascenti, James H., Accrington.
Dickson, Amanda J., London.
de Grefte, Glaudina J. M., Tilburg, Netherlands.
Dharmadasa, Sunil P. S. H. M., Colombo, Sri Lanka.
Eckermalm, Hjördis M. E., Tumba, Sweden.
Eger, Christine R., Lynchburg, Va, U.S.A.
Eide, Gry V., Bergen, Norway.
Elzinga, Vivienne, Cape Town, S.Africa.
Etoh, Tomooki, Fukuoka, Japan.
Fairlie, Alison H., Cheltenham.
Falkus, Geoffrey C., London.
Farooqi, Farooqi M. A. A., Peshawar, Pakistan.
Farrow, Karen A., Belton.
Faux, Teresa M. F. A., Winslow.
Ford, Karen J., Annapolis, Md, U.S.A.
Fraquet, Helen R., Frinton-on-Sea.
Fujihara, Shigeru, Tokyo, Japan.
Fujiwara, Osamu, Hyogo, Japan.
Gabella, Laurent P., London.
Gallardo Bravo, Matilde, Barcelona, Spain.
Gaudy, Monica E., Solna, Sweden.
Glen, Jill, London.
Goatly, Andrew M., Surbiton.
Goby, Jacqueline A., Nairobi, Kenya.
Gonzalez-Quiros Corujo, Ma Angeles, Barcelona, Spain.
Gordon, Clement R. I., Brisbane, Qld, Australia.
Gowling, Leslie G., Toronto, Ont., Canada.
Graus, Jeremy Z., London.
Green, Richard D., Sedgley.
Greeson, Gordon, San Diego, Ca., U.S.A.
Guinot Sierra, Agustin I., Barcelona, Spain.
Guinot Sierra, Carlos Ma., Barcelona, Spain.
Hall, Michael G., Builth Wells.
Harris, Barbara, Toronto, Ont., Canada.
Harrison, Kathryn M., Doncaster.
Hata, Kenichi, Kyoto, Japan.
Heeney, Barbara A., Hong Kong.
Heiskanen, Erkki T., Helsinki, Finland.
Hellmark, Thorsten A., Örebro, Sweden.

Hetherington, George, Ashton-under-Lyne.
Hiraoka, Satoshi, Tokushima, Japan.
Horvath, Elsa, Ste Julie, Que., Canada.
Huizinga, Jeroen, Amsterdam, Netherlands.
Hurst, Adam K., Solihull.
Ishii, Hajime, Kyoto, Japan.
Jackson, John G., Sunderland.
Johnson, Colin M., Birmingham.
Jones, L. Bruce, Seattle, Wash., U.S.A.
Jones, Mark L., Cromer.
Junquera Sanchez Del Rio, Mercedes, Barcelona, Spain.
Kämäri, Arvi N., Helsinki, Finland.
Kajita, Yukio, Tokyo, Japan.
Kawakami, Sumiyo, Osaka, Japan.
Kemp, Roy E. H., Farnham.
Kerr, D. J., Auckland, N.Zealand.
Knight, Antony J., Chippenham.
Krapenc, Terry S., Painesville, Ohio, U.S.A.
Kuehn, Robert L., Dallas, Tex, U.S.A.
Laine, Paul D., Guernsey
Lakdawalla, Zubin N., Bombay, India.
Lamb, Revital T., Salisbury, Zimbabwe
Larcombe, David B., Wincanton.
Lau, Theodora, Hong Kong.
Lee, Anthony H., London.
Leria Bernaus, Magda, Barcelona, Spain.
Levine, Carolyn E., Hong Kong.
Linko, Ilpo I. K., Espoo, Finland.
Lundholm, Carolyn L., Stockholm, Sweden.
McCallum, Marcus A., Newbury.
Maeda, Kosaku, Fukuoka, Japan.
Maguire, Martin P., Liverpool.
Mai, Lionel, Brussels, Belgium.
Matsunobu, Hiroshi, Fukuoka, Japan.
Mindry, Ernest R., Manningtree.
Miyake, Yasuhiro, Kyoto, Japan.
Moury, Armand J. A., Brussels, Belgium.
Murphy, Mary M., New York, N.Y., U.S.A.
Naebers, Joseph L. M. G., Hulsberg, Netherlands.
Nakajima, Minako, Birmingham.
Nelson, James B., London.
Ng, Shirley S. Y., Hong Kong.
Nichols, Robert T., Albuquerque, N.M., U.S.A.
Noach, Louis, London.
Noble, George E., London.
O'Grady, Gabriel F., Dublin, Ireland.
Oosterwaal, Frans T. G. J., Loon op Zand, Netherlands.
Owen, Neil T., Romford.
Parr, Dorothy M., Toronto, Ont., Canada.
Pascual Armengou, José, Barcelona, Spain.
Payne, Nicholas G., Bournemouth.
Perera, Priyani A. M., Colombo, Sri Lanka.
Perkins, Joanna C., London.
Perrella Estelles, Loto, Barcelona, Spain.
Pine, Michelle Ann, London.
Piunno, John C., Heidelberg, W.Germany.
Poff, Stephen G., Invercargill, N.Z
Potter, Matthew S., Tokyo, Japan.
Riedl, Inge, Barcelona, Spain.
Robbins, Susan C., Vancouver, Canada.
Rogers, John, Portrush, N.Ireland.
Rosen, Elly, Brooklyn, N.Y., U.S.A.
Ross, Rosemary D., London.
Rutzler, Nigel P., Twickenham.
Ruÿten, André G. F., Woerden, Netherlands.
Salvat Alegre, José, Barcelona, Spain.
Samaratunga, Edith K., Heidelberg, W.Germany.

Sever, Katherine M., Altrincham.
Shackley, Ian W., Christchurch, N.Z.
Shah, Paresh N., Bombay, India.
Shanmuganathan, Kathirithamby, Colombo, Sri Lanka.
Shibataka, Yasuhiro, Osaka, Japan.
Sibtsen, Johannes C., Heerjansdam, Netherlands.
Sjöström, Bjarne J., Stockholm, Sweden.
Smith, Alan J., Birmingham.
Smith, Shirley M., St Albans.
Spence, Lynette M., Sydney, Australia.
Stalman, Margareth A. E., Susteren, Netherlands.
Sweeney, Patrick J., London.
Tajika, Kazutaka, Tokyo, Japan.
Takahashi, Toshio P., Tokyo, Japan.
Takai, Toshisuke, Shizuoka, Japan.
Takayama, Tetsuo, Ooita, Japan.
Tamai, Hideo, Osaka, Japan.
Tan-Bouman, Els, Schoonhoven, Netherlands.
Taylor, Richard P., Mold.
Thomas, Judy, Skipton.
Timms-Hackworthy, David, Majorca, Balearic Is.
Tolin, Harvey S., New Canaan, Conn., U.S.A.
Tomas Soler, Ma Rosa, Barcelona, Spain.
Tormino, Frederick J., North Brunswick, N.J., U.S.A.
Toshima, Tetsuo, Fukuoka, Japan.
Tsujikawa, Kayoko, Kobe, Japan.
Uematsu, Yasuo, Kobe, Japan.
Underwood, Barbara C., Manchester.
Uren, Derek C., Aylesbury.
van der Riet, Diane M., Stellenbosch, S.Africa.
van Kalleveen, Allard, Paris, France.
Versendaal, Johannes, Hendrik Ido Ambacht, Netherlands.
Vlaun, Mirela C. E., Willemstad, Curaçao, N.A.
Wakefield, Raymond S., Durban, S.Africa.
Wall, Stephanie, Alcester.
Waller, John R., Toronto, Ont., Canada.
Welch, Mark G., Cardiff.
Wickramaratna, H. P. D., East Croydon.
Wieman, Jacob, Amsterdam, Netherlands.
Wijesuriya, Guthila, Moratuwa, Sri Lanka.
Wilkinson, Ben R., Nanaimo, B.C., Canada.
Wilson, Andrew R., St Ives.
Wright, Michael W., Epsom.
Yielding, Daniel N., Toronto, Ont., Canada.
Yoshida, Katsuji, Wakayama, Japan.
Zimmermann, Ursula Th., Hong Kong.
Zoysa, Gamini E. G., Colombo, Sri Lanka.

PRELIMINARY EXAMINATION

QUALIFIED

Absalom, Christine S., Effingham.
Acheson, Michael A., Geneva, Switzerland.
Adlestone, Mark I., St Annes-on-Sea.
Ahmad, Zaheer, Nairobi, Kenya.
Akizuki, Haruo, Ichikawa, Japan.
Aliprandi, Riccardo, Ostia, Italy.
Almazan Gurumeta, Francisco J., Madrid, Spain.
Alvis, Alayne, Colombo, Sri Lanka.
Anderton, Duncan M., Glasgow.
Angelo, Luiz, Rio de Janeiro, Brazil.
Ansell, Martin F., Epping.

Aoussat, Claude A., Vienna, Va, U.S.A.
Ashra, Shirish, London.
Ashworth, Marie C., Toronto Ont., Canada.
Astridge, Elaine, London.
Atkinson, Jane L., Carnforth.
Avila Martinez, Vicente S., Barcelona, Spain.
Babber, Harish R., Southall
Bailey, Catalena, Colombo, Sri Lanka.
Baker, Keith R., London.
Bambrick, Joseph E., Don Mills, Ont., Canada
Bannerman, John M., Weybridge.
Barber, Anjali, Nairobi, Kenya.
Bardsley, John N., London.
Batycki, Charlene G., Toronto, Ont., Canada.
Beard, Thomas E., Jr, Atlanta, Ga, U.S.A.
Bell, Lorna M., Gronant.
Black, Grant J., Glasgow.
Bonanno, Kathryn L., Fredericksburg, Va, U.S.A.
Bond, Gerald S., Maidstone.
Boorman, Robert F., Bisley.
Bottom, Ian, Chesterfield.
Bowie, Hamish I. C., Solihull.
Boyd, Robert T., Toronto, Ont., Canada.
Braun, Leslie H., Southport, Qd, Australia.
Breau, Karen L. J., Toronto, Ont., Canada.
Brown, Allen G., Hamstall Ridware.
Buchanan, Vera A., Augher.
Bury, Stephen W., Blackpool.
Buser, Charles S., III, Michanisburg, Pa, U.S.A.
Caldwell, Sandra J., Toronto, Ont., Canada.
Cameron, Stewart J., Auckland, N.Z.
Cassim, Mohamed F., Colombo, Sri Lanka.
Cespedes Garcia, Adelardo, Barcelona, Spain.
Chandrasiri, Imiya K. N., Mirigama, Sri Lanka.
Chavan, Umesh, Bombay, India.
Choi, Yat How, Hong Kong.
Choi, Siew-Cheong, London.
Chouiki-Doorn, Jacqueline, Spykenisse, Netherlands.
Clegg, Niel F., Bridgwater.
Currie, Lynnette J., Manurewa, Auckland, N.Z.
Darmudas, Nat, London.
Davies, Angela, Gerrards Cross.
Davies, Margaret, Frinton-on-Sea.
Davis, Robert J., Margate, Tas., Australia.
Day, Ghislaine H., Arlington, Va, U.S.A.
Day, William, H. L., Arlington, Va, U.S.A.
Dayasagara, Kalupahana L. D., Colombo, Sri Lanka.
Dayrit, Jacqueline S., Metro Manila, Philippines.
de Rooy, Franciscus J. M., Tilburg, Netherlands.
de Silva, G. Ranjan J., Singapore.
Devarajah, Rajeswari, Colombo, Sri Lanka.
Dewar, Penelope S., Stockport.
Dickens, Adrian Q., Lewes.
Dolleslager, James T., Houston, Tex., U.S.A.
Dorricott, Jeffrey K. M., Ringwood.
Doughty, Suzanne M., Wembley.
Douthwaite, Elaine M., Bradford.
Dowell, Ronald A., Gloucester.
Duffin, Charline D., Denton, Tex., U.S.A.
Duke, Paul E., Vancouver, B.C., Canada.
Ebata, Taiichiro, Takaoka, Japan.
Ebelthite, Alexander, Twickenham.
Eckley, Gareth, D., Talgarth.
Ehara, Nobuyuki, Tokyo, Japan.
Ekanayake, Eileen F., Kotte, Sri Lanka.

Endean, Christine H., Hong Kong.
Enlander, Martin A., Belfast, N.Ireland.
Esteba Suquet, Carmen, Barcelona, Spain.
Etoh, Tomooki, Omuta, Japan.
Fadnes, Jane B., Stavanger, Norway.
Fell-Smith, Simon A., Brisbane, Australia.
Fernando, Edward F. W., East Malling.
Ford, Karen J., Annapolis, Md, U.S.A.
Foster, Amanda L., Toronto, Ont., Canada.
Fountain, Clair, Toronto, Ont., Canada.
Freeman, Darlene M., Belmont, Ca, U.S.A.
Froehlich, Regina, North York, Ont., Canada.
Fujiwara, Osamu, Kawanishi, Japan.
Furmage, Janet E., Hull.
Gailterie, Marie C., Geneva, Switzerland.
Gajasinghe, Ann L., Pannipitiya, Sri Lanka.
Galt, Jessie J., Scarborough, Ont., Canada.
Gand, Philippe, Villars sur Glane, Switzerland.
Ganesh, Narendran, Colombo, Sri Lanka.
Ganesh-Alingham, Sussee-Lathevi, London.
Gans, Elizabeth B., London.
Garcia Vaquero, Alfredo, Barcelona, Spain.
Garcia Ripoll, José Ma, Barcelona, Spain.
Garside, Janet, Larkfield.
Gasco Galindo, Ignacio, Barcelona, Spain.
Gea Lopez, Francisco J., Barcelona, Spain.
George, Niel, Portmadoc.
Gettings, Barbara A., London.
Gideon, Lester P., Vandenberg, Ca, U.S.A.
Girling, Matthew D., London.
Glover, Howard N. G., Wallasey.
Golby, Nicholas G. J., London.
Gold, Stephen A., Northolt.
Gowling, Leslie G., Toronto, Ont., Canada.
Grant, Judith M., Carmel, Ca, U.S.A.
Green, Margaret H., Hove.
Greenaway, Suzanne E., London.
Grima, Phillip, Zurich, Switzerland.
Grimston, Lady Iona C., London.
Grishko, Irene, Agincourt, Ont., Canada.
Grøndahl, Merete, Stabekk, Norway.
Guarne Terrado, Francesc, Barcelona, Spain.
Guillemot Boix, Nuria J., Barcelona, Spain.
Haniffa, Ahamed I., Colombo, Sri Lanka.
Harsheim, Elna F., Oslo, Norway.
Hatenboer, Willem J., Krimpen a/d Ijssel, Netherlands.
Hattori, Toshikazu, Osaka, Japan.
Hauge, Pia H., Colombo, Sri Lanka.
Hawker, Robin W. A., Kempton, Tas., Australia.
Hayes, George R., Jr, Canton, Ohio, U.S.A.
Hedges, Karen A., Kuala Lumpur, Malaya.
Heiskanen, Anu P.K., Helsinki, Finland.
Hellmark, Thorsten A., Örebro, Sweden.
Henderson, Shirley, Bothwell.
Hermans, Johannes S., Delft, Netherlands.
Hill, David R., London.
Hill-Tout, Randy M. M., Toronto, Ont., Canada.
Hinduja, Anuradha J., Bombay, India.
Hiwale, Shyla, Bombay, India.
Hogan, Ann G., London.

Hogarth, Graeme R., Perth.
Hopper, Gerald S., Boston.
Horton, David R., London.
Houseago, James A., Lowestoft.
Howe, Susan E., Taunton.
Hrynczak, Stephen M., Ilford.
Huges, Richard W., Boulder, Colo., U.S.A.
Huguette, Mourad, Lebanon.
Hurlburt, Catherine J., Willowdale, Ont., Canada.
Hutchinson, Marjorie E., London.
Hynes, James B., London.
Ickowicz, Steven, London.
Ifthikar, Ifthikar U. M., Kandy, Sri Lanka.
Illueca Domenech, Enrique, Barcelona, Spain.
Inches, Deirdre M. H., Wembley.
Ismath, Abdul M. M., Colombo, Sri Lanka.
Itoyama, Emiko, Osaka, Japan.
Iwata, Kazuyoshi, Gifu, Japan.
Jacobson, Karl F., Camarillo, Ca, U.S.A.
Janssen, Hubertus W., Rotterdam, Netherlands.
Jathar, Shripad S., Bombay, India.
Jayasekera, Mahadura C. de S., Negombo, Sri Lanka.
Jennings, Melvyn, Greetland.
Jollien, Marcel A., Zurich, Switzerland.
Jones, L. Bruce, Seattle, Wash., U.S.A.
Jones, Gwilym M., Abergavenny.
Jones, John A., Wrexham.
Jones, Maureen D., Wellington, N.Z.
Kaersenhout, George E., Amsterdam, Netherlands.
Kaleel, Abdul R. M., Mt Lavinia, Sri Lanka.
Kanokvaliwongs, Pornchai, Barcelona, Spain.
Kassamali, Shirin H., Nairobi, Kenya.
Keefe, James E., IV, Santa Monica, Ca, U.S.A.
Keegan, Dermot, Thika, Kenya.
Kelly, Susan M. B., Woodridge, Qld, Australia.
Kennedy, Karen K., Toronto, Ont., Canada.
Kettley, Helen M., London.
Keuskamp, Diederik N. G., Streefkerk, Netherlands.
Khandwani, Riyaz S., Bombay, India.
Kilburn, Kenneth, Shipley.
King, Antoinette E., Iden.
Kingsley, Ann S., Sidmouth.
Kinoshita, Kazuko, Ashiya, Japan.
Kirwin, Philip M., Cheadle.
Kitamura, Seiki, Tokushima, Japan.
Kjeldsen, Dag S., Moss, Norway.
Koralage, Sita P., Dondra, Sri Lanka.
Kosik, Thomas A., Arlington, Va, U.S.A.
Kothari, Rajan A., Bombay, India.
Krot, Johannes H., Amsterdam, Netherlands.
Kujanpää, Asko J., Helsinki, Finland.
Kumarage, Jayantha P. R., Piliyandala, Sri Lanka.
Kuruppu, Sarat L., Ratmalana, Sri Lanka.
Kwan, Yim Lin, Hong Kong.
Lacambra Pifarre, Carmen, Barcelona, Spain.
Lai, Kam Wing, Hong Kong.
Lam, Ronald, Chatham.
Lambley, Jenifer G., Hong Kong.
Landau, Sidney L., Miami Beach, Fla, U.S.A.
Law, Sheila, London.
Leaton, Colin J., London.
Lee, Chun-Sang R., Hong Kong.
Le Fevre, Robert S., Jr, Virginia Beach, Va, U.S.A.
Leggett, Andrew P., Worthing.
Lenhoff, Louis, Stellenbosch, S.Africa.

Leong, Daniel K. T., Macau.
Lewis, Kathleen A., Luton.
Liddle, Robert, Inverkeithing.
Litchfield, Anne-Marie, Northampton.
Little, Derek, Dundee.
Littlejohn, Gordon H., Tunbridge Wells.
Livstrand, Ulf R., Stockholm, Sweden.
Love, John, St Helier.
Lueking, Edward N., Costa Mesa, Ca, U.S.A.
Lundsrud, Atle, Nesøya, Norway.
Lundsrud, Randi, Nesøya, Norway.
Lupton, Elaine C., Paddock Wood.
MacDonald, Andrea C., Amersham.
McDonald, Jessie L., Riyadh, Saudi Arabia.
McDowell, Robert B., Beltsville, Md, U.S.A.
McEwan, Robert S., Perth.
McIntosh, Marsha S., Arlington, Va, U.S.A.
McKellar, John R., Evenjobb.
McPherson, Heather, Coalville.
McShane, Charles S. P., Teddington.
Maeda, Katsutoshi, Fukuoka, Japan.
Magri, John P., Northolt.
Malhar, Lateef M., Banstead.
Malpas, Robert F., Leeds.
Manamperi, Sisira D. B., Ratnapura, Sri Lanka.
Mansfield, Stephen M., Burton.
Mariathasan, Loganayagi, Colombo, Sri Lanka.
Marshall, Sarah L., West Bridgford.
Martijnse, Christiaan J., Groot-Ammers, Netherlands.
Mater, Louise H., Laren, Netherlands.
Matthews, Marguerita E., Lancaster.
Mayer, Anton S., St Saviour.
Mayor, Norah, Soham.
Meggitt, Corinna A. W., London.
Middleton, Neil M., Stoke-on-Trent.
Mikami, Akira, Tokyo, Japan.
Mills, David K., Hucknall.
Minogue, Caroline E., Leigh-on-Sea.
Misaki, Kyoko, Tokyo, Japan.
Molagoda, Tikiri B. P., Talatuoya, Sri Lanka.
Moore, Paul R., Camberley.
Morris, Kelsey S., Hayling Island.
Morrow, Lisbeth J., Mold.
Nakamura, Masanori, Osaka, Japan.
Nakamura, Takeshi, Kanazawa, Japan.
Nakayama, Keiichi, Komatsushima, Japan.
Navarro Ribero, Conrado, Barcelona, Spain.
Nelischer-Millar, Anita I. A., Toronto, Ont., Canada.
Nelson, Eunice, West Hill, Ont., Canada.
Nithiaraj, Sellappu I., Mt Lavinia, Sri Lanka.
Nooten-Boom, Apollonius, II, Kingsland.
Norton, Sharon L., High Wycombe.
Oakley, Leslie P., Toronto, Ont., Canada.
O'Brien, Peter P., Glasgow.
Oliete Artal, Ma Amparo, Barcelona, Spain.
Onodera, Noritoshi, Sagamihara, Japan.
Otsuka Nobuko, Tokyo, Japan.
Ottaway, Terri L., Toronto, Ont., Canada.
Pagliero, Margaret S. G., Edegem, Belgium.
Palanques Monteys, Alberto, Barcelona, Spain.
Paranamana, Palitha K. P., Nakulugamuwa, Sri Lanka.
Parcel, Rodney F., Jr, Perris, Ca, U.S.A.
Parry, Sarah, Wadhurst.
Paxton, Jeremy M., Fordingbridge.
Peacocke, Patrick T., Cambridge.
Peebles, Kathleen W., Johannesburg, S.Africa.
Perera, Navaratne M. R., Rajagiriya, Sri Lanka.

Perren, Llewelyn J., Worthing.
Peryer, Keith G., Barnet.
Pettit, Angela L., Keighley.
Philipou, Philip, Byfleet.
Phoenix, Susan E., Nottingham.
Pickford, Michael G., Bicester.
Pidcock, Julie M. A., Matlock.
Pitt, John R., Kingswinford.
Pitts, Carl C., Huntington Beach, Ca, U.S.A.
Piunno, John C., Washington, D.C., U.S.A.
Piziura, Irene T., Gedling.
Postma, Renate E., Breda, Netherlands.
Pothof, Helga, Schoonhoven, Netherlands.
Potter, Brian S., London.
Powell, Lori C., Newmarket, Ont., Canada.
Price, Stephen A., Ipswich.
Prince, Ann-Elise, London.
Pujol Moragas, Lydia, Barcelona, Spain.
Quincey, Mary E., Willey.
Quinn, Patrick D., Miami, Fla, U.S.A.
Rademaker, Jaap, Baarn, Netherlands.
Rajayohan, Rasiah, Mt Lavinia, Sri Lanka.
Ralls, Elizabeth L. W., Asheville, N.C., U.S.A.
Raniga, Umesh C. G., Vancouver, B.C., Canada.
Raymond, Robert S., Brentwood.
Rennie, Margaret M., Bothwell.
Renton, Valerie, Jersey.
Ridgell, Pinckney, Alexandria, Va, U.S.A.
Riseley, Madge B., Wembley.
Roberts, Ian M., Toronto, Ont., Canada.
Roberts, Sylvia, Liverpool.
Robinson, Stuart A., Norwich.
Robshaw, Hillary, Lofthouse.
Rubin, Léon P. J., Brussels, Belgium.
Sabel, Peter L. T., Lichfield.
Sadler, Philip A., London.
Saez Balsalobre, Lidia, Barcelona, Spain.
Salcman, Laurell, Downsview Ont., Canada.
Salim, Salim A., Nairobi, Kenya.
Samarakoon, Ralalage P., Kotadeniyawa, Sri Lanka.
Samuel, Diana, Aberdare.
Sanders, Sonja M., Oshawa, Ont., Canada.
Saraf, Vandna V., Bombay, India.
Sastrowidjojo, Hendro, Surabaya, Indonesia.
Schoe, Marjolein B., Bussum, Holland.
Schofield, Nicola J., Huddersfield.
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EXAMINATIONS 1981

Examination dates for 1981 are as follows:

Gem Diamond Examination: Monday, 8th June

Examinations in Gemmology:

Preliminary: Tuesday, 30th June

Diploma:

Theory, Wednesday, 1st July

Practical, Thursday, 2nd July (London: Tuesday, 30th June and Friday, 3rd July.)

The *last* date for receiving examination entry forms is Friday, 27th February, 1981.

REVISED EXAMINATION SYLLABUSES

At the meeting of Council on 30th April, 1980, revised Syllabuses for the Preliminary and Diploma Examinations in Gemmology were approved for printing as follows:

Syllabus of Examinations

Preliminary

1. *Nature of Light*
   The electro-magnetic spectrum.

2. *Units of Measurement*
   Metric carat, pearl grain. Kilogram (kg), Gram (g), Milligram (mg). Metre (m), Millimetre (mm), Micrometre (μm), Nanometer (nm). Ångstrom Å (obsolescent). Litre (l), Millilitre (ml).

3. *Nature of Gemstones*
   Formation of minerals (elementary). Qualities necessary in gems (beauty, rarity, durability).

4. *Elementary Crystallography*
   Nature of crystals: distinction between crystalline and amorphous materials. Crystal symmetry: axis of symmetry; plane of symmetry; centre of symmetry. Crystal form. Crystal habit. Seven crystal systems. Optical properties: singly and doubly refractive gems; anomalous double refraction; optic axes.

5. *Physical and Optical Properties*
   Hardness: definition; Mohs's scale, selection of reference minerals; application in gemmology; limitations of use. Cleavage: definition; description; importance in gemmology and lapidary work. Specific gravity: definition; determination—hydrostatic weighing, heavy liquids (bromoform, methylene iodide and Clerici

solution), flotation and pycnometer methods. Reflection: laws of reflection; importance in gemmology—lustre, sheen, chatoyancy, asterism. Refraction: laws of refraction; refractive index; total reflection—use in design of refractometer; measurement of RI using refractometer; birefringence and its determination. Polarized light: nature and production of polarized light; design and construction of polariscope; use of polariscope in gemmology. Nature of colour: absorption of light; allochromatism, idiochromatism; differential absorption of light, pleochroism; dichroscope—construction and use; interference; play of colour; dispersion; use of Chelsea colour filter.

6. *Apparatus*
   Use of the balance. Description and use of the ×10 lens. Description of the microscope and an awareness of its other applications in addition to its use as a magnifier. Design and construction of spectroscope.

7. *Description of Gem Materials*
   (a) Natural gemstones:
   Occurrence and localities, Colour, Chemical composition, Crystal system and habit, Cleavage, Hardness, Specific gravity, Refractive index (with birefringence), Pleochroism and lustre of all gem varieties of the following: beryl, chrysoberyl, corundum, diamond, garnet group, jadeite, moonstone, nephrite, opal, peridot, quartz (including chalcedony), spinel, topaz, tourmaline, turquoise and zircon. Elementary methods of identification.

   (b) Synthetic and imitation stones:
   Synthetic corundum and spinel—their manufacture by the Verneuil process. Elementary methods of identification of composite and paste stones. Elementary methods of identification of synthetic stones including corundum, spinel and emerald. A brief outline of other methods—flux melt, hydrothermal and Czochralski 'pulling' methods.

   (c) Organic products:
   Native, cultured and imitation pearls—their formation and structure. Amber. Coral. Jet. Including an elementary knowledge of the formation, nature and properties of this group.

8. *Fashioning of Gemstones*
   Description of the following cuts, including diagrams: brilliant; step; mixed; rose; cabochon; scissors or cross. Including ideal proportions for diamond.

Note: The Preliminary Examination consists of theory papers only.

Diploma—Theory

The Diploma syllabus comprises the whole of the Preliminary syllabus and:

1. *Elementary Crystallography*
   Twinning, parallel growth. Massive, cryptocrystalline and metamict states. Isomorphism and isomorphous replacement.

2. *Physical and Optical Properties*
   Specific gravity. Optical properties of crystals. Refractive index and birefringence: their measurement by refractometer and by other methods. Colour: its causes and artificial alteration. Spectroscopy and absorption spectra. Luminescent and electrical properties. Application of x-rays and ultraviolet light to gem testing. Inclusions and other internal features.

3. *Apparatus*
   Principles and use of: microscope, polariscope, refractometer, dichroscope, spectroscope, ultraviolet lamps, thermal conductivity and reflectivity meters. Principles of endoscope and table spectrometer.

4. *Description of Gem Materials*
   (a) Natural gemstones:
   Occurrence and localities, Colour, Chemical composition, Crystal system and habit, Cleavage, Hardness, Specific gravity, Refractive index (with birefringence), Pleochroism and lustre of all gem varieties of the following: all species listed in the preliminary syllabus with the addition of andalusite, apatite, benitoite, bowenite, chrysocolla, danburite, diopside, enstatite, feldspar (in addition to moonstone), fluorite, hematite, idocrase, iolite (cordierite), kornerupine, lapis-lazuli, malachite, natural glasses (particularly moldavite and obsidian), phenakite, pyrite, rhodochrosite, rhodonite, scapolite, sinhalite, sodalite, sphene (titanite), spodumene, steatite and zoisite.

   (b) Synthetic and composite stones, glass and plastic imitations:
   Methods of manufacture where generally published and identification of synthetics (including synthetic alexandrite, corundum, diamond, emerald, opal, quartz, rutile, spinel, strontium titanate, turquoise, YAG, GGG and cubic zirconia).

   (c) Organic products:
   Pearls, native and cultured (both nucleated and non-nucleated), their formation and structure. Imitation pearls. Amber, copal, coral, jet, ivory, odontolite, shell (cameo, mother-of-pearl), tortoiseshell, and their simulants. Occurrence and methods of identification of all groups.

5. *Fashioning of Gemstones*
   Outline of methods used by diamond cutters and lapidaries.

Diploma—Practical

The determination of the refractive indices and birefringence. Dichroism. Specific gravity. Absorption spectra of gemstones. Identification of gem materials and gemstones (both cut and uncut, mounted and unmounted). Estimation of weight of gemstones. *(Tables of constants are provided for this section of the examination.)*

Note: The gem materials likely to occur in refractive index determinations in the practical examination are not restricted to those listed in the syllabuses for the Preliminary and Diploma examinations.

C.I.B.J.O. DIAMOND RULES

Set out in detail below are Articles 1 to 6 of the second edition (1980) of the C.I.B.J.O. Rules of Application for the Diamond Trade:

Art. 1
Definition of the diamond

(1) A diamond is a natural mineral of crystallized carbon with cubic or pseudo-cubic structure.

(2) The genuineness of a diamond must not be specifically mentioned because the use of the word 'diamond' by itself is automatically a statement of its genuineness.

(3) It is prohibited to use the word 'diamond' to describe such products that have either partly or wholly crystallized due to human intervention, no matter which basic-material or methods are used. Products made in this way can only be named as 'synthetic diamonds' when their structural, physical and chemical properties correspond in their total mass to diamond. The word 'diamond' must then be clearly preceded by the term 'synthetic' or 'artificial'.

(4) Trade marks or fancy names must not use words similar to 'diamond' (e.g. Diamantine, Diamlite).

Names of firms, manufacturers or trademarks are not to be used in connection with synthetic or artificial diamonds, unless such names are clearly preceded by the word 'synthetic' or 'artificial'. Example: The definition 'GE-diamond' (General Electric) is inadmissable and should be reworded into 'synthetic diamond GE'.

Art. 2
Weight of the diamond

(1) The weight of the diamond is always expressed in carats (international abbreviation 'ct') to at least two decimal points. It can be rounded off upwards to two decimal figures only if the third decimal figure is a nine.

(2) If the total weight of all the diamonds contained in an article is given the weight must be specified clearly and unambiguously by the terms 'total weight' or words of similar importance.

Art. 3
Colour

(1) The diamond colours are determined by the seven C.I.B.J.O. masterstones (see Art. 8)* these describe the lower limit of each colour.

*According to Art.8:—'A set of seven diamonds has been selected and aproved . . . . as the official set of masterstones for determining the colour-grades. These are the diamonds 1.00, 1.17, 1.07, 1.03, 1.00, 1.17, 1.09. The same has been done with three reference-stones 0.33, 0.30 and 0.31 ct. for determining the intensity of the fluorescence . . . . National duplicates of masterstones are to be compared and chosen equivalent to the official C.I.B.J.O. set . . . .'—Ed.

(2) The colours have to be named as follows:

C.I.B.J.O.— International Colour Grading Scale	(1)	(2)
Exceptional White (4)	D	River
Exceptional White	E	
Rare White (4)	F	Top Wesselton
Rare White	G	
White	H	Wesselton
Slightly tinted white	I J	Top Crystal/ Crystal
Tinted White	K J	Top Cape
Tinted Colour (3)	M Z	From Cape to Yellow
Fancy Diamonds		

(1) G.I.A. terms as comparison
(2) Transitional use until 1984
(3) Optional subdivision for some countries (i.e. South Africa)
(4) The subdivision of the colours Exceptional White and Rare White into two further subdivisions may only be done for sizes of 0.47 ct. and larger.

---

(3) Colour specification must be made by an experienced professional, carried out by comparison to a masterset chosen according to the original C.I.B.J.O. masterstones, under normalized artificial light equivalent to approx. 5.500° Kelvin (D55).
If no difference is observed between one of these masterstones and the diamond to be graded, the colour of the masterstone is conclusive. If the colour lies between those of two masterstones, the colour of the darker one is conclusive.

(4) Non-yellow hues (i.e. brownish) are graded according to the intensity of the colour compared to the masterstones.

(5) Fancy-coloured diamonds which have a clear and distinct colour are separately described.

(6) Photometric measurements have no determinative value.

(7) The fluorescence of a diamond has merely a descriptive value and is to be expressed as either:

none—slight—medium—strong

as seen under longwave UV (366 nm). These degrees are defined by the three C.I.B.J.O. fluorescence-reference-stones described in Art. 8.

(8) The body-colour of fluorescent diamonds must be determined under normalized light (D55 CIE).

(9) If an offer contains the quality of a diamond, the colour may not be mentioned without the purity and vice versa.

Art. 4
Purity

(1) All internal characteristics belong to the inclusions which are internally perceptible. These are:

— crystalline and solid inclusions, clouds, pin points,
— fissures, feathers, fissures at the girdle (bearding),
— structure phenomena (only in the case of clear visibility inside the stone, i.e. brown-coloured growth-lines, reflective grain-planes).

(2) The purity of a diamond must be examined by an experienced professional under 10-power magnification in normal light by means of an achromatic, aplanatic lens and described as follows:

loupe-clean (lc)	A diamond is called loupe-clean if, under these conditions, it has been found absolutely transparent and free from inclusions.
vvs (vvs 1, vvs 2)	Very very small inclusion(s), very hard to find with a 10× loupe.
vs (vs 1, vs 2)	Very small inclusion(s) which can hardly be found with a 10× loupe.
si	Small inclusion(s), easy to find with a 10× loupe, not seen with the naked eye through the crown-side.
PI (Piqué I)	Inclusion(s) immediately evident with a 10× loupe, difficult to find with the naked eye through the crown-side, not imparing the brilliancy.
PII (Piqué II)	Large and/or numerous inclusion(s), easily visible to the naked eye through the crown-side and which slightly reduce(s) the brilliancy of the diamond.
PIII (Piqué III)	Large and/or numerous inclusion(s) very easily visible to the naked eye through the crown-side and which reduce(s) the brilliancy of the diamond.

Terms such as 'pure', 'pure to eye', 'Commercially pure' or other misleading expressions or definitions are not to be used.

The subdivision of the degrees vvs and vs into two further subdivisions may only be done for sizes of 0.47 and larger.

(3) External characteristics do not impair the purity. This applies particularly to:

— polishing lines, rough edges, burn marks and very slightly bearded girdle.
— externally located damage such as scratches and pinpoint-shapes damage,
— extra facets and the remaining parts of the rough diamond (naturals),
— twinning-lines, growth-lines, knot-lines, surface grain-lines.

Major external characteristics which cannot be removed by repolishing without considerable loss of weight should be taken into account when the purity grade is determined.

(4) Interim Rules: France:
During a transition period until 1984 France will endeavour to adopt these international purity regulations and to use none but the 10-power magnification for purity determination after this period at the latest. Until then the following will apply:

(a) If any other than 10-power magnification has been used for purity determinations, it must be clearly indicated; e.g. '3-power magnification', etc.

(b) Foreign branches of French companies have to comply with the regulations of the host country, i.e. to use exclusively the 10-power magnification and to dispense with the 2- and 8-power loupe for determinations or definitely to point out the difference to their customers.

Scandinavia:
The Scandinavian countries are using the 'clarity grading' only for a transitional period until 1984.

Art. 5
Cut and Shape

(1) It is inadmissible to describe diamonds as 'correctly cut' if the proportions and symmetry of the diamond do not correspond to the norms in common usage. These norms take into account the general proportions of the stone and, following the laws of optics, allow a maximum of brilliance for the modern cut of a diamond.

(2) A modern brilliant cut is based on specific optical calculations aiming at a maximum of beauty which is a result of brilliancy and dispersion. Different combinations of proportions can give an equally good result and the evaluation of the quality of the cut can therefore not be determined by measurements only.

On the other hand, the finish is independent of the proportions and of minor importance as to the quality of the cut. Two separate indications are given to which extent deviations are observed concerning symmetry and polish. These do not pertain to the brilliancy.

(3) The term 'brilliant' without any additional description of the material may only be applied to round diamonds with brilliant cut.

(4) The brilliant cut or 'fullcut' is the round form consisting of an upper portion (crown) with at least thirty-two facets (excluding the table) and a lower portion (pavilion) with at least twenty-four facets (excluding the culet). The other cuts (8/8, 16/16, etc.) must be designated as such.

(5) Other common shapes are marquise, pear, oval, heart, emerald-cut, triangle, baguette, etc.

Art. 6

Designation of treatments and combinations of stones

(1) If the natural colour of a diamond has been artificially altered, it has to be clearly declared as 'treated', 'artificially coloured' or 'irradiated'.

(2) Diamonds that have been artificially treated to alter their purity by means of laser-drillings or other techniques must be clearly declared as 'drilled' or 'laser-drilled'. The classification should correspond to the original purity degree. The drilling hole itself is also graded as an inclusion.

(3) Any piece of jewellery put on display or presented for sale, composed of natural as well as synthetic or artificial elements must be accompanied by an obvious legible label, showing composition details according to the rules of the nomenclature. When diamond (or pieces of jewellery thereof) are displayed together with artificial or synthetic products (or pieces of jewellery thereof), an easily visible label must indicate the nature of the objects shown.

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CORRIGENDA

On p.209 above (line 17), for 'Mr Geoffrey Toombs' read 'Mr Geoffrey Tombs'.

On p.248 above (line 12), for 'band' read 'baud'.

On p.259 above (line 18), for 'anisotrophy' read 'anisotropy'.

On p.263 above (line 6), for 'emenate' read 'emanate'.

On p.267 above (line 28), for '179-83' read '179-82'.

On p.272 above (line 5), for 'or' read 'of'.

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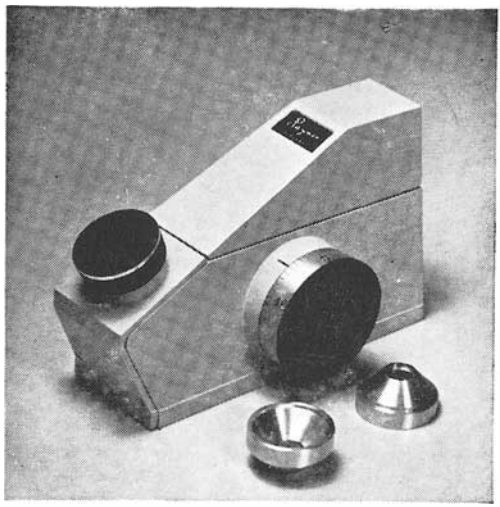

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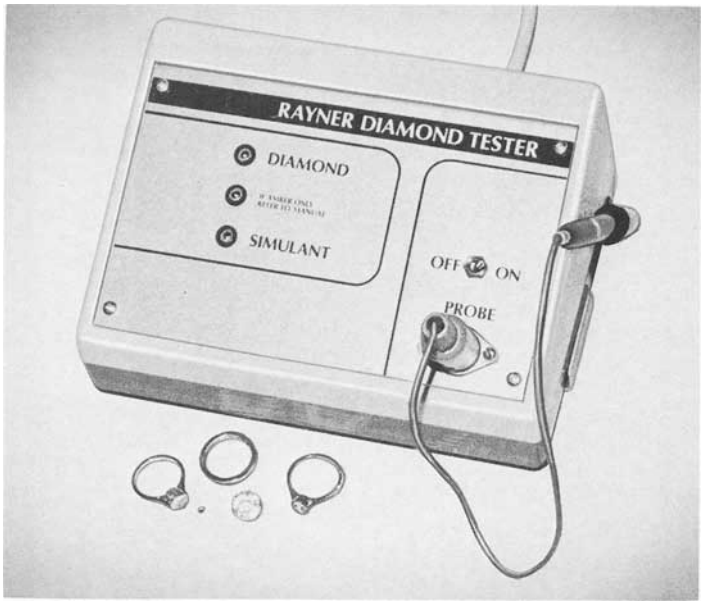

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Historical Note

The Gemmological Association of Great Britain was originally founded in 1908 as the Education Committee of the National Association of Goldsmiths and reconstituted in 1931 as the Gemmological Association. Its name was extended to Gemmological Association of Great Britain in 1938, and finally in 1944 it was incorporated in that name under the Companies Acts as a company limited by guarantee (registered in England, no. 433063).

Affiliated Associations are the Gemmological Association of Australia, the Canadian Gemmological Association and the Rhodesian Gem and Mineral Society.

The *Journal of Gemmology* was first published by the Association in 1947. It is a quarterly, published in January, April, July, and October each year, and is issued free to Fellows and Members of the Association. Opinions expressed by authors are not necessarily endorsed by the Association.

Notes for Contributors

The Editor is glad to consider original articles shedding new light on subjects of gemmological interest for publication in the *Journal.* Articles are not normally accepted which have already been published elsewhere in English, and an article is accepted only on the understanding that (1) full information as to any previous publication (whether in English or another language) has been given, (2) it is not under consideration for publication elsewhere and (3) it will not be published elsewhere without the consent of the Editor.

Articles published are paid for, and any number of prints of individual articles may be supplied to authors provided application is made on or before approval of proofs. Current rates of payment for articles and terms for supply of prints may be obtained on application to the Secretary of the Association.

Although not a mandatory requirement, it is most helpful if articles are typed (together with a carbon copy) in double spacing on one side of the paper, with good margins at sides, top and foot of each page. Articles may be of any length, but it should be borne in mind that long articles are more difficult to fit in than short ones: in practice, an article of much more than 10 000 words (unless capable of division into parts or of exceptional importance) is unlikely to be acceptable, while a short note of 400 or 500 words may achieve early publication.

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ON MONAZITE INCLUSIONS

By S. HORNYTZKYJ, F.G.A.

INTRODUCTION

It has been shown by Murata and Bastron,[1] and Jobbins *et al.*,[2] that nonopaque, nonmetamict monazite, which is a phosphate mineral of the lighter rare earths (Ce, La, Pr, Nd, Y, Th)PO_4, changes colour under special light. When monazite is illuminated with the unfiltered light of a medium-pressure mercury-vapour lamp (principal emission lines at 405, 436, 546 and 578nm), the violet and blue radiations (405 and 436nm) are absorbed as they lie in the region of general absorption in the spectrum of monazite (Figure 1). On the other hand the yellow radiation (578nm lies within the strong absorption lines of neodymium and is greatly weakened whereas the green radiation (546nm) lies in a spectral region of relatively high transmittance; hence monazite assumes the green colour of the unabsorbed component. This colour-change phenomenon is related to the rare-earth metals, primarily to

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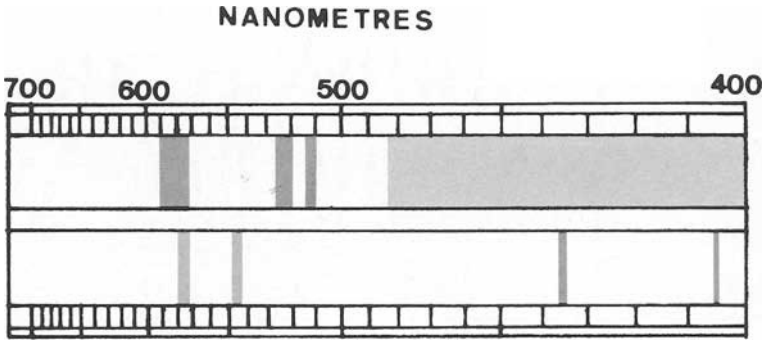

FIG. 1. Absorption and emission spectrum as seen through prism spectroscope. Above: the main absorption lines in the monazite spectrum (water-worn rolled pebble from river gravel; Lapland, North Finland). Below: the four main spectral-line radiations emitted by a medium-pressure mercury-vapour lamp.

neodymium, which cause the strong absorption lines in the yellow and green part of the spectrum of monazite. As these lines can be observed with an ordinary hand spectroscope, they have been used for recognizing monazite by field geologists.[3,4] However, to the author's knowledge all the monazite samples to which both these methods have been applied, with the exception of a study by Hornytzkyj and Korhonen,[5] have been loose grains or crystals; therefore it was interesting to see whether these methods could also be applied to monazites as inclusions. Here it deserves to be mentioned that a small parisite inclusion in a Colombian emerald was discovered with the aid of the spectroscope.[6] Parisite, which is a rare fluocarbonate of calcium and the cerium group of rare earths, $(Ce,La)_2Ca(CO_3)_3F_2$, and forms pyramidal to slender prismatic crystals, usually contains some (didymium) neodymium and praseodymium which cause absorption lines similar to those observed in the spectrum of monazite.

DESCRIPTION

According to Gübelin[7] monazite inclusions have been encountered in the following gem quality minerals, viz. topaz, garnet, iolite and sapphire. For this study about 3000 samples, which comprised rough and cut gem quality topaz, garnet, iolite and sapphire from different localities, were studied. They were first examined, immersed in suitable liquids, under a Wild Heerbrugg binocular microscope and the samples containing inclusions similar

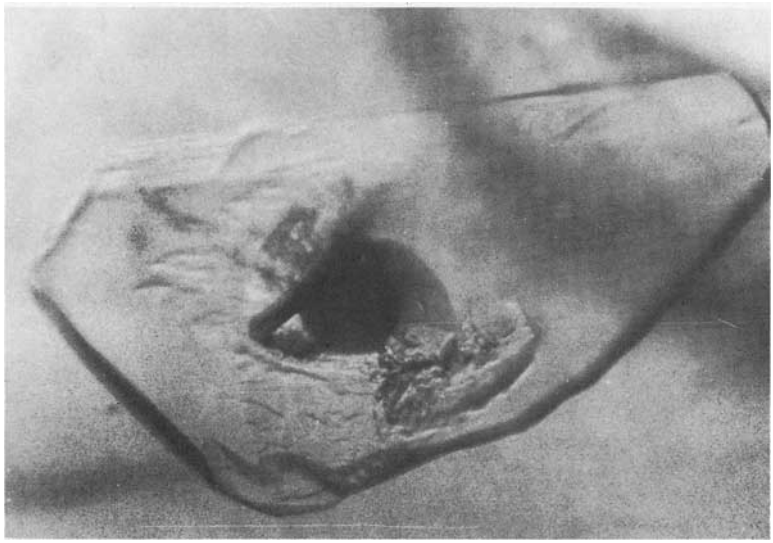

FIG. 2. Tabular crystal inclusion in topaz from Nigeria. (223 ×)

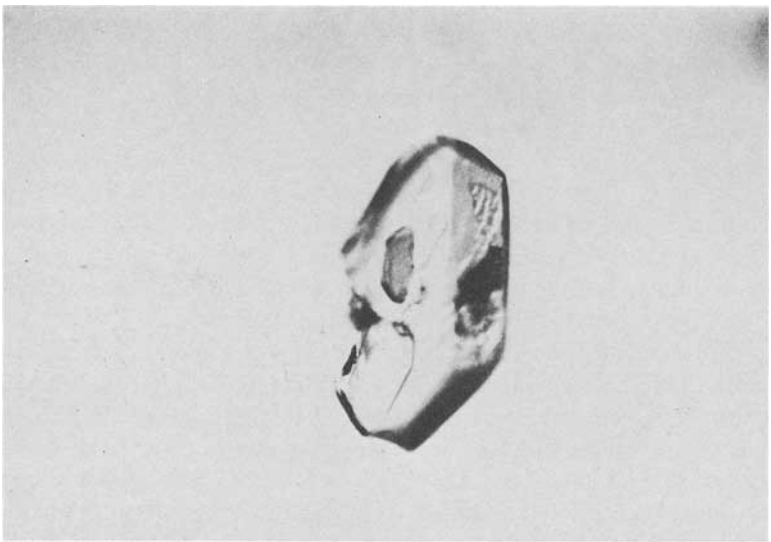

FIG. 3. Tabular crystal inclusion in topaz from Madagascar. (220 ×)

to monazite in habit and colour were placed aside. In all, 36 out of these 3000 samples seemed to contain monazite inclusions. These 36 specimens were then examined under the same microscope by the unfiltered light of a medium-pressure quartz-mercury lamp (Hanovia No. 11) directed to each specimen from below by the microscope mirror. Finally the inclusions in these specimens were sharply focused (magnification 100×) and the eyepiece of the microscope, this time Leitz SM-pol, was removed and a Rayner prism spectroscope placed on the top of the microscope.

Topaz

Flat tabular crystal inclusions of yellow colour and angular profile (Figures 2, 3) were observed in some colourless topazes from Nigeria and Madagascar. The crystal faces of these inclusions were etched to a certain degree. Between crossed polars they showed vivid interference colours and their refractive index was higher than that of their host (>1.610-1.620). By the quartz-mercury lamp the colour change was distinctive: their colour turned light green – bright green and the intensity of this green colour seemed to be dependent on the thickness and size of the inclusions. In addition, the green colour of these inclusions in topazes from Nigeria was less intense than that from Madagascar. When these inclusions were large enough, the spectroscope revealed a group of lines at about 510-520 and 570-590nm. The host mineral (topaz) showed no observable absorption spectrum.

Garnet

Orange brown, thin, tabular crystal inclusions of angular to rounded profile were met in garnets from India, Sri Lanka, Australia and Finland. All of them were surrounded by a single halo (Figures 4, 5) and displayed vivid interference colours between crossed polars. Their refractive index was close to that of their host (1.774-1.810) but higher. Under the quartz-mercury lamp their colour change varied from vague to distinctive: from greyish olive-green to greenish and in some cases to bright green. The three strong absorption bands in the yellow-green part of the spectrum of garnet (the specimens examined belonged to the pyrope-almandine intermediate series) apparently reduced the transmittance of the 546 and 578nm wavelength. The best results were obtained when the host mineral had a weak almandine spectrum. Furthermore, the

FIG. 4. Thin tabular crystal inclusion, surrounded by a single halo, in garnet from Finland. (180 ×)

FIG. 5. Two rounded crystal inclusions, surrounded by single haloes, in garnet from India. (180 ×)

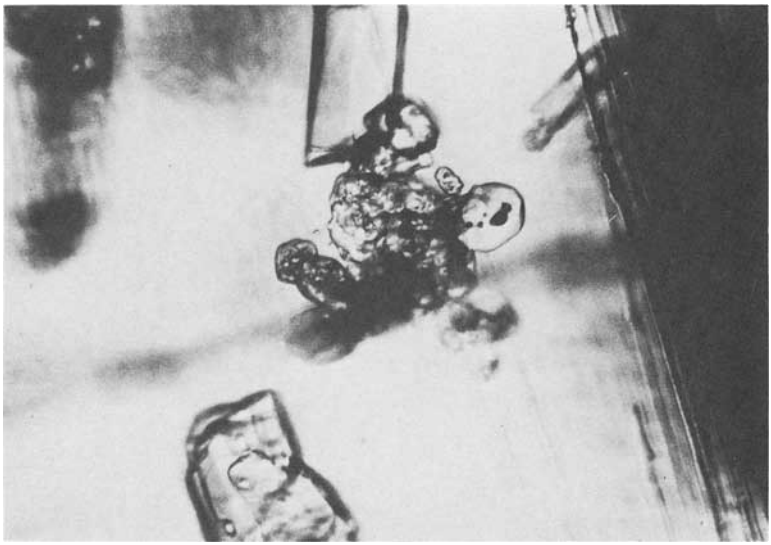

FIG. 6. Dense aggregate of thin rounded crystal inclusions in kyanite from Rhodesia. (200 ×)

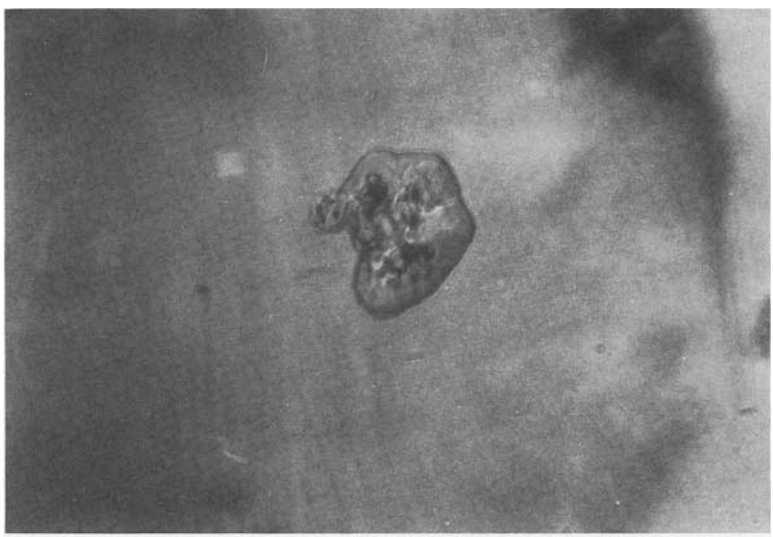

FIG. 7. Thin angular crystal inclusion in kyanite from Rhodesia. (210 ×)

intensity of the colour change seemed to vary according to the thickness and size of these inclusions.

Iolite

No inclusions similar to monazite were observed in specimens from Sri Lanka and Finland.

Sapphire

No inclusions resembling monazite were met in specimens from different (unknown) localities.

In addition to the before-mentioned minerals some rough and cabochon-cut kyanites from Rhodesia were found to contain inclusions reminiscent of monazite. These crystal inclusions were slightly rounded, angular, yellowish thin tabular platelets and their size was smaller than that in the two cases mentioned before. Their refractive index was higher than that of their host (>1.714-1.729) and between crossed polars they showed moderate interference colours. By the quartz-mercury lamp the colour change was distinctive: their colour turned light green. These inclusions occurred singly or in dense clusters (Figures 6, 7). When such an aggregate of crystal inclusions was large enough, the spectroscope revealed a group of lines at about 510-520 and 570-590nm. The host mineral (kyanite) showed two absorption lines in the deep blue and a line in the deep red.

SUMMARY

All the before-mentioned crystal inclusions were nonopaque, nonmetamict, tabular, angular or slightly rounded crystals of yellow or reddish orange colour. By the quartz-mercury lamp their colour change was distinctive except when enclosed in garnet. When they were large enough or occurred in sizable aggregates, the spectroscope revealed a group of absorption lines in the yellow and green part of the combined spectrum. On the face of these results it seems most probable that these crystal inclusions are monazites and that both these methods can be applied to recognizing monazite inclusions, provided however that the host mineral transmits the two radiations of the quartz-mercury lamp, the size of the inclusions in question is large enough and the lighter rare earths, particularly neodymium, are present in the right proportion to produce the absorption lines.

ACKNOWLEDGEMENTS

The author's sincere thanks are due to Mr J. R. H. Chisholm, M.A., F.G.A., for his valuable suggestions at the initial stages of this study. The author is also indebted to Professor Th. G. Sahama for his advice, interest and support in the course of this study. Thanks are also due to Mr K. T. Korhonen, M.Sc., and Mr H. Koivisto, for their assistance in this study. Last but not least the author would like to thank Miss S. Martikainen, who kindly made the photographs.

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FIRST OCCURRENCE OF GEM SPHENE IN SRI LANKA

By MAHINDA GUNAWARDENE, F.G.A., D.Gem.G. and HENRY A. HÄNNI,† Ph.D., F.G.A.*

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INTRODUCTION

Once more, the careful investigation of a mixed parcel of tourmalines from Sri Lanka has yielded a surprising result. This study deals with an oval, faceted, brown stone, which attracted attention because of its shining inclusions located slightly below the table facet. This feature is unknown in tourmalines. The result of a refractivity measurement was negative; that is, the refractive index must be higher than 1.8. On the basis of its specific gravity and the observed absorption spectrum showing didymium-lines, the stone was suspected to be a sphene. Because sphene of gem quality has not to date been reported from Sri Lanka, it was necessary to undertake a mineralogical and chemical investigation of this stone. At the same time, three additional sphenes from well known localities were analysed as a means of comparison. They are described in Table 1.

TABLE 1

Sample description

No. 1 Yellow-green faceted gem from Madagascar, 0.49 ct: SG = 3.52

No. 2 Green crystal fragment, Swiss Alps (too small for RI measurement)

No. 3 Emerald-green crystal from Baja California, Mexico, 4.99 ct: SG = 3.53

No. 4 Dark brown faceted gem with oval form, from Sri Lanka, 4.48 ct: SG = 3.52

CHEMISTRY

Although the chemical formula of sphene is simply $CaTiSiO_5$, this mineral normally contains small proportions of foreign elements. There is a substitution of major elements by minor proportions of rare-earth elements and others. It was observed that

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TABLE 2
Microprobe analyses of gem-material sphenes

	1	2	3	4
SiO_2	29.87	29.72	29.92	29.92
TiO_2	37.63	38.39	38.39	38.61
Al_2O_3	1.21	1.06	.82	.85
Fe_2O_3	.60	.69	.26	.45
Cr_2O_3	.21	.16	.38	.00
MnO	.23	.00	.00	.00
MgO	.09	.00	.06	.17
CaO	28.63	28.78	28.97	28.53
Na_2O	.02	.00	.00	.40
K_2O	.03	.02	.03	.03
Total	98.52	98.82	98.83	98.96
Si	0.9934	0.9844	0.9912	0.9897
Al	0.0474	0.0414	0.0320	0.0331
Ti	0.9411	0.9569	0.9564	0.9604
Mg	0.0044	0.0000	0.0029	0.0083
Fe	0.0150	0.0174	0.0064	0.0112
Cr	0.0031	0.0041	0.0099	0.0000
Mn	0.0064	0.0000	0.0000	0.0000
Na	0.0012	0.0000	0.0000	0.0256
Ca	1.0202	1.0221	1.0283	1.0111
K	0.0012	0.0008	0.0012	0.0012

Analyst H. Schwander, Basel.
oxides in weight-%; number of ions on the basis of 5(O)
1 yellow-green sphene from Madagascar
2 yellow-green sphene from the Swiss Alps
3 emerald-green sphene from Mexico
4 dark-brown sphene from Sri Lanka
The sample from Sri Lanka contains approximately 0.5% Nb. Further rare-earth elements were not detected by this analytical determination.

Ca could be replaced in small quantities by Na,Mn,Sr,Ba. Furthermore, Ti could be substituted in slight amounts by Al,Fe,Mg,Nb,Ta,V,Cr. Finally oxygen indicated a small degree of replacement by OH or F. In sphenes, traces of rare-earth elements are characteristically found. Among these, Ce and Y are common, and Nd and Pr cause an absorption spectrum in which a group of fine lines appears in the yellow region. In order to have a means of comparison of the chemical analysis of the stone from Sri Lanka, the additional three sphenes from Table 1 were analysed as well. The analyses were made using an ARL electron microprobe, operating the wavelength dispersive method as well as the energy dispersive method. The chemical standards were silicates with simple compositions (minerals) and oxides. All samples were coated with carbon in order to have a conductive surface. The analytical results are presented in Table 2. The main constituents of all samples are fairly constant; minor elements differ in small limits. The concentrations of the trace elements are too low to be analysed by the microprobe. Nevertheless the sample from Sri Lanka showed a small Nb peak, and a concentration of 0.5% was estimated. The dark brown colour is not necessarily related to the total iron content as indicated by samples No. 1 and 2, which are both lighter in colour than No. 4, yet have a higher iron concentration. Literature indicates that the brown colour is due to iron, with as little as 1% Fe_2O_3 causing a dark brown stone.

Optical Properties of the Stone from Sri Lanka

The most attractive sphenes have a bright yellow, green or brown (blue and red are also reported) colour which does not completely obscure the strong dispersion, thus such stones produce a remarkable fire. The stone No. 4 is lacking in such fire, its dark brown colour masking this esteemed property. Because of the high refractive index of sphene we had to use a special Riplus type refractometer. The values, including the comparative stones, are shown in Table 3. Stone No. 2 was too small to get a reading.

The obvious inclusions in the stone consist of disc-shaped fine tension fissures similar to those seen in metamict zircons from Sri Lanka. These fissures are oriented parallel to each other, and no mineral grains were discovered which could have caused the defects, using both microscope and microprobe.

TABLE 3
Refractive Indices

	nα	nγ	DR
No. 1	1.910	2.070	0.160
No. 3	1.908	2.080	0.181
No. 4	1.909	2.099	0.190

The absorption spectrum is as reported in many books, the typical rare-earth spectrum. It consists of a group of fine lines in the yellow. Further lines are not seen in the hand spectroscope. Table 4 shows the absorption spectrum recorded with an ultra-violet spectrometer Pye Unicam SP 8-100 under rapid scanning conditions, but narrow band width (0.5 nm). Wavelength indications are accurate to ±0.5 nm or better. General absorption for the very dark red-brown ray starts below approximately 470 nm, the lighter greenish-brown ray below about 440 nm. The peak positions are not sensitive to crystal orientation; the absorption intensities, however, depend strongly on it.

The spectrum essentially is identical with those of yellow and green sphenes, except for the much lighter line intensities in the described brown Sri Lanka stone. The attractive green sphenes from Baja California have additional bands and lines due to chromium.

Occurrence

Sphene occurs as a common accessory mineral in magmatic as well as in metamorphic rocks. In Sri Lanka it is reported from wollastonite-bearing gneisses of the Galle Series and from gneisses close to the hill country, in which it appears much rarer (H. S. Gunaratne, personal communication). Although these rock-forming sphenes do not reach cuttable sizes, it is surprising that the subject of this paper originates from a remote area near Galle.

Acknowledgements

We are grateful to Professors M. Frey and H. Schwander, in whose institute and laboratories the chemical investigations were carried out. We also wish to express our thanks to Mr E. Uhl for

TABLE 4

Absorption spectrum of sphene from Sri Lanka

The absorption spectrum consists of four line-groups

	Int.	nm		Int.	nm
Group 1	m	820	Group 3	vw	596
	vw	813		vw	593
	st	806		w	590
	m	799		vw	587
	m	795		m	586
	vw	789		w	582
				w	579
Group 2	vw	779		vw	575
	vw	776		vw	573
	vw	771		w	569
	w	764			
	st	751	Group 4	vw	536
	vw	746		vw	533
	vw	744		w	528
	vw	741		vw	524
	w	739		w	512
	m	732			

Intensities: st = strong, m = medium, w = weak, vw = very weak

providing us the comparative samples and Mr J. Häfliger from Siber and Siber Ltd for operating the Krüss ER602 Riplus refractometer. Thanks are due to Mr G. Bosshart, M.Sc., G.G., from the Swiss Foundation for the Research of Gemstones, who provided the spectroscopic data.

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AN INVESTIGATION OF SYNTHETIC TURQUOISE AND THE TURQUOISE SUBSTITUTE OF GILSON

By Dr K. SCHMETZER and Prof. Dr H. BANK, F.G.A.

SUMMARY

The so-called synthetic turquoise of Gilson consists of turquoise with one or more additional crystalline phases. The designation 'synthetic turquoise' does not correspond with the composition of the material. The turquoise substitute of Gilson consists mainly of calcite.

INTRODUCTION

For several years, P. Gilson, the French producer of synthetic stones and imitations, who has become well known for his synthetic emeralds, has offered synthetic turquoise as well as a substitute for turquoise. According to chemical and x-ray investigations of Williams and Nassau (1976-1977), Gilson's synthetic turquoise is the only product on the market which may be really called synthetic turquoise. Other substitutes of turquoise as well as the Gilson turquoise studied by the authors mentioned, consist of the same constituents as natural turquoise (CuO, Al_2O_3, P_2O_5 and H_2O), which crystallizes in the triclinic system with the formula $CuAl_6[(OH)_2|PO_4]_4 \cdot 4H_2O$.

The substitutes differ, however, from the natural gemstone in their crystal structures. Although Eppler (1973-1974) as well as Arnould and Poirot (1975) through microscopic investigations and infrared spectroscopy observed differences between natural turquoise and the synthetic one of Gilson, the reasons for these differences are yet unknown. Microscopic observation of a second crystalline phase, which occurs as matrix between turquoise spheres (Eppler, 1973-1974), indicates that one should expect additional x-ray lines in the pattern of the substance by Gilson, called synthetic turquoise. The investigations by Williams and Nassau (1976-1977) on natural turquoise from Nevada, U.S.A., and synthetic turquoise from Gilson however resulted in general in the same x-ray powder diagrams for both materials. Differences

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include only a small shift of the line at 3.28 Å to a lower d-value as well as a spreading of the same line with the synthetic material.

EXPERIMENTAL

For the present paper, three samples of synthetic turquoise (Gilson) and one sample of Gilson's substitute as well as natural turquoise from Nevada were studied for comparison. The main elements with an atomic number>11 were determined by a SEM-micrograph in connexion with an energy-dispersive system. X-ray investigations were performed by a powder diffractometer and with film methods (Guinier- and Debye-Scherrer-techniques).

RESULTS

1. Synthetic turquoise of Gilson

In all three samples of Gilson's product only the main elements Cu, Al and P, characteristic also for natural turquoise, could be determined.

The x-ray powder diagram of the synthetic material indicates several lines not yet observed in natural turquoise (Table 1). It is worth mentioning, that the d-values of the strongest of these additive lines at 3.25 and 3.22 Å are identical with the d-value of the shifted line at 3.28 Å, which is illustrated in the figure given by Williams and Nassau (1976-1977), as already mentioned. So the x-ray investigations of the synthetic material of Gilson's product, which until now has been named synthetic turquoise, show that this

TABLE 1

Additional lines in the x-ray powder pattern of 'synthetic turquoise' produced by Gilson.

d[Å]	I/I_1
4.91	15
3.93	50
3.25	100
3.22	90
2.76	10
2.55	15

the strongest line of turquoise at 3.68 Å has, in the three samples investigated in our laboratory, an intensity of 60.

product consists of one or more additive crystalline phases in addition to turquoise. Using the d-values given in the ASTM-Index for Al- and Cu-phosphates or Al- and Cu-hydroxides and hydrates showed a similarity of several of the d-values of Gilson's synthesis, which do not belong to turquoise, to those of the crystalline phase $AlPO_4 \cdot 1.1—1.3\ H_2O$ (ASTM 15-265). But it was not possible to assign the two strongest additive d-values to any certain crystalline phase. The results can be explained by comparing the data of Williams and Nassau (1976-1977): both series of 'synthetic turquoise' of Gilson contain, besides turquoise, one or more other crystalline phases. Less matrix is contained in the sample of Williams and Nassau than in our samples.

The synthetic turquoise of Gilson consisting of synthetic turquoise and further crystalline phases must be regarded as a mixture which, until now, has not yet been described in nature. The term 'synthetic turquoise', therefore, does not designate the composition of the material. According to the rules of nomenclature, it should not be used.

2. Turquoise substitute of Gilson

In the substitute of turquoise produced by Gilson, Ca has been determined as the main element as well as traces of Si, P, S and Fe. The x-ray powder diagram shows lines of calcite as well as some additive lines of minor intensity (Table 2). The lines with d-values

TABLE 2

Additional lines in the x-ray powder pattern of calcite produced as turquoise substitute by Gilson.

d[Å]	I/I_1
4.91	5
2.784	7
2.751	5
2.629	10
2.191	4

the strongest calcite line at 3.035 Å has an intensity of 100.

of 4.91 and 2.629 Å can be caused by $Ca(OH)_2$. An assignment of the other weak lines is difficult without knowledge of the mode of manufacturing of the substitute. The imitation of turquoise produced by Gilson can be regarded as a mixture of mainly calcite and other crystalline phases.

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NOTES FROM THE LABORATORY—THE ENJOYMENT OF GEMMOLOGY

By A. E. FARN, F.G.A.

The Gem Testing Laboratory of the London Chamber of Commerce and Industry

To me the enjoyment of gemmology is *not* hastening towards the 'Diamond Eye' with a colourless stone, neither is it placing a green subtranslucent stone upon the spectroscope stand to check whether it is jadeite-jade or californite, etc.

Rather it is to employ the eye (an intricate piece of equipment) aided by a 10× lens. 'The first impact of a gemstone upon the eye is its colour'—this sentence being the subject of a talk I gave in Idar-Oberstein in 1979.* The conference itself was an international affair † in which every variety of gemmologist seemed to be present. Geologists, mineralogists, physicists of world repute rubbed shoulders and in so doing by this very attrition added a little polish to each other by the garnering and dissemination of knowledge. Every variety of gemmologist was present. Quite a sweeping statement! What in fact is a gemmologist?

Gemmology, the study of gemstones, is the broad discipline of the gemmologist embracing crystallography, optics, chemistry, physics, etc.: a gemmologist knows perhaps a little of each of them. It is also possible to be a specialist in the gemmological field. Famous among them must be B. W. Anderson and spectroscopy, Edward Gübelin and inclusions, Robert Webster on x-ray fluorescence to name but a few. Certainly gemmology—to coin a phrase—'has a broad spectrum'. Basically, to me that spectrum must be the visible one which the eye can determine. Even here we have individual limitations and human factors. Some people cannot see very well in the red end of the spectrum, others find it nigh on impossible to see 'alpha' or even 4370Å in jadeite. I must hasten to explain that 'alpha' was used freely in the 'good old days' of Ångström Units for the 4155Å line in the Cape spectrum of diamond.

*The first impact of a gemstone, *Z.Dt.Gemmol.Ges.*, **28** (4), 188-90, 1979—Ed.

† See *J.Gemm.*, **XVII** (3), 206-9, 1980.—Ed.

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Although there are individual limitations on eyesight, generally speaking most of us ordinary people see rubies as red, sapphires as blue and emeralds as green. The subtlety though is in the *impact* of that colour; upon opening a stone paper containing a loose stone or being shown a coloured stone in a ring the eye registers the colour and sends *that* message to the brain. Most of us in the trade will automatically react and recognize (for want of a better word) a Verneuil synthetic ruby. Generally this Verneuil has too much chromium and it is cut at random—a fatal combination giving the garish colour of a typical synthetic ruby.

This impact effect is the result of practice and practical handling of gemstones. It is a scoring point tradespeople have over narrower specialists in gemmology.

When I first started work in the Laboratory, not having had any real training except six years in the Army, I was totally depressed upon engagement to find that our commissionaire could tell cultured pearl necklaces from natural as they came through his hands. He would say to B. W. Anderson 'John Smith has sent in a single-row cultured pearl necklace' or '(someone else) has sent in a pair of natural pearl ear-pendants!'

Because of war conditions, with B. W. Anderson being on his own, the sergeant had to help Anderson much more than his duties demanded and he handled goods so much that he 'got his eye in'.

It takes time and plenty of goods, but slowly it comes and you find yourself deciding the nature of a stone *before testing*. It is very, very gratifying to find that your instinct and eye have responded to that first impact of a gemstone.

Lots of people unfortunately do not have the opportunity to handle the stones that we in the laboratory have. We are indeed fortunate—sometimes (although we restrain ourselves) it seems we ought to pay for the pleasure of looking at such treasures!

Dwelling upon gemmology from a trade point of view, an extension of the first impact of a gemstone is afforded by that primary weapon, the 10× lens. This to a gemmologist is as a rifle was said to be to a soldier—his best friend! Many ex-service readers will agree that there are some aspects of weapon training that did not endear them to their rifle! However, it is hoped that the enthusiastic gemmologist will be a volunteer and not a pressed man. Although change is inevitable with the advent of more and more sophistication in the manufacture of synthetics and artefacts

requiring considerable technical skills in the use of equipment, the 10× lens must surely keep its place in the gemmologists' fight and be used in the preliminary encounter with the enemy.

I had once considered writing an article upon the sartorial garb of a gemmologist and intended a plea for the conventional three piece suit, the idea being that a waistcoat is the ideal practical garment for the retention of (for right handed people)—

10× lens in bottom right pocket,

Chelsea filter in bottom left pocket,

Stone gauge in top right pocket,

Radiological protection badge in top left pocket, (I realize, of course, that most gemmologists do not possess x-ray sets).

Enjoying gemmology, the challenge of 'What is it?', the ability to spot a green metamict zircon by its colour and zoning are rewards offered to the enthusiast. I find considerable pleasure in trying to go through a whole necklace and prove every 'pearl' cultured by dint of demarcation lines of nacre and mother-of-pearl and/or 'varicose veins' particularly at the drill holes. Thin-skinned cultured pearls have a regularity about them plus that gleam of artificial dentures, and if the necklace is rotated sometimes a flash of extra lighting will indicate the zonal nature of the mother-of-pearl bead barely covered by a lick of nacre. B. W. Anderson used to say these cheap quality cultured pearls had a sucked look like some sweets of long ago which used to change as you sucked them, necessitating an examination between saliva-dripping fingers (happy days!).

Garnet topped doublets can be detected by the join on a facet of the hard garnet and soft glass: when polished, the difference is seen by reflection. Perhaps one of the easiest examinations is that of a pink pearl: 'flame structure' is the term used to describe this unique pattern which really has to be seen and once seen is easily remembered. Ivory (elephant) has its lines of Retzius—somewhat akin to engine-turning—but one needs a polished rounded surface to see them fully displayed. Strangely enough one of the cleverest breakthroughs in gemmological synthesis, that of opal, is in itself fairly characteristic in structure. The effect seen by lens is variously described as lizard-skin or chicken-wire effect.

Before the advent of synthetic opal we seldom really *looked* hard at the surface, since opal was unique and needed no expert to tell what it was. Certainly successful synthesis causes us to look that

much harder at gems. The 10× lens scores many times because of its *low* power. Very recently one of our more extrovert clients came in to see me. He brashly stated that despite a 'distinction' in gemmology and twenty years in the trade he had spent hours on a sapphire in a cluster ring. Could I help? The stone was about five carats and open at the back. Over a sheet of matt white paper with a 60-watt bench-lamp shining down upon the paper it was easy to see the curved lines looking through the stone at a steep angle. And in any case it *looked* wrong.

Microcline feldspar (amazonite) is a very easy material to prove by 10× lens, the flashes (schiller) from myriad cleavages being almost a hallmark. Stained blue jasper imitating lapis lazuli has islands of porosity revealing deeper penetration of colour and sometimes reflection from quartz crystal impregnations.

The first impact of a gemstone apart from colour can be its heft, which is a sensory perception of density. An important colourless stone recently brought to us should have weighed about 5½ct as a diamond. It felt very heavy in the hand and weighed just over 11ct: we knew it could not be diamond. Horsetail feathers in a green stone which has a certain amount of fire can indicate demantoid garnet. The out-of-focus look seen in some colourless zircons is easily resolved as the exceptional doubling of back facets (plus heft). Golden brown hessonite garnets with their heavily included apatite crystals (once thought to be diopside) are another beautiful effect easily seen by the 10× lens. Aventurine quartz with its fuchsite mica platelets—these have a very distinctive structure totally divorcing it from emerald. Hardness has an effect upon polish and reflection. Reflection and hardness result in lustre; these effects which impinge upon the eye give clues to a stone's nature. The hardness of chrysoberyl compared to quartz helps determine a cat's-eye by the nature of the reflected ray. Chrysoberyl cat's-eye has a fine sharp silvery ray compared to the best of quartz, which usually has a coarser, wider ray and a softer look. The surface lustre again looks to be harder and finer in polish than that of quartz.

Most imitations of gemstones look wrong, and where they are simply imitations little difficulty arises in detection. Usually imitations are too good in colour or too strong in colour. Nature seldom blesses us with superb qualities in colour—thus the rarity aspect of a gemstone. Our laboratory has to use non-destructive

methods (for obvious reasons); this leads to careful examination of stones as a preliminary approach. The use of a 10× lens and the first impact of a gemstone are two of the main facets in the approach to gem testing.

Gem testing for me is practical gemmology in all of its forms. We do, of course, use sophisticated equipment and techniques, because our customers mostly buy and sell 'subject to test'. Since we are trade oriented, merchants bring us their difficult stones usually in a hurry. This 'hurry up' attitude rampant throughout the trade makes us *lens conscious,* because many merchants, fully intending a full test to be made on their goods, will often tell us of their hurry (having held the goods for days) and then finally submit them for test with a question as you open the parcel or packet—'What do you think?'. . . Out comes the 10× lens and the first impact has been made by the colour—a mental note suggests synthetic sapphire, etc., a cursory inspection gives added information, and the merchant is assured of when he can expect a result and its possibility. This aspect of gemmology in a laboratory is characteristic of trade requirements, speed and service. The impact of the gemstone and the demands of trade push forward the need to be able to assess goods rapidly. Thus in full circle practice—practice and yet more practice—makes perfect.

'The first impact of a gemstone is its colour'; the continued examination of stones after this is to me in fact enjoying gemmology.

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OBSERVATIONS ON SOME SCAPOLITES OF CENTRAL TANZANIA

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ABSTRACT

The authors deal with some colourless and yellow scapolites from Central Tanzania and their numerous inclusions, many of which are euhedral and variously corroded growth tubes of different sizes. Electron microprobe analyses show in them a high iron content. The other inclusions consist of pseudo-hexagonal plates of pyrrhotite with metallic lustre.

The chemical composition of these scapolites is determined. Optical observations were conducted: refractive indices and density were defined. The physical chemical growth conditions with respect to pyrrhotite and dehydration of lepidocrocite are inferred.

INTRODUCTION

The study of scapolites proved to be of considerable interest owing to the varying interdependence of their crystallographical, optical and compositional aspects (Shaw, 1960). Moreover these minerals are interesting for their evident chatoyancy and cat's-eye effects, which can be attributed to the presence of thin, hollow channels or to liquid-filled channels and to long needles of double-refractive crystals, all following the main axis of scapolite. Sometimes, patches of specular iron, also following the general orientation, could be observed (Eppler, 1958).

The scapolite from Tanzania has a particular interest due to its high birefringence and evident chatoyancy and asterism effects. These were recently attributed to needle-like channels, rigorously iso-oriented, with a brownish-red or orange-red colour. SEM observations revealed the presence of iron as single chemical component of the inclusions; consequently, the presence of iron oxides or hydroxides was suggested (Schmetzer *et al.*, 1977).

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In Tanzanian scapolites, coming from Umba, however, prismatic channels have already been observed, filled with both transparent and brownish-red matter. These channels mostly started from the bottom of triangular etch pits (Zwaan, 1971). Moreover, the scapolites from such area showed an unusually high birefringence, which allowed them to be classified as intermediate members of the Marialite-Meionite series (Krupp and Schmetzer, 1975; Bank, 1978).

It seemed appropriate to conduct this study in order to determine the nature of the different kinds of crystals included in this mineral, particularly the filling of the tubes, and to formulate hypotheses on the genetic modalities of the host mineral.

EXPERIMENTAL

The specimens consisted of two cut crystals (*ca.* 4.0 × 5.0 × 3.0 mm), one yellowish and the other colourless, in which numerous mineral inclusions of various shapes could be observed.

In particular, the former (Figure 1) was furrowed by numerous channels (*ca.* 0.2 × 3.0 mm) of yellowish-red colour. A large number of thin channels were also present, with the same orientation as the previous ones and both parallel to the optical axis of scapolite. Generally in this direction, sporadic black laminae were found, with metallic lustre and pseudohexagonal habit.

The second specimen (Figure 2) featured also a multitude of inclusions, mainly consisting of the previously-described laminae with metallic lustre, but of considerable size (*ca.* 0.4 × 0.4 mm), perfectly euhedral and with hexagonal habit, as well as thin channels.

Furthermore, both specimens were traversed by numerous healed fractures, often sealed by a light yellow or colourless matter. Such fractures, very numerous in the colourless specimen, crossed the channels, nearly connecting them, and, very frequently, departed from their end forming a wide halo.

It was deemed appropriate to characterize the embedding scapolite, some minute inclusion-free fragments of which were isolated.

The experimental data for both specimens are shown in Tables 1 and 2, for the yellowish and colourless specimens respectively.

TABLE 1. Microprobe analysis, optical properties and x-ray data of the yellowish scapolite from Central Tanzania.

		Numbers of ions on the basis of 12 (Si, Al)		
SiO_2	44.88 wt.%	Si	6.918	12.00
TiO_2	—	Al	5.082	
Al_2O_3	27.97	Ti	—	4.27
FeO*	0.19	Mg	0.133	
MnO	—	Fe	0.024	
MgO	0.58	Mn	—	
CaO	17.20	Na	1.157	
Na_2O	3.87	Ca	2.841	
K_2O	0.56	K	0.110	
H_2O^+ / H_2O^-	0.92	H	0.946	
CO_2†	3.98	C	0.838	0.90
SO_3	0.30	S	0.035	
F	—	F	—	
Cl	0.10	Cl	0.026	
	100.55			
O ≡ Cl, F	0.02			
Total	100.53			

$$\frac{100 \times (Ca + Mg + Fe + Mn + Ti)}{(Na + K + Ca + Mg + Fe + Mn + Ti)} = 70.3$$

ε	=	1.557 ± 0.003	a	=	12.107 ± 0.005
ω	=	1.587 ± 0.003	c	=	7.583 ± 0.003
δ	=	0.030	c/a	=	0.626
$\varrho_{obs.}$	=	2.716 ± 0.005 g/cm³	$\varrho_{calc.}$	=	2.709 ± 0.005

*Total iron as FeO.
†:Dosed with a Carbon dioxide analyser.

Optical observations were carried out. In particular, the refractive indices were determined, obtaining very similar values for both specimens and a high birefringence.

X-ray powder diffractograms were performed in order to determine the cell dimensions, whose values proved to be very similar for both specimens. Furthermore, the correlations proven by Burley *et al.* (1961) were tested and a close agreement was found between the angular separation (Δ) of the (400) and (112) peaks with composition and the average of refractive indices. Density was measured on a Berman microtorsion balance, which provided data slightly lower for the first than for the second specimen. These

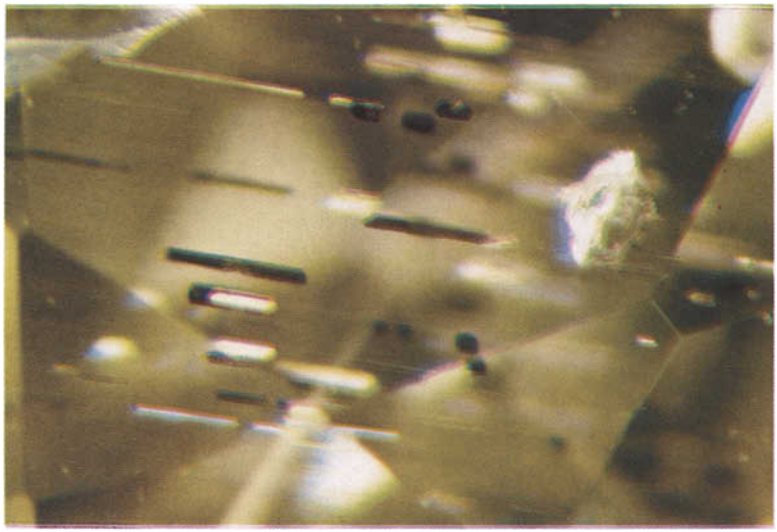

FIG. 1 Scapolite from Central Tanzania. Sample 1. Growth tubes following regularly the *c*-axis of the embedding mineral. ×25.

FIG. 2 Scapolite from Central Tanzania. Sample 2. Pyrrhotite plates are nearly perpendicular to the *c*-axis of the embedding mineral. ×20.

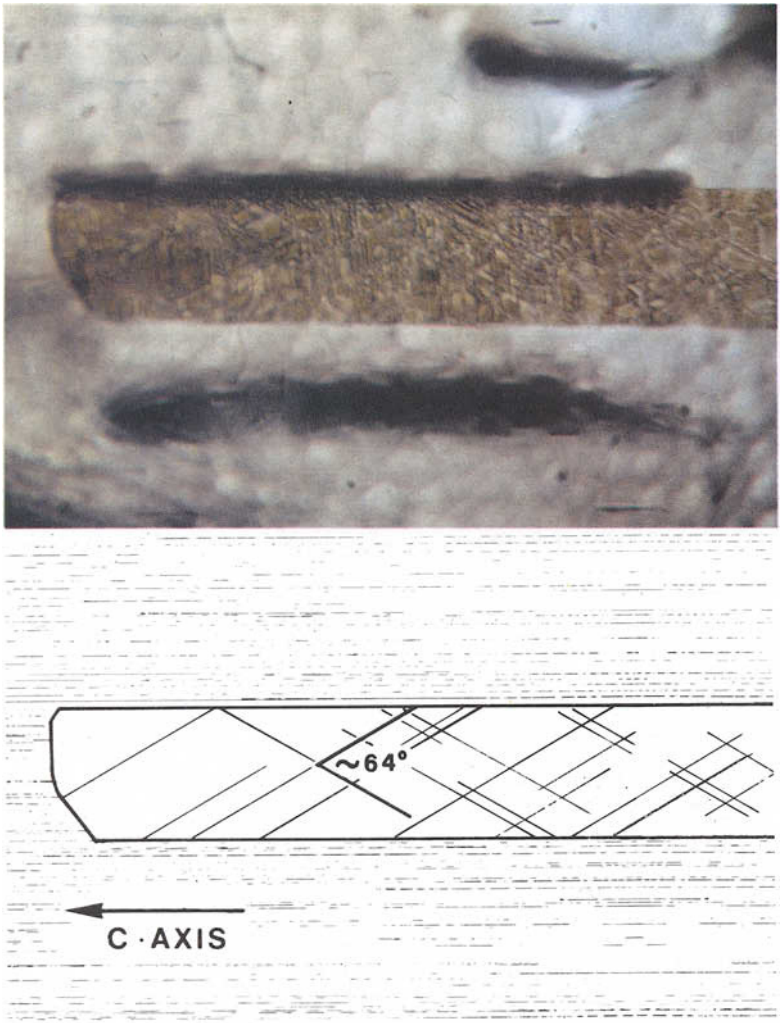

FIG. 3 Scapolite from Central Tanzania. Sample 1. Above: a growth tube filled with regularly shaped lepidocrocite plates. ×80.
Below: outline of the (201) planes forming an angle of nearly 64°.

TABLE 2. Microprobe analysis, optical properties and x-ray data of the colourless scapolite from Central Tanzania.

		Numbers of ions on the basis of 12 (Si, Al)		
SiO_2	44.87 wt.%	Si	7.441	12.00
TiO_2	—	Al	4.559	
Al_2O_3	25.40	Ti	—	4.34
FeO*	0.21	Mg	0.134	
MnO	—	Fe	0.027	
MgO	0.59	Mn	—	
CaO	14.84	Na	1.479	
Na_2O	5.01	Ca	2.421	
K_2O	1.43	K	0.278	
H_2O^+ / H_2O^-	0.28	H	0.284	
CO_2†	2.46	C	0.511	0.57
SO_3	0.26	S	0.030	
F	—	F	—	
Cl	0.12	Cl	0.031	
	99.47			
O ≡ Cl, F	0.03			
Total	99.44			

$$\frac{100 \times (Ca + Mg + Fe + Mn + Ti)}{(Na + K + Ca + Mg + Fe + Mn + Ti)} = 59.5$$

ε	=	1.556 ± 0.004	a	=	12.085 ± 0.002
ω	=	1.582 ± 0.003	c	=	7.577 ± 0.002
δ	=	0.026	c/a	=	0.627
$\varrho_{obs.}$	=	2.709 ± 0.005	$\varrho_{calc.}$	=	2.690 ± 0.005

*Total iron as FeO.
† Dosed with a Carbon dioxide analyser.

values are in close agreement with the relation proposed by Shaw (1960) as a function of Meionite content.

In order to investigate the chemical composition of these scapolites, the samples were analysed by an electron microprobe Jeol-50A, using a series of natural and synthetic standards. The analytical data shown in Tables 1 and 2 derived from the average of five different positions for each sample where the absence of inclusions was ascertained.

The CO_2 content was measured by means of the method described by Scarano and Calcagno (1975). The ignition loss was calculated by difference measuring the weight loss of the scapolites

after heating at 800°C. For the two specimens, Meionite percentages of 70.3 and 59.5% respectively, were obtained. As a result, these are two Mizzonites, two intermediate sodic-calcic end-members of the Marialite-Meionite series.

Based on the values of lattice constants and on chemical composition, density of these scapolites was calculated as if they were totally free from inclusions. Knowing the volume of the samples and the experimental and calculated values of density, it was possible to obtain the total percentage volume of inclusions, since the specimens are mainly characterized, the first, by growth tubes and the other by laminae, which correspond to the percentage volumes of 0.4 and of 0.9% respectively.

Optical observations were then conducted, at considerable enlargements, in order to better characterize the inclusions.

In the yellowish scapolite, the channels, of sizeable diameter (max. 0.2 mm), evidenced fillings made up by scaly aggregates with a colour varying from yellow to brownish-red and variously mixed. In particular it was possible to recognize some fracture-free euhedral channels and other channels with irregular contour from the ends of which fractures departed radially. The first channels were almost exclusively filled with lamellae, often forming palmate or plumose aggregates of clear yellow colour (Figure 3a).

The laminae (0.04 × 0.03 mm), which were like flattened lamellae, with pseudohexagonal contour, were lying on a plane parallel to a prismatic face of the embedding scapolite and thus to the table. It was observed that the laminae intersected along two preferential directions which formed an angle of 64°±30′ (Figure 3b). These observations were carried out using a universal stage in order to orient the channels normally to the direction of observation.

In other euhedral channels, however, it was also possible to note, among the previously described laminae, sporadic and minute groupings of lenticular plates of brownish-red colour as well as wide homogeneous clear-yellow transparent areas (Figure 4).

The channels with not well-defined shape, instead, involved brownish-red laminae and yellow areas (Figure 5).

In addition to the already described laminae with pseudohexagonal contour, the colourless scapolite also included sporadic channels filled with yellow laminae identical to those identified in the previous sample.

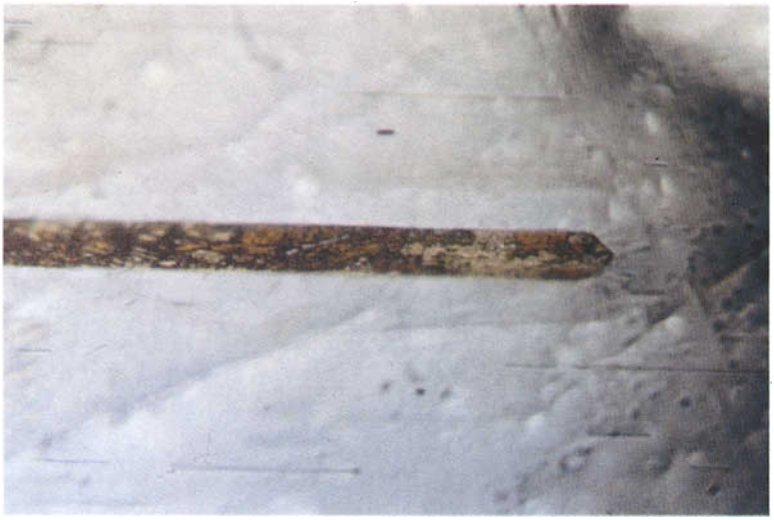

FIG. 4 Scapolite from Central Tanzania. Sample 1. A growth tube with yellow lepidocrocite plates and Fe_2O_3 ones showing a bright red colour, and the yellow transparent areas, healed by the yellowish fluid. × 100.

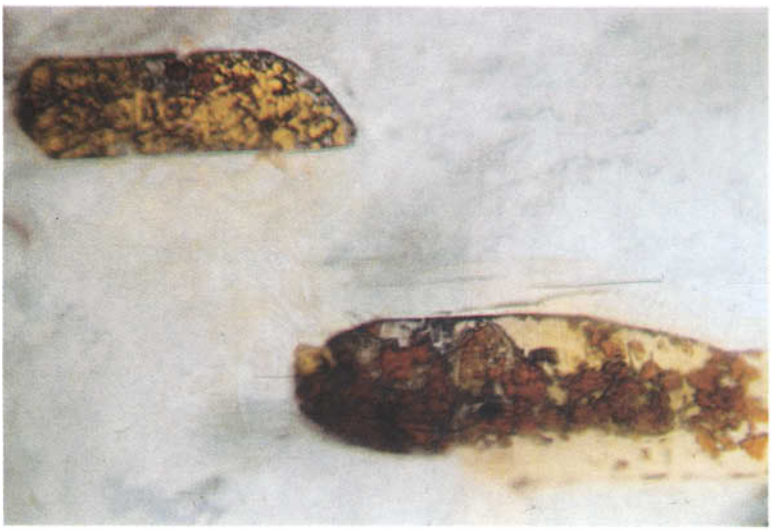

FIG. 5 Scapolite from Central Tanzania. Sample 1. Two typical growth tubes. The first (above) with partially dehydrated lepidocrocite; the second (bottom) shows an irregular shape and a complete alteration of lepidocrocite. Around this tube is evident a yellow halo in the area intersected by the healed fractures. × 110.

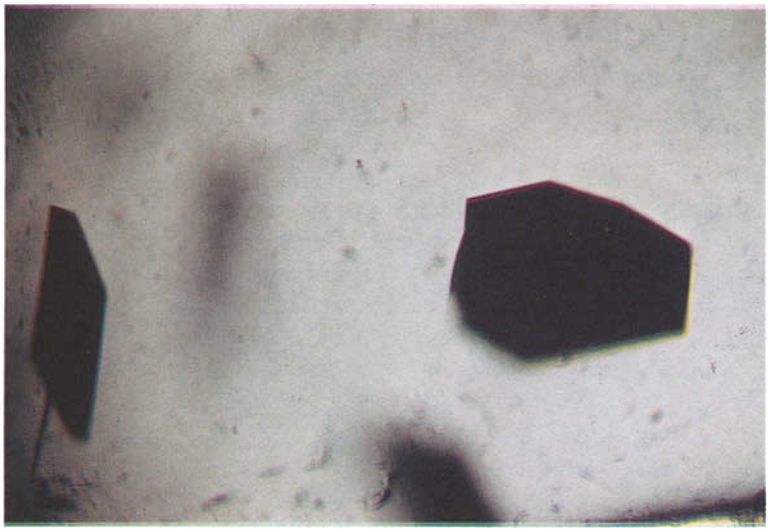

FIG. 6 Scapolite from Central Tanzania. Sample 2. Hexagonal pyrrhotite plates. ×60.

With a view to characterizing these inclusions, electron microprobe analyses were performed. It was thought useful to cut the samples obliquely with respect to the elongation axis in order to analyse a wider surface of the channel filing and thus to diminish the matrix effect due to the embedding scapolite. Particular care was taken during lapping, since the scales making up the filling were easily abraded. The electron microprobe analyses showed the almost exclusive presence of iron in both red and yellow scales. Consequently, they were ascribed to iron oxides or hydroxides, in agreement with the results reported by Schmetzer *et al.* (1977). In the colourless sample, as well as in the previous sample, the wide and thin, black, pseudohexagonal laminae, even if sporadic, revealed the presence of iron, sulphur and copper in weight percentages of 61.76, 37.35 and 0.29% respectively. The corresponding Fe/S ratio proved to be equal to 0.95. It was therefore considered to be a cupriferous pyrrhotite (Figure 6).

Results and Conclusions

The two Mizzonites examined, which have very similar physico-chemical characteristics, stand out due to the presence of the same type of inclusions. These, however, are preferentially

distributed in each specimen. Indeed, the growth tubes represent the near-totality of the inclusions in the yellowish scapolite. But they are also associated with rare pyrrhotite laminae, whereas the opposite situation occurs in the colourless crystal. As a result, it is permissible to infer that the genetic conditions of both specimens should be very similar.

In yellowish scapolite, both clear yellow and brownish-red scales can be generally correlated. In effect, if they reveal the same chemical composition in the electron microprobe, they can be referred to different mineralogical species. In particular, the yellow laminae which, as a first approximation, might be considered as more or less hydrated and not better identifiable iron oxides, can be interpreted as lepidocrocite, considering appearance, colour and idiomorphous habit.

This hypothesis is corroborated by the fact that the planes (201) of this mineral form an angle of approx. 64°. On the other hand, both the evaluation of the wide angle between the optical axes, estimated at approx. 80°, and the pleochroism confirm this identification.

The tabular reddish scales have a more uncertain identification, since they may be referred to both haematite and maghemite. The uneven distribution of these mineralogical species and the presence of haloes preferentially surrounding irregular-contour channels suggest a logic sequence of transformations of these iron compounds. Indeed, it can be supposed that the filling was originally lepidocrocite which was subsequently dehydrated with changing environmental, physico-chemical conditions.

Such variation is testified by the presence of radial fractures, sealed by mother fluid, whose iron enrichment determined the presence of yellow haloes (Figure 5). Haematite or maghemite were thus produced by lepidocrocite dehydration, thus determining the progressive corrosion of the channels and consequent formation of transparent yellow-coloured areas and of the haloes surrounding the channels. This sequence is documented in Figures 3, 4 and 5.

The presence of the pseudohexagonal laminae of syngenetic pyrrhotite containing copper permits the estimation of the lower temperature limit, at not high pressures, to which the formation of these scapolites can be related. Such limit can be located around 700°C (Roseboom and Kullerud, 1958).

During this phase, the growth channels were presumably full of an iron-rich liquid phase which, with decreasing temperature, crystallized scapolite on the inside surfaces of the channels and subsequently lepidocrocite. A rapid variation of the physico-chemical conditions was likely to produce the fractures through which the mother fluid penetrated into the embedding crystal.

On the other hand, the presence of haematite or maghemite produced by lepidocrocite dehydration suggests temperatures in excess of 350°C (Kulp and Trites, 1951). More exactly, if temperature remained not higher than 500°C, maghemite would be obtained, while if this limit was exceeded, haematite would have been segregated.

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'KORITE'—FOSSIL AMMONITE SHELL FROM ALBERTA, CANADA

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'Korite' is the latest of three names which have been given to the iridescent shell of fossil ammonites found in southern Alberta, Canada.

This type of fossil shell on matrix was first advertised as 'ammolite' in 1969 as a lapidary material, although ammonites have been known from Alberta since the beginning of the century. 'Calcentine' was sold during Calgary's Centennial year, 1975, as quartz-topped composite cabochons mounted in gold jewellery (Crowningshield 1977; Zeitner 1978). Now we have 'Korite' from Korite Limited, of Calgary, Alberta. Their original rough material was obtained from the Kormos farm on the St Mary River, south of Lethbridge, Alberta. They now hold claims on several other farms as well.

AMMONITES

Ammonites are extinct molluscs of the class Cephalopoda, subclass Ammonoidea. They have been studied extensively because their abundance and world-wide distribution make them very useful to palaeontologists as index fossils. The univalve, coiled shell is comparable to that of the modern *Nautilus,* of the subclass Nautiloidea, a presumed relative.

The modern *Nautilus* lives at moderately shallow depths in the south-west Pacific Ocean. Ancient ammonoids, however, ranged in oceans and seas over the world, their fossil remains being found in rocks representing marine deposits from the Devonian period to the end of the Cretaceous period some 65 million years ago. (Arkell *et al.* 1957; Miller and Furnish 1957).

The Alberta ammonites which are providing the gem material have been identified as *Placenticeras meeki* (Figure 1). Found in the

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FIG. 1 *Placenticeras meeki* (27 × 21 × 6cm)

dark-grey shale of the Bearpaw Formation of south-central Alberta, they are about 71 million years old (Upper Cretaceous). The average specimen is about 20-25 cm in diameter with a shell thickness less then 6 mm (Sinkankas 1976). Another smaller and rarer species, *Placenticeras intercalare,* also provides some iridescent shell.

It should be emphasized that only broken pieces of shell are used; no complete ammonite fossils are cut up to be polished as gems. The Provincial Government of Alberta requires that any fossil material with scientific value for stratigraphic, taxonomic or display purposes be preserved and that permits be obtained for collecting. Much fractured shell occurs loose or within calcareous shale nodules or ironstone concretions. The proportion of gem-quality shell is small. Less than 5% of all ammonites found yield any gem material, and only about 20% of that shell can be used.

Ammonoid shells consist predominantly of aragonite and proteinaceous organic matrix (conchiolin) arranged into three

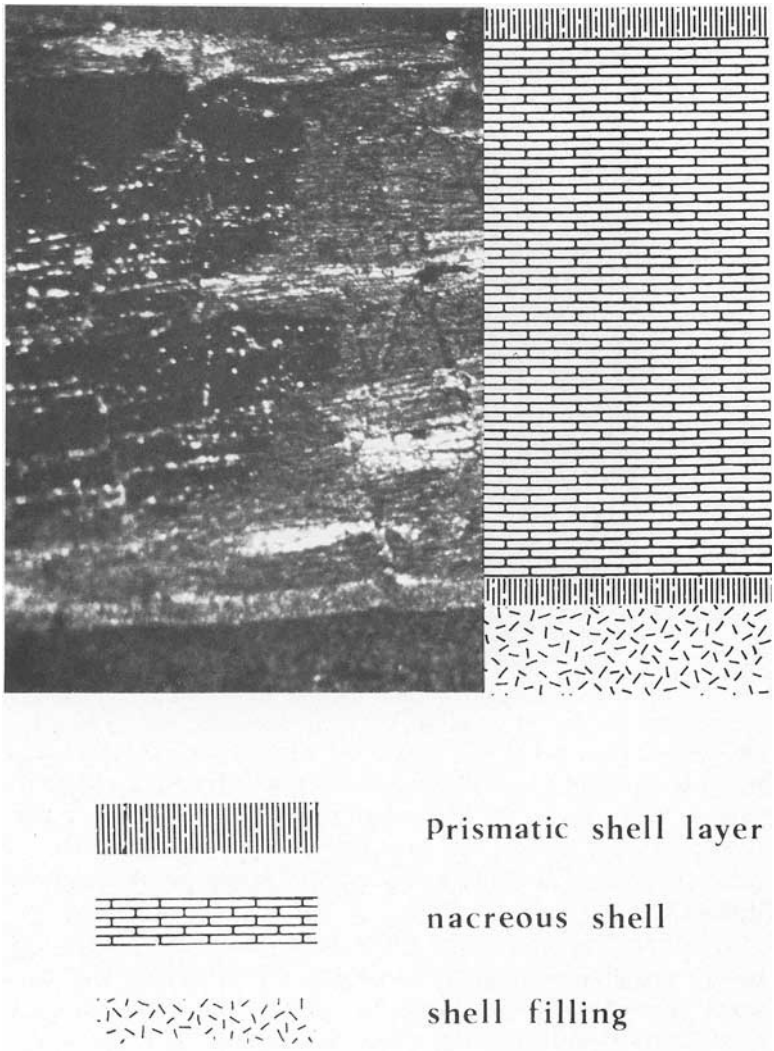

FIG. 2 Ammonite thin-section showing the three layers of the shell. Shell is 2.3mm thick.

layers (Figure 2): a thin outer prismatic layer, a nacreous layer, and an inner lining of prismatic habit (Kennedy and Cobban 1976).

Description and Properties of Gem 'Korite'

The gem material is actually the nacreous layer of the ammonite shell. It presents a brilliant iridescence, predominantly red and green, but some pieces show all the spectral colours. Most pieces show a red and orange iridescence when the incident white light is perpendicular to the shell surface, and green when it is almost parallel. Blue and purple are rarely seen. Some of the shell is well preserved, but much of it has been cracked and subsequently re-healed during the long years of fossilization. In many of these pieces, the appearance is similar to that of a stained-glass window with small patches of brilliant colours framed by darker, non-iridescent lines (Figures 3, 4). Under the microscope, in transmitted light, the thinner pieces of shell are light brown in colour with a very fine-grained granular texture (Figure 5). There are often dark-brown inclusions (probably conchiolin).

X-ray diffraction analysis confirmed the composition of the iridescent nacreous shell layer to be chiefly calcium carbonate in the form of aragonite. The crack-filling material of the fossil shell is also aragonite, but it fluoresces bright yellow under long-wave ultraviolet light and a less intense yellow under short-wave rays. Thin-sections studied in polarizing light show the unbroken shell to be extremely fine-grained; the crack-filling aragonite is much coarser and secondary in origin (Figure 6).

Trace elements detected by spectroscopic analysis of the *Placenticeras* nacreous layer were strontium (0.48%), iron (1%), silicon (1%), titanium (0.6%), aluminium, barium, chromium, copper, magnesium, manganese and vanadium. Other analyses indicated a water content of 0.44% (by heating) and an organic material component of 5.34% (by loss on ignition). In comparison, *Nautilus* shell is composed of aragonite with traces of strontium, magnesium, aluminium, iron, silica, calcium phosphate and 2.03% conchiolin (Stenzel 1964). Modern, nacreous mother-of-pearl shell contains about 85% aragonite, 12% organic material and 3% water (Poirot 1965; Sinkankas 1959; Webster 1975).

Refractive indices were measured on polished pieces of 'Korite' with a Rayner Dialdex refractometer and sodium light.

FIG. 3 'Korite' cabochon surrounded by four 'Korite' triplets (NMNS 20788-792). Large cabochon is 30×40mm.

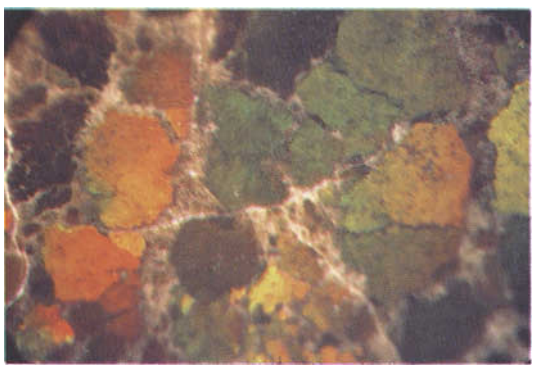

FIG. 4 Polished 'Korite', iridescent ammonite shell. Reflected light. Field is 16mm across.

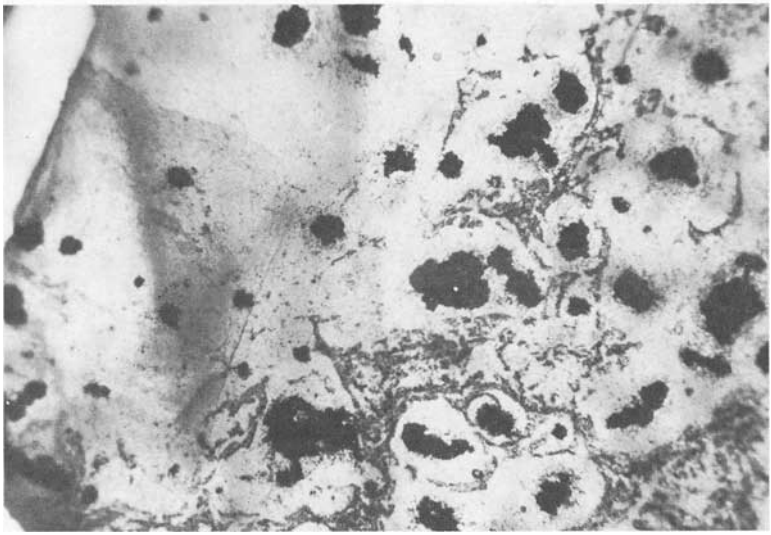

FIG. 5 Iridescent ammonite shell in transmitted light is light brown with dark-brown blobs of conchiolin. Field is 0.35mm across.

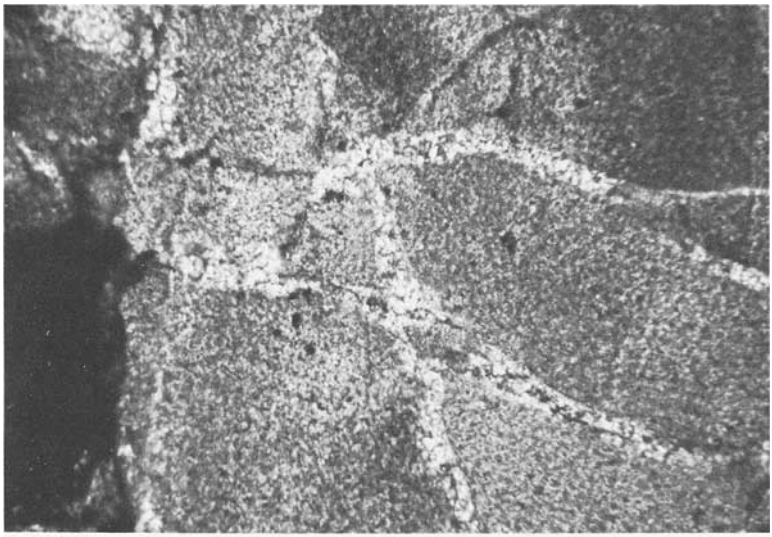

FIG. 6 Transverse section of iridescent ammonite shell showing healed fractures. Transmitted polarized light. Field is 1.4mm across.

Refractive indices of 'Korite' compared with those of aragonite and Recent aragonite shell.

	α	β	γ	birefringence
Ammonite shell *Placenticeras* (9 specimens)	1.512 to 1.528		1.662 to 1.672	
Average	1.520		1.670	0.150
Aragonite (Deer, Howie & Zussman 1962)	1.530	1.680	1.685	0.155
Recent Mother-of-Pearl Shell (Bøggild 1930)	1.523	1.659	1.662	0.139
Recent Mother-of-Pearl Shell (NMNS 20625)	1.520		1.655	0.135

The specific gravity of gem 'Korite' by means of heavy liquids was between 2.67 and 2.85. The specific gravity as determined by hydrostatic weighing was 2.80±0.01. The reported SG of modern nacreous shells is 2.75 to 2.80 (Poirot 1965), lower than the SG of aragonite (2.93) because of the presence of organic conchiolin (SG 1.34) and water. Hardness on the Mohs scale is about 4.

Nacreous Shell Structure and Iridescence

The structure of the nacreous layer of mollusc shells has been well investigated (Gregoire 1962; Stenzel 1964; Watabe 1965). The nacreous layer is composed of closely-packed, tabular, hexagonal crystals of aragonite oriented with their *c*-axes vertical to the shell surfaces, and united into thin lamellae. The organic matrix conchiolin (a complex mixture consisting of poly-saccharides, polypeptides and scleroprotein fractions) is interposed between these lamellae as thin horizontal sheets, and between the crystals as vertical walls, giving a brick-wall type structure. The thickness of these lamellae in the nacreous layer is of the same magnitude as the wavelengths of the spectral colours which make up white light. Thus, when white light is incident upon these regularly-spaced thin layers, diffraction occurs, and flashes of spectral colours are seen (Pfund 1917; Fox 1966). Mother-of-pearl and abalone shells are well known for their beautiful iridescence.

'Korite' viewed in transmitted light is a non-iridescent, light-brown colour (Figure 5). Thin-sections of the iridescent shell show the nacreous structure described above (Figures 7, 8). Fossil shells vary greatly in the degree of preservation of their original components, depending on the conditions to which they have been subjected. Many have altered from aragonite to calcite (the more stable structure for calcium carbonate), and many also have lost organic material. It seems that gem 'Korite' has altered very little; there is no evidence of calcite. The nacreous structure has been preserved and diffraction of light takes place to produce the vivid spectral colours seen in reflected light. The main change seems to have been the fracturing and re-healing of the shell. This results in iridescent patches of various sizes surrounded by non-iridescent lines produced by the re-healing process, i.e. a 'stained-glass' effect.

Lapidary Treatment

Simple cabochons, usually with a flat top, can be cut and polished very successfully from the thicker, more consolidated pieces of the ammonite shell, particularly if some shell-filling matrix remains attached. Since most of the shell is thin, brittle and somewhat splintery, it is prepared as triplets, with a natural shale backing and a quartz cap. This produces a gem which is durable and very satisfactory for any piece of jewellery. The fossil shell itself has a hardness of about 4 on the Mohs scale, so that care is needed to prevent scratching.

Conclusion

Shells, of course, have been used by man for adornment for centuries. Fossils such as petrified wood, silicified dinosaur bone, silicified coral and fossil ivory are commonly used in jewellery. Fossil shells used as gem material include silicified *Turritella* in agate from Wyoming and lumachelle, iridescent bivalve mollusc shells in dark-grey or dark-brown marble from the lead mines of Bleiburg, Austria and Italy. Lumachelle is the only fossil shell known to approach 'Korite' in intensity of colour.

'Korite' is a very beautiful and interesting gem material, certainly the most attractive ever found in Alberta. Its appearance has been compared to that of black opal, but the only similarity is that spectral colours are produced from a regular, microscopic,

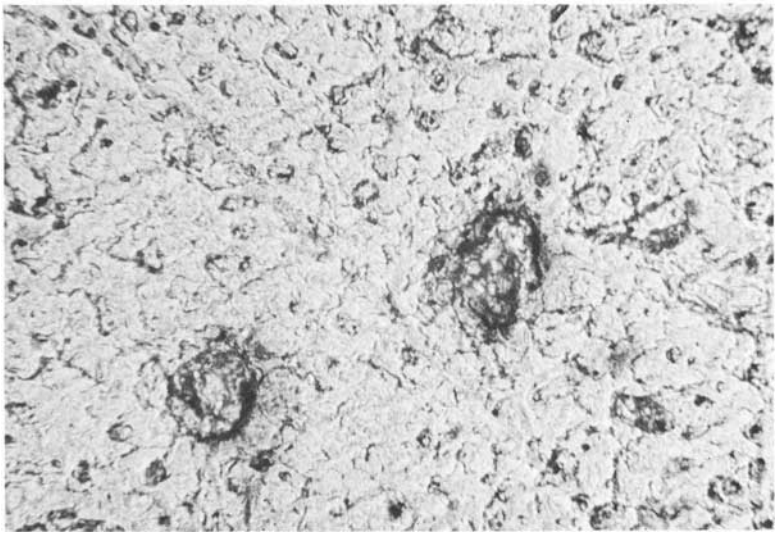

FIG. 7 Transverse section of 'Korite' shell showing hexagonal crystals of aragonite typical of nacreous layer. Field is 0.35mm across.

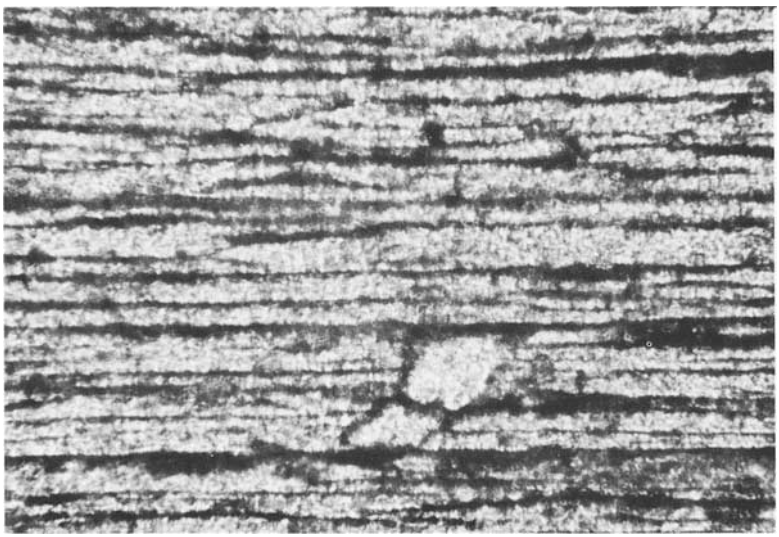

FIG. 8 Vertical section of 'Korite' shell showing 'brick-wall' structure (light aragonite and dark conchiolin) typical of nacreous layer. Field is 0.35mm across.

internal structure. Both opal and 'Korite' are spectacular, each in its own way. 'Korite' is certainly more bright and brilliant than any modern shell, even the vivid abalone.

ACKNOWLEDGEMENTS

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Special thanks are due to R. Vandervelde and Korite Limited, Calgary, Alberta, for the donation of specimens to the National Museum and for initiating this project.

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[*Manuscript received 21st August, 1980.*]

GEMMOLOGICAL ABSTRACTS

BALITSKY (V. S.). *Synthetic amethyst: its history, methods of growing, morphology and peculiar features.* Z.Dt.Gemmol.Ges., **29**, 1/2, 5-16, 9 figs, bibl., 1980.

Synthetic amethyst is grown hydrothermally from KOH- or NH_4OH-containing solutions. The violet colour is produced by addition of Fe^3 in the form of oxides or hydroxides and subsequent x-radiation. The morphology of synthetic amethyst crystals as dependent on the growth method is discussed. Inhomogeneities in the colour distribution are explained by the irregular positioning of the Fe in the lattice. The synthetic stone is grown from hydrothermal solution as it is in nature and many features are therefore the same—especially, amethyst grown in alkaline solution shows the development of rhombohedron faces; there is also a unique resemblance in the infrared absorption spectra of natural and synthetic amethysts grown in strong alkaline potassium solutions, showing a broad band at $3400cm^{-1}$.

E.S.

BALL (R. A.). *Nephrite jade from Cowell, South Australia.* Aust. Gemmol., **14**, 4, 53-6, 3 figs, 1980.

A report on a 9 km^2 surface area on the eastern margin of the Cleve Uplands which contains about 100 large olive-green to black nephrite pods or lenses, some up to 100 m long and 3 m wide. Black nephrite is sought after. Figures are unnumbered.

R.K.M.

BANK (H.). (a) *Geschliffener grüner 'smaragditischer Grammatit' (= Tremolit-Actinolith) aus Tansania.* (Cut green 'smaragdite-grammatite' (tremolite-actinolite) from Tanzania.) Z.Dt.Gemmol.Ges., **28**, 4, 201-2, 1979; (b) *Smaragdgrüner geschliffener 'Smaragdit' als Diopsid angesehen.* (Emerald-green cut smaragdite thought to be diopside.) Id., 203-4, 1979; (c) *Geschliffene durchsichtige blaue, grüne und blaugrüne Dumortierite aus Brasilien.* (Cut transparent blue, green and blue-green dumortierite from Brazil.) Id., 205-6, bibl., 1979.

(a) Describes transparent cut smaragdite, i.e. emerald-green Cr-containing grammatite, which is a tremolite-actinolite from Tanzania. (b) Relates how an emerald-green cut smaragdite was at first believed to be a diopside. (c) Describes transparent cut, blue, green and blue-green dumortierite from Brazil. Dumortierite is usually translucent (not transparent) and of a violet-blue colour. Rarely is this stone found as a transparent gem; a brown variety from Sri Lanka and a blue one from Brazil have been described. These new blue, green and blue-green examples from Brazil, however, are quite transparent. E.S.

BANK (H.). (a) *Changierender Korund mit hoher Lichtbrechung aus Sri Lanka.* (Colour-change corundum with high refraction from Sri Lanka.) Z.Dt.Gemmol.Ges., **29**, 1/2, 86-7, 1 fig. in colour, 1980; (b) *Grüner schleifwürdiger synthetischer Periklas.* (Green cuttable synthetic periclase.) Id., 88-9, 1 fig. in colour, 1980; (c) *In rohpartien natürlicher Smaragde aus Sambia synthetische Smaragde entdeckt.* (Synthetic emeralds found in parcels of natural emeralds from Zambia.) Id., 90-1, 2 figs in colour, 1980; (d) *Seltene Aquamarinparagenese mit Granat und Einschlüssen von Columbit-Tantalit.*

(Rare paragenesis of aquamarine with garnet and inclusions of columbite-tantalite.) Id., 92-3, 2 figs in colour, 1980; (e) *Über die Paragenese des Schlossmacherit.* (On the paragenesis of schlossmacherite.) Id., 94-5, bibl., 1980; (f) *Sternspinelle aus Sri Lanka.* (Star spinels from Sri Lanka.) Id., 96-7, bibl., 1980; (g) *Lichtbrechung-sindizes von Spinellen aus Sri Lanka.* (Refractive indices of spinels from Sri Lanka.) Id., 98-9, bibl., 1980; (h) *Geschliffenes blaues Glas mit n um 1.575 als Aquamarin betrachtet.* (Cut blue glass with RI 1.575 thought to be aquamarine.) Id., 100, 1980; (i) *Sehr hochlichtbrechender Smaragd aus Sambia.* (Very highly refractive emerald from Zambia.) Id., 101-3, bibl., 1980; (j) *Gefahren der 'zerstörungsfreien' gemmologischen Diagnostik.* (Dangers of 'non-destructive' gemmological methods.) Id., 104-5, 1980.

(a) Dr Bank describes a corundum with colour-change from Sri Lanka. The stone was faceted, weighed 1.52 ct, was greyish blue in daylight and red in artificial light, and had a high RI, 1.764-1.773, with DR 0.009. (b) A green periclase from Israel was found to be synthetic, RI 1.738, SG 3.75. (c) Mentions synthetic emeralds which were found in parcels of natural emeralds from Zambia. (d) A rare aquamarine paragenesis with garnet and a beryl with columbite inclusions are described. (e) Another paragenesis dealt with is Schlossmacherite. (f) Towards the end of 1979 for the first time star spinels were obtained from Sri Lanka. Of the 11 specimens four were blue, and seven of reddish colour, RI between 1.715 and 1.720, SG 3.60. Under microscope needle-like inclusions were recognized as rutile. (g) Refractive indices of spinels from Sri Lanka are discussed. They vary for red spinel from 1.714 to 1.729 and for blue to grey stones from 1.718 to 1.742. The Zn-rich spinels have an RI from 1.725 to 1.753 and the name 'gahnospinel' has been suggested for them. (h) A cut blue glass with RI of 1.575 was at first taken to be an aquamarine. (i) A dark green emerald from Zambia with very high RI values (1.592-1.602, with DR 0.010) was tested for trace elements and found to have the normal chrome content and a very high iron content. (j) Discusses the dangers of so-called 'destruction-free' diagnostic methods, mainly in the field of x-ray applications.

E.S.

BERKA (R.). *Strahlender Edelstein Zirkon.* (Irradiated Zircon.) Mineralien Magazin, **4**, 10, 462-3, 1 fig in colour, 1980.

A colour plate of rough and cut zircon is accompanied by a short description of the mineral. M.O'D.

BROWN (G.). *Gemmology study club report. The radiographic features of keshi pearls.* Aust. Gemmol., **14**, 3, 28-9, 2 figs, 1980.

Radiographic examination of three keshi, or adventitious, pearls accidentally produced by fragments of shell falling into the body of the oyster during the culturing operation. Three 'dumbell' [*sic*] shaped pearls also examined appear in radiographs to consist of a cultured bead pearl joined to an adventitious pearl of the above type. [Author's explanation is quite acceptable.] R.K.M.

BROWN (G.). *Gemmology study club report. An examination of a clam pearl.* Aust. Gemmol., **14**, 3, 38-40, 2 figs, 1980.

A white clam pearl with a smooth mat surface but irregular in shape showed no 'flame-like' sub-surface markings. SG 2.80. R.K.M.

BROWN (G.). *An evaluation of the Gem Instrument Corporation's gem diamond pen.* Aust. Gemmol., **14**, 3, 42-6, 6 figs, 1980.

The Instrument Evaluation Committee of the Australian Gemmological Association found that this instrument was useful in the rapid testing between diamonds with sufficiently large facets and imitant substances, provided that other simple tests were taken into account. R.K.M.

BROWN (G.), SNOW (J.). *Battery powered light sources for hand lenses.* Aust. Gemmol., **14**, 4, 73-5, 6 figs, 1980.

A G.A.A. Instrument Evaluation Committee Report. The Coddington magnifier, by Bausch & Lomb, has a built-in light source but is only partly corrected for spherical and chromatic aberration. It was found awkward to use and in time the magnifying lens parted from the torch handle.

The Gem Penlight, by the Gem Instrument Corporation, is a light source only, but to use it with a stone held in tongs and a ×10 lens really needs a third hand. A useful slip-on attachment is suggested which partly overcomes this problem. R.K.M.

BROWN (G.), SNOW (J.). *An evaluation of the Krüss portable microscope.* Aust. Gemmol., **14**, 4, 69-72, 2 figs, 1980.

A G.A.A. Instrument Evaluation Committee Report on a horizontal portable microscope. Instability of tripod mount and other design faults are pointed out and suggestions made to overcome them. A zoom facility is incorporated, but to focus at any given magnification means moving the specimen, since no normal rack focusing is provided. R.K.M.

BROWN (G.), SNOW (J.), TAYLOR (B.). *An evaluation of the Dipro diamond testing probe.* Aust. Gemmol., **14**, 2, 3-9, 3 figs, 1980.

An apparently rather confused report on a probe operating on a 'slightly different principle' from that of the Ceres diamond probe. It is said to work on the rate of change of voltage in the test surface rather than measuring the maximum voltage decrease.* Test takes up to 30 seconds after an initial 5 minutes warming up period. Imitant materials are not identified, but diamond is. R.K.M.

BUTLER (J. N.). *An attempt to assess the recent popularity of different gems.* Aust. Gemmol., **14**, 4, 77-82, 1980.

Based on the publicity given to each gem mineral by advertisement or press article in a variety of publications over a period of six years (1973-8), this can only be an attempt. R.K.M.

DEICHA (G.), DEICHA (C.). *Effets du désequilibre cristallogénétique sur la croissance du diamant.* (Effects of crystallographic disequilibrium on the growth of diamond.) Revue de Gemmologie, 64, 8-9, 5 figs, 1980.

Variations in crystal growth processes have an effect on the crystallographic architecture of diamond. Some effects are shown with the aid of the electron microscope. M.O'D.

*Do writers mean temperature rather than voltage?—R.K.M.

GOLDSMID (H. J.), GOLDSMID (S. E.). *Thermal conduction in gemstones. Part II. A simple thermal comparator.* Aust. Gemmol., **14**, 3, 49-51, 2 figs, 1980.

The thermal 'squeak' proving less than totally reliable,* these experimenters constructed two thermocouple probes, the second of which contains a built-in heater. These gave direct e.m.f. readings indicating thermal conductivity of substances when the probes were placed in contact with them and adequately identified diamond, separating it from its imitants.

[Note: the 'squeak' depends on heat being brought rapidly to the contact point by the diamond; the probes depend on diamond conducting heat rapidly away from the point of contact.] R.K.M.

GÜBELIN (E.). *Letter to the Editors.* Aust. Gemmol., **14**, 4, 69, 1980.

Mentioning that in electron microprobe analyses of so-called cacoxenite needles in amethyst by two different institutes phosphorus could never be found and the result reported was goethite, Dr Gübelin asks whether any exact analysis of these inclusions has been made in Australia or is likely. J.R.H.C.

GÜBELIN (E.), SCHMIDT (K.). *Scheinbare Unstimmigkeiten in gemmologischen Textbüchern.* (Apparent disagreements in gemmological textbooks.) Z.Dt. Gemmol.Ges., **29**, 1/2, 20-32, bibl., 1980.

The authors stress the importance of checking data to be published in textbooks. All too often wrong data are taken from old texts and re-used. Authors and gemmologists should take their own measurements. Details of mistakes occurring are given. Between the years 1850 and 1932 the density of lapis lazuli was taken to be 2.38-2.42 instead of 2.7-2.9.† Details of disagreeing data with various sources are given for chalcedony, chrysoberyl, herderite, hypersthene, serpentine, zoisite, jeremejevite, boracite and chrysocolla. E.S.

HAHN (H.), HAHN (E.). *Zuchtperlen und ihre Produktionsstätten.* (Cultured pearls and their places of production.) Z.Dt.Gemmol.Ges., **29**, 1/2, 33-9, 6 figs, 1980.

Description and pictures of freshwater and various salt-water cultured pearls. Most freshwater cultured pearls come from Lake Biwa in Japan, but there are also other farms in Japan, and also China. There are many more sea-water farms, mainly in Japan, but also in the Thursday Isles near Northern Australia, also near the north west coast of Australia. New Guinea, Tahiti, Celebes, Philippines, Burma and China are also producers. The production in the south of Thailand is described in more detail and the mortality rate of the oysters discussed. E.S.

HANNEMAN (W. W.). *Educating the eyeball—the Hodgkinson method.* Lapidary Journal, **34**, 7, 1498-1519, 16 figs (15 in colour), 1980.

Describes the 'visual optics' method of testing gemstones, with illustrations [but see *Letter to the Editor,* J.Gemm., 1980, XVII(1), 66-7]. M.O'D.

JOBBINS (E. A.). *Opal in Piaui State, Brazil.* Z.Dt.Gemmol.Ges., **29**, 1/2, 40-54, 2 maps, 6 photographs, 1980.

Paper read to the 17th International Gemmological Conference in Idar-Oberstein. Opal has been reported and worked in Piaui State, but exact localities

*See Abstract of Part I on p. 423 below, s.v. Thwaite (R.) *et al.*—Ed.

†Louis Dieulafait (1871) gave the SG of lapis lazuli as 2.95 in his *Diamants et Pierres Précieuses.*—Ed.

and nature of the material were in some doubt. During 1973 P. G. Linzell and E. A. Jobbins investigated the occurrences for the State Government. Precious opal at Pedro II occurs at a sandstone quartz-dolerite contact where it has been mined on a small scale. Alluvial opal is found up to about a 10km radius. The opal at Varzea Grande, Castelo do Piaui and elsewhere occurs mainly in thin veins and pockets along joints in dyke rocks; mostly these are common opal, but some are reddish-orange and have been described as fire opal. Only at Pedro II is the opal of economic value. E.S.

KANIS (J.). *Gemstone news from Southern Africa.* Z.Dt.Gemmol.Ges., **29**, 1/2, 55-7, 1 map, 1980.

Paper read to the 17th International Gemmological Conference in Idar-Oberstein. Short note about the occurrence of emerald in Zambia and Rhodesia, precious coral near Port Elizabeth, and tourmaline in Kenya. E.S.

KOSKI (K.), KOSKI (D.). *Spectrolite, Finland's gem labradorite.* Lapidary Journal, **34**, 7, 1476-84, 17 figs (in colour), 1980.

The location for spectrolite is 250km east of Helsinki. Details for fashioning are given. M.O'D.

KNISCHKA (P. O.). *Isometrischer Habitus von gezüchteten Korundkristallen mit grosser Flächenzahl.* (Isometric habit of grown corundum crystals with a large number of faces.) Aufschluss, **31**, 469-77, 16 figs (1 in colour), 1980.

Corundum crystals with an isometric habit have been grown by the flux-melt method. M.O'D.

LANDAIS (E.). *Un réfractomètre selon l'angle de Brewster pour la mesure des hauts indices de réfraction.* (A refractometer using Brewster's angle to measure high refractive indices.) Revue de Gemmologie, **64**, 6-7, 4 figs, 1980.

A prototype refractometer using the principle of Brewster's angle to measure materials with high refractive indices has been developed. The relationship between Brewster's angle and RI is explained. M.O'D.

LENZEN (G.). *Sicheres Erkennen von Diamantimitationen: Die Wärmeleitfänigkeit als gemmologisch nutzbare Eigenschaft.* (Certain recognition of diamond simulants: heat conductivity as a useful gemmological property.) Z.Dt.Gemmol.Ges., **28**, 4, 197-200, 1 fig, 1979.

As it becomes increasingly difficult to determine definitely what is diamond and what is diamond imitation, the development of qualitative measuring of the heat conductivity is a great aid. In the States the 'Ceres Diamond Probe' has been developed specifically for this purpose. The author found this instrument very reliable, independent of the size of stone to be tested and usable for loose and set stones. The instrument is described in some detail. The dial is adjusted in such a way that the zero level is in the middle, diamond readings to the right, imitations to the left. A table gives heat conductivity figures taken at room temperature in watt per second per centimetre per kelvin, from diamond Type I, IIa and IIb to djevalite, cubic zirconia, YAG. Between these two extremes readings are given for silver,

copper, gold, aluminium, corundum and topaz. The figures for spinel, quartz, rutile, zircon and beryl are similar to those of djevalite. E.S.

MALLALIEU (Huon). *Polar Star diamond ring sold for £1,960,784.* The Times newspaper, 60783, p.14, 22nd November, 1980.

An account of recent sales at Christie's and at Sotheby's, including the sale by Christie's in Geneva on 20th November, 1980, for 8m Swiss francs (£1 960 784) to Razin Saliah, a dealer based in Sri Lanka, of the 'Polar Star', a diamond of 41.285 ct, mounted in a ring: it came from Golconda, was owned by King Joseph Bonaparte, the Youssoupoff family, and Lady Lydia Deterding. The pavilion is applied with a two-fold eight-pointed star and the symmetry is so perfect that it can be balanced on its culet. J.R.H.C.

MUMME (I.). *Modern methods of gemstone colouration.* Aust. Gemmol., **14**, 2, 10-11, 1980.

A reiteration of the various established methods, some far from modern. R.K.M.

NOGUÉS-CARULLA (J. M.), VENDRELL-SAZ (M.), ARBUNIES-ANDREU (M.). *Structure microscopique des couches de la perle.* (Microscopic structure of pearl coatings.) Revue de Gemmologie, **64**, 10-12, 10 figs, 1980.

SEM techniques are used to examine the surfaces of pearls. It is noted that aragonite crystals are tabular and are made up of lamellae in a matrix of organic matter. Coating thickness is estimated at 1-2μm. M.O'D.

PERHAM (J.). *Maine tourmaline—a study in lapidary.* Lapidary Journal, **34**, 6, 1400-2, 6 figs, 1980.

Increased supplies of tourmaline from the Dunton mine, Newry, Maine, have resulted in a variety of objects being manufactured in addition to cabochon-cut and faceted stones. M.O'D.

POIROT (J.). *A propos du traitement thermique des Gemmes.* (About the heat treatment of gemstones.) Z.Dt.Gemmol.Ges., **29**, 1/2, 58-61, 1980.

Paper read to the 17th International Gemmological Conference in Idar-Oberstein. The author discusses heat treatment of gemstones seen as a historical technique and the nomenclature which has been derived from these methods. E.S.

POUGH (F. H.). *New gemmological instruments—part 1.* Lapidary Journal, **34**, 6, 1396-9, 3 figs, 1980.

This introductory article deals chiefly with apparatus designed to detect diamond and its simulants. M.O'D.

RAMSEY (J. L.). *Faceted treated stones—an overview.* Lapidary Journal, **34**, 7, 1534-7, 1980.

Lists stones which are commonly treated by heat or irradiation before being sold. M.O'D.

REYMER (H.). *Ammonite fossils from Alberta, Canada.* Z.Dt.Gemmol.Ges., **29**, 1/2, 62/3, 1980.

Paper read to the 17th International Gemmological Conference at Idar-

Oberstein. The fossil ammonite consists mainly of aragonite and method of working it is described. It can be used for jewellery purposes and has been sold commercially under such names as 'Korite' and 'Calcentine'. E.S.

SASAKI (E.). *Thailand's merchant's domination toward gem marketing.* Z.Dt.Gemmol.Ges., **29**, 1/2, 64-5, 1980.

Paper read to the 17th International Gemmological Conference in Idar-Oberstein. The author discusses occurrences of gems in Thailand and also the marketing position. The country has a well deserved reputation as a gem centre, but there are many pitfalls in Bangkok's 800 to 1000 jewellery shops. E.S.

SASAKI (E.). *Treatment of sapphires.* Z.Dt.Gemmol.Ges., **29**, 1/2, 66, 1980.

Paper read to the 17th International Gemmological Conference at Idar-Oberstein. Description of colour-alteration in sapphire by heating. Most sapphires on the market appear to have been treated. E.S.

SAUL (J. M.). *Some rarer African gem minerals.* Z.Dt.Gemmol.Ges., **29**, 1/2, 67, 1980.

Paper read to the 17th International Gemmological Conference at Idar-Oberstein. A few rare gemstones, such as bright green tanzanite and bright green sphalerite amongst others, were shown. Most of these gems came from Kenya and Tanzania. E.S.

SAVKEVITCH (S. S.). *Méthodes physiques de la détermination des sources géologiques de l'ambre et autres résines fossiles.* (Physical methods for determining the geological sources of amber and other fossil resins.) Revue de Gemmologie, 64, 17-19, 2 figs, 1980.

A review of possible methods of identifying the geological sources of amber is given. Infrared and mass spectrometry are discussed. M.O'D.

SCHMETZER (K.), BANK (H.). *Zur Unterscheidung natürlicher und synthetischer Amethyste.* (Differentiation between natural and synthetic amethysts.) Z.Dt.Gemmol.Ges., **29**, 1/2, 17-19, 1 fig, bibl., 1980.

The authors refer to amethyst grown hydrothermally with the addition of iron oxides and hydroxides and subsequent x-ray treatment. These synthetics cannot be distinguished from the natural variety by their structural, chemical or physical characteristics. In the case of the rough stone the seed can usually be detected, but this is not the case with cut stones. The authors advise the use of infrared spectroscopy. While natural amethyst shows absorption bands at 3200, 3410, 3685 and 3615, the synthetic amethysts examined had additional bands at 3300, 3380 and 3540. Infrared spectra of synthetic Russian amethyst and natural amethyst from Zambia are shown. E.S.

STEVENS (E. L.). *Inclusions in N.S.W. gemstones.* Aust. Gemmol., **14**, 3, 23-6, 2 figs, 1980.

A wide variety of gems are found and almost all 'containing inclusions of all types'. Author is satisfied that beryl localities can be identified by inclusions and physical constants. Deals only with beryl, quartz and, briefly, with topaz. R.K.M.

SUPERCHI (M.), ROLANDI (V.). *A proposal for delimiting ruby (from rose and violet corundum) and emerald (from light green to dark green beryl).* Z.Dt.Gemmol.Ges., **29**, 1/2, 68-70, 2 figs, 1980.

Paper read to the 17th International Gemmological Conference in Idar-Oberstein. Gem varieties are characterized with the help of DIN colour tables and differentiation between emerald and green beryl and ruby and pink and violet corundum is discussed. E.S.

THOMPSON (W. H.). *The determination of the maximum and minimum refractive indices of a gemstone.* Aust. Gemmol., **14**, 2, 13-15, 2 figs, 1980.

A report to confound unnamed gemmologists 'of considerable standing' who apparently dispute the well-established fact that the highest and lowest readings for any birefringent stone can be obtained from any convenient facet of that stone. Tables of readings for three surfaces of quartz, and five of peridot, at 30° intervals of rotation, are given from 0° to 180°, very slight variations for different facets being well within limits of experimental error and probably due to the adherence to this strict interval of arc.

[Author proves his point beyond argument, but should not need to do so with experienced gemmologists.] R.K.M.

THWAITE (R.), JAMES (J.), GOLDSMID (S.). *Thermal conduction in gemstones. Part I, Oscillations induced by dry ice.* Aust. Gemmol., **14**, 3, 47-8, 2 tables, 1980.

Mechanical oscillations occur when certain substances are pressed against dry ice (solid CO_2). They are due to heat from the foreign body vaporizing the CO_2. The gas formed cuts off the heat until it has escaped, allowing further contact, which sequence repeats rhythmically. The greater the conductivity of the foreign substance (gem) the more rapid the oscillation. Diamond, conducting heat rapidly to the interface, produces a recognizable squeak. So do some other substances. R.K.M.

TIFFANY (E. B.). *Some very important but little known historic diamonds.* Z.Dt.Gemmol.Ges., **29**, 1/2, 71-8, 16 photographs, 1980.

Paper read to the 17th International Gemmological Conference in Idar-Oberstein. Little known but important diamonds are to be found in the crown jewels of Iran, the Soviet treasury and in private hands of Indian Princes. E.S.

TOMBS (G.). *Further thoughts and questions on Australian sapphires, their composition and treatment.* Z.Dt.Gemmol.Ges., **29**, 1/2, 79-81, 1980.

Paper read to the 17th International Gemmological Conference in Idar-Oberstein. The author describes possibilities of alteration of colour in Ceylon and Australian sapphires by heat treatment, and also the underlying causes of such alterations. A table shows proportions of trace elements in sapphires from both localities. E.S.

TOMBS (G.). *Further thoughts and questions on Australian sapphires, their composition and heat treatment.* Aust. Gemmol., **14**, 4, 64-5/68, 1980.

Paper* read to the 17th International Gemmological Conference at Idar-

*This is the same paper as that published in Z.Dt.Gemmol.Ges., **29**, 1/2, 79-81 (abstracted above) with a few minor verbal changes and omitting the table.—Ed.

Oberstein, compares treatment of Australian sapphires and that of Ceylon (Sri Lankan) stones. Low titanium content in Australian material suggests silk, when present, may be alpha corundum and not rutile as usually assumed. Leaves many questions to be answered. Some Sri Lankan heat-treated sapphires are said to have reverted in colour. Australian stones, similarly treated, are colour stable. R.K.M

TOMBS (G.). *Natural and man induced irradiation of diamond. Possible identification between irradiation types.* Aust. Gemmol., **14**, 3, 30-2, 1980.

A paper presented at the Federal Conference, 1979, deals with known facts on naturally irradiated diamonds and those artificially irradiated. ['All natural green diamonds do not owe their colour to x-radiation' would be better stated 'Not all natural green diamonds owe their colour—etc.'. Author apparently confuses G.A. of G.B. with the London Chamber of Commerce Gem Testing Laboratory. He also suggests that advanced training in this subject is available here. To abstracter's knowledge it is not, being still very much in the experimental stage.] R.K.M.

TOMBS (G. A.). *Some highlights from papers presented at the International Gemmological Conference.* Aust. Gemmol., **14**, 3, 32-5, 1980.

A report on the XVIIth International Gemmological Conference held at Idar-Oberstein in September 1979. J.R.H.C.

VARGAS (G.), VARGAS (M.). *A new quartz gem material.* Lapidary Journal, **34**, 7, 1504-6, 10 figs (in colour), 1980.

Quartz combining the colours of amethyst and citrine has been found in the North of Uruguay; some theories as to its origin are advanced. M.O'D.

WIJESEKERA (M.). *Gemstones of Sri Lanka.* Lapidary Journal, **34**, 7, 1616-18, 6 figs, 1980.

A short description of the varieties of gemstone found in Sri Lanka, with notes on their occurrence. M.O'D.

WILSON (A. F.). *Metamorphic processes in gemstone formation.* Aust. Gemmol., **14**, 4, 57-63, 6 figs, 1980.

Discusses formation of gem minerals in existing rock by pressure and/or heat and indicates where in the petrological picture a given mineral might be expected. Some terminology is delightfully unfamiliar (e.g. poikiloblastic garnets) but the paper is full of well-informed theory and facts of natural mineral occurrence and growth. Metasomatic gems, in which additional elements are added to the original rock composition by percolating fluids, are also discussed. R.K.M.

ZWAAN (P. C.), ARPS (C. E. S.). *Properties of gemscapolites from different localities.* Z.Dt.Gemmol.Ges., **29**, 1/2, 82-5, 2 graphs, bibl., 1980.

Paper read to the 17th International Gemmological Conference in Idar-Oberstein. The physical properties of scapolites in gem quality in the collection of the National Museum of Geology and Mineralogy in Leiden, Netherlands, are given. The authors discuss the position of the gem scapolites within the mixed crystal series marialite-meionite. E.S.

BOOK REVIEWS

CHESTERMAN (C. W.). *The Audubon Society field guide to North American rocks and minerals.* Knopf, New York, 1980. pp.850. Illus. in colour. £6.95.

In this attractive book minerals are arranged by colour for the illustrated section and chemically for the descriptive section. The quality of the colour reproduction is high. Descriptions include quite a lot of locations, and modes of occurrence are given. There is a very short bibliography and an index. For its size this is a respectable book. M.O'D.

FRIESS (G.). *Edelsteine im Mittelalter.* (Gemstones in the Middle Ages.) Gerstenberg Verlag, Hildesheim, 1980. pp.206. DM48.

The major portion of the book, arranged by stone, gives references by author, some of these being classical in date. Introductory chapters discuss mystic and medicinal properties of gemstsones with notes on selected authors. M.O'D.

KIVIENKO (E. I. A.). (Prospecting and evaluation of deposits of precious and economic stones.) Nelra, Moscow, 1980. pp.165. Illus. in black-and-white. 55k. (In Russian.)

A useful book on deposits of economically important minerals and gems. M.O'D.

LEEDER (O.). *Fluorit.* (Fluorite.) Verlag Deutscher Verlag für Grundstoff-industrie, Leipzig, 1979. pp.266. Illus. in black-and-white. 40M.

This useful volume forms part of the series Monographienreihe Nutzbare Gesteine und Industrieminerale; a good deal of attention is paid to the crystal structure of the mineral and also to its synthesis. Maps show the world's main locations and the remainder of the book discusses the industrial applications of fluorite. There is a very full bibliography and an index. M.O'D.

SEMENOV (V. B.). *Jasper.* Middle-Urals Publishing House, Sverdlovsk, 1979. pp.352. Illus. in colour. 14r.

This is the most attractive book on any earth science topic that I have yet seen from the USSR. After an introductory chapter (in Russian, with an English summary) the rest of the book consists of photographs of Soviet jasper locations and artefacts, each detailed in a list at the end of the book. The wealth of material is considerable as the excellent pictures show. M.O'D.

(Precious and coloured stones.) Isdateltsvo Nauka, Akademia Nauk SSSR. Moscow, 1980. pp.290. Illus. in black-and-white. 1r.30k. (In Russian.)

One could wish for such a book in English or at least in a Western European language, since it deals with the occurrence of gem material with particular reference to mineral associations. M.O'D.

ASSOCIATION NOTICES

OBITUARY

PROFESSOR DR KARL SCHLOSSMACHER, F.G.A.

An Obituary Note by B. W. Anderson

In the death of Professor Karl Schlossmacher last November at the age of 93 we have seen the passing of the third 'Grand Old Man' of gemmology to die during the past decade. The first, and oldest of them all, was Dean Kraus of Michigan, who died in 1973 at the remarkable age of 97, and who will be remembered as senior co-author of that excellent textbook 'Gems and Gem Materials'. The second was Robert M. Shipley, founder and first President of the Gemological Institute of America, who was 91 at his death in 1978.

Of the three, Prof. Schlossmacher was the most academically learned as a mineralogist and skilled as a practical gemmologist. His influence on the growth of gemmology in Germany was indeed tremendous. In his student days at the University of Marburg he underwent a thorough mineralogical training, and his propensity for gemmology was ensured from the beginning by his being a pupil of Prof. Max Bauer, author of the justly famous work 'Edelsteinkunde', first published in 1896. This was for many years the finest and most complete textbook on the subject and was translated by L. J. Spencer and his wife for the English edition, which was published as 'Precious Stones' in 1904 and reprinted fairly recently in paper-back form. Much later, Schlossmacher was himself destined to prepare a greatly altered version of 'Edelsteinkunde', which appeared in serial parts during the period 1928-1932.

The present writer as a keen young gemmologist was much inspired by this Schlossmacher version—partly because there were many references therein to original sources in the literature which opened up a world of science beyond the hackneyed 'textbook' material, too often copied or rehashed from one book to another.

Before that time Dr Schlossmacher held posts at Heidelberg and later at Berlin University, where he organized the first official German course in gemmology. In 1926 he was appointed Professor of Mineralogy and Petrography in the University of Königsberg, with all the resources of a fine new Institute at his disposal. Here for a time his chief interest lay in the colour absorption of gemstones as revealed by a

Prof. Dr Karl Schlossmacher *(Photo: Z.Dt.Ges. für Edelsteinkunde, 1967)*

spectrophotometer. In 1938 Schlossmacher was elected an Honorary F.G.A.—a distinction awarded only to a very few.

Towards the end of the Second World War he was appointed Professor of Mineralogy at Freiberg before settling into his last professional niche as Director of the Precious Stone Research Institute in Idar-Oberstein, the very heart of the gem-cutting and precious stone trade in Germany. There, enveloped in an aura of immense prestige, he taught and carried out routine gem-testing and research for many years.

Amongst the more important of the specialized instruments which he designed during this period was a horizontally disposed polarizing microscope which simplified the thorough examination of a gemstone in any desired orientation while immersed in a cell of liquid. He also wrote two useful books for students, 'Leitfaden für die exakte Edelsteinbestimmung' ('A Guide to the Accurate Determination of Gemstones'), and 'Edelsteine und Perlen', which went through several editions.

During his long years of retirement Prof. Schlossmacher received many honours. A small street in Idar-Oberstein was labelled with his full name and title as 'Professor Dr Karl Schlossmacherstrasse', and quite recently (1980) a newly-discovered mineral (a calcium aluminium sulphate and arsenate) was christened *Schlossmacherite* by its discoverers, Schmetzer and Bank.

The death even of so aged a veteran must cause sorrow to those who were close to him, while the many gemmologists who knew him chiefly by reputation can feel thankful that Karl Schlossmacher's long life was so valuably spent in the service of his chosen science.

* * *

Mr Leslie Frank Austin, F.G.A. (D.1952 with Distinction), Evesham, Worcester, died on 26th May, 1980.

Mr Donald A. Light, F.G.A. (D.1952), Sutton Coldfield, died in October, 1980.

Mr Albert Shindler, F.G.A., (D.1972), Kenton, died on 20th January, 1981.

Mr Hubert E. Smith, F.G.A. (D.1936), Hove, Sussex, died on 14th November, 1980.

Mr Edward E. Webb, F.G.A. (D.1949), Wimborne, Dorset, died on 26th December, 1980.

GIFTS TO THE ASSOCIATION

The Council of the Association is indebted to the following for their gifts:

Mrs David Merson (formerly Mrs Rutland) for manuscripts of 'An introduction to the world's gemstones', by the late Dr E. H. Rutland, F.G.A. (Country Life, London, 1975).

Mr E. A. Thomson, London, for an oval cabochon-cut calcatricite weighing 4.06 ct.

NEWS OF FELLOWS

On 8th October, 1980, Mr M. J. O'Donoghue, M.A., F.G.S., F.G.A., gave a talk on man-made gemstones to the Medway Lapidary and Mineral Society. Mr O'Donoghue also recently visited the Academy of Mining and Metallurgy and the Skawina Aluminium plant near Cracow; the latter produces corundum, which is cut at the plant.

Mr John G. Rae, F.G.A., Shetland, was made a M.B.E. in the last New Year's Honours.

On 26th February, 1981, Mr Alan Hodgkinson, F.G.A., was the guest speaker at a practical seminar and reunion of old gemmology-students at Openshaw Technical College.

MEMBERS MEETINGS

Midlands Branch

On 30th January, 1981, at the Society of Friends, Dr Johnson's House, Colmore Circus, Birmingham, Mr Hugh Ransom gave an illustrated talk on valuations.

On 26th February, 1981, at the Society of Friends, Mr D. R. G. Walker, Deputy Keeper of the Natural History Department, City of Birmingham Museum, gave an illustrated talk on the gem and mineral collections of the Museum.

North-West Branch

On 29th January, 1981, at Church House, Hanover Street, Liverpool, Messrs Walter and Don Hartshorne, of Isis Minerals, gave a short lecture and displayed crystal specimens.

South Yorkshire and District Branch

On 27th January, 1981, at Sheffield City Polytechnic, Mr Peter Harrison, of Treak Cliff Cavern, gave an illustrated talk on Blue John, covering the properties of the mineral, the particular difficulties found working it, and the history of the industry at Castleton.

ANNUAL REUNION OF MEMBERS AND PRESENTATION OF AWARDS

The Annual Reunion of Members was held at Goldsmiths' Hall during the evening of Monday, 17th November, 1980, when a large number of members attended.

The Reunion was followed by the Presentation of Awards, when the Vice-Chairman, Mr Noel Deeks, welcomed over 300 members and recipients of awards with their relations and friends. He mentioned that people from eleven countries apart from the U.K. had come to receive their awards in person, some coming from places far afield. He presented the apologies of the Chairman, Mr David Callaghan, who unfortunately was ill and could not be there but who sent his best wishes to everyone. Also he apologized for the fact that Sir Edward Ford, who was to have presented the awards, was not able to come because of a bereavement, and thanked Mr C. T. Smith, Prime Warden of the Worshipful Company of Goldsmiths, who had very kindly, at short notice, come along that evening.

In his opening remarks Mr Deeks said that 46 persons had sat for the Gem Diamond, 425 for the Diploma and 746 for the Preliminary examinations. Although the numbers were slightly less than last year, there was a better percentage of passes. The Tully Medal was not awarded, but Christine Woodward had received the congratulations of the Examiners for her excellent work. The Rayner Prize in the Preliminary examination had been awarded to Graeme Hogarth. He then thanked the Examiners, the Association's staff and everyone else who assisted in any way with the examinations, without whose co-operation the whole exercise would be impossible.

Mr C. T. Smith, Prime Warden of the Worshipful Company of Goldsmiths, was then introduced and presented the awards. After the presentation the Prime Warden delivered the short address which is recorded in full below.

Dr Allnutt expressed the thanks of the Association to Mr Smith for presenting the awards, and Mr Noel Deeks in closing reminded members that 1981 marked the 50th Anniversary of the Association and special events were being held in London between 4th and 7th October. Some of the world's leading gemmologists, Basil Anderson, Robert Crowningshield, Edward Gübelin and Richard Liddicoat, would be coming to give addresses to members. There would also be an exhibition at Goldsmiths' Hall showing the progress of gemmology and new gems that had been discovered during the Association's fifty years, and including among the exhibits some outstanding and rare gems.

ADDRESS BY MR C. J. SMITH, PRIME WARDEN OF THE WORSHIPFUL COMPANY OF GOLDSMITHS

I am so sorry that I have to stand in for Sir Edward Ford. He is my immediate predecessor as Prime Warden, and, as he is still the chairman of the Goldsmiths' Company's Craft Committee, he would have very much enjoyed this occasion. He takes a great deal of interest in our industry. Sir Edward at one time was a private

secretary to the Queen, and you can well imagine that on a State occasion at Buckingham Palace he would have seen more magnificent gemstones, of many carats, than most of us would see in a lifetime. As I am here in his place this evening, to misquote an old saying, I trust that you will accept half a carat rather than no carats at all.

My interest in gemstones was first aroused at an exhibition of diamonds at Christies many years ago. There I saw diamonds of every colour, blue, brown, green, yellow and pink, all rare colours and not one smaller than 2 carats. It was the beautiful yellow one that I liked the most. Since then I have taken an amateur's interest in gemstones and gem materials. But, being a poor silversmith, there it has remained!

It has given me great pleasure to present the diplomas and prizes this evening. I expect that you feel that you have achieved something, and you certainly have. It is a wonderful feeling to look back after many months of study to find that you have 'made it'. You have satisfied the examiners in both theory and practical work, in all the aspects of gemmology—crystallography, mineralogy, refractive indices and a dozen other subjects, including the study of synthetics, which today is becoming increasingly important as the techniques improve. The Technical Advisory Committee of the Goldsmiths' Company thought this subject of such importance that they commissioned a survey by Mr M. J. O'Donoghue to compile a reference to all the available material on synthetics. Strangely, for a book written in English, the greatest sales have been in Europe and the Far East.

I think it is important, for many of you, to remember that this is only the beginning of your career and only a great deal of practical experience can take you to the top. But you will find that you will be regarded as experts, because you are qualified gemmologists. Similarly on my side of the industry we are regarded as experts. Nothing could be further from the truth. We have not learnt it all. Nevertheless we are asked questions and very often asked to give an opinion on a piece of silver. Generally it is something with which you are quite familiar, and there is no problem.

It is sad, but very often when I have been shown pieces of silver which have been highly regarded by their owners, they have been of very little value. You, in time, will have many similar experiences. May I suggest that you do not instantly destroy a cherished belief, probably associated with someone near and dear to the person seeking your opinion. Acquaint your customer, friend or whoever it may be, that it is possible that it is not what they believed it to be. Treat them kindly and gently. In this way they will retain their dignity, you will retain their respect and they will value your advice. You will, of course, get the blusterer who will tell you that you don't know what you are talking about; usually they are only after a free valuation. Do not be perturbed; just suggest that they get a second opinion.

I am most interested to learn that Messrs Rayner & Keeler are presenting one of the awards. Before the war—that seems a long time ago—I was with Ross Ltd, the manufacturers of binoculars and telescopes, and I had the greatest respect for them, and here this evening I find that they are so splendidly supporting the gemmologists.

May I wish all the diploma holders and prize winners every success in the future and that the Gemmological Association will continue to prosper as they enter their 50th anniversary next year. Thank you very much for having me, and may the Goldsmiths and Gemmologists continue in harmony.

PRESENTATION OF AWARDS IN JAPAN

Once again the Gemmological Association of All Japan arranged a ceremony at the Imperial Hotel, Tokyo, on 26th November, 1980, for the presentation of awards to those persons in Japan who had qualified in the 1980 Diploma Examination. Mr R. P. Martin, the Cultural Counsellor and British Council Representative in Japan, presented the Diplomas.

ISTITUTO GEMMOLOGICO ITALIANO

Mr H. J. Wheeler, F.G.A., Secretary of the Association, was invited to give a talk to members of the Istituto Gemmologico Italiano at their 4th National General Meeting held at the National Museum of Science and Technology in Milan, on Sunday, 30th November, 1980. About 300 persons were present and the talk, at their request, was on the subject of the ways we teach gemmology in the U.K. The talk, which was restricted to thirty minutes, dealt first with the history from 1908 to the present day and how interest has grown. It was pointed out that the G.A. of G.B. only conducts teaching by correspondence which is available to anyone in the world, but evening classes are held at schools and colleges in the U.K. The Association does organize examinations which can be taken by anyone taking its correspondence course or who may study at evening classes, or undertake their own studies. In addition to gemmology we have also laid down a syllabus and arrange an examination related to gem diamond studies.

Representatives from Belgium, Italy, Spain and Switzerland also presented papers. In the afternoon talks were given by a number of their Italian members covering subjects such as coral, its treatment and imitations; unusual specimens; modern gemmology assisting the archaeologist; non-destructive methods to distinguish natural turquoise from imitations by x-ray diffraction; and why trust and honesty are essential in the jewellery trade.

At the end of the talk the Association was presented with a copy of *Il Diamante—Manuale Pratico,* by Gianmaria Buccellati (President of the Italian Gemmological Association), which had just been published.

ANNUAL GENERAL MEETING

The Association's Annual General Meeting will be held at Saint Dunstan's House, Carey Lane, London EC2V 8AB, on Wednesday, 20th May, 1981, at 6.30 p.m.

GOLDEN JUBILEE CELEBRATIONS
1931—1981

Over a period of four days, from 4th to 7th October, 1981, the Gemmological Association will celebrate its first fifty years as an independant institution as follows:

Sunday, 4th October:

6.30 - 8.30 p.m. Reception at the Institute of Geological Sciences.

Monday, 5th October:

11 a.m. Lecture by Mr B. W. Anderson, B.Sc., F.G.A., F.K.C. (Vice-President).

6 p.m. Grand Opening of Exhibition at Goldsmiths' Hall (which will remain open to the public from Tuesday 6th to Friday 16th October from 10.30 a.m. to 5 p.m. daily, except on Sunday, 10th October).

Tuesday, 6th October:

11 a.m. Lecture by Prof. Dr E. Gübelin, F.G.A., C.G. (Research Diploma, 1957).

6 - 11 p.m. Cruise down the River Thames on M.V. *Naticia.*

Wednesday, 7th October:

10.30 a.m. Lecture by Mr R. T. Liddicoat, Jr, (President of the Gemological Institute of America) and Mr G. R. Crowningshield, C.G., F.G.A.

7 p.m. Celebration Dinner in the Captain's Room at Lloyds.

Full particulars and booking forms may be obtained from the Secretary and have already been posted to all Members.

THE SOCIETY OF JEWELLERY HISTORIANS

The 2nd International Symposium on the History of Jewellery Materials and Techniques will be held at the Society of Antiquaries, Burlington House, Piccadilly, London, W.1., on 28th-29th May, 1981. Further details may be obtained from the Symposium Secretary, Mr Jack Ogden, 42 Duke Street, St James's, London SW1Y 6DJ.

On 21st September, 1981, at 6 p.m., Mr Ogden will lecture on 'Profitable Trickery: Imitation Gemstones in the Ancient World', also at the Society of Antiquaries, in Burlington House.

RESIDENTIAL COURSE AT CHICHESTER

A closed week-end residential course for second-year G.A. Correspondence Course students, covering the use of gem-testing instruments, will be tutored by Mr Peter G. Read, C.Eng., F.G.A., at West Dean College on 29th-31st May, 1981. Further details may be obtained from the Course Supervisor, Miss S. Overman, West Dean College, West Dean, Chichester, Sussex. PO18 0QZ.

MICROFILMED JOURNAL

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GEM CRYSTAL TRANSPARENCIES

A third, and enlarged, edition of this useful instructional set of colour slides, by R. Keith Mitchell, is now available from the Gemmological Association, price £10.35 inclusive of V.A.T.

The completely revised booklet accompanying the transparencies gives necessary information and descriptions of most of the 280 or so specimens depicted. These include normal habits, twin forms, some comparatively rare crystal habits and examples of parallel growth. Where relevant, cabochon cut stones have been included to underline special effects. Kodak copies having proved to be less sharp in definition, each of these slides is a direct photograph, using high quality equipment, and crystals are, for the most part, lined up with the appropriate crystal drawings for the mineral species. The twelve principal gem minerals are dealt with; corundum being represented by 37 specimens; zircon by 38, including a rare twin form; spinel

28; diamond 25 and so on down to topaz with a mere 14 specimens shown.

Finally a new section, 'Looking at Crystals', gives the student basic hints on how to start tackling the problem of sight identification of gem minerals.

SRI LANKAN GEMMOLOGISTS

The State Gem Corporation of Sri Lanka is compiling a directory of Sri Lankan gemmologists. Any F.G.A. who wishes to be listed in the directory should communicate direct with the Deputy General Manager, Research & Development Division, State Gem Corporation, 112/1 D.S. Senanayake Mawatha, Colombo 8, Sri Lanka.

LETTER TO THE EDITOR

From Mr Ian McGlashan

Dear Sir,

The Sancy Diamond

The Scots have a proverb 'Mony a mickle maks a muckle', so may I add my scraps to the two articles you published in the *Journal* in 1977 (E. A. Jobbins, *J. Gemm.*, XV(5), 240-2) and 1978 (H. Tillander, *J. Gemm.*, XVI(4), 221-8)?

1. According to 'Uncensored Recollections', by 'Anon' (the British Museum Catalogue calls the author 'Mr Field'), 1924, p.62, *Paul* Demidoff, nephew of *Anatole,* used to carry the Sancy around in his pocket. Until Mr Tillander stated that Nicholas Demidoff bought the Sancy in 1828, I had assumed it was Anatole who owned it and could not understand why a boy of fourteen should buy such a diamond and also why no obituary of Anatole mentioned his owning the Sancy—journalists as a rule do not miss out on such things!

2. *The Illustrated London News* (11th March, 1865) carried a diagram of the Sancy, which, according to the accompanying script, 'has been purchased for £20,000 by Messrs R. and S. Garrard and Co., of the Haymarket, for Sir Jamsetjee Jejeebhoy.... This diamond is of peculiar form, being neither of a brilliant nor a perfect rose cut. It is what is called a briolette—that is, a solid drop; but it differs from a briolette in having flattened tables back and front, a perfect briolette being cut to a point. The facets are very regular and well cut, which leads to the belief that, although the stone retains its original form, the work has been gone over and improved at no very distant date. We are the more inclined to this idea from the fact that the stone was said to weigh originally 55 carats, but its weight is now only 53¼ carats.'

3. This weight business recalls the Levrat case referred to by E. W. Streeter ('The Great Diamonds of the World', 1882, pp.266-7). Levrat, he says, got the price reduced from 600 000 francs to 145 800 francs because it had been greatly reduced in weight by being recut. Some reduction!

4. In 1867 a diamond called the Sancy was exhibited in Paris, yet also went to India, having been bought by the Maharajah of Patiala (Streeter, pp.267-8). Surely this must have been the Patiala stone which is stated to weigh 60 carats. It could not have been the Sancy as we know it, for Lord Astor said to members of the British Museum that he bought it in 1892 and Jejeebhoy was the previous owner.

5. The story of the stone as given in 'Dix Siècles de Joaillerie Françaises' (Ministère d'État, Affaires Culturelles, Paris, 1962), the catalogue of an exhibition at the Louvre in which the Sancy was item no. 20, says that it was 'mis en vente par l'Indian Art Gallery à Londres en 1887'. The India Office Library could not find any reference to the Indian Art Gallery, when I asked them, and suggested it might be the Indian Section of the Colonial and Indian Exhibition held in London in 1886: unfortunately there is no mention of a diamond in the catalogue of that exhibition.

There are still a number of gaps which I hope somebody sometime will be able to fill.

Yours etc.,
IAN MCGLASHAN.

16th January, 1981.
Montagues, Alphamstone, Bures, Suffolk.

[*NOTE. It appears that the story as told by Tillander (1978)—provided his sources are trustworthy and subject to establishing the relationship of the various members of the Demidoff family—is reasonably satisfactory down to 1854, when the widow Karamsin settled in Helsinki after the death of her husband. Then there is a gap until 1865 (when the Sancy was sold to Sir Jamsetjee Jejeebhoy) which could perhaps be filled if we knew the name of the vendor to Sir J. J. (the widow Karamsin?—Streeter says 'the Demidoff family'): and we do not really know what happened to the Sancy between 1865 and its acquisition by Lord Astor—whether in 1892 (McGlashan) or 1906 (Tillander)—but a stone called the Sancy was (according to Streeter) shown at the Paris Universal Exhibition of 1869 and sold to the Maharajah of Patiala, who wore it at the Grand Durbar for the Prince of Wales on his tour of India (1875) and died shortly thereafter. If the Patiala stone was indeed 'our' Sancy—which at best seems doubtful—and if Lord Astor acquired the Sancy* from Jejeebhoy *(whether in 1892 or later), it might mean simply that Jejeebhoy having sold the stone to Patiala bought it back after the latter's death.—Ed.*]

CORRIGENDA

On p.287 above, line 20, for 'course' read 'coarse'.
On p.339 above, line 5 from bottom, for 'aparatus' read 'apparatus'.
On p.340 above, line 24, for *'crysoberyl'* read *'chrysoberyl'*.
On p.343 above, line 6, for 'ant' read 'and'.
On p.358 above, line 7, for 'Huges' read 'Hughes'.
On p.365 above, line 1 of footnote, for 'aproved' read 'approved'.
On p.366 above, second column (following 'Tinted White' in first column), for 'J' read 'L'.

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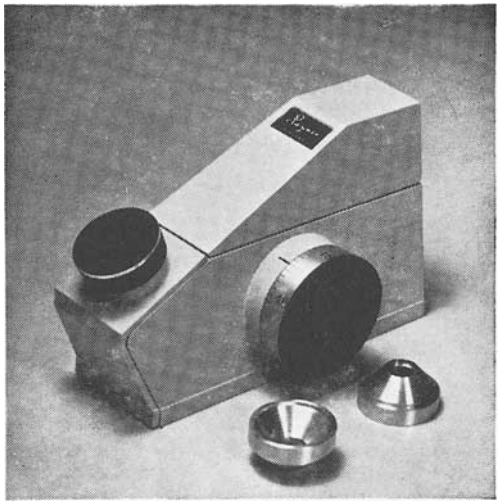

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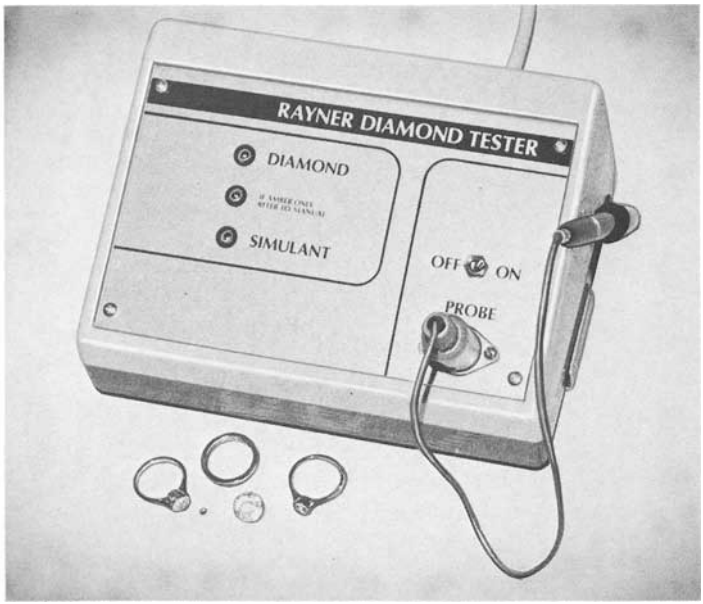

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The Editor is glad to consider original articles shedding new light on subjects of gemmological interest for publication in the *Journal.* Articles are not normally accepted which have already been published elsewhere in English, and an article is accepted only on the understanding that (1) full information as to any previous publication (whether in English or another language) has been given, (2) it is not under consideration for publication elsewhere and (3) it will not be published elsewhere without the consent of the Editor.

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THE JOURNAL OF GEMMOLOGY

and

PROCEEDINGS OF THE GEMMOLOGICAL ASSOCIATION OF GREAT BRITAIN

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THE JOURNAL OF GEMMOLOGY
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Vol. XVII No. 7 JULY 1981

GOLDEN YELLOW TOURMALINE OF GEM QUALITY FROM KENYA

By HENRY A. HÄNNI, Ph.D., F.G.A., ERIK FRANK, Ph.D.,* and GEORGE BOSSHART, Dip.Min., G.G.†*

*Institute of Mineralogy and Petrography, Basel University, Switzerland.

†Swiss Foundation for the Research of Gemstones, Zurich, Switzerland.

Yellow and brown tourmalines are mainly reported from Sri Lanka, Burma and Brazil (Dunn, 1977), but are known from less important localities (Madagascar, Namibia, U.S.A., etc.) as well. Recently, tourmalines of very attractive golden yellow colour appeared in the trade, originating from Voi-Taveta area, Kenya. Although the rough material is found in rather small chips, it yields very pleasing gemstones after cutting. It is hoped that further findings will provide bigger fragments or whole crystals as well. On rough and cut specimens various mineralogical and gemmological investigations were performed. All results proved the tourmalines to be members of the dravite-uvite series with a ratio of 78:22.

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TABLE 1

Representative list of partial microprobe analyses of yellow tourmalines from Kenya (Voi-Taveta)

	a				b			c			d			
SiO_2	36.81	36.64	36.24	36.52	36.28	36.61	36.56	36.94	36.64	36.10	36.36	36.30	36.90	36.56
Al_2O_3	35.27	35.38	35.06	35.12	34.77	35.06	34.86	35.35	34.95	34.96	34.88	35.04	35.23	34.94
TiO_2	.74	.80	.21	.36	.61	.76	.66	.30	.31	.68	.80	.76	.80	.69
MnO	—	—	—	—	—	—	—	—	—	—	—	—	—	—
FeO_{tot}	—	—	—	—	—	—	—	—	—	—	—	—	—	—
MgO	9.61	9.30	9.28	9.15	8.95	9.26	9.40	9.51	9.42	9.45	9.60	9.52	9.61	9.64
CaO	1.20	1.05	1.07	1.12	.98	1.05	1.04	1.02	1.15	1.02	1.19	1.10	1.20	1.30
Na_2O	2.02	2.06	2.03	2.00	2.06	2.07	2.06	2.00	2.01	2.08	2.07	2.03	2.02	2.04
K_2O	.06	—	—	—	.08	.08	—	.05	—	—	—	—	.05	.07
V_2O_5	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Cr_2O_3	—	—	—	—	—	—	—	—	—	—	—	—	—	—
anhydrous total	85.71	85.23	83.89	84.27	83.73	84.89	84.58	85.17	84.48	84.29	84.90	84.75	85.81	85.24

—Elements as Mn,Fe,V,Cr are below detection limit of 0.05 oxide wt%.
—a,b,c and d stand for four different samples, on which the point analyses were performed. This shows the variability within one crystal.

Chemical Composition

Carbon-coated specimens were analysed by an ARL-SEMQ microprobe combined with an energy dispersive detector system (Tracor Northern), using an acceleration voltage of 15 kV and a sample current of 15 nA. For standardization natural and synthetic minerals were used. Data reduction was performed using a ZAF-type matrix correction program. More analytical details are described by Schwander and Gloor (1980).

A representative list of partial microprobe analyses, done on four specimens, is given on Table 1. The results show that the crystals from Voi-Taveta area are Mg-Al tourmalines of the dravite-uvite series, with Na/Ca ratios ranging from 3.1 to 3.8. Recalculating the analyses to the general formula of tourmaline (Table 2), assuming 3 B atoms per formula unit, we obtained compositions close to ideal formulae. However, there is some deficiency of Mg, (Na,Ca) and some corresponding excess in Al which may suggest a substitution as Al $\rightleftharpoons$ Na,Mg.

No Mn,Fe,V or Cr could be detected by microprobe; these elements were checked too in the ppm-range by EDS-XRF-technique* Only minor amounts of Fe (500-1000 ppm) were found. It is surprising that Ti is the dominant transition element in these crystals and that the saturation of yellow colour can be related with the Ti-content, ranging from 0.30 to 0.80 wt% of TiO_2. So far this is the first dravite-uvite tourmaline with such low Fe content.

On some rough crystal fragments there is sometimes a thin rim of green colour, this zone containing more Fe, as proved by XRF-analysis.

From the observed partial compositions and calculated atomic proportions we can exclude the presence of tsilaisite or elbaite components, although for that yellow colour one might have expected it. This confirms the assumption that no solid solution exists between dravite and elbaite as already reported in literature (Epprecht, 1953, Donnay and Barton, 1972, Sahama *et al.*, 1979).

X-Ray Data

The lattice constants (Table 3) are calculated from x-ray powder diagrams (Bradley camera, Ni-filtered Fe Kα radiation).

*energy-dispersive x-ray fluorescence

The strongest lines have the following d-values in Å: 2.573(100), 3.973(90), 2.955(80), 4.218(60), 3.475(50), the estimated intensities in brackets. It is not possible to determine the type of tourmaline by its lattice constants alone. Together with chemical information, the constants fit with the observations of Epprecht (1953) and the diagrams of Sahama *et al.* (1979).

TABLE 2
Chemical composition of Dravite-Uvite tourmalines

(Mg-Al-tourmalines)

Dravite	$NaMg_3Al_6((BO_3)_3Si_6O_{18})(OH)_4$
Uvite	$CaMg_3Al_5((BO_3)_3Si_6O_{18})(OH)_4$

golden yellow tourmaline Kenya (partial microprobe analysis)*

	wt%		
SiO_2	36.64	Si	5.83
Al_2O_3	35.38	Al	6.00
TiO_2	.80	B	3.00
MnO	.00		
FeO	.00	Al	.63
MgO	9.30	Ti	.10
CaO	1.05	Mg	2.21
Na_2O	2.06	Ca	.18
K_2O	.00	Na	.64
B_2O_3†	10.90		
V_2O_5	.00		3.76
Cr_2O_3	.00	Number of ions on the basis of 29 O per formula unit	
anhydrous total	96.13		

*for technical reasons Boron and other very light elements are not able to be analysed by microprobe technique.
†B_2O_3 calculated on basis of ideal formula containing 3 B.

TABLE 3

Physical and optical properties of Dravite-Uvite tourmalines

	Dravite*	golden yellow tourmaline	Uvite
$n\varepsilon$	1.617	1.619	1.619
$n\omega$	1.638	1.642	1.638
Δn	0.021	0.022	0.019
a_o	15.939Å	15.915	15.918
c_o	7.199Å	7.183	7.207
c/a	0.4517	0.4513	0.4509
SG	3.03	3.044	3.01
Dravite:Uvite ratio	80:20	78:22	4:96
Reference	Bridge *et al.* (1977)	this study	Dunn *et al.* (1977) NMNH #C5212

Optical Features

The refractive indices were obtained from oriented crystal sections on a Topcon refractometer, working with Na_D-light. The figures (Table 3) are consistent with the well known range of optical data for tourmaline. The axial image of a slice cut perpendicular to the *c*-axis, observed in a polarization microscope, is uniaxial negative, with a slight tendency to biaxial.

Inclusions are profiled negative crystals parallel to *c*-axis, curved growth tubes (trichites) and flat healing fissures consisting of long and short droplets of residual liquids.

Absorption spectra for both rays, registered on a Pye-Unicam SP8-100 spectrophotometer, show good transmission from red to yellow and a wide absorption band from blue to violet, followed by

*According to the analysis of Bridge *et al.* (1977) this sample does not represent a dravite end-member, but no other data were available

a minimum at 378 nm and an absorption edge around 320 nm for $n\omega$ and 300 nm for $n\varepsilon$. Dichroism is stronger than can be recognized by visual inspection, with absorption $n\omega \gg n\varepsilon$. The strongly absorbing ray is responsible for the colour. The extraordinary ray is very pale yellow. For hue, saturation and degree of darkness the DIN 6164 indices are 3:5:1.5 (body colour) and 3:8:1 (internal reflexions).

Fluorescence is absent under long wave, and medium strong yellow under short wave violet radiation.

The absence of transition elements other than Ti and very little Fe, purity and small variation of the orange-yellow hue observed in these tourmalines are to be expected. The saturation of colour, as mentioned before, is governed by Ti content. A wide Absorption band centred around 440 nm appears to be caused by Ti alone.

ACKNOWLEDGEMENTS

Thanks are due to Dr W. B. Stern for performing the XRF-analyses.

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[*Manuscript received 11th February, 1981.*]

AN UNUSUAL PLEOCHROISM IN ZAMBIAN EMERALDS

By Dr KARL SCHMETZER and Prof. Dr HERMANN BANK, F.G.A.†*

*Institute of Mineralogy and Petrography, Heidelberg University, West Germany

† Idar-Oberstein, West Germany.

The Zambian emerald deposits (Miku-Kafubu-deposits), which were rediscovered in 1967/1968, have been up to now the subject of intensive scientific and commercial interest (Bank 1973, 1974; Campbell 1973, Kanis 1980). The emerald deposits were first discovered by Baker in 1931 and have been investigated later by Brock and Sharpe. But until the early sixties they were only of little commercial importance. According to Kanis (1980), the first mine (Miku) was given up in 1972. In the neighbourhood, however, there were discovered seven further deposits south and south-west of Miku in the Kafubu region. The production of the mines, coming to the gem market since 1977, make Zambia at present probably the most important producer of emeralds in the world.

The optical data of the emeralds are generally n_o 1.589-1.590, n_e 1.580-1.581, DR 0.008-0.010; the density is given as 2.74 g/cm^3 (Bank 1974). A dark green emerald of Zambian origin with unusually high refractive indices of n_o 1.602 and n_e 1.592, due to its high contents of Fe and Cr, is mentioned by Bank (1980). The colour of the stones is described as ranging from a turbid or barely visible shade to an intensive green, which is somewhat comparable to fine stones from Sandawana (Zimbabwe) and Muzo (Colombia). Some of the stones which are now on the market show a peculiar phenomenon: they look blue to bluish-green with a pleochroism $\parallel c$ blue, $\perp c$ yellowish-green. The authors had never seen such pleochroism in emeralds before. The recognition of this peculiar coloration, which differs very much from the green of emeralds from other localities and also from their pleochroism, which generally is $\parallel c$ green, $\perp c$ yellowish-green, was the reason for the following investigation.

To clarify the causes of the colour and pleochroism in the Zambian emeralds mentioned, microprobe analyses and absorption spectroscopical investigations were carried out. The microprobe

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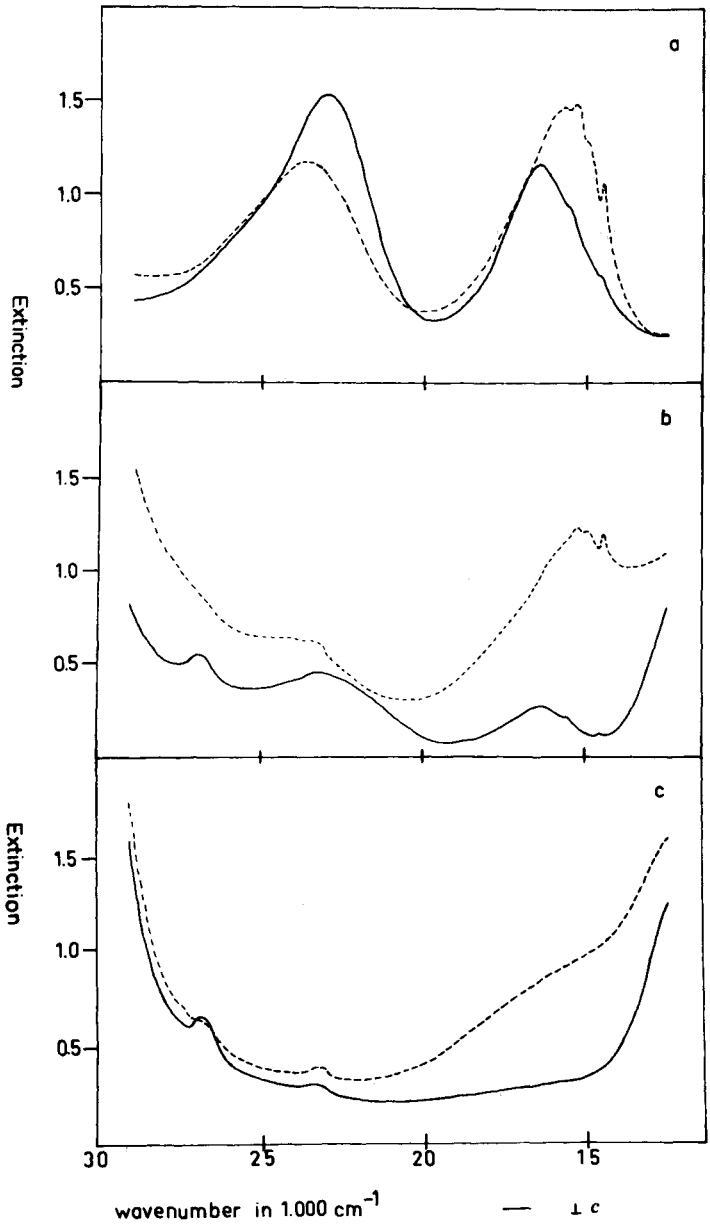

FIG. 1. Absorption spectra of beryls: (a) emerald, Muzo, Colombia. Pleochroism ∥ *c* green, ⊥ *c* yellowish-green; (b) emerald, Miku, Zambia. Pleochroism ∥ *c* blue, ⊥ *c* yellowish-green; (c) aquamarine, Tongafino, Madagascar. Pleochroism ∥ *c* dark blue, ⊥ *c* almost colourless.

investigation of the bluish-green emeralds from Zambia shows besides Cr and V as trace elements also a distinct Fe content, which, however, was also observed in emeralds from other localities (Table 1).

TABLE 1

Chemical data of emeralds (microprobe)

Locality	colour	V	Cr	Fe
Kwale District, Kenya	green	0.01	0.14	0.32
Lake Manyara, Tanzania	green	0.01	0.06	0.40
Miku, Zambia	bluish-green	0.01	0.07	0.73

The absorption spectra of the bluish-green emeralds from Zambia differ very distinctly from the spectra of green emeralds from other occurrences. They consist of a spectrum produced by the Cr bands of 'normal' green emeralds on which is superposed the spectrum of blue aquamarine caused by Fe bands [Fig. 1; for comparison see also Wood & Nassau (1968), Schmetzer *et al.* (1974), Parkin *et al.* (1977), Goldman *et al.* (1978), Platonov *et al.* (1979)]. The bluish-green emeralds from Zambia owe their unusual colour and spectra to the coincidence of an emerald component and an aquamarine component in the same crystal. Since the visible part of the absorption spectrum of the stones $\perp c$ is hardly influenced by the Fe bands of the aquamarine (aquamarines are generally colourless $\perp c$), emeralds from Zambia and emeralds from other localities show $\perp c$ a yellowish-green colour. However, in the spectrum $\parallel c$ the colour-determinating absorption minimum of 'normal' emeralds, which is in the green part of the spectrum, has superposed on it the Fe bands of the aquamarine component of the stone and is therefore shifted from the green to the blue part of the spectrum. Therefore, the stones $\parallel c$ are blue in colour. The coloration of the bluish-green emeralds from Zambia, therefore, is explained as due to a coincidence of an emerald and an aquamarine component in the same individual stone.

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SOME FALLACIES OF GEMMOLOGY

By R. KEITH MITCHELL, F.G.A.

In two papers published in overseas gemmological journals in the past year or two some confusion has been found regarding the working of the diamond pen as a test between diamond and its imitants. I suspect that the second paper, in the *Australian Gemmologist,* which was printed as a working report on the instrument, took this part of its information from an earlier paper, published in *Gems & Gemology,* the American journal, without questioning its facts.

Both papers mention the 'surface tension of diamond'. This is a misuse of terms since surface tension as now understood is a property of liquids and not of solid crystals, though in the past it was sometimes used in respect of unsatisfied electron bonds at the surface of solids.

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Both also associate the 'ink' test with the hydrophobic (water repellant) property of diamond, with the water spot test and with the somewhat dubious breath test.

Unless I am greatly mistaken the test depends, not upon the diamond's non-wettability at all, but upon that mineral's other notable property, its affinity for hydro-carbons, the ink used being based on a glycol. Water is miscible with glycol and may be present to assist flow, but the continuous line or defined spot of ink is due to the presence of the hydro-carbon.

THE BREATH TEST

For a great many years one has seen dealers and jewellers react to the sight of a diamond by breathing on it. This was done long before any seriously deceptive imitants were known and has the effect of masking the internal life of the stone in order that its actual colour can be assessed. It has probably been in use for that purpose since colour, or the lack of it, became recognized as a factor in diamond values.

Recently this very basic test has been 'promoted' to being a test between diamond and its imitants. It was even demonstrated in a TV programme on gemmology. It is said that misting resulting from breathing on the stones clears more quickly from diamond than from other stones.

Although there may be some slight scientific reasoning behind this belief, i.e. that diamond conducts heat to the misted surface more quickly, there is also the fact that it conducts heat away from the warm moisture more readily and so more, or larger, droplets are deposited.

Further, one has to be quite sure that all stones are breathed upon at the same moment and for the same length of time. Once misted the stones must not be subjected to any outside source of heat or draughts. Radiated heat from the face or hands while the stones are examined by lens is quite enough to vitiate the result. In the TV programme mentioned above, I seem to remember that the rings tested were hand-held. No reliable result could be expected even if the test were workable under more careful conditions. In my opinion the rather dramatic difference shown in the programme was obtained by other means.

In controlled experiments in which all stones tested were placed in a refrigerator to ensure an even starting temperature, and

then placed on the stage of a microscope with no artificial lighting and with a cardboard shield between the operator and all but the oculars of the instrument in order to eliminate body heat and warm up-currents of air, it was found that the stones demisted at roughly the same rate or, where there were differences, these were not necessarily repeatable with the same stones in subsequent runs. In no case did I find that a diamond was misted for a markedly shorter time than most other stones, and in one case a paste demisted at the same time as the diamond.

Grahame Brown, of Queensland, has introduced a volatile spray test, using aerosol freon. This produces a cold fine spray, cold because of the sudden release of pressure, which presumably chills the stones tested. Does it chill all stones equally? Even if it does, the same sources of error must apply. Mr Brown has, himself, commented on the inconsistency of results obtained from such tests.

No, I must contend that the breath test as a means of proving diamond is at best hit or miss and at worst a bit of gemmological flummery which we can well do without. Keep it as it was originally intended, to assess colour in the diamond examined.

THE DICHROSCOPE

A textbook published in 1977 dismissed this instrument as 'having very little gem-testing value provided that other gem-testing instruments are at hand.' Yet a question on the dichroscope was set in the 1980 examinations. Examiners still think it sufficiently important.

In point of fact the dichroscope, where it applies, is less subject to error than is the polariscope, which the author in question rather persistently advocates. The polariscope will give a positive answer for strain birefringence and this could be misleading. The dichroscope would not show pleochroism in such a case. No one has suggested that either of these instruments in isolation can identify a stone beyond doubt. But, in practice, the dichroscope is the safer instrument where coloured stones are concerned .

THE CHELSEA COLOUR FILTER

The same textbook dismisses this as 'of little practical use on its own' and later, 'of precious little use in the identification of

emerald today', basing his opinion on the fact that demantoid garnets, green zircons and green fluorite all appear reddish through the filter. He says that the filter was produced in answer to the 'soudé emerald'. The latter were first made many years before the Chelsea filter was introduced, and demantoids, green fluorite and zircon were all around at that time.

Intelligently used the Chelsea filter is still a powerful tool in gem identification and should not be dismissed out of hand. I do know of one instance where a stained chalcedony bead bracelet was sold as emerald because it showed a pinkish residual colour through the filter, but I did say that it needed to be used intelligently. No one familiar with the material would have mistaken the bracelet for anything other than what it was.

Having, hopefully, put right some gemmological misconceptions I will now try to add something to gem knowledge while again destroying a widely held belief.

Some time ago I was going through a large collection of fragmentary rough gem material when I came across a flattish chunk which had very marked dichroism, a distinct yellow-brown in one direction and a bright and pleasing green at right angles to it. Without identifying it I sent it away to be cut into two stones, one to give the green colour and the other the yellow-brown. I thought I had something quite out of the ordinary. The stones came back looking rather dark and with a less marked difference in colour than I had hoped, due to the reflections from back facets which effectively mixed the two dichroic colours. But I was amazed to find, on testing them, that the material was tourmaline, which is normally expected to have a dichroism consisting of light and dark of one colour.

Subsequently I tested about 80 tourmalines of different colours and found one other which had this unexpected contrast in its pleochroism. I mentioned this to Christopher Cavey, of Cavey McCallum Ltd, and he produced an even more startling example, a stone which appeared almost black when examined normally but which showed dichroic colours of a fine deep tourmaline green for the extraordinary ray and a deep garnet red for the ordinary ray. Complementary colours in fact, which accounted for its lack of colour as a gem i.e. it was practically black. Another point emerged during this investigation and that was the considerable variation in the degree of dichroism between different colours. It is already

known that heat-treated fine green stones from S.W. Africa show little dichroism, but it was found that some of the light pinks also showed scarcely perceptible differences in the absorption of the two rays.

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AN INTERESTING FIND

By PHILIP JEROME, F.G.A.

About four years ago I was approached by an elderly German gentleman, in connexion with some laboratory apparatus he wished to sell. He told me that he was administering his recently deceased brother's estate as sole executor. At the time I was a student of gemmology and required a chemical assay balance. He informed me that his brother was an analytical chemist and he would like to have his equipment sold to someone who would use it and not to a dealer. We agreed on a date and time and met at his brother's house. I was guided upstairs and led into the laboratory. I was told that I could purchase anything that would be of use to me; in fact there was very little equipment of use, most of it being very old, or else there were bottles marked 'Radium Salts' that were covered in a heavy corrosion, and these I avoided like the plague!

However as I was about to leave, I had whispered in my ear 'How about the library?'. I could not resist the call, and in I went.

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The books were tied up in dusty bundles, and as far as I could see related to analytical and chemical microscopy—although of some interest, not really gemmological. I had browsed through a couple of boxfuls, when I came across a box full of geological and mineralogical editions. To my surprise the deceased gentleman had a keen interest in gemmology, and most of the books were printed at the turn of the century.

One book titled *Lehrbuch der Mineralogie und Geologie,* written by Dr Aug. Nies and Dr Ernst Dull, contained the most beautiful colour plates and illustrations of several minerals. To my surprise it contained a few folded newspaper cuttings, in English and dated around 1920-1933. The first cutting was dated October 1926, and revealed an advertisement for Greys (non-filter) cigarettes, ten for sixpence! The reverse side was an article on coloured diamonds from a publication called *The African World:*

COLOURED DIAMONDS

THE RED STONE OF ELANDSPUTTE

Among the gems recently found near Lichtenburg was a deep red port-wine coloured diamond, weighing eighteen carats and rather irregular in shape, which was discovered at Elandsputte early in August. This is only the second red stone found in South Africa, while another was found in Brazil some twenty years ago, states Mr. David Draper, the well-known geologist. These small stones (about a carat each) fetched very high prices. The African one was bought by a dealer for £50, and sold for £500, and £1,500 is the price put upon it by the present owner. The value of the Elandsputte stone depends entirely on the colour after cutting. As an instance of this, Mr. Draper mentions an ordinary diamond found in Brazil which was sold for $48, the price for the ordinary run of stones. After cutting it exhibited the peculiar kerosene tinge of light violet so highly prized by the Americans, and a well-known New York firm immediately offered $600 for it. On the Pretoria diamond mines—especially on the Montrose when first discovered—the red top soil yielded blue, green, pink, brown, and black diamonds, in addition to the white gems of all qualities; while similar stones were found in the Sonambula Forest diggings in Rhodesia over twenty years ago.—*The African World.*

The next article was dated 26th August 1933, and reported on the museum theft of unique gems stolen from the Jermyn Street Geological Survey Museum; the most interesting reading was under the section headed 'The Finest Specimens' as follows:

THE FINEST SPECIMENS

Among the stones stolen were fancy-coloured sapphires, tourmalines, zircons, a diamond, and specimens of green beryl and gold ore. This case of 'recent additions'—some 3ft long by 2ft deep—contained the cream of the museum's cut gem-stones.

A number of the missing stones are certainly among the finest known specimens of their kind, and some of them probably unique. But they are almost without exception of a class which holds far greater value and interest for the collector than for the practical jeweller.

Among the outstanding stones which the case contained were:

A large oval aquamarine of a wonderful blue colour;

A large round brilliant-cut kunzite—a lilac-pink stone of the spodumene variety—which disputed with an almost identical stone at South Kensington the claim to be the finest in the world;

A number of fancy coloured sapphires; and

Some half-dozen very fine tourmalines.

Two of the tourmalines—one a deep red, and the other showing five distinct colours (brown, yellow, white, green, and red)—were probably unique.

One cannot help but think and wonder whatever became of these stones, especially the last item, a five-colour tourmaline, something I have never seen.

And on to the third item dated 28th December, 1921, this time on a lighter note. This article is written by an anonymous person, who calls himself 'A Diamond Merchant'; it is headed 'Testing Precious Stones' and will make any respectable gemmologist raise a smile:

TESTING PRECIOUS STONES

By A DIAMOND MERCHANT

Although hardly a year passes without some new way of faking gems is discovered, comparatively few imitation stones succeed in passing the vigilant eyes of the experienced tester.

When handling packets of gems from all sources every week one naturally acquires a kind of intuition in detecting imitations. And this merely by passing the eye over a row of gems just to see how they glisten. Likewise after glancing at the facets on a stone one can usually hazard a good opinion as to the genuineness of the gem.

As soon as a suspicious stone is detected it is tested by two, three, or even more individuals, each using some test he thinks most suitable.

The five methods of testing in common use are known as 'brilliancy,' 'globule,' 'dot,' 'marking,' and 'facets.' A faked gem is less brillinat than a real one. As trusting to the naked eye is unsatisfactory, the gem is dropped in a bowl of water. If the stone is genuine it glistens through the liquid, whereas an imitation gem loses all its brilliancy.

The globule test is almost as simple to perform and is just as efficient. A drop of water is placed upon the diamond's face. It is then touched with the point of a finely-sharpened pencil to see if the globule breaks or spreads. When the stone is genuine the globule keeps its form, while the surrounding parts of the face remain dry. The reverse happens in the case of a 'faked' gem.

The dot method consists of looking through a diamond at a black dot on a sheet of white paper. If the dot appears in any way blurred the stone is held back for other tests as to its genuineness.

In gems the degree of hardness also counts for much. A file will run smoothly over a genuine stone and leave no trace of marks. But the best of imitation stones rarely withstand the severity of this method and will splinter and fly in all directions.

The last named test probably seems easier than any of the others. It is carried out by examining the facets of a genuine and an imitation stone side by side. With the latter extra care has been given to the grinding and polishing, so that there is no likelihood of irregularity in the reflection of the light. With a genuine gem this is unnecessary.

In other words the facets of an imitation stone are often more accurate than in the genuine stone of quality.

It is no wonder that the writer remained anonymous, especially when we are told that 'a file will run smoothly over a genuine stone and leave no trace of marks, but the best imitation stones rarely withstand the severity of this method, and will splinter and fly in all directions.' One presumes at this point, that the splinters of the

stone under test will be passed on to a gemmologist for positive identification! I know that this article was written in 1921, but we must be thankful for such men as Herbert Smith, Bristow Tully, Robert Webster, Basil Anderson and others, who have helped educate both gemmologists and (dare I say?) diamond merchants!

[*Manuscript received 14th January, 1981.*]

A FIBRE-OPTIC REFLECTIVITY METER

By PETER G. READ, C.Eng., F.G.A.

Since the first electronic reflectivity meter was introduced in 1974,[1] a number of commercial gem test instruments have been marketed which use the Fresnel relationship[2] between refractive index and reflectivity as a means of identification. These instruments have ranged in sophistication from the relatively simple Hanneman 'Jeweler's Eye'[3] to the more complex Martin 'Gem Analyser',[4] the latter using a pulsed light source.

Once the requirements for a flat, clean and scratch-free test surface are taken into account, these instruments can provide a

1 Webster, R., A Report on the Gemeter '75, *J.Gemm.*, 1975, **XIV** (8), 378-81.

2 $$\text{Reflectivity} = \frac{\text{intensity of reflected ray}}{\text{intensity of incident ray}} = \frac{(n-a)^2}{(n+a)^2}$$

where n = RI of gemstone
a = RI of surrounding medium

3 Webster, R., The 'Jeweler's Eye': A Report, *J.Gemm.*, 1976, **XV** (1), 19-24.

4 Read, P. G., The Martin MGA-1 Gem Analyser: A Report, *J.Gemm.*, 1978, **XVI** (1), 50-4.

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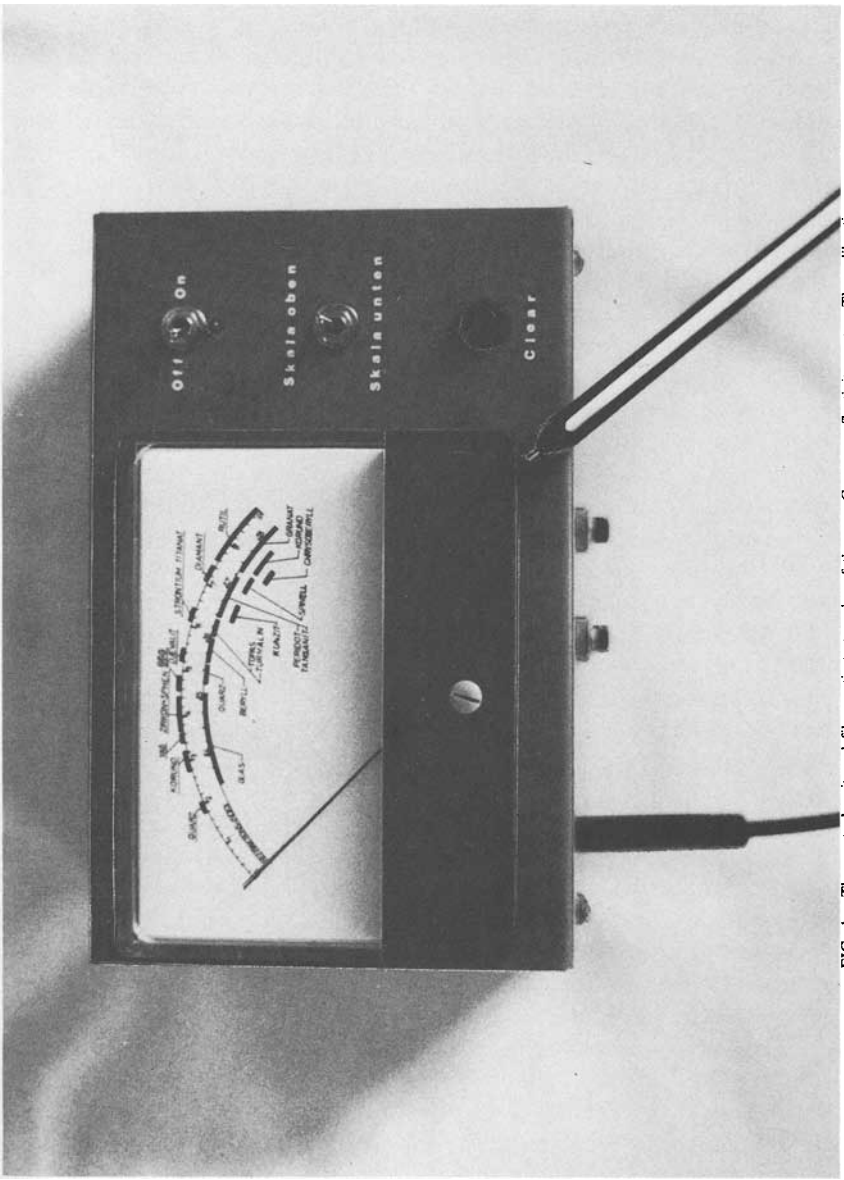

FIG. 1. The control unit and fibre-optic test probe of the new German reflectivity meter. The calibration presets for the instrument's two ranges can be seen in the front edge of the unit.

useful and portable means of gem identification, although they lack the precision and range of information available from the critical-angle refractometer (e.g., DR and optic sign).

One area in which the reflectivity meter excels is the identification of diamond and its simulants (in particular those man-made stones whose RI is above the range of the standard glass-prism refractometer). Even here, the instrument suffers from three limitations; one is the size of the gemstone's facet, which must be larger than the test aperture (usually 1-1.5mm diameter); the second is the need for the gemstone's test surface to be flat against the aperture (which rules out recessed stones), and the third is the instrument's inability to identify stones having a curved surface (i.e. cabochons).

For diamond identification, the first two of these limitations can now be overcome by the use of a thermal conductivity tester.[5] More recently, the second and third limitations have been eliminated in a new German reflectivity meter which is capable of identifying deeply recessed stones, and those with curved surfaces.

This new instrument (Figure 1) uses a bifurcated non-coherent glass-fibre light guide to transmit pulsed infrared energy to the gemstone's test surface, and to return the reflected energy to a photo-detector. Both the IR source (a light-emitting diode or LED) and the detector are mounted in the control box, and are optically coupled to the two end sections of the light guide. The light guide is terminated at the test probe end in a 1mm diameter metal ferrule which contains a miniature converging lens having a focal length of 1mm.

Before testing a gemstone, the instrument's 'Clear' button is pressed to reset the meter-reading to zero. The test probe is then held at right-angles to the gemstone's surface, and slowly brought into contact with it. When the probe tip approaches within 1mm of the stone's surface, the IR beam reaches its optimum focus and the reflected energy (as collected by the detector section of the light guide) rises to a maximum.

The peak value of this reflected energy is automatically fed into the instrument's memory circuits to produce a latched (i.e. steady) meter-reading. As a result of the very small dimensions of the IR beam at its focal point, the instrument is able to measure the reflectivity of a curved surface as well as that of a flat surface.

5 Read, P. G., Thermal Diamond Probes, *J.Gemm.*, 1980, **XVII** (2), 85-94.

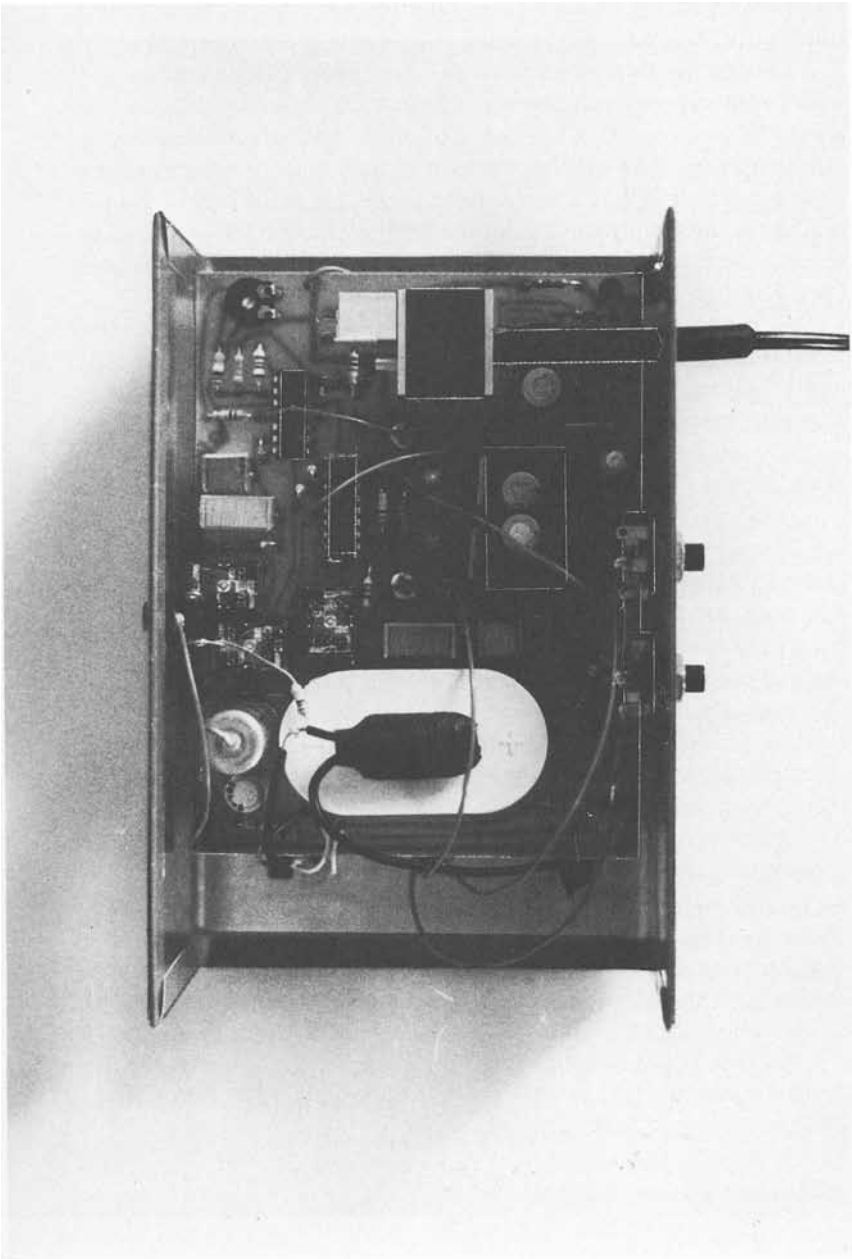

FIG. 2. Underside of the control unit showing the electronic components mounted on a double-sided printed circuit board. The re-chargeable battery is the white unit on the left. The LED/detector assembly is in the square fibre-optic connector on the right.

After each test, the latched meter-reading is displayed continuously until the 'Clear' button is pressed.

During the development of the instrument, some calibration drift problems were experienced. These were caused by the thermal sensitivity of the IR LED/detector unit, and are overcome by automatically feeding the detector's output into the memory circuits each time the 'Clear' button is pressed. This 'background' reading is then subtracted from the gemstone's reflectivity reading by the electronic circuits, thus providing continuous calibration compensation against thermal drift.

The unit has two ranges, the lower one covering materials from glass to corundum and the garnets. The upper range includes quartz, zircon, diamond and the man-made diamond simulants. The instrument's power source is a built-in re-chargeable battery which, together with the electronic components, is mounted on a double-sided printed circuit board (Figure 2).

Tests made by the writer confirmed the ability of the unit to identify gemstones having both flat and curved surfaces, the main problem experienced being that of touching the probe tip on the gemstone surface at approximately right-angles. Until this skill has been mastered it is necessary to make several tests and to take the highest reading (a sound precaution with any reflectivity meter). Occasionally, with small stones in a close-set mount, a false high reading was produced by the focal point of the IR beam passing through the stone, and the detector 'seeing' the high reflectivity of the surrounding metal.

Apart from its ability to identify recessed gems and cabochons, the instrument also appears to be less sensitive to surface scratches (probably because the very small beam makes it easier to find an unscratched area). However, as with the more conventional reflectivity meters, the normal gemstone cleaning and handling precautions still need to be strictly observed if errors of measurement are to be avoided.

Further details on this instrument can be obtained from the designer/manufacturer, Mr U. A. Aldinger, 7000 Stuttgart-1, Lenbachstrasse 1, West Germany.

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DEMISE OF THE BEILBY-BOWDEN THEORY OF POLISHING

By PETER J. CROWCROFT, Ph.D.

Jakarta, Indonesia.

Gemmology literature generally ascribes the nature of the polished gem surface to the formation of a 'Beilby Layer': the polishing process is viewed as generating heat sufficient to melt the surface of the material being polished so that it smears to form a thin amorphous layer. This is the Beilby-Bowden theory of polishing. It was first proposed by Beilby in 1901[1] and in more detail later.[2,3] The theory received experimental support by Bowden and co-workers in 1937.[4] Some electron diffraction experiments in the 1930s also gave the theory support (as it applied to the polishing of non-metals),[5] but some did not.[6] It is to be noted that Beilby actually proposed that a surface layer was formed not only during polishing but also by cutting, filing and grinding the surface of crystalline solids. However, these parts of his theory never received independent support.

Even at the time the Beilby-Bowden theory of polishing was not widely accepted,[7] and by the late 1950s the theory had been completely superseded. However, within the confines of the current gemmology journals and textbooks, the writer can find no reference to this fact and the Beilby-Bowden theory continues to be propagated. Discussion on the nature of the polished surface stops with experimental work of the late 1930s. The purpose of this paper is to present a brief summary of recent developments in the field of surface grinding and polishing and to give a comprehensive list of references to the relevant scientific literature, so that readers may follow up the topic for themselves.

EXPERIMENTS OF DR L. E. SAMUELS

Most of Beilby's experimental results came from observing the surfaces of metals after grinding and polishing. Thus it is appropriate that we should first look at what has happened subsequently in this field. In the 1950s, Dr L. E. Samuels repeated all of Beilby's experiments as well as carrying out electron

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diffraction experiments.[8,9,10,11,12] Samuels could find no evidence to support the Beilby-Bowden theory and advocated a return to the Classical Theory of polishing as held by Newton, Hooke and Herschel.

> 'The new view, then, is that metallographic polishing occurs primarily by cutting, the individual abrasive particles acting in a similar manner to a planing tool. Material is removed and scratches are produced, the better the polish the finer the scratches.'[11]

Polishing agents which polish in this way are diamond powder, alumina powder and emery and silicon carbide papers. Direct evidence for this mechanism was published in 1970.[13]

Experiments of Dr D. C. Cornish and Co-Workers

In the early 1960s, Dr D. C. Cornish and co-workers at the SIRA Institute, Kent, studied the polishing of glass in detail under many different conditions. For example, using different polishing powders calcined at different temperatures, using varying pressures and slurry temperatures, using different pH, using solutions other than water and using glass of different silica content. Most importantly, they studied with the electron microscope changes to the *same* area of glass during *successive* stages of polishing.[14]

Cornish concluded from these studies that no significant contribution to polishing was made by surface flow or redeposition of material on a scale greater than 50 Ångströms. The polish was formed by the *removal* of glass first from the high spots and then from the low spots as the surface was removed.

> 'Throughout this initial stage of polishing, pieces of glass flake out from the surface as strain is relieved in the layer immediately below the surface. This strained substructure is formed during the previous smoothing operation and its depth depends on the conditions then prevailing. To achieve a good finish it is imperative that the surface be lowered beyond this strained region.'[14, *Report* 348]

In Report 348, three sequences of electron microscope photos are published showing the polishing process in detail (see Figure 1). One sequence is continued to show the effect of subsequent etching on the polished surface. Physically they found the rate of material

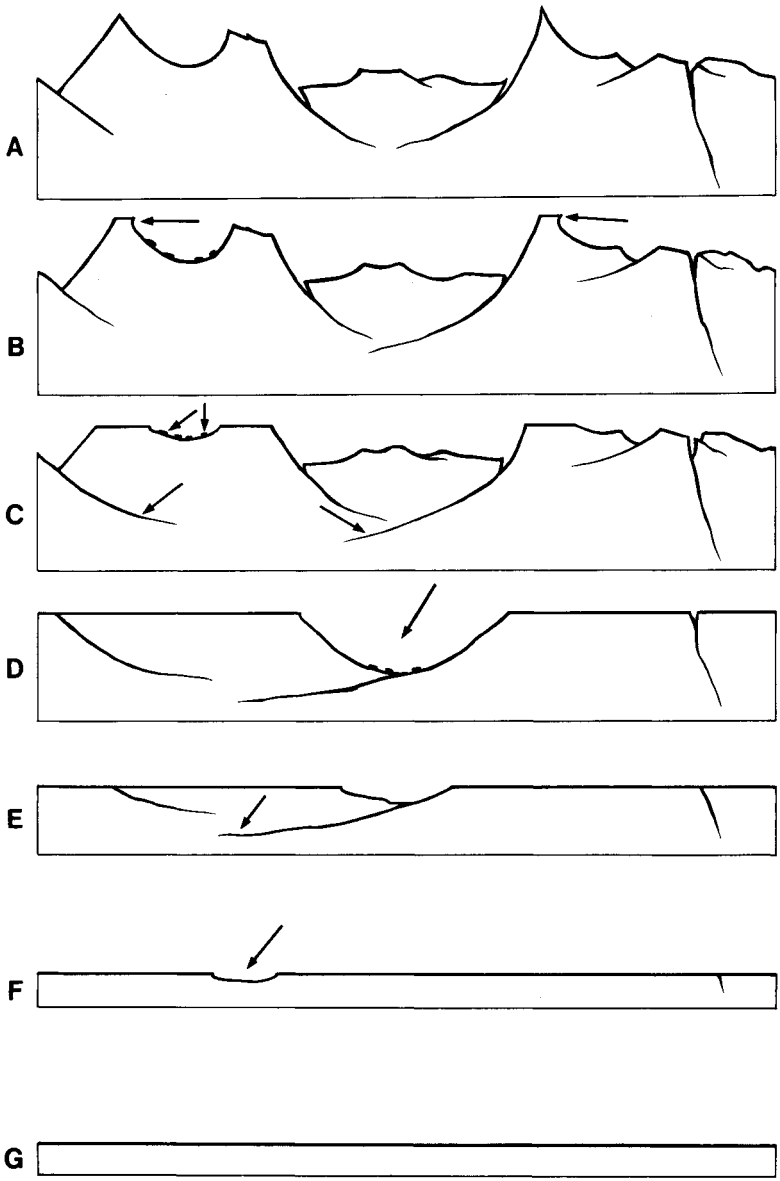

FIG. 1 Schematic illustration of the surface changes of glass during polishing.

A	Pre-polished surface.
B	Initial polishing removes glass from high points. Some shear-over (arrows).
C	Continued polishing. Surface cracks extend and debris collects in surface depressions.
D	Some chips flake out as surface cracks extend.
E & F	Increased area polished. Continued flake out of glass from areas with deepest cracks.
G	Polished, crack-free surface.

(Diagram after Figure 56, Report 348, Ref. 14. Used with permission).

removal depended directly on the applied pressure and the machine speed. It was temperature-independent. Chemically the rate depended on the activity of the polishing powder (as determined by its calcination conditions) and on the silica content of the glass. In a non-aqueous slurry the removal rate was decreased. The removal rate was independent of pH. Effective polishing powders were cerium oxide, chromic oxide, ferric oxide, cupric oxide, zirconium oxide, stannic oxide, plumbic oxide and zirconium silicate. With the exception of zirconium silicate all are the oxides of multi-valent metals.

A chemical mechanism of polishing was proposed which involved the adsorption of hydrated silica from the glass by the polishing powder following disruption of the surface Si-O-Si bonds. Note that this mechanism of glass polishing was not new: it was first put forward in 1931 and was the subject of further papers in 1937 and 1945. In the 1950s East German workers were actively promoting it. (For a full discussion see Ref. 14, Report 267). However, it was Cornish and co-workers who presented conclusive evidence for the theory (only a small portion of which has been mentioned here).

Re-examination of Bowden's Evidence

The work of Samuels and Cornish briefly presented above demonstrated directly that no Beilby Layer was formed during normal metal or glass polishing. But this still left the evidence of Bowden[4] to be explained, particularly as his laboratory produced additional evidence in 1954[15] and 1958[16] to support the Beilby flow theory.

Detailed examination of these papers, however, shows them to be capable of alternative explanation. The arguments will not be presented here, but readers who follow up these references should note the following points.

1. The 1954 paper by Bowden & Thomas[15] was repeated and reinterpreted by Heighway & Taylor in 1966.[17] Using more sensitive equipment and much lower masses (as low as 2 grams), Heighway & Taylor were able to examine the characteristics of *individual* hot-spots. They showed that Bowden & Thomas had generated *aggregate* hot-spots and had made conclusions all appropriate to them.

2. The pressures used by Bowden and co-workers are 2 to 3 orders of magnitude higher than that necessary to achieve a glass (or metal) polish. The conditions described are closer to those of burnishing and grinding rather than to polishing.
3. Typical values of the $v\sqrt{W}$ parameter[16] to achieve a polish in gemmological work are two orders of magnitude lower than that stated as being necessary.
4. Samuels[8] discusses the Bowden & Hughes 1937 paper[4] and does not find their evidence conclusive.

Recent Studies

The use of glass and ceramics for heat shields, missiles and electronics has ensured continuing research into the nature of non-metallic surfaces after abrasion and polishing. A recent publication gives an excellent survey of the state of much present-day research.[18] Some of the articles are of interest to gemmologists: several examine the characteristics of subsurface damage in glass after grinding, the *polishing* of glass by normal *grinding wheels* is reported (page 107), electron microscope photos of glass melted by grinding are shown (page 68) and the polishing of sapphire with superheated steam is reported (page 157). Several other recent studies have specifically examined the mechanism of glass grinding and the interface temperatures generated under various conditions.[19,20,21]

All of these four papers report that under certain conditions melting or softening of glass can occur during grinding in the zone immediately under the abrasive particles in the grinding wheel. This is shown very clearly in three electron micrographs published in another paper (see Figures 14, 15 and 16 of Ref. 22). In these figures the glass surface is one of conchoidal fracture except where plastic flow has occurred in the area where the abrasive particles have moved over the surface.

Conclusions

It has been shown that there is no evidence to support the Beilby-Bowden theory of polishing. The polishing process occurs beyond the resolution of the light microscope. It was only with the development of scanning and transmission electron microscopy that its direct study was possible. Polishing of both Classical and

(in the case of silica-containing compounds) Chemical kinds involves the *removal* of material to below the damaged and deformed layers of material resulting from the prior pre-polishing operation. There is no reason to believe that these mechanisms do not also apply to the polishing of all gemmological material.

However, it still remains for a comprehensive theory of gemmological polishing to be put forward. Such a theory must embrace polishing by all techniques and must be consistent with the many rule-of-thumb procedures advocated currently. In addition there are numerous questions which require further scientific study—for example, polishing by tumbling and polishing of cabochons on leather.

It is hoped that this paper will contribute significantly towards the development of a new theory.

ACKNOWLEDGEMENTS

The writer wishes to thank Drs Cornish, Heighway, Hockey and Samuels for discussing their work with him.

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DIAMOND PRODUCTION IN GUYANA

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INTRODUCTION

In 1923 diamond production in British Guiana reached nearly a quarter of a million carats, averaging about 5.2 stones per carat. This was the peak in the colony's gemstone production and although there was a modest rush during the 1960s—112 000 carats in 1961—the industry has gone into a decline in recent years (see Figure 1). Some say that it will never fully recover.

In the 1920s and indeed in the early 1960s British Guiana was a typical colony, with trade (and in some respects the whole way of life) oriented towards Britain. Today Guyana is a Socialist Republic. Many of the industrial concerns and retail stores are now state owned and all foreign trade is carefully controlled by the state. The economy is based almost entirely on sugar, bauxite and rice, and, although the country has many precious stones together

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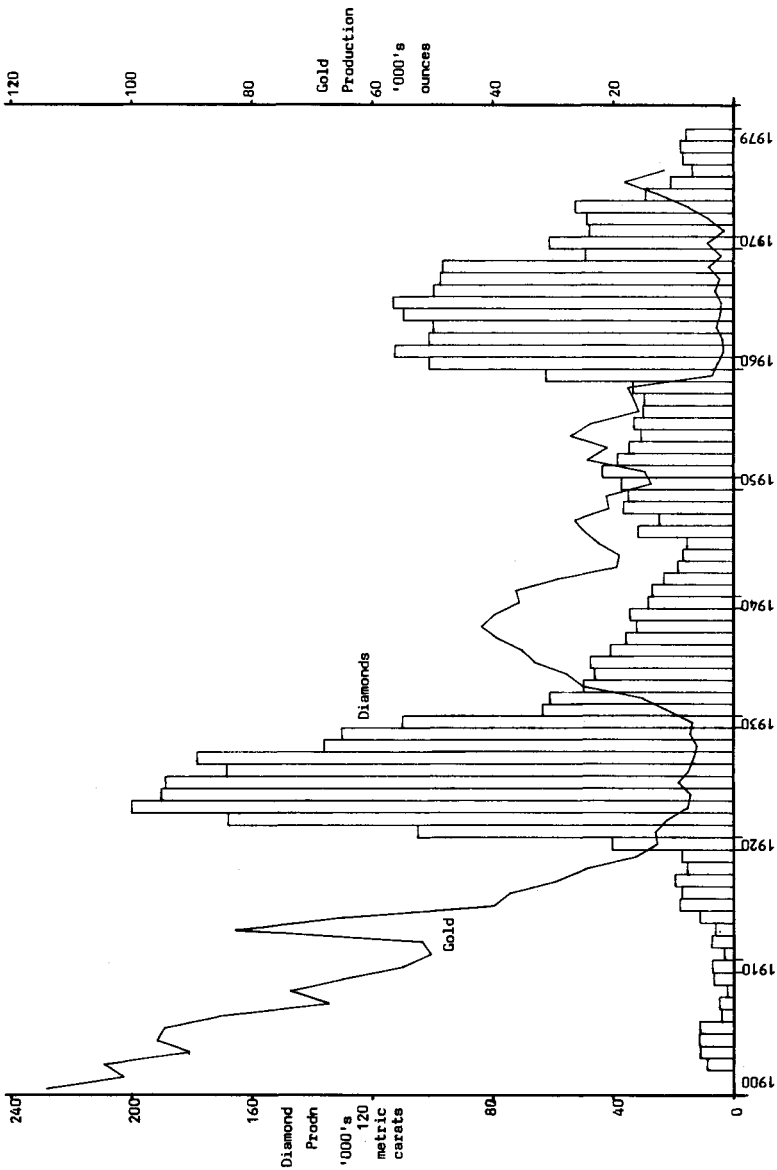

FIG. 1. Diamond and Gold Production.

with extensive gold deposits, the local jewellery industry is still in its infancy. There is little or no interest in design, and stones are generally sold unmounted to individual buyers. About a quarter of the gem material originating in Guyana is shipped to the Caribbean islands (Barbados and Trinidad) for cutting and disposal. The rest is cut and sold in Georgetown, but of this a high percentage finds its way onto the European and American markets.

Industrial stones, which presently account for about a quarter of the total declared production, are all exported to London, but there is a tax on all such exports in addition to the royalty of $5.00 per carat.

GEOLOGY

Diamonds in Guyana (see Figure 2) are all recovered from bands of gravel in alluvial deposits of which four different categories have been described[2]—

(1) The high alluvials, or hill deposits (between 100 and 150 metres above sea level), are thought to be the remnants of old flood plain deposits.
(2) Between the hill deposits and river channels there are terrace deposits which are related to the present drainage having been derived from channels cut in the older high alluvials.
(3) The third type of deposit occurs in the river flats themselves. They are obviously directly related to the present drainage and probably constitute the most important type of deposit for present day production.
(4) To the west of Guyana there is a plateau about 1000 metres above sea level and dotted with mesettas the highest of which, Roraima, reaches over 3000 metres. The plateau is made up of almost horizontally bedded sandstones and conglomerates and all diamond deposits have shown a striking relationship to this formation. Most of the workable deposits are found within a band, 25 km wide, around the delineating escarpment and it is suggested that these deposits are largely the result of the redistribution of the alluvial fans radiating from gorges in the escarpment. The fourth type of deposit is found on top of the plateau or directly associated with it.

The bulk of all the alluvial deposits is made up of smooth, sub-angular, water-worn quartz pebbles together with worn grains of rutile, tourmaline, limonite, jasper and quartz crystals.[5] Some

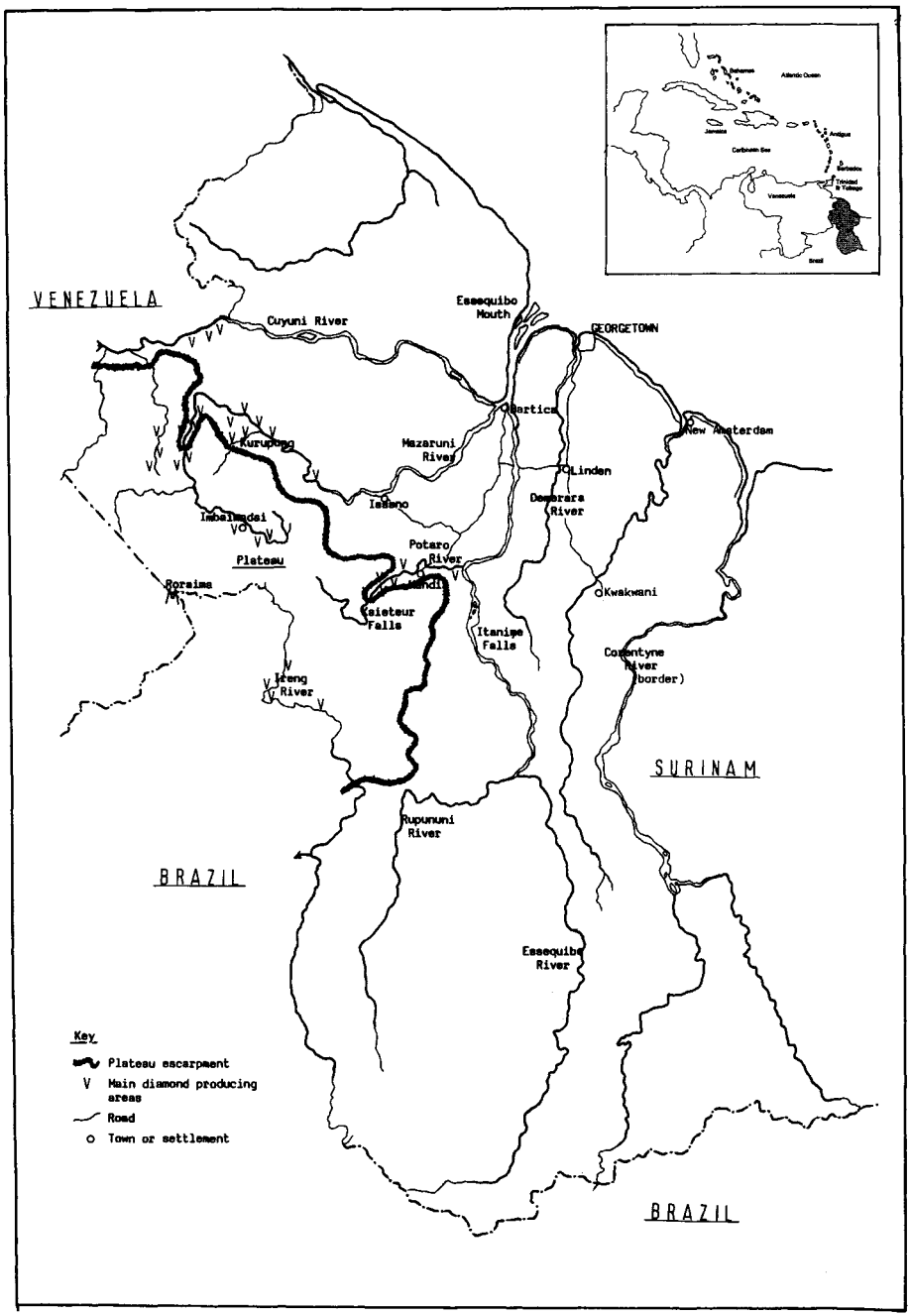

FIG. 2. Guyana: showing location of Diamond Workings (with inset—Caribbean map).

sapphire crystals have also been found. The richest diamond deposits are usually associated with the coarsest conglomerates.

It is a fair assumption that all of Guyana's diamonds have been derived from the sandstones of the Pakaraima Mountains, as the plateau is called. However, the sandstones themselves are secondary in origin. Where they came from and where the diamonds in them came from is still a matter for conjecture. Continental drift offers a very neat and convenient solution. If South America and Africa are fitted together, Guyana roughly coincides with Sierra Leone and there are indeed some similarities between the diamonds from both countries, but there are also many flaws in the argument and it is unlikely to stand up to severe criticism. Hence the search for diamondiferous pipes is continued by one or two academics. Pyrope garnets and other indicators have been found, but hampered by rain forests and the thick soil of such tropical climates, success in the search is unlikely.

History of Production

Gold and diamond production in Guyana are linked together by the nature of the alluvial deposits. Thus any discussion of the history of diamond-mining in the country must start with gold.

It is almost impossible to say when gold was first discovered in Guyana, but ever since Raleigh's voyages in the sixteenth century, El Dorado was believed to lie here. One imaginative writer described 'a city of golden palaces and streets paved with precious stones which reflected their gorgeous beauty in the translucent waters of the parima.' Raleigh believed that after the conquest of Peru the Inca dynasty founded a new empire in the Guianas, and, although there is no real basis for this, Amerindian superstitions about the evils of gold have been linked to the cruelty of the Incas. The idea certainly provides food for thought.

It was in 1850 that the 'Royal Gazette' announced the discovery of gold in large quantities in the Caratal district of Venezuela, and in 1857 gold was reported in the border region of British Guiana. In October 1863 the British Guiana Gold Company was formed and the gold rush was on. Then in 1887 diamonds were discovered in the gold washings of the Potaro River and interest mounted to a fever.

Meanwhile, in the sugar industry of the colony there was a crisis in the 1880s. In 1884 exports fell by 30%, and the sugar

estates responded by retrenchments and sweeping curtailments of expenditure. Wages to the labourer were cut by half, and a season of acute privation and destitution ensued among the creole population. There was unrest, but, instead of bloody revolution, many simply packed what few belongings they had and moved into the bush. They arrived in the diamond and gold fields without food or equipment, in search of the hidden riches they had dreamt of. To live, they had to obtain credit or 'knock' for the salt pork which forms the basis of a bush diet. The 'pork-knocker' was born and this name, for a miner or bush prospector, has remained to the present day—'those small bands of men with little money and much faith'.

However, in the early stages, diamond and gold workings were in the hands of various syndicates.[3] Americans, Germans and British came to the country with extensive plans and high hopes. They brought modern mining ideas and equipment together with the much needed capital, but they had little sound knowledge of the country or the nature of the deposits. Simple dredging techniques were well established by the turn of the century, and a European syndicate therefore established a dredge on the Barima River in 1901. The dredge was operated for only nine months and produced just 130 ounces of gold before it was abandoned. In 1912 a group of pork-knockers worked exactly the same area and recovered 1032 ounces in just 47 days. In 1909 there were five major syndicates working in the Mazaruni District and the largest, The Mazaruni Company Ltd, produced over 2000 carats. By 1912 the Mazaruni Co. Ltd was the only one left and it produced a mere 322 carats. By 1914 the pork-knocker was alone in the field, and, except for a few brief periods of outside interest, it has remained that way throughout the century. Today all of Guyana's diamonds are produced by pork-knockers from small-claim workings.

Methods of Working

The method of working a 'high alluvial' or 'terrace' deposit is obviously very different from the method used when the deposit occurs in river flats or in the bed of one of the country's main rivers.

(i) *The land claim* is opened up by digging a pit down to the gravel, once the bush has been cleared in the area (see Figure 3). Where to dig a pit is, of course, part of the skill—or luck—of the

pork-knocker, but 'prodding' with a pole and small trial pits are used in prospecting.

The gravel bands are generally near to the surface, but even so a pit 6 or 7 metres deep is frequently necessary. The sides must be carefully shored up using timber cut and trimmed on site and a pump is usually necessary to drain the excavation. A team of three or four men will usually tackle a pit, and the 'spade-men' will have to move in the region of 250 cubic metres of sand and clay before reaching the 'pay ground'. The gravel is then removed and stored on the edge of the pit prior to the concentration and beneficiation. Depending on conditions, it will take the pork-knocker between one and two weeks to reach gravel from the day he decides where to dig.

The use of a Tom and Box, which was first described in 1927,[1,6] remains the most popular basic method of concentrating the gravel from a land claim. The system is usually constructed on site and, except for the 'Tom iron', discarded when the area is worked out. The description used by Bracewell in 1927 is still quite applicable today: 'Gravel is thrown into the 'tom box' and puddled

FIG. 3. A small group of pork-knockers completing a pit on a land claim.

FIG. 4. A pork-knocker prospecting in the 'back-dam'. A set of three sieves is used to recover any diamonds, while the batel which he is holding is used to concentrate the gold.

by riddling against the 'tom iron' (a metal plate forming one end of the box, resting at an angle of 45° and perforated by holes ½″ in diameter). Finer material passes through the plate and is collected in a second 'box'. Coarse gravel is thrown out of the 'tom' after cursory examination. The finer constituents are removed from the box by shovel or bailer and placed in a circular sieve of 1/16″ mesh.'

In fact today it is usual to see three sieves in use—½″, ¼″ and 1/16″. The fine sand is usually collected in a batel—a prospector's 'pan'—where it is concentrated for any gold that might be present (see Figure 4). The sieves are circular, about 1 metre in diameter and locally referred to as Brazilian sieves. The pork-knocker holds all three together (in descending size) and bails the box onto the top sieve. The sieves are then immersed in water—either in a creek, a second pit or even a large wooden tub—and jigged. During jigging the sieves are given a rapid twist through a few degrees while keeping the base of the sieve quite horizontal. The heavy material slowly becomes concentrated in the centre of the sieve while the lighter material slowly moves out to the edge of the sieve from where it is gradually scraped away. When the bulk of the light material has been removed, the heavy minerals are re-examined for diamonds. This is either done in the sieve itself or by emptying the contents of the sieve quickly onto flat ground to form a neat pile. The heaviest minerals are then on top of the pile in the centre, and any diamonds are quickly picked out by the experienced eye. The operation of jigging/twisting is repeated about a dozen times before the top sieve is examined and having removed any diamonds the rest of the large material is discarded. The remaining two sieves are then worked together for a dozen more cycles and the search procedure is repeated for the second and finally the third grades of material. It is curious to note that most pork-knockers keep their diamonds in an empty 'Marmite' jar full of water while working the sieves, and, once sorted, the diamonds are stored in discarded 'Vick' inhaler tubes.

The only real modification to the tom and box system has been the introduction of a 'Baby' between the tom and box (see Figure 5). The 'baby' is just a 1/16″ mesh screen roughly triangular in shape, and it is placed so that fine material coming through the tom iron must pass through the baby before entering the box. Only the material retained by the baby is hand jigged for diamonds in the previous manner. The fine sand passing through the baby is

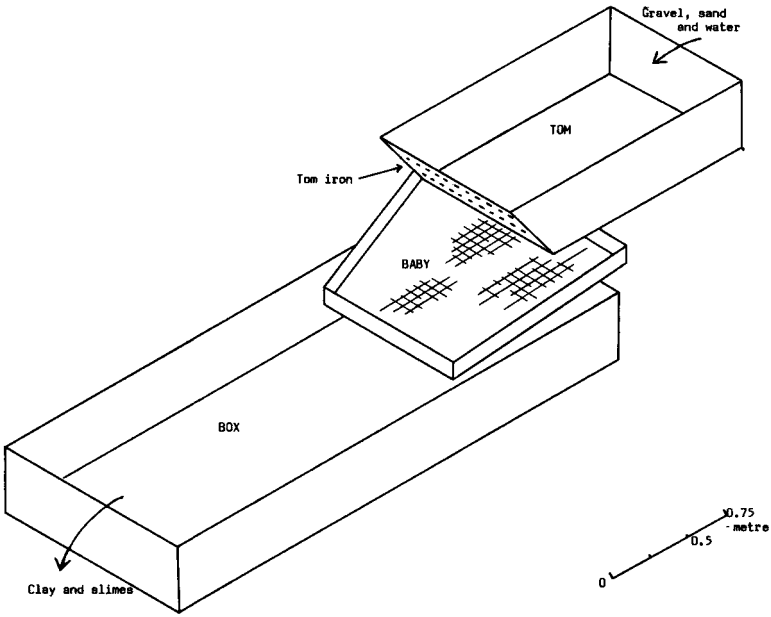

FIG. 5. The TOM and BOX, plus BABY.

concentrated to recover any gold either by panning in a batel or by converting the box into a sluice. The latter is the most common arrangement. The sluice is designed to suit the nature of the gold, and, when the gold is very fine, sluices of 5 metres or more in length are common. Various baffles or weirs are constructed down the length, and sacking is frequently nailed to the bottom of the sluice. The gold is recovered from the heavy mineral concentrate by adding mercury and forming an amalgam. The mercury is finally burnt off using a blow torch.

(ii) *The river claim* (see Figures 6, 7, 8, 9). When diamonds are found in the gravel in the bed of a river, the deposit is worked from a barge floating on the river. The barge is essentially just two wooden punts with a sluice slung between them. It carries a large suction pump with which to recover the gravel and a compressor to supply air to a diver. A pork-knocker wearing a mask and a rubber wet-suit (or frequently just old trousers and a shirt) enters the water using surface demand breathing equipment. He is weighted to sink

to the bed of the river where he directs a 10 cm pipe into the gravels. He frequently takes down an electric bulb, and the cable from the generator acts as his life-line and means of communication. The diver's attendant signals instructions to the diver by pulling on the cable. The water of most tropical rivers is naturally a dark brown colour and frequently very muddy, thus making the light-bulb virtually useless. The diver usually locates gravel by groping with his toes. He uses the pipe just like a vacuum cleaner, but instead of going into a bag the gravel passes down the sluice on the barge. The bottom of the sluice is fitted with deep riffle plates which easily hold back any heavy minerals together with the gold. As soon as the barge operator feels that he is losing values in the waste from the sluice (essentially an arbitrary decision based on previous experience), the diver is recalled and the pump is turned off. The sluice is allowed to drain, the riffle plates are removed and the heavy minerals and coarser gravel held in the sluice are shovelled out and worked through sieves in a wooden tub on the side of the barge. The sieving/jigging operation with Brazilian sieves is basically the same as for the land operation—the only difference being that the material is all examined in the sieve and the under ⅙″ material (the black sand) is allowed to accumulate in the wooden

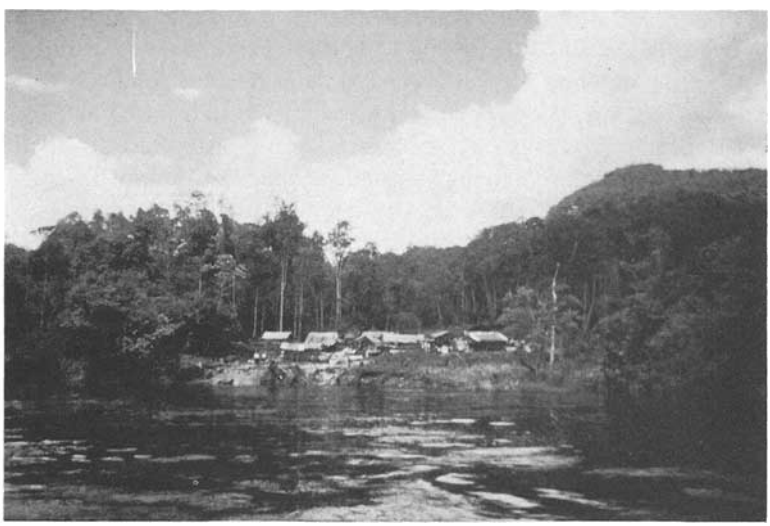

FIG. 6. Mapoura landing. A pork-knockers' camp on the Mazaruni River.

tub. At the end of a day, this sand is concentrated by panning, and the gold is again recovered using mercury amalgam.

These mining operations are hampered by two main factors; (i) the weather, and (ii) supply of fuel. During the rainy season, the tropical rivers become deep raging torrents and diving is impossible. Thus production can sometimes be restricted to just seven or eight months per year. The whole essence of the barge is the pump, and the pump operates on diesel fuel. Most of the mining areas are a long way from Georgetown, and fuel must be carried in by air. The Guyana Airways Corporation offers a limited cargo service to a few areas of the hinterland; otherwise supplies must be ferried in by charter flights, and this is available from only one or two private aircraft.

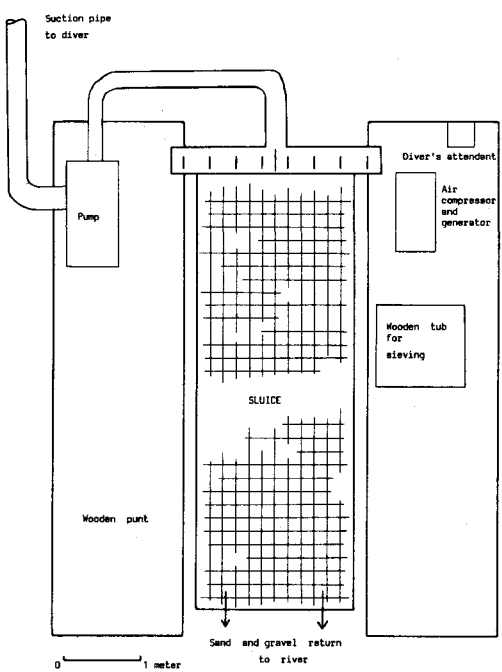

FIG. 7. Lay-out of Pork-knockers' Dredge.

FIG. 8. A group of barges on the Mazaruni River about five miles west of Imbaimadi. They are held in place by ropes stretched across the river which is about 100 yards wide at this point.

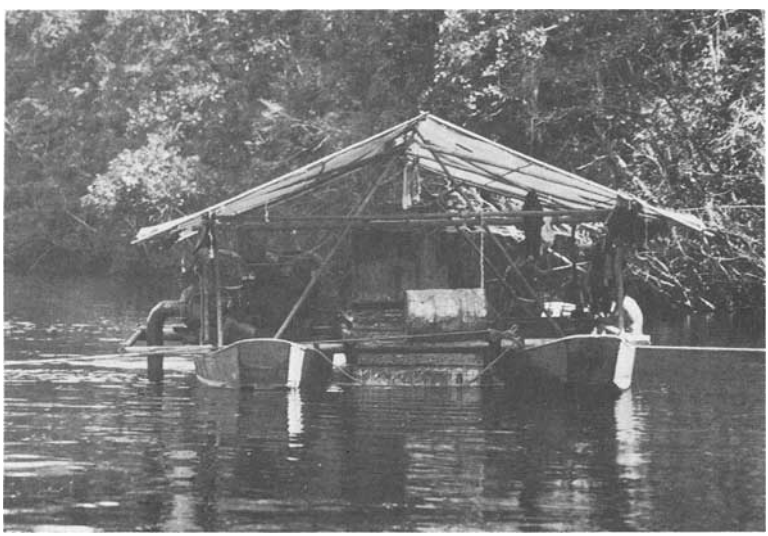

FIG. 9. A pork-knockers' barge on the Mazaruni River. Suction-pump and compressor can be seen on one pontoon, while a diver kits up on the other. The sluice for recovering the gold and diamonds is between the pontoons.

Control and Marketing

The development of the pork-knocker was absolutely dependent on the presence of the bush trader in the mining fields. The relationship continues today. The bush trader carries supplies of food, liquor and equipment in to the mining fields, which he sells to the pork-knocker at a nice profit to himself. Since many of the bush traders are also registered with the Ministry of Energy, Mines and Natural Resources, as traders in gold and diamonds, money rarely changes hands. The 'knocking' aspect of the pork-knocker is still very much in evidence. He will obtain credit from one particular trader to whom he will sell his diamonds and pay off his debts. If he has been very successful, he will have some spare cash. The trader will then either sell to another trader or will himself carry the stones to the Mines Division of the Geological Commission where they will be registered and royalty paid.

Occasionally the pork-knocker may decide himself to sell in Georgetown. This will happen either because he feels the price offered by the trader is unfair or because the stone or stones are so big that the bush trader does not want to handle them. In this case, the pork-knocker must declare his production to the police or local mines officer who seals the package, which is then carried to the mines division and royalty paid. Royalty had remained at G$1.00 per carat for many years but was increased to G$5.00 per carat in October 1979. It is still too early to see what effect this increase will have on declared production!

The diamonds eventually find their way to one of the three firms cutting and polishing diamonds in Georgetown. They generally take packages from the larger traders and only occasionally deal directly with individual pork-knockers. The cutters are obviously very reluctant to disclose too much detail about their operation, but a few observations can be made.

The type of stone being found in Guyana has not changed very much during the past 30 years, and a statement made in the early 1950s[4] ('Octahedra and rounded dodecahedra are common. Colours include white, yellow, brown and green but blue-white are very rare') is still a fair comment today. But perhaps it should be modified slightly to—'No blue-whites are found and whites are becoming rare'. This trend is also reflected in the quality and size of stones being received in Georgetown. Table I shows a definite movement away from first grade gem-quality stones. And whereas

TABLE I

% Make-up of a typical parcel of stones received in Georgetown

	1952	*1980*
First grade gems	59%	10%
Second grade gems	22½%	65%
Industrial stones	18%	25%

in the mid 1950s it was estimated that almost 10% of the stones arriving in Georgetown were one carat or larger in size, today such stones must account for only about 2% of the total by weight. Most of the cutting that takes place in Georgetown is on stones of ⅓ carat or less. When one cutter was asked what price would be paid for a '1 carat rounded white stone', the reply was, 'A rare stone indeed!', but a figure of G$15 000.00 was suggested. (£1 = G$6, July, 1980). In 1952 $65.00 would have been a typical price. Even allowing for world-wide inflation, this means that this type of stone is now commanding a significantly higher price than ever before (cf. Table II). In June, 1980, a typical mixed parcel of gem-quality stones would fetch an average price of about $2 290.00 per carat while about $80.00 per carat would be paid for industrial stones.

TABLE II

*The Price of Rough Stones, Sold in Georgetown, Compared with the UK Wholesale Price Index (WPI)**

	Av. Price per carat	WPI (1963 = 100)	Real value $= \frac{\text{Price}}{\text{WPI}} \times 100$
1910	$5.00	21	24
1915	10.00	30	33
1920	35.00	68	52
1925	21.00	37	57
1930	14.00	26	54
1935	11.00	23	48
1940	16.00	35	46
1945	30.00	43	70
1950	37.00	66	56
1960	51.00	96	53
1980	1,800.00	Dec 1979 = 440	410

*A fair comparison, since virtually all manufactured goods and food stuff were imported from the UK until quite recently.

Virtually all industrial stones are exported to London, but the fate of the gem-quality stones is much less certain. There is a trade in uncut stones—both legal and illegal!—and it is felt that most of the stones leaving the country find their way to North America rather than Europe. As for the stones that remain in Georgetown, at least half are sold locally to individual private buyers after cutting. What actually happens to these stones, in view of Guyana's strict currency regulations, would be a matter of pure speculation. The rest are sold to dealers who will certainly export, mainly to Trinidad and Barbados, where the stones find their way into the tourist market.

CONCLUSION

Guyana is still producing some fine diamonds, and even last year a 12 carat stone was found. But the industry is, without doubt, declining. Young men still leave Georgetown and head for the interior to become 'Diving Pork-knockers'. But with ever increasing opportunities in the capital, the numbers are decreasing every year and it is very rare indeed to see young men opening up a land claim. With decreasing numbers in the mining fields, the bush trader is finding life more difficult. So they too are pulling out. The pork-knocker cannot then obtain provisions easily, so he is reluctant to leave Georgetown. The industry is into a downward spiral. There is however one hope. After one pork-knocker had checked his bottom sieve for diamonds, the author went through the material and found six pieces of deep blue sapphire. When asked about it, the pork-knocker replied that he had seen lots, but nobody was interested in buying, so it was thrown back in the river. Perhaps, soon we will see Guyana sapphires on the market as well as the occasional diamond.

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GEMMOLOGICAL ABSTRACTS

ABEL-RÉMUSAT (M.). *Histoire de la ville de Khotan.* (History of the town of Khotan.) Bulletin of the Friends of Jade, **1**, 1, 1-50, 1980. (In English with French title.)

This is a translation of the first major work in a Western language on the topic of jade and forms the second part of a larger work. The original was published in 1820. Much of the study is taken up with a discussion of what was meant by 'jade' in early times and in this connexion there is a discussion of the use of the word usually romanized as 'yu'—now taken to mean almost any precious object but at one time reserved for jade. M.O'D.

AKIZUKI (M.), SHIMADA (I.). (Texture and minerals in opal from Hôsaka, Fukushima Prefecture, Japan.) J.Geol.Soc. Japan, **74**, 274-9, 9 figs, 1979. (Japanese with English abstract.)

Precious and common opal from the Hôsaka mine were studied optically and by TEM. The precious opal consists of amorphous silica spheres 400-500 Å in diameter. Common opal contains acicular crystals of diameter ~200 Å, but which vary in length from 1000 to 100 000 Å; their electron diffraction pattern shows these to be disordered high tridymite. R.A.H.

BANCROFT (P.). *A great gem and crystal mine: St John's Island, Egypt.* Lapidary Journal, **34**, 10, 2138-46, 12 figs (7 in colour), 1981.

An account of a visit to the Island of St John in the Red Sea, one of the classic peridot locations. No mining takes place there now, but some crystals may be found on the dumps. M.O'D.

BANK (H.). (a) *Geschliffener durchsichtiger roter Klinozoisit aus Arendale, Norwegen.* (Cut transparent red clinozoisite from Arendale, Norway.) Z.Dt.Gemmol.Ges., **29**, 3/4, 186-8, 1980; (b) *Schleifwürdiger manganhaltiger durchscheinender roter Zoisit (Thulit) aus Norwegen.* (Cuttable manganese-containing translucent red zoisite (thulite) from Norway.) Id., 188-189, 1980; (c) *Neues Vorkommen von Euklas in Brasilien.* (New occurrence of euclase in Brazil.) Id., 190, 1 fig. in colour, 1980; (d) *Geschliffener smaragdgrüner Kyanit (=Disthen) aus Tansania.* (Cut emerald-green kyanite (disthene) from Tanzania.) Id., 191-2, 1 fig. in colour, bibl., 1980; (e) *Rosaopal von Idaho (USA).* (Rose-coloured opal from Idaho, U.S.A.) Id., 193, bibl., 1980; (f) *Granate aus Mexiko.* (Garnets from Mexico.) Id., 194-5, 1 fig. in colour, 1980; (g) *Niedriglichtbrechender mit synthetischem Smaragd überzogener Beryll nach Lechleitner.* (Low refractive beryl covered with a synthetic emerald skin according to Lechleitner.) Id., 197, bibl., 1980; (h) *Glas für schwarzen Onyx ausgegeben.* (Glass offered as black onyx.) Id., 200, 1980; (i) *Blaues Glas mit n = 1.615 für blauen Topas angesehen.* (Blue glass with n = 1.615 thought to be blue topaz.) Id., 201, 1980; (j) *Angebliche grünliche Berylle als Quarze identifiziert. Problematik der 'zerstörungsfreien Diagnostik'.* (Green stones apparently beryls, identified as quartz. Problems of the 'non-damaging diagnostic'.) Id., 202, 1980.

(a) The stone is described, RI and double refraction given, as well as density and pleochroism. It is compared with red thulite, epidote and piemontite. (b) RI 1.695-1.701, double refraction 0.006, density 3.09. (c) Up to now euclase found in Ouro Preto and Santana de Encoberto, now also in Diamantina, Minas Gerais. The stones are colourless to pale yellow or pale green and some crystals yield up to 50 ct large stones, if cleavage can be overcome. (d) The green crystal was found to have the following trace elements: Cr, Fe, V, Ti. Density 3.68±0.02. RI: n_x 1.714, n_y 1.725, n_z 1.732. Definite pleochroism. (e) Some time ago a pink opal was offered on the market, but proved to be palygorskite. This material from Idaho is real rose-coloured opal. (f) The garnets were shown to be grossularite, andradite and uvarovite. (g) Report on a lechleitner emerald, which is a colourless beryl under a synthetic emerald skin, with—for hydrothermal products—an exceptionally low RI (1.565-1.569) and very low double refraction (0.004). (h) (i) and (j) In these three articles Dr Bank relates that black onyx imported from the East was found to be glass, blue glass with n = 1.616 was wrongly assumed to be a blue topaz, and some green beryls were identified as quartz. E.S.

BANK (H.) and (M.). (a) *Spezialphänomene bei der Refraktometerablesung von synthetischen Smaragden (nach Lechleitner) mit überzogenen Beryllkernen.* (Special phenomena observed with synthetic emerald-covered beryls, (according to Lechleitner) when reading the refractometer.) Z.Dt.Gemmol.Ges., **29**, 3/4, 198, 1980; (b) *Sehr hoch lichtbrechender mit synthetischem Smaragd nach Lechleitner überzogener Beryllkern.* (Very highly refractive beryl covered with synthetic emerald according to Lechleitner.) Id., 199, 1980.

(a) Lechleitner emeralds were examined and some found with very high RI and double refraction (1.601-1.610; double refraction 0.009; density 2.71) as opposed to the very low values described in the article by H. Bank on Lechleitner emerald abstracted above. (b) The Lechleitner stones were further examined and examples found showing various lines when viewed through the refractometer. When the stones were repolished this phenomenon vanished and reappeared when the stone was re-heated. It seems to be caused by the Cr_2O_3 content and is purely a surface phenomenon. E.S.

BARKER (B.). *Aschentrekker.* Gems & Gemology, **XVI**, 11, 375-8, bibl., 1980.

Old Dutch name for tourmaline given because a crystal could be used to remove the ashes from a long clay tobacco-pipe (which could not be knocked out, for obvious reasons). Pyroelectricity and piezoelectricity are discussed briefly. R.K.M.

BROWN (G.). *How pearls form.* Wahroongai News, 10-14, 2 figs, December 1980.

This account of the pearl oyster in its several species suggests that deposition of 'calcific material' in the form of calcite (prismatic layer) or aragonite (nacreous layer) is controlled by the protein nature of conchyolin, α-conchyolin causing calcite and β-conchyolin giving rise to nacreous aragonite, and also suggests that conchyolin is deposited before the inorganic calcium carbonates, i.e. the latter act as a filler. [It does seem more logical to expect the organic material to be the filler.]

R.K.M.

BROWN (G.). *The genesis of a pearl—an unlikely fairy-tale.* Wahroongai News, 17-20, 3 figs, December 1980.

A further account of pearl formation repeating much of the information, again assuming 'priorly secreted conchyolin'. [The two papers raise interesting and well thought-out theories on a subject which has yet to be fully understood.] R.K.M.

BROWN (G.). *The colour of cultured pearls.* Wahroongai News, 9-12, 5 figs, January 1981.

Colour is due to a combination of orient and of intrinsic colour of the conchyolin structure. The latter may be due to the type of oyster used, e.g. *P. margaritifera,* the black-lipped oyster, which gives black [cultured] pearls. Most [cultured] pearls are produced in *P. martensi* and have a bluish or greenish hue which is bleached out and a more pleasing colour substituted by dyeing. Black is obtained artificially by soaking in silver salt and developing the colour as one would a photographic negative. In all cases the colour is absorbed by the conchyolin layer or by interstitial conchyolin in the surface layers of aragonite. R.K.M.

BROWN (G.), SNOW (J.). *The Regency created emerald.* Wahroongai News, April 1981 (Information Sheet, pp.A-D).

This synthetic emerald* is the old hydrothermal version as developed by Linde Air Products from the work originally done by Lechleitner, the patents having been taken over by Vacuum Ventures Inc. Describes the process of synthesis in some detail. A comprehensive table is included which underlines the differences between natural emerald, hydrothermal synthetic emerald and the more usual flux-grown synthetic emerald. Briefly the important identifying features of these hydrothermal stones are very bright red fluorescence under longwave ultraviolet light and through the Chelsea filter, and 'dagger shaped' inclusions, which are quite unlike those seen in natural stones or in flux-grown synthetics. [Authors have not mentioned the infrared spectrum test which identifies flux-grown stones, but, of course, would not differentiate the hydrothermal material from natural emeralds.] R.K.M.

CASSEDANNE (J. P.) and (J. O.). *A new find of crystallized rose quartz in Minas Gerais.* Mineral. Record, **11**, 6, 377-9, 3 figs, 1980.

Rose quartz has been found at a location known as Laranjeira (or Pegmatito) on the right side of the Jequitinhonha river near the township of Itinga, Minas Gerais, Brazil. The rose quartz forms 'crowns' on rock crystal; some elbaite is also found but only as broken pieces; these are, however, sometimes of gem quality. M.O'D.

CASSEDANNE (J. P.) and (J. O.), SAUER (D. A.). *The Cruzeiro mine, past and present.* Mineral. Record, **11**, 6, 363-70, 9 figs (1 in colour), 1980.

The Cruzeiro mine is north-west of Governador Valadares in the centre of the Brazilian state of Minas Gerais. Tourmaline is found in a pegmatite in the area which was originally worked for mica. M.O'D.

*See M. O'Donoghue, 'Regency Emerald', A New Synthetic from the U.S.A., *J.Gemm.*, 1979, XVI(7), 463-4.—Ed.

CHRONIC (J.). *Diamond-bearing Palaeozoic diatremes in Colorado and Wyoming. In* Epis (R. C.) & Weimer (R. J.), eds, *Studies in Colorado field Geology.* Prof. Contr. Colorado School Mines, **8**, 101-9, 6 figs, 1976.

Diatremes containing fossiliferous limestones of Silurian age, other Early Palaeozoic sedimentary rocks, and kimberlitic materials have been found in the Precambrian granitic core of the Front and Laramie Ranges. The kimberlite has yielded a few diamonds less than 1mm in diameter. Palaeontological and mineralogical studies suggest that the diatremes were emplaced in Devonian time along a N-S trend and that they represent intrusive activity from great depth. R.G.L.

CORNWALL (J. H.). *That's only garnet?* Lapidary Journal, **34**, 10, 2114-63, 43 figs (27 in colour), 1981.

A lengthy review of all the gem varieties of the garnet family and their locations. Inclusions and some crystals are illustrated in colour. M.O'D.

CROWNINGSHIELD (R.). *Developments & highlights at GIA's Lab in New York.* Gems & Gemology, **XVI**, 315-23, 32 figs in colour, (Summer) 1980.

More 'overlayered' orange yellow corundums seen, the coating often partly removed in polishing. One stone gave anomalous RI 1.765-1.800; time factor prevented more exhaustive testing. Several heat-treated sapphires discussed and a synthetic with healed-crack type 'fingerprint' inclusions, which a Bangkok student reports are being induced during heating. Boules reportedly being cut to natural-looking bipyramids, fingerprints induced, and sold as natural rough. Such flaws always reach the surface. A natural star ruby (Burmese) had radically altered in colour when heated to remove silk. Blue 'natural' sapphires seen with surface colour, like the orange ones above, again with some facets having lost their coating in polishing. There is still confused thinking and little factual evidence of the methods and results of heating corundum. The scene needs clarification by actual experiment. Thai heating of geuda sapphire from Sri Lanka is apparently as hit-or-miss as any other. Considerable heat is generated using large steel drums filled with charcoal. Synthetic-backed/natural-topped doublets of ruby and sapphire are again being found. Identification of Chatham and Kashan flux-grown rubies emphasized as difficult but (obviously) important. Not all Kashan synthetic rubies show the normally expected high fluorescence. A natural corundum cabochon, half white and half red with a slight star in the red section, is illustrated. A purplish sapphire with exceptionally coarse silk is also illustrated. More orangy-yellow sapphires; natural Thai stones of this colour show strong iron absorption and no UV fluorescence. The coated stones have no iron absorption but show chromium absorption lines, fingerprint and silk inclusions or angular growth lines. Writer was indecisive in view of many treatments now being carried out on corundums.

An 18 pound crystal of chrysoberyl (not gem quality) and a fine 207 carat yellow apatite cat's-eye are depicted. A pair of black rose diamonds with identical 'iron cross' inclusions and an aquamarine of blue-green colour with strong blue/yellow-green dichroism and both chromium and iron absorption lines are also described, the latter being considered emerald on its chromium absorption, although of unusual colour. [There is a case for an emerald to be so called only when it is of emerald colour and has the required chromium spectrum.]

Reddish potch honey-comb structure, seen in a natural opal, resembled synthetic opal structure. A red cat's-eye chrysoberyl is described as being dark red with no green phase in daylight, hence not alexandrite. [But it has photographed dark green: an example of the delicate balance of colour involved in stone and in colour film?] Dolphin, rabbit and rectangular inclusions in diamond have been found. Finally, a 'malaya' garnet of 18 ct is illustrated. R.K.M.

DEINES (P.). *The carbon isotopic composition of diamonds: relationship to diamond shape, color, occurrence and vapor composition.* Geochim. Cosmochim. Acta, **44**, 943-61, 10 figs, 1980.

Together with published data, 330 new ^{13}C analyses of diamond indicate a range of ~30‰ in the C isotopic composition of diamonds. The frequency distribution of diamond $\delta^{13}C$ analyses show a pronounced mode at −5 to −6‰ (*vs* PDB), a large negative skewness, and a sharp boundary at ~−1‰. Analyses of diamonds from the Premier and Dan Carl mines, South Africa, demonstrate that: (1) difference in ^{13}C that can be related to diamond colour and shape are <1‰; (2) the mean ^{13}C content of kimberlite carbonates is 1-2‰ lower than that of associated diamonds; (3) significant differences in ^{13}C content exist between the mean isotopic compositions of diamonds from these two pipes; (4) the variability of $\delta^{13}C$ differs from one mine to another. Computations were carried out evaluating the effect on the ^{13}C content of diamonds of: (i) various precipitation processes; (ii) abundance of species H_2, H_2O, CH_4, CO, CO_2, and O in the vapour; (iii) the initial isotopic composition of the source C; (iv) effects of *P* and *T* on C isotopic composition; and (v) reservoir effects (Rayleigh fractionation). The presence of methane during diamond formation is compatible with the C isotopic composition data, possible fO_2 in the mantle, and with the composition of gases liberated from diamonds. C isotope effects in the diamond formation process were probably small, and the very large range in $\delta^{13}C$ observed was most likely inherited from the source C. C.M.B.H.

FU (H.), ZHU (C.). (Morphological peculiarities of synthetic diamond and a preliminary discussion of its fine crystal growth field.) Geochimica, 23-30, 5 figs 1 pl., 1980. (Chinese with English abstract.)

The crystal habit and morphological peculiarities of synthetic diamond have been studied at various *T* and *P*. A model is presented of the optimum *P-T* conditions for fine diamond synthesis. P.Br.

GILL (J. O.). *Where have all our answers gone?...or...let me introduce you to Gill's Index.* Gems & Gemology, **XVI**, 11, 366-8, 1980.

An author in praise of his own work, which was reviewed before in this journal (Gems Gemol., 1979, XVI (6), 190). The 'Index' is restricted to English language publications. R.K.M.

GREEN (H. S.), SMITH (A. H. V.), YOUNG (B. R.), HARRISON (R. K.). *The Caergwrle Bowl: its composition, geological source and archaeological significance.* Rept Inst. Geol. Sci., **80/1**, 26-30, 1 fig, 1 pl., 1980.

This decorated boat-shaped object of possible Bronze Age date was discovered in 1823 near Caergwrle Castle, Powys. It is composed of gel-like kerogen-rich material resembling Kimmeridge oil shale, giving an XRD pattern with lines of

goethite, quartz, mica, and possibly siderite and lepidocrocite. Its decorative elements were made partly by incision on gold leaf and partly by wrapping gold leaf around a white substance identified now as a mixture of romarchite (SnO) and cassiterite (SnO_2), presumably originally metallic tin. R.A.H.

GÜBELIN (E. J.). *Le diamant et ses imitations.* (Diamond and its imitations.) Schweizerische Uhrmacher und Goldschmiede Zeitung, **103**, 2, 12-17, 28 figs (24 in colour), 1981.

Illustrations of inclusions and reviews of other tests are given to indicate the differences between diamond and its imitations. M.O'D.

GÜBELIN (E.). *Seberged—Die Peridot-Insel im Roten Meer.* (Zeberged—the peridot island in the Red Sea.) Lapis, **5**, 11, 19-26, 14 figs in colour, 1980.

The Island of Zeberged (or St John) is described with particular reference to the deposits of gem-quality peridot found there. Numerous references to historical reports of the stone are given, in addition to geological and mineralogical data. M.O'D.

GÜBELIN (E.), SCHMETZER (K.). *Alexandritartige Edelsteine.* (Alexandrite-like gemstones.) Z.Dt.Gemmol.Ges., **29**, 3/4, 126-34, 2 diagrams, bibl., 1980.

The name alexandrite-effect is given to the colour change of certain minerals which are blue, blue-green to violet during daylight and red to red-violet under artificial light. This effect was discovered during the last century in chrome-containing chrysoberyls from the Urals; lately it has been observed in certain varieties of garnet, corundum, spinel and fluorite. The absorption spectrum of all alexandrite-like minerals is characterized by lines in the blue-green and red zones of the visible spectrum as well as some lines in the yellow. The colour of such stones is determined by the transmission of the violet and blue-green of the daylight and under candle light or the light of a red-rich light bulb by the relation of the transmission in the red to the transmission in the blue-violet. E.S.

HAACK (E. M.). *Collecting gems and minerals in South Africa.* Lapidary Journal, **34**, 9, 1936-47, 12 figs in colour, 1980.

The author gives an account of a tour to the Republic of South Africa and Namibia. The tour appears to have been devoted as much to places of interest as to serious collecting. M.O'D.

KAMINSKIY (F. V.), GALIMOV (E. M.), IVANOVSKAYA (I. N.), KIRIKILITSA (S. I.), POLKANOV (Yu. A.). *Isotopic distribution in carbon of small diamonds from the Ukraine.* Dokl. Acad. Sci. USSR, Earth Sci. Sect., **236**, 174-5, 1977. Transl. from Dokl. Akad. Nauk SSSR, **236**, 1207-8, 1977.

Comparative analysis of geological information on small diamonds from sandy sediments in the Ukraine led to the conclusion that they were polygenetic, but probably not derived from kimberlites. Several varieties of small diamonds from the Dnieper region were selected for comparative study: (1) amorphous colourless chips probably kimberlite-derived; (2) and (3) yellow and black cubes of kimberlite and/or

meteorite origins; and (4), (5) and (6) violet cubes and 'shaly' yellow and black grains of probable non-kimberlitic origins. The heavy carbon isotopic distribution in the diamonds and associated graphite were analysed. The data indicate the isotopic distribution in all varieties of small diamonds from Ukrainian placers differs clearly from kimberlite diamonds and shows that they were probably formed by shock metamorphism. V.S.G.

KANDA (H.), YAMAOKA (S.), SETAKA (N.), KOMATSU (H.). *Etching of diamond octahedrons by high pressure water.* J. Crystal Growth, **38**, 1-7, 9 figs, 1977.

A natural diamond octahedron was etched using water at 1100 °C to 1500 °C and 50 kbar for 5-30 min. The etch figures were almost the same as the trigons seen on natural diamonds. P.H.

KANE (R. E.). *The elusive nature of graining in gem quality diamonds.* Gems & Gemology, **XVI**, 10, 294-314, 75 figs (70 in colour), (Summer) 1980.

A very full account of visible grain in faceted diamonds, extensively illustrated. This can be surface or internal and is often elusive—coloured in some instances, with changes of colour with slight alteration of viewing angles. Author suggests connexion between graining and glide planes, both being in some way caused by patches of strain present in almost all diamonds, which also cause anomalous birefringence which may be seen between crossed polars.

[An important paper which would be improved if the sequence of the figures followed that of their mention in the text. It serves to underline the very considerable work load in the G.I.A.'s diamond-grading laboratories.] R.K.M.

KANE (R. E.). *Developments & highlights at GIA's Lab in Los Angeles.* Gems & Gemology, **XVI**, 12, 391-400, 32 figs (30 in colour), 1980.

Natural emeralds reported with 4270 Å absorption spectrum line, normally seen only in iron-rich Gilson type III synthetics. The natural stones exhibit this more faintly and have RI above 1.583, higher than the synthetics. A natural grey fancy diamond had a narrow absorption line at 5510 Å, fluorescing strong blue with yellow zones in long UV light. A mobile gas bubble was found in an emerald. Such bubbles are normally held in one position, restricted by the very flat inclusion typical of emerald. The present negative crystal was not flat and the bubble was therefore able to move. A negative crystal in corundum is demonstrated to have a mobile bubble of CO_2 and a loose crystal of haematite. Several epigenetic inclusions in diamond are illustrated and explained, also cloud-like formations in various well-known configurations, maltese cross, octahedron, etc. A fine tricolour tourmaline is illustrated. R.K.M.

KAPLAN (G. R.). *A new view of diamond's beauty—the 'cone of brilliance'.* Gems & Gemology, **XVI**, 10, 324-5, 4 figs (3 in colour), (Summer) 1980.

Brilliance and 'fire' of two diamonds at different viewing angles are compared, one with a 55% table and the other with a 65% table [viz. % of girdle diameter]. The first gave a 36° cone of brilliance while the other, with a wider table, gave only a 20° cone. R.K.M.

KIRK (P. D.). *Cutting and polishing 'Victoria Stone'.* Lapidary Journal, **34,** 9, 1978-9, 2 figs, 1980.

'Victoria Stone' [composition close to glass] can be fashioned into a wide variety of shapes. The colour varies within each specimen, and care is needed when slabbing begins since after removal of a 'rind' the stones may need to lose stress.

M.O'D.

KNISCHKA (P. O.), GÜBELIN (E.). *Synthetische Rubine mit Edelstein-qualität, isometrischem Habitus und hoher Zahl unbeschädigter Kristallflächen.* (Synthetic rubies of gem quality with isometric habit and large number of undamaged crystal faces.) Z.Dt.Gemmol.Ges., **29,** 3/4, 155-85, 50 figs (16 in colour), bibl., 1980.

These rubies are produced by P. O. Knischka and the method of production is not explained. They are termed Ꝁ rubies, [the sign being a reversed P and K (for P. Knischka)]. They are grown by methods which are characterized by resulting in a large number of growth faces. By modifying the parameter the number of the faces can be influenced. The synthetic rubies can be single crystals, twins, triplets and other multiple crystals and also cluster formations. They are compared with Verneuil and natural rubies. The new Ꝁ synthetic rubies need careful examination: they are slightly violet; absorption similar to natural rubies; strong dichroism (similar to the natural product); density 3.976 ± 0.001, although a cluster showed only 3.941 ± 0.001, RI n_ϵ 1.760-1.761, n_ω 1.768-1.769, $n_\epsilon - n_\omega = -0.008$. Only by microscopic examination can one really distinguish this product. The article is well illustrated to explain difficulties.

E.S.

KOIVULA (J. I.). *Brief notes on Chatham flux sapphires.* Gems & Gemology, **XVI,** 12, 410-11, 5 figs in colour, 1980.

Faceted flux synthetic sapphires recently examined were of much better quality than earlier products. Platinum flakes and splinters were present with some residual flux. Fingerprint inclusions, curved, cloud and veil-like were also observed. Colour zoning in straight layers was seen in two stones. X-ray fluorescence ranged from white to bluish to yellowish white, no phosphorescence. [Author does not mention whether x-rays produced any normally expected temporary yellowing of the colour.] Fluorescence under long and short-wave UV produced whitish-yellow and brownish colours respectively, with two stones having patches of bright yellow.

R.K.M.

KOIVULA (J. I.). *Carbon dioxide as a fluid inclusion.* Gems & Gemology, **XVI,** 12, 386-90, 7 figs in colour, bibl., 1980.

CO_2 in liquid form is the second most common liquid inclusion in minerals, the first being water. Either may contain contaminants. They are immiscible. Discovered by Sir David Brewster, the nature of the inclusion was long a mystery. At a critical temperature of about 31.2 °C the liquid becomes a gas and fills the whole inclusion, the former bubble effect becoming invisible. Hollow inclusions contain CO_2 under very considerable pressure even at room temperature. Heating in colour treatment or in repair work may cause the stone to crack or to shatter explosively.

R.K.M.

KOIVULA (J. I.). *Citrine-amethyst quartz—a gemologically new material.* Gems & Gemology, **XVI,** 10, 290-3, 8 figs in colour, (Summer) 1980.

This form of Brazil twin, with its alternate triangular segments of amethyst and colourless quartz in the prism section, has been known for upwards of two hundred years and is now found in gem quality with citrine and amethyst alternating. Brazilian in origin, it gives cut stones of pleasing, if confused, appearance. Nassau attributes colour in citrine to Fe^{+3} placed in a particular position in the lattice where irradiation, artificial or natural, will change the colour to amethyst. Experiment suggests that the positive rhombohedra attract iron more readily and, with more iron present, this form is more likely to irradiate to amethyst. [This infers that the phenomenon could occur in untwinned quartz, but all such stones are alternations of right- and left-handed quartz in the form of interpenetrant twins, and the explanation may be an over-simplification.] Interesting uniaxial interference figures, showing three different versions in the one stone, are illustrated. R.K.M.

KOIVULA (J. I.). *More news on citrine-amethyst quartz.* Gems & Gemology, XVI, 12, 409, 1980.

Kurt Nassau, Ph.D., has produced amethyst-citrine twinned intergrowth from amethyst-colourless material by radiation. Further and larger sources of material are being investigated. R.K.M.

KOIVULA (J. I.). (a) *Diopside as an inclusion in peridot.* (b) *Negative crystals ? in synthetic Verneuil spinel.* Gems & Gemology, **XVI,** 10, 332-3, 3 figs (2 in colour), (Summer) 1980.

Very short accounts of diopside crystal inclusions in Arizona peridot and of a cubo-octahedral negative inclusion (bubble) in blue synthetic spinel. R.K.M.

K[OIVULA] (J. I.). *Gübelin identifies apatite in taaffeite.* Gems & Gemology, **XVI,** 12, 409, 1 fig. in colour, 1980.

A photograph of this euhedral inclusion is published. [No indication of magnification.] R.K.M.

KOIVULA (J. I.). *Inclusions in andalusite—a comparison of localities.* Gems & Gemology, **XVI,** 12, 401-4, 8 figs in colour, bibl., 1980.

Identifies inclusions of limonite, apatite, quartz, rutile, biotite and andalusite in andalusite from various localities. Rutile and apatite are typical of Brazilian material, while quartz and limonite are found in stones from Sri Lanka. R.K.M.

KOIVULA (J. I.). *Observations on an imperfect (?) diamond.* Gems & Gemology, XVI, 12, 410, 1 fig. in colour, 1980.

A large brilliant diamond, which had to be graded I_1 for clarity, contained an exceptionally perfect octahedral cloud inclusion. Author considers that the natural perfection here should receive some recognition in the grading system. R.K.M.

KOIVULA (J. I.). *'Thin films'—elusive beauty in the world of inclusions.* Gems & Gemology, **XVI,** 10, 326-30, 14 figs (13 in colour), (Summer) 1980.

A clear explanation of the optics thought to be involved in iridescence at thin films (Newton's rings) seen in gems with ultra thin cracks or inclusions in overhead

lighting. [Succeeds in making possibly reject stones interesting and beautiful when lighting is right.] R.K.M.

KOIVULA (J. I.). *The three-phase inclusion—a product of environment.* Gems & Gemology, **XVI**, 11, 338-42, 15 figs, bibl., 1980.

Three-phase inclusions prove natural emerald. They are the product of a natural hydrothermal or pegmatitic growth environment. Hot liquid holds salts to saturation. Emprisoned in a closed cavity, this cools and salts crystallize out; the liquid contracts, leaving gas or vapour bubble—a three-phase inclusion, solid, liquid and gas. Fluorite, quartz, pink beryl, topaz, spodumene, tourmaline, spessartine garnet, blue sapphire and others are illustrated, the solids ranging from rock salt to haematite. All prove natural origin. R.K.M.

KUZVART (M.). *Industrial minerals and rocks in Czechoslovakia.* Industrial Minerals, 162, 19-35, 4 figs, 1981.

Pyrope is recovered from the Quaternary alluvia on the southern slopes of the Caské Středohoří mountains near Třebívlice. Precious opal was worked up to the present century from andesite of the Dubník deposit near Prešov. M.O'D.

KVASNITSA (V. N.), KHAR'KIV (A. D.), VISHNEVSKY (A. A.), AFANAS'EV (V. P.), ARGUNOV (K. P.). (Small diamonds (sparklers) from kimberlites and placers.) Min. Zhurn, **2**, 3, 40-52, 8 figs, 1980. (In Russian.)

A description is given of the crystallography of plane-face, plane-face—curved-face, and curved-face small diamonds from kimberlites (Yakutia), eclogite xenoliths (Yakutia), and placers (Ukraine and Yakutia). The small diamonds from these sources are found to have impurity centres of a nitrogenous nature, which is normal for diamonds from kimberlites and eclogite xenoliths. D.A.B.

LANG (A. R.). *Defects in natural diamonds: recent observations by new methods.* J. Crystal Growth, **42**, 625-31, 7 figs, 1977.

Impurity platelets precipitated on {100} planes and dislocations have been observed using TEM and various topographical methods (ultraviolet absorption, x-ray, cathodoluminescence). The available evidence supports the hypothesis that the impurity platelets are composed of nitrogen rather than of interstitial carbon. P.H.

LEITHNER (H.). *Die Topase der sächsischen Könige.* (Topaz from the Kingdom of Saxony.) Lapis, **5**, 12, 9-12, 8 figs (3 in colour) 1980.

Topaz from sites in Saxony is described; Schneckenstein is one of the best-known of these and some representative crystals are illustrated. M.O'D.

LESH (C.). *Gemlure: born in the depths: the perfect pearl.* Gems & Gemology, **XVI**, 11, 356-65, bibl., 1980.

An account of the myth, history, legend and poesy of the pearl. Gives needless publicity to some outrageous and nonsensical beliefs but confirms the expected fact that pearl is among the earliest of gems known to man. [The last sentence—'A woman clasps a strand of pearls around her neck...and Aphrodite weaves her magic once again.'—is a fair indication of the gemmological content.] R.K.M.

LESH (C.). *Remodelling the ivory tower.* Gems & Gemology, **XVI,** 11, 370-2, 1980.

Conservation of elephants (and whales) restricts ivory imports. Author suggests alternative materials, bone, deer antlers, antique sources (imported before the ban), plastics, plaster of Paris and vegetable ivory (described as 'unexpected'). R.K.M.

McCAWLEY (E. L.). *Cubic moissanite, a gem material of the diamond family.* Lapidary Journal, **34,** 10, 2244-7, 1981.

Artificial cubic moissanite, SiC, has a hardness of 9½, specific gravity of 3.218, RI 2.651 and dispersion 0.044. Crystals are grown from materials heated in electric furnaces. Colours can be made and it is expected that these will reach the gem market in due course. M.O'D.

McCOLL (D. H.), WARREN (R. G.). *First discovery of ruby in Australia.* Mineral. Record, **11,** 6, 371-5, 6 figs (2 in colour), 1980.

Ruby has been found in an amphibolitic complex formed on a limestone in the Harts Range of the Northern Territory. Crystals are found as well-formed tabular hexagons, the best colour being shown by the smaller pieces. RI is 1.760-1.768 and SG 3.98, this rather low figure being due, possibly, to the presence of gas-filled fissures. A notable iron content darkens the colour and weakens the luminescence. So far only cabochon grade has been found. M.O'D.

MALKIN (S. A.). *Gemology as a profitable sales tool.* Gems & Gemology, **XVI,** 11, 372-4, 1980.

Discusses introducing gemmology in sales patter. R.K.M.

MILEY (F.). *An examination of red beryl.* Gems & Gemology, **XVI,** 12, 405-8, 2 figs in colour, bibl., 1980.

Specimens were examined from the Wah-Wah and Thomas Mountains, Utah, and the Black Range, New Mexico. RIs of 1.561-1.569 obtained were at variance with the G.I.A. Gem Identification Course figures of 1.585-1.594 [which surely are those for morganite?]. The SG was also lower than the quoted value. Largest stones are still from the Wah-Wah Mountains of Utah. Stones heavily included with healed cracks. [Again this rather insignificant and scarcely gem-quality red beryl is given publicity which it scarcely warrants.] R.K.M.

MORENO GOMEZ (J.). *La reflectividad, nuevo concepto en la identificación de piedras preciosas.* (Reflectivity, a new concept in gemstone identification.) Boletín del Instituto Gemológico Español, **20,** 42-6, 1 fig., 1980.

The principles behind the use of reflectivity meters are discussed. M.O'D.

MRÁZEK (I.). *Gemstones found in the Jabal al Hasáwnah and Jabal as Sawdá' mountains, Libya.* Z.Dt.Gemmol.Ges., **29,** 3/4, 135-48, 18 figs, 1980.

Geological and mineralogical conditions of gemstone occurrences in the region of the Jabal al Hasáwnah and Jabal as Sawdá' mountains, Libya, are described. Technological properties of the raw materials and possibilities of their utilization are given. Cherts and silicates represent raw material of good quality suitable for use. Olivines were not found to be suitable for cutting because of intensive joining of

grains. Quartz geodes containing chalcedony or agate, quartz or rock crystal are good collectors' pieces. Libyan chalcedony was used for cabochons and slabs, specially those showing pleasant colour shades and delicate striping. E.S.

MÜLLENMEISTER (H. J.). *Neue Chrysoberyll-Varietät entdeckt.* (New chrysoberyl variety discovered.) Z.Dt.Gemmol.Ges., **29**, 3/4, 196, 1980.

The stone weighed 2.13 ct, with RI n_x 1.740, n_z 1.750, n_y 1.745, and double refraction 0.010. X-ray examination confirmed suspicion that it was white chrysoberyl, source Sri Lanka. According to an editorial note it is not sure whether the stone is natural or synthetic. E.S.

NASSAU (K.). *Irradiation-induced colours in gemstones.* Gems & Gemology, **XVI**, 11, 343-55, 5 figs, 2 tables, 1980.

A summary of irradiation sources; stability of colour centres to light or heat; and identification of irradiation in stones other than diamond. Visible light, UV, x-rays, gamma rays, electrons, protons and neutrons will each change colour in certain gemstones.

Dr Nassau explains the effects of various radiations on colour centres and makes the point that some fading in very brilliant light can be due to heat rather than light. Materials are listed under I. Colour centres with shallow energy traps, producing phosphorescence and fluorescence; II. Colour centres with medium energy traps in which colour is bleached by light or heat over a variable period of time; III. Colour centres with deep energy traps in which change is permanent at room temperatures, but bleached by heating; IV. Irradiation effects which do not involve colour centres.

[Author shows an enviable understanding of his subject and an equal ability to explain it clearly.] R.K.M.

NASSAU (K.). *The optical constants of GGG.* Gems & Gemology, **XVI**, 11, 370, 1980.

Gadolinium gallium garnet RI, measured by Dr D. L. Wood, is established at 1.970 with dispersion 0.045, with slight variations with composition. [This is the paper previously published in *J. Gemm.*, 1980, XVII (3), 148.] R.K.M.

NASSAU (K.). *Synthetic emerald: the confusing history and the current technologies.* J.Crystal Growth, **35**, 211-22, 8 figs, 1976.

A critical review of methods used at present and in the past to produce emerald of gem quality. P.H.

O'DONOGHUE (M.). *Cameos.* Gems, **12**, 5, 35-8, 3 figs, 1980.

A short history of the cameo with notes on the substances used and the methods of fashioning adopted. (Author's abstract.) M.O'D.

O'DONOGHUE (M.). *Characterization of crystals with gem application.* Progress in Crystal Growth and Characterization, **3**, 2/3, 193-209, 10 figs, 1981.

This paper reviews a number of man-made crystals and describes their internal characteristics. Substances are arranged under method of growth with a separate section on the simulants of diamond. Line drawings illustrate various points.

(Author's abstract.) M.O'D.

O'DONOGHUE (M.). *Coral.* Gems, **12,** 6, 8-9, 3 figs, 1980.

Gives a short résumé of the formation, properties and uses of coral with illustrations from recent sales. (Author's abstract.) M.O'D.

O'DONOGHUE (M.). *Gemmology in Paris.* Gems, **12,** 4, 22-3, 1980.

An account of a visit by the author to a number of Parisian establishments, including the Gem Testing Laboratory and the Museum of the École des Mines.

(Author's abstract.) M.O'D.

O'DONOGHUE (M.). *Great mineral locations: East Africa.* Gems, **12,** 2, 27-8, 1 fig. in colour, 1980.

East Africa has come into prominence as a gem producing area in the past few years. A number of species are reviewed including the various colours of zoisite.

(Author's abstract.) M.O'D.

O'DONOGHUE (M.). *Great mineral locations: Mogok, Burma.* Gems, **12,** 1, 17-18, 1 fig. in colour, 1980.

A brief description of the Mogok stone tract is given with notes on the gem species found there. Diamond is one of the more unusual minerals quoted.

(Author's abstract.) M.O'D

O'DONOGHUE (M.). *Great mineral locations: The Thomas Range, Utah.* Gems, **12,** 6, 32-3, 1 fig in colour, 1980.

The Thomas Range is celebrated for topaz and the manganese-bearing red beryl. (Author's abstract.) M.O'D.

O'DONOGHUE (M.). *The literature of gemmology.* Gems, **12,** 5, 20-1; **12,** 6, 30-1; 2 figs in colour, 1980.

Basic gemmological texts are reviewed, including monographs and journals.

(Author's abstract.) M.O'D.

O'DONOGHUE (M.). *Poland as a mineral and gem locality.* Pt. 1. Gems, **13,** 1, 8-9, 1981.

Introduces the gem and mineral potential of Poland with special reference to the Krakow region. (Author's abstract.) M.O'D.

PLOTNIKOVA (S. P.), KLYUEV (Yu. A.), PARFIANOVICH (I. A.). (Longwave photoluminescence of naturally-occurring diamonds.) Min. Zhurn., **2,** 4, 75-80, 6 figs, 1980. (In Russian.)

The long-wave photoluminescence (PhL) of natural diamonds was studied in the 550-850 nm range. The properties of PhL systems with 578, 603.8, 700, 788 and 793 nm loading lines are described. The 603.8, 700 and 788 nm systems are shown to be characteristic of diamonds with mixed cube-octahedral growth, with increased content of nitrogen A-centres. The 793 nm system is related to known S2 and S3 PhL centres. Natural plastically-deformed diamonds of brownish colour are found to have a broad structureless PhL band with a maximum at 730 nm. A similar band, but with a structure, has been found in diamonds of crater origin and in a

polycrystalline variety from the Yakutian placers. The structure against the background of the broad band is considered to result from the presence of lonsdaleite. D.A.B.

PREST (Michael). *De Beer's diamond search.* The Times newspaper, No. 60,915, p.26, 30th April, 1981.

De Beer's production in 1980 was 14.7m carats, 4.51m being from Kimberley Division, 1.43m from Namaqualand Division, 2.04m from the Premier Mine, 1.56m from Consolidated Diamond Mines (Namibia), and over 5m from Orapa and Letlhakane (Botswana). The Jwaneng pipes (southern Botswana) could be bigger than previously supposed and on present plans will treat 4.8 tonnes of material a year: the proportion of gemstones is high, but size and quality appear at present not to match the best from other mines. J.R.H.C.

READ (P.). *Better reflectivity meters.* Retail Jeweller, **20**, 479, 6, 2 figs, 5th February 1981.

Describes the new Gemlusta 400X which has an expanded sensitivity over the previous model and is claimed to differentiate between polished natural and synthetic corundum. Different polishing procedures are thought to account for this discriminatory factor; the natural stones, having the better polish, give the higher readings (but there is slight overlap possibly due to some natural stones being polished with diamond dust today). Similar discrimination is claimed between natural and synthetic emerald possibly due to lower RI of the synthetic. Other reflectivity meters were then found to give similar discriminatory readings. The Japanese Diamond Checker uses a pulsed infrared lamp and detector and its readings are unaffected by high ambient light. Both meters are expensive. R.K.M.

READ (P. G.). *Separating diamond from its simulants by thermal conductivity.* Industr. Diamond Rev., 288-9, 4 figs, 1980.

At room temperatures, the thermal conductivity of diamond single-crystal ranges from 10 (Type I) to 26 $Wcm^{-1}\ °C^{-1}$ (Type IIa), whereas cubic ZrO_2 has a very low value (0.1) and of other simulants corundum has the highest value (~0.4). Brief notes are given on three instruments using thermal conductivity to distinguish diamonds: the Ceres diamond probe, the 'Dipro' tester, and the 'Rayner Diamond Tester'. This type of instrument can be used on stones which are recessed in their mounts. R.A.H..

ROTHSTEIN (J.). *Stilbite, stevensite, arandisite, touchonite (four unusual gems) and some ideas on gem nomenclature.* Lapidary Journal, **34**, 9, 2042-54, 1980.

Interesting account of the materials cited with notes on how they were first encountered. The author describes the occasional confusion over nomenclature arising when new materials are introduced. M.O'D.

SARMIENTO CARPINTERO (L.). *Imitaciónes de diamante.* (Imitations of diamond.) Boletín del Instituto Gemológico Español, **20**, 11-35, 15 figs in colour, 1980.

A general overview of the various materials which have been used to imitate diamond. M.O'D.

SAVKEVICH (S. S.). *Physical methods used to determine the geological origin of amber and other fossil resins; some critical remarks.* Physics and Chemistry of Minerals, **7**, 1, 1-4, 2 figs, 1981.

Succinite has been identified by infrared and mass spectrometry though thin-layer chromatography and emission spectrometry did not yield significant results. Succinite may be located in the area comprising the Black Sea, Carpathian Mountains, South Baltic, Sweden, Denmark and Great Britain. M.O'D.

SCHMETZER (K.), BANK (H.). *Smaragde aus Sambia mit ungewöhnlichem Pleochroismus.* (Emeralds from Zambia with unusual pleochroism.) Z.Dt.Gemmol.Ges., **29**, 3/4, 149-51, 1 diagram, bibl., 1980.

The colour of the Zambian emeralds can be comparable to stones from Sandawana, Zimbabwe or even Muzo. Lately some stones have come on to the market which show a blue-green colour with a blue/yellow green pleochroism never before seen in emeralds. These emeralds were examined, and it was found that they combine an emerald and an aquamarine component in the same stone. E.S.

SCHMETZER (K.), BANK (H.). *Eine Untersuchung der Türkissynthese und Türkisimitation von Gilson.* (An examination of the synthetic and imitation turquoise of Gilson.) Z.Dt.Gemmol.Ges., **29**, 3/4, 152-4, 2 tables, bibl., 1980.

The synthetic turquoise produced by Gilson contained one or several crystalline phases. The name 'synthetic turquoise' does not correspond to the composition of the material. The turquoise imitation of Gilson consists mainly of calcite. E.S.

SCHULTZ (Paul R.). *Colorado lapis lazuli from the Blue Wrinkle Mine in Gunniston County.* Lapidary Reporter, 255, 8/10, 2 figs, 1st February, 1981.

A further report (see Truebe, H. A., *Lapis lazuli in the Italian Mountain area of Colorado,* abstracted in J.Gemm., 1978, XVI (1), 56) on the Blue Wrinkle claims, worked since 1939 but sold in 1979, and stated now to be producing lapis in sizable quantity and good quality, varying in colour from azure blue to royal blue to a deep purple blue, with pyrite ranging from large to exceedingly fine in all shades (but exceedingly fine mostly in the deep purple blue). Mining (at present by stripping off the over-burden) may change in the next few years to an underground operation. Weather limits operations to three or four months a year. J.R.H.C.

STONE (J.). *Australia likely to be major supplier of jade.* Gems & Gemology, **XVI**, 10, 331, (Summer) 1980.

An Australian publicity report on nephrite workings on Eyre Peninsula, S. Australia, with estimated reserves of 49 000 tonnes. R.K.M.

SUPERCHI (M.). *La gemmologia come scienze accademica a sè stante, non una parte della mineralogia: principi generali e concetti.* (Gemmology as an academic science on its own, not a part of mineralogy: general principles and concepts). Rend. Soc. Italiana Min. Petr., **35**, 199-215, 2 figs, 1979.

A general index of a gemmological compendium is considered, divided in three parts: general principles, descriptive theoretical part, and a practical part. Facsimiles for the arrangement and listing of samples are given. A scientific expression of colour or chromaticity is recommended. F.B.

TISDALL (F. S. H.). *Reminiscences.* Gems, **12,** 5, 6-7, 1 fig., 1980.

The writer tells of some of his experiences during a lifetime spent with gemstones. M.O'D.

VACEK (J.). *Blueberries! In Arizona?* Lapidary Journal, **34,** 9, 1942-4, 10 figs in colour, 1980.

The blueberries referred to are in fact nodules containing crystals of azurite found at the Blueball Mine on the northern slopes of the Pinal Mountains in Arizona. Malachite crystals are also found. M.O'D.

VOGT (H.-H.). *Nachbildung oder Fälschung?* (Imitation or false?) Mineralien Magazin, **1,** 34-9, 6 figs (2 in colour), 1981.

A brief summary of the methods used to manufacture gem materials. M.O'D

WALTERS (D.). *Polishing agates 150 years ago.* Gems, **12,** 5, 8-9, 1 fig., 1980.

The traditional method of agate polishing with water as the source of power has changed little from early times, except for the use of electric motors. M.O'D.

WÜTHRICH (A.), WEIBEL (M.). *Optical theory of asterism.* Physics and Chemistry of Minerals, **7,** 1, 53-4, 2 figs, 1981.

The scattering of light by thin cylinders and refraction by curved surfaces are the two processes involved in the observation of asterism. A star can be obtained from a stone with a plane surface. M.O'D.

YADA (K.), TANJI (T.), SUNAGAWA (I.). *Application of lattice imagery to radiation damage investigation in natural zircon.* Physics and Chemistry of Minerals, **7,** 1, 47-52, 11 figs, 1981.

High, low and intermediate zircons were examined with a 1000kV high resolution electron microscope. Lattice images thus obtained were in accordance with existing theories of the metamorphism of zircon. M.O'D.

YAMAOKA (S.), KOMATSU (H.), KANDA (H.), SETAKA (N.). *Growth of diamond with rhombic dodecahedral faces.* J. Crystal Growth, **37,** 349-52, 7 figs, 1977.

Diamonds with {110} habit were synthesized using Ni, Co, or Ni-Cr alloy as a catalyst metal. The {110} faces were flat and smooth while small adjacent {111} faces showed no trace of dissolution, so {110} is considered to be formed by growth. The *P-T* conditions where {110} occurs are restricted to a narrow region adjacent to the graphite-diamond equilibrium line. P.H.

YU (R. M.), HEALEY (D.), WING (Y.). *The jade trade in Hong Kong.* Lapidary Journal, **34,** 10, 2256-64, 13 figs, 1981.

An interesting account of the methods, largely traditional, of selling rough jade in Hong Kong. M.O'D.

YUSHKIN (N. P.), SERGEYEVA (N. Ye.). *Textures of amber from the Yugorskiy Peninsula.* Dokl. Acad. Sci. USSR, Earth Sci. Sect., **216,** 151-3, 1 fig., 1974. Transl. Dokl. Akad. Nauk SSSR, **216,** 637-40, 1974.

Internal structures of both brittle and viscous ambers from a deposit at the Preschanaya River, Yugorskiy Peninsula, were studied in detail by thin section,

scanning, and transmission microscopy. Three types were distinguished from Cretaceous age resins that were redeposited in a metre thick bed, yielding 2 kg/m^3 of amber, in Pleistocene sand and gravel. Conclusions from the work show: (1) the various types differ substantially in quantity, distribution and shape of pores, (2) the size of pores decreases from transparent to osseous varieties, but their quantity increases, (3) the largest pores originated in early stages from addition of plant sap to oleoresin; the various generations of micropores are products of periodic evaporation of volatile components of oleoresin after its secretion: and pores were redistributed and deformed during plastic flow and contracted upon oxidation of the amber. W.J.F.

ZAPATERO (L.), BARBOSA (J. E.). *Dumortierita transparente en Minas Gerais, Brasil.* (Transparent dumortierite from Minas Gerais, Brazil.) Boletín del Instituto Gemológico Español, **20**, 37-9, 3 figs in colour, 1980.

A transparent variety of dumortierite from Minas Gerais is described. The hardness is given as 7½-8, gravity specific gravity as 3.35 and refractive index 1.668-1.688 with a birefringence of 0.020. The colour is bluish-green. No absorption spectrum was detected; some of the crystals showed fibrous inclusions. M.O'D.

ZHIKHAREVA (V. P.), SHTURMAN (V. L.), KULAKOVA (I. I.), RUDENKO (A. P.). (The morphology of catalytically-etched natural diamonds.) Min. Zhurn, **2**, 4, 80-3, 2 figs, 1980. (In Russian.)

Etching of plane-faced octahedral and curvifaced rhombdodecahedral diamonds with water vapour shows that the patterns obtained are morphologically and geometrically identical to those in rare natural crystals and are crystallographically different from the etch-pattern obtained in oxygen-rich media. D.A.B.

Australian opal standard proposed. Wahroongai News, 5-7, January 1981.

A reprint of a Public and Consumer Affairs proposal to standardize opal classification. The suggestion seems to be to classify on a basis of—A. All natural opal, cut or uncut; A1. Natural opal laminated to natural materials as doublets or triplets; A2. Natural opal laminated to other than naturally occurring materials; B. Naturally occurring matrix opal; B1. Matrix opal which has been treated [stained?]; Synthetic opal; Imitation opal. [It is not clear whether the proposal is to sell opal as 'A1 opal' without further description, or other such coded descriptions. If so then they are not solving the problem, only compounding it.] R.K.M.

Diamond Exploration Hopes in Ontario. The Times newspaper, No. 60,853, p.18, 16th February, 1981.

Further tests will be needed to determine whether any of the pipes near Hearst, Ontario, contain diamonds and, if so, whether a commercial deposit exists. J.R.H.C.

Interview: Allan Caplan. Mineral. Record, **11**, 6, 351-60, 14 figs (6 in colour), 1980.

Allan Caplan has prospected for gem and good quality mineral specimens in Brazil for many years. He describes how a number of important purchases were made, with particular reference to topaz crystals. M.O'D.

Utah red beryl available at Tucson. Lapidary Reporter, 253, 34, 1 fig., 1st December 1980.

Ruby-red beryl, found along narrow seams in rhyolite quartz matrix in the Wah Wah Mountains of western Utah, U.S.A., is offered by Cathay Corporation. A few two-phase inclusions are mentioned. The crystals turn black on heating to 2500 °F but return to original colour on cooling. The colour is attributed to caesium and manganese. A 31 ct crystal of 23 × 13 mm, 4.3 ct emerald-cut stone of 9.3 × 8.9 mm and 3.8 ct round cabochon of 9 mm [diameter?] are illustrated. J.R.H.C.

NOTE: to avoid confusion, the Summer 1980 number of Gems & Gemology is so described above, because, although in fact part 10 of volume XVI, it carries the number 9. Parts 11 and 12 were correctly numbered.

BOOK REVIEWS

BANK (H.). *Meine kleines Diamantenbuch.* (My little diamond book.) Pinguin Verlag, Innsbruck, 1979. pp.85. Illus. in black-and-white and in colour. Price on application.

This pocket-sized book succeeds in giving the lay reader a complete picture of the genesis, recovery, fashioning and testing of diamond and a translation into English would be worth while. M.O'D.

COCKS (A. S.). *Courtly jewellery.* Victoria & Albert Museum, London, 1980. pp.48. Illus. in colour. Price on application.

A short, well-illustrated book giving a history of jewellery from the fifteenth to the seventeenth centuries, this account was timed to coincide with an exhibition of Renaissance jewellery held at the Victoria and Albert Museum in 1980/81. There are many fine pictures (all are in colour) and the text is authoritative. A short bibliography is appended. M.O'D.

HUNT (H.). *Lapidary carving for creative jewelry.* Desert Press, Bouse, Arizona, 1980. pp.144. Illus. in black-and-white. Price on application.

This book concentrates on the carved ringstone and carved pendant, two fields of the lapidary art which have been neglected in recent years. The illustrations of carved pieces are most interesting and considerable detail of the methods is given. Ten stones are selected for detailed discussion of high-quality faceting. This is a well-written book which contains much more than the title suggests. M.O'D.

KAMINSKII (A. A.). *Laser crystals, their physics and properties.* Springer, Berlin, 1981. pp.xiv, 456. DM128.

This book is devoted to the properties and characteristics of those crystals with some degree of laser application. Since most crystals need to be doped before they can be used for laser work the possibility of some of them having an ornamental application is clear, and although much of the detail given in this book is outside the field of the average gemmologist it is none the less worth while looking through it to see how the laser action takes place in a particular crystal and what type of doping gives the best results. There is a first-class list of references, many of them to Soviet journals. M.O'D.

LENGELLÉ (M.). See TARDY, LEVEL (D.). *Les Pierres Précieuses,* below (p.499).

PAMPLIN (B.), ed. *Crystal growth.* 2nd edn. Pergamon Press, Oxford, 1980. pp.xviii, 609. Illus. in black-and-white. £45.

This second edition of what quickly became a standard work on crystal growth is of similar size to the first without re-running any of the material. This shows how quickly the science (or art?) of the crystal grower has developed in the five years since the original text. Less is given here on the flux-melt method (which was exhaustively treated previously), but, as if to make up, a good deal of information on chemical vapour deposition and molecular beam epitaxy is provided. There is, too, much useful data on crystal growth environment and equipment and as always copious references are attached to each chapter. M.O'D.

SACHANBINSKI (M.). *Kamienie szlachetne i ozdobne Slaska.* (Precious and ornamental stones of Silesia.) Zaklad Narodowy im. Ossolinskich, Wroclaw, 1980. pp.238. Illus. in colour. 50Zl.

This is a well-produced introduction to the gem minerals with particular reference to those found in Poland. Maps are provided which clearly indicate the extent and location of Polish gem deposits (these include chrysoprase, cornelian, turquoise, tourmaline, amethyst and other varieties of quartz). A good bibliography of works in Polish is given and should prove most useful to those working on minerals from this area. M.O'D.

SACHANBINSKI (M.). *Polnische Edel- und Schmucksteine im Barockschloss Moritzburg.* (Polish gem and jewellery stones in the Baroque castle of Moritzburg.) Sekretariat für Kunstausstellungen des Bezirkes, Dresden. Unpaged. 1M.

This is a set of five postcards with a short introductory and descriptive booklet issued on the occasion of an exhibition displayed from 27th June to 12th July, 1980. The postcards depict nephrite from Jordanow, agate from Queisser Bergland, rock crystal from the 'Stanislaw' mine at Isergebirge, and quartz from Strzegom. M.O'D.

STALDER (H. A.), SICHER (V.), LUSSMANN (L.). *Die Mineralien der Gotthardbahntunnels und des Gotthardstrassentunnels N2.* (The minerals of the Gotthard railway tunnel and of the Gotthard road tunnel no. 2.) Repof AG, Gurtnellen, 1980. pp.160. Illus. in colour. Price on application.

Among a number of fine quartz minerals found during excavation of the various Gotthard tunnels is a beautiful pink fluorite. Titanite is also found in small sizes. This book, which includes a number of maps, is a fine example of a work commissioned to cover a particular project. M.O'D.

TARDY [identified in preparatory matter as Maurice Lengellé], LEVEL (D.). *Les pierres précieuses.* (Precious stones.) 5th edn. Tardy et Dina Level, Paris, 1980. pp.504. 34 colour plates. 300 Fr.

The bulk of this book consists of an alphabetical listing of stones, prefaced by introductory chapters on gem testing. Much if not all of this section remains unchanged from the 4th edition, published in 1965. Some additions have been made to the alphabetical section (cubic zirconia gets a hurried mention under zircon). A large amount of each descriptive section is devoted to a listing of discredited names which are thereby given an extension of life—this is scarcely a scholarly way of producing a book and indeed a good deal of the matter is inaccurate or carelessly researched. This is a pity for the book is well-produced and the coloured pictures, though largely taken from H.-J. Schubnel's *Pierres précieuses dans le monde,* are none the worse for a second airing. The whole text needs revision by someone familiar with present-day gemmology. M.O'D.

ASSOCIATION NOTICES

BASIL WILLIAM ANDERSON

On 3rd July, 1981, Mr B. W. Anderson attained the age of eighty. On behalf of the readers of this *Journal* and confident of their unqualified approval, the Editor has great pleasure in wishing Britain's premier gemmologist **Many Happy Returns of the Day.**

NEWS OF FELLOWS

On 17th February, 1981, Mr Peter C. Read, C.Eng., F.G.A., gave an illustrated talk on 'New Gem Test Instruments' to the Gemmological Association of Hong Kong in the Knowle's Building of the University of Hong Kong, and on 24th February, 1981, he presented an illustrated seminar to the China Arts and Crafts Corporation in Peking (Peiping), China, on 'Diamond Mining in Southern Africa', 'Gemstone Mining in Sri Lanka' and 'Gem Test Instruments'.

On 25th February, 1981, and again on the following day, Mr E. Stanley, F.G.A., gave lectures on hallmark identification and gemstone recognition at a Retail Jewellery Practical Seminar in Manchester.

On 28th March, 1981, Mr Michael O'Donoghue, M.A., F.G.S., F.G.A., gave a talk on 'Gemstones of Central and East Africa' at the British Mineral and Gem Show, Leicester.

On 7th April, 1981, Mr Alan Hodgkinson, F.G.A., gave an illustrated talk on the major precious stones to a large mixed audience of retail jewellers, gemmologists and those involved in the manufacturing side of the trade at the North British Hotel, Glasgow. He indicated some simple tests available with a minimum of equipment but stressed the importance of the microscope in determinative gemmology: in a selling situation he advocated applying gemmology in a positive way and not 'having to make unnecessary apologies for something that is Nature's guarantee that the stone is natural'.

On 28th-29th April and again on 30th April-1st May, 1981, Messrs Alan Hodgkinson and David Kent, FF.G.A., were the lecturers at two-day gem identification courses organized by *Retail Jeweller.*

OBITUARY

Mr Richard M. Pearl, M.A. (Colorado), A.M. (Harvard), C.G., F.G.A. (D.1946 with Distinction), Colorado, U.S.A., died on 28th November, 1980, in his 68th year. He was a Professor at Colorado College from 1962 until his retirement in 1978 and was the author of many books on geological and mineralogical subjects, including *Popular Gemology* (1948) and *Gem Identification Simplified* (1968).

On 20th March, 1981, Mr Edgar W. MacDonald, F.G.A. (D.1949 with Distinction), Cheddar, Somerset, died. He was for more than 20 years the mainstay of gemmological instruction in Glasgow and the West of Scotland. In 1952 he was a founder member of the West of Scotland Branch (later to become the Scottish Branch) and as a committee member his knowledge and guidance were invaluable.

GIFTS TO THE ASSOCIATION

The Council of the Association is indebted to the following for their gifts:

Mr R. Holt, F.G.A., London, for the following specimens: a Blue John slice, a ruby in schist, a quartz crystal, an amethyst slice, a hessonite garnet crystal and two jadeite cabochons.

Korite Ltd of Calgary, Alberta, Canada, for a very attractive piece of 'Korite'* on rock background, and four cut and polished oval specimens.

Mr John L. Pyke, F.G.A., Birkenhead, for 28 colour slides dealing with mining of gems in Burma, Sri Lanka, Tanzania, Thailand and Zimbabwe.

Mr R. C. Trigg, F.G.A., Capetown, S. Africa, for assorted emerald crystals and garnet-dioptase minerals for research and students' use.

RETIREMENT OF MR A. E. FARN

Mr A. E. Farn, F.G.A., retired as Director of the London Chamber of Commerce and Industry Gem Testing Laboratory on 17th March, 1981. There follows an appreciation of Mr Farn written by Mr David Callaghan, Chairman both of the Association and of the Diamond Pearl and Precious Stone Trade Section of the LCCI.

'One of the best-known and longest serving gemmologists, Alec Farn of the London Chamber of Commerce and Industry's Gem Testing Laboratory retired on 17th March.

'He started his working life in the retail jewellery and pawnbroking trade nearly fifty years ago and joined the LCCI Gem Laboratory following war service in 1946. This was to be the beginning of a 35-year career, which culminated in his promotion to director of the Laboratory in 1972. He obtained his F.G.A. with distinction in 1947. His early career at the Gem Laboratory was dominated by three men who had achieved world recognition in the field of gemmology. B. W. Anderson and C. J. Payne were both graduates of Kings College (University of London), while Robert Webster was the author of a pocket compendium which is still in demand today.

'By joining the Laboratory staff in 1946, Alec Farn became the fourth member of a team that was to work together for twenty-five years. It is probable that this team was the most influential gemmological diagnostic team that has ever been formed.

'For twenty-seven years Alec Farn worked alongside these giants until their retirement, which happened in fairly quick succession. His appointment as director

*For the nature of 'Korite' see pp.406-15 above.—Ed.

coincided with a period of rapid expansion and unprecedented change.

'In June 1977 he was made a Freeman of the Worshipful Company of Goldsmiths and a Freeman of the City of London, a fitting tribute to one whose career had done much to enhance the reputation of the City.'

GEM TESTING LABORATORY: NEW DIRECTOR

Mr K. V. G. Scarratt, F.G.A., has been appointed as Director of the Gem Testing Laboratory by the Standing Committee of the Diamond Pearl and Precious Stone Trade Section of the London Chamber of Commerce and Industry in succession to Mr A. E. Farn.

Mr Scarratt joined the Laboratory staff in June 1974 after some four years in the retail jewellery firm of Austin Kaye & Co. While there, he studied gemmology, passed the Diploma Examination and became F.G.A. in 1973 and passed the Gem Diamond Examination in the next year. He had previously seen service with the First Battalion Grenadier Guards in Cyprus, the Middle and Far East, and Northern Ireland.

While carrying out the general commercial gem testing provided by the Laboratory for the Trade, he has specialized in the recognition of the modern synthetic gemstones* and has developed the highly skilled technique required to detect radiation-induced colour in diamonds, using the equipment installed in the Laboratory for the study of absorption spectra in diamonds using liquid nitrogen, which he has described in his paper, 'Investigating the visible spectra of coloured diamonds', in the *Journal of Gemmology,* 1979, XVI (7), 433-47.

RETIREMENT OF HARRY WHEELER

The Chairmen of the N.A.G. and G.A. have announced that after serving both Associations since 1934 Mr Harry Wheeler has decided to retire in December 1982 at the age of 65. A successor is now being sought and a firm of Management Consultants has been appointed to deal with all applications on behalf of both Associations.

MEMBERS' MEETINGS

London

On 24th March, 1981, at the Central Electricity Generating Board Theatre, London E.C.1., two films were shown. The first, a new film produced by the Los Angeles County Museum of Natural History and the G.I.A., entitled 'Gems of the Americas' told of the evolution, mining, fashioning, and marketing of the gems. The second film was 'Orapa', the story of establishing a new diamond mine in a new area in Botswana.

Midlands Branch

On 27th March, Mr Robert Deans, of the Friends of Jade, gave an illustrated talk on jade and the aims of the Friends of Jade, at the Society of Friends, Dr Johnson's House, Colmore Circus, Birmingham.

*See his 'Notes on Gilson synthetic white opal (September 1975)', *J.Gemm.*, 1976, XV (2), 62-5; 'Study of recent Chatham synthetic ruby and synthetic blue sapphire crystals with a view to the identification of possible faceted material', *J.Gemm.*, 1977, XV (7), 347-53; and, with E. A. Jobbins and P. M. Statham, 'Internal structures and identification of Gilson synthetic opals', *J.Gemm.*, 1976, XV (2), 66-75.—Ed.

On 24th April, 1981, also at the Society of Friends, the Annual General Meeting of the Branch was held, when Mrs S. E. Spence, F.G.A., and Mrs J. S. Leek, F.G.A., were re-elected Chairman and Secretary respectively. The A.G.M. was followed by an illustrated talk by Mr D. H. Ariyaratna on 'The Gem Industry of Sri Lanka'.

North-West Branch

On 26th March, 1981, Mr R. V. Huddlestone gave an illustrated talk on 'Diamonds', at Church House, Hanover Street, Liverpool.

On 30th April, 1981, Mr A. E. Farn, F.G.A., gave an illustrated talk on 'Jade and Jade-like Substances', at Church House.

On 7th May, 1981, Mr P. G. Read, C.Eng., F.G.A., gave an illustrated talk on diamonds, including a feature on mining, at Church House.

South Yorkshire and District Branch

On 19th March, 1981, at the Sheffield City Polytechnic, Dr Stanley Holgate, F.G.A., gave a talk entitled 'Let's make a Solitaire'. Dr Holgate was until recently lecturer for the Gem Diamond and Practical Diploma classes at Liverpool and has been experimenting with different stone-mounting techniques. A collection of stones was circulated for identification purposes. Dr Holgate's detailed description of the methods of making a simple prong setting was of particular interest to the student members present.

COUNCIL MEETING

At the Meeting of the Council held on Tuesday, 10th February, 1981, at Saint Dunstan's House, the following were elected to membership:

FELLOWSHIP

Attanayake, Walter, Ratnapura, Sri Lanka. 1978
Bennett, David W., Ware. 1980
Bill, David N., Cannock. 1980
Bonanno, Kathryn L., Fredericksburg, Va, U.S.A. 1980
Bramwell, William J., Tynemouth. 1980
Carlsson, Bjørn, Täby, Sweden. 1980
Cartier, Richard H., Toronto, Ont., Canada. 1980
Charlton, Maurine, Scarborough, Ont., Canada. 1980
*Chinkul, Manwit, Jeddah, Saudi Arabia. 1970
Cooper, Judith M., Colchester. 1980
Day, Ghislaine H., Arlington, Va, U.S.A. 1980
Day, William H., Arlington, Va, U.S.A. 1980
de Grefte, Glaudina J., Tilburg, Netherlands. 1980
Ford, Karen J., Annapolis, Md., U.S.A. 1980
Fraquet, Helen R., Frinton-on-Sea. 1980
Gallardo Bravo, Matilde, Valencia, Spain. 1980
Gowling, Leslie G., Toronto, Ont., Canada. 1980
Graus, Jeremy Z., London. 1980
Harris, Barbara, Toronto, Ont., Canada. 1980
Heiskanen, Erkki T., Helsinki, Finland. 1980

*Manwit Chinkul qualified in 1970 under the name of Minn Wai

Hellmark, Thorsten, Örebro, Sweden. 1980
Hunger, Giselle, Lugano, Switzerland. 1980
Jackson, John G., Sunderland. 1980
Johnson, Colin M., Birmingham. 1980
Jones, L. Bruce, Seattle, Wash., U.S.A. 1980
Jones, Mark L., Cromer. 1980
Kämäri, Arvi N., Helsinki, Finland. 1980
Krapenc, Terry S., Concord, Ohio, U.S.A. 1980
Laine, Paul D., Vale, C.I. 1980
Lakdawalla, Darayus N., Bombay, India. 1980
Lakdawalla, Zubin N., Bombay, India. 1980
Lamb, Revital, Salisbury, Zimbabwe. 1980
Linko, Ilpo I., Espoo, Finland. 1980
Naebers, Joseph L., Hulsberg, Netherlands. 1980
Nakajima, Minako, Tokyo, Japan. 1980
Nichols, Robert T., Albuquerque, N.M., U.S.A. 1980
Oosterwaal, Fransiscus T., Loon op Zand, Netherlands. 1980
Pascual Armengou, José, Barcelona, Spain. 1980
Perera, Priyani A., Colombo, Sri Lanka. 1980
Piunno, John C., Washington, D.C., U.S.A. 1980
Reynolds, Roderick H., La Moye, C.I. 1980
Riedl de Argiles, Inge, Barcelona, Spain. 1980
Robbins, Susan C., London. 1980
Ross, Rosemary D., London. 1980
Ruÿten, Andreas G., Woerden, Netherlands. 1980
Samaratunga, Edith K., Heidelberg, West Germany. 1980
Shackley, Ian W., Christchurch, New Zealand. 1980
Shah, Paresh N., Bombay, India. 1980
Shanmuganathan, Kathirithanby, Colombo, Sri Lanka. 1980
Stalman, Margareth A., Susteren, Netherlands. 1980
Takada, Fujio, Osaka, Japan. 1980
Tan-Bouman, Els, Schoonhoven, Netherlands. 1980
Tolin, Harvey S., New Canaan, Conn., U.S.A. 1980
Tomas Soler, Ma Rosa, Valencia, Spain. 1980
van Muyden, Paulus M., Rotterdam, Netherlands. 1980
Versendaal, Johannes, Hendrik Ido Ambacht, Netherlands. 1980
Wall, Stephanie, Alcester. 1980
Waller, John R., Scarborough, Ont., Canada. 1980
Welch, Mark G., Cardiff. 1980
Wijesuriya, Guthila, Colombo, Sri Lanka. 1980
Wilkinson, Ben R., Nanaimo, B.C., Canada. 1980
Yielding, Daniel N., Markham, Ont., Canada. 1980

TRANSFERS FROM ORDINARY MEMBERSHIP TO FELLOWSHIP

Carrera Poblet, Jaime, Barcelona, Spain. 1975
Carson, Constance, London. 1980
O'Donnell, Francis X., East Greenbush, N.Y., U.S.A. 1979
Osborne, Annie, Hong Kong. 1979

ORDINARY MEMBERSHIP

Abrami, Aurelio, Milan, Italy.
Ainsworth, Nicola L., London.
Albuquerque, Antonio R., São Paulo, Brazil.
Ali, Narin, London.
Ariyaratna, D. H., London.
Atsumi, Ikuo, Tokyo, Japan.
Auerbach, Louis, Long Island, N.Y., U.S.A.
Bennett, Norman P., Plymouth.
Berkowitz, Joseph, Toronto, Ont., Canada.
Berndt Arfstrom, George, Bro, Sweden.
Birkinshaw, David W., Edmonton, Alta, Canada.
Bolton, Robert G., Leeds.
Bonetti, Ettore, Rome, Italy.
Brown, Ian A., Hoppers Crossing, Vict., Australia.
Brugnoli, Giacomo F., Barry.
Bushnell, Nicola G., Taunton.
Buss, Marinda M., Hong Kong.
Chan, Cecilia, Hong Kong.
Chan, Peter K., Kowloon, Hong Kong.
Chi Yung, Jim, Reading.
Choksi, Chandrakant C., Dubai, U.A.E.
Chokyu, Kozo, Osaka, Japan.
Clark, Patricia A., Wrotham.
Cornioley, Jean-René, Fribourg, Switzerland.
Couston, John F., Kerala, India.
Cramer-Langohr, Monique, Verviers, Belgium.
Crossley, Simon W., Harwich.
Cvetkovic, Borjanka, Kerala, India.
Damboritz, Alfred L., Bayonne, N.J., U.S.A.
Darracott, Britt-Marie, London.
Davies, Angela, Gerrards Cross.
Davies, Garry, Hyde.
Denton, John M., Corbridge.
De Ridder, Herwig, Rijmenam, Belgium.
Diaz-Legorburu, Federico, Caracas, Venezuela.
Dixon, Leonard W., Wolfenbüttel, W. Germany.
Ebine, Junichi, Tokyo, Japan.
Eckley, Gareth D., Brecon.
Edelstam, Ingrid K., Stockholm, Sweden.
Ehrenborg, Charlotte, Gex, France.
Elias, Abdul H., Mombasa, Kenya.
Ellis, Maurice E., Evesham.
Enger, Antoinette C., Voorburg, Netherlands.
Fukushima, Tsukasa, Yokohama City, Japan.
Gemayel, Farid, Ante Lias, Lebanon.
Gerrard, Charles, London.
Giraldo Cuellar, Rodrigo A., Bogota, Colombia.
Gobla, Michael J., Westminister, Colo., U.S.A.
Gono, Teruko, Tokyo, Japan.
Gooneratne, Sinhamuni M., London.
Guy, Peter M., Solihull.
Haggarty, Ronald T., Edinburgh.
Hakoune, Jacques, Antwerp, Belgium.
Ham, Elizabeth R., Rondebosch, Cape, S. Africa.
Hamamoto, Keiko, Tokyo, Japan.
Hibino, Osamu, Kyoto City, Japan.
Ho, Henry, Los Angeles, Ca, U.S.A.
Houseago, James A., Lowestoft.
Imazawa, Satoru, Yamanashi Pref., Japan.
Inches, Deirdre M., Wembley.
Inoue, Yoshiaki, Asahigawa City, Japan.
Ishii, Koji, Chiba Pref., Japan.
Ishiwatari, Tamotsu, Saitama Pref., Japan.
Isowa, Keiko, Oita Pref., Japan.
Ito, Yasuo, Nagoya City, Japan.
James, Isabel E., Aberdeen.
Jason, Neville H., Prestwich.
Jedrzejewski, Mark J., Gdynia, Poland.

Kageyama, Chiyomi, Hyogo Pref., Japan.
Kamidoi, Yoko, Hiroshima Pref., Japan.
Kano, Shinzo, Osaka, Japan.
Karpelowsky, Raymond, London.
Kasagi, Nobuko, Hyogo Pref., Japan.
Kato, Kenzo, Tokyo, Japan.
Kawaguchi, Machiko, Yokohama City, Japan.
Kawai, Junko, Osaka City, Japan.
Kawasaki, Teruko, Tokyo, Japan.
Kennedy, Stephen J., Basingstoke.
Keuskamp, Diederik H., Streefkerk, Netherlands.
Kishida, Seiko, Birmingham.
Kobayashi, Yuko, Tokyo, Japan.
Kodaka, Katuyoshi, Tokyo, Japan.
Kohmura, Kyohko, Kyoto City, Japan.
Kojo, Kazuko, Tokyo, Japan.
Kosugi, Hajime, Tokyo, Japan.
Krementz, Richard, III, Newark, N.J., U.S.A.
Kusamura, Keiko, Tokyo, Japan.
Lai, Wing F., Kuala Lumpur, Malaysia.
Langford, Michael L., Hereford.
Laycock, Susan W., Henfield.
Leidensdorff, Carine, Brussels, Belgium.
Leung, Man-Fai, Hong Kong.
Leung, Tat-Tung R., Hong Kong.
Li, Randy K., Tamuning, Guam, U.S.A.
Livstrand, Ulf R., Saltsjöbaden, Sweden.
Logan, Sandra E., Milford, Auckland, N.Z.
Lu, Chung C., Taipei, Taiwan.
Ma, Lai Ha, Hong Kong.
McKellar, John R., Presteigne.
McKenna, Murial, Swindon.
McLean, Peter J., Ryde, N.S.W., Australia.
Maeda, Fumiyo, Tokyo, Japan.
Mainwaring-Burton, Jeremy J., London.
Margiotta, Antonio A., Hove.
Masuda, Masami, Shizuoka Pref., Japan.
Matsuda, Tomoko, Tokyo, Japan.
Matsui, Kunifumi, Kanagawa Pref., Japan.
Meggitt, Corinna A., London.
Merrell, Charles E., Milwaukie, Oreg., U.S.A.
Michaels, David B., Alexandria, Va, U.S.A.
Middleton, Neil M., Stoke-on-Trent.
Midorikawa, Nobuko, Tokyo, Japan.
Mikami, Tatsuo, Tokyo, Japan.
Miller, Dawn J., Gloucester.
Mine, Kayoko, Fukuoka Pref., Japan.
Minowa, Hiroyuki, Tochigi Pref., Japan.
Misaki, Kyoko, Tokyo, Japan.
Miske, Walter, Honolulu, Hawaii, U.S.A.
Mizushima, Nobuhiro, Osaka City, Japan.
Moriyama, Jun, Fukuoka Pref., Japan.
Murahashi, Kozo, Nagasaki Pref., Japan.
Nakao, Kazuya, Wakayama Pref., Japan.
Nanji, Farida, Nairobi, Kenya.
Nomura, Shoji, Kyoto City, Japan.
Ohno, Hiroko, Tokyo, Japan.
Okamoto, Yoshitaka, Osaka, Japan.
Okayasu, Tetsuya, Tokyo, Japan.
Okino, Sanae, Hiroshima Pref., Japan.
Okuda, Makoto, Osaka, Japan.
Ono, Yuko, Tokyo, Japan.
Ro, Yosetsu, Tokyo, Japan.
Robert, Dominique, Chamonix, France.
Saito, Michiko, Tokyo, Japan.
Saitoh, Masanori, Chiba Pref., Japan.
Sakurai, Takemitsu, Ibaraki Pref., Japan.
Samaraweera, Bentotakumara S., Basingstoke.

Sato, Ayako, Yamanashi Pref., Japan.
Sawada, Haruhito, Osaka, Japan.
Seaman, James S., Brookfield, Wis., U.S.A.
Seaton, Glynice D., Hong Kong.
Shah, Sunil, London.
Shaner, Karen E., Burbank, Ca, U.S.A.
Shepherd, Niall, C., Poynton.
Sherwin, Andrew E., Nottingham.
Sheth, Dilip S., St Julians, Malta.
Shimada, Michiko, Tokyo, Japan.
Skalicky, Jirt, Brno, Czechoslovakia.
Speake, Phyllis J., Tadworth.
Stavron, Stavros D., Ndola, Zambia.
Steckenrider, Troy B., San Gabriel, Ca, U.S.A.
Stephen, Susan C., Birmingham.
Sugita, Nobuko, Chiba Pref., Japan.
Suzuki, Yuko, Tokyo, Japan.
Tagawa, Masahide, Tokyo, Japan.
Tainio, Ulla-Maria, Brasília, Brazil.
Takakura, Momoyo, Tokyo, Japan.
Tamura, Minoru, Tokyo, Japan.
Tanaka, Junichi, Tokyo, Japan.
Tate, Stephen J., Farnham.
Terasaka, Misao, Tokyo, Japan.
Thavat, Paul, Titirangi, Auckland, N.Z.
Thomson, Ian C., Dumfries.
Thorne, Deirdre, Salisbury, Zimbabwe.
Tolstrup, David A., Malden, Mass., U.S.A.
Tremblay, Mousseau, Le Plessis-Robinson, France.
Unhasut, Pichai, Bangkok, Thailand.
van Rhee, Hendrik L., Hoogvliet, Netherlands.
Watson, Pauline E., Dorking.
Wayne, Barry, Hornchurch.
Wright, Beatrice, Coventry.
Yamashita Catter, Junko, Tokyo, Japan.
Yamazaki, Koji, Tokyo, Japan.
Yapp, Russell J., Mansfield.
Yin Eng Haw, Carlson, Singapore.
Yoho, Gerald A., Crown Point, Ind., U.S.A.
Yokoo, Kenji, Tokyo, Japan.
Yoshida, Takeshi, Osaka City, Japan.
Yoshino, Mariko, Tokyo, Japan.
Yoshiyama, Masaru, Chiba Pref., Japan.
Yoshizawa, Keiko, Tokyo, Japan.

GOLDEN JUBILEE CELEBRATIONS

The response to the special arrangements being organized for October has been overwhelming. All the places for the Boat Cruise on Tuesday, 6th October, and the Celebration Dinner in the Captain's Room at Lloyds on Wednesday, 7th October, have been allocated, but an additional 'Celebration Dinner' has been arranged, again at Lloyds, for Friday, 9th October. There are a limited number of places available which will be filled in strict order of receipt of application.

GEM & MINERAL SOCIETY OF ZIMBABWE

The Rhodesian Gem and Mineral Society (affiliated to the Association) has changed its name to the Gem and Mineral Society of Zimbabwe.

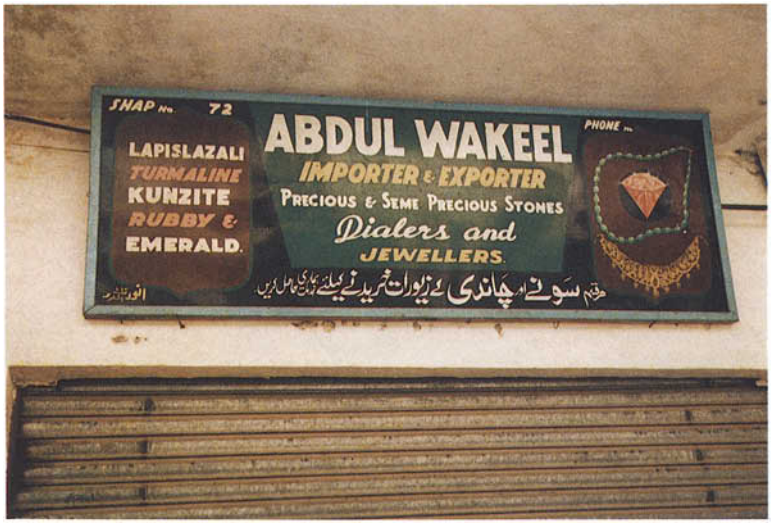

Abdul Wakeel's shop sign.

Main street of Landi Kotal.

LETTER TO THE EDITOR

From Mr M. J. C. Brocklehurst, F.G.A.

Dear Sir,

A month or two ago I was travelling in the North West Frontier Province of Pakistan, right up along the Afghan border. I went to Torkham, the crossing point between the two countries, and on the way back I spent several hours in Landi Kotal, the last town on the road from Peshawar to Kabul. Thinking it might interest readers of the *Journal* to see how a leading local 'dialer in seme precious stones, rubby, lapislazali' and others advertises his wares I photographed the sign over his 'shap' *(sic)*. Unfortunately the 'shap' was shut so I could not call to pay my respects to Abdul Wakeel, take tea with him (quite probably it would have been 70% proof but camouflaged by being poured from a teapot!) or discuss his stock. To put it all in better perspective I also photographed the main street in which he has his business. It may be safely assumed that Abdul Wakeel dresses in a way similar to the man in the foreground.

Landi Kotal is a name to evoke many memories in the minds of those who were familiar with that part of the world in the days of the Raj, when so many soldiers of the British and Indian armies were trained and received their baptism of fire in encounters with the Pathan tribesmen. The Khyber Pass is now dotted with large new mud forts, the homes of dozens of those same tribesmen who in recent years have acquired immense wealth through smuggling—though there is little in their appearance to distinguish them from the local goatherds and lorry drivers. Smuggling is a flourishing industry to which the Government turns a blind eye; indeed, unofficially it is encouraged because of the prosperity, and therefore peace, it brings to a harsh and arid area which was lawless for hundreds of years. It is interesting that even the Russians have apparently made no serious attempt to curb the widespread two-way traffic, presumably because, in the one direction, it is a source of a wide range of expensive Western household goods otherwise unobtainable and, in reverse, secures foreign currency, however illegally, by the export of such commodities as rugs and a variety of gemstones. It was also extremely interesting to find, particularly in the wilder parts of Pakistan, what a very warmhearted welcome is extended to the now rare visitor from the U.K.—and primarily *because* he is British.

Yours etc.,
M. J. C. BROCKLEHURST.

20th February, 1981.
4 Fulham Park Road, London SW6 4LH.

CORRIGENDA

On p.201 above, line 18, for 'Hartshorn' read 'Hartshorne'.

On p.330 above, 4th line below Table 1, for 'θ_c>v, i.e. ring-negative' read 'θ_c<v, i.e. ring negative'.

On p.417 above, line 5, for *'lichtbrechung-sindizes'* read *'lichtbrechungsindizes'*.

On p.428 above, line 7, for 'in October' read 'on 5th August'.

On p.430 above, line 6 from bottom, for 'them' read 'the two firms'.

THE RAYNER DIAMOND TESTER

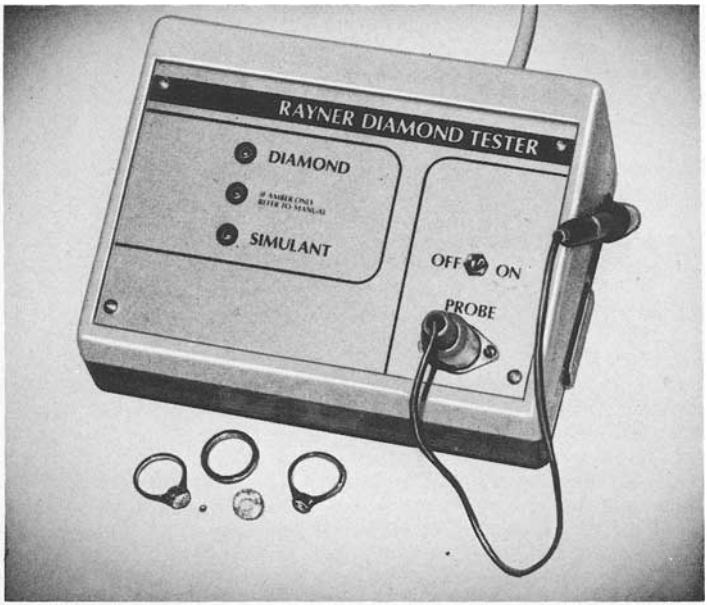

An instrument using thermal conductivity to detect diamond from simulants. It has a small hand-held probe which allows small stones, and stones which are recessed in their mount, to be tested. Mains operated (240V or 110V).

Price UK £135.00 plus postage and VAT.

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GEM TESTING EQUIPMENT

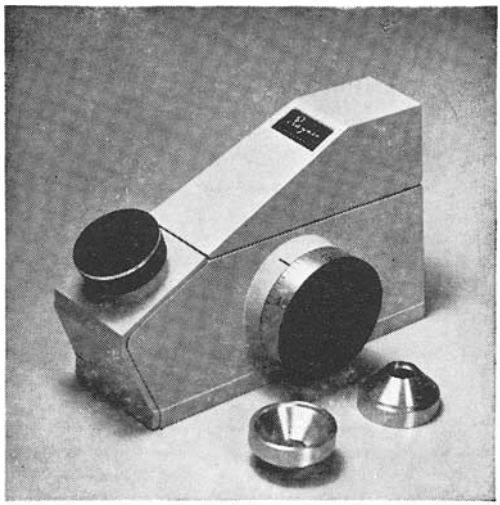

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Historical Note

The Gemmological Association of Great Britain was originally founded in 1908 as the Education Committee of the National Association of Goldsmiths and reconstituted in 1931 as the Gemmological Association. Its name was extended to Gemmological Association of Great Britain in 1938, and finally in 1944 it was incorporated in that name under the Companies Acts as a company limited by guarantee (registered in England, no. 433063).

Affiliated Associations are the Gemmological Association of Australia, the Canadian Gemmological Association and the Gem and Mineral Society of Zimbabwe.

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Notes for Contributors

The Editor is glad to consider original articles shedding new light on subjects of gemmological interest for publication in the *Journal.* Articles are not normally accepted which have already been published elsewhere in English, and an article is accepted only on the understanding that (1) full information as to any previous publication (whether in English or another language) has been given, (2) it is not under consideration for publication elsewhere and (3) it will not be published elsewhere without the consent of the Editor.

Articles published are paid for, and any number of prints of individual articles may be supplied to authors provided application is made on or before approval of proofs. Current rates of payment for articles and terms for supply of prints may be obtained on application to the Secretary of the Association.

Although not a mandatory requirement, it is most helpful if articles are typed (together with a carbon copy) in double spacing on one side of the paper, with good margins at sides, top and foot of each page. Articles may be of any length, but it should be borne in mind that long articles are more difficult to fit in than short ones: in practice, an article of much more than 10 000 words (unless capable of division into parts or of exceptional importance) is unlikely to be acceptable, while a short note of 400 or 500 words may achieve early publication.

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THE JOURNAL OF GEMMOLOGY

and

PROCEEDINGS OF THE GEMMOLOGICAL ASSOCIATION OF GREAT BRITAIN

GEMMOLOGICAL ASSOCIATION
OF GREAT BRITAIN
SAINT DUNSTAN'S HOUSE, CAREY LANE
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THE JOURNAL OF GEMMOLOGY
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EDITORIAL

It is unusual for the *Journal of Gemmology* to begin with an Editorial, but special issues call for special treatment, and I have a precedent in the brief introduction by the late Gordon Andrews to Vol. XII, No. 7 (July 1971), which was a 70th Anniversary Tribute to B. W. Anderson.

The present issue of the *Journal* is a special one to celebrate the Golden Jubilee of the Gemmological Association, which, after over twenty years existence as a Committee of the National Association of Goldsmiths, finally 'came of age' in its own name on the 24th September, 1931.

That is not, however, the only anniversary calling for celebration this year. The 3rd July, 1981, was the eightieth birthday of B. W. Anderson, that great gemmological researcher, practiser and teacher to whom, like so many others, I owe all such knowledge of gems and gem materials as I possess—apart, in my case, from such elements as had first been instilled in me by the late C. J. Payne, with whom I had been at school twenty-five years

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earlier and who, as my correspondence-course tutor, with exemplary patience and lucidity answered the no doubt surprising questions of a student reared on the classics and entirely devoid of scientific training.

James Payne unhappily is no longer with us, but it is good to be able once again to wish Basil Anderson many more happy returns of his birthday and to see another article from his pen leading off this Jubilee number of the *Journal.* In his article, Mr Anderson traces the progress of gemmology up to 1931, progress which has continued during the past fifty years with increasing momentum and to which both he and the Gemmological Association have made—and surely will continue to make—significant contributions: for, though anniversaries come and go, the work of research and the spread of knowledge continues, and it is worth emphasizing on an occasion like this that in addition to progress made in the past there is much still to be made in the future, in which it is reasonable to predict that the Gemmological Association and its Fellowship will play their part. In this connexion it is pertinent to observe that all the papers in this Jubilee number are contributed (in whole or in part) by Fellows—among them the President and Vice-president of the Gemological Institute of America, which also celebrates this year a fiftieth anniversary—its foundation in 1931—and to which we offer our fraternal greetings.

J.R.H.C.

THE GROWING PAINS OF GEMMOLOGY

By B. W. ANDERSON, B.Sc., F.K.C., F.G.A.

This being the Jubilee Year of Britain's Gemmological Association, it seems an appropriate time to look back through the years and trace the progress of gemmology since the inception of the science during the closing years of the nineteenth century.

As long as a hundred years ago a number of mineralogists had shown a special interest in the branch of mineralogy dealing with the properties of precious stones and had demonstrated a clear way to progress in this fascinating science.

But for a very long time, on the part of those whom we can describe collectively as 'The Trade' (that is, the men who make a living from gemstones whether as prospectors, lapidaries, dealers, manufacturers, retail jewellers, or pawnbrokers), any attempt to introduce scientific methods in their approach to gems was in general viewed with hostility or suspicion. After all, each in his own field had built up and inherited an array of special skills and rule-of-thumb knowledge which enabled him to make a comfortable living and be acknowledged as an 'expert', so that when eventually classes were first instituted for training jewellers' assistants in the first principles of gemmology, there was seldom much encouragement for pupils from their seniors, who (naturally enough) disliked the thought of being corrected in any of their judgements by some junior armed with a textbook and some newfangled instruments.

Admittedly, until the turn of the century, the problems (apart from tricky decisions on values) were relatively few and simple. Only four gemstones were ranked as 'precious'—diamond, ruby, sapphire, and emerald, together with pearl, which occupied a special place in the same high rank. The remaining gemstones were labelled 'semi-precious' or 'ornamental' and their naming was largely based on their colour. Thus all red stones were thought of as some inferior form of ruby, all green stones, some form of emerald, etc., with accepted adjectives attached to distinguish between them. The only fakes to resemble at all closely the sacred four were either pastes or the simpler forms of doublet, which

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could be dealt with with the aid of a hard file or detected by an experienced eye behind a watchmaker's glass. Unusual problems or uncertainties could be referred to the lapidary of their choice (lapidaries being more numerous and more influential than they are today), quite a wise procedure, as in the course of handling and working on multitudes of stones of all kinds these craftsmen acquired an intimate knowledge of their appearance, habits, cleavages, hardness and that mysterious factor, their 'feel on the wheel'.

One major drawback (though not considered as such by the Trade) concerned that traditional unit of weight, the carat, which, like the grain, was originally based on a seed, and varied (incredibly enough) from country to country, between the limits 0.1885 gram to 0.2135 gram. In England a weight called the carat is said to have been in use since Norman times, but had never been recognized as a 'legal' weight. This, for precious stones and metals, was the Troy ounce which, until 1914, was equivalent to 151.5 carats. To make matters more complicated the actual weights used by gem merchants with their balances were numbered 1000, 500, 200, 100, 64, 32, 16, 8, 4, 3, 2 and 1 carats, followed by the fractions ½, ¼, ⅛, 1/16, 1/32 and 1/64. Moreover, it was against convention to present the weight (when found) as a single fraction, but rather as a succession of the weights actually used. Thus, a stone paper might be marked '5 fine blue sapphires: 65 ½ 1/32 1/64'. I remember once seeing a positive tangle of such fractions on the outside of an old stone packet belonging to my friend and mentor Edward Hopkins, and realized that these represented an attempt to carry out a hydrostatic density experiment using the fractional weights available! There was nothing, of course, to prevent any dealer from buying a set of metric weights (grams and milligrams) from a laboratory supplier for use in such an experiment, but such behaviour would mark one as decidedly eccentric in those early days.

There were, admittedly, a number of enlightened, responsible people in the trade, who were ready to attend the lectures on gemstones occasionally given by noted mineralogists. Two such lectures were delivered in 1897 at the Royal Society of Arts by Professor Henry Miers (who, as Sir Henry Miers, was, nearly forty years later, elected the first President of the Gemmological Association). These talks were remarkable in their scope, detailing

Sir Henry Miers, M.A., D.Sc., F.R.S., the Association's first President. *(After the drawing by H. McD. Campbell, by courtesy of the Principal of London University.)*

methods for measuring density, refractive index, dichroism, etc., and even the use of the spectroscope in seeing absorption bands in zircon and almandine garnet. He mentioned the tiny diamonds presumed to have been made by Moissan, and the synthetic rubies made by Frémy, and stated: 'large numbers of artificial rubies are now used in jewellery. The only respect in which they differ from the natural stone is that they have been formed by a different process'. And in his concluding remarks Miers added: *'The absolute necessity of accurate scientific knowledge in commercial and practical undertakings is now fully recognized. The jeweller's trade stands almost alone in failing to realize that such knowledge has a real commercial value'.*

It is remarkable that these words were spoken several years before the first of the Verneuil synthetics burst upon the jeweller's world. As an interesting example of a continuing chain of witness to the gemmological message in those early days, Noel Heaton, B.Sc., in 1911 delivered an excellent and well illustrated lecture (also at the Royal Society of Arts) on 'Artificial Gemstones' and on that occasion Henry Miers himself was in the chair. It is also interesting to note from the records of the occasion that remarks were made after the lecture by such well-known names as J. H. Steward (maker of the Herbert Smith refractometer), who gave credit to Herbert Smith for the instrument he had designed; E. Hopkins (lapidary, dealer, and future examiner) and B. J. Tully, known later for a remarkable refractometer of his design and for the Medal named in his memory.

A notable occasion in the history of trade gemmology came in 1908, when Samuel Barnett, of the Education Committee of the National Association of Goldsmiths, proposed the formation of teaching classes and examinations in gemmology. This, when eventually implemented, marked the beginning of organized Trade gemmology, not only in this country but in due course for the whole world. Getting things going was a slow and difficult process: jewellers on the whole were still apathetic or even hostile to being taught their job. Any prospective students were scattered throughout the country, and there was at first no suitable textbook to give coherence to the movement. A few lectures were given in 1909 and a correspondence course for jewellers initiated, while in 1910 Noel Heaton (already mentioned above) was appointed special lecturer by the Education Committee, and delivered his

excellent talks in several different centres. It was at this point that the beneficial intervention of Dr G. F. Herbert Smith began to show effect.

Herbert Smith was a mineralogist, who for years held responsible posts in the Mineralogical Department of the British Museum (Natural History). In 1907 the improved second model of his jeweller's refractometer, skilfully and robustly manufactured by J. H. Steward, made its first appearance on the market. This famous little instrument enabled the jeweller for the first time to make positive identifications of almost any faceted gemstone even when mounted as a jewel. A year or two later Herbert Smith added to this service when the first edition of his book *Gemstones* appeared in 1912. The book was of special value, not only for its full instructions on how to use the refractometer, but for its workmanlike descriptions of the various gemstones and their properties. The next advance came when, just before the Great War, Irvine G. Jardine, M.Sc., a physicist with a good working knowledge of mineralogy, was persuaded to prepare and conduct the first complete course in gemmology at Chelsea Polytechnic, under the title 'Mineralogy for Jewellers'. Examinations were held in 1913, 1914, and 1915 at Chelsea before the war put an end to such humane activities. Classes were renewed in 1922, and exams have been held annually ever since without a break, though in World War II I must admit that I was at one point teaching only two students in various odd places according to the bombing schedule at that time!

At long last, in 1914, the Board of Trade, having found that there was now sufficient trade support for such a change, issued an Order in Council which decreed that the metric carat of 200 milligrams should be adopted as the legal weight for precious stones.

Having reached this point I should like to go back in time again before the end of the nineteenth century to give a brief account of what a splendid lead had been given to gemmology for those who cared to take it, by mineralogists in Britain and other countries.

In 1883, A. H. Church (a name well known to gemmologists) published *Precious Stones* as a slender volume serving as an excellent introduction to gemmology and particularly noteworthy in giving really careful instructions for measuring specific gravity,

which was at that time the surest non-destructive means of identifying any unmounted gemstone. The density figures quoted by Church were those he himself had determined—an unusual and welcome feature. In the U.S.A. *Gems and Precious Stones of North America* by the famous mineralogist G. F. Kunz was published in 1890 and was of far more than local importance. But the greatest book on gemmology in those early days was undoubtedly *Edelsteinkunde* by Max Bauer, published in Leipzig in 1896. Bauer was the earliest of a long chain of German professors of mineralogy to which gemmology owes a profound debt. One of his pupils, incidentally, was Karl Schlossmacher who later (1931) revised Bauer's book and himself became a professor and one of the world's most respected gemmologists. Fortunately for English-speaking readers Dr L. J. Spencer (substantially aided by his wife) translated Bauer's work, and this was published as *Precious Stones* in 1904 by Charles Griffin & Co. in London. This massive and valuable descriptive account of gemstones would by now be an expensive collector's item, to be consulted only in libraries, had it not been made available to everyone by Griffin, and by Dover Publications Inc. in 1968 in a two-volume paper-back at £2.10s., which must be the greatest bargain ever offered in books on our subject.

I should like to emphasize that it is a great mistake to think that there is nothing to be gained in reading books on gemmology written long ago: nearly always something can be learned—always provided that the author is a sincere student of the subject and not merely a copyist and compiler of books for profit. Other books that can be commended which appeared in the early years of the century are *The Gem Cutter's Craft* by L. Claremont (London, 1906), which is much more than a craftsman's handbook; *Precious Stones* by W. Goodchild (London, 1908); and *A Book of Precious Stones* by L. Wodiska (New York and London, 1909), which has a particularly interesting section on synthetic gems.

Then in 1912 came G. F. Herbert Smith's *Gemstones* as already mentioned above. The fourth edition (1923) was my stand-by when I first started work in the Gem Testing Laboratory, but one had to wait until 1940 for a much needed enlargement and revision. After Herbert Smith's death in 1953, *Gemstones* did not die, but took on a new and valuable life thanks to tactful and scholarly revisions by F. Coles Phillips.

The opening of an independent pearl and gem testing laboratory in Hatton Garden in 1925 was a very necessary step in providing the trade with a specialized centre where authoritative reports could be obtained. Though understandably enough its services were at first available only to members of the Precious Stone Section of the London Chamber of Commerce who were responsible for its inception and all the costs involved, it was before long available to members of the N.A.G. and other Trade organizations.

The year 1931, to which the above outline is intended as a preparatory introduction, despite the fact that the world was only slowly emerging from the Great Depression which followed the Wall Street Crash of 1929, undoubtedly marked the birth of a sudden expansion of gemmology in almost every civilized country. The 'Zeitgeist' was for some reason all in our favour. In addition to the birth of our Association as a separate entity, a parallel German organization was being founded; a pearl and gem testing laboratory was established in Paris under the tutelage of Georges Gobel; Robert M. Shipley with little but a G.A. Diploma, a Herbert Smith refractometer and unrelenting determination on his side was beginning his conquest of North America with 'Gemology' as his banner; and finally, and not the least important of these promising signs of growth, there came in August 1931 the first number of Arthur Tremayne's brainchild *The Gemmologist,* which for the first time provided a vehicle for the exchange of gemmological information. For all its faults this remarkable little monthly journal was a godsend to our growing science and its eventual demise in 1962 is still lamented by those veterans who remember it in its heyday.

[*Manuscript received 6th May, 1981.*]

GARNETS FROM UMBA VALLEY, TANZANIA: IS THERE A NECESSITY FOR A NEW VARIETY NAME?

By Dr KARL SCHMETZER

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ABSTRACT

The garnets from Umba Valley, Tanzania, consist of solid solution series of the garnet end members pyrope, almandine, and spessartite with low contents of a grossularite component. Density and refractive index of members of the series pyrope-almandine vary between 3.71 and 4.04 g/cm^3 and between 1.738 and 1.787 respectively. Members of the solid solution series pyrope-spessartite show density values between 3.82 and 4.05 g/cm^3 and refractive indices between 1.751 and 1.788. A gemmological distinction of members of both solid solution series is possible by a spectroscopic investigation. The name pyralspite garnets for all members of the solid solution series pyrope-almandine-spessartite, which is used in petrology and mineralogy, is also recommended for gemmological nomenclature.

Since about 1979 orange-red coloured garnets have been offered in the gemstone trade whose colour is similar to that of spessartite. Though a large variation in the colour of these new garnets exists, it can generally be described as somehow lighter and more yellowish than that of spessartite, which is closer to orange-brown. The garnets (as pebbles) originate from one or more placer deposits in the Umba Valley, Tanzania, and were first sold without an exact investigation of their chemical composition under the name of 'Malaya-garnets' (Bank 1979, Curtis 1980). When the necessity of naming these garnets properly, i.e., according to scientific standards, was put before the authors, several samples of these garnets were first investigated by physical and chemical methods. It had to be clarified whether the samples mentioned belong to a new, naturally occurring phase with garnet structure, which would justify a new mineral name, or whether they were members of a solid solution series of the already known end members of the garnet group without a necessity for a new mineralogical name. The results of these investigations were described comprehensively

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by Schmetzer & Bank (1981) and are compared in this article with the investigations of other garnet specimens from the Umba Valley.

The so called 'Malaya-garnets' are members of the solid solution series between the already known end members pyrope and spessartite. The values of density and refractive index are found to be between 3.82 and 4.05 g/cm^3, and between 1.751 and 1.788, respectively. For these gemstones known as 'Malaya-garnets', two or more different solid solution series seem to exist, which probably come from different prospects and/or various mother rocks. On the one hand, members of the solid solution series pyrope-spessartite with grossularite components up to 10% were observed, without, however, a distinct Fe-content—that means, without an almandine component. On the other hand, a different garnet solid solution series is also present, consisting of the end members pyrope-spessartite, but these grains also show a distinct almandine component. Garnets similar to this second series have already been described by Jobbins *et al.* (1978) from the Umba Valley, Tanzania, and by Schmetzer & Ottemann (1979) from the same locality and from the placer deposits near Ratnapura, Sri Lanka. Garnets from this series, containing small amounts of V_2O_3 and/or Cr_2O_3, show an alexandrite-like colour change.

Taken as a whole, the samples of the different series mentioned up to now differ distinctly in their chemical composition from another main group of garnets from the Umba Valley. This second group of garnets was comprehensively investigated by Zwaan (1974) and Jobbins *et al.* (1978), who showed that it consists of members of the solid solution series pyrope-almandine with small molecular components of spessartite and grossularite. Their density values were determined to range from 3.71 to 4.04 g/cm^3 and their refractive indices from 1.738 to 1.787.

Members of the solid solution series spessartite-almandine, which is another series of natural almandine garnets, are not yet known from the Umba Valley, whereas they were described from other East African localities (cf. Medenbach *et al.* 1978).

Before the correct naming of the 'Malaya-garnets' from the Umba Valley can be discussed, the possibility of their gemmological determination has to be considered. As in most of the natural solid solution series one can observe a correlation between the physical properties and the chemical composition of a

specific crystal also in the different known garnet series. The garnets from the Umba Valley show a broad variation in their chemical composition and therefore also respective differences in their physical properties.

Since in gemmological practice it is not possible to investigate each single stone with chemical or x-ray methods, only the gemmologically relevant data of a sample which can be determined with certainty, will be regarded in the following text. For this reason it is necessary to look first at the properties of the respective end members of the garnet solid solution series. These data were investigated either on synthetically produced end members or calculated from the values of members of the natural garnet solid solution series with known chemical composition. Within the limits of error of both methods, these data are in good agreement (Table 1, Figure 1). It is evident, that by means of the gemmological

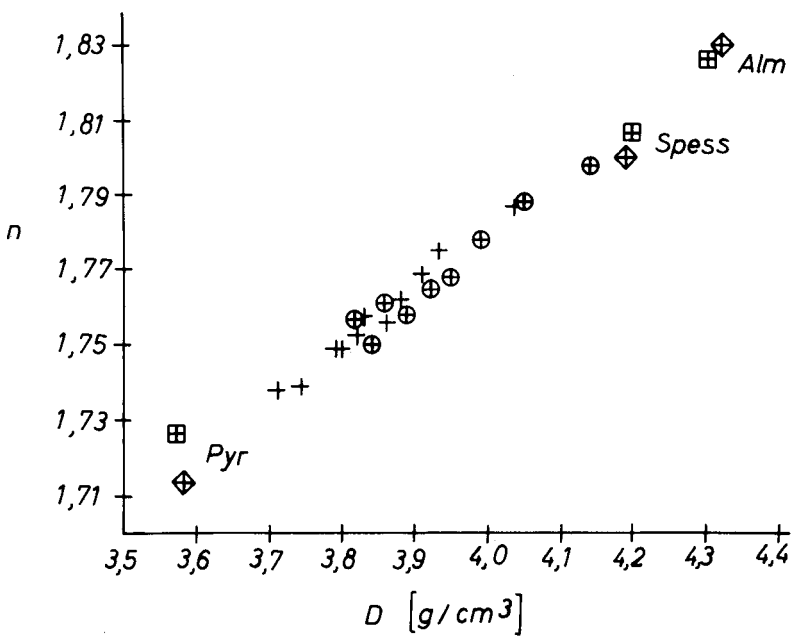

FIG. 1. Refractive index and density of pyralspite garnets, Umba Valley, Tanzania; after Zwaan (1974), Jobbins *et al.* (1978), Schmetzer & Bank (1981). + members of the solid solution series pyrope-almandine, ⊕ members of the solid solution series pyrope-spessartite, ⊞ pyrope, almandine and spessartite (end members) after Skinner (1956), ⊞ pyrope, almandine and spessartite (end members) after McConnell (1966).

TABLE 1

Density and refractive index of garnet end members.

garnet end member	formula	density [g/cm³]		refractive index	
		1	2	1	2
Pyrope	$Mg_3Al_2[SiO_4]_3$	3.582	3.570	1.714	1.727
Almandine	$Fe_3Al_2[SiO_4]_3$	4.318	4.298	1.830	1.827
Spessartite	$Mn_3Al_2[SiO_4]_3$	4.190	4.194	1.800	1.808
Grossularite	$Ca_3Al_2[SiO_4]_3$	3.594	3.598	1.734	1.732

1 after Skinner (1956)
2 after McConnell (1966)

properties, density and refractive index, which can be easily determined, samples of the garnet solid solution series from the Umba Valley, pyrope-almandine and pyrope-spessartite, can easily be distinguished from members of the solid solution series spessartite-almandine or from nearly pure spessartite end members. Neglecting the almandine and grossularite components in the series pyrope-spessartite as well as the spessartite and grossularite components in the series pyrope-almandine which rarely amount to more than 10%, the chemical composition of a single stone can be determined. The properties of the garnets from Umba Valley are located on a straight band between the end members pyrope, spessartite, and almandine, as shown by Figure 1 and in Table 2.

Unfortunately it is more difficult to distinguish between members of the pyrope-spessartite and the pyrope-almandine series, because this is not possible with the density and the refractive index of a sample. Sometimes a distinction is possible by means of the colour; however, in general there is no distinct difference between the colour of a pyrope-almandine garnet with a certain spessartite component and members of the pyrope-spessartite series with a certain almandine component. A spectroscopic determination of members of the described solid solution series by means of a comparison of the intensity of the Fe-absorption bands produced by the almandine component, with that of the Mn-absorption bands, produced by the spessartite component, is possible in gemmological practice with the hand

TABLE 2

Density and refractive index of garnets from Umba Valley, Tanzania; after Zwaan (1974), Jobbins *et al.* (1978), Schmetzer & Bank (1981).

composition, members of the solid solution series	density [g/cm³]	refractive index
pyrope-almandine ± spessartite ± grossularite	3.71 - 4.04	1.738 - 1.787
pyrope-spessartite ± grossularite	3.84 - 3.95	1.751 - 1.768
pyrope-spessartite ± almandine ± grossularite	3.82 - 4.05	1.757 - 1.788
spessartite ± pyrope ± almandine ± grossularite	4.14	1.798
spessartite-almandine	not described from Umba	

spectroscope; but this method needs chemically analysed garnets as standards and certainly very much time, skill and experience. Furthermore, it has to be mentioned here that in some of the Umba garnets, investigated chemically by means of the electron microprobe, a strong chemical zoning was observed. This zoning did not produce differences in the colour in various parts of a stone.

In summary, the garnets up to now called 'Malaya-garnets' from the Umba Valley, Tanzania, are members of the solid solution series pyrope-spessartite, with varying contents of an almandine and grossularite component. Garnets of this composition are not restricted to the Umba Valley but were also described from Ratnapura, Sri Lanka. A distinction of members of the pyrope-spessartite series from those of the pyrope-almandine series on the basis of the colour of a sample is not possible with certainty. A spectroscopic distinction is possible but very expensive and time consuming.

The difficulty of a rapid and certain distinction of the garnet solid solution series described raises the question of whether there is a strong necessity for a differentiation of members of the pyrope-spessartite series from those of the pyrope-almandine series in the

gemmological nomenclature, or whether it is possible to use one expression for all garnets from the Umba Valley.

However, the possibility exists to call the garnets from the Umba Valley with a name which refers to the chemical composition of both series. This possibility is given by an abbreviation customary in petrology; here, garnets of different series between the end members pyrope, almandine, and spessartite are called pyralspites or pyralspite garnets (Matthes 1961). It seems proper to the authors to use this name for all garnets from the Umba Valley, because this name corresponds to the chemical composition of the samples. In case of need, the colour of a specific stone could be added to the name in order to give a better description. Therefore, in our opinion, there is no necessity to introduce a new 'fantasy name' for the Umba garnets, just to promote the sale of garnets from a new locality.

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THE HEAT AND DIFFUSION TREATMENT OF NATURAL AND SYNTHETIC SAPPHIRES

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INTRODUCTION

The subject of heat treatment of corundum has been touched upon only lightly in the gem literature. Although rumours that purplish rubies could be improved by heating were circulated more than thirty years ago, the commercial heating of blue sapphire has become so important that it can no longer be dismissed.

One of the first references that we can find is in an article 'Fakes & Frauds, Caveat Emptor' by J. H. Oughton in the *Australian Gemmologist,* Vol. 11 (4), 91, p.17, November 1971. In this article he refers to a single 'fraud' in which very silky Australian sapphires were presumably heated in a liquid; this was supposedly drawn into hollow tubes which appeared as silk and greatly improved the transparency of the stone. Later, he theorized, the liquid evaporated and the silk became visible again. This account seems to be that of an isolated case since we have not heard reliable reports that heated stones revert. Since the silk in Australian sapphire is caused by rutile needles rather than by hollow tubes, it is doubtful that this is an accurate report. However, a note by the same author in the November 1974 issue of the *Australian Gemmologist* (Vol. 12, p.117) seems to be on the track: here he states that a great deal of inky Australian sapphire is exported for treatment and that he has found no means to detect such treatment.

Also, in 1971 E. A. Jobbins described the 'Heat Treatment of Pale Blue Sapphire from Malawi' in Vol. 12, p.342 of the *Journal of Gemmology.* Evidently this experiment was conducted with the goal of darkening the colour under the assumption that this occurs when blue-green beryls are heated to turn them blue, when in fact the yellow component is merely bleached and the blue aquamarine remains (K. Nassau, *Gems & Gemology,* Vol. 16, p.343, Fall 1980).

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In recent months the GIA-GTL, Inc. has come to realize that the equating of blue sapphires and aquamarines in the matter of heat treating is highly misleading. First, the heat-treatment of many heated blue sapphires is detectable and, secondly, the potential value differences are great. Moreover, insidious additional treatments are being practised so that the sapphire problem is far from clear cut.

Information on the behaviour of ruby and sapphire on heat treatment is known from the manufacture of the synthetic material (K. Nassau, *Gems Made by Man,* Chilton, 1980) and from other technological studies. Based on such knowedge we can define the nine types of treatment of Table 1. The changes of the first five treatments can penetrate completely throughout a stone, but the effect of the next four is confined to the surface of a stone and is easily lost on repolishing. Several of the processes can occur simultaneously, depending on the condition used. More detail will be given in a forthcoming report (K. Nassau, to be submitted to *Gems & Gemology*).

There are also many hearsay reports, some of which are obviously unreasonable, and all of which should be taken with a heavy sprinkling of salt until confirmed by hard evidence. Thus the 4000 °C heat treatment reported to G. Tombs (*Z.Dt.Gemmol.*

TABLE 1.
Heat Treatments used on Sapphires and Rubies*

TREATMENT	RESULT
A. Heating only:	
1. Medium temperature	Develops potential asterism
2. High temperature, rapid cooling	Removes silk and asterism
3. Reducing heating	Develops potential blue colour
4. Oxidizing heating	Diminishes blue colour
5. Extended heating	Diminishes Verneuil banding and strain
B. Heating under unknown conditions:	
6. ?	Introduces fingerprint inclusions
C. Heating plus surface diffusion of impurities:	
7. Adding TiO_2	Produces asterism †
8. Adding TiO_2 and/or Fe_2O_3	Produces blue colour †
9. Adding Cr_2O_3, NiO, etc.	Produces other colours †

*Treatments 1 to 4 correspond to processes also occurring in nature; treatments 5 and 6 are used on synthetic material; treatments 7 to 9 do not correspond to natural processes, can be detected and, accordingly, it would seem that their use should be disclosed.

† Effect is limited to a region near the surface.

Ges., Vol. 29, p.79, 1980) is even above the melting point, while the 1000 °F reported to E. Sasaki (ibid., p.66) is as unreasonably low.

Simple Heat Treatment and Identifying Characteristics

In the mid 70s we began to hear that Thai dealers were appearing in Colombo, Sri Lanka, in search of a type of milky white corundum that has become known as 'Geuda stone' (possibly the name of a mine). It was rumoured that back in Bangkok this material was heated to produce quite acceptable clear blue faceted stones. This treatment is presumably a combination of treatments 2 and 3 of Table 1. GIA-GTL, Inc. received a sample of Geuda sapphire from New York dealer Alan Caplan in 1977 (Figure 1). For a short time in about 1976, parcels of heated blue sapphire were offered in New York as treated sapphires for considerably less than untreated stones. Buyers were wary until it was discovered that no positive proof of heat treatment was forthcoming. Gradually the trade here and abroad began to equate the heating of sapphires with the heat treatment of aquamarine, for which no tests exist. Geuda stones have been discussed by H. S. Gunaratne in this *Journal,* (January 1981, Vol. 17, p.292.).

Looking back twenty-five to thirty years at the tests on which we used to rely for distinguishing natural blue sapphires from synthetics, it now appears that most heated Ceylon sapphires do have indentifying characteristics. For one thing, we rarely ever encountered a natural blue sapphire with the dull, chalky green fluorescence we see in a large percentage of heat treated stones. At the same time, we do not see the iron absorption line at approximately 4500 Å in the spectroscope in most heated stones. Under magnification we frequently see internal stress fractures (Figure 2) around single crystal inclusions and in areas where there had been fingerprint inclusions. Also, cross-hatched colour-banding (Figure 3) and areas of rutile needles reduced to Kashmir-like colour-zoning were never seen in the past, while the then common rutile silk is no longer seen now. Cut stones that are heated need to be repolished and evidence of this takes the form of pock-marked facets or girdles not completely retouched (Figure 4). Also the girdles may have many planes unlike a normal girdle (Figure 5).

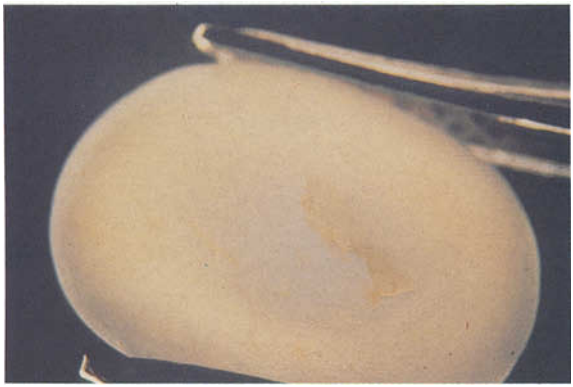

FIG. 1. Geuda sapphire.

FIG. 2. Internal stress fractures around single-crystal inclusions in heat-treated natural sapphire.

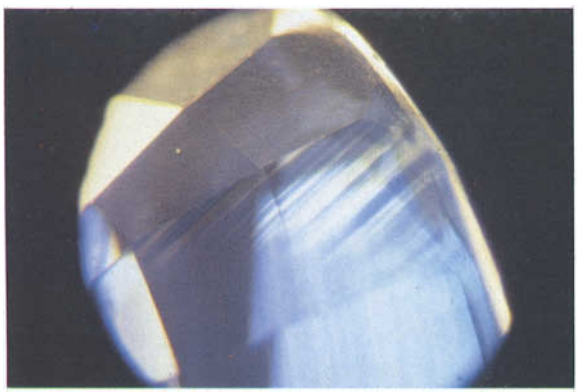

FIG. 3. Cross-hatched colour-banding in heat-treated natural sapphire.

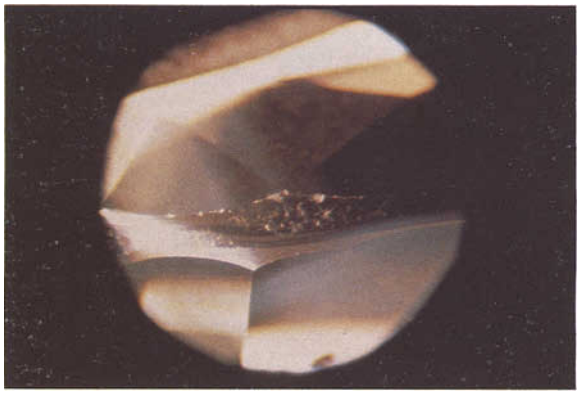

FIG. 4. Pock-marks in incompletely retouched girdle of cut stone after heat treatment.

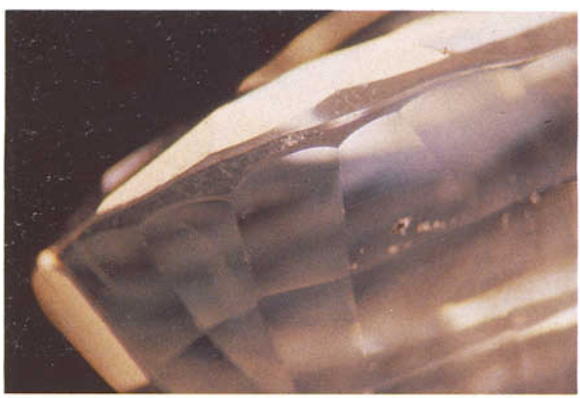

FIG. 5. Girdle of cut stone after heat treatment, having many planes (unlike normal girdle).

Rumours that yellow colour in natural sapphires is being produced through heat treatment by a laboratory in the U.S.A. have persisted since early 1980. The GIA-GTL, Inc. has had occasion to test several orange-yellow to yellow-orange natural sapphires (*Gems & Gemology,* Summer 1980, Vol. 16, p.320.) which did not have a characteristic fluorescence or an iron absorption. Failing to secure permission to conduct a simple fade test in direct sunlight, the reports indicated that the origin of the colour is unknown, but if it were due to irradiation, as all

gemmologists know, the colour will fade. We have now had an opportunity to fade-test some beautiful orange-yellow sapphires which did not fade and were claimed to be a product of this new lab.

In view of the fact that the colour is unnaturally intense and the fact that the colour is due to treatment, the Labs indicate this on reports. This would appear to be a case of discrimination, since so many blue sapphires have their colour and appearance enhanced by heating and the Labs do not at present mention it. The reason, of course, is that tests for blue sapphires are not conclusive in many cases. If a yellow to orange sapphire had no diagnostic inclusions, it would be necessary to do a careful Plato test to separate it from a Verneuil synthetic.

The development of potential asterism by employing heating as in process 1 of Table 1 where nature did not complete the process, has been used on an experimental basis for a long time.

Lightening of a deep blue colour by process 4 of Table 1 has been reported; this may lead to green or yellow sapphire if an underlying yellow colour is also present. This process is probably used on the pale and/or milky Ceylon and Australian rough reportedly heat-treated to produce yellow to orange sapphire (although, if it turned colourless, irradiation could then have been used to produce a yellow to orange, which is, however, not commercially acceptable as the colour is not stable to light or heat). Similarly produced may be the heated Australian sapphires, presumably lightened from the very dark blue and reported to have a pronounced green dichroic direction. Purple sapphire could be converted to ruby by this treatment.

Much less is known about the heating of rubies. It is felt by many experienced dealers that a great percentage of Thai rubies have been improved in colour by heating. At one time such stones were said to be from a new mine. The old purplish to brownish typical Thai ruby has virtually disappeared from the market, suggesting that it now reaches the market enhanced by heat. The red ruby coloration is not affected by heat, but undesirable modifiers such as blue can be removed.

Even less is known about the prevalence of heating cloudy Burma rubies to increase transparency and improve colour. It is rumoured that it may require several heatings to accomplish the desired results and there is considerable risk of damage involved.

SURFACE DIFFUSED SAPPHIRES AND IDENTIFYING CHARACTERISTICS

In the fall of 1979 we reported in *Gems & Gemology* (Vol. 16, p.194) the testing of a red-orange natural sapphire in which most of the colour lay on the surface (Figure 6) with some facets lacking colour entirely. We deduced that it seemed to be an example of colour diffusion using process 9 of Table 1. This process is among those outlined in U.S. patent 3,897,529 issued to R. R. Carr and S. D. Nisevich of the Union Carbide Corporation in 1975 and can produce a full range of diffusion colours from orange to red to pink. At that time we did not anticipate seeing the same process used with blue sapphires. However, in September of 1980 in the New York lab we encountered the first of an avalanche of such blue, diffusion-enhanced stones, clearly made by process 8 of Table 1. Their detection is simple if they are unset and can be immersed in methylene iodide. It is usually not necessary to use the microscope if a clear immersion cell is available. The stone and cell are held a few inches above a white paper so that the splotchiness of colour caused by unequal repolishing of the facets is revealed (Figure 7). Because the raw material may be heavily colour-zoned and the diffused surface colour evens out the appearance, the Gem Trade Laboratory simply states on reports for these stones—'Natural Sapphire, Wt. . Note: Color has been surface enhanced by an artificial diffusion process'.

In May, 1981 we encountered our first heavily zoned stones in which colour seemed to be concentrated at facet junctions (Figure 8). Such zoned rough is reported to be typical of the Ootu Mine in Sri Lanka. The explanation has to be that the stones were diffused in the preform stage, possibly after unsuccessful heat-treating attempts. It resulted in some of the most handsome blue treated stones we have seen. This type of diffused colour treatment is not recognizable without immersion and might be impossible to detect in a mounting. At the same time we encountered our first example of a colour-diffused cabochon. The colour has been removed from an area around the girdle (Figure 9) reminding us of the faceted stone in Figure 22 in the Spring 1981 issue of *Gems & Gemology,* Vol. 27, p.46). Most of the surface-diffused stones we have seen do not fluoresce under short UV. None of the twenty cabochons in the necklace (Figure 10) from which this stone was removed for testing

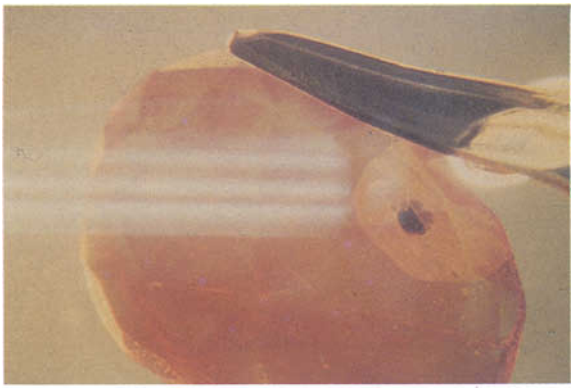

FIG. 6. Red-orange sapphire with most of the colour on the surface.

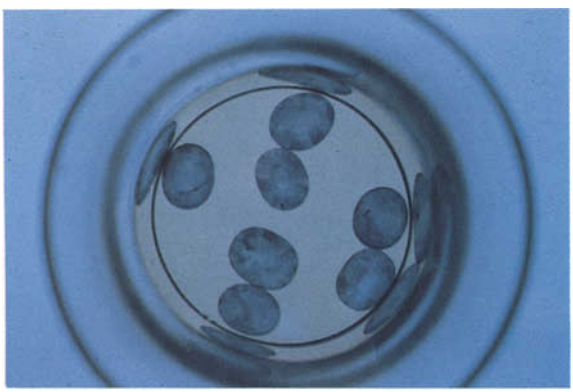

FIG. 7. Splotchiness of colour in diffusion-enhanced sapphires.

FIG. 8. Colour apparently concentrated at facet junctions in a heavily zoned stone.

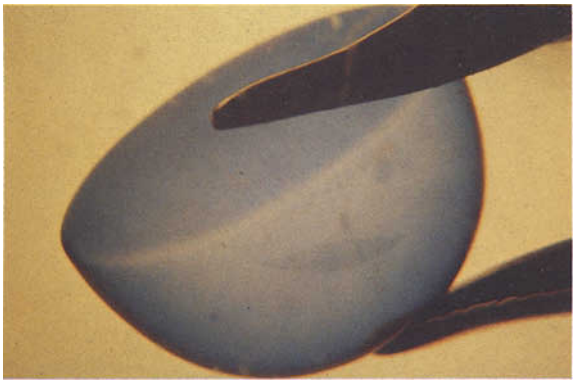

FIG. 9. Colour-diffused cabochon sapphire, with colour removed from an area around the girdle.

FIG. 10. Necklace from which colour-diffused cabochon sapphire in Figure 9 was removed.

FIG. 11. 'Bleeding' inward of colour in colour-diffused cabochon sapphire.

was recognized as diffused when first observed in the setting. Then we noted a clue in a few of the stones which indicated diffused treatment: this was the 'bleeding' inward of colour from open pits, fissures, and fractures (Figure 11). We examined some of our own faceted diffused stones and noted the same features.

Many experienced dealers feel they can recognize both diffused and heat treated blue sapphires by a certain watery appearance or thinness of colour. Perhaps compared with older Burma, Ceylon, and Australian stones this is a factor, but, if the heated or diffused stone was originally heavily colour-zoned, this characteristic is not evident.

We and others have reported the lack of success in securing eyewitness accounts of the actual heating process. We have had reports that heating is done with crucibles (Figures 6 and 7 of Summer 1980 issue of *Gems & Gemology,* Vol. 16, p.318) packed into 55-gallon drums serving as ovens. But we have also heard that sophisticated furnaces and platinum crucibles are used. In fact, one dealer claimed he was present when such an oven exploded in the next room while visiting a supplier in Bangkok.

Asterism can be added by a surface diffusion step as described in U.S. Patent 2,690,630 issued to W. G. Eversole and J. N. Burdick of Union Carbide and Carbon (Linde) in 1954 and also in the Carr and Nisevich patent. This is process 6 of Table 1 but only seems to have been used experimentally. It was not until 1968 that the GIA-GTL, Inc. in New York was shown some of these stones (Figure 12). Since they were never available commercially, we had not seen any since that time until May, 1981 as this manuscript was being prepared.

Three star sapphires (Figure 13) were submitted to the Los Angeles Gem Trade Lab and subsequently forwarded to the New York Lab for study. They were reported to have been a recent purchase in Bangkok. Like the stones we first examined in 1968, the individual star-causing needles are extremely fine and the star unnaturally sharp. The colour of two of the stones is 'not right' and 'bleeding' of colour around pits and fractures indicated colour diffusion (Figure 14), while the fine needles indicate the induced asterism. Two stones showed weak greenish fluorescence under short UV and all showed a weak iron line at 4500Å in the spectroscope. The third stone is a pleasing blue, but the star is 'too

FIG. 12. Asterism added by a surface diffusion step (process 7, Table 1).

FIG. 13. Three star-sapphires with induced asterism. These stars are sharper than they appear in the photograph.

FIG. 14. 'Bleeding' of colour around pits and fractures indicates colour- diffusion.

sharp'. All three stones exhibited iridescent internal fractures. Possibly, such flawed material is not suitable for faceting, hence it is relegated to being processed as star material.

CHANGES IN INTERNAL STRUCTURE (TREATED VERNEUIL SYNTHETICS)

Dealers have tried to secure information on heat treatments for us, for which we are most grateful. One dealer's Bangkok supplier, after many requests, finally sent him three parcels of sapphires purported to be three stages in the heating process. We were delighted to see some heavily colour-zoned preformed 'Ootu' stones before heating, some evenly coloured similar shape preforms presumably heated and some quite beautiful cut stones. However, upon testing the three lots, only the unheated preforms were natural sapphires. The rest were heated Verneuil synthetics, most with induced fingerprint inclusions (Figure 15)! One report states that the heating of Verneuil synthetics (which improves the appearance considerably) is not done in Bangkok, but in California, Japan, and Switzerland. The donor of the crucibles mentioned in the Summer 1980 issue of *Gems & Gemology,* Vol. 16, p.315, says that heating of Verneuil synthetics with induced fingerprint inclusions is carried out in Bangkok. To the jeweller gemmologist who must identify them, it really makes no difference where the treatment is performed. We have noted that a positive Plato test is more difficult to secure since the heating eases some of the strain in the crystal structure in addition to improving the colour immensely. However, we doubt that repeated heating of natural banded sapphires finally causes the bands to curve, as several Bangkok dealers have mentioned in defence of their heat treated Verneuil synthetics!

We have encountered Verneuil synthetic rubies and pink sapphires containing induced fingerprint inclusions (Figure 16). It would seem logical to anticipate similar deceptions with all colours of synthetic corundum. The pink synthetic sapphire shown here was beautifully 'native' cut. It had fingerprint inclusions and repeated twinning lines. However, it also had tiny gas bubbles and characteristic chalky green over red fluorescence under short UV. The diminishing of the curved growth lines of Verneuil rubies and sapphires is process 5 of Table 1, while the unknown process involved in producing fingerprint inclusions is process 6 of Table 1.

FIG. 15. Induced fingerprint inclusion in heated Verneuil synthetic sapphire.

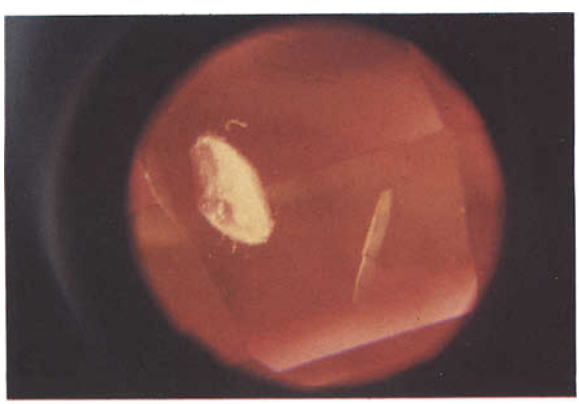

FIG. 16. Induced fingerprint inclusion in Verneuil synthetic pink sapphire.

SUMMARY

The jeweller gemmologist today is confronted with a wide variety of treatments and processes which have complicated the task of identifying many colours of sapphire. A blue or yellow faceted stone that appears to be a sapphire may with careful testing be identified as any one of the following: a natural, unheated stone; a synthetic stone; a simply heat-treated natural stone (lightened or darkened); a heat-treated synthetic stone (with or without induced

fingerprints); a natural sapphire with surface colour diffused either when the stone was preformed or finished; an irradiated yellow to orange fading sapphire. When one considers the imminent commercial appearance in the market of flux-grown synthetic blue sapphires to say nothing of garnet and glass doublets and natural/synthetic sapphire doublets, the comparison with heating beryl to produce aquamarine is indeed inappropriate.

Only by becoming aware of all the possible treatments used on corundum can one know for what specific signs to be alert. Unlike the heat-treatment used on aquamarine, it is often possible to detect the heat or diffusion treatments in sapphire.

If diffusion has been used, the effects are limited to a very thin skin at the surface of the stone and can accidentally be removed if recutting becomes necessary. This has become a definite problem for dealers world wide as well as in Bangkok.

Aside from unusual inclusions seen in heated Burma rubies such as rutile needles that have been incompletely absorbed, the evidence of heat treatment is scant.

The first four treatments of Table 1, correspond to processes also occurring in nature. The reason why some of those can be recognized lies in the rapidity of these treatments: since geological periods of time are not available, it is necessary to use somewhat higher temperatures than nature uses and this sometimes leaves evidence in the stones. The last four treatments do not correspond to natural processes and are identifiable; accordingly, it would seem that disclosure of their use is essential.

As a last point, it is clear that corundum from different localities can show considerable variation in its reaction to these treatments.

[*Manuscript received 4th July, 1981.*]

THE FIFTIETH PARALLEL

By A. E. FARN, F.G.A.,

lately Director of the Gem Testing Laboratory of the London Chamber of Commerce and Industry.

Have you ever sat in a train or a bus opposite someone reading a newspaper with intriguing headlines? Have you ever suffered eye strain or neck pains through craning in attempts to wrest more information literally from an appetite-whetting situation? Such was my predicament or position the other day. I was writing a report at my desk on a pearl necklace; I saw across from me my colleagues notes inadvertently displayed. The heading I read (upside down) was: 'What is a gem?' This seemed to me an ideal heading for an article dealing perhaps with etymological derivation, the history of gemmology or some particular facet of the fascinating science we pursue. When I was invited to write something for the fiftieth anniversary-year celebration of the Gemmological Association of Great Britain I felt honoured and frankly flattered. Equally I felt a little concerned.

In earlier years, when renowned gemmologists achieved three score years and ten, special tributes were written in their honour. These well-deserved tributes stemmed from pens of erudite scientists each offering some new finding or item of specialized research. *This* is the kind of worry I have both in this instance and when I attend an international conference—the question or demand arises, in effect, what to contribute?

Far from being a scientist I am a member of the trade, fortunate enough to have secured a job in the Laboratory, a job which I was not seeking but when offered I accepted. I hoped some mistake in identity had not occurred, but if so I hoped I could be kept on. Following this stroke of luck I spent the next thirty-five years at this fascinating job. I met people from all walks of life in the jewellery/gemmological world in its broadest concept. Nineteen eighty-one is the fiftieth anniversary year of the Gemmological Association of Great Britain; it is equally my own fiftieth year of working in the jewellery trade.

I have entitled my contribution 'The fiftieth parallel', because on looking back upon my years in the Laboratory and those of the G.A., I was struck by this parallel aspect. I was surprised upon

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looking at the very close association, friendship and progress made by Harry Wheeler, F.G.A., of the Gemmological Association, and myself in our respective, respected and closely complementary careers.

Just before the War (1939-1945) both Harry Wheeler and myself were students at Chelsea Polytechnic under the tuition of B. W. Anderson, B.Sc., F.G.A., then the director of the Laboratory of the London Chamber of Commerce Inc.; Gordon Andrews, a Tully Medallist, was then secretary of the G.A. and director of examinations. Harry Wheeler and I both passed our first year examinations and received a Chelsea Polytechnic certificate (a collector's item now?). Then followed six years of war service in H.M. forces. In 1946 we both re-enrolled for our second year course in gemmology. B. W. Anderson was still teaching at Chelsea Polytechnic. Both Harry Wheeler and myself passed our second year examination not without distinction—considering six years interruption, a satisfactory result.

Harry continued working with Gordon Andrews at the G.A.'s various addresses in Hatton Garden, Ely Place, and now at Carey Lane. The Laboratory under B. W. Anderson continued at various addresses in Hatton Garden; I was his junior colleague. The laboratory of the London Chamber of Commerce was a gemmological centre. As well as this aspect, the actual work of gem testing for the trade continued. We tested scores of thousands of pearls and scores of thousands of rubies annually as part of our job. Woven inextricably in our everyday conversation would be the G.A., its examinations, the questions, the examiners, the instructors, the presentation of awards, the Goldsmiths' Hall. All would be part of the potpourri of a working day. With B. W. Anderson and Robert Webster as principal instructors and myself as a later assistant at classes, it is small wonder the students thought that *we* were the G.A. laboratory! Certainly we were a gemmological laboratory. Our visitors and friends in those days, it seemed, were gemmologists who were bird-watchers (ornithological mostly) as well as *Times* crossword addicts. Ernest Rutland, Ph.D., F.G.A., was a member of our evening class in 1947. He soon made his mark by becoming an instructor, later examiner. Lunch times in those days would find Ernest Rutland, Robert Webster, C. J. Payne, B. W. Anderson and often Gordon Andrews at one table *devouring The Times* crossword, but otherwise dining normally.

Gordon Andrews had a penchant for anagrams, Ernest Rutland was strong on Shakespeare, C. J. Payne was the history expert and Robert Webster supplied his own broad knowledge culled from a long working life. Anderson was the master.

Later, when erudite gemmological discussions arose, exams were examined, students studied, questions questioned and the results reviewed. This conversation of those eminent men served to keep me in a sort of friendly fringe atmosphere (small fry perhaps). I seldom contributed to the solving of *The Times* crossword! The continued contact of intelligent and intellectual conversation, the proper use of words, etc., did at least help to afford a little polish to my trade knowledge, for which I have been grateful ever since.

On practically every working day at the Laboratory we would receive from or deliver to the G.A. some items of work or the results of enquiries. There was (and is) a continual coming and going of their messengers. The telephone rings daily with calls to and fro bound up with gemmology and its participants. I think the basis of so much understanding stems from the strong links forged over the years between Andrews and Anderson and Webster and Andrews, with Harry Wheeler and myself in the background doing the basic *real* work! In our own manner I would like to think that Harry Wheeler for the G.A. and myself for the Laboratory have continued on that same parallel.

To have been asked to contribute something for this anniversary has provided me with a nostalgic opportunity to look back and reminisce upon my very happy early days in the company of gemmological friends. I can only talk 'shop', since as a child I lived over a jewellers'/pawnbrokers' shop, as a young man I 'lived in' over a jewellers'/pawnbrokers' shop and have been trade orientated all of my working life, Looking back, I think to myself 'Fifty years—it doesn't seem all *that* long.'

Harry Wheeler, now secretary of the Gemmological Association, and myself, now director of the Gem Testing Laboratory,* meet frequently—unlike parallel lines which only *seem* to merge. We have arrived at this our '50th parallel' as a fitting tribute, I hope, to this our anniversary gemmological celebration.

[Manuscript received 10th January, 1981]

*Mr Farn retired on 17th March, since this article was written.—Ed.

RECENT OBSERVATIONS ON AN APPARENTLY NEW INTERNAL PARAGENESIS OF BERYLS

By Prof. Dr E. J. GÜBELIN, C.G., F.G.A.
Meggen, Lucerne, Switzerland

That ingenious artist Nature, gifted with highly fanciful imagination, has granted the prolific womb of the pegmatite the prerogative of bringing forth innumerable variations of design and combinations of inclusions in its precious gems. Notwithstanding this immense multitude of varying formations, repeated similarities do occur, and many a pegmatitic species or varieties thereof excel with characteristic internal features which are specifically inherent to these particular gemstones. To mention a few: the growth tubes running through an aquamarine parallel to the *c*-axis (the so-called 'rain') and being filled with one or two fluids or with quartz and apatite and/or epidote respectively; or those partly-healed fractures surrounding a central grain, lying parallel to the basal plane and rendered visible by radially arranged or dendritic residual drops (so-called 'snow-flakes'); or those tell-tale curtains hovering in topazes and consisting of negative crystals in strict alignment with the original prism faces and comprising two immiscible fluids, normally water and carbon-dioxide, as well as the latter in gaseous state; or those unmistakable trichites which faithfully mark tourmalines of all hues and shades and from whatever sources; let alone the well-known golden fibres of byssolite (an amianthus) in demantoid garnets.

With the exception of several elucidating and eloquently illustrated articles by Eppler (1960, 1963, 1964, 1967, 1970a&b), Graziani *et al.* (1979a, b & c, and 1980) and Zwaan (1958), little has indeed so far been reported about the inclusions in common beryls. Their light has always been hidden under the bushel of the gemmologically more enlightening and often locally differing inclusions in the more sumptuous precious stones such as emerald, ruby, sapphire, and also garnet, quite apart from the scientifically highly informative mineral inclusions in diamond.

Strangely enough, the conclusive consistency adding special merit to the above-mentioned gems has not been observed in

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common beryls (i.e. colourless, yellow and green varieties) until recently. Thus it came as a surprise when during the lapse of the last three years, the author time and again noticed an apparently 'new' association of guest minerals in colourless, greenish and bluish beryls. Although the complete paragenesis, as it could be established as time went on, was not always present, two of the component minerals could always be perceived. Curiously enough these various beryls originated from deposits as remote and far apart as Afghanistan, Brazil, Kenya and Switzerland, and it appeared rather striking that all these beryls, although coming from such distant sources, shared at least one guest mineral in common. This consisted either of a large pseudohexagonal colourless or brown crystal and/or brownish-orange isometric crystals obviously belonging to the cubic crystal system. The particularly interesting compositions will be described in brief detail hereafter.

Worth mentioning is a colourless beryl (a so-called goshenite) from Brazil, which had been cut so as to facilitate the inspection of the inclusions. To the unaided eye the host gem exhibited a large brown guest mineral accompanied by numerous small black spots (Figure 1). The large brown inclusion was wrapped in a whitish coat reflecting a silvery lustre, and minute flakes reminiscent of fish scales ejected from it into the clear and transparent body of the goshenite (Figure 2). Under the microscope a few discrete and transparent parcels and single platelets were observed. They possessed a slightly higher RI than the host gem because, upon raising the tube of the microscope, the bright Becke line would move into the alien guests. One of these flakes happened to be exposed at the surface of the colourless beryl, thus allowing a microprobe examination to be carried out. This enquiry revealed the presence of Al (twice as much as in the embracing beryl!), Si, and K. Consequently the parcels and individual platelets were *muscovite.* The large brown inclusion (Figure 2) on the other hand, although also mica, proved to be *phlogopite* on account of the elements K, Mg, Si, and Al, whose presence the microprobe analysis confirmed. The black grains, which under the microscope reflected a strong metallic lustre and iridesced with vivid tarnish colours, indicated the elements Mn, Fe, *Nb* and Ta, and could therefore be declared as *niobite* crystals (Figure 3). The association of muscovite, phlogopite and niobite in one host gem is a new

FIG. 1. Survey of the mineral association (phlogopite, muscovite and niobite) in a goshenite from Brazil. 25 ×

FIG. 2. Detail of Figure 1: cluster of pseudohexagonal crystals of phlogopite accompanied by black grains of niobite. 100 ×

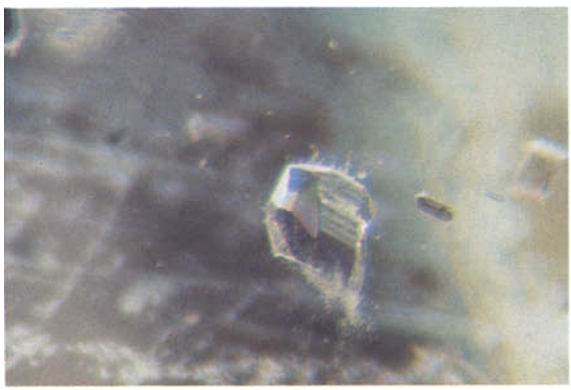

FIG. 3. One well-shaped niobite crystal with metallic lustre and tarnish colours. 50 ×

FIG. 4. Survey photomicrograph of part of the internal paragenesis of the second goshenite from Brazil. We recognize large brownish pseudohexagonal crystals of biotite accompanied by numerous black grains of niobite.

FIG. 5. The truncated, barrel-shaped dark green crystal of Mn-apatite covered by a coat of muscovite in the second goshenite. 20×

paragenesis which has not been previously observed. The presence of mica, but particularly that of niobite, delivers ample proof of a pegmatitic parentage of this goshenite.

Another goshenite, also excavated in Brazil, looked very similar to the afore-mentioned specimen, in that it displayed two very large inclusions of different nature, but also both shrouded in the same kind of sheath with a silvery lustre. They were escorted by numerous black grains or euhedral crystals of metallic lustre or glittering tarnish colours (Figure 4). The assumption that they were *niobite* crystals was again proved correct when the microscope investigation betrayed the combination of Mn with Fe, Nb, and Ta.

The more eye-catching of the two large inclusions was a monocrystal of dark green colour with a distorted hexagonal habit, the prism faces of which were so strongly terraced that it simulated a truncated barrel. The microprobe manifested the elements Ca, P, Mn (and Fe) whose stoichiometric ratio is characteristic for *manganese-apatite* (Figure 5). The other large inclusion was easy to identify by experience and its colour, and the conjecture that it was *phlogopite* (Figure 4) was verified when the electron microprobe responded to the elements K, Mg, Al, Si (and Na). Despite encountering old acquaintances within this second goshenite, we have met with yet another combination of trapped minerals, which supply an equally eloquent testimony as to the origin of the host gem.

The next assays were of three crystals of pale blue, greenish to bluish-green beryls from three different continents. The first sample was a light blue aquamarine which had been found in the gemmiferous province of Nuristan in eastern Afghanistan. Besides a large, colourless and hexagonal prism in its centre, it accommodated several of the above-mentioned brownish isometric crystals. Although most of these were completely enclosed by the aquamarine, a few happened to be exposed at the surface of the host crystal and were thus most enticing for an electron microprobe analysis. This examination registered the elements Mn, Fe, Al, Si (and Ca) in stoichiometric amounts that suggested *spessartine* (Figure 6). Though the cubic morphology of these isometric guest crystals concurred with this result, it seemed at first incredible, since spessartine had not been hitherto known as a regular mineral inclusion in aquamarine. Consequently more analyses were carried out, which nevertheless all led to identical findings. The large, colourless, hexagonal prism was sufficiently big to be visible to the naked eye, and at first sight it was taken for an apatite crystal—mainly so because it displayed several parallel cleavage planes. However, cautioned by a previous publication by Eppler (1964), and using optical means, it was possible to reliably determine this large prismatic crystal to be a pseudohexagonal *muscovite* (Figure 7). This alien crystal was not oriented after the crystallographic directions of the host crystal.

The most elucidating and rewarding specimen of all these beryls was a greenish blue aquamarine from Kenya, which was exceptionally well qualified to confirm the previous observations

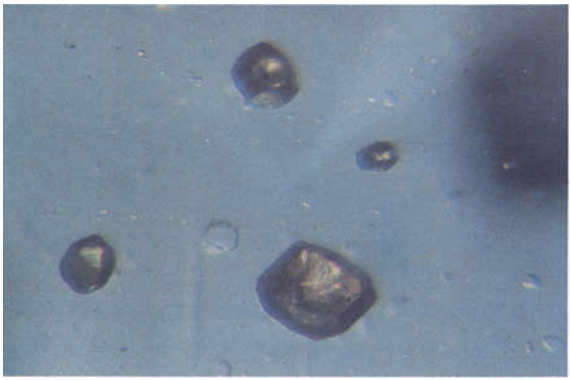

FIG. 6. Brownish spessartine crystals in aquamarine from Nuristan (Afghanistan). 80 ×

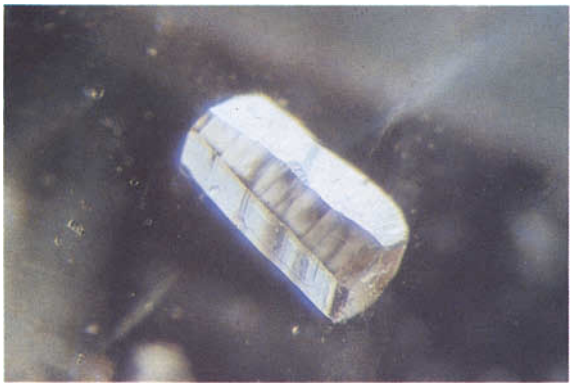

FIG. 7. Large crystal of muscovite distinctly exhibiting pseudohexagonal habit in aquamarine from Nuristan. 40 ×

and analyses. It turned out to be a true bonanza of abundant inclusions encompassing two very conspicuous clusters of white crystals (Figure 8) (part of which protruded beyond the surface of the aquamarine), several brown isometric crystals again (irregularly disseminated through the host crystal), black grains and needles, and, last but not least, a small cluster of a few well-shaped crystals of green hue. All of these inclusions could be subjected to electron microprobe scrutiny, yielding the ensuing results: the white cluster consisted of the elements Na, Al, and Si, and hence was *albite;* the orange isometric crystals agreed with previous findings manifesting the elements Mn, Fe, Al, Si (and Ca) and therefore were *spessartine* (Figure 9). The presence of Mn-rich garnets suggested that the

FIG. 8. Large white cluster of albite crystals on which an orange spessartine crystal and a black platelet of tantalite are perching. Greenish aquamarine from Kenya. 35×

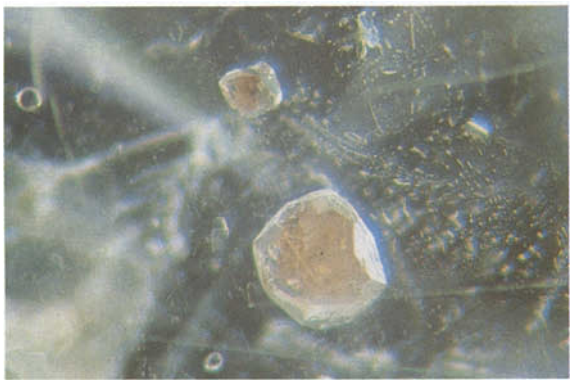

FIG. 9. Orange spessartines complete the internal paragenesis of the aquamarine from Kenya. 100×

black inclusions might be members of the isomorphous columbite series of mixed crystals. Indeed, the elements found, namely Mn, Fe, *Nb* and *Ta,* pleaded for *niobite* or *tantalite.* The tabular crystals (Figure 8) were richer in Nb, while an excess of Ta was responsible for the acicular habits (Figure 10). A further component of this variegated paragenesis was a group of three pseudohexagonal, reddish brown crystals of phlogopite, grown together in parallel arrangement (Figure 11). From the small group of euhedral green crystals near the basal pinacoid, tiny fragments were removed after the basis had been cut down to expose the inclusions. The latter were investigated in an x-ray Gandolfi camera and determined as green *tourmaline* (variety dravite: $NaMg_3Al_6B_3Si_6O_{27}(OH)_3(OH,F)$)

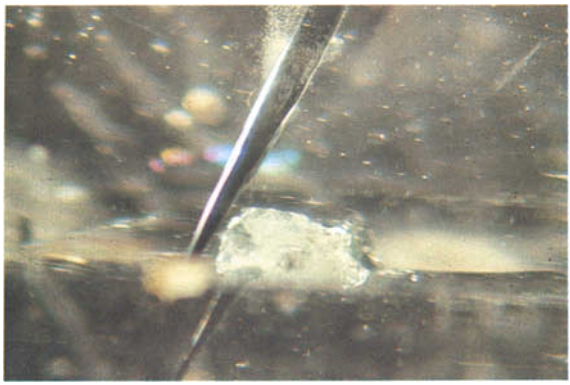

FIG. 10. Two acicular crystals of niobite piercing through the interior of the greenish-blue aquamarine from Kenya. Between the two needles is one of the clusters of albite. 25 ×

FIG. 11. Group of three large pseudohexagonal crystals of phlogopite partly coated by muscovite flakes in close proximity to a large fracture. Greenish-blue aquamarine from Kenya. 35 ×

FIG. 12. A small group of green tourmaline crystals in close contact with gahnite crystals—forming a most unusual internal paragenesis of beryl. 50 ×

in intimate contact with dark green *gahnite* (zinc spinel: Al_2ZnO_4). These two minerals have never before been observed as inclusions in beryl (Figure 12). Thus, this host aquamarine generously granted accommodation to a highly unusual assemblage of guest minerals, namely: albite, gahnite, niobite, spessartine and tourmaline, delivering a quintessence of Nature and proving that she still holds many secrets in store to be discovered by gemmologists.

The presence of mica in pegmatitic gem minerals is quite normal, but the association of mica with albite, spessartine and two varieties of the columbite series was an unexpected surprise.

For the sake of completion, and to emphasize the similarity of the internal paragenesis in beryls from sources far apart, a pale blue aquamarine from Verabbio in the Mesoggio Valley in Switzerland may be referred to as the last item. It housed one relatively large orange isometric crystal (Figure 13), whose faces could effortlessly be recognized as the main growth faces of garnet, and, apart from a few vicinal faces, could be designated by the Miller indices of (110) = garnetohedron and (211) = leucitohedron. In view of this determination and a strong reluctancy to cut down this rare and beautiful host crystal to expose the inclusion, it was decided to abstain from a more elaborate investigation, and to accept the conclusion that this inclusion was another *spessartine garnet* in an aquamarine.

From the various internal parageneses described above, and from their illuminating investigation, emerges the realization that

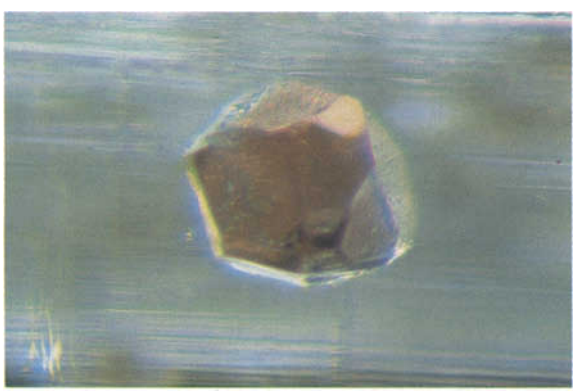

FIG. 13. Large euhedral crystal of spessartine constituting the remarkable internal feature of a pale blue aquamarine from Switzerland. 50×

niobite is the indicative mineral inclusion of paramount importance with regard to unveiling the environment of the host gems in their birth chambers. The growth milieu of niobite is a Mn-rich granitic pegmatite with much albite and lithium-minerals (Klockmann, 1978); consequently it was possible for Mn-rich garnet (spessartine) and Mn-rich apatite to occur and accompany niobite in one and the same host beryl, which itself is a typical product of pegmatite. The large pseudohexagonal mica crystals and their characteristic appearance (marked by cleavage planes parallel to the basal face), represent a most distinctive and unique feature of the internal paragenesis of beryl, by means of which beryls containing them may readily be recognized. In one aquamarine (not described here because of the lack of a picture) a Li-rich mica—a so-called *lepidolite*—was found to form the internal paragenesis together with niobite.

ACKNOWLEDGEMENTS

The author wishes to express his gratitude to Dr H. Krupp, Heidelberg, and to Bill Larson, Fallbrook, for their co-operation in finding gems with interesting inclusions; as well as to Prof. Dr M. Weibel, of the Institute for Crystallography and Petrology of the Federal High-school of Technology in Zürich, for the electron microprobe analyses and valuable comments.

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THE PAILIN RUBY AND SAPPHIRE GEMFIELD, CAMBODIA*

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The Pailin gemfield was discovered by Burmese pedlars as late as 1874, in contrast to the Burmese deposits at Mogok which have been known for centuries. Further contrasts are provided by the geology of the deposits, the gems in Cambodia coming from small basaltic bodies whereas the Burmese rubies originate from limestone, and several rocks including types of syenite are the sources of the sapphires. The Pailin gemfield was investigated by the authors in the mid-seventies and the following account is based upon that visit and subsequent laboratory work.

GEOLOGY

The small gem-mining town of Pailin lies athwart a fault zone trending NW-SE and roughly parallel with the main road (see Map 1, facing p.560). This zone separates a northern region of low relief, underlain by the ancient Precambrian Pailin Crystalline Complex and some Devonian and Carboniferous rocks, from a mountainous region in the south composed largely of Triassic sandstones and greywackes. During the Himalayan orogeny of Tertiary times this southern area—the Tadeth mountains—was uplifted by block faulting and small gem-bearing basaltic bodies were intruded in the vicinity of the fault zone with subsequent extrusion of lavas. Subsequent erosion during Tertiary times, especially by the northward flowing rivers, led to the formation and spread of the bouldery sands and clays of the Ancient Alluvium over the area. This has been reworked into the present river alluvium (Recent Alluvium) and outwash fan deposits during Quaternary times.

As a result of this survey the authors were able to show that the rivers which drained from the small basaltic bodies carried gem minerals including ruby, sapphire, zircon and garnet. Rivers rising in other areas were barren unless they were joined by tributaries

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draining from the basalts (see Map 1). Additional proof for the source of the gems was provided by the relatively rich concentrations of gem fragments (the eluvial deposits) in the *in situ* weathered basalt and the soil profiles overlying the basaltic bodies.

The lavas form four separate hills of varying aspect. Phnum O Tang is a breached crater rising some 40-60 m above the surrounding plains with a lobe of lava extending westwards for almost one kilometre. The Phnum Ko Ngoap lavas form a W-SW trending plateau some 20-40 m above the surroundings and cover an area some 3 km by 1 km. Phnum Ko Ngoap itself—the eroded remnants of a volcano cone—rises some 40 m above the plateau. The Phnum Yat lavas form an elongated plateau, about 600 m wide, which extends roughly N-S for approximately 3 km. Pailin town lies on this plateau (see Figure 1) and the volcanic cone of Phnum Yat (254 m), south of the town is surmounted by a Buddhist temple. The fourth lava outcrop seen in a coffee plantation, is only 200 m in diameter and is considered to be a volcanic pipe.

A thin-section study of the lavas from the Pailin and Chantaburi-Trat (Thailand) gemfields (and from other bodies between them) shows that they are all of an essentially similar basic to ultrabasic silica-deficient type. The chemical composition of the Pailin rock (Lacroix 1933) is very similar to the average basanites quoted by Cox, Bell and Pankhurst (1979). Pailin 'basalt' composition with average 'basanite' in brackets: SiO_2 43.50 (44.30), TiO_2 2.82 (2.51), Al_2O_3 13.91 (14.70), Fe_2O_3 3.62 (3.94), FeO 8.50 (7.50), MnO 0.15 (0.16), MgO 8.48 (8.54), CaO 10.78 (10.19), Na_2O 3.30 (3.55), K_2O 2.20 (1.96), H_2O+ 0.78 (1.20), H_2O- 0.43 (0.42), P_2O_5 0.84 (0.74), Rest 1.03 (0.18 etc.), Total 100.34 (99.89).

The main crystal phases of the groundmass appear to be analcime and feldspar, often in the range of oligoclase-andesine. Microlites of augitic pyroxene are sometimes identifiable, but mostly the groundmass is fine grained with low relief and very low birefringence. An x-ray examination of the light fraction (SG$<$2.9) showed major analcime and some feldspar. All rocks are porphyritic with phenocrysts of augite, euhedral olivine (often serpentinized) and feldspar. Vesicles containing opaline and chalcedonic silica, andesine and radiating zeolites were noted. The lavas are tentatively referred to as analcime-basanites.

FIG. 1. Pailin looking west: foreground - alluvial workings in O Ta Prang river; middle distance - volcanic vent of Phnum Yat (temple on extreme left) and lava flows extending to north (right); slopes to Tadeth mountain at rear.

The other notable feature of the Pailin lavas is the presence of large megacrysts of magnetite, ilmenite, dark spinel, clinopyroxene, garnet, olivine, phlogopite mica and feldspar. Zircon, ruby and sapphire are found in the gem gravels and have been weathered out of the lava, but we found only one zircon in the lava and only one ruby in matrix was reliably reported although others were reported by the miners. This suggests a sparse distribution of the gem minerals in the lavas, with a marked concentration as a result of weathering. There appears to be an erratic distribution of the megacrysts and not all occur in every outcrop and no rubies, sapphire or zircon were found near the small volcanic pipe.

FIG. 2. Pailin rubies and sapphires (from 1 to 3 ct) showing colour variations, with clinopyroxene xenocryst from the basalt.

A study of the xenocrysts as recovered reveals that many of them, especially the sapphires and clinopyroxenes (see Figure 2), show marked corrosion reminiscent of the ablation marks on meteorites. We suggest that the xenocrysts of corundums, clinopyroxenes, garnets, spinels and others were originally formed at great depth by metamorphism and/or metasomatism on the margins of a basic pluton and were then intruded rapidly with the basic magmas at a later date.

Reference to Map 2 will show that the basaltic bodies in Indo-China may be divided into two broad groups—small and large. The small bodies of the Pailin-Chantaburi type carry ruby, sapphire, zircon and garnet, whereas the larger, and more easterly, bodies are relatively barren save for the zircons at Ratanakiri described by Lacombe (1968-70). Work on the dating of these lavas is still in progress, but determinations on the Pailin lavas have yielded ages between 2.14 and 1.4 million years (U. Pliocene-L. Pleistocene) in contrast to ages for the larger bodies which go up to 12 million years. It may be that the older bodies initially carried gem corundum, but that later outpourings were barren and that gems are buried under later lavas.

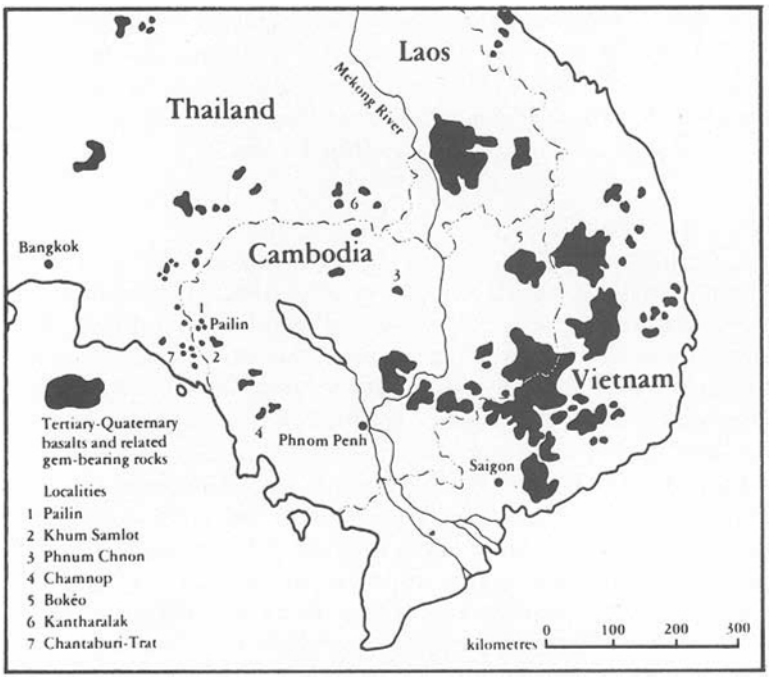

MAP. 2. Gem localities and basaltic vulcanism in south-east Asia.

Examining the gem-bearing bodies in more detail shows that the small basaltic plateau (with its two volcanic necks of Khao Ploi Waen and Khao Wua), some 8 km west of Chantaburi, yielded blue, green and yellow sapphires and the so-called 'black star-sapphires'. Some 37 km to the east the workings near Ban Bo Na Wong produce mainly rubies (ruby:sapphire ratio said to be 20:1). Still farther east (and near the Khmer border) the deposits near Ban Thung Chug Ka Chan produce rubies with very small amounts of blue sapphire. The deposits at Bo Rai (some 28 km south of Pailin) are almost certainly ruby producers as are those at Bar Khal Stung (about 9 km NE of Bo Rai and often referred to as Khum Samlot). Finally we have the eastern bodies at Pailin which are ruby producers save for the Phnum Yat body producing sapphires.

These deposits are all derived from similar basaltic rocks and it is interesting to note the colour changes (and, of course, the colouring agents) from blue/green/yellow in the west through red and back to blue at Pailin where no yellow sapphires were reported.

The reasons for these changes are not immediately apparent—are they connected with the relative ages of the intrusions, with the colouring agents changing as vulcanicity proceeded, are they the result of tapping different levels in the deep-seated magma or has local assimilation of country rocks played a part?

THE GEM MINERALS

Probably the most striking aspect of the corundums of the Pailin area is the virtual absence of colourless, yellow and green stones. None were seen by the authors, and the local diggers and gem merchants could only vaguely recall the very occasional yellow stone. Nevertheless there is considerable range in colour from pink to brownish-red in the rubies of the Phnum Ko Ngoap and Phnum O Tang bodies and from very pale blue to deep blue in the sapphires from Phnum Yat. The rubies may sometimes attain a virtual 'pigeon's blood' or 'Burma ruby' red and these stones become only slightly more red in tungsten lighting; the directional change in colour due to pleochroism is small, the extraordinary ray being only very slightly more yellowish-red. Good colour rubies were reported from the gemfields near Khum Samlot. Paler and more purple stones which occur in all three bodies often show a wider pleochroic change from yellowish-red to purplish-red and there is a noticeable increase in redness when viewed by tungsten lighting. Pronounced colour-change material is not uncommon in the gravels from Phnum Ko Ngoap and to some extent from Phnum O Tang. These stones appear violet when viewed along the optic axis but a pale yellowish-grey in other directions; under tungsten lighting they change colour to deep pinkish-red and pale yellowish-brown, and such stones could be mistaken for reasonable rubies if viewed by artificial illumination. Deep pink and bright red stones show the chromium spectrum normally asociated with ruby, but as the colour deepens with increasing percentage of iron and the reds become brownish or purplish, the chromium spectrum tends to be modified or even swamped by absorption in the green and blue due to iron which is a characteristic of many stones from this area. The sapphires, which were usually of good commercial colours and not of inky hues, show an attenuated absorption spectrum only with a distinct line at 4500Å and a very faint line at 4600Å.

The fluorescence of the Pailin stones under ultraviolet light (long wave 3650Å) is generally weak, the bright red stones

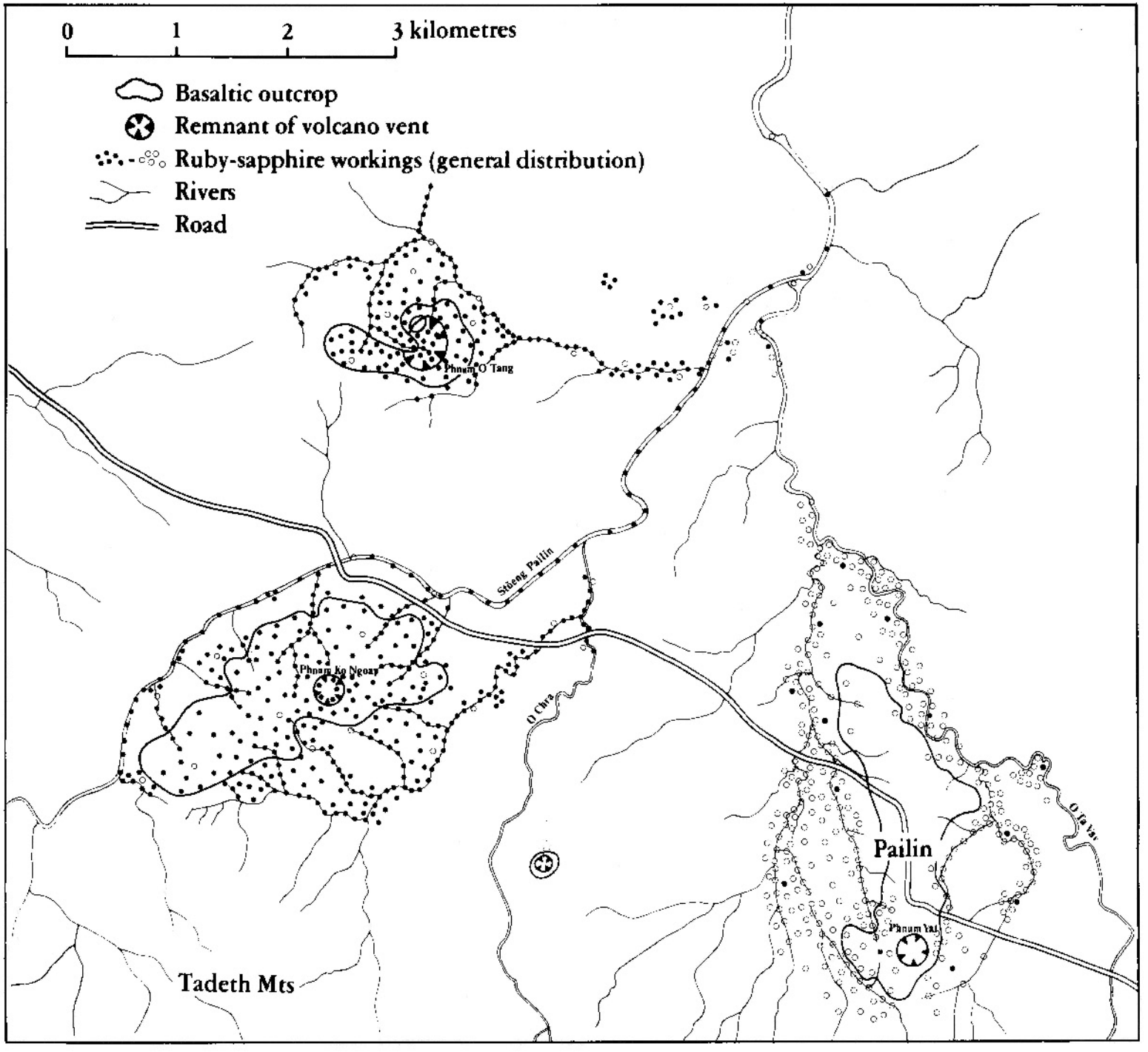

MAP. 1. Distribution of ruby and sapphire occurrences in the Pailin gemfield, Cambodia.

appearing a dull red, whereas the darker and more brownish-red stones are almost inert. Blue stones show no fluorescence and virtually all stones examined were inert under short wave (2537Å) radiation.

The refractive indices of the stones were normal, being in the ranges 1.760 to 1.762 for the extraordinary ray, and 1.768 to 1.770 for the ordinary ray, with a constant birefringence of 0.008. Specific gravities determined were in the range 3.993 to 4.007.

Colour zoning is common in the stones, and many sapphires are quite cloudy due to microscopic inclusions. We were assured that these imperfections and some of the larger inclusions become almost invisible to the naked eye and the colour improved by the heat-treatment process (which often included the use of chemicals) to which a high proportion of the sapphires and rubies are subjected either in Pailin itself or in other marketing centres such as Bangkok.

Zircon, mainly seen as fragments up to 5 cm long, from the Phnum Yat body ranged from colourless through pale straw to reddish-brown and brown in colour. Tiny euhedral, but broken, zircon crystals of a bright orange-red colour were also seen. As with corundum, euhedral material was uncommon and the subhedral and other grains showed much evidence of corrosion in their smooth, very bright surfaces, which appear to be a characteristic of many zircons of basaltic parentage. Freshly broken surfaces were also found, probably due to fracture during river transportation.

Unlike gem zircons from Burma and Sri Lanka which contain uranium and and/or thorium and show rich absorption spectra, the zircons from Pailin hardly show a spectrum although faint lines in the red are sometimes just discernible.

The garnets are invariably an intense brownish-red colour and the grains show their transparency only when held to sunlight or an intense light source. The specific gravities of grains determined are in the range 3.756 to 3.768 and the refractive indices are in the range 1.748 to 1.750. As might be expected from the deep colour, the absorption spectrum is intense with complete absorption of the blue and much of the green part of the spectrum, with a faint line in the orange. These properties indicate that the stones are in the pyrope-almandine range and nearer to the pyrope end of the series. These garnets are mostly too deeply coloured to look really attractive when cut.

The garnets are generally angular to subangular in shape but close examination of some grains shows them to have rounded edges. In addition many surfaces show etch-pits of triangular or lozenge-shaped cross-section which may develop into fine channels commonly crossing at angles which suggest a relationship with the crystallographic symmetry of the mineral. These features point to fragmentation into angular pieces whilst still in the magma, followed by rapid corrosion and etching, which in some instances produces a fine saccharoidal surface pattern. More rounded fragments showing dull water-worn edges are not uncommon in the gem gravels.

Dark brown to black clinopyroxenes are a characteristic heavy mineral of the gravels. Near the vent of Phnum O Tang fragments up to 10 cm in length of these shiny black clinopyroxenes are abundant, and similar material but of smaller size is common in the gravels over the whole gemfield. Specimens derived from gem gravels remote from the vents are usually rounded by abrasion in the fluvial cycle. These clinopyroxenes have specific gravities in the range 3.32 to 3.37, and determination of the refractive indices of one specimen from the Phnum O Tang vent area gave values of α-1.688, β-1.691, γ-1.711.

Other heavy minerals include dull-black magnetite, a black spinel and greyish-black ilmenite, often showing fine striae and lamellar structure and sometimes intergrown with rutile.

Rounded fragments of green olivine are found locally in the gravels and feldspar occurring as xenocrysts in the parent rock appears near the basaltic bodies.

Examination of the surface features of the heavy minerals from the gem gravels gives some idea of their history. The corundums have angular to subangular outlines, but generally have a rounded surface relief with scalloped or fluted features resembling surfaces sometimes seen on meteorites. A high surface polish is common in grains recovered near the vents. Euhedral corundums are rare, and even on recognizable crystals the edges are rounded. The clinopyroxene fragments, frequently have a blocky form, controlled by the cleavage, but again the edges are generally rounded and the surfaces finely etched producing a silky sheen. There is clear evidence of etching out along the cleavage traces on surfaces broadly perpendicular to the cleavage direction.

FIG. 3. Hand working the shallow surface (eluvial) deposits above the 'basalt' on the crater rim. Note sacks of 'rai' (gem gravel) ready for tractor transport. Phnum O Tang body.

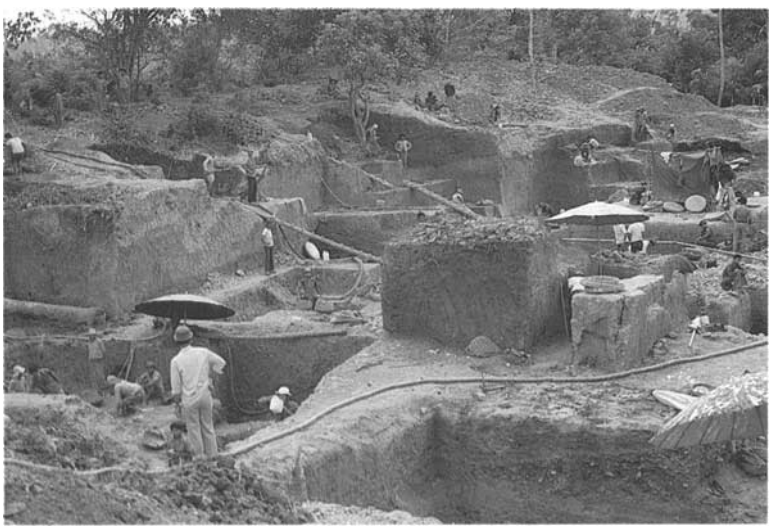

FIG. 4. Open cut workings in alluvium near Pailin. Note the stepped rectangular pattern of excavation, the competent vertical faces of the alluvium and the dumped overburden in the background.

These surface features all point to the fact that the megacryst minerals were in disequilibrium with their surrounding lava environment and were being actively corroded at some stage during their ascent. This is confirmed by the recrystallization of the outer layers of many of the clinopyroxene xenocrysts as seen in thin section.

METHODS OF WORKING

For convenience the methods of working have been divided as shown below but one type may grade with another.

1. Surface clearing
2. River bed working
3. Pitting
4. Open cuts
5. Trenching
6. Mechanized clearing of soil and overburden prior to 4 and 5.

1. Surface clearing of the eluvial deposits was in operation over the crater area of Phnum O Tang at the time of our visit—the whole of the top soil and decomposed basalt being scraped down to bedrock, placed in sacks and transported to the river for washing (see Figure 3).

2. Washing of the alluvial deposits in the river beds was widespread—operations mostly completed on the spot using flat baskets and sieves.

3. Pitting is the obvious way to locate a gem bearing horizon at depth and in many areas, especially over Phnum Ko Ngoap, pits (60-90 cm diameter) were sunk to 4 m or more. Spacing might be a mere 2 to 3 m apart.

4. Open cuts were seen at several localities (see Figures 4 and 5). In these workings the overburden is removed over a series of adjacent rectangular areas (possibly concessions) which descend to the gem gravel(s) in a series of irregularly arranged steps with slippery walkways or planks spanning open cuts at various levels. The gem gravel may be recovered over the whole area, but it often seems to require the double handling of quantities of overburden which have to be moved from one place to another. Various classes of worker are often employed, and overburden diggers are sometimes paid by the cubic metre dug out and on a sliding scale which increases with depth.

Left: FIG. 5. Locally made shaking table made of three superimposed screens and driven by an eccentric cam from a diesel motor. The 'rai' (gem gravel) is fed on at the upper end and is washed and sorted into sized fractions. Gems most frequently occur in the ½ inch to ¼ inch and the ¼ to ⅛ inch fractions which emerge separately at the two chutes. Open cut workings near Pailin town.

Right: FIG. 6. Pailin: trench working some 100 m long and 8 m deep in alluvium, O Ta Prang river.

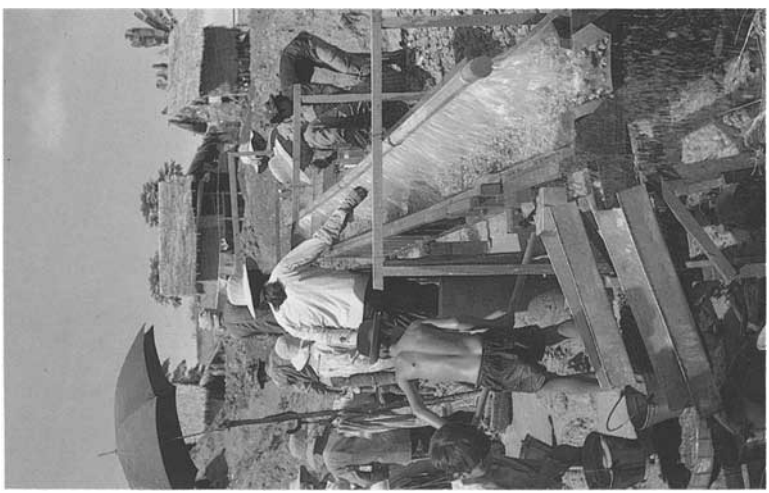

5. Trenching methods over reasonably large sites were only seen at O Ta Prang, but they possibly exist elsewhere in the area or have been operated in the past. At O Ta Prang a long trench to a depth of some 8 to 10 m was opened up along the line of the river for a distance approaching 100 m (see Figure 6). A considerable depth (*c.* 5 m) of overburden was being re-worked so as to reach the lower gem gravels which could not be de-watered for working prior to the advent of the portable motor pump. By this trenching method it is possible to avoid the neutralizing of any gravel, but the re-working of the overburden as at O Ta Prang (because of the two levels of gem gravels) is obviously highly undesirable and could be avoided in future workings by careful planning. Mechanized working had been forbidden by the authorities at the time of our visit, probably since a large pool of cheap labour was available and the men needed the work. However, bulldozers and other mechanical equipment had been used to clear the overburden down to the gem gravel level in the past, and this method has many advantages in time and efficiency if the social aspects are ignored. Working of the underlying gemmiferous layers may best be carried out using an advancing system of trenches.

It is regrettable that highly inefficient and wasteful methods of extraction were in everyday use over the whole of the Pailin gemfield.

Marketing and Cutting

We think we were able to gain a reasonably accurate picture of the local marketing scene during our visit to Pailin, but the international ramifications were less easy to assess. A typical pattern of events might be that a small-scale miner or group would sell the daily output at the diggings to intermediate dealers who were able to reach even the most remote workings on their motor cycles. These dealers, who would buy individually or as a syndicate, would then either trade the uncut stones in the market place at Pailin amongst themselves or offer them to larger dealers. Cutting might take place after any stage in this marketing procedure. At the top there were perhaps 10 to 15 principal dealers some of whom had international connexions and may have had their own agents at the actual workings. From our enquiries it appeared that the highest profits were at the top of the chain, and were principally

made when the stones left Pailin and were sold in Bangkok or elsewhere, the transactions often being in the hands of non-Khmer dealers. A very small proportion of stones was exported via Phnom Penh, and little direct revenue was received by the Government. On the other hand the gem industry at Pailin probably supported between 100 000 and 200 000 Khmers who might otherwise have been an embarrassing charge on the Government.

A substantial proportion of the stones produced were heat-treated and cut in Pailin but the treatment was also carried out in Bangkok. The standard of cutting we saw was not always high, but neither was it as poor as cutting in other gemfields of southern Asia where the stones are cut locally. Orientation to produce the best colour from a piece of rough was often very good, but more emphasis was laid upon getting the maximum possible weight rather than upon obtaining the best looking and most symmetrically cut stones.

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A BRIEF SUMMARY OF GEMMOLOGICAL INSTRUMENT EVOLUTION*

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INTRODUCTION

Compared to chemistry or physics or its parent science, mineralogy, gemmology is still in its infancy, and the early instrumentation used by the gemmologist had to be borrowed almost exclusively from mineralogy or physics. For example, the polarizing microscope was primarily a mineralogical tool, and instruments such as the spectroscope came from optical physics. Even gemmological equipment that had been developed much earlier elsewhere was not available for sale in America. Many years ago, the late Robert M. Shipley told me that in 1930 to the best of his knowledge only one gem refractometer existed in the United States.

GEM MICROSCOPES

The monocular petrographic microscope (Figure 1), which was used by most early gemmologists, was not a very effective tool for gemstones. Although highly effective for powders, this microscope did not enable the user to examine effectively the interior of a stone. Lighting the interior of gems being tested was difficult and the result usually poor. In the early days, for practical purposes, magnification was provided either by loupes or by monocular microscopes.

Of the major advances in gemmological instrumentation made by Shipley's son, Robert Shipley, Jr, probably the most important was adapting dark-field illumination and stereoscopic magnification for the study of gemstones. A patent on the combination, which was called the Diamondscope, was granted in 1938 (Figure 2). There were two great advantages to the combination the younger Shipley chose: (1) with the stone lighted from the side, inclusions appeared as bright objects against a dark background; and (2) the stereoscopic magnification provided a large field of view with upright images, as well as a great depth of

*Note: This article refers only to instruments used for gem identification. It does not discuss instruments designed for grading the colour, clarity or proportions of diamonds.

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FIG. 1. Petrographic Microscope.

Left. FIG. 2. An early Diamondscope.

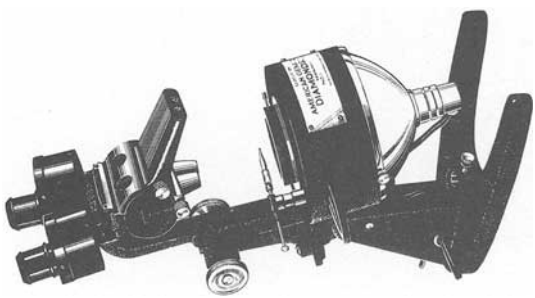

Right. FIG. 3. Custom B Gemolite with zoom.

focus. This contrasted with the inverted images, small field, dark objects against a light background and small depth of focus of the monocular petrographic microscope.

Another distinct addition to the microscopy of gemstones was the mechanical stone holder that young Shipley devised. He worked on this with an old French tool-and-die maker named Raoul Francoeur, who also built the first polariscope for him (Figure 5). This stone holder is still in use on 1980's microscopes—without any significant change (Figures 3 and 4).

In the early days of gemmology, the principal means of distinguishing singly refracting from doubly refracting materials was the polarizing microscope. For gemstones of more than a fraction of a carat, this instrument was very awkward to use. After Edwin Land developed the efficient polarizing sheet film he called Polaroid, Robert Shipley, Jr, was immediately intrigued and soon developed the first gem polariscope. It had Polaroid plates in place of the complicated Nicol Prisms which the polarizing microscope used. The Nicol Prisms were much more expensive and had size limitations the Polaroid material did not have. Shipley's earliest polariscope used small squares of Polaroid, but later instruments used large circular pieces. This instrument is still important for determining optic character; the details of its use are not within the scope of this article.

The dichroscope, another instrument for determining single and double refraction, uses a different material: Iceland-spar. The function of the dichroscope is to determine the differential absorption of light between different vibration directions in doubly refracting coloured stones. This small instrument uses the strong birefringence of calcite to separate the two polarized vibration directions in a dichroic gem. Early dichroscopes contained an elongated cleaved section of calcite, usually ground and polished flat on the opposite small ends, with a square or rectangular aperture at one end. A lens at the other end is focused on the aperture, which appears doubled. The calcite separates light into two polarized rays that have vibration directions at right angles to one another. Pleochroic coloured stones show different colours in the two images of the aperture; often the colours are distinctive.

Another form of dichroscope uses two or four pieces of sheet Polaroid. If two are used, the two vibration directions are set at right angles, to one another. If four are used, pairs are lined up

FIG. 4. Stone-holder.

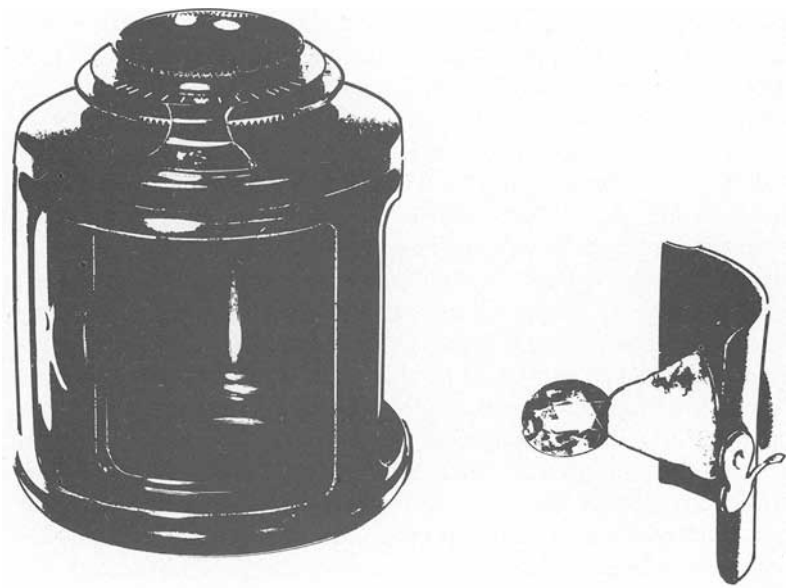

FIG. 5. An early polariscope.

parallel in diagonally opposite quadrants and at 90° to the vibration direction in the other two quadrants.

The increasingly serious shortage of Iceland-spar forced G.I.A.'s subsidiary, Gem Instruments Corporation, to go from the original Iceland-spar dichroscope to sheet Polaroid around 1977. Gale Johnson, a Vice-President for Gem Instruments Corporation, produced an ingenious device that permitted the use of much smaller pieces of Iceland-spar to get the same effect as when large sections were used.

REFRACTOMETERS

Before the advent of the jewel refractometer (or the total reflectometer, as it is sometimes called), the only reliable means of determining refractive index readily available to the gemmologist was the polarizing microscope using calibrated index liquids. The first refractometer designed to measure the refractive indices of gemstones was designed by the late G. F. Herbert Smith of

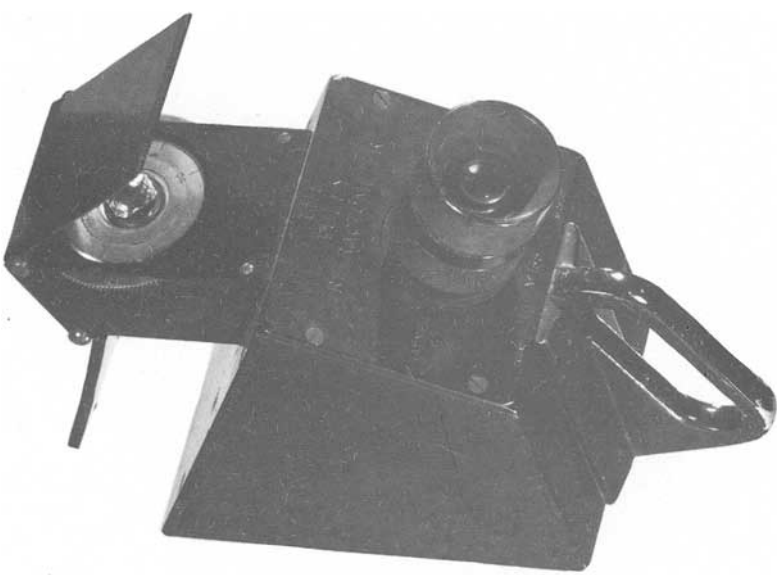

FIG. 6. Tully Refractometer.

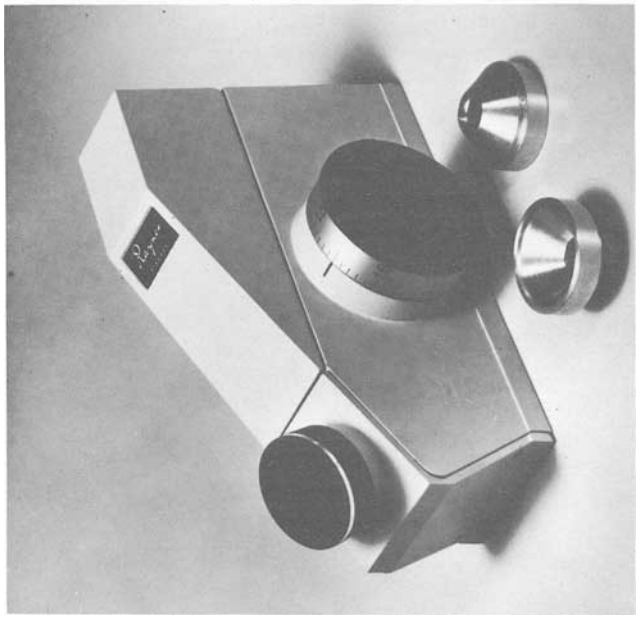

FIG. 8. The Rayner Dialdex Refractometer.

FIG. 7. The Duplex II Refractometer.

England, the author of the famous *Smith's Gemstones.* His first one, made in 1903, did not have a scale, but a model made two years later did. This was followed by the Rayner and Tully (Figure 6) refractometers, which were also made in England. Rayners, at the suggestion of Basil Anderson, also produced refractometers with a diamond contact prism and others with synthetic spinel and zinc blende.

In the United States, the Erb & Gray refractometer was made for G.I.A. shortly after World War II. There were two models, one with a rotating hemisphere and the other with a stationary hemisphere. A few years later, Robert Shipley, Jr, made the tiny Gem Refractometer. G.I.A. later developed the Duplex Refractometer (Figure 7), the first instrument designed specifically to take advantage of the spot, or distant-vision, method for taking refractive index readings on curved surfaces or tiny flat facets. This method was discovered by the former Director of Research at G.I.A., the late Lester B. Benson, Jr.

In recent years, the Rayner refractometer has been redesigned. The first new model was the Dialdex (Figure 8), which has an exterior dial that gives the refractive index reading. A second model has an interior scale. Rayner-type refractometers are also now made in Japan.

The most recent developments in conventional refractometry are a new design by Cornelius Hurlbut, Professor Emeritus of Mineralogy at Harvard, using a cubic zirconia hemicylinder in a G.I.A. Duplex Refractometer, and the newly announced Krüss refractometer with a refractive index upper limit of about 2.2. The latter uses a strontium titanate prism and a solid contact material. A solid contact material must be melted to make the optical contact between gem and hemisphere. Our analysis of this contact material showed thallium, a highly toxic ingredient.

Tools for Determining Specific Gravity

One measurable property used widely, particularly in the early days, is specific gravity. The specific gravity of gemstones is obtained either through weighing the stone both in air and in water, or by observing the results when loose stones are dropped into heavy liquids of known densities. Both heavy liquids and the hydrostatic methods are very appealing in that they provide useful

information relatively quickly and inexpensively. Unfortunately, specific gravity tests are useless with mounted stones.

1. Heavy liquids

The most versatile heavy liquid is methylene iodide, which in pure form at about 70 °F has a density of 3.32. It is relatively safe to use, compared with most other liquids. Bromoform, at the slightly lower specific gravity, of 2.89, was widely used until it was discovered to be a dangerous liquid; prolonged inhalation may be very harmful.*

Many other high-density liquids have been used in gem testing. Perhaps the most useful of the high range is Clerici's solution. However, it includes thallium malonate and thallium formate; these thallium salts are highly toxic, so the liquid is dangerous to use. In saturated solution at room temperature, it has a density of about 4.15. When diluted with distilled water, its specific gravity (SG) is easily determined by taking its refractive index (RI), since the relationship is linear, as pointed out by Anderson, Payne, and Webster. (At RI 1.56, the SG is 3.10; at 1.61, the SG is 3.52; and at 1.668, the SG is 4.0.) The solution should be used with extreme caution to avoid contact with the skin.

2. Balances

Almost any balance used for weighing gemstones can be equipped to weigh the stone while immersed in water as well as in air. A number of balances have been designed expressly to test specific gravity. The Berman balance is a torsion balance designed by a Harvard professor to give accurate specific gravities for stones of less than one-third carat, for which measurements are likely to be very inaccurate when using the normal balance.

There have been a number of direct-reading balances such as the Westphal, the Penfield, and the Hanneman. On these, the stone's weight in air becomes a zero setting. Then when the stone is weighed in water, the resultant reading is the specific gravity. With today's sophisticated gemmological testing procedures, specific gravity is used less frequently perhaps, but it remains a very useful test.

HARDNESS

Determining a stone's hardness has some value in testing.

*See *J.Gemm.*, 1979, XVI(6), 430, lines 7-14.—Ed.

However, testing hardness is very likely to damage the gemstone being tested. The usual tool for this determination is a set of hardness points commonly in whole numbers from 5 to 10 on the Mohs Scale. To test an unknown stone with a hardness point would leave a scratch, so it really has no place in the testing of fine gemstones. Perhaps better suited for this purpose is a set of hardness plates over which the girdle of the unknown can be drawn. If this is done carefully the gemmologist is able to determine the hardness of the material relative to the Mohs Scale with somewhat less chance of damage.

Tools for Distinguishing Cultured from Natural Pearls

When, in the early 1920s, cultured pearls began to reach the market in some quantity, it became imperative to develop a means by which they could be distinguished from the very expensive natural pearls. At that time almost the only effective means (other than indications such as determining the slight differences in specific gravity or the use of the 'pearl compass'), was a careful examination of the drill hole. The examiner looked for the usually darker conchiolin layer between the mother-of-pearl bead and the nacreous layers of the cultured pearl. This is a reasonably effective test even today.

In the mid-twenties René Bloch, of Paris, a pearl dealer, devised the ingenious endoscope in which a hollow needle was cut in a manner that provided two mirrors set at 90° to one another and at 45° to the length of the needle. Light passing through the needle (actually a syringe needle) would strike the first mirror, pass through the concentric layers of nacre on a natural pearl, and thus reach the second mirror and show a flash of light to the eye through a microscope focused on the end mirror. Since the nacreous layers of the large mother-of-pearl bead in a cultured pearl are parallel instead of concentric as in the natural pearl, the cultured pearl did not display a flash of light. This test worked only for drilled pearls, and it required cutting a necklace entirely apart so each pearl could be tested individually, a laborious and time-consuming task.

In 1938, Dr A. E. Alexander, of the Pearl Associates Laboratory in New York City, (later turned over to what is now the G.I.A. Gem Trade Laboratory) devised a means by which x-rays could be used to identify and distinguish cultured from natural

pearls without cutting the strand. He found that natural salt-water pearls did not fluoresce to x-rays, while cultured pearls with fresh-water mother-of-pearl beads did. X-ray fluorescence indications can be confirmed by x-radiography, and the whole strand can be recorded on film at once. The layer of rich conchiolin that surrounds the bead of the cultured pearl before nacre starts to be added is readily discernible on the x-radiograph, because of its greater transparency to x-rays. There is another x-ray method which can only be used for testing individual pearls—the Lauegram method. It is very useful when the nacre layers make up less than one half of the pearl's diameter. A collimated x-ray beam passing through the centre of the pearl is deflected in a manner that creates a spot pattern on a film. Since the pseudohexagonal aragonite crystals in the concentric layers of nacre in a natural pearl are arranged in a spoke-like pattern, the beam traverses their length. This produces a six-sided spot pattern. There is only one direction in a cultured pearl in which the mother-of-pearl bead would produce that pattern—in most directions a four spot pattern is seen. Confirmation of the hexagonal pattern in a natural pearl is provided by a second shot taken after the pearl is rotated 90°.

Instruments for Detecting Diamond Simulants

The advent of a number of fairly realistic diamond simulants such as gadolinium gallium garnet (GGG) and cubic zirconia brought forth new instruments to distinguish between diamonds and simulants. The first one of importance was the reflectivity meter.

1. Reflectivity Meters

All other things being equal, the higher the refractive index, the greater the surface reflection, that is, the higher the percentage of light striking a gem's surface that is reflected back to the sensor. Unfortunately, this percentage also depends on other factors in addition to refractive index; the quality of the polish, the flatness of the surface and cleanliness of the stone also affect reflection. Because of these variables, reflectivity meter results tend to be much less dependable than those obtained from the conventional gem refractometer. As a result, gemmologists usually tend to use the meter only for materials with indices above the refractometer's upper limit (1.81).

The early reflectivity meters used an infrared light source that was a good match with a sensor that could pick up the reflections. A variety of reflectivity meters have appeared on the American market and recently European and Japanese instruments have been offered.

Two other instruments designed to distinguish between diamonds and simulants were introduced in the late 1970s. One is the Ceres Probe, which tests heat conduction: Diamond's unsurpassed heat conduction distinguishes it from any simulant. The other is the Diamond Pen, developed by the Gem Instrument Corporation, which differentiates simulants and diamonds by the behaviour of a special liquid that spreads on the surface of a diamond but beads on simulants.

THE SPECTROSCOPE

The spectroscope was of little consequence in gemmology until Basil W. Anderson of the Gem Testing Laboratory of the London Chamber of Commerce proved how valuable it could be for gem identification. His pioneering work was of enormous importance to the field. He investigated some of the findings of an earlier scientist, Arthur Church, and studied the spectra of garnets, rubies, zircons and various other gemstones using a hand spectroscope. From the viewpoint of his fellow gemmologists, Anderson's findings introduced a new era in testing.

The spectroscope is somewhat more difficult for the novice to learn to use effectively than some of the other instruments, but the results are particularly rewarding. There are many types of spectroscope available, including hand and wavelength types, as well as spectrometers. Anderson hand-held a Beck spectroscope over a microscope tube, through which a strong light was directed from below through the gemstone being examined.

Robert Crowningshield used the wavelength type on the G.I.A. Spectroscope Unit (Figure 9) in his discovery of a means to distinguish between irradiated and naturally coloured diamonds, and between naturally coloured and dyed green jadeite.

ULTRAVIOLET RADIATION, X-RADIATION, AND FLUORESCENCE

Short- and long-wave ultraviolet radiation was added to the gemmologist's instrument arsenal relatively early. Long-wave radiation (at about 3660Å) excites bright fluorescence in more gems

than short-wave (at about 2537Å), but both are useful in gem identification. Since the strength and colour of fluorescence often depend on the presence of small amounts of impurities or colouring agents (such as chromium), and are subject to dampening in the presence of other impurities (such as iron), fluorescence is less dependable than many other tests.

For those who have x-ray equipment, fluorescence caused by x-radiation also may provide useful information. The fluorescence of transparent diamonds to x-rays is so dependable that it is used to separate diamonds from heavy mineral concentrates in diamond recovery from ores. Several other gems, such as translucent green grossularite and kunzite also have distinctive x-ray fluorescence.

FIG. 9. Gem spectroscope unit with Beck Wavelength model.

Another test used occasionally to separate natural emerald from synthetic is transparency to short-wave ultraviolet radiation, a characteristic of synthetic emerald. One quick way to make the test is to direct a short-wave ultraviolet lamp at the unknown, which is placed so it completely covers an opening in an opaque shield. Below the opening is placed a piece of scheelite, which will fluoresce only under short-wave ultraviolet radiation. If the scheelite fluoresces, the unknown passes ultraviolet at least down to 2537Å.

SPECIAL-PURPOSE INSTRUMENTS

There have been many special-purpose or minor instruments developed over the years. The thermal reaction tester, a tiny, electrically heated metal point, was developed specifically to detect paraffin treatment of turquoise (it causes the paraffin to melt and well up to the surface), but other uses soon became apparent. One is the easy separation of amber from plastic substitutes by odour.

The conductometer was developed when it was found that colourless diamonds subjected to electron bombardment turn blue. In nature, only Type IIb diamonds are blue, and they conduct electricity; treated blues do not. The conductometer determines whether an unknown blue stone conducts a current.

Occasionally, scintillometers or geiger counters are used to detect radioactivity in an ekanite or a radium-treated diamond.

The Luminoscope permits binocular magnification of the luminescence caused by an electron beam. Its effect is to make structural oddities obvious, and differences between the reactions of synthetic and natural materials may become apparent.

FILTERS

Various colour-filters have been employed in gem testing with different degrees of success. Undoubtedly the best of them is the Chelsea Filter (also known as the Emerald Filter). Basil Anderson and C. J. Payne of the London Chamber of Commerce Laboratory noted that the light-transmission curve for emerald is unusual for a green stone: a portion of the yellow-green is largely absorbed, but most of the deep red is transmitted. They prepared a filter that transmitted the deep red wavelengths but absorbed the green—except in the yellow-green sector. Most (but not all) natural and synthetic emeralds appear red through the filter, but most green substitutes do not. This filter has a few other uses, but generally provides more of an indication than a proof of identity.

Anderson also devised an interesting way to check red fluorescence—particularly that caused by chromium. Light is directed through a saturated copper sulphate solution (cutting out the red end of the spectrum) and then through a gem. The emerging light is passed through a red gelatin filter. Stones coloured by chromium appear bright red, because the fluorescence is triggered by wavelengths not absorbed by the copper sulphate. Other filters

are used to sharpen refractometer readings and for other less important purposes.

Other minor tests include refractive index determination by the appearance of facet junctions when gems are immersed in a liquid of known refractive index, reaction to acids, and fade tests for irradiation.

Advanced Research Instrumentation

A number of advanced techniques are used for gem identification in research laboratories. Probably the most widely used is x-ray powder diffraction. A tiny amount of gem material powder is picked up with cement and placed in a spindle, which is rotated in front of the collimated x-ray beam. Reflections of different planes of atoms are recorded on a strip of film, usually in a camera with a film diameter of 114.7 mm. The intensity and spacing of the lines representing these reflections are characteristic for each gem mineral. (G.I.A.'s Charles Fryer is able to obtain excellent results using so tiny an amount of powder (scraped from the girdle of a fashioned stone) that no weight change is measurable on a balance that is accurate to less than 0.01 carat).

The combination of a scanning electron microscope, with its enormous magnifications, and an electron microprobe or an energy dispersive unit enables the tester to determine fairly accurately the chemical composition of an unknown material. With the energy dispersive unit, no damage is done to the gem material. Electron spin resonance is another source of information for the fully equipped, modern research laboratory, but such equipment is too expensive and bulky for any but the largest laboratory. Several other types of equipment present possible uses in gemmology.

Instruments for the Future

Several new and even revolutionary instruments are on the drawing boards, or have recently been produced at Gem Instruments Corporation. The new Colormaster duplicates the hue, tone and intensity or saturation of a coloured stone on an image selected in the general shape and facet pattern desired. Calibrated dials are adjusted to increase or decrease each of three primary colours individually, providing a numerical reading for the combination that best matches the colour of the original gemstone. With this instrument, it would be possible for an appraiser to

describe a colour to a supplier and determine the current cost of a matching stone from its reading. It also would be possible to order stones in this fashion or to provide the desired colour for a customer who is not quite satisfied with the colour of an emerald, ruby, sapphire, or other stone in stock. (It requires little imagination to conceive of further uses.)

Generally speaking, the 1980s promise exciting developments in gemmological instrumentation. There may well be a parade of ingenious new aids to identification and grading in the next few years. In view of the rapid pace in the development of new forms of treatment to improve apparent quality and new simulants or synthetics, the gemmologist will need as much help as possible. The prospects are exciting and challenging.

[*Manuscript received 10th July, 1981.*]

STAR INCLUSIONS IN DIAMOND

By R. KEITH MITCHELL, F.G.A.

From time to time apparently six-rayed star inclusions are found in diamonds, usually in crystals, since such blemishes are not acceptable in the cut stone. They seem to be quite rare and, since they all have common characteristics, could possibly originate from a single source. One example, showing only part of the formation in a cleavage flake, was possibly Indian.

Figure 1 illustrates the star in a crystal lent to me by Christopher Cavey, then of Roughgems Ltd, now of Cavey McCallum Company Ltd. This is a good example of the phenomenon and shows the darker star-form as an ill-defined formation or cloud, with more pronounced ribs of deeper colour making a definite star. Between the arms of this dark star is another six-rayed star, which is effectively of clearer material and therefore appears white.

I have said 'apparently' six-rayed stars. Careful examination of the actual crystal shows that the six-rayed phenomenon is seen identically through each of the octahedral faces. It follows therefore that the formation must, in fact, have eight arms, although it has not been possible to find a viewpoint from which all eight arms can be seen at once. Looking directly down on any octahedral face one is looking straight down one pair of arms and these two are not visible in the photograph, or indeed in visual examination, unless the crystal is searched carefully for other indications of the structure.

My second example is shown in Figure 2 and is a crystal which came into my possession some twenty years ago and was irretrievably lost not long afterwards. It was appreciably larger than Mr Cavey's crystal and the star inclusion is much denser and was much more complex, generally grey in colour. Its complexities can still be related to faint features seen in the first crystal. The morphology of both stones was essentially the same, a combination of the octahedron and cube forms with the former slightly predominating. But my stone had two dodecahedral faces, one of which was sufficiently clear to allow photography through it. The cube form consisted entirely of octahedral peaks which ended approximately where a cube plane might be expected to occur.

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FIG. 1. Diamond cubo-octahedron crystal with star inclusion. *(Photo by E. A. Jobbins)*

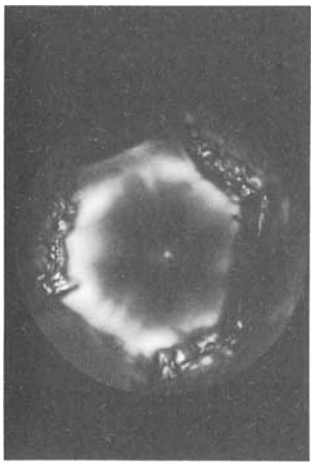

FIG. 2. Funnel or 'hopper'-shaped inclusion in another cubo-octahedron crystal, focused at top of the funnel. Seen through (111) face.

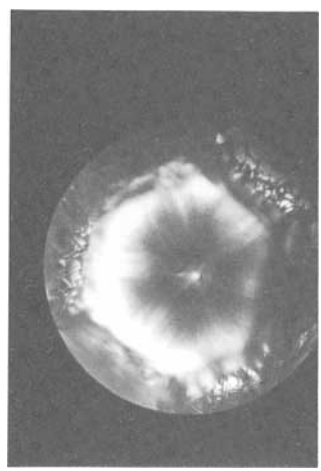

FIG. 3. The same funnel, but with focus near the centre of the diamond crystal. (111) face.

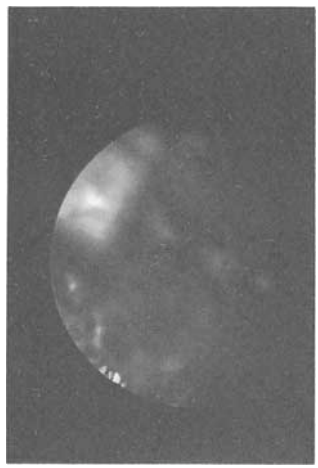

FIG. 4. Two funnel inclusions meeting in the centre of the crystal, seen through the one clear dodecahedral face on the diamond. (110).

This stone had the inclusions sufficiently developed and dense enough to allow one to see clearly those which have been surmised in my third paragraph, and, looking down into the octahedral faces, one sees that each arm of the eight is triangular in outline, with the triangle in opposed position to the octahedral edges, and the whole shape under each face is that of a hopper, in that it tapers towards the centre of the crystal. If one realizes that the three smoother edges in this figure are the octahedral edges (the very rough ones are those of the cube form) then the distorted triangular outline of the top of the 'hopper' can be seen in relation to the octahedral face. In this the inclusion resembles the orientation of trigons on the normal growth surface.

Focusing through the stone one comes to the opposite octahedral face and another triangular end to that arm of the inclusion, but both are reversed in position relative to the nearer ones. The original print of the Cavey crystal shows centrally a very faint curved triangle, which reveals that a similar structure is present and that we are dealing with practically identical formations. In Figure 2 it will be seen that the distorted triangular top edge of the 'hopper' shows evidence of having a double outline with clearer material between the two layers; the centre in this instance is filled with coarser inclusions which do not extend down into the crystal.

In Figure 3 I have focused approximately at the centre of the crystal. Some unidentified inclusions are to be seen, but this view shows the essentially star-shaped mass of sub-microscopic dust inclusions which give the main star effect. It has to be remembered that each arm is a triangular pyramid pointing its blunt end towards a different octahedral face. Thus in this view we have three arms diverging towards faces forward of the point of focus and a further three diverging towards three such faces beyond the focal plane. The two funnels directly in the line of sight are more or less lost by the change of focus. Absolutely sharp focus is impossible, partly because of the diffuse nature of the total inclusion and rather more because the total effect is three dimensional and impossible to bring to focus in one plane at this magnification. A better idea of the total inclusion was to be obtained by raking the focus back and forth through the whole crystal. Figures 2 and 3 were both taken through the same face. Other octahedral faces gave similar glimpses of the star structure but were marred by surface growth

lines and trigons and would not photograph even with this degree of clarity. The density of the dust cloud masks the star effect, and it is seen rather in the form of six 'brushes' as opposed to the more clear-cut line effect seen in the Cavey stone.

Figure 4 gives the view through the one dodecahedral face and shows two of the 'hopper' structures in profile, meeting at the centre of the crystal. It was difficult to photograph and I can only hope that the points I want to make will reproduce sufficiently well in printing to make my meaning clear. Other branches of the star are there but are not clearly identifiable. The broad ends of these formations point directly to opposed octahedral faces, in one of which one can see the triangular outline of the end of the funnel shape.

Going up to about 250×, the limit available on my Koritska microscope of those days, I was just able to see that the dust cloud consisted of short rod-like particles mostly oriented in a direction vertical to the octahedral face. In all there must have been millions of the tiny things. The 'hopper' structures did not come right to the surface on any of the faces. In Figure 3 structural lines of inclusions may be detected if it has printed reasonably well.

It is now possible to arrive at some conjectural interpretation of the star as seen in Figure 1. I have already said that the dark star, which is fairly well defined, fades in density as one moves away from the darkest lines. Having established that the dust-like inclusions are formed into eight hollow three-sided pyramidal 'hoppers', other points may be made. First, the particles are less densely aggregated towards the centre of the crystal, i.e. the phenomenon became progressively more intense as growth proceeded, until for some reason it stopped altogether, and secondly there appears to be a greater concentration of the dust particles in the angles of the 'hoppers'.

We now have to explain why, in Figure 1, there are vague areas of darker colour separated by an ill-defined white star and concentrating in a central 'rib' of grey which is the most marked feature of each arm of the dark star. The white star can, I think, be dismissed as the result of the comparatively clear centre of each 'hopper'. Similar questions arise in the case of the second crystal, which is even more complex and therefore less easy to interpret.

In an effort to arrive at a reasonable explanation of this apparent concentration of the dust particles into definite star forms

I constructed a hollow model of the octahedron from thin transparent plastic sheet and then threaded coloured silks through it to represent the approximate edges of the 'hopper' structures. Looking vertically through an octahedral face of this model, it was at once evident that the position of each arm of the eight-fold star is one in which four 'hopper' edges are fairly close together directly in the line of sight and that two of each set in fact superimpose. The view from a dodecahedral direction was also as expected from Figure 4.

Looking again at Figure 1, it has to be remembered again that the star form is not in one nice convenient plane, easily focused in what is a very shallow field indeed. Its arms diverge from the sharp centre both forward and back from the focal point, alternating in direction. The two faces parallel to the line of sight have to be ignored, although their 'hopper' edges almost certainly contribute to the final star.

In Figure 4 we are seeing two edges of each of two tapering forms converging in the centre of the crystal. Why no third edge is seen is not easily explained, but my model, which regrettably is too crude to give usable photographs, does show that these two formations are more or less in one plane, although not sharply so. Indeed scarcely any features of the stars are other than diffuse in structure.

To summarize, this is a diamond inclusion which is both rare and very interesting and, in the second crystal, quite complex. The accurate interpretation of the directions of the darker arms or brushes is exceptionally difficult, especially from two-dimensional photographs. Any contribution these observations may have made towards the interpretation of diamond growth is even more obscure to the writer.

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AFRICAN STAR CORAL, A NEW PRECIOUS STYLASTERINE CORAL FROM THE AGULHAS BANK, SOUTH AFRICA

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INTRODUCTION

The use of the stylasterine corals for personal adornment is not new. Most standard texts on gemmology mention it in passing but Bolman[2] specifically makes two references of historic merit. Firstly, it was harvested and used by the Polynesians of the Samoan Islands to adorn themselves with unworked fragments of the red, blue and violet varieties of the coral; secondly, the stylasterine coral *Allopora subviolacea* was an important and highly prized commodity in Cameroon, off the West African Gulf, before the eighteenth century. Here the blue and violet varieties were fashioned into necklaces as well as being used for adorning clothes and weapons. It was locally known as 'Akori' (coral). However, its popularity waned, and by the beginning of the eighteenth century it was no longer sought after. All that seemed to have remained is the term 'Akori coral' which has since been used indiscriminately, not only to describe the original stylasterine coral, but also a variety of beads fashioned from coral and coral simulants.

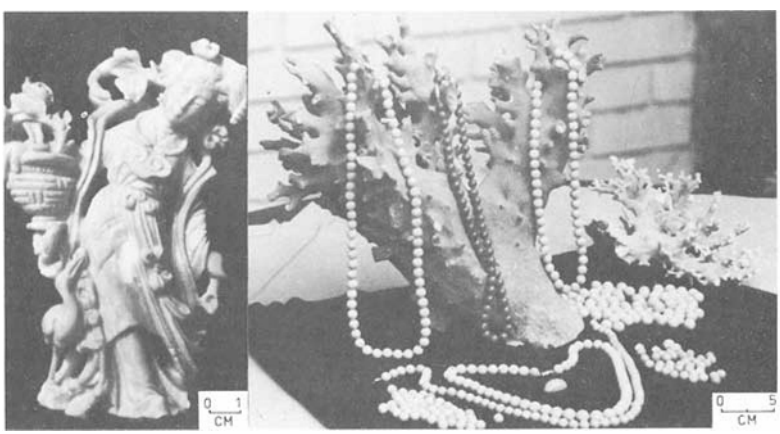

FIG. 1. Stylasterine coral—worked and unworked.

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During the past two years, another stylasterine coral *Allopora nobilis* has reappeared on the world market as 'African Star Coral'. Presently it is being exported from South Africa to Asia, Europe and the Americas in the form of polished beads and unworked slabs and cylinders. The latter are especially in demand for the manufacture of engraved cabochons and carvings (Figure 1).

GEOGRAPHIC DISTRIBUTION AND ZOOLOGICAL DESCRIPTION

Allopora nobilis was originally discovered at a depth of 55 metres in False Bay, near Cape Town, and described by Kent in 1871[1,8]. It has been found to exist in both the colder polar Benguella and the warmer equatorial Mozambique ocean currents, from Saldanha in the west to East London in the east (Figure 2).

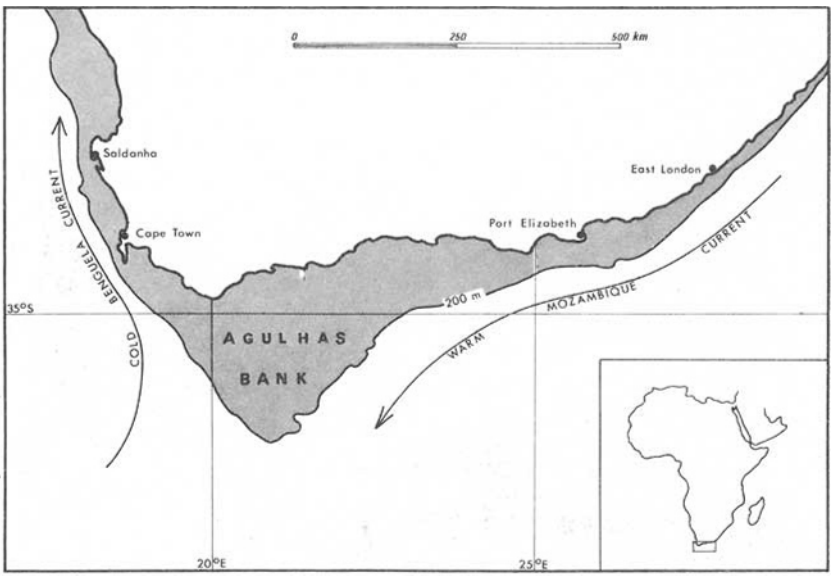

FIG. 2. Locality Map of the Agulhas Bank, South Africa.

The organism seems to be photosensitive and lives in crevices and caves at depths greater than 15 metres on the Agulhas Bank, which is the local geological expression of the continental shelf. Taxonomically it may be classified as follows[1,7]:

DIVISION	CLASSIFICATION	EXPLANATION
KINGDOM:	*Animalia*	An animal
SUBKINGDOM:	*Metazoa*	with cell differentiation
BRANCH:	*Eumetazoa*	organized into organs,
SUB-BRANCH:	*Radiata*	having a radial symmetry
PHYLUM:	*Coelenterata*	and tentacles with stinging cells, situated around a mouth.
CLASS:	*Hydrozoa*	A gullet-lacking polyp
ORDER:	*Stylasterina*	arranged into discrete star-shaped groupings of polyps—the central polyp developing a prominent stylus—
GENUS:	*Allopora*	with other openings
SPECIES:	*nobilis*	and is precious

The hydrozoans are a class of coelenterate or polyp that has the ability to reproduce in two different ways. Asexual reproduction, a process of cell-division and of budding, leads to the formation of a colony. This colony of polyps is housed in a porous exoskeleton which in turn is harvested for ornamental use. Budding allows certain polyps to break off from the colony and develop into unisexual medusae which reproduce sexually to produce larvae. These larvae attach one of their ends to a rocky ledge and in turn commence to reproduce through cell division, thus forming a new colony.

The *A. nobilis* colonies are found as squat, dense, arborescent structures which are supported by a central, thick-set, asymmetrical cylindrical trunk—somewhat reminiscent of a miniature baobab tree (Figure 3). The branches tend to be aligned in a flat plane which usually coincides with the direction in which the current flows. On average, single *A. nobilis* trees having a trunk diameter of 25 mm, a height and spread of 200 mm, and a mass of 1.5 to 2 kg, are harvested. Yet specimens of up to 10 kg are regularly encountered. To date the largest single colony found had a mass of just under 50 kg and a trunk diameter of approximately 150 mm.

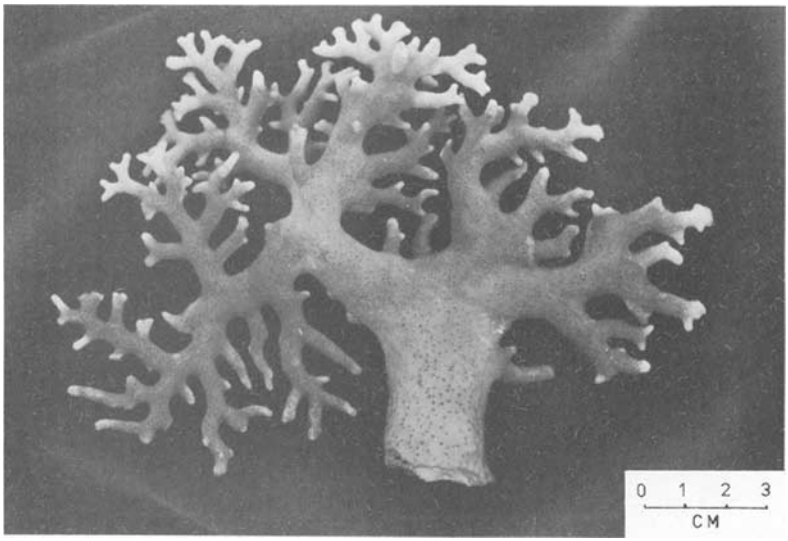

FIG. 3. Typical arborescent form of a stylasterine coral colony.

The calcareous exoskeleton is coloured by a yet undetermined organic pigment. Colours found include yellow-orange, pink, deep salmon pink and rarely amethyst-violet. The violet material is highly prized and seems to occur sporadically with the other colours in crevices on the rocky terrains as well as in caves that specifically mouth away from the prevailing ocean current. Furthermore, the tips of the branches are white and have a rounded and stubby appearance. Divers report that these tips fluoresce and phosphoresce in the light emitted by their underwater diving lamps.

The natural surface of the polyp colony is hard and even, but slightly harsh to the touch. This abrasive sensation is caused by small concentric groupings of cavities, breaking the surface in randomly spaced pimple-like mounds of about one millimetre. These pinholes are biologically referred to as 'pores'. They are the chambers that house specialized individuals of the polyp colony and from which or into which they are extended or retracted, respectively. Each grouping of pores is characterized by a large central gastropore which has a central stylus, and which measures on average 0.35 mm in diameter. It houses the gastrozooid or feeding polyp. The gastropore is surrounded concentrically by five

to seven circular dactylopores, each with an average diameter of 0.1 mm. These pores in turn house the dactylozooids or food-collecting and protecting polyps (Figure 4). This star-like arrangement of groups of dactylopores around a central stylus-bearing gastropore is diagnostic for this class of *Hydrozoa,* and hence the name *Stylasterina.*

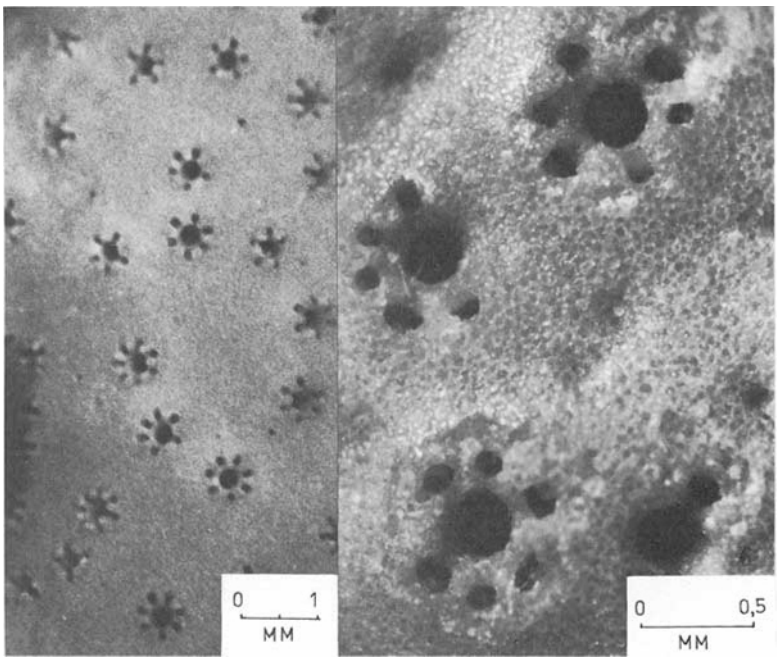

FIG. 4. Natural surface of a stylasterine coral displaying cyclosystems of gastropores and surrounding dactylopores.

The porosity of the hard exoskeleton seems to change as the polyp colony enlarges itself. Microscopic examination of cross-sections of branches reveals that the white central zone (also finding expression in the white tips of the branches) is the area of maximum porosity. Lateral thickening is associated with the addition of the organic pigmentation together with a lessening of porosity. The least porous areas are found, on average, to be the outer 5 mm, while the surface itself is covered by a very thin organic layer (Figure 5).

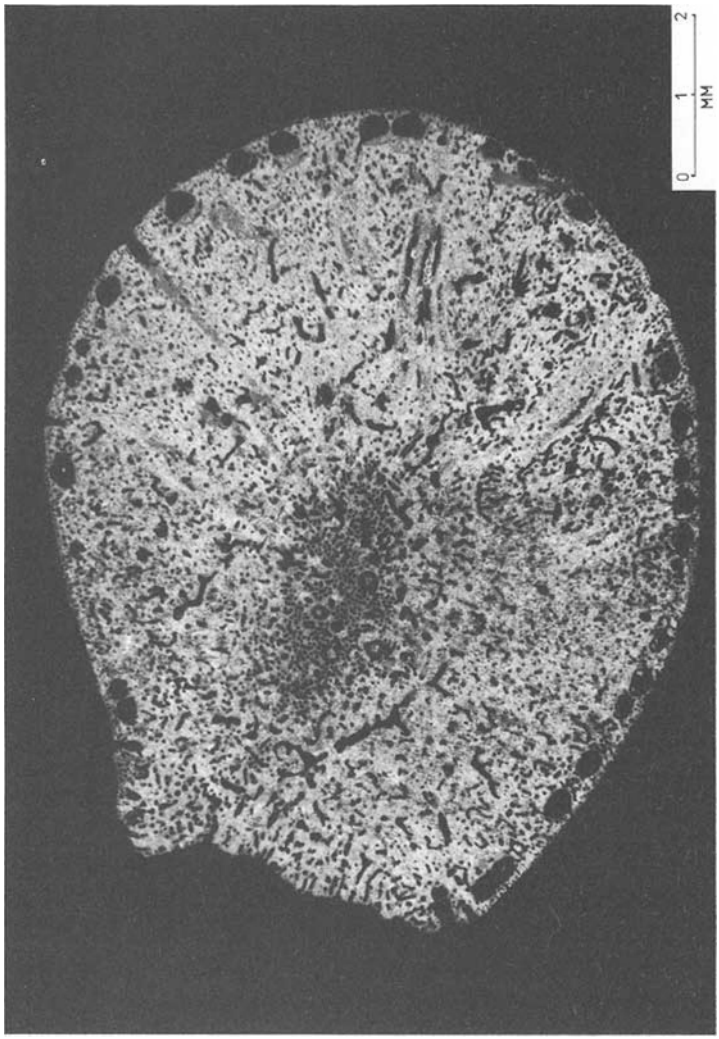

FIG. 5. A cross-section of a stylasterine coral branch (crossed polaroid filters) showing structure and porosity.

EXPLOITATION, RECOVERY AND TREATMENT

Although the presence of the precious stylasterine coral *A. nobilis* has long been known to occur off the South African coast, it has only been successfully exploited since November 1978, when a group of divers, working from Port Elizabeth, were granted a concession from the Ministry of Agriculture and Fisheries to do so. The concession restricts the harvesting to certain prescribed areas and a maximum of 25 metric tons (wet mass) is permitted annually. Moreover, only polyp trees with a trunk diameter greater than 20 mm may be gathered by divers using scuba equipment. No other means of recovery may be used. The coral occurs at depths greater than 15 metres, but the present restriction limits harvesting to between 25 metres and the 60 metre depth contour. The quality of coral improves with depth; the shallower coral being more porous. Usually, the material suitable for gem use is reported to have been collected at depths of 35 to 45 metres.

Once brought ashore, the coral trees are cleaned and desalinated by washing them repeatedly in fresh water. Thereafter they are treated with a vigorous oxidant to remove any biological or organic remains and to ensure that the pores are open. Then they are allowed to dry on racks placed either in the sun or in large desiccating rooms. The next step includes sorting and sawing into large segments, slabs or cubes, depending on whether the coral will be used for carvings, engraved cabochons or beads respectively. A slightly acid cutting fluid is used to ensure that the pores remain open.

Now the coral is ready for the so-called 'stabilizing' treatment. The treatment is a vacuum-impregnation technique whereby a critical mixture of methyl and butyl methacrylate monomer is allowed to infuse into the open pores throughout the coral and undergo subsequent polymerization, aided by a catalyst (benzoyl peroxide), into a tough co-polymer plastic. Final shaping and polishing are carried out in accordance with the usual techniques prescribed for ornamental stones.

Further treatment may include bleaching or dyeing. The pink coral is sometimes bleached with peroxide to produce a pale, whitish pink product which approaches 'angels' skin' quality. The yellow-orange coral in turn is sometimes dyed a deep red, duplicating the 'moro' coral tint prized in the Orient. When used, dyeing is incorporated with the plastic monomer in the stabilizing process.

CHEMISTRY AND PHYSICAL PROPERTIES

The chemical composition of *A. nobilis* is similar to that of *Corallium rubrum* in being $CaCO_3$ with a small percentage of organic material, and reacts similarly with acids. However x-ray diffraction studies indicate that the $CaCO_3$ has crystallized as platelets of orthorhombic aragonite.

The hardness varies from 3 to 4 (Mohs's scale) while the toughness could be described as excellent. The natural friability resulting from the platey nature of the aragonite exoskeleton is eliminated by the methacrylate impregnation.

There is no fluorescence when exposed to either 254 nm or 365 nm ultraviolet irradiation; but specimens that were dyed to imitate 'ox-blood' or 'moro' coral fluoresce brilliant scarlet under 365 nm irradiation.

Refractive index values are difficult to determine. At best a vague spot reading of 1.65 is possible on a gemmological refractometer. A twinkling effect seen through a rotating polarizing filter confirms the strong double refraction expected from aragonite.

Relative porosity measurements on the unstabilized coral gave values of up to 18 per cent, the white areas being the most porous. After impregnation with the methacrylate polymer (RD = 1.18 to 1.20), the relative density of the stabilized coral is 2.41 ± 0.08.

Thermal tests applied with a red-hot needle do not induce 'sweating' on the surface of the treated coral, but a fruity aroma characteristic of the plastic does become apparent. Continued heating chars the surface.

A microscopic examination of the surface exhibits the following three diagnostic features which reflect the biological organization of the polyp colony:

(a) *Parallel concentric growth banding* (not unlike the growth rings seen in wood) resulting from the accretion of the exoskeleton (Figure 6);

(b) *White star-like spots* consisting of a central concentric double circle surrounded usually by five or six smaller, symmetrically placed, satellite circlets—collectively having the appearance of a small star (Figure 7). (The large central double circle is the expression of a cross-section through the central stylus within

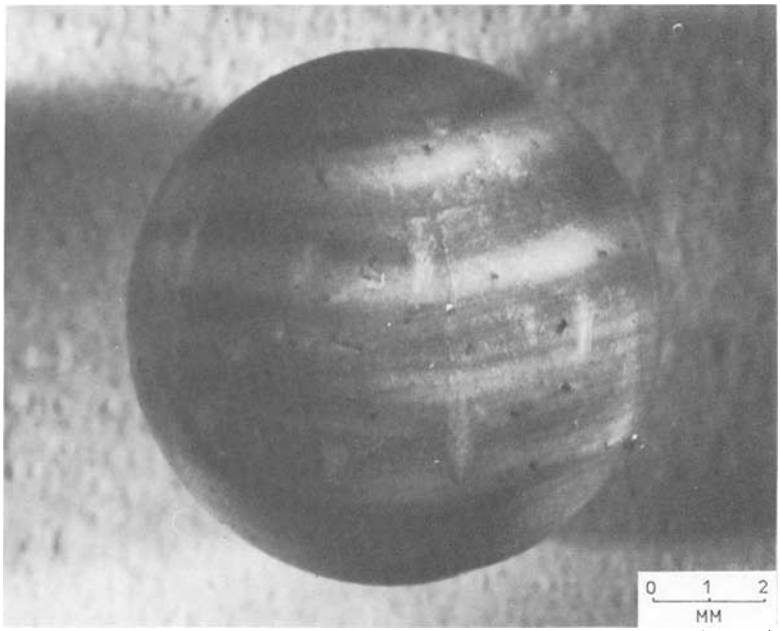

FIG. 6. Parallel concentric banding of stylasterine coral.

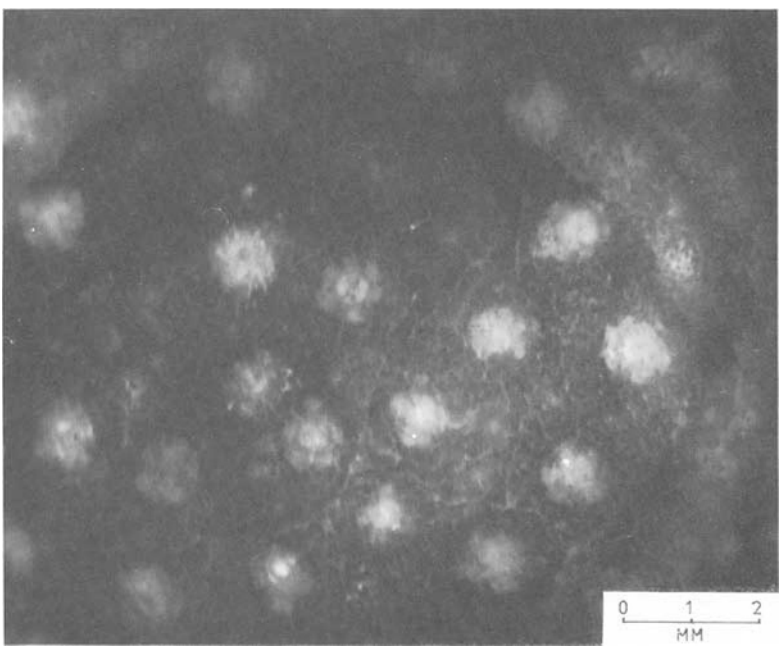

FIG. 7. White star-shaped inclusions in stylasterine coral

the gastropore, while the satellite circlets represent cross-sections through the smaller dactylopores, respectively).

(c) *White 'comet-tails'* with a fluted appearance that usually cut across the concentric growth banding (Figure 8). (This feature is caused by longitudinal cross-sections through the canals connecting the various groupings of gastrozooids and dactylozooids with each other).

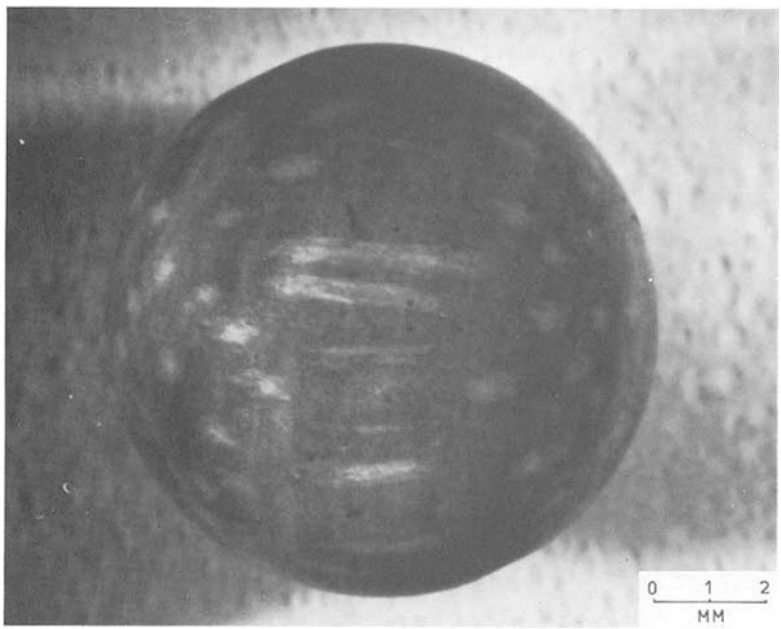

FIG. 8. 'Comet-tail' inclusions in stylasterine coral.

Moreover, the relative positions of these three characteristic features allow one to reconstruct the orientation of the polished gem in relation to the original polyp branch from which it was polished. The white star-like spots are found on planes parallel to the growth banding, while the 'comet-tails' are orientated perpendicularly to both the stars and the banding.

THE CORAL CONFUSION

A certain amount of confusion seems to have been caused by the proliferation of the different 'corals' that are used for ornamental purposes. Although it has clearly been shown [4,7] that the reef-building corals are not to be associated with those commonly occurring as gems, there still seems to be a great confusion when discussing corals in general. Moreover, taxonomically speaking, one is confounded by the conflicting classifications encountered in the literature. Ideally, it should be possible to identify and name each coral by its genus and species. But presently this is almost impossible because of the uncertainty that still exists amongst taxonomists.

Alternatively, it is possible to group the corals in terms of common denominators and to create a useful terminology for gemmology which is in keeping with zoological taxonomy. One such common denominator is that all corals belong to the Phylum, *Coelenterata.* These coelenterates in turn are divided into three Classes, namely, *Hydrozoa, Anthozoa* and *Scyphozoa.* Corals are found amongst the hydrozoans and the anthozoans but not in the schyphozoans. Although the corals start diversifying rapidly beyond this level of classification, it is still practicable to use the next taxonomic subdivision, namely, the Order, to make a meaningful grouping (Figure 9).

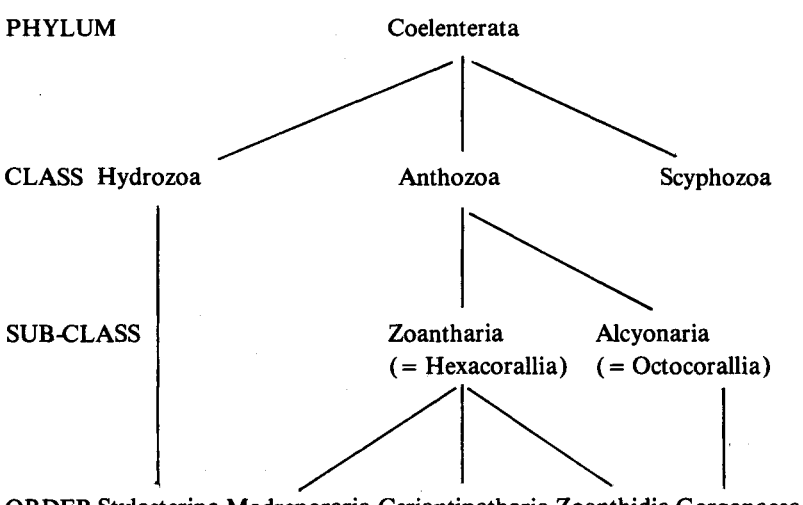

FIG. 9. Taxonomic Classification of Coral.

1. GORGONACEAN CORALS

Genus and Species	Appearance	Common Name
Corallium rubrum	red, pink, white	Precious coral
Corallium secundum	pink	,, ,,
Corallium japonicum	red,	,, ,,
Corallium konojoi	white	,, ,,
Corallium elatius	pink	,, ,,
Keratoisis sp.	yellow-brown	Bamboo coral
Gorgonia sp.	black	False black coral

2. STYLASTERINE CORALS

Allopora subviolacea	blue, violet	Akori coral
Allopora nobilis	red, pink, violet, yellow-orange	African star coral

3. CERIANTIPATHARIAN CORALS

Antipathes spiralis	black	Black coral
Cirrhipathes sp.	yellow	Golden coral

4. ZOANTHIDIAN CORALS

Gerardia sp.	yellow	Gold coral

5. MADREPORARIAN CORALS

All the reef-building corals

FIG. 10. Proposed Gemmological Classification of Coral.

The gemmological subdivision shown in Figure 10 is proposed as a possible means of minimizing the confusion. Presently five groups are sufficient to differentiate between the existing types of coral[3,4,5,6]. However, should a new discovery be made which does not fall within the present scheme, an additional group could be created and added by using the taxonomic Order to generate it.

ACKNOWLEDGEMENTS

I wish to thank Messrs Transvaal Tigerseye Industries (Pty) Ltd, Johannesburg, and Laroc Manufacturing Company (Pty) Ltd, Port Elizabeth, for supplying specimens and relevant information for this study, as well as the technical staff of the Department of Geology, Stellenbosch University, for the photographs, maps and the processing of the manuscript.

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[*Manuscript received 6th June, 1981.*]

REPORT ON COLOURED CUBIC ZIRCONIA

By PETER G. READ, C.Eng., F.G.A.

Several manufacturers of cubic zirconium oxide (ZrO_2) are now growing crystals of the material in a range of attractive gem colours, in addition to the colourless variety used as a diamond simulant. In March, 1980, the writer received a batch of coloured zirconia specimens from the Ceres Corporation, of Waltham, U.S.A., which illustrated not only the range of colours now available in this material but also the distinctive profiles of the crystals as grown by the skull crucible process (Figure 1).

To check the subjective effect of zirconia's high dispersion (0.06) in the various colour-varieties, the writer had a sample gem cut from a crystal of each colour. Although some of the resulting brilliant-cut gemstones could have been confused at first glance with natural stones such as amethyst or topaz, their high dispersion was easily detectable as 'fire' through the body-colour of the stone. Indeed, the only stone that might have served as a simulant was the light olive-green variety, whose colour and dispersion made it similar in appearance to sphene.

FIG. 1. Seven coloured cubic zirconia crystals (courtesy of Mr J. F. Wenckus, of Ceres Corporation), and seven polished specimens (courtesy of Mr J. F. Turner, of Glenjoy Lapidary Supplies).

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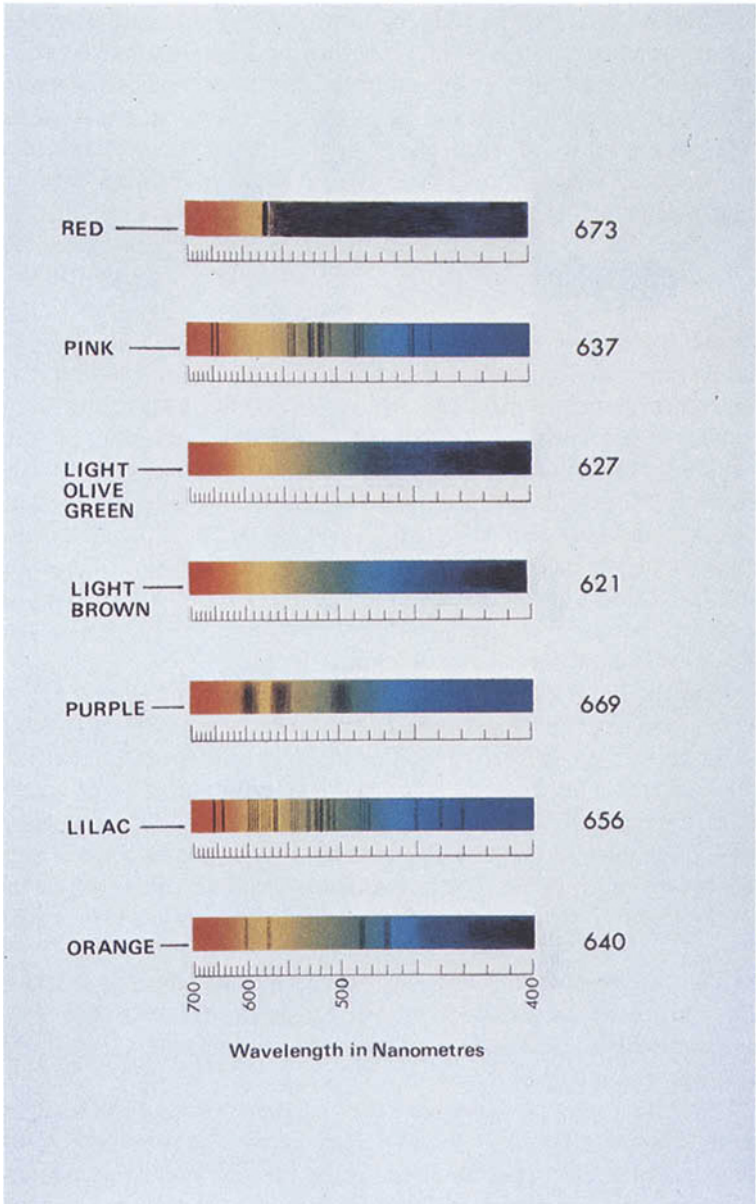

FIG. 2. Absorption spectra of the seven coloured cubic zirconia crystals. The figures on the right-hand side are the Ceres process numbers.

In the Ceres crystals, the dopants used to produce the various colours consist of transition metal ions and rare earths, both as individual additives and in multiple combinations. Irradiation techniques aimed at inducing or modifying colour in the crystals have also been tried experimentally by this company, but the resulting hues were prone to fading when the crystals were exposed to strong UV or subjected to low temperature annealing.[1]

The use of rare-earth dopants in some of the stones is immediately apparent on viewing their absorption spectra (Figure 2). In the pink and lilac crystals, the prominent fine line spectra are caused by oxides of erbium (Er_2O_3) and neodymium (Nd_2O_3) respectively. Cerium oxides (CeO_2 and Ce_2O_3) are responsible for the colour in the orange and red varieties, the latter being very heavily doped with Ce_2O_3. No information is available on the remaining colours, but the purple colour may be due to the presence of ferrous oxides, and the light olive-green and light brown shades may also be caused by one of the transition elements. Other manufacturers have used oxides of thallium (Tm_2O_3), holmium (Ho_2O_3) and terbium (Tb_2O_3), the latter as a stabilizer, to produce various shades of green; praseodymium (Pr_2O_3) has also been used to produce an amber colour.[2]

Under LW UV, the pink crystals fluoresced a yellow-green, the orange crystals fluoresced red, and the lilac crystals fluoresced a bright peridot green. The remaining crystals were inert. Under SW UV both the pink and the lilac crystals exhibited a faint green fluorescence, and the orange crystals fluoresced pink. The light olive-green and the light brown crystals fluoresced pale green and pale brown respectively. The remaining crystals were inert. None of the crystals showed any signs of phosphorescence under LW or SW UV.

When tested on a reflectivity meter, all the polished samples had a lustre which was slightly, but consistently, lower than that obtained with colourless specimens (these readings were, however, still appreciably higher than that for GGG).

Specific gravity tests on the crystals (using hydrostatic weighing) gave figures which varied from 5.95 to 6.06 (for comparison, a 646 carat colourless crystal of cubic zirconia had an S.G. of 5.95). However, the specific gravity and refractive index constants of cubic zirconia are reported[3] to be influenced mainly by the concentration of the stabilizer (Y_2O_3 in the Ceres product)

rather than by the colouring dopants. The specific gravity of cubic zirconia can, for example, range from 5.54 to 5.95, and its refractive index from 2.09 to 2.18. Some variation in these constants can also be expected within a single specimen, as the stabilizer concentration tends to vary along the length of the crystal.[1]

A comparative test of the thermal conductivity of the coloured crystals (by adjusting the calibration trip point on a Rayner Diamond Tester) showed that this was virtually the same as for the colourless variety (i.e. somewhere between glass and lithium niobate).

Because of their high dispersion, gems cut from coloured cubic zirconia do not qualify as effective simulants of any natural gem (except maybe for sphene or even diamond fancies), but with a hardness of 8-8½ and a lustre approaching that of diamond they will no doubt find a worthwhile niche as attractive and durable man-made gems.

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[*Manuscript received 15th October, 1980*]

NOTES FROM THE LABORATORY

By KENNETH SCARRATT, F.G.A.

London Chamber of Commerce and Industry Gem Testing Laboratory

After a visit to the Laboratory in October of last year, Pierre Gilson, Jnr, as he had promised, sent to us samples of his latest production of synthetic white opal. Of the eight samples we received, M. Gilson informed us that three (two pieces of rough and one cabochon cut) were plastic impregnated. We were not, however, told precisely which of the specimens these were.

So far as commercial gem testing is concerned the fact that a 'synthetic' opal has been plastic impregnated is not the most important factor to ascertain, the main object being the recognition of the stone's synthetic origin. The importance of recognizing such treatment, though, increases when the stone appears to be natural.[1,2,3]

A short time prior to our receiving the samples from M. Gilson, during the course of our normal gem testing function, one particular natural black opal had been giving us cause for concern. Examination under the microscope revealed that the stone was a little unusual in its colouring, just enough to arouse one's suspicions. The SG was calculated to be 1.76, which, if this stone were an untreated gem opal, would be extremely low, and it would be expected to be of the porous variety,[4] which this stone to any great extent was not. With this information and a refractive index in the region of 1.47, we were sure that this stone had been plastic impregnated. Naturally as this was a relatively important stone, the client was less than enthusiastic about the applying of any tests during which there was a possibility of damage occurring. Time also, as always, being a relevant factor, on this occasion proof positive eluded us. Certainly nowadays it is foolish to attempt the identification of an opal of apparent natural origin whilst it is mounted. Having been a little frustrated with this stone, when M. Gilson's samples arrived, it was felt that it would be a useful exercise if we were to examine these closely with a view to identifying those which had been impregnated.

The results of this examination are given in Table 1. The SGs were obtained by hydrostatic weighing, using distilled water. No

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TABLE 1

Specimen		CT Weight	SG	Luminescence: X-ray	Luminescence: Long Wave Ultraviolet	Luminescence: Short Wave Ultraviolet	Reaction to Thermal Probe *	Reaction on Heating in A Test Tube	Structure
1.	Untreated specimens	5.76 (Rough)	2.22	Strong blue with blue phosphorescence. Discoloured in the area where the beam passed.	Dull blue with a weak phosphorescence in the area where the x-ray beam had passed.	Bright strong green on three surfaces otherwise almost inert. Moderate to strong phosphorescence.	No reaction.	Colourless residue. No smell or Condensate.	See Figure 2.
2.	Untreated specimens	4.94 (Rough)	2.22	As for specimen No. 1.	As for specimen No. 1.	Very bright strong green on four surfaces otherwise almost inert. Phosphorescence where x-ray beam had passed.	As for specimen No. 1.	As for specimen No. 1.	See Figure 2.
3.	Untreated specimens	1.48 (Cabochon)	2.24	As for specimen No. 1.	Almost inert. Moderate to strong phosphorescence where the x-ray beam had passed.	Almost inert. Weak phosphorescence where the x-ray beam had passed.	As for specimen No. 1.	Not tested.	See Figure 2.
4.	Untreated specimens	2.36 (Cabochon)	2.12	Moderate light green which changes to a light blue. With phosphorescence.	Dull green. Very weak phosphorescence.	Bright green. Weak phosphorescence.	As for specimen No. 1.	Not tested.	See Figure 1.
5.	Untreated specimens	1.88 (Cabochon)	2.17	As for specimen No. 4.	Almost inert. Weak phosphorescence.	As for specimen No. 4.	As for specimen No. 1.	Not tested.	See Figure 1.
6.	Treated specimens	3.48 (Rough)	1.91	Inert.	Bright strong blue. Fast fading (2 sec.) phosphorescence.	Strong blue. Strong phosphorescence where the x-ray beam had passed, otherwise weak.	Surface is marked. See Figure 3.	Red-brown residue. Strong smell of burning plastic. Condensate on wall. (Fig. 4).	See Figure 2.
7.	Treated specimens	1.50 (Cabochon)	1.92	Slight blue.	As for specimen No. 6.	As for specimen No. 6.	As for specimen No. 6.	Not tested.	See Figure 2.
8.	Treated specimens	3.10 (Rough)	1.93	Inert.	As for specimen No. 6.	As for specimen No. 6.	As for specimen No. 6.	As for specimen No. 6.	See Figure 2.

*The thermal reaction tester, as manufactured by the Gem Instruments Corporation.

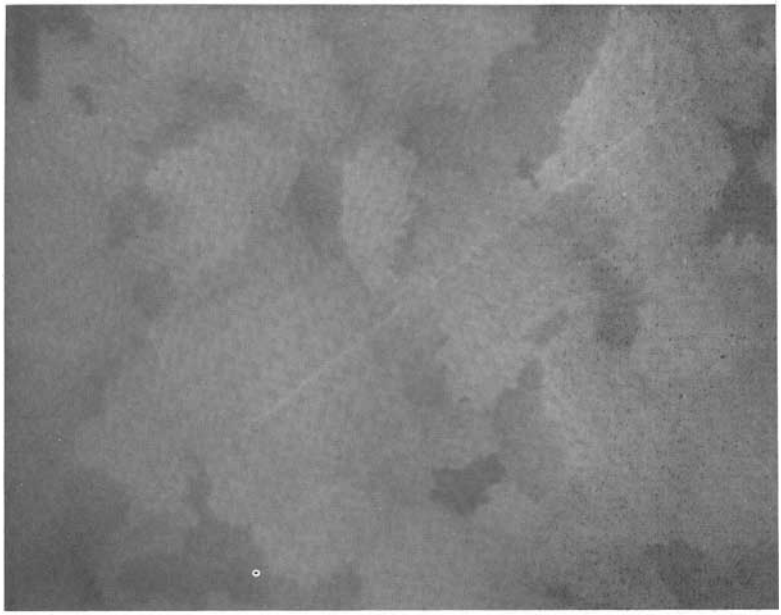

FIG. 1. 'Lizard skin' structure in Gilson synthetic white opal (SG 2.12-2.17).

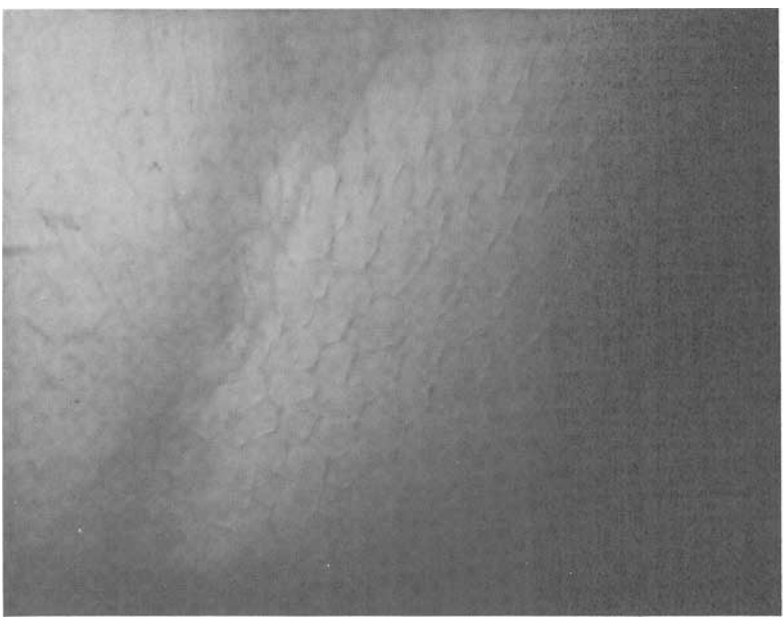

FIG. 2. 'Chicken wire' structure in Gilson synthetic white opal (SG 2.22-2.24 and 1.91-1.93).

significant porosity was noted. The SG range for the untreated opals was found to be from 2.12 to 2.24, whereas the plastic impregnated opals ranged from 1.91 to 1.93. This latter lower SG reminded me of the 'porous variety' M. Gilson placed on the market in 1975,[5,6]—possibly a good reason for plastic impregnation! Of the untreated samples, there appeared to be a relationship between the SG and the internal structures. The two stones with the lower values (2.12 and 2.17) revealed the 'lizard skin' structure in Figure 1, whilst the three with the higher values (2.22 and 2.24) revealed the 'chicken wire' structure in Figure 2. The treated stones also revealed the 'chicken wire' structure.

Naturally, destructive tests are of no use under normal gem testing conditions; however, they were employed in this examination to confirm our suspicions that the samples with the lower SGs were the treated stones. Only small fragments were required from the rough samples to observe the reactions recorded in Table 1 under the heading 'heating in a test tube' and in Figure 4. The test tube in this case was held in the flame of a spirit lamp. It was necessary to place the tip of the thermal probe lightly on to the surface of the impregnated synthetic opal to obtain the reaction recorded in Table 1 under the heading 'reaction to thermal probe' and in Figure 3.

* * *

Heat treated blue sapphires[7] have been a fact of life for some time. On occasions it is possible to identify these stones but often one can only be suspicious. In either case positive identification is not required, for under a C.I.B.J.O. ruling these stones are placed in a category along with such stones as zoisite and aquamarine[8].

A departure from this 'normal' heat treatment is a new type of 'treated corundum', warnings about which have been issued by the French delegation to the C.I.B.J.O. Coloured Stone Commission, in recent months[9]. The colour of these stones is produced by coating what could be a colourless corundum with a 'chemical dye', heating the stone so that the colour is diffused into the surface and then repolishing. The Coloured Stone Commission decided that these stones should be described as 'treated corundum'.

We have had the opportunity to examine two of these stones and feel that identification is not difficult once the examiner is

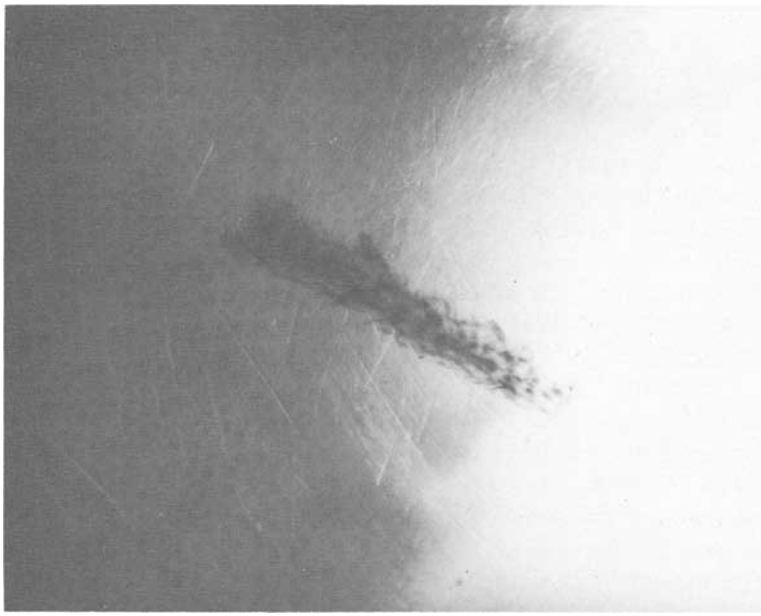

FIG. 3. The mark produced when the surface of the plastic-impregnated synthetic white opal is lightly touched with the tip of the thermal reaction tester.

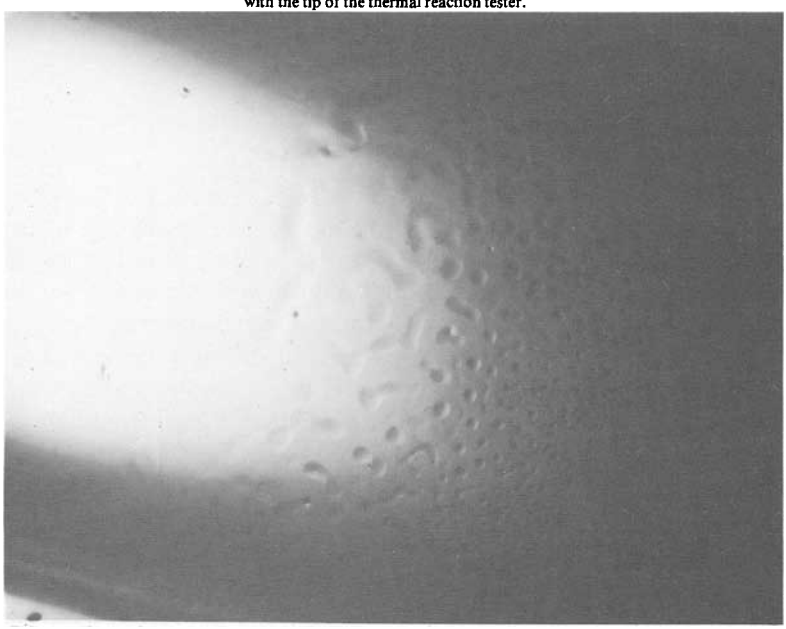

FIG. 4. The condensate on the inside wall of the test tube after small fragments of the plastic-impregnated synthetic opal had been heated.

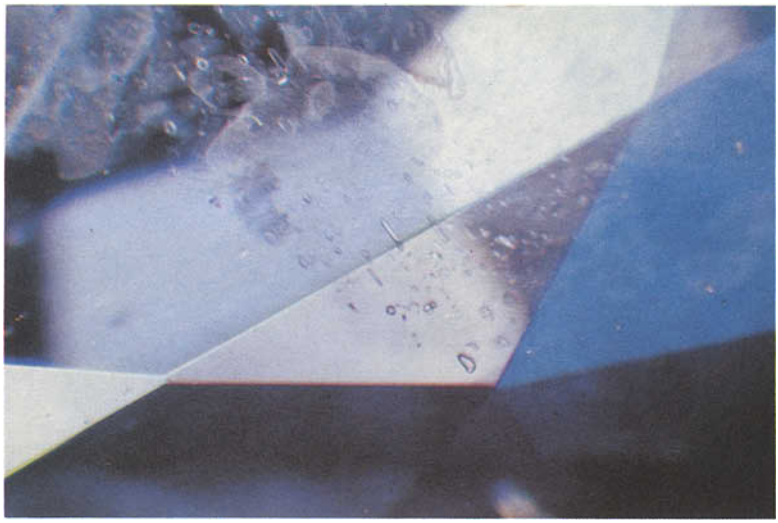

FIG. 5. 'Ceylon feathers' in a blue treated corundum.

FIG. 6. The patchy colour-zoned appearance of a normal heat-treated blue sapphire.

FIG. 7. The 'glassy' or 'watery' centres to Ceylon feathers, which are so characteristic of many heat-treated sapphires, seen here in a treated blue corundum.

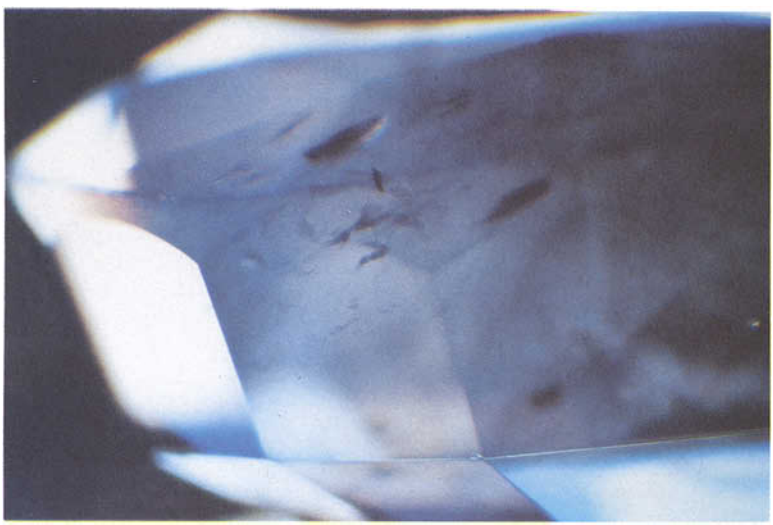

FIG. 8. The colour concentration in feathers which reach or come close to the surface in a treated blue corundum.

made aware of what to look for. Mistakes could occur, though, where the stone or stones are set in an item of jewellery and are only given a cursory examination under the normal lighting conditions of a retail outlet, for these stones can contain the 'Ceylon feathers' so characteristic of natural sapphires from Sri Lanka (Figure 5).

Both of the stones examined were a good over-all blue with none of the patchy or colour zoned appearance seen in some of the heat treated stones (Figure 6). The first was oval and faceted weighing 2.84ct and the second was a round cabochon cut stone weighing 4.58ct. None of the fluorescence characteristics proved to be of any aid to identification and the refractive indices for the faceted stone were normal for corundum. An indication that the stones were not all they purported to be, was the absence of any absorption in the 450 nm region as observed with the hand spectroscope. Natural sapphires of this colour should at the very least show some weak absorption in this area.

It is however the observations made through the microscope that give the examiner the proof necessary for identification. The first impression gained, from the examination of the inclusions in the faceted stone, was that they were typically Sri Lankan in appearance. Upon closer examination of the feathers, the 'glassy'

FIG. 9. The colour concentration at the surface of a treated blue corundum, seen here as a royal blue rim following the girdle line.

or 'watery' centres (Figure 7) which are so characteristic of many of the heat treated sapphires could be seen. Further examination of those feathers which came close to, or reached the surface, revealed that there was a colour concentration within them (Figure 8). The most important identifying factor though was found to be the colour concentration at the surface. This could be most easily seen when the stone was immersed in benzyl benzoate, so that the girdle area could be inspected with the crown facets uppermost (Figure 9), when a royal blue band could be seen just inside, and following the girdle line. As the colour of a cut stone is normally a little darker in this area, care should be taken when coming to a decision, but if the effect seen in Figure 9 is visible, then this is enough to identify such a stone as 'treated corundum'.

It is with pleasure that I acknowledge the continued generosity of Pierre Gilson, Jnr, and thank E. A. Thomson Ltd for allowing us to examine the treated corundum. Figures 5-9 were produced by Mr E. A. Jobbins, whom I thank for these and his many valuable comments.

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UNSTABLE COLOUR IN A YELLOW SAPPHIRE FROM SRI LANKA

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Among the many cases of routine testing in a laboratory, from time to time there comes an enquiry for ascertaining colour-stability of gemstones under daylight or other conditions. In keeping with gemmological rules of non-destructive testing, the possibilities are rather limited, especially for large or very valuable gems, unless the owner accepts the risk of a possible loss of value for the sake of knowledge, in giving permission to carry out an adequate investigation.

Such a case occurred some time ago, being worth mentioning in consideration of the large size of the faceted yellow sapphire involved, weighing 45 carats, of rectangular shape, 20 mm in length, a very pleasant gem of a good saturated yellow colour, matching approximately the colour hue 2:6:1 of the DIN 6164 system. Together with clear-cut physical properties for natural corundum, this sapphire proved its origin from Sri Lanka through tell-tale inclusions, as well as the usual, strong, orange fluorescence under 365 nm ultraviolet radiation.

The owner said that the sapphire had been sent on consignment, and, after it was returned, he had got the impression that the colour had slightly faded. As he suspected that the stone might have originally been submitted to some kind of treatment to improve its colour, he asked to have it checked for colour-stability, giving the laboratory permission to carry out appropriate tests. Rather than relying only on the impression of the eye to judge the colour, in order to get a better comparison basis, the transmission was first recorded on a two beam spectrophotometer, resulting in a curve as shown by the plain line in Figure 1. The following features are to pointed out:

—a rather even and broad transmission between 800 and 550 nm;

—a steep decrease below 550 and 0% transmission limit at about 340 nm.

In the condition as received the dichroism was weak, the colours being yellow and pale yellow.

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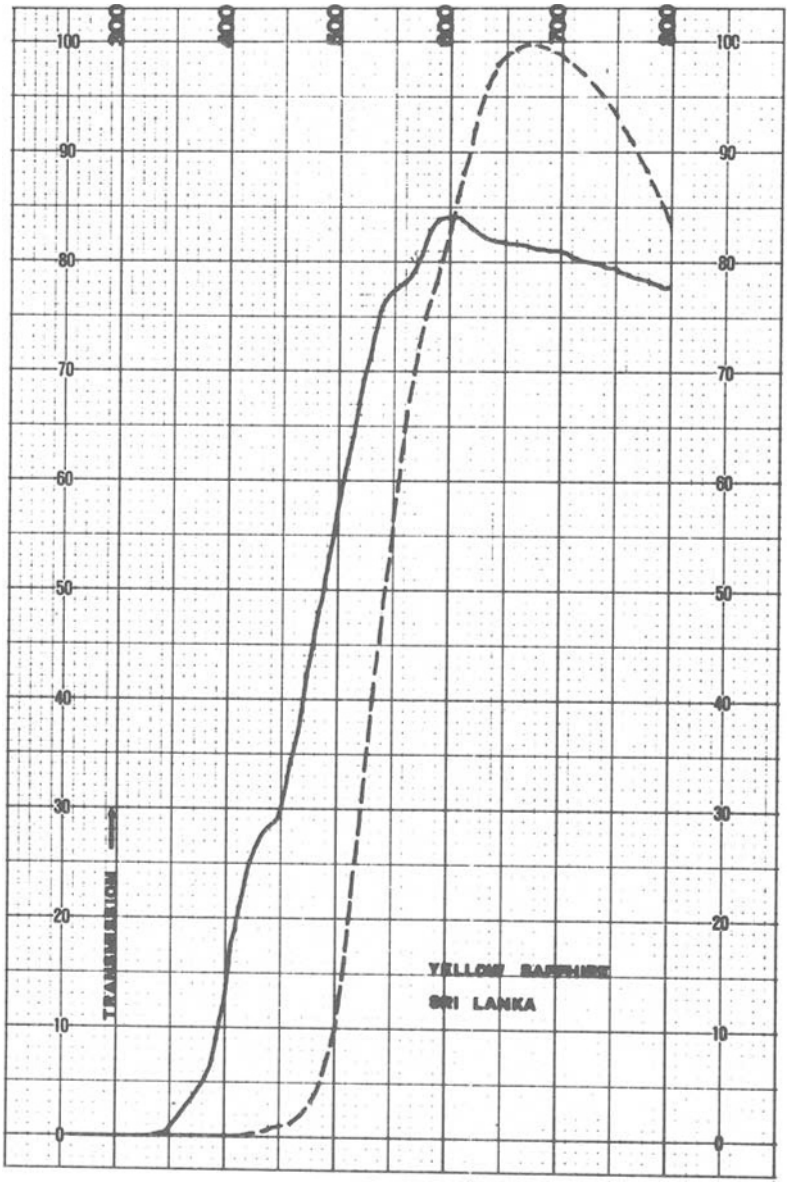

FIG. 1. Spectrophotometric recording of colour transmission in a 45 ct yellow sapphire from Sri Lanka.
Plain line, condition as received.
Dotted line, after irradiation under x-rays, 60 kV 25 mA during 3 hours.
(Photograph by the author)

To duplicate the possible bleaching action of daylight through part of the ultraviolet radiation it contains (however, in a shorter period of time), the sapphire was left for 36 hours under the 365 radiation of a B-100 A ultraviolet lamp made by Ultraviolet Products Inc. The result was a considerable loss of the colour-saturation. At this point, it was already clear that the colour was not lasting.

The next step involved was trying to impart the colour again, by means of irradiation by x-rays at a rate if 60 kV 25 mA for a period of 3 hours in a Siemens Kristalloflex x-ray unit. The deepening of the colour in one-hour steps was easily recognizable to the eye. At the end, the hue had turned to a saturated, orangy yellow colour, the dichroism being then more distinct, in colours of yellow and pale yellow. To increase the appreciation of the colour-change, a colour transmission recording was made again, as per the dotted line in Figure 1, featuring the following changes:

—a shift of the main transmission as a broad peak culminating at about 675 nm

—a more drastic decrease under 600 nm to a 0% transmission at about 420 nm.

Comparing both curves renders the colour-change quite evident, the conclusion being that x-rays have a definite action of deepening the colour. In order to avoid possible damage we did not try to

FIG. 2. Yellow sapphire from Sri Lanka, 45 ct. Original size, length 20 mm.
Orangy yellow part induced by x-rays; faded part after exposure to 365 ultraviolet radiation.
(Photograph by the author)

influence or stabilize the colour by heating. Microscopic examination proved the colour-change to be throughout the stone.

Due to previous experiments with other yellow sapphires, we know that the colour-activation through x-rays may be reversible under ultraviolet radiation. This was tried again, and to make the effect more obvious, the sapphire was partly wrapped in aluminium foil, about one third only being left uncovered under the action of the same lamp as before, under similar conditions. The colour-fading at one end of the stone is quite striking, as shown in Figure 2. Our tests prove that, under these conditions, the colour would fade and might be reactivated at will, confirming our former experience.

In consideration of this situation, a few words of caution to people dealing in yellow sapphires might seem appropriate, because of the commercial consequences involved with unstable, artificially-induced colour.

The phenomenon discussed here is different from the artificial colour-change met with in sapphires of various shades as a thin skin of deeper colour—induced superficially, with the result that these might be expected to lose part of their colour if recut.

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THE CARAT WEIGHT

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For many people the word 'carat' is partly a mystery. Frequently it is somehow associated with quality, but usually confused with size. There is some foundation for both conceptions, for quality with regard to gold and for size in so far that a larger stone in most cases weighs more than a smaller. Two gems of equal size may, however, have different weights, depending on their SG and how they are proportioned.

One carat is today a weight unit equal to one fifth of a gram, i.e. 200 milligrams. But this was not always the case. The history of our carat weight will therefore be related here in detail, since a complete compilation never seems to have been published yet. The association of carat with the various gold standards will be discussed as well.

When originally the flow of diamonds into the Western world began, much of the traditions and conceptions were taken over from India, the one and only source of supply. However, neither the tandula* nor any other oriental weight unit was adopted. At the source diamonds were obviously weighed and valued for taxation purposes, but the prices quoted and accepted respectively were no doubt based on size and beauty alone. For the importers' inventory and marketing purposes the gems eventually had to be weighed and their respective weight expressed in terms generally understood by everybody, specially by the prospective customers.

In those early days the smallest weight units used in commerce were specified seeds. In England and on the Continent north of the Alps 'the least portion of weight' was the grain, usually the weight of the local grain of wheat. By Robert Recorde (1542)† this is quoted as 'a grayne of corne or wheate, drie, and gathered out of the middle of the eare'. But the weight of a grain unfortunately varied considerably. There were various 'diamond grains', 'pearl grains' and, of course, 'grains troy' and 'grains avoirdupois', and in other countries still other grains. Eventually (probably in the

*See Lenzen, 1970, pp.41-5.

†Robert Recorde, *The ground of artes, teachynge the worke and practise of arithmatike.* — Ed.

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sixteenth century) a 'carat grain' was most fortunately introduced all over Europe. This now compared with the carat weight and became equivalent to 1/4 of a carat. We will revert to this later in the text, after having first discussed the carat weight.

Since the trade routes from the Far East to Europe for diamonds, pearls and coloured gems ended in the Mediterranean region, a local and abundantly available seed with a weight as small and as constant as possible had to be chosen.

The long established pearl and gold merchants already had at their disposal an accepted, suitable weight. It was the bean of the locust pod or carob tree (*Ceratonia siliqua*), which produces a curved fruit, something like a horn. Inside the pod is a sweet syrup and many small seeds (St John's bread*). These seeds are remarkably constant in weight and those taken from the ends of the pulpy pods are not smaller than those from the middle. Whether dry or affected by humidity the weight of every seed remains practically the same. Some recent authors have, however, found even considerable differences, but these observations are in all probability due to some specific trees from a remote region, different from the normal ones. The small differences in weight normally met with were surely too small to have been measurable by the simple balances available to the traders of the time. As far as they could judge, such seeds were absolutely identical, and this fact is a remarkable tribute to the astuteness of the ancient pearl and gold dealers. In this connexion it must be remembered that the original carat weight was not subdivided into fractions, although obviously a seed may occasionally have been cut into two or even four equal pieces.

The term *carat* is derived from the old Greek word *keration* (κεράτιον), which refers to the horn-like shape of the fruit-pod. The equivalent in Arabic was *quirrat* or *qīrāt,* and became *quirate* in old Portuguese; it is now *quilate* both in Portuguese and in Spanish alike. In English it was originally (according to Thomas Nicols, writing in 1652 in *A Lapidary)* written *ceratium,* in plural *ceratia.* Around 1677 (*The Merchants Map of Commerce,* by Lewis Roberts) the spelling was *carot,* but simultaneously also the present *carat.* This term is practically universal, with some slight variations like *carato, karaat, karaatti.* Formerly abbreviations like C and Ca were common; now it is agreed to read 'ct'.

*See Matt. iii, 4.—Ed.

As commerce in gems increased, various countries began to standardize the carat in relation to their own unit of weight, which also varied. Simultaneously the carob seed was exchanged into metal weights in a sequence, as for instance 1, 2, 3, 4, 8, 16, 32, 64, 100, 200, 300, 500 carats, thus permitting individual stones and lots of any intermediate weight to be quickly calculated. Furthermore, smaller weights—fractions of a carat—were introduced, the smallest of which was 1/64th of a carat. Following the then normal subdivision of units a diamond weighing (say) exactly 1 ct and 63/64 was described as 1 carat 1/2c, 1/4c, 1/8c, 1/16c, 1/32c, 1/64c—indeed taking up much space and cumbersome to interpret, but easy when just adding continuously smaller weights on the scale. This awkward habit survived even after the metric system began to gain ground, and it is not long since, e.g., carpenters often preferred to divide the inch in that way and wrote (say) 1/2, 1/8, 1/16 for 11/16. In 1884 Jacobs & Chatrian listed weights slightly over 205 milligrams as, e.g., 205 milligr. 1/10e 1/2.

Some jewellers adopted a decimal notation of the fraction of an old carat, but in most cases we find a reluctance to use the smaller fractions and instead a remark like 'just over' or 'just below'. In many instances the weights were indicated in 'carat grains'. One good example is to be seen in the catalogue of the Hope collection, which was exceptional in that the grain was subdivided up to 1/32, corresponding to 1/128 ct! Another example is the Green Vault, where the grain was used throughout.

Even though the carat weight was well established, it varied in different trade centres. It also varied from one period to another and from one dealer to another. However, as a rule a carat was pretty close to 205 milligrams. In Bologna, Florence and Amboina it was below 200, and in Madras, Turin and Leghorn well over 205 mg. Exact values have been quoted by many authors, but the figures vary too much between themselves to be worth listing. As a rule of thumb it may be suggested that an old carat weight of say 10 ct corresponds with 10.25 of our modern metric carats.

As a warning against blind conversions it may be said that in principle a London carat was different from a Paris carat and both were different from, e.g., a Venice carat. But at least six different carat weights have been observed in England alone. Another observation is that the Florentine diamond by Tavernier was said to weigh 139 1/2 ct and by the Austrians only 133 1/5. This indicates

the fact that carat weights of 196.8 and 206.1 mg respectively were used. In 1884 Jacobs & Chatrian checked the carat weights with four famous French jewellers and found them to weigh 205, 205.3, 205.45 and 205.5 mg respectively. As late as in the 1890s M. D. Rothschild wrote to three prominent balance-makers in the United States for their carat standards and found that they all differed.

It was therefore not surprising that a first step towards standardization was taken. A syndicate of Parisian gem dealers in 1871 suggested 205 mg as the new standard. An agreement was reached in 1877, as a result of a conference between diamond merchants of London, Paris and Amsterdam and followed by most other countries. The small differences between individual dealers and retail jewellers, however, remained. No wonder, therefore, that discussions went on. At the International Congress of Weights and Measures in 1893 Dr G. F. Kunz suggested that the carat be incorporated with the metric system and reduced to the nearest metric equivalent, 200 milligrams. This would depreciate the '205' ct by a little less than 2.5% to the advantage of the dealers, and it would above all involve new weights, the correctness of which would be easily and rapidly checked against metric standard weights. In order to facilitate the abolition of the old carat, the new one should be called 'the metric carat' and the weights stamped with C.M. or a similar abbreviation. The first resolution, recognizing the advantages to the international trade in gems by a metric carat and suggesting this, was universally adopted. The legalization in the various countries was unfortunately a long and laborious procedure, and prior to World War I only the following countries introduced this unity: Spain, in 1908; Japan and Switzerland in 1909; Bulgaria, Denmark, Italy and Norway in 1910; Holland, Portugal, Romania and Sweden in 1911; France in 1912; Belgium and U.S.A. in 1913, and Great Britain in 1914. The rest of the world handled the question first after the War and either legalized the metric carat or considered it unnecessary to do so, since it could well be used under the metric system already in force.

The metric carat is obviously the one and only international unit for weighing gemstones and in universal acceptance. The intermediate usage, when it was agreed to indicate the difference from the earlier units by saying metric carat and writing m.ct., c.m., etc., is no more necessary. Instead there is a kind of

gentleman's agreement to quote gem weights of past times in fractions, e.g. 1 1/2 instead of 1.50 ct.

Modern carat weights are now internationally written with two decimals, even if the second is a zero. If weighed with precision balances a third decimal may be quoted, but in brackets, for instance 1.50 (1.508). The third decimal is thus neglected and serves only the purpose of an easier identification.

THE GOLD CARAT

Since we know that the carob seed was the commonly used smallest weight in the Mediterranean region long before our Christian era, it is not surprising that the weight of old Roman coins was fixed in 'carats'. Thus the Roman emperor Constantine the Great in the year 312 A.D. minted a gold coin named *solidus,* weighing the equivalent of 24 carats at 190 mg, or 4.55 g. This replaced the depreciated *aureus* introduced by Caesar* and soon became the currency of the civilized world. However, inflation forced Valentinian I already in 367 to reduce the content of fine gold from the full value of 24 units to 20 1/2. In the year 700 it was further reduced to 20 units.

During this period the alloy thus sank from 24 down to 20 carat and later to 18. A numismatist will eventually be inspired to make a more detailed investigation and write a paper on how the gold caratage was introduced and generally accepted. Today it is replaced by metric figures stating how many thousandths of the total weight of an alloy is pure gold.

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[*Manuscript received 22nd May, 1981.*]

*C. Julius Caesar (102-44 B.C.).—Ed.

SPHENE, ANOTHER GEM MINERAL FROM SRI LANKA

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INTRODUCTION

In the past Ceylon has been of considerable interest regarding the production of different gemstones and in the future it seems Sri Lanka will continue to be so. Those gemmologists who visit the island regularly will be impressed by the enormous developments the country has made in this field in a short time. This is undoubtedly due to the great influence of the State Gem Corporation, which is promoting the improvement of cutting and is educating the people dealing with gemstones. It, therefore, is no longer easy to buy parcels of tourmaline in which rare stones like kornerupine, ekanite and sinhalite may be discovered. It is even so that rare and unusual gemstones will be sold under their own correct name. The valuable activities of the State Gem Corporation do also promote the discovery of new gemstones in Sri Lanka. Some years ago kornerupine cat's-eyes were mentioned for the first time (Korevaar & Zwaan 1977) and now they are rather common on the market in Sri Lanka. The occurrences of axinite near Balangoda and fibrolite at Paradise Tea Estate in the Ratnapura area are not yet officially reported. Very recently gem quality sphenes from Sri Lanka were first described (Zwaan & Arps 1980), while a dark brown cut sphene of 4.48 ct from Sri Lanka has been reported by Gunawardene & Hänni (1981).

In October 1980 the author visited Sri Lanka and bought three beautifully cut sphenes from the well-known gem dealer Faust A. Saheed in Colombo. According to Mr Saheed they originated from the Tissamaharama area in the southern part of the island. Although the occurrence of sphene near Galle was known since the early fifties, and the sphene described by Gunawardene & Hänni is ascribed to the same area, the stones mentioned above belong to the first sphenes of good gem quality found in Sri Lanka. Gem mining started about a year and a half ago in the Tissamaharama area, and a good production may be expected based on the results of the exploration during the last years.

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In February of this year the author visited Sri Lanka again and went to the above mentioned area. The main places of interest are Amarawewa (Figure 1), situated about six miles from Tissamaharama along the road to Kataragama and Kochipadana, which is about half an hour's drive by landrover from Kataragama in a easterly direction (Figure 2).

People are not yet familiar with gemstones in the area. Material for cutting is sent to Colombo and Ratnapura. Until now it has been found in alluvial deposits only. The ways of mining and washing are similar to those applied in other gem mining areas of the island (Figure 3). As these activities were started recently, no deep levels have yet been mined; on the contrary only many reconnaissance pits up to about one yard deep may be observed, a gem-bearing zone being situated at about that depth. This is especially the case in Kochipadana (Figure 2). The occurrence of sphene in this part of the country, in particular in Amarawewa, has been confirmed by the Scientific Division of the State Gem Corporation.

Since October 1980 five cut sphenes, weighing together 10.02 carats, have officially been exported to the United States of America and another five cut stones were brought to Holland for

FIG. 1. Gem mining in Amarawewa.

FIG. 2. Gem mining in Kochipadana.

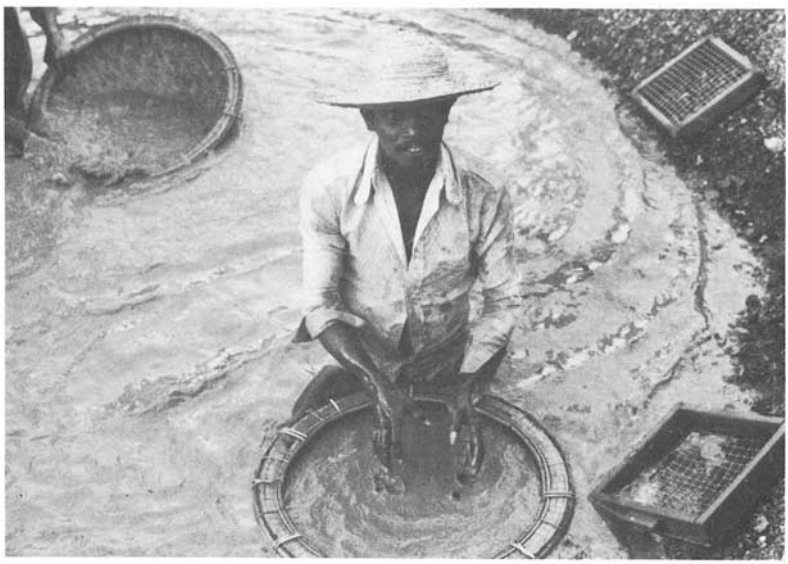

FIG. 3. Gem washing in Amarawewa.

further investigation by the above-mentioned gem dealer in March of this year. Three of them are stored in the collection of the Rijksmuseum van Geologie en Mineralogie, Leiden, the total amount of cut sphenes from Sri Lanka in that collection now being six. The are registered with numbers prefixed with RGM.

Refractive indices were measured with a refractometer provided with a cubic zirconia prism and a scale recalculated by the author. Due to the high figures for sphene only α could be observed.

Specific gravity measurements were carried out by means of a hydrostatic balance using both ethylene dibromide and alcohol as immersion liquids. The data obtained are the average of repeated measurements.

X-ray powder photographs were made using Fe-radiation and a Debye-Scherrer camera of 114.6 mm. Since cut stones only were available for investigation, use was made of the 'sphere' method of Hiemstra (1956), to restrict the damage of the investigated stones as much as possible.

Electron microprobe analyses were performed at the electron microprobe laboratory of the Instituut voor Aardwetenschappen, Vrije Universiteit Amsterdam, with financial and personal support by ZWO-WACOM (Research Group for Analytical Chemistry of Minerals and Rocks, subsidized by the Netherlands Organization for the Advancement of Pure Research).

From the gemmological point of view not very much has been published on sphene. Cassedanne & Cassedanne (1971, 1974) reported on sphene of gem quality from Campo do Boa, Capelinha municipality, Minas Gerais State in Brazil. In these papers crystallographic properties are given besides density data, details about accompanying minerals and a comparison with other sphene deposits in the world. Chemical data of sphene from Capelinha have been published by Higgins & Ribbe (1976).

In their recent paper Zwaan & Arps (1980) gave preliminary results of an investigation of the three cut sphenes purchased in October 1980. The properties of these stones were compared with those of sphenes from Capelinha, Brazil, belonging to the collections of both the museum and the Netherlands Gem Laboratory (NEL), which is housed in the museum. In their very recent paper Gunawardene and Hänni (1981) describe one sphene, which is said to originate from a remote area near Galle in Sri

Lanka. Microprobe analysis and absorption spectrum data are given in detail. The properties of the stone are compared with those of sphenes from three other localities and are found to be very similar to them.

The aim of the present paper is to draw attention again to the discovery of this new gem quality mineral in Sri Lanka and to give additional data on the origin of the cut sphenes.

PROPERTIES

Available for investigation were six cut stones; their properties are given in Table 1. With the exception of RGM 151 856, the colour of these sphenes is honey-yellow to brown. All have a strong pleochroism in tones of yellow-green and orange-brown. Due to the enormous birefringence in all stones, double facet edges at the base side are to be observed while looking through the table, in some cases even with the naked eye. Although use is made of a refractometer provided with a cubic zirconia prism, which makes it possible to get readings up to about 2.06, it was only possible to get a shadow-edge near 1.910, which is apparently the lowest figure, more or less corresponding with α. One of the stones (RGM 151 863) gave the two readings 1.908 and 1.940 on the table facet. These can only be related to the double refraction in the direction of observation.

The stones have distinct absorption spectra, due to the content of rare earths, with sharp intensive lines at 586 and 582 nm, in particular specimen RGM 151 854 has a very well developed spectrum. In these sphenes five lines can be seen in the yellow part of the spectrum at 599, 586, 582, 580 and 575 nm, while three absorption lines may be observed at 534, 530 and 528 nm, the strongest of them being the two lines in the yellow as mentioned above and the 530 nm in the green.

This 'didymium' spectrum, due to the presence of the rare-earth elements neodymium and praseodymium, is less developed in the yellowish green sphene RGM 151 856. It has ill-defined lines in both the yellow and the green part of the absorption spectrum. It is evident, moreover, that the quality of the spectrum is not only due to the colour but also to the intensity of that colour.

In Table 2, x-ray powder diffraction data are given for two sphenes from Sri Lanka and Brazil respectively. There are hardly any differences between these data, which indicates that these

TABLE 1.
Properties of six cut sphenes from Sri Lanka

Number	*Colour*	*Style of Cutting*	*Weight in ct*	*Size in mm*	*D (measured)*	*n (α)*
RGM 151 854	brownish-yellow	oval faceted	4.94	11.8 × 9.5 × 6.1	3.535	1.912
RGM 151 855	honey-brown	mixed	6.48	11.7 × 11.7 × 6.8	3.538	1.910
RGM 151 856	yellowish green	mixed	4.60	10.3 × 10.3 × 6.4	3.528	1.910
RGM 151 862	honey-yellow	trap	4.17	8.6 × 8.3 × 6.4	3.529	1.910
RGM 151 863	honey-yellow	trap	1.30	7.4 × 5.3 × 3.7	3.536	1.908
RGM 151 864	honey-yellow	trap	1.25	7.4 × 5.2 × 3.7	3.535	1.913

TABLE 2. X-ray powder diffraction data for two sphenes

	RGM 151 855 Sri Lanka		RGM 151 858 Brazil	
hkl	*d(obs.)*	*I*	*d(obs.)*	*I*
$\bar{1}11$	4.93	1	4.91	½
$\left.\begin{matrix}111\\002\end{matrix}\right\}$	3.22	10	3.21	10
$\bar{2}02$	2.98	8	2.98	8
200	2.84	1	2.84	½
$\left.\begin{matrix}\bar{2}21\\022\end{matrix}\right\}$	2.59	9	2.59	9
$\left.\begin{matrix}\bar{1}13\\220\end{matrix}\right\}$	2.36	½	2.34	½
$\left.\begin{matrix}112\\\bar{1}32\end{matrix}\right\}$	2.27	6	2.27	6
$\bar{1}31$	2.22	½	2.21	½
$\bar{3}12$	2.11	½	2.11	½
311	2.06	5	2.06	5
221	1.972	½	1.972	½
$\bar{3}13$	1.942	2	1.942	2
$\left.\begin{matrix}\bar{2}04\\310\end{matrix}\right\}$	1.850	½	1.850	½
$\left.\begin{matrix}042\\\bar{2}41\end{matrix}\right\}$	1.802	½	1.802	½
$\bar{3}32$	1.741	1	1.741	1
$\bar{2}24$	1.703	6	1.704	6
$\bar{3}33$	1.641	7	1.641	7
$\left.\begin{matrix}151\\241\end{matrix}\right\}$	1.553	4	1.553	4
$\left.\begin{matrix}043\\\bar{1}34\end{matrix}\right\}$	1.528	2	1.527	2
133	1.492	7	1.495	7
400	1.419	5	1.418	5
	1.345	5	1.345	5
	1.303	4	1.303	3
	1.272	3	1.271	3
	1.223	1	1.223	1
	1.201	½	1.202	½
	1.143	½	1.143	½
	1.133	4	1.133	4
	1.114	1	1.114	1
	1.107	4	1.107	4
	1.077	2	1.076	2
	1.063	½	1.063	½
	1.040	½	1.040	½
	1.029	½	1.028	½
	1.014	½	1.014	½
	0.997	½	0.997	½

TABLE 3.
Electron microprobe analyses and unit cell contents of two sphenes from Sri Lanka and one from Brazil.

	RGM 151 854 Sri Lanka	RGM 151 856 Sri Lanka	VUA Brazil
CaO	28.4	28.7	28.6
MnO	0.07	0.04	0.04
TiO_2	38.4	38.6	38.2
Al_2O_3	1.25	1.11	1.37
Fe_2O_3	0.70	0.60	0.41
Cr_2O_3	0.015	—	0.015
SiO_2	30.4	30.4	30.4
total	99.2	99.5	99.0

Unit cell contents on the basis of 19 O

Ca	3.80	3.81	3.84		3.84
Mn	0.01		—		—
Ti	3.61	3.86	3.62	3.85	3.60
Al	0.18		0.17		0.20
Fe	0.07		0.06		0.04
Cr	—		—		—
Si	3.80		3.79		3.81
total	11.47		11.48		11.49

stones have very similar properties although their colours are different. The sphene from Sri Lanka is honey-brown, while the Brazilian stone, originating from Capelinha, is yellow-green. It is not unlikely that the contents of rare earth and other trace elements will make it possible to differentiate between stones from the two sources.

The results of electron microprobe analyses of three sphenes are given in Table 3. Two of them are from Sri Lanka; one is from Malacacheta near Capelinha, Brazil and is in the collection of the analyst Dr P. Maaskant.

Standards used were olivine (Mg,Fe,Ni), gehlenite (Al), diopside (Si,Ca), ilmenite (Ti,Mn), spinel (V, Cr,Zn) and V_2O_3 (V). For Si and Ca reference standards were gehlenite, åkermanite and

andradite. If present, the contents of Na, Mg, Ni and Zn are less than 0.01%. Analyses on three different spots per stone did not reveal significant differences in major and minor element contents of the sphenes. The results of the major element analyses compare well with those in the literature (e.g., Deer *et al.*, 1962; Higgins & Ribbe, 1976; Gunawardene & Hänni, 1981)

Trace element analyses, e.g. rare-earth and other elements, could not be performed without damaging the faceted stones. As soon as rough specimens from the Tissamaharama area are available, they will be carried out. These additional data are necessary, because the present data of the sphenes do not give distinct differences between stones from the two sources.

INCLUSIONS

The most striking type of inclusions are liquid feathers comparable with those occurring in tourmalines. This may especially be observed in sphene RGM 151 854. Another type of liquid inclusion is very similar to the liquid feathers which are characteristic for corundums from Sri Lanka. They can be seen in sphene RGM 151 856.

Figure 4 shows inclusions in sphene RGM 151 855. It is

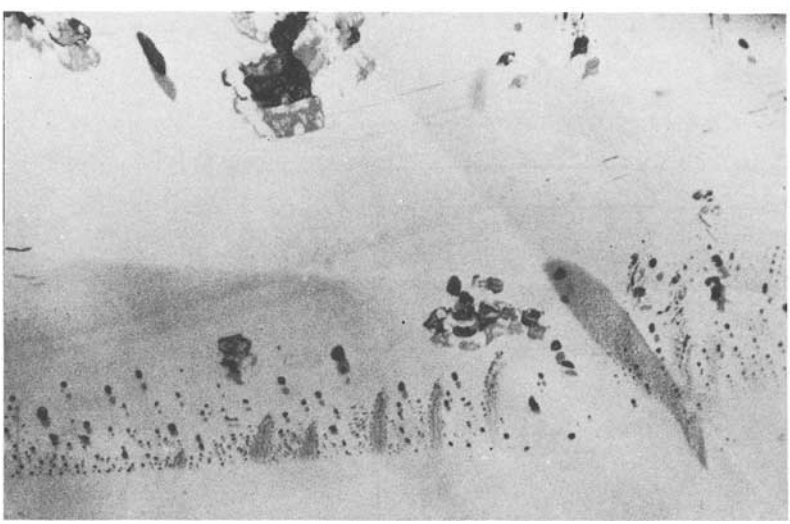

FIG. 4. Liquid inclusions in sphene RGM 151 855, ×25.
Note the strong doubling of the inclusions.

FIG. 5. Crystal inclusions, probably apatite, in sphene RGM 151 863, ×25.

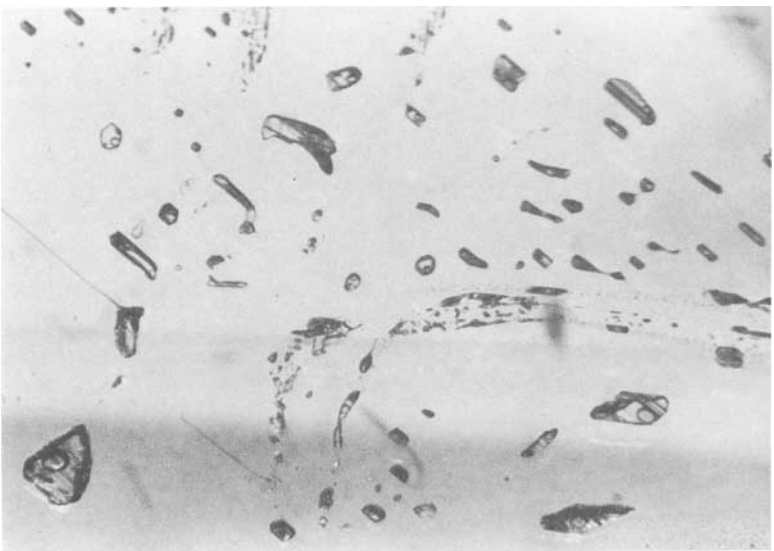

FIG. 6. Two-phase inclusions in sphene RGM 151 862, ×25.

difficult to identify the nature of them, but they most probably are both liquid inclusions and healed fissures, the strong doubling of the inclusions, due to the enormous birefringence of the stone, being very striking. Similar inclusions can be seen in sphene RGM 151 864.

Sphene RGM 151 863 contains some very small crystals which from their habits and optical properties, as far as these could be observed, are very likely apatite crystals (Figure 5). Apatite is a rather common inclusion in several gemstones from Sri Lanka, like corundum, almandine garnet and spinel, but naturally not described before as such in sphene.

In sphene RGM 151 862 superb two-phase inclusions occur. They resemble the type of inclusion which is characteristic for pegmatite minerals, like topaz and spodumene (Figure 6). However, these observations do not allow us to draw a conclusion on the mode of origin of these sphenes.

Concluding Remarks

The physical properties of the available sphenes from the Tissamaharama area in Sri Lanka are very similar to those of investigated sphenes in the collections of both the museum and the Netherlands Gem Laboratory (NEL), which are said to originate from Capelinha in Brazil. In their recent paper Zwaan & Arps (1980) state that also from electron microprobe analyses it is clear that the compositions of the sphenes are very similar. However, these 'Brazilian' sphenes were bought by the author in February 1978 as 'Brazilian tourmalines' in Singapore. Now the question whether these stones are really from Brazil is becoming very interesting, because those sphenes in the collection of the museum which are undoubtedly from Brazil, like specimen RGM 151 858, have a different colour, that is yellow-green, and a less distinct absorption spectrum. It is not unlikely, therefore that the stones which were bought in Singapore are also from Sri Lanka. The author discussed this problem with both gem dealers and members of the State Gem Corporation staff in Colombo. They are all of the opinion that, although official mining started about two years ago in the Tissamaharama area, stones from that area came on the market much earlier. They were apparently exported in a rough state, because they are all machine-cut, a technique not commonly

used in Sri Lanka in and before 1978. Anyway, further work on more material will be necessary to draw more definite conclusions. Moreover one may hope that the expected good production of this very attractive stone will be realized.

ACKNOWLEDGEMENT

The author is much indebted to his collegue Dr C. E. S. Arps for his valuable advice and for critical reading of the manuscript.

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GEMMOLOGICAL ABSTRACTS

BAMBA (T.). *Chrome-diopside jade from Chisaka, Hidaka Province, Hokkaido.* J.Gemm.Soc. Japan, **7**, 1, 9-13, 4 figs, 1980.

A material similar to nephrite in colour but consisting of chrome diopside, uvarovite, chromite and pectolite has been found in the central part of Hokkaido, Japan. It is found as networks cutting the boundary between serpentine and rodingite. M.O'D.

BUCHANAN (K.). *Fresh water pearls.* Lapidary Journal, **35**, 1, 76-9, 10 figs, 1981.

Describes pearls found in some of the rivers in Oklahoma. M.O'D.

DILLON (S.) ed. *Gem News.* Gems & Gemology, **XVII**, 1, 56-7, 1981.

Reports on the Afghanistan situation and lapis lazuli; diamond exploration in Australia, India, China, U.S.A., and U.S.S.R.; ruby in Kenya, Australia and Pakistan; sapphires in Kashmir and North Queensland; a gem-cutting enterprise in Sri Lanka and (from Tucson Gem & Mineral Show) aquamarine from Idaho; red beryl from Utah; synthetic red beryl; sugilite or 'Royal lavulite' (a new gem mineral); pink fluorite from Peru; and Brazilian topaz. R.K.M.

FOLGUERAS-DOMINGUEZ (S.), BARBOSA (J.-E. C. A.), YANEZ-LOZANO (S.). *Fluorescence des topazes aux rayons u.v.* (The fluorescence of topaz under ultraviolet light.) Revue de Gemmologie, 66, 10, 1981.

Topaz may show a slight alteration in fluorescence after heating above 200 °C. The change is most noticeable in some rose-coloured stones. M.O'D.

FRANKS (M.). *The deadly lure: a story from the Lightning Ridge opal fields.* Lapidary J., **34**, 12, 2664-70, 1981.

Anecdotal account of a field trip to Lightning Ridge, New South Wales. M.O'D.

FRYER (C.) ed., CROWNINGSHIELD (R.), HURWIT (K. N.), KANE (R. E.). *Gem Trade lab notes.* Gems & Gemology, **XVII**, 1, 40-6, 23 figs (16 in colour), 1981.

A carved bead cut from trapiche-type aquamarine is illustrated and described. Cyclotron treated diamonds, others with natural radiation stains on unpolished crystal surfaces left at girdles of brilliants, yet more diamonds with strangely shaped inclusions, all described and illustrated. A faceted golden cube of diamond also shown. Type II diamonds distinguished from Type I by photographic transparency test using short-wave UV in two second exposure to show that Type II is highly transparent at this wavelength, while Type I is comparatively opaque. An emerald had varying transparency at different angles; a synthetic emerald of Russian manufacture had needle-like inclusions and a cavity filled with yellow liquid as well as normal synthetic 'veils' and 'Venetian blind' banding.

Cultured pearls: a necklace with one shell bead completely without its nacreous layer; other cultured pearls of various colours reported, including dyed bronze and drop-shapes.

Chatham flux rubies showed angular silk-like inclusions as well as expected flux 'fingerprints'. A Verneuil synthetic had induced healed-crack inclusions. Sapphires are being 'packed in chemicals' and heated to diffuse colour into their surfaces. Short-wave UV reveals patchy fluorescence. Polishing removes the colour. Two spinel stars showed 4 and 6 rayed effects respectively. R.K.M.

GARCIA-GUINÉA (J.). *Les beryls espagnols d'un intérêt gemmologique.* (Spanish beryl of gemmological interest.) Revue de Gemmologie, 66, 2, 3 figs, 1981.

Some green and blue beryl is found in Spain, two important locations being at Sierra de Jurès and Pereña. Constants are given. M.O'D.

GÜBELIN (E.). *Zabargad: the ancient peridot island in the Red Sea.* Gems & Gemology, **XVII,** 1, 2-8, 6 figs in colour, 1981.

An excellent first-hand account of the most anciently known source of peridot, once called 'topazos', on this 4.5 km^2 island, which Dr Gübelin visited in 1980. No longer a viable source. Some account of the gem's history from classical Greek times is given. [Atlases use 'Zebirget' spelling; alternative name is 'Isle of St John'.] R.K.M.

HAAS (L. M.). *Venezuelan pearls of Margarita Island.* Lapidary J., **35,** 1, 114-16, 6 figs in colour, 1981.

Describes a visit to Margarita and experiences of pearl buying. M.O'D.

HOBBS (J.). *A simple approach to detecting diamond simulants.* Gems & Gemology, **XVII,** 1, 20-33, 18 figs (17 in colour), 1981.

Starting with careful observation of see-through effects, dispersion, facet edges, girdle defects, grain and polish lines, Ms Hobbs goes on to identify the simulants by SG tests, relating SG to size, and then immersion techniques, before touching on fluorescence, which is of minimal value. She then deals with the diamond pen and the diamond probe. [For some reason the infrared reflectometer is omitted.] R.K.M.

JONES (B.). *Blue ball azurite.* Rock & Gem, **10,** 9, 48-81, 4 figs (1 in colour), 1980.

Small nodules of azurite with some malachite are found in the Pinal Mountains south of Miami, Arizona, U.S.A. Some of the nodules are sufficiently hard to take a good polish. M.O'D.

KOIVULA (J. I.). *The hidden beauty of amber: new light on an old subject.* Gems & Gemology, **XVII,** 1, 34-6, 6 figs in colour, 1981.

An interesting and beautifully illustrated account of some inclusions to be seen in amber, using crossed polars to reveal strain caused by insect death-struggles which occurred millions of years ago. R.K.M.

KOMOTAUER (S. K.). *Granat.* (Garnet.) Mineralien Magazin, **5,** 5, 198-207, 17 figs in colour, 1981.

A short but well-illustrated survey of the garnet family of minerals. M.O'D.

KRAUS (P. D.). *A visit with the Maui divers.* Lapidary J., **35**, 1, 118-34, 34 figs (7 in colour), 1981.

Maui divers of Hawaii are a company founded in 1958. Pink and other varieties of coral are found and sold and a description of their fashioning is given. M.O'D.

NASSAU (K.). *Artificially induced color in amethyst-citrine quartz.* Gems & Gemology, **XVII**, 1, 37-9, 3 figs in colour, 1981.

More on this new particoloured type of quartz and information on the irradiation used to alter similarly twinned and segmented amethyst quartz to produce the same combination of colours. R.K.M.

NASSAU (K.). *Cubic zirconia: an update.* Gems & Gemology, **XVII**, 1, 9-19, 9 figs (4 in colour), 1981.

An authoritative and very thorough account of this man-made simulant of diamond, the most successful so far. It has been found occurring naturally but has no mineral name. R.K.M.

NASSAU (K.). *Natural, treated and synthetic amethyst-citrine quartz.* Lapidary J., **35**, 1, 52-60, 8 figs (7 in colour), 1981.

Crystals in which amethyst and citrine colours exist side by side have been available for some time, but there is no single method by which this effect can be obtained, nor is there any test by which artificially irradiated and heated stones can be distinguished from those occurring naturally. M.O'D.

PRESSY (M. R.). *Amethyst prospecting in the second Appalachian range.* Lapidary J., **34**, 12, 2528-44, 20 figs (12 in colour), 1981.

An account of the location and recovery of amethyst from Georgia, U.S.A. M.O'D.

RAMSEY (J. L.). *Buying faceting rough.* Lapidary J., **35**, 1, 30-50, 9 figs in colour, 1981.

A very general outline of the major gem materials with notes on the selection of rough pieces for faceting. Illustrations show finished stones only and so are unhelpful; surprisingly little is given on selection points. M.O'D.

RICE (P. C.). *Alluring amber.* Lapidary J., **35**, 1, 64-70, 4 figs, 1981.

This is a brief overview of amber, loosely extracted from the author's *Amber, golden gem of the ages.* M.O'D.

ROLANDI (V.). *Les gemmes du règne animal: étude gemmologique des sécrétions des Cnidaires.* (Gems from the animal kingdom: gemmological study of the secretions of the Cnidaria.) Revue de Gemmologie, 66, 3-9, 4 figs (1 in colour), 1981.

The family *Cnidaria* includes the corals and their relatives and this study examines those with an ornamental significance. Constants are given. M.O'D.

SHINDO (I.). *Growth of modified cat's-eye gemstones $MgTiO_3$ solid solutions by the floating zone method.* J.Gemm.Soc. Japan, **7**, 1, 3-8, 8 figs, 1980.

A chatoyant material with gem application has been manufactured by

preparing boules of $MgTiO_3$ by the floating zone method of crystal growth followed by annealing to lighten the colour. Crystals of up to 8 mm diameter and 100 mm length have been grown. M.O'D.

SOLANS HUGUET (J.), DOMÈNECH (M. V.). *Defectos reticulares y color en las gemas.* (Lattice defects and colour in gemstones.) Gemologia, **13**, 47/48, 9-22, 2 figs, 1980.

Colour in gemstones may be caused by defects in the crystal lattice, by which energy is absorbed in the visible region. There are three types of defect, involving vacancies, interstitial atoms and substitutional atoms. Amazonite, topaz, diamond, fluorite and quartz are discussed with brief notes on other minerals. M.O'D.

STÄHLIN (W.), WOLFENSBERGER (R.). *Gadolinium gallium garnet.* Chimia, **35**, 4, 147-52, 8 figs, 1981.

GGG is grown by the Czochralski pulling method and dislocation densities as low as $0.5/cm^2$ can be obtained. Details of apparatus used are given. M.O'D.

VENDRELL SAZ (M.), PAGÈS (A.), ALBAR-FONTE (F.). *Electrogem: equipo para la medición de indices de refracción a partir de la reflectancia. Descripción tecnica.* (Electrogem: equipment for the measurement of refractive indices on the basis of reflectivity. Technical description.) Gemologia, **13**, 47/48, 5-8, 1 fig, 1980.

Electrogem is the trade name of a reflectivity meter measuring in refractive indices and with two scales divided at the point 1.81. The method of operation is described. M.O'D.

WÜTHRICH (A.), WEIBEL (M.). *Optical theory of asterism.* Phys.Chem.Min., **7**, 53-4, 2 figs, 1981.

A simple explanation of chatoyance and asterism is given in terms of physical and geometrical optics. The basic phenomena resolved are the scattering of light by thin cylinders and its refraction by curved surfaces. To substantiate this theory, it is shown that the star can also be observed in asteriated stones having a plane surface. P.Br.

YU (R. M.), HEALEY (D.). *A note on the 'black pearls' of the Philippines.* Lapidary J., **35**, 1, 80-1, 6 figs, 1981.

Material offered in the Philippines as 'black pearl' is neither pearl nor the black variety of coral with an SG of 1.35; the material examined had a cross-section consisting of mother of pearl and a brownish-black coral-like substance whose exact nature has yet to be determined. It has an SG of about 2.6. M.O'D.

ZEITNER (J. C.). *Amber and jet.* Lapidary J., **35**, 1, 92-9, 10 figs, 1981.

Gives a list of localities for both materials in the United States. M.O'D.

ZEITNER (J. C.). *Organic gems.* Lapidary J., **35**, 1, 16-28, 24 figs (11 in colour), 1981.

Amber, pearl, shell and other well-known ornamental materials of organic origin are described briefly. Hardwoods are also mentioned. M.O'D.

£225,000 diamond. The Times newspaper, No. 60936, p.10, 25th June 1981.

The South African Press Association says that a diamond digger has discovered a 148 ct diamond, said to be flawless and worth £225 000. J.R.H.C.

NOTE: the Spring 1981 issue of Gems & Gemology is the first of Volume XVII, which now appears in a new and enlarged format (8½″ × 11″) with a minimum of 64 pages: a section of Gemological Abstracts is now included as well as Book Reviews.

BOOK REVIEWS

BALITSKII (V. C.), LISITSYNA (E. E.). *Sinteticheskie analogi i imitatsii prirodiykh dragotsennykh kamnei.* (Synthetic counterparts and imitations of natural precious stones.) Nedra, Moscow, 1981. pp.157. Illus. in colour. 1.20R. (In Russian.).

This is a completely new survey of synthetic and imitation gemstones with a bibliography of 410 entries. All the major stones are covered and there is a long section devoted to the manufacture of quartz. General gemmological notes concerned mainly with standard testing methods are also given. M.O'D.

BLÜCHEL (K.), MEDENBACH (O.). *Zauber der Mineralien.* (Wonder of minerals.) Ringier AG, Zürich, 1981. pp.287. Illus. in colour. 45Fr.

This is a book composed almost entirely of photographs with some explanatory text. The quality of the pictures is quite superb—even the scale is given—and the text forms a general introduction to the mineral kingdom. There is a short bibliography, a list of locations for the minerals depicted and an index. Not a book for the student but for one looking for a subject with which to fall in love. M.O'D.

MCNEVIN (A. A.), HOLMES (G. G.). *Gemstones.* 2nd edn. Geological Survey of New South Wales, Sydney, 1980. pp.119. Illus. in black-and-white. Price on application.

This useful compendium on gemstones found in New South Wales forms no. 18 of the series 'Mineral Industry of New South Wales'. Naturally much information is provided on opal, but diamond and corundum also feature largely. A map of New South Wales with gemstone occurrences is provided. M.O'D.

PAGEL-THIESEN (V.). *Diamond grading ABC.* 7th edn. Rubin & Co., Antwerp, 1980. pp.275. Illus. in black-and-white and in colour. 950Fr.

This well-known manual has been completely reworked to take into account the recent developments in grading consequent on the CIBJO version of grading standards. The latest testing instruments are described and the bibliography is updated. As always the illustrations provide the chief reason for buying the book.

M.O'D.

ASSOCIATION NOTICES

GIFTS TO THE ASSOCIATION

The Council of the Association is indebted to the following for their gifts:

Mr D. W. Chase, Yelverton, Devon, for a collection of cut specimens suitable for students, including jet, agate, sapphire, jadeite, nephrite, peridot, amber, emerald, aventurine quartz, moonstone, coral.

Mr R. Holt, F.G.A., London, for one step-cut emerald weighing 50.48ct, one cabochon-cut blue aquamarine weighing 48.97ct, one rough piece of aquamarine and one rough piece of ruby crystal.

Dr J. B. Nelson, Ph.D., F.R.M.S., F.Inst.P., F.G.S., F.G.A., for four books entitled *The Optical Performance of the Light Microscope* by H. Wolfgang Zieler, Microscope Publications Ltd., London, part 1 1972, part 2 1973; *Teaching Microscopy* by John Gustav Delly, Microscope Publications Ltd., London, 1976; *Polarized Light Microscopy* by W. C. McCrone, L. B. McCrone and J. G. Delly, Ann Arbor Science Publishers Inc., Ann Arbor, Mich., U.S.A., 1979.

Mr Per Paulin, B.Sc., F.G.A., Uppsala, Sweden, for 16 cut and polished garnets weighing 14.5ct, all showing typical inclusions and spectra.

Professor Dr Pieter Zwaan, F.G.A., for a copy of *Scripta Geologica,* No. 58, 'Sphene, Sri Lanka's Newest Gemstone'.

NEWS OF FELLOWS

On 6th May, 1981, the following Fellows of the Association were granted the freedom of the Worshipful Company of Goldsmiths—Mr J. P. Astley-Sparke, Mr T. J. O'Donoghue and Mr J. A. Styles.

On the 6th May, 1981, Mr M. J. O'Donoghue, M.A., F.G.S., F.G.A., gave a talk entitled 'Man-made crystals', with emphasis on non-gem materials, to the West Midlands Mining and Mineralogical Society, and on the 30th June, 1981, Mr O'Donoghue gave a talk entitled 'Some rare gemstones' to the Amateur Geological Society in London.

OBITUARY

Queene Alice (Renée) Lady Walton, widow of the late Sir James Walton, K.C.V.O., M.S., M.B., B.Sc., F.R.C.S., L.R.C.P., F.A.C.S., F.G.A. (Chairman, 1955), died on 6th June, 1981, at Lindfield, Sussex. Lady Walton was elected a Vice-President of the National Association of Goldsmiths in 1955.

MEMBERS' MEETINGS

North-West Branch

On 7th July, 1981, a social evening was held at the Northern Cricket Club, Thornton, Liverpool.

South Yorkshire & District Branch

On 28th May, 1981, a meeting was held in the City Museum, Sheffield, when Mrs V. E. Duke, a resident of Brazil, showed her extensive collection of gemstones from that country, both cut stones and crystals.

COUNCIL MEETING

At the Meeting of the Council held on Wednesday, 9th May, 1981, at Saint Dunstan's House the business transacted included the following:

1. Honorary Fellowships

The following were elected Honorary Fellows in recognition of their distinguished services to gemmology:

Mlle Dina Level, late of Laboratoire des Pierres Précieuses et Fines et des Perles, Paris.

Mr Richard T. Liddicoat, jnr, President of the Gemological Institute of America.

2. Examinations—Prizes

In 1980 Professor Dr Hermann Bank, F.G.A., of Idar-Oberstein, offered to give a sum of money for a prize to be linked with the name of Mr Basil Anderson. As a result the Council reviewed all the prizes to be awarded in the gemmology examinations and the money provided by Professor Dr Bank, to whom the Council expressed the Association's grateful appreciation for his generous gift, is to be used for an Anderson/Bank Prize and also for an Anderson Medal. It was decided that as from the examinations held in 1981 the following would be awarded:

Tully Medal

To be awarded to the candidate (trade and non-trade) who submits the best set of answers in the Gemmology Diploma Examination which, in the opinion of the Examiners, are of sufficiently high standard to meet the award.

Anderson/Bank Prize

A prize to be awarded to the best non-trade candidate of the year in the Gemmology Diploma Examination. The prize to be books, selected by the winner, to the value of approximately £120.

Rayner Diploma Prize

A prize to be awarded to the best candidate of the year who derives his/her main income from activities essentially connected with the jewellery trade. The prize to be Rayner instruments, selected by the winner to the value of approximately £120.

Anderson Medal

A silver medal to be awarded to the best candidate of the year in the Gemmology Preliminary Examination.

Rayner Preliminary Prize

A prize of a Rayner Refractometer to be awarded to the best candidate under the age of 21 years at July 1st of the year of the examination, who derives his/her main income from activities essentially connected with the jewellery trade.

3. *Membership*

The following were elected to membership:

FELLOWSHIP

Cook, Graham A., Dundee. 1980
Huizinga, Jeroen, Amsterdam, Netherlands. 1980
Perkins, Joanna C., London. 1980
van Kalleveen, Allard, Paris, France. 1980

TRANSFERS FROM ORDINARY MEMBERSHIP TO FELLOWSHIP

Berkowitz, Joseph, Toronto, Ont., Canada. 1980
Clarke, Donald H., Cadiz, Spain. 1979

ORDINARY MEMBERSHIP

Anavil, Sriraj, Cerritos, Ca, U.S.A.
Andreasson, Ralph R., Akersberga, Sweden.
Athauda, Weerasinha A., Warrington.
Beauchamp, Wayne, Breitenbach, Tyrol, Austria.
Bilkoski, Tannis M., Calgary, Alta, Canada.
Blenkinsopp, Robert J., York.
Borrill, Kathleen M., Hull.
Bottom, Ian, Chesterfield.
Bramley, Patrick F., Carlow, Ireland.
Buddington, Jeff, Hyannis, Mass, U.S.A.
Burbidge, Norma P., New Plymouth, N.Z.
Carpenter, Thomas D., Yelden.
Champness, Peter T., Bury St Edmunds.
Currie, Lynnette J., Auckland, N.Z.
del Rey, Mario, S. Caetano do Sul, Brazil.
des Baux, Jeanne R., Romsey.
de Silva, John I., Trier, W. Germany.
Desmond, Jerry, Welwyn Garden City.
Dye, Reginald E., London.
Eickhorst, Manfred, Hamburg, W. Germany.
Gabel, John A., Toronto, Ont., Canada.
Glatt, Rodney D., Johannesburg, S. Africa.
Hall, Michael D., Derby.
Hayashi, Wataru, Kumamoto, Japan.
Hee Kim San, Vincent, Singapore.
Horton, David R., London.
Hutton, Michael P., South Benfleet.
Ikuwa, Daniel N., Voi, Kenya.
Jalaludin, Syed, Kuala Lumpur, Malaya.
Kaneko, Fumiya, Tokyo, Japan.
Kularatnam, Samuel K., Colombo, Sri Lanka.
Kyle, Alan J., Neilston.
Laladia, Cashyap L., Dubai, U.A.E.
Lee, Eric, Singapore.
Macdonald, Roy W., Glasgow.
Mangrolia, R. D., Bolton.
Mangrolia, Ved Lata, Bolton.
Melleck, Joel, Harrow.
Monaghan, Neil, Umtali, Zimbabwe.
Monogyios, George, Athens, Greece.

Morris, Roy B., London.
Moussaieff, Tamara, London.
Murphy, Jack, Newry, N. Ireland.
Myers, Robert, London.
Nasser, Shertaz, Northwood.
Pattani, Rasiklal A., London.
Peebles, Kathleen W., Johannesburg, S. Africa.
Petrillo, Nicholas J, Scranton, Pa, U.S.A.
Porter, James W., Coventry.
Purcell, Jeremy C., Brighton.
Roberts, Charles, McAllen, Tex., U.S.A.
Sakamoto, Kanichi, Kumamoto, Japan.
Schofield, Nichola J., Huddersfield.
Smith, Barry K., Fielding, N.Z.
Smith, Margaret S., Dana Point, Ca, U.S.A.
Stephanides, George, Nicosia, Cyprus.
Suzuki, Schoichiro, Ibaragi-Ken, Japan.
Veera, Rajesh, Port-Louis, Mauritius.
Waller, Myra L., Victoria, B.C., Canada.
Waterworth, Eileen, Hong Kong.
Watson, Gordon, Lanark.
Weare, Richard M., York.
Webber, Michael, Macclesfield.
Wehrly, Tony, Sligo, Ireland.
Winiecki, Halina, London.

ANNUAL GENERAL MEETING

The 50th Annual General Meeting of the Association was held at Saint Dunstan's House, on 20th May, 1981, at 6.30 p.m., and was attended by thirty-five members.

Mr David Callaghan, the Chairman, welcomed all those attending and said how nice it was to have a larger number than usual present. Sincere thanks were expressed to all members of Council for their support during the year, to the Branch Chairmen and Secretaries for the help that they gave, and to the Examiners and Instructors who were doing so much for gemmology as a whole. The special Committee concerned with the review of examinations-prizes was specially thanked for its work. Mr Callaghan praised the quality of the *Journal of Gemmology* and its high standing in the gemmological world and said how fortunate the Association was to have Mr John Chisholm as its Editor, together with his Assistant, Mrs (Mary) Burland. Due to the excellent guidance of the Treasurer the Association's finances were in good order. Lastly he thanked the staff for the work done throughout the year, in particular the Secretary, Mr Harry Wheeler. Although not specific to the year in question, he made reference to the fact that this year (1981) we were celebrating our Fiftieth Anniversary. A Committee had been formed to make all the arrangements, and the events planned for October should do justice to the Association and the work it has done for so many years.

The Treasurer then reported on the Accounts which showed a surplus of £31314 and said that the reserves which had accumulated would allow the Association to undertake its Fiftieth Anniversary celebrations without financial problems. He thanked the Assistant Secretary, Mr Douglas Wheeler, for his good work during the year in ensuring that all available funds were invested to obtain the maximum amount of interest.

The Chairman moved that the Audited Accounts and Report of the Council for the year ended 31st December, 1980, be adopted and Mr Ian Lewis seconded the motion, which was carried *nem. con.*

Sir Frank Claringbull was re-elected President, and Messrs D. J. Callaghan, N. W. Deeks and F. E. Lawson Clarke were re-elected Chairman, Vice-Chairman and Treasurer respectively. Messrs A. J. French, D. Inkersole, D. M. Larcher, P. W. T. Riley and C. H. Winter were re-elected and Dr J. B. Nelson and Mr W. Nowak were elected to the Council.

Messrs Hard Dowdy, Watson Collin & Co. were re-appointed as auditors to the Association.

G.A. FELLOWSHIP TIE

Together with other Jubilee celebrations the Council has decided to have a new design for the Fellowship tie. The tie is made of polyester material and is available in two colours—dark blue *or* maroon. The Coat of Arms of the Association is attractively woven in colour (red, silver, blue and gold) in the centre of the tie.

Price—U.K. (including postage & V.A.T.)	£4.40
Overseas (including air mail)	£4.60

The enamelled badge brooch of the Association's Coat of Arms is still available. Pin fitting makes it suitable for female and male dress.

Price—U.K. (including postage & V.A.T.)	
metal gilt	£15.50
9 ct gold	£66.60
Overseas (including air mail postage)	
metal gilt	£15.00
Overseas (including air mail Regd post)	
9 ct gold	£60.00

Year Diploma was awarded must be stated with each order.

Orders to Gemmological Association.

EXAMINATIONS 1982

Examination dates for 1982 are as follows:

Gem Diamond Examination:

Theory, Monday, 7th June

Practical, Monday, 7th and Tuesday, 8th June.

Examinations in Gemmology:

Preliminary: Tuesday, 29th June

Diploma:

Theory, Wednesday, 30th June

Practical, Thursday, 1st July, and Friday, 2nd July.

The *last* date for receiving examination entry forms is Wednesday, 31st March, 1982.

I.M.M. GEMSTONES MEETING

The Institution of Mining and Metallurgy is arranging a one-day Gemstones Commodity Meeting at Goldsmiths' Hall, Foster Lane, London, E.C.2., on the 3rd December, 1981. The Meeting will start at 08.45 and end at approximately 18.00 hours. Subjects to be covered by well-known experts include—

'The World of Gemstones', 'Emeralds at Sandawana', 'Production of Diamonds in Southern Africa', 'Opals and Sapphires in Australia', 'Production and Identification of Synthetic Gemstones', 'Detection of Treated Diamonds', 'East African Coloured Gemstones', 'Diamond Discoveries in the

Kimberlies, Western Australia', 'Recent Discoveries in the Transvaal and Botswana', 'Prospect of Diamonds in the Southwest Pacific' and 'Marketing and Trends in Coloured Stones'.

The cost to non-members of the Institution is £60 (including V.A.T.) and interested persons should apply direct to the Institution at 44 Portland Place, London, W.1. (tel: 01-580 3802).

CONFERENCE IN COLOMBO, FEBRUARY 1982

Notice has been received of the First International Coloured Gemstones Conference and Gem and Jewellery Exhibition which is to be held on 1-2 February 1982 at the Bandaranaike Memorial International Conference Hall, Colombo. Dr E. Gübelin is to speak on the first day. Further information may be obtained from the Organizers, Conventions (Colombo) Ltd, P.O. Box 94, Colombo 1, Sri Lanka (telephone 21124).

G.I.A. INTERNATIONAL SYMPOSIUM

The Gemological Institute of America invites those who have earned its Gemologist or Graduate Gemologist Diploma and others from the world-wide gemmological community to its first International Gemological Symposium to be held at the Century Plaza Hotel, Los Angeles, from Friday, 12th February to Monday, 15th February, 1982.

As a culmination of its 50th Anniversary celebrations, G.I.A. has announced this gathering of gemmologists for a series of lectures and discussions to be led by speakers of international repute on subjects to include the most recent findings in research of diamonds and coloured stones, including treatments, synthetics and substitutes, with reports on important sources, changing patterns of supply, marketing, retailing and instrumentation. The proceedings will be published.

Members interested in attending the symposium should communicate with the Gemmological Association of Great Britain, Saint Dunstan's House, Carey Lane, London EC2V 8AB—telephone 01-606 5025/6.

INDEX FOR VOLUME XVII

The Index for Volume XVII (1980-1981) will be issued with part 1 of Volume XVIII in January 1982.

LETTERS TO THE EDITOR

From Mr Dan E. Mayers, M.Sc., A.I.M.E., A.G.A.

Dear Sir,

I refer to the note entitled 'Japanese Synthetic Emeralds?' by R. Keith Mitchell, in the *Journal,* January 1981 (XVII, 5, 290-1).

The stones in question, sold under the Crescent Vert trade name, are indeed manufactured in Japan by Kyocera. In addition I examined, at their factory last month, samples of excellent quality Ruby, Padparadsha Sapphire, and Alexandrite. All are made by the standard Gilson procedure.

The only real challenge yet to be surmounted is that of growing Jadeite. I would be surprised if we have long to wait.

Yours etc.,
DAN E. MAYERS.

5th May, 1981.
Crystals S.A., Geneva-2, Switzerland.

From Mr R. Keith Mitchell, F.G.A.

Dear Sir,

I read with interest the Gunawardene and Hänni paper in this *Journal,* XVII (6), 381-5, on what they claim to be the first gem sphene found in Sri Lanka. Without wishing to detract from what is an unusual find in that country, I would point out that Paul Desautels, in his book 'The Mineral Kingdom', published in 1968, lists sphene among the gems which may be found in Ceylon illam. Also that the late Louis C. Siedle, of Colombo, found a very fine green sphene among faceted Ceylon gems as long ago as the early 1950s. He sent this stone to me for confirmation, and I eventually mentioned it in a letter to Dr Edward Gübelin. It was undoubtedly sphene.

In 1974, after the untimely death of this old friend and fellow Tully Medallist, I was able to purchase the stone from Mrs Eunice Siedle. Its weight then was 5.47 carats, and it was a very bright and pleasing green colour, showing considerable dispersion. The green was less dense than that normally seen in the Baja Californian (Mexican) green sphenes. The stone eventually went to a Swiss buyer.

While writing, I would mention that early in 1968 I bought two parcels of light green sphenes, which had been sent from an Indian source. Two stones, which were sent as 'peridot', weighed 9.84 carats and 8.66 carats respectively, while a second parcel of 15 stones, sent as 'zircon', weighed a total of 43.75 carats. All these were gem quality but very crudely cut and polished, and it is reasonable to suppose that the rough was of Indian origin and cut by a local and inexperienced cutter. On this reasoning, this was evidently a new source of gem sphene and I now wish to record it, albeit vaguely. The supplier died shortly after these stones were purchased and no further information on their exact provenance can be obtained. The colour of both parcels was a light peridot green with one or two of the smaller ones tending to a brownish green.

Yours etc.,
R. KEITH MITCHELL.

27th May, 1981.
Orpington, Kent.

CORRIGENDA

On p.400 above, in Table 2, for 'SiO_2 44.87 wt%' read 'SiO_2 48.87 wt%'.

On p.433 above, in lines 11 and 10 from bottom, for '53¼ carats' read 53½¼ carats' (=53¾ ct. For this method of recording weights, see page 516 above, lines 10-33, and page 621 above, lines 1-17.)

On page 433 above, in the bottom line, and on page 434 above, in lines 18 and 26, for 'Jejeebhoy' read 'Jeejeebhoy'.

CONGRATULATIONS

to the

GEMMOLOGICAL ASSOCIATION

of

GREAT BRITAIN

on its

50th ANNIVERSARY

Gemmological Instruments Ltd.
Saint Dunstan's House, Carey Lane, Cheapside,
LONDON EC2V 8AB, ENGLAND

Write for illustrated catalogue
of gem testing instruments.

Historical Note

The Gemmological Association of Great Britain was originally founded in 1908 as the Education Committee of the National Association of Goldsmiths and reconstituted in 1931 as the Gemmological Association. Its name was extended to Gemmological Association of Great Britain in 1938, and finally in 1944 it was incorporated in that name under the Companies Acts as a company limited by guarantee (registered in England, no. 433063).

Affiliated Associations are the Gemmological Association of Australia, the Canadian Gemmological Association, the Gem and Mineral Society of Zimbabwe and the Gemmological Association of Hong Kong.

The *Journal of Gemmology* was first published by the Association in 1947. It is a quarterly, published in January, April, July, and October each year, and is issued free to Fellows and Members of the Association. Opinions expressed by authors are not necessarily endorsed by the Association.

Notes for Contributors

The Editor is glad to consider original articles shedding new light on subjects of gemmological interest for publication in the *Journal.* Articles are not normally accepted which have already been published elsewhere in English, and an article is accepted only on the understanding that (1) full information as to any previous publication (whether in English or another language) has been given, (2) it is not under consideration for publication elsewhere and (3) it will not be published elsewhere without the consent of the Editor.

Articles published are paid for, and any number of prints of individual articles may be supplied to authors provided application is made on or before approval of proofs. Current rates of payment for articles and terms for supply of prints may be obtained on application to the Secretary of the Association.

Although not a mandatory requirement, it is most helpful if articles are typed (together with a carbon copy) in double spacing on one side of the paper, with good margins at sides, top and foot of each page. Articles may be of any length, but it should be borne in mind that long articles are more difficult to fit in than short ones: in practice, an article of much more than 10 000 words (unless capable of division into parts or of exceptional importance) is unlikely to be acceptable, while a short note of 400 or 500 words may achieve early publication.

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Names of authors are printed in capitals, pages of abstracts and book reviews in italics.
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GEMMOLOGICAL ASSOCIATION
OF GREAT BRITAIN
SAINT DUNSTAN'S HOUSE, CAREY LANE
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GEMMOLOGY THEN

By R. KEITH MITCHELL, F.G.A. (Tully Medallist, 1934)

In 1932 a poster outside the Chelsea Polytechnic in London advertised a 'Course in Applied Mineralogy for Jewellers'. This was Gemmology, and it was in those days, limited to the Trade. Only some years later did the L.C.C. open all classes to all comers.

At that time I had spent four poorly paid years in the basement buying-department of a well-known Jewellers in Oxford Street, handling silver, enamel, leather goods, ivory, tortoiseshell, china, glass and many other sundries outside the elite jewellery section of the firm. With a keen interest in geology, awakened by visits as a schoolboy to the Mineral Gallery of the Natural History Museum and to the Geological Survey Museum, I felt that this Course might further my intent to take out in experience what I was unlikely to get from my employers in salary. I joined the class and on one evening a week a new world opened for me.

The instructor was Mr Irvine G. Jardine, a somewhat pedestrian schoolmaster, who was assisted by Thorold G. Jones, an instantly likeable young man of considerable enthusiasm, from the Geological Survey Museum which was then in a marvellously evocative building in Jermyn Street, on the site now occupied by Simpson's of Piccadilly.

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The class was perhaps twenty strong and mostly from firms where they were already handling gems in their daily work. In this they had the advantage of me. Some names were to become well known in Trade and wider circles in later years, among them A. Ross Popley, J. G. Shenton, W. Flower and Robert Webster.

Our textbook was the quite elementary 6th edition of Dr G. F. Herbert Smith's 'Gemstones', which still treated the trigonal or rhombohedral system as a sub-division of the hexagonal system and even used the old-fashioned three equal and inclined axes of reference for that division. Our class notes updated the axes but kept the system as a sub-division—an out-dated practice which survives in American textbooks even today, although x-ray crystallography has shown us that the two systems differ basically in their symmetry.

Our most successful refractometer was a tiny instrument invented and perfected by Dr Herbert Smith some years before. Its minute scale gave comparatively sharp readings but, without a cover to exclude top light, using it was something of a juggling feat, one hand manipulating the stone and holding or steadying the instrument while the other shielded the stone from extraneous light.

A much larger and quite heavy table instrument, inspired by the late B. J. Tully, was much in demand, for it had a rotating hemisphere of optically dense glass which made double refraction easy to measure. But, lacking a ball-bearing race, this soon showed signs of wear and became inaccurate. For both instruments we had only a 1.785 liquid, made by dissolving sulphur in methylene iodide. This was barely adequate for sapphires and rubies, and quite useless to test the higher red garnets which could in those days be tested only by a hydrostatic weighing.

The 1.81 liquid, the spinel, blende and diamond refractometers, Clerici solution and polaroid were all in the future and quite unknown to us, as were the Chelsea Filter, crossed filter tests, fluorescence tests, and absorption spectra, so far as gemmology was concerned.

The only commercial synthetics were Verneuil sapphires, rubies and blue or white spinels. They were simply made and comparatively easy to detect, for the modern furnace with its computerized feed-back temperature control was unknown. Hydrothermal and flux-diffusion synthetics were also unknown to us, although the Germans had made the first synthetic emeralds.

Commercial production of these and of the many other clever synthetics of today was then a very long way in the future. Many of the latter were to be the result of research into other substances, especially in the laser field, which did not begin until 1960.

Thorold Jones constructed some clever little wooden stands for the Smith refractometer which not only stabilized the instrument but also screened the truncated hemisphere from top light. This was probably the major advance in that year of 1932/33, so far as Chelsea Polytechnic was concerned.

Towards the end of the Summer Term in 1933 we learned that Jardine was moving to higher things in the education world, and rumour suggested that Thorold Jones was taking over as instructor. But we were left in the dark until the first evening of the Autumn Term when the class-room door opened and admitted the tall athletic figure of Mr B. W. Anderson who was, in those days, blessed with a fine head of fair curly hair. An instant rapport was established, for Anderson had, and indeed still has, an enviable ability to talk and write on his subject with great clarity and most infectious enthusiasm. Under his inspired teaching the 1933/34 class blossomed remarkably.

Almost at once we had 1.81 refractometer liquid, Clerici solution and the little gadget which eventually became known as the Chelsea Filter.

Personally I achieved a move into my employers' jewellery department and began to handle some exceptionally fine gems. I lived gemmology.

Each day, at lunch time, I would snatch a brief snack at a tea shop and them make my way rapidly through the deserted back streets (Carnaby Street is one which has since achieved a crowded fame) to the Geological Museum, in Jermyn Street. This wonderful old building, later to be lamented by John Betjeman, the son of a well-known supplier to my old department, had a domed roof which, in all the years that I knew it, was supported by an impressively massive shoring of square timbers which passed right up from the basement floor through the centre of the oval shaped display galleries. Here I would spend a precious forty minutes, gazing at gems and crystals in glass display cases until their essential appearance was firmly impressed on my memory. Then with exactly seven minutes in hand I would make the return dash to work. Weekends were spent in similar visits to the Mineral Gallery

of the Natural History Museum and the Jewellery Department of the Victoria and Albert Museum.

At this time Anderson's 'Gem Testing for Jewellers' (later 'Gem Testing' and to run to nine editions), Webster's 'Gemmologist's (Pocket) Compendium' and 'Practical Gemmology' (at first little more than an expanded version of our class notes) were all to be written. The study of gem inclusions was still in its infancy and Edward Gübelin's life work on this subject scarcely started. Webster's 'Gems', which was in truth based on the work of the London Laboratory as a team, the author to some extent acting as resident scribe and collating the vast store of information for publication, was also some thirty years away.

Yet in these primitive conditions we still found much to interest us and classes were enjoyed to the full. In many ways one can look back at those far simpler days with a certain nostalgia. Life was less exacting and gemmology a great deal less complex than it is today.

[*Manuscript received 6th June, 1981.*]

ZAMBIAN TOURMALINE

By ARTHUR E. THOMAS, F.G.A.

Johannesburg

In the past tourmaline from sources in Zambia has tended to be too dark to be of anything other than academic interest. The tourmaline associated with the emerald occurrence at the Miku Mine was such a dark red that it required strong sunlight to distinguish it from the schorl which is abundant in that area. A very dark green material was found in the pegmatites near the bridge

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which carries the great east road over the Luangwa river. Finds in other areas were equally uninspiring. In recent months however an interesting range of Zambian tourmaline has come onto the market. This material is alleged to originate from sources near Lundazi in the eastern province. Pegmatites mined in that area a number of years ago did show indication of gem material. The Aries mine in particular produced a quantity of light aquamarine and dark tourmaline.

The first parcels of commercial quality material to arrive in Johannesburg were a rather pleasing green but showed either smoky or dark olive green parallel to the *c* axis. The next consignment contained samples of material described by the miners as 'khaki' tourmaline. This was a very apt description for the dull greeny brown; however, several pieces looked a more interesting cognac colour under the tungsten desk light. Illuminated by a daylight lamp a number of these specimens revealed an attractive rose pink colour. While in other pieces the colour change from cognac to a shade of salmon pink was less dramatic, it was still considerably more marked than the familiar minor variations in hue seen in Moçambique material.

Fourteen stones have been cut from this material to date, ranging in size from slightly under one carat to twelve and one half carats. The largest stone is a rectangular step cut which is bi-colour in addition to showing a very distinct colour change.

The dichroscope reveals a wide range of colour combinations even in material of a superficially similar colour.

Chartreuse	—	Russet Brown
Peach	—	Rose Pink
Very Pale Pink	—	Cerise
Eau de Nil	—	Dusky Pink
Oil Green	—	Russet Red

Examined through the Chelsea colour filter, in tungsten light the cognac coloured stones assume a dull green hue, while under a daylight lamp the pink becomes a very light green. The spectrum revealed a broad hazy absorption in the region of the blue-green from 4900Å—5300Å.

RI	1.619	—	1.639
SG range	3.022	—	3.029

This material is unlikely to reach the market in its natural state, since heat treatment removes the brown coloration and leaves an attractive and far more saleable pink.

[*Manuscript received 17th October, 1981.*]

THE PURIFICATION OF BROMOFORM

By C. WASHINGTON, B.Sc., G.R.S.C.

Chemistry Department, The University of Sheffield

ABSTRACT

A simple technique for the purification of bromoform is described which requires no complex laboratory facilities. It is particularly suited to the purification of aged and discoloured samples, and batches which have been diluted with low b.p. solvents.

INTRODUCTION

Heavy liquids are frequently used by the gemmologist and jeweller for rapid density determination by a 'sink-or-float' comparison technique. One oft-used is bromoform, which has a density of 2.89 g cm^{-3}.

The author was prompted to find a simple purification technique for bromoform for a number of reasons:

1. A commercial sample (Fisons SLR) contained 4% ethanol stabilizer and had a density of 2.56 g cm^{-3}; as such it was incapable of floating quartz. Workers should be warned that samples stabilized in this way may not be assumed to have the density of pure bromoform.
2. Gemmologists often accumulate quantities of bromoform residues of low density which have been diluted with other liquids; these can only have their densities raised by addition of large quantities of heavy liquids or by separation of the valuable dense component.

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3. Bromoform may become badly discoloured with age.
4. Many workers may not have the facilities for the usual distillation techniques of separation.

With these factors in mind the technique described below was developed. It is based on the fact that bromoform, having a freezing point of 8.3 °C, will crystallize out of many mixtures in a pure form when cooled in ice.

METHOD

The bromoform sample or residue is placed in a suitable container (e.g. a conical flask which it should approximately half-fill; a jam jar will suffice in an emergency) which should be securely stoppered and preferably taped to prevent the ingress of water. It is then placed in a bucket of ice-water slurry until the bromoform has crystallized out (up to two hours depending on quantities). The flask may then be removed from the slurry, opened, and the unfrozen liquid poured back into the bromoform residues bottle. The solid, when melted, consists of nearly pure (∿98%) bromoform.

RESULTS

Two samples of bromoform were purified by this method; the first sample (Fisons A.R.) containing 4% ethanol with a density of 2.56 g cm^{-3}; from 100 ml of sample, 83 ml of bromoform with density 2.84 g cm^{-3} was recovered.

The second was a sample which had been diluted to a density of 2.65 g cm^{-3} for quartz flotation purposes; 100 ml yielded 52 ml bromoform of density 2.83 g cm^{-3}.

DISCUSSION

This method of purification relies upon the crystallization of bromoform, with a melting point above those likely for other components in the mixture, when cooled to just above 0 °C.

However, it should be noted that many substances that may well be present have melting points only slightly below that of bromoform. In particular benzene (m.p. 5.5 °C) and methylene iodide (m.p. 6.1 °C) may be present, and these will not be eliminated if the freezing is carried too far. The answer here is to introduce a thermometer through the bung of the vessel into the bromoform; while it indicates 8 °C bromoform is crystallizing, but

when it falls below this temperature the freezing process should be stopped or other materials may crystallize. In such cases fractional distillation is a superior technique, but this method will yield acceptable results.

Finally, I have been informed that bromoform of density 2.60 g cm^{-3} is available for pharmaceutical purposes. This is presumably the ethanol-stabilized material, and it may prove cheaper, for anyone needing bromoform in quantity, to purchase this material and purify it than to buy the expensive pure liquid.

It is hoped that the technique described will prove useful to anyone who uses heavy liquids. With care, it may prove useful in the purification of other substances, providing that an appropriate freezing mixture is chosen and no high melting point impurities are present.

[*Manuscript received 17th June, 1981.*]

HORNBILL IVORY

By G. BROWN, Dip.D.T., F.G.A., F.G.A.A. and
A. J. MOULE, Ph.D., F.G.A., F.G.A.A.

Hornbill ivory, one of the world's rarest organic gem materials, has been carved and traded within the south-east Asian region for the last two thousand years. The material is obtained from the casque (a dense ivory-like protuberance located above the beak on the frontal aspect of the bird's cranium) of a single species of hornbill—the *Rhinoplax vigil.* This large, ungainly bird lives in a tree-top habitat that is restricted geographically to lower Burma, southern Thailand, peninsular Malaysia, Sumatra and Borneo.

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The *Rhinoplax vigil* or Helmeted Hornbill (Figure 1) is one of forty-six species belonging to the family *Bucerotidae.*[1] It is the only species from this family which possesses a casque that is suitable for carving into decorative objects and objects of art.

Helmeted hornbills are large birds,[2] often 2 m in length. They have a rather dull plumage with a characteristic distribution of colours. Its black crested head contrasts spectacularly with chestnut eye covers and a carmine-coloured casque which extends onto the lateral surface of the bird's skull. A black, featherless neck

FIG. 1 Drawing of the Rhinoplax vigil or Helmeted Hornbill. The casque from which hornbill ivory is obtained is arrowed.

joins this attractively patterned head to the bird's body. Wings and its upper body are covered with reddish brown feathers, while the bird's lower body and upper legs are covered by whitish feathers. Two long tail feathers protrude beyond the normal tail feathers, giving the bird an elongated appearance.

The helmeted hornbill's flight is noisy, as the base of its flight feathers are uncovered. One of the unique characteristics of this bird is its call—a series of toks, increasing in intensity and frequency until the call resembles an insane laugh. The uniqueness of this call has led the Malays to dub the bird the 'kill your mother-in-law bird'.

The much prized casque (Figure 2) of the helmeted hornbill is formed from a dense ivory-like mass ($5 \times 5 \times 4$ cm) located on the frontal and antero-lateral aspect of the bird's cranium. Its top and sides are covered by a thin adherent carmine-coloured sheath of casque material, while the frontal surface and body of the casque is formed from yellowish-brown material. With age, the carmine-coloured sheath of the casque tends to wrinkle and crack, so becoming less valuable for carving purposes.

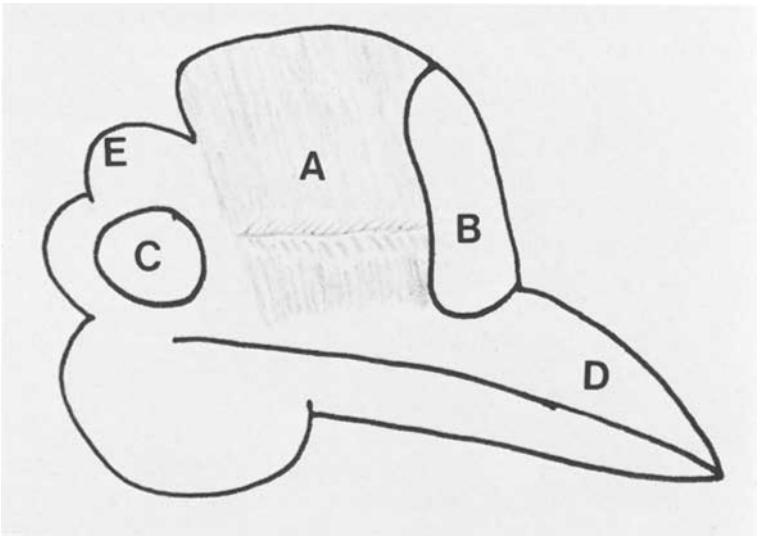

FIG. 2 Diagramatic representation of the skull of the Helmeted Hornbill indicating:
A. The ridged carmine coloured outer sheath of the casque. B. The anterior yellowish-brown surface of the casque. C. Orbit. D. Beak. E. Cranium.

Why the *Rhinoplax vigil* possesses such a dense casque, and what the chemical nature of the material that forms the casque is, is not known. However, Robinson (1928)[3] offered a possible explanation for the existence of casques on all hornbills. '. . . it has been suggested that the bird uses its head to compact the gum with which it closes the nesting hole of its mate. The frontal plate is extremely hard and dense, like vegetable ivory; about one third of an inch thick, but behind it the casque is composed of loose spongy cancellous tissue, which no doubt prevents the shock being transmitted to the brain'. Unfortunately, Robinson's explanation may only be applied to the helmeted hornbill with some caution, as this bird has a totally dense casque.

DERIVATION OF TERMS

Hornbill ivory is known by a variety of names, including: *Calao Ivory, Hoting,* and *Hōden.*[4] All these terms, including that of hornbill ivory, are apparent misnomers.

Best available evidence seems to suggest that the word, commonly used to describe hornbill ivory, was invented by Malay-speaking Chinese traders who first discovered the material. They transliterated the Malay word for ivory *(gading)* into Chinese, and so the term *ho-ting* evolved. It has been suggested that the first written account of this new trade material was found in the trading records of the Ming Dynasty. In these accounts the words *ho-ting* and *ho-ting hung* first appear. Literally, these words can be translated to mean *crane's crest* and *crane's crest red* respectively. It would appear that the early Chinese scholars were under the misapprehension that this new material was the product of the crane. It was not until the early part of the Ch'ing Dynasty that the helmeted hornbill was verified as the source of *ho-ting.* By this time, the terminology was so well established that *ho-ting* became a word of every day use.

With the spread of appreciation of the value of hornbill ivory to other parts of the world, other terms soon evolved. The Japanese coined the word *hōden* to describe the hornbill ivory used in the manufacture of netsuke, inro and ojime, while the European export market used such terms as *Calao ivory* and *crane's crest ivory* to describe the material from which hornbill ivory export wares were made.

A Brief History of the Use of Hornbill Ivory

It is believed the original users of hornbill ivory were the native inhabitants of Sumatra and Borneo. Dyak artefacts, manufactured from hornbill ivory, have been discovered at archaeological sites in Borneo. Within their culture Dyaks used hornbill ivory to manufacture decorative sword-hilts, carved toggles for sword-belts, decorative ear-ornaments, and the much sought after tiger's-tooth ornaments.

Hornbill ivory was first brought to the Ming Court by the fifteenth-century Chinese traders, who traded with Malay intermediaries. Soon, within China, hornbill ivory became the prized possession of the ruling classes, with most value being given to *ho-ting hung*—the thin carmine-coloured outer sheath of the hornbill casque. From this material, Ming artisans produced ceremonial belt-buckles and ornate combs for the court.

It was soon discovered that the relatively small casque of the helmeted hornbill was thermoplastic; so it could be heated and pressed to produce flattened masses of larger size, greater strength, and superior translucency, than exist naturally. Initially, only the carmine outer sheath was stripped from the casque, steamed(?) and pressed, to produce the large homogeneous masses from which the decorative objects of the Ming Dynasty were manufactured. Later, it appears, techniques were evolved to reconstruct thick layers of both carmine-coloured and yellowish-brown casque material and then fuse them together. Details of these reconstructive techniques are still trade secrets; however, it would seem reasonable to assume that the reconstructive process would be relatively similar to that used to reconstruct and mould tortoiseshell or horn.

By the time the Ch'ing Dynasty was established, the Manchus possessed all the necessary technology for producing a range of decorative items from hornbill ivory. Ceremonial belt-buckles, plume-holders for hats, and archers thumb-rings, were some of the aesthetically pleasing objects produced during this dynasty. Once the tobacco habit was introduced into China from the West, the Manchus and their Chinese subjects quickly adopted the habit of taking snuff. As a consequence, the snuff bottle—originally a functional item—rapidly became an object of art. Hornbill ivory was one of the valuable materials used in the manufacture of these bottles.

Use of hornbill ivory spread to Japan during the Tokugawa Period; during which time the Shoguns and the aristocracy commissioned the making of some superb netsuke carved from hornbill ivory. Subsequent loosening of the harsh Japanese trade laws allowed the Japanese artists and craftsmen to manufacture and decorate a range of hornbill ivory netsuke and inro.

It was not until the nineteenth century that Europeans first became familiar with hornbill ivory. Since that time, Chinese artisans have manufactured a range of jewellery items, snuff bottles, decorative spoons and cuff links, especially for the export trade. Today, some hornbill ivory is still being carved in Singapore and Hong Kong. No details seem available concerning today's trade in hornbill ivory.

PROPERTIES OF HORNBILL IVORY

Although some of the properties of hornbill ivory have been previously published in the gemmological literature,[5,6] more information is required to assist the discrimination of natural hornbill ivory from its possible imitations and simulants.

A search of the gemmological and related literature has indicated that it is possible for hornbill ivory to exist in one of two forms: in its natural state, and in a reconstructed form. The only details that could be located concerning the reconstructive process are contained in Cammann's classic monograph,[4] *The Story of Hornbill Ivory*. He noted that reconstructed hornbill ivory possessed improved properties of:

Firmer adhesion between the carmine outer sheath and the yellowish-brown core;

More uniform texture;

A glistening, luminous surface lustre.

As the authors of this paper were unable to obtain samples of reconstructed hornbill ivory for examination, this investigation is restricted to a study of the gemmological properties and microscopic appearance of naturally occurring hornbill ivory.

GEMMOLOGICAL PROPERTIES

The physical properties for hornbill ivory, found in this study, are illustrated in Table 1. These properties differ slightly from those previously reported by Webster[5] (Hardness—2½;

Density—1.28 to 1.29; Refractive Index—about 1.55; Ultraviolet Light Fluorescence—greenish to bluish-white; Hot Point Test—smell of burning hair).

TABLE 1
The physical properties of Hornbill Ivory

Property	*Carmine Casque*	*Yellowish Casque*
Colour	Carmine	Yellowish-brown
Diaphany	Translucent	Translucent
Lustre	Resinous	Resinous
Hardness	3 Mohs	3 Mohs
Sectility	Easily pared	Easily pared
Fracture	Hackly	Hackly
Specific Gravity	1.30	1.30
Refractive Index	1.53	1.52
UV Fluorescence		
Long Wave	Greenish	Greenish-white
Short Wave	Whitish superficial	Inert
Hot Point Test	Smell—burning hair	Smell—burning hair
Thermoplastic Temperature	110 to 125 °C	110 to 125 °C

LIGHT MICROSCOPY

Little useful information has been published concerning the microscopic appearance of hornbill ivory. Munsuri (1973)[6] describes the microscopic characteristics as:

'fibres—but irregular ones—which have a tendency to come together and separate like whirlwinds'.

Unfortunately Munsuri's description and one black-and-white photomicrograph which accompanied this otherwise excellent paper were of little use for discrimination. In contrast, Wang Tso[7]—a Ming Dynasty writer—offers a relatively similar description:

'This is true ho-ting . . . On the surface of the material are fine wavy lines; examples without which are counterfeit.'

It would seem that Munsuri was describing the external surface of hornbill ivory—not its internal microscopic structure.

For this investigation, the block of hornbill ivory was sectioned in three directions at right angles: vertically along the long axis of the beak (longitudinal section); vertically across the beak (cross section); and horizontally.

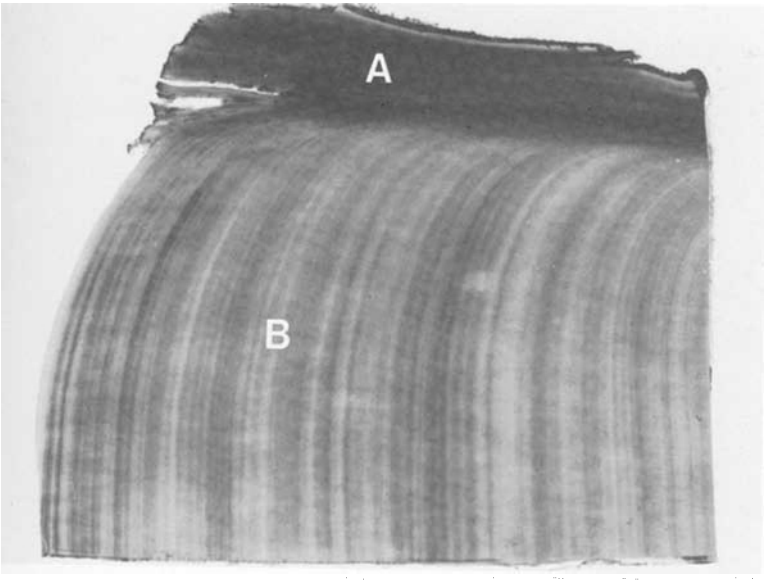

FIG. 3 Longitudinal section through the middle of the casque of the Helmeted Hornbill showing the upper carmine layers (A) which show a striated structure roughly at right angles to the curved striations of the yellowish-brown cassque material which makes up the bulk of the casque (B). (Unstained. × 10 magnification).

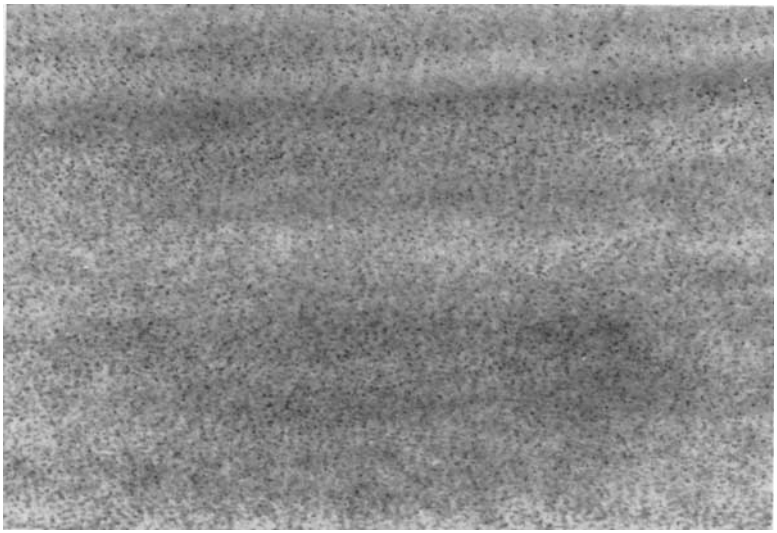

FIG. 4 Photomicrograph of the upper outer carmine-coloured sheath of Hornbill casque showing the light and dark bands interspersed within and between which were small particles of material resembling pigment granules. (unstained. × 40 magnification).

Macroscopically, in longitudinal section (Figure 3), the two different parts of the hornbill casque are readily discernible. The thin sheath was carmine-coloured and appeared to be formed from a series of layers producing a striated structure. These laminations ran antero-posteriorly, roughly at right angles to the curved striations in the yellowish-brown material which made up the bulk of the mass of the casque.

Microscopically (Figure 4), the thin sheath was composed of light and dark bands of carmine-coloured casque material within which were interspersed many small particles of darker material. These small particles have the morphology of pigment granules. It

FIG. 5 Photomicrograph of the junction between the outer layer (A) and inner layer (B) of the Hornbill casque. The junctional zone between the two layers is rich in granules; some of which are cell size. (Unstained. ×40 magnification).

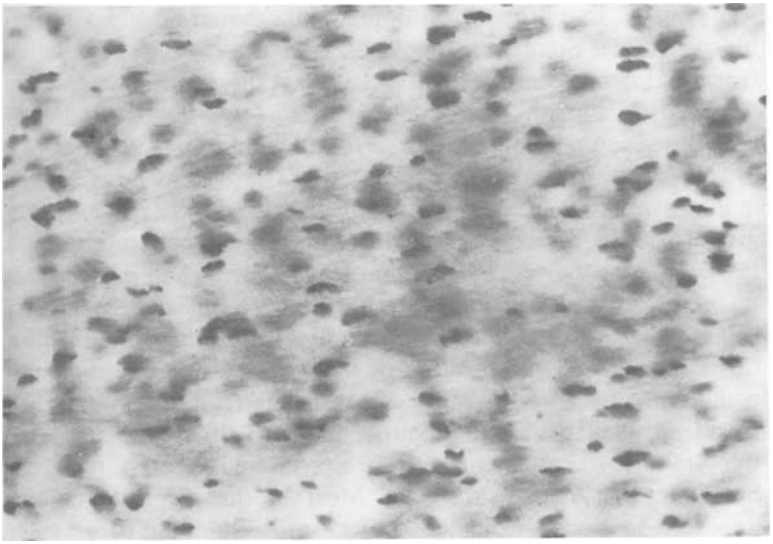

FIG. 6. High power photomicrograph of the junctional zone between the two layers of Hornbill casque showing the appearance of the pigment granules in the area. (Unstained. × 100 magnification).

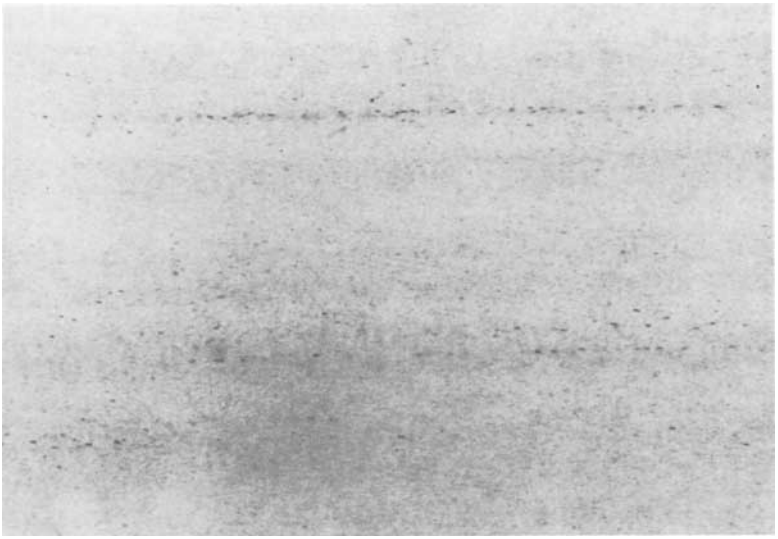

FIG. 7. Photomicrograph of a vertical section of the inner layer of Hornbill casque, showing the parallel light and dark bands within this material. The granules are arranged in rows parallel to the light and dark bands. (Unstained. × 40 magnification).

was noted that the sheath material shared many of the morphological characteristics of buffalo horn.[8] Pigment granules (Figure 5) were very numerous at the junction of the inner and the outer portions of the casque. Some of these granules were larger than others; some being of cell size (Figure 6).

In both longitudinal and horizontal section, the inner casque material was banded and yellowish in colour. Lines of pigment granules were present parallel to the banded pattern, but the pigment granules were smaller and less frequent than those found in the external sheath of the casque (Figure 7). In cross section (Figure 8), the banded pattern was not evident, indicating that the three dimensional visualization of the inner portion of the casque could represent parallel planes of casque material running roughly parallel to the cross sectional direction. Within these cross sections the granules of pigment appeared scattered over a relatively homogeneous ground-substance. Most of the pigment granules appeared to be individual; however, some clumping of granules was also a feature of this direction of sectioning.

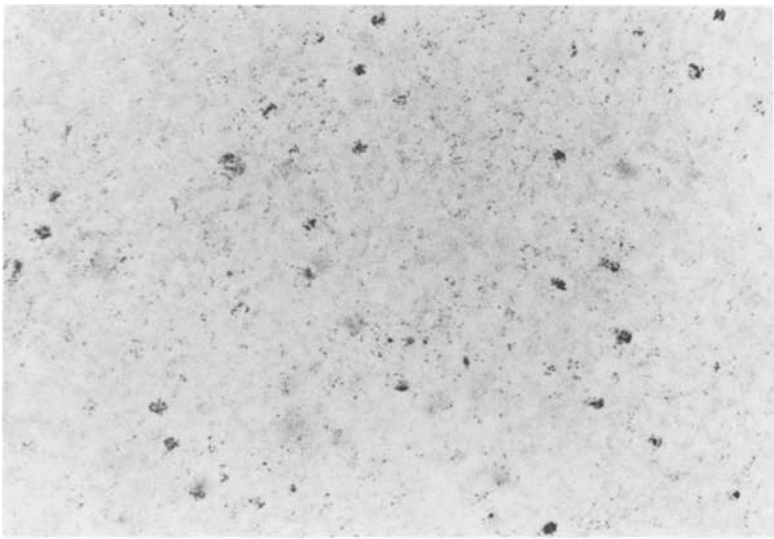

FIG. 8. Photomicrograph of a section of the inner layer of Hornbill casque in a plane parallel to the direction of the banding, showing scattered granules between which are interspersed large clumps of granular material. (Unstained. × 40 magnification).

CONCLUSIONS

This investigation has provided a description of the major physical properties of interest, and the microscopic appearance of natural hornbill ivory. Its identification should be relatively simple for the practising gemmologist. If its characteristic appearance, specific gravity of 1.30, and refractive index of about 1.52 is not sufficient to ensure positive identification, then a thin peeling, examined by low power light transmission microscopy, will readily display the layered structure, with oriented pigment granules, which should facilitate identification.

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FERROAXINITE—ANOTHER NEW GEM FROM SRI LANKA

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INTRODUCTION

Foreign visitors from Fa-Hien in the fifth century A.D. to Robert Knox in the seventeenth century through Arabian Nights to contemporary science-fiction author, Arthur C. Clarke, have referred to the abundance of gemstones in Sri Lanka. As one of the productive localities of valuable gemstones its collection extends to many of the rarer minerals. There is every reason to expect still more new findings in this South-East Asian locality.

During his visit to Sri Lanka in October 1980, one of the authors (M.G.) was shown a parcel of rough stones by courtesy of the firm Many Gems, of Colombo, Sri Lanka. The distinct trichroic effect and the preliminary refractive index determination suggested it to be axinite.

Axinite is known as a mineral typically formed under pneumatolytic conditions. Although it has not yet been reported from Sri Lanka, axinite occurs in the Swiss Alps, Dauphiné in France, in the Ural mountain range of U.S.S.R., in Australia, U.S.A. and Tanzania. Since axinite is easily confused with kornerupine, an x-ray powder diffraction photograph was taken to confirm its authenticity. The lines and intensities were similar to the data published by J.C.P.D.S. (1974). Mineralogical and chemical analyses were carried out and the comparison was done in order to introduce this new finding to the gemmological literature. Three axinites from other origins were selected for comparison (Table 1).

TABLE 1

List of axinites referred to in this paper

1 Ferroaxinite, Thissamaharama, Sri Lanka, present work.
2 Ferroaxinite, Bourg d'Oisons, Dauphiné, France, Jobbins *et al.* (1975).
3 Magnesioaxinite, iron-rich, New South Wales, Australia, Vallance, (1966).
4 Magnesioaxinite, Tanzania, Jobbins *et al.* (1975).

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TABLE 2

Chemical analyses of axinites

Oxides in wt-%

	1	2	3	4
SiO_2	42.70	42.20	42.39	44.00
TiO_2	nt.fd.	0.03	n.d.	0.03
B_2O_3	nt.fd.	**	5.52	**
Al_2O_3	18.31	17.50	17.10	17.90
Cr_2O_3	nt.fd.	nt.fd.	n.d.	nt.fd.
V_2O_3	nt.fd.	nt.fd.	n.d.	0.13
Fe_2O_3	*	*	1.68	nt.fd.
FeO	10.40	6.10	5.18	nt.fd.
MnO	0.38	3.30	1.38	0.40
MgO	1.40	1.60	4.20	6.90
CaO	19.35	20.10	20.31	21.70
ZnO	nt.fd.	nt.fd.	n.d.	0.06
CoO	nt.fd.	nt.fd.	n.d.	nt.fd.
Na_2O	nt.fd.	0.04	0.06	nt.fd.
K_2O	0.01	0.02	0.03	0.01
$H_2O>105°$	n.d.	n.d.	1.67	n.d.
$H_2O<105°$	n.d.	n.d.	0.31	n.d.
totals	92.55	90.89	99.83	91.13

* the total iron is calculated as FeO

** the presence of boron was confirmed by chemical tests

nt.fd. = not found, n.d. = not detected

Number of ions on the basis of 28 (O)

B	—		—		1.772		—		
Si	7.997		8.025		7.885		8.012		
Al	4.042		3.923		3.634		3.842		
Fe^{3+}	—	4.042	—	3.927	0.235	3.869	—	3.865	
Ti	—		0.004		—		0.004		
V	—		—		—		0.019		
Mg	0.380		0.454		1.165		1.872		
Fe^{2+}	1.621		0.970		0.806		—		
Mn	0.060		0.531		0.217		0.061		
Zn	—	5.949	—	6.070	—	6.265	0.008	6.177	
Ca	3.883		4.095		4.049		4.234		
Na	—		0.015		0.021		—		
K	0.005		0.005		0.007		0.002		
Fe-Mn-Mg-ratio	79:3:18		50:27:23		37:10:53		0:3:97		
Authors	1. this paper		2. Jobbins *et al.*, (1975)		3. Vallance, (1966)		4. Jobbins *et al.*, (1975)		

CHEMISTRY

The name axinite is derived from the Greek word *axine* (ἀξίνη), meaning 'axe', in allusion to its acute edged form of triclinic symmetry. It is rather a complex calcium aluminium borosilicate containing ferrous iron, manganese, magnesium and a considerable amount of water. The chemical composition can be formulated as:

$$(Ca, Fe^{2+}, Mn, Mg)_3 Al_2 BO_3 (Si_4O_{12}) OH$$

The proportions of CaO, FeO, MnO and MgO may vary in different axinites. Three end-member compositions are stated, namely *ferroaxinite* (Ca, Fe), *manganoaxinite* (Ca, Mn), and *magnesioaxinite* (Ca, Mg).

The sample from Sri Lanka was analysed by an ARL electron microprobe. Light elements as B, OH could not be detected by this method. The results of this partial analysis are listed in Table 2 together with literature analyses of the comparative stones from Table 1. The total iron is expressed as FeO and the number of ions is calculated on the basis of 28 (O).

The iron content of the Sri Lanka axinite is fairly high compared to the analyses shown by Deer *et al.* (1962) and Jobbins *et al.* (1975). The Fe-Mn-Mg ratios are 78.6 : 2.9 : 18.4—thus the name ferroaxinite is correct.

PROPERTIES

The colour of the present Sri Lanka stone and of other pieces of the same origin visually inspected by one author (M.G.) were all of cinnamon brown with differently coloured internal reflections due to pleochroism. The colour is directionally obscured by the strong pleochroism. The strong trichroic colours are: n_α reddish-brown, n_β dark violet, n_γ colourless-yellowish. In magnesioaxinite and manganoaxinite colours like blue and green respectively are reported.

The refractive indices determinations were carried out by using a Krüss ER 60 critical angle refractometer with Na_D light. The angle between the optical axes was measured in immersion on a spindle stage (Steck, 1968). For recording the absorption spectra a Pye-Unicam SP-8 100 spectrophotometer with polarization filter was used. The spectrum is shown in Figure 1.

Specific gravity determination was done by hydrostatic weighing in ethylene dibromide as an immersion liquid. The results of the optical and physical determinations are presented in Table 3,

FIG. 1. *Absorption spectrum of ferroaxinite*

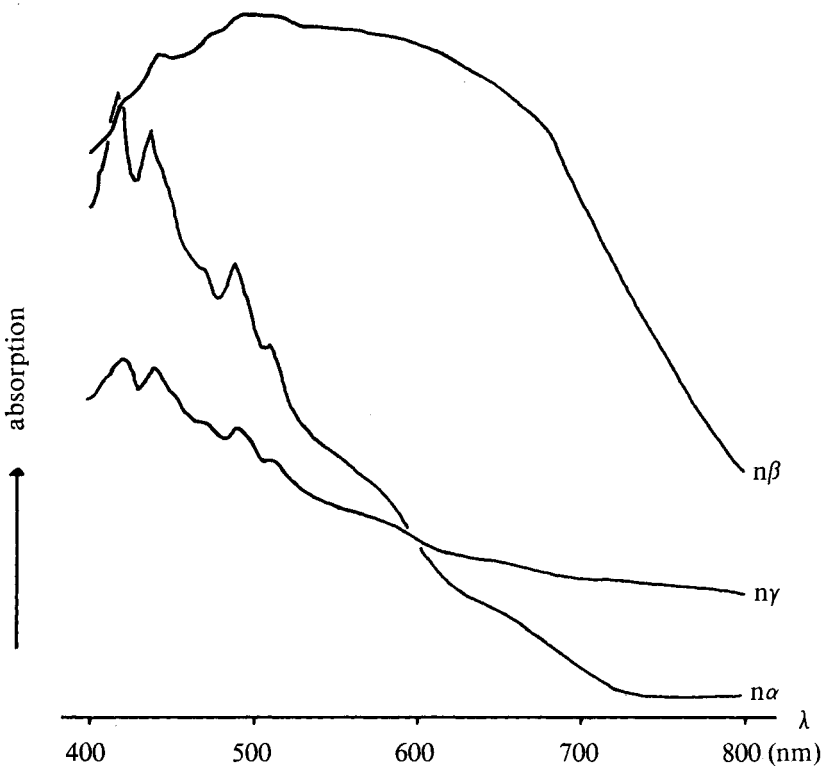

The absorption curves were recorded on a Pye-Unicam SP8-100 spectrophotometer with polarization filter. The unpolarized curve beyond 400 nm shows an absorption band at 376 nm and general absorption in the ultraviolet region below 340 nm.

TABLE 3

Physical constants of axinites

Refractive indices	1	2	3	4
nα	1.675	1.672	1.659	1.656
nβ	1.681	1.679	1.665	1.660
nγ	1.685	1.682	1.668	1.668
Birefringence	0.010	0.010	0.009	0.012
Optical character	Bi−	Bi−	Bi−	Bi +
Axial angle* 2Vx	69.5°	—	—	—

*Determination of axial angle in immersion on a universal spindle stage (Steck *et al.*, 1968).

Specific gravity	3.314	3.288	3.190	3.178

Absorption spectrum of sample 1

nα: 580, 510, **488,** 470, 450, **436, 416** nm

nβ: **540** (broad band), 472, 438, 416

nγ: 584, 512, 489, 474, **438, 418**

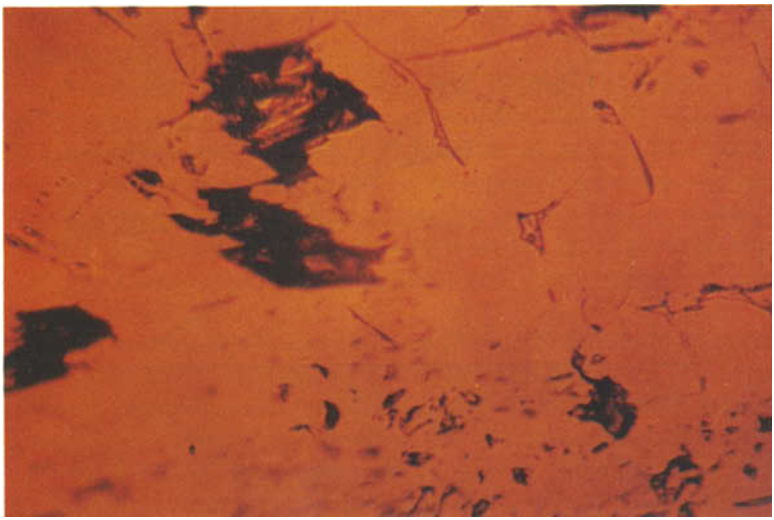

FIG. 2. Two-phase fillings in axinite from Sri Lanka. *(Photo: M. Gunawardene. 60×.)*

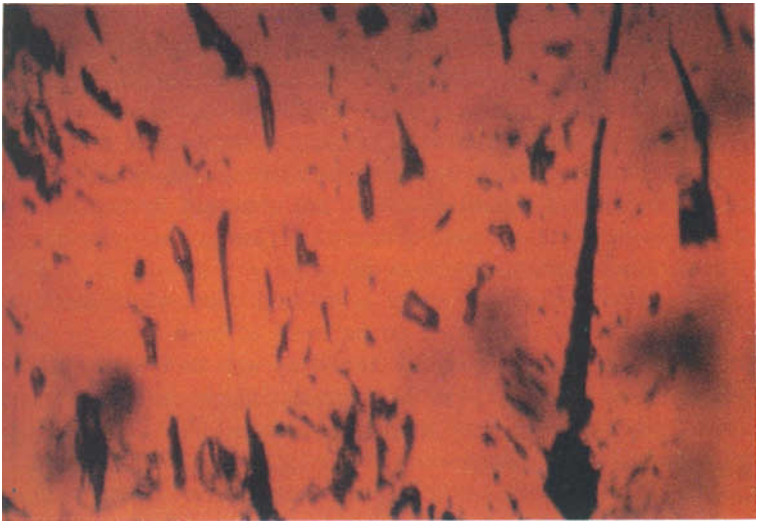

FIG. 3. Two-phase fillings in axinite from Brazil. *(Photo: M. Gunawardene. 60×.)*

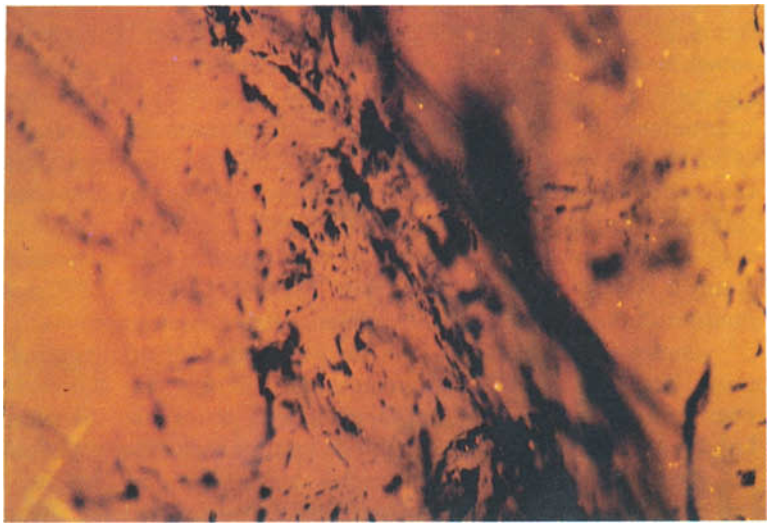

FIG. 4. Black feathers, probably healed fissures in Sri Lanka axinite. *(Photo: M. Gunawardene. 60×.)*

together with comparative literature values. The optical character of magnesioaxinite (Table 1, no. 4) is not reported as positive by mistake. The explanation is given by the substitution of Mg for Fe. With increasing Mg content n_β gets small more quickly than n_α and n_γ; in the meantime the axial angle $2V_x$ grows and the optical character turns from negative to positive. It should be stressed (Gübelin, private communication) that apparent discrepancies in gemmological textbooks frequently have their cause in isomorphous replacement, as in this case.

A visual inspection under long- and short-wave ultraviolet radiation showed the stone to be inert in both types of light. Inclusions in axinite from Sri Lanka as well as from Brazil are illustrated in Figures 2 to 4. The aspect of the inclusions is similar from both localities. They mainly consisted of liquid feathers with two-phase fillings reminiscent of the inclusions in tourmaline or topaz. The exact nature of those inclusions was not determined.

OCCURRENCE

Different geological units may be distinguished in the southern part of Sri Lanka. The precambrian Khondalite system (archaic metasediments), the Vijaya gneiss series and their alluvial cover are important with respect to the occurrence of gemstones. These rocks sometimes are intruded by dolerite dykes and pegmatites. Pegmatites frequently bear gemstone quality zircon, beryl, tourmaline, etc. The pegmatite formation (pneumatolytic phase) is often followed by a hydrothermal phase. Under both circumstances the conditions for an axinite formation are physically given. Axinite is formed in contact metamorphic calcareous sediments and less commonly in altered basic rocks, too. The geological frame (Gübelin, 1968; Herath, 1980) allows different interpretations of the type of the present axinite occurrence.

Our stone is reported from the southern part of the island, most probably from Tissamaharama district. In this area pegmatites intruded into the Vijaya gneiss series. On the other hand, the Khondalite complex with its various rock types is not too far away with a possible parent rock. The production of axinite is rather common now and even well developed crystals are found (Gübelin, private communication).

CONCLUSION

With x-ray powder diffraction we confirmed the suspicion of a new member in Sri Lanka's list of gemstones. The physical properties agree with the range of data in gemmological literature, but the high SG value requires an extension of the recorded range since our sample exceeds the noted upper value for axinite. The reason is most probably the very high iron content of the stone which was confirmed by a microprobe analysis. According to Sanero & Gottardi (1968) this mineral has to be named a Ferroaxinite.

ACKNOWLEDGEMENTS

Our sincere thanks are due to Dr G. Lenzen, of Deutsche Gemmologische Gesellschaft, and Prof. H. Schwander, Mineralogical Institute, University of Basel, who helped us in realizing this work. Finally we thank the firm Many Gems, of Colombo, Sri Lanka, who kindly allowed us to investigate their material and so to introduce gem axinite to the Isle of gems—Sri Lanka.

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THE USE OF A STEREOMICROSCOPE BRIGHTFIELD/DARKFIELD ILLUMINATOR IN CONJUNCTION WITH THE ZEISS PHOTOMICROSCOPE II FOR THE EXAMINATION AND PHOTOGRAPHY OF GEMSTONE INCLUSIONS

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INTRODUCTION

The use of the microscope is firmly established as an essential part of the testing procedure necessary for the examination and identification of gemstones. The microscope can help the gemmologist in many ways but is most frequently used for the investigation of gemstone inclusions. One of the difficulties confronting the would-be student of inclusions is the provision of adequate illumination for the gems he wishes to examine with the microscope. If the illumination of the specimen is unsatisfactory the observer will inevitably miss features within a gemstone which may be significant or even diagnostic. Many modern microscopes allow a choice of two illumination techniques. One is called 'brightfield' and the other 'darkfield' illumination.

Brightfield illumination is achieved when the microscope is set up in the conventional manner for observations in transmitted light. Ideally light from a substage illuminator follows a 'straight line' path through the gemstone, objective and eyepiece to the observer. With 'dry' faceted gemstones this technique is rarely satisfactory because much light is lost by reflection and refraction at the surface of the stone. A closer approach to ideal brightfield illumination conditions can be achieved if the gemstone is immersed in a liquid of high refractive index. Monobromonaphthalene (RI = 1.66) is a familiar example of a widely used immersion liquid. Under good brightfield conditions inclusions appear as relatively dark objects against the light background of the host gemstone.

In darkfield illumination the gemstone lies at the apex of a 'hollow' cone of light again produced by a substage illuminator.

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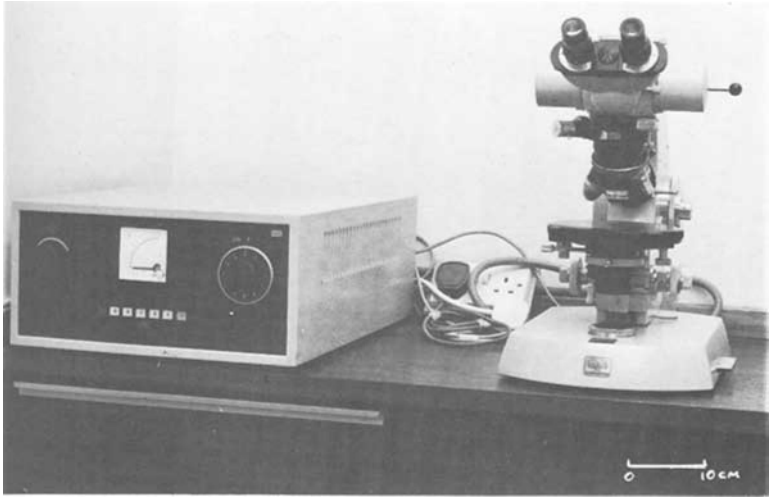

FIG. 1. The Zeiss Photomicroscope II (right) and control unit (left).

With this technique all light enters the stone obliquely from the sides; consequently no light can follow a 'straight line' path from the illuminator, through the stone and into the microscope objective. The image which the observer actually sees is produced mainly by scattered light which is reflected from the surface of the stone or from inclusions within it. Under these circumstances inclusions appear brightly illuminated against a predominantly dark background. Most gemstones, particularly those of high RI, may be studied dry when using darkfield illumination. In some instances, however, the darkfield effect may be considerably enhanced if the stone under examination is, once again, immersed in a suitable liquid.

A fuller account of both types of illumination, and the various means by which they may be produced, is given in the standard books on gem testing.

THE ZEISS PHOTOMICROSCOPE II

Some years ago the Mining Department at Sunderland Polytechnic acquired a Zeiss (polarizing) Photomicroscope II (Figure 1). The optical performance of this remarkable instrument

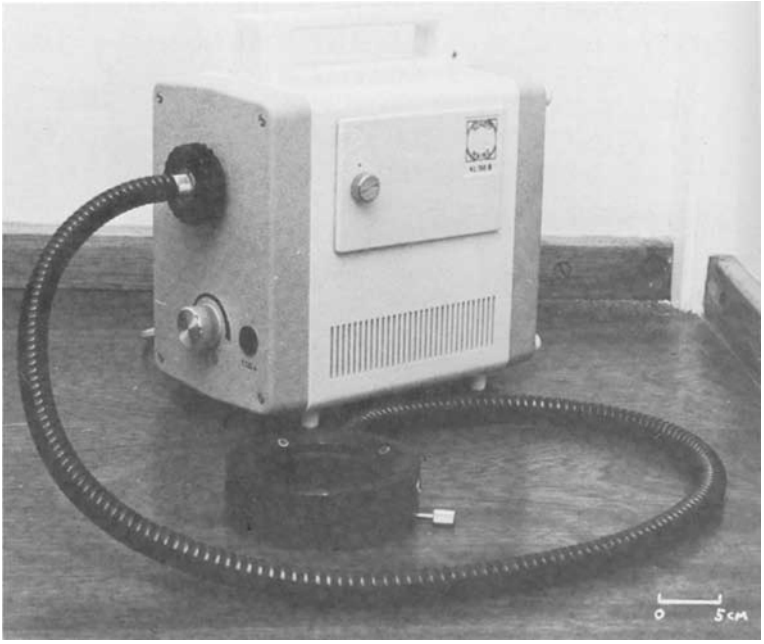

FIG. 2. The Schott four-point circular lamp, flexible fibre optic light guide and 15 V 150 W cold-light source.

is quite outstanding. A built-in camera, coupled to an automatic exposure control unit, is fitted as standard. A wide range of accessories, capable of considerably extending the versatility of the microscope, are readily available and easily fitted.

Although designed primarily for thin-section work, it soon became apparent that the Photomicroscope could be easily adapted for the study of inclusions in unmounted, transparent gemstones. In nearly all cases gemstones to be examined are covered in a highly refractive liquid contained in a glass immersion cell. The cell is placed directly on the microscope stage beneath the objective in use. The presence of an immersion cell necessitates the use of low power objectives (up to 10×)—only these objectives have sufficiently long working distances to allow thorough examination of the interior of a gemstone whilst normally avoiding any risk of a collision occurring between the objective and cell during focusing.

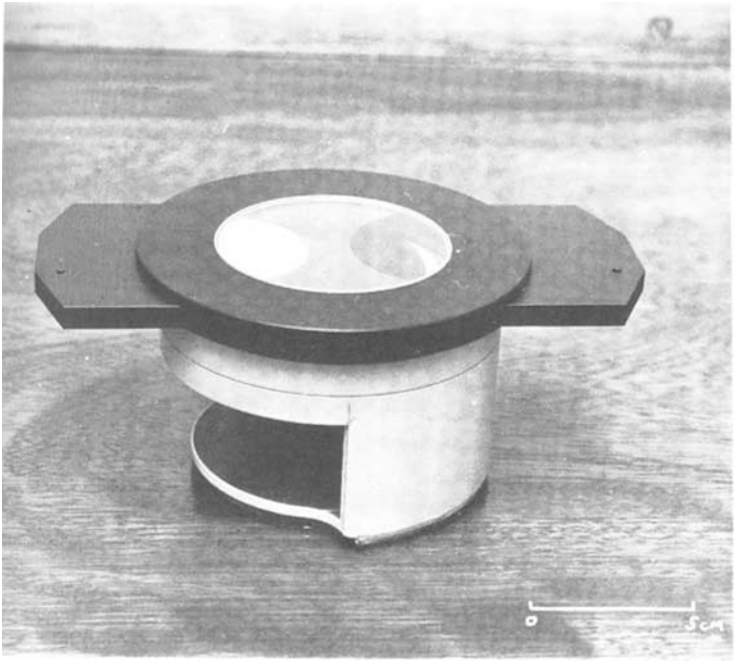

FIG. 3. The Zeiss HD (brightfield-darkfield) transilluminator.

The limitation imposed by the use of low magnification objectives can be partially overcome if the Photomicroscope is fitted with an Optovar system. This device is a stepped magnification changer which allows the magnification to be increased by up to a factor of 2 without changing the objective. It is broadly comparable with the 'zoom' system found on many modern stereomicroscopes. The Optovar system is operated by a knurled ring located in the microscope body tube between the objective and eyepieces. In practice, however, the system is rarely required, because high magnification is not often necessary in gemstone work.

Over the past two years the technique outlined above has been successfully employed in the examination and photography of gemstone inclusions with the Photomicroscope. With few exceptions, this work was carried out using brightfield illumination.

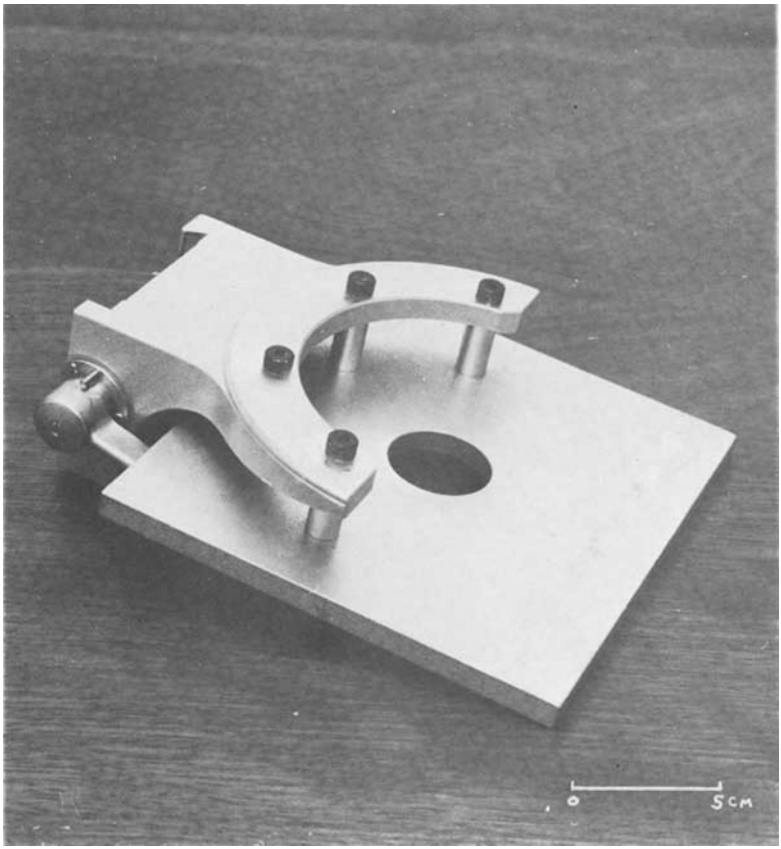

FIG. 4. The modified Photomicroscope stage-carrier showing the mild steel plate bolted to the underside of the carrier.

DARKFIELD ILLUMINATION WITH THE PHOTOMICROSCOPE

Some months ago the writer was asked to comment on the inclusions in a number of emeralds and garnets. After initial inspection under brightfield conditions it became apparent that the investigation would benefit from the use of darkfield illumination. It was therefore decided to explore the possibility of adapting the Photomicroscope for darkfield work. It appeared that the acquisition of a Zeiss darkfield condenser, which could be easily fitted beneath the microscope stage, would provide the necessary oblique illumination. Enquiries revealed, however, that Zeiss do

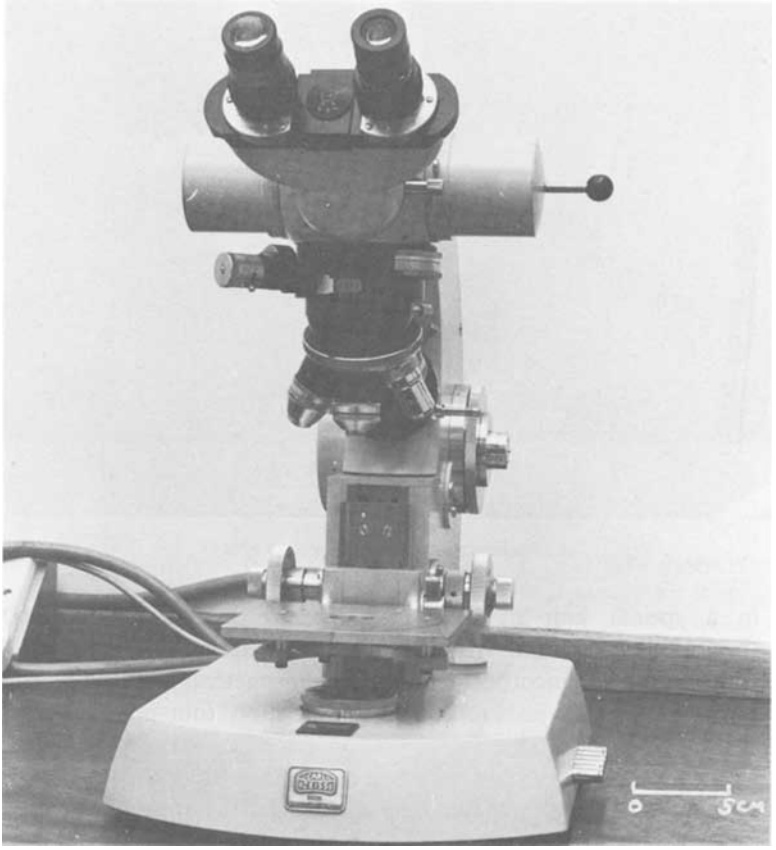

FIG. 5. The modified stage carrier and steel plate assembly fitted to the microscope.

not manufacture a suitable condenser which is optically matched to the low power objectives which would be used for gemstone study. After some preliminary set-backs the problem was finally solved by adapting a relatively new type of stereomicroscope illuminator for use with the Photomicroscope.

The illuminator selected is manufactured by the German firm of Schott. It consists of a four-point circular lamp which is connected by a flexible fibre optic light guide to a powerful 15 V 150 W halogen light source (Figure 2). The circular lamp is housed

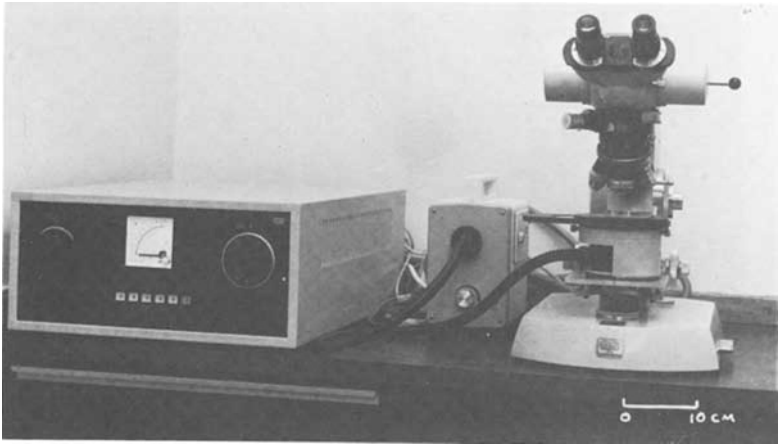

FIG. 6. The apparatus ready for use.

in a special unit of Zeiss manufacture known as the HD (brightfield-darkfield) transilluminator (Figure 3). The HD transilluminator incorporates a large hemispherical lens, the central portion of which is blacked out. The Schott four-point circular lamp fits beneath this lens. A sliding device, which allows the microscope operator to change from darkfield to brightfield illumination at will, is fitted to the top of the transilluminator. Above the sliding device is a fixed glass plate on which the specimen rests. Unfortunately the overall height of the HD transilluminator prevents it being used directly on the normal Photomicroscope stage. If this is attempted the stage simply cannot be lowered far enough to allow a specimen to be focused. (N.B. On the Photomicroscope focusing is achieved by up and down movement of the microscope *stage*). This difficulty was overcome by modifying an ordinary Photomicroscope stage carrier. A mild steel plate measuring 127 mm × 114 mm × 6 mm thick was bolted to the *underside* of a spare stage carrier (Figure 4). This steel plate functions as a new microscope stage. Having first removed the conventional stage and substage condenser assembly from the Photomicroscope, the modified stage carrier was then *inverted* (so that the mild steel stage plate was uppermost) and attached to the

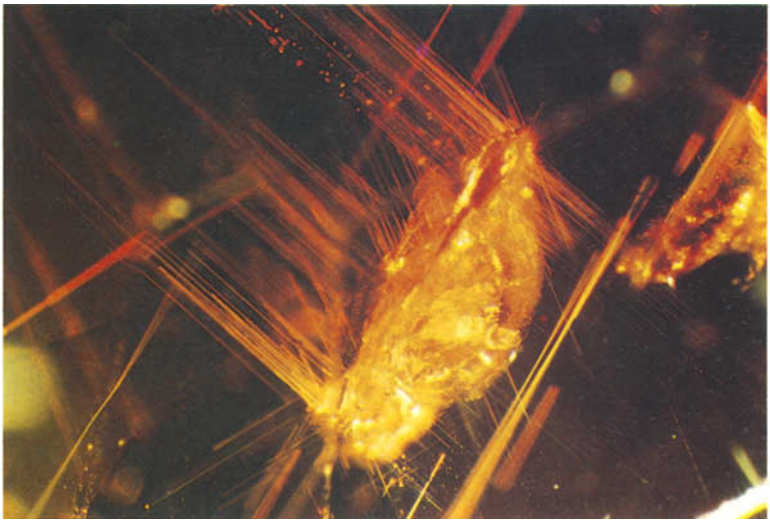

FIG. 7. Rutile needles in almandine. Darkfield 6.3 × .

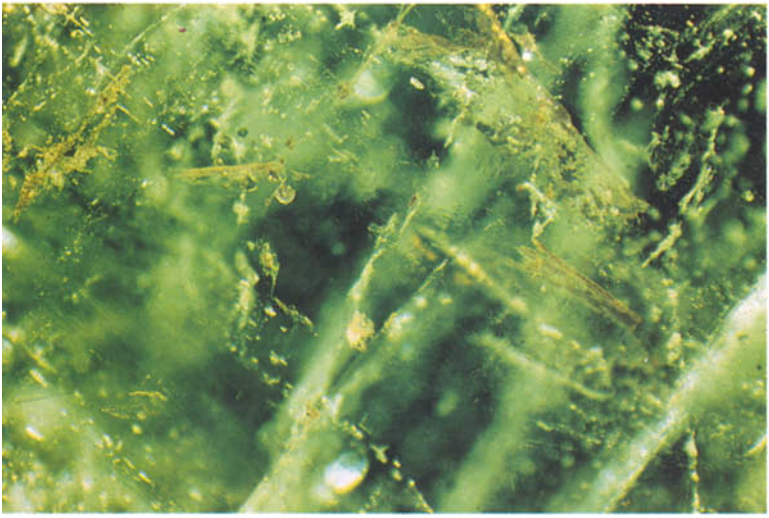

FIG. 8. Liquid and solid inclusions in Indian emerald. Darkfield 6.3 × .

microscope body in the usual way (Figure 5). Inversion of the stage carrier results in the location of the new stage at a much lower level than the conventional stage. This simple modification ensures that the HD transilluminator housing (containing the Schott circular lamp) can be placed directly on the new stage plate while allowing ample room for focusing of a specimen beneath the objectives. To facilitate centring of the illumination a thin strip of magnetized rubber was cut to size and stuck (using araldite) to the underside of the transilluminator housing. The magnetized rubber holds the housing securely on the stage plate in any desired position, and yet allows it to be easily moved when pressure is applied by the hand. Figure 6 shows the HD transilluminator set up on the Photomicroscope ready for use.

The modification to the Photomicroscope outlined above can be easily carried out by anyone with the necessary facilities. Using this technique excellent darkfield illumination can be obtained. The chief advantage of the system is that it allows a very high quality stereomicroscope illuminator to be used in conjunction with the superb optical performance of the Photomicroscope. Preliminary results have proved most encouraging. Two of the photographs obtained, using the apparatus described, are reproduced in Figures 7 and 8.

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COLOUR CENTRES IN DIAMOND

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1. INTRODUCTION

Diamond is, of course, the most prized of gemstones. Its high refractive index, its hardness and the natural occurrence of stones which are, from the gemmological point of view, almost perfect, place it in a class of its own. Diamond is also a material of considerable interest to the solid-state physicist. Carbon is the first element in group IV of the periodic table, which also contains the industrially important semiconductors silicon and germanium (both of which have the diamond crystal structure). The physical properties of these three substances are greatly influenced by 'point defects' and an enormous amount of research work has been carried out to determine how these point defects may be introduced into crystals (either naturally or artificially in the case of diamond) and how they may be studied.

When point defects give rise to optical absorption in the visible spectral region for a material that would otherwise be transparent they are often referred to as 'colour centres'. It is natural that such centres should be studied using optical spectroscopy. The use of the hand spectroscope in the examination of gem diamonds was pioneered by Anderson[1] and an enormous amount of valuable information has been obtained from the use of this instrument in

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gem testing laboratories world-wide. Detailed spectroscopic examinations of diamonds by physicists have also been in progress for more than 40 years (see, for example, Nayar[2], Mani[3] and Clark *et al.*[4,5]), but it is only recently that the origin of some of the absorption bands has become understood. Even so, there is still much to learn. Many, many different absorption and luminescence bands are observed in diamond; some occur naturally and others may be produced artificially by 'treatment'.

1.1 *Absorption Systems in Diamond*

For the newcomer to the spectroscopy of diamond the list of absorption lines is truly bewildering. Some have a 'name' based on a particular author's classification system while others are known by the wavelength or the energy at which the line is observed. We have, as typical examples, GR1, N2, 3H, H4, 4152Å, 595 nm, 1.945 eV, as well as descriptive terms such as Cape and canary; there are well over 100 others! In this article I propose to discuss only those colour centres which have gemmological significance and to refer the interested reader to articles which review more fully the optical properties of diamond (see for example Davies[6] and Walker[7]). In treating the subject in a highly selective way from my own viewpoint I am aware that there may be important omissions from the article. However I hope that the information I do give may cast some new light on a familiar subject and will prove generally useful in the field of diamond gem testing.

The diamond classification scheme used, and the models described for some of the colour centres, are those generally accepted in the West but differ in some cases from those used by Russian workers.

1.2 *Units*

Most people regard the visible spectrum as covering the wavelength region 4000Å in the violet to 7000Å in the red (or, in S.I. units, from 400 to 700 nm). Visible radiation, as we know, may be considered to be a stream of photons, and the physicist normally considers the energy, rather than the wavelength, of the photon. If the energy E is expressed in electron-volts (eV) the wavelength λ in angstroms is given by

$$\lambda = 12398/E \qquad (1)$$

It is important to realize that the wavelength thus calculated is the wavelength *in vacuo*. If high accuracy measurements are being

undertaken, the refractive index of air (approximately 1.00028 in the visible region) must be taken into account and we have

$$\lambda_{air} = 12395/E \quad (2)$$

Equation (2) is normally most appropriate, and we see that, for example, the 1.945 eV transition is the familiar 6372Å line observed in treated pink diamonds (see section 6.7). This transition is at 6372Å when the diamond is cooled to liquid nitrogen temperature; at room temperature the line is at about 6380Å.

In the infrared part of the spectrum wavenumbers and microns (or, more correctly, micro-metres) are generally used. The wavenumber is just the reciprocal of the wavelength, where the wavelength is expressed in cm. The inter-relation between these units is as follows:

$$1 \text{ micro-metre } (\mu m) = 1000 \text{ nm} = 10\,000 \text{Å} \quad (3)$$

$$1 \text{ wavenumber } (cm^{-1}) = 10^8/\lambda(\text{Å}) \quad (4)$$

Equations (2), (3) and (4) allow us to write, for example, that $7.3\ \mu m \equiv 1370\ cm^{-1} \equiv 0.1698$ eV

1.3 *Absorption Coefficient*

In some cases, as we shall see, in order to decide whether a diamond has been artificially coloured it is not enough merely to determine whether certain absorption lines are present in the spectrum—we must determine *how strongly* the diamond is absorbing at these wavelengths. The reason, quite simply, is that many of the absorption lines produced when a diamond is artificially coloured may be created *to some extent* by natural processes.[8] Ideally, then, we need to know the concentration of colour centres in the diamond under investigation, and to decide whether this concentration is significantly higher than may be observed in untreated diamonds. The hand spectroscope must then be abandoned and a spectrophotometer employed which produces a graph of absorption coefficient (or absorbence) plotted against wavelength. The spectrophotometer has the further advantage that broad, featureless absorption bands are shown up that are often not observed by eye, since the eye only responds to sharp changes in transmission levels. The range of measurement may also be extended into the infrared or ultraviolet, if required.

Consider in Figure 1 the ideal case of light with intensity I_o at a certain wavelength falling on a parallel-sided sample of thickness t and with absorption coefficient α. The intensity I_t of the

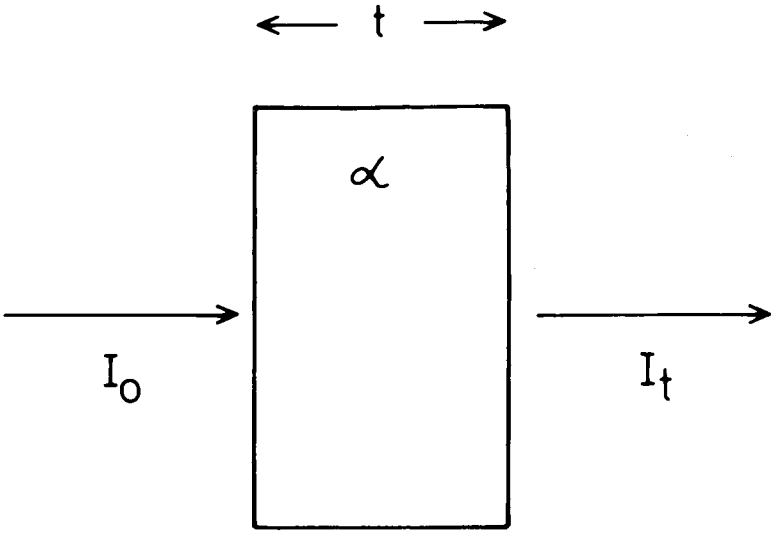

FIG. 1. Transmission of light through a parallel slab of thickness t and absorption coefficient α.

transmitted light depends on the product of α and t, and α is proportional to the concentration of colour centres (assuming the absorption is due to only one type of colour centre). At the risk of stating the obvious, the *transmission spectrum* of a thin, strongly absorbing, diamond can be virtually identical with that for a thick, weakly absorbing, diamond. It is easy to jump to the conclusion, when examining a large diamond with a hand spectroscope, that the colour is due to treatment, whereas when the absorption coefficient is actually measured on a spectrophotometer it is found to be well within the range encountered in diamonds coloured by natural processes (see Figure 19 for example).

To a reasonably good approximation

$$\alpha t = \log_e(I_o/I_t)\text{—constant} \qquad (5)$$

For the parallel slab shown in Figure 1 the value of the constant is about 0.34, due simply to reflective losses at the front and back surfaces. By increasing the gain of the measuring instrument when the sample is inserted it is possible to compensate for these reflective losses, and to set $\alpha t = 0$ at a wavelength where the absorption is known to be zero. In the non-ideal case—for example a rough diamond or a faceted diamond—some of the light will be scattered or internally reflected, less light will emerge from the

stone than in the case of a parallel-sided sample and the constant in equation (5) will be greater than 0.34. However, provided the same procedure is followed, increasing the gain of the instrument to correctly set the zero, the absorption coefficient is given, with an error not exceeding 6% by

$$\alpha = \frac{1}{t} \log_e (I_o/I_t) \qquad (6)$$

Normally t is measured in cm and the units of α are cm^{-1}.

On a commercial spectrophotometer the data can be output as *absorbance* which is given by $A = \log_{10} I_o/I_t$. The *absorption coefficient* in this case is given by $\alpha = 2.3\ A/t$, and this can be calculated quite easily from the spectrum.

Because of the nature of the log function it does not matter if the zero-absorption condition is not correctly set—the effect is merely to move the spectrum up or down the absorbance axis, but the shape of the spectrum remains unchanged.

2. Instrumentation

A diamond gemstone, particularly a brilliant cut, is designed to totally internally reflect most of the light incident on the front surface. To obtain an absorption spectrum, therefore, the beam of light is best focused through one of the pavilion facets and out of an opposite facet, and the fraction of the incident light that emerges, even for a colourless stone, is often very small. We shall see in Section 5 that the absorption spectra of diamond are very much sharper if the stone is cooled to about 100 K, at which temperature the lines may be only 1 or 2Å wide.

When setting up the equipment to be described I was not aware of any commercial spectrophotometer which would handle the low throughput of light for cut gemstones (or natural diamonds with rough faces), would accept a 'cold-cell' to cool the diamond to 100 K and would record spectra with the required resolution (better than 1Å). My own system is therefore based on a high resolution grating monochromator and an on-line micro-computer. Recent developments in spectrophotometers may well mean that machines of adequate performance are now available.

Figure 2 illustrates the external optical system. The image of the filament of a tungsten strip lamp is focused (with an image reduction of about 3:1) onto the diamond by lens L1, and the light emerging from the diamond is focused onto the entrance slit of the monochromator by a symmetrically positioned lens L2. Both the

lenses are glass achromats. A yellow filter F is used for measurements at wavelengths longer than 625 nm to prevent overlapping orders.* The diamond is mounted in a glass cell similar to that described by Scarratt[9] through which cold nitrogen gas is flowing.

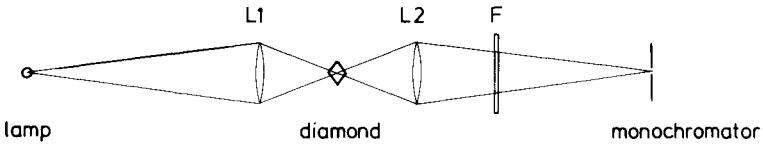

FIG. 2. Optical system used to focus light through a small area of a diamond.

Basically this optical arrangement produces an image of the lamp filament on the entrance slit of the monochromator, having passed the light through a pair of opposite facets of the diamond. Even with strongly luminescing diamonds, the intensity of the transmitted light is much greater than the intensity of the luminescence collected by L2, and no interference is experienced. By contrast, when the diamond is diffusely illuminated and then most of the light emerging from the diamond is collected and fed into the spectrometer using a system of parabolic reflectors, brightly luminescing diamonds can give problems (V. Manson, personal communication). If multiple reflections prove troublesome in the arrangement described, those facets which are not used can be blacked out with a dilute solution of 'dag' in alcohol, but this is rarely necessary.

We have seen in Section 1.3 that the quantity required is

$$\alpha = \frac{1}{t} \log_e I_o/I_t$$

plotted against photon energy or wavelength. In the author's system this is achieved by carrying out an initial scan from 750 to 380 nm with no sample in position, scanning at 25 nm/min. The output from the photomultiplier amplifier is digitized to an accuracy of 1 part in 4096 four times every second and stored in the computer. This is the I_o spectrum with more than 3500 points

*When a grating monochromator is set to pass a wavelength λ, wavelengths of $\lambda/2$, $\lambda/3$ . . . . will also be passed. These 'overlapping orders' must be removed by a suitable filter. In the system described the glass lenses filter out the unwanted orders when λ is less than 625 nm.

spaced just over 1Å apart. The diamond is then inserted and the gain of the photomultiplier amplifier increased as necessary. The thickness of the sample is entered into the computer, the monochromator is again scanned from 750 to 380 nm and the signal digitized and stored as before. This is the I_t spectrum, and the computer evaluates α at each point and plots the result on an X-Y recorder. If required, any region of the spectrum can subsequently be expanded and replotted from the computer's memory.

By using a very stable lamp and electronics* the same stored I_0 spectrum can be used for all subsequent runs, so that spectra can be obtained from two or three diamonds per hour. In addition to the copy of the final spectrum produced, the digital data may be stored on punched paper tape, magnetic tape or floppy disk for archiving or more detailed analysis.

Similar equipment is used to record luminescence spectra. In this case the tungsten lamp is not used, but the diamond is illuminated from the side using a mercury lamp with an appropriate filter, or a laser. Obtaining luminescence spectra is a more difficult exercise than recording absorption spectra, and is rarely required in gemmological applications. A detailed description of the apparatus and experimental techniques would therefore be out of place in this article.

3. Pure Diamond

Diamond is a covalently bonded material. An isolated carbon atom has four outer electrons and in the diamond structure each carbon atom bonds with four neighbouring carbon atoms to produce a very stable structure in which each atom is surrounded by eight electrons. This is shown schematically in two dimensions in Figure 3a. In three dimensions the carbon atoms are at the centre and the corners of a regular tetrahedron. The energy required to remove an electron from one of the bonds is about 5.5 eV; this corresponds to a wavelength of 225 nm in the ultraviolet and is the longest wavelength at which absorption involving electrons can occur in a pure diamond. At shorter wavelengths all diamonds are strongly absorbing. Diamond also absorbs energy at wavelengths which will set the atoms into *vibration.* This gives rise to absorption in the infrared between about 2.6 and 7.2 μm (3800 to 1380 cm^{-1}).

*i.e. the intensity of the lamp and the response of the light-measuring system do not change with time.

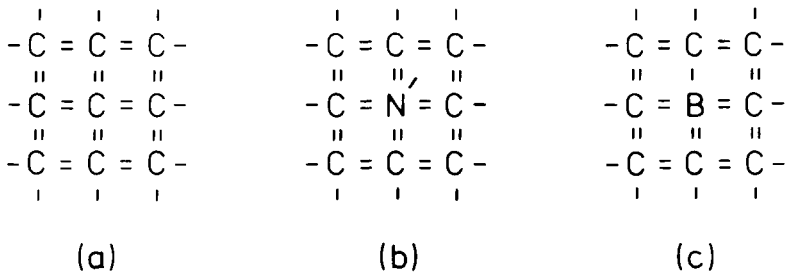

FIG. 3. Two-dimensional representation of the atoms and electron-bonds for (a) a pure diamond, (b) single substitutional nitrogen in diamond and (c) substitutional boron in diamond.

There is, however, no absorption in the visible region and a pure diamond is therefore completely colourless.

4. Donors and Acceptors

For silicon and germanium the group V and group III impurities give rise to donor and acceptor centres respectively, and these dramatically affect the electrical properties of the host material. As far as is known nitrogen and boron are the only elements which will substitute for carbon atoms in the diamond crystal and the properties of these centres are described below. In contrast with earlier work, aluminium is *not* now believed to be electrically or optically active in diamond.

4.1 *Nitrogen*

In Figure 3b we represent schematically a single-nitrogen atom that has substituted for a carbon atom. Nitrogen is in group V of the periodic table and has five outer electrons; four of these are required for bonding to the surrounding carbon atoms. The fifth electron is relatively weakly bound and requires only about 2 eV to dislodge it, compared with the 5.5 eV required to remove an electron from a carbon-carbon bond. Diamonds which contain significant concentrations of single-nitrogen atoms (say 30 parts per million) show appreciable absorption for photon energies greater than 2.2 eV (wavelengths less than 560 nm) and appear yellow in colour. Diamonds like this are classed as Type Ib, and a typical absorption spectrum is shown in Figure 4a. The colour of such a stone is often referred to as 'canary yellow' although this description is normally reserved for Type Ib diamonds which exhibit yellow or orange luminescence when excited with a long

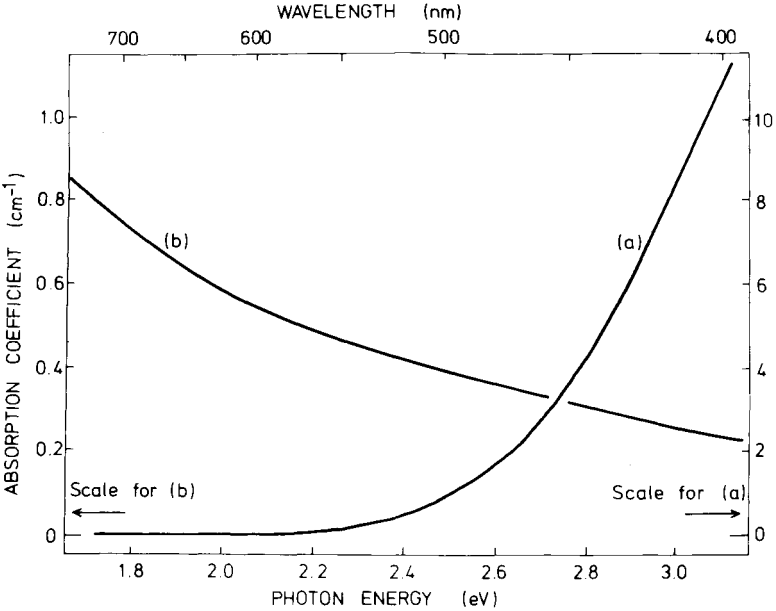

FIG. 4. Absorption curves for (a) a Type Ib diamond and (b) a Type IIb diamond.

wave ultraviolet lamp.[10,11] Type Ib diamonds are rare in nature because the long period of time spent by most diamonds in the Earth's crust at elevated temperatures favoured the almost complete transformation to aggregated forms of nitrogen. Diamonds containing aggregated nitrogen are classified as Type Ia, and about 95% of all diamonds fall into this category. I have summarized the properties of nitrogen in diamond in a previous issue of this *Journal*[11] and will not reiterate them here, except to mention that neither the A-aggregate nor the B-aggregate of nitrogen gives rise directly to any absorption in the visible spectral region, and that most colourless gem quality diamonds contain substantial concentrations (typically 0.1 to 0.3%) of aggregated nitrogen. The three different major forms of nitrogen in diamond give rise to characteristic absorption bands in the infrared spectral region between about 7 and 12 μm (1400 to 800 cm^{-1}) from which the concentrations of nitrogen in the different forms can be determined. (See, for example, the spectra given by Davies[6]). When the nitrogen concentration is too small to detect by

conventional infrared absorption spectroscopy the diamond is classified as Type II.

4.2 *Boron*

Boron from group III of the periodic table has only three valence electrons and so there is a missing electron, or hole state, when boron substitutes for carbon in the diamond structure, as indicated in Figure 3c. It turns out that only 0.37 eV is required to transfer an electron from a neighbouring bond into this hole state, and so the diamond absorbs radiation for wavelengths shorter than 3.35 μm. The 'tail' of this absorption band extends into the red end of the visible spectrum, as shown in Figure 4b, giving the diamonds a pale blue colour.

In semiconductor terminology single-nitrogen in diamond is a donor and boron is an acceptor. At room temperature the thermal energy available from the surrounding atoms (about 1/40 eV) is insufficient to ionize (i.e. release electrons from) a significant fraction of nitrogen donors, and a Type Ib diamond is a very poor conductor of electricity. It is even more difficult to ionize the aggregated nitrogen centres in Type Ia diamonds, requiring an energy of at least 3.7 eV, and such diamonds are therefore excellent insulators. However, a small fraction of the boron acceptors *can* be ionized at room temperature, and diamonds containing boron as the major impurity will conduct electricity to a certain extent. The electrical current is said to be carried by positive holes, and the electrical conductivity increases as the temperature is increased. This behaviour is entirely characteristic of a p-type semiconductor, and such diamonds are classed as Type IIb. The electrical conductivity of Type IIb diamonds enables them to be distinguished easily from diamonds that have been coloured blue by irradiation with high energy electrons (see Section 6.8.1). Diamonds with immeasurably small nitrogen concentrations, but which are not semiconducting, are classed as Type IIa.

When nitrogen and boron are present simultaneously in a diamond the properties are determined by the major impurity. Boron is only ever present as a trace impurity with a concentration around 1 ppm in natural diamonds; the nitrogen concentration in Type IIb diamonds must therefore be less than 1 ppm and these specimens represent the purest form of naturally occurring diamond.

5. Vibronic Centres—Description

The word 'vibronic' is a contraction of vibrational-electronic and is used to describe absorption and luminescence bands which arise when the *electron* in an optical centre is excited (i.e. given energy) and at the same time *vibrational* energy is transferred to the crystal. Vibronic bands are so common in diamond—all but one of the remaining colour centres to be described in this article are vibronic centres—that it is worthwhile trying to obtain a general understanding of the processes involved and of the nomenclature often employed in describing the spectra.

I shall try to explain some of the underlying principles by means of an analogy. As with all analogies, it cannot be pushed too far and indeed the picture I present here is not even accurate since it separates the electronic and vibrational terms in a way which is not valid. Nevertheless I believe that some useful insights may emerge from this approach.

Imagine that we have a snooker table as shown in Figure 5 and that the legs at the top have been propped up slightly so that there is a gentle uphill slope from bottom to top. Near the top of the table we have a pack of three balls, each interconnected by a spring and each anchored to the table by another spring. The ball E shown shaded has a layer of glue on it; this glue has rather special properties which we shall describe later.

Consider now striking the cue ball from the point Q on the bottom cushion. The cue ball has its lowest possible energy here, and the bottom cushion represents the 'ground state' of the system. There is assumed to be no friction between the cue ball and the table, and there are three cases that we can consider:

(i) The cue ball is hit gently so that it rolls part way up the table then rolls back to the lower cushion. In this case no net energy has been gained by the cue ball, and this corresponds to the situation in a crystal where the energy of the light is too small (i.e. the wavelength is too long) for absorption to occur at the optical centre.

(ii) The cue ball is hit very precisely so that it just reaches E and sticks to it. The cue ball is now in an 'excited state' and this corresponds to the *electronic transition* at a colour centre in a crystal.

(iii) If the cue ball is hit somewhat harder than it was in case (ii) then the cue ball will stick to E and also set the pack of balls

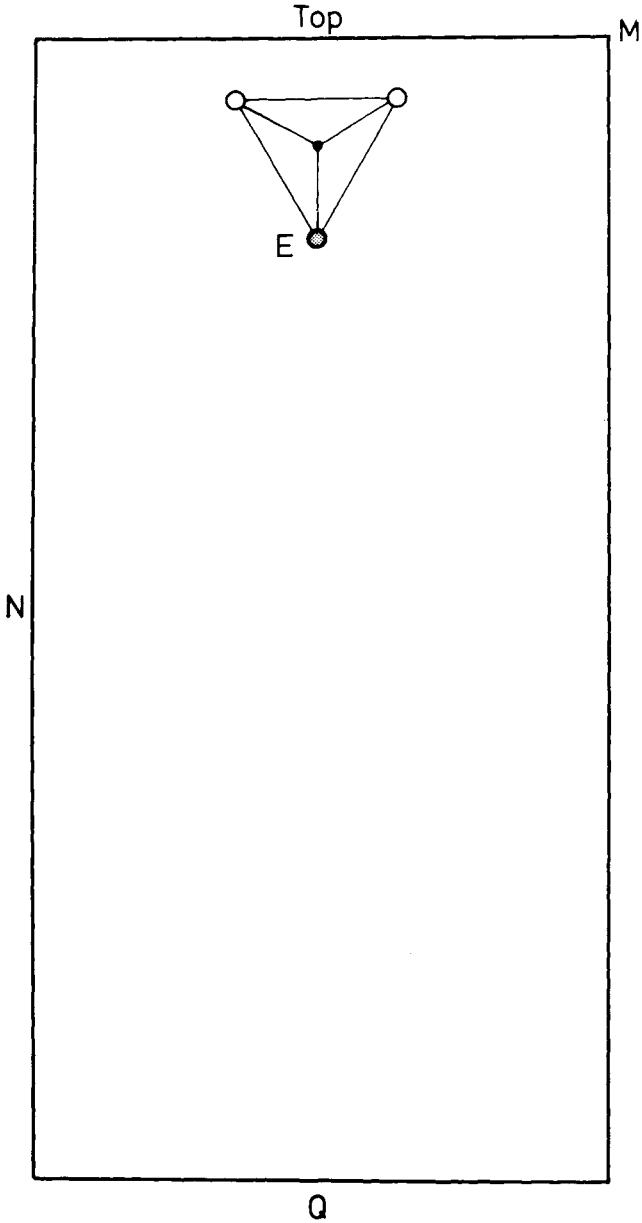

FIG. 5. Snooker table and balls used in analogy to represent vibronic interactions in diamond. The lines interconnecting the three balls, and between each ball and the anchoring point at the centre of the triangle, represent springs.

into vibration. The frequency of the vibration will be determined by the mass of the balls and the strength of the springs. In a real crystal the atoms of the colour centre are bonded to the diamond lattice and the vibrating atoms in the centre force the surrounding carbon atoms into motion and the vibrational energy spreads out into the diamond. The vibrational waves which propagate through the crystal are referred to as PHONONS, which have a characteristic frequency or energy.

Our simple model does not allow us to predict the shape of the absorption band, but calculation based on a simple theoretical model which assumes there is only one characteristic phonon energy yields a typical band shape like that shown in Figure 6a. The essential features are a sharp line marked O corresponding to the electronic transition, and a broad band at higher energy which shows peaks 1, 2, 3 . . . . whose spacings from O are multiples of the phonon energy. These peaks become more diffuse at higher energies. The line O is referred to as the phononless, no-phonon or zero-phonon line (the latter term being most generally used in the diamond literature) and the peaks 1, 2, 3 . . . . as the first, second, third . . . . phonon replica (or sideband). In a real situation the

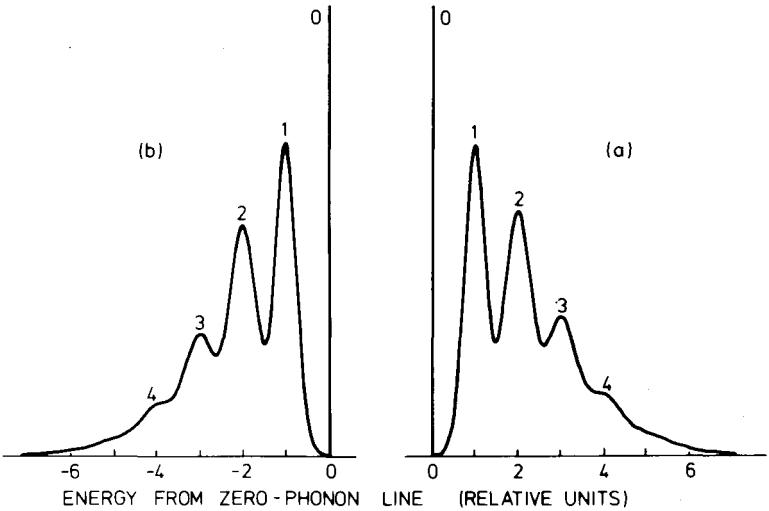

FIG. 6. Theoretical spectra representing (a) the absorption spectrum and (b) the luminescence spectrum associated with an ideal vibronic centre. In each case 0 represents the zero-phonon line and 1, 2, 3 . . . are the first, second, third . . . phonon sidebands.

electronic transition may couple to more than one phonon energy so that the spectrum is more complicated than that shown in Figure 6a, but often there is one dominant feature which repeats at equal energies. For just a few bands in diamond the coupling between the electronic and vibrational terms is so strong that the zero-phonon line is too weak in intensity to be detected, and the phonon replicas are broadened out into a single band. The transitions which give rise to the amber yellow (Section 6.2) and natural pink (Section 6.6) colours are believed to be of this type.

5.1 *Temperature dependence*

In our snooker table analogy we have assumed that the pack of balls near the top of the table is absolutely stationary. In a real crystal the atoms are continuously vibrating at random, unless the temperature is reduced to absolute zero. Furthermore the higher the temperature of the crystal the larger is the amplitude of vibration. If the balls in our model are allowed to vibrate to represent a finite temperature the ball E will sometimes be nearer to, and sometimes farther from, the bottom of the table than it would be when absolutely stationary, and this means that there is no longer a single precise energy at which the electronic transition takes place, but that there is a spread of energies. This means that the zero-phonon line in the absorption spectrum, and the features in the vibronic band, become broader as the temperature is increased. There are two further temperature effects which emerge from detailed theoretical analyses of vibronic bands.[12] The intensity of the zero-phonon line, relative to the vibronic band, decreases as the temperature is raised and the line moves to lower energy (longer wavelengths). For most optical centres in diamond there is very little change in the width, intensity or position of the zero-phonon line for temperatures up to 100 K, but between 100 K and room temperature ($\sim$ 300 K) the effect of temperature is quite considerable. For example the width of the N3 zero-phonon line increases typically by a factor of 3, its intensity decreases by a factor of 2 and its position changes from 415.2 to 415.6 nm.[12] (The N3 centre is discussed in Section 6.1). When an absorption spectrum is plotted as absorption coefficient versus energy the *area* under the zero-phonon line is a measure of its intensity. As a rough approximation we may regard the zero-phonon line as being triangular in shape, and its area is then $\frac{1}{2} \times$ width $\times$ height. Since

the intensity decreases, and the width increases, with increasing temperature, the *height* of the line on the absorption spectrum drops off very considerably at higher temperatures. Many zero-phonon lines vary with temperature more rapidly than the N3 line and are difficult, if not impossible, to measure at room temperature.

From what has been said so far it would seem that the width of a zero-phonon line should be close to zero at low temperatures. In reality this is not so—the lines are typically a few Å wide, although occasionally line-widths less than 1Å may be observed. The origin of this residual line-width is strain broadening.[12] Diamond crystals are not perfect; they contain impurities and have often experienced plastic deformation resulting in a high concentration of dislocations. Dislocations and impurities produce random elastic strains in the crystal which slightly alter the energy of the electronic transition at a particular centre. A cubic millimetre of diamond may contain 10^{14} optical centres of a particular type. On our snooker table analogy the effect of the random strain is to squeeze some colour centres a little nearer to the top of the table and squeeze others a little further away, resulting in a spread of energies for the electronic transition, even at low temperature. As we have seen, nitrogen is the dominant impurity in diamond, and it has been shown that the width of the H3 zero-phonon line increases as the nitrogen content increases,[13] because of the increasing strain.

5.2 *Luminescence*

Thus far in our discussion of vibronic centres we have considered only absorption processes. Suppose that after a time t_1 the glue on ball E in Figure 5 ceases to be sticky and releases the cue ball. The ball will roll back to the bottom cushion releasing energy equal to the electronic excitation energy. This is equivalent to the production of a zero-phonon line in emission (i.e. luminescence) and the time t_1 is called the lifetime of the centre. Suppose now that the glue does not always release cleanly but behaves like some of the 'stringy' adhesives the handyman encounters from time to time. Then as the cue ball rolls back down the table it will occasionally tug on the pack of balls, setting them into vibration, and will be slowed down in the process so that it arrives at the bottom cushion (the ground state) with *less* than the zero-phonon energy. Again this simple picture does not allow us to visualize the exact details of

the luminescence band, but the shape of this can be calculated, using the same assumptions as were used to calculate the absorption band. A typical theoretical luminescence band is shown in Figure 6b, and we notice that it is a mirror image of the absorption band.

The effects of temperature and strain-broadening are virtually the same for the absorption and luminescence bands, and because of coupling to more than one phonon energy the absorption and luminescence spectra will, in general, be more complicated than shown in the simple example in Figure 6. Furthermore, because of a phenomenon called the Jahn-Teller effect, the absorption and luminescence spectra are not usually exact mirror images, and for some optical centres (for example GR1[14]) the departure from mirror symmetry may be considerable.

5.3 *Radiationless Transitions*

In our model described so far each optical centre that has been excited decays after time t_1, giving out luminescence. In practice there are ways in which a centre can decay without producing luminescence. We can envisage this on our snooker table (and here the analogy becomes exceedingly strained) if we suppose that from point M balls are fired off at random, with an average time between successive balls of t_2, with a trajectory such that if the cue ball is in an 'excited state' (i.e. stuck to E) it will be knocked off into the centre pocket at N. From here it must be collected by hand and returned to the bottom cushion; we can define this to be a radiationless transition or non-radiative process (i.e. one that does not produce luminescence). If t_2 is very long compared with t_1, very few cue balls will be knocked into the pocket. For a colour centre in a crystal this would correspond to the situation where most of the energy *absorbed* is re-emitted as luminescence, a process which is described as having high quantum efficiency. If $t_2 = t_1$ the luminescence quantum efficiency would be about 50% and if t_2 is very short compared with t_1 the quantum efficiency would be very low.

Research work on the H3 and N3 centres[13,15] has shown that the smaller the separation between the colour centre and an A-aggregate of nitrogen the smaller is the value of t_2 which determines the probability of non-radiative decay. Increasing concentrations of A-nitrogen in diamond therefore quench the luminescence from

these centres. It is probable, although it has yet to be demonstrated experimentally, that this quenching mechanism operates for all colour centres in diamond.

6. Vibronic Centres—Examples

In this section I shall discuss some of the gemmologically important vibronic centres in diamond, working through the visible spectrum from violet to red.

6.1 *The N3 centre*

The N3 centre is the most common naturally occurring point defect in diamond, and is responsible for the coloration of the vast majority of yellow diamonds. The centre has been investigated for at least 90 years and Davies *et al.*[16] list some of the earlier work although they do not include the important contribution made by Anderson.[17] The absorption spectrum is shown in Figure 7a and the luminescence spectrum is given in Figure 7b and we see that they are classic examples of vibronic spectra, being almost mirror images about the zero-phonon line at 2.985 eV (415.2 nm). On the low energy side of the absorption line there is a weaker series of lines, shown on an expanded scale in Figure 7c, with the most prominent feature at 2.593 eV (478 nm). This is the N2 peak, which correlates in intensity with the N3 band.[16] The N2 line is not, however, a zero-phonon line, and there is no corresponding N2 luminescence.[16] The absorption spectrum in Figure 7 is characteristic of Cape yellow diamonds, and most of the perceived colour is due to the N2 band since the eye is very insensitive at wavelengths less than 400 nm. It has been noted by K. Scarratt and also by G. Bosshart (personal communications) that when strongly absorbing Cape yellow diamonds are examined at low temperature (around 100 K) a series of sharp absorption lines is observed at wavelengths between 420 and 440 nm. Bosshart has determined the wavelength of these lines as 424, 429, 432, 434, 437 and 439 nm.

The currently accepted model for the N3 centre is a triangle of three nearest-neighbour nitrogen atoms, bonded to a common carbon atom.[16] Thus the conditions in nature which favoured the creation of larger nitrogen aggregates in diamond would be expected to have favoured the production of the N3 centre, and there is certainly a tendency for the N3 absorption to be strong in diamonds which have a high concentration of B-nitrogen.[18]

When Cape yellow diamonds are illuminated by a longwave ultraviolet lamp (365 nm) many exhibit bright blue luminescence (the spectrum in Figure 7b was recorded for such a stone). However, as was originally noted by Anderson,[17] there is no relation between the strength of the luminescence and the strength of the absorption band, and the present writer has observed many

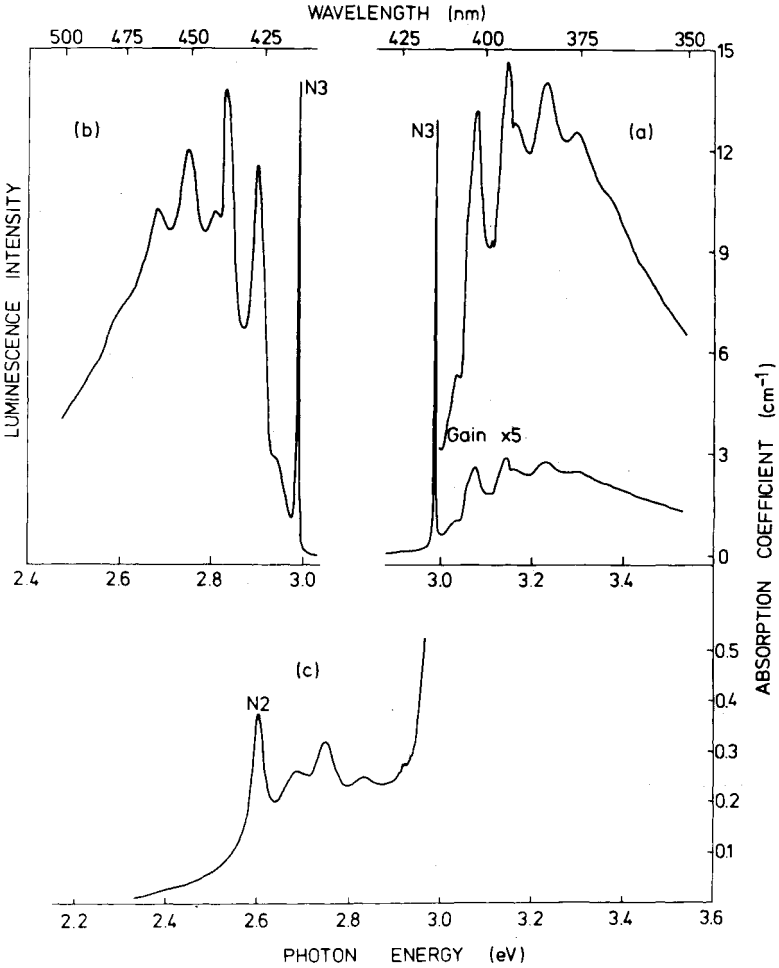

FIG. 7. (a) Absorption spectrum measured for a Cape yellow diamond. (b) Luminescence spectrum for the same diamond. The N3 zero-phonon line in (a) and (b) is indicated. (c) Absorption spectrum in the region of the N2 peak, shown on a vertically expanded scale. All the spectra were recorded at a temperature around 100 K.

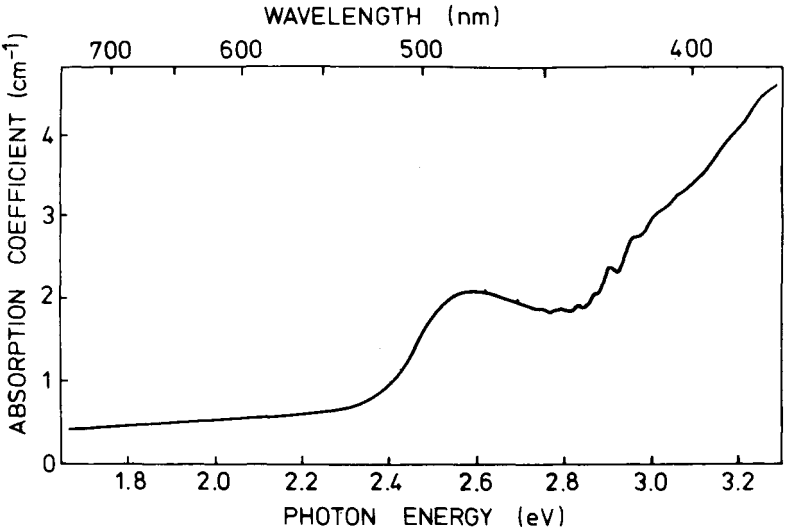

FIG. 8. The 2.6 eV absorption band observed in diamonds which exhibit bright yellow luminescence in long wave ultraviolet.

yellow diamonds which are, to the eye, non-luminescent. An explanation of this phenomenon, already mentioned in Section 5.3, has been given recently by Davies and Thomaz.[15] Luminescence from N3 centres (and probably from all colour centres in diamond) is quenched by high concentrations of A-nitrogen. If two diamonds have the same concentration of N3 centres, with one sample having no nitrogen present in the A-aggregate form and the second having 0.3% A-nitrogen, then Figure 8 from Reference 15 indicates that the luminescence intensity from the first stone will be about 30 times greater than that from the second.

Non-luminescent samples are normally selected for the production of treated yellow diamonds. The resulting yellow colour in this case is predominantly associated with the H3 and H4 bands (Section 6.3), and the green luminescence which would be excited by daylight in strongly luminescing diamonds gives the stones an undesirable appearance (F. Pough, personal communication).

6.2 *The 2.6 eV band*

Some diamonds exhibit bright yellow luminescence when excited with long wave ultraviolet. All such stones examined in the author's laboratory have an absorption spectrum like that shown in

Figure 8. This shows a featureless band, with a peak near 2.6 eV (477 nm) together with an underlying absorption, characteristic of Type Ib diamond (see Figure 4a). Infrared measurements show that the total nitrogen concentration is relatively low (and so the luminescence efficiency is high). Detailed investigations[19] show that the 2.6 eV peak is indeed a vibronic band, but because the coupling between the electronic and vibrational terms is very strong the zero-phonon line cannot be observed, and there are no features on the absorption band. The 2.6 eV band is not, in fact, responsible for the yellow luminescence; absorption of light in the 2.6 eV band produces red luminescence, the emission spectrum being approximately a mirror image of the absorption band.[19] The yellow luminescence appears to be associated with a vibronic band which is too weak to detect by conventional absorption spectroscopy, and which always occurs with the 2.6 eV band.

In white light diamonds with well developed 2.6 eV bands are an attractive amber colour.

6.3 *The H3 and H4 Centres*

When a Type Ia diamond is subjected to radiation damage and then annealed at typically 800 °C we obtain a treated yellow specimen, and the colour is due to absorption in the H3 and/or H4 bands. The H3 centre has a zero-phonon line at 2.463 eV (503.2 nm) and the zero-phonon line of the H4 centre is at 2.499 eV (496.0 nm). Davies has shown that the H3 centre is a vacancy trapped at an A-aggregate of nitrogen and the H4 centre is a vacancy trapped at a B-aggregate.[20] (We shall encounter the vacancy in Section 6.8) Thus in treated diamonds we find H3/H4 = A/B where H3, H4, A and B represent the concentrations of the corresponding defects, as estimated from the absorption spectra. (This relationship has been established using high energy electrons to create the initial radiation damage).

The H3 line is also found naturally-occurring in some diamonds, particularly brown stones, and there is some evidence that naturally-occurring H4 absorption may be observed, but in the author's experience this is very rare. Furthermore the relationship given in the previous paragraph generally does not apply, but instead H3/H4 is very much greater than A/B.[21, 22] If artificially irradiated and annealed diamonds containing predominantly H4 centres are heated to 1500 °C the intensity of the H4 absorption

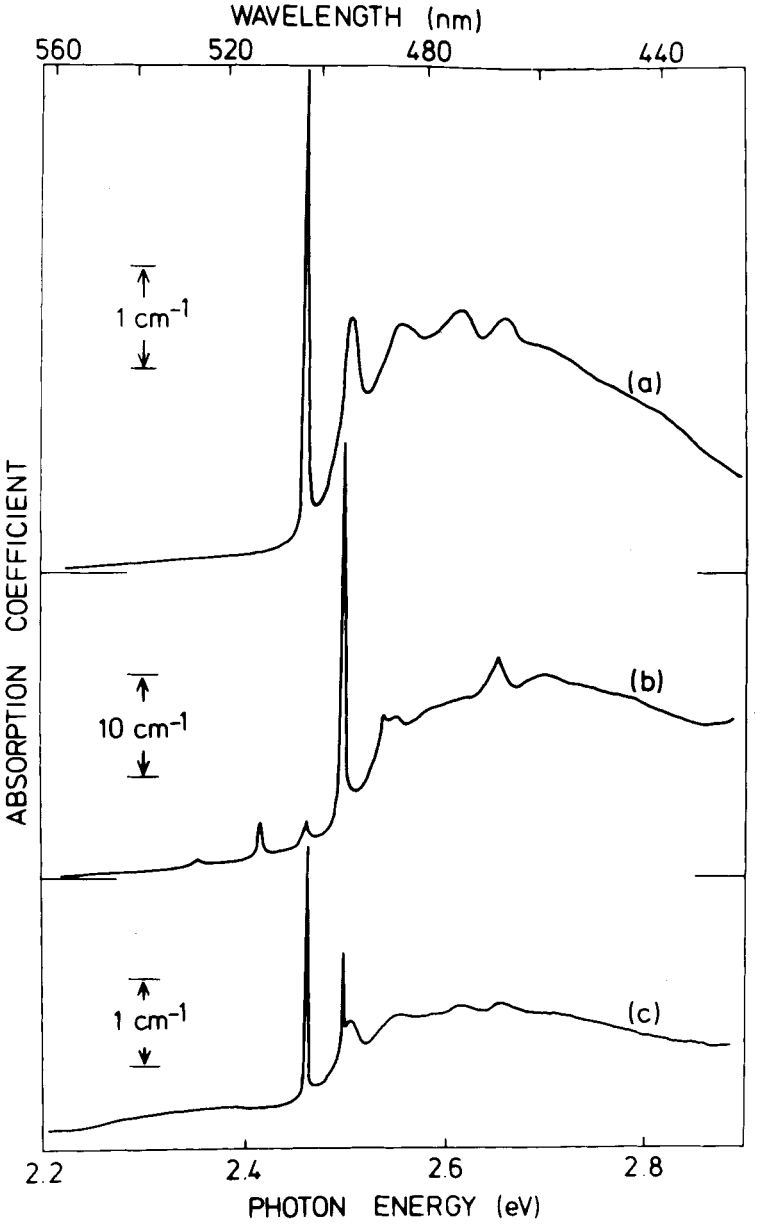

FIG. 9. Absorption spectra recorded at about 100 K for (a) a diamond with naturally-occurring H3 (503 nm) absorption, (b) a treated diamond showing predominantly H4 (496 nm) absorption and (c) a diamond with H3 and H4 absorption—believed to be naturally-occurring.

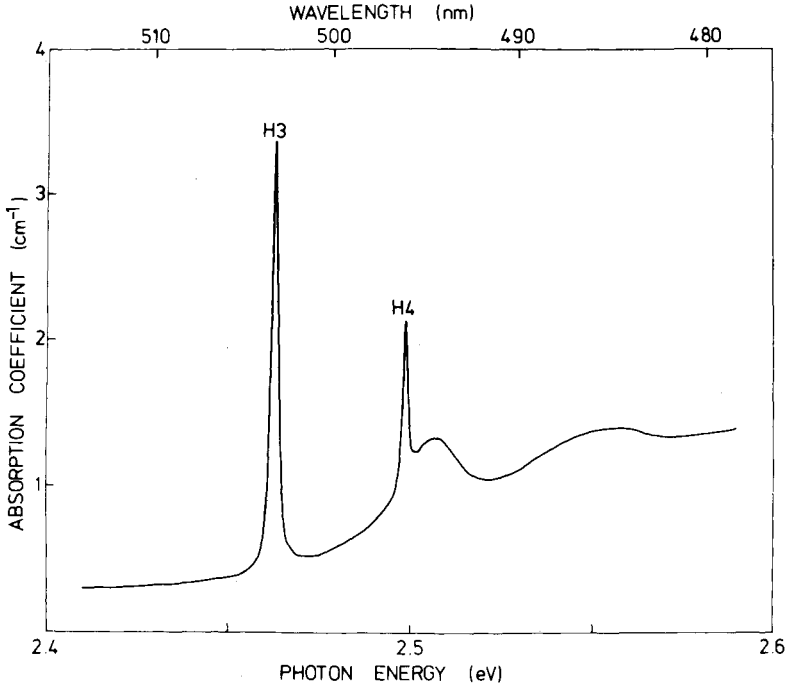

FIG. 10. Absorption spectrum recorded at about 100 K for a diamond with H3 and H4 absorption, shown on an expanded plot. The H3 and H4 zero-phonon lines are labelled, and the latter is seen to be superimposed on the first phonon replica in the H3 band.

decreases and that of the H3 increases to produce a situation more nearly like that observed in nature.[23] Although this observation casts some light on the processes of natural H3 and H4 formation, the heating of valuable gem-quality diamonds to 1500 °C is an exceedingly risky business and it is most unlikely that diamonds treated in this way are currently being used in the gem trade.

In Figure 9 we show the absorption spectra of *(a)* a diamond with a naturally-occurring H3 system, *(b)* a treated diamond showing predominantly the H4 band and *(c)* a stone containing both H3 and H4 centres. Diagrams *(a)* and *(b)* show that the H3 and H4 systems are further examples of typical vibronic bands and we notice from diagram *(c)* that when H3 and H4 centres are present simultaneously in a diamond the H4 zero-phonon line is very close to the peak of the first phonon sideband of the H3 centre. There is unfortunately a considerable amount of misleading

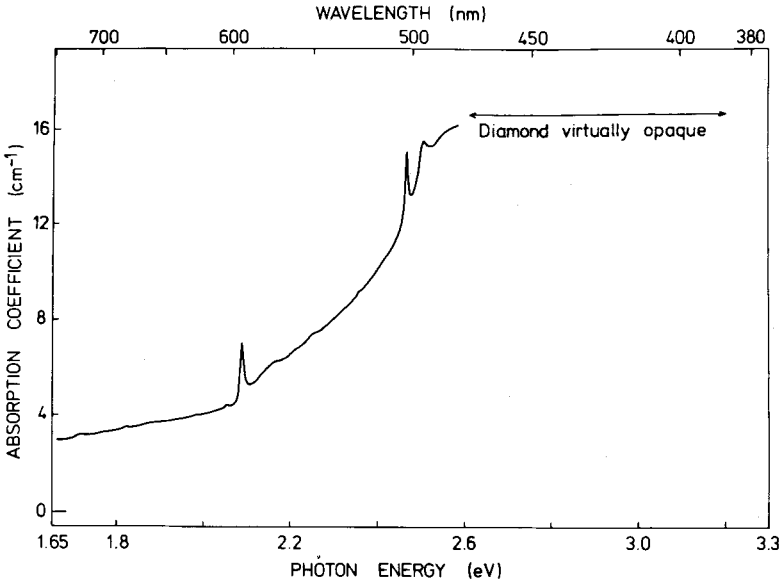

FIG. 11. Absorption spectrum recorded at about 100 K of a heavily irradiated diamond that has been annealed. The stone is virtually opaque at wavelengths less than 490 nm and appears orange in colour. A strong 595 nm (2.086 eV) line is also observed.

information in the gemmological literature about the relative intensities of the 503.2 and 496.0 nm peaks, from which incorrect conclusions have been drawn about the relative H3 and H4 concentrations. It is essential before making such comparisons that the stones are cooled to make the zero-phonon lines as sharp as possible, and that the absorption coefficient is recorded with an instrument capable of fully resolving the narrow lines. Part of Figure 9c is shown expanded in Figure 10 to make this point more clearly.

The diamond for Figure 9a is interesting in that, although it shows only the H3 system, virtually all the nitrogen is in the B-aggregate form. There is therefore very little luminescence quenching by A-nitrogen and the stone exhibits bright green luminescence in white light. The combination of absorption and luminescence gives the sample a 'Vaseline-like' appearance. The diamond for Figure 9c is a particularly important specimen. It was loaned to the author by Basil Anderson who is confident that the stone has not been artificially coloured. We will deal with this specimen again in Section 7.

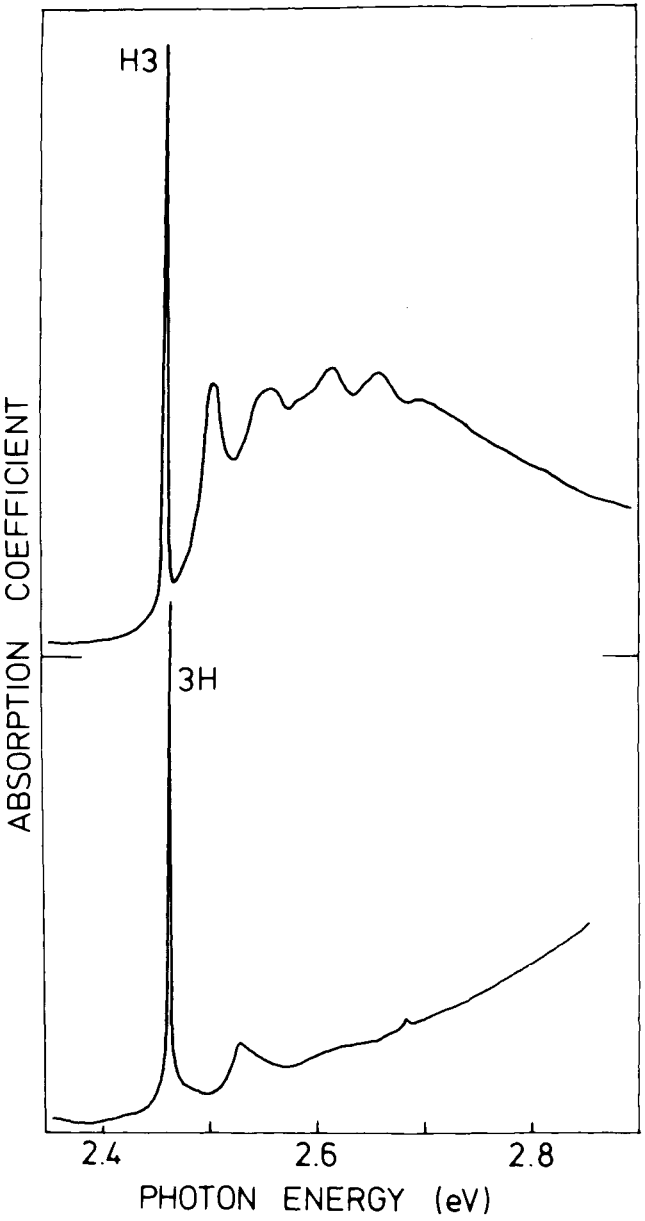

FIG. 12. Comparison of the H3 and 3H absorption spectra recorded about 100 K. Although the zero-phonon lines are at almost the same energy the band shapes are quite different.

When a diamond is very heavily irradiated and then annealed the absorption in the H3 and H4 bands is intense and the stone becomes virtually opaque at wavelengths shorter than about 500 nm. The diamond then acquires an orange colour unlike any naturally-occurring stone (in the author's experience). A typical absorption spectrum is shown in Figure 11.

6.4 *The 3H Centre*

In his pioneering paper on the effects of neutron-radiation damage and annealing Dugdale[24] found that when bombarded stones were heated at 350-400 °C an absorption line at 504 nm appeared in considerable strength, sometimes accompanied by a band at 492 nm (the spectra were measured with the sample at room temperature). After heating to 425 °C these bands vanished completely. However, when the annealing temperature was raised to 700-1000 °C, a line at 504 nm was again observed, sometimes accompanied by a companion line at 497 nm.

We now recognize that the 504 and 497 nm lines obtained after annealing at above 700 °C are the zero-phonon lines of the H3 and H4 bands discussed in the previous section. Davies[25] has shown that the 504 nm line obtained at lower annealing temperatures is the zero-phonon line of a quite different optical centre. Because of the closeness of the two zero-phonon lines it has been suggested that the description 3H should be used for this centre. High resolution spectroscopy shows that the lines occur at slightly different wavelengths (503.2 nm and 503.6 nm for the H3 and 3H lines respectively measured at 77 K) and as shown in Figure 12 the band shapes are quite different.

6.5 *The 595 nm Centre*

When Type Ia diamonds are irradiated and annealed at about 800 °C to produce treated yellow or orange stones (Section 6.3) an absorption band with a zero-phonon line at 595 nm (2.086 eV) is always produced, together with a related line at 425 nm (2.916 eV). These lines are indicated in the absorption spectrum shown in Figure 13. It is only very rarely that the 595 nm line is observed naturally in diamond, and it had been thought that it is never observed in an untreated diamond once it has been cut and polished (B. W. Anderson, personal communication), but see Section 7. Until recently the presence of the 595 nm line in the absorption

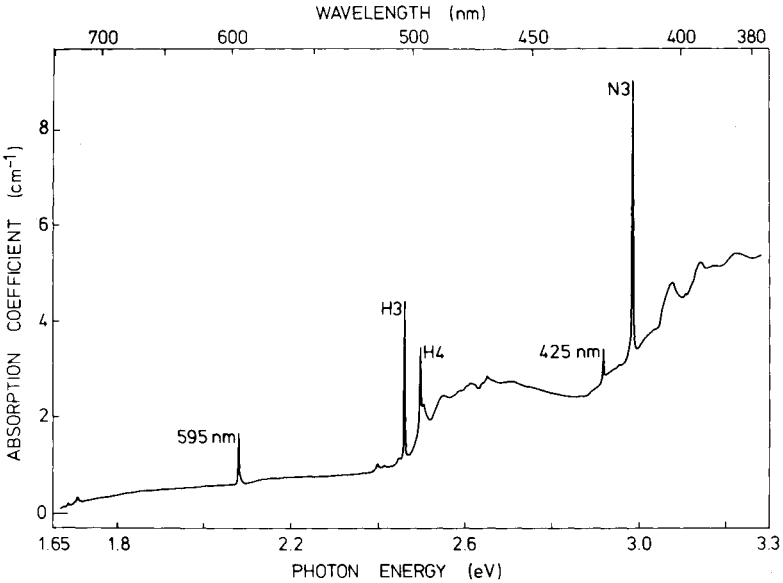

FIG. 13. Absorption spectrum recorded at about 100 K for an irradiated and annealed diamond. The 595 nm (2.086 eV) and related 425 nm (2.916 eV) lines are labelled.

spectrum of a coloured stone was considered as positive proof that the colour was associated with treatment, and, by implication, that if this line were absent then the colour was natural. However, work by the author[26] has shown that if a treated yellow diamond is heated to 1000 °C the 595 nm line is destroyed, without significantly changing the colour of the stone. It is probable that this result has been known for some time by those operators who try to pass off treated diamonds as being naturally coloured. The implications of this in the field of gem testing are considered in Section 7.

6.6 *Natural Pink and Mauve Diamonds*

Raal[27] discovered a broad, featureless absorption band with a peak near 2.2 eV (563 nm) in all natural pink and mauve diamonds, and some brown ones. The pink diamonds have additional peaks at 3.13 and 3.18 eV (396 and 390 nm), and the absorption spectrum of such a stone is shown in Figure 14. Some preliminary work in the author's laboratory has shown that the 2.2 eV peak is a vibronic band. Absorption of light in the high energy part of the band produces red luminescence, and the band

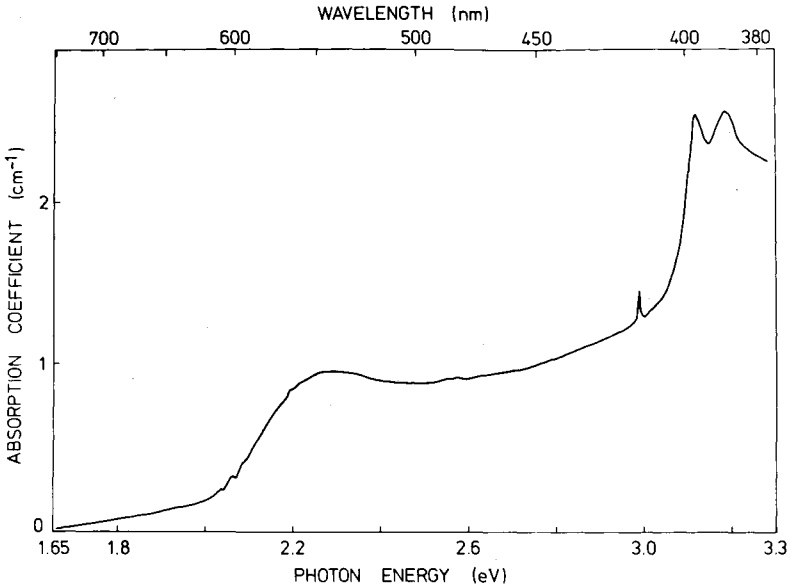

FIG. 14. Absorption spectrum of a natural pink diamond recorded at 77 K.

shape of the luminescence spectrum is approximately a mirror image of the absorption band.

Relatively little is known about the colour centres responsible for the pink and mauve coloration. Diamonds classified as pink are usually Type IIa, while the mauve diamonds contain substantial concentrations of nitrogen and often show N3 absorption features in addition to the broad band at 2.2 eV.[28] The earlier suggestion[27] that the colour is associated with the presence of manganese has been shown to be incorrect.[28, 29]

6.7 *Treated pink diamonds*

If a Type Ib diamond is subjected to radiation damage and then annealed at 700-800 °C an absorption spectrum like that shown in Figure 15 is produced.[28] This is a completely typical vibronic band with a zero-phonon line at 1.945 eV (637 nm). Various other weak zero-phonon lines may also be superimposed on the band, in particular at 2.086, 2.156 and 2.463 eV (595, 575 and 503 nm)—the latter being the H3 line. The relative strength of the 2.156 eV line appears to depend on the annealing conditions.[30] Davies and Hamer[30] have shown that the 1.945 eV

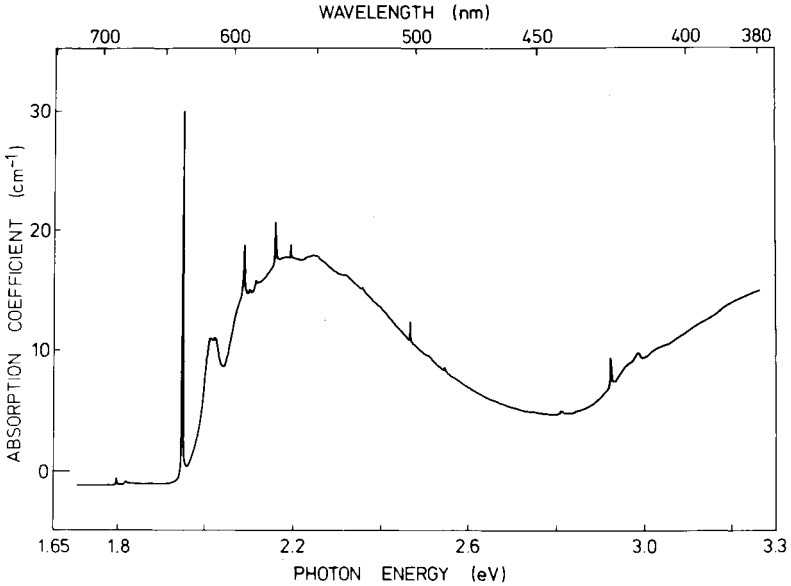

FIG. 15. Absorption spectrum of a 'treated pink' (irradiated and annealed Type Ib) diamond recorded at about 100 K. The zero-phonon line is at 637 nm (1.945 eV).

centre is a vacancy trapped at an isolated substitutional nitrogen atom.

The final colour of the treated stone will depend on the strength of the yellow colour before irradiation and on how heavy an irradiation is used. A pale yellow diamond given a short irradiation produces a pink colour, whilst a longer irradiation gives a mauve colour. The similarity of these colours to the natural pinks and mauves is because the vibronic band of the 1.945 eV centre reaches a maximum near 2.2 eV (compare with Figure 14).

Occasionally naturally-occurring 1.945 eV absorption is observed in Type Ib diamonds. This is not surprising in view of the frequency with which Type Ia diamonds with naturally-occurring H3 absorption are found. In the author's experience, however, the 1.945 eV absorption produced in nature is very weak and makes no significant contribution to the colour of the diamond. A stone which has a good fancy-yellow colour, with the typical Type Ib absorption shown in Figure 4a, can safely be certified as 'not treated' even if there is a weak zero-phonon line at 637 nm in the low temperature spectrum.

6.8 *The GR1 Centre*

The GR1 zero-phonon line at 1.673 eV (741 nm) is the first (i.e. lowest energy) transition produced by the *G*eneral *R*adiation of diamond; it is produced in all types of diamond by all types of radiation damage (neutrons, 1 MeV γ-rays, α-particles and high energy particles—e.g., 2 MeV electrons). Other transitions at the centre give rise to the GR2—8 lines between 2.881 and 3.007 eV (430-412 nm). The effect of the radiation damage is to knock some of the carbon atoms away from their normal lattice position leaving a vacancy. The displaced carbon atoms are pushed into spaces (interstitial positions) in the regular framework of atoms. Although the radiation damage produces equal numbers of vacancies and interstitials, virtually nothing is known about what happens to the interstitial. The GR defect, however, has been positively identified with the vacancy.[31]

The colour of the diamond following irradiation and the detail in the absorption spectra are dependent on the diamond type and the method of irradiation. Some of the important variations are given below.

6.8.1 Electron Irradiation

In Figure 16a we show the absorption spectrum of a Type IIb diamond which has been irradiated with 2 MeV electrons at low temperature, such that during the irradiation the temperature of the sample did not rise above −25 °C. The GR1 vibronic band is very clearly defined, and the GR2—8 transitions at higher energy are well resolved. Most of the absorption is at the red end of the visible spectrum and the sample has a blue coloration.

Figure 16b shows the absorption spectrum of a Type Ia diamond which has also been irradiated with 2 MeV electrons at low temperature. This diamond contains a high concentration of nitrogen in the A-aggregate form, and the effect of this is to broaden all the sharp features in the spectrum. If the diamond is carefully annealed, some sharpening of the structure is observed after heating to 275 °C and after heating to 400 °C the features in the spectrum are almost as well resolved as in Figure 16a. This annealing also causes a reduction in the total band strength.

Diamonds to be coloured commercially are not normally irradiated at low temperature, but the effective temperature during

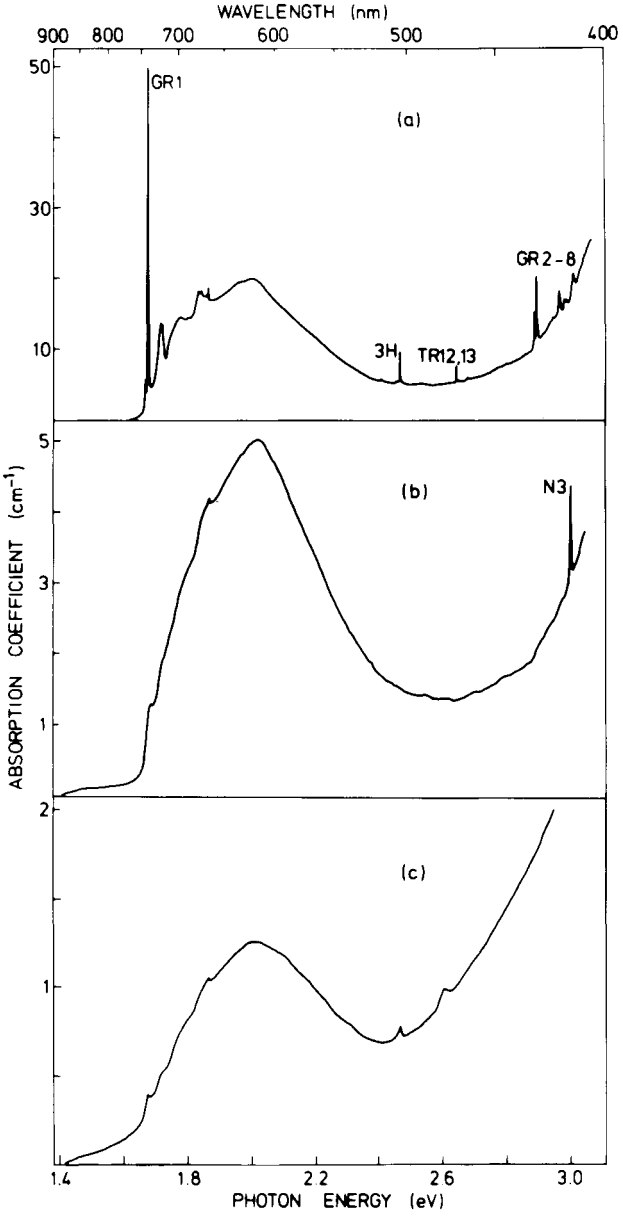

FIG. 16. Absorption spectra recorded at about 100 K for (a) a Type IIb diamond irradiated with 2 MeV electrons at low temperature; (b) a Type IaA diamond irradiated with 2 MeV electrons at low temperature; (c) a Type IaA diamond that has been neutron-irradiated (without cooling). The TR12 and TR13 lines shown in (a) are produced by radiation damage only in Type II stones, and will not normally be observed in gem diamonds.

the irradiation is rarely as high as 400 °C. The absorption spectrum of a treated blue is therefore usually somewhere in between the two extreme cases shown in Figure 16a and 16b. It is also not unusual for some absorption to be present in the 3H band (see Section 6.4).

If a colourless Type Ia diamond is irradiated with electrons the colour obtained is normally blue. However, as it is only off-white (Cape yellow) diamonds that are usually chosen for treatment, the combination of GR absorption with the substantial N2 and N3 absorption results in a blue-green colour.

The penetration depth of 2 MeV electrons in diamond is about 2 mm. Thus although a large diamond might not be coloured all the way through, it is not practicable to polish off the irradiated region.

6.8.2 γ-ray Irradiation

γ-rays of energy around 1 MeV will colour a diamond uniformly throughout, but even with the most powerful radioactive sources available the process is very slow, taking several months. The effective temperature during the irradiation is only slightly above room temperature, and the absorption spectrum of a Type Ia diamond is very similar to Figure 16b.[5] Once again, annealing to about 450 °C results in a sharpening of the features in the spectrum, and a reduction in the total absorption.[5]

6.8.3 Neutron Irradiation

Figure 16c shows the spectrum of a diamond that has been irradiated with fast neutrons in a nuclear reactor. Again we have an almost featureless GR1 band, but there is in addition a continuously increasing background absorption (scanning from low to high photon energies). The total absorption gives the diamond a distinctive green colour, which is uniform throughout the whole diamond. In this case also, annealing to 450 °C results in sharper absorption lines and a reduction in the total absorption in the GR1 band.[5]

Neutrons are almost 2000 times heavier than electrons, and in addition to creating vacancies it is believed that regions of complete disorder are formed as the neutrons tear through the diamond lattice. The continuous background absorption is thought to be associated with the multiply-damaged regions of the diamond.[5]

6.8.4 α-particle Irradiation

The earliest irradiation of diamonds by α-particles was carried out by Crookes[32] who placed diamonds in close contact with radium salts for several months. In addition to colouring the stones green this process imparts a substantial radioactivity to the diamond which persists for at least 50 years.[8] The absorption spectrum of diamonds irradiated in this way is similar to that for neutron-irradiated stones (Figure 16c), because the relatively heavy α-particle creates multiple damage as well as vacancies. The penetration depth of α-particles is, however, only a few μm and the coloured (and radioactive) region of the diamond is easily polished off.

Radiation of diamonds by α-particles is not used commercially because of the unacceptable risk associated with the resulting radioactive diamond. It is interesting, however, that α-particle damage is not uncommon in natural diamond. This may produce a uniform surface-coloration in cases where the stone has been surrounded by an aqueous solution of a radioactive salt, or results in small green spots when the diamond has been in contact with a speck of radioactive ore. Spectroscopic measurements show that the green tinge exhibited by these diamonds is indeed due to the GR1 band. Sometimes the zero-phonon line is well defined whilst in other stones it is virtually impossible to detect. Presumably this is because the diamonds have experienced natural annealing for different times and at different temperatures. Often the radiation spots are brown, rather than green, indicating that such diamonds have been subjected to temperatures above 500 °C after (or simultaneously with) the α-particle damage (see Section 6.8.6). In all cases the colour is only skin deep and is easily polished off.

6.8.5 Natural Green Diamonds

In addition to the 'green-skinned' diamonds described in the previous section, diamonds are occasionally found which have a *uniform* bottle-green coloration.[33] There are no spectra described in the literature for such diamonds, and the writer has not had the opportunity to examine any stones of this type. In view of the fact that diamonds with uniform absorption caused by H3 centres are found from time to time (Section 6.3, Figure 9a) it is possible that diamonds with uniform, natural, GR1 absorption exist, and these would have a green colour. It would be of considerable help in the

understanding of naturally-occurring colour centres if absorption spectra could be obtained for green diamonds of the type described.

6.8.6 Annealing of Radiation Damage

The way in which radiation damage anneals depends to some extent on the diamond type. Temperatures quoted are therefore only examples. At about 500 °C some of the vacancies become mobile and are trapped by one or more of the forms of nitrogen to form H3, H4 or 1.945 eV centres (Sections 6.3 and 6.7). As the temperature is increased from 500 to 800 °C the strength of the GR1 band continuously decreases to zero, and the strength of the H3, H4 or 1.945 eV absorption continuously increases to reach a maximum value. (See, for example, Figure 1 of Reference 26). During this annealing the colour of the diamond changes from blue or green to yellow, brown, orange, pink or mauve depending on the end product and on how strongly the diamond is absorbing. During the production of a treated diamond the annealing need not necessarily be taken to completion, and, for example, the GR lines and the H3 and H4 lines may be present simultaneously.

6.9 *Brown Diamonds*

Some diamonds have a featureless absorption spectrum which continuously increases in strength from the red end to the blue end of the visible spectrum. Such diamonds are often, though not necessarily, Type IIa. The absorption gives the diamond a brown colour. X-ray measurements show that these diamonds have been subjected to severe plastic deformation[33] but it is not clear how this is related to the absorption observed. Many brown diamonds exhibit, in addition, some absorption in the 2.2 eV band characteristic of natural pink/mauve stones (Section 6.6) and some brown Type I diamonds have naturally-occurring H3 absorption, sometimes in considerable strength.

6.10 *Miscellaneous Absorption Lines*

In addition to the major colour centres already described in this article numerous other lines may be observed from time to time in spectroscopic tests on diamonds, although none is normally present in sufficient strength to appreciably affect the colour of a stone. A significant number of brown diamonds luminesce pink in

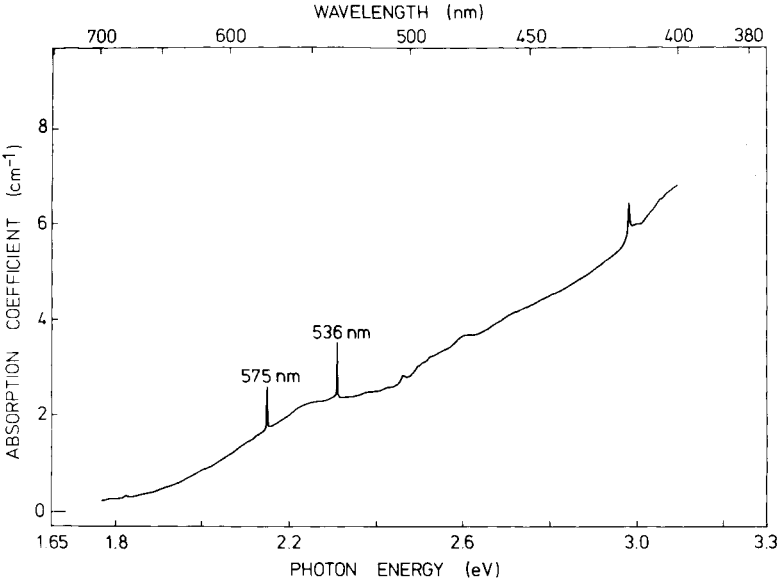

FIG. 17. Absorption spectrum recorded at about 100 K for a brown diamond with absorption lines at 575 and 536 nm. (2.156 and 2.312 eV). This stone showed pink luminescence in long-wave ultraviolet.

long-wave ultraviolet. The pink colour is often caused by emission in the band associated with the zero-phonon line at 575 nm (2.156 eV), and in some diamonds this line may be seen in absorption. A typical absorption spectrum is shown in Figure 17, and this illustrates our observation, on a limited number of samples, that when naturally-occurring absorption at 575 nm is detected a line at 536 nm is frequently present as well. This latter absorption line is also observed in some brown diamonds which have naturally-occurring H3 absorption,[34] and Anderson has previously noted that diamonds showing 575 nm luminescence may also display an emission line at 536 nm.[34] The only report in the literature regarding formation in the laboratory of the colour centre which gives rise to the 536 nm absorption line suggests that very high temperatures (around 1500 °C) are required.[23] In nature, more modest temperatures for much longer time periods would also be effective.

Finally it is worth recording that in a recent survey of rough diamonds we have observed weak absorption lines at 432, 440, 473 and 561 nm (measured at about 100 K) in several diamonds, and a

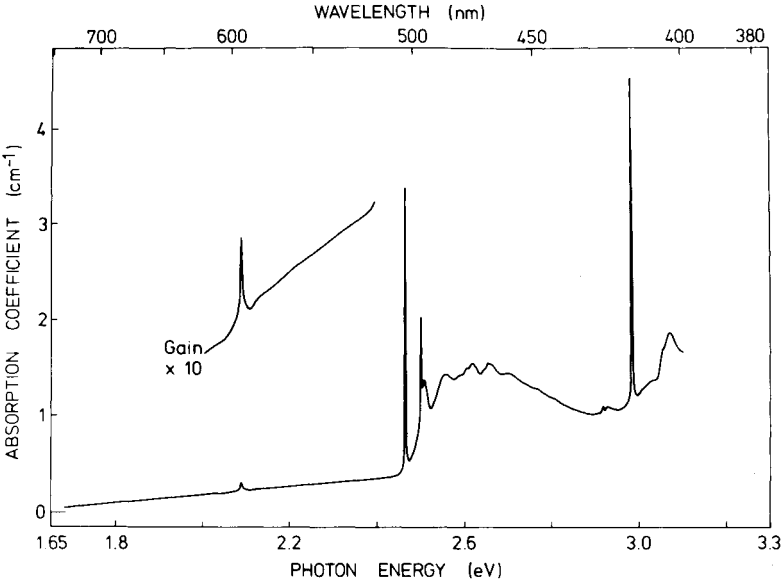

FIG. 18. Absorption spectrum recorded at about 100 K, shown over the whole visible spectral region, for a diamond believed to be naturally coloured.

number of other sharp lines have been noted just once. Other laboratories can no doubt add to the list of miscellaneous absorption lines. Many more sharp lines may be observed using luminescence techniques, but these have little significance in the field of gem testing.

7. THE FUTURE OF DIAMOND GEM-TESTING

Gem testing laboratories are frequently required to determine whether a particular diamond owes its colour to treatment. In many cases the diamond in question will be yellow or brown, and it is here that the situation is most confused.

In Figure 18 we show the full absorption spectrum for an old-cut yellow-green diamond which was loaned to the author by Basil Anderson. The H3 and H4 lines are both present (see Figures 9(c) and 10 for detail) as well as the 595 nm (2.086 eV) line characteristic of treatment (Section 6.5). This is one of few gem diamonds for which measurement in the 7-10 μm infrared region is possible, and this shows that the A/B ratio is the same as the H3/H4 ratio (see Section 6.3). The absorption spectra of this stone,

then, are *entirely characteristic* of a Cape yellow diamond that has been artificially coloured. However, Anderson's records show that the diamond was purchased in 1948, many years before artificial colouring of gem diamonds became fashionable. The colour is a body colour, and there is no radioactivity, so there is no question of this being a diamond artificially coloured by α-particles. Furthermore, part of the girdle on this stone has not been polished—it is still the original diamond surface—and this shows the brown markings characteristic of natural radiation damage. Similar surface markings are present on a number of uncut stones in the author's possession in which the natural H3 absorption is comparable in strength with that shown in Figure 17.

The only respect in which this diamond differs from a conventional treated diamond is that, because the A-nitrogen concentration is low, the diamond is strongly green fluorescent in daylight. As noted in Section 6.1 fluorescent diamonds are not nowadays selected for treatment.

Diamonds with moderately strong, naturally occurring, absorption in the H3 and H4 bands present a puzzle to physicists and a dilemma to gemmologists. Although the formation of a 'green skin' on diamonds due to α-particle damage is well understood (Section 6.8.4), the bulk coloration of a diamond by natural radiation damage seems improbable because of the very high flux of energetic (i.e. 1 MeV or greater) γ-rays that would be required. And yet, as already noted, many samples show the small brown circular patches on the surface that are usually attributed to natural radiation damage.

Anderson's diamond is the only polished stone in which I have observed naturally-occurring H4 absorption (Figures 9(c) and 10) and 595 nm absorption (Figure 18), although these two lines have been found together in two rough diamonds examined in this laboratory. The absorption in these rough diamonds was much less intense than in Anderson's stone, but if, as the records indicate, that specimen is naturally coloured, how does the gemmologist assess another diamond with a similar absorption spectrum? Take, for example, the spectrum of the diamond shown in Figure 19(a). This is plotted as percentage transmission and shows 'very strong' absorption in the H3 and H4 bands. This particular stone weighed almost 40 carats, and the path length of the light in the diamond was 11.55 mm; if the spectrum is plotted properly as absorption

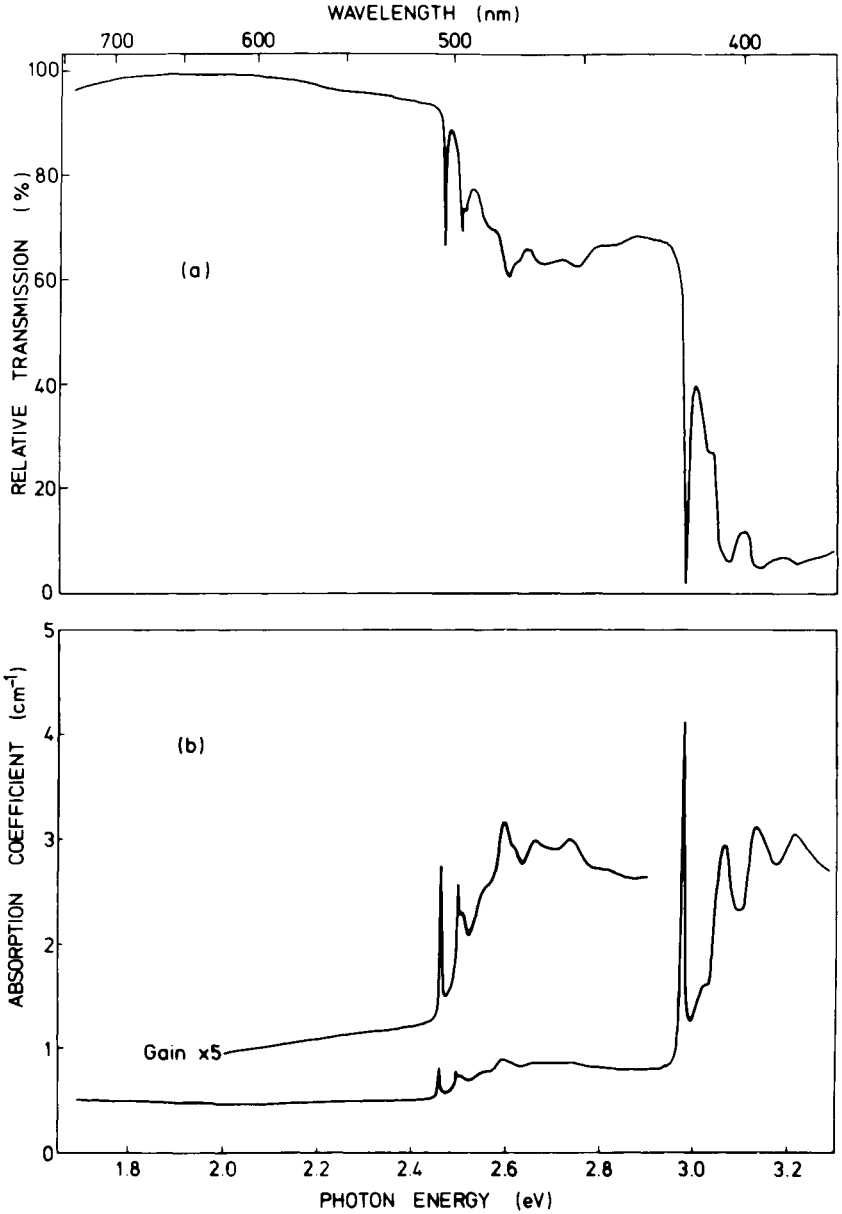

FIG. 19. Spectra recorded for a 40 carat diamond cooled to about 100 K plotted as (a) percentage transmission and (b) absorption coefficient. The path length of the light in the diamond was 11.55 mm.

coefficient (Figure 19(b)) then we see that the H3 and H4 bands are, in fact, considerably weaker than in Anderson's stone. Furthermore, there is no hint of an absorption peak at 595 nm, and so if the colour is indeed due to treatment, whoever carried it out must have heated the stone to at least 1000 °C (see Section 6.5). With such a valuable diamond this would have required very considerable courage. Unfortunately the diamond was far too large to obtain any data about the A to B nitrogen ratio in the 7-10 μm infrared spectral region.

I am inclined to believe that this particular diamond is naturally coloured, but what emerges from this article is that, with the present state of knowledge, no one can decide with certainty from the spectroscopic tests described whether such a diamond is treated.

8. Summary

I have described the prominent absorption bands responsible for the colours of many natural and treated diamonds, but there will doubtless be some stones whose colour is not accounted for. I have presented a picturesque treatment of the band shapes and explained why it is necessary to make measurements at high spectroscopic resolution with the diamond at low temperature. I have emphasized that sensible conclusions about whether a diamond has been treated can only be reached by measuring the absorption coefficient, rather than the percentage transmission, and that even then there will be cases where doubt remains. Some of the puzzles about naturally coloured stones may be resolved by further detailed spectroscopic study, particularly of uniformly green diamonds and those with strong H3 and H4 (503 and 496 nm) bands.

Acknowledgements

I am grateful to Mr Basil Anderson and Mr Roy Huddlestone for the loan of coloured diamonds and to Mr Khalid Mohammed for obtaining the data for Figures 8 & 14 and carrying out the calculations for Figure 6. I have had interesting discussions on the topic of coloured diamonds with Mr Kenneth Scarratt and Mr George Bosshart, and I am grateful to them and Mr Anderson for their comments on the first draft of this paper.

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[*Manuscript received 25th June, 1981.*]

GEMMOLOGICAL ABSTRACTS

ANDERSON (B. W.). *The development of synthetic emeralds.* Gem World, **8**, 4, 38-42, 1981.

A review of synthetic emerald is given with notes of some recent productions. (Article first appeared in Retail Jeweller, date not given.) M.O'D.

ANDERSON (C. O.), HUTTON (D. R.), TROUP (G. J.). *Magnetic resonance distinction between synthetic and natural blue sapphire.* Aust. Gemmol., **14**, 5, 87-9, 3 figs, 1981.

An attempt to identify blue sapphire by a complex test. Depends on Cr^{3+} being added in small quantities to synthetic production to aid nucleation of iron and Ti^{4+} impurities which give the colour. This is detectable in magnetic resonance spectra but is fallible if Cr^{3+} is present in the natural stone. 'Forbidden' lines seen when tested parallel to trigonal axis seem to be more conclusive. R.K.M.

BADZIAN (A. R.), KLOKOCKI (A.). *On the catalytic growth of synthetic diamonds.* Journal of Crystal Growth, **52**, 843-7, 2 figs, 1981.

Diamond crystals grown with cobalt and nickel were studied by x-ray diffraction methods. Inclusions of metastable cobalt or nickel carbides were the commonest inclusions. It is thought that the metal atoms are located in the octahedral holes of the structure, which suggests that they play a part in nucleation and crystallization. M.O'D.

BANK (H.). *Erzminerale als Edelsteine.* (Ore minerals as gemstones.) Z.Dt.Gemmol.Ges., **30**, 2, 71-89, 36 colour photographs, extensive bibl., 1981.

Ore minerals are described which have become known as gemstones. Some are important gemstones, such as corundum, quartz, malachite and rhodonite, while others are collectors' items. The article is dedicated to Prof. Dr P. Ramdohr, who is celebrating his 90th birthday and on whose early work Dr Bank has based this work. The minerals are listed according to their chemical formula and include sulphides (sphalerite, marcasite, pyrites, proustite), halogenides (fluorite), oxides (cuprite, zincite, gahnite, magnetite, haematite, corundum, rutile, anatase, quartz), carbonates (siderite, rhodochrosite, smithsonite, witherite, cerussite, azurite, malachite), sulphates (anglesite and barytes), wolframite (scheelite), molybdate (wulfenite) and silicates (rhodonite, pyroxene mangite and willemite). E.S.

BANK (H.). *Gemmologische Untersuchungsmethoden und ihre sinnvolle Verwendung.* (Gemmological investigation methods and their intelligent use.) Z.Dt.Gemmol.Ges., **30**, 2, 90-4, 1 fig., 1981.

The different steps of a gemmological examination, which do not destroy the material to be investigated, are described, using polariscope, refractometer, microscope, spectroscope, UV lamp, colour filter. Most features which can be examined by the use of polariscope and microscope are listed. E.S.

BANK (H.). *Über die Lichtbrechung und Farbe von Topasen, speziell geschliffener Topase vom Schneckenstein, Sachsen.* (On the refractive index and colour of topaz, especially cut topaz from Schneckenstein in Saxony.) Z.Dt.Gemmol.Ges., **30**, 2, 98-100, 2 colour figs, bibl., 1981.

The well-known topazes from Schneckenstein in Saxony in the Democratic Republic (East Germany) are mainly faintly yellow and possess higher refractive indices than generally mentioned for them and lower ones than given for yellow topaz from other localities. Besides colours, refractive indices and birefringence of topaz in general are listed. E.S.

BANK (H.). (a) *Avanturisierender Beryll aus Norwegen.* (Aventurine beryl from Norway.) Z.Dt.Gemmol.Ges., **30**, 2, 107-8, 1981; (b) *Irisierender Aragonit aus Kanada.* (Iridescent aragonite from Canada.) Id., 109-11, 3 figs in colour, 1981; (c) *Zur gemmologischen Diagnostik: Topas für Spinell gehalten.* (Gemmological diagnosis: topaz mistaken for spinel.) Id., 114-15, 1981; (d) *Mit synthetischem Smaragd überzogene Berylle für Dubletten angesehen—eine Nomenklaturfrage.* (Synthetic emerald coated beryl diagnosed as doublet: a question of nomenclature.) Id., 118-19, 1981.

(a) The aventurism in the beryl from Norway is caused by inclusions of haematite. The author also mentions star beryls which owe their asterism to inclusions of needle-like crystals. (b) The iridescent aragonites described are recovered from fossil upper cretaceous ammonites. Some doublets and triplets are made of this material. (c) Reports on a colourless topaz taken to be a colourless natural spinel and explains how dangerous it is to make a diagnosis without instruments and how easy it is to distinguish gemmologically between the two minerals. (d) A case where a coated beryl was diagnosed as a doublet since the synthetic material had been polished off and thus different RIs had been obtained from table and back. It is a question of nomenclature as to whether coated stones should be called doublets or triplets. E.S.

BANK (H.) and (F. H.). *Beim Erhitzen milchig-trüb gewordener Rosaturmalin mit ungewöhnlich niedriger Lichtbrechung.* (Rose-coloured tourmaline became milky-opaque when heat-treated, with unusually low refractive index.) Z.Dt.Gemmol.Ges., **30**, 2, 116-17, 1 fig. in colour, 1981.

Pink tourmalines heated to 900 °C became milky, less intense in colour, and showed RI as low as 1.605 for the extraordinary, 1.620 for the ordinary ray and 1.608 and 1.623 respectively. X-ray analysis proved that they were still tourmalines. E.S.

BANK (H.), BECKER (G.). *Synthetischer rosa-farbener Beryll.* (Synthetic pink beryl.) Z.Dt.Gemmol.Ges., **30**, 2, 112-13, 1 fig. in colour, 1981.

A new synthetic pink beryl is described, probably produced hydrothermally. E.S.

BROWN (G.). *An evaluation of the Snow pocket polariscope.* Aust. Gemmol., **14**, 5, 90-1, 2 figs, 1981.

Describes and assesses a useful folding self-illuminating polariscope. R.K.M.

BROWN (G.). *An evaluation of the Snow dichroscope.* Aust. Gemmol., **14,** 5, 97-9, 3 figs, 1981.

A new type of dichroscope employing polaroid and achieving two images of a single aperture by using a pentagonal prism combined with the cross-orientated polaroids to refract images to the viewing lens. Approved. R.K.M.

BROWN (G.). *Gemmology study club report: examination of a fossil pearl.* Aust. Gemmol., **14,** 6, 131-4, 5 figs,* 1981.

A report on a fossil Pinna from Cretaceous shales in Kansas. The optical nature of the pearl was found to be different from that of a present-day pinctada pearl. [After 150 million years this should not cause surprise.] R.K.M.

BROWN (G.), MAIN (P.), RICHARDS (P.), SNOW (J.), TAYLOR (B.). *An evaluation of the Gemlusta reflectometer. Part 1.* Aust. Gemmol., **14,** 6, 120-6, 7 figs,* 1981.

An evaluation of a rather complex dual-range infrared reflectometer giving an electronic LED numerical read-out. Trouble experienced with switch leading to disparate readings for the one stone. Usefulness of the lower range questioned. The imposition of an arbitrary scale which is the same for both ranges seems very confusing. [Lustre, whether of visible wavelengths or infrared is not usually numerically identified.] R.K.M.

BROWN (G.), SNOW (J.). *Examination of two Iimori imitations.* Aust. Gemmol., **14,** 5, 100-5, 4 figs, 1981.

Victoria-stone, a chatoyant nephrite-like imitation material, and Meta-Hisui, an imitation jade, were examined. Described as attractive partially devitrified glasses. SG 3.00 and 2.80, and RI 1.61 and 1.50 respectively; H 6 for both glasses. R.K.M.

BROWN (G.), SNOW (J.). *Examination of a prehnite cat's-eye.* Aust. Gemmol., **14,** 5, 93-4, 3 figs, 1981.

A 9.68 carat greenish-yellow cabochon of prehnite from Prospect, N.S.W., exhibited chatoyancy. H 6 to 7; SG 3.00; RI 1.62; no fluorescence or usable absorption spectrum. R.K.M.

BROWN (G.), SNOW (J.). *Some observations on goldstone.* Aust. Gemmol., **14,** 6, 139-40, 1 fig, 1981.

Observations, generally what one would expect of a crown glass, conclude that the many millions of copper particles in each specimen are 'prefabricated . . . machined and not crystalline'. [This is nonsense, on the score of cost, if no other.] R.K.M.

BUKIN (G. V.), MATROSOV (V. N.). *Growth of alexandrite crystals and investigation of their properties.* J. Crystal Growth, **52,** 537-41, 5 figs, 1981.

Crystals up to 120 mm long and 20 mm in diameter have been grown by the Czochralski method in an inert gas atmosphere in iridium crucibles. A narrow line at 645.5 nm was observed in both the absorption and excitation spectra. It is attributed

*Fig. 3 in these two papers is transposed.

to Cr^{3+} ions and may be due to the phonon-free electron transition in the U-band. This particular effect has not been previously noted from any other crystals doped with Cr^{3+} ions. M.O'D.

DAHANAYAKE (K.). *Modes of occurrence and provenance of gemstones of Sri Lanka.* Min. Deposita, **15**, 81-6, 2 figs, 1980.

The dominant gemstones mined in Sri Lanka are blue sapphires, ruby, and beryl, associated with eluvial, residual, and alluvial sediments. Source rocks are garnetiferous and cordierite gneisses, marbles, and pegmatites. L.G.L.

DRESCHHOFF (G. A. M.), ZELLER (E. J.). *Identification markings for gemstones.* U.K. Patent Application GB 2047215A, filed 18th April 1979, published 26th November, 1980.

The patent describes a new method for producing permanent identification markings within a gemstone by means of proton bombardment, such markings not being visible to the naked eye. A metal template or stencil mask is placed between the gemstone and the proton source to produce a pattern of radiation in the form of numbers or letters, and the gemstone is cooled to confine the resulting crystal lattice reaction to a closely defined plane and to a depth beneath the stone's surface which is a function of the proton beam energy level. The markings produced in this way are claimed to be stable, permanent and ineradicable. When used to print an identification code beneath the surface of a diamond, the irradiated areas are converted to amorphous carbon by the proton beam. In this application, the energy level of the proton beam is within the range of 0.25 MeV to 4 MeV, and the diamond is cooled to the temperature of liquid nitrogen during irradiation. P.G.R.

GÜBELIN (E.). *Die Eigenschaften der undurchsichtigen Schmucksteine und deren gemmologische Bestimmung.* (The properties of non-transparent gemstones and their gemmological determination.) Z.Dt.Gemmol.Ges., **30**, 1, 3-61, 1981.

The whole issue is devoted to Dr Gübelin's excellent survey of non-transparent gemstones. He first discusses colour, density and hardness, and follows this with detailed tabulated descriptions of streak colours. After mentioning acid spot tests, the author lists the most important absorption lines and goes on to dichroism, double refraction, luminescence and fluorescence (table). Microscopic examination is shortly touched on. Possibly the most helpful table lists the stones, their description, RI, density, hardness, peculiarities, occurrences and remarks, subdivided into white/black, yellow/brown, pink/red, blue/violet, and green groups with special sub-tables dealing with jade minerals, jade-like minerals (mainly green), and serpentine group stones.

Another interesting table lists turquoise and sixteen of its simulants, again with description, composition, RI, density, hardness, spectrum and helpful hints for each item. Finally there is a table ennumerating multi-coloured gemstones with their description and properties. E.S.

LIPINSKY (A.). *Archeogemmologia: proposta di una nuova scienzia sussidaria per l'archeologia e la storia dell'arte della gioielleria.* (Archeogemmology: a proposal for a new science subsidiary to archeology and the history of the jeweller's art.) La Gemmologia, **6**, 1/2, 7-40, 1980.

The argument is put forward that the study of gemstones can be a useful adjunct to the work of the archaeologist and the art historian. Numerous examples are given, with some liguistic notes, of the ways in which such a separate science might operate. M.O'D.

MANUTCHEHR-DANAI (M.). *Faustit in der Türkislagerstätte von Neyschabour (Iran) in Zusammenhang mit der Frage der Türkisbildung.* (Faustite in the turquoise occurrences in Nishapur in Iran in relation to the question of the formation of turquoise.) Z.Dt.Gemmol.Ges., **30**, 2, 95-7, bibl., 1981.

A description of turquoise-faustite isomorphic mixed crystals is presented together with a discussion of their formation as a weathering product (of vulcanic trachyte). X-ray investigation allows distinction from similar material. E.S.

NOTTES (G.). *Eine Reise zu den Smaragd-Gruben Kolumbiens.* (A journey to the Colombian emerald mines.) Aufschluss, **32**, 325-34, 7 figs (3 in colour), 1981.

The present state of emerald mining in Colombia is described with a map of the main working areas. M.O'D.

O'DONOGHUE (M.). *Alcuni sviluppi nella produzione di materiali di interesse gemmologico.* (Further developments in the production of gemmologically interesting materials.) La Gemmologia, **6**, 1/2, 41-4, 1980.

Recent developments in the field of man-made crystals are reviewed with particular reference to those of ornamental interest. (Author's abstract) M.O'D.

O'DONOGHUE (M. J.). *Man-made gems—what next.* Aust. Gemmol., **14**, 5, 106-8, 1981.

Discusses present synthetics and man-made materials and possible further developments in this field, rather optimistically. R.K.M.

O'DONOGHUE (M.). *Man-made crystals and the gemmologist: some recent developments.* British Association for Crystal Growth Newsletter, pp 3-4, April 1981.

Some of the more recent man-made gemstones are reviewed, including coloured varieties of beryl made in Japan, opal and cubic zirconia.

(Author's abstract) M.O'D.

PASTERNAK (L. B.), SEVASTYANOV (B. K.), OREKHOVA (V. P.), REMIGAILO (Yu L.). *Growth and light induced colour centres in crystals of yttrium aluminium garnet doped with Cr^{3+} ions.* J. Crystal Growth, **52**, 546-51, 6 figs, 1981.

The absorption spectrum of growth induced colour centred YAG:Cr shows bands at 285, 310, 335, and 446 nm. Annealing in a hydrogen atmosphere destroys those at 446 and 335 nm. In the absorption spectrum of light-induced colour centred YAG:Cr are bands at 380 and 480 nm. Both these and the bands in the GCC YAG crystals are removed on annealing in an oxidation atmosphere. M.O'D

PERNER (B.), KVAPIL (Ji.), KVAPIL (Jo.), PLESTIL (Z.). *The influence of protective atmosphere on the growth of ruby single crystals by Czochralski method.* J. Crystal Growth, **52,** 552-5, 4 figs, 1981.

The purity of an inert gas used to prevent chemical reactions between crucible and heater when ruby is grown by the Czochralski process must be at least 5N. Optical quality of crystals grown in He is higher than that of crystals grown in Ar.

M.O'D.

READ (P.). *Sri Lanka, island of gems.* Gems, **13,** 4, 22-5, 8 figs (7 in colour), 1981.

The gem mining industry of Sri Lanka is reviewed and the major gem species discussed. The construction of an irrigation reservoir may assist in the discovery of further gem material. M.O'D.

ROBERTSON (A. D.). *Chrysocolla 'a little known gemstone'.* Aust. Gemmol., **14,** 6, 127-9, 1981.

Author confirms known fact that this is a mineral variable in composition, water content, colour and constants. Colours generally due to copper but varied by many impurities. R.K.M.

SAHAMA (T. G.). *Growth structure of Ceylon zircon.* Bulletin de Minéralogie, **104,** 89-94, 7 figs, 1981.

Prismatic zircon crystals 1-2 cm long, from the gem-bearing gravels of the Ratnapura area, SW Sri Lanka, show concentric growth structures. These growth bands do not represent normal chemical zoning but reflect a variation in the degree of radiation damage. Detailed electron probe, optical, and density determinations on a polished {100} face gave an empirical equation: $D = 4.078 + (10.678 \times \text{birefringence})$. There is also a negative correlation between the UO_3 content and the birefringence. In some crystals the density decreases from core to margin, others show the opposite trend. The variation within a single crystal is due apparently to irregularity in the convective flow of the crystallizing medium.

R.A.H.

STEINERT (H.). *Die Einschlüsse der Granate Schwedens.* (Inclusions in garnets found in Sweden.) Z.Dt.Gemmol.Ges., **30,** 2, 101-6, 1981.

The inclusions in garnets from Swedish river sands were investigated for a further development of the sedimentiological methods of heavy mineral analysis. With the investigation of 60 samples from all the larger rivers, a general survey of inclusion types was developed. The wide variety of inclusions, which were found during these preliminary investigations, show also some inclusions new to garnet, such as zoisites, tremolites and tourmalines. Distinct new mineral associations of inclusions were found. Rutile was seen in numerous forms. E.S.

STOTT (C. R.). *How it works—the Stott dichroscope.* Aust. Gemmol., **14,** 5, 85-6, 5 figs, 1981.

Describes an ingenious dichroscope using two pieces of polaroid immediately behind a convex lens with a central section removed. This cut lens gives two images of the single aperture and obviates the need to compare two different parts of the specimen when testing for dichroism. R.K.M.

TAKAGI (K.), OI (T.), FUKAZAWA (T.). *Growth of high purity $ZnWO_4$ single crystals.* J. Crystal Growth, **52**, 580-3, 4 figs, 1981.

Zinc tungstate (the mineral sanmartinite) can be grown as transparent single crystals using the Czochralski technique. Easy cleavage limits a possible ornamental application. M.O'D.

THOMPSON (W. H.). *Determination of the maximum and minimum refractive indices of a gemstone.* Aust. Gemmol., **14**, 6, 142-3, 1981.

Part of a paper which appeared in the May 1980 issue but which was omitted. Appeals for specimens which do not yield their full birefringence when tested by refractometer on a single facet. And a note makes clear the fact that the refractometer tests a stone in a direction parallel to the tested surface and to the optical path of the instrument. R.K.M.

TOWNER (J. M.). *Sapphires and gold.* Lapidary Journal, **35**, 3, 640-4, 13 figs (9 in colour), 1981.

An account of working for sapphire in Montana. M.O'D.

TROUP (G. J.). *Letter to the Editor.* Aust. Gemmol., **14**, 6, 141, 1981.

Dr Troup records that synthetic alexandrite has highly desirable laser properties and predicts that this material will inevitably become more available to the gem market. Its absorption spectrum should give sharp chromium (Cr^{3+}) lines and no Fe^{3+} lines. Material should be very clean and will need microscope and other tests to identify it. [Transparency to UV light?] R.K.M.

ZECCHINI (P.), MÉRIGOUX (H.). *Étude de l'absorption infrarouge des quartz hyalin et colorés, naturels ou de synthèse: application à la gemmologie.* (Study of the infrared absorption of colourless and coloured quartz, natural or synthetic; application to gemmology.) C.R. Acad. Sci., Paris, **290**, ser. D, 291-4, 1980.

One may identify synthetic gem quartz by IR spectroscopy using the following data: synthetic rock crystal: thin band at 3585 cm^{-1}, no absorption at 3480 cm^{-1}. Synthetic amethyst: extra absorption bands in the range 3700-3300 cm^{-1}. Synthetic citrine: total absorption at wave numbers lower than 3600 cm^{-1}. J.C.T.

ZWAAN (P. C.), ARPS (C. E. S.). *Sphene, Sri Lanka's newest gemstone.* Scripta Geol., **58**, 11pp., 5 figs, 1980.

Three cut sphenes, originating from the Tissamaharama area of Sri Lanka, are comparable with gem-quality sphene from Capelinha, Brazil. Electron microprobe analyses are given for two sphenes from Sri Lanka and for three from Brazil. A yellowish green 4.60 ct stone from Sri Lanka gave SiO_2 30.4, TiO_2 38.6, Al_2O_3 1.11, Fe_2O_3 0.60, MnO 0.04, CaO 28.7, = 99.45; SG 3.5276 ± 0.0008, *a* 1.910. Indexed x-ray powder data are tabulated for Sri Lankan and Brazilian specimens, and fluid inclusions in sphenes from both areas are illustrated. The absorption spectra of brownish yellow stones show lines due to rare earths; these lines are less developed in the yellowish green stones. R.A.H.

Stones seen. Aust. Gemmol., **14**, 5, 86, 1981.

Describes a transparent kyanite crystal (with colour-change from sea-green to deep mauve purple) from the Harts Range, Northern Territory. J.R.H.C.

BOOK REVIEWS

BARNES (L. C.), *et al. Some semiprecious and ornamental stones of South Australia.* Geol. Surv. South Australia, 1980. pp.159, 40 figs, 73 pls. $5.00.

This handbook, prepared from a selection of reports, describes the location, geology, and mineralogy of some well-known 'semiprecious' stones in South Australia. 'Semiprecious' stones listed include jade, amazonite, amethyst, agate, chrysoprase, turquoise, scholzite, and chiastolite. W.A.F.

DESAUTELS (P. E.). *The gem collection.* Smithsonian Institution Press, Washington, D.C., 1979. pp.77. Illus. in colour. £4.95.

Although it is not stated to be such, it is clear that this most attractively presented work is intended as a successor to the various guides to the Smithsonian gemstone collections that have appeared in the past. Since the last of those guides was published, considerable additions have been made to the collections, particularly in the field of important jewellery, some of which is illustrated.

The guide does not only discuss the important and spectacular specimens to be seen in this cabinet; it outlines the properties of the major species and gives, with weights and provenance, a list of some of the more outstanding pieces. M.O'D.

GÜNTHER (B.). *Bestimmungstabellen für Edelsteine, synthetische Steine, Imitationen.* (Identification tables for gemstones, synthetic stones and imitations.) Elisabeth Lenzen, Kirschweiler, 1981. pp.168. Price on application.

This work consists entirely of tables in which all the necessary constants for identification are given. Species are listed in the main table in order of refractive index and the commoner ones are given a bolder type-face for greater clarity. Many absorption spectra are included in colour. A preliminary table, also arranged in order of refractive index, points to particular places in the main table once a starting position is arrived at.

As far as the tables go they seem perfectly workmanlike, though somewhat overloaded by species of little gem application, such as durangite, chondrodite and mimetite. There is a short bibliography, an index, and pages for supplementary material to be added by the reader. Presentation is attractive and clear; the book opens easily and lies flat—even today few working manuals are as well made as this.

M.O'D.

HIGGINS (R.). *Greek and Roman jewellery,* 2nd edn. Methuen, London, 1981. pp.xliii, 243. Illus. in black-and-white. £18.00.

The first edition of this standard work was published in 1961. Since then many new discoveries have been made, and this edition takes them into account both in the main text and in the first-class bibliography. 64 pages of plates are provided.

M.O'D.

HOFMANN (F.). *Schöne und seltene Mineralien.* (Beautiful and rare minerals.) Herder, Freiburg, 1981. pp.224. Illus. in black-and-white and in colour. Price on application.

This is another of the large format general descriptive mineral books consisting largely of good quality colour plates with the minimum of text. Many of the minerals depicted are not, in fact, rare but the quality of the photographic work is in general good. One good example is the colour plate of legrandite (the specimen itself is quite large). Scales are given with the illustrations; there is an index and a bibliography. Each mineral has a reasonable amount of descriptive text with it.

M.O'D.

LIDDICOAT (R. T.). *Handbook of gem identification,* 11th edn. G.I.A., Santa Monica, U.S.A., 1981. pp.xv, 450. $2.50.

Though this familiar classic still gives good value for a competitively low price, it now shows signs of hastiness and a need for a thorough revision. As expected, details of reflectivity meters, diamond pens and probes are given; new synthetics—Kashan ruby (recently restored to the market), Regency emerald, CZ (but not the coloured varieties)—are mentioned and the tables expanded to take them into account. There is a new section dealing with the alteration of stones. For the rest the book gives brief details of the major gem materials (though quite a lot of species could have been included, such as sogdianite) and of man-made products. Here there is no mention of the opal imitation made from monodisperse latex nor of the cat's-eye imitation manufactured by Cathay Corporation. The index with unaccustomed misprints and some bad errors (chrysoberyl is referred to the wrong pages) could do with expert revision; the lack of any useful bibliography is a detraction from the overall merits of the book.

Much of the material is given as before under the colours of the stones. These sections become harder to read the more they are expanded and consideration should now be given to opening them out, improving the style and omitting the considerable repetition. All classics need the occasional daylight. M.O'D.

READ (P. G.). *Gems, Questions and Answers.* Newnes Technical Books, London, 1981. pp.107. £1.95.

One of the *Questions and Answers* series, this book contains many of the problems likely to face the gemmology student. The treatment is basic and some degree of knowledge is expected of the reader, since terms are not explained; rather, the sections are intended to lead the reader on from stage to stage without the need for explanatory halts. Simple tables are given. This is a handy-sized book and should be useful for such onerous tasks as examination revision. M.O'D.

RÖSLER (H. J.). *Lehrbuch der Mineralogie.* (Text-book of mineralogy.) 2nd edn. VEB Deutscher Verlag für Grundstoffindustrie, Leipzig, E.Germany, 1981. pp.833. Illus. in black-and-white. 60M.

This is a large standard mineralogical text, well produced on good quality paper. With some resemblances to Klockmann's book of the same title, it is a useful addition to the ranks of German mineralogy texts. This edition includes minerals quite recently described such as liddicoatite, and the main part of the text is devoted

to mineral descriptions; less space is given to techniques of mineral testing, though what there is is up-to-date. There is an excellent bibliography and an index. M.O'D.

SCHUBNEL (H.-J.). *Larousse des mineraux.* (The minerals' Larousse). Librairie Larousse, Paris, 1981. pp.363. Illus. in colour. Price on application.

After a brief skirmish with mineral chemistry, crystallography and an account of major mineral collections, this attractively produced book battles with the whole kingdom of minerals so far identified. These are arranged in alphabetical order and the more important ones have details of hardness, specific gravity, optical properties, as well as chemical composition and mode of occurrence, which are the only features given for the less significant species. There are a short glossary and a list of synonyms and recent discoveries.

Although well written, it is difficult to see clearly the potential readership for this book. It will not be possible for the beginner or even the adept to find more than brief accounts of species, and such descriptions are quite easily found elsewhere by those who would otherwise find the book useful. The pictures are very good and few have been published before; most, but not all, have the size given. There is neither index nor bibliography, two serious omissions. A useful addition to the sparse literature on mineralogy in French. M.O'D.

VOLLSTADT (H.), BAUMGARTEL (R.). *Edelsteine.* (Precious stones.) VEB Verlag für Grundstoffindustrie, Leipzig, E.Germany, 1979. pp.218. Illus. in black-and-white and in colour. 28M.

This is a book well produced from the scientific standpoint and is clearly aimed at student level. Especially interesting, on account of their rarity, are the illustrations of gemstones from German localities, such as topaz from Saxony. The rest of the book follows a pattern similar to that of other recently published gemmological books. There is a short bibliography and an index, with identification tables. M.O'D.

An exhibition of fine jade. Spink & Son Ltd, London, 1981. pp.28. Illus. in black-and-white and in colour. £5.

This is an exhibition catalogue in which each piece is illustrated. Measurements are given, and the pieces are dated. The whole is well produced and informative.

M.O'D.

ASSOCIATION NOTICES

GIFTS TO THE ASSOCIATION

The Council is indebted to the following for their gifts:

Mr Christopher Cavey, F.G.A., Greenford, Middlesex, for one particoloured (blue/white) euclase crystal group from Miami district, Zimbabwe.

Mr George K. L. Chan, F.G.A., Coober Pedy, Australia, for an opalized fossil shell from Coober Pedy opal field.

The Gemmological Association of Hong Kong for an ivory fan and a carved rosewood stand. The fan is the emblem of the Hong Kong Association.

Mr A. B. Jayasundera, F.G.A., Ratnapura, Sri Lanka, for a copy of the Ceylon National Museum's publication 'Some extinct elephants, their relatives and the two living species' by P. E. P. Deraniyagala, 1955.

The Norwegian Gemmological Association (Norges Gemmologiske Selskap) for a quartz crystal together with anatase from Hardangervidda, Norway.

Dr Marcio D. de Mendonca Porto, Minas Gerais, Brazil, for a collection of cut and polished topaz specimens, gold and yellow, golden brown, pink and blue, together with some topaz crystals.

Mr C. R. Smith, F.G.A., Kannesaw, Georgia, U.S.A., for a slice of lazulite containing kyanite, pyrite and quartzite.

Mrs Joyce Ward, F.G.A.A., West Perth, W. Australia, for a rare cut transparent petalite of 4.43 carats.

NEWS OF FELLOWS

On 16th August, 1981, Mr Russell K. Bennett, F.G.A., gave the last in a series of five fortnightly talks on gemstones on Radio Severn Sound.

On 30th August, 1981, Mr Michael O'Donoghue, M.A., F.G.S., F.G.A., gave a talk entitled 'Some unusual gemstones' at a show held at Harrogate by the British Lapidary and Mineral Dealers Association, and on the 13th November, 1981, he addressed the Gemmological Association of Hong Kong on 'Some man-made materials with possible gem application'.

On 26th September, 1981, Mr Peter G. Read, C.Eng., F.G.A., demonstrated an expanded 'professional' version of his Gem-data computer program to members of the German Gemmological Association during their autumn Technical Weekend at Idar-Oberstein.

MEMBERS' MEETINGS

Midlands Branch

On 25th September, 1981, at the Society of Friends, Dr Johnson's House, Colmore Circus, Birmingham, the film 'A very special stone' was shown. Also Messrs D. E. Price and D. Morgan, FF.G.A., addressed the meeting on stone cutting, and brought some new and interesting specimens for examination.

On 29th October, 1981, at the Society of Friends, Mr David J. Callaghan, F.G.A., gave a talk entitled 'Antique gems and jewellery'.

On 27th November, 1981, at the Society of Friends, a 'Swap, chat and news' evening was held, when members had an opportunity to exchange specimens and notes on all aspects of gemmology.

North-West Branch

On 24th September, 1981, at Church House, Hanover Street, Liverpool, Mr Alan Hodgkinson, F.G.A., gave an illustrated talk entitled 'Journey into gemmological space'. The lecture covered rubies, emeralds, sapphires, opals and amber.

On 22nd October, 1981, at Church House, the Annual General Meeting of the Branch was held, when Mrs Irene Knight, F.G.A., was elected Chairman, and Mrs E. Cartmel re-elected Secretary.

On 19th November, 1981, at Church House, Messrs D. Alderson and W. Hartshorne from Isis Minerals visited the Branch, and members had the opportunity to view crystals and pottery.

South Yorkshire and District Branch

On 6th September, 1981, a trip was arranged to London, visiting the International Watch, Jewellery and Silver Trades Fair at Earls Court, and the Institute of Geological Sciences and Natural History Museum, South Kensington.

On 19th November, 1981, members visited the City Museum, Sheffield. The Keeper of Natural Sciences, Mr Tim Riley, gave a conducted tour of the geological gallery.

GEM DIAMOND EXAMINATION 1981

In the Post-Diploma Gem Diamond Examination, fifty-one candidates sat and forty-nine passed, three with Distinction. The following is a list of their names arranged alphabetically.

QUALIFIED WITH DISTINCTION

Guinot Sierra, Agustin Ignacio, Castellon de la Plana, Spain.
Ross, Rosemary Daphne, London.
West, Clive Graham, London.

QUALIFIED

Ali, Syed Jafer, London.
Anderson, Maximillian Joseph, Harrow.
Bennett, Elaine, Hazel Grove.
Bentley, Carolyn Isabel, Liverpool.
Bill, David Nigel, Hednesford.
Blake, Jeannette Alexandra, London.
Castellote Mas, Guillermo Fernando, Xativa, Spain.
Coelho, Susan Osborn, Richmond.

Coombes, Martin Lewis, Crewe.
Cottrill, Susan D., Cheadle Hulme.
Dickson, Amanda Jane, London.
Emms, Eric Charles, Brentwood.
Falkus, Geoffrey Charles, Hainault.
Faux, Teresa Mary, Winslow.
Fung, Tsee Hung, London.
Gallardo Bravo, Matilde, Valencia, Spain.
Glen, Jill, London.
Goatly, Andrew Martin, Surbiton.
Green, Richard Douglas, Wolverhampton.
Guinot Sierra, Carlos Ma, Castellon de la Plana, Spain.
Günther, Birgit, Idar-Oberstein, W. Germany.
Hall, Michael Geoffrey, Builth Wells.
Harrison, Kathryn, Scawsby.
Hurst, Adam Keith, Lapworth.
Johnson, Colin Michael, Bournville.
Jones, Gwilym Morus, Abergavenny.
Kemp, Roy E. H., London.
Knight, Irene, Liverpool.
Leria, Bernaus, Magdalena, Barcelona, Spain.
Machlup, Peter Mark, London.
Owen, Neil T., Romford.
Perkins, Joanna Cathryn, London.
Perrella Estelles, Loto, Montgat, Spain.
Pietruska, Julia E. J., London.
Reynolds, James Ian, Stannington.
Riedl, Inge, Barcelona, Spain.
Robbins, Susan Carol, London.
Salvat Alegre, José, Barcelona, Spain.
Sayer, D. J., Weston-super-Mare.
Sever, Katherine Mary, Altrincham.
Shaw, Raymond Noah, Prestwich.
Sweeney, Patrick J., London.
Underwood, Barbara C., Manchester.
Williams, Geoffrey Francis, Cobham.
Wilson, Geoffrey Alexander, Prestwich.
Wright, Michael William, Redhill.

EXAMINATIONS IN GEMMOLOGY, 1981

In the 1981 Examinations in Gemmology, 484 candidates completed the Diploma Examination and of these 190 succeeded in passing, twenty of them with Distinction. In the Preliminary Examination 922 candidates sat and 542 passed.

In the opinion of the Examiners, no candidate achieved the high standard needed to warrant the award of the Tully Medal.

The Anderson/Bank Prize for the best non-trade candidate of the year in the Diploma Examination was awarded to Mrs K. E. Sneddon, of Hong Kong.

The Rayner Diploma Prize for the best candidate for the year who derives his main income from activities essentially connected with the jewellery trade was awarded to Mr E. B. Taylor, of Middlewich.

The Anderson Medal for the best candidate of the year in the Preliminary Examination was awarded to Miss A. F. Voll, of Kowloon, Hong Kong.

The Rayner Preliminary Prize for the best candidate of the year under 21 years of age who derives her main income from activities essentially connected with the jewellery trade was awarded to Miss I. M. Nash, of Watford.

The following are lists of the successful candidates arranged alphabetically.

DIPLOMA EXAMINATION

Anderson/Bank Prize

Sneddon, Katherine E., Hong Kong.

Rayner Diploma Prize

Taylor, Ernest B., Middlewich.

QUALIFIED WITH DISTINCTION

Ashworth, Marie C., Toronto, Canada.
Batycki, Charlene G., Toronto, Canada.
Ebata, Taiichiro, Toyama, Japan.
Grimston, Lady Iona C., London.
Hawker, Robin W. A., Hobart, Australia.
Jones, Jeffrey M., London.
Kano, Shinzo, Toyonaka, Japan.
King, Antoinette E., Rye.
Laurie, Amanda, Bicester.
Little, Derek, Dundee.
McKellar, John R., Presteigne.
Meckoni, Prafulla H., Bombay, India.
Otsuka, Nobuko, Tokyo, Japan.
Peebles, Kathleen W., Johannesburg, S. Africa.
Rademaker, Jaap, Baarn, Netherlands.
Sastrowidjojo, Hendro, Surabaya, Indonesia.
Venning, Ronald O., Toronto, Canada.
Walton, Betty M., Toronto, Canada.

QUALIFIED

Absalom, Christine S., Effingham.
Acheson, Michael A., Geneva, Switzerland.
Adlestone, Mark I., St Annes-on-Sea.
Advani, Vinod, Bombay, India.
Ahmad, Zaheer, London.
Akizuki, Haruo, Ichikawa, Japan.
Ali Mohamed, Shabia K., Santa Ana, U.S.A.
Aliprandi, Riccardo G., Rome, Italy.
Allyn, Dale F., Eugene, U.S.A.
Alvis, Alayne G. D., Colombo, Sri Lanka.
Anfield, Jennifer J., Birmingham.
Ashra, Shirish, London.
Babber, Harish R., Southall.
Bana, Habibullah, San Clemente, U.S.A.
Barber, Anjali, Nairobi, Kenya.
Bardsley, John N., London.
Beevers, Jacintha M., Hong Kong.
Begeer, Dolfje M., Voorschoten, Netherlands.
Bekesch, Nicholas, Oshawa, Canada.
Bell, Keith, Ottawa, Canada.
Bennett, Sharon L., Little Marlow.
Boorman, Robert F., Bisley.
Boyd, Robert T., Toronto, Canada.
Boyes, Richard W., Garston.
Breau, Karen L. Johnson, Toronto, Canada.
Caffoor, Ali A. A., Banjul, Gambia.
Chavan, Umesh, Bombay, India.
Chawla, Gulzari, Downsview, Canada.
Chouiki-Doorn, Jacqueline, Spykenisse, Netherlands.
Clarke, Francis B., Upminster.
Cowing, Michael D., Glen Burnie, U.S.A.
Currie, Lynnette J., Manurewa, N.Z.
Darracott, Britt-Marie, London.
Davis, Robert J., Margate, Australia.
Dayasagara, Kalupahana L. D., Colombo, Sri Lanka.
Dewar, Penelope S., Stockport.
Dolleslager, James T., Houston, U.S.A.
Endean, Christine H., Hong Kong.
Fell-Smith, Simon A., Paddington, Australia.
Francey, Donald T., Christchurch, N.Z.
Freeman, Darlene M., Belmont, U.S.A.
Furse, Anna A., London.
Gasco Galindo, Ignacio, Barcelona, Spain.
Gea Lopez, Francisco J., Barcelona, Spain.
Gettings, Barbara A., London.
Girling, Matthew D., London.

Graham, Peter D., Liverpool.
Grant, Judith M., Carmel, U.S.A.
Haghani, Victor J., London.
Hamada, Shiko, Suita, Japan.
Haniffa, Ahamed I., Colombo, Sri Lanka.
Heiskanen, Anu P. K., Helsinki, Finland.
Henderson, Shirley W. A., Bothwell.
Hermans, Johannes S., Delft, Netherlands.
Hettena, Andre, London.
Hettiaratchi, Theja C., Berlin, W. Germany.
Hinde, Rosemary J., Hong Kong.
Hogarth, Graeme R., Kendal.
Honse, Dennis R., Portland, U.S.A.
Horton, David R., London.
Houseago, James A., Lowestoft.
Hutchinson, Marjorie E., London.
Iwata, Kazuyoshi, Gifu, Japan.
Jensen, Edna, Huddinge, Sweden.
Jones, Maureen D., Wellington, N.Z.
Kageyama, Chiyomi, Kobe, Japan.
Kelly, John S., Cardiff.
Kelly, Susan M. B., Algester, Australia.
Kennedy, Karen K., Toronto, Canada.
Kettley, Helen M., London.
Keuskamp, Diederik, Streefkerk, Netherlands.
Khancharoensuk, Somsri, Los Angeles, U.S.A.
Kinoshita, Kazuko, Ashiya, Japan.
Kita, Masako, Fukuoka, Japan.
Kitamura, Seiki, Tokushima, Japan.
Kobayashi, Yuko, Tokyo, Japan.
Kosik, Thomas A., Arlington, U.S.A.
Kothari, Rajan S., Bombay, India.
Kröger, Carol M., Rio de Janeiro, Brazil.
Krstic, Jovanka, Beograd, Yugoslavia.
Lacambra Pifarre, Carmen, Barcelona, Spain.
Lal, Daulet R. B., Bombay, India.
Lambley, Jenifer G., Hong Kong.
Law, Sheila, London.
Lindlau, Gisela, Aichwald, W. Germany.
Litchfield, Anne-Marie, Northampton.
Littlejohn, Gordon H., Tunbridge Wells.
Livstrand, Ulf R., Saltsjöbaden, Sweden.
Louw, Everhardus J., Cape Town, S. Africa.
McAteer, Alice M., London.
McEwan, Robert S., Perth.
McGeorge, Robyn, L., Beecroft, Australia.
McPherson, Heather, Coalville.
Maeda, Katsutoshi, Fukuoka, Japan.
Malkani, Sunil C., Bombay, India.
Mansfield, Stephen McL., Burton.
Mariathasan, Loganayagi, Colombo, Sri Lanka.
Marikar Bawa, Mohamed S. N., Idar-Oberstein, W. Germany.
Martin, Paul, Nuneaton.
Martuccio, Celeste, Leamington Spa.
Masuda, Masami, Shizuoka, Japan.
Masurel, Helga, Leiden, Netherlands.
Mater, Louise H., Laren, Netherlands.
Mizushima, Nobuhiro, Osaka, Japan.
Molagoda, Tikiri B. P., Talatuoya, Sri Lanka.
Mourad, Huguette, Beirut, Lebanon.
Nakamura, Masanori, Osaka, Japan.
Nakamura, Takeshi, Kanazawa, Japan.
Nakao, Kuzuya, Wakayama, Japan.
Nakayama, Keichi, Komatsushima, Japan.
Nelischer-Millar, Anita I. A., Toronto, Canada.
Nojiri, Masatomi, Fukuoka, Japan.
O'Hare, Jane, Corwen.
Ohno, Hiroko, Tokyo, Japan.
Okuda, Makoto, Osaka, Japan.
Ottaway, Terri L., Toronto, Canada.

Paramalingam, Jayanthi, Mt Lavinia, Sri Lanka.
Parcel, Rodney F., Jr, Perris, U.S.A.
Parry, Sarah, Wadhurst.
Pattni, Pravin A., London.
Pietroboni, Carlo, Forch, Switzerland.
Podsiadly, Maria T., Birmingham.
Postma, Renate E., Breda, Netherlands.
Potter, Brian S., London.
Preston, Stephen P., Birmingham.
Prince, Ann-Elise, London.
Protopopoff, Monica, Beecroft, Australia.
Puig-Doria Pala, José Ma, Barcelona, Spain.
Quincey, Mary E., Rugby.
Raymond, Robert S., Brentwood.
Rigby, Ian W., Wolverhampton.
Ro, Yosetsu, Tokyo, Japan.
Rome, Martin L., London.
Ruplinger, Peter K., Sandy, U.S.A.
Ryan, Margaret E., Hong Kong.
Sadler, Philip A., London.
Saez Balsalobre, Lidia, Barcelona, Spain.
Shimada, Nobuo, Kashiwa, Japan.
Shimomura, Seisaku, Tokyo, Japan.
Singleton, Graham S., Sudbury.
Smith, Catharine, Lutterworth.
Spooner, Carole A., Wokingham.
Steward, Annelies, Calgary, Canada.
Suguro, Norio, Tokyo, Japan.
Swain, Anthony P., Deganwy.
Swersky, Ann H., Ramat Hasharon, Israel.
Thorne, Deirdre, Salisbury, Zimbabwe.
Trinkl, André A., Johannesburg, S. Africa.
Troth, Peter D., St Ouen, Jersey.
Trueman, Laraine M., Stafford.
van den Berge, Tania A. P., St Amandsberg, Belgium.
van der Zwaag, Hemko, Zeist, Netherlands.
Vermaas, Franciska J. M., Rotterdam, Netherlands.
Versendaal-Ovink, Beatrix E. W., Hendrik Ido Ambacht, Netherlands.
Vietti, Stuart, Penrith.
Vigo Ripoll, Leticia, Barcelona, Spain.
Vikamsey, Indira J., Bombay, India.
Warrenberg, Jonathan M., Ilkley.
Wescott, H. Marjatta, Tokyo, Japan.
Wijeratne, Chakkrawarthige H. R., Colombo, Sri Lanka.
Wilkie, William, Helensburgh.
Williams, Bruce M., Walla Walla, U.S.A.
Wong, Kitty, Kowloon, Hong Kong.
Yamamoto, Kazui, Fukuoka, Japan.
Yenson Chu, Mabel, Kowloon, Hong Kong.
Yoshino, Mariko, Tokyo, Japan.
Zanoon, Norfel W., Colombo, Sri Lanka.
Zebrak, Tracy J., Hove.
Zipf, William T., Bethel Park, U.S.A.
Zwikker, Marijke, Nijmegen, Netherlands.

PRELIMINARY EXAMINATION

Anderson Medal
Voll, Aloha F., Kowloon, Hong Kong.

Rayner Prize
Nash, Isobel M., Watford.

QUALIFIED

Aalto, Veikko O., Hämeenlinna, Finland.
Abi-Habib, Cynthia S., Riyadh, Saudi Arabia.
Aburrow, Michael B., Wimborne.
Adams, Myra, Huddersfield.
Advani, Vinod, Bombay, India.
Aguilar Agraz, Amparo, Barcelona, Spain.
Ainsworth, Nicola L. A., London.
Alabaster, David R., Stratford-upon-Avon.
Alfsen, Edgar J., São Paulo, Brazil.
Ali Mohamed, Shabia K., Santa Ana, U.S.A.
Allyn, Dale F., Eugene, U.S.A.
Amos, Gillian L., Pontypridd.
Anand, Sumedha, Bombay, India.
Andrews, Clive G., Selsdon.
Anwar, Abdul A. M., Beruwala, Sri Lanka.
Arbestain Ribas, Inmaculada, Barcelona, Spain.
Arendtsz, Natalie A., Negombo, Sri Lanka.
Ärfström, Berndt G., Märsta, Sweden.
Arjalaguer Vilardell, Daniel, Barcelona, Spain.
Armstrong, Gillian, Preston.
Arora, Ravindera, Hounslow.
Ash, Malcolm J., Bradford.
Baixauli Sanjuan, José F., Barcelona, Spain.
Baker, Judith, Ottawa, Canada.
Bala's, Aranka, Colombo, Sri Lanka.
Balius Matas, Pilar, Barcelona, Spain.
Bana, Habibullah, San Clemente, U.S.A.
Bandarage, Samangi, Colombo, Sri Lanka.
Bank, Monika I., Idar-Oberstein, W.Germany.
Barre Martin, Anne M., Barcelona, Spain.
Basnayake, Senarath B., Katugastota, Sri Lanka.
Beckley, Robert A., Carshalton.
Beech, Georgina, Eccles.
Beesley, Janet S., Skipton.
Begeer, Dolfje M., Voorschoten, Netherlands.
Bekesch, Nicholas, Oshawa, Canada.
Bell, John A., Sevenoaks.
Bell, Keith, Ottawa, Canada.
Bennett, Andrahennadige S., Tangalle, Sri Lanka.
Bennett, Edward O., Nugegoda, Sri Lanka.
Bennett, Norman P. J., Plymouth.
Bercott, David S., Glasgow.
Bird, Nigel G. D., Epsom.
Bishop, Ian C., Gillingham.
Blackburn, Mary-Rose, Roodeport, S.Africa.
Block, Rachel J. K., London.
Bolton, Robert G., Guiseley.
Bon, Maria H., Schoonhoven, Netherlands.
Borofsky, Norman, Toronto, Canada.
Boutureira Rilo, Juan L., Barcelona, Spain.
Bowman, Josephine T., London.
Bradley, Alison A., Didcot.
Bratz, Kristin M., Oslo, Norway.
Brookes, Hilary A., Birmingham.
Brown, Sheila, London.
Buckingham, Nola E., Brisbane, Australia.
Bull, Christopher J., Pulborough.
Cabanas Casas, Terencia, Barcelona, Spain.
Capella Tomas, Ma Josefa, Barcelona, Spain.
Cardew, Charles J. S., Thornton Heath.
Carlin, John, Brighouse.
Carvey, Robyn, Hong Kong.
Castro Masaveu, Alicia, Barcelona, Spain.

Cattermole, Mavis E., Nairobi, Kenya.
Caycedo, Miguel J., Ilford.
Cervera Perez, Rafael, Barcelona, Spain.
Cestaro, Thomas L., Cheshire, U.S.A.
Chao, George Y., Ottawa, Canada.
Cheung, Cliff P. L., Toronto, Canada.
Choi, Tony Y. M., Happy Valley, Hong Kong.
Chow, Yin L., Hong Kong.
Christou, Chris, London.
Chung, Penelopie O. L., Kowloon, Hong Kong.
Clarke, Norman V., Blandford Forum.
Clipston, Neville W., Durban, South Africa.
Clowes, Paul R., Solihull.
Collins, Glen M., Glasgow.
Collins, Susan M., Liverpool.
Collyer, Christine A., Birmingham.
Cornioley, Jean-René, Fribourg, Switzerland.
Cottafavi, Aliette, Geneva, Switzerland.
Cousins, Nigel T., Deal.
Couston, John F., Kerala, India.
Cowie, Gillian A., Liverpool.
Cowing, Michael D., Glen Burnie, U.S.A.
Cox, Amanda R., London.
Cruickshank, Mary, Nairobi, Kenya.
Cvetkovic, Borjanka, Raipur, India.
D'Adamo, Marina, Milan, Italy.
Dalmau, Rubert, Ma Magdalena, Barcelona, Spain.
Dam, Hegwig M., Warnsveld, Netherlands.
Danielsen, Alf P. T., Oslo, Norway.
Dayrit, Michelle S., Makati, Philippines.
Dean, Rebecca A., Poynton.
de Beer, Christiaan T. J., Durban, S.Africa.
Deeley, Peter J., Birmingham.
Del Rey, Mario, São Caetano Do Sul, Brazil.
Denyer, Philip, Rickmansworth.
de Silva, Antoinette T. J., Colombo, Sri Lanka.
Dias Abeyegunawardene, Christina S., Colombo, Sri Lanka.
Dijkman, Christine S., Taitam, Hong Kong.
Dillon, Stephanie, Los Angeles, U.S.A.
Dirlam, Dona M., Santa Monica, U.S.A.
Dixon, Zoë H., St Albans.
Dodding, Susan D., Great Harwood.
Dotterer, Ford K., Hong Kong.
Dougherty, William C., Alexandria, U.S.A.
Dowie, Anthony R., Christchurch, N.Z.
Dowie, Nigel J., Christchurch, N.Z.
Doyle, Martin, Hull.
Dūblin, Theo, Arlesheim, Switzerland.
Duerden, David A., London.
Duke, Ray, Southend-on-Sea.
Duque Oliart, Francisco, Barcelona, Spain.
Eadie, John, Glasgow.
Ebers, Carl N., Frinton-on-Sea.
Edmondes, Eleanor J. C., Birmingham.
Ehrenborg, Charlotte, Gex, France.
Elapata, Sam A. I. G., Colombo, Sri Lanka.
Elias, Abdul H., Mombasa, Kenya.
Elias, Farook A., Mombasa, Kenya.
Elias Sospedra, Gemma, Barcelona, Spain.
Ellerton, Anne L., Toronto, Canada.
Elvidge, Caroline A., London.
Emerick, Heather, London.
Esterhuizen, Karel F., Durban, S.Africa.
Esufally, Mohamed M. H., Colombo, Sri Lanka.
Faiers, Caroline, Aldham.
Faller, Noel P., Londonderry, N.Ireland.

Fanning, Jill, Birmingham.
Fernandez Nunez, Carlos L., Barcelona, Spain.
Fernando, Dudley L., Colombo, Sri Lanka.
Fernando, Phedias C. B., Moratuwa, Sri Lanka.
Ferreira, Anslem C., Colombo, Sri Lanka.
Finell, Mona, Helsinki, Finland.
Firth, Barbara, London.
Franks, Patrick M., Altrincham.
Fritzen, Tove, Bekkestua, Norway.
Fuller, Maris E., Kowloon, Hong Kong.
Furnival, Michele E., Toronto, Canada.
Furr, Gregory E., Wokingham.
Galloway, Jane E., Toronto, Canada.
Galsterer, Maureen G., Saginaw, U.S.A.
Garton, Anthony M., Bournemouth.
Gaw, Rossana W., Hong Kong.
Gemayel, Farid, Antelias, Lebanon.
Geurts, Godefridus R. J. M., Heerlen, Netherlands.
Gibbon, Michael T., Luton.
Gilbert, Charles F., New York, U.S.A.
Gilbert, Clive L., London.
Gill, Jogindar S., Kuala Lumpur, Malaysia.
Gill, Rani, Edgware.
Gilmour, Kevin D., Sheffield.
Gimpel, Beatrice, London.
Gimpel, Remy F., London.
Glover, Brian M. G., Wallasey.
Gobla, Michael J., Westminster, U.S.A.
Goeritz, Louise, London.
Gonsalves, Bonita S., Colombo, Sri Lanka.
Goss, Alan C., Welwyn Garden City.
Grabau, Antonella, Geneva, Switzerland.
Gracia Armendariz, Luis, Barcelona, Spain.
Gracia Mañez, Marina, Barcelona, Spain.
Greatwood, Sheila O., Mitcham.
Greene, Michael A. F., London.
Griffiths, Paul A., Sutton Coldfield.
Grimal Moreno, Sara, Barcelona, Spain.
Grinyer, Raymond F., Newcastle, S.Africa.
Grishko, Alexander, Agincourt, Canada.
Grootswagers, Johannes P. J., Breda, Netherlands.
Gunaratne, Renuka J., Moratuwa, Sri Lanka.
Guneratna, Witanage D., Panadura, Sri Lanka.
Ha, Shek T., Kowloon, Hong Kong.
Hadfield, Margit E., Canterbury.
Haghani, Victor J., London.
Hakoune, Jacques, Antwerp, Belgium.
Hall, Cheryl D., Toronto, Canada.
Hamer, Saskia M., The Hague, Netherlands.
Hamilton, Ann, Bridge of Weir.
Hammam, Nada, Riyadh, Saudi Arabia.
Harding, Richard W., Solihull.
Hardman, Elaine S., Stanley, Hong Kong.
Hardy, Joanna, London.
Harmer, Inge, Brisbane, Australia.
Harmer, John B., Brisbane, Australia.
Hartley, Alison K., Westhoughton.
Hawkins, Sandra C., Toronto, Canada.
Hay, Elizabeth R., Rondebosch, S.Africa.
Healey, John M., Windsor.
Hebden, Leonora A., London.
Heikkilä-Tiainen, Merja M., Hämeenlinna, Finland.
Heino, Tauno T. T., Eura, Finland.
Heinonen, Elina K. J., Loimaa, Finland.
Hendrick, D. M. Sriya, Kandy, Sri Lanka.

Henwood, Amelia R., Basingstoke.
Henwood, Glyn A., Basingstoke.
Hettiaratchi, Theja C., Berlin, West Germany.
Hodgson, Joanna K., Glossop.
Hofer, Stephen C., Santa Monica, U.S.A.
Hong, Kuong S., Causeway Bay, Hong Kong.
Honse, Dennis R., Portland, U.S.A.
Hoogewerff, Regitse C., Diepenveen, Netherlands.
Hook, Allen J., Brighton.
Horn, Graeme F., Glasgow.
Horsey, Anita C., Washington, D.C., U.S.A.
Housley, John G., Sheffield.
Hung, Chi-chuan, Manila, Philippines.
Hurlbert, Kim E., Cayucos, U.S.A.
Hutchinson, Leslie B., London.
Hutton, Andrew J., South Croydon.

Imai, Seiichi, Fukuoka, Japan.
Inamochi, Sachiko, Niigata, Japan.
Inoue, Kazuo, Tokyo, Japan.
Irani, Khodadad B., Bombay, India.
Iriarte Villar, Alberto, Barcelona, Spain.
Ishii, Koji, Funabashi, Japan.
Ishiwatari, Tamotsu, Tokorozawa, Japan.
Isohaaro, Hannu Y. T., Hämeenlinna, Finland.
I. te Brinke, Wilhelmina C., Winterswijk, Netherlands.

Jarché, Lynne R., London.
Jayawardene, Padma, Kew.
Jayaweera, Susil, Peradeniya, Sri Lanka.
Jhaveri, Kalpana R., Bombay, India.
Jokela, Leena A., Helsinki, Finland.
Jolliff, James V., Edgewater, U.S.A.
Jonas, Zeev, Jerusalem, Israel.
Jones, Mark S., London.

Kadota, Hiroka, London.
Kageyama, Chiyomi, Kobe, Japan.
Kallio, Marja-Leena, Lohja, Finland.
Kanagasabapathy, Gowry, Colombo, Sri Lanka.
Kano, Shinzo, Toyonaka, Japan.
Karpelowsky, Raymond, London.
Kasagi, Nobuko, Nishinomiya, Japan.
Kauhanen, Pentti R., Helsinki, Finland.
Kavanagh, James P. X., Dublin, Ireland.
Kawai, Junko, Osaka, Japan.
Kawai, Yoshito, Utsunomiya, Japan.
Kawasaki, Teruko, Tokyo, Japan.
Kearny-Kibble, Mathilde F., Repulse Bay, Hong Kong.
Kelderman, Klass P., Alphen a/d Rijn, Netherlands.
Kellner, Louis, Hove.
Kennedy, Stephen J., London.
Kesola, Kalervo J., Valkeakoski, Finland.
Ketelaar, Arend C. R., Leidsendam, Netherlands.
Key, Roger, Nairobi, Kenya.
Khan, Deborah R., Bromley.
Kierkels, Johannes J. P. E., Belfeld, Netherlands.
Kikelo, Peter Muindi, Nairobi, Kenya.
Kishida, Seiko, Birmingham.
Kjellen, Ewa B., San Clemente, U.S.A.
Knights, Bridget C., Shrewsbury.
Kobayashi, Yuko, Tokyo, Japan.
Kohmura, Kyoko, Kyoto, Japan.
Kok-Visser, Astrid S., Nairobi, Kenya.
Kolamunne, Ahangamgoda A. S., Sri Lanka.
Korhonen, Pentti K., Hämeenlinna, Finland.
Kothari, Harsukh N., Bombay, India.
Kozen, Shigekazu, Osaka, Japan.
Kraan, Jan W., Amsterdam, Netherlands.
Krementz, Richard, III, Newark, U.S.A.

Kularatnam, Kulasingham S., Colombo, Sri Lanka.
Kularatne, Rajapkse P. G., Muruthalawa, Sri Lanka.
Kumaratilake, Wickramasinghe L. D. R. A., Kelaniya, Sri Lanka.
Kussela, Irene, Hämeenlinna, Finland.
Lack, Kenneth A., San Clemente, U.S.A.
Laguna Manchon, Ma José, Barcelona, Spain.
Laine, Raimo E. L., Hämeenlinna, Finland.
Laitinen, Mauri P., Valkeakoski, Finland.
Lake, Anne M., Oakville, Canada.
Larsson, Alf C., Kyrkslatt, Finland.
Latham, Glenn M., Gambrills, U.S.A.
Law, Ada P. K., Aberdeen, Hong Kong.
Leary, Sean P., Washington, D.C., U.S.A.
Leckie, Frances, London.
Lee, Karen E., Twickenham.
Leidensdorff, Carine L., Brussels, Belgium.
Leung, Ronald T. T., Hong Kong.
Li, Jollio C. M., Kowloon, Hong Kong.
Lietwiler, Christian W., Oxon Hill, U.S.A.
Lindlau, Gisela, Aichwald, W.Germany.
Lithander, Brita K., Stockholm, Sweden.
Lopez Vidal, Antonio, Barcelona, Spain.
Lu, Milton R. K., Taipei, Taiwan.
Lui, Tsze C., Kowloon, Hong Kong.
Lum, Koke C., Kuala Lumpur, Malaysia.
Lyyvuo, Raili T., Helsinki, Finland.
Macdonald, Roy W., Eaglesham.
McGeorge, Robyn L., Beecroft, Australia.
McHugh, Charles, Adlington.
McKendrick, Stewart W., Reading.
McKinney, Landrum G., Jr, Kowloon, Hong Kong.
McLean, Peter J., Ryde, Australia.
McLeod, John W., Papakura, N.Z.
McQueen, B. Young, Jacksonville, U.S.A.
Ma, Lisa L. H., Wanchai, Hong Kong.
Machin Hernandez, Pedro, Barcelona, Spain.
Mak, Michael M. C., Hong Kong.
Malkani, Sunil C., Bombay, India.
Mallawarchchi, Gayani N., Kadawata, Sri Lanka.
Manmatharahah, Soosaipillai R. P., Jaffna, Sri Lanka.
Mann, Hazel J., Chatham.
Mantecon Burgos, Jesús, Barcelona, Spain.
Manzi, Michael, Penzance.
Marasinghe, Keerthiratne, Avissawella, Sri Lanka.
Marti Beltran, José Ma, Barcelona, Spain.
Masuda, Masami, Shizuoka, Japan.
Masurel, Helga, Leiden, Netherlands.
Matsuda, Tomoko, Tokyo, Japan.
Mau, Enoch C. Y., Kowloon, Hong Kong.
May, Brian J., Stellenbosch, S.Africa.
May, Brian H., Camberley.
Mayer, Stefan P., Idar-Oberstein, W.Germany.
Meacham, John F., Victoria, Canada.
Mednuik, Melanie A., Witham.
Mehta, Rohinton S., Bombay, India.
Mehtonen, Margaretha E. G., Espoo, Finland.
Mellows, Jacqueline M., Bexleyheath.
Meppelink, Jan P., Amsterdam, Netherlands.
Michaels, David B., Alexandria, U.S.A.

Miller, Marvin D., Fairfax, U.S.A.
Miller, Victoria J., Toronto, Canada.
Mine, Kayoko, Kita Kyushu, Japan.
Miralles Morey, José L., Barcelona, Spain.
Miravette Martinez, Ma Gloria, Barcelona, Spain.
Mizushima, Nobuhiro, Osaka, Japan.
Mok, Dominic W. K., Kowloon, Hong Kong.
Molyneux, John D., St Helens.
Moore, Roscelyn M., Camberley.
Moore, Stephen A., Leicester.
Mora Balcells, Helena, Barcelona, Spain.
Moran, Diane M., Upton.
Morgan, Gerald W. G., London.
Morishita, Kentaro, Tokyo, Japan.
Morishita, Yukuru, Tokyo, Japan.
Moseley, Tanya L., Ashford.
Mouzannar, Nabil I., Beirut, Lebanon.
Mulaffer, Mohamed Z., Colombo, Sri Lanka.
Munasinghe, Kalyani S., Colombo, Sri Lanka.
Murahashi, Kozo, Sasebo, Japan.
Murlans Ferrando, Núria, Barcelona, Spain.
Nakao, Kazuya, Wakayama, Japan.
Nakao, Shigeru, Nara, Japan.
Napola, Jussi P. D., Vantaa, Finland.
Naya Daniel, Francisco, Barcelona, Spain.
Naya Daniel, Mario, Barcelona, Spain.
Neale, David A., Copthorne.
Negueruela Tremino, Antonio, Barcelona, Spain.
Nevalainen, Aarne E., Hämeenlinna, Finland.
Nevill, Amanda J., Hong Kong.
Newing, Robin J. T., London.
Newman, Susan W., Henfield.
Ng Chan, Cecilia P. K., Hong Kong.
Nicholas, Christopher E., Colombo, Sri Lanka.
Nilam, Mohamad C. M., Weligama, Sri Lanka.
Nishino, Teiichi, Osaki, Japan.
Nivera, Maria D. G., Hong Kong.
Noon, Graham, Epsom.
Novejarque Lopez, Ma del Carmen, Barcelona, Spain.
Nurminen, Tuija P. A., Helsinki, Finland.
Obbink, Gertrude J., Aalten, Netherlands.
Ohno, Hiroko, Tokyo, Japan.
Øiesvold, Astri S., Aarnes, Norway.
Okada, Mari, San Clemente, U.S.A.
Okuda, Makoto, Higashiosaka, Japan.
Oliete Sainz, Juan A., Barcelona, Spain.
Olson, A. Richard, Manzini, Swaziland.
Orchant, Lewis, Glasgow.
Osacar Soriano, Ma Cinta, Barcelona, Spain.
Palfreyman, William D., Canberra, Australia.
Palmer, Robert B., London.
Palomäki, Jukka A. J., Katinala, Finland.
Palomäki, Tuula M. L., Katinala, Finland.
Paradise, Thomas R., Millbrae, U.S.A.
Parisée, Claudette, Vanier, Canada.
Parker, David T., Sunderland.
Parker, Hazel, Macclesfield.
Pattani, Hitesh K., Bombay, India.
Pattiaratchi, Chandrika L., Colombo, Sri Lanka.
Pattni, Rajendra A., Nairobi, Kenya.
Pellicer Beltran, Rodrigo, Barcelona, Spain.
Percival, Colin A., Sheffield.
Perera, Lekamage A. R., Pannipitiya, Sri Lanka.
Perera, Welliwattage P. R., Pannipitiya, Sri Lanka.

Perez Segarra, Montserrat, Barcelona, Spain.
Peto-Shepherd, Michael D., London.
Phillips, Jean M., Hong Kong.
Pickett, Diana J., Waterlooville.
Pierre, Robert E, La Jolla, U.S.A.
Pierre, Rosemary J., La Jolla, U.S.A.
Pong, Hilda M. M., Hong Kong.
Posner, Lorraine E., Woodford Green.
Prosser, Phillip M., Upper Hutt, N.Z.
Protopopoff, Monica, Beecroft, Australia.
Ranabahu, Mallikage K. T. S., Ratnapura, Sri Lanka.
Raths, Isabelle M., Almeria, Spain.
Rerolle, Jean-Claude, London.
Revert Guillart, Teresa, Barcelona, Spain.
Rhodes, Alexandra M., London.
Rich, Leonard, Manchester.
Rich, Louise R., Manchester.
Ro, Yosetsu, Tokyo, Japan.
Roberts, Kassandra, Bromborough.
Robertson, Melanie A., Guildford.
Roos, Beatrice M., Lucerne, Switzerland.
Rosen, Peter M., Stanmore.
Rosier, Jane L., Thorpe-le-Soken.
Roux, Isabeau R., Cape Town, S.Africa.
Rubera, Anthony N., Dehiwela, Sri Lanka.
Ruiz Vazquez, Christina, Barcelona, Spain.
Ruud, Paul, Drammen, Norway.
St Amand, Mary J., Mill Valley, U.S.A.
Salloway, Nigel J., London.
Santaularia Junyent, Ma Lourdes, Barcelona, Spain.
Sarath, Karunakalage, Ambalangoda, Sri Lanka.
Sarid, Smadar, Chorleywood.
Scales, Jacqueline C., Dunstable.
Schwan, Susanne, Pforzheim, W.Germany.
Schyllander, Anna M., Lidingö, Sweden.
Seaman, James S., Brookfield, U.S.A.
Selmon, Simon, Northwood.
Serra I Castella, Xavier, Barcelona, Spain.
Shah, Chandi R., Nairobi, Kenya.
Shajahan, Ismet K., Colombo, Sri Lanka.
Shannon, Heather, Ottawa, Canada.
Shau, Ying, Hong Kong.
Shaw, Constance H., Toronto, Canada.
Shepherd, Niall C., Poynton.
Shimomura, Seisaku, Tokyo, Japan.
Shivaji, Renuka, Edinburgh.
Sibblies, Howard St L., London.
Silvela Canosa, Jesús A., Barcelona, Spain.
Simon, Patrizia, Idar-Oberstein, W.Germany.
Sin, Shiu K., Kowloon, Hong Kong.
Singh, Janaki, Paris, France.
Sirkiä, Paula I., Pori, Finland.
Sivarajasingham, Tharmarajah, Kelang, W.Malaysia.
Smiley, Laurianne, Clondalkin, Ireland.
Smith, Frank K. T., Oldham.
Smith, Jackie E., Cumbernauld.
Smith, Raymond, Ponteland.
Smith, Vaughan A., Aldershot.
Snell, Keith H., Maghull.
Solis Mariscal, Ma Angeles, Barcelona, Spain.
Somasiri, Asurappulige S., Thulhiriya, Sri Lanka.
Soni, Sara, London.
Soriano Meler, Esther, Barcelona, Spain.
Specterman, Andrew M., Manchester.
Speed, Graham C., Slough.
Steert, Ineke, Amsterdam, Netherlands.
Steinhauer, Mary H, Adelphi, U.S.A.

Stephens, Gareth O., Auckland, N.Z.
Stern, Ngoc T., London.
Stewart, Robert M., Swanmore.
Stimler, Stuart I., Harrow.
Strøm-Blakstad, Torilo, Moss, Norway.
Suarez Corbato, Teresa, Barcelona, Spain.
Subiros Domingo, Bernadette, Barcelona, Spain.
Summersgill, Susan M., Warrington.
Susinno, Marie H., Rockville, U.S.A.
Suzuki, Yuko, Tokyo, Japan.
Takakura, Momoyo, Tokyo, Japan.
Takamura, Kozue, London.
Tam, David C. C., Kowloon, Hong Kong.
Tan, Hup F., Singapore.
Tate, Stephen J., Farnham.
Tate, Yvonne, Farnham.
Taylor, James D., London.
Taylor, Timothy C. H., London.
Termier, Françoise, London.
Termier, Jean P., London.
Tether, John G. G., Lusaka, Zambia.
Thavat, Paul, Auckland, N.Z.
Thomson, Ian C., Dumfries.
Thomson, Pearl J., New Barnet.
Tiainen, Kauko K., Hämeelinna, Finland.
Tielinen, Tapio T., Hämeenlinna, Finland.
To, Matthew K. H., Hong Kong.
Toivainen, Heidi S., Helsinki, Finland.
Tomas Martin, Isabel, Barcelona, Spain.
Tomasella, Yves, Douai, France.
Tong, Kwong K., Hong Kong.
Townson, Peter R., London.
Torode, Carl F., Gillingham.
Trickey, Sheila A., Henley-on-Thames.
Trueman, Laraine M., Stafford.
Tsuda, Takashi, Osaka, Japan.
Tsui, Carol, Kowloon, Hong Kong.
Tsui, Juliana Y. W., Hong Kong.
Tsuji, Takao, Saga, Japan.
Turk, Noriko, Hong Kong.
Turley, Warren J., Stafford.
Tuokko, Marjo A., Helsinki, Finland.
Vaintola, Eevaleena, Hämeenlinna, Finland.
van Deijl, Wilhelm M. E., Bloemfontein, S.Africa.
van Deijl, Willem L., Parow, S.Africa.
van Stockkom, Francisca A. J. A., Dongen, Netherlands.
van Veltzen-Ritmeÿer, Elisabeth T. H., Rotterdam, Netherlands.
Vedeler, Nina, Hosle, Norway.
Venemans, Anne C., Schoonhoven, Netherlands.
Vidal Noguera, Francisco, Barcelona, Spain.
Virani, Nilesh A., Bombay, India.
Virtanen, Juha, Helsinki, Finland.
Waghela, Mahesh R., Bombay, India.
Warren, Timothy D., London.
Waterworth, Eileen, Hong Kong.
Watson, Dermot, Belfast, N.Ireland.
Watson, Gordon, Lanark.
Watson, Pauline E. A., Dorking.
Wear, William F., Bedford.
Weber, L., Breda, Netherlands.
Weerasekera, Cheryl C., Colombo, Sri Lanka.
Weerasuria, Ajith H., Colombo, Sri Lanka.
Wells, Bruce I., Glasgow.
Weston, Anne E., London.
Wetten, Veronica F. K., Hong Kong.
Whatley, David G., London.
Wibbens, Casandra, Schoonhoven, Netherlands.
Wickramasinghe, Rohan H., Colombo, Sri Lanka.
Wigbout, Olga C., Leeuwarden, Netherlands.
Wigley, Reginald H., Hong Kong.

Wijekoon, Sumeda K., Halgranoya, Sri Lanka.
Wijenayake, Meththananda D., Nugegoda, Sri Lanka.
Wilkins, Kenneth E., Christchurch, N.Z.
Williams, Paula R., London.
Wittin, Shirley J., Birmingham.
Wojda, John A., Whitchurch.
Wong, Josha C. C., Hong Kong.
Wong, Dorothea S., Hong Kong.
Wong, Kin W., Kowloon, Hong Kong.
Worp, Paulien, Almelo, Netherlands.
Wright, Mary, Lymm.
Yamasaki, Kazutaka, Kochi, Japan.
Yoshino, Mariko, Tokyo, Japan.
Yuen, Yau T., Hong Kong.
Zain, Zahari, Birmingham.
Zappa, Chrissanthe, North Cheam.
Zarzuela Mondaray, Ma Jesus, Barcelona, Spain.
Zwikker, Marijke, Nijmegen, Netherlands.
Zylstra, Christine, Schoonhoven, Netherlands.

COUNCIL MEETING

At the meeting of Council held on Tuesday, 22nd September, 1981, at Saint Dunstan's House the following were elected to membership:

FELLOWSHIP

Bennett, Sharon L., Little Marlow. 1981
de Silva, Carmel L., Morden. 1979
Machlup, Peter M., Johannesburg, S. Africa. 1979
Parry, Sarah, Wadhurst. 1981
Potter, Brian S., London. 1981
Prince, Ann-Elise, London. 1981
Salakian, Silva, Salisbury, Zimbabwe. 1979
Troth, Peter D., Jersey. 1981
Trueman, Laraine M., Stafford. 1981
Yoshida, Katsuji, Wakayama, Japan. 1980.

TRANSFERS FROM ORDINARY MEMBERSHIP TO FELLOWSHIP

Absalom, Christine S., Effingham. 1981
Acheson, Michael A., Geneva, Switzerland. 1981
Ahmad, Zaheer, London. 1981
Akizuki, Haruo, Ichikawa, Japan. 1981
Aliprandi, Riccardo, Rome, Italy. 1981
Beevers, Jacintha M., Hong Kong. 1981
Boorman, Robert F., Bisley. 1981
Boyes, Richard W., Garston. 1981
Caffoor, Ali A., Banjul, Gambia. 1981
Currie, Lynnette J., Manurewa, N.Z. 1981
Darracott, Britt-Marie, London. 1981
Davis, Robert J., Margate, Tas., Australia. 1981
Dolleslager, James T., Houston, Tex., U.S.A. 1981
Freeman, Darlene M., Belmont, Ca, U.S.A. 1981
Furse, Anna A., London. 1981
Grant, Judith M., Carmel, Ca, U.S.A. 1981
Hamada, Shiko, Suita-City, Japan. 1981
Hermans, Johannes S., Delft, Netherlands. 1981
Hinde, Rosemary J., Hong Kong. 1981
Horton, David R., London. 1981
Houseago, James A., Lowestoft. 1981

Hutchinson, Marjorie E., London. 1981
Kageyama, Chiyomi, Hyogo Pref., Japan. 1981
Kano, Shinzo, Toyonaka, Japan. 1981
Keuskamp, Diederik, Streefkerk, Netherlands. 1981
Kinoshita, Kazuko, Ashiya, Japan. 1981
Kita, Masako, Fukuoka, Japan. 1981
Kobayashi, Yuko, Tokyo, Japan. 1981
Kosik, Thomas A., Arlington, Va, U.S.A. 1981
Kothari, Rajan S., Bombay, India. 1981
Kröger, Carol M., Rio de Janeiro, Brazil. 1981
Lambley, Jenifer G., Hong Kong. 1981
Laurie, Amanda, Bicester. 1981
Littlejohn, Gordon H., Tunbridge Wells. 1981
Livstrand, Ulf R., Saltsjobaden, Sweden. 1981
McKellar, John R., Presteigne. 1981
Maeda, Katsutoshi, Fukuoka, Japan. 1981
Masuda, Masami, Shizuoka, Japan. 1981
Mizushima, Nobuhiro, Osaka, Japan. 1981
Mourad, Huguette, Beirut, Lebanon. 1981
Nakamura, Masanori, Osaka, Japan. 1981
Nakao, Kazuya, Wakayama, Japan. 1981
Nakayama, Keichi, Komatsushima, Japan. 1981
Nojiri, Masatomi, Fukuoka, Japan. 1981
Ohno, Hiroko, Tokyo, Japan. 1981
Okuda, Makoto, Osaka, Japan. 1981
Otsuka, Nobuko, Tokyo, Japan. 1981
Parcel, Rodney F., Jr, Perris, Ca, U.S.A. 1981
Pattni, Pravin, London. 1981
Peebles, Kathleen W., Johannesburg, S. Africa. 1981
Podsiadly, Maria, Birmingham. 1981
Quincey, Mary E., Rugby. 1981
Rademaker, Jaap, Baarn, Netherlands. 1981
Ro, Yosetsu, Tokyo, Japan. 1981
Ruplinger, Peter K., Sandy, Utah, U.S.A. 1981
Ryan, Margaret E., Hong Kong. 1981
Shimomura, Seisaku, Hiroshima Pref., Japan. 1981
Singleton, Graham S., Cardigan. 1981
Spooner, Carole A., Wokingham. 1981
Swain, Anthony P., Deganwy. 1981
Swersky, Ann H., Ramat Hasharon, Israel. 1981
Thorne, Deirdre, Salisbury, Zimbabwe. 1981
Williams, Bruce M., Walla Walla, Wash., U.S.A. 1981
Wong, Kitty, Hong Kong. 1981
Yamamoto, Kazui, Fukuoka, Japan. 1981
Yenson Chu, Mabel, Hong Kong. 1981
Yoshino, Mariko, Tokyo, Japan. 1981

ORDINARY MEMBERSHIP

Abi-Habib, Cynthia S., Riyadh, Saudi Arabia.
Amini, Soraya, London.
Anand, Shalini, Bombay, India.
Andrews, Clive G., Selsdon.
Ashworth, Ian E., Bristol.
Austin, William E., Colton, Ca, U.S.A.
Bahtiarian, B. Alex, Englewood, N.J., U.S.A.
Baxter, Gordon E., Whangarei, N.Z.
Beech, Georgina, Manchester.

Beeson, Ronald H., Bexleyheath.
Benham, Robert M., Fair Grove, Mo., U.S.A.
Bernheiser, Charles A., Mohrsville, Pa, U.S.A.
Berthelsen, Lawrence J., Townsville, Qld, Australia.
Bickley, Kerry B., Pretoria, S. Africa.
Booker, Martin, Chester.
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Broad, Arline E., Thames, N.Z.
Bruner, Samuel S., Springfield, Pa, U.S.A.
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Burrill, Douglas, Sintaluta, Sask., Canada.

Chan, Chan-Kuen, Hong Kong.
Chan, Lai K. R., Hong Kong.
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Davidson, Christopher R., Nairobi, Kenya.
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De Silva, G. Ranjan, Singapore.
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Gaw, Rossana W., Hong Kong.
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Mughal, Abdul G., Abu Dhabi, U.A.E.
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Murton, John, Townsville, Qld, Australia.
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Ngan, Hon Ming, Hong Kong.
Nicolaides, Despina, Astoria, N.Y., U.S.A.
Nivera, Divina G., Hong Kong.
Ousley, Mitchell D., Birmingham, Ala, U.S.A.
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Petrides, Demosthenes, Hamburg, W. Germany.
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Poon, Eileen O., Hong Kong.
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Pritchard, David A., London.
Ratliff, David I., Townsville, Qld, Australia.
Rebuck, Craig N., London.
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Shein, Leone, Johannesburg, S. Africa.
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Tomasella, Yves, Bouglon, France.
Tremain, Geraldine, Hong Kong.
Tsui, Carol, Hong Kong.
Upperton, Lesley J., London.
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Whitehead, Wendy I., London.
Williams, Paula R., London.
Wong, Ngiam C., Singapore.
Woo, Po Kun A., Hong Kong.
Yakoob, Elias A., Karachi, Pakistan.
Yates, Holly E., Ft Lauderdale, Fla, U.S.A.

GOLDEN JUBILEE CELEBRATIONS

On Sunday, 4th October, 1981, a reception was held at the Institute of Geological Sciences in Kensington. The main Hall, containing a magnificent collection of rough and polished gemstones and other minerals, was filled to capacity by over 600 gemmologists from all over the world—nearly all Fellows of the Association—and during the proceedings the President, Sir Frank Claringbull, presented Mr Richard T. Liddicoat, Jr, Hon. F.G.A., President of the Gemological Institute of America, and Mlle Dina Level, Hon. F.G.A., late of the Laboratoire des Pierres Précieuses et Fines et des Perles, Paris, with their Fellowship Diplomas after first introducing them to the assembled company with a felicitous speech of welcome, to which the two Honorands made suitable replies.

On Monday, 5th October, 1981, H.R.H. the Duke of Gloucester opened the Association's exhibition, 'Fifty Years of Gemmology', at Goldsmiths' Hall at a private view in the evening attended by upwards of 600 members. The exhibition was open to the public from 6th to 16th October and was attended by over 3000 visitors. A 76-page Souvenir Catalogue of the Exhibition, containing also a history of the Association and a complete list of all who obtained the Diploma in Gemmology by examination from 1913 to 1980, is available from the Association. The price in the U.K. is £3.10 (including postage and packing) and abroad £3.25 by surface mail or £4.50 by air mail.

In the mornings of Monday, Tuesday and Wednesday, 5th-7th October, lectures were delivered to large audiences of 500 and more in the Great Hall of Kensington Town Hall. The substance of the lectures by Mr B. W. Anderson on the Monday and by Mr R. T. Liddicoat and Mr Robert Crowningshield on the Wednesday was published in the October *Journal* (B. W. Anderson, *The Growing Pains of Gemmology,* J.Gemm., 1981, XVII (8), 515-21: R. T. Liddicoat, *A Brief Summary of Gemmological Instrument Evolution,* J.Gemm., 1981, XVII (8), 570-85: R. Crowningshield and K. Nassau, *The Heat and Diffusion Treatment of Natural and Synthetic Sapphire,* J.Gemm., 1981, XVII (8), 528-41). The substance of Dr Edward Gübelin's lecture on the Tuesday on 'The Significance of Mineral Inclusions in Diamonds' will be reproduced in a future issue of the *Journal.*

On the Tuesday evening there was a boat trip on the River Thames with a buffet meal and dancing. During the journey, a commentary was given on places of interest.

An anniversary dinner was held in the Captain's Room at Lloyds during Wednesday evening when 300 people attended. The Chairman of the National Association of Goldsmiths, Mr Peter Hopper, F.G.A., presented Mr Callaghan, on behalf of the Association, with a magnificent badge of office (see pp. 105/6 below). The speakers were Mr John Pyke, F.G.A., President of the N.A.G., Mr Richard T. Liddicoat, F.G.A., President of the Gemological Institute of America, and the Chairman, Mr David Callaghan, F.G.A.

A second dinner was held on Friday evening in the Captain's Room, when over 250 were present and the principal speakers were Mr Karl Lauvland, F.G.A., Mr Arthur B. Monnickendam and the Chairman. During the evening Mr Oivind Modahl, on behalf of the Norwegian Gemmological Association, presented the Association with a quartz crystal group containing crystals of the rare mineral anatase.

ANNUAL REUNION OF MEMBERS AND PRESENTATION OF AWARDS

The Annual Reunion of Members was held at Goldsmiths' Hall on Monday, 16th November, 1981, and will be more fully reported in the April *Journal.*

PRESENTATION OF AWARDS IN HONG KONG AND TOKYO

The presentation of awards in Hong Kong on 3rd November, 1981, and in Tokyo on 7th November, 1981, will be more fully reported in the April *Journal.*

CHAIRMAN'S BADGE OF OFFICE

To mark the 50th anniversary of the Gemmological Association, the National Association of Goldsmiths commissioned a badge of office for the Chairman.

The badge is a striking but simple design in 18 carat yellow and white gold with bevelled millegrain edges, which are designed to resemble the facets of a cut gemstone. At the top of the design is the coat of arms of the N.A.G., with a textured loop entwined with a diamond loop suspended below it. The diamond loop encloses the larger enamelled coat of arms of the Gemmological Association.

The design symbolizes the close ties between the two Associations and illustrates the G.A.'s origins within the N.A.G., while showing that it grew to become a large and important organization in its own right. Setting off the design is a background of black oxidized gold which highlights the colourful G.A. arms. The total effect is a highly individual one, simple and classic.

Four designers were asked to submit proposals for the badge, and the design chosen is by Michael Laing, of Edinburgh.

The badge was presented to the Chairman, Mr David Callaghan, by Mr Peter Hopper, Chairman of the N.A.G., at the Golden Jubilee Celebration Dinner on 7th October, 1981.

F.G.A. TIE

The new Fellowship tie (see J.Gemm., 1981, XVII (8), 645) is illustrated on p. 106. Prices are now as follows:

U.K. (including postage and V.A.T.)	£4.70
Overseas (including Air Mail)	£4.60

TWO-DAY COURSES—COACHING FOR PRACTICAL EXAMINATION

Mr Alan Hodgkinson, F.G.A., announces two-day courses of individual coaching for the Diploma Practical Examination, with morning sessions involving the setting of an exact replica of the format of the Practical Examination and afternoon sessions looking at the student's performance and showing various ways to improve it, with specific help in the areas requested. Time will be given to showing the techniques of answering the questions and obtaining maximum potential in both practical and theoretical sections. Students will be 'paired', to allow maximum time for practical preparation and coaching, and the two-day sessions will run between mid-May and mid-June. Cost per person for the two-day course will be £100 plus V.A.T. Applications to join the courses should be addressed to Mr Hodgkinson at 2 Hillview Drive, Clarkston, Glasgow, G76 7JD [Telephone: (041) 638 8888].

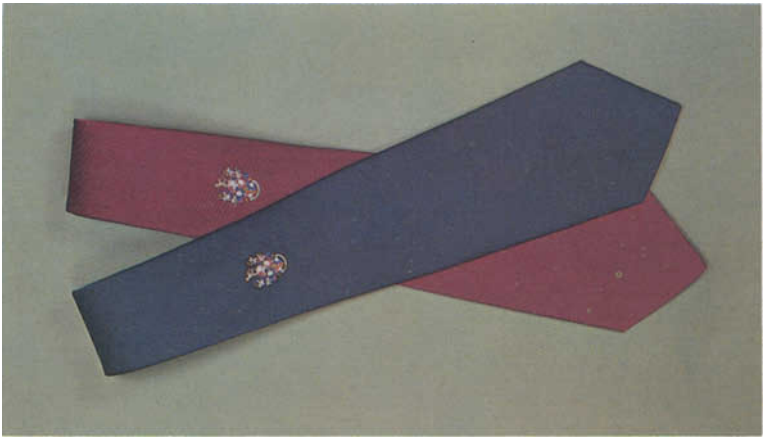

Left. The Chairman's Badge of Office, designed by Michael Laing, of Edinburgh, and made by Padgett and Braham Ltd, of London. (See p. 105).
Right. F.G.A. Ties. (See p. 105).

XVIIIth INTERNATIONAL GEMMOLOGICAL CONFERENCE

The XVIIIth International Gemmological Conference held in Japan from 8th to 13th November, 1981, will be more fully reported in the April *Journal.*

INDEX FOR VOLUME XVII

The Editor regrets that owing to difficulties in communications due to the recent severe winter weather it has not proved possible to have the Index ready in time for issue with this number of the *Journal.* It will therefore be issued with Part 2 in April.

LETTER TO THE EDITOR

From Mr R. Keith Mitchell, F.G.A.

Dear Sir,

Mr Philip Jerome's interesting find of old 'gem-oriented' newspaper cuttings, described in your July issue,* brings back memories.

He queries what happened to the gems stolen from the old Geological Survey Museum in Jermyn Street, in August 1933. I remember the occasion well. The thief was said to have secreted himself in the Museum when it closed, robbed the display case, and broken out of the Museum. A man was apprehended a few days later.

The theft was reported in the September issue of the *Gemmologist,* and an account of the magistrate's hearing, when the accused elected to be tried by jury, was printed in the November issue. On November 21st Harold Joseph Bennett, 33, a glazier, was sentenced to 17 months hard labour for receiving some of the gems, which he said he had found. He was found not guilty on the charge of breaking out of the Museum. During the hearings adverse comments were made on the part played by some Trade personalities, especially in view of low prices paid and the apparent haste with which some of the stones were recut.

Most of the larger gems were eventually restored to the Museum and are probably still in their public display today. This is, of course, at South Kensington, for they moved from the Jermyn Street site shortly after the theft. There is some mystery about the five-coloured tourmaline, which does not appear in the schedule of gems stolen and is certainly not among those regained. I suspect that the newspapers got hold of the statement that five (different) coloured tourmalines were stolen.

Yours etc.,
R. KEITH MITCHELL

18th August 1981.
Orpington, Kent.

*J.Gemm., 1981, XVII (7), 450-4.—Ed.

CORRIGENDA

In J.Gemm., 1981, XVII (8), on p.588, line 14, for 'parallel' read 'vertical' and on p.627, line 5, for 'The' read 'They'.

GEM TESTING EQUIPMENT

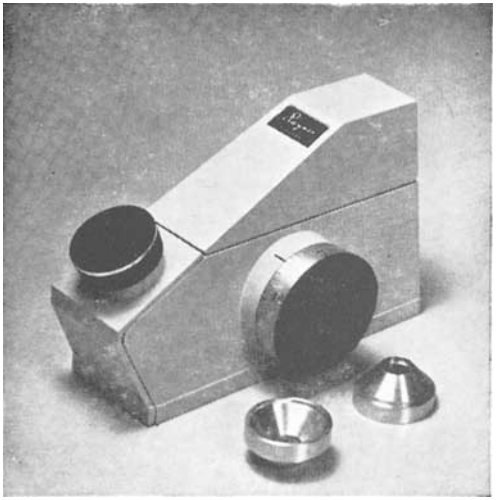

For details and illustrated catalogue write to

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Historical Note

The Gemmological Association of Great Britain was originally founded in 1908 as the Education Committee of the National Association of Goldsmiths and reconstituted in 1931 as the Gemmological Association. Its name was extended to Gemmological Association of Great Britain in 1938, and finally in 1944 it was incorporated in that name under the Companies Acts as a company limited by guarantee (registered in England, no. 433063).

Affiliated Associations are the Gemmological Association of Australia, the Canadian Gemmological Association, the Gem and Mineral Society of Zimbabwe and the Gemmological Association of Hong Kong.

The *Journal of Gemmology* was first published by the Association in 1947. It is a quarterly, published in January, April, July, and October each year, and is issued free to Fellows and Members of the Association. Opinions expressed by authors are not necessarily endorsed by the Association.

Notes for Contributors

The Editor is glad to consider original articles shedding new light on subjects of gemmological interest for publication in the *Journal.* Articles are not normally accepted which have already been published elsewhere in English, and an article is accepted only on the understanding that (1) full information as to any previous publication (whether in English or another language) has been given, (2) it is not under consideration for publication elsewhere and (3) it will not be published elsewhere without the consent of the Editor.

Articles published are paid for, and any number of prints of individual articles may be supplied to authors provided application is made on or before approval of proofs. Current rates of payment for articles and terms for supply of prints may be obtained on application to the Secretary of the Association.

Although not a mandatory requirement, it is most helpful if articles are typed (together with a carbon copy) in double spacing on one side of the paper, with good margins at sides, top and foot of each page. Articles may be of any length, but it should be borne in mind that long articles are more difficult to fit in than short ones: in practice, an article of much more than 10 000 words (unless capable of division into parts or of exceptional importance) is unlikely to be acceptable, while a short note of 400 or 500 words may achieve early publication.

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No. 1
January, 1982

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THE JOURNAL OF GEMMOLOGY

and

PROCEEDINGS OF THE GEMMOLOGICAL ASSOCIATION OF GREAT BRITAIN

GEMMOLOGICAL ASSOCIATION OF GREAT BRITAIN

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(A)MUSING ON PEARLS PEOPLE AND POETRY

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Alexander Selkirk's soliloquy on his life on a desert island by W. Cowper—so well portrayed by Daniel Defoe's book *Robinson Crusoe*—contains the lines '...better dwell in the midst of alarms than reign in this horrible place'.

In retrospect, in retirement, I have dwelt upon such lines, fortunately in happier vein than poor Selkirk. My own choice might have been 'Far from the madding crowd' (of commuters?).

This well-known incomplete quotation from Gray's *Elegy* is one of many from that fine poem. Another quotation, 'Full many a gem of purest ray serene the dark unfathomed caves of ocean bear', is a most apt gemmological line. In their monumental work *The Book of the pearl*,* Kunz and Stevenson use these lines to emphasize the longevity of diamonds and rubies whereas pearls may 'be born to live and die unseen'; such is their fate. They state that 'probably only a small percentage of pearls produced gladden the sight of man'.

**The Book of the Pearl*, by George Frederick Kunz and Charles Hugh Stevenson: Macmillan & Co., London, 1908.

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Having dipped and delved into this superb book, first published in 1908, I felt pleased that I had not erred in my own independent choice of that phrase. The study of the structure and formation of pearl, and that of its cultured counterpart, inadvertently set in motion today's gemmological knowledge in our trade.

Having been without a telephone for a few months, I have had to resort to more letter writing than usual. My friends and colleagues, presently working and/or retired, may well have noticed some repetition of what I call 'news' and others term 'shop'.

One very pleasant letter from that renowned gemmologist, F. S. H. Tisdall, in an elegant hand despite his eighty plus years, dwelt upon some aspects of gemmology, chiefly colour and the use of the 10 × lens—we have much in common in our appreciation and approach to gem testing.

Another letter, from R. K. Mitchell, mused upon the Laboratory and its problems. Mitchell, a Tully Medallist of 1934, was a contemporary of Robert Webster, and has been a life long friend of us all in the Laboratory. I was interested a day or two later, to read in my copy of the *Journal** his article *Some fallacies of Gemmology,* and equally pleased to note his observations in it on dichroism in tourmaline. I have sometimes noted curved structure lines in synthetic rubies when viewed through a dichroscope. In such cases I was establishing random orientation of cutting as an additional check against the optical correct cutting of natural ruby—a useful point in cases where little can be deduced due to rubbed surface, no microscope, no x-ray phosphorescence, but the eye tells you by the *first impact of colour* that 'here is a doubtful stone'.

The dichroscope, like the 10× lens and what I term the 'Chelsea filter', can provide much useful information. As well as being simple, they are extremely manoeuvrable, unlike x-ray sets or zoom-lens binocular microscopes.

In the same *Journal* I read of the demise of one of the characteristics taught in my day—that of the Beilby layer—but what started me dwelling upon the madding crowds of gemmology was the article entitled *An unusual pleochroism in Zambian*

*J.Gemm., XVII (7), July, 1981.—Ed.

Emeralds. In this article by Dr Karl Schmetzer and Prof. Dr H. Bank, they discuss colour causes and quote 'normal' emerald and its chromium content. Zambian emeralds, they say, have a *normal* chromium spectrum but superimposed on it is that of the aquamarine (iron) spectrum.

I like to see and read articles by such authorities mentioning chromium spectra as in normal emeralds. It is true that I am an advocate of 'chromium as a criterion for emeralds'. When working in a busy laboratory for tradespeople, it is useful to have a yardstick or level to measure by or start from. The 'quality' does not matter; that financial aspect can be safely left to the competent merchants who buy, sell and exist by their financial judgement.

Thus the scent of chromium sparked off my musing upon this madding crowd. In similar vein I read with relish in *Gems and Gemology* (Vol. XVI, No. 10*, pp.321-2, Summer 1980) an article by Bob Crowningshield of the New York Laboratory, on the difficult colour determination of a blue-green beryl. He ended his description as follows: 'With the *chromium* we felt it had to be considered emerald'. This is what I consider to be an unsolicited testimonial to the 'chromium as a criterion for emerald' cult from a source which does not normally subscribe to this particular requirement.

On the question of colour, the use of colour charts to decide ruby, pink sapphire, green beryls of fine colour (with the desire to give them the accolade of emerald), to me is a *bête noire.*

Being free or far from the madding crowd has its compensations in that one can, as a practical, experienced, trade gemmologist, give opinions which are not necessarily in line with protocol or requirements of a director of a laboratory. One feels free. In similar vein, being very recently a grandfather one can now enjoy the delights of parenthood, but if fractious behaviour occurs, one can readily relinquish the reins and avoid being left holding the baby!

So that, far from dwelling in the midst of alarms, I am happy in my retirement from the madding crowd, writing, if not pearls of wisdom, at least something of and around our mutual interest—gemmology.

[*Manuscript received 26th August, 1981.*]

*The Summer 1980 issue, though in fact No. 10, bore 'Number 9' in the contents page (p.289).—Ed.

'TAPROBANITE' IS TAAFFEITE

By R. KEITH MITCHELL, F.G.A.

For some time a gem, hailed as a new mineral from Sri Lanka and named tentatively 'taprobanite' after an early name for that island,* has caused some excitement among a select few of the world's leading gemmologists.

This material, known so far in two faceted gems only, was analysed by electron probe techniques, which, although very accurate and efficient even for microscopic fragments of a mineral, have the enormous advantage of leaving the test specimen completely unaltered and undiminished. These analyses proved that this 'new' mineral, which has been found only in red and orange colours, has a composition of $MgO + Al_2O_3 = 95\%$, leaving only 5% of BeO; and unit cell dimensions of $a \approx 5.7$Å and $c \approx 18.3$Å.

These results are fairly close to, but certainly not identical with, the analysis of the first known taaffeite carried out by Dr Max Hey in the early 1950s. Dr Hey was working by normal chemical means and with what was then considered to be a very small amount of material, a mere 0.03 carat, and on this he reached an approximate estimate of $MgO + Fe_2O_3 + Al_2O_3 = 89\%$ with BeO 11%. The cell measurements were $a = 5.72$Å and $c = 18.38$Å.

On the death of Count Taaffe in 1967, I was offered his entire stock of stones, most of which were small and of little interest, contained in 44 boxes each crammed with stone papers, totalling several thousand in all. Since the remainder of the type specimen of taaffeite was among these and could not be bought separately, I bought the lot with the principal idea of preventing this important stone from falling into commercial hands where it might be sold and lost to public view. In pursuance of my original idea I later arranged for the stone to be put on long term loan with the Institute of Geological Sciences on the understanding that it should be displayed in their public collection in the Geological Museum.

Dr K. Schmetzer, of Heidelberg University, has been concerned with the investigation of the taprobanites and he wished

*E. Gübelin, Neue Edelsteine aus Sri Lanka. *Z.Dt.Gemmol.Ges.*, 1979, 28(4), 194-6.—Ed.

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to compare these with the original taaffeite, using the modern and more accurate non-destructive electron probe tests. The I.G.S. sought my permission and it was arranged that the stone should be sent via Prof. Dr Hermann Bank, of Idar Oberstein, to Dr Schmetzer.

The latter gentleman has now confirmed beyond reasonable doubt that taaffeite and taprobanite have the same chemical composition and the same unit cell measurements and crystal symmetry.* So they are one mineral, and taprobanite, as a new mineral, does not exist.† This means that there is no reason whatsoever to alter the original name of taaffeite, given to it in honour of Count Taaffe who, in 1945 with little more than a low-powered dissecting microscope for equipment, found what he concluded, correctly, was a new mineral.

The type specimen is now back on display in the I.G.S. Museum. Readers may also see the second of the discovered taaffeites in the Mineral Gallery of the Natural History Museum, to whom it was presented by Mr B. W. Anderson. That museum has also acquired the first known crystal of taaffeite and a minute portion of this was used in Dr Schmetzer's investigation. The crystal is not on display at the time of writing.

[*Manuscript received 27th January, 1981; revised 11th January, 1982.*]

**Zur Mineralogie ternärer Oxide in System BeO-MgO-Al_2O_3*. Naturwissenschaften, 67, S471 (1981). Dr Schmetzer has asked me to add that this was a short preliminary paper only and that a further paper with much more data is in preparation.

† The Commission on New Minerals and Mineral Names of the International Mineral Association have agreed unanimously that taprobanite and taaffeite are accepted as belonging to the same species. The voting for the retention of the original name of 'taaffeite' was 15 to 1 in favour.

VISUAL IDENTIFICATION OF GILSON LAPIS

By R. KEITH MITCHELL, F.G.A.

C. A. Schiffmann has dealt in considerable detail with the scientific distinction of the Gilson lapis lazuli substitute from natural lapis.* He has not, in that paper, mentioned the fairly obvious visual differences between them.

The Gilson material is available in two main types, without pyrite inclusions and with pyrite inclusions.

The first of these is quite rare in nature and any lapis lazuli of fine colour and a very even small grain should be automatically suspect as being probably the man-made product. Acid tests would confirm this, but there are still visual tests which could be applied. These will be described below.

The other Gilson material, containing pyrite specks, is a more convincing imitation of the real stone. But, again, there are several quite easily identified visual differences when the material is closely examined under magnification.

As in the first type, the grain sizes of the substitute material are very regular, and there are no patches or veins of white or colourless calcite. Possibly the most obvious difference lies in the shapes of the pyrite fragments.

Gilson is known to have said that it is quite simple to synthesize pyrite but, with the natural mineral so plentiful, it is just not worth the expense. So he uses natural pyrite, crushed and sieved to size.

Now pyrite has only indistinct cleavage and its fracture is uneven rather than strongly conchoidal. This means that it breaks normally into quite simply shaped chunky pieces with rather smooth sides.

On the other hand, when formed in lapis lazuli, natural pyrite is found to be in exceedingly complex multiple penetration-twins of both the cube and the pyritohedron leading to immensely contorted masses despite their very small size. When cut through in polishing, these usually give outlines which are obviously far more convoluted than those of the pyrite fragments in the Gilson product. The latter are sometimes so smooth shaped that the mere act of polishing is

*J.Gemm., 1976, XV (4), 172-9.

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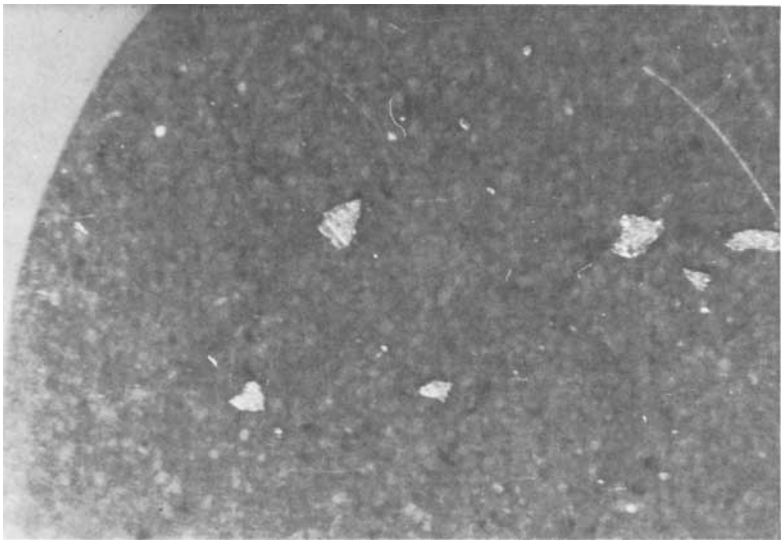

FIG. 1. Lapis lazuli substitute, showing the simple shapes of the crushed and sieved pyrite and the small regular grains of the blue matrix minerals.

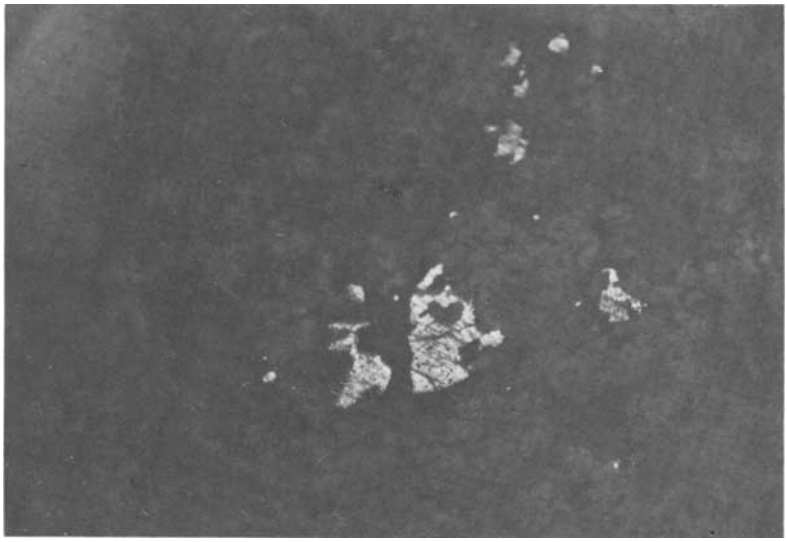

FIG. 2. A small group of pyrite in natural lapis showing the contorted outlines of these inclusions and also the large and variable grains of other minerals in the matrix.

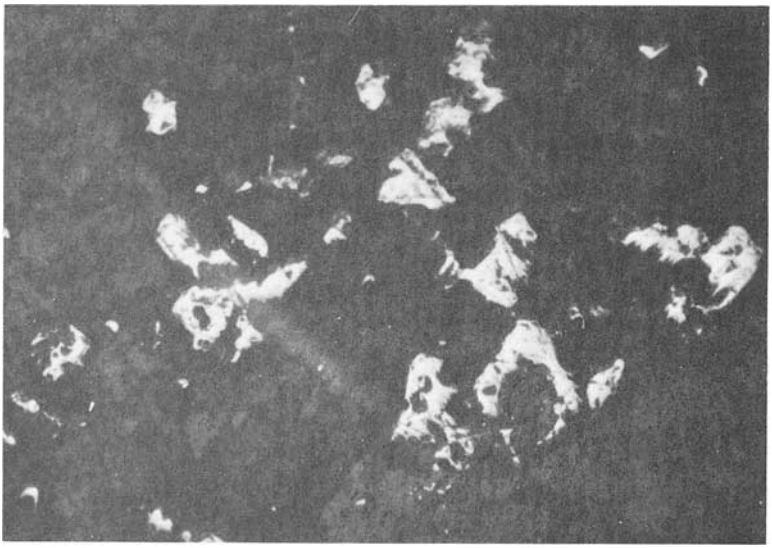

FIG. 3. Another group showing similar features to those in Figure 2. Note that in both there are pyrite inclusions which actually enclose 'lakes' of the blue matrix minerals.

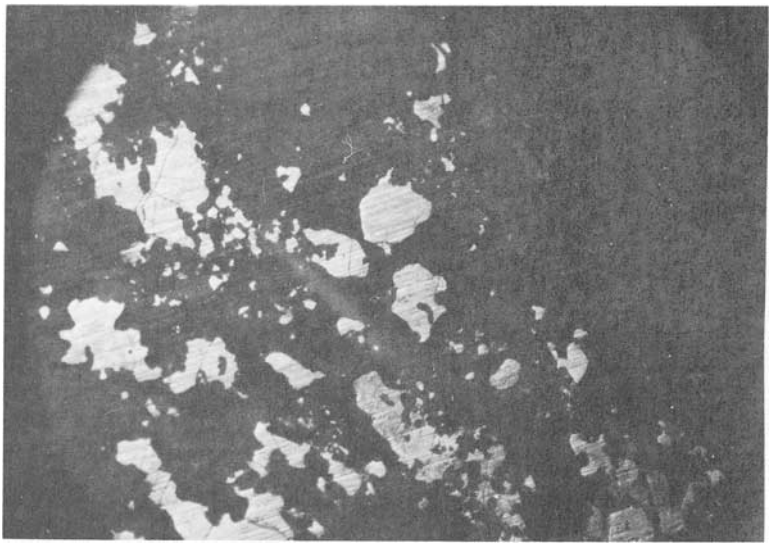

FIG. 4. A larger group of pyrite inclusions in natural lapis. Although the great majority of the specks are complex in outline, one or two can be seen which approach the simpler shapes found in the crushed material used by Gilson. On their own these could confuse, but not if the grain size of the matrix is taken into account.

sufficient to lift them out of the matrix, leaving an empty hole, possibly with a tiny fragment of the brassy mineral at its base. Figure 1 illustrates the type of pyrite inclusion to be expected in the Gilson material, although in this instance they are grouped a little more closely than is usual. In most specimens examined the distribution through the material has been very regular.

Figures 2, 3 and 4 are of pyrite inclusions in natural lapis lazuli and it will be seen that many of these are of quite fantastically contorted shapes, even, in some instances, entirely surrounding tiny 'lakes' of blue lapis in their brassy outlines. It will also be noticed that, although it is quite possible for isolated specks of pyrite to occur, in the majority of cases the mineral tends to occur in close groups or in veins. It is rarely regularly distributed through the rock in the way that it is in the Gilson substitute. Another quite noticeable feature in the natural material is the fact that the blue of the matrix is very often much deeper around the pyrite inclusions, and that the grain sizes of the blue minerals are often variable and can be comparatively large and irregular in shape. This may possibly be visible in Figures 2 and 3. Natural lapis may also show patches of white or colourless calcite, or these may occur in straight veins. Figure 4 shows polishing lines which would not be visible without magnification. The pyrite in almost all specimens examined tended to be slightly under-cut and the polish was far from perfect although the brassy mineral looked very bright. This is because the blue constituents are exceptionally soft and it is not advisable to continue polishing long enough to bring the harder pyrite to a fine polish. In the natural stones the pyrite crystals beneath the surface are still very complex in shape and are well keyed into the matrix. They scarcely ever lift out in polishing.

Another point became apparent when examining the different materials under a binocular microscope, and this applies to both the Gilson types of material. In all natural lapis it was found that areas occurred in which there was a shallow degree of transparency, probably to a depth of not more than a half millimetre, but quite obvious in the exaggerated 'depth' of stereoscopic vision given by such an instrument. The Gilson stones did not show this and were apparently quite opaque. I find that Anderson has noted this feature and the fact that the imitation does not show crystal outlines, in his ninth edition of *Gem Testing*.* However, I should

*pp.144-5.—Ed.

point out that the pyrite in natural lapis is so complex in its twinned shapes that any simple crystalline outline is rarely to be identified. But the essentially greater diversity of shape is quite marked in the natural rock.

[*Manuscript received 1st April, 1981*]

ENSTATITE FROM MAIRIMBA HILL, KENYA

By Dr K. SCHMETZER and Dr H. KRUPP

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ABSTRACT

Enstatite of yellowish green colour from the region of the Mairimba Hill, Kenya, is described. The crystals have refractive indices of $n_x = 1.652$, $n_z = 1.662$, $\Delta = 0.010$ and a density of 3.23 g/cm^3 and owe their attractive colour to a content of 1.45% FeO and 0.22% Cr_2O_3.

During a visit to Kenya in the beginning of 1981, one of the authors (H. K.) received a number of crystal fragments with a yellowish-green colour. On cutting these fragments, transparent gemstones up to 2 ct in weight were obtained. The stones were tested by optical and x-ray methods and were determined as enstatites; the chemical and physical data for these stones are given later in this paper. According to our knowledge, enstatite crystals of gemstone quality were known to occur in East Africa, up to now, only from localities in Tanzania. No data for samples from Kenya are published or available.

Enstatite is the magnesium end member of the orthopyroxene solid solution series with the general formula of $(Mg, Fe)_2Si_2O_6$. From natural samples, a complete solid solution series between the end members enstatite, $Mg_2Si_2O_6$, and orthoferrosilite, $Fe_2Si_2O_6$, is known, but only crystals with iron-contents smaller than 16.32% FeO (enstatite and bronzite) are reported to occur of gemstone

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quality. Such crystals are described from localities in Tanzania, Sri Lanka, Burma, Arizona (U.S.A.), Brazil, Mexico, and India. The samples are green, yellowish-green or brown, and sometimes stones with asterism or chatoyancy are observed (Bank 1974, 1977; Dunn 1976, 1978).

Enstatites from Tanzania are brown or green. The samples probably originate from at least two or more different localities, which are not exactly known. The following physical data of crystals from these localities are published:

	green enstatite, Tanzania Bank (1974)	yellowish-brown enstatite, Tanzania Bank (1977)	brown enstatite, Tanzania Dunn (1976)
n_x	1.665	1.654	1.653
n_z	1.675	1.664	1.663
Δ	0.010	0.010	0.010
D[g/cm^3]	3.25	3.28	3.25

The optical data mentioned above show that the green enstatites are iron-rich while the brown and yellowish-brown stones are iron-poor members of the orthopyroxene solid solution series. By electron microprobe analyses of the second group samples, iron contents of 1.89 and 2.00% FeO were found (Dunn 1976).

The enstatite crystals investigated on this occasion were found in an alluvial deposit in the Mairimba Hill region, south of the Taita Hills, southern Kenya. Other gem minerals from this locality, which occur together with enstatite, are small fragments of actinolite. The actinolites are emerald green, due to a small chromium content and resemble the chromium-actinolite crystals from Merelani, Tanzania, described by Schmetzer and Krupp (1979). Unfortunately the actinolite fragments from Mairimba Hill are so small, that cut stones of this material are not available.

The enstatite fragments of the Mairimba Hill region are yellowish-green and show a weak pleochroism between a light green and an intensive yellowish-green. Optical data and density are: $n_x = 1.652$, $n_z = 1.662$, $\Delta = 0.010$, $D = 3.23$ g/cm^3. These values show only small differences compared with the data of the yellowish-brown enstatites from Tanzania and indicate a smaller iron content in the Kenyan enstatites.

A chemical analysis of enstatite from Kenya, done with the electron microprobe, is given in Table 1. The crystal contains only a

TABLE 1

Chemical data of enstatite from the region of the Mairimba Hill, Kenya.

Analysis by electron microprobe, in weight−%		cations calculated to O = 6	
SiO_2	55.57	Si	1.894
Al_2O_3	3.60	Al	0.145
Cr_2O_3	0.22	Cr	0.006
FeO	1.45	Fe	0.041
MgO	38.27	Mg	1.945
Σ	99.11	Σ	4.031

small iron content of 1.45% FeO, but also traces of chromium (0.22% Cr_2O_3). After normalization of the analysis to O = 6, a defined crystal chemical formula is

$$(Mg_{1\cdot95}Fe_{0\cdot04}Cr_{0\cdot01})_{\Sigma 2\cdot00}\,(Si_{1\cdot89}Al_{0\cdot15})_{\Sigma 2\cdot04}O_6.$$

The percentage of the iron-free end member enstatite is calculated to 98%. A comparison of the absorption spectra of some enstatite crystals from Kenya with the absorption spectra of enstatites from different localities, given by Runciman *et al.* (1973) and Rossman (1980), shows that the attractive colour of the stones is caused by the small contents of iron and chromium replacing magnesium in the enstatite lattice.

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AN OCCURRENCE OF GEM QUALITY ELBAITE FROM GLENBUCHAT, ABERDEENSHIRE, SCOTLAND

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Tourmaline is not uncommon in many of the schists, gneisses and granites of Scotland, but until the discovery of elbaite all tourmaline to date had been described as the black, non gem-quality, ferrous iron, species, schorl.

OCCURRENCE

The elbaite locality is approximately 0.8 km due north of Peatfold Farm, Glenbuchat, Aberdeenshire. Here mica schists and phyllites are overlain by foliated diorite, epidiorite and hornblende schists. Into these are intruded granite pegmatites and aplites, which are probably related to the large granite masses to the north and south. Although there are several granite pegmatites in the surrounding area, so far only one has produced gem-quality tourmaline. This pegmatite, although obscured for the most part by overburden, is clearly indicated by linearly distributed float material, running approximately ENE-WSW, with a tongue of float on the downslope side due to creep. Within the float there is a distinct lithological variation towards its centre. The rock changes from a normal coarse-grained granite pegmatite containing microcline, quartz, muscovite, and schorl tourmaline, with minor garnet and biotite, through graphic intergrowths of quartz-feldspar and quartz-muscovite, the latter containing minor amounts of blue-black schorl, into a lithium-rich pegmatite containing clevelandite, quartz, muscovite, lepidolite, elbaite and schorl. Accessory minerals include cassiterite, columbite-tantalite, zircon, galena, albite, arrojadeite and triplite. Apart from elbaite and lepidolite no other lithium minerals, such as spodumene and amblygonite/montebrasite, were found. Some minor chalcedony veining was also evident. This mineralogical and structural variation in the float indicates that the underlying pegmatite is complex and zoned. The distribution of the elbaite throughout the pegmatite is limited, but where found it is locally abundant,

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FIG. 1. Particoloured elbaite (14 × 2 mm). *(Crown Copyright Reserved)*

occurring as hexagonal prismatic crystals in a wide range of colours from pink and mauve to various shades of green, including blue-green. Some colourless (achroite) crystals also occur. Where the matrix consists mainly of muscovite and lepidolite, the elbaite is usually pink; sometimes with a thin exterior of green elbaite giving rise to the so-called watermelon structure. All colours, including the colour-zoned watermelon and particoloured crystals, are found where the matrix contains a significant amount of exceptionally fine-grained pale green muscovite coating euhedral to sub-hedral quartz and joint surfaces. The coloured elbaite crystals, although small, are practically all of gem quality. Their average size is in the order of 8 mm by 3 mm, but gem crystals up to several centimetres (max. 4 cm) have been found (Figure 1). Many of the larger pink elbaites have an unusual cavernous core partially filled with irregular rod-like structures aligned parallel to the prismatic faces (Figure 2). It is postulated that this structure is ultimately the result of channel leaching. Later generations of elbaite, not affected by such a mechanism, have long capillary-like growth tubes running

FIG. 2. SEM photograph of rod-like structures (×45). *(Crown Copyright Reserved)*

parallel to the prismatic faces, and these, in earlier generations, could possibly have acted as pathways for later leaching solutions. The channels could, however, be a function of exceptionally well developed growth striations formed during early crystallization or even skeletal growth. Often these channels and cavities are filled with muscovite, and rarely complete replacement of the pink core of watermelon tourmaline occurs. Other inclusions include shorter densely packed growth tubes, mica and twisted veils.

Many of the elbaite crystals show rupturing across the prism, sub-parallel to {0001}. Where the fracture pieces have moved apart, subsequent regeneration is evident. Some crystals also show healing of rupture scars by a later differently coloured elbaite.

PHYSICAL AND CHEMICAL PROPERTIES

Dark blue-black, blue-green, green and pink coloured varieties were analysed using an electron microprobe, and the resultant partial analyses are presented in Table 1 (boron, lithium and oxygen cannot be detected by the microprobe).

TABLE 1
Partial analyses of tourmalines from Glenbuchat

Colour	*SiO_2*	*Al_2O_3*	*FeO*- Na_2O*	*MnO**		*CaO*	*Cr_2O_3*	*Total*	*Species*
very dark blue-black	34.83	35.51	12.73	0.92	1.35	—	—	85.33	schorl
very dark blue-black	35.51	35.40	13.42	0.91	2.04	—	—	87.28	schorl
blue-green	37.46	37.67	4.47	1.89	3.05	0.22	—	84.78	elbaite
blue-green	37.60	37.42	4.5	1.77	2.39	0.20	—	83.87	elbaite
green	37.13	37.77	4.58	1.66	2.50	0.18	—	83.82	elbaite
green	37.55	37.75	5.03	1.72	2.47	0.21	0.10	84.83	elbaite
pink	37.64	42.37	0.20	0.25	1.77	0.08	—	82.31	elbaite
pink	37.65	42.48	—	—	1.65	—	—	81.78	elbaite

*The iron and manganese content of Glenbuchat tourmaline has been calculated as divalent oxides but it may actually be in part or wholly trivalent.

These results are consistent with published data (Deer, Howie and Zussman 1963) for schorl and elbaite. The decrease in iron content is also consistent with changes in colour from blue-black through green (verdelite) to pink (rubellite).

The refractive index (RI), double refraction (DR) and specific gravity (SG) presented in Table 2 are also consistent with published data (Dunn 1975). These properties show the normal reduction in RI, DR and SG with reducing iron content. This is most noticeable

TABLE 2

Species	*Colour*	*Refractive Index*		*Double Refraction*	*Specific Gravity*
		ω	ε		
schorl	blue-black	1.660	1.630	−0.027	3.18
elbaite	blue-green	1.640	1.618	−0.022	2.988
elbaite	green	1.638	1.617	−0.021	3.039
elbaite	pale green	1.640	1.618	−0.022	2.980
elbaite	pale green	1.640	1.620	−0.020	3.047
elbaite	pink	1.630	1.611	−0.019	3.039
elbaite	pink	1.635	1.618	−0.017	3.022
elbaite	pink	1.633	1.615	−0.018	2.963

TABLE 3

Apparent Colour	*Pleochroic Colours*	
	ε	ω
dark blue-green	very pale green	blue-green
blue-green	colourless	blue-green
blue-green	pale blue-green	blue-green
blue-green	blue-green	blue-green
pale blue-green	colourless	pale blue-green
pink	colourless	pink
pink	pale pink	pink
pale pink	colourless	pale pink
purple pink	pale pink	dark pink

between schorl and elbaite with only minor variations in these physical properties between colour varieties. Table 3 gives the pleochroic colours.

CONCLUSION

The float material containing gem-quality tourmaline and indicating an underlying complex pegmatite represents a very interesting occurrence. The existing evidence indicates that the potential of the pegmatite as a gem producer is probably low, as only the very smallest of gemstones could be cut from the crystals discovered so far. Nevertheless further investigations in the area will be necessary to determine the actual nature, extent and gem-producing potential.

ACKNOWLEDGEMENT

I am most grateful to Mr Gordon Sutherland for allowing me to photograph his fine specimen of particoloured elbaite tourmaline.

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GROSSULAR GARNET FROM THE JEFFREY MINE, ASBESTOS, QUEBEC, CANADA

By WILLOW WIGHT, B.A., F.G.A., and J. D. GRICE, Ph.D.

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The Jeffrey Mine is the second largest asbestos deposit in the world. Located about 160 km east of Montréal, the Jeffrey Mine has been producing since 1881. Now owned by the Canadian Johns-Manville Company, it supplies about 13% of the world production of chrysotile asbestos (some 600 000 tonnes a year) from an open pit which measures over 275 m deep and 1250 m across. Grice and Williams (1979) have given an overview of the geology and notable minerals (at least 66 mineral species are represented) of this locality.

Grossular garnet, associated with diopside, K-feldspar and quartz, is most commonly found on granitic rocks that intrude the Jeffrey Mine ore body. The grossular varies from colourless through shades of white, pink, orange and green (Figure 1). Since about 1950, the orange-coloured variety, hessonite, has been known to mineral collectors in North America and Europe with individual crystals ranging up to 3 cm in diameter. Some have been faceted into beautiful gems. The collection of the National Museum of Natural Sciences contains gems of 24 and 14 carats

FIG. 1. Grossular garnet from the Jeffrey Mine, Asbestos, Québec, Canada. Hessonite (NMNS #20206) 8.5 ct, 13 × 11 mm.

FIG. 2. Grossular, hessonite variety (NMNS #32028) Crystal diameter is 1.3 cm.

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which are particularly noteworthy. Smaller gems in the 1-5 carat range and small crystal groups mounted in jewellery have been commercially marketed in Canada with some success.

The green grossular, which has been incorrectly reported as uvarovite, is much less abundant than hessonite. Green grossular crystals also are smaller, commonly less than a centimetre across. The one faceted gem in the National Museum's collection weighs only 0.25 carat and has many inclusions.

A few crystal specimens of colourless to pale yellow grossular have been observed at the Jeffrey Mine over the years. Recently, six faceted colourless grossular gems were brought to the National Museum of Natural Sciences by Frank and Wendy Melanson, of Hawthorneden, Bannockburn, Ontario. To our knowledge, these are the first of their kind, and they have been described by Wight and Grice (1981).

A few crystal specimens of an attractive pale pink colour are known, but no suitable faceting material has been found.

Only two crystal forms have been observed on the Jeffrey Mine grossulars: the rhombic dodecahedron d{110}, which has 12 faces, and the trapezohedron n{211}, which has 24 faces. These forms may occur independently or may be combined in the same crystal. Crystals showing both forms exhibit bright, even,

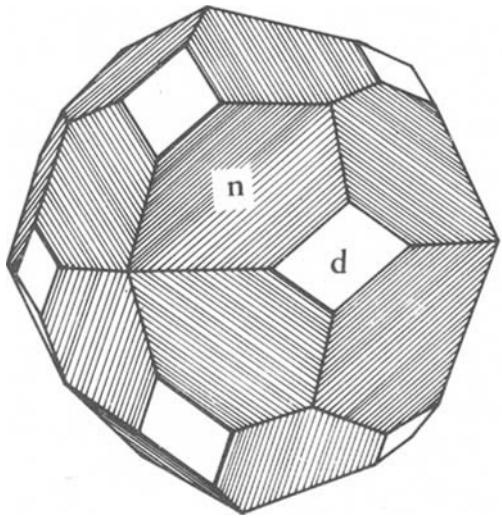

FIG. 3. Sketch of grossular crystal in Figure 2. Crystal forms are the trapezohedron n{211}, which is lined to represent striations, and the rhombic dodecahedron d{110}.

TABLE 1. Chemical Analyses of Grossular

Colour	COLOURLESS				PINK	HESSONITE		GREEN		
SPECIMEN	IDEAL	NMNS 43018	NMNS 40146 (rim)	TANZANIA*	NMNS 37489	NMNS 32755	SRI LANKA	NMNS 40146 (core)	KENYA	TANZANIA*
REFERENCE	Deer *et al.*, 1962		Grice & Williams, 1979	Muije *et al.*, 1979		Grice & Williams, 1979	Bauer, 1904	Grice & Williams, 1979	Gübelin & Weibel, 1975	Muije *et al.*, 1975
CaO	37.36	38.3	37.74	39.7	37.8	36.84	30.57	35.88	35.1	34.5
Al_2O_3	22.63	22.1	21.69	19.9	21.9	22.17	23.00	17.04	20.9	20.5
SiO_2	40.01	39.8	39.49	39.5	39.4	39.29	40.01	37.80	38.7	42.5
Na_2O		0.0	0.00		0.0			0.00	0.1	
MgO		0.0		0.1	0.0	0.00	0.33	0.03	0.5	0.3
TiO_2		0.0	0.06	0.4	0.2	0.05		1.20	0.25	0.3
V_2O_3		0.0		0.06	0.0				3.3	1.2
Cr_2O_3		0.2		0.0	0.2	0.01		6.97	0.19	0.12
MnO		0.1	0.31	0.2	0.5	0.57	0.59	0.77	0.75	0.5
FeO		0.4	0.47	0.1	0.5	1.85	3.31	0.94	0.05	0.1
Total	100.00	100.9	99.76	99.96	100.5	100.78	97.81	100.63	99.84	100.02
R.I.	1.734	1.734	1.734		1.736	1.738		1.742		
R.I. gems		1.733 (6 gems)		1.731 to 1.732		1.736 to 1.741 (7 gems)	1.753 NMNS 20213	1.738 NMNS 20619	1.739 to 1.744	

*faceted gems

dodecahedral faces while the trapezohedral faces are heavily striated (Figures 2, 3)—the result of oscillatory growth between the dodecahedral and trapezohedral forms. This oscillatory growth is also illustrated in the growth dislocation inclusions observed (Wight and Grice, 1981) in the faceted colourless grossulars.

Chemical analyses of the four different colours of grossular were performed on an electron microprobe, using an energy dispersive spectrometer for all samples except for specimens numbered 40146 and 32755 where a wavelength dispersive spectrometer was used. The results are given in Table 1, together with comparable analyses from the literature. When possible, the corresponding refractive index was determined by grain mounts in oil immersion. The refractive index of the faceted gems in the Museum's collection was measured in sodium light with a Rayner Dialdex refractometer. These values are included at the bottom of the table. All gems from the Jeffrey Mine, with the exception of the green grossular, showed anomalous double refraction and strain colour fringes when viewed between the crossed polars of a polariscope.

Chemically pure grossular, $Ca_3Al_2(SiO_4)_3$, is colourless and has a refractive index of 1.734 (Deer *et al.,* 1962). Its crystal structure is such that it readily accepts a number of cation substitutions, most frequently some elements from the first transition series of metals (titanium, vanadium, chromium, manganese and iron). With the substitution of these elements, colour is imparted to the mineral, and the colour intensity and refractive index increase proportionally with increasing amounts of these cations.

For the Jeffrey Mine grossular specimens the following observations and comparisons can be made. The colourless variety is almost pure end-member grossular with $\eta = 1.733$. This is similar to the colourless grossular from Tanzania (Muije *et al.,* 1979). A yellow tint in the Jeffrey grossular is probably caused by very minor amounts of iron. The pale pink variety contains approximately the same amount of iron as the colourless grossular (Table 1), but in addition there is a minor amount of manganese ($\sim$0.5 wt% MnO), which is likely responsible for the pink colour. With such a pale tint the refractive index does not change appreciably from that of pure grossular. The hessonite contains significant iron ($\sim$2 wt% FeO) and its refractive index has

increased accordingly. The Jeffrey hessonite is orange as compared to the Sri Lanka hessonite, which is a darker cinnamon-brown colour because of its higher iron content. This results in an even higher refractive index. The green colour and increase in refractive index of the Jeffrey Mine grossular is attributed to chromium. The analysis given in Table 1 is for a dark-green example but Grice & Williams (1979) found that as little as 0.25 wt% Cr_2O_3 imparted a pale green colour. The Jeffrey Mine chromium-bearing grossular has the same hue as the vanadium-bearing grossular from Kenya and Tanzania (Gübelin & Weibel, 1975; Muije *et al.*, 1979). The effect of titanium is uncertain but it is present in the Jeffrey Mine grossular as well as those from Kenya and Tanzania. There is no apparent correlation between titanium content and colour intensity or hue.

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FLUORITE INCLUSIONS IN TOPAZ FROM NIGERIA

By S. HORNYTZKYJ, F.G.A.

While examining colourless water-worn pebbles of topaz from Nigeria (Figure 1) under the microscope, I observed small (41μm to 595μm) transparent light yellow and light green, and transparent colourless to milky, crystal inclusions in several topaz pebbles. What the inclusions seemed to have in common was the cubic crystal system to which they belonged: they were either cubes, octahedrons and rhombic dodecahedrons or their combinations (Figures 2 to 10). The decreasing order of their abundance in the examined topaz pebbles was: (1) different combinations of cube, octahedron and rhombic dodecahedron; (2) octahedron; (3) cube; (4) rhombic dodecahedron. The inclusions occurred singly or as clusters, and the different forms and their combinations were often

FIG. 1. Part of the examined topaz pebbles from Nigeria.

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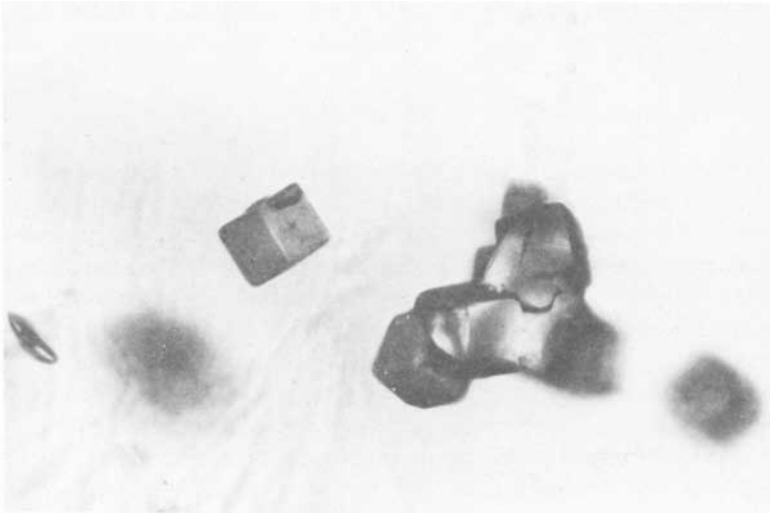

FIG. 2. Cubic fluorite inclusions in a topaz from Nigeria. (190 ×)

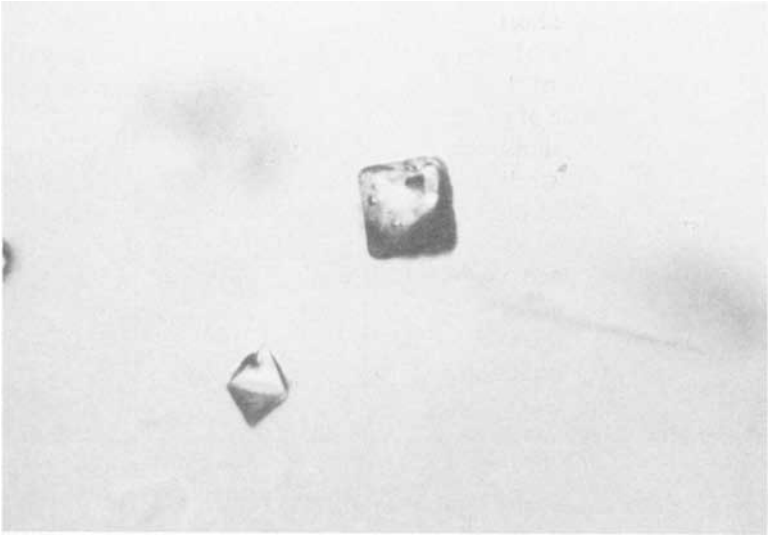

FIG. 3. Octahedral fluorite inclusions in a topaz from Nigeria. (140 ×)

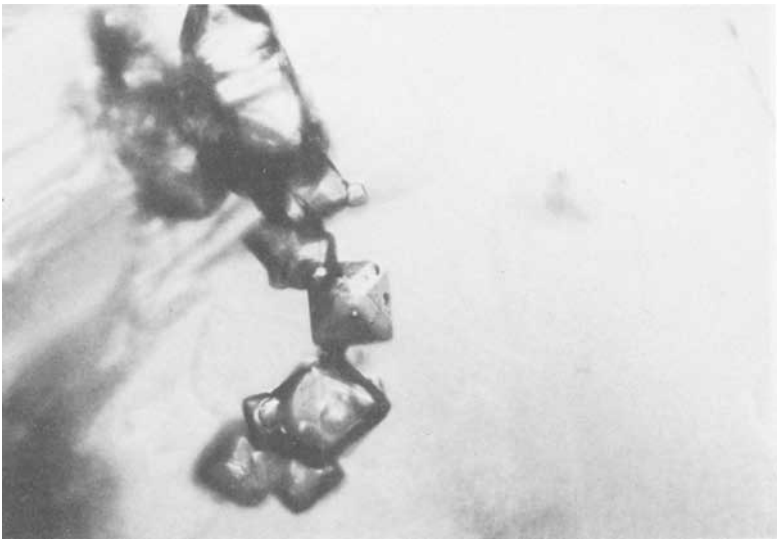

FIG. 4. Cluster of fluorite inclusions (a combination of octahedron and rhombic dodecahedron at the centre) in a topaz from Nigeria. (180 ×)

met together in one and the same host crystal. Generally they showed no particular orientation in respect to the host topaz, although they sometimes appeared to be embedded in some earlier crystal faces of the host. The inclusions often had a surface texture closely reminiscent of etch figures and growth hillocks (Figures 5 and 9), and some of them contained fluid inclusions consisting of liquid and a bubble of gas (Figure 10).

Of the inclusions, the cubic ones greatly resembled those described by Webster[1] as a characteristic feature in topaz from Nigeria, which according to him are probably fluorite crystals. As it was impossible to identify the inclusions merely on the basis of the before-mentioned observations, some of the topaz pebbles with numerous inclusions of the types already described were cloven in very thin plates, and from these a few whole crystals were hand-picked for more detailed study.

The crystals were isotropic between crossed polars. Microscopical examination in different liquids of known refractive indices gave a value 1.43, strongly indicative of fluorite. This conclusion was confirmed with a series of x-ray precession photographs, which proved these crystal inclusions to be fluorite crystals.

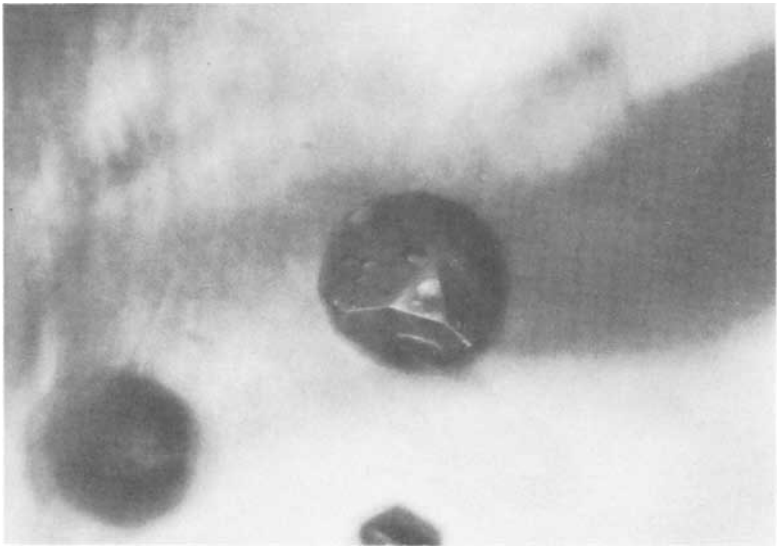

FIG. 5. Fluorite inclusion (a combination of cube and octahedron) with a surface texture resembling growth hillocks in a topaz from Nigeria. (110 ×)

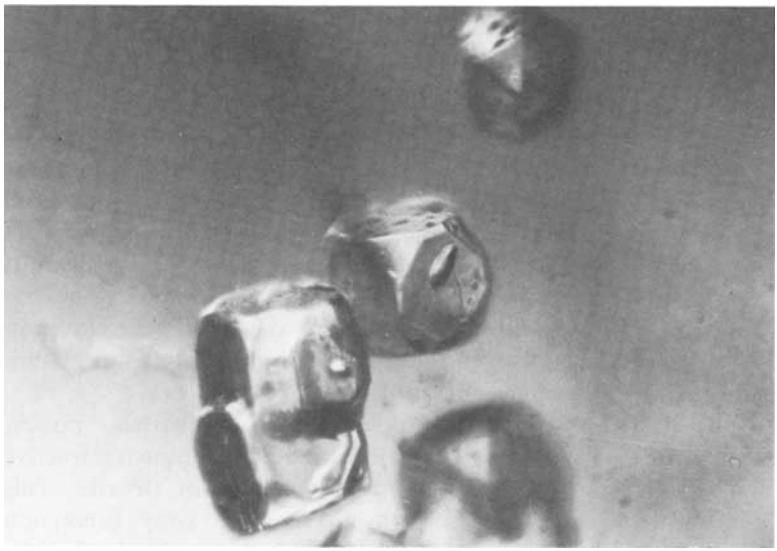

FIG. 6. Fluorite inclusions (a combination of cube, octahedron and rhombic dodecahedron at the centre) in a topaz from Nigeria. (160 ×)

FIG. 7. Fluorite inclusion (a combination of cube, octahedron and rhombic dodecahedron) in a topaz from Nigeria. (210×)

Colourless topaz is found as crystals and as rolled pebbles in the surroundings of the tin-workings of Rop in northern Nigeria,[1] the locality from which the examined topaz pebbles were derived. The crystals occur there in the altered biotite granites in greisen veins caused by the younger granitic intrusions of the plateau.[2, 3] The water-worn topaz pebbles are found in streams, and in alluvial gravel deposits originated with the biotite granites. Because fluorite is widespread as an accessory mineral in the greisen veins,[4] its occurrence in the topaz refers to common origin.

Well formed fluorite crystals were quite common as inclusions in the examined colourless topaz pebbles from Rop, Nigeria. Their presence in a topaz, either rough or cut, would thus seem to give a good indication of this particular locality. In addition, the two-phase inclusions found in the fluorite crystals could possibly be used in fluid inclusion thermometric study, in combination with the excellent fluid inclusions also occurring in the host topaz, to acquire valuable information about the geological conditions under which these two minerals crystallized.

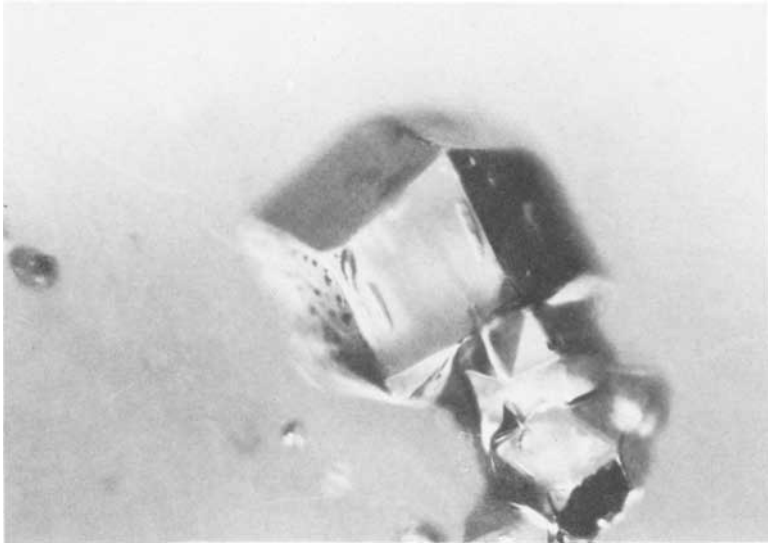

FIG. 8. Cluster of fluorite inclusions (a large rhombic dodecahedral crystal at the centre) in a topaz from Nigeria. (170×)

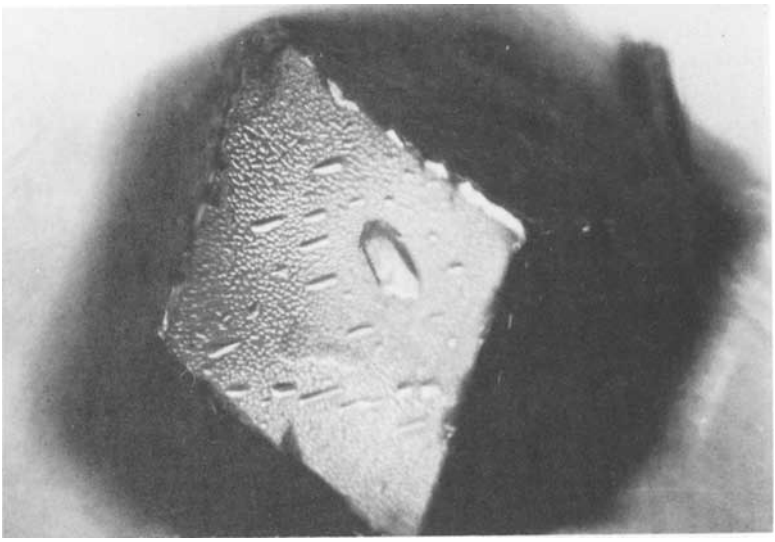

FIG. 9. Surface texture reminiscent of etch figures on the 110 face of a fluorite inclusion in a topaz from Nigeria. (165×)

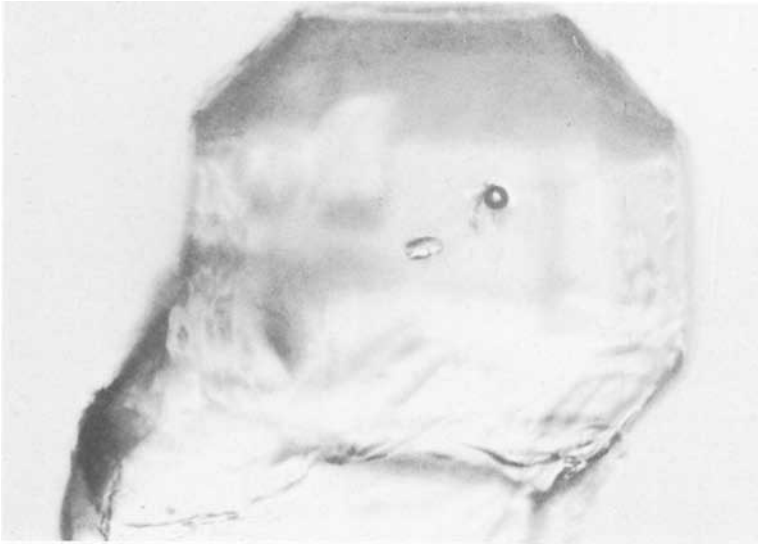

FIG. 10. One fluid inclusion and a smaller mineral inclusion in a fluorite crystal. The crystal itself is embedded in a topaz from Nigeria. (160 ×)

ACKNOWLEDGEMENTS

The author is indebted to Professor Th. G. Sahama for his advice and support, to Dr K. Kinnunen for information and great interest, and to Dr M. Lehtinen for the x-ray precession photographs. Thanks are also due to Miss S. Martikainen for the inclusion photographs.

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A CONTRIBUTION TO THE SEPARABILITY OF NATURAL AND SYNTHETIC EMERALDS

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There are various features to be used as a means of discriminating between natural and synthetic emeralds. In general, refractive indices and birefringence are lower in synthetic stones. Also the specific gravity is lower in synthetic stones in comparison with natural. But again there are exceptions, like Linde and Lechleitner hydrothermal synthetics (Webster, 1975). Another diagnostic feature is fluorescence. It cannot be used exclusively but has its diagnostic value only in connexion with other observations. A very important criterion is the internal aspect, i.e. the inclusions and growth marks. In many cases observation of these allows a rapid and secure diagnosis (Gübelin, 1969). But too often inclusions are lacking or undiagnostic, being difficult to interpret or never having been seen before. At the same time, the physical constants may be found to be in the overlapping region between natural and synthetic stones. In such troublesome cases the ingenious gemmologist has to look for new methods and sometimes is well advised to borrow techniques from neighbouring sciences. I have in mind, for instance, the method of x-ray topography (Schubnel and Zarka, 1971), which reveals characteristic growth defects in crystalline matter.

We know emeralds as a variety of beryl. Its green colour derives from a small admixture of Cr, but V and Fe may contribute to this colour too. Besides these visible impurities in originally colourless beryl there may be invisible impurities as well. These are elements which do not lead to absorptions in the visible part of the spectrum and thus do not cause colour. This contamination in the atomic dimension is best seen from chemical analyses of different beryls (Bakakin and Belov, 1962). In Table 1 chemical analyses of two emeralds (one synthetic, one natural) are presented in comparison with the theoretical concentrations calculated from the beryl formula. Gilson synthetic emerald is still very close to the ideal composition, containing a small proportion of Cr which

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replaces some Al in the crystal lattice. The natural emerald from Sandawana, however, is far away from the ideal beryl composition. It has considerable amounts of Na_2O and MgO and a certain content of FeO, MnO and, of course, Cr_2O_3.

TABLE 1

Theoretic and real compositions of beryl and emeralds in comparison

	$Be_3Al_2Si_6O_{18}$	Gilson synth. emerald	Sandawana, Zimbabwe
SiO_2	67.0	67.0	64.2
Al_2O_3	18.9	17.8	15.1
TiO_2	—	—	0.0
FeO	—	—	0.2
MgO	—	0.1	2.4
MnO	—	—	0.2
K_2O	—	—	0.0
Na_2O	—	0.1	2.4
Cr_2O_3	—	0.6	0.3
V_2O_3	—	—	0.0
BeO	14.1*	14.0*	13.9*
H_2O	—	—	2.0**
	'pure'	→	'impure'

* Stoichiometric content of BeO. Be is not detectable by microprobe.

** This value is put from experience and gives only the range of H_2O concentrations expected in natural emerald (Hänni, 1980).

It would therefore appear that this difference in purity could be a basic diagnostic feature in distinguishing between natural and synthetic emerald. To test this, 45 cut stones of different origins and manufacturers were examined. They were analysed chemically by electron microprobe (see Appendix, p.144); on every sample four point analyses were carried out. The purpose of this investigation was to check whether the result found would be characteristic and to a certain extent safe. Obviously 45 stones cannot represent the whole range of emerald compositions found today. Nevertheless the diagrams (Fig. 1) give persuasive evidence of useful and characteristic differences between natural and synthetic emeralds, capable of being used as a means of discrimination.

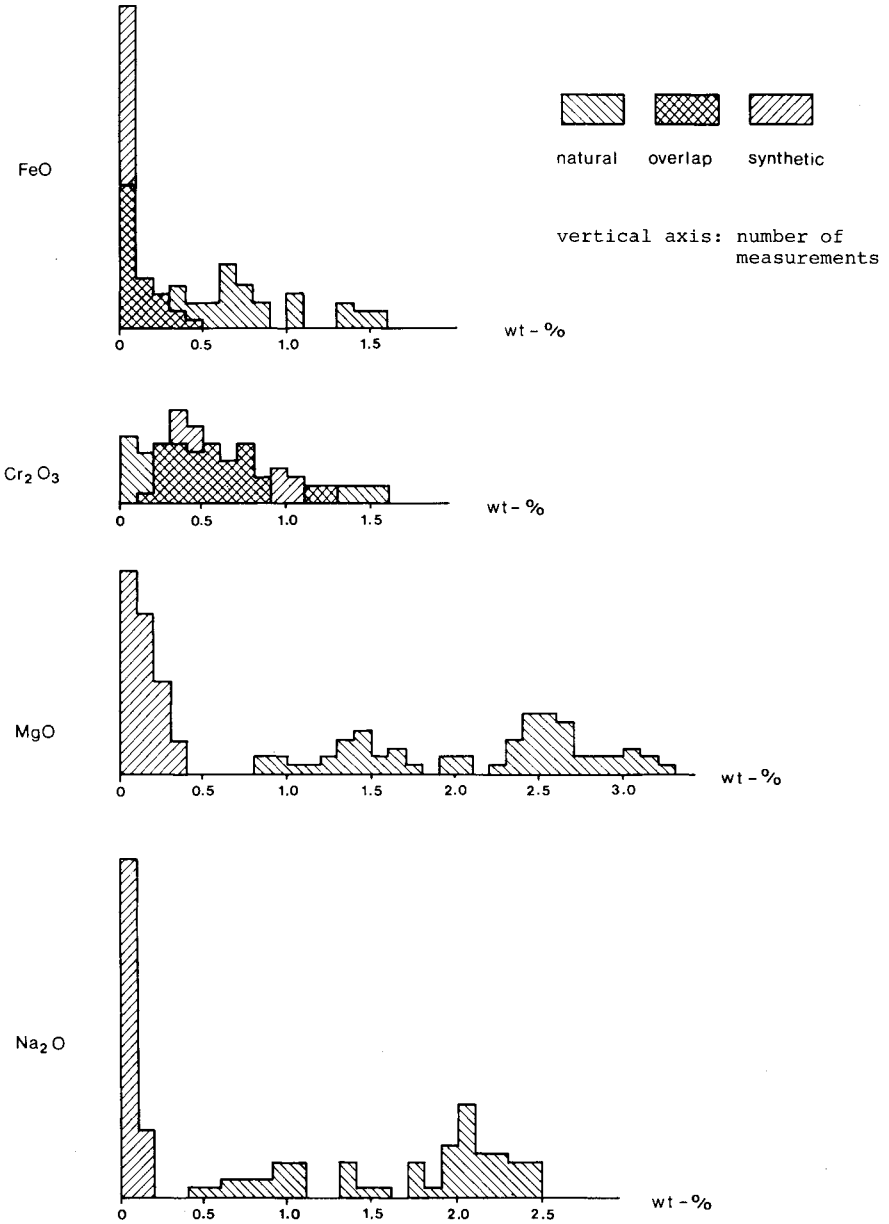

FIG. 1. Comparitive graphs of minor element concentrations in natural and synthetic emeralds.

(Vertical axis: number of measurements. Horizontal axis: weight %.)

NATURAL EMERALDS

The concentrations of Cr_2O_3, FeO, MgO and Na_2O were plotted against the number of measurements (Figure 1). Also, the variations of contents show typical patterns for the different localities (Figure 2). Other main elements were not very rewarding in respect of separability. Minor elements and traces showed slight differences in emeralds from different localities or were below the detection limit of the microprobe. The concentrations of MgO and Na_2O may satisfactorily be used to distinguish between natural and synthetic emerald. The lowest MgO concentration found was 0.8 wt%, but most of the stones contained between 1.5 and 3.0% MgO, typically being around 2.0%. Cr_2O_3 and FeO concentrations of natural and synthetic emeralds overlap and thus have no diagnostic value. A surprising result came from a stone labelled 'emerald, Conquista, Brazil'. It contained no chromium, but 0.7% V_2O_3 and 0.9% FeO (Taylor, 1977).

SYNTHETIC EMERALDS

The contents of MgO and Na_2O are distinctly lower, leaving a broad gap between synthetic and natural stones. The MgO concentrations are frequently 0.1% going up to 0.4% in some Lechleitner products. Also the Na_2O concentrations are clearly set off from the lowest natural emeralds. Most of the synthetic emeralds do not contain measurable amounts of Na_2O, while natural emeralds showed at least 0.4%. The highest value found was 0.2% Na_2O in a Lechleitner Sandwich.

Two more observations are worth mentioning: Linde hydrothermal synthetic emerald always had 0.3-0.4% Cl. And Lechleitner synthetic emerald coated beryls showed surprisingly high Cr_2O_3 concentrations (6.5-7.5%) and according to Bank (private communication) up to 13.2%. The netlike fissures in this overgrowth, well known from microscopic examinations, are best explained by the differences in lattice dimensions caused by the larger Cr^{+3} ions on Al sites.

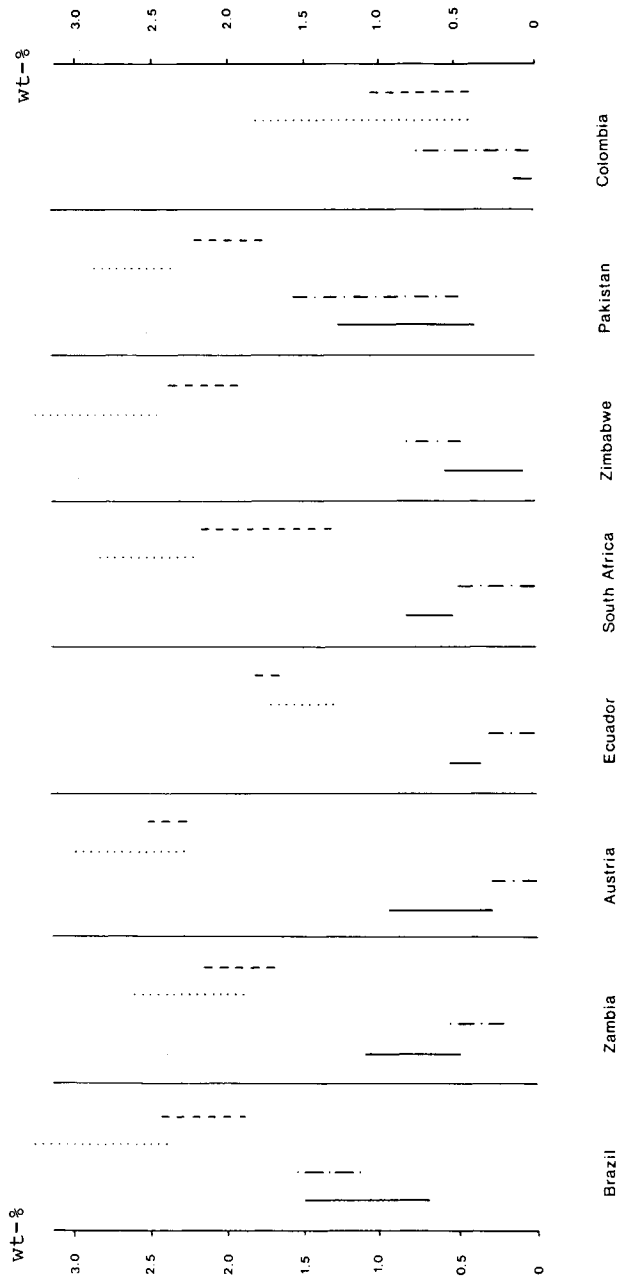

FIG. 2. Variations of minor element concentrations in emeralds of different origins.

DISCUSSION

Microprobe analysis as a chemical technique has been introduced in gemmology for some years (Gübelin, 1969; Dunn, 1977). Its application in this field becomes more and more popular with the increasing number of instruments installed. Thus chemical information is much more easily available. The most important condition in identification of gemstones is to work non-destructively. This premise and the need to obtain chemical data are entirely fulfilled by microprobe technique.

Analysing a cut emerald in this way yields important information, as shown above. If concentrations of Na_2O and MgO> 1.0% are detected, it seems that such material can be considered as natural emerald. Only Colombian emeralds tend to be purer and occasionally only slightly exceed this lower limit. New synthetic products as well as many more natural emeralds need to be analysed to obtain a more complete account of the 'invisible impurities'. Other parameters, like H_2O content and trace element concentrations, are potential features for a separation as well. But their determination is either not non-destructive or the method is not yet a routine procedure.

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For the APPENDIX, see next page.

[*Manuscript received 11th June, revised 19th August 1981.*]

APPENDIX: Microprobe partial analyses of natural and synthetic emeralds (see p.139 above).

Natural Emeralds

	Brazil		Zambia		Ecuador		South Africa		Zimbabwe		Pakistan		Colombia		Trapiche		Austria		
SiO_2	64.7	63.6	63.7	63.9	65.6	65.9	64.9	65.4	63.7	63.2	64.2	63.7	66.4	66.6	65.2	64.6	63.0	63.4	SiO_2
Al_2O_3	16.1	13.4	14.2	14.9	16.9	16.4	14.8	16.6	14.3	14.1	14.8	13.7	16.9	17.7	16.3	16.3	14.3	14.5	Al_2O_3
TiO_2	.0	.0	.0	.1	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.1	.0	.0	TiO_2
FeO	.6	.8	.7	1.1	.7	.8	.8	.7	.4	.6	.4	1.3	.0	.0	.0	.0	.7	.5	FeO
MgO	1.8	3.0	2.4	2.1	1.4	1.7	2.6	1.6	3.1	2.6	2.7	2.4	1.4	1.0	1.0	1.2	2.4	2.6	MgO
MnO	.0	.0	.0	.0	.0	.0	.1	.0	.0	.0	.0	.1	.0	.0	.0	.0	.0	.0	MnO
Cr_2O_3	.4	.0	.4	.3	.2	.2	.2	.2	.5	.6	.8	1.4	.2	.3	.2	.2	.1	.2	Cr_2O_3
V_2O_3	.0	.9	.0	.0	.1	.0	.1	.0	.0	.0	.1	.0	.3	.4	.8	.6	.0	.0	V_2O_3
Na_2O	1.6	2.3	2.0	1.7	1.4	1.5	2.1	1.3	2.3	2.1	2.1	1.9	1.0	0.6	.8	.8	2.0	2.0	Na_2O

Synthetic Emeralds

	Lechleitner Emerita Sandwich				Linde		Chatham		Japan Crescent vert		Gilson			Zerfass	Lennix		
SiO_2	64.7	64.6	65.2	65.9	66.1	66.2	66.8	68.0	67.1	66.8	67.6	66.3	66.9	66.7	66.4	66.0	SiO_2
Al_2O_3	13.9	18.0	18.2	17.7	18.6	18.8	19.5	19.1	19.8	19.9	19.3	19.3	19.4	19.4	18.1	18.7	Al_2O_3
TiO_2	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	TiO_2
FeO	.0	.0	.2	1.1	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	FeO
MgO	.3	.0	.2	.1	.0	.2	.2	.2	.3	.3	.0	.4	.0	.2	.0	.0	MgO
MnO	.1	.0	.0	.0	.0	.0	.0	.0	.0	.1	.0	.2	.0	.0	.0	.0	MnO
Cr_2O_3	7.0	.6	.5	.5	.8	.5	.4	.8	1.0	.9	.3	.6	.8	1.0	1.4	1.9	Cr_2O_3
V_2O_3	.0	.0	.0	.0	.0	.0	.1	.0	.1	.0	.0	.1	.0	.1	.0	.0	V_2O_3
Na_2O	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.1	.0	.0	.0	Na_2O
Cl	.0	.0	.0	.0	.3	.4	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	Cl

for analytical details see Hänni (1980)

DISTINCTION OF NATURAL AND SYNTHETIC RUBIES BY ULTRAVIOLET SPECTROPHOTOMETRY

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ABSTRACT

For the purpose of securing the identification of natural and synthetic rubies (the inclusions of the latter are becoming increasingly scarce and unspecific), a procedure has been set up which evaluates their differential transmission behaviour in the ultraviolet region (Figures 1 and 2). This is the refined version of former investigations by short-wave immersion contact photography. The method is diagnostic, with the Burma rubies at the front of the natural ruby populations and certain Chatham, Kashan and Knischka stones at the respective front opposed to the natural populations areas (Figures 3 and 4).

An absorption band at 266 nm, presumably due to Ti^{3+}, and weak Fe^{3+} bands affect the position, width and depth of the UV absorption minimum. Elevated titanium contents are the cause of the abnormal dichroism so far observed only in Kashan synthetic rubies. Vanadium and manganese are present in minor amounts and appear only in some fluorescence excitation spectra if at all (Figure 5).

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(1) INTRODUCTION

Rubies as well as sapphires and emeralds belong to the most coveted class of coloured gemstones. It is due to this fact that commercial crystal growth still concentrates in a large measure on these three varieties. As a consequence of the increasing

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improvement of these growth techniques, e.g. by influencing the inclusion patterns of the synthetic stones, new or refined identification methods become indispensable.

The examination of the ultraviolet (UV) transparency aimed at distinguishing between natural and synthetic rubies does not really represent a new means of diagnosis. The method applied hereto however was empiric and barely semi-quantitative. It was a matter of photographically recording the differential transmission behaviour of rubies exposed to short-wave UV irradiation (immersion contact photography). These pictures are difficult to interpret, at least for natural low-iron rubies and iron-bearing synthetic samples. The following investigation presents the refinement of the method in terms of measurement data which can be assessed from the UV-VIS absorption spectra of the rubies and which allow a diagnosis.

(2) Test Specimens

Ninety-four rubies from Burma, Sri Lanka, Kenya, Tanzania and Thailand, a few rubies from Hunza (Pakistan), Cambodia, Brazil and Australia and forty-six synthetic rubies were analysed. The synthetic stones were from productions by the Verneuil, Chatham, Kashan and Knischka procedures (Knischka & Gübelin, 1980) and of older as well as of latest date. Apart from ruby-red samples, purple, brownish-red and pink to pink-orange varieties were tested also, provided that they showed a minimum chromium content. At the conclusion of the investigation, approximately 250 absorption spectra could be disposed of. They may be considered trustworthy, since the inclusion patterns confirmed the gemstone dealers' indications of origin.

(3) Absorption Measurements and Results

A detailed description of the measuring procedure follows to enable other analysts to verify the results on their own photometer.

a. *Measuring Instrument and Recording Conditions*

All spectra were run on a Pye Unicam SP8-100 UV-VIS spectrophotometer. This is a so-called double-beam, ratio-recording instrument containing a grating monochromator, coated optical parts, automatic lamp and filter changes, end-on photomultiplier (detector), wavelength programmer unit,

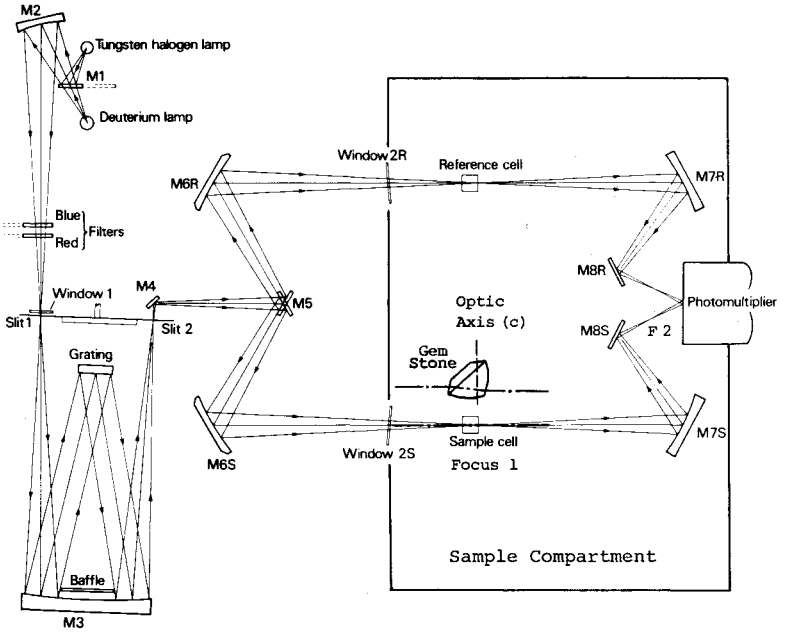

FIG. 1. Optical light-path in a Pye Unicam SP8-100 UV-VIS Spectrophotometer, from lamp-house (top left) via grating monchromator (bottom left), beam chopper (rotating mirrors M5) and sample compartment to the detector (photomultiplier). The gemstone is positioned in the first focus of the sample beam, with the optic axis ideally parallel or perpendicular to one of the directions of transmissibility. For gemstone spectra the reference beam is free (no cell).

automatic gain control and built-in recorder. The instrument scans from 900 to 190 nm. The detector is less sensitive at both ends of the spectral range (Figure 1).

For comparable survey diagrams, the following instrumental conditions were found to be optimal: spectral bandwidth 0.5 nm, wavelength range 800 (or 700) to 200 nm, scan speed 1 nm/sec, recorder advance rate 20 sec/cm, scale of registration 20 nm/cm and recording width 2 A (sensitivity, in absorption units).

In the sample compartment of the instrument, the reference and sample beam, symmetrical to each other, are focused at two points. Most rubies could be analysed in the first focus of the sample beam. This resulted in undisturbed, reproducible and specific spectra. Small rubies had to be measured in the second focal plane immediately in front of the detector. A difference in the character of the absorption curves which would have to be

attributed to a fluorescence influence, however, was not noted, and stray-light effects made their appearance only above 650 nm.

Without applying expensive polarizer equipment, it was intended to position the sample in the beam in an orientated manner and to record absorption spectra which would be as separated as possible for the vibrations of the ordinary (o) and extraordinary ray (e). Sometimes size, shape, proportions and orientation of the cuts impeded the registration of oriented spectra. Due to the almost random orientation of the optic axis *(c)* relative to the mostly oval stone shapes and due to the transmissibility being essentially limited to two directions, it was not always possible to run parallel and perpendicularly to the *c*-axis. It is noteworthy that the proportion of the o- and e-vibration can easily be estimated from the registered spectra (e.g. absorption 475>476 nm for o and 476>475 nm for e). Unpolarized light travelling perpendicular to *c* shows a mixture of the o- and e-component. In the ray parallel to the *c*-axis, the e-vibration cannot possibly occur but only the pure o-component. Therefore it is remarkable that e was, none the less, frequently encountered in the spectra.

b. *Transmission and Absorption*

The notions transmission, absorption, concentration, colour hue, colour saturation and colour purity may briefly be set into relation to each other.

Transmission T (correctly: transmittance) of a matter is defined as the proportion of transmitted to incident light intensity I ($T = I_t/I_o$). It is inversely and logarithmically connected with the absorption A (correctly: absorbance) by

$$A = \log 1/T = -\log T.$$

Range of T:	100%	30%	10%	1%	0.1% ($= 10^{-3}$)	.....	0%
Range of A:	0	0.5	1	2	3	.....	∞

It can be deduced from the comparison of T and A that transmission produces less specific spectra than absorption for values of T below about 30%.

In addition the absorption is *linearly* related to the concentration C of the absorbing elements and to the light path length L (Lambert-Beer law $A = kCL$, where k is the wavelength-dependent absorption coefficient).

The transmission of many coloured gemstones distinctly is inferior to 30%. Their elevated absorption levels are responsible for this state but also the high light losses on the outside and inside of the irregular gemstone bodies. A direct determination of the chromophore contents from the absorption maxima and stone sizes consequently is not possible (or at best approximately by a colourless cut corundum in the reference beam and by external chemical calibration).

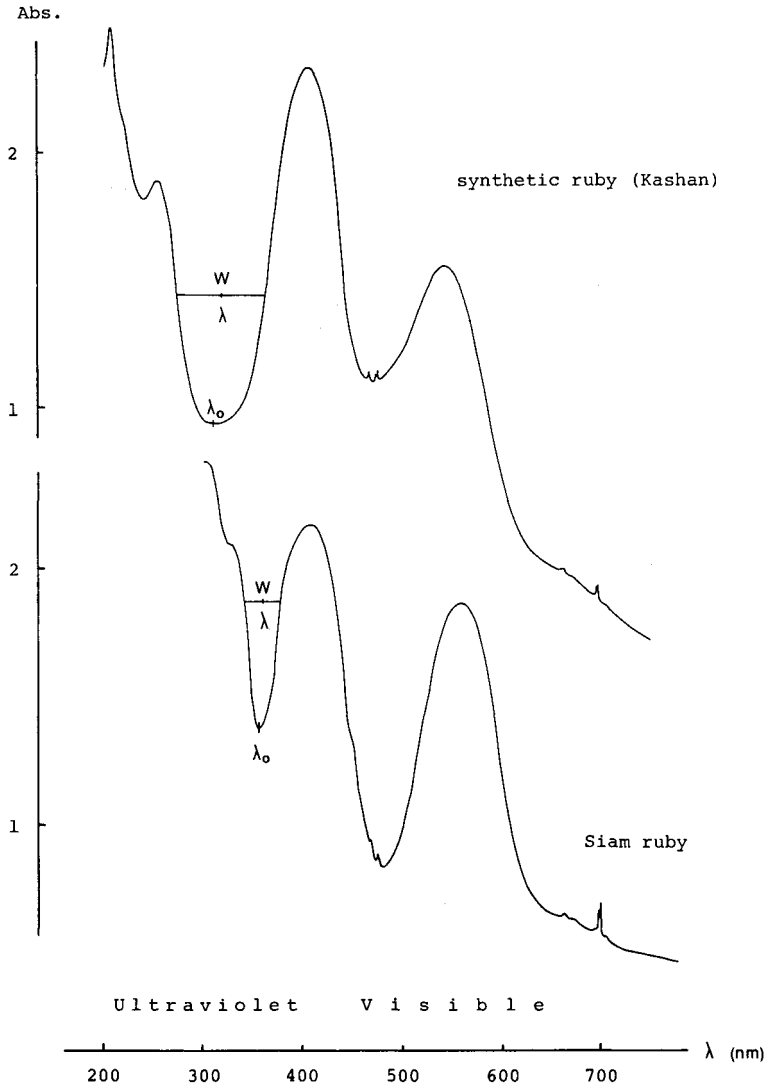

FIG. 2. Oriented absorption spectra of a natural ruby from Thailand (2.267 ct, vibrational component o > e) and of a synthetic ruby by Kashan (2.898 ct, vibrational component e > o) with characteristic differences in position, width and depth of the ultraviolet absorption minima. Evaluation by means of the position λ of the absolute minimum and by the profile parameters λ and W. Chromium bands near 550 and 405 nm (see section (3)c.—Ruby Spectra) and chromium lines e.g. near 693, 476 (doublets) and 469 nm. Absorption figures are approximate.

The hue of a gemstone colour corresponds to the sum of the wavelengths transmitted in the visible part of the spectrum (Figure 2, in rubies: red, stronger than blue). It is complementary to the absorbed colours.

The saturation of a gemstone colour depends on the depth of the transmitting visible areas (absorption minima) lying between the absorption bands.

The colour purity is a function of the strength and steepness of the absorption bands.

Each of the above-mentioned optical properties depends on the chromophore concentrations of the solids. In addition the absorption and colour saturation depend on the size of the sample.

The absorption maxima differ from the minima in that the maxima mostly are disturbed, in variable strength, by reflection and diffusion effects (polish, inclusions of the gemstone bodies). Experience shows that the position and shape of the minima, on the other hand, are influenced almost exclusively by the chemical composition of the specimens and can therefore be used as criteria for identification work.

c. *Ruby Spectra*

Prior to the evaluation of the ruby spectra, the influence on the UV absorption minima of the trace elements concerned is sketched below.

Pure colourless corundums absorb neither in the UV nor in the visible. They possess an absorption edge below 200 nm. Any deviations from this spectrum have to be ascribed to the presence of chromophores (Schmetzer & Bank (1981); only exception: lattice defects in irradiated light yellow corundums). In ruby crystals, some Al^{3+} of the corundum is replaced by Cr^{3+}. In the crystal field of a ruby, the three unpaired electrons of the Cr-3d-orbit may be lifted from the ground state to excited, unstable energy levels by absorbing defined energy quanta. They relax again under emission of light (fluorescence) and release of heat (Nassau, 1980). In rubies, two spin-allowed electron transitions correspond to these energy quanta. They are linked to two specific wavelengths which are characteristic for the positions of the strong chromium absorption maxima and for the resulting ruby-red colour:

polarization $\perp c$ (o-vibration): abs. maxima at 556 and 410 nm
polarization $\parallel c$ (e-vibration): abs. maxima at 542 and 397 nm

Values between these four maxima (such as 550 and 405 nm), produced by a mixture of the o- and e-spectrum, were identified in all recorded spectra. The pure chromium spectrum of some

synthetic rubies reveals that an additional weak absorption band due to Cr occurs in the UV (after Schneyer (1971) at 254 or 250 nm respectively) and that the general absorption starts near 210 nm as can be seen from the Kashan spectrum of Figure 2.

Any absorption bands in addition to those already mentioned must be caused by other chemical elements. Most likely are the *transition elements* iron, titanium, vanadium and manganese. Schmetzer (1978) indicated the following band centre positions for these ruby impurities:

Fe^{3+} 697, 452-440, 392-386, 376-371 and 345 or 308 nm

Ti^{3+} wide band with maxima at 542 and 493 nm (e>o)

V^{3+} 574 and 395 (o) and 571 and 401 nm (e).

Apart from the *iron* band at 697 nm, all given maxima were found in iron-leading rubies, however feebly developed. The series of weak absorption lines sitting on a band between 345 and 326 nm and the band at 314 nm (not 308 nm) are helpful as they indicate iron traces in otherwise pure, Cr-rich rubies, as e.g. in Burma, Chatham and Knischka samples. Rubies from Thailand, typically richer in iron, sometimes exhibit the band at 450 nm (Figure 2).

A relatively narrow band near 266 nm is more conspicuous than the wide and weak *titanium* band in the visible. Both bands occur simultaneously. Obviously the band at 266 nm considerably influences the position, width and depth of the UV absorption minimum. This band is the most pronounced in pale, pink Kashan synthetics which uniformly show raised Ti levels. Therefore it is assumed that the band is associated with the trivalent, substitutional titanium ion. Furthermore it is conceivable that this chromophore is applied as a lightener of synthetic rubies (Verneuil synthetic rubies with comparatively high chromium and iron contents show garnet colour). To judge from indications by Recker (1973), this lightening process indeed appears to take place with additions of Ti_2O_3 (pink coloration) and not with TiO_2.

Vanadium maxima in corundums are but slightly shifted against the Cr peaks, so that V must be present at least in equally high concentration as Cr to appear in the spectrum. Schmetzer (1978) showed for such rubies (from Longido, Tanzania) that their red colour is only slightly altered. In view of the peculiar colour of synthetic alexandrite-like corundums and of one rare colour-changing Ceylonese corundum, all displaying undisturbed V-spectra, this is remarkable. In the present spectra the vanadium

maxima near 572 nm were hinted at best in corundums from Sri Lanka, Kenya and Tanzania.

According to Recker (1973) synthetic corundums doped with MnF_2 are red-coloured. If then *manganese* contents do not necessarily alter ruby colours, absorption lines and bands can still be expected in the examined spectral range. However, the manganese traces found and mentioned in the section on Chemical Data did not show up in the diagrams.

It follows that all phenomena encountered in the ruby spectra are explained by iron and titanium contents, besides chromium.

d. *Evaluation of the Spectra*

For the numerical representation of the absorption minima, several parameters were chosen. In the course of the evaluation they were reduced to three. They are the wavelength of the absolute absorption minimum in the UV (λ_o) and the centre position and width of a profile situated at 0.5 absorption units above the minimum (λ and W in Figure 2). This profile is optimal in several aspects. It is free of the slightly shifted λ values found in the lowest parts of the minima (due to iron interferences). Then the profile is on a level which can be measured out in the spectrum of almost any ruby. It also is suited to characterize the whole absorption minimum and should be reproducible on any other photometer. Profiles on higher levels have comparable properties. However, they are measurable only in particularly UV-transparent rubies and synthetic stones.

The most significant parameter which was bracketed out is the value of the absorption minimum in the UV relative to the one in the blue region, on the basis of the absorption in the red at 640 nm (A_{UV}-A_{640}/A_{BI}-A_{640}). This figure is more time-consuming to determine and not always unambiguous. For many cases, nevertheless, it can be considered in the evaluation as a fourth independent parameter.

Most absorption minima displayed fairly vertical axes ($\lambda \approx \lambda_o$), the slight inclinations of which were not sufficiently discriminative.

e. *Distribution of the Populations*

As could be expected, the o- and e-spectra of rubies, both of which are diagnostic, do not produce completely identical λ_o and λ/W values. The separation of the natural ruby areas from those of the synthetic rubies is clearly recognizable in Figure 3. This is even

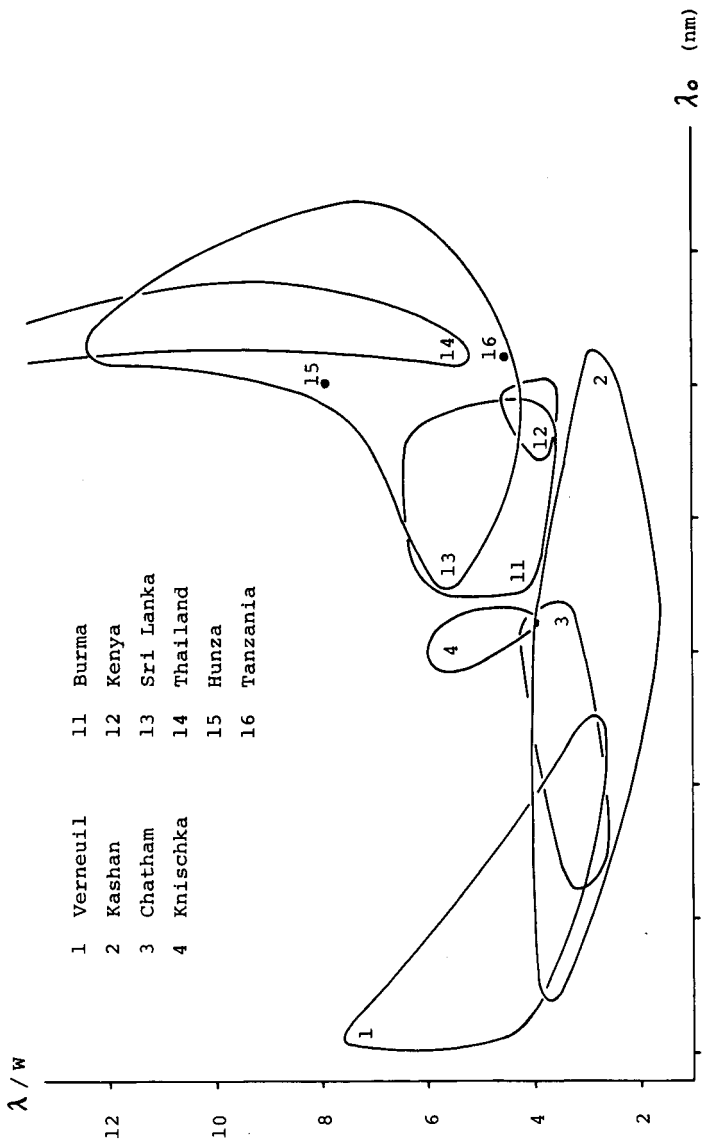

FIG. 3. Diagnostic population distribution of natural rubies (top right) and of synthetic rubies (left and bottom), determined from the UV absorption minima (vibrational component $o > e$). In general natural rubies show a narrower minimum than synthetic rubies, located at higher wavelengths (larger λ/W ratio and λ_o).

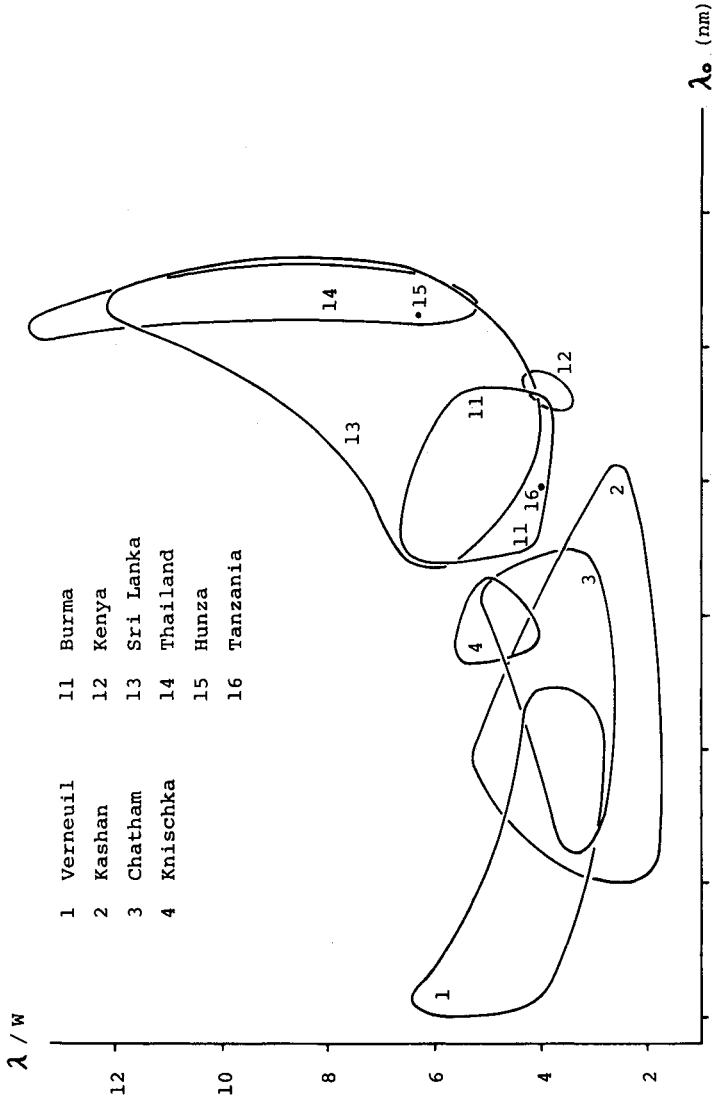

FIG. 4. Diagnostic population distribution of natural rubies (top right) and of synthetic rubies (left and bottom), determined from the UV absorption minima (vibrational component e>o).

more evident in Figure 4. Overlapping of these population areas has not been observed, although, in a restricted measure, intersections are theoretically conceivable in the adjacent regions of genuine and synthetic rubies.

The sizes of the areas have a multiple significance. Small fields originate from dense populations with chromophore compositions of apparently narrow limits (Burma, Thailand) or from populations with relatively few data (Kenya, Knischka). Wide areas indicate considerable variability of the trace contents (Sri Lanka, Kashan). The extreme range of the Thailand population is equivalent to a strong Fe + Cr coloration, that of the Verneuil population to a pure Cr colour.

The location of the populations also has a meaning. Natural rubies show a narrower minimum than synthetic rubies, located at higher wavelengths (larger λ/W ratio and λ_o).

f. *Additional Criteria for Identification*

In special cases the need for further criteria may arise. These are:

1. The relation of the UV to the blue absorption minimum: $(A_{UV}-A_{640}/A_{BI}-A_{640})$. Variation of the values between 1 and 6 for natural rubies (Burma 0.5 to 2.2). Variation between 0 and 2 for the o-spectra and between −0.3 and +1.2 for the e-spectra of synthetic rubies (one means equal absorption of UV and blue, zero means equal absorption of UV and red).
2. Profiles at other levels, e.g. 0.1 A or 1 A above the minimum.
3. A maximum at 266 nm or, if hidden in the general absorption, a side minimum near 246 (o) and 242 nm (e) in Kashan synthetics and other titaniferous rubies.
4. With caution: the wavelength of beginning general absorption in the UV lying between 260 and 345 nm in natural and between 205 and 270 nm in synthetic rubies (exception: Knischka stones 260 to 290 nm).
5. Abnormal dichroism in Kashan synthetics with absorption $o \approx e$ (instead of $o > e$) and e = intense brownish-orange (instead of pale pink-orange) due to an asymmetric transmission in the green-blue part of the e-spectrum.
6. Absorption lines at 706, *701* and 698 nm (according to Schneyer (1971) due to pairs and larger aggregates of Cr^{3+}) in certain natural and synthetic rubies. Singular wide band near 703 nm only in synthetic rubies by Kashan.

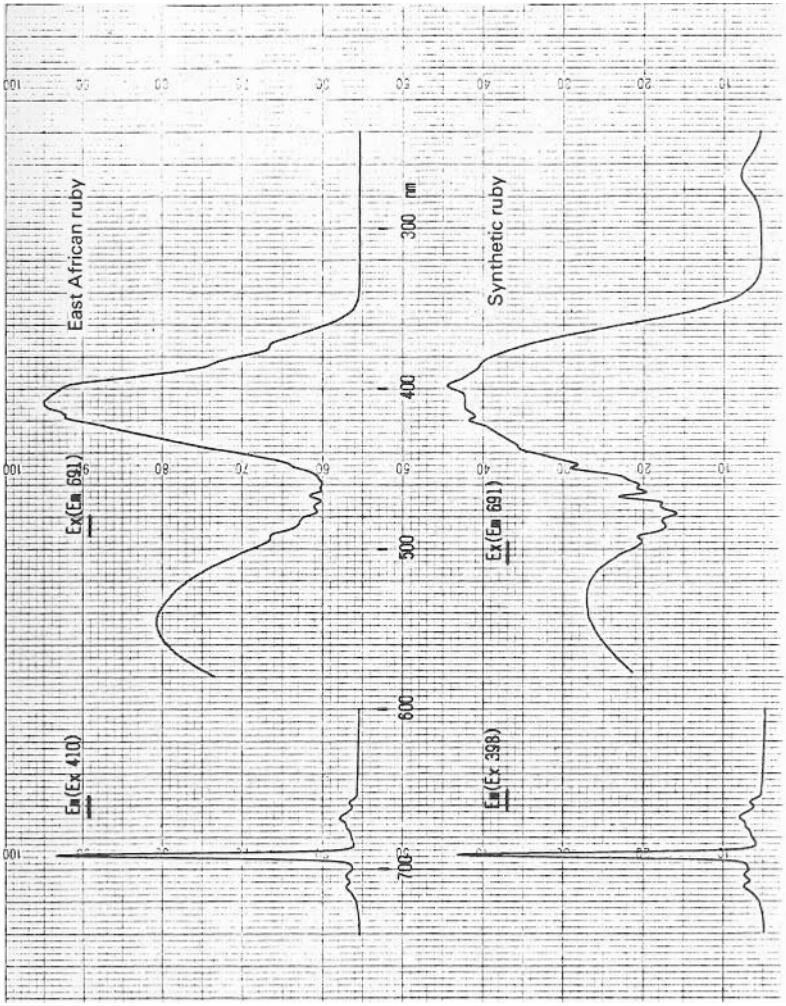

FIG. 5. Fluorescence spectra of an East African and a synthetic ruby (top/bottom) with identical chromium emission (left) but differential excitation bands (right). Graph by B. Suhner.

(4) FLUORESCENCE-SPECTROMETRIC RESULTS

Emission (Em) and excitation (Ex) spectra may be applied to trace element analysis (Schwarz, 1977). B. Suhner, of Herisau (Switzerland), recorded the spectra of some sixty rubies of various localities and productions on a Perkin-Elmer Fluorescence Spectrophotometer 650-10S. He intended to determine whether natural and synthetic rubies could be distinguished by this method. With his friendly permission the results will be summarized here and correlated with the absorption data.

The following can be stated:

1. The Em-spectra show a main line at about 692 nm for all rubies. It is accompanied by at least two weaker satellite lines on each side (Figure 5, left side). At room temperature it is a single line and not a doublet as in the absorption spectrum. Em-spectra are not suited for the intended separation.

2. The Ex-spectra qualitatively are comparable with the chromium absorption diagrams, with the exception of item 4.

3. Ex-spectra exhibit clearly distinguishable peak widths for most natural and synthetic rubies (Figure 5, right side). However, many Burma and some Sri Lanka rubies display the same band near 268 nm as synthetic stones do, but the band is absent in the bulk of natural rubies. It must be identical with the absorption band at 266 nm.

4. The Cr bands at 410 (o) and 397 nm (e) are suppressed in the Ex-spectra of certain Knischka synthetics. They are dominated by a number of lines between 420 and 500 nm, of which those at 468, 450 and 492 nm are the most important. These lines can hardly appertain to the fluorescence-quencher element iron. Eventually they are caused by the vanadium or manganese traces. In very reduced form these lines are detectable in both spectra of Figure 5.

It may be concluded that an identification is possible only for relatively extreme colouring ion compositions. In this respect the synthetic rubies are too similar to many Burma, Kenya and some Sri Lanka rubies. Low-temperature spectra might yield more specific information.

(5) CHEMICAL DATA

Chemical data are available not only rapidly but non-destructively by analysis on the microprobe and, as a recent asset, by energy-dispersive x-ray fluorescence (EDS-XRF). The significance of the latter is demonstrated by Hänni (1982) for the discrimination of natural and synthetic emeralds. Also Stern & Hänni (1982) described shortly that XRF analysis enables the recognition of flux fusion products, under favourable circumstances.

Several minor components and trace elements were examined qualitatively on an EDS-XRF spectrometer (model Tracor Northern 1710, AgL radiation), specifically for one ruby from each of four different localities and four different growing techniques. The findings are summarized in Table 1 and confirm the presumptions based on the absorption and excitation spectra. Comparisons in the columns (vertical) are admissible but not in the lines (horizontal). Apart from Cr, Fe, Ti and V, minor amounts of manganese were detected in several of the eight rubies. More extensive studies by XRF are under way.

TABLE 1	Relative Trace Element Contents in Rubies			
	Cr	Fe	Ti	V
Thailand	***	***	*	**
Sri Lanka	**	***	***	*
Kenya	**	**	**	*
Burma	**	**	**	**
Chatham	***	*	*	*
Kashan	*	**	***	*
Knischka	***	**	**	*
Verneuil	**	*	*	*
Trace Content	major ***	medium **	minor*	

(6) SUMMARY

A procedure was developed allowing the evaluation of the UV transmission of natural and synthetic single-crystal rubies, with the following main results:

(a) Rubies from Thailand and many from Sri Lanka differ chemically so much from synthetic rubies that they cannot be confused in terms of colour and transmission behaviour. In contrast, the similar trace element composition of Burma and Kenya rubies and of the lighter Chatham, Kashan, Verneuil and Knischka synthetic rubies causes their red colorations to be comparable or even confusible. Their excitation spectra therefore are ambiguous also. The absorption minima in the UV, however, allowed a safe identification of 150 natural and synthetic rubies. Moreover it may be expected that extensive microprobe or XRF studies will produce new criteria of separation, as is shown by Hänni (1982) for genuine and synthetic emeralds.

(b) To judge from the colour and absorption diagrams of a few rubies from Hunza (Pakistan), Brazil, Cambodia and Australia, they lie, chemically speaking, between the extremes of rubies from Burma and Thailand. Tanzania rubies with their high vanadium content are in the front region of the population areas of natural rubies but exhibit much less transparency in the UV than in the blue region. This is typical of most natural rubies.

(c) It is an advantage that heat-treated rubies display the same absorption properties as naturally coloured rubies from the same locality.

(d) The method naturally is limited by synthetically overgrown genuine rubies (e.g. Knischka products). They present spectra with intermediate values for λ_o and λ/W, dictated by the colour saturation and light-path length in the proportion of genuine nucleus size to thickness of synthetic overgrowth.

(e) An absorption band at 266 nm presumably is associated with Ti^{3+} traces. It accompanies the bands in the visible spectrum of titaniferous rubies (Kashan synthetics). Additional chemical data are required for trustworthy designation as a titanium band.

(f) Until now an abnormal dichroism was noted only in Kashan synthetic rubies. It is caused by raised Ti levels and is connected with an asymmetric transmission of the green-blue.

(7) ACKNOWLEDGEMENTS

Sincere thanks are extended to Dr W. Heinzelmann, University of Zurich, for numerous suggestions regarding photometer application and valuable hints for spectrum evaluation. Without the support with specimens of mostly known origin by gemstone dealers and jewellers from Zurich, the present investigation would have remained fragmentary. Special thanks go to Dr W. B. Stern for supplying the XRF data, to Dr H. A. Hänni for technical discussions and material assistance, and to Mr U. Näf for drawing Figures 2 to 4 (all of the University of Basle). The spontaneous conveyance of fluorescence data by Mr B. Suhner, Dip. Eng., of Herisau (Switzerland), merits particular recognition.

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GEMMOLOGICAL ABSTRACTS

BAKER (D. M.). *Revolution in diamond cutting: laser sawing of diamond crystals.* Gems & Gemology, **XVII**, 3, 150-2, 3 figs in colour, 1981.

A computerized method of using an infrared laser beam to 'saw' diamonds in directions which cannot be sawn (or cleaved) normally. Cutting is by a neodymium doped YAG laser giving a beam that is focused down to a spot 25 microns in diameter, and is carried out by multiple traverses of the diamond crystal back and forth across the fixed beam which thus burns off a minute amount each time. Wastage (5%-7%) is slightly higher than with conventional sawing, but method allows otherwise impossible cuts to be made. Resultant surfaces are rather striated.

R.K.M.

BASTOS (F. M.). *Emeralds from Itabira, Minas Gerais, Brazil.* Lapidary J., **35**, 9, 1842-8, 12 figs, 1981.

Emerald has been found at Itabira, north-east of Belo Horizonte Minas Gerais, Brazil. Emerald is said to occur in a schist with biotite within a pegmatite. Quality of the best stones is said to equal that of Chivor and Muzo material. Three-phase inclusions, mica flakes with profuse tremolite needles are reported. RI is 1.580-1.589; SG 2.71 to 2.74. M.O'D.

BROWN (G.). *The emerald.* Wahroongai News, 7-12, September 1981.

A reasonably thorough account of emerald as a gem mineral, which mentions the dichotomy which exists in the definition of emerald (with Cr^{3+}), while emerald-coloured beryl is known which owes its colour to V^{3+}. R.K.M.

BROWN (G.). *Cathaystone—an effective cat's-eye chrysoberyl imitation.* Wahroongai News, 13-14, September 1981.

This is the cat's-eye made from material resembling that used in fibre optics. Made in several colours it is said to be an excellent imitation of chrysoberyl cat's-eye, too good perhaps in some of them. R.K.M.

BROWN (G.). *Opal.* Wahroongai News, 10-14, October 1981.

A summary of opal which goes into its history in some detail and lists varieties which will be new to many readers. Sedimentary opal occurrences in Australia are described and illustrated by rough sketches. R.K.M.

BROWN (G.). *Synthetic emeralds.* Wahroongai News 15-19, October 1981.

Follows on from the paper published in the September issue on natural emerald. First paragraph suggests that large single crystals of emerald have been grown for almost 100 years. [Size is comparative, but abstracter does not think the 1 mm crystals of Hautfeuille and Perrey can be regarded as 'large'.] Otherwise this account is fair enough and effectively summarizes the facts as they are known.

R.K.M.

BUTLER (J. N.). *The quartz minerals of Redcliffe Peninsula.* Wahroongai News, 10-12, November 1981.

A summary of the chalcedonies and altered quartz and chalcedonies from a Tertiary basalt zone north of Brisbane. These are to be found on the beaches along the peninsula and are generally weathered to a greater or lesser extent. Weathering is of two types, chert and a more chalky form. In extreme cases these can replace almost all of a given nodule. R.K.M.

CASSEDANNE (J.-P.). *Note sur la brazilianite et ses gisements brésiliens.* (Note on brazilianite and its Brazilian locations.) Revue de Gemmologie, **68,** 14-17, 6 figs (3 in colour), 1981.

Brazilianite is found in pegmatites in several locations in Minas Gerais, Brazil. These are shown on a map in the text, together with illustrations of typical crystals. Constants are given and there are 19 references. M.O'D.

CASSEDANNE (J.-P.). *Le quartz à rutile de Ibitiara.* (Rutilated quartz from Ibitiara.) Revue de Gemmologie, 69, 7-11, 9 figs (2 in colour), 1981.

Rutilated quartz is found at Ibitiara, 400 km west-north-west of Salvador in the State of Bahia, Brazil. Details of the geology and associated minerals are given, with a map of the area. M.O'D.

CLOCCHIATTI (R.), MASSAIRE (D.), JEHANNO (C.). *Origine hydrothermale des olivines gemmes de l'ile de Zabargad (St Johns), Mer Rouge, par l'étude de leur inclusions.* (The hydrothermal origin of gem olivines from Zabargad (St John's) Island, Red Sea, by the study of their inclusions.) Bulletin de Minéralogie, **104,** 354-60, 4 figs, 1981.

The fluid inclusions in these peridots are rich in the volatile elements (CO_2, N_2, Cl, S, H_2O) with low partial pressure of CO_2. These olivines were crystallized by a hydrothermal process which affected the parent peridotite of the island. R.A.H.

COTTRANT (J.-F.), CALAS (G.). *Étude de la coloration de quelques diamants du Muséum national d'histoire naturelle.* (Study of the coloration of some diamonds in the National Museum of Natural History.) Revue de Gemmologie, **67,** 2-5, 7 figs, 1981.

Diamonds from Brazil and South Africa were studied with an automatic spectrometer working in the visible, ultraviolet and the near infrared. Examination of the absorption spectra allowed the origin of the coloration to be deduced and also the effect of aluminium and other impurities. M.O'D.

DÉLÉ-DUBOIS (M.-L.), MERLIN (J.-C.). *Étude par spectroscopie Raman de la pigmentation du squelette calcaire du corail.* (Raman spectroscopical study of the coloration of the calcareous skeleton of coral.) Revue de Gemmologie, **68,** 10-13, 5 figs (2 in colour), 1981.

Raman spectra for different colours of coral are given. This method will distinguish true coral from imitation products. M.O'D.

DESHPANDA (M. L.), NENE (S. G.), RAJARMAN (S.). *Diamonds in India.* Wahroongai News, 13-17, November 1981. 'Abstracted from Indiaqua No. 26 (1980).'

Each author contributes one part of this paper.

1. *Indian kimberlites.* Of some 5000 world-wide known kimberlite pipes only 10% are diamondiferous and only one fifth of these is commercially viable. Kimberlites were found in 1925 in the ancient alluvial diamond areas of Andhra Pradesh and Madhya Pradesh. Only two out of six known pipes are diamond bearing and in these the output is low (2 to 4.5 carats per 100 tons of ore).

2. *Diamond exploration.* These Indian pipes are far older than those of Africa etc., and have therefore eroded much more, and it is accepted that yield decreases with depth. It is suggested that secondary (alluvial) deposits, as yet unexploited, will be more viable than possible pipes; these include hard and soft conglomerates, sources unusual in other diamond areas. Geophysical surveys are locating probable further pipes and more are hoped for; methods include remote sensing by satellite. It is suggested that the Krishna delta and its off-shore sands may be a further source of alluvial diamonds, as in South Africa.

3. *Examinations of old workings.* Sandstone/conglomerate outcrops, alluvial workings on slopes near the river, alluvial workings covered by further alluvium have been extensively worked in ancient times in the Krishna Valley. Mostly open-cast mines removed up to 8 metres of overburden to reach a metre of diamond bearing gravel. Old workings found by aerial survey; some formerly rich sources are remote from the known kimberlite pipes. Golconda mines so named because stones were marketed near there, although nearest mining area was 150 km distant. Mining ceased in late 18th century for a variety of economic and political reasons. Ancient miners removed only soft conglomerates (easily crushable), about a 15 cm layer and probably rich in diamonds. Mining of conglomerate lenses was seen by Tavernier in 1665; grit layers, 30 or 40 cm thick, were excavated horizontally to a depth of 20 metres, using crow-bars, long-handled spades and 'small sized children . . . to crawl into these narrow drives and push out the loosened gravel'. Some diamonds still found occasionally by villagers after heavy rains. R.K.M.

DILLON (S.), ed. *Gem news.* Gems & Gemology, **XVII**, 2, 117-18, 1981.

Reports Argentine Capillitas rhodochrosite mine to reopen. Australian gem-cutting centre mooted for Perth. Diamonds found at Kimberly, Western Australia, include an 11 carat crystal and fancy pinks. Aga Khan mine, W. Australia, is being explored and emerald and scheelite stockpiled. 30 square miles of Central Queensland are being mined by up to 40 companies, producing mainly yellow sapphires of small size. San Carlos Apache Reserve, near Phoenix, Arizona, now claimed to be the most important source of gem peridot; comprehensive report promised. About 10% of Zaire diamonds (mostly industrial) are being sold outside the De Beers marketing organization. R.K.M.

DILLON (S.), ed. *Gem news.* Gems & Gemology, **XVII**, 3, 180-2, 1981.

Diamond production in Angola, Australia, Botswana, Lesotho, U.S.A. and U.S.S.R. is reported. Predicted 20-25 million carats from 5 million tons of ore in Ashton Joint Venture (Argyle, W. Australia) seems extremely optimistic. Jwaneng Mine, Botswana, should increase production to 10 million carats by 1985.

Murfreesboro, Arkansas, Crater of Diamonds reports find of 8.83 carat diamond, second largest from that mine. U.S.S.R. have started to sink new deep mine in Yakut area. Prof. E. Gübelin reports that Pakistan is producing emeralds of good colour, ruby and spinel, topaz (natural pink), aquamarine, chrome diopside, kunzite, pyrope, chrome tourmaline, quartz and ornamental chalcedonic quartzes for additional interest, although not all are commercially viable. R.K.M.

DILLON (S.). *GIA's golden anniversary.* Lapidary J., **35**, 7, 1402-12, 14 figs (7 in colour), 1981.

The whole range of work of the Gemological Institute of America is discussed and notes on leading personalities are given. Some of the stone collection is illustrated. M.O'D.

DUNN (P. J.), BENTLEY (R. E.), WILSON (W. E.). *Mineral fakes.* Mineral. Record, **12**, 4, 197-219, 47 figs (8 in colour) 1981.

The history of faking mineral specimens is extensively reviewed. Among practices which the gemmologist may encounter are the development of copper bloom in chalcedony (by exposure to laser light); various methods of affixing diamond crystals to matrix; emerald or beryl crystals attached to an inappropriate matrix; plastic imitations of tourmaline on matrix; the grinding of faces onto a crystal and the various ways of dyeing specimens. Methods of detection are also discussed. M.O'D.

DUYK (F.). *Sur l'emploi du microscope en gemmologie.* (On the use of the microscope in gemmology.) Revue de Gemmologie, **67**, 8-12, 17 figs, 1981.

Adaptation of a microscope for the better study of inclusions is described. M.O'D.

DUYK (F.). *Un appareil bien simple—1.* (A very simple tool.) Revue de Gemmologie, 69, 16-17, 7 figs, 1981.

The device in question is intended to make easier the observation of interference figures. M.O'D.

FRYER (C.), ed., CROWNINGSHIELD (R.), HURWIT (K. N.), KANE (R. E.). *Gem Trade Lab Notes.* Gems & Gemology, **XVII**, 2, 101-6, 14 figs (13 in colour), 2 tables, 1981.

These combine reports from the three GIA Labs which have in past years been published individually. Mossy patches on a green diamond, normally indicative of radium salt treatment, gave no radioactivity; some other form of treatment suspected. A good green olivine (peridot) inclusion is illustrated in another diamond. Linde-like synthetic emeralds, lacking phenakite nuclei, possibly new; a natural emerald crystal in a faked matrix; and a plastic jadeite substitute used in making a snuff-bottle, are shown. Dyed and waxed lapis lazuli, and a natural opal which improved markedly when wet, also reported. Large cultured blister pearls with M.O.P. centres, distinct from Mabe pearls, and a fire-damaged natural pearl necklace were identified. A ruby with a large thin film inclusion gave startling interference colours under vertical illumination. Banded purple sugilite was compared with sogdianite and leucophoenicite, but was proved to be correctly identified. A multi-coloured polished mineral slab comprised pink corundum, green tourmaline and blue kyanite. R.K.M.

FRYER (C.), ed. CROWNINGSHIELD (R.), HURWIT (K. N.), KANE (R. E.) *Gem Trade Lab Notes.* Gems & Gemology, **XVII**, 3, 161-6, 20 figs (18 in colour), 1981.

A triangular cut diamond with three (cylindrically) concave facets framing the table; a thin slice of emerald carved on both sides in bas relief; three interesting and beautiful ivories and a nephrite based clock (ruby-inlaid with enamel-framed smoky quartz 'see-through' dial) reminiscent of the style of Fabergé; are described and illustrated. A black opal with a resin filled cavity in its back; mabe pearls set back to back in a metal band to look like a solid pearl; synthetic, flux-grown Chatham rubies containing typical unmelted flux, some looking rather like 'fingerprint' inclusions, whispy veils, hexagonal platinum flakes (not to be confused with sub-metallic haematite plates in natural Sri Lankan and African rubies), angular, near colourless, crystals, twinning and growth lines of various types, have also been examined and identified. The latter show very strong red fluorescence under longwave UV. Shortwave UV and x-rays gave weak to moderate reds. A parti-coloured purple sapphire with an orange centre exhibited contrasting weak and strong orange fluorescence in long-wave UV light. A cat's-eye sillimanite, resembling apatite, showed absorption at 4400Å, spot RI gave 1.66 and a rotated polaroid suggested birefringence was between 0.015 and 0.020. Stone checked by powder x-ray diffraction. R.K.M.

GATES (C.), GATES (S.). *How to buy CZ facet rough.* Lapidary J., **35**, 8, 1588-98, 6 figs, 1981.

Some useful hints on the properties and behaviour of cubic zirconia crystals are given, with particular reference to faceting. M.O'D.

GILL (S.). *Gemstone gleanings in the Kingdom of Nepal.* Gemmological Review, **3**, 12, 6-11, 12 figs, 1981.

A list of the gem materials found in Nepal is arranged by locality. M.O'D.

GONTHIER (E.), SCHUBNEL (H.-J.). *Les derniers lapidaires du néolithique de la vallée de la Baliem.* (The last neolithic lapidaries of the Baliem valley.) Revue de Gemmologie, 69, 12-15, 10 figs (3 in colour), 1981.

Neolithic artefacts from the Baliem valley in New Guinea are discussed. Some actinolite and serpentinized peridotite have been employed as tools. M.O'D.

GOOD (A.). *Chemically-induced colour in sapphire.* Gems, **13**, 5, 32, 1 fig, 1981.

Pale blue and heavily included sapphire from Sri Lanka can be altered in certain circumstances to much clearer and better-coloured material by appropriate heat treatment. The stones in which this process has been carried out are known as Geuda stones. M.O'D.

GÜBELIN (E.), MOOR (R.), OBERHOLZER (W. F.). *La taprobanite, une nouvelle pierre précieuse du Sri Lanka.* (Taprobanite, a new gemstone from Sri Lanka.) Revue de Gemmologie, **67**, 6-9, 2 figs, 1981.

A cut stone of 1.02ct and of a red corresponding to DIN 6164, annexe 8, location between 8:4:2 and 8:5:2, had SG 3.607 and refractive index 1.717-1.721 with a birefringence of 0.004 (all these are mean figures). Hardness is over 8 on Mohs's scale and the stone belongs to the hexagonal crystal system. It was first

believed to be a red form of taaffeite but the chemical composition was later found to be $BeMg_3Al_8O_{16}$. Chromium provides an emission line at 685.2nm and some reddish luminescence. Space group is $P6_3mc$. The first stone examined is now kept as the type specimen at the Institute of Crystallography and Petrography, Ecole Polytechnique Federale, Zürich. M.O'D.

HEALEY (D.). *Sun, sapphires and serendipity.* J.Gemm.Assoc. Hong Kong, 2, 8-17, 1981.

An interesting and full account of a visit to Sri Lanka made by some members of the Gemmological Association of Hong Kong. A visit to a gem pit is described. M.O'D.

HOFER (S. C.), MANSON (D. V.). *Cryogenics, an aid to gemstone testing.* Gems & Gemology, **XVII**, 3, 143-9, 5 figs, 1981.

The G.I.A. have recently adopted techniques introduced by Dr Collins, of King's College, London, which have been available to the London Gem Laboratory, using liquid nitrogen, since 1976. Their apparatus is the best available and includes a Zeiss PMQ_3 spectrophotometer and a custom designed cryogenic system using liquid helium to lower stone temperatures to around 50 K (about −223 °C). Ingenious use of thermocouples monitors temperatures. Cool-down periods seem rather long but the temperatures reached are exceptionally low. R.K.M.

HURLBUT (C. S., Jr.). *A cubic zirconia refractometer.* Gems & Gemology, **XVII**, 2, 93-5, 1 fig, 1981.

With the advent of this hard, highly-refracting, isotropic material its use as a refractometer prism was predictable and it has now been used in an adapted American Duplex II instrument. The main limitations for the important region between 1.81 and 2.06, its upper reading, are imposed by the available contact liquids, either West's solution, which is explosively combustible, or selenium compounds which are unpleasantly poisonous. R.K.M.

KANE (R. E.). *Hornbill ivory.* Gems & Gemology, **XVII**, 2, 96-7, 3 figs (in colour), 1981.

Describes this rare yellow 'ivory' made from the solid casque of the helmeted hornbill. (A protected species, so it is hoped the 'ivory' will remain very rare.) Not a true ivory, the casque is modified feathers rather than teeth. R.K.M.

KELLER (P. C.). *Emeralds of Colombia.* Gems & Gemology, **XVII**, 2, 80-92, 12 figs (10 in colour), 1981.

A short account of the Muzo and Chivor mines, their history, geology and production. Several large and important crystals and cut stones are illustrated [some, strangely, against emerald green backgrounds]. The 'Spanish Inquisition' necklace is one of these, said to be 300 years old [despite the presence of baguette diamonds and, apparently, a platinum mount. The main stones may well be the age claimed]. R.K.M.

KENNICUTT (W.). *The ruby mines of Franklin.* Lapidary Journal, **35**, 3, 744-6, 1981.

Corundum is found in stream beds in the Franklin area of North Carolina. Many are recovered by panning. M.O'D.

KOIVULA (J. I.). *Photographing inclusions.* Gems & Gemology, **XVII,** 3, 132-42, 20 figs (14 in colour), 1981.

A very interesting paper on photomicrography which emphasizes the need for vibration-free equipment, clean gems and apparatus, and careful preparation—also the many problems of lighting which must be overcome if first class pictures are to be obtained. Mr Koivula seems to be working under conditions where time and cost are not limiting factors and his results, some of which illustrate the paper, are a tribute to his expertise and patience, and a delight to the eye. He advocates working dry not with immersed stones. R.K.M.

KOMOTAUER (S. K.). *Quarz, SiO_2.* (Quartz, SiO_2.) Mineralien Magazin, **6,** 1, 5-19, 19 figs in colour, 1982.

A useful overview of quartz with particular reference to its crystal form and with helpful illustrations of twinning depicted in colour. Further information is promised for a later paper. M.O'D.

KVAPIL (Ji.), KVAPIL (Jo.), MANEK (B.), PERNER (B.). *Czochralski growth of YAG:Ce in a reducing protective atmosphere.* J. Crystal Growth, **52,** 542-5, 4 figs, 1981.

Ce^{3+} ions destroy colour centres in YAG crystals grown in a reducing protective atmosphere. M.O'D.

LEITHNER (H.). *Russische Topase und Berylle.* (Russian topaz and beryl.) Lapis, **6,** 9, 9-14, 15 figs (9 in colour), 1981.

Most topaz and beryl found in the U.S.S.R. come from the area of Sverdlovsk, which is discussed. M.O'D.

LEVINGSTON (K. R.). *Gem diggings—Chudleigh Park.* Wahroongai News, 16-23, 2 maps, November 1981. (Reprinted from Queensland Government Mining Journal, **80,** 35-8.)

A small region between Hughenden and Mount Garnet in North Queensland which produces peridot and some poor quality spinel; sapphire formerly, but this is now rare. Basalt cone is known unofficially as Mount Batchelor [a nice tribute to H. H. Batchelor who discovered it and at one time contributed most fascinating short accounts of his 'gemming' trips to the *Gemmologist*]. Open to the public the prospect area is gemmiferous to about 40 cm and is mined by shovelling, screening and sorting. Main part of paper is concerned with geology and mineralogy of the region and with its topography. R.K.M.

MAGGART (H.). *Sapphires of Montana.* Lapidary J., **35,** 7, 1444-52, 18 figs, 1981.

The Rock Creek area of Montana and its sapphire deposits are described. M.O'D.

MEYER (H. O. A.), GÜBELIN (E.). *Ruby in diamond.* Gems & Gemology, **XVII,** 3, 153-6, 1 fig. in colour, 1981.

An occurrence of a ruby crystal inclusion in diamond has been authenticated. Ruby is assigned to the eclogitic group of possible inclusions. Some interesting conclusions are drawn. R.K.M.

MUNASINGHE (T.), DISSANAYAKE (C. B.). *The origin of gemstones of Sri Lanka.* Economic Geol., **76,** 1216-25, 1981.

The sequence involved the emplacement of basic and ultrabasic igneous rocks into metamorphosed argillaceous rocks. Then followed the intrusion of beryllium-enriched pegmatitic fluids. Finally, chemical weathering and alluvial-gravity transportation localized the gem concentrations. R.A.H.

NASSAU (K.). *Heat treating ruby and sapphire: technical aspects.* Gems & Gemology, **XVII,** 3, 121-31, 10 figs in colour, 1981.

The practice of heat treating sapphires has been rumoured, reported and debated for many years. Dr Nassau has put the matter on a factual basis which outlines nine different processes which are apparently in use: 1, to develop asterism; 2, to remove silk or asterism; 3, improve blue colour; 4, lighten blue colour (can result in a greenish stone); 5, diminish banding and strain in Verneuil synthetics; 6, introduce fingerprint inclusions in synthetics; 7, add asterism by diffusion; 8, add blue by diffusion; 9, add other colours by diffusion. Most treatments seem to involve temperatures approaching that of actual fusion of corundum and leave blister damaged surfaces which need repolishing where cut stones have been treated. Most processes are detectable in some stones but not necessarily easily so. [Following Mr Robert Crowningshield's important lecture on this subject during the Gemmological Association's Jubilee celebrations, this is a very valuable paper. Mr Crowningshield's lecture was substantially reproduced in the paper entitled *'The heat and diffusion treatment of natural and synthetic sapphires',* by Crowningshield (R.) and Nassau (K.),—J.Gemm., 1981, XVII (8), 528-41—which covers much the same ground as the Nassau paper but does so from a rather more practical point of view, since it emphasizes detection methods where these are available; also there is some attempt to discuss the ethics which arise from artificial treatments of this kind. Not all the processes are yet known in full detail.] R.K.M.

O'DONOGHUE (M.). *The dealer looks at gemstones.* Gems, **13,** 5, 26-8, 1 fig. (in colour), 1981.

This forms the first part of a series describing the criteria employed by gemstone dealers when selecting rough and cut material for sale.

(Author's abstract) M.O'D.

PAYNE (T.). *The andradites of San Fenito County, California.* Gems & Gemology, **XVII,** 3, 157-60, 5 figs (4 in colour), 3 tables, 1981.

A new source, not precisely identified, of gem andradite, one of the rarer gem garnets. It occurs as small yellowish-green to orange-brown and emerald green crystals, in situ and in alluvial deposits derived therefrom. Some of the orange brown (topazolite) stones exhibit chatoyancy. Pale yellow-green, dubbed 'Greenfire' for no very rational reason, is the commonest colour, emerald green (demantoid) is rare. RI 'greenfire' 1.851 approx, and 1.888 for demantoids; brownish stones fall between these values. Greenfire appears to display iron absorption centred at 4450Å. Demantoid exhibits 3 bands in red orange. Drawings do not convey spectra very convincingly. R.K.M.

POUGH (F. H.). *Treatments, betterments and chicaneries in gemmology.* Lapidary J., **35**, 9, 1804-41, 1981.

The substance of a talk given at the International Gemmological Congress in Kyoto, 1981, this gives a useful overview of present trends in alteration of colour while adding little fresh material. M.O'D.

READ (P.). *Gem stone carving and jewellery of China.* Gems, **13**, 5, 16-19, 8 figs (2 in colour), 1981.

The writer describes the state of the jewellery industry in the People's Republic of China. A number of divisions of the National Arts and Crafts Corporation deal with various aspects of jewellery and gemstone fashioning. M.O'D.

READ (P. G.). *Gemstones of Sri Lanka.* Gem World, **8**, 4, 18-20, 1981.

Recent developments in mining and selling gemstones in Sri Lanka are mentioned. Japan takes much of the alexandrite and cymophane production.

M.O'D.

ROSSMAN (G. R.). *Color in gems: the new technologies.* Gems & Gemology, **XVII**, 2, 60-71, 24 figs (17 in colour), 1981.

An excellent account of the causes of colour and colour change in a wide range of popular gems. Well illustrated and clearly explained with some information on the detection of artificially altered colour. R.K.M.

SCHMETZER (K.), BANK (H.), STÄHLE (V.). *The chromium content of Lechleitner synthetic emerald overgrowth.* Gems & Gemology, **XVII**, 2, 98-100, 2 figs in colour, 2 tables, 1981.

Emerald overgrowth of selected Lechleitner stones giving sharp RI readings, examined for chromium content by electron microprobe. Another sample gave broad shadow edges and varied in its Cr^{3+} content from 7.64% to 13.20% across the table facet. Others varied from 0% to 10.01%, the first having no emerald deposit on its table (removed in repolishing?). Most had very high Cr^{3+} ratios in the surface overgrowth by comparison with normal synthetics and natural emerald, rather as one would expect. R.K.M.

STOCKTON (C. M.), MANSON (D. V.). *Scanning electron microscopy in gemology.* Gems & Gemology, **XVII**, 2, 72-9, 12 figs, 1981.

Explains in reasonably simple language working and capabilities of the scanning electron microscope-energy dispersive system (SEM-EDS), including very high magnification and great depth of field, and its limitations (e.g., examines surfaces only and does not penetrate interiors as would a light microscope). Secondary electrons, back-scatter electrons and x-rays generated by the stream of electrons each yield different types of information, the last duplicating the normal function of the expensive electron microprobe in analysis. Uses in identifying microscopic inclusions surfacing on a stone, and mixtures of minerals, such as maw-sit-sit, are illustrated. Other projects are in hand. R.K.M.

SUNAGAWA (I.). *Natural and synthetic gem materials, a comparison.* Bulletin de Minéralogie, **104,** 128-32, 3 figs, 1981.

Differences detectable between natural and synthetic crystalline materials include external morphology, surface microtopography of crystal faces, growth bands, sector structures, inclusions, dislocation, planar defects, micro-twinning, stacking faults, etc. Some of these differences are demonstrated using high-resolution TEM lattice images of natural and synthetic emerald, x-ray topography, and surface microtopography of natural and synthetic diamonds and emeralds.

R.A.H.

UBAL (K.). *Die Mine der Weissen Königin.* (The White Queen mine.) Mineralien Magazin, **5,** 12, 540-1, 1 fig. in colour, 1981.

A brief history of the White Queen tourmaline mine in the Pala district of southern California is given. M.O'D.

WEIBEL (M.), WESSICKEN (R.), WOENSDREGT (C. F.), WUTHRICH (A.). *Sternsaphir und sternquartz.* (Star sapphire and star quartz.) Schweiz. Mineralog. Petrograph. Mitteilungen, **60,** 133-6, 2 figs, 1 photo, 1980.

The basic phenomena involved in chatoyancy and asterism is the scattering of light by extremely thin rods or cylinders, The star effect is described as seen in the white star quartz from Ratnapura, Sri Lanka, and the black star sapphire from Bang-kha-cha, Thailand. R.A.H.

WOENSDREGT (C. F.), WEIBEL (M.), WESSICKEN (R.). *Star quartz asterism caused by sillimanite.* Schweiz. Mineralog. Petrograph. Mitteilungen, **60,** 129-32, 5 figs, 1980.

The asterism of star quartz from Ratnapura district, Sri Lanka, is caused by acicular inclusions of sillimanite (identified by electron diffraction pattern). The sillimanite needles are preferentially oriented with their *c*-axes parallel to [100] of the host quartz. R.A.H.

ZHURAVLYOV (V.). *Mirny, the town of diamond miners.* Gem World, **8,** 4, 36-7, 1981.

A brief account of mining for diamond in Siberia. M.O'D.

Gemology from art to science. Jeweller's Circular-Keystone, Sept., part 2, 15-251, illus. in black-and-white and in colour, 1981.

Based on a celebration of the 50th anniversary of the Gemmological Institute of America, this piece reviews developments in gemmology ranging from the advances in instrumentation to the discoveries of new gem materials. The work of pioneer and present-day figures in G.I.A. is discussed. M.O'D.

BOOK REVIEWS

KALOKERINOS (A.). *Opal, Edelstein der tausend Farben.* (Opal, gemstone of a thousand colours.) Kosmos, Stuttgart, 1981. pp.139. Illus. in colour. DM 48.

This is a German version of a book first published in 1971 but with some additional colour plates and a short section on synthetic opal by Rudolf Mertens, who has also supplied some of the illustrations. The book covers opal from all known locations with particular emphasis on Australia. Quality of illustration is very high and since the publishers have named this as part of a series ('Kosmos Edelstein-Monographie') it is to be hoped that others in the series are equally well conceived and executed. M.O'D.

ST MAUR (S.), STREEP (N.). *The jewellery book.* Magnum Books, Methuen, London, 1981, pp.198, illus. in black-and-white (line drawings). £1.95

Described as the first really practical book about jewellery, it is scarcely that. Most of the writing appears to be from the somewhat garrulous pen of Ms St Maur, Mr Streep having been brought in 'to provide the technical back-up'. Thus it is written for the lay public largely by a lay-person, and, rather inevitably, it contains some silly errors.

We are told that gems originated from rotten chips of wood, churned down into the depths of the earth, fossilized and crystallized; that .999 bullion gold contains colouring matter to make it golden; that citrine and topaz are not dissimilar in value; that cat's-eye and tiger's-eye are roughly the same value; that white sapphires are almost as precious as diamonds; that it takes 250 tonnes of mined rock to produce one carat of diamond; that opals absorb grease, which makes them less brittle, and so on. There are many other inaccuracies.

Ms St Maur's stated difficulty in finding interesting books and an expert on the subject is scarcely acceptable. There are plenty of each if she knows where to look.

It is regrettable that this book, written expressly for the general public, should not have been researched with greater care. Its slightly flippant and loose use of English makes for tedious reading. The gemmological content is negligible. R.K.M.

WISNIAK (J.). *Phase diagrams: a literature source book.* Elsevier, Amsterdam, 1981. 2 vols. Fl 655.00.

This work brings together references on phase diagrams published between 1900 and 1980. The arrangement is alphabetical by element—this part takes us well into the second volume, the remainder of which is devoted to the references which are quoted by number in the first section. There are 17,381 of them. Anyone working on crystal growth will find the work invaluable. M.O'D.

Colored gem digest. Ge-Odyssey Gem Publications, Garden Grove, California. Annual subscription $20.00.

The issue examined (Vol. 2, No. 3) contained articles dealing with the evaluation of cuts of faceted gems; on appraisals; on an auction at which gem rarities were sold at less than the commercial prices obtaining generally at the time; and on land appraisals and their link with gemstone investment. M.O'D.

ASSOCIATION NOTICES

GIFTS TO THE ASSOCIATION

The Council of the Association is indebted to the following for their gifts:

Mr S. H. Chung, Taiwan, for a nephrite cat's-eye weighing 2.17 ct.

Mr John L. Pyke, F.G.A., Birkenhead, for a collection of eight cut and polished gemstones (mixed varieties) suitable for students' use.

Mr Jiří Skalický, Brno, Czechoslovakia, for a collection of moldavites from South Bohemia together with copies of his articles on the Czech moldavites published in overseas journals.

Mr Peter van Blommestein, Kimberley, S.A., for a set of 12 colour transparencies showing the Kimberley Diamond Mine in its various stages of progress from 1871 to 1895, and a set of 14 slides of current methods in use there.

Mr Frank D. Walker, Dallas, U.S.A., for a copy of *Turquoise the gem of the centuries,* by Oscar T. Branson, Treasure Chest Publications Inc., Santa Fe, New Mexico, 1975.

NEWS OF FELLOWS

On 23rd November, 1981, Messrs E. Colman, G. M. Jones, J. S. Kelly and P. W. Spacey, FF.G.A., formed the nucleus of a 'get together' of members and friends from the South Wales and Border areas at the Angel Hotel, Abergavenny. Slides of gemstone inclusions were shown and the evening was adjudged a success by those present. It was agreed that regular meetings be held, albeit on an informal basis. Any member interested please contact Mr G. M. Jones on Abergavenny 3429.

'Gemstones' was the subject of the sixth annual 'Commodity Meeting' of the Institution of Mining and Metallurgy. This one-day meeting was held on 3rd December, 1981, at Goldsmiths' Hall, London, E.C.2. During the meeting Dr J. B. Nelson, F.G.A., demonstrated a visual colorimeter developed by him for the measurement of the body colour of all faceted stones, using the CIE Colour System. He also exhibited an optical ray-path device which shows the behaviour of a beam of white light as it enters and leaves each of three polished glass gemstone profiles (brilliant-cut, 'fish-eye' cut and 'lumpy' cut).

Dr Nelson also gave a talk on 'CIE colour measurement and its application to gemstones' to the Hampstead Scientific Society on 14th January, 1982, at Burgh

House, Hampstead. A model of CIE Colour Space was demonstrated, showing the point positions of 38 measured gemstone colours lying within it.

On 5th January, 1982, Mr M. J. O'Donoghue, M.A., F.G.S., F.G.A., spoke on 'Mineral inclusions' to the Mid-Herts Lapidary and Mineral Society.

OBITUARY

Mr Kenneth Arthur Banks, F.G.A. (D. 1956), Chorlton-cum-Hardy, died on 31st December, 1981.

Mr Geoffry Howard Parsons, F.G.A. (D. 1937), Westbury-on-Trym, died on 28th December, 1981.

Mr Robert Weston, F.G.A. (D. 1930 with Distinction), Birmingham, died on 19th October, 1981.

MEMBERS' MEETINGS

Midlands Branch

On 29th January, 1982, at the Society of Friends, Dr Johnson's House, Colmore Circus, Birmingham, Mr Peter Harrison, of the Treak Cliff Cavern, Castleton, Derbyshire, gave an illustrated talk on Blue John, the famous mineral mainly found in the Castleton area of the Peak District. The talk covered the properties of the mineral, difficulties experienced in working it, and the history of the industry at Castleton.

On Friday, 26th February, 1982, also at the Society of Friends, an illustrated talk was given by Mrs Edna Holloway, the Black Country peasant carver. Mrs Holloway carves ivory in the Japanese Netsuke style and has demonstrated her skill in a special programme on television.

North-West Branch

On Thursday, 25th February, 1982, at Church House, Hanover Street, Liverpool, Mr Nicholas Wainwright, F.G.A., gave a talk on gemstones in the retail business. Members were able to view specimens.

South Yorkshire and District Branch

On 21st January, 1982, at the Sheffield City Polytechnic, the Annual General Meeting of the Branch was held. Mr I. R. M. Lewis, F.G.A., and Miss J. I. Platts, F.G.A., were re-elected Chairman and Secretary respectively. The A.G.M. was followed by an informal talk and demonstration on the recognition of diamond and its simulants by Messrs I. R. M. Lewis and J. Reynolds, FF.G.A.

ANNUAL REUNION OF MEMBERS AND PRESENTATION OF AWARDS

The Annual Reunion of Members and the Presentation of Awards took place at Goldsmiths' Hall on 16th November, 1981.

The Chairman, Mr David Callaghan, F.G.A., who presided, said that it had been an important year. The Association was the senior of its kind in the world, having celebrated its 50th anniversary but having sprung from the National Association of Goldsmiths. It was for this reason that Mr Peter Hopper, F.G.A., the N.A.G. Chairman, was present to distribute the awards. There were some new

awards this year. The Anderson/Bank Prize for the best non-trade candidate of the year in the Diploma Examination was being presented to a Hong Kong student by the Secretary, Mr Harry Wheeler, on his way to visiting Japan to take part in the Eighteenth International Gemmological Conference. There was also the Anderson Medal in the Preliminary Examination, commemorating the Association's Jubilee and Mr Anderson's 80th birthday: this had also been awarded to a candidate from Hong Kong.

Mr Callaghan then alluded to the two items on the table in front of him. One was a Jubilee present to the Association from Hong Kong, a marvellous fan given by their Gemmological Association; the other, a fine mounted crystal from the Norwegian Association.

Mr Hopper, after presenting the awards and recording his pleasure at the Association again being able to use the Goldsmiths' Hall, referred to the Jubilee exhibition which had also been held there and revealed that it had been visited by 3000 people apart from the members on the first day. It was a happy coincidence that he was Chairman of the N.A.G. at the same time as their anniversary. The Examinations had got a lot harder since he took them in 1958. He valued his F.G.A. above all other qualifications that he possessed, and urged all who possessed this qualification to use it to enhance the good name of the G.A. here and abroad.

Following the presentations, the Treasurer, Mr F. E. Lawson Clarke, F.G.A., recalled that his father had also been the Association Treasurer*.

The meeting ended with a vote of thanks to Mr Hopper by the Vice-Chairman, Mr Noel Deeks, F.G.A.

HONG KONG GEMMOLOGICAL ASSOCIATION AND PRESENTATION OF AWARDS

On 3rd November, 1981, Mr Alan Jobbins, F.G.A. and the Secretary, Mr Harry Wheeler, F.G.A., attended a specially organized reception and dinner given by the newly affiliated Gemmological Association of Hong Kong. Over 60 persons attended. This was an excellent opportunity to talk informally with their members, most of whom are F.G.A.s. After the dinner Mr Jobbins gave a talk on 'A Comparison between Volcanic and Breccia Agates of India' illustrated with slides, and Mr Wheeler spoke about the history of the G.A. of G.B. Then there followed a ceremony when the Secretary presented, on behalf of the Association, the Diplomas and Prizes that had been gained in the 1981 examinations by candidates in Hong Kong. In presenting the awards Mr Wheeler mentioned that it was an historic evening for the Hong Kong Association, because affiliation had only just been granted, it was the first time that an official of the G.A. of G.B. had presented awards outside the U.K., and the two new prizes, being awarded for the first time, the Anderson/Bank Prize and the Anderson Medal, had both been won by candidates from Hong Kong.

*V. W. Clarke, Treasurer 1924-25 and 1932-42.—Ed.

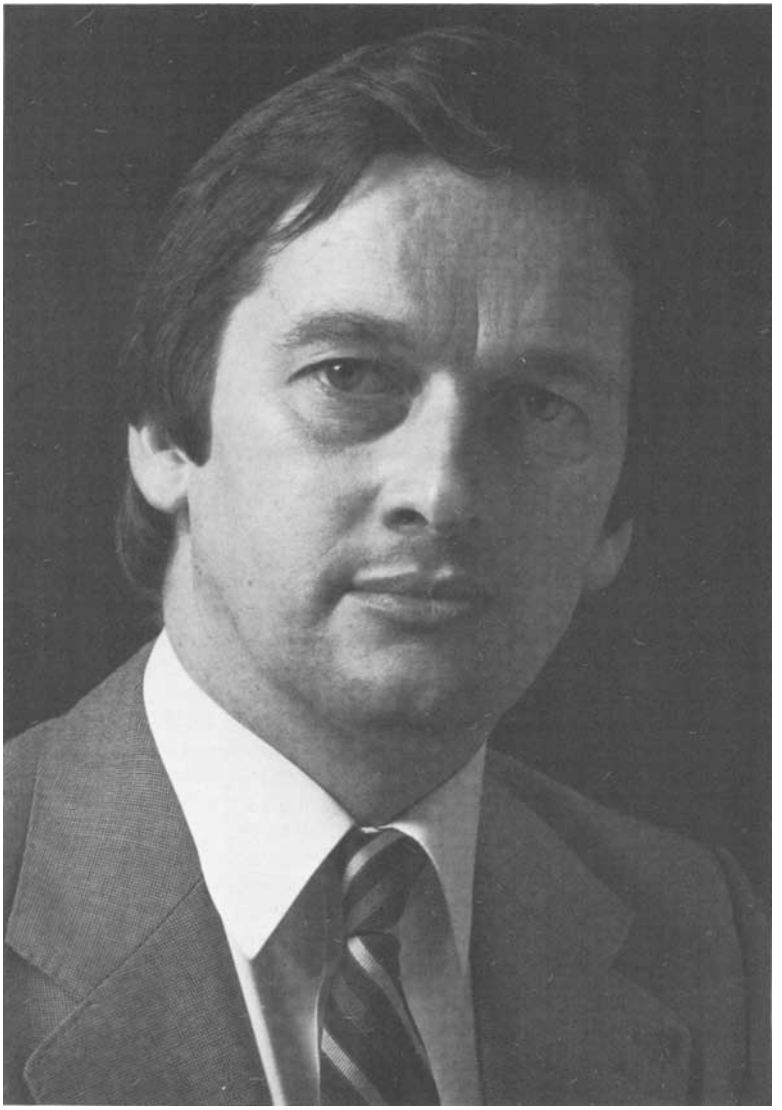

Mr Cornelius (Con) Lenan, F.G.A.
Secretary Designate
(see p.176)

PRESENTATION OF AWARDS—TOKYO

On Saturday, 7th November, 1981, the G.A. of All Japan held a Presentation of Awards at the Imperial Hotel, Tokyo, at which Mr R. P. Martin, the Cultural Counsellor and British Council Representative in Japan, was present. The Chairman of the G.A. of All Japan, Mr Yamada Wadachi, introduced Mr Harry Wheeler, F.G.A., Secretary of the G.A. of G.B., who then presented Diplomas to those present who had qualified in our 1981 examinations. Following this, the Vice-Chairman of the G.A. of A.J., Mr Watanabe, thanked Mr Wheeler and then presented Certificates to those who had qualified in his own Association's examinations. Almost 100 persons were present. Afterwards a special evening reception (with buffet) was held, attended by about 150 persons. Mr Alan Jobbins, F.G.A., was also present.

COUNCIL MEETING

At a Meeting of the Council held on Tuesday, 2nd March, 1982, at Saint Dunstan's House, the business transacted included the appointment of Mr Cornelius (Con) Lenan, F.G.A., as Secretary Designate, to succeed as Secretary on Mr Wheeler's retirement in December 1982. A list of those elected to membership will be included in the July issue of the *Journal.*

SECRETARY DESIGNATE

Mr Cornelius (Con) Lenan, who as recorded above has been appointed to succeed as Secretary on Mr Wheeler's retirement, is a Fellow of the Gemmological Association (D. 1966), holds the N.A.G. Retail Jewellers' Diploma and is also a Member of the Institute of Marketing: he has also recently been appointed Executive Director-Designate of the National Association of Goldsmiths. His career commenced in the retail jewellery industry with Crouch the Goldsmiths in Cardiff. He continued his business career through service and manufacturing industries, gaining wide experience in the U.K. and on assignments in Europe, the U.S.A. and Australia. A Welshman, he is thirty-five and married with three children. His interests include oil painting, swimming, music and literature.

Mr Lenan has taken up his appointment and works closely with Mr Harry Wheeler, who continues as the Secretary until he retires in December 1982.

XVIIIth INTERNATIONAL GEMMOLOGICAL CONFERENCE

The XVIIIth International Gemmological Conference was held in Kashiko-jima and Kyoto in Japan from 8th to 13th November 1981. At the commencement of the proceedings all stood in silence as a tribute to the late James Payne, F.G.A. Invited delegates from the U.K. were Mr Alec Farn, F.G.A. (former Director of the London Gem Testing Laboratory), Mr E. Alan Jobbins, F.G.A. (Institute of Geological Sciences and a Senior Examiner of the Association) and Mr Harry Wheeler, F.G.A. (Secretary). Delegates from the following countries attended: Australia, Brazil, Canada, China, Denmark, France, Hong Kong, Italy, Japan, Korea, Netherlands, Singapore, South Africa, Spain, Sri Lanka, Switzerland, Taiwan, U.K., U.S.A., U.S.S.R., West Germany, and many interesting papers were submitted during the

scientific sessions. The programme included a visit to Mikimoto Pearl Farm and Laboratories, where the harvesting of cultured pearls was seen and a visit to Pearl Island at Toba, where a special display of the Ama diving girls was organized (these diving girls are no longer used by Mikimoto, since the oysters are now reared artificially in their laboratories). Finally there was a visit to Lake Biwa to visit a freshwater cultured pearl company, followed by a boat trip to see the cultured pearl fisheries at close quarters.

The Conference finished with a 'Sayonara' party in Kyoto, when it was announced that the next Conference will be held in Sri Lanka in 1983. Professor Sunagawa and his Organizing Committee are to be complimented on the excellent organization and the arrangements made for a successful conference.

The various papers presented at the Conference are listed below:

Gemstone Resources of Australia, by E. R. Segnit, Australia.
Canadian Gemstones and Ornamental Mineral Occurrences, by W. F. Boyd and W. Wight, Canada.
Gem Minerals from Taiwan, by C. K. Huang, Taiwan.
Gem Occurrence in Sri Lanka with Special Emphasis on Elahera Gem Field, by E. Gamini and G. Zoysa, Sri Lanka.
Gemstones from the Tissamahara Area in Sri Lanka, by P. C. Zwaan, Netherlands.
Gemmy Minerals in Japan, by A. Chikayama, Japan.
Geochemical Aspects of the Central Australian Ruby Deposits, by D. H. McColl and R. G. Warren, Australia.
Sapphires of the Inverell District, New South Wales, by A. G. Tombs and J. H. Myers, Australia.
The Transvaal Emerald Deposits (South Africa), by Jan Kanis, South Africa.
Indian Agate Deposits, by E. A. Jobbins, England.
Geology and Mineralogy of Jadeite in Japan with Special Reference to Jadeite from the Kotaki-Omi Area, by Kazuya Chihara, Japan.
A Glimpse at the Gem Materials of China, by Liu Guobin, China.
The Kalahari Manganese Field near Kuruman, South Africa, by H. S. Pienaar, South Africa.
Recent Discoveries and Observations made in the Gem Trade Laboratory, by R. Crowningshield, U.S.A.
Gemmological News, by H. Bank, West Germany.
Some Gems from the Collection of the Fersman Mineralogical Museum, by V. S. Sobolev and L. V. Bulgak, U.S.S.R.
Pakistan Gem Deposits, by E. Gübelin, Switzerland.
External, Internal and Geochemical Aspects of Gem Garnets from Sri Lanka, by C. E. S. Arps and R. C. Litjens, Netherlands.
Tourmaline Chatoyancy, by Giorgio Graziani and Sergio Lucchesi, Italy, and Edward Gübelin, Switzerland.
The Last Neolithic Lapidary Men, by H. J. Schubnel, France.
New Possibilities of Corundum Identification Through Spectrophotometric Recording in Daily Gemmology, by C. A. Schiffmann, Switzerland.
Electron Spin Resonance in Gemmology, by L. V. Bershov, L. V. Bulgak, and A. V. Speranski, U.S.S.R.
Colorimetry in Gemmology, by Jean-Paul Poirot, France.

Diffraction-Grating (Spectrochromatic) Gemstones, by F. H. Pough, U.S.A.
New Views About Dichroism and Pleochroism, by Dina Level, France.
Application of Interference Contrast Microscopy to Identify Coated Diamonds, by Joji Sato and E. Sasaki, Japan.
Application to Gem Identification of Fluorescent X-Ray Analysis, by H. Ohguchi and E. Sasaki, Japan.
Gemology of Coloured Varieties of Synthetic Quartz, by V. S. Balitsky and A. A. Shaposhnikov, U.S.S.R.
The Origin of Diamonds and the Deep Gas Hypothesis, by J. M. Saul, France.
The Evolution of Diamond Grading Equipment, by R. T. Liddicoat, Jr, U.S.A.
The Pearl Challenge, by A. E. Farn, England.
Pearls, by Koji Wada, Japan.
The International Gemmological Conference—A Short Review, by Ove Dragsted, Denmark.
Garimpeiro Types of Gem Mining, by E. J. McGregor, Brazil.
Short History of the Gemmological Association of Great Britain, 1908-1981, by H. J. Wheeler, England.
Flashback, by Xaver Saller, West Germany.
Gemmology at a Crossroad, by Hans Reymer, Canada.
Gemmology and Physics, by L. Etienne-Amberg, Switzerland.

FELLOWS IN NEW SOUTH WALES

Mr John J. Douglas, F.G.A., of 31 Granada Avenue, Cardiff 2285, New South Wales, Australia, is interested in communicating with other Fellows of the Association in New South Wales. Anyone interested please communicate with him direct.

LETTER TO THE EDITOR

From Professor Dr E. Gübelin, C.G., F.G.A.

Dear Sir,

The voluminous Jubilee Issue of the *Journal of Gemmology* is such a fine publication—beautifully laid out with an impressive number of highly interesting and instructive contributions—that I feel urged to send you my enthusiastic congratulations for this outstanding publication, which will enjoy a prominent place in my gemmological library.

Having done some studies on inclusions in the new garnets from the Umba Valley in Tanzania, and also having vehemently opposed the ugly misnomer 'Malaya' garnet, I was particularly interested in reading the paper by Dr K. Schmetzer and Prof. H. Bank. With regard to the nomenclature of this new garnet, the authors emphasize that for the end members of the isomorphous series pyrope-almandine-spessartine garnet the designation 'pyralspite' is being used, wherefore no new fancy name is necessary. I certainly agree with this statement, and I am particularly satisfied that the problem is thus clarified, and the obscene misnomer 'Malaya' garnet (which actually means 'prostitute' garnet) is thus extinguished.

Strongly as I have always defended names officially acknowledged by mineralogy, in this case one should consider that the name of a gemstone which should attract the market must be a well-sounding, mellifluous and easily memorable name, which one certainly could not claim of the name 'pyralspite' even if it is scientifically justified. Therefore I wish to stick to my suggestion to endow this magnificent new garnet from the Umba Valley with the name *Umbalite* at least for commercial use. Names referring to the source or origin of gemstones have often been favoured by the trade as well as the public because it facilitates a closer relationship to the gem. See: benitoite, sinhalite, tanzanite, tsavolite, etc.

Yours etc.,
E. GÜBELIN

14th January, 1982.
Meggen, Lucerne, Switzerland.

GEM TESTING EQUIPMENT

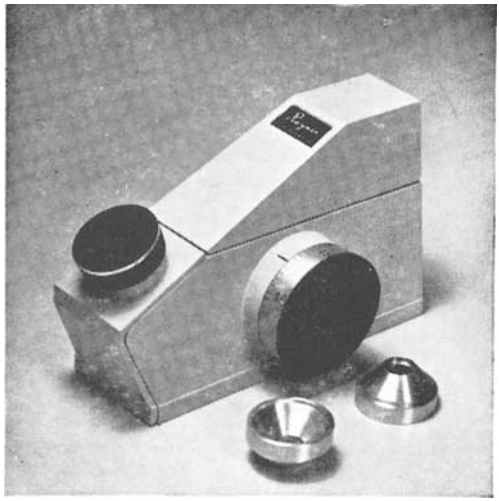

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Historical Note

The Gemmological Association of Great Britain was originally founded in 1908 as the Education Committee of the National Association of Goldsmiths and reconstituted in 1931 as the Gemmological Association. Its name was extended to Gemmological Association of Great Britain in 1938, and finally in 1944 it was incorporated in that name under the Companies Acts as a company limited by guarantee (registered in England, no. 433063).

Affiliated Associations are the Gemmological Association of Australia, the Canadian Gemmological Association, the Gem and Mineral Society of Zimbabwe and the Gemmological Association of Hong Kong.

The *Journal of Gemmology* was first published by the Association in 1947. It is a quarterly, published in January, April, July, and October each year, and is issued free to Fellows and Members of the Association. Opinions expressed by authors are not necessarily endorsed by the Association.

Notes for Contributors

The Editor is glad to consider original articles shedding new light on subjects of gemmological interest for publication in the *Journal.* Articles are not normally accepted which have already been published elsewhere in English, and an article is accepted only on the understanding that (1) full information as to any previous publication (whether in English or another language) has been given, (2) it is not under consideration for publication elsewhere and (3) it will not be published elsewhere without the consent of the Editor.

Articles published are paid for, and any number of prints of individual articles may be supplied to authors provided application is made on or before approval of proofs. Current rates of payment for articles and terms for supply of prints may be obtained on application to the Secretary of the Association.

Although not a mandatory requirement, it is most helpful if articles are typed (together with a carbon copy) in double spacing on one side of the paper, with good margins at sides, top and foot of each page. Articles may be of any length, but it should be borne in mind that long articles are more difficult to fit in than short ones: in practice, an article of much more than 10 000 words (unless capable of division into parts or of exceptional importance) is unlikely to be acceptable, while a short note of 400 or 500 words may achieve early publication.

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and

PROCEEDINGS OF THE GEMMOLOGICAL ASSOCIATION OF GREAT BRITAIN

GEMMOLOGICAL ASSOCIATION OF GREAT BRITAIN

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THE JOURNAL OF GEMMOLOGY
AND PROCEEDINGS OF THE GEMMOLOGICAL ASSOCIATION OF GREAT BRITAIN
Vol. XVIII No. 3 JULY 1982

TOURMALINE CHATOYANCY

By Prof. Dr GIORGIO GRAZIANI,*
Prof. Dr EDWARD GÜBELIN, C.G., F.G.A.†
*and Dr SERGIO LUCCHESI**
*Institute of Mineralogy and Petrography, University of Rome, Italy.
†Meggen, Lucerne, Switzerland.

ABSTRACT

Various laminae and cabochon-cut tourmaline samples were examined to represent all the elongated inclusions which may occur in this mineral with respect to the type, colour and site of the embedding crystal.

The specimens were characterized by means of x-ray powder patterns, being attributed essentially to elbaites and, in a few cases, to dravites. The elongated inclusions which may cause the cat's-eye effect are growth-tubes and needles, which microchemical analyses proved to be mainly constituted of tourmaline, the former sporadically by prosopite and cookeite, the latter by epidote. It has been noted that the growth-tubes most frequently occur in green samples, while the needles occur in red and blue ones.

INTRODUCTION

A great number of minerals show the chatoyancy effect when a multitude of relatively short needles or microscopic tubes traverse the embedding crystal in a strictly parallel manner along its main direction of growth. The intensity of such a phenomenon is due to the thinness and density of the elongated inclusions which cause the *scattering* of light.

Various types of elongated inclusions occur in tourmaline, and may be classified as (a) unorientated capillaries—thread-like

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cavities, called trichites, which often contain two-phase contents (Figure 1), and (b) strictly parallel inclusions, which may produce chatoyancy (Figure 2).

However, the trichites are not responsible for producing the chatoyant effect, since they are mainly gathered on bent planes referable to fractures which trapped residual drops of mother-fluid during their healing. Moreover, such thread-like capillaries are unorientated, trending irregularly and crossing one another at random. Usually the capillaries spread from a central nucleus which makes the generation of the cat's-eye effect more difficult, and in which two-phase inclusions occur. Tourmalines are occasionally characterized by other elongated fibrous inclusions which could be differentiated into growth-tubes and needles (Figure 3).

The former are primary cavities which may be caused both by evident strains generated by the embedding of an inclusion in the lattice of the crystal, and by irregularities in growth-modalities, as well as conditions of rapid growth of the host tourmaline (Bradley *et al.,* 1953). Such channels may be filled by two-phase inclusions as well as by birefringent (and rarely by opaque) materials. On the other hand, the needles are elongated thin fibrous crystals which, during the tourmaline's growth, aligned themselves strictly parallel to the main growth direction of the crystal. However, sometimes these are bent or curved at their extremities (Figure 4).

The chatoyant effect was suggested to be induced also by bundles of included mineral fibres, possibly members of the amphibole family (Eppler, 1973; Gübelin, 1974). Occasionally columnar assemblages with sub-hexagonal habit may yield a large and ill-defined cat's-eye effect.

Since the aim of this research is the study and determination of the cause of the cat's-eye effect, a considerable number of tourmaline specimens were examined in order to represent significantly all the elongated inclusions which may occur in this mineral with respect to the colour, type and site of the embedding crystal (Table I). Such samples were kindly made available from the collections of Professors Eppler and Gübelin. The specimens from the former's collection, nos 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, and 16, are made up of polished slabs (max. sizes: approx. $10 \times 5 \times 2$ mm) orientated parallel to the optical axis of the mineral. The other samples from Gübelin's collection, nos 13, 14, 15, 17, 18, 19, 20, 21

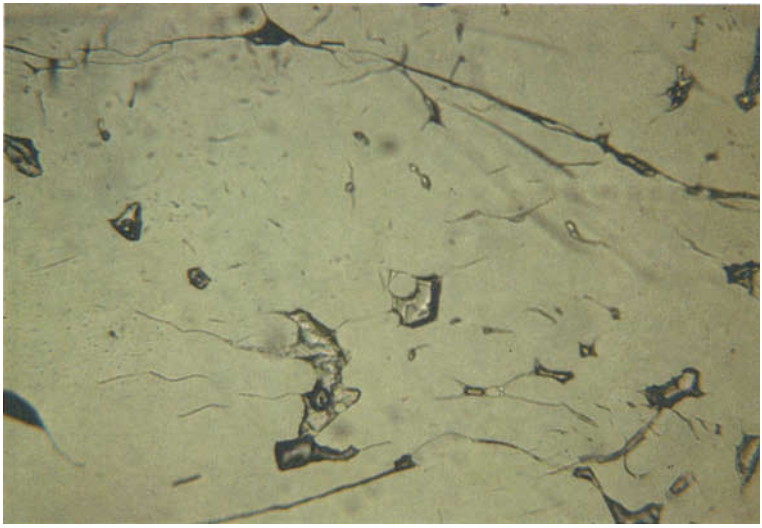

FIG. 1. Tourmaline chatoyancy: Sample 1. Green-yellowish tourmaline from Minas Gerais (Brazil). Capillary thread-like trichites, typically unorientated, with two-phase contents. × 80.

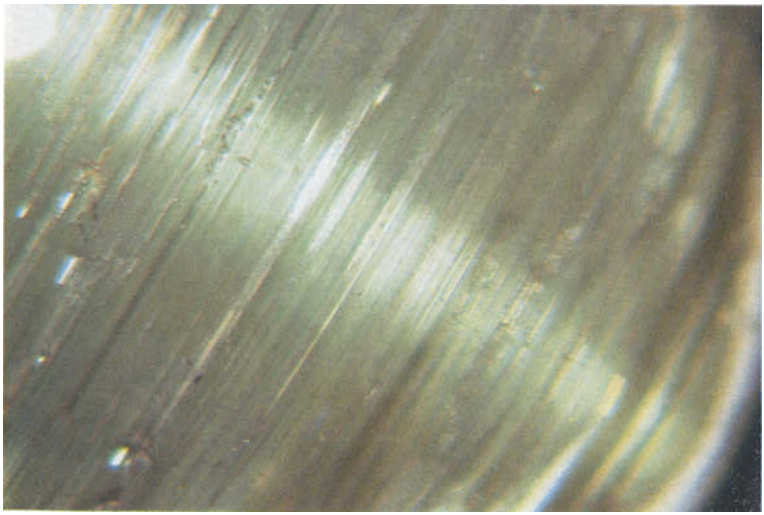

FIG. 2. Tourmaline chatoyancy: Sample 14. Green tourmaline from Himalaya mine, Pala (U.S.A.). Cat's-eye streak running over the curvature of the cabochon. × 30.

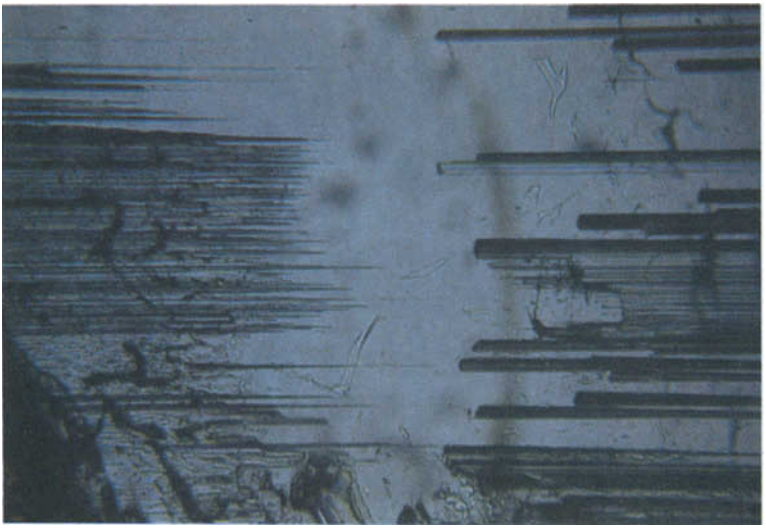

FIG. 3. Tourmaline chatoyancy: Sample 5. Light-green tourmaline from Pala, San Diego (U.S.A.). The various growth stages of the embedding crystal are evidenced by the presence of growth-tubes and needles. × 20.

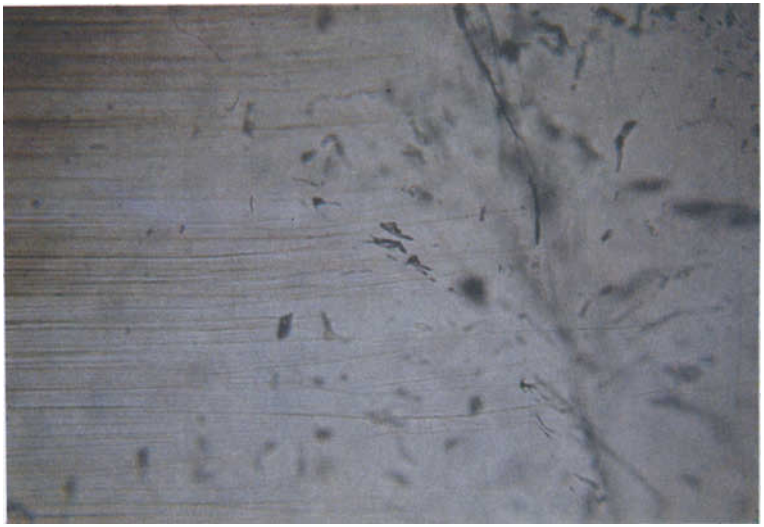

FIG. 4. Tourmaline chatoyancy: Sample 9. Green tourmaline from Minas Gerais (Brazil). Needles with sporadically bent or curved endings. × 25.

TABLE I. Selected tourmaline samples.

Sample number	Colour	Type of inclusions	Locality	Varieties of tourmaline
1 □	Green-yellowish	Trichites	Minas Gerais	Dravite
2 □	Blue-green	,,	,,	Elbaite
3 □	Light-green	,,	,,	,,
4 □	Pink	,,	Pala, S. Diego	Dravite
5 □	Light-green	Growth tubes	,,	Elbaite
6 □	Pink	,,	,,	,,
7 □	Blue-green	,,	Minas Gerais	,,
8 □	Green	,,	,,	,,
9 □	,,	,,	,,	,,
10 □	Light-green	,,	,,	,,
11 □	Green	,,	,,	,,
12 □	,,	,,	,,	,,
13 ○	,,	,,	Himalaya Mine, Pala	,,
14 ○	,,	Needles and growth-tubes	,,	,,
15 ○	Pinkish	,,	Minas-Gerais	Schorl-dravite
16 □	Blue	Needles	,,	Elbaite
17 ○	,,	,,	,,	,,
18 ○	,,	,,	,,	,,
19 ○	Grey-bluish	,,	,,	Dravite
20 ○	Green	,,	Newry	Elbaite
21 ○	Pink-white	Needles and Laminae	,,	,,
22 ○	Green/pink	Needles and laminae/granular	Alto Ligonha, Mozambique	,,

□ Eppler's collection.
○ Gübelin's collection.

and 22, are fine, cabochon-cut tourmalines all showing a conspicuous cat's-eye effect.

The specimens were first sorted with respect to their colour, and an attempt was made to evaluate the refractive indices, while the density was determined by means of the Berman balance. However, the data collected proved to be unreliable due to the peculiar characteristics of these tourmalines rich in fibres. It was thus not possible to define a clear correlation between these data and the total weight-percentage of the Fe, Mn, and Cr oxides content (Quensel, 1957).

Hence, the tourmalines were characterized by means of x-ray diffraction powder patterns, evaluating the unit cell parameters and using the assignation method suggested by Epprecht (1953). X-ray powder diffractograms were obtained with Ni-filter CuKα radiation from 10° to 70° 2θ per minute, with semiconductor grade silicon metal as an internal standard (Jarrel Ash J. M., spectroscopy impurity < 300 ppm). Unit cell parameters were established by the least-squares refinement of the collected data (Appleman & Evans, 1973) indexed by comparison with the reflections listed by the Joint Committee of Powder Diffractions Standards, Card nos 14-76, 19-1372 and 26-964.

Electron microprobe analyses have been carried out to clarify the chemical composition of the matrix and to identify the elongated inclusions. At first, optical observations were accomplished with the purpose of determining the areas most suitable for each sample, both on the bulk crystal and on the inclusions, to carry out the microprobe analyses.

The micro-analyses of the fibres embedded in the cabochons were performed on the protruding terminations of such inclusions; it was thus necessary to operate on the curved sides of the samples, resulting in a larger experimental uncertainty. Such analyses were performed using an E.D.S. system from Link, on a Jeol JXA-50A probe with on-line matrix corrections, Zaf-4 program. Boron, lithium and both H_2O^+ and H_2O^- were not determined because of their failure to respond in the microprobe, and also because of the impossibility of utilizing destructive methods of analysis. Eight-spot analyses were carried out on each selected area for every sample, averaging the collected data.

The two-phase inclusions have been studied by means of a heating plate Leitz 1350, utilizing both transmitted and reflected light with a dry nitrogen current of 2 ml/min. The homogenizing temperatures have thus been determined using a chromelalumel thermocouple, with an experimental uncertainty of about ± 1 °C.

Results and Discussions

The experimental measurement of the refractive indices proved to be extremely difficult, due to the characteristics of the samples. In addition, it proved extremely difficult to determine the total weight-percentage of the oxides of the heavy elements, since the data obtained from the diagrams happened to be excessively sporadic. Moreover, since chemical composition does not always

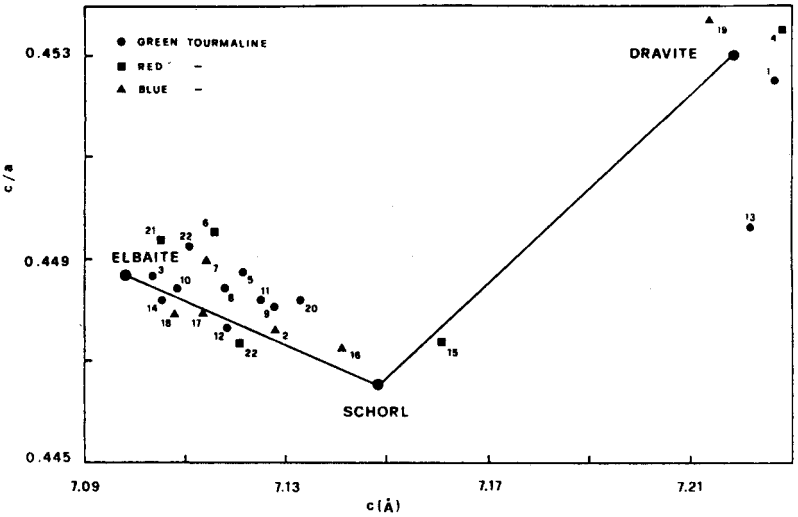

FIG. 5. Tourmaline chatoyancy: Interdependence between c/a ratio and a parameter.

succeed in discriminating the percentage content of dravite, schorl and elbaite of a sample with sufficient accuracy, it was necessary to make use of the relation existing betwen the lattice constants, attributing the examined samples mainly to elbaites and, in a few cases only, to dravites (Figure 5). However, it should be noted that no close relationship between such structural classification and colour has been recognized, and consequently a noticeable dispersion of the specimens in the whole diagram is evident.

All the different elongated inclusions shown by the samples were then grouped according to the colour of the embedding tourmaline, disclosing a peculiar preference of each inclusion for one or another of the various colours (Figure 6). These inclusions were roughly classified into three groups: trichites, growth-tubes and needles. The trichites particularly seem to be generally distributed and not linked to the colours, while the growth-tubes are remarkably characteristic of the green samples (Figure 7). Inversely the needles are most abundant in the pink-red and blue tourmalines. Two-phase inclusions, which occur both as trichites and growth-tubes, were examined by means of a hot plate and the homogenizing temperatures were determined, suggesting in this way the presence of CO_2 and H_2O as main constituents, indicating typically hydrothermal environments (Figure 8).

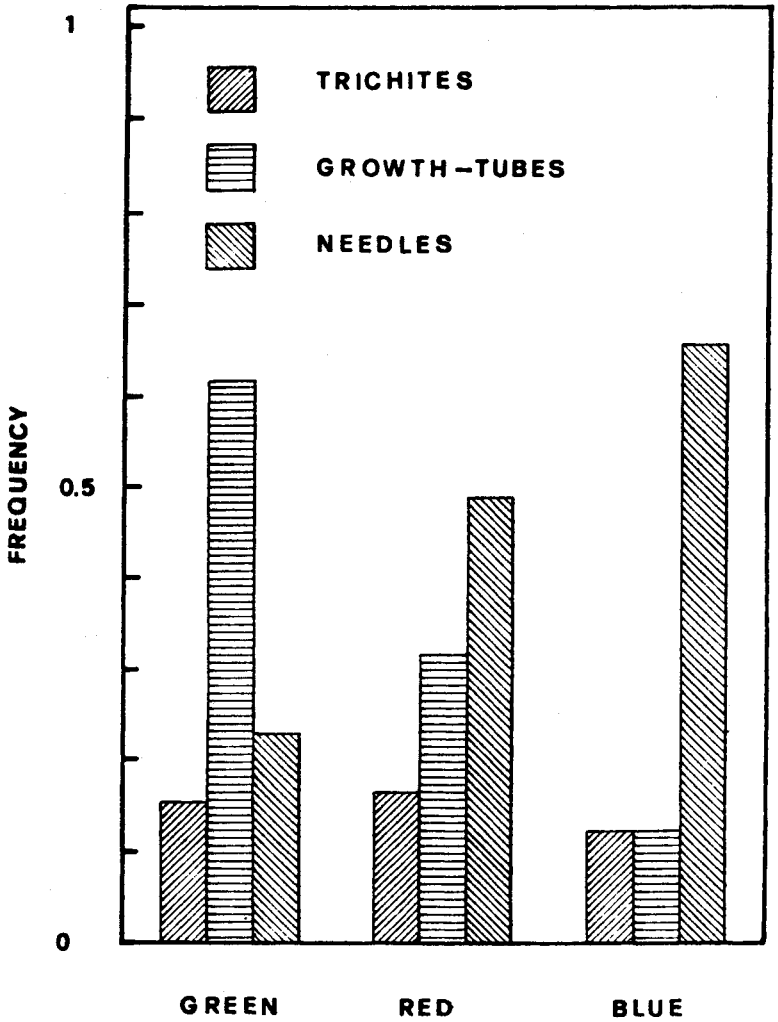

FIG. 6. Tourmaline chatoyancy: Inclusions frequency with respect to the colour of the embedding crystal.

Most frequently however, the growth-tubes are filled with birefringent material, which at times appears powdery. Microchemical determinations have been carried out with the purpose of defining the nature of such material, which was found to be mainly made up of silica aluminates whose chemical

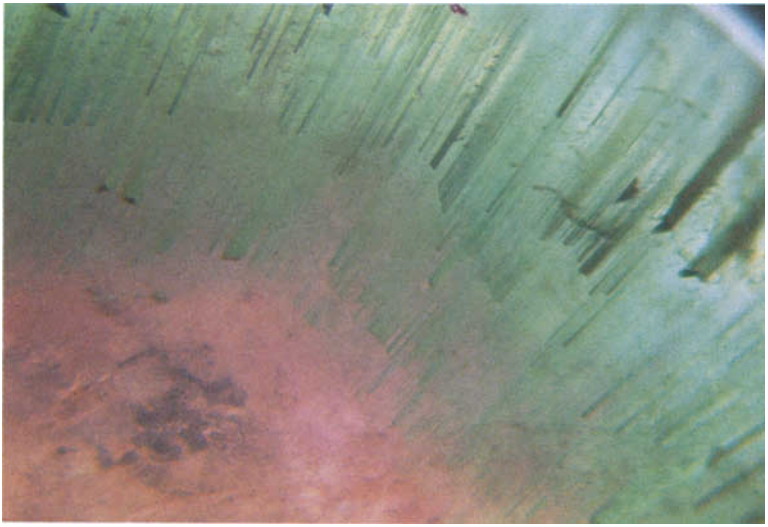

FIG. 7. Tourmaline chatoyancy: Sample 22. Green/pink tourmaline from Alto Ligonha (Mozambique). The growth-tubes are evidently gathered in the green area. × 60.

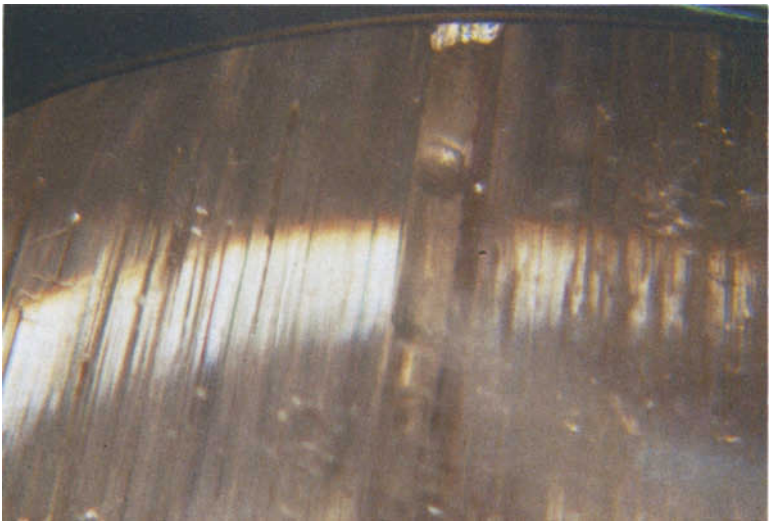

FIG. 8. Tourmaline chatoyancy: Sample 15. Pinkish tourmaline from Minas Gerais (Brazil). Two-phase inclusions evident in the growth-tubes. × 30.

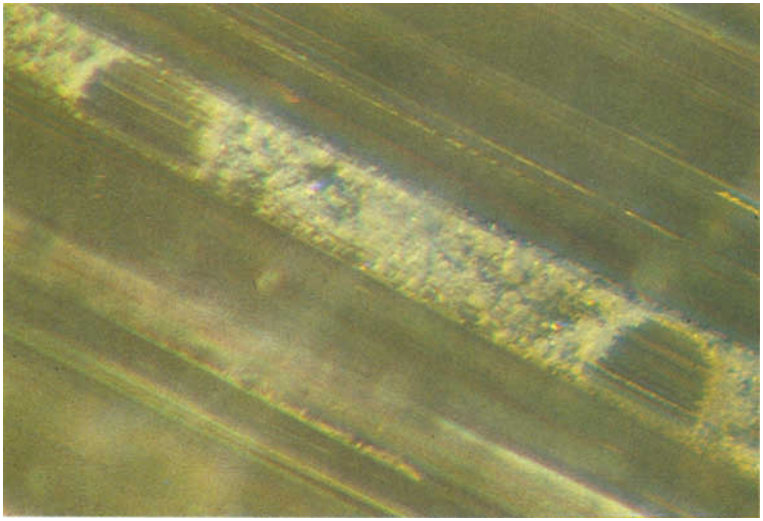

FIG. 9. Tourmaline chatoyancy: Sample 20. Green tourmaline from Newry, Maine (U.S.A.). Growth-tubes filled with powdery crystal material of prosopite. ×250.

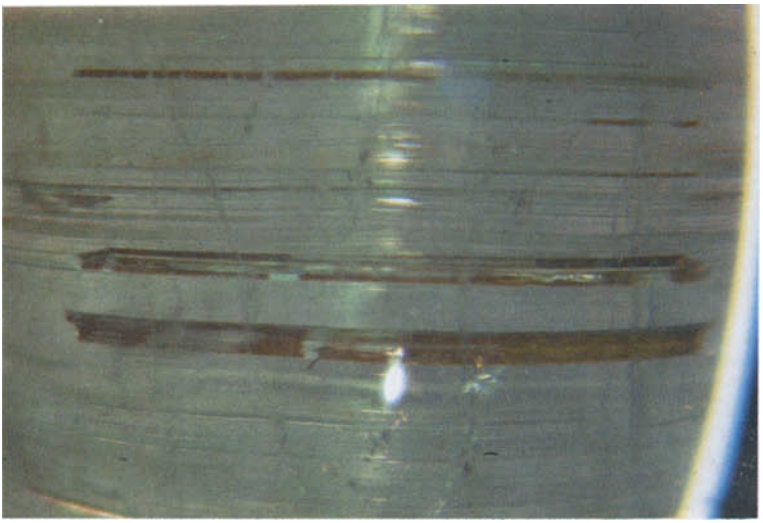

FIG. 10. Tourmaline chatoyancy: Sample 22. Green/pink tourmaline from Alto Ligonha (Mozambique). Laminae of iron oxides and hydroxides filling the growth-tubes. ×60.

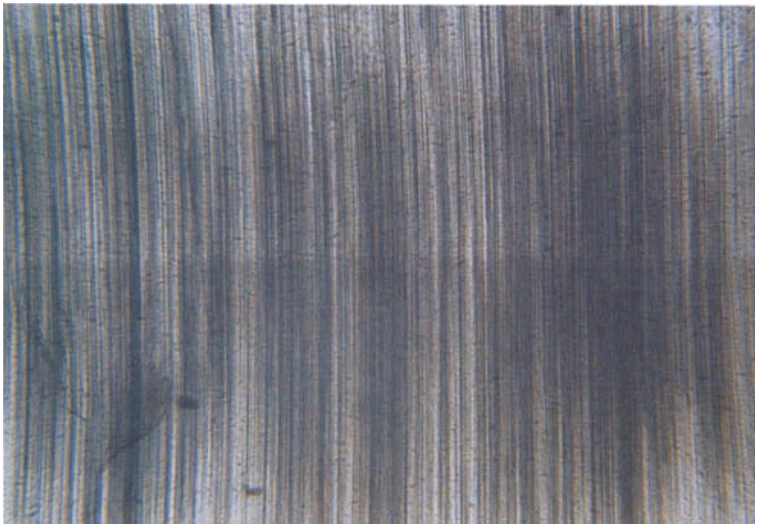

FIG. 11. Tourmaline chatoyancy: Sample 11. Green tourmaline from Minas Gerais (Brazil). The needles are rigorously iso-orientated parallel to the *c* axis of the embedding crystal. × 20.

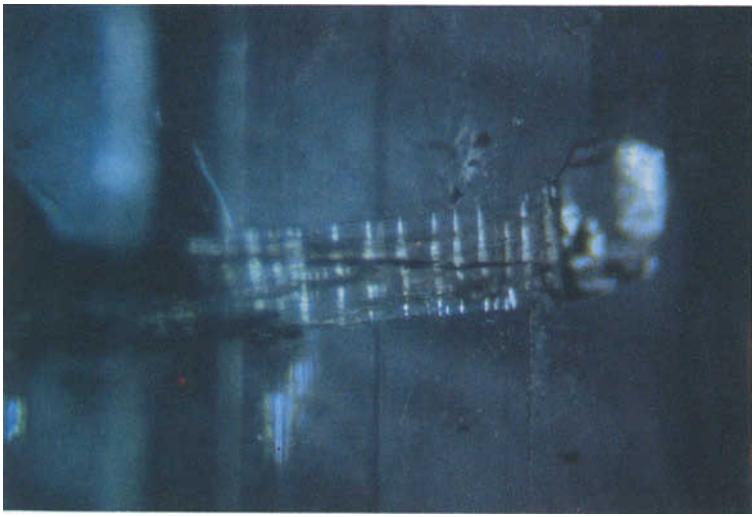

FIG. 12. Tourmaline chatoyancy: Sample 16. Blue tourmaline from Minas Gerais (Brazil). Columnar assemblages referable to muscovite laminae. × 40.

composition did not differ from that of the host crystal. It may therefore be concluded that the most usual filling of the growth-tubes is tourmaline showing a chemical composition as well as a pattern of minor elements similar to that of the embedding crystal.

The other materials recognized in the growth-tubes are prosopite and cookeite (Figure 9). Prosopite usually occurs in veins and greisen associated with quartz, fluorite, mica and caolin as well as tourmaline, and formed apparently as an alteration product of topaz-bearing porphyries. Prosopite can easily be found both in the channels, associated and mixed with tourmaline, and sometimes in the healed fractures as powdery material. Cookeite is also a characteristic of pegmatitic and hydrothermal environments, forming in the last stages of the replacement process developing after early lithium minerals: mainly rubellite and lepidolite, tourmaline and microcline. The opaque material which occurs in the channels was found to be pyrrhotite owing to its iron-sulphur ratio and its appearance.

Laminae of iron oxides can usually be found on the inside surfaces of the growth channels. Their colour varying from red to brownish would suggest their attribution to haematite-maghemite or lepidocrocite respectively (Figure 10). Yellowish haloes have also been noted surrounding some of the channels; the electron microprobe analyses indicated enrichment of iron which would suggest the presence of various iron oxides, related to the previously described ones.

The needles, which are also responsible for setting up the phenomenon of chatoyancy, are both consituted by birefringent long thin crystalline fibres and by straight elongated birefringent rods (Figure 11).

The former sometimes appear slightly undulating, though strictly parallel among themselves, and their ends often deviate from a strictly linear direction. Microanalyses show in this case also no difference between the chemical composition of the inclusions and that of the embedding tourmaline. Small fragments and laminae of opaque material, presumably sulphides, are frequently interbedded with such fibres.

The birefringent rods turned out to be made up of epidote, whose chemical composition was close to that of the calcium end-member clinozoisite. This mineral, which is characteristic of medium grade regionally metamorphosed igneous and sedimentary

rocks, can be found also in metasomatic environments, sometimes crystallizing from hydrothermal liquids in vugs and fissures extremely poor in iron as clinozoisite.

The columnar assemblage which was found in a few green elbaite samples consists of a succession of subhexagonal muscovite laminae (Figure 12). This mineral is characterized of the same late magmatic stage as tourmaline, being found in a pegmatitic and hydrothermal environment. Its low sodium content suggests crystallization temperatures below 400 °C for all samples.

CONCLUSION

The data collected from the numerous tourmaline samples examined suggest that, among the various inclusions which may be found in this mineral, the trichites are not linked to the colour of the embedding crystal, the growth-tubes seem more frequent in the green specimens, while the needles are more often found in the blue and red ones.

As far as the cat's-eye effect is concerned, it may be stated that it is mainly caused by growth-tubes, filled primarily with tourmaline and secondly with prosopite, cookeite, iron-oxides and sulphides, as well as by needles also consisting of tourmaline and, in a few cases, of epidote.

ACKNOWLEDGEMENTS

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AN UNUSUAL GARNET FROM UMBA VALLEY, TANZANIA

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ABSTRACT

A yellowish-brown garnet from Umba Valley, Tanzania, is described. The unit cell dimension, refractive index and density were found as $a_0 = 11.627$ Å, $n = 1.762$, and $D = 3.68$ g/cm^3, respectively. The garnet is a member of the pyrope-spessartite solid solution series with an extremely high grossularite component and has a composition of 28.5% pyrope, 24.0% grossularite, 43.6% spessartite, 3.3% almandine, and 0.6% goldmanite. The absorption spectrum shows bands of Fe^{2+} and Mn^{2+} on X-sites, and of Fe^{3+} and V^{3+} on Y-sites of the garnet lattice. Because of the low vanadium content of only 0.2% V_2O_3, the intensity of the V^{3+}-absorption band is too weak to produce an alexandrite effect, as described in other vanadium-bearing garnets.

Garnets are nesosilicates with the general formula $X_3Y_2[SiO_4]_3$. In nature different garnet solid solution series are observed, e.g., between the end members pyrope, $Mg_3Al_2[SiO_4]_3$, almandine, $Fe_3Al_2[SiO_4]_3$, and spessartite, $Mn_3Al_2[SiO_4]_3$. In the members of the solid solution series mentioned, the Y-position of the garnet structure is occupied by Al^{3+} while the X-position is occupied by different amounts of Mg^{2+}, Fe^{2+}, and Mn^{2+} as well as to a certain extent by Ca^{2+}. The members of the solid solution series pyrope, almandine, and spessartite, which may also contain distinct amounts of CaO, i.e., distinct amounts of the grossularite end member, are called pyralspite garnets.

The variously coloured pyralspite garnets from Umba Valley, Tanzania, are members of the solid solution series pyrope-almandine and pyrope-spessartite (Schmetzer & Bank, 1981a). Chemical investigations by the electron microprobe showed the members of the solid solution series pyrope-almandine to have a composition between 26% and 73% pyrope, between 15% and 61% almandine, between 1% and 11% as well as between 0% and 20% spessartite and grossularite. The garnets of the solid solution series pyrope-spessartite from this locality were found to contain between 5% and 51% pyrope, between 38% and 86% spessartite and minor amounts of almandine (between 1% and 10%) and grossularite (between 4% and 11%). In garnets of this second solid solution series, containing additional, but small, amounts of V_2O_3 and/or Cr_2O_3, a distinct alexandrite effect is observed. Crystals of

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this composition are described from Umba Valley, Tanzania, and from Ratnapura, Sri Lanka (Zwaan, 1974; Jobbins *et al.*, 1978; Schmetzer & Ottemann, 1979; Schmetzer & Bank, 1981b).

The investigations, described in this paper, were undertaken because of the unusual yellowish-brown colour of a garnet from Umba, which was not observed before in a member of the different garnet solid solution series from this locality (Figure 1). Chemical investigations showed the composition of the sample to be outside of the known solid solution field for Umba garnets. Therefore, the chemical and physical data of the garnet and the cause of its unusual colour are discussed in this paper.

FIG. 1. Yellowish-brown member of the pyrope-spessartite-grossularite solid solution series, Umba Valley, Tanzania; size of the sample approx. 6 × 9 mm.

The results of the chemical and physical investigations of the yellowish-brown garnet from Umba are given in Table 1. The sample is a member of the solid solution series pyrope-spessartite with an extremely high content of 24.0% of the grossularite molecule. The pyrope-spessartite garnets, described by different authors, show a maximum content of 6.85% CaO (17.7% of the grossularite end member), which was found in a greyish/orange brown crystal by Jobbins *et al.* (1978).

The parameter of the unit cell, determined to be $a_o = 11.627$ Å is larger than for other members of the pyrope-spessartite solid solution which contain smaller amounts of CaO. The refractive index ($n = 1.762$) is distinctly higher, while the density ($D = 3.86$ g/cm^3) shows only a small increase compared with other garnets of the pyrope-spessartite solid solution series with similar MnO contents (e.g., sample E, Schmetzer & Bank, 1981b). These differences in the physical data are explained by an isomorphic replacement of Mg^{2+} and Ca^{2+} on X-positions of the garnet lattice.

TABLE 1

Chemical and physical data of pyrope-spessartite-grossularite garnet, Umba Valley, Tanzania.

Microprobe analysis, in weight-%		cations calculated to $\Sigma 0 = 12$	
MgO	7.41	Mg	0.842
CaO	8.88	Ca	0.725
MnO	19.94	Mn	1.288
FeO[+]	1.53	Fe	0.098
Al_2O_3	22.03	Al	1.980
V_2O_3	0.18	V	0.011
Cr_2O_3	———[+++]	Cr	———
SiO_2	39.56	Si	3.017
TiO_2[++]	0.24	Ti	0.014
Σ	99.77	Σ	7.975

[+]total iron as FeO
[++]total titanium as TiO_2
[+++]$Cr_2O_3 < 0.05$

Composition of end members, in wt%		Physical data
pyrope	28.5	$a_o = 11.6267(2)$ Å
grossularite	24.0	$n_D = 1.762(1)$
spessartite	43.6	$D = 3.86(1)$ g/cm^3
almandine	3.3	colour after DIN 6164
goldmanite	0.6	between 2:5:3 and 2:5:4
Σ	100.0	

The chemical composition of pyrope-spessartite-grossularite garnets from Umba Valley, Tanzania, and Ratnapura, Sri Lanka, is shown in Figure 2. The garnets of both localities have similar chemical compositions; therefore, a single garnet crystal cannot be assigned to either of these localities because of its composition and physical properties (refractive index, density, parameter of the unit cell). The pyrope-spessartite-garnets from Sri Lanka are, up to now, very rare, whereas great quantities of the orange brown coloured pyralspites from Umba are available in the gemstone market.

According to Novak & Gibbs (1971), all garnets of the system pyrope-almandine-spessartite-grossularite are situated in one stability field because of the ionic radii of the X- and Y-cations. The stability of garnets in the quaternary system has been calculated by Ganguly & Kennedy (1974). The members of the solid solution series mentioned above are found to be stable at 600 °C for all compositions. Therefore, it has to be clarified by further

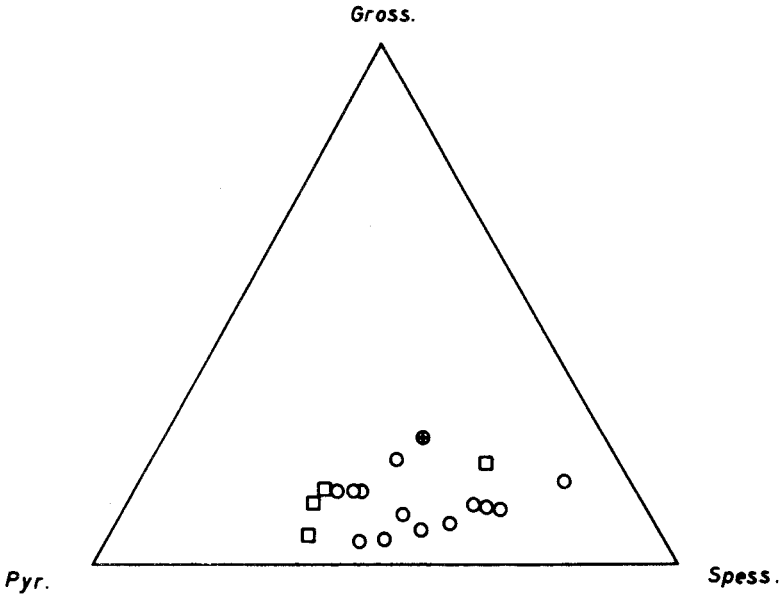

FIG. 2. The pyrope-spessartite-grossularite ratio of members of the pyrope-spessartite solid solution series from Umba, Tanzania (○), and Ratnapura, Sri Lanka (□); chemical data from Jobbins *et al.* (1978), Schmetzer & Ottemann (1979), Schmetzer & Bank (1981a, b). The crystal with a content of the grossularite end member of 24.0% is individually marked (⊕).

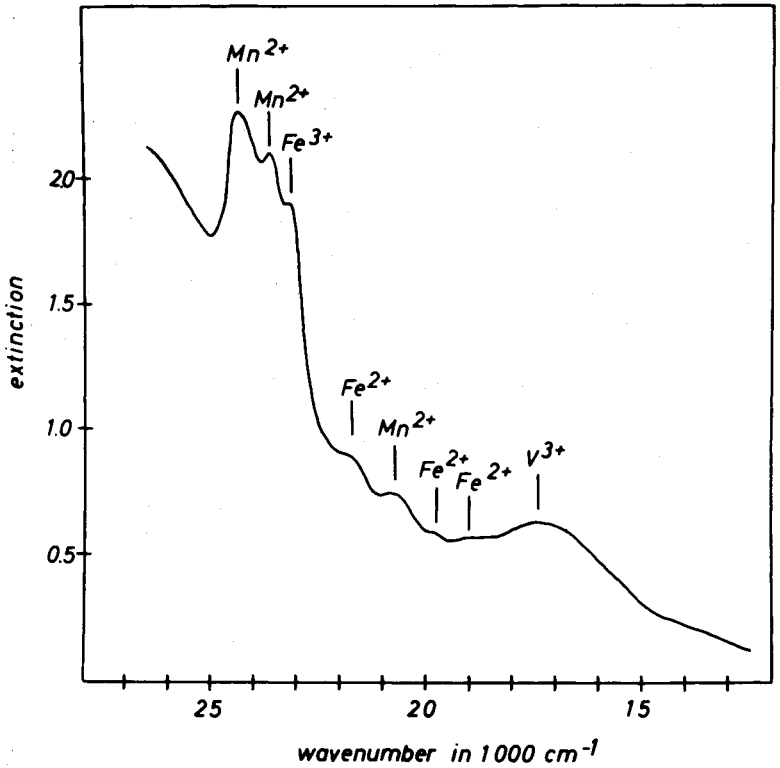

FIG. 3. Absorption spectrum of a pyrope-spessartite-grossularite garnet, Umba Valley, Tanzania.

chemical investigations and not by theoretical considerations as to whether the solid solution field shown in Figure 2 can be enlarged for other garnets of different chemical composition. Only little information is available on the metamorphic p-t-conditions of the wall rocks of the Umba garnets; therefore, the exact pressure and temperature of formation are still unknown.

The absorption spectrum of the pyrope-spessartite-grossularite crystal described in this paper, shows absorption bands, whose positions are identical with those known for pyralspite garnets (Moore & White, 1972; Loh, 1975; Schmetzer & Ottemann, 1979). The absorption bands are assigned to Fe^{2+} and Mn^{2+} on cubic X-sites and to V^{3+} and Fe^{3+} on octahedral Y-sites in the garnet lattice (Table 2). The spectrum of the garnet shows an absorption band of V^{3+} at 17 500 cm^{-1}, which is not observed in the spectra of orange-

TABLE 2

Spectroscopic data of pyrope-spessartite-grossularite garnet, Umba Valley, Tanzania.

Absorption maxima [cm^{-1}]	Assignment cation	lattice site
17 500	V^{3+}	Y (oct.)
19 000	Fe^{2+}	X (cub.)
19 800	Fe^{2+}	X (cub.)
20 800	Mn^{2+}	X (cub.)
21 800	Fe^{2+}	X (cub.)
23 200	Fe^{3+}	Y (oct.)
23 700	Mn^{2+}	X (cub.)
24 450	Mn^{2+}	X (cub.)

coloured pyralspite garnets from Umba. This absorption band, however, is known from the spectra of alexandrite-like garnets from the same locality (Schmetzer & Ottemann, 1979). These alexandrite-like garnets, in general, contain distinctly higher amounts of V_2O_3 and/or Cr_2O_3 compared with the garnet described in this paper. The absorption at 17 500 cm^{-1} (yellow region of the visible area) in those alexandrite-like pyralspites is stronger and therefore produces a distinct minimum in the bluish-green area, which is also observed in other solids showing an alexandrite effect (Schmetzer *et al.*, 1980). The bluish-green minimum, however, is not found in the spectrum of the yellowish-brown garnet and, therefore, an alexandrite-effect is not observed in this crystal. Due to its colour, the sample is the connecting link between the V- and/or Cr-containing alexandrite-like pyralspites from Umba and the orange-coloured members of this solid solution series, in which, generally, no V- or Cr-contents are observed.

The author is grateful to Dr H. Krupp, of Heidelberg, for the sample and to Dr H.-J. Bernhardt, of Hamburg, for the microprobe analysis.

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A STRANGE REPORT ON GOLDSTONE

By R. KEITH MITCHELL, F.G.A.

A recent gemmological study report published in the *Australian Gemmologist* (1981, 14, 6, 139) and entitled 'Some observations on goldstone' draws some extraordinary conclusions which cannot be accepted. Predictably the investigation found the material to be crown glass with the constants and physical characters expected of that material, and to contain angular flakes of metallic copper. It is in the nature of the copper particles that the investigation appears to be at loggerheads with the established facts. The conclusions in question are: 'The reflective flakes in goldstone are *not* the product of crystallization; the flat *machined* flakes being added to the molten glass before it is cooled.' 'Included reflective flakes appear to possess a *preferred orientation*—sub-parallel sheets parallel to the surface of the glass.'* This preferred orientation seems to be advanced as justification for the first conclusion.

*The italics are mine.

Now each piece of 'goldstone' is crowded with thousands, possibly millions, of these microscopic specks, varying in size from about 0.2 mm down to invisibility at 50 × magnification. They are by no means always oriented in the way described. I have a three-sided seal stone of this material which has faceted edges and ends. There is no apparent difference in the spangling of any of the surfaces thus exposed. Further, as the angle of the surface is changed under a fixed light source some flakes extinguish and others start to reflect without any real diminution of the over-all effect.

The suggestion that these millions of ultra-thin plates could be machined, presumably shaped, cut and polished, before inclusion in the molten glass (the fact that this is before it is cooled is rather obvious) is economically quite unsound. Even if it were feasible costwise, such admixture could not be achieved without oxidation of the copper and would almost certainly show swirls and concentrations of flakes which are not usually present. A few old pieces have shown swirls suggesting that the glass was stirred, probably as a deliberate decorative effect, or pressed into moulds, while in a viscous state.

The vast majority of the flakes are equilateral triangles, although they can photograph to look isosceles or even scalene when they are inclined to the film plane of the camera. Some have their corners truncated by other faces of the octahedron, some to the extent that they become hexagonal. But the angles are always precisely 60° or 120°, which argues beyond doubt that they are the product of crystallization.

Copper crystallizes in the cubic system, and one of its common habits is that of octahedral plates, i.e. equilateral triangles. In the circumstances a cooling glass containing a labile (super-saturated) solution of copper could be expected to give an even distribution of ultra-thin microscopic octahedral plates in the essential form of equilateral triangles or truncated forms derived therefrom. It may also be noted that a few flakes examined in the course of my own work have shown surface markings paralleling crystal edges, which again suggest crystals rather than artificially shaped particles. Under greater magnification I have been able to get reflection from angled edges on some triangular flakes, which suggest truncation by a neighbouring octahedral face.

A letter from Dr Michael Cable, of the University of Sheffield Department of Ceramics, Glasses and Polymers, gives the following information: 'Aventurine glass is made in the usual way and the crystals precipitated out and grown by very slow cooling (e.g. 4 days to cool to annealing temperature). It is not made by stirring copper filings in glass merely to get a physical mixture. . . . . According to Peligot* the copper is always added to the original glass batch and will therefore either all dissolve in the melt or, possibly, form a pool of molten metal at the bottom of the pot: I have done this myself many times.'

Now this information that the glass is cooled over a long period suggests a reason for the apparently preferred orientation of the copper crystals. This feature is certainly seen in flat pieces of goldstone intended for use in seal rings or other articles needing a thin flat stone. Obviously a preformed flat sheet represents a saving in manufacturing costs and I would suggest that it is probably a practice to pour the saturated molten glass on to a smooth horizontal surface, where it is maintained at high temperature for the required cooling period. With the glass completely molten the embryo copper crystallites, being some four times as dense as the host glass, would gravitate to the bottom and, like leaves falling from a tree, would tend to lie flat. This, I submit, deals adequately with the matter of the 'preferred orientation'.

Dr Cable goes on to say that he has encountered aventurine glass with green spangles. These are due to the addition of chromium in the form of chromic oxide. Also, some coppery crystals seen in other examples are possibly cuprous oxide rather than the pure copper crystals seen in most examples of this decorative paste. In the latter case it is recorded by Peligot that iron filings are stirred in to reduce and to cause the copper to precipitate out.

But I think the case for the spangles being crystalline is beyond all doubt. Regrettably, I feel that the Australian Study Club have been hasty in arriving at conclusions without due thought and consideration. This is unusual. Their work in the past has made some interesting contributions to gemmology.

[*Manuscript received 15th September 1981.*]

*Eugene Peligot, *Le Verre; son histoire, sa fabrication*, Paris, 1877.

AN INTERESTING GREEN CABOCHON

By R. KEITH MITCHELL, F.G.A.

My old friend and former student, Henry Whitehead, the Correspondence Instructor whose untimely death was reported in 1980,* was a travelled man and twice in his retirement he visited Sri Lanka. Inevitably he collected various gems but, unfortunately, did not always record their provenance.

Christopher Cavey bought some of these stones and I helped Dr Colin Whitehead, the son, by buying the remainder. Among Mr Cavey's selection is a small green cabochon of 1.60 carats, closely resembling very fine jadeite, or possibly Australian chrysoprase, in colour. But its most puzzling features are the masses of acicular inclusions which radiate from a number of centres in the stone (see Figure 1). These needle-like crystals appear to be isotropic, but between crossed polars something resembling a uniaxial interference figure is to be seen over the points of origin of the groups.

A careful RI was taken, giving 1.523, and the SG was found to be below 2.86 (Anderson, 2.64). Under the Chelsea filter the stone remained green. There was no observable absorption spectrum. Mr Anderson found that the gem scratched glass and it was apparently harder than 5. It was, however, warm to the tongue, although no bubbles or swirls were detected.

No other similar stone had been seen by any of us and I was sufficiently intrigued to enlist the aid of Mr Alan Jobbins and Dr Roger Harding, of the Institute of Geological Sciences. The former confirmed the findings and observations so far made and the stone was passed to Dr Harding for analysis by electron microprobe, with the following results.

The needle-like inclusions were positively identified as apatite, while the host material, which apparently provided the fine green colour, was identified as a glass with a composition essentially that of a sodium calcium silicate ($Na_{19}K_1Ca_{10}Mg_2Si_{38}O_{100}$), plus about 10% of some other unidentified constituent, possibly boron, lithium or even water. Colour may have been due to iron or

*J.Gemm., 1980, XVI, 3, 201 and 5, 345.—Ed.

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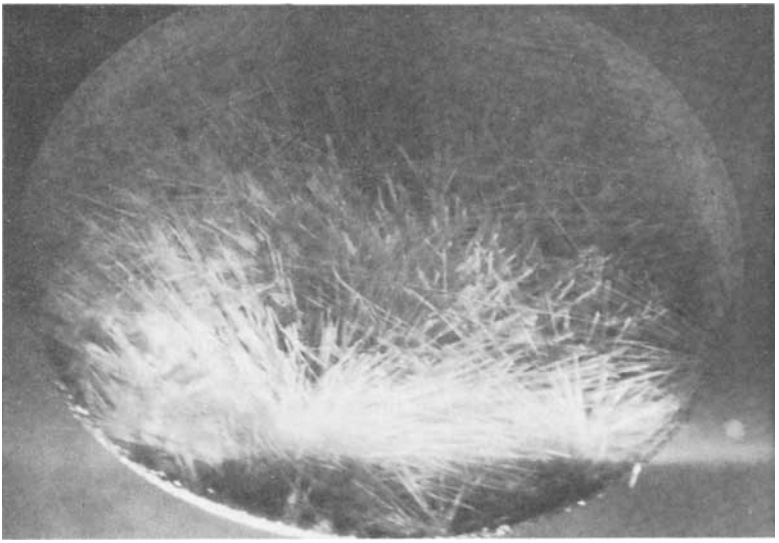

FIG. 1 Radiating needle-like crystals of apatite in a matrix of fine green glass.

chromium in the glass, but this was not evident in the absorption spectrum.

No indication whatsoever has been found of how the stone came into Henry Whitehead's possession. It could possibly be a natural glass, but a fortuitous slag seems more likely. There is always the possibility that it has been made deliberately to imitate fine jadeite. It would not be the first time that has been done, especially by the Chinese. But the resemblance is superficial and in colour only, the inclusions being quite incompatible with natural jadeite. Perhaps a reader somewhere has more information on this interesting material. There must be more than this single specimen around. One thing is certain, and that is that even a glass can provide some surprises!

I record with considerable appreciation and gratitude the work done by Dr Harding and Mr Jobbins in this investigation, and at the same time thank Mr Cavey for permission to publish the details.

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BLUE COLOUR-CHANGING KYANITE FROM EAST AFRICA

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ABSTRACT

The chromophore pairs Fe + (Ti) and Cr + Fe are shown to produce the various blue colorations of Kyanites rather than titanium traces, claimed in earlier reports to be the only cause for the blue hues. Vanadium and manganese have no apparent influence on the blue when present at trace levels.

As a novelty, Cr + Fe or Cr alone has been found to be responsible for an alexandrite effect displayed by a kyanite crystal from East Africa.

INTRODUCTION

Kyanite is rarely encountered as a faceted gem because it is difficult to cut. This is due to its perfect cleavage and marked anisotropy in hardness. The mineral commonly occurs in blue to bluish green hues. The intensely blue kyanites from Kenya and Tanzania are especially attractive, some resembling sapphire in colour and transparency. Three years ago, one of the authors was shown a crystal of this colour by a gemstone dealer in Nairobi. During a recent visit, the authors were presented with another unusual crystal specimen of kyanite. It exhibited a strong pleochroism and, in one direction, was definitely light green in daylight and changed to reddish in incandescent light. The term 'alexandrite-like' arose in the discussion with the dealer. It was decided to analyse this kyanite sample, together with three other collection stones from East Africa.

CHEMICAL COMPOSITION

Detailed analyses were performed on four kyanite samples (Table 1) using an ARL-SEMQ microprobe combined with an energy-dispersive detector system (Tracor-Northern). The microprobe was operated at an accelerating voltage of 15 kV and a sample current of 15 nanoamperes. To minimize drift effects,

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TABLE 1. Microprobe analyses of East African Kyanites

sample	(1) colour-changing kyanite	(2) dark blue kyanite	(3) blue kyanite	(4) brown kyanite	blue kyanite (Kenya)	blue kyanite (India)
SiO_2	37.08 ± 0.30	37.00 ± 0.29	37.44 ± 0.32	36.85 ± 0.31	—	—
Al_2O_3	62.10 ± 0.18	62.20 ± 0.20	61.83 ± 0.17	61.30 ± 0.19	—	—
TiO_2	≲.04*	<.05	<.05	<.05	.07	.01
Fe_2O_3	.35 ± 0.04	.87 ± 0.05	1.20 ± 0.10	1.15 ± 0.09	.04	.11
Mn_2O_3	≲.04*	<.05	<.05	.30 ± 0.06	—	—
Cr_2O_3	.50 ± 0.07	<.05	<.05	.10 ± 0.05	.23	.01
V_2O_3	≲.04*	<.05	<.05	<.05	.60	.03
total	100.03	100.07	100.50	99.70		
	cations on the basis of 20 oxygens					
Si	4.01	4.00	4.03	4.01		
Al	7.92	7.92	7.86	7.86		
Fe^{3+}	.03 } 7.99	.07 } 7.99	.10 } 7.96	.09 } 7.98		
Mn^{3+}	—	—	—	.02	References	
Cr^{3+}	.04	—	—	.01	Schmetzer (1978)	White (1967)

no. 1 intense greenish blue kyanite crystal from Kenya/Tanzania, 10 × 5 × 3 mm
no. 2 dark blue kyanite, cut gem, 0.31ct, from Kenya/Tanzania, 4.2 × 3.9 × 2.1 mm
no. 3 blue kyanite crystal, Machakos District, Kenya, 30 × 10 × 8 mm
no. 4 translucent brown kyanite crystal, Emali (?), Tanzania, 14 × 5 × 3 mm
*EDS-XRF data

counting time was controlled by means of beam current integration. For standardization, natural and synthetic compounds were used. Data reduction was accomplished with a ZAF-type correction program. Analytical details are described by Schwander & Gloor (1980).

Kyanite, the high pressure polymorph of Al_2SiO_5, usually contains only minor amounts of impurities such as Ti, Fe, Mn, Cr, or V. White & White (1967) reported that the characteristic blue colour of kyanite is caused by the presence of very small Ti^{3+} contents. Smith & Strens (1976) and Schmetzer (1978) related it to the charge transfer pair Fe^{2+}/Ti^{4+} and to the variable chromophore contents. Chromium-bearing kyanites are typically found in high-pressure rocks, as, e.g., eclogite or glaucophane schist, and show a blue or green colour. The presence of transition elements causes different colours. This has been summarized by Ribbe (1980):

substitution of Al^{3+} on octahedral sites in synthetic kyanites by	resulting colour
Fe^{3+}	yellow-green
Mn^{3+}	orange-yellow
V^{3+}	greyish-green
Cr^{3+}	green

The analyses of East African kyanites represented in Table 1 reveal considerable amounts of Fe, Cr and, in one case, Mn, whereas Ti as well as V are below the detection limit of the microprobe ($\leqslant$ 0.05%). It should be stressed that V is common in East African kyanites and often exceeds the Cr concentration (Schmetzer, 1978). Variable amounts of Fe can be observed in our four samples. They range up to 1.20 weight-% Fe_2O_3 in sample no.3. Specimen no.4 exhibits a brown colour which is due to the combination of Mn with Fe and Cr.

Of special interest is the composition of sample no.1. It shows a distinct colour-change effect. This sample contains a substantial amount of chromium which clearly exceeds the iron content. An additional XRF analysis of this specimen by an energy-dispersive detector system showed concentrations of Ti, Mn, and V, each of them being < 300 ppm. From this it may be concluded that the special colour effect observable in no.1 is mainly due to Cr, in the relative absence of V.

ABSORPTION SPECTRA OF BLUE KYANITES

White & White (1967) postulated that the characteristic blue colour of kyanites is generated by Ti^{3+} concentrations of as little as 50 ppm (0.005%), while considerably higher ferric iron contents could vary widely without affecting the colour. No clear correlation to minor contents of chromium, vanadium or manganese was detected either.

The first three samples of Table 1 seem to contradict the statement that Ti is the only cause for the blue coloration. The UV-VIS spectra of samples no. 2 and 3 are dominated by a very broad absorption band between approximately 540 and 800 nm. According to Schmetzer (1978) it has to be attributed to the charge transfer pair Fe^{2+}/Ti^{4+} and to eventual traces of Cr. Titanium, however, being supposed to produce a very strong and sharp peak at 600 nm in the gamma ray spectrum at trace level already, does not clearly show up in the absorption of the two iron-bearing samples. In contrast, Fe^{3+} underlines its presence by a triplet in the violet region (431 > 446 > 452 nm) and a slightly stronger one in the near ultraviolet (379 > 369 > 374 nm). The alpha and gamma ray spectra of no. 2 and 3 are strikingly similar to the extraordinary and ordinary ray absorption of blue sapphire, with a corresponding pleochroism of light bluish green and intense blue.

The alexandrite-like sample no. 1, strongly deviating in its chromophore content, is bound to exhibit a different optical spectrum and pleochroism but not necessarily another colour than blue. Bank (1980), though, described a kyanite from Tanzania with Cr, Fe, V, and Ti impurities to be 'emerald green' (but not colour-changing). The absorption of all three rays in Figure 1 essentially is characterized by the bands and absorption lines of chromium, the strongest of which appear in the red region as in many other chromic solids (e.g. in aluminates and aluminosilicates). The alpha ray of no. 1 displays the purest chromium spectrum while only the gamma vibration shows a clear but comparatively weak iron interference in the violet portion and around 620 nm as described above for samples no. 2 and 3. Gamma is almost the same greenish blue as beta but more saturated. Both are intense colours visible through the planes of the cleavage platelets. As is common in blue kyanites, the alpha ray is the weakest. It is seen in the direction parallel to the planes of the perfect cleavage (100) and perpendicular to the length of the crystal as a light green colour in daylight, changing to an obvious purple in incandescent light.

References to blue kyanites in recent mineralogical literature are numerous, but reference to specimens of kyanite with an elevated chromium content in gemmological journals is scarce. Liddicoat (1973) pictured a fine drawing of a spectroscope observation, however not giving any description or interpretation. As shown in Table 1, the chromium concentration of sample no. 1 is unusually high for cuttable material from East Africa, and exceeds the iron (and vanadium) contents. Line and band centre positions therefore are listed briefly, the relative intensities being left away for the sake of clarity:

Alpha 706, 688, 668, 657, 648, 578, 482, 475, 466, 461, 417 nm (± 1 nm)

Beta 704D, 688D, 663, 657, 651, 643, 582, 482, 475, 466, 461, 415 nm

Gamma 707, 688, 668, 660, 652, 616, 486, 476, 461, 443, 428, 415 nm

At liquid nitrogen temperature (LNT) the bands (underlined figures) shift to lower wavelengths and the lines sharpen up and become stronger. A number of new weak lines appear and the beta doublet at 704 nm (D) resolves into a triplet. The absorption edge moves from approximately 320 nm (RT) to 310 nm (LNT).

The chromium containing specimen no. 1 weakly fluoresces red under the stimulus of long-wave ultraviolet radiation as opposed to the iron-rich samples no. 2 and 3 which are inert.

The Alexandrite Effect in Blue Kyanite

Purity and depth of a colour depend on the steepness and strength of the absorption bands and on the degree of transparency between the bands. If the positions and depths of these transmitting areas (absorption minima) are appropriate, the alexandrite effect may become visible. It follows that the strength of this colour change phenomenon also depends on the position, steepness and intensity of the absorption minima, i.e. on the composition of the colouring transition metal impurities (substituting aluminium on the sites of certain distorted coordination octahedra). This phenomenon has been explained and the conditions for it to be observable have been derived by White *et al.* (1967) and Schmetzer *et al.* (1980). The prediction that a greater number of minerals could theoretically show the colour-change is supported by recent reports on alexandrite-like garnet, corundum, spinel, fluorite and, as a latest addition to the list, kyanite.

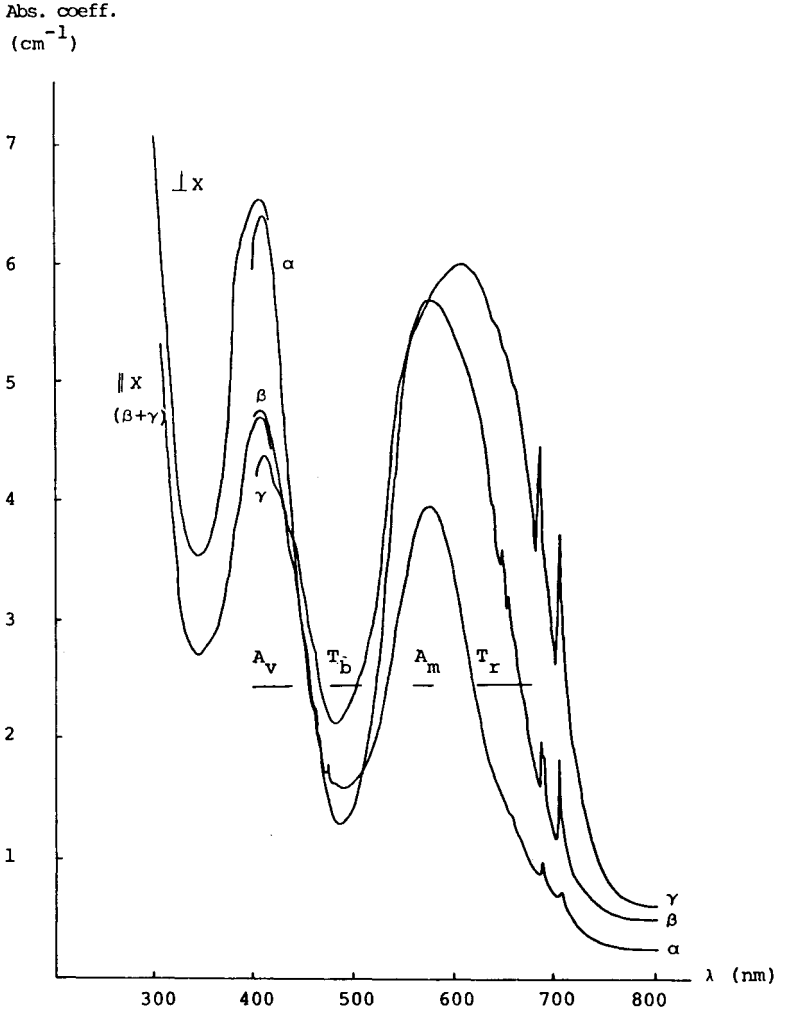

FIG. 1. Optical absorption spectra of chromium in a transparent blue colour-changing kyanite crystal from East Africa, polarized in the range of 400 to 800 nanometres and recorded at room temperature on a PYE Unicam SP8-100 UV-VIS spectrophotometer. Absorption coefficient is approximate.

The conditions for the alexandrite effect to become visible are (according to Schmetzer *et al.*, 1980):

—transmission in the red region above approximately 625 nm (T_r in Figure 1),

—strong absorption in the yellow-green part with a maximum between approx. 580 and 560 nm (A_m),

—transmission in the green to green-blue region (T_b) with an absorption minimum between approx. 510 and 475 nm,

—continuous absorption in the violet part from about 460 nm to the end of the visible (A_v),

—appropriate spectral composition of the two illuminants (White *et al.*, 1967).

The phenomenon in sample no. 1 is caused by one vibration only (Figure 1). The pure chromium spectrum of the alpha ray fulfils the conditions and accordingly presents light green in daylight and purple in incandescent light. The beta ray does not transmit enough of the red wavelengths and gamma absorbs them almost totally. As a result of their strong transmission around 485 nm, the hue of beta and gamma is an intense greenish blue.

At present there are no criteria how to classify colour changes differing from the alexandrite effect *sensu stricto* (green/red).

Physical Data

Refractive indices of specimen no. 1 were determined as:

$$n_\alpha = 1.714 \qquad n_\beta = 1.724 \qquad n_\gamma = 1.731$$

The birefringence is −0.017 and the optical axial angle $2V_x$ was determined as being 82° (universal stage with immersion). These figures are slightly on the high side, but typical for gem material and reflecting the minor element contents it possesses. The specific gravity was found to be 3.676 ± 0.004.

The alexandrite-like kyanite yields a variety of inclusions; the most frequent and interesting ones are oriented exsolutions of what appears to be rutile (Deer *et al.*, 1962). These reflective inclusions are long and short acicular when parallel to the platelet faces but more platy when perpendicular to them. Long growth tubes are parallel to the long direction of the crystal. In the same direction there are planar healing fissures consisting of mainly small negative crystals filled with a liquid and little gas. Other inclusions are fissures encrusted with goethite or haematite and colourless resorbed crystal prisms with tension haloes.

ACKNOWLEDGEMENTS

Thanks are due to Dr W. B. Stern for the analysis of trace element contents by EDS-XRF, and Mr U. Näf for assistance in drawing Figure 1, both of the Mineralogical Institute, University of Basel, Switzerland.

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NEAR-COLOURLESS ENSTATITE FROM SRI LANKA

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A roughly faceted gemstone obtained in Sri Lanka in 1981 was submitted for examination to the Institute by one author (C.H.W.). The stone was broken during postal transit when the facile cleavage became only too apparent; several pieces resulted from the impact, the largest weighing 8.08 carats and measuring $14 \times 5 \times 7$ mm. The large fragment is almost colourless, but shows a faint brownish-pink colour when viewed along its length. Pleochroism is not apparent in sections 1 mm thick and barely visible at 2 mm; above 7 mm faint tints of brownish-pink and greyish-green are visible in the adjacent windows of a calcite dichroscope. The material is inert under ultraviolet light and between crossed filters (copper sulphate solution and red glass); it shows green through the Chelsea filter.

The refractive indices, determined in sodium light using a Rayner Dialdex refractometer, were α 1.658, β 1.661, γ 1.668 (all $\pm$ 0.001). The material is optically biaxial positive. The density, determined by hydrostatic weighing in toluene, is 3.250.

The absorption spectrum is notable with the typical strong narrow band in the green at 506 nm, which appears to be a doublet but is not quite resolvable. This band is flanked on either side by very faint lines at 510 nm and 502.5 nm. A further broad weak band is centred around 543 nm; no bands were seen in the red or blue. This spectrum, usually attributed to ferrous iron in enstatite, is very prominent despite the virtual absence of colour and the low percentage (2.92% FeO) of iron (see Table 1).

Chemical analyses of a polished section of the enstatite were made using a Link Systems energy-dispersive (E.D.) x-ray analyser on a Cambridge Instruments Geoscan electron microprobe. An

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accelerating voltage of 15 kV, a specimen current of 5×10^{-9} amps and an electron beam focused to approximately 5 μm were used. The microprobe can measure elements of atomic number 11 (Na) and above, and the limits of detection for each of the oxides measured are about 0.2 wt%. Analyses of seven spots on the enstatite were made and the range, mean and atomic proportions are given in Table 1. The analyses indicate that the enstatite is relatively homogeneous and that the composition lies close to the magnesium end-member of the enstatite-ferrosilite series of pyroxenes. In addition to the elements listed in Table 1, Ti, Mn, Cr, Ni, Ca and Na were sought but not found, and they are below the detection limit of 0.2 wt% oxide. On the basis of 6 oxygen atoms the enstatite formula is $(Mg_{1\cdot84}Fe_{0\cdot08}Al_{0\cdot06})\ (Al_{0\cdot02}Si_{1\cdot98})O_6$.

TABLE 1.
Electron microprobe analysis of enstatite

Wt%	Range (7 analyses)	Mean	Atomic ratio		
SiO_2	57.97– 58.78	58.23	Si	1.980	2.000
Al_2O_3	1.71– 2.11	1.91	Al	0.020	
FeO*	2.86– 3.03	2.92	Al	0.057	1.982
MgO	36.13– 36.70	36.34	Fe	0.083	
Total	99.21–100.34	99.40	Mg	1.842	
			O	6.000	

*Total iron given as FeO.

The Sri Lankan gem is more magnesian than any igneous orthopyroxene quoted by Deer, Howie & Zussman (1978, p.35), but it is closely comparable to a metamorphic enstatite described from the Pamirs, U.S.S.R. (op. cit., p.41). However, it would be rash to infer a metamorphic origin for the Sri Lankan stone merely on a compositional basis. Very tiny colourless inclusions with low relief and high birefringence were examined near the gemstone surface and although microprobe analyses indicated the presence of forsterite (olivine) or another enstatite inclusion there was some overlap into the host mineral and the results were not conclusive. If further stones come to light however, determination of the inclusions would give the best indication as to the geological origin of the gem.

TABLE 2

Observed and calculated x-ray powder diffraction data for gem enstatite from Sri Lanka

I/I_1	d_{obs}	d_{calc}	hkl
2	6.33Å	6.334Å	210
10	4.403	4.404	020
1	4.335	4.337	111
1	4.044	4.048	410
1	4.013	4.010	211
14	3.300	3.300	121
90	3.166	3.167	420
35	3.149	3.149	221
1	3.039	3.039	600
16	2.938	2.937	321
100	2.874	2.873	610
8	2.825	2.824	511
3	2.795	2.795	230
10	2.703	2.702	421
30	2.531	2.530	131
1	2.512	2.512	611
10	2.492	2.492	202
18	2.468	2.469	521
		2.468	430
2	2.382	2.383	302
4	2.356	2.355	331
<1	2.300	2.300	312
4	2.279	2.279	800
3	2.250	2.252	402
		2.250	711
2	2.228	2.228	431
<1	2.183	2.182	412
<1	2.141	2.1404	240
12	2.112	2.1114	630
10	2.092	2.0920	531
5	2.057	2.0574	721
5	2.053	2.0534	512
5	2.024	2.0240	820
4	2.014	2.0141	141
7	1.982	1.9827	440
7	1.978	1.9782	241
12	1.955	1.9552	631
2	1.923	1.9236	612
		1.9224	341
3	1.885	1.8852	821
1	1.852	1.8517	441
1	1.850	1.8501	332
1	1.837	1.8365	702
1	1.800	1.8003	830
		1.7991	622
8	1.7856	1.7854	10.1.0
5	1.7717	1.7713	541
10	1.7296	1.7296	250
4	1.7004	1.7005	831
4*	1.6952	1.6951	722

I/I_1	d_{obs}	d_{calc}	hkl
2	1.6797Å	1.6796Å	812
1	1.6498	1.6499	242
2	1.6408	1.6406	251
3	1.6077	1.6075	023
2	1.6019	1.6020	10.2.1
2	1.5958	1.5957	902
5	1.5873	1.5872	931
5*	1.5833	1.5836	840
		1.5831	223
<1	1.5700	1.5701	912
1	1.5661	1.5662	451
6	1.5236	1.5240	650
8	1.5194	1.5193	12.0.0
1	1.5004	1.5002	922
16	1.4836	1.4839	10.3.1
12	1.4683	1.4687	642
		1.4680	060
2	1.4164	1.4165	352
1	1.4044	1.4045	751
		1.4043	10.4.0
4	1.3959	1.3961	11.0.2
		1.3957	261
9	1.3903	1.3904	11.3.1
<1	1.3782	1.3780	533
<1	1.3592	1.3598	813
		1.3588	043
<1	1.3553	1.3554	10.4.1
1	1.3368	1.3366	633
<1	1.3260	1.3260	343
7	1.3056	1.3058	12.3.1
4*	1.3022	1.3023	14.0.0
3	1.2959	1.2962	12.1.2
2	1.2883	1.2883	14.1.0
<1	1.2783	1.2781	114
4	1.2666	1.2669	10.5.0
		1.2666	304
4	1.2646	1.2648	262
2	1.2494	1.2498	362
		1.2488	14.2.0
1	1.2272	1.2273	852
2	1.1823	1.1824	134
1	1.1396	1.1395	16.0.0
2	1.0704	1.0702	480
2	1.0604	1.0604	381
2	1.0558	1.0558	10.0.4
		1.0557	12.6.0
4	1.0470	1.0472	14.5.0
		1.0468	971
2	1.0204	1.0205	11.0.4
4	0.9115	0.9116	20.0.0

The intensities are relative peak heights

*Intensity enhanced by overlapping α_2 peak

X-ray powder diffraction data for the gem enstatite were determined from diffractometer charts taken with CuKα radiation at room temperature (around 22 °C) and a scanning speed of 1/8 ° 2θ/min. Silicon (a = 5.43088Å at 25 °C) was used as an internal standard. The d-spacings, which are listed in Table 2, were provisionally indexed by comparison with data for synthetic enstatite (Stephenson *et al.*, 1966) and were refined using the U.S. Naval Laboratory least squares program for refining cell parameters, giving cell dimensions $a = 18.232 \pm 0.002$Å, $b = 8.808 \pm 0.001$Å, $c = 5.180 \pm 0.001$Å, (V = 831.9Å^3), space group *Pbca*. The density corresponding to these cell dimensions and the formula is 3.243 gm cm^{-3} (cf. 3.250 measured density).

In the past most gem enstatites (in yellowish, reddish and greenish-browns) have come from Burma, Sri Lanka and southern India, with bright green chromian stones from the kimberlites of southern Africa. It remains to be seen whether further examples of virtually colourless material are found in the gravels of Sri Lanka or elsewhere.

We acknowledge with thanks helpful discussions with colleagues in the Petrology Unit of the Institute and we are especially indebted to Mr J. E. Rouse for making available the computer program for the refinement of the x-ray data and to Mr D. J. Bland for processing the data. This paper is published by permission of the Director, Institute of Geological Sciences, (NERC).

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THERMOLUMINESCENCE IN ELBAITE

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Tourmaline crystallizes in the trigonal system with the symmetry of space group R3m. Chemically, tourmaline shows a complex formula which may be written as:

$$RY_3Z_6(BO_3)_3Si_6O_{18}(OH,F)_4$$

where R = Na,Ca; Y = Mg,Li,Al,Mn,Cr,V; Z = Al,Fe,Ti.

As is well known, there are three end members in the tourmaline solid-solution series: the magnesian tourmaline or dravite, the iron tourmaline or schorl and the alkali tourmaline or elbaite. An alkali cation-deficient series has also been reported[1].

Extensive crystal structure analyses have been carried out on all members of the tourmaline group[2,3,4,5,6,7].

Group theory predicts the following lattice phonons in tourmaline:

$$\tau = 28\ A_1 + 21\ A_2 + 49\ E$$

Only modes A_1 and E are both IR and Raman active optical phonons. It has been shown elsewhere[8] that all Wyckoff sites present in tourmaline contribute without discrimination to both of the resulting A_1 and E Raman active phonons. Accordingly, it is better to regard tourmaline structure as a framework silicate than as a ring silicate, contrary to what is currently assumed in some structural classifications of minerals.

Diverse nearest neighbour cation interactions in tourmaline have been studied at some extent over the past fifteen years using NMR spectroscopy[11], Mössbauer spectroscopy[14,15,16,17,18,19] and EPR spectroscopy[20,21].*

Tourmaline occurs in a wide range of colours and hues which can be related to its composition. Generally, iron-bearing tourmalines are black, green or blue, while elbaites are pink (rubellite) or colourless (achroite) and dravites are dark brown, yellow or colourless. In addition, some colour changes have been reported on heating[16,18] and gamma irradiation[22a].

*See D. R. Hutton. *Magnetic Resonance—a Non-destructive Probe of Gemstones,* J.Gemm., 1979, XVI (6), 372-85.—Ed.

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Thermoluminescence (TL) phenomenon in solids often appears to be associated with radiation-induced coloration. As discussed by Nassau[22b] the trap concept contributes to understanding the varying stability of electron and colour centres in minerals with respect to heat bleaching and thermoluminescence.

Under short wave ultraviolet radiation colourless elbaite shows a bright violet emission while crystals with shades of pink and green show a weaker violet fluorescence[23]. However, as far as we are aware, no basic research has been devoted to the luminescent behaviour of tourmaline. We report here new data on the thermoluminescence of a single crystal of elbaite before and after x-ray irradiation.

Cell parameters, as well as optical constants and density data belonging to this elbaite, are included in Table I. By means of the electron microprobe a Mn content lower than 0.1% and nil Mg content have been detected in it. Differential scanning calorimetry (DSC) was performed within the 300-750 K temperature range. Our elbaite shows an endothermic peak at 636 K ($\Delta H = 0.1$ cal/g). The above temperature range was also covered in search for thermoluminescence. Further details of experimental set used may be seen in Reference 24.

TABLE I—Physical constants of our elbaite.

Cell Parameters	a_0	15.99 ± 0.01
	c_0	7.06 ± 0.01
Optical constants	ω	1.640
	ε	1.618
Density	D	3.07

Before x-ray irradiation, our elbaite shows at least four TL peaks at 510, 572, 670 and 714 K. After irradiation, the TL maxima appear at 338, 350, 450, 520, 670 and 714 K. In addition, some particular features regarding the intensity, broadening and sift temperature of glow peaks can be seen (Figure 1).

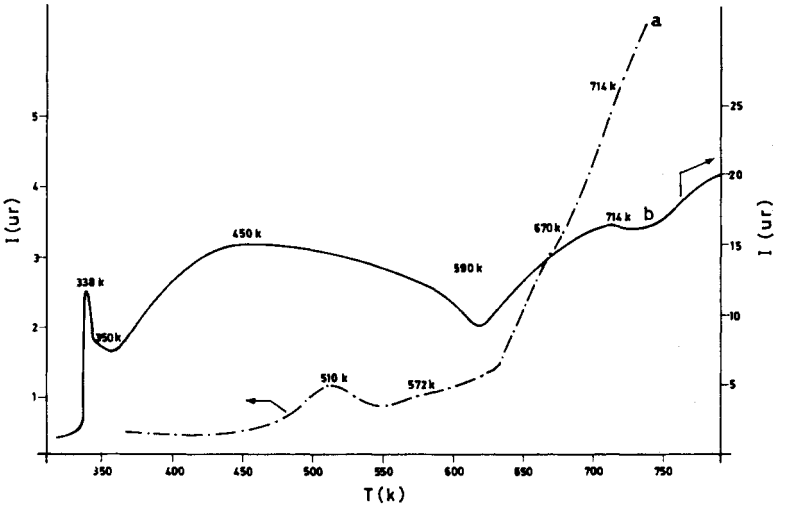

FIG. 1. TL spectrum of elbaite: (a) before and (b) after, x-ray irradiation.

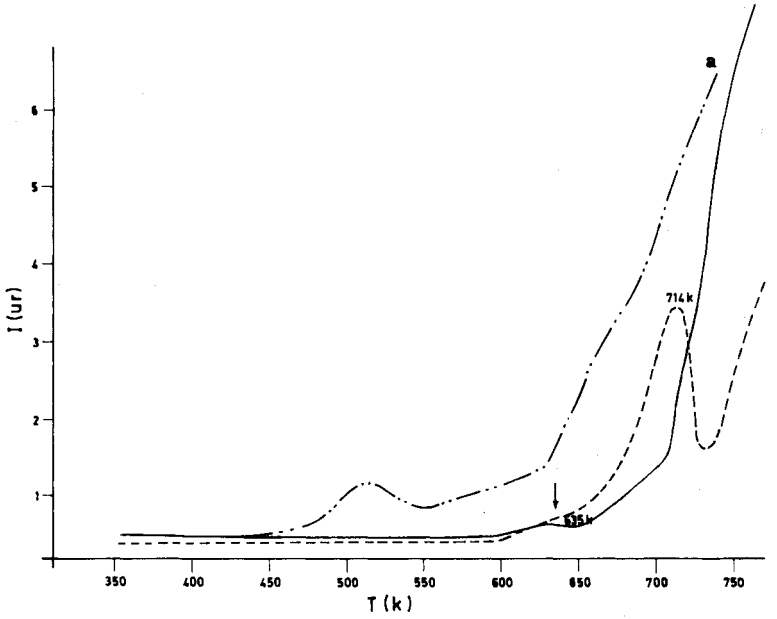

FIG. 2. TL spectra of elbaite before x-ray irradiation separated by standard cleaning technique.

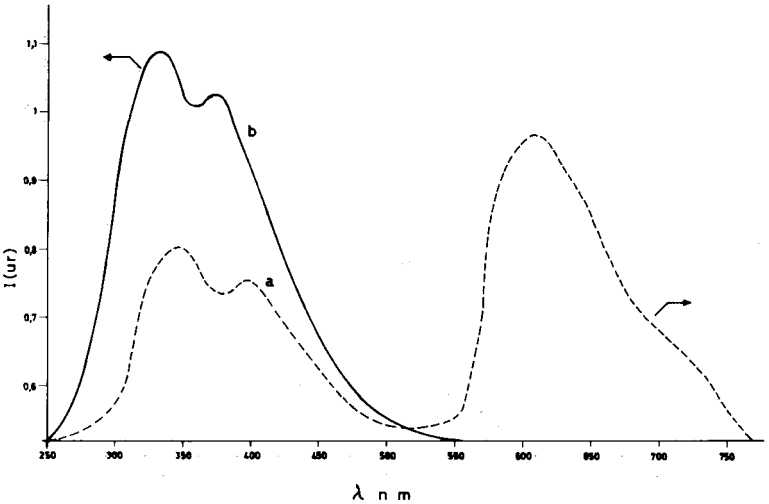

FIG. 3. Emission spectrum of elbaite: (a) before and (b) after, x-ray irradiation.

We were unsuccessful in our attempts to obtain some quantitative information about the TL peaks kinetics because wide overlappings exist among glow peaks. This source of complication has been studied by means of the standard cleaning technique (Figure 2). A salient fact can then be observed: the 636 K TL peak coincides with the temperature at which we have detected a DSC minimum.

All recorded TL peaks show the same emission spectrum. Figure 3 shows the emission spectrum of our elbaite before and after x-ray irradiation. The former consists of three emission bands at 350, 400 and 620 nm. The latter only shows two emission bands at 330 and 375 nm. Tentatively, we believe that the 620 nm emission band could be related to the well known $^4G-^6S$ transition of Mn^{2+} in octahedral coordination[25,26].

At present, no evidence is yet available to us to be able to assume a mechanism by which the experimental observations shown here can be explained, namely the annihilation with radiation of the 620 nm emission band. We hope, however, that additional luminescence studies in connexion with EPR spectroscopy will further provide a more reliable basis to understand the thermal annihilation of colour centres in tourmaline.

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UNDERSTANDING THE HODGKINSON METHOD

By W. WILLIAM HANNEMAN, Ph.D.

Hodgkinson[1] described a technique (visual optics) for deriving, without the aid of instruments, information concerning the RI, birefringence, dispersion, and spectral absorption of a gemstone. In response, Mitchell[2] submitted a 'Letter to the Editor' expressing the opinion that this approach did not produce valid

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results and had not warranted publication. Meanwhile, in America, Hanneman[3] published an article extolling Hodgkinson's approach. This article was abstracted by O'Donoghue[4] with the admonition to 'see' Mitchell's letter. By such action, O'Donoghue raised this letter to the status of a formal scientific report and implied his support of its contents. This indeed represents formidable opposition to an idea.

Gemmologists must be wary to avoid the trap of judging an idea on the basis of its proponents or opponents rather than its intrinsic merits. Science progresses through the resolution of differences of opinions among investigators. To that end, I would like to offer a rebuttal to the Mitchell letter.

Hodgkinson's Method, in its simplest form for a round brilliant-cut gem, consists of three steps.

1. Look through the table of the gem towards a distant light source. Keeping the table perpendicular to the direct line to the light, choose a circle of images formed by light passing through facets having pavilion angles of about 40 degrees. Mentally calculate the diameter of that circle and compare it to what you have observed for known reference gems. On this basis, estimate the RI.

2. Considering the diameter of the circle and the 'spread' of each image, estimate the dispersion of the unknown. This estimate is based on experience gathered from examining known specimens of similar RI (circle diameter). At this point merely deciding whether the dispersion is high, medium or low is usually sufficient.

3. Determine the maximum Birefringence:Dispersion (B:D) ratio as will be described below. It will be necessary to make estimates through several sets of facets to insure obtaining the highest possible value.

In many instances sufficient information may be obtained to positively identify the gem. This is especially true if the impact of colour is also considered.

According to Mitchell, there are four variables militating against the Hodgkinson Method. 1. The unknown RI of the stone. 2. The angle of incident light relative to the pavilion facet. 3. The effects of optic axes. 4. The size of the stone.

I would first like to respond to Mitchell's fourth point concerning the size of the gem as a variable. The size of the gem is not a variable. Exactly the same results are obtained with a 2 mm

stone as are obtained with a 100 mm stone cut with the same angles. The inclusion of this point indicates that Mitchell, himself, does not fully understand the optical principles involved. Such being the case, it is understandable why he discarded the idea 45 years ago. However, the fact that Bauer, Dieulafait, Kluge and Mitchell could use the technique only for determining the presence of birefringence is less of an indictment of the technique than of their limitations.

The laws of optics are well founded. Consequently, it is reasonable to expect to be able to provide a physical explanation for every image seen by the eye. Conversely, it is reasonable to expect that effects associated, not only birefringence, but also dispersion, absorption and RI, should be manifested.

Attempts at rationalizing the observed images have been made by Hodgkinson;[1] and Crowningshield & Ellison.[5] In both cases, the explanations were faulty. However, a faulty explanation does not in any way change the fact that differences do indeed exist and they have an origin related to the laws of optics. An explanation is presented below which the author believes is more nearly correct.

PINHOLE REFRACTOMETER

The eye, a camera and a pinhole can be optically related. One can create a pinhole refractometer in the following manner. Support a flat plate having a pinhole in its centre above a white card, the surface of which has been scribed with a series of concentric circles. Place a round brilliant cut gem over the hole and illuminate it from above. Circles of images of the light will be seen on the card. If the light source is a narrow slit;[3] the images will appear as small spectra (rainbows). This is precisely what one observes in the Hodgkinson Method.

All concepts relating to the pinhole refractometer can also be related to Hodgkinson's visual optics. If the gem is singly refractive, a single image is projected through each facet of the pavilion. If the gem is doubly refractive then two images are seen. This is the point at which Mitchell would have gemmologists stop. However, it is just the beginning.

REFRACTIVE INDEX (nD)

Figure 1 shows the path of a ray of monochromatic sodium light through a single facet of a gem placed on the pinhole

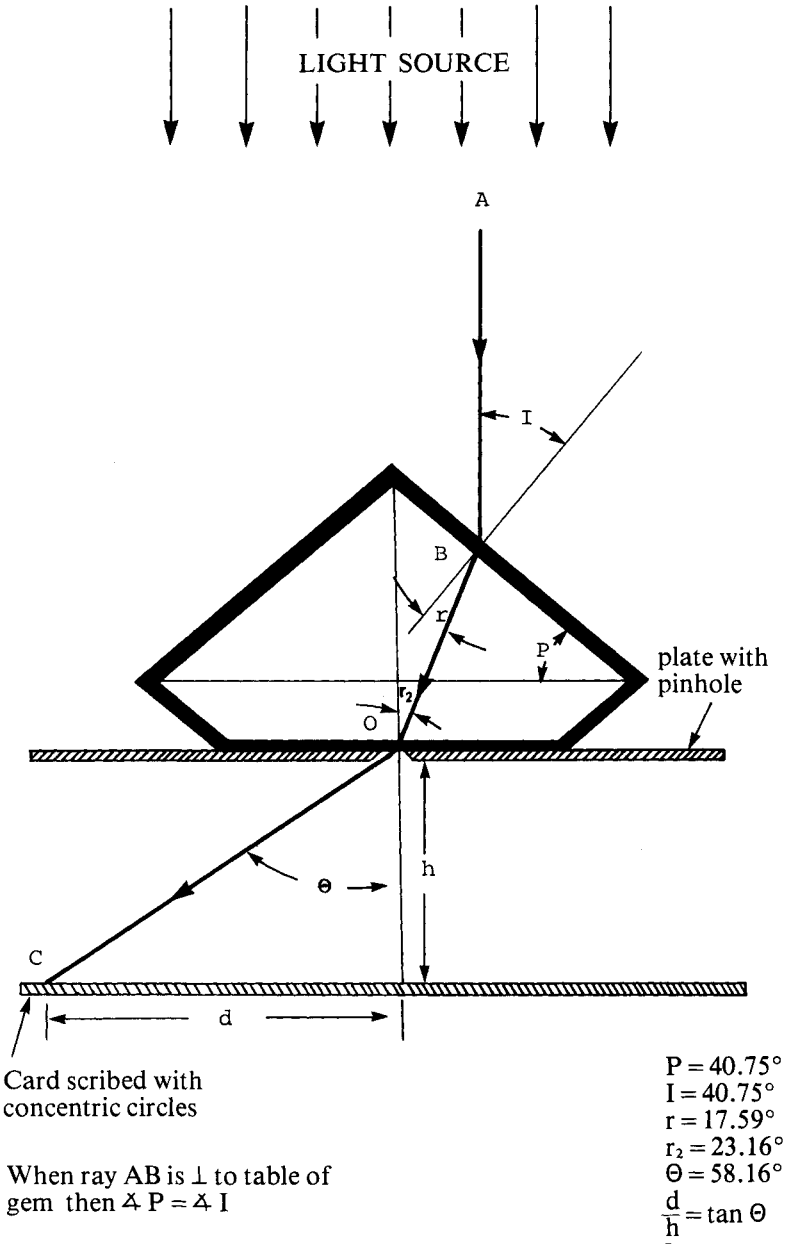

FIG. 1. Pinhole Refractometer

refractometer. This is related to Mitchell's first variable. Utilizing the laws of optics, one can derive the formula relating the pavilion angle P of the gem, angles I and θ, and the index of refraction (n) of the gem. One form of the expression is

$$RI = n_D = \sqrt{\sin^2 I + \left[\frac{\sin\theta + \sin I \cos I}{\sin I}\right]^2}$$

The complexity of this expression is why the early investigators, who had no computers, carried the approach no further.

For the moment, let's assume a constant pavilion angle (ca. 40 degrees) for a well cut brilliant gem. By designating a value for h in Figure 1, it is possible to calibrate the distance d in units of nD. The length d is equal to the radius of the circle of images of a light source whose rays are initially travelling parallel to each other, perpendicularly to the table, and transmitted through facets cut at angle P. The diameter of the circle of images seen in the Hodgkinson Method is thus a function of the RI of the gem.

Gross changes in pavilion angles as found in fish-eye gems of course produce gross variations which can, with practice, be accommodated by an agile mind. The Hodgkinson Method has never been promoted as a tool for robots. The average gemmologist can, with a little practice, easily learn to estimate the refractive index of round brilliant cut gems to ± 0.05.

DISPERSION

In a pinhole refractometer utilizing white light, each image appears as a spectrum. This is due to the dispersion of the gemstone. If the pinhole refractometer scale were calibrated (constant P) in units of n it would be a simple matter to determine the numerical dispersion $(\frac{\Delta n}{\Delta \lambda})$ value of the gem. Incidentally, dispersion cannot be measured directly by means of a critical angle refractometer. This is one reason why very few gemmologists routinely utilize dispersion as an aid to identification.

When examining images originating through facets cut at steeper angles, the spectra will appear to be broader. However, the numerical value of dispersion measured with a properly calibrated pinhole refractometer scale would be identical. It is just that altering P (or I) alters the value of d for the same value of n and calls for a different calibration scale. In order to estimate dispersion numerically for an irregularly cut gem, one should

choose an image which passed through a facet cut at about 40 degrees. This will coincide with round brilliants with which one should have become familiar.

BIREFRINGENCE

In the case of doubly refractive gems two images (spectra) will be seen. For quartz, the two spectra will appear overlapped. For peridot, the spectra will usually appear widely separated.

Using a 'calibrated' scale of n of a pinhole refractometer, one can, as previously described determine the dispersion. Using the position of the yellow of a spectrum, it is possible to determine nD (RI). With doubly refractive gems, two values of nD can be determined. The difference between these values is the birefringence.

In the Hodgkinson Method, in cases where the spectra overlap, the positions of the yellows are often difficult to ascertain precisely. Equivalent results will be obtained by measuring between the positions of the red at the begining of each spectrum. This is akin to the use of a red filter for refractometer readings obtained from a white light source. The absolute n values differ slightly from nD, but the more important birefringence value is correct.

BIREFRINGENCE:DISPERSION RATIO (B:D)

Two facts are apparent from the preceding paragraphs:

1. RI (nD) is related to the size of the circle of images.
2. Dispersion and Birefringence both are measured as Δn.

In regards to Mitchell's second variable, irrespective of angle, one can examine any pair of images from a doubly refractive gem and derive a value for B:D. B is proportional to the distance between reds of two spectra while D is proportional to the distance between the red and the blue* of the inner spectrum. For the purpose of this estimation, one can assume that the n scale is linear over that range. Actually it isn't. B:D ratios will be found to vary from zero in the case of singly refractive gems and glass to 2.6 for sphene.

At this point we shall consider Mitchell's third variable. All gemmologists should be aware that the 'apparent birefringence' seen by critical angle refractometers and/or the Hodgkinson Method varies with the orientation of the facet, the gem, the optic axis or axes and the light source. The 'true birefringence' of course

*i.e. Fraunhofer B line (687 nm) to G line (430.8 nm).

is the maximum value. Dispersion, on the other hand, is virtually unaffected by orientation.

It is imperative that one try to observe the maximum B:D ratio. Ruby or pale tourmaline cut along its *c* axis, at first, appears to be singly refractive. To observe the birefringence it may even be necessary to look across the stone through the crown facets. All that is necessary is two non-parallel polished faces and the patience to orient the light properly. The apparent B:D ratio can be observed in any position. Since D is a constant (although the apparent width may vary due to the effective change in the angle P and the position of the light) the B:D ratio can be determined. You just have to satisfy yourself that you have found the maximum value.

Cubic Zirconia and Diamond

Mitchell's final objection was that diamond and cubic zirconia were not fairly compared. He believed that it was necessary to tilt the cubic zirconia to see the spectrum. He also believed that doing likewise with diamond would produce similar results. Reply to this provides a good opportunity to point out some of the 'finer points' of the method.

We are speaking now of well cut round brilliant gems cut with about a 40 degree pavilion angle. With quartz (RI 1.54), one should line up the pupil of the eye perpendicular to the table of the gem and in direct line with the culet and the light source. One or more circles of images of the light will be readily visible. What the eye is actually assessing is the path of the ray forming the angle θ (Figure 1).

With topaz (RI 1.62), the diameter of the circle is noticeably larger than with quartz. As the RI of the gem increases, angle θ gets larger and it is necessary to put your eye closer to the gem to see the full circle. At an RI about equivalent to spinel, the size of the circle reaches the limit of the field of view of the eye. No longer can the complete circle be observed. Because of the large size of the angle θ, it becomes necessary to move the eyeball and/or the head in a circular motion to see the complete circle. One can, however, see several images at once. From this arc of images, the diameter of the circle can be estimated.

Another approach which can be used for high RI gems is to assume the original fixed position of eye, gem, and light. Nothing,

of course, will be seen. However, as one bends forward at the waist the angle of incidence (angle I in Figure 1) is increased and the image comes into view from below. An astute student can, with experience, learn to relate the degree of forward bend to the RI of the gem.

As with all good things, there comes an end. The case of cubic zirconia is shown in Figure 1. The angle θ approaches 60 degrees and one must move the eye above the level of the stone. This gives the impression that one is looking almost parallel to the table of the gem. However, contrary to Mitchell's belief, one cannot do this with a diamond. The cut off point is a RI of about 2.37. The recent article by Wong[6] dealing with the dot-ring test provides the mathematical proof. This test is a very basic form of the pinhole refractometer in reverse. The spot corresponds with the pinhole. Its appearance indicates light travels from that point through the stone and out of the pavilion. Since light travels equally well in both directions, the absence of the spot, as in the case of diamond, indicates no image is formed in a pinhole refractometer or in the Hodgkinson Method.

EPILOGUE

A trained gemmologist has the numerical values for RI, birefringence and dispersion committed to memory. It is a simple matter to calculate the B:D ratio.

Since the visual images seen in the Hodgkinson Method are subject to the laws of optics, a trained gemmologist ought to be able to explain the reason for the appearance of any image he might see. Mastering this technique should be considered a required postgraduate course in gemmology.

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[*Manuscript received 18th September, 1981.*]

THE THERMAL PROPERTIES OF GEMSTONES AND THEIR APPLICATION TO THERMAL DIAMOND PROBES

By DONALD B. HOOVER, D.Sc., F.G.A.

Mr P. G. Read in the April 1980 issue of this *Journal** presented an evaluation of the Ceres Diamond Probe which, like the similar G.I.A. instrument, is described as a thermal conductivity comparator. Due to the completeness of Read's evaluation two anomalous points became apparent. Read noted that diamond's thermal conductivity is greater than any other material, yet aluminium foil and silver gave higher readings on the Ceres Probe. Also, the range of thermal conductivities from glass to diamond covers a range of over 1000 to 1, while the Ceres probe gives a range of about 25 to 1 on these materials. This paper examines the measurement of thermal properties and attempts to explain the above anomalies.

Read describes the Ceres Probe as using a pulsed thermistor heat source with a second thermistor measuring the temperature of the probe tip at the interface of the gem under test. The reading is taken when a steady value is obtained. This suggests that the probe is measuring thermal inertia and not thermal conductivity of the gem. Because thermal properties are not well discussed in gemmological texts, a brief discussion should help to make concepts of the various thermal properties clearer.

Thermal conductivity (K) is an intrinsic material property which relates the heat flux (F) transferred by conduction through an object to the temperature difference across the object. In the c.g.s. system of units, which will be used throughout this paper, F has units of calories per sec cm^2, and K units of calories per sec cm °C. Thermal conductivities are normally measured by what are called steady-state methods (Carslaw & Jaeger, p.25, 1959), which merely means that the measurements are made after all parts of the measuring apparatus have reached thermal equilibrium after a constant temperature difference is established across the test sample. A simple schematic diagram of a one-dimensional thermal

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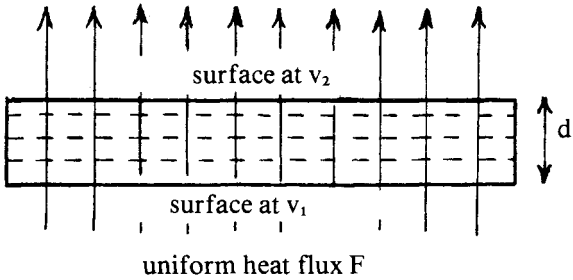

FIG. 1. Diagram illustrating a common means of measuring thermal conductivity by measuring the temperature difference across two surfaces normal to a uniform heat flux. Dashed lines are isothermal surfaces.

conductivity experiment is shown in Figure 1. If one knows the heat flux (F), the temperature difference across the slab (v_2-v_1) and its thickness (d), then the thermal conductivity may be calculated.*

In conductive processes thermal energy is transferred by quantized elastic wave vibrations of the atoms of the material called photons by analogy with the photon in electromagnetic radiation, and by electrons as well in metallic materials. This transfer of thermal energy constitutes a thermal wave similar to the more familiar wave motion of light. The idea of a thermal wave is important, and will be developed more fully later.

The thermal conductivity of any material is not a fixed constant. For most materials at room temperature it increases slightly as the temperature decreases. For example, the thermal conductivity of spinel at 35 °C is 0.033, decreasing to 0.026 at 68 °C (Clark, 1966). However for the small temperature change, as used in the Ceres Probe, K may be considered a constant. For most materials the thermal conductivity continues to increase to close to absolute zero (−273 °C) and then abrubtly decreases. Corundum has a maximum value of 15 cal/sec cm °C at −223 °C while diamond only reaches a maximum of 7 cal/sec cm °C (Kittel, 1956). For reference, silver the best metallic conductor at room temperature has a value of 1 cal/sec cm °C.

*The equation relating these properties for the one-dimensional case illustrated is

$$F = \frac{-K(v_2 - v_1)}{d}$$

For the convenience of the reader who wishes to consult Carslaw and Jaeger (1959), their nomenclature will be followed as closely as possible.

To further complicate the picture, thermal conductivity is a function of direction in non-homogeneous or non-isometric crystalline solids just as the optical properties are. The thermal ellipsoid which describes the variation of K with crystallographic orientation will in general have the same symmetry properties, for a given crystal, as the optical properties (Washburn, 1929). Unfortunately the directional thermal properties of gem minerals are poorly known. A few values may be found in Washburn (1929) and Clark (1966). The difference with direction can be significant, for quartz is given as 0.030 parallel to the *c* axis and 0.016 normal to *c* (Washburn, 1929).

Another intrinsic thermal property we need to consider is the specific heat or heat capacity (c) of a gem. This is defined as the amount of heat in calories required to raise one gram of a substance one degree Celsius.* The specific heat also is a slowly varying function of temperature, increasing with increasing temperature. As with thermal conductivity it is usually considered a constant for experiments involving small temperature excursions. It also is quite uniform for most gem materials differing little from 0.2 cal/g °C at room temperature, so is not of practical diagnostic value. The specific heat is dependent on the experimental situation, whether conducted under constant pressure or constant volume conditions. For solids the difference is small and will be ignored in what follows.

Now consider what happens to the slab in Figure 1 if initially it is at room temperature and then we suddenly bring a source of heat near one side. The side nearest the source increases most rapidly in temperature as the heat flows into it. Some of the heat is used in raising the temperature of the slab as required by the specific heat property. This heat may be thought of as being stored temporarily in the slab. The rest flows into and through the slab governed by the physical principals discussed under thermal conductivity. Because there are not heat sources or sinks in the slab, the total heat must sum to zero; i.e. the heat flowing into the slab must equal that flowing out plus that stored by the increase of temperature. When this relationship is expressed mathematically it is called the heat conduction equation and a new thermal constant (k) is introduced.

*Mathematically this is expressed as

$$F = c\varrho V(v_2 - v_1)$$

where ϱ is the density of the material, and V is its volume.

It is called the thermal diffusivity with units of cm^2/sec.* Thermal diffusivity k is related to thermal conductivity by

$$k = K/\varrho c.$$

Thermal diffusivity is normally measured by transient heat conduction experiments (Carslaw and Jaeger, 1959).

If in Figure 1 a sinusoidal heat flux, $F = F_0 \sin \omega t$, is substituted for the steady flux, and the thickness extended to infinity, solution of the heat conduction equation shows that after an initial transient disturbance is over the surface temperature also varies sinusoidally at the same frequency. However the amplitude of the sinusoidally varying temperature is not a function of K or k, but of $1/\sqrt{K\varrho c}$. The quantity $\sqrt{K\varrho c}$ is called the thermal inertia, (I), and is usually measured by experiments using a periodic heat source (Carslaw and Jaeger, 1959). A classic example of the use of a periodic heat source to measure thermal inertia occurs in geophysical exploration. The diurnal or annual solar flux constitutes the periodic source. Measurement of the surface or subsurface temperatures then gives a measure of the thermal inertia of the near-surface material of the earth (Carslaw and Jaeger, 1959; Watson, 1975). Surface temperature measurements obtained from aircraft have even been used to map variations in the earth's thermal inertia so as to infer variations in rock type.

While many details of the Ceres Probe and similar instruments are not known, it seems reasonable from the above discussion that such probes are measuring thermal inertia. If this assumption is correct then the probe response should be proportional to thermal inertia and not thermal conductivity. In order to verify this prediction, I looked up available data on the thermal constants of gem materials and calculated their thermal inertia. Some problems were encountered in making the compilation due to the scarcity of adequate thermal conductivity measurements on single-crystal gem materials. Values of K reported in the literature have varied by as much as 2 to 1 (Horai, 1971), and often the orientation is not given for measurements on anisotropic material. Diamonds represented a special case with recent references showing a range of over 10 to 1 for the value of K. Examination of the literature however showed that most of the lower values (0.29) of K originate with the

*The classic heat conduction equation may be found in most texts on mathematical physics. For the one-dimensional case illustrated in Figure 1 it is given by

$$\frac{\partial v}{\partial t} = \frac{K}{\varrho c}\frac{\partial^2 v}{\partial x^2} = k\frac{\partial^2 v}{\partial x^2}$$

TABLE 1

Thermal properties of some gem minerals and metals at room temperature

Material	Thermal Conductivity cal per cm sec °C	Specific Heat cal per g °C	Density g per cm³	Thermal Diffusivity cm² per sec	Thermal Inertia cal per cm² °C sec½
diamond	1.6 to 4.8	0.12	3.52	3.79 to 11.36	0.822 to 1.42
copper	0.92	0.092	8.89	1.125	0.867
silver	1.0	0.056	10.5	1.701	0.767
gold 24 carat	0.70	0.031	19.3	1.170	0.647
aluminium	0.49	0.214	2.70	0.848	0.532
platinum	0.166	0.032	21.37	0.243	0.337
platinum-10% iridium	0.074	0.032	21.62	0.107	0.226
corundum	0.060	0.206	4.0	0.0728	0.222
pyrite	0.0459	0.136	4.91	0.0687	0.175
kyanite	0.0338	0.201	3.66	0.0460	0.158
haematite	0.0269	0.169	5.14	0.031	0.153
topaz	0.0269	0.2*	3.53	0.0381	0.138
spinel	0.0226	0.216	3.63	0.0288	0.133
fluorite	0.0227	0.220	3.19	0.0324	0.126
quartz (mean)	0.0184	0.196	2.65	0.0354	0.0978
quartz ∥ c axis	0.030	”	”	0.0578	0.125
quartz ⊥ c axis	0.016	”	”	0.0308	0.0912
andalusite	0.0181	0.202	3.10	0.0289	0.106
jadeite	0.0159	0.206	3.20	0.0241	0.102
magnesite	0.0139	0.236	2.99	0.0197	0.0990
rutile	0.0122	0.189	4.24	0.0152	0.0989
grossular	0.0131	0.196	3.49	0.0192	0.0947
peridot	0.0115	0.210	3.47	0.0158	0.0915
elbaite	0.0126	0.2*	3.13	0.020	0.089
zircon	0.0108	0.140	4.63	0.0167	0.0837
beryl	0.00953	0.2*	2.7	0.018	0.072
rhodochrosite	0.00731	0.184	3.58	0.0111	0.0694
sphene	0.00558	0.187	3.52	0.00848	0.0606
fluor-apatite	0.00328	0.195	3.22	0.00522	0.0454
barite	0.00319	0.113	4.41	0.00640	0.0399
silica glass	0.00325	0.201	2.20	0.00735	0.0379
hyalite	0.0029	0.2*	2.08	0.00697	0.0347
flint glass	0.002	0.117	3.5	0.0049	0.029

*estimated values

measurements of Euken in 1911. These low values I believe are in error. The most thorough modern study I have found is that of Burgemeister (1978) who reports measurements on 100 natural diamonds and a few synthetic stones. He finds that Type II diamonds, at room temperature, have a constant K of 4.8 cal/cm sec °C, but that Type I diamonds vary downwards to a low of 1.6 cal/cm sec °C. The variance is dependent on the nitrogen content. The limits reported by Burgemeister are used in my compilation.

Table 1 gives the results of the compilation showing values of K, c, ϱ, k, and I for some metals and a variety of gem materials. For the gem minerals most values of K are taken from Horai (1971) who gives an extensive list of mean values because his measurements were on powdered samples. The specific heats were calculated from the tables of Robie and Waldbaum (1968). The densities are from Horai (1971) or Webster (1975). Examination of Table 1 shows that the Ceres Probe is approximately measuring

TABLE 2

Comparison of the relative values of thermal conductivity and thermal inertia to the relative measured response of diamond thermal probes referenced to spinel.

Material	Thermal Conductivity	Thermal Inertia	Measured Read	Measured G.I.A.*
silver	44.2	5.8	3.1	n.d.*
aluminium	21.7	4.0	3.1	n.d.
gold 24 carat	31.0	4.9	2.7	n.d.
diamond	70.7 to 212.	6.2 to 10.7	3.0 (0.75ct)	2.1
corundum	2.65	1.6	1.75	1.5
zircon	0.48	0.63	1.4	1.2
spinel	1.0	1.0	1.0	1.0
quartz	0.81	0.74	0.63	n.d.
rutile	0.54	0.74	0.63	n.d.
glass	0.088	0.22	0.13	0.27

*from G.I.A. advertising literature; n.d. = no data.

thermal inertia rather than thermal conductivity. This is more clearly shown by Table 2 where the relative responses of the Ceres Probe and the G.I.A. probe, both referenced to spinel, are compared to the ratios K/K spinel or I/I spinel. Table 2 shows that the predicted response I/I spinel, correlated reasonably well with the relative measured values and much better than K/K spinel. Some discrepancy however occurs for diamond, metals, and zircon. The discrepancy noted for zircon is probably due to a wide range in thermal inertia for this mineral. The computed value is for metamict Australian material while Read's measurement was made on high zircon. An increase in the disorder of the crystal lattice due to the metamict state would be expected to decrease the thermal inertia, and this is what is observed. To understand the cause of the discrepancy between measured and predicted values for metals and diamond requires that the thermal wave in the gem be better understood.

The solution for the one-dimensional heat conduction equation with periodic heat flux is given in the Appendix for those interested. Examination of this solution shows that the thermal

TABLE 3

Thermal wave propagation velocity and wavelength for selected materials at 1 and 60 hertz.

	1.0 hertz		60 hertz	
Material	Velocity cm/sec.	Wavelength cm.	Velocity cm/sec.	Wavelength cm.
silver	4.66	4.66	35.8	0.60
diamond	6.9 to 11.9	6.9 to 11.9	53.5 to 92.5	0.89 to 1.54
spinel	0.73	0.73	4.66	0.78
beryl	0.47	0.47	3.64	0.060
flint glass	0.25	0.25	1.92	0.032

wave has a very low velocity and short wavelength.* At a frequency of one hertz the velocity ranges from 10.3 cm/sec for diamond to 0.25 cm/sec for flint glass. At this frequency the wavelength is equal to the velocity. Table 3 gives the propagation velocity at 1 hertz and 60 hertz for several gem materials. Combined with a slow velocity is a rapid attenuation rate.† After only one wavelength of travel in the gem the amplitude of the sinusoidal temperature wave has decreased to 0.0019 of its surface value! We assumed in solving the one-dimensional equation that the gem was semi-infinite in extent, but the rapid attenuation means that, if the back of the slab, or gem, is more than 1/2 wavelength from the surface, then its effect will hardly be noticed. From Table 3 it is evident that, except for diamond, the Ceres Probe with its 1 hertz operating frequency should give accurate measurements of thermal inertia for gems of about 1 ct and above.

Figure 2a shows the relative magnitude of the thermal wave and its attenuation for glass, spinel and diamond. The amplitude of the surface heat flux is assumed the same for all materials. The graph shows that glass has a high surface temperature, but that the thermal wave penetrates only a short distance. Diamond on the other hand has a much smaller surface temperature, but the wave penetrates much farther before suffering significant attenuation.

Figure 2b shows the thermal wave as it would appear in a probe tip and gem under test. The figure has been scaled to a 10 mm diameter zircon. The large size was chosen for illustrative purposes to avoid having to show reflections from the pavilion. Crown reflections also are not shown. It should now be clear why Read's measurements on diamonds and metal are lower than predicted. The wavelength in these materials was long enough that reflections of the thermal wave returned to the measuring surface causing the surface temperature to be too high thus making the thermal inertia appear too low. It would take a very large diamond for the Ceres Probe to give an accurate measure of thermal inertia. It should be obvious also from Figure 2b that the thermal wave falls off faster in the gem than predicted by the one-dimensional solution due to geometrical spreading of the wave front.

*The velocity is given by $V = \sqrt{2\omega k}$

†The attenuation for this one-dimensional case is given by $\varepsilon^{-x\sqrt{\omega/2k}}$

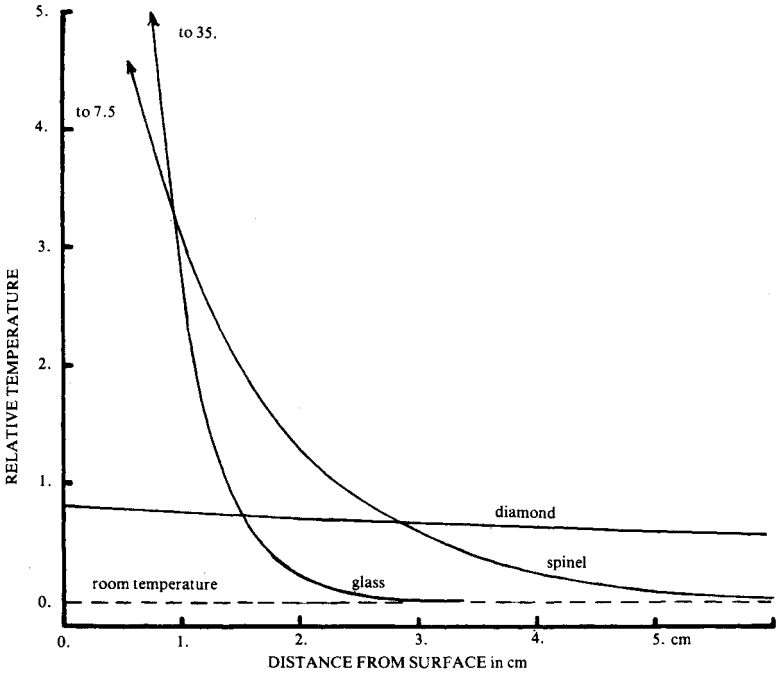

2a.

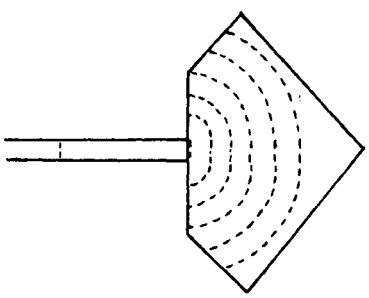

2b.

FIG. 2. Illustration of the fall-off of the thermal wave in various materials for a sinusoidal heat flux at 1 Hz. (a) The variation of amplitude with distance from the surface for glass, spinel and diamond. (b) Isothermal contours every 0.1 wavelength in a gem zircon of 10 mm diameter.

The question of how small a diamond can be reliably distinguished is difficult to answer theoretically because of problems in solving the heat conduction equation subject to the actual boundary conditions. The question is best answered by experiment with the instrument. The simple theory presented here, however, does suggest that loose melee should be tested by placing them on a plate of copper or silver. A recessed tip, such as supplied with the Kashan probe, can then be placed over the pavilion. Under these conditions a diamond should give a reading essentially the same as would be obtained on the metal while a simulant would give a lower value.

Although the probes are designed as go, no-go instruments, Table 1 suggests that they may have value if used in a more quantitative manner. For example the Table shows a difference of about 2 to 1 in thermal inertia between topaz and beryl. If the variation of K with direction of these two minerals is not extreme, then the probe might provide a simple means of distinguishing blue topaz from aquamarine when an index of refraction is not easily measured. To test this prediction a Ceres Probe was used to measure the response of six beryl and six topaz gems, all above 1 ct. For the gems tested the Ceres Probe gave distinctive results for both materials. Measured along the lower edge of the red coloured zone, and referenced to the 'zero' value in air, beryl gave a range of 5-9 mm and topaz a range of 14-17 mm. Several surfaces of the gem were tested to make sure that differing crystallographic orientations were taken into account. While not conclusive, it appears that the new thermal probes could have a much broader range of application then previously recognized. Nassau (1978-79) reported on tests with a prototype Ceres Probe in which he states the speed with which the thermistor temperature falls is measured following the application of a short pulse of current. This may imply that the prototype was measuring thermal diffusivity. Nassau mentions that production models will be somewhat different in appearance but will function in the same manner as the prototype. The calculations presented in this paper however show that the response of production models is proportional to thermal inertia.

It is hoped that this brief review of the operation of the thermal diamond probes not only has provided a better understanding of their operation, but will stimulate users to investigate more fully the potential application of these devices.

APPENDIX

The one-dimensional heat flow equation is given by equation 1

$$\frac{\partial v}{\partial t} = k\frac{\partial^2 v}{\partial x^2} \tag{1}$$

The general solution and means of solving it are given in most texts on differential equations to which the interested reader is referred. The general solution may have many forms. For convenience I will take it in the form given in 2, with two constants for satisfying the boundary conditions.

$$v = A\varepsilon^{-x\sqrt{\omega/2k}} \cos \omega(t - x/\sqrt{2k\omega}) + B\varepsilon^{-x\sqrt{\omega/2k}} \sin \omega\,(t - x/\sqrt{2k\omega}) \tag{2}$$

This solution represents a wave travelling in the positive x direction with velocity $\sqrt{2k\omega}$ and attenuated by the factor $\varepsilon^{-x\sqrt{\omega/2k}}$. What is now required is to solve equation 2 for A and B subject to any boundary conditions we choose to apply. If we assume the surface temperature is given by 3,

$$v = A_0 \cos \omega t \tag{3}$$

then evaluating 2 at the surface, $x = 0$, gives

$$v = A_0\varepsilon^{-x\sqrt{\omega/2k}} \cos \omega\,(t - x/\sqrt{2k\omega}) \tag{4}$$

However, we assumed the Ceres Probe gave a constant heat flux at the surface of the stone. The heat flux is given by

$$F = -K\frac{\partial v}{\partial x} \tag{5}$$

Evaluating 5 and assuming a constant heat flux in the form, $F_0 \cos \omega t$, gives the solution

$$v = \frac{F_0}{K\sqrt{\omega/k}} \cos(\omega t - \pi/4) = \frac{F_0}{I\sqrt{\omega}} \cos(\omega t - \pi/4) \tag{6}$$

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GEMMOLOGICAL ABSTRACTS

AMSTUTZ (G. C.), WANG (N.). *Ein 'Schneeflocken-Obsidian' aus dem Cascadengebirge von Oregon, Nordamerika.* (A 'snow-flake obsidian' from the Cascade Mountains of Oregon, North America.) Z.Dt.Gemmol.Ges., **30**, 3/4, 226-9, 4 figs in colour, bibl., 1981.

An occurrence (possibly new) of snow-flake obsidian from the west face of the Three Sisters in the Cascade Mountains of Oregon is described, including description of the outcrop and examination under the microscope and by x-rays: and a genetic interpretation is offered. It is suggested that during the lava flow the pressure decreased and that then gas pressure distributed the fluid phases into all directions. These phases are now frozen and visible as white isolated spots, i.e. snow-flakes. E.S.

BALL (R. A.), HENNESSY (L.). *Stones Seen: 'White Nephrite'.* Aust.Gemmol., **14**, 9, 228-9, 1 fig, 1982.

Cabochon of 'white nephrite' is thought to be xonotlite. RI 1.583 and SG 2.73 both far too low for nephrite. R.K.M.

BANK (H.). (a) *Smaragde aus Sambia mit relativ hoher Lichtbrechung und Doppelbrechung und starkem Eisengehalt.* (Emerald from Zambia with relatively high refractive index and double refraction and high iron content.) Z.Dt.Gemmol.Ges., **30**, 3/4, 230-1, 1981; (b) *Natürlicher Smaragd aus Sambia mit ausgeprägtem Zonarwachstum als Smaragd-Beryll Dublette angesehen.* (Natural emerald from Zambia with definite zonal growth mistaken for emerald-beryl doublets.) Id., 232-3, 2 figs in colour, 1981; (c) *Über die Variation des Brechungsindex von Ekanit.* (About the variation of refractive indices in ekanite.) Id., 234-5, 2 figs in colour, 1981; (d) *Farbloser Andalusit aus Brasilien.* (Colourless andalusite from Brazil.) Id., 236-7, 1 fig. in colour, 1981; (e) *Viridinartige Andalusite aus Brasilien.* (Viridine-like andalusite from Brazil.) Id., 238-9, 1 fig. in colour, 1981; (f) *Kunstprodukt als Hämatit ausgegeben.* (Artificial product mistaken for haematite.) Id., 242, 1981; (g) *Grün überzogene Quarzkristalle in einer Partie Rohsmaragde aus Sambia.* (Quartz coated by green material found amongst rough emerald from Zambia.) Id., 242-3, 1981; (h) *Glas für Opal ausgegeben.* (Glass offered as opal.) Id., 244, 1981.

(a) Emeralds from Zambia have a high Fe content and the highest known RI of natural emeralds, up to 1.602, while generally they remain at 1.590. Crystals have recently been observed with a value n_0 of between 1.590 and 1.600, closing the open space of until now known Zambian emeralds. (b) Zambian emeralds are described which show very distinct zonal growth, the core being colourless with low RI, the edge intensely green with high RI. Stones cut from these crystals may be taken for doublets, especially as upper and lower part show different RIs. (c) Ekanites have until now been described as dark green but have recently been observed also light

brown and emerald green with RI varying from 1.590 to 1.597. (d) A colourless andalusite as one part of a cut bi-coloured stone is described originating from Brazil with low RI, free of or poor in Fe. (e) Fe-rich andalusites with high RI and containing Mn_2O_3 can be regarded as viridine-like. (f) Haematite beads were found to be imitations. Suspicion was first aroused when the beads were re-strung and the string was found to be green instead of red. The RI could not be read, but x-ray diffraction showed the beads to be imitations. (g) Quartz crystals covered with a green substance found in a lot of rough emeralds from Zambia. Suspicion was aroused by the matt faces and quartz-like crystals. (h) Glass was substituted for opal—this was finally proved by the presence of bubbles and by an RI of 1.495. E.S.

BANK (H.) and (F. H.). *Das Phänomen 'multiplier' Brechungsindizes bei rohen Turmalinen aus Tansania.* (The phenomenon of multiple refractive indices of rough tourmalines from Tanzania.). Z.Dt.Gemmol.Ges., **30**, 3/4, 240-1, 1 fig. in colour, 1981.

The phenomenon of multiple RIs so far described in dark-green tourmalines (heat treated to high temperature) and in coated beryls (after Lechleitner) have now been observed in several rough crystals of uvites (tourmalines) from Tanzania (due to vicinal faces). E.S.

BARIAND (P.). *The Sorbonne collection.* Mineral. Record, **13**, 1, 31-4, 7 figs in colour, 1982.

The mineral exhibition room which houses the mineral collection of the Faculty of Sciences, University of Paris, contains some fine gem-quality materials including tourmalines. Some details of architectural and technical features of the collection room are given. M.O'D.

BARRINGTON (E. N.). *Computers and Gemmology.* Aust. Gemmol., **14**, 7, 166-8.

A feasibility study of the computerization of gemmological data. R.K.M.

BELSHER (D. O.). *Pink octahedral fluorite from Peru.* Mineral. Record, **13**, 1, 29-38, 1 fig in colour, 1982.

Fine quality pink fluorite has been found at the Huanzala mine, approximately 240 km north of Lima, Peru. The occurrence is in a working mine producing lead and zinc. Although green fluorite is also found, the pink is exceptionally fine; it occurs as simple octahedra. There is some doubt as to the stability of the colour. M.O'D.

BERNHARDT (H.-J.), SCHMETZER (K.), MEDENBACH (O.). *Berdesinskiit, V_2TiO_5, ein neues Mineral.* (Berdesinskiite, V_2TiO_5, a new mineral.) Z.Dt.Gemmol.Ges., **30**, 3/4, 143-5, 3 figs (2 in colour), 1981.

The new mineral was named berdesinskiite in honour of Prof. Dr W. Berdesinski, who is celebrating his 70th birthday. It was discovered in a vanadium-bearing kornerupine mine six miles south-east of Lamsamba Hill in the Kwale district of Kenya. A similar material, schreyerite, $V_2Ti_3O_9$ was found in 1978. The new material is black with metallic lustre. Optical, chemical and x-ray data are given. E.S.

BOSSHART (G.). *Die Unterscheidung von echten und synthetischen Rubinen mit UV-Spektralphotometrie.* (The differentiation between natural and synthetic rubies with the help of UV spectrophotometry.) Z.Dt.Gemmol.Ges., **30**, 3/4, 157-69, 5 figs, 1 table, bibl., 1981.

This paper, as slightly revised, was published in English in *J.Gemm.*, 1982, **XVIII**, 2, 145-60.

BROWN (G.). *The Biwa pearl.* Aust.Gemmol., **14**, 7, 153-6, 6 figs, 1981.

A detailed account of a subject on which the Japanese Cultured Pearl industry is reticent. Describes flesh culturing procedure and 1st and 2nd crops harvested from the same long-lived mussels. First crop is cultured in 6 to 7 year old bivalves and needs up to three years to develop. These have cavity centres. They are removed and the mussels returned to the water for a further three years when a second crop of rather larger and rounder pearls is obtained which have slit-like cavity centres. A third crop is possible but is uneconomic. A map (Figure 2) has the Kaizu and Kasumiga-ura localities transposed. R.K.M.

BROWN (G.). *The Biwa pearl: Part 2.* Aust.Gemmol., **14**, 8, 186-93, 11 figs, 1981.

A second part to the paper in the previous issue (**14**, 7) of this journal. Gives identification criteria. Some experimental bead nucleation of freshwater cultured pearls may still be going on but is difficult in this mussel. Structures of pearls and of Biwa pearls, on which original investigation has been done, are discussed at length and a sequence of events in their formation is suggested. The two parts of this paper make an important contribution to literature on pearl cultivation. R.K.M.

BROWN (G.). *SWUV diaphany of ruby.* Aust.Gemmol., **14**, 8, 200-3, 1 fig., 1981.

Mr Brown has found that a dark purplish-red Kashan ruby (which showed traces of iron in its absorption) is, as might be expected, opaque to short UV light; rather more so than natural Siam rubies. R.K.M.

BROWN (G.). *Golden corals: a brief note.* Aust. Gemmol., **14**, 8, 204-8, 3 figs, 1981.

Distinction between natural golden coral and the cheaper smooth golden coral which seems to be produced by bleaching black gorgonian and antipatharian corals in hydrogen peroxide. R.K.M.

BROWN (G.), SNOW (J.). *Three brief evaluations.* Aust.Gemmol., **14**, 9, 223-8, 6 figs, 1982.

A Report of the Instrument Evaluation Committee of the G.A.A.

Kashan diamond detector. A heat probe detector with a 'red light for diamond' facility, functioning very much as other examples of this instrument. An adaptor is described, but not evaluated, which is said to aid testing of loose stones below 0.1 ct.

The Winter diffraction grating spectroscope. A pocket instrument with fixed slit, giving high resolution spectra similar to those expected in a prism instrument, probably because a silvered plastic diffraction grating is used.

The Discrimagem filter. Yet another attempt to improve on the Chelsea filter. Committee quotes Webster's reservations in respect of all colour filter tests. R.K.M.

BROWN (G.), TAYLOR (B.), SNOW (J.). *An evaluation of the Presidium gem tester.* Aust.Gemmol., **14,** 7, 169-76, 3 figs, 1981.

Report of the Instrument Evaluation Committee of the G.A.A. on an Australian heat-probe instrument which includes diamond and simulant test discs for calibration purposes. In use the probe worked well, defining diamond by needle deflection to a green area of a scale and all simulants by lesser deflection to a red area. R.K.M.

CASSEDANNE (J.-P.), LOWELL (J.). *The Virgem da Lapa pegmatites.* Mineral. Record, **13,** 1, 19-28, 23 figs (3 in colour), 1982.

This pegmatite, north-west of the town of Virgem da Lapa in north-eastern Minas Gerais, Brazil, has produced high quality crystals of topaz, elbaite tourmaline and hydroxyl-herderite. The topaz in this locality is blue, the tourmaline green, pink, blue or multi-coloured. Maps of the occurrences and references are given. M.O'D.

COLLINS (A. T.), MOHAMMED (K.). *Optical studies of vibronic bands in yellow luminescing natural diamonds.* J.Phys.C: Solid St.Phys., **15,** 147-58, 7 figs, 1982.

Absorption and luminescence measurements are described for a large number of gem-quality brown diamonds. The stones were examined under long wave ultraviolet light (365 nm) where a bright yellow luminescence was observed. A vibronic band with a peak near 2.6 eV (488 nm) could be detected in all stones giving the bright yellow luminescence. Evidence that the electron-phonon coupling is strong is suggested by the absence of vibronic structure on the 2.6 eV band. Absorption in this band gives red luminescence. Yellow luminescence is associated with a second strongly coupled vibronic system with a zero-phonon line at 2.721 eV. In the infrared absorption spectrum a minor peak at 1240 cm^{-1} was observed in the spectra of all diamonds studied which appeared to correlate with the 2.6 eV band. M.O'D.

CROWNINGSHIELD (R.). *Irradiated topaz and radioactivity.* Gems & Gemology, **XVII,** 4, 215-17, 1 fig. in colour, 1981.

Parcel of blue irradiated topaz found to be radioactive, thought to have been colourless material treated by neutrons in a reactor. Degree of radioactivity is considered dangerous. Other gems known to be being similarly irradiated, and author advises checking all stone parcels for dangerous radiation levels. R.K.M.

DAWKINS (J. C. F.). *The application of diamond tools.* Gems, **14,** 1, 9-13, 1 fig., 1982.

Diamond particles used as an abrasive have been developed in recent years and now are extensively used in the lapidary industry. A diamond mesh or cloth, which is embedded with diamond particles, is capable of being cut to any desired shape and can be used to polish almost any shape of rough gem material. M.O'D.

EYSEL (W.), BREUER (K.-H.). *Dioptas: Kristallstruktur, Entwässerung und Farbänderungen.* (Dioptase: crystal structure, dehydration and colour changes.) Z.Dt.Gemmol.Ges., **30,** 3/4, 219-23, 6 figs (2 in colour), bibl., 1981.

When heated dioptase ($CuSiO_3 . H_2O$) shows two types of colour changes

depending on whether the stone has been heated in air or hydrothermally. There is a continuous change from green to bluish green to greyish black or green to blue, the first includes a loss of crystal water, the second does not. In both cases the basic structure is preserved, but volume shrinkage occurs. E.S.

FISCHER (K.). *Cabochonschleifen.* (Cabochon cutting.) Lapis, **7**, 2, 20-40, 10 figs (5 in colour), 1982.

Chatoyancy and asterism are described from the point of view of the lapidary and illustrations are given of gem materials showing these effects. M.O'D.

FISCHER (R.). *Der Elfenbeinhandel in der Bundesrepublik Deutschland unter Beachtung des Washingtoner Artenschutzübereinkommens.* (The trade in ivory in the Federal German Republic in relation to the Washington Convention on Endangered Species.) Z.Dt.Gemmol.Ges., **30**, 3/4, 146-51, 2 tables, 1981.

The Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) came into force in the Federal Republic of Germany on 20th June, 1976. The import of ivory from Indian elephants is prohibited, ivory from African elephants can be imported and re-exported on presentation of the relevant documentation. The import of rough ivory had decreased since 1980, while the import of ivory products has increased slightly. Prices have risen sharply. E.S.

FRANCO (R. R.). *Brazilian gemstones.* Earth Science Reviews, **17**, 207-19, 1 map, 1981.

Most Brazilian states and territories produce gemstones, the state of Minas Gerais being the most important producer both in volume and number of species. Diamonds are chiefly derived by panning alluvial deposits in Minas Gerais, Mato Grosso, and Goias. Among other gemstones, the most important are aquamarine, beryl, chrysoberyl, topaz, amethyst, tourmaline, emerald, and agate. The occurrences of these gemstones and a great number of others are described for each state in which they are found. P.Br.

FRYER (C.) ed., CROWNINGSHIELD (R.), HURWIT (K. N.), KANE (R. E.). *Gem Trade Lab Notes.* Gems & Gemology, **XVII**, 4, 226-30, 18 figs in colour, 1981.

Dyed marble coral substitute, angular grooves in cut diamond, badly burned treated yellow diamond, diamonds with photosynthetic colour change and various other coloured diamonds, natural or otherwise, are illustrated. Dyed beryls to imitate emerald, a natural emerald with very large three phase inclusion, totally worn pearls in a necklace, 'pearls' of lacquered M.O.P., crackled quartz in green and red, a light bluish-grey quartz showing a good star and a parcel of over 50 yellow-orange sapphires, which were shown to have been heat-treated by their weak fluorescence in LWUV, stress fractures and multi-plane repolished girdles, all described and illustrated. R.K.M.

GÜBELIN (E. J.). *Einschlüsse im Granat aus dem Umba-Tal.* (Inclusions in garnets from the Umba Valley.) Z.Dt.Gemmol.Ges., **30**, 3/4, 182-93, 21 photomicrographs in colour, bibl., 1981.

Fourteen specimens with representative scenes of inclusions were selected from a large number of new garnets from the Umba Valley. The gems were cut so that the

mineral inclusions became exposed at the surface and could be analysed by electron microprobe. The properties and mineral inclusions of the 14 garnets are described. It is emphasized that on account of mutual overlapping the various properties are (except a special constellation of absorption lines and the presence of large pyrite crystals) hardly diagnostic with regard to occurrence and species. Amongst the inclusions the following were found: quartz, apatite, zircon, rutile (needles and prisms), pyrrhotite, monazite and pyrites. The author also expresses his appreciation to K. Schmetzer and H. Bank for suggesting that this type of garnet should be called pyralspite.* E.S.

GÜBELIN (E.), MOOR (R.), OBERHOLZER (W. F.). *Taprobanit -ein neuer Edelstein aus Sri Lanka.* (Taprobanite—a new gemstone from Sri Lanka.) Z.Dt.Gemmol.Ges., **30**, 3/4, 197-206, 3 figs (2 in colour), 3 tables, bibl., 1981.

Taprobane is the old Greek name for Sri Lanka, 'tapa' meaning meditation and 'bove' garden. The stone was originally offered on the market in Ratnapura by a gem digger as spinel, then as ruby, then acquired by A. G. B. Amarasinghe (who had just qualified as an F.G.A.) as a taaffeite. The stone was found to have an idealized formula of $BeMg_3Al_8O_{16}$. RI 1.717-1.721; DR −0.004. Observed density 3.605 g/cm^3, calc. density 3.588 g/cm^3. Strong dichroism, absorption and emission lines at 685.2. Weak UV luminescence. Hardness 8+, no cleavage. It is a hexagonal crystal, x-ray diffraction pattern given. Taprobanite seems to fill a missing link between spinel and chrysoberyl; because of its space grouping it was found to be a mineral species in its own right.† E.S.

HÄNNI (H. A.). *Chemischer Vergleich zwischen natürlichen und synthetischen Smaragden.* (Chemical comparison between natural and synthetic emeralds.) Z.Dt.Gemmol.Ges., **30**, 3/4, 214-18, 1 fig., 2 tables, 1981.

Synthetic emeralds show a low concentration of Na and Mg while natural emeralds show these elements in a percentage range. E.S.

HÄNNI (H. A.). *Energiedispersive Röntgenfluoreszenz-Analyse in der gemmologischen Diagnostik.* (Energy-dispersive x-ray fluorescence in diagnostic gemmology.) Z.Dt.Gemmol.Ges., **30**, 3/4, 207-9, 2 figs, 1981.

EDS-XRF is a non-destructive physical method for qualitative or quantitative determination of chemical constituents, which can also contribute towards information as to the gemstone's nature. E.S.

HORIUCHI (N.). *New synthetic opal made of plastics.* Aust.Gemmol., **14**, 9, 213-18, 9 figs, 1 table, 1982.

A translation of a paper which appeared first in The Journal of the Gemmological Society of Japan‡ this describes an imitation of opal rather than a synthetic opal. Polystyrene spheres of 200 nm diameter close-packed by gravity

*See *J.Gemm.*, 1981, **XVII** (8), 527.—Ed.

†But see ''Taprobanite'' is Taaffeite', *J.Gemm.*, 1982, **XVIII** (2), 112-13.—Ed.

‡Briefly abstracted in *J.Gemm.*, 1979, **XVI** (8), 547.—Ed.

sedimentation process lasting three to six months. Sediment lacks strength so is enclosed in acrylic coating. Latter visible from side of stone. Water beads on plastic but not on opal, real or synthetic. Some conclusions may have been drawn on insufficient data when comparing with Gilson synthetics. R.K.M.

HUMBLE (P.). *"Star" diamond.* Aust.Gemmol., **14**, 9, 219-20, 1982.

A paper based on a photograph of a star in a diamond crystal which is reproduced on the front cover of this greatly improved journal. Dr Humble has gone to a lot of needless trouble to find and prove an optical explanation of the star. [My own paper on *Star Inclusions in Diamond* (J.Gemm., 1981, XVII, 8, 584-8) deals with the same crystal and with one about ten times the size, and in both the formation is of dust-like particles giving a complex eight-armed star, seen as six-armed through each of the octahedral faces.] R.K.M.

KOIVULA (J. I.). *San Carlos Peridot.* Gems & Gemology, **XVII**, 4, 205-14, 17 figs in colour, 1981.

Mr Koivula obtained the necessary permission to visit Peridot Mesa in the San Carlos Apache Reservation and describes it in detail; a volcanic 'table' capped by dark grey basalt in which the peridot is found. Mining by hand using pick, pry bars and hammer and chisel to avoid too much blasting, which shatters peridot nodules. Excellent pictures of typical inclusions, most of which are known in peridot from other localities, but chrome diopside and smoke-like veiling, due probably to exsolution of impurities, seem unique to San Carlos. R.K.M.

KRAUS (P. D.). *Korite from Alberta, Canada.* Lapidary J., **35**, 10, 1994-6, 11 figs in colour, 1982.

Korite [a somewhat undesirable name] is the aragonite portion of the fossilized shell of the ammonite *Placenticeras.* The play of colour seen is thought to be a diffraction effect. The material had disappeared from the market for a while, though when it first appeared it had the name ammolite, which is, in fact, a name to be preferred. M.O'D.

LAPWORTH (P. B.). *The Golden Jubilee of the Gemmological Association of Great Britain,* Aust.Gemmol., **14**, 9, 220-1, 1982.

An account of the Jubilee celebrations in October 1981, mentioning some Australians who were present and others who had obtained their (British) Diplomas in Gemmology (including the Tully Medallist of 1956). J.R.H.C.

MACFALL (R. P.). *Historic Blue John and other fluorites.* Lapidary J., **35**, 10, 1998-2018, 9 figs (3 in colour), 1982.

A full account of the history and occurrence of the Derbyshire form of fluorite known as Blue John is given. Other fluorite deposits are reviewed. M.O'D.

MANSON (D. V.), STOCKTON (C. M.). *Gem garnets in the red-to-violet color range.* Gems & Gemology, **XVII**, 4, 191-204, 3 tables, 11 figs (1 in colour), 1981.

First of a series of papers which will investigate scientifically relationship between chemical composition and colour in garnets. After much erudite scientific

work conclusion is reached that colour does not depend on proportions of end-members, e.g. pyrope/ almandine/ spessartine, but is influenced by trace impurities. R.K.M.

MEYER (I.). *Roter Beryll.* (Red beryl.) Lapis, **7**, 1, 31, 1 fig. in colour, 1982.

Red transparent beryl from Thomas Range and the Wah Wah Mountains of Utah is described and illustrated. One example contained 0.24% Cs compared to 0.05% from a Madagascan specimen. A Cs-content of 0.90% is reported from a specimen from the Thomas Range. M.O'D.

MITCHELL (J. R.). *Fossils and a variety of agate near Green River, Wyoming.* Lapidary J., **35**, 10, 2110-12, 9 figs, 1982.

Moss agate, various colours of jasper and a turritella agate are found in the Green River of Wyoming. M.O'D.

MITCHELL (R. K.). *Letter to the Editor—Birefringence,* Aust.Gemmol., **14**, 9, 221-2, 1982.

Emphasizes that the full birefringence of a gemstone can be obtained from a single polished flat facet: only to determine optic sign is it sometimes necessary to test again on a second facet. J.R.H.C

MOOR (R.). OBERHOLZER (W. F.), GÜBELIN (E.). *Taprobanite, a new mineral of the taaffeite group.* Schweiz. Min. Petr. Mn, **61**, 1, 13-21, 1981.

A new red hexagonal-prismatic crystal cut as a 204 mg gemstone and sold as taaffeite is shown to be a new species. It is named after the old Greek name for the island of Sri Lanka, Taprobane, and has Mohs's hardness ~ 8; D 3.605 g/cm^3; no cleavage; weak red fluorescence in UV radiation. It is optically uniaxial, ε (yellow-rose) 1.717, ω (carmine red) 1.721. Chemical analyses lead to the formula $BeMg_3Al_8O_{16}$. X-ray powder data are given; a crystal structure determination is reported and shows that taprobanite is related to taaffeite. It has *a* 5.684, *c* 18.322 Å; space group $P6_3mc$.* R.A.H.

MUNTZ (S. R.). *Oregon diamond find has been verified.* Oregon Geology, **43**, 26, 1981.

A clear white flattened hexoctahedron of 0.6 ct was found near Wedderburn, Curry County, prior to 1938, and is now in the Smithsonian Natural History Museum (R7826). W.T.H.

NASSAU (K.), PRESCOTT (B. E.). *Non-fading Maxixe-type beryl?* Gems & Gemology, **XVII**, 4, 217-19, 2 figs (1 in colour), 1981.

Non-fading Maxixe-type beryl reported but was 'ordinary' fading material which had probably been kept in poor light so that fade was unnoticed. No authentic instance of non-fading Maxixe-type material has yet been proved. R.K.M.

*But see ' "Taprobanite" is Taafeite', *J.Gemm.*, 1982, **XVII** (2), 112-3.—Ed.

NICKEL (E. H.). *So you think you have a new mineral!* Aust.Gemmol., **14**, 8, 181-4, 1981.

Outlines the steps in confirming a mineral as new, and naming it. Appendix gives a case history of one such new mineral. Interesting paper. R.K.M.

NUBER (B.), SCHMETZER (K.). *Strukturverfeinerung von Liddicoatit.* (Structural refinement of liddicoatite.) N.J. Miner. Mnh., 5, 215-19, 1981.

A continuous solid solution between liddicoatite (Ca-Li-Al tourmaline and elbaite, its sodium analogue, is predicted. The structure of liddicoatite was refined to an R-value of 3.3%. M.O'D.

O'DONOGHUE (M.). *The dealer looks at gemstones—2.* Gems, **13**, 6, 33, 1981.

The second piece in this series deals with asterism, chatoyancy, inclusions in emerald and the part they play in identifying origin. (Author's abstract.) M.O'D.

O'DONOGHUE (M.). *The dealer looks at gemstones—3.* Gems, **14**, 1, 29-30, 1982.

The various colours of tourmaline are reviewed with their commercial potential in mind. Pakistan and Afghanistan have recently provided fine quality material. (Author's abstract.) M.O'D.

PEARSON (G. M.). *Reflections on the use of the hand spectroscope.* Aust.Gemmol., **14**, 7, 157-9, 1981.

A general summary of methods of use. Author is mistaken in his interpretation of the term 'reflected light' when used in absorption spectroscopy. This is light which passes through a stone and reflects at an inside surface giving a longer light path and light undiluted by stray illumination from the original source. He also advocates using a wide open slit to facilitate the location of an absorption line or band. This is contrary to normal practice and will swamp fine lines completely. R.K.M.

PFAFFL (F.). *Der Edelstein des Zaren Alexandrit.* (Alexandrite, gemstone of the Czars.) Mineralien Magazin, **6**, 2, 73-7, 7 figs (5 in colour), 1982.

The occurrence of alexandrite in the Urals is interestingly located on a sketch map and the crystal form usefully described. M.O'D.

POUGH (F. H.). *Japanese manmades.* Lapidary J., **35**, 10, 2004-8, 7 figs (4 in colour), 1982.

Opal made from monodisperse latex, beryl and alexandrite made in Japan are described. References would have been welcome. M.O'D.

RAMSEY (J. R.). *The cutting properties of kunzite.* Gems & Gemology, **XVII**, 4, 220-5, 6 figs in colour, 1981.

The cutter, Tom Carleton, undertook to cut with tables normal to the *c* axis, (something commercial cutters are usually not keen to do because of the facile and perfect prismatic cleavage). The one kilo fine quality crystal was sawn into four pieces to give stones of 703.5, 725, 514, and 145 carats respectively. First stone took 2½ hours to saw and 14 days to cut and polish. Illustrations vary in colour and final shade is difficult to assess. Problems and difficulties in cutting are explained. R.K.M.

ROBERTSON (A. D.). *Letter to the Editor—Gem Sphene in Australia,* Aust.Gemmol., **14,** 9, 222, 1 fig, 1982.

Gem quality sphene has been known from Australia for a number of years. Deposits in the Harts Range, found before 1977, yielded crystals capable of cutting as gems of over 20 ct: colour ranged from honey-brown to yellowish green with a high degree of transparency. J.R.H.C.

SANDERS (J. V.). *Jelly opal from White Cliffs.* Aust.Gemmol., **14,** 7, 161-5, 5 figs, 1981.

A valuable paper which adds to the knowledge of opal structure. Electron-photomicrographs reveal that this type of opal often has a lattice of larger opal spheres regularly arranged among the smaller spheres. These are probably responsible for the flashes of monochrome colour which characterize this kind of opal. The optics of this are complex. R.K.M.

SCHMETZER (K.). *Zur Mineralogie ternärer Oxide im System BeO-MgO-Al_2O_3.* (The mineralogy of ternary oxides in the system BeO-MgO-Al_2O_3.) Naturwissenschaften, 67, 471, 1981.

The system BeO-MgO-Al_2O_3 is discussed with particular reference to taaffeite and taprobanite. M.O'D.

SCHMETZER (K.), BANK (H.). *The colour of natural corundum.* N.J. Miner. Mnh., 2, 59-68, 1 fig, 1981.

The colour of natural corundum is ascribed to various trace elements and in some cases to lattice defects. Colours other than the basic ones are attributed to the superimposition of absorption bands of trace elements or pairs of elements. Lattice imperfections, together with trivalent chromium, are responsible for the colour of orange (padparadschah) sapphire. M.O'D.

SCHMETZER (K.), BANK (H.). *Garnets from Umba Valley, Tanzania—members of the solid solution series pyrope-spessartine.* N.J. Miner. Mnh., 8, 349-54, 1981.

A number of garnets from the Umba Valley area of Tanzania were examined and found to belong to a series with end members pyrope and spessartine. The range of specific gravity was 3.95-3.84 and of refractive index 1.768-1.751. M.O'D.

SCHMETZER (K.), BANK (H.). *Die Farbursachen und Farben der Mineralart Korund.* (Causes of colour and colour of the mineral corundum.) Z.Dt.Gemmol.Ges., **30,** 3/4, 152-6, 2 tables, bibl., 1981.

The colour of corundum and its gemstone varieties ruby, sapphire and padparadschah is caused by ions of the transition metals iron, titanium, chromium, and vanadium as well as by lattice imperfections. Crystals whose colour is due to only one transition metal ion or one pair of transition metal ions are not often found in nature. Most natural corundum crystals have different causes for their specific colours. By adding several basic colours a great number of mixed colours can be produced in natural corundums. The absorption spectra of such crystals are interpreted as a superposition of several basic types of spectra. E.S

SCHMETZER (K.), BANK (H.). *Granate aus dem Umba-Tal, Tansania: Ist ein neuer Varietätsname erforderlich?* (Garnets from the Umba Valley, Tanzania: is a new name needed for this variety?) Z.Dt.Gemmol.Ges., **30**, 3/4, 177-81, 1 fig. in colour, 1 graph, 2 tables, bibl., 1981.

An English version of this paper was published in *J.Gemm.*, 1981, **XVII**, 8, 522-7.

SCHMETZER (K.), BANK (H.), STÄHLE (V.). *Zum Chromgehalt in synthetischen Smaragdüberzügen von Beryllkernen ('Synthetische Smaragde' der Herstellung Lechleitner).* (The chrome content of synthetic emerald skin over beryl ('synthetic emeralds' as produced by the Lechleitner method.)) Z.Dt.Gemmol.Ges., **30**, 3/4, 210-13, 1 table, 1 graph, bibl., 1981.

The RIs of the synthetic skin over the beryl seed of the Lechleitner synthetic emerald show a linear correlation with the chromium content of the coating. In a sample with RIs n_o1.580, n_e1.572, a Cr_2O_3 content of 3.99% was found; a stone with n_o1.610, n_e1.601, contained 10.01% Cr_2O_3. Very broad, faint shadow edges on the refractometer in one sample were caused by an unhomogeneous distribution of Cr_2O_3 between 7.64 and 13.20% in the synthetic emerald overgrowth. It seems that the higher the chromium content in the coating, the darker the coating, i.e. the darker the stone. E.S

SCHMETZER (K.), KRUPP (H.). *Enstatit vom Mairimba Hill, Kenia.* (Enstatite from Mairimba Hill, Kenya.) Z.Dt.Gemmol.Ges., **30**, 3/4, 194-6, 2 tables, 1981.

An English version of this paper was published in *J.Gemm.*, 1982, **XVIII**, 2, 118-20.

SNOW (J.), BRACEWELL (H.), BROWN (G.). *An examination of the Cathaystone cat's-eye.* Aust.Gemmol., **14**, 9, 230-2, 4 figs, 1 table, 1982.

A well illustrated paper on this artificial cat's-eye apparently made from fibre-optics material. Use of scattered or patterned inserts of coloured fibres imparts colour to the latest examples seen. R.K.M.

SNOW (J. J.). *The hand lens—its usefulness to the jewellery trade.* Aust. Gemmol., **14**, 9, 233-7, 14 figs, 1982.

An excellent and valuable paper dealing very fully with this indispensable optical aid and explaining diagrammatically spherical and chromatic aberration, and the virtues or otherwise of various compound lenses from simple to aplanatic triplet. Good instructive paper full of excellent advice. R.K.M.

TAYLOR (B.), BROWN (G.), SNOW (J.). *An evaluation of the Gemlusta reflectometer.* Aust. Gemmol., **14**, 8, 196-9, 1 fig, 1981.

Report of the Instrument Evaluation Committee of the G.A.A. A thorough testing assessment of an updated and improved infrared reflectometer for which high claims are made. This has a digital read-out and a remote probe which can be brought to a stone in a setting. Readings were not readily reproducible with the latter. Lower values, those for gems which can be readily tested by ordinary refractometer, had many overlapping ranges and corroborative test by other instruments would be needed. R.K.M.

WANG (N.). *The superstructural pattern of lapis lazuli.* Z.Dt.Gemmol.Ges., **30,** 3/4, 224-5, 1 table, 1981.

The very weak satellite peaks observed in the powder pattern of a pure lapis lazuli can be accounted for by a supercell with edge length $a_o = 4 \times 9.07$Å. E.S

WEIBEL (M.), WESSICKEN (R.). *Hämatit als Einschluss im schwarzen Sternsaphir.* (Haematite as inclusion in black star sapphire.) Z.Dt.Gemmol.Ges., **30,** 3/4, 170-6, 7 figs (3 in colour), 1981.

Asterism in black star sapphires from Bang-kha-cha in south-east Thailand is caused by perfectly orientated intergrowth of elongated haematite lamellae in the [100] directions of corumdum. The interphase between the two minerals produces a periodic contrast pattern which can be recognized as narrow-spaced additional intensities in electron diffraction patterns. E.S.

WICKETT (H. C.). *Determination of refractive indices.* Aust.Gemmol., **14,** 8, 194.

Author suggests that full birefringence cannot always be obtained from one facet of a cut stone because of small size and bad polish of specimens. Advocates using distant vision method on such stones, but that would not give birefringence. R.K.M.

WYART (J.), BARIAND (P.), FILIPPI (J.). *Lapis lazuli from Sar-e-Sang, Badakshan, Afghanistan.* Gems & Gemology, **XVII,** 4, 184-90, 8 figs (7 in colour).

An excellent account of the ancient historic, and still the only, source of fine lapis lazuli, investigated ten years ago. Blue colour depends on sulphur content. Sar-e-Sang, considered difficult of access, is almost incredibly so, a fact brought home by the illustrations. Access to the camp at 2500 m is over high passes. The mines are then even higher and very difficult to reach. Annual output approximately one ton of usable rock, only 16% is fine enough for jewellery, rest used ornamentally. Mined by blasting. Rock carried by men to a point where donkeys can carry it to a jeep track. Region is strongly metamorphic and lazurite is found in grey skarns through a white micaceous marble. Pyrite almost always included. Mines now in hands of Afghan Nationalists. Not worked officially since Russian invasion. Some material still smuggled to Pakistan. R.K.M.

Index to Volume 17, Numbers 1-4, Gems & Gemology, **XVII,** 4, 245-8, 1981.

Previously two years to the volume, this four issue volume is a new departure as, of course, is the whole format of this now important magazine. Index is excellent but might be improved by including abstracted papers, which in this volume form an important section of the journal for the first time. R.K.M.

Stones Seen. Aust.Gemmol., **14,** 7, 160, 1 fig, 1981.

A fly in Baltic amber was probably of an Oligocene type about 40 million years old. R.K.M.

BOOK REVIEWS

ROBINS (B.). *An A-Z of gems and jewellery.* David & Charles, Newton Abbot, 1982. pp.96. £3.95.

A completely unnecessary and derivative book which contains a large number of errors undoubtedly based on ignorance of the subjects surveyed. Tanzania and Tasmania, beryl and chrysoberyl, East Germany and Bohemia are confused; reconstructed ruby makes yet another tedious appearance and there is no bibliography. M.O'D.

SINKANKAS (J.). *Emerald and other Beryls.* Chilton Book Company, Radnor, Pa, U.S.A., 1981. pp.xvi, 665; figs 196 black & white, 24 colour; tables 88. £30.00.

This a monumental work of encyclopaedic proportions and conception, and represents the results of 15 years of painstaking research and compilation. It is divided into three parts; some 150 pages are devoted to History and Lore, 200 pages to optical and physical properties and 350 pages to Beryl deposits.

Part I goes back to 3500 BC and traces the history of beryl in Ancient Egypt through antiquity, mediaeval and modern Europe and in other continents. The author goes on to describe beryl in magic, mystery and medicine, and in art and ornament. A notable feature of this part (and indeed of the whole work) is the citing of important historical works dealing with gems and lapidary work. References in the text are augmented by carefully verified bibliographies which terminate chapters: they represent one of the most desirable features of the book.

In Part II the crystal structure and chemical composition, the physical and optical properties, colour and luminescence, crystallography, inclusions, artificial and synthetic beryls and the cutting and polishing of beryl are described, the section concluding with the geological classification of beryl deposits. Despite the extraordinary volume of facts gathered together in this part it is, nevertheless, very readable both by the amateur and professional. Well annotated diagrams abound and the numerous tables succinctly present a series of facts culled from widespread sources.

Part III forms the real 'meat' of the book. The arrangement of the deposits is alphabetical by countries. It abounds with good locality maps and black-and-white photographs; many of the latter were taken decades ago and some lack definition and contrast, but they *are* records. The treatment is comprehensive and includes details of the geological setting and the production history of the various mines, chemical analyses and other properties of the various beryls. Emphasis is placed on deposits outside N. America and upon those described in languages other than English.

An appendix (with its own bibliography) traces the nomenclature of beryl and its derivation, and includes a glossary of the various terms which have been applied to beryl and its varieties.

This fat monograph owes its inspiration to Joseph E. Pogue's (1915) work on 'The Turquoise'. The present work covers a comparatively wider field and will, it is hoped, inspire its author to yet further 'instant classics' on other gem minerals. For its size, scope and erudition the book is not expensive at £30.00, and it will appeal to a wide readership in the gemmological, mineralogical, geological and mining fields.

E.A.J.

Sweat of the sun, tears of the moon—gold and emerald treasures of Colombia. Natural History Museum of Los Angeles County, Los Angeles, Ca, U.S.A., 1981. pp.96. Illus. in black-and-white and in colour. Price on application.

Though the gemmologist will turn at once to the superb colour pictures of rough and cut emeralds, the remainder of this outstanding book gives some idea of the richness of the collections of the Museo del Oro in Bogota, Colombia, and of the civilizations which those collections represent. The photographs of emerald include some of the largest known emerald crystals as well as cut examples; a separate chapter of the catalogue is devoted to emerald and the writer is optimistic about the possibility of further deposits being located.

M.O'D.

ASSOCIATION NOTICES

GIFTS TO THE ASSOCIATION

The Council of the Association is indebted to the following for their gifts:

Mrs N. Goulandris, Kifissa, Greece, for two pieces of branch coral from Greek waters.

Miss M. A. Lapworth, F.G.A.A., Guildford, Surrey, for a copy of *Edelsteine,* the German version of *Gemstones,* by Eduard Gübelin, C.G., F.G.A., Silva-Verlag, Zurich, 1969.

Mr Peter van Blommestein, Kimberley, S.A., for one piece of rough sugilite (wesselite) from Wessel's Manganese Mine, Hotazel, Northern Cape, South Africa, and also for a polished piece of rough stichtite from South Africa.

OBITUARY

Major Joe D. Hanna, Jr, G.G., F.G.A. (D.1965), St Louis, Mo., U.S.A., died on 16th December, 1981.

Mr Kenneth Parkinson, F.G.A. (D.1939), Hull, died on 15th December, 1981.

Mr Jack Raymond Shaw, F.G.A. (D.1950), Birmingham, died on 21st March, 1982.

NEWS OF FELLOWS

During the First International Coloured-Gemstones Conference, held from 1st to 3rd February, 1982 in the Bandaranaike Memorial Conference Hall, Colombo, Sri Lanka, the following Fellows spoke or presented papers: Dr Joel Arem on 'The Future Role of Collector Stones', Professor Dr E. Gübelin on 'The significance of mineral inclusions in coloured gemstones', Mr Herbert Gunaratne (chief valuer of the State Gem Corporation) and Mrs Barbara Edrisinghe (president of the Gemmologists Association of Sri Lanka) jointly on 'Sri Lankan Gemstones', and Mr Peter G. Read, C.Eng., on 'Grading Systems for Coloured Stones—their Problems and Remedies'.

Mr Ian C. C. Campbell, F.G.A., has been appointed to be the head of a new coloured-stones laboratory opened by The Jewellery Council of South Africa.

In January 1982 Mr N. H. Harding, F.G.A., was elected Chief Commoner (of the City of London) for 1982 and Chairman of the City Lands and Bridge House Estates Committee. He is First Warden of the Worshipful Company of Gold and Silver Wyre Drawers and in January 1983 he becomes their Master.

H.R.H. The Duke of Gloucester with the Chairman, Mr David Callaghan, at Goldsmiths' Hall, on Monday 5th October 1981, before the opening of the Association's exhibition, 'Fifty Years of Gemmology'.

MEMBERS' MEETINGS

London

On 17th March, 1982, in the Flett Theatre at the Geological Museum, Exhibition Road, South Kensington, Mr E. Alan Jobbins, B.Sc., F.G.A., presented 'New Zealand Jade' by Russell J. Beck, F.G.A. The talk was illustrated by superb colour slides, and almost 200 members attended the meeting.

On 20th April, 1982, in the Central Electricity Generating Board Theatre, Sudbury House, 15 Newgate Street, London E.C.1., Mr Peter G. Read, C.Eng., F.G.A., gave an illustrated talk on 'New Gemmological Instruments, 1980-1982'. A selection of equipment was available for inspection.

Midlands Branch

On 26th March, 1982, at the Society of Friends, Dr Johnson's House, Colmore Circus, Birmingham, Mr Harry Wheeler, F.G.A., gave a talk entitled 'History and growth of the Gemmological Association and overseas visits.'.

On 30th April, 1982, also at the Society of Friends, Mr Peter G. Read, C.Eng., F.G.A., gave a talk on 'More new and exciting gemmological instruments'. Mr Read's talk was followed by the Annual General Meeting at which Mr Douglas Morgan, F.G.A., was elected Chairman and Mrs Janet Leek, was re-elected Secretary.

North-West Branch

On 25th March, 1982, at the Royal Institute, Colquitt Street, Liverpool, Mr A. E. Farn, F.G.A., gave a talk on 'Pearls, cultured pearls and non-nucleated pearls'.

On 5th May, 1982, at Church House, Hanover Street, Liverpool, Mr E. Alan Jobbins, B.Sc., F.G.A., gave an illustrated talk entitled 'The occurrences of nephrite in New Zealand and its fashioning by the Maori and modern man'.

South Yorkshire and District Branch

On 18th March, 1982, at the Sheffield Polytechnic, Pond Street, Sheffield, a practical evening was held, when gem-testing equipment, specimens and books were available for members' use.

COUNCIL MEETING

At the meeting of Council held on Tuesday, 2nd March, 1982, at Saint Dunstan's House, the following were elected to membership:

FELLOWSHIP

Adlestone, Mark I., St Annes-on-Sea. 1981
Advani, Vinod, Bombay, India. 1981
Allyn, Dale F., Eugene, Oreg., U.S.A. 1981
Alvis, Alayne G. D., Ashfield, N.S.W., Australia. 1981
Andre, Andre, London. 1981
Anfield, Jennifer J., Birmingham. 1981
Ashra, Shirish, London. 1981
Ashworth, Marie C., Toronto, Ont., Canada. 1981
Babber, Harish R., Southall. 1981
Bana, Habibullah, San Clemente, Ca, U.S.A. 1981

Barber, Anjali, Nairobi, Kenya. 1981
Bardsley, John N., London. 1981
Batycki, Charlene G., Toronto, Ont., Canada. 1981
Bekesch, Nicholas, Oshawa, Ont., Canada. 1981
Bell, Keith, Ottawa, Ont., Canada. 1981
Boyd, Robert T., Toronto, Ont., Canada. 1981
Breau, Karen L. J., Toronto, Ont., Canada. 1981
Chandrasena, Kalutantrige N. R., Panadura, Sri Lanka. 1975
Chavan, Umesh, Bombay, India. 1981
Chawla, Gulzari, Downsview, Ont., Canada. 1981
Chouiki-Doorn, Jacqueline, Spykenisse, Netherlands. 1981
Clarke, Francis B., Upminster. 1981
Cowing, Michael D., Glen Burnie, Md, U.S.A. 1981
Culpin, Ivor D., Weston-Super-Mare. 1980
Dayasagara, Kalupahana L. D., Colombo, Sri Lanka. 1981
de Hayes, Cecil, London. 1937
Dewar, Penelope S., Stockport. 1981
Ebata, Taiichiro, Takaoka City, Japan. 1981
Endean, Christine H., Auckland, N.Z. 1981
Fell-Smith, Simon A., Brisbane, Qld, Australia. 1981
Francey, Donald T., Christchurch, N.Z. 1981
Fujihara, Shigeru, Tokyo, Japan. 1980
Gasco Galindo, Ignacio, Valencia, Spain. 1981
Gettings, Barbara A., London. 1981
Girling, Matthew D., London. 1981
Grimston, Lady Iona C., London. 1981
Haghani, Victor J., London. 1981
Haniffa, Ahamed I., Urdorf, Switzerland. 1981
Hawker, Robin W. A., Kempton, Tas., Australia. 1981
Henderson, Shirley W. A., Hamilton. 1981
Hogarth, Graeme R., Kendal. 1981
Iwata, Kazuyoshi, Gifu Shi, Japan. 1981
Jones, Jeffrey M., London. 1981
Jones, Maureen D., Wellington, N.Z. 1981
Kelly, John S., Cardiff. 1981
Kelly, Susan M. B., Brisbane, Qld, Australia. 1981
Kettley, Helen M., London. 1981
King, Antoinette E., Rye. 1981
Krstic, Jovanka, Beograd, Yugoslavia. 1981
Lal, Daulet R. B., Bombay, India. 1981
Law, Sheila, London. 1981
Lindlau, Gisela, Aichwald, W. Germany. 1981
Litchfield, Anne-Marie, Northampton. 1981
McAteer, Alice M., London. 1981
McEwan, Robert S., Perth. 1981
McPherson, Heather, Leicester. 1981
Malkani, Sunil C., Bombay, India. 1981
Mansfield, Stephen McL., Burton. 1981
Mariathasan, Loganayagi, Colombo, Sri Lanka. 1981
Marikar Bawa, M. S. N., Colombo, Sri Lanka. 1981
Martin, Paul, Nuneaton. 1981
Martuccio, Celeste, Leamington Spa. 1981
Mater, Louise H., Laren, Netherlands. 1981
Meckoni, Prafulla H., Bombay, India. 1981
Mitchell, Peter J., London. 1957
Molagoda, Tikiri B. P., Kandy, Sri Lanka. 1981
Nakamura, Takeshi, Ishikawa, Japan. 1981

Nelischer-Millar, Anita I. A., Toronto, Ont., Canada. 1981
Pietroboni, Carlo, Forch, Switzerland. 1981
Postma, Renate E., Breda, Netherlands. 1981
Preston, Stephen P., Birmingham. 1981
Protopopoff, Monica, Beecroft, N.S.W., Australia. 1981
Raymond, Robert S., Brentwood. 1981
Rigby, Ian W., Wolverhampton. 1981
Rome, Martin L., London. 1981
Sadler, Philip A., London. 1981
Sastrowidjojo, Hendro, Surabaya, Indonesia. 1981
Shimada, Nobuo, Chiba-Ken, Japan. 1981
Smith, Catharine, Lutterworth. 1981
Sneddon, Katherine E., Hong Kong. 1981
Steward, Annelies, Calgary, Alta, Canada. 1981
Suguro, Norio, Tokyo, Japan. 1981
Taylor, Ernest B., Middlewich. 1981
Trinkl, André A., Johannesburg, S.Africa. 1981
van den Berge, Tania, A. P., St Amandsberg, Belgium. 1981
van der Zwaag, Hemko, Zeist, Netherlands. 1981
Venning, Ronald O., Toronto, Ont., Canada. 1981
Vermaas, Franciska J. M., Rotterdam, Netherlands. 1981
Vietti, Stuart, Penrith. 1981
Vikamsey, Indira J., Bombay, India. 1981
Warrenberg, Jonathan M., Ilkley. 1981
Wescott, H. Marjatta, Tokyo, Japan. 1981
Wijeratne, Chakrawarthige H. R., Colombo, Sri Lanka. 1981
Zanoon, Norfel W., Colombo, Sri Lanka. 1981
Zebrak, Tracy J., Hove. 1981
Zipf, William T., Bethel Park, Pa, U.S.A. 1981
Zwikker, Marijke, Nijmegen, Netherlands. 1981

ORDINARY MEMBERSHIP

Adams, Myra, Huddersfield.
Akasah, Khairuddin Bin, Selangor, Malaysia.
Alexander, Anthony P., Port St Mary.
Amedeo, James R., New York, N.Y., U.S.A.
Andrews, George C., London.
Aoki, Hisashi, Yamanashi, Japan.
Ariizumi, Keiji, Tokyo, Japan.
Attwell, William G., Toronto, Ont., Canada.
Banks, Derek R., Surabaya, Java, Indonesia.
Barnaby, Harold, Lincoln.
Bechtol, Lauren L., Bryan, Ohio, U.S.A.
Benham, Thomas R., Richardson, Tex., U.S.A.
Bhatt, Bharat K., London.
Bowman, Josephine T., London.
Breckenridge, Ian T., St Louis, Mo., U.S.A.
Bruce, H. Elizabeth, Hessle.
Buchan, David R., Nelson, N.Z.
Cardew, Charles J., Thornton Heath.

Carr, William A., New York, N.Y., U.S.A.
Carvey, Robyn, Hong Kong.
Castro, Ronaldo M., Rio de Janeiro, Brazil.
Chan Kai Chung, Marcus, Hong Kong.
Chan, Wing L., Hong Kong.
Chow, Yvonne Y., Hong Kong.
Chung, Penelopie, Hong Kong.
Clark, Margaret E., Royston.
Clark, Patricia M., Hong Kong.
Clarke, Norman V., Blandford Forum.
Cotogno, Romano, Borgomanero, Italy.
Cowell, Kenneth, Mahalarye, Botswana.
Cruickshank, Mary, Nairobi, Kenya.

Daulatani, Shambhu L., Dubai, U.A.E.
Dayawathie, Pinatuwa H., Kurawita, Sri Lanka.
Deeley, Peter J., Birmingham.
de Graaff, Martinus, Cambrils, Spain.
Demoray, Scott B., Grand Rapids, Mich., U.S.A.
Dodhia, Rohit K., Harrow.
Düblin, Theo, Arlesheim, Switzerland.
Duguid, Keith B., Salisbury, Zimbabwe.
Dunga, Kiran, Birmingham.

Edmondes, Eleanor, Bridgend.
Egeland, George S., Quaker Hill, Conn., U.S.A.
Elmer, Bruce L., St Peters, Mo., U.S.A.
Elvidge, Caroline A., Tonbridge.
Evert, Janice A., Townsville, Qld, Australia.

Fache, Frank, Edegem, Belgium.
Fancourt, Mavis J., Lilyfield, N.S.W., Australia.
Fernando, Devapurage P., Moratuwa, Sri Lanka.
Flanders, Katherine J., London.
Fordham, Robert J., Gidea Park
Frame, Olive, Nassau, Bahamas.
Fujimoto, Naoko, Hyogo Pref., Japan.
Fukazawa, Masaho, Shizuoka Pref., Japan.
Fukushima, Yasuo, Nagasaki Pref., Japan.
Fuller, Millie D., Point Richmond, Ca, U.S.A.

Gallagher, Gerard J., New Paltz, N.Y., U.S.A.
Gilbert, Leslie, Chessington.
Giodano, Sandra L., West Chester, Pa, U.S.A.
Gonggryp, Hendrik S., The Hague, Netherlands.
Goss, Alan C., Welwyn Garden City.
Graefin Grote, Isabelle E., London.
Grant, Milton G., Burlington, N.C., U.S.A.
Greatwood, Sheila, Mitcham.
Greig, Edward S., London.
Guinn, Betty R., Houston, Tex., U.S.A.
Gupta, Madan L., Kitwe, Zambia.

Hahmann, Bruno, Guatemala.
Hamachi, Heiji, Fukuoka Pref., Japan.
Hamada, Masatoshi, Shimoniikawa Gun, Japan.
Hamann, W. Richard, Lincoln, Neb., U.S.A.
Hansteen-Fossum, Bjørn, Oslo, Norway.
Hardy, Joanna, London.
Harris, Caroline A., Sutton Coldfield.
Hayashi, Junju, Fukuoka City, Japan.
Hayashi, Toshiko, Fukuoka City, Japan.
Heaton, Sally J., Dorchester.
Hegarty, Kathleen M., New York, N.Y., U.S.A.
Hickel, Stephen M., Sewell, N.J., U.S.A.
Hirokawa, Hideki, Tokyo, Japan.

Horikawa, Yoichi, Tokyo, Japan.
Horne, Allan R., Brighton.
Hurley, Christopher P., Caerphilly.
Ibara, Koichi, Tokyo, Japan.
Ichinose, Chie, Nishiyatsushiro Gun, Japan.
Ikoma, Nobuo, Kobe City, Japan.
Issadeen, Abdul M., Colombo, Sri Lanka.
Ito, Hitoshi, Yamanashi, Japan.
Jacques, Susan M., Santa Ana, Ca, U.S.A.
James, Sarah D., East Horsley.
John, Bryan C., Carmarthen.
Johnson, Mark R., Omaha, Neb., U.S.A.
Jones, Sandra L., New Plymouth, N.Z.
Kan, Michael S., Aruba, Netherlands Antilles.
Kano, Mieko, Fukuoka City, Japan.
Kasai, Reiko, Yamanashi, Japan.
Kearny-Kibble, Mathilde F., Lindfield, Australia.
Kibayashi, Misuzu, Paris, France.
Kirby, Paul A., Southport.
Knight, Barry, Bergen-op-Zoom, Netherlands.
Kobayashi, Shigeki, Ishikawa-Ken, Japan.
Kocziczka, Michael R., Vienna, Austria.
Koh, Yim F., Pahang, W.Malaysia.
Kuruppu, D. Edward, Pelmadulla, Sri Lanka.
Kyellin, Ewa, San Clemente, Ca, U.S.A.
Lane, Richard J., Townsville, Qld, Australia.
Lau, Paul C., London.
Lauer, Deborah J., Springfield, Ill., U.S.A.
Lavender, James G., Uckfield.
Law, Ada, Hong Kong.
Leolini, Franco, Florence, Italy.
Leong, Choy Y., Kuala Lumpur, Malaysia.
Levinson, Michael, Burnaby, B.C., Canada.
Lieberum, William R., Philadelphia, Pa, U.S.A.
Lim, Pauline, Hong Kong.
Lin, Chin S., Taipei, Taiwan.
McGeorge, Robyn L., Eleebana, N.S.W., Australia.
McKendrick, Stewart W., London.
McLeod, John W., Papakura, N.Z.
McPherson, George L., Speers Point, N.S.W., Australia.
Mak, Michael M., Hong Kong.
Marcus, Alec, Jerusalem, Israel.
Marsh, Brian, Keynsham.
Matongo, Winner M., Lusaka, Zambia.
Maynard, Mavis A., Sturminster Newton.
Mellows, Jacqueline M., Bexleyheath.
Millard, David A., New Orleans, La, U.S.A.
Mirza, Kaleem U., Peshawar, Pakistan.
Miyata, Takeshi, Yamanashi, Japan.
Moore, Stephen A., Leicester.
More, Barbara E., Toronto, Ont., Canada.
Morita, Yutaka, Yamanashi Pref., Japan.
Morrissey, William H., Fairfield, Conn., U.S.A.
Motegi, Hiroshi, Yamanashi, Japan.
Motozawa, Masuki, Yamanashi, Japan.
Mughal, Abdul M., Abu Dhabi, U.A.E.
Muraoka, Yasuyuki, Yanai City, Japan.
Nagasaka, Yuji, Kofu City, Japan.
Nakamura, Yasuhisa, Kitakyusho City, Japan.
Nakazawa, Akira, Yamanashi, Japan.
Nanayakkara, Vivian I., Maharagama, Sri Lanka.
Nevill, Amanda J., Hong Kong.
Ninomiya, Mutsuko, Yamanashi, Japan.

Obadia, Ménaché, Antwerp, Belgium.
Ohkawa, Minoru, Tokyo, Japan.
Ohno, Yaeko, Tokyo, Japan.
Okuya, Yukie, Tokyo, Japan.
Pancher, Sukhdev S., Hounslow West.
Patel, Makki, Bombay, India.
Patel, Shirish, London.
Pettersson, June C., Midhurst.
Pharaoh, Martin, Halifax.
Pierre, Robert E., La Jolla, Ca, U.S.A.
Pritchard, Janet M., London.
Quane, David, Bradford.
Rahman, Aman U., Singapore.
Ramamoorthy, Narayanan, Hong Kong.
Reed, Ronald W., Augusta, Ga, U.S.A.
Rerolle, Jean-Claude, London.
Retty, A. T., Singapore.
Richards, James, Saugerties, N.Y., U.S.A.
Sakita, Yoshizo, Sumoto City, Japan.
Saunders, Corinne M., Florida, S.Africa.
Saunders, Geoffrey P., Florida, S.Africa.
Sayers, Ronald J., Dhahran, Saudi Arabia.
Segreti, Adolfo, Reggio Emilia, Italy.
Selby, Gerald, Chorleywood.
Selmon, Simon, Northwood.
Setsuda, Yasuko, Tokyo, Japan.
Shariff, Amir G., Nairobi, Kenya.
Sheen, Alison M., Ossett.
Shimmi, Yoko, Tokyo, Japan.
Shinoka, Keiko, Tokyo, Japan.
Shiraishi, Motoko, Tokyo, Japan.
Shiroya, Yoshie, Funabashi City, Japan.
Siriyananda, J. Subasinghe, Pelmadulla, Sri Lanka.
Silver, Richard, Ft Lauderdale, Fla, U.S.A.
Smith, Michael P., Whitley Bay.
Steinhauer, Mary H., Adelphi, Md, U.S.A.
Stevens, Julie M., London.
Sulaiman, Zahari Z., Birmingham.
Suzuki, Setsuko, Yamanashi, Japan.
Tachikawa, Toshiaki, Yamanashi, Japan.
Tagawa, Koji, Tokyo, Japan.
Tanaka, Hideaki, Nagasaki City, Japan.
Tangkathach, Siriwan, Bangkok, Thailand.
Tanuwidjaja, D., Jakarta-Timur, Indonesia.
Theophilis, Maria U., London.
Toda, Taketoshi, Yokohama City, Japan.
Tsuchiya, Manabu, Yamanashi, Japan.
Tsunoda, Koki, Yamanashi, Japan.
Turk, Noriko, Hong Kong.
Turkel, Howard, London.
Turner, Starla E., Hillsborough, Ca, U.S.A.
Uesaka, Noriko, Osaka, Japan.
Uetake, Yasunao, Kashiwa-shi, Japan.
van Doren, Jean-Paul, Bognor Regis.
Walker, Mary C., Toronto, Ont., Canada.
Wallach, Edward M., New York, N.Y., U.S.A.
Warriner, Elizabeth R., Solihull.
Watanabe, Yuichi, Hokkaido, Japan.
Waterhouse, Winifred C., Auckland, N.Z.
Weerasuria, Ajith H., St Albans.
Weir, Juliet C., Dublin, Ireland.
White, Gerald A., Fareham.
Wolfe, Brian W., Calgary, Alta, Canada.
Yamaguchi, Maki, Fukuoka City, Japan.
Yamazaki, Hideki, Shimizu City, Japan.
Yanagisawa, Natsuko, Yamanashi, Japan.
Yasunaga, Jun, Fukuoka City, Japan.
Younger, June E., Bangkok, Thailand.
Yung, Joanna C., Hong Kong.

G.I.A.—INTERNATIONAL GEMOLOGICAL SYMPOSIUM

The First International Gemological Symposium organized by the Gemological Institute of America as part of its 50th Anniversary celebrations was held at the Century Plaza Hotel, Los Angeles, from 12th to 15th February, 1982. About 700 persons attended, many of them from outside the U.S.A.

The G.I.A. President, Mr Richard T. Liddicoat, Jr, Hon. F.G.A., started with a talk entitled 'The Development of Gemological Training in America by the G.I.A.', which was an historical survey of the G.I.A.'s foundation by Mr Robert M. Shipley, F.G.A., in 1931 and its growth and activities to the present time. Mr Shipley had obtained his F.G.A. in London in 1929. In the last session, Mr Harry Wheeler, F.G.A., gave a talk on the 'History of Gemmology in the U.K.' This covered the period from 1908 to the present day.

In addition there were over sixty talks which covered:

Diamonds—origin, sources and properties, marketing and grading.
Coloured Stones—properties, sources, supplies and marketing.
Synthetics and Simulants—growth and properties.
Pearls—sources, supplies and properties.
Selling Gemmology to the public.
Reports on Gem and Gem Occurrences.
Inclusions.
Advances in Gemmology.
Gemmology and the Market.
An Appreciation of Gems.

Although a very wide coverage was obtained by having so many talks and speakers, there was the problem of deciding which session to attend, because at times there were four different talks being given at the same time in different rooms. There was also an audio-visual programme including films by De Beers and Multimedia and talks on *Gem Carving in Idar-Oberstein, Opal Mining in Australia,* and *Colour Art and Fashion in Gemmology.*

The social programme was first class, starting with the Saturday evening when a Gala Evening with buffet supper was held in the Hotel. On the Sunday there was 'Open House' at the G.I.A. Headquarters in Santa Monica, with a complete tour of the educational facilities, the Bookstore and Instruments Factory, and a buffet luncheon in the grounds. On Monday evening there was a dinner/dance at the Los Angeles Museum of Natural History, with the opportunity of seeing some impressive mineral specimens and the superb cut-stone collection in the F. C. Hixon Gem Vault.

The Symposium was an excellent way to celebrate the 50th Anniversary and it is intended to hold further events every second or third year.

A copy of the *Proceedings* of the Symposium, containing a copy of the talks that were presented, is available from the G.I.A. Bookstore, 1735, Stewart Street, Santa Monica, California 90404, U.S.A., price (US)$43.95 plus $3.25 postage.

IRISH BRANCH

Mr Gabriel O'Grady, F.G.A., of 7 Rathfarnham Road, Terenure, Dublin 6, is desirous of forming a branch of the Association in Ireland. Will any member who is interested please communicate with him direct.

DATE FOR YOUR DIARY

The Reunion of Members and Presentation of Awards is to be held on Monday, 15th November, 1982, at Goldsmiths' Hall, Foster Lane, London E.C.2.

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The test report on the Krüss ER602 refractometer by Peter Read (J.Gemm., 1981, XVII (5), 321-4) contained the manufacturer's claim that the *'new "Riplus Kleber" contact fluid is a viscous non-toxic brown paste'*. Recently it has been revealed that the Kleber material consists of a Cargille high refractive index 'melt' which contains arsenic tribromide, a toxic and corrosive chemical. Anyone using the Kleber contact fluid is therefore advised to avoid contact with it and to remove any material on the body immediately by thorough scrubbing with water. The greatest danger is from ingestion, and the possibility of this is greatly reduced by avoiding eating and smoking when using the material.

JOURNAL OF GEMMOLOGY AND *GEMMOLOGIST*—BACK NUMBERS

A member has a complete set of the *Journal of Gemmology* from Volume 1 to date (some are bound) and a set of the *Gemmologist* from 1949 to 1963 (April 1962 missing). Anyone interested in purchasing these should write to Box 82, G.A. of G.B., Saint Dunstan's House, Carey Lane, London, EC2V 8AB.

GEM TESTING EQUIPMENT

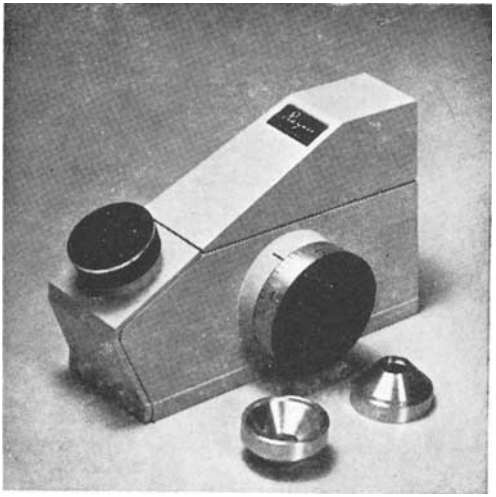

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Historical Note

The Gemmological Association of Great Britain was originally founded in 1908 as the Education Committee of the National Association of Goldsmiths and reconstituted in 1931 as the Gemmological Association. Its name was extended to Gemmological Association of Great Britain in 1938, and finally in 1944 it was incorporated in that name under the Companies Acts as a company limited by guarantee (registered in England, no. 433063).

Affiliated Associations are the Gemmological Association of Australia, the Canadian Gemmological Association, the Gem and Mineral Society of Zimbabwe and the Gemmological Association of Hong Kong.

The *Journal of Gemmology* was first published by the Association in 1947. It is a quarterly, published in January, April, July, and October each year, and is issued free to Fellows and Members of the Association. Opinions expressed by authors are not necessarily endorsed by the Association.

Notes for Contributors

The Editor is glad to consider original articles shedding new light on subjects of gemmological interest for publication in the *Journal.* Articles are not normally accepted which have already been published elsewhere in English, and an article is accepted only on the understanding that (1) full information as to any previous publication (whether in English or another language) has been given, (2) it is not under consideration for publication elsewhere and (3) it will not be published elsewhere without the consent of the Editor.

Articles published are paid for, and any number of prints of individual articles may be supplied to authors provided application is made on or before approval of proofs. Applications for prints should be made to the Secretary of the Association—not to the Editor—and current rates of payment for articles and terms for the supply of prints may be obtained also from the Secretary.

Although not a mandatory requirement, it is most helpful if articles are typed (together with a carbon copy) in double spacing on one side of the paper, with good margins at sides, top and foot of each page. Articles may be of any length, but it should be borne in mind that long articles are more difficult to fit in than short ones: in practice, an article of much more than 10 000 words (unless capable of division into parts or of exceptional importance) is unlikely to be acceptable, while a short note of 400 or 500 words may achieve early publication.

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THE JOURNAL OF GEMMOLOGY

and

PROCEEDINGS OF THE GEMMOLOGICAL ASSOCIATION OF GREAT BRITAIN

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AND PROCEEDINGS OF THE GEMMOLOGICAL ASSOCIATION OF GREAT BRITAIN
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GEM QUALITY GAHNITE FROM NIGERIA

By BRIAN JACKSON, F.G.A.
Department of Geology, Royal Scottish Museum, Edinburgh.

PREAMBLE

Natural blue spinels are reasonably common, gahnospinels comparatively rare and gahnite (zinc spinels) of gem quality even rarer. It was not surprising, therefore, that, when the Royal Scottish Museum was presented with several, blue to blue-green, gem-quality octahedral crystals of gahnite, of cuttable size (maximum size approximately 1 cm in diameter), enquiries were made to find out if cut stones were available. Regrettably all the cut stones to date (July 1981) had already been sold to a German company and no more would become available until later in the year. All the work therefore was done on the available rough material, with or without polished faces.

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OCCURRENCE

The gem quality blue octahedral crystals of gahnite occur in a complex pegmatite 3.2 km NNW. of Jemaa (locally known as Gidan Wiya), Nigeria. The pegmatite, which is 18 metres wide, strikes north-south and cuts dark hornblende-biotite streaky gneiss. The extent of the pegmatite, which forms a distinct very heavily forested ridge, is difficult to determine but is in excess of 91 metres. Mineralogically the pegmatite consists of quartz, muscovite and albite with accessory tantalite and schorl tourmaline. Other pegmatites in the Jemaa area have produced dark green opaque gahnite.[1]

Previously reported occurrences of gahnite include Sweden at Falun,[2] Western Australia,[2] New Zealand,[2] Scotland,[2] Portugal,[2] Bavaria at Bodenmais,[3] Brazil,[3] Canada,[4] Spain,[4] Italy,[4] Finland,[4] India,[4] Madagascar[4] and at various localities in the U.S.A.[3] The majority of these localities do not produce gahnite of suitable gem quality. The only references to gem-quality gahnite are transparent material of very good green colour (similar to tourmaline) from Brazil[3] and nearly pure gahnite, green in colour and transparent recently found and cut as a gemstone,[5] from Madagascar.[6]

At Jemaa the gahnite is moderately abundant and of gem quality, but it is not known if there is sufficient suitable material available to take this gemstone out of the collectors item category.

PROPERTIES

Gahnite is a member of the spinel series and there is an isomorphous series from spinel ($MgAl_2O_4$) to gahnite ($ZnAl_2O_4$) as indicated by the gahnospinels [$(ZnMg)Al_2O_4$]. Similarly an isomorphous series exists from spinel to hercynite ($FeAl_2O_4$) as indicated by the black opaque pleonaste or ceylonite [$(MgFe)Al_2O_4$] which is sometimes cut for use in mourning jewellery.

The blue gahnite was analysed, using atomic absorption techniques, by Mr Richard A. Batchelor, of the Department of Geology, St Andrews University, and corrected for an Al_2O_3 component identified by x-ray diffraction, which from the d spacings and chemistry is a good fit for αAl_2O_3, i.e. corundum. The analysis is reproduced below in Table 1.

In addition to the isomorphous replacement of magnesium by zinc the Nigerian gahnite also has 4% ferrous iron, for magnesium,

TABLE 1

		corrected for calculated Al_2O_3 inclusion
SiO_2	0.72	0.77
Al_2O_3	59.10	56.00
FeO	3.58	3.85
MnO	0.08	0.09
MgO	0.12	0.13
CaO	0.10	<0.10
ZnO	36.68	39.44
SnO_2	<0.04	<0.04
Total	100.42	100.42

TABLE 2

Gahnite[5] *(green stone)*
585 nm weak
553 nm moderately strong
509 nm moderately strong
460 nm strong
433 nm moderately strong

Gahnite (Nigeria) (blue stone)
700–677.5 nm strong
677.5–660 nm weak
645–617.5 nm moderately strong
605–585 nm moderately strong
580–560 nm weak
556 nm moderately strong
554–553 nm weak
480–465 nm weak
465–457.5 nm moderately strong
433–400 nm weak becoming moderately strong

Spinel[6] *(blue stone)*
632 nm weak to moderately strong
592 nm weak to moderately strong
555 nm weak to moderately strong
480 nm weak to moderately strong
459 nm weak to moderately strong

Gahnospinel[7] *(blue stone)*
632 nm moderate
592 nm weak
577 nm weak
557 nm moderately weak
552 nm moderately weak
508 nm very weak
480 nm moderately strong
459 nm strong
443 nm very weak
433 nm very weak

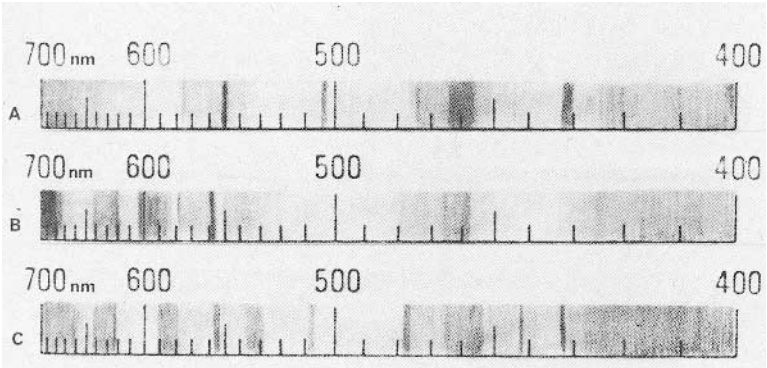

FIG. 1. A. Gahnite.[8]—B. Gahnite from Jemaa, Nigeria (blue).—C. Spinel (blue).[6]
(Crown Copyright Reserved)

isomorphous replacement. It is this iron which is responsible for the blue colour of the stones and a typical, rich looking, ferrous iron spectrum was obtained on an Eickhorst cold-light spectroscope unit. This absorption was very similar to that of blue spinel[6] and gahnospinel[7] rather than that of gahnite[8] described by Liddicoat (Figure 1 and Table 2).

The Nigerian gahnite appears to lack any moderate to strong absorption centred around 433 nm. It also has two sharp well defined fine lines of non-absorption between areas of mixed absorption intensities. These are at 580 nm and 555 nm and could possibly be mistaken for weak emission lines. Further the Nigerian gahnite has absorption bands in the red-orange-yellow range (700 nm–570 nm) similar to that of spinel and gahnospinel but not previously described for gahnite.

The refractive index, determined on a Rayner Dialdex refractometer, using sodium light, was between 1.793 and 1.794.

The specific gravity, measured on a Berman density torsion balance using as pure and homogeneous mineral fragments as possible, and within the 10–25 mg range for greatest accuracy, was found to lie within the range 4.400 to 4.589. The specimens with the greener hue tending to be at the lower end of the range (Figure 2).

There was no fluorescence under long-wave and short-wave ultraviolet light, and no change under the Chelsea colour filter when the stones were illuminated with a quartz incandescent lamp.

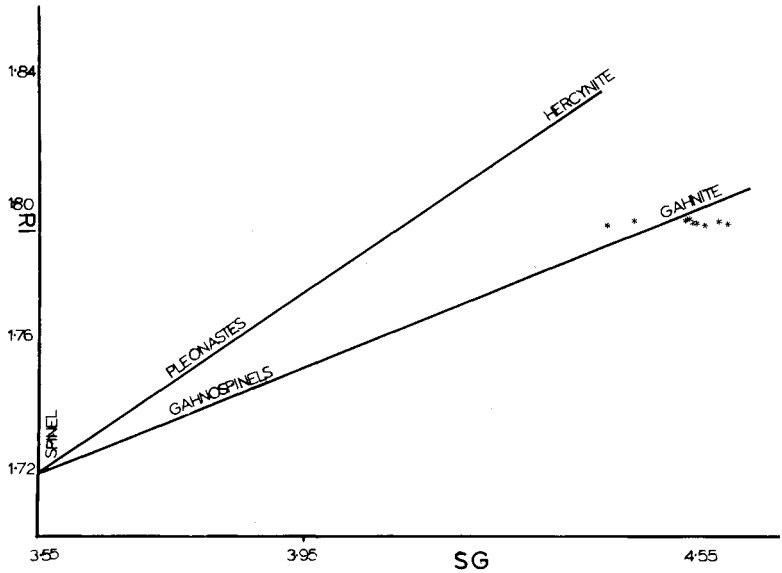

FIG. 2. RI/SG plots of gahnite grains on a spinel-gahnite-hercynite framework. *(Crown Copyright Reserved)*

When illuminated with a tungsten incandescent lamp, the stones showed a marked red coloration.

On exposure to x-rays for 1 hour 20 minutes there was no permanent or temporary colour change. However when the gahnite was heated, in an oxidizing environment, there was a distinct and permanent colour change. The exact point of colour change was not seen as stones retained their colour up to the point of their glowing red hot, at which point and thereafter the incandescence masked any natural body colour. Stones kept at 1000 °C for 1 hour showed, on cooling, a colour change from blue to blue-green, while stones heated to 1400 °C turned a dark olive green. No rupturing of the crystals occurred during heating, even though they were moderately included and flawed. It is postulated that the colour change is due to some of the ferrous iron being oxidized to ferric iron, which normally gives a yellow colour. This in conjunction with the ferrous (blue colour) iron gives an over-all green effect.

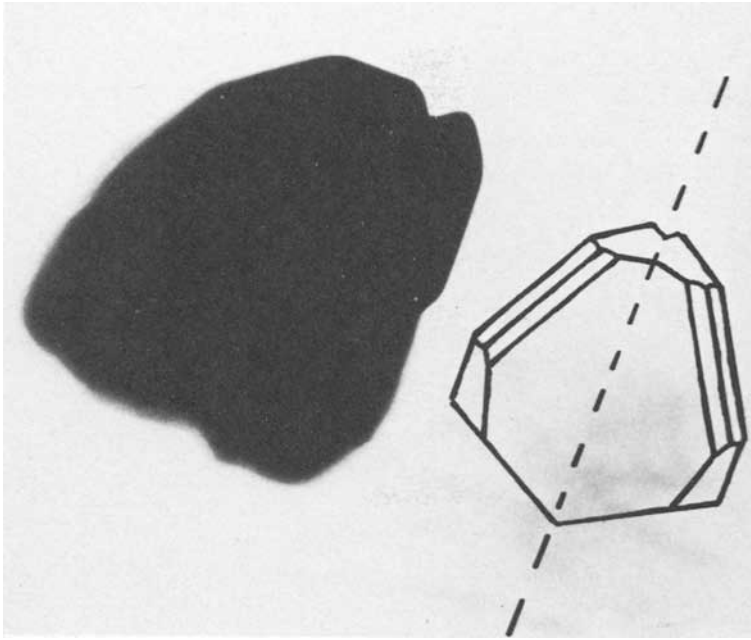

FIG. 3. Heart-shaped twin crystal of columbite with the ideal form sketched alongside. × 600.

INCLUSIONS

The majority of the gahnite crystals are rich in inclusions. These were studied using a Leitz Dialux polarizing microscope and a Vickers M41 microscope with camera attachment and automatic exposure unit. Crystals were immersed in methylene iodide (RI 1.742) to facilitate the study. Most crystals had flaws and cracks and these were in some cases filled with reddish-brown or yellow-brown films of secondary iron oxides. Other inclusions are described hereunder.

1. *Black opaque plates and tabular prismatic crystals.*

A large grain of this mineral which was near the surface of a gahnite crystal was removed and proved on microprobe analysis to be columbite, not previously described as an inclusion in gahnite.[9] The common heart-shaped twins of columbite were also identified (Figure 3).

Reddish anhedral grains, with a refractive index greater than that of the gahnite (Becke line test), showing pleochroism and

extinction under crossed nicols, are thought to be thin sections of columbite.

2. *Very dark red to reddish-brown sub-translucent anhedral to sub-euhedral grains with hexagonal markings.*

These grains have a higher refractive index than the host gahnite (Becke line test) but show no pleochroism and remain dark between crossed nicols (Figure 4). On this basis they are thought to be haematite.

3. *Transparent hexagonal, prismatic, doubly terminated, crystals.*

These crystals show a random orientation and distribution throughout the gahnite. They show parallel extinction and interference colours ranging from middle 1st order to high 2nd order. Their refractive index is less than that of the host gahnite (Becke line test) (Figure 5). On this basis they are thought to be either apatite, quartz or beryl. A gahnite crystal was broken to reveal a colourless inclusion of the type described. This small fragment was identified by x-ray diffraction as beryl. This does not mean that the other alternatives proposed are not present in the gahnite.

4. *Small prismatic transparent colourless to pale yellow, sometime greenish or with pale green halo, crystals, most of which are doubly terminated.*

The refractive index of these crystals is greater than that of the gahnite (Becke line test). Most crystals show tension cracks radiating from them, but these are difficult to see in many cases except under crossed nicols. Extinction is parallel to the prismatic faces and crystals show vivid interference colours (Figure 6). On this basis they are thought to be zircons.

5. *Transparent thin hexagonal platy crystals with cleavage traces parallel to the planar surface.*

These crystals have a refractive index less than that of the host gahnite (Becke line test) and show interference colours from 1st to high second order. Sections parallel to the cleavage gave 1st order colours. Extinction is parallel to the cleavage trace. Where one

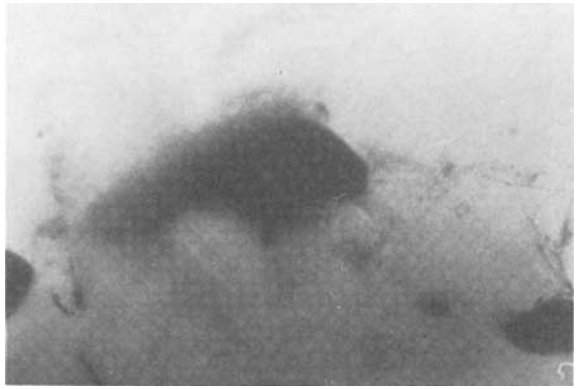

FIG. 4. Haematite inclusion. *(Crown Copyright Reserved)*

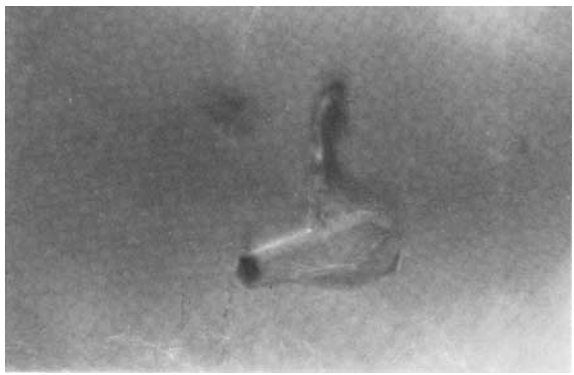

FIG. 5. Colourless hexagonal crystal. × 500. *(Crown Copyright Reserved)*

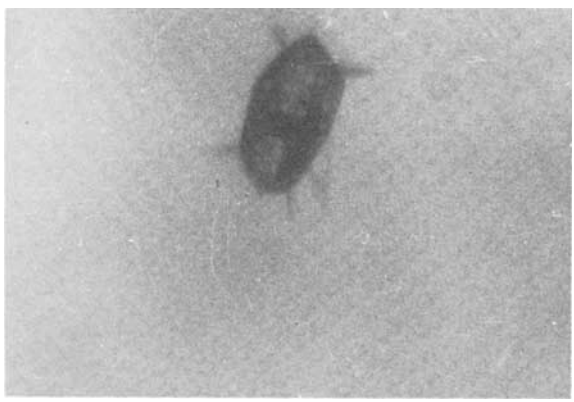

FIG. 6. Prismatic, doubly terminated, crystal with tension haloes. × 900. *(Crown Copyright Reserved)*

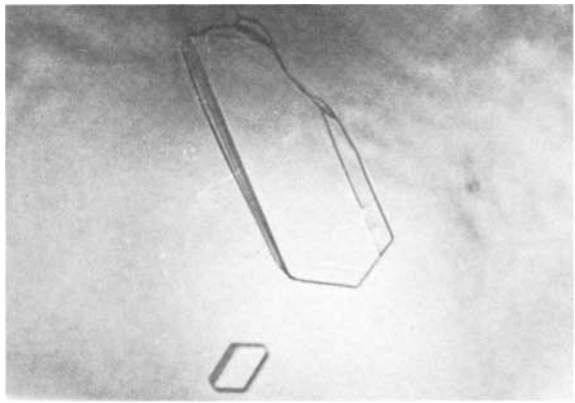

FIG. 7. Mica crystals. × 800. *(Crown Copyright Reserved)*

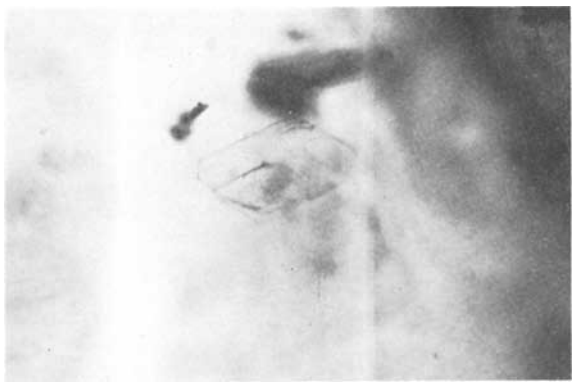

FIG. 8. Mica crystals. × 200. *(Crown Copyright Reserved)*

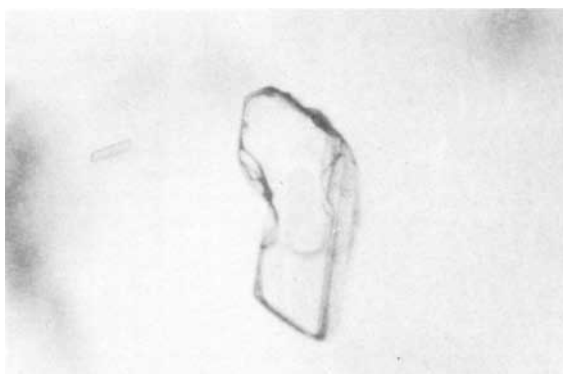

FIG. 9. Mica crystals. × 500. *(Crown Copyright Reserved)*

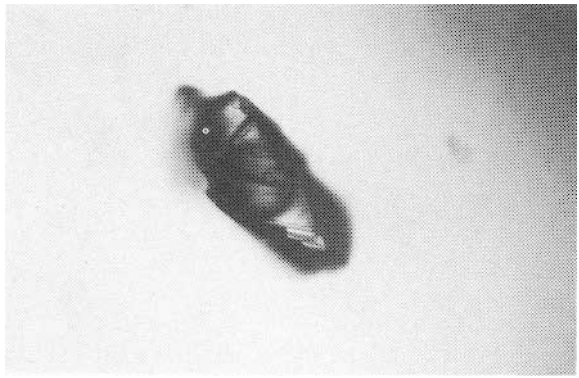

FIG. 10. Two-phase inclusion. × 500. *(Crown Copyright Reserved)*

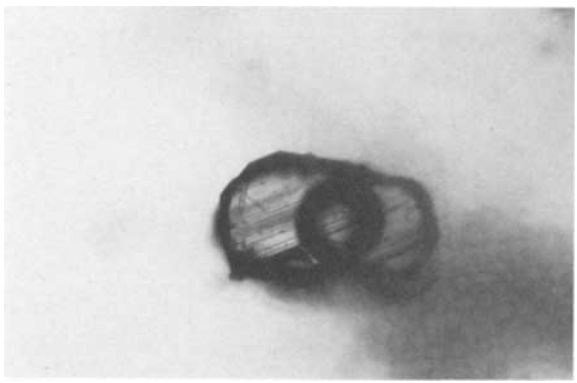

FIG. 11. Two-phase inclusion. × 500. *(Crown Copyright Reserved)*

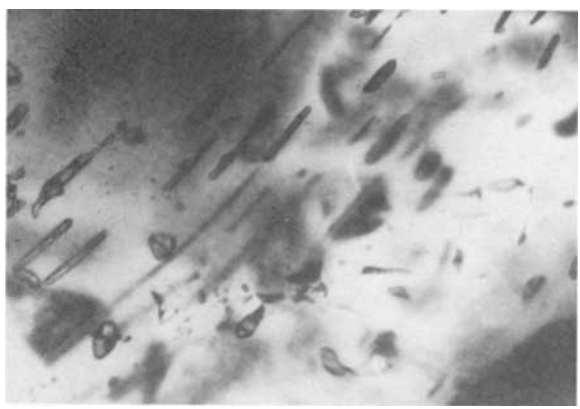

FIG. 12. Elongated two-phase inclusions. × 450. *(Crown Copyright Reserved)*

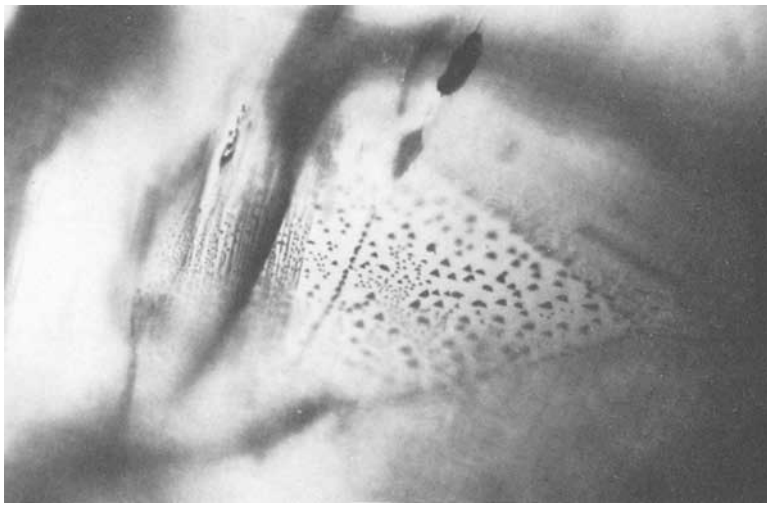

FIG. 13. Gahnite-gahnite interface markings. ×600. *(Crown Copyright Reserved)*

grain reached the surface of a polished face a negative biaxial interference figure was obtained. On this basis they are thought to be mica (Figures 7, 8, 9).

6. *Negative euhedral crystals with two-phase inclusions, liquid and gas.*

These two-phase inclusions are very common in most crystals. The forms of the negative crystals are distorted octahedra; and in most cases the distortion is quite extreme (Figures 10 & 11). In cases of exceptional distortion they give the impression of liquid feathers with two-phase inclusions (Figure 12).

Other negative inclusions, not showing two phases, are also abundant. These either occur as large octahedra, or arguably dodecahedra, randomly distributed within the gahnite crystals or else as small groups or swarms, sometimes with preferential alignment to the crystallographic structure of the gahnite. Many of these octahedra are quite dark and may in fact not be negative crystals but octahedra of hercynite.

Gahnite crystals are also found as inclusions within the gahnite and these sometimes showed black triangular markings at the interface with the host (Figure 13). These may represent a separate mineral phase.

7. As stated earlier corundum was identified as a phase in powdered gahnite during x-ray diffraction. It was not possible, however, even tentatively to identify corundum in the specimens examined. No hexagonal inclusions, either tabular or prismatic, showed a relief only slightly less than that of the gahnite, nor was there any parting or twinning visible.

CONCLUSION

Dependant upon the availability of suitable gem quality material these Nigerian gahnites could represent a significant addition to the gem market. Although they could well match sapphire in appearance, their physical properties, spectra and inclusions are so distinctive that there should be no possibility of mistaken identity if tests are carried out.

ACKNOWLEDGEMENTS

I am most grateful to Mrs Judith Kinnaird, of the Geology Department, University of St Andrews, for providing the specimens on which the work was done and for the description of the gahnite occurrence.

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SILLIMANITE CAT'S-EYES FROM KANGAYAM, MADRAS, INDIA

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INTRODUCTION

Some months ago four cabochon-cut greyish green stones with a fair cat's-eye effect were sent in for identification to the Netherlands Gem Laboratory (NEL), which is housed in the National Museum of Geology and Mineralogy in Leiden. They were said to originate from Kangayam, Madras, India, and were sold as 'apatite cat's-eyes'.

Although it would have been of interest to report on these stones, as they were found to be sillimanite cat's-eyes, it was not possible to do so as they could not be kept for careful examination. The same applied to two other stones with the same appearance and properties, which were much better cut and sent in by another gem dealer in the same period.

However, another seven stones became available for investigation through the co-operation of Mr H. J. Korevaar, F.G.A., the gemmologist who provided us in the past with

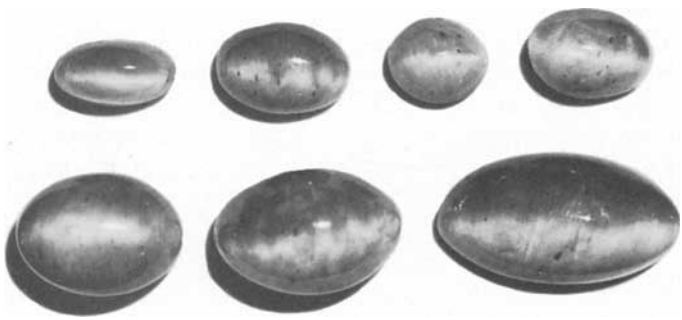

FIG. 1. The seven sillimanite cat's-eyes. 2×

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kornerupine cat's-eyes and cordierite cat's-eyes (Korevaar & Zwaan 1977; Zwaan & Korevaar 1977). He bought the parcel also as 'apatite cat's-eyes' in Madras and was told that the stones were found in Kangayam, 'some 200 miles from Madras in south-westerly direction'.

TABLE 1
Properties of seven cabochon-cut sillimanite cat's-eyes

Number	*Weight in ct*	*Size in mm*	*D (measured)*
1	11.42	14.8 × 10.0 × 9.1	3.210
2	10.77	19.0 × 10.4 × 6.7	3.219
3	9.43	13.0 × 9.7 × 8.7	3.224
4	3.92	10.6 × 7.3 × 5.3	3.226
5	2.95	9.8 × 7.0 × 5.5	3.226
6	2.66	9.7 × 5.3 × 5.8	3.221
7	2.04	7.8 × 6.7 × 5.2	3.196

PROPERTIES

The properties of the stones are given in Table 1. Stone No. 2 is stored in the collection of the above mentioned museum and is officially registered with a number prefixed by 'RGM'. The specimens No. 5, 6 and 7 belong to the collection of the Netherlands Gem Laboratory (NEL); the remaining stones were kindly loaned for examination only.

All specimens have a greyish green colour and a whitish cat's-eye, which is not very sharp (see Figure 1). As these stones are almost opaque, neither their pleochroism nor their optical character could be observed. Some vague absorption bands occur in the blue and violet parts of the spectrum, but they are not of any diagnostic value.

Being cat's-eyes, the stones are cabochon cut. Their refractive indices were therefore measured by using the 'distant vision' method. All stones gave readings near 1.66, which is the mean value for sillimanite.

The density of the specimens was measured by using a hydrostatic balance and ethylene dibromide as an immersion liquid. This property varied from 3.196 to 3.226, with an average of 3.217, which is extremely low for sillimanite.

To obtain a definite identification, x-ray powder photographs of five stones were made by using Fe-radiation and a Debye-Scherrer camera of 114.6 mm. All photographs gave a pattern of diffraction lines, characteristic for sillimanite. The x-ray data of photograph RGM 202 430, taken from cat's-eye RGM 151 867, are given in Table 2.

TABLE 2
X-ray powder diffraction data for sillimanite cat's-eye No. 2 (RGM 151 867).

hkl	*d(obs.)*	*I*	*hkl*	*d(obs)*	*I*
110	5.34	6	332	1.517	7
101	4.56	½	004	1.440	5
200	3.73	5	250	1.419	½
120	3.41	9	520	1.393	½
210	3.35	10	124	1.328	3
002	2.88	6	350	1.307	1
220	2.67	7	252	1.273	5
112	2.53	8	610	1.228	4
130	2.42	5	260	1.213	1
202	2.28	4	532	1.178	1
122	2.20	9	404	1.141	1
230	2.11	5	244	1.102	1
400	1.865	4	542	1.094	2
312	1.832	3	172	1.016	3
330	1.786	½	254	1.012	3
240	1.705	3	370	1.004	4
420	1.679	4	462	0.992	3
042	1.595	6	730	0.986	3
402	1.567	3	444	0.982	3

INCLUSIONS

The cat's-eye effect is most probably due to a fibrous structure. It is not likely that oriented needle-shaped inclusions cause this chatoyancy. Experiments to analyse these inclusions by x-rays only indicated the sillimanite itself. Perhaps the low density of the stones can be ascribed to this fibrous structure.

FIG. 2. Magnetite and haematite included in sillimanite cat's-eye No. 2 (RGM 151 867). 45 ×

FIG. 3. Magnetite and haematite in sillimanite cat's-eye No. 1. 45 ×

Distinct inclusions occur in all the stones and can be seen with the naked eye. They consist of black grains and elongated shapes with a high metallic lustre. The grains resemble the black spots which are characteristic for nephrite from the Lake Baikal district of eastern Siberia. These grains were found to be magnetite by means of x-ray powder photograph RGM 202 500, taken from inclusions in specimen No. 2 (RGM 151 867). The elongated flakes are mainly built up by haematite, according to x-ray powder photograph RGM 202 501, taken from inclusions in sillimanite cat's-eye No. 5. Both iron minerals are intergrown; Figures 2 and 3 illustrate them in specimens No. 2 and 1 respectively.

CONCLUDING REMARKS

Cat's-eyes of sillimanite are often described in the literature. Most gemmological handbooks mention this type of cat's-eye, but it is always considered to belong to the category of unusual stones. Bank *et al.* (1978) describe two specimens from a parcel of cabochon cut stones from Sri Lanka.

The author bought a sillimanite cat's-eye of 1.11 carats from a gem dealer in Mount Lavinia, Sri Lanka, in December 1958. So, this type of cat's-eye is occasionally seen on the market.

As a relatively large number of stones were identified in Leiden only a few months ago, it may be expected that in the near future sillimanite cat's-eyes will come on the market in large quantities.

The stones so far examined, with the exception of the two mentioned above, are badly cut. If cutting can be improved, a type of cat's-eye can be introduced which can be considered as a real enrichment of gemmology.

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THE FRUITS OF THIRTY YEARS OF JAPANESE GEMMOLOGY—A REPORT ON THE AKIRA CHIKAYAMA GEM LABORATORY IN TOKYO

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The XVIIIth International Gemmological Conference was held in November 1981 in Japan.* In view of this, and since one of its hosts, Professor Akira Chikayama, F.G.A., C.G., was then currently celebrating his thirtieth year in gemmology, perhaps it is an appropriate time to give a brief account of both Professor Chikayama's career, inextricably interwoven as it is with the development of gemmological science in Japan, and of the fine gemstone collection at the Akira Chikayama Gem Laboratory (A.C.G.L.) here in Tokyo.

Professor Chikayama began studying gemmology in 1951 and during the 1960s taught the science at the Yamanashi Prefectural Lapidary Research Institute at Yamanashi National University in Kofu, Japan's stone cutting centre. He obtained the G.A.'s Diploma in Gemmology and was elected a Fellow in 1966. The following year he began lecturing in Tokyo at the All Japan Jewellers Association, which in 1969 was incorporated into the new Gemmological Association of All Japan. As Director-General of the G.A.A.J., Professor Chikayama supervised its education and research programs as well as designing all of its gemmological instrumentation himself. He is the sole recipient of a government-authorized engineering consultant's licence in gem technology.

The A.C.G.L. began operations in 1979 and was founded to promote a broader and higher education amongst gemmologists. The symbol chosen as its mark was a Japanese twinned quartz crystal for which Kofu, Professor Chikayama's birthplace, is famous. The A.C.G.L.'s sister organization, the Gemmologists' Society of Japan now has a membership of about six hundred.

Professor Chikayama has travelled to almost all of the world's major gem localities, and to many of them more than once. Obversely, when he is in Tokyo he receives many visits from

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foreign gemmologists and gem dealers. His books on gems, gem identification and gem cutting number over twenty and are the staple fare of the Japanese gemmologist.

When I arrived here from England in 1980, I was introduced to Professor Chikayama by my good friend, Mr Takayasu Imai, F.G.A., President of the Japan Diamond Exchange, and have subsequently several times been privileged to view his personal collection, the bulk of which constitutes the study collection at the A.C.G.L. It is, by all accounts, the most extensive gemstone collection in Japan, outdoing even the museums. There are approximately 10 000 stones in all—4000 cut gems and 6000 rough specimens. The cut stones are arranged by species as well as by locality and the rough in general by locality alone. The majority of stones have been acquired abroad, often at source, and brought or sent back to Japan. Really large stones are accordingly few, but the variety of localities within each species is truly remarkable.

To mention but a few, there are good collections of cut corundum (including padparadscha), beryl (including Australian emerald), spinel (including gahnospinels), jadeite (in all colours—several visits to Burma), tourmaline (many localities besides Brazil), cat's-eye stones (as a separate collection) and synthetics (Russian, American, Japanese, Gilson in the main—including fancy-coloured cubic zirconia, rutile and YAG). Amongst the extensive rare stone collection I found some interesting 'moldavite' cabochons from both Indonesia and Japan. There are cut stone collections (by locality) from Brazil, Sri Lanka, Burma, Taiwan, Korea and Japan. Needless to say, both in quantity and quality the cut and rough Japanese gemstone collections are unique and include fine jadeite, large topaz, obsidian and both rhodonite and rhodochrosite. By virtue of the nature of the gem minerals occurring in Japan most of the cut material, however, is in cabochon form.

In addition to Japan there are collections of rough (only specimens of known locality) from the U.S.A., Mexico, Colombia (including trapiche emeralds), Brazil, Peru (including palygorskite), Tanzania, Kenya, Malagasy, the rest of Africa (including some splendid Nigerian sunstone), Europe, the U.S.S.R., India, Sri Lanka, Burma, Thailand, Taiwan, South Korea (including large sceptre-shaped amethyst) and Australia.

As one might expect, all shapes and all shades of colour are represented in both the pearl and coral collections. Both are built around Japanese specimens but also include material from various other localities. There is an unusual collection of both cut and uncut glass which includes superb Japanese 'tombodama' beads.

An extensive collection of euhedral crystals of all types must be of tremendous practical value in the teaching of crystallography and an equally complete store of cut stones containing typical inclusions is kept for microscope work. A large series of inclusion photos (taken by the Professor himself) aids in this sphere of study and research.

In his time as a gemmologist Professor Chikayama has designed and developed a gemmological microscope (Olympus J.M.) as well as a brand-new halogen-illuminated one; the Topcon refractometer and a new internally-illuminated one (light-emitting diode type); a spectroscope; the Multispec ultraviolet light source; the Topcon portable diamond proportionscope; the Marumo hydrostatic balance; a diamond conductometer; a portable light source (primarily for diamond grading); a hot-point tester (for use with the microscope); and, of late, a diamond price computer program. Much of this technical development has taken place at the A.C.G.L. recently.

To round off this guided tour of the Gem Laboratory I should make mention of the comprehensive gemstone book library (over 1000 volumes in many languages), the journal collection, a vast gem localities slide library and (rather unusual) a sizeable collection of gemstone and mineral stamps from all over the world.

The over-all impression I wish to convey is one of scope—the scope of the collection in particular, but also the scope of gemmological facilities in general. As always in Japan, everything is impeccably organized, and the visitor is welcomed with the utmost courtesy. It may have taken thirty years to create such a well-equipped institution but it may well be (if it is not already) in the vanguard of world gemmology before another thirty years have passed.

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ENERGY DISPERSIVE X-RAY SPECTROMETRY: A NON-DESTRUCTIVE TOOL IN GEMMOLOGY

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SUMMARY

Energy dispersive x-ray spectrometry is a fast and reliable, in a true sense of the word non-destructive, analysing technique for all elements from sodium to uranium. A qualitative chemical determination of gemstones is easily obtainable; in specific cases the discrimination of natural and synthetic material is possible.

Up to ten years ago, x-ray fluorescence analysis was a wavelength dispersive technique. Its use in gemmology remained limited for basically two reasons: purchase and maintainance costs of x-ray equipment are relatively high, and its application may be somewhat restricted since the strength of the exciting primary x-ray source may damage gem materials (Bank, 1980). Colours of gemstones eventually change reversibly, or nearly irreversibly during short exposure times.

Since the discovery of x-rays by Wilhelm Röntgen in 1895, many applications of this short-wavelength-radiation have been developed—not only medical ones, but methods for crystal lattice determination (x-ray diffractometry *sensu lato*), and of spectroscopy (x-ray fluorescence analysis, XFA or XRF) as well.

X-rays are described in terms of wavelength (λ, Å), or of energy (E, eV), both related by $\lambda = 12400/E$. Thus, two principally different spectroscopic applications have to be distinguished, i.e. wavelength dispersive (WDS)—and energy dispersive (EDS)—XRF. Moseley proved as early as 1913 that atomic number Z of a chemical element, and the wavelength (or energy) of its x-ray spectrum is linked in a systematic manner, since, e.g., for the K-family of spectral lines $c_1/\lambda = c_2 \cdot (Z-1)^2$. Similar equations hold for L and M spectra (the symbols K, L, etc. refer to electron transitions between atomic shells, induced by the excitation).

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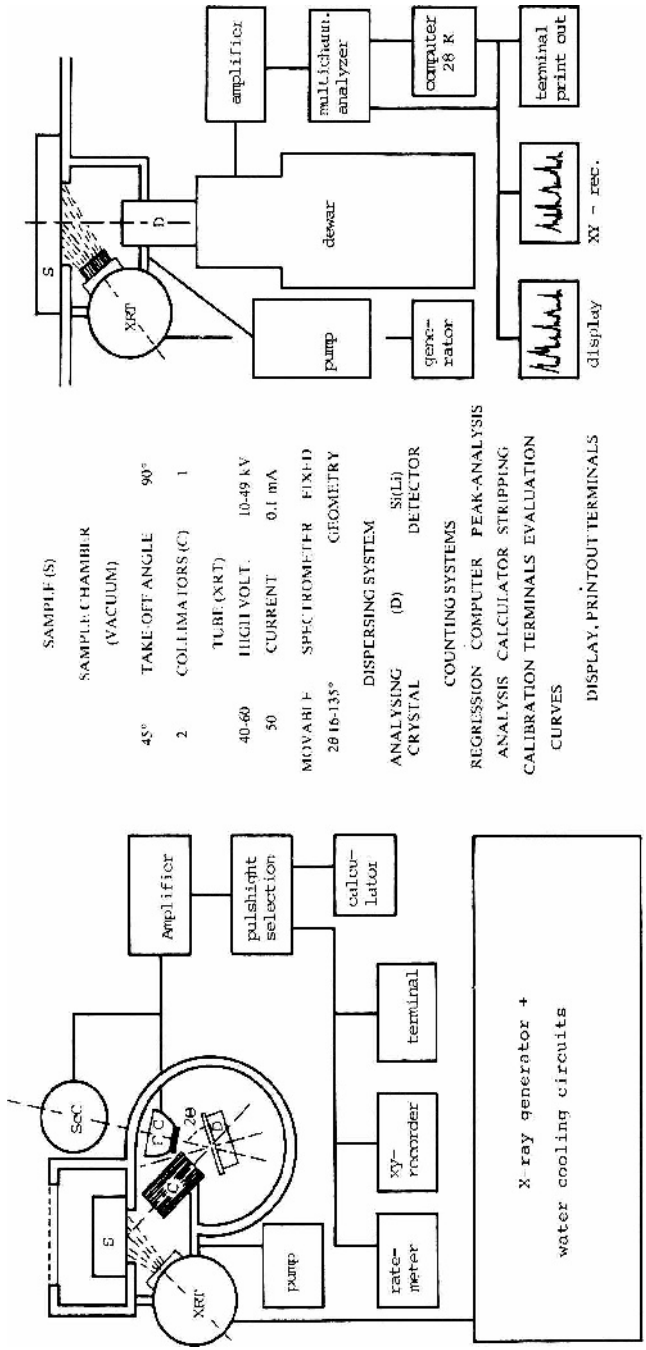

FIG. 1. Schematic set up of a conventional wavelength dispersive (left) and of an energy dispersive (right) x-ray fluorescence device.

As in all other spectroscopic techniques, a sample has first to be excited. This is done in the case of XRF either by electron/ion bombardment (electron/ion microprobe) or by primary x-rays/γ-rays (XFA). The excited, secondary* x-rays consist of different wavelengths/energies corresponding to the chemical elements present in the excited sample. These x-rays have to be split by an appropriate dispersing medium. In WDS analysis this dispersing medium is a crystal with known d-value separating the incoming complex radiation according to Bragg's law $\lambda = 2d \cdot \sin \theta$, where θ is the angle of reflection, d is the lattice constant of the dispersing crystal, and λ finally is the wavelength of an analytically interesting radiation. This implies that WDS spectrometers are operated generally with movable goniometers: the analytical information (to be recorded by appropriate counting systems like gas flow or scintillation counters) comes in sequentially since θ varies for each element (Figure 1).

In EDS—XRF the dispersing medium is a solid state Li-drifted silicon detector with a dispersing power of approx. 150 eV. The incoming complex radiation is split up into distinct energy distributions and displayed by a multichannel analyser. EDS spectrometers have a fixed geometry; the analytical information comes in simultaneously (Figure 1). Since the dispersing power of a solid state detector is much weaker for light elements than that of an analysing crystal (WDS—XRF), overlapping of energy distributions belonging to neighbouring elements ($K\alpha/K\beta$) is widespread. Special peak stripping and deconvolution programs are needed to overcome this principal disadvantage of EDS—XRF. In fact, EDS spectra can only be handled in an easy way, if computer/calculator facilities and suitable software programs are available. This is one of the reasons why EDS—XRF only recently became more popular—the advantages of versatile, cheap and small computers are obvious.

Like other physical analysing techniques, x-ray spectrometry is a *relative* method: for quantitative analysis, measurements on unknown samples have to be compared with those obtained on standard/reference materials. If the chemical composition and physical behaviour of unknown and standard samples are similar, a direct comparison may lead to quantitative results. If, however,

*'secondary' only in case of conventional XRF where a x-ray tube is used for sample excitation.

strong chemical differences exist, mathematical treatment (absorption correction) of the raw data may become necessary (Bertin, 1978). In cases where sample shape or surface conditions differ greatly, quantitative evaluation of raw data may be difficult, if not impossible. To overcome these problems, either specific methods of sample preparation (like dilution or glass fluxes) or eventually a restriction of the excited sample area to small spots ($\leqslant 0.1$ cm^2) by using appropriate collimating systems become necessary. The latter solution is often used in EDS—XRF, and is of considerable interest in gem analysis, where unknown samples usually tend to be small.

These special difficulties of quantitative analysis, however, are of minor importance when *qualitative* information is being sought: a non-destructive, qualitative analysis of an unknown sample is carried out in a few minutes or even seconds. The energy spectrum, obtained under routine conditions, gives quick information on the elemental composition as far as main constituents are concerned; all elements from sodium ($Z=11$) to uranium ($Z=92$) are detectable, i.e. approx. 90% of all natural elements. An experienced operator may even obtain a rough estimation of elemental concentrations.

As mentioned earlier, in EDS—XRF the entire spectrum is treated simultaneously; too much x-ray quanta per time unit would lead to a saturation of the detection system. Thus, the excitation power has to be reduced—either by reducing the tube current, or by inserting a primary filter—until saturation phenomena disappear. Generally, in EDS—XRF the excitation is some thousand times weaker than in WDS—XRF; as a consequence, problems of radiation damage normally do not occur.

An interesting feature of EDS—XRF analysis is the fact that diffraction phenomena may occur. If the primary x-radiation is polychromatic, i.e. if no primary filters are used, diffraction on specific lattice plains of crystalline sample may happen according to Bragg's law (Giessen 1967). Though this technique is not yet widely used, information of diagnostic value can certainly be obtained. In some cases, however, diffraction phenomena are confusing, and the use of primary filters is advisable.

To summarize, quite a few features of energy dispersive x-ray fluorescence (EDS—XRF) are different from conventional wavelength dispersive x-ray fluorescence (WDS—XRF):

EDS—XRF	WDS—XRF
simultaneous recording	sequential or multichannel recording
low excitation power	high excitation power
10 to 50 kV, 0.1 mA = 1 to 5 W	30 to 60 kV, 40 to 50 mA = 2000 to 3000 W
no radiation damage in gemstones	colour of gemstones may change
sample size mm to dm	sample size mm to inch
detectable elements: all chemical elements from sodium to uranium, Z = 11 to 92	
detection limits: 20 to 500 ppm acording to energy of analyte line, and of analysing conditions	
data storage electronically on floppy discs	data stored as numerical values
on-line-computer necessary	on-line computer optional
costs of completely equipped device XX	costs of completely equipped device XXX

In mineralogical—and gemmological—characterization of materials several physical methods of examination are traditionally used. From this tradition a somewhat misleading opinion results as if crystalline matter were defined *only* by its physical properties. In fact, however, chemical data are as important, but—again by tradition—were not looked at closely enough in the past. This traditional attitude obviously has reasons: chemical investigations used to be time *and* sample consuming. In gemmology especially the latter was contra-indicative.

Since nowadays fast and non-destructive means of chemical analysis exist, quite a few problems can be solved, such as chemical similarities/differences of gemstones of different origin (natural or industrial). Some possible applications are mentioned below; not much thorough work has yet been done but knowledge will develop with increasing experience. Valuable and reliable information can be expected in cases of

—certification in rare gem diagnosis
—separation in jade group
—separation of turquoise from its imitations
—detection of diamond substitutes in diamond lots
—cabochon and mounted stone identification
—natural and synthetic glass determination
—characterization of garnets
—discrimination of natural and synthetic gemstones in some special cases

Various gem materials were analysed by EDS—XRF from which the following examples were selected. The content of

information varies from qualitative determinations to more refined conclusions, depending on how precise the question that was previously asked. If already much is known on a specific gemstone group, more detailed knowledge on a sample-in-question is obtainable.

Ruby

The energy spectra of a Siam ruby and a synthetic Chatham ruby are shown in Figure 2. Siam ruby, according to the chemical formula of corundum, displays a strong Al line. The continuum (background) and Ag line series are due to the primary x-ray source (Ag tube). Minor elements visible are Cr and Fe. Diffraction peaks are also present. Chatham synthetic ruby has approximately the same energy spectrum. But flux grown synthetic material eventually contains droplets of residual flux as inclusions (Webster, 1975). The Chatham rubies investigated have generally high chromium to iron ratios, similar to Burmese rubies. The molybdenum peak observed in case of the synthetic ruby (Figure 3) is due to the Li-Mo-flux used. It has to be emphasized that the print out has a much poorer resolution than the original spectrum, since 8 channels of the multichannel analyser are contracted to one bar (original resolution being 20 eV/channel).

Emerald

In Figure 4, a Gravelotte emerald and a synthetic Gilson emerald are compared. The characteristic content of traces and minor elements in Gravelotte emerald is obvious. Unfortunately inclusions contribute to the element-rich spectrum as well. The Mg-content is a diagnostic dimension for separation of natural and synthetic emerald (Hänni, 1982). In general, natural gemstones are less pure than their synthetic counterparts.

Alexandrite

Russian and synthetic alexandrite are compared (Figure 5). Again, the synthetic stone is remarkably pure, containing only main elements of the formula, and elements needed for the colour effect. On the other hand, natural alexandrite contains different impurities which were available during the individual formation process of Tokowaya alexandrite. In synthetic alexandrite (Creative crystals) no platinum (crucible material) but molybdenum (flux) was found.

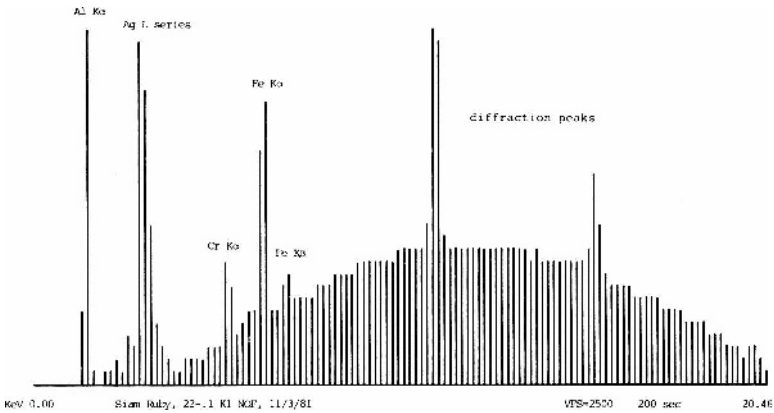

FIG. 2a. Energy spectrum of Siam ruby. The line series of silver L is due to the primary radiation of the exciting Ag-tube.

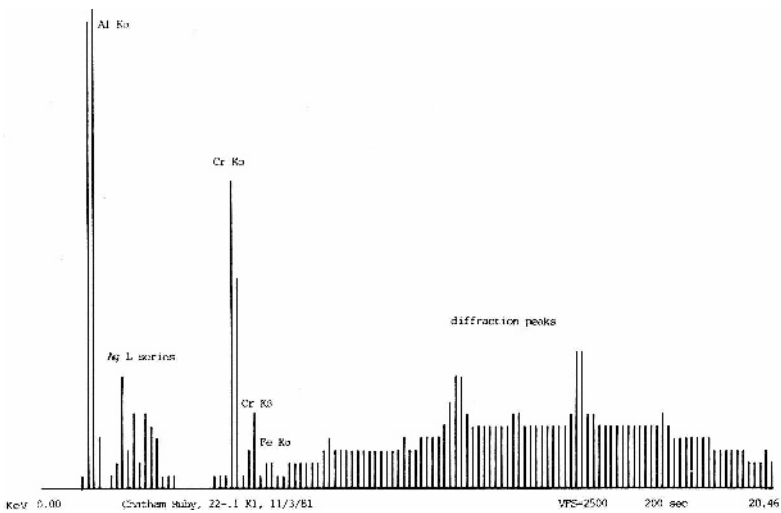

FIG. 2b. Energy spectrum of synthetic Chatham ruby.

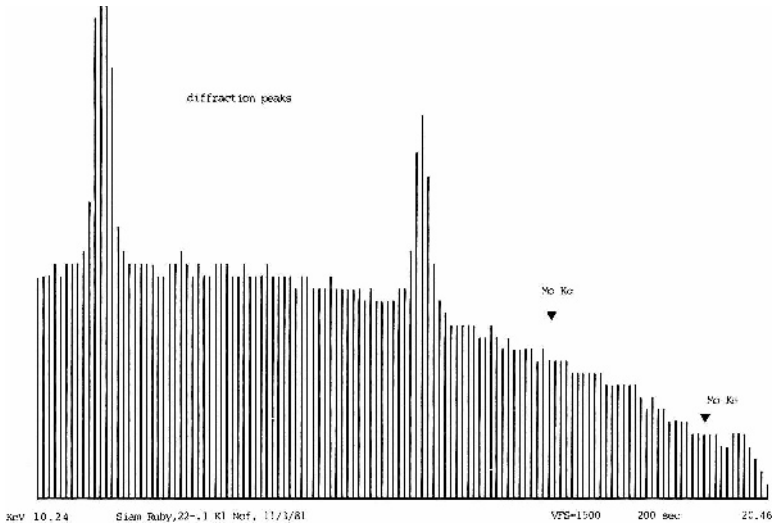

FIG. 3a. Upper half of energy spectrum: Siam ruby, no molybdenum lines.

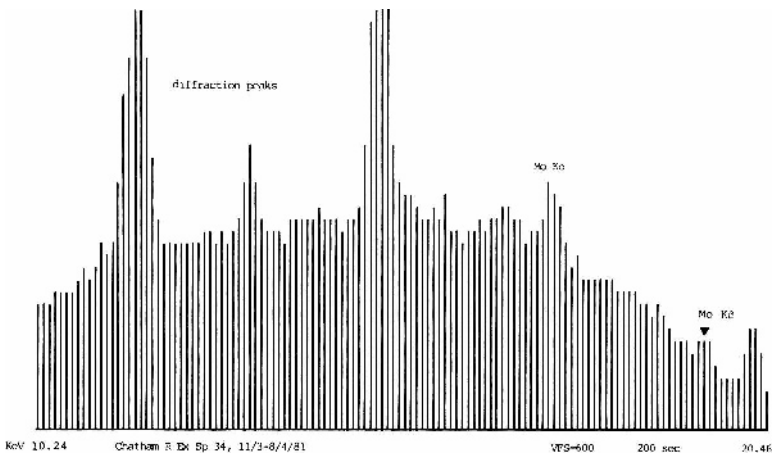

FIG. 3b. Upper half of energy spectrum: synthetic Chatham ruby containing droplets of flux (Mo Kα and Mo Kβ).

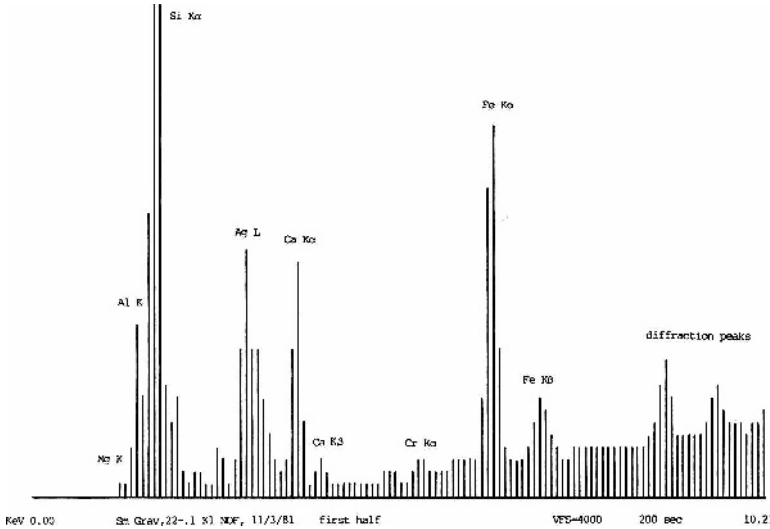

FIG. 4a. Energy spectrum of natural Gravelotte emerald, lower half of spectrum.

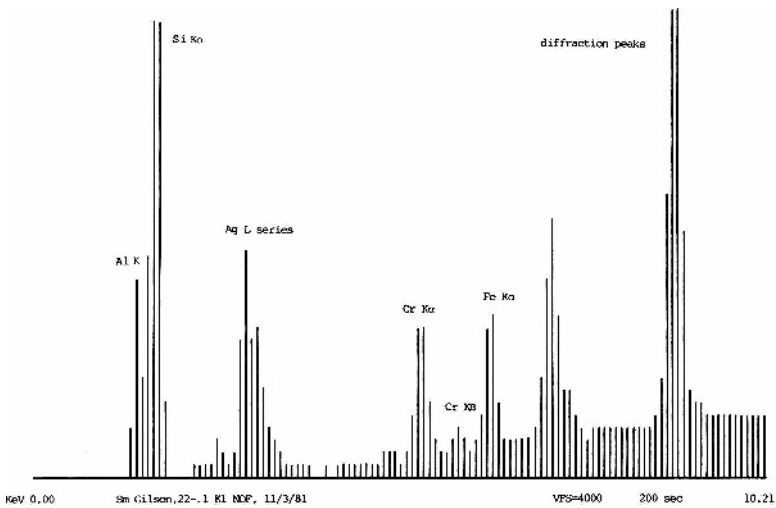

FIG. 4b. Energy spectrum of synthetic Gilson emerald, lower half of spectrum.

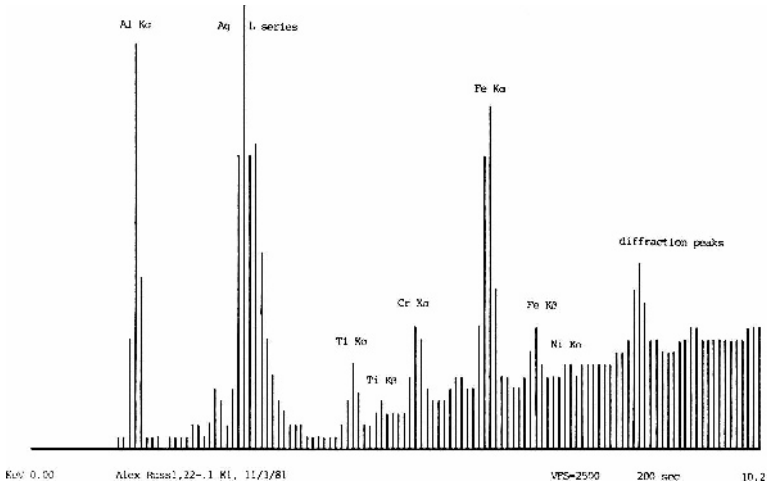

FIG. 5a. Energy spectrum of Russian alexandrite, lower half of spectrum.

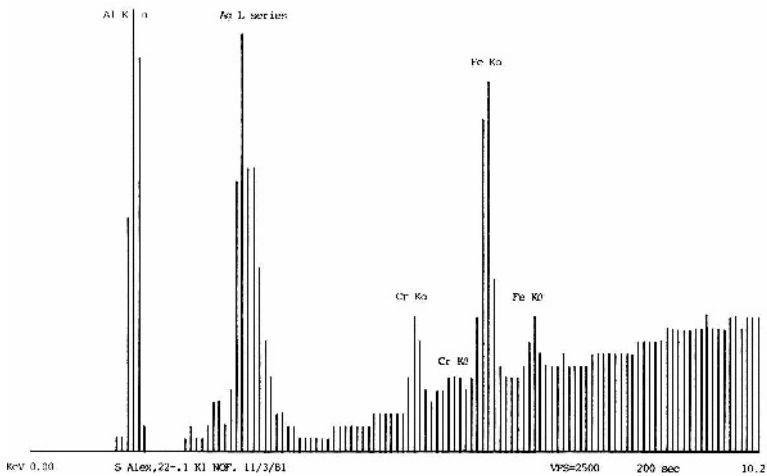

FIG. 5b. Energy spectrum of synthetic alexandrite, lower half of spectrum.

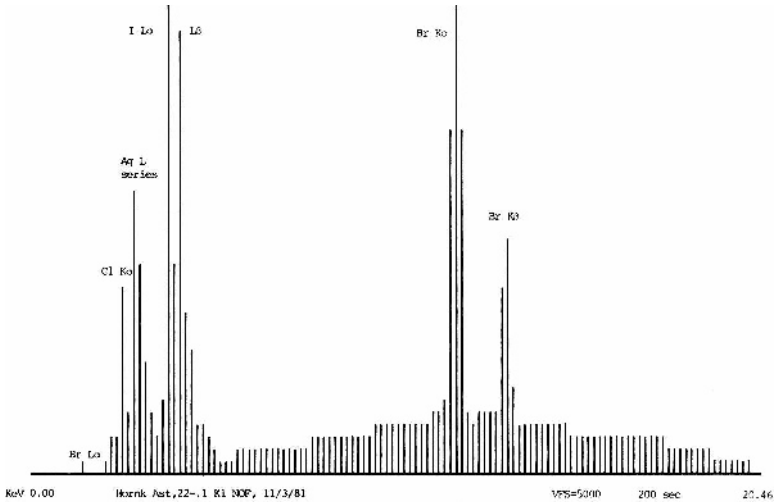

FIG. 6a. Energy spectrum of horn coral.

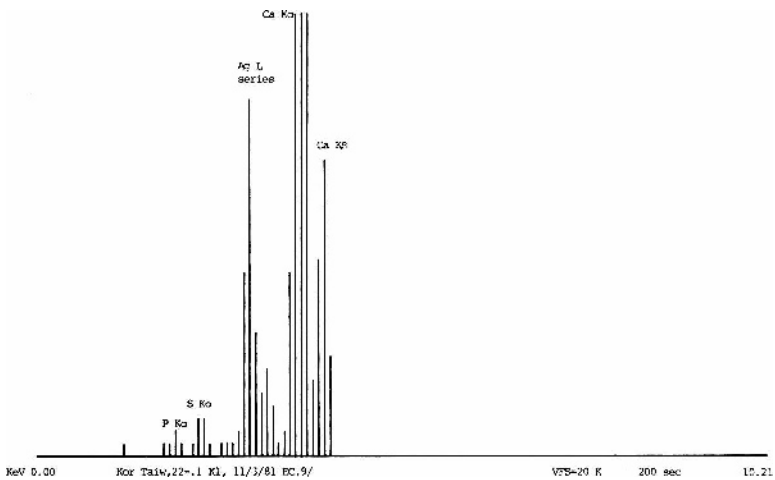

FIG. 6b. Energy spectrum of red coral, Taiwan.

Corals

An investigation of red and black coral (Figure 6) gave typical information on both materials. The red coral consists of calcium-carbonate, as expected. The Ca signals are very strong. Additional minor elements such as S, P, Mg and Sr were observed. In a naturally red coral the colour is due to iron oxide, which is present in sea-water. Dyed red corals generally do not contain iron but are treated with aniline dyes which are free of iron. The black coral of horn substance was surprising, since the main constituents were found to be Cl, I, S, Br and some Fe.

The list of applications of EDS—XRF will be extended when more attempts are made to use compositional characteristics for gem identification. In this sense, this study is just a hint for further development of this rapid and reliable method.

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MINERAL INCLUSIONS CONTRIBUTE TOWARDS ELUCIDATING THE GENESIS OF THE DIAMOND

By Professor Dr E. GÜBELIN, C.G., F.G.A.

(being a revised version of the lecture given to the Gemmological Association of Great Britain in the Great Hall of Kensington Town Hall on 6th October, 1981)

The genesis of the diamond has been the subject of intensive scientific investigation for many years, and its mineral inclusions have decidedly contributed towards shedding brighter light on the many enigmas and secrets it has been guarding for so long. Indeed, the mineral inclusions qualify as exhibits in a unique showcase, demonstrating the course of events which promoted the formation of their host crystal in regions below the Earth's Crust, far beyond our reach.

Nowadays an increasing mineralogical curiosity is awakening about the significance of the chemical relationships of coexisting minerals as a means of explaining the P-T conditions prevailing during the formation of crystals. On the whole, both experimental and naturally-occurring systems yield evidence of the initial crystallization and subsolidus changes in silicate minerals. Thus, frequent entrapment of olivine, pyroxene and garnet inclusions in diamond, as well as the characteristic and interrelating epi- and syn-taxial growths of these four principal mineral components of the diamond-bearing xenoliths in the kimberlite, undoubtedly corroborate that these four minerals are *in sensu stricto* paragenetic. This means that they crystallized simultaneously, from one and the same mother melt. Growth features, morphologies and sizes, further reveal that they formed while floating in a melt, and that diamond in particular has crystallized as a stable phase. By means of the well-known stability field of these paragenetic minerals, it has become possible to elicit the equilibrium conditions of the accompanying diamond which so often plays the part of their host. Although it has thus become possible to gain a definite idea of the P-T conditions under which diamond crystallized, its more intimate secrets—the stimulating event and subsequent stages of diamond growth—are not yet precisely understood.

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Systematic analyses of the main chemical elements of mineral inclusions in diamond have also resulted in the now established knowledge that these guest minerals belong to two different mineral suites: chrome-bearing olivine, chrome-pyrope-garnet, the orthopyroxene enstatite and chrome diopside, comprise the *ultramafic suite,* while ordinary forsteritic olivine, pyrope-almandine-garnet and omphacitic clinopyroxene containing appreciable amounts of Na and Al, are ascribed to the *eclogitic suite.* It is quite plausible that these two suites were subjected either to different physical or chemical conditions of formation, or to both, because mineral inclusions belonging to both groups have not yet been observed in a single diamond, whereas various mineral inclusions from the same suite may coexist within the same diamond.

The accompanying illustrations depicting mineral inclusions in diamond are arranged in two groups according to these two mineral suites—that is to say they are separated into ultramafic and eclogitic inclusions. Yet, ere the reader's interest is allowed to turn to the portraits of these guest minerals in the diamond as manifested by the illustrations, the author wishes to premise a few preliminary remarks concerning some of the characteristic features which are common to many of them: the guest minerals in diamond have been effectively protected against further chemical reactions with other silicates and oxides as well as sulphide-phases due to their sealed enclosure within the inert diamond host.

A distinctive feature of many of the syngenetic inclusions is their morphology: the guest crystals usually exhibit well shaped forms, but they are xenomorphous, i.e. they are not their inherent habits, but rather those of the host diamond, which means that the diamond has imprinted its own habit onto the entrapped crystals.

The specific types of minerals that occur as inclusions in diamond have similar chemistry, despite their origin in geographic localities remote from one another.

The concurring presence of the same mineral species in the external as well as the internal mineral assemblage of the diamond, permits the conclusion that the diamond crystallized from a melt during rock-forming processes.

Furthermore, the different chemistry of the guest minerals in diamond and the same mineral components of the kimberlite, reveals that the diamond was not formed in the kimberlite—at least

not during its later stages, i.e. not during its ascent and volcanic eruption through the Earth's Crust.

Surely, the presence of mineral inclusions in diamond can only be understood with reference to diamond growth.

The outstanding theory acknowledged today concerning the formation of diamond is based upon the knowledge that genetically ideal conditions varying from 40 to 60 kbar and amounting to approximately 1250 °C prevailed at relatively great depths in the Earth and that such conditions must be expected in regions of the Upper Mantle. The evidence of crystal perfection and of external crystal morphology of diamonds suggests that diamonds grew in equilibrium and crystallized during the solidification of an ultramafic silicate melt, saturated with carbon. In agreement with this interpretation, thorough investigation of mineral inclusions in diamond discloses that they crystallized from a picritic (= olivine-rich) magma, rich in water and carbon-dioxide, in the presence of immiscible iron-, nickel- and copper-sulphides. In the course of this highly reactive phase, and while the rocks themselves must have undergone several changes, the diamond and its guest minerals were born.

Yet, before we may deal with these details, it may be advantageous to examine the Earth's internal structure and to locate the actual birthplace of the diamond. In the course of geological research, some definite ideas have developed about the structure of our Earth, and we believe these to be quite trustworthy. We may assume that the innermost core consists of iron and nickel—with a composition somewhat concurring with the iron meteorites which drop to our Earth as samples from other cosmic bodies.

The core is surrounded by a sphere of Al-Ca-Fe-silicates which we call the Lower Mantle, including a transition zone.

The Lower Mantle is embraced by an exterior silicate-shell consisting of minerals and rocks partly in molten, partly in solid condition.

It is only the outermost skin of this Upper Mantle which is accessible to our direct observation. Everything that lies below these depths must always be left to conjecture. Our deepest drill-holes have only reached a depth of 10 000 m, and the deepest shafts sink down to merely 5200 m—just a few miles. In comparison with the thickness of the individual strata, these human drill-holes are

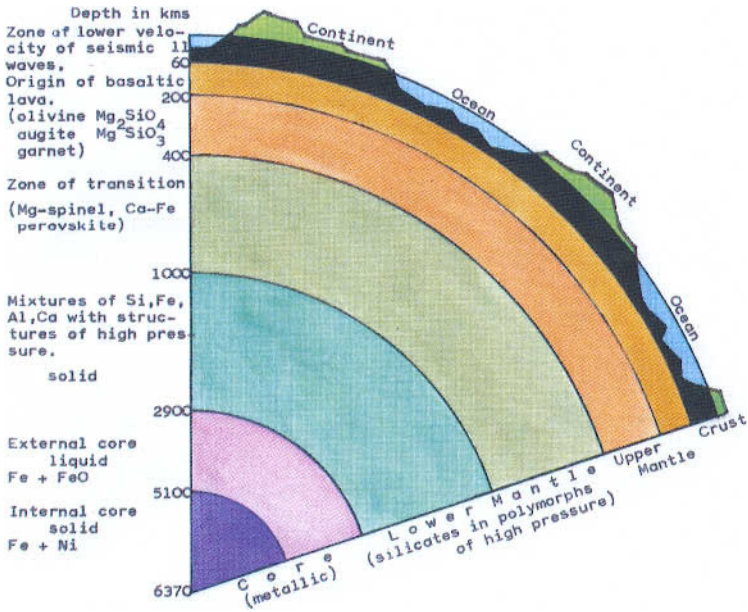

FIG. 1. Section of the Earth showing its internal structure (after Schick & Schneider, 1973).

but pin-pricks! It is comprehensible that geologists have tried to obtain better ideas about greater depths of the Earth's interior, because all processes in the external border-zone—the so-called Crust—where the majority of our raw material is deposited, are closely connected with the interior of our planet. Thus geologists have established a triple division of the silicate zone—which is named the Upper Mantle—according to which the uppermost layer—the Crust—consists of rocks known to us. The Crust is estimated to measure between 11 and 60 km (with an average of 33 km) in thickness.

Below the Crust, the Mohorovicic-discontinuity forms the boundary towards the middle zone of the Upper Mantle, where in places the material is in that molten state which we call *magma*.

Magma, or liquid rock, probably only occurs locally in small

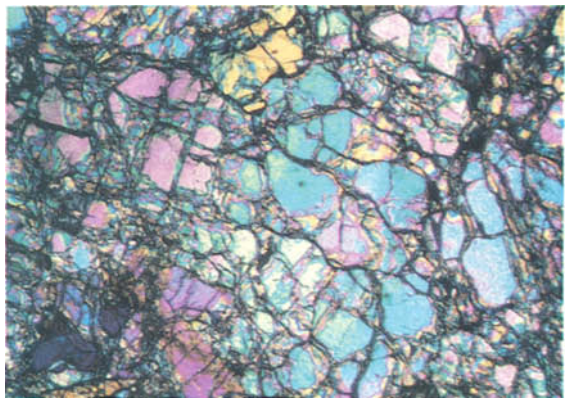

FIG. 2. Thin section of peridotite, a monomineralic rock consisting entirely of olivine grains. + polars.

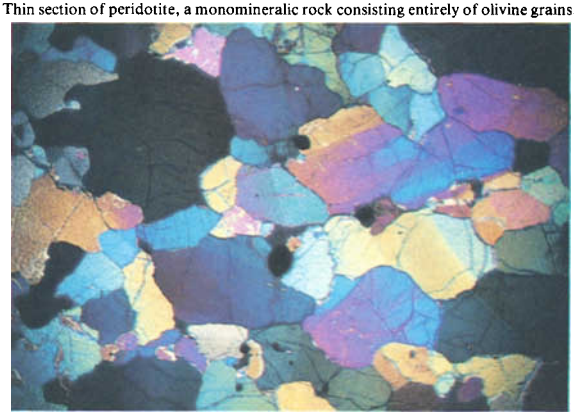

FIG. 3. Thin section of dunite, a peridotite in which the mafic mineral is almost entirely olivine, with accessory chromite (black grains). + polars.

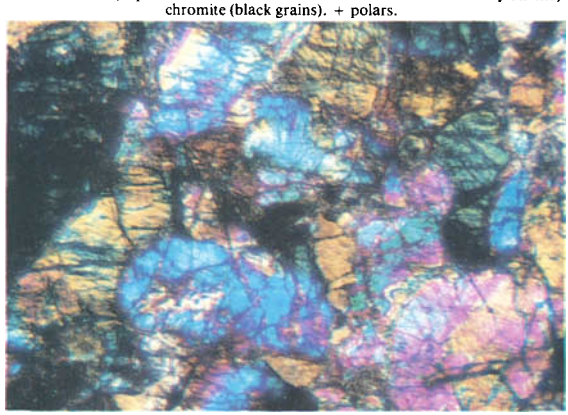

FIG. 4. Thin section of garnet-lherzolite, a peridotite mainly composed of olivine (which is normally predominant) and bimineralic pyroxene. The cataclastic condition of the grains is quite conspicuous. (The angular black grain at the lower edge is garnet). + polars.

areas where melting has taken place. This shell reaching down from about 33 to about 200 km—and according to our ideas, playing host to ultramafic rocks—is of eminent importance to the formation of diamond, because it is this shell which supplies the molten basic material—so to say the matter of the womb—from which diamond crystallized. We must assume that this zone of magma in the Upper Mantle has approximately the same homogeneous composition throughout its entire extension, though some areas must be quite heterogeneous and differ chemically at different horizons and localities. This must especially be the case below those areas of the Crust where diamond is found.

The general composition of the Upper Mantle is peridotitic (Figure 2), i.e. it is characterized by a combination of silica (SiO_2) and magnesia (MgO), and therefore used to be called SIMA (unfortunately this descriptive acronym has more recently been abolished). Besides these oxides of silicon and magnesium, alumina (Al_2O_3), iron, calcium and alkalis are also present.

The Upper Mantle is the main source of ultrabasic and ultramafic rocks, and among the latter we find some of the diamond's mother-rocks. The difference between 'ultrabasic' and 'ultramafic' rocks lies in their chemical and mineralogical compositions respectively, so that a rock is called 'ultrabasic' if it contains less than 45% SiO_2, while the term 'ultramafic' refers to the mineral composition of a rock: ultramafic rocks are often monomineralic, consisting mainly of mafic material such as augite, hypersthene, olivine etc. "Thus a rock can be both ultrabasic and ultramafic, but it can also be ultrabasic yet not ultramafic (e.g. carbonatite) and vice versa (e.g. websterite). The ultramafic rocks of the Upper Mantle are of igneous origin, yet when *some* of them are examined with regard to texture, it is obvious that they have undergone cataclasis and/or recrystallization, and they would best be considered as recrystallized igneous rocks, as there has probably been little—if any—chemical mobilization between minerals (in this instance the discussion is entirely confined to the xenoliths in kimberlite)".*

*This and subsequent passages printed between "double quotation marks (inverted commas)" are personal communications by Professor Dr H. O. A. Meyer, Purdue University, West Lafayette, Ind., U.S.A.

The far-reaching distribution of diamond occurrences—from Australia to Borneo, Malacca, India, South Africa and Brazil; from Tanzania via Zaire to Ghana, Sierra Leone, Liberia and Guyana, as well as in Yakutia in Siberia and in the Ural Mountains—offers evidence that diamond must have originated from a widely spread and similarly composed, though in places heterogeneous, magma in the Upper Mantle.

The abundance and variety of inclusions—both monomineralic and multimineralic even in a single diamond—suggest that a complex history must have preceded the genesis of the host diamond itself. The history would appear to have forerun the formation and emplacement of kimberlite. The coexistence of specific mineral-inclusions with the diamond, i.e. their forming the internal paragenesis of the diamond, offers the following interesting interpretation of the diamond's evolution:

"The ultramafic xenoliths in kimberlite include lherzolite ± garnet; harzburgite ± garnet; websterite ± garnet, and dunites. The xenoliths in which diamonds have been found are mainly dunites (Figure 3) and harzburgites, but two lherzolites (Figure 4) have also been known: garnet is present in these rocks. The story of these xenoliths in kimberlite is further complicated by the fact that there are what are called 'fertile' and 'sterile' ultramafic xenoliths. These terms are closely associated with the attributes 'sheared' and 'granular', which were used by Boyd, F. R. & Nixon, P. H. (1975 & 1978) to describe xenoliths with specific textures. In general, a fertile xenolith is one that could upon partial melting produce 'basaltic' material plus a residuum. A sterile xenolith cannot produce 'basaltic' material through partial melting, and may perhaps itself be the residuum of a previous partial melting episode. Thus, in summary, there is some *deus ex machina* that introduces fertile ultramafic rocks into the Upper Mantle. Partial melt episodes applied to these fertile rocks result in 'basaltic' liquid plus sterile residuum rock. Principally, there has only to be enough carbon present, in order to obtain diamond, and hence diamond may occur in several types of ultramafic xenolith—and this concurs with actual observations. The role of CO_2 and of H_2O has been neglected in the above discussion, but it is plausible that these volatiles take an active part in the partial melt episodes by lowering melting temperatures, etc."

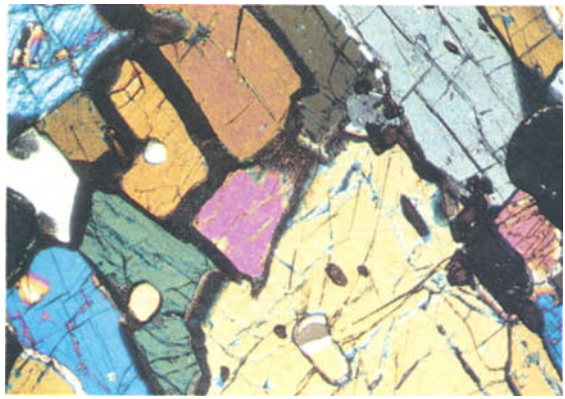

FIG. 5. Thin section of eclogite, an igneous derivate from ultramafic, fertile peridotite consisting of clinopyroxene, garnet (two black grains at the short edges), olivine, and rutile (brown grains). + polars.

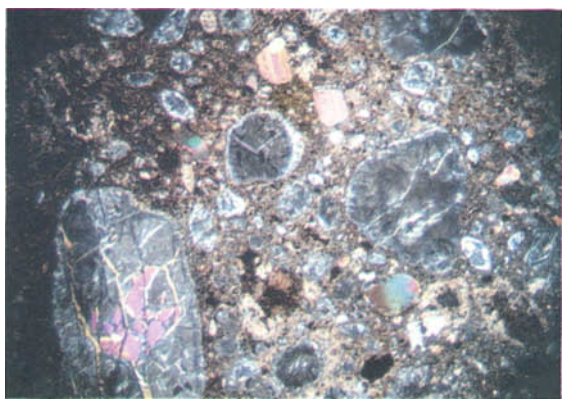

FIG. 6. Thin section of kimberlite, a basic igneous porphyritic rock containing abundant phenocrysts and xenoliths, some of the latter being mother-rocks of diamond. + polars.

The diamond-bearing ultramafic xenoliths consist, in varying compositions and mixtures, chiefly of olivine, pyrope garnet, orthopyroxene (enstatite), diopsidic clinopyroxene (chrome-diopside) with some accessory minerals such as chalcopyrite, pentlandite, graphite and—DIAMOND (Figures 2, 3, and 4).

The other main suite of xenoliths in which diamond occurs are the eclogites (originally called 'griquaites') (Figure 5). These are igneous rocks, for no evidence of classic metamorphism may be perceived, and they consist of an assemblage of bimineralic clinopyroxenes and garnet with a proportion of jadeite molecule in the clinopyroxene. It has been suggested, "that some of the eclogite xenoliths are in fact the crystallization products of the 'basaltic' liquid that was expelled from fertile ultramafic rocks during episodes of partial melting. The idea appears highly plausible since it explains the apparent intermixing of ultramafic and eclogitic rocks in the Upper Mantle."

The principal mineral components of eclogite are pyrope-almandine garnet and omphacitic clinopyroxene. The rarity of clinopyroxene inclusions in diamond is surprising in view of the abundance of this mineral in kimberlite and associated xenoliths. Rutile and to a certain extent also olivine, are common accompanying minerals, and the following even rarer subordinate minerals may occur: coesite, corundum, cyanite, ilmenite, jadeite, pyrrhotite, quartz, high sanidine, spinel, graphite and—DIAMOND (Figure 5).

The relationship of the ultramafic and the eclogitic mother-rocks of diamond to each other seems clear: eclogite is the solidified low-melting fraction of fertile ultramafic rocks, precipitated after partial melting, whereas the ultramafic xenoliths are most likely the result of an early high cataclasis and/or re-crystallization.

There is a strong implication, if not a certainty, from natural deposits, that diamond crystallized by slow precipitation from a molten or partly molten peridotite (Figure 4), on condition that this occurs in the stability field of diamond. For a 'dry' peridotite this means theoretically a temperature above 1800 °C and a pressure of at least 68 kbar (depth 200 km), but for a phlogopite-bearing peridotite, these equilibrium conditions would be reduced to some 1100 °C and 45 kbar (depth approx. 135 km) (Figure 7). Either of these events may have taken place during a period or periods of

partial melting, which resulted in cataclastic ultramafic rocks and truly igneous eclogites—the recognized mother-rocks of diamond. Consequently, these diamond-bearing xenoliths may be considered as igneous high pressure derivates of cataclastic and melting processes, whereas diamond is to be understood as a side-product of these extrordinary incidents. This formidable evolution of the diamond occurred in various periodic successions (Figure 21).

With regard to diamond growth, there are some rules which must be observed; for instance, no diamond forms unless the pressure is high enough for diamond to be stable at the particular prevailing temperature. The habit of the diamond depends principally upon the pressure and temperature at the instant of formation. The temperature probably also influences the colour.

Large diamonds were formed by processes of pressure increase and/or temperature decrease close to the transition line diamond/graphite (Figure 7): the slower these processes, the larger and more perfect diamond crystals could have formed. When these processes happened rapidly, and/or at pressures considerably higher than those necessary for equilibrium, the rate of nucleation and growth of the crystals was greater, resulting in smaller and less perfect crystals (carbonado, ballas and other polycrystalline forms).

It is well known that diamonds from different regions or mines can, statistically, be distinguished on the basis of their dominant crystal form, structure, average dimensions, colour grade, and to some extent also by their inclusions, although mineral inclusions more decidedly differentiate between the ultramafic and eclogitic origin of the diamond. From the above discussion, such differences may be interpreted in terms of different growth conditions.

A number of outstanding problems still exist, such as the source of carbon necessary for diamond to crystallize as well as nitrogen, which is a common impurity and is responsible for yellow, brown and green colours. In the case of carbon, its source is still a matter of conjecture, "though one may assume that carbon was concentrated beyond its saturation level in the magma. Consequently the most important carbonate mineral, calcite, occurs in some xenoliths of kimberlite and in kimberlite itself. Yet strangely enough calcite is uncommon in the eclogite and ultramafic xenoliths, although some of these contain diamond and occasionally graphite. Apparently carbonate minerals could not

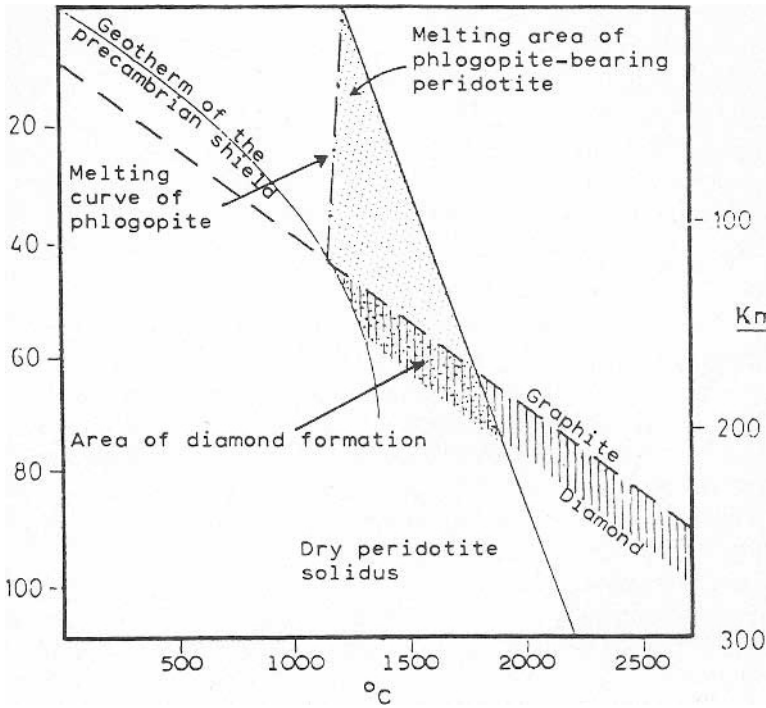

FIG. 7. Diagram demonstrating the influence of mica upon Mantle melting and the genesis of diamond.

readily form in the diamond-bearing xenoliths, and thus carbon was caused to crystallize as diamond". It may be recalled at this instance, that for diamond to form, all that is required is the presence in sufficient quantities of carbon! "Whether or not the magma was eclogitic or ultramafic is immaterial, as it is the physico-chemical rules governing crystallization that are important, and the presence or absence of carbon."

Quite possibly, a carbon or diamond phase originated from the reduction of carbon dioxide. The reduction could be centred around a specific reducing agent—where its absence in abyssal magma could mean absence of diamond as well. Pyrrhotite could fill this role as a reducing agent. It is a common primary inclusion in many diamonds from various sources.

A possible moderate-temperature/high-pressure reaction between iron-rich pyrrhotite and carbon dioxide is:

$$2FeS_{(solid)} + CO_{2\,(gas)} = 2FeO_{(solution)} + S_{2\,(gas)} + C_{(cryst.)}\,(\text{Diamond})$$

(Langford *et al.*, 1974)

This open-system reaction would be diffusion controlled by the carbon dioxide. The diamond phase could form directly, by-passing a graphite- or carbide-phase. The FeO (ideal) would either combine with excess silica or dissolve in the host-rock's silicates.

Another possibility consists in the following reaction:

$$2FeO + CO_2 = Fe_2O_3 + CO$$
$$2FeO + CO = Fe_2O_3 + C \quad (\text{Diamond})$$

The results of more recent investigations of the composition of gases such as H_2, CH_4, H_2O, C_2H_4, N_2, CO_2, CO, and Ar, trapped within diamonds, are not inconsistent with the genesis of diamond by a gas-phase—solid-phase reaction under a variable environment. Water has been observed as a major component of the included gases and this may suggest that water was present in the Upper Mantle during diamond crystallization. As a matter of fact, it is accepted today that the H_2O-CO_2-rich fluids and Fe-Ni-Cu-Co-sulphides play an important part in the genesis of natural diamond. They are present in the silicate melt from which diamond crystallized—probably as miscible volatiles and immiscible sulphides.

Preliminary calculations indicate that the following secondary reactions are combined with similar primary reactions and explain the observed data qualitatively:

$$H_2 + CO_2 \rightleftharpoons H_2O + CO \qquad 4H_2 + CO_2 \rightleftharpoons CH_4 + 2H_2O$$
$$CH_4 + CO \rightleftharpoons H_2O + H_2 + C\,(\text{Diamond})$$

These reactions adequately explain the composition of the gases released from the natural diamonds, except for N_2 and Ar. The latter gases are believed to be inert in the diamond growth process (Giardini *et al.*, 1975).

Since the diamond converts into graphite when heated to more than 1200 °C in a vacuum, it would have altered into graphite during cooling if it had not refrigerated very rapidly, which, so to say, caused the diamond structure to undergo 'deep freezing'!

The basis of this knowledge was also offered by ore in diamond, when a black mineral inclusion was analysed which was basically pyrrhotite (FeS) in composition, and was found to contain a high proportion—almost 8%—of nickel. Apparently little or no exsolution of nickel had taken place during the cooling of the

original mixed mineral, which suggests that the diamond host cooled very quickly, granting no opportunity to the nickel minority to exsolve. Pyrrhotite can only accommodate about 1-2% of Ni in solid solution (Figure 20). (Gübelin, 1977.)

From those focal places in higher regions of the Upper Mantle where diamond was formed, the diamond was shot into higher spheres of the Crust and even above the Earth's surface by sporadically occurring eruptions, during which the rocks resulted in a breccial kind of rock—known to us as kimberlite (Figure 6). In the course of this event many diamonds became embedded in the kimberlite rocks of the volcanoes and their conduits. Diamond is not an inherent but an accessory mineral of these kimberlite rocks, which fill the chimneys of the volcanoes or spread as lava over the adjacent terrestrial surfaces. The speed of ascent must have been sufficiently great to preclude sedimentation of the high-density peridotite- and eclogite-xenoliths, and also to prevent resorption or inversion of the diamond into graphite.

Unfortunately, the foregone hypotheses, while explaining many features of the genesis of diamond and its deposits, offer no elucidation as to the peculiar phenomenon of time and space of diamond deposits. A startling majority of kimberlite pipes—perhaps as much as 90%—were all emplaced in the Late Cretaceous era, i.e. about 140 to 200 million years ago, through volcanic eruptions which brought the diamond to the surface of the Earth. One may well wonder about the tremendous forces on the Crust-Mantle of the Earth during part of this geological era which promoted these volcanic eruptions. We certainly have to be grateful that diamonds were preserved for us and, further, that they have become accessible above the surface of the Earth and thus come into the hands of men.

PHOTOMICROGRAPHS OF MINERAL INCLUSIONS IN DIAMOND

Olivine is the most frequent and most important mineral inclusion in diamond (Figure 8). It furnishes a typical example of epitaxial growth within the diamond: the crystals are stretched pinacoids after the body-diagonal, whose pinacoidal face (010) grows on octahedral faces (111) of the diamond in such a way that the longitudinal axis extended along the diagonal [110] runs in

FIG. 8.

parallel alignment with the edges of the octahedron. The identity period of the structure of olivine in the direction [110] is $\sqrt{a_0^2 + b_0^2} = 7.75$ Å and in the diamond along the same direction $a_0 . \sqrt{2} = 5.04$ Å (Strunz, 1968). The difference of 2.71 Å does not

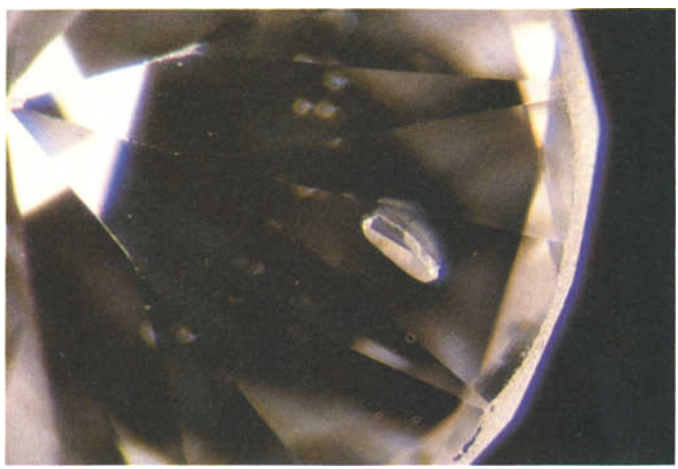

FIG. 9.

seem to be an obstacle in the way of epitaxial growth. Olivine in ultramafic diamond contains bivalent chromium, the content of which varies from 0.01% to 0.1% or more. Pre-cambrian olivine contains more CrO than mesozoic olivine. (Meyer & Boyd, 1972).

Frequently, the olivine crystals in ultramafic diamond distinguish themselves by containing a tiny dark brown grain of chromite (Figure 9).

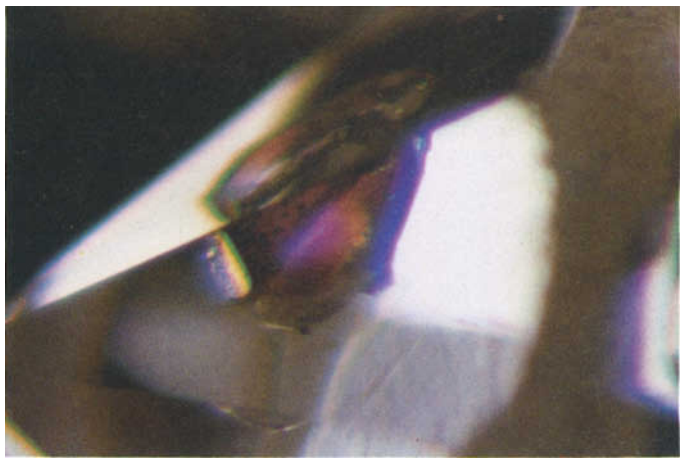

FIG. 10.

Pink to dark red chromium-rich pyrope garnet is a characteristic hallmark of ultramafic diamond (Figure 10). The proportion of trivalent chromium in pyrope garnet also varies remarkably, as may be assumed by the difference in the shades of a hue that might be called claret or burgundy red. The content of Cr_2O_3 may sometimes reach as high an amount as to place the pyrope garnet into the neighbourhood of knorringite-garnet.

FIG. 11.

Reddish-brown to brown garnets are pyrope-almandine garnet (Figure 11) and belong to the eclogitic suite of mineral inclusions in diamond; they are more iron- than chromium-rich. Guest garnets in diamond do not seem to be aligned to any crystallographic or preferred direction of the host crystal. Both varieties of garnet excel with a slightly increased proportion of Na_2O which indicates high formation pressure.

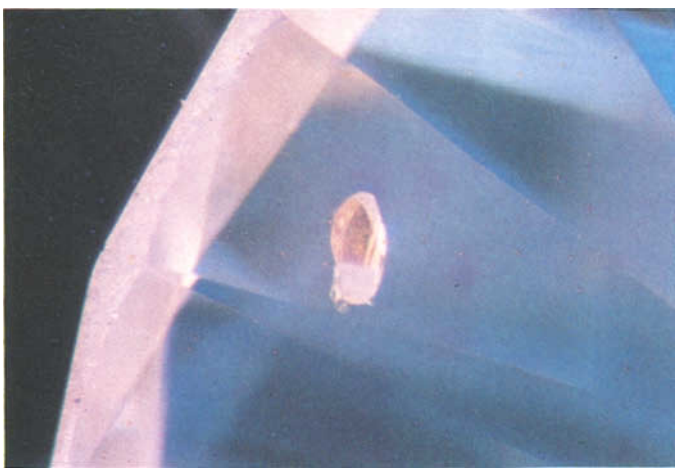

FIG. 12.

The *orthopyroxene enstatite* (Figure 12) characteristically occurs as a significant inclusion in diamond originating from an ultramafic mother-rock. It is noteworthy for its limited tolerance of chemistry in that it is constituted of 92% En in most cases, the remaining molecules being bronzite and/or hypersthene. Consequently it appears most often colourless (and is then difficult to discern from olivine) or pale brown. Enstatite was first mentioned by the author (1952).

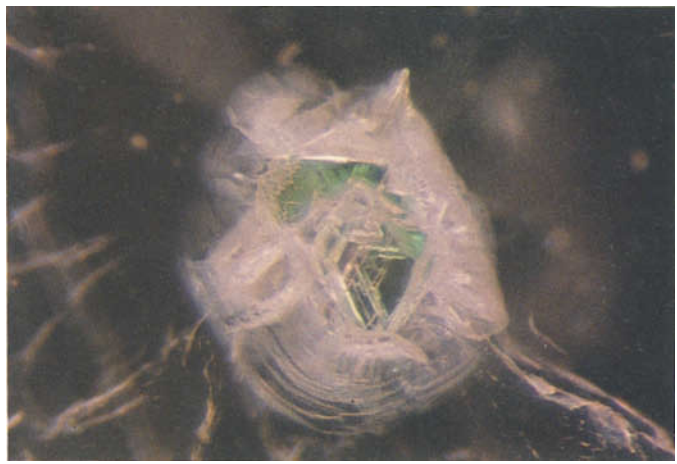

FIG. 13.

Of the *clinopyroxene* inclusions the *diopsidic* variety is also assigned to ultramafic diamonds (Figure 13). It is easy to recognize by its conspicuous emerald-green colour, which it owes to an admixture of chromium oxide, which may reach contents as high as 15 wt%. The author was the first to identify chrome-diopside in diamond (1969). The guest mineral in diamond strongly resembles its counterpart in ultramafic xenoliths, and usually seeks the association of chrome-bearing olivine, pyrope-garnet and chromite.

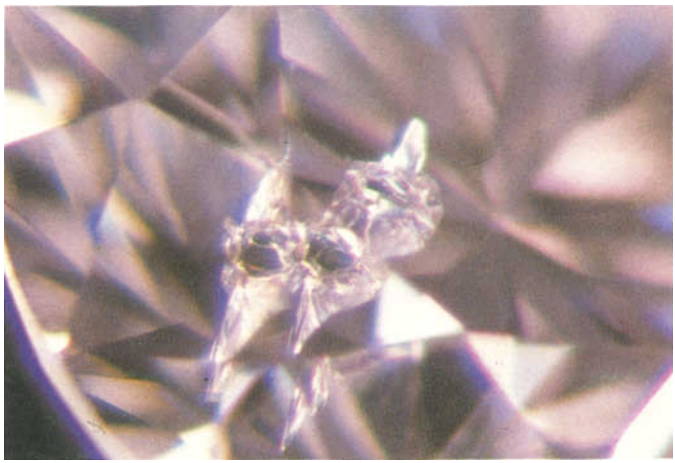

FIG. 14.

Omphacitic clinopyroxene (iron-bearing diopside) (Figure 14), typically marks the internal paragenesis of eclogitic descendancy and is more abundant in Premier diamonds than elsewhere. In many instances these pyroxenes are very pale greyish-green, and their colour may be masked by the high refractive index of the host diamond (as, by the way, is often the case with mineral inclusions

FIG. 15.

in diamond). Some of these omphacitic diopsides belong to the space-group C2/c instead of P2/n, the latter being normal for the same mineral in eclogite.

In concurrence with most chromium-bearing mineral inclusions, *chromite* (Figure 15) also belongs to the mineral association in ultramafic diamonds. It forms dark brown to black grains or well-shaped octahedra with a strong metallic lustre. Chromite inclusions in diamond are the most magnesian and chromian of terrestrial chromites (Meyer, 1975).

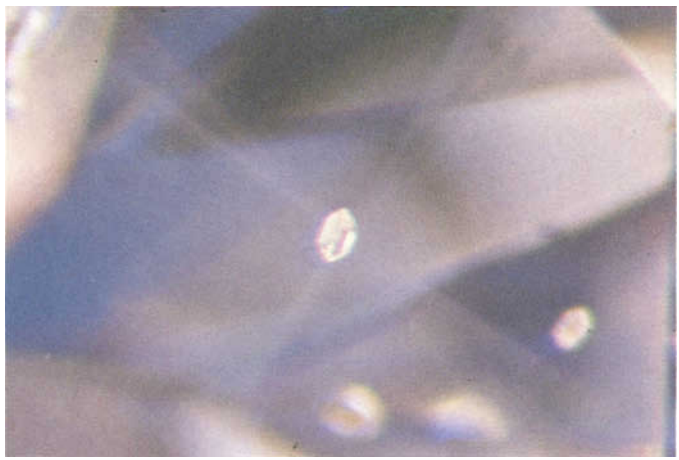

FIG. 16.

Minor mineral inclusions designating their host diamond's eclogitic origin are coesite, ruby and rutile, and, in extremely rare cases, also cyanite and ilmenite. Coesite, the high pressure polymorph of quartz (Figure 16), was first discovered as a guest mineral in diamond, before it had been found in a free state in nature. Whenever SiO_2 is incorporated in crystalline form in diamond, it should be coesite and not quartz, for the boundary curve of the stability field of coesite runs from 30 kbar and 500 °C to 45 kbar and 1500 °C, and therefore crystallizes under equal growth conditions to those of diamond. Only a very few diamonds have heretofore become known with coesite inclusions, and most unfortunately their original source is still uncertain.

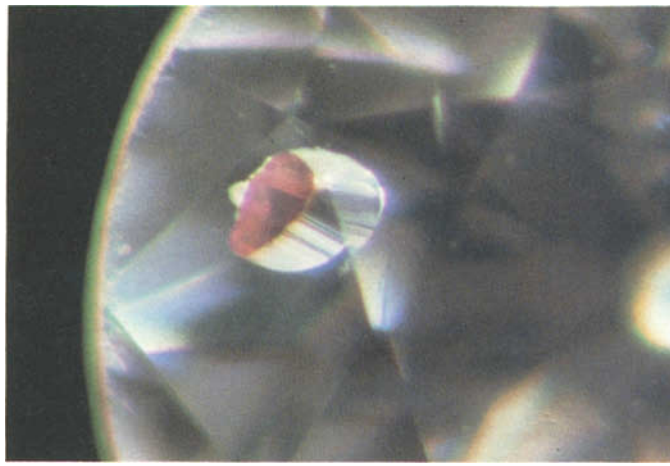

FIG. 17.

The possibility that corundum could take shelter in diamond was doubted for a long time, and it was indeed only two years ago that a ruby (Figure 17) was identified as a guest mineral in diamond for the first time (Meyer *et al.,* 1981). While weak reddish fluorescence and an extremely fine emission line at about 693 nm seemed to indicate ruby, a quantitative analysis by the electron microprobe confirmed its nature. Compared to a Burmese ruby, it disclosed similar though slightly different amounts of trace elements, e.g. SiO_2 0.18% (0.29%); TiO_2 0.00% (0.09%); Cr_2O_3 0.96% (1.30%); and FeO 0.00% (0.22%). (The figures in brackets refer to natural Burmese ruby). It is interesting to notice that it shared a small percentage of SiO_2 with ordinary natural ruby, while it was devoid of FeO. Interestingly, the ruby inclusion was not in epitaxial relationship with its host crystal, contrary to what one might expect in view of the high P-T conditions under which the ruby-diamond couple crystallized.

Rutile, (Figure 18) being one of the more abundant accessory minerals in eclogite, may be expected to occur as a guest mineral in diamond of eclogitic origin. Strangely enough it does not seem to be frequently found inside diamonds. Those few samples which

FIG. 18.

have been observed were reddish-brown in colour, moderately transparent, and prismatic, and two chemical analyses showed them to be conspicuously pure, with less than 0.4 wt% of other oxides (Meyer *et al.*, 1976).

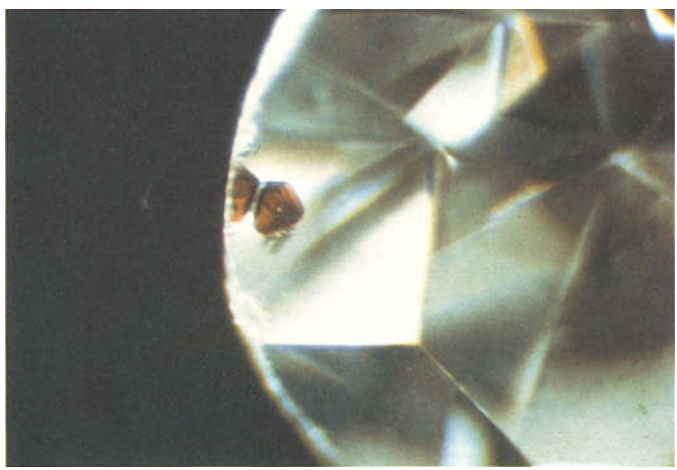

FIG. 19.

The existence of iron-rich biotite as an inclusion in diamond (Figure 19) is highly suggestive, because biotite decomposes to olivine plus other solid phases below 40 kbar, and to garnet plus other solid phases above 40 kbar. It is of value to remember at this instance that olivine in particular, but also garnet, are common primary inclusions in diamond. So far, however, mica has appeared only rarely as a guest mineral in diamond. The circumstances may indicate that biotite was only marginally stable under minimal conditions for diamond formation (Figure 7) (Giardini *et al.*, 1974).

FIG. 20.

Sulphide inclusions either with clearly pronounced crystal shapes or as irregular fragments are quite often encountered within diamond. The morphology is hardly ever theirs, but usually adopts the crystal faces and edges of the diamond habit. The inclusion portrayed in Figure 20 consists of a multimineralic assemblage pyrrhotite (FeS—major component), pentlandite (NiS—minor component in solid solution inside the iron sulphide), chalcopyrite (Cu-Fe-S—forms a kind of crust wrapping the other components)

and SiO_2, whose structure could not be determined, but which can only be coesite. The tension cracks darting out from this multi-mineralic inclusion into the diamond matter are very characteristic of many similar inclusions. Their blackness is not due to total reflection of light but to finely disseminated sulphide material, or graphite lining the walls of the fractures. The mechanism of deposition of these ultra-fine black films within fractures completely enclosed by the diamond host is not yet understood (Gübelin, 1977).

FIG. 21.

Diamond crystals within diamond (Figure 21) substantiate the conviction that diamond did not crystallize in one continuous process, but in periodical successions. The fact that in numerous host diamonds the guest diamond is not in congruent crystallographic orientation, elucidates that the latter did not act as a seed, but was rather overgrown at random. Sometimes two or even more generations may be found inside the youngest host diamond, and often the entrapped diamond is of darker colour (yellow to brown) than the enclosing crystal.

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AMBER FROM THE DOMINICAN REPUBLIC

By HELEN R. FRAQUET, F.G.A.

There has been some confusion in the gem world following the appearance of large quantities of amber from the Dominican Republic. Initial reaction has been guarded—that it is not amber at all, or that there is something, unspecified, wrong with it. In fact this amber was first noted by Christopher Columbus in the fifteenth century during his second voyage to the West Indies, and by the early twentieth century its appearance was being widely reported in quite obscure journals. The following is taken from the *Transactions of the Dumfriesshire and Galloway Natural History and Antiquarian Society* (Labour, 1914-15).

'A few years ago an interesting discovery of amber was made in the island of San Domingo. It appears to exist in considerable amount, and often in pieces of good size suitable for making carved objects of much beauty. It possesses a fluorescence similar to that seen in some of the amber from Catania, Sicily.'

The lack of identity for Dominican amber is explained by commerce, for until 1979 Germany purchased nearly all the amber direct from the island, and back in Europe it was mingled with Baltic amber, its source unacknowledged. Today any piece of amber has to be polished by the Dominicans before exportation, and it is against the law to export rough resin.

Research into amber has taken great steps forward since the mid 1960s. Tradition dictated that amber came from a pine-like tree, but most Baltic ambers give different infrared spectral patterns from modern pine resins, the pattern being nearer to that of the araucarian *Agathis Australis*. Also modern pine resins lack succinic acid—the second traditional attribute for amber (Langenheim, 1969).

The presence of succinic acid in ambers is now thought by some to be a by-product of ageing. 'Succinic acid occurs as a normal oxidation product of amber and is thus by no means indicative of its origin' (Rottlander, 1970).

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Whilst many papers are available on Baltic amber and ambers from North America, very little has been published about Dominican amber. With this in mind I made a field trip to the island in 1981, and the following is a report of my findings. I am greatly indebted to the staff and students of the Universidad Catolica Madre y Maestra (U.C.M.M.), at Santiago de los Caballeros, to Dr Pompelio Brouwer, retired Minister of Mines and Petroleum Products, and to his son Salvador Brouwer, Geologist with Falconbridge Nickel Ltd, for permission to refer to key, unpublished papers. In Europe I have received assistance from Dr Dieter Schlee, of the Staatlichen Museum fur Naturkunde, Stuttgart, Georg Dommel, of Ambar del Caribe, Dusseldorf, and Alan Jobbins, of the Institute of Geological Sciences, London.

The Dominican Republic comprises the eastern two-thirds of the island of Hispaniola (see map on page 323). It covers an area of 48 442 km^2 and is traversed by two mountain ranges—the northern Cordillera Septentrional, and the Cordillera Central, which boasts the highest peak in the Caribbean (Pico Duarte). The climate is sub-tropical (30 to 35 °C), and the Spanish-speaking population of five million is concentrated in three or four large towns, leaving much of the hinterland unpopulated and unmapped.

The amber found on the island is of several varieties, thought to be of differing geological ages. In the main it ranges from 25 to 35 million years old, but resin found in 1981 at Cotui is much more recent and should be classed with copal. The finding of a variety of ambers in one place is a common phenomenon; the amber from the Baltic region varies in age from Jurassic (Bornholm), through early Eocene (Danish Mo-Clay deposit—which does not contain succinic acid), to late Eocene (Samland Peninsula). Due to a deterioration in the climate the formation of amber in the Baltic seems to have stopped early in the Oligocene, somewhat later in Romania, while it was still functioning in the Miocene in Sicily (Larsson, 1975 & 1978).

Jean Langenheim, of the University of California, (1969) gives a list of geological occurrences and botanical affinities between some fifty ambers, using infrared spectroscopy to match absorption peaks in fossil and modern resins. The following examples have been extracted as being of interest to gemmologists:

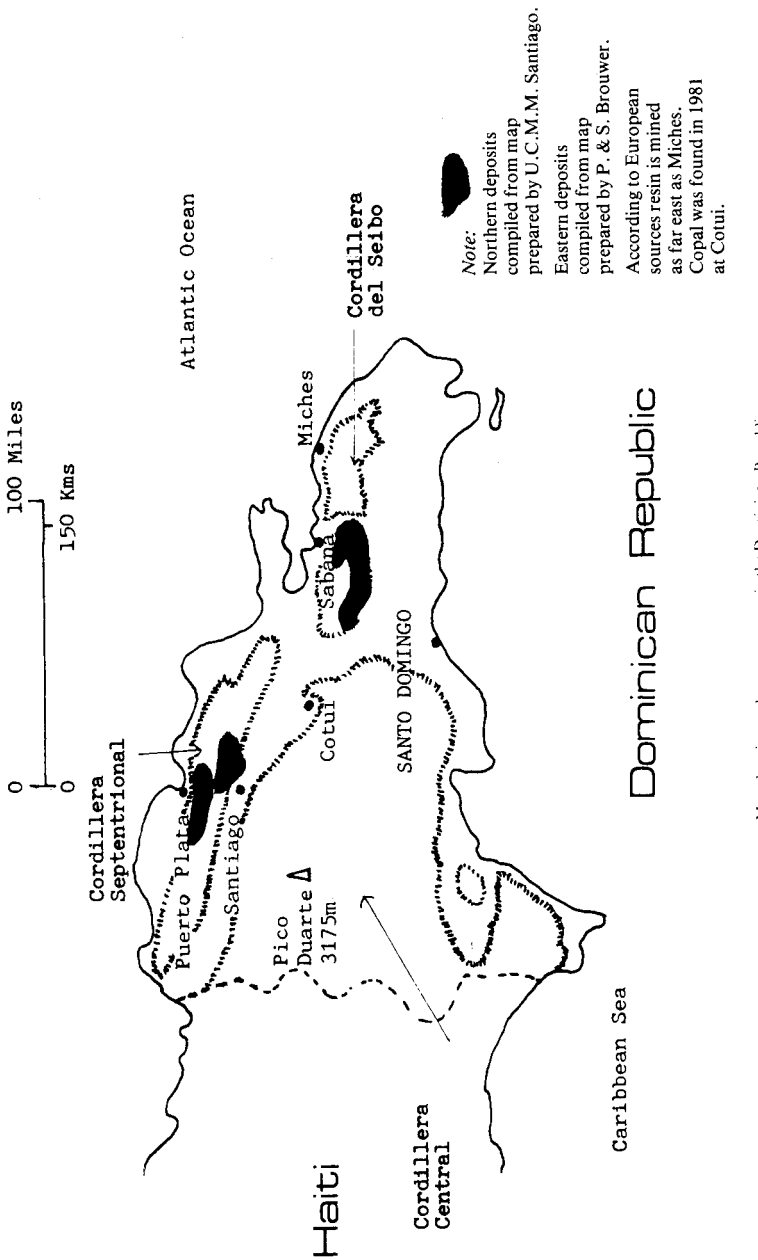

Map showing amber occurrences in the Dominican Republic.

Occurrence	*Geological Age*	*Possible Plant Type*
SE. Coast, England (London Clay formation)*	Paleocene-Eocene	*Burseraceae*
Hukawang Valley, Burma	Eocene	—
Baltic Coast	Eo-Oligocene/Miocene	*Pinaceae*
Dominican Republic	Oligocene	—
Chiapas, Mexico	Oligo-Miocene	*Leguminosae (Hymenaea courbaril)*
Romania	Miocene	—
Northern Sicily	Tertiary	—

Comparisons of infrared absorption spectra featuring Dominican amber appear in papers by Saunders *et al.* (1974) and Langenheim & Beck (1968). Six spectra of Dominican amber were shown in the latter paper. Four came from the Santiago area and gave a similar trace, but two from Palo Quemado gave more generalized spectra—possibly due to increased oxidation. The varieties were classified as Types I and II (although they came from the same region) and their spectra were found to be different from other North and South American ambers. As no extant group gave a similar pattern, the botanical source could not be ascertained at that time. Following my visit to the island in 1981 the Natural History Museum in London made a series of infrared spectra tests on my samples; their findings are given in the Appendix (page 332).

For the purpose of this report I am calling the two major amber deposits by the geological formations in which they occur. This is to prevent the oft-repeated errors which occur due to duplication of place names on the island.

Amber from the Altamira Formation

Amber is found scattered in a 60 km^2 area to the north and east of Santiago de los Caballeros in the Cibao valley. Within this area lie the deposits of Los Cacaos, Palo Quemado and Loma el Peñón, which produce high quality amber. The amber-bearing strata are exposed along three faults within the Cordillera Septentrional in the northern part of the island included in the Bahamas Arc. This fact is important, as it has long been speculated that there might be rich amber deposits in Haiti, which occupies the western third of the island, but the arc does not extend into Haiti.

*Highgate Copalite, included here since Judith Frondel, Harvard Univ., linked Highgate Copalite with the Baltic amber glessite. Using x-ray diffraction techniques to identify α-amyrin, these two fossil resins were linked to the *Burseraceae* family of angiosperm trees (Frondel, 1967).

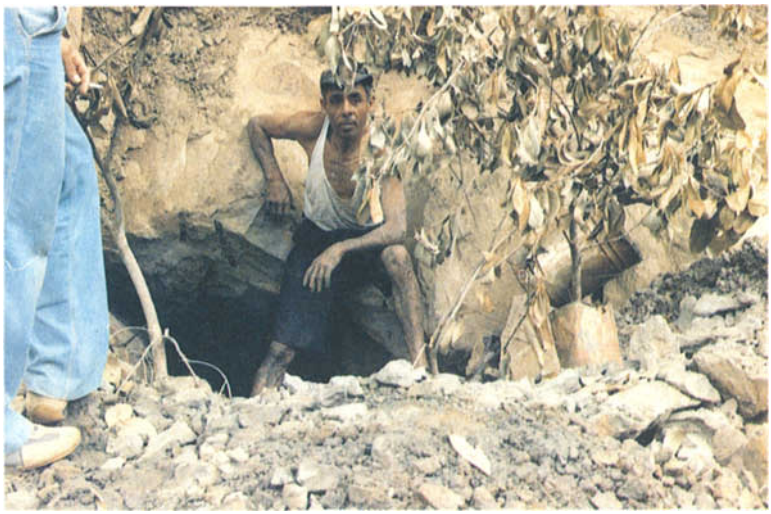

FIG. 1. Excavations for amber in grey mudstone near La Cumbre, Dominican Republic.
(Photo Helen Fraquet)

The amber occurs in a sequence of limestone, sandstone, mudstone and conglomerate, exposed by tectonic movements. It is restricted to the grey carbonaceous mudstone beds and is often associated with lignite. The mines of La Toca are associated with the upper NW.-SE. fault, those of Los Higos, Pulido and Rio Arriba with the central fault, and those of Palo Quemado and Los Cacaos with the lower SW.-NE. fault. The strata around the mines are extensively faulted, and altitudes vary from 300 to 1000 metres within short distances.

The following concise description of deposits is from a local university project undertaken in 1979 (Diaz *et al.*)

Location	*Altitude*	*Observations*
Palo Quemado	420m	Along a fault line, on the eastern side of Palo Quemado stream
west of Pulido	720m	Near a fault line, in unconsolidated mudstones
near La Cumbre road	700m	In layers of carbonaceous mudstones
Rio Amina	460m	On the west bank of the Arriba river, in a well-cemented sandstone
Los Cacaos	620m	Unconsolidated clay
Loma de Carlos Diaz, Rio Licey Blanco	500m	In massive material (limolita arenosa)
La Toca	700/800m	In layers of carbonaceous mudstones

The steeply-sided hills are covered with rough pasture or tropical hardwood forest, and access between settlement and mine is usually by footpath only. This difficult terrain hinders large-scale modern extraction of the amber, and most of the mines are simply holes, dug to a depth of 3 to 6 metres with the aid of pickaxes and shovels. There are many accidents due to landslips and seepage of water into the workings.

I visited two mines in the area. The first was about a kilometre off the La Cumbre road, down one side of a steep hill, across the boulder-strewn river in the valley, and about 100 metres up the other side. A vein of grey mudstone was being extracted from the sandstone hill, the miners working at some distance from each other to prevent landslips. The holes were dug with pickaxes, the harder sandstone being retained as a roof support. The mudstone was then collected in large tin cans or sacks and passed to workers outside the mine who washed the loosely consolidated mudstone with water and removed the amber. The extraction of the amber was unsystematic, and it was not clear why the mudstone was not taken to the near-by river to be washed in running water. One of the mines had caved in three weeks before my visit, and the owner was laboriously clearing away the overburden with the help of a wheelbarrow.

The second mine was about 10 km distant, and we were able to take the university Land Rover (a gift as part of an aid-project from the U.K.) to the site. Here a group of twenty miners were stripping the top-soil with the aid of a bulldozer. The machine had been hired by a merchant in Santo Domingo, the capital, and he was to take a percentage of all amber found. The expense would be justified, in the miners' view, as the amber they hoped to locate was of the blue fluorescent variety which commands the highest prices for export. At both mines I was told that the blue amber outcropped at the top of the hills, near the surface.

Amber from the Yanigua Formation

There is a certain lack of agreement between Dominicans and Europeans about the characteristics of amber from the east of the island. I myself found it to be a much brighter yellow, and brittle under the diamond saw unlike its northern neighbour, which can be sliced very finely indeed and is most satisfactory to work with.

The following information about amber from the Yanigua area is taken from a treatise prepared by S. and P. Brouwer (1980). It represents the Dominican viewpoint.

The amber from the east of the island is softer, and is thought to be younger than that of the north. However, its large size and the predominance of blue and green fluorescing varieties has encouraged the extraction of amber from this remote and inhospitable site since the 1950s.

The Yanigua sedimentary formation is of Miocene age, and its amber has much in common with amber found in Chiapas, Mexico. Amber-bearing strata occur in a series of small valleys, bounded to the north and west by the Los Haites karst platform, and to the south and east by igneous rocks, in part belonging to the Cordillera del Seibo. The sediments are similar to those of the Altamira—limestone, clay and carbonaceous mudstone (lutite). The amount of lignite associated with amber declines westward. The sediments are horizontal with little tectonic movement except at La Cumbre (El Valle zone) where the formation has tilted.

About fifteen small mines are concentrated around Sierra de Agua, Colonia San Rafael and Yanigua, the outcrops at Sierra de Agua being at the top of the formation and Yanigua the base. Extraction is by pickaxe, the mudstone is often softer than in the northern formation, and up to 80 lbs of amber may be found in a pocket. Problems associated with a difficult terrain (altitude varies from 100 to 400 m) and a high rainfall (2000 mm) limit mechanization, although transverse trenches are dug at Sierra de Agua and intermediate platforms for collecting waste are frequently constructed.

The amber is usually very clear and clean, and the fact that it is of larger size than that of the Altamira is possibly due to the area having experienced less tectonic disturbance. Inclusions in the amber from this location have been analysed at the Smithsonian Institution in Washington and were found to have associations with *Hymenaea courbaril.* This is the tree thought to have produced the amber from Chiapas, Mexico, and is of especial interest as it is an extant species, now growing near mangrove swamps in the tropics.

The largest piece of amber found on the island to date comes from the Yanigua, although it is invariably credited to the Altamira in translated literature available overseas. It weighs 18 lbs and was found in March 1979 in Sabana de la Mar county. The piece is now

displayed in Santo Domingo in the Plaza Criolla. Another fine piece weighing 10.56 lbs was displayed in the summer of 1982 at an exhibition of amber in Schaffhausen, Switzerland. The provenance of this piece is not known apart from the rough designation of 'northern cordillera'. It was found quite recently by a child planting a coffee bush. Both these pieces are oval and flat, of a dense rich brown colour similar to burmite.

COLOUR

The majority of amber from the Dominican Republic is of a transparent golden yellow colour. This is often not realized, for much of the amber appears to be rich mottled brown, but this colour is due to detritus included within the clear yellow amber. Very little of this 'brown' amber reaches Europe, most of it being exported to the U.S.A., where it commands high prices for curiosity value. The yellow grades from almost colourless (which I found for sale only at Puerta Plata on the northern coast) to a deep red. This latter is often due to a portion of the rough exterior being retained to lend depth of hue, a point confirmed by the frequency of crazing, associated only with newly-polished amber of this colour. Dominican amber will redden due to oxidation in common with other ambers. I examined several sacks of rough amber at source in the mountains, and extracted three or four pieces of ruby-red, deeply crazed amber which had a 'rusty' coating similar to Etruscan amber carvings found in museums. I had previously been shown lignite by the miners and told that this was 'over-ripe amber'; they were not convinced of the truth when I showed them the friable deep-red amber.

The blue fluorescent amber is an interesting phenomenon as the brilliant oily sheen only appears by reflected light as a surface effect. The blue can in some cases be replaced by a green or even purple hue, and these pieces are much sought after.

The finding of fluorescent amber (rather than amber placed under UV light in a laboratory) is very exciting, as it was previously thought that this type of amber only came from Sicily (simetite). The Sicilian source is now worked out, and, as the colour appears to fade once taken from the ground, I had despaired of ever handling any. The colour fades quite rapidly. Pompelio Brouwer had some blue amber photographed for an American magazine in

FIG. 2. Dominican amber showing colour variations in rough and worked material. *(Photo E. A. Jobbins)*

1977;* and when it is examined today, only a few years later, the marked deadening of the colour is very apparent.

The most famous amber fluorescing necklace was made of simetite for W. A. Buffum† in the nineteenth century. I located the gems in 1974, in an attic where they had lain undisturbed for 20 years. The once-brilliant red, pink, blue and green drops, which feature in so many jewellery books, are now a uniform cherry red.

Dr Dieter Schlee has undertaken a detailed study of this natural fluorescence and considers it to be due to the spread of organic particles emanating from wood, induced during a heating and melting of the amber lump (possibly due to volcanic action). Certainly the blue is evidenced widely in deep brown multi-inclusioned pieces. Amber which is quite clear and yet still shows a blue or green tinge is rare; it is very possible, however, that these pieces were altered by their close proximity to the more common wood-included amber.

Cloudy amber is rare. I only have one piece in my possession—a deep orange with cream swirling clouds. This is quite unlike anything else and bears a close visual affinity to amber found in Arkansas, U.S.A.

*Zahl, P. A., Nat. *Geo.Mag.*, September, 1977, 423-35.
†Author of *The Tears of the Heliades, or Amber as a Gem*, London, 1896.—Ed.

During my visit I also purchased three cloudy pieces of green amber—one blue/green and two olive green. Green amber is very rare indeed, I only saw one other piece, placed in a jeweller's window in Santo Domingo. It measured 2 inches by 1 inch and had been carved into a frog.

INCLUSIONS

The Dominican amber is very rich in inclusions, over 100 animal species have been identified already, and, because there is no mechanization, most of the insect, plant or mineral 'fossils' are seen by the labourers before they are lost in the production of amber jewellery.

Cataloguing of inclusions is now being carried out in Germany, Switzerland and the U.S.A., with the number of relatively large inclusions giving much excitement. It must however be remembered that, although bees, parts of geckos and even a complete frog have been recovered, these specimens are much smaller than their modern equivalents. When one speaks of a bee or a wasp in amber, the actual inclusion is probably only 5 mm in size. If one is presented with a modern look-alike which measures 25 mm, the piece is a fake. The fossil inclusions have not shrunk; it is simply that the larger specimens had the power to climb out of the sticky resin and free themselves.

Occasionally the inclusion will have retained its colour. There is a very famous example of a beetle with brilliant green iridescent wings, and flies with red or yellow eyes. The inclusions which I find most interesting are those which depict movement, ants carrying young grubs, or fighting termites. Dr Paul Whalley, of the Natural History Museum at South Kensington, was kind enough to examine a series of inclusions I brought back to this country, and his initial comments are as follows:

Specimens 1 & 2 contain small parasitic wasps *(Hymenoptera)*

Specimen 3—a large peltid beetle, a scolytid beetle and a fly

Specimen 4—a caterpillar—probably an early instar of a noctuid moth

Specimen 5—fragments of plants, a beetle and a delicate gall-midge

Specimen 6—a spider and termites—the latter are the family *Termitidae* and are one of the workers of the group

Specimen 7—plant debris
Specimen 8—plant debris
Specimen 9—Crane-fly *(Diptera, Tipulidae)*
Specimen 10—Parasitic wasps *(Hymenoptera)*
Specimen 11—Mordellid beetle *(Coleoptera)*
Specimen 12—*Lepidoptera,* gelechoid moth

One of the termites and the caterpillar skin are being investigated more fully, and the plants are to be dealt with at a later date.

Little work has been carried out to date on the mineral inclusions, and unfortunately the paper by Flamini *et al.* (1975) did not cover Dominican amber. However, I have observed two-phase (gas-bubble in liquid) inclusions, and metallic dendritic forms. I found no 'sun spangle' stress inclusions in Dominican amber, confirming the findings of Crowningshield (1977-8). This surprised me as they are a common occurrence in nature, even in amber from our own East Coast, as evidenced by the Perowne Collection in the Sedgwick Museum, Cambridge.

MANUFACTURE

Most of the amber is transported from the hills by mule, and polished in the larger towns behind the merchants' shops. Even the smallest pieces are used, the outer crust being removed on an emery or wooden wheel and the finish applied with tripoli powder and a cloth wheel. The poorer pieces are sold by street vendors and, although cheap, are usually chipped and ill-matched when examined in detail. The only evidence I found of processed amber was the production of tiny chips into cast resin picture-frames. From the gemmologist's point of view the most dangerous development has been the coating of recent copal-like resin, which comes from the Cotui area, with an epoxy compound to render it more stable and less likely to craze. This venture to my mind has put in doubt the whole production capacity of several hundredweights of genuine fossil resin a year, and, unless it is stopped or the government press for it to be sold under a separate name, I foresee major problems.

Amber has been finished into jewellery on the island since the 1950s, when a Cooperative of Industrial Artists was set up by the Government. Many similar schemes have followed, the last being set up in Santiago in March 1981, but the Dominicans seem happier

to produce at their own pace, without western-imposed regimes of order-dates and completion schedules.

The quality of the jewellery is poor with few exceptions. This is very sad, as the quality of the amber is excellent. What seems to be missing is a sense of pride or self-discipline, which would ensure that the beads of a necklace were at least drilled through the centre or that pendants were finished without cavities due to slipshod workmanship. I found only one merchant on the island who stocked really first-class items, but unfortunately he was not on the government list of official exporters, and I have had monumental difficulty in obtaining shipments from this man.

The design of the jewellery is pleasing; the clear, limpid character of the resin lends itself to the production of free-form pendants and pastille-drop necklaces. Bands of soft wire are bound round the amber lumps to make them secure and attached to each other by s-linked chains. This style of jewellery is very distinctive and unique to Dominican amber.

Much of the carving is geared to the American market. Americans have long visited the island in cruise ships, and larger lumps tend to be carved with North American Indian braves. Smaller lumps depict Central American folkart or even Buddhas. I asked about this strange subject matter and was told that the market tended to divide into the ethnic and the antique, so the Dominicans covered both spheres. Less common were carvings of elephants, domestic animals, or odd mis-shapes glued together to represent mushrooms, a man walking his dog, a couple sitting on a bench, etc. However, the pieces I consider a real success are the heart, leaf or natural drop-shaped pendants; these are quite beautiful and merit a place in any jewel box.

The only care Dominican amber needs is the usual prevention of oxidation. To keep the surface from crazing or becoming dull, an application of natural wax should be used. The amber should be kept away from strong light and heat and preferably stored in a box to prevent it being smashed by harder objects in the gemmologist's collection.

Appendix

The infrared spectra of five specimens were obtained using a Perkin Elmer model 683 spectrophotometer. A few milligrammes of each resin were ground with dried potassium bromide and pressed into discs before recording their spectra over the wavenumber range 4000 to 400 cm^{-1}.

1. Miches specimen. This clear yellow, very friable material gave a typical copal or recent resin spectrum with sharp intense peaks. The spectrum very closely matches those of some African copals in the collection of the British Museum (Natural History), particularly those from Sierra Leone, Congo and Zanzibar.

2. 'Best Santiago Amber'. A pale yellow-brown cohesive resin, difficult to grind.

3. La Cumbre (Santiago deposit). A deep red resin.

4 and 5. 'True Green Amber'. Two pale green, cloudy carved specimens bought in Santiago or Santo Domingo.

These last four specimens gave similar spectra, typical of retinite type fossil resins. The differences in the spectra are almost entirely in the intensities of the two peaks at 1640 and 885 cm^{-1} and hence are probably related to age or degree of oxidation.

The Miches specimen has the highest volatile content and shows the strongest 1640 and 885 cm^{-1} peaks, while the others show a progressive decrease in the intensity of these peaks together with a general broadening of the spectral pattern from specimen 2 to 5. These other spectra also show a gradation between the two Dominican types given by Langenheim and Beck (1968) and have a close resemblance to their type 1 spectral pattern for amber from Chiapas, Mexico.

G. C. Jones, Department of Mineralogy, British Museum (Natural History).

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THE STRUCTURE OF CAMEO SHELL

By R. KEITH MITCHELL, F.G.A.

Comments on this subject at the end of A. E. Farn's interesting contribution to the October 1980 issue of this *Journal** prompted me to take a closer look at some of the cameos in my possession. Mr Farn and I are both somewhat fanatical in our belief in making full use of the 10× lens, and I feel slightly surprised that neither of us has commented on this structural feature before.

In most, if not all, cameos examined, I found that the brown, orange-brown or pink layer (the inside of the shell which is normally used as the background surrounding the raised white shell of the cameo) has its very fine grain running in more or less parallel lines in one direction, while that of the white raised cameo runs approximately at 90° to it. Simple and easily seen grain is illustrated in Figure 1, but it will be noticed that here it apparently does not extend over the whole cameo. Careful lighting and focusing might find it in other parts, but grain is rarely obvious in the white part of the shell. In fact it is present over almost all of this small broken fragment, and on the hip of the figure and the rump of the horse its direction is at right angles to the grain I have illustrated.

It is almost impossible to get macrophotographs showing all the grain in the several layers involved, owing partly to the fact that white grain on white shell needs very careful lighting and exposure and, more particularly, to the further fact that each layer is at a different focal distance and the depth of field is not sufficient to bring them all into focus at one time even when working at the smallest apertures. For this reason the fine cameo head in Figure 2 has had the directions of the grain inked in. The dark brown background is grained vertically; the edges and other lower parts of the outlined head are grained roughly at 90° to the brown layer grain, while the major part of the head is high (thick) enough to break into yet another layer in which the graining is again parallel with that of the brown base layer. The graining of the lower layers continues, of course, under all higher layers. The inked lines indicate only the directions of this graining. The actual spacing of grain lines is variable, but is usually very fine and close together.

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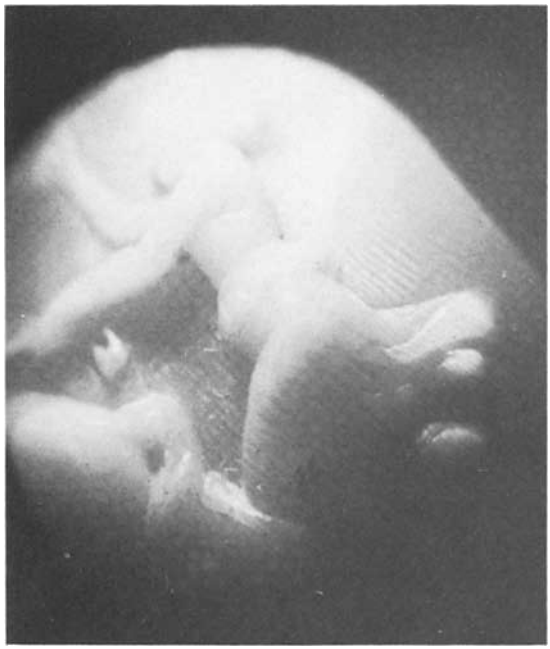

FIG. 1. White 'grain' seen quite clearly in part of an antique shell cameo. ×6

The appearance is not unlike that of the flecking that is seen on conch pearls. There are about thirty grain lines in the length of the nose of this cameo, while there are more than 100 lines in about a 6 mm length of the coat collar. In each case the effect is seen most clearly when light is shining along the grain rather than across it, and often only then. In some areas it is quite difficult to see and requires much manipulation of lighting, cameo and lens to bring the grain into prominence.

Microscopic examination of a fairly thick broken edge of another cameo showed that the grain lines appear to be composed of criss-crossing straps of rather fibrous-looking crystals, approximately at the angles expected of aragonite rhombohedra. In the sea, any spaces present would be water-filled. In dry shell they contain air. The visible grain marks the lines of weakness in each single layer and any cracking tends to follow the grain direction. This is a serious matter affecting the survival of the univalve animal, and nature has seen to it that strength is obtained by allowing successive layers to cross, rather in the way that wood

FIG. 2. A fine shell cameo in which grain directions have been lined in to show how successive layers have the 'grain' in directions roughly at 90° to each other. × 4

grain is crossed in a plywood sheet. Some parts of each shell may contain areas which are too dense to exhibit graining, and it may be that successive layers are separated by very thin ungrained layers. The coat of the head illustrated has exceptionally close grain and is probably approaching an area which would show no graining.

Mr Farn's interest was awakened by a question about shell cameo doublets and he rightly pointed out that these are unlikely to have been made owing to the difficulty in finding two pieces of concave shell which would exactly fit each other.

But, in searching through my own shell cameos, I found an antique one (Figure 3) in a simple gold mount which is made from almost flat shell, the carved front showing nicely developed grain and a backing which appears to be the normal orange-brown layer, but which is badly cracked (Figure 4) without any sign of the cracking being visible from the front. A powerful fibre optic light source allowed me to see into the cameo and obtain the photomicrograph shown in Figure 5. This shows a layer of what is

FIG. 3. An antique cameo which on closer examination proved to be a doublet. ×5

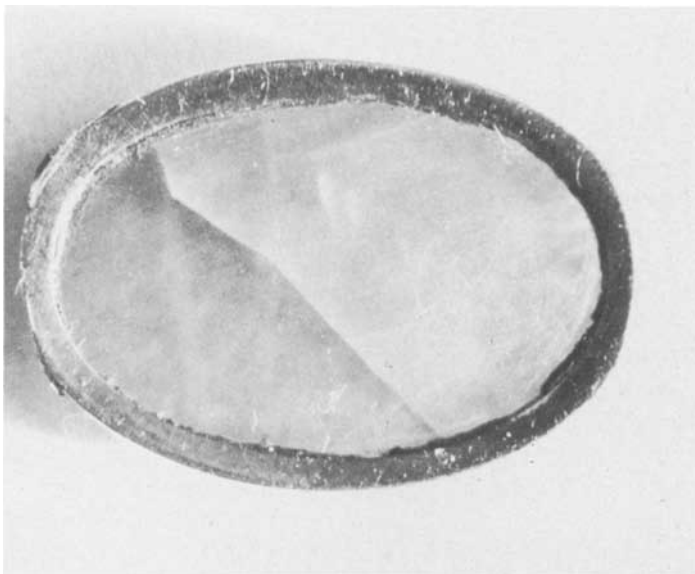

FIG. 4. Back of Figure 3, showing that this is badly cracked while the front is undamaged, suggesting that the two layers are not contiguous.

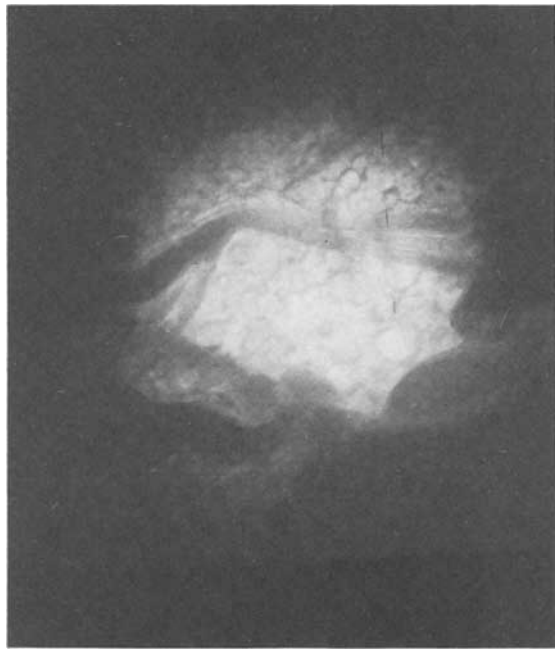

FIG. 5. A powerful light shone through the cameo doublet reveals a layer of what can only be a dried organic adhesive. The orange-brown of the back was almost certainly in this layer and when fresh probably affected the low-carved areas of the cameo front. × 10

undoubtedly dried out adhesive, almost certainly an organic glue, which is also probably responsible for most of the colour seen in the backing layer. Mr Farn is probably right in his surmise that such a cameo would be difficult to make, but this is proof that it is not impossible. *Why* it was made is not known.

A further reward resulted from this search. Another white cameo, earlier dismissed as a thin and rather uninteresting shell carving, showed no signs of any of the expected graining and had a very glassy looking base layer. It was cold to the tongue (shell cameos are also colder than paste in this test), was birefringent in all positions between crossed polars and eventually proved to be a very nice antique chalcedony hard-stone carving on a classical satyr-and-nymph theme.

Cameos have been moulded in a porcellanous pink and white paste, but these never show any graining.

[*Manuscript received 7th May, 1981.*]

OILED OPALS

By R. KEITH MITCHELL, F.G.A.

Way back in pre-war days I remember a very reputable jewellery manufacturer buying a badly cracked ruby and commenting that I would not recognize the stone once he had finished oiling it.

It is fairly common knowledge that cutters have made a practice of oiling some emeralds to reduce the visibility of cracks. Here it is said that heated tallow is used, but there is no definite information on the process, which is probably regarded as a lapidary's secret.

In the past year or so I have seen a number of very nice opals offered with a note that they have been oiled. The prices asked have been quite low for the apparent quality of the stones.

Opal is known to consist of close-packed spheres of amorphous silica which, when these are in regular layers and of one size, give rise to the well-known play of colour due to diffraction at a lattice of voids. These voids are the spaces between the submicroscopic spheres which, although in contact with their neighbours, cannot fill all the space available.

It is known that all opal contains from 6% to 10% of water. Most of this is held in the voids or interstices between the spheres, but some may be trapped in the spheres themselves.

In opals from some localities there are sufficiently spaced gaps in the structure to allow a very slow evaporation of this water content, and eventually fine hair-line cracks develop due to shrinkage, and, being air-filled, these are all too obvious and spoil the opal.

Figure 1 illustrates such an opal ruined by drying cracks. In this stone the play of colour is confined to the front of the cabochon. The back is a putty-coloured potch which was evidently less porous and did not shrink by the same amount. Another large opal had a similar structure, but both the gemmy section and the potch had developed drying cracks. In this case the cracks in the two layers were roughly at 90° to each other.

Cracks in opals are more easily seen if the stones are examined with light passing from one side across the cracks. If it passes down

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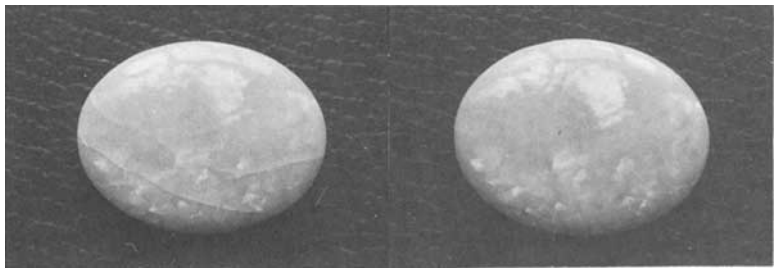

FIG. 1. Untreated opal ruined by drying cracks. FIG. 2. The same opal after immersion in a fine oil. Cracks are completely concealed but are *not* cured.

their length the cracks are less easily seen. Vertical illumination also tends to make them less visible.

By no means all potch-backed stones will develop cracks. Equally it cannot be said that a homogeneous stone will not crack. Usually stones from certain localities seemed to be more prone to the trouble than are stones from another area. Drying cracks usually come right to the surface of the stone but rarely go right through it.

Figure 2 shows the same opal after immersion in a fine oil at room temperature for several hours. The oil has a RI of 1.413, a little lower than that of the opal. Ideally they should be of the same RI, but it is not easy to find a stable oil, which will not discolour, with the exact RI. This one is close enough, and it has entered the cracks and removed the air in all but one place on the left-hand edge of the stone. They are no longer visible. The failure to fill this one crack is probably due to its width at this point. One might expect air to be trapped by the oil, but it seems to penetrate fully and to push out the air.

The cracks may become visible again fairly quickly as the oil itself evaporates, but it will be some time before they become as obvious as they were before treatment. Oil might oxidize, but, cut off from air by the closeness of the cracks, this would take time. It is more likely to become dirty by contamination.

If such opals are offered as untreated stones their detection may be a little difficult. Newly treated stones might have a faint scent of the oil about them; their surface may be slightly oily and difficult to wipe clean. Immersion in a solvent, such as spirit, may

remove some of the oil and bring the cracks into prominence again. Soaking in warm water for some hours in a black container may reveal 'oil-slick' traces.

A very careful examination of the surface of the stone will often reveal the edges of otherwise invisible oiled cracks as very fine hair-lines. To see these it is necessary to allow light to reflect from the surface and to examine this closely with a 10× lens. Concentrate on the reflected light and ignore play of colour or any subsurface light. In the stone illustrated only two of the several cracks were detectable in this way. If the crack edges are easily seen then the stone can be one which was unusually badly affected by the drying cracks. Easy-to-see cracks after treatment usually mean that the cracks were wider than usual, or that the stone has been repolished. Felt-pen ink rubbed into the surface of the opal may concentrate in the edges of cracks and make them more easy to see. This is destructive testing, but such ink can usually be removed by wiping it immediately with a swab of cotton wool moistened with spirits. The ink may collect in surface scratches, so some care in interpretation is needed.

The ethics of oiling are not clear. If an opal is sold with the information that it is an oiled stone then no one can complain. If the seller knowingly omits to mention the fact of oiling and obtains a higher price for a damaged stone, then clearly that is improper. But difficult problems may arise when a seller is quite unaware that the stone he is selling has been oiled. Whether it is actionable as contrary to law is a question for lawyers, depending as it does both on the precise facts and on whether they can be proved.

[*Manuscript received 25th May 1982.*]

SOME OBSERVATIONS AND MISCONCEPTIONS REGARDING OPAL

By G. A. COOK, F.G.A.

Now the melancholy god protect thee, and
the tailor make thy doublet of changeable
taffeta, for thy mind is a very opal!
Shakespeare, *Twelfth Night*

Opal—that wonder of the mineral world whose mysterious fire has lighted men's imaginations since early times—has had a curious and chequered history as a gemstone of worth comparable to the change in its own scintillating patterns.

Until recent times, opal must have been a rare gemstone. Pliny states that India was the sole origin of the stone. This location is disputed by many authorities, who state that Hungary must have been where the mines were situated since it was closer. Hungary in those days was possibly incorporated in the frontier province of Dacia, the Hungarian plain being the western portion of this area. The situation of the mines is only a 'stone's throw' from the plain at Červenica, and other locations nearby, which are in present day Czechoslovakia. Records suggest that mining started in the thirteenth or fourteenth centuries, and evidence is required of mining prior to this.

The Romans, Pliny in particular, are generally accurate in describing locations of gems. For instance, India is held to be the source of diamonds, rubies, sapphires, star sapphires, aquamarine, moonstones and emeralds. India produces these stones to this day, emerald having comparatively recently been rediscovered there. There is thus little reason to dispute Pliny stating that India is the only location in his time, although he describes another stone called 'Paederos' which seems to be similar to opal and has a white 'background': the finest quality of this came from India, but he mentions other sources for lower grades. Common opal is found near Bombay. Could not the mines be long lost and await rediscovery? Or were they perhaps worked out? Or was Pliny referring to other stones which display iridescence, like labradorite, opalized agate, or the recent discovery in Canada called Ammolite?* The name of opal itself is of Sanskrit origin and means

*See W. Wright, 'Korite'—Fossil Ammonite Shell from Alberta, *J. Gemm.*, 1981, XVII, 6, 406-15; the name for this material now approved by C.I.B.J.O. is 'ammolite'.—Ed.

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'precious stone', having reached us through Latin.

Opal has had a reputation in recent times for bad luck. This is probably due in part to its softness, its sensitivity to sharp knocks and pressure. Amorphous material lacks the durability of crystal.

Bad luck? Possibly as an investment. However, if opal is taken care of, it should stand the test of time. There is a specimen in the Museum of London which is a fine water opal—part of a jeweller's hoard from the seventeenth century. The stone is as fresh as the day it was cut. It would be intriguing to discover the origin of this stone.

Opal should avoid modern detergents. If the stone has crazing, the solution of water can seep into these fissures through the lowering of surface tension and undermine the stability of the gem. Tales of woe have been heard of opal disintegrating during the domestic chore of washing dishes, not to mention the deleterious effect of the abrasion of this process. Gemstones deserve better treatment.

Sir Walter Scott is regarded as the instigator of the legend of the 'Curse of the Opal', possibly drawing, we hear, on earlier Germanic legends. The relevant passages occur in *Anne of Geierstein* published in 1829. This late production of Scott was written at a time when he was endeavouring to wipe out a large debt and prolifically produced several uninspiring works. The novel takes place in medieval Germany and Switzerland during the time of Charles the Bold and concerns the fortunes of one Arthur Philipson, who is in reality the son of the Earl of Oxford, working for the Lancastrians who are anxious to secure the Duke of Burgundy's favours.

A minor character, Lady Hermione, who has little bearing on the main plot, wears an opal talisman clasp in her hair. This lady is said to be of Persian origin and she appears as if out of nowhere. She marries the Baron Arnheim and becomes his spiritual tutor. Hermione fancies that the opal reflects her many moods. A malevolent character called Madame de Steinfeldt tries to cause rumours about the family indulging in sorcery. To 'confute the calumnies' of this lady, Baron Arnheim makes a display of dropping holy water on his wife's forehead, a drop of which accidentally touches the stone with which Hermione always

avoided having contact. At this moment the stone gives out a sparkle and goes lifeless. After which time the girl goes into a swoon and is carried off to her room. When the room is opened after a period of time, nothing is found except a pile of ashes on her bed. Later in the novel it is mentioned that the Baroness de Steinfeldt was thought to have administered poison. The opal was supposed to warn its wearer of the approach of poison. This indicates that, although the lady suffered an unfortunate fate, it was not in fact due to the opal. But, although the gem changed, its wearer could not avoid the subtle poison of hate. Scott states that the holy water dulled the stone. This property does not occur with normal water. Opal brightens in water; this fact is often used when rough material is sold. Hydrophane opal too becomes iridescent when immersed in water.

In the book it mentions the malignant baroness also possibly laid claim to the stone as the Persian lady's family won it in battle from the Soldan (Sultan) of Trebizond. This is interesting as Trebizond is in present day Turkey, which is a minor source of opal; in the region of Gediz in Anatolia fire opal occurs in rhyolite. Later in the book, however, another girl, Annette Veilchen, states: 'Oh! a single daisy twisted with content into one's hair is worth all the opals in India, if they bind us to torment ourselves and other people, or hinder us from speaking our mind, when our heart is upon our tongue'. This indicates that country as being thought to be a major source of the gem in Scott's day; the rest of the sentence is open to interpretation.

As far as being a Talisman to warn the bearer of the approach of poison—the present writer can attest that once, while camping on a beach in Mexico, he awakened in the nick of time as a scorpion was about to sting his neck. He had in his possession a box of opals recently negotiated. Bad luck? Certainly not. A Talisman? Well, he would certainly like to think it was at least due to this in part.

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[*Manuscript received 14th April, 1982.*]

GEMMOLOGICAL ABSTRACTS

BAKER (E.). *The 'big hole' has been drained.* Lapidary J., **36,** 1, 36-58, 20 figs (19 in colour), 1982.

Gives an account of a visit to some of the South African diamond mining operations. M.O'D.

BALL (R. A.). *Further studies on iridescence of marine shells.* Aust.Gemmol., **14,** 10, 266-71, 2 diagrams, 8 figs, 1982.

An account of earlier work on this subject with photomicrographs which emphasize the structural dependence of the phenomenon. R.K.M.

BANERJEE (A.), PENSE (J), SCHNEIDER (W.). *Der schwarze Diamant.* (Black diamond.) Uhren, Juwelen, Schmuck, 6, 47-9, 5 figs, 1979.

The possibilities of black diamond as an ornamental stone are discussed. M.O'D.

BOLICK (K.). *We mined for emeralds.* Lapidary J., **36,** 2, 410-12, 1982.

An account is given of amateur mining in the Hiddenite area of North Carolina. M.O'D.

BOSCH FIGUEROA (J. M.), DE LA FUENTE CULLELL (C.), ARBUNIÉS ANDREU (M.). *Estudio mineralogico y gemologico de los olivinos de Yaiza (Lanzarote).* (Mineralogical and gemmological study of olivine from Yaiza (Lanzarote).) Gemologia, **14,** 49/50, 5-18, 9 figs (1 in colour), 1981.

Olivine from the basaltic lava of Lanzarote has some gemmological interest. Physical and optical properties are established; material is found as rounded pebbles, some containing chromite crystals. SG is 3.341-3.364, RI 1.650-1.659, 1.688-1.694 with a DR of 0.035-0.038. Three absorption bands were detected at 497, 474 and 455 nm.

M.O'D.

BROWN (G.). *The geological time scale.* Wahroongai News, 9-10, December, 1981.

Lists geological ages, eras, periods and epochs, but not all in the same direction. R.K.M.

BROWN (G.). *A system for identifying turquoise.* Wahroongai News, 21-3, December, 1981.

A logical sequence for identification of turquoise and detection of imitants, simulants, synthetics, dyed and waxed stones. R.K.M.

BROWN (G.). *Identifying Gilson synthetics.* Wahroongai News, 5-6, January, 1982.

Very brief identifying features for Gilson synthetic emerald, turquoise, opal, lapis lazuli and coral. R.K.M.

BROWN (G.). *A visit to Australia's first commercial emerald mine.* Wahroongai News, 13-17, 2 figs, April, 1982.

An interesting account of an historic mine near Emmaville in the mountains of NE. New South Wales which was discovered in 1890. It produced green beryl which shows no apparent sign of chromium content and so is referred to by the writer as '? emerald'. The yield was poor in quality, and, once the exploratory vertical shaft had been driven to 300 feet without finding more and better deposits, it was more or less abandoned until 1965, when it was surveyed again. In 1981 it was 'dewatered and demucked' with the idea of working the shallow lode again. [Abstracter has a small parcel of 'Australian emerald rough' which almost certainly dates from the 1890s. The crystals correspond closely with Mr Brown's description of the beryl from this mine. They show no sign of chromium but are recognizably an emerald colour.]

R.K.M.

BROWN (G.). *An interesting amber imitation.* Aust.Gemmol., **14,** 10, 272-3, 3 figs, 1982.

A bead necklace of amber enclosed in polyester resin. R.K.M.

BROWN (G.) *Lechleitner coated beryl inclusions.* Aust.Gemmol., **14,** 10, 274-5, 6 figs, 1982.

Well illustrated account of these inclusions. R.K.M.

BROWN (G.). *Metamict gemstones.* Wahroongai News, 19-21, May, 1982.

A general explanation of the metamict condition. Raises question why U and Th atoms cause metamictization in some minerals and not in others. [Age of mineral deposits has something to do with it. Gem deposits of Sri Lanka, source of the only two metamict gems, low zircon and ekanite, have derived from extremely old rocks. The process is a very long slow one.] R.K.M.

BROWN (G.). *Korite = a unique organic gem.* Wahroongai News, 17-18, May, 1982.

A description of this ammonite gem material* which retains its spectacular iridescence despite 70 million years as a fossil. History of its discovery and marketing is given. Author suggests that it can be identified by its RI (1.52-1.67) and its SG (about 2.80). [But most material is made up into doublets with quartz cabochon tops which would make such tests difficult. Iridescence is probably enhanced by the dark matrix.] R.K.M.

BROWN (G.), BRACEWELL (H.). *Chudleigh Park peridot.* Aust.Gemmol., **14,** 10, 253-6, 8 figs, 1982.

Interesting account of a little-known source of gem peridot at Mount Batchelor in North Queensland. Cut stones up to 20 ct possible in yellow-green to deep green. Brown shades are not found, suggesting that the material is low in iron. Reticulated cracks and other inclusions are thought to be peculiar to this source. R.K.M.

BROWN (G.), SNOW (J.). *The Portalab.* Aust.Gemmol., **14,** 10, 258-63, 11 figs, 1982.

A report of the G.A.A. Instrument Evaluation Committee on a portable testing kit of zoom microscope with fibre optic quartz halogen light source, polariscope,

*The name for this material approved by C.I.B.J.O. is 'ammolite'.—Ed.

spectroscope, UV lamps, refractometer, heavy liquids, dichroscope, hot-point tester, polishing cloth and electric circuitry, which packs into a 45 × 33 × 15 cm carrying case and weighs 13.5 kg. Total cost £1500 plus. Stability of microscope mount is criticized. R.K.M.

BROWN (G.), KELLY (S. M. B.), MAIN (A.). *Examination of a cat's-eye iolite.* Aust.Gemmol., **14,** 10, 264-5, 6 figs, 1982.

A rare form of this gem. R.K.M.

BUTLER (J.). *Suggested fluctuations in trade popularity of some gem materials during 1980.* Wahroongai Nes, 7-8, January, 1982.

Attempt to assess popularity by amount of trade advertising. [This confuses cause with effect.] R.K.M.

COOKE (C.). *Collecting gemstones in Wyoming.* Lapidary J., **36,** 1, 228-34, 9 figs, 1982.

Though jade is the most important gem material found in the State of Wyoming, other materials of ornamental interest are also found. They include agatized wood, dinosaur bone, chalcedony with black dendrites, small diamonds and obsidian. M.O'D.

CROWNINGSHIELD (R.). *Cultured ¾ blister pearls.* Gems & Gemology, **XVIII,** 1, 36-8, 8 figs in colour, 1982.

A new type of three-quarter blister cultured pearl from the Philippines, in which the nacre covers a large bead very closely. Compares favourably in durability with the much more fragile mabe blister pearl which suffers from structural weakness and is easily damaged. The new type is often attractively coloured and marked with slight convergent grooves. R.K.M.

DAHLBERG (J. C.). *Take another look at Minnesota rocks.* Lapidary J., **36,** 1, 66-72, 17 figs in colour, 1982.

Among ornamental stones found in the State of Minnesota are quartz (rock crystal), jasper, massive goethite, pyrite, marcasite, yellow binghamite and haematite in the form of kidney ore. M.O'D.

DAVIES (G.). *The origin of the 'N2' absorption band in natural yellow diamonds.* Portugaliae Physica, **12,** 3/4, 241-61, 6 figs, 1981.

The N2 band, one of the causes of the yellow colour in some natural diamond, is shown to correlate in strength with the N3 band (which absorbs mainly in the ultraviolet portion of the spectrum). The N2 band absorbs in the visible. The yellow colour is caused by the operation of both bands. The N2 band is discussed. M.O'D.

DILLON (S.), ed. *Gems news.* Gems & Gemology, **XVIII,** 1, 58-61, 3 figs (2 in colour), 1982.

Ashton Mining (Australia) predict annual production circa 20 million carats of diamond by 1986. Cut diamonds mêlée from Russia is causing anxiety among cutters in Belgium. Ghana's remaining diamond mine may close. Australia is backing diamond production in Guinea. Indian cutters seeking new sources of rough

diamond. Israel diamond processing is increasing. South Africa opens diamond bourse. Sunsvall, Sweden, is location of first diamonds found in Europe. South African company has started diamond cutting in Taiwan for Far East market. General Electric, U.S.A., are imprinting diamonds with electro-static identification which attracts a dust to form numbers which can then be wiped away.

Aquamarine specimen from Dassu, Pakistan, is illustrated. Synthetic amethyst is being marketed as natural and is largely undetectable. Russia is producing synthetic opal. Israel is now the largest emerald polishing centre. A 4.02 carat taaffeite is reported. Pala tourmaline mine has tunnelled 715 feet into new pegmatite areas and found four pockets of crystals, mostly uncuttable.

Tucson Gem and Mineral Show: aquamarine from Brazil and Afghanistan, fine emeralds from Afghanistan and Pakistan, Umba River corundums, orange garnets and tsavolites, cultured Biwa pearls from Japan and China, peridots, spinel, spodumene, sugilite, topaz and tourmaline were on display. Tanzanite was scarce.

R.K.M.

DONNAY (G.), DONNAY (J. D. H.). *Symmetry and twinning in diamond.* Soviet Physics-Crystallography, **26**, 6, 729-32, 1981.

Though tetrahedral habit is known in natural diamond it has never been reported from synthetic material. It is believed that natural tetrahedra grow in the presence of graphite and methane (i.e. 3- and 4-coordinated carbon). Diamond is assigned by structural crystallographers to point group $m\bar{3}m$, which assumes eight equivalent carbon atoms in the cell. Morphologists assign observed forms to $\bar{4}3m$, which postulates two types of carbon atom. M.O'D.

FERGUSON (R. W.). *Graveyard Point 'Pilgrimage'.* Lapidary J., **36**, 2, 384-401, 23 figs (15 in colour), 1982.

Graveyard Point lies just inside the Oregon border with Idaho. The material sought is plume agate with a clear to white background with plume-like formations which can be orange to brown or even black due to marcasite inclusions. M.O'D.

FRYER (C.), ed., CROWNINGSHIELD (R.), HURWIT (K. N.), KANE (R. E.). *Gem Trade Lab Notes.* Gems & Gemology, **XVIII**, 1, 44-9, 21 figs (18 in colour), 1982.

Diamond with roiled table facet, an emerald ring from a three hundred year old wreck, and a fake emerald crystal made by hollowing out a low grade beryl crystal and filling it with green cement, are described and illustrated. A possible synthetic green beryl reported from Australia. Other unusual synthetic emeralds are described and illustrated, some transmitting red flashes in strong lighting. A light pink carved head proved to be pink common opal. Mr Crowningshield reports that Lake Biwa pearl cultivators have some control over the colour and shape of the pearls produced. He saw Australian blister pearls which used coloured plastic inserts which were highly transparent to x-rays. Also he reports that most Australian yellow sapphire rough is heated to remove the green element and to lighten colour. Some Bangkok light yellow sapphire from heated colourless rough is colour fugitive. Darker stones said to be permanent in colour. Sugilite used in bead, cabochon and carved forms is splendidly illustrated. A 10.13 taaffeite identified at Santa Monica lab. is thought to be the largest one so far recorded. R.K.M.

GOLDMAN (S.). *GE develops process to brand codes in diamonds.* National Jeweler, pp.41-2, 2 figs, May 1, 1982.

A report on the work of Dr R. C. DeVries and R. E. Tuft, of General Electric, Schenectady, N.Y., which describes the formation of an identification code or symbol beneath the table facet of a polished diamond by means of ion implantation techniques. The ion implanter emits a beam of charged ions which penetrates the diamond's surface, creating through a code-bearing mask a pattern which has an electrical conductivity different from the surrounding area. This implanted pattern can be revealed for identification purposes by giving the diamond an electrostatic charge and then dusting it with a special powder. Application of the method may be inhibited by the high cost of the equipment and by the fact that the implanted pattern can be altered or removed by repolishing. P.G.R.

GOOD (A.). *Chemically-induced colour in sapphire.* Gems, **13**, 5, 32, 1 fig, 1981.
[The Abstracter has asked for the abstract of this paper already published in J.Gemm., 1982, XVIII (2), 165 to be replaced by the fuller abstract which follows.—Ed.]

Geuda stones from Sri Lanka can be clarified by causing titanium dioxide in the stone to migrate into the lattice as a result of heating. Stones without latent rutile are now being treated chemically to produce a similar improvement in colour and clarity. One treatment consists of coating the sapphire in a powder containing the necessary transition element and then applying heat. One stone examined had an even colour and characteristic Geuda colour (steel blue). A surface skin of colour was seen on immersion in methylene iodide, together with surface pitting and diminution of colour towards the edges of the main pavilion facets. These were shown to have been repolished. The stone was inert under UV and only a faint trace of absorption at 450 nm could be seen. M.O'D

HOBBS (J. M.). *The jade enigma.* Gems & Gemology, **XVIII**, 1, 3-4, 6-19, 16 figs (13 in colour), 1982.

A careful summary of jades and jade imitants, including natural minerals, dyed minerals and glasses, and of methods of identifying them. [It is not clear whether the inserted, unattributed article on page 5, with one unnumbered fig. in colour, entitled *The Question of Jade Nomenclature,* is, or is not, part of Ms Hobbs's paper. This attempts to clarify the nomenclature of the two true jades, never easy when there are substantial variations in composition between specimens.] R.K.M.

HODGKINSON (A.). *Methods for identifying new diamond doublet.* Retail Jeweller, **21**, 522, 21, 4 figs, 1982.

In the absence of reflectivity and thermal conductivity meters a doublet with diamond crown and CZ pavilion will show reflection of an outside object or of light in both table and junction planes. Differences in girdle texture serve to identify unmounted specimens M.O'D.

JENSEN (D. E.). *Travels with two rolling stones.* Lapidary J., **36**, 2, 390-4, 13 figs (12 in colour), 1982.

Reminiscences by the retired Vice-President of Ward's Natural Science Establishment of Rochester, New York, in which travels to Idar-Oberstein, Castleton (Derbyshire, England) and a variety of locations in the eastern United States are described. M.O'D.

KOIVULA (J. I.). *Some observations on the treatment of lavender jadeite.* Gems & Gemology, **XVIII,** 1, 32-5, 5 figs in colour, 1982.

42 specimens of lavender jadeite were sawn in two, and one half of each was heated. Organic dye should be bleached by this treatment, and 28 specimens were so bleached. These all showed strong orange fluorescence under long-wave ultraviolet light before heating. Assumption that these were stained stones was confirmed by visual identification of dye in crevices in stones. Remaining 14 stones showed weak brownish-red fluorescence under long and short ultraviolet; no dye was seen in cracks. The two groups differed in their fluorescence under x-rays. It is still uncertain whether the second group contained jadeite treated with inorganic dyes.

R.K.M.

LIVINGSTONE (A.). *Laser saw cuts diamonds without breakage fear.* National Jeweler, p.69, 1 fig., May 1, 1982.

Contains a description of the equipment developed by J. Ehrenwald, President of Laser Sawing Services, New York. The cutting loss of 3 to 4% using the laser saw (this is 2% higher than with conventional sawing methods) is compensated by the ability to saw difficult stones and to produce ornate shapes such as butterflies, horse heads and hearts. Laser sawing is two to three times faster than conventional sawing or cleaving methods, but is five times more expensive to operate. P.G.R.

MCMACKIN (C. E.). *Hunting Arizona's banded agate nodules.* Lapidary J., **36,** 1, 166-70, 10 figs, 1982.

A personal account of the discovery of nodules of banded agate, some with an attractive orange tint, in the eastern Arizona. M.O'D.

NOGUES CARULLA (J. M.). *Tecnicas de crecimiento cristalino.* (Techniques of crystal growth.) Gemologia, **15,** 51/52, 5-24, 11 figs, 1981.

A useful summary of the various techniques by which gem quality crystals may be grown. M.O'D.

PARADISE (T. R.). *The natural formation and occurrence of green quartz.* Gems & Gemology, **XVIII,** 1, 39-42, 2 figs in colour, 1982.

In a region of the Nevada-California border, amethyst, green quartz and citrine are found in the one locality. All three colours are due to iron in one form or another. Distribution suggests that green was produced by heat from an ancient rhyolite extrusion. R.K.M

PENSE (J.), BANERJEE (A.). *Identifizierung von Perlen nach einer neuen Methode.* (A new method of pearl identification.) Uhren, Juwelen, Schmuck, 22, 31, 2 figs, 1978.

The possibilities of neutron activation analysis in pearl testing are briefly discussed. M.O'D.

SCHNEIDER (W.). *Der Opal und seine Nachahmungen.* (Opal and its imitation.) Uhren, Juwelen, Schmuck, 22, 23-5, 6 figs, 1978.

Opal, synthetic opal and Slocum stone are reviewed and their constants and composition tabulated. M.O'D.

SCHNEIDER (W.). *Die instrumentelle Neutronenaktivierungsanalyse (INAA) und Möglichkeiten ihrer Anwendung in der Edelsteinkunde.* (Neutron activation analysis and its possibilities for use in gem testing.) Uhren, Juwelen, Schmuck, 21, 63-5, 4 figs in colour, 1981.

Neutron activation analysis may be useful in gem testing since it can identify trace elements in the specimen without destroying it. Ir, Pt and Mo have been usefully identified by this method and its use for the detection of some man-made stones is thus clear. M.O'D.

SCHRADER (H.-W.). *Zur Unterscheidung von natürlichen und synthetischen Smaragden.* (The recognition of natural and synthetic emerald.) Uhren, Juwelen, Schmuck, 19, 105-10, 5 figs, 1981.

Data so far available on natural and synthetic emerald are collated and reviewed. M.O'D.

SCHWARZ (D.). *Kubisch-stabilisierte Zirkonoxide als Diamant-Imitationen.* (Cubic stabilized zirconium oxide as a diamond imitation.) Uhren, Juwelen, Schmuck, 22, 26-8, 6 figs, 1978.

Composition, structure and physical constants for ZrO_2 are given. Eu-doped material shows a characteristic absorption spectrum. M.O'D.

SCHWARZ (D.). *Fluoreszenz von Mineralien, Edelsteinen und Edelstein-Imitationen.* (Fluorescence of minerals, gemstones and gemstone imitations.) Uhren, Juwelen, Schmuck, 7, 210-16, 9 figs, 1980; 9, 87-92, 7 figs, 1980; 15, 41-4, 12 figs, 1981.

A comprehensive review of luminescence as it effects minerals and gemstones. M.O'D.

SCHWARZ (D.). *Chemismus und Fluoreszenzverhalten natürlicher und synthetischer Spinelle.* (Chemistry and fluorescence behaviour of natural and synthetic spinel.) Uhren, Juwelen, Schmuck, 20, 57-60, 3 figs, 1981.

Synthetic spinel was found to be very pure when examined by optical emission spectroscopy; some Si and some Fe were detected in addition to the elements used for coloration. Mn^{2+} and Cr^{3+} are the chief ions involved in fluorescence. Ti^{4+} is responsible for the bluish-white fluorescence in synthetic spinels. Ga, Ni and Zn have been detected in some natural stones. M.O'D.

SMITH (W. D.). *Missouri lace agate.* Lapidary J., **36**, 1, 90-2, 7 figs, 1982.

Most lace agate in the State of Missouri is found in Washington County where it occurs on the surface with barite. M.O'D.

SRIVASTAVA (S. B. L.). *Gemstone deposits in Rajasthan.* Gem World, **9**, 11, 21-30, 1981.

Chief among the gem deposits in Rajasthan are those in which beryl (emerald and aquamarine) are found. Garnet, topaz, fluorite and apatite also occur. Some pink corundum not of gem quality has been discovered, and it is hoped that better qualities may appear in the future. Almandine garnet occurs at 34 different places in the state. M.O'D.

SUNAGAWA (I.). *Natural and synthetic gem materials, a comparison.* Bulletin de Minéralogie, **104**, 2/3, 128-32, 3 figs, 1981.

A general comparison of growth features of natural and man-made gemstones with particular reference to surface microtopography (emerald), internal morphology (diamond). M.O'D.

SWINDLE (L. J.). *Amethyst quartz with goethite inclusions.* Lapidary J., **36**, 1, 144-57, 21 figs, 1982.

Amethyst with inclusions of goethite are found in the pegmatite areas of Pike's Peak, Colorado. Some unusual specimens are described and illustrated. M.O'D.

TAYLOR (G.). *The new science.* Wahroongai News, 7-8, December 1981.

Expounds the basic law that all systems must fall to their lowest energy state and shows how this affects the growth of crystals. R.K.M.

TUCKER (E.). *Jade forms from ancient China.* Gems & Gemology, **XVIII**, 1, 20-31, 9 figs in colour, 1982.

A superbly illustrated paper on the historic and mythological significance and origins of the forms of jade carvings. R.K.M.

VASHISHTHA (S.). *Diamond and its simulants—1.* Gem World, **9**, 11, 25-36, 1 fig., 1981.

The chemical composition and physical constants of diamond are given with illustrations of some of the commoner forms. Important world sources are also listed. M.O'D.

VILARDELL (A.). *Relación entre las proporciónes de talla perfecta en estilo brillante del diamante.* (Relationship between the proportions of a perfect cut in brilliant style of diamond.) Gemologia, **15**, 51/52, 25-34, 5 figs, 1981.

Various angular relationships are illustrated in an attempt to find the ideal brilliant. M.O'D.

ZEITNER (J. C.). *The quest for green bolts—1.* Lapidary J., **36**, 2, 378-410, 22 figs (13 in colour), 1982.

This paper deals with emerald localities in North Carolina, with particular reference to the Rist mine, Hiddenite, Alexander County, where a large good quality parcel with a total weight of 3507ct was found in 1979. Some of the best emerald was found in a pocket with quartz and feldspar. A few of the stones have been cut. M.O'D.

Barite, the fascinating mineral. Journal of Gem Industry, **19**, 6, 69-74, 1981.

A general review of barytes and its (limited) gem potential. M.O'D.

The structure of matter. Wahroongai News, 11-16, February 1982.

An interesting resumé of the known facts of molecules, atoms and crystals. Basic facts clearly explained. R.K.M.

BOOK REVIEWS

BAUER (J.), BOUSKA (V.), TVRZ (F.). *Der Kosmos Edelsteinführer.* (Kosmos guide to gemstones.) Franckh'sche Verlagshandlung, Stuttgart, 1982. pp.226. Illus. in black-and-white and in colour. DM24.

This is a small-format guide of a kind by now familiar to those readers who find general works convenient to carry about. This one, translated from Czech and written by Czech authorities on minerals, is of more than passing interest to Western readers, since the examples depicted are almost all from East European or Russian localities. The text is unexceptional and the illustrations and production of quite good quality; a quick glance through the pictures shows a doubtful euclase depicted as such though the crystal is clearly tetragonal; too much red from the reproduction process spoils the picture of cordierite and the use of the names olivine, peridot and chrysolite is confusing, but on the whole the book is recommended. M.O'D.

CHU (A.) CHU (G.). *Jade—Stein des Himmels.* (Jade—stone of heaven.) Franckh'sche Verlagshandlung, Stuttgart, 1982. pp.151. Illus. in black-and-white and in colour. DM48.

Providing that the German title is not literally translated should the book as a whole be put into English, there should be no confusion with *Jade—stone of heaven* by Richard Gump, first published in 1962. This new book is well produced and covers the origin, working, pricing and detection of the jade minerals, with some quite elegant illustrations. There are a short bibliography and a list of German museums possessing jade collections. M.O'D.

LITTICH (F.). *Historische Diamanten und ihre Geschichte.* (Historic diamonds and their study.) Rühle-Diebener-Verlag, Stuttgart, 1982. pp.163. Illus. in colour. Price on application.

With unexpectedly and inexplicably large type (for these straitened days) this is an alphabetical list of most, if not all, named and celebrated diamonds. Preceding the text is a section of fairly well produced colour reproductions. Tables of diamonds by weight (both cut and rough) and a short bibliography conclude the book. M.O'D.

PERRY (N.), PERRY (R.). *Practical gemcutting.* David & Charles, Newton Abbot, 1982. pp.95. Illus. in black-and-white. £6.95.

This is a workmanlike addition to the already extensive range of books on faceting. Profusely illustrated in the text, it is intended to enable the reader to cut stones for himself without necessarily attending a formal class. It succeeds very well. The absence of a bibliography matters little in this case since it would only refer in the main to works similar to this one. M.O'D.

STRACK (E.). *Perlenfibel.* (A primer on pearl.) Rühle-Diebener-Verlag, Stuttgart, 1982. pp.168. Illus. in black-and-white and in colour. Price on application.

This bids fair to be the standard textbook on pearls in German, and an English translation would be welcome. Preceding the text is a section of 174 coloured photographs, and there are more pictures, in black-and-white, in the text. Well drawn diagrams illustrate some features of testing and a good deal of space is devoted to the various methods of pearl recovery. M.O'D.

ASSOCIATION NOTICES

OBITUARY

NORMAN ADAMSON HARPER

The untimely death, on 8th July 1982, of Norman Harper, F.G.S., F.R.G.S., F.G.A., Vice-President of the Gemmological Association, brought to an end the career of a remarkable man who had fought valiantly against increasing ill-health for a number of years.

A friendly, generous and kind-hearted man, with a natural ability to organize and to communicate, he had been Vice-Chairman and then an excellent Chairman of the Association for almost twenty-five years.

In the past Norman would introduce me as the chap who had 'done him out of the Tully Medal in 1934', and I would point out that Robert Webster was making a similar claim—they would have to fight for second place between them. These exchanges were made with the best possible good humour and without the slightest hint of animosity. Norman Harper was like that.

Born in Newcastle-upon-Tyne and educated in the North-East, Norman came down to Birmingham to join W. A. Perry & Co. in 1932. He was basically a forthright man, and this and much of his good natured humour and his very real appreciation and enjoyment of life undoubtedly stemmed from his early Geordie background. He was made a director of the firm, when it was formed into a limited company, and became joint Managing-Director when Alderman Perry died.

He obtained his Diploma in 1934, a year which he liked to describe as 'Vintage'. The War years saw service with the Auxiliary Fire Service and in 1946 he was among the first students to sit the Retail Jewellers' Examination and was the first holder of the Greenough Trophy. He became a member of the Gemmological Association Council in 1952 and was elected Vice-Chairman in 1955. In that year he organized, with others and in conjunction with the Birmingham Museum and Art Gallery, a very fine exhibition of gems. His 'Introduction to Gemstones', written at that time, is now the official guide to that section of the Museum.

From 1947 he taught Gemmology at the Birmingham School for Jewellers and was responsible for the gradual build up of instruments and specimens into a first class teaching collection.

He was the instigator of the Gemmological Association's Diamond Course, which had its beginning in his diamond classes in Birmingham in 1962. In 1965 he

became our Chairman and served in that capacity with considerable distinction until ill-health forced his retirement in 1978. He then became a Vice-President of the Gemmological Association.

A member of the National Association of Goldsmiths' Council from 1954 to 1978, he was their Vice-Chairman and then their Chairman in the early 60s. He was a Guardian of the Birmingham Assay Office, a Freeman of the Worshipful Company of Goldsmiths and a Freeman of the City of London.

It is perhaps typical of a man with so great a zest for life that he should have taken up flying and become a skilled amateur pilot, taking part in International Air Races and specializing in aerobatics. In his younger days he enjoyed horse riding. He played golf, but described himself, with characteristic honesty, as an 'atrocious player'. Despite his many honours and achievements he was essentially a modest man.

Norman Harper leaves a widow, Brenda, and four sons and a daughter. Our heartfelt sympathy is extended to them in their great loss. He was an expert gemmologist and a very good jeweller, who strove always towards educating others to his own high standards. He worked constantly to promote the provincial centres of training. A fine public speaker and a good friend, whose passing is a grievous blow to all those who knew him, he will be greatly missed. R.K.M.

Mr Taichiro Imai, F.G.A. (D.1965), Tokyo, Japan, Chairman of the Gemmological Association of Japan, died on the 13th June, 1982. He was the first person in Japan to study and obtain our Diploma. He then devoted himself to promoting the study of gemmology in his country and set up the G.A.J. The British rules were used as a basis for the Association. Since then he had done much in Japan to improve the knowledge of gems and the standards of trading.

Professor Dr W. F. Eppler died on 5th June, 1982: a Tribute by B. W. Anderson will be published in the *Journal* in January next.

GIFTS TO THE ASSOCIATION

The Council is indebted to the following for their gifts:

Mr C. R. Cavey, F.G.A., Greenford, for a piece of rhino horn.

Mr R. A. Holt, London, for two fancy-coloured cut sapphires, one red tourmaline, one aquamarine crystal, one opal carving and one tourmaline cat's-eye.

NEWS OF FELLOWS

In May 1982, Mr Michael O'Donoghue, M.A., F.G.S., F.G.A., gave a course of four lectures on 'Gemstones' to the University of Kent Adult Extension Class at Sevenoaks. Mr O'Donoghue also gave a lecture on 'Commercial features of gemstones' to the Amateur Geological Society on 29th June, 1982.

On 12th August, 1982, Dr W. G. Cross, M.B., M.S., B.D.S., F.G.A., was elected Master of the Worshipful Company of Barbers (the 593rd Master since the Worshipful Company was formed in 1308).

MEMBERS' MEETINGS

Midlands Branch

On 4th July, 1982, members visited Wollaton Hall, Nottingham, and viewed the fine mineral collection exhibited there.

North-West Branch

On 3rd June, 1982, a social evening was held at the Northern Cricket Club, Moor Park, Thornton, Liverpool.

South Yorkshire and District Branch

On 8th June, 1982, at the Sheffield City Polytechnic, Mrs E. Holloway gave an illustrated talk entitled 'Myth and legend of the Japanese netsuke'.

ANNUAL GENERAL MEETING

The 51st Annual General Meeting of the Association was held at Saint Dunstan's House on the 12th May, 1982, at 6.00 p.m.

Mr David Callaghan, the Chairman, welcomed members and reported upon the work of the year, referring particularly to the various gifts received by the Association, especially the Chairman's Badge, the Hong Kong fan, and the Norwegian crystal group. He also mentioned the visits by the Secretary to Milan, Hong Kong, Tokyo and the XVIIIth International Gemmological Conference and G.I.A. Symposium in order to put the G.A. of G.B. in the forefront of the world of gemmology. He thanked the organizers of the practical gemmology week-ends to help students and also all those connected with the Jubilee celebrations, in particular Mr Eric Bruton for producing the catalogue and writing up the history and the Secretary for researching and collecting many of the facts.

The Chairman spoke of the changes in the Examination Prizes and the generosity of Prof. Dr Hermann Bank, F.G.A., which enabled us to offer annually two prizes—to be known as the Anderson/Bank prize for the Diploma Examination and the Anderson silver medal—in commemoration of Basil Anderson's 80th birthday.

Mr Alec Farn's retirement and Mr Ken Scarratt's appointment as Director of the L.C.C. Gem Testing Laboratory were mentioned by the Chairman; he also drew attention to the new Fellowship tie, which was produced to commemorate the Golden Jubilee. He expressed his thanks to Rayners for their continued interest in the Association and the production of gem-testing instruments, and finally he gave special thanks to Mr John Chisholm for all his good work with the *Journal* and Mr Lawson Clarke for his willingness to continue in office for another year.

The Treasurer gave his Financial Report and proposed the motion, which was seconded by Mrs S. Hiscox, 'That the audited Accounts and Report of the Council for the year ended 31st December, 1981 be and are hereby adopted', and it was carried unanimously.

Sir Frank Claringbull, Messrs David Callaghan, Noel Deeks and F. E. Lawson Clarke were re-elected as President, Chairman, Vice-Chairman and Treasurer respectively, and Messrs L. F. Cole, P. Daly, A. E. Farn, A. Hodgkinson, C. B. Jones and A. W. Round were re-elected and Mr J. P. Brown elected to the Council.

Mr Douglas King tendered his resignation from the Council, as he felt that the time had now come for him to step down to allow a younger person to be elected. His resignation was accepted with regret.

Messrs Hard Dowdy Watson Collin & Co. were re-appointed as Auditors of the Association.

COUNCIL MEETING

At the meeting of Council held on Wednesday, 12th May, 1982, at Saint Dunstan's House, (1) it was decided that with effect from 1st January, 1983, the membership subscription rates would be as follows:

Ordinary Members: £15 per annum
Fellows: £12 per annum.

(2) the following were elected to membership:

FELLOWSHIP

Coote, James W., Westlake Village, Ca, U.S.A. 1950
Heiskanen, Anu P. K., Helsinki, Finland. 1981
Hettiaratchi, Theja C., Berlin, W. Germany. 1981

ORDINARY MEMBERSHIP

Azaz, Henri N., Witney.
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EXAMINATIONS 1983

Examination dates for 1983 are as follows:
Gem Diamond Examination: Monday, 6th June.
Examinations in Gemmology:
Preliminary: Tuesday, 28th June
Diploma:
Theory, Wednesday, 29th June
Practical, Thursday, 30th June (also in London Tuesday, 28th June and Friday, 1st July).

THREE-DAY DIAMOND GRADING AND GEM IDENTIFICATION COURSES

The Gem Testing Laboratory of the London Chamber of Commerce started in September a series of three-day courses for Diamond Grading and a separate course for Gem Identification. Both courses will be repeated monthly. Full details available from The Director, L.C.C. & I., Gem Testing Laboratory, 36 Greville Street, London, EC1N 8AU.

GEMS, JEWELS AND GEOLOGY COURSE

The Geological Museum and the Department of Extra-Mural Studies of the University of London are arranging a 12 week lecture course to be held at the Museum. The course, which is entitled 'Gems, Jewels and Geology', begins on the 12th January, 1983, and meetings will start at 18.30 hours. The fee for the whole course is £12 and anyone wishing to have further information should write to the Department of Extra-Mural Studies, University of London, 26 Russell Square, London, WC1 5DQ.

The course is designed to link the formation of gem minerals in their geological environment with various methods used in their mining and recovery and their ultimate use in jewellery both ancient and modern. The lecturers are experts in their respective fields and will be drawn from the national museums and famous gemmological laboratories.

DR JOHN SINKANKAS

Captain John Sinkankas, U.S.N. (retd), well known to all gemmologists as the author of fine books on gemmological subjects, received the degree of Doctor of Humane Letters, *honoris causa,* on 20th May, 1982, from the William Paterson College of New Jersey, where he was a member of the class of 1936.

G.I.A. ALUMNI ASSOCIATION

The formation of the G.I.A. Alumni Association has recently been announced by Mr Richard T. Liddicoat, jr, Hon. F.G.A., President of the Gemological Institute of America. Fellows of the Gemmological Association may become Associate Members (annual subscription $60). Further information may be obtained from Mr Robert A. Earnest, Executive Director, 1660 Stewart Street, Santa Monica, California 90404, U.S.A. [telephone (213) 829 2991, ext. 279].

LETTERS TO THE EDITOR

From Mr R. J. Peace, B.Sc., F.G.A.

Dear Sir,

Many gemmology students apparently find difficulty in visualizing the precise shape of the spinel twin. The usual diagram presented in textbooks is Figure 1.

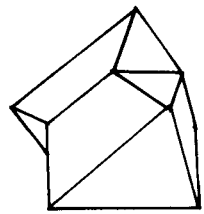

FIG. 1.

The twin is theoretically derived by cutting a regular octahedron with a plane passing through the midpoints of the six sides (the twinning plane) and rotating one of the resulting halves through an angle of 180° in this plane (Figures 2 and 3).

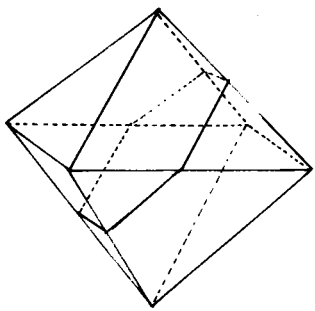

FIG. 2.

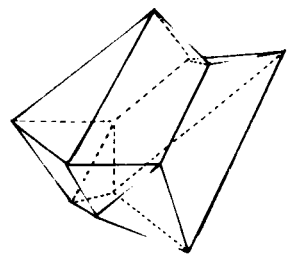

FIG. 3.

The spinel twin diagrams, Figure 1 and Figure 3, do not readily show that

(i) the cross section through the octahedron is a regular hexagon,

(ii) the front and rear faces are parallel equilateral triangles,

(iii) the re-entrant angles formed by the small triangular faces are equal to and in the reverse direction of the angles between the tetragonal faces.

As an alternative approach, I suggest that the spinel twin shape can be *envisaged* as being made from a hollow equilateral triangular prism that has been subjected to pressure at the midpoints of the three vertical sides in directions along the bisectors of the equilateral angles and acting in a horizontal plane (Figure 4).

When this occurs, the mid cross-section becomes a regular hexagon, the vertical height very slightly decreases and re-entrant angles are formed, whilst the remaining alternate faces of the hexagon 'bulge outwards'. The resulting shape can be represented as Figure 5.

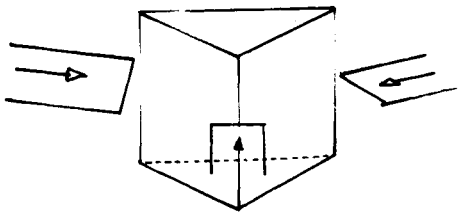

FIG. 4.

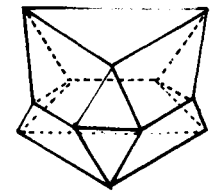

FIG. 5

In thinking of a trigonal prism subjected to pressure in this way it must be clearly understood that there is no suggestion that this basic shape in the trigonal crystal system could ever create a shape belonging to the cubic crystal system. Both the twisting of the sliced octahedron and this present suggestion of compression and expansion of edges are, of course, quite impossible in actual crystal formation. They are only put forward in an effort to explain the shape of the three-dimensional octahedral twin in the two dimensions of a written text.

Yours etc.,
R. J. PEACE.

16th May, 1982.
Withernsea, North Humberside.

From Mr Peter Read, C.Eng., M.I.E.E., M.I.E.R.E., F.G.A.

Dear Sir,

Since my report on the Ceres Diamond Probe was published in this *Journal*,* at least a dozen different models of this type of instrument have appeared on the market. I have personally tested nine of these instruments, and am also responsible for the electronics design of both the original and the improved version of the Rayner Diamond Tester for Gemmological Instruments Ltd.

All of these instruments have so far been described as thermal conductivity testers, and have been designed to detect the drop in temperature of a heated probe tip when thermal energy is transferred from it, via a material such as diamond, into a heat sink. This heat sink comprises either the gemstone mount, or a metal test plate. It is instructive, however, to read the excellent theoretical analysis of the heat flow mechanisms as presented by Dr D. B. Hoover in his article in the July 1982 issue of the *Journal*,† as this helps to explain the various anomalies in the operation of these instruments.

*Read, P. G. Thermal Diamond Probes, *J.Gemm.*, 1980, XVII (2), 85-94.
†Hoover, D. B. The Thermal Properties of Gemstones and their application to Thermal Diamond Probes, *J.Gemm.*, 1982, XVIII (3), 229-39.

One design feature in some of the simpler thermal probes is the use of a very hot probe tip (in some instances the manufacturers warn against blistering the fingers!). This results in both an increase in the ability to discriminate between diamond and its simulants, and a decrease in the instrument's dependence on gem temperature and ambient temperature ranges.

The majority of thermal probes use a semiconductor element such as a thermistor or a silicon voltage-reference diode to act as both a source of heat and a temperature sensor. One model, the Singapore-built 'Presidium Gem Tester,' is unique in that it uses a copper-constantan thermocouple and a separate heating element (this is the instrument marketed by the G.I.A as their 'Gem Diamond Master' and referred to in Hoover's article).

Hoover's suggestion that thermal probes could be used in a more quantitative manner to distinguish between other gem species has already been exploited by Gemtek in their 'Gemmologist' instrument. This is designed to discriminate not only betweeen diamond and its simulants, but also between stones such as aquamarine and blue topaz whose thermal conductivities (or thermal inertias) are sufficiently separated. As the thermal conductivities of non-diamond gems lie in the range of 10 to 40 Watts/m/°C* (compared with diamond's range of 1000 to 2600) this is no mean technical feat. The necessary increase in sensitivity of the instrument demands careful handling, however, as stone temperature, ambient temperature and probe pressure become critical factors. (I am preparing a test report on this model for a future issue of the *Journal*).

The most searching test for a thermal probe type instrument is to check whether it will discriminate between a small diamond at body temperature (i.e. in a ring worn on the finger) and a large corundum at room temperature. Although colourless sapphire would not normally be mistaken for a diamond, it makes a good test stone in this respect as its thermal properties are closer to those of diamond than any of the other simulants. Cubic zirconia, by way of contrast, has very poor thermal conduction and is easily identified by the simplest of the thermal testers.

Even with the most sophisticated of the thermal diamond probes it is prudent (as with the reflectivity type instruments) to check calibration against a known diamond and corundum before making a test. In keeping with good gemmological practice, results should always be confirmed by the use of at least one alternative test (e.g. reflectivity measurement, facet condition, inspection, etc.).

Yours etc.,

PETER READ

16th August, 1982
Bournemouth, BH1 3UB, Dorset.

*Quoted in preferred S.I. units.

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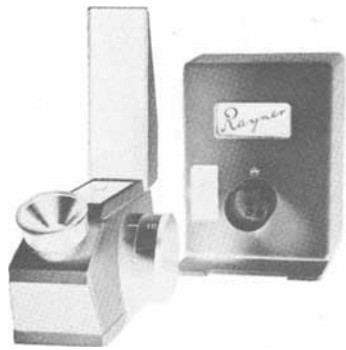

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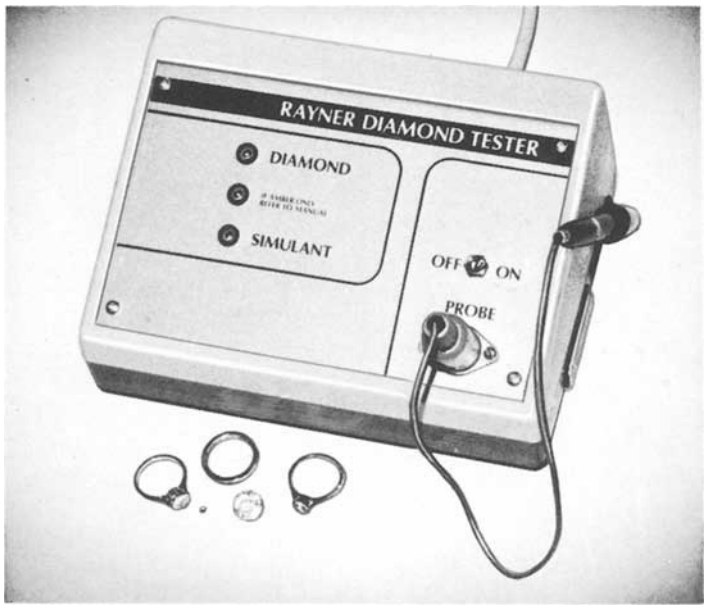

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Historical Note

The Gemmological Association of Great Britain was originally founded in 1908 as the Education Committee of the National Association of Goldsmiths and reconstituted in 1931 as the Gemmological Association. Its name was extended to Gemmological Association of Great Britain in 1938, and finally in 1944 it was incorporated in that name under the Companies Acts as a company limited by guarantee (registered in England, no. 433063).

Affiliated Associations are the Gemmological Association of Australia, the Canadian Gemmological Association, the Gem and Mineral Society of Zimbabwe and the Gemmological Association of Hong Kong.

The *Journal of Gemmology* was first published by the Association in 1947. It is a quarterly, published in January, April, July, and October each year, and is issued free to Fellows and Members of the Association. Opinions expressed by authors are not necessarily endorsed by the Association.

Notes for Contributors

The Editor is glad to consider original articles shedding new light on subjects of gemmological interest for publication in the *Journal.* Articles are not normally accepted which have already been published elsewhere in English, and an article is accepted only on the understanding that (1) full information as to any previous publication (whether in English or another language) has been given, (2) it is not under consideration for publication elsewhere and (3) it will not be published elsewhere without the consent of the Editor.

Articles published are paid for, and a minimum of 25 prints of individual articles may be supplied to authors provided application is made on or before approval of proofs. Applications for prints should be made to the Secretary of the Association—not to the Editor—and current rates of payment for articles and terms for the supply of prints may be obtained also from the Secretary.

Although not a mandatory requirement, it is most helpful if articles are typed (together with a carbon copy) in double spacing on one side of the paper, with good margins at sides, top and foot of each page. Articles may be of any length, but it should be borne in mind that long articles are more difficult to fit in than short ones: in practice, an article of much more than 10 000 words (unless capable of division into parts or of exceptional importance) is unlikely to be acceptable, while a short note of 400 or 500 words may achieve early publication.

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THE JOURNAL OF GEMMOLOGY

and

PROCEEDINGS OF THE GEMMOLOGICAL ASSOCIATION OF GREAT BRITAIN

GEMMOLOGICAL ASSOCIATION OF GREAT BRITAIN

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THE JOURNAL OF GEMMOLOGY
AND PROCEEDINGS OF THE GEMMOLOGICAL ASSOCIATION OF GREAT BRITAIN

Vol. XVIII No. 5 JANUARY 1983

SYNTHETIC RUBY MADE BY KNISCHKA

By MAHINDA GUNAWARDENE, F.G.A., D.Gem.G.

Deutsche Gemmologische Gesellschaft E.V., Idar-Oberstein 2, W. Germany.

ABSTRACT

This paper deals with the newly created Knischka synthetic rubies in respect to their identification by gemmological methods. The growth of extra crystal faces is briefly discussed and the different crystal forms are compared with those made by Knischka. Further, the typical inclusions are presented to make the identification procedure as easy as possible.

INTRODUCTION

Quite recently Professor Paul Otto Knischka, of Steyr, Austria, announced the production of a new synthetic ruby under the name 'Knischka Synthetic Ruby' (K-ruby after **P**aul **K**nischka). The growth has been achieved by using a modification of the gradient transport technique involving supercooling and

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supersaturation. The crystals are characterized by many resulting modified lustrous faces. This higher number of faces has not yet been reported from any other synthetic corundum crystal manufacturers. These new synthetic rubies have been grown as single crystals (Figure 1), twins, triplets and other multiple crystals including cluster formations.

FIG. 1. Single crystal of synthetic ruby made by Knischka showing the pseudohexagonal bipyramidal form with horizontal striations.

CRYSTALLOGRAPHY

Different corundum manufacturing processes are known, and gem quality material has already been introduced by various manufacturers (Nassau 1980). K-rubies are rather dissimilar to synthetics reported previously in relation to their crystallization

phenomena. Gradient transportation is achieved by high-pressure-solution growth with the influence of melt-diffusion method or using both methods together.

Different synthetic growth techniques are reported. It has also been reported that by doping of Mn and Mg with slight temperature changes like 10 °C to 20 °C from the crystallization point, the number of faces can be increased even up to 20 (Siesmayer *et al.* 1975). Such increased numbers of faces in synthetic corundum crystals are illustrated in Figures 2 to 9.

In their crystallization process ℭ-rubies have shown even more faces than illustrated in Figures 2 to 9. By modification of the parameter the number of faces is influenced in this new product by Professor Knischka as reported in 1980. They often showed the five different faces of *d* $\{01\bar{1}2\}$, *y* $\{01\bar{1}5\}$, *r* $\{10\bar{1}1\}$, *n* $\{22\bar{4}3\}$ and *c* $\{0001\}$ in a single crystal. Some of them even presented the sixth face $\cdot\{10\bar{1}9\}$. Further development of *a* $\{11\bar{2}0\}$ is possible.

With the explanations given above ℭ-rubies have shown higher numbers of faces often amounting to 32 or 38 or occasionally 44 in a single crystal. The type with 38 faces is illustrated in Figure 10.

The new synthetic rubies were analysed in the crystallographic section of the district museum *Joanneum* in Graz, Austria, for crystallographic investigations. The results were reported by Professor Knischka in his paper (1980) and are detailed below:

The crystal class was *Ditrigonal Scalenohedron* $D^{6}_{3d}-R^{-}_{3c}$
Typical forms possible to occur with ℭ-rubies are:

$c=\{0001\}$	$d=\{01\bar{1}2\}$
$n=\{22\bar{4}3\}$	$?y'=\{03\bar{3}.16\}$
$r=\{10\bar{1}1\}$	$a=\{11\bar{2}0\}$*
$\cdot=\{10\bar{1}9\}$	* for $\mathfrak{K}_6$-rubies.

Different forms of single crystals with indices are shown in Figures 11 to 14. As mentioned, apart from single crystals, twins, triplets, multiple crystals and cluster formations may occur through

(a) temperature variations (possibly by lowering the temperature), or
(b) inherent chemical process, or
(c) evaporation in an oxidization process.

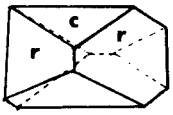

FIG. 2. Remeika (1963) corundum crystal with 8 faces.

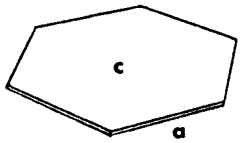

FIG. 3. Remeika (1963) corundum crystal with 8 faces.

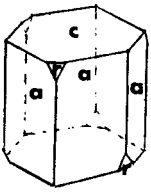

FIG. 4. Neuhaus *et al.* (1962) corundum crystal with 14 faces formed at high-pressure.

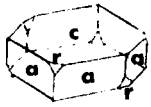

FIG. 5. Neuhaus *et al.* (1962) corundum crystal with 14 faces formed at low-pressure.

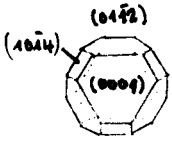

FIG. 6. White *et al.* (1965) corundum crystal with 14 faces.

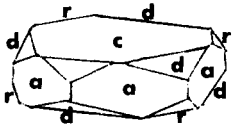

FIG. 7. Chase (1966) corundum crystal with 20 faces.

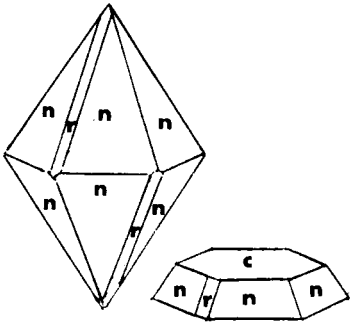

FIG. 8. Yanovskii *et al.* (1970) corundum crystal consisting of 20 faces (bi-pyramid with or without basal pinacoid).

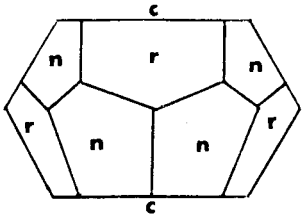

FIG. 9. Watanabe *et al.* (1976) corundum crystal consisting of 20 faces (bi-pyramid with basal pinacoids).

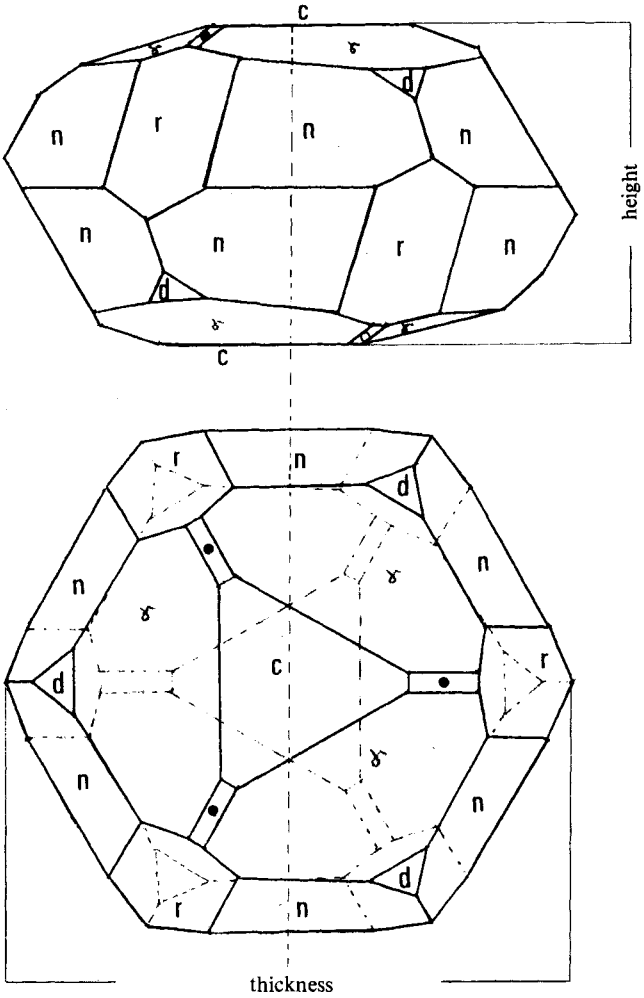

FIG. 10. Knischka (1980) Synthetic corundum crystal consisting of 38 faces.
above = side view below = top view

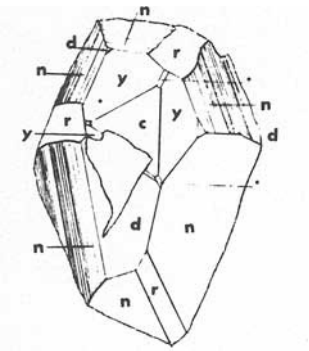

FIG. 11. K-ruby of 1.029 carat showing the face nomenclature.

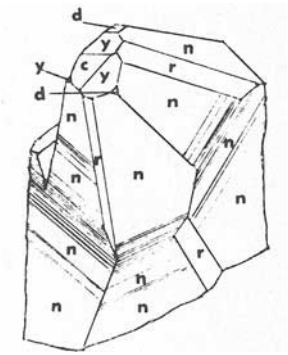

FIG. 12. K-ruby of 1.710 carat showing the face nomenclature.

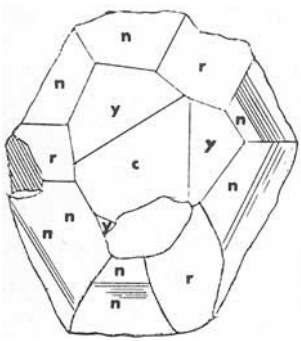

FIG. 13. K-ruby of 0.59 carat showing the face nomenclature.

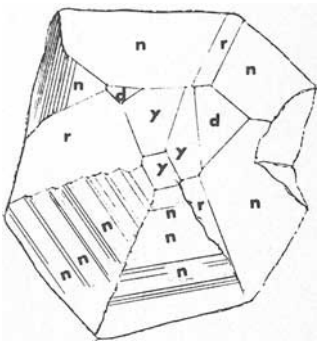

FIG. 14. K-ruby of 1.825 carat showing the face nomenclature.

All the Knischka examples showed striations according to $22\bar{4}3$

CHEMISTRY

Chemical investigations have shown that these new rubies contained less Fe than naturals. On the other hand Cr percentage is much higher as in some Chatham or Verneuil synthetic rubies. Such chemical analysis does not really differentiate the new synthetics from other natural or synthetic rubies. Powdered ruby samples including three K-rubies, one natural and one Verneuil were analysed and reported by Knischka & Gübelin (1980). Further the relative foreign element percentages were given by Bosshart (1981). The analytical reports of these two investigations are given in Table 1 and Table 2 respectively.

TABLE 1. Foreign element percentages comparison (after Knischka & Gübelin 1980)

Powdered rubies (weight in mg)	42.6 mg	12.2 mg	102.6 mg	100.7 mg	102.2 mg
selected samples	K-1 ruby	K-2 ruby	K-3 ruby	nat. ruby	Vern. ruby
Elements %					
Fe	0.073	0.13	0.065	0.241	0.073
Zn	0.013	0.041	0.0068	0.022	0.047
Ni	0.031	0.126	0.034	0.028	0.017
Ti	lower than 0.3% in all samples			0.99	present
Au	0.03	0.08	0.02	0.01	0.011
Co	0.025	0.073	0.016	0.01	0.008
Pb	0.199	0.776	0.076	0.034	0.044
Cr	1.585	0.796	0.558	0.305	0.841

elements like Bi, W, Pt, V, Ba, Si, Rh, Cu, Ag, etc., were not detected.

TABLE 2. Relative foreign element content in ℭ-rubies compared with other natural and synthetic rubies (after Bosshart 1981)

	Cr	Fe	Ti	V
Knischka	***	**	**	*
Verneuil	**	*	*	*
Chatham	***	*	*	*
Kashan	*	**	***	*
Burma	**	**	**	**
Thailand	***	***	*	**
Sri Lanka	**	***	***	*
Kenya	**	**	**	*

Element content major *** medium ** minor *

GEMMOLOGICAL INVESTIGATIONS

The production developments may, perhaps, reach the market in quantities. In 1980 Knischka & Gübelin have already reported the possible identification criteria of these new synthetics. The author analysed 12 ℭ-rubies at the gem testing laboratory of Deutsche Gemmologische Gesellschaft which are reported below.

In dealing with the identification of these new ℭ-rubies the following were taken into consideration, their appearance and colour, pleochroism, absorption, luminescence, refractive indices and inclusions.

Where the colour is concerned there was not much difference from other natural or man-made rubies. Most of them were reddish-violet in colour similar to those from Thailand or Kashan synthetics. Some of them appeared pinkish with many internal imperfections lowering the degree of transparency. By comparing the colours with the DIN 6164 colour chart they were between 10:7:3 from red to 10: 5:6/5:4 violet red. The dichroism was not of much importance and showed purple-red and orange-red of varying intensities.

Absorption spectroscopy was determined by using a Krüss prism-type KL 10 spectroscope, and the following lines were noted. The chromium emission doublet was at 694.2 and 692.8 nm with other lines at 668, 659.2, 476.5, 475 and 468.5 nm, as with other

comparison stones. Available stones were visually inspected under both long- and short-wave ultraviolet radiations. K-rubies behaved rather differently under UV radiations. Some of them showed an inert centre with a crimson glow on the coating (Figure 15). This is probably due to the natural seed used which contained some iron. Private communication between Dr Lenzen and Professor Knischka (1980) revealed the use of seeds of natural Indian (Montgomery) rubies.

The refractive indices were measured using a Topcon critical-angle refractometer with Na_D light. The results were:

$n_e = 1.760\text{-}1.761$

$n_e\text{-}n_w = -0.008$

$n_w = 1.768\text{-}1.769$

The specific gravity determinations under controlled conditions gave values between 3.940 to 3.982 g cm^{-3}/4 °C. It was noted that those with natural seeds gave higher values than the ones with synthetic (Verneuil) seeds.

INCLUSIONS

With the above mentioned gemmological means it was difficult to confirm the origin of these new synthetic rubies. Inclusions had always been a necessary criterion in terms of ruby separations. Under the microscope these rubies revealed some interesting inclusions which are shown in Figures 16 to 26. Some inclusions were not encountered previously with other synthetic rubies. In most cases the overgrowth was evident.

CONCLUSION

K-rubies need to be treated with care. It is clear that with the above mentioned properties there is a possibility of confusion with their natural counterparts. Therefore much care must be taken in dealing with these stones either in the rough state or as a fashioned gem.

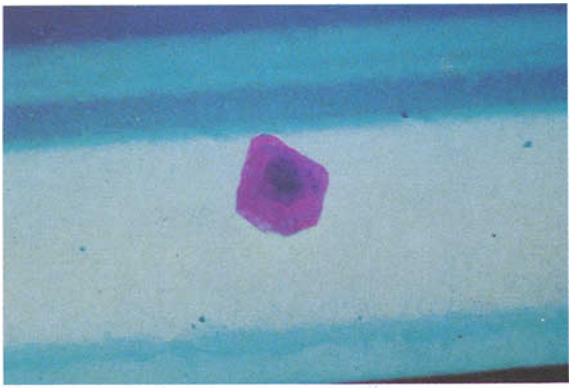

FIG. 15. A K-ruby under short-wave ultraviolet radiations showing the inert inner seed with the glowing coating.

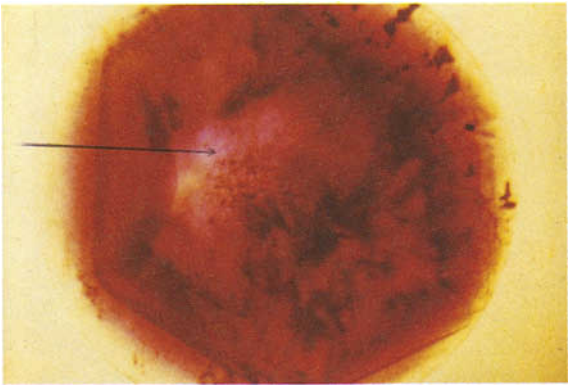

FIG.16. Overgrowth of a natural seed. At first appearance this may look like a natural ruby. Upon further examination the patchy colour of the natural seed (arrowed) was noted. Black particles were detected as flux remainings. 25 ×

FIG. 17. K-rubies contained flux inclusions, which appeared with a metallic lustre under reflected lighting conditions. It was clear that the growth conformed to a pseudohexagonal structure. 25 ×

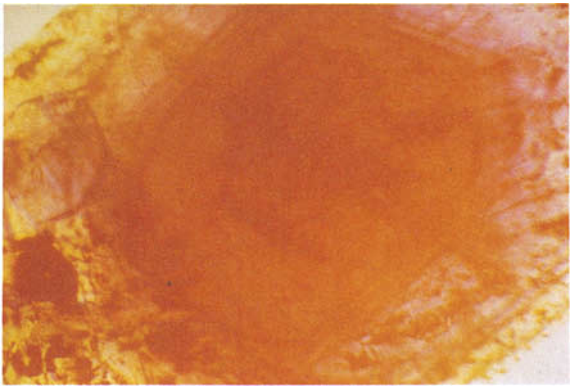

FIG. 18. Overgrowth on a natural seed which appeared darker than the synthetic coating. This was very distinct under ultraviolet radiations (see Figure 15). 30 ×

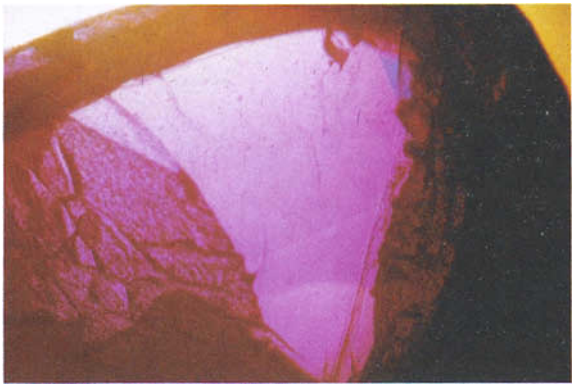

FIG. 19. K-rubies contained not only natural seeds, but also synthetic seeds. Characteristic curved growth lines are visible in this picture. 45 ×

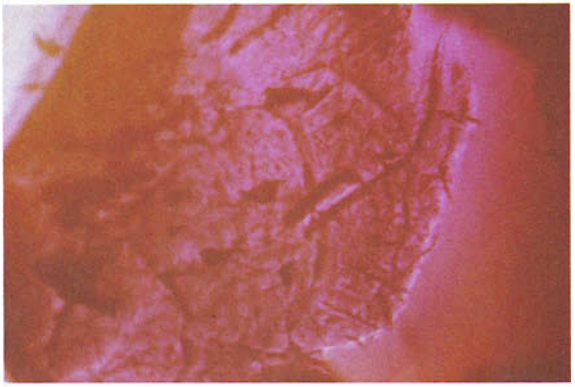

FIG. 20. This type showed a feather rather similar to that of natural ruby with some flux particles. 25 ×

FIG. 21. Wispy veil-like inclusions were presented on one plane of the stone. 25 ×

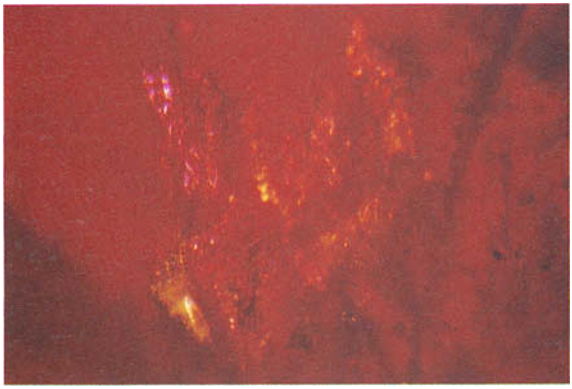

FIG. 22. Metallic appearance of the flux under reflected light. 45 ×

FIG. 23. K-rubies showed two-phase inclusions as a common feature. Much care must be taken in this connexion. 60 ×

FIG. 24. Two-phase inclusions were present rather characteristically here. The cavity showed irregular edges. 60×

FIG. 25. Veil-like feathers and a group of two-phase inclusions (arrowed) in a K-ruby. 30×

FIG. 26. Triangular flux particles were confirmed as a typical inclusion of these synthetic rubies. 60×

ACKNOWLEDGEMENTS

The author wishes to express his sincere thanks to Professor H. Bank, F.G.A. and Dr G. Lenzen, F.G.A., D.Gem.G., G.G., of Deutsche Gemmologische Gesellschaft, for providing laboratory facilities for experimental work and to R. Mertens, F.G.A., D.Gem.G., for his valuable advice and for critical reading of the manuscript.

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OBSERVATIONS ON SOME SCAPOLITES OF CENTRAL TANZANIA: FURTHER INVESTIGATIONS

By Prof. Dr GIORGIO GRAZIANI, Prof. Dr EDWARD GÜBELIN, C.G., F.G.A.,† and Dr SERGIO LUCCHESI**

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†Meggen, Lucerne, Switzerland.

Among various scapolite crystals of gem quality, those from Tanzania are of particular interest because of their high birefringence, homogeneity and, at times, evident chatoyancy. In the Umba deposit, North-East Tanzania, such mineral can be found both in contact zones referable to calcareous metasediments and in pegmatite intrusions related to basic and ultrabasic rocks (Solesbury, 1967), and in secondary deposits (Zwaan, 1971).

The scapolite chatoyancy effect has recently been attributed to iso-orientated needle-like channels of reddish colour, which were revealed to be due to iron oxides or hydroxides (Schmetzer *et al.*, 1977). Further investigations of this material indicated that the growth tubes, which were often filled with brownish-red or yellow laminae, had the same chemical composition, when examined with the electron microprobe, as the bulk crystals. They were thus considered to be filled by scapolite, while the laminae were found to be of a different mineralogical species (Figure 1).

The yellow laminae might be more or less hydrated iron oxides—i.e. lepidocrocite, according to appearance, colour and idiomorphous habit. The tabular reddish scales were more difficult to identify, since they might be either haematite or maghemite. It was assumed that they were produced by a dehydration of lepidocrocite; maghemite would have been obtained at temperatures not higher than 500 °C, while if this limit was exceeded, haematite would have segregated (Graziani & Gübelin, 1981).

Recent studies carried out on some idiomorphous transparent scapolite samples of various geneses and geological settings, gave evidence that their refractive indices increase during heating (Graziani & Lucchesi, in press).

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FIG. 1. Scapolite from Central Tanzania. Sample 1: two typical laminae. Top left: with partially dehydrated lepidocrocite. Bottom right: shows irregular shape and complete alteration of lepidocrocite. In both laminae the dark brown scales consist of maghemite. 110×.

Optical observations were carried out for each sample at high temperatures, and then, at room temperature, after cooling.

The former measurements continued up to a maximum of 450 °C, since beyond this temperature the radiating energy of the heated scapolite prisms made it impossible to discern the emission doublet of sodium clearly. The measurements at room temperature were made after the sample had been heated to a maximum of 800 °C, a limit slightly below the temperature at which scapolite exsolves into plagioclase, sodium and potassium chloride. The heating experiments indicated that rising temperature leads to a linear increase in the values of the refractive indices from 350 to 375 °C, at a slightly higher rate in the case of ε than in that of ω. To a first approximation, this increase was proportional to the meionite content of the sample. At higher temperatures, a sudden increase was recognized for both refractive indices, referable to loss of H_2O (Figure 2).

Measurements carried out at room temperature after cooling showed almost constant values for each sample over the whole temperature range investigated. Colour too was affected by heating. There was a progressive fall in colour intensity until the

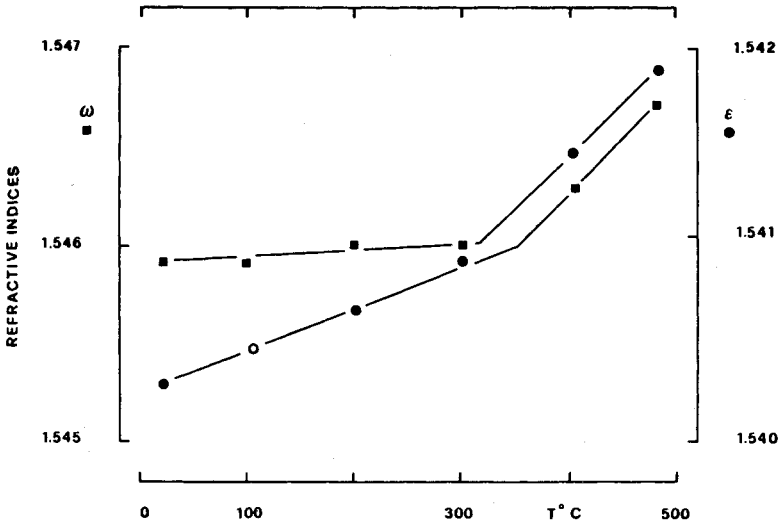

FIG. 2. Increase in value of refractive indices during heating.

sample became completely colourless at temperatures between 350 and 400 °C.

Thus it was possible to define the environmental conditions of this scapolite sample from Tanzania better considering the previously described results (Graziani & Gübelin, 1981). Particularly since this sample showed a faint yellow colour which would have been lost after heating up to temperatures beyond 350 to 450 °C, it was possible to conclude that this crystal never reached such a high temperature after its formation. Thus the reddish laminae which fill the growth channels are more likely made up of maghemite than haematite.

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THE OUGHTON SPECTRA

By R. KEITH MITCHELL, F.G.A.

In 1976 the obituary of John H. Oughton, F.G.A.A., editor of the *Australian Gemmologist* and a gem expert of considerable distinction, mentioned a seemingly impossible feat which he had performed many times.

Faced with a sapphire, Jack Oughton would hold it close to his eye 'at a certain angle' and look through it at a suitable light source, and would say 'I can see a strong absorption line in the blue,' or 'The iron band at 4500Å is missing', and would identify the stone as natural or synthetic accordingly.

My own first reaction to this was that it was not possible—an absorption spectrum seen without a spectroscope, with its essential slit and collimating lens—it couldn't be done. Most rainbow effects seen in ordinary life are not sequences of discrete wavelengths but are overlapping images due to the breadth of the original light-source. Even the spectroscope version suffers from overlap, which is the reason why we work with as narrow a light slit as possible. Seriously overlapped images such as those seen without a spectroscope are usually far too confused to permit absorption lines to be seen.

Later a paper on 'Visual Optics', which went against my own experience of 'look through' testing, caused me to re-examine the facts and to do again the many experiments I had first tried in the mid-Thirties, before writing on the subject.

The bright multiple images of the light source seen through a stone tested in this way always consist of spectra, either discrete or in associated pairs, the double ones indicating that the stone is birefringent.

Since a clear electric light bulb is used, the spectra will be C shaped, for they are images of the C filament of the bulb.

The light source will be several feet away, so there is no need for a collimating lens. The eye can focus the light image quite

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normally at a distance equivalent to the actual light-to-eye distance divided by the refractive index of the stone. At such a distance the filament is equivalent to a very narrow slit of light. Thus we have effectively disposed of the need for both slit and collimator.

While repeating my own experiments of many years before, and being now aware of the claim made for Jack Oughton's powers of observation, I suddenly noticed that a faceted red stone was giving bright spectra in each of which, despite their extreme shortness, the highly characteristic three band absorption of almandine could be seen. Using a straight filament bulb it was even easier to see this.

Mr Oughton was dealing with Australian sapphires which are iron rich and have a dark broad band centred at 4500Å. This would be easily visible in this 'look through' technique. Its absence in synthetics would also be quite obvious. The procedure is extremely simple provided the light is not diffused by a 'pearl' bulb, and involves little more than just looking through the table facet of the stone and adjusting it to give the longest possible spectrum, which will still be extremely short.

It must be noted, however, that this method works only when we are dealing with gem species which give broad and strong absorption bands. The observed spectra are minute by comparison with those beautifully spread ones seen through a spectroscope and cannot possibly allow us to distinguish very fine lines.

In this type of testing the facets of a stone are acting as a series of prisms and give dispersion depending on their angles to each other, on the position of the optic axis or axes, and the positions of the prisms relative to the light source and to the eye and, finally, upon the actual dispersive power of the stone. It has to be accepted that only the latter is a fixed factor and that the visual manifestation of this can be varied by the other three factors. These remarks apply equally to the determination of the actual birefringence by this method.

We can say that the 'look through' technique can be used safely to detect birefringence, or its lack, and, where a broad emphatic absorption occurs in a gem this will probably be seen. The determination of the amount of birefringence and the dispersion by this method involves calculation which is extremely difficult to achieve visually, although with practice some degree of approximation may be obtained.

Although Jack Oughton was probably using a method which he himself had found, and should have every credit for the acute observation that was involved, it has to be pointed out that Robert Crowningshield saw and identified absorption in this way as early as 1951.*

Dr W. W. Hanneman† has told me, in a personal communication, that paired spectra may be seen through quartz crystals and through calcite cleavage rhombs. I have seen them myself in quartz, but in my experience uncut calcite rhombs do not allow both the widely separated spectra to be seen at one time. The method might be useful in field work in the rather unlikely case where a mineralogist is not able to recognise transparent quartz crystals on sight.

[*Manuscript received 25th November, 1981.*]

Gems Gemol.*, 1951, **VII, 4, 120-4.

†Mr Mitchell complained to me that Dr Hanneman had misrepresented him in his 'Understanding the Hodgkinson Method' (*J.Gemm.*, 1982 XVII (3) 221-8): but these two writers are in broad agreement that interesting phenomena may be seen by this method. Basically they disagree only on the ease with which an observer can interpret observed phenomena with reliable accuracy. Enough space, however, has now been devoted to this subject in this *Journal*, and readers must be left to draw their own conclusions.—Ed.

A DIAMOND DOUBLET AND THE INFRARED REFLECTOMETER

By R. KEITH MITCHELL, F.G.A.

While writing a report on diamond testing instruments recently it occurred to me to try them out on a diamond doublet. This was one with diamond top and white synthetic sapphire base.

Not surprisingly the four different diamond heat probes, which are said to assess the heat conductivity of diamond, but which, Dr D. B. Hoover suggests,* are more likely to be responding to the thermal inertia of stones tested, were completely fooled by this fake. Only when, knowing what the stone was, I tested the base did I get a reject signal from these instruments. Normally one would not expect to have to test the base of a diamond.

I then tried the doublet on three different infrared reflectometers, and in each case it gave a needle deflection far greater than for normal diamond and so rejected the stone as a fake. This was evidently due to reflection from the parallel junction layer between the diamond crown and the sapphire base. It was a high enough reading to be confused with that for synthetic rutile, but the stone did not have the gaudy play of colour of the latter species.

Diamond doublets are quite rare, so the tests were perhaps academic to some extent, but it is nice to know that a comparatively simple instrument is now available which will cope with them should the need arise. Formerly the diamond doublet was checked principally by close observation with a lens or microscope, looking for reflections from the junction layer, which were not always easy to see. The 'new' test is far more positive.

[*Manuscript received 20th February, 1982.*]

*The Thermal Properties of Gemstones and their Application to Thermal Diamond Probes, *J.Gemm.*, 1982, XVIII (3), 232.

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THE INFLUENCE OF THE INTERNAL STRUCTURE OF PEARLS ON LAUEGRAMS

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INTRODUCTION

Among other possibilities, two types of x-ray methods are used for the examination of pearls. They are direct radiography (the shadow method) and the Laue method (x-ray diffraction). Both methods are of restricted use if applied exclusively, since each of them gives specific information which may not be conclusive for certain types of pearl. Thus in each case of a pearl test one has to decide on which method to place the greater reliance when deciding upon whether a pearl is natural or cultured. This study deals with the factors which influence the patterns of lauegrams.

Doing authenticity tests for the trade, we often found that lauegrams resulted in which neither a clear pseudohexagonal pattern nor a two-fold symmetry pattern showed, which is what an unprejudiced observer would expect from the pictures shown in textbooks. Most of these pearls deviated more or less from the ideal shape of a sphere. It is the purpose of this study to investigate any correlation of pearl shape and direction of the primary beam in respect of the resulting laue pattern. Furthermore it is of interest to evaluate the effects produced by a relatively thick overgrowth on the bead of a cultured pearl. To understand the pseudohexagonal spot patterns, the questions of the presence and type of aragonite twins and the arrangement of aragonite tablets are investigated.

DIRECT RADIOGRAPHY

The direct radiography method utilizes the fact that x-rays are weakened to varying degrees by the differing forms of matter they penetrate. The extent of the weakening depends on the thickness, the density and the chemical composition of the object being investigated. When x-raying a pearl, a shadow image is produced behind it on a photographic film. This image indicates the conditions of thickness and density as an effect of this absorption. In pearls, the relatively darker areas deriving from the conchyolin-rich parts are considered valuable in respect of diagnosis. These

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zones enriched with organic matter have a lower x-ray density than the surrounding calcium carbonate, and are thus weakening the radiation to a lower degree. Such zones may be situated in the centre of the pearl or in the form of single or repeated arcs or circles approximately concentric to it. In most cases, direct radiographs of natural pearls show such features. In addition to this, a typical, discontinuous course of darkness from the centre to the rim may be observed. In cultured pearls with a bead, usually one dark ring near the periphery is seen, which represents the conchyolin-rich shell around the bead. In non-nucleated cultured pearls, besides the mostly irregular external shape, an irregular shaped cavity lined with conchyolin is resolved in the radiograph as a quite striking dark irregular area at or near the centre of the pearl.

In some cases it is unfortunately not possible to make visible such fine growth inhomogeneities. These pearls show us the limitations of direct radiography. References for the technique and interpretation of this method are Webster (1975), Brown (1979), Anderson (1980) and Farn (1980).

Technical Details

The lauegrams needed for his investigation were produced by the author in the x-ray laboratory of the Institute of Mineralogy and Petrology of Basel University. Since there is no specialized Laue camera, a precession camera with a 0.7 mm diaphragm was used instead. The molybdenum tube was operated with a Philips generator (40 kV/20 mA). The radiation was used unfiltered, for a continuum is required. The pearls were placed directly on the diaphragm, leaving an interspace of 4.5-6 cm to the film (plastic wrapped dental film). Exposure time, according to the thickness of the pearl, ranged between 4 to 10 hours.

The photographs of pearl surfaces were made by means of scanning electron microscopy (SEM) with a Stereoscan mark IIA instrument (Cambridge). It was operated with an acceleration voltage of 20 kV. The samples were coated with an approximately 20 nm thick gold layer.

Lauegrams (X-ray Diffraction)

The German physicist Max von Laue succeeded in 1912, with his colleagues, in proving the wave character of x-ray radiation and the lattice character of crystalline matter. With this knowledge,

W. H. Bragg and his son, W. L. Bragg,* started to investigate crystal structures. Since at latest 1924 the Laue method has been applied in pearl testing (Galibourg & Ryziger, 1927; B. W. Anderson, pers. com., 1982). The Laue method is used to show the intrinsic symmetry of a crystal. If a narrow beam travels through a crystal parallel to a symmetry axis, it will deviate from this primary direction. It is diffracted (i.e. it will follow all directions in which the conditions of Bragg's law, $n.\lambda = 2d.\sin\theta$, are fulfilled). In total these diffracted rays will form a spot pattern on the film behind the crystal. This spot pattern or lauegram exhibits the symmetry which the crystal possesses in the selected direction.

Natural pearls are more or less good ordered aggregates of microscopic crystals. Their regulation follows a concentric or radial structure respectively. This is also evident from cross sections (Alexander, 1977). The tiny tabular crystals consist of Aragonite ($CaCO_3$, orthorhombic), but in some cases, (after Alexander, 1977), Calcite ($CaCO_3$, trigonal) is also found involved as a pearl material. The dominant faces of aragonite tablets or platelets are always set tangentially to the surface of the sphere. Their main symmetry axes (*c*-axes) point towards the centre of the pearl. Therefore, from whichever direction the x-ray beam passes through the centre of a spherical pearl, it will meet the same conditions. It will follow the symmetry axes of thousands of crystallites. Because of the pseudohexagonal symmetry pattern, Webster (1975) supposed the crystals to be twinned repeatedly (cyclic twinning). For orthorhombic minerals in the untwinned state, the resulting spot pattern should exhibit at the most two-fold symmetry. Other orthorhombic minerals show a tendency to form cyclic twins (e.g. chrysoberyl, cerussite) and thereby obtain a higher state of symmetry.

Thus, if a spherical natural pearl is struck centrally by an x-ray beam, an apparently hexagonal pattern or a ring (halo) will appear on the film.

Cultured pearls with nacreous beads are well ordered aggregates of microscopic crystals, too. But the type of arrangement is different. The cultivated layer consists of a skin with considerably varying thickness from pearl to pearl, from less than 10% up to possibly more than 70% (Scarratt, pers. com.,

*Respectively Presidents of the Gemmological Association from 1937 to 1942 (Sir William Bragg) and from 1954 to 1972 (Sir Lawrence Bragg).—Ed.

1982). This outer skin has the same built up structure as described for natural pearls. If cultured pearls have a core of mother-of-pearl, as they do in most cases, the aragonite platelets of this core are arranged in more or less even, parallel layers. Their main symmetry axes are all oriented approximately parallel to each other. The resulting lauegram is produced mainly by the set of crystals forming the core, since this inner bead normally represents the main part of the pearl. It now depends upon the angle at which the x-ray beam hits the layered structure of the bead. Oriented lauegrams of a cultured pearl with a thin skin illustrate this directional dependence (Figures 1a-d). If the beam direction coincides with the main symmetry axes (*c*-axes), i.e. is perpendicular to the layers of tablets, the well known six spot pattern arises. In all other directions patterns with a lower symmetry appear, since the crystallites are struck obliquely or perpendicular to their *c*-axes. Such a pattern shows at most two-fold symmetry and has been used to prove the presence of a nucleated cultured pearl (Webster, 1975; Anderson, 1980), (Figures 1b-d, 17).

Investigations by Scanning Electron Microscopy (SEM)

With a 10× lens lines are already visible on the surface of pearls which resemble contour lines. They bound relatively extended aragonite tablets or scales which overlie each other in a terrace or tile-like manner. To obtain more information on these structures, we produced photographs by means of a SEM. The advantage of this instrument lies in the high degree of sharpness and the better resolution compared with the conventional light microscope, even at low magnification. Figure 2 shows the structure in cross section of a broken piece of the cultivated layer of a cultured pearl. In this strictly speaking authentic part the aragonite tablets follow the curved surface of the sphere (see also Figure 5). The surface of this cultivated layer is illustrated in Figure 4. The tile-like and displaced aragonite tablets are clearly seen. Less clearly visible is a polygonal honeycomb-like pattern within these platelets. In Figure 3 a cross section of the spherical bead of a nucleated pearl is shown. Most beads are worked out of mother-of-pearl from the shell of an American river mussel. The beads are implanted into the mantle tissue of a pearl oyster to induce pearl

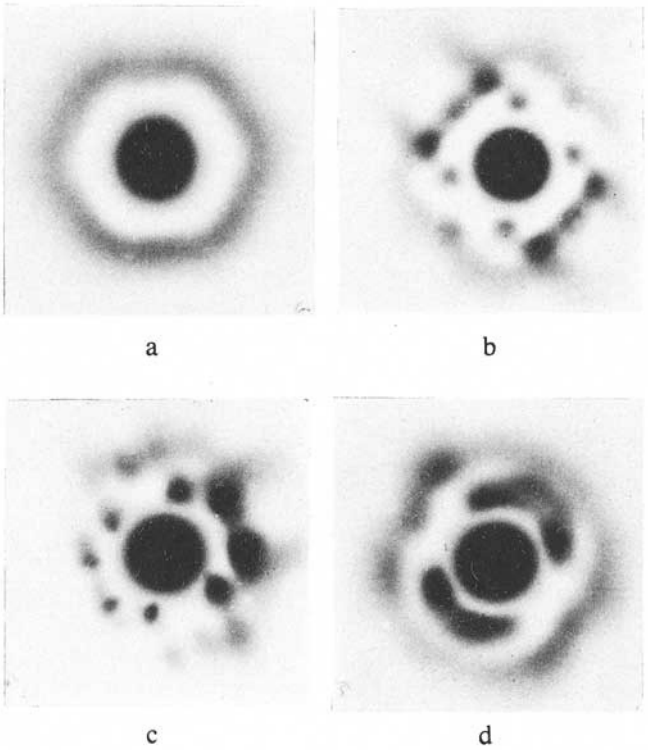

FIG. 1. Lauegram of a cultured pearl with bead, round, ⌀ 7 mm, with a thin overgrowth.
a: perpendicular to the aragonite layers of the core.
b: parallel to the aragonite layers of the core and perpendicular to the direction of a.
c: perpendicular to the directions in a and b.
d: oblique to the three preceding directions.

Scanning Electron Microscopic pictures of structures in pearls.

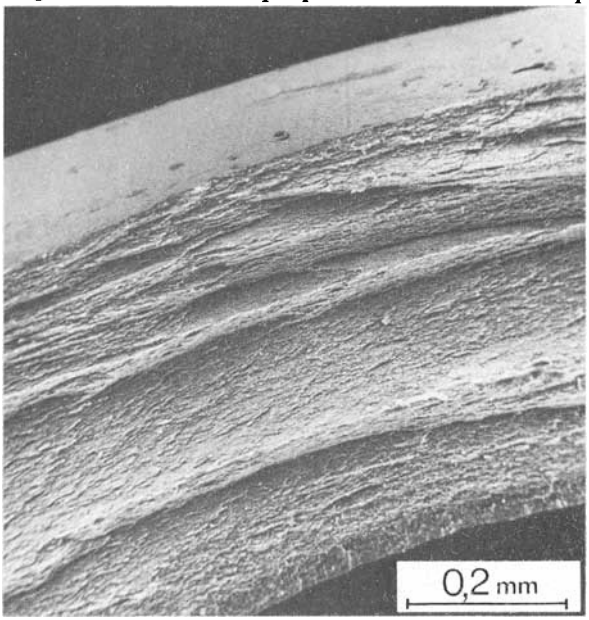

FIG. 2. Broken surface of a cultivated layer of a marine cultured pearl, with bow-structures. (SEM photograph)

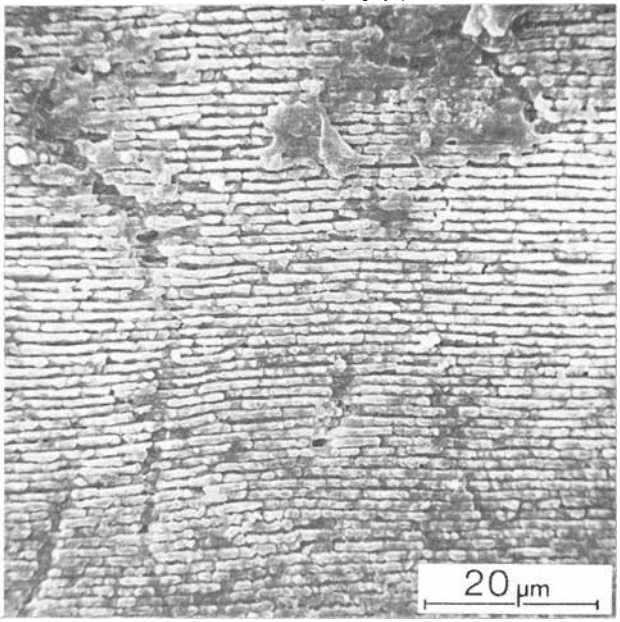

FIG. 3. Cross section through an etched bead of a cultured pearl, with brick-wall-like arrangement of the aragonite platelets. (SEM photograph)

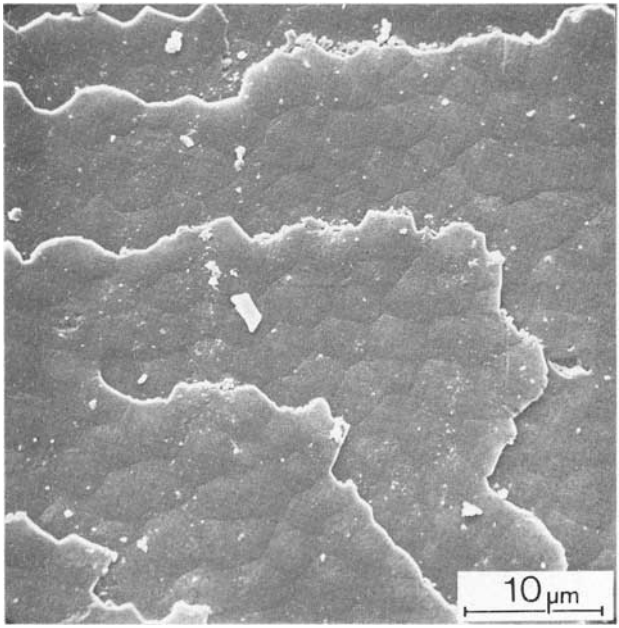

FIG. 4. Terrace or tile-like arrangement of aragonite platelets at the surface of a pearl. Honeycomb structures are visible. (SEM photograph)

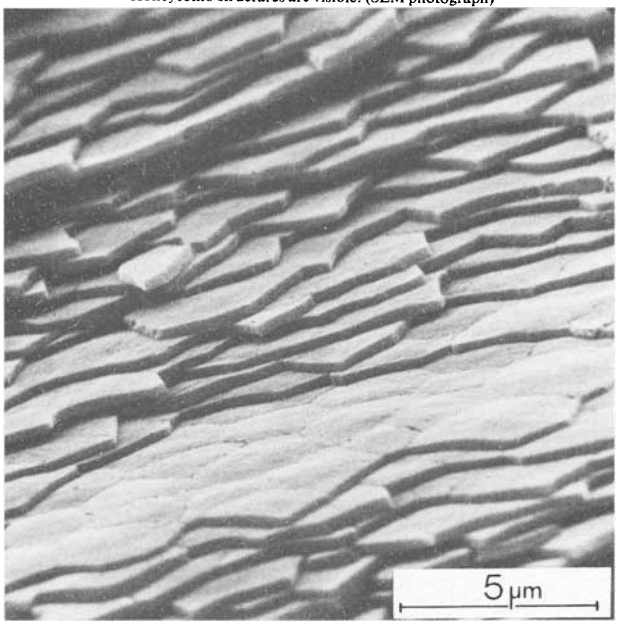

FIG. 5. Section out of Figure 2, with stacked aragonite platelets which show a polygonal split-up. (SEM photograph)

growth, i.e. to be overgrown by a pearly substance. These cores of mother-of-pearl have an even, layered structure, in contrast to the natural overgrowth which has a concentric build up. Figure 3 shows clearly the brick-wall-like arrangement of the plates which do not follow any curves of the pearl surface.

The honeycomb structure on the individual tiles of pearls deserves special attention (Figure 4). In search of twin structures which might prove the expected cyclic twinning, the surface was etched with dilute formic acid before inspection with the SEM, but no boundary lines between any twin individuals became visible, as expected according to the results of Mutvei (1977). He investigated different shells of moluscs, which showed after treatment with acid a strange type of regular intergrowth of aragonite. In Figure 6 different possibilities for twin formation are presented (Ramdohr & Strunz, 1967; Mutvei, 1977). The individual plates of the pearls are composed of a mosaic of polygons (honeycombs). In some places they are nearly regular hexagons; in other places, which are less ordered, distorted squares or pentagons are recognized.

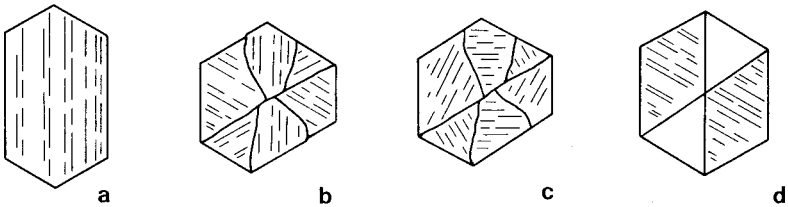

FIG. 6. Twin formations of aragonite. a: untwinned crystal. b&c: penetration-twins and repetition-twins respectively. d: twins according to Mutvei (1977). The *c*-axes of all individuals are perpendicular to the paper. The marked areas correspond to identically oriented individuals.

THE ARRANGEMENT OF ARAGONITE AGGREGATES IN PEARLS

To investigate the mutual crystallographic orientation of the polygons in the plates, the boundary angles were measured. The assumption that three preferred orientations existed, each being rotated 120° to the next, could not be confirmed for the time being. The verification of such a rule failed at the impossibility to orientate the individual polygons or domains with respect to the others. Such a statistical order within a plate would yield the effects of juxtaposition twinning and triplet-forming (Figure 7). The triplet state is also reached if, instead of an ordered arrangement embracing an entire plate, an arrangement between different 'floors' or in stacking is present. The 'honeycombs' which overlie

each other and belong to different plates, i.e. different levels, may be rotated 120° from one to another (or a whole number of times of 120°). This arrangement would yield the effects of twinning in superimposition and triplet-forming (Figure 8). Both the first model of juxtaposition-triplets as well as the model of superimposition give an explanation for the pseudohexagonal Laue symmetry pattern. But it is not clear if, in the strict mineralogical sense, such formations are allowed to be named triplets, since the individual plates are separated from each other by organic membranes. They are thus not intergrown directly.

A pearl aggregate of aragonite plates possesses a maximum of regulation, if both principles of ordering are fulfilled. It is interesting to note that in our SEM investigations no prismatic layers became visible. Former authors (Smith, 1972; Eppler, 1973; Hurlbut & Switzer, 1979) may have interpreted stacked plates as prisms.

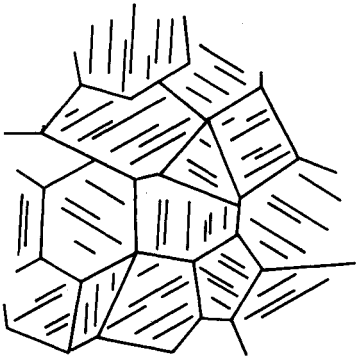

FIG. 7. A statistically ordered planar triplet aggregate, regulated after three directions (Triplet in juxtaposition).

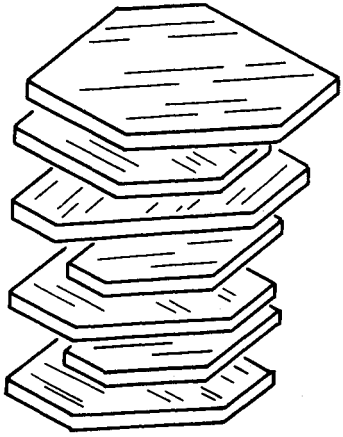

FIG. 8. A statistically ordered vertical triple aggregate, regulated after three directions (Triplet i superimposition).

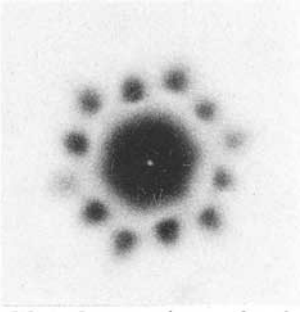

FIG. 9. Lauegram of a natural pearl, round, ⌀ 10 mm.

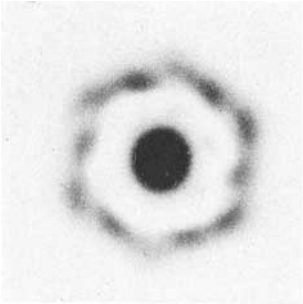

FIG. 10. Lauegram of a natural pearl, drop shape, 21 × 11 mm, taken through the short axis.

a

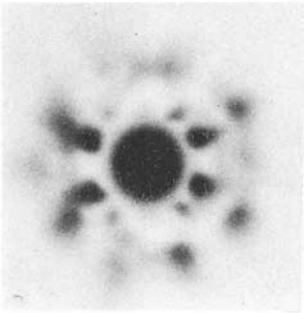

b

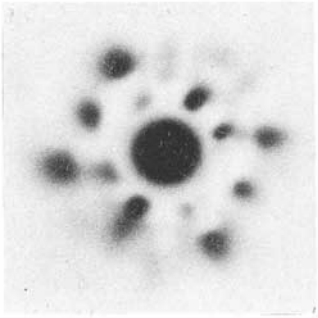

c

FIG. 11. Lauediagrams of a natural pearl, bouton shape, 8 × 9 mm.
a: perpendicular to the flat region.
b: through the thickest place, perpendicular to a.
c: 2 mm eccentric, parallel to b.

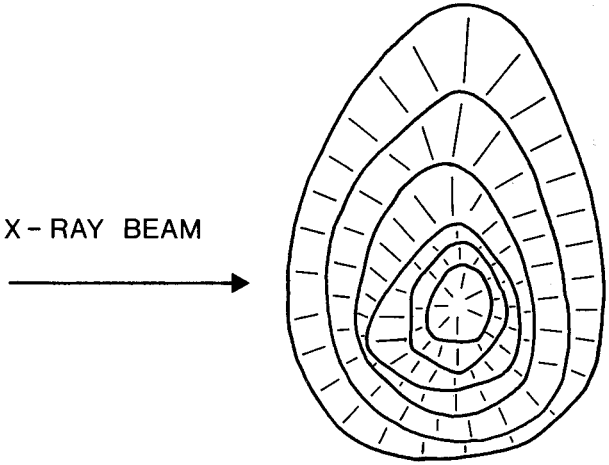

FIG. 12. Schematic built-up of an unround pearl. The small lines indicate the directions of the *c*-axes, which are at right angles to the platelets. The x-ray beam hits the crystallites under various angles, depending on how the pearl is situated/placed.

PRACTICAL EXAMPLES OF LAUEGRAMS

The author supposes that in pearls producing lauegrams like Figure 9 both principles of orderly arranged aragonite plates are relatively well realized. With a poor observance of the 120° angle to which one domain may be rotated in respect to another, we would expect lauegrams with diffuse hexagons (Figure 10) or even haloes (Figure 11a). So far only spherical pearls, in which the speed of growth has been equal in all directions, have been cited. If one direction accumulates the pearl substance more rapidly than another, button-, pear- or drop-shaped deviations from the sphere develop. In the course of the development of a pearl such growth inhomogeneities may occur several times and at different places on the then surface. Occasionally a formerly deformed pearl may grow on to become rounded.

The addition of unequally thick layers of shell which lead to an onion-like build-up has an important meaning in lauegraphy. In this way formations originate, which offer differing circumstances to a fixed x-ray beam (Figure 12). Frequently the beam will meet many crystals obliquely to their main symmetry axes. It will pass along a direction of two-fold symmetry. The resulting lauegrams

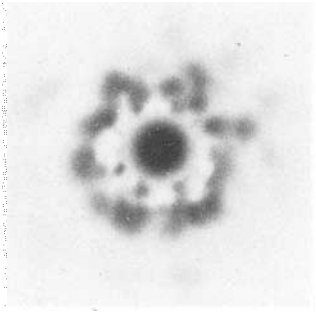

FIG. 13. Lauegram of a natural pearl, drop shape, 19 × 12 mm, in the direction of the short axis.

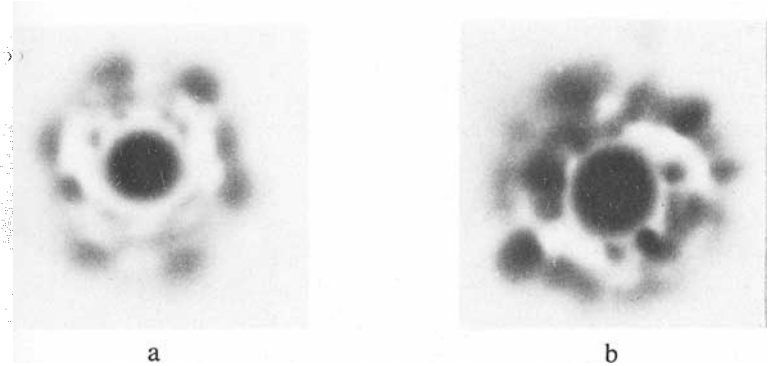

FIG. 14. Lauegram of a natural pearl, pear shape, 12 × 9 mm. a: through the short axis. b: obliquely, on the thin side.

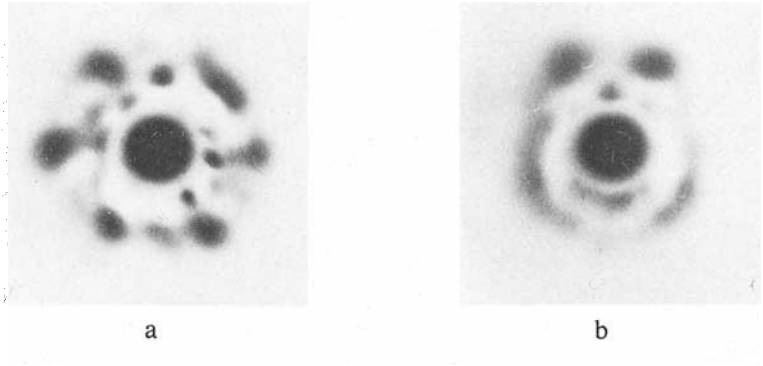

FIG. 15. Lauegram of a Natural pearl, drop shape, 20 × 11 mm. a: through the short axis. b: 2 mm above the short axis.

from such examples show a multitude of spots among which the six 'real' refections are not resolved (Figures 13, 14b). Sometimes even mixed pictures arise, where the four spot pattern which is typical for nucleated cultured pearls may get through quite strongly (Figures 11b, 15b).

The most intriguing pictures arise from button- or drop-shaped pearls. In both shapes, from the outside it is not clear in which position the possibly displaced nucleus is located, and for a decisive lauegram the beam should pass through the centre of the nucleus. Depending on the direction of the primary beam, mostly very complex lauegrams are produced (Figure 14). A directly misleading picture occurs if the beam strikes a drop pearl at the neck, somewhat displaced from the long axis (Figures 14b, 15a). In such cases it is best to produce several lauegrams from differing directions. A direct radiograph produced in advance may reveal some of the internal particularities and may recommend a direction for a lauegram, but, if direct radiography is informative in its characteristics, in most cases no further lauegrams are needed except for scientific curiosity. They then help us to understand the influence of a complex internal situation in such pearls.

When seedless (non-nucleated) cultured pearls are investigated by x-ray methods, direct radiography yields the most reliable information. Lauegrams of such formations show the pseudohexagonal symmetry of natural pearls, or a halo. These lauegrams are somewhat diffuse and characterized by fine radiating lines (Figures 16a, 16b) which are not yet explained. Thus in the case of a seedless cultured pearl it would be most imprudent to rely on the lauegram only, as the 'spot patterns' produced would be the same as for natural pearl.

In cultured pearls with a thick cultivated layer the signals from the kernel pierce the mantle and are able to put the four diagnostic spots on the lauegram. For example, in the cultured pearl of Figure 17 the outer layer (37% of the diameter) cannot produce a pseudohexagonal pattern (in spite of its identical structure to natural pearls), while the cultured pearl of Figure 18 (with an outer layer of 59% of the diameter) shows a superimposition of both patterns. It is remarkable that the smaller proportion of the mother-of-pearl bead in this latter pearl gives a more prominent pattern than the very thick overgrowth. It is thus reassuring that the diagnostically valuable information is able to penetrate the

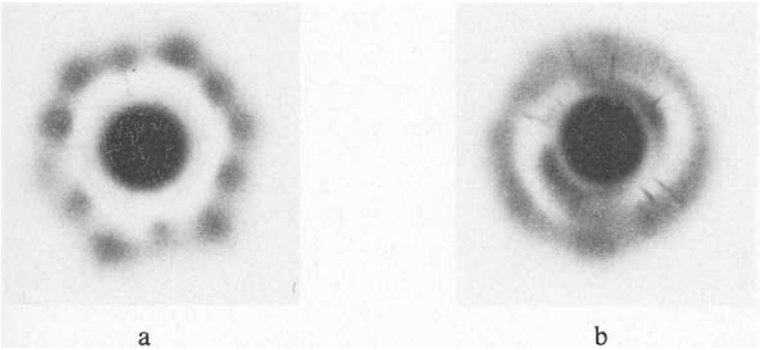

FIG. 16. Lauegram of a non-nucleated cultured pearl, baroque shape, 14×6×4 mm, a and b: two directions, at right angles to each other.

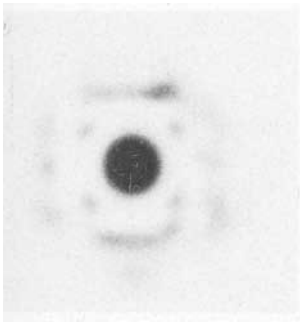

FIG. 17. Lauegram of a cultured pearl with nacreous bead, round, ⌀ 13 mm, thickness of the cultured layer 2×2.4 mm.

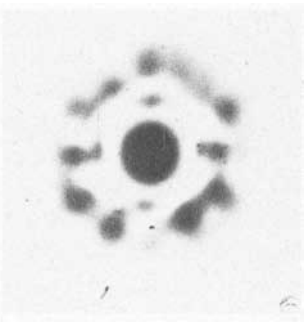

FIG. 18. Lauegram of a cultured pearl with nacreous bead, oval, 16×13 mm, thickness of the cultured layer 2×3.9 mm.

cultivation layers even if the coatings are very thick. It is therefore important to observe the central part of the lauegram (Figures 17, 18), looking for a strong four spot pattern.

CONCLUSIONS

Lauegraphy therefore yields indications for answering the question whether a pearl contains a mother-of-pearl bead or not. Lauegraphy is not the appropriate means to prove the authenticity of a pearl in general (e.g., seedless cultured pearls). Normally two lauegrams taken at 90° to each other are sufficient to demonstrate a

possible two-fold symmetry pattern. But the technique has to be used with skill, since with a disadvantageous conduction of the primary beam on unround natural pearls two-fold symmetry patterns may be produced too.

ACKNOWLEDGEMENTS

Thanks are due to Professor Dr S. Graeser (Mineralogical Institute of Basel University) and Dr R. Guggenheim (Laboratory for Scanning Electron Microscopy, Basel University) for valuable discussions. I am also grateful to Mr M. Düggelin from the SEM-Laboratory for preparation of the samples and supplying the SEM-pictures. Furthermore my thanks go to Mr K. Scarratt (The Gem Testing Laboratory of the London Chamber of Commerce and Industry) for his important professional advice and critical reading of the manuscript.

The author was recently informed by Dr E. Gübelin of the existence of a thorough investigation, similar to the one presented here, carried out by Dr William H. Barnes in 1944 in Montreal, Canada. This research was done for the Gemmological Laboratory of Mappins Limited, Montreal, Canada. The report, entitled 'Pearl Identification: The Diffraction of X-rays by Pearls', was never published; however a small number of typed copies for local distribution were produced. The interest of Dr Gübelin is gratefully acknowledged here both for mentioning the existence of this report to me and for giving me access to his copy. Barnes treated both natural pearls and mother-of-pearl as being similar to fibrous aggregates. His results with respect to identification however are more or less identical to the results presented in this paper.

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NATURAL CORAL AND SOME SUBSTITUTES

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INTRODUCTION

It is well known that varieties of coral—*rubrum, japonicum* and *secundum** (Brown, 1980)—nowadays on the market are sometimes replaced by synthetic products and natural coral treated by different methods.

One of the best man-made imitations, Gilson's 'Imitation Coral' (Nassau, 1979) has been widely investigated and its properties published. Not so well known are treated coral substitutes. The first type of coral we are going to mention is the so called resin epoxy-esters type treated coral (Aliprandi and Butini, 1981). The material consists of poor quality coral, very rich in cavities, produced by action of polyps. This coral is very little valued because of lack of compactness, posing some problems for the shaping and polishing.

Cavities are filled with some colourless organic resins, of the epoxy-esters type, presumably using vacuum techniques or embedding the specimens in the mould chamber of a hydraulic press. This treatment imparts a high degree of compactness which will render this material, otherwise considered valueless, more suitable for cutting and using in jewellery. The external appearance, once treated, is very similar to the natural coral, causing some difficulties in identification.

The second type of treated coral could be classified as dyed coral. This material becomes pigment-treated by the employment of various techniques which are not yet completely understood. In some cases the treatment is easily detected, in some others the dye-stuff penetrates the porous coral completely, and detection of the treatment in this case turns out to be more problematical.

EXPERIMENTAL

The following samples have been tested: (a) natural coral bead, (b) dyed coral bead, (c) resin treated coral bead, and (d)

*See *J.Gemm.*, 1981, XVII (8), 600 for H. S. Pienaar's proposed classification.—Ed.

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TABLE 1.

Optical and physical properties of the corals

	Specimen reference	Colour	Weight ct.	D	RI*	Additional diagnostic data
(a)	Natural coral	dark red	4.71	2.62	1.55	Striped structure, colourless streak, good polish, translucency.
(b)	Stained coral	pink-white	5.21	2.62	1.56	Weak fluorescence UV 365 nm.
(c)	Resin treated coral	pink-white in patches	6.51	2.42	1.56	Poor polish, waxy lustre.
(d)	Gilson imitation coral	ox blood red	5.52	2.50	1.58	Coloured streak, grainy texture, very good polish.

*mean values

Gilson 'Imitation coral' bead. A summary of the tested specimens is shown in Table 1.

The hardness of all specimens tested proved to be 3½ on the Mohs scale, while the density differed notably in the Gilson product and in resin-treated coral. Our test reported a value of 2.50 g/cm^3 for Gilson's and 2.42 g/cm^3 for the resin-bonded specimen, both lower than the natural, which lies between 2.6 and 2.7 g/cm^3.

Refractive indices on all specimens were measured on a Krüss ER 60 refractometer. Only one mean value could be taken on the round surface of the bead, using the distant vision method. The RI values obtained were 1.55 for the natural and 1.56 for the stained material, 1.56 for the organic resin-treated bead and 1.58 for the Gilson substitute.

The chemical reaction of the beads to diluted hydrochloric acid was examined. Effervescence was noted and some small residual red pigments were seen in the Gilson material. The attack of acid on the resin-bonded coral slowly produced total reaction on the calcium carbonate composition, leaving at the end a porous spongy semitransparent round aggregate, which further investigation proved to be epichlorhydrin.

A comparative streak test of the four specimens gave no valuable information, except that the Gilson material produced a dark red streak, compared with the colourless streak of the other specimens.

We found fluorescence under both long- and short-wave UV light of no diagnostic value, except only that in testing the colour-stained bead we found, along certain minute veins hiding almost invisible fractures, a weak purplish red fluorescence when bathed by a beam of long-wave UV. The effect is due, most probably, to the presence of small amounts of the colouring agent, supposed to be an organic aniline dye, concentrated in surface cracking. Immersing the coral in ether or acetone causes the dye to be deposited in the liquid, which becomes slightly coloured, leaving behind a bleached specimen.

What we found to be a very diagnostic feature for the identification of natural coral, was the degree of translucency of all *Corallium* when tested with a transmitted concentrated beam from an optic fibre. Synthetic products consisting of pressed calcite or resin-impregnated material on the contrary appear opaque.

Furthermore this technique will clearly render visible those straight lines parallel to the skeleton of the coral tree considered important features for the positive identification of the natural coral (Cavenago-Bignami, 1972).

Micrographs of surfaces, both polished and rough were taken of all specimens, using SEM techniques (Figures 1-6). The analysis of polished surfaces has clearly shown the porous structure of the resin-treated coral (Figure 3a). The specks of resins were here easily and clearly identified as spots of different consistency, breaking the homogeneity of the surface. The Gilson coral has a grainy structure and is made up of particles of different shape and size (Figure 4a). Microscopical examination and further SEM determinations gave no clues which would enable one to distinguish stained from natural coloured coral (Figures 1 and 2). Figure 6 shows two spicules produced by the action of polyps in the solidified structure. The same polished surfaces were subsequently investigated for Ca, Si and Fe concentration patterns. Comparative tests on all specimens have demonstrated uniform distribution of Ca and Si in natural (Figures 1b and 1c) and stained coral (Figures 2b and 2c).

On the contrary the patterns found in the specimen treated with epoxy resins appear quite different. Ca is absent in some areas of the surface (Figures 3c and 5c). The arrangement of Ca and Si is different in Gilson imitation coral; Ca seems evenly spaced (Figure 4c), while Si is distributed in an irregular way (Figure 4b). Figure 5a shows the surface of resin-treated coral after the attack of a drop of diluted hydrochloric acid.

CONCLUSION

The samples investigated in this paper have demonstrated that separation with traditional gemmological instruments of natural coral from treated or substitute material always presents different grades of difficulty. However it is possible without using destructive tests to discriminate between natural coral and simulated or treated coral.

The only test which produced colour alteration, performed in separating stained from naturally coloured material, was that of immersing the bead in a solution of ether or acetone. Such a test, which is always left to the discretion of the operator, in any case needs the approval of the owner of the sample, since in this case a colour-destructive technique is being applied.

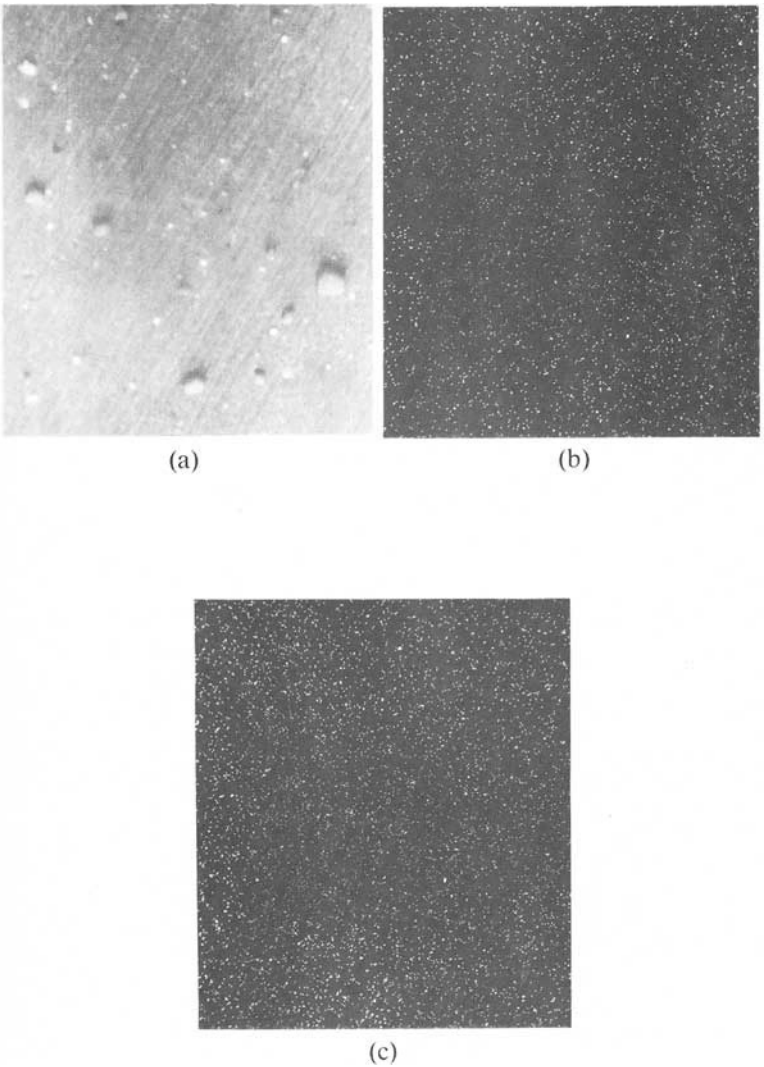

FIG. 1. Natural Coral. (a) Polished surface, ×1200. (b) Polished surface, elemental distribution, Si Kα. (c) Polished surface, elemental distribution, Ca Kα. (Fe absent).

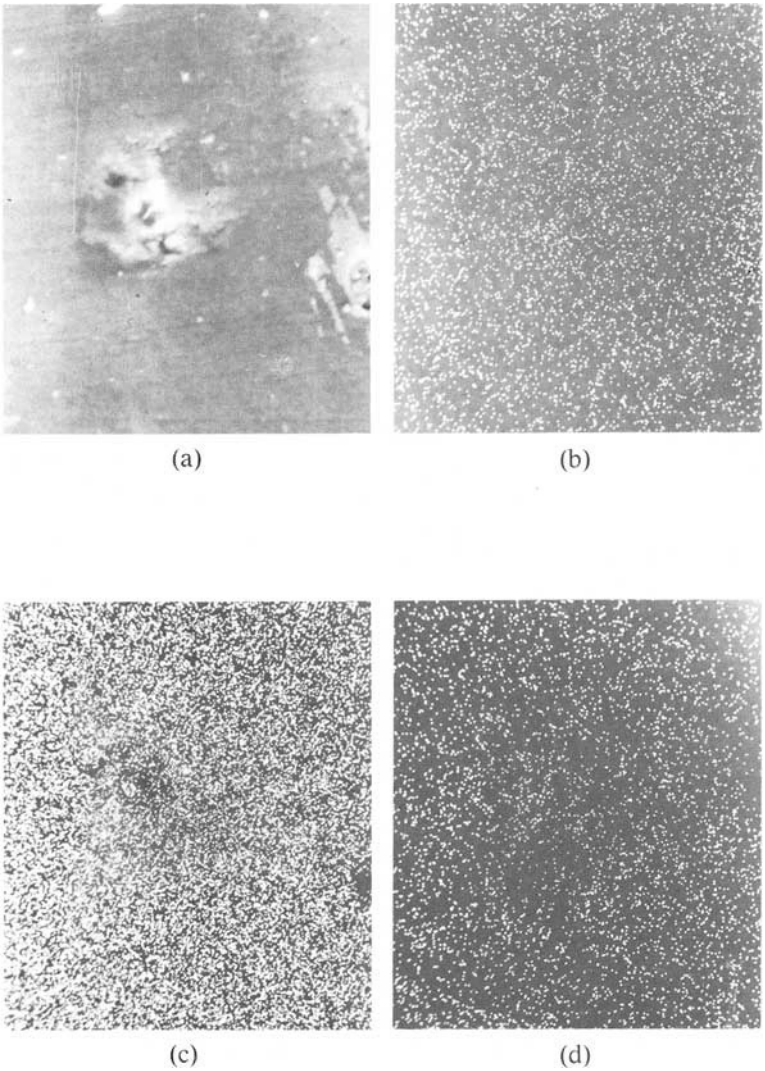

FIG. 2. Stained Natural Coral. (a) Polished surface, × 1200. (b) Polished surface, elemental distribution, Si Kα. (c) Polished surface, elemental distribution, Ca Kα. (d) Polished surface, elemental distribution, Fe Kα.

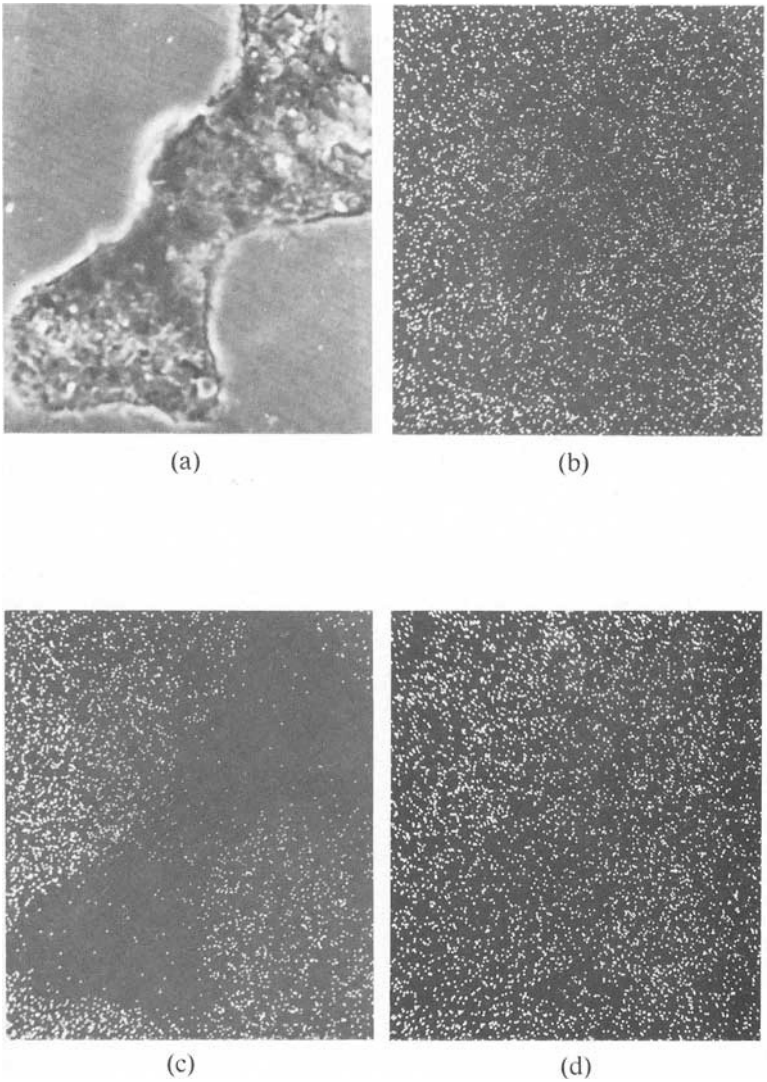

FIG. 3. Resin-treated Coral. (a) Polished surface, × 1200. (b) Polished surface, elemental distribution, Si Kα. (c) Polished surface, elemental distribution, Ca Kα. (d) Polished surface, elemental distribution, Fe Kα.

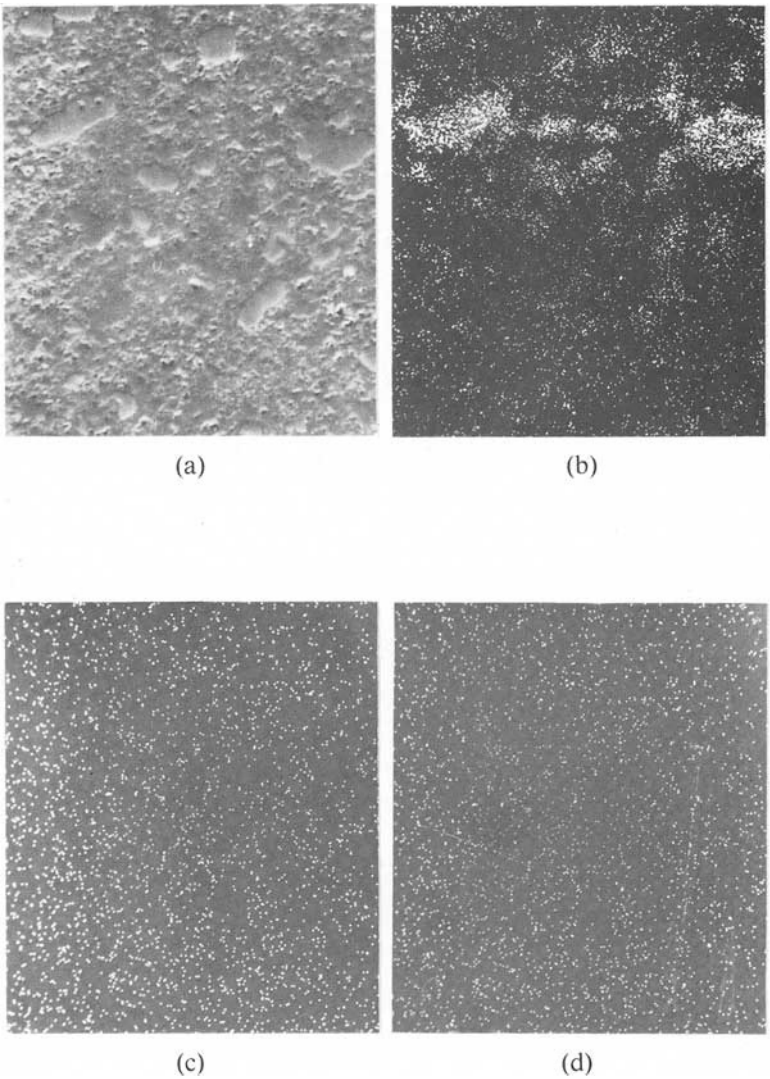

FIG. 4. 'Gilson Coral'. (a) Polished surface, ×1200. (b) Polished surface, elemental distribution, Si Kα. (c) Polished surface, elemental distribution, Ca Kα. (d) Polished surface, elemental distribution, Fe Kα.

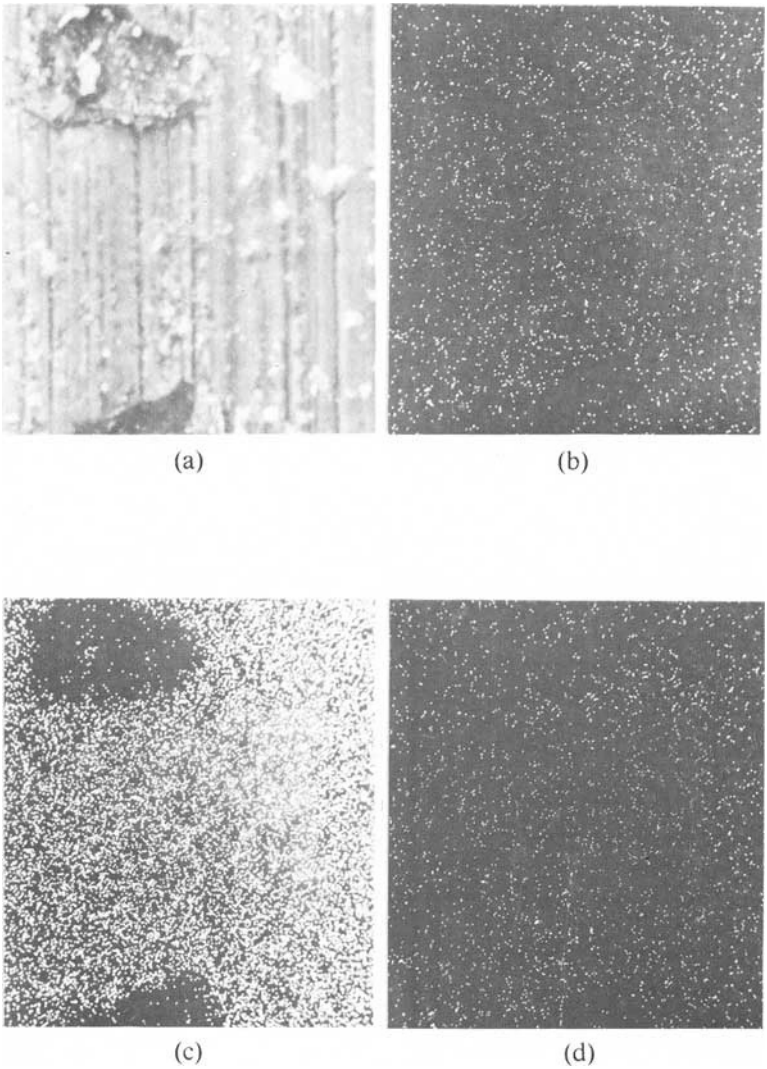

FIG. 5. Resin-treated Coral after treatment with HCl. (a) Polished surface, ×1200. (b) Polished surface, elemental distribution, Si Kα. (c) Polished surface, elemental distribution, Ca Kα. (d) Polished surface, elemental distribution, Fe Kα.

FIG. 6. Natural Coral. Rough surface, × 1000, evidencing spicules fused into the skeleton.

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A METHOD FOR MEASURING THE INFRARED SPECTRA OF FACETED GEMS SUCH AS NATURAL AND SYNTHETIC AMETHYSTS

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ABSTRACT

A method which allows infrared measurements of faceted gems in transmission is described. This method enables distinction of synthetic amethysts of Russian production from natural stones. Effects caused by dispersion are minimized by immersion in liquid paraffin (nujol) (RI = 1.484 at 589 nm). The volume of immersion liquid traversed by the infrared light is much reduced by using a variable cell which was specially constructed. The influence of the immersion liquid on the infrared spectra can be compensated for, if necessary, by placing a second, identical cell, into the reference beam. In the manner described, it is possible to record infrared spectra of faceted stones, which have about the same quality as the spectra of plane-parallel plates.

The principal function of gemmology is acquiring criteria for identification of gems and for distinguishing them from their imitations in the widest sense. As a matter of fact, the distinction of natural gems from the corresponding synthetic stones by means of conventional gemmological techniques is getting more and more difficult, because progress in the science of materials during recent decades has led to exact knowledge of the conditions of growing ultra-pure single crystals—especially in laser, maser and communication engineering. Today, several producers offer synthetic gems whose attributes are very similar to those of natural ones. Permanent improvement of growing conditions has even led to synthetic stones which cannot be identified by measuring physical properties easily available to the gemmologist, such as density, hardness and refractive indices, and which have no diagnostic inclusions. The trained gemmologist accordingly will still be able to make a decision in most of the relevant cases just by means of using a gem microscope, but the quota of synthetic gems which cannot be identified in this way is increasing. To avoid upsetting the gemstone market in view of this fact, new detection methods have to be worked out and provided, so that one can fall back on them if necessary.

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Different growing conditions of synthetic and natural crystals lead to differences in structural properties, such as the number and types of displacement in the lattice, and incorporation of foreign atoms. One of the methods which can be used to detect such structural differences is infrared spectroscopy. With this method, one can investigate the absorption or the transmission of electromagnetic radiation by the sample in the infrared region of the spectrum (4000-100 cm^{-1}). Electromagnetic radiation in the infrared region has frequencies which correspond to molecular vibrations or to lattice modes of solids. These vibrations can be excited by electromagnetic radiation of the same frequency, if the vibration is coupled with the change of the corresponding dipole moment. The energy of the radiation is then absorbed and transformed into vibrational energy of the molecules or the solid. Modern infrared spectrometers record continuously the absorption of a sample which is brought into the radiation path. The spectrometer is scanned through the complete frequency range of interest. From the position and the intensity of the absorption bands one can draw conclusions concerning the composition of the sample (certain molecular groups exhibit so-called 'characteristic frequencies') and the way certain molecules are incorporated into the substance.

Infrared spectroscopical investigation on crystals is done either by reflection spectroscopy (for measuring surface effects, as, for example, adsorption, or for measuring the lattice modes), by the use of KBr-pellets (1-2 mg substance pressed together with about 200 mg KBr to a glassy pellet), by the use of nujol mull* or by thin, plane-parallel plates. The application of infrared spectroscopy for distinguishing natural from synthetic gems has been pointed out for emeralds (Wood & Nassau, 1968; Nassau, 1976, 1980), turquoise (Arnould & Poirot, 1975) and quartz, especially amethyst (Zecchini, 1979; Zecchini & Mérigoux, 1980; Schmetzer & Bank, 1980). With this method it is also possible to identify treated turquoises, which show additional bands induced by plastic (Banerjee, 1972). Whereas emerald and quartz are normally investigated as single crystals, natural or treated turquoise can be investigated as KBr-pellets or by reflection spectroscopy.

*According to the O.E.D. Supplement (H-N, 1976), 'nujol' is a preparation of paraffin oil used for making mulls in infrared spectroscopy, and 'mull' is a preparation of finely ground material suspended in oil for the purpose of studying the infrared spectrum.—Ed.

Natural and synthetic emeralds show different mechanisms of incorporation of H_2O molecules into the channels of the beryl structure, as was shown by Wood & Nassau (1968). The infrared absorption bands of natural and synthetic emeralds, which are induced by incorporated H_2O molecules therefore differ in frequency and intensity.

The differentiation of natural amethysts from synthetic ones, which are produced in the U.S.S.R. and can be found on the gem market in growing quantities, is possible by examining the infrared spectra in the range from 3800-3000 cm^{-1}. Infrared investigations on α-quartz have been done long since (e.g. Saksena, 1958; Kats, 1962; Dodd & Fraser, 1965; Chakraborty & Lehmann, 1978), and the absorption measurement of synthetic quartz is done as a routine procedure for quality control. The relationship between trace element concentrations and intensities of the infrared absorption bands, especially the origin of infrared bands of amethysts, has not yet been clarified completely. Infrared reflection measurements of emeralds and amethysts are, however, not suitable for investigating the incorporated H_2O and OH^-, because the depth of penetration of the radiation is too low, so that only surface effects can be measured. The application of the KBr-pellet or the nujol mull method is also impossible, because the relevant concentrations and, accordingly, the infrared band intensities are too small.

Wood & Nassau as well as Schmetzer & Bank used plane-parallel plates, which were mounted perpendicular to the incident beam, so that no refraction and no variation of the symmetry of the radiation path took place. This method is well suited for working out criteria for distinguishing synthetic from natural stones, but less suitable for gemmological routine investigations, because the principal requirement of investigation without damage is not fulfilled. Faceted gems are cut in such a way, that a radiation path like the one through a plane parallel plate is avoided; light should be totally reflected by the pavilion facets and come out again through the table facet (Figure 1). As the refractive index is changing continuously with the wavelength of the incident radiation (dispersion), the symmetry of the radiation path is also varied continuously with the wavelength. A symmetrical path of radiation between the reference beam and the beam through the sample is, therefore, not guaranteed if a faceted stone is mounted into a spectrophotometer. Furthermore, only a small part of the

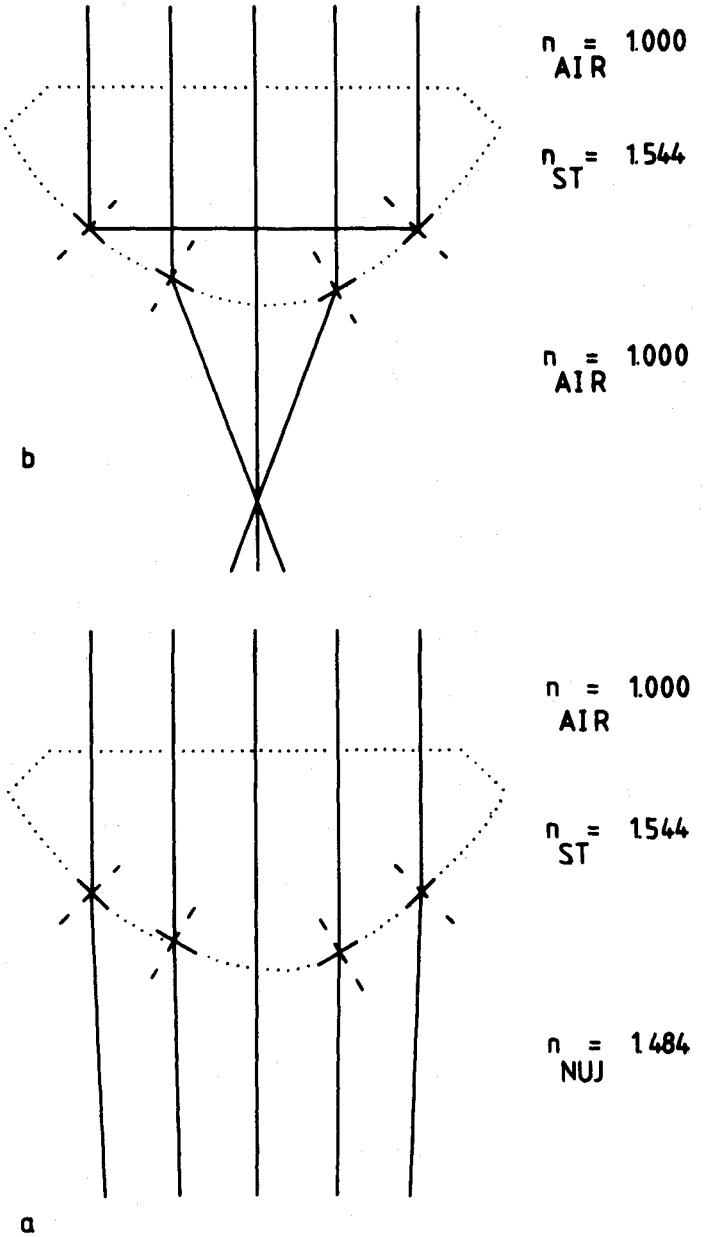

FIG. 1. Radiation paths through a faceted amethyst, when using nujol as immersion liquid (a) and in air (b).

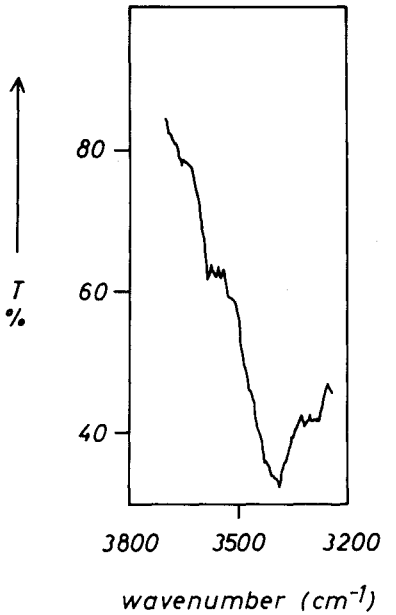

FIG. 2. Infrared spectrum of synthetic amethyst of Russian production; faceted stone, spectrum recorded without using an immersion liquid.

incident radiation will be registered by the detector after having passed through the stone (Figure 1). The forementioned facts are the reasons for the spectra of faceted gems (Figure 2) being of a much poorer quality than those of plane-parallel plates (Figure 3), when they have been mounted without further precautions. Only a few, suitably cut stones will allow the recording of a somewhat characteristic spectrum, after a skilful and time-consuming orientation has been done. This method is not suitable for routine investigations.

Zecchini (1979) pointed out the disturbing influence of refraction and dispersion when infrared spectra of faceted gems have to be recorded. He therefore investigated faceted quartz crystals in an open, constant path-length cell which was filled with CCl_4 as an immersion liquid. This liquid has a refractive index of 1.4607 at a wavelength (of the incident radiation) of 589 nm. The

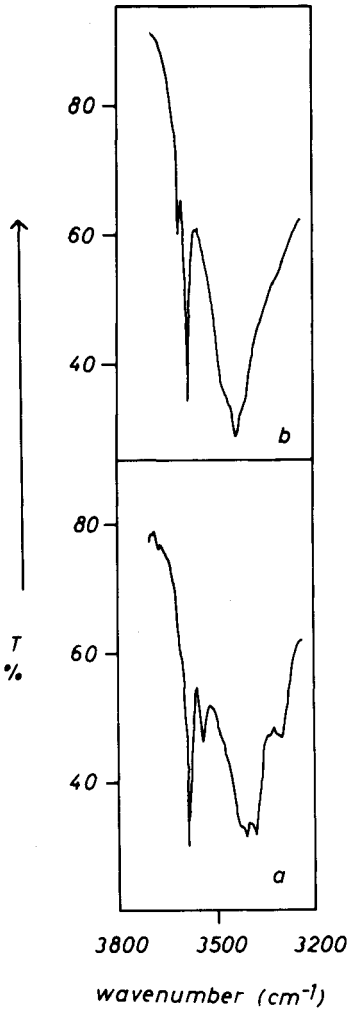

FIG. 3. Infrared spectra of synthetic amethyst of Russian production (a) and natural amethyst from Africa (b); plane-parallel plates; spectra recorded without using an immersion liquid.

above mentioned effects can be clearly reduced by using this immersion liquid, and a better interpretation of the spectra is possible.

When using halogenated hydrocarbons in an open cell, there is the danger, that the mirrors of the optical systems of customary infrared spectrophotometers are damaged by halogen hydrides, which are produced at the radiation source. CCl_4 should therefore not be used routinely in open cells. As a liquid that does not contain any halogens and which has no absorption bands in the range of 3800-3000 cm^{-1} and a refractive index near that of quartz, we have chosen liquid paraffin (nujol, $n = 1.480$-1.484 at 589 nm). This liquid is used as a suspension medium in infrared spectroscopy and can be handled without problems. The only disadvantage is the relatively low transmission which makes it impossible to use a constant path-length cell. Therefore, a cell was constructed the path-length of which is variable. For gemmological routine investigations, this cell has to be open, so that the gems can easily be mounted. To provide a great range of application, the windows can be exchanged. In the range of 3800-3000 cm^{-1} polished KBr windows have been used. By using such a cell (Figure 4), it is possible to minimize the variation of the symmetry of the radiation path through the stone and to minimize the immersion layer thickness. After the stone has been brought into the cell by the sample holder, the cell is closed until the table facet touches one of the windows and the back of the stone touches the other one. A diaphragm, the diameter of which should be nearly the same as that of the table facet of the stone, is installed in front of the first window. The radiation path through the cell is shown in Figure 1. The greatest part of the beam enters the stone without being refracted. The difference between the refractive indices of the stone and the immersion liquid being very small, the beam will leave the stone with very little refraction and pass through only a small layer of liquid. If a second, identical cell is brought into the reference beam for compensation, it is possible to gain infrared spectra of faceted stones which are of about the same quality as those of plane-parallel plates (Figure 5). The method described is easy to handle and makes it possible to record infrared spectra of faceted amethysts in a routine manner.

It stands to reason that other gems can also be investigated with the described cell. If gems with a higher refractive index are to

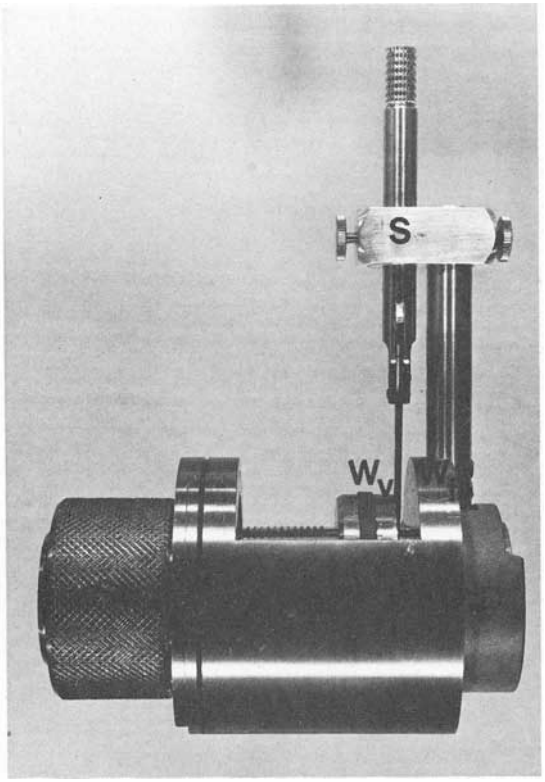

FIG. 4. Liquid cell for measuring infrared spectra of faceted gems; S sample holder; W_f fixed window; W_V variable window; Sc adjusting screw for variable window; D diaphragm.

be measured, it is impossible to avoid the use of halogenated hydrocarbons, which makes the handling of this method more difficult. The cell has to be welded into plastic foils which have no bands in the spectral range that is under investigation. Very suitable for this purpose is polyethylene, which has a very good transmission in almost the whole infrared range.

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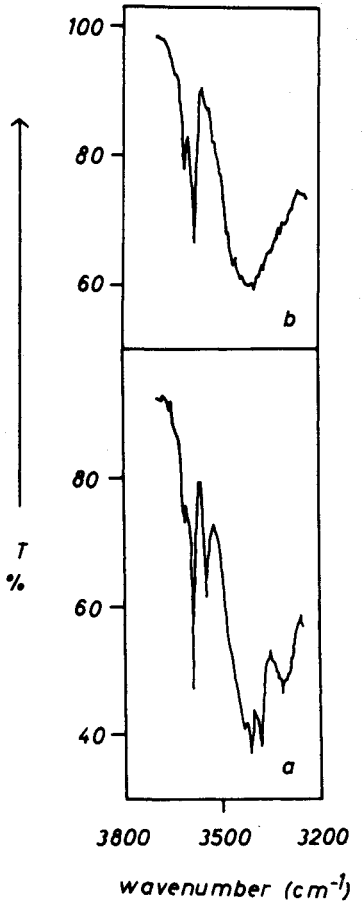

FIG. 5. Infrared spectra of synthetic amethyst of Russian production (a), and natural amethyst from Zambia (b); faceted stones; spectra recorded using nujol as immersion liquid in variable cell (see Figure 4).

Oberstein; A. Pick, Mackenrodt; H. Thul, Kirschweiler; Weinz & Nebert, Kirschweiler; J. Ph. Wild, Idar-Oberstein; K. E. Wild, Kirschweiler.

The measurements have been done in the Inorganic Chemical Institute of the University of Heidelberg by kind permission of Prof. H. Siebert and Prof. H.-H. Eysel.

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THE USE OF ELECTRON SPIN RESONANCE SPECTROSCOPY TO DISTINGUISH SYNTHETIC FROM NATURAL GEMSTONES

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INTRODUCTION

In a previous article (Hutton, 1979) for this *Journal,* one of us described the use of magnetic resonance spectroscopy (known either as electron spin resonance, ESR, or electron paramagnetic resonance, EPR) in gemmology. In this article, it is proposed to review briefly an exciting recent development in the application of ESR spectroscopy at about 3 cm wavelength to gemmology—the ability to distinguish synthetic from natural gemstones, and even, in some cases, to say by which process the synthetic stones were made.

The theory and apparatus associated with ESR spectroscopy as applied to gemmology have been described previously (Troup, 1969, Hutton, 1979), and therefore we will not present them again here. Rather, we will present the spectra for the natural and the synthetic stones, discuss the features of difference and the reasons for them, and show why the identification of (say) the synthetic stone is very secure.

EXPECTED DIFFERENCES BETWEEN NATURALS AND SYNTHETICS

It is convenient to list here some quite general differences we might expect between natural and synthetic stones, so that we can to some extent predict the differences to be expected in the ESR spectra.

Particularly with modern crystal growing techniques and modern technology, we would expect that, in many crystal species, the synthetic lattice would be more perfect than the natural one, because of the lack of inclusions, and of 'impurities' other than those required (these comments do *not* apply in the unusual but well known case of spinel). Immediately, we are given two differences in the spectra: the lines for the synthetic will be

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narrower, because the environment of the paramagnetic ions will be more uniform, and certain lines appearing in the natural crystals from various impurities there will not appear in the synthetic. The reverse can also be true, since it may be easier to substitute a certain impurity in a synthetic in order to colour it, than to incorporate the naturally occurring impurity.

The narrower lines will mean that certain small but important features of the spectrum of the (single) common impurity will be more evident in the synthetic spectrum. For example, lines due to neighbouring pairs of impurity atoms will show up more clearly, because they will be narrower. All these features discussed will be described below.

Apparatus and Technique

The apparatus used in all investigations was either that described in Hutton (1979), or standard commercial apparatus (e.g. the Varian system) operating at wavelengths in the 3 cm region. Magnetic fields of up to 10 kilogauss (1 tesla) were required. The specimens were oriented so that the magnetic field lay along principal magnetic axes for the spectra, and the spectra along each such axis recorded. The 3 cm wavelength resonant cavity allows the use of fairly large specimens (about the size of a little-finger nail in perimeter), which has proved convenient when identification has been required for commercial reasons.

Results and Discussion

(a) Golden Sapphire

We choose to begin with yellow sapphire, since this was the first system to be established historically (Scala & Hutton, 1975). Figure 1(a) shows the typical spectrum (ESR) of a natural golden sapphire with the steady magnetic field perpendicular to the trigonal axis, and 1(b) shows the ESR spectrum of a synthetic golden sapphire under the same conditions. It will be seen that there is very little or no Cr^{3+} in the natural stone, while the Fe^{3+} lines are broad and prominent: in the synthetic stone, there is very little Fe^{3+} present, but considerable Cr^{3+}. The spectrum of synthetic brown sapphire is also shown, in Figure 1(c); here, the percentage of Fe^{3+} has increased with respect to that of Cr^{3+}.

The multiplicity of small lines on either side of the middle Fe^{3+} line in the natural stone is also a feature of the spectrum. They are

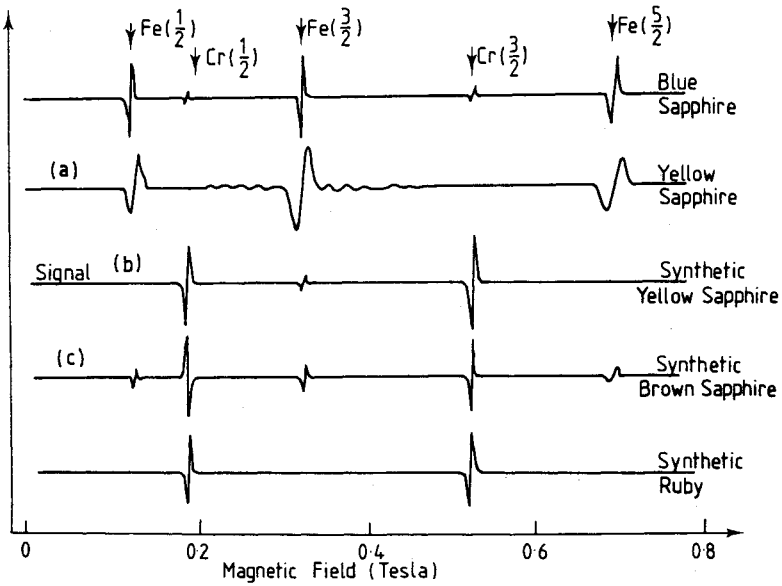

FIG. 1. ESR spectra of various sapphires at ~3 cm wavelength taken with the steady magnetic field perpendicular to the trigonal axis.

absent in the synthetic stones. Their origin is not known at this stage: pair spectra, or Mn^{2+}, or radiation damage are possibilities.

(b) Blue Sapphire

The ESR spectra for various natural blue sapphires, taken with the steady magnetic field perpendicular to the trigonal axis, are shown in Figure 2(2)-(6). The multiplicity of small lines about the middle Fe^{3+} line (labelled B) are clearly seen in all natural stones, except perhaps the Ceylon blue. They are effectively absent in the boule fragment (synthetic), whose Fe^{3+} lines are also very much narrower than those of the naturals. The linewidth is effectively the distance between the peak and the trough of the signal denoting the line.

It may be argued that this case is not as conclusive as that for the golden sapphire. It is really necessary to pass to the spectra with the magnetic field parallel to the trigonal axis, as shown in Figure 3(1)-(4). In this case, even the Ceylon blue clearly shows the many

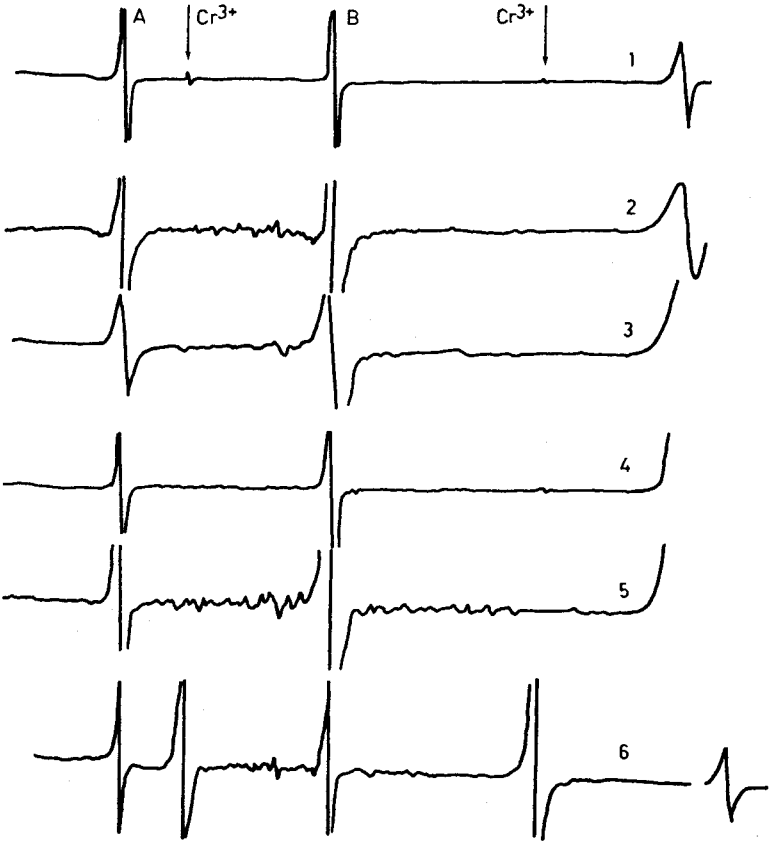

FIG. 2. ESR spectra of various blue sapphires, taken under the same conditions as Figure (1). 1: Boule fragment. 2: Certain natural, origin unknown. 3: Australian blue. 4: Ceylon blue. 5: Cambodian pale blue. 6:Montana blue.

small lines about the middle Fe^{3+} line (B), but the most important feature of the spectrum of the synthetic is the appearance of the lines labelled F. These are identified as the so-called 'forbidden' lines, arising from transitions not between neighbouring energy levels (see, e.g., Hutton 1979) but between levels and their next nearest neighbour. When the magnetic field lies parallel to the trigonal axis, these transitions have a low probability: hence the name 'forbidden'.

They are very narrow because next-to-nearest neighbouring levels will converge or diverge more rapidly as the magnetic field is

FIG. 3. ~3 cm wavelength ESR spectra of various blue sapphires: steady magnetic field parallel to trigonal axis. 1: Boule fragment. 2: Ceylon blue. 3: Australian blue. 4: Cambodian pale blue.

increased than the nearest neighbouring levels. Any imperfections in the lattice will broaden these lines and hence their peak-to-peak height will decrease. Their clear presence and *narrowness* is an indication of the perfection of the lattice. They are just visible in the Ceylon blue, perhaps the most perfect of the natural specimens we used. However, they are clearly present, and narrower, in the synthetic.

The combination of 'perpendicular' and 'parallel' spectra, then, makes the test very nearly conclusive for blue sapphire (Anderson, Hutton & Troup 1981). To make the test fully conclusive, what is needed is a statistical study of the linewidths of synthetic and Ceylon sapphires, and a further investigation of the possible effects on ESR spectra of the heat-treatment of natural

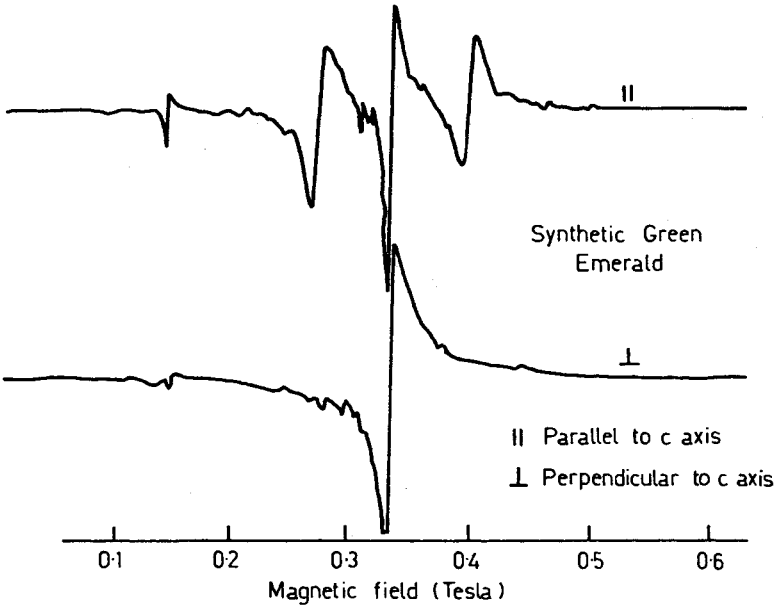

FIG. 4. ~3 cm wavelength ESR spectrum of synthetic green 'emerald' coloured by V^{3+}.

sapphires. However, at this stage, it would be fair to say that there is a very good case for considering blue sapphires having pronounced and narrow forbidden transitions as synthetic, unless they can be proven natural by other means.

(c) Emerald

There have been (Campbell, 1974; Farn, 1975) arguments about how to define emerald. For example, *to the eye,* beryl containing V^{3+} can have the same 'characteristic' colour of emerald which is, in general, beryl coloured by the presence of Cr^{3+} (with little Fe^{3+} in comparison).

The spectra of the synthetic beryl containing V^{3+}, taken at room temperature, are shown in Figure 4. V^{3+} does not show up at room temperature, but the Fe^{3+} spectrum does. Such a stone also remains green under a Chelsea filter.

The spectra of natural emeralds from various sources are shown in Figure 5(a)-(b). The Rio Tinto specimen shows chromium but no iron, but others show spectra characteristic of both. Differences in the parallel spectra satellite lines are quite marked.

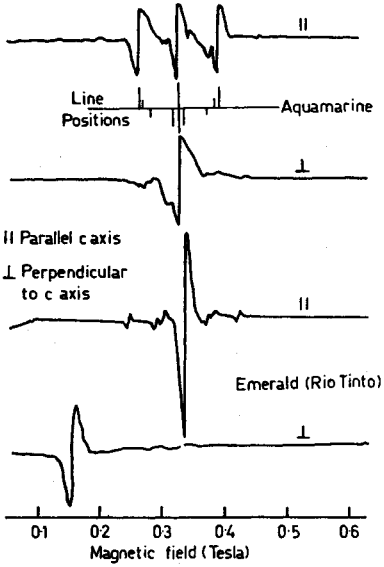

FIG. 5(a). ESR spectrum of Rio Tinto emerald, with Aquamarine spectrum for comparison.

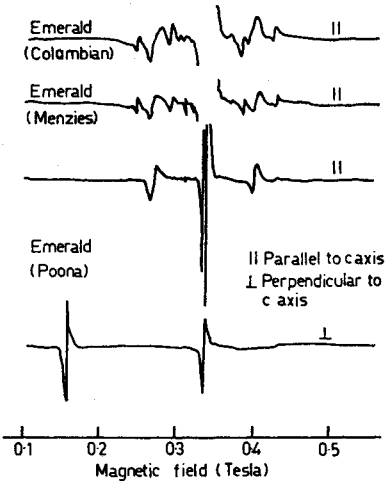

FIG. 5(b). ESR spectra of Colombian, Menzies, and Poona emeralds.

The Poona sample has well resolved iron lines and the spectra are characteristic of low concentrations in a well-ordered crystal. The Colombian and Menzies samples have higher chromium concentrations and are not as well ordered.

Spectra for Gilson and Chatham synthetic emeralds are shown in Figure 6(a)-(b). The many sharp satellite lines clearly distinguish these synthetics from the naturals. In addition, the Gilson, but not the Chatham, shows a pronounced iron spectrum, which explains why the line at 4270 Å is seen in the optical region (Liddicoat, 1971). The satellite lines which distinguish these synthetics from the naturals have been shown to be due to Cr-Cr pairs (Edgar & Hutton, 1978).

(d) Alexandrite

Very good quality synthetic alexandrite, made for laser purposes, has recently become available (Walling & Peterson, 1980). Since the crystal is orthorhombic, three spectra, with the steady magnetic field parallel to each of the principal magnetic axes, are required for specification. One of these is shown in

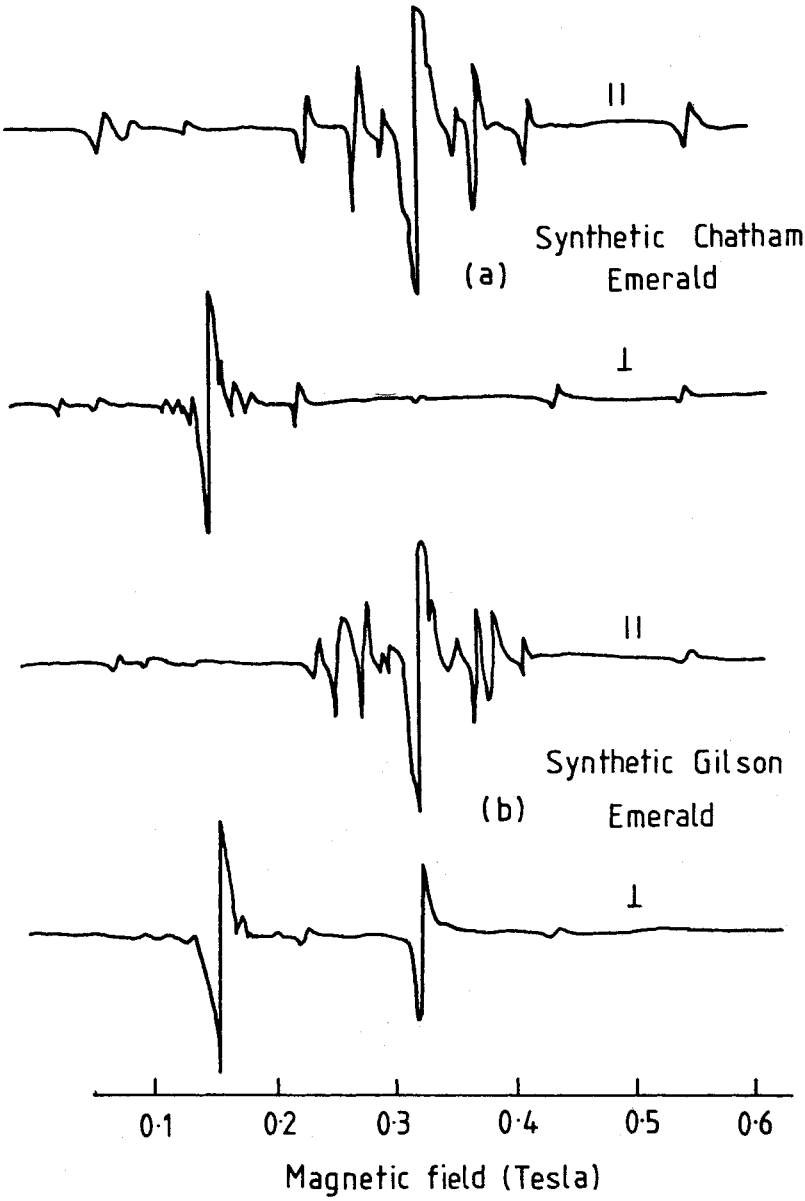

FIG. 6. ESR spectra of (a) synthetic Chatham emerald (b) synthetic Gilson emerald.

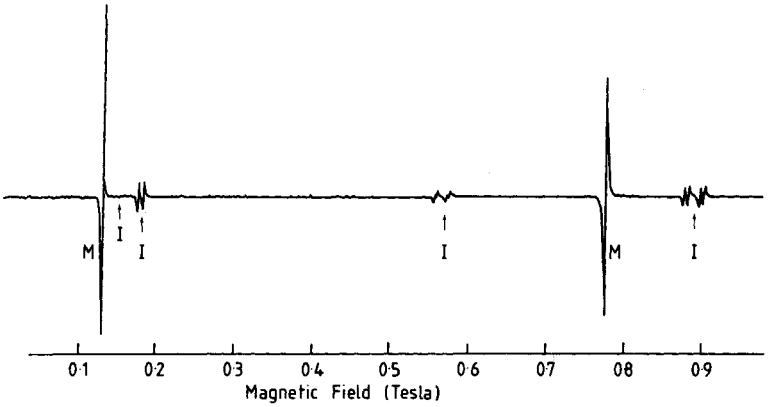

FIG. 7. ~3 cm ESR spectrum of laser quality synthetic Alexandrite: steady magnetic field along *b* axis. The lines labelled 'M' arise from Cr^{3+} ions in sites having inversion symmetry. The steady magnetic field is slightly misaligned from the *b* axis: when it is exactly along the *b*-axis, the lines labelled 'I' become single, not doubled as shown.

Figure 7, taken on a synthetic sample kindly supplied by Dr J. C. Walling, of Allied Chemicals, New Jersey, U.S.A.

In previous work (Barry & Troup, 1969), over fifty natural alexandrite samples were studied by ESR. All contained Fe^{3+} as well as Cr^{3+}, leading to a far greater number of lines in the spectrum, and to broadening of all lines by exchange coupling. A flux-melt grown synthetic crystal, kindly supplied by Dr E. F. Farrell, of M.I.T., was also studied. This gave spectra similar to those of Figure 7, but the lines were broader: the crystal was not of good optical quality. Thus the breadth of the lines and the presence of many extra lines due to Fe^{3+} are what enable the natural alexandrite to be distinguished from the synthetic.

(e) Mg Spinel (Cr^{3+})

Naturally occurring $MgAl_2O_4$ is almost completely ordered as regards crystal structure, but the corresponding synthetic material is not.

In the natural material, the linewidth of the ESR transition does not vary very much with the angle θ made by the steady magnetic field and the [lll] direction, whereas in the synthetic material, the disorder imposes a considerable variation (Atsarkin, 1963: Schindler, Gerber & Waldner, 1970). A table (after Atsarkin) is reproduced overleaf.

Compound	Angle θ (degrees) O	15	70	90	
Natural Spinel (Light Pink)	24	25	27	24	Linewidth (Gauss) at half intensity
Synthetic (Stoichiometric, 0.6% wt Cr_2O_3)	32	70	90	70	Linewidth (Gauss) at half intensity

Schindler *et al.* (1970) have also performed ESR experiments on synthetic $ZnAl_2O_4$ coloured pink by the inclusion of Cr^{3+}. This material does *not* have the disorder of the synthetic $MgAl_2O_4(Cr)$.

While it is known that careful refractive index measurement can distinguish natural $MgAl_2O_4(Cr)$ from synthetic $ZnAl_2O_4$, we have a further test involving ESR, because the spectral parameters are different. Careful observation of the field strengths at which the Cr^{3+} ESR lines appear for a given frequency allows distinction between the spinels. Unfortunately, the quoted literature for this work on spinel is somewhat more specialized than that in the previous sections, and published spectra are not available for reproduction.

Discussion

We believe some considerable progress has been made in using ESR to distinguish between certain natural and synthetic stones. The work needs to be extended to other stones, but more importantly, the technique needs to be made more readily available to the gemmologist. A 3 cm wavelength ESR spectrometer, and associated fairly large electromagnet, to obtain the necessary steady magnetic fields, is not portable, and hence the stones for identification must be brought to the laboratory where the spectrometer is sited. However, there is another possibility, currently being investigated in our laboratory, and that is the use of a 10 cm wavelength ESR spectrometer. This can be almost completely transistorized, the necessary transmission lines can be made very compact, and the electromagnet can be made much smaller, as one needs to go only to about 0.3 tesla instead of the 1 tesla required for 3 cm wavelength ESR. Thus, there is some hope of a fairly low-cost commercial instrument one day becoming available.

ACKNOWLEDGEMENTS

The substance of this article (up to Section (d) of the results and quoted spectra) formed the subject of a seminar at the Physik Institut der Universität Zurich, Schönbergasse 9, Zurich at the invitation of Professor Detlef Brinkmann, in late 1980. The information on spinel was most kindly and generously brought to our notice by Dr F. Waldner, of the same Institut. The Gemmological Association of Australia, especially the Victorian Branch, have been most generous always in supplying us with gemmological specimens.

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[*Manuscript received 6th November 1981, revised 17th April 1982.*]

GEMMOLOGICAL ABSTRACTS

ABRAHAM (J. D. S.). *Heat treating corundum: the Bangkok operation.* Gems & Gemology, **XVIII**, 2, 79-82, 4 figs (3 in colour), 1982.

Something over 95% of corundums exported from the Far East have been heat-treated in one way or another. Stones are first trimmed of cracked or heavily included areas, and usually coated with borax paste. Heating processes are secret, but sapphires are heated to 1600 °C for upwards of 24 hours, rubies for four to eight hours. Process is often repeated many times. Results largely a matter of luck and many stones are ruined. Hit or miss methods vary greatly, successful ones are not revealed in detail. R.K.M.

ANDERSON (A.). *Is it really a Kashan?* Jewelers' Circular Keystone, pp.54-7, 8 figs in colour, March 1982.

The report gives some notes on the Kashan synthetic ruby. Characteristics listed include solid-filled very coarse negative crystals with high reflectivity; clusters of parallel rod-like negative crystals, also solid-filled; networks of solid-filled negative crystals; wispy patterns resembling rain, sometimes resembling a tailed comet; straight growth lines. Some Kashan stones are reported to be inclusion-free up to magnifications of 126×. M.O'D.

ANDERSON (J. E.). *Color grading ruby with the Color Master.* Lapidary J., **36**, 3, 534-6, 1982.

The Color Master is sold by Gem Instruments Corporation and places stones according to an arbitrary table of colour. In this case ruby was the stone selected, and a table is given of the grading notation. M.O'D.

BALL (R. A.). *Common opal and potch opal.* Aust.Gemmol., **14**, 11, 305-10, 7 figs, 1982.

Discusses the difference between potch opal and common opal. The terms are often used synonymously, but this writer shows that potch is found only in association with precious opal and differs from common opal in its structure quite substantially. Common opal does not show the sphere structure. Potch does, but has spheres of mixed sizes which prevents the play of colour. An interesting and well illustrated paper despite the fact that these differences can only be seen when an electron microscope is available. R.K.M.

BALL (R. A.). *Honey opal.* Aust.Gemmol., **14**, 12, 324-5, 2 figs, 1982.

Deals with opal of this colour and outlines major sources. Mexican material may have play of colour. One reference calls it 'Bernsteinfarbener opal'—amber coloured opal. R.K.M.

BLAK (A. R.), ISOTANI (S.), WATANABE (S.). *Optical absorption and electron spin resonance in blue and green natural beryl.* Physics and Chemistry of Minerals, **8**, 4, 161-6, 13 figs, 1982.

EPR spectra taken on natural blue and green beryl from the Governador Valadares area of Minas Gerais, Brazil, show that trivalent iron in blue beryl occupies a trivalent substitutional aluminium site and that in green beryl trivalent iron is localized in the structural channels between two 0_6 planes. Infrared spectra on the other hand show that the alkali content of blue beryl is mostly at substitutional and/or interstitial sites and mostly in the structural channels in green beryl. M.O'D.

BRACEWELL (H.). *Mt Surprise to Mt Isa.* Wahroongai News, 10-11, August 1982.

A report from a former editor of this excellent little magazine who is, with her husband, on an extended 'rock-hound' trip. She writes vividly of the gem fields of North Queensland from Mt Surprise to the Gulf of Carpentaria and then south to Mt Isa. Topaz, aquamarine, rhodolite garnet, malachite, quartz, gold, amethyst, chrysocolla, staurolite and unakite were found. They are heading for the Harts Range. R.K.M.

BRACEWELL (H.). *Mt Isa—mine and minerals.* Wahroongai News, 12, August 1982.

A further report from the world's largest underground mine, producing lead and silver, zinc and copper. City boundaries encompass 40 977 square kilometres, making it the world's largest city in area. Mining and civic programmes appear to be very well organized. R.K.M.

BRIGHTMAN (R. F.). *Surface topography of gem crystals.* Aust.Gemmol., **14**, 11, 300-4, 12 figs (10 in colour), 1982.

Multibeam interferometry has been used to produce spectacular colour pictures of shallow surface features emphasizing growth patterns and symmetry. Colours obtained are due to interference and bear no relation to the colours of the crystals photographed. R.K.M.

BRIGHTMAN (R. F.). *Stones seen—viridine with low R.I.* Aust.Gemmol., **14**, 12, 322-3, 2 tables, 1982.

A green Brazilian andalusite which had lower constants than usual for this variety. R.K.M.

BROWN (G.), BRACEWELL (H.), KELLY (S. M. B.). *Mt Surprise topaz: a gemmological study.* Aust.Gemmol., **14**, 12, 326-33, 16 figs, 1982.

In depth examination of blue and colourless topaz from creeks 40 km north of the town of Mt Surprise in northern Queensland. Two figures appear to have been printed upside down, but habit of crystals is typical of (Australian!) topaz. Inclusions are discussed and illustrated in some detail. R.K.M.

BROWN (G.), SNOW (J.), LUND (D.). *Examination of an unusual item of 'native' jewellery.* Aust.Gemmol., **14**, 12, 334-7, 5 figs, 1982.

A crudely fashioned pendant made from the full thickness, including bone, of the carapace of a Central African land turtle. Not the usual hawks-bill marine turtle which yields most of the commercial shell used. R.K.M.

BROWN (G.). *How to improve the 'life' of a gemstone.* Wahroongai News, 14-16, June 1982.

An account of the effects of coating gems with such substances as magnesium fluoride which, it is suggested, significantly improves 'the "life" of the colour improved gemstone.' The method employed is not described, and there seems to be no suggestion that the practice is wide-spread. Hypothetical examples are discussed. R.K.M.

BROWN (G.). *Identifying turquoise.* Aust.Gemmol., **14,** 11, 289-99, 14 figs, 1982.

An account of this species and of its many simulants and of methods of distinguishing and identifying them from each other. An important paper on what has been described as the most difficult stone in gemmology. R.K.M.

BROWN (G.). *Malachite—Azurite.* Wahroongai News, 11-13, June 1982.

Two closely allied copper carbonate minerals. Deals principally with paragenesis, petrology and mineralogy. Basic gemmological facts and figures are given. R.K.M.

BROWN (G.). *Peridot.* Wahroongai News, 17-21, June 1982.

A monograph dealing with paragenesis, crystal structure, petrology and mineralogy and gemmological testing constants. [640 nm absorption line is not usually quoted for this gem. Is it correct?] R.K.M.

BROWN (G.). *Trapiche emeralds.* Wahroongai News, 15-16, 1 fig., August 1982.

An account of these 'gear' shaped crystals found in the Muzo and Chivor mine regions of Colombia. Chivor trapiche has a 'spindle' of emerald material, those from Muzo have a centre core of carbonaceous mineral which also occupies the prism corners. R.K.M.

BROWN (G.), SNOW (J.). *The AIGS master viewer.* Aust.Gemmol., **14,** 11, 311, 1 fig., 1982.

A very short evaluation of a new stereo viewer and slides illustrating grading standards for sapphires and rubies. R.K.M.

BURCH (C. R.). *Inclusions—an aid to the identification of gemstones—6.* Gems, **14,** 2, 26-30, 3 figs in colour, 1982.

This part of the series discusses liquid inclusions with examples. M.O'D.

BUTLER (J.). *A letter from Mt Isa.* Wahroongai News, 5-6, August 1982.

Writer reports euhedral pale yellow, yellow-green and blue beryl crystals of large size (30 cm × 100 cm plus) mined at Mica Creek, S.W. of Mt Isa. Feldspar, quartz, cassiterite, tourmaline, rutile, rhodonite, garnet, fluorite, apatite and topaz are listed among other minerals found in these pegmatites. Staurolite and massive iolite found in the vicinity. R.K.M.

BUTLER (J. N.). *The quartz minerals of the Redcliffe Peninsula.* Aust.Gemmol., **14,** 12, 338-41, 4 figs, 1982.

Various chalcedonic nodules are found along the Redcliffe Peninsula north of Brisbane. Most are altered to a greater or lesser depth to chert. R.K.M.

CASSEDANNE (J.-P.). *L'onyx de San Luis (Argentine).* (Onyx from San Luis, Argentina.) Revue de Gemmologie, 70, 11-15, 9 figs (2 in colour), 1982.

A green calcite from San Luis province, Argentina, is sold as 'green onyx'. The geological occurrence is described together with differences in chemical composition. References are given. M.O'D.

CASSEDANNE (J.-P.), SAUER (D.-A.). *Les emeraudes de Santa Terezinha (Goias).* (Emerald from Santa Terezinha (Goyaz).) Revue de Gemmologie, 71, 4-8, 8 figs (2 in colour), 1982.

Emerald has been found in the south-east part of the state of Goyaz, Brazil. The area is a large lateritic plain upon which emerald is found in talc schists; it forms well-shaped crystals, not usually more than 1 cm in length and showing prism and pinacoid forms. From 0 to 1% Fe and a much larger proportion of Cr are found. Iron and manganese oxides are found as inclusions. SG is approx. 2.70, though for crystals with pyrite inclusions the value increases to 3.05. RI is 1.588, 1.580 with a DR of 0.008. Dichroic colours are bluish-green and clear yellowish-green; sharp absorption lines are seen at 692 and 695 nm, partial absorption from 635 to 600 nm and from 445 to 400 nm. M.O'D.

COLLINS (A. T.), WOODS (G. S.). *An anomaly in the infrared absorption spectrum of synthetic diamond.* Phil.Mag., B, **46**, 1, 77-83, 2 figs, 1982.

Apparently contradictory observations have been made on the infrared spectra of synthetic diamonds. First, there is a good correlation between the strengths of nitrogen-induced absorption at 1130 cm^{-1} and the local-mode absorption peak at 1344 cm^{-1}. But the incorporation of ^{15}N into crystals shifts the 1130 cm^{-1} band to lower wavelengths while leaving the 1344 cm^{-1}unaffected. The suggestion is that N atoms do not participate in the 1344 cm^{-1} vibration. M.O'D.

COZAR (J. S.), FERNANDEZ (M.). *Inclusiones cristalinos en el rubi sintetico Chatham.* (Crystalline inclusions in Chatham synthetic ruby.) Boletín del Instituto Gemológico Espanol, 22, 11-26, 20 figs (6 in colour), 1982.

Three different types of crystalline inclusions have been detected in Chatham ruby. Platinum with tabular and prismatic habit, lithium aluminate, and matrix material have been illustrated and described. M.O'D.

DARRAGH (P. J.), WILLING (M. J.). *A new synthetic emerald.* Aust.Gemmol., **14**, 12, 344, 1982.

An Australian hydrothermal synthetic emerald with trade name Biron was examined. Remarkably clean and good colour. RI 1.570-1.577, so higher and with greater birefringence than expected in most synthetic emeralds. Preliminary report. R.K.M.

DILLON (S.), ed. *Gem News.* Gems & Gemology, **XVIII**, 2, 120-2, 2 figs (1 in colour), 1982.

Diamonds. De Beers to handle 75% (including 10% expected gem quality) of Ashton Joint Venture output in Western Australia. Depressed market conditions are affecting diamond-oriented economy in Botswana. Only one mine producing in Ghana; a cutting industry is being considered. India is exploring in Madhua Pradesh and Andhra Pradesh for new diamond sources. Israel has removed some customs

duty and the import licence requirement. Mine closures reported from Lesotho, Namibia and S. Africa. Zaire also reports very substantial drop in diamond output.

Emerald. Aga Khan mine, West Australia, is stockpiling, about 10% gem quality: all small crystals. Brazil reports emeralds of superior colour discovered recently: RIs high.

Pearl. Japan worried that China may process their own freshwater [cultured] pearls which are at present processed in Japan.

A fine pink topaz and peridot suite of jewellery is illustrated with a request for information on the unusual hall marks, also illustrated. R.K.M.

DILLON (S.), ed. *Gem News.* Gems & Gemology, **XVIII,** 3, 183, 1982.

A diamond cutting operation is starting in Sri Lanka, sponsored by Belgian interests and by Sri Lankan government.

Brazil. Report of good quality emerald cat's-eyes found near Itabira, Minas Gerais. Also fine blue-green tourmaline and brazilianite near Taquaral.

Pakistan. Dr Edward Gübelin confirms existence of aquamarine mines in Haramosh valley and that 'chrome diopside' from Hunza River is proved to be the low iron mineral pargasite.

Ruby. New Kenya mine producing cabochon material similar to Burmese ruby in colour. Dr P. Keller reports that despite the political situation in Cambodia many miners cross daily from Thailand and stones are taken back through Bo Rai. He confirms that Thai gem centres routinely heat corundum rough. R.K.M.

ELLIOTT (D. G.). *Amethyst from the Thunder Bay region, Ontario.* Mineral. Record, **13,** 2, 67-70, 8 figs, 1982.

A gem-quality amethyst occurs in the Thunder Bay region of Ontario, Canada. Some specimens contain haematite inclusions; normally the terminal rhombohedron alone is found. M.O'D.

FERGUSON (R. W.). *Sunstones by the square mile.* Lapidary J., **36,** 3, 570-8, 13 figs, 1982.

Sunstone from the southern Oregon area is described, with an account of its recovery. M.O'D.

FRYER (C.), ed., CROWNINGSHIELD (R.), HURWIT (K. N.), KANE (R. E.). *Gem Trade Lab Notes.* Gems & Gemology, **XVIII,** 2, 102-8, 21 figs in colour, 1982.

Alexandrite disfigured by scratched number on pavilion facet; yellow-green cyclotron-treated diamond; beryls painted emerald colour; a pink grossular necklace; jadeite bleached by repair heat; a kornerupine with apatite inclusions; an opal with a flow structure and a rare oolitic opal are described and illustrated. Ironstone opal was a doublet held together by cement and powdered opal to conceal join.

Blister pearls attached to shells created problem and it is still uncertain whether they are natural or induced. A baroque pearl of 26 mm diameter was exceptionally light and very smelly, suggesting that the natural nucleation was around an organic fleshy centre which was decaying.

Synthetic star ruby boule was cut to give cat's-eye effect and the pedestal end cut to give interrupted star with clear centre. A fine yellow sapphire had been altered

to yellow green by careless heating in sizing. Other types of heat damage are described. A heat-induced star in a cabochon sapphire; a synthetic sapphire, which had been diffusion treated by heat to mask the curved lines, was detected by immersion examination, but not easily. Three pictures of inclusions in spinels, two of them unusual. Cat's-eye tourmalines are discussed and two are illustrated.

R.K.M.

FRYER (C.), ed., CROWNINGSHIELD (R.), HURWIT (K. N.), KANE (R. E.). *Gem Trade Lab Notes.* Gems & Gemology, **XVIII**, 3, 169-73, 17 figs in colour, 1982.

A chalcedony cameo repaired with plastic cement; a fake octahedral diamond crystal made from cubic zirconia; a colour-changing garnet inclusion in diamond and two fine rare cat's-eye emeralds are described and illustrated, as are several fake matrix emerald specimens. A Lennix synthetic emerald, described as 'new', contained opaque black inclusions. An iolite cat's-eye; a fine green glass imitation of jadeite; dyed marble 'lapis lazuli'; and a carved bird in pink opal are all discussed and pictured. A fine conch pearl; diffusion-coloured cabochon sapphire and a stone 'faceted from a meteorite' but suspected of being black spinel conclude the account of fascinating gemmological 'finds' from these laboratories. R.K.M.

GRUSSING (T.). *Carving gem-quality opal.* Gems & Gemology, **XVIII**, 2, 95-9, 6 figs (in colour), 1982.

An interesting account of the planning and execution of three carved opal ornaments. Author emphasizes the difficulties and the pitfalls of this very skilled art. R.K.M.

GÜBELIN (E.). *Die Edelsteinvorkommen Pakistans—I.* (Gemstone localities of Pakistan—I.) Lapis, **7**, 5, 19-31, 22 figs in colour, 1982.

Ruby and red spinel are found in a marble in the Hunza valley of Pakistan. Calcite and pyrite are found as inclusions in the ruby, with apatite in both the ruby and the spinel. Geological maps of the area are provided together with a table of compositions in which it can be seen that the Hunza ruby has a chromium content of 0.81 (one stone) compared with 1.30 and 1.81 in Burmese stones tested. M.O'D.

GÜBELIN (E.). *Die Edelsteinvorkommen Pakistans—II. Die Smaragdvorkommen im Swat-Teil.* (Gemstone deposits of Pakistan—II. Emerald deposits of the Swat Valley.) Lapis, **7**, 6, 19-26, 19 figs in colour, 1982.

Emerald with an SG of 2.77, RI of 1.588, 1.596 and DR of 0.007 is found in the Swat Valley near Mingora, in the region of the Hindu Kush. The stones have calcite and dolomite inclusions as well as various patterns of liquid droplets. They show orange-red through the Chelsea filter and are of a fine colour. M.O'D.

GÜBELIN (E.). *Erkennungsmerkmale der neuen synthetischen Rubine.* (Identification signs of new synthetic rubies.) Goldschmiede Zeitung, **80**, 5, 53-9, 42 figs (41 in colour), 1982.

Coloured pictures of the inclusions in Chatham and Kashan rubies show a wide variety of useful recognition signs. M.O'D.

GÜBELIN (E. J.). *Gemstones of Pakistan: emerald, ruby, and spinel.* Gems & Gemology, **XVIII**, 3, 123-39, 25 figs (23 in colour), 1982.

Dr Gübelin has visited potentially important new emerald, ruby and spinel mine sites on the Swat and Hunza rivers in remote northern Pakistan. Swat emeralds are fine in colour with high RI (1.597-1.590), mostly cabochon material. Hunza rubies also very fine in colour but largely cabochon grade. A detailed and important paper. R.K.M.

GÜBELIN (E. J.). *New synthetic rubies made by Professor P. O. Knischka.* Gems & Gemology, **XVIII**, 3, 165-8, 8 figs (6 in colour), 1982.

Description of well-developed melt-fusion multi-faceted ruby crystals, some with pseudo-cubic habit. Distinctly violet in colour. Constants, etc., similar to those for other synthetics and for natural stones. Inclusions need magnification to reveal net-like veils of healed cracks typical of melt-fusion synthetics. Not easy to prove cut stones. R.K.M.

GÜNTHER (A.). *Polyedrische Quarz-Drusen aus Brasilien.* (Quartz polyhedroids from Brazil.) Aufschluss, **33**, 147-51, 3 figs (1 in colour), 1982.

Quartz druses of polyhedroid shape have been found in Brazil. M.O'D

HÄNNI (H. A.). *Caractéristiques des corindons chauffés et traités par diffusion.* (Characteristics of heat- and diffusion-treated corundum.) Schweiz.Uhrmacher und Goldschmiede Zeitung, **104**, 9, 15-62, 10 figs in colour, 1982.

Some of the characteristics of heat- and diffusion-treated corundum are described and illustrated. M.O'D.

JENSEN (A.), PETERSEN (O. V.). *Tugtupite: a gemstone from Greenland.* Gems & Gemology, **XVIII**, 2, 90-4, 6 figs (5 in colour), 1982.

Mineral discovered at Tugtup agtakôrfia in South Greenland in 1957 is quite wide-spread in the area, but gem red material has been found in only one 25 × 5 metre spot on Kvanefjeld plateau. Red colour fades if not exposed to ultraviolet light. A pale blue variety is known but is very rare. Full gemmological details are given. Original source is now exhausted but it is hoped that more will be found when uranium mining is started. R.K.M.

KANE (R. E.). *The gemological properties of Chatham flux-grown synthetic orange sapphire and synthetic blue sapphire.* Gems & Gemology, **XVIII**, 3, 140-53, 20 figs (16 in colour), 1982.

These are now available as crystals but not as cut stones. A valuable paper giving diagnostic features with emphasis on inclusions which are illustrated and described in detail. R.K.M.

KEELEY (H. H.) *The ruby mines of Burma—1.* Gems, **14**, 2, 6-8, 1 fig., 1982.

Introduces ruby, the Mogok Stone Tract of Upper Burma and some of the legends associated with the recovery of the stone. M.O'D.

KEELEY (H. H.) *The ruby mines of Burma—2.* Gems, **14**, 3, 8-11, 1982.

Further legends are recounted, centring round the Laung Zin area. M.O'D.

KERR (W. C.). *A report on the new Watermeyer split-facet diamond cuts.* Gems & Gemology, **XVIII**, 3, 154-9, 9 figs (4 in colour), 1982.

Basil Watermeyer, of Johannesburg, has perfected new marquise and pendeloque cuts which eliminate the objectionable 'bow-tie' effect which normally spoils these styles. Diagrams and photographs of cubic zirconia in old and new cuts prove his point. An advance important to diamond cutters. R.K.M.

KOIVULA (J. I.). *Shadowing: a new method of image enhancement for gemological microscopy.* Gems & Gemology, **XVIII**, 3, 160-4, 7 figs (4 in colour), 1982.

Increased contrast obtained in microscopy of inclusions by inserting laterally light-shields of various shapes between light source and object. Explained and illustrated in detail. R.K.M.

KOIVULA (J. I.). *Pinpoint illumination: a controllable system of lighting for gem microscopy.* Gems & Gemology, **XVIII**, 2, 83-6, 7 figs in colour, 1982.

A hand-held fibre-optic illuminator of exceptional flexibility and precision is shown to have considerable potential in the examination of inclusions. Needs clamping for photography but is expected to receive wide acceptance. Some more superb photomicrographs from the camera of this skilled G.I.A. Senior Staff Gemologist. R.K.M.

KOMOTAUER (S. K.). *Chalcedon, SiO_2.* (Chalcedony, SiO_2.) Mineralien Magazin, **6**, 7, 315-22, 14 figs (13 in colour), 1982.

A beautifully illustrated summary of the chalcedony varieties. M.O'D.

KOZLOVA (O. G.), BELOV (N. V.). *Twisted quartz crystals as Brazil penetration twins.* Soviet Physics Doklady, **26**, 9, 805, 3 figs, 1982.

The occurrence of Brazil twins of synthetic quartz is most marked when crystals are grown in a weakly alkaline solution with K_2CO_3 at a high degree of supersaturation. Twisted crystals are thought to be Brazil twins formed by the intergrowth of crystals along faces of the oblique [$\bar{1}$11] band. M.O'D.

LAMBERT (J. B.), FRYE (J. S.). *Carbon functionalities in amber.* Science, **217**, 55-7, 2 figs, 1982.

High-resolution NMR spectra of carbon nuclei in powdered amber are obtained by a technique known as magic angle spinning, which, together with cross polarization, provides information on types of carbon functionalities. Amber from the Baltic area and specimens from Sicily, Burma, Romania and Bohemia are examined and compared. M.O'D.

MADDERN (D.). *A fossicking guide to the Harts Range.* Wahroongai News, 17-26, 2 sketch maps, July 1982.

A practical guide to rock-hunting in a remote and gemmy area of Northern Territory, Australia. Gives sound advice on equipment and working and underlines the aridity of the Harts Range. R.K.M.

MEHTA (K.). *Serpentine, the pride of Jaisalmer.* Gem World, **9**, 2, 36-7, 4 figs, 1982.

Several varieties of serpentine occur in the Rajasthan area of India, including antigorite and williamsite. A brief summary of the serpentine group is given.

M.O'D.

MENZEL (M.). *Über den Pegmatitaufschluss Landsverk I bei Evje, Setestal, Südnorwegen.* (On the pegmatite workings at Landsverk by Evje, Setestal, South Norway.) Aufschluss, **33**, 129-41, 13 figs, 1982.

The pegmatites in the Evje area are rich in feldspars, some of which are of gem quality. M.O'D.

MINAKAWA (T.), MOMOI (H.). *Ruby from the Sanbagawa metamorphic belt, in the Hodono valley, Ehime Prefecture, Japan.* Mineralog.J., **11**, 2, 78-83, 3 figs, 1982.

Transparent purplish red to pink ruby up to 5 cm in diameter occurs in an amphibole-zoisite rock found as boulders in the Hodono valley, on the southern flanks of Mt Gongen. It has ε 1.761, ω 1.769, D 3.887 g/cm^3; red fluorescence is shown in both long- and short-wave UV light. Microprobe analyses for dark purplish red, light purplish red, and light purplish pink ruby show respectively Cr_2O_3 0.41–0.14, 0.16–0.07, 0.10–0.01 and Fe_2O_3 0.44–0.37, 0.41–0.33, and 0.44–0.42%, the abundance of Cr_2O_3 thus corresponding with the shade of red. R.A.H.

MOREAU (M.). *Voyage au pays des opales.* (Trip to opal country.) Revue de Gemmologie, **70**, 7-10, 11 figs (1 in colour), 1982.

A *tour d'horizon* of the Australian opal fields. M.O'D.

MORIYA (K.), OGAWA (T.). *Growth history of a synthetic quartz crystal.* J. Crystal Growth, **58**, 115-21, 6 figs, 1982.

Growth interfaces of a synthetic quartz crystal are marked by fluctuation of hydroxyl concentration. This fluctuation is thought to be caused by growth breathing in turn due to fluctuating convection of solution in the vessel. Undecorated dislocation lines and plate-like defects have been observed in synthetic quartz, using light-scattering tomography. M.O'D.

MYERS (J.). *Opal nomenclature.* Wahroongai News, 10-12, July 1982.

An intelligent listing of types, origins and factors controlling quality etc. Poses some questions by introducing such expressions as 'crystal', 'skin to skin', without clearly explaining their meanings. R.K.M.

NASSAU (K.). *Heat treating ruby and sapphire.* Lapidary J., **36**, 4, 708-19, 17 figs (16 in colour), 1982.

A reprint of a paper first published in *Gems & Gemology,* XVII, 3, 121-31, 1981 (abstracted in *J.Gemm.,* XVIII, 2, 168, 1982). M.O'D.

NOVAK (G. A.). *Verde Web variscite from Lander County, Nevada.* Lapidary J., **36**, 3, 544-52, 1 fig. in colour, 1982.

A new deposit of fine quality variscite has been found in Crescent Valley, Nevada. It is monomineralic (compared with variscite from Fairfield County, Utah, which contains up to twelve phosphate minerals). The variscite occurs as both nuggets and vein fillings in or near a shear zone which is on the flank of an Ordovician shale tending upwards in a north descending anticline. Colour of the variscite varies from pastel green to sky or pale blue. M.O'D.

O'DONOGHUE (M.). *The dealer looks at gemstones—4.* Gems, **14,** 2, 31, 1982.

Alteration of colour is discussed with special reference to topaz, beryl and kunzite. Some dark blue topaz has been shown to display some radioactivity.

(Author's abstract.) M.O'D.

O'DONOGHUE (M.). *The carbonate group of minerals—2.* Gems, **14,** 4, 34, 1982.

Dolomite is the chief mineral discussed and some notes on cerussite are given.

(Author's abstract) M.O'D.

O'DONOGHUE (M.). *The dealer looks at gemstones—5.* Gems, **14,** 3, 14-15, 1982.

The selection of rough material and its availability, varying due to political reasons as much as geological ones, is discussed. (Author's abstract.) M.O'D.

O'DONOGHUE (M.). *The carbonate group of minerals—1.* Gems, **14,** 3, 30-1, 1982.

Calcite is the first carbonate discussed after general remarks on the group as a whole. (Author's abstract.) M.O'D.

O'DONOGHUE (M.). *The dealer looks at gemstones—6.* Gems, **14,** 4, 15-18, 1982.

Star stones and business methods are discussed. (Author's abstract.) M.O'D.

O'DONOGHUE (M.). *Man-made gemstones—8.* Gems, **14,** 3, 26-7, 1 fig. in colour, 1982.

Kashan ruby and some of the coloured beryl recently made in Japan are discussed. (Author's abstract.) M.O'D.

O'DONOGHUE (M.). *Man-made gemstones.* Gems, **14,** 5, 28, 1982.

Deals with a synthetic emerald by Lechleitner, an imitation haematite, some varieties of spinel and of sodalite. (Author's abstract.) M.O'D.

PEARSON (G.). *The approximate iron content of some sapphires.* Aust.Gemmol., **14,** 12, 347-9, 1982.

An investigation by x-ray fluorescence to determine the relative iron content in various Australian sapphires and comparing this with that found in sapphire from Sri Lanka and Thailand. Sri Lanka stones were yellowed temporarily by x-rays. Thai and Australian stones of deep colour were not affected. R.K.M.

PONOMARENKO (A. I.), SPETSIUS (Z. V.). *Mineral rims on diamonds from kimberlites.* International Geology Review, **24,** 7, 829-34, 4 figs, 1982.

A wide variety of minerals can be found as coatings on diamond crystals, the thickness of the coating varying from tenths of a millimetre to 1-2 mm. It is postulated that in common with other minerals diamond was removed from different strata in the upper mantle. Rims of hydrothermal minerals were produced in the late stages of formation of the kimberlite bodies. M.O'D.

ROSSMAN (G. R.), QIU (Y.). *Radioactive irradiated spodumene.* Gems & Gemology, **XVIII,** 2, 87-9, 2 figs (1 in colour), 1982.

Report on citrine-coloured spodumene mixed in parcel of citrine from Brazil. The spodumenes were radioactive to a dangerous degree. Similar irradiation by scandium-46 had been detected earlier in topaz. Dangerous to handle in quantity and would remain so for some years. Irradiation by neutrons gives highly

penetrating radioactivity and no autoradiograph could be expected, so Geiger counter test is essential. R.K.M.

ROTHSTEIN (J.). *Just what is an emerald?* Lapidary J., **36**, 4, 734-43, 1982.
Discussion of the criteria distinguishing emerald from green beryl. M.O'D.

SAHAMA (Th.G.). *Asterism in Sri Lankan corundum.* Schweiz.Mineral. Petrograph.Mitteilungen, **62**, 1, 15-20, 3 figs, 1982.

Slightly bluish and turbid, barrel-shaped corundum crystals are described from the Elahera area of Sri Lanka. They are up to 7 cm long and show a well-developed rhombohedral parting with holhmite in the seams. The inclusions of rutile which cause the asterism are almost invariably twinned, and are either of a needle-like habit with two individuals or geniculate with three or four individuals; the twin plane is [011] and the needle axis is not the *c* axis but <00$\bar{1}$>. The orientation of the rutile relative to the corundum host is rutile <010>||corundum [0001], rutile <01$\bar{1}$>||corundum [11$\bar{2}$0]. R.A.H.

SARMIENTO CARPINTERO (L.). *El opalo.* (Opal.) Boletín del Instituto Gemológico Espanol, 22, 27-43, 12 figs in colour, 1982.

A comprehensive account of opal with notes on its imitations and on the various kinds of synthetic opal now on the market. M.O'D.

SCARRATT (K. V. G.). *The identification of artificial coloration in diamond.* Gems & Gemology, **XVIII**, 2, 72-8, 11 figs (7 in colour), 1982.

An excellent paper on identification of irradiated diamonds which summarizes the facilities and the difficulties encountered in this specialized work. There is still some confusion between artificially and naturally irradiated stones. Stones are examined at a temperature of −160 °C to sharpen the diffuse bands. R.K.M.

SCHWARZ (D.). *Chemismus und Fluoreszenzverhalten von Zirkon ($ZrSiO_4$).* (Chemistry and fluorescence behaviour of zircon ($ZrSiO_4$).) Uhren, Juwelen, Schmuck, 3, 217-20, 10 figs, 1982; 7, 237-40, 5 figs, 1982.

Natural zircons from a variety of localities were examined by fluorescence spectrophotometry, by optical emission spectroscopy and neutron activation analysis. The main fluorescence band, found in 80-90% of specimens, lies in the yellow-green and is very strong. It is probably due to defect centres in the lattice. Some zircons show, in addition, groups of lines ascribed to Dy^{3+}. Many of these specimens were from Sri Lanka. Much more rarely seen was a weak emission in the UV region due to Gd^{3+}. All 43 stones from locations in Sri Lanka, Thailand, Norway, Liberia and Miask/Ilmengebirge showed a dominance of the heavy lanthanides (Eu-Lu). M.O'D.

SIRAKIAN (E.). *La taille du diamant.* (The cut of a diamond.) Revue de Gemmologie, **70**, 4-6, 16 figs, 1982.

The first part of a series devoted to diamond polishing, this covers crystal form and habit. M.O'D.

STOCKTON (C. M.). *Two notable color-change garnets.* Gems & Gemology, **XVIII**, 2, 100-1, 2 figs (1 in colour), 1982.

Two pieces of East African waterworn garnet rough gave different colours in fluorescent and in incandescent light. They also showed further marked differences

in colour depending upon whether the light was transmitted or reflected. Colours are illustrated within the limits of photography. Chemical compositions are anomalous and both stones are principally spessartite/grossular, one with a leaning towards almandine, the other towards pyrope. R.K.M.

TOMBS (G. A.), JORIS (W. J.). *More synthetic opal.* Aust.Gemmol., **14**, 12, 345, 1982.

Half-drilled white synthetic opal beads offered as natural opal in Sydney. Surfaces heavily pitted by cut-through bubbles, colour play muted with 'rolling' pattern and 'chimney' effect as seen in some Gilson opal. 20× revealed crenelations and 'lizard skin' pattern on colour patches. Warning issued on bead opal.

VASHISHTHA (S.). *Gadolinium gallium garnet.* Gem World, **9**, 4, 27-9, 1982.

GGG is described with notes on its production. M.O'D.

VASHISHTHA (S.). *Yttrium aluminium garnet.* Gem World, **9**, 2, 28-35, 2 figs, 1982.

A comprehensive account of the growth and properties of YAG. M.O'D.

WEIBEL (M.). *Wie entsteht der Stern?* (How do stars arise?) Lapis, **7**, 10, 25-30, 10 figs (7 in colour), 1982.

The origin of chatoyancy and asterism is discussed with particular reference to the part played by rutile in the corundum gems. M.O'D.

WIGHT (W.). *Notes from the National Museums of Canada: two varieties of opal from Mexico.* Canadian Gemmologist, **3**, 3, 8-12, 4 figs, 1982.

A hyalite variey of opal weighing 0.98 ct and showing profuse swirls and striae and two small purple opals were recently obtained by the National Museum of Natural Sciences of Canada. All stones described were faceted. M.O'D.

WILD (K. E.). *Das Museum unterhalb der Felsenkirche in Idar-Oberstein.* (The museum below the Felsenkirche in Idar-Oberstein.) Aufschluss, **33**, 257-64, 5 figs (1 in colour), 1982.

The well-known museum in Oberstein celebrates its fiftieth anniversary this year. The history is summarized and the exhibits described and illustrated. M.O'D.

WILSON (A. F.). *The genesis of noble metal nuggets.* Aust.Gemmol., **14**, 11, 285-8, 1982.

Theories on the precipitation and growth of large nuggets of comparatively pure gold. Suggest that it is leached from narrow impure veins by water containing humic acid, and deposited when carbonates are encountered. Platinoid metals are also thought to accrete in a similar way. R.K.M.

ZEITNER (J. C.). *The quest for green bolts—2.* Lapidary J., **36**, 3, 558-66, 12 figs, 1982.

Emerald mining at the Rist, Crabtree and Old Plantation mines in North Carolina is described. Only the Rist mine is open at present. M.O'D.

ZEITNER (J. C.). *Spinel.* Lapidary J., **36,** 4, 684-92, 11 figs, 1982.

A general review of the spinel group of minerals with some reference to North American localities. M.O'D.

ZEITNER (J. C.). *Why agate is the favorite.* Lapidary J., **36,** 5, 842-50, 16 figs in colour, 1982.

An attractively illustrated summary of agate varieties. M.O'D.

ZWAAN (P. C.). *Sri Lanka: the gem island.* Gems & Gemology, **XVIII,** 2, 62-71, 14 figs in colour, 1982.

A short account of the gem areas, mining, cutting and marketing in this beautiful island. R.K.M.

BOOK REVIEWS

ARACIC (S.). *Fortunes in Australian opals.* Sapphire Books, Strathfield, N.S.W., 1979. pp.vii, 150. Illus. in black-and-white and in colour. $9.50.

This is an account of the author's experiences as an opal miner and is due to be followed by a second volume in which the nature and occurrence of opal will be discussed. In this book the material is mainly anecdotal, but there are some comments to interest the general as well as the specialist reader. M.O'D.

BURY (S.). *Jewellery Gallery summary catalogue.* Victoria and Albert Museum, London, 1982. pp.252. Illus. in black-and-white. £4.95.

This is a case-by-case handlist of the items in the recently re-opened Jewellery Gallery of the Victoria and Albert Museum in London. The collections of Lady Cory and Dame Joan Evans, with earlier bequests, have been amalgamated to form a continuous chronological and type sequence. It is hoped that a *catalogue raisonné* may appear in due course, but until that time this is a most useful guide and easy to use. M.O'D.

HAILL (R. G.). *Opals of the Never Never.* Horwitz Grahame Books, Cammeray, New South Wales, 1981. pp.viii, 152. Illus. in black-and-white and in colour. Price on application.

This book is about the opal fields of the Coober Pedy area of South Australia though there is a good deal about opal in general. The style is journalistic and anecdotal but the book is well produced and readable. Useful maps are provided in the text. M.O'D.

MENCHINSKAYA (T. I.). *Biryuza.* (Turquoise.) Nedra, Moscow, 1981. pp.159. Illus. in black-and-white and in colour. 85 kopecks. (In Russian.)

This is a full account of the geology and mineralogy of turquoise deposits over the world, with a full bibliography of both Russian and European works. A translation would be of the greatest interest. M.O'D.

READ (P. G.). *Dictionary of Gemmology.* Butterworths Scientific, London, 1982. pp.vi, 240. Illus. in black-and-white. £15.

This is a useful and readable book with a good deal of out-of-the-way information in it. It is marred by consistent misspelling of foreign institutional titles, which leads to misfiling in some cases (this should have been caught by the publisher's editor) but, this apart, the facts presented are accurate and relevant. This author's speciality is instrumentation and the book is specially useful in this area. At the end are some tables and some notes on grading systems. M.O'D.

STRUNZ (H.). *Mineralogische Tabellen.* (Mineralogical tables.) 8th edn. Akademische Verlag Geest & Portig K.-G., Leipzig, 1981. pp.viii, 621. Diagrams in the text. 54M.

Though described as '8 Auflage' this is not a new edition but a reprint of an earlier text. This was also the case with the previous (7th) printing (1978).* None the less the book remains a valuable standard text, though it now needs to be read in conjunction with Fleischer's Glossary of Mineral Species and Mineralogical Record. M.O'D.

WILSON (A. N.). *Diamonds from Birth to Eternity.* Gemological Institute of America, Santa Monica, California, U.S.A., 1982. pp.xxv, 450. Illus. in black-and-white and in colour. $43.95.

This is a large book in which the various diamond-producing areas of the world are reviewed, with notes on their history and a considerable amount of material given on the presumed geological origins of diamond from particular regions. While much of this may be authoritative, the author's remarks in the preliminary matter—'the bibliography of books and scientific papers digested for the purpose of this book makes a formidable body of technical and semi-technical literature. It would serve little purpose to specify them in detail'—lead the reader to wonder whether due consideration has been paid to the value of the many theories set out. Without knowing the sources it is impossible to know whether there has been a journalistic selection of interesting speculations or whether there has been considered scientific evaluation of one paper against another. The genesis of diamond is an area where much work remains to be done and the impression given by the book, that it is a conspectus of work known to be well-founded at the time of writing, must be suspect without there being a view of the actual detailed foundations upon which it is based. It is a great pity that what is admittedly an interesting and well-compiled work should carry an aura of doubt and uncertainty with it. Naturally it is very possible and even likely that if all the details of the foundations were given we might not be very much further forward in many areas, so uncertain is the field, but the author should have set his teeth and tried and the publishers should have insisted. Then we should have had a work of immense value. So far from giving a complete bibliography, the author has given nothing at all; the pictures are pleasant but pretty much the type of thing one has come to expect as routine in this kind of book—a considerable journalistic effort, but no more.

M.O'D.

*Reviewed *J.Gemm.*, 1980, XVII (3), 199.—Ed.

ASSOCIATION NOTICES

OBITUARY

THE LATE DR W. F. EPPLER

A Tribute by B. W. Anderson

In the death of Prof. Dr W. F. Eppler on June 5th last, the world has lost one of its greatest gemmologists, while I personally feel deep regret at the passing of an old and valued friend. Wilhelm Friedrich Eppler was born on 6th August 1902 at Detmold in N.W. Germany. His father, Dr Alfred Eppler, was well known as a mineralogist and as author of *Edelsteine und Schmucksteine,* first published in 1912, which was at that time one of the fullest and best textbooks on gemmology available. It was natural that Wilhelm should follow in his father's profession, and he benefited from an extensive education at Bonn and Hamburg Universities, in which his studies embraced not only mineralogy but also chemistry, physics and mathematics. After graduating in mineralogy at Hamburg he remained at the University for eighteen months as an assistant in the mineralogical faculty.

There followed during the next few years (1927-1931) two extensive tours in the East during which Eppler was able to study at first hand all aspects of the gem deposits and production in the world's most famous centres. These included what were then known as Ceylon, Siam, Indo-China, India and Afghanistan. As a result Eppler became probably the world's most thoroughly informed scientist in that field of study. During this period he also learned to speak excellent English with an indefinable 'colonial' accent.

The following years were largely spent in the writing of two valuable books. The first (published in 1934) was a revised and extended version of his father's *Edelsteine und Schmucksteine.* This was a major work of over 500 pages, the main part of which was taken up by a full description of 130 gemstones arranged (most unusually) in order of their increasing hardness. The book was illustrated by over 300 text figures and contained several excellent coloured plates. The other work, which appeared in the following year, formed the second part of *Lagerstätten der Edelsteine,* in which Dr O. Stutzer wrote the first section, which dealt with the sources of diamond only, while Eppler, in the second section, treated with all the other gems of commercial importance. The work was rich in geological information concerning the various mines and deposits, and additional information of a more

Dr W. F. Eppler, Lucerne, 1938.

commercial nature was provided in the form of production figures for a range of years. A full bibliography of the relevant literature was also appended, and the book still makes valuable reading.

There followed for Dr Eppler a number of appointments. In 1935 he became Director of the precious stone trade school in Idar-Oberstein: in 1938 he taught in the Mineralogical Department in Bonn University, and in 1941 was appointed a lecturer in mineralogy in the University of Frankfurt. In 1942 until after the end of the War he was an instructor in applied mineralogy in Strasbourg University. In 1946 there came a change of course from a hitherto academic teaching career to work in a commercial concern, when he accepted an appointment as works manager in the synthetic gemstone section of the giant chemical firm Weides Carbidwerk in Frankfurt. In this post, as might be expected, he acquired an intimate knowledge of the Verneuil flame-fusion process. Amongst other advances in technique Eppler enabled his firm to produce synthetic star corundums of superior quality to those pioneered by the Linde Air Products Co. in the U.S.A. shortly before. It should be mentioned that some years earlier (1943) Eppler had made the commercially

Dr W. F. Eppler (right) with Dr E. Gübelin, Munich, 1956.

important discovery that jewels used for instrument bearings if fashioned from synthetic spinel instead of corundum (thus avoiding the use of the scarce and expensive diamond powder) could be made to attain a surface hardness almost equal to that of sapphire by careful heat treatment.

In later years Dr Eppler was able to return to his true profession as a teacher and in 1955 his outstanding achievements in that sphere were rewarded by the title Honorary Professor of Mineralogy which was bestowed on him by the University of Munich. For many years Eppler enriched the journals with valuable articles on gemmology, and in 1973 his important new work *Praktische Gemmologie* was published. This outstanding book contains over 400 illustrations (mostly of inclusions photographed by the author) and concentrates entirely on accounts of the gem species. I understand from his widow, Renate, that the manuscript of a revised edition was nearly completed before his death and there is hope that this may be published in due course.

My first personal contact with Dr Eppler was in 1938, when there was an informal meeting in Lucerne between G. Gobel, Prof. K. Schlossmacher and myself, representing the precious stone laboratories of Paris, Idar-Oberstein and London. Wilhelm was staying in the same hotel, and he and I made full use of the opportunity to enjoy pleasant walks and long conversations together, resulting in a warm and lasting friendship. We met again in London shortly before the War, and in post-war years were happy to renew contact at the first International Gemmological Conference, which took place in Amsterdam in October 1953, and at many other Conferences thereafter. These early annual gatherings in different European capitals were small, friendly, and informal. Many of the talks centred round inclusions in gemstones and their synthetic counterparts, and these were illustrated by 35 mm coloured slides of high quality. Edward Gübelin and Wilhelm Eppler were the main

protagonists in this field and vied with each other in the excellence of their slides. Eppler's particular skill lay in his ability to produce photomicrographs showing splendid detail at high magnification,* and these would often give rise to a spontaneous burst of applause as they appeared on the screen. He was an excellent lecturer, his slow, clear utterance making one appreciate the sonorous quality of the German tongue.

Dr W. F. Eppler, 1973.

Although he suffered considerably from ill-health in recent years, his keen interest in gemmology never flagged and he responded at once whenever I wrote asking his advice. He belonged to that happy band for whom gemmology is a lifetime addiction. The three photographs chosen show Wilhelm Eppler at intervals of some twenty years. The first was taken in Lucerne in 1938 at our first meeting. The second was taken during the Conference in Munich in 1956, and shows him conversing with his great friend Edward Gübelin, while the third was taken in 1973. I have to thank Renate Eppler for providing the last two photographs, and to her and Prof. Dr Hermann Bank I owe information concerning Dr Eppler's many professional appointments.

*Examples of his remarkable photomicrographs may be found in *J.Gemm.*, 1976, XV (1), 2-4.—Ed.

Mr Kenneth Robert Baker, F.G.A. (D.1971), Whitehaven, died on 8th April, 1982.

Mr Robert M. Shipley, Jr, died on 10th September, 1982, in Santa Rosa, California, U.S.A. He was the son of the late Robert M. Shipley, F.G.A. (see The late Robert M. Shipley: an Appreciation, by B. W. Anderson; *J.Gemm.*, 1979, XVI(5), 285-9) and in the early 1930s assisted his father in establishing the Gemological Institute of America. He devised and/or improved a number of gem-testing instruments (see A Brief Summary of Gemmological Instrument Evolution, by Richard T. Liddicoat, Jr: *J.Gemm.*, 1981, XVII(8), 568-75), including the first Diamondscope which he patented in 1938, but, although after military service in World War II he resumed his work of developing and improving gemmological instruments and was awarded the title of Honorary Research Member of the G.I.A., he abandoned gemmological research in the early 1950s and thereafter employed his inventive talents in other fields.

Mr James W. Watts, B.Sc., M.Inst.P., F.G.A. (D.1963), Berkhampsted, died on 23rd September, 1982.

FAREWELL NOTE FROM THE RETIRING SECRETARY

I am writing this just a few days before my official retirement. The long period of service with the Association has for me been very enjoyable and culminated with the unforgettable party at Goldsmiths' Hall, when over 200 members and guests came to personally express their thanks. I now wish to thank all of those other members who have sent good wishes and also contributed to my retirement gift and cheque. I do appreciate your kindness very much, and, although I will no longer be at the office, my interest in gemmology will remain, and for a time at least I will continue as one of the proof-readers of the *Journal.*

Con Lenan, my successor, will, I am sure, carry on the good work of looking after the interests of members and gemmology in general and do everything possible to ensure that the high regard of the Association throughout the world will continue.

My very best wishes for the future of the G.A. of G.B. and all its members.—Harry Wheeler.

GIFTS TO THE ASSOCIATION

The Council of the Association is indebted to the following for their gifts:

Mrs W. A. N. Athauda, F.G.A., London, for a collection of Sri Lankan mineral specimens showing good crystal form including corundum, feldspar, quartz, tourmaline, zircon and kyanite.

Mr Denis Bradshaw, F.G.A., Orpington, Kent, for an old-type Steward Dichroscope and a 2458 Beck Prism Spectroscope.

Mr Gary Flewelling, F.G.A., Arthur, Ontario, Canada, for a collection of quartz crystals (Herkimer County, U.S.A.).

Mrs Cynthia Mendis, F.G.A., Halifax, Nova Scotia, Canada, for one cut apatite with rutile needle inclusions, weighing 6.03 ct.

NEWS OF FELLOWS

Mr M. J. O'Donoghue, M.A., F.G.S., F.G.A., gave a talk entitled 'Identifying man-made gemstones' to the Highgate Literary and Scientific Institution on 19th October, 1982.

On 8th September, 1982, at the Post-Graduate Medical Centre, Royal Victoria Hospital, Boscombe, Dorset, Mr Peter G. Read, C.Eng., F.G.A., gave an illustrated talk to the Bournemouth and Poole Medical Society on 'Colour in Gemstones'. Mr Read also attended the Technical Meeting of the German Gemmological Association in October 1982, of which he has provided the following report.

'During the bi-annual 2-day D.Gem.G. Technical Meetings, the Saturday venue is traditionally located in the Association's Training Centre in Idar-Oberstein. This year (1982), on Saturday 2nd October, two working and discussion groups in the Centre were led by Prof. Dr H. Bank, F.G.A., who showed new gemstones and synthetics (including mellite, adamin and the Japanese plastic opal simulant), and Dr G. Lenzen, F.G.A., who described and demonstrated the Okuda DC530-A Diamond Color Checker.

'On Sunday 3rd October, in the Bourse lecture hall, D.Gem.G. diplomas were awarded to successful students, and this ceremony was followed by a series of formal lectures on gemmological themes. Among these, Dr K. Schmetzer talked on the problems of detection of synthetic and treated gemstones, Dr H. A. Hänni, F.G.A., spoke on the examination of heated and diffusion-treated corundum, Mr G. Becker gave an illustrated talk on the Tucson Mineral Fair, and Mr R. Dröschel gave a practical demonstration of optical differences he had discovered between natural and synthetic amethyst (synthetic samples had, so far, shown no characteristic lamellar growth patterns under polarized light).

'Although 1982 was the fiftieth anniversary of the founding of the German Gemmological Association, celebration of this event is being postponed until October 1983, when the extension to their Training Centre in Idar-Oberstein will be completed. This extension will approximately double the size of the Training Centre and will allow the Association to dispense with the separate use of the Gewerbehalle premises.'

MEMBERS' MEETINGS

London

On 26th October, 1982, at the Central Electricity Generating Board Theatre, Sudbury House, 15 Newgate Street, London E.C.1, the A.T.V. film 'Muzo, the emerald mine', produced by Brian Moser, was shown.

Midlands Branch

On 24th September, 1982, at the Society of Friends, Dr Johnson's House, Colmore Circus, Birmingham, Mr Roy Starkey, a founder member of the British Micromount Society, gave a talk and demonstration on micromounts and micro-crystals.

On 29th October, 1982, at the Society of Friends, the Revd S. B. Nikon Cooper, B.D., F.G.A., gave a talk on 'Gemstones of the Bible'.

On 26th November, 1982, at the Society of Friends, Mr Neal Oliver, Master Engraver and Teacher of Engraving, gave a talk and demonstration on hand engraving on precious metals and glass.

North West Branch

On 16th September, 1982, at Church House, Hanover Street, Liverpool 1, Mr Alan Williams, F.G.A., gave a talk on 'Cubic zirconia and the retailer'.

On 21st October, 1982, at Church House, Mrs H. Müller, M.Sc., F.G.A., gave a talk entitled 'All about jet'.

On 18th November, 1982, at Church House, the Annual General Meeting was held, at which Mrs I. Knight, F.G.A. and Mrs E. Cartmel were re-elected Chairman and Secretary respectively.

South Yorkshire and District Branch

On 5th October, 1982, at the Sheffield City Polytechnic, Mr A. E. Farn, F.G.A., gave a talk entitled 'Pearl and the Laboratory'.

On 2nd December, 1982, at the Sheffield City Polytechnic, a practical evening was held. Some aspects of valuation were covered, with emphasis on organic materials, coral, amber, etc., which are currently causing some problems.

COUNCIL MEETING

At the meeting of Council held on Wednesday, 29th September, 1982, at the Charing Cross Hotel, London, W.C.2, the business transacted included the following:

(1) it was agreed that the rate of subscription for Fellows [see *J.Gemm.*, 1982, XVIII (4), 357] should apply to our one remaining Associate;
(2) the resignation as an Examiner in Gemmology of Mr John Chisholm, who had been an Examiner for 27 years, was accepted with regret.
(3) the appointment of Mr Philip Sadler, B.Sc., F.G.S., F.G.A., as an Examiner in Gemmology was approved;
(4) the resignation as an Examiner of Dr Judith Milledge, who had been the Gem Diamond Theory Examiner for 10 years, was accepted with regret;
(5) the appointment of Mr Eric Bruton, F.G.A., as Gem Diamond Theory as well as Practical Examiner was approved;
(6) the following were elected to membership:

FELLOWSHIP

Amos, Gillian L., Enniscorthy, Ireland. 1982
Anderton, Duncan MacG., Glasgow. 1982
Ansell, Martin F., Epping. 1982
Armstrong, Gillian, Preston. 1982
Astridge, Elaine, London. 1982
Bannerman, John M., Weybridge. 1982
Blackshaw, Cheryl K., Alderley Edge. 1982
Bonanno, Kenneth E., Fredericksburg, Va, U.S.A. 1982
Bond, Gerald S., Maidstone. 1982
Christou, Christos G., Limassol, Cyprus. 1982
Courtliff, Steven Paul, Liverpool. 1982

Cousins, Jonathan, Deal. 1982
Dawson, Jane, London. 1982
Dougherty, William C., Alexandria, Va, U.S.A. 1982
Douthwaite, Elaine M., Bradford. 1982
Forshaw, Edward D. J., Newcastle upon Tyne. 1982
Fuller, Maris E., Church Crookham. 1982
Gandhy, Uday P., Bombay, India. 1982
Goeritz, Louise C., London. 1982
Gould Michael A., McLean, Va, U.S.A. 1982
Hadfield, Margit E., Canterbury. 1982
Hannedouche, Bérangére M., Paris, France. 1982
Hawkins, Sandra C., Toronto, Ont., Canada. 1982
Honse, Dennis R., Portland, Oreg., U.S.A. 1981
Hopkinson, Barbara J., Newark. 1982
Horn, Graeme F., Glasgow. 1982
Housley, John G., Sheffield. 1982
Hughes, Richard W., Bangkok, Thailand. 1982
Hurlbert, Kim E., Cayucos, Ca, U.S.A. 1982
Hutchinson, Leslie B., London. 1982
Jackson, Christopher P., London. 1982
Jeng, Jiin Hwa, Kaohsiung, Taiwan. 1982
Key, Roger M., Nairobi, Kenya. 1982
Kierkels, Johannes Jan P. E., Belfeld, Netherlands. 1982
Kothari, Harsukh N., Bombay, India. 1982
Laframboise, Michel E., Bangkok, Thailand. 1982
Lam, Alan Wah Ching, Bangkok, Thailand. 1982
Lietwiler, Christian W., Springfield, Va, U.S.A. 1982
Malpas, Robert F., Leeds. 1982
May, Brian H., Camberley. 1982
May, Brian J., Stellenbosch, S.Africa. 1982
Moore, Roscelyn M., Camberley. 1982
Newing, Robin J. T., London. 1982
Olson, A. Richard, Manzini, Swaziland. 1982
Ottaway, Terri L., Toronto, Ont., Canada. 1981
Oxley, Peter J. M., Chichester. 1982
Paradise, Thomas R., Millbrae, Ca, U.S.A. 1982
Phillips, Jean M., Hong Kong. 1982
Pickett, Diana J., Waterlooville. 1982
Rosier, Jane L., Thorpe-le-Soken. 1982
Rydfors, Anne, Brasilia, Brazil. 1978
Salloway, Nigel J., London. 1982
Snell, Keith H., Liverpool. 1982
Thomson, Pearl J., New Barnet. 1982
Tsuda, Takashi, Osaka, Japan. 1982
Voll, Aloha F., Hong Kong. 1982
Walters, Raymond J. L., London. 1982
Whittingham, Jill E. A., Farnham. 1982
Wood, Elaine, Nottingham. 1982
Woollings, Joan E., Toronto, Ont., Canada. 1982
Wright, C. John, Chorleywood. 1982
Wycherley, Megan S., Liverpool. 1982

TRANSFERS FROM ORDINARY MEMBERSHIP TO FELLOWSHIP

Adams, Myra, Huddersfield. 1982
Ainsworth, Nicola L. A., London. 1982
Andrews, Clive G., Onchan, I.O.M. 1982
Ariyaratna, Don H., Colombo, Sri Lanka. 1982
Athauda, W. A. Nanda, West Bromwich. 1982
Barlow, Peter Charles, Kidderminster. 1982

Blanckenberg, Antoinette, Durban, S.Africa. 1982
Bolton, Robert G., Ilkley. 1982
Bowman, Josephine T., London. 1982
Brom, Frederik W., Oegstgeest, Netherlands. 1982
Brown, Harold G., Glasgow. 1982
Buchanan, Vera A., Ballinamallard, N.Ireland. 1982
Buhl, Robert Anthony, West Vancouver, B.C., Canada. 1982
Cardew, Charles J. S., Thornton Heath. 1982
Cestaro, Thomas L., Cheshire, Conn., U.S.A. 1982
Chan, Cecilia P. K., Hong Kong. 1982
Cole, Jo E., Santa Monica, Ca, U.S.A. 1982
Crout, Stephen J., Christchurch, N.Z. 1982
D'Adamo, Marina, Milan, Italy. 1982
Daulatani, Shambhu L., Dubai, U.A.E. 1982
Del Rey, Mario, S. Caetano do Sul, S.P., Brazil. 1982
de Silva, G. Ranjan J., Singapore. 1982
Düblin, Theo, Arlesheim, Switzerland. 1982
Ehrenborg, Charlotte E., Gex, France. 1982
Elvidge, Caroline A., Tonbridge. 1982
Faller, Noel P., Londonderry, N.Ireland. 1982
Ford, Hermione Dolores, Hereford. 1982
Fujimoto, Naoko, Nishinomiya City, Japan. 1982
Gaw, Rossana W., Hong Kong. 1982
Gemayel, Farid V., Antelias, Lebanon. 1982
Gimpel, Beatrice L. F., London. 1982
Gobla, Michael J., Westminister, Colo, U.S.A. 1982
Golby, Nicholas G. J., London. 1982
Goss, Alan C., Welwyn Garden City. 1982
Greatwood, Sheila O., Mitcham. 1982
Griffiths, Paul A., Sutton Coldfield. 1982
Hardy, Joanna, London. 1982
Hart, Judith E., Denby. 1982
Hatenboer, Willem J., Yssel, Netherlands. 1982
Hayashi, Junji, Fukuoka City, Japan. 1982
Hayes, George R., Jr, Louisville, Ohio, U.S.A. 1982
Henwood, Glyn A., Basingstoke. 1982
Hòrikawa, Yoichi, Itabashi-Ku, Japan. 1982
Hutton, Andrew J., Croydon. 1982
Ikoma, Nobuo, Kobe City, Japan. 1982
Inches, Deirdre M. H., Edinburgh. 1982
Inoue, Kazuo, Yokohama-Shi, Japan. 1982
Ishii, Koji, Funabashi City, Japan. 1982
Ishiwatari, Tamotsu, Tokorozawa City, Japan. 1982
Jacques, Susan M., Santa Ana, Ca, U.S.A. 1982
Jolliff, James V., Edgewater, Md, U.S.A. 1982
Jones, Joyce M., Walsall. 1982
Jones, Sandra L., New Plymouth, N.Z. 1982
Kagita, Mayumi, Kyoto City, Japan. 1982
Kennedy, Stephen J., London. 1982
Klaver, Gerardus J., Jeppestown, S.Africa. 1982
Krementz, Richard, III, Newark, N.J., U.S.A. 1982
Kularatnam, Samuel K., Colombo, Sri Lanka. 1982
Langford, Michael Leslie, Hereford. 1982
Larsson, Alf C., Kyrkslatt, Finland. 1982
Law, Ada P. K., Hong Kong. 1982
Lum, Koke Cheong, Kuala Lumpur, Malaysia. 1982

MacDonald, Roy W., Glasgow. 1982
McDowell, Robert B., Beltsville, Md, U.S.A. 1982
McIntosh, Marsha S., Arlington, Va, U.S.A. 1982
McLeod, John W., Papakura, N.Z. 1982
Mak, Michael Man Chiu, Hong Kong. 1982
Martijnse, Christriaan-Jan, Groot-Ammers, Netherlands. 1982
Mau, Enoch C. Y., Hong Kong. 1982
Mayor, Norah, Ely. 1982
Mellows, Jacqueline M., Bexleyheath. 1982
Michaels, David B., Alexandria, Va, U.S.A. 1982
Morris, Kelsey S., Hayling Island. 1982
Nevill, Amanda J., Hong Kong. 1982
Nivera, Ma Divina G., Hong Kong. 1982
Nooten-Boom, Apollonius, II, Kingsland. 1982
Ohno, Yaeko, Tokyo, Japan. 1982
Okuya, Yukie, Tokyo, Japan. 1982
Parker, Hazel, Macclesfield. 1982
Quane, David J., Bedford. 1982
Raniga, Umesh C. G., Vancouver, B.C., Canada, 1982
Rubin, Leon, Brussels, Belgium. 1982
Schofield, Nicola J., Huddersfield. 1982
Selmon, Simon, Northwood. 1982
Shah, Chandni R., Nairobi, Kenya. 1982
Sherwin, Andrew E., Nottingham. 1982
Shiraishi, Motoko, Tokyo, Japan. 1982
Stears, Trevor W., Bromley. 1982
Steinhauer, Mary H., Adelphi, Md, U.S.A. 1982
Tanaka, Hideaki, Nagasaki City, Japan. 1982
Tether, John G. G., Lusaka, Zambia. 1982
Thavat, Paul, Auckland, N.Z. 1982
To, Matthew K. H., Hong Kong. 1982
Trickey, Sheila A., Henley-on-Thames. 1982
Tsui, Carol, Hong Kong. 1982
Tsui, Juliana Yee Wah, Hong Kong. 1982
Turk, Noriko, Hong Kong. 1982
Uesaka, Noriko, Osaka, Japan. 1982
Wake, Barry A., Sidcup. 1982
Watson, Gordon, Lanark. 1982
Yasunaga, Jun, Fukuoka City, Japan. 1982

ORDINARY MEMBERSHIP

Ahamed Humbel, Mohamed K., Colombo, Sri Lanka.
Ahmed, Zohra R., Jleeb As Shuykh, Kuwait.
Aikawa, Mitsuo, Yamanashi-Ken, Japan.
Baccan, João A., Belo Horizonte, Brazil.
Balderston, Catriona I., London.
Berger, Clark J., London.
Birchall, Steven, Stockport.
Bond, Darryl N., Brisbane, Qld, Australia.
Bonn, Marc A., Kenosha, Wis., U.S.A.
Brookman, Charles L., Walla Walla, Wash., U.S.A.
Buerki, Andreas, Geneva, Switzerland.
Chang, Julius, Hong Kong.
Chellingsworth, John M., Nottingham.
Chow, Lorraine M., Hong Kong.
Church, Susan T., New York, N.Y., U.S.A.
Coffin, Martin R., Carlisle.
Davis, Albert S., London.
de Castro Mendes, Gerson, São Paulo, Brazil.

Denney, Shane S., Jacksonville, Ill., U.S.A.
Derrick, William O., London.
de Ruyter, Gerald H., Tokoroa, N.Z.
de Rycke, Anne-Marie, Dartmouth.
de Souza, Philip F., Kobe, Japan.
Dickinson, Emelline, Hong Kong.
Douglas, Lynn, Glasgow.
Ducenne, Charles J., Brussels, Belgium.
Ehlenbach, Richard J., Newton Lower Falls, Mass, U.S.A.
Ellis, Julia L., Aylesbury.
Filliette, J. P., Lugano, Switzerland.
Foong, Yee Tuck, Kuala Lumpur, Malaysia.
Friedman, David, Los Angeles, Ca, U.S.A.
Goebel, Mayr E., Leysin, Switzerland.
Grabau Hillgarth, Antonella C., Geneva, Switzerland.
Grebitus, Robert D., Sacramento, Ca, U.S.A.
Hanakawa, Masaya, Yamanashi, Japan.
Hata, Kazunori, Yamanashi, Japan.
Henderson, Mark McA., Dundee.
Hendricks, Mogamat L., Cape Town, S.Africa.
Hennessy, Linda L., Wahroonga, N.S.W., Australia.
Hinde, Margaret A., Little Sutton.
Holdo, Nelson A., Newport Beach, Ca, U.S.A.
Hosaka, Masahiro, Yamanashi, Japan.
Hughes, Gwendoline A., Beaconsfield.
Hussain, Azher, Karachi, Pakistan.
Iino, Masato, Yamanashi, Japan.
Introna, Ilarione G., Cape Town, S.Africa.
Itoh, Yasuhiro, Osaka, Japan.
Jensen, Brenda B., Nesbru, Norway.
Kamei, Shinichi, Yamanashi, Japan.
Kamiya, Takeo, Yamanashi, Japan.
Karim, Hamza H., Colombo, Sri Lanka.
Klein, George P., Pensacola, Fla, U.S.A.
Lange, Ulf, Bremen, W.Germany.
Larsen, Robert D., Arlington, Va, U.S.A.
Lau, Hueng K., Johore, Malaysia.
Laudes, Karin, Idar-Oberstein, W.Germany.
Lee, Peng Wah, Singapore.
Leenman, Walter J., Rotorua, N.Z.
Leggett, Nancy E., London.
Lewton-Brain, Charles J., Halifax, N.S., Canada.
Littlefair, Michael J., Grantham.
Loup, Daniel, Geneva, Switzerland.
MacKay, Wilma, Nedlands, W.A., Australia.
Mann, William R., Suitland, Md, U.S.A.
Marclay, Gregory, Geneva, Switzerland.
Marsh, Lesley F., Harare City, Zimbabwe.
Martinsson, Kenton A., Colombo, Sri Lanka.
Mendelson, Myron S., Somerville, N.J., U.S.A.
Mettler, Eva, Zurich, Switzerland.
Mila de la Roca, G., Caracas, Venezuela.
Miyata, Takeshi, Yamanashi, Japan.
Moir, Richard C., Kenthurst, N.S.W., Australia.
Monnas, Maria L., Mombasa, Kenya.
Moore, Christopher S., Market Deeping.
Mortimer, Derek K., London.
Nakanishi, Kimiyo, Yamanashi, Japan.
Nakayama, Sonomi, Yamanashi, Japan.
Nelson, William L., Milan, Italy.
Ninomiya, Mutsuko, Yamanashi-Ken, Japan.
Palfreyman, William D., Civic Square, A.C.T., Australia.
Pamment, Sharon L., Letchworth.

Peshwa, Krishna V., Pune, India.
Peskett, Anthony F., Solihull.
Pornthitines, Poonsiri, Bangkok, Thailand.
Preston, Allyson B., London.
Quinn, Patrick D., Sacramento, Ca, U.S.A.
Ravenstein, Dennis M., Jackson, Miss., U.S.A.
Read, William J., Colchester.
Roach, Michael P., Howell, N.J., U.S.A.
Rowlands, Nicholas S., Weston super Mare.
Roy, Stephen B., Tucson, Ariz., U.S.A.
Sadik, Marcel, Geneva, Switzerland.
Scanlon, James G., Cavan, Ireland.
Schreier, Lawrence, Skokie, Ill., U.S.A.
Shelley, Ann M., London.
Sheppard, John F., Taos, N.Mex., U.S.A.
Sheriff, Mohamed M., Colombo, Sri Lanka.
Shiao, Leu M., Taipei, Taiwan.
Shimizu, Yoshimi, Yamanashi, Japan.
Shiratori, Yoshiko, Yamanashi, Japan.
Stimac, Ornella P., Jeddah, Saudi Arabia.
Swayne, Kenneth, Leighton Buzzard.
Takayama, Shouji, Yamanashi, Japan.
Themelis, Theodore, Rego Park, N.Y., U.S.A.
Thornley, Joan A., Green Bay, Wis., U.S.A.
Tsakiris, Theodore G., Mombasa, Kenya.
Turgis, Alison, Chesham.
Turner, Martin C., Cirencester.
Unwin, Christine, Greenford.
Valenti, Gian P., Parma, Italy.
Wackan, Susan K., Woking.
Wan, Kai-Ho, Hong Kong.
Ward, Douglas, Thirsk.
Ward, Edmund, Thirsk.
Warne, Richard A., Newbury.
Wong, Christine H., Hong Kong.
Wykoff, Dale E., Frederick, Md, U.S.A.
Yagami, Noriko, Yamanashi, Japan.
Yamada, Keiko, Yamanashi, Japan.
Young, Michael, Monroeville, Pa, U.S.A.

GEM DIAMOND EXAMINATION, 1982

In the Post-Diploma Gem Diamond Examination thirty-four candidates sat and thirty-two passed, three with Distinction. The following is a list of the successful candidates, arranged alphabetically.

QUALIFIED WITH DISTINCTION

King, Antoinette E., London.
Sadler, Philip A., London.
Woodward, Christine M., London.

QUALIFIED

Anfield, Jennifer J., Birmingham.
Ashra, Shirish, London.
Babber, Harish R., Southall.
Bardsley, John N., London.
Cooper, Roy, Disley.
Dewar, Penelope S., Stockport.

Eyre, George, Denton.
Gasco Galindo, Ignacio, Barcelona, Spain.
Gea, Lopez, Francisco José, Barcelona, Spain.
Grimston, Lady Iona C., St Albans.
Haghani, Victor J., London.
Horton, David R., London.
Jones, Owen D., Derby.
Kelly, John S., Cardiff.
Lacambra Pifarre, Carmen, Barcelona, Spain.
Law, Sheila, London.
Martuccio, Celeste, Leamington Spa.
Moody, Kenneth O., Cheltenham.
Pattni, Pravin A., London.
Podsiadly, Maria T., Birmingham.
Potter, Brian S., London.
Rigby, Ian W., Wolverhampton.
Rome, Martin L., London.
Saez Balsalobre, Lidia, Barcelona, Spain.
Smith, Catharine, Lutterworth.
Tomas Soler, Ma Rosa, Barcelona, Spain.
Tose, Christine, Oldham.
Vigo Ripoll, Leticia, Barcelona, Spain.
Zebrak, Tracy J., Hove.

EXAMINATIONS IN GEMMOLOGY, 1982

In the 1982 Examinations in Gemmology, 620 candidates sat the Diploma Examination and of these 300 succeeded in passing, 22 of them with Distinction. In the Preliminary Examination 797 candidates sat and 521 passed.

In the opinion of the Examiners, no candidate achieved the high standard required to merit the award of the Tully Medal.

The Anderson/Bank Prize for the best non-trade candidate of the year in the Diploma Examination was awarded to Mrs Sandra C. Hawkins, Toronto, Ontario, Canada.

The Rayner Diploma Prize for the best candidate whose main income is derived from activities essentially connected with the jewellery trade was awarded to Miss Susan M. Jacques, of Santa Ana, California, U.S.A.

The Anderson Medal for the best candidate of the year in the Preliminary Examination was awarded to Mr Douglas Andrew Bagnall, of Don Mills, Ontario, Canada.

The Rayner Preliminary Prize for the best candidate of the year under 21 years of age whose main income is derived from activities essentially connected with the jewellery trade was awarded to Miss Andree J. Richardson, of Eastbourne.

The following are lists of the successful candidates arranged alphabetically.

DIPLOMA EXAMINATION

Anderson/Bank Prize
Hawkins, Sandra C., Toronto, Ont., Canada.

Rayner Diploma Prize
Jacques, Susan M., Santa Ana, Ca, U.S.A.

QUALIFIED WITH DISTINCTION

Ainsworth, Nicola L. A., London.
Armstrong, Gillian, Preston.
Bolton, Robert G., Ilkley.
Buchanan, Vera A., Ballinamallard, N. Ireland.
Del Rey, Mario, S. Caetano do Sul, Brazil.

Dewendra, Rekha, Matara, Sri Lanka.
Dijkman-Vos, Christine S., Taitam, Hong Kong.
Fernandez Nuñez, Carlos Luis, Barcelona, Spain.
Garrigos Fernandez, Ma José, Barcelona, Spain.
Gould, Michael A., McLean, Va, U.S.A.
Hawkins, Sandra C., Toronto, Ont., Canada.
Hofer, Stephen C., Santa Monica, Ca, U.S.A.
Housley, John G., Sheffield.
Jacques, Susan M., Santa Ana, Ca, U.S.A.
Jolliff, James V., Edgewater, Md, U.S.A.
Kennedy, Stephen J., London
Kumaratilake, Wickramasinghe L.D.R.A., Kelaniya, Sri Lanka.
McCall, Lois G., Wooster, Ohio, U.S.A.
Matsuda, Tomoko, Tokyo, Japan.
Nevill, Amanda J., The Peak, Hong Kong.
Pellicer Beltran, Rodrigo, Barcelona, Spain.
Pike, Corinna A. W., London.

QUALIFIED

Adams, Myra, Huddersfield.
Alva, Shyamala J., Mangalore, India.
Amos, Gillian L., Enniscorthy, Ireland.
Anderton, Duncan MacG., Bearsden.
Andrews, Clive G., Onchan, I.O.M.
Ansell, Martin F., Epping.
Anwar, Abdul A. M., Beruwala, Sri Lanka.
Aoussat, Claude A., Vienna, Va, U.S.A.
Arbestain Ribas, Inmaculada, Barcelona, Spain.
Arendtsz, Natalie A., Negombo, Sri Lanka.
Ariyaratna, Don H., Colombo, Sri Lanka.
Arjalaguer Vilardell, Daniel, Barcelona, Spain.
Astridge, Elaine, London.
Athauda, W. A. Nanda, West Bromwich.
Baixauli Sanjuan, José F., Barcelona, Spain.
Baker, Judith, Ottawa, Ont., Canada.
Balas, Aranka, Budapest, Hungary.
Bambrick, Joseph E., Markham, Ont., Canada.
Bandarage, Usha Samangi, Colombo, Sri Lanka.
Bannerman, John M., Weybridge.
Barlow, Peter Charles, Kidderminster.
Bell, John A., Sevenoaks.
Bennett, A. Sirisena, Tangalle, Sri Lanka.
Berthet, William L., Jacksonville, Fla, U.S.A.
Blackshaw, Cheryl K., Knutsford.
Blanckenberg, Antoinette, Durban, S.Africa.
Bon, Maria H., Schoonhoven, Netherlands.
Bonanno, Kenneth E., Fredericksburg, Va, U.S.A.
Bond, Gerald S., Maidstone.
Bouman, Henrietta A. E., Bangkok, Thailand.
Bowman, Josephine T., London.
Braunstein, Joan, Potomac, Md, U.S.A.
Brom, Frederik W., Oegstgeest, Netherlands.
Brown, Harold G., Glasgow.
Buhl, Robert Anthony, West Vancouver, B.C., Canada.
Cabanas Casas, Terencia, Barcelona, Spain.

Capella Tomas, Ma Josefa, Barcelona, Spain.
Cardew, Charles J. S., Thornton Heath.
Cassarino, Paul R., Rochester, N.Y., U.S.A.
Castro Masaveu, Alicia, Barcelona, Spain.
Cestaro, Thomas L., Cheshire, Conn., U.S.A.
Chan, Cecilia P. K., Hong Kong.
Chao, George Y., Ottawa, Ont., Canada.
Chaturvedi, Vimal K., Jagdalpur, India.
Cheung, Cliff P. L., Toronto, Ont., Canada.
Christou, Christos G., London.
Cole, Jo E., Santa Monica, Ca, U.S.A.
Cooper, Sean, Stockport.
Cornioley, Jean-René, Fribourg, Switzerland.
Courtliff, Steven Paul, Liverpool.
Cousins, Jonathan, Deal.
Cowie, Gillian A., Liverpool.
Crout, Stephen J., Christchurch, N.Z.
D'Adamo, Marina, Milan, Italy.
Daulatani, Shambhu L., Jaipur, India.
Dawson, Jane, London.
de Beer, Christiaan T. J., Durban, S.Africa.
de Poli, Vesta, Cortina d'Ampezzo, Italy.
de Regt, Marcus N., Goes, Netherlands.
Desai, Madhav C., Hartford, Conn., U.S.A.
de Silva, G. Ranjan J., Singapore.
Dirlam, Dona M., Santa Monica, Ca, U.S.A.
Dougherty, William C., Alexandria, Va, U.S.A.
Douthwaite, Elaine M., Bradford.
Düblin, Theo, Arlesheim, Switzerland.
Ehrenborg, Charlotte E., Gex, France.
Elvidge, Caroline A., Tonbridge.
Esterhuizen, Karel F., Karoi, Zimbabwe.
Faller, Noel P., Londonderry, N.Ireland.
Fernando, Dudley L., Colombo, Sri Lanka.
Fonseka, Ruwan K. M., Colombo, Sri Lanka.
Ford, Hermione Dolores, Hereford.
Forshaw, Edward D. J., Newcastle upon Tyne.
Foster, Amanda L., Willowdale, Ont., Canada.
Fritzen, Tove, Oslo, Norway.
Fujimoto, Naoko, Nishinomiya City, Japan.
Fuller, Maris E., Kowloon, Hong Kong.
Galsterer, Maureen G., Saginaw, Mich., U.S.A.
Galt, Jessie J., Toronto, Ont., Canada.
Gandhy, Uday P., Bombay, India.
Gaw, Rossana W., Hong Kong.
Gemayel, Farid V., Antelias, Lebanon.
Geurts, Godefridus R. J. M., Heerlen, Netherlands.
Gimpel, Beatrice L. F., London.
Glover, Brian M. G., New Brighton.
Gobla, Michael J., Denver, Colo, U.S.A.
Goeritz, Louise C., London.
Golby, Nicholas G. J., London.
Goss, Alan C., Welwyn Garden City.
Greatwood, Sheila O., Mitcham.
Griffiths, Paul A., Streetly.
Grishko, Alexander, Toronto, Ont., Canada.
Gupta, Manoj B., Bombay, India.
Hadfield, Margit E., Canterbury.
Hall, Sarah Cheryl D., Toronto, Ont., Canada.
Hamer, Saskia M., Hague, Netherlands.

Hannedouche, Bérangére M., Paris, France.
Hardy, Joanna, London.
Harmer, Inge, Brisbane, Qld, Australia.
Hart, Judith E., Denby.
Hartenboer, Willem J., Krimpen a/d Yssel, Netherlands.
Hayashi, Junji, Fukuoka City, Japan.
Hayes, George R., Jr, Louisville, Ohio, U.S.A.
Heino, Tauno T. T., Eura, Finland.
Hendriks, Fransiscus R. A., Amsterdam, Netherlands.
Henwood, Glyn A., Basingstoke.
Hinduja, Anuradha, Bombay, India.
Hoogewerff, Regitse C., Diepenveen, Netherlands.
Hopkinson, Barbara J., Newark.
Horikawa, Yoichi, Tokyo, Japan.
Horn, Graeme F., Glasgow.
Hughes, Richard W., Boulder, Colo, U.S.A.
Hurlbert, Kim E., Cayucos, Ca, U.S.A.
Hutchinson, Leslie B., London.
Hutton, Andrew J., Croydon.

Ickowicz, Stephen, London.
Ifthikar, Mohamad U. M., Kandy, Sri Lanka.
Ikoma, Nobuo, Kobe City, Japan.
Illueca Domenech, Enrique, Barcelona, Spain.
Inches, Deirdre M. H., Edinburgh.
Inoue, Kazuo, Tokyo, Japan.
Ishii, Koji, Funabashi City, Japan.
Ishiwatari, Tamotsu, Tokorozawa City, Japan.

Jackson, Christopher P., London.
Jayaweera, Susil, Peradeniya, Sri Lanka.
Jeng, Jiin Hwa, Kaohsuing, Taiwan.
Jhaveri, Kalpana R., Bombay, India.
Jokela, Leena A., Helsinki, Finland.
Jones, Joyce M., Walsall.
Jones, Sandra L., New Plymouth, N.Z.
Kaersenhout, George E., Amsterdam, Netherlands.
Kegita, Mayumi, Kyoto City, Japan.
Kasagi, Nobuko, Nishinomiya City, Japan.
Kauhanen, Pentti R., Helsinki, Finland.
Kawai, Yoshito K., Utsunomiya-shi, Japan.
Kelderman, Klaas P., Alphen a/d Rijn, Netherlands.
Kesola, K. Juhani, Valkeakoski, Finland.
Ketelaar, Arend C. R., Leidsendam, Netherlands.
Key, Roger M., Cardigan.
Kierkels, Johannes J. P. E., Belfeld, Netherlands.
Klaver, Gerardus J., Hengelo, Netherlands.
Kohmura, Kyohko, Kyoto City, Japan.
Kolamunne, A. A. Susila, Kadawatte, Sri Lanka.
Korhonen, Pentti K., Hämeenlinna, Finland.
Kothari, Harsukh N., Bombay, India.
Kraan, Jan W., Amsterdam, Netherlands.
Krementz, Richard, III, New York, N.Y., U.S.A.
Krishnamoorthy, K. L. Narayanan, Trivandrum, India.
Kuittinen, Raili T., Helsinki, Finland.
Kujanpää, Asko J., Helsinki, Finland.
Kularatnam, K. Samuel, Colombo, Sri Lanka.
Kumarage, Jayantha P. R., Homagama, Sri Lanka.
Laframboise, Michel E., Cornwall, Ont., Canada.
Laine, Raimo E. L., Hämeenlinna, Finland.

Lam, Alan Wah Ching, Kuala Lumpur, Malaysia.
Lam, Yat Hoong, Singapore.
Langford, Michael Leslie, Hereford.
Larsson, Alf C., Kyrkslätt, Finland.
Law, Ada P. K., Hong Kong.
Lietwiler, Christian W., Springfield, Va, U.S.A.
Love, John, Jersey, C.I.
Lum, Koke Cheong, Kuala Lumpur, Malaysia.
McClain, Robert J., Washington, D.C., U.S.A.
Macdonald, Roy W., Glasgow.
McDowell, Robert B., Beltsville, Md, U.S.A.
McIntosh, Marsha S., Arlington, Va, U.S.A.
McLeod, John W., Papakura, N.Z.
McQueen, B. Young, Jacksonville, Fla, U.S.A.
Mak, Michael Man Chiu, Hong Kong.
Mallawarchchi, Gayani N., Kadawata, Sri Lanka.
Malpas, Robert F., Leeds.
Mantecon Burgos, Jesús, Barcelona, Spain.
Marti Beltran, José Ma, Barcelona, Spain.
Martijnse, Christiaan-Jan, Groot-Ammers, Netherlands.
Mau, Enoch C. Y., Hong Kong.
May, Brian H., Camberley.
May, Brian J., Stellenbosch, S.Africa.
Mayor, Norah, Ely.
Medniuk, Melanie A., Witham.
Mellows, Jacqueline M., Bexleyheath.
Michaels, David B., Alexandria, Va, U.S.A.
Miralles Morey, José L., Barcelona, Spain.
Mok, Dominic W. K., Hong Kong.
Moore, Roscelyn M., Camberley.
Mora Balcells, Helena, Barcelona, Spain.
Morishita, Kentaro, Tokyo, Japan.
Morishita, Yuzuru, Tokyo, Japan.
Morris, Kelsey S., Hayling Island.
Nevalainen, Aarne E., Hämeenlinna, Finland.
Newing, Robin J. T., London.
Nicholas, Christopher E., Colombo, Sri Lanka.
Nieuwenhuys, Erik F. T. M., Bloemendaal, Netherlands.
Nilam, Mohamed C. M., Weligama, Sri Lanka.
Nivera, Ma Divina G., Philippines.
Nooten-Boom, Apollonius, II, Kingsland.
Novejarque Lopez, Ma del Carmen, Barcelona, Spain.
Ohno, Yaeko, Tokyo, Japan.
Okada, Mari, Utsunomiya, Japan.
Okuya, Yukie, Tokyo, Japan.
Olson, A. Richard, Manzini, Swaziland.
Oxley, Peter J. M., Birdham.
Paradise, Thomas R., Millbrae, Ca, U.S.A.
Parker, Hazel, Macclesfield.
Perez Segarra, Montserrat, Barcelona, Spain.
Phillips, Jean M., Hong Kong.
Pickett, Diana J., Waterlooville.
Piziura, Irene T., Nottingham.
Quane, David J., Bedford.
Ralls, Elizabeth L. W., Spokane, Wash., U.S.A.
Ranabahu, Millakage K. T. S., Ratnapura, Sri Lanka.
Raniga, Umesh C. G., Vancouver, B.C., Canada.
Rosier, Jane L., Thorpe-le-Soken.
Rubera, Anthony N., Dehiwela, Sri Lanka.
Rubin, Leon P. J., Brussels, Belgium.
St Amand, Mary J., Mill Valley, Ca, U.S.A.
Salloway, Nigel J., London.
Schofield, Nicola J., Huddersfield.

Schutt, Karl Robert, Manotick, Ont., Canada.
Schyllander, Anna M., Lidingö, Sweden.
Selmon, Simon, Northwood.
Senanayake, Nimalka R., Homagama, Sri Lanka.
Senanayake, Sripathi P. A. M. A., Gampaha, Sri Lanka.
Shah, Chandni R., Nairobi, Kenya.
Shah, Sanjay S., Bombay, India.
Shenker, Ian L., Edgware.
Sherwin, Andrew E., Nottingham.
Shiraishi, Motoko, Tokyo, Japan.
Smiley, Laurianne, Clondalkin, Ireland.
Snell, Keith H., Maghull.
Soriano Meler, Esther, Barcelona, Spain.
Staley, Nancy C., Potomac, Md, U.S.A.
Stears, Trevor W., Bromley.
Steert, Ineke, Amsterdam, Netherlands.
Steinhauer, Mary H., Adelphi, Md, U.S.A.
Stratton, Victoria J., Toronto, Ont., Canada.
Takakura, Momoyo, Tokyo, Japan.
Tam, David C. C., Hong Kong.
Tanaka, Hideaki, Nagasaki City, Japan.
Tether, John G. G., Lusaka, Zambia.
Thavat, Paul, Auckland, N.Z.
Thomson, Ian C., Dumfries.
Thomson, Pearl J., New Barnet.
To, Matthew K. H.,, Hong Kong.
Toivainen, Heidi S., Helsinki, Finland.
Torode, Carl F., Gillingham.
Trickey, Sheila A., Henley-on-Thames.
Tsuda, Takashi, Osaka, Japan.
Tsui, Carol, Hong Kong.
Tsui, Juliana Yee Wah, Hong Kong.
Turk, Noriko, Hong Kong.
Uesaka, Noriko, Osaka, Japan.
van Andel-Wierda, Catharina J., The Hague, Netherlands.
van Bork, Margaretha A. C., Leiden, Netherlands.
van Velzen-Ritmeÿer, Elisabeth T. H., Rotterdam, Netherlands.
van Zeijst, Raymond M. E., Nieuwegein, Netherlands.
Vaughan, Susan E., Nottingham.
Venemans, Anne C., Schoonhoven, Netherlands.
Verjee, Nasim K., Nairobi, Kenya.
Vidal Noguera, Francisco, Barcelona, Spain.
Voll, Aloha F., Tokyo, Japan.
Vuorinen, Jorma T., Hämeenlinna, Finland.
Waghela, Mahesh R., Bombay, India.
Wake, Barry A., Welling.
Walsh, Francine, Dundas, Ont., Canada.
Walters, Raymond J. L., London
Watson, Gordon, Lanark.
Weber, Leo, Breda, Netherlands.
Whittingham, Jill E. A., Farnham.
Wols, René P., Rotterdam, Netherlands.
Wood, Elaine, Brinsley.
Woollings, Joan E., Toronto, Ont., Canada.
Wright, C. John, Chorleywood.
Wycherley, Megan S., Formby.
Yacub, Rafiq, Erode, India.
Yamasaki, Kazutaka, Kochi-shi, Japan.
Yasunaga, Jun, Fukuoka City, Japan.
Ypyä, Teuvo H., Kemi, Finland.
Zylstra, Christine, Schoonhoven, Netherlands.

PRELIMINARY EXAMINATION

Anderson Medal
Bagnall, Douglas A., Don Mills, Ont., Canada.

Rayner Prize
Richardson, Andree J., Eastbourne.

QUALIFIED

Aarskov, Ann, Hong Kong.
Abrami, Aurelio, Milan, Italy.
Addison, Helen, Auchenflower, Australia.
Adlam, Raymond J., Uddingston.
Aguado Roca, Fernando J., Barcelona, Spain.
Ahamed Marzook, Mohamed N., Colombo, Sri Lanka.
Aked, Francis J., Leeds.
Aldworth, Pamela M., Liskeard.
Altenloh, Jacques P. C. J., Brussels, Belgium.
Anderton, Brian G., Bearsden.
Anselot, François J. R., Canterbury.
Arandle, Christine A., East Looe.
Aroos, Mohamed A. M., Colombo, Sri Lanka.
Arzem, Frances, Willowdale, Ont., Canada.
Ashworth, Ian E., Bristol.
Athauda, Premalatha, Gonapola Junction, Sri Lanka.
Atkinson, Paul C., Weston super Mare.
Attwell, William G., Toronto, Ont., Canada.
Avargues Perles, Antonia, Barcelona, Spain.
Axon, Martin W., London.
Bach, Michelle M., Bangkok, Thailand.
Bae, Sang K., Seoul, Korea.
Bagnall, Douglas A., Don Mills, Ont., Canada.
Balasch Borras, Ma Mercé, Barcelona, Spain.
Baldellou Celma, Juan, Barcelona, Spain.
Balderston, Catriona I., London.
Ball, Andrew J., Loughton.
Banks Lyon, Rodney, Lancaster.
Barnard, Stephen J., Leigh-on-Sea.
Baxter, Gordon E., Whangarei, N.Z.
Beasley, Rosemary E., Toronto, Ont., Canada.
Beattie, Roy A., Jimboomba, Qld, Australia.
Beckett, Michael J., London.
Bell, William A., Prudhoe.
Benford, Rosemary S., London.
Bengali, Malcolm, London.
Bengali, Neville K., London.
Benham, Robert M., Great Bend, Kans., U.S.A.
Benham, Thomas R., Great Bend, Kans., U.S.A.
Beresford, Martin P., Ashford.
Berger, Nicolaas H. M., Woerden, Netherlands.
Bernad Soria, Pedro J., Barcelona, Spain.
Berthelsen, Lawrence J., Townsville, Qld, Australia.
Berthet, William L., Jacksonville, Fla, U.S.A.
Bickley, Kerry B., Pretoria, S.Africa.
Bielby, Robert W., Leicester.
Birkin, Paul M., Stoke on Trent.
Bisset, Ross, London.
Blackshaw, Cheryl K., Alderley Edge.
Bloodworth, Roy N., Stanley.

Boek, Gerriedina J., Baarn, Netherlands.
Boldova Sanchez, Pilar, Barcelona, Spain.
Bonanno, Kenneth E., Fredericksburg, Va, U.S.A.
Boreham, Kevin M., Truro.
Bouman, Henrietta A. E., Bangkok, Thailand.
Braunstein, Joan, Potomac, Md, U.S.A.
Broad, Arline E., Thames, N.Z.
Brom, Frederik W., Oegstgeest, Netherlands.
Bucy, Rodger Dale, Ellicott City, Md, U.S.A.
Budd, Lesley H., Exeter.
Buddington, Jeffrey P., Hayannis, Mass, U.S.A.
Bugg, John R., Wolverhampton.
Burbidge, Norma P., New Plymouth, N.Z.
Burman-Roy, Kumar H.,, Glasgow.
Canêlhas, Maria da G. P. S. A., Lisbon, Portugal.
Cartmell, Fiona A., Manchester.
Cassarino, Paul R., Rochester, N.Y., U.S.A.
Castell Andujar, Joaquín, Barcelona, Spain.
Catchon, Tuan J. A., Ratmalana, Sri Lanka.
Chan, Kum Bun M., Quarry Bay, Hong Kong.
Chan, Lai Kuen R., Kowloon, Hong Kong.
Chan, Lye Keng, Barking.
Chan, Yuet Mei, Kowloon, Hong Kong.
Chant, Joanna K., Dorchester.
Chanter, James E., Newton Abbot.
Chaturvedi, Vimal K., Jagdalpur, India.
Cheung, Yiu Wai D., Kowloon, Hong Kong.
Chow, Kam Ming H,. Kowloon, Hong Kong.
Chow, Lorraine M., Kowloon, Hong Kong.
Chu, Kit-Chun Q., Central, Hong Kong.
Chung, Yuk Wah C., Kowloon, Hong Kong.
Cirone, Monica A., Campbell, Ca, U.S.A.
Citron, Marc R., London.
Clappison, Diana J., Hull.
Clark, Patricia M., Pokfulam, Hong Kong.
Clarke, Julia, Aylesbury.
Cloke, Ho Ning D., Headland, Hong Kong.
Cole, Jo E., Santa Monica, Ca, U.S.A.
Collado Castelles, Ma Dolores, Barcelona, Spain.
Comas Andres, Juan, Barcelona, Spain.
Condrup, Jonathan R., Haslemere.
Conway, Jeremy P. M., Toronto, Ont., Canada.
Corbin, Janet R., Liverpool.
Cotton, Pamela D., Chorlton-cum-Hardy.
Courage, Belinda J., Truro.
Cowell, Gawin, Salisbury, Zimbabwe.
Cowell, Kenneth, Robertson, S.Africa.
Cunningham, Colin D., Townsville, Qld, Australia.
Danku, James E., London.
Dart, Nigel E., Newquay.
Daulatani, Shambhu L., Dubai, U.A.E.
Davey, Frances V., Invercargill, N.Z.
Davies, Karen, North Harrow.
Davies, Stephen, Wallsend.
Demoray, Scott B., Grand Rapids, Mich., U.S.A.
den Hartog, Maria J. M., Baarn, Netherlands.
Denton, Gary M., London.
Deogun, Surinder S., Milton Keynes.

de Poli, Vesta, Cortina d'Ampezzo, Italy.
Desai, Madhav C., Hertford, Conn., U.S.A.
de Silva, Uyanage D. N., Singapore.
de Swart, Johan, Wÿchen, Netherlands.
de Vries, Jacqueline A., Gouda, Netherlands.
Dewever, Jan A., Sittard, Netherlands.
Dings, Christianne A. M., Valkenswaard, Netherlands.
Dobson, John D., Glasgow.
Dormer, Joseph L., Corringham.
Dorren, Margot S. C., Lopik, Netherlands.
Dowie, Richard S., Christchurch, N.Z.
Dunga, Kiran D., Birmingham.
Dunn, Andrew C., Reading.
Durafourg, Isabelle. F. A., Lausanne, Switzerland.
Dykstra, Jeannine B., Toronto, Ont., Canada.
Eisenburger, Sabine F., Thalheim, Austria.
Elsten, Antonius R. M., Rucphen, Netherlands.
Emerson, Michael E., London.
Euwema, Jos, Schoonhoven, Netherlands.
Fache, Frank E. A. M., Edegem, Belgium.
Faridi, Waris J., Karachi, Pakistan.
Fernando, M. Preethi, Panadura, Sri Lanka.
Fernando, Ramani S. F., Enfield.
Finkelman, Steven L., London.
Flacks, Naomi, Sale.
Flower, Jonathan S., Plumley.
Floyd, Nancy E., Toronto, Ont., Canada.
Fonseka, S. D. H. R. Franklin, Enfield.
Ford, John P., London.
Fox, Kathleen P., Townsville, Qld, Australia.
Fretzin, Leonard H., Chicago, Ill., U.S.A.
Froehlich, Adam, Willowdale, Ont., Canada.
Fujimoto, Naoko, Nishinomiya City, Japan.
Gandhy, Uday P., Bombay, India.
Garcia Gisbert, Rocio, Barcelona, Spain.
Garcia-Elias Cos, Montserrat, Barcelona, Spain.
Gardner, Mary R., Toronto, Ont., Canada.
Gardner, Robert J., Manchester.
Garrod, Douglas J., Exeter.
Gascon Cuello, Fernando, Barcelona, Spain.
Gavin, Sandra R., Thornton Heath.
Genis Perez, Manuel, Barcelona, Spain.
Gent, Rosemary J., Tonbridge.
Gilliland, Hilary L., Newtownabbey, N.Ireland.
Glaholm, Janice A., Paris, France.
Goad, Jane B., Toronto, Ont., Canada.
Gonzalez Violan, Francesc, Barcelona, Spain.
Goodden, Rick K., Kansas City, Mo., U.S.A.
Goodland, John R. S., Gstaad, Switzerland.
Gould, Michael A., McLean, Va, U.S.A.
Graham, Kimberley E., Toronto, Ont., Canada.
Grant, Noeline L., Pietermaritzburg, S.Africa.
Greatwood, John, Mitcham.
Greig, Edward S., Kingston Hill.
Guerin Tarafa, Antonio, Barcelona, Spain.
Guerrero Ramon, Desamparados, Barcelona, Spain.
Gunter, Margaretha E., Schoonhoven, Netherlands.
Gupta, Manoj B., Bombay, India.

Gwizdala, Elzbieta M., Toronto, Ont., Canada.
Hakanen, Veikko T., Karvia, Finland.
Hall, Suzie N., London.
Hamada, Ritsuko, Tokyo, Japan.
Hannedouche, Bérangére, Paris, France.
Hansen, Joanne, Corvallis, Oreg., U.S.A.
Hapangama, Janaka P., Colombo, Sri Lanka.
Harriman, Allen L., Cue, W.Australia.
Haththotuwa, Chandrasiri, Kamburugamuwa, Sri Lanka.
Haughton, Michael, Bolton.
Hayashi, Junji, Fukuoka City, Japan.
Hayashi, Toshiko, Fukuoka City, Japan.
Hayes, Anne-Maria, London.
Hearsum, Paul A., Godalming.
Hee, Kim San V., Singapore.
Hegarty, Kathleen M., New York, N.Y, U.S.A.
Helton, Janet L., Toronto, Ont., Canada.
Hempshall, George H., Sheffield.
Hendriks, Fransiscus R. A., Amsterdam, Netherlands.
Herrero Romeu, Susana, Barcelona, Spain.
Hewitt, Georgina F., London.
Hill, Stephen E., St Albans.
Hills, Gavin A., Moonah, Tas., Australia.
Hindley, Angela, Bromborough.
Hollis, Patricia A., New York, N.Y., U.S.A.
Horikawa, Yoichi, Tokyo, Japan.
Horne, Allan R., Brighton.
Houghton, Mark W., Stockport.
Howe, John A., Huddersfield.
Howell, Stephen Q., San Francisco, Ca, U.S.A.
Hu, Shirley, Oxford.
Huddy, William R. H., Newton Abbot.
Hughes, Keith W., Liverpool.
Hurst, Patricia H., Carradale.
Hutchings, Trevor J., Bellewstown, Ireland.
Ikoma, Nubuo, Kobe City, Japan.
Inoue, Satomi, Sakai City, Japan.
Inoue, Yoshie, Tokyo, Japan.
Isowa, Keiko, Shima-gun, Japan.
Issadeen, Abdul M., Colombo, Sri Lanka.
Ito, Yasuo, Nagoya City, Japan.
Iyer, Sundaram V., Bombay, India.
Jacques, Susan M., Santa Ana, Ca, U.S.A.
Jane Riera, Inmaculada, Barcelona, Spain.
Jayasundara, Mudiyanselage A. S., Idar-Oberstein, W.Germany.
Jayawardana, Sisira L., Gampaha, Sri Lanka.
Jayaweera, Sumana, Kandy, Sri Lanka.
Jeng, Jiin Hwa, Kaohsuing, Taiwan.
Jennings, Joan M., Verulam, S.Africa.
John, Bryan C., Carmarthen.
Jones, Brenda C., Liverpool.
Jones, Deborah G., Sale.
Jones, Sandra L., New Plymouth, N.Z.
Jongstra, Femia E. M., Schoonhoven, Netherlands.
Kaga, Mari, Tokyo, Japan.
Kamara, Moulai M., London.
Kanoh, Mieko, Fukuoka City, Japan.
Karmakar, Sambhunath, Bombay, India.
Karmokar, Tapan, Bombay, India.
Kawamura, Yasuki, London.
Keast, Edmund J., Sanderstead.
Kennedy, Muriel D., Toronto, Ont., Canada.
Kerr, Marian, Busby.
Kimura, Mariko, Tokyo, Japan.
King, Barry J., Bury St Edmunds.

King, Clive H. M., Tsumeb, Namibia.
Kirkwood, Alan D., Liverpool.
Kiuipuro, Antti P., Pori, Finland.
Klauda, Frank P., Rochester, Minn., U.S.A.
Koff, Laurence R., Chicago, Ill., U.S.A.
Kor, Wai Yin, Shatin, Hong Kong.
Kong, Chor Ki, Kowloon, Hong Kong.
Konrath, Anthony M., Richmond.
Koshilka, Mike, Collingwood, Ont., Canada.
Koutsicas, Constantine, Athens, Greece.
Kowitz, Leslie B., Albany, Ca, U.S.A.
Krieger, Christine, Norfolk, Va, U.S.A.
Krikos, Alexandra, London.
Krishnamoorthy, Karana L. Narayanan, Trivandrum, India.
Kunzle, Andree-Evelyne, Geneva, Switzerland.
Kwan, Irene N. Y. Y., Hong Kong.
Kwok, Addy S. C., Kowloon, Hong Kong.
Kwok, Pui Chung, North Point, Hong Kong.
Ladell, Peter, St Albans.
Laframboise, Michel E., Bangkok, Thailand.
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Lai, Wing Cheong, Hong Kong.
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NEW CANADIAN GEMMOLOGY COURSE

Carleton University launches a new credit course in gemmology for its third year geology students during the 1983 winter semester. Carleton is the first university in Canada to include the study of gemmology in its bachelor of science degree programme. The course will involve 24 hours of lectures and 36 hours of laboratory work. It will teach the crystallographic, optical, physical and chemical properties of individual gemstones; their genesis, occurrences, synthesis and identification; quality determination. The prerequisites are two second year courses: Mineralogy (67-222) and Crystallography and Optical Mineralogy (67-221).

This will be the University's second involvement in the study of gemmology. The first was in 1980, when its Continuing Education Department introduced a 10-session non-credit gemmology course in its evening division. This general interest course will continue to be offered. The lecturer for both courses is A. P. Sabina, F.G.A., G.G., mineralogist with the Geological Survey of Canada. For more information contact the Geology Department, Carleton University, Ottawa, Ontario K1S 5B6.

LETTERS TO THE EDITOR

From Mr J. R. Eason, F.G.A.

Dear Sir,

I am writing to aquaint you of the fact that the Gemmological Association of New Zealand has been born, and in the hope that you will publish a short note to that effect. At the moment we have a membership of 40. There are two classes of membership. Full members must hold a recognized fellowship of an approved Gemmological Association (that is to say, a fellowship by examination). Associate members must have undertaken, or be undertaking, a formal study of gemmology. The Gemmological Association of New Zealand was formed, at the instigation of Mr S. Currie, F.G.A., by fellows of the G.A. of G.B. resident in New Zealand, who felt the need for closer contact with other gemmologists in N.Z. to share items of interest and ideas, and to keep up to date with the latest developments in gemmology.

Gemmologists wishing to contact the G.A.N.Z. may do so c/o Easons Pharmacy, Cnr. Lodge and Edinburgh Sts, Pukekohe, New Zealand.

Yours faithfully,
J. R. EASON.

9th November, 1982.
Pukekohe, New Zealand.

From Mr S. A. Price

Dear Sir,

I have recently acquired a copy of *The Boy's Playbook of Science* by that Mr Pepper famed for his demonstrations of Pepper's ghost, and I take the liberty of sending you a small extract from this work. I do this, firstly because of the urge to share at least one nugget from so rich a mine and secondly in case you should feel that De Beers and G.E.C. should at least be apprised of the possibility of their being overtaken by some obscure researches at Kew.

Referring to the extract, I am unable to decide whether the conclusions drawn from Brewster's examination of the Koh-i-Noor are his own or those of Mr Pepper.

With regard to the book in general, the liberal use of phosphorus, ether, heated mercury, potassium, etc., in the suggested experiments in the first section on chemistry, seems to make it problematical whether its readers would have survived to enjoy Mr Goddard's splendid oxy-hydrogen (lime-light?) polariscope or learn which tourmalines are unsuited for making tongs (because of their colour) in the optical section.

Yours faithfully,
S. A. Price

5th August, 1982.
Ipswich, Suffolk.

The extract from *The Boy's Playbook of Science* (J. H. Pepper, 1860) enclosed by Mr Price is reproduced below:

CARBON

A piece of carbon, in the shape of the Koh-i-Noor, was one of the chief attractions at the first Exhibition in Hyde Park. The diamond is the hardest and most beautiful form of charcoal; how it was made in the great laboratory of nature, or how its particles came together, seems to be a mystery which up to the present time has not yet been solved . . . . Sir D. Brewster, speaking of the Koh-i-Noor, remarks that on placing it under a microscope, he observed several minute cavities surrounded with sectors of polarized light, which could only have been produced by the expansive action of a compressed gas or fluid, that had existed in the cavities when the diamond was in the soft state.

Now it is known that bamboo, which is of a highly silicious nature, has the property of depositing in its joints a peculiar form of silica, called tabasheer. Silicon is one of the triad with carbon—i.e. it is allied to carbon on account of certain analogies; may it not then be supposed that, in times gone by, ages past, when the atmosphere was known to be highly charged with carbonic acid gas, there might possibly have existed some peculiar tree which had not only the power of decomposing carbonic acid (possessed by all plants of the present period), but was enabled, like the bamboo, to deposit, not silica, which is the oxide of silicium, but carbon, the purest form of charcoal—viz. the diamond? Speculation in these matters is ever more rife than stern proof . . . .

THE RAYNER DIAMOND TESTER

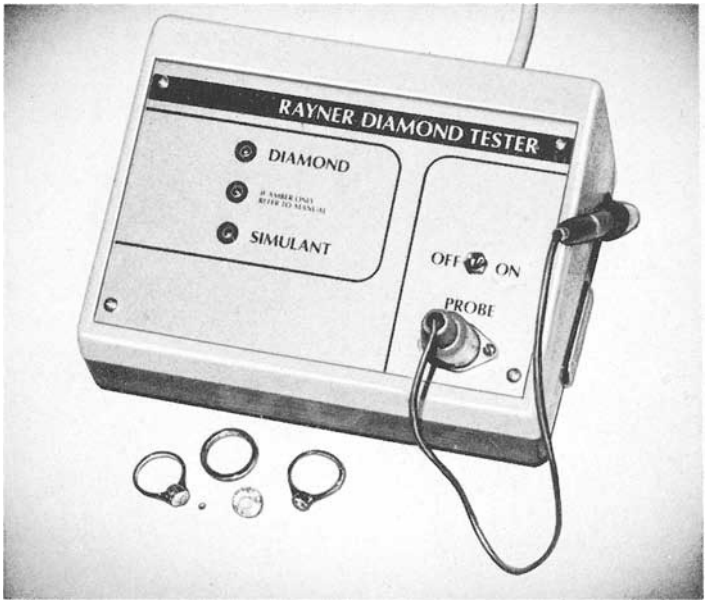

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Historical Note

The Gemmological Association of Great Britain was originally founded in 1908 as the Education Committee of the National Association of Goldsmiths and reconstituted in 1931 as the Gemmological Association. Its name was extended to Gemmological Association of Great Britain in 1938, and finally in 1944 it was incorporated in that name under the Companies Acts as a company limited by guarantee (registered in England, no. 433063).

Affiliated Associations are the Gemmological Association of Australia, the Canadian Gemmological Association, the Gem and Mineral Society of Zimbabwe and the Gemmological Association of Hong Kong.

The *Journal of Gemmology* was first published by the Association in 1947. It is a quarterly, published in January, April, July, and October each year, and is issued free to Fellows and Members of the Association. Opinions expressed by authors are not necessarily endorsed by the Association.

Notes for Contributors

The Editor is glad to consider original articles shedding new light on subjects of gemmological interest for publication in the *Journal.* Articles are not normally accepted which have already been published elsewhere in English, and an article is accepted only on the understanding that (1) full information as to any previous publication (whether in English or another language) has been given, (2) it is not under consideration for publication elsewhere and (3) it will not be published elsewhere without the consent of the Editor.

Articles published are paid for, and a minimum of 25 prints of individual articles may be supplied to authors provided application is made on or before approval of proofs. Applications for prints should be made to the Secretary of the Association—not to the Editor—and current rates of payment for articles and terms for the supply of prints may be obtained also from the Secretary.

Although not a mandatory requirement, it is most helpful if articles are typed (together with a carbon copy) in double spacing on one side of the paper, with good margins at sides, top and foot of each page. Articles may be of any length, but it should be borne in mind that long articles are more difficult to fit in than short ones: in practice, an article of much more than 10 000 words (unless capable of division into parts or of exceptional importance) is unlikely to be acceptable, while a short note of 400 or 500 words may achieve early publication.

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and

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GEMMOLOGICAL ASSOCIATION OF GREAT BRITAIN
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THE RECOGNITION OF THE NEW SYNTHETIC RUBIES

By Prof. Dr E. J. GÜBELIN, C.G., F.G.A.
Meggen, Lucerne, Switzerland

The older generations in the gemstone and jewellery branches of our trade will look upon the new synthetics made by Chatham, Kashan and Knischka—particularly the new synthetic rubies—with a certain amount of nostalgia for the 'good old days' when it was comparatively easy to distinguish synthetics from their natural counterparts. Whereas in those days the tendency among manufacturers was to create best quality stones, that is to say purer synthetics, the aim nowadays is to produce synthetic stones with inclusions as similar as possible to those in the natural mineral.

For several years now synthetic rubies (and soon sapphires will too) have crept in increasing quantities into the market. Their inclusions are bewilderingly similar to those found in natural rubies, and indeed many dealers, jewellers and even gemmologists have been deceived lately and have purchased synthetic rubies as natural ones.

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Uncertainty about synthetic stones is nothing new, but the synthetic rubies by Chatham and Kashan as well as the newest by Knischka (K-rubies) are quite a different matter; that is to say, they differ so widely from previous synthetics and are so similar to their natural counterparts that all the old rules of distinguishing them are no longer valid. Inclusions of liquid banners, rutile dust, rutile needles, and even angular zonal structure, can no longer be regarded as identifying proof of the natural stone. The author therefore spent a great deal of time and care on a thorough investigation of possible distinguishing factors, and he is convinced that, thanks to the experience thus gained, synthetic rubies no longer present serious problems. The diagnostically important properties of the new synthetics are:

Colour

It is well known to all experts that the colour of a gem, whether natural or man-made, is the least dependable factor, and that one can therefore not rely upon it. This rule applies for synthetic rubies too—especially for the products of Chatham and Knischka, but also for the paler synthetics by Kashan. Dark red synthetic Kashan rubies often show a subordinate tinge of brown to orange which is even more intensive than in the majority of Thai rubies, to which they nevertheless bear a strong resemblance.

Dichroism

It is well known that the mixture of the twin colours of a stone procures the hue beheld by the human eye. The dichroism of the new synthetic rubies by Chatham and Knischka as well as of the paler ones (pink and rose) by Kashan does not differ from that of natural rubies. On the other hand the dark red rubies with a brownish or orangy cast by Kashan betray themselves by their conspicuously orange hue for the extraordinary ray, and this feature may be valued as an indication.

Behaviour under Short-wave Radiation

The luminescence varies according to the colour of the synthetic ruby and the wavelength of the radiation. In short-wave ultraviolet light it is a medium to strong red; in long-wave ultraviolet light, medium to bright red. The deep red samples

luminesce less intensively than the pale to pink samples, which contain some titanium.

The x-ray luminescence varies from strong to very strong red with an afterglow. This—known as phosphorescence—although visible, is neither intense nor of long duration (approx. 3-7 seconds), but can nevertheless be considered as a definite indication.

Absorption-spectrum

Viewed through the normal gemmological absorption-spectroscope, the difference between natural and synthetic rubies is seldom apparent. The synthetic rubies behave in the same way as natural ones, that is to say, they show the familiar lines in the red region at 694.2, 692.8, 668 and 659.2 nm, and in the blue region at 476.5, 475 and 468.5 nm. Under the spectrophotometer, which also covers the ultraviolet region, the result is quite different: at the short-wave end of the spectrum the absorption-curve shows a marked transmission gap of varying breadth between 250 and 400 nm which reaches its maximum at 335 nm (Figure 1). A similarly reliable distinguishing factor is the shape of the transmission in the blue region between 465 and 478 nm. These characteristics of the absorption and transmission in the new synthetic rubies, although not equally strong in each case, are a certain and reliable distinguishing factor for the experienced spectroscopist.

Inclusions

The confusingly natural-looking inclusions in the interior of the new synthetic rubies are largely responsible for the fact that so many buyers have already been hoodwinked; for with a pocket lens or even with the microscope these can hardly be distinguished from each other by inexperienced professionals. For this reason the main emphasis of the following study is laid upon inclusions. Honouring the Chinese saying: 'A single picture is more eloquent than a thousand words', the following descriptions are exemplified by many illustrations.* For a comparison with similar inclusions in natural rubies, the reader is invited to turn to pages 117-26 of 'Internal World of Gemstones' (Gübelin, 1973).

A certain type of inclusion in the new synthetic rubies catches the eye immediately whenever it occurs, and could be described

*Figures 2-42, which follow on pages 483-496.

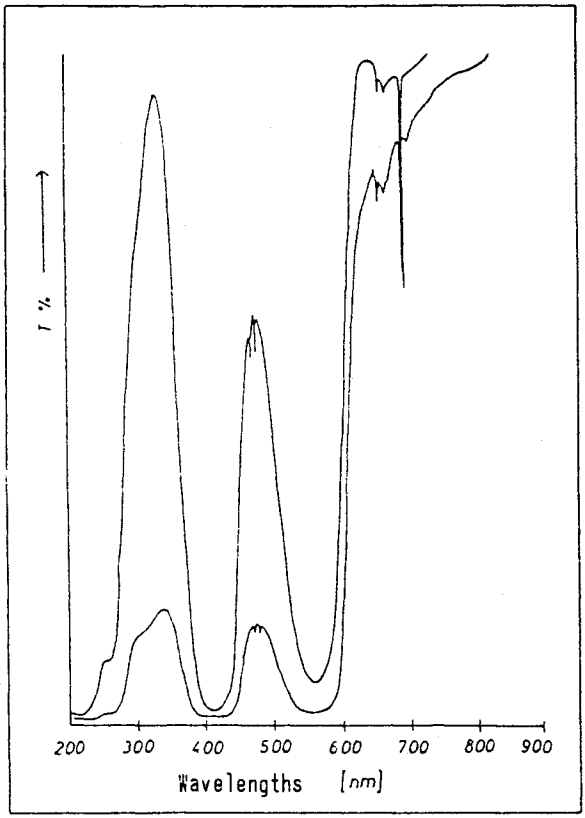

FIG. 1. Two superimposed absorption curves of synthetic rubies by Kashan demonstrate two extreme cases with regard to their transmission maxima in the near ultraviolet region of the spectrum. The transmission ends at 210 nm and 270 nm respectively. For a predominant majority of natural rubies the absorption edge occurs closer to 300 nm.

with expressions such as 'flags', 'veils', 'nets', 'wisps', or something similar (Figures 2 & 13-23). These formations occur singly as well as in the form of crazily-wound spools, producing an inclusion pattern reminiscent of those in the early synthetic emeralds (Figures 2-4). According to the method of synthesis (i.e. whether hydrothermal or by flux fusion) these inclusions consist either of drops or liquid tubes or as grains, feathers, and irregular shapes of flux. They usually form whitish, irregular accumulations of individual drops or grains (Figures 11, 12 & 35), coarse feathers (Figures 16-23), formless rags (Figures 6 & 7), parallel tubes

(Figures 9, 10 & 13), single or manifold chains of grains (Figures 11-13), or zones of varied drops (Figure 15), or lace-like concentrations of flux (Figures 22-26), which permeate and traverse the interior of the new synthetic rubies.

The lace-like formations are particularly typical of the synthetic Chatham rubies (Figures 16-18). The appearance of the coarser inclusions can best be compared to that of the sugary precipitation of quince jelly (Figures 6-10). Two x-ray analyses made with the Gandolfi-camera proved that these flux inclusions are a fine white powder of cryolite (Na_3AlF_6). Cryolite occurs in nature as a monoclinic crystal (high-temperature-polymorph > 570 °C—cubic) as a result of granitic intrusions and their pegmatites. It appears as a dull-white, altered, paramorphic mineral. Today this substance is synthetically produced in great quantities for technical purposes, and it is obviously used by Kashan as a flux to keep the temperature of the melt down.

Single grains are often aligned in zig-zag rows or V-shapes (Figure 24), or they take on the appearance of hieroglyphics (Figure 25), simulate baroque and oddly-shaped pearls, and even look like negative crystals and crystalline guest minerals (Figure 26). The fantastic variety of shapes is indescribable, and thus different in every stone, although certain elements are always present which facilitate identification, as is shown clearly by the accompanying illustrations. It is these formations which are most easily confused with the liquid feathers (healed fractures) in natural rubies from Burma, Sri Lanka and Thailand.

Far more difficult to determine are the fog-like swathes which either fill the interior of these synthetic rubies as a whitish cloud (Figure 27), or traverse it in narrow bands or even fine lines (Figures 28 & 29). This type of inclusion is usually observed in the deep to dark red stones by Kashan. The so-called 'hair-pins'—two or more divergent lines (Figure 30)—and the 'comets', also belong to this category. The latter consist of tiny bright melt-drops from which a tail of two or more extremely fine white lines emerge, as shown in Figure 31. They provide an absolutely infallible identifying factor of synthetic Kashan rubies! 'Fog', 'hair-pins' and 'comets' are very difficult to perceive and can usually only be made visible with the help of fibre-glass illumination, whereas, on the other hand, the triangular and hexagonal black platelets of platinum very often present in synthetic rubies by Chatham and

Knischka are not only very easy to see but are also a highly characteristic internal hall-mark of synthetics (Figure 7). In inclined position they reflect with a strong metallic, silvery lustre. So far, Kashan synthetic rubies seem to be devoid of the latter, yet one must always be aware of the fact that the producers of synthetic stones are free to alter or completely abolish such features. Fine well-formed, bright or black needles of varying length—in some cases very short and in other cases very long (Figures 32 & 34), and yet sometimes in broken lines like a row of dashes (Figure 33), or in divergent lines, or even 'knee-twins', like rutile (Figure 35)—present a grave challenge, for they look like fine rutile needles, and might indeed be so, for because of their fineness they have not yet been identified. However, these are distinctly different from the well-known traces of the edges of twin lamellae which traverse Thai rubies, forming a pattern like a chess-board. Therefore single needles and concentrations as well as bundles of needles, not only parallel to each other but also at various angles to each other, can no longer be rated as proof of natural origin.

The inclusion elements in the new synthetic rubies which are the most confusing, are the straight parallel growth-bands (Figure 36), sometimes at regular angles to each other (Figures 37-39) exactly like those we were accustomed not only to observe but also to value as the exemplary symptoms of natural origin. The phenomenal appearance of these growth-bands is extremely elusive, that is to say, they are extremely difficult to find and apprehend. They disappear with the slightest movement of the stone or the objective of the microscope. This means that the observer must adjust the stone, the light-source and the objective constantly during the examination in order to view the interior of the stone in all positions. These angular zones often lie near the girdle of the stone, that is to say, under the crown facets, or in a similar position of the pavilion. There is hardly any difference in appearance between these angular bands in synthetic rubies and the well-known angular zonal banding of natural rubies. On the other hand, they are readily distinguishable from the appearance of polysynthetic twin-lamellae in natural ruby. Whereas the planes of the twin-lamellae can be followed deep into the interior of the gem, the synthetic growth-bands disappear when raising or lowering the objective. Thus they behave very similarly to those familiar curved growth-bands in the synthetic rubies by Verneuil.

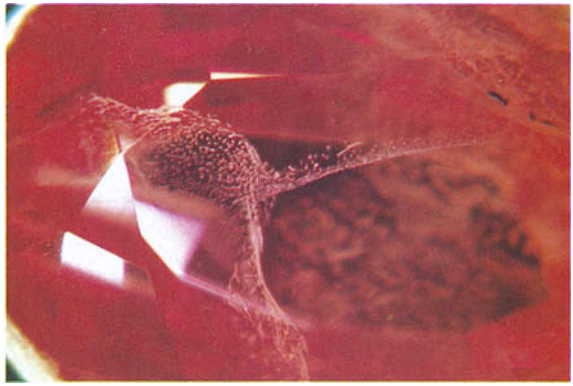

FIG. 2. Wisp-like appearance of 'fingerprint'-feathers in a synthetic ruby by Chatham. 10×

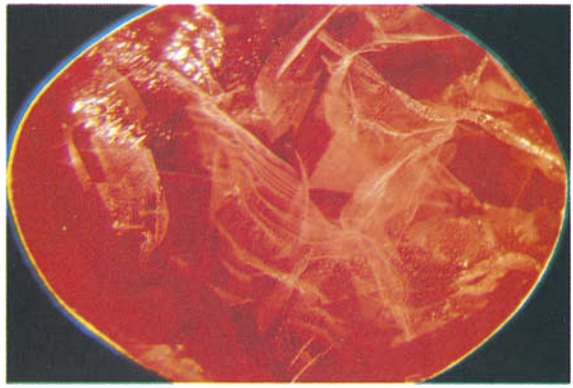

FIG. 3. Survey of the inclusion scenery with wisp-like feathers in a synthetic ruby by Kashan. 18×

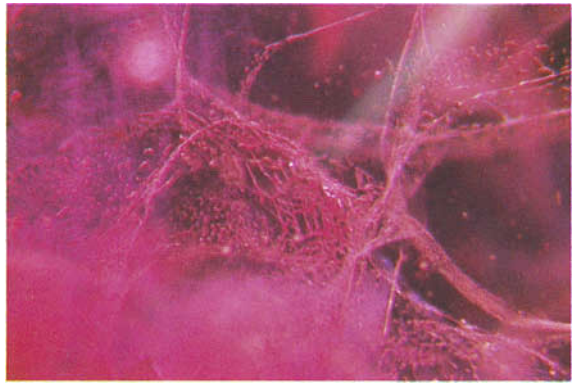

FIG. 4. Typical entanglement and appearance of 'feathers' surrounding a turbid cloud in a synthetic ruby by Knischka. 25×

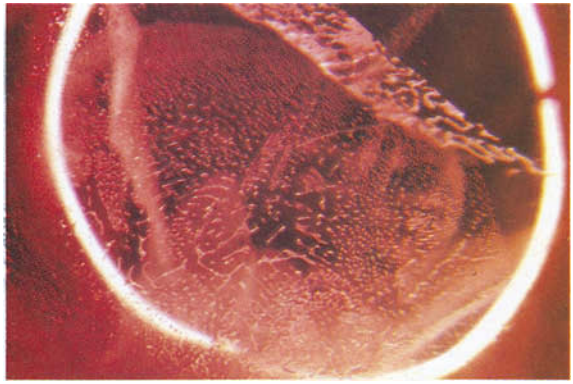

FIG. 5. Deceptive inclusion scenery draped by a large and delicately designed 'fingerprint'-feather and a feather of coarse pattern of flux in a synthetic ruby by Kashan. 25 ×

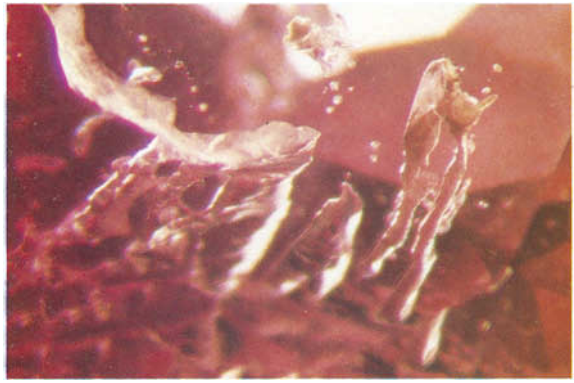

FIG. 6. Coarse 'rags' of flux inclusions (cryolite) in a synthetic ruby by Kashan. 35 ×

FIG. 7. Large shapeless flux inclusion enveloped by a net-like feather (misleadingly consistent with the rosettes in Thai rubies) in a synthetic ruby by Knischka. 32 ×

FIG. 8. Profiled 'tubes' of flux inclusions in parallel alignment in a synthetic ruby by Kashan. 30 ×

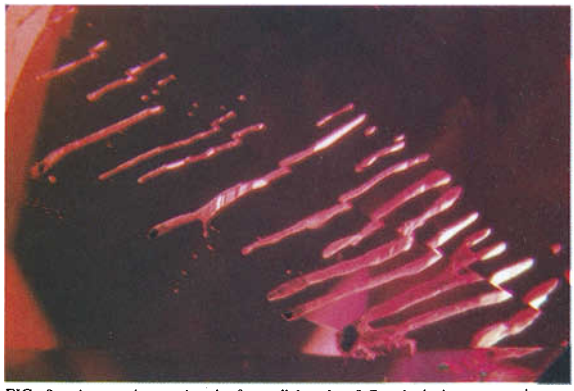

FIG. 9. A conspicuous band of parallel rods of flux inclusions traversing a synthetic ruby by Kashan. 30 ×

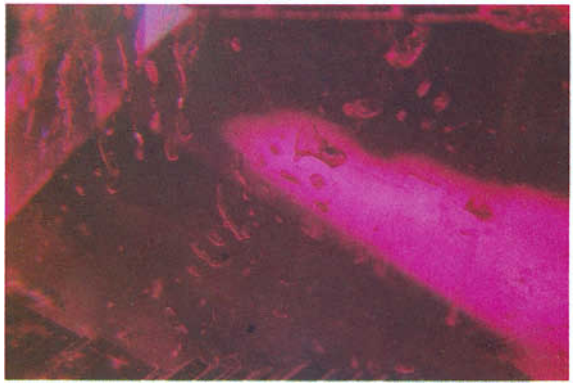

FIG. 10. Tube-like flux inclusions swarming around an unusual three-phase inclusion, the solid phase of which is a black platelet of platinum. Synthetic ruby by Knischka. 25 ×

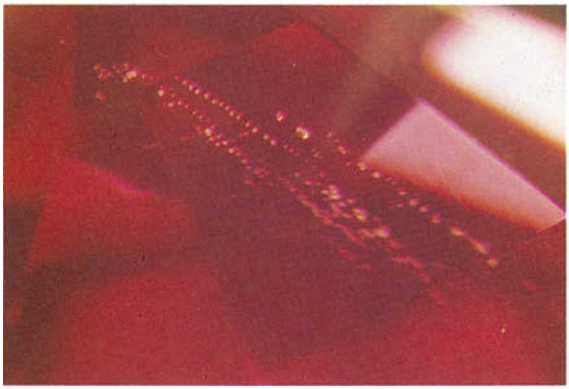

FIG. 11. Parallel rows of small to tiny grains of flux (some with crystalline aspect) in a synthetic ruby by Kashan. 30×

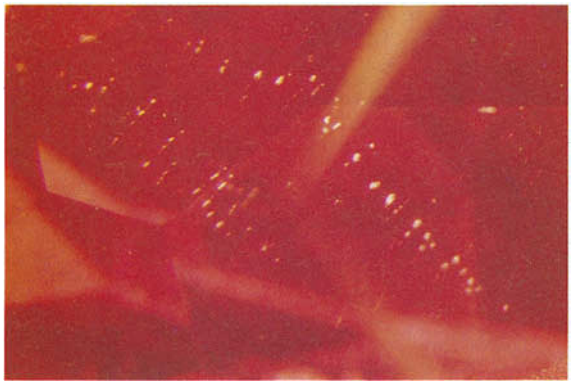

FIG. 12. Parallel bands of minute flux grains (in parallel alignment among themselves) in a synthetic ruby by Kashan. 30×

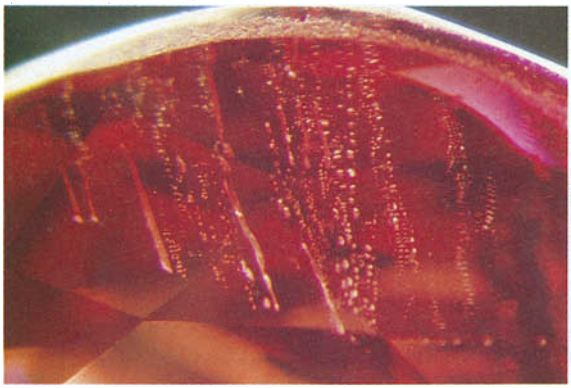

FIG. 13. Rods and tube-like formations accompany rows of tiny flux grains in parallel orientation in a synthetic ruby by Kashan. 16×

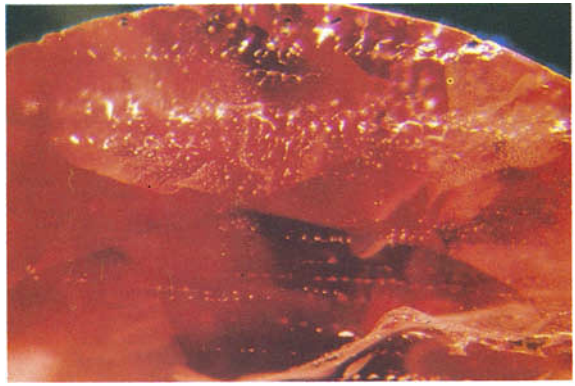

FIG. 14. Dotted rows and bands of coarser inclusions of drops and grains of flux in a synthetic ruby by Kashan. 13 ×

FIG. 15. Broad zones of delusive dactyloptical inclusions in a synthetic ruby by Kashan. 32 ×

FIG. 16. Tell-tale lace-like inclusions (left in dark-field, right in bright-field illumination) in a synthetic ruby by Chatham. 8 ×

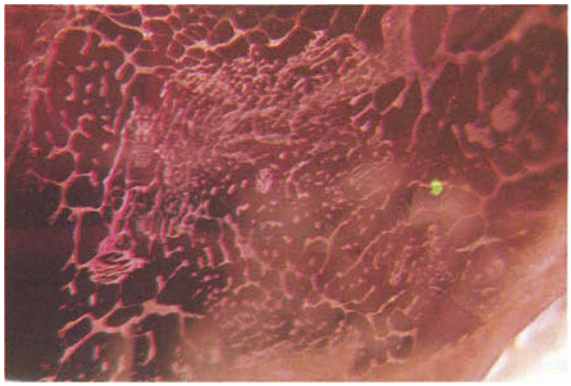

FIG. 17. Inclusions reminiscent of a shredded net identifying a synthetic ruby by Chatham. 30×

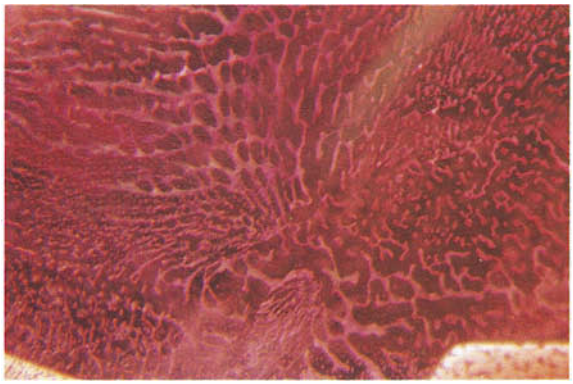

FIG. 18. Characteristically lace-like pattern of a large 'feather' in a synthetic ruby by Chatham. 40×

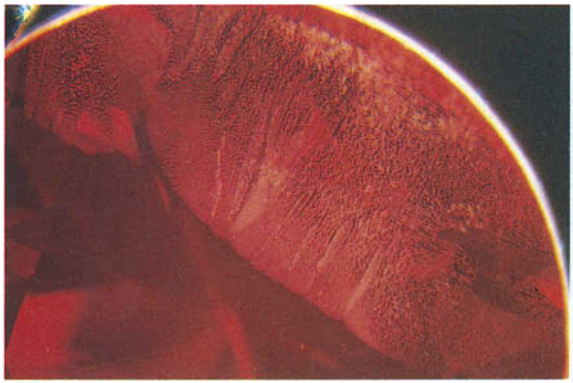

FIG. 19. 'Feathers' with such 'folds' have heretofore been considered as typical hallmarks of Burma rubies. Yet here they were observed in a synthetic ruby by Kashan. 25×

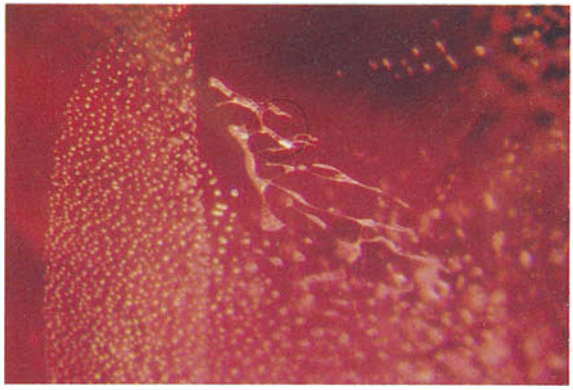

FIG. 20. Tiny grains and large irregular flux inclusions in a synthetic ruby by Kashan. 30×

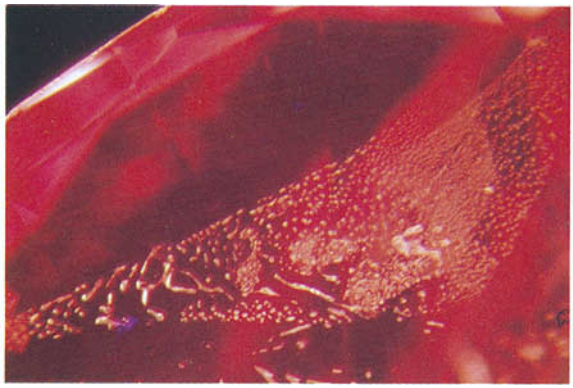

FIG. 21. Illusive feather of variously formed flux inclusions in a synthetic ruby by Kashan. (Such formations might just as readily appear in genuine rubies) 35×

FIG. 22. Misleading inclusion scene which one might expect to find in Thai rubies, yet photographed in a synthetic ruby by Kashan. 30×

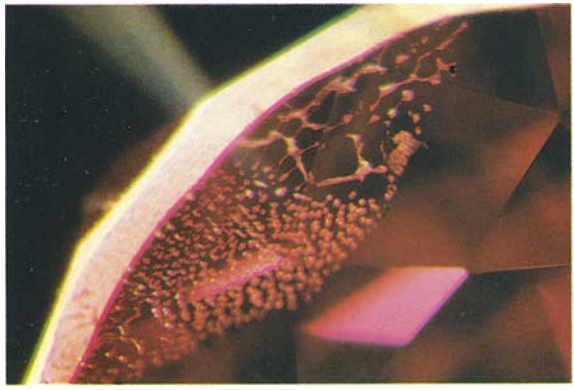

FIG. 23. Deceptive 'feather' near the girdle of a synthetic ruby by Kashan. 25 ×

FIG. 24. A V-shaped arrangement and discrete rows of tiny grains of flux in a synthetic ruby by Kashan. 28 ×

FIG. 25. Flux inclusions simulating archaic characters in a synthetic ruby by Kashan. 30 ×

FIG. 26. Tiny flux inclusions looking like crystal shapes accompanied by a double row of minute flux grains in a synthetic ruby by Kashan. 50 ×

FIG. 27. Survey picture of a synthetic Kashan ruby rendered turbid by a large cloud with numerous 'hairpins' and 'comets'. 13 ×

FIG. 28. Narrow, parallel striations of so-called 'fog' in a synthetic ruby by Kashan. 15 ×

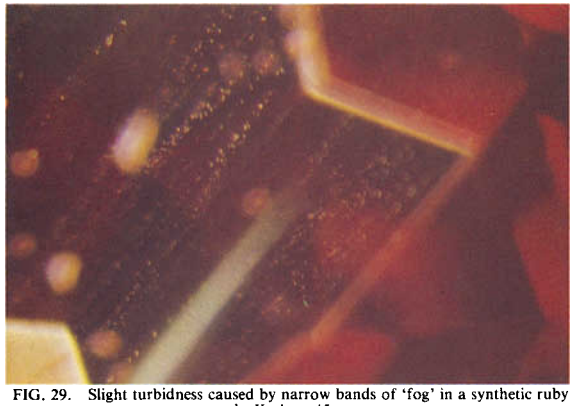

FIG. 29. Slight turbidness caused by narrow bands of 'fog' in a synthetic ruby by Kashan. 45 ×

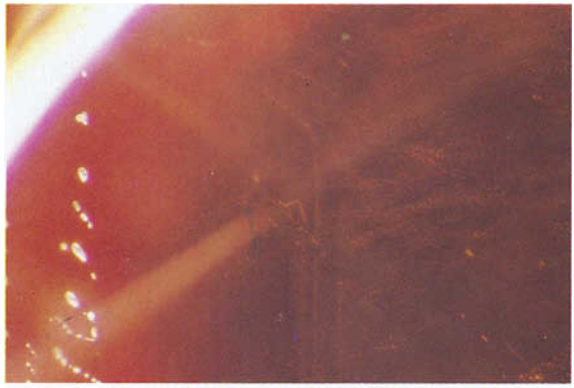

FIG. 30. Two 'hairpins' and a slight fog, being typical internal features of synthetic rubies by Kashan. 50 ×

FIG. 31. Several 'comets' consisting of a tiny grain of flux in connexion with divergent tails of ultra-fine flux in a synthetic ruby by Kashan. 50 ×

FIG. 32. A minute, almost invisible needle, highly reminiscent of a slender rutile needle, in a synthetic ruby by Kashan. 40×

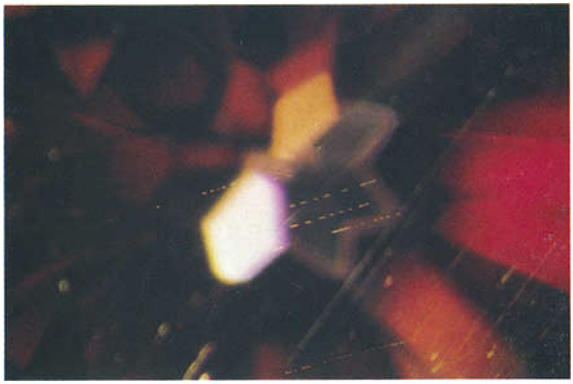

FIG. 33. Parallel rows of broken lines, deceptively similar to natural rutile needles, in a synthetic ruby by Kashan. 20×

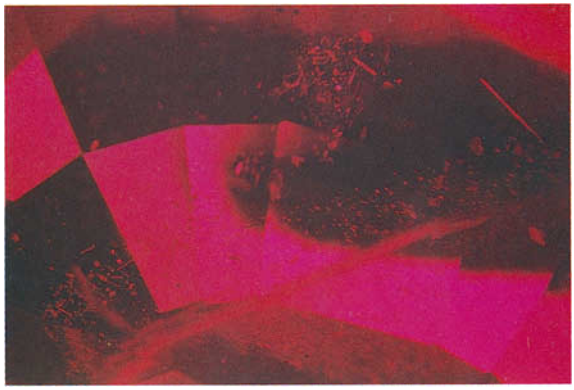

FIG. 34. Very similar short and long needles, misleadingly like rutile needles in genuine rubies, observed in a synthetic ruby by Chatham. 15×

FIG. 35. Two needles meeting at an odd angle simulate one of the rare knee-twins of natural rutile, here accompanied by tell-tale grains of flux in typical arrangement in a synthetic ruby by Kashan. 80×

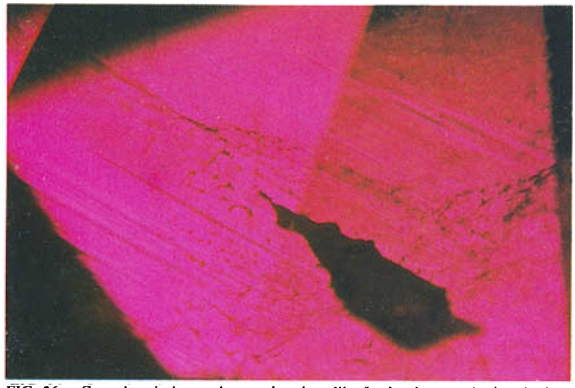

FIG. 36. Growth striation and exemplary lace-like feather in a synthetic ruby by Chatham. 35×

FIG. 37. Hexagonal growth-bandings, imitating those which have until recently hallmarked genuine rubies only, in a synthetic ruby by Kashan. 32×

FIG. 38. A narrow blue band appears to mark the hexagonal outline of a seed crystal in a synthetic ruby by Chatham. 13 ×

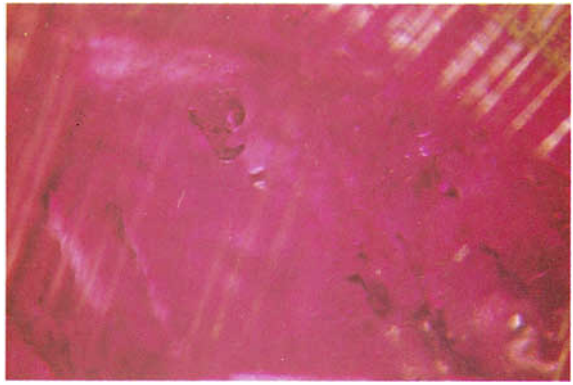

FIG. 39. One of those strange two-phase inclusions in front of a background of hexagonal banding in a synthetic ruby by Knischka. 20 ×

FIG. 40. Small and large negative crystals in parallel orientation and filled with a fluid and a gas bubble in a synthetic ruby by Knischka. 25 ×

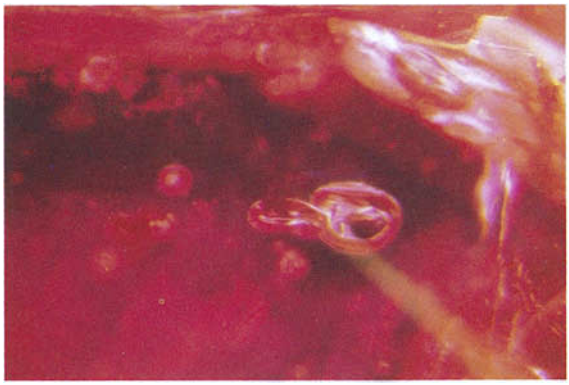

FIG. 41. Two large ellipsoidal two-phase inclusions, which may occasionally extend into long hoses. They always contrast strongly with the enclosing body of the synthetic rubies by Knischka. 50×

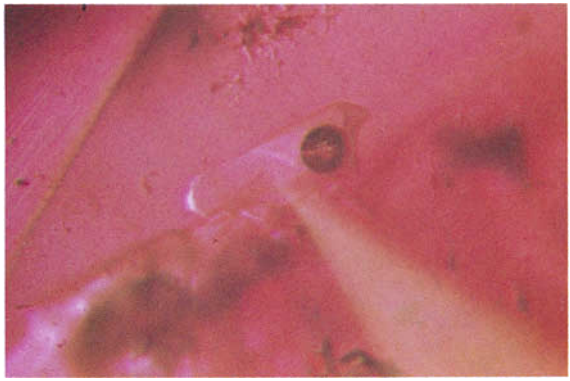

FIG. 42. One of those strange two-phase inclusions with almost invisible relief, yet large and conspicuous gas bubble, in a synthetic ruby by Knischka. 64×

Professor Paul Otto Knischka, an Austrian engineer, has been successfully producing synthetic rubies by a new method that he invented. This material is distinctive from other synthetic rubies in various features such as crystal forms, optical properties, and inclusions.

Although it is known that these new synthetic rubies are grown from a melt, Professor Knischka thus far has revealed only that they are crystallized synthetically by an as yet undisclosed method of gradient technique through supercooling and supersaturation. The finished crystals display flat brilliant growth faces with mineralogically significant indices. So far he has grown a very great quantity of discrete crystals, twins and clusters, which he is

mounting as pieces of personal adornment in gold jewellery. Nevertheless, nothing can prevent him from having his synthetic ruby crystals cut, and thus introducing them on the gem market, and as this possibility must be taken into account, it appears imperative to include this new synthetic ruby in the present review. The product will eventually be marketed under the trade-mark Ꝁ-ruby (Paul Knischka's initials with the 'P' inverted).

As far as colour is concerned, the synthetic rubies made by Chatham and by Knischka, contrary to those by Kashan, resemble more, and in a deceptive way, Burma rubies, and they also distinguish themselves clearly from synthetic Kashan rubies, which look more like Thai rubies. Compared to the physical properties (except absorption) of natural and other synthetic rubies, the Knischka synthetic rubies do not excel by any distinction. Yet the internal scenery of the inclusions is so characteristic as to distinguish synthetic Knischka rubies distinctly from genuine rubies and other synthetic rubies. Indeed, despite a certain similarity between the inclusions in these new synthetic rubies and those in natural rubies, one can, with careful and concentrated investigation, discover distinguishing characteristics which permit an undeniable statement.

While to the unaided eye there is nothing to be seen inside the material that might give definite and immediate proof of synthesis, viewed with a pocket lens—or even better under the microscope—the variegated wealth of inclusions is revealed in considerable detail with swirls of colour, clouds, liquid feathers, negative crystals, black platelets, melt residues and two-phase inclusions.

The nature of the turbid clouds could not be determined even with the strongest magnification. The liquid feathers, with their irregular course and net-like pattern (Figure 4) are remarkably similar to those in the synthetic rubies by Chatham, and are sometimes difficult to distinguish from the fluid inclusions in natural ruby.

The negative crystals (Figure 40) unmistakably follow the characteristic habit of rubies grown by this particular method. They perch, usually alone or in small groups, on the ends of long crystalline tubes, and they can be considered identifying features.

Equally characteristic are the small, triangular or hexagonal distorted platelets of platinum or silver that can be observed now

and then in synthetic K-rubies (Figure 7), but are never seen in natural gemstones. However, the manufacturer of this product can now repress the formation of such platelets during the growth process.

Being the result of a melt process, flux residues may be expected in synthetic Knischka rubies, and indeed they are present with similarly bizarre shapes to those in synthetic rubies by Kashan (Figures 7 & 10), and are equally efficient as marks of distinction.

Apart from the negative crystals of Figure 40, there are two types of two-phase inclusions: those with a strong relief and a large gas-bubble which are therefore readily observed (Figure 41), and those whose contours within the ruby are astonishingly delicate—almost to the point of invisibility (Figure 42). These inclusions, which sometimes appear as negative crystals and sometimes as irregular shapes, must contain a highly refractive substance, the chemical properties of which could only be determined by mass-spectroscopy or by the manufacturer's disclosure of the process he has developed. This knowledge, however, is of little importance in the recognition of these synthetic rubies, or in their distinction from either natural or other synthetic rubies. In extremely rare cases, even three-phase inclusions may be observed, in that a platinum platelet forms the solid phase in connection with a liquid and a gaseous phase (Figure 10). These distinctive two-phase and three-phase inclusions in the interior scene of these synthetic rubies are a novelty, and can be regarderd as an identifying characteristic of Professor Knischka's synthetic rubies.

Summary and Outlook

Although the new synthetic rubies no longer present a problem for the gemmological laboratories, this does not however apply for the trade; that is to say, the problem remains for all those who have access to neither an x-ray apparatus nor a spectrophotometer. For the more modestly equipped professional, the inclusions (perhaps together with the dichroism in the case of orangy Kashan rubies) therefore present the most important means of identification, and he is urgently advised to obtain a small collection of representative Chatham, Kashan and Knischka synthetic rubies with exemplary inclusions, so that in case of doubt, comparisons can be made.

The producers of the new synthetic rubies decidedly and very credibly deny any suggestion that they desire to cheat or deceive; indeed, they even attempt to control the sale and distribution on the market. However, they must nevertheless be aware of the possibilities of cheating and deception, when they proudly declare that they have not only copied the natural product but improved on Nature. The opportunity of the fraud—somewhere along the distribution line—lies precisely under these circumstances.

The trade centre of synthetic Chatham and Kashan rubies today is Bangkok, where rough as well as cut stones are traded. The cut stones are offered either singly or in parcels—often together with natural rubies!—whereby the salesman is often ignorant of the exact composition of the lots. It is therefore absolutely necessary for buyers to obtain experience and practice in noticing the characteristics—especially the typical inclusions—with a pocket lens at home (a microscope will hardly be available abroad!). May the inclusion-scenes illustrated here help to protect all buyers of rubies—tradesmen, goldsmiths and jewellers—from grave future errors of judgement.

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PHLOGOPITE AS AN INCLUSION IN PAINITE

By S. HORNYTZKYJ, F.G.A., and A. M. CLARK, Ph.D.

A well-formed, though rather water-worn, singly terminated transparent deep-red crystal weighing 1.7 g was discovered in 1952 in gem gravel from one of the small ruby mines near Ohngaing village, Mogok, Upper Burma. Claringbull *et al.* (1957)[1] identified the crystal as a new mineral of gem quality and named it after A. C. D. Pain who had first recognized its unusual nature. Moore and Araki (1976)[2] found the crystal structure of painite to be related to that of jeremejevite and fluoborite; they also redetermined its chemical composition. Povarennykh *et al.* (1978)[3] demonstrated, on the basis of a study of its infrared spectrum, that the structure is better represented by the formula $CaAl_9ZrO_{15}(BO_3)$.

Painite is hexagonal with a Mohs' hardness of 8 and a specific gravity of 4.01. It is uniaxial negative with refractive indices of ω 1.816 and ε 1.787. It is pleochroic, ranging from ε ruby-red to ω pale brownish-orange. The absorption spectrum shows faint chromium lines. Between crossed polars the original specimen showed a red colour; in long-wave ultraviolet light a weak red glow, and a stronger red under short-wave UV. In x-rays the glow was a very dim bluish-yellow.

Painite is an extremely rare mineral; only three specimens have so far been found, two of which are preserved in the British Museum (Natural History). The second of these was also found by A. C. D. Pain, while the third, a much smaller stone also from Burma, is in the possession of the Gemological Institute of America[4].

Claringbull *et al.*[1] give a short description of inclusions in the original painite crystal. They state (p.421) that 'The crystal contains a number of inclusions, some rounded and others tabular and hexagonal in outline, as well as some feather-like sheets of minute cavities similar to those seen in gem-corundum'.

Recently the authors have examined a small tabular yellowish-brown crystalline inclusion about 0.5 mm in diameter situated in a slight depression in the $(1\bar{1}00)$ face of the original painite crystal (BM 1954, 192). This inclusion was partially exposed, with its

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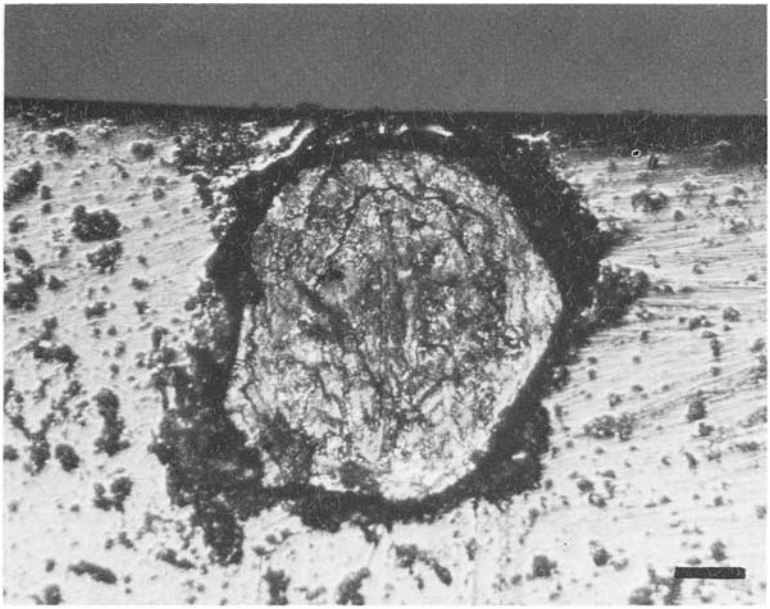

FIG. 1. Tabular and hexagonal phlogopite inclusion partly exposed in the $(1\bar{1}00)$ face of painite crystal BM 1954, 192. This is the striated face shown to the left-hand side of Figure 2 of Claringbull *et al.*[1] The scale bar here represents 0.1 mm.

tabular face parallel to the plane of the painite crystal face (Figure 1), and was therefore suitable for examination with the electron microprobe. The analysis (Table I) was obtained by mounting the whole painite crystal in a Cambridge Instruments Geoscan microanalyser fitted with an energy dispersive system. The analysis was obtained using a 15 kV accelerating potential and 100 sec live-time. As reported it gives a somewhat low total which is thought to be largely due to the lack of polish on the inclusion surface. A fully treated surface for the analysis was out of the question because of the extreme rarity of the mineral and the necessity to preserve its natural crystal faces. The analysis has therefore been normalized to 100% following the assumption that 4 (OH) are present in the mineral's formula.

The analysis shows the presence of Al, Mg, K and Si, with some Fe and Ti and traces of Cr. The oxide percentages, together with the results of an optical examination and the typical hexagonal tabular habit, indicate that the inclusion is the mica phlogopite.

TABLE I.
Electron microprobe analysis of phlogopite inclusion in painite.

	Wt %	Normalized with 4 (OH)	Recalculated to 24 (O, OH)		
SiO_2	34.93	38.64	Si	5.36	8.00
TiO_2	2.05	2.27	Al	2.64	
Al_2O_3	17.85	19.75	Al	0.59	5.83
Cr_2O_3	0.19	0.21	Ti	0.24	
FeO	0.74	0.82	Cr	0.02	
MgO	21.34	23.61	Fe	0.10	
Na_2O	0.47	0.52	Mg	4.88	
K_2O	8.91	9.86	Na	0.14	1.89
H_2O	—	4.32	K	1.75	
Total	86.48	100.00	OH	4.00	

Claringbull *et al.* describe the inclusions they observed as 'tabular and hexagonal in outline' (there is a good photograph in Webster,[5] p.300). They were oriented parallel to the *a* crystallographic axes of the painite crystal and it is likely that these, too, are phlogopite crystals.

Phlogopite commonly occurs in metamorphosed limestones and ultrabasic rocks.[6] It is abundant and evenly distributed in the Mogok limestone from which the spinels and most of the rubies found in the gem gravels of Mogok are derived.[7] The limestone is a white, coarse-grained, partly dolomitic marble, in places intruded by pegmatite and granite.[7] The sapphires found with the rubies and spinels are generally derived from the pegmatite and granite, although they have also been reported in the limestone.[7] Gübelin[8, 9] records the occurrence of phlogopite as an inclusion in red spinel and blue sapphire from Mogok, attributing it to syngenetic growth.

Both the high MgO/FeO ratio of the phlogopite inclusion (Deer *et al.*[6]) and its position on the ($Fe_2O_3 + TiO_2$)-(FeO + MnO)-MgO diagram of Heinrich[10] associate it with phlogopites from metamorphosed limestones. It seems probable therefore that the Mogok limestone is the source of the phlogopite and, consequently, of its host mineral, painite.

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HELIOLITE, A TRANSPARENT, FACETABLE PHASE OF CALCIC LABRADORITE

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A number of years ago, when the U.S. National Museum of Natural History's gemstone display was of modest significance and educationally oriented, visitors might notice, if they were gemmologically informed, a small carat-sized red brilliant-cut stone that seemed obviously mislabelled and mislocated; it was clearly a red spinel. The only problem was that it was in an institution where one does not question labels, and its label said it was labradorite, and so it must have been. However, it was, and is, unlike any labradorite with which gemmologists are familiar. Its source was near Plush, Oregon, a general-store post-office group of homes, fairly near Lakeview, about in the centre of the southern part of the state (see Map). Geologically, it is a volcanic area in a region where there have been numerous volcanic episodes, with

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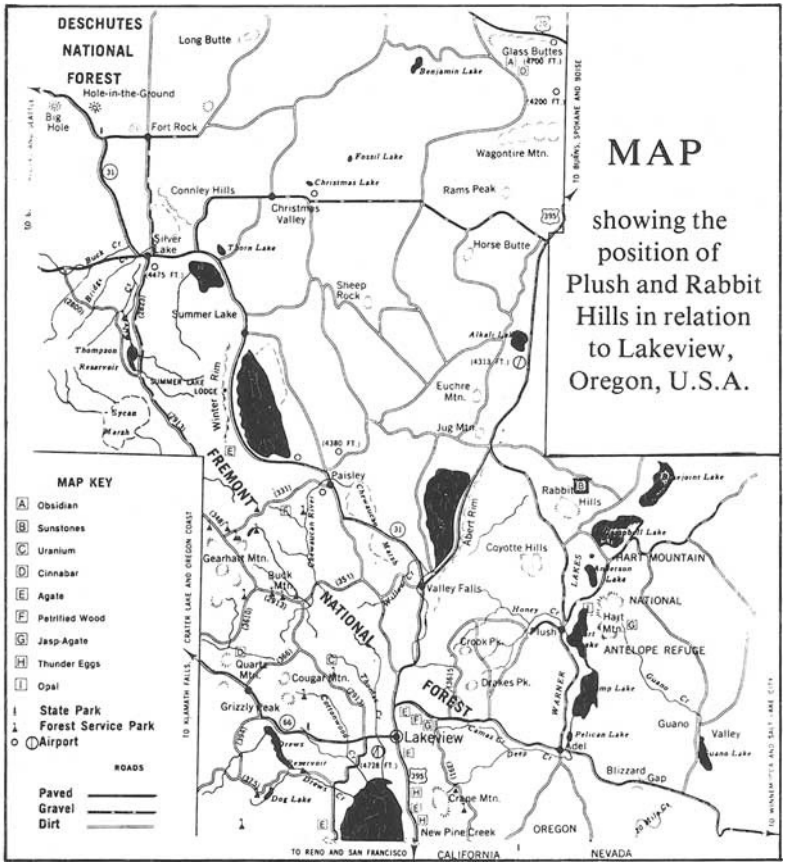

flows emerging from low dome volcanoes and fissures. The flow with which we are concerned is very late, a pahoehoe-type flow covering about seven square miles and forming a small ridge, the Dudeck Ridge, overlying a pumice-rich tuff. The tuff, in turn, overlies a dense black basalt of undetermined thickness. The basalt is very coarsely granular and consists of at least 50% feldspar, with small amounts of pyroxene, olivine, and magnetite. In the normal sense of a typical basalt, a dense fine-grained black rock, it is very different. With a coarse shattered feldspar groundmass, it is, nevertheless, a basalt porphyry, for the fresh rock is studded with flat crystals several inches in length and width, but under one inch in thickness. The phenocrysts can be exposed on a fractured

surface, where they exhibit a frosted face, rounded corners and innumerable fractures. Intact crystals could only be recovered by fossil-collecting techniques, for all are shattered as they lie in the rock. Their surroundings would appear to have been a mush of shattered colourless, glassy feldspar fragments of like composition. Sudden cooling and viscous flow probably contributed to the shattering of the phenocrysts. Although feldspar has several distinct cleavages few of the larger size broken surfaces are flat cleavage planes, most are conchoidal when they are freed, by weathering, from their prison. The smaller fragments of the matrix, on the other hand, show the plane reflections we would expect. Until lately, this particular flow unit, occupying only a small area in the Rabbit Basin north of Plush, seemed to be unique. As such, it would represent the surface expression of a small differentiated lava pocket; one might interpret it as a magma bit which dawdled upwards and managed to stratify itself by selective crystallization into a crystal mush with scattered larger phenocrysts just strong enough to hold themselves together for the journey and probably not unlike the feldspar crystals at other localities.

Calcic labradorites, normal labradorites and bytownite phenocrysts in basalt lava flows are known to many amateur mineral hobbyists as collectables at numerous localities all over the world. An area in Mexico, near Rocky Point, at the head of the Gulf of Lower California, is well known as a source of clear feldspar fragments, essentially identical with the common ones lying beneath the volcanic slopes of the Rabbit Hills. Milford, Utah, has also been a source of similar colourless to straw-hued glassy fragments of labradorite. The Oregon area seems richer, however, and the proportion of labradorite in the lava very much higher. The matrix in Utah and in Mexico seems more of a normal basalt in grain size and appearance.

So rich is this area that it has become known as the 'Sunstone Area' and a summer-time collecting goal of many a lapidary hobbyist. Little soil covers the basalt and much of the erosion has probably been wind erosion. As the rock broke down into tiny fragments breezes swept away the sand-grain size particles, leaving behind the larger, coarser pieces which lie strewn over the near-desert surface, hardly concealed by the sparse vegetation. Hundreds of collectors have trudged up and down, back and forth, over this seven square miles, seeking the now scarce and elusive

FIG. 1. Oregon's Sunstone area, a weathered lava surface windswept almost bare of soil and strewn with labradorite chips. (Photo by H. M. Dunn)

larger bit of facetable material. In the beginning, inch-size pieces were not at all uncommon, with phenomenally large bits, two or three times this size, not impossible. Their surfaces were slightly dulled by sand-blasting in many cases, but their clarity was such that they gleamed in the slanted rays of the sun (collecting is best going toward the sun in early morning and toward evening—summer noons are very hot anyway!). Local dealers sold run-of-the-field pieces by the pound, only a few dollars, so abundant were the sunstones; a family, from any age up, had no trouble collecting many pounds in a few hours. To the local, the name sunstone has come to have a different meaning from the original usage. Today, it is the Sunstone Area, where the ground is studded with gleaming 'sunstones': clear, white to yellowish, and sparkling. That is not correct, nor is it in accord with the original use.

Parenthetically, it is an interesting fact that physiographers seem to have overlooked in their studies of 'Dreikanters' and sand ablation. We note here, as we did in the Namibian Desert, that sand blasting and shaping of pebble forms on the desert surface is not a current wind activity and must represent some earlier time of stronger winds, perhaps a glacial period. Rose quartz in Namibia,

labradorite fragments in Oregon have a coating of desert varnish which would seem to be an anachronism if current wind-blown sand were actively shaping protruding pebbles on the desert floor. On black basalt one notes it not, but on white or pink glassy fragments it is all too evident after an acid wash, how brightly they then sparkle.

To revert to the question of the nomenclature and the term sunstone. Sunstone, of course, is the accepted, traditional, name for a feldspar with numerous schillering haematite (or some similar oxide) inclusions which give something of the appearance of brown aventurine or the glass known as 'goldstone'. Originally it was correctly applied to 1% of the finds in the Rabbit Hills area. About one of every hundred bits collected contained an array of tiny reddish inclusions which are aligned to give a plane of golden-red reflections when turned to a proper angle. Most, and traditional, sunstone is a reddish-brown, clouded white to orange feldspar, found as the feldspar constituent of pegmatites, as in Norway, Ontario and India. The Oregon sunstone is a very different substance, a gem material (in the past we would have said semi-precious, were we not sworn to eschew this term) as opposed to a decorative stone. A cabochon cut is favoured, though they are often faceted (an unsuitable treatment for a dusty stone). Nonetheless, they are attractive and, on occasion, spectacular.

In the past, lucky searchers came upon really red stones, labradorite chips bounded by conchoidal frosted surfaces, that were clear, no haematitic motes, and actually red. The old ratio was one to a hundred of the schiller stones; today it is considerably lower. Colour patches in the labradorite tend to occupy only a portion of the chip, so with the earlier, larger bits, there were more often areas with schiller and with red. Now that all the larger bits are gleaned, the red ratio has sunk close to the vanishing point and few are found in surface scans. Fortunately, free enterprise has discovered another route to the red: excavation.

In the years before 1970, when the Bureau of Land Management heeded the local collectors' request to withdraw a large area, about four square miles, from mining claims, a number of the more enterprising collectors discovered that there were pipe-like areas of local decomposition where the lava was crumbly and pits could be sunk. A number of claims were staked within the bounds of the now withdrawn area, and have been the subject of

FIG. 2. The camp site of the Rodgers Claim, a dry and dusty summer-time haven; cold, snowy and bleak in winter, uninhabitable for man or beast. (Photo by H. M. Dunn)

some discussion with the B.L.M. as to the validity of a retroclosure. As of the moment the chief claimant, Robert Rodgers, seems to have been able to support his right to a valid claim, staked and proven some years before the withdrawn area was delineated. Subsequently, numerous other optimists have staked out all the sunstone-bearing area outside of the withdrawn area, though in most cases little or no claim work is apparent and one would wonder how many are currently valid. Meanwhile, Rodgers has pursued his work and has amassed, in over a decade of hard, primarily manual, labour, a respectable stock of the transparent coloured stones.

Somewhat larger sagebrush bushes are recognized as an indication that their root system has been able to penetrate the ground more deeply, and indication to the digger that below for five to ten feet lies a potentially softer and diggable 'pipe'. The cause of these locally weak zones in the lava is unexplained, but from personal experience trudging over Parícutin flows, the writer inclines toward a theory that areas of potentially easier decomposition in the aeons to come lie beneath gas vents, known as

FIG. 3. Typical bulldozed excavation of soft area within the flow confines, an operation only allowed on a patented claim. Handwork is the general rule for peripatetic collectors. (Photo by H. M. Dunn)

hornitos in Mexico. (Could zeolites zones, too, be seeded by rainwater running down gulleys beneath a flow, which, in Parícutin, at least, did not dam the runoff, and boiling up through it while the lava remained hot?)

In excavating in the crumbling rock, the labradorite phenocrysts are found in place and still intact, though shattered almost beyond intact recovery. Some measure two inches across and in many there are red and green areas near their cores. The origin of the colour is still unknown; various attempts to explain it have been unavailing. Microprobe analyses show no significant compositional differences between the clear and the coloured labradorite and the highest magnifications show no visible intruders in the clearest red or green regions. The origin of the colour remains a mystery, though in many cases we note a combination of red body-colour and schillerizing particles. Some of the red is pleochroic; we find many bits where the red area is rimmed with green, in plain or polarized light, but above the latter, as the stone is turned the green area becomes red too. Not all the green is pleochroic in this fashion; some green stones remain green. The red, on the other hand, generally remains red through the rotation cycle. We have discussed the problem with several feldspar specialists, who turned out to be as mystified as we, so we leave the explanation to our readers.

FIG. 4. Sorting apparatus at mine location. (Photo by Laura J. Ramsey)

The colour-distribution is unpredictable but tends to be central in the phenocrysts. The crystals, as they lie in the rock and as they are freed, are crossed by numerous fractures which only casually follow the cleavage planes and are not what we would expect in a mineral with feldspar's cleavage. (In wear and cutting, too, we find the cleavage not a dominant or really weakening factor.) The colour never reaches the fracture surface, and seems to have been leached from the last mm of labradorite. Often it is zoned, a thin skin of green separates the clear margin from the red centre of the

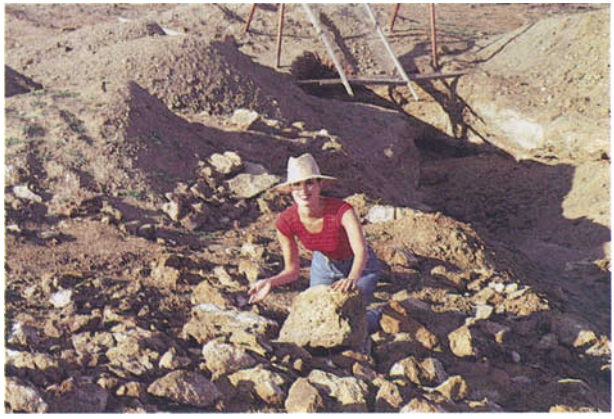

FIG. 5. Finding heliolite at the mining location. (Photo by Laura J. Ramsey)

FIG. 6. Heliolite rough with typical colour distribution: a clear border, green (dichroic red-green) band enclosing red (non-dichroic) core—photographed in immersion cell with 35 mm edge. (Photo by author)

chip. A skilled lapidary can make very attractive and interesting stones from these bits; only a little red at the culet, as Sri Lankans well know in their sapphire cuts, will impart a fine red hue to a much larger stone.

Inasmuch as gem labradorite is long and well known as a decorative (and even near-precious from Finland) stone and the average gemmologist and every lay reader thinks of the Brazilian-butterfly blue-sheened stone when labradorite is mentioned the question of proper nomenclature is a real problem. 'Spectrolite' for a slightly richer-hued and better, but yet identical, phenomenal labradorite is a questionable complication of our gem names; 'precious labradorite' would be a not unprecedented Finnish alternative to warrant the switch from pound to carat price quotes. But transparent, faceted, red, green, and andalusian red and green combinations are a far cry from what the jeweller and his clients envisage when labradorite is mentioned. Hence, it has seemed essential that a new name be supplied along with the stones, so, harking back to tradition, Mrs Rodgers has proposed what

appears to be a logical, euphonious and practical species name, heliolite. While out of the purview of the I.M.A., the name was presented to a session in Orleans and met with no clamorous dissent, so it would seem to be acceptable. (We shall not insult our readers by going into the roots of the word; we give them credit for not needing it.)

Heliolite is a feldspar; hence its hardness is 6. Though normally possessed of a good cleavage which might be a risk factor in wear, these stones seem to be less prone than usual to fracture on the cleavage planes. Whilst their refractive index is low, about the same as quartz, they cut surprisingly bright stones, an observation we made years ago in discussing clarity as a factor in stone brilliance, when it was noted that Madagascar orthoclase seemed more brilliant than most rock crystal quartz of seemingly perfect transparency. The majority of heliolites will be small, carat sizes for the most part. Unlike many other stones, the colour distribution and range is great, so that hardly any two are exactly alike. The reds range from pink, sometimes almost a pink sapphire pink, to rich spinel reds. The greens are much scarcer, few entirely greens will be offered. The green resembles that of some light tourmalines or the greened amethyst that was produced some years ago by heating Brazil's Montezuma Mine stones. (We proposed the name 'peridine' for this material, but it did not meet with enthusiastic acclaim, logical though it was, from proponents of *prasiolita* and other more rootless names.) Interesting variants are the bi-colour stones, better seen in non-brilliant cuts, that are very reminiscent of bi-colour tourmalines, with hues very like andalusite green and redder reds.

Through the decade of dedicated work, Rodgers has managed to collect a considerable weight of larger sizes of the rough, with the consequence that some impressive stones are available, ten and twenty carat sizes. Each is an individual; no two are alike. The larger sizes have been cut by skilled semi-amateur lapidaries to get the most from the rough; when such rough is cut, one dares not leave it to the average mass-production commercial cutter.

No real marketing arrangements have yet been made; Rodgers would like to sell his claim and stock; years of summers in a wind-swept Oregon desert do leave a little something to be desired in the way of life fulfilment, but he dares not leave unguarded his lifetime grubbings. A corporation to promote the mining and distribution

FIG. 8. A drop of red in the centre area of this large heliolite shows a common way in which the colour presents itself. (Photo by Laura J. Ramsey)

FIG. 7. Unusually large heliolite with very deep red colour, with the green as well. (Photo by Laura J. Ramsey)

FIG. 10. An extremely unusual heliolite, that is a fine rich red colour with schiller across the entire face of the stone to give it the sparkling look. (Photo by Laura J. Ramsey)

FIG. 9. Common colour of heliolite-sunstone with salmon-colour schiller. (Photo by Laura J. Ramsey)

of the heliolites, an All-American gem of considerable merit and rarity, was tentatively formed last year, but it needs financing and implementation, so it is presently hard to say what the future will bring. There are some other claims, one quite actively worked, outside the withdrawn area; so the supply is not entirely a one-man dependent operation. There is also a possibility of further deposits.

At the outset we mentioned that the Rabbit Hills area had, until recently, been regarded as unique, a single tiny differentiated lava pocket. However, two or three years ago, a second locality for very similar material was discovered in Harney County, near Burns, Oregon, over a hundred miles to the north, by Charles Weightman and John Hinton, of Burns and Hines, Oregon. Their stones are very similar in hue, some perhaps a little richer but, as yet, none so large as the best of Rodgers's stock. Their association, the H. & W. Mining Company, is still locating and delineating their claims as well as cutting and selling a few stones. It is too soon to venture any predictions about the importance of their production, except to indicate that heliolite is no longer confined to a single region, and that there exists a possibility for further extrusions of this unusual lava in intermediate terrains.

As a jewellery stone, heliolite seems to have good possibilities; it is attractive, it is as durable as many of the newer highly advertised stones (tanzanite and tsavolite), it is common enough in smaller sizes to be commercial and rare enough in larger and impressive sizes to bring a good price. There is little danger of excessive supply, and the rarity of really fine stones insures its retention of value. It remains to be seen whether it becomes popular and well known or fades back into the purlieu of the amateur rockhounds and lapidaries. It is our impression that it has considerable merit and deserves its day in the limelight.

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AN UNUSUAL ORNAMENTAL STONE: COLLOPHANE

By J.-P. POIROT

Service Public du Contrôle des Diamants, Perles Fines et Pierres Précieuses, Paris.

We recently had an opportunity to examine a carved snuff-bottle, green with some small yellow chatoyant areas (Figures 1, 2 and 3). The macroscopic appearance of the stone did not suggest any known material. The oriental shape of the specimen could not, of course, reveal its true origin; and its geological or even its geographical source is consequently unknown.

This snuff-bottle, 5.95 cm high, 4.05 × 2.42 cm in greatest and least sectional width, with a weight of 45.28 g, had a specific gravity of 2.01. Scratched by calcite, but not by gypsum, its hardness was about 2½, and it was therefore a 'soft rock' in spite of the delicacy of the carving. By the distant vision method, we were able to determine a refractive index near 1.61-1.62. Some very inconsistent physical data!

Chemically a drop of concentrated hydrochloric acid (d = 1.19) on the surface turned yellow, with a slight effervescence.

The texture of this rock can be described as a juxtaposition of perceptibly cylindrical patches, with minute yellow fibres radiating from a dark green centre. An amorphous material, light green, very small in amount,* cements these elements together (Figures 4 and 5). The yellow chatoyancy macroscopically seen in some areas proceeds from the play of the light on the minute yellow sub-parallel fibres.

The Debye-Scherrer x-ray powder diffraction pattern shows some diffuse lines corresponding to d-spacings 2.85 Å to 2.70 Å (strong band with a maximum of darkness near 2.80 Å), 3.40 Å (medium), 2.26 Å, 1.96 Å, 1.83 Å and 1.74 Å (weak), 3.06 Å, 1.46 Å and 8.3 Å (very weak). These data are close to those of P D F† cards for apatite (see Table 1). The absence of the weakest reflections and the width of all the reflected rays (particularly that

*So small as to be negligible in considering the composition of the whole of the rock.
†Powder Diffraction File published by JCPDS—International Center for Diffraction Data, 1601 Park Lane, Swarthmore, Pa 19081, U.S.A.

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FIGS. 1, 2 and 3 General view of the snuff-bottle with scale in millimetres

FIG. 4 Structural details: total length 2.5 cm

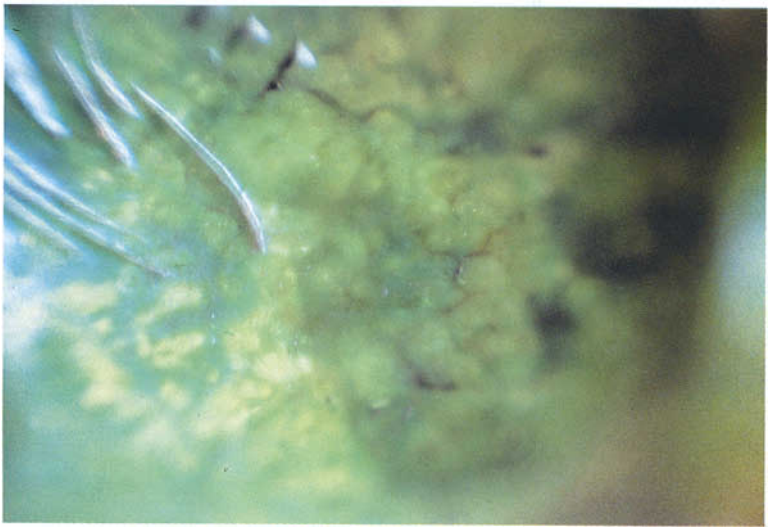

FIG. 5. Structural details: total length 1.5 cm

TABLE 1

X-ray powder data for various apatites

hkl	Hydroxyl-apatite PDF 25/166		Snuff bottle		Odontolite (office's collection)		Carbonate-hydroxyl-apatite PDF 21/145		Carbonate-fluorapatite PDF 31/267	
	d Å	I/I_1	d Å	I/I_1	d Å	I/I_1	d Å	I/I_1	d Å	I/I_1
100	8.24	8	8.3	10	8.1	10	8.13	18	8.04	18
101	5.28	4								
110							4.69	4		
200	4.12	6			4.03	10	4.06	10	4.04	16
111	3.90	4			3.86	10				
002	3.45	35	3.4	50	3.44	50	3.43	16	3.43	20
102	3.16	6			3.16	20			3.16	6
210	3.11	16	3.06	10	3.05	20	3.08	25	3.05	35
211	2.827	100	2.85		2.80	100	2.811	80	2.790	35
112	2.775	30	to	100			2.774	25	2.769	16
300	2.730	75	2.70		2.69	50	2.717	100	2.692	100
202	2.632	16			2.61	20	2.627	12	2.619	8
301	2.544	4					2.526	4	2.506	4
212/003	2.298	4			2.29	5	2.293	6		
310	2.281	10	2.26	30	2.25	20	2.261	35	2.240	45
311	2.162	4					2.149	6	2.134	4
203/400	1.997	4							2.021	4
222	1.950	30	1.96	30	1.93	20	1.941	16	1.931	12
312/132	1.901	8					1.889	8	1.887	8
230	1.883	10			1.88	10			1.855	8
213	1.842	50	1.83	30	1.83	20	1.841	12	1.834	10
231/321	1.819	10					1.805	16	1.790	12
410	1.794	10			1.78	10	1.781	12	1.783	25
402	1.761	6	1.74	30	1.75	10				
303							1.757	8	1.754	8
004	1.718	8			1.73	10	1.720	4	1.720	4
322	1.653	4			1.65	5				
133	1.614	6								
214	1.499	4			1.50	10				
324	1.453	8	1.46	10	1.46	10				
511	1.445	4								

band enveloping the indexed reflections at 2 1 1, 1 1 2 and 3 0 0) yet show a certain disorder in the dimensions of the crystal's cells in the specimen.

So the snuff-bottle we examined is composed mineralogically of a massive carbonate-hydroxyl-apatite; however, in view of its massive fibrous radiated texture, it is preferable to call it 'collophane,' a name which is used as a generic designation for many cryptocrystalline types of apatites. The inhomogeneity of the crystal-cells of apatite in this rock, the low specific gravity which (as also the low hardness) indicates a certain porosity, and its fibrous radiated texture along dark more or less parallel filaments, all suggest fossilization as a possibility; the texture, very different from that of fossilized ivory (or odontolite, which is phosphatized mammoth tusks found especially near Auch in southern France and suggests the colour of turquoise), is similar to that of haversian systems in bones. We are thus led to believe that the snuff-bottle which we examined was a carved piece of apatite-fossilized bone, which, to the best of my knowledge, has never clearly before been noticed in the literature.

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[*Manuscript received 8th October, 1982.*]

'SILK' IN SAPPHIRES FROM A NEW SOURCE

By R. KEITH MITCHELL, F.G.A.

In the last ten years some quite large parcels of sapphires of a somewhat washed-out blue colour have been offered by one firm, with African connexions, on the London market. Often lacking in 'life', the stones superficially resemble those known to come from the Umba River in northern Tanzania, and, when I questioned this origin with the suppliers' representative, it was not contradicted. A few finer stones were produced and some fancy colours, including some with colour changes, as in the case of the Tanzanian material.

It is now known that these parcels originate from material mined in substantial deposits occurring at Chimwadzulu (Chiradzulu?), some 800 miles south of the Umba River and close to the border between Malawi and Mozambique, fairly near Blantyre—a wild and none too safe area, if my informant is now to be believed.

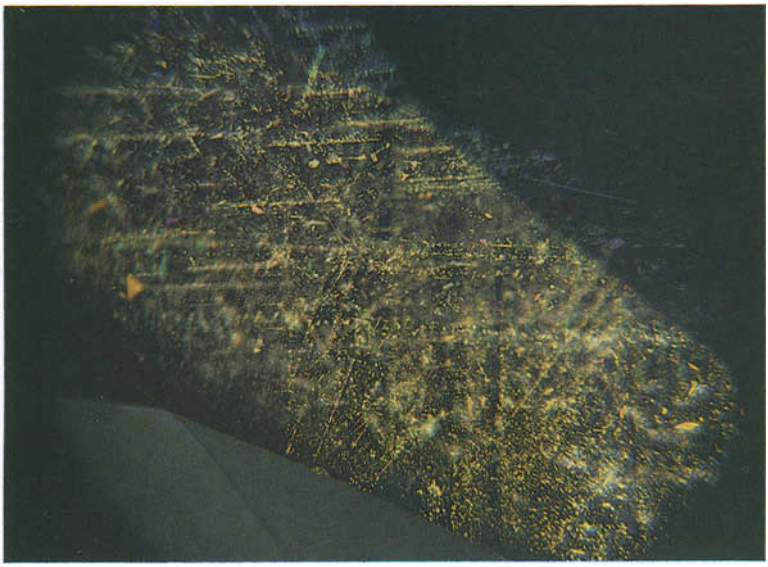

FIG. 1. Unusually angled 'silk' in sapphire from a new source.

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Most stones show inclusions and cracks rather similar to those in the Tanzanian sapphires, and there is some suspicion that cracks, at least, may have resulted from heating to try to improve the colour. But a few stones exhibit a coarse and very marked 'silk' which differs from silk found in any other corundums that I have seen.

Under magnification this is seen to group in straight lines, often nearly at right angles, but in the form of extremely thin and apparently hollow cavities, and not the normally expected needles of rutile. These are often sufficiently thin to impart Newtonian interference colours to light reflected vertically from them.

What is even more interesting is the strange assortment of angles of intersection that can be seen between the lines, and in the angles of the larger inclusions themselves. My illustration (Figure 1) gives a good idea of the mass of silk encountered in one of these stones. A negative print was made from this transparency and the lines were then extended to allow angles to be measured with an ordinary protractor. The photograph is taken through the table facet so there is no distortion caused by the inclusions being seen through several different facets.

Angles measured range from some very low ones, for lines which at first glance appear to be parallel, but which are not, through groups which are probably the same angles suffering from the inaccuracies of my rather crude measuring, to very large angles. The predominant groups are nearly but not quite at right angles. The latter consist of intersections at 87°/93°, close enough to the angle between rhombohedral faces of corundum (93°56′) to be connected with that form. The angle between the rhombohedron and the basal pinacoid (57°34′) is also closely approached. But the actual values measured were very wide ranging indeed and I have recorded 4°, 7°, 11°, 13°, 19°, 24°, 29°, 31°, 37°, 49°, 52°, (56°, 57°, 58°), 62°, 64°, 71°, (86°, 87°, 88°), (91°, 92°, 93°, 94°), 105°, 110°, 116°, 125°, 142°, 144°, 150°, and 161°. The groups bracketed are probably equal angles which have suffered from experimental errors on my part, many of the lines of inclusions are of substantial width, and I have had to approximate to their mean centres.

Most of the lines are more or less parallel to one plane, but in some cases measurement has had to be made on inclusion lines which are receding from the main plane. I acknowledge that this

may have upset some measurements. But this does not affect the basic fact that here we have a sapphire with silk which does not conform even remotely to the normal 120° which we always expect in corundums.

I have no explanation for the phenomenon beyond the possibility that some of the lines may be following parting directions normal to sapphire. But why are they restricted to a linear formation? Individual exsolution cavities show angles approximating to 93°, 49°, and 38°, but there are others which have narrow wedge shapes with angles of 4° and 7° to their sharp points. What dictates these wide variations in what are so evidently exsolution cavities?

I have seen these angles in 'silk' in perhaps half a dozen stones among the many which were superficially examined. The best example came to hand at a time when it was quite impossible to photograph it, and I had to wait a while before the present stone turned up. Most of the others showed the 87°/93° angles and little else. This was unusual enough, but I wanted to show the much greater range of angles I had seen in the one fine example. I think the present picture shows this reasonably well.

[*Manuscript received 4th November, 1981.*]

NOTES FROM THE LABORATORY

By KENNETH SCARRATT, F.G.A.

The Gem Testing Laboratory of the London Chamber of Commerce

It is remarkable how the use of a few seemingly innocent words can have the effect of either galvanizing a person into action or calming him. In particular I am thinking of two phrases which are widely used in the gemstone trade.

The first is used in connexion with the higher quality gems and is a phrase which often misleads one into thinking a perfectly natural stone is a synthetic or an imitation—'too good to be true'—but, at least, it plants the seed of suspicion which turns the mind to thoughts of the very real possibility of the stone being other than natural.

The second phrase is used when referring to gems of a moderate quality, but whereas the first phrase worries the mind into action, this one has a calming effect—'who would bother manufacturing something of "that" quality?'. It almost has the effect of a tranquillizing drug; when used it is often enough to suppress any suspicions a person might have. It is certainly enough to dissuade a trader from incurring the expense of having his stones authenticated. This latter attitude is dangerous in the extreme. Synthetics and imitations of the lower qualities of gemstones *are* made, and the cost of recalling large stocks can be enormous.

It is a sad thing to request, but in this very trusting trade we must ask traders to be always on their guard, no matter what type or quality of gem they are dealing in. In recent weeks there have been a number of incidents, chiefly concerning the importation of goods from the Far East, which bring this point to the fore.

* * *

The first concerned that ever troublesome material, turquoise. To see the perfect piece with no imperfections and a superb colour would make most gemmologists assume the worst—plastic bonding, silica bonding, waxing, imitation, synthetic, etc. However, to see a piece with black veins running through it brings the guard down, and this is where the problem begins.

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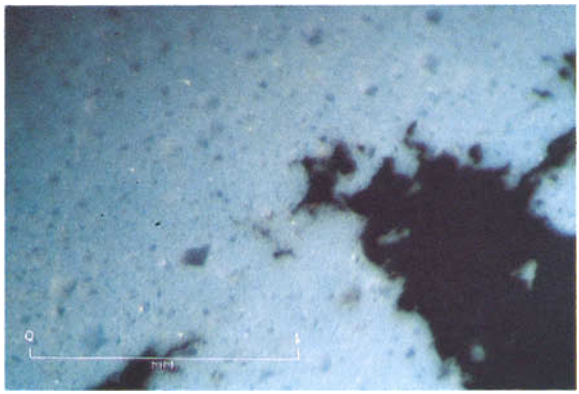

FIG. 1. The surface structure of an imitation turquoise with a high proportion of calcite.

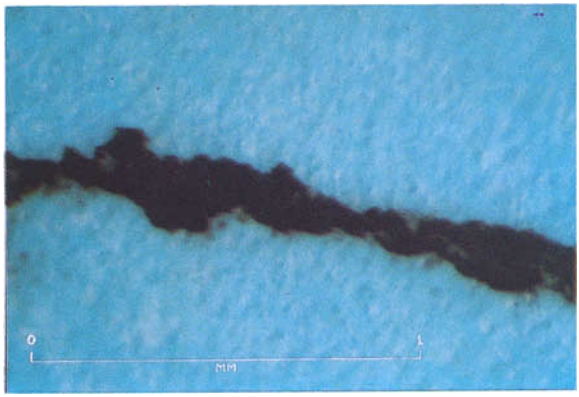

FIG. 2. The surface structure of the 'neolith' imitation turquoise.

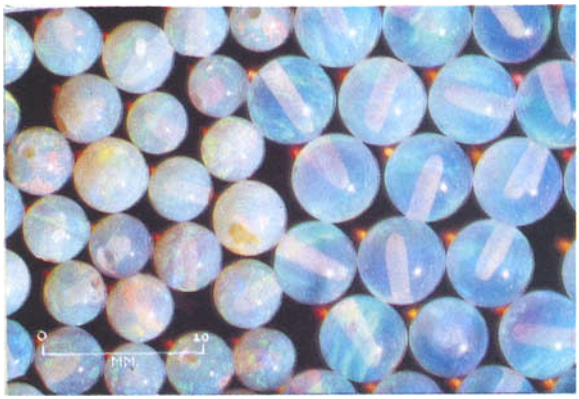

FIG. 3. Larger synthetic opal part drilled beads compared with smaller natural opal part drilled beads *(photo E. A. Jobbins).*

In 1957 an imitation of turquoise with dark veins running through it was produced in Germany. It was a mixture of Bayerite and copper phosphate.[1] The Laboratory samples of this material revealed that the surface was easily etched with dilute hydrochloric acid and that the SG was in the region of 2.36. This material has rarely, if ever, been seen on the British market in the last decade, and so when similar looking material started to appear, set in odd items of jewellery, during the past year, we insisted on the clients removing them from the settings. Whilst this material superficially appeared identical to the German material, which incidentally was marketed under the name 'neolith', examination revealed that a high proportion of calcite was present and that the SG was somewhat lower—in the region of 2.22. Under magnification the surface structure of this and the German material seemed quite similar (Figures 1 and 2) but the neolith's structure was a little finer and appeared a little more 'regular' than this latter material. We have more recently examined parcels of the calcite material and have been told that they emanate from the Far East. We are assuming at present that this material is the same as that investigated by Schmetzer and Bank,[2] and therefore a product of Gilson.

* * *

The next item is also a product of Gilson. Most gemmologists have seen and can easily recognize the better qualities of the Gilson synthetic opal, both black and white. Some of the structures seen in this product[3] are very distinctive and this has created an attitude of security, so much so that it is often thought that should these structures not be observed, then the stone must be natural. This is not a desirable attitude to take, especially when combined with the fact that the opal may not appear to be of the best quality (where the second 'tranquillizing phrase' may once again take effect).

We have, in recent months, examined a number of parcels or samples from parcels of synthetic white (almost water opal) opal beads, both drilled and part drilled (Figure 3) and cameos carved from the same material. In all cases the usual cross section structure to the columns of colour, either the 'lizard skin' or 'chicken wire' type, was either extremely difficult to observe, or, as in most cases, not visible at all. The columnar colour structure was in many cases

the only indication of synthetic origin and this very often, as can be seen from Figure 3, was not very obvious. To prove the origin of these stones a very close and careful examination is required for each stone, nothing is obvious and patience is of the essence. If one first finds the columnar structure and then finds the cross section to that structure, whilst in the main the 'lizard skin' or 'chicken wire' effect will not be present, with a little agility one should be able to pick up the crenulate margins[3] (Figure 4) to these cross sections.

Whilst not being a positive identifying factor, as some synthetic white opals do phosphoresce, it was found that all of these synthetics did not phosphoresce after exposure to long wave ultraviolet radiation. All the natural white opals I have examined, of this quality, phosphoresce quite strongly after such exposure.

* * *

A number of articles have been written about the diffusion process for the colouring of corundum both in this and other journals.[4,5] Identifying factors have been discussed and published,[6,7] and in the main it is considered that identification, particularly of faceted stones, is quite straightforward. There are, however, a number of problems concerning the identification of cabochon cut stones and I will touch upon them briefly here.

If the natural colour zoning is very strong it may be very difficult to observe any surface coloration, especially if a great deal of it has been taken off during repolishing, and if there are no surface cavities in which one may observe the 'bleeding' effect described by Crowningshield[4] then identification becomes difficult.

After examining a parcel of thirty cabochon 'blue sapphires' recently, all of which showed signs of heat treatment and had strong colour zoning, we were able to identify one of that number as having been treated by the diffusion process. The identifying factor was the colour concentration along the line where a feather broke the surface of the gem (Figure 5). I hope that this discovery amongst a parcel of otherwise acceptable sapphires is the exception rather than the rule. If it isn't, then obviously every parcel of sapphires imported into this country would have to be thoroughly examined before general distribution.

* * *

The new Knischka (K) synthetic rubies which have been so excellently described by Knischka and Gübelin[8] could, if only conventional methods are used, prove at times to be one of the more difficult rubies to identify.

The observation of either the platinum platelets depicted in Figure 6 or especially the peculiar two phase inclusions depicted in Figure 7, however, should certainly point the examiner toward the correct conclusion.

* * *

Whilst going through the Laboratory collection recently, I came across an almost colourless octahedron which proved to be a spinel. In itself this, to some people, might not appear to be something to delight in, but since then, as a way of light relief, I have had a good deal of harmless fun with colleagues, students and friends, because on the octahedral faces of this near colourless crystal are, as can be seen in Figure 8, some quite clear 'trigon'-like markings!

* * *

Unfortunately from time to time we are asked to examine damaged gemstones. This is not one of our more pleasant tasks, because the damage in most cases is irreparable. Jewellers in the main make sure that their staff are given as much trade education as is practicable, so that they may give the buying public the correct advice about the item of jewellery they are buying, but at the same time there is still a lot of ignorance within certain areas of the trade about the goods they are handling. One of the sorriest sights I have seen for some time was the result after what was presumably a nice piece of lapis lazuli, set in a ring, was placed in an 'acid bath' for cleaning! (Figure 9.)

* * *

It is with gratitude that I acknowledge the photographic expertise of Mr Alan Jobbins in producing Figure 3 and the generosity of Professor P. O. Knischka in donating a sample of his synthetic ruby to the Laboratory. I also wish to express my appreciation to Mr George Bosshart and Dr Henry Hänni for the loan of further Knischka synthetic ruby specimens.

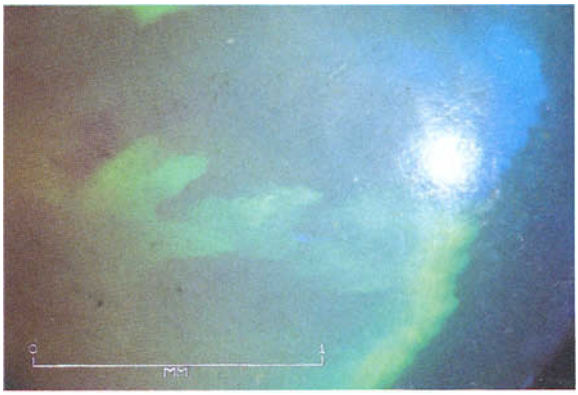

FIG. 4. The barely visible crenulate margins to the cross sections of the columns of colour in a synthetic opal bead.

FIG. 5. The blue colour concentration where a feather meets the surface of a cabochon-cut treated blue corundum.

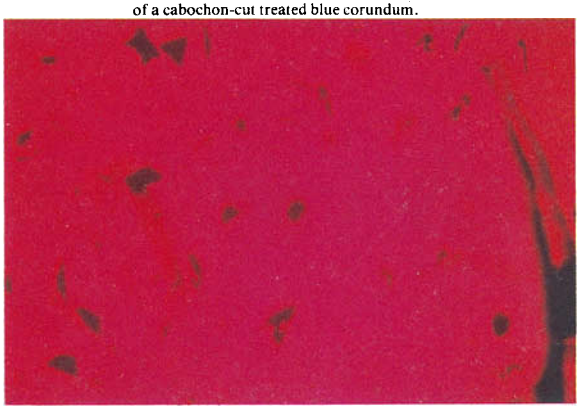

FIG. 6. Platinum platelets in the Knischka synthetic ruby.

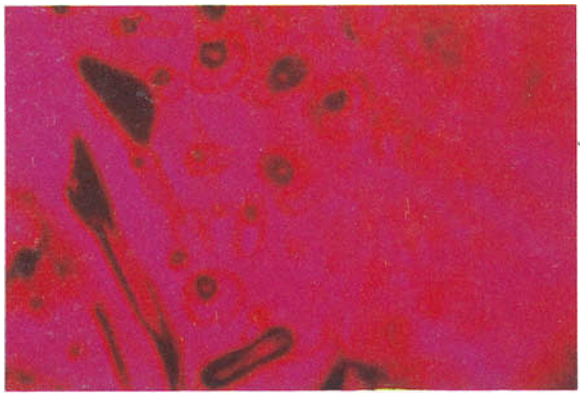

FIG. 7. Peculiar two-phase inclusions in the Knischka synthetic ruby. The high relief of the bubbles contrasts with the hardly visible outlines.

FIG. 8. 'Trigons' on the surface of an octahedral face of a near colourless spinel octahedron.

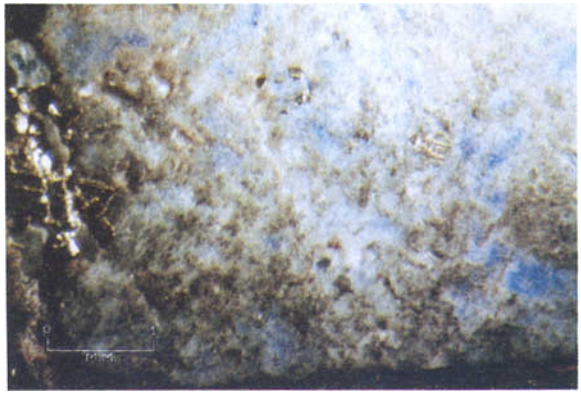

FIG. 9. The surface of a piece of lapis lazuli after 'cleaning' in an 'acid bath'.

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CONTRIBUTIONS TO THE STUDY OF THE DISTINCTION OF NATURAL AND SYNTHETIC EMERALDS

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(a summary based on a thesis submitted to the University of Mainz in 1981 and partially reported at the annual meeting of the Deutsche Gemmologische Gesellschaft at Idar-Oberstein the 24th of May 1981.)

ABSTRACT

The chemical analyses of trace elements of emeralds may be taken as a modern method that can be used to distinguish between natural stones and their synthetic counterparts. It is also possible to differentiate between the localities of the natural emeralds according to their chemical composition. The significant chemical characteristics of both natural and synthetic emeralds are discussed in this paper.

INTRODUCTION

Generally synthetic and natural emeralds are distinguished mainly by their physical properties and by the appearance of their inclusions as seen under the microscope. Although it is obvious that differences in the chemical content, particularly of trace elements,

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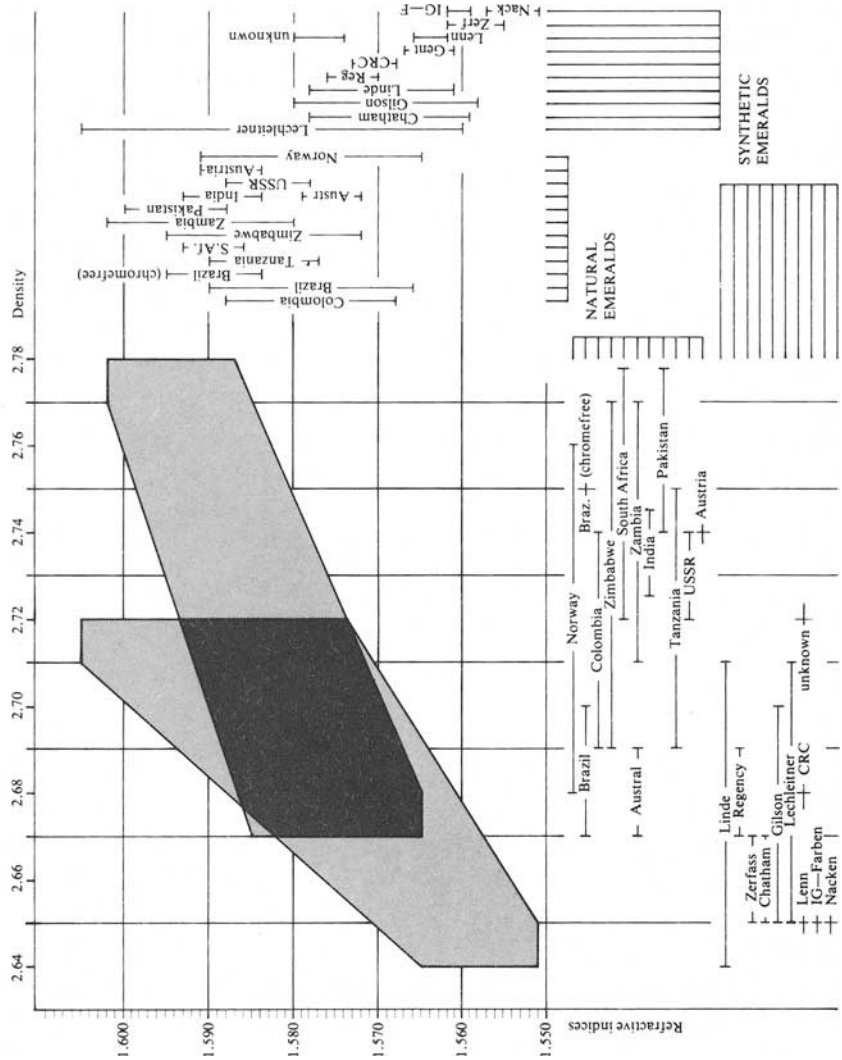

FIG. 1. Sectors of the natural and the synthetic emeralds from different occurrences and producers with regard to their densities and their refractive indices

cause alterations of the physical characteristics, such as refractive indices, double refraction, density etc., it has been shown in Figure 1, that these small differences do not provide an unambiguous way of distinguishing emeralds, since the sectors of the synthetic and natural emeralds with regard to their refractive indices and their densities overlap each other.

Moreover with recent technical improvements there has been a drastic reduction in the number of inclusions in the synthetic emeralds. In some cases the synthetic emeralds are completely devoid of inclusions of any kind. Due to the fact that the inclusions in synthetic emeralds are very similar to those in natural ones and also because the existence of totally 'clean' stones could not be excluded in nature it is of great importance to discover specific criteria that distinguish synthetic from natural emeralds. This is particularly so when both synthetic and natural types are of high quality.

It is known that emeralds from different localities show marked differences in colour and quality. These differences have been attributed to the varying conditions of their origin and also to the variations of trace element contents in the samples. The different conditions of origin of synthetic and natural emeralds should be revealed in differences in their trace element contents. By the application of the analytical techniques of neutron activation analysis (NAA) and optical emission spectroscopy (OES) significant differences in these trace element contents have been found.

Analytical Methods

A total of fifty-eight natural and synthetic emeralds—specimens from different occurrences and producers (see Table I)—have been investigated in order to study their characteristic chemical differences according to their place of origin or synthesis as the case may be, i.e. natural or synthetic.

Seven specimens, one from each group, were chosen and their element contents determined by NAA—an extremely accurate and reliable method used in the investigation of trace elements in gemstones. The disadvantages of this method however are:

—the need for a nuclear reactor,

—the long time required to obtain an analysis from a sample (order of days),

Natural emeralds	Africa	A	33	South Africa, Cobra Mine, Transvaal
		A	36	South Africa, Cobra Mine, Transvaal
		A	40	South Africa, Cobra Mine, Transvaal
		A	42	South Africa, Cobra Mine, Transvaal
		A	43	South Africa, Cobra Mine, Transvaal
		A	48	South Africa, Cobra Mine, Transvaal
		A	55	South Africa, Cobra Mine, Transvaal
		A	62	South Africa, Cobra Mine, Transvaal
		A	64	South Africa, Cobra Mine, Transvaal
		A	66	South Africa, Cobra Mine, Transvaal
		A	L 1	South Africa, Leydsdorpdistrict
		A	L 2	South Africa, Leydsdorpdistrict
		A	Rh 1	Zimbabwe (Rhodesia)
	America	B	9	Brazil
		B	10	Brazil
		B	11	Brazil
		B	13	Brazil
		B	14	Brazil
		B	16	Brazil
		B	17	Brazil
		B	19	Brazil
		B	20	Brazil
		B	22	Brazil
		B	S 1	Brazil, Salininha
		B	S 2	Brazil, Salininha
		B	C 1	Brazil, Carnaiba
		B	ST 1	Brazil, Santa Terezinha de Goiaz
		B	MG 1	Brazil, Minas Gerais
		B	MG 2	Brazil, Minas Gerais
		C	45	Colombia, Chivor
		C	49	Colombia, Chivor
		C	60	Colombia, Chivor
		C	62	Colombia, Chivor
		C	73	Colombia, Chivor
		C	78	Colombia, Chivor
		C	84	Colombia, Chivor
		C	87	Colombia, Chivor
		C	89	Colombia, Chivor
		C	91	Colombia, Chivor
	Asia	P	1	Pakistan
		P	2	Pakistan
	Europe	R	1	USSR, Takowaja, Siberia
		R	2	USSR, Takowaja, Siberia
		Ö	1	Austria, Habachtal, Salzburg
Synthetic emeralds		CH	1	Chatham, USA
		CH	2	Chatham, USA
		CH	3	Chatham, USA
		CH	4	Chatham, USA
		CH	5	Chatham, USA
		G	1	Gilson, France
		G	2	Gilson, France
		G	3	Gilson, France
		G	4	Gilson, France
		G	5	Gilson, France
		G	6	Gilson, France
		LL	1	Lechleitner, Austria
		Le	1	Len Lens, France
		CV	1	Inamori (Crescent Vert), Japan

TABLE I
Samples investigated

—the fact that certain elements cannot be investigated by this method, and
—the high cost involved.

Due to these reasons all samples, including the seven investigated by NAA, have been investigated by OES, which provides very good comparable results. A great advantage of the method of OES is that only a small amount of the sample (10 mg) is needed.

RESULTS

Iron (Fe)

Even though iron was found in all the specimens, the amount of iron in the samples varies considerably according to their origin (see Figure 2)*; however even in the samples from the same occurrence (Africa, Brazil, Colombia) wide variations in iron content were found.

In general the emeralds from Brazil, Soviet Union, Austria and Pakistan have been found to contain 0.4%->0.5% iron, whereas African emeralds have less iron (up to 0.4%); and

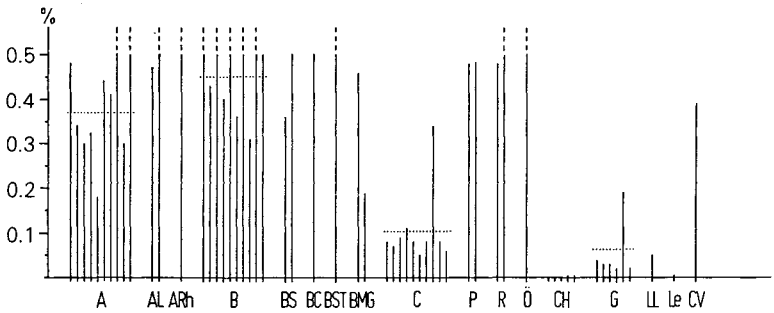

FIG. 2. Diagram showing the contents of iron in the samples

*Abbreviations and signs in Figures 2-9:

A	= South Africa, Cobra Mine	P	= Pakistan
AL	= South Africa, Leydsdorpdistrict	R	= USSR, Takowaja, Siberia
ARh	= Zimbabwe (Rhodesia)	Ö	= Austria, Habachtal, Salzburg
B	= Brazil	CH	= Chatham synthetic emerald, USA
BS	= Brazil, Salininha	G	= Gilson synthetic emerald, France
BC	= Brazil, Carnaiba	LL	= Lechleitner synthetic emerald, Austria
BST	= Brazil, Santa Terezinha de Goiaz	Le	= Len Lens synthetic emerald, France
BMG	= Brazil, Minas Gerais	CV	= Inamori (Crescent Vert) synthetic emerald, Japan
C	= Colombia, Chivor		

····· average content

limit of the standard i.e. content greater than. . . .

The sequence of the samples in Figures 2-9 (left to right) is the same as listed in Table I.

distinctly smaller contents of iron are present in the Colombian emeralds (0.1%).

On the other hand in comparison with natural stones synthetic emeralds have been found to be almost free of iron. With one exception they have less than half of the already small iron content of the Colombian emeralds.

In general it could thus be said, that the Colombian emeralds can be easily distinguished from natural emeralds from other countries. Synthetic emeralds contain distinctly less iron. Previous generations of synthetic Gilson emeralds with higher iron contents could be easily detected by their characteristic optical spectrum (Eppler 1973).

Magnesium (Mg)

Magnesium has also been found only in natural emeralds, the exception being one synthetic emerald from Lechleitner with 0.02% magnesium content (Figure 3). Whereas relatively small amounts of magnesium have been found only in some African samples; the magnesium concentrations in other samples range from 0.3% to >0.5%.

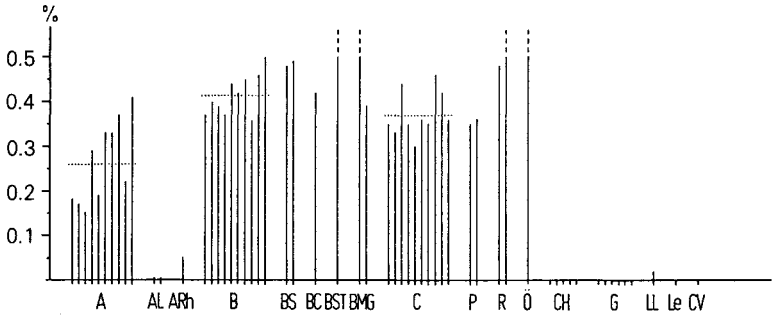

FIG. 3 Diagram showing the contents of magnesium in the samples

Manganese (Mn)

Because of the very sensitive methods of investigation manganese could be detected even in very small contents (detection limits by OES for Mn: 2 ppm or 0.0002%).

In synthetic emeralds only traces of manganese, less than 2 ppm, were found, whereas the manganese contents in natural emeralds were found to lie between 0.0010% and >0.0035% (i.e.

10 ppm to >35 ppm)—see Figure 4. Remarkably strong variations were found in the Brazilian (15 ppm to >35 ppm) and Colombian samples (<10 ppm to 26 ppm).

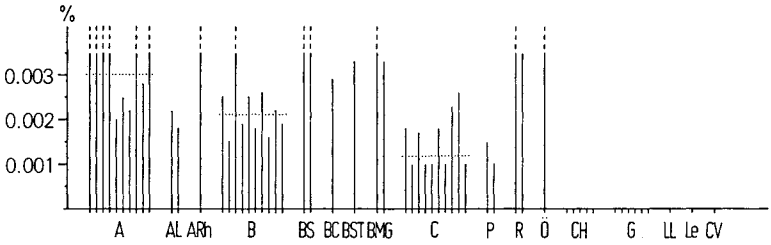

FIG. 4 Diagram showing the contents of manganese in the samples

Gallium (Ga)

Chemically gallium is similar to aluminium and in natural emeralds it ranges from 13 ppm to 18 ppm, while in synthetic stones a lower range of 11 ppm to 14 ppm was found.

Molybdenum (Mo)

As expected molybdenum was found only in synthetic emeralds, the amounts ranging from less than 10 ppm up to 1120 ppm. Molybdenum can thus be used to clearly distinguish between synthetic and natural emeralds. However, due to the fact that the composition of a flux generally depends on the system of synthesis, the absence of molybdenum does not necessarily prove the natural origin of an emerald.

Chromium (Cr)

Chromium (Figure 5) has been found in all the specimens examined, the exception being the emeralds from Salininha, Brazil. Even in these specimens chromium has been found by Leiper, (1965) in quantities which are lower than the limits of detection for chromium by the OES-method (0.05%):

As a rule chromium contents of natural stones vary considerably even in stones from the same locality, and similarly synthetic stones from the same producer also vary (natural emeralds : 0.05% to 0.47%, synthetic emeralds: 0.13% to 0.5%).

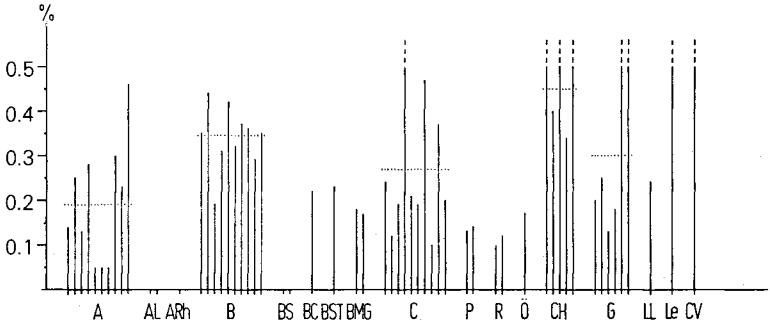

FIG. 5 Diagram showing the contents of chromium in the samples

Vanadium (V)

Vanadium has been found in nearly all the natural specimens with considerable variations in stones from one locality. Some African emeralds appear to have no vanadium. Only in newer synthetic emeralds made by Gilson, was vanadium found. These amounts range from 289 ppm to 430 ppm (Figure 6).

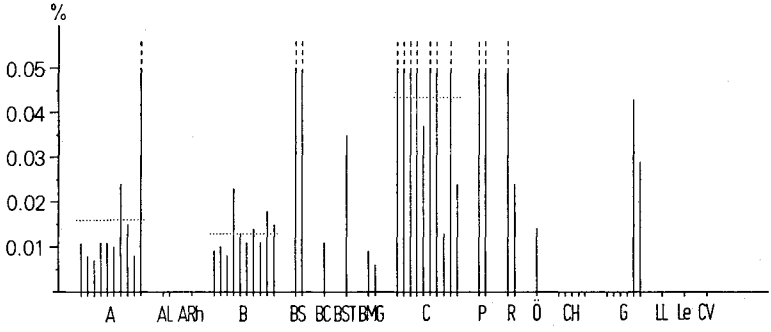

FIG. 6 Diagram showing the contents of vanadium in the samples

Calcium (Ca) and Zinc (Zn)

These two elements were found only in very few samples.

Rhodium (Rh)

Contents of rhodium have been found only in Gilson synthetic emeralds (16 ppm to 60 ppm). The origin of the rhodium content can be explained by the fact that a small wire of platinum serves as a suspension wire in the crucible during the synthetic growth of the

crystals: with the aid of laser emission spectroscopy (LMA) it was shown, that this wire was coated with rhodium for enhancing the protection.

Scandium (Sc)

Nearly all natural emeralds were found to contain scandium in varying amounts (Figure 7). The concentration of scandium in emeralds from Pakistan (0.1% to 0.17%) is significantly higher than that in emeralds from other occurrences (to 0.03%).

Synthetic emeralds have scandium contents always less than 1 ppm.

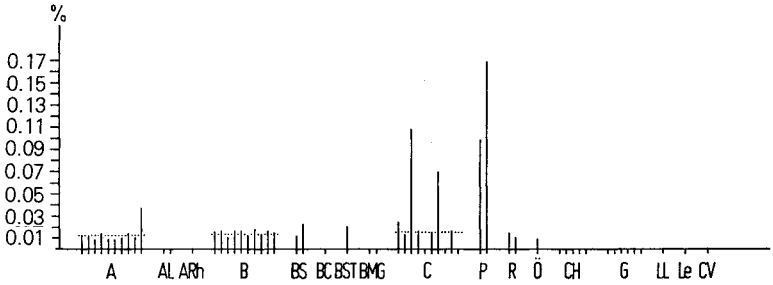

FIG. 7 Diagram showing the contents of scandium in the samples

Sodium (Na)

Sodium has been found in all specimens (up to >1.7%)—Figure 8. Only one African and all synthetic emeralds (12 ppm to 306 ppm) showed amounts very close to the limits of detection for Na (300 ppm) by OES.

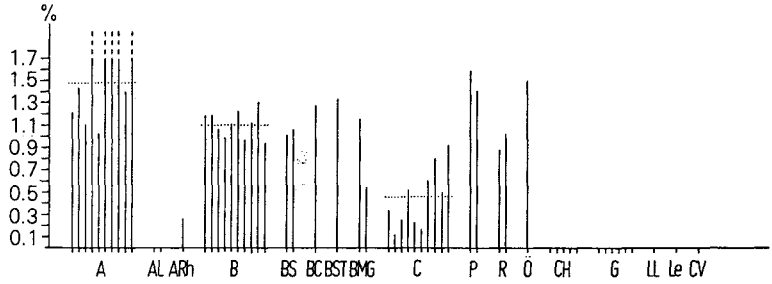

FIG. 8 Diagram showing the contents of sodium in the samples

The emeralds from Pakistan and Africa, which as a rule show higher sodium contents, can easily be distinguished from emeralds from Colombia and Zimbabwe (Rhodesia), which have lower sodium contents.

Nickel (Ni)

According to the chemical data published by various authors nickel has been found only in emeralds from Zimbabwe (Metson & Taylor 1977). But suprisingly nickel has been found in several samples from other occurrences, too. African and Pakistan emeralds have relatively high contents of nickel.

Only some new synthetic emeralds made by Chatham and Gilson have small nickel (6 to 27 ppm). A surprising high amount (283 ppm) was proved for the Japanese synthetic emerald called 'Crescent Vert Emerald' (see Figure 9).

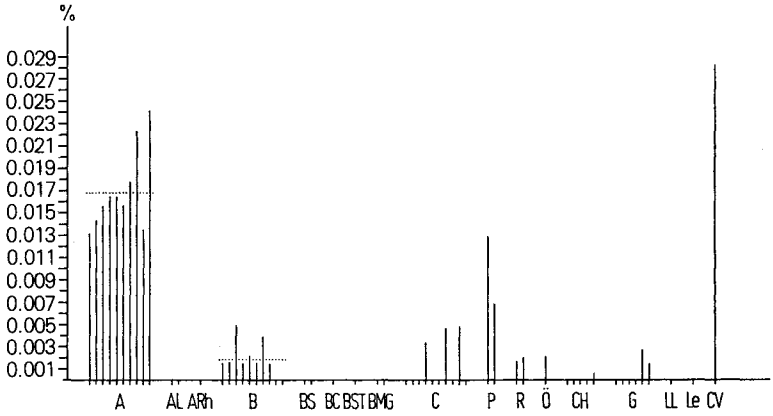

FIG. 9 Diagram showing the contents of nickel in the samples

Yttrium (Y), Titanium (Ti), Copper (Cu) and Zirconium (Zr)

These elements have been found in nearly all the samples investigated, although they have been unknown in emeralds up till now. But the contents of these elements do not enable distinction either between occurrences of natural emeralds or between natural and synthetic emeralds. Only the synthetic emerald from Japan contained remarkably high titanium, 126 ppm.

Caesium (Cs), Potassium (K) and Rubidium (Rb)

These alkalis have been detected in the emeralds in amounts similar to those found in beryls and as reported by other authors (Zambonini & Cagliotti 1928, Jakob 1938, Jayaraman 1940, Simpson 1948, Gübelin 1958, Leiper 1965, Staatz *et al.* 1965, Flanigen *et al.* 1967, Wood & Nassau 1968, Nassau & Jackson 1970, Hickman 1972, Metson & Taylor 1977, Graziani & Lucchesi 1979).

Of these three elements caesium is found in largest concentrations whereas that of rubidium was the least.

In natural emeralds the potassium contents are slightly higher than in synthetic ones (natural emerald : 200 to 330 ppm, synthetic emeralds : 4 to 110 ppm).

Caesium and rubidium contents show very strong variations. By far the largest contents of caesium have been found in the African and Brazilian specimens. Unexpectedly a surprisingly high amount of caesium has been found in one synthetic emerald from Lechleitner, the amount being even higher than the caesium content in natural Colombian and Pakistan emeralds.

Tungsten (W)

The chemical behaviour of tungsten is very similar to molybdenum. Tungstates can be used as flux components, and two synthetic emeralds have been found with small tungsten contents (less than 1 ppm).

Platinum (Pt)

Platinum, besides other metals, is used for the crucibles during the synthesis of emeralds, and so it is quite natural that platinum is present in synthetic emeralds. One specimen from Lechleitner contained platinum.

Lanthanum (La) and Gold (Au)

Lanthanum and gold have been found in some samples in very small traces (Lanthanum : 2 to 5 ppm, gold : less than 1 ppm).

It should be mentioned that the above results do not reflect a complete survey of the trace elements of emeralds. These results show only the ranges and contents of the elements examined in the samples.

DISCUSSION

Comparison of the Natural Emeralds

The chemical analyses present additional criteria that could be used to distinguish between natural emeralds according to locality. On the average, Colombian emeralds have distinctly less iron than the emeralds from all other occurrences. Further characteristic features are the smaller sodium and higher chromium and vanadium contents.

The alkali contents of the African emeralds show some characteristic differences, namely: higher caesium and smaller rubidium contents. In some cases even nickel has been found in abnormally high amounts.

Brazilian emeralds on the other hand have similar caesium but higher chromium and magnesium contents.

Similarly Pakistan emeralds have characteristically high scandium amounts. Besides this, they have higher vanadium and smaller rubidium contents.

The Austrian and the Russian samples show higher magnesium contents. Moreover, the Russian samples are remarkable also for their higher vanadium contents.

Comparison of Synthetic Emeralds

Gilson synthetic emeralds showed characteristic rhodium (16 to 60 ppm). Those from earlier generations contain small chromium amounts (of the order of 0.2%).

Lechleitner synthetic emeralds had significant zinc (0.05%) and rubidium contents (~ 10 ppm). In addition they showed higher contents of iron and caesium.

The Japanese synthetic emerald contained characteristic nickel and titanium contents.

Chatham synthetic emeralds showed some similarities to those of Colombian emeralds, i.e., small iron contents were accompanied by higher chromium contents.

Chemical characteristics that could be used in the detection of different generations of the production of synthetic emeralds could not be found.

Only a sample produced by Lechleitner permits the supposition that natural seed-plates were used in this case of synthesis. The unusual caesium and rubidium contents in this synthetic emerald may therefore have come from the seed.

General Comparison of Synthetic and Natural Emeralds

For the definite identification of emeralds by chemical investigations the natural or synthetic nature of emeralds can be characterized by the presence or absence of a particular element. Bearing in mind that the synthetic emeralds in future could contain certain elements found in the natural stones, additional elements in the synthetic emeralds should be investigated. In this respect the elements molybdenum, rhodium, zinc, platinum and tungsten could be of great use in proving the synthetic origin of a sample.

This can also be indicated by the presence or absence of iron, scandium, sodium, potassium, rubidium and caesium. Up till now very high iron, sodium and potassium contents have been considered as general indicators for a natural origin.

Lanthanum was found only in the natural emeralds.

According to the present investigation the amount of manganese (more than 10 ppm) also indicates a natural origin, whereas synthetic emeralds generally contain less than 1 ppm manganese.

The Colour of Emeralds

As the colour of a gemstone influences its commercial value, it is appropriate at this point of the discussion to consider the causes of coloration in emeralds.

The colour of the emeralds is not caused by chromium alone and it is known for example that vanadium causes similar or even equal tints of green in beryls.

Many critical investigations have shown that manganese, nickel, and iron also cause a green coloration in beryls (Emel'yanova *et al.* 1965, Jayaraman 1940). Since these elements have been found in all natural stones, one should not neglect their influence, and chromium, vanadium, iron, manganese and partly nickel occur in widely varying amounts in stones of comparable shades of green. We know some emeralds of good colour contain only small amounts of chromium and important amounts of other colouring elements, and this has a bearing on the definition of 'emerald'.

A proposal of A. M. Taylor (1977) should be mentioned in this context. He distinguishes all green beryls* as Type I, and Type

*Taylor (1977) at the same time also suggested that emerald be defined as a "'grass-green" or "bright-green" variety of beryl', so a green beryl even if containing sufficient chromium to be detectable by hand-spectroscope would not be classified as emerald if not of a 'colour acceptable for emerald'.—Ed.

II emeralds. All green-coloured beryls, which contain enough chromium to be detected by a handspectroscopic method belong to Type I. Emeralds of Type II are those, which have too little chromium to be detected by the handspectroscope. To this type belong all samples, which are coloured green by elements other than chromium or combinations of elements like iron, vanadium, manganese, and nickel. Even specimens with more vanadium than chromium could be easily classified without undue problems, if the chromium content exceeds the limits as described above. This classification is of unique importance since the examination of a stone does not involve its destruction, and the use of dubious terms such as 'chromefree emerald' would no longer be necessary.

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GEMSTONES OF CANADA

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ABSTRACT

Large and relatively unexplored, Canada has yet to produce significant quantities of facetable gemstones. Nephrite jade from British Columbia is the only gemstone produced in large amounts today. Ornamental minerals such as amethyst crystals, labradorite, sodalite, rose quartz, rhodonite, peristerite and amazonite are exploited on a limited scale. Ammolite, an interesting new fossil gem material, has recently appeared on the market. The hessonite variety of grossular and green apatite have had limited commercial success.

Other gemstones discussed are uncommon and/or occur at localities difficult to reach. They are as follows: diamond, corundum, beryl, quartz, grossular and almandine garnets, cordierite, vesuvianite, amber, oligoclase and lapis lazuli.

INTRODUCTION

Canadian gemstones have not received wide recognition in gemmological literature. Aside from the brief descriptions by Field (1948 to 1951) and popular articles by Steacy (1974) and Sabina (1980), little has been published beyond minor references in geological or mineralogical treatises. This paper endeavours to bring up to date descriptions of the more interesting and economic finds. The information has been gleaned from published literature, from specimens in the collections of the National Museum of Natural Sciences in Ottawa and the Royal Ontario Museum in Toronto, and from private collectors. This is not an exhaustive study as it does not include those gemstones we felt to be of minor significance.

DIAMOND

Recently, Brummer (1978) summarized the occurrences of kimberlite pipes and the four known occurrences of diamonds in Canada (Figure 1). Kimberlite is the rock type that is the principal source of most economic concentrations of diamonds throughout the world. Two of the Canadian diamonds were found in

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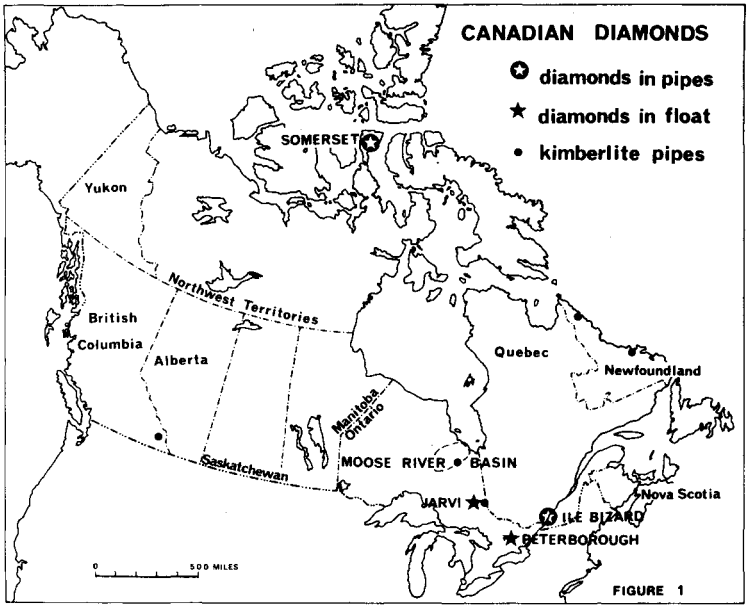

FIGURE 1

transported glacial till in Ontario: the poorly-documented 'Peterborough' diamond (33 ct) discovered before 1920, and the 'Jarvi' diamond (0.255 ct) found in 1971 near Timmins. In 1967, ten small diamonds, weighing only 0.0605 carat, were recovered from a diatreme kimberlite breccia on Ile-Bizard just outside of the city of Montréal, Québec. In the mid 1970s, bulk sampling of several kimberlite pipes on Somerset Island, Northwest Territories, revealed five or six small diamonds (J. Brunet, pers. comm.) but no details are available.

In the north-eastern United States, approximately 82 diamonds of various sizes have been recovered from glacial deposits within the Great Lakes region. These diamonds are believed to have been transported by glaciers from the James Bay Lowlands of Ontario (Gunn, 1968; Satterly, 1971). Since 1960, extensive surveys by government and private exploration companies have resulted in the discovery of numerous kimberlite-indicator minerals in the rivers throughout the area to the south and south-west of James Bay (Brown *et al.*, 1967; Ferguson *et al.*, 1978; Wolfe *et al.*, 1975). These surveys, analysed and interpreted

in conjunction with the distribution of glacial drift from the latest Wisconsinian glaciation, narrowed the potential source area to the vicinity of the Moose River Basin. Subsequent exploration in the late 1970s and early 1980s has resulted in the discovery of numerous kimberlite breccias (Selco, 1981), which have yet to be bulk sampled. No *in situ* occurrences of diamonds have been reported from this area and full analytical data on these breccias are not yet available.

Grieve (1981) described numerous diatreme breccias in south-eastern British Columbia, but only one of the three examined in detail contained indicator minerals characteristic of kimberlites. No diamonds have yet been reported from this area, although several private companies are now engaged in the active exploration and definition of other diatreme breccias and kimberlites in this mountainous area of British Columbia.

In summary, there are no known concentrations of diamonds in Canada, although recent intensive kimberlite exploration suggests some potential for commercial diamond concentrations.

CORUNDUM (SAPPHIRE AND RUBY)

The mineral corundum has been known in Canada for close to 100 years and there has been much speculation about the existence of the gem varieties ruby and sapphire. To date, no commercial concentrations have been found. In Hastings Co., Ontario, there are many corundum occurrences, usually of opaque dark-brown crystals. These supplied large quantities of commercial abrasive powder in the years 1902-1917. The Gutz Farm in Brudenell Township, Renfrew Co., Ontario, produces similar bronze-brown crystals, some of which have been cut to show a star (National Museum of Natural Sciences (NMNS) specimen to 5.2 ct). The only known occurrence of sapphire of gem quality is about 16 kilometres north-east of Bancroft, Ontario (Figure 2). This locality near the York River in Hastings County has been known for many years (Ellsworth, 1924; Traill, 1970). The sapphire, found in gneiss, is usually badly fractured but the colour is a 'very fine deep cobalt blue' (Field, 1951a, p.76). Faceted gems (6.02, 2.77, 1.00 ct) are in the collection of the National Museum of Natural Sciences. Fine cabochon gems are also known, some of which show weak asterism (Waite, 1945). The crystals are externally a pale greyish colour; only the cores are blue. Specimens were exhibited in the Pan-

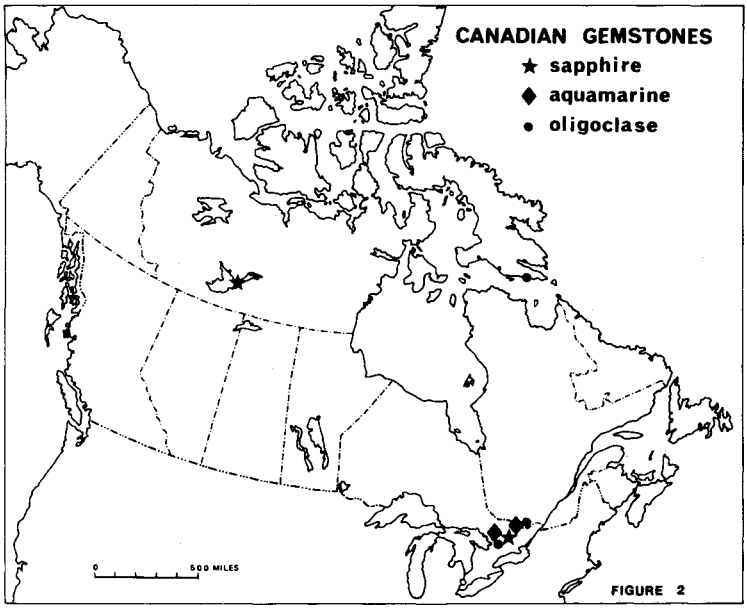

FIGURE 2

American exhibition in Buffalo, New York in 1901 (Field, 1951a). The Lillie Robertson corundum showing, also near Bancroft in Hastings Co., has produced black star-sapphire gems (NMNS 14.40, 5.45, 6.79 ct). These are probably more common than the blue star-stones.

Rounded crystals of blue corundum have been reported from Methuen Township, near Peterborough, Ontario (Field, 1951a). Lord (1951) reported small crystals of sapphire (up to 1.5 cm across) in pegmatitic quartz bodies at the Philmore Mine on a small island in Great Slave Lake, Northwest Territories.

In the north-western United States, particularly in Montana, concentrations of sapphire occur in river gravels that are similar to the gem gravels of the Orient. This area is in the foothills of the Rocky Mountain Range. There are two interesting reports from British Columbia, also in the Rocky Mountains and immediately north of the United States-Canada border. A transparent, rolled fragment (7 mm diameter) of green corundum was found in gold washings from the Pend-d'Oreille River, Kootenay District (Field, 1951a; Hoffman, 1898). Similarly, grains of ruby came from

gravels of some creeks flowing into the Tulameen River (Johnston, 1915; Sinkankas, 1959). These occurrences indicate that the Canadian Cordillera may have some potential for concentrations of alluvial sapphire and ruby.

BERYL

Beryl in gem-quality crystals is often found in rare-earth, beryllium or lithium pegmatites, which are quite common throughout Canada (Mulligan, 1960; Traill, 1970). Unfortunately little gem-quality beryl has been found, although Field (1948b) and Waite (1945) reported facetable aquamarine from two localities in Ontario (Figure 2)—near Kearney in the Nipissing District, and near Quadeville, Lyndoch Township, Renfrew County. The National Museum's collection has five gems (the largest is 3.1 ct) from Quadeville. There are no other documented occurrences of gem-quality aquamarine in Canada.

With the exception of 'translucent and emerald green' beryl reported from two kilometres north of Quadeville, Ontario (Sabina, 1964b, p.90), there has been no specimen or gem-quality emerald documented in Canada.

QUARTZ FAMILY

Quartz is an extremely common mineral in Canada (Figure 3) as in the rest of the world. No mention will be made of the numerous localities for chalcedony (agate, jasper, cornelian), and silicified petrified wood and dinosaur bone, commonly seen as decorative objects or as cabochons.

Amethyst

Although amethyst quartz has been reported from numerous locations throughout Canada (Sabina, 1964a,b,c; Traill, 1970), there are only two areas in Canada that have produced material of gem quality. The Thunder Bay District of Ontario along the north-west shore of Lake Superior is Canada's most productive amethyst area. The amethyst is associated with major fault structures trending in a south-west to north-east direction in Precambrian granite. There are many outcrops of amethyst veins in this area, and substantial quantities of ornamental and decorative specimens are produced for export. Many crystals contain conspicuous red haematite inclusions and gem-quality amethyst is rare. Robinson

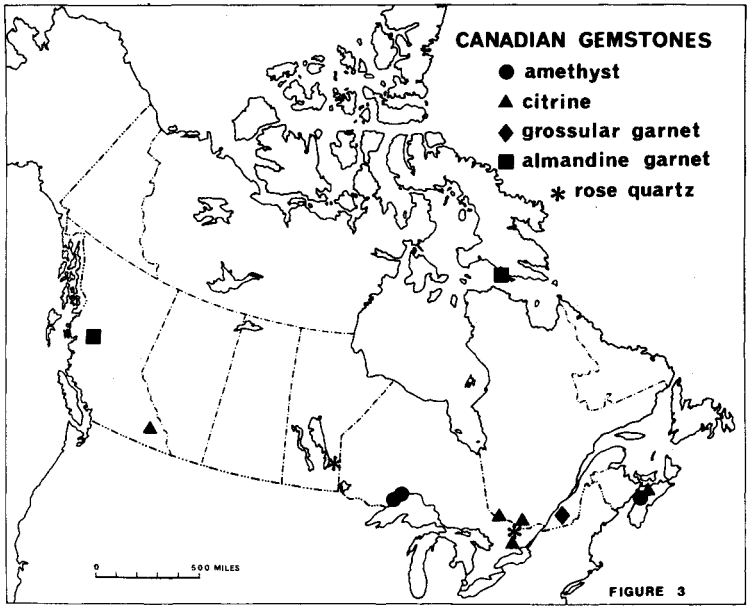

FIGURE 3

(1969, p.265) reported that 'nearly every large crystal from the Dzuba Mine has a dark, solid core of cutting grade amethyst'. Unfortunately, this is not the case at other deposits. Gems from McTavish Township (4.70, 4.40 ct) and Nagunagisic Lake near Nipigon (14.25, 10.9 ct) are in the collection of the National Museum of Natural Sciences, Ottawa.

In Nova Scotia, on the beaches between Cape Blomidon and Cape Split in the Minas Basin, fine amethyst specimens have been found. As long ago as 1605, ten amethyst crystals from Nova Scotia were sent to King Henry IV of France by the Acadians. The gems fashioned from these crystals were part of the French regalia for centuries (Field, 1948a). Unfortunately, such fine material is not available today. The National Museum's collection contains two gems (0.74 ct dark purple; 2.79 ct pale lavender) from this area. Gem-quality crystals of deep-purple amethyst on massive magnetite have been reported by Traill (1970) near Berwick, Nova Scotia. The amethyst at both these localities is derived from amygdaloidal basalts.

Citrine

Some citrine quartz was found recently near Lac Sairs in Villedieu Township, Témiscamingue Co., Québec (Shearer, pers. comm.). There are two very fine gems (69.3, 36.3 ct) from this locality in the National Museum's collection.

Rock Crystal

Fine rock crystal specimens of faceting quality have been found in a quartz pegmatite near Black Rapids in Leeds County, Ontario. They were originally mined for their piezoelectric properties before synthetic quartz production made deposits such as these obsolete. Several other areas in Canada produce quartz crystals which could be faceted: Five Islands in the Minas Basin, Colchester Co., Nova Scotia; Lawrenceville, Shefford Co., Québec; Saint-Rémi-d'Amherst, Papineau Co., Québec (Parsons, 1938) and the Bluebell Mine, Riondel, Kootenay District, British Columbia. The collection of the Royal Ontario Museum contains a 13.4 ct gem from Saint-Rémi-d'Amherst.

Rose Quartz

Massive rose quartz occurs in pegmatites in Ontario and Manitoba. The Ontario locality is near Quadeville in Lyndoch Township, Renfrew County. The National Museum's collection has faceted gems of 23.8, 12.5, 5.9 and 4.6 ct. Some specimens show asterism. The Manitoba deposit, also in a large pegmatite dyke, is near Birse Lake. Cabochons and a carving of this material are in the collection of the Royal Ontario Museum.

Smoky Quartz

Smoky quartz crystals were once found in fields in Annapolis County, Nova Scotia (Field, 1951d), but there are no recent reports.

GROSSULAR GARNET

The Jeffrey Mine at Asbestos, Richmond Co., Québec (Figure 3) is the only major producer of gem-quality grossular garnet in Canada. The locality has been known since 1950 as a source of fine mineral specimens, but faceted gems are less well known. The Jeffrey Mine has been worked for asbestos since 1881.

Grossular garnet, associated with diopside, K-feldspar and quartz, is most commonly found on granitic rocks that intrude the Jeffrey Mine ore body. The grossular varies from colourless through shades of white, pink, orange and green (Grice & Williams, 1979; Wight & Grice, 1981, 1982). The orange-coloured hessonite variety is the most abundant; gems in the 1-5 carat range and small crystal groups mounted in jewellery have been commercially marketed in Canada with some success. The collection of the National Museum of Natural Sciences contains gems of 24 and 14 carats that are particularly noteworthy. The green grossular crystals are less abundant and very small. The one faceted gem in the National Museum's collection weighs only 0.25 ct. Recently, faceted colourless grossular (NMNS 4.64 and 2.94 ct) was described (Wight & Grice, 1981), but it is rare.

ALMANDINE GARNET

Almandine of faceting quality has been reported by Field (1951d) from the Skeena River, Coast District, and the Stikine River, Cassiar District in British Columbia (Figure 3). Transparent cabochons (7.45 and 4.90 ct) of good colour from Stikine River are in the National Museum's collection.

Beautiful red almandine gems have been cut from material brought from 'Garnet Island, Baffinland' in the Northwest Territories *circa* 1915 (Field, 1949, 1951d; Traill, 1970; Walker, 1915, p.64). The National Museum has a 6.3 ct triangular brilliant and there are other gems in the Royal Ontario Museum.

AMMOLITE

Ammolite is the most recent gemstone to become commercially available in Canada. Ammolite has been known under the trade names 'Calcentine' or 'Korite', but the term 'Ammolite' has recently been approved by the Coloured Stone Commission of the C.I.B.J.O. Ammolite is derived from the shell of an extinct ammonite, a mollusc (class Cephalopoda, subclass Ammonoidea), distantly related to the extant *Nautilus,* which is uncommon from the tropical Indo-Pacific Ocean (Wight, 1981). The ammonites that provide the gem material are found in Cretaceous marine deposits exposed along river banks near Lethbridge, Alberta (Figure 4). It is the nacreous layer of the

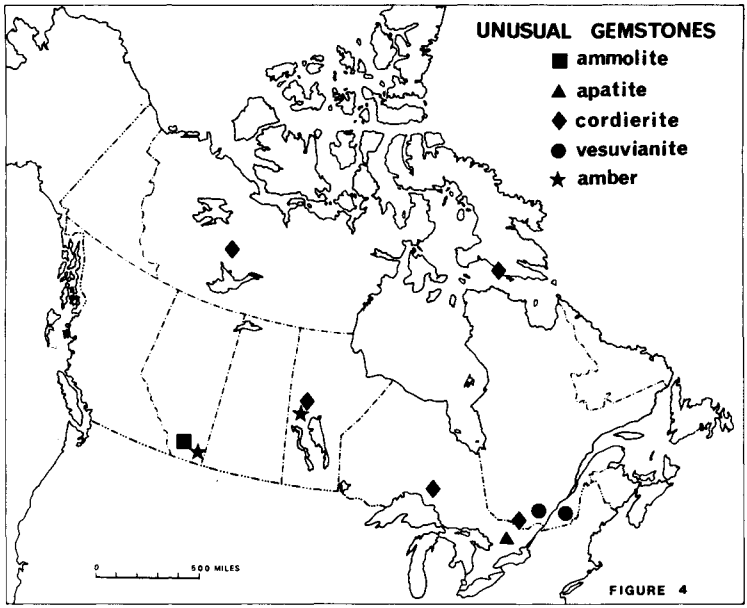

FIGURE 4

ammonite shell that shows the brilliant iridescence, predominately red and green, seen in gem ammolite. Much of the shell material has been cracked and rehealed during the process of fossilization, giving a stained-glass window effect of small patches of brilliant colour framed by darker, non-iridescent lines. The hardness is only four and thus ammolite is often prepared as triplets with a natural shale backing and quartz or synthetic spinel cabochon top.

APATITE

There are several localities (Figure 4) for gem-quality apatite in Canada, near Wilberforce, Haliburton Co., Ontario (Field, 1951c). The Liscombe mine had not been worked since the 1930s, although collectors frequently visited the site to collect apatite crystals and specimens of other minerals. In the mid 1970s, a company called Trilliumite Explorations claimed the old workings and successfully produced some fine specimens, marketing the faceted apatite under the trade name of 'Trilliumite' (Shearer, 1975). One piece of rough (approximately 177 ct) produced an 87 ct gem of a pleasant blue-green colour. Other specimens from this locality include fine green

gems (65.5 and 24.6 ct) in the collection of the National Museum in Ottawa. The Cardiff Uranium Mine has calcite—fluorite—apatite veins cutting uranium-rich pegmatites south-south-east of Wilberforce (Sabina, 1964b) and some of this dark-green apatite is said to be gemmy. The National Museum's collection has one fine green gem (3 ct) from a small deposit near Tory Hill, Monmouth Township.

CORDIERITE (IOLITE)

Blue cordierite of gem quality has long been known from several localities in the Northwest Territories: Ghost Lake, north-west of Yellowknife (Lord, 1951) (NMNS 1.5 ct); near Great Slave Lake (NMNS 3.9 ct); and a somewhat-uncertain locality on 'Garnet Island, Baffinland' (Field, 1949, 1951e; Walker, 1915, p.65). Several cabochons from Garnet Island are in the Royal Ontario Museum's collection.

Cordierite of faceting grade has been collected from the Geco Mine, Manitouwadge, Ontario. Fine blue gems (up to 2.2 ct) are in the collection of the National Museum. Similar material occurs at the Stall Lake Mine, near Snow Lake, Manitoba. Near Otter Lake, Pontiac Co., Québec, clean cordierite of 'a cornflower blue to a deep blue' has been collected (Sabina, 1964b, p.153).

VESUVIANITE (IDOCRASE)

Green vesuvianite gems have recently been reported (Wight & Grice, 1981) from the Jeffrey Mine at Asbestos (Figure 4), Richmond Co., Québec. The gems are less than a carat in weight and of a medium dark, slightly yellow-green colour. Larger, golden-brown vesuvianite gems were once obtained from Laurel, Argenteuil Co., Québec (Figure 4), and marketed as 'Laurelite' (Field, 1948b; Sinkankas, 1959). Most gem material from the now-flooded pits of this occurrence has been removed. Several fine golden-brown gems (3.15, 2.95, 2.28, 2.08 ct) are in the National Museum's collection.

AMBER

Amber called 'chemawinite' was first discovered in Canada from the beach of Cedar Lake, Manitoba (Figure 4) by W. C. King, who was in charge of the Hudson's Bay Company trading-post at Chemahawin (Walker, 1934). This is a golden-brown amber of the

retinite group, i.e. it does not contain succinic acid as does Baltic amber. The amber is believed to be a secondary deposit, having been washed out of Upper Cretaceous lignitic deposits upstream on the Saskatchewan River, which flows into Cedar Lake (McAlpine & Martin, 1969). The grains of amber are quite small, usually less than 3 cm, and frequently contain insects and other fossils. There were attempts to mine chemawinite commercially; about one tonne was obtained between 1895 and 1937. Construction of a dam has since raised the water level of Cedar Lake, flooding the amber locality.

McAlpine & Martin (1969) have studied amber collected from about 50 Canadian localities, usually associated with low-grade coal and lignite deposits. The collection of the National Museum of Natural Sciences contains polished gem amber from Cedar Lake, Manitoba; Medicine Hat, Alberta, and Coalmont, British Columbia.

NEPHRITE JADE

Nephrite jade from British Columbia (Figure 5) is the best known of all Canadian gemstones, and the only one of commercial significance. According to Leaming's (1980) excellent summary of British Columbia and Yukon Territory jade occurrences, total production in 1975 was 641 tonnes with a value of $1 702 764. There are strong demands for nephrite by consumers in Taiwan, Hong Kong, the Peoples' Republic of China, West Germany, the United States and elsewhere. The estimated world demand is 1180 tonnes per annum, and Canada supplies a large portion of this because of inconsistent or inadequate supplies from other countries such as the United States, Australia, and U.S.S.R.

Most *in situ* deposits of nephrite are associated with metasomatically-altered serpentinite in fault contact with a variety of host rocks. The nephrite deposits are generally small, (110-200 tonnes) ellipsoidal or tabular bodies. The largest mass observed by Leaming was about 10 m × 30 m × 30 m. Alluvial boulders are most commonly found first and traced to source. More nephrite deposits are likely to be found in known ultramafic bodies in areas of mid-Paleozoic to Triassic rocks of the Canadian Cordillera.

There are six areas of nephrite production in the Canadian cordillera, in four principal sections—Southern, Central and Northern British Columbia, and Yukon Territory (Leaming, 1980).

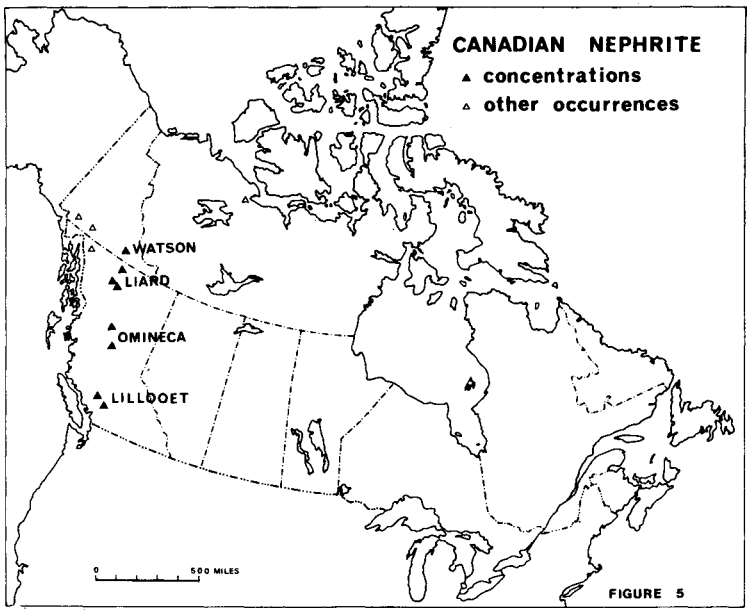

FIGURE 5

The earliest known alluvial and *in situ* concentrations of nephrite are along the Fraser and Yalakom rivers near Lillooet in southern British Columbia. Numerous alluvial nephrite boulders from this area were used by the Indians for many hundreds of years to make tools, items for trade, and decorative artefacts, which were highly prized by the tribes of the Mainland Coast and Vancouver Island (Holland, 1961). Among the Tlingits of northern B.C., a small adze blade was worth two or three slaves (Schmidt, 1975). In Central British Columbia, the Omineca Mining Division has two main areas of production. The first is Mount Ogden, where both *in situ* deposits and alluvial material are known. Over 2000 tonnes of commercial-grade nephrite have been produced from this lode to date. The large 21-tonne boulder that was on display in the British Columbia Pavilion at Expo '70 in Osaka, Japan, was from this area (Sinkankas, 1976). In the second more southerly area of the Omineca Division, subsurface lode concentrations of nephrite are known from Mount Sidney Williams at the head of O'Ne-ell Creek. Sinkankas (1976) reported that this relatively accessible area has estimated reserves of 4000 tonnes of well-exposed nephrite, but

much material is of low quality (Leaming, 1980). The Liard Mining Division in Northern British Columbia has the largest concentrations of alluvial boulders and lode deposits in Canada. There are two principal areas within this Division: Cry Lake and Cassiar. The Cry Lake area, 80 km east of Dease Lake, has the potential to produce considerable quantities of nephrite but is severely limited by accessibility. The Cassiar area has been less productive. The Cassiar Asbestos mine used to dump nephrite as a by-product of its mining activities, but the value of the nephrite has now been realized. Cassiar nephrite is somewhat atypical of B.C. jade, since it contains bright flecks of a green chrome garnet. Small *in situ* deposits of nephrite are known near Frances Lake, north of Watson Lake in Yukon Territory. About 16 tonnes were brought out in 1969 (Sinkankas, 1976).

Reports of non-productive nephrite discoveries include boulders from the Rae River, District of Mackenzie, Northwest Territories, first reported in 1851 (Lord, 1951); from the Atlin Lake area in north-western British Columbia (Leaming, 1973); from gravels of the Lewes River near Miles Canyon south of Whitehorse, Yukon Territory (Sabina, 1964a); and from Klukshu Lake in the extreme south-west Yukon Territory (ibid.). These localities are shown on Figure 5.

FELDSPAR GROUP

Feldspar minerals are extremely common in Canada. There are two broad classes of the Feldspar Group—the alkali and the plagioclase feldspars. The alkaline feldspar most commonly seen as a gemstone in Canada is amazonite, a variety of microcline. The plagioclase feldspars include albite, oligoclase and labradorite. Commonly the two feldspar classes crystallize together in solid exsolution, producing a laminated intergrowth. The name perthite was applied to this type of feldspar when it was first observed associated with other minerals in pegmatite dykes near the town of Perth, Ontario. Peristerite is a micro-perthitic intergrowth of plagioclase feldspars which exhibits a schiller effect (Deer *et al.*, 1963).

Labradorite

Labradorite is the plagioclase feldspar that is commonly associated with Canada and derives its name from Labrador

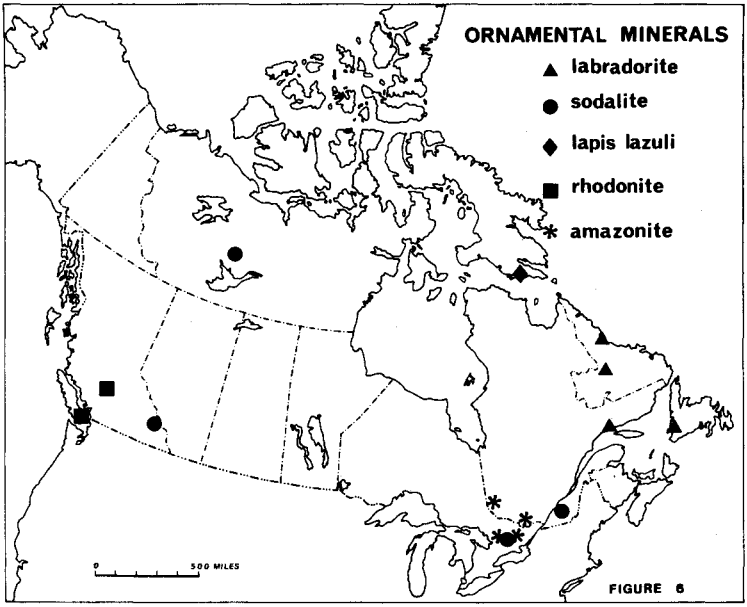

FIGURE 6

(Figure 6), a district of the province of Newfoundland on the east coast of Canada. Labradorite feldspar was first reported from the coast of Labrador by a Moravian missionary in 1770. A quarry on Tabor Island about 17 kilometres south-south-west of Nain has been producing sporadically since 1935, when it was opened by the International Grenfell Association. Since then several organizations have operated this quarry, including British Newfoundland Exploration Limited (Brinex), from 1961 to 1964, and subsequently the Nain Crafts Council. Recently, Watson (1980) completed a detailed evaluation of the labradorite gemstone potential in the area of Nain. He found numerous occurrences of labradorite crystals up to 50 cm in diameter showing characteristic blue, green, yellow, bronze, purple and red schiller (or labradorescence) throughout this coastal area. He concluded 'that there is an abundance of labradorite in the Nain area suitable for gem purposes' (Watson, 1980, p.245).

Other occurrences of labradorite showing the characteristic labradorescence have been reported from various locations throughout Labrador and Québec (Sinkankas, 1976). They are all associated with the large bodies (5 to 50 km in diameter) of

Proterozoic anorthosite that intrude rocks of the Grenville and Churchill Structural provinces of the Precambrian Canadian Shield.

Oligoclase

Beautiful specimens of the peristerite variety of oligoclase, usually with a blue schiller on a white or pink background, occur in many places in Ontario (Figure 2): Dungannon and Monteagle Townships, Hastings Co.; Bathurst Township, Lanark Co; Murchison Township, Nipissing District (Field, 1951b; Sinkankas, 1959, 1976) and McConkey Township, Parry Sound District (Traill, 1970). A yellow translucent peristerite has been found near Sundridge, Parry Sound District (Sinkankas, 1959). Peristerite is also abundant in Québec: Villeneuve and Buckingham Townships, Papineau Co.; Callières Township, Charlevoix-Est Co.; and Wakefield Township, Gatineau Co. (Sinkankas, 1959, 1976; Traill, 1970).

The sunstone variety occurs in Ontario at the Gole Quarry, Murchison Township, Nipissing District and at McCue Lake, Monmouth Township, Haliburton Co. (Sinkankas, 1976).

Colourless to pale blue, transparent oligoclase has been found recently near Lake Harbour, Baffin Island, Northwest Territories (Figure 2) by D. D. Hogarth of the University of Ottawa. Faceted gems weighing 6.7 ct (colourless) and 6.8 ct (blue) are in the National Museum's collection, along with a cabochon cut from opaque white oligoclase which shows narrow bands of silvery-white schiller.

Microcline variety Amazonite (Figure 6)

Canada's best amazonite is found in Québec near Kipawa at the north end of Lac Sairs, Témiscamingue Co., (Sabina, 1964b). The National Museum of Natural Sciences has many fine specimens. Amazonite has also been found at the Leduc mine, Wakefield Township, Gatineau Co. (ibid.) in association with gem tourmaline and other fine mineral specimens.

In Ontario, amazonite has been reported from the McCormack, MacDonald and Woodcox mines near Bancroft, Hastings Co.; near Eganville, Renfrew Co.; and north of Quadeville, Lyndoch Township, Renfrew Co. (ibid.). Field (1951b) also reported amazonite from Lyndoch and Sebastopol Townships,

Renfrew Co., and Monteagle Township, Hastings Co. Sinkankas (1959) listed an occurrence in Cameron Township, in the Nipissing District of Ontario.

SODALITE

There are two main occurrences of sodalite known in Canada (Figure 6). The only commercial and easily accessible source is the Princess Quarry east of Bancroft, Hastings Co., Ontario, where medium to fine-quality sodalite occurs within nepheline syenite host rocks (Field, 1951c; Sabina, 1964a; Sinkankas, 1976). The National Museum's collection has many fine blue cabochons and a translucent faceted gem (1.9 ct) from this locality. Steacy (1974) reported that 117 tonnes of this sodalite were shipped overseas as early as 1906. Fine sodalite also occurs in the Ice River Alkaline Complex in nepheline and sodalite syenites near Field, Kootenay District, British Columbia (Allan, 1914). Most of the Ice River Complex is now within the boundaries of Yoho National Park and collecting is forbidden. Specimens at the National Museum of Natural Sciences were collected by early Geological Survey field parties or with special permission by Museum staff. The terrain is mountainous and very difficult.

An ornamental rock known as 'beloeilite', found on the north-east slope of Mont St-Hilaire, Québec, is composed of up to 80% sodalite and minor amounts of albite and nepheline (Sabina, 1964b). Sodalite has also been reported from many localities in central Ontario (Sinkankas, 1959), as well as at Bigspruce Lake on Snare River, Northwest Territories (Lord, 1951).

LAPIS LAZULI

There is only one known occurrence of lapis lazuli in Canada—on southern Baffin Island just north of the Innuit community of Lake Harbour, Northwest Territories (Figure 6). The deposit was described by Hogarth (1971), who recorded two deposits within a few kilometres of each other on the north-west side of Soper River. The first published report of this locality was recorded on a map by Davison (1959), although local Innuit had known of the locality for several decades.

The lapis lazuli occurs in Aphebian ($\geqslant$1740 m.y.) metasedimentary rocks and peridotites of the Churchill Structural Province of the Canadian Shield, and is associated with marbles

folded within biotite gneisses. There is some finely-coloured material, but in general the quality of the lapis lazuli is considered to be substandard in comparison to lapis lazuli from Afghanistan or Chile. The rock is very often badly fractured because of severe freeze and thaw actions.

RHODONITE

Rhodonite is a beautiful pink ornamental mineral that often has interesting black veining. It is a favourite lapidary material in British Columbia, where it occurs at several localities (Figure 6). Probably the best known area is Hill 60 on the north side of Cowichan Lake on Vancouver Island. The main deposit was once worked as a source of manganese ore and was still posted against trespass in 1966 (Leaming, 1966). The Holling's Claim on Saltspring Island, also in cherty rocks of the Sicker Group, was operated commercially on a small scale in the 1960s (Danner, 1978). The Williams Lake area, mentioned as a rhodonite prospect by Leaming (1966), has since produced cabochons of fine pink colour, some with brown and black veining, which are in the National Museum's collection.

CONCLUSION

Large and relatively unexplored, Canada has yet to produce facetable gemstones in large quantities. Widespread glaciation removed surficial deposits that may have contained gem concentrations. Difficult terrain and harsh climatic conditions prevailing during much of the year in northern Canada cause many problems. Despite these problems, Canada has produced small numbers of gemstones of almost every species, and commercial quantities of some ornamental minerals.

Recent finds of new and unusual gem materials such as ammolite have stimulated more intensive searches for Canadian gemstone localities. As the North becomes easier to reach, and the population increases, it is possible that finds of economic importance will be made.

ACKNOWLEDGEMENTS

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[*Manuscript received 17th December, 1981.*]

GEMMOLOGICAL ABSTRACTS

BALITSKY (V. S.), LISITSINA (E. E.). *Synthetic materials used for jewellery and carving and their place among gems.* In: Gem Minerals; Proceedings of the XI General Meeting of IMA, Novosibirsk, ed. Bukanov (V. V.) *et al.,* (see Book Review on p. 575 below), 28-36, 1980. (In Russian, with English abstract.)

There are two groups of synthetic materials used for jewellery and carving; (1) the synthetic analogues of natural stones, e.g. synthetic ruby, sapphire, spinel, opal, turquoise, etc., and (2) new materials having no natural analogue, e.g. fabulite, YAG, cubic zirconia. The main methods of production of synthetic gems and the treatment of natural gems are outlined. R.A.H.

BANK (H.). (a) *Brauner und gelbbrauner Danburit aus Madagaskar.* (Brown and yellow-brown danburite from Madagascar.) Z.Dt.Gemmol.Ges., **31**, 1/2, 85-6, 1982; (b) *Turmaline diverser Grün- und Rottöne aus Sambia.* (Tourmalines with varying green and red tinges from Zambia.) Id., 91-2, 1982; (c) *Über Grossular und Hydrogrossular.* (About grossularite and hydrogrossularite.) Id., 93-6, 1982.

(a) An old deposit of danburites (described by Lacroix in 1922) yielded some beautiful big crystals producing clean yellow and brown cut stones up to 50 ct. Optical data given. (b) Recently tourmalines of various colours were found in Zambia besides deposits of amethysts and emeralds, along the border with Moçambique. Two types of stones were found: (i) yellow-green stones similar to those of Brazil with very strong pleochroism up to nearly black, nearly clean, yielding cut stones of up to 50 ct. Some green tourmalines with a blue hue can be improved by heat treatment. (ii) Red, brown and violet tourmalines, not quite as clean, but showing good red colour when heated; various sizes, up to 25 ct. Strong pleochroism, but not as strong as the green stones. (c) Green and red translucent 'Transvaal jade' is a mixture of grossularite and hydrogrossularite and vesuvianite. The green variety consists of grossularite and vesuvianite causing anomalous double refraction and low RI = 1.720. The red variety is a mixture of grossularite and hydrogrossularite, the RI depending on proportion lies between 1.700 and 1.712; SG 3.32 and 3.36. E.S.

BANK (H.). *Aus der Untersuchungspraxis.* (Research in practice.) Z.Dt.Gemmol.Ges., **31**, 1/2, 97-9, bibl., 1982.

Notes on findings in the laboratory. An isotropic stone with RI 1.554 in a parcel of citrines was found to be paste, as was a cut stone with RI 1.495 offered as opal: no H_2O bands could be seen with infrared spectroscope. X-ray fluorescence can blacken stones: this was observed in synthetic emeralds and synthetic alexandrites, which became lighter again after a short while. Topaz, citrine and apatite were found in a parcel of yellow-brown danburites. E.S.

BANK (H.). (a) *Geschliffene zonar gebaute Smaragde aus dem Gebiet der Tokowaja, Ural, UdSSR.* (Cut, zonal oriented emeralds from the district of Tokowaja, Urals, U.S.S.R.) Z.Dt.Gemmol.Ges., **31**, 3, 193-4, 1 fig., 1982; (b) *Petalit-Analcim-Katzenaugen aus Simbabwe.* (Petalite-analcime cat's-eyes from Zimbabwe.) Id., 197-8, 1982; (c) *Blassblauer, fast farbloser Cordierit aus Sri Lanka.* (Pale blue, nearly colourless cordierite from Sri Lanka.) Id., 199-200, 1982; (d) *Violetter Skapolith aus Ostafrika.* (Violet scapolite from East Africa.) Id., 201-2, 1982; (e) *Brauner schleifwürdiger Herderit aus Brasilien.* (Brown cuttable herderite from Brazil.) Id., 203-4, 1982; (f) *Geschliffener Pyrargyrit in einer Partie Hämatite.* (Cut pyrargyrite in a parcel of haematites.) Id., 205, 1982

(a) Like Columbian and Zambian stones, these emeralds show definite zonal growth. Inclusions show that these zonal growth characteristics are not interrupted as is the case in other emeralds. The stones can be mistaken for doublets. (b) As well as the colourless and light yellow transparent petalite from the Minas Gerais, Brazil, some translucent pinkish-brown material which consisted mainly of petalite and analcime was found near to Arassuahy. This material shows a good chatoyancy. (c) The pale blue, nearly colourless iolite from Sri Lanka has a low RI of 1.530-1.540 and a Fe content of only 1.14% FeO. (d) Optical data and densities as well as low meionite content of violet scapolites from East Africa published by Zwaan were confirmed. (e) New material from the Virgem da Lapa Mine in Minas Gerais in Brazil was found to be cuttable brown hydroxyl-herderite with the highest so far known RI for that material: $n_x = 1.610$, $n_y = 1.630$, $n_z = 1.642$. The fluorine content was found to be 0.20%F. (f) The pyrargyrite was found in a parcel of cut haematites from Brazil. It is much softer (3½ instead of 6½) and is a silver ore (Ag_3SbS_3). E.S.

BANK (H.), BANK (F. H.). *Schleifwürdige rote Berylle aus Utah, U.S.A., mit niedrigen Brechungsindizes.* (Cuttable red beryls from Utah, U.S.A., with low RIs.) Z.Dt.Gemmol.Ges., **31**, 1/2, 87-8, 1982.

Samples of red beryl with low RI were collected, the RI confirmed and trace elements determined. Specimens from unknown locality with even lower RI (similar to those of pink beryl) seem to be natural as they have same trace elements as those found in Utah, presumably have an even higher alkaline content and even lower RI readings. E.S.

BANK (H.), BECKER (G.). *Durchsichtiger rötlicher, rosa farbener und violetter Adamin aus Mapimi, Mexiko.* (Transparent, reddish, pink and violet adamite from Mapimi, Mexico.) Z.Dt.Gemmol.Ges., **31**, 3, 195-6, 1982.

The adamite crystals were found in the Ojuela mine in Mapimi in Mexico. They are transparent, colourless as well as pink and violet, crystallize in the orthorhombic system and are a zinc-arsenate. E.S.

BANK (H.), PETSCH (E.). *Über ein neues Vorkommen von Smaragd bei Sta. Terezinha, Goyaz, Brasilien.* (About a new occurrence of emeralds near Santa Terezinha, Goya, Brazil.) Z.Dt.Gemmol.Ges., **31**, 1/2, 89-90, bibl., 1982.

The occurrence can be reached from Rio via Belo Horizonte to Goiana, from there to Ceres and then Santa Terezinha. The township is situated on the Rio Acu, a tributary of the Rio Araguaya which flows towards the Amazon. All qualities seem to be present, from very fine to poor. SG 2.66, RI 1.594-1.586 with 0.008 DR. E.S.

BECK (C. M.). *Physical methods used to determine the geological origin of amber and other fossil resins; some critical remarks: comment.* Physics & Chemistry of Minerals, **8**, 3, 146-7, 1982.

The author defends his use of IR spectrometry for determining the geological origin of amber and other fossil resins against the criticisms of S. S. Savkevich (see abstract, J.Gemm., XVII, 7, 494). P.Br.

BOUŠKA (V.). *Moldavites as the precious stones.* In: Gem Minerals; Proceedings of the XI General Meeting of IMA, Novosibirsk, ed. Bukanov (V. V.) *et al.,* (see Book Review on p. 575 below), 122-7, 2 figs, 1980.

Moldavites dated at 14.8 m.y. occur in S. Bohemia and SW. Moravia. Their total original weight has been estimated at 3000 tons; the average weight of the moldavites as found is 8.03 g. They vary in colour from light green to brown (partial chemical analyses, microhardness, specific gravity and refractive index are tabulated for six colour ranges). In medieval times moldavites were mounted in pendants or in the tops of gentlemen's walking-sticks; later they were cut as gemstones, having some resemblance to peridot or diopside. Nowadays they are used as jewellery in their natural form. R.A.H.

BUKANOV (V. V.), LIPOVSKY (Yu. O.). *New finds of precious corundum in the Eastern Baltic shield.* In: Gem Minerals; Proceedings of the XI General Meeting of IMA, Novosibirsk, ed. Bukanov (V. V.) *et al.,* (see Book Review on p. 575 below), 110-16, 1 fig., 1980. (In Russian, with English abstract.)

Ruby occurs in highly aluminous rocks of the amphibolite facies in Karelia, where it is associated with rhodolite garnet. It is found as well-formed prismatic crystals up to 1-5 cm long and 0.5-3 cm in diameter, pink and violet in colour, sometimes translucent and suitable for cutting as cabochons. Sapphires occur in pegmatites of the Khibiny alkaline massif, where they are confined to the roof of the complex, in aluminous hornfelses. They have curved faces and form tabular or prismatic crystals up to 3-20 mm; the cornflower blue varieties are 2-15 mm across and confined to nepheline-bearing pegmatites. R.A.H.

BUKIN (G. V.), GODOVIKOV (A. A.), KLYAKHIN (V. A.), SOBOLEV (V. S.). *Synthetic emerald.* In: Gem Minerals; Proceedings of the XI General Meeting of IMA, Novosibirsk, ed. Bukanov (V. V.) *et al.,* (see Book Review on p. 575 below), 36-44, 6 figs, 4 photos, 1980. (In Russian, with English abstract.)

Synthetic emeralds have been produced in $PbO\text{-}V_2O_5$ fluxes at 1000-1200 °C. Emerald crystals containing Cr and V and weighing up to 10 g have been obtained by hydrothermal methods in acid solutions of complex composition. A description is given of the growth of beryl with the help of gas transport reactions. The relationship between ω RI and the Cr and Fe content and the differences between natural and synthetic emeralds are discussed. A correlation between ω and D is noted; the cell parameter a_0 increases regularly with increasing Cr, V and Fe while c remains constant. R.A.H.

BUKIN (G. V.), ELISEEV (A. V.), MATROSOV (V. N.), SOLNTSEV (V. P.), KHARCHENKO (E. I.), TSVETKOV (E. G.). *The growth and examination of optical properties of gem alexandrite.* In: Inhomogeneity of Minerals and Crystal Growth; Proceedings of the XI General Meeting of IMA, Novosibirsk, ed.

Sidorenko (A. V.) *et al.,* Academy of Sciences of the U.S.S.R., Leningrad, 317-28, 4 figs, 1 photo, 1980. (In Russian, with English abstract.)

Crystals of alexandrite 100 × 20 × 10 mm in size were grown by the Czochralski method on orientated seeds from melt stoichiometric to chrysoberyl with V_2O_3, Cr_2O_3 and Fe_2O_3 doping. The isomorphous admixture of Cr_{3+} ions colours the crystals cherry-red in the direction 001, blue-green on 010, and yellow-green on 100.

P.Br.

COLLINS (A. T.). *Farbzentren in Diamanten.* (Colour centres in diamonds.) Z.Dt.Gemmol.Ges., **31**, 3, 157-92, 19 graphs, 1982.

This is a translation from the article published in J.Gemm., 1982, **XVIII**, 1, 37-75. E.S.

DATTA GUPTA (S.). *A note on the inclusions in diamonds from Panna area, Madhya Pradesh and Jungel Valley, Uttar Pradesh.* Indian Minerals, **35**, 3, 35, 1981.

Microscopic studies on 117 diamonds were carried out; garnet, magnetite, olivine, calcite, ilmenite and chrome diopside were found as inclusions. In general diamonds from India are more free from inclusions than those from other areas.

M.O'D.

DÉLÉ (M. L.), DHAMELINCOURT (P.), SCHUBNEL (H. J.). *Application de la microsonde Raman-laser à l'identification d'inclusions dans différentes gemmes.* (Application of the Raman-laser probe to identify inclusions in various gemstones.) In: Gem Minerals; Proceedings of the XI General Meeting of IMA, Novosibirsk, ed. Bukanov (V. V.) *et al.,* (see Book Review on p. 575 below), 5-17, 12 figs, 1980.

The Raman-laser probe has been used to study micro-inclusions in gemstones. Some details are given of pargasite in sapphire, sphalerite and calcite in ruby, feldspar in aquamarine, monazite, zircon and britholite in sapphire, apatite in garnet, and liquid and gaseous CO_2 in beryl. R.A.H.

DESHPANDE (M. L.). *Diamond bearing kimberlites.* Indian Minerals, **34**, 1, 1-9, 1980.

A general account of diamond-bearing formations on a world-wide scale is given. M.O'D.

DIEHL (R.). *Edelstein-Nachahmungen.* (Imitation gemstones.) Diebeners Goldschmiede- und Uhrmacher- Jahrbuch, 43-50, 2 figs, 1981.

A review of glass gemstone imitations and composite stones. M.O'D.

DIEHL (R.). *Möglichkeiten der Edelsteindiagnose mit Hilfe der Röntgentopographie.* (Possibilities of gem identification with the help of x-ray topography.) Z.Dt.Gemmol.Ges., **31**, 1/2, 3-22, 30 figs, bibl., 1982.

In the course of crystal growth, defects such as dislocation or small angle boundaries are incorporated in the crystal lattice. These defects can be highly diagnostic for the growth method, whether synthetic or natural. The defect structure is shown by means of x-ray topography, as crystal defects generate characteristic intensity contrasts during x-ray diffraction. The potential of x-ray topography to fingerprint gemstones, especially diamonds, is discussed. Modern imaging techniques include projection, section and surface reflection topography. E.S.

FOORD (E. E.), ERD (R. C.), HUNT (G. R.). *New data for jeremejevite.* Canadian Mineralogist, **19**, 303-10, 1981.

A new study of material from the two known localities of Mt Soktuj, U.S.S.R. and Cape Cross, Namibia, has given the composition as $Al_6B_5O_{15}F_3$ with a hardness of 7½, SG of 3.288. Refractive indices are 1.644, 1.637. M.O'D.

FRÈRE (A.). *Proportionen bei Diamant-Brillanten.* (Proportions of brilliant-cut diamonds.) Diebeners Goldschmiede- und Uhrmacher- Jahrbuch, 51-3, 1981.

The ideal proportions of the brilliant-cut for diamonds are illustrated. M.O'D.

GERUVOL (M. T.), ALKHAZOV (V. Yu.), YURGENSON (G. A.). *Mineralogy of pegmatite productive mineral complexes with precious stones in Nuristan (Democratic Republic of Afghanistan).* In: Gem Minerals; Proceedings of the XI General Meeting of IMA, Novosibirsk, ed. Bukanov (V. V.) *et al.,* (see Book Review on p. 575 below), 63-70, 1980. (In Russian, with English abstract.).

Brief details, including refractive indices, are given for various Nuristan gemstones which occur in the magmatic to hydrothermal stages of pegmatite bodies. Those described are beryl (aquamarine, vorobievite), tourmaline (schorl, indicolite, verdelite, achroite, dravite, uvite), and spodumene (kunzite, hiddenite, nuristanite). There is a wide development of cleavelandite, and veins and crusts of pink cookeite with spodumene and green tourmaline are indicative of the presence of gem varieties. R.A.H.

GRUTTMANN (K.). *Diamanten-gradierung.* (Diamond grading.) Diebeners Goldschmiede- und Uhrmacher- Jahrbuch, 49-51, 1 fig., 1979.

Brief scheme for diamond grading. M.O'D.

GÜBELIN (E. J.). *Neue Mikrosonden-Analysen von Mineral-Einschlüssen einschliesslich eines Rubins im Diamant.* (New electron microprobe analysis of mineral inclusions, including that of a ruby in diamond.) Z.Dt.Gemmol.Ges., **31**, 1/2, 23-40, 17 figs (16 in colour), 2 tables, bibl., 1982.

The mineral inclusions of nine diamonds are described. Two methods of exposure were used. In the first, the diamond host was crushed and the inclusion sorted out; in the second the diamond was cut down until the inclusion was exposed to the surface. In both cases the inclusions were analysed by means of an electron microprobe. In the first, mineral inclusions were subjected to further examination by x-ray, for instance for the determination of their structure. The results are described and with some samples the genetic significance of the inclusions is discussed. E.S.

GUNAWARDENE (M.), MERTENS (R.). *Die Edelsteine Thailands.* (The gems of Thailand.) Z.Dt.Gemmol.Ges., **31**, 3, 151-6, 8 figs in colour, 1 map, bibl., 1982.

Article on the occurrences of corundum in Thailand which can be subdivided into eluvial, alluvial and coluvial. The most famous occurrences are listed and mining methods used are shortly described. There seem to be about 200 000 lapidaries working in Thailand, mainly in Bangkok and Chanthaburi, not only working gem materials found locally, but also imported material from Sri Lanka, Colombia, Australia and Brazil. Synthetic stones are also worked, of some danger to the tourists, although lately some gemmological knowledge is being introduced to the Thais. E.S.

HÄNNI (H. A.). *Zur Erkennung diffusionsbehandelter Korunde.* (Identifying heat-treated corundums.) Z.Dt.Gemmol.Ges., **31**, 1/2, 49-57, 7 figs in colour, 1 table, bibl., 1982.

When dealing with heat-treated corundum, it is important to establish whether any foreign material has been added. In normal heat treatment no additional components are added to affect the colour. In diffusion heat treatment, trace impurities are inserted to stain the stone. Normal heat treatment results in a more or less even colour throughout the stone, while diffusion heat treatment results in a surface stain along a thin layer of approx. 0.2 mm depth. Repolishing can remove this layer. Heat treated and diffusion treated corundums can be distinguished by characteristic inclusions and surface features. The first signal to test is a dark circle along the girdle visible with the naked eye: this is where the stone is thinnest and the effect of the diffusion treatment strongest. E.S.

HÄNNI (H. A.). *Perlendiagnose mit Laue-Aufnahmen.* (Investigation of pearls with the help of diffraction x-ray patterns.) Z.Dt.Gemmol.Ges., **31**, 3, 131-42, 18 figs, bibl., 1982.

An English version of this article was published in J.Gemm., 1983, **XVIII**, 5, 386-400, under the title *The Influence of the Internal Structure of Pearl on Lauegrams.* E.S.

HÄNNI (H. A.), GUNAWARDENE (M.). *Untersuchungen an Titanit, einem für Sri Lanka neuen Edelstein.* (Investigations into titanite, a new gemstone in Sri Lanka.) Z.Dt.Gemmol.Ges., **31**, 1/2, 65-70, 2 figs in colour, 4 tables, bibl., 1982.

Generally sphenes from different sources do not show significant differences in content of major elements, but they can be distinguished by their different optical constants. The recently found brown to yellowish-green material from Sri Lanka has distinctive inclusions characteristic for this source. E.S.

HÄNNI (H. A.), KLEIN (H. H.). *Ein Smaragdvorkommen in Madagaskar.* (An emerald occurrence in Madagascar.) Z.Dt.Gemmol.Ges., **31**, 1/2, 71-7, 6 figs in colour, 1 table, 1 graph, bibl., 1982.

The new emerald mine Ankadilalana lies in the south-east of the island. Stones are found in mica schist and are similar to Zambian emeralds in colour (blue-green) and optical constants. There are some minor chemical differences, and they can also be identified by their inclusions, which can be brown biotite, muscovite, apatite, haematite, goethite, quartz, ilmenite, tourmaline, two-phase inclusions; there is also often some colour zoning. The mine is at present worked sporadically and with primitive technical means. E.S.

HAYNES (S. J.). *Turquoise color and supergene environment, Sar Cheshmeh, Iran.* In: Gem Minerals; Proceedings of the XI General Meeting of IMA, Novosibirsk, ed. Bukanov (V. V.) *et al.*, (see Book Review p.575 below), 105-10, 2 figs, 2 tables, 1980.

Turquoise occurs locally in the Sar Chesmeh porphyry copper deposit, where it is associated with a 20 cm wide quartz pebble dyke at the boundary between the supergene oxide and enrichment zones in the andesitic host rocks. Both blue and green varieties are found. The blue turquoise has H.5 with CuO 7.51, total Fe as

FeO 2.93%; whereas the green variety has H.6, CuO 6.51, FeO 6.86%. The green variety was partly due to the replacement of Cu by ferrous sulphate; the origin of the phosphate was probably the breakdown of apatite. R.A.H.

IVANOV (V. G.), SAMOILOV (V. S.), SAPOZHNIKOV (A. N.), KASHAYEV (A. A.), VINOGRADOV (A. P.). *Mineralogy of lazurite deposits of the USSR.* In: Gem Minerals; Proceedings of the XI General Meeting of IMA, Novosibirsk, ed. Bukanov (V. V.) *et al.,* (see Book Review p.575 below), 97-104, 1980. (In Russian, with English Abstract.)

The mineralogy of the lazurite deposits of the near-Baikal region has been studied in detail. These rocks were produced by metasomatism at the contact between magnesian marbles and aluminosilicate rocks (syenites, nepheline syenites, etc.) in alkaline conditions at 520-605 °C. Chemical analyses and optical properties are given for lazurite (4), triclinic lazurite (2), hackmanite, afghanite and 'sulphide cancrinite'. The mineralogy of the cancrinite group is reviewed, and a division is proposed into (a) the cancrinite-vishnevite group with the formula $A_{6-8}B_{12}O_{24}X_{1-2}.nH_2O$, and (b) the afghanite group with fromula $A_{6-8}B_{12}O_{24}X_3.nH_2O$. From a crystal-chemistry viewpoint the afghanite group is intermediate in the feldspathoids between the sodalite and cancrinite groups. Analysis of triclinic lazurite gave SiO_2 31.84, Al_2O_3 27.41, Fe_2O_3 0.05, MgO 0.14, CaO 6.01, Na_2O 18.40, K_2O 0.51, SO_3 11.41, S 1.70, Cl 0.20, CO_2 1.50, H_2O 2.14, less O = Cl, S 0.90, = 100.41; RIα1.503, β1.509, γ1.509; SG 2.43; *a* 9.08, *b* 12.85, *c* 25.70Å. The 'sulphide cancrinite' gave SiO_2 31.1, Al_2O_3 24.4, Fe_2O_3 0.4, MgO 0.2, CaO 5.7, Na_2O 14.0, K_2O 1.5, SO_3 13.4, S 7.8, Cl 1.5, CO_2 1.56, H_2O 2.74, less O = Cl, S 4.2, = 100.1; RIω1.578, ε1.655; SG 2.56; *a* 12.85, *c* 10.69Å. R.A.H.

KORAGO (A. A.), KALIKOV (V. N.), GOLUBEV (B. F.). *New data on the composition of pearl found in the northwest of the USSR.* In: Gem Minerals; Proceedings of the XI General Meeting of IMA, Novosibirsk, ed. Bukanov (V. V.) *et al.,* (see Book Review p.575 below), 116-21, 2 figs, 1980. (In Russian, with English Abstract.)

Quantitative spectral analyses of freshwater pearls from NW. U.S.S.R. reveal microimpurities of Mg (0.01-0.12%), Mn (0.004-0.400%), Sr (0.1-0.3%), Ba (0.03-0.08%), Si (0.03-0.10%) and Al (0.01-0.03%). These microimpurities are found to be localized in the organic cement. R.A.H.

LIND (Th.), SCHMETZER (K.). *Infrarotspektroskopie geschliffener Edelsteine, dargestellt am Beispiel von echten und synthetischen Amethysten.* (Infrared spectroscopy of cut gemstones shown using the example of natural and synthetic amethysts.) Z.Dt.Gemmol.Ges., **31**, 3, 143-50, 5 figs, bibl., 1982.

An English version of this article was published in J.Gemm., 1983, **XVIII**, 5, 411-20, under the title *A Method for Measuring the Infrared Spectra of Faceted Gems such as Natural and Synthetic Amethysts.* E.S.

MASCHMEYER (D.), LEHMANN (G.). *Ein Strahlungsdefekt als Ursache der Färbung bestimmter 'Rosenquarze'.* (A defect in radiation as cause of coloration in certain rose quartzes.) Z.Dt.Gemmol.Ges., **31**, 3, 117-24, 3 figs, bibl., 1982.

A radiation defect with an unpaired electron on an oxygen bridging between

one substituted aluminium and phosphorus, each has been identified by electron paramagnetic resonance measurements as the cause of coloration of certain rose-coloured quartzes. No sign of lower stability compared to the smoky quartz centres was found. E.S.

METALIDI (S. V.), ZARITSKY (A. I.), TSYMBAL (S. N.), POTEBIYA (M. T.), KVASNITSA (V. N.), SLYSH (R. A.), YASVINSKY (B. I.). *Pervaya nakhodka almazov v konglomeratakh verkhnego proterozoya na territorii Vostochno Evropeiskoi platformy.* (The first discovery of diamonds in upper Proterozoic conglomerates on the East European Platform.) Mineralogicheskii Zhurnal, **4**, 3, 20-9, 6 figs, 1982. (In Russian, with English abstract.)

A description is given of the crystal morphology and physical properties of diamonds discovered for the first time on the south-western margin of the East European Platform [not more specifically located] in upper Proterozoic conglomerates which had formed during the 1500-1100 m.y. interval. Colourless or yellow-tinted crystals of octahedral habit predominate; colourless dodecahedral and cubic-dodecahedral crystals play a minor role, and crystals of cubic habit and intensely worn grains of ellipsoidal shape are very rarely encountered. From their physical characters, these diamonds are Type Ia, and only isolated grains are Type IIa. In colour, crystal morphology, and physical properties, these diamonds are indistinguishable from those quantitatively predominant in the kimberlites of other regions, for instance, Yakutia. The bedrock sources of the diamonds in the conglomerates examined were kimberlites with an age greater than 1100-1200 m.y. D.A.B.

PETRUSENKO (S.), ARNAUDOV (V.). *Emeralds from desilicified pegmatites in Bulgaria.* In: Gem Minerals; Proceedings of the XI General Meeting of IMA, Novosibirsk, ed. Bukanov (V. V.) *et al.*, (see Book Review on p. 575 below), 74-9, 2 figs, 1980. (In Russian, with English abstract.)

The properties and paragenesis of beryls (including emeralds) in various pegmatites of the NW. Rhodope massif are described. The zonal desilicified pegmatites cutting ultrabasic rocks contains some 50 mineral species, including fuchsite, emerald, chrysoberyl, allanite, cyrtolite, apatite, garnet, fluorite, chromite and various sulphides. Beryl is commonly associated with quartz, apatite and garnet in the plagioclase-phlogopite zone; it ranges from light blue to green and emerald-green. Analysis of an emerald gave SiO_2 66.63, Al_2O_3 15.95, Cr_2O_3 0.04, Fe_2O_3 0.48, BeO 13.10, MgO 1.00, CaO 1.53, Na_2O 0.90, K_2O 0.07, Rb_2O 0.02, Cs_2O 0.06, H_2O^+ 1.16, H_2O^- 0.21, ign. loss (900 °C) 1.39, =99.54; RI ε 1.572-1.575, ω 1.572-1.580; SG 2.690-2.694. R.A.H.

PSCHICHHOLZ (D.). *Edelsteine Nordamerikas.* (North American gemstones.) Diebeners Goldschmiede- und Uhrmacher- Jahrbuch, 40-3, 5 figs, 1979.

Brief review of the major stones found on the North American continent. M.O'D.

RAJARAMAN (S.). *A short note on the Williamson diamond mines, Mwadui, Shinyanga Region, Tanzania.* Indian Minerals, **33**, 1, 52, 1979.

A brief account of the diamond bearing body is given. M.O'D.

ROGOVA (V. P.). *Formation conditions of charoite rock—new stones for jewellery and carving.* In: Gem Minerals; Proceedings of the XI General Meeting of IMA, Novosibirsk, ed. Bukanov (V. V.) *et al.,* (see Book Review on p. 575 below), 79-86, 1980. (In Russian, with English abstract.)

The occurrence of charoite-bearing rock in the K-rich alkaline syenites of the Murun massif in the Aldan region is described. K-Ca metasomatism has affected the igneous rocks, locally accompanied by the introduction of Fe, Ti, Ba, Sr, F and H_2O, which gave tinaksite, charoite, canasite and pectolite. Chemical analyses are reported for charoite (3), canasite and tinaksite. R.A.H.

ROSSOVSKY (L. N.), KONOVALENKO (S. I.). *Gemstones in the pegmatites of Hindukush, Southern Pamyrs and Western Himalayas.* In: Gem Minerals; Proceedings of the XI General Meeting of IMA, Novosibirsk, ed. Bukanov (V. V.) *et al.,* (see Book Review on p. 575 below), 52-62, 1980. (In Russian, with English abstract.)

The pegmatites in this area include rare-metal pegmatites of medium depth which may contain kunzite, tourmaline, aquamarine and vorobievite (Cs-bearing beryl); the more deep-seated pegmatites yield sapphire, ruby and dravite. The gemstones in these rare-metal pegmatites were formed at the last stage of pegmatite formation by direct crystallization from pegmatite melt-solutions. Finds of deep blue, violet and pink corundum crystals are reported from the SW. Pamyrs; they are similar to the Himalayan sapphire deposits. R.A.H.

SACHANBINSKY (M.). *Mineralogy of chrysoprases from the deposits of Lower Silesia.* In: Gem Minerals; Proceedings of the XI General Meeting of IMA, Novosibirsk, ed. Bukanov (V. V.) *et al.,* (see Book Review on p. 575 below), 128-40, 13 figs, 1980. (In Russian, with English abstract.)

Chrysoprase from the Skliary deposit and from the magnesite deposit at Vira, near Vroclav (Wroclaw), have been studied. At Skliary chrysoprase occurs in veins and druses in serpentinite; it ranges from opaque light green masses to uniformly fine-grained translucent dark green: n 1.447. NiO is the chromophore and amounts to 0.03-1.30%; mineralogically it consists of α-quartz with a minor amount of α-tridymite. The chrysoprase from Vira occurs as thinner veins and is somewhat lighter in colour; it has ω 1.543, ε 1.552, and x-rays show it to consist of chalcedony with NiO 1%. In both these Silesian chrysoprases the Ni is in the form of pimelite. R.A.H.

SAVKEVICH (S. S.). *New developments in amber and other fossil resins: mineralogical studies.* In: Gem Minerals; Proceedings of the XI General Meeting of IMA, Novosibirsk, ed. Bukanov (V. V.) *et al.,* (see Book Review on p. 575 below), 17-28, 4 figs, 1980. (In Russian, with English abstract.)

Museum samples and recent finds of amber have been investigated by IR; many samples designated as amber (succinite) are not amber in the strict sense and are of no value for jewellery. However, fossil resins possessing good mechanical and decorative properties, fit for jewellery, occur in Sakhalin and the Transcaucasus; these are rumanite analogues. Geochemical conditions for the fossilization of resins and the formation of succinite, rumanite and schraufite are outlined. Further mineralogical work is necessary to reclassify museum collections of amber and other resins. R.A.H.

SCHMETZER (K.). *Absorptionsspektren und Farben Vanadium- und Chromhaltiger Minerale.* (Absorption spectra and colours of minerals containing vanadium and chrome.) Z.Dt.Gemmol.Ges., **31**, 3, 125-30, 6 graphs, bibl., 1982.

The position of the absorption maxima of V^{3+} and Cr^{3+} in silicates and oxides is mainly dependent on the crystal field parameter in the vanadium-oxygen and chromium-oxygen octahedron respectively. A decrease of this parameter as well as a shift of the absorption bands to smaller wavelength numbers (greater wavelengths) is caused either by lattice expansion or by a contra-polarization effect. The colour of vanadium and chromium containing minerals (green and blue or green and red) is explained by the position of the absorption maxima of V^{3+} and Cr^{3+} in the visible region. E.S.

SCHMETZER (K.). *Ein ungewöhnlicher Granat aus dem Umba-Tal, Tansania.* (An unusual garnet from Umba Valley, Tanzania.) Z.Dt.Gemmol.Ges., **31**, 1/2, 59-64, 3 figs (1 in colour), 2 tables, bibl., 1982.

An English version of this article was published in J.Gemm., 1982, **XVIII**, 3, 194-200. E.S.

SCHMETZER (K.), BANK (H.). *Untersuchungen an Exemplaren der 'Smaragd-Vollsynthese' von Lechleitner.* (Investigation of specimens of the Lechleitner fully synthetic emeralds.) Z.Dt.Gemmol.Ges., **31**, 1/2, 79-80, 1 table, bibl., 1982.

The chromium content of the synthetic Lechleitner emeralds was found to vary between 0.84-0.40% Cr_2O_3, much lower than that of the synthetic emerald coat grown on colourless beryl seeds by the same producer. The fully synthetic stones had RI between 1.566-1.562 and 1.562-1.559. E.S.

SCHMETZER (K.), BANK (H.). *Gelbgrüner Grossular aus Ostafrika.* (Yellow-green grossularite from East Africa.) Z.Dt.Gemmol.Ges., **31**, 1/2, 81-4, 1 fig in colour, 1 graph, 2 tables, bibl., 1982.

The yellowish-green grossularite from East Africa was found to consist of 94.6% grossularite, 2.3% pyrope, 2.3% andradite, 0.7% spessartine and 0.1% goldmanite. The colour was caused by V^{3+}, Fe^{3+} and Mn^{2+}. RI 1.740; SG 3.68; a_o 11.858Å. E.S.

SHATSKY (V. S.), LEBEDEV (A. S.), KLJAKHIN (V. A.). *Micromorphology of crystals of synthetic hydrothermal emerald.* In: Inhomogeneity of Minerals and Crystal Growth; Proceedings of the XI General Meeting of IMA, Novosibirsk, ed. Sidorenko (A. V.) *et al.*, Academy of Sciences of the USSR, Leningrad, 255-61, 6 figs, 1980 (In Russian, with English Abstract.)

The micromorphology of emerald crystals grown in hydrothermal conditions was investigated. The crystals have the following faces: $000\bar{1}$, $10\bar{1}0$, $11\bar{2}1$, $11\bar{2}0$, and $10\bar{1}1$. The flaky-spiral mechanism of growth is characteristic of all the faces of the crystals studied and is in agreement with the data from microcrystallomorphological investigations. The centres of spiral generation are shown to be microcrystals of beryl or foreign particles adhering to a face. It is noted that there is no essential difference between the growth mechanisms of natural and synthetic beryls. P.Br.

SINGH (K. N.). *On the occurrence of semi-precious tourmaline in the crystalline formation of Dudhatoll District Pauri, and Chamoli, Uttar Pradesh.* Indian Minerals, **32**, 2, 28-33, 4 figs, 1978.

Pale-yellow transparent to translucent tourmaline has been found in a muscovite schist and a darker, yellowish-brown variety in a pegmatite. Mode of occurrence of dravite is discussed. M.O'D.

STANEK (J.). *Two types of beryllium pegmatites with gemstones in Northern Moravia, Czechoslavakia.* In: Gem Minerals; Proceedings of the XI General Meeting of IMA, Novosibirsk, ed. Bukanov (V. V.) *et al.,* (see Book Review p.575 below), 70-4, 1980. (In Russian, with English Abstract.)

Syntectonic pegmatites in this area contain albite, quartz, muscovite and sillimanite but are lacking K-feldspar; chrysoberyl occurs, but beryl is rare. The post-tectonic pegmatites contain beryl of two generations; early beryl forms large yellowish crystals associated with K-feldspar, whereas the later beryl is smaller and occurs as aquamarine associated with sugar-like albite. Bertrandite, bavenite, euclase and milarite have also been found in this type of pegmatite, but chrysoberyl is very rare. R.A.H.

SUPERCHI (M.). *Gemmology as a master academic science, not a part of mineralogy: general principles and concepts.* In: Gem Minerals; Proceedings of the XI General Meeting of IMA, Novosibirsk, ed. Bukanov (V. V.) *et al.,* (see Book Review p.575 below), 140-50, 1 fig., 1980.

A syllabus for a course in gemmology is outlined. Chromaticity diagrams are discussed, and it is suggested that the best scheme of arrangement for gemstones in a museum display is by colour. R.A.H.

SUTURIN (A. N.), ZAMALETDINOV (R. S.), LETNIKOV (F. A.), SEKERIN (A.P.), BURMAKINA (G. V.), SUTURINA (T. A.), PLATONOV (A. N.), BELITCHENKO (V. P.), VOKHMENTSEV (A. Ya.). *Mineralogy and genesis of nephrites in the USSR.* In: Gem Minerals; Proceedings of the XI General Meeting of IMA, Novosibirsk, ed. Bukanov (V. V.) *et al.,* (see Book Review p.575 below), 87-97, 2 figs, 1980. (In Russian, with English Abstract.)

The nature of the colouring and quantitative estimates of the colour (in *xyz* CJE co-ordinates) of nephrites from a wide range of localities have been investigated by optical transition and reflection spectra and Mössbauer, IR and EPR spectroscopy. Chemical analyses are reported for nephrites from 14 deposits and determination of the chromophoric trace elements (Cr, Ni, Co, V, Ti) are tabulated for 12 specimens. The colour of nephrite is due to Cr^{3+} and Fe^{2+} ions occupying distorted octahedral positions instead of Mg^{2+}. Nephrite commonly forms as a result of infiltration-diffusion Ca-metasomatism, along antigorite serpentinite fibres at the contact with gabbroic or granitic rocks. R.A.H.

TAKUBO (H.), KITAMURA (Y.), KUME (S.), KOISUMI (M.). *Preparation of star-ruby containing large crystals of rutile. Preliminary investigation.* In: Inhomogeneity of Minerals and Crystal Growth; Proceedings of the XI General Meeting of IMA, Novosibirsk, ed. Sidorenko (A. V.) *et al.,* Academy of Sciences of the USSR, Leningrad, 305-9, 2 figs, 3 photos, 1980.

A method for preparing rutile-bearing ruby crystals is described in detail and

the results of microscopic and x-ray observations of the synthetic crystals are presented. It is concluded that if appropriate controls on *T* variation and Ti-concentration are maintained, it will be possible to make synthetic star-ruby similar in both external and internal appearance to a natural star-ruby of first grade. P.Br.

TOMBS (G. A.). *Heat treatment of Australian blue sapphires.* Z.Dt.Gemmol.Ges., **31**, 1/2, 41-8, 24 figs in colour, 1982.

The author discusses the difficulty of distinguishing untreated and heat-treated sapphires. In cut and polished heat-treated stones the main identifying feature (if present) is (1) the presence of vacant tubes under dark field illumination, (2) sharpness of zonal banding combined with the contrast of areas almost vacant of colour between coloured zones and (3) slight loss of dichroism as compared to untreated specimens of Australian blue sapphire which is almost always strong blue-green. In some heat-treated Ceylon sapphires one finds occasionally a gas bubble in association with a residual inclusion. E.S.

VAKANYATZ (B.), ZARIĆ (P.). *Gemstones in Yugoslavia.* In: Gem Minerals; Proceedings of the XI General Meeting of IMA, Novosibirsk, ed. Bukanov (V. V.) *et al.,* (see Book Review p.575 below), 44-52, 1980. (In Russian, with English abstract.)

Yugoslavian gem minerals occur in various types of rock: (1) pegmatites (beryl, aquamarine, spodumene, zircon, amethyst, citrine, morion, rose quartz and amazonite), (2) metamorphic complexes (ruby, garnet, amethyst, kyanite, citrine, jasper), (3) volcanogenic complexes (opal, amethyst, agate, jasper), (4) ultrabasic rocks (chrysoprase, serpentine), and (5) other occurrences (vesuvianite, garnet, epidote, rhodonite, onyx). R.A.H.

WILD (K. E.). *Das Edelsteingraveurgewerbe in Idar-Oberstein.* (Gemstone carving in Idar-Oberstein.) Diebeners Goldschmiede- und Uhrmacher- Jahrbuch, 31-9, 7 figs, 1979.

Details of gemstone carving in the town of Idar-Oberstein are given. M.O'D.

Bodenschätze sibiriens. (Siberia's mineral wealth.) Veröffentlichungen aus dem Naturhistorischen Museum Wien, neue Folge, **20**, illus. in colour, 1982.

Some gemstones found in Siberia are described and illustrated. M.O'D.

Diamantgewinnung in der Premier Mine. (Mining at the Premier Mine.) Diebeners Goldschmiede- und Uhrmacher- Jahrbuch, 44-8, 1 fig., 1979.

A brief history of the Premier mine and of some of the stones recovered from it. M.O'D.

Gem & jewelry fact sheets. American Gem Society, **2**, 1, 1982.

A specimen issue of this series was examined. The contents were market orientated with comments on pearl (considerable demand, stable prices), on coloured stones and precious metals. No great detail is given and in this respect readers would be better served by the commercial section of *Jewelers' Circular-Keystone.* M.O'D.

BOOK REVIEWS

BUKANOV (V. V.), SIDORENKO (A. V.), SOBOLEV (V. S.), RUNDKWIST (D. W.), SHAFRANOWSKY (I. I.), SAVKEVICH (S. S.), eds. *Gem Minerals; Proceedings of the XI General Meeting of IMA, Novosibirsk, 4-10 September, 1978.* Academy of Sciences of the U.S.S.R., Leningrad, 1980. pp.152. 37 figs, 14 photos. Price 70 k.

This book contains 18 papers presented to the I.M.A. Working Group on Gem Materials. Many are in Russian, but all except one have abstracts in English. Abstracts of each paper appear in Gemmological Abstracts. R.A.H.

GAY (P.). *An introduction to crystal optics.* Longmans, London, 1982. pp.ix, 262. £6.95.

First published in 1967, the present text is a re-issue with small modifications including a minimal up-dating of the bibliography. Designed for students of mineralogy, the general level is above that necessary for the adequate testing of gemstones, but diligent students will not find the concepts and applications too difficult should they wish to pursue their studies into the wider world of mineralogy. Diagrams are clear and the text lucid. I should certainly recommend this work both for those reasons and for the modest price. M.O'D.

SCALISI (P.), COOK (D.). *Classic mineral localities of the world: Asia and Australia.* Van Nostrand Reinhold, New York, 1982. pp.xvii, 226. Illus. in black-and-white and in colour. £25.10.

This is to be the first of a series intended eventually to cover the mineral deposits of the world, or rather those deposits which include materials of importance to the collector as well as to the economic geologist. Japan, India, Burma and the U.S.S.R. are among the countries covered by this volume, and in each case the chief deposits are described with profuse illustrations of characteristic crystal forms. Most of these are reproduced from Goldschmidt's *Atlas der Krystallformen,* published for the first time in 1913 and now, in its complete form of 9 volumes, virtually unobtainable. Though there is a short list of references to each chapter and a fairly short general bibliography, there is something lacking from the work in that many of the descriptions are sketchy and clearly reproduced from other work, in some cases from an original of some age. This prevents the reader from knowing exactly how up to date the descriptions are and also how scholarly is the criticism and selection employed on so vast a mass of original data. Though most readable and attractively produced the general air given is that of the amateur collector rather than the scholar; far more attention should have been paid to the presentation of detail, especially with respect to dates. But none the less it is very good to have such material, albeit in a somewhat imperfect form and we look forward to further volumes in the series. M.O'D.

ASSOCIATION NOTICES

OBITUARY

Mr V. G. Jones, F.G.A. (D.1953), London, died on 27th December, 1982.

Mr Bapusaheb Shamrao Mahajan, F.G.A. (D.1954), Bombay, India, died on 6th January, 1983.

Mr Theo Stern, F.G.A. (D.1949), London, died on 4th February, 1983.

NEWS OF FELLOWS

On 12th November, 1982, Mr M. J. O'Donoghue, M.A., F.G.S., F.G.A., gave a talk on mineral identification to the Cheltenham Mineral and Geological Society.

On 8th January, 1983, Mr Peter G. Read, C.Eng., F.G.A., gave an illustrated talk to the Wessex Branch of the N.A.G. at the Wessex Hotel, Bournemouth, based on his recent visit to the new underground workings at the Finsch diamond mine in South Africa.

On 10th January, 1983, Mr W. H. Pluckrose, R.J.Dip., F.G.A., gave a talk on gemmological instruments and the identification of gemstones to the Ulster Jewellers' Association. Four mini-laboratories were set up and everyone present had the opportunity of using the instruments.

Mr HARRY WHEELER'S RETIREMENT

A full report (with photographs) of the parties held in connexion with Mr Harry Wheeler's retirement last year will be found by members of the Association in the Annual Report for 1982 accompanying the Notice of the Annual General Meeting.

MEMBERS' MEETINGS

Midlands Branch

On 27th January, 1983, at the Society of Friends, Dr Johnson's House, Bull Street, Birmingham, Mr P. West, F.G.A. and Ms Carole Gibbs addressed the meeting on 'Turtles and tortoiseshell'.

On 24th February, 1983, at the Society of Friends, Dr J. B. Nelson, F.G.S., F.Inst.P., F.G.A., gave a talk entitled 'Colour perception and measurement of gemstones'.

North-West Branch

On 20th January, 1983, at Church House, Hanover Street, Liverpool 1, Mr A. Hodgkinson, F.G.A., gave an illustrated talk entitled 'Gemmology and the shop'.

On 24th February, 1983, at the Liverpool Museum, William Brown Street, a talk was given by Dr J. Trecise on two collections of gemstones displayed at the Museum.

South Yorkshire & District Branch

On 20th January, 1983, at the Sheffield City Polytechnic, the Annual General Meeting was held, at which Miss J. I. Platts, F.G.A., and Mr J. I. Reynolds, F.G.A., were elected Chairman and Secretary respectively. The A.G.M. was followed by an illustrated talk by Mr N. Grist, F.G.A., entitled 'History of Jewellery'.

ANNUAL REUNION OF MEMBERS AND PRESENTATION OF AWARDS

The Annual Reunion of Members and the Presentation of Awards took place at Goldsmiths' Hall on 15th November, 1982.

The Chairman, Mr David Callaghan, F.G.A., who presided, reflected on a year of change and on the development and progress of the Association. It was both a sad and a happy year; sad because Harry Wheeler, F.G.A., had reached his retirement after serving the Association for 48 years and being its Secretary since 1973, and happy because we had found his replacement in Con Lenan, F.G.A. In 1934, when Harry joined the Association, 21 students gained their Diploma and were all from the U.K.: this year 300 students from the U.K. and Overseas gained their Diplomas and 102 centres were set up in many countries of the world, where both Preliminary and Diploma students were able to sit their examination. Through his many efforts, Harry could look back on a splendid achievement in his final year.

'The Association continues to be recognized as the premier gemmological association internationally and it is our intention to perpetuate this recognition. To help expand our interests and to develop, an Executive Committee will be formed and an Education Committee has been set up.'

The Chairman then introduced Mr E. A. Thomson, President of the Coloured Stones Commission of C.I.B.J.O. and Vice-Chairman of the London Chamber of Commerce Executive Committee of the Diamond Pearl and Precious Stone Section, one of whose functions is to control the Gem Testing Laboratory. Mr Thomson thereupon presented the awards and delivered the address which is recorded in full below.

The President, Sir Frank Claringbull, then thanked Mr Thomson for presenting the awards, and the proceedings were concluded.

ADDRESS OF MR E. A. THOMSON, PRESIDENT OF THE COLOURED STONES COMMISSION OF C.I.B.J.O.

Mr Chairman, Ladies and Gentlemen,

Firstly, I wish to congratulate once again all those to whom I have given their Diplomas tonight and also, of course, those who have qualified and have been unable to join us. The G.A. Diploma is not a qualification obtained easily, and I do appreciate the really hard work you have done to pass this difficult test.

Secondly, I also congratulate you on deciding to study and qualify in this really exciting and colourful world of coloured stones—a world that is getting more and more difficult for the professionals as constant discoveries of new varieties of precious stones and cleverer and cleverer synthetic stones hit the market. That is why we need more and more knowledge and expertise coming into the trade at all levels.

A word of warning, however; please do not think that because you have got your Diploma you are now professional experts. You are not. But what you have got is a basic knowledge on which you can advance. Full knowledge only comes with constant practice and handling of stones. Dealing in your own office with your instruments around you is one thing, but the test is when you are outside your environment and you just have your loupe and tweezers. That is when you develop a feel and a second sense of the stones. The background knowledge you now have will be a great help, and the trade does need more knowledgeable and practical gemmologists, which I hope you all will become.

I am, as you know, President of the Coloured Stones Commission of C.I.B.J.O., that is the International Confederation of Jewellery, Silverware, Diamonds and Precious Stones. This is a controlling body for nineteen countries on the ethics of the trade, laying down the definitions, rules of application and permitted list of gemstone names. These are in our Blue Book, which lays these out in four languages, of which English is the original text. It is now in the course of publication, and I would suggest that directly it is available you obtain a copy and base your actions on it. In that way you will help our gemmology and trade both at home and internationally.

Lastly, under another hat I am at present Vice-Chairman of the L.C.C. Executive Committee of the Diamond, Precious Stone and Pearl Section, one of whose functions is the control of our British Gem Testing Laboratory. This Laboratory was the home of Anderson, Webster, Payne and Farn and is internationally respected. Now under the control of Ken Scarratt it is in the process of moving to larger and more prestigious surroundings on the corner of Greville Street and Saffron Hill. The Laboratory is a recognized C.I.B.J.O. Laboratory and not a commercial undertaking. It is and has to remain an independent and non-profit-making concern in order to make correct and unbiased judgements. It now has a highly trained, young and enthusiastic team. Please do make use of the Laboratory whenever you find that more advanced knowledge and equipment are needed to test stones with which you may have problems in the future, and in particular keep them informed of any new discoveries you make yourselves or new information that comes your way. It is vital that our national Laboratory is kept fully informed to hold its rightly esteemed position world wide.

Once again I sincerely congratulate each and every one of you, and I am sure you will permit me to give a special personal congratulation to my daughter-in-law, Jenny Thomson, F.G.A.

ANNUAL GENERAL MEETING, 1983

The Association's 52nd Annual General Meeting will be held at Kensington Town Hall on Wednesday, 4th May, 1983, at 6 p.m., followed by a buffet supper.

RESIDENTIAL WEEK-END COURSE AT CHICHESTER

A residential course for second-year G.A. Correspondence Course students, covering the use of gem-testing instruments, will be held at West Dean College on 17th to 19th June, 1983, (Friday evening to Sunday afternoon). The Course Tutor will be Mr Peter G. Read, C.Eng., F.G.A., and full particulars may be obtained from the Course Supervisor, Miss Susan Overman, West Dean College, West Dean, Chichester, West Sussex, PO18 0QZ—telephone (0243) 63301.

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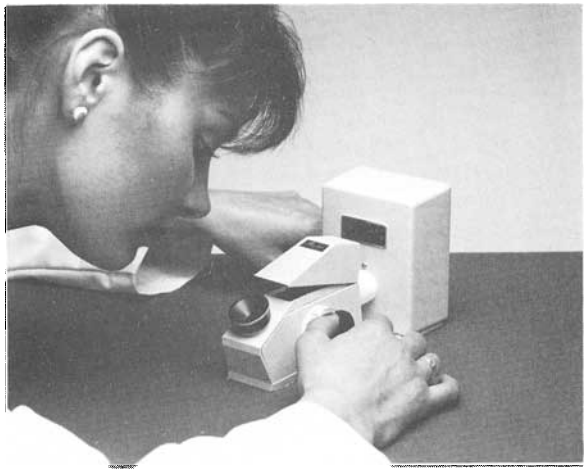

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Historical Note

The Gemmological Association of Great Britain was originally founded in 1908 as the Education Committee of the National Association of Goldsmiths and reconstituted in 1931 as the Gemmological Association. Its name was extended to Gemmological Association of Great Britain in 1938, and finally in 1944 it was incorporated in that name under the Companies Acts as a company limited by guarantee (registered in England, no. 433063).

Affiliated Associations are the Gemmological Association of Australia, the Canadian Gemmological Association, the Gem and Mineral Society of Zimbabwe and the Gemmological Association of Hong Kong.

The *Journal of Gemmology* was first published by the Association in 1947. It is a quarterly, published in January, April, July, and October each year, and is issued free to Fellows and Members of the Association. Opinions expressed by authors are not necessarily endorsed by the Association.

Notes for Contributors

The Editor is glad to consider original articles shedding new light on subjects of gemmological interest for publication in the *Journal.* Articles are not normally accepted which have already been published elsewhere in English, and an article is accepted only on the understanding that (1) full information as to any previous publication (whether in English or another language) has been given, (2) it is not under consideration for publication elsewhere and (3) it will not be published elsewhere without the consent of the Editor.

Articles published are paid for, and a minimum of 25 prints of individual articles may be supplied to authors provided application is made on or before approval of proofs. Applications for prints should be made to the Secretary of the Association—not to the Editor—and current rates of payment for articles and terms for the supply of prints may be obtained also from the Secretary.

Although not a mandatory requirement, it is most helpful if articles are typed (together with a carbon copy) in double spacing on one side of the paper, with good margins at sides, top and foot of each page. Articles may be of any length, but it should be borne in mind that long articles are more difficult to fit in than short ones: in practice, an article of much more than 10 000 words (unless capable of division into parts or of exceptional importance) is unlikely to be acceptable, while a short note of 400 or 500 words may achieve early publication.

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and

PROCEEDINGS OF THE GEMMOLOGICAL ASSOCIATION OF GREAT BRITAIN

GEMMOLOGICAL ASSOCIATION OF GREAT BRITAIN

SAINT DUNSTAN'S HOUSE, CAREY LANE
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TOPAZ AND ANDALUSITE MINING IN BRAZIL

By P. K. RUPLINGER, B.Sc., F.G.A.
Sandy, Utah, U.S.A.

Brazil is one of the greatest gem sources in the world. Within a short radius of Belo Horizonte alone, most of the world's popular and unusual gems can be found. This article will look at two of these stones, the prized 'Imperial' topaz and the less known andalusite.

Next to aquamarine, Brazil is probably most noted for its production of topaz. Topaz is encountered in several localities, but the finest stones, known as 'Imperial topaz', come from the area of Ouro Preto, about three hundred kilometres north of Rio de Janeiro. Stones from this area are typically yellow, varying to brown. The finest colours have a lively peach hue, and unusual colours demanding very high prices have tinges of red, orange, or purple. Stones from other areas in Brazil, not considered 'Imperial', are commonly blue and command much less in price.

'Imperial topaz' parent earth runs in a north-easterly mountain range approximately five kilometres wide and at least fifty kilometres long. The stones are found in several varieties of

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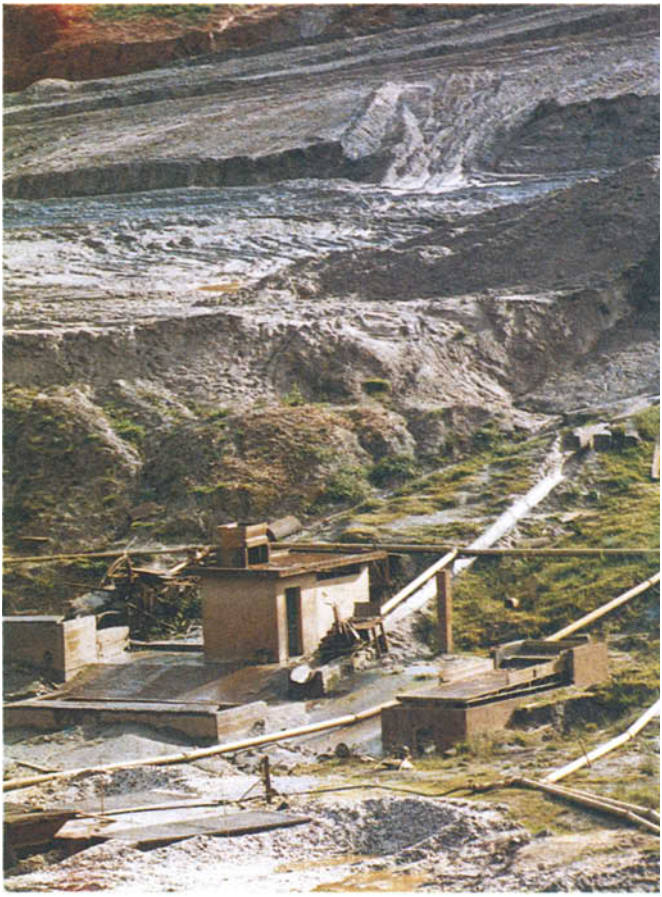

FIG. 1. At the Capao Mine topaz-bearing earth is tumbled down a trough: the topaz is separated by hand.

matrix including haematite, quartz, pegmatite, clay and kaolin. Dolomite, gold, bauxite and iron ore are also mined in the area. In colonial times the area was one of the world's greatest gold producers.

There are several large topaz-mining ventures in the Ouro Preto area. The major operation is near the small town of Rodrigo Silva, at the Capao Mine (Figure 1). Here Imperial Topaz Minerals and Industries Ltd has a substantial operation removing the entire

FIG. 2. Free-lance miners work in teams and live in small huts constructed of mud and sticks.

side of a mountain. As work progresses, a drilling team continually makes test holes probing the earth to guide the correct path of excavation.

Five bull-dozers remove fifty to seventy feet of overburden, exposing a light blue parent earth. At the bottom of the mountain a small river is dammed and several pumps pump thousands of litres per minute to the top where water washes overburden to a settling pond. The bull-dozers then scrape and push parent earth into a holding bin. From the bin it is washed down a trough. The tumbling action separates the crystals from parent earth. Landing on a screen with other stones they are separated by hand.

Seven hundred cubic metres of parent earth are processed on an average day. The mining operator was not at liberty to say how many grams of topaz are retrieved. The mine has contracts to sell its better quality stones through specific channels. Most of it is cut in Belo Horizonte and exported to Europe.

In addition to commercial operations there are hundreds of free-lance miners (Figures 2, 3 and 4). Using only hand tools, they are confined to river bottoms but find exceptionally fine stones.

FIG. 3. Free-lance miners dig in river bottoms near Ouro Preto for excellent quality topaz.

FIG. 4. This miner is especially proud of a ten gram topaz. River-bottom stones of this size are unusual.

FIG. 5. Topaz in haematite matrix.

FIG. 6. Topaz growing out of a quartz crystal.

FIG. 7. Topaz produced by seven men in one week.

Unlike the excellent crystals which are found by commercial operations in parent earth (Figures 5 and 6), the stones found in river bottoms are rounded pebbles, but much freer of imperfections.

A group of seven men working for a week will typically find six stones weighing three to five grams each (cf. Figure 7). On Saturday they take these to Belo Horizonte or Ouro Preto, where they sell them for US$ 15.00 to 40.00 each. Once cut they may sell for as high as US$ 100.00 per ct, but most sell for 15.00 or less. Brazilian lapidaries do remarkable faceting, considering that it is all done by eyesight, without the aid of calibrated dop mounts (Figures 8 and 9).

Topaz from the Capao Mine appears to have constants representative of established figures for yellow topaz. Several

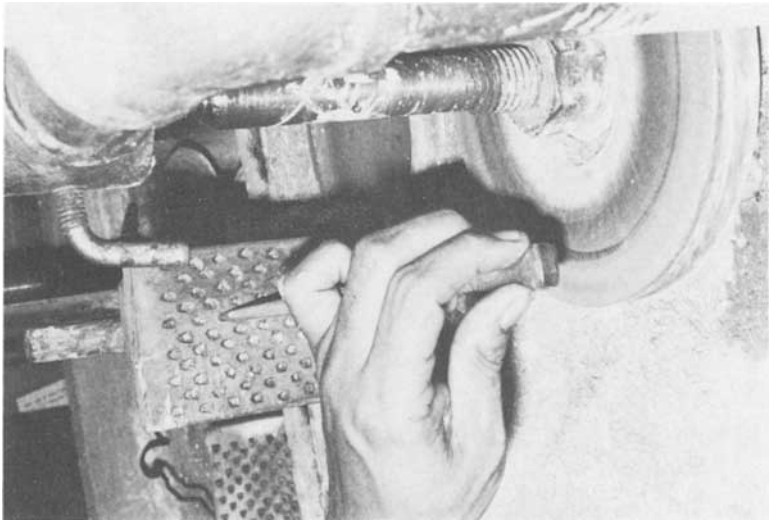

FIG. 8 and FIG. 9. Brazilian lapidaries do excellent work without the aid of calibrated dops.

FIG. 10. Andalusite is found in sandy gravel under about two metres of clay. Water seeps back almost as fast as it is pumped out of the pit.

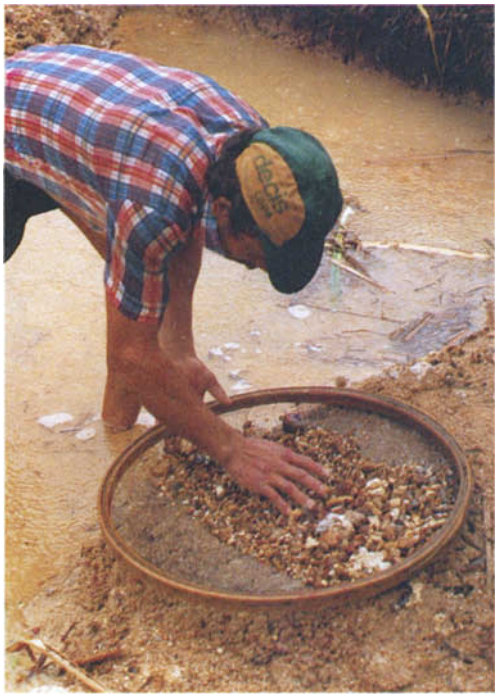

FIG. 11. Andalusite is found by carefully looking through washed gravel.

FIG. 12. Poor quality andalusite mined in one week by four workers.

stones randomly selected and tested were shown to have the following average values. All were light amber in colour.

Specific gravity	3.52 ± 0.02
RI (sodium light)	$1.630 \pm 0.002 - 1.639 \pm 0.002$
Dispersion	0.015 ± 0.002

No clearly visible absorption was observed in any stone.

Brazilian mining operators are required to submit exact reports on production, but everyone knows that documented mining as well as exportation figures are a small portion of reality. With this in mind, the Brazilian government has estimated actual exportation values of most gem stones. The value of exported topaz is represented overleaf.

Brazilian Exportation of Topaz in US$ 1000

	1970	1971	1972	1973	1974	1975
Rough	34.9	55.4	39.1	50.5	45.4	35.3
Faceted	185.5	147.2	476.3	1417.3	1300.9	1038.0

	1976	1977	1978	1979	1980	1981
Rough	41.1	82.7	129.4	160.3	126.2	103.6
Faceted	746.7	923.9	1632.4	2913.6	3912.7	3358.9

Approximately 350 kilometres east of this topaz region is Santa Teresa, a small town noted for production of andalusite. Despite its remarkable trichroism, andalusite has never been a very popular stone. Even in Brazil it is seldom encountered. Most is exported to Europe. It shows three distinct colours, red, yellow, and green with the dichroscope, and, when properly oriented, a cut gem will display a dramatic colour-change when tilted slightly. Unfortunately, most stones are cut with no consideration for this effect.

Andalusite is mined in river beds in several locations not far from the town. In Brazil mines are not owned, but leased from the government. Ten kilometres outside of Santa Teresa is a typical operation. Four miners and a cook live in a small shack a short distance from the diggings. The operator lives in Santa Teresa and has another business. The workers systematically excavate sections of river bottom which are approximately three metres square. The stones lie below an extremely dense ground cover of ferns, about sixty centimetres of steel-mesh-like roots, and one and a half or two metres of clay (Figure 10). At this level the clay turns to sandy gravel which contains scattered smoky quartz stones, frequently as large as 100 grams, and much less frequently andalusite (Figure 11).

Some areas of river bottom tend to produce better than others. The mine operator is successful depending on how he selects the areas to excavate. Work is entirely by hand with the exception of two single-cylinder gasoline* pumps, which seem to pump only slightly faster than water seeps back into the pit. The pumps use one litre of fuel per hour. Gas costs US$ 0.80 per litre. Two or three workers stand in the pit sifting through sand and gravel. The

**Anglice* petrol.—Ed.

unpleasantness of the chilling water is exceeded only by the danger of snakes, which frequently kill workers.

In a four hour visit to a mining area worked by two men, they produced about fifty grams of very poor quality andalusite (cf. Figure 12), worth almost nothing. Occasionally, however, a large clear stone of good colour in the five to six gram size may be found. Such a stone will sell for US$ 120.00 to $150.00. Workers are paid in proportion to production. The operator sells his stones in Victoria.

Unlike river-bottom topaz, which is found in rounded pebbles, andalusite is usually found in a habit recalling its original crystal form. The edges are often slightly rounded, but the almost square prism shape is usually recognizable (Figure 12). Andalusite from Santa Teresa appeared to have RI and SG within the ranges of most established standards, but the dispersion, as determined by the author,* seemed to be slightly higher. Several stones randomly selected yielded the following averages. All were olive green in colour.

Specific gravity	3.17±0.03
RI (sodium light)	1.633±0.003–1.647±0.003
Dispersion	0.019±0.002

No clearly visible absorption was observed in any stone.

As with other stones from Brazil, andalusite has no exact mining or exportation reporting. Because it is a less popular stone, the government has not attempted to estimate its exportation.

[*Manuscript received 20th February, 1982.*]

*Dispersion was determined with a GIA refractometer, high intensity lamp, and red and blue filters approaching the Fraunhofer B and G lines. Wavelength transmissions of these two filters are shown below.

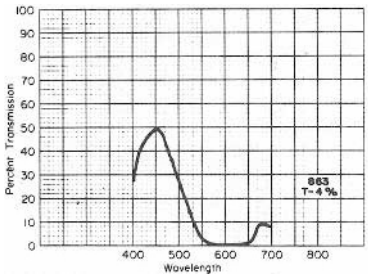

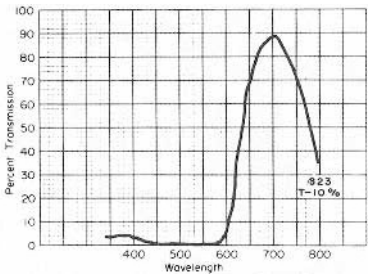

A NEW GEMSTONE VARIETY FROM TANZANIA

By Prof. Dr E. GÜBELIN, C.G., F.G.A., and Dr K. SCHMETZER,†*

*Meggen, Lucerne, Switzerland. †Heidelberg, West Germany.

INTRODUCTION

Very similar to other gemmiferous countries such as Brazil, Burma, and especially Sri Lanka, which have been such prolific and apparently inexhaustible sources of choice gemstones for centuries and even millennia, East Africa—Kenya and Tanzania in particular—is developing into a surprisingly rich source of an increasing wealth of gemstones.

Apatite cat's-eyes have been known from Brazil and India, and now there is a new source: Tanzania. Whereas the nature of the parallel fibres (the cause of the cat's-eye effect) had not been determined before because of the extreme fineness of the fibres in apatite cat's-eyes from Brazil and India, the relatively coarse acicular inclusions in these newly-discovered apatite cat's-eyes from Tanzania inspired a microprobe analysis of their nature.

THE SPECIMENS

Recently, on the native market in Nairobi, several kilos of cuttable crystal fragments of yellowish-green, green, greenish-brown to red-brown colour were offered as feldspar. These specimens were claimed to originate from the Umba Valley in north-east Tanzania, a region which has become famous recently for the multitude of its gemstones. Some of these samples were transparent, but the majority contained fine fibrous inclusions of parallel orientation, which indicated that a cabochen cut would produce beautiful cat's-eyes. This proved to be true indeed (Figure 1), as the resulting cut gems not only displayed a clearly defined chatoyancy but in their general appearance, including their colour, compared most favourably with the best chrysoberyl cat's-eyes from Sri Lanka.

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FIG. 1. A greenish-yellow and a reddish-brown apatite with fine cat's-eye effect, which is produced by scattering of light on goethite fibres. Umba Valley, Tanzania. Long axis of oval cabochon = 15mm.

FIG. 2. Densely concentrated fine goethite fibres of reddish and brownish coloration and in parallel alignment cause chatoyancy on yellowish-green, cabochon-cut apatite. 8 ×

FIG. 3. Extremely fine goethite fibres causing chatoyancy on a green apatite cat's-eye are superposed by black blebs of haematite. 12 ×

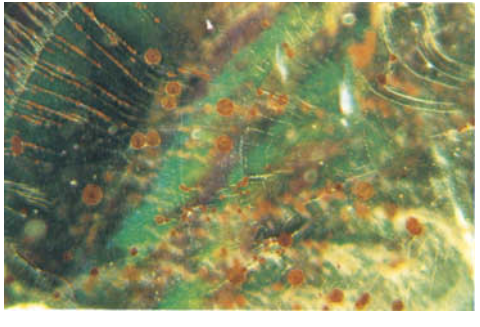

FIG. 4. Brown, disc-like concretions of radially arranged goethite fibres are secondary formations often occurring in fractures. 15 ×

GEMMOLOGICAL TESTS

A primary diagnosis with the polariscope showed all these specimens to be uniaxial, thus banishing the idea that they were biaxial feldspar. The x-ray examination then proved that they were apatite, and the following properties were manifested:

Refraction: The readings obtained by means of the Spinel-Refractometer lay between $n_\varepsilon = 1.632 - 1.636$ and $n_\omega = 1.636 - 1.640$, with a very constant birefringence of $n_{\varepsilon-\omega} = -0.004$.

Dichroism: The colours parallel and vertical to the crystallographic *c*-axis showed as a break-up of the colour-combinations, which could be seen even with the naked eye, of: ε = yellowish and ω = greenish, ε = yellow and ω = green, ε = brownish and ω = greenish, ε = reddish and ω = brown. Occasionally a zonal coloration was observed.

Absorption Spectrum: Viewed through the hand spectroscope, the typical sharp lines in the yellow region caused by didymium were observed (these are lines of the rare earth-elements praseodymium and neodymium, appearing between 570 and 590 nm; vide Anderson, 1953-56; and Grisafe & Hummel, 1970). By means of these absorption lines, apatite could have been recognized at first sight.

Density: The density appeared to be influenced to a certain extent by the density of the fibrous inclusions, as it varied between 3.22 and 3.35 with an average of 3.225 g/cm^3.

Inspection through the Microscope: All the above mentioned properties fall within the normal bounds, and together with the x-ray analysis, they provide absolute proof that the specimens examined are indeed apatite. However, the unusual factor is the cat's-eye effect, caused by the scattering of light as it impinges on the fibres of the inclusions, and an examination with the microscope showed that these inclusions consist of fine fibres or needles, partly blackish and partly reddish in colour (Figure 2). The orientation of these fibres is parallel to the crystallographic *c*-axis of the hexagonal apatites, which is easy to recognize when examining the conoscopical image. Some of the fibres were fortunately coarse enough to be analysed by means of the electron microprobe.

THE MICROPROBE ANALYSIS

A qualitative analysis of two polished thin slabs of the material by means of the electron microprobe, showed in the case of 15 needlelike inclusions that only iron was present. The diameter of these needles was however too small in most cases for the area to be excited by the electron beam of the microprobe, wherefore only a few of the thicker needles allowed a quantitative analysis of the iron. These measurements disclosed an iron compound corresponding with the composition FeOOH, which occurs in nature as goethite or lepidocrocite. Whereas the former usually crystallizes as needles, the latter appears rather as platelets, so that the analysed needles must therefore be goethite.

These fibres described previously, are intercalated with larger formless masses (Figure 3). Analysed by the electron microprobe, these inclusions also proved to be iron, but because of their fineness, a quantitative analysis was only possible with one grain. This was found to be haematite

Furthermore, red-brown discs of goethite fibres in radial arrangement were observed in some of the samples (Figure 4). These discs, which have often been found before in many apatites (Gübelin, 1974), are found almost without exception in fissures, and thus had formed as secondary or epigenetic inclusions. As a point of interest, these inclusions indicate that even after the relatively large quantities of iron were used up in the formation of goethite and haematite inclusions, the growth-chamber of these apatites was still rich in iron.

It is to be hoped that more of these exquisite apatite cat's-eyes from Tanzania will find their way onto the gem market, especially so since their beauty may easily vie with finest chrysoberyl cat's-eyes from other sources.

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[*Manuscript received 10th February, 1983.*]

MORE UNCOMMON GEMSTONES

By MICHAEL O'DONOGHUE, M.A., F.G.S., F.G.A.
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In the January 1980 issue of this *Journal** I gave a brief account of a number of gemstones not commonly encountered, with the comment that the best plan when acquiring an unusual mineral is to refrain from fashioning it. Since that MS was prepared in August 1978 I have acquired several other rare species, safely faceted before I could obtain the crystals; the stones may be of interest to readers.

Probably the most unusual of the stones is the manganese borate, chambersite. Containing some chlorine, it is found in only one place in the world, a brine in a gas storage well at Barber's Hill Salt Dome, Chambers County, Texas. Material has to be recovered by divers and when it is found can be seen to form tetrahedral shapes. The colour of my faceted stone (the mode of fashioning is dictated by the original crystal from which the points are sawn and polished) is a mauvish-grey, closer to some Madagascar kornerupine than to any other mineral, though confusion is unlikely to arise. Chambersite has a hardness of about 7 and a specific gravity of 3.49; refractive indices are 1.732-1.744.[1] Weight of stone 0.06 ct.

Hodgkinsonite takes its name from H. H. Hodgkinson, of Franklin, New Jersey, a locality name which immediately suggests zinc or manganese. In this case manganese and zinc make up a silicate with the composition $MnZn_2SiO_5.H_2O$. This is an attractive pink transparent stone with a hardness of about 4½, specific gravity of 3.95 and refractive indices 1.720-1.746. Crystallizing in the monoclinic system, hodgkinsonite forms stout prisms or acute pyramids. It is found with the classic Franklin minerals willemite, franklinite and calcite, with other species. There is a faint reddish or pink luminescence under long-wave ultraviolet light.[2,3] Weight of stone is 0.13 ct.

Still in the North American continent, boleite is found at Boleo, Baja California, Mexico. It occurs as fine single crystals of a

**J.Gemm.*, 1980, XVII (1), 7-9. 'Some Less Common Gemstones'.

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bright rich blue, though most material is opaque. My stone, weighing 0.14 ct, is best examined with a microscope. Boleite is $Pb_9Ag_3Cu_8Cl_{21}(OH)_{16}.H_2O$. It is a member of the tetragonal system, forming pseudo-cubes. The hardness is about 3½ and the specific gravity just over 5. Refractive indices are 2.05 and 2.03 for the ordinary and extraordinary rays respectively. It occurs as a secondary mineral in lead and copper deposits and is associated with other secondary lead minerals. The crystals are sought by collectors.[4]

Hauyne is best known to gemmologists as one of the minerals which make up lapis lazuli. It is probably less well known that there are fine royal blue transparent crystals (grains would be a better description) in the area of the Laacher See in West Germany; excellent sanidine is also found here. Hauyne is $(Na,Ca)_{4-8}[Al_6Si_6O_{24}](SO_4,S)_{1-2}$. It is a member of the cubic system and has a hardness of about 5½ with specific gravity 2.5. Refractive index is near 1.50. It occurs in alkaline igneous rocks with another rare mineral, leucite, also cut as a gemstone from time to time. With the minerals sodalite and nosean it forms part of the sodalite group. Some hauyne is reported as showing an orange luminescence but my specimen does not show it.[5]

Milarite (not to be confused with millerite) has the composition $KCa_2AlBe_2(Si_{12}O_{30}).H_2O$ and is a member of the hexagonal system. The name is taken from the Swiss location of Val Milar, though it is now known that the mineral is not in fact found there. It forms yellowish-green crystals and all faceted crystals are from either Mexico or Namibia—mine is from the latter country. It is found in vugs in granites or in syenites and has a hardness of about 5½. Specific gravity is about 2.5 and refractive index 1.52-1.55. The weight of my specimen is about 0.10 ct.[6]

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THE LABORATORY MOVES

By A. E. FARN, F.G.A.

The heading of this article can be accepted as singular or plural. Singular, perhaps, because it is in fact an unusual and interesting event, new to some. Plural because it has happened before, each move being in itself a formidable undertaking and representing an era in the history of the Laboratory.

Since I am writing for gemmologists, perhaps I may be allowed the assumption that by the Laboratory, of course, I mean the Gem Testing Laboratory of the London Chamber of Commerce and Industry. At least that is its recent title. Such moves, apart from being milestones in lab history, also represent a new outlook and thinking as well as a new address. I have mentioned this latter fact before in talks and articles (on pearls and cultured pearls) 'that gemmology in Great Britain owes a lot to the Japanese and the team of B. W. Anderson and C. J. Payne.'

The Laboratory was not originally conceived as a gem-testing laboratory but as a pearl-testing station to combat the cultured pearl threat to the vast and important pearl trade extant in the twenties. When B. W. Anderson was engaged in 1925 he was a young graduate of University of London King's College. He knew nothing of pearls. The venture was not at first the Laboratory of the London Chamber of Commerce but a laboratory whose furniture, fixtures, fittings, etc. were subscribed for personally by the leading pearl merchants of the day. Later it was decided that to give the Laboratory a soundly based official representation it should be administered by the London Chamber of Commerce. This cachet served to remove from it any possible criticism of bias, etc., towards any particular founder member. This was the strength of the Laboratory, ensuring its utter independence. It may well be that it was hoist with its own petard in not searching for other means of income when testing fees and income from membership fell well below the requirements of salaries, rent, etc.

The first Laboratory premises were in Diamond House, Hatton Garden, from 1925 to 1929. These were somewhat simple premises with minimal equipment, but were the base whence

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FIG. 1. B. W. Anderson positioning pearls for lauegrams on the 1929 x-ray generating set.

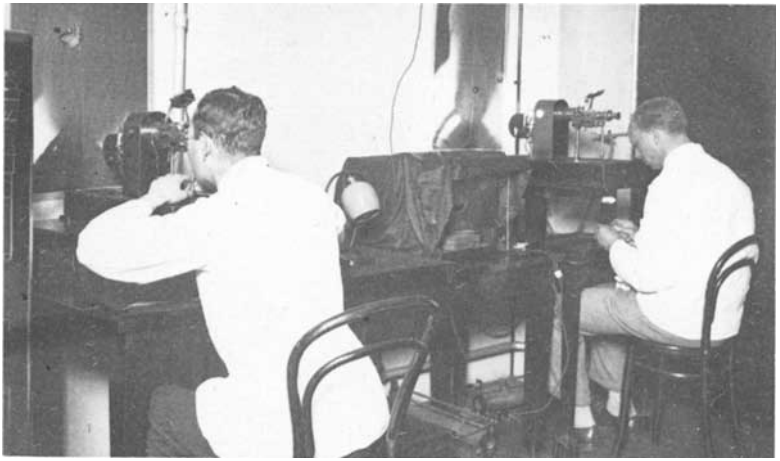

FIG. 2. C. J. Payne (left) and B. W. Anderson (right) testing drilled pearls by endoscope (usually in darkness).

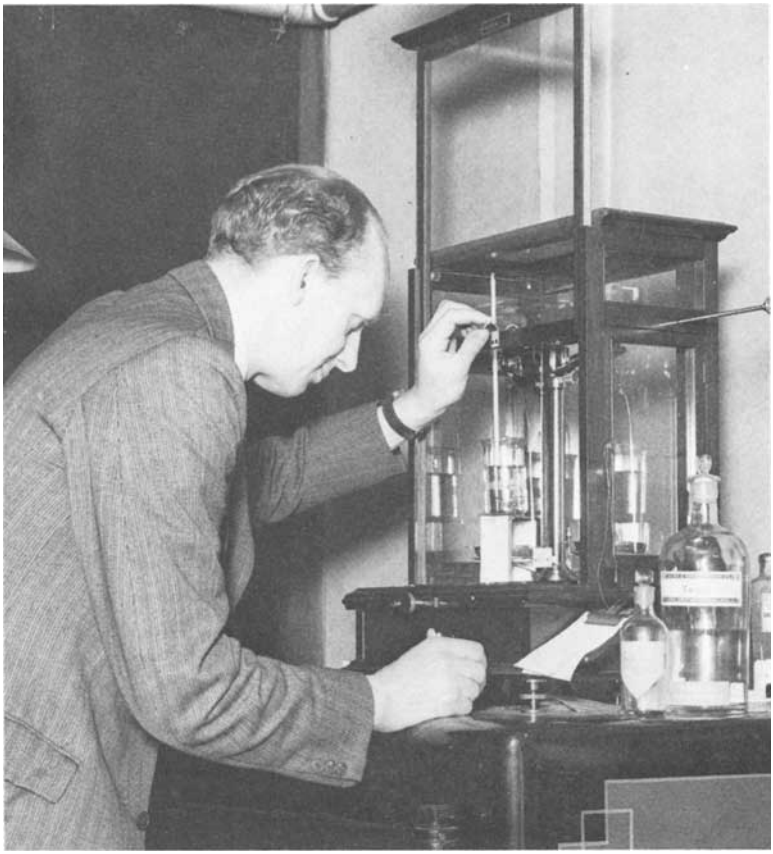

FIG. 3. B. W. Anderson doing a hydrostatic weighing.

gemmology research began. The most important move in the Laboratory's history was made in 1929, when new premises at 55 Hatton Garden were opened on 1st July. An x-ray generating set for the testing of undrilled and part-drilled pearls, which had been ordered in 1928, was successfully installed and proved satisfactory (Figure 1). In October of that year the premises were inspected by Lord Herbert Scott, Sir Geoffrey Clarke and other officers of the Chamber. In that first year at 55 Hatton Garden, over 45 000 pearls were tested; these contained a larger proportion of cultured pearls than in the previous years' testing (Figure 2). From that

FIG. 4. B. W. Anderson using spectroscope with microscope.

Laboratory and from Diamond House came the work on gemstones which was largely made possible by the world slump conditions of the late twenties and early thirties. The drop in the pearl market was tremendous and left the two graduates of London University, B. W. Anderson, B.Sc., and C. J. Payne, B.Sc.,

virtually unemployed within their laboratory. This period proved of great benefit to research on many aspects of gemstones, earlier textbooks having been produced by virtually re-hashing older books and quoting incorrect figures and characteristics. These mistakes were discovered by Anderson and Payne, and more careful routine work followed (Figure 3). At that time they were given considerable support by public-spirited merchants who foresaw the necessity for research in their trade.

To C. J. Payne goes the credit for devising the light-gathering method using the microscope tube for the study of spectra (cf. Figure 4).

B. W. Anderson produced his famous thirty-nine articles on the absorption spectra of gemstones, which are universally accepted as standard today. Thus the pearl-testing station which originated from the cultured-pearl threat inadvertently benefited the gemstone trade. The war years intervened at 55 Hatton Garden (Figure 5). C. J. Payne joined the Territorials and left Anderson to carry on the Laboratory, plus working as an active member of the Auxiliary Fire Service.

After the war a pile-up of work awaited clearance, together with mountainous stocks of small calibré rubies and sapphires. Additional staff of Robert Webster, F.G.A., and myself were taken on in 1946.

Following the very noisy explosion and blowing of the x-ray set in March 1948, a new set was planned and ordered. The new x-ray set had an inbuilt viewing chamber for the observation of fluorescence and phosphorescence. Altogether it was a vast improvement on the old 1929 set (Figure 6).

The Laboratory moved to new premises in 1954 at number 15 Hatton Garden. This address, being most central in Hatton Garden, was to us at that time the most enjoyable. It was a partitioned basement with good facilities for endoscope and dark room work at the rear. The front had two very reasonable windows of a sub-basement elevation, affording considerable light plus fire escape. A very narrow cell-like room, just wide enough for my desk at one end, faced the door with a small window at which trade members called to deliver and collect goods. Thus I was constantly in touch and, of course, on view. This contact gave me a considerable knowledge of people in the trade and vice versa. It was from here that Robert Webster retired, causing the first break in a

FIG. 5. No. 55 Hatton Garden (centre) during the war years (Laboratory on second floor).

team of four which had lasted twenty-five years. Later C. J. Payne retired, causing us to engage new staff. These, of course, by necessity, needed to be young men. When I now look at their photographs they do indeed seem young—what they thought of 'we four' must be imagined.

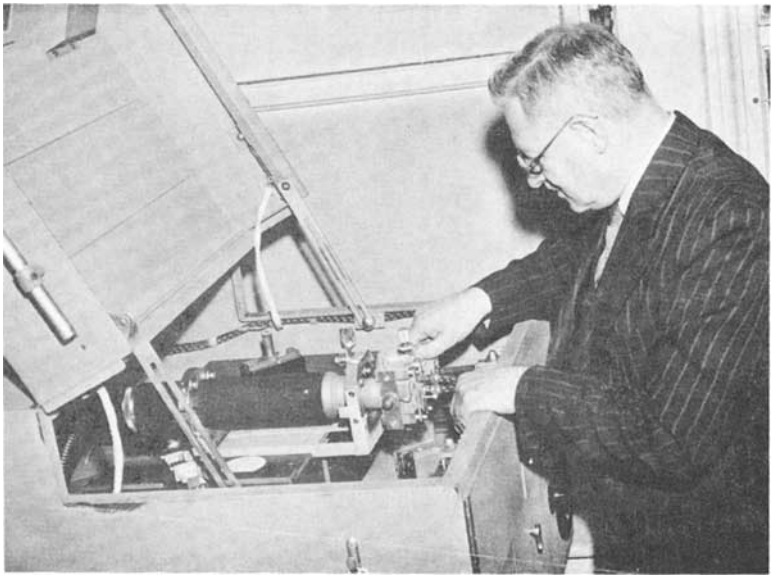

FIG. 6. Robert Webster operating the present x-ray set for undrilled pearls.

Up to this time at 15 Hatton Garden, until our next move, the Laboratory had been one hundred per cent gemmological, i.e. the investigation and detection of gemstones, synthetics and artefacts, pearls, cultured pearls and imitation pearls. The biggest and saddest blow came with the eventual retirement of B. W. Anderson in 1971.

We had tenure of 15 Hatton Garden until Christmas Day 1971 and removed from there just after Christmas. To me it was a real and final break with my immediate past and colleagues, the end of an era. We had, again, a new laboratory to furnish, fresh staff to teach, interior alterations to suffer, whilst still providing a service to the trade. These were for me the hardest years of all, having suffered considerably from a long bout of shingles in the head and having lost my old and irreplaceable colleagues.

Staff came and went, the new Laboratory at 36 Greville Street, again a basement, suffered as did 15 Hatton Garden from flooding, debris and damp. Much improvement was introduced by warm-air ventilation and pavement lights replaced, etc. Perhaps one of the biggest alterations in policy was that of the acceptance of diamond grading under the auspices of C.I.B.J.O. The Laboratory became

the officially recognized C.I.B.J.O. laboratory for Great Britain. Again, not only new but extra staff were engaged and much more expensive equipment purchased. Security printing (certificates) and extra security precautions were necessary. The concept of gem merchants entering our inner hall and ringing the bell for attention disappeared. Crime statistics made T.V. screening and security imperative. Attending C.I.B.J.O. meetings on nomenclature and technical help towards correct wording of trade regulations made additional demands on the Laboratory. To say simply that the old order changeth is an understatement. With new demands and changed policies plus younger staff, it is inevitable that yet again, with the once more 'new move,' new address, the Laboratory will function in a new role.

The Laboratory now includes diamond grading as part of its services; and teaching courses have courageously been launched within the Laboratory. These latest changes have been an attempt to increase income over that gained solely by fees from gem testing.

It was whilst at a meeting that I noted the lack of knowledge among some participants of the contributions that the Laboratory has made to the good of the trade and gemmological knowledge. One question was, 'What has the Laboratory to do with education?'—meaning 'why are they starting classes, etc?' One wonders where classes, instructors, invigilators, examiners and the supply of suitable questions for examinations or the checking of examination stones would have been, had it not been for such stalwarts of the Laboratory staff as B. W. Anderson and Robert Webster. Those two people must have instructed and inspired many of today's instructors—perhaps some of the more recent gemmologists may not have had the benefit or pleasure of such inspiration. Nevertheless the basis of most of modern gemmological knowledge stemmed from the Laboratory at 55 and 15 Hatton Gardens.

Because the Laboratory never started off by making profits from its knowledge, it has never been able to make enough money by its fees from gem testing or fees from membership. It has undoubtedly had considerable and consistent help from De Beers, from the National Association of Goldsmiths, the Gemmological Association, and the British Jewellers' Association, among others, plus several individual acts of generosity by its own members. Although it is a trade orientated laboratory, it is not supported by

the entire jewellery trade, i.e. no general levy is enforced or asked for. The trade without the Laboratory would not have progressed far.

The trade proper and gemmologists in general throughout the world have benefited from freely published findings of densities, structure in synthetics, the whole range of absorption spectra of gemstones, refractive index/indices measurements, contact liquids for refractometers, the Chelsea filter, crossed filter techniques, fluorescence and phosphorescent effects by x-ray and ultraviolet excitation, cooling techniques to enhance fugitive spectra in diamonds, etc. Many observations on structures in natural brown diamond and much work on the spectra of diamond stemmed from 55 and 15 Hatton Garden.

With the new move in mind* and concern for the well-being of the Laboratory I have written these few lines, hoping that when and if the Laboratory in its work and researches needs help, the response will come, not only from the trade, but also from gemmologists in other walks of life. Yes, the Laboratory has had a lot to do with theory and practical gemmological education.

[*Manuscript received 10th November 1982.*]

*This article was intended by Mr Farn to appear as closely as possible to the opening date of the Laboratory's newest premises, which are on the third floor of 27 Greville Street and were officially opened on 16th February 1983.—Ed.

NATURALLY-COLOURED AND TREATED YELLOW AND ORANGE-BROWN SAPPHIRES

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ABSTRACT

Natural yellow, orange and orange-brown sapphires owe their colour to colour centres and/or to trace elements (Fe^{3+}, Ti^{3+}, Cr^{3+}). Similar colorations can be achieved in synthetic corundums by Ni^{3+} and Cr^{3+} as well as by an additional annealing procedure. With colourless or pale yellow natural corundums, comparable hues can be obtained by irradiation or by annealing. Both types of treatment (irradiation or annealing) generate colour centres which cause a continuous increase of light absorption from orange to the blue end of the visible spectrum. They also produce a broad absorption band at approximately 21 500 cm^{-1} (465 nm). These treated natural corundums appear in intense yellow to orange-brown colours. While the colour centres, artificially induced by irradiation, are extremely unstable, the colour centres created by annealing do not heal out on further heating up to 1000 °C. For use in jewellery annealed stones can thus be considered colour-stable.

With regard to absorption, the irradiated or heated corundums differ little from naturally-coloured light yellow sapphires from Sri Lanka, apart from the generally stronger absorption in the violet and ultraviolet regions. On the contrary, intensely yellow to yellow-brown sapphires exhibit a pronounced iron or iron-chromium spectrum and synthetic yellow to orange corundums show a nickel or nickel-chromium spectrum. The inclusions of annealed golden yellow sapphires present the same modified characteristics as those encountered in heated corundums of the other hues.

In practical gemmology, the problem of identifying irradiated as well as synthetic yellow and orange-brown corundums has repeatedly been a matter of discussion (Oughton, 1970; McColl, 1970; McColl & Oughton, 1971; Schiffmann, 1981). The present study compares the results of an investigation on a *new type of golden-yellow corundums* (on one side) with the well-known natural and synthetic yellow and brown sapphires (on the other side). These new stones have been on the gem market for some time, occasionally offered by the dealers as corundums of 'treated' yellow to orange-brown colour. Colorations similar to these treated ones are shown by untreated natural yellow corundums known to originate from Sri Lanka, Thailand, Tanzania and Australia and

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TABLE 1. Causes of coloration of yellow, orange and orange-brown corundums

	Colour	Colour causes	Colour after heating to 500 °C	Colour after irradiation with x-rays
untreated natural corundum	pale yellow[a]	colour-centres ± Fe^{3+}	colourless*	more intensely yellow-orange
	pink-orange[a] (padparadshah)	colour-centres + Cr^{3+} ± Fe^{3+}	pink (pale ruby)	
	intensely yellow[b,c,d]	Fe^{3+} + Ti^{3+} Fe^{3+} + Cr^{3+} Fe^{3+} + Ti^{3+} + Cr^{3+}	unchanged	
	yellow-orange to orange-brown[d]	Fe^{3+} + Cr^{3+}	unchanged	
annealed natural corundum	intensely yellow, yellow-orange or orange-brown	colour centres	unchanged	more intensely yellow, orange or brown
irradiated natural corundum	intensely yellow, yellow-orange or orange-brown	colour centres	colourless*	intensely yellow, yellow-orange or orange-brown
synthetic corundum, in part annealed, doped with Ni ± Mg, Fe, Ca Cr ± Mg, Fe, Ca Ni + Cr ± Mg, Fe, Ca	yellow or yellow-orange†	Ni^{3+} or Cr^{3+} or Ni^{3+} + Cr^{3+} ± colour-centres (produced by annealing)		

Sources: a Sri Lanka, b Australia, c Thailand, d Tanzania

*Occasionally a residual pale yellow coloration is visible (Fe^{3+}).

†Further possibilities of yellow coloration of synthetic corundums are conceivable. In a yellow-orange specimen of Verneuil corundum Ca and V were detected experimentally (in the absence of Ni and Cr).

TABLE 2. Chemical data for natural and synthetic yellow and orange sapphires, in weight % (atomic absorption spectroscopy*)

Source	Colour	Mg	Cr	Mn	Fe	Ni	Spectrum
Sri Lanka	pale yellow	0.008	0.004	0.002	0.05	0.011	Fig. 1c
Sri Lanka	pale yellow	0.010	0.005	0.002	0.11	0.004	Fig. 1b
Anakie, Australia	intensely yellow	0.008	0.004	0.002	0.75	0.007	Fig. 4b
Umba, Tanzania	intensely yellow	0.015	0.008	0.004	0.50	0.006	Fig. 5a
Umba, Tanzania	intensely yellow	0.007	0.012	0.003	0.42	0.003	Fig. 5b
synthetic sapphire, Verneuil (annealed?)	light yellow	0.010	0.013	0.004	0.04	0.011	Fig. 7a
synthetic sapphire, Verneuil (annealed?)	orange	0.006	0.016	0.003	0.02	0.007	Fig. 7b

*Ti<0.05; V≪0.005; Ca<0.05 (in all specimens); the vanadium contents of the samples are near the limit of detectability of the method used; in small concentrations vanadium reinforces the colour due to Cr^{3+} (Schmetzer & Bank, 1981).

by the padparadshah variety from Sri Lanka. The golden-yellow colours also are comparable to those of artificially irradiated yellow to orange-brown sapphires as well as to the coloration of synthetic yellow to orange-brown corundums by Verneuil, produced by the addition of nickel or nickel plus chromium (Recker, 1973). The colours of the latter can be intensified by an additional heat treatment. A compilation of the various types of natural and synthetic yellow, orange and orange-brown corundum and of the origin of their colours is presented in Table 1 (cf. Schmetzer & Bank 1980, 1981). New analytical data are given in Table 2.

Natural pale yellow corundums are coloured by colour centres and so far are known to the authors to originate only from Sri

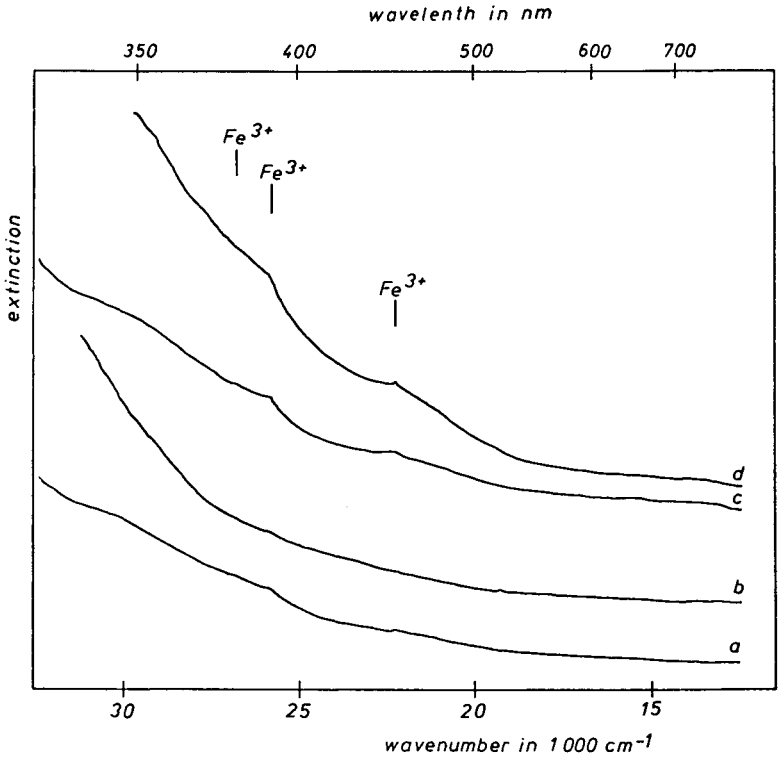

FIG. 1. Absorption spectra of pale yellow naturally-coloured corundums from Sri Lanka.

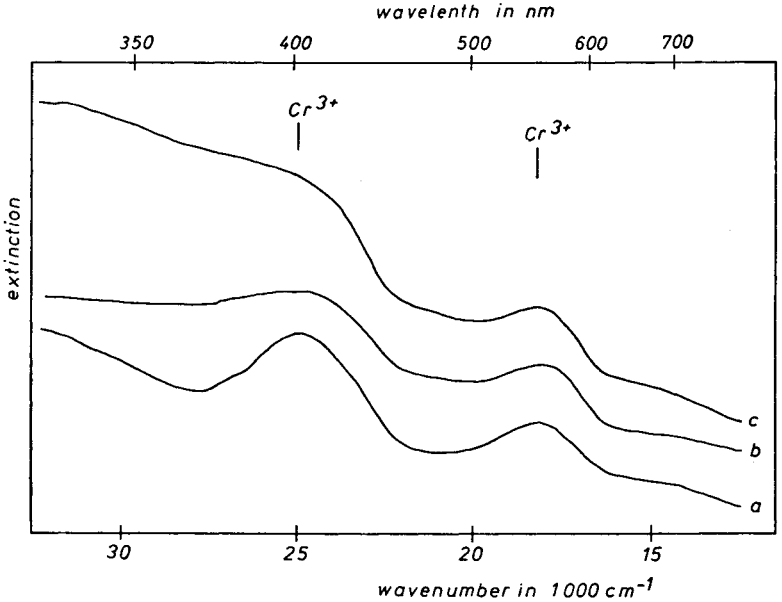

FIG. 2. Absorption spectra of the pink-orange corundum variety padparadshah from Sri Lanka.

Lanka. In the visible region their absorption continuously rises from orange to violet without showing any pronounced absorption maximum. Frequently weak Fe^{3+} absorption bands can be observed (Figure 1) which, however, have no distinct effect on the colour due to the low Fe contents of about 0.005 to 0.11% (Harder 1969, cf. also Table 2). The chromium contents of these yellow corundums are too low to clearly influence the colour (Harder 1969; Table 2). Sapphires containing higher proportions of Cr^{3+} (Figure 2) or Cr^{3+} and Fe^{3+} (Figure 3) and showing the absorption spectrum of light yellow corundums from Sri Lanka, caused by colour centres, are coloured pink-orange and called padparadshahs. Heat treatment at 500 °C heals out the colour centres of the described yellow and pink-orange stones. Specimens without chromium are practically colourless, those with chromium show the typical red of pale rubies. According to trade views, untreated natural yellow and orange sapphires are colour-stable.

Another type of *yellow sapphire* comes from Thailand and Australia. Stones from these sources show iron contents between

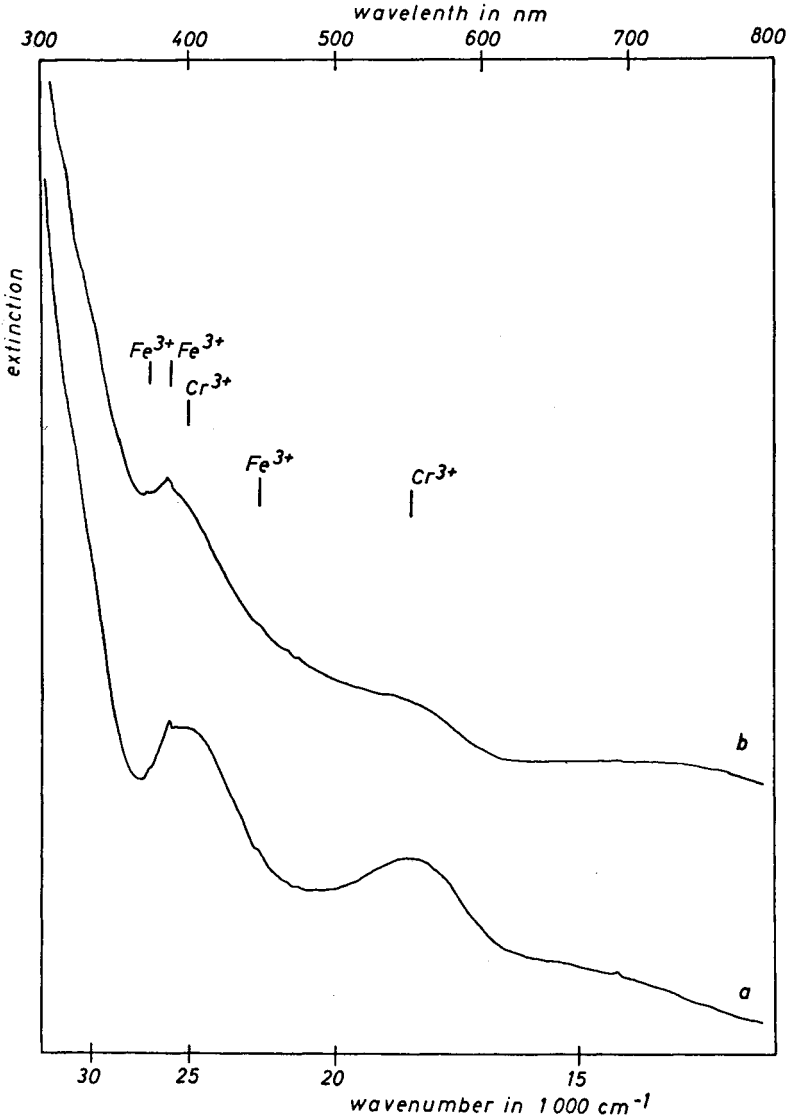

FIG. 3. Absorption spectra of the pink-orange corundum variety padparadshah from Sri Lanka.

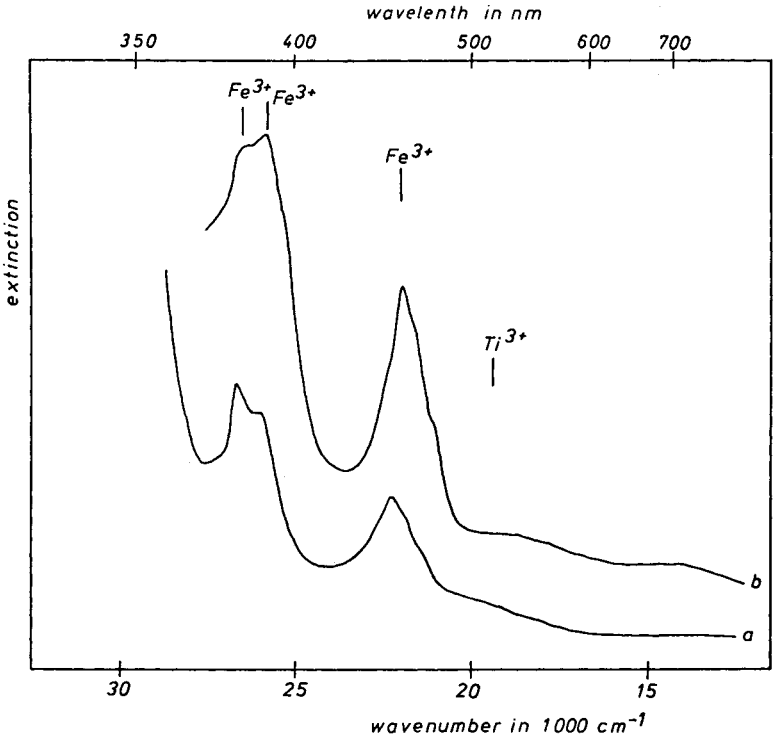

FIG. 4. Absorption spectra of golden yellow naturally-coloured sapphires from (a) Thailand, (b) Anakie, Australia.

0.5 and 0.75% Fe (Harder 1969, cf. also Table 2), which thus lie distinctly above those of the light yellow corundums from Sri Lanka. The cause for the coloration of these intensely yellow corundums is a combination of Fe^{3+} and (to a lesser extent) Ti^{3+}; here Cr^{3+} traces virtually are not colour-efficient (Figure 4). Since the valence of Fe^{3+} and Ti^{3+} cannot be changed on heating up to 500 °C (and higher temperatures), the colour of such specimens is stable under the conditions mentioned. Corundums from Umba, Tanzania, present definite amounts of Cr^{3+} in addition to the comparable Fe^{3+} percentages (Table 2). Specimens with small amounts of chromium are yellow (Figure 5), crystals with high chromium concentrations are yellow-orange to orange-brown in colour (Figure 6). As yet sapphires of this type have been noted only from Umba, Tanzania. Heating up to 500 °C does not alter the described colours.

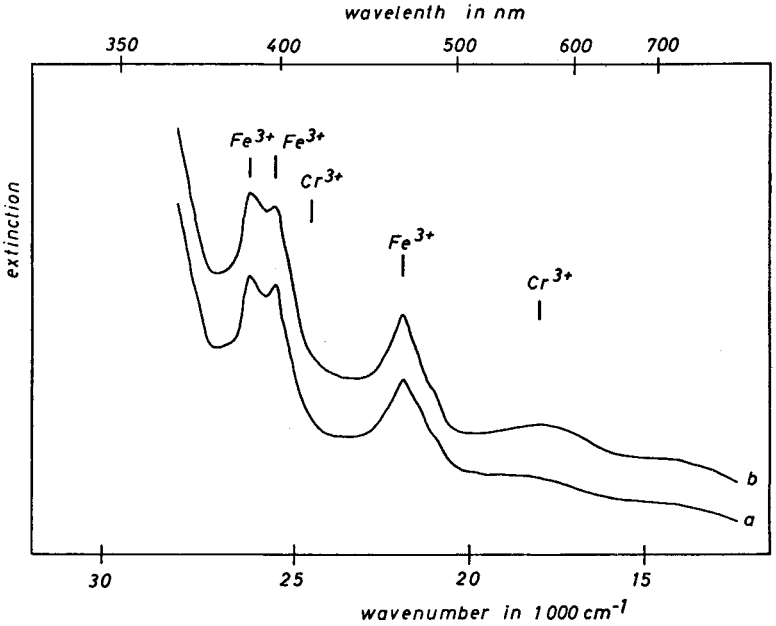

FIG. 5. Absorption spectra of yellow naturally-coloured sapphires from Umba, Tanzania.

Synthetic sapphires exhibit similar hues to those of natural sapphires although the latter mostly have other causes of coloration. The yellow colours of Verneuil synthetics are produced by Ni^{3+}, while orange hues are brought about by Cr^{3+} and Ni^{3+} (Figure 7, Table 2). By the addition of divalent cations (Mg^{2+}, Fe^{2+}, Ca^{2+}) and by subsequent annealing the colours of the commercially grown synthetic stones can be intensified, according to information on hand (cf. Table 1).

It has been known for quite some time that x- or γ-rays produce bright yellow and yellow-orange hues with originally pale yellow or almost colourless sapphires from Sri Lanka. The improved colours, however, become unstable when exposed to daylight (Pough & Rogers, 1947). Similarly after short-term heating to 500 °C the colour centres created by irradiation can be healed out too: the heated stones ordinarily turn completely colourless. Therefore the finding came as a surprise that the colour of *the new type of 'treated' sapphire,* which is indistinguishable

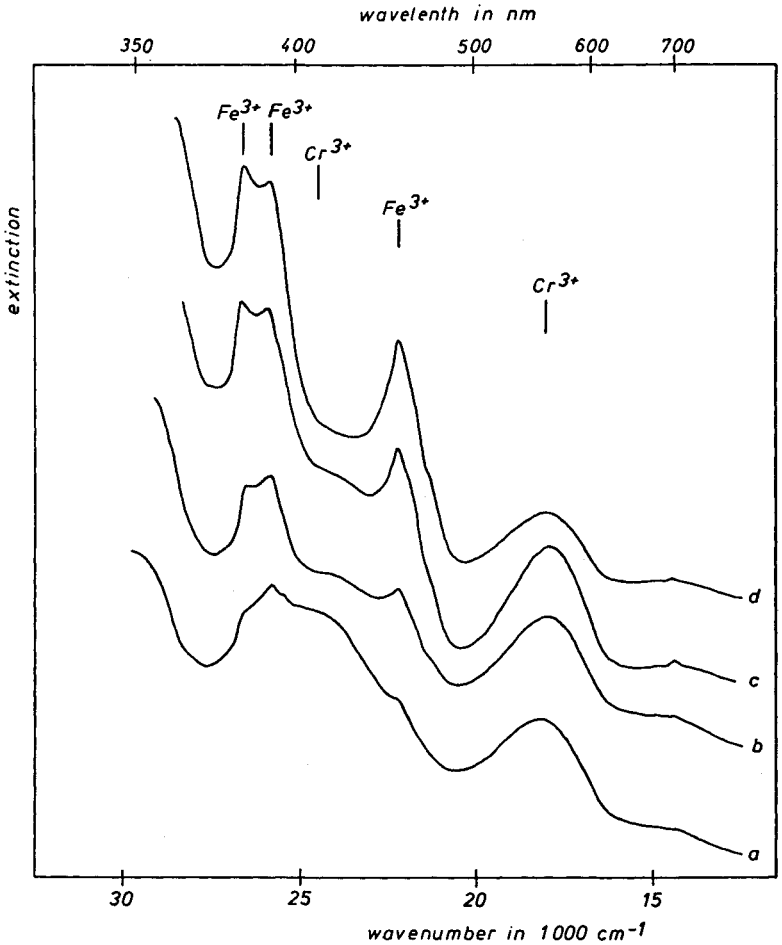

FIG.6. Absorption spectra of orange-brown naturally-coloured sapphires from Umba, Tanzania.

from the irradiated one in terms of colour, remained stable on heating at 500 °C and even up to 1000 °C. An irradiation could thus not be the cause of the strong yellow or orange coloration.

The examination of the *inclusions* of some rough and cut stones which in part stemmed directly from the corundum cookery in Thailand produced the following results (Figures 8 to 11):

— clouds of tiny inclusions mostly concentrated in certain zones and of turbid appearance under the microscope.

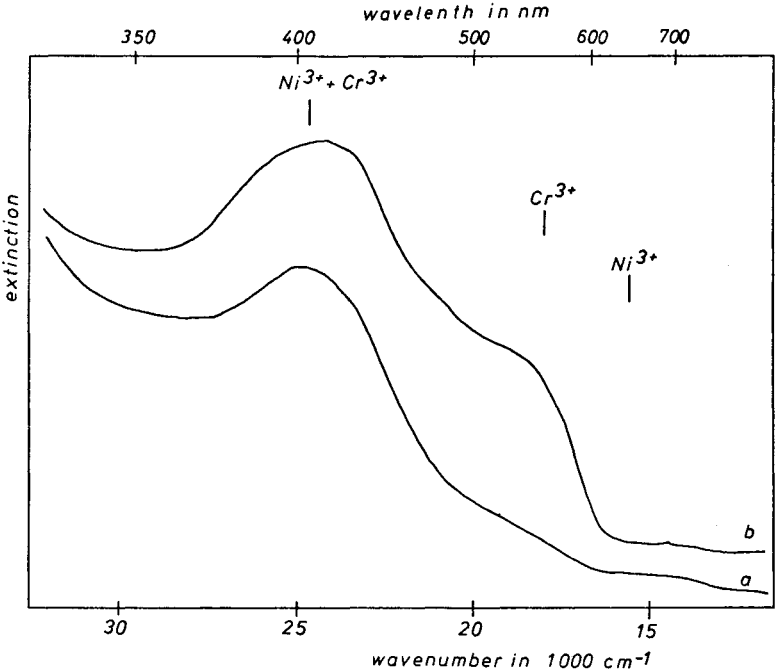

FIG. 7. Absorption spectra of synthetic corundums by Verneuil, (a) light yellow, (b) orange.

— small oval reflective tension fissures showing a more or less wide, white rim and resembling atolls. Frequently they contain a tiny mineral grain which might have caused the fissure during the heat treatment.
— spherical white aggregates of a spiky surface, occasionally surrounded by a healed tension fissure.
— larger healing cracks (feathers) with drop-shaped to tube-like cavities.
— altered fibre-like zonal structures with oriented inclusions (rutile, hollow tubes?).

The inclusions of these golden-yellow corundums thus exhibited the characteristics of the types of inclusion found in annealed natural corundums (Nassau, 1981; Crowningshield & Nassau, 1981; Hänni, 1982). A heat treatment as described recently in several articles (Gunaratne, 1981; Nassau, 1981; Crowningshield & Nassau, 1981; Harder, 1982) therefore can also be considered

proven for the specimens of the new yellow type. According to Harder (1982), temperatures above 1550 °C are applied in the annealing process for yellow sapphires, but no explanation for the cause of the yellow coloration can be given at the present time. Possibly it is related to the resorption of pre-existent mineral inclusions during annealing. Chemical analyses (microprobe, x-ray fluorescence) indicate limited contents of Fe and sometimes also of Cr and Mg. Already before the heat treatment, these elements were present in some form inside the crystal (as inclusion constituents or on Al sites of the corundum lattice) and became colour-efficient by the strong annealing. A diffusion treatment by Cr and/or Ni as described by Nassau (1981) can be excluded for the specimens at disposal, because they were rough stones or else no signs of such a treatment were observed microscopically for the cut specimens.

The absorption spectra of burnt orange-brown corundums (Figure 12 a to c) show increasing absorption in the visible range from orange to violet as well as a broad absorption band with a peak position near 21 500 cm^{-1} (465 nm). Consequently the spectra are identical with the spectra of irradiated vividly orange to orange-brown sapphires (Figure 12 e, f) which were colourless or pale yellow before irradiation like the corundums of the type represented in Figure 1. The absorption spectra of annealed or irradiated yellow to orange-brown corundums thereby differ clearly from the Fe-Cr spectra of natural yellow, orange or orange-brown sapphires (Figure 2 to 6). By subsequent additional irradiation of the annealed yellow corundums, their coloration can be reinforced. The absorption spectra of such heated and irradiated corundums exhibit the same characteristics as the spectra of solely annealed or solely irradiated sapphires (Figure 12 d). A second heat-treatment heals out the colour centres additionally produced by the irradiation. The coloration and the intensity of the absorption bands correspond to the status before irradiation (after the first annealing), which means that the stones still are yellow-orange to orange-brown in colour.

The influence of the various *colour centres* on the optical properties of rubies and sapphires as well as the methods of their creation in synthetic corundums have been discussed in a considerable number of papers. While formerly synthetic chromiferous corundums (rubies) were of primary interest due to their importance for laser techniques (e.g. Flowers & Jenney, 1963;

FIG. 8. Clouds of tiny inclusions and reflective, marginally structured tension fissures in an annealed yellow corundum; 40×.

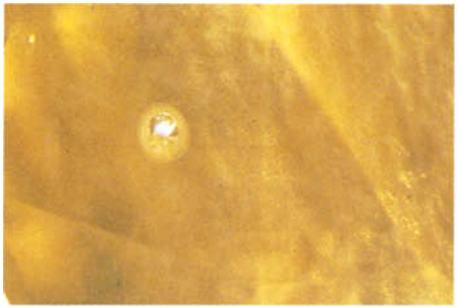

FIG. 9. Plate-like tension fissure resembling an atoll, in an annealed yellow corundum; 30×.

FIG. 10. Healing fissure of drop-shaped and tubular cavities in an annealed yellow corundum; 40×.

FIG.11. Fibre-like altered, oriented inclusions and plate-like tension cracks in an annealed yellow corundum; 10×.

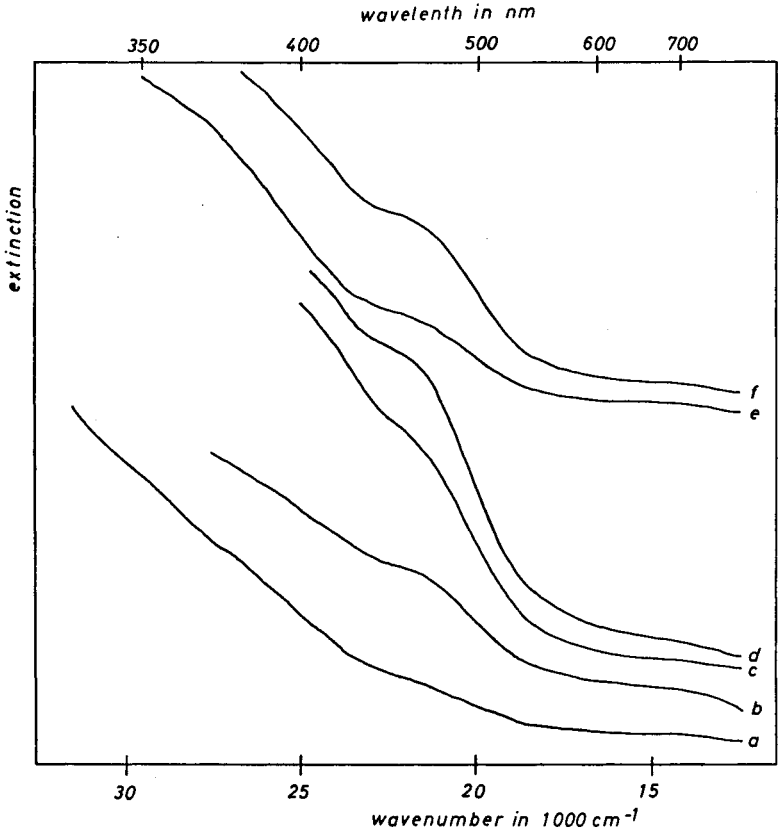

FIG. 12. Absorption spectra of treated yellow, yellow-orange and orange-brown sapphires; (a,b,c) annealed corundums, (d) sample b additionally irradiated, (e,f) originally pale yellow, irradiated corundums from Sri Lanka.

Schultz, 1964; Hoskins & Soffer, 1964; Standley & Vaughan, 1965; Arkhangelskii *et al.*, 1967, 1969; Sviridov, 1968; Borer *et al.*, 1970; Sidorova *et al.*, 1972, 1973; Sandreyev *et al.*, 1973; Bessonova *et al.*, 1974; Kvapil *et al.*, 1981), more recently a series of studies deals with the optical properties of undoped corundums following heat-treatment and/or irradiation as well as of corundums doped with divalent cations, e.g. Fe^{2+}, Mg^{2+}, Ca^{2+}, Be^{2+} (Gamble *et al.*, 1964; Bartram *et al.*, 1965; Gorban' & Kondratenko, 1972; Kvapil *et al.*, 1972, 1973; Govinda, 1976; Lee *et al.*, 1977; Lee & Crawford, 1978; Kulis *et al.*, 1979, 1981). Without specifying the nature of the colour centres, described in the various articles but not yet entirely

explained in detail, it may be stated that colour centres with absorption maxima in the visible and UV similar to those mentioned here can be produced in synthetic corundums as well. The colour centres in synthetic crystals are created by doping with divalent cations and/or chromium and a subsequent annealing at high temperatures or by subsequent irradiation of the crystals. The absorption bands produced by annealing synthetic corundums can also be intensified by a subsequent irradiation. The radiation-induced colour centres heal out on heating e.g. to 500 °C while those of annealed, doped corundums are fairly stable.

The cation or the various cations necessary to form colour centres in the heated natural corundums examined in this study, cannot be indicated at present. Natural corundums usually show several di- and tri-valent cations as impurities, but only in trace amounts (cf. Harder, 1969; Table 2). In the annealed yellow sapphires in question, traces of Fe were identified by non-destructive analytical methods (XRF and microprobe analyses, both in energy- and wavelength-dispersive mode). The concentrations of other cations like Cr, Ni, and Mg used to dope synthetic crystals only occasionally were found within the limits of detectability of the applied methods. As Table 2 demonstrates, trace amounts of Cr and Mg were detectable in all natural corundums analysed with the aid of the more sensitive atomic absorption spectroscopy. These results are also valid for annealed yellow corundums so that the presence of several cations (e.g. Mg, Fe, Cr) in minor concentrations can be assumed. So far it is a matter of uncertainty, if the colour centres are created during the annealing process by a divalent cation like Fe^{2+} or Mg^{2+}, by a trivalent cation like Cr^{3+} or Fe^{3+} or by several di- and tri-valent cations.

The *distinction* of annealed or irradiated natural corundums from yellow to orange-brown corundums and synthetic corundums is possible on the basis of their spectroscopic and microscopic characteristics compiled in Figures 1 to 12. A diffusion treatment is discernible by optical examination (Hänni, 1982).

The annealing of pale yellow corundums leads to stable colorations. According to CIBJO *nomenclature* this treatment is a practice tolerated by the trade and has not to be declared explicitly. This stands in contrast to the diffusion-treatment of corundums, which must be indicated without exception.

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TAAFFEITE OR TAPROBANITE—A PROBLEM OF MINERALOGICAL NOMENCLATURE

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ABSTRACT

By chemical and crystallographic investigations of samples originating from Sri Lanka, U.S.S.R. and China, the identity of the natural Be-Mg-Al-oxides taaffeite and taprobanite, named by Anderson *et al.* (1951) and Moor *et al.* (1981) respectively, was established. For both minerals a formula of $BeMg_3Al_8O_{16}$ is valid; all samples investigated were found to be hexagonal with lattice parameters of $a_o \approx 5.7$, $c_o \approx 18.3$Å, space group $P6_3mc$ (extinction rule hhl: $l = 2n$).

The problem of a correct naming of this mineral species (taaffeite or taprobanite) leads to a general question of descriptive mineralogy: has a definition of a mineral by its type material priority over a definition by its original description? The consequences of both procedures for the commonly used system of mineralogical nomenclature are discussed.

Due to a vote of the Commission on New Minerals and Mineral Names of the International Mineralogical Association a definition of a mineral species by its type material has priority over a definition by its original description. A second vote of the Commission decided, that for the hexagonal mineral corresponding to the chemical formula $BeMg_3Al_8O_{16}$ the name taaffeite should be used in future.

In October 1945 Count Edward Charles Richard Taaffe bought a parcel of 50 or more cut stones from a Dublin jeweller, all of which were broken out of old jewellery. During the gemmological investigations of these stones, which were determined as zircons, opals, garnets, quartzes, spinels, rubies, sapphires, and emeralds, an unusual bluish-violet stone resembling spinel in its colour was found by Count Taaffe. This gemstone had a distinct double refraction and, therefore, could not be a spinel. The sample was given to B. W. Anderson in London for further investigations, leading finally to the description of a new mineral species, which was named taaffeite in honour of its discoverer (Anderson *et al.*, 1951).

Taaffeite was the first mineral, which was found for the first time in form of cut gemstones, originating probably from Sri Lanka. Natural taaffeite crystals from localities in China, U.S.S.R. and Australia became available later between 1963 and 1977. However, these crystals were very small in size, and material

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suitable for cutting was not found in the rock samples from these countries. As already mentioned above, taaffeites from Sri Lanka resemble spinels in their bluish-violet colour. A distinction of both minerals, however, can easily be done with the gemstone refractometer by means of the small double refraction of 0.004 of taaffeite. It is known that several individuals of cut taaffeites were discovered in parcels of spinel from Sri Lanka. Therefore, such gemstones are often systematically searched with the polariscope and refractometer for taaffeite, which is one of the rarest gem minerals presently known.

At the time of the original description of the new mineral taaffeite (Anderson *et al.*, 1951), only two cut samples of this rare gemstone were known: as already mentioned, the first taaffeite of 1.42 carats was found in 1945 by Count Taaffe in Dublin, and a second stone of 0.87 carats was found in 1949 by C. J. Payne in London. The quantitative chemical analysis of only 6 mg(!) substance and the x-ray single crystal and powder data, which were published by Anderson *et al.* (1951), were mainly carried out with fragments of Count Taaffe's stone (holotype specimen of taaffeite). From this specimen, a cut stone of 0.56 carats remained, which was kept in the private collection of Count Taaffe (Figure 1); for further details of the history of this gemstone compare a recently published paper by Mitchell (1982). Only two additional cut taffeites became available between 1951 and 1974: a stone of 0.84 carats was found in 1957 by R. Crowningshield in New York, and a bigger sample of 5.34 carats was discovered in 1967 by an American collector (cf. Liddicoat, 1967; Mitchell, 1967; Anderson, 1968, 1974).

The most important chemical and physical data given in the original description of taaffeite by Anderson *et al.* (1951) are set out in Table 1. According to these values, taaffeite is a hexagonal Be-Mg-Al-oxide, whose formula can be derived from spinel by a replacement of one half of the Mg-atoms by Be: $4\times$ the formula unit of spinel $MgAl_2O_4$ leads to the formula $Mg_4Al_8O_{16}$; the taaffeite formula is given by Anderson *et al.* as $Be_2Mg_2Al_8O_{16}$.

In order to understand some of the decisions of the following period, it has to be mentioned, that after 1951 no further chemical or x-ray data of taaffeite from Sri Lanka were published. Under these pre-conditions, i.e., with the knowledge of the publication by Anderson *et al.* (1951), a cut gemstone of red colour from Sri

Lanka was offered in the trade as red taaffeite (Figure 2). The crystal showed the gemmological properties of taaffeite, e.g., refractive indices, density, hardness, and was bought by E. Gübelin, of Meggen, Switzerland. The investigations of this gemstone with modern analytical methods, which were not available in 1951, showed two distinct differences between the already published data of taaffeite from Sri Lanka and the red crystal (Moor *et al.*, 1981). By x-ray single crystal investigations a different extinction rule, i.e., a different space group, was observed. Chemical investigations gave a different composition, leading to a new formula for the red gemstone (cf. Table 1).

FIG. 1. Original taaffeite of Anderson *et al.* (1951), Sri Lanka; sample A6, 0.56 carats. *(Photo by E. A. Jobbins, London.)*

FIG. 2. Original taprobanite of Moor *et al.* (1981), Sri Lanka; sample A8, 0.33 carats. *(Photo courtesy of E. Gübelin, Meggen.)*

Deriving this new formula again from spinel, in contrast to the old analysis, only one fourth of the Mg-atoms have to be replaced by Be: 4× the formula unit of spinel $MgAl_2O_4$ leads to $Mg_4AL_8O_{16}$; the formula of the red gemstone is given by Moor *et al.* as $BeMg_3Al_8O_{16}$. Comparing some further properties of the new gemstone with the data published for taaffeite, no significant differences were found, e.g., in density, refractive indices, crystal system, lattice parameters, x-ray powder diffraction pattern (Table 1). The complete mineralogical description of the red gemstone was given to the Commission on New Minerals and Mineral Names of the International Mineralogical Association, and the new mineral taprobanite and its name were approved by the Commission in March 1980 (cf. Moor *et al.*, 1981). The red colour of the crystal, which had been the reason for the intensive investigations, was found to be caused by traces of 0.12% Cr_2O_3. This allochromatic

TABLE 1.

Chemical and physical data of taaffeite and taprobanite, taken from the original descriptions of Anderson *et al.* (1951) and Moor *et al.* (1981).

	Chemical Data [weight %]	
	Taaffeite	Taprobanite
Al_2O_3	70.0	73.63
Cr_2O_3		0.12
Fe_2O_3	5.9	
FeO		1.24
MgO	13.4	21.64
BeO	11.0	4.4
Formula	$Be_2Mg_2Al_8O_{16}$	$BeMg_3Al_8O_{16}$

	Physical Properties	
	Taaffeite	Taprobanite
Crystal system	hexagonal	hexagonal
Lattice parameters		
a_o[Å]	5.72	5.684
c_o[Å]	18.38	18.332
Extinction rule	001 l = 2n	hhl l = 2n
Space group	$P6_322$	$P6_3mc$
Strongest lines in the x-ray powder diffraction pattern [Å]	4.57; 2.61; 2.43; 2.05; 1.476; 1.428	4.58; 2.595; 2.415; 2.043; 1.469; 1.421
Density [g/cm³]	3.613	3.605
Hardness	8	8
Refractive indices n_o	1.723	1.721
n_e	1.718	1.717
Double refraction	−0.005	−0.004

colour is, however, of no interest in the discussion of the nomenclature problems of this phase.

The published data of taaffeites from various localities are compared with those of the original descriptions of taaffeite and taprobanite (holotype material of taaffeite and taprobanite): for taaffeite from China and U.S.S.R. the extinction rule and space group of taprobanite are given; quantitative chemical analyses of taaffeite from both localities were not yet published in these descriptions (Peng & Wang, 1963; Kozhevnikov *et al.,* 1977). For taaffeite of an Australian occurrence only chemical data (microprobe analyses) are given (Teale, 1980). A calculation of these analytical data leads to the formula given for taprobanite rather than to the formula of taaffeite.

A third mineral, resembling taaffeite in its chemical composition, was described by Hudson *et al.* (1967) from a locality called Musgrave Ranges in Australia, and recently by Grew (1981) from Antarctica. This mineral is hexagonal (rhombohedral) with unit cell dimensions of a_o 5.68, c_o 41.1Å, and a formula of $BeMg_2Al_6O_{12}$. Both, unit cell dimensions and chemical formula, of this natural Be-Mg-Al-oxide are different from the data published for taaffeite and taprobanite. Using the proposal of the I.U.Cr.-I.M.A. Joint Committee on Nomenclature (Bailey, 1977) this mineral has to be called a polytypoid of taaffeite. For this mineral the mineral name musgravite was suggested referring to the type locality; a more detailed discussion of the nomenclature problem of this mineral is given elsewhere (cf. Schmetzer, 1981, 1983).

The initial stimulus towards a comprehensive investigation of taaffeites came from a brief note on 'new gemstones from Sri Lanka' (Gübelin, 1979). For this mineral the name taprobanite was published; the complete description of the new mineral species was given by Moor *et al.* (1981). Since the gemmological data of taaffeite and taprobanite (e.g., density, refractive indices) were almost identical, a possibility for an identification of some of the taaffeites in gemstone collections as taprobanites was theoretically seen. Beginning with four stones from the collections of E. Gübelin, Meggen, Switzerland, and of H. Bank, Idar-Oberstein, West Germany, (Table 2), chemical investigations were done by microprobe analysis, and space group determinations were carried out by x-ray single crystal techniques. Surprisingly, these investigations showed the four 'taaffeite' crystals to have the

TABLE 2

Samples

No.	Description	Locality	Collection
A1	cut gemstone of 2.71 ct.	Sri Lanka, probably from Niriella Village, Ratnapura, Sabaragamuwa	E. Gübelin, Meggen, Switzerland.
A2	cut gemstone of 3.15 ct.		E. Gübelin, Meggen, Switzerland.
A3	cut gemstone of 4.26 ct.		E. Gübelin, Meggen, Switzerland.
A4	cut gemstone of 0.75 ct.		H. Bank, Idar-Oberstein, W.Germany.
A5	cut gemstone of 11.24 ct.		E. Gübelin, Meggen, Switzerland.
A6	cut gemstone of 0.56 ct. original taaffeite of Anderson *et al.* (1951)		Owner: R. K. Mitchell, Orpington, Great Britain. Collection: Institute of Geological Sciences, London, Great Britain.
A7	cut gemstone of 2.03 ct.		B. Suhner, Herisau, Switzerland.
A8	cut gemstone of 0.33 ct. original taprobanite of Moor *et al.* (1981)		Owner: E. Gübelin, Meggen, Switzerland. Collection: Eidgenössische Technische Hochschule, Zürich, Switzerland.
A9	small fragment of 0.007 gm.		British Museum No. 1979,417, London, Great Britain.
A10	cut gemstone of 1.74 ct.		K. E. Wild, Kirschweiler, W.Germany.
A11	cut gemstone of 5.3 ct.		Smithsonian Institution No. G4509, Washington, D.C., U.S.A.
B	very small fragments of green crystals	Hsianghualing, Southern Hunan Province, China	R. Kristiansen, Torp, Norway. Smithsonian Institution No. 128386, Washington, D.C., U.S.A.
C	very small fragments, taaffeite intergrown with spinel	The Pitkäranta mining district, Lake Ladoga, Karelian S.S.R., U.S.S.R.	R. Kristiansen, Torp, Norway. Smithsonian Institution No. 134008, Washington, D.C., U.S.A.

FIG. 3. Various cut taaffeites, Sri Lanka; upper row left to right: sample A3, 4.26 carats; sample A5, 11.24 carats; sample of 4.08 carats, not investigated; lower row left to right: sample A1, 2.71 carats; sample A8 (original taprobanite), 0.33 carats; sample A2, 3.15 carats.
(Photo courtesy of E. Gübelin, Meggen; about natural size—millimetre scale at side.)

FIG. 4. Taaffeite, Sri Lanka; sample A4, 0.75 carats.
(Photo by M. Gunawardene, Idar-Oberstein.)

FIG. 5. Taaffeite, Sri Lanka; sample A7, 2.03 carats.
(Photo courtesy of E. Gübelin, Meggen.)

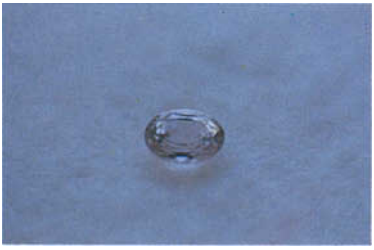

FIG. 6. Taaffeite, Sri Lanka; sample A10, 1.74 carats.
(Photo by M. Gunawardene, Idar-Oberstein.)

chemical formula and space group of taprobanite. In order to determine whether a mineral with the chemical and crystallographic data given for taaffeite exists at all, the investigation of further taaffeites from Sri Lanka and from samples originating from other localities was necessary (Table 2). Fortunately, the rest of the holotype specimens of taaffeite and taprobanite investigated by Anderson *et al.* (1951) and Moor *et al.* (1981) respectively were available. Some further cut gemstones from Sri Lanka, which were kept in different private or public collections were also given for investigation (Figures 3-6). In general, ten cut taaffeites or taprobanites and one small fragment of a rough crystal from Sri Lanka as well as some small fragments of crystals from China (Figure 7) and U.S.S.R. (Figure 8) were investigated by chemical and crystallographic methods (microprobe analyses and x-ray single crystal techniques). In addition to the ten cut taaffeites mentioned, four more cut stones were available, but analytical investigations could not be done on these samples. Only a few additional cut taaffeites are known to the author in mineralogical or gemmological collections. Therefore, at present, at least 20 cut taaffeites are known. Some of these crystals were discovered only recently in parcels of cut and rough spinels from Sri Lanka. Therefore, the discovery of more cut stones in the future has to be taken into account.

The results of the investigations of all taaffeite samples are only summarized in this paper (Table 3, cf. Schmetzer, 1981, 1983); all samples from Sri Lanka, China and U.S.S.R. were found to be hexagonal with unit cell dimensions of $a_o \approx 5.7$, $c_o \approx 18.3$Å. The extinction rule was determined as hhl: $l = 2n$ and leads to the space group given for taprobanite. The microprobe analyses gave a formula of $BeMg_3Al_8O_{16}$ for all samples; small amounts of Fe (samples from Sri Lanka), Fe, Mn, Zn (samples from China), and Zn, Fe (samples from U.S.S.R.) are found, replacing Mg in the crystal lattice of this mineral. Therefore, a general formula of $Be(Mg,Fe,Zn,Mn)_3Al_8O_{16}$ with $Mg > Fe,Zn,Mn$ is derived. These analytical results confirm the formula given for taprobanite, which is also valid for the holotype material of taaffeite and other taaffeites from Sri Lanka, as well as for all samples investigated from other localities.

Therefore, the minerals called taaffeite and taprobanite have to be considered as identical according to the rules of mineralogical

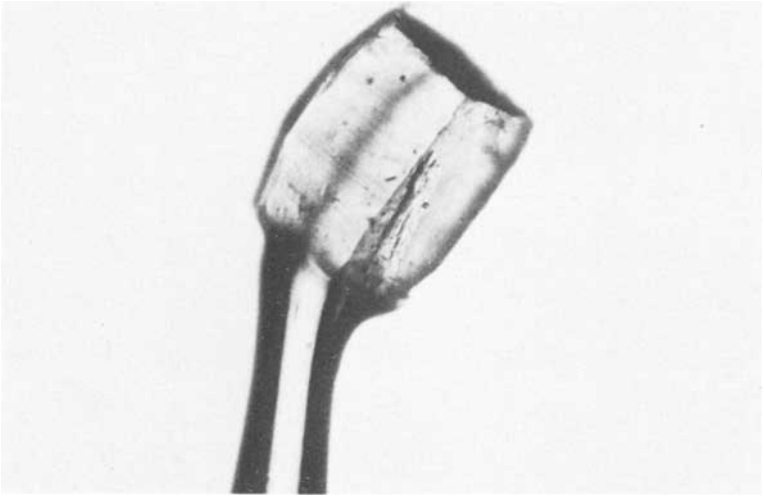

FIG. 7. Taaffeite, Hsianghualing, China; sample B.
(Photo by O. Medenbach, Bochum, 200×.)

nomenclature (the small difference in the chromium content and the different colour is of no significance for the mineral's name). In general, only one mineral name is used for a single mineral, and, therefore, the problem of a correct naming of this natural phase arose. Although similiar problems have been at times treated in the literature, no general vote of the Commission on New Minerals and Mineral Names of the International Mineralogical Association on

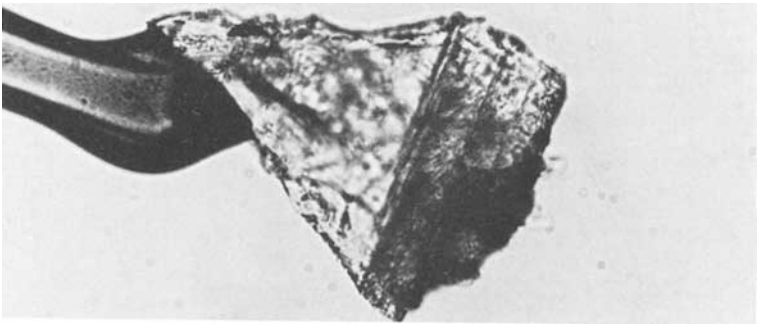

FIG. 8. Oriented intergrowth of spinel with taaffeite: (111) spinel ∥ (001) taaffeite, Pitkäranta mining district, U.S.S.R.; sample C; spinel is on the left, taaffeite on the right.
(Photo by O. Medenbach, Bochum, 200×.)

TABLE 3

Chemical and physical data of taaffeite from Sri Lanka, China, and U.S.S.R.

		Sri Lanka	China	U.S.S.R.
Chemical data [weight %]	BeO	4.4	4.31	n.d.
	MgO	20.07-21.32	14.27-14.79	17.17
	MnO	0.00- 0.11	2.87- 3.03	0.09
	CaO	0.01- 0.02	0.03- 0.05	0.01
	ZnO	0.00- 0.66	1.89- 2.78	4.27
	FeO	0.38- 2.00	5.52- 5.88	2.83
	Al_2O_3	72.61-74.05	69.84-70.16	71.37
	V_2O_3	0.00- 0.15	0.00- 0.03	0.15
	Cr_2O_3	0.00- 0.24	0.00- 0.02	0.17
	Ca_2O_3	0.05- 0.11	0.00- 0.13	0.10
	SiO_2	0.01- 0.11	0.02- 0.06	—
	TiO_2	0.00- 0.10	0.00- 0.09	0.09
Formula		$Be\,(Mg,Fe,Zn,Mn)_3\,Al_8\,O_{16}$		
Crystal system		hexagonal		
Lattice parameters [Å]		a_o 5.69±0.02	c_o 18.3±0.1	
Extinction rule		hhl l=2n		
Refractive indices	n_o	1.721- 1.723(1)	1.747(2)	1.735(2)
	n_e	1.717- 1.718(1)	1.741(2)	1.726(2)
Double refraction		0.004- 0.005	0.006	0.009

n.d. = not determined

this general problem was made since the beginning of the Commission's work in 1962. Therefore, the chemical and physical data were given to the IMA Commission in April 1981 in order to solve the problem of mineralogical nomenclature. During the discussion of the general point of view included in the special problem with taaffeite and taprobanite, it was decided to be desirable to have a general first vote about the problem of the significance of the original description of a mineral, and later a second vote about the correct naming of the mineral corresponding to the formula $BeMg_3Al_8O_{16}$.

The general question of mineralogical nomenclature found in the taaffeite or taprobanite problem is, whether a mineral species is definable by its original description or by the type material used for the original description. If the definition of a mineral species is given by the original description, the mineral could be renamed in a later investigation with different experimental results. Certainly, this procedure would lead to great problems in the whole mineralogical nomenclature. If the definition of a mineral species is given by its original description alone, the deposition of type material in a public mineralogical collection, as usually done, is worthless. If the definition of a mineral species is given by the type material, a correction of the description by later investigations is possible without a necessity of renaming the species. Without a possibility of a correction of the original description every new technology, e.g., new analytical methods, would lead to a renaming procedure of parts of the mineral species already known.

For the decision on the general problem of mineralogical nomenclature described here, the members of the Commission were asked to vote about the following question. The precise formulation of this question was chosen under the influence of a general principle, given already by Dana (1868):

'Given that type material of a species exists, and that the original description is not so defective, that, in the opinion of the Commission, it bears no reasonable resemblance to the material, should the species be defined by the type material, or by the original description?'

The majority of the members of the Commission voted for the definition of a mineral species by the type material (cf. Embrey & Hey, 1970) and against the definition by the original description, unless the original description is so defective, that a recognition of

the mineral by this description is impossible. This vote implies that errors in the original description can be corrected later in the future by reference to the type material and that errors cannot be held to discredit a mineral species. An example for such a procedure is given by Moore & Araki (1976) by the new determination of the chemical formula of the gem mineral painite.

By the vote on the priority of the type material over the original description, a decision over the priority of taaffeite or taprobanite was prepared. According to a second vote of the Commission the name taaffeite has priority and corresponds to the hexagonal mineral with the formula $BeMg_3Al_8O_{16}$. Should a mineral with a composition of $Be_2Mg_2Al_8O_{16}$ given originally for taaffeite, be discovered, a new naming procedure, consequently, has to be done. According to this vote, the name taprobanite is not to be used in future.

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Map 1. Plan showing the area near Meetiyagoda where the famous gem mines are located. *(M. Gunawardene)*

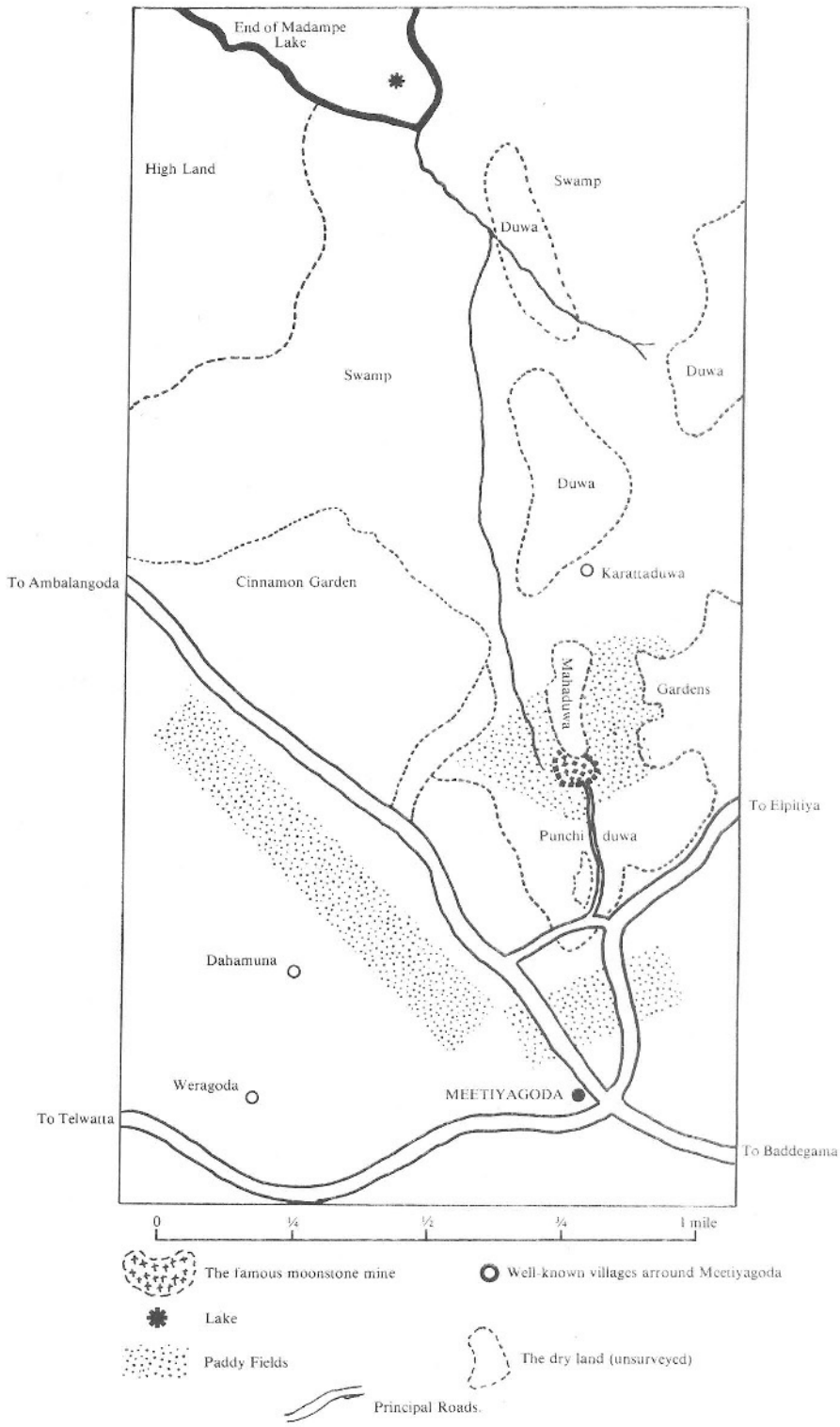

Map 2. Plan showing the moonstone, marcasite and pyrite occurrence at Meetiyagoda. In comparison with Map 1 the mining area is very small. *(M. Gunawardene)*

PYRITE AND MARCASITE OCCURRENCE IN SRI LANKA WITH SPECIAL EMPHASIS ON MEETIYAGODA GEM FIELD

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Deutsche Gemmologische Gesellschaft, Idar-Oberstein, West Germany

INTRODUCTION

Gems have gained a significant position in the economic and social life of Sri Lanka during the past few years. The gem industry has yielded unprecedented fortunes to individuals' earnings as no other minor commodity had done before. Interest in gemstones and gemmology has gained recognition among trade and individuals. In recent years many new gem findings have been reported from the Island of Sri Lanka which have received world-wide interest (Gübelin, 1979; Gunawardene & Hänni, 1981; Zwaan, 1981; Hänni & Gunawardene, 1982 a & b).

In September 1981 the author visited the famous moonstone mine at Meetiyagoda near the south-west coast of the Island. Careful observations within the mines and the clay soil of the area revealed an occurrence of distinct minerals, such as pyrite, marcasite and feldspars adhering to the parent rock. The natives introduced the 'gold-like' material by the local term *diya rathran,* meaning 'water gold'. Dealers of the area have already made arrangements to trade this new material to foreign tourists at high prices as a rare gem of the country. The subject of this paper is the occurrence of pyrite and marcasite in Sri Lanka with special reference on these gem deposits at Meetiyagoda.

CHEMISTRY AND CRYSTAL STRUCTURE

Pyrite and marcasite are two structural modifications of similar chemical composition, FeS_2. Theoretically a weight percentage of about 46.6 iron (Fe) and 53.4 sulphur (S) are reported (Komotauer, 1981). Fe can be replaced by Ni, Co, or As, while Cu, Zn, Ag, Ti and Au may be present in very minute quantities as impurities. Samples from Sri Lanka showed the presence of S and Fe, and no impurities were detected on a larger scale by a chemical test under Energy-Dispersive X-ray Fluorescence (EDS-XRF).

The cubic mineral pyrite is more stable in structure than the rhombic marcasite. The former can commonly crystallize as

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hexahedron or cube {100}, pentagonal dodecahedron or pyritohedron {210}, octahedron {111}, or a combination of many cubic forms. About 60 different crystal forms of pyrite have been reported, including single and combined forms. It belongs to the *Diploidal class* $-2/m\ 3^{-}$ of the isometric system and shows a lower symmetry $3A_2$, $4A_3$, 3P and C (after Dana, 1944). This lower symmetry has resulted, due to oscillation during formation. Marcasite rarely shows pure single crystals. Combined crystals are common. The atomic structures of pyrite and marcasite are shown in Figures 1a and 1b respectively.

Since they are both of similar chemical composition, the environmental conditions can cause an epitactic growth of marcasite and pyrite. Material from Sri Lanka was confirmed as marcasite by x-ray powder diffraction. The resulting lines were compared with data from the PDF values. Beside the strong marcasite pattern, similar to PDF 3-799, a faint superimposed pyrite pattern was observed. This confirms that these two minerals may form intergrown aggregates of fine lamellar structure (see also Dana, 1944). Figures 2a and 2b show the twinning structures of marcasite on pyrite and pyrite on marcasite respectively. The externally visible features are shown in Figures 3a and 3b respectively.

Physical Properties

The appearance of pyrite and marcasite is almost similar. Both these opaque minerals show a metallic lustre with a yellowish body

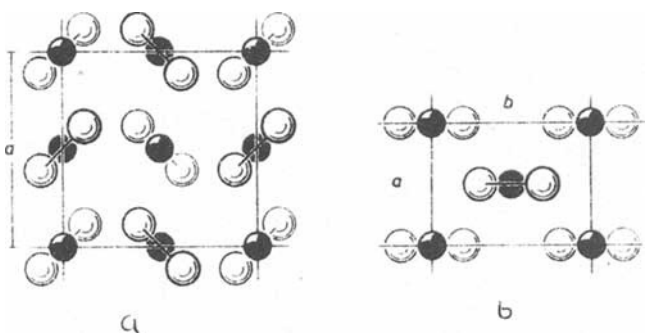

FIG. 1. Atomic orientation of (a) pyrite, parallel to the 4-diagonal directions of the cube, and (b) marcasite, parallel to 2-diagonal directions of the rhombic lattice projected at (001).

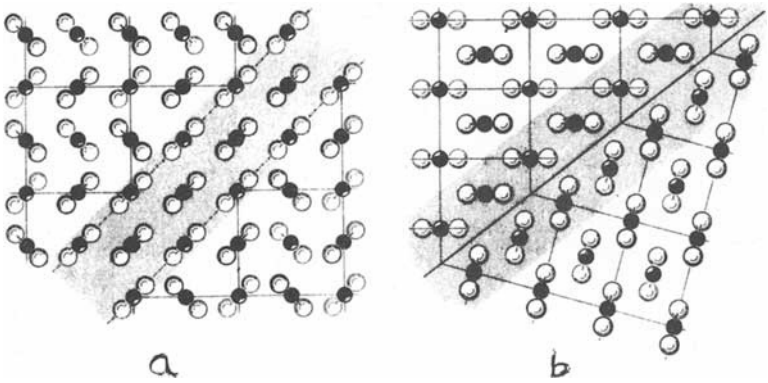

FIG. 2. Twinning of (a) marcasite on pyrite and (b) pyrite on marcasite. The twinning plane is indicated with dotted background.

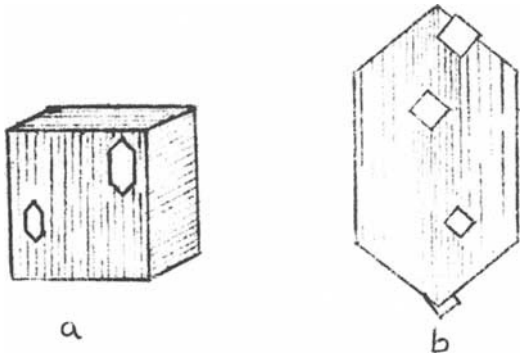

FIG. 3. External appearance of twinning of (a) marcasite on pyrite and (b) pyrite on marcasite.

colour. The specific gravity determination of few samples from this new discovery in Sri Lanka, under controlled conditions, gave values between 4.95 and 5.15. On comparing these with literature values the difference was insignificant.

GEOLOGY

The most abundant and wide-spread sulphide mineral is pyrite. Though it is a well-known hydrothermal mineral its occurrence in pegmatites, in sedimentary beds and even in contact metamorphosed zones is not a rarity. In Sri Lanka pyrite and

marcasite occur in quartz veins (at Ragedara), in pegmatites (the Galle group of rocks including Meetiyagoda) and in limestone (at Timbalketiya). These occurrences were neglected by the natives until the new find at Meetiyagoda.

A classical place of moonstone occurrence is Meetiyagoda, located about 6.8 km east of Ambalangoda in the southern province of the Galle district (Gübelin, 1968). The locality is in a large area of swampy land at about sea level continuing into Madampe Lake, 3.4 km to the north, known as Dahamuna near the village of Weragoda (Map 1).* The hard dry land masses in the swamp are known as *duwas* (islands) by the natives. Cultivation of cinnamon and coconut is carried out in the *duwas,* and the swamps are used for paddy cultivation during the dry season. The whole of the commercially important gem mining is carried out on a small *duwa* adjoining the swamp (Map 2).* The gemmy area is under dispute among the land owners, giving rise to many law-suits, settlements of which are still unknown.

Geologically the area is well known for clay minerals, particularly kaolinite, montmorillonite and the micaceous clay minerals. Associated with the clay minerals are a large number of accessory minerals, which have an important influence on the properties of the clays in which they occur. They include the hydroxides of aluminium (gibbsite—$Al(OH)_3$; boehmite, γ-AlO.OH, and diaspore, α-AlO.OH). Quartz, feldspar, mica, pyrite, marcasite, rutile, ilmenite, monazite, zircon, tourmaline, garnet, calcite and dolomite are the other minerals found in this wet-zoned clay deposit (Geological Survey, 1982). Rare occurrences of corundum and spinel are reported from this area (Parsons, 1907).

Mining Methods

The gem bearing gravel is reached by sinking 20 to 30 metres deep pits in the swamp. The methods are still primitive, and modernization would not be profitable where the gemmy area is concerned. Private traders own the whole mining operation, and the cutting is done in Galle, which is not far from the original locality. The sifting and washing of the gemmy gravel are shown in Figures 4 and 5.

*Maps 1 and 2 are inset between pp. 636 and 637.—Ed.

FIG. 4. Vertically sunk pit mining at Meetiyagoda. *(Photo: M. Gunawardene.)*

FIG. 5. The milky colour of the river after washing the gem-bearing clay gravel. *(Photo: M. Gunawardene.)*

ACKNOWLEDGEMENTS

The author is grateful to Dr H. A. Hänni, F.G.A., of the Mineralogical Institute, University of Basel, and to Mr Athula Mudunkotuwa, of the Geological Survey Department of Sri Lanka, for EDS-XRF analysis and valuable documentation respectively: and last, but not least, to Mr J. R. H. Chisholm, F.G.A., for his valuable suggestions made on the maps.

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[*Manuscript received 28th August, 1982.*]

A NEW GEM HOLDER

By Dr ROBERT M. YU, F.G.A., G.G.

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Gem holders incorporated in gemmological microscopes are usually crocodile clips. They cover parts of the gem from view and tend to squeeze out the gem. This article describes a new G-clamp type gem holder which does not have the shortcomings of the conventional gem holders. Moreover with this new holder a round brilliant stone may be held by its table and culet so that its girdle may be observed through 360° without taking it out of the holder.

The construction of the new gem holder is schematically shown in Figure 1. To mount a gem the plunger (P) is pulled back by pulling the knob (K). After the gem has been put in place, (K) is released. The spring (S) will press the plunger (P) and the gem securely against the G-clamp base (B). If the gem is held between its table and culet, as shown in Figure 1, all parts of the girdle may be successively brought into view by holding the G-clamp steady and rotating the knob (K) through 360°. The gem will follow the plunger (P) and rotate about its axis. Figure 2 is a photograph of a diamond held by its table and culet. Figure 3 shows an oval cut ruby held by its girdle.

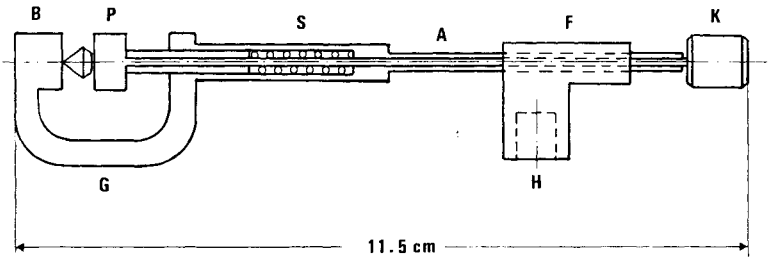

FIG. 1. Sketch of the gem holder.

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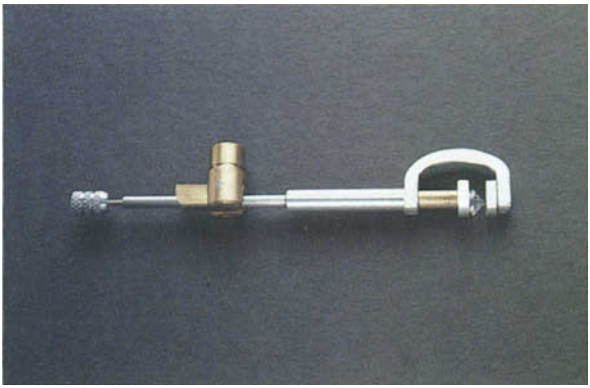

FIG. 2. Photograph of the gem holder holding a diamond by its table and culet.

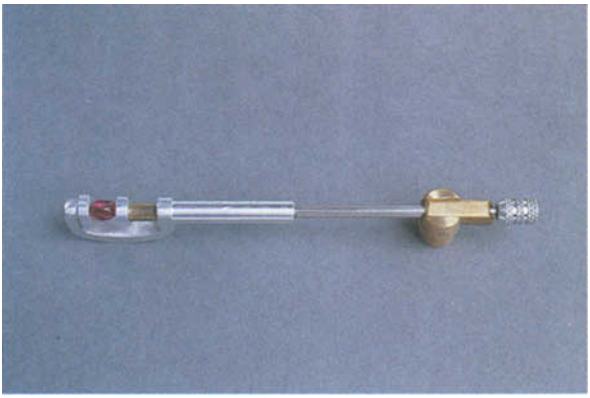

FIG. 3. Photograph of the gem holder holding an oval cut ruby by its girdle.

The arm (A) of the gem holder can slide in the fulcrum (F) which has a hole (H) to fit snugly on to a protrusion on the microscope stage. The fulcrum (F) also allows the gem holder to tilt up or down, but this mechanism is not shown in Figure 1.

[*Manuscript received 26th October, 1982.*]

THE GEMTEK GEMMOLOGIST—A TEST REPORT

By PETER G. READ, C.Eng., F.G.A.

Since my test report[1] on the Ceres DiamondProbe, which appeared in the *Journal of Gemmology* three years ago, many different versions of this type of instrument have been marketed, all of them exploiting the unique thermal properties of diamond as a means of distinguishing it from its various simulants.

While it has been claimed that these instruments indicate the degree of thermal conductivity of a stone, and although they have generally been described as thermal conductivity testers, there is both practical and theoretical evidence to support the idea that they are actually measuring thermal inertia.[2]

With the possible exception of the Ceres DiamondProbe, all of these instruments depend on the thermal energy from a probe tip being conducted through the stone under test into either a metal heat sink plate (for unmounted stones) or into the metal surround of the gemstone mount. This mode of operation is probably the reason for their classification as thermal conductivity testers.

In the case of the Ceres model, the provision of a sizeable panel meter makes it possible, with care, to differentiate not only between diamond and its simulants, but also between some of the simulants themselves. It is also possible, again with care, to detect differences in the meter readings for rolled gold, electroplated nickel silver/9 carat gold, 22 carat gold, 24 carat gold and sterling silver (other instruments such as the Rayner Diamond Tester can be calibrated against sample materials and used as comparators in the same way). Because of the variables of ambient temperature and sample size/temperature manufacturers of thermal gem testers are, however, reluctant to promote these less reliable test possibilities.

More recently, in the Gemtek 'Gemmologist' thermal tester (Figure 1), an attempt has been made to exploit the even smaller thermal differences between the non-diamond gems as a method of identifying them. To put the technical difficulties of such a feat into perspective, it is worth recalling that the thermal conductivity of diamond ranges from 1000 W/m/°C (for Type I material) to 2600 W/m/°C (for Type II material). The thermal conductivities of

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FIG. 1. The Gemtek 'Gemmologist'. Later models have the 'temp' and 'range' pre-sets accessible at the front edge of the control box.

diamond simulants, including both natural and man-made stones, range from 1.0 for glass to 40.0 for sapphire, and their separation from diamond is relatively easy.

What the 'Gemmologist' attempts, in addition to the relatively simple task of distinguishing between diamond and its simulants, is to differentiate thermally between gems having thermal conductivities in the much more limited range of 1.0 to 40.0 W/m/°C.

One of the problems associated with the design of thermal gem testers is the difficulty of producing reliable results over a wide range of both ambient and stone temperatures. With some testers this problem is minimized by the manufacturers, who specify a

limited temperature operating range for the instrument and instruct the user to make the test with the gem raised to body temperature. Others have chosen room temperature as the test baseline, and stipulate that the gem's temperature is first stabilized by immersing the stone in room-temperature water. Still other manufacturers have chosen to increase the temperature of the probe tip to a point where the ambient and stone temperatures have much less effect on the test results. Unfortunately, this latter remedy can also result in burns to the skin, and may even damage some heat-sensitive gems.

With diamond-only thermal testers, perhaps the best test for reliability is to check whether the instrument will differentiate between a small diamond at body temperature and a large sapphire at room temperature (over a range of 18 to 25 °C), corundum being the nearest in thermal conductivity to diamond (40 W/m/°C).

As a further safeguard when using these instruments, particularly the less sophisticated ones, they are best treated as comparators, and their calibration checked against a known diamond and sapphire before each test.

In order to reduce the even more serious problems associated with detecting the differences between gems having thermal conductivities in the range 1.0 to 40.0 W/m/°C, the 'Gemmologist' uses a high test tip temperature, and requires that stones are first raised to near body temperature and tested within a limited ambient temperature excursion of ±3 °C. (The unit is factory-calibrated for operation over a range of 18 to 24 °C, but can be re-calibrated to suit individual operating environments). One other requirement is that the probe tip is applied at right-angles to the test surface with a constant pressure.

Measuring Technique

The method of operation of the Gemtek 'Gemmologist' is similar to that used in other thermal testers in that the instrument detects the temperature drop in a heated probe tip when this is applied to the surface of a gemstone. The technique of translating this temperature drop into a digital reading is, however, unique.

After the probe tip touches the gemstone, an internal circuit detects when the temperature of the tip has dropped to an initial pre-determined level. At this point a green signal lamp is extinguished and the output of an oscillator is switched into a counter/panel display unit. When the temperature of the probe has

dropped to a second pre-set level, the output of the oscillator is switched off, a bleep note is sounded and the digital panel meter displays the total number of cycles of oscillation which have occurred between the initial and second temperature points. In effect, the instrument measures and displays the time taken for the probe tip temperature to fall from one pre-set level to another.

The operating temperature of the probe tip is set by means of a 'temp' adjustment, and the lower of the two temperature switching points is set by means of a 'range' adjustment. Both of these are accessible (in later versions of the instrument) as pre-set adjustments through the front edge of the control box, and instructions are provided which enable them to be set to suit individual operating environments.

Operating Mode

When the unit is first switched on, there is a warm-up period of between 30 seconds and 5 minutes (depending on calibration and ambient temperature). When the probe tip has reached its correct operating temperature, a green signal lamp lights. The 'reset' button is then pressed to set the counter display to zero. When making a test, the probe tip is applied to the gem's surface at right-angles and with sufficient pressure to retract the spring-loaded tip by about 1/32 of an inch. When the green lamp extinguishes, and the counter has completed its cycle count, the internal bleeper is pulsed and the number on the digital counter display indicates the relative thermal conductivity of the gem (a low number indicates high thermal conductivity).

Before the next test is attempted, the test probe must first be allowed to reach its operating temperature again (as indicated by the green lamp being energized) and then the 'reset' button is pressed to set the display to zero.

If the red 'too hot' lamp lights in between tests, the manufacturers advise that this can usually be ignored. However, if the red lamp has been on for more than five seconds, then the probe tip should be cooled by blowing on it gently until the red lamp just extinguishes. Too much cooling will also extinguish the green lamp, and further testing cannot begin until this lamp is energized again.

The manufacturers recommend that unmounted stones, or stones in lightweight mounts, should be tested on a metal heat sink

or held in metal stone tongs or pliers. They also suggest that for best results the unit should be left switched on all day.

TEST RESULTS

The results of tests made with a range of gemstones and gem materials are given in Tables 1 to 3. The unit was calibrated before the sequence of tests in accordance with the 'User Calibration Instructions'. At the start of each set of ten tests, the sample was first raised to near body temperature by holding it in contact with the wrist for 30 seconds (as recommended by the manufacturers). The sample was then tested ten times in succession, with just sufficient pause between each test to allow the green lamp to light, but not the red one. The size of the stones tested varied from 0.75 carat to 4 carats (tests carried out over a larger size range showed that this factor did not affect the results).

TABLE 1—Gemtek Test Readings

	Sample					
Test No.	Diamond	Ruby	Sapphire*	Sapphire†	Blue Topaz	Blue Spinel
1	28	44	44	52	57	78
2	21	36	46	52	49	68
3	23	44	52	48	46	68
4	21	42	47	47	56	75
5	25	39	52	52	57	67
6	26	42	52	50	51	70
7	28	41	45	47	59	68
8	18	39	47	45	61	70
9	18	42	44	45	62	70
10	24	49	49	47	57	67
Average	23.2	41.8	47.8	48.5	55.5	70.1
Quoted Range	15-35	40-60	40-60	40-60	55-75	60-100

*Heat-treated (surface diffused) †Non heat-treated

TABLE 2—Gemtek Test Readings

	Sample					
Test No.	Gilson Emerald	Natural Emerald	Peridot	Blue Tour-maline	Aqua-marine	Garnet
1	76	183	150	170	158	182
2	83	198	150	168	138	282
3	81	183	155	168	154	218
4	83	178	155	178	157	282
5	68	168	178	178	189	308
6	78	188	168	150	184	280
7	71	168	155	155	182	280
8	74	180	139	150	154	280
9	83	178	155	150	139	280
10	81	183	168	150	182	283
Average	77.8	180.7	157.3	161.7	163.7	267.5
Quoted Range	80-100	150-300	115-170	110-180	130-300	175-300

TABLE 3—Gemtek Test Readings

	Sample					
Test No.	Cubic Zirconia	Glass	Plastic	Alumi-nium	Sterling Silver	24 carat Gold
1	355	Off scale	No test	20	21	30
2	398			20	22	28
3	480			18	20	25
4	680			15	22	25
5	Off scale*			20	20	28
6				20	21	30
7				18	23	28
8				20	23	25
9				20	23	28
10				20	23	25
Average	—	—	—	19.1	21.8	27.2
Quoted Range	300-off scale	—	—	—	—	—

*Reading climbing as sample warms up under test.
† Insufficient heat transferred to initiate test.

Similar tests were made with aluminium, sterling silver and 24 carat gold. Although the 'User Instructions' indicate that heat-treated stones are likely to read 10 to 15 points higher than non heat-treated stones, this claim could not be confirmed with the limited number of samples available.

Further tests emphasized the importance of raising the test material to body temperature, particularly in the case of medium to poor thermal conductivity samples. Garnet, for example, varied from 258 at body temperature to 128 at 23 °C, and cubic zirconium oxide varied from 800 to 250. With corundum it was especially important to raise the stone's temperature above ambient to prevent it from producing a reading in the diamond range.

In contrast, high thermal conductivity materials, such as diamond and the metals, produced virtually the same results at both body temperature and ambient temperature (23 °C).

CONSTRUCTION

The unit is housed in a moulded 2-section plastic box whose dimensions are 110×190×90 mm. The probe is permanently connected to the control box, and the electronic/electrical components, including a bleeper unit, a voltage regulator, six transistors and eight integrated circuits are all mounted on a well made printed circuit board (Figure 2). The instrument is mains-operated via a plug-in 220/240 V, 50Hz adaptor.

CONCLUSIONS

During tests, the Gemtek 'Gemmologist' was able to separate ruby from garnet, aquamarine from blue spinel and topaz, and sapphire from blue tourmaline. It could also distinguish between natural emerald and flux-melt emerald.

In common with the reflectivity meter, however, many of the other gems had readings which overlapped each other, either because of the inherent thermal conductivity of the stones, or because of repeatability errors in the test results (see Tables 1 to 3).

For gems with an RI less than 1.81, the standard refractometer undoubtedly provides a more precise means of identification. However, for diamonds, diamond simulants, and for very small non-diamond gems, particularly those mounted in such a way as to make it impossible to check them either with a refractometer or on

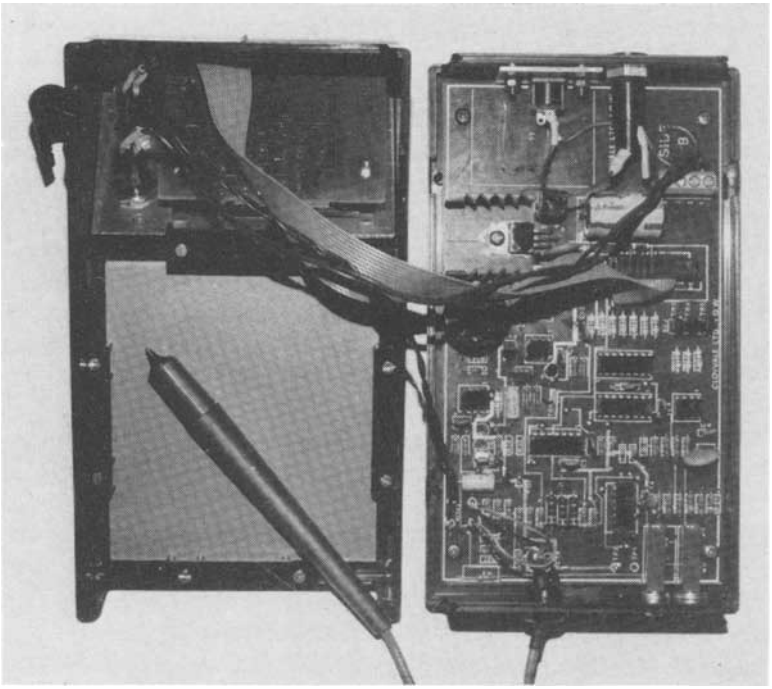

FIG. 2. An interior view, showing the various components mounted on the printed circuit board. The test probe can be seen lying in the left-hand section of the control box. The two calibration pre-sets at the lower right corner of the printed circuit are accessible to the user in later models.

a reflectivity meter, the 'Gemmologist', with its small probe tip, can provide additional identification data.

Although the instrument has been designed for use by non-gemmologists with a limited knowledge of gem materials, this is perhaps the type of user for whom the instrument's specialized operating requirements could easily produce misleading results.

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[*Manuscript received 23rd September, 1982.*]

GEMMOLOGICAL ABSTRACTS

AMMERLAAN (G.). *De veelbezongen kracht van de Smaragd.* (The great power of the emerald.) Chronos, **32,** 11, 22-6, 7 figs (3 in colour), 1982.

A summary of the properties, recovery and use of emerald, with some notes on its synthesis. M.O'D.

ARGUNOV (K. P.), ZUEV (V. M.), NIKIFOROVA (T. M.), PRISHCHEPA (V. I.). *Korrozionnaya i regeneratsionnaya skul'ptura kristallov almaza.* (Corrosion and regeneration sculpture in diamond crystals.) Mineralogicheskii Zhurnal, **4,** 3, 66-70, 1 fig, 1982. (In Russian, with English abstract.)

Intense corrosion has been observed on coloured small individual crystals and on the facets (distinguished by a reduced structural density) of large diamonds, whereas the colourless forms of isometric aspect have been more subject to regeneration.

	Crystal Habit, %	
Macrodefects	*Octahedral*	*Rhombdodecahedral*
Graphite inclusions	43.5	51.8
Smoky-cinnamon colour	16.6	33.8
Etch canals	6.4	13.6
Shagreen sculpture	0.3	10.8
Split diamonds	24.6	31.6

	Number of crystals	*Sculpture, %*	
Crystal form	*examined*	*Regeneration*	*Corrosion*
Octahedra	527	26.0	15.0
Rhombdodecahedra	41	34.0	22.0
Colourless slivers	1065	47.7	30.0

D.A.B.

BALFOUR (I.). *The 'Wittelsbach' diamond.* Indiaqua, 32 (1982/II), 135-7, 7 figs, 1982.

A history of the 35.50 carat blue diamond known as the Wittelsbach, which is of Indian origin and has been thought to be from the same rough as that which yielded the 44.50 carat Hope diamond. This, however, is unlikely. It is now in private ownership. R.K.M.

BALFOUR (I.). *The 'Williamson Pink' diamond (Famous diamonds of the world, XIV).* Indiaqua, 33 (1982/III), 125-8, 10 figs, 1982.

An account of the finding of this rare stone, its ultimate presentation by Dr Williamson to the then Princess Elizabeth, and its cutting to a perfect 23.60 carat brilliant and mounting in a brooch in the form of a stylized jonquil. R.K.M.

BALL (R. A.). *Precious opal from New Zealand.* Aust. Gemmol., **15**, 1, 12-16, 12 figs (2 in colour), 1 map, 1983.

Investigates three specimens of jelly and milk opal from site on the Coromandel Peninsula, North Island. Electron micrographs confirm structure as that of opal from a volcanic locality. [Expression 'crystal opal' is used; this needs explaining since it is not recognized terminology.] R.K.M.

BANK (H.). *Durchsichtiger geschliffener goldgelber Mellit.* (Transparent cut gold-yellow mellite.) Z.Dt.Gemmol.Ges., **31**, 4, 281-2, bibl., 1982.

A cut golden yellow mellite is described with its properties. Unfortunately the stone is unsuitable for commercial use because of its softness (Mohs hardness = 2), which also made cutting very difficult. E.S.

BERKOWITZ (R.). *Lab Report on Spectroscopes.* Can. Gemmol., **1**, 4, 27-9, N.D. [1977].

A comparison of three hand-held prism spectroscopes—Beck, Zeiss Jena, and Carl Zeiss (W. Germany). All were good, specific reading with the Beck being slightly easier. Price and availability also recorded. J.R.H.C.

BERKOWITZ (R.). *Pleochroism and the Dichroscope.* Can. Gemmol., **1**, 2, 6-8, 1976.

The subject simply explained, with a cautionary tale of a lady who bought an andalusite ring while she was wearing polaroid sunglasses. J.R.H.C.

BOYD (F. R.). *Predicting the occurrence of diamondiferous kimberlites.* Indiaqua, 33 (1982/III), 31-4, 10 figs, 1982.

Suggests methods of predicting content of diamond by mineralogical examination of peridotite nodules in kimberlite. R.K.M.

BRACEWELL (H.). *Random ravings at the 'Range'.* Wahroongai News, 9-12, November, 1982.

Local advice and comment resulting from a trip to the remote Harts Range gem area. R.K.M.

BRACEWELL (H.). *From Mt Isa to 'the Centre'.* Wahroongai News, 13-14, November, 1982.

Continues the travelogue of the Bracewell 'Round Australia' rock-hunting and fossicking trip, covering the route from Mt Isa to Alice Springs via Mt Oxide (azurite) and Tennant Creek (gold, silver and copper). These are valuable accounts for anyone contemplating such a trip into the desert out-back of central Australia. R.K.M.

BRACEWELL (H.), BROWN (G.). *Harts Range hessionite.* Aust. Gemmol., **15**, 1, 6-10, 6 figs, 1983.

Hessonite from Sri Lanka and from Ontario compared with a stone from an unidentified new source in the Harts Range, Northern Territory. Inclusions are markedly different from the 'sugary' Sri Lankan material. [There is no etymological justification for the incorrect spelling of hessonite adopted throughout this paper.] R.K.M.

BROWN (G.). *Coloured diamonds.* Wahroongai News, 13-21, 10 diagrams, October, 1982.

A summation of known facts gathered from various written sources. Includes lists of natural and artificially induced colours together with diagnostic criteria.

R.K.M.

BROWN (G.). *Lapis Lazuli.* Wahroongai News, **17**, 1, 5-10, January 1983.

An exhaustive summary of facts regarding this ornamental blue gem rock. SG range is almost certainly too broad. Some typographical errors, e.g. lazulite where lazurite is obviously intended. [Lazulite is an entirely unrelated phosphate. Lazurite is the principal constituent of lapis lazuli.] R.K.M.

BURROW (D.). *Arkansas quartz crystal mining.* Lapidary J., **36**, 10, 1758-60, 7 figs, 1983.

Personal account of mining for quartz in the state of Arkansas during the present century. M.O'D.

BURTON (J.). *Gemfari with the Miltons.* Wahroongai News, 23-4, November, 1982.

A journey by mini-bus of a party of nine from Brisbane to Chinchilla (petrified wood), Cheepie (opal), Quilpie, Augathella and over the Drummond Ranges to Sapphire (corundum), on to Mt Hay (thunder eggs), Marlborough (chrysoprase), Windera (agates) and back via Gympie. R.K.M.

CASSEDANNE (J.-P.). *Les agates de type Umbu.* (Umbu agates.) Revue de Gemmologie, 73, 5-8, 10 figs, 1982.

Umbu is the name given to certain Brazilian agates from the Rio Jacui in Porto Alegre. The methods of recovering the agates are described; most of them are sent for staining. M.O'D.

DAVIES (G.). *Diamond in science.* Indiaqua, 32 (1982/II), 125-9, 10 figs (unnumbered), 1982.

An explanation in easily understood terms of some of the unique properties of diamond. R.K.M.

FIELD (D. S. M.). *An Introduction to Gemmological Microscopy.* Can. Gemmol., **1**, 3, 6-10, 6 figs, N.D. [1977]; **1**, 4, 11-13, 1 fig., N.D. [1977]; **2**, 2, 2-8, 9 figs, N.D. [1978].

An admirable introduction, intended to describe the fundamental principles of optics as applicable to the loupe and the microscope simply, accurately and with minimal mathematics. Though Part III ended with the words 'to be continued', no more was published. J.R.H.C.

FRANCIS (P.). *Gem olivine from Afghanistan.* Lapidary J., **36**, 9, 1596-7, 1982.

Olivine is said to come from the area of Galicha, Afghanistan (the name most recently spelt Galeh Cha). This account is not based on a personal visit to the area but on sources in the literature and on the occurrence of olivine beads on the Iranian market. M.O'D.

FRÈRE (A.). *Beobachtungen an Altschliff-Diamanten.* (Reports on old cut diamonds.) Diebeners Goldschmiede- und Uhrmacher- Jahrbuch, 18-31, 14 figs, 1982.

An extensive report on the numerous cuts used for diamond in the past. M.O'D.

FRYER (C.), ed., CROWNINGSHIELD (R.), HURWIT (K. N.), KANE (R. E.). *Gem Trade Lab Notes.* Gems & Gemology, **XVIII**, 4, 228-33, 21 figs (15 in colour), 1982.

A yellow-green 'chameleon' diamond which changed to orange yellow when heated; a diamond with a cross etched on its table; another with long 'fringes' of short needle-like inclusions; and a burnt diamond in which pavilion facet edges appeared dark, are all described and illustrated. Another yellow diamond had a very faint 5920Å absorption, which proved it to be a treated stone; its LWUV colour was strong yellow. A fine 6 ct Zambian emerald had an absorption line at 4270Å, which seems to occur in these and in Pakistani stones *and* in iron-rich Gilson synthetic emeralds. Zambian emeralds have very high RI (1.585-1.592) and are almost inert under UV light.

Parisite, which, although not itself a gem mineral, is associated with Muzo emeralds and has a very striking and distinctive absorption spectrum, is discussed at length but the spectrum illustrated has been confused with siderite and is incorrectly titled. A large blister pearl was x-rayed and found to have been plugged. A star quartz with heavy rutile silk was thought to be from Sri Lanka; a brilliant orange-yellow natural sapphire was proved to have been heat-treated; another yellow sapphire which had faded in daylight may also be a heat-treated stone, although such behaviour is usually considered to indicate yellowing by x-radiation cobalt. For some reason the sapphire (purple-blue) is accepted as natural while the spinel (blue) is doubted on the grounds that cobalt coloured blue stones cannot occur in nature [they are normally pink]. This report is largely conjecture.

Grey-purple star spinel with both six and four-rayed stars; a man-made lithium fluoride with an intricate isometric pattern of inclusions, are described and illustrated. Another man-made fragment of potassium chloride is also described although hardly a gem species. R.K.M.

FUMEY (P.). *Orapa.* Revue de Gemmologie, 73, 9-11, 9 figs, 1982.

An account of the Orapa diamond pipe in Botswana. M.O'D.

GEISLER (R. A.). *The Ruby Deposits of Fiskenaesset, Greenland.* Can. Gemmol., **1**, 2, 4, 1 map, 1976.

Ruby deposits have been found at Fiskenaesset, SW. coast of Greenland, in a huge layered igneous intrusive complex, first observed by the Geological Survey of Greenland, associated with sapphirine, pargasite, gedrite, cordierite, kornerupine, phlogopite, enstatite, spinel, zircon and pyrope garnet. The rubies range to 3 inches across, varying from light pink to dark red, some with a slight violet cast. J.R.H.C.

GESCHWENDT (F.). *Ein Jadesammler und sein Katalog.* (A jade collection and its catalogue.) Diebeners Goldschmiede- und Uhrmacher- Jahrbuch, 84-7, 4 figs, 1982.

The jade collection of Heber R. Bishop and its catalogue are described. M.O'D.

GONTHIER (E.). *Les outils en jade de Nouvelle-Guinée. Part 1.* (Jade artefacts from New Guinea.) Revue de Gemmologie, 73, 12-14, 5 figs (3 in colour), 1982.

The term jade is loosely given to more than one mineral worked in New Guinea. Serpentines and quartzites are used for the manufacture of ceremonial and other objects. M.O'D.

GOODGER (W. D.). *Ruby with Kornerupine and Associated Minerals from Greenland.* Can. Gemmol., **1**, 2, 2-3, 1976.

Rock from Fiskenaesset, Greenland, contains ruby, kornerupine, pargasite, sapphirine, gedrite, cordierite, phlogopite, and spinel. It did not contain rubies of sufficient size/quality for economic cutting. Potential for gems in Greenland appears high. Tugtupite also mentioned. J.R.H.C.

GOODGER (W. D.). *Tsavorite.* Can. Gemmol., **1**, 1, 9-10, 2 figs, 1976.

A description of tsavorite [now properly called tsavolite] with two photomicrographs of inclusions. J.R.H.C.

GRAY (R.). *The Geology of the Fiskenaesset area.* Can. Gemmol., **1**, 2, 5, 1976.

The area in SW. Greenland is underlain by Precambrian gneisses with remnants of anorthosite and ultramafic rocks. Interbanded anorthosite, amphibolite, peridotite and norite occur as horizons up to 2 km wide, conforming with the gneisses' banding: intensely folded, reconstituted by granulite facies metamorphism, and affected by later retrograde metamorphism. Some doubly-metamorphosed anorthosite-norite rocks contain sapphirine, and related rocks contain hornblend, pyroxene, corundum, cordierite, spinel. Ruby occurs as subhedral to fractured euhedral crystals pseudomorphing sapphirine laths. J.R.H.C.

GÜBELIN (E.), SCHMETZER (K.). *Gemstones with alexandrite effect.* Gems & Gemology. **XVIII**, 4, 197-203, 5 figs (3 in colour), 1982.

Colour-change gems include chrysoberyl (alexandrite), garnets, sapphire, and, more rarely, spinel, kyanite, fluorite and monazite. [A well-written paper, but some colour illustrations seem inaccurate, possibly because unnecessary blue backgrounds have been used.] R.K.M.

GÜBELIN (E.), SCHMETZER (K.). *Eine neue Edelstein-Varietät aus Tansania: Gelbe, grüne und rötlich-braune Apatit-Katzenaugen.* (A new variety of gemstone from Tanzania: yellow, green and reddish-brown apatite cat's-eyes.) Z.Dt.Gemmol.Ges., **31**, 4, 261-3, 4 figs in colour, 1982.

A new occurrence of apatite cat's-eyes from the Umba Valley, Tanzania. A small percentage of the stones was clear and transparent, but most had fine, fibre-like inclusions. These were cut en cabochon and showed a very good, clearly defined chatoyancy caused by small needles of goethite. E.S.

GÜBELIN (E.), WEIBEL (M.), WÜTHRICH (A.). *Elucidating the optical theory of asterism.* J.Gemm.Soc. Japan, **9**, 1, 18-21, 4 figs, 1982.

Chatoyancy is explained in terms of physical and geometrical optics. M.O'D.

GURNEY (J.). *Diamond riches in the rollers.* Wahroongai News, May, 15-16, 1982. 'Abstracted from Indiaqua No 26 (1980).'

Discusses the contentions on the various trip concessions along the west coasts of South Africa and of Namibia. Shore concessionaires have rights to mine only to 100 feet below low-water mark. Low-water mark is a variable line open to many interpretations so the demarcation is nebulous. [The writer does not make it clear whether the 100 feet are in actual depth of water or 100 feet *beyond* the low-water line.]

Sea concessions allow vacuum dredging beyond this strip and are held by different companies. It is said that sea recovery by one company has produced 23 000 carats in six months. A figure of R500 per carat is put on this production. [An optimistic estimate?]

Origins of these diamonds are speculated upon. R.K.M.

HÄNNI (H. A.), STERN (W. B.). *Über die gemmologische Bedeutung des Gallium-Nachweises in Korunden.* (About the gemmological importance of the gallium inclusion in corundums.) Z.Dt.Gemmol.Ges., **31**, 4, 255-60, 1 graph, 1 table, 1982.

Twenty-four natural and eight synthetic corundums of different origins were investigated by energy-dispersive x-ray fluorescent analysis. All natural stones showed the presence of measurable Ga concentrations, while Ga was not detected in the synthetic stones. The use of this diagnostic feature is discussed in the light of general trace element investigations in gemstones. E.S.

HARRIS (J.). *Diamonds from Orapa or Brazil?* Indiaqua, 32 (1982/II), 35-8, 14 figs, 1982.

Describes classification of bulk parcels from individual mines by crystal form and colour. Shows that each mine has certain fairly constant percentages of each form/colour and suggests that the title question could ultimately be answered by such analyses. R.K.M.

HEALEY (D.), YU (R. M.). *Quality grading of corundum.* Lapidary J., **36**, 7, 1190-6, 3 figs, 1982.

An original and useful account of the methods used for grading ruby and sapphire at the Thai gem centre, Bangkok. Criteria in operation are discussed. M.O'D.

HEALEY (D.), YU (R. M.). *Quality grading of jadeite.* Lapidary J., **36**, 10, 1670-4, 4 figs (1 in colour), 1983.

Various colours of jadeite are referred to the Munsell colour system with a view to establishing a system of grading. Both colour and clarity are assessed. M.O'D.

KANDA (H.), SETAKA (N.), OHSAWA (T.), FUKUNAGA (O.). *Growth condition for the dodecahedral form of synthetic diamonds.* Journal of Crystal Growth, **60**, 441-4, 1982.

A dodecahedral habit was observed in a synthetic diamond grown in molten nickel at high temperature and pressures when a small amount of water was added to the reaction cell. The (110) surface showed striations parallel to the <110> direction with some elongated ridges also present. M.O'D.

KAO (J. R.). *Taiwan's jade and lapidary transitions.* Lapidary J., **36,** 7, 1172-82, 11 figs, 1982.

A useful account with maps and analysis of nephrites, this piece describes the ornamental minerals to be found in Taiwan. M.O'D.

KATO (M.). (Main facet cutting angle.) J.Gemm.Soc.Japan, **9,** 1, 3-17, 21 figs, 1982. (In Japanese.)

Geometrical optics are employed to re-examine the optimum cutting angles between main facets of gemstones. M.O'D.

KELLER (P. C.). *The Chanthaburi — Trat gemfield, Thailand.* Gems & Gemology, **XVIII,** 4, 186-96, 14 figs in colour, 1982.

The geology, history and mining methods used to obtain ruby and sapphire in the Chantaburi and Trat region of SE. Thailand. Distinctions between these and corundum from Burma are given. Heat treatment to improve colour is discussed at some length and clues given for its detection. R.K.M.

KODAIRA (K.), IWASE (I.), TSUNASHIMA (A.), MATSUSHITA (T.). *High pressure hydrothermal synthesis of beryl crystals.* J. Crystal Growth, **60,** 172-4, 3 figs, 1982.

Beryl crystals were synthesized hydrothermally under a pressure of 10 kbar. Size of the crystals increased with rising temperature and reached 0.3 mm in length maximum. Shapes were hexagonal plates from pure water and hexagonal prisms from a solution of 0.1N NaOH. Infrared spectra were found as for the natural crystals. M.O'D.

KOIVULA (J. I.). *Tourmaline as an inclusion in Zambian emeralds.* Gems & Gemology, **XVIII,** 4, 225-7, 2 figs in colour, 1982.

Needles of dark dravite tourmaline identified for the first time in emeralds from an African source. R.K.M.

LIVSTRAND (W.). *Chantaburi, Thailand's sapphire centre.* Lapidary J., **36,** 7, 1224-30, 12 figs, 1982.

An account of sapphire mining, dealing and grading in Thailand. M.O'D.

MADDERN (D. T.). *Irradiation controversy on rubellite.* Wahroongai News, **17,** 1, 17-18, January 1983.

Discusses controversy which has arisen in America on whether fine Brazilian rubellite tourmaline from Ouro Preto has had its colour enhanced by irradiation. From evidence quoted it seems that this is unlikely in the case of recent finds of exceptionally good reds. Some other reds may respond to such treatment. It is suggested that irradiation might even reduce the colour to some extent. The view is expressed that the blue tourmaline (indicolite) is also free from the taint of this treatment by irradiation. [Nothing is said about heat treatment.] R.K.M.

MANSON (D. V.), STOCKTON (C. M.). *Gem quality grossular garnets.* Gems & Gemology, **XVIII,** 4, 204-13, 12 figs (mostly graphs), 1982.

A careful study of this sub-species which is now known to occur in colours

varying from colourless through reddish-brown, orange, golden, yellow, light and dark green. An attempt is made to define tsavorite [tsavolite] more carefully.

R.K.M.

MATHUR (S. M.). *The diamond deposits of India.* Indiaqua, 33 (1982/III), 21-9, 31 figs, 1982.

A summary of the known and historic diamond areas in the subcontinent which identifies various kimberlites and diatremes [volcanic pipes in general] in Panna and Andhra Pradesh, reaching the conclusion that India's pre-eminent position as a diamond producer is lost for ever, but putting forward several valid suggestions for exploitation of likely river and coastal alluvial areas, which might prove to be profitable. R.K.M.

MILEY (F.). *Facts about diamonds.* Lapidary J., **36**, 9, 1534-44, 1982.

General overview of diamond, its recovery, cutting and pricing. M.O'D.

MOOR (W. F.), OBERHOLZER (W. F.), GÜBELIN (E.). *Taprobanite, a new mineral of the taaffeite group.* Schweiz.Mineral.Petrogr.Mitt., **61**, 13-21, 1981.

A mineral with hexagonal symmetry and belonging to space group $P6_3mc$ was claimed to be a new mineral from tests made on a cut gemstone. [Later study proved the mineral to have identical x-ray pattern and density, with optical properties, to those of taaffeite. The name taprobanite is deemed unnecessary.] M.O'D.

O'DONOGHUE (M.). *The dealer looks at gemstones—7.* Gems, **14**, 5, 15, 1982.

Discusses danburite from a Madagascar location (stones of a topaz colour); dark blue topaz and what to look for in the cutting of a stone.

(Author's abstract.) M.O'D.

O'DONOGHUE (M.). *Man-made gemstones.* Gems, **14**, 5, 16, 1982.

Discusses work in progress at the Royal Radar Establishment and an early book on crystal growth. (Author's abstract.) M.O'D.

PAGE (B). *The Diamond Rush.* Telegraph Sunday Magazine, 334, 18-24, 10 photos in colour, 1 map, 6th March 1983.

A well illustrated journalistic report by Bruce Page on the discovery in 1979 of diamonds in the Kimberley Ranges in the north of Western Australia and subsequent development by the Ashton Joint Venture, down to February 1982 when agreement was announced (subject to review in 5 years) between the Joint Venture and De Beers Central Selling Organisation that C.S.O. would take most of the gem diamonds and 75% of the 'near gems' and industrials, leaving the rest for direct marketing. [According to the Annual Report of the Rio Tinto-Zinc Corporation PLC for 1982, the mining and marketing proposals were approved by the Western Australian Government and commercial production commenced in January 1983: the diamond export sales agreement with C.S.O. completed on behalf of CRA Ltd and Ashton Mining Ltd (together holding 95% of the joint venture) provides for CRA and Ashton Mining to retain 25% of their share of lower value gems and industrial diamonds for open market sales independent of C.S.O. from mid-1984.]

J.R.H.C.

PEARSON (G.). *Seismic gem prospecting.* Aust. Gemmol., **15**, 1, 17-18, 1983.

Describes simple seismic prospecting and suggests that it could be useful in locating gemmiferous placer deposits. R.K.M.

PIENAAR (H. S.). *Gem quality friedelite from the Kalahari manganese field near Kuruman, South Africa.* Gems & Gemology, **XVIII**, 4, 221-4, 4 figs (2 in colour), 1982.

A rare cryptocrystalline chloro-manganese silicate, which has been found at one place in that area in rose-red to carmine, opaque to semi-opaque, material suitable for cabochon gems. R.K.M.

REYMER (H.). *Lab Reports.* Can. Gemmol., **1**, 1, 12-13, 1976.

Records colour-improved jade cabochons (revealed by spectroscope), Verneuil-type synthetic rubies with curved lines parallel to girdle, synthetic flux-grown rubies, distinction of green tourmaline from low zircon, plastic imitation conch pearl given away by 'molding mark on "back"'. J.R.H.C.

REYMER (H.). *Laboratory Reports.* Can. Gemmol., **1**, 2, 23, 1976; **1**, 3, 29, N.D. [1977].

(1) The importance of three-phase inclusions in Colombian emeralds as against two-phase inclusions in those from Brazil, Russian-grown synthetic citrine in the rough, and a 2 ct natural ruby apparently without flaws, showing what at 100× appeared to be a cloud of round bubbles but at 280× were clearly negative crystals, are mentioned. A 'spot' RI reading of 1.54 showed that what looked like a poor emerald or jadeite cabochon was a moss agate. A small green stone pronounced as chrysoberyl by a student after test was shown to be sapphire when the RI was read correctly—showing the danger of guessing and then making the tests fit. (2) An Australian sapphire doublet was given away by a fluorescent pavilion and a non-fluorescent table. J.R.H.C.

RISLING (M.). *The Diagnostic Value of Inclusions.* Can. Gemmol., **1**, 3, 2-5, 4 photomicrographs, N.D. [1977].

The first of a series, this contains Part 1, which, after a brief Introduction, covers the classification into Protogenetic, Syngenetic and Epigenetic, following Dr Gübelin. J.R.H.C.

RISLING (M.). *The Diagnostic Inclusions of Ruby and Sapphire.* Can. Gemmol., **1**, 4, 2-7, 5 photomicrographs, N.D. [1977].

Part 2 of the series on the *Diagnostic Value of Inclusions.* [Parts 3 and 4 were abstracted in J.Gemm., 1978, **XVI**, 2, 135 and 7, 481, respectively.] J.R.H.C.

RITCHIE (C.). *Making ivory jewellery—1.* Gems, **14**, 5, 32-6, 6 figs, 1982.

The various types of ivory are listed and the first stages in fashioning explained. M.O'D.

ROBINSON (R.). *Anakie gemfields—sapphire mining.* Wahroongai News, 17-21, 6 figs, November, 1982.

Mining and mining methods in this extensive field, which yields something less

tnan 10% of its total corundum output as gem quality. Dark blues, parti-colours, greens and, rarely, yellows are found, also bronze stars. Red and brown zircons also are found in quantity. R.K.M.

ROTHSTEIN (J.). *Hydrophane.* Lapidary J., **36**, 9, 1490-514, 1982.

A description, with a good deal of historical material, of the hydrophane variety of opal. Special reference is made to occurrences in the United States.

M.O'D.

ROTHSTEIN (J.). *The gem feldspars.* Lapidary J., **36**, 10, 1718-23, 1983.

Somewhat breathless account of the varieties of feldspar with possible ornamental application. A list of variental names (including commercial ones) is appended. M.O'D.

SCHMETZER (K.), BOSSHART (G.), HÄNNI (H. A.). *Naturfarbene und behandelte gelbe und orange-braune Sapphire.* (Natural and treated yellow and orange-brown sapphires.) Z.Dt.Gemmol.Ges., **31**, 4, 265-79, 4 figs in colour, 8 graphs, 2 tables, bibl., 1982.

Natural yellow and orange-brown sapphires owe their colour to trace elements (Fe^{3+}, Ti^{3+}, Cr^{3+}). Similar colour is achieved in synthetic stones with Ni^{3+} and Cr^{3+} and by an additional annealing process. With colourless and pale yellow sapphires similar colour can be obtained by irradiation or annealing, both processes generating colours which cause a continuous increase of light absorption from orange to the blue end of the spectrum. For commercial use, annealed stones can be considered colour-stable. Absorption of irradiated or heated corundums differs little from natural light yellow sapphires from Sri Lanka, apart from stronger absorption in the violet region. Inclusions in annealed yellow sapphires have the same characteristics as those in heated corundums of other hues. E.S.

SHEARER (J.). *Excerpts from the disclosure on his find in the Bancroft area of Ontario of a source of gemstone named "Trilliumite".* Can. Gemmol., **1**, 1, 10-12, 1976.

Records the finding and marketing under the trade-name 'Trilliumite' of blue-green facetable apatite. J.R.H.C.

SINKANKAS (J.). *Artistry in rock crystal: the Van Pelt collection.* Gems & Gemology, **XVIII**, 4, 214-20, 4 figs (3 in colour), 1982.

Describes the hollow rock-crystal faceted egg and a pair of vases designed and cut by this brilliant husband-and-wife team. R.K.M.

SNOW (J.). *An unusual stone.* Wahroongai News, 3-4, November, 1982.

A transparent purplish rough fragment with corundum constants was found to have a biaxial interference figure. After some confusion with possible [?] chrysoberyl, it was confirmed as corundum in a negative biaxial form. [Dana Ford says 'Often abnormally biaxial'.] R.K.M.

SPRINGER (P. G.). *The agates of Nova Scotia.* Lapidary J., **36**, 8, 1330-8, 16 figs (15 in colour), 1982.

Agates are found in the North Mountain range of Nova Scotia and can also be picked up on the shores of the Bay of Fundy. M.O'D.

STREIGHT (S. G.). *Letter to the Editor; Beilby Layer.* Aust. Gemmol., **15**, 1, 20, 5 (unnumbered) figs in colour, 1983.

Accompanied by five 'gemscapes' by R. F. Brightman, praises his *Surface Topography of Gem Crystals* (abstracted on p. 433 above), but criticizes his reference to the Beilby Layer and recommends reading of P. J. Crowcroft, *Demise of the Beilby-Bowden Theory of Polishing* (J.Gemm., 1981, **XVII**, 7, 459-66) for better understanding of the polishing process. J.R.H.C.

THORSSON (H.), RISLING (M.). *The Reflectancespectrophotometric Method of Colour-grading Diamonds.* Can. Gemmol., **1**, 4, 8-10, N.D. [1977].

A comparison of the efficiency in colour-grading diamonds of numerous human subjects and the most advanced colorimeter on the one hand with that of the reflectancespectrophotometer on the other left no doubt of the great superiority of the reflectancespectrophotometer. J.R.H.C.

TOMBS (G. A.). *A new synthetic emerald.* Aust. Gemmol., **15**, 1, 24-6, 6 figs (4 in colour), 1983.

Describes a new synthetic emerald of unknown origin with RI 1.567-1.572, SG 2.67, transparent to short UV but no fluorescence. Spectroscope indicates low chromium content plus vanadium. Inclusions veil-like, some solid material, possible phenakite 'nails' with acute angled colour and growth zoning. It is suggested that this is due to a wedging process (a reversal of seeding?) [I have no idea what this means.] No natural type of emerald inclusion was seen. Stone remarkably clean but rather yellowish in colour. R.K.M.

VÁVRA (N.). *Bernstein und andere fossile Harze.* (Amber and other fossil resins.) Z.Dt.Gemmol.Ges., **31**, 4, 213-54, 12 figs (3 in colour), extensive bibl., 1982.

An extensive review of spectroscopic and chromatographic methods used for the identification of amber and other fossil resins. Chemical composition, formation of deposits, mining and use of these resins are discussed, and their varieties and differences in quality discussed. Fossil inclusions in amber and other resins are described and some examples are illustrated. Imitation, falsification and 'improved' products to be found on the market are mentioned and methods for identification discussed. A list of commercial products is included. E.S

WADDINGTON (F.). *The History of Jewellery and Gemmology: Part I—The Shadowy Beginnings of Jewellery.* Can. Gemmol., **1**, 1, 4-5, 1976.

From an ox-rib with stone-cuts carbon-dated at about 237 000 years old, via Cromagnon Man about 37 000 years ago and French cave-frescoes, Middle East goldsmithing of 5000 B.C., garnet and other cabochons of 4000 B.C., and a rock-crystal loupe (?) of 1600 B.C., to Babylonian cylinder seals of about 1500 B.C.

J.R.H.C.

WADDINGTON (F.). *The History of Jewellery and Gemmology: Part II—Jade.* Can. Gemmol., **1**, 2, 14-15, 1976.

Nephrite jade has been worked and revered for perhaps 4000 years. A Chinese prince and princess 2000 years ago were enclosed in jade coats to preserve them for eternity—the prince had over 2000 pieces of jade plates drilled and fastened together

with gold wire. Most Chinese jade apparently came from Turkestan: recently great quantities from a nephrite mountain in British Columbia have been exported to China for carving. Jadeite mixed with another mineral (from Guatemala) was expertly carved in Central America by the Olmecs before the Christian era and later by the Mayas until the sixteenth century. In New Zealand the Maoris used nephrite 1000 years ago. But jadeite from Burma was almost unknown in China until the late eighteenth century. J.R.H.C.

WADDINGTON (F.). *The History of Jewellery and Gemmology: Part III—On Cutting and Engraving.* Can. Gemmol., **1**, 4, 16, N. D. [1977].

A brief account of the shaping of stones, from flint axe-heads in the Stone Age, agates rubbed on wood or leather with fine sand with more uniform shapes following the wheel about 3000 B.C., ancient engraving with a sapphire point in Egypt, Greece and Rome, faceting 1300 A.D. in India, to 'Tassie Gems' (glass reproductions of Greek and Roman intaglios) in the 1800s. J.R.H.C.

WAITZMAN (M. D.). *Grape's the color, sugilite's the stone.* Lapidary J., **36**, 8, 1334-8, 6 figs (5 in colour), 1982.

A brief account of the discovery and properties of manganoan sugilite. Absorption bands forming two pairs were located in the green-blue and blue areas of the spectrum. M.O'D.

WILD (K. E.). *Lapis-lazuli und Turkis.* (Lapis lazuli and turquoise.) Diebeners Goldschmiede- und Uhrmacher- Jahrbuch, 77-83, 1982.

Brief review of these two materials and their imitations. Testing notes given. M.O'D.

WUTHRICH (A.), WEIBEL (M.), GÜBELIN (E.). *Elucidating the optical theory of chatoyancy and asterism.* Aust. Gemmol., **15**, 1, 3-5, 4 figs, 1983.

An explanation of the optics of star-stones and cat's-eyes recognizing that the effects seen are in general virtual images. R.K.M.

ZEITNER (J. C.). *Anyway it's royal—the story of sugilite.* Lapidary J., **36**, 8, 1316-24, 8 figs, 1982.

Manganoan sugilite with gem potential was discovered at a manganese mine north-east of Hotazel in the Kalahari region of South Africa. Some material is translucent; hardness is quoted as 6½-7½, SG 2.74, RI 1.607-1.610. M.O'D.

ZEITNER (J. C.). *How to carve amber, jet, coral and more.* Lapidary J., **36**, 7, 1148-58, 11 figs, 1982.

A largely derivative article on simple fashioning of the materials described. M.O'D.

Bangkok gemmologist discovers very rare taaffeite specimen. Retail Jeweller, **22**, 541, 20, 10th March 1983.

A colourless water-worn mineral fragment identified as a 2.41 carat taaffeite was found in Bangkok in a parcel of rough bought in Thailand. RI 1.716-1.720 and SG 3.59 are quoted. Article cites an optimistic fifty known specimens. R.K.M.

BOOK REVIEWS

ANTHONY (J. W.), WILLIAMS (S. A.), BIDEAUX (R. A.). *Mineralogy of Arizona.* Revised reprinting. University of Arizona Press, Tucson, 1982. pp.263. Illus. in colour. Price on application.

About 40 new minerals have been added in a chapter at the back of the original text which is still superb value as a mineralogical guide in general as well as being an official state mineralogy. Very fine pictures make the book worth obtaining.

M.O'D.

DEER (W. A.), HOWIE (R. A.), ZUSSMAN (J.). *Rock-forming minerals.* 2nd edn. vol.1A. (Orthosilicates). Longman, London, 1982. pp.919. £50.

This second edition of what is the major work on the rock-forming minerals contains information on the gem species garnet, topaz, olivine, staurolite, kyanite, zircon, sphene, andalusite and vesuvianite. Volume 1B will cover the disilicates and ring silicates. Though the conception and layout remain the same as in the first edition, the amount of work done in the twenty years since that edition appeared has meant that what could be comfortably accommodated in one volume now needs two. In each entry the structure is discussed first, followed by the chemistry, optical and physical properties, distinguishing features and paragenesis. Then follows an exhaustive bibliography. To the serious mineralogist the complete work is a necessity, and even the gemmologist will find a great deal of information lucidly set out and easily located. Though the price is high, the cost of compiling bibliographies and collating a vast amount of data from many sources is also considerable, so that for these days the price is not unreasonable. M.O'D.

MACKENZIE (W. S.), DONALDSON (C. H.), GUILFORD (C.). *Atlas of igneous rocks and their textures.* Longman, Harlow, 1982. pp.148. Illus. in colour. £9.95.

It is rare today to see so well-produced a book at such a competitive price. This one, divided into two parts, first dealing with igneous rock textures, shown by the presentation of thin section material in both plane-polarized and cross-polarized light, and with a second section in which the varieties of igneous rocks are treated in the same way, succeeds in being both beautiful and informative. It is a salutary discipline to observe the appearance of rock types in thin section and to try to identify both the crystals and the rock. The authors unashamedly admit that they have included some pictures on the grounds of their attractiveness irrespective of their didactic purpose. To me all pictures in the book serve both functions. M.O'D.

MUMME (I. A.). *The emerald.* Mumme Publications, Port Hacking, N.S.W., Australia, 1982. pp.135. Illus. in black-and white and in colour. Price on application.

After a short introduction the book continues with reports of the major emerald deposits of the world, and within this section there is a good deal on the geology and mode of occurrence of the material. Much mining activity is shown in photographs and there are details of production where available, together with

appropriate references scattered in the text. Details of the physical and optical features of emerald are given next and there is a section on emerald synthesis. Quite a lot of information is given on the emerald deposits of Australia and the stones shown in colour appear to be of good colour. There is a general bibliography but no index. This book is a very useful addition to the somewhat scattered emerald literature and, in the Australian deposits at least, nicely complements Sinkankas's *Emerald and other beryls.* One or two factual slips (the SG of synthetic spinel is 3.64, not 3.60) do not detract from overall worth. M.O'D.

SCHLEE (P.). *Bernstein-Raritäten.* (Amber rarities.) Staatliche Museum für Naturkunde, Stuttgart, 1980. pp. 88. Illus. in colour. Price on application.

This book is quite magnificent and the quality of the coloured pictures such that it is hard to put down. The illustrations are almost all of inclusions in amber, though towards the end of the book there are some artefacts represented. The text, which to some extent takes second place to the pictures, deals with all aspects of amber and discusses features which help to give a locality for a particular specimen. There is a short but useful bibliography. M.O'D.

SCHÜTT (E.). *Umgang mit edlen Steinen.* (Getting acquainted with gemstones.) Rühle-Diebener Verlag, Stuttgart, 1982. pp.271. Illus. in colour. DM87.60.

Gemstones are described in alphabetical order and there are no text diagrams, index or bibliography. Constants are not provided but the colour plates, of good quality, show broken or imperfect pieces or stones with prominent inclusions. This is an interesting and quite worthwhile feature. M.O'D.

STRÜBEL (G.), ZIMMER (S. H.). *Lexikon der Mineralogie.* (Dictionary of Mineralogy). Enke Verlag, Stuttgart, 1982. pp. 363. DM 24.80.

A pocket-sized dictionary which includes both mineralogical terms and names of minerals, this is an up-to-date account of mineralogy at the beginning of the 1980s. The authors have taken pains to include virtually all minerals officially named, and there are some useful text drawings and a bibliography, chiefly of works in German. M.O'D.

WORNER (H.), SEGNIT (R.). *Minerals of Broken Hill.* Australian Mining Co., Box 384D, Melbourne, 1982. Available in U.K. from Lythe Minerals, 2 Wellsic Lane, Rothley, Leics., LE7 7QB. pp.259. Illus. in colour. £31.50 post paid.

Mining of the orebody at Broken Hill in New South Wales began one hundred years ago. This superbly illustrated book describes the minerals found there, gives a history of mining development and outlines the way in which the mineralogy came about. The bulk of the book is occupied by a section in which the minerals are listed and described alphabetically; descriptions are confined to the appearance of the crystals and their place in the mine, together with their associations. There is no attempt to give details of constants since there are plenty of sources of information of this kind. There is a very comprehensive list of references keyed to mineral name and a more general though scholarly bibliography. This will probably be the last monograph of this size and scale to deal with one locality. It is in no sense a popular book, but for students of mineralization it is unmatched. M.O'D.

ASSOCIATION NOTICES

GIFTS TO THE ASSOCIATION

The Council of the Association is indebted to the following for their gifts:

Mr Glyn A. Henwood, F.G.A., Basingstoke, for a copy of *'The Gemmologist' Chart: Gems of the World,* compiled by R. Dick-Larkam.

Mr Geoff Neary, F.G.A., Huddersfield, for a framed sheet, published in 1809 and in excellent condition, of drawings of outline crystals showing different growth patterns.

Mr S.H. Ramshad, London, for crystallized chrysocolla and pink opal from the mine of Nishapur, Khorasan, Iran.

OBITUARY

Dr Haruo Akizuki, D.Sc., F.G.A. (D.1981), Ichikawa, Japan, died on 24th November, 1982. Dr Akizuki was a former Professor of Mineralogy at the University of Nairobi, Kenya, and a member of and adviser to the Gemmological Association of Japan.

Mr Czeslaw Krakowiak, F.G.A. (D.1978), Gdańsk, Poland, died on 18th November, 1981.

Mr Arthur Stuart Murray, F.G.A. (D.1948), Leeds, died on 26th March, 1983.

NEWS OF FELLOWS

Mr Peter G. Read, C.Eng., F.G.A., has been appointed Editor of a new quarterly publication called *Gem Instrument Digest,* which will report on and discuss new gemmological test instruments, identification techniques and grading equipment.

Mr P. G. Read, C.Eng., F.G.A., and Mr M. J. O'Donoghue, M.A., F.G.S., F.G.A., are Directors of Precious Stone Training Service Ltd and have given several two-day courses on diamond and on corundum during 1983. Mr Eric Bruton, F.G.A., has also spoken at some of these courses.

MEMBERS' MEETINGS

London

On 12th April, 1983, at the Central Electricity Generating Board Theatre, Sudbury House, 15 Newgate Street, London E.C.1., a talk was given by Mr Julius Petsch on new gemstone discoveries in Africa and Brazil, and, allied to this, he gave details of the latest emerald, ruby, aquamarine and amethyst mines in those two countries.

Midlands Branch

On 25th March, 1983, at the Society of Friends, Dr Johnson's House, Birmingham, Mr David Kent, F.G.A., gave a talk entitled 'Gemmology in a practical sense'. Members were able to view Mr Kent's comprehensive collection of gemstones.

On 28th April, 1983, at the Society of Friends, Mr C. R. Cavey, B.Sc., F.G.A., gave a talk on 'Gem sources and varieties'.

On 12th May, 1983, at the Society of Friends, the Annual General Meeting was held, at which Mr Douglas Morgan, F.G.A., and Mrs Janet Leek were re-elected Chairman and Secretary respectively. The A.G.M. was followed by a discussion on gemmological topics.

North-West Branch

On 21st April, 1983, at Church House, Hanover Street, Liverpool 1, Mr M. J. O'Donoghue, M.A., F.G.S., F.G.A., gave a talk entitled 'Some rare gemstones'.

On 19th May, 1983, at Church House, Mr C. R. Burch, B.Sc., F.G.S., gave a talk entitled 'Some inclusions in quartz and other silica gems'.

On 16th June, 1983, at Church House, Mrs Val Duke spoke about some of her visits to the gem mines in Brazil.

South Yorkshire & District Branch

On 24th March, 1983, at the Sheffield City Polytechnic a practical evening was held. The emphasis was on crystallography and members brought a variety of specimens for identification.

On 10th May, 1983, at the Sheffield City Polytechnic Mr Peter G. Read, C.Eng., F.G.A., gave a talk entitled 'New gem testing instruments'.

ANNUAL GENERAL MEETING

The 52nd Annual General Meeting of the Association was held on Wednesday, 4th May, 1983, at the Small Hall, Kensington Town Hall, Hornton Street, London, W.8.

Mr David Callaghan, the Chairman, presiding over the meeting, mentioned some of the items covered in the Annual Report. He referred to the Association's loss sustained by the death of Mr Norman Harper, Vice-President and former Chairman, and the retirement of his immediate predecessor as Chairman, Mr Douglas King, and also the retirements of Mr John Chisholm as Examiner after 27

years and Dr Judith Milledge as Examiner after 12 years, the former of whom, however, with the able assistance of Mrs Mary Burland, was continuing to edit the enlarged and improved *Journal.*

Mr Callaghan observed that once again the important special awards had gone overseas, this time to Canadians, after being won by students from Hong Kong the previous year, and went on to refer to the formation of an Education Committee under the chairmanship of Dr George Harrison Jones as an important move. He then paid tribute to Mr Lawson Clarke, who was retiring from the office of Honorary Treasurer which he had held continuously since 1951, an office that his father, the late Mr V. W. Clarke, had held before him in 1924-25 and 1932-42—a remarkable family record of service.

Mr Lawson Clarke, in moving the adoption of the Annual Report and Accounts, presented the Accounts for 1982: there was, however, an invisible asset, he said, which affected the figures appearing in the Balance Sheet, namely the high quality knowledge and support of the Officers, Council and Members. Looking back to his first year as Treasurer, Mr Lawson Clarke added that the current figures shed light on the value of this invisible investment: the Association's income had gone up by 120 times and its expenditure by a similar amount, whilst other figures had gone up by about 85 times. The motion for adoption having been duly seconded and put to the meeting was carried unanimously.

Sir Frank Claringbull, Mr David Callaghan and Mr Noel Deeks were then re-elected as President, Chairman and Vice-Chairman respectively; Mr Nigel B. Israel was elected Honorary Treasurer, and Mrs S. Hiscox, Messrs C. R. Cavey, A. C. Hilbourne, M. J. O'Donoghue, and P. G. Read were re-elected and Mr Brian Jackson was elected to the Council.

On the nomination of Council, the Chairman proposed the election of Mr Harry Wheeler as a Vice-President, and, on Mr Wheeler indicating his willingness to stand, he was duly elected a Vice-President of the Association by acclamation. In expressing his thanks, Mr Harry Wheeler, who was accompanied by his wife, Rene, said 'This is an honour beyond my wildest dreams.'

Messrs Hard Dowdy Watson Collin & Co. were re-appointed Auditors, and the proceedings then terminated.

THE NEW HONORARY TREASURER

Mr Nigel B. Israel, who, as recorded above, was elected at the Annual General Meeting to succeed Mr F. E. Lawson Clarke as Honorary Treasurer, is thirty-eight, a Fellow of the Gemmological Association (D.1978 with Distinction) and passed the Gem Diamond Examination in 1979. He was educated at University College School, Hampstead, where he obtained four Science A Levels. He spent ten years working for a firm of Chartered Accountants, involved in the preparation and auditing of accounts and with personal and company taxation. Since leaving accountancy he has dealt in fine jewellery and educational books, and after gaining his gemmological qualifications he has taught gemmology and associated subjects and is a regular member of the Post-Diploma Class.

COUNCIL MEETINGS

At the meeting of Council held on 23rd February, 1983, at Saint Dunstan's House, the business transacted included the following:

(1) following a report by Dr G. Harrison Jones, an Education Committee was formed with general responsibility to the Council for (a) the formation of educational policy (subject to the approval of the Council) and (b) all other educational matters including the review, creation, development, content, administration and promotion of all educational courses and activities and with power to co-opt persons thereto and/or to the Education Committee, and was constituted as follows, namely Dr G. Harrison Jones (Chairman), Drs A. J. Allnutt, R. R. Harding and J. B. Nelson, and Messrs P. J. E. Daly, A. E. Jobbins and D. Inkersole, with Mr Jonathan Brown as Secretary;

(2) the resignation from the Council of Mr Jonathan Brown, consequent upon his taking up full-time employment with the Association, was accepted;

(3) the following were elected to membership:

FELLOWSHIP

Anwar, Abdul A. M., Beruwala, Sri Lanka. 1982
Aoussat, Claude A., Vienna, Va, U.S.A. 1982
Arendtsz, Natalie A., Negombo, Sri Lanka. 1982
Baker, Judith, Ottawa, Ont., Canada. 1982
Balas, Aranka D., Budapest, Hungary. 1982
Bell, John A., Sevenoaks. 1982
Berthet, William L., Jacksonville, Fla, U.S.A. 1982
Bon, Maria H., Schoonhoven, Netherlands. 1982
Bouman, Henriëtta A. E., Bangkok, Thailand. 1982
Braunstein, Joan, Potomac, Md, U.S.A. 1982
Cassarino, Paul R., Rochester, N.Y., U.S.A. 1982
Chao, George Y., Ottawa, Ont., Canada. 1982
Chaturvedi, Vimal K., Jagdalpur, India. 1982
Cheung, Cliff P.-L., Toronto, Ont., Canada. 1982
Cowie, Gillian A., Liverpool. 1982
de Beer, Christiaan T. J., Durban, S.Africa. 1982
de Poli, Vesta, Genoa, Italy. 1982
de Regt, Marcus N., Goes, Netherlands. 1982
Dijkman-Vos, Christine S., Hong Kong. 1982
Esterhuizen, Karen F., Karoi, Zimbabwe. 1982
Fernando, Dudley L., Kew, Vic., Australia. 1982
Foster, Amanda L., Willowdale, Ont., Canada. 1982
Galsterer, Maureen G., Saginaw, Mich., U.S.A. 1982
Galt, Jessie J., Scarborough, Ont., Canada. 1982
Gea Lopez, Francisco J., Valencia, Spain. 1981
Geurts, Godefridus R. J. M., Heerlen, Netherlands. 1982
Glover, Brian M. G., Wallasey. 1982
Grishko, Alexander, Toronto, Ont., Canada. 1982
Gupta, Manoj B., Bombay, India. 1982
Harmer, Inge, The Gap, Qld, Australia. 1982
Hata, Kenichi, Kyoto-City, Japan. 1980
Hendriks, Fransiscus R. A., Amsterdam, Netherlands. 1982

Hinduja, Anuradha, Bombay, India. 1982
Hofer, Stephen C., Kensington, Conn., U.S.A. 1982
Hoogewerff, Regitse C., Diepenveen, Netherlands. 1982
Ickowicz, Steven, London. 1982
Jayaweera, Susil, Peradeniya, Sri Lanka. 1982
Jhaveri, Kalpana R., Bombay, India. 1982
Kauhanen, Pentti R., Helsinki, Finland. 1982
Kawai, Yoshito K., Utsunomiya-shi, Japan. 1982
Kesola, K. Juhani, Valkeakoski, Finland. 1982
Ketelaar, Arend C. R., Leidsendam, Netherlands. 1982
Kolamunne, Ahangangoda A. S., Kadawatte, Sri Lanka. 1982
Korhonen, Pentti K., Hämeenlinna, Finland. 1982
Kraan, Jan W., Amsterdam, Netherlands. 1982
Krishnamoorthy, K. L. N., Trivandrum, India. 1982
Kujanpää, Asko J., Helsinki, Finland. 1982
Kumaratilake, Wickramasinghe L. D. R. A., Kelaniya, Sri Lanka. 1982
Lam, Yat Hoong C., Singapore. 1982
McCall, Lois G., Wooster, Ohio, U.S.A. 1982
McQueen, B. Young, Jacksonville, Fla, U.S.A. 1982
Medniuk, Melanie A., Witham. 1982
Morishita, Kentaro, Tokyo, Japan. 1982
Morishita, Yuzuru, Hiroshima-Ken, Japan. 1982
Nicholas, Christopher E., Colombo, Sri Lanka. 1982
Nilam, Mohamed C. M., Weligama, Sri Lanka. 1982
Okada, Mari, Los Angeles, Ca, U.S.A. 1982
Piziura, Irene T., Nottingham. 1982
Ralls, Elizabeth L. W., Spokane, Wash., U.S.A. 1982
Ranabahu, Mallikage K.T.S., Ratnapura, Sri Lanka. 1982
Rubera, Anthony N., Dehiwela, Sri Lanka. 1982
St Amand, Mary J., Mill Valley, Ca, U.S.A. 1982
Schutt, Karl R., Manotick, Ont., Canada. 1982
Senanayake, Nimalka R., Homagama, Sri Lanka. 1982
Senanayake, S. A. M. A. S. P., Gampaha, Sri Lanka. 1982
Shah, Sanjay S., Bombay, India. 1982
Shenker, Ian L., Edgware. 1982
Staley, Nancy C., Potomac, Md, U.S.A. 1982
Toivainen, Heidi S., Östersundom, Finland. 1982
Uwais, M. Ifthikar., Kandy, Sri Lanka. 1982
van Velzen-Ritmeÿer, Elisabeth T. H., Rotterdam, Netherlands. 1982
van Zeijst, Raymond M. E., Nieuwegein, Netherlands. 1982
Vaughan, Susan E., Nottingham. 1982
Venemans, Anne C., Groenekan, Netherlands. 1982
Verjee, Nasim K., Nairobi, Kenya. 1982
Vuorinen, Jorma T., Hämeenlinna, Finland. 1982
Waghela, Mahesh R., Bombay, India. 1982
Walsh, Francine E., Dundas, Ont., Canada. 1982
Wols, René P., Rotterdam, Netherlands. 1982
Yamasaki, Kazutaka, Kochi City, Japan. 1982
Ypyä, Teuvo H., Kemi, Finland. 1982

TRANSFER FROM ORDINARY MEMBERSHIP TO FELLOWSHIP

Cornioley, Jean-René, Fribourg, Switzerland. 1982

ORDINARY MEMBERSHIP

Abe, Nobuko, Tanashi City, Japan.
Alexander, Jean, Wantage.
Anderson, Iris K., Christchurch.
Apland, Ken A., Cottage Grove, Oreg., U.S.A.
Arita, Kouzi, Saga City, Japan.
Asagai, Toshiki, Sakai City, Japan.
Ashraf, Ashfaq A., Nairobi, Kenya.
Auberson, Viviane, Geneva, Switzerland.
Beveridge, Ronald R., Seacombe Heights, S.A., Australia.
Birkin, Paul M., Stoke-on-Trent.
Blackstock, George, Ewell.
Bottoms, Robert, Bicester.
Cox, Patrick P., Calgary, Alta, Canada.
Dathi, Kaniz, Harrow.
Davey, Frances V., Invercargill, N.Z.
Davis, H. Trevor, Liphook.
Dunn, Andrew C., Reading.
Duperray, Marie-Hélène, Gex, France.
Ellefsen, Sigmund M., Bergen, Norway.
Fletcher, Hazel J., Derby.
Gardener, Robert J., Stockport.
Gardener, Sheila, Yeovil.
Gibbs, Margaret E., Beaworthy.
Gibson, Dorothy, Chatham, N.J., U.S.A.
Glaholm, Janice A., Paris, France.
Gold, Ruth G., Anaheim, Ca, U.S.A.
Gordon, Ben, Houston, Tex., U.S.A.
Hatabu, Katuski, Kitakyushu City, Japan.
Hewitt, Paul R., Amersham.
Horovitz, Theodore, Geneva, Switzerland.
Hubrt, Ludek, Prague, Czechoslovakia.
Hui-Nam, Oh, Seoul, Korea.
Iyama, Isao, Kyoto-City, Japan.
Jaffery, Zulfiquar A., Machakos, Kenya.
Josephson, Jeffrey, Glasgow.
Kaye, Anthony M., Chester.
Kennedy, Muriel D., Toronto, Ont., Canada.
Khanna, Atul, Birmingham.
Kimishima, Yoko, Yokosuka City, Japan.
Kon, Mark J., Orwell, Ohio, U.S.A.
Koseki, Norio, Fukushima-Shi, Japan.
Kovithavongs, Panya, Edmonton, Alta, Canada.
Kwan, Ng Yue Yuk, Hong Kong.
Levy, Margot, Hong Kong.
Liggett, Sonia A., Cardiff.
Lippelt, Ulrich W., Karachi, Pakistan.
Long, Yvonne M., Dover.
Lopezzo, Lorraine V., London.
McMurrie, Alfred G., Liverpool.
Marczycha, Michael J., Leeds.
Matheson, Brian D., Adelaide, S.A., Australia.
May, Gerard, Belfast.
May, John K., Mt Pleasant, S.C., U.S.A.
Medcraft, Joseph, Perth, W.A., Australia.
Mitchell, Kenneth P., Crowborough.
Mitchell, William G., Fremont, Ca, U.S.A.
Moir, Evelyn A., Cove.
Murakami, Ryutaro, Osaka, Japan.
Naina Marikar, Mohamed R., Colombo, Sri Lanka.
Nakamura, Midori, Ichikawa City, Japan.

Nakamura, Yoshihiro, Wakayama City, Japan.
Narang, Ram C., Bombay, India.
Nawaz, Rab, Belfast.
Newton, Brian G., Saltash.
Ng, Fen Sin, Singapore.
Nishimoto, Hiroko, Takarazuka City, Japan.
Nist, Donald E., Los Angeles, Ca, U.S.A.
Nitta, Hisako, Tokyo, Japan.
Norberg, Arvid, Sollentuna, Sweden.
Ohta, Kumi, Tokyo, Japan.
Perks, Tessa G., London.
Platt, Eric, Colne.
Quam, Maurice D., St Paul, Minn., U.S.A.
Raniga, Dhiraj L., Richmond, B.C., Canada.
Reiner, Steven, Houston, Tex., U.S.A.
Rens, Gerald J., Johannesburg, S.Africa.
Richards, Sara, Rhosneigr.
Risbridger, Anne, Redhill.
Robinson, Stanley, Clayfield, Qld, Australia.
Ross, Gloria, Los Angeles, Ca, U.S.A.
Sakamoto, Masako, Ueda City, Japan.
Sato, Toshiko, Osaka, Japan.
Scoble, Bride P., Lytchett Matravers.
Sentell, Eric D., Aspen, Colo., U.S.A.
Shigeno, Katsuharu, Tokyo, Japan.
Shimada, Takanori, Tokyo, Japan.
Shum, Chan Hui, Kuala Lumpur, Malaysia.
Silk, David J., Uxbridge.
Singh, Jang B., Edgware.
Smallwood, Anthony G., Gray's Point, N.S.W., Australia.
Soanes, Stuart E., Oakville, Ont., Canada.
Sodel, Abdul H., Nairobi, Kenya.
Stroud, Louise M., Harrogate.
Suita, Shigeo, Kyoto City, Japan.
Surjaatmadja, F. K., Jakarta Timur, Indonesia.
Tagliamonte, Nino, Vicenza, Italy.
Tambuyser, Paul B., Schoorl, Netherlands.
Tamura, Hiroto, Ichikawa City, Japan.
Tazaki, Noriko, Tokyo, Japan.
Tazaki, Yasuko, Tokyo, Japan.
Teng, Albert C., London.
Terauchi, Toshihiro, Kyoto, Japan.
Terpilak, Thomas J., Silver Spring, Md, U.S.A.
Thilesen, Georg, Fredrikstad, Norway.
Thomis, Helen M., Halifax.
Todd, Sally E., London.
Toohey, Judith, Surbiton.
Uesugi, Tohru, Osaka, Japan.
Vander Brugge, Willy T., Ghent, Belgium.
Van Valkenburg, Eric, Tucson, Ariz., U.S.A.
Verheÿ, Elizabeth C., Vlaardingen, Netherlands.
Washio, Hiroaki, Funabashi City, Japan.
Wetten, Veronica, Hong Kong.
Williams, Kevin G., Cowbridge.
Woolley, Joseph G., Nelson, N.Z.
Yazu, Chiharu, Krume City, Japan.

At the meeting of Council held on 4th May, 1983, at the Small Hall, Kensington and Chelsea Town Hall, Hornton Street, London W.8., the business transacted included:

(1) the acceptance by Professor Dr Hermann Bank, F.G.A., of the Council's invitation to present the awards this year, which is the Fiftieth Anniversary of the foundation of the German Gemmological Association (Deutsche Gemmologische Gesellschaft) was reported, the Presentation of Awards being on 14th November at Goldsmith's Hall;

(2) it was decided to form an Advisory Committee to assist the Officers and Secretary in preparatory decisions before they come to Council;
(3) it was agreed that because of the relationship of the Association with the Gem Testing Laboratory of the London Chamber of Commerce and Industry, its Director for the time being should be invited to attend meetings of the Council;
(4) the Annual Subscriptions for 1984 were fixed as follows:
Fellows £15: Ordinary Members £18: Associate £18;
(5) it was agreed that—
from 1983 the Correspondence Course fees should be raised to:
Preliminary: U.K. £55.00 inc.15% V.A.T.
Europe $(U.S.)182.
Elsewhere overseas $(U.S.)231.
Diploma: U.K. £62.00 inc.15% V.A.T.
Europe $(U.S.)209
Elsewhere overseas $(U.S.)253.
and that from 1984 the Examination fees should be:
Preliminary: U.K. £22.00 inc.15% V.A.T.
Overseas $(U.S.)143.
Diploma: U.K. £30.00 inc.15% V.A.T.
Overseas $(U.S.)215.
Reduced Examination fees for Correspondence Course Members:
Preliminary: U.K. £20.00 inc.15% V.A.T.
Overseas $(U.S.)88.
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LETTER TO THE EDITOR

From Mr Peter G. Read, C.Eng., M.I.E.E., M.I.E.R.E., F.G.A.

Dear Sir,

It is several years now since the nanometre replaced the Ångström unit as a unit of measurement for the wavelength of the visible, infrared and ultraviolet sections of the electromagnetic spectrum. Although there was some initial resentment to this change, the only numerical modification required was the moving of the decimal point one place to the left, and this change caused very little confusion when absorption spectra were quoted in nanometres or nm.

Communication difficulties do arise, however, when articles written by our physicist colleagues appear in the *Journal of Gemmology* containing less familiar wavelength terms such as wavenumber, electron volt, megahertz, micron, μ, and micrometre.

Of all these alternative units, at least the last three bear a numerical similarity to the nanometre in that one micron, μ or micrometre is equal to 1000 nm (use of the terms micron and μ is now 'generally deprecated' according to the French standards publication 'Le Système International d'Unités).

No such easy relationship exists with the other terms. In order to convert a wavenumber into nanometres, it is necessary to divide it into 10^7. To change an electron volt (eV) value into nanometres, it must first be multiplied by 8.006 and the result then divided into 10^4. Similarly, megahertz (MHz) must be divided into 300×10^9 to convert it to nanometres.

One solution to this problem would be to require authors to use the accepted and familiar gemmological wavelength unit of the nanometre when submitting articles to the *Journal.* I would go even further and also ask the *Journal's*

abstracters to convert, where appropriate, any such wavelength references into the more recognizable nm. For the far infrared wavelengths this may result in the occasional rather cumbersome number, but this can easily be overcome. A wavenumber of 500 can, for example, be shown either as 20 000 nm, or more compactly as 2×10^4nm.

Yours faithfully,
PETER READ.

11th March, 1983.
Bournemouth, Dorset.

[*NOTE. In this connexion, readers' attention is called to (1) the note headed 'The Journal of Gemmology' (J.Gemm., 1976, XV(3), 164) and (2) 'The International System of Units and its Application to Gemmology', by Dr K. Nassau (J.Gemm., 1977, XV(5), 243-7).—Ed.*]

CORRIGENDA

On p.461 above, for 'Ickowicz, Stephen,' read 'Ickowicz, Steven,' and delete 'Ifthikar, Mohamad U. M., Kandy, Sri Lanka.'

On p.462 above, for 'Ranabahu, Millakage K. T. S.,' read 'Ranabahu, Mallikage K. T. S.,'

On p.463 above, insert 'Uwais, Mohamad I., Kandy, Sri Lanka.'

In J.Gemm., 1981, XVII (5), on p.358 delete 'Ifthikar, Ifthikar U.M., Kandy, Sri Lanka., and on p.361 insert 'Uwais, Mohamad I., Kandy, Sri Lanka.'

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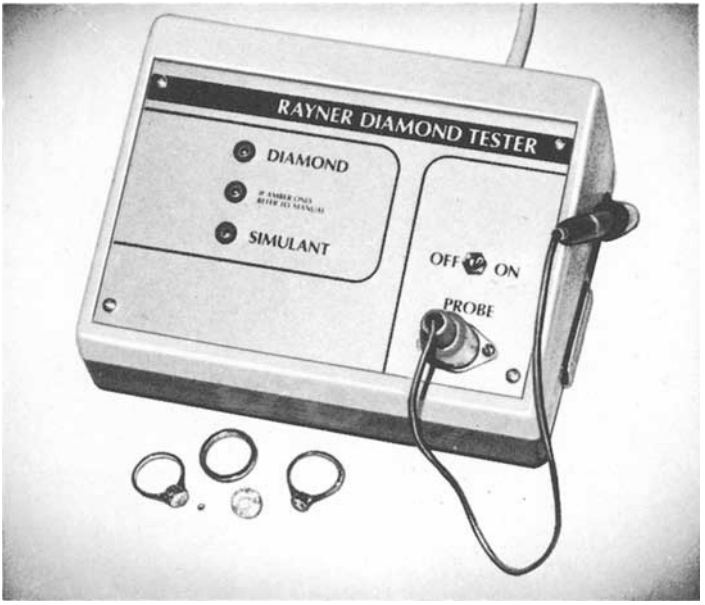

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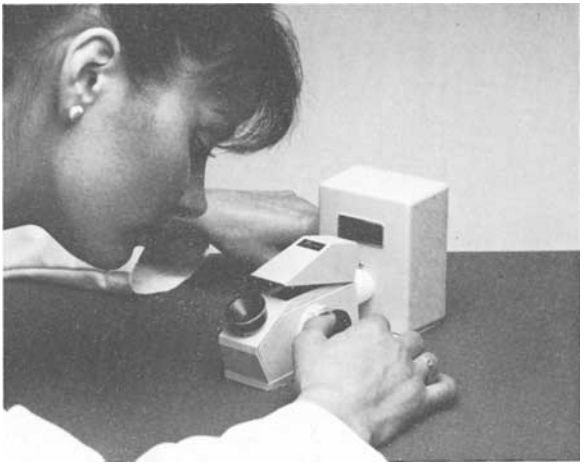

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Affiliated Associations are the Gemmological Association of Australia, the Canadian Gemmological Association, the Gem and Mineral Society of Zimbabwe and the Gemmological Association of Hong Kong.

The *Journal of Gemmology* was first published by the Association in 1947. It is a quarterly, published in January, April, July, and October each year, and is issued free to Fellows and Members of the Association. Opinions expressed by authors are not necessarily endorsed by the Association.

Notes for Contributors

The Editor is glad to consider original articles shedding new light on subjects of gemmological interest for publication in the *Journal.* Articles are not normally accepted which have already been published elsewhere in English, and an article is accepted only on the understanding that (1) full information as to any previous publication (whether in English or another language) has been given, (2) it is not under consideration for publication elsewhere and (3) it will not be published elsewhere without the consent of the Editor.

Articles published are paid for, and a minimum of 25 prints of individual articles may be supplied to authors provided application is made on or before approval of proofs. Applications for prints should be made to the Secretary of the Association—not to the Editor—and current rates of payment for articles and terms for the supply of prints may be obtained also from the Secretary.

Although not a mandatory requirement, it is most helpful if articles are typed (together with a carbon copy) in double spacing on one side of the paper, with good margins at sides, top and foot of each page. Articles may be of any length, but it should be borne in mind that long articles are more difficult to fit in than short ones: in practice, an article of much more than 10 000 words (unless capable of division into parts or of exceptional importance) is unlikely to be acceptable, while a short note of 400 or 500 words may achieve early publication.

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THE JOURNAL OF GEMMOLOGY

and

PROCEEDINGS OF THE GEMMOLOGICAL ASSOCIATION OF GREAT BRITAIN

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THE JOURNAL OF GEMMOLOGY
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Vol. XVIII No. 8 October 1983

IDENTIFICATION OF THE NEW SYNTHETIC AND TREATED SAPPHIRES

By Professor Dr E. GÜBELIN, C.G., F.G.A.

Meggen, Switzerland.

The fact that the new techniques of synthesis are now being applied to the production of sapphires is not surprising when one considers the imposing success attained recently by Chatham, Kashan and Knischka in synthesizing rubies.

Although the new synthetic sapphires have not yet reached the market in such overwhelming quantities as those new synthetic rubies, it is nevertheless high time for gemmologists to arm themselves with some knowledge of how to distinguish them from their natural counterparts.

SYNTHETIC BLUE SAPPHIRES

The experiments which led to the production of synthetic sapphires by the new flux-growth method lasted for many years, and in 1980 Messrs C. and Th. Chatham introduced their first samples of synthetic sapphire of gem quality to the trade. These

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early productions by Chatham contained a great number of inclusions, some of which were of totally unnatural nature, and these stones were therefore clearly distinguishable from natural sapphires, thus making them incompatible on the market. However, having attained a certain degree of success, Chatham & Son have improved their product to such an extent that the latest synthetic sapphires to enter the market from this source have considerably less inclusions. The author was able to acquire a good number of samples of each generation of these synthetic Chatham sapphires, and a thorough examination revealed the fact that with some experience these can be readily distinguished not only from natural sapphires, but also from synthetic Verneuil sapphires. The results of these examinations are therefore presented forthwith for the benefit of all readers of this *Journal* interested in this field of gem-testing. As was expected, the physical properties differed very little from those of natural sapphires.

General Appearance. Both crystals and cut specimens were available for the examinations. All the crystals were remarkable for their irregular coloration: dark blue patches alternated with pale blue and even colourless zones, the latter often being tinted with yellow. The cores of the crystals were also mainly yellow (Figure 1). As cut stones, these synthetic Chatham sapphires bore some resemblance to natural sapphires from Australia (see also Figures 22 and 23). The crystals were rhombohedral in their main forms; medium sized rhombohedra and rhombohedral dipyramids combined with truncated prism faces, while the basal planes were so well developed that the crystals displayed a pronounced tabular habit (Figure 2). Many smaller crystals had grown together in clusters.

The refractive indices varied for n_ε from 1.758 to 1.762, and for n_ω from 1.766 to 1.770, with an absolutely constant birefringence of $n_\Delta = -0.008$.

The density ranged from 3.942 to 4.05 g/cm^3 and appeared be strongly influenced by the inclusions.

The dichroism showed twin-colours: pale greenish-blue for the extraordinary ray and dark blue for the ordinary ray.

The spectro-optical examination revealed no absorption lines at all for the blue area of the stones, but the yellow zones showed a very weak suggestion of a delicate band at 450 nm, only visible with a blue filter.

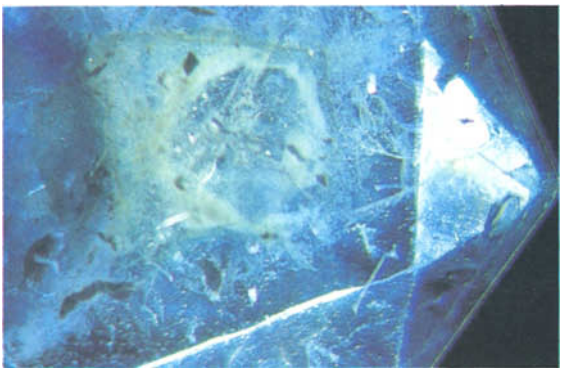

FIG. 1. Synthetic flux-grown sapphire by Chatham. Tabular crystal with large basal plane surrounded by triangular rhombohedra. Note greenish core. 8×

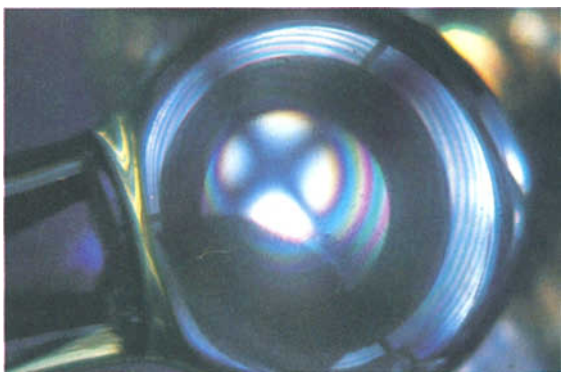

FIG. 2. Sapphire crystal in same position as in Fig. 1. The conoscopical image of the optical monoaxis passing vertically through the basal plane is made visible by a glass ball between crossed polars. 10×

FIG. 3. Parallel, structural zones flexed at an angle of 120°. 20×

The luminescence in ultraviolet light provided the only optical distinguishing factor in comparison with natural sapphires, as synthetic Chatham sapphires glowed with an intense pale green in long-wave ultraviolet light, and appeared dull green in short-wave ultraviolet light, especially the yellow areas. No phosphorescence was observed. Natural blue sapphires do not react to ultraviolet light, and synthetic Verneuil sapphires appear whitish- to milky-green in short-wave ultraviolet light. (However, two synthetic blue faceted sapphires by Chatham—obtained very recently—do not display any luminescence.)

Inclusions

Just as with the synthetic stones by Verneuil and the new synthetic rubies by Chatham, Kashan and Knischka, the best possibility of a successful and reliable identification lies in the inclusion scene.

Although this is not so variegated by far as in the new synthetic rubies, it is none the less confusing, for it is very similar to that of natural sapphire in many ways. With low magnification such as a pocket lens, irregular coloration and crazily intertwined or single unfurled banners are apparent, as well as coarse flux-inclusions and black daggers and platelets which glint silvery in reflecting incident light.

The impression of irregular coloration is caused by colourless, yellow and blue areas, and phantoms occurring either singly or in combination with each other. The latter are usually yellowish of varying intensity, and are situated in the centre of the crystal (Figure 1). In faceted stones these may or may not be present, depending upon the cut. These yellow patches are often more strongly populated and defiled with flux-formations than the colourless or blue areas. The variegated colour-zones are not curved like those in the synthetic Verneuil sapphires, but straight and often angular like those in natural sapphires: i.e. they represent the growth-stages of the hexagonal prisms or rhombohedra, and very often both forms are represented (Figures 3 & 4). Sometimes these zones are formed by lamellae as a result of polysynthetic twinning which, in contrast to the zonal structure, show no angles (Figure 5). Rough flux inclusions are much commoner than in the

FIG. 4. Characteristic inclusion scene in synthetic sapphire by Chatham, comprising angular zones, tiny flux grains and black platelets of platinum (one of them in the top right-hand corner with silvery reflection). 15 ×

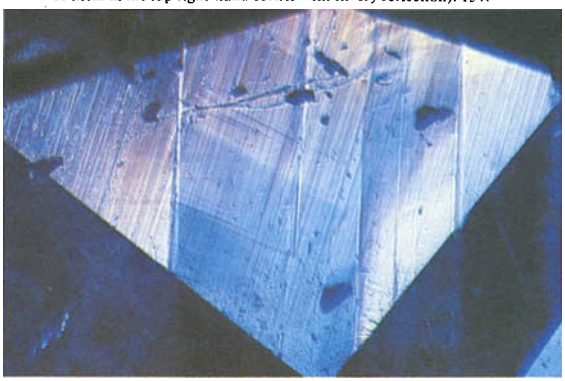

FIG. 5. Broad straight polysynthetic twin lamellae in parallel alignment. 25 × (*Photo by J. Koivula, G.I.A.*)

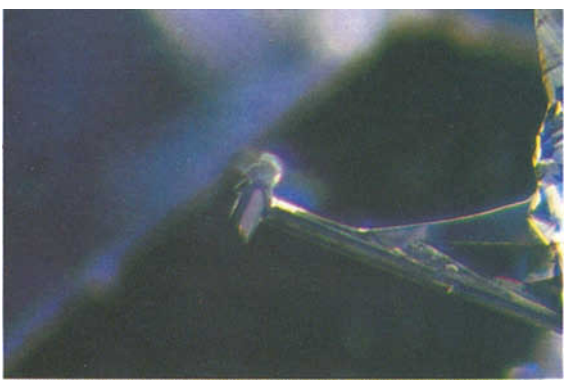

FIG. 6. Strange combination of prismatic platinum crystals with flux residue. 40 ×

FIG. 7. Coarse formation of flux inclusion. 40 ×

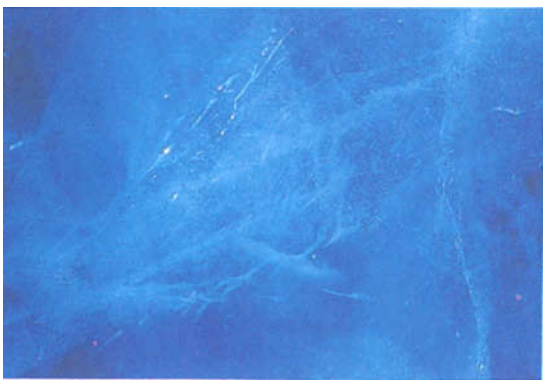

FIG. 8. Nebulous cloud formed by very fine wisps of flux inclusions. 20 ×
(Photo by J. Koivula, G.I.A.)

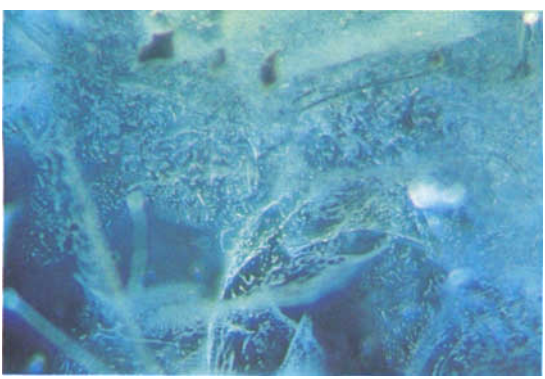

FIG. 9. Dense accumulation of 'feathers' representing various kinds of patterns as are often observed in synthetic sapphires by Chatham. 25 ×

synthetic Kashan-rubies, and do not appear white like those, but dirty grey, yellow, and brownish. Their shapes and sizes vary from small circular shapes through torn scraps to indescribably irregular forms (Figures 6 & 7).

The more subtle flux-inclusions form the well-known 'fingerprints' (healing fractures) of many varieties which are so easily confused with those in natural sapphires and will certainly be mistaken for such by many gemmologists who are unacquainted with this new phenomenon in synthetics. In those Chatham sapphires which contain numerous inclusions, these create an impression of wildly interwoven veils similar to the unmistakable inclusion-scenes—under low magnification—of the early synthetic emeralds (Figure 8), as well as of inclusion-rich synthetic Chatham and Kashan rubies. Under stronger magnification they disclose themselves as fantastically lacy, net-, mesh- or fingerprint-like, spotted, veined, striped or otherwise patterned banners, veils or cloudy smoke-like formations, having sometimes the detrimental effect of dulling the interior of the host stone (Figures 9-20). It is extremely difficult, if not in some cases almost impossible, to distinguish these inclusions from the natural ones, and since even the most elaborate descriptions could never do justice to the full quantity of their forms and patterns, an appropriately large number of microphotographs portray these in detail.

The black splinters and platelets which glint in reflected light like silver (Figures 21, 22; 24-27) occur either in close masses, scattered groups or singly, and some observers might consider them as a definite means of identification. Yet those who have examined Australian sapphires with ilmenite inclusions and sapphires from other sources housing hexagonal haematite flakes, will at least consider them as an unreliable criterion (Figure 23). However, a means of identification of the platinum inclusions in synthetics does exist in the silvery reflection of these (Figures 24 & 27), while haematite and ilmenite remain black under all conditions. Gemmologists are already familiar with the occurrence of platinum flakes in certain synthetic emeralds, synthetic alexandrites and synthetic Chatham and Knischka rubies. An x-ray analysis with the Gandolfi camera identified these splinters and platelets without doubt as platinum, thus indicating that platinum crucibles are being used in combination with this process of synthesis.

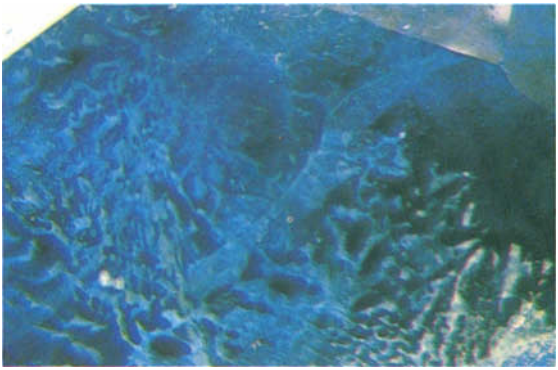

FIG. 10. Lace-like pattern of an extended plane of residual flux. 20 ×

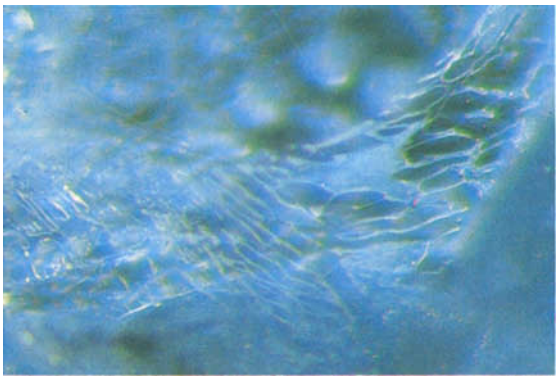

FIG. 11. Net-like distribution of film-like flux inclusions. 20 ×

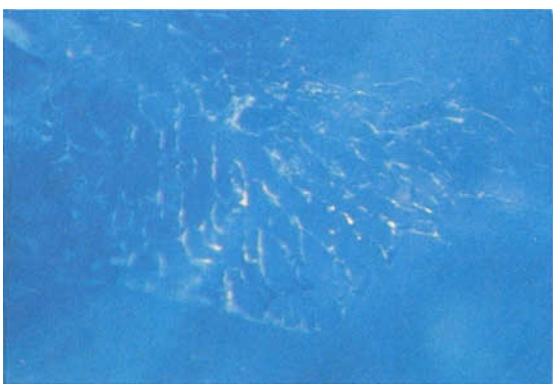

FIG. 12. Mesh-like arrangement of small discrete flux inclusions of bizarre shapes. 80 × (*Photo by J. Koivula, G.I.A.*)

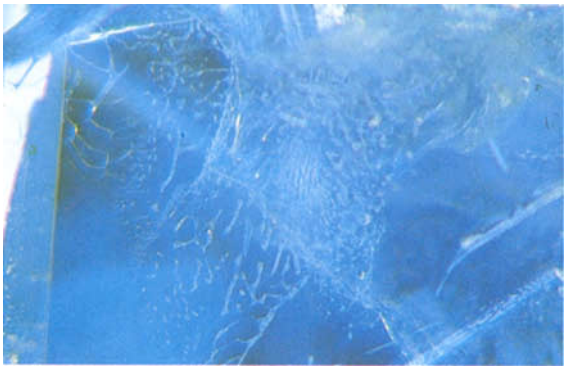

FIG. 13. A loosely designed 'fingerprint' inclusion superposed by a 'feather' of dense lace-like flux-remnants. 20 ×

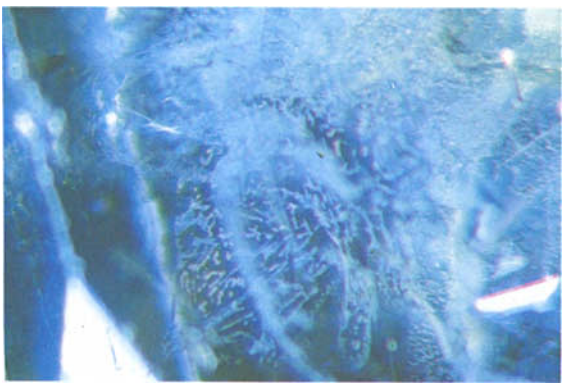

FIG. 14. Dense concentration of residual flux inclusions with shred-like forms. 25 ×

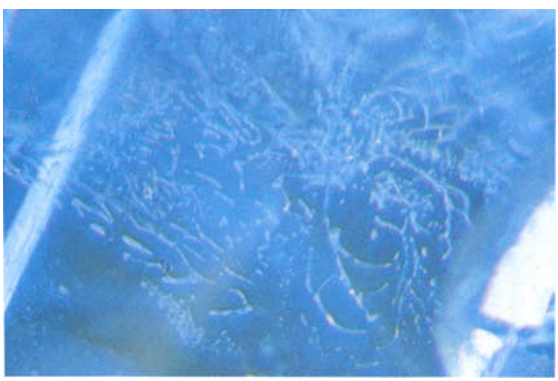

FIG. 15. 'Fingerprint' inclusion of white flux, highly confusing with similar inclusions in natural sapphire. 25 ×

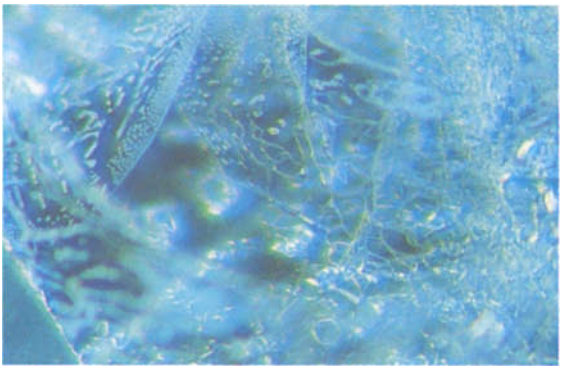

FIG. 16. Intertwined 'feathers', 'nets', and 'fingerprints' of white flux inclusions. 25 ×

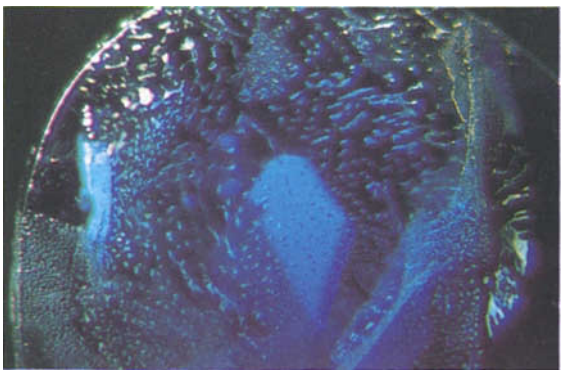

FIG. 17. Various irregular shapes of individual flux remnants massed to form a large flat inclusion. 20 ×

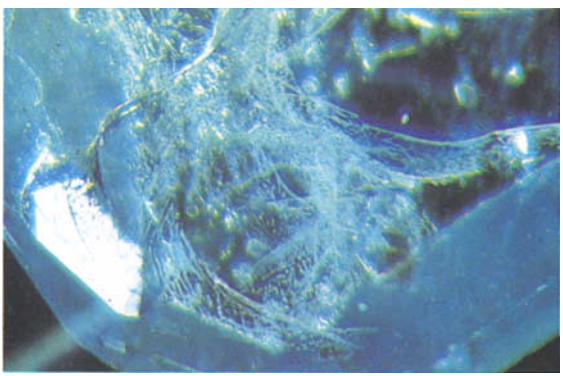

FIG. 18. Combination of various hammock-shaped flux inclusions, the appearance of which is quite typical for synthetic sapphires by Chatham. 16 ×

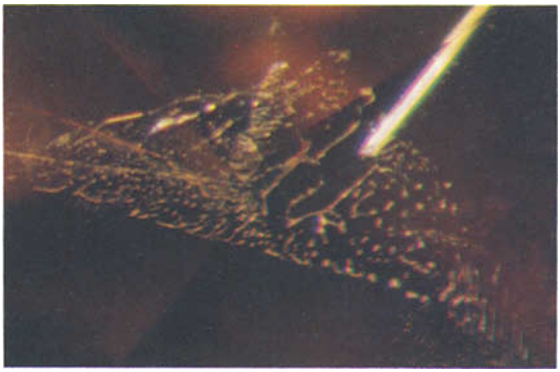

FIG. 19. Illusive 'fingerprint' inclusion of residual flux in a flux-grown synthetic orange sapphire (padparadschah) by Chatham, simulating 'fingerprint' inclusions in natural padparadschahs. White streak is a reflecting platinum needle. 40 ×

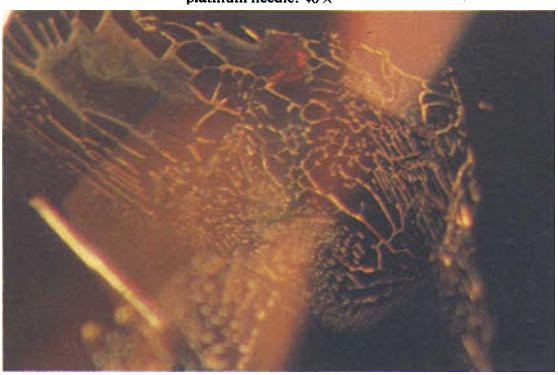

FIG. 20. Net-like pattern of stretched flux inclusions in a synthetic orange sapphire (padparadschah) by Chatham (easily mistaken for a partially healed fracture in a genuine padparadschah). White streak is a reflecting platinum needle. 32 ×

Inclusions depicted in Figs. 3, 5 and 7-20 may also be observed in natural sapphires, and are therefore highly misleading.

FIG. 21. Flux-grown sapphire by Chatham teeming with platinum inclusions of various shapes (hexagonal, triangular and rectangular platelets, rods, spikes, splinters, etc.) 8 ×

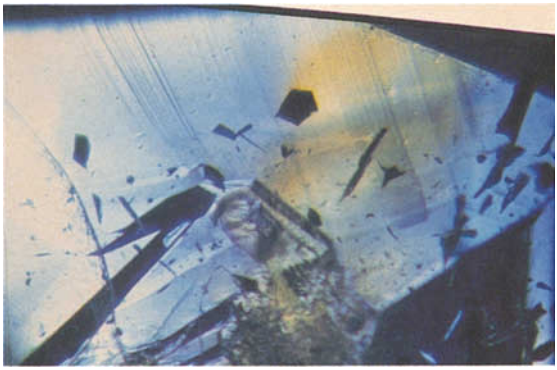

FIG. 22. Hexagonal and wedge-shaped platinum inclusions marking a flux-grown Chatham sapphire. 26 ×

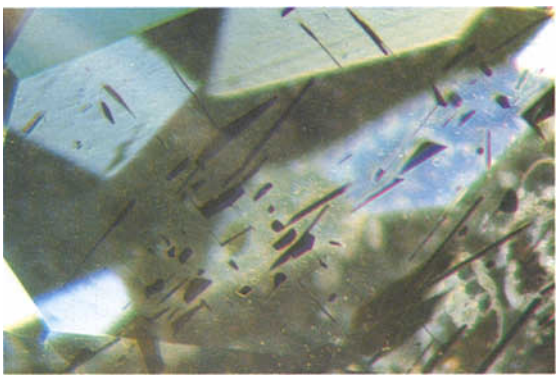

FIG. 23. For comparison: black ilmenite inclusions in a green-blue sapphire from Australia. 35 ×

FIG. 24. Large misleading 'fingerprint' inclusion superimposed by two tabular platinum crystals reflecting the impinging light with a silvery lustre. 26 ×

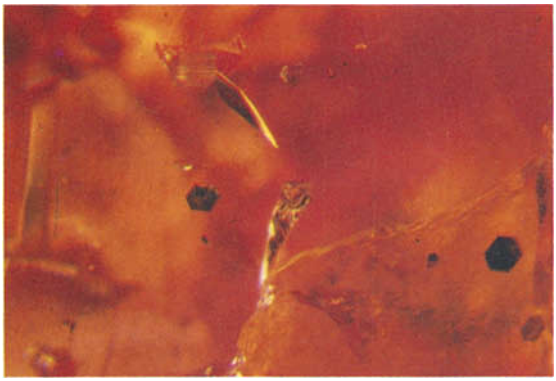

FIG. 25. Hexagonal platinum platelets and coarse flux inclusions in a synthetic orange sapphire (padparadschah) by Chatham. 22 ×

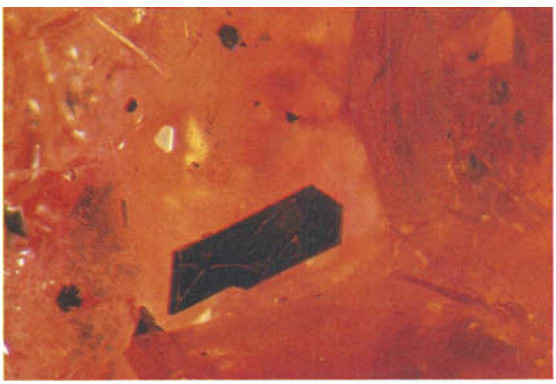

FIG. 26. Concentration of platinum platelets of various shapes within a small area betray the synthetic origin of the host padparadscah. 17 ×

FIG. 27. Hexagonal platinum platelet reflecting the impinging light with a metallic silvery lustre. 25 ×

SYNTHETIC ORANGE SAPPHIRES

Quite recently, after having reached satisfactory results with their blue synthetic sapphire, Messrs C. and Th. Chatham succeeded in realizing a more ambitious project by producing orange synthetic sapphire, yet simultaneously involving the gem trade and gemmologists in even more intriguing problems and dilemmas.

The colour range of these latest synthetic sapphires encompasses all the hues from brownish orange via pure orange to orange-red, excelling in the finest pinkish orange of the lotus flower called padparadschah, which is extremely difficult to discern from the natural counterpart—at least by the inexperienced. Brown and orange sapphires have been manufactured for decades by the Verneuil process, yet their colours were definitely less attractive, and they could be identified by their inclusions—gas bubbles and curved growth lines (in immersion)—and the absolutely pure ones by means of electron spin resonance (Figures 28 & 29). In congruity with the blue synthetic sapphires by Chatham, the physical properties of these orange synthetic corundums hardly differ from those of the natural gems, i.e. the *refractive indices* vary within the same limits (n_D = 1.60-1.70); the *birefringence* (n_Δ = −0.008) and the *density* (d = 4.00 g/cm^3) are conspicuously constant; even the *dichroism* (pink for ε and brownish yellow for ω) and (to a certain extent only) the *luminescence* concur with those manifested by natural orange sapphires.

The latter characteristic, however, deserves some more detailed discussion, because a careful observer may perceive some slight differences. While in long-wave ultraviolet light the fluorescence is intense and of pure orange colour, in short-wave radiation the intensity of the dark orange hue is dimmed and some synthetic stones display a greenish cast; the synthetics tend to be rather patchy, whereas the fluorescence of the natural gems is quite homogeneous.

The *spectroscopic examination* discloses several interesting peculiarities, which, if permanent through many more future tests, might serve as a means of identification. In general the details of the absorption spectrum closely resemble those of ruby. The telltale absorption doublet at 692.8 and 694.2 nm in the red section converts into a bright emission line centred at 693.5 nm under oblique illumination. The absorption in the green at 550 nm and the

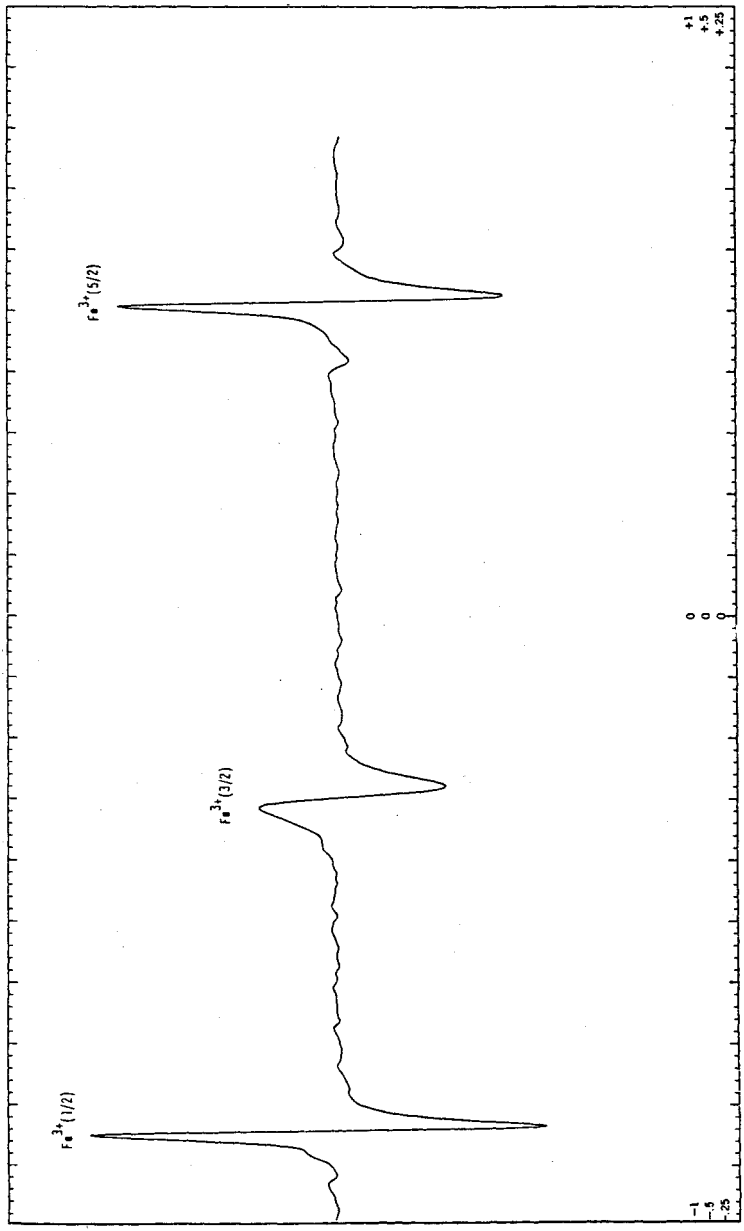

FIG. 28. Electron spin resonance spectrum of a natural golden brown sapphire from Bang Kah Cha (Thailand) ⊥ c-axis, recorded at a modulation frequency of 100 kHz and a microwave frequency of 9.48 GHz with a medium signal for Cr^{3+} and strong signals for Fe^{3+} (*recorded by Dr L. O. Andersson, Zug*).

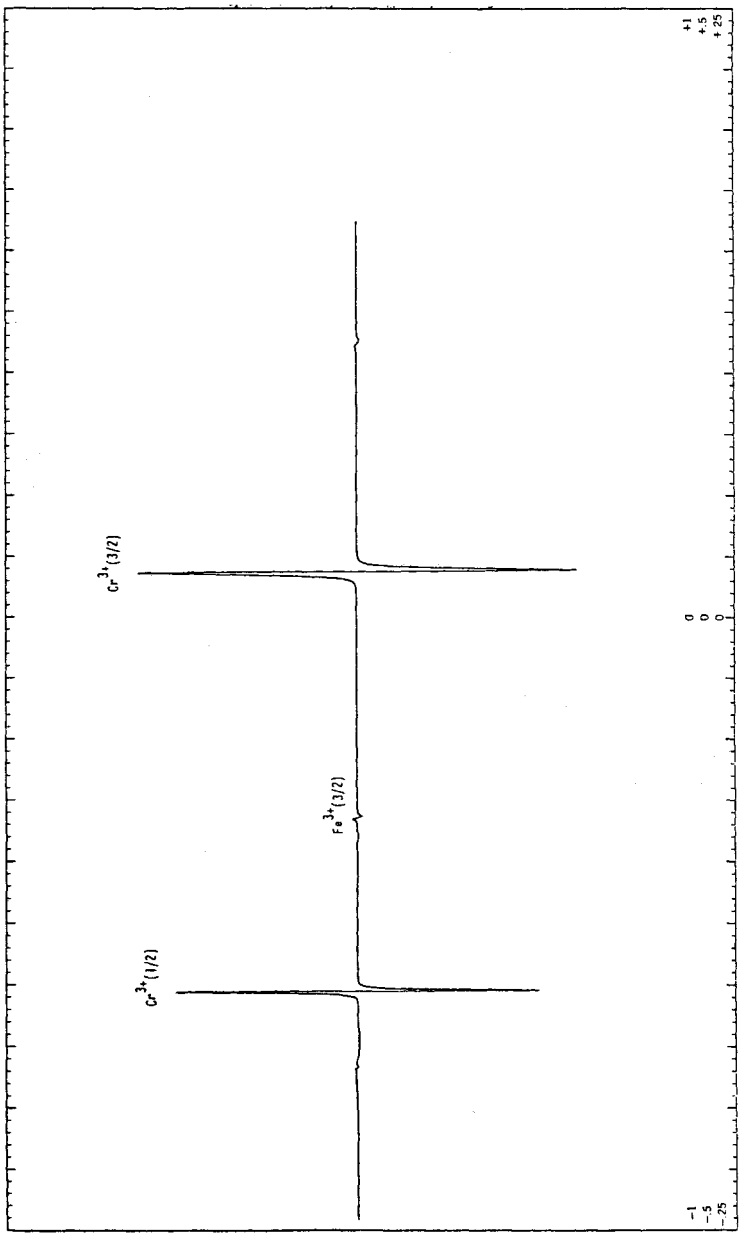

FIG. 29. Electron spin resonance spectrum of a synthetic brown yellow sapphire (Verneuil) *c*-axis, recorded at the same frequencies as Figure 28, gives very strong signals for Cr^{3+} and an extremely weak signal for Fe^{3+} (*recorded by Dr L. O. Andersson, Zug*).

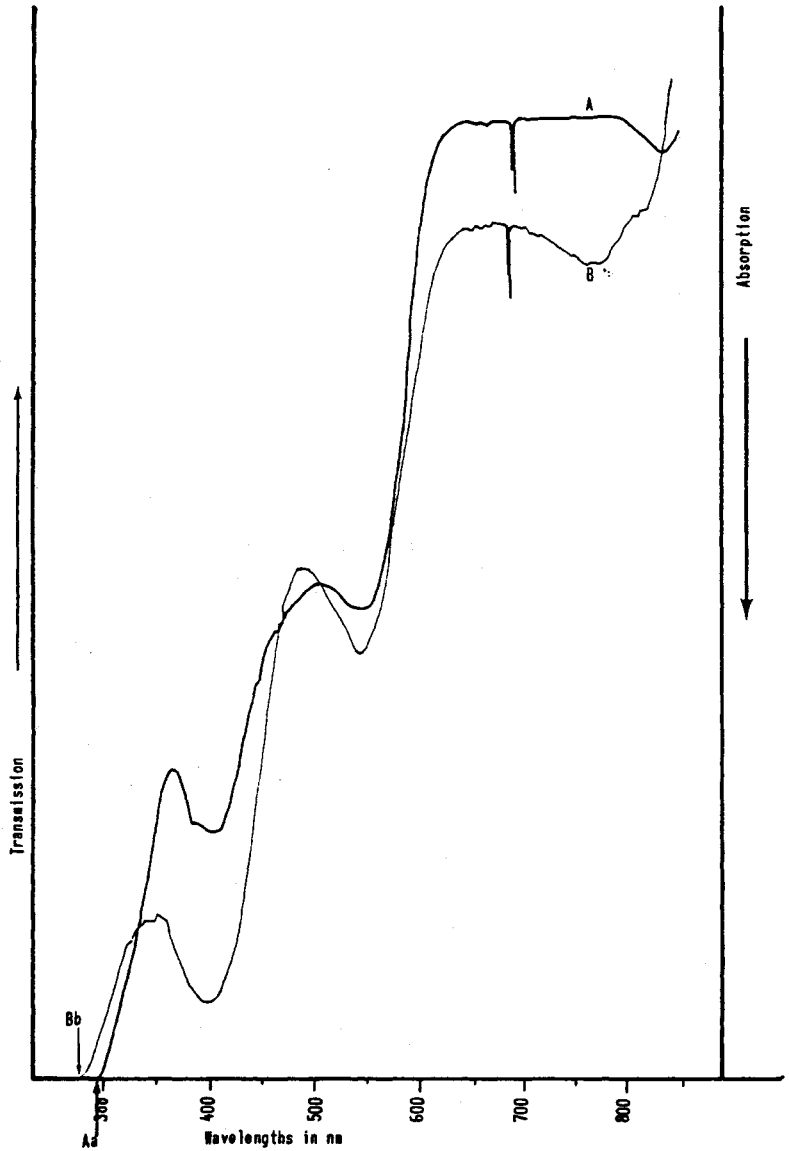

FIG. 30. Absorption curves of a natural padparadschah (bold curve A) and of a synthetic orange sapphire (Chatham) (fine line B). The former reaches complete absorption at 295 nm, the latter at about 270 nm (*recorded by C. A. Schiffmann, Lucerne*).

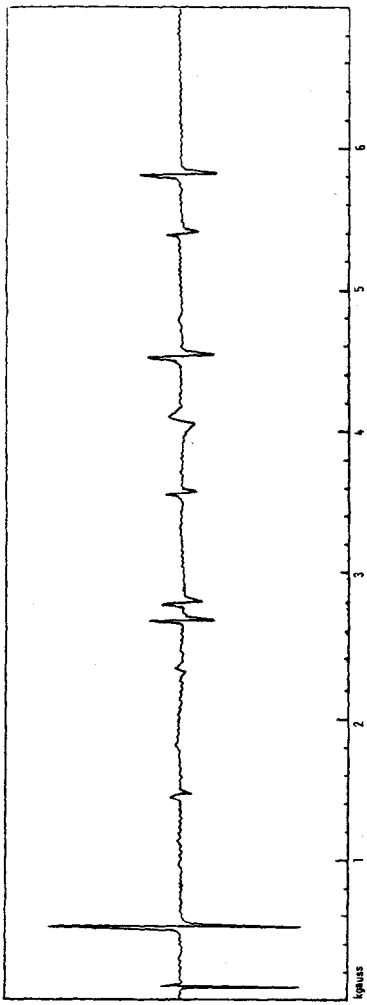

FIG. 31. Electron spin resonance spectrum of a natural padparadschah from Sri Lanka c-axis, recorded at a modulation amplitude of 10.0 G and a microwave frequency of 9.40 GHz depicting a medium number and medium intensity of signals within the magnetic field H[hOe] between 2.5 and 7 kgauss (*recorded by Dr D. Barberis, Zurich*).

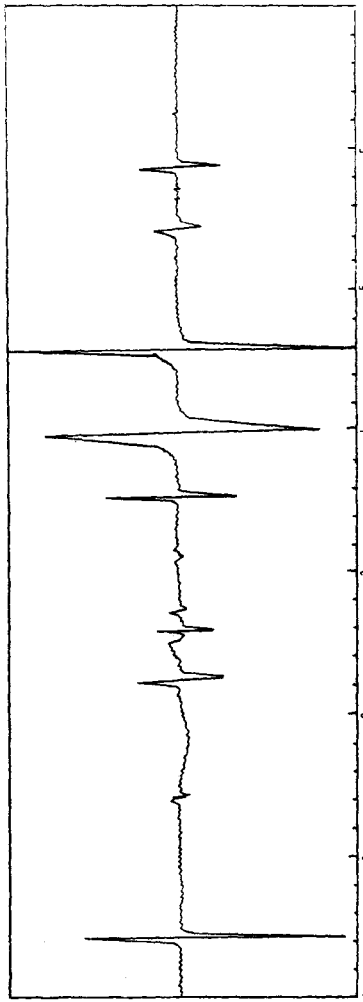

FIG. 32. Electron spin resonance spectrum of a synthetic orange sapphire (Chatham^{TM}) c-axis, recorded at a modulation amplitude of 6.3 G and a microwave frequency of 9.506 GHz manifesting a medium number of very strong signals within the magnetic field H[hOe] from 2 to 7 kgauss (*recorded by Dr D. Barberis, Zurich*).

transmission in the blue-green region at 500 nm are somewhat more pronounced in the orange synthetic sapphire. Beyond a second gap of transmission at 368 nm for the natural and at 350 nm for the synthetic padparadschah, the absorption increases rapidly towards shorter wavelengths and reaches a *maximum at about 300 nm for the natural gem* and *at about 270 nm for the synthetic* (Figure 30). With regard to the trace elements, the comparison of the absorption features of a natural and a synthetic padparadschah of precisely the same hue reveals that both contain about the same percentage of chromium, while the synthetic stone has very little or no iron.

The inclusions in the new synthetic padparadschahs are very similar to and equally as confusing as those in Chatham's blue synthetic sapphires. They also consist of unmolten flux-remnants of almost indescribably varying patterns. They are either extremely fine—like wispy clouds or gossamer veils—or they present formations with lace-, mesh-, net-like and other fantastic intertwined patterns (comparable to Figures 19 & 20), which are almost impossible to distinguish from similarly shaped and designed healing fractures in natural padparadschahs. Sometimes, but rather rarely, the very coarse flux inclusions may be observed—like those in blue synthetic sapphires by Chatham as depicted in Figures 6 & 7. The other kind of inmate of synthetic orange sapphires is represented by platinum platelets of various shapes—hexagonal, triangular, rectangular, spiky and other more or less geometrical forms (Figures 25 & 26). Black inclusions of some ore such as haematite, pyrrhotite and ilmenite might occasionally, yet rarely, occur in genuine orange sapphire, but they would not reflect with the same silvery, highly metallic lustre as the platinum platelets (Figure 27). If orange sapphire happens to house an accumulation of various forms of black platelets throughout the entire body, or even within a relatively small area, it is a strong indication of the host stone's synthetic nature.

Not completely satisfied with the relatively small number of distinguishing features and reliable tests, the author pondered on other methods of distinction between natural and synthetic orange sapphires. Encouraged by the comparatively good results of the electron spin resonance employed 4 years ago (see Figures 28 & 29) to discriminate synthetic brown yellow sapphire from its genuine

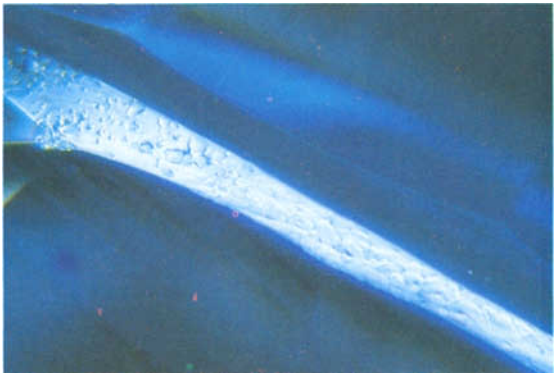

FIG. 33. Scabs on the surface of the reflecting half of a 'double girdle', indicating that this sapphire was heat treated. 25 ×

FIG. 34. Pockmarked upper half of a 'double' girdle on a heat treated sapphire. 40 ×

FIG. 35. Tell-tale inclusion scene consisting of several 'cooked' mineral inclusions surrounded by circular lace-fringed fractures. 32 ×

FIG. 36. Characteristic appearance of the interior of heat-treated sapphires: turbid zones encompassing white, dusty particles and typically atoll-like inclusions (the one near the upper right-hand corner shows high reflection). 25 ×

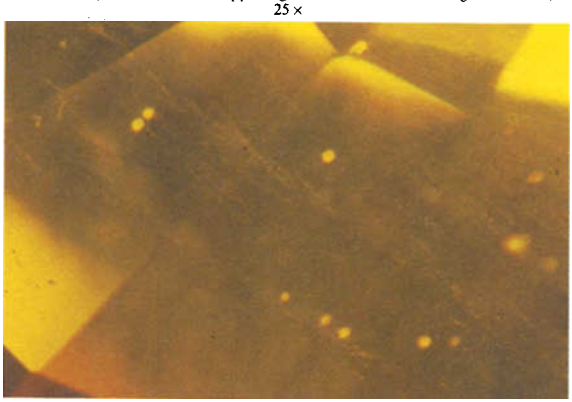

FIG. 37. Typically fringed perimeter of an inclusion modified by heat treatment. 64 ×

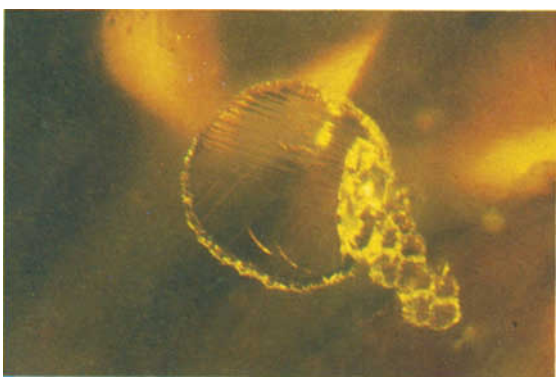

FIG. 38. Unusual cluster of molten mineral inclusions in contact with a circular tension fracture in front of zonal turbidity in a heat treated yellow sapphire. 40 ×

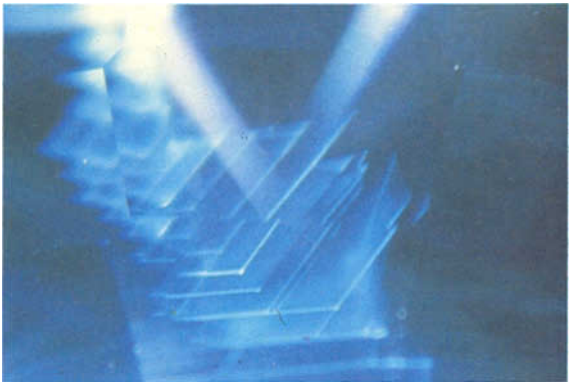

FIG. 39. Strongly emphasized textural pattern indicating thermal improvement of colour. 32 ×

FIG. 40. Phantom-like cloud enhanced by thermal heat treatment. 32 ×

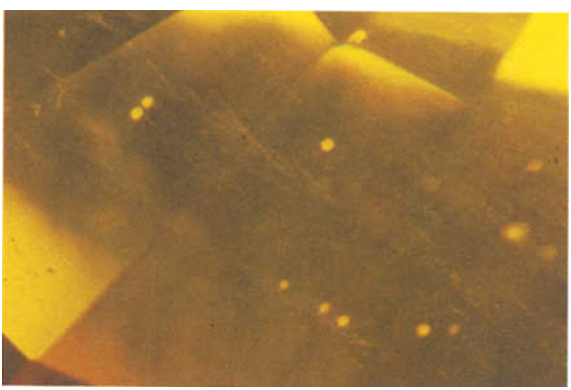

FIG. 41. Unambiguous appearance of the interior of a heat treated yellow sapphire: rounded 'cooked' mineral inclusions amidst striped 'fog' causing turbidity. 25 ×

FIG. 42. Molten mineral inclusions and dense cloud of some whitish exsolved matter of yet unknown nature. 25 ×

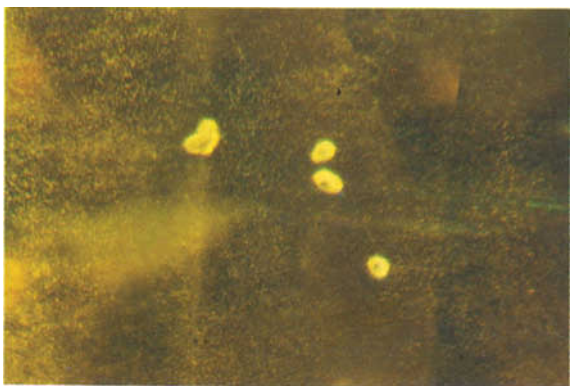

FIG. 43. Typically rounded molten mineral inclusions and fog-like turbidity characteristically associated with heat-induced colour alteration. 32 ×

FIG. 44. Fracture, open at the surface of a diffusion treated sapphire, dyed deep-blue by penetration of the dye. 16 ×

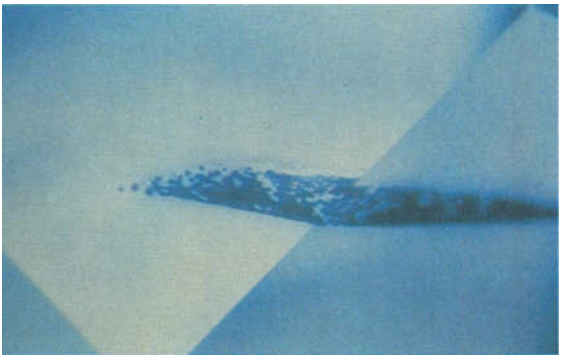

FIG. 45. Slender fissure touching the surface of a diffusion coloured sapphire. The dye entered the fissure by diffusion and double-dyed it by coating its walls. 30 × (*Photo by C. A. Schiffmann, Gem Laboratory Gübelin*)

FIG. 46. Enhanced coloration of an inclusion cut flush with the surface of a sapphire diffusion treated for colour alteration. 50 × (*Photo by C. A. Schiffmann, Gem Laboratory Gübelin*)

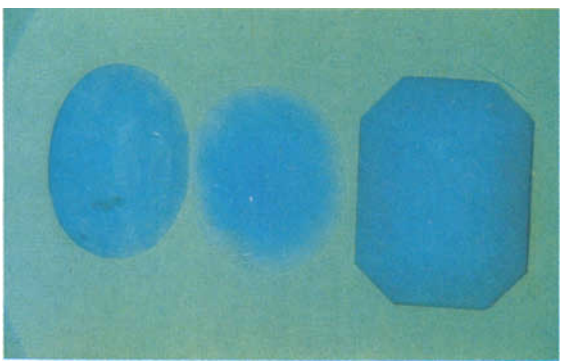

FIG. 47. Oval-cut gem in the centre is a Burma sapphire of natural colour, revealing neither facet edges nor girdle, flanked by two sapphires whose surface had been coated by the diffusion method to improve coloration. Note emphasis of blue colour along the facet junctions and the girdle of the two treated sapphires (immersed in methylene iodide). 7 ×

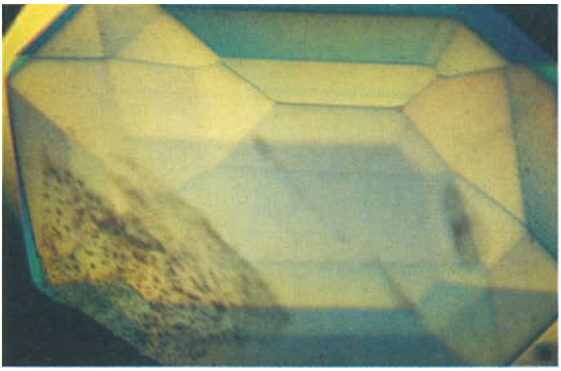

FIG. 48. Diffusion treated sapphire immersed in methylene iodide showing strong blue relief of facet edges and girdle. 16×

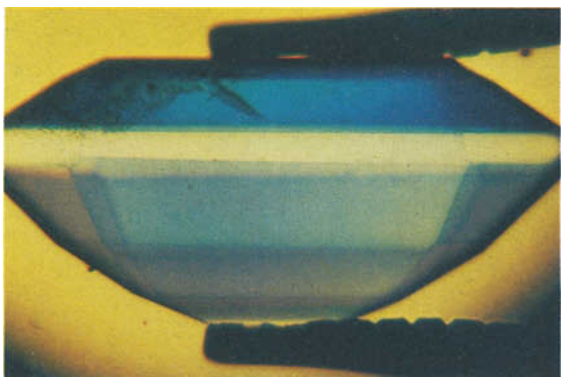

FIG. 49. Diffusion treated sapphire displaying irregular coloration and colour concentration on facet junctions and contour. The girdle has been repolished too much, so that it has become too broad and lost its diffused colour skin: hence it appears colourless. 16×

counterpart, he sought the co-operation of Prof. Dr F. Walder, of the Institute of Physics at the University of Zürich, who is a specialist in this field of investigation. His assistant, Dr D. Barberis kindly made several records of natural padparadschahs and synthetic orange sapphires, of which two representative spectra are portrayed in Figures 31 and 32. The visual difference of the signals in the magnetic field H [hO_e] between 2 and 7 kgauss* is quite

* 10 kgauss ≈ 1 tesla.—Ed.

obvious. The accurate interpretation of the individual signals and their precise significance (whether they are quanta transitions or indicate various trace elements) call for many more experiments on many more samples. This task will be carried out in the near future. Nevertheless, for the time being it appears quite comforting to know that there are further methods—though rather elaborate and complicated ones—of separating synthetic orange sapphires from genuine padparadschahs. Even if they are rather limited with regard to their application (because only small specimens < 10 ct may be examined) and may not easily be employed by the ordinary gemmologist, they definitely help to increase the number of testing methods and thus develop the degree of reliability.

In summarizing, it may be suggested that only the intense green fluorescence in long-wave ultraviolet light—if present—in blue sapphire, and total absorption below 270 nm of orange sapphire (padparadschah) as well as the tell-tale platinum platelets in their interior, may be considered as a warning indication of synthetic origin. However, should platinum platelets be absent in certain samples of the present and future synthetic Chatham sapphires, every feature—i.e. the macroscopic appearance, all the physical properties and the microscopic characteristics—will have to be checked very precisely and carefully compared to each other before formulating a definite verdict. Probably it would be wiser and more prudent to have the stone in question tested thoroughly by a gemmological laboratory in order to obtain a reliable opinion, particularly if the co-operation of a university is needed.

NATURAL SAPPHIRES TREATED FOR COLOUR ALTERATION

Quite apart from the difficulties of distinguishing natural from synthetic specimens, the artificially coloured natural sapphires which have been invading the market in quantities for some time now also present many additional problems, as they have caused a feeling of insecurity and confusion in our branch of the trade. It is therefore perhaps not out of place to add a full description of the distinguishing characteristics of artificially coloured blue, yellow, golden and brown sapphires to this paper, without going into the

details of the methods of coloration (thermal colour-improvement and diffusion-coating) which have been fully described several times already (see bibliography). However, it is worth mentioning that in both processes high temperatures between 1200 °C and 1700 °C and more are applied. The resulting colour-change has no great influence on the diagnostically important physical properties of the sapphire in question—such as refraction, birefringence, dichroism, absorption of light and density—since these remain unchanged. However, some blue sapphires subjected to heat-treatment for colour improvement display a soft but distinct blue fluorescence under long-wave ultraviolet light. Further changes are in the appearance to the naked eye, i.e. colour and surface marks, and especially the internal scene visible under the microscope. On the polished facets, and especially on the girdles (often doubled) of these treated sapphires, tiny scabs form through the influence of great heat and these are frequently left untouched by the lapidaries (Figures 33 & 34).

It is only possible to carry out the thermal colour-change if a supersaturated solid solution of the colouring agents is present in the sapphire. This condition often occurs in combination with the existence of solid inclusions, e.g. calcite, feldspar (albite, orthoclase, plagioclase), mica (biotite, muscovite, phlogopite), niobite, pyrite, pyrrhotite, uraniumpyrochlore and others, which melt at high temperatures and at the same time, because of greater expansion, stress the body of the host crystal, i.e. develop an inner tension that releases itself by forming a fracture. The molten mineral inclusions have lost their crystal forms, have turned white, and merely display rounded melt-shapes. The tension haloes create an unmistakable picture, which in many ways is reminiscent of the 'lily-pads'' in peridots from San Carlos (Arizona). They are almost circular and have a smooth, conchoidal surface from which the incident light is strongly reflected (Figures 35-38). They iridesce with lively interference colours when light impinges vertically. On their inner surface they seldom bear any marks, but the rims on the other hand are characteristically fringed with lace-like patterns. If a comparison is permitted: in the blue treated sapphires, they might best be likened to circular coral reefs (atolls) washed by white breakers in the blue ocean, as seen from an aircraft (Figure 37). If the coefficient of thermal expansion of the guest minerals is less than that of the host corundum, the former simply melt and assume

rounded melt-shapes, but do not produce a circular fracture (Figures 41-43).

Any dark or light coloured zones, cloudy structures or other ghost-like internal features which were already in existence before treatment, are emphasized and appear as defined foggy layers, patches or phantoms with sharp contours (Figures 39 & 40). As a result of exsolution, occurring during cooling, some minor solid solution of still unknown nature (perhaps boehmite, diaspore or gibbsite) is deposited as ultra-tiny grains in treated yellow, golden and brown sapphires, forming stripes and clouds, which themselves cause a more or less distinct turbidity (Figures 41-43). Whether partially healed fractures (feathers, fingerprints, wings and veils) are produced or altered during the annealing process is difficult to assert, if the treated gem was not examined before treatment.

For coloration by the diffusion method, clear sapphires, usually without inclusions and poor in TiO_2 are generally preferred, as they are unsuitable for colour improvement by the thermal method since they lack the necessary trace elements which become colour-active through annealing. Since the diffusion method also requires high temperatures, existing mineral inclusions are altered in exactly the same way as in the sapphires treated by the thermal process, and thus they can be recognized as being artificially coloured (Figures 33-43). Another characteristic which betrays the coloration by diffusion is the intense coloration of fissures which penetrate the interior of the sapphire from the outer surface, because the colouring matter diffused into these fissures during the treatment (Figures 44 & 45). Inclusions which extend as far as the surface of the host gem are also coloured an intense blue for the same reason (Figure 46).

Whereas both cut gemstones and rough crystals are suitable for thermal treatment, only cut stones can be used for the diffusion coloration. The facets become rough and matt during this process, and have to be repolished. Since this work is seldom accomplished with the necessary care, the relatively thin film of diffusion coloration not only becomes thinner, but is polished off unevenly so that an irregular coloration results—paler facets with uneven colour intensity and stronger-coloured edges—which fact can be considered as a reliable means of recognition (Figure 48).

These characteristics can be seen best if the stone is immersed in a highly refractive liquid such as monobromonaphthalene or, even better, methylene-iodide. In order to do this, the stone should be laid in a glass cuvette (circular glass dish with a flat bottom) and covered with highly-refractive liquid. Then the cuvette should be held over a diffused light-source such as a fluorescent tube or the daylight lamp of the 'Gemolite' tipped forward, and then viewed under low magnification such as a pocket lens or a reading glass. In the case of a naturally-coloured sapphire, all the facet edges, including the girdle, disappear, and only a blurred blue shimmer remains (Figure 47). Diffusion-coloured sapphires on the other hand, display a patchy coloration, and all the facet edges including the girdle appear sharply defined, just as if the sapphire had been designed with a blue pen on the bottom of the glass cuvette (Figure 48). In case of uncertainty it is advantageous to hold the sapphire girdle-up with a pair of tweezers, so that the table facet is vertically aligned to the eye, in order to view the girdle, which on the diffusion-coloured sapphires appears very sharply contoured (Figure 49).

May the above descriptions, together with the very eloquent illustrations, help the reader to distinguish natural and naturally coloured sapphires from synthetic and from artificially coloured sapphires.

ACKNOWLEDGEMENTS

The author wishes to extend his gratitude to Messrs C. and Th. Chatham for supplying him with samples of synthetic blue and orange sapphire, to Dr L. O. Andersson, Varian AG., Zug, Prof. Dr Waldner, University of Zürich, and Mr C. A. Schiffmann, Gemmological Laboratory of Gübelin, Lucerne, for their co-operation in recording Figures 28 to 32.

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FURTHER INVESTIGATIONS ON OPAL IMITATION MADE OF PLASTIC

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INTRODUCTION

Since the conclusion of the report in 1964 of the Commonwealth Scientific and Industrial Research Organization (CSIRO) on the cause of 'play of colour' in gem opal, the interest in producing opal-like substances attracted many a scientist. Pierre Gilson of France achieved the honour of being the first manufacturer of gem quality synthetic opal (Nassau, 1980). Even though John L. Slocum, of U.S.A., intended producing a synthetic gem opal, the result was an effective opal simulant referred to in the trade by the term 'Slocum stone' (Dunn, 1976; Farn, 1979).

Recently Dr Akira Kose, of the Japanese Institute for Applied Optics (JIAO), and Dr Sei Hachisu, of Kyoiku University in Tokyo, proved that by using spheres of plastic suspended in another mass of plastic, the effect of play of colour can be produced. The successful growth of such an opal-like imitation was initially reported in this *Journal* (O'Donoghue, 1980) and elsewhere (Horiuchi, 1978; Pough, 1982). Further investigations done by the author on these opal-like plastic imitations are detailed below.

PRODUCTION METHOD

Details given by Dr Kose and Dr Hachisu in their paper (in 1976) are insufficient for a commercial production in large quantities. However, the process described in the present paper is sufficient for the purposes of the discussion. The prime requirement, polystyrene spheres of 150 to 300 nm in diameter, are produced by introducing sodium polyacrylate into a polystyrene latex. At a polymerization degree* of 400 000 the polystyrene forms as hexagonal crystallites, which act like the silica crystallites (α-cristobalite) of gem opal. Suspended in water these plastic spheres have revealed a milkiness without play of colours.

The play of colour effect can be achieved by arranging the spheres in a regular order. This regularity will create the conditions

*Polymerization degree = the number of basic molecules forming the larger molecule of the substance.

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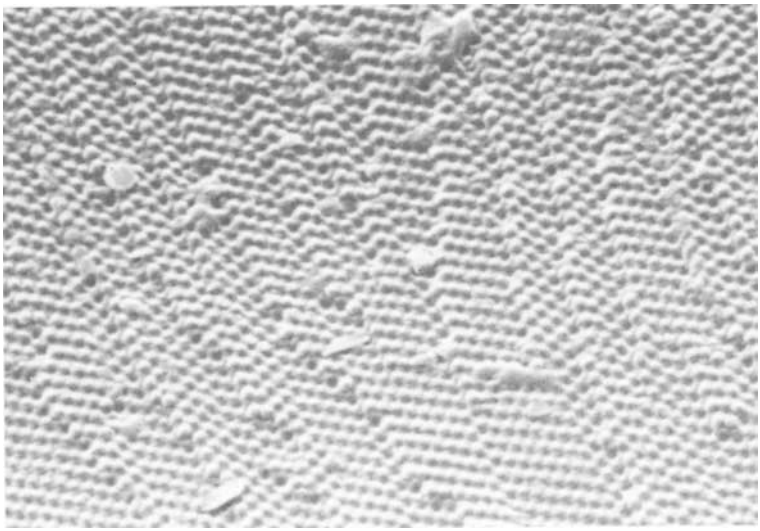

FIG. 1. Scanning electron microscope view of the cross-section examination of plastic opal imitation made in Japan. *(Photo: H.-G. Röpert, TÜV Rheinland)*

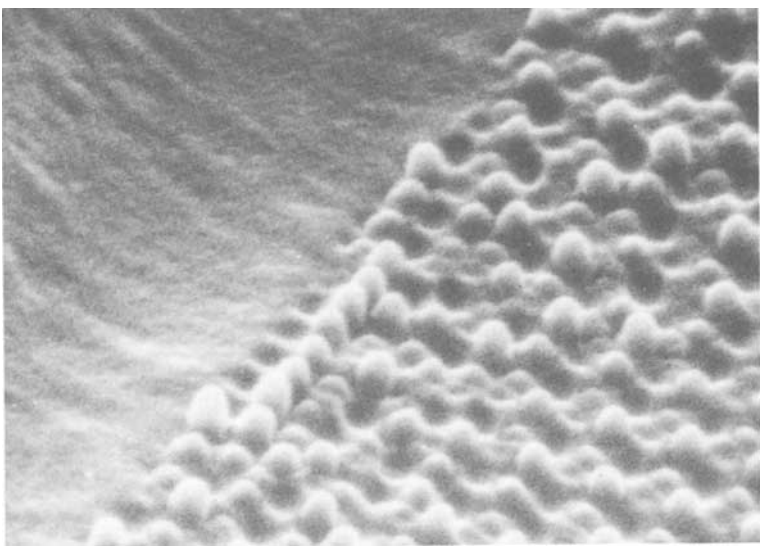

FIG. 2. Demarcation line of the polystyrene latex and the methacrylate coating. *(Photo: H.-G. Röpert, TÜV Rheinland)*

The play of colour effect can be achieved by arranging the spheres in a regular order. This regularity will create the conditions for the 'Bragg reflection' effect to occur. Rapid arrangement of the plastic particles can lead to lattice defects and dislocations which in turn would disturb the play of colour effect. These defects can be controlled by allowing the sedimentation at successive time intervals. This settling is similar to the natural α-cristobalite arrangement process occurring in nature. Reported speed of sedimentation under such conditions is about 3.5 mm per month and the optimum length of time required in forming quality material is about 3 to 6 months. Any disturbances caused during the sedimentation would disperse the spheres and a new start in such case is necessary.

Even though the actual transformation of the flocculated, monodisperse latex into opal-like plastic masses is kept as a secret, the interstices resulting after the evaporation of the liquid matter is filled by polymerization of polymethyl methacrylate which has a quite different refractive index from that of the latex. This forms as a coating to the sphered layer to strengthen the finished product.

As reported by the co-workers of CSIRO the varying sizes of cristobalite spheres in natural gem opals produce different colours in the visible spectrum. Similarly, varying sizes of plastic spheres, as in Figures 1 and 2, have shown varying colours according to Dr Kose's experiments (1976).

GEMMOLOGICAL CHARACTERISTICS

The stones observed by the author in this determination were divided into two types. One with *'compact colour domains'* and the other with *'scattered colour domains'*.

Visual and microscopic examinations

In *compact type* imitations the visual observations revealed a similar grain structural appearance to that of harlequin type Gilson opal, showing clear-cut boundaries between the colour domains. However, the typical honeycomb or lizard-skin effect of synthetic opal was not present in this *compact type.* Plate-like colour patches were seen somewhat similar to goldstone-type glass imitations. The grain structure of *scattered type* showed no distinct boundaries between the colour domains. The appearance of this type of imitation was very similar to that of natural opal. Therefore further investigations under magnification seemed necessary.

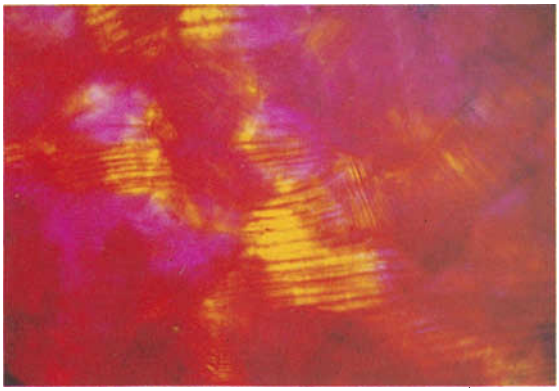

FIG. 3. The *compact colour domain type* showing the 'zebra-skin' pattern under reflected light method. *(Photo: M. Gunawardene. 20×)*

FIG. 4. The *scattered colour domain type,* between the crossed polarizers, showing the strain-knots with longitudinal gas bubbles. *(Photo: M. Gunawardene. 20×)*

FIG. 5. A side-view observation of both types of plastic imitations showing the acrylic resin coating and polystyrene inner structure. (Arrow indicates the division). *(Photo: M. Gunawardene. 20×)*

Careful observations under the gem microscope, using reflected light, without immersion liquids, revealed that the colour domains of the *compact type* displayed a 'zebra-skin' (also similar to an uneven paint brush movement) effect (Figure 3). The *scattered type* imitations displayed no such effect as in Figure 3. Employing crossed polarizers with magnification revealed another interesting feature in the transparent *scattered type.* This feature is very similar to an effect seen in certain synthetic spinels, namely strain-knots. These knots were seen attached to longitudinal gas bubbles as in Figure 4. Side-view examination of both types is shown in Figure 5 with the colourless acrylic coating. Gas bubbles were even seen on the acrylic coating.

Behaviour under transmitted light

Both tungsten and mercury vapour fluorescence lighting conditions were used. The *compact type* plastic imitations transmitted a mixture of red and orange wavelengths corresponding to 620-640 nm. The *scattered type* transmitted shorter wavelengths in the blue at about 430 nm. On comparison with natural and synthetic opals, the *scattered type* showed close resemblance, whilst the *compact type* displayed no such similarity.

Absorption spectrum

In spite of the fact that the main component of the plastic opal-like imitations is colourless polystyrene, an absorption region between 565-590 nm was detected in both types. The cause of this absorption is most probably due to the structure. A spectrophotometric absorption curve diagram recorded by the Leitz Unicam SP 800 is given in Figure 6.

Refractive index and optical polarization.

The recorded refractive index determination was 1.485 (± 0.005). The values obtained were higher than for natural and synthetic opals. These RI values correspond to the acrylic layer. The RI of polystyrene is known to be about 1.53-1.59 (Webster, 1975). This RI difference is clearly shown in Figure 5. Many *compact type* stones showed a doubly refractive aggregate-like reaction due to the close-packing of the polystyrene spheres. Some of them showed anomalous double refraction. The anomaly effect was very prominent with the *scattered type.*

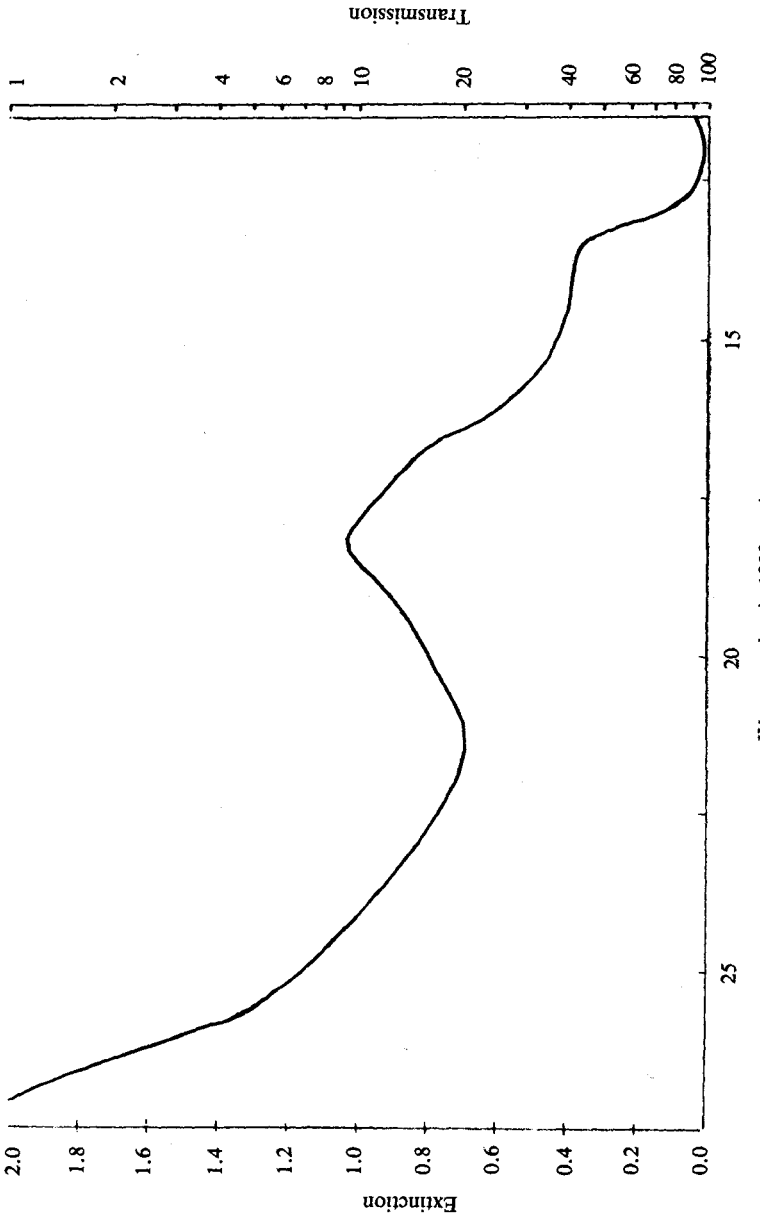

FIG. 6. Recorded transmission absorption curve of plastic opal-like imitation.

Specific gravity

Owing to the high surface tension of water it was difficult to immerse these plastics for accurate work. A few drops of liquid detergent were added to the water in obtaining the density values of $1.19\ g/cm^3$ ($\pm$ 0.01).

Reaction under ultraviolet radiations

All the samples were subjected to both long- and short-wave ultraviolet radiations. A strong bluish-white glow was seen under the long-wave (365 nm) radiations and a weaker, but similar, glow under the short-wave ultraviolet (253 nm) radiations. There was no phosphorescence detected in these imitations.

Thermal conductivity and affinity for water

Plastic opal-like imitations are warm to the touch; therefore the thermal conductivity should be much lower than that of natural or synthetic opals. Tests with a thermal conductivity probe indicated no reactions. The exposed methacrylate layer was hydrophobic*, opposed to the hydrophilic† nature of natural and synthetic opals.

CHEMICAL COMPOSITION

The two types of plastic imitations mentioned consist of Styrene-divinyl benzene copolymer and polymethyl methacrylate. The physical and chemical properties may possibly correspond to those of these polymers. Analysis by electron microprobe showed no distinct elements to be present.

DISCUSSION

These plastic imitations are sold under such names as 'Pastoral Opal', 'neo-noble opal', etc. Fire opal has been made by giving an orange colour to the acrylic resin, and doublets are also available.

Although it may be easy for an experienced gemmologist to identify these imitations, possibly they may find their way into jewellery items. The above mentioned properties must be considered in future discriminations. The internal characteristics, refractive index, lack of reaction to thermal conductivity probes, and, lack of affinity for water are of prime importance to consider in distinguishing these 'cheap' imitations.

*hydrophobic - ὕδωρ, water + φόβος, fear) = having a lack of affinity for water.
† hydrophilic = having a strong affinity for water.

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ON THE IDENTIFICATION OF PEARLS BY X-RAY DIFFRACTION

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PREAMBLE

A convenient way to distinguish between *natural* and *cultured* pearls is to examine them by x-ray radiography. In transmission, cultured pearls often show additional contrast close to their surface, which is due to the different x-ray absorption coefficients of the 'mother-of-pearl'* bead and the deposit of conchiolin. If such an inhomogeneity can be detected on the x-ray radiograph, the pearl is almost certainly cultured. The inverse, however, is not always true, i.e. the *absence* of a detectable inhomogeneity close to the pearl's surface does *not* prove that the pearl is natural. Such a situation may arise, for instance, with pearls of large size, whose correct identification is of particular interest because of their potentially high value. For such pearls, additional methods for testing are required. A safe, although elaborate method is to study their structural symmetry by x-ray diffraction methods, such as the *Laue technique.*

As can be seen in Figure 1, a natural (genuine) pearl is made up essentially of concentric layers of aragonite crystallites with their principal axes oriented radially, while a cultured pearl consists of a few concentric layers of aragonite crystallites arranged with their principal axes oriented radially which surround a mother-of-pearl bead nucleus made by more or less parallel layers of aragonite crystallites with their principal axes oriented perpendicularly to these layers. If these pearls are placed into a narrow beam of polychromatic x-rays, they will show different diffraction diagrams.[2,3] Those of natural pearls show sixfold symmetry, which is due to the fact that the aragonite crystallites growing away from the pearl's centre tend to form cyclic twins having pseudohexagonal symmetry. The over-all aspect of these patterns does not change much if the pearl is rotated about its centre, provided the x-ray beam always passes through its centre.

*Mother-of-pearl' consists of thin plates of aragonite with conchiolin deposits which are deposited parallel to the surface of the shell.[1]

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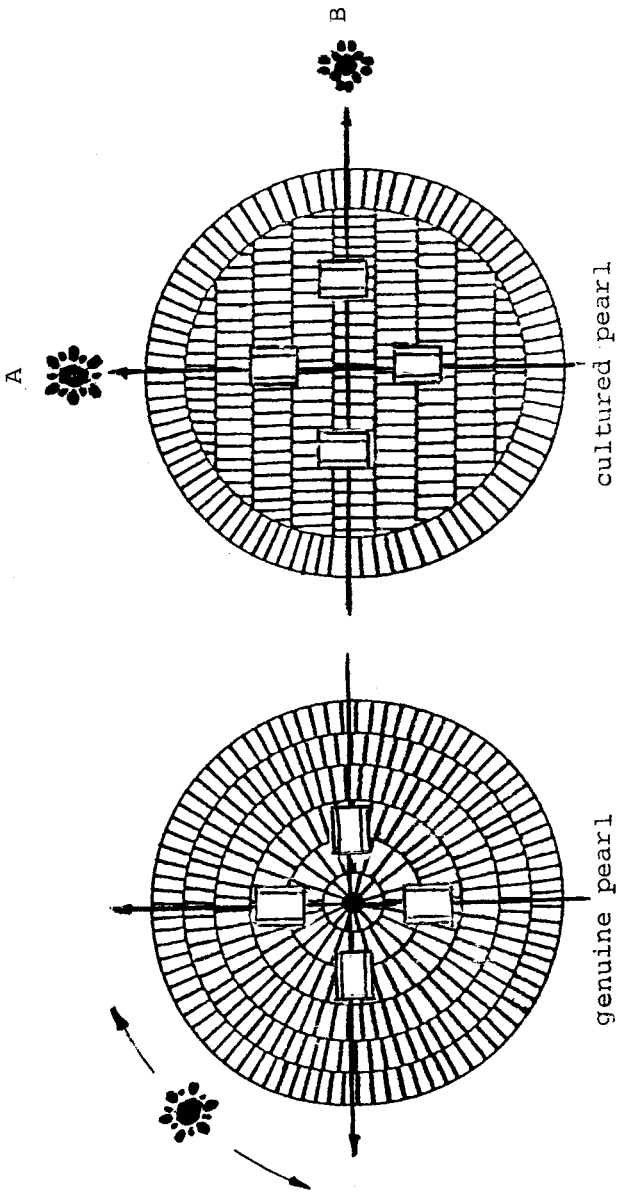

FIG. 1. Diagrammatic arrangement of aragonite crystals in pearls (after Refs 2, 3 & 8) and the symmetry of their x-ray diffraction patterns at different orientations.

The diffraction patterns of cultured pearls* show hexagonal symmetry only with respect to one particular orientation (position A in Figure 1). Usually they show lower than hexagonal symmetry (position B in Figure 1). In contrast to the patterns of natural pearls, their over-all aspect changes markedly if the pearls are rotated about their centre.

X-ray diffraction studies using this technique have so far only been described in handbooks[2, 3] without, however, specifying experimental conditions, nor stating the precautions necessary to avoid errors of identification. As will be shown in this communication the successful application of the Laue technique to natural pearls imposes rather stringent requirements on the experimental set-up such as, for instance, a careful alignment of the pearl's centre of nucleation with respect to the x-ray beam. If the pearls to be examined are of big size and/or irregular shape, their centre of nucleation cannot always be determined by visual inspection. Consequently, in preliminary experiments the x-ray beam may be travelling considerably off-centre, leading to diffraction patterns which can easily be confused with those of cultured pearls.

The pearls studied in this work (Figure 2) were bronze-coloured and pear-shaped, and they were of rather big size (maximum/minimum diameter : approx. 11.0/11.4, 12.0/11.6 mm). They were mounted on ear pendants, and their origin was unknown to the authors. Preliminary tests confirmed that they were pearls. The important point was to determine whether they were genuine or cultured, and whether their colour origin was natural or not.

COLOUR ORIGIN

A simple means of identification would have been to take a cotton swab with a very weak solution of nitric or hydrochloric acid, and, at an inconspicuous place, try to obtain a discoloration on the swab.[4] However, this method was not used, since it could have been destructive to the pearls beauty in case of surface artificial colour. Another non-destructive test determining the colour origin of black pearls consists of studying their UV fluorescence. White pearls which have been centre-treated to

*We would like to stress that the test procedure described in this paper applies only to nucleated cultured pearls. Unnucleated cultured pearls would in all cases invariably show an hexagonal spot pattern.

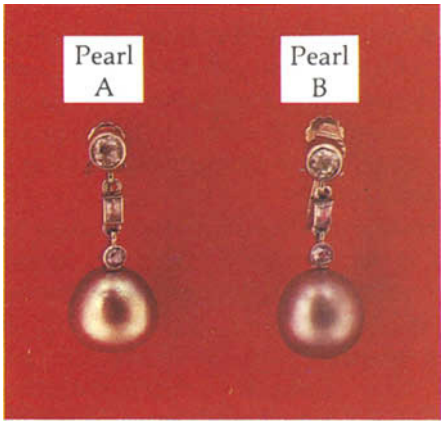

FIG. 2. Pearl A and pearl B in their setting (actual size).

impart a desirable dark body colour, and whose surface nacreous layers are not saturated with the dye, will usually fluoresce with a strong white or nearly white colour. Other white pearls treated by various coatings, dyes, or silver nitrate do not fluoresce. So far white fluorescence has never been encountered in naturally coloured black pearls tested to date (except in mottled low-quality specimens), while nearly all naturally coloured black pearls (about 99% of them) show a reddish fluorescence.[4, 5]

The two pear-shaped pearls studied in this work were exposed to UV radiation of 365 nm wavelength. They both showed a pinkish-yellow glow, suggesting that their colour origin was natural.

Unfortunately, a natural colour does not mean that the pearl is genuine. Cultured black pearls using black-lipped pearl oysters (pinctada margaritifera) have been produced since 1912,[6] and they show the same UV fluorescence as the genuine black pearls.

In order to establish whether the pearls were cultured or natural, they were examined by x-ray methods.

X-RADIOGRAPHS

The triangular pear-shaped pearl (label A in Figure 3) showed no contrast in any of the different radiographs taken. Thus one was left with a strong impression that this pearl could have been

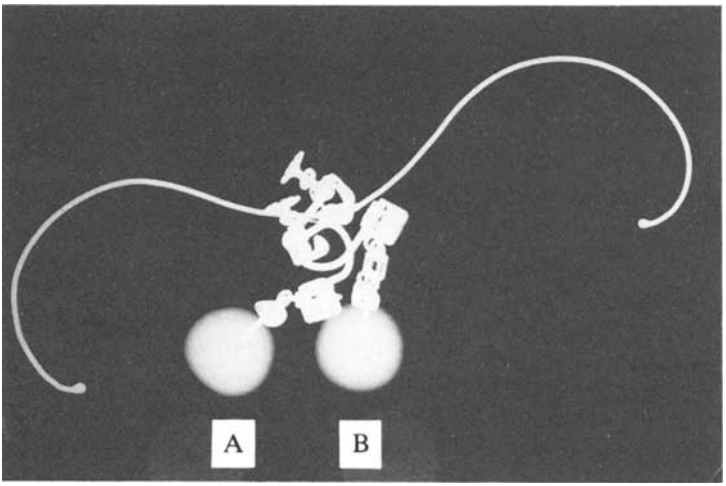

FIG. 3. X-radiographs of pearls A and B mounted on ear pendants (actual size).

cultured. For the roundish pear-shaped pearl (label B in Figure 3) the radiographs showed a regular circular line very near its edge. This pearl therefore also looked as if it had been cultured. At this point it was thought that a conclusive test would be to check for x-ray fluorescence. If hardly any genuine sea-water pearls fluoresce under x-rays (those which do, fluoresce in a particular manner), all cultured pearls which have a fresh water mother-of-pearl bead do fluoresce.[4, 7]

Surprisingly, no fluorescence could be detected with either one of the pearls, thus leaving the possibility open that they were of natural origin. In these circumstances, the only test which could have given a conclusive answer was to take x-ray diffraction patterns.

LAUE X-RAY PHOTOGRAPHS

The pearls were placed into a polychromatic collimated x-ray beam of 1 mm diameter, which was produced by a standard x-ray generator (Philips PW 1008; operating conditions, 45 kV, 20 mA). The distances between the centre of the pearl and the x-ray tube focus was 160 mm. A photographic film (Kodak, SB5) was placed

at a distance of 60 mm behind the pearl, corresponding to the standard set-up for Laue transmission photography. Particular care was taken to align the pearls so that the x-ray beam was passing through their centres of gravity, supposing that the latter corresponds to a good approximation to the centre of nucleation. The axis of the pearl's support was oriented perpendicularly to the x-ray beam. Due to the large size of these pearls, exposure times of up to 10 days were necessary to obtain photographs of sufficient quality.

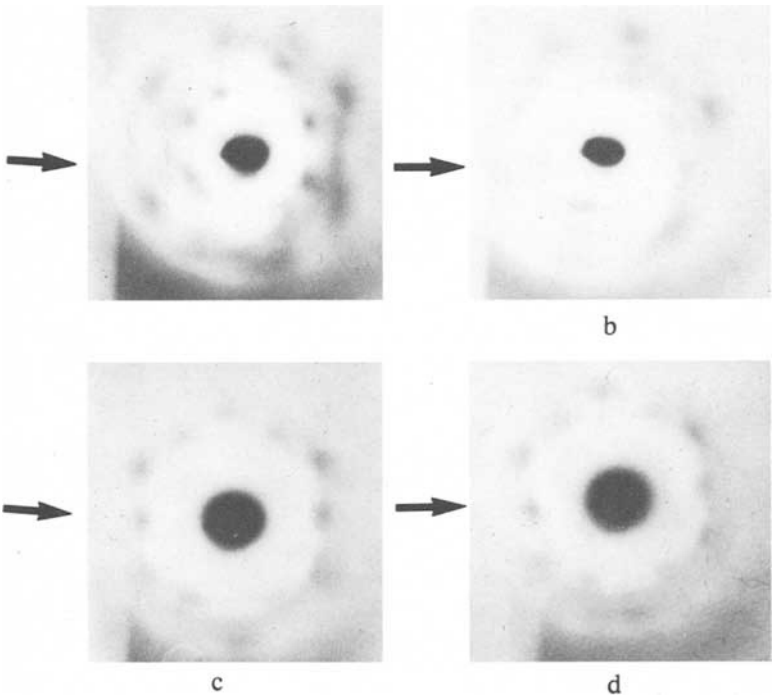

FIG. 4. X-ray Laue diffraction patterns of pearl A in positions 1 (a), 2 (b), and 3 (c), and after rotation by 90°(d). Positions 1-3 correspond to displacements of about 1 mm of the pearl in a plane perpendicular to the x-rays. The arrows indicate the axis of the pearl's mounting.

The first Lauegram (position 1) of the pearl A is represented in Figure 4a. It shows low symmetry (possibly of type m) and can be considered as being typical for a cultured rather than a natural pearl. Thus from this exposure one might have concluded that pearl A is cultured.

It was decided to perform additional x-ray Lauegrams by displacing the pearl *laterally* with respect to the x-ray beam, thus deliberately passing away from its presumed centre of gravity. An exposure (position 2) taken at about 1 mm away from position 1 is shown in Figure 4b. Its diffraction pattern is quite different from that obtained in position 1, and it shows a very vague possible pseudohexagonal symmetry. Finally, a third Lauegram was recorded in position 3 by displacing the pearl about 1 mm away from both position 1 and position 2. The pattern obtained (Figure 4c) showed almost perfect hexagonal symmetry, thus suggesting that pearl A was in fact of natural origin.

Unfortunately, the bead of cultured pearls, in one direction only, can also give the hexagonal spot pattern of genuine pearls. This is due to the fact that most beads consists of mother-of-pearl made up by more or less parallel layers of pseudohexagonal aragonite crystallites arranged with their principal axes oriented perpendicularly to these layers. Therefore a bam of x-rays passing through the pearl at right angles to the layers (position A in Figure 1) will be travelling along the vertical axes of the crystallites and will give a pseudo-sixfold symmetry figure similar to that in genuine pearls,[2] while in directions at right angles to this, the x-rays will be travelling across the prisms of the crystallites, and the diagram will have nearly twofold symmetry (position B in Figure 1).[3]

Another photograph was therefore taken with the pearl turned by 90°. This fourth photograph (Figure 4d), showed again a hexagonal pattern. This was the final proof that pearl A was genuine. The second pearl (B in Figures 2 & 3) which on all radiographs seemed to be cultured, was tested in the same manner, two photographs (not represented here) were taken in two different positions (after a rotation of 90°), and both showed the characteristic hexagonal spot pattern of genuine pearls. This second pearl was therefore also confirmed as natural.

CONCLUSION

This study shows that the identification of natural pearls by the x-ray diffraction (Laue) technique may be troublesome. The main problem arises from the fact that the pearl's centre of nucleation may not coincide with its centre of mass and thus cannot be aligned in the x-ray beam by visual inspection.[7] The need for an empirical centring procedure becomes apparent from inspection of the series of photographs reproduced in Figure 4, which show that small displacement of the pearl by about 1 mm may totally change the overall aspect of the x-ray diffraction patterns. This indicates that in some cases *several* photographs in *different* positions are necessary, in order to obtain diffraction patterns of hexagonal symmetry indicative for pearls of natural origin. On the other hand, the failure to observe a pattern of hexagonal symmetry on a visually well centred pearl does *not* always indicate that it is of cultured origin.

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We would like to thank Dr Bernard Chabot for his help while taking the x-ray photographs, and express our gratitude to Phillips Fine Art Auctioneers, and in particular to Mr Ian Blowfield, Director of their Geneva office, for his interest and kind permission for publication.

Note added in proof

The authors would like to draw attention to a thorough independant study of the above subject which has been reported by Dr Hänni in a recent issue of the *Journal of Gemmology*.[9]

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THE SENSE(S) OF GEMMOLOGY

By *A. E. FARN, F.G.A.*
Frinton-on-Sea

Nothing can be so tedious as an elderly person relating to someone much younger how it was done in his day. 'When I was your age', or, 'When I first started', are two phrases often used to start this form of diatribe. 'They never had it so good' is a now well worn cliché, almost as annoying to those to whom it is directed as the accusation of feather bedding was to the farmers! Having pointed out the annoyance caused by these practices, I am now going to preach a little upon matters gemmological of my day and age which stretch up to the present.

Some few years ago—just before the Second World War—the railings which surrounded Chelsea Polytechnic in Manresa Road bore framed placards describing the various evening classes conducted therein. One was 'Mineralogy for Jewellers', which is gemmology as we know it. The venue has now been changed due to an upgrading of the status of Chelsea Polytechnic. Classes are now conducted under the Inner London Education Authority and are not strictly trade orientated as was an earlier tendency. The examinations are organized by the Gemmological Association of Great Britain, which is an offspring of the National Association of Goldsmiths. The 'N.A.G.' as it is popularly known is primarily a body representing the retail jewellery trade and has long been a keen leader in trade education. A member at an annual conference of the N.A.G. in 1908 proposed that teaching should be provided and examinations in gemmology held—he was Samuel Barnett, of Peterborough. Thus the seed sown by Samuel Barnett was, according to B. W. Anderson, 'the beginning of organized Trade gemmology, not only in this country but in due course for the whole world' (*J. Gemm.*, 1981, XVII (8), 518).

Samuel Barnett provided a good example by sitting the gemmology examination in 1913 and passing to become holder Number 1 of a diploma in gemmology. All of those who passed in 1913 were from the provinces, none from London.

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The First World War interfered considerably with classes and exams; it was in 1922 that a fresh start was made. There are many famous names in those earlier days, many from trade houses, auctioneers, pearl merchants, factors, pearl stringers, etc., etc. It would be invidious to mention specific names, but the vast majority were in the jewellery trade. Without being racist it is equally true to state that the major portion were from Great Britain; the compliment of the invasion by overseas contingents had not yet started—and it *is* a compliment.

The Gemmological Association (which stemmed from the N.A.G.) and the Laboratory of the London Chamber of Commerce contributed considerably to the conducting of classes, the supply of specimens and the provision of instructors. In fact, most Chelsea and Northern Polytechnic students who were trade-employed became so used to the presence of Anderson and Webster at evening classes and subsequently seeing them again in their daytime role as gemmologists at the laboratory of the London Chamber of Commerce in Hatton Garden that they thought it was the N.A.G or G.A. laboratory.

Anderson and Webster between them inspired many of the earlier students to become practical gemmology instructors as classes expanded and the older instructors eased from their very heavy commitments of evening class teaching. In the earlier days of examinations at centres outside London it was not unusual for Robert Webster to travel to set up the practical examinations with apparatus laboriously carried from London to supplement the less well catered for centres. It is also true that on these occasions the laboratory was almost denuded of small glass cells, its best refractometers and, of course, the services of Robert Webster.

The accent most of this time was upon tradespeople and their requirements. The laboratory which played such an important part in the supply of teachers, specimens, instruments, as well as the checking of examination specimens, had the lengthy title of 'The Laboratory of the Diamond, Pearl and Precious Stone Trade Section of the London Chamber of Commerce'. Lengthy it was and certainly descriptive of its precise role and for whom it worked. Its importance was emphasized precisely by the content of the words, *diamond, pearl* and *precious stone trade* section and *commerce.* The accent was upon trade and commerce, the needs and

requirements basically of jewellers being the identification of gemstones, pearls, their imitations and synthetic counterparts.

From the researches of B. W. Anderson, B.Sc., F.G.A., at the Laboratory came the gift to all gemmologists of his monumental work on the absorption spectra of gemstones. His findings and teachings put Great Britain in the forefront of gemmology for many years. The use of the hand spectroscope was an art reasonably easy for students to acquire. It was positive, speedy, non-destructive and could be used on large or microscopic specimens, cut or rough, mounted or unmounted. It was equally very manoeuvrable, portable and relatively inexpensive.

Without launching upon too long a peroration of the Laboratory's role I want to try to arrive at gemmology today and its participants. Since the war we have seen a tremendous expansion in the number and variety of people who have sat for and passed the examinations in gemmology, a great compliment to Great Britain and an acknowledgment of the status of our gemmological diploma. Together with an influx of overseas examinees, we have had an increase of people who are not trade based or trade orientated. This leavening must of course be to our advantage—and disadvantage in some respects.

The earlier volumes of the *Journal of Gemmology* and *The Gemmologist* seemed to me to be more readable and understandable than they are today. The reason for this may well be that because of the advancement of techniques in the manufacture of synthetics and artefacts of new types of gemstones greater expertise and more sophisticated equipment are required. Gone perhaps are the days when one could rely upon a good polarizing microscope, a hand spectroscope, a refractometer, hardness points, careful hydrostatic density tests, etc. to identify all and every gemstone successfully. Certainly with the very awkward Kashan synthetic rubies a good practical knowledge of inclusions is paramount. With an experienced trade gemmologist it might be possible to write a certificate positively for such stones. Certainly it seems that further sophisticated tests need to be carried out upon this particularly difficult synthetic ruby. The use of ultraviolet spectrophotometry is a modern method recently explained in the *Journal of Gemmology*. The use of an electron microprobe for chemical analysis is another of today's methods in gem testing or

rather research. This kind of equipment requires expertise of a very high degree and funds to provide it. Usually these instruments are found in universities or museums. Certainly today's gemmology needs the back up of these advanced workers and their equipment. We cannot put the clock back, whether it be today's quartz oscillation design or the thirty hour spring wind alarm of yesteryear.

Equally certain is the fact that some of today's gemmologists are not just Fellows of the Gemmological Association of Great Britain, neither are they products of the retail jewellery trade. They have those very necessary extra qualifications in certain fields. The foundations of gemmology were based upon the needs and requirements of the jewellery trade; today's researches have stemmed from these needs. It is an unfortunate fact of life that the pre-war and immediate post-war shop assistant was extremely poorly paid and often worked long hours. This applied to the jewellery trade as well. The retail trade was not sufficiently attractive to interest lively minds, and so I believe we suffered from this handicap. The actuality that people of the calibré of Robert Webster *did* emerge from this employment is a compliment to tenacity and interest. Today one needs qualifications of sufficient quality to ensure the adequate understanding and appreciation of the techniques employed to detect synthesis, heat treatment, irradiation, etc., to name but a few.

Having discussed the contents of our *Journal of Gemmology* with one of our leading gemmologists who is also a scientist, I was somewhat pleased and relieved to find that he didn't understand all of the articles all of the time. Comforted by this I am encouraged to suggest the phrase 'Nil desperandum' to all ordinary gemmologists, who may well be from trade sources (as I was).

Despite the facts of today's requirements in the detection of modern artefacts and synthetics, there are many opportunities for the use of very ordinary gemmological tests based upon the sense (common) and senses. One cannot always afford ultra sophisticated equipment, neither (despite some very ingenious attempts at portability) can one easily carry a case equipped for tests under the 'while you wait' system. However, we are all equipped with eyesight, noses, teeth (some of us) and hands. If we have had some gemmological teaching and know some basic facts

and can use a 10× lens, we are reasonably equipped to detect and/or reject quite a lot of gemstones which a practised scientist with a microprobe or spectrophotometer might even miss! The handling of gems and gem material conveys a sense of texture or finish as is exemplified by that well worn quote, 'the inner aspect of a well-educated thumb'. (Sir Arthur Church related how he successfully chose the true topazes from a bag of mixed yellow quartz and topaz by the superior silk-like finish obtained on the much harder surface of topaz compared to quartz.)* Certainly a light glancing touch across a quartz specimen feels a little tackier or more resistant to the finger than across a topaz. This handling of gems, whether touch or feel, is a use of one of the senses. Handling in another aspect can give a sense of heft, and it is possible, say, to decide between a very clever plastic imitation of carefully carved 'ivory' and the real thing by heft alone. A 10× lens would assist in determining the lines of Retzius in ivory or the Haversian canals in bone (a combination of heft and lens). Before the advent of polishing gems with diamond powder, which achieved a near perfect surface polish on jadeite-jade, it was possible to identify this material by its dimpled surface due to hardness (structural) differences which caused little variations in surface finish. To heft and feel I must add sound. A non-gemmologist friend of mine—a successful gem merchant—can distinguish between plastic imitation amber and true amber by the sound of amber or plastic beads rattled in the cupped hands. He can recognize the clack of plastic compared to the ringing/resonance of amber. Another merchant once relieved my worries over a very heavy 'silver' dish by holding it close to my ear, and on bending the metal it creaked, which to him spelled antimony (and it was too heavy for silver).

Those of us possessing our own teeth can distinguish between imitation pearls and both natural and cultured pearls. Imitation pearls slide smoothly if drawn lightly across the teeth. Both natural and cultured pearls have a gritty pull to them due to the surface structure of the thin sub-microscopic overlapping platelets of nacreous aragonite. Natural pearls will bounce rapidly with a resonant rhythm compared to the short-lived flat thud of cultured pearls. This is due to the regular radial and concentric structure of natural pearls compared to the banded one direction of mother-of-pearl bead in cultured pearls. Again, with drilled pearls a 10× lens

*B. W. Anderson, *Gem Testing*, 9th edn, p.294: Butterworths, London, 1980.—Ed.

examination at the drill hole will reveal the discontinuity layer of nacreous pearl exterior and the cold grey of the mother-of-pearl bead. The 10× lens will show junction lines of garnet-topped glass-based doublets, particularly if examined under a table or bench lamp. The difference in polish is seen between the superior hardness of garnet and the softer glass; where the two media are jointly polished over the junction is easily seen. If tested by microprobe or spectrophotometer one wonders what the results would be.

The fascinating curved fine lines of asbestos seen in demantoid garnet are a positive hallmark, sometimes referred to as 'horse tail' inclusions. Another easily observed characteristic seen by 10× lens is the flame structure of pink pearl (conch pearl)—this is something like pink lines of Retzius or the banding seen in some red/pink corals. Just as decisive is the schiller seen in amazonite (microcline feldspar) due to reflections from myriad cleavages of the material. Asterism in both forms of epiasterism and diasterism can be seen by 10× lens. With diasterism the effect is the reflection of asterism as seen in rose quartz cabochons sealed with a blue mirrored *base;* this *reflects* the asterism of the rose quartz and reveals its diasteric effect by the reflection of the examining light bulb at the intersection of the rays at the surface. No natural star sapphire will show a light bulb at the intersection of its rays. For that matter, most synthetic star stones have a too perfect symmetry, a very suspect sharp intersection, a too good or strong body colour plus a flat ground finish base with no signs of natural structure. This is probably the easiest test with a 10× lens for the practised gemmologist. There are many other hints and tips which can be usefully employed with a 10× lens and a background of gemmology.

Apart from the sense of light, sound and touch, there is the very important olfactory sense which is commonly called our sense of smell. It is mostly the organic products which produce a characteristic smell. Celluloid, which can be a convincing imitation of ivory, often has a distinct smell of camphor when rubbed on cloth, and, of course, it burns very readily! The latter test is *not* recommended, although one of my gemmologist trade friends had the pleasure of his doubted word being vindicated when the somewhat overbearing know-it-all non-gemmologist shopkeeper

pooh-poohed the suggestion that his buffalo carving was celluloid. With just the aid of a match he proved it in a flash. Celluloid is sectile—it peels easily with a sharp knife—but ivory is much tougher. The smell of burning hair is obtained if a hot needle is applied to tortoiseshell whereas its plastic similar-looking imitation smells of burnt milk. One of the earliest, if not the earliest, of materials we now label 'plastic' is bakelite, which is produced from a condensation of creosol or phenol with formaldehyde. When vigorously rubbed or lightly heated it will smell of carbolic or coal tar soap. Bakelite incidentally is named after L. J. Baekeland (1863-1944).

The smell of sulphuretted hydrogen (rotten eggs) is readily attained if a piece of reconstructed Gilson lapis lazuli is crushed; the same material, because it contains calcite in finely divided (scattered) content, gives an immediate furious effervescent effect when touched by a small drop of dilute hydrochloric acid. The *entire* surface of the drop bubbles. In natural lapis lazuli the calcite is not regularly distributed and the acid test, whilst not recommended on potentially fine pieces, does not have a fast immediate or all-over reaction; it is in fact hard to find and is a slow bubbling reaction.

Whilst I have dwelled on only a few simple unsophisticated tests (there are many more), I hope I have made a point that the experience of a trade gemmologist can be followed or emulated by commonsense application. There is ample room for all of us, whether trade orientated or sophisticated academics. Gemmology, the science and study of gemstones, is a broader subject today than when suggested as a course of instruction and examination by Samuel Barnett in 1908. Whilst we need the special skills of the trained scientist, there is a lot we can still do and enjoy for ourselves by dint of application and observation, particularly with that portable simple microscope the 10× lens.

Commonsense demands, of course, that non-destructive tests are a requirement when dealing with expensive precious stones. If the acid drop test is conducted, obviously it should be on the back of a piece of lapis lazuli or in some place hidden by the mounting in jewellery. The acid reaction will leave a flat matt stain. Care is needed. One of my colleagues once tested a very fine bonamite (zinc carbonate) by this acid test. It took him a long time to carefully and painstakingly polish out the attacked material, even

though it was in the back of a ring. Heat tests on beads should, if possible, be at or just inside the drill hole and one should avoid testing the largest centre bead. If they all appear to be similar, test the smallest at the clasp end. The same advice applies to sectility tests. Many of these tests, whether by acid or peeling (sectile), can be observed with the aid of a microscope. For those who wish to go further there are the intriguing chemical tests described by Robert Webster in his great book 'Gems, their sources, description and identification'. It is not very difficult for a gemmologist to obtain specimens of most gem material, plastics, etc., which need not be of jewellery quality. With these comparison specimens he can practise, a sort of aide-memoire.

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RUDDIGORE

By the Revd S. B. NIKON COOPER, B.D., F.G.A.

'. . . who would have thought the old (bird?) to have had so much blood in him?'[1] Maybe not the exact words of Lady Macbeth—but she might have said it, had she been a student of gemmology; had she been considering, that is, the ruby—of which we all know one fact: that its colour is that of 'pigeon's blood'.

It is fascinating to see how a vivid and lively description—one presumably, originally, easily identifiable—has so captured the imaginations of generations of gem-writers, even when its original significance has long since (thankfully) passed into oblivion. (How many pigeons have *you* killed today?) Or has it become so much a part of the folk-history of gems that the various authorities dare not but reiterate it?

At any rate all seemingly pay lip-service to the term. Max Bauer[2] *Precious Stones* (1904) (*Edelsteinkunde*—1896):- 'this colour has been compared by the Burmese to that of the blood of a freshly-killed pigeon, hence the reference to such stones as being of "pigeon's-blood" red.' Or Kunz[3] (1892):- 'the finest pigeon's-blood-colored rubies are found in Mandalay in Burmah.' Herbert Smith,[4] *Gemstones* (1912), has the decency to add a qualifying 'so-called' ('The most highly-prized shade of red is the so-called pigeon's blood . . .'). L. J. Spencer[5] (1936) gave the perfect—and unwittingly prophetic—comment:- 'The colour of the best rubies is said to be "pigeon's blood red", *a statement slavishly copied parrot-like from book to book.*' (our italics.)

And so true! We meet the same description again in Anderson's[6] *Gem Testing* (1942):- 'Only in one locality, the Mogok stone tract in Upper Burma, are stones found which have the coveted "pigeon's blood" red . . .' Robert Webster, too[7] —but with a qualification:- 'the so-called and one may say indefinable "pigeon's blood" . . . is the prized colour of the best

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Burmese rubies.' And Gübelin[8] as well, with his poetic '. . . the crown of all beauty, the noblest and most precious nuance is pigeon blood red . . .'

And so on . . . Sinkankas[9] (1968), Desautels[10] (1969), Hurlbut[11] (1969), Bancroft[12] (1973), et cetera. . . Was there ever a description that has so captivated the minds of gem-lovers, or—as evidenced by their unquestioning 'homeworks'—succeeding generations of students even today? But some of us are heartily tired of it and wish only that the unfortunate Burmese Bird could at long last be laid to rest.

It might be said, does not this description keep alive the original etymology? We trace the pedigree of our modern ruby back via its medieval ancestors (rubie, rubis, rubith) to the Latin 'ruber' = 'red', itself coming from the Greek 'erythros' (ἐρυθρός), but originally from Sanskrit 'rudhira'—which meant, not just 'red', but 'blood', 'blood red' (it is unspecified whether of pigeon derivation or not).

What are the alternatives? Colour (as Robert Webster[7] said) is so indefinable. Once we have seen a fine specimen of ruby we *know* the colour—but try to describe it! The authors we have mentioned above, referring to the same gem, vary from 'a deep red'[11], 'a deep rich red'[10], 'a saturated shade of carmine red'[8], 'a carmine red with a slight bluish tinge'[2] to 'a red which is slightly inclined to purple'. [9, 4, 7] It is fortunate that we recognize a perfection colour at sight—once seen, never forgotten.

The less poetic would seek to tie us down to mathematical exactitudes, for instance a Munsell Notation of 9.5RP 3.3/8.9 . . . How easily this falls from the tongue is a moot point, but even with defined parameters of Hue, Value and Chroma the doubt remains—*is* this the colour? It is notoriously difficult to compare the shade of a transparent gem with that of a given colour sample.

We would suggest a practical solution lies with the 'eye of experience'. A perfection colour is recognized at sight by those who handle them daily—to those with less facility a synthetic control stone could be reasonably available. Forget about 'pigeon's blood' and the not necessarily geographically exact 'Burma' label—let it

be named 'ruby red', with a qualifying term for those that fall from that standard. It is our trade, it is our experience; we believe that we should have the right to define our own terms—but, please, let the meaningless 'pigeon's blood' be consigned back where it belongs—to the realms of ornithology.

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STABILIZED CERULEITE

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ABSTRACT

Plastic-impregnated (stabilized) ceruleite is described. The plastic impregnation procedure of ceruleite is comparable with the stabilization treatment of turquoise; the distinction of treated and untreated ceruleite material is possible by infrared spectroscopy.

The Cu-Al-arsenate-hydrate ceruleite was first described by Dufet (1900). At that time, the type material originated from the Emma Luisa gold mine near Huanaco, Taltal Province, Chile. For a long time this mineral was cited in mineralogical tables and textbooks only as an inadequately defined mineral. Recently, the existence of ceruleite as a natural phase was confirmed by the investigation of samples which were described to come from Bolivia (Schmetzer *et al.,* 1976a, b; 1978). Meanwhile, it came to our knowledge, that the new material, which also appeared on the gemstone market, probably originated from the Emma Luisa mine or at least from a locality close to this place in northern Chile, too.

Only part of the material described by Schmetzer *et al.,* (1976b) was of compact quality, which could be cut to intensively blue coloured gem material resembling turquoise without further treatment (cf. Schmetzer *et al.,* 1976a, 1978). A great part of the samples, however, were of high porosity with a light bluish or even white coloration. In an untreated state this material was not suitable for the gemstone industry without improving its properties by a treatment procedure.

Similar problems have been known for a long time with the gem mineral turquoise. A great part of the rough material of this mineral species is not suitable for gem purposes without treatment of the samples. At present, the best treatment procedure for turquoise is thought to be a stabilization treatment by plastic impregnation techniques. A great part of turquoise rough material of all qualities is treated in this manner. For a recognition of treated and untreated turquoise material a combination of x-ray diffraction methods and infrared spectroscopy is suggested (Lind *et al.,* 1983a, b).

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Meanwhile, it is not astonishing, that those qualities of ceruleite, which were not suitable for gem purposes due to their high porosity, are stabilized by a plastic impregnation procedure. The material available to us for investigation has an intensive blue colour, which is comparable to the colour of the more compact material in untreated state. The density of the plastic-impregnated ceruleite is found to be 2.58 g/cm^3, which is distinctly lower than the density of the untreated material, which can be given as 2.70 g/cm^3. The investigation by x-ray powder diffraction methods showed the plastic-impregnated ceruleite to have the powder diffraction pattern of the untreated material without further additional diffraction lines. By infrared spectroscopy, however, an additional absorption band is found in the spectrum of the treated material at 1725 cm^{-1} besides the characteristic absorption bands of the untreated material (cf. Schmetzer *et al.*, 1976b). This additional infrared absorption band is also found in plastic-impregnated turquoise.

For an investigation of unknown blue material, i.e., for the determination of the crystalline phases in an unknown sample, an investigation of the x-ray powder pattern is necessary. Infrared spectroscopy is suggested for the recognition of plastic impregnation of a sample, which is found to consist of ceruleite by x-ray diffraction techniques. According to the nomenclature of turquoise, in our opinion every treatment of ceruleite is also necessary to be mentioned in the trade. Therefore, the samples described in this paper should be named stabilized ceruleite or plastic-impregnated ceruleite.

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ORANGE SYNTHETIC CORUNDUM

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The writer recently received through the courtesy of Mr Tom Chatham, a group of orange corundum crystals manufactured by his well-known firm. A similar group has recently been reported by Kane (1982). My group, weighing just over 13 ct, consists of a number of crystals which are less bladed in habit than those of blue sapphire produced by the same firm some years ago. The orange crystals in my specimen range up to about 1 cm in height and show basic rhombohedral form. The colour is a fine reddish-orange with some zoning, though again this feature is less marked than with the blue sapphire crystals. The crystals could be faceted since they are sufficiently thick but there are numerous inclusions, particularly of angular flakes recorded as platinum by Kane. These are large enough to be seen with the unaided eye. On the back of the group is a substance containing numerous gas bubbles and Kane states this to be a liquid silica-based ceramic glaze which is applied to the groups and fired at 1000°C in a kiln (information from the manufacturer). It is also stated that a similar practice is routine for all orange and blue Chatham crystal groups.

The most interesting features of these groups were their behaviour between crossed filters and the absorption spectra recorded. My specimen was examined by the light of a high-intensity lamp passed through a flask of copper sulphate, the ray being picked up through a red gelatine filter. The specimen glowed a very bright reddish-orange, which was also seen to a lesser extent under long-wave ultraviolet radiation. Examined with a hand spectroscope, a sharp emission line was noted in the deep red: this was so prominent that even students who had never used the instrument before could see it with ease. There was no change of colour after exposure to daylight for several days nor after ultraviolet irradiation. This was not in action for very long (one hour on two separate occasions) but such a change, though

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recorded for some Chatham blue sapphires after exposure to x-rays, would not be expected in a Cr-bearing material. Kane records the SG of his specimen as 4.00± 0.003 and the refractive index as 1.762-1.770 with a birefringence of 0.008. I was not able to measure these constants on my specimen, but have no reason to suspect that they would be materially different. The pleochroism recorded by Kane (strong pink-orange and brownish-yellow) is substantially the same in my specimen, allowing for slight differences in the meaning of the words.

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CANADIAN VESUVIANITE GEMS

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INTRODUCTION

Vesuvianite occurs in many colours and at many localities in a variety of geological environments. It has a very complicated chemical formula and crystal structure. Indeed, mineralogists are still studying this mineral and presenting us with differing views on its crystal chemistry. Even its name is in dispute—vesuvianite (from the Italian locality at Mount Vesuvius) tends to be used by mineralogists, while idocrase (from the Greek *idos* = appearance and *krasis* = a mixture, because its crystal forms resemble those of other minerals) is more likely to be used by gemmologists and jewellers. For the sake of consistency, the use of 'vesuvianite' is encouraged.

Vesuvianite gems are usually seen in yellow to brown and green shades (Arem, 1977; Webster, 1975). Facetable vesuvianite comes from Italy, Québec (Canada), Pakistan, Kenya, and New York (U.S.A.). It crystallizes in the tetragonal crystal system, the most common crystal forms being a square prism terminated by pyramids and a basal pinacoid. With a hardness of 6½, it is suitable for some types of jewellery, and the golden-brown stones are definitely attractive. A fairly common massive green vesuvianite, often intergrown with grossular garnet, is found in California ('Californite') and has been used as a jade imitation.

Golden-brown transparent vesuvianite was collected from Laurel in Argenteuil County, Québec, Canada, early in this century, and faceted gems were marketed with limited success as 'Laurelite'. Unfortunately the crystals (up to 2″ in diameter and 3-4″ long) were badly shattered and there were very few stones over 2 carats in weight (Sinkankas, 1959). Most gem material from the now-flooded pits of this occurrence has been removed. Several fine golden-brown gems (2.95, 2.28, 2.08 ct) are in the National Museum's collection, as well as a 3.15 ct, greenish-brown stone (Boyd and Wight, 1981).

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Our interest in Canadian vesuvianite gems was stimulated by the recent appearance of olive-green gems from the Jeffrey mine at Asbestos, Richmond County, Québec (Wight and Grice, 1981). Comparison of the green vesuvianite from the Jeffrey mine with the golden-brown vesuvianite previously known from Laurel showed differences in their optical properties.

The Jeffrey mine has produced vesuvianite in several colours—greens, brown, mauve (reddish-violet), and light red, although only green has been available as faceting material. This wide range of colours offered an opportunity to correlate colour with chemical composition, and the results were presented by Grice and Wight (1982).

GEOLOGY

The Jeffrey mine is located about 160 km east of Montréal in the second largest asbestos deposit in the world. It is notable for an extensive suite of Ca-silicates (vesuvianite, grossular, diopside, prehnite, pectolite and wollastonite) which are associated with rodingites—dykes that have undergone extensive calcium metasomatism (Grice and Williams, 1979).

There is little information available on the geology of the Laurel deposit, which is about 75 km north-west of Montréal. Sinkankas (1959) describes the Laurel deposit as a small pit in forested land within the marble of the Grenville series with additional mineralization provided by intrusion of a feldspar pegmatite. The mining of the pegmatite for mica first brought to light the gemmy yellow vesuvianite.

OPTICAL PROPERTIES

Table 1 gives the chemical analyses and refractive index for the various colours of vesuvianite from the Jeffrey mine and from Laurel. Our analysis of Laurel material agrees very well with that of Manning (1975). Optical properties of the faceted gems are listed in Table 2.

In general, vesuvianite has a low birefringence due to the pseudo-cubic nature of its crystal structure. All the Jeffrey mine samples were uniaxial negative with very low birefringence. The refractive index of the green gems (6 specimens) is 1.716. Double refraction was easily observed with the polariscope but not on the refractometer. In contrast, the Laurel vesuvianite gems generally

TABLE 1. Vesuvianite Chemical Analyses* and Refractive Indices

	Jeffrey Mine, Asbestos, Québec					Laurel, Québec
Colour	Green	Emerald green	Brown	Mauve	Pale Red	Brownish yellow
NMNS #	32839	42913	36884	42936	47774	42853
SiO_2	37.0	36.4	36.0	37.1	36.6	36.2
TiO_2	0.28	0.00	0.48	0.00	0.00	2.1
Al_2O_3	17.8	15.0	17.4	18.6	17.9	16.2
Cr_2O_3	0.19	0.18	0.08	0.18	0.12	0.17
Mn_2O_3	0.11	0.00	0.00	0.27	0.59	0.00
Fe_2O_3†	1.93	5.24	2.47	0.73	0.34	0.54
FeO	0.19	0.28	0.90	—	—	0.44
MgO	2.48	2.90	1.71	2.28	3.03	3.1
CaO	37.3	37.0	36.9	37.6	37.3	36.4
H_2O‡	2.72	3.00	4.06	3.24	4.12	4.85
Total	100	100	100	100	100	100
ε	1.704	1.717	1.711	1.703	—	1.705
ω	1.708	1.721	1.714	1.704	—	1.710

* Electron microprobe analyses by Dr D. Smith, University of Alberta.
† Total iron unless FeO determined separately by titration.
‡ By difference.

have a higher birefringence of 0.005 to 0.007, which is easily measured on the refractometer. We have found one exception, however—a greenish-brown gem (NMNS #20515, 3.15 ct) with only a single measurable refractive index of 1.725.

Dark orange-brown gems had a higher RI than the golden-brown stones, presumably because of higher iron and/or titanium content. The Jeffrey mine gems had a higher RI than all except one of the Laurel gems. Our chemical analyses show that the Laurel gems contain significantly less iron (0.98% iron oxide v. 2.12 to 5.52%) and more titanium (2.1% titanium oxide v. 0 to 0.48%).

TABLE 2. Optical Properties of Vesuvianite Gems

Locality	Jeffrey Mine, Asbestos, Québec		Laurel, Québec		
Colour	olive green	light green	yellowish brown	dark orange brown	greenish brown
RI	1.715 to 1.718	1.712 to 1.717	ε 1.702 ω 1.709	ε 1.706 ω 1.711	1.725
Birefringence	not visible	not visible	0.007	0.005	not visible
Dichroism	strong green/orange	distinct green/greenish yellow	strong olive green/ dark orange	strong olive green/ orange brown	strong dark olive green/orange

Cause of Colour in Vesuvianite

Details of experimental work on the colour of Jeffrey mine vesuvianite and grossular are given by Grice and Wight (1982). Readers are referred to this paper as only a brief overview is given here.

The chemical composition of vesuvianite may be stated as $Ca_{19}Al_4Fe(Al,Mg,Fe)_8(SiO_4)_{10}(Si_2O_7)_4(O,OH)_{10}$, with the possible substitution of transition metal ions (titanium, chromium, manganese and iron) in the Ca, Fe, and Al/Mg/Fe crystal structure sites. These substitutions impart colour to vesuvianite, and a higher content of transition metal ions corresponds to an increase in colour intensity and refractive index.

Transition metal ions have *d* orbital electrons. These electron orbitals, when placed in a crystal structure, have discrete energy levels which are capable of absorbing radiation energy within the visible spectrum (400 to 700 nm). Two electronic processes need to be considered: the energy required to absorb light caused by internal electron transitions between *d* orbital energy levels within a single co-ordination site, and by electron transitions between elements in adjacent atomic sites. The wavelengths that are not absorbed are then transmitted to our eyes as colour.

The valency state and co-ordination polyhedra for each of the transition metal elements are also important in colour theory. The combination of these factors makes the optical absorption spectra of vesuvianite very complicated. Much has been written on the subject of colour in vesuvianite, and readers are referred to Burns (1970) and Manning (1975, 1976, 1977) for further discussions.

In the vesuvianite from these two localities, we have five cations with different numbers of d^n electrons: Ti^{4+} with d^0; Cr^{3+} with d^3; Mn^{3+} with d^4; Fe^{3+} with d^5 and Fe^{2+} with d^6. For the substitution of these transition metal ions in vesuvianite, there are three possible co-ordination symmetries: square antiprism (8-fold co-ordination), octahedral (6-fold co-ordination) and square pyramidal (5-fold co-ordination). In general, the 8-fold co-ordination site is occupied by calcium; the 6-fold co-ordination site has either aluminium, magnesium or iron; and the 5-fold co-ordination site is occupied by iron (Figure 1).

For the Jeffrey mine vesuvianite, the green colour can be attributed almost entirely to ferric iron in the octahedrally co-ordinated Al/Mg/Fe site. The intensity of the green depends on the

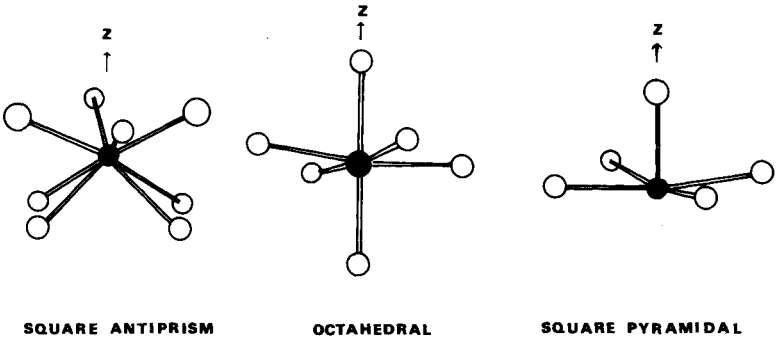

FIG. 1. Co-ordination Polyhedra of Vesuvianite
o oxygen ion • cation

Fe^{3+} content. Mauve or light red vesuvianite is often an overgrowth on light green, and this combination illustrates how sensitive colour change is to chemical composition. The green contains ~2% Fe_2O_3 and 0.1% Mn_2O_3, while the mauve contains ~0.5% Fe_2O_3 and ~0.5% Mn_2O_3. The optical absorption spectrum for mauve vesuvianite shows a broad absorption band in the green part of the spectrum while red and blue are transmitted. Iron is present as Fe^{3+} in the square pyramidal site, and Mn^{3+} is probably in the octahedral Al/Mg/Fe site.

The final colours to be discussed, brown and yellow, have the most complicated OAS since three cations (Fe^{2+}, Fe^{3+}, Ti^{4+}) are present in all three co-ordination sites. It appears that as the Fe^{2+}/Fe^{3+} ratio increases, the colour becomes brown rather than green, as observed in the Jeffrey mine specimens. This decrease in the charge of iron is no doubt coupled in response to the charge balance required by increasing amounts of Ti^{4+}. In general Ti^{4+} is in the octahedral Al/Mg/Fe site and Fe^{2+} is in the square pyramidal Fe site, but minor amounts of each occupy the 8-fold antiprismatic sites. The Fe^{3+} is divided between the octahedral and square pyramidal sites perhaps with some in the antiprismatic site (Manning, 1976). The Ti^{4+} ion does not have any *d* electrons and thus cannot have any internal crystal field transitions, but there is an $Fe^{2+} \rightarrow Ti_{4+}$ charge transfer process involved in the colouring of brown vesuvianite. The 'golden' yellowish brown or brownish yellow of the Laurel vesuvianite is an extension of this argument. As the titanium content and the ferrous/ferric ratio increase, the resulting colour is more yellow.

PLEOCHROISM

In large grains and faceted gems, vesuvianite from both the Jeffrey mine and Laurel exhibits strong dichroism, in contrast to vesuvianite from many other localities that displays only weak dichroism (Deer, Howie and Zussman, 1962; Webster, 1975). The dichroic colours of the gems are given in Table 2. Brown grains of Jeffrey material showed greenish brown/brown, while mauve grains showed magenta/greyish pink.

Pleochroism in the visible spectrum is the phenomenon of differential selective absorption of light as it passes through a coloured, doubly-refractive mineral. The ordinary and extra-ordinary rays in uniaxial crystals such as vesuvianite (or the three rays corresponding to the three principal vibration directions in biaxial crystals) take different paths through the crystal, and differential absorption can occur. Two causes of this are the presence of asymmetric co-ordination sites, and electron charge transfers along a specific crystallographic direction. These conditions can exist in vesuvianite since the square pyramidal site is asymmetric, and the $Fe^{2+} \rightarrow Ti^{4+}$ charge transfer occurs along the *z*-direction. At present the authors have no explanation for the varying degrees of pleochroism in vesuvianite.

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OBSIDIANS AND GEMMOLOGY

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'Among the various types of glass also belongs obsidian, that is like the stone found by Obsidius in Ethiopia. This type of glass is completely black, dense, sometimes transparent and, when used in wall mirrors, reflects silhouettes instead of a picture. It has frequently been used for gems, and I have personally seen obsidian busts of Emperor Augustus, who loved the substance for its density and also, for its remarkableness, had four obsidian elephants made and set up in the Temple of Concord.' (Pliny, *Natural History,* Book 36.)*

As the natural physical conditions obtaining when minerals and igneous rocks, the inorganic matter in nature, are formed clearly favour crystallization, most rocks and minerals are crystalline. Glass is the rare exception. It is thermodynamically unstable and devitrifies in (geologically speaking) a short period of time during which it decomposes completely.

Of the variety of natural glasses accessible to us in the surface of the earth (Table 1), *obsidian* is the most wide-spread. It is a separation product of magma containing large quantities of silicic

*C. Plinius Secundus, *Historia naturalis.*

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TABLE 1

TYPES OF NATURAL ROCK GLASSES IN THE EARTH'S SURFACE

Obsidians	Magmatic melts with acid character, that consolidate on or near the earth's surface as glass
Basalt Glasses	Mostly basaltic melts that consolidate under water as glass
Tektites	
Impact Glasses	Mainly melts that consolidate as glass and originate in connexion with the impact of large meteorites on the earth's surface, whether they become liquid just before impact or while travelling through either the earth's atmosphere or outer space (moldavites, billitonites, australites, etc.)
Fulgurites	Glasses formed when lightning strikes and locally melts sands or the surface of quartziferous rocks
Libyan Desert Glass	Genesis uncertain
Pseudo-Tachylites	Partially vitreous consolidations of rocks that are melted by the heat from friction caused by the sliding during great landslips

acid, which, due to its high viscosity upon rapid cooling, solidifies as glass. This differentiation (the process of splitting a magma into a variety of partial products) explains why obsidians are found in so many places even if they are unevenly distributed. Large numbers of obsidians are found in volcanic areas above subduction zones of tectonic layers (e.g., the Mediterranean, Asia Minor, the Caucasus). Others are found in rift zones (like the East African Valley, Iceland), and still a few others over hot spots of continental or oceanic segments of the earth's crust (see Table 2). They should all, however, be classified as rocks rather than as minerals.

Due to its hardness and the sharp edges it can form under pressure or impact, obsidian was the material preferred by many early cultures for tools and weapons. Moreover, archaeological findings also give proof of export trading in obsidian from source areas in central and eastern Asia Minor to Mesopotamia as early as

TABLE 2

SELECTED OBSIDIAN SOURCE LOCALITIES

Europe	Hungary (Tokaj)	
	Slovakia	
	Iceland	
Mediterranean	Sardinia (Monte Arci)	
	Pontine Islands	
	Pantellaria	
	Lipari	
	Melos	
	Antiparos	
	Yali (Giali)	
Asia	Cappadocia	
	(Acigöl, Çiftlik)	
	Van Lake District	
	(Bingöl, Nemrut Dağ)	
	Kars District	
	Armenia	
	Caucasus, Georgia, Iran	
	SW. Arabia	
	Japan	
Oceania	Indonesia	
	New Zealand	
Africa	Tibesti (Libya, Chad)	
	Abyssinia	
	Kenya	
America	California, U.S.A.	Widespread Occurrence
	Nevada, U.S.A.	
	Oregon, U.S.A.	
	Mexico	
	Guatemala	
	El Salvador	
	Peru	

TABLE 3

VARIETIES OF OBSIDIAN PARTIALLY USED AS GEMSTONES (BY NAME)

'Snowflake' or 'Flowering' Obsidian	black with numerous grey-white spots due to gas cavities (California, Yali)
'Mountain Mahogany'	brown-grey stripes
'Chatoyant' Obsidian	iridescent in various colours due to inclusions
Marekanite	transparent, partially coloured obsidian, globes of perlite (see below), named from the Marekanka River near Ochotsk in East Siberia
'Tokaj Deluxe Sapphire'	brown-black (Tokaj, Hungary)
Also:	
Perlite	rock glass that, due to internal tension, decomposes into little globes
Pitchstone	obsidian dissolved as a result of water absorption, partially re-crystallized

the seventh to the fifth millenia B.C. Indeed, aside from rock salt, obsidian was probably the first article of trade, at least in that geographical area. In the Mediterranean and the Near East obsidian was in wide use until well into the chalcolithic period. In other parts of the world it remained in use almost until today. Throughout the pre-Columbian cultures of Central America and in the Indian cultures of California, for example, obsidian was an important raw material.

As mentioned above, these early cultures used obsidian to make weapons (chiefly arrow heads) and various kinds of tools (blades, sickles, saws, scrapers, drills, etc., but due to the brittleness of the material, however, it was not used for hammering or impact tools.) In addition, articles for everyday use, such as ornaments and religious objects, were fashioned from obsidian quite early. Grinding and polishing obsidian could transform it into—needless to say, rather dark—mirrors, and such mirrors were already to be found in the Late Stone Age in the ceramics of Çatal Hüyük in Asia Minor. Razors made of obsidian were still in use in the Aegean area during the Bronze Age.

Owing to the colour and brilliance of this natural glass, obsidian also came into use as a gemstone (see Table 3): and what considerable knowledge and skill in handling this hard and brittle material that required! Yet pre-Columbian Mexico, in particular, achieved extreme technical perfection, as is evidenced by a large number of sculptured and relief figures and personal ornaments.

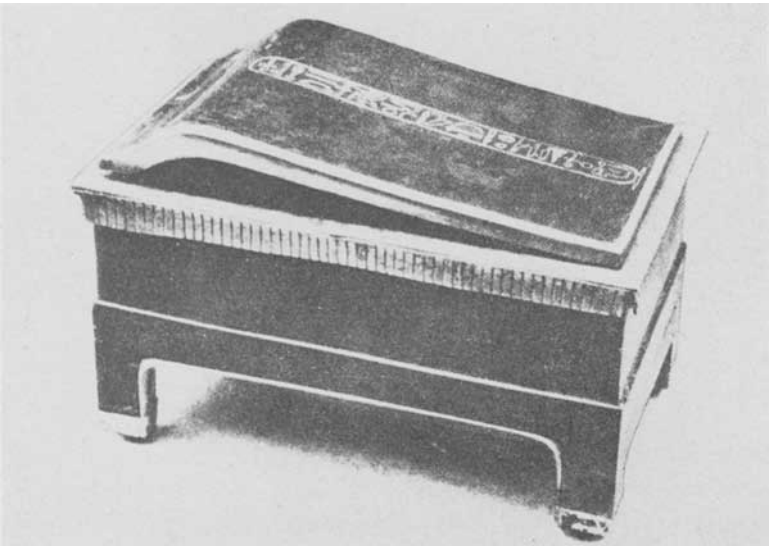

FIG. 1. Egyptian jewellery box made of obsidian with hieroglyphic inscription and golden appliqué. (*Byblos/National Museum, Beirut.*)

Obsidian artefacts were by no means lacking in the early cultures of the Near East either, but they appear to have been less common. A high point in obsidian handicraft was reached in Egypt, however, during the second millenium B.C., when obsidian pieces of absolute perfection were made, especially vessels and sculptures (see Figure 1). We know of obsidian vessels from Crete as well (Figure 2), and through Pliny we know of obsidian sculptures in ancient Rome. Not only have fragments of such works been actually found in Rome, but also diggings in the ancient Italian town of Stabiae have uncovered obsidian vessels which provide impressive proof of artisans' skill in working with the material during the Roman Empire (Figure 3).

FIG. 2. Minoan chalice of 'snowflake' obsidian. (*Palace of Kato Zakro, Heraklion/National Museum, Crete.*)

FIG. 3. Richly decorated cup made of obsidian, from Imperial Rome. (*Stabiae/National Museum, Naples.*)

For a rather long time it was customary in ancient Greece to employ obsidian as pupils for the eyes of statues and portrait-busts that were made of other materials. During the archaeological investigation of Phidias' workshop obsidian scraps were found, which suggest that Phidias probably also used obsidian for his great statue of Zeus with its lustrous surface of gold and ivory. Stone-cutters in antiquity sometimes used obsidian for making seals and gems—infrequently, and probably first in Assyria, but we have proof also of their perfection in manipulating this and other extremely brittle materials.

Yet this highly developed technique of tooling obsidian was somehow lost in the late periods of antiquity. Obsidian thus disappeared from the palette of minerals and rocks used for decorative purposes, not to reappear until its use as jewellery for mourning in quite recent times. The current use of synthetic black glasses for such jewellery today, however, has once more pushed obsidian back into oblivion. As a result the gemmologist's interest in obsidian will, in general, remain restricted to historical objects for which he may receive enquiries as to origin and genuineness.

The assignment of an obsidian artefact to a particular culture must first be made on the basis of stylistic considerations. But in the case of tools such classification may well present problems, especially as the purpose of the tool and the properties of the material largely determined the form of the tool without regard to the peculiarities of the individual culture.

For exact determination of origin the chemical compostion or typical physical characteristics of the artefact (Table 4) must be compared with those of the other possible source-localities. The prerequisites for such comparisons are:

1. that the composition and characteristics of obsidians from the localities in question are known;
2. that the obsidians from such sources differ so greatly from group to group (as to composition and properties) that they are recognizable as being of specific types; and
3. that the various sample pieces from each place of origin are so homogeneous that variation in composition and properties for the one source-locality is small in comparison with variations found in pieces of different origins.

Until the present, determination of the origin of obsidian artefacts has been made almost exclusively on the basis of the traces of the other chemical elements they contain. Incidentally, this has shed light on a large number of prehistoric trade routes, particularly in the Mediterranean area and in the Near East. The methods used for determination (optical spectroscopy and neutron activation analysis), however, still remain the preserve of special laboratories and are largely or completely non-destructive.

As yet there have been practically no investigations of homogeneity in the distribution of trace elements for the various source localities. Indeed, hardly any locality has been subjected to thorough geochemical exploration to date, although it might well reduce the value of many existing expertises on origin.

More recent studies have revealed that the relative contents of the major components (SiO_2, Al_2O_3, CaO, K_2O, Na_2O) may be put to very good use in establishing the chemical peculiarities of the various localities of occurrence. Genetically, these substances, together with a few secondary elements (Fe, Ti, Mn, Mg, P), are closely connected with the magmatic development of the respective

TABLE 4

DETERMINATION OF ORIGIN OF OBSIDIAN PIECES

Possible by

1. *The Chemical Composition*

1.1 Major Components
(Si, Al, Na, K, Ca)
Calculation of the normative minerals content

Na_2O	+	Al_2O_3	+	SiO_2	→	$Na[Al\,Si_3O_8]$ albite
CaO	+	Al_2O_3	+	SiO_2	→	$Ca[Al_2\,Si_2\,O_8]$ anorthite
K_2O	+	Al_2O_3	+	SiO_2	→	$K[Al\,Si_3O_8]$ orthoclase
				SiO_2	→	SiO_2 quartz

means total amount of respective oxide in the analysis

Concentration Diagrams: 1. orthoclase-anorthite-albite,
2. quartz-albite-anorthite.

1.2 Secondary and Trace Elements (Geochemical Fingerprinting)
For example: Fe, Ti, Mn, P
Ba, Zr, Y, Nb . . . . . .

Correlation Diagrams Showing Elements in Characteristic Pairs

2. *Physical Properties*
depending upon the chemical composition and characteristic for distinct Obsidian source localities (Colour, Fluorescence, crystalline and non crystalline inclusions).

3. *Geological Age and/or Age of Manufacture of the artefact.*

TABLE 5

CHEMICAL COMPOSITION OF OBSIDIANS

Rhyolitic Obsidians
correspond, in their composition, to the effusive rocks Quartz porphyries/rhyolites and the deep-seated aplitic granite.

		Wt %
SiO_2		70-76
Al_2O_3		10-17
K_2O		1-7
Na_2O		3-7
Fe_2O_3	Less than	2.5
FeO	"	1.5
CaO	"	1.5
MgO	"	0.5
TiO_2	"	0.5

Rarer Obsidians

Dacitic Obsidians
correspond to the partially crystalline effusive rock dacite and the plutonic Quartzdiorite.

	Wt %
SiO_2	55-70

Trachytic Obsidians
correspond to the partially crystalline effusive rock trachyte and the plutonic Syenite.

	Wt %
SiO_2	50-65

volcanic areas so that it is also possible to distinguish between localities even if they lie close together either in time or space (Table 5).*

Studies not only of the chemical but also the physical peculiarities—colour, light-absorption, perhaps also fluorescence, Mössbauer spectrum, devitrification tendencies (crystallites), gas and liquid constituents—can give indications of the individual source localities. As yet, however, there have been no systematic studies made in this direction either.

*cf. H. G. Büchholz and E. Althaüs, *Archäologische Obsidian-forschüngen,* vol. 1, Nisyros-Giali-Kos, pp. 66-77, Verlag Philipp von Zabern, Mainz, 1982. [Also cf. R. E. M. Hedges, (1980), Archaeological Evidence from Chemical Analysis, *Science & Industry,* **15**, 12-15.—Ed.]

Megascopic observations of colour and surface properties (Table 6), though quite typical for individual localities (for example, for the locality of Nychia on the Isle of Melos), in general do not suffice for exact determination of origin.

TABLE 6

OBSIDIAN: MEGASCOPIC PECULIARITIES

Colour	black, grey, brown, reddish, greenish, white, colourless (seldom) Colour Distribution: even, cloudy, doughy, spotted, striped, opaque, visible at edges, transparent (seldom)
Lustre	glassy, mother-of-pearl
Tenacity, Fracture	brittle, conchoidal, splintery, upon mechanical stress (impact, pressure) forms extremely sharp edges
Hardness	6 on Mohs's scale, may be compared with Cr Ni-steel
Density	2.3-2.5 g cm^{-3}, depending upon composition, gas bubbles and included crystalline bodies
Refractive Index	1.45-1.55

In addition, the geological age of an obsidian, meaning the length of time that has passed since its magmatic solidification, can also aid in determining its origin (Table 7). Methods for establishing the age of an obsidian are the dating of

1. fission tracks,
2. thermoluminescence.

They are based on changes in the glass base (1) and crystalline inclusions (2) under the influence (in ppm) of ever-present radioactive elements, particularly of uranium, and they presuppose similar findings in age tests of the localities in question. Yet, due to the relatively large test quantity required (approximately 1 cm^3), these methods may hardly ever be applied in the case of very valuable artefacts.

TABLE 7

DETERMINATION OF AGE OF OBSIDIAN

Geological Age (Time of Genesis)

1. Fission Track Dating

   Exposure of radiation damage (by etching)

   Comparison of the spontaneously formed fission track density with that which has been induced (by defined neutron radiation in the reactor)

   Absolute method in range 10^2 to 10^7 years, depending upon uranium content.

2. Thermoluminescence Dating

   Release, through heating away, of energy stored in the radiation damage (glow curve), comparison of spontaneously formed thermoluminescence with that which is induced (by defined neutron radiation)

   Method for absolute age of minerals, ceramics, slags; applicable for obsidian as well as under certain conditions.

   Note:

   Both methods reveal the last time of use of an artefact which—for example, during a catastrophic fire—has been heated above 500 °C. In this case the fission tracks and the thermoluminescence (acquired as a result of irradiation during geological times) are removed.

Age of Genesis or Manufacture

3. Dating Hydration Layer Thickness

   Measurement of thickness (which is dependent upon the time, climate and soil) of hydration layers.

   Geological age since formation of unchanged surfaces.

   Age of artefacts and scraps (from time in which they originated).

   Note:

   Relative method, especially for distinguishing archaeological objects from recent copies.

The investigating methods discussed so far make it possible—at least in principle—to determine the origin of an obsidian artefact, and, as already described, origin, in turn, is especially important in answering questions concerning cultural history through geographic location of places in which obsidian was won and tooled in antiquity and in earlier prehistoric times and of where trade was undertaken with this highly cherished material.

The period in which obsidian artefacts were made is also interesting from the historical viewpoint, and such knowledge becomes essential when historic obsidian objects are to be distinguished from later copies.

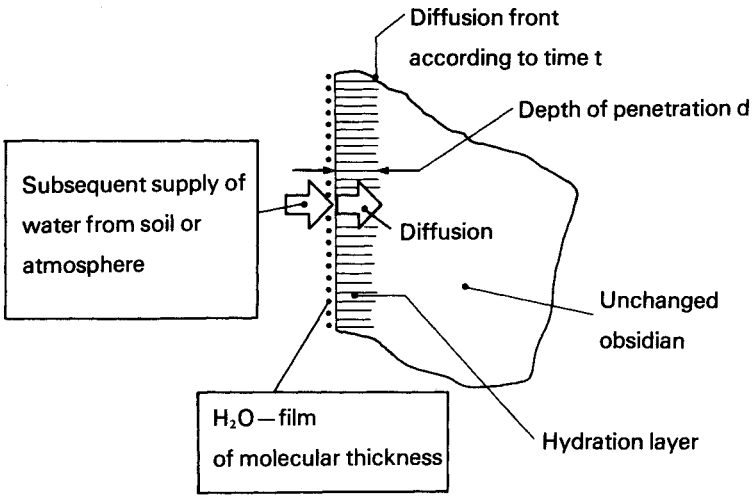

FIG. 4. Schematic Representation of the Formation of a Hydration Layer in Obsidian by Way of Diffusion of the Solid.

One possibility of dating artefacts made of obsidian is based on the observation that all obsidians absorb water from their surroundings and change—from the surface inward—in a characteristic way. That is to say that on the surface a hydration layer is formed, which grows in thickness according to a simple time law (Figure 4).* Hydration begins—*in situ*—with the cooling of the surface of the lava flow. When artefacts are made, it begins

*The thickness of hydration layers grows according to a simple formula:

$$d = \sqrt{k.t}$$

with thickness d (in μm)
time t (in years) and
diffusion coefficient k

$$k = A.e^{-E/RT}$$

with the hydration temperature T (in K), the general gas constant R, the energy of activation of the diffusion E (in k cal/mol), the coefficient A.
A and E depend upon the physico-chemical properties of the obsidians.
The two coefficients may be experimentally determined for each kind of obsidian by diffusion.
[Calorie (cal) is not a S.I. unit but equals 4.184 J.—Ed.]

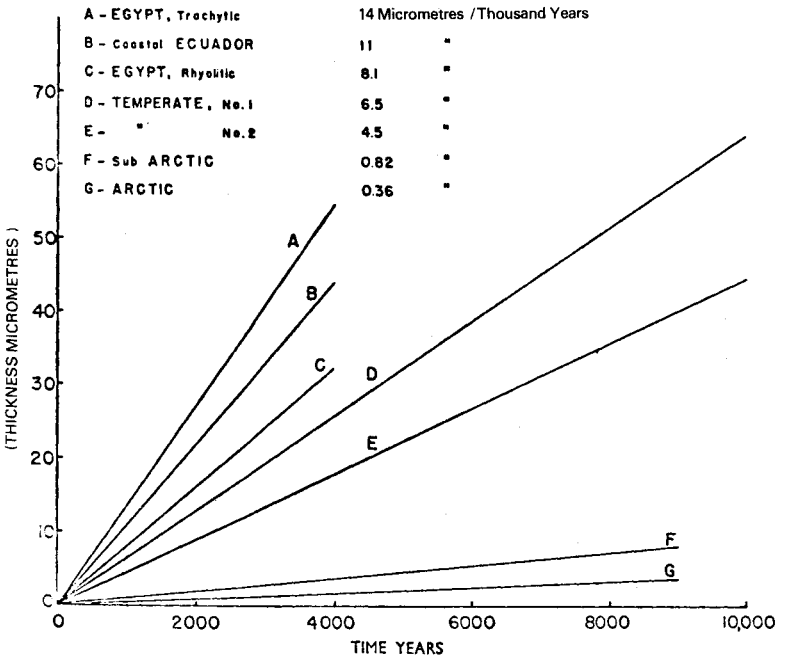

FIG. 5. Influence of climatic conditions on the hydration speed of obsidians (according to I. Friedman and R. L. Smith, 1960, *Am. Antiquity*, 25, 476-522.)

at the moment at which a fresh surface is formed—either on the artefact or on the residual scrap—as a result of the work procedure. Once the artefact is buried in the earth, hydration continues until the piece is recovered by the archaeologist.

Depending upon the temperature and the chemical composition of the soil, the thickness of the hydration layer may amount to 0.2 to 4μm in 1000 years. Once a petrological thin section has been obtained by cutting vertically into the surface, the thickness of the hydration layer may be measured directly under the polarizing microscope. When such a layer is totally missing, it is an indication of fresh surfaces, in other words, of recent origin.

Obsidian dating by determining the thickness of hydration layers is a comparatively recent method of establishing age (Figures 5 and 6). It was developed around 1960 and is applied routinely in several laboratories in the United States, primarily in connexion with archaeological problems encountered in North and Central

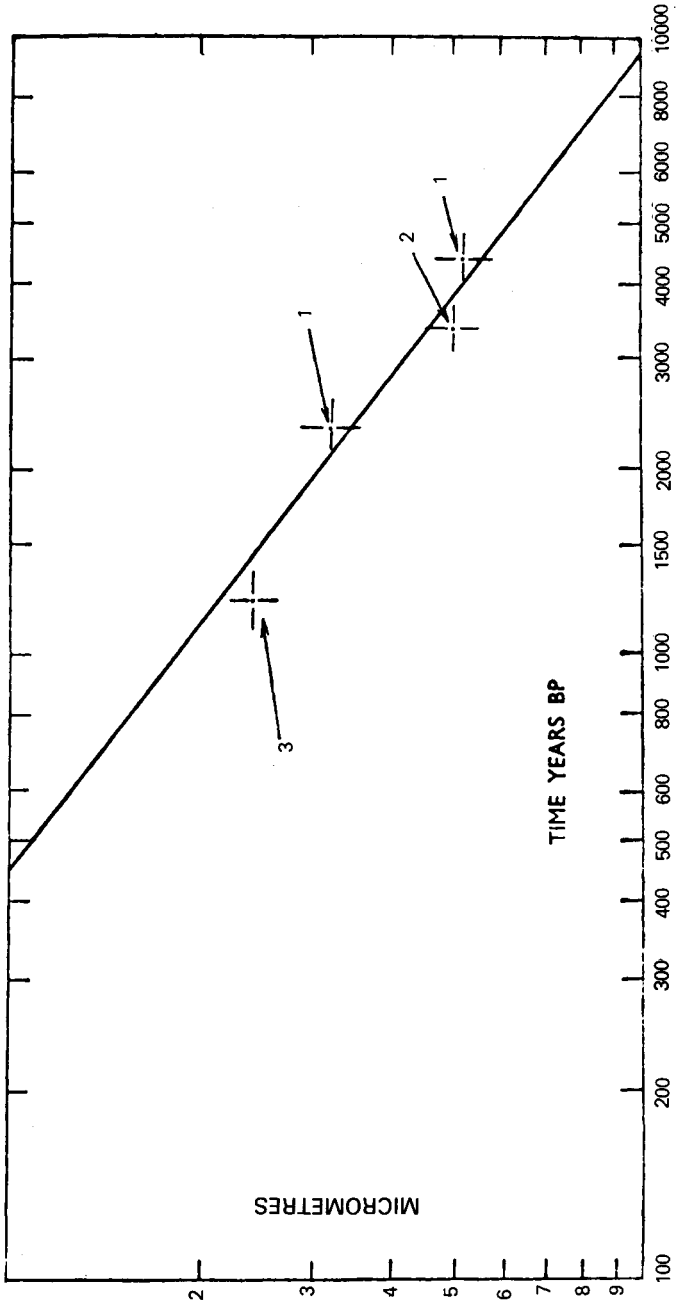

FIG. 6. Thickness of hydration layers on obsidian artefacts from California and absolute age of the respective strata, determined by the ^{14}C-Method (found in D. L. Clark, 'Arch. Chronology of California and the Obsidian Hydration Method' in *Ann. Report of the Arch. Survey*, Dept. of Anthropology, University of California, 1964.)

America. Due to the complex effect of soil temperature and chemical composition on the growth in thickness of the hydration layer, this method is not yet completely satisfactory for determining the absolute time of manufacture of an obsidian artefact. Yet coupled with radiocarbon dating, for instance, it nonetheless supplies valuable indications of the age sequence of strata between the various fixed points on the absolute time scale. Moreover, this method requires only modest test costs and equipment (tools for preparing the petrological thin section, and a polarizing microscope). Even more important: only very small test quantities (approximately 1 mm^3) are needed, so that even rather valuable artefacts can usually be tested.

Obsidian, a subject for gemmological research? Certainly not, when the obsidian is viewed from the standpoint of its value as a 'rough stone'. Yet, if we consider the properties of many obsidians, we might perhaps answer this question with 'Yes'. If we take the beauty of artefacts made of natural obsidian and their value to cultural history into account, we might well come to the conclusion that investigation of this volcanic glass would be a rewarding task—even for the gemmologist.

BIBLIOGRAPHY

Literature on obsidian as a material used in antiquity and in prehistoric time is extensive and widely scattered. A good summary may be found in:

R. E. Taylor, ed., *Advances in Obsidian Glass Studies.* Noyes Press, Park Ridge, N.J., U.S.A. 1976. See especially the article by J. E. Dixon, 'Obsidian Characterisation Studies in the Mediterranean and Near East', pp. 288-333.

On obsidian dating by the thickness of the hydration rings, see

J. W. Michels and C. A. Berbrich, 'Obsidian Hydration Dating' in *Dating Techniques for the Archaeologist,* M.I.T. Press, Cambridge, Mass, U.S.A., 1971.

[*Manuscript received 9th November, 1981.*]

GEMMOLOGICAL ABSTRACTS

ANDERSON (J. E.). *Green fire from the Antarctic.* Lapidary J., **37**, 1, 84-6, 4 figs (3 in colour), 1983.

Peridot from the Antarctic is described: the location is Ross Island. M.O'D.

ANDRYCHUK (D.). *Measuring parameters characterizing gemstone performance.* Lapidary J., **37**, 3, 468-74, 8 figs, 1983.

Brightness, brilliance, dispersion, sparkle, life and fire are the areas for which parameters are determined for diamond, YAG and quartz. M.O'D.

ATKINSON (D.), KOTHAVALA (R. Z.). *Kashmir sapphire.* Gems & Gemology, **XIX**, 2, 64-76, 13 figs in colour, 1983.

An account of the history, geology and locality of the sapphire mines in Paddar in the Zanskar [Zaskar?] Range. The writers succeeded in visiting these in 1981. Sapphires have been found in weathered feldspar, or china clay, and in unweathered pegmatites. Mine areas are in high, very difficult terrain, just below the snow line and some 110 km from any proper road. The journey in took eight days in this expedition. Sapphires are not now being produced due to the difficult terrain and to the political situation in that part of the sub-continent. Mines are small and have been worked by hand in the past, although much blasting has been used more recently. Associate gems are beryl and tourmaline, but these appear to be rarer than the sapphires. Writers consider that the region still has undiscovered sources of fine sapphires. R.K.M.

BANK (H.). *Durchsichtiger Lazulith oder Scorzalith aus Brasilien.* (Transparent lazulite or scorzalite from Brazil.) Z.Dt.Gemmol.Ges., **32**, 1, 6-9, tables, bibl., 1983.

Transparent to translucent light and dark blue, even green, members of the isomorphous series lazulite-scorzalite are described and physical properties including x-ray powder data given. They can be distinguished from each other easily by optical and chemical investigation (due to their isomorphous replacement of Fe and Mg) but only with great difficulty by means of x-ray data. E.S.

BANK (H.). *Grüner, durchsichtiger, geschliffener Ludlamit.* (Green, transparent, cut ludlamite.) Z.Dt.Gemmol.Ges., **32**, 1, 75, bibl., 1983.

This is a short description under the 'gemmological short note' series. The stone was named in honour of Ludlam of London by Maskelyne and Field in 1877. It is a Fe-phosphate, monoclinic, H 3-4, SG 3.1, RI 1.653-1.693, double refraction 0.040. E.S.

BRACEWELL (H.). *Harts Range and beyond.* Wahroongai News, **17**, 2, 13-14, 1983.

A further instalment of the 'Round Australia' trip by the Bracewells. Zircon, beryl, garnets, epidote, sphene, kyanite, iolite, fluorite and others were found.

R.K.M.

BRACEWELL (H.) *Kings Canyon—Henbury—Ayers Rock.* Wahroongai News, **17**, 2, 15, 1983.

Visits to geologically interesting tourist spots, but not gemmologically productive R.K.M.

BRACEWELL (H.). *The opal fields of Mintabie and Coober Pedy.* Wahroongai News, **17**, 3, 11-12, 1983.

240 km apart, these areas are the two biggest producers of opal in Australia, Coober Pedy being the larger of the two. Mining at Mintabie is mainly by bull-dozer after opal has been found by drilling. Mechanization leaves much opal in the huge mullock heaps, where 'noodlers' do well. Mintabie is owned by an aboriginal tribe. Information on Coober Pedy is sparse and the place seems to have been far from friendly. R.K.M.

BRACEWELL (H.). *The next epistle in the around Australia trip.* Wahroongai News, **17**, 6, 9-11, 1983.

Takes us from Mt Gunson to Adelaide and thence via Koppio to Port Lincoln and Elliston, to Ceduna and then West across the Nullarbor Plain to Eucla and eventually to Norseman. A further contribution to a long saga, a vastly entertaining account of an ambitious journey, visiting gem localities, museums and gemmologists on the way. R.K.M.

B[ROWN?] (G.). *The structure of synthetic non-silicate garnets.* Wahroongai News, **17**, 3, 15-16, 1 fig, 1983.

An attempt to explain how YAG and GGG and other synthetic 'garnets' conform to the structure of natural garnet. R.K.M.

BROWN (G.). *Data on the Biron synthetic emerald.* Wahroongai News, **17**, 6, 23, 1983.

Information on a single example of a new high quality synthetic emerald from Australia. SG 2.68, RI 1.570-1.577, DR 0.007. Inert to UV, eye clean. This material would appear to be exceptional—better-looking than most natural emeralds.R.K.M.

BROWN (G.). *Notes on the heat treatment of corundum.* Wahroongai News, **17**, 6, 15-18, 1983.

Summarizes available information on the heating of rubies and sapphires to improve colour, diaphaneity or asterism. R.K.M.

BROWN (G.). *Supplement to Wahroongai News.* **17**, 5, 36pp, May 1983.

A compilation of available facts on rarer gem species—apophyllite, charoite, chlorastrolite, gypsum, hemimorphite, idocrase, lazulite, meerschaum, odontolite, pyrite and marcasite, smithsonite, sogdianite, steatite, stichtite, sugilite, thomsonite, tugtupite, violane and wardite. Some of these are 'way out' gems but the concentrated information is very valuable. R.K.M.

BROWN (G.). *Rhinoceros horn: some observations of use to the gemmologist.* Aust. Gemmol., **15**, 2, 38-43, 7 figs, 1983.

The rhinoceros is an endangered species in east Asia and Africa and is likely to become extinct because of demand in China and SE. Asian countries for its horn, which is valued, not as an aphrodisiac, but for anti-pyretic medical properties. Gemmological use is principally in carvings. H. 2, SG 1.30, RI (vague) 1.54; fluorescence, greenish-blue in long UV; microscope, oriented filaments incompletely fused together, probably related to hair. R.K.M.

BROWN (G.), BRACEWELL (H.). *Mt Isa iolite.—a preliminary note.* Aust. Gemmol., **15**, 2, 53-6, 7 figs in colour, 1983.

A report on samples from this region, mainly concerned with inclusions. Red haematite flake-like crystals appear to be common. [Abstracter reported these as a rare inclusion in Ceylon iolite in June 1955 (*Gemmologist,* XXIV, 110).] R.K.M.

BROWN (G.), MOULE (A. J.). *Gutta-percha—a rare organic gem material.* Aust. Gemmol., **15**, 2, 50-2, 3 figs, 1983.

A Victorian moulded cameo of this material is examined and discussed in detail. Moulded in two parts—surface painted black. H.2, SG 1.89, RI 1.58. R.K.M.

BROWN (G.), SNOW (J.). *The Regency synthetic emerald.* Aust. Gemmol., **15**, 2, 57-60, 8 figs, 1983.

This is the Linde synthetic now manufactured under licence by Vacuum Ventures Inc. Crystals and growth characteristics and four pictures of inclusions are given. Material is identical with the Linde product. H. 7-8, SG 2.68, RI 1.568-1.573, dagger-like and phenakite inclusions, strong red fluorescence. R.K.M.

CASSEDANNE (J.). *La mine de 'topaze' de la Fazenda Serra do Salto (Bahia-Bresil).* (The 'topaz' mine of Fazenda Serra do Salto, Bahia, Brazil.) Revue de Gemmologie, 75, 3-6, 8 figs, 1983.

Despite the name, the mineral produced at this mine in an area north-north-east of Brasilia, in the municipality of Licinio de Almeida, is not topaz but amethyst. Details of the occurrence and of the properties of the amethyst are given. M.O'D.

CLARE (S.). *What to facet—2.* Gems, **15**, 1, 13-14, 1983.

Deals with the selection of rough with particular reference to cleavage. M.O'D.

COLLINS (A. T.), THOMAS (M. F.), JORGE (M. I. B.). *Luminescence decay time of the 1.945eV centre in Type Ib diamond.* Journal of Physics C:solid state physics, **16**, 2177-81, 2 figs, 1983.

The luminescence decay time of the 1.945eV centre is determined as 13±0.5ns for natural Type Ib diamonds. The value for synthetic diamonds is slightly lower. M.O'D.

CROWLEY (J. A.). *Axinite—old and new.* Lapidary J., **37**, 3, 444-8, 15 figs in colour, 1983.

Axinite has been found in California, the occurrence being discovered during the construction of the New Melones dam in Calaveras County. Some crystals are up to four inches in length, glassy in appearance and very clear. The colour is moderate to dark brown with purple as one of the dichroic colours. They occur in albite-axinite-quartz veins traversing dark metamorphic rock. Crystals from one part of the area have been found to be magnesium-rich ferroaxinite (dark violet-brown), while crystals from another part are lighter brown and manganese-rich ferroaxinite.

M.O'D.

CROWNINGSHIELD (R.). *Padparadschah: what's in a name?* Gems & Gemology, **XIX**, 1, 30-6, 7 figs in colour, 1983.

A rationalization of the use of this name derived from the Sinhalese word *padmaragaya* (lotus colour), concluding that an effort should be made to standardize the acceptable colour as pinkish-orange or orange-pink. Dark brownish-orange stones from East Africa would not qualify. Nomenclature is confused by the introduction of synthetics under this name. [And possibly by the fact that the lotus itself varies in shade?]

R.K.M.

DAVIES (G.). *Diamond, strength in symmetry.* New Scientist, 1348, 638-41, 12 figs, 1983.

An interesting account of how diamond obtains its remarkable properties and of the uses to which they can be put.

M.O'D.

DURAND (P.). *Amethyst, the royal gem.* Lapidary J., **36**, 11, 1824-6, 1983.

Reminiscences of a lapidary and notes on the availability of amethyst today.

M.O'D.

EBERT (J. M.). *Art Deco: the period, the jewelry.* Gems & Gemology, **XIX**, 1, 3-11, 9 figs (8 in colour), 1983.

Summarizes this rather indeterminate period in terms of the more unconventional jewellery designs it produced.

R.K.M.

FRYER (C.), ed., CROWNINGSHIELD (R.), HURWIT (K. N.), KANE (R. E.). *Gem Trade Lab Notes.* Gems & Gemology, **XIX**, 1, 43-9, 21 figs (20 in colour), 1983.

A fine alexandrite cat's-eye, a carved diamond fish, a painted 'pink' diamond, and a natural one which became redder when heated, are described and a warning given on irradiation of diamonds of this colour. An emerald and diamond necklace, earrings and ring/pendant had as its largest stone a painted beryl which lost colour when steam-cleaned. Spicules seen in a low RI synthetic emerald were compared with rather similar tubules in a high RI natural emerald. A pale green fluorite, rose quartz and pearl necklace is described, as are 'buff-topped' garnet and green glass doublets. 'Buff-topped' means cabochon crown on a faceted base. A 1.5 carat orange-brown opal cat's-eye with a very strong eye is illustrated; a calcareous fossil

trilobite suitable for jewellery use is also depicted. Flat button pearls on a brooch were mixed natural and tissue-nucleated and were compared with a large parcel of similar, flat-based, regular, fresh-water, tissue-nucleated cultured pearls of various colours; method of cultivating such regular shapes is not known. A hank of multi-coloured baroque seed pearls of a new type is causing identification problems. More button pearls of fresh-water origin were unmounted to find that they were tissue-nucleated, again by an unknown cultivation process, information is asked for. An unusually fine large quartz cat's-eye, and a ruby and synthetic ruby doublet were described; a blue spinel with a colour change to purple-blue in incandescent light was identified as natural spinel coloured by cobalt. An organic concretion found in a tin of tuna fish was not identifiable. R.K.M.

FRYER (C.), ed., CROWNINGSHIELD (R.), HURWIT (K. N.), KANE (R. E.). *Gem Trade Lab Notes.* Gems & Gemology, **XIX**, 2, 112-17, 22 figs (19 in colour).

Odd inclusions in diamond, 'seagull in flight', 'Thomas Jefferson's Head'; a painted (nail varnished) pink diamond which was switched for a genuine pink stone in a Sotheby Parke Burnet presale viewing, described and illustrated. A very thin rose diamond of 20 mm diameter was set with 'faceted' foil backing; cubic zirconias were submitted for diamond grading and an intense yellow diamond had a GIA certificate as a naturally coloured light yellow stone while spectrum showed 5920A line which proved that stone had been treated after the certificate had been issued.

New synthetic emeralds from Russia had whitish seed plates and appeared to be hydrothermal stones, but no UV fluorescence and little red through colour filter. RI 1.572-1.580 gives exceptionally high DR of 0.008. SG 2.67.

A dyed turquoise-blue jadeite, a black opal naturally embedded in a yellow brown white opal with little play of colour, from Lightning Ridge; a black non-nacreous pearl with 'fur-like' markings and a bald patch, all described and illustrated. Early mabe pearls on a choker necklace had unusual structure and could be from around 1890: they did not fluoresce under x-rays. A large green quartz of good colour was thought to be naturally coloured; a faded natural yellow sapphire (over-heated) was restored by exposure to x-rays, and colour is (hopefully) permanent; two taaffeites are illustrated. Two different imitations of turquoise are discussed, one with RI 1.58 or 1.59, SG 2.35, was dyed gibbsite, the other, RI 1.57, SG 2.27, was a mixture of materials, mainly quartz and zinc oxide; neither exhibited any absorption spectrum. R.K.M.

GREENBERG (E.), KATZ (G.), REISFELD (R.). *Radiative transition probabilities of Er^{3+} in yttria stabilized cubic zirconia crystals.* J. Chemical Physics, **77**, 10, 4797-803, 1982.

The method of growing ZrO_2:Er by the skull-melting technique is described. Eigenvectors for Er in the range 330-1700 nm were calculated together with the transition matrix between each pair of electronic levels. Possible laser levels are indicated. M.O'D.

GÜBELIN (E.). *Genetische Aspekte der Mineraleinschlüsse in Farbsteinen.* (Genetic aspects of mineral inclusions in coloured stones.) Z.Dt.Gemmol.Ges., **32,** 1, 10-27, 33 figs (30 in colour), bibl., 1983.

In addition to giving character to the interior of gemstones their inclusions are essential witnesses to genetic conditions and processes in the silica zone of the earth. The guest minerals are primary phases of information because they have been effectively armoured against alien external influences, retaining their original condition. Investigations have been made into inclusions typical of definite phases of formation or shedding light on the complex correlationship during crystal growth under varying conditions. Local conditions could be observed and influence of syngenetic inclusions on form and habit and alien coloration of host gem could be examined and described. Notes on localities of finds are included. E.S.

GUNAWARDENE (M.), MERTENS (R.). *Japanische Opalimitationen aus Plastik.* (Japanese opal imitations made of plastic.) Z.Dt.Gemmol.Ges., **32,** 1, 59-68, 12 figs (6 in colour), bibl., 1983.

The plastic opals are made of styrene-divinyl-benzene-copolymer and polymethyl methacrylate. The effect of play of colour and manufacturing methods are described, as are physical constants. There is no sharp dividing line between the various colours. There are some tension knots together with stretched gas bubbles. SG 1.19 ± 0.01, RI 1.485 ± 0.005. The opals are offered under the names of 'pastoral opal' and 'neo-noble opal'. Fire opal is made by the addition of orange colour to the resin. There are also doublets of these materials on the market. E.S.

HANNEMAN (W. W.). *A new classification for red-to-violet garnets.* Gems & Gemology, **XIX,** 1, 37-40, 4 figs, 1983.

A slightly contentious paper which argues rather against the classification of pyrope/almandine garnets proposed by Manson/Stockton. R.K.M.

HÄNNI (H. A.), KEREZ (C. J.). *Neues vom Smaragd-Vorkommen von Sta. Terezinha de Goiás, Goiás, Brasilien.* (News from the emerald find of St. Terezinha de Goiás, Goiás, Brazil.) Z.Dt.Gemmol.Ges., **32,** 1, 50-8, 12 figs in colour, 2 tables, bibl., 1983.

Emerald crystals and rock samples from the new mining area of St Terezinha have been investigated by optical methods and by microprobe. The emeralds are characterized by inclusions of dolomite and picotite. The first discovered southern part is not worked any more, as 500 m north better material is found. The area is subdivided into many small claims (40-50 m^2). The rock is loosened by explosion, winched up and taken by lorry to the washes in the Rio Peixe. No production during the rainy season. RI 1.585-1.587, 1.592-1.595, double refraction 0.006-0.008, SG 2.752-2.764. Many crystals show internal fractures, but there are no liquid films or feathers. E.S.

HÄNNI (H. A.), KLEIN (H. H.). *Un gisement d'émeraudes à Madagascar.* (A madagascan emerald location.) Revue de Gemmologie, 74, 3-5, 4 figs, 1983.

French translation of a paper first appearing in *Z.Dt.Gemmol.Ges.,* **31,** 1/2, 71-7, 1982, and abstracted in *J.Gemm.,* **XVIII,** 6, 568, 1983. M.O'D.

HARDER (H.). *Qualitäten und Schönheitskriterien bei Edelopalen.* (Quality and beauty criteria for precious opal.) Aufschluss, **34**, 3, 121-33, 4 figs (3 in colour), 1983.

The main types of precious opal coloration are reviewed and their commercial significance assessed. M.O'D.

HEYLMUN (E. B.). *Map of the Queretaro opal mines, Mexico.* Lapidary J., **37**, 2, 344-5, 1 fig, 1983.

A useful map of the area with each mine marked. M.O'D.

HOOVER (D. B.). *The Gem Diamondmaster and the thermal properties of gems.* Gems & Gemology, **XIX**, 2, 77-86, 4 figs (2 in colour), 1983.

Describes the Australian made instrument which, like others, measures thermal inertia, and discusses the possibility of extending the use to discriminate between gems of different species and similar colour. Instrument is intended only to identify diamond and reject other species. Care is needed if its use is to be extended in this way and points to watch are given. R.K.M.

JAYAKODY (D. F.). *Taaffeite—a rare gemstone of Sri Lanka.* Lapidary J., **37**, 1, 74-8, 3 figs, 1983.

The discovery of taaffeite and its properties are described. M.O'D.

KELLER (P. C.). *The Capao topaz deposit, Ouro Preto, Minas Gerais, Brazil.* Gems & Gemology, **XIX**, 1, 12-20, 11 figs in colour, 1983.

An account of the history, geology and mining methods in one of the principal 'Imperial' Topaz mines of this small area. R.K.M.

KELLER (P. C.). *The newly expanded Deutches Edelsteinmuseum of Idar-Oberstein, Germany.* Gems & Gemology, **XIX**, 2, 97-102, 7 figs in colur, 1983.

An account of the new and greatly improved museum display at this important gem-cutting centre. Claimed to be one of the best of its kind in the World. R.K.M.

KOIVULA (J. I.), FRYER (C.), KELLER (P. C.). *Opal from Querétaro, Mexico: Occurrence and inclusions.* Gems & Gemology, **XIX**, 2, 87-96, 16 figs in colour, 1983.

Describes this important source of Mexican opal with fine colour play and illustrates in some detail a wide variety of volcanic inclusions found in these stones. R.K.M.

KRASHES (L. S.). *Harry Winston: a story told in diamonds.* Gems & Gemology, **XIX**, 1, 21-9, 6 figs in colour, 1983.

A brief account of the late Harry Winston and of some of the exceptional diamonds bought and sold by him. R.K.M.

LAURENCE (C.). *£5m bids invited for diamond heart.* Daily Telegraph, No. 39,871. pp.1, 32, 1 photo, 25th August, 1983.

Bids of at least £5m are invited by Graff's, Knightsbridge, for a 70.03 ct heart-shaped diamond, presently called Le Grand Coeur d'Afrique. The rough from

which it was cut weighed 278 ct and was found in Kankan, [Guinea,] West Africa. Cut in New York, it yielded also a 14.25 ct gem (sold in New York) and a second heart-shape of 25.22 ct, called Le Petit Coeur. J.R.H.C.

LEAMING (S.). *A jade update from British Columbia.* Lapidary J., **37**, 2, 384-6, 1983.

The author states that there are jade fields in British Columbia other than the well-known Fraser river areas. Much nephrite now comes from the Cassiar jade field in the far north of the Province and another field is being worked in the Yukon Territory. M.O'D.

LIND (Th.), SCHMETZER (K.), BANK (H.). *Zur Bestimmung natürlicher, behandelter und synthetischer Türkise sowie von Türkisimitationen.* (On the determination of natural, treated and synthetic turquoise and turquoise imitations.) Z.Dt.Gemmol. Ges., **32**, 1, 69-74, 2 tables, bibl., 1983.

For the investigation of natural, treated, synthetic and imitation turquoise a combination of infrared spectroscopy and x-ray powder diffraction methods is suggested. Both these investigations can be done with a small quantity (3 mg) of the specimen. Some colours and lacquers are dissolvable in water or fat, paraffin can be got rid of by heating and turquoises are sometimes hardened, i.e. stabilized, with colourless or dyed synthetic resins or inorganic substances. In all these instances, light stones tend to darken. E.S.

MCLAREN (A. C.), COOK (R. F.), HYDE (S. T.), TOBIN (R. C.). *The mechanisms of the formation and growth of water bubbles and associated dislocation loops in synthetic quartz.* Physics and Chemistry of Minerals, **9**, 2, 79-94, 21 figs, 1983.

TEM has been used to monitor the development of water bubbles in synthetic quartz by studying the intensity of the light scattered and the increase in volume of the crystal, both as a function of temperature and time. M.O'D.

MANSON (D. V.), STOCKTON (C. M.). *A response to 'A new classification for red to violet garnets'.* Gems & Gemology, **XIX**, 1, 41-2, 1983.

Denies some of Dr Hanneman's contentions and underlines the fact that the investigation of garnets by these authors is not yet complete. R.K.M.

MEEK (J. H.). *Gems, minerals and artifacts in the panhandle of Texas.* Lapidary J., **37**, 2, 316-27, 13 figs in colour, 1983.

The principal ornamental materials found in the area are Alibates flint/agate and quartz; examples of their use are given. M.O'D.

MITCHELL (J. R.). *An extensive agate deposit near Carter, Wyoming.* Lapidary J., **36**, 12, 1964-6, 11 figs (5 in colour), 1983.

Multi-coloured agate and some cornelian are found on a number of sites near Carter, Wyoming, U.S.A. Some of the material is of fashioning quality. M.O'D.

MITCHELL (R. K.). *The visual detection of Gilson 'lapis'.* Wahroongai News, **17**, 6, 7, 1983.

A brief exposition of the subtle visual differences between this artificial material and natural lapis which are quite sufficient to distinguish between them.

(Author's abstract) R.K.M.

NELSON (R. S.), HUDSON (J. A.), MAZEY (D. J.), PILLER (R. C.). *Diamond synthesis: internal growth during C ion implantation.* Proc. Roy. Soc. London, A386, 211-22, 9 figs, 1983.

A new technique for the synthesis of diamond relies on the creation of extra diamond lattice planes within the bulk crystal. High energy carbon ions are implanted into the crystal which needs to be heated for the process to succeed. Carbon ions of this energy (e.g. 20 keV) finish up many atomic layers below the surface and if they take up positions in conformity with the surrounding lattice will give diamonds synthesis. One disadvantage of the process is that irradiation with ions of this type of energy may lead to sputtering and to radiation damage which could limit the growth of crystalline material. M.O'D.

O'DONOGHUE (M.). *Industrial review:gemstones.* Encyclopedia Britannica Book of the Year, p.439, 1983.

Prices fell generally, diamonds of lower grades suffering most. In general, coloured stones have kept their price in the higher qualities. Treatment of diamond is still giving trouble. (Author's abstract) M.O'D.

O'DONOGHUE (M.). *The carbonate group of minerals—5.* Gems, **15**, 1, 33-4, 1 fig., 1983.

Some of the rarer carbonate minerals are discussed, including gaylussite, northupite and parisite. (Author's abstract) M.O'D.

O'DONOGHUE (M.). *The dealer looks at gemstones—9.* Gems, **15**, 1, 30, 1983.

Discusses a report from the Bourse at Idar-Oberstein in which the prices and availability of ruby, emerald, tsavolite and tourmaline are mentioned.

(Author's abstract) M.O'D.

O'DONOGHUE (M.). *Franklin, the Mecca of fluorescent minerals.* Gems, **15**, 1, 21, 1983.

A history of the activities of the New Jersey Zinc Company who worked the mines at Franklin, New Jersey, until 1954, with some notes on the minerals found.

(Author's abstract) M.O'D.

O'DONOGHUE (M.). *The carbonate group of minerals—6.* Gems, **15**, 2, 29, 1983.

The minerals stichtite and siderite are among those discussed. Constants and occurrences are given. (Author's abstract) M.O'D.

O'DONOGHUE (M.). *The dealer looks at gemstones—10.* Gems, **15**, 2, 35-6, 1983.

Details of the operation of the gem trade are given, with some notes on current prices and trends. (Author's abstract) M.O'D.

PEARSON (G.). *X-irradiation of spodumene.* Aust. Gemmol., **15**, 2, 45, 1983.

A colourless crystal irradiated with white x-rays for two hours became light green to a depth of about 4 mm on the side exposed and an odour of ozone was detected, possibly due to generation of short ultraviolet. Yellow and orange phosphorescence was observed to last for about three minutes. Induced colour faded completely after one day's exposure to sun. R.K.M.

PFAFFL (F. A.). *Topaz aus dem Fichtelgebirge.* (Topaz from the Fichtelgebirge.) Mineralien Magazin, **7**, 4, 183-5, 3 figs (2 in colour), 1983.

Light blue crystals of topaz showing good crystal form have been found in the Fuchsbau quarry near Leopoldsdorf in the Fichtelgebirge, West Germany. Yellow crystals are also known from the area. M.O'D.

READ (P.). *The Finsch diamond mine.* Australian Gem & Treasure Hunter, 78, 29-31, 2 figs, 1983.

Account of a visit to the Finsch mine 100 miles north-west of Kimberley, South Africa. M.O'D.

READ (P.). *The Kimberley Mine revisited.* Gems, **15**, 1, 22-4, 8 figs, 1983.

The Open Mine Museum constructed round the 'Big Hole' at Kimberley, South Africa, contains many relics of the original diamond workings and commercial activities of the 1870s. M.O'D.

ROBERTSON (A. D.). *Gem azurite from the Eclipse Mine, Muldiva-Chillagoe area, Queensland.* Aust. Gemmol., **15**, 2, 46-9, 3 figs in colour, 1983.

Fine azurite crystals found in abandoned silver mine. Divided into three crystal (habit) groups, none of which seem to conform with mineralogies consulted. This is chessylite and the expected replacement by malachite was found in some crystals. [Some crystal descriptions are puzzling, e.g. 'The dominant termination . . . . . is the prism (110)'.] R.K.M.

SATO (K.), SUNAGAWA (I.). *Quantitive evaluation of colour of diamonds by spectrophotometric method.* J. Gemm. Soc. Japan, **9**, 4, 8-16, 13 figs, 1982.

A spectrophotometer is used to evaluate the colour of a diamond in place of the eye. Absorption coefficients of colour-graded stones are measured and placed on a chromaticity diagram, enabling a correlation between the positions thereon and a conventional grading scale to be plotted. M.O'D.

SCHMETZER (K.). *Taaffeit oder Taprobanit—ein mineralogisches Nomenklaturproblem.* (Taaffeite or taprobanite—a mineralogical nomenclature problem.) Z.Dt.Gemmol.Ges., **32**, 1, 39-49, 8 figs (6 in colour), 3 tables, bibl., 1983.

An English version of this article was published in *J.Gemm.*, 1983, **XVIII**, 7, 623-34. E.S.

SCHMETZER (K.), BANK (H.). *Investigation of a cat's-eye scapolite from Sri Lanka.* Gems & Gemology, **XIX,** 2, 108-10, 2 figs in colour, 1983.

Describes a scapolite with fairly coarse included needles of pyrrhotite which was cut to give a 1.68 carat cat's-eye with a rather broad, intense eye. RI 1.583-1.553, negative. SG not quoted. R.K.M.

SCHNEIDER (W. L.), DRÖSCHEL (R.). *Beobachtungen an polysynthetisch verzwillingten Quarzen—ein Beitrag zur Unterscheidung natürlicher und synthetischer Amethyste.* (Observations of polysynthetic twinned quartz—a help in distinguishing natural and synthetic amethysts.) Z.Dt.Gemmol.Ges., **32,** 1, 28-38, 13 figs (8 in colour), bibl., 1983.

Gem quality synthetic amethyst—unlike natural amethyst—does not show polysynthetic twinning. Simpler than by spectroscopic analyses of the infrared part of the spectrum, synthetic amethyst can be recognized by the different interference figure in convergent polarised light. By slight repolishing with a fine grit on a soft wheel at low speed it is possible to produce visibly twin lamellae of cut natural stone. Then lamellae can be seen in natural stone with the naked eye, while synthetic material offered in the trade shows no lamellae. A second polishing of the stone reproduced the perfect cut without noticeable loss of weight. E.S.

SIMON (R. E.). *Creativity in jade sequel.* Lapidary J., **37,** 1, 18-22, 20 figs (16 in colour), 1983.

An illustrated account of jade carving, principally in Burmese jadeite. M.O'D.

SPALL (K.). *Reflections of a Harts hound.* Wahroongai News, **17,** 2, 11-12, 1983.

An account of gem possibilities in the Harts Range. R.K.M.

STOCKTON (C. M.), MANSON (D. V.). *Peridot from Tanzania.* Gems & Gemology, **XIX,** 2, 103-7, 6 figs (4 in colour), 1983.

A new source of gem peridot, which was at first marketed as rough enstatite. Material is compared with peridot from other sources. It is less iron-rich than all but the Norwegian material. It is shown that percentage of iron does not relate to the depth of colour. R.K.M.

SUNAGAWA (I.). *Gem materials, natural and artificial.* Current Topics in Materials Science, **10,** 351-506, illus. in black-and-white, 1982.

A comprehensive survey of minerals with gem application and of similar man-made substances. M.O'D.

SWERSKY (A.). *The High Priest's breastplate.* Ariel, 54, 107-20, 4 figs (2 in colour), 1983.

The breastplate is described and illustrated and an attempt made to identify the stones in present-day nomenclature. M.O'D.

VAVILOV (V. S.), GIPPIUS (A. A.), DRAVIN (V. A.), ZAITSEV (A. M.), ZHAKUPBETOV (B. S.). *Cathodoluminescence of natural diamond associated with implanted impurities.* Soviet Physics: semi-conductors, **16**, 11, 1288-90, 3 figs, 1983.

Cathodoluminescence spectra of diamonds doped by ion implantation showed lines associated with luminescence centres containing Cr, Ni, Zn, Ag and Tl.

M.O'D.

WIGHT (W.). *Faceted wollastonite from the Jeffrey Mine, Asbestos, Quebec.* Can. Gemmol, **4**, 1, 13-15, 2 figs, 1983.

A white transparent wollastonite, H 4½-5, SG 2.8-3.09, RI 1.610-1.634, is found at the Jeffrey mine, Asbestos, Quebec, Canada. It occurs with vesuvianite and contains some liquid healing-feather inclusions and signs of incipient cleavage. A stone of 4.05ct cut from this material forms part of the collections of the National Museum of Natural Sciences, Ottawa. M.O'D.

YU (R. M.). *An ineffective optic-fiber reflectivity meter.* Lapidary J., **36**, 12, 2038, 1983.

A reflectivity meter employing fibre optic light transmission mechanism was tested and found to be inadequate because of poor physical condition (many of the fibres were broken in transit) and because it was found impossible to calibrate even for plane surfaces. M.O'D.

ZEITNER (J. C.). *Some magnificent beryls from the Proctor collection.* Lapidary J., **36**, 11, 1836-43, 5 figs in colour, 1983.

Brief and personal survey of the beryl gems with particular reference to those in the celebrated mineral collection formed by Keith Proctor. M.O'D.

ZIRLIN (S. H.). *Hexagonite, New York State's purple tremolite.* Lapidary J., **36**, 11, 1864-7, 6 figs, 1983.

The purple transparent variety of tremolite is found in New York State and has occasionally been faceted. M.O'D.

Émeraude synthétique fabrication Lennix. (Synthetic emerald made by Lennix.) Revue de Gemmologie, 75, 2, 2 figs, 1983.

Details are given of a synthetic emerald with SG 2.652 ± 0.002, RI 1.563-1.565 and showing a bright red under the Chelsea filter. Characteristic inclusions from the flux-melt growth process can be seen. M.O'D.

World's Industrial Diamond Center. Lapidary Reporter, 283, 21-2, 1 June 1983. (Reprinted in Lapidary Journal, September 1983).

Antwerp is the centre of industrial diamond business. Three out of four diamonds mined go to industrial use, estimated 30-35 million carats a year, while synthetic products amount to about 50 million carats. Uses of industrial diamonds for different industries and the role of the Antwerp merchant are described.

J.R.H.C.

BOOK REVIEWS

ANDERSON (B. W.). See WEBSTER (R.)

BENDER (F.). *Geology of Burma,* vol. 16 of *Beitrage zur regionale Geologie der Erde.* (Contributions on the regional geology of the Earth.) Gebrüder Borntrager, Stuttgart, 1983. pp.viii, 293. Price on application.

Though there are numerous references to the various gem materials found in the country, the whole book is a detailed exposition of its geology. A number of chapters have been farmed out to different authors. After a general introduction and a description of regional geology, stratigraphy, tectonics and magmatism are described. The book then examines economic geology with chapters on energy, metallic and non-metallic raw materials, water and soil. There is a very extensive bibliography with a locality index and subject index. A geological map is provided in a pocket at the back of the book and there are numerous black-and-white illustrations throughout the text. M.O'D.

BELYAEV (L. M.), ed. *Ruby and Sapphire.* Amerind Publishing Co., New Delhi, 1980. pp.xix, 443. Illus. in black-and-white. Price on application.

This is a long-awaited translation of *Rubin i sapfir,* first published in Moscow in 1974. This edition has been revised and enlarged and now contains almost all the information necessary for a complete study of the growth of corundum. The greater part of the book is devoted to a discussion of the characterization of corundum crystals and the associated techniques. Details of the various methods used to grow the crystals are given in the first part of the book. There is an extensive bibliography, with a preponderance of Russian items. M.O'D.

CHERNOV (A. A.), MÜLLER-KRUMBHAAR (H.), eds. *Modern theory of crystal growth I.* Springer-Verlag, Berlin, 1983. pp.146. DM88.

Forming No 9 of the series *Crystals:growth, properties and applications,* this book covers the melting and solidification of epitaxial structures and intergrowth compounds, with further chapters on the microscopic theory of the growth of two-component crystals and on the statistics of surfaces, steps and two-dimensional nuclei. The final chapter deals with surface and volume diffusion controlling step movement. These are quite hard concepts and an attempt is made to enhance our admittedly incomplete knowledge of how defects and dislocations are formed. Transport between growing crystal and liquid is still not fully understood, and the authors make it clear that impurities in a crystal may result either from the time scales of convection patterns or interplay between kinetic incorporation, diffusion and convection.

Each paper has its own bibliography, and the volume also contains a general index to vols 1-9 of the series. M.O'D.

McLINTOCK (W. F. P.). *Gemstones in the Geological Museum.* Fourth edition, revised by P. M. Statham. H.M.S.O., London, 1983. pp.v, 81. Illus. in colour. £1.95.

Worthy if a little unadventurous update of an old classic of the enhanced handlist variety, this booklet is quite well produced, quite well written and quite well illustrated with the all-too-familiar photographs once beloved by all but whose power to charm is fast fading. The style is lumpy, capitalization capricious and not enough has been done to eliminate discredited and dated names. There should also be a much better bibliography. M.O'D.

MEYER (W.). *Geologische Wanderführer: Eifel.* (Geological guide to the Eifel.) Kosmos Franckh, Stuttgart, 1983. pp.111. Illus. in colour. DM29.50.

The Eifel region of West Germany is important to mineralogists for in it is the celebrated Laacher See district in which fine sanidine and some peridot with many rarer minerals can be found. Mining in the area dates from the earliest times and this beautifully-produced book includes not only geological features but a good deal of history, botany, palaeontology and architecture. M.O'D.

OGDEN (J.). *Jewellery of the ancient world.* Trefoil Books, London, 1983. pp.185. Illus. in black-and-white and in colour. £30.00.

The aim of this book is to relate the jewellery of early periods to the materials available at the time and to the tools which could be employed. In this task the author succeeds, and though he claims that the work is inspired to a large extent by the work of others he is, I feel, a little modest since, though a good deal of information has been published on the use of metals in history (to take one example), it is notoriously difficult to track it down since almost all is contained in a very wide range of papers. However the author has tracked down what appears to be the bulk of important data and for this alone readers owe him a great debt. He has done more: the book is very well produced and there is a first-class bibliography, a feature notably lacking from a number of large books in the field. Introductory chapters introduce the metals from which artefacts are made and some attention is paid to relating refining methods to the ultimate appearance of the metal (particularly in the case of gold). Further chapters deal with gemstones and ornamental materials and the way in which they are fashioned, including engraving techniques. Throughout the book there are constant references to ancient authorities and, where necessary, their statements are translated into modern and understandable terms.

This book, not at all highly priced for the value of the information it contains, should become a standard reference work. M.O'D.

SAUER (J. R.). *Brazil, paradise of gemstones.* Sauer, Rio de Janeiro, 1982. pp.136. Illus. in colour. Price on application.

This is the best-illustrated book on gemstones that I have yet seen. Most of the photographs have been taken by the celebrated Los Angeles partnership of Erica and Harold Van Pelt, well-known to readers of *Gems & Gemology* and the *Mineralogical Record.* The details of current Brazilian mining are given and one or two of the mines are depicted; it is most useful to know the names and whereabouts of individual locations in the State of Minas Gerais, for example. There is a small

glossary and a map at the end of the book, but it is to the superb photographs that the reader will return. M.O'D.

WEBSTER (R.). *Gems, their Sources, Descriptions and Identifications.* 4th edn, revised by B. W. ANDERSON. Butterworths, London, 1983. pp.XXII,1006. Illus. in black-and-white with 17 coloured plates. £40.

This new edition of Webster's *Gems* brought up to date by B. W. Anderson will be reviewed in the next issue of this *Journal.*

ASSOCIATION NOTICES

OBITUARY

Mr Wilbur E. Dyer, F.G.A. (D.1971), Joliet, Ill., U.S.A., died on 4th February, 1983.

Mrs Lorraine A. Jamieson (née Fish), F.G.A. (D.1974), London, died on 17th June, 1983.

Mrs Doreen Read, wife of Mr Peter G. Read, C.Eng., F.G.A., died on 23rd July, 1983, after a short illness: although her main contribution to gemmology was by way of typing and proof-reading her husband's many articles and books, and acting as his projectionist at Branch lectures, she was also an enthusiastic collector of thematic stamps covering gems, minerals and mining.

GIFTS TO THE ASSOCIATION

The Council of the Association is indebted to the following for their gifts:

Mr R. Acker-Holt, F.G.A., London, for several star quartz cabochons for study purposes.

Mrs Lilian L. Jackson, F.G.A., Clarendon, South Australia, for two specimens of nephrite jade from Covell, Eyre Peninsula, South Australia.

NEWS OF FELLOWS

On 15th June, 1983, Mr David J. Callaghan, F.G.A., the Association's Chairman, was elected to the Livery of the Worshipful Company of Goldsmiths.

Mr David Crouchley, F.G.A., and Mr Douglas Wheeler, F.G.A., the Association's Assistant Secretary, were admitted to the Freedom of the Worshipful Company of Goldsmiths, on 18th May and 20th July, 1983, respectively.

On 28th May, 1983, Mr Alan Hodgkinson, F.G.A., gave two lectures entitled 'Diamond Close-up, including its uses in technology, in medicine and in space' and 'Sapphires and rubies—testing for origin and treatment' at the Professional Centre, Colombo, Sri Lanka, under the auspices of the Gemmologists' Association of Sri Lanka, with its Vice-Chairman, Mr Hilal Abdulla, in the Chair. Mr Hodgkinson was introduced by Mr S. Nalliah, F.G.A., and received a vote of thanks proposed by Mr Hazim Narook, F.G.A. (Reported by Mrs Ameena Kaleel, F.G.A., Hon. Treasurer, Gemmologists' Association of Sri Lanka).

On the 10th May, 1983, Mr Alan Hodgkinson, F.G.A., gave a talk entitled 'Keep your moths in your diamonds' to the Ulster Jewellers Association Gem Group, at the Ulster Museum, Belfast.

Mr Richard T. Liddicoat, Jr, Hon.F.G.A., President of the Gemological Institute of America since 1952, has been elected Chairman of G.I.A.'s Board of Governors.

Mr M. J. O'Donoghue, M.A., F.G.S., F.G.A., gave a talk entitled 'The literature of mineralogy' to the Amateur Geological Society on 21st June, 1983.

Mr P. G. Read, C.Eng., F.G.A., and Mr M. J. O'Donoghue, M.A., F.G.S., F.G.A., were lecturers in two further two-day courses on 21-22 and 24-25 May, 1983. The first included topics in the syllabus for the Diploma Examination, with emphasis on the use of instruments, and the second was concerned with the beryl family of gemstones.

MEMBERS' MEETINGS

North-West Branch

On 15th September, 1983, at Church House, Hanover Street, Liverpool 1, Dr J. W. Franks, F.G.A., gave a talk on 'Gemstones in Jewellery'.

South Yorkshire & District Branch

On 4th September, 1983,members joined the Sheffield Amateur Geological and Lapidary Society for a field trip to Pindale and Dirtlow Rake, where specimens of barytes, calcite, galena and fluorite can be found.

On 11th September, 1983, a trip was arranged to Treak Cliff Cavern, Castleton.

BANGKOK DIAMOND SEMINAR IN NOVEMBER

A two-day seminar on 'Diamond (Natural and Synthetic) and Diamonds Simulants' will be given in Bangkok on 9-10 November, 1983, by Mr Roy V. Huddlestone and Mr Peter G. Read, C.Eng., F.G.A., hosted by the Asian Institute of Gemological Sciences (of which Mr John D. Rouse, M.A., G.G., has recently been appointed Managing Director). The seminar will include both formal lectures and practical sessions, and it will cover the history, mining, cutting and grading of diamonds, together with the evolution of diamond simulants from glass to CZ, with particular emphasis on the identification of diamonds (natural and synthetic) and its simulants.

The cost of the two-day seminar is US$88.00. For further particulars, apply to the Seminar Secretary, Asian Institute of Gemological Sciences, 987 Silom Road, Rama Jewelry Building, 4th Floor, Bangkok 10500, Thailand. [Telephone 233-8389; Telex 87971 AIMTHAI TH; Cable GEMSEARCH.]

EXAMINATIONS 1984

The examination dates for 1984 are as follows:

Gem Diamond Examination:

Theory, Monday, 4th June

Practical, Monday, 4th or Tuesday, 5th or Monday, 11th June.

Examinations in Gemmology:

Preliminary (Theory): Tuesday, 26th June.

Diploma: Theory, Wednesday, 27th June.

Practical, Thursday, 28th June (but in London the Practical Examination may be held on other days in that week).

The *last* date for receiving examination entry forms is 31st March, 1984.

INDEX FOR VOLUME XVIII

The Index for Volume XVIII (1982-83) will be issued with Part 1 of Volume XIX in January 1984.

CORRIGENDA

On p.375 above, the curved lines mentioned in the caption of Fig. 19 were clearly visible in the original but were lost in the reproduction, and on p.629 above, Figs 4 and 6 were reproduced quite wrongly coloured blue: for which regrettable errors the Editor tenders his apologies to the respective authors and photographers.

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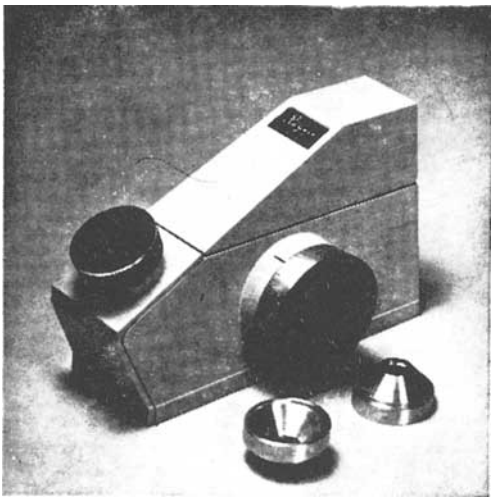

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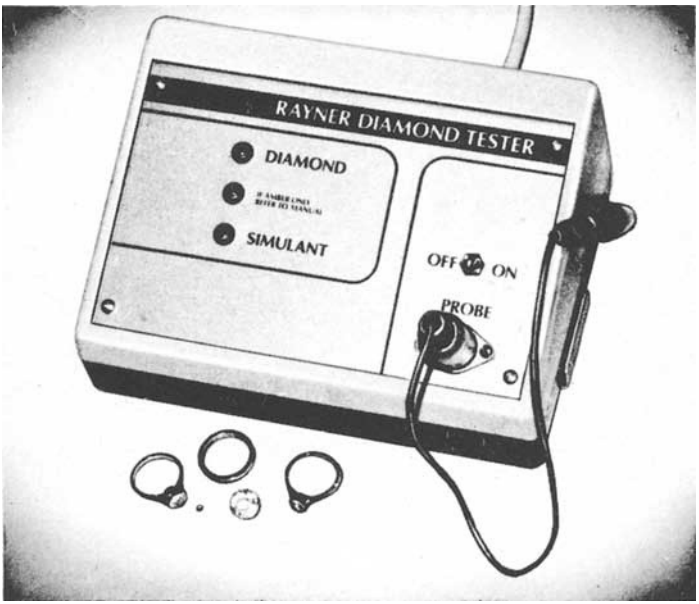

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Historical Note

The Gemmological Association of Great Britain was originally founded in 1908 as the Education Committee of the National Association of Goldsmiths and reconstituted in 1931 as the Gemmological Association. Its name was extended to Gemmological Association of Great Britain in 1938, and finally in 1944 it was incorporated in that name under the Companies Acts as a company limited by guarantee (registered in England, no. 433063).

Affiliated Associations are the Gemmological Association of Australia, the Canadian Gemmological Association, the Gem and Mineral Society of Zimbabwe and the Gemmological Association of Hong Kong.

The *Journal of Gemmology* was first published by the Association in 1947. It is a quarterly, published in January, April, July, and October each year, and is issued free to Fellows and Members of the Association. Opinions expressed by authors are not necessarily endorsed by the Association.

Notes for Contributors

The Editor is glad to consider original articles shedding new light on subjects of gemmological interest for publication in the *Journal.* Articles are not normally accepted which have already been published elsewhere in English, and an article is accepted only on the understanding that (1) full information as to any previous publication (whether in English or another language) has been given, (2) it is not under consideration for publication elsewhere and (3) it will not be published elsewhere without the consent of the Editor.

Articles published are paid for, and a minimum of 25 prints of individual articles may be supplied to authors provided application is made on or before approval of proofs. Applications for prints should be made to the Secretary of the Association—not to the Editor—and current rates of payment for articles and terms for the supply of prints may be obtained also from the Secretary.

Although not a mandatory requirement, it is most helpful if articles are typed (together with a carbon copy) in double spacing on one side of the paper, with good margins at sides, top and foot of each page. Articles may be of any length, but it should be borne in mind that long articles are more difficult to fit in than short ones: in practice, an article of much more than 10 000 words (unless capable of division into parts or of exceptional importance) is unlikely to be acceptable, while a short note of 400 or 500 words may achieve early publication.

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THE JOURNAL OF GEMMOLOGY
AND PROCEEDINGS OF THE GEMMOLOGICAL ASSOCIATION OF GREAT BRITAIN

Vol. XIX No. 1 January 1984

A BRIEF DESCRIPTION OF A SPECTACULAR 56.71 CARAT TABULAR DIAMOND

By E. A. JOBBINS, B.Sc., F.I.M.M., F.G.A., and
R. R. HARDING, B.Sc., D.Phil., F.G.A.
Institute of Geological Sciences, Exhibition Road, London SW7 2DE
and K. SCARRATT, F.G.A.
Gem Testing Laboratory, Greville St., Hatton Gardens, London EC1N 8SU

In June 1983 a large, flat diamond of octagonal outline was shown to Miss Anna Somers-Cocks, of the Victoria and Albert Museum, London, who suggested that it should be taken to the Geological Museum for further examination; the owner had wondered if it might be part of the 'Great Table' shown to the explorer Tavernier at Golconda, India, in 1642. We quickly assured him that this was unlikely in view of the convincing study carried out by Meen, Tushingham & Waite (1967) in Teheran in 1967. The study showed

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beyond reasonable doubt that the Darya-i-Nur diamond and a pink brilliant, both among the Iranian Crown Jewels, were derived from and comprise the major part of the Great Table shown to Tavernier. The history of the present important stone is not known before 1893, when the father of the present owner is reported to have had it in his possession during a visit to Paris.

The diamond is attached to a recent Indian-style necklet of braided gold wire with faceted pyrope-almandine beads by means of two holes drilled near one edge of the diamond (see Figure 1).

FIG. 1 Front view of 56.71 ct diamond showing large rectangular table facet.

The corners by the drill holes appear to have been 'ground' away, and there is some evidence from marks along the edge of the diamond of earlier drill holes (see Figure 9). Thus there may have been attempts to drill more widely spaced holes which failed because of fracturing, and the stone may have weighed considerably more before the present set of holes was drilled. The necklet prevented accurate weighing of the diamond, but the owner assures us that its weight is 56.71 carats. The weight of the stone with the necklet is 104.95 carats. The diamond could not be

FIG. 2 and FIG. 3 Views of diamond showing large rear facets.

FIG. 4 Edge view of diamond with 1.33 ct diamond for scale. The plan view is an inclined mirror reflection.

removed from the necklet and it was not possible to determine its specific gravity. The dimensions of the diamond are 44.6 × 33.0 × 3.6 mm and the exact shape is shown by the (water) immersion contact prints (Figures 5 and 6), which also show the facet arrangements of crown and pavilion. The upper surface (see Figure 5) is step cut, and the very large table facet (approx. 27.5 × 19.0 mm) is extraordinarily smooth and well polished with an adamantine lustre. However, it is not plane, but slightly curved as

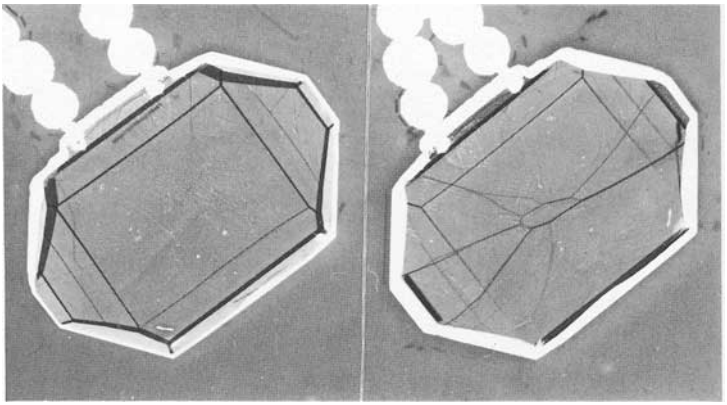

FIG. 5 and FIG. 6 Immersion contact prints showing outlines of front (left) and rear facets (natural size).

shown by the slightly distorted reflections of window frames. The rear facets (Figures 2, 3, 6) are very irregular with interfacial angles of only a few degrees, and it was not possible to measure these angles in the short time available for study. The large rear facet adjacent to the drill holes shows particularly prominent curved ridges (Figure 1), which have possibly resulted from the polishing of a stepped cleavage face; other rear facets also show polishing marks. The cutting of the rear facets especially may appear crude, but when the stone is viewed in subdued lighting it displays an extraordinary ability to pick up any available light and reflect it brilliantly. The girdle is polished (in planes essentially at right

angles to the table facet) and a 'natural' showing three cleavage directions is retained on one corner of the stone (see Figure 7).

The stone obviously draws colour to some extent and this was, perhaps, best demonstrated by the owner, who inserted it between layers of white cleaning tissue and held it to the daylight; the stone showed a distinct pale pink colour. A grading colour might be 'fancy light pink', but the stone was not examined under ideal grading conditions.

Careful search by all three authors failed to reveal any absorption spectrum; it was not possible (or prudent!) to examine the stone for a spectrum at liquid nitrogen temperatures. The diamond shows no fluorescence under long-wave (365 nm) ultraviolet light, but under short-wave (253.7 nm) radiation a very faint pale blue fluorescence was seen. A (water) immersion contact print using short-wave ultraviolet light shows the outline only of the stone which is, therefore, transparent to this radiation to a considerable degree. Between crossed polars the stone shows notable strain birefringence. In most areas the strain pattern resembles albite feldspar twinning (Figure 10) or the cross-hatching typical of microcline twinning, but in addition there are a few points or nodes of radial strain around minute inclusions.

The stone contains no prominent inclusions, but iron staining is present in cracks near one corner. Cleavage traces are present in several areas, and these were carefully noted with a view to attempting to orientate the stone in an octahedral framework. Near one corner of the stone one cleavage trace (see Figure 8) was seen to be essentially parallel to the table facet, and it was then possible to orientate the tiny cleavage traces within the stone and those visible on the girdle of the stone with the theoretical cleavage traces of the octahedron. The diagram (Figure 11) shows one possible orientation which is consistent with the cleavages seen at three edges of the diamond, but there may be others!

The origin of this stone is intriguing: Miss Sue Stronge, of the Victoria and Albert Museum, has drawn our attention to paintings of Shah Jahangir (reigned 1605-27) in the Freer Gallery, Washington, in which he is wearing flat 'table-cut' stones as wrist bracelets; they are not dissimilar to the present stone. Diamond

FIG. 8. Part of 56.71 ct diamond showing cleavage traces in two directions and scratch 2.5 mm long.

FIG. 7. 'Natural' on corner of diamond showing cleavage traces in three directions.

FIG. 10. Part of diamond viewed between crossed polars and showing strain birefringence resembling albite (feldspar) twinning.

FIG. 9. Corner of diamond showing re-drilled support hole and traces of former hole.

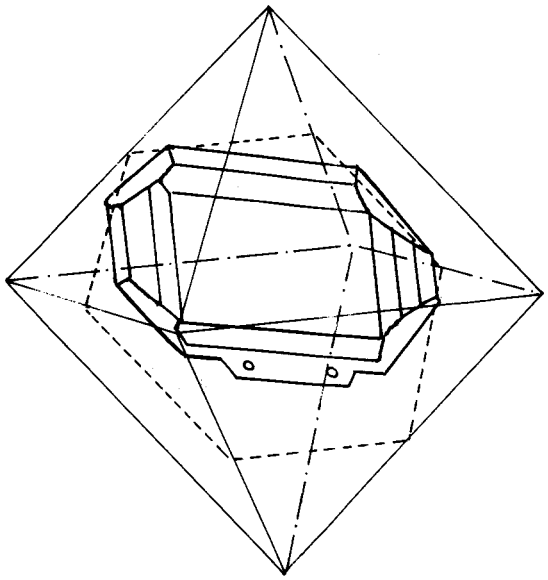

FIG. 11 Approximate orientation of 56.71 ct flat diamond with table facet coplanar with octahedral cleavage direction.

cleavages and lasques have been known for centuries in India, and the size and style of cutting of the present stone are consistent with its being of Indian origin and cutting, possibly from the seventeenth century.

REFERENCE

Meen, V. B., A. D. Tushingham and G. G. Waite. 1967. Long-lost Darya-i-Nur—largest pink diamond rediscovered. *Lapidary Journal*, **XXI**, 11, 1000-9.

[*Manuscript received 10th October, 1983.*]

A REMARKABLE SPHALERITE WITH AN INTENSE GREEN COLOUR

By IVO QUINTENS and THEO MULLER

Secretary and Chairman respectively of the Belgian Foundation for Gemmology
(Belgische Stichtung voor Gemmologie)

ABSTRACT

Gemstones made of a rare specimen of sphalerite*, having a deep green colour, coming from Kipushi, Zaire, are described.

A sample of a deep green sphalerite was found in a collection of Zairian minerals. It was reported by a previous mine engineer to be a curious specimen of which only a few were found. In old mine documents the existence of green sphalerite was mentioned in only two different analysis reports. Neither geological nor mineralogical information could be obtained, even from the best specialist on the Zaire mines.

The sphalerite is found in paragenesis with other copper-, gallium- and germanium-containing minerals. In clear green crystals small inclusions of chalcopyrite can be detected at magnifications of 300-1250 with a reflecting polarizing microscope. More sophisticated investigations have been started. An x-ray powder diffractogram showed a typical sphalerite pattern.

The absorption spectrum is characterized by three bands:

— the red is absorbed to 625nm;
— in the yellow a band from 595 to 580 nm;
— the blue is absorbed starting from 470 nm.

The specific gravity was found to be 4.18 (for a 0.825 ct stone) and 3.98 (for a 0.260 ct stone). The largest cut stone weighed 0.98 ct and 23 stones were obtained having a total weight of 6.28 ct.

During cutting and polishing no particular unusual behaviour was observed compared with common sphalerite. Further investigations to determine the colour mechanism will be carried out.

We thank Mr H. W. Lorenz, of Idar-Oberstein, for his information about the cutting and polishing properties and Dr N. Blaton, of the Catholic University of Louvain, for the diffractograms.

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*Sphalerite (ZnS) is perhaps more commonly known as 'blende'—Ed.

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A RECENT FIND OF TAAFFEITE

By R. B. McDOWELL, F.G.A.

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ABSTRACT

Several taaffeites have been found recently in spinel gravels. Identification is simple with the use of the hand spectroscope. The article details the observations made of one recently discovered stone.

INTRODUCTION

In October 1982, it was my good fortune to have an opportunity to examine a taaffeite. I was told that the stone was found in spinel gravels, in Sri Lanka, during 1982. No more information on origin was available, except that several other taaffeites were found in the same location at about the same time.

CHARACTERISTICS

This particular taaffeite weighs 1.65 ct, after having a spot on one side polished to allow the RI to be taken and to allow internal observation. The shape of the stone is a somewhat triangular water-worn pebble. One edge of the stone has a notch in it suggestive of possible twinning (see Figure 1). There is also a slight ridge running lengthwise along the top of the stone.

The external appearance is slightly frosty with occasional pin-points of glitter suggesting a fairly high dispersion. The over-all colour is a light greyish lavender, becoming a pale lavender, without much greyish component, when polished.

No colour zones or growth lines were observed, either externally or internally. But there are some external and internal black specks, at first glance similar to those encountered in zircon rough. Under 30× magnification, these black specks are blocky to flat and/or slightly fibrous (or perhaps acicular) shiny crystals.

Other inclusions are small white breadcrumb-like crystals, most occurring as part of an irregular underside of the pebble surface. In the area polished, most of these inclusions were removed, but what remained were a couple of oval areas where the inclusions extended to a slightly greater depth.

There is also an area containing a fingerprint pattern located well within the stone, at least partly composed of moderately long,

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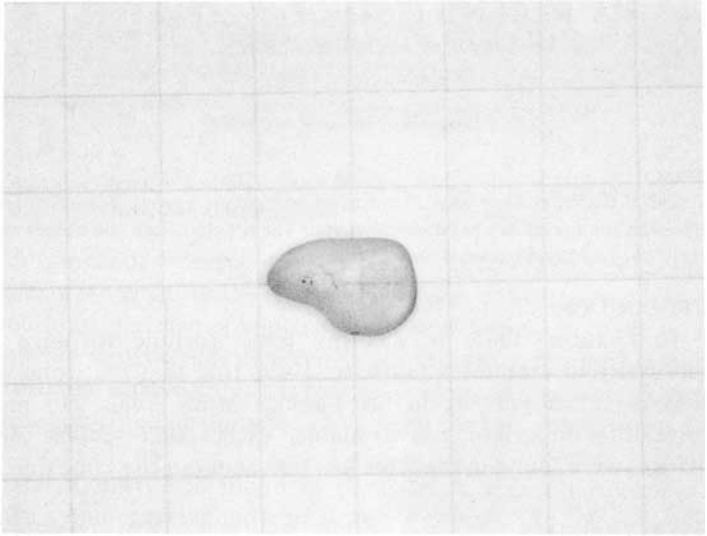

FIG. 1 Taaffeite pebble—external shape on ¼" squared graph paper. *(Photo A. C. Bonnano)*

flat, shiny crystal inclusions. I have observed a similar set of fingerprint inclusions in the only other taaffeite I have seen. This, therefore, may be a diagnostic inclusion. Figure 2 shows this rather distinctive inclusion, which includes several circularly arranged groups of the fingerprint crystals. There are actually three sets of fingerprints, along with some larger crystals and an inclusion with an outline shaped like a shoulder of lamb, shown in Figure 3. Finally Figure 4 shows the crystals within one of the fingerprints at 70×, revealing an apparent two-phase structure for some of them.

No fractures or negative crystals were observed. There were no stains. In general, the stone was quite clean and, in this respect, quite similar to spinel. With appropriate polishing, the taaffeite is also very transparent and would make a very nice cut gem that is eye-clean.

The taaffeite is faintly dichroic with a calcite dichroscope (but dichroism was not observable with a plastic polars-type dichroscope). The colours are light pink (with a possible yellowish cast) and light lavender, which is slightly darker than the pink ray.

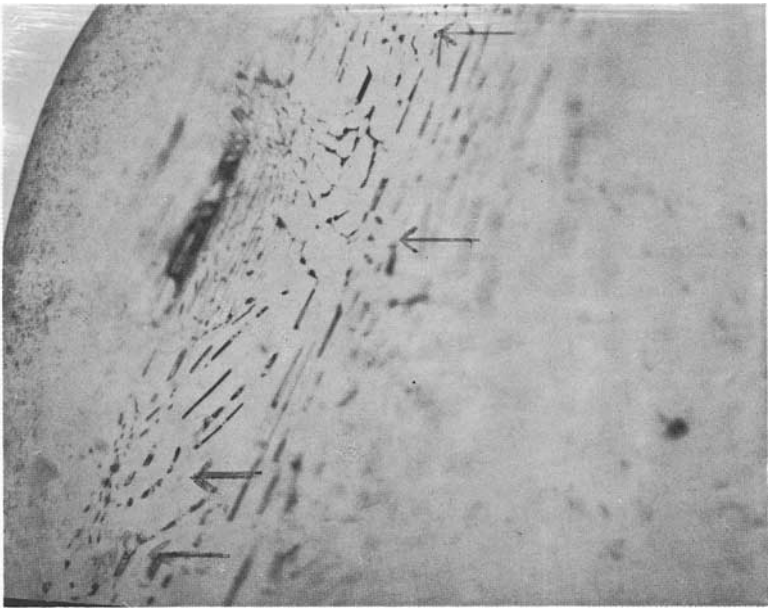

FIG. 2 Fingerprint inclusion with circularly arranged groups (arrowed). 50× *(Photo A. C. Bonnano)*

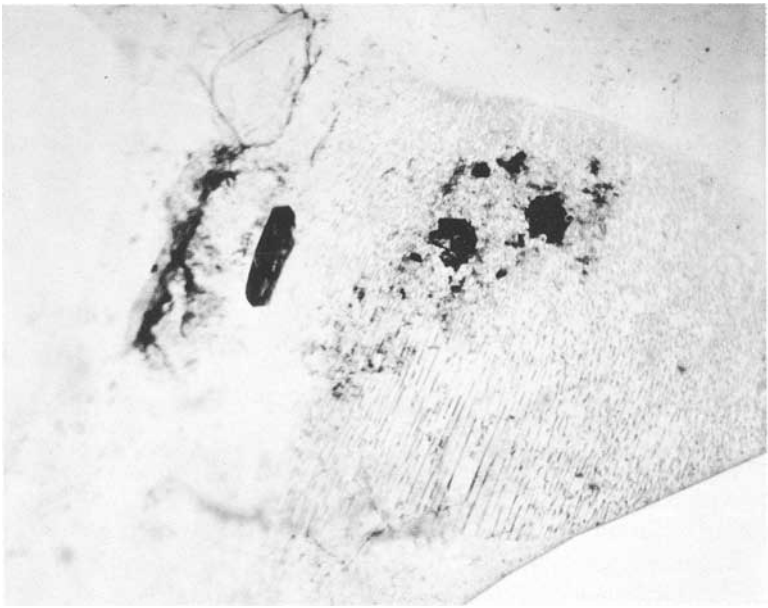

FIG. 3 Fingerprint inclusion with larger crystals and an inclusion with outline shaped like a shoulder of lamb. 30×. *(Photo A. C. Bonnano)*

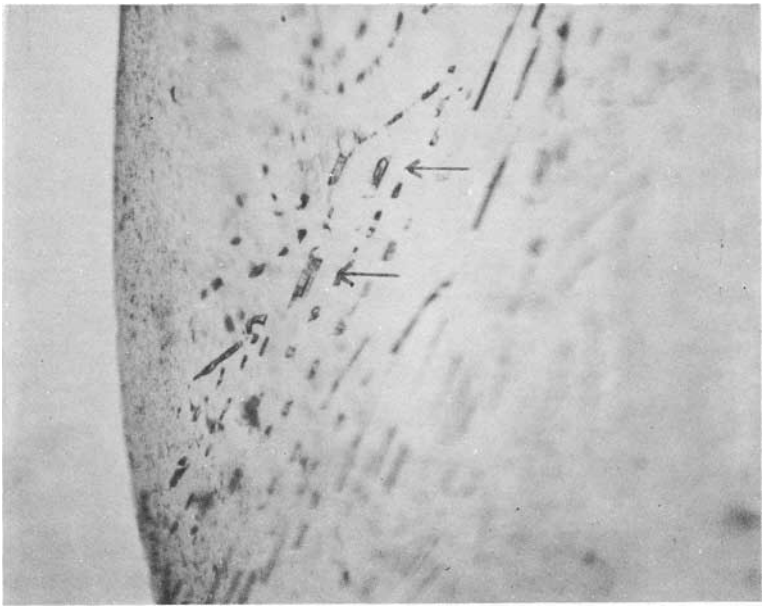

FIG. 4 Fingerprint inclusion with some two-phase structures (two are arrowed). 70 ×. *(Photo A. C. Bonnano)*

Examination with a hand spectroscope showed a general absorption above approximately 670 nm. Otherwise, no lines and no significant attenuation of the visible spectrum was observed. It was a little surprising that the violet wavelengths were not attenuated, since many stones restrict this end of the spectrum: in particular, spinel in all colours greatly attenuates the blue and the violet.

The spectroscope, therefore, may be the easiest way to separate spinel and taaffeite, though a polariscope or refractometer may also be used.

Through the Chelsea filter the taaffeite showed virtually no colour, even in quite strong lighting. At most there may be a slight pink tint. Using a so-called beryl filter made in Austria and sold by Advance Electric in the U.S.A., the stone, in strong white light, is a bright pink. In long-wave ultraviolet the stone fluoresces weakly with a dull green colour. The stone is inert under short-wave UV.

TABLE I. Taaffeite Constants

RI	DR	Disp.	SG	Optics
1.717-1.721	0.004	0.018 est.	3.60	Uniax. (-)

Table I gives the list of constants measured by the author. The value for dispersion was estimated from taking the RI reading for the ordinary ray (in this case, the 1.721 reading) using a sodium lamp (589 nm) and then a green lamp (546 nm).* The difference between these two RI readings was then multiplied by the ratio of the differences in wavelength between the Fraunhofer B and G lines and the yellow and green lines noted above. Assuming a linear relationship for taaffeite between RI readings at different wavelengths across the spectrum between B and G, the dispersion should be about .018. The following formula describes these calculations:

$$(RIg-RIy)\frac{\lambda B-\lambda G}{\lambda y-\lambda g} = \text{Dispersion}$$

ACKNOWLEDGEMENT

My thanks are due to Mr A. C. Bonanno, F.G.A., of Columbia School of Gemology, Silver Spring, Md, U.S.A., for the photographs, which were taken by transmission lighting from a quartz-halogen lamp with the stone immersed in methylene iodide.

[*Manuscript received 28th November, 1982.*]

*These were the only two calibrated light sources available to the author.

X-RAY UNIT FOR GEMMOLOGICAL USE

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THE USE OF X-RAYS IN GEMMOLOGY

There are many references to the use of x-rays as a means of gem diagnosis by transparency or by luminescence excitation.[1, 2] Most of the references to transparency are related to diamonds and pearls.[2, 3, 4] Webster[5] describes the value of luminescence under ultraviolet radiation at 3650 Å and 2537 Å. He emphasizes, however, the limitation of the use of UV radiation in diamonds and the more significant response to x-rays.[5, 7] This means of diagnosis is also useful for other gemstones and particularly in the case of mounted gemstones when other tests cannot be used for identification. The phosphorescence and fluorescence exhibited by diamonds and some synthetic gems under x-rays can be a guide to their classification and identification.

THE TRANSPARENCY OF GEMS TO X-RAYS

Brown *et al.*[1] and Moule & Brown[2] considered the transparency of gems to x-rays. According to these authors the transparency of a gem can be evaluated by radiographers observing the films or measuring its optical density. In the present work the transparency is related to the electronic density and the atomic number of the atoms in the gem composition. This approach allows the transparency calculation of gems of any thickness.

Diamond is a form of carbon and has atomic number 6 and a low electronic density. Its imitations are made of materials containing heavy atoms with high atomic numbers and electronic density. Their transparency to x-rays is very low. This property can be used to provide a quick identification by using a fluorescent screen or a radiographic film.[2, 5, 6, 8] This method can also be used for other gems, requiring in this case an exact adjustment of the voltage and the current in the x-ray tube. A close control of the time of exposure related to the gem and its thickness may also be necessary.

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THE DIAMOND AND ITS IMITATIONS

Optical properties only allow a differentiation between the diamond and its imitations in the cases when these properties are observable in a quantitative way.[9] Specific gravity is useful under the same conditions. The radiograph is independent of mounting, size and other difficulties in performing an accurate gem analysis, especially in the case of the diamond.

The absorption of x-rays by the materials follows the equation:[10]

$$\frac{I_x}{I_o} = e^{-\mu x} \tag{1}$$

In this equation the relation I_x/I_o is the fraction of the incident radiation passing through the material of thickness x. The parameter μ is the linear absorption coefficient equivalent to the product $(\mu/\varrho)\ \varrho$ of the mass absorption coefficient μ/ϱ and the density ϱ of the material. If this material is a compound μ/ϱ is calculated by the formula

$$\left(\frac{\mu}{\varrho}\right)_c = w_1\left(\frac{\mu}{\varrho}\right)_1 + w_2\left(\frac{\mu}{\varrho}\right)_2 + \ .\ .\ .w_n\left(\frac{\mu}{\varrho}\right)_n \tag{2}$$

where the indexes c, 1, 2, . . .n are related to the compound and the elements forming the compound, respectively. The values w_1, w_2, . . . w_n are the weight fractions of these elements. The mass absorption coefficient μ/ϱ of each element can be calculated by this formula:

$$\frac{\mu}{\varrho} = k\lambda^3 Z^3 \tag{3}$$

where λ is the wavelength of the x-rays, Z is the atomic number of the element and k is a constant of each element varying discontinuously as λ varies. The discontinuities of the mass absorption coefficient lead to the absorption edges.[10] From the formulae above and the mass absorption coefficients of the

elements[11] the μ/ϱ of the gems at a radiation with a maximum of intensity corresponding to $\lambda = 0.5$ Å approximately can be calculated. This radiation is obtained from a tungsten tube.

The transparency was evaluated in Table I (for Tables I and II see insert between pp. 16 and 17) as the radiation fraction passing through 1 mm of the material. This fraction is recorded as a factor I_x/I_o and in the % form. The 89% value in the diamond indicates an x-ray transmission through the gem of 89% of the incident radiation. The % values of transmitted x-radiation for a material of thickness 2 mm and 3 mm respectively corresponding to expression 100 (I_x/I_o) are in the last two columns of Table I. From these values the % of transmitted radiation for other thicknesses can be computed. In the case of diamond, for example, the % for 5 mm of thickness can be computed approximately:

2 mm	+	3 mm	=	5 mm
$(I_x/I_o)_{2\,mm}$	×	$(I_x/I_o)_{3\,mm}$	=	$(I_x/I_o)_{5\,mm}$
79/100	×	70/100	=	0.553

Thus, the % of x-rays transmitted is

$$100 \times 0.553 = 55.3\% \text{ for 5 mm thickness.}$$

The transparency of diamond to x-rays is closer to that of beryl, quartz, spinel, topaz, and corundum in decreasing order.

Taking the diamond as reference, the transparency of the remaining gemstones can be compared to its transparency, for the various thicknesses of the material. Table II serves as an example of this comparison. In each column headed by the corresponding thickness (1 mm, 2 mm, 3 mm) the values of the last three columns of Table I were placed on the left and the transmitted radiation on the right, considering the diamond as equal to 100.

It should be observed that not all of the gems of Table I and Table II would be adequate as diamond imitations, which depends on the values of the refractive index, of the birefringence and of the dispersion.

From the values of Table II it is clear that on increasing the material thickness, the differentiation of the various gems by the x-rays is increased. With 1 mm of thickness beryl transmits 80% of the radiation which the diamond would. The distinction between both gems is clearer with 3 mm of thickness in which the beryl

TABLE I

Gem	Chemical Formula	Refr. Index	Birefr.	Disp.	Density ϱ g/cm³	M.A.C. μ/ϱ	I_x/I_o for x = 0.1 cm	% X-rays passing through a thickness of x = 0.1 cm	x = 0.2 cm	x = 0.3 cm
Barium titanate	$BaTiO_3$	2.40	0		5.90	12.57	6.01×10^{-4}	0.06	3.62×10^{-5}	2.17×10^{-8}
Beryl	$Be_3Al_2Si_6O_{18}$	1.577-1.583	0.006	0.014	2.65-2.75	1.26	0.71	71	51	36
Calcium titanate	$CaTiO_3$	2.40	0		4.05	5.31	0.12	12	1.4	0.16
Corundum	Al_2O_3	1.76	0.008	0.018	3.90-4.00	1.31	0.62	62	38	24
Cubic Stab.Zirconia	$Zr_{0.90}Y_{0.10}O_{1.95}$	2.17-2.18	0	0.060	~5.65	31.43	3.05×10^{-8}	3.05×10^{-6}	9.29×10^{-14}	2.83×10^{-21}
	$Zr_{0.85}Ca_{0.15}O_{1.85}$					29.83				
Demantoid	$Ca_3Fe_2(SiO_4)_3$	1.89	0	0.057	3.82-3.85	5.52	0.12	12	1.4	0.17
Diamond	C	2.42	0	0.044	3.52	0.34	0.89	89	79	70
Flint glass (Beryl imit.)		1.567	0		3.0	8.33	0.082	8.2	0.68	0.06
Fluorite	CaF_2	1.434	0	0.007	3.18	3.97	0.28	28	8	2.3
Gadolinium Gallium Garnet (GGG)	$Gd_3Ga_5O_{12}$	1.970	0	0.045	7.05	19.98	7.63×10^{-7}	7.63×10^{-5}	5.82×10^{-11}	4.44×10^{-17}
Lithium niobate	$LiNbO_3$	2.21-2.30	0.09	0.13	4.64	28.77	1.59×10^{-6}	1.59×10^{-4}	2.54×10^{-10}	4.04×10^{-16}
Lithium tantalate	$LiTaO_3$	2.22	0	0.087	7.45	29.38	3.12×10^{-10}	3.12×10^{-8}	9.73×10^{-18}	3.04×10^{-27}
Quartz	SiO_2	1.544-1.553	0.009	0.013	2.65	1.44	0.68	68	47	32
Rutile	TiO_2	2.63-2.90	0.287	0.28	4.2	5.45	0.10	10	1	0.1
Scheelite	$CaWO_4$	1.918-1.937	0.016		5.9-5.61	26.72	2.10×10^{-7}	2.10×10^{-5}	4.40×10^{-12}	9.23×10^{-19}
Sphalerite	ZnS	2.37		0.156	4.08-4.10	15.59	1.70×10^{-3}	0.17	2.89×10^{-4}	4.93×10^{-7}
Spinel	$MgAl_2O_4$	1.714-1.736	0	0.020	3.58-3.65	1.27	0.63	63	40	25
Strontium titanate (Fabulite)	$Sr\ TiO_3$	2.41	0	0.19	5.13	20.46	2.76×10^{-5}	2.76×10^{-3}	7.64×10^{-8}	2.11×10^{-12}
Topaz	$Al_2SiO_4(F,OH)_2$	1.630-1.638	0.008 0.010	0.014	3.53-3.56	1.27	0.63	63	40	25
Yttrium aluminate	$YAlO_3$	1.938-1.955	0.017	0.039	5.35	22.08	7.41×10^{-6}	7.41×10^{-4}	5.49×10^{-9}	4.07×10^{-14}
Yttrium Aluminium Garnet (YAG)	$Y_3Al_5O_{12}$	1.83	0	0.026	4.57-4.60	18.63	1.95×10^{-4}	0.02	3.81×10^{-6}	7.43×10^{-10}
Yttrium oxide (Yttria)	Y_2O_3	1.92	0	0.050	4.84-4.90	31.72	2.00×10^{-7}	2.00×10^{-5}	3.82×10^{-12}	7.47×10^{-19}
Zircon	$ZrSiO_4$	1.925-1.984	0.059	0.039	4.67-4.70	21.81	3.65×10^{-5}	3.65×10^{-3}	1.33×10^{-7}	4.87×10^{-12}

TABLE II

gem	thickness 1 mm		thickness 2 mm		thickness 3 mm	
	% transparency		% transparency		% transparency	
	measured	relative to diamond	measured	relative to diamond	measured	relative to diamond
diamond	89	100	79	100	70	100
beryl	71	80	51	65	36	51
quartz	68	76	47	59	32	46
spinel	63	71	40	51	25	36
topaz	63	71	40	51	25	36
corundum	62	70	38	48	24	34

transmits only 51% of the corresponding value of the diamond. In corundum the differentiation is even larger, going from 70% at 1 mm to 34% at 3 mm.

As for the remaining gems of Table I, it is not necessary to compare the values since they are truly opaque to x-rays.

In addition to the measurements of gemstones described above, the equipment can be used to obtain radiographs of pearls, but it is not suitable for Laue photography, because its x-ray tube can work only for short periods.

THE PROPOSED X-RAY UNIT

On the x-ray equipment proposed here, fluorescence and gem phosphorescence can be seen directly[12] and transparency can be seen on a fluorescent screen[13] or on a radiographic film. The price of the whole unit is in the region of US$1000, and its components are available in virtually any country.

The components of the x-ray camera are indicated by letters corresponding to those in Figure 1:

A. The x-ray tube generator is used in dentistry. This tube works in a continuous range to 70 kV and to 10 mA with a maximum power of 700 W. The voltage, the current and the time exposure are controlled electronically. The installation requirements are very simple and do not require a cooling circuit.

B, C. This is a box internally covered with lead foil of 1 to 2 mm thickness and divided into two parts with a rectangular window between them to accommodate the fluorescent screen H. This screen allows the observation of gem transparency on the mirror F, through the lens L_2 in the adjustable tube E. Covering the screen H with an opaque plate G, the fluorescence and the phosphorescence can be observed through the lens L_1. In both tubes, E and D, the screw threads K and L in the draw tubes I and J can be adjusted to accommodate a photographic camera with the lenses L_1 and L_2 working as approximation lenses. These lenses must be protected with lead glass equivalent to 1 mm of lead foil.

THE UNIT USE

The radiographs of Figures 2 to 4 and 7 to 10 were made with the described unit on radiographic film. They show the aspect which would be observable on the fluorescent screen with the opaque materials shown dark. The observation on an original

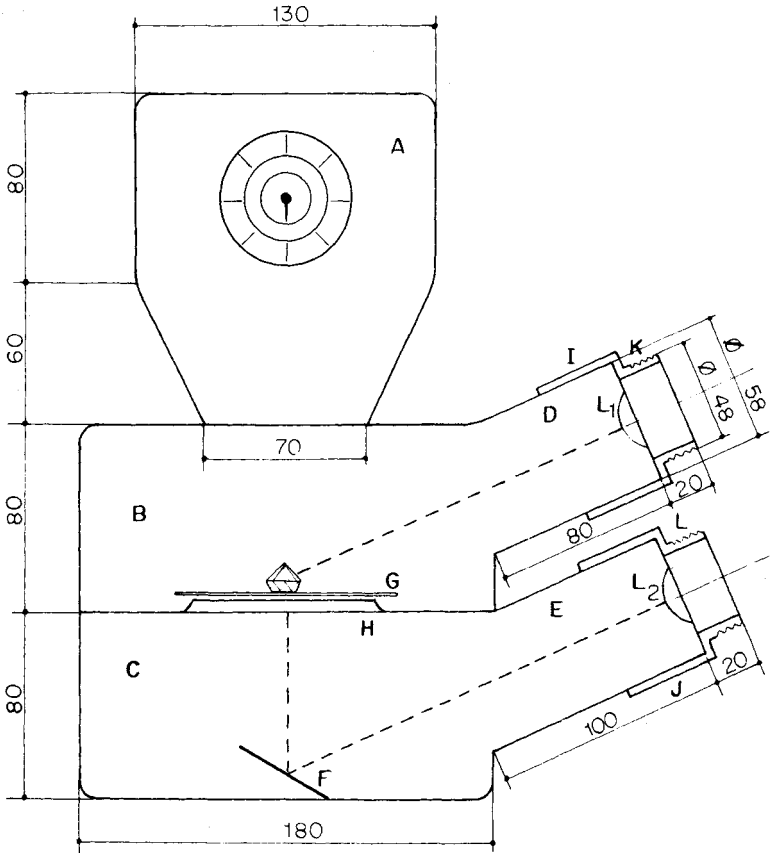

FIG. 1. Gemmological x-ray unit.
A: X-ray tube generator. B, C: Box with intermediate fluorescent screen. D, E: Adjustable tubes. F: Mirror. G: Opaque plate. H: Fluorescent screen. I, J: Draw-tubes. K, L: Screw threads. L_1, L_2: Lenses. (The numbers indicate the length in millimetres).

radiograph would be the reverse of this with the opaque material shown light.

Figure 2 shows a comparison of a diamond mounted with three synthetic spinels of several sizes. In Figure 3 the comparison is with cubic zirconia. In Figure 4 three series of gemstones are compared: from left to right, beryl, cubic zirconia and synthetic spinel. Figure 5 shows a view of the fluorescent screen of the x-ray unit with a mounted diamond and two cubic zirconias. This photograph was taken with the photographic camera attached to the unit (Figure 6).

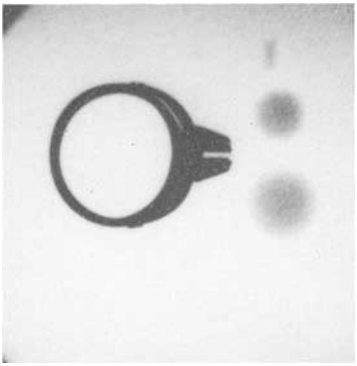

FIG. 2 Mounted diamond and synthetic spinels.

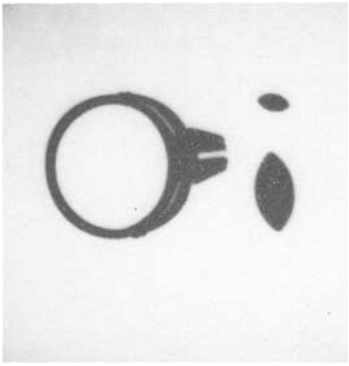

FIG. 3. Mounted diamond and cubic zirconias.

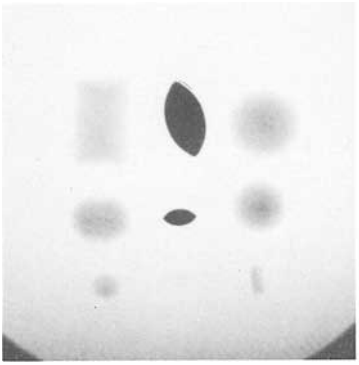

FIG. 4. Left to right, beryls, cubic zirconias and synthetic spinels.

FIG. 5. Photograph of the fluorescent screen of the x-ray unit with a mounted diamond and two cubic zirconias.

The three radiographs and the photograph of the screen were obtained with an x-ray unit of 220 volts, but connected to only 165 volts, the tube operating around 26 kV with a time exposure of 1 second.

The influence of the input voltage of the unit can be evaluated by the continuous radiation intensity emitted each second by an x-ray tube which can be expressed thus:[10]

$$I = AiZV^m \tag{4}$$

where A is a constant, i the tube current, Z the atomic number of the element used in the tube ($Z = 74$ for tungsten), and V is the voltage applied to the tube in a constant approximately equal to 2.

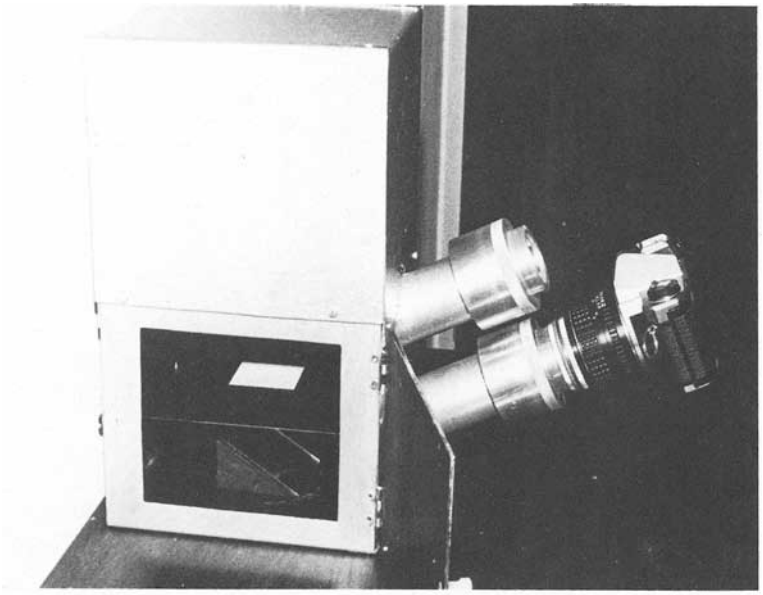

FIG. 6. Photographic camera attached to the unit.

Using an x-ray unit capable of 220 V of input, and a tube regulated for 35 kV, its working power can be controlled by the input voltage.

In the radiographs of the Figures 7, 8 and 9, quartz gems were used with the following conditions of the unit respectively:

Input voltage	tube voltage	intensity (I)
220 V	35 kV	1
165 V	26 kV	0.42
145 V	23 kV	0.29

In the 3rd column the variation of the energy irradiated by the tube was calculated from the equation (4) and presuming that i varies in a way nearly proportional to the input voltage. The advantage which can be observed in the photographs is that of differentiating or equalizing the transparencies according to the thickness or to the nature of the material when that is the case. There is also the advantage of the x-ray tube lasting longer when the equipment is used with a voltage lower than the nominal one.

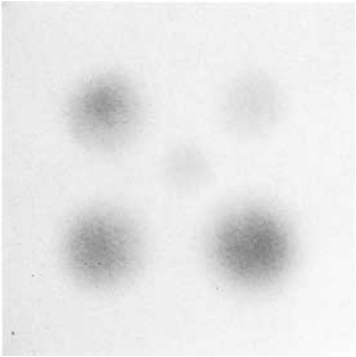

FIG. 7.

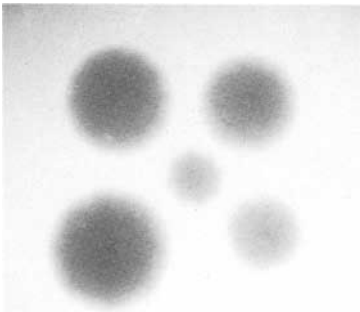

FIG. 8.

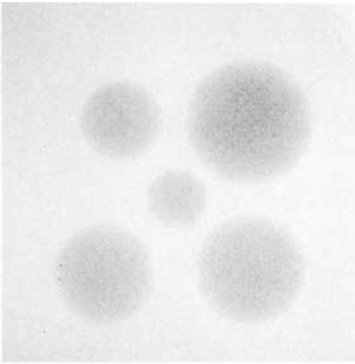

FIG. 9. Quartz gems at 35 kV, 26 kV and 23 kV.

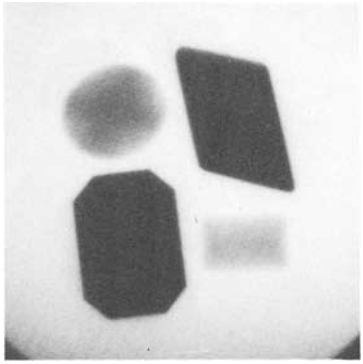

FIG. 10. Above-synthetic sapphire and fluorite.
Below-glass and beryl.

The radiograph in Figure 10 shows four gems. The oval one, in the upper left corner, is a synthetic sapphire with pavilion showing two crossed edges which appear in the photograph. On the right is a fluorite. The octagonal gem is an imitation beryl, made in flint glass, and the smallest, rectangular, stone is a natural beryl. The radiography conditions were the same as those of Figures 2, 3 and 4.

Figure 11 shows the unit being used in the observation of gem luminescence.

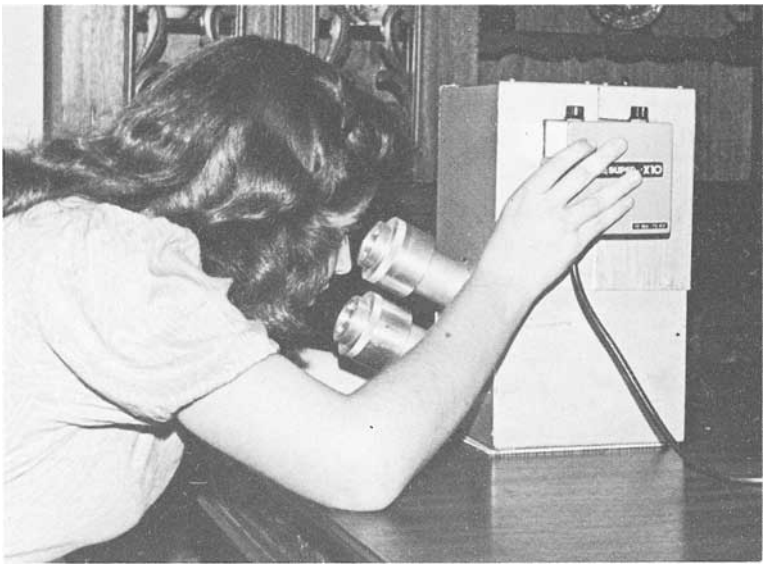

FIG. 11. Use of the unit in the observation of gem luminescence.

SPECIAL CARE

The x-ray gemmological unit proposed in this work generates a radiation which can be harmful to the operator if no special care is taken. The generating unit and the box where the gems are placed must be adequately shielded.

This shielding should be sufficient to prevent the transmission of direct radiation from the tube. The final test of shielding should be made with a detector with a scale of mR/h units or with solid state dosimeters. Assistance may be requested from some radiological safety department or from universities working on irradiation or x-ray diffraction.

In any case, with the indicated shielding, the equipment should be quite safe, mainly because the observations are made over periods of only 1 second. If it is used with radiographs only it is even safer, and a red plastic transparent box allows working in a normal environment without the necessity of a darkroom. This box is commonly used in dentistry.

Concerning the gemstones, a brief x-irradiation is insufficient to stimulate any kind of colour or transparency change. To generate any change in a gemstone would require an intensity of irradiation several times greater and applied over a longer time than the conditions described here.

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PARTICOLOUR IN TOURMALINES

By R. KEITH MITCHELL, F.G.A.

In 1981 Mr Philip Jerome raised the matter of particoloured tourmalines in connexion with the report of the Geological Museum robbery in 1933, which mentioned a five-coloured tourmaline.* At the time I was able to ascertain that this was almost certainly a case of erroneous reporting in the press of the day, and that what had actually been stolen were five differently coloured tourmalines.†

However, particolour in tourmaline is so much a feature of that mineral that it deserves some further comment.

This is a mineral in which chemical composition is unusually complex, and isomorphous replacement can occur at the same time in more than one part of the unit cell structure and can involve any two or more of three alkali elements and any two or more of six metallic elements. No wonder tourmaline covers a greater colour-range than any other gem mineral.

Compositional changes can and apparently often did occur during the growth of a crystal and, in the best known examples, resulted in crystals which are yellow-green on the outside and reddish pink at their core. This coloration has given rise to the generally used name 'water-melon tourmaline'. Crystals can vary in colour concentrically around the *c* axis, or can vary in colour along the length of the crystal.

The possible colours are far from being limited to red and green. In recent years some blue and pink material, originating from SW. Africa, has appeared on the market. This was usually so heavily flawed as to make it hardly suitable for faceting, although much of it was in fact cut this way and sold at quite high prices.

In my own collection I have several green and red particoloured stones covering a range of shades; a yellow and green; a grey and red, a blue and pale yellow; and a red and green cat's-eye in which the division between colours is so sharp as to give

*J.Gemm., 1981, XVII(7), 452.—Ed.
†J.Gemm., 1982, XVIII(1), 107.—Ed.

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the impression of two separate stones cemented together. It is, however, a completely natural stone apart from the fact that it has been cut as a cabochon.

I also have a number of sections cut across the prisms of Madagascan tourmalines in which multicoloured banding can be seen quite clearly, and even more so when a lens is used. In one such section a sequence of narrow pink, yellow, green and orange zones followed by broader areas of pink and purple-red may be seen. Another is black, colourless, blue, pink and red. Yet another is opaque black, transparent blue with a green centre.

FIG. 1. Particoloured cabochon tourmaline of 57 ct (with millimetre scale).

Perhaps the most extraordinary example of particoloration in tourmaline that I have seen was a large cabochon which I bought and sold about seven years ago. This is illustrated in Figure 1.

This 57 carat stone can be seen to consist of a very large number of colour-bands. In fact there are 23 distinct colour-zones. The dark lines are a very dark green, while all the lighter areas, except one which is pink, are a pale straw yellow. But with a lens further variations are to be seen where each dark green line has a very narrow region of light green on one or both sides of it. If these are taken into account there are some 35 changes of colour along the length of this stone.

The millimeter scale at the bottom of the illustration gives some idea of its size. The stone was heavily marked by cracks and almost certainly would not have been cut if it had not been so uniquely zoned.

Such colour-zoning in tourmalines generally seems to give fairly sharp edges between the colours, but a few stones show a very gradual change from one colour to another or, in some instances, two less well defined colours fading into and out of a central colourless area.

Although it is best known in tourmaline, colour-zoning is by no means restricted to that species. Corundum is quite commonly zoned in this way although the colours involved are less varied. Emerald may also have colourless areas adjacent to areas of very fine colour. Here the dividing surface between the two contrasting colours is often strangely 'roiled' and the division is an abrupt one. Green diopside, among the rarer stones, may also have this same particoloration between green and almost colourless areas.

Perhaps the rarest example of the phenomenon which has come my way was a zircon with one end green and the other end orange. Again this was a heavily cracked stone, but my friend, the late C. J. Payne, of the London Chamber of Commerce Gem Laboratory, used a diamond refractometer to obtain RI values of 1.853 and 1.863 for the green end and 1.866 and 1.876 for the orange end of the stone. I still have this specimen which was described in this *Journal* as long ago as January 1952.* It poses some problems when it is realized that both colours have to be the result of the metamict process, which seems to have developed to a different extent at either end.

[*Manuscript received 9th March, 1983.*]

*Some speculations on an unusual zircon, *J.Gemm.*, 1952, III(5), 202-3.—Ed.

AN INVESTIGATION OF THE SYNTHETIC PRODUCTS OF GILSON SHOWING A PLAY OF COLOURS

By Dr KARL SCHMETZER

Institute of Mineralogy and Petrography, University of Heidelberg, West Germany.

ABSTRACT

A characterization of five man-made products of Gilson showing a play of colours is given. In all five man-made products investigated, the play of colours is caused by a close-packed array of uniformly sized amorphous silica spheres. Three of Gilson's man-made products with white, grey and yellowish-brown body colours have a chemical composition which is distinctly different from that of natural opals: all three products contain only small amounts of water (< 1%); in one sample an admixture of crystalline ZrO_2 (≈ 0.5%) was observed. In the sample with a yellowish-brown body colour, a great amount of organic compounds (≈ 16%) was detected. According to the results mentioned, these products have to be designated as opal imitations, rather than synthetic opals. In two of the synthetic products investigated with a black body colour, only small amounts of water (< 2%) were detected, and admixtures of organic compounds (≈ 0.5 - 1.0%) were also found. Using the nomenclature proposed, and the criteria for a distinction of synthetic and imitation gemstones given by Nassau (1976) in a strict sense, these two products also do not deserve the synthetic label, and have to be designated as black opal imitations.

INTRODUCTION

Since 1974, different synthetic products showing a play of colours were manufactured, and sold by P. Gilson, of Saint-Sulpice, Switzerland. For all synthetic products designated as synthetic opals, a formula of $SiO_2.nH_2O$ is given, which corresponds to the composition of natural opals; additional admixtures are not mentioned (advertisement brochure of P. Gilson). Synthetic products with white and black body-colour corresponding in appearance to white and black opals have been available on the gemstone market since 1974. Recently, a new product with a yellowish-brown body-colour, corresponding to fire opal with a play of colours, was also offered under the designation 'created fire opal', or 'created honey opal'.

Different possibilities for the production of opals have been discussed by several authors (e.g., Iler, 1965; Darragh & Perdrix, 1975; Darragh *et al.*, 1977; Falter & Liebertz, 1978; Liebertz &

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Falter, 1979). A first step for the production of opaline materials is the growth of uniformly sized silica spheres, with diameters in the range of 170-380 nm. A method suitable for such a process was developed by Stöber *et al.,* (1968). This method is based on hydrolysis of tetraesters of silicic acid, e.g., in a solution of tetraethyl silicate, methanol and ammonia. The silica particles were allowed to settle in close-packed arrays by sedimentation over a period of several weeks; in the next step, the liquid is removed. The play of colours of the opaline body in a dry state is distinctly diminished compared to the wet state; in addition, the body without liquid-filled voids is of high porosity and brittleness. In order to use the product for gem purposes, an impregnation of the open voids with opaline silica is necessary. In general, this last step in the production process of synthetic opal is noted to be highly problematic, and a method satisfactory for this purpose is not described in detail (e.g., sintering or hydrothermal treatment). Though similar effects (hardening and improvement of a play of colours) are also caused by plastic impregnation, the result of such a procedure is the production of an opal imitation and not of a synthetic opal (Darragh & Perdrix, 1975). Due to the great difficulties with an impregnation process of amorphous, hydrous silica, the patents held by CSIRO, of Melbourne, Australia, since 1968, are not at present applied for commercial production of synthetic opal for gem purposes.

Up to now, the process used by P. Gilson for the synthesis of materials showing a play of colours has been kept secret. The investigation of one single sample by infrared spectroscopy showed the synthetic product of Gilson to contain smaller amounts of water compared to the water content of natural opals (Darragh & Perdrix, 1975). By investigations with the electron microscope, the internal structure of Gilson's products was found to consist of uniformly sized silica spheres, which are arranged in close-packed aggregates (Darragh & Perdrix, 1975; Falter & Liebertz, 1978). The gemmological distinction of the synthetic products of Gilson from natural opals is based on a microscopic investigation (columnar structure, lizard skin effect). The observations of microscopic investigations are described by various authors; for details see Eppler (1974, 1975), Jobbins *et al.,* (1976), Scarratt (1976), Mertens (1977), Darragh *et al.,* (1977), Ball (1977, 1978, 1979), Jamieson (1978), and Robertson (1979). The gemmological properties and

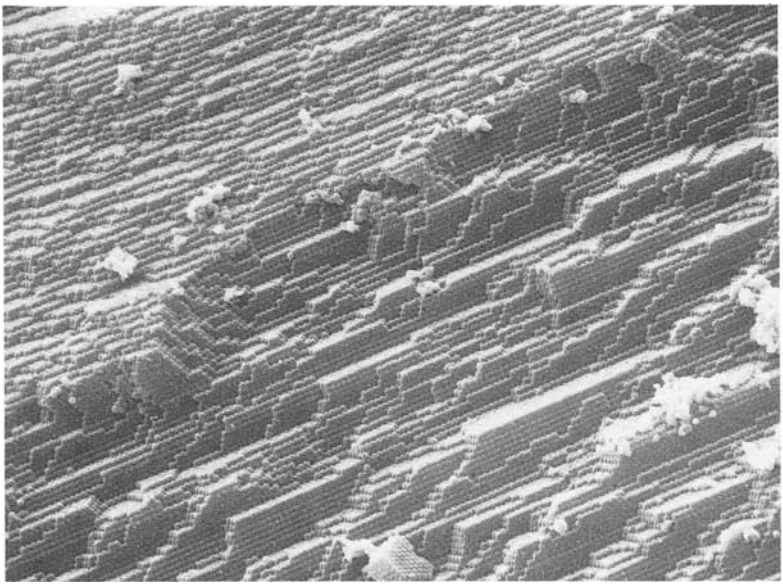

FIG 1. Fire opal imitation of Gilson.—SEM micrograph, 3000 ×.

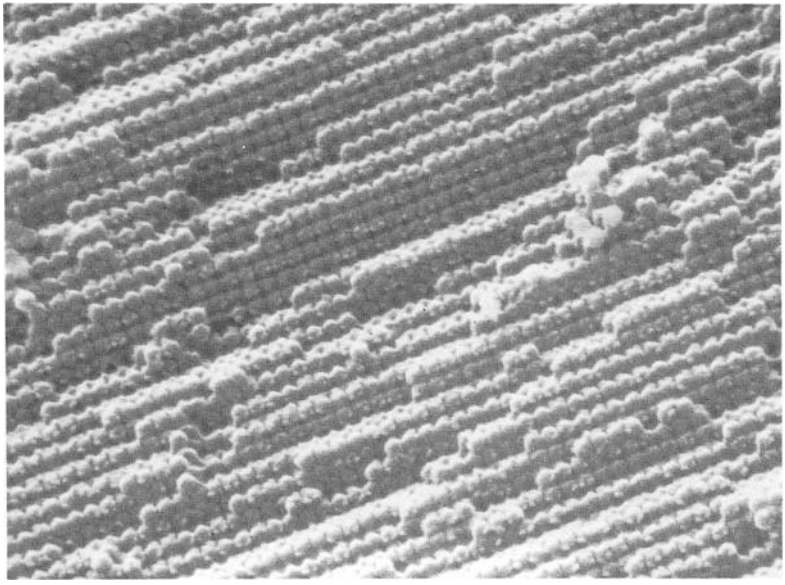

FIG. 2. Fire opal imitation of Gilson.—SEM micrograh, 10 000 ×.

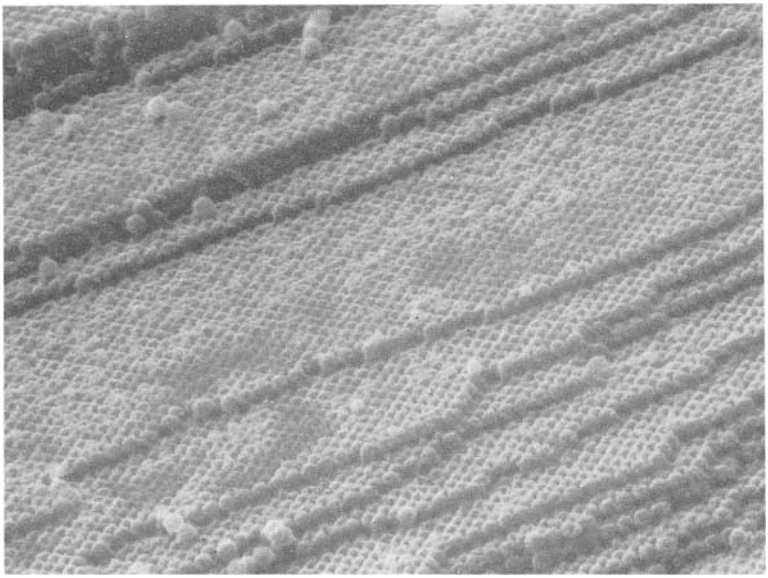

FIG. 3. Fire opal imitation of Gilson.—SEM micrograph, 10 000 ×.

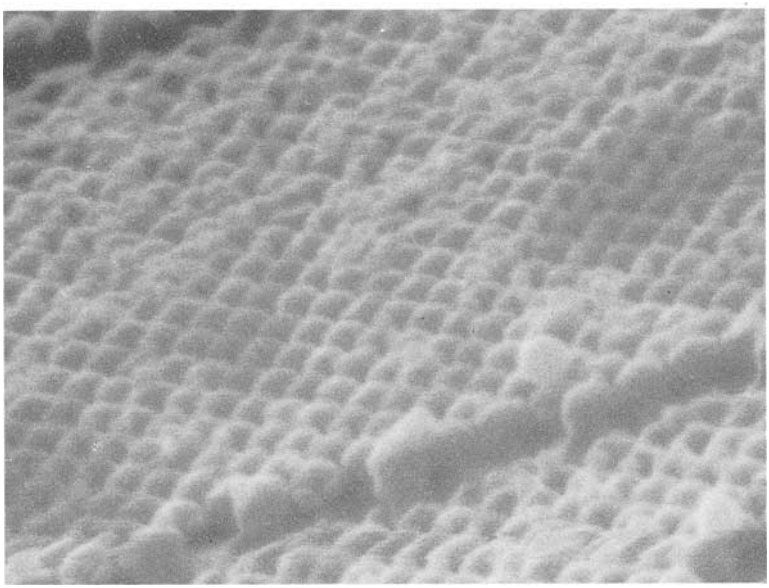

FIG. 4. Fire opal imitation of Gilson.—SEM micrograph, 30 000 ×.

the results of microscopic investigations of the new Gilson product imitating fire opal with a play of colours are described in detail by Gunawardene & Mertens (1984).

A systematic investigation of the synthetic products of Gilson was initiated by the appearance of the new substance with a play of colours, having a yellowish-brown body colour, the so-called 'synthetic fire opal'. A thermogravimetric analysis of this new product showed a loss of weight of about 16% between 300 and 400 °C, a result which was highly unusual compared with data from the literature on natural opals. Though an investigation of the new product by the electron microscope showed an internal structure consisting of uniformly sized silica spheres (Figures 1-4), a detailed investigation of the unusual reaction of heat on this sample seemed necessary. For comparison, additional synthetic products of Gilson as well as some natural opals of different localities were investigated.

MATERIALS AND EXPERIMENTAL DETAILS

For the investigations cited in this paper, five different types of synthetic products of Gilson were available:

Sample 1: several identical pieces, body-colour white with a play of colours violet to green (Figures 5, 6)

Sample 2: body-colour grey with a play of colours violet to red (Figure 7).

Sample 3: body-colour black (opaque) with a play of colours violet to blue (Figure 8).

Sample 4: body-colour black (opaque) with a play of colours violet to red (Figure 9).

Sample 5: several identical pieces, body-colour yellowish-brown, with a play of colours violet to red (Figure 10).

Investigations of the x-ray powder diffraction pattern of the samples were conducted with a powder diffractometer or with Debye-Scherrer cameras. For thermogravimetry between 20 and 1000 °C, a 1090 Du Pont thermal analyser with TGA 951 thermobalance was available; heating rate: 10 °C/min. in 50 ml air/min. Qualitative chemical analyses were done with the energy dispersive systems of an electron microprobe and a scanning electron microscope. The quantitative contents of SiO_2 and ZrO_2 were evaluated by classical chemical methods. SiO_2 was determined

FIG. 5. Opal imitation of Gilson with white body colour, sample 1.—Size 12 × 5 mm.

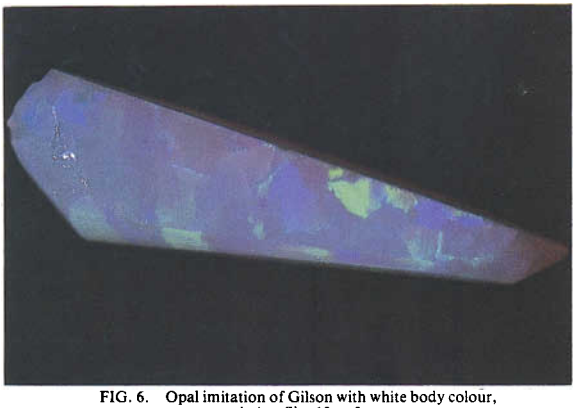

FIG. 6. Opal imitation of Gilson with white body colour, sample 1.—Size 12 × 3mm.

FIG. 7. Opal imitation of Gilson with grey body colour, sample 2.—Size 7 × 4 mm.

FIG. 8. Opal imitation of Gilson with black body colour, sample 3.—Size 3 × 4 mm.

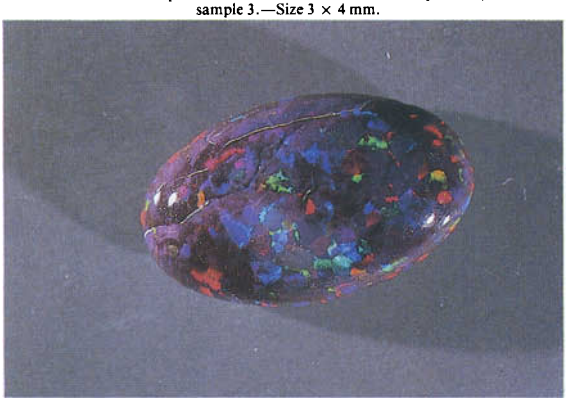

FIG. 9. Opal imitation of Gilson with black body colour, sample 4.—Size 18 × 11 mm.

FIG. 10. Opal imitation of Gilson with yellowish-brown body colour, sample 5.—Size 8 × 7 mm.

by atomic absorption spectroscopy, after fusion of the samples with Na_2CO_3/K_2CO_3. Five samples of synthetic quartz, heated to 1100 °C, were used as standards, which were analysed parallel to the unknown samples. ZrO_2 was precipitated in H_2SO_4 as a phosphate and determined as pyrophosphate. A standard sample with a known content of 3.3% ZrO_2 was investigated parallel to sample 1 of Gilson. The water contents of the samples were chemically determined by means of Karl-Fischer-titration, after decomposition of the samples by heating to 1200 °C. Organic compounds, which were also found to be present in the synthetic products of Gilson, were characterized by flame ionization (rock-eval-analysis) and mass spectrometry. A method of high temperature pyrolysis in connexion with flame ionization, commonly used in petroleum geochemistry, is called rock-eval-analysis: the samples were first heated for 3 min. in a helium atmosphere at 250 °C. Parallel to further heating at a rate of 30 °C/min. up to 500 °C, the organic compounds released by cracking processes were analysed by a flame ionization detector. Investigations by mass spectrometry were conducted with a ZAB mass spectrometer from Vakuum Instruments, attached to a VG data system with a direct inlet, sample temperature of 20-400 °C, and source temperature of 240 °C, with dynamical 6000 resolution. As a reference substance, perfluorkerosene was used. Taking an investigation of the empty sample holder under conditions identical to those for investigation of the unknowns, no background reading for the mass spectrometer was found.

RESULTS

The experimental results of the investigations described in this paper are summarized in concise form in Table 1.

Sample 1 (white): The thermogravimetric investigation shows a loss of weight <0.1% up to 1000 °C. The water determination by means of Karl-Fischer method was conducted to a water content of 0.07% H_2O. By qualitative chemical analysis with energy dispersive systems only Si and Zr were found. The quantitative determinations by classical chemical methods yielded up to 99.2% SiO_2 and 0.56% ZrO_2. The investigation of the x-ray powder pattern of the sample showed the diffuse diffraction line at about 4.1 Å, which is typical for opal-A, or silica glass, along with some additional weak diffraction lines. Using exposure times up to 12 h

TABLE 1

Physical and chemical properties of man-made products of Gilson showing a play of colours.

	X-ray powder diffraction pattern	Thermogravimetry	Chemical analysis			Flame ionization rock-eval-analysis	Mass spectrometry
			SiO_2	ZrO_2	H_2O		
Sample 1 (white)	4.1 Å (diffuse) and lines of tetragonal ZrO_2	no loss of weight	99.2%	0.56%	0.07%		
Sample 2 (grey)	4.1 Å (diffuse)	no loss of weight	100.0%				
Sample 3 (black)	4.1 Å (diffuse)	1.6% between 20 and 1000 °C continuous	99.2%		0.75%		butylphtalester and fragments between 240 and 400 °C
Sample 4 (black)	4.1 Å (diffuse)	2.9% between 20 and 1000 °C continuous			1.86%	0.4% organic compounds between 250 and 500 °C, 0.06% CO_2	
Sample 5 (yellowish-brown)	4.1 Å (diffuse)	a) 16.6% b) 16.0% between 300 and 400 °C	85.0%		0.53%	16% organic compounds between 250 and 400 °C, 0.1% CO_2	at least two organic compounds and their fragments between 240 and 400 °C

for Debye-Scherrer films, these weak diffraction lines become stronger; the d-values of these lines are assigned to the tetragonal modification of ZrO_2 (ASTM 24-1164). As a result, sample 1 consists of SiO_2, amorphous to x-rays, and small admixtures of tetragonal ZrO_2. The water content of the sample is extremely low.

Sample 2 (grey): This specimen is similar to sample 1, but without a distinct Zr content. TGA of sample 2 proved the loss of weight to be < 0.1%. The sample consists of SiO_2, without distinct admixtures; the x-ray powder pattern revealed only the diffuse diffraction line at 4.1 Å.

Sample 3 (black): TGA shows a continuous loss of weight of 1.6% between 20 and 1000 °C. Only the diffuse diffraction line at 4.1 Å was observed. SiO_2 determination: 99.2%; a water content of 0.75% was found. From these results, a distinct difference between the loss of weight of 1.6%, measured by TGA, and the Karl-Fischer water determination of 0.75% becomes evident. Therefore, additional admixtures are present, which are released by heat treatment up to 1000 °C. By means of mass spectrometry, the presence of butylphtalesters were established as the main components of the organic compounds released between 240 and 400 °C. The determination of masses showed at least four fragment compounds:

m/z	223,0951	$C_{12}H_{15}O_4$
m/z	205,0878	$C_{12}H_{13}O_3$
m/z	149,0250	$C_8H_5O_3$
m/z	57,0712	C_4H_9

Sample 3 therefore consists of amorphous SiO_2, 0.75% H_2O and at least one organic compound of butylphtalester.

Sample 4 (black): Similarly, as above, TGA shows a continuous loss of weight of 2.9%, up to 1000 °C (Figure 11). The water content was established to be 1.86%, i.e., the amount of water in this sample is distinctly higher compared to sample 3. Again, a significant difference between the loss of weight and the value of the chemical water determination was found. By means of flame ionization (rock-eval-analysis), the release of about 0.4% of organic compounds occurred between 250 and 500 °C. According

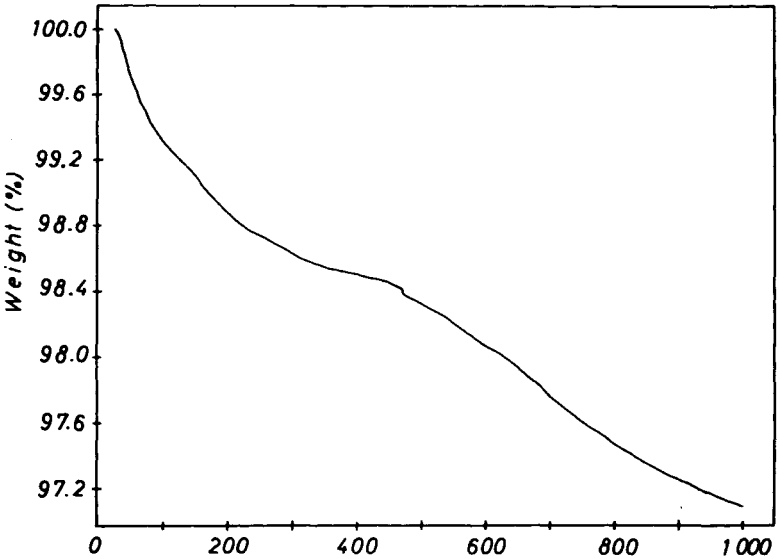

FIG. 11. TG curve of opal imitation of Gilson with black body colour, sample 4.

to these investigations, part of these substances (T>350 °C) have to be regarded as cracking products of complex organic compounds. In sample 4, a CO_2 content of 0.06% was also determined. Sample 4 consists of SiO_2 as a main component, with admixtures of water, and at least of one organic compound.

Consequently, samples 3 and 4 should come from an identical type of manufacturing process, but from different generations or steps in the synthesis.

Sample 5 (yellowish-brown): These specimens are also amorphous to x-rays, but show significant differences toward heat treatment. Between 300 and 400 °C, a loss of weight of about 16% was observed (Figure 12). The water content of the sample (0.53%) is distinctly lower than the loss of weight; the SiO_2 content was established to be 85.0%. By means of flame ionization (rock-eval-analysis), about 16% in organic compounds were detected in this sample, and are released between 250 and 400 °C. A CO_2 content

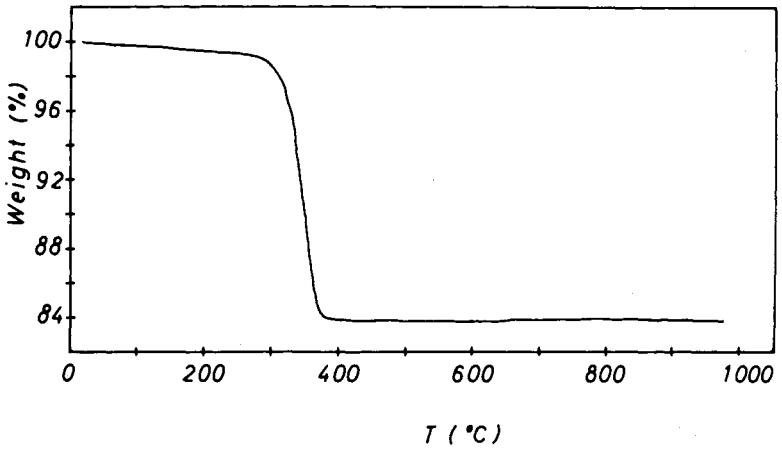

FIG. 12. TG curve of opal imitation of Gilson with yellowish-brown body colour, sample 5.

of 0.1% was found. The investigation by mass spectrometry showed fragments of organic compounds, which are assigned to at least two substances due to their genetic relationship; only C-H-O containing compounds were taken into consideration:

m/z	198.0668	$C_{13}H_{10}O_2$
m/z	154.0758	$C_{12}H_{10}$
m/z	122.0353	$C_7 H_6 O_2$
m/z	105.0334	$C_7 H_5 O$

Substance B:

m/z	100.0521	$C_5 H_8 O_2$
m/z	99.0448	$C_5 H_7 O_2$
m/z	69.0375	$C_4 H_5 O$
m/z	41.0332	$C_3 H_5$
m/z	39.0176	$C_3 H_3$

Consequently, sample 5 consists of about 85% SiO_2, amorphous to x-rays, of 0.5% H_2O and of 16% organic compounds. The presence of at least two different organic compounds was proven.

DESIGNATION OF THE SAMPLES INVESTIGATED

It was not the intention of the investigations described in this paper to clarify production processes. However, significant differences in chemical composition between natural gem opals and synthetic products of Gilson were established. Therefore, the correct designation of these substances is debatable. A proposal for a distinction between non-single-crystal synthetics and imitations is given by Nassau (1976, 1977). The author suggests five levels of investigation:

(a) chemical composition (analysis)
(b) crystal structure (x-ray diffraction)
(c) sub-micro-structure (electron microscope)
(d) micro-structure (optical microscope)
(e) visible appearance (unaided eye)

According to Nassau, the only way in which synthetic material is permitted to differ from natural material is at the microscopic level of investigation. At the levels of crystal structure, sub-micro-structure and visible appearance of man-made gem materials, the properties of a synthetic gemstone have to meet exactly the properties of natural material. In chemical composition only those components which are variable in natural material are allowed to vary within the limits found in natural samples too. No foreign binder, filler or colouring matter may be present in material which deserves or claims the label 'synthetic'. An examination of the criteria suggested by Nassau with respect to the man-made materials of Gilson leads to the conclusions given below:

(a) At the level of chemical composition all samples investigated have significant differences as compared to natural gem opals.* All five samples fail to duplicate the natural substances. In samples 1, 2 and 5, distinct water contents, which are always present in natural opals (Bayliss & Males, 1965; Jones & Segnit, 1971; Langer & Flörke, 1974; Darragh & Perdrix, 1975), were not found. In samples 3 and 4, the water contents are lower than in natural opals (≈ 3-10%). A limit of 1% H_2O for the designation opal was suggested by Jones & Segnit (1971). This limit is extremely important for the distinction of hyalite and silica glass (compare Flörke *et al.*,

*Contrary to opaline silica formed by geologic processes, plant opal separated from soil may contain a distinct amount of organic matter which was protected by the opal from oxidation (Jones & Beavers, 1963).

1973; Langer & Flörke, 1974). Comparing this limit with the H_2O contents in samples 3 and 4, only sample 4 meets the compositional range of opals.

In sample 1, an amount of crystalline ZrO_2 was observed which may not be present in natural opals. This admixture is supposed to be added in order to produce the white body colour of the samples. In samples 3 and 4, admixtures of organic compounds were detected. These compounds may be regarded as residues of the production procedures. Sample 5 even contains great quantities of organic material (≈16%).

(b) By means of x-ray powder diffraction, congruency is observed between samples 2, 3, 4 and 5, and natural opaline material of the amorphous type (Jones *et al.*, 1964; Jones & Segnit, 1971). In addition to the diffuse diffraction line at 4.1 Å in the diffraction pattern of sample 1, the lines of tetragonal ZrO_2 were observed. A diffraction pattern similar to the pattern of opal-CT was not observed during the investigations of Gilson's products (the Mexican fire opals are assigned to this group; compare Sanders, 1975).

(c) In the electron microscope, close-packed aggregates of silica spheres were observed (Figures 1-4; compare Darragh & Perdrix, 1975; Falter & Liebertz, 1978; Liebertz & Falter, 1979). However, no internal structure of shells within the silica spheres was observed in Gilson's products (Darragh & Perdrix, 1975; Ball, 1977; Darragh *et al.*, 1977; Jamieson, 1978), as it was described for natural opals of the amorphous type (Darragh *et al.*, 1966; Cole & Monroe, 1967; Jones & Segnit, 1969; Monroe *et al.*, 1969; Sanders & Darragh, 1971).

(d) As mentioned before, the man-made products of Gilson show distinct differences against natural opals at the level of microscopic observations (compare Gunawardene & Mertens, 1984).

(e) The visual appearance of the synthetic products of Gilson showing a play of colours is in good congruency with its natural counterparts.

Between natural opals and all five of the man-made products of Gilson investigated in this paper, significant differences were

detected. The main differences are in sample 1: no water, ZrO_2; in sample 2: no water; and in sample 5: no water, 16% organic compounds. As a result of these observations, the three products mentioned do not deserve the synthetic label. An application of the criteria of Nassau (1976, 1977), in a strict sense, to the results obtained during the investigation of samples 3 and 4, does not allow the designation of these two products as synthetic opals. Due to their contents of organic compounds, they too have to be assigned to the group of imitations.

A clear decision by an International Commission on Gemstone Nomenclature (CIBJO or Commission on Gem Materials of IMA) concerning the distinction of synthetics and imitations is highly desirable in the opinion of the author.

ACKNOWLEDGEMENTS

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GILSON CREATED FIRE OPAL IMITATION WITH PLAY OF COLOURS

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ABSTRACT

In the chain of opal simulants made by Gilson, the new-comer is the 'Mexican opal synthetic' (according to the manufacturer). Compared with natural opals, this simulant behaved unnaturally and was proved to be an imitation rather than a synthetic (Schmetzer, 1984). Upon this the chemical and physical properties are compared with those opals of natural origin. Gemmological identifications are presented with intensive microscopic studies.

INTRODUCTION

Synthesis of gem materials is a well understood process to the solid state chemist and ceramist. Thus deep knowledge of chemistry has taken up a notable position in present day gemmology. However, considering opal, chemistry alone does not help to bring out the 'play of colour' effect. The cause for this magnificent splendour phenomenon was explained by Sanders (1964) during early days of investigations on natural opals. In the late 1960s scientific organizations in U.S.A. and Australia proceeded further and patented the synthesizing of opals. The commercial aspects of these patents were employed by Gilson, who announced the availability of black and white laboratory-made opals (Jobbins *et al.*, 1976). His product contained (according to Gilson) $SiO_2.nH_2O$, indicating a similarity to that of natural opal. However, Kose & Hachisu (1976) proved that 'play of colour' effect can be achieved by using dissimilar chemical ingredients (see also Gunawardene, 1983).

New developments achieved by the Swiss scientist were shown to the authors during October 1982 by courtesy of the Litzenberger firm in Idar-Oberstein. The samples were introduced by the producer under such names as 'Mexican fire opal type synthetic' or 'synthetic honey opal'. Visually, they resembled the appearance of honey opal (after Ball, 1982), having 'play of colours' like those found in Australia or Mexico.

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Fire opal imitations consisting of one slab weighing 12.07, one cabochon of 3.62 carats, and a parcel of chipped pieces, six natural gem-quality fire opals (also called honey opals) and four black and white (two from each colour variety) opal simulants of the manufacturer were used in this investigation.

CHEMISTRY

It is known that gem opal is chemically a hydrous silica. Certain colour varieties are caused by the presence of transition elements—for instance, the iron coloration in natural fire opal. The chemical analysis according to Schmetzer (1984) in this new simulant measured contents of 85.0% SiO_2, 0.53% H_2O and 16.0% organic componds. Investigated by thermogravimetry (TGA) the samples gave a loss of weight of 16.0% at a temperature range between 320 °C and 370 °C and then remained constant upon the increase of heat. A Mexican fire opal, on the other hand, showed a loss of weight of 9.5% between 20 °C and 1000 °C (Figure 1).

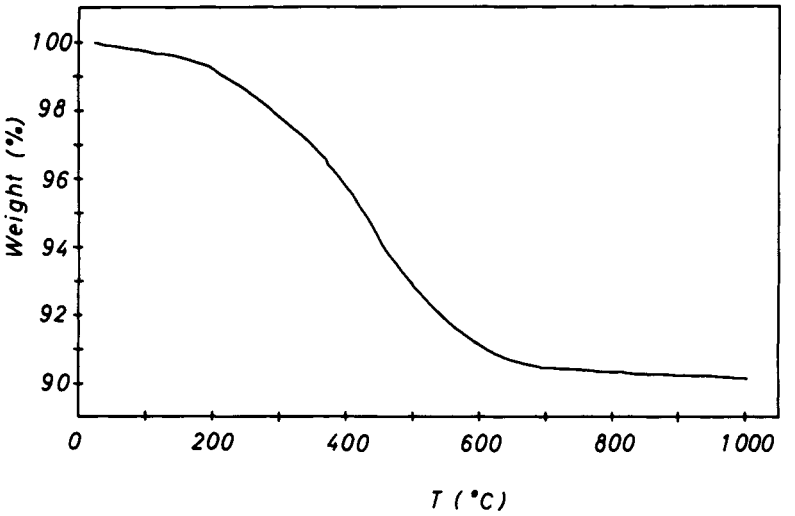

FIG. 1. TG curve of Mexican fire opal showing the continuous loss of weight between 20 °C and 1000 °C.

STRUCTURE

As reported by Sanders (1964) the sedimentation of spheres should take an ordered array in a three-dimensional network in the formation of opals of gem quality. Similar structural appearance of the new product was evident under the scanning electron microscope. The approximate diameter size of the spheres was about 200 nm (Schmetzer, 1984). The careful observations made on the available slab indicated that the colour columns were at right angles to the base of the container used during the growth. Examination of the other samples showed no such effects. This may have been due to some influence of periodic gentle disturbance caused to the sedimentation of the structure.

BODY COLOUR

The newly made opal stimulant is of distinct yellowish-brown body colour having notable 'play of colour' effect. It is much better in appearance than the natural samples of high grade with which it was compared. The unpolished part of the slab showed an unnatural nature much more clearly than the cabochon cut samples of the imitation, in that the reddish flashes of colour were more prominent than those of other colour segments such as green, blue and violet.

PHYSICAL PROPERTIES

The measured refractive indices and specific gravity values were not very different from those of natural or previous varieties of man-made opals. Both distilled water and toluene were used in determining the specific gravity. The physical properties are given in Table 1 along with those of comparision stones.

The noted affinity for water, after a 30 minutes soak, was much less than that reported previously for imitations (Jobbins *et al.*, 1976). The porosity of those simulating black and white varieties revealed a propensity for sticking to the tongue. However, this porosity was absent in the new fire-opal imitation. The cause is probably due to the impregnation of a synthetic material which hardens and influences the 'play of colour' effect (see Schmetzer, 1984). Polished surfaces of the new product and the natural honey opal felt rough and smooth respectively to the moistened thumb. This 'feeling' test may be used as an additional method of descrimination by an experienced dealer.

TABLE 1. Summary of the characteristics of the fire opal imitation made by Gilson and natural fire opals.

	Gilson fire opal imitation with 'play of colours'	Natural fire opal with or without 'play of colours'
Chemistry*	SiO_2 85.0% H_2O 0.53% organic compounds 16.0%	
X-ray powder pattern*	Amorphous	CT—opal
Thermogravimetry*	loss of weight about 16% between 300 °C and 400 °C	loss of weight about 8-9% between 20 °C and 1000 °C
Refractive index	1.41±0.001	$1.44^{+0.003}_{-0.007}$
Specific gravity (g/cm³)	1.91±0.001	$2.15^{+0.007}_{-0.009}$
Affinity for water	hydrophilic**	hydrophilic
'feeling' test	cool feeling; rough to the thumb	cool feeling; smooth to the thumb
UV Luminescence Long-wave	strong bluish-white	weak orange
UV Luminescence Short-wave	weak bluish-white	none
Thermoluminescence at 30 °C to 40 °C	strong chalky bluish-white	none

*after Schmetzer (1984)

**affinity less due to impregnated synthetic material

LUMINESCENCE

The stones were examined under both long- and short-wave ultraviolet radiations. The cabochon cut sample of the new imitation and all the natural opals were inert to both radiations. However, the remaining samples of new and previous products showed a distinct fluorescence with a chalky bluish-white body glow and a much stronger surface glow of the same colour. A phosphorescence effect was noted after switching off the ultraviolet radiations. The fluorescence and phosphorescence effects were stronger under the long-wave than under the short-wave ultraviolet. The experiments were repeated with different distances between the radiation source and the object, and with different exposure times. Stronger and more distinct glows and afterglows were evident when the radiation was nearer to the object and exposed for longer periods.

Further, a thermoluminescence was noted on those samples which reacted under ultraviolet radiations. The heat was induced by using the microscope light source and the amount of heat induced produced a fluorescence and an afterglow which also depended on the length of time of heating. The gemmologist is warned about heating opals in repeating such experiments —extreme heating may result in cracking the material.

MICROSCOPIC EXAMINATIONS

Examinations were done on both *horizontal* and *vertical* microscopes. Under high intensity fibre-glass optic light coupled with the *horizontal* gem microscope, the new Gilson product revealed a structural effect similar to the 'chicken wire' in appearance (Figure 2). Individual colour segments, made visible under oblique orientation of the fibre-glass tube, showed structural patterns similar to those reported by Scarratt (1976). However this effect was absent in the natural stones used for comparisons (Figure 3).

Since most of the microscopic examinations are done on low intensity lighting conditions, the investigations were then turned to usual gemmological procedure with the light sources supplied by the manufacturers of both types of microscope (Read, 1979; Lenzen *et al.*, 1983). The transmitted light was directed at different angles and the visibility of the red colour segments was noted (Figure 4). Apart from a few healed fractures, perhaps due to

FIG. 2. Gem microscopic examination using high intensity fibre-glass optic light showing 'chicken wire' appearance. (transmitted light. 20 ×)

temperature increase after the growth (we do not know whether these samples were examined under intensity lighting conditions—causing some heat—by the supplier beforehand?), dendritic patterns similar to those seen in moss agate were apparent (Figure 5). On the other hand the colour patches in the natural gem-quality fire opal with colour flashes showed striations (Figure 6). In further examinations the new imitation opal variety showed the characteristic 'lizard skin' or 'fish-scale' effect (Figure 7) similar to those reported by Jobbins *et al.,* (1976) on the black and white imitations of the manufacturer. In oblique directions a characteristic dangling stalactitic colour-distribution was noted (Figure 8). The stones viewed from the side showed the substructural boundaries of colour patches rising in columns (Figure 9). The possible cause for this is discussed in the section on body colour. Similar colour boundaries were noted in early black and white varieties of the imitations and are reported by the previous investigators in this *Journal* (Jobbins *et al.,* 1976) and elsewhere (Mertens, 1977).

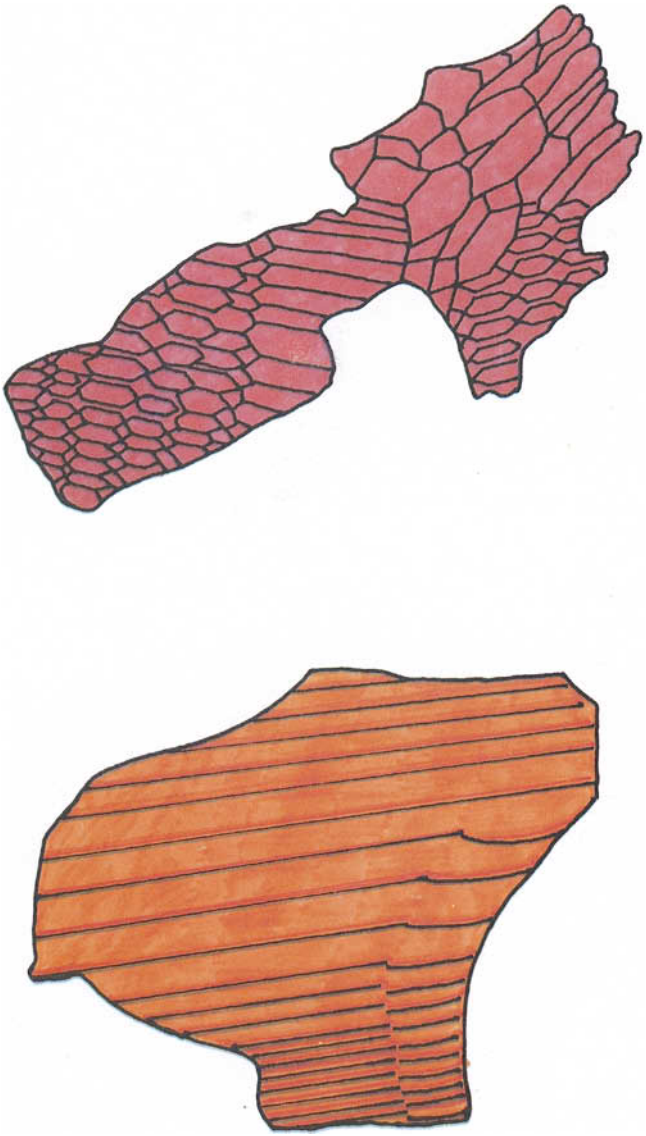

FIG. 3. Drawings of red and orange colour-segments in new opal imitation *(above)* and Mexican fire opal *(below)* respectively.

FIG. 4. Often visible red colour-patches and typical dendritic patterns seen in the Gilson imitation. (transmitted light. 20 ×)

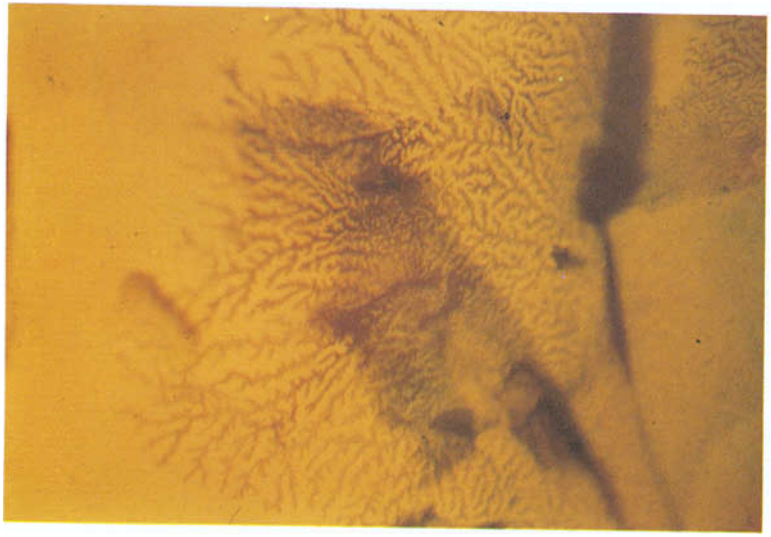

FIG. 5. Enlarged dendritic pattern in fire opal imitation of Gilson. (transmitted light. 100 ×)

FIG. 6. The structural pattern seen in most of the colour segments of natural honey opal. (transmitted light. 40 ×)

FIG. 7. Typical 'lizard skin' structure in fire-opal-like Gilson imitation. (reflected light. 25 ×)

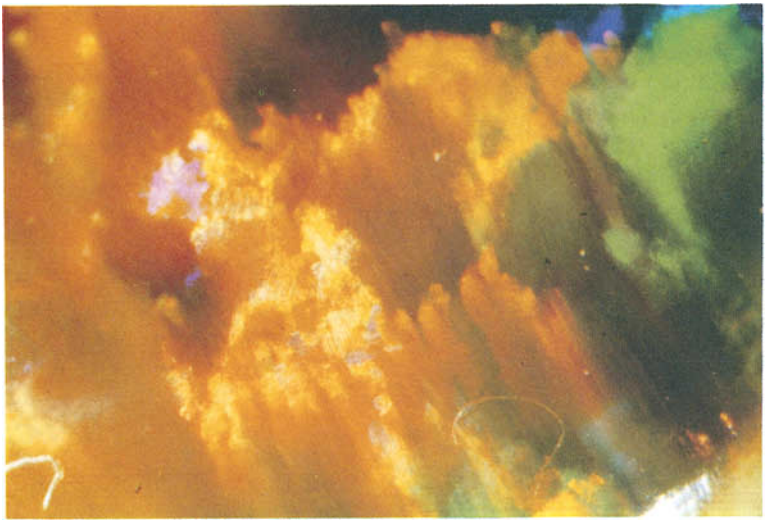

FIG. 8. Characteristic 'dangling stalactitic' colour distribution in the new fire opal imitation. (oblique light. 40 ×)

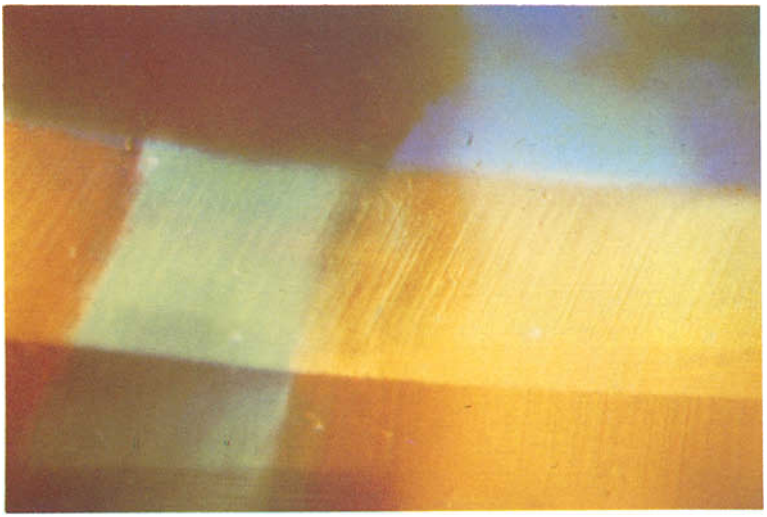

FIG. 9. Substructural boundaries of colour columns in side-view observations in fire opal imitation of Gilson. (reflected light. 25 ×)

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SOME OBSERVATIONS ON A KASHAN SYNTHETIC RUBY

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ABSTRACT

Three visually distinct types of inclusions observed in a flux-grown Kashan synthetic ruby are illustrated and described and some speculations are presented on their possible origins. It is tentatively suggested that all of the inclusions in the stone consist essentially of trapped flux which may occur either in a crystalline or vitreous state depending on factors such as size, cooling rate and amount of alumina dissolved. None of the inclusions appear to contain any liquid phases.

1. INTRODUCTION

In recent years flux-grown synthetic rubies have become increasingly important in the gemstone markets of the world. The major producers are Chatham and Kashan, both of the United States, but the recently introduced Knischka ruby of European origin is likely to be marketed in the near future. Although research laboratories, equipped with sophisticated instrumentation, can usually distinguish the flux-grown stones from each other and from natural rubies, the average gemmologist will have to rely heavily on inclusion characteristics if he hopes to confidently separate these deceptive synthetics from genuine rubies. Several excellent papers on flux-grown rubies have appeared in the gemmological literature in the last few years, the most recent being the magnificently illustrated summary by Dr E. J. Gübelin in the April 1983 issue of this *Journal.*

In recent months the author had the opportunity of examining a particularly interesting Kashan ruby, kindly loaned to him by Alan Hodgkinson. The paper describes and illustrates the inclusions observed in this stone and speculates on their possible origin. As only one stone is under discussion, and no analytical work was undertaken by the author, the article is not intended to serve as a guide to the identification of Kashan rubies in general nor is it implied that the inclusions described will necessarily be found in other Kashan stones. It is hoped, however, that the photographs and descriptions will be useful, for comparative purposes, for those seeking evidence of flux growth in other specimens.

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2. Description

Three distinct kinds of inclusion were noted in the stone—'metallic' solid inclusions, 'crazed' solid inclusions and 'fingerprints'.

Type I—'Metallic' Solid Inclusions

These inclusions were the most conspicuous internal features present. Their general shape was irregular in the larger examples and elliptical, rod-like or even spherical in the smaller ones.

In transmitted light only the structures were completely opaque, but using a combination of transmitted and oblique overhead illumination they were revealed as strongly reflecting inclusions with a distinctly 'metallic' lustre. Precise determination of their colour was difficult, as this varied according to the angle at which the oblique overhead lighting was directed into the stone; colours recorded were dark red, bronze, greenish and 'white'. Most of these inclusions appeared to be solid, homogeneous bodies.

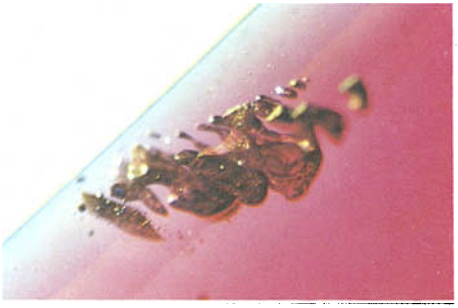

FIG. 1. Type I. Coarse crystalline flux inclusions. Kashan ruby 6.3 ×.

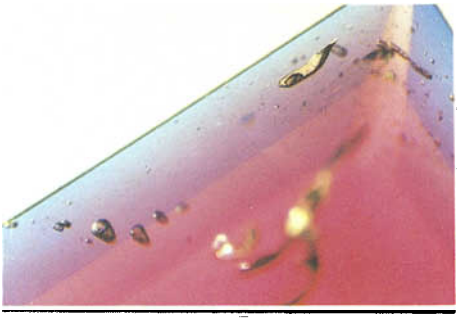

FIG. 2. Type I. Elliptical flux inclusion with a bubble-like structure (top right). Kashan ruby 6.3 ×.

Figure 1 shows a typical grouping of Type I inclusions. In Figure 2 some of these 'metallic' inclusions are seen to possess an approximately elliptical shape. The elongate inclusion towards the top right of Figure 2 is of particular interest. The usual metallic appearance is evident but in addition this inclusion contains a black oval structure resembling a bubble.

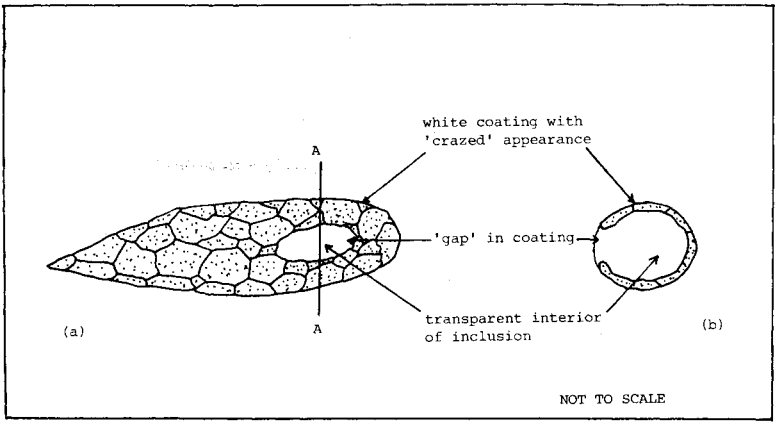

FIG. 3. Probable structure of a Type II inclusion. (a) Lateral view of inclusion. (b) Vertical section along line A-A.

Type II—'Crazed' Solid Inclusions

Most of these inclusions occurred in elongate, well shaped forms with angular to sub-angular terminations (negative crystals?). All of the Type II inclusions observed contained an opaque or translucent substance with a granular, sugary or 'crazed' appearance (resembling 'crazy' paving) which was dazzling white in oblique overhead lighting. Interestingly none of the inclusions seemed to be completely filled with this white material, the latter occurring rather as a thin outer coating or layer. Moreover numerous 'gaps' or breaks in the white coatings enabled the observer to examine the insides of the structures in some cases. Where this was possible the interiors always consisted of a homogeneous, transparent material which in fact comprised the main bulk of the individual inclusions. These observations indicated that Type II inclusions were composite bodies. Their presumed structure is shown diagrammatically in Figure 3.

FIG. 5. Type II. Note large bubble-like 'gap' in flux coating in uppermost inclusion. Kashan ruby 10×.

FIG. 7. Type III. 'Fingerprint' inclusion (left). Kashan ruby 6.3×.

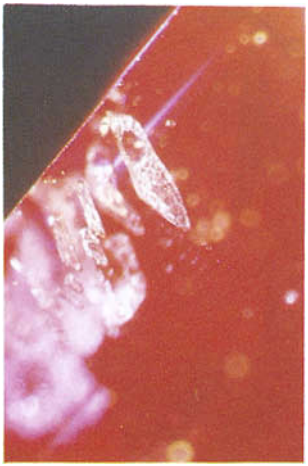

FIG. 4. Type II. Elongate, well shaped inclusions with 'crazed' surface coatings of flux. Kashan ruby 10×

FIG. 6. Type III. 'Fingerprint' inclusion (upper part of photograph). Kashan ruby 6.3×.

Some actual examples of Type II inclusions are shown in Figures 4 and 5. The elongate shape of the inclusions is apparent in the photographs and the 'crazed' appearance of the white coatings is particularly clear in the largest inclusion in focus in Figure 4. Their composite nature is indicated by the occasional presence of bubble-like structures; the latter are not bubbles but represent 'gaps' in the opaque outer layers through which the interiors of some of the inclusions can be seen.

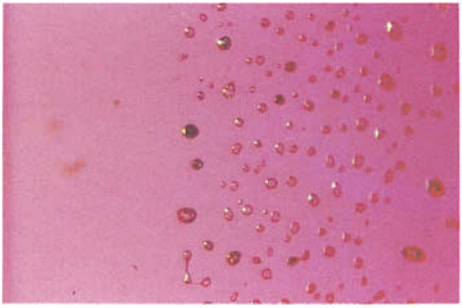

FIG. 8. Type III. Details of 'fingerprint' showing rounded to spherical two-phase inclusions. Kashan ruby 25 ×.

Type III—'Fingerprint' Inclusions

Several good 'fingerprint' inclusions, superficially resembling similar features in natural rubies, were present in the stone. Examples are shown towards the top of Figure 6 and on the left hand side of Figure 7. These inclusions were composed essentially of a large number of very small spherical or near spherical structures which appear in the low magnification photographs (Figures 6 and 7) as tiny, bright pinpoints of light separated by darker areas of corundum. When examined under higher magnification (see Figure 8) the rounded nature of the inclusions within a fingerprint become even more obvious. Many of them in fact approached perfectly spherical, bubble-like shapes; a few displayed 'dumb-bell' forms. Apart from a very small number which were opaque (black), the vast majority of these rounded inclusions showed a high degree of transparency and appeared to be two-phase bodies—individually not unlike the liquid-and-gas inclusions sometimes seen in natural rubies.

3. Discussion

There seems little doubt that the metallic inclusions, designated Type I in this account, represent coarse crystalline residues of flux trapped during the growth of the host ruby. The origin of the 'bubble' in the inclusion shown in Figure 2 is unknown. It may be a genuine gas bubble (oxygen?) produced during shrinkage of the flux on cooling but the possibility that it is a solid body, differing in properties from the surrounding flux, cannot be discounted.

Alan Hodgkinson (personal communication), who has had these inclusions analysed, confirms that they contain a high proportion of zinc—indicating the use of a flux, or flux additive, of somewhat unusual composition during synthesis.

Since nothing comparable with them in every respect has ever been recorded from natural rubies, or indeed from any other types of synthetic ruby, such coarse inclusions can be regarded as valuable indicators of flux growth. Information from Kashan, however, suggests that these useful inclusions are rare or absent altogether from faceted stones currently being marketed. The nature of the other types of inclusions present in the stone is much more speculative. Type III inclusions are considered first because their origin may have a bearing on that of Type II.

Type III inclusions seemed to be typical 'fingerprints' such as are often found in many natural and synthetic gemstones. The spherical, or near spherical shape of the individual inclusions has already been mentioned but their nature is debatable. At first sight they *appeared* to be ordinary two-phase liquid-and-gas inclusions. The presence of gas bubbles is not at all surprising in flux grown gemstones—one would expect gas, probably oxygen, to be liberated during the manufacturing process, perhaps in large quantities. Attempts to persuade any of the gas bubbles to move within their spherical cavities proved fruitless, however, and suggested (but did not prove) that mobility of the bubbles may have been impossible *perhaps because no liquid was present.*

An alternative view is that these are far less common types of two-phase inclusions consisting of a gas bubble combined with a transparent *solid* phase. Without analysis of course, the nature of such a solid phase is purely conjectural. Kurt Nassau, however, in his excellent book *Gems Made by Man** has pointed out that

*See also K. Nassau's Did Professor Nacken ever grow hydrothermal emerald? *J.Gemm.*, 1979, **XVI**(1) at p.47—Ed.

apparently two-phase liquid-and-gas inclusions in Nacken synthetic emeralds are in reality transparent *solid* inclusions associated with gas bubbles, the latter being liberated as a result of shrinkage during cooling. Even more surprising were the results of Nassau's analyses of the solid components of the two-phase inclusions in the Nacken material—they were found to consist of trapped flux containing the ingredients of beryl with extra chromium, but in a *vitreous* (glassy) state. It is tempting to suggest that the inclusions which make up the fingerprints in the Kashan stone studied have a similar origin. If this is true then these tiny inclusions consist essentially of spheres of flux-glass, perhaps containing some Al_2O_3 and Cr, together with small gas bubbles. The process envisaged would involve very rapid cooling of droplets of residual flux, which would prevent its crystallization, followed by contraction with the formation of a shrinkage gas bubble and ultimate solidification as glass.

The white sugary material forming the coatings to the Type II inclusions is definitely solid and is probably composed of residual flux. The 'crazed' pattern of this material suggests rapid crystallization around a large number of closely spaced nucleation centres. It is conceivable that such a process could occur around the walls of gas-filled cavities which contained small amounts of trapped flux. The general shapes of these inclusions, however, are nothing like typical gas bubbles so it is unlikely that these inclusions are gas filled. It also seems extremely doubtful that any liquid is present either. The interesting possibility remains that the interiors of these inclusions are again *solid.* Their transparency might indicate that they are also composed of flux-glass as postulated above for the Type III inclusions. A satisfactory explanation for the precise development of these unusual inclusions is difficult to give. Perhaps the amount of alumina dissolved in the flux is an important factor, coupled with cooling rate, which determines whether flux-glass or crystalline flux develops. If this is true the interiors of these inclusions are probably richer in dissolved alumina than the crystalline flux coatings. The original sizes of Type II inclusions may also be significant in determining how they subsequently develop.

4. CONCLUSION

The above observations suggest that the three types of inclusions are related to each other. Type II inclusions seem to contain a combination of the features (namely crystalline flux *and* possibly flux glass) seen independently in Types I and III, and this may indicate that a transition exists between the three types. This is certainly true on the basis of size—Type I are the largest, Type II are intermediate in size and Type III the smallest.

It is therefore possible that all of the inclusions consist essentially of solid flux—either crystalline or vitreous. The amount of alumina dissolved in the flux, original size disparities between the inclusions and differences in cooling rates, could all contribute to the totally different visual characteristics of the three types of inclusions. There is no apparent evidence for the existence of liquid in any of the inclusions examined and described.

ACKNOWLEDGEMENT

The author wishes to thank Alan Hodgkinson for the loan of the Kashan ruby which is discussed in this paper.

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Nassau, K. 1980. *Gems Made by Man.* Chilton, Radnor, Pa.

[*Manuscript received 25th July, 1983.*]

IMPROVEMENTS ON THE RAYNER REFRACTOMETER

By R. M. YU, Ph.D., F.G.A., G.G.

Physics Dept., University of Hong Kong.

In the last few years I have had the pleasure of teaching hundreds of jewellery-trade people in practical gemmology. In our laboratory both the Rayner (S model) and the Duplex refractometers are provided for students' use. Most novices find the Rayner refractometer easier to use because they can read refractive index scale by just positioning their eyes close to the refractometer eyepiece. With the Duplex refractometer they have to position their eyes at a suitable distance by trial and error before a refractive index can be read. However, by the time they progress to the distant vision method (spot test) of measuring the refractive index of cabochons, they find the Duplex refractometer much easier to use. This is because the Duplex refractometer has a wider field of view of about thirty small divisions, corresponding to a refractive index range of 0.3. In contrast the field of view in the Rayner refractometer is only about four small divisions, corresponding to a refractive index range of 0.04. If the 'spot' does not lie near to any one of the marked scale reading 1.4, 1.5, 1.6, 1.7 and 1.8, the user cannot read the refractive index of the cabochon directly. Such a situation is indicated in Figure 1 where the field of view is shown by a dotted circle and the 'spot' is represented by an ellipse. We have overcome this inconvenience by placing a divergent lens on top of the eyepiece of the Rayner refractometer whenever the 'spot test' is conducted. With a divergent plano-concave lens of focal length -148 mm (Ref.1) the field of view can be increased to about nine small divisions, corresponding to a refractive index range of 0.09. One of the marked values of the refractive index scale will then fall inside the field of view.

Although the divergent lens can be used as it is, readers who have access to a mechanical workshop may wish to make a holder for the lens. We have constructed a holder to attach the divergent lens permanently to the refractometer eyepiece (Figure 2). With this

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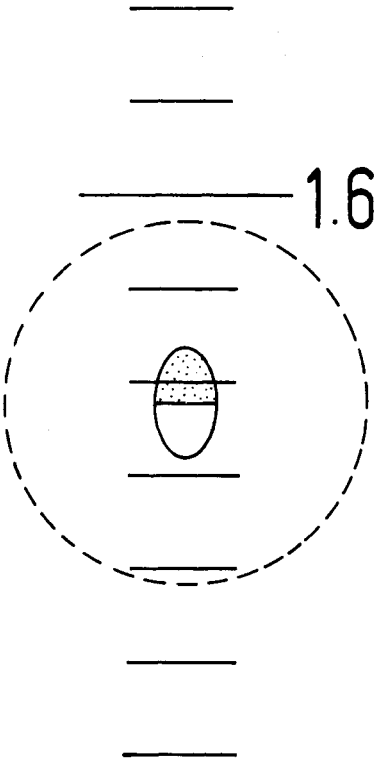

FIG. 1. Rayner refractometer 'spot test' field of view.

holder the divergent lens may be swung out of view when it is not required, thereby allowing either a polarizing or monochromatic filter to be placed on top of the refractometer eyepiece.

Another possible improvement on the Rayner refractometer concerns the yellow monochromatic filter supplied by the manufacturer. Such a filter is placed on top of the refractometer eyepiece to enable the refractive index to be read more accurately in monochromatic light. It is essential for determining the birefringence (double refraction) of faceted gems. Our experience shows that the yellow filters bought in 1978 are quite adequate but that those bought in later years are so dark as to transmit

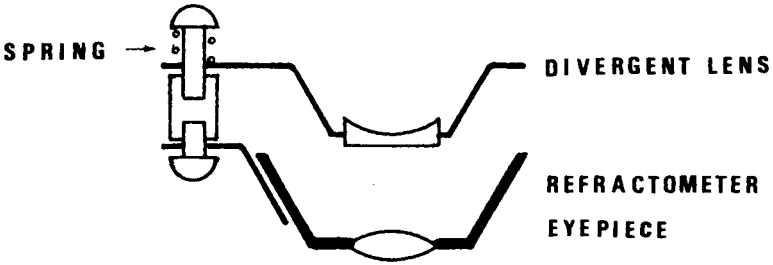

FIG. 2. Sketch of the divergent lens holder.

insufficient light for comfortable reading of refractive indices. We have now dispensed with these dark yellow monochromatic filters, and instead place a 589.6 nm interference filter (Ref.2) in front of either the ground glass window of the refractometer or the white light source, whichever is more convenient. White light from any incandescent lamp becomes a strong beam of yellow monochromatic light after passing through the 589.6 nm interference filter. The filter can be stuck on to the refractometer window with cellotape. Alternatively a holder made of aluminium sheet or even cardboard can be glued on to the refractometer to hold the interference filter. Then the filter may be installed or removed from the holder easily.

In conclusion I hope the manufacturer will incorporate the above mentioned features in their next generation of Rayner refractometers for users' convenience.

REFERENCES

1. Divergent lenses are available from Edmund Scientific Co., 101E Gloucester Pike, Barrington, N.J. 08007, U.S.A. #95,425 consists of two plano-concave lenses of focal length -148 mm and diameter 12 mm at total cost US$2.85.
2. Edmund Scientific Co. #30698 interference filter (589.6 nm) at US$16.75 each.

[*Manuscript received 4th February, 1983.*]

GEMMOLOGICAL ABSTRACTS

BANCROFT (P.). *Australia's black jade.* Lapidary J., **37**, 5, 700-14,22 figs (19 in colour), 1983.

A 'black' variety of nephrite has been found near Cowell, South Australia. Other colours, including a fine dark green, are also found in the area. General notes on the jade minerals are given. M.O'D.

BEASLEY (A. W.). *Australian topaz for faceting.* Australian Gem and Treasure Hunter, 82, 45-6, 1 fig., 1982.

A number of Australian topaz locations are described. M.O'D.

CASE (L. C.). *A lot of jadeite is an adventure in jade.* Lapidary J., **37**, 6, 840-54, 24 figs in colour, 1983.

Describes the sorting of a large quantity of jadeite and the criteria employed in selection of material for cutting. M.O'D.

CASSEDANNE (J. P.), CASSEDANNE (J. O.), VACHEY (H.). *L'axinite de la Lagoa da Tabua (District de Lagoa Real-Etat de Bahia-Brésil).* (Axinite of Lagoa da Tabua, district of Lagoa Real-Etat, Bahia, Brazil.) Anales, Academia Brasileira de Ciencias, **55**, 1, 93-103, 6 figs, 1983.

Axinite crystals said to be larger than those found at Santa Rosa (Bahia, Brazil) have recently been recovered from Lagoa da Tabua in the same state. The crystals occur in veins with andalusite, actinolite, calcite, quartz and feldspar. Some crystals exceed 20 cm in length. The iron content places the newly discovered material in the ferroaxinite category. M.O'D.

CHIRKIN (A. P.), PUSTYL'NIK (A. I.), KAPACHINSKAYA (O. G.). *The thermal field in a furnace for growing crystals by the Verneuil method.* Soviet physics—crystallography, **27**, 5, 592-5, 4 figs, 1982.

A method of studying the thermal field in a Verneuil furnace is suggested and the distribution of the particles of the charge in the burner flame in flow and temperature-rate change conditions is discussed. Changes in the charge flow rate noticeably affect temperature fluctuations at the crystallization front. M.O'D.

DALLOW (L.). *Pakistan.* Australian Gem and Treasure Hunter, 82, 26-31, 8 figs (6 in colour), 1983.

Interesting account of a recent visit to Pakistan. M.O'D.

DANIEL (P.). *Tiger eye gems machined by diamond.* Industr. Diamond Rev., 4/83, 184-5, 4 figs, 1983.

Advances in diamond tool technology and machining methods have resulted in the tiger-eye variety of quartz no longer being considered as a problem stone for

cutting by the manufacturing jewellers. Fine-grade workable-quality tiger-eye is only found in South Africa, and government legislation prevents it from being exported except in the polished state. The polishing sequence now includes cutting the rough material into slabs using a diamond saw (taking careful account of the angle so as to exploit the material's chatoyancy) and then coring the slabs with a special diamond drill to produce cylindrical blanks. These blanks are next secured to dop pins and ground on a diamond-impregnated cabbing wheel to a preform shape. Finally, the preforms are tumble-polished in a vibratory lap using a conventional abrasive with water plus sawdust from a particular wood. The latter component is added as a 'cushion' to prevent stones from chipping or cracking each other. P.G.R.

DAY (E.). *Jade hunting in New Zealand.* Lapidary J., **37**, 5, 726-35, 10 figs, 1983.
Several areas of jade production in New Zealand are described. M.O'D.

GIPPIUS (A. A.), ZAITSEV (A. M.), VAVILOV (V. S.). *Formation, annealing and interaction of defects in ion-implanted layers of natural diamond.* Soviet Physics: Semiconductors. **16**, 3, 256-61, 8 figs, 1982.
Cathodoluminescence techniques were used to discover what the features of ion-implanted diamonds were. It is thought that the features could be explained using existing ideas on the properties of disordered regions created by ions. Nitrogen was found to have a specific influence on the formation of defects in ion-implanted layers. M.O'D.

HEYLMUN (E. B.). *Opal localities in west central Mexico.* Lapidary J., **37**, 4, 598-602, 1 map, 1983.
Deals with the opal-producing locality of Magdalena, west of the city of Guadalajara, Jalisco, Mexico. Some opal with blue and green coloration is found there. M.O'D.

HEYLMUN (E. B.). *Four opal localities in Mexico.* Lapidary J., **37**, 6, 880-2, 3 maps, 1983.
Two of the localities, the Jada opal district and La Curva opal district, are in the state of Nayarit; the other two, the Huanimaro and Penjamo opal districts, are in the state of Guanajuato. In all cases the opal occurs in a rhyolitic rock. M.O'D.

HUTCHINSON (J.). *Opal fever in the outback.* Reader's Digest, **123**, 737, 142-6, 2 figs in colour, 1983.
Brief and accurate account of opal mining in Australia. M.O'D.

KAMO (M.), SATO (Y.), MATSUMOTO (S.), SETAKA (N.). *Diamond synthesis from gas phase in microwave plasma.* J. Crystal Growth, **62**, 642-4, 3 figs, 1983.
Crystalline diamond has been grown on a non-diamond substrate from a gaseous mixture of hydrogen and methane. Microwave glow discharge conditions were used and the crystals showed predominantly {100} and {111} faces. M.O'D.

KOGO (K.). *Persian Gulf pearls.* Gemmological Review, **4**, 6, (English translation section) 1-5, 1982.
A brief history of pearl fishing and the Kuwait pearl market. M.O'D.

McMahon (B.). *Zircons from Lake Bullenmerri, Victoria.* Australian Mineralogist (bound with Australian Gem and Treasure Hunter No. 81, 1983), 42, 235-6, 3 figs, 1983.

Well-formed crystals of zircon showing a range of colour from pale orange-brown to straw, with some a pale greenish yellow to colourless, have been found on the shore of Lake Bullenmerri, Victoria, Australia. The crystals, many containing black inclusions of (?) allanite, occur in a heavy mineral sand layer. M.O'D.

Milledge (H. J.), Mendelssohn (M. J.), Seal (M.), Rouse (J. E.), Swart (P. K.), Pillinger (C. T.). *Carbon isotopic variation in spectral type II diamonds.* Nature, **303**, 791-2, 1 fig, 1983.

Type II diamonds measured for this study showed a carbon isotopic composition (δ ^{13}C values) of from −5 to −31.9%. The composition for most diamonds falls in a range from −5 to −9%. M.O'D.

Nogués Carulla (J. M.). *Obtención de gemas sinteticas.* (Obtaining of synthetic gemstones.) Gemologia, **16**, 53/54, 5-37, 5 figs, 1982.

Comprehensive survey of the synthetic gem field. M.O'D.

O'Donoghue (M.). *The dealer looks at gemstones—11.* Gems, **5**, 3, 16-17, 1983.

Price changes in ruby, emerald, sapphire, topaz, pearl and coral are discussed and notes given on the current state of the Brazilian market.

(Author's abstract.) M.O'D.

O'Donoghue (M.). *Some beryl minerals.* Gems, **15**, 3, 28-9, 1983.

Taaffeite, bromellite and the element beryl and its compounds are discussed.

(Author's abstract.) M.O'D.

O'Donoghue (M.). *Man-made gemstones.* Gems, **15**, 3, 34-5, 1983.

A previous account of the hydrothermal growth of quartz is continued and followed by discussion of the Knischka synthetic ruby, turquoise and emerald.

(Author's abstract.) M.O'D.

Read (P.). *Artificial enhancement of coloured gemstones.* Australian Gem and Treasure Hunter, 82, 49-50, 1 fig, 1983.

Summarizes the position in gemstone heating and irradiation. M.O'D.

Ritchie (C. I. A.). *Tortoiseshell jewellery.* Gems, **15**, 3, 8-11, 5 figs, 1983.

An introduction to the occurrence and fashioning of tortoiseshell. M.O'D.

Skalicky (J.). *Interesting opals from Czechoslovakia.* Lapidary J., **37**, 4, 578-84, 12 figs (11 in colour), 1983.

Describes opal occurrences in a number of Czech localities. In general the material is dendritic, banded or glassy rather than displaying a play of colour.

M.O'D.

Stuker (P.). *Mineralien mit seltenen Erden.* (Minerals with rare earths.) Schweizer Strahler, **6**, 7, 288-95, 6 figs, 1983.

Discusses the use of the spectroscope in identifying minerals with a rare earth content. M.O'D.

SUHNER (B.). *Bestimmung von Mineralien mit Infrarot-Spektroscopie.* (Identification of minerals with infrared spectroscopy.) Schweitzer Strahler, **6**, 7, 296-306, 8 figs, 1983.

The use of infrared identification techniques in mineral identification is discussed. M.O'D.

SWART (P. K.), PILLINGER (C. T.), MILLEDGE (H. J.), SEAL (M.). *Carbon isotopic variation within individual diamonds.* Nature, **303**, 793-5, 1 fig, 1983.

Sections of Type I diamonds were analysed to see if there was an intra-specimen variation in carbon isotopic content. In many cases a trend from the centre to the exterior was noted. Some samples showed cores enriched in ^{12}C whereas the edges became heavier. Controlled laser dissection was employed to show up the very small scale of internal structures during an effort made to pinpoint areas in individual stones which might have been formed in differing conditions. M.O'D.

TENNYSON (C.). *Granat von Bayerischen Fundstätten.* (Garnet from Bavarian localities.) Aufschluss, **34**, 275-85, 6 figs, 1983.

Analyses and crystal structure for a number of garnets from various locations in Bavaria are given. M.O'D.

THIMES (J. L.). *A simple polariscope and dichroscope combination.* Lapidary J., **37**, 4, 556-66, 14 figs, 1983.

Details are given of the method of making a combination dichroscope and polariscope at low cost. M.O'D.

ZAITSEV (A. M.), GIPPIUS (A. M.), VAVILOV (V. S.). *Luminescence of impurity-defect complexes containing nitrogen in ion-implanted layers of natural diamond.* Soviet Physics: Semiconductors, **16**,3, 252-6, 5 figs, 1983.

An examination by cathodoluminescence of diamond crystals with nitrogen impurities induced by ion implantation showed specific lines in the spectra. The lines were associated with complexes containing nitrogen atoms. M.O'D.

ZEITNER (J. C.). *Proctor's rough and cut collection.* Lapidary J., **37**, 4, 572-6, 5 figs in colour, 1983.

The Keith and Mauna Proctor collection of fine gem crystals is described. Mining anecdotes relating to some of the specimens are given. M.O'D.

ZEITNER (J. C.). *Iron in gems.* Lapidary J., **37**,5, 684-92, 11 figs, 1983.

Iron gem minerals and the role played by the element in coloration are discussed. M.O'D.

Gemstones of China. Gemmological Review, (page numbers in English translation section) (a) **4**, 7, 1-4; (b) **4**, 8, 1-4; (c) **4**, 9, 1-4; (d) **4**, 10, 1-5; 1982.

(a) The regions of China most likely to produce gemstones are listed. The original Japanese text includes a map. (b) Nephrite occurrences and uses are described. (c) Jade-like minerals and their occurrences are described. (d) Localities for fluorite, amber, pyrophyllite, andalusite, turquoise and pearl are given. M.O'D.

Indian gemstone localities. Gemmological Review, **4**, 11, (English translation section) 1-4, 1982.

General geological survey of India with reference to gem-producing areas. The original Japanese text includes a map. M.O'D.

Jewellery News Asia. Issue no. 1. Jewellery News Asia Ltd., Hong Kong, 1983. Annual subscription for U.K., £30.

A standard form journal with newspaper-type articles, brightly presented and illustrated. M.O'D.

The paradise of gems has still other surprises. Brazil Trade and Industry, **6**, 61, 23-6, 2 figs in colour, 1983.

Gives a short account of the present state of Brazilian gem production. M.O'D.

BOOK REVIEWS

ANDERSON (B. W.). See Webster (R.).

BARNETT (F.). *Opal and how to work it.* Gemcraft Publications Pty Ltd, East Malvern, Victoria, 1981. pp. iv, 60. Illus. in black-and-white. Price on application.

A practical and clearly-written booklet which would be useful to those able to buy rough and who wish to fashion it. Details of fashioning occupy the bulk of the book, but there is also a useful chapter on evaluating stones. I recommend this as a no-nonsense guide. M.O'D.

BLAKEMORE (K.). *The retail jeweller's guide.* 4th edn, Butterworths, London, 1983. pp. vii, 359. Illus. in black-and-white. £18.

It is always pleasing to see an old friend reappearing and in this case I have always regarded Blakemore as a perennial to which one could always turn when faced with the query that is just on the fringe of one's field (or completely out of it). The first edition of the *Guide* came out in 1969 and replaced Selwyn's *Retail Jeweller's Handbook,* which ran to a number of editions; I have the impression that the present work is to some extent streamlined and lacks the slightly garrulous air that the old *Handbook* used to have but I suppose that is a change for the better. In any case this is a good book; information is concisely presented and brought up to date, especially in areas where there have been changes in laws (hallmarking of platinum is an example). Some useful appendices and a good index complete a textbook which every student should have by them. M.O'D.

DIETRICH (R. V.), WICANDER (R.). *Minerals, rocks and fossils.* Wiley, New York, 1983. pp. 212. Illus. in black-and-white. £7.50.

This book forms part of the Wiley self-teaching guides series and aims to instruct the reader as he goes along. To this end each chapter closes with a set of

questions (you cannot find the answers at the back of the book). Considerable assistance is given by text illustrations and the style is lucid. M.O'D.

EPSTEIN (E. J.). *The death of the diamond.* [Previously published under the title *Diamond invention.*] Sphere Books, London, 1983. pp. 270. £1.95.

The author summarizes the history of diamond mining and distribution with an attempt at a breakdown of the interlocking companies in which De Beers have an interest. It is not possible to say how accurate this breakdown is, nor to come to any conclusion about an argument put forward that a number of factors will eventually cause the breakdown of the system by which diamond prices are controlled. An index and chapter notes are provided. M.O'D.

MACINTOSH (E. K.). *Rocks, minerals and gemstones of Southern Africa.* 2nd edn, C. Struik, Cape Town, 1983. pp.120.Illus.in colour.£7.00.

Minerals from southern Africa (widely interpreted) are classed by their properties, rock types, and economic importance in this handy-sized guide. Colour reproduction is good and factual information reliable. It is good to see illustrations of specimens from Namibia as well as from the Republic. M.O'D.

READ (P. G.). *Gemmological instruments.* 2nd edn, Butterworths, London, 1983. pp. 328. Illus. in black-and-white. £20.

The main difference between the first and second editions of this excellent book is that the instruments reviewed are evaluated in this later volume. There are, too, many more of them. A comparative value guide to the instruments is another useful departure from previous practice. Experimental equipment and microphotography are covered and the author's own computer system for the identification of gemstones is outlined. A great deal of the equipment described is shown in photographs which have reproduced quite well; each chapter has a most useful bibliography, and there are tables and lists of suppliers at the end of the book. This work is now essential for all who need to test stones and is also a most enjoyable experience to read casually. M.O'D.

VOLLSTÄDT (H.), BAUMGARTEL (R.). *Edelsteine.* (Gemstones.) 2nd (revised) edn. VEB Deutscher Verlag für Grundstoffindustrie, Leipzig, 1982. pp. 260. Illus. in black-and-white and in colour. M32.80.

An extensive bibliography, good quality coloured pictures and an informative text make this an excellent introduction to the study of gemstones. A good deal of time has been spent on chasing up references, and the material is up to date. M.O'D.

WEBSTER (R.). *Gems, their sources, descriptions and identification.* 4th edn, revised by B. W. Anderson. Butterworths, London, 1983. pp. xxii, 1006. Illus. in black-and-white, with 17 coloured plates. £40.

This new edition of Webster's *magnum opus* has been brought up to date by B. W. Anderson, who, as was to be expected, has done his work well.

The general arrangement and a substantial amount of the text remains unchanged, though names of newly found occurrences are added and new discoveries are recorded at appropriate places throughout. Among new additions

may be mentioned descriptions of Brazilian opal, charoite, crystalline (non-metamict) ekanite, diaspore, 'elephant pearls', 'Gilson created' coral and lapis lazuli, plastic imitation opal, prosopite, slocum stone, sogdianite, sugilite, synthetic opal and 'synthetic turquoise' (this list is far from exhaustive, and I regret that the wrongly formed name of one new gemstone has been given further currency as 'tsavorite'—backed up by the mis-spelling of 'Tsavo' as 'Tsavor'—despite the decision of C.I.B.J.O. in favour of the correctly formed 'tsavolite'.* Another addition is a lively account of de Boimenu's pre-1914 apparently successful and inexplicably ignored manufacture of diamonds (one of them large enough to be cut in Amsterdam as a tiny brilliant with 32 facets). Several methods of diamond growth other than that of the G.E.C. are described, and the present state of knowledge regarding both heat-treated sapphires and the absorption spectra and fluorescence of bombarded colour-changed diamonds is clearly summarized.

The Australian Kimberley (Ashton Joint Venture) diamond story is brought up to the end of 1982, which is remarkable in a book published early in 1983. The chapter on RI measurement has a re-written and extended section on refractometers and also includes 'relative reflectivity meters': these are followed by clear descriptions of thermal conductivity probes and the Gem Diamond Pen, in the same chapter since the prime use of these is likewise to distinguish diamond from its modern imitations. As Mr Anderson emphasizes in his Preface, these new instruments were the direct reply to the challenges of strontium titanate, of GGG and in particular of cubic zirconia as increasingly credible imitations of diamond: 'a full description of CZ and of these new instruments was obviously a foremost concern of this new edition.'

The publishers too have done their work well, so far as appearance and ease of handling are concerned. The text, now printed in clearer type, is much easier on the eye, and, although now 1028 pages in all as against the third edition's 949, the weight in the hand has been reduced by about 5 oz. (*ca.* 142g) without—it would seem—impairing in any way the strength of the volume. But even for these days they have permitted a quite unusually large number of misprints, mainly new misprints introduced into the parts copied verbatim from the previous edition, where there is least excuse for them: *per contra* some of the third edition's misprints are corrected, but it is sad that the misprinted 'parasite' (3rd edn, p. 671) having been corrected to 'parisite' (4th edn, p.771) the third edition's correct 'parisite' (p. 88) should have been misprinted 'parasite' in this fourth edition (p. 104).

The colour plates have been reduced from twenty-three to seventeen without loss of value. The five quite unsuitable and unhelpful photographs in the third edition adversely criticized by this *Journal's* reviewer† have been omitted, and for some of the good gemstone photographs, whose rather 'wooden arrangement' he also criticized, even better ones have been substituted. It is, however, a pity that in the captions of five of the retained plates the weights of the stones illustrated, given in the previous edition, have now been left out.

When I reviewed the first edition of Webster's *Gems* twenty-one years ago,‡ my main criticisms concerned matters of literary rather than gemmological

*J. Gemm., 1979, **XVI** (8), 554.
†J. Gemm., 1975, **XIV** (7), 350.
‡J. Gemm., 1962, **VIII** (8), 306-8.

interest—lapses in style, misuse of words, misprints, etc.—and the only gemmological error to which I called attention was the inaccurate description of the monoclinic crystallographic axes: despite frequent reminders to the author this remained in his second and third editions, and I am sorry to see that it has survived unchanged into this fourth.

Nearly all the failings in this important work, however, are either matters of the original author's style of writing (Mr Anderson's contributions are recognizable as limpid pools of clarity amidst Mr Webster's sometimes rather turbid prose) or such as could and should have been eliminated in this or previous editions by knowledgeable and conscientious publishers' editors. Echoing what I wrote of the first, I can confidently say of this fourth edition that to the serious gemmologist it will be—like his microscope, his spectroscope and his refractometer—an indispensable tool and a valued possession. J.R.H.C.

Cristaux géants. (Giant crystals.) Hachette, Paris, 1983. pp. 77. Illus. in black-and-white and in colour. Fr45.

This attractive book summarizes a project conducted under the aegis of the Muséum National d'Histoire Naturelle in Paris, the aim being to preserve a representative collection of crystals of great size. Since so many very large crystals are cut up or ground down for a variety of purposes the acquisition by the Muséum of the Ilia Deleff collection was timely, since it contains 78 Brazilian specimens of sizes ranging from 200-400 kg, with other pieces of smaller size. The book discusses crystal formation and the setting up of the exhibition now at the Muséum. M.O'D.

ASSOCIATION NOTICES

OBITUARY

Mr Leslie Thomas Boxall, F.G.A. (D.1954), Kingston-upon-Thames, died on 30th August, 1983.

Mr David Lewis Jones, M.A., F.G.A. (D.1972 with Distinction), Kew, Richmond, died on 12th September, 1983.

GIFT TO THE ASSOCIATION

The Council of the Association is indebted to Dr Masahiro Hosaka, Yamanashi, Japan, for a scroll depicting a postal scene.

NEWS OF FELLOWS

At the First European Conference on Precious Stones, which took place in Antwerp, Belgium, on 21st-22nd October, 1983, Mr Peter G. Read, C.Eng., F.G.A., gave a talk on 'Diagnostic methods of distinguishing between natural and synthetic gemstones'.

MEMBERS' MEETINGS

London

On 19th October, 1983, at the Central Electricity Generating Board Theatre, Sudbury House, Newgate Street, London E.C.1., Mr Roy Huddlestone gave an illustrated lecture on Siberian diamonds. It is hoped that the substance of the lecture will be published in a future issue of the *Journal*. Before the lecture Mr Peter G. Read, C.Eng., F.G.A., presented to Mr Noel Deeks, F.G.A., the Vice-Chairman, on behalf of the Association, the thematic gem, mineral, mining and jewellery collection of postage stamps made by the late Mrs (Doreen) Read, and Mr Deeks expressed the thanks of the Association for this generous gift. A small cross-section of the collection is illustrated on p.74.

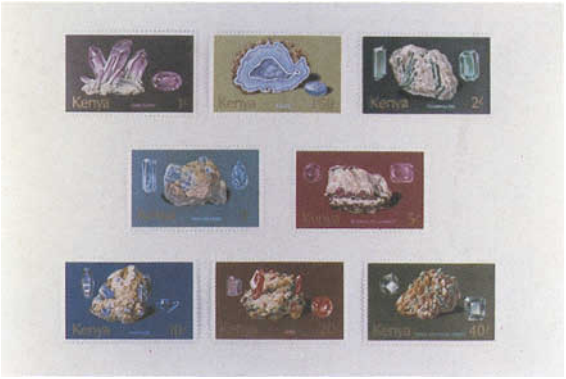

1. Part of a set of 15 stamps from Kenya (1978), illustrating amethyst, agate, tourmaline, aquamarine, rhodolite garnet, sapphire, ruby and green grossular garnet.

2. Set of six stamps from the U.S.S.R. (1963) with topaz, jasper, amethyst, emerald, ruby and malachite.

3. (Top) set of four stamps from Sri Lanka (1976) showing sapphire, cat's eye, star sapphire, ruby.; (Centre) three stamps from Brazil (1977)—emerald, topaz, and aquamarine.; (Bottom) Four stamps from Thailand (1972)—ruby, yellow sapphire, zircon, star sapphire.

Midlands Branch

On 28th October, 1983, at the Society of Friends, Dr Johnson's House, Bull Street, Birmingham, an illustrated talk was given by Mr Eric Bruton, F.G.A., entitled 'The wonder of diamonds'.

On 25th November, 1983, at the Society of Friends, a talk was given by Mr J. I. Reynolds, F.G.A., and Mr R. M. Wood, F.G.A., on the firm A. Ruppenthal, the well-known gem merchants.

North-West Branch

On 20th October, 1983, at Church House, 1 Hanover Street, Liverpool, the Annual General Meeting was held at which Dr John W. Franks, F.G.A., was elected Chairman and Mrs Edna Cartmel re-elected Secretary. The meeting was followed by a cheese and wine supper.

On 17th November, 1983, at Church House, Mr Alec Farn, F.G.A., gave a talk entitled 'Jade and jade-like minerals'.

South Yorkshire & District Branch

On 18th October, 1983, at the Sheffield City Polytechnic, Detective Inspector Wilde of the South Yorkshire Police gave a talk on crime prevention.

COUNCIL MEETING

At the meeting of Council held on Thursday, 29th September, 1983, at the Royal Automobile Club, London, S.W.1, the business transacted included the election to membership of the following:

FELLOWSHIP

Aburrow, Michael B., Wimborne. 1983
Alva, Shyamala J., Bombay, India. 1982
Askew, Mark A., Bristol. 1983
Axon, Martin W., London. 1983
Barnard, Stephen J., Theydon Bois. 1983
Bercott, David S., Glasgow. 1983
Bienert Albaladejo, Rosario, Barcelona, Spain. 1977
Bird, Nigel G. D., Epsom. 1983
Bishop, Ian C., London. 1983
Bisset, Ross, London. 1983
Bugg, John R., Wolverhampton. 1983
Chow, Herman K. M., Hong Kong. 1983
Cloke, Debbie H. N., Hong Kong. 1983
Collins, Glen M., Glasgow. 1983
Condrup, Jonathan R., London. 1983
Darmudas, Nat, London. 1983
Davies, Stephen, Wallsend. 1983
Doughty, Michelle S., Wembley. 1983
Eadie, John, Glasgow. 1983
Firth, Barbara, London. 1983
Fitzgerald, Leslie E., Stanmore. 1983
Flower, Jonathan S., Knutsford. 1983
Fonseka, Ruwan K. M., Colombo, Sri Lanka. 1982
Garrod, Douglas J., Exeter. 1983
Gavin, Sandra R., Thornton Heath. 1983
Gilliland, Hilary L., Newtownabbey, N. Ireland. 1983
Gilmour, Kevin D., Sheffield. 1983
Goodland, John R., Gstaad, Switzerland. 1983

Greatwood, John, Mitcham. 1983
Groom, Peter J., Luton. 1983
Hayes, Anne-Maria, London. 1983
Holness, Neil P., London. 1983
Houghton, Mark W., Poynton. 1983
Hu, Shirley S., Oxford. 1983
Huddy, William R. H., Newton Abbot. 1983
Hurst, Patricia H., Carradale. 1983
Konrath, Anthony M., Richmond. 1983
Krot, Johannes H., Amstelveen, Netherlands. 1983
Lumley, John S. P., London. 1983
McFarlane, Patricia A., London. 1983
McNair, George A., Newcastle upon Tyne. 1983
Ma, Chi Wing C., Hong Kong. 1983
Matthys, Nigel J., Ickenham. 1983
Mehta, Anoop K., London. 1983
Mizrahi, David A. S., Frankfurt, W. Germany. 1983
Mok, Dominic W. K., Hong Kong. 1982
Morling, Anthony J. D., St Mary, Jersey, C.I. 1983
Munster, Sarah H., London. 1983
Nash, Isobel M., Watford. 1983
Orchant, Lewis, Glasgow. 1983
Park, Stephen W., Romford. 1983
Pedersen, Julie, Liverpool. 1983
Purcell, Ian R., Dunstable. 1983
Rennie, Margaret M., Bothwell. 1983
Richardson, William F., Northwich. 1983
Roberts, Kassandra M., Bromborough. 1983
Schurch, Marie-Louise, Geneva, Switzerland. 1983
Sealey, Ralf E., London. 1983
Shapland, Leonora A., London. 1983
Shotton, Dominic E. J., Tring. 1983
Smith, Ian J., Rochdale. 1983
Styles, Suzanne S., Christchurch. 1983
Sutton, Janine R., Birmingham. 1983
Tam, David C. C., Hong Kong. 1982
Taub, Giselle-Karen, London. 1983
Tong, Ka-Shing, Hong Kong. 1983
van den Arend, Willem A., Rotterdam, Netherlands. 1983
Vaughan, Malcolm J., London. 1983
Wells, Bruce I., Glasgow. 1983
Wiesauer, Georg, Graz, Austria. 1983

TRANSFERS FROM ORDINARY MEMBERSHIP TO FELLOWSHIP

Abrami, Aurelio G., Milan, Italy. 1983
Amoroso, Robert E., Boston, Mass, U.S.A. 1983
Ashworth, Ian E., Bristol. 1983
Attwell, William G., Toronto, Ont., Canada. 1983
Balderston, Catriona I., London. 1983
Baxter, Gordon E., Whangarei, N.Z. 1983
Berthelsen, Lawrence J., Townsville, Qld, Australia. 1983
Carvey, Robyn, Hong Kong. 1983
Chow, Lorraine M., Hong Kong. 1983
Clark, Patricia M., Hong Kong. 1983
Clarke, Norman V., Blandford Forum. 1983
Cottafavi, Aliette, Geneva, Switzerland. 1983
Deer, Georgina, Salford. 1983
Demoray, Scott B., Grand Rapids, Mich., U.S.A. 1983
Denney, Shane S., Jacksonville, Ill., U.S.A. 1983
Eckley, Gareth D., Brecon. 1983
Eisenburger, Sabine F., Vienna, Austria. 1983
Elias, Abdul H., London. 1983
Gimpel, Remy F., London. 1983
Glaholm, Janice A., Paris, France. 1983
Greig, Edward S., London. 1983
Harre, Hendrik, Berchem, Belgium. 1983

Hee, Vincent Kim San, Singapore. 1983
Hegarty, Kathleen M., New York, N.Y., U.S.A. 1983
Hills, Gavin A., Moonah, Tas., Australia. 1983
Horne, Allan R., Brighton. 1983
Iber, Beverley A., Peoria, Ill., U.S.A. 1983
Imai, Seiichi, Fukuoka-Shi, Japan. 1983
Imazawa, Satoru, Ichikawa City, Japan. 1983
Itoh, Yasuhiro, Osaka, Japan. 1983
John, Bryan C., Carmarthen. 1983
Kanô, Mieko, Fukuoka City, Japan. 1983
Karpelowsky, Raymond, London. 1983
Kennedy, Muriel D., Toronto, Ont., Canada. 1983
Khanna, Atul, Birmingham. 1983
King, Clive H. M., Tsumeb, Namibia. 1983
Klauda, Frank P., Rochester, Minn., U.S.A. 1983
Kok-Visser, Astrid S., Nairobi, Kenya. 1983
Kwan, Ng Yue Yuk I., Hong Kong. 1983
Lee, Robert C. S., Hong Kong. 1983
Lemen, John R., Long Beach, Ca, U.S.A. 1983
Liggett, Sonia A. M., Cardiff. 1983
Lu, Milton R. K., Taipei, Taiwan. 1983
Ma, Lisa L. H., Hong Kong. 1983
Mainwaring-Burton, Jeremy J., Johannesburg, S. Africa. 1983
Marczycha, Michael J., Leeds. 1983
Mayer, Anton S., St Saviour, Jersey, C.I. 1983
Maynard, Mavis A., Sturminster Newton. 1983
Miyata, Takeshi, Yamanashi, Japan. 1983
Monnas, Maria L., Mombasa, Kenya. 1983
Mouzannar, Nabil I., Beirut, Lebanon. 1983
Munday, John J., Eltham, Vict, Australia. 1983
Nakamura, Midori, Ichikawa City, Japan. 1983
Nawaz, Rab, Belfast, N. Ireland. 1983
Ninomiya, Mutsuko, Yamanashi-Ken, Japan. 1983
Nitta, Hisako, Tokyo, Japan. 1983
Nomura, Shoji, Kyoto City, Japan. 1983
Poon, Eileen O. W., Hong Kong. 1983
Pritchard, Janet M., London. 1983
Quinn, Patrick Damian, Sacramento, Ca, U.S.A. 1983
Raney, Gerard E., Redwood City, Ca, U.S.A. 1983
Risbridger, Anne, Redhill. 1983
Rouse, Kenneth A., Newton Abbot. 1983
Segreti, Adolfo F., Reggio Emilia, Italy. 1983
Sivarajasingham, T. S., Ipoh, Perak, W. Malaysia. 1983
Soanes, Stuart E., Oakville, Ont., Canada. 1983
Soni, Anu, London. 1983
Stroud, Louise M., Harrogate. 1983
Subramaniam, Manoharan, Farnborough. 1983
Tai, Joyce C. S., Hong Kong. 1983
Tazaki, Noriko, Tokyo, Japan. 1983
Tazaki, Yasuko, Tokyo, Japan. 1983
Terauchi, Toshihiro, Kyoto, Japan. 1983
Termier, Jean-Pierre, London. 1983
Toughlouian, Grégoire, Chaville, France. 1983
Tsui, Sunny K., Hong Kong. 1983
Unwin, Christine, Greenford. 1983
Van Haaren, Mariette M., Hong Kong. 1983
Verheij, Elizabeth C. M., Vlaardingen, Netherlands. 1983
Ward, Edmund, Thirsk. 1983
Watson, Pauline E. A., Dorking. 1983

Weir, Juliet C. E., Dublin, Ireland. 1983
Wetten, Veronica F. K., Hong Kong. 1983
Williams, Kevin G., Cowbridge. 1983
Worden, Robert J., Blackpool. 1983
Wykoff, Dale E., Frederick, Md, U.S.A. 1983
Yamaguchi, Maki, Fukuoka City, Japan. 1983
Yamazaki, Hideki, Shimizu City, Japan. 1983
Young, William R., London. 1983

ORDINARY MEMBERSHIP

Ambrose, Ella P., London.
Ambrose, Thomas A., London.
Babnik, Frenk, Ndola, Zambia.
Barr, Norma E., Toronto, Ont., Canada.
Beldan, John G., Rotherham.
Bell, Rhonda S., Leavenworth, Kans., U.S.A.
Benedict, Patrick F., Seattle, Wash., U.S.A.
Bonn, Marc A., Kenosha, Wis., U.S.A.
Brown, Delmer L., Lakewood, Colo, U.S.A.
Burda, John S., Unionville, Conn., U.S.A.
Burman-Roy, Kumar, Glasgow.
Butland, Peter S., Pietermaritzburg, S. Africa.
Bydairk, Walter J., Ballston Spa, N.Y., U.S.A.
Carle, Alison E., Strathaven.
Carpenter, Dawn, Fleet.
Carthy, Patrick C., Dublin, Ireland.
Cattermole, Mavis E., Nairobi, Kenya.
Clench, Terry A., Mevagissey.
Cogswell, Jill D., Taupo, N.Z.
Conde Casado, Juan M., Sevilla, Spain.
Credland, Earl D., San Diego, Ca, U.S.A.
Digioia, Lisa M., Murrysville, Pa, U.S.A.
Dodson, Michael J., Plymouth.
Donnelly, Catherine B., Brighton, Mass, U.S.A.
Durrant, Roger W., Portsmouth.
Dyson, Esme C., Bangor.
Fitzgerald, Jennifer, London.
Franklin, June H., San Diego, Ca, U.S.A.
Fry, Kate E., Bath.
Furuya, Kimiko, Yamanashi-Ken, Japan.
Goldschmidt, Marina V., Charl, Denmark.
Gray, William D., Bangkok, Thailand.
Grinberg-Rabow, Andrew, Beverley Hills, Ca, U.S.A.
Gruys, Lorraine G., Santa Monica, Ca, U.S.A.
Guinand, François, Neuchatel, Switzerland.
Halford, James T., Northampton.
Harding, Keith J., Worcester, Mass, U.S.A.
Hardy, Joan A., London.
Heller, E. Michael, West Babylon, N.Y., U.S.A.
Higgins, Bruce I., Santa Monica, Ca, U.S.A.
Hishinuma, Mary, Chicago, Ill., U.S.A.
Hughes, Lyn, Angmering on Sea.
Hunt, John L., Lima, Peru.
Jefferies, Ahmed D., Mombasa, Kenya.
Jewell, Norman E., Sydney, Australia.
Johnstone, Frank E., Vienna, Md, U.S.A.
Jones, Michael H., Northampton.
Kahn, Stanley B., Pine Bluff, Ark., U.S.A.

Kawamoto, Midori, Hong Kong.
Kochhar, Narinder J., London.
Lance, Kay C., London.
Larson, Len, Thornton, Colo, U.S.A.
Leiberg, Cara B., Bordentown, N.J., U.S.A.
Ly, Khai, Cabramatta, N.S.W., Australia.
McKee, Marjie, Harrogate.
Malmstrom, Georgina, Upplandsvasby, Sweden.
Mealey, Clive J., Brixham.
Melvyn-Taylor, Michael, Bath.
Metcalfe, Audrey M., Tewkesbury.
Middleton, John C., Bath.
Minehan, Robyn G., Rooty Hill, N.S.W., Australia.
Miyayake, Toyoko, Osaka, Japan.
Mizobata, Kazumi, Gobo City, Japan.
Moore, Elaine P., Oslo, Norway.
Nootenboom, Rosanna L., Hong Kong.
Nuntapanish, Luz, London.
Oh, Wilhelmina, Hong Kong.
Paul, Joseph V., Tacoma, Wash., U.S.A.
Puig-Doria Pala, Jose M., Barcelona, Spain.
Rawson, Anthony, Bristol.
Reddy, James J., Carlow.
Reed, Paul R., Hamilton, N.Z.
Reyman, Mark E., Mount Vernon, N.Y., U.S.A.
Richards, Colleen H., Hong Kong.
Rockwell, Alan M., Southfield, Mich., U.S.A.
Sambandan, Vedagiri T., Singapore, Singapore.
Sauer, Daniel A., Rio de Janeiro, Brazil.
Shearer, John D., Toronto, Ont., Canada.
Shyrock, Charles L., Malvern, Ark., U.S.A.
Stather, Memory H., Hong Kong.
Steil, Patricia, Hong Kong.
Strogen, Charles E., Dover, N.H., U.S.A.
Sweeney, Noel V., Sydney, N.S.W., Australia.
Szeto, Raymond, Hong Kong.
Tailor, Jay, Gillingham.
Tankosic, M., St Catharines, Ont., Canada.
Taylor, Caroline H., Ripley.
Tolani, Nandlal P., London.
Toledo, Suzanne, Hong Kong.
Troilett, Esther L., Harare, Zimbabwe.
Watson, Charles E., Kimberley, S. Africa.
Watts, Peter J., St Austell.
Weatherley, Julie L., Sandhurst.
Welsh, Joseph C., London.
Wildi, Miranda J., London.
Winckler, Patricia J., Lakewood, Colo, U.S.A.
Young, Patrick P., Hong Kong.
Yuo, Toshio, Tokyo, Japan.
Zavahir, Izmeth A., Dehiwela, Sri Lanka.

GEM DIAMOND EXAMINATION, 1983

In the Post-Diploma Gem Diamond Examination fifty-four candidates sat and all succeeded in passing, four with Distinction. The following is a list of the successful candidates arranged alphabetically.

QUALIFIED WITH DISTINCTION

Ansell, Martin F., London.
Capella Tomas, Ma Josefa, Barcelona, Spain.
Elvidge, Caroline A., London.
Ickowicz, Steven, London.

QUALIFIED

Ainsworth, Nicola L. A., London.
Anderton, Duncan Mac G., Glasgow.
Arbestain Ribas, Inmaculada, Barcelona, Spain.
Ariyaratna, Don H., London.
Arjalaguer Vilardell, Daniel, Barcelona, Spain.
Blackshaw, Cheryl K., Alderley Edge.
Bosch Senao, Ma del Pilar, Barcelona, Spain.
Brown, Harold G., Glasgow.
Cabanas Casas, Terencia, Barcelona, Spain.
Domenech Casellas, Ma Victoria, Barcelona, Spain.
Faller, Noel P., Londonderry, N.Ireland.
Ferguson, William F., Balloch.
Fernandez Nunez, Carlos Luis, Barcelona, Spain.
Fookes, Mark H., Brentwood.
Garrigos Fernandez, Ma Jose, Barcelona, Spain.
Gettings, Barbara A., London.
Goeritz, Louise C., London.
Good, Amanda G., London.
Greatwood, Sheila O., Mitcham.
Griffiths, Paul A., Sutton Coldfield.
Hardy, Joanna, London.
Henderson, Shirley W. A., Hamilton.
Illueca Domenech, Enrique, Barcelona, Spain.
Jackson, C. P., London.
Kennedy, Stephen J., London.
Langford, Michael L., Hereford.
Little, Derek, Monifieth.
MacDonald, Roy W., Selsdon.
McEwan, Robert S., Perth.
Mantecon Burgos, Jesús, Barcelona, Spain.
Marti Beltram, José Ma, Barcelona, Spain.
Mellows, Jacqueline M., Bexleyheath.
Miralles Morey, José Luis, Barcelona, Spain.
Mora Balcells, Helena, Barcelona, Spain.
Nooten-Boom, Apollonius, II, Kingsland.
Novejarque Lopez, M. del Carmen, Barcelona, Spain.
Parker, Hazel, Macclesfield.
Perez Segarra, Montserrat, Barcelona, Spain.
Perrett, Roy, Manchester.
Schofield, Nicola J., Huddersfield.
Selmon, Simon, Northwood.
Shenker, Ian L., Edgware.
Soriano Meler, Esther, Barcelona, Spain.
Stears, Trevor W., Bromley.
Taank, Ashok P., London.
Vidal Noguera, Francisco, Barcelona, Spain.
Watson, Gordon, Lanark.
Wake, Barry A., Sidcup.
Walters, Raymond J. L., London.
Wilkie, William, Helensburgh.

EXAMINATIONS IN GEMMOLOGY, 1983

In the 1983 Examinations in Gemmology, 544 candidates sat the Diploma Examination and of these 277 succeeded in passing, 23 of them with Distinction. In the Preliminary Examination 665 sat and 400 passed.

In the opinion of the Examiners, no candidate achieved the high standard required to merit the award of the Tully Medal.

The Anderson/Bank Prize for the best non-trade candidate of the year in the Diploma Examination was awarded to Mr Douglas Andrew Bagnall, of Don Mills, Ontario, Canada.

The Rayner Diploma Prize for the best candidate of the year whose main income is derived from activities essentially connected with the jewellery trade was awarded to Mr Patrick Damian Quinn, of Sacramento, California, U.S.A.

The Anderson Medal for the best candidate of the year in the Preliminary Examination was awarded to Mrs Fiona Ann Quick, of Harare, Zimbabwe.

The Rayner Preliminary Prize for the best candidate of the year under 21 years of age whose main income is derived from activities essentially connected with the jewellery trade was awarded to Mr John Paul Eldred Chieveley-Williams, of Poole, Dorset.

The following are lists of the successful candidates arranged alphabetically.

DIPLOMA EXAMINATION

Anderson/Bank Prize

Bagnall, Douglas Andrew, Don Mills, Ont., Canada.

Rayner Diploma Prize

Quinn, Patrick Damian, Sacramento, Ca, U.S.A.

QUALIFIED WITH DISTINCTION

Ashworth, Ian E., Bristol.
Bagnall, Douglas Andrew, Don Mills, Ont., Canada.
Berthelsen, Lawrence J., Townsville, Qld, Australia.
Castell Andujar, Joaquin, Barcelona, Spain.
Chow, Herman K. M., Hong Kong.
Chu, Hong-Sung, Taipei, Taiwan.
Goodland, John R. S., London.
Hegarty, Kathleen M., New York, U.S.A.
Holness, Neil P., Bath.
Lowes, Elizabeth H., Toronto, Ont., Canada.
McLean, Donald P., Toronto, Ont., Canada.
Marczycha, Michael J., Leeds.
Moreno Valero, Eloy, Barcelona, Spain.
Noguera Borel, Inés, Barcelona, Spain.
Poon, Eileen Oi-Wan, Hong Kong.
Quinn, Patrick Damian, Sacramento, Ca, U.S.A.
Rhodes, Alexandra M., London.
Soanes, Stuart E., Oakville, Ont., Canada.
Taub, Giselle-Karen, London.
Terauchi, Toshihiro, Kyoto, Japan.
van Haaren, Mariette M., Rotterdam, Netherlands.
Wetten, Veronica F. K., Hong Kong.
Worden, Robert J., Blackpool.

QUALIFIED

Abrami, Aurelio G., Milan, Italy.
Aburrow, Michael B., Wimborne.
Amoroso, Robert E., Winchester, Mass, U.S.A.
Anand, Sumedha, Bombay, India.
Askew, Mark A., Bristol.
Attwell, William G., Toronto, Ont., Canada.
Avargues Perles, Antonia, Barcelona, Spain.
Axon, Martin W., London.
Balderston, Catriona I., London.
Bank, Monika I., Idar-Oberstein, W. Germany.
Barnard, Stephen J., Theydon Bois.
Basnayake, Senarath B., Katugastota, Sri Lanka.

Baxter, Gordon E., Whangarei, N.Z.
Beattie, Roy A., Jimboomba, Qld, Australia.
Bercott, David S., Glasgow.
Berger, Nicholas H. M., Woerden, Netherlands.
Bird, Nigel G. D., Ewell.
Bishop, Ian C., Norwich.
Bisset, Ross, London.
Blankestijn, Janna G., Leersum, Netherlands.
Block, Rachel J. K., London.
Bonham, Frank C., Newport Beach, Ca, U.S.A.
Brand, Lester J., Stellenbosch, S. Africa.
Bugg, John R., Wolverhampton.
Carvey, Robyn, Hong Kong.
Chamberlain, Roger P., Belfast, N. Ireland.
Chant, Joanna K., Dorchester.
Cheong, Lai W., Hong Kong.
Chow, Lorraine M., Hong Kong.
Clark, Patricia M., Hong Kong.
Clarke, Norman V., Winterborne Kingston.
Cloke, Debbie H. N., Hong Kong.
Collado Castelles, Ma Dolores, Barcelona, Spain.
Collins, Glen M., Glasgow.
Condrup, Jonathan R., London.
Cottafavi, Aliette, Geneva, Switzerland.
Dam, Hedwig M., Nijmegen, Netherlands.
Darmudas, Nathaniel R., London.
Davies, Stephen, Wallsend.
Deer, Georgina, Manchester.
Demoray, Scott B., Grand Rapids, Mich., U.S.A.
den Hartog, Maria J. M., Baarn, Netherlands.
Denney, Shane S., Jacksonville, Ill., U.S.A.
de Swart, Johannes G. M., Wÿchen, Netherlands.
de Vries, Jacqueline A., The Hague, Netherlands.
Dings, Christianne A. M., Valkenswaard, Netherlands.
Dorren, Margot S. C., Lopik, Netherlands.
Doughty, Michelle Suzanne, London.
Dykstra, Jeannine B., Toronto, Ont., Canada.
Eadie, John, Cambuslang.
Ebert, Gabriela E., Heidelberg, W. Germany.
Eckley, Gareth D., Talgarth.
Eisenburger, Sabine F., Vienna, Austria.
Elias, Abdul H., London.
Elsten, Antonius R. M., Rucphen, Netherlands.
Emerson, Michael E., London.
Feather, Russell C., II, Fairfax, Va, U.S.A.
Firth, Barbara, London.
Fitzgerald, Leslie E., Stanmore.
Flower, Jonathan S., Plumley.
Floyd, Nancy E., Toronto, Ont., Canada.
Fretzin, Leonard H., Chicago, Ill., U.S.A.
Garcia Gisbert, Rocio, Barcelona, Spain.
Garrod, Douglas J., Exeter.
Gavin, Sandra R., Thornton Heath.
Genis Perez, Manuel, Barcelona, Spain.
Gilliland, Hilary L., Newtownabbey, N. Ireland.
Gilmour, Kevin D., Sheffield.
Gimpel, Remy F., London.
Glaholm, Janice A., Paris, France.
Gonzalez Violan, Francesc, Barcelona, Spain.
Greatwood, John, London.
Greig, Edward S., London.
Groom, Peter J., Luton.
Grootswagers, Johannes P. J., Breda, Netherlands.
Guerrero Ramon, Desamparados, Barcelona, Spain.
Harre, Hendrik, Berchem, Belgium.
Haughton, Michael, Bolton.

Hayes, Anne-Maria, London.
Hee, Vincent Kim San, Singapore.
Helton, Janet L., Toronto, Ont., Canada.
Hillgarth, Antonella C., Geneva, Switzerland.
Hills, Gavin A., Hobart, Tas., Australia.
Hindley, Angela, Bromborough.
Hiwale, Shyla H., Bombay, India.
Hollis, Patricia A., New York, U.S.A.
Horne, Allan R., Brighton.
Houghton, Mark W., Stockport.
Hu, Shirley S., Oxford.
Huddy, William R. H., Newton Abbot.
Hurst, Patricia H., Carradale.
Hutchings, Trevor J., St Peter, Jersey, C.I.
Iber, Beverly A., Peoria, Ill., U.S.A.
Imai, Seiichi, Fukuoka, Japan.
Imazawa, Satoru, Chiba, Japan.
Inoue, Yoshie, Tokyo, Japan.
Itoh, Yasuhiro, Osaka, Japan.
Jashnani, Navin B., Bombay, India.
Jennings, Joan M., Durban, S. Africa.
John, Bryan C., Carmarthen.
Jongstra, Femia E. E. M., Schoonhoven, Netherlands.
Kadota, Hiroka, Sapporo City, Japan.
Kanô, Mieko, Fukuoka Pref, Japan.
Kaper, Robert C., Washington, D.C., U.S.A.
Karmakar, Sambhunath N., Bombay, India.
Karpelowsky, Raymond, London.
Kennedy, Muriel D., Toronto, Ont., Canada.
Khanna, Atul, Birmingham.
King, Clive H. M., Tsumeb, Namibia.
Kjellin, Ewa B., Umea, Sweden.
Klauda, Frank P., Rochester, Minn., U.S.A.
Kok-Visser, Astrid S., Nairobi, Kenya.
Kong, Chor K., Hong Kong.
Konrath, Anthony M., London.
Kozen, Shigekazu, Wakayama City, Japan.
Krikos, Alexandra A., Athens, Greece.
Krot, Johannes H., Amselveen, Netherlands.
Kwan, Irene N. Y. Y., Hong Kong.
Kwok, Addy S. C., Hong Kong.
Laitinen, Mauri P., Hameenlinna, Finland.
Lam, Leung K. L. C., Hong Kong.
Lee, Jeffrey K., Don Mills, Ont., Canada.
Lee, Robert C. S., Hong Kong.
Lemen, John R., Long Beach, Ca, U.S.A.
Letros, Tony G., Scarborough, Ont., Canada.
Lette, Edward C. G., Amsterdam, Netherlands.
Liggett, Sonia A. M., Cardiff.
Lloyd, Stephen R., London.
Lu, Milton R. K., Taipei, Taiwan.
Lumley, John S. P., London.
Ma, Claudio C. W., Hong Kong.
Ma, Lisa L. H., Hong Kong.
McCornack, Constance B., Vashon, Wash., U.S.A.
McFarlane, Patricia A., London.
McGorrian-Morgan, Pauline J., Downpatrick, N. Ireland.
McNair, George A., Newcastle upon Tyne.
Mahajan, Maryada D., Bombay, India.
Mainwaring-Burton, Jeremy J., London.
Majeed, Ismath A. M. M., Colombo, Sri Lanka.
Mascetti, Daniela, Varese, Italy.
Mata, Carmen, Barcelona, Spain.
Matthys, Nigel J., Ickenham.
Mayer, Anton S., St Saviour, Jersey, C.I.
Maynard, Mavis A., Stalbridge Weston.
Mehta, Anoop K., London.

Merchant, Sandhya J., Bombay, India.
Miyata, Takeshi, Kofu, Japan.
Mizrahi, David A. S., New York, U.S.A.
Mohideen, H. M. Sultan, Madras, India.
Monnas, Maria L., Mombasa, Kenya.
Moore, Stephen S., Los Angeles, Ca, U.S.A.
Morling, Anthony J. D., St Mary, Jersey, C.I.
Mouzannar, Nabil I., Beirut, Lebanon.
Munday, John J., Eltham, Vict., Australia.
Munster, Sarah H., London.
Murakami, Kazuo, Osaka, Japan.
Nakamura, Midori, Chiba Pref., Japan.
Nash, Isobel M., Watford.
Nawaz, Rab, Belfast, N. Ireland.
Nikiforides, Constantine W., Brisbane, Qld, Australia.
Nikiforides, Tina, Brisbane, Qld, Australia.
Ninomiya, Mutsuko, Kofu, Japan.
Nitta, Hisako, Tokyo, Japan.
Nomura, Shoji, Kyoto, Japan.
Obbink, Gertrude J., Schoonhoven, Netherlands.
Orchant, Lewis, Glasgow.
Palomaki, Jukka A. J., Katinala, Finland.
Pandya, Manoj K., Bombay, India.
Park, Stephen W., Romford.
Pattani, Hitesh K., Bombay, India.
Pedersen, Julie, Formby.
Percival, Colin A., Sheffield.
Pitt, John R., Stourbridge.
Ponn, Roger E. F., Tulsa, Okla, U.S.A.
Pothof, Helga, Wageningen, Netherlands.
Pritchard, Janet M., London.
Punchihewa, Leslie J., Ratnapura, Sri Lanka.
Purcell, Ian R., Rugby.
Rajayohan, Rasiah, Colombo, Sri Lanka.
Ramaiya, Rajendra D., Bombay, India.
Raney, Gerard E., Redwood City, Ca, U.S.A.
Rennie, Margaret M., Bothwell.
Richards, David, Nottingham.
Richardson, William F., Northwich.
Rikkoert, Abraham, Schoonhoven, Netherlands.
Risbridger, Anne, Nutfield.
Roberts, Kassandra M., Bromborough.
Rouse, Kenneth A., Newton Abbot.
Ruest, Andre E., Gloucester, Ont., Canada.
Rugg-Gunn, Naomi E., Tewkesbury.
Ruiz Vazquez, Ma Cristina, Barcelona, Spain.
Rustwijk, Monique J., Zoetermeen, Netherlands.
Sakita, Yoshizo, Tokyo, Japan.
Sanchez Rodriguez, Raúl de J., Barcelona, Spain.
Sasaki, Mitsuo, Ibaragi City, Japan.
Schurch, Marie-Louise, Geneva, Switzerland.
Sealey, Ralf E., London.
Segreti, Adolfo, F., Paola, Italy.
Shapland, Leonora A., London.
Shaw, C. Helen, Toronto, Ont., Canada.
Shinoda, Keiko, Tokyo, Japan.
Shotton, Dominic E. J., Tring.
Sivarajasingham, T. S., Kelang, W. Malaysia.
Smith, Edward, Vineland, Ont., Canada.
Smith, Ian J., Whitworth.
Smith, Ronald G., Nottingham.
Soni, Anu, London.
Soni, Sara, London.
Spengler, William H., Bangkok, Thailand.
Steil, Patricia, Hong Kong.
Stroud, Louise M., Harrogate.
Styles, Suzanne S., Christchurch.

Subramanian, Manoharan, Farnborough.
Suenaga, Eiji L., Los Angeles, Ca, U.S.A.
Sutton, Janine R., Birmingham.
Swaders, Leonardus A. S., Enschede, Netherlands.
Tai, Joyce C. S., Hong Kong.
Tazaki, Noriko, Tokyo, Japan.
Tazaki, Yasuko, Tokyo, Japan.
Termier, Françoise, London.
Termier, Jean-Pierre, London.
Tong, Ka-Shing, Hong Kong.
Topitz, Ursula A., Colombo, Sri Lanka.
Toughlouian, Grégoire, Chaville, France.
Triantaphyllides, Zoe M., Athens, Greece.
Tsui, Sunny K., Hong Kong.
Unwin, Christine, Greenford.
Valls Bascu, Joaquin, Barcelona, Spain.
van den Arend, Willem A., Rotterdam, Netherlands.
van Loenen, Willem J., Lopik, Netherlands.
van Soest, Wilhelmina N. M., Wychen, Netherlands.
van Stokkom, Francis A. J. A., Dongen, Netherlands.
Vaughan, Malcolm J., London.
Vedeler, Nina, Baerum, Norway.
Verheij, Elizabeth C. M., Vlaardingen, Netherlands.
Virani, Nilesh A., Bombay, India.
Ward, Edmund, Thirsk.
Watson, Pauline E. A., Dorking.
Weir, Juliet C. E., London.
Wells, Bruce I., Glasgow.
Wennberg, Mats T., Stockholm, Sweden.
Weyn Banningh, Thomas F. M., Groenlo, Netherlands.
White, J. Marlene, Minneapolis, Minn., U.S.A.
Wiesauer, Georg, Graz, Austria.
Wiggin, Richard C., Midland, Tex., U.S.A.
Williams, Kevin G., Cowbridge.
Wykoff, Dale E., Frederick, Md, U.S.A.
Yamaguchi, Maki, Fukuoka Pref., Japan.
Yamazaki, Hideki, Shizuoka Pref., Japan.
Young, William R., London.
Zawacki, Charles G., Anchorage, Alaska, U.S.A.
Ziogos, Georgios, Thessaloniki, Greece.
Zorzanello, Giancarlo, Barcelona, Spain.
Zunz, Laura A., London.

PRELIMINARY EXAMINATION

Anderson Medal

Quick, Fiona A., Harare, Zimbabwe.

Rayner Preliminary Prize

Chieveley-Williams, John P. E., Poole.

QUALIFIED

Aherne, Elizabeth, South Amboy, N.J., U.S.A.
Akel, Eugenia, Athens, Greece.
Alavi, Mohammed A. M., Colombo, Sri Lanka.
Alexander, Jean, Wantage.
Alford, Donald H., Huntsville, Ala, U.S.A.
Aloupas, Phivos, London.
Apland, Ken A., Oregon, U.S.A.
Arulanantham, Rohini P., Colombo, Sri Lanka.
Asagai, Toshiki, Osaka, Japan.
Au-Yeung, Siu M., Hong Kong.
Aziz, Khalid, Karachi, Pakistan.
Baker, Carolyne J., Godalming.
Balakrishnan, Kanapathippillai, Salford.
Bandara, Sunil P. M. M., Kelaniya, Sri Lanka.

Barker, Stephen J., Norwich.
Barlow, Alice M., Appleton, Wis., U.S.A.
Barnard, Julie A., Nottingham.
Bartlett, Lynne, London.
Bastiaanse, Paul A., Eindhoven, Netherlands.
Bauer, Gunilla M., Uppsala, Sweden.
Baxendale, John F., Widnes.
Belda Selva, Fernando, Barcelona, Spain.
Berger, Clark J., London.
Beringen, Johannes J. G., Utrecht, Netherlands.
Bernal Garcia, Jose E., Barcelona, Spain.
Biosca Bas, Ma de los Angeles, Barcelona, Spain.
Bjørge, Eli, Lierfoss, Norway.
Blankestijn, Janna G., Leersum, Netherlands.
Bliss, Stephen J., Liverpool.
Bodifee, Brigitte K., Schoonhoven, Netherlands.
Boermans, Antoon P. E. M., Venlo, Netherlands.
Bolton, Janet M., Bolton.
Bonham, Frank C., Newport Beach, Ca, U.S.A.
Bonnema, Menno, Heerenveen, Netherlands.
Bonvehi Sola, Joan, Barcelona, Spain.
Bosch, Coert E., Hoevelaken, Netherlands.
Bourner, Anne, Manchester.
Brand, Lester J., Stellenbosch, S. Africa.
Brattan, David, Wakefield.
Brown, Sandra J., Hong Kong.
Budi, Elisabeth A., Athens, Greece.
Buis, Jan D. B., Lopik, Netherlands.
Burns, Brian, Huddersfield.
Bushby, Christine D. A., Broadstone.
Calduch Sendra, Ma Esmeralda, Barcelona, Spain.
Calje, Nicoline, Schiedam, Netherlands.
Callan, Frank, Liverpool.
Canas Aguilar, Jose V., Barcelona, Spain.
Cannon, Mark F., Stockport.
Caracciolo, Marie E., McLean, Va, U.S.A.
Cartana Martinez, Jorge, Barcelona, Spain.
Caruthers, Peter M. A., Manchester.
Casanovas Ramon, Ma Rosa, Barcelona, Spain.
Cass, Laurence, London.
Castello Costa, Antonia, Barcelona, Spain.
Chamberlain, Roger P., Newtownards, N. Ireland.
Chan, Hung C., Hong Kong.
Chan, Kai C. M., Hong Kong.
Chan, Yau-Lap, Santa Monica, Ca, U.S.A.
Chang, Julius, Hong Kong.
Cheshire, Sam J., Droitwich.
Chib, Phillip D., London.
Chieveley-Williams, John P. E., Poole.
Chinn, Jeffrey, St Helier, Jersey, C.I.
Chu, Hong-Sung, Taipei, Taiwan.
Clare, Caroline L., Chorley.
Clewer, Patricia A., Nottingham.
Cody, Carol J., London.
Coffin, Martin R., Carlisle.
Cohen, Gilbert, Montreal, Canada.
Comber, Takako K., Hong Kong.
Corbett, Timothy M., London.
Courtenay, Jutta W., Hong Kong.
Cox, Nicholas P., Warley.
Cox, Steven G., London.
Cragg, Deborah A., Knutsford.
Crolly, Sharon J., Scarborough, Ont., Canada.
Crowder, Michael J., Camberley.
Cuijpers, Heleen M., Schoonhoven, Netherlands.
Currie, John S., Manurewa, Auck., N.Z.
Curtis, Ranjana G., Colombo, Sri Lanka.
Curtis, William R., Sheffield.

Dagli, Yogeshkumar, Bombay, India.
Dale, Marlene L., Hong Kong.
Dathi, Kaniz F., Riyadh, Saudi Arabia.
Davies, Neil R., Chester.
Davis, Lisa M., Sale.
Davis, Meriel, London.
De Cunha, Kevin I. G., Portsmouth.
de Lacombe, Aliette, London.
Denney, Shane S., Jacksonville, Ill., U.S.A.
Dent, Peter J., Guildford.
De Ruyter, Gerrit H. G., Tokoroa, N.Z.
de Silva, John I. C., Trier, W. Germany.
de Silva, Neelamanee P., Leeds.
Dewan, Shobha, Deherdun, India.
Dey, Madeleine R. L., Wirral.
Dhont, Eddy C. H., Gent, Belgium.
Dicks, Graham J., London.
Dixon Phillip, John G., Wallasey.
Donoghue, Martin D., Glasgow.
Duckett, Karen L., Skipton.
Duguid, Keith B., Eiffel Flats, Zimbabwe.
Dunn, Nigel P., Brierley Hill.
Ebert, Gabriela E., Heidelberg, W. Germany.
Edirisuriya, Anura S., Dickwella, Sri Lanka.
Ehlenbach, Richard J., Winchester, Mass, U.S.A.
Feather, Russell C., II, Fairfax, Va, U.S.A.
Fein, Murray, Whitestone, N.Y. U.S.A.
Felstead, Kevin R., Brentwood.
Ferguson, Brian, Ottawa, Ont., Canada.
Ferran Estrada, Alejandro, Barcelona, Spain.
Fitzgerald, Jennifer G., Hong Kong.
Floriach Devant, Ma Teresa, Barcelona, Spain.
Foote, Lisa A., Brisbane, Qld, Australia.
Fournier-Laroque, Maryse M. J., Geneva, Switzerland.
Francis, Shirley J., Frinton-on-Sea.
Franks, Karen M., Manchester.
Freeman, Glen H., Winnipeg, Man., Canada.
Fussell, Louise, London.
Galindo Merino, Ma del Carmen, Barcelona, Spain.
Gambin Forne, Ma Neus, Barcelona, Spain.
Gibson, Dorothy, Chatham, N.J., U.S.A.
Giel, Caroline, Schoonhoven, Netherlands.
Glenn, Helen H., Darwen.
Goad, Jane F. C., London.
Gonzalez De Las Heras, Benito, Barcelona, Spain.
Goodchild, Gordon E., Colchester.
Goonatilake, Manique M., Colombo, Sri Lanka.
Goossens, Xavier A., London.
Gormley, Brendan M., Belfast, N. Ireland.
Gottlier, Kristoffer, Stockholm, Sweden.
Gould, Lewis, London.
Gresham, Catherine A., Chloorkop, S. Africa.
Griffiths, Raymond J., London.
Grotenhuis, Ingrid, Winterswijk, Netherlands.
Groves, Lesley C., Eastbourne.
Groves, Patricia, Brisbane, Qld, Australia.
Guinand, François, Neuchatel, Switzerland.
Halford, Bridget A., Hong Kong.
Hall, Michael J. B., Oxshott.
Hardman, Christopher D., Ipswich.
Harrington, Christina M., Seattle, Wash., U.S.A.
Harwood, Bruce R., London.
Hay, Scott, Rothesay.
Heikkila, Tero P. V., Tampere, Finland.
Hellman, Ulla M., Stockholm, Sweden.
Hendricks, Mogamat L., Cape Town, S. Africa.

Hendriks, Cornelius A., Eindhoven, Netherlands.
Hennessy, Linda L., Sydney, N.S.W., Australia.
Hirons, Glen W., Liverpool.
Ho, Hay-Ming J., Hong Kong.
Ho, Ka K., Hong Kong.
Ho, Wai K., Hong Kong.
Holemans, Thierry J. N., Brussels, Belgium.
Hollins, Peter A., Birmingham.
Holmes, Irene V., Tadworth.
Holness, Neil P., London.
Hookins, Gary C., Thames Ditton.
Horton, Julie A., Wolverhampton.
Hosaka, Masahiro, Kofu, Japan.
Hughes, John M., Netherton.
Humphreys, Deborah M., Liverpool.
Hunt, Jill M., Hong Kong.
Hunter, Anne L., Oregon, U.S.A.
Hunter, Dugald C., Glasgow.
Ichinose, Atsuko, Tokyo, Japan.
Imazawa, Satoru, Chiba Pref., Japan.
Introna, Ilarione G., Cape Town, S. Africa.
Itoh, Yasuhiro, Osaka, Japan.
Iversen, Bodil, Eidsvoll, Norway.
Jaffery, Zulfiquar A., Machakos, Kenya.
Jakob, Beatrice, London.
Jashnani, Navin B., Bombay, India.
Jayasekera, Palitha R. J., Colombo, Sri Lanka.
Jerndell, Bo E. O., Stockhlom, Sweden.
Johanns, Pieter G. J., Veghel, Netherlands.
Johnson, Benjamin C., Bilston.
Jones, Julia D., Wolverhampton.
Kalubanda, Hitihamillage, Ratnapura, Sri Lanka.
Kaper, Robert C., Washington, D.C., U.S.A.
Kasliwal, Deepak, Bombay, India.
Khanna, Atul, Birmingham.
Kikano, Margo M., London.
Kinnvnen, Juha P., Espoo, Finland.
Klinberg, Baltzar H., Stockholm, Sweden.
Kodaka, Katuyoshi, Tokyo, Japan.
Kort, Karin J., Hellevoetsluis, Netherlands.
Koseki, Norio, Tokyo, Japan.
Kothari, Prajesh R., Madras, India.
Kranz, Kurt B., Woodridge, Qld, Australia.
Kumarasuriar, Geetha K. K., Colombo, Sri Lanka.
Lam, Hiu C. O., Hong Kong.
Lam, Jeremiah T. K., Hong Kong.
Lange, Ulf, Bremen, W. Germany.
Laurikainen, Markku J., Helsinki, Finland.
Law, Bik W., Hong Kong.
Lee, Cheung, Hong Kong.
Leung, Pui F., Hong Kong.
Lewton-Brain, Charles J., Halifax, N.S., Canada.
Lim, Pauline, Worcester.
Lin, Chorn-Yu, Santa Monica, Ca, U.S.A.
Lintunen, Eva E., Finland.
Lippelt, Ulrich W., Karachi, Pakistan.
Lo, Siu-Man B., Hong Kong.
London, Jan, Colombo, Sri Lanka.
Loup, Daniel L., Geneva, Switzerland.
Loveday, Elsje, St Martin, Guernsey, C.I.
Lui, Elizabeth S. H., Hong Kong.
McAleese, Daniel, Newtownabbey, N. Ireland.
McCallum, Andrew, Croydon.
McCloskey, William P., London.
McDermott, Bernard A., Manchester.
MacFadyen, Donald A., Scarborough, Ont., Canada.
McKearney, Michael C., London.
McKinney, Shona, London.
McLean, Donald P., Ottawa, Ont., Canada.
Mainwaring-Burton, Jeremy J., Johannesburg, S. Africa.
Major, Christine B., Hong Kong.
Malkani, Monica, Bombay, India.
Malmstrom, Bridget K. M., Vasby, Sweden.

Malmstrom, Georgina M. F., Vasby, Sweden.
Mann, William R., Suitland, Md, U.S.A.
Mantere, Juha M., Rauma, Finland.
Marikar Bawa, Mohamed S. R., Colombo, Sri Lanka.
Marlow, Joseph S., Birmingham.
Massey, Steven M., Altrincham.
Meguro, Sadayuki, Tokyo, Japan.
Mercer, Francis G. J., Welwyn Garden City.
Michener, John, Raybrook, N.Y., U.S.A.
Mohideen, H. M. Sultan, Madras, India.
Moir, Richard C., Kenthurst, N.S.W., Australia.
Monnas, Edith S., Mombasa, Kenya.
Montanni, Claire, Newarthill:
Monzonis Garcia-Correcher, Alejandro, Barcelona, Spain.
Moore, Elaine C., Oslo, Norway.
Moore, Fiona, Londonderry, N. Ireland.
Moore, Stephen S., Los Angeles, Ca, U.S.A.
Morgan, Leon D., Aylesham.
Morin Reyes, Luisa M., Tenerife, Canary Is, Spain.
Mousavi, Morteza, Bombay, India.
Muchlinski, Michael, Clacton-on-Sea.
Munster, Sarah H., London.
Murakami, Ryutaro, Osaka, Japan.
Murray, Jacqueline K., Morpeth.
Nadim, M. S. M., Colombo, Sri Lanka.
Nakamura, Midori, Chiba Pref., Japan.
Nakanishi, Kimiyo, Yamanashi, Japan.
Nancarrow, Peter H. A., West Horsley.
Navarrete Navarrete, Fernando, Barcelona, Spain.
Nawaz, Rab, Belfast, N. Ireland.
Nelson, William L., Ogdensburg, N.Y., U.S.A.
Ng, Fen S., Singapore.
Nial, Brian L., Southport, Qld, Australia.
Nikiforides, Constantine W., Brisbane, Qld, Australia.
Nikiforides, Tina, Brisbane, Qld, Australia.
Nitta, Hisako, Tokyo, Japan.
Noakes, Karen, J., Dudley.
North, Michael, Matlock.
Nystrom, Erik, Stockholm, Sweden.
Nystrom, Louise, Stockholm, Sweden.
Oh, Wilhelmina A. P. C., Hong Kong.
O'Keeffe, Ursula M., Sale.
O'Riordan, Sylvia, Epsom.
Palwankar, Balwant B., Bombay, India.
Papadopoulou, Daphni-Marina, Athens, Greece.
Parker, Claire E., Worthing.
Payne, James F., Minsterworth.
Pearson, Susan, Chorley.
Pease, Orville H., Burbank, Ca, U.S.A.
Peeris, Malwattege R. L., Kotte, Sri Lanka.
Pellicer Garcia, Miguel Angel, Barcelona, Spain.
Peltonen, Stella P., Handen, Sweden.
Pemadasa, Tawalama G., Colombo, Sri Lanka.
Perera, Cabandugamage L., Nugegoda, Sri Lanka.
Perera, Dewamullage J. P., Colombo, Sri Lanka.
Pescod, Ian S., Whitley Bay.
Peshwa, Krishna V., Pune, India.
Phillips, Carol S., Bridgend.
Posthuma, Sandra M., Schoonhoven, Netherlands.
Poulis, Johannes A. M., Roosendaal, Netherlands.
Prescott, Philip, Wigan.
Preston, Mitchell R., Morpeth.
Pritchard, Nichola E., Worsley.
Puddy, Patricia J., Market Harborough.

Quam, Maurice D., St Paul, Minn., U.S.A.
Quick, Fiona, A., Harare, Zimbabwe.
Quy, Caroline E., Chalfont St Giles.
Raniga, Dhiraj L., Richmond, B.C., Canada.
Ravn, Christine K., London.
Rawson, Anthony, Bristol.
Redgrave, Martin, Hessle.
Reed, Donna L., Manchester.
Reid, John E., III, Rex, Ga, U.S.A.
Rens, Gerald J., Johannesburg, S. Africa.
Rich, Frederick S., London.
Rigby, Martin P., Ashton-under-Lyne.
Rikkoert, Jasper D., Schoonhoven, Netherlands.
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GERMAN GEMMOLOGICAL ASSOCIATION FIFTIETH ANNIVERSARY

(Report by Mr Peter Read, C.Eng., F.G.A.)

Although the German Gemmological Association (Deutsche Gemmologische Gesellschaft) was founded in 1932, the official celebration of its fiftieth anniversary was postponed until 1983, so that it could coincide with the opening of the extension to the Association's training centre in Idar-Oberstein.

Each year, the Association holds two 'Working Conference' week-ends, one in the spring and one in the autumn. These gemmological week-ends consist of a series of discussion groups in the class-rooms of the training centre, demonstrations and talks in the town's trade hall, and the awarding of certificates and the presentation of formal lectures in the auditorium of the Diamond and Gemstone Bourse. This year, the autumn week-end of 7th-9th October, was chosen for the Fiftieth

Anniversary celebrations, and the invited guests included Professor Dr E. Gübelin, F.G.A., Mr J. E. Roux (of De Beers), Mr E. A. Jobbins, F.G.A., and the Secretary of our own Association, Mr Con Lenan, F.G.A.

The celebrations began on the Friday evening with a welcoming speech by the German Gemmological Association's Director, Professor Dr Hermann Bank, F.G.A. This was followed by a tour of the new class-rooms and facilities of the training centre, and a visit to the re-sited and enlarged cafeteria, where the refreshments included local wine and the traditional *spiessbraten.*

On the Saturday and throughout the rest of the week-end, three class-rooms in the centre were used to display and demonstrate various gem test instruments from the range of the Eickhorst, Krüss and Günter-Schneider companies. The Association's well-stocked bookstore was also open for inspection during this period. Added interest was provided by the De Beers coloured diamond collection and the gem collection of August Wild, which were on view in the Diamond and Gemstone Bourse. For those wishing to purchase gem specimens there was also the annual gemstone exhibition and fair in a hotel in the nearby village of Veitsrodt, where the products of the local cutters were on display.

During a celebratory buffet given in the Bourse on Saturday evening, a series of slides were shown which traced the history of the German Association through its meetings and attendant personalities up to the present day.

The formal lectures presented in the auditorium of the Bourse included a talk on 'Synthetic Diamonds' by Professor Dr Recker, of the University of Bonn. This covered the many commercial and experimental synthesis techniques ranging from the molten solvent-catalyst method to the more recent metastable process using carbon dioxide gas and a diamond seed crystal, the relationships between these being displayed by means of an expanded phase diagram. Definitive examples of gemstone inclusion photographs were shown during the lectures of Professor Dr Gübelin ('Examination of Fluid Inclusions in Gemstones'), and Mr Koivula ('Inclusions in a Better Light'), the latter speaker reminding us of the continuing diagnostic value of inclusions now that synthetic gem manufacturers are introducing trace elements such as gallium (normally found only in natural stones) into the melt.

The final lecture of the week-end was given by Dr Keller, whose talk ('A recent Update on Worldwide Gem Sources') dealt mainly with the emerald mines of Chivor and Muzo in Colombia. His talk was illustrated by slides taken during the filming of the G.I.A. production 'Gems of the Americas'.

By doubling the size of its training centre, the German Gemmological Association has become one of Europe's leading full-time teaching centres for the science of gemstones, and now offers a multiplicity of courses on gemmology and diamond grading throughout the academic year.

19TH INTERNATIONAL GEMMOLOGICAL CONFERENCE

The 19th International Gemmological Conference was held in Beruwala in Sri Lanka from the 31st October to 4th November, 1983.

Prior to the formal opening of the Conference the delegates were escorted to the Conference centre by a drummer party and on arrival at the centre entered into the traditional Sri Lankan custom of lighting the lamps, in which each delegate lit a wick.

Delegates from the U.K. were Mr Kenneth Scarratt, F.G.A., Director of the London Gem Testing Laboratory, Mr Alan Jobbins, F.G.A., Keeper of Minerals and Gemstones, Institute of Geological Sciences, London, and a senior Examiner of the Association, and Mr Con Lenan, F.G.A., the Secretary. Mr Harry Wheeler, F.G.A. attended as an observer. Delegates from the following countries attended: Australia, Brazil, Denmark, France, Italy, Japan, the Netherlands, South Africa, Spain, Sri Lanka, Switzerland, the U.K., the U.S.A. and West Germany.

At the commencement of the proceedings the delegates stood in silence as a tribute to the late Dr W. F. Eppler.*

A number of papers were presented to the Conference and a wide range of subjects with many interesting elements from the fields of mineralogy and geology complemented the gemmological presentations.

An interesting visit to the gemstone mines and cutting centres at Ratnapura was rewarding and illuminating.

Prof. Dr E. Gübelin, C.G., F.G.A., invited Mr Lenan to become 'postmaster', to which Mr Lenan agreed, and the Conference concluded with a spectacular cultural show and a dinner hosted by the Gemmologists' Association of Sri Lanka.

The papers presented at the Conference are listed below:

'Geology and occurrence of gems in Sri Lanka', Dr M. M. J. W. Herath.
'Worldwide distribution of coloured gemstones', Dr John M. Saul.
'Gemstones of Victoria, Australia', Dr E. R. Segnit.
'Investigation on fluid inclusions', Prof. Dr E. Gübelin, C.G., F.G.A.
'New emerald mines at Santa Terzinha do Goias', R. T. Liddicoat, Jr., Hon. F.G.A.
'News about Ole Roemer', O. Dragsted, F.G.A.
'Additional data on gem minerals from Kataragama area (Sri Lanka)', Prof. P. C. Zwaan, F.G.A.
'Verdite and ruby verdite from Zimbabwe', E. A. Jobbins, F.G.A.
'Gemstones from Nepal', A. Chikayama, F.G.A.
'Gemstones from Indonesia (diamonds from Kalimantan and quartz varieties and opal from Java)', Dr C. E. S. Arps, F.G.A.
'Pink topaz of natural colour from Pakistan', Prof. Dr E. Gübelin, C.G., F.G.A.
'Identification by use of the spectroscope of Kashan synthetic rubies', 'Pearls from Bangladesh', C. A. Schiffmann, F.G.A.
'Recent gemmological observations', Prof. Dr H. Bank, F.G.A.
'A new versatile lamp using standard illuminants C & D for precise colour matching of gemstones', Dr J. Ponahlo, F.G.A.
'Interdependence among chemical composition, optical properties and structural data on natural and synthetic beryl', Prof. Dr G. Graziani.
'A few interesting issues and recent findings', K. Scarratt, F.G.A.
'New observation technique for gem testing', K. Sato.
'Orthopyroxenes of Sri Lanka', G. Zoysa, F.G.A.
'Surface microtopographical studies of diamond crystals from Thailand', Prof. I. Sunagawa.

*See *J.Gemm.*, 1983, XVIII (5), 446-9.—Ed.

'Theory and application of microprobe analysis in gemmology', Dr S. Vochten.
'Some comments on natural pearl', M. Masso.
'Emeralds produced in Brazil', Mrs E. MacGregor.
Mr C. A. Schiffmann also read a paper entitled 'Lennix Emeralds', by J. P. Poirot.

DENVER GEMOLOGICAL ASSOCIATION

The Denver Gemological Association has recently been formed to provide a forum for all professional gemmologists in the greater Denver area. Membership is limited to qualified gemmologists such as F.G.A.s and Graduate Gemologists of the Gemological Institute of America (G.G.). Meetings are bi-monthly with formal presentations given on subjects of current gemmological interest. Further information may be obtained from The Denver Gemological Association (Ms Patricia Winckler, G.G., or Dr D. Hoover, F.G.A.), P.O. Box 27541, Bear Valley Station, Denver, Colo 80227, U.S.A.

FORUM OF INDIAN GEMMOLOGISTS

The recently formed Forum of Indian Gemmologists is a non-profit-making educational organization, whose basic objectives are to popularize gemmology and educate the members and the general public in the study of gemstones. Membership is restricted to F.G.A.s and G.G.s (Graduate Gemologists of the Gemological Institute of America). Plans include the organization of seminars, conferences and study-groups, and gemmologists passing through India will be welcomed. Meetings are held on the first Friday of each month. For further information, apply to the Forum, c/o Gemmological Association of India, 29 Gurukul Chambers, 187/189 Mumbadevi Road, Bombay, 400 002, India (telephone 32 0039).

JOURNAL OF GEMMOLOGY—BOUND SET FOR SALE

A member has a set of bound *Journals* for sale at the price of £125. Anyone interested in purchasing this set should write to Box No. SC3, G.A. of G.B., Saint Dunstan's House, Carey Lane, London EC2V 8AB.

INDEX FOR VOLUME XVIII

It is regretted that the Index is not quite ready for distribution. It will be sent with the April issue of the *Journal,* if not before.

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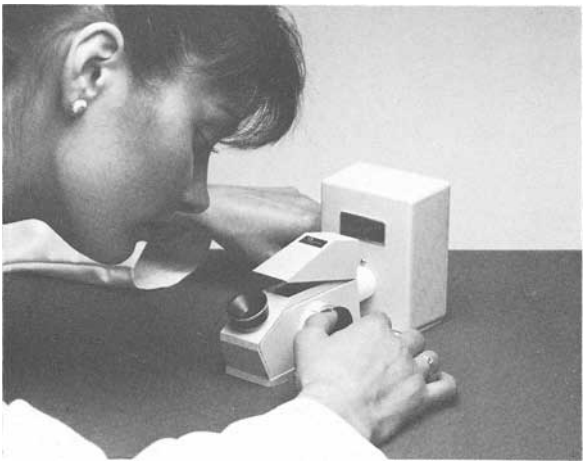

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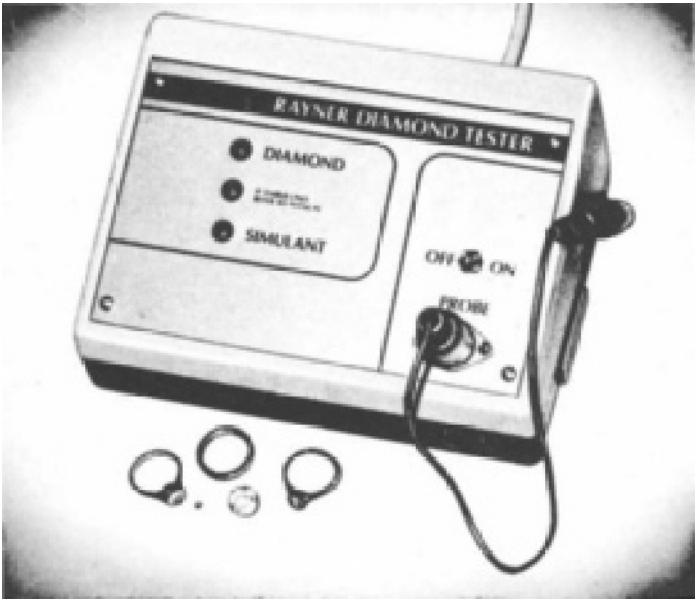

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Historical Note

The Gemmological Association of Great Britain was originally founded in 1908 as the Education Committee of the National Association of Goldsmiths and reconstituted in 1931 as the Gemmological Association. Its name was extended to Gemmological Association of Great Britain in 1938, and finally in 1944 it was incorporated in that name under the Companies Acts as a company limited by guarantee (registered in England, no. 433063).

Affiliated Associations are the Gemmological Association of Australia, the Canadian Gemmological Association, the Gem and Mineral Society of Zimbabwe and the Gemmological Association of Hong Kong.

The *Journal of Gemmology* was first published by the Association in 1947. It is a quarterly, published in January, April, July, and October each year, and is issued free to Fellows and Members of the Association. Opinions expressed by authors are not necessarily endorsed by the Association.

Notes for Contributors

The Editor is glad to consider original articles shedding new light on subjects of gemmological interest for publication in the *Journal.* Articles are not normally accepted which have already been published elsewhere in English, and an article is accepted only on the understanding that (1) full information as to any previous publication (whether in English or another language) has been given, (2) it is not under consideration for publication elsewhere and (3) it will not be published elsewhere without the consent of the Editor.

Articles published are paid for, and a minimum of 25 prints of individual articles may be supplied to authors provided application is made on or before approval of proofs. Applications for prints should be made to the Secretary of the Association—not to the Editor—and current rates of payment for articles and terms for the supply of prints may be obtained also from the Secretary.

Although not a mandatory requirement, it is most helpful if articles are typed (together with a carbon copy) in double spacing on one side of the paper, with good margins at sides, top and foot of each page. Articles may be of any length, but it should be borne in mind that long articles are more difficult to fit in than short ones: in practice, an article of much more than 10 000 words (unless capable of division into parts or of exceptional importance) is unlikely to be acceptable, while a short note of 400 or 500 words may achieve early publication.

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January, 1984

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THE JOURNAL OF GEMMOLOGY

and

PROCEEDINGS OF THE GEMMOLOGICAL ASSOCIATION OF GREAT BRITAIN

GEMMOLOGICAL ASSOCIATION
OF GREAT BRITAIN
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THE JOURNAL OF GEMMOLOGY
AND PROCEEDINGS OF THE GEMMOLOGICAL ASSOCIATION OF GREAT BRITAIN

Vol. XIX No. 2 April 1984

B. W. ANDERSON

This number of the *Journal* is isssued under the shadow of the death of B. W. Anderson, who died on 24th February. Tributes from Keith Mitchell and Alec Farn follow on pages 188 and 194.

The world has lost a great man and gemmology has lost a great gemmologist. He will be greatly missed by all who at any time have met him, whether in work or in play or only through the medium of the written word, and to those who have been privileged to be his colleagues and to know and love him for many years both in work and in retirement—though in a sense he never retired but was working until the day of his death—his loss is indeed desolating; and all our thoughts of sympathy and gratitude must go out to his devoted wife, Barbara, who gave him so much help and comfort for the last twenty-five years.

A gemmologist of genius, poet, teacher, bird-watcher, athlete and much else—a whole man with a gift for friendship—we shall not see his like again.

J.R.H.C.

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NOTES FROM THE LABORATORY

By KENNETH SCARRATT, F.G.A.

London Chamber of Commerce and Industry, Gem Testing Laboratory

It is not unusual for a group of gemmologists to disagree over the colour of a gemstone. Some coloured diamonds in particular tend to possess colours which are most difficult to describe. However, when you see a diamond actually change from one distinct colour to another before your eyes it can shake any confidence you may have in your own eyesight.

Such was the case when late one afternoon I decided to make a start on identifying the nature (natural or treated) of the colour of a 2.02 ct brilliant-cut diamond.

All I really had time for was to make out my work-sheet, giving a full description of the stone, and a short microscopic examination before it had to go into the safe for the night. On the work-sheet I stated in a most positive fashion that the colour of the stone was green. The next morning when the safe was opened I immediately retrieved the envelope containing the diamond, took it to a work-bench and removed the stone from it. There before me lay a brilliant *yellow* stone! After checking the envelope to make sure that it was the one I put in the safe the night before (it was) I decided to check the stone's weight against my record, but as I picked it up to take it to the balance its colour started to change through various shades of yellow and yellow/green until it was back to the colour it was the night before.

These so called 'chameleon diamonds' have been reported upon before,[1] and the change has been variously described as being associated either with changes in temperature or in the amount of light reaching the stone. A manufacturer would notice the effect because it is said that these stones glow red on 'the wheel'[1] and change to yellow shortly afterwards, from which they return to their normal green at room temperature; whereas a trader might become aware of the type of stone he had in a similar manner to that in which I had become aware of the peculiarities of this stone.

The colour change from green to yellow, unless one includes the slight cooling which may occur if the stone is placed in a safe overnight, is usually described as being dependent upon a

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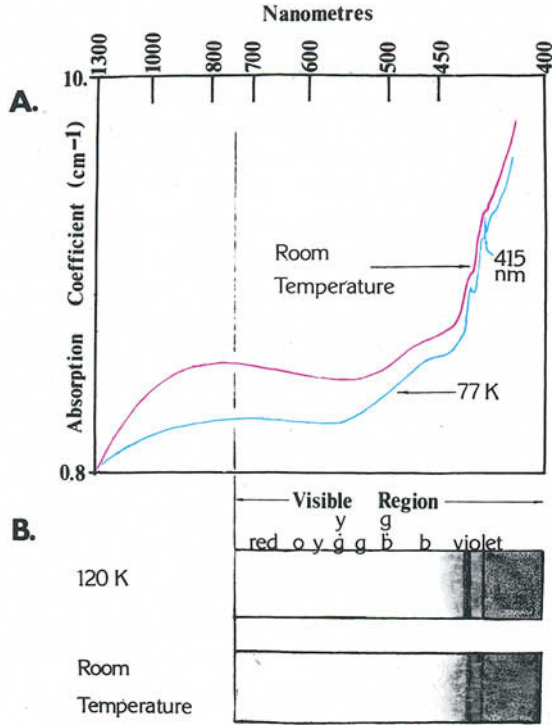

FIG. 1 The room and low-temperature spectra of a 'chameleon' diamond. (A) As a recorded absorption curve and (B) as seen with the hand spectroscope.

temperature increase, such as placing the stone on a hot plate, rather than a decrease; and so it was interesting to discover that when we reduced the temperature of this stone to at first 120K in the Laboratory and then to 77 K at King's College, London, whilst recording the spectra reproduced in Figure 1, the colour of this stone once again became a brilliant yellow.

The differences between the room and low temperature spectra depicted in Figure 1 are quite evident. The general appearance of the spectrum at room temperature is approaching that of a normal Type 1b with a weak 415 (Type 1a) peering out of the gloom and an unusual absorption hump covering the yellow, orange, red and N.I.R.—the area of greatest transmission being in the green. At the lower temperatures there is clearly a sharpening up of the 415, but more importantly there is a lessening of the absorption hump in the red, orange and yellow, allowing the stone to transmit to a greater extent in this region as well as in the green, thus resulting in a yellow stone.

One assumes that changes of a similar nature may take place when the stone is heated; however, we restricted ourselves to room and low temperature spectroscopy only.

The luminescence effects produced by this stone were—long-wave ultraviolet, a very strong bright yellow followed by a very strong greenish phosphorescence; short-wave ultraviolet, a strong and bright yellow/green followed by a very strong greenish phosphorescence; and x-rays, a blue/green followed by a strong green phosphorescence.

* * *

An item that we have seen quite a number of examples of over the past few years is the imitation crystal.

One interesting specimen made to imitate ruby was composed of fragments of natural and synthetic (Verneuil) ruby held together by an adhesive and coated in mica. More often than not though, these imitations are made to resemble emerald, in particular the type of mica-coated rough that emanates from East Africa.

Sometimes produced with obvious crystal form, as in the example shown in Figure 2, or more convincingly with the minimum of form, the basic material for this type of imitation is either very poor quality emerald, beryl or glass. The poor quality emerald or beryl varieties may be manufactured either by slicing the crystal down its length and gluing the two pieces back together with a green adhesive and then coating the whole in mica, or by hollowing out the crystal, infilling with a green substance and then coating the base with a matrix-like material.[2]

The example in Figure 2 is made of green glass and has just enough mica adhering to the surface (Figure 3) to be reasonably convincing.

* * *

FIG. 2 An imitation emerald crystal made of glass and with mica adhering to its surface (see Fig. 3).

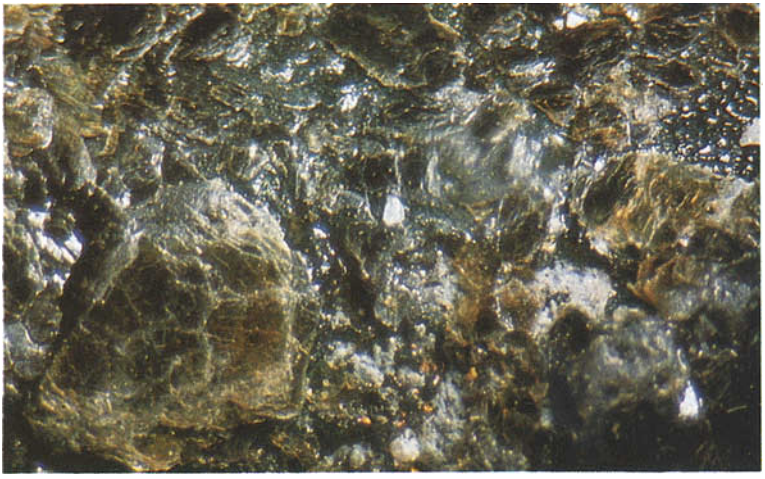

FIG. 3 The mica adhering to the surface of the imitation crystal in Fig. 2.

FIG. 4 A colourless natural sapphire before exposure to x-rays.

FIG. 5 The same natural sapphire as seen in Fig. 4 after a ten-minute exposure to x-rays.

A requirement of most gem identification processes is that whenever possible they must be of a non-destructive nature; indeed in the vast majority of cases gemstones can be and are identified in this manner. There are some cases, though, where the only means left open to one require either a 'minor' destructive test, such as taking an insignificant scraping from the girdle of a stone for an x-ray powder diffraction photo, or something possibly more destructive such as attempting to fade or drive off the colour of a suspected x-ray irradiated stone.

Understandably not many people are very happy when we ask for permission to test for colour stability upon being presented with a yellow sapphire for examination, but in some instances it is essential having established the natural origin of such a stone that a test of this nature is carried out. Some colourless sapphires may attain a yellow colour quite quickly when they are irradiated with x-rays,[3] but this colour is not permanent, and exposure to sunlight will gradually return the stone to its normal light yellow or colourless state.

It didn't take long to realize when recataloguing the laboratory collection recently, that a 'colourless' stone found in a stone paper marked 'irradiated "yellow" sapphire' (Figure 4) was not a misplaced stone but one that had been x-ray irradiated and had subsequently faded. It took just a ten minute exposure at a setting of 45 kV and 19 mA in close proximity to the x-ray tube window to reproduce the yellow colour (Figure 5).

When a little while ago we were confronted with two large apparently natural, intensely orange sapphires of a hue that we had not observed in nature before, quite naturally our suspicions were aroused. The two stones weighing 32.44 and 8.72 ct (Figure 6) were very similar in colour to the Verneuil type synthetic orange sapphire and did not approach the colour of the heat treated yellow sapphires we see so many of nowadays (Figure 6). The refractive indices were normal for corundum, but the absorption spectrum (Figure 7) was a very intense version of that expected from a synthetic yellow sapphire—the stones were strongly absorbing in the blue and violet and there were no signs of any sharp lines in the red or the 'normal' sapphire bands in the blue.

To the unaided eye the stones had a somewhat cloudy appearance and a microscopic inspection revealed the cause of this to be light reflecting from a multitude of dust-like particles within

FIG. 6 Four small heat-treated yellow sapphires and two large orange sapphires which owe their colour at least partly, if not wholly, to heat treatment.

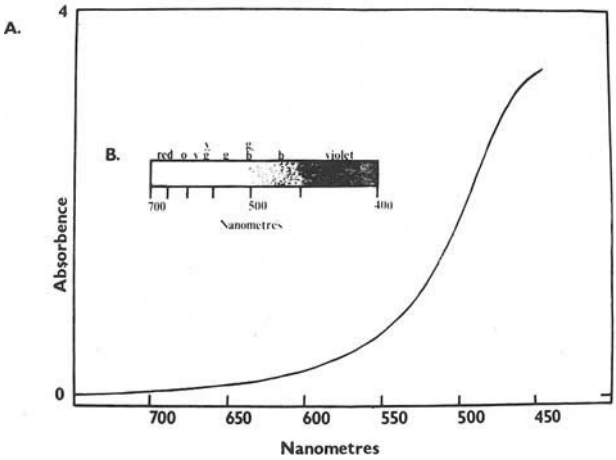

FIG. 7 The absorption spectrum of the smaller of the two large orange sapphires seen in Fig. 6, (A) as a recorded absorption curve and (B) as seen with the hand spectroscope.

FIG. 8 Fine dot-like 'silk' producing a cloudy appearance to the orange sapphires seen in Fig. 6.

FIG. 9 Fine dot-like 'silk' orientated around small angular areas in the orange sapphires seen in Fig. 6.

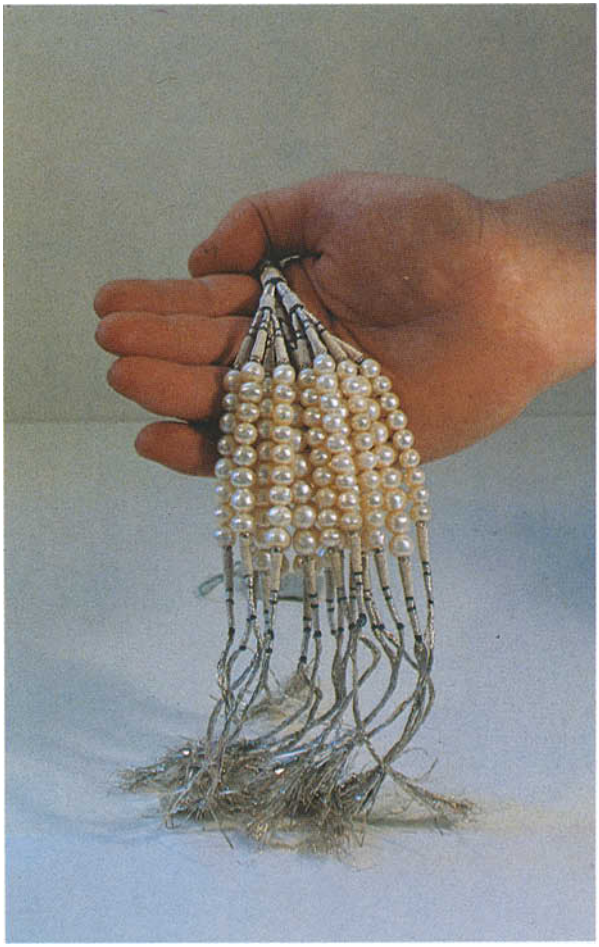

FIG. 10 A 'Bombay Bunch' of natural pearls.

the stones. Over all these particles took on the appearance of very fine 'silk' (Figure 8), and they were generally orientated in specific directions travelling through the stones, although as may be seen in Figure 9, the particles also tended to orientate themselves around small angular areas. Also included were other indications that these were natural sapphires that had undergone heat treatment, such as the glassy centres to some feathers.[4,5] However, as both the colour and its intensity were so unusual, it was felt that a colour stability test was definitely needed, firstly because of some recent reports of colour instability in some heat-treated yellow sapphires, and secondly just in case they were treated stones that had been subject to further x-ray treatment. Unfortunately permission to attempt to fade these stones under controlled conditions was refused, and so the situation remained unresolved.

* * *

Even though many thousands of natural pearls pass through the laboratory every year, it is quite rare nowadays for them to be submitted as 'Bombay bunches'.[6] The first such bunch to be submitted for many months (Figure 10) reminded us just what a work of art these items are in themselves.

* * *

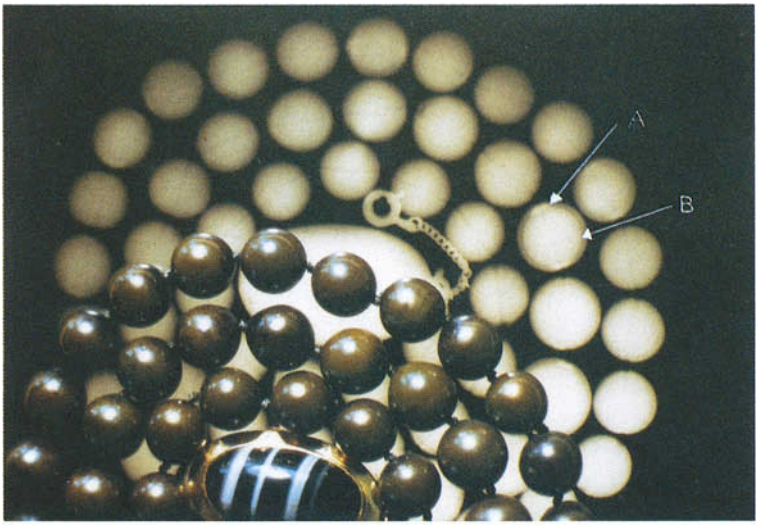

FIG. 11 A necklace of mottled brown stained cultured pearls together with the x-ray picture, showing the demarcation between the bead and the outer layers (B) and the way in which the stain alters the normal x-ray transparency of the demarcation (A).

The radiograph taken of an unusually coloured—mottled brown—'pearl' necklace (Figure 11) revealed not only that the pearls were cultured but also the way in which the stain had altered the normal x-ray transparency (11A) of the demarcation between the bead and the 'pearl' layer (11B).

* * *

Being a trade laboratory, naturally the majority of our work concerns the identification of the more important commercial stones, and so it is a most welcome break from routine when something outside this grouping is submitted. When the bead in Figure 12 was placed before us (looking for all the world like a lacquered peach stone), upon an eye inspection all sorts of suggestions about its possible identity were put forward, many of them not very complimentary.

The microscopic inspection revealed that the bead had a fairly thick coating of clear plastic (Figure 13), and, as this would inhibit an accurate SG determination and completely rule out RI measurements, it was quickly realized that, although the structure, visible now, appeared to be similar to that of coral, this was so distorted by the coating that we would have to resort to a destructive test so that we could 'get at' the structure without having to peer through the plastic.

We were fortunate in this case that the client had included in his instructions to us 'test to destruction if necessary'. Taking him at his word we sliced the bead into two, when a very coarse coral structure became all too obvious in its nakedness (Figure 14). A small drop of dilute hydrochloric acid was then placed on the newly exposed area as a confirmatory test, causing effervescence.

* * *

In the July 1979 issue of this *Journal*[7] I reported the occurrence in the visible spectrum of three brown diamonds of an absorption line that had previously only been associated with treated diamonds. Since then we have observed this line at 637 nm not only in brown stones but also in yellows and two 'odd' green stones.

I subsequently reported[8] that we were reasonably satisfied that when the 637 was observed in the sort of strengths described (that is, either very weak at room temperature or only visible at 120 K) and in the sort of stones described (that is, Type 1b in which the

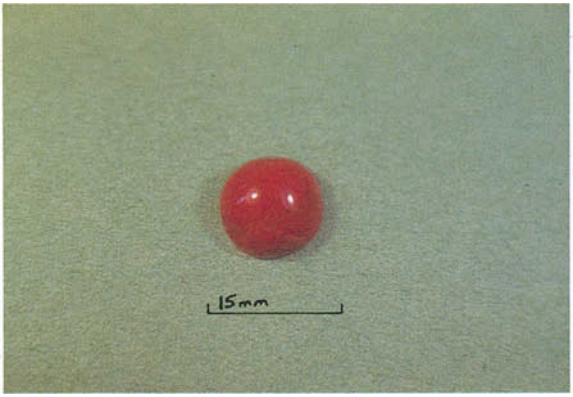

FIG. 12 A plastic coated coral bead.

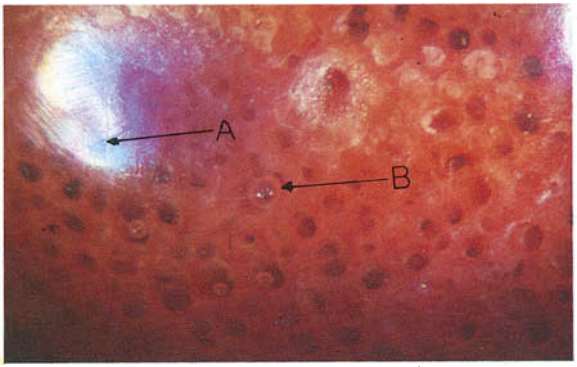

FIG. 13 (A) light reflecting from the surface of the clear plastic coating and (B) gas bubbles in that coating of the coral bead in Fig. 12.

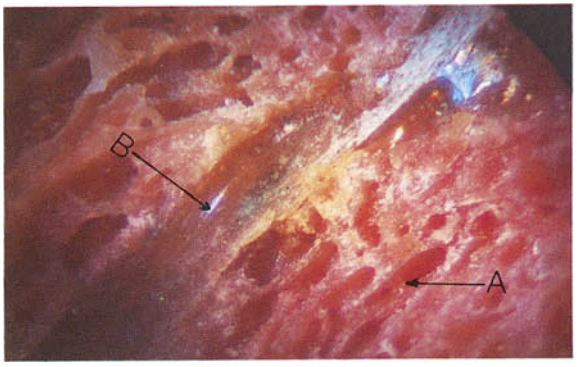

FIG. 14 (A) the 'coarse coral structure' and (B) the plastic coating adhering to the sides of the drill hole of the bead in Fig. 12.

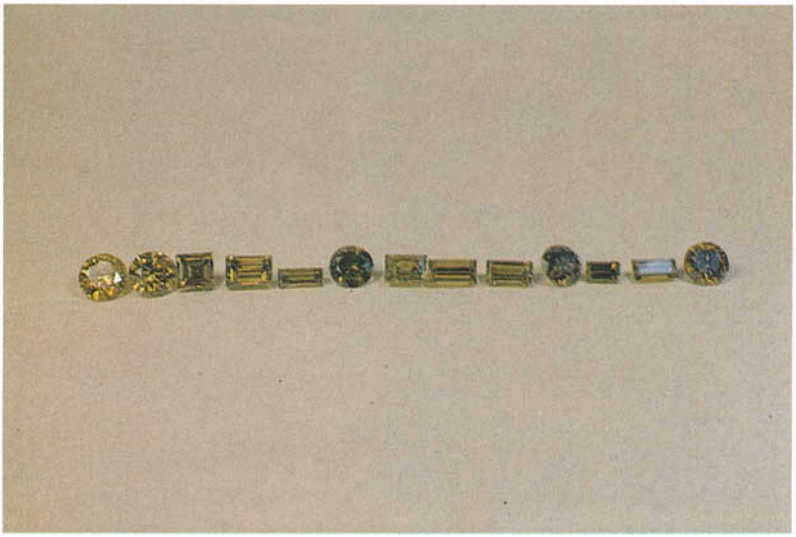

FIG. 15 Thirteen coloured diamonds which not only all come from the same item of jewellery, but also all contain the 637 nm absorption line in their spectra when examined at low temperatures.

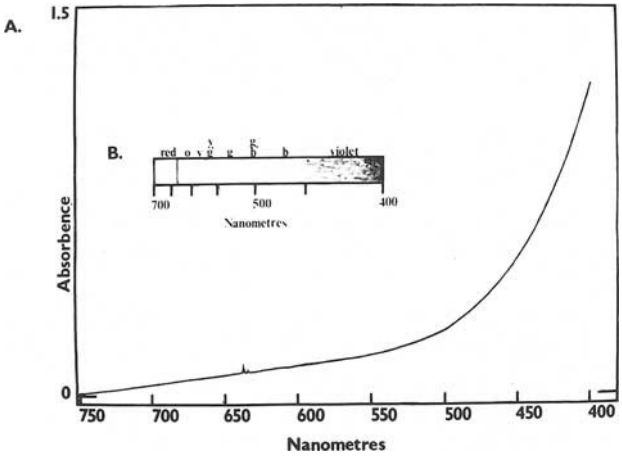

FIG. 16 The low temperature absorption spectrum typical of the stones seen in Fig. 15, (A) as a recorded absorption curve and (B) as seen with the hand spectroscope.

body colour was obviously due to the naturally occurring absorption in the violet and blue) it should be treated as yet another naturally occurring radiation-related band. We still believe this to be the case today.

During the four year period between the first report and a few weeks ago only 19 stones in which the naturally occurring 637 nm lines could be observed were examined in this Laboratory. More recently a further 15 have been added to that number. Somewhat incredibly though, 13 of this latest 15 (Figure 15) not only came from the same item of jewellery, a brooch, but also they were the only stones in that item.

Of these 13 stones, there was only one that revealed the 637 rather weakly at room temperature, all the rest only revealed the line at 120 K. Figure 16 shows the absorption curve of one of the two other stones at 77 K, this curve being fairly typical for the type of stone.

It is not too unusual with coloured diamonds to find the same type of stones, with similar spectra, in the same item of jewellery. This occurs quite often because the person making up the item has successfully matched the stones for body colour and in so doing has chosen stones of the same 'type'. What is unusual about this instance is that these stones are far from being matched for colour; as can be seen in Figure 15 the colours range from a distinct yellow through to brown.

* * *

A very high percentage of the coloured diamonds submitted to us for examination turn out to be naturally coloured, and so, when a treated stone turns up, although it may not be a pleasurable experience for the owner, for us this must undoubtedly produce a sense of achievement in that the lengthy procedures we strictly adhere to in the examination of coloured diamonds do pay dividends.

One such stone is worth a mention here, because it is so often said that only very low quality diamonds are irradiated, and in our experience this is very often not the case, certainly purity-wise if not colour-wise.

The stone weighed exactly 6 ct and was marquise shaped with a nice yellow body colour (Figure 17). Under both long-wave and short-wave ultraviolet radiations the stone fluoresced yellow/green and there was no phosphorescence. The absorption spectrum

FIG. 17 A 6.00 ct treated yellow diamond.

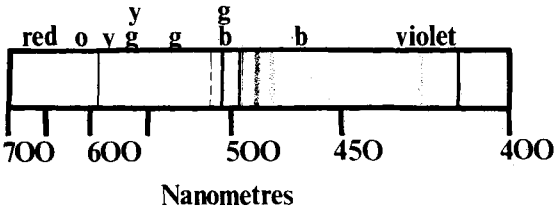

FIG. 18 The absorption spectrum, as seen with the hand spectroscope at 120 K, of the treated diamond seen in Fig. 17.

(Figure 18) at 120 K was unmistakably that of a treated stone with a strong 595 nm line and very strong lines at 503, 496 and 415 nm, the first three being induced by irradiation and subsequent annealing and the last naturally occurring. Whilst the 415 was fairly strong there was no 478 nm absorption, and therefore it is fair to assume, although it is by no means certain, that the pre-treatment colour of this stone would not have been significant, fancy-diamond-wise, but would have been evident under normal colour-grading standards.

Whilst we were not asked to grade the stone for purity, it is quite normal for us to give all coloured diamonds a thorough microscopic examination, and it was found that this stone at 10× magnification was clear of any internal imperfections apart from a few cleavages in the area of the girdle, which could have been removed to produce a flawless or loupe-clean stone.

* * *

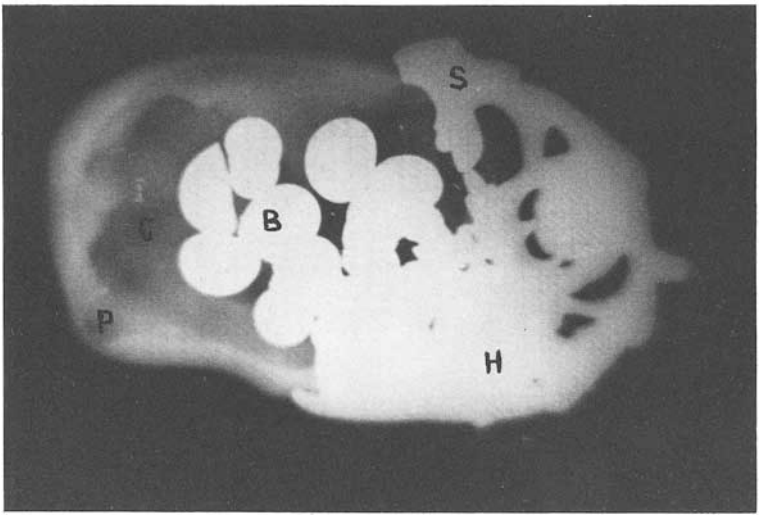

FIG. 19 The radiograph of a pendant-set large hollow baroque pearl, inside the cavity of which can be seen a number of beads with an opacity to x-rays similar to that of the setting. (P) pearl: (C) cavity: (B) beads: (S) setting: (H) the area of the setting which hides the 'cap'.

During one of our recent courses a participant produced a large baroque pearl, which seemed to be an ideal subject with which to demonstrate how direct radiography may help with pearl identification. The resulting picture, however, revealed a little more than was expected.

The pearl itself, which was mounted as a pendant, with the setting (S in Figure 19) covering the major portion of one 'corner', was found to be little more than a comparatively thin layer of nacre surrounding a large cavity (P and C respectivly). Within the cavity could be seen a number of beads (B) with an opacity to x-rays comparable with that of the setting. A further microscopic inspection exposed the 'cap' that had to be present. It was well hidden under the setting in the area marked H in Figure 19.

A fair assumption about the history of the pearl might be that at some stage it had been drilled and subsequently to this the area around the hole had collapsed, at which time it could have been decided to infill the cavity with a number of beads to give the pearl the weight expected of a pearl of that size.

* * *

The generally small 'Biwa' type[9] non-nucleated cultured pearls, when seen in long single or multi-row necklaces, are for the most part quite easy to identify when a radiograph is taken, and most people who handle pearls can virtually identify these necklaces just by seeing their shape and colour (usually very white). Increasingly, however, today we are seeing the much larger single non-nucleated cultured pearl in which the colour and shape vary considerably. It is certainly not possible without the aid of x-rays to even hazard a 'professional guess' about the origin of these pearls, and even when a direct radiograph is taken sometimes it is not the easiest of tasks to identify them.

Figure 20 shows some of the shapes, sizes and colours that are at present on the market. All eleven were identified as non-nucleated cultured pearls by direct radiography.

* * *

There are some gemmologists who appear to be able to find the most extraordinary items on their travels, and not least amongst these is one of the Laboratory's regular benefactors, Chris Cavey. During one of his visits with us latterly he placed in my hand what appeared to the naked eye to be a miniature portrait mounted as a fob (Figure 21). He then proceeded to tell us that he had bought it in a badly worn condition, and by way of offering a clue to its identity he added that he had had it *repolished.*

FIG. 20 11 non-nucleated cultured pearls.

A microscopic examination unveiled the true nature of the object. It was clearly made entirely of glass and was all one piece (not a mosaic) and the portrait, which was quite detailed (Figure 22) was continuous from one side of the object to the other with very little if any deviation—something similar to the name of a seaside town running through a long 'stick of rock' (candy)—therefore, no matter how many times it was repolished (provided there was still some of the item left!) the 'portrait' would remain practically unaltered.

Very often as gemmologists we are awe-struck by the artistic arrangement of included material in natural gemstones, but it is not so often that we are able to let out a gasp of admiration for the artistic achievements, within our sphere, created by man. This for me was certainly a case for the latter.

A week or so prior to Mr Cavey showing us this lovely object, he brought in five most attractive orange stones (Figure 23), the colour and lustre of which did not strike me as being peculiar to any of the more common gemstones. They had, he said, been offered to him as clinohumite from the U.S.S.R.

Clinohumite ($4Mg_2SiO_4.Mg(F,OH)_2$) [10] is a monoclinic member of the Humite group, and its constants are given in Dana's

FIG. 21 A coloured glass 'portrait' set as a fob.

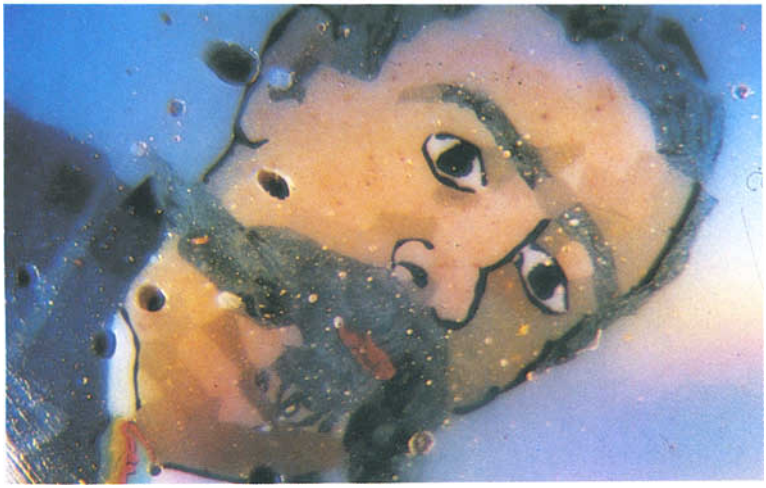

FIG. 22 Detail of the portrait in Fig. 21.

FIG. 23 Five faceted examples of clinohumite averaging approximately 3 ct.

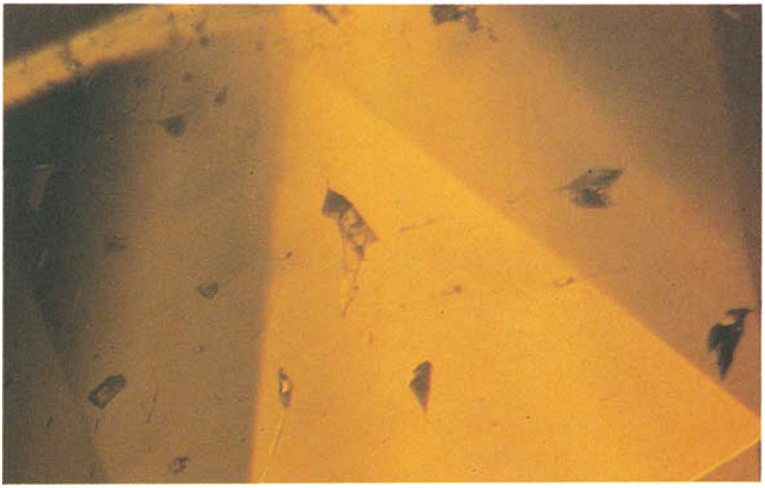

FIG. 24 2-phase inclusions in a clinohumite.

FIG. 25 A group of crystals in a clinohumite.

FIG. 26 Twin planes in a clinohumite.

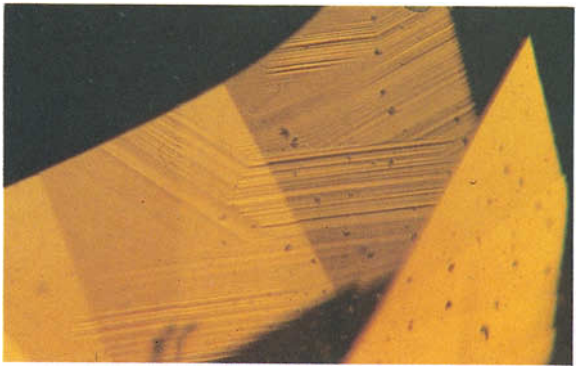

FIG. 27 Angular growth zoning in a clinohumite.

Textbook of Mineralogy[10] as RI α = 1.62 - 1.66, β = 1.64 - 1.67, γ = 1.65 - 1.69; SG 3.1 - 3.2 and H. 6 - 6.5; and one of the occurrences cited is near Lake Baikal in Siberia.

The average weight of these five stones was approximately 3 ct, the largest stone weighing 4.59 ct. Their SGs ranged from 3.223 - 3.230 and their RIs were α 1.630 - 1.633, β 1.644, γ 1.662 - 1.665 with DR varying from 0.031 to 0.033, all of which fall reasonably close to the range recorded by Dana.

By way of confirming their identity Steve Kennedy took a small powder scraping from the girdle of the smallest stone and produced an x-ray powder diffraction photograph which proved to be characteristic of clinohumite.

Under the microscope all the stones were a feast for the eyes. Figures 24-27 show the main types of included features (2-phase and other cavity types in Figure 24, crystal groups in Figure 25, twin planes in Figure 26 and growth zoning in Figure 27), and of course the double refraction was clearly evident upon viewing the facet edges through the stones.

The absorption spectrum for each stone resembled closely that produced in Figure 7 in that there were no sharp absorption lines or bands, just a strong absorption of wavelengths shorter than 450 nm in the visible region.

* * *

When something a little unusual is submitted to the Laboratory for examination it sometimes occurs that in the coming weeks several other examples of the same material are placed before us. However, in the weeks, months or indeed years, following this surge we may not be required to examine it again.

At the end of last year the pearl trade became very worried about the number of large mauve pearls entering the market, and we were asked to examine a number of examples. All were examined by direct radiography and none revealed any evidence on the radiographs which might have indicated a cultured origin, either non-nucleated or nucleated. Indeed the only structure revealed, indicated a natural origin. Apart from a re-examination of one of these pearls recently, we haven't seen any new examples, since the initial 'surge'.

FIG. 28 Two very pale pink natural pearls flanking a natural mauve pearl weighing 16.47 ct.

FIG. 29 The 'flat' side of the centre pearl in Fig. 28.

An example of the type of pearl involved is depicted in Figures 28 and 29. In Figure 28 it has been placed between two very pale pink natural pearls weighing 4.96 and 22.36 ct. The mauve pearl itself weighs 16.47 ct and measures 16.38 × 8.81 mm, and in Figure 29 the difference in colour between the base and the top of the pearl can be noted, and a peculiar central area can also be seen.

Whilst we could find no evidence to indicate that this pearl or any of the others we examined were cultured, it must be said that it should not be long before non-nucleated cultured pearls of a similar colour to these are available in this country.[11]

* * *

In the early part of 1983 we noticed an advertisement in one of the trade publications in which the various merits of the 'Angelo pearl' were being expounded. The descriptions given of these 'pearls' and some of the claims made intrigued us enough to request a sample of the material from the U.K. distributors, who immediately forwarded to us a number of loose specimens for our examination. All were fully drilled beads measuring approximately 5.5 mm in diameter.

A major portion of the advertisement hinges around the fact that 'the core' of the Angelo pearl 'is made of fragments of fresh water shells which are found in the waters of the Mississippi River', and it is stated further that 'only first class shell material for the core is used and is identical to that implanted in oysters for the nucleus of the cultured pearl'.

Shell based imitation pearls are not new.[12, 13] In 1978[14] Farn described an imitation pearl that produced a Laue diffraction pattern typical of a cultured pearl; it was in fact a lacquered mother of pearl bead, and before I received these samples, this was the sort of 'pearl' I was expecting to see—but this was not to be the case.

Firstly, by way of confirming the manufacturers' statements about the nucleus of the samples, one was sliced into two, whereupon it could be seen that they were in fact constructed of a solid central bead and some kind of coating to that bead (Figure 30). As the central bead effervesced when a small drop of hydrochloric acid was brought into contact with it and as it also had a banded structure (Figure 32) along with other properties

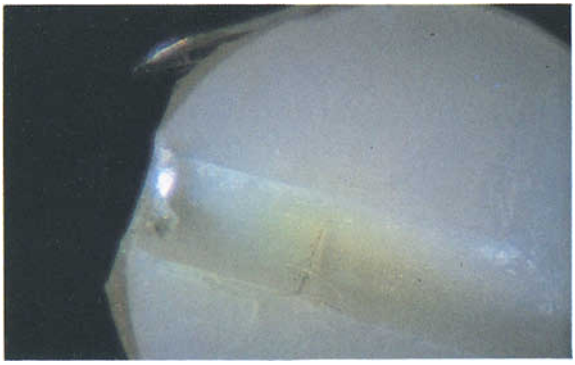

FIG. 30 A sliced 'Angelo' imitation pearl showing the shell bead centre and the thickness of the outer layer.

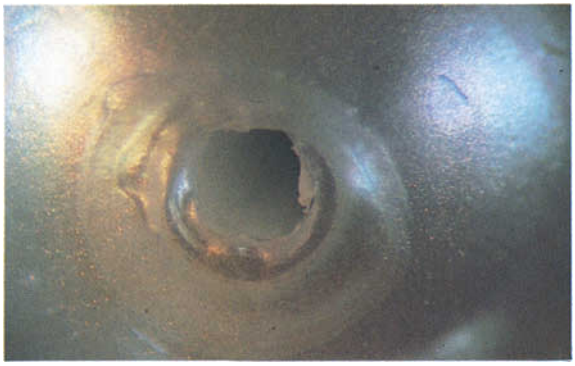

FIG. 31 The 'Angelo' imitation pearl showing a discretely speckled play of colour.

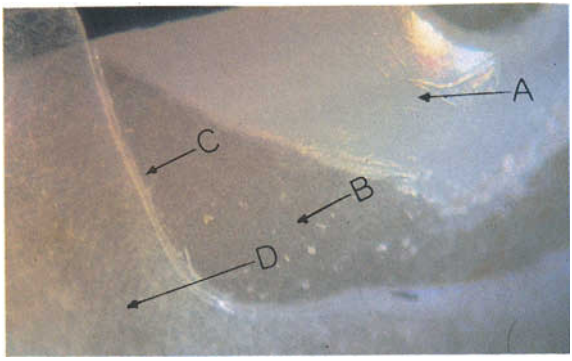

FIG. 32 The 'layers' of the 'Angelo' imitation pearl. (A) The shell bead nucleus showing a banded structure. (B) The layer closest to the bead, (C) the layer in which the 'play of colour' appeared to be confined and (D) the outermost layer.

which are characteristic of Mother of Pearl, such as x-ray induced fluorescence and phosphorescence and the production of four- and six-spot Laue diffraction patterns, the manufacturers description of the central core would seem to be accurate. The specific gravity of the whole pearl was found to be 2.65.

To the unaided eye there seemed to be a little more 'life' to these Japanese manufactured 'pearls' than there normally is with imitation pearls, although to the experienced eye they were 'not quite right' in comparison to the natural or cultured pearl. Under magnification it was found that this 'extra life' could be attributed to a discretely speckled play of colour (Figure 31) and that the coating consisted of three easily separable layers (Figure 32). The play of colour appeared to be confined to the centre layer, C in Figure 32, and did not seem to be present in the two other layers of this 'plastic like' material. Imitation pearls usually 'leave me cold' but I was really quite impressed with the visual impact of these. However, it remains to be seen just how resistant the coating is to damage from contact with the various cosmetics.

ACKNOWLEDGEMENTS

The author gratefully acknowledges the continued assistance given by Dr A. T. Collins in the production of absorption curves and in particular those depicted in Figures 1, 7 and 16. Thanks are due to Delroy Jewellery Ltd for supplying the samples of the 'Angelo' imitation pearl.

It is also a pleasure to acknowledge the generosity of Mr C. Cavey, F.G.A. over the years, and more particularly in this instance we wish to thank him for taking the time and trouble to show us the coloured glass portrait and the samples of clinohumite.

As ever, these notes could not be completed were it not for the assistance of the Laboratory staff, and on this occasion the author thanks Mr I. Shenker for the production of Figures 8 and 9, Mr E. C. Emms for Figures 10, 11 and 17, and Mr S. Kennedy for the production of the x-ray powder diffraction photograph of the clinohumite specimen.

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'RAMAURA'—A NEW SYNTHETIC RUBY MADE IN U.S.A.

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INTRODUCTION

The flux growth of ruby was first introduced by Remeika (1963). Following his Patent, Chatham and Arden Associates (Kashan) now produce synthetic rubies extensively to match the various colours and hues of natural ruby. P. O. Knischka from Austria introduced another undisclosed method of growing suitable crystals of ruby. Japanese manufacturers, influential in every branch of our industry and technology, reproduced the red and orange varieties of the corundum family under the trade name 'Inamori'.

In the course of time the growth of crystals in laboratories expanded. More research continued into the synthesis of corundum varieties than into any other crystal growth. In addition to the majority of synthetic rubies available from different manufacturers, Chatham & Son grew blue and orange varieties of the family, which are now obtainable as rough or faceted stones (Gübelin, 1983b). To crown each effort the production of corundum in laboratories has developed, and another commercially available successful growth of ruby by a Californian manufacturer is now known.

During the Tucson gem and mineral show in 1983 a Los Angeles distributor announced the availability of a new synthetic ruby. The Overland Gems Inc. of California now market this new product under the name 'Ramaura' synthetic ruby. The distributor further reported the marketing of the faceted stones at the beginning, and lower grade (heavily included) stones later for fashioning into beads and cabochons, as well as single crystals and clusters. According to Mr Peter Flusser, principal of Overland Gems Inc., over 1000 carats of cut Ramauras are already marketed. He intends to cut the goods in Thailand, in the United States and in Idar-Oberstein. However, enquiries made during his very recent visit to Thailand and also in Idar-Oberstein have revealed to the author that up to date no steps have been taken to cut the Ramaura

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product in either of these localities. However, if the intentions of the distributor are carried out, gem cutters in Asia and in Europe will probably join the business in the near future.

The intention of this article is to provide an extensive and updated report on the new product. During the investigations many Ramauras were examined including two rough crystals. Gemmological methods have been thoroughly considered rather than the mineralogical methods which are far beyond the reach of the average gemmologist. However, certain important criteria involving such methods are discussed. The procedures mentioned below would readily indentify the Ramaura products.

IDENTIFICATION CHARACTERISTICS OF RAMAURA SYNTHETIC RUBY

Appearance and colour

The stones examined by the author revealed the colours of Ramaura flux ruby in relation to those of natural rubies. They resembled the colours of most Thai and Burma rubies and even the lighter pink of Sri Lanka corundums (pink sapphires). Therefore this least dependable factor of colour cannot any longer be used, even as an aid, in separating natural from synthetic rubies. According to Mr Flusser, the Ramauras are cut with very precise angles (Figure 1). However, this cannot be considered as a means of recognition, since certain natural and other synthetic rubies too undergo similar fashioning processes. Refractive indices, birefringence values, optical character and specific gravity of corundum as reported in the literature were noted in Ramaura synthetic rubies.

Dichroism

The respective two colours of the Ramaura synthetic ruby clearly showed a purple hue along the ordinary vibrations and an orange hue parallel to the extraordinary vibrations. The overall dichroic effect varied from weak to strong with intermediate intensities. However, only a well experienced eye can distiguish such differences. Therefore the average gemmologist should not depend on this effect of purple $\parallel$ and orange $\perp$ hues as a characteristic sufficient alone for identification.

FIG. 1. Faceted Ramaura flux rubies marketed by Overland Gems Inc., of California. The average weight varies from 0.60 to 0.80 carat.

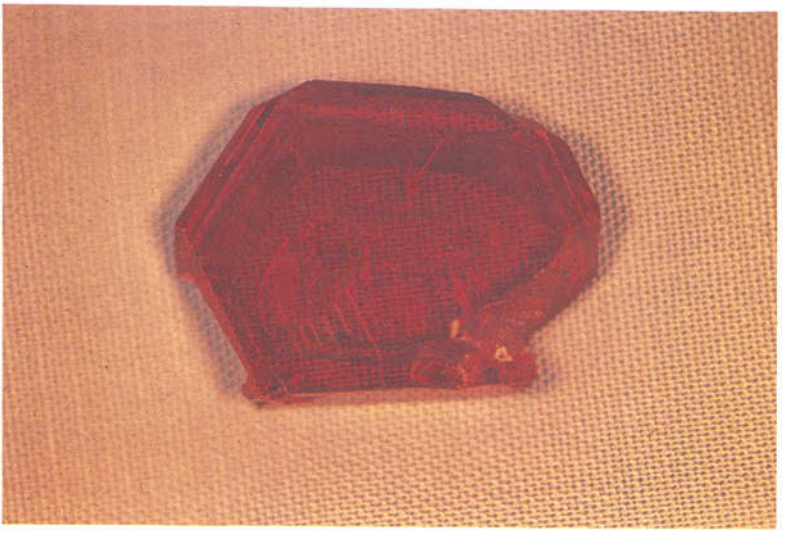

FIG. 2. A tabular crystal of Ramaura synthetic ruby weighing 7.46 carats.

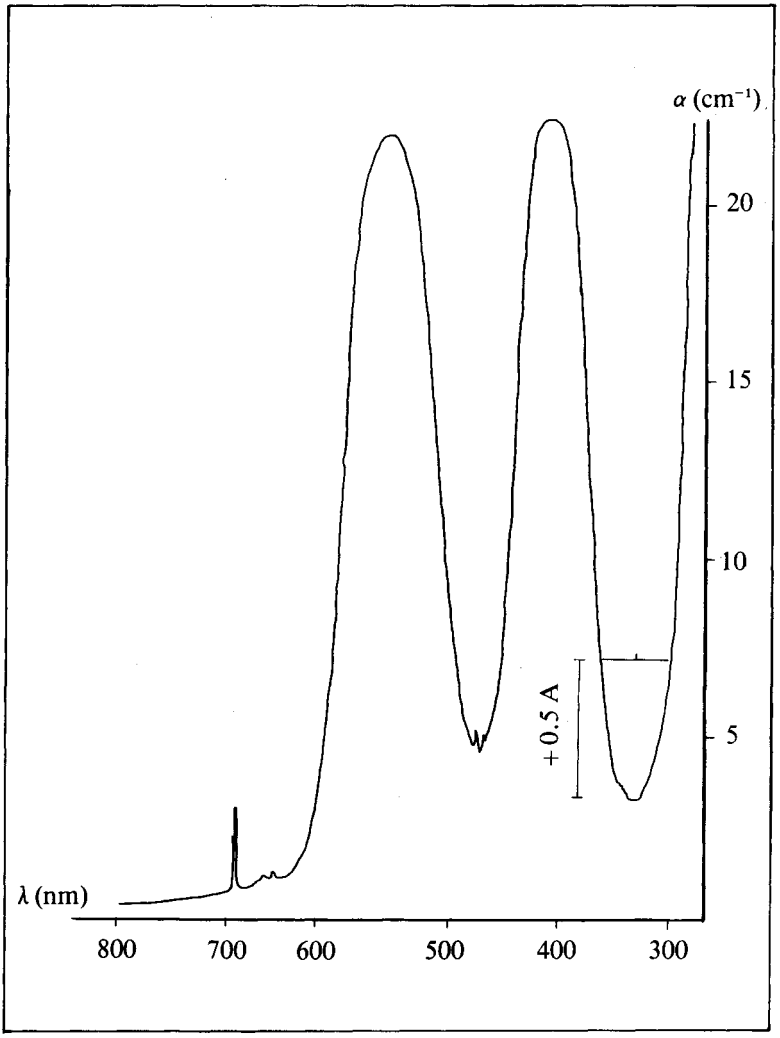

FIG. 3. Polarized absorption spectrum of a Ramaura synthetic ruby from U.S.A., recorded at room temperature in the range from 800 to 200 nm (*e*-vibration parallel, *o*-vibration perpendicular to the optic axis). Absorption coefficient is approximate *(legend after Bosshart).*

Absorption spectrum investigations

A prism-type gemmological spectroscope reveals the diagnostic absorption spectrum of ruby on investigation of Ramaura flux rubies. The transparent flat crystal (Figure 2) was analysed by Mr G. Bosshart (Director of the Swiss Foundation for the Research of Gemstones, Zürich) on a Pye Unicam, SP8–100 spectrophotometer. The results are shown in Figure 3. According to Bosshart, new and interesting information was obtained in this connexion. The ultraviolet transmission of Ramaura quite overlaps the population regions characterized by natural and synthetic rubies (see Bosshart, 1982). He further added that the Ramaura samples investigated by him fall into the natural rather than into the synthetic region. The sample stone, which he kindly analysed on the request of the author, fits into the Knischka population field with $\lambda/W = 331/61 = 5.3$ at $\lambda = 331$ nm., Up to date, the ultraviolet spectrometric analysis overlaps, to a certain extent, the results of Ramaura synthetic ruby.

Reaction to ultraviolet radiations

The luminescence effects are variable on the new product under the long (365 nm) and short (254 nm) wavelengths of the ultraviolet region. Most of the stones fluoresced weak to very weak in effect. The results could be judged only under well controlled conditions. A few, however, consisted of fluorescence which was moderate to strong in intensity. The manufacturer has announced the doping of a chemical agent to influence the fluorescence, and this in turn would easily identify the Ramaura flux ruby. According to the available information the ultraviolet reaction is reported to be yellowish orange glow on the surface. One of the rough stones examined revealed this identifiable fluorescence, but it became no longer apparent during a repolishing process. It was therefore concluded that the doping is probably concentrated just below the crystal surface and not in any significant amounts deeper within the stone.

Microscopic examinations

It is now established that synthetic rubies of flux methods are grown on a seed crystal. However, the growth of Ramaura synthetic ruby is achieved by a self-nucleation involving the melt diffusion process. Owing to this spontaneous nucleation, as it is also referred to by the crystal chemist, the optical orientations as

well as the resulting crystal faces of the crystals may obey random growth directions. Similar features were even distinct on Ramaura synthetic rubies. Frequent occurrences of flat crystals and crystal clusters are known. However, the manufacturer has obtained cuttable quality crystals in the growth process.

INCLUSIONS

The inclusions present in synthetic materials, in relation to their growth procedures, are quite definite in comparison to the unlimited number of inclusions enclosed within natural gemstones. The nature of included particles and the manner in which they have been trapped within the synthetic host supply evidence enabling the distinction of natural from synthetic stones as well as the separation of the various synthetics of different manufacturers. As has been frequently explained to the trade, this has up to now been true of synthetic rubies. Commercially available synthetic ruby from Verneuil (with its diagnostic curved growth striae), Chatham (with unlimited number of twisted veil-like flux feathers), Kashan (with remarkable drippy flux arranged in a parallel orientation) and Knischka (with its characteristic two-phases in which the outline of the cavity is almost invisible) have their well defined internal marks (see also Gübelin, 1983a; Gunawardene, 1983). To this list, the new product distributed by Overland Gems can be added. Those of Ramaura flux rubies, now available in the trade, consist of various structural growth phenomena, flux feathers and residues and occasionally negative cavities as their own particular characteristics. Recently Kane (1983) reported with similar inclusion descriptions about Ramaura synthetic rubies.

Structural growth phenomena and colour zoning

From the rough crystal to the fashioned gem, straight growth lines were clearly evident in most Ramauras (Figure 4). Their appearance may, as in Figure 5, recall to some the scenery of polysynthetic twin lamellae in natural ruby (compare Figure 8). Often they intersected nearly at 120° (Figure 4). These grainings, as they can also be described, often resembled the 'Scotch in water' effect (Figure 6). This identifying 'hallmark' of Ramaura can easily be seen in an immersion microscope using methylene iodide (n_D = 1.74) with a narrow beam of transmitted light. The effect can be seen in any undefined direction or directions and, as an example, Figure 7

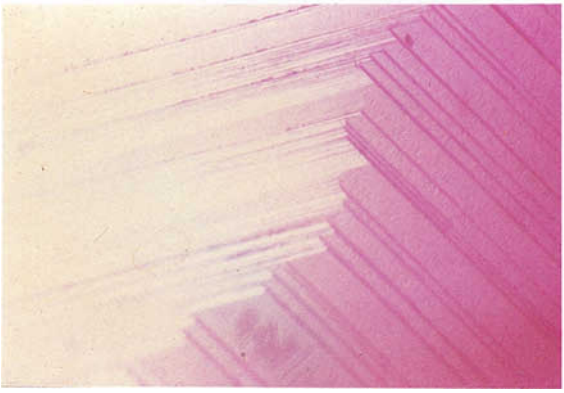

FIG. 4. Striations meeting at an angle of 120° arranged parallel to the basal plane [c (0001)] of the crystal. 30×.

FIG. 5. Straight growth phenomenon seen under the immersion microscope using methylene iodide ($n_D = 1.74$) and a narrow beam of light. 20×.

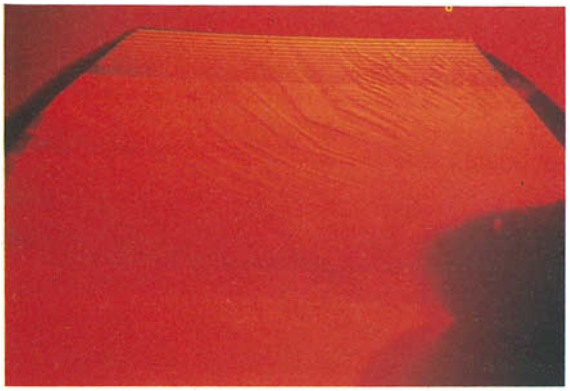

FIG. 6. Diagnostic 'hallmark' of Ramaura flux ruby 'Scotch in water' or 'heat wave' effect. (immersion microscope) 25×.

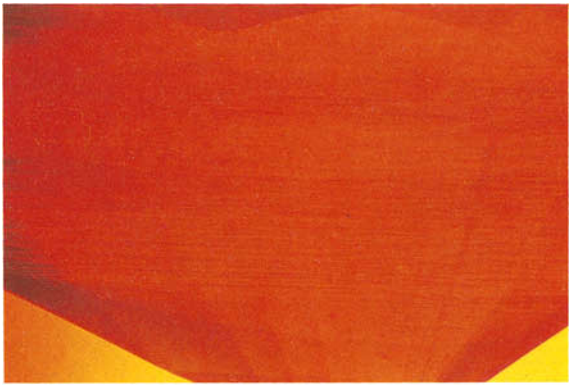

FIG. 7. Graining observed from girdle to girdle in the new synthetic ruby from U.S.A. (immersion microscope) 22 ×.

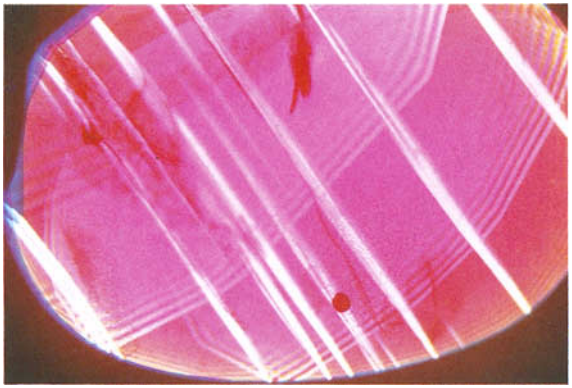

FIG. 8. Polysynthetic twin lamellae in a natural ruby from Chanthaburi, Thailand, with characteristic interference rings along the twin planes under crossed polars. 18 ×.

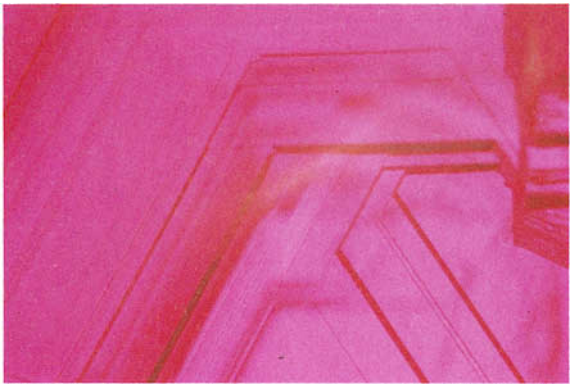

FIG. 9. Orientation of tube-like dense flux parallel to the pseudohexagonal zonal lines. Note the uneven colour concentrations. (dark-field illumination) 60 ×.

shows the observations made through the girdle of the stone. Since the growth features shown in Figures 4 to 7 are quite fine and arranged in a specific manner, the observation of them may undoubtedly pose difficulties to the unexperienced eye. On the other hand it may appear as a new type of inclusion to the gemmologist. How to avoid misunderstanding the graining effect in Ramaura flux ruby and to distinguish it from the polysynthetic twin lamellae present in many natural rubies is explained here. The most successful results in this connexion can be achieved by the use of an immersion microscope and crossed polarizers. The twinning in natural ruby distinctly reveals interference colour rings on the twin planes (Figure 8) between crossed polarizers. If such planes are examined while moving the objective towards or away from the stone, the twin lamellae will be distinct right through the stone. The twinning characteristics mentioned in natural rubies are absent in the Ramaura product.

Angular zonings are also observed in some of the sample stones. They intersect each other nearly at an angle of 120°. If dark-field illumination is used, the uneven coloration, as in Figure 9, along the zonal planes is evident. Concentration of the flux along the zonal planes can be seen (Figure 9) or a random orientation of flux to the zoning (Figure 10). If the microscope light is reflected into these dense flux tubes a yellowish metallic reflection can result and may misleadingly suggest the impression of rutile needles in a natural ruby.

Various flux inclusions

The flux formations in Ramaura synthetic rubies have undergone various stages of solidification. The flux inclusions are recognized as of three different types in accordance with their growth. They can be either (a) *opaque, dense straight tubes or comet-like, or* (b) *opaque to nearly translucent feathers of orange-yellow colour, or* (c) *translucent to nearly transparent fine 'fingerprints':*

(a) *opaque, dense straight tubes or rarely comet-like flux*

As shown in Figures 9 and 10 such dense linear flux is so far not detected in any of the other synthetic rubies made by Chatham, Kashan or Knischka. Although the 'comet tails' are frequently observed in Kashan flux rubies (Gübelin, 1983a) their presence in the observed samples were very rare. The only comet-like inclusion available is illustrated in Figure 10.

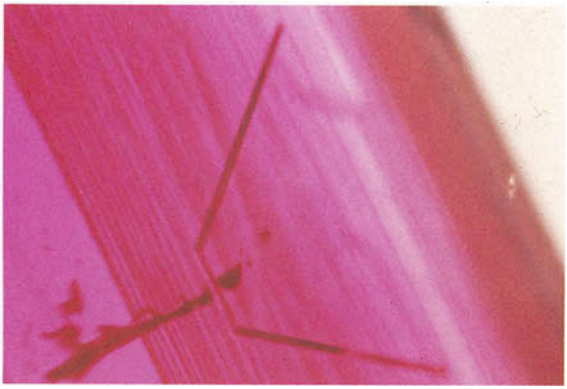

FIG. 10. Orientation of secondary dense flux in a random direction to that of the preliminary concentrated flux. The drippy appearance of the flux can also be noted. (dark-field illumination) 40 ×.

FIG. 11. Characteristic orange-yellow flux arrangement near the girdle of a Ramaura flux ruby. Observations reveal the dense to thin distribution of the flux. Another noted feature was the dragon's-tail-like contours of the residual feathers. (dark-field illumination) 30 ×.

FIG. 12. Orange-yellow flux globules with radiating fine flux feathers in Ramaura product. (dark-field illumination) 35 ×.

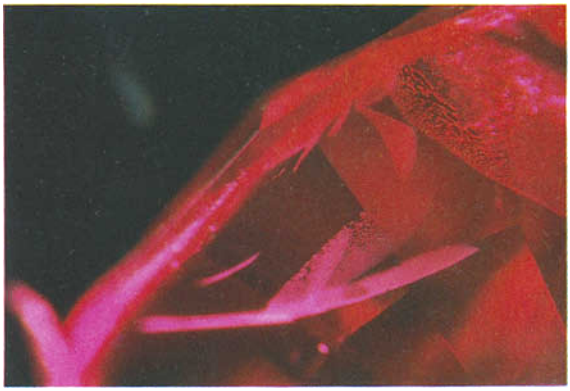

FIG. 13. Fine flux feathers resembling the appearance of feathers seen in heat-treated natural rubies from Thailand. They can be quite dangerous in future discriminations. (dark-field illumination) 30×.

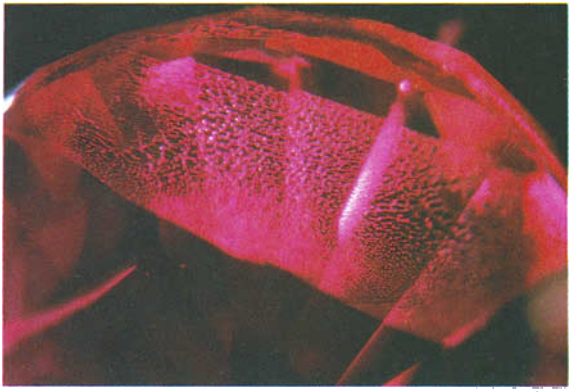

FIG. 14. Inclusions reminiscent of a lace curtain may mislead the eye. However, in Ramaura flux rubies the feathers show clear-cut boundaries. (dark-field illumination) 30×.

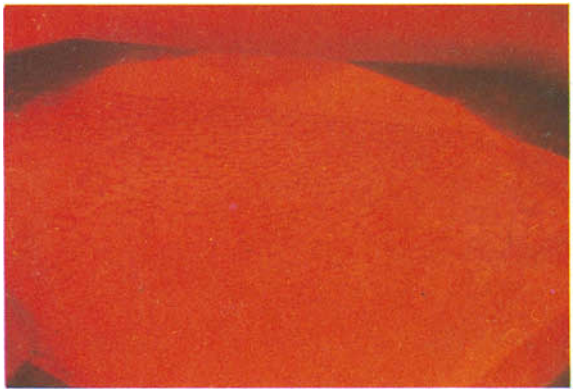

FIG.15. Further study of the feather in Figure 14, now observed in immersion microscope. The particles of flux remain darker than the transparent fluid inclusions in natural rubies. (transmitted light) 35×.

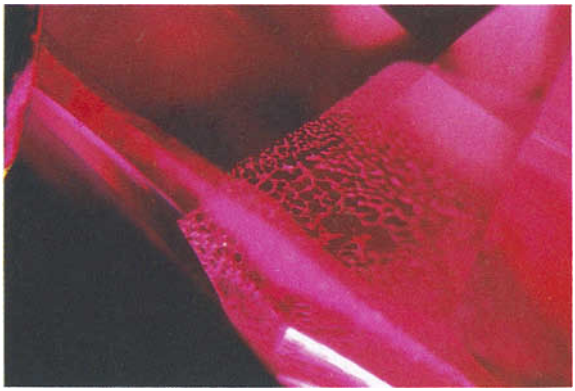

FIG. 16. The lace-like flux feather with diagnostic clear-cut appearance frequently seen in Ramaura flux ruby. (dark-field illumination) 30 × .

(b) *opaque to nearly translucent feathers of flux having an orange-yellow colour*

Often observed in this new synthetic ruby are the opaque to translucent orange-yellow or, as in some cases, white flux feathers; which are concentrated mostly towards the girdle of the cut stone (Figure 11). The contours of semi-dense areas of the feather appear like the tail of a dragon (Figure 11). Opposed to the high relief portions of yellow-orange colour they also exhibit portions of very

FIG. 17. Under crossed polars some of the observed Ramauras revealed negative cavities. 35 × .

low relief. As in Figure 11, they become almost invisible in certain areas. Although the veil-like twisting of flux feathers is absent in Ramaura, the flux feathers may often form a fan-like appearance (Figure 12) with fine mesh-like flux.

(c) *translucent to nearly transparent very fine 'fingerprints'*
Very fine, translucent to nearly transparent 'fingerprints' like flux feathers are noted in the new synthetic ruby. They may, at first glance, impress the eye as natural feathers, similar to those seen in heat-treated Thai rubies. The presence of such feathers, as in Figure 13, should not be considered as the only means of differentiating natural and synthetic rubies. Since their visibility is unreliable for a conclusive result, higher magnifications must be employed (Figure 14). It is advisable also to study the nature of the feather under dark-field illumination (Figure 14) or in immersion microscopy (Figure 15). In both these figures, the unnatural nature of clear-cut lace-like or cobweb-like feathers provides a positive answer that it is a synthetic. In Ramaura flux rubies the feathers often appeared with clear-cut outlines (Figure16). Influenced by the mode of crystallization, resulting negative cavities were evident in a few Ramaura flux rubies (Figure 17). They may often create voids within the stone and can appear in many other forms.

CRYSTALLOGRAPHY OF RAMAURA SYNTHETIC RUBY

Only very little can be explained in relation to the ideal crytallization of Ramaura synthetic ruby. Figure 18 reveals a tabular habit, often resulting from spontaneous nucleation. Such faces as c (0001), r $(10\bar{1}1)$, d $(10\bar{1}2)$ and n $(22\bar{4}3)$ can be recognized with many growth features.

CONCLUDING THOUGHTS

Ramaura synthetic flux rubies of various colour hues and different cuts are now available in the trade. They may be included in parcels of rubies either as rough or fashioned stones. The recognition of them must be concluded under the microscope. The inclusions mentioned, such as growth phenomena, flux feathers and residues and rarely the negative cavities, should be considered in future discriminations. Since the results provided by ultraviolet spectrometric analyses are, up to date, uncertain, the inclusions are the prime identification characteristics of this new product.

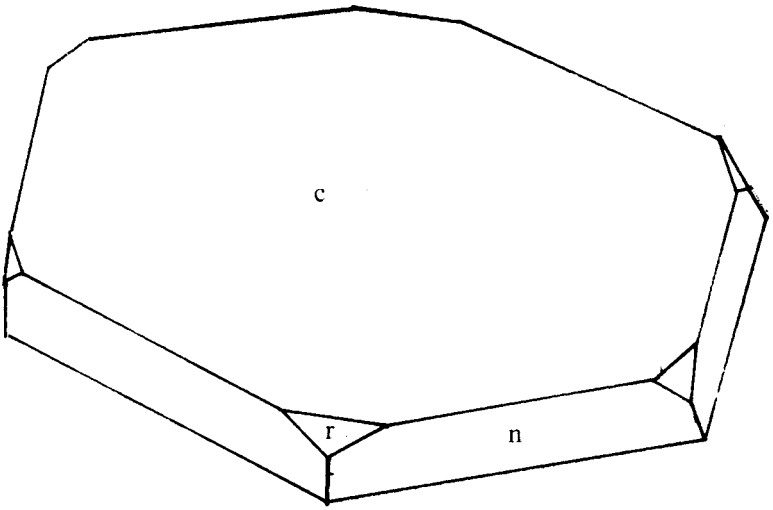

FIG. 18. Flat ruby crystal of Ramaura sketched to show the c (0001), r $(10\bar{1}1)$ and n $(22\bar{4}3)$ faces.

ACKNOWLEDGEMENTS

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REDDISH-BROWN SAPPHIRES FROM UMBA VALLEY, TANZANIA

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INTRODUCTION

As known to the gemmologist and jeweller, East Africa's famous gem locality, Tanzania, is well known not only for garnets of various colour varieties, but also for corundums of many colours and hues. The occurrence of corundum in Tanzania is reported by many researchers (Zwaan, 1974; Dolenc, 1976; Amstutz & Bank, 1977; Bank, 1978). However, these reports mainly describe the common corundum varieties such as ruby and blue and yellow sapphires. Recent observations made by the author on new occurrences of sapphires from Umba Valley revealed a reddish-brown colour variety which has often been termed as 'padparadschah' in the trade. It therefore became necessary to investigate systematically the differences between the 'real' padparadschah and this new occurrence. The chemical and physical properties of the latter are given with special emphasis on the cause of colour. Further, the inclusions are reported, which may be of help in documenting the locality.

CHEMICAL AND PHYSICAL PROPERTIES

Visual colour observations revealed a reddish-brown to brownish-orange body colour often with a yellowish or greenish tint. According to the DIN colour system the colour indices were between 6:6:2 and 7:5:2. Stones with a darker body-colour showed distinct dichroism, which may be helpful to the field gemmologist in separating them from similarly coloured *pyralspite* (or *umbalite*) garnets, which also occur commonly in this locality.

The chemical composition of four samples was analysed by an ARL electron microprobe. Transition metal ions were detected to determine the cause of colour (described below). The analytical values along with the determined refractive indices and specific gravity are given in Table 1.

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TABLE 1. The physical and chemical data of reddish-brown sapphires from Umba Valley, Tanzania.

Sample:	1.	2.	3.	4.
Carat weight:	7.80	3.25	1.97	0.88
Colour:	reddish-brown	reddish-brown with a greenish tint	reddish-brown	reddish-brown
Dichroism:				
o — ray:	brownish-orange	brownish-orange	purplish-red	weak for visual observations
e — ray:	yellowish-green	yellowish-green	greenish	
Refractive indices:				
n_ω:	1.771	1.771	1.773	1.773
n_ε:	1.763	1.763	1.765	1.765
Birefringence:	−0.008	−0.008	−0.008	−0.008
Specific gravity at 4 °C*:	4.02	3.99	4.05	4.06
Microprobe analysis (oxides in Wt %)				
Fe_2O_3†	1.10	1.10	1.53	1.62
Cr_2O_3	0.12	0.13	0.09	n.f.
TiO_2	n.f.	0.36	0.03	0.03
V_2O_5	n.f.	n.f.	n.f.	n.f.

* accuracy ± 0.01

† the total iron is calculated as Fe_2O_3

n.f. = not found (below detection limit of the microprobe)

Cause of Colour

The basic possibilities existing for colour of corundum are due to transition metals such as iron, titanium, chromium and vanadium or to lattice imperfections. Experiments have shown that in natural corundum the colour is mainly due to the usual presence of two or more transition metal ions as opposed to the rare occurrence of a single chromophore. If a colour is produced by a single transition metal ion the result is a basic colour which may be green to yellowish-green (due to Fe^{3+}) or pink (due to Ti^{3+}) or red (due to Cr^{3+}) or reddish-green to greyish (due to V^{3+}). Lattice defects may cause a yellowish colour in corundum (Schmetzer & Bank, 1981a and b; Schmetzer *et al,* 1982).

According to the data in Table 1, the reddish-brown stones from Tanzania contained a higher percentage of iron than of the total Cr and Ti content. However, the microprobe cannot determine the oxidation state of iron. It is probable that Fe^{2+} and Fe^{3+} are in different sites within the crystal lattice, causing a somewhat darker hue to the body-colour of the stone. On the other hand the possibility exists that lattice defects also influence the colour of these sapphires, with different positionings of Fe^{2+}, Fe^{3+}, Cr^{3+} and Ti^{4+} within the lattice. Both these explanations can apply to the coloration of the reddish-brown colour in sapphires from Tanzania. The minute quantity of Cr_2O_3 is easily masked by the much larger proportion of iron oxides present. Therefore these stones cannot be referred to as *padparadschah,* whose colour is due to Cr^{3+} and Ti^{4+}.

Absorption and Ultraviolet Behaviour

Schmetzer & Bank (1981a) mentioned that the absorption spectrum of corundum can be due to the presence of one or more metal ions within the structure, which may also lead to the superposition of several basic types of spectra. This type of absorption spectrum was noted with those reddish-brown stones from Umba Valley.

The two colour-causing metals found are iron and chromium, in variable proportions producing orange-brown and orange-red hues. The most distinct line in the blue at 450 nm results, without doubt, from the higher iron content. In every spectrum the Cr lines and bands are detectable, sometimes in considerable strength (doublet at 693 nm, etc.). The presence of vanadium in Tanzanian

FIG. 1. Survey of the most typical internal scene, pressure parting lines in Umba Valley sapphire of reddish-brown colour. 40×. (dark field illumination).

FIG. 2. Typical feather of crystallites, another common feature in reddish-brown sapphires of Tanzanian origin. 40×. (dark field illumination).

FIG. 3. Round zircon crystal with high relief, inside a sapphire from Umba Valley. 80×. (light-field illumination).

ruby, as indicated by Bosshart (1982), does not show up in the spectra of orange sapphire dealt with in this work. However, the rather weak and broad absorptions in the yellow and yellow-green are probably due to superposition of several absorption spectra (see again Schmetzer & Bank, 1981a).

Again, owing to the high iron content the stones were inert under both short- and long-wave ultraviolet radiations.

INCLUSIONS

Various internal scenes were investigated in a large number of corundums having the body-colour mentioned. The most common and typical internal parageneses are shown as photomicrographs in Figures 1 to 3. The crystal inclusions were minute fragments or platelets in appearence. Most of the fragments showed the habit taken by apatite, but were too small for the exact nature to be identified. The feathers were often formed of minute crystals or were healed. Dislocations caused during growth were apparent in most of the specimens. This can be taken as an inclusion typical of the sapphires of this colour originating from Umba Valley.

DISCUSSION

This new occurrence of reddish-brown sapphires from Umba Valley in Tanzania is another natural colour variety to the corundum family. The presence of the transition elements Fe, Cr and Ti along with certain growth defects cause the colour in these sapphires, and it should be mentioned that many intermediate colour hues may be presented in the trade, with false names such as 'padparadschah' or 'umbalite-sapphire'. However, the introduction of a separate name to this new find does not seem to be necessary. In future they can be called *reddish-brown sapphires.*

ACKNOWLEDGEMENTS

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FURTHER LIGHT ON THE SANCY DIAMOND

By R. KEITH MITCHELL, F.G.A.

Some years ago the late John Forster, one time chairman of the Gem Section of the London Chamber of Commerce and the sole remaining active director of the firm of James A. Forster & Sons Ltd, retired and at the that time passed over to me a very mixed assortment of gemmological specimens originally collected by his uncle, or great-uncle, a Mr A. A. Forster, towards the end of the last century. Among these was a very nice cut-paste replica of the Sancy diamond in a simple silver mount as a pendant. With it was a tattered and yellowing scrap of paper. These I now illustrate (Figure 1), and I think this note goes some way toward clearing up any mystery which may still surround the ownership of the smaller of the two Sancy stones.[1] The larger stone apparently passed into the ownership of the Maharajah of Patiala. Its present owner is not known.

1. See E. A. Jobbins, A brief look at the Sancy diamond, *J.Gemm.*, 1977, **XV** (5), 240-2; H. Tillander, Another brief look at the Sancy diamond, *J.Gemm.*, 1978, **XVI** (4), 221-8; Ian McGlashan, Letter to the Editor, *J.Gemm.*, 1981, **XVII** (6), 433-4; Corrigenda, *J.Gemm.*, 1981, **XVII** (8), 647.—Ed.

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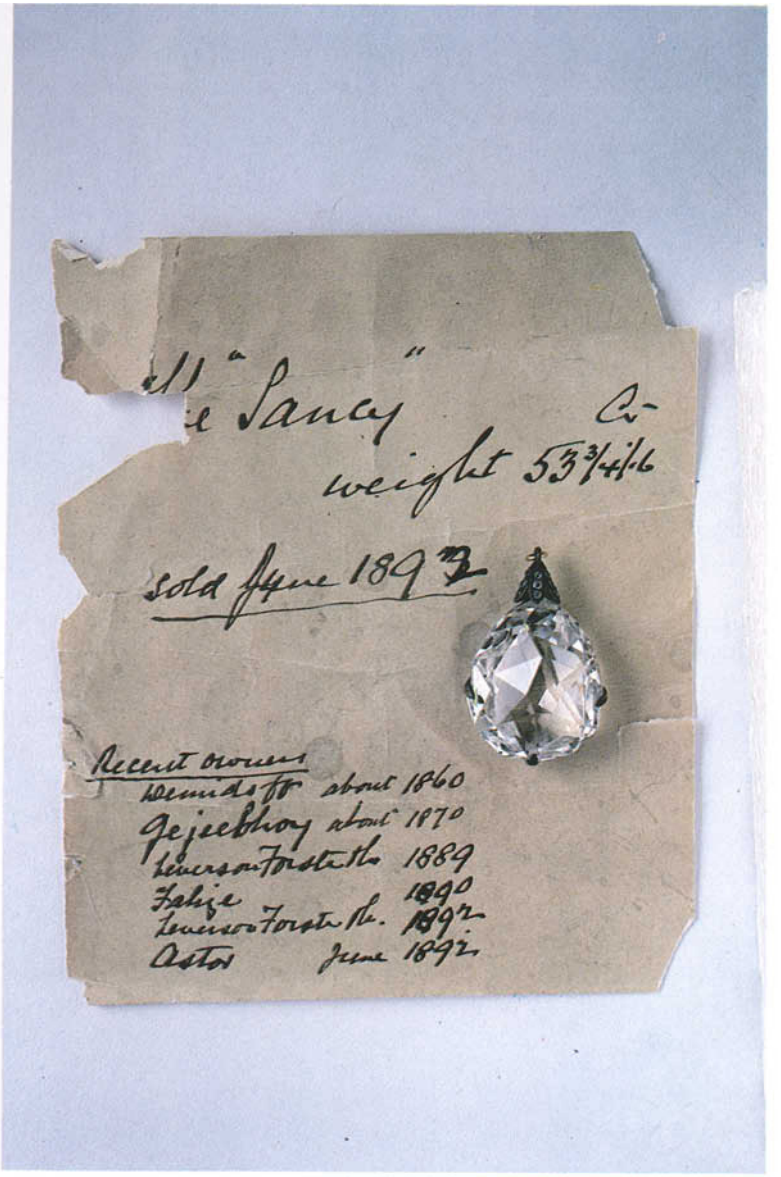
"Sancy"
weight 53 3/4 c.
sold June 1892
Recent owners
Demidoff about 1860
Gejeebhoy about 1870
Emerson Forstetter 1889
Felix 1890
Emerson Forstetter 1892
Astor June 1892

The note, which is probably in the hand-writing of A. A. Forster, can safely be assumed to have been written in 1892, or very shortly afterwards, and lists a number of 'recent' owners of the Beau, or Little, Sancy.

The Russian Count, or Prince, Demidoff, who purchased it in 1828, died a year later, and the stone passed via his son Paul to Paul's wife, who remarried after his death to an Andrew Karamsin. It was acquired 'about 1870' by Sir Jamsetjee Jeejeebhoy, Bt., from Aurora Karamsin, who was again a widow. This date is probably five years out and there is reason to believe that this transaction took place in 1865.[2] The purchaser was originally Cursetjee Jeejeebhoy, who in accordance with tradition, assumed his father's name on succeeding to the title.[3]

The note next refers to the period in which the Forster family are involved, and it seems to establish that they held the stone in 1889, selling it the following year to Falize. This is undoubtedly Lucien Falize, goldsmith to the French Court, historian, archaeologist and painter of quite extraordinary merit. Back to Leverson Forster in 1892, when it was finally sold to Lord Astor. I think this date more or less disposes of the 1906 date suggested by Tillander.

Leverson Forster were precursors of J. A. Forster & Sons, or family connexions. There is a Leverson family in the Australian gem trade, and they had connexions with Haberer Brothers in London. I do not know anything about the Forster connexion.

It will be noted that the weight of the stone is recorded in fractions of a carat. This was the custom before the British carat went metric, the weights used in weighing being listed just as they were, without any attempt to add them together. Thus the weight of 53 ¾ $^{1}/_{16}$carats was in 'old' carats, pre-metrification, which in the gem trade means before 1913. It is the equivalent of 55.23 metric carats, the weight obtained by E. A. Jobbins in January 1976.

[*Manuscript received 10th July 1983.*]

2. *Illustrated London News,* 11th March 1865.—Ed.

3. Sir Jamsetjee Jeejeebhoy(1783-1859) . . . created a Baronet of the U.K. in 1857 . . . was succeeded in the baronetcy by his eldest son, Cursetjee, who in 1860 assumed the name of his father in accordance with a statute which applied to every succeeding holder of the baronetcy. The second baronet died 17th June 1908. (D.N.B., compact edn, O.U.P., 1975, vol. I, p.1070).—Ed.

THE GREEN MONSTER

By DAVID MINSTER, F.G.A.
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It is, I imagine, everyone's dream to own a really outstanding gem specimen. A few years ago I was offered an emerald specimen which I considered of exceptional beauty, large size, good colour and crystal form. I immediately purchased it: maybe it is not of outstanding gem quality—no large stones could be cut from it—but nonetheless it deserves the name of 'The Green Monster'. I showed it to a large number of people attending the Gemmological Association's Golden Jubilee Celebrations in October 1981, and readers who were there may remember me as 'the Man with the Big Emerald'.

The size of the stone is exceptional: its dimensions are 87.85 × 41.5 × 37.6 mm, and it weighs 1250 ct (see Figures 1, 2 and 3). It is brilliant grass-green in colour. The prism faces are well developed with striations parallel to the length of the crystal. There is evidence of quartz inclusions, and part of the matrix (biotite mica) is apparent on the back of the specimen. The hexagonal symmetry can be clearly seen in Figure 2: unfortunately the basal face was sawn off by a previous owner to make the specimen stand well!

Clarity. The stone has a number of fissures extending right through at about 45° to the basal plane. The areas between these fissures are of fine clear green gem-quality, to which the photographs do not do justice. These areas, however, are not large enough to facet stones of more than 0.10 to 2 ct from.

Inclusions. Using a Gemolite Mark 5 Custom de Luxe microscope with both dark-field and bright-field illumination revealed numerous cracks running through the stone, a few biotite inclusions, and one unidentified very bright orange inclusion near the surface.

Spectroscope. A Beck 2522 spectroscope was used. In transmitted light, only red and green 'windows' from 480 to 560 nm and from 590 to 640 nm were observed, the rest of the spectrum being absorbed. In reflected light, there was a typical emerald spectrum, with strong absorption of the blue/violet.

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FIG. 1

FIG.2.

FIG.3.

FIGS. 1, 2, 3. Three different views of the 1250 ct emerald, with scales in inches.

Locality. I have every reason to believe that it was mined in Mozambique. I acquired it in 1979, just after the Portuguese exodus from Mozambique, when the new regime was installed. The man I bought the stone from is now untraceable, but at that time he had some of the Portuguese refugees staying with him, who had brought with them an amazing collection of gems from Mozambique. I myself saw some of this collection, which included a couple of *flawless* tourmaline crystals measuring approximately twelve inches in length and two or three inches thick; they were then on sale for about £35000 each and were promptly snapped up by Americans. There were also some fantastic beryls weighing thousands of carats, and I was able to obtain a 2 kg (flawed) morganite crystal. When the refugees had sold most of their stones, they moved on elsewhere with their money but left behind a few specimens, including the emerald which I subsequently bought, as payment to the people with whom they had stayed for services rendered.

I have enquired about the locality of the mine and understand that it is in northern Mozambique and is known as the Maria Mine—presumably the same as that referred to by Webster (1983). Details are unfortunately sketchy, because the mine is run by Russians and for political reasons it is difficult to obtain information in South Africa from Mozambique.* But my friend, Arthur Thomas, F.G.A., who I believe has actually visited the mine, tells me that the inclusions in my emerald are similar to those in emeralds from the Maria Mine.

All in all, this stone really 'measured up' to my expectations.

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[*Manuscript received 12th May 1980; revised 17th May 1983.*]

*A news item in *The Times* (23rd December 1983, p.5) stated that, according to an official of the Soviet Embassy at Maputo, guerrillas of the Mozambique National Resistance in August 1983 had attacked a mine in Zambezia Province, where they had killed two Soviet geologists and kidnapped twenty-four, of whom two had subsequently died and eight had been freed and returned to the U.S.S.R. This may well well refer to the Maria Mine.—Ed.

VERDITE AND RUBY-VERDITE FROM ZIMBABWE

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The deep green rock verdite has been known from the Barberton district of Transvaal since 1907. More recently, deposits have been found in Zimbabwe and local artists and craftsmen are using the material to produce a variety of carvings which range from small animals for the tourist market to exclusive, large, 'spirit' carvings. Many of the latter have been created by world-famous sculptor-carvers and have drawn critical acclaim during exhibition in London, Paris and New York. The superb woman's head illustrated in Figure 1 shows the range in both colour and texture which is commonly found in the Zimbabwe verdite, and the buffalo (Figure 2) is a fine carving in green and golden brown banded verdite. The material comes from the Concession Corundum Mine about thirty miles north of Harare and is a by-product of the open-cast working for corundum. About 75% of the verdite recovered from this operation contains too much corundum for working by the sculptors, but some ruby corundum in the verdite is accepted and can add significantly to the beauty of the carvings. In the absence of corundum the verdite is a relatively soft rock with hardness 3 on Mohs's scale, but it varies considerably according to its mineral composition and corundum-rich bands approach hardness 9.

In view of the renewed interest in the rock and in order to determine in detail the composition of the Zimbabwe verdite, two examples were examined in detail using optical microscope and electron microprobe techniques, and a series of 19 samples representing different colours and rock textures were subjected to specific gravity measurement. The SG values obtained from verdite range from 2.70 to 2.87, specimens with substantial brown areas or with significant contents of albite (SG 2.63) giving the lower values. Higher specific gravities generally correspond with overall green colour and two dark green specimens from the Transvaal gave values of 2.85. The presence of corundum also raises the overall density and the ashtray of ruby-verdite (Figure 3) has a specific

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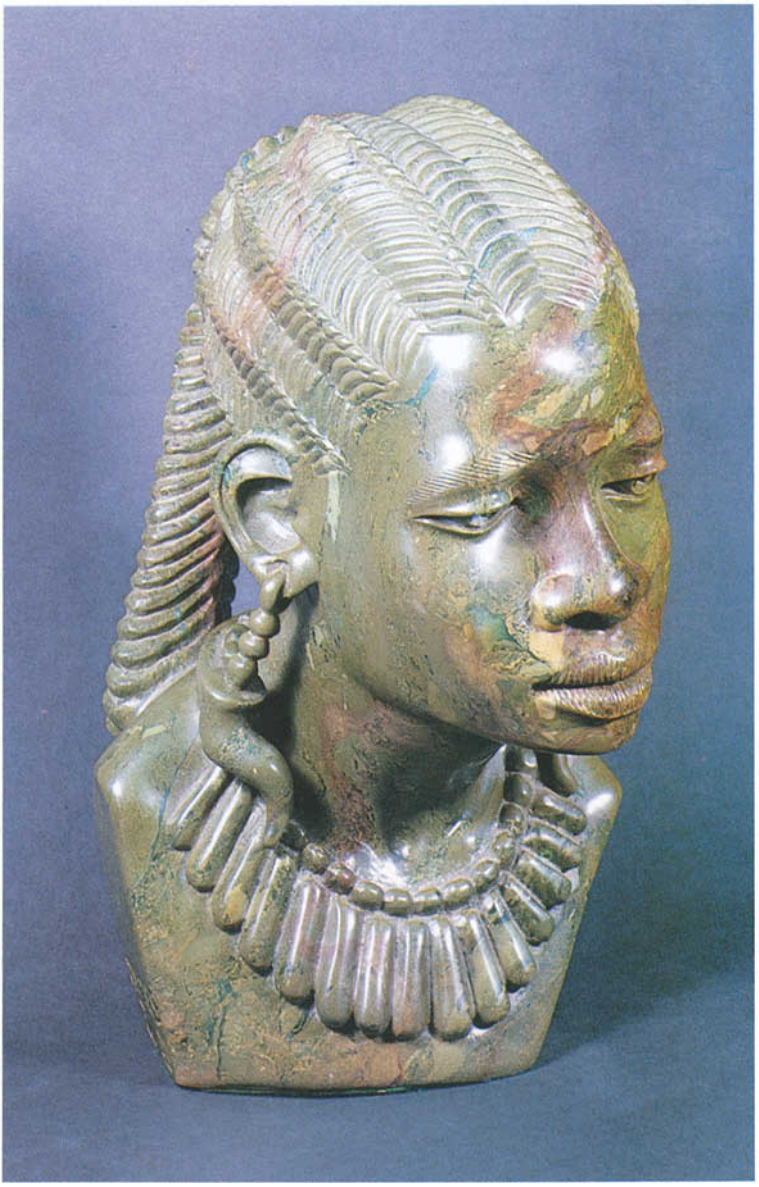

FIG. 1. Woman's head carved in green and brown banded and brecciated verdite from Zimbabwe. Carving 28 cm high.

FIG. 2. Buffalo carved in green and golden brown finely banded and brecciated verdite from Zimbabwe. Carving 27 cm long.

FIG. 3. Ashtray, 26 cm long, fashioned from typically banded ruby-verdite, Zimbabwe.

gravity of 3.15. The higher the proportion of ruby corundum, of course, the closer will the SG approach the value of 4. It is not easy to obtain spectra in a hand-held spectroscope from light reflected off the surface of the verdite and the best results are seen from parts of verdite blocks and carvings which are thin enough to allow some transmission of light. Indistinct absorption lines above 640 nm and vague absorption at the blue end of the spectrum can be seen in some specimens and these results are in accord with the observations of Webster (1983 p.366).

Verdite is a deep green rock consisting essentially of finely intergrown chromian muscovite mica or fuchsite. Scattered grains of rutile are present in the Transvaal verdite and this is also a feature of the Zimbabwe rocks. The fine structure exhibited by the banding or brecciation in many examples (see Figures 1 to 4) is emphasized or brought out by the different colours of the impurities present and it was to identify these that the present study was undertaken. Two samples from the Mazoe-Concession area about thirty miles north of Harare, Zimbabwe, and two from the Transvaal were selected for sectioning and mineralogical analysis. In both localities the rocks are similar in texture and consist of grains of muscovite less than 0.1 mm across finely intergrown in a 'felted' mass (Figures 6, 7). The impurities are generally also of this grain size although some albite grains in the Transvaal rocks reach 2 mm. In thin section the banding is not nearly as sharply defined as in hand specimen, but changes in mineralogy can be seen in Figures 6, 7 and 8 where the dark grains are responsible for the dark brown areas visible in carvings such as that shown in Figure 1.

The two samples from Zimbabwe consist in detail of two mineral assemblages. The first, MI 37073, is largely muscovite with impersistent bands of rutile grains (<0.01 mm). In places there are irregular patches which are orange brown, pale brown or opaque, and these consist of mixtures of hydrous iron oxides and arseniosiderite ($Ca_3Fe_4(AsO_4)_4(OH)_6.3H_2O$). The Ca:Fe:As ratios generally lie between 2:3:3 and 3:4:4, but in some places Fe is dominant, indicating the possible presence of scorodite, and in others As is absent, indicating that goethite or limonite are present. Some grains contain up to 0.5% of Ni, Te, Cu or Bi and their presence is consistent with the occurrence of gold nearby. In these analyses Cr is below the limit of detection of 0.2 wt% oxide. Some grains consist of arseniosiderite cores and iron arsenate rims. The

FIG. 4. Close-up of banding and of irregular patches of fine-grained ruby in verdite, Zimbabwe. Red-ruby, green-chromian muscovite, brown-hydrated iron oxides, arsenates and other minerals.

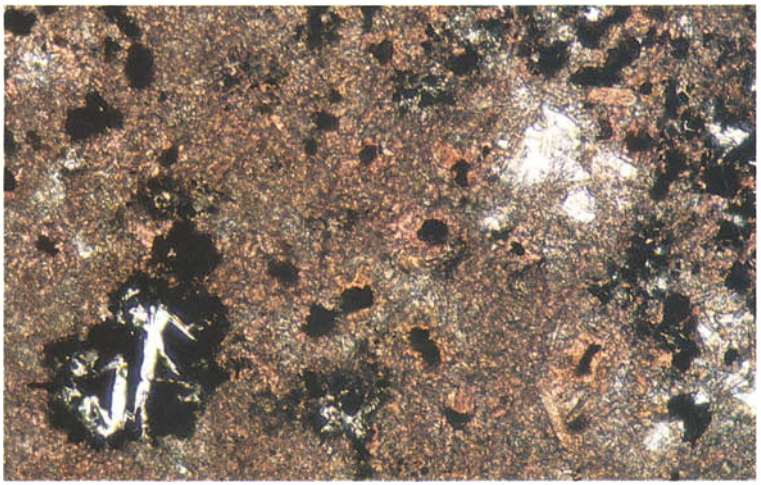

FIG. 5. Pink corundum associated with opaque rutile grains and surrounded by turbid muscovite occurs with patches of chlorite (clear) and gersdorffite (opaque) intergrown with ?andalusite (clear). Zimbabwe verdite MI 37367, field 1 mm wide, plane polarized light.

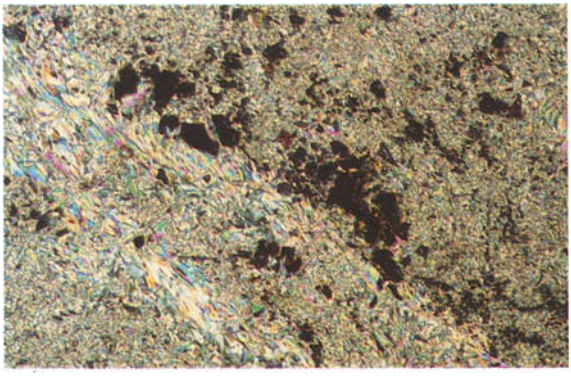

FIG. 6. Verdite from Zimbabwe. Photomicrograph showing muscovite (bright interference colours) with clusters of opaque grains (rutile) and sparse grains of golden brown arseniosiderite. MI 37073, field of view 1 mm wide, cross polarized light.

FIG. 7. Sinuous bands of tiny opaque grains of rutile rest in finely intergrown flakes of muscovite (bright interference colours). Transvaal verdite, MI 26804, field 1 mm wide, cross polarized light.

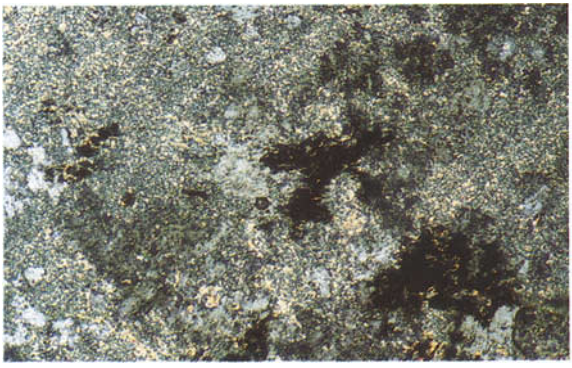

FIG. 8. Groundmass of muscovite flakes with patches of opaque rutile and albite (grey) which are responsible for the 'spotty' character of some Transvaal verdites. MI 35476, field 1 mm wide, cross polarized light.

second Zimbabwe sample is ruby verdite, MI 37367. It consists partly of a fine-grained intergrowth of muscovite, phengitic mica and chlorite with sinuous bands of tiny rutile grains, and partly of a fine-grained (<0.1 mm) intergrowth of corundum with minor quantities of chlorite, muscovite, margarite, aluminium silicate, rutile, gersdorffite and sulpharsenates (Figure 5). The patches and streaks of ruby (Figures 3, 4) consist of masses of tiny unoriented plates of corundum with contents of up to 1% SiO_2, 1% TiO_2 and 4.5% Cr_2O_3. The grains of Al_2SiO_5 are rare and small, and without x-ray crystallographic data it is not possible to be sure if they are andalusite, kyanite or sillimanite; they too contain traces of Cr_2O_3 up to 0.6%. Chlorite is the low-silica variety sheridanite, with up to 1.9% Cr_2O_3, and the calcium mica margarite contains variable amounts of MgO (up to 1.4%), K_2O (up to 1.5%) and Cr_2O_3 (up to 1.2%). The margarite is intergrown with gersdorffite (NiAsS) with minor amounts of Fe and Co. X-ray diffraction studies by Mr B. R. Young confirmed that TiO_2 is present as rutile in MI 37073 (chart DX 2978) and in MI 37367 (DX 2979). The pattern of trace Cr content in many of the verdite minerals is continued in the rutile grains some of which contain 2.5% Cr_2O_3. In the corundum-free part of the rock chromian muscovite is associated with rutile, the only dark mineral, and a second, phengitic mica. Phengite is essentially a solid solution of muscovite with Mg, Fe and Si partially replacing Al, and some grains in this rock contain up to 7.2% MgO and 1.3% FeO, although less Cr_2O_3 is present in this mica than in the Mg-free muscovite. Throughout specimens MI 37073 and MI 37367 the composition of muscovite is consistent except for Cr_2O_3, which ranges from 0.3-1.9% in the former and from 2.1-2.9% in the latter (see Table 1).

The two samples of verdite from the Transvaal, MI 26804 and MI 35476, show less mineralogical variation than the Zimbabwe specimens. Both consist largely of chromian muscovite and rutile, but whereas there is only a trace of albite feldspar in MI 26804, MI 35476 contains up to 30% (Figure 8). In the latter, the feldspar composition ranges from $Ab_{95}An_4Or_1$ to $Ab_{90}An_6Or_4$. The occurrence and composition of rutile resembles closely that in the Zimbabwe verdite with sinuous bands of tiny grains which again contain minor amounts of Cr_2O_3. In addition, however, small amounts of Ca and P were detected and the rutile may contain submicroscopic inclusions or intergrowths of apatite.

TABLE 1
Energy-dispersive electron microprobe analyses of muscovites.

Wt%	1	2	3	4
SiO_2	45.52	45.14	47.42	45.08
TiO_2	0.23	0.34	0.42	0.39
Al_2O_3	35.16	35.10	31.78	30.89
FeO	<0.2	<0.2	0.20	0.33
MgO	0.37	<0.2	1.61	1.72
Na_2O	0.91	0.68	0.59	0.43
K_2O	10.23	10.19	10.88	10.36
Cr_2O_3	1.23	2.60	1.86	4.20
Total	93.65	94.05	94.76	93.40

Notes. An accelerating voltage of 15 kV, a specimen current of 5×10^{-9} amps and an electron beam focused to about 5μm were used. Elements of atomic number 11 (Na) and above can be measured by this method and the limits of detection for each of the oxides are about 0.2 wt %. Total iron was assigned to FeO. The low totals do not include H_2O and the possible presence of oxides of low atomic number elements. Numbers refer to specimens in the collection of the British Geological Survey, London.

1. Mean of 10 analyses of muscovite in verdite MI 37073 (SG 2.84) from near Harare, Zimbabwe. Cell dimensions: a 5.184 ± 0.002Å b 8.997 ± 0.003Å c 20.044 ±0.003Å β 95 ° 45′ ± 1′.
2. Mean of 3 analyses of muscovite in ruby-verdite MI 37367 (SG 2.84) from Concession Corundum Mine, north of Harare, Zimbabwe.
3. Mean of 7 analyses of muscovite in verdite MI 26804 (SG 2.85) from Barberton, Transvaal. Cell dimensions: a 5.195 ± 0.001Å b 9.013 ± 0.002Å c 20.020 ± 0.002Å β 95 ° 47′ ± 1′.
4. Mean of 4 analyses of muscovite in verdite MI 35476 (SG 2.70) from Verdite Mine, Transvaal.

The major constituent of verdite is muscovite and the mean compositions in specimens from the two countries are given in Table 1. In the Transvaal verdites, the muscovite composition throughout each rock is relatively consistent with the largest variation shown by Cr_2O_3 (columns 3 and 4). It ranges from 1.4-2.7% in MI 26804 and from 1.2-6.8% in MI 35476. The muscovites in the Zimbabwe verdites are richer in Al_2O_3 and poorer in MgO and Cr_2O_3 than those from the Transvaal, but the differences are very slight and should not be considered significant on the basis of only two samples from each country. Muscovites in the verdites

from both countries are well crystallized and x-ray powder diffraction data were obtained from diffractometer charts using Cu Kα radiation at room temperature (22 °C) and a scanning speed of 1/8 °2Θ/min, using silicon (a = 5.43088Å at 25 °C) as an internal standard. The data were refined using the computer program of Appleman and Evans (1973).

The analyses of the muscovite and rutile and the textures of the rocks suggest that the Zimbabwe and Transvaal verdites are essentially the same. However, in addition to the colour, the beauty of the stone also lies in its banded and brecciated structure, and this is emphasized by the different minerals associated with the muscovite and rutile. Arsenic-bearing minerals, ruby and aluminous silicates are responsible for a whole range of colours in Zimbabwe verdite. Some may have resulted from metamorphism of a banded sedimentary sequence of clay or shaly rock, perhaps tuffaceous with variable contents of heavy minerals, and others, such as the arsenates, may be the result of metasomatic or hydrothermal activity. Ferguson and Wilson (1937) have described fuchsite rocks and andalusite corundum granulites from the area around Concession and they consider them to be part of the largely volcanic Greenstone series of the Basement Schists, which are Precambrian in age. The corundum granulites probably arose from thermal metamorphism of an aluminous sedimentary layer interbanded with the volcanics but they consider (op. cit., p.32) the origin of the fuchsite rock to be very obscure. The origin of the Cr-mica rocks in other parts of the world is likewise not well understood and a complex history of Cr-mica schists of the Erris Complex in Ireland has recently been described by Max *et al.* (1983). They conclude that a wide range of rock types (ultrabasic to acid) had been dismembered and recombined during two periods of metamorphism, and that the Cr-mica grew at a late stage under the influence of hydrothermal fluids. According to Heinrich (1965) Cr-muscovite is found both in medium grade metamorphic rocks (schists and quartzites) in which there is no evidence of metasomatism, and in hydrothermal veins and replacement deposits. Whitmore *et al.* (1946) outline a three-fold classification based on associated minerals in low, medium or high-grade metamorphic environments, and comment on the association of Cr-muscovite with ruby corundum and kyanite in NE. Transvaal (op. cit., p.18). However, phengitic mica, which occurs in the

Concession ruby-verdite, is typical of low grades of metamorphism (prehnite-pumpellyite to low chlorite zone of the greenschist facies) and may well have developed as a result of hydrothermal activity. It is evident that Cr-muscovites and Cr-phengites are typically associated with complex metamorphic terrains, and in order to determine the origin of the Zimbabwe verdites the detailed geology of the surrounding rocks will also have to be known.

ACKNOWLEDGEMENTS

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UNUSUAL EPR PROPERTIES OF MIKU EMERALDS

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INTRODUCTION

An unusual pleochroism was recently found by Schmetzer and Bank (1981) in emeralds from Miku (Zambia). These dark green emeralds show a pleochroism || *c* blue and ⊥ *c* yellowish-green, and this phenomenon was explained as due to 'a coincidence of an emerald and aquamarine component in the same individual stone'. The microprobe analysis revealed a high iron content, while chromium and vanadium were present as trace elements only. Schmetzer and Bank's (1981) suggestions imply that the iron atoms are replacing in solid solution the octahedral and tetrahedral cations in the beryl structure.

In order to clarify this point we have performed EPR (Electron Paramagnetic Resonance) investigations on 12 emeralds from Miku. The EPR is a non-destructive technique* and gives useful and sensitive indications on the paramagnetic impurities occurring in gemstones, the number of the signals and their position depending on the impurity and the type of the crystal.

RESULTS AND DISCUSSION

EPR measurements were performed using a Varian E-9 spectrometer operating at x-band frequency and equipped with a static magnetic field up to 1.6 tesla. In our apparatus the changing of the sample is very rapid, and we can study single crystals ranging from 1 mm^3 to 1 cm^3. The EPR spectra were recorded as a function of the angle between the applied magnetic field $\vec{H}$ and the hexagonal *c* axis.

Chromium and iron are usually found as impurities in both natural and synthetic emeralds (Hutton and Barrington, 1977), and

*See D. R. Hutton (1979), Magnetic Resonance—a Non-destructive Probe of Gemstones, *J.Gemm.*, **XVI**(6), 372-85.—Ed.

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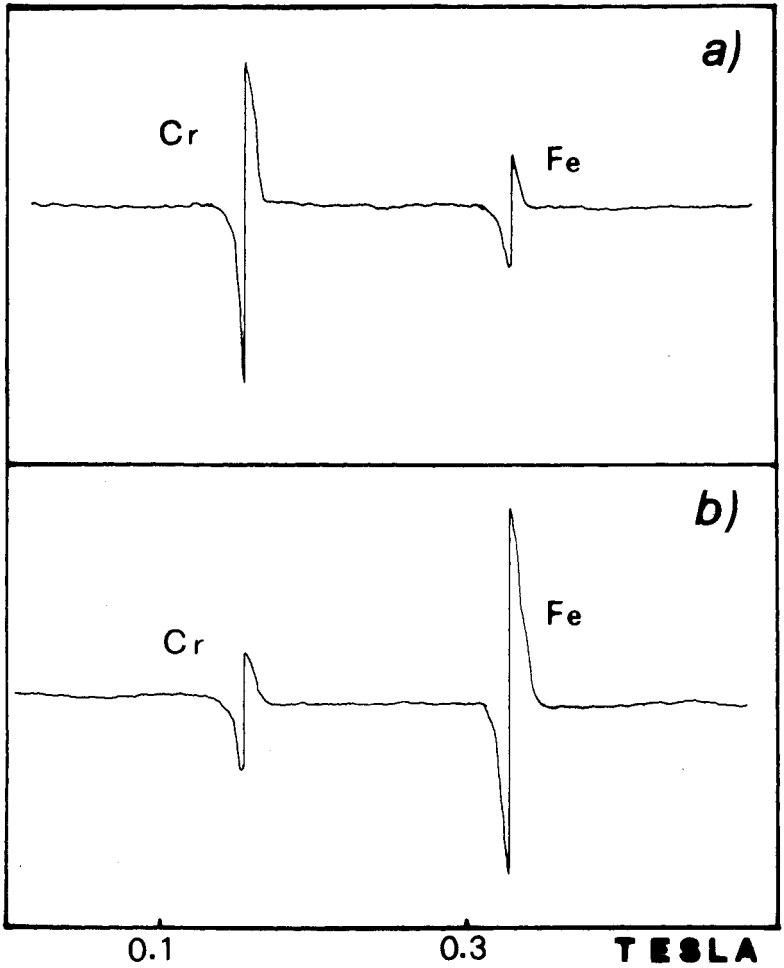

FIG. 1 EPR spectra of (a) synthetic emerald Gilson N; (b) emerald from the Urals (U.S.S.R.). $\vec{H} \perp c$ axis.

they can be easily identified performing EPR experiments with $\vec{H} \perp c$. In Figure 1 we record the EPR spectra of a Gilson N synthetic emerald and a natural emerald from the Urals (U.S.S.R.). These spectra are commonly found in synthetic as well as natural emeralds (Viticoli *et al.,* 1984), indicating that chromium and iron are present as trivalent ions replacing the Al^{3+} ions in the octahedral

sites of the beryl structure. The intensity of the signals is directly related to the concentration of the impurities, and the linewidths are of the order of 3×10^{-3} tesla.

Miku emeralds show instead a very different EPR spectrum (Figure 2) : the Cr^{3+} and Fe^{3+} signals appear as very narrow bands superimposed on a very broad absorption with a linewidth of 1.8×10^{-1} tesla.

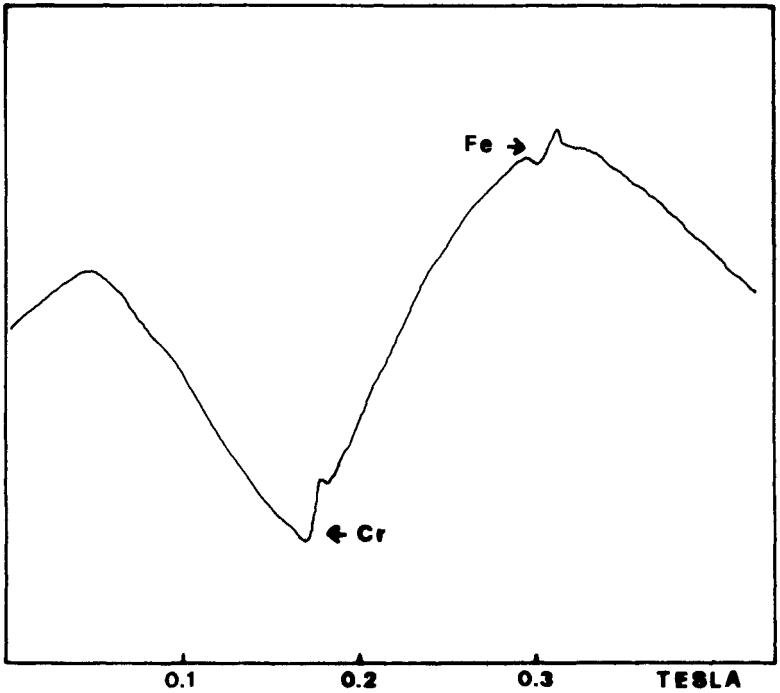

FIG. 2 EPR spectrum of Miku emerald ($\vec{H} \perp c$ axis).

The Fe^{3+} and Cr^{3+} signals are comparable in intensity, suggesting that the iron atoms present in the octahedral sites of the beryl are a small fraction of the total iron content found by the microprobe analysis. Therefore we suggest that the broad EPR signal originates from the presence, in these emeralds, of a magnetic concentrated compound of iron. A more complete

analysis of the optical spectrum (350-2000 nm) could help to identify this compound and its possible effects on the visible spectrum of Miku emeralds.

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Viticoli, S., Gastaldi, L., Flamini, A., & Grubessi, O. (1984) Optical absorption and EPR investigations on natural and synthetic emeralds. *La Gemmologia*, in press.

[*Manuscript received 29th March, 1983.*]

A NEW LAMP USING STANDARD ILLUMINANTS A, C AND D 65 FOR COLOUR-GRADING OF GEM STONES

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1. THE E.Ö.G.G. STANDARD LAMP-UNIT

Colour measurements of gemstones should provide data based on visual judgements. They form the 'colour'-basis when grading coloured stones. Gemmologists are used to making visual estimations of colour of gemstones by comparison under variable conditions. What they find in this way are arbitrary values based on personal criteria and different conditions of tests and judgement. With the boom in the diamond and coloured stone markets accurate and more reliable systems for colour-measurements were asked for and seem now to be in their developmental states. Most of them are based on visual estimations, only rarely on the

tristimulus method or photo-electric measurements. None uses standard colour charts, which for years have widely been accepted in industry for visual colour matching.[1,2,3,4,5] There does not exist a world-wide agreement on the use of a standardized light-source. Gemmologists still prefer to work with fluorescent lamps with or without built-in colour-filters. But these lamps show large deviations of radiance from CIE[1] standard values. Moreover, there are marked differences in colour-temperatures with various types.

In 1965 the standard light-source D 65 was introduced by the CIE.[1,3] This light-source is, nowadays, available in most commercial, though expensive, photometers, but mostly through the use of built-in computers. Gemmologists and gemstone dealers would possibly need less sophisticated instruments. It was therefore a most asked-for prerequisite to build a modern standard light-source with standard illuminants D 65 and C tailor-made for the colour-grading of gemstones of any kind. This aim was achieved through a special research program of the E.Ö.G.G.*

This lamp-unit houses a tungsten filament OSRAM Wi 410 light-source for standard light D 65. The first one includes a CIE-based liquid filter system.[1,3,8] Without these filters the tungsten lamp produces standard light A. The second one makes use of a specially E.Ö.G.G.-developed solid filter system. There are two compartments for visual colour-matching. The interior of both compartments is covered with barium sulphate white (DIN 6164). There are exchangeable stone-holders, one for diamond-grading and others for visual colour-matching of coloured stones of different carat weights. The compartments and stone-holders are of such sizes that practically any cut stone can be visually compared with from two to four chips from the DIN colour-chart. With rotatable stone-holders the conditions of 45/0° for visual colour-matching as recommended by the DIN 5033[3,8] are easily fulfilled. The stone-holders facilitate colour-grading of diamonds by means of master-stones, with both standard illuminants C and D 65, without resetting the stones.

Figure 1 shows the lamp with the standard illuminant D 65 on the left compartment and the standard illuminant C on the right.

Figure 2 gives a closer view of the interior of one compartment with coloured stone and chips.

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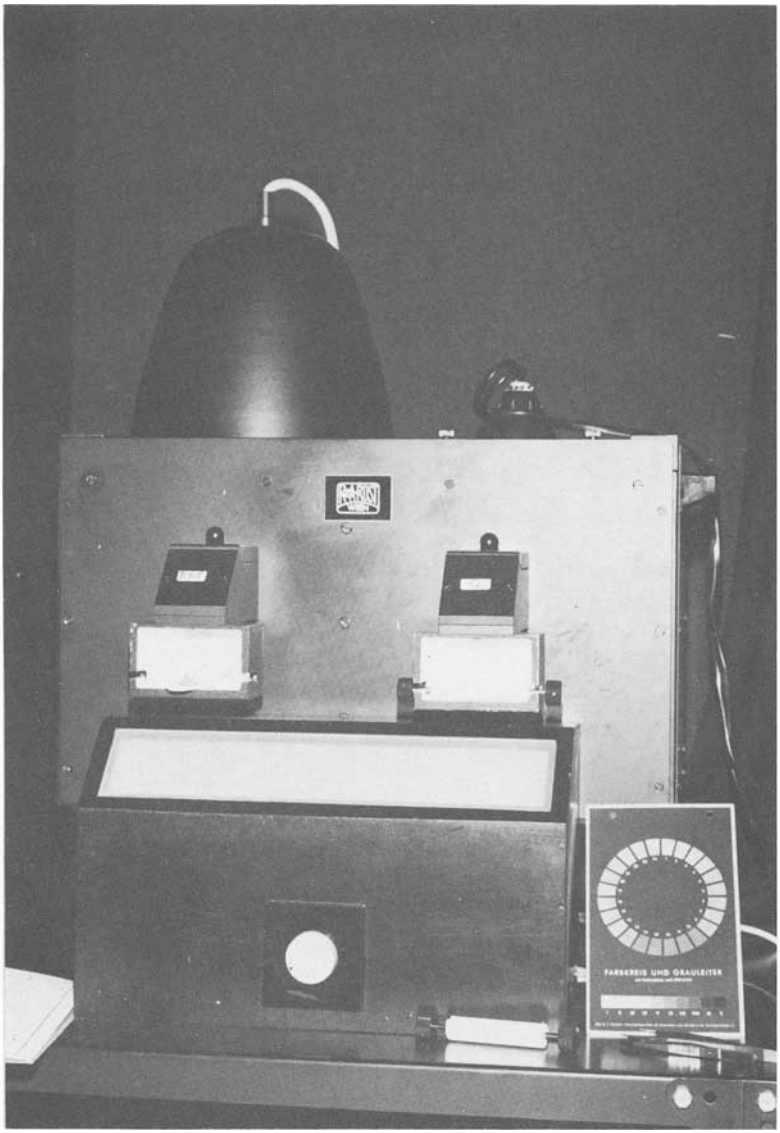

FIG. 1. E.Ö.G.G. grading lamp with standard illuminants A, C and D 65, ready for use. In the left D 65 compartment a large fire-opal rests on a plate. Two forms of rotatable stone-holder are shown on the right side, one in the C-compartment, the other below. In front of the lamp unit there is a long fluorescent lamp fitted with a dimmer control. This lamp facilitates the rapid accommodation of the eyes prior to any colour-matching test.

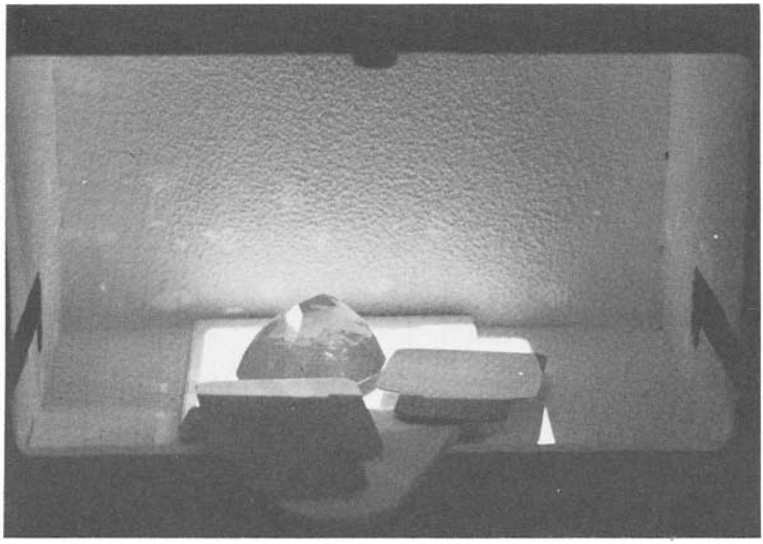

FIG.2. The interior of the left D 65-compartment with stone and glossy colour-chips. Oblique trays are used with other forms and sizes of cut stones; thus conditions for 45/0°-angles for incident light/visual matching according to DIN 5033, part 7, are easily met with.

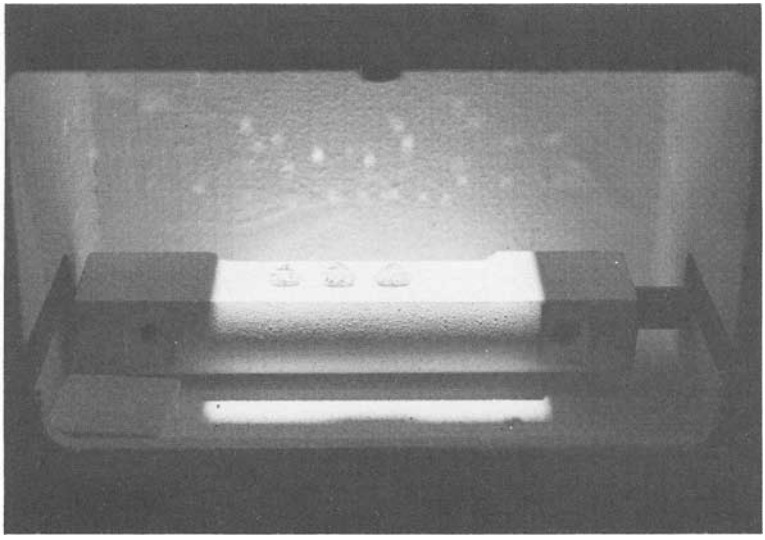

FIG. 3. The interior of the right C-compartment with rotatable stone holder for colour-grading of diamonds using master stones.

Figure 3 demonstrates how the rotatable stone-holder is used for colour-grading of diamonds by means of master-stones.

The colour-temperatures of the standard illuminant C and D 65 of the E.Ö.G.G. grading lamp have been carefully measured by the Bundesanstalt für Eich und Vermessungswesen, Vienna, using the liquid filters according to DIN 5033, part 7, page 2, or the specially designed conversion filter to produce standard illuminant D 65. The x, y chromaticity co-ordinates of both standard illuminants C and D 65 are given in Table 1.

TABLE 1

x, y chromaticity co-ordinates of the standard illuminants C and D 65 of the E.Ö.G.G. grading lamp

illuminant and filter	x, y chromaticity co-ordinates		theoretical values of chromaticity co-ordinates	
'D 65' Osram XBO 150 W/1 + special filter combination of E.Ö.G.G.	0.313	0.331	0.3127	0.3290
same lamp + special filter combination + heat-shield	0.316	0.345	—	—
'C' Osram Wi41/1 + liquid filters	0.310	0.316	0.3101	0.3162

There exist two sets of the DIN colour-charts. The older one uses non-glossy chips for standard illuminant C.[2] The new one contains glossy chips to be used with standard illuminant D 65. Normally, for a trained observer to judge intermediate values, four chips of the chart are sufficient for visual colour-matching. The

Pflanzenfarbenatlas, by Professor Biesalski, used already by Rösch,[9] proved to be a valuable additional means for colour-matching of gemstones. It contains those colour-chips based on DIN 6164 for illuminant C of high saturation values, which in the older DIN colour-chart have been omitted. The psychologically well balanced System of the DIN colour-chart based on hue (Farbton T), saturation (Sättigung S, chroma) and relative brightness (Dunkelstufe D, value V) can be tranformed by means of special graphic charts or through specially programmed computers into CIE (x, y) chromaticity co-ordinates.[6,7] It is also possible to calculate the Munsell notation or renotation values for hue, chroma and value from the measured T-, S- and D-values.

2. Visual Colour-Matching of some Turquoises and Fire Opals

Using the chips of the DIN 6164 colour-chart, fourteen observers were chosen to estimate the colour of nine turquoises. Each observer was familiar with handling gemstones and had passed medical tests for colour deficiences. The T-, S- and D-values found in these tests were statistically treated and tranformed into CIE x, y chromaticity co-ordinates. The loci of these co-ordinates are reproduced in Figure 4. It can been seen that the loci of the turquoises are concentrated within a small rectangular field starting at the lower part of the colour-triangle in the blue region and extending in an upward direction to colours with less saturation and a greenish tint. The 95% confidence-limits of the median-values of the calculated chromaticity co-ordinates are marked by the length of the horizontal and vertical bars.

Likewise the chromaticity co-ordinates of some fire opals were calculated from visual colour-matching using this time DIN colour chips for both illuminants, source C and D 65. The choice of fire opals was a necessity because of the lack of some of the new glossy chips of the DIN colour-chart for standard illuminant D 65 at the time of the experiments. For the 'opal-tests' twenty-eight observers had to make their independent estimations on seven fire opals. The result of their visual colour-matching tests are presented in Figures 4 and 5 for illuminant C and D 65 respectively with the bars of the 95% confidence-limits of the median-values. It can be seen that with two standard illuminants C and D 65 slightly different but otherwise coherent results were gained by the same twenty-eight

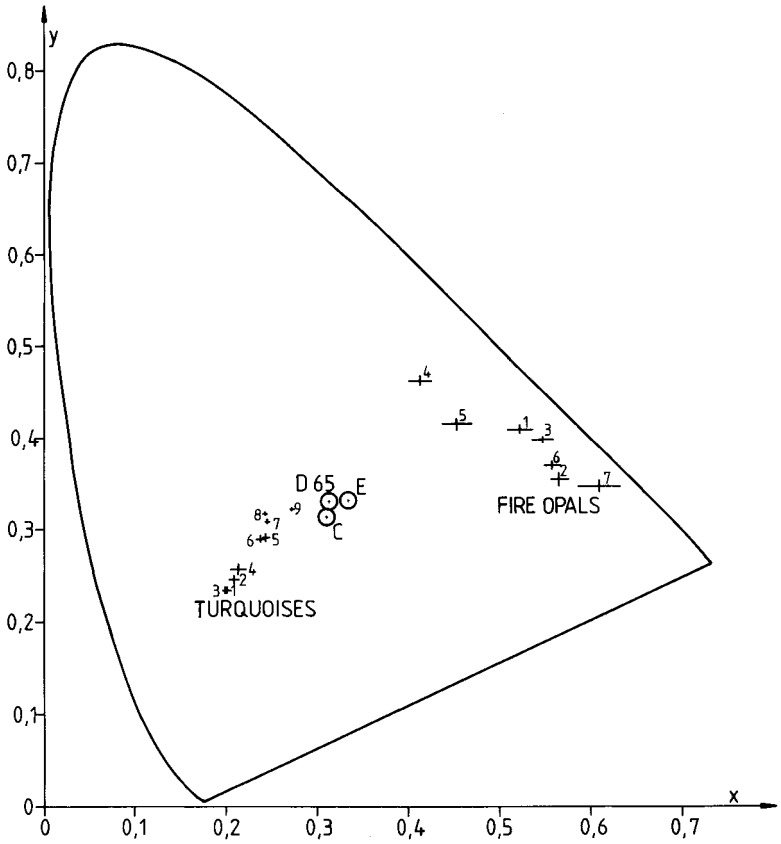

FIG. 4. CIE (x, y) chromaticity co-ordinates of turquoises and fire opals with standard illuminant C. Co-ordinates of standard illuminants C and D 65 together with centre of gravity E of the colour-triangle presented as circle. Horizontal and vertical bars = 95% confidence-limits of median-values.

observers. From the loci of the chromaticity co-ordinates of both figures it can be deduced that the fire opals used were of high colour-quality concerning the close proximity of their saturation values to the spectrum locus of the colour-triangle in the yellow range of colours.

3. THE COLOUR-GRADING OF DIAMONDS

In spite of the agreements reached on grading of diamonds by means of master-stones, no universally accepted standard illuminant has been proposed by various committees. CIBJO

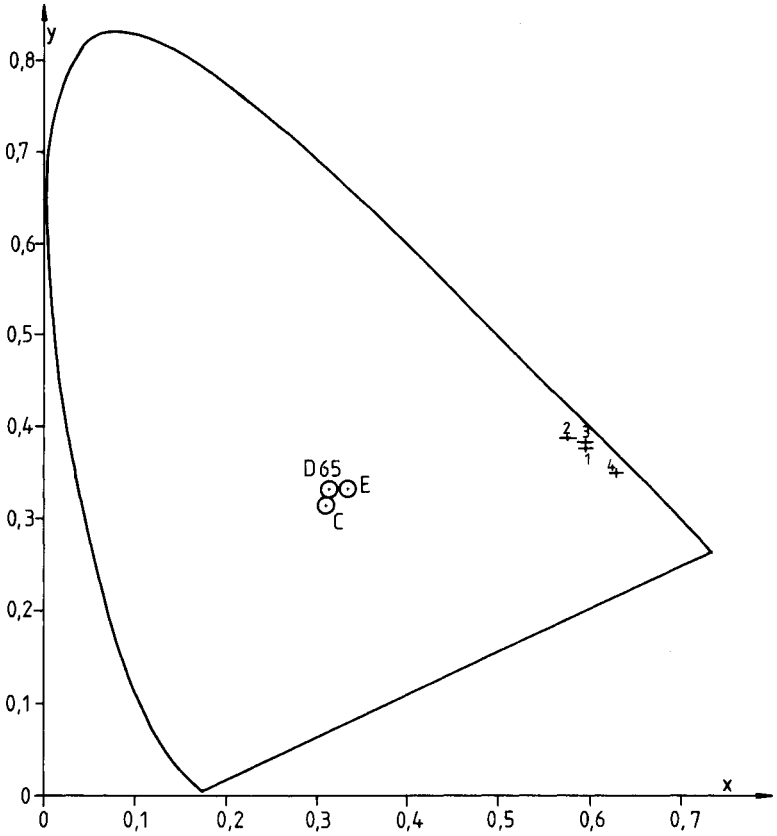

FIG. 5. CIE (x, y) chromaticity co-ordinates of four fire opals with standard illuminant D 65, number and stones identical with those of Figure 4. Horizontal and vertical bars = 95% confidence-limits of median-values.

specifies a 5000 K colour temperature, the IDS rules recommend D 65 as a standard illuminant. This means that nowadays fluorescent lamps and non-standard illuminants as well as standard illuminants C and D 65 can be used.

In order to test the newly developed E.Ö.G.G. standard lamp-unit for diamond-grading four different types of lamp were chosen, whose colour temperatures and chromaticity co-ordinates are given in Table 2. The lamps A and B were separate units not mounted in the E.Ö.G.G. grading lamp unit.

TABLE 2

Colour temperatures and x, y chromaticity co-ordinates of the four illuminants used in the colour-grading tests of brilliant-cut diamonds

illuminant	chromaticity co-ordinates x	y	colour-temperature (K)
A	0.376	0.388	4230
B	0.322	0.346	5950
D 65	0.313	0.331	6504
C	0.310	0.316	2856*

*colour-temperature of illuminant C without CIE liquid filter combination.

The two fluorescent lamp-units were of commercially available types. They are designated by the capital letters A and B. Thirty-seven observers participated in this test, the results of which were subjected to a rigorous statistical treatment. These tests were made with ten different diamonds, which were comparison graded against a set of master stones (CIBJO), and Table 3 contains the results of these tests. It can be seen that with the new lamp-unit rather consistent results could be achieved.

TABLE 3

Results of colour-grading of brilliant-cut diamonds by means of four different illuminants (GIA nomenclature, 37 observers)

type of lamp unit and illuminant	weight of cut diamonds in metric carats									
	0.590	0.478	0.475	0.474	0.588	0.522	0.612	0.708	0.745	0.752
E.Ö.G.G. grading lamp unit: standard illuminant D 65	G+	I	I−	H	E+	G	H−	E−	G+	F+
E.Ö.G.G. grading lamp unit: standard illuminant C	G+	I−	I−	H	E+	G	H−	E−	G	F
fluorescent lamp unit 'A'	F−	I+	J	H−	D−	G−	I+	E−	G−	F−
fluorescent lamp unit 'B'	F	I	J	H−	D−	G−	H−	E	G	F

Some observers found it difficult to use the illuminant D 65 for colour-grading of diamonds, giving preference to the fluorescent lamps A or B or standard illuminant C, which are definitely of lower colour-temperatures. This implies that the higher content of UV light of the standard illuminant D 65 caused some inconvenience with 'white stones'.

The data given in Table 3 makes it obvious—and this is generally felt among many experienced diamond-graders—that the recently introduced subdivision of colour-grades D to K with signs of + or − seems to be of no practical value. For it is now proved that the variances of statistics use are consistently much greater than the calculated confidence-limits. These findings are independent of the colour-grades of the tested diamonds and of the type of illuminant used.

The result of these colour matching tests is the scientifically based confirmation of the opinion of many colour-graders—who have well founded backgrounds in colour-metrics—that first of all a standard illuminant must be found and accepted on a world-wide basis, together with a standardization of the background-conditions of illumination (barium sulphate DIN 6164 in these tests!) if any further improvement in colour-grading of diamonds is to be achieved. The same holds true under even more severe conditions of a standardized procedure of colour-grading of coloured stones.

This work was financially supported by Forschungsförderungs-fond für die gewerbliche Wirtschaft, Vienna, to whom we express our gratitude. We are indebted to Messrs R. and A. Rost, Vienna, for their assistance in building the prototype of E.Ö.G.G. lamp. To the thirty-eight observers who participated in the various colour-matching tests cordial words of thanks are expressed.

4. Conclusions

A new standard two-compartment lamp unit has been developed using standard illuminants C and D 65 (which can be easily extended to illuminant A) specially designed for colour-grading of gemstones. Visual colour-matching can be carried out by means of master-stones with special stone holders, or by comparison with colour-chips, preferably standardized colour-chips according to DIN 5033, making use of the DIN 6164 colour-

chart. Stones and chips rest on plates or rotatable holders painted with barium sulphate white according to DIN 6164, thus any influence of background-colours is rigorously eliminated. Stones need not be reset when changing from one to the other compartment. The results of the visual colour-matching tests can be expressed in T:S:D values (hue:chroma or saturation:relative brightness). These values can be transformed into x, y chromaticity co-ordinates either by use of special nomograms or computer calculations. Conversion into respective Munsell renotation values is possible. Some colour-matching results gained with fire opals and turquoises from up to twenty-eight observers are quoted. The E.Ö.G.G. grading lamp unit can also be used for colour-grading of diamonds by means of master stones. Tests with thirty-seven observers have shown that the subdivision of the GIA colour grades D-K with + or − signs is not justified on statistical grounds.

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(3) DIN-standards: colour measurements 5033, parts 1-9, Beuth-Vertrieb Ges.m.b.H., Berlin 30, BRD, West Germany, 1979-1980.
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(5) Richter, M.: The official German standard colour chart, *J. Opt Soc. Amer.*, **54**, 223-6, 1955.
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(8) Richter, M.: *Einführung in die Farbmetrik*, Walter de Gruyter, Berlin & New York, 1976.
(9) Rösch, S.: Messung der Absorptionsfarben von Mineralen und ihre Auswertung, *Optica Acta*, **11**, 267-84, 1964.

[*Manuscript received 10th June 1983.*]

GEMMOLOGICAL ABSTRACTS

ANDERSON (J. E.). *Clinohumite, the newest gem.* Lapidary J., **37**, 7, 984-7, 3 figs in colour, 1983.

Clinohumite, an orange yellow member of the humite group of minerals, has been found in the Pamirs of the U.S.S.R. and has appeared on the market both as facetable crystals and faceted stones. It is a member of the monoclinic crystal system with hardness over 6, SG 3.2-3.3 and RI 1.631-1.688. M.O'D.

BANK (H.). (a) *Seltene Edelsteine: farbloser Yugawaralith aus Indien, rötlicher Friedelit aus USA und rötlicher Eudialyt aus Schweden.* (Rare gemstones: colourless yugawaralite from India, reddish friedelite from U.S.A. and reddish eudialite from Sweden.) Z.Dt.Gemmol.Ges., **32**, 2/3, 138-40, 1983; (b) *Über Gahnospinelle und Gahnite.* (About gahnospinels and gahnites.) Id., 141-2, 1983; (c) *Farbloser bis gelbicher Hydroxylherderit, ergänzende Daten.* (Colourless to yellowish hydroxyl-herderite, additional data.) Id., 143-4, 1983.

(a) Three rare minerals, cut as gemstones are described: (i) colourless yagawaralite from India, SG 2.21, RI 1.590-1.597, monoclinic and a tekto-silicate; (ii) reddish friedelite from U.S.A., probably from the Hotashell mine where transparent rhodochrosite is found. Colour caused by manganese. RI 1.659-1.627, SG 3.09; (iii) reddish eudialite from Sweden is a ring silicate and trigonal, RI 1.593-1.597, DR 0.004, hardness 5-6 on Mohs's scale, SG 2.88. (b) Mixed crystals of spinel and gahnite were called gahnospinels, RI between 1.796 and 1.803. Mentioned also are a green Brazilian gahnite with RI 1.792 and gahnospinels showing asterism. The gahnites had SG 4.60. (c) The hydroxyl-herderite from Brazil was found to have RI 1.610-1.645 and SG 3.08. E.S.

BANK (H.). *Varieties of beryl found in Madagascar.* Goldschmiedezeitung, **81**, 12, 77, 1983.

The types of beryl found in Madagascar are listed. An emerald with very high RI has recently been found at the Ankadilalana mine in the south-east of the island. M.O'D.

BLACK (P.). *Jade.* Australian Gem & Treasure Hunter, Part 1, 85, 8-10, 3 figs, 1983; Part 2, 86, 25-6, 6 figs, 1983.

The jade minerals and their possible imitations are described gemmologically. Part 2 describes modern mining methods. M.O'D.

BOSSHART (G.). *Cobalt glass as a lapis lazuli imitation.* Gems & Gemology, **XIX**, 4, 228-31, 4 figs (2 in colour), 1983.

A moulded bead necklace offered as 'blue quartz from India' resembled fine lapis lazuli but was proved by absorption spectra and other tests to be a non-transparent cobalt glass. White inclusions of low-cristoballite gave necessary colour irregularities. Dendritic and radial inclusions were seen, completely different from lapis lazuli structure. No pyrite inclusions or bubbles or swirls were present. Macroscopic appearance was confusing. R.K.M.

BRACEWELL (H.). *Diamond in Western Australia.* Wahroongai News, **17**, 10, 9-16, 2 maps, 1983.

A summary and history of the discovery of diamonds by the Ashton and Argyle Mines ventures. Many diamantiferous kimberlite pipes have been found, as well as a number of alluvial deposits. The large pipe, known as AK-1, is expected to come into production in 1985. Sampling so far carried out seems to indicate high productivity, with about 5% of gem quality. R.K.M.

BRACEWELL (H.). *The goldfields of W.A. and the emerald mine.* Wahroongai News, **17**, 8, 20-22, 1983.

Round Australia trip reaches Coolgardie and Kalgoorlie, finding citrine and prase among relics of the gold-mining past. Then on to Menzies and an emerald mine. Areas now producing nickel. Leonora, Gwalia and Kookynie and on to Yundamindera, where chrysoprase, apatite and jasper were sought and fire opal found. R.K.M.

BROWN (G.). *The assessment of gemstone colours: a survey of potential problems.* Aust. Gemmol., **15**, 3, 81-9, 15 figs (13 in colour), 1983.

A very full summary of the problems and possibilities of accurate colour evaluation of gems, assessing available systems, aids, and possible problems arising from sight defects. Paper tends to emphasize the complexities without offering answers. R.K.M.

BROWN (G.). *Direct x-radiography of pearls.* Aust. Gemmol., **15**, 4, 105-21, 36 figs (30 radiographs), 1983.

A very well illustrated paper on the determination of pearls by direct x-rays, which indicates requirements in technique to obtain usefully diagnostic negatives. Advocates the use of dental x-ray apparatus and film. R.K.M.

BROWN (G.). *Western Australian tiger iron.* Wahroongai News, **17**, 8, 11-2, 1 map, 1983.

An ornamental rock, golden crocidolite interfoliated with red, brown or black jaspilite (haematite-rich jasper) found near Mt Goldsworthy, W.A. R.K.M.

BUCHERT (J.), ALFANO (R. R.). *Emerald—a new gem laser material.* Laser Focus/Electro-optics, **19**, 9, 117-23, 4 figs, 1983.

Emerald as a laser medium has been found to have an emission cross section and gain characteristics approximately twice those of alexandrite and it is possible that they may exceed those of alexandrite by as much as four times. Emerald

appears to have the widest spectral band width of any known laser material in which laser action has been achieved. It may be possible for sub-picosecond pulses to be generated. It can also work at high temperatures, conditions in which the inversion population is increased above the ground state. Compared to alexandrite and ruby, emerald has a weaker crystal field to act on energy levels of chromium ions; higher gain permits faster operation and the generation of very short high-intensity pulses. Material used experimentally has been grown hydrothermally. M.O'D.

CASSEDANNE (J.). *Note sur les agates brésiliennes à contours géometriques.* (Note on Brazilian agate with geometric shapes.) Revue de Gemmologie, 77, 8-13, 6 figs, 1983.

The material in question is found at Sitio Garguelo in the extreme west of the state of Paraiba, about 375 km south of Fortaleza. The agates are angular with sections of clear and dark chalcedony, with some quartz, and the centres appear to be hollow. Large specimens may reach nearly 1 m in length; in cross-section they show from three to five faces. Some speculations on origin are given. M.O'D.

CLOCCHIATTI (R.), MASSARE (D.), JEHANNO (C.). *Origine hydrothermale des olivines gemmes de l'ile de Zabargad (St Johns) Mer Rouge par l'étude de leurs inclusions.* (Hydrothermal origin of Zabargad (Red Sea) peridot proved by studying the inclusions.) Bulletin Minéralogique, 104, 354-60, 5 figs, 1981.

A study of the inclusions shown by St John's Island peridot proves the hydrothermal origin of the mineral. Circulations of hypersaline fluids with abundant volatiles and a low pressure caused the major elements in the peridotite to mobilize. M.O'D.

COLLINS (A. T.). *Excited states if the H3 vibronic centre in diamond.* J. Physics C: solid state physics, **16,** 6691-4, 3 figs, 1983.

The H3 vibronic centre in diamond with a zero-phonon line at 2.463 eV has a series of excited states giving absorption lines between 3.2 and 3.6 eV. The transition from the excited regions to the ground state does not give luminescence, but the centre relaxes to the lowest excited level and the H3 luminescence band is produced by transition from this level to the ground state. M.O'D.

DE GOUTIERE (A.). *Unusual amethyst inclusion.* (letter) Gems & Gemology, **XIX,** 3, 170, 1 fig. in colour, 1983.

Illustrates brush-like tufts of cacoxenite in amethyst. R.K.M.

DILLON (S.), ed. *Gem News.* Gems & Gemology, **XIX,** 3, 185-7, 1 fig. in colour, 1983.

Gives diamond news from Australia, Belgium, Israel, Thailand, United States (diamonds have been found on border between Colorado and Wyoming) and Zaire. News of amethyst from Para, Brazil; blue chalcedony from Namibia; Pacific coral from deep waters; a new source of Californite idocrase and a reduction in malachite exports from Zambia and Zaire. Synthetic cat's-eye chrysoberyl from Japan, and C-OX a new synthetic from Russia, said to be similar to cubic zirconia, are reported. R.K.M.

DUIJVESTIJN (M. J.), VAN DER LUGT (C.), SMIDT (J.), WIND (R. A.). *^{13}C NMR spectroscopy in diamonds using dynamic nuclear polarization.* Chemical Physics Letters, **102**, 1, 25-8, 2 figs, 1983.

Unpaired electrons associated with nitrogen impurities can be used to enhance the ^{13}C NMR signal. ^{13}C NMR spectra of three natural and two synthetic diamonds are shown. The magnitude of the signal gives information on the number of paramagnetic impurities and the width of the lines in the signal gives information on the number of ferromagnetic impurities. It is possible that all synthetic diamonds will show a characteristic broadening of the ESR spectrum due to ferromagnetic impurities. M.O'D

DUYK (F.). *Lacunes cristallines dans un saphir.* (Crystalline voids in a sapphire.) Revue de Gemmologie, 77, 14-15, 9 figs, 1983.

A sapphire cabochon of 51 ct and appearing from its colour to be from Sri Lanka showed two voids with crystalline shape. One was about three-quarters filled with liquid and a small black crystal was also present. The smaller of the two voids contained non-miscible liquids. M.O'D.

FRENZEL (G.), STÄHLE (V.), BANK (F. H.). *Granat-Glas-Dublette als Smaragd-Imitation in einem alten Fingerring.* (Garnet-glass doublet as emerald imitation in an antique ring.) Z.Dt.Gemmol.Ges., **32**, 2/3, 92-8, 6 figs (3 in colour), 2 tables, bibl., 1983.

The metal of the ring circa 1830 consisted of gold, silver and copper, the hoop divided at the shoulder. The bezel is formed by a cross of four green stones (0.7 ct total) with a small 'pearl' at the centre which was wax-filled glass. The four green stones were almandine-topped with and without rutile needles fused to the base of potassium-silicate glass high in lead oxide with low softening temperatures. The green colour in the glass was produced by small addition of CuO and Cr_2O_3. E.S.

FRYER (C.), ed., CROWNINGSHIELD (R.), HURWIT (K. N.), KANE (R. E.). *Gem Trade Lab Notes.* Gems & Gemology, **XIX**, 3, 171-6, 18 figs in colour, 1983

An alexandrite cat's-eye of 32.69 carats is illustrated in incandescent and in fluorescent light, a lovely stone! Cubic zirconia, laser 'drilled' to pass as diamond; a pavé-set diamond ring showed extraordinary facet-edge wear; 'fancy' diamonds were found to have been 'painted' (with vitreous enamel?) on pavilion only. Diaspore, a rare aluminium hydroxide gem, SG 3.35, RI 1.702-1.750, biaxial +, identified and illustrated. An emerald exhibited a spiral helical inclusion parallel to *c* axis. A new lapis imitation, differing from natural lapis and from Gilson imitation, was found and illustrated. [Pyrite inclusions were simple in outline.] New and better Gilson synthetic black opals described and illustrated; all contained gas bubbles, short UV gave yellowish-green chalky fluorescence.

Cultured bouton pearls had an unusual radial structure on centre flat base. An Oriental carved stone had approximate RI 1.57, poor polish, and estimated SG 2.70, H about 3; identified as pinite by x-ray powder diffraction, a massive impure form of muscovite mica. A tanzanite (purple zoisite) with rounded facet edges described and illustrated; suggested that this is due to use of a polishing buff on the mount after stone was set. R.K.M.

FRYER (C.), ed., CROWNINGSHIELD (R.), HURWIT (K. N.), KANE (R. E.). *Gem Trade Lab Notes.* Gems & Gemology, **XIX**, 4, 232-7, 22 figs in colour, 1983.

Sapphire with thin colour zone on one surface was thought to be heat-treated, not diffusion coloured; a 2.55 carat fine ruby had been badly fractured by heat treatment; C-Ox is trade name for green and blue forms of cubic zirconia, both stones having strong and characteristic absorption spectra; all diamonds in a brooch fluoresced under long UV; a 4 carat diamond had pronounced fern-like white dendritic inclusions; a carved yellow/black, grey/green jade-like ornament was found to be mainly serpentine; a sawn jade boulder was maw-sit-sit on one side and chloromelanite on the other; new Inamori synthetics are described; three-quarter blister pearls were found with bead completely enclosed but visible through thin back; a ring pearl showed very marked erosion by body acids around each claw of the setting.

Reddish-brown quartz is thought to be heat-treated natural stone; an early 'Geneva' synthetic ruby is described; recently most yellow sapphires tested in New York Lab owed colour to Thai heat-treatment; a group of natural yellows are also discussed; rare cat's-eye zircon is also described. All are illustrated. R.K.M.

GRAY (F. L.). *Engraved gems: a historical perspective.* Gems & Gemology, **XIX**, 4, 191-201, 12 figs, 8 in colour, 1983.

An account of engraved gems from Egyptian times to the present day, when ultrasonic drills are being used to mass-produce cameos and intaglios, thus removing skill from this ancient art. R.K.M.

GÜBELIN (E.). *Black jade from Cowell.* (Letter). Aust. Gemmol., **15**, 3, 79, 1983.

Analyses of black nephrite show that colour is due to high content of FeO, about twice that found in green nephrite. R.K.M.

GÜBELIN (E.). *Marques de distinction des nouveaux rubis synthétiques.* (Distinctive marks shown by some new synthetic rubies.) Revue de Gemmologie, 76, 9-16, 42 figs (41 in colour), 1983.

Details of characteristic inclusions shown by Chatham, Kashan and Knischka rubies are illustrated and discussed. M.O'D.

GÜBELIN (E.). *Rosa topas aus Pakistan.* (Rose topaz from Pakistan.) Lapis, **9**, 1, 23-8, 17 figs in colour, 1984.

A rose-coloured topaz of gem quality is reported from the area of Katlang, north-east of Peshawar, Pakistan. Chemical composition was SiO_2 = 34.34%; Al_2O_3 = 48.13%; Cr_2O_3 = 0.03%; V_2O_3 = up to 0.01%; TiO_2 = up to 0.01%; FeO = up to 0.02%; MgO = up to 0.01%; MnO = up to 0.01%; F = 14.75%; H_2O = 3.01%. RI was 1.629-1.642, DR 0.009-0.011, SG 3.515-3.53. Pleochroic colours were yellow, purple and lilac to violet. An emmission line of some strength is at 682 nm, and there is a faint dark-red luminescence under LWUV. Some colourless and brown stones are also found in the area. Crystals are well-developed and contain two-phase inclusions and parallel needle-like growths. M.O'D.

GUNAWARDENE (M.), MERTENS (R.). *Untersuchungen der neuen Opal-Imitation von Gilson.* (Examination of the new opal imitation by Gilson.) Z.Dt.Gemmol.Ges., **32,** 2/3, 119-25, 8 figs (6 in colour), 1 graph, 1 table, bibl., 1983.

An English version of this article was published in *J.Gemm.,* 1984, **XIX,** 1, 43-53. E.S.

HALL (J.). *Colored gemstones.* Lapidary J., **37,** 7, 978-82, 6 figs in colour, 1983.

A general guide to the coloured stone trade but with some fine coloured pictures. M.O'D.

HÄNNI (H. A.). *Comparaison chimique des émeraudes naturelles et synthétiques.* (Chemical comparisons between natural and synthetic emeralds.) Revue de Gemmologie, 76, 6-8, 1 fig, 1983.

The relative content of secondary elements in the natural and artificial varieties of emerald are discussed and shown in graph form. M.O'D.

HÄNNI (H. A.). *Weitere Untersuchungen an einigen farbwechselnden Edelsteinen.* (Further examination of several gemstones which show colour changes.) Z.Dt.Gemmol.Ges., **32,** 2/3, 99-106, 3 tables, 1 graph, bibl., 1983.

Four colour-changing gemstones were investigated. The material responsible for the colour change was found to be Cr^{2+} in the case of kyanite and diaspore and V^{3+} in pyrope and grossularite-rich spessartites and corundums. In strongly pleochroic specimens certain absorption features are present in one direction only. Colour changes also occur which are different from alexandrite effect, especially in a described garnet. It is questioned therefore whether the effect is to be called alexandrite effect generally. E.S.

HAUNER (U.). *Bayerischer Saphir.* (Bavarian sapphire.) Lapis, **8,** 11, 19-20, 3 figs (2 in colour), 1983.

Blue sapphire not of gem quality has been found in the pegmatite in the Schwarzeck area of Bavaria. M.O'D.

JENKINS (A.). *The Lightning Ridge opal fields.* Part 1. Australian Gem & Treasure Hunter, 85, 29, 2 figs, 1983.

The author arrived on the field in 1969 and begins his account with details of the methods of opal recovery in use at that time. M.O'D.

JEYNES (C.). *A proposed diamond polishing process.* Phil. Mag., A. **48,** 2, 169-97, 15 figs, 1983.

A polishing method for diamond based on a brittle wear-chip mechanism with two stages is described. The size of the chips is determined by cracking in the elastic stress field behind the polishing grains. This field is not considered to be qualitatively changed by plastic deformation. In the second stage the wear chips may be released by a variety of other mechanisms. Plastic deformation may encourage their release. The effects of different grain sizes are discussed. M.O'D.

KANE (R. E.). *The Ramaura synthetic ruby.* Gems & Gemology, **XIX**, 3, 130-48, 26 figs (21 in colour), 1983.

Another new flux synthetic to confuse the gem dealer. This one is 'seed-less', nucleation obtained by slowly cooling the melt. Less inclusions than in 'seeded' growth. Manufacturer says that he is including a characteristic fluorescence under UV to aid recognition. This was not detected in most stones examined. Gemmological properties overlap those for natural stones. Inclusions: no platinum flakes; fractures, healed cracks and various inclusions of orange-yellow and white flux were seen, straight line growth patterns. A considerable variety of such features is illustrated. Any clean ruby must be suspect. R.K.M.

KELLER (P. C.). *The rubies of Mogok: a review of the Mogok stone tract.* Gems & Gemology, **XIX**, 4, 209-19, 11 figs in colour, 1983.

An excellent account of the geology and mining methods of the tract, and of the gemmology of its stones. R.K.M.

KOIVULA (J. I.). *Induced fingerprints.* Gems & Gemology, **XIX**, 4, 220-7, 11 figs in colour, 1983.

Since 1980 heat-induced healed-crack fingerprints have been found in some Verneuil synthetic corundums. The author has successfully reproduced such inclusions in clean synthetic material and their artificial formation is explained in detail. It is suggested that they are induced to up-date cheap Verneuil stones to look like the more expensive flux synthetics. Synthetic corundum slabs were quench-crackled and then placed in a Chatham flux-growth environment for 42 days, causing cracks to heal to give fingerprint-type inclusions. Other stones were subjected to heat alone, but did not heal in this way. A further attempt to induce chemical dendrites was successful, but the fingerprints were not natural-looking. It is thought that such healed cracks occur accidentally when the Thais heat the stones to reduce the visible curved zoning.

Recognition is a problem and depends on basic clues of curved zoning, bubbles, UV transparency beneath the false appearance conferred by the fingerprints. Czochralski pulled crystals can be essentially flawless, so fingerprint inclusions in any otherwise flawless stone must be treated with suspicion. Straight and sharply angled growth or colour zoning and recognized natural included crystals will be further important clues to the natural stone. Induced fingerprints *must* be disclosed. However, Koivula envisages a time when it may be possible to repair a cracked or broken natural stone using one of the techniques described. An important paper!

R.K.M.

KOIVULA (J. I.), ed. *Gem news.* Gems & Gemology, **XIX**, 4, 246-7, 1983.

Australian Ashton Joint Venture has sold its first 200 000 carats of rough for about US$9.50 per carat; C.S.O. starts a quarterly journal; improvement in diamond market expected; Japan cancels duty on diamonds; in 1982 Laurence Graff bought a 278 triangular diamond in West Africa. It cut three stones, including one of 70.03 carats claimed to be the world's largest heart-shaped diamond. India is banning export of rough gems; opal production in Australia fell by estimated 60% last year, driving prices on all grades up; Yogo Gulch sapphire deposit, Montana,

plans to go into full production; in Sri Lanka, Swedish gemmologist Olle Fjordgren has found a first blue zoisite in Rakwana material; information on C-Ox is given; scientists at Marwell,* Oxon, said to have grown diamond on diamond, using high-energy particle accelerator. Carbon atoms fired into diamond crystal and incorporated in structure by annealing at 800 °C. Theoretically claimed to be a possible growth method for large synthetic diamonds. R.K.M.

KOMOTAUER (S. K. K.). *Turmalin.* (Tourmaline.) Mineralien Magazin, **7**, 11, 488-98, 16 figs (13 in colour), 1983.

A beautifully illustrated though simple description of the tourmaline family of gemstones. A short bibliography is included. M.O'D.

LAGACHE (H.). *Méthode de reconnaissance des substituts du diamant de taille 'brillant'.* (How to recognize brilliant-cut diamond substitutes.) Revue de Gemmologie, 76, 18-20, 4 figs, 1983.

Simple methods of distinguishing diamond from its substitutes are given for cut stones. M.O'D.

LEBEDEV (A. S.), ILYIN (A. G.), KLYAKHIN (V. A.). *Variétés de béryl 'gemme' hydrothermal.* (Varieties of beryl gemstones made hydrothermally.) Revue de Gemmologie, 76, 4-5, 5 figs, 1983.

Extract from an uncited paper giving details of the manufacture of various types of beryl by the hydrothermal method. M.O'D.

LESTOCK (J.). *Dinosaur bone agate.* (Letter) Gems & Gemology, **XIX**, 3, 169, 1 fig. in colour, 1983.

Describes and illustrates this unusual material. R.K.M.

LIND (T.), SCHMETZER (K.), BANK (H.). *The identification of turquoise by infrared spectroscopy and x-ray powder diffraction.* Gems & Gemology, **XIX**, 3, 164-8, 1 fig, 1983.

Most turquoise products other than some paraffin-impregnated natural turquoise can be identified by x-ray diffraction and infrared spectroscopy. R.K.M.

LIND (Th.), SCHMETZER (K.), BANK (H.). *Untersuchungsmethoden zur Unterscheidung von natürlichen und synthetischen Amethysten.* (Methods of differentiating between natural and synthetic amethysts.) Z.Dt.Gemmol.Ges., **32**, 2/3, 126-37, 24 figs, bibl., 1983.

The efficiency of several experimental methods for differentiating between natural and synthetic amethysts is discussed. Under the microscope the natural stone shows polysynthetic twin lamellae, mono- and bi-phase inclusions, negative crystals; sometimes one can see residues of the seed in the synthetic product. By repolishing, 'fingerprints' may be produced on a facet of the natural cut stone. Infrared investigation can help. Investigation is suggested to be as follows: (1) conoscopy (uninterrupted cross can be seen in the natural product); (2) (a) microscopy, (b) repolishing and (c) infrared spectroscopy. E.S.

**sic:* obviously should be Harwell.—Ed.

LOOK (G.), SUSSIECK-FORNEFELD (C.). *Sri Lanka.* Magma, **1**, 1, 20-5, 8 figs (6 in colour), 1983.

General well-illustrated introduction to the gemstones of Sri Lanka with a note on treated stones. M.O'D.

MCLEOD (N.). *Mt Surprise topaz field.* Australian Gem & Treasure Hunter, 84, 22-5, 5 figs (4 in colour), 1983.

Details of the material available in the field (topaz, beryl) are given with notes for the guidance of amateur prospectors. M.O'D.

MARTIROSYAN (R. M.), MANVELYAN (M. O.), MNATSAKANYAN (G. A.). *Width of an ESR line of Cr^{3+} ions in emerald.* Soviet Physics: Solid State, **25**, 5, 904-5, 2 figs, 1983.

An investigation of the line profile and line width of the 3 ↔ 4 ($-\frac{1}{2} \leftrightarrow \frac{1}{2}$) intradoublet transition was carried out at a frequency of 9.2 GHz. Concentration dependence of the line width was non-linear; this may have been due to errors in the estimation of the Cr content of the sample or to accidental impurities. Internal stresses may contribute to inhomogeneous broadening of the line profile. M.O'D.

MASCHMEYER (D.), LEHMANN (G.) *New hole centers in natural quartz.* Physics and Chemistry of Minerals, **10**, 2, 84-8, 1 fig., 1983.

Five new hole centres were detected in natural citrines. They were analysed by electron paramagnetic resonance. Another hole was detected in rose quartz, the cause of the coloration being radiation defects. Characteristic patterns caused by the proximity of a neighbouring aluminium impurity were resolved in the spectra of three of the centres. M.O'D.

MELBY (J. H.), TAYLOR (A. M.). *Phenakite, a lucky find in Colorado.* Lapidary J., **37**, 9, 1276-82, 17 figs (10 in colour), 1983.

Phenakite crystals have been found on Mt Antero, in the Collegiate Range about 135 miles south-west of Denver. Crystals occur in a quartz-feldspar pegmatite and are associated with smoky quartz. M.O'D.

NASSAU (K.). *The current status of gemstone treatment.* Lapidary J., **37**, 8, 1124-34, 17 figs in colour, 1983.

Techniques for altering the colour of gemstones are reviewed and assessed. Some remarks on whether or not treatment should be disclosed are given. M.O'D.

NORWOOD (V. G. C.). *Recognizing flaws in gemstone rough.* Lapidary J., **37**, 7, 1084, 1983.

For immersion purposes the writer recommends glycerine for materials with a low refractive index. Dulite, a proprietary product of ICI, is recommended for higher index materials, with the proviso that it is caustic and care needs to be taken. M.O'D.

O'DONOGHUE (M.). *The dealer looks at gemstones—8.* Gems, **14**, 6, 24, 1982.

The factors influencing the price and nature of pearl are discussed with special reference to size, weight and trade practices. (Author's abstract.) M.O'D.

READ (P. G.). *A computer program for gem identification.* Gems & Gemology, **XIX,** 3, 157-63, 14 figs, 1983.

A further account of the Gem Data Bank computer program devised by this writer, using floppy disk storage. R.K.M.

RINGSRUD (R.). *The oil treatment of emeralds in Bogota, Colombia.* Gems & Gemology, **XIX,** 3, 149-56, 8 figs in colour, 1983.

Cut emeralds boiled in alcohol to remove oil used on rough. Treated with HCl and HNO_3 acids. Acid boiled out. Then stones immersed in hot oil. Cedar-wood oil is most favoured. Various methods of detecting oiling are suggested. Use of green oil to improve colour is not favoured. R.K.M.

ROEMER (U.). *Achate.* (Agate.) Goldschmiede und Uhrmacher Jahrbuch, (1984), 88-91, 1984.

A brief review of the agate group of the quartz family. M.O'D.

ROEMER (U.). *Edelsteinvorkommen in der Tschechoslowakei.* (Gemstone occurrences in Czechoslovakia.) Goldschmiede und Uhrmacher Jahrbuch, 84-6, 1984.

Most gemstones found in Czechoslovakia belong to the quartz family, though some tourmaline and chrysoberyl occur in small quantities. M.O'D.

ROUCAN (J.-P.). *Trois nouvelles pierres ornamentales violettes, charoite, sogdianite et sugilite.* (Three new violet ornamental stones, charoite, sogdianite and sugilite.) Le Monde et les Minéraux, 58, 12-14, 3 figs in colour, 1983.

Three fairly newly described minerals with ornamental application are briefly reviewed. M.O'D.

RUPASINGHE (M. S.), BANERJEE (A.), PENSE (J.), DISSANAYKE (C. B.). *The geochemistry of beryllium and fluorine in the gem fields of Sri Lanka.* Mineralium Deposita, 19, 86-93, 3 figs, 1983.

Beryllium is found in a range of 1-13 parts per million in Sri Lankan gem sediments. Fluorine is found in the range of 400-2000 ppm and the F/Be ratios for all areas examined give a range of 54-441. The distribution of Be in the sediments is irregular. M.O'D.

SANDERS (J. V.). *Crystal Opal* (Letter to the Editor). Aust. Gemmol., **15,** 4, 129, 1983.

Writer answers my oft repeated query about the term 'crystal opal'. From his description of the material it seems apparent that this Australian term is synonymous with our 'water opal'—a colourless, transparent body with a rich play of colour. The Editor asks for the earliest published use of the term. I would expect it to date from the first discovery of this type of material in Australia. I am obliged to Dr Sanders for clarifying this matter. R.K.M.

SANDERS (J. V.). *A proposal for the classification of opals.* Aust. Gemmol., **15,** 3, 75-8, 2 figs, 1983.

A more scientific approach than that of Sherman (G.)* and suggested

*See SHERMAN (G.) below.—Ed.

classification is more logical. Recognizes that play of colour is due to diffraction, or interference. R.K.M.

SATO (K.), SUNAGAWA (I.). *Quantitative evaluation of colour in diamonds (by spectrographic method.* A summary by SANDERS (J. V.). Aust. Gemmol., **15,** 3, 91-2, 1983.

Team used a spectrophotometer/computer link-up to off-set the effect of stone size on apparent colour in Cape diamonds. Scientific approach allows yellow factor to be assessed regardless of stone size and of a greying factor which masks some colour. UV filter is used to eliminate fluorescent effects. Sanders points out that the actual appearance of a stone to the eye is the factor on which value is based, and the subjective, non-scientific approach must be adopted. R.K.M.

SAXENA (M. P.). *Gemstones of Pamirs.* Gem World, **10,** 4, 26, 1983.

A bright green marble, fresh deposits of lazurite and a patterned onyx have been recently discovered in the Pamirs. Some notes on the production of amethyst by the hydrothermal method are given. M.O'D.

SCHMETZER (K.). *Eine Untersuchung der opalisierenden Syntheseprodukte von Gilson.* (An investigation of the opalescent synthetic product of Gilson.) Z.Dt.Gemmol.Ges., **32,** 2/3, 107-18, 10 figs (6 in colour), 2 graphs, 1 table, bibl., 1983.

An English version of this article was published in *J.Gemm.,* 1984, **XIX,** 1, 27-42. E.S.

SCHMETZER (K.), BANK (H.). *Untersuchung eines Skapoliths mit Katzenaugeneffekt aus Sri Lanka.* (Examination of a scapolite with cat's-eye effect from Sri Lanka.) Z.Dt.Gemmol.Ges., **32,** 2/3, 86-9, 3 figs in colour, bibl., 1983.

The scapolite from Sri Lanka showed intensive chatoyancy. RI n_o = 1.583, n_e 1.553. Microprobe analysis established a meionite content of 69%. Chatoyancy was caused by needle-like inclusions with orientation parallel to the *c*-axis of the scapolite host crystals; the needles were found to be pyrrhotite. E.S.

SCHMETZER (K.), LIND (Th.), BANK (H.). *Stabilisierter Coeruleit.* (Stabilized ceruleite.) Z.Dt.Gemmol.Ges., **32,** 2/3, 90-1, bibl., 1983.

An English version of this article was published in *J.Gemm.,* 1983, **XVIII,** 8, 734-5. E.S.

SCHMID (F.), KHATTAK (C. P.). *Large crystal sapphire optics.* Laser Focus/Electro-optics, **19,** 9, 147-52, 6 figs, 1983.

Large sapphire boules which are free from light scattering have been grown by the heat exchanger method. Diameters of up to 8 inches have been routinely achieved. M.O'D.

SEEHERR (H.). *Heilendes Gestein.* (Healing stone.) Goldschmiede und Uhrmacher Jahrbuch, (1984), 51-65, 1 fig, 1984.

An account of the therapeutic value placed on gemstones at various times. M.O'D.

SHERMAN (G.). *Certification of opal.* Aust. Gemmol., **15**,3, 71-4, 1983.

Explains need for, and evolution of, the appraisal and identification certificate of opal. Author says this is not a valuation, [although 'appraisal' means 'to put a value on',] and seeks to justify the term 'crystal opal'. He still does not define it.* R.K.M.

SNOW (J.), BROWN (G.). *The Kyowa GR1 gemmological refractometer.* Aust. Gemmol., **15**, 4, 130-2, 2 figs, 1983.

A report on a new Japanese refractometer which seems to be essentially similar to most other makes, but which includes a scale adjustment screw which is said to make for far greater accuracy. A diagram of the lay-out of major optical components fails to show the light path and leaves one wondering whether two additional prisms, fore and aft of the high RI prism, are correctly depicted. R.K.M.

STOCKTON (C. M.), MANSON (D. V.). *Gem andradite garnets.* Gems & Gemology. **XIX**, 4, 202-8, 7 figs (2 in colour), 1983.

A careful study of the garnet subspecies generally known as demantoid. A range of twenty-one stones was tested, and RI 1.880 to 1.883, SG 3.80 to 3.88 were recorded. These did not include the highly prized, rare vivid green. Detailed electron-microprobe chemical analyses underlined the unusually constant composition of the variety. Colour did not directly relate to the small amount of Cr_2O_3 that was found. Manganese and titanium, also in minute amounts, may influence colour. Authors suggest that cutters deliberately orient stones to include characteristic byssolite fibres under the table facet. [From observation of rough I would say that these usually radiate from the centre of the crystal and the cutter has little choice if size and colour are to be maintained.] R.K.M.

STRIPP (D. M). *Exceptional gem trio unveiled at American Museum of Natural History.* Lapidary J., **37**, 9, 1284-91, 8 figs, 1983.

The three stones quoted were loaned to the Museum and are a carved emerald of 217.80 ct (the Mogul); a 667.14 ct emerald crystal and a 15.97 ct cut Burma ruby. M.O'D.

TAYLOR (A. M.). *A new synthetic emerald* (Letter to the Editor). Aust. Gemmol., **15**, 3, 79-80.

Underlines difficulties in producing vanadium-doped green beryl and questions whether the new synthetic reported by G. A. Tombs (Aust. Gemmol., **15**, 1)† originated there or elsewhere. Dr Taylor points out that V^{3+} doping of emerald is comparatively easy in hydrothermal growth, but much less so in flux melts, which oxidize the dopant to V^{5+}. They can be distinguished by the liquid in the two-phase inclusions. In flux-melt stones this is, in fact, a solid glass of higher RI than the host emerald. In hydrothermal stones, natural or synthetic, it is salt water, with an RI well below that of the host beryl, [and the gas bubble will be mobile]. R.K.M.

*See SANDERS (J.V.) *Crystal opal.* (Letter to the Editor). above.—Ed.
†See *J.Gemm., 1983* **XVIII** (7), 661.—Ed.

THOMPSON (D.). *Sapphires in New South Wales.* Australian Gem & Treasure Hunter, 83, 28-30, 6 figs, 1983.

Describes sapphire production in New South Wales with particular reference to the New England area which includes Inverell. M.O'D.

TOMBS (G.). *Diamond grading system foundations and comparisons.* Aust. Gemmol., **15**, 4, 124-7, 1983.

Compares different grading scales and nomenclature, explaining difficulties and suggesting some solutions. R.K.M.

VOCHTEN (R. F.). *Blaugrüner Apatit von Gravelotte, Ost-Transvaal, Südafrika.* (Blue-green apatite from Gravelotte, East Transvaal, South Africa.) Z.Dt.Gemmol.Ges., **32**, 2/3, 83-5, 2 graphs, 1 table, 1983.

Gravelotte is an emerald mine yielding also some cubic pyrites crystals and apatite, which is bluish-green and of cuttable quality. The crystals are hexagonal and have been identified as fluoro-hydroxyl-apatites. An irreversible colour change takes place with increasing temperature. E.S.

ZEITNER (J. C.). *A review of green gems.* Lapidary J., **37**, 9, 1252-62, 13 figs, 1983.

A review giving considerable historical detail pertaining to green gemstones. M.O'D.

Thailand, jeweller of the world. (Department of Commercial Relations, Ministry of Commerce, Thailand.) Gem World, **10**, 4, 21-5, 3 figs, 1983.

A brief history of the gem trade in Thailand. M.O'D.

BOOK REVIEWS

BINNEWEIS (B.). *Steinschleifen.* (Stone cutting.) Kosmos Verlag, Stuttgart, 1979. pp.95. Illus. in colour. Price on application.

A beautifully-produced and comprehensive guide to cutting with all the stages clearly described. Photographs are by Samuel Rothenberg. This is the best guide I have seen to cover a small compass and still get in everything that is needed. Naturally a great number of gem species are not described—for that one must turn to the much larger productions of Sinkankas and Vargas. Even for non-German speakers, this would still be worth buying. M.O'D.

FUHRMANN (R. J.). *Granat.* (Garnet.) Rühle-Diebener-Verlag, Stuttgart, 1983. pp.113. Illus. in black-and-white and in colour. Price on application.

This book contains less information than the number of pages might suggest, since the print is unusually large and the illustrations plentiful, though of indifferent quality. The aim is to review the garnet family of minerals from the point of view of the amateur jewellery maker. Though illustrations of crystals and occurrences are provided, they are not described. There is no index or bibliography. M.O'D.

GODONIKOV (A. A.). *Mineralogiya.* (Mineralogy) [In Russian.] Nedra, Moscow, 1983. pp. 646. Illus. in black-and-white. R3.50.

A well produced introductory textbook in which structural diagrams make a welcome appearance. Drawings and reproductions are of good quality and there is a bibliography. M.O'D.

HINKS (P.). *Twentieth century British jewellery, 1900-1980.* Faber & Faber, London, 1983. pp.192. Illus. in black-and-white and in colour. £27.50.

This is a first-class book and quite magnificently illustrated. The author gives just enough of the historical and social trends of the century to place its jewellery in the appropriate context, and for this reason the chronological order followed in the text is to be preferred to any other. Within each period more attention is paid to detail of ornament than to methods of manufacture, but there are already many satisfactory books on technique. There are many illustrations in the text and a short bibliography. Any student of jewellery will find this book essential, though not cheap. M.O'D.

UNTRACHT (O.). *Jewelry concepts and technology.* Hale, London, 1982. pp. xxiii, 840. Illus. in black-and-white and in colour. £25.

This very comprehensive book is so large that a lectern would be needed to accommodate it comfortably. At the price it is very good value, since so much of the jewellery manufacturer's art is contained in it. After an introductory chapter discussing the reasons for jewellery, speculation is abandoned in favour of details of workshop design and operation, metals, basic techniques, the forming of sheet metals and the drawing of wire and its uses. All these parts are well illustrated in the text, with some colour work which is not of top quality but serves adequately in a book of this price. After a section on tubing the book turns to ornament and fabrication, the use of various gemstones and coloured metals and coating techniques. The final sections contain tables, a glossary and a good bibliography. Altogether a very good buy. M.O'D.

VLEESCHDRAGER (E.). *Dureté 10: le diamant.* (Hardness 10: the diamond.) Gaston Lachurié, Paris, 1983. pp. 301. Illus. in black-and-white. Fr 210.

This is a complete survey of diamond from its mining to its final end in jewellery. The journey takes in the customary stops; characteristics of diamond crystals, properties, cutting (a large and well constructed section) and grading (also well constructed). There is an extensive glossary, quite a good bibliography and an index. For readers whose main language is French, this represents a good bargain at the price. M.O'D.

ASSOCIATION NOTICES

OBITUARY

BASIL WILLIAM ANDERSON—PIONEER GEMMOLOGIST (1901-1984)

The death on 24th February, 1984 of Basil William Anderson, a Vice-President of the Gemmological Association of Great Britain and a Fellow of King's College, London, one of the world's leading gemmologists for nearly sixty years, must inevitably mark the end of an era. Perhaps the greatest of the pioneers of this specialized science, it would be difficult to over-estimate the importance of his many contributions to trade integrity and to the greater understanding of the gems upon which it largely depends.

An immensely popular, generous-hearted and friendly man, Basil Anderson was held in high esteem and in very real affection by all members of the British gem trade who knew him, in the world-wide field of gemmology and by his many personal friends. Guide, mentor and friend to so many, his passing leaves a very deep sense of personal loss. It will not be easy to reconcile the fact that such a fount of gemmological wisdom is no longer with us.

Born in South London on 3rd July 1901, Basil was the grandson of Frederick Field, F.R.S., a chemist and mineralogist of considerable standing. His mother, to whom largely he owed his interest in minerals and a life-long appreciation and love of nature and the countryside, was herself an acknowledged authority on the essayist Charles Lamb and engendered in the young boy an interest in English literature which was to be reflected in the lucidity of his lectures and writings later in life. In a very recent letter he mentioned the delights of frequent visits as a young boy, with his mother, to the Natural History Museum, and the enormous treat of having tea afterwards 'at the very good ABC in South Ken. Station arcade.' Simple pleasures which helped to shape the man.

We know little of his father beyond the fact that a serious illness had at some time deprived him of the power of speech. His son was known to have been adept at reading sign language.

FIG. 1. Basil and Barbara Anderson, 1974.*

FIG. 2. B. W. A., 1983.

*Earlier photographs of B. W. A. may be found in *J.Gemm.*, 1975, XIV(6) on p.259 and 1983, XVIII(7) on pp.599, 600 and 601.—Ed.

B. W. was educated at Sedbergh School in a rugged region of Yorkshire, close to the Lake District. Here he excelled in fell-running, an up-and-down hill sport requiring exceptional stamina. Then on to King's College, London, obtaining there an Honours Degree in Chemistry, with Geology as his subsidiary subject, and gaining considerable repute in athletics and games *en passant*.

His entry into the gem trade was not planned, and like my own, was a result of the circumstances of the day.

In the early 1920s Japanese cultured pearls were marketed secretly by them as natural pearls and very soon were seriously contaminating the Bombay 'bunches', the normal source of matched and drilled pearls intended for western markets. The appropriate committee of the London Chamber of Commerce saw that a laboratory capable of testing and certifying pearls as natural, or as cultured, was an immediate need. W. T. Gordon, Professor of Geology at King's, was already concerned with a certain amount of gem identification for the Hatton Garden trade and, when approached, recommended B. W. Anderson as a suitably qualified scientific expert. Thus in 1925, Basil, then 24, became a full-time professional gemmologist responsible for organizing the World's first independent gemmological laboratory.

He has written and talked many times on those early days when he was thrust in 'at the deep end' with little knowledge of pearls and even less of methods of testing them. The pearl trade was in a chaotic state with leading dealers holding vast stocks which might or might not be natural pearls, and with more adulterated bunches coming in all the time. At first assisted only by a rather unhelpful commissionaire and equipped with nothing more than a lucidoscope (a powerful water-cooled lamp) and a telephone, he was helped enormously six months later when a hazardous trip by air to Paris led to the purchase of one of the recently improved endoscopes which allowed drilled pearls to be sorted laboriously one by one, but with 100% accuracy.

A very good chemical balance, a mineralogical microscope, a Tully table refractometer and a dichroscope were added to the laboratory equipment, often at B. W.'s personal expense. But these were to be little used at this stage, for the work for the first five years was almost entirely with pearls. The most valuable acquisition at this time was undoubtedly the late Mr C. J. Payne, an honours geologist, again from King's College, who joined the laboratory at the end of 1928, beginning a most important partnership with Anderson which was to last, interrupted only by the war, until Payne's retirement in 1970. In 1928 B. W. had himself tested over 49,000 individual pearls.

A move to larger premises in 1929 allowed him to have x-ray apparatus installed, which made it possible at last to test undrilled and half-drilled pearls by means of Laue diffraction patterns.

The world depression, which was to become known as 'the Slump', hit this country towards the end of 1929, and the deluge of pearl testing slowed to a trickle. The two young men, with time on their hands, turned their attention to other gems and to possible lines of research, while relaxing each lunchtime by solving *The Times* crossword puzzle which became a daily obsession with them both.

With a refractometer which was capable of reading up to 1.86 they quickly realized that much of its potential was being lost owing to the fact that the optically densest contact fluid, methylene iodide saturated with sulphur, had an RI of only 1.785. So the search was on for a 'higher' liquid.

Many combinations were tried, with near disaster as the end product of some, when they resulted in corrosive, highly noxious, or even explosive mixtures. Eventually three liquids were found:

1. Methylene iodide + sulphur + tetra-iodo-ethylene, RI 1.81.
2. Selenium bromide, RI 2.00.
3. Phenyldi-iodo-arsine, RI 1.85.

The 1.81 was comparatively innocuous and suitable. This became the standard refractometer liquid and was at one time sold as 'andersonol', until B. W. protested. The other two were corrosive and attacked the dense glass of the instrument, but might be useful if some other test surface could be used. A fourth liquid, West's solution, consisted almost entirely of yellow phosphorous and, on occasion, would explode spontaneously in air with near disastrous results.

That research inspired the designing of the blende and the diamond refractometers and, much later, the spinel version. These were made by Rayners, to the requirements of Anderson, and the use of truncated prisms in place of the more expensive dense glass hemispheres led eventually to the use of similar prisms in the Rayner standard instrument.

Now the crude beryloscope test for emeralds attracted Anderson's attention and experiments with photographic filters produced the more transparent and better Chelsea emerald filter.

Basil Anderson next turned his attention to the neglected subject of absorption spectroscopy and, assisted by Payne, pioneered its use in the identification of gems, the results of the research eventually appearing in a series of forty papers in the *Gemmologist* in the 1950s. This spectroscopic technique became standard in British gemmology long before it was adopted by other countries.

In 1933 B. W. Anderson was appointed lecturer to the 'Mineralogy for Jewellers' classes at Chelsea Polytechnic. I had attended his lectures at the Royal Society of Arts in 1932 and was now to study under his guidance in my Diploma year. His enthusiasm for the subject was infectious and that class blossomed remarkably. The following year's examinations produced nine passes with distinction, including such well-known names as Robert Webster, A. Ross Popley, Norman Harper and others, and out of 21 entries not one student failed to pass. I became Anderson's 'first Tully Medallist.'

In the late nineteen-thirties Basil Anderson made a very considerable contribution to the parent science of mineralogy. Having found a big discrepancy between the published specific gravity for lapis lazuli and that which he had actually determined himself by careful hydrostatic weighing, he embarked upon another period of intense activity during which the laboratory checked and rechecked some five hundred specimens of lapis, and then went on to determine exhaustively the physical constants of all known gem minerals in their cuttable qualities. In the course of this work gahno-spinel was found and named, and the first Sri Lankan kornerupine was discovered. The new figures, together with the several new techniques introduced by Anderson and Payne, were incorporated in the 1940 edition of the standard textbook, *Gemstones,* which was being re-written by the author, Dr G. F. Herbert Smith. The importance of the Anderson-Payne contribution can be assessed if the corrected constants of that edition are compared with those of the 1930 edition.

War came, and James Payne, a Territorial Army volunteer, was called up. Basil Anderson, then 38, volunteered for the Auxiliary Fire Service. His memories of

those years are summarized by a passage from the last letter I received from him on about 10th February:

'*Very* peculiar days, those, with opportunities to do things impossible in a steady job and married life situation. To be in charge of a N.F.S. crew on night duty at St Paul's, for instance, and walk around the Whispering Gallery in complete darkness with only a single neon bulb on the altar steps to help give one orientation—and to see incendiary bombs bouncing off the dome and on to some of the flat roofs—each bigger than a tennis court—and "see to them" as best one could. And to go to a lunch-time concert given by Myra Hess in the National Gallery and soak up all the pleasure one could from the *one* fine painting available to the public eye at that time:- Renoir's "Les Parapluies" has had a special place in my affections ever since.'

Shortly after the end of the war the Laboratory secured the valuable services of Robert Webster and Alec Farn, thus completing a quartet which, headed by B. W. A. was to work in remarkable harmony for the next twenty-five years.

1945 had seen the finding of the rare gem which was eventually to be known as taaffeite, after Count Taaffe who discovered it. Basil recognized this as a possibly new mineral and initiated a prolonged investigation which culminated in confirmation, although not in completely accurate chemical composition, five years later. Painite was another new mineral, possibly the rarest of them all, with which he was closely concerned. Ekanite (1953) was found first as an asteriated dark green cabochon and hopefully greeted as 'New mineral' by the late F. L. D. Ekanayake. Anderson at first thought it was a natural glass, but instigated a very full investigation which showed it to be indeed new and also a metamict, thus joining Sri Lankan green zircon in a most exclusive mineral category.

The 'crossed filter' test for the red fluorescence of chromium was yet another Anderson innovation, using a flask of copper sulphate solution to filter out the red end of the spectrum and a red filter to eliminate the resultant blue light. A simple but quite inspired idea which provided a most beautiful demonstration of the brilliant red fluorescence. He also investigated immersion contact photography and established it as an additional method of assessing relative RI. Further work gave a bonus when it was realized that synthetic stones, being iron free, were, in general, more transparent to short ultraviolet light than were natural stones.

B. W. Anderson retired from teaching in 1966, and from the Laboratory in 1972 when, to the surprise of almost everyone apart from B. W. himself, he reached the age of 70. He had been an examiner to the Gemmological Association since 1951, and was to remain as principal examiner right up to the end of his life. In his 46 years as Director of the Laboratory he had kept personal notes on every test. These provided him with some of the material for his book, first published in 1942 under the title *Gem Testing for Jewellers* and then, in post-war reprints, to be called quite simply *Gem Testing,* going on eventually in many successful editions to the 9th in 1980, of what is now recognized as one of the most valuable and certainly the most lucid of all English textbooks on the subject. A second book *Gemstones for Everyman* appeared in 1976, and was intended to appeal to the wider public, but was rather overshadowed by the phenomenal success of *Gem Testing.*

In 1982, despite serious eye problems, Anderson undertook a very necessary revision of the 4th edition of Robert Webster's vast work, *Gems,* with the comment that he regarded this as a memorial to an old and valued colleague. The eye trouble

was eventually corrected by surgery in two skilful operations. It was completely in character that, the day after the second of these, he should write a long letter to me with a description of the 'ordeal' and amusing comments on his hospital experiences. His sense of humour was still intact.

About 1934 Basil Anderson had moved to the village of Ditchling, by the Sussex Downs, where he was able to take a keen interest in local matters and to join in amateur dramatics in a rural environment which was entirely to his liking. Sadly, this ideal existence was interrupted by the long illness and death of his first wife, Irene ('Frinton'). He had a holiday home near Hartland in North Devon and now spent part of each summer down there.

In the late 1950s he married Barbara, who was to care for him so wonderfully for his remaining years. He once told me that this was by far the happiest thing he ever did.

On retirement they went to live permanently at Hartland, but total retirement was not for him. He had loved his work and now, as is often the case, was to work in some respects even harder than before. The 1970s were years of considerable change with many new synthetic gems and as many methods of dealing with them, and Anderson kept fully informed on these developments, attending international conferences and maintaining contact with his many friends in the gemmological field both at home and overseas. Eventually the changes of that period were incorporated in the largely re-written 9th edition of *Gem Testing* and in the 4th edition of *Gems*. By now the first of these had been translated into many languages and was to appear in Japanese in the coming year.

In 1977 Basil Anderson was made a Fellow of King's College in recognition of his great services to gemmological science. This, the highest award within the gift of the College, was well deserved. More recently Professor Dr Hermann Bank, of Idar-Oberstein, inaugurated an Anderson/Bank Prize and an Anderson Medal as awards in the Gemmological Association's examinations, in honour of Basil Anderson's eightieth birthday.

With all this self-imposed work-load Basil still found time to take his two lively dogs for long daily walks through the Devon countryside, enjoying the while the wild-life and flowers of moorland and valley. His delight in country life was often reflected in verse, pleasing little poems which gave glimpses of his inner thoughts in an environment which gave him enormous pleasure.

For the most part he had enjoyed good health, apart from back problems which stemmed almost certainly from a fall whilst fruit-picking. To me he seemed younger than his years, physically and intellectually, and his very considerable mental powers were in no way impaired by age. The end came suddenly and, mercifully, without suffering. He had led a good and happy life, wisely and with thought for his fellow men. He had enhanced his profession immeasurably by the keenness and brilliance of his enquiring mind. I, for one, am proud to have had the privilege of knowing him and to have called him friend.

Basil leaves his dear wife Barbara, who took such great care of him for nearly 25 years. On behalf of the gemmological world I can only express our great sympathy to her on the passing of a great and kindly man.

I have mentioned the last letter I had from Basil, a long one of six closely written pages, crammed with nostalgia and reminiscence, which ended differently from any other I had received from him before. While Basil himself would be the first to insist that his words had no hidden meaning, for he had no more

premonition of death than any other vigorous, healthy and contented man of his age, the subsequent event gives them significance and, since they happen to be appropriate to his many other friends, I share them now. The letter ended:

'At last I bid you farewell
and thank you for listening!
Your friend,
B. W.'

For me at least it has been a pleasure and privilege to 'listen' for more than fifty years.

R. Keith Mitchell

B. W. Anderson—an Appreciation

It would be accurate, but perhaps a little too apt, to describe B. W. Anderson as a man of vision, yet this is precisely what he was. We, as gemmologists, will regard and remember him as Great Britain's greatest gemmologist. In this appreciation of Basil Anderson I would like to portray the man I knew in turn as lecturer, colleague and friend. I would like to tell people about the other facets reflecting the character and personality of a man popularly known and renowned as a scientist, yet who had a wealth of interests totally divorced from the gemmological field one usually associates with Basil William Anderson, gemmologist extraordinary. Others, great friends of Basil Anderson, will write upon his great gemmological achievements. I like to think of him as a man who loved the correct use of words, someone who wrote with fluency and a style which captivated.

Who else but Anderson could on the very first page of *Gemstones for Everyman,* in the opening chapter, 'What exactly *is* a gemstone?', write:

'The world is full of a vast variety of beautiful things, but most of them are ephemeral. The dewdrop and the daffodil, the rainbow and butterfly, last for a few moments or a few days and are gone; preserved only in memory, or in lines written by a great poet. Precious stones . . . endure . . . eternally.'

Basil Anderson will have left an imprint upon many people depending upon the circumstances under which introduction or meeting occurred. Many of his earlier students will remember his end of term competitions combining gemmological queries with attractively illustrated clues wherein lay subtle hidden word-play.

He had the gift of teaching with enthusiasm, and the power to impart or implant that enthusiasm. He was a big man, physically, mentally and morally, and like many big men he was gentle in nature.

Every day at lunch time he, with C. J. Payne and Robert Webster, solved *The Times* crossword puzzle. It was a sort of fetish; the discussion over words and the constant use of dictionaries or encyclopaedias were typical of B. W. Anderson.

His mother took considerable interest in his education. He told me that it was she who instilled in him this attitude to look things up, to make sure; almost, one might say, 'to leave no stone unturned'. His earliest memories of home embraced a grandfather who was a mineralogist, a cabinet of mineral specimens, and delightfully as he told me a quartz sphere which B. W. A. pronounced as glass. His mother, a lady chess champion, was also a devotee and collector of the works and

papers of Charles Lamb. Certainly Basil Anderson inherited this enjoyment of literature and use of the English language which is seen in the style of his writing. Few people write so elegantly upon gemmology, a difficult subject. A lover of poetry, and himself a useful composer, it would be a mistake to imagine that B. W. Anderson was anything like a willowy long haired 'poetic' type.

He had a rugged schooling at Sedbergh in Yorkshire where any signs of meekness, shyness or even gentleness of nature were soon ironed out and dispersed by the very public attitude the boys of his age took to such characteristics. One of the tough sports at that time was fell racing, which meant both uphill and downhill running over boulder-strewn and boggy conditions. Anderson excelled at this. I often saw him run for a bus down Hatton Garden and along Holborn Viaduct when he was well into his sixties.

Whilst a graduate at King's College he held a record for putting the shot, and in later years at Ditchling, his home in Sussex, he held the scoring record for the local cricket club. He was essentially an outdoor man, a country lover and keen ornithologist. He participated in amateur dramatics and had a good voice and loved singing. I have heard him suddenly burst into song at the old Lab in sheer exuberance for a lovely day. He was fond of music and had a keen eye for artistic ability. He was regularly asked to judge at local art shows.

This man of science who put Britain well to the fore by reason of his researches was no back-room boy or scientific boffin. Although he gained his degree in chemistry, he was very much anti-chemicals when it came to soil and food production. For some considerable time at his home in Ditchling he grew his own vegetables, using only gardening compost and organic matter. He kept goats for milk, and had a clutch of Marham hens which layed only brown eggs. At home they baked bread from whole-meal flour.

He lived at one time in the only thatched cottage on Farleigh Common, Surrey, a mere fifteen miles from the centre of London. In those days, as a much younger man, he rode a motor-cycle and sidecar combination to East Croydon station. Each day, he told me, he tried to clip seconds off his time for the journey. During the war years he rode a bicycle to Hassocks station, although he confessed not to be terribly good on repairs or maintenance.

We visited him at Ditchling when my son was about two years old (1952). We were met at the station by Basil Anderson driving a somewhat battered baby Austin Seven. He had not lost his zest for cutting corners and, being familiar with the somewhat narrow roads, seemed to be hurtling around in rallying style. He soon had my son in a wheelbarrow and was busy running up and down the large lawn to the considerable delight of the then youngest Farn.

He was a man of many interests, outdoors, athletic, artistic, music lover, a man of letters and superb gemmologist.

After having worked with Basil Anderson for many happy years, having been taught by him at Chelsea Polytechnic, and having had his friendship and corresponded with him over these last twelve years in retirement, I am still amazed at the many facets of B. W. Anderson. This good living, outdoor man, this man of vision whose scientific reputation has earned him a perpetual memorial in gemmological annals, is unique in our history. Who else but B. W. Anderson could start a book with such beautifully rendered words? Who else but B. W. Anderson could finish up an equally erudite paper on 'The Classification of Diamonds on the

Basis of their Absorption and Emission of Light' (*J.Gemm,* IX, 2, 44-54, April 1963) quoting

'Reason has moons, but moons not hers
Lie mirror'd in her sea,
Confounding her astronomers,
But O! delighting me'?

Basil Anderson ends with a plea, speaking of diamond, hoping that some mystery will remain, and that this incomparable mineral will remain unpredictable. Who else but Basil William Anderson, Fellow of King's College, Batchelor of Science, Fellow of the Gemmological Association, could write on science with the pen of a poet? He is unique, a man one could hope to imitate, but never aspire to equal.

A. E. Farn

* * *

Mr R. E. H. Jeffreys, F.G.A. (D.1956), Stroud, died on 5th November, 1983.

Mr William A. Peplow, F.G.A. (D.1928 with Distinction), Stourbridge, died on 29th November, 1983.

Mr Michael Syder, F.G.A. (D.1964), Nottingham, died on 30th October, 1983.

GIFTS TO THE ASSOCIATION

The Council of the Association is indebted for her gift to Miss P. Lapworth, F.G.A.A., Guildford, Surrey, for a set of the Australian Gemmologist for 1982, Vol. 14, Nos 9, 10, 11 and 12; also for a brochure on sapphires in New South Wales prepared by the Department of Mineral Resources, New South Wales, 1983.

NEWS OF FELLOWS

On 15th November, 1983, at the Woodlands Hotel, Lisburn, N.Ireland, Mrs Vera Buchanan, F.G.A., gave a talk on gem testing to the Ulster Jewellers' Association gem group.

Between 5th and 9th November, 1983, Mr Richard T. Liddicoat, Jr, Hon. F.G.A., Chairman of the Board of Governors of the Gemological Institute of America, visiting India on the invitation of the Forum of Indian Gemmologists, addressed a meeting of gemmologists and traders in Bombay and had a series of other meetings with individuals and groups, at which he met a number of other Fellows (see Figure 3: reading from left to right—Mr S. R. Ghaswala, F.G.A., Mr G. Bhashkaran, F.G.A., Mr U. G. Chavan, F.G.A., Mr D. N. Lakdawalla, F.G.A., Miss Vispi R. Lal, D.Gem.G., Dr N. J. Lakdawalla, F.G.A., Mrs D. R. B. Lal, F.G.A., Mr Richard T. Liddicoat, Jr, Hon.F.G.A., Mr K. R. Jhaveri, G.G., Mrs I. J. Vikamsey, F.G.A., Mr N. Jashnani, G.G., F.G.A., Mrs K. R. Jhaveri, F.G.A., Miss Monica Malkani, Mr R. Jhaveri, F.G.A., and Mr K. T. Ramchandran, F.G.A.).

On 9th November, 1983, Mr Gwilym M. Jones, F.G.A., of Abergavenny, gave an illustrated talk to the Bristol & West of England Jewellers' Association on his work as a consultant gemmologist and some of the unusual items which he had come across.

FIG 3.

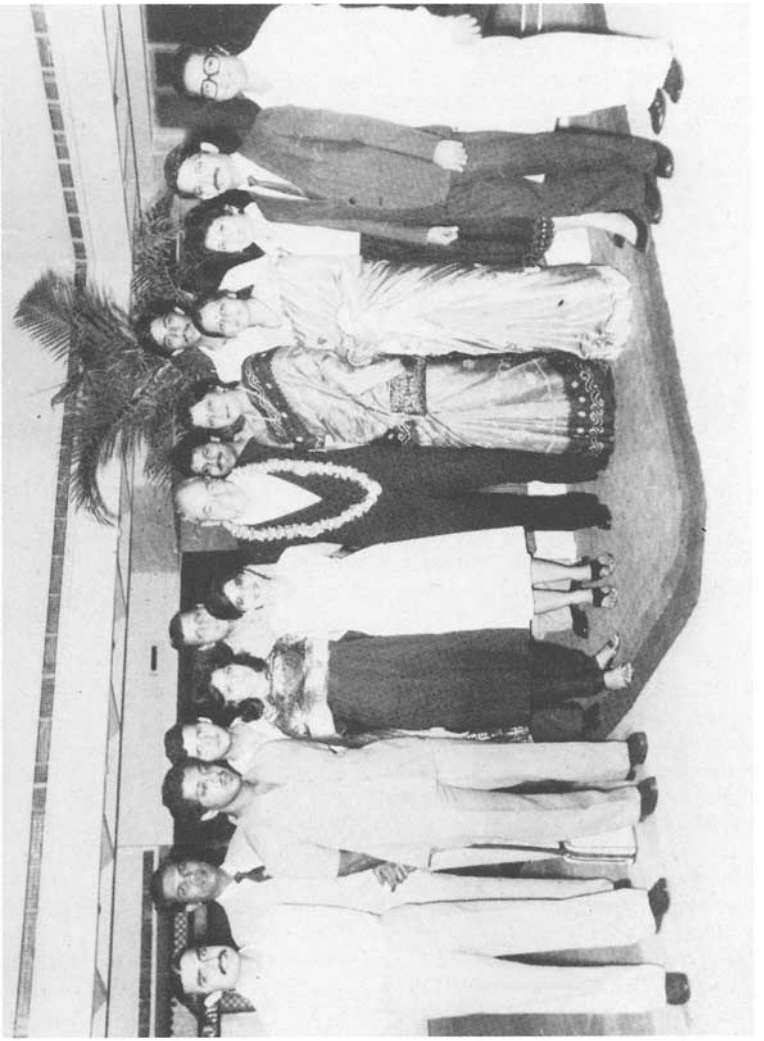

MEMBERS' MEETINGS

Midlands Branch

On 27th January, 1984, at the Society of Friends, Dr Johnson's House, Bull Street, Birmingham, Messrs E. G. Butcher and R. Rushforth (from Johnson Matthey Jewellery Products) gave a talk (followed by a discussion) on 'Refining and Processing of Gold as it affects the Jewellery Industry': they also showed a video film called 'Gold', covering extraction and refining.

On 24th February, 1984, at the Society of Friends, Mr B. A. Cooley from De Beers Industrial Diamond Division at Ascot, Berks., gave a talk entitled 'Diamond grits and powders, natural and synthetic'.

North West Branch

On 19th January, 1984, at Church House, Hanover Street, Liverpool, Mr Alan Hodgkinson, F.G.A., gave an illustrated talk entitled 'To Venus through Sri Lanka and back'.

On 16th February, 1984 at Church House, Mr Alan Williams, F.G.A., gave a talk entitled 'Basic instruments for the gemmologist'.

On 21st March, 1984, at Church House, Mr D.Wilkins, F.G.A., gave a talk entitled 'Rescued from the scrapbox'.

South Yorkshire & District Branch

On 6th December, 1983, at the Sheffield City Polytechnic a practical evening was held with emphasis on synthetic gemstones.

On 26th January, 1984, at Sheffield Polytechnic, the Annual General Meeting was held, at which Miss J. I. Platts, F.G.A., and Mr J. I. Reynolds, F.G.A., were re-elected as Chairman and Secretary respectively. Immediately after the A.G.M., Miss J. I. Platts, gave an illustrated talk following her recent trip to Australia, which included a visit to the Coober Pedy opal location.

MR DOUGLAS WHEELER'S RETIREMENT PARTY AT GOLDSMITHS' HALL

In honour of Mr Douglas Wheeler, F.G.A., on the occasion of his retirement, a Reception attended by 160 people and hosted jointly by the Gemmological Association of Great Britain and the National Association of Goldsmiths of Great Britain and Ireland (of which he was Assistant Secretary and Deputy Secretary respectively) was held at Goldsmiths' Hall on 18th November, 1983.

Douglas Wheeler joined the two Associations forty-seven years ago. In 1941 he volunteered for the R.A.F. and after training in Canada saw active service flying Lancaster bombers. He was commissioned at the age of twenty-one. In 1946 he returned to his desk and two years later passed the Diploma Examination and was elected F.G.A., having studied at Chelsea Polytechnic under B. W. Anderson.

During the evening, presentations were made to Mr Wheeler by Mr David Callaghan, F.G.A., Chairman of the G.A., (of a Sanyo Compact Disc Player and a cheque—see Figure 4), Mr Robert Croydon, F.G.A., Chairman of the N.A.G., Mr Jack Murphy on behalf of the Retail Jewellers of Ireland and Ulster Jewellers Association, and Mr John Green, of Rayner Optical Company Limited, all of whom paid tribute to his unfailing cheerfulness and willingness to share his vast knowledge of the trade and gemmological matters gained through years of experience, and emphasized how much he would be missed by members and staff alike.

FIG. 4. The Chairman making the presentation to Mr Douglas Wheeler in Goldsmiths' Hall, with Mrs (Kath) Wheeler on the right.

In his reply, Mr Wheeler—Douglas to all those present—said that he had greatly enjoyed his years with the two Associations and had been lucky in the people he had met and worked with. He said also that, although he was very sorry to be leaving all his many friends, he looked forward to a new life of retirement in Norfolk. A bouquet of flowers was presented to his wife, Kath, who had been closely associated with the N.A.G. for many years, keeping their sales ledger in order.

ANNUAL REUNION OF MEMBERS AND PRESENTATION OF AWARDS

The Annual Reunion of Members and the Presentation of Awards took place in Goldsmiths' Hall on 14th November, 1983. The Chairman, Mr David Callaghan, F.G.A., presided and welcomed as the Association's guest to present the awards Professor Dr Hermann Bank, F.G.A., President of the German Gemmological Association (Deutsche Gemmologische Gesellschaft), which was celebrating its fiftieth anniversary. Professor Bank's daughter Monika also was present that evening to receive her Diploma.

In 1983 the gemmological examinations had been conducted in twenty-six centres in the United Kingdom and ninety centres throughout the world, all of which required the services of officials and provision of examination materials, including specimens and instruments for the practical examination.

In addition to Professor Bank's daughter, Mr Callaghan was glad to welcome Mr Leslie Fitzgerald, who in addition to organizing the gemmological courses and examinations was also responsible for the administration of the educational courses and examinations of the N.A.G. It was regrettable, however, that again this year the Tully Medal had not been awarded: this had not been given since 1976, and, while they looked forward to the next occasion when it would be awarded, the Examiners jealously guarded the high standard they had set for it.

Professor Bank then presented the awards to the successful candidates and delivered an address, which is recorded in full below.

The Vice-Chairman, Mr Noel Deeks, F.G.A., then thanked Professor Bank and congratulated him on the double event of the Fiftieth Anniversary of the Deutsche Gemmologische Gesellschaft and his daughter's success in the examinations.

There followed a presentation to Mr F. E. Lawson Clarke, F.G.A., on his retirement as Honorary Treasurer. The Chairman first recalled that Mr Lawson Clarke had been Treasurer of the Gemmological Association for thirty-two years (1951-1983), following in the footsteps of his father, the late Victor W. Clarke, Hon. F.G.A., who had held the same office in 1924-1925 and again from 1932-1942, when he became Chairman. (Another example of long service to the Association was Mr Douglas Wheeler, F.G.A., the Assistant-Secretary, who would be retiring at the end of the year after forty-seven years service). Mr Callaghan then presented Mr Lawson Clarke with a carved sodalite dish with a silver plaque in the centre engraved with the arms of the Gemmological Association (see Figure 5), the dish being contained in a case to which is affixed the silver plaque shown in Figure 6. After a bouquet of flowers had been presented to Mrs Clarke and Mr Lawson Clarke had expressed thanks, the proceedings terminated.

FIG. 5. Carved sodalite dish (diameter approximately 6 inches) with central silver plaque presented to Mr F. E. Lawson Clarke, F.G.A., on his retirement as Honorary Treasurer.

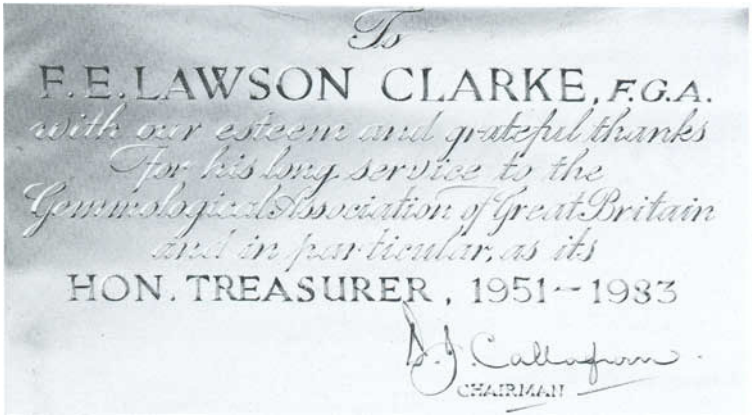

FIG. 6. Silver plaque on the case containing the sodalite dish.

PROFESSOR HERMANN BANK'S ADDRESS

Es war für mich eine grosse Ehre, nach 7 Jahren wieder von der Gemmological Association of Great Britain eingeladen zu werden, um den erfolgreichen Kandidaten der Diplom-Prüfungen des Jahres 1983 ihre Urkunden auszuhändigen. But as in 1976 I think that you would prefer that I try to continue in your language, and I beg you to excuse my poor English.

It was a great honour for me to be invited to present the awards of the Gemmological Association of Great Britain to the successful candidates of 1983, and I thank you very much for this invitation and the friendly welcome. The occasion is particularly pleasing for me for several reasons—(1) it is exactly 30 years since I passed the Diploma Examination in 1953 and became F.G.A.; (2) as you have realized already, my eldest daughter is among you successful candidates; (3) it was pleasant to be able to present the Anderson-Bank Prize this year after Basil Anderson did it last year; (4) one must enjoy such an occasion anyhow. Since I have been asked to address you after having fulfilled my first task, I shall now try to fulfil my second too, and I should like especially to speak to the candidates.

You have now got your Diplomas, and we hope that you do not think, as Goethe expressed it in his *Faust,*

What you possess black on white you can confidently carry home,

and relax on your success. It is one of your duties to always perfect your gemmological education, to keep your knowledge on a high standard, and you must allow me now to give you some advice.

Gemmology was much easier thirty years ago, and, if students of 1953 such as myself had remained on the level of knowledge of that time, they would now be lost. The developments and the progress have been so enormous in all fields of gemmology that it has been necessary for us to learn steadily to keep always up to date.

There have been discovered new minerals. There have been found old minerals worth cutting. There have been invented new synthetics and artificial products. There have been effected new colour manipulations, so many irradiations and diffusions and heatings, that it has also been necessary to use new techniques to disclose all these phenomena. Often the techniques must be more and more scientific to get the right results.

For a long time gemmology was regarded only as a more commercial and technical appendix of mineralogy. The discovery of new mineral species by gemmologists and the necessity of adoption of scientific methods to distinguish between gemstones and their substitutes or their manipulations have brought gemmology to the level of a science. Last year the I.M.A. (International Mineral Association) has formed its own commission on gem materials. That means, the I.M.A. has accepted gemmology on its own as a scientific part of mineralogy. More and more mineralogists are taking an interest in gemmological problems and assisting us to solve them, doing research on new minerals and varieties as well as on synthetic and imitation stones, their properties and distinguishing characteristics. Comprehensive information is increasingly important, and jewellers' customers want more information. Therefore jewellers must have better education to be able to pass the required information on to their interested customers.

The Gemmological Association of Great Britain recognized this demand at the earliest stage and started gemmological education courses over fifty years ago, and

the courses have become an example and a model for gemmological Associations in other countries. The title 'F.G.A.' is highly esteemed throughout the world—hence the number of students every year. It is your proud duty to uphold the professional reputation which this title implies.

In the Preliminary Course the Gemmological Association of Great Britain tries to give to the students a general idea, and, in the Diploma Course, special theoretical knowledge and practical ability to use the various methods. However, we can only give and receive instruction until the day of the examination.

Education combines the knowledge of the past with the unknown dark of the future by using wisely the present.

The candidates of today know—or at least should know—what we knew thirty years ago, and they also know what happened in these thirty years, but they and we do not not know what problems will occur in the next thirty years. The unknown dark is spread over the developments of the future.

One fact is certain. New technologies will create new problems, and we can solve these problems only when we study steadily and try to keep on the newest stand of knowledge of the theoretical part and of the practical know-how of the methods.

A poet once said

We must demand the extraordinary from ourselves to be able to do the ordinary.

This we should at least try to do.

If you have the slightest doubt, do not hesitate to consult an experienced colleague. We have a German proverb:

Was für einen vielzuviel,
ist für 2 ein Kinderspiel.
(What one cannot do
is child's play for two.)

Experts are not made in Heaven, and it is better to ask than to make an error.

Student is, who wants to learn something:
Fellow or journey-man is, who knows something:
Master is, who devised or invented something.

Always take enough time to test a stone; never be in a hurry. Take your time also to study the *Journal of Gemmology* and other sources of information, and try to think, as Goethe expressed it:

Do not say, 'Tomorrow I will do this and that':
Do it, and wait until tomorrow and say then 'I did it.'

which means

Never put off till tomorrow what you can do today

Mineralogical gemmologists and mineralogists try always to find and to develop new scientific equipments and methods which are suitable for easily distinguishing between gemstones and their substitutes, if possible without detroying them (neither gemstones nor substitutes).

Do not think that you only need to know a bit.

A ltle learning is a dang'rous thing:
Drink deep, or taste not the Pierian spring. *

That means that we should try to obtain a thorough and comprehensive, broadly based knowledge.

*Pope, *Essay on Criticism*, 216.—Ed.

The old Chinese said:

What you hear, you easily forget:
What you see, you keep better in mind:
Only what you have touched and worked with, you keep forever.

So, please, use your instruments and get practice. In over ninety-nine per cent of cases you can identify a stone by means of our classical gemmological instruments—the polariscope, the conoscope, the refractometer, the microscope, the spectroscope, the UV lamp, etc. Only in very few cases is it necessary to consult x-ray powder methods or x-ray fluorescence or even x-ray topography or tomography, the microprobe, IR spectroscopy or other more scientific equipments. But they are absolutely necessary for basic research and for doubtful cases.

It is not enough to have knowledge, it is necessary to use it:
And it is not enough to be willing, you must also do it.

So do work to get acquainted with methods and with all gemstones and their substitutes. The more you gain practice for yourself, the more you become sure on the one side but the more you also understand the verity of the two words of Socrates:

Scio nescio. (I know that I do not know.)

But Goethe consoles us when he writes:

It is not important what we do know,
But that we always have the right idea at the right moment.

And it also is not correct that you should only *buy* instruments and text-books, because often the purchase of a book is mistaken for the appropriation of the contents. So buy, *use* and *read.*

Successful candidates, I congratulate you on your Diplomas and I welcome you among the Fellows of the Gemmological Association of Great Britain. I wish you every success in your gemmological future.

It is not so important that one or the other of you will become a famous gemmologist, but it is important that each and every one of you does his or her duty so that your Clients have confidence in gemmology and gemmologists. To merit this confidence, do not remain on your present level of knowledge: study carefully to keep always up to date. Then I hope that your gemmological practice will be characterized by a minimum of errors, a maximum of perfect results, and an optimum of joy. I wish you all the best and what is generally necessary in human life—a bit of good luck. Thank you.

COUNCIL MEETING

At the meeting of Council held on Tuesday, 21st February, 1984, at the London Tara Hotel, Wrights Lane, Kensington, London, W8., the business transacted included the election to membership of the following:

FELLOWSHIP

Anand, Sumedha, Bombay, India. 1983
Bagnall, Douglas A., Don Mills, Ont., Canada. 1983
Bank, Monika I., Kirschweiler, W. Germany. 1983
Basnayake, Senarath B., Katugastota, Sri Lanka. 1983

Beattie, Roy A., Jimboomba, Qld, Australia. 1983
Berger, Nicolaas H. M., Woerden, Netherlands. 1983
Bonham, Frank C., Laguna Beach, Ca, U.S.A. 1983
Brand, Lester J., Germiston, S. Africa. 1983
Campion, John E., Rosyth. 1954
Chant, Joanna K., Dorchester. 1983
Chu, Hong-Sung, Taipei, Taiwan. 1983
Collado Castelles, Ma Dolores, Valencia, Spain. 1983
Dam, Hedwig M., Franeker, Netherlands. 1983
Dings, Christianne A. M., Valkenswaard, Netherlands. 1983
Dykstra, Jeannine B., Toronto, Ont., Canada. 1983
Ebert, Gabriela E., Neckarsteinach, W. Germany. 1983
Elsten, Antonius R. M., Purmerend, Netherlands. 1983
Feather, Russell C., II, Fairfax, Va, U.S.A. 1983
Floyd, Nancy E., Toronto, Ont., Canada. 1983
Fretzin, Leonard H., Chicago, Ill., U.S.A. 1983
Haughton, Michael, Bolton. 1983
Hillgarth, Antonella C., Geneva, Switzerland. 1983
Hollis, Patricia A., New York, N.Y., U.S.A. 1983
Inoue, Yoshie, Tokyo, Japan. 1983
Jashnani, Navin B., Bombay, India. 1983
Jennings, Joan M., Natal, S. Africa. 1983
Kaper, Robert, Washington, D.C., U.S.A. 1983
Karmakar, Sambhunath N., Bombay, India. 1983
Kjellin, Ewa B., Umea, Sweden. 1983
Kozen, Shigekazu, Osaka, Japan. 1983
Kwok, Addy S. C., Kowloon, Hong Kong. 1983
Lam, Cecilia L. K. L., Kowloon, Hong Kong. 1983
Langoulant, Peter B., Inglewood, W.A., Australia. 1978
Lee, Jeffrey K., Don Mills, Ont., Canada. 1983
Lette, Edward C. G., Amsterdam, Netherlands. 1983
Lloyd, Stephen R., London. 1983
Lowes, Elizabeth H., Toronto, Ont., Canada. 1983
McLean, Donald P., Toronto, Ont., Canada. 1983
McCornack, Constance B., Seattle, Wash., U.S.A. 1983
McGorrian-Morgan, Pauline J., Downpatrick, Co. Down, N. Ireland. 1983
Mahajan, Maryada D., Bombay, India. 1983
Majeed, Ismath A. M. M., Colombo, Sri Lanka. 1983
Mallawarachchi, Gayani N., Kadawatha, Sri Lanka. 1982
Mascetti, Daniela, Milan, Italy. 1983
Mata, Carmen, London. 1983
Merchant, Sandhya J., Bombay, India. 1983
Mohideen, H. M. Sultan, Madras, India. 1983
Moore, Stephen S., Pacific Palisades, Ca, U.S.A. 1983
Niinobe, Hiroko, Hyogo, Japan. 1973
Nikiforides, Constantine W., Surfers Paradise, Qld, Australia. 1983
Nikiforides, Tina, Surfers Paradise, Qld, Australia. 1983
Pandya, Manoj K., Bombay, India. 1983
Pattani, Hitesh K., Bombay, India. 1983
Pitt, John R., Stourbridge. 1983
Ponn, Roger E. F., Tulsa, Okla, U.S.A. 1983
Punchihewa, Leslie J., Colombo, Sri Lanka. 1983

Rajayohan, Rasiah, Karainagar, Sri Lanka. 1983
Ramaiya, Rajendra D., Bombay, India. 1983
Rhodes, Alexandra M., London. 1983
Rikkoert, Abraham, Schoonhoven, Netherlands. 1983
Ruest, Andre E., Gloucester, Ont., Canada. 1983
Shaw, Constance Helen, Toronto, Ont., Canada. 1983
Smith, Edward, Vineland Station, Ont., Canada. 1983
Smith, Ronald G., Nottingham. 1983
Soni, Sara, London. 1983
Steil, Patricia R., Hong Kong. 1983
Suenaga, Eiji L., Sapporo, Japan. 1983
Svendsen, Nina Vedeler, Rud, Norway. 1983
Valls Bascu, Joaquin, Barcelona, Spain. 1983
van Soest, Wilhelmina N. M., Wychen, Netherlands. 1983
van Stokkom, Francis A. J. A., Dongen, Netherlands. 1983
Virani, Nilesh A., Bombay, India. 1983
Wennberg, Mats T., Stockholm, Sweden. 1983
White, J. Marlene, Sacramento, Ca, U.S.A. 1983
Zawacki, Charles G., Anchorage, Alaska, U.S.A. 1983
Ziogos, Georgios, Thessaloniki, Greece. 1983
Zunz, Laura A., London. 1983

ORDINARY MEMBERSHIP

Abe, Kazumi, Kofu, Japan.
Aketa, Harou, Tokyo, Japan.
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Kojima, Yaeko, Tokyo, Japan.
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Taank, Joshna, Ilford.
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van Doren, Jean-Paul, Bognor Regis.
Vanderhaeghen, Ivan, Gent, Belgium.
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Watson, Thomas N., Nairobi, Kenya.
Wayne, Barry W., Chigwell.
Wilcox, Margaret, Marlow.
Wolkonsky, Alexander, St Cloud, France.
Woods, James M., Costa Mesa, Ca, U.S.A.

Yamamoto, Kaoruko, Kofu, Japan.
Yamanaka, Kimiko, Kobe City, Japan.
Yamauchi, Mineharu, Tokyo, Japan.
Yoshioka, Tadayuki, Kofu, Japan.
Zapatero, Luis M., Madrid, Spain.

ULSTER MUSEUM, BELFAST

In November 1983, the Geology Department of the Ulster Museum ran a course organized by Dr Rab Nawaz, F.G.A., comprising five lectures, one by Dr John Malone (Queen's University) on 'Diamonds', one by Dr John Preston (Queen's University) on 'Corundum and its Gems: Ruby and Sapphire', and three by Dr Nawaz on 'Beryl and its Gems : Emerald and Aquamarine'. 'Opal and Zircon Gems' and 'Topaz and Chrysoberyl Gems' respectively.

AMERICAN GEM SOCIETY GOLDEN JUBILEE CONCLAVE

The American Gem Society, founded (like the Gemological Institute of America) by Robert M. Shipley, celebrated its Golden Jubilee this year and for the first time invited international gemmologists to its Annual Conclave, which took place in Atlanta, Georgia, U.S.A., from 30th March to 3rd April, 1984.

SINGAPORE GEMOLOGIST SOCIETY

Information has been received of the formation in Singapore of the Singapore Gemologist Society. Among its objects are the promotion of increased understanding among and intercommunication between gemmologists in Singapore and around the world and the advancement of its members' knowledge in the gemmological field. Associate membership is open to gemmologists throughout the world. Entrance fee S$50: annual subscription S$50. Enquiries should be addressed to the Society at 3 Lengkok Merak, Singapore 1024.

CORRIGENDA

In *J.Gemm.*, 1983, XVIII(7)—
on p.654, between lines 23 and 24 insert 'Spinel and sapphire examined in New York Lab were found to be coloured by'
on p.656, line 3, for 'trip' read 'strip'

In *J.Gemm.*, 1983, XVIII(8)—
on p.678, line 25, for 'rhombohedrae' read 'rhombohedral'
on p.690, line 24, for 'only the' read 'only) the'
on p.772, line 9, for 'wollasonite' read 'wollastonite'
on p.772, line 10, for 'vesuviantite' read 'vesuvianite'
on p.773, line 4, for 'East' read 'Earth'

In *J.Gemm.*, 1984, XIX (1), on p.93, line 6, between 'Australia,' and 'Brazil,' add 'Austria,'

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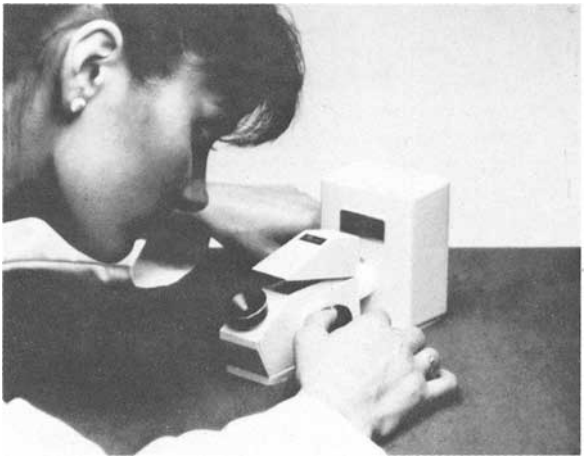

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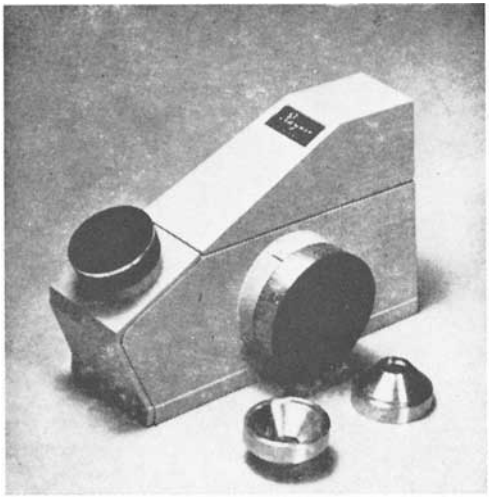

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Historical Note

The Gemmological Association of Great Britain was originally founded in 1908 as the Education Committee of the National Association of Goldsmiths and reconstituted in 1931 as the Gemmological Association. Its name was extended to Gemmological Association of Great Britain in 1938, and finally in 1944 it was incorporated in that name under the Companies Acts as a company limited by guarantee (registered in England, no. 433063).

Affiliated Associations are the Gemmological Association of Australia, the Canadian Gemmological Association, the Gem and Mineral Society of Zimbabwe and the Gemmological Association of Hong Kong.

The *Journal of Gemmology* was first published by the Association in 1947. It is a quarterly, published in January, April, July, and October each year, and is issued free to Fellows and Members of the Association. Opinions expressed by authors are not necessarily endorsed by the Association.

Notes for Contributors

The Editor is glad to consider original articles shedding new light on subjects of gemmological interest for publication in the *Journal.* Articles are not normally accepted which have already been published elsewhere in English, and an article is accepted only on the understanding that (1) full information as to any previous publication (whether in English or another language) has been given, (2) it is not under consideration for publication elsewhere and (3) it will not be published elsewhere without the consent of the Editor.

Articles published are paid for, and a minimum of 25 prints of individual articles may be supplied to authors provided application is made on or before approval of proofs. Applications for prints should be made to the Secretary of the Association—not to the Editor—and current rates of payment for articles and terms for the supply of prints may be obtained also from the Secretary.

Although not a mandatory requirement, it is most helpful if articles are typed (together with a carbon copy) in double spacing on one side of the paper, with good margins at sides, top and foot of each page. Articles may be of any length, but it should be borne in mind that long articles are more difficult to fit in than short ones: in practice, an article of much more than 10 000 words (unless capable of division into parts or of exceptional importance) is unlikely to be acceptable, while a short note of 400 or 500 words may achieve early publication.

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THE JOURNAL OF GEMMOLOGY

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CHROME DIOPSIDE FROM U.S.S.R.

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Institut für Edelsteinforschung, University of Mainz, W. Germany.

A lot of chrome diopside stated to be from an occurrence in the U.S.S.R. was to be investigated. Doubts of the natural origin of these stones arose caused by inclusions, which in their appearance resembled those from synthetic flux crystals (see Figures 1 and 2).

Diopside, $CaMg(Si_2O_6)$, is a member of the pyroxene group and is one end of the continuous crystalline solution of diopside—hedenbergite ($CaFe(Si_2O_6)$) caused by the diadochy of Mg and Fe^{2+}. According to Betechtin (1977) chrome diopside may contain some percentage of chromium oxide. A remarkable green coloration caused by chromium, which is perceptible in thin sections, needs more than 3% Cr_2O_3 (Tröger *et al.*, 1971). The specimens under discussion have a strong emerald-green colour.

Because for diopside the physical data vary, corresponding to the Fe^{2+} content (Tröger *et al.*, 1971), a similar variation should be expected for chrome diopside too. Their densities were measured by hydrostatic weighing and varied between 3.247 and 3.284 (average 3.27), which are in accord with those of reference samples of natural chrome diopsides from U.S.S.R. with 3.168 to 3.323.

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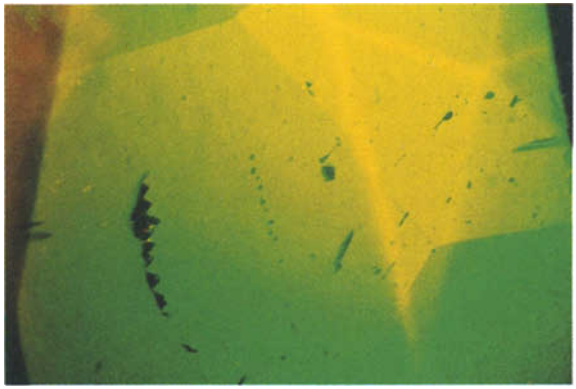

Fig. 1. Strange inclusions in a chrome diopside (30×)

Fig. 2. Inclusion from Figure 1 (140×)

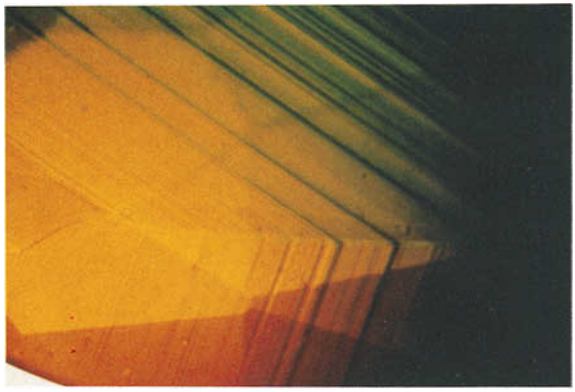

Fig. 3. Angular growth striae (30×)

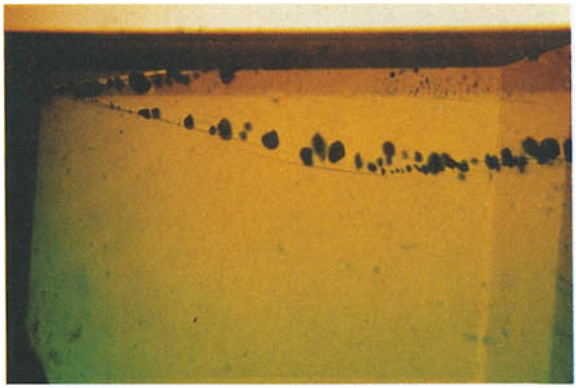

Fig. 4. Crystal inclusions, crystallized at a healing fissure (30×)

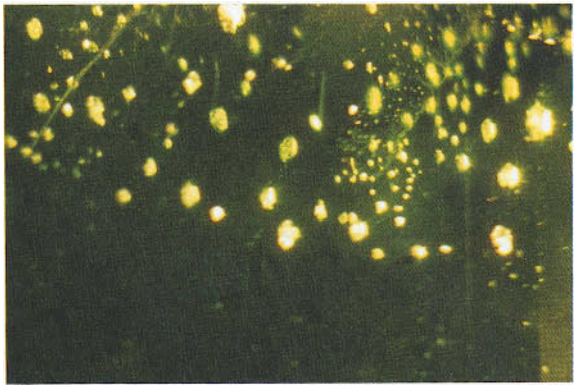

Fig. 5. Crystal inclusions, crystallized at a healing fissure, (see Figure 4, 30×, darkfield)

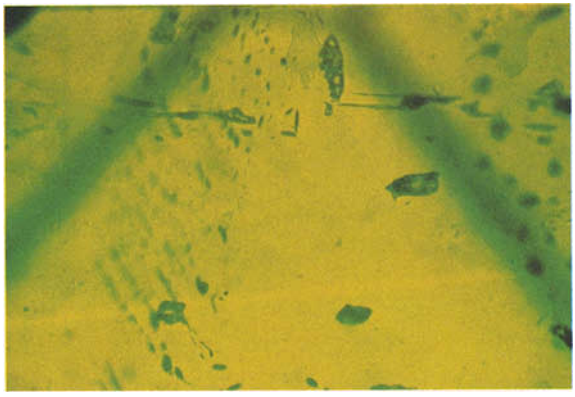

Fig. 6. Two phase inclusions (liquid, gas, 70×)

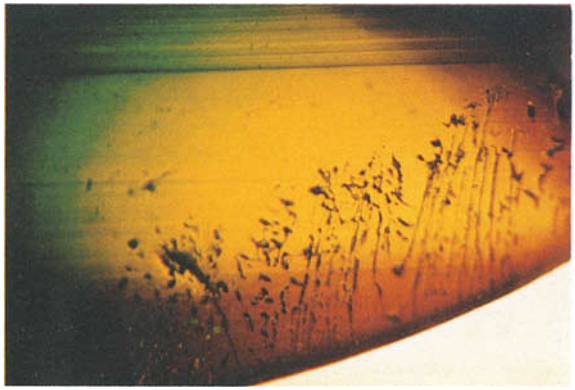

Fig. 7. Dendritic formed liquid inclusion of a healing fissure and growth striae (30×)

Eppler (1973) and Webster (1975) found a density of 3.29 for diopside, Schmetzer & Medenbach (1974) 3.31 for chrome diopside from Kenya, Bank (1976) 3.27 for specimens from Brazil.

The behaviour of the measured refractive indices was very similar, they lay between n_x = 1.670 (± 0.002) and n_z = 1.700 (± 0.002) with a birefringence of 0.030 and only small deviations: they also corresponded to those in the literature.

An investigation of the samples by electron microprobe analysis found an average content as follows:

SiO_2	54.601	wt %
TiO_2	0.070	”
Al_2O_3	0.219	”
V_2O_3	0	”
Cr_2O_3	0.591	”
FeO	1.032	”
CaO	23.528	”
MgO	18.003	”
MnO	0.033	”
Na_2O	0.341	”
K_2O	0.012	”
	98.430	”

These results differ slightly from those found by Schmetzer & Medenbach (1974) in one chrome diopside from Kenya.

Because of the fact that electron microprobe analysis is able to find out only contents of the surface of the sample, an additional method was used for the sample in Figure 1, viz. neutron activation analysis. This method ascertains contents of trace elements of the whole specimen, including those of the inclusions, which can give information as to the origin of the crystal.

The neutron activation analysis revealed:

Fe	8002	ppm
Na	3127	ppm
Sc	49	ppm
Cr	4674	ppm
Mn	354	ppm
Co	15	ppm
Sr	1863	ppm
La	6	ppm
Ce	21	ppm
Nd	13	ppm
Sm	2	ppm
Eu	150	ppb
Lu	111	ppb
Hf	680	ppb

By this method of analysis also no elements were found which could prove a possible synthetic origin. So we have to say that these chrome diopsides from U.S.S.R. are natural.

Further investigations of the inclusions are not yet completed.

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INTENSIVE YELLOW TSILAISITE (MANGANESE TOURMALINE) OF GEM QUALITY FROM ZAMBIA

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ABSTRACT

Transparent gem tourmalines with an intensive yellow coloration from Zambia are described. Chemical and physical properties are given. The tourmalines with manganese contents of 6-7% MnO were proved to be members of the solid solution series elbaite-tsilaisite (manganese tourmaline). The mechanism of coupled substitution in manganese tourmalines and the formula of the end members in the elbaite-tsilaisite solid solution series are discussed.

INTRODUCTION

Most of the transparent tourmaline varieties of gemstone quality are members of the solid solution series elbaite-liddicoatite or members of the series dravite-uvite. In both groups of gem tourmalines small amounts of iron, i.e., small percentages of the schorl molecule, are also present. In general, manganese-containing tourmalines of gem quality were determined as elbaites with only small percentages of MnO < 2%. The rose or rose-red colour of such elbaites is thought to be caused by the small manganese contents of the samples (e.g., Bradley & Bradley, 1953; Slivko, 1959, 1961; Manning, 1969a,b, 1973; Dunn, 1975; Nassau, 1975; Leckebusch, 1978).

A great number of gem tourmalines from different localities with yellow or brown coloration were proved by microprobe analysis to be members of the dravite-uvite series (e.g., Dunn, 1977; Schmetzer *et al.*, 1979; Hänni *et al.*, 1981). Surprisingly, however, when testing some tourmaline specimens of yellow and yellowish-brown colour, which were said to come from a new occurrence near Chipada in Zambia, by microprobe analyses, no magnesium but distinct manganese contents of about 6-7% MnO were found. A more detailed mineralogical investigation (compare Schmetzer & Bank, 1984) showed those tourmalines to be the first tsilaisites (manganese tourmalines) of gem quality known to the authors.

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The name tsilaisite was given by Kunitz (1929) for the hypothetical end member of the series elbaite-manganese tourmaline, who at that time, assumed a formula of $NaMn_3Al_6(BO_3)_3Si_6O_{18}(OH)_4$ for this tourmaline. This formula requires a manganese content of 20.26% MnO. Due to the facts that the highest amount of manganese ever mentioned was a value of 8.21% MnO in an analysis by Kunitz (1929) and that the manganese contents in other Mn-rich tourmalines were found to lie only between 3 and 6% MnO (Scharizer, 1889; Prendel, 1892; Duparc *et al.,* 1913; Agafonova, 1947; Epprecht, 1953), the formula of tsilaisite was changed by Slivko (1959, 1961) to $Na(MnAl_2)Al_6(BO_3)_3(Si_6O_{18})(O,OH)_4$, which corresponds to the manganese contents found in natural samples.

Synthetic tsilaisite was produced by Tomisaka (1968). The synthetic tourmalines of Tomisaka, however, were not analysed chemically, and, therefore, the Mn:Al ratio in the unit cell of the synthetic tsilaisite is unknown. Recently, coupled substitutions in the tourmaline group were examined by statistical methods (Foit & Rosenberg, 1977). Manganese-containing tourmalines, however, were not considered individually. The mechanism of an isomorphic substitution of manganese in the tourmaline structure is not known in detail. Most of the tourmalines with high amounts of manganese contain different percentages of iron. Therefore, the influences of percentages of manganese on the colour of tourmalines and the valence state of this transition metal ion (bi- and/or trivalent) are doubtful.

Chemical and Physical Properties of Tsilaisite from Zambia

The samples available for investigation were mainly cut gemstones (Figure 1), and only some small rough fragments without individual crystal faces were observed. The microprobe analyses show the samples to be very high in their manganese and extremely low in their iron contents. An idealized formula of the tsilaisite from Zambia may be written as $Na(Li_{0.5}Mn_{1.0}Al_{1.5})Al_6(BO_3)_3Si_6O_{18}O(OH,F)_3$. The only difference between this formula and the formula of Slivko (1959, 1961) for the hypothetical tsilaisite end member is the presence of appreciable amounts of Li in the natural sample.

The MnO contents of different crystals from Zambia were found to lie between 6.3 and 6.9% MnO. The refractive indices vary slightly with the manganese contents of the samples, and values of n_e 1.622-1.623, n_o 1.645-1.648, Δ 0.023-0.025 were measured for samples with manganese contents between 6.37 and 6.80% MnO. The refractive indices are closely related to the values given for members of the solid solution series elbaite-tsilaisite with different manganese contents (Duparc *et al.*, 1913; Kunitz, 1929), e.g., the optical properties of tsilaisite with low and high manganese contents were given by Kunitz (1929) as n_e 1.621, n_o 1.642 (2.04% MnO) and n_e 1.630, n_o 1.655 (8.21% MnO), respectively.

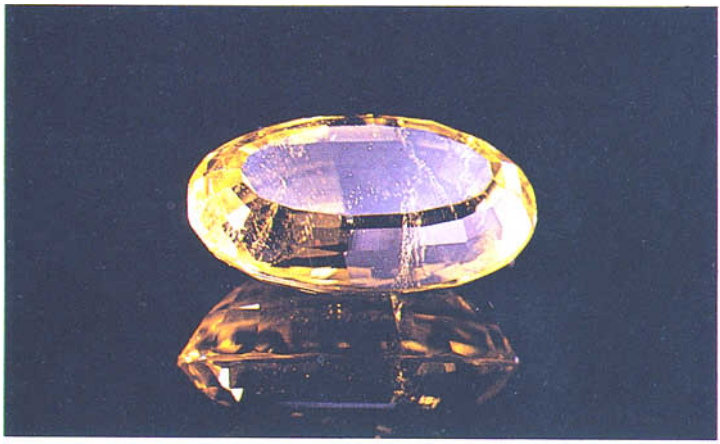

Fig. 1. Yellow tsilaisite (manganese tourmaline) from Zambia; size of the sample approx. 16 × 10 mm. *(Photo. by O. Medenbach, Bochum.)*

The strongest lines in the powder diffraction pattern of tsilaisite from Zambia are 4.21 (80), 3.99 (80), 3.45 (60), 2.942 (80), 2.572 (100) and 2.034 Å (60); the powder diffraction patterns of tsilaisite and elbaite do not show any distinct differences (compare Schmetzer & Bank, 1984). The unit cell dimensions (a_o 15.915, c_o 7.123 Å) lie close to the direct line connecting the Mn-free tourmaline end members, elbaite and schorl, as given by different authors (Epprecht, 1953; Slivko & Yorish, 1964; Tomisaka, 1968; Kornetova, 1975; Schmetzer *et al.*, 1979; Sahama *et al.*, 1979).

Therefore, a distinction between members of the solid solution series elbaite-schorl and the series elbaite-tsilaisite or between tsilaisites with different iron contents is thought to be impossible by means of the unit cell dimensions of an individual sample. The density of tsilaisite from Zambia was determined as 3.13 g/cm^3.

The homogeneous colour of tsilaisite specimens from Zambia may be described as intensive yellow, greenish-yellow or yellowish-brown with distinct pleochroism o > e. The absorption spectrum in the visible area consists of a broad absorption band at 15 800 cm^{-1}, an increasing absorption from about 17 000 cm^{-1} to the blue end of the visible area, and a weak shoulder at about 24 100 cm^{-1}. The variation of colours in the Zambian tsilaisite (yellow, brown, or greenish-yellow) is dependent on the ratio of the intensity of the 15 800 cm^{-1} band versus the intensity of the increasing absorption from 17 000 cm^{-1} to the blue end of the visible area. The absorption at 24 000 cm^{-1} is not responsible for the different colours of the samples.

Due to the absence of the strong absorption band at 19 200 cm^{-1}, which is assigned to a Mn^{3+} absorption in rose to rose-red manganese tourmalines (elbaites), manganese in Zambian tsilaisites is assumed to be present in the bivalent state only. The absorption at 24 100 cm^{-1} is due to Mn^{2+} d-d transitions; the assignment of the 15 800 cm^{-1} absorption, however, is difficult. A colour centre, probably in connexion with manganese, or manganese-iron charge-transfer may be the reason for this absorption band (for further details compare Schmetzer & Bank, 1984).

Isomorphous Replacement in the Series Elbaite-Tsilaisite and Formula of Tsilaisite End Member

Coupled substitutions in the tourmaline group were described by Foit & Rosenberg (1977). For members of the elbaite-schorl series, three types of an isomorphous replacement were regarded to be present. Though these types of coupled substitution may also be present to a minor extent, the chemical composition of Zambian tsilaisite is not explained by these three types of an isomorphous replacement. From chemical data of Zambian tsilaisite, a new type of coupled substitution was found to be dominant in those samples:

$$Li^+ + (OH)^- \rightarrow Mn^{2+} + O^{2-} \qquad (1)$$

Accepting this type of an isomorphous replacement, the chemical properties of Zambian tsilaisites are clearly understood. The end

members of this coupled substitution in the elbaite-tsilaisite series are represented by the formulae
$Na(Li_{1.5}Al_{1.5})Al_6(BO_3)_3Si_6O_{18}(OH,F)_4$ for the ideal elbaite, and $Na(Mn_{1.5}Al_{1.5})Al_6(BO_3)_3Si_6O_{18}O_{1.5}(OH,F)_{2.5}$ for the ideal tsilaisite. The tourmaline from Zambia represents a solid solution of 69% of the ideal tsilaisite and 31% of the ideal elbaite end member, the schorl component of the sample is smaller than 1%.

However, the isomorphous replacement in natural manganese tourmalines is thought to be even more complicated. A calculation of the incomplete analysis of manganese tourmaline from Nertschinsk with 8.21% MnO (Kunitz, 1929), on the basis of Si = 6, leads to an approximate formula of

$$(Na_{0.83}Ca_{0.13})(Li_{0.52}Mn_{1.16}Al_{1.38})Al_6(BO_3)_3Si_6O_{18}(O,OH,F)_4.$$

This formula is not completely understood assuming only an isomorphous replacement as given by equation (1). Another type of coupled substitution is thought to be present, too:

$$Al^{3+} + O^{2-} \rightarrow Mn^{2+} + (OH)^- \qquad (2)$$

Both types of isomorphous replacement, which are thought to be present in tsilaisite from Nertschinsk are combined by the following equation:

$$Li^+ + Al^{3+} \rightarrow 2Mn^{2+} \qquad (3)$$

The chemical formula of tsilaisite from this locality is understood by an additional substitution of type (1) and type (3), respectively. In the tourmaline analysed by Kunitz (1929) an isomorphous replacement according to type (1), however, is found to be dominant over a substitution according to type (3). The complete isomorphous replacement by type (3) leads to a formula of $NaMnAl_6(BO_3)_3Si_6O_{18}(OH,F)_4$, as proposed by Kunitz (1929) for the tsilaisite end member with 20.26% MnO. At present, it is unknown to what extent such coupled substitution of type (3) between (Li,Al), and Mn is compatible with the tourmaline structure. A manganese content in tourmaline leading to three Mn atoms in the formula unit was never proved to be present in tourmalines up to now. Therefore, a formula as given by Kunitz (1929), and representing a complete substitution of type (3), is thought to be only hypothetical.

From all those considerations, a dominant substitution of type

$$(1) \qquad Li^+ + (OH)^- \rightarrow Mn^{2+} + O^{2-}$$

is assumed to represent natural manganese tourmalines. A formula

with 1.5 Mn atoms in the formula unit

$$Na(Mn_{1\cdot5}Al_{1\cdot5})Al_6(BO_3)_3Si_6O_{18}O_{1\cdot5}(OH,F)_{2\cdot5}$$

is suggested to be used for the tsilaisite end member. Following the reintroduction of uvite by Dunn (1977), tsilaisite is the second new (old) member of the tourmaline group, which is no longer regarded to be a hypothetical end member of this series only.

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MEDICINE NOT MINERALS

By A. E. FARN, F.G.A.

I have never really subscribed to the efficacy of the healing or curative properties of gemstones or gem materials. Neither do I care too much for such stories as Cleopatra's dissolving a fine pearl in wine to impress Mark Antony, even if the wine turned to vinegar. I do not care for the story of Nero watching bloody gladiatorial combats through an emerald slice to cut down glare; at times emerald was termed Neronianus. Some names, however, do have a certain parallel or association with medicine or well-being. In his book, *Pearls,* 1913, W. J. Dakin, D.Sc., F.L.S., Professor of Biology, University of Western Australia, Perth, states: 'We find that many of our common herbs and lowly plants came to be used as medicine and they were used for whatever their shape suggested. So we get the origin of the kidney bean and the liver wort. The pearl seemed so beautiful and pure that the idea arose that it too must have some value in this respect.'

It is not my intention to dwell too much upon the subject of pearls at this juncture except to mention the secondary use of poor quality seed pearls, etc., as aphrodisiacs and the use of the lowest quality non-nucleated cultured pearls as tomb pearls. One function to raise the spirits, the other to appease them?

The reference to the kidney bean reminds me strongly of an interesting item in a lecture given by B. W. Anderson to our diploma class at Northern Polytechnic just after our departure from Chelsea. The lecture was on 'Jade and Similar Materials'. In it Anderson discussed the use of the umbrella-term jade to cover both jadeite-jade and nephrite-jade. Because of the derivation stemming from Le Jade (French) from 'pierre de l'ejade', a direct translation from the Spanish, 'piedra de la yjada', or stone of the kidney or flank, a mix-up occurred.

The interest of authors in those days was so much concentrated on its powers of healing kidney troubles that in the Bibliothéque Nationale de Paris, as late as 1900, books on jade were listed in the section for *medicine,* instead of minerals. Damour, the French chemist, in 1863 separated the two minerals and decided to call the amphibole (nephrite) 'jade néphrétique' and to call the pyroxene 'jadeite', which, as a name, sounds rather 'like-jade' or 'jade-like'.

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But I will not spend more time on jade at present except to mention that gems, gemstones, minerals and gemmology have an interesting aspect other than strictly that of beauty or decoration. Most of us as gemmologists think of gemstones in terms of colour. I never think of diamonds in my ideas on gemmology—perhaps because basically they are *colourless,* and secondly they are cut and polished by diamond cutters and polishers, a race apart, whereas gemstones are cut and polished by lapidaries.

'The first impact of a gemstone is its colour' was the substance of a talk I gave to an international conference at Idar-Oberstein in 1979.* The basis of this idea was that, as a laboratory worker, on seeing a stone, one's reaction is to classify instinctively, i.e. a red stone could be natural/synthetic ruby, garnet, spinel, glass, etc., and the steps to follow would be guided by competent use of the 10× lens, noting double/single refraction, etc., spectroscopic/microscopic examination and so on. The accent is upon the first appearance and impact upon the eye of colour. Nature we know is not prolific in providing richly coloured gemstones whether rubies, sapphires, emeralds, etc. In fact, rubies, sapphires and emeralds are impure samples of corundum and beryl respectively. Ideally corundum and beryl are colourless as are most crystalline varieties of gemstones except the idiochromatic materials such as malachite, peridot, etc.

It seems to me that there is another aspect of gemmology which could be that of the non-gems gemmology but which nevertheless carries the mineral, rock or gemstone name or chemical composition. Such gemmological materials as I have in mind have an important secondary role in commercial markets. I have touched upon the aphrodisiac value of pearls which, according to a well informed Asian source, has indeed some interest. He quotes a case of a Chinese gentleman who has wined and dined well and suffers a little discomfort: it is not uncommon in such cases in Hong Kong to go to a chemist and ask for a draught, which will be made up on the spot by grinding with pestle and mortar seed pearls in distilled water. This is swallowed, followed by a hearty belch, thus proving that the basis of good stomach powder is calcium carbonate (seed pearl). The feeling of well-being engendered does not, I fear, go further than the digestive system!

*Z.Dt.Gemmol.Ges., **28**, 4, 188-90.—Ed.

Calcium carbonate (calcite) when burned gives us lime which has considerable use in the building industry and in soil balance—brassicas love it. Another useful gem material in the building industry is gypsum—the subtranslucent type is termed selenite, while satinspar is the name given to a fibrous variety. Gemmologically it is important as number 2 on Mohs's scale of hardness. When burned it forms 'Plaster of Paris', so called from its source in Montmartre (Paris) gypsum quarries.

Slightly softer than gypsum is talc, being number 1 on Mohs's scale: it is known to most gemmologists in its ornamental garb as soapstone. Soapstone has a slippery touch and as a powder provides that smoothness that caresses the body or lubricates the dance floor.

In terms of powders one of the most interesting is haematite, an iron oxide used for carving intaglios and, when crushed, becomes a red powder known as rouge (and a basis for lipstick) or Jewellers' rouge. It is used extensively as a fine polishing agent. Haematite has a red streak when tested. Two other well known polishes and abrasives are derived from synthetic powdered Al_2O_3 (corundum), namely Aloxite and Alundum. Emery or emery paper, suitably graded, can be used wet or dry as a fine finishing agent in metal cleaning and particularly in car body repair work. It is interesting to note that emery consists of corundum, magnetite and haematite, the grain structure of which readily fractures to offer fresh sharp faces for cutting/abrading.

Talking of mixtures in the form of rock material, one of the commonest, interesting and most useful is granite. Granite has occasionally been polished and used in pendants as an ornamental stone, but as a building material and kerb stone it is supreme. I never fail to examine chunks of granite jettisoned by the builders of our local sea-wall. The inclusions of quartz, feldspar and mica reflecting in the sun attract me and usually end up at home on the rockery.

Ornamental stones such as crushed lapis-lazuli were originally used as pigments for artists, ultramarine being the derivation from lapis-lazuli.

In the January 1974 issue of this *Journal* I wrote an article entitled 'An Appetite for Gemmology',* no pun being intended or play upon a similar sounding gem material, apatite. Apatite occupies position number 5 halfway up or halfway down Mohs's

*J. Gemm., 1974, **XIV**, 1, 16-19.—Ed.

scale. It is a collector's stone, being too soft for real jewellery use. It does, however, have a secondary interest. Despite some enthusiasm in Canadian circles at one of our international conferences where we were presented with useful little samples of 'Trilliumite' (pale green apatite), the broad use of the term 'mineral phosphate' indicates its use as a *fertilizer*. The derivation of the word apatite was from the Greek for 'to deceive', being confused in early days with aquamarine, tourmaline, etc. (fertile imagination?). When one considers such secondary roles of gem minerals, it is not surprising to follow on to differing physical appearances of the same chemical compound, one of the most remarkable, to my way of thinking, being a calcium carbonate which, being basically $CaCO_3$, occurs in oysters and pearls in the labile and stable forms of calcite and aragonite respectively, each having differing hardnesses, densities and crystal formations but both being calcium carbonate. (E. S. Dana does not accept biomineralization products as minerals.)

As an abrasive, diamond is, to all intents and purposes, the hardest known substance and is, almost entirely, carbon; yet in another form known as graphite, carbon is a soft lubricant. Graphite is rhombohedral and occurs as six-sided tabular crystals sometimes showing triangular markings on the basal plane. Although diamond is chemically described as pure carbon, whilst graphite is described as carbon (very often impure), it is interesting to note that some graphite burns more readily than diamond—a somewhat expensive and not absolutely definitive method of differentation.

Most school children are familiar with pencils marked H, HB, etc., which is indicative of the grade of the pencil lead. This lead is graphite (plumbago, black lead) and usually it comes from Sonora, Mexico. Thus we have a fascinating example of the complete range of Mohs's scale of hardness, diamond 10—graphite 1 = carbon; both have the same end result when burned. These differing physical appearances of materials having the same chemical composition are an aspect of gemmology which I find as interesting as I do the other roles of gem materials. I think that these aspects—the senses, the impact and the use of the ten times lens—are of considerable importance and contribute to the enjoyment of the gemmological scene.

[*Manuscript received 25th July, 1983.*]

SAPPHIRES FROM KANCHANABURI PROVINCE, THAILAND

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ABSTRACT

An occurrence of sapphires in the Kanchanaburi province, Thailand, is dealt with here. Detailed descriptions of the location and accessibility of the area are given. Recent geological investigations of the Kanchanaburi province are reported and compared with the well-known gemfields to the east, namely, Chanthaburi-Trat. Chemical and physical analyses are presented with gradings of colour according to DIN colour system. The most typical internal scenes of the sapphires found are presented in photomicrographs and carefully analysed.

INTRODUCTION

Thailand—the land of free people, long noted for its collection of gem quality rubies and sapphires—has today become the world's premier ruby centre. The distribution of these rubies is mainly concentrated around the Chanthaburi-Trat area, as reported by Pavitt (1973), Berrangé & Jobbins (1976), Gunawardene & Mertens (1982) and Keller (1982). However, the basaltic distributions extend to the north and the west covering the gemfields in Phrae and Kanchanaburi respectively. During the last 10 to 12 years the Kanchanaburi area has become an interesting sapphire locality and was mentioned by Angkatavanich (1975) in Thai geological reports. Short mentions were made by Findlay (1979) in this *Journal,* and elsewhere (Healy & Yu, 1982).

Kanchanaburi is one of the most beautiful provinces of Thailand. It is famous among war historians and movie buffs as the site of the notorious 'Death Railway' and the 'Bridge over the River Kwai', and among archaeologists for its Neolithic burial grounds. Many other tourist attractions like Kao-Poon cave, located about 1 kilometre away from the 1750 prisoners Chung-Kai war cemetery, and Kao-Phang waterfall are worth mentioning.

The beautifully landscaped gemming area is in Bo Phloi. The mines have yielded an enormous quantity of commercial grade blue sapphire; fine gem material, of course, has also been found.

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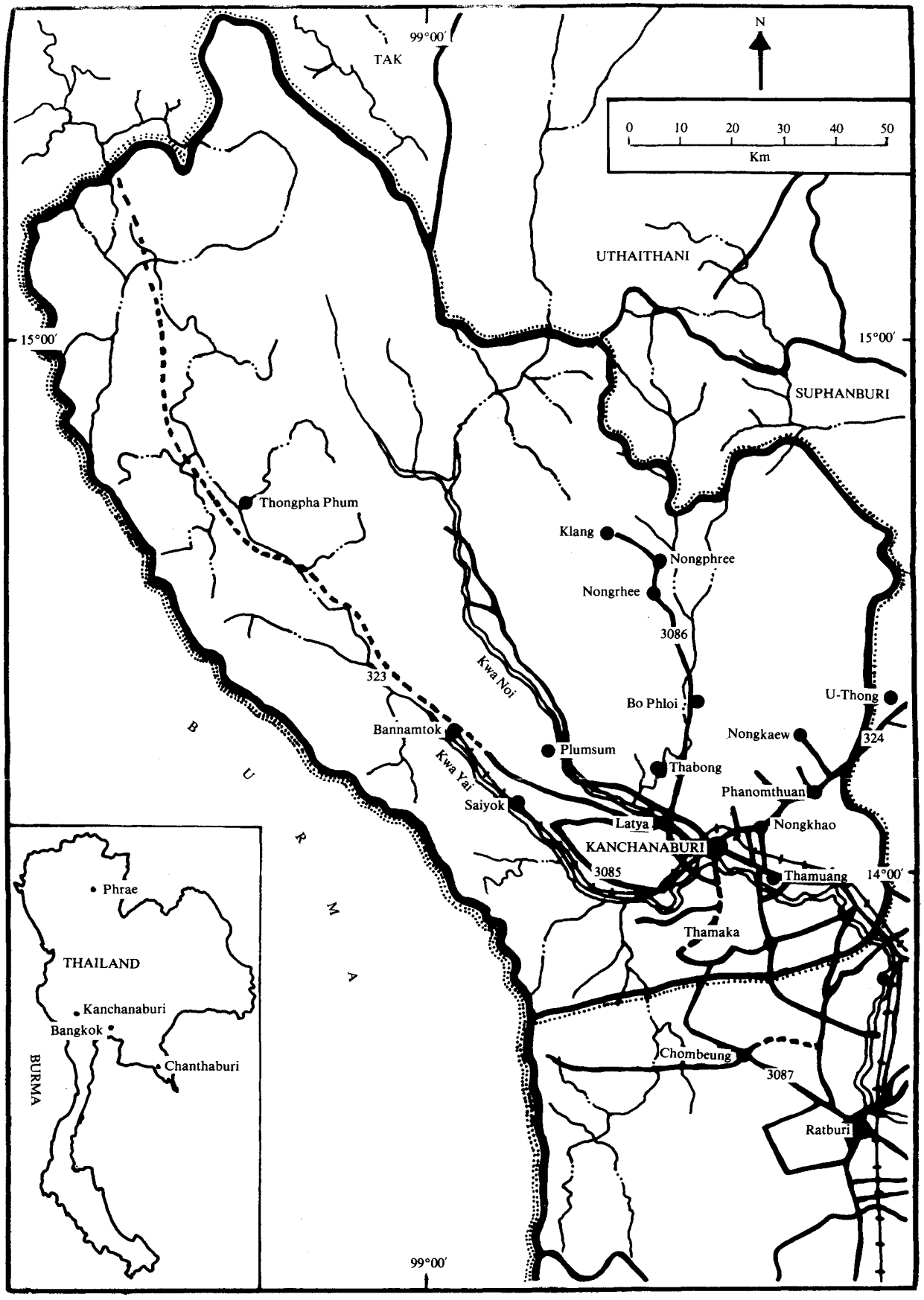

LEGEND

River

Road

Minor towns

International borders

Major towns

Highways

Provincial borders

Figure 1. A sketch-map showing the Kanchanaburi Province and its surroundings.

LOCATION AND ACCESSIBILITY

Kanchanaburi is located approximately 129 kilometres west of the capital of Thailand, Bangkok. As shown in Figure 1, the mining centre Bo Phloi (Bo Phloi means 'gem mines' in Thai) is situated 44 kilometres due north from Kanchanaburi town in the Kanchanaburi province. The mining area is centred approximately in the middle part of a large area which extends from approximately 99°00′ to 100°00′ and 13°00′ to 15°00′. Running through the area are two tributaries, the Kwa Noi and Kwa Yai, which meet to form the Mae-Klong river (Mae-Klong means 'mother of rivers' in Thai) near to Kanchanaburi town.

Thanks to the Thai engineers, one can easily reach Kanchanaburi town from Bangkok by super-highway 323; after passing through this town one must turn right to a smaller highway 3086 and continue to Bo Phloi (distance from Bangkok to Bo Phloi is 173 km). The drive can be comfortably accomplished in two and a half hours by car. Bo Phloi is a typical little Thai village, with wooden houses and corrugated tin roofs. The main mode of transportation of the local miner is the motorbicycle, which they use to reach the remote mines and along dirt tracks extended from here to the various gem pits. Yes, indeed, the scene is very picturesque, and all is usually peaceful; the stones are mined, the rice is cultivated and life continues at a gentle pace.

GEOLOGY

Under such tropical climatic conditions the sedimentary and metamorphic rock cycles in the Kanchanaburi area show alluvial, eluvial or residual deposits predominating in the underlying basalt (Vichit *et al.*, 1978; Gunawardene & Mertens, 1982).

The age of the basalt of the area is not yet determined. However, overlies of the tertiary to Permian and carboniferous Devonian aged Kanchanaburi formation are reported (Javanaphet, 1969). The Permian layer consists of light grey limestone interbedded with shale sandstone, conglomerate and volcanic tuff. The deposits are composed of quartz, quartzite, slate and granite. The presence of sapphires in a basaltic outcrop is quite usual when considering the general gem occurrences in Thailand (Berrangé & Jobbins, 1976). The overlie situation in Kanchanaburi was

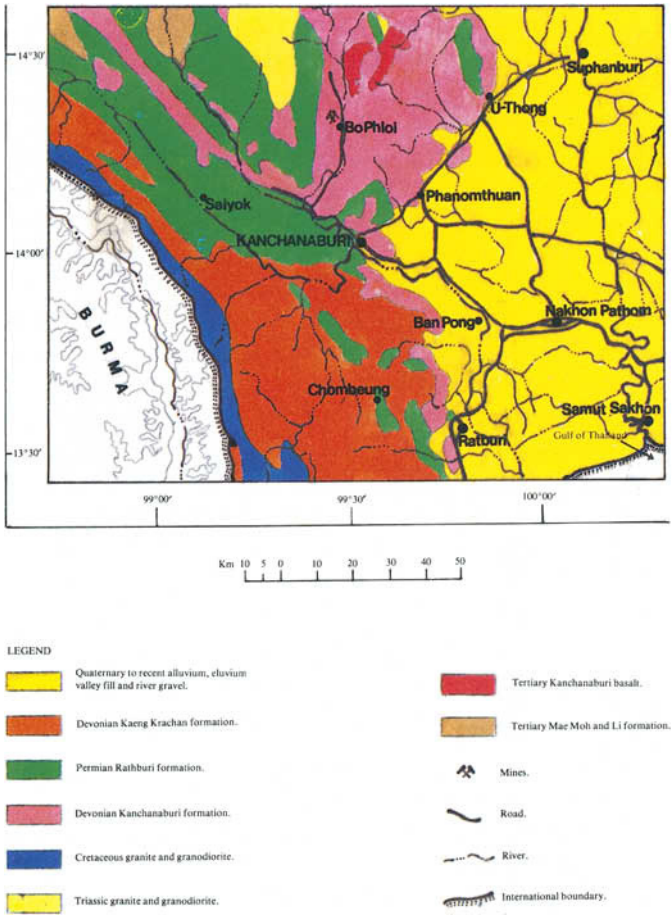

Figure 2. Geological map of the area around Bo Phloi (after Javanaphet, 1969).

mentioned by Javanaphet (1951) and supports the paper published by Berrangé & Jobbins in 1976. Illustrated geological framework of the Kanchanaburi Province is shown in Figure 2.

The famous gem locality of the area is Bo Phloi, where sapphires are extensively mined. Owing to deep chemical weathering and rapid erosion the solid rock is rarely found except occasionally in beds of streams. Apart from the major occurrence of sapphires (mostly blue and partly yellow and colourless) as shown by Vichit (1977), the abundant occurrence of feldspar and fluorite in the hornblende biotite granite was reported by Angkatavanich in 1975. However, information received by the author (M. G.) in this connexion (the Royal Thai Survey department, private communication) revealed the rarity of their gem quality counterparts. Equally possible is that the less durable minerals like fluorite or feldspar may not survive in ideal cuttable sizes under such upheavals of alluvial or eluvial deposits. The corundum would not suffer so much change under such environmental conditions owing to its durability and heaviness. Blue sapphires are the main occurrence in this basalt field, with few yellow and colourless sapphires. Sample examinations at the mines revealed the presence of black spinels embedded in the rocks.

MINING METHODS

As with other corundum mines in Thailand, these fields are worked most primitively. Principally two distinct mining modes are employed—pit mining and open shaft mining.

Hundreds of pits ranging in depths from 5 to 15 metres have been sunk (some pits being only 2 metres apart). The walls of the pits have been reinforced with bamboo canes, and workers lower themselves by means of 'bamboo ladders' as shown in Figure 3, where they dig out and collect the gem-bearing gravels into the buckets. The buckets are hoisted up by means of crude pulley-type mechanism (Figure 4).

In other areas of the mining region, large open shaft mines are used. A large amount of overburden (or top soil) is removed, creating craters about 20 metres across. The gem-bearing gravel is collected and washed, using various schemes which have been

Figure 3. Pit mining of sapphires in Bo Phloi. The walls of the pit are reinforced with bamboo canes and the 'bamboo ladder' used to climb down to the pit.

Figure 4. Hoisting the buckets containing the gem gravel by means of crude pulley-type mechanism.

developed to facilitate the excavation and cleaning of gem gravels. Artificial pools are created by diverting water from a nearby river (a tributary of the Kwa Noi).

This water flow is passed through wooden gravel-containing crates (which are termed 'Thraka Mai' by the natives), so that the clays in which the sapphires are imbedded loosen and crumble. The decomposed material then travels downwards into the pool, the sapphires and other larger rock types being collected by sieves which are fixed in crates.

Figure 5. Use of strong jets of water to clean the remaining clay at the final stage of cleaning. Later, the workers sit on these large wooden crates and pick out the sapphire crystals by hand.

The rocks and sapphires are then transported to a separate series of large, wooden crates with fine-meshed bottoms. Again strong jets of water are used to clean the remaining clays as shown in Figure 5. As the last step the workers sit in these crates and carefully pick out the sapphire crystals by hand.

TABLE 1. Colour grading of Kanchanaburi sapphires according to DIN colour system.

No. of stones used	Colour system after DIN 6164	Standard colour estimation X_c	Y_c	Z_c	Comments on colour	Other remarks
4	16:4:4	9.0	7.5	20.5	Dark blue resembling somewhat the Australian blue with a greenish hue.	Oval mixed cut. Strong zoning of dark blue.
2	16:5:4	7.8	6.2	20.5	Deep inky blue similar to darker Pailin blue and slightly visible greenish hue.	Oval mixed cut. Zoning running through the stones.
3	16:3:5	6.9	6.2	20.5	Inky blue with a greenish-yellow hue.	Antique mixed cut. Zoning and many fractured feathers.
1	16:4:5	5.8	4.9	13.4	Blue colour resembling fine Sri Lanka stones.	Round mixed cut. Even colour concentration. Fine silk.
5	17:2:2	28.9	28.7	46.1	Blue colour with zoning.	Many shapes of mixed cut stones. Fine zoning.
8	17:1:3	24.1	24.1	31.0	Slightly inky blue with whitish-green hue.	Many shapes of mixed cut stones. Zoning with lighter coloured gaps in between.
4	17:2:3	19.4	19.3	31.0	Light blue colour with greyish hue.	Oval mixed cut. Strong zoning.
5	17:3:3	16.0	15.9	31.0	Light blue.	Many shapes of mixed cut stones. Zoning.
4	17:2:4	12.9	12.8	20.6	Very light blue.	Flat antique mixed cut. Zoning.
3	17:3:4	10.6	10.5	20.6	Very light milky blue.	Many shapes of mixed cut. Strong milky zoning.

GEMMOLOGICAL CHARACTERISTICS

The sapphires found in Kanchanaburi can readily be distinguished from the sapphires found in alluvial deposits of Sri Lanka or Australia by the study of various properties mentioned below, including the internal characteristics.

Besides the main chemical component of Al in the sample stones analysed a Cl percentage was recorded by the microprobe. Since the analysis was qualitative, the exact percentage of this unusual Cl content as well as the usual Fe and Ti percentages were not calculated in this determination.

Thirty-nine well cut Kanchanaburi sapphires of different blue tones and hues were used in the colour-grading according to the DIN 6164 system. The darker-coloured blue sapphires were in the 16:4:4 to 16:4:5 range and the lighter-coloured stones ranged between 17:2:2 and 17:3:4. The graded stones and their colour numbers are given in Table 1. Most of the stones examined revealed a greenish to greyish hue in directional observations. Most of the cabochon cut commercial grade are of the lighter colour grade.

The refractive indices and specific gravity values are slightly variable in these sapphires from Kanchanaburi (RI $1.761 \pm^{0.008}_{0.001}$ — $1.769 \pm^{0.008}_{0.001}$, DR − 0.008, SG 4.00 ± 0.001 at 4°C); however, a distinct difference from sapphires from other localities was not found. Those with higher Fe content often showed the typical blue sapphire spectrum with distinct lines at 450 and 460 nm. All the stones exposed to both short- and long-wave ultraviolet radiations remained inert.

The growth conditions in such an environment of basaltic terrain have left readable evidence presented in the form of mineral inclusions in these sapphires. Such an eloquently informative pre-formed feldspar crystal is shown in Figure 6. Equally characteristic mineral paragenesis is a dominant primary sulphide in an iron-rich basalt, namely pyrrhotite, which may alter to goethite with attendant metallic appearance (Figure 7). Qualitative microprobe analysis proved the presence of Na, Al, Mg with Si confirming hornblende in the form of crystals as in Figure 8. Fractured feathers, often filled with the remaining iron oxide can be taken as a common inclusion in Kanchanaburi sapphires (Figure 9). Frequent dislocations in the form of needle-like structures were often seen within the sapphires from this locality (Figure 10), but

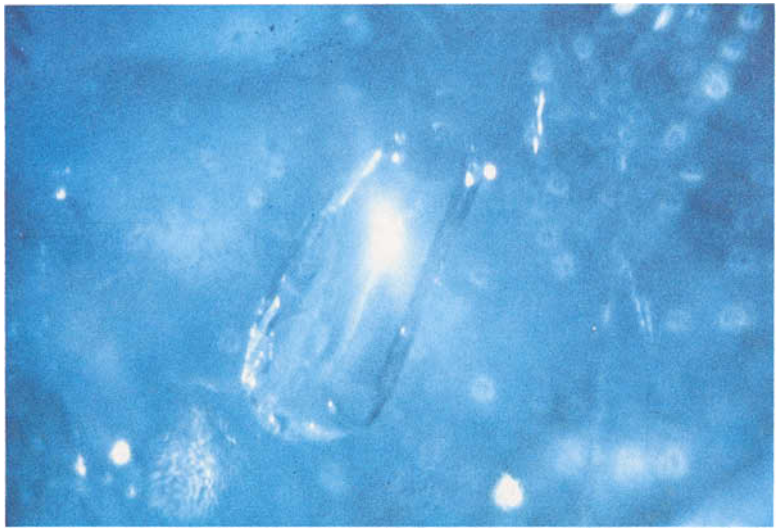

Figure 6. Moderately transparent, abundant occurrence of feldspar ($KAlSi_3O_8$) crystals. 60 × .
(*photo: M. Gunawardene*)

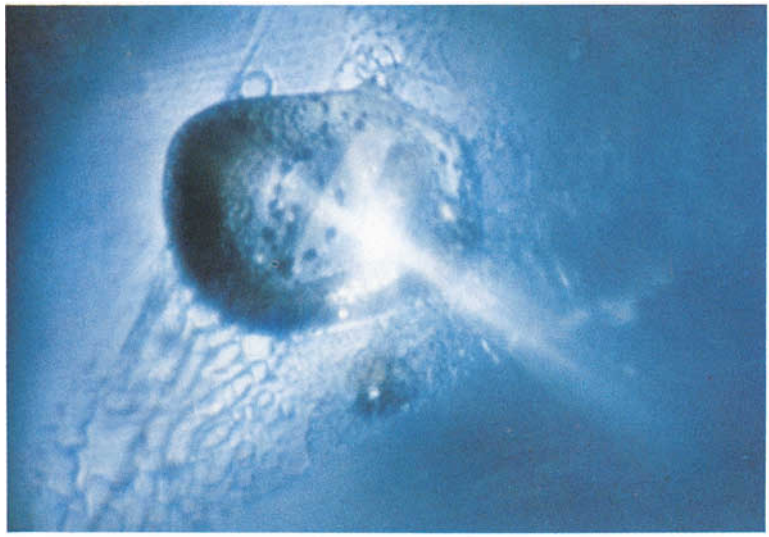

Figure 7. Intruded submetallic appearance of pyrrhotite ($Fe_{1-n}S$) crystals. 80 × .
(*photo: M. Gunawardene*)

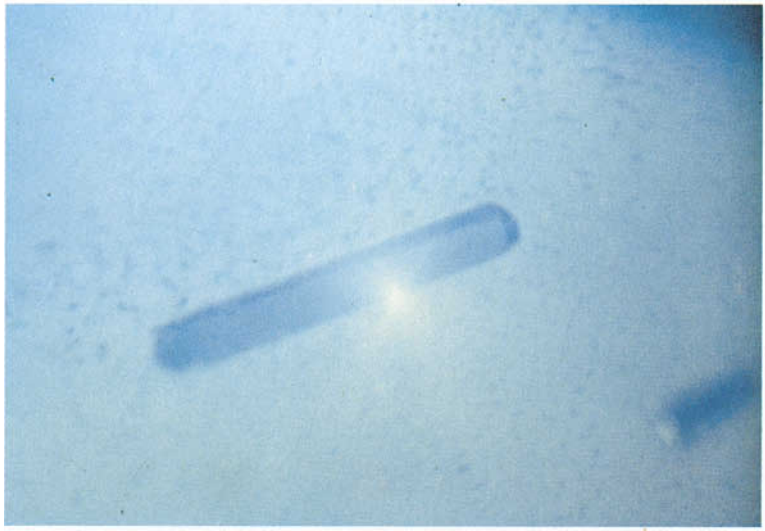

Figure 8. Typical prisms of hornblende seem to be a common mineral inclusion in these sapphires. 40 ×.
(*photo: M. Gunawardene*)

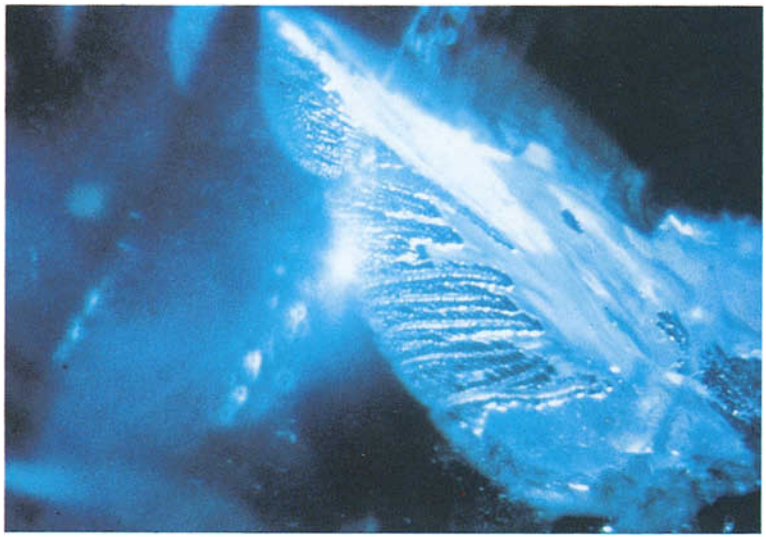

Figure 9. Naturally formed leaf-like healed feather in Kanchanaburi sapphire. 20 ×.
(*photo: M. Gunawardene*)

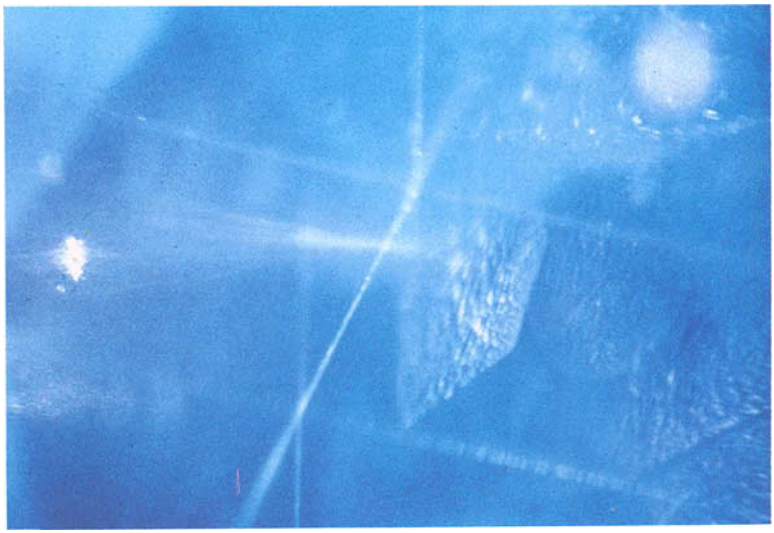

Figure 10. Needle-like structures of dislocation directions are frequently seen in sapphires from this locality. 25 ×. (*photo: M. Gunawardene*)

without the typical rutile orientation as in sapphires from Sri Lanka. The stones studied indicated the presence of fine stubby rutiles similar to those seen in blue sapphires from Burma as described by Gübelin (1974). The characteristic polysynthetic twin planes, which are usually present in corundums from Thailand (other than Kanchanaburi), Cambodia, Australia and E. Africa, were observed also in this investigation of sapphires from Kanchanaburi.

CONCLUSION

The past military activities in Cambodia reduced the production of blue sapphires in the famous gemfield Pailin. This stimulated the mines in the Kanchanaburi area to market their gemmy material in the Thai gem trade. However, the decrease of the military forces in Cambodia has effected the blue sapphire market of this region during the last few years: and the small basaltic rock area comprises only a limited number of gem quality sapphire deposits and fruitful production has become less in the trade now than before.

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HYDROTHERMAL GROWTH: THE FIRST HISTORICAL ACHIEVEMENT BY GIORGIO SPEZIA ON QUARTZ

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ABSTRACT

One of the two original bombs devised and employed by Giorgio Spezia, at the beginning of this century, is kept at the Museum of the Mineralogy Institute of Turin University. It is here described and illustrated with several photographs. An account is given of the technique, with comments on the first results by Spezia. The conclusions are contained, in practice, in an interesting letter dated in 1948, from the United States of America, reproduced at the end of the article.

INTRODUCTION

Several methods for growing artificial crystals are named after their inventors. A typical example, well known in gemmology, is that of the Verneuil corundums, which are in fact obtained using the special furnace invented by Professor Auguste Verneuil at the end of the last century and reported for the first time in 1902.[1] A similar origin can be traced for the names of other methods: Czochralski (1918), Bridgman (1925), Kyropoulos (1926), etc.[2]

Nonetheless, one of the growth methods most widely employed, not only for jewellery but chiefly for electronics, is not named after the inventor, but after the growth process on which it is founded. Actually, the reason why the *hydrothermal method* is not known as the *Spezia method* may be confidently attributed to the fact that it is not alternative to and different from the natural process, like many others, but just the result of the laboratory reproduction of natural genetic conditions.

Nowadays we increasingly hear about gems grown by hydrothermal synthesis. Although the working principle of the method is generally known, I think a short illustration of it to be worthwhile as an introduction to the main subject of this paper.

The principle is that of increasing the solubility in aqueous solutions of substances nearly insoluble under room conditions by an adequate increase of temperature and pressure.

The vessel for the hydrothermal synthesis is a sort of autoclave (Figure 1), nicknamed 'bomb', which consists essentially of a long

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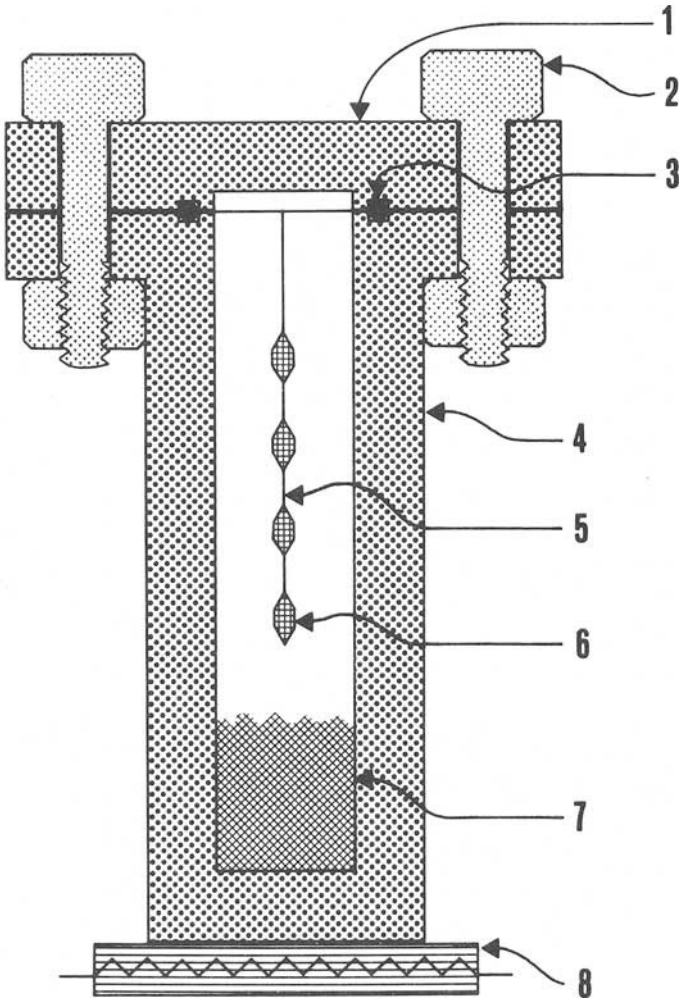

Fig. 1. Scheme of the apparatus for hydrothermal growth: 1, lid; 2, bolt; 3, gasket; 4, vessel body; 5, noble metal wire; 6, seed; 7, nutrient; 8, heating element.

cylindrical steel body, thick walled, provided with a hermetical sealing resistant to the high pressures and relatively high temperatures. The bomb is externally heated by an electric resistance. It is charged with an amount of fragments or powder of the substance to be crystallized (or of reagents to yield the wanted

crystals) called *nutrient,* plus a water solution of other compounds easily soluble under room conditions. Such compounds, e.g. potassium hydroxide, sodium carbonate, sodium or lithium chloride, etc., facilitate the dissolution of the nutrient, and therefore they are called *mineralizers* according to their function.

The solution expands during the bomb heating (approaching the vapour phase): a hydrostatic pressure is generated in this way; the higher the temperature and the initial per cent volume taken by the solution, the higher the final pressure.

With the heating element in the lower part of the vessel (Figure 1), as is now common practice, the working scheme is as follows:
(1) because of the temperature and pressure generated by the heating (according to the choice and needs of the operator) part of the nutrient dissolves and, therefore, a *solution* originates inside the bomb;
(2) the temperature difference between the lower zone (hotter, since nearer to the heater) and the upper one originates *convective streams* in the solution (movements from the bottom to the top of the hotter and less dense solution and, counterwise, movements from the top to the bottom of the colder and denser solution).

The solution can keep a certain amount of nutrient as solute which depends on the fixed values of temperature and pressure (*equilibrium values* corresponding to the *saturation*). By lowering the temperature and maintaining the initial pressure, this equilibrium no longer holds: the solution cannot retain the previous amount of solute (this new condition corresponds to a *supersaturated* solution). A well determined quantity of solute must necessarily be released (it *precipitates*) in order to obtain a new equilibrium.

In the common practice, as mentioned before, the solution moves up from the bottom side of the vessel; by cooling in the upper side it becomes supersaturated.

Owing to the simultaneous action of the two effects quoted above at (1) and (2), a steady flow takes place: the ascending solution separates some *precipitate* in the upper part of the bomb, whilst when descending to the bottom it does 'reload' with solute so that the cycle can be continued. The solute fraction precipitating from the solution during the ascension, deposits upon small crystal *seeds* hung inside the bomb at preselected heights. The seed size increases so generating the artificial crystals.

Corrosive effects by the solution at high temperature and pressure are avoided either by lining the inner walls of the bomb with inert materials (e.g. silver, gold, platinum), or by making a sealed capsule into which crystals grow and by filling the interspace between the capsule and inner walls of the bomb with distilled (virtually inert) water.

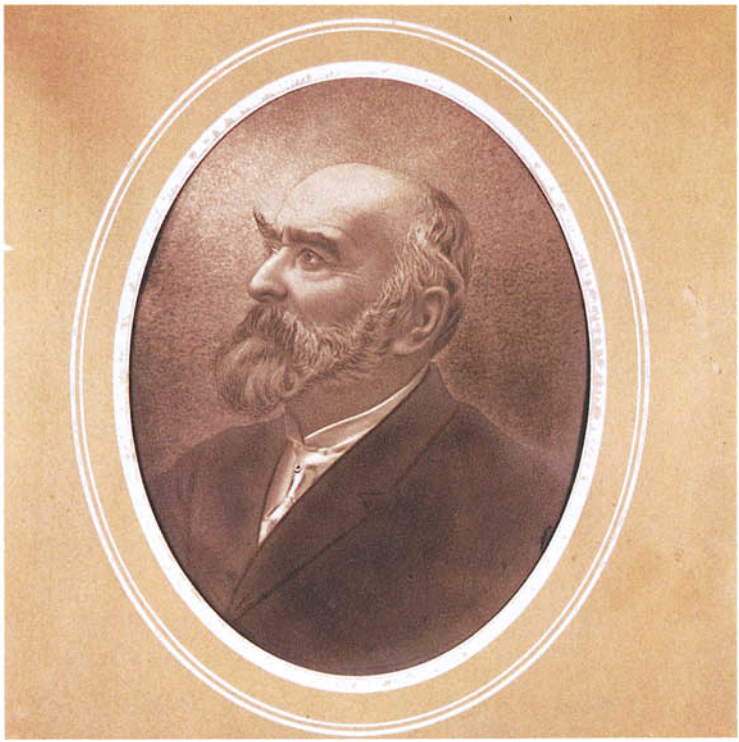

Fig. 2. Giorgio Spezia (1842-1912).

DESCRIPTION OF SPEZIA'S APPARATUS

Whilst many people know the fundamentals of the hydrothermal method for growing crystals, only a few know that it was devised, as mentioned above, by Professor Giorgio Spezia (1842-1912) (Figure 2) at the beginning of this century (1905), when he was the head of the Istituto di Mineralogia dell' Università di

Fig. 3. One of the two original apparatuses devised and used by Giorgio Spezia. (Overall height: 500 mm).

SPEZIA G. Contribuzioni di geologia chimica

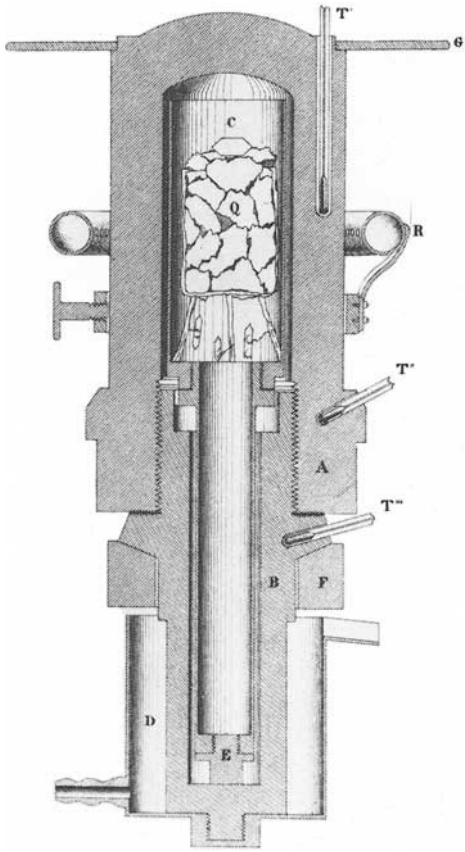

Fig. 4. Diagram of Spezia's apparatus (reproduced from the original paper (Spezia, 1905)).

Torino (Italy), which now bears his name. Finally, very few know that one of the two instruments he used personally has been preserved in its original assemblage in the Museum annexed to the Istituto (Figure 3).

Spezia's bomb (he never used this nickname) was not built by a cylinder and tight cover as today's bombs, but by two steel halves

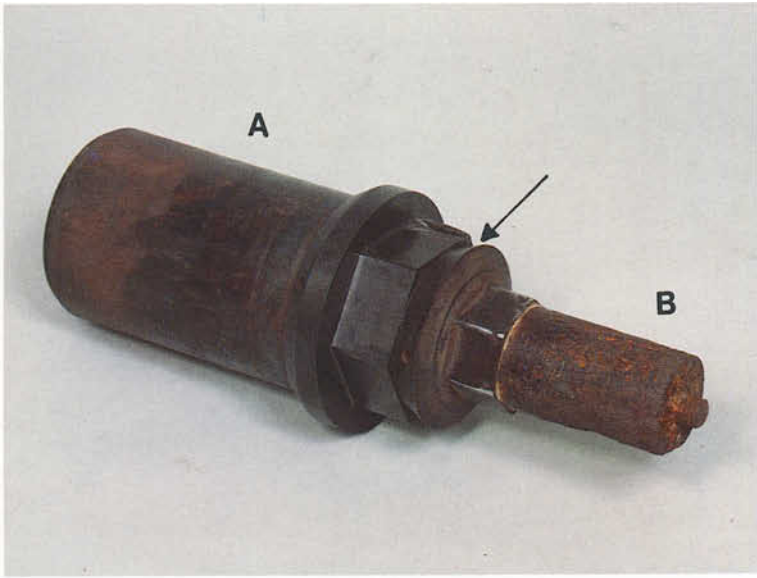

(a)

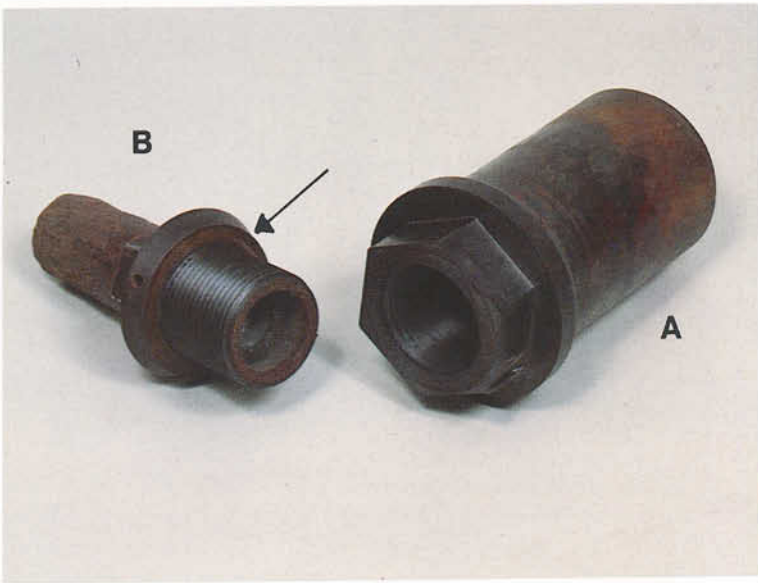

(b)

Fig. 5. The two halves of Spezia's apparatus body. The arrow points at the silver gasket. (a) Halves screwed together. Note part (B) corroded and made rusty by the cooling water circulation. (Length: 380 mm; ext. diam. of the upper part: 107 mm). (b) Halves unscrewed.

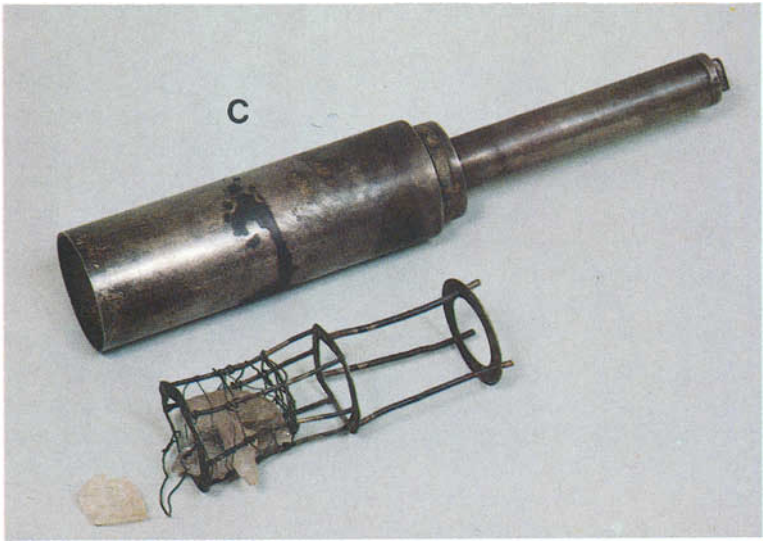

Fig. 6. Top. The silvered copper container (C). (Length 313 mm; external larger diameter 54 mm).
Bottom. The silver basket, to be placed inside (C), containing quartz fragments used as nutrient. (Length 141 mm; diameter 48.5 mm).

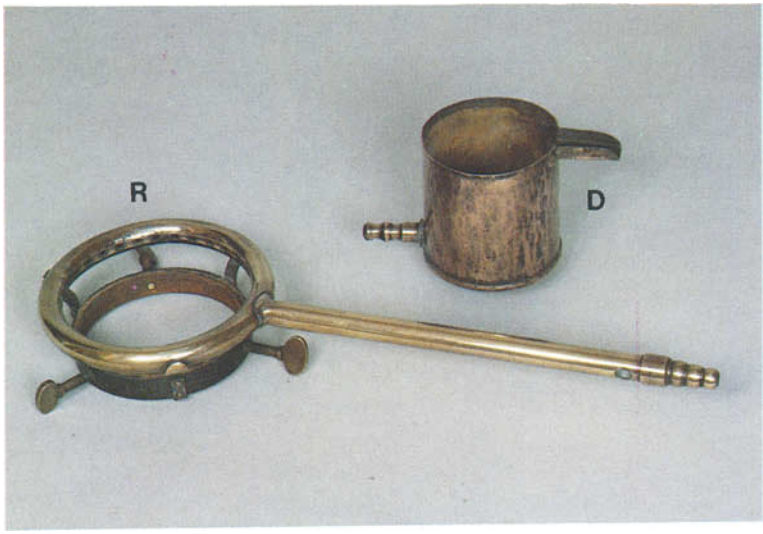

Fig. 7. Top. The muff (D) (to be screwed at the lower end of the bomb body) for the circulation of the cooling water. (Height 110 mm; diameter 92 mm).
Bottom. Gas annular burner (R) mounted on crown locking with three wing-screws. Note the holes for the flame outlet in the inner surface of the ring. (Length 453 mm; external diameter 155 mm).

(A) and (B) screwed one into the other, as shown in Figures 4 and 5, the first of them taken from Spezia's paper.[3]

Inside both halves the long container (C) was placed (Figures 4, 6), made with silvered copper. Apropos of this container (that, oddly enough, was left *open* at the upper end) Spezia wrote: '. . . I employed silvered copper because from a different experiment, having placed in a copper container vitreous sodium silicate plus distilled water, keeping the whole at high temperature for a few days, I obtained crystalline quartz aggregations with copper inclusions . . .'. [3, pp.256-7]

Spezia used, as heater, an annular gas burner (R) (Figures 3, 4, 7) with small holes in the inner surface of the ring, placed at about half the height of the upper half of the bomb. The lower part of the assemblage was cooled by water circulating in the muff (D) (Figures 3, 4, 7); T′, T″, T‴ (Figures 3, 4) are mercury thermometers to check the temperature during the experiments.

A tight closing between parts (A) and (B) was secured by a silver gasket placed just above T‴ (Figures 4, 5); the two parts show an external hexagonal section to allow locking with appropriate spanners. Thermometer T′ was thermally insulated from (R) with an asbestos circular sector placed at (G) (Figures 3, 4).

Spezia himself complains that screwing of the two halves of the bomb 'presents the drawback of large resistance when having to open the apparatus when it works for a long time: therefore it would be better that the two parts were tied together by some projecting tongues screw tightened'. [3, p.258] A kind of closure (by means of many screws) similar to that here suggested is now adopted for a certain kind of bomb of large size.

Spezia had two identical instruments manufactured: [4, p.159] both were supported by a ring (F) at the level of the hexagonal section (B); in one case the ring (F) was linked to a walled bar, in the other case it rested on a four-legged support. The second apparatus is that still kept in the Mineralogical Museum of Turin University (Figure 3).

For the growth runs Spezia placed in the upper part of the cylinder (C), astride the zone in contact with the flame, a silver basket (Q) (Figure 6b) filled with fragments of natural quartz; the seeds destined to capture the solute fraction from supersaturated solution were placed in a lower place.

From the above description a peculiarity results, both of scientific and historical interest. Spezia, for the 'transport' of the solute from the dissolution to the crystallization zone, did not exploit the convection effect as it is commonly done nowadays.

In point of fact in Spezia's apparatus dissolution and deposition zones were *reversed* because of the placement in the upper part of the heating element and in the lower part of the cooling element.

In this device natural convection of solute does not occur. Nevertheless, the crystallization does. This can be done by solute diffusion only. In fact, when in a given volume of solution the solute concentration is not homogeneous, the solute particles propagate from the higher concentration zones to the lower ones. With this method the growth rate of the crystals is much lower but more regular.

FIRST RESULTS BY SPEZIA

For his first run, that lasted six months, Spezia employed a solution of sodium metasilicate octahydrate ($Na_2SiO_3.8H_2O$) dissolved in water so as to obtain a 2% solution of Na_2SiO_3. The average temperatures over the whole run time were: 338 °C at T′, 221 °C at T″, 164 °C at T‴: '. . . Therefore, assuming that 338 °C was the maximum temperature, a uniform pressure of 150 atmospheres must have taken place in the whole apparatus afforded by the water vapour pressure of the aqueous solution at this temperature . . .'. [3, p.259]

Spezia could note first of all a deep corrosion of the quartz fragments placed as nutrient strictly astride the heated zone, whilst the fragments below appeared cemented one to the other and crystal faces developed only where the deposition was not hindered.

In his first paper, Spezia describes, reproducing the two photographs (Figure 8), 'two fragments removed from the little basket after cutting the silver thread imprisoned by them'. [3, p.260] Unfortunately, only one of two samples has been recovered up to now; it is shown in Figure 8c.

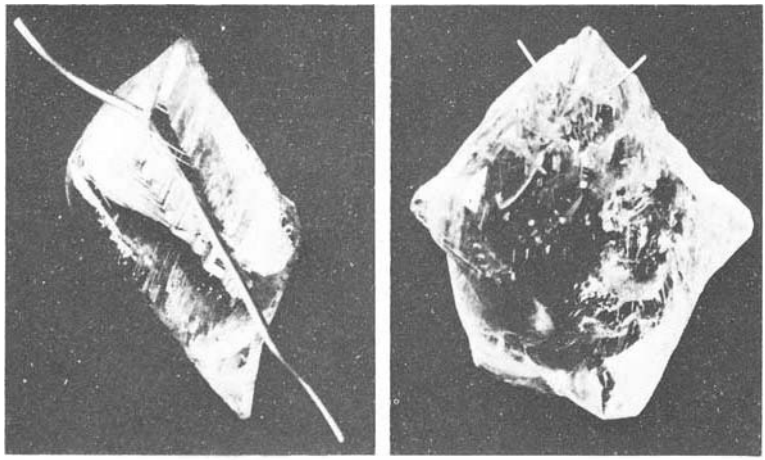

(a) (b)

(c)

Fig. 8. Fragments removed by Spezia from the basket after the first run.
(a) & (b) The silver threads of the basket imprisoned during artificial growth are clearly visible (reproduced from Spezia's original paper (Spezia, 1905)).
(c) Colour picture of the fragment shown in (a). Note the thread groove visible with difficulty in (a). (Diagonal 24.1 mm).

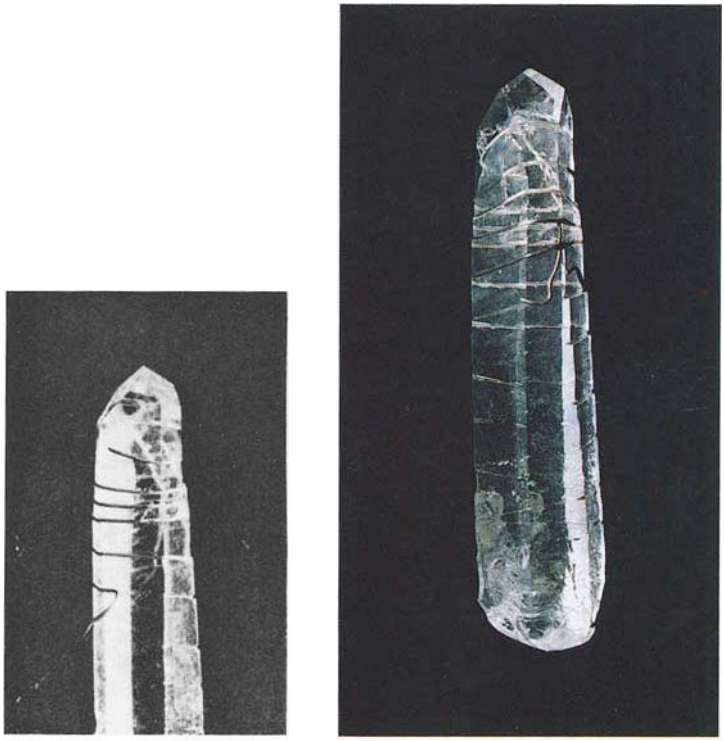

(a) (b)

Fig. 9. Quartz crystal with a thin synthetic layer at the top.
(a) Picture reproduced from Spezia's original paper (Spezia, 1906).
(b) Whole crystal in colour. Note the base partially dissolved and the silver thread caught by synthetic layer, near the sound upper apex. (Length 47 mm).

One of the three crystals placed as seeds below the basket '. . . showed a growth of quartz with partial inclusion of the wire . . .' (3, p.260)

With regard to this point, Spezia is probably right in deeming that the distance of the seeds from the dissolution zone was not very appropriate in order to have a large deposit.

Better results were obtained from a new series of runs.[4] A quartz crystal from Dauphiné (France) with hexagonal habit, about 4.5 cm long and 1.1 cm in section, broken at one end, was placed in the bomb with the broken end in the 'dissolution milieu' (to report Spezia's expression) and the sound apex inside the 'deposition milieu'. After 100 days, employing the same kind of solution and

under conditions similar to those of the first experiment, the crystal appeared as in Figure 9. Three other squat prisms cut from different crystals had grown as shown in Figure 11. On illustrating his results, Spezia reports: '. . . I also looked for inclusions and noticed them in the long crystal subjected to growth. They are in the thin growth layer of the prism faces; they are liquid inclusions with gas bubble, and are large; . . .'. [4, p.162] The inclusions are in fact shown in Figure 10.

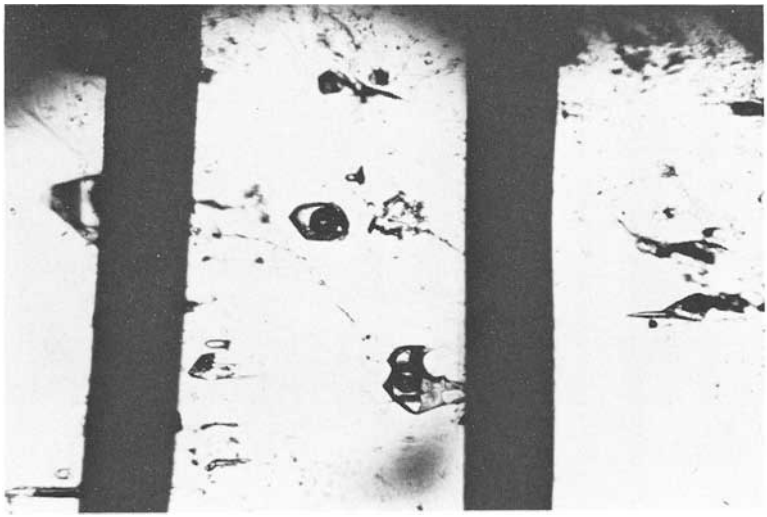

Fig. 10. Two-phase inclusions in the synthetic layer of the crystal in Figure 9. The two nearly parallel dark bands are the silver thread shadows. (Transmitted light, 40 ×).

LAST REPORTED RESULTS

In the last paper[5] on the hydrothermal growth of quartz, Spezia (1909) gave the results about further experiments carried out with his devices. For one of the runs he employed a different water solution: 12.7% in NaCl and 1.9% in Na_2SiO_3.

'The quartz preparation placed in the deposition milieu consisted of hexagonal prisms made by cuts normal to the principal symmetry axis of elongated quartz crystals as can be understood from figure' [5, p.96] (see Figure 12a).

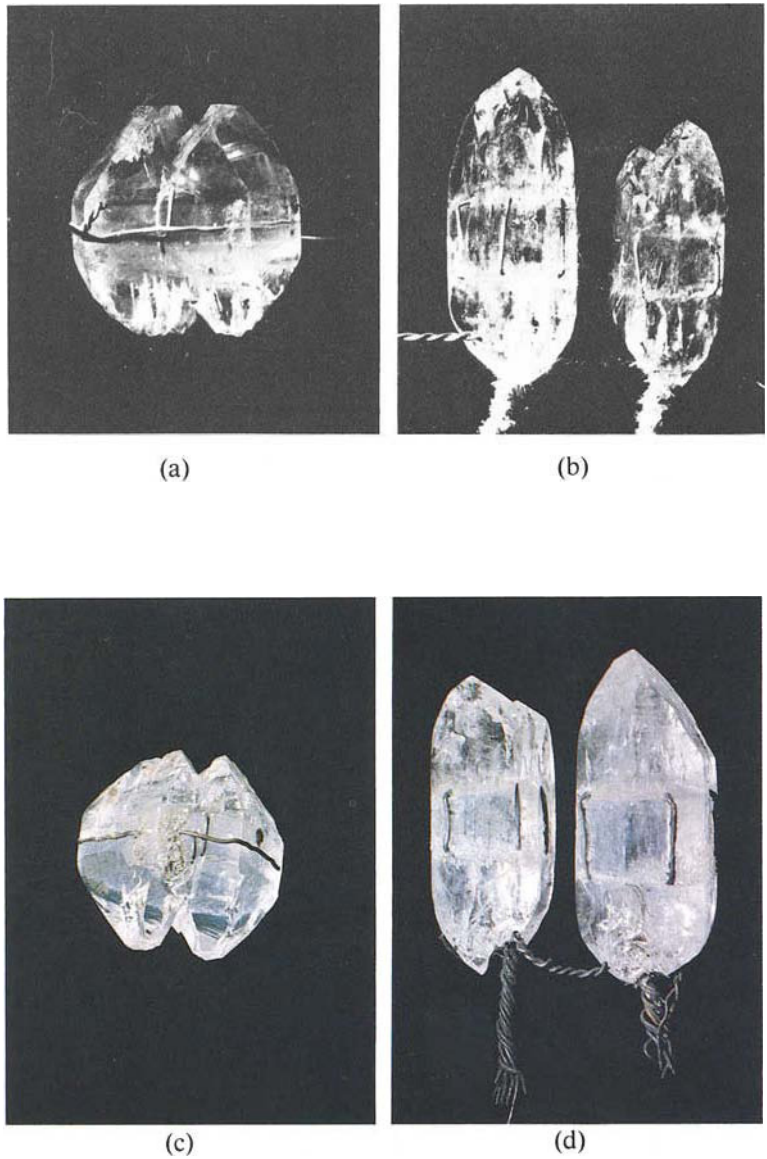

Fig. 11. Hydrothermal growth on hexagonal prisms of quartz cut before the run. (a) Print from original glass plate negative used by Spezia (Spezia, 1906). (Height 16.2 mm). (b) Picture reproduced from Spezia's original paper (Spezia, 1906). (Left: Length 25.4 mm. Right: Length 22.8 mm). (c) & (d) Colour pictures of crystals in (a) and (b). (Note: in crystals of (a) and (c) the silver thread stimulated parallel growth with doubling of both apexes).

This experiment was carried on for five months and at the end Spezia obtained the crystals of Figure 12b.

By another experiment, [5, pp.98-9] again five months long, employing a water solution 11.33% in NaCl and 1.24% in Na_2SiO_3, Spezia was able to show that the growth rate was greater on those surfaces perpendicular to the flow of the SiO_2 bearing solution. In fact he cut two nearly equal seeds from the same natural crystal: the one placed with the artificial basal faces orthogonal to the flow, showed a gain of 96.88% in weight, the one with the basal planes parallel to the flow, during the same experiment and placed at the same height as the former one, increased only by 78.65%. Besides, with this experiment, Spezia obtained further evidence of an effect already noticed: quartz grows more rapidly along its triad axis than along other directions, at least under the experimental conditions used by him.

From this experiment Spezia also obtained an impressive growth of two broken terminations of a crystal from Traversella Mine (near Turin), twinned according to the Japan law. Figure 13 shows the crystal before and after the run. The more impressive aspect of this growth is that the artificially grown sectors appear clearer and finer than the seed. Spezia maintains: 'From these experiments it follows that on adding sodium chloride to the sodium silicate solution, one obtains much clearer crystals'. [5, p.101]

In this experiment Spezia had also placed in the deposition zone a small specimen of ferruginous quartz (probably from Compostella, Spain) '. . . with a perfect hexagonal bipyramid . . .'. [5, p.102] After the run the crystal showed a growth of three faces of only one of the rhombohedra, whilst the transparent deposit of artificially grown quartz allowed one to see the whole of the two rhombohedra (six faces) simulating one end of the 'bipyramid'. Unfortunately, this crystal was not preserved till now; nonetheless Figure 14 shows another ferruginous quartz specimen with one apex of the 'bipyramid' intact, whilst the opposite one was purposely cut. The deposition took place on both ends. This result was one of several not published by Spezia.

Actually, at Turin Museum there is other material left by Spezia that bears witness to the large amount of research carried out by him (Figure 15).

Unfortunately, nobody in Italy after his death (1912) continued his pioneering work. It was only during World War II

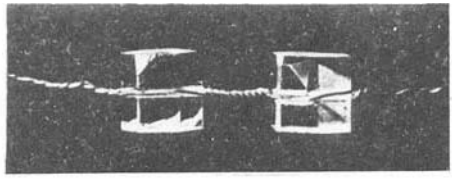

(a)

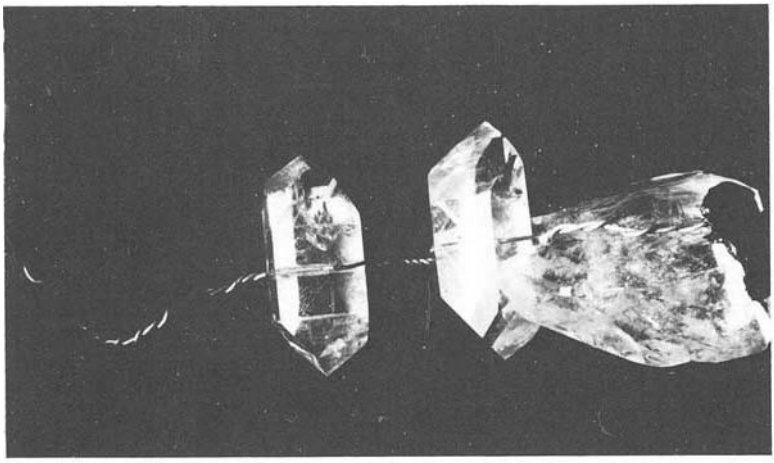

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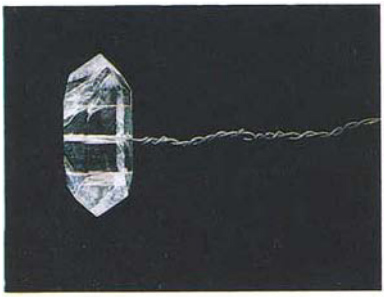

(c)

(d)

Fig. 12. (a) Small hexagonal prismatic seeds obtained by cutting quartz crystals (reproduced from Spezia's original paper (Spezia, 1909)). (b) Artificial quartz growth on seeds shown in (a). A nutrient fragment was dropped from dissolution milieu and joined to the crystal on the right; its surface was being covered by many small face planes. (Print from original glass plate negative used by Spezia (Spezia, 1909)). (Left: 15.8 mm in length. Right: 17.4 mm in length). (c) & (d) Colour pictures of crystals shown in (b). The silver thread had been broken in the course of time.

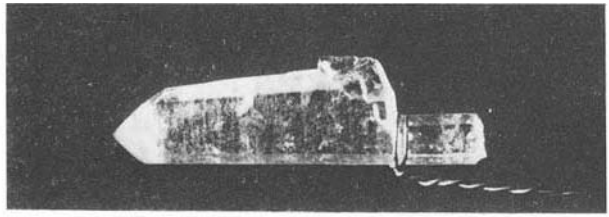

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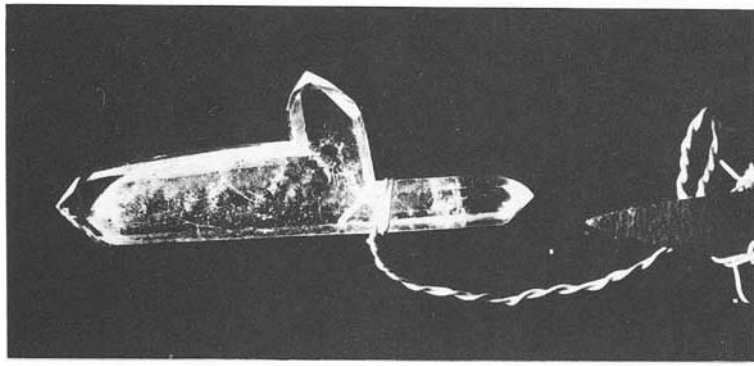

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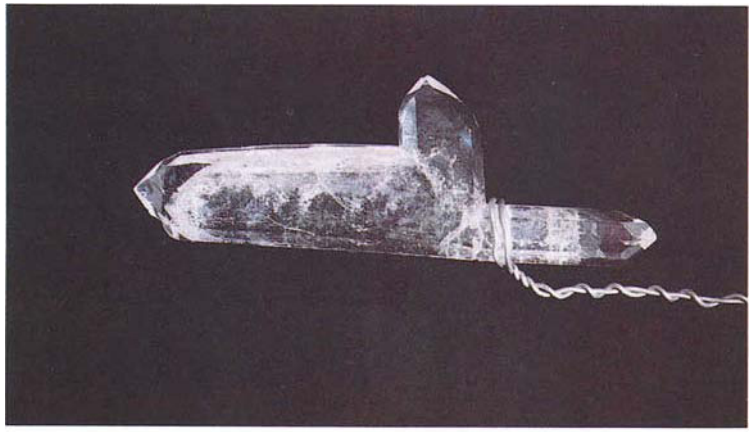

(c)

Fig. 13. (a) Quartz crystal twinned after Japan law (from Traversella Mine) before the hydrothermal growth. (Picture reproduced from Spezia's original paper (Spezia, 1909)). (b) The same as in (a) after the run. Note the artificial growth clearer than the seed, and more developed along the main symmetry axis. (Print from original glass plate negative used by Spezia (Spezia, 1909)). (c) Colour picture of the crystal shown in (b). (Length 38.7 mm).

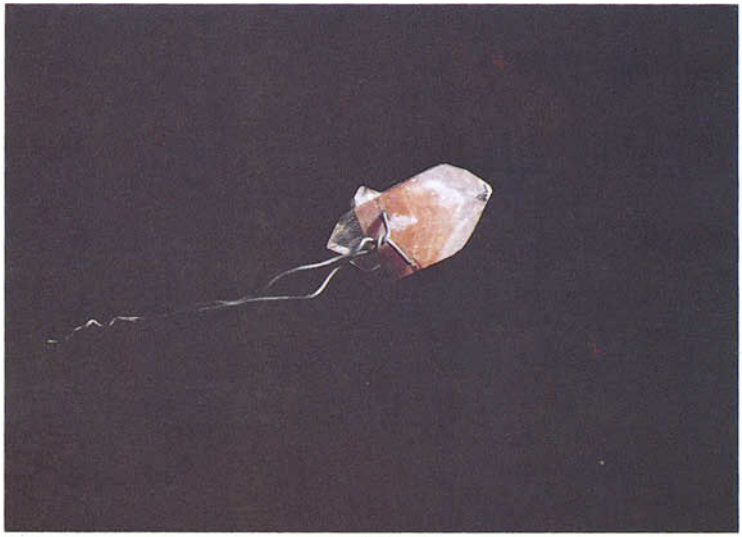

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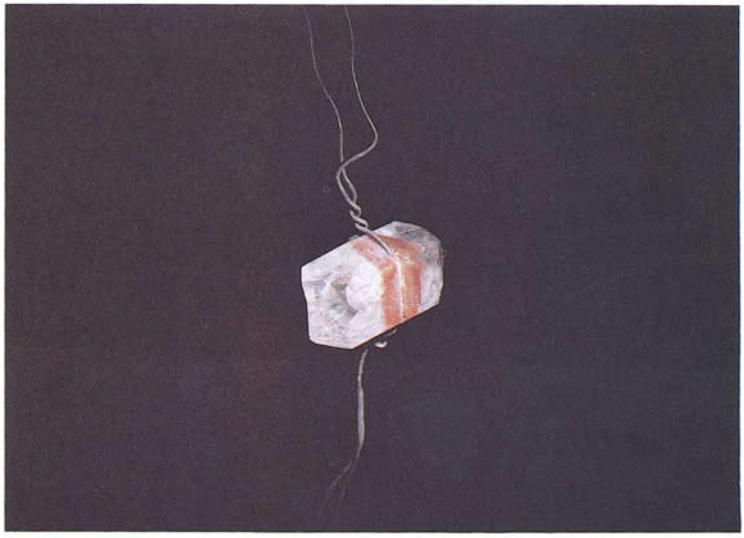

(b)

Fig. 14. (a) Hydrothermal growth of colourless quartz on ferruginous seed.
(b) The parallel growth on the artificial face made by sawing is clearly visible. (Length 13.7 mm).

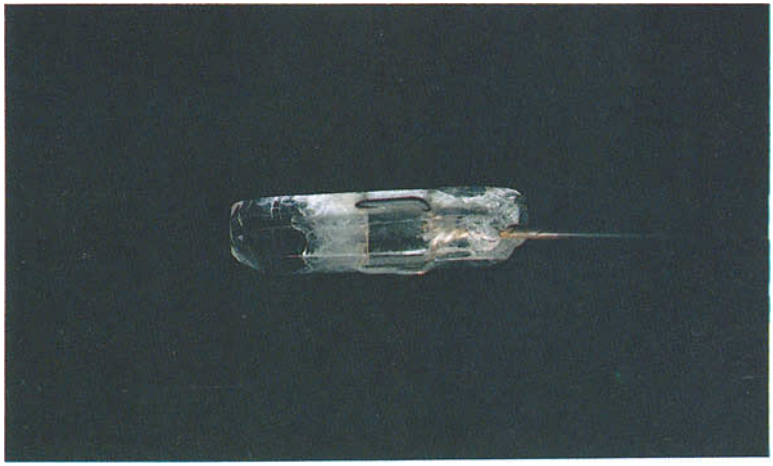

Fig. 15. One of the several results not published by Spezia. Note: the wire is made of copper, and the synthetic growth is clearer than the seed and much more developed along the main symmetry axis of the crystal. (Length 24 mm).

(1943) that Richard Nacken in Germany restarted the investigation on the hydrothermal growth of quartz, which was a raw material of vital importance for the production of oscillator devices employed in the field of radio-communications, since the traditional Brazilian sources were then barred to Germany. [6, p.393] It seems that Nacken had not time enough to start a large scale production, but he succeeded in having a pilot plant working before the end of the War.

N. and W. A. Wooster [7, p.791] in 1946, using an apparatus quite similar to Spezia's demonstrated the reproducibility of his results, thus confirming the scientific and practical validity of his method.

In 1948 Danforth R. Hale, of Brush Development Company, Cleveland (Ohio), carried out new experiments on the hydrothermal growth of quartz exploiting Spezia's and Wooster & Wooster's experiences. [6, p.393-4]

CONCLUSIONS

In 1948 the letter reproduced in Figure 16 was received at the Istituto di Mineralogia, Turin University.

THE BRUSH DEVELOPMENT COMPANY

TELEPHONE ENDICOTT 3315

3405 PERKINS AVENUE
CLEVELAND 14, OHIO

CABLE ADDRESS BRUDEV CLEVELAND

May 20, 1948

Dipartimento di Mineralogia
Universita di Torino
Torino, Italy

Attenzione di Professore Giorgio Spezia

Dear Sir:

You have the honor to be the first to grow synthetic quartz crystals of a size that can be held in the hand and examined with the unaided eye. I refer to your papers in the Atti della reale accademia delle scienze di Torino about 1904 - 1908.

I would like to acknowledge my indebtedness to you not only for information and suggestions, but also for inspiration. With the relatively simple facilities at your disposal you assisted in the creation of crystals of a size not heralded by any previous experiment nor by any experimenter in the thirty-five or forty years thereafter; and in closing up an opaque autoclave for a six-month period, yours was a patience well rewarded.

I enclose a reprint of a short article on growing quartz, and although I feel that we can show a high rate of growth over a short period, we are still far from being able to control the growth conditions as we wish to.

(2)

I am pleased that this scientific work on quartz adds emphasis to the unity of peoples through the contribution of several nationalities, and as such may add support to the ideals of the United Nations Organization.

Respectfully yours,

THE BRUSH DEVELOPMENT CO.

Danforth R. Hale
Crystal Research Dept.

DRH/fp

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Fig.16. Letter of 20th May 1948 from Danforth R. Hale.

ACKNOWLEDGEMENTS

The author is greatly indebted to Dino Aquilano (Professor at Mineralogy Institute of the University, Turin) for helpful discussions and valuable criticisms, and to Mariano Calleri (Professor at Mineralogy Institute of the University, Turin) for the careful translation.

Note: this article is a new and partly rewritten version of a previous paper, 'Giorgio Spezia, il padre della sintesi idrotermale'* (*La Gemmologia,* 1975, **1**, 1, 9-24).

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[*Manuscript received 27th July, 1983.*]

*'Giorgio Spezia, the father of hydrothermal synthesis.'

THE ALPHA-TEST GEMSTONE IDENTIFIER—A TEST REPORT

By PETER READ, C.Eng., F.G.A.

The first thermal conductivity gem tester developed specifically to identify not only diamond and its simulants but also a range of other gemstones was the Gemtek Gemmologist. This instrument, like the simpler thermal testers for diamond identification, employed a heated probe tip whose temperature was monitored by the associated control box electronics. In the case of the Gemtek Gemmologist, however, a more sophisticated measuring technique was necessary to detect the much smaller differences in thermal conductivities (or thermal inertias[1]) between other materials such as corundum (at 40 W/m/°C, the next highest in thermal conductivity to diamond's 1000-2600 W/m/°C) and glass (around 1.0 W/m/°C). This technique uses two pre-set temperature sensing levels. When the heated tip of the probe is applied to the surface of the gem, its temperature begins to fall. When it reaches the first predetermined level, the output of an oscillator is fed into a digital counter/display unit. As the temperature of the probe tip continues to fall, it reaches the second predetermined level and this switches off the output of the oscillator.

The number displayed on the digital display unit is a measure of the time taken for the probe tip to fall between these two predetermined temperature levels, and is used as a direct indicator of the thermal conductivity of the stone under test (the lower the reading, the greater the gem's ability to conduct heat away from the probe).

Because of the very small differences in thermal conductivities between the non-diamond gems (1.0 to 40.0 for the complete range), it is necessary to impose several operating constraints in order to produce repeatable results. The instrument has to be used in a draught-free environment having an ambient temperature between 18 and 25 °C (64 and 77 °F), the gem under test has first to

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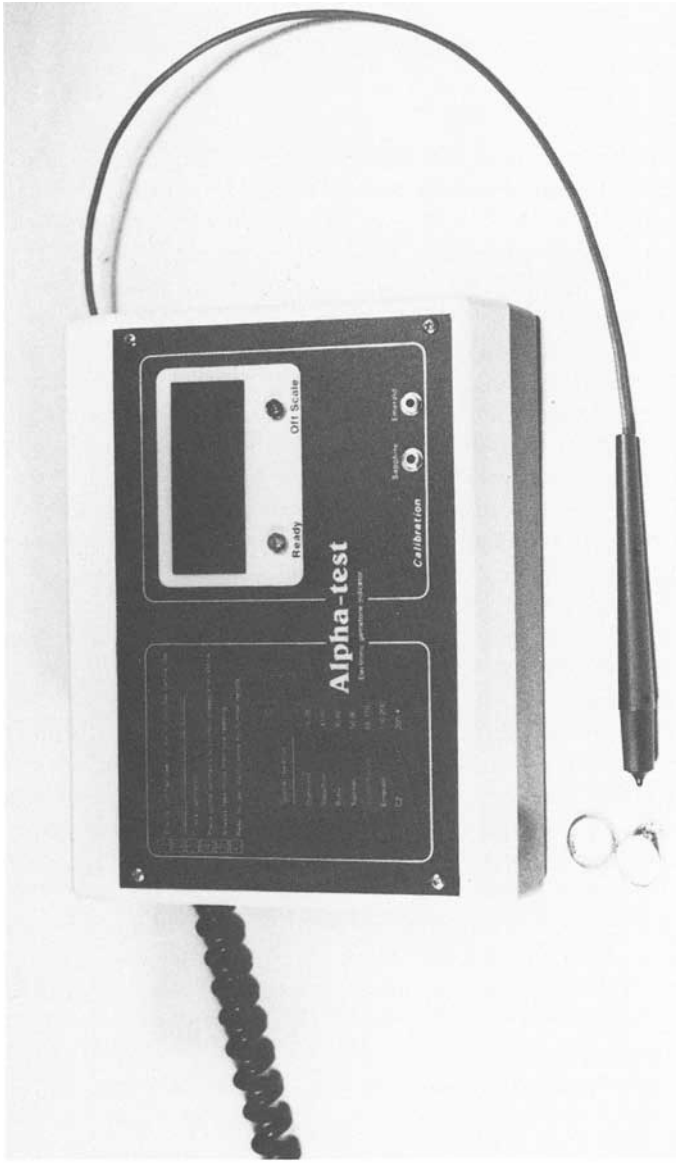

FIG. 1. The Alpha-test electronic gemstone identifier

be warmed up to body temperature, and the probe tip must be applied at right-angles to the test surface with a reasonably precise pressure. Even then, the usefulness of the instrument is limited to those gemstones whose thermal conductivity is not overlapped by that of other gems.

Following the introduction of the Gemmologist, a new instrument has been developed which is also able to identify a range of gemstones in addition to diamond and its simulants. This instrument is called the Alpha-test (see Figure 1), and uses a similar measuring technique to that employed in the Gemmologist. It also has the same operating constraints, but unlike the Gemmologist is relatively simple to use. With the Gemmologist it was necessary to press a 'Reset' button before each test in order to zero the display, and if a 'Too Hot' lamp was illuminated the probe tip had to be manually cooled before use.

The Alpha-test automatically resets its counter display as soon as the probe is applied to a stone, and the temperature of its probe tip is thermostatically regulated. As with the Gemmologist, a 'Ready' lamp indicates that the probe tip temperature has reached its operating temperature. Rather than use a 4-digit display to indicate very low thermal conductivities, the Alpha-test's top reading is limited to 999, and an 'Off Scale' lamp lights when this figure is exceeded.

Two calibration pre-sets are provided on the instrument's front panel, one enabling sapphire to be used as a calibration reference, and the other for calibration against emerald. This method of two-point calibration ensures reasonable accuracy across the measuring range.

One disadvantage which the Alpha-test has in comparison with the Gemmologist is that its probe is permanently connected to the control box instead of via a connecting plug. This could present a problem if the probe is damaged, as the complete unit would have to be returned for service.

During tests on the new instrument, a range of gemstone specimens were checked after first calibrating the unit on a sapphire and a natural emerald. Each stone was tested ten times, and the table below gives the average of these readings. The listed spread between each set of ten readings was quite small for high thermal conductivity stones (e.g. 4 to 10 for diamond, corundum, high zircon, topaz and spinel). The spread became progressively larger

for stones of lower thermal conductivities (e.g. 15 and 100 for emerald and low zircon). This spread of readings is simply an indication of the repeatability of measurement using the same stone. Different stones of the same species would give a wider range of average readings as indicated on the instrument's panel and in the operating manual.

TABLE OF TEST READINGS

GEM	Diamond	Corundum	Topaz	High Zircon	Natural Spinel	Synthetic Spinel
Average of 10 readings	15.2	40.5	49.3	51.9	54.2	64.6
Spread of readings	4	5	9	9	10	10

GEM	Gilson Emerald	Andalusite	Natural Emerald	Garnet	Zoisite	Low Zircon	Cubic Zirconia
Average of 10 readings	75.8	84.4	150.5	161.0	207.4	427.0	200 to off scale
Spread of readings	15	20	30	80	60	100	—

As was mentioned in the test report on the Gemtek Gemmologist,[2] this type of instument is mainly of use for the identification of diamonds, diamond simulants, and very small non-diamond gems (particularly those which are mounted in such a way as to make it impossible to use either a refractometer or a reflectivity meter). With care, positive separation is possible between ruby and garnet; aquamarine, spinel and topaz; sapphire and tourmaline, and between natural and some flux-melt synthetic emeralds. Andalusite and zoisite also have quite distinctive readings. The readings for natural spinel are significantly different from those for synthetic spinel, and low zircon is dramatically

different to high zircon. Readings for topaz, high zircon and natural spinel are too close, however, to provide positive differentiation by this method.

The Alpha-test is distributed by Mann-Marketing (U.K.) Ltd., Goldfly House Annexe, Sarum Road, Winchester, Hants SO22 5QH.

REFERENCES

(1) Hoover, D. B. The Thermal Properties of Gemstones and their application to Thermal Probes. *J.Gemm.*, 1982, **XVIII** (3), 229-39.

(2) Read, P. G. The Gemtek Gemmologist—A Test Report. *J.Gemm.*, 1983, **XVIII** (7), 643-50.

[*Manuscript received 17th March, 1984*]

GEMMOLOGICAL ABSTRACTS

ANDERSON (B. W.). *The fluid and the filter.* Lapidary J., **37,** 11, 1590-4, 1984.

Notes on the development and use of the liquids used in gem testing with reminiscences of early days at the Laboratory of the Diamond, Pearl and Precious Stone Trade Section of the London Chamber of Commerce. The piece concludes with some notes on the Chelsea colour filter. M.O'D.

BALDWIN (J. R.), VON KNORRING (O.). *Compositional range of Mn-garnet in zoned granitic pegmatites.* Canadian Mineralogist, **21,** 4, 683-8, 4 figs, 1983.

A correlation between the composition of some garnets and their occurrence in zones in large complex granitic pegmatites has been established. Mn-rich garnet is found in the inner and replacement zones, garnet with Mn and Fe in intermediate mineral assemblies and garnet with a greater iron than manganese content in the wall and contact zones. Pure spessartine is most likely to be found in replacement and quartz-rich core zones of pegmatites containing lithium minerals. M.O'D.

BANK (H.). (a) *Durchsichtiger Analcim aus Australien.* (Transparent analcime from Australia.) Z.Dt.Gemmol.Gess., **32,** 4, 204-5, 1983; (b) *Gelber und gelbbrauner Klinohumit aus Russland.* (Yellow and yellow-brown clinohumite from U.S.S.R.) Id., 206, 1983; (c) *Neue synthetische Rubine nach Lechleitner als Überzug auf natürlichen und synthetischen Rubinen sowie farblosen Korunden der Verneuilsynthese.* (New synthetic ruby with Lechleitner skin over natural and synthetic ruby, also over Verneuil synthetic corundum.) Id., 207, 1983.

(a) Transparent colourless analcime from Australia with RI of ε 1.486, ω 1.487. (b) Rough and cut yellow-brown stones from Russia were found to be clinohumite, RI 1.625-1.636, DR 0.024, SG 3.18. (c) New synthetic rubies with a Lechleitner skin-layer over natural and synthetic rubies, as well as over Veneuil colourless corundums. E.S.

BOSSHART (G.). *Ramaura—eine neue Rubinsynthese (erste Untersuchungsergebnisse).* (Ramaura—a new synthetic ruby (first test results).) Z.Dt.Gemmol.Ges., **32,** 4, 164-71, 7 figs (6 in colour), bibl., 1983.

The synthetic rubies are produced by Overland Gems, Ramaura Division, Los Angeles. Seven specimens were examined and found to be chromium-rich, intensely red; and there was also a chromium-poor, paler violet-red version. The first type shows flux veils and has the characteristic UV absorption behaviour of synthetic rubies. The second type has few inclusions, contains no platinum crystal platelets and absorbs UV radiation like a natural ruby. For the time being, this synthetic version can only be recognized by growth features consisting of acute, wedge-shaped colour zones and spindle shaped growth inhomogeneities. These new synthetics are not cloudy and show no unusual colours or dichroism. E.S.

BOSSHART (G.). *Cobalt glass as a lapis lazuli imitation.* Gems & Gemology, **XIX,** 4, 228-31, 4 figs (2 in colour), 1983.

A moulded bead necklace offered as "blue quartz from India" resembled fine lapis lazuli but was proved by absorption spectra and other tests to be a non-transparent cobalt glass. White inclusions of low-cristoballite gave necessary colour irregularities. Dendritic and radial inclusions were seen, completely different from lapis lazuli structure. No pyrite inclusions or bubbles or swirls were present. Macroscopic appearance was confusing. R.K.M.

BRACEWELL (H.), BROWN (G.). *Turquoise or chrysocolla from Jervois area, Northern Territory.* Aust. Gemmol., **15,** 6, 189-95, 10 figs in colour, 3 maps, 1984.

Turquoise (?) from Plenty River mine was investigated in detail and found to be chrysocolla-rich quartz. Colours blue to greenish-blue. Some cabochons examined were found to be reconstituted material bonded with plastic. Natural material resembles Eilat stone in appearance. R.K.M.

BREITER (K.), PASAVA (J.). *Agate from Horni Halze, Czechoslovakia.* Lapidary J., **37,** 11, 1556-7, 7 figs (6 in colour), 1984.

Horni Halze is north-west of Prague and close to the border with East Germany. Blue, red and ribbon agates are found. M.O'D.

BROWN (G.). *Fairfield variscite.* Wahroongai News, **18,** 3, 16-18, 1984.

A mineralogical and geological description of this little known gem, based on material from its classic location described in an American Mineralogist paper by Larsen (E. S.) in 1942. R.K.M.

BROWN (G.). *Inclusions in synthetic corundum by Chatham.* Aust. Gemmol., **15,** 5, 149-54, 8 figs in colour, 1984.

A careful study of inclusions to be found in Chatham flux-grown synthetic rubies and sapphires, with a list of those reported by other observers. R.K.M.

BROWN (G.). *Korite—a unique organic gem.* Aust Gemmol., **15,** 6, 206-8. 6 figs (4 in colour), 1984.

The iridescent ammonite material [now properly called 'ammolite'—see J.Gemm., 1983, XVIII, 6, 551] from south Alberta, Canada, is described and illustrated. R.K.M.

BROWN (G.). *Notes on the cause of colour in labradorite and moonstone.* Wahroongai News, **18,** 2, 19-23, 1984.

Writer disagrees with conventional explanation quoted by Webster and others. Suggests that paper by Ribbe (P. H.) on 'Exsolution textures and interference colours in feldspar' shows that iridescence in labradorite is due to relative thickness of stacked paired lamellae of alternating albite and anorthite, and that sheen in moonstone is due to Tyndall-scattering of incident light at albite crystallites, and not to interference. Reflections are blue when crystallites are smaller than the wavelength of incident light. [I question the statement that 'schiller is always bluish within an opaque whitish background'. Most gem 'blue' moonstones are in almost transparent material.] R.K.M.

BROWN (G.). *The Seward gemmological microscope.* Aust. Gemmol., **15,** 6, 196, 1 fig., 1984.

A description of a 1930 hand-held microscope. R.K.M.

BROWN (G.)., MENDIS (H.). *An unusual cultured pearl necklace.* Aust. Gemmol., **15,** 5, 155-7, 4 figs (1 in colour), 1984.

A large very baroque cultured pearl necklace x-rayed to reveal an exceptional collection of oddities. Largest pearl had a pear-shaped MOP bead centre which had been loosely wrapped in metal wire before thinly culturing. Some others contained more than one bead, or a bead and a large conchiolin-filled cavity. An interesting investigation. R.K.M.

BROWN (G.), SNOW (J.). *Bits and pieces.* Aust. Gemmol., **15,** 5, 158-9, 162-3, 10 figs, 1984

A report from the Instrument Evaluation Committee of the G.A.A. covering the Mark 2 Portalab, the Diamond and White Gem Constants Comparator (a rotating data disc), the Snow Pocket Polariscope, and the Gemtek Diamond Detector.

R.K.M.

BROWN (G.), SNOW (J.). *Inclusions in Biron synthetic emeralds.* Aust. Gemmol., **15,** 5, 167-71, 9 figs (1 in colour), 1984.

A study club report on the new Australian hydrothermal synthetic emerald from Perth, which examines production rejects to find identifying inclusions which seem to be eliminated from the cut stones. A patchy red fluorescence may be seen in cut specimens under strong lighting. R.K.M.

BROWN (G.), SNOW (J.), TAYLOR (B.). *National FF-393E Light Scope.* Aust. Gemmol., **15,** 6, 197-9, 4 figs, 1984.

A report on a modern pocket microscope with built-in light source. Magnification ×30. Found to be useful for flat surfaces but not for inclusions.

R.K.M.

BROWN (G.), WAINWRIGHT-SMITH (N.). *Experimental pearl radiography.* Aust Gemmol., **15,** 6, 182-8, 9 figs, 1984.

Macroradiography (×2) was achieved by distancing the pearl from the recording film. Since x-rays diverge from the point source an enlarged image was obtained and yielded greater detail than the normal pearl/film contact radiograph.

Another technique called tomography, using oblique x-ray beams, is said to eliminate obscuring factors and enhance detail. Explanation is confused by the wrong numbering of a diagram, but writers conclude that this complex technique does not greatly assist diagnosis of pearls. R.K.M.

CASSEDANNE (J. P.), SAUER (D. A.). *The Santa Terezinha de Goiás emerald deposit.* Gems & Gemology, **XX,** 1, 4-13, 10 figs in colour, 1984.

A well-illustrated account of new mines which are producing good quality emeralds in small sizes, SG 2.70, RI 1.580-1.588, DR 0.008, emerald filter—inert to pink, absorption normal, inclusions pyrite, chromite, talc and calcite. 'Average

yield is 11 carats of emerald per cubic meter.' 'It is accepted that 6 cubic meters yield about 1 kilogram.' One or other of these statements must be wrong. R.K.M.

CASSINELLI (C.). *Le pagina dei micromounts.* (Micromounts page.) Rivista Mineralogica Italiana, **7**, 4, 134-6, 6 figs in colour, 1983.
Among the minerals described is elbaite from Elba. M.O'D.

CHIKAYAMA(A.). (New gemstones.) J. Mineralog. Soc. Japan, **15**, 3, 163-8, 1981. (Japanese with English abstract.)
Gemmological properties and keys for identification of the new natural gemstones, which have been discovered or appeared in the gem market from 1945, are described briefly together with their histories of discovery. The minerals described are brazilianite, taaffeite, sinhalite, amblygonite, greened amethyst, ekanite, painite, tugtupite, trapiche emerald, jade-albite, grossular garnet, blue zoisite, red tourmaline, jeremejevite, transparent sodalite, bixbite, treated blue beryl, herderite, prosopite, ceruleite, charoite, transparent rhodochrosite, palygorskite, ammolite and sodalite. T.Y.

CLARE (S.). *What to facet—5.* Gems, **16**, 1, 12-13, 1984.
The technique of sawing pebbles is described. M.O'D.

COLLINS (A. T.). *Pitfalls in colour grading diamonds by machine.* Gems & Gemology, **XX**, 1, 14-21, 8 figs (1 in colour), 1984.
An expert assessment of colour grading by spectrophotometer which shows that these can give unreliable results because of fluorescence and of scattered reflections. This necessitates recourse to comparison with master stones by eye. Author shows that DGL method of assessing intensity of the 415 nm absorption line and the Eickhorst diamond photometer can both give false grades for brightly fluorescent diamonds. An important paper. R.K.M.

FRYER (C. W.), ed., CROWNINGSHIELD (R.), HURWIT (K. N.), KANE (R. E.). *Gem Trade Lab Notes.* Gems & Gemology, **XX**, 1, 45-50, 22 figs in colour, 1984.
Iridescent coatings on aquamarine and synthetic emerald; coral stained blue and plastic coated; diamond with large conical laser drillings and another with 'stepped' laser hole are illustrated and reported upon. An emerald showed white dendritic deposits of oil dried out by heat; haematite proved to be magnetic, possibly as a result of heating; jadeite offered as dyed in Japan proved to be natural in colour; a small dyed nephrite and several examples of hollow natural pearls are described and illustrated. A ruby 'crystal' fashioned from a flame-fusion synthetic had the 'habit' of beryl, and a new reddish-brown scapolite cat's-eye from Kenya is depicted and described. R.K.M

FRYER (C.), ed., CROWNINGSHIELD (R.), HURWIT (K. N.), KANE (R. E.). *Gem Trade Lab Notes.* Gems & Gemology, **XIX**, 4, 232-7, 22 figs in colour, 1983.
Sapphire with thin colour zone on one surface was thought to be heat-treated, not diffusion coloured; a 2.55 carat fine ruby had been badly fractured by heat treatment; C-Ox is trade name for green and blue forms of cubic zirconia, both

stones having strong and characteristic absorption spectra; all diamonds in a brooch fluoresced under long UV; a 4 carat diamond had pronounced fern-like white dendritic inclusions; a carved yellow/black grey/green jade-like ornament was found to be mainly serpentine; a sawn jade boulder was maw-sit-sit on one side and chloromelanite on the other; new Inamori synthetics are described; three-quarter blister pearls were found with bead completely enclosed but visible through the thin back; a ring pearl showed very marked erosion by body acids around each claw of the setting.

Reddish-brown quartz is thought to be heat-treated natural stone; an early 'Geneva' synthetic ruby is described; recently most yellow sapphires tested in New York Lab owed colour to Thai heat-treatment; a group of natural yellows are also discussed; rare cat's-eye zircon is also described. All are illustrated. R.K.M.

GIANNINI (W. F.), PENICK (D. A., Jr.). *Large gem topaz crystal discovery.* Virginia Minerals, **29**, 1, 1-3, 6 figs, 1 map, 1983.

A large, colourless, gem-quality topaz crystal was discovered in the dump of the Herbb no. 2 pegmatite in Powhatan County, Virginia. The virtually flawless crystal weighs 8.9 pounds and measures 10.9 × 3.5 inches. It is terminated by crystal faces at one end and by a cleavage plane at the other. Two small liquid inclusions are present. The deposit, explored and briefly worked in 1944, is approximately 40′ thick and 240′ long. Other minerals occurring there include quartz, beryl (crystals up to 300 pounds), albite (cleavelandite), tantalite-columbite, muscovite, spessartine, microcline (amazonite) and kaolinite (from altered feldspars). R.S.M.

GRANDIN DE L'EPREVIER (A.), ITO (J.). *Flux grown orthoenstatite by a multiple slow-cooling technique.* J. Crystal Growth, **64**, 411-12, 1983.

Large gem-quality enstatite $MgSiO_3$ has been grown with a lithium vanado-molybdate flux. Crystals up to 13 × 6 × 4 mm have been obtained. M.O'D.

GRAY (F. L.). *Engraved gems: a historical perspective.* Gems & Gemology, **XIX**, 4, 191-201, 12 figs (8 in colour), 1983.

An account of engraved gems from Egyptian times to the present day, when ultrasonic drills are being used to mass-produce cameos and intaglios, thus removing skill from this ancient art. R.K.M.

GUNAWARDENE (M.). *Über die synthetischen blauen und orangefarbenen Sapphire von Chatham.* (About the synthetic Chatham blue and orange-coloured sapphires.) Z.Dt.Gemmol.Ges., **32**, 4, 196-203, 8 figs (6 in colour), bibl., 1983.

The author discusses the fact that it becomes increasingly difficult to distinguish between natural and the new synthetic stones. Only photomicroscopy seems to be a reliable method. The blue and orange Chatham sapphires show remains of the melt, platinum inclusions, the growth marks being similar to those of the natural stone, although there are some slight variations. E.S.

HAGEMANN (C.). *Insitut für Edelsteinforschung.* Lapidary J., **37**, 11, 1550-2, 2 figs, 1984.

The institut is located at the University of Mainz and is engaged upon the testing of gemstones with particular reference to the exploration of gem deposits. M.O'D.

HASSAN (I.), GRUNDY (H. D.). *The crystal structures of sodalite-group minerals.* Acta Crystallographica, B, **40**, 6-13, 6 figs, 1984.

Sodalite, hauyne and nosean have significance in gemmology. Their crystal structure is discussed and illustrated. M.O'D.

HEFLIK (W.). (Turquoise.) Mineralogia Polonica, **12**, 2, 105-8, 1981. (In Polish).

This is the first of a series of articles in Polish dealing with minerals and gems of Poland, written specifically to stimulate co-operation between mineralogists (amateur and professional) and gemmologists. The occurrence of turquoise at Wroclaw is described. R.A.H.

HOSAKA (M.), TAKI (S.). *Hydrothermal growth of amethyst and citrine in NaCl and KCl solutions.* J. Crystal Growth, **64**, 572-6, 6 figs, 1983.

Since natural quartz grows from solutions containing mainly Na^+, K^+ and Cl^- ions, growth of synthetic quartz was attempted using NaCl and KCl solutions. Quartz cut from r-cut and R-cut plate seeds with iron added was colourless, but a purple colour was produced by gamma-irradiation. Quartz grown from X-cut plate and Y-bar seeds was yellow. This colour deepened with increase in iron. M.O'D.

KELLER (P. C.). *The rubies of Mogok: a review of the Mogok stone tract.* Gems & Gemology, **XIX**, 4, 209-19, 11 figs in colour, 1983.

An excellent account of the geology and mining methods of the tract, and of the gemmology of its stones. R.K.M.

KOIVULA (J. I.), ed. *Gems News.* Gems & Gemology, **XIX**, 4, 246-7, 1983.

Australian Ashton Joint Venture has sold its first 200 000 carats of rough diamonds for about US$9.50 per carat; C.S.O. starts quarterly journal; improvement in diamond market expected; Japan cancels duty on diamonds. In 1982 Laurence Graff bought a 278 triangular diamond in West Africa; it cut three stones, including one of 70.03 carats, claimed to be the world's largest heart-shaped diamond. India is banning export of rough gems; opal production in Australia fell by estimated 60% last year, driving prices on all grades up; Yogo Gulch sapphire deposit, Montana, plans to go into full production; in Sri Lanka, Swedish gemmologist, Olle Fjordgren, has found a first blue zoisite in Rakwana material; information on C-Ox is given. Scientists at Marwell,* Oxon, said to have grown diamond on diamond, using high-energy particle accelerator; carbon atoms fired into diamond crystal and incorporated in structure by annealing at 800 °C; theoretically claimed to be possible growth method for large synthetic diamonds.

R.K.M.

KOIVULA (J. I.), ed. *Gem News.* Gems & Gemology, **XX**, 1, 58-60, 1984.

Diamonds; there is news of exploration in Guinea, Swaziland, off coast of Namaqualand and in or near the Argyle locality in W. Australia. The first diamonds from the latter locality are sold in Antwerp. Andhra Pradesh, India, yields steady supply of gem diamond rough; exploratory drilling in Panna diamond belt in

*Sic—obviously meaning Harwell.—Ed.

Madhya Pradesh. The 10.73 Eureka diamond (claimed the first discovered in S. Africa) is on permanent loan to De Beers Mine Museum, Kimberley, which also received a gift of over 1000 technically important diamonds purchased by S.A. Diamond Producers' Association from the estate of A. F. Williams, author of *The Genesis of the Diamond* (1932).

Coloured stones: three new gem tracts identified and other areas explored in South India's state of Karnataka; Sri Lanka forms state company to heat treat geuda quality sapphires there rather than allow export to Thailand; Korean amethyst of 'very attractive colour' is reported; various reports on gold production.

Synthetics: Seiko are growing synthetic gems by floating zone method; a sintered rod is rotated while a small region near the top is brought to melt temperature by convergent reflection, heat is slowly lowered down the rod, producing a high quality single crystal. Method, originally used to make high quality silicon crystals, refractory metals and other semi-conductors, is now employed to make ruby, sapphires,and alexandrite. Constants are normal, inclusions swirled and curved, with gas bubbles. Marketed under name of Bijoreve; a flux emerald also made. R.K.M.

KOIVULA (J. I.). *Induced fingerprints.* Gems & Gemology, **XIX,** 4, 220-7, 11 figs in colour, 1983.

Since 1980 heat-induced healed-crack fingerprints have been found in some Verneuil synthetic corundums. The author has sucessfully reproduced such clean synthetic material. The formation of fingerprints is explained in detail. It is suggested that they are induced to up-grade cheap Verneuil stones to look like the more expensive flux synthetics. Synthetic corundum slabs were quench-crackled and then placed in a Chatham flux-growth environment for 42 days causing cracks to heal to give fingerprint-type inclusions. Other stones were subjected to heat alone, but did not heal in this way. A further attempt to induce chemical dendrites was successful, but the fingerprints were not natural looking. It is thought that such healed cracks occur accidentally when the Thais heat the stones to reduce the visible curved zoning.

Recognition is a problem and depends on basic clues of curved zoning, bubbles, UV transparency beneath the false appearance conferred by the fingerprints. Czochralski pulled crystals can be essentially flawless, so fingerprint inclusions in any otherwise flawless stone must be treated with suspicion. Straight and sharply angled growth or colour zoning, and recognized natural included crystals will be further important clues to the natural stone. Induced fingerprints *must* be disclosed. However, Koivula envisages a time when it may be possible to repair a cracked or broken natural stone using one of the techniques described. An important paper!

R.K.M.

KOIVULA (J. I.), FRYER (C. W.). *Lepidolite with simulated matrix.* Gems & Gemology, **XX,** 1, 42-4, 4 figs in colour, 1984.

A fine pink crystal of lepidolite mica was found to have had 'matrix' glued onto it. Bubbles found in adhesive, which fluoresced yellow under UV. Lepidolite proved by x-ray powder diffraction pattern. R.K.M.

KUHLMANN (H.). *Emissionsspektralanalyse von natürlichen und synthetischen Rubinen, Sapphiren, Smaragden und Alexandriten.* (Emission spectrum analysis of natural and synthetic rubies, sapphires, emeralds and alexandrites.) Z.Dt.Gemmol. Ges., **32**, 4, 179-95, 8 figs, 1 table, bibl., 1983.

Using a grating spectrograph, 207 samples of natural ruby, sapphire, emerald and alexandrite, and 61 synthetic samples were investigated for eleven trace elements. The analytical data show characteristic trace elements for natural samples of different localities which are different from the trace element patterns of synthetic samples. The method is shown to be helpful in the determination of the natural or synthetic origin of the stone. E.S.

LAYTON (N. A.), BROWN (G.), SNOW (J.). *A scrimshaw imitation.* Aust. Gemmol., **15**, 6, 201-5, 8 figs, 1984.

An account of the scrimshaw art and of a polystyrene 'walrus tusk' imitation which was betrayed by presence of round bubbles. Material soluble in acetone, insoluble in nitric acid, melted readily in flame. RI 1.56, SG 1.85, (very high due to calcite mixed with the core filler). R.K.M.

LOWTHER (J. E.). *The form of the different charge states of the vacancy in diamond.* J.Phys.Chem.Solids, **45**, 2, 127-31, 12 figs, 1984.

A number of different centres are formed in diamond and many of them display similar optical features including a sharp zero phonon line and phonon sidebands. The paper analyses the electronic structure and behaviour of some of the defects using an intrinsic lattice vacancy model. A comparison of stress matrix elements for the GR1 ND1, H3 and 1.945 eV centres is made, and it is concluded that the main behaviours of these defects can be attributed to the charged states V^0, V^-, V^{2-} and V^{3-}. Nitrogen lowers the symmetry about the vacancy. M.O'D.

MOREL (B.). *La veritable histoire du 'Sancy'.* (The true history of the Sancy.) Revue de Gemmologie, **78**, 13-15, 2 figs in colour, 1984.

A short history of the sancy diamond. M.O'D.

NAMIKA (M.). (The state of the art in gem testing.) J. Mineralog. Soc. Japan, **15**, 3, 151-62, 7 figs, 1981. (Japanese with English abstract.)

In recent years, because of technical progress in making synthetic or man-made stones and diversification of making such stones, it has become extremely difficult to distinguish between natural stones and imitations. The introduction of new instruments and testing methods for the identification of gemstones in the jewellery trade has been discussed, and new techniques such as XRF, UF, IR, etc., are employed. These instruments are, however, expensive and are not as effective as one would expect. It is most important in the jewellery trade to become proficient in gem-testing with the unaided eye and the simple methods based on gemmology.

T.Y.

NASSAU (K.). *The early history of gemstone treatments.* Gems & Gemology, **XX**, 1, 22-33, 9 figs (6 in colour), 1984.

Dr Nassau takes us back into classical times to trace the origins of foiling, crackle staining, heating, painting and doublets, and shows that, although never

accepted, the majority of such practices survive in more sophisticated form to this day. There are some quaint recipes for 'improving' gems. R.K.M.

O'DONOGUE (M.). *The dealer looks at gemstones—13.* Gems, **16**, 1, 51-2, 1984.

Mostly concerned with the wording of opal advertisements, the article also discusses clinohumite, lepidolite, deep blue aquamarine and Kashan ruby identification kits. (Author's abstract.) M.O'D.

O'DONOGUE (M.). *Man-made gemstones.* Gems, **16**, 1, 37-8, 1984.

A cobalt glass imitating lapis lazuli, a new synthetic opal and the material C-OX (cubic zirconia) are described. (Author's abstract.) M.O'D.

O'DONOGHUE (M.). *Some beryl minerals—2.* Gems, **16**, 1, 38-9, 1984.

The emerald deposit of Muzo, Colombia, that of Bom Jesus dos Meiras, Brazil, and the occurrence of phenakite and euclase are described.

(Author's abstract.) M.O'D.

O'DONOGHUE (M.). *Spessartine from Amelia Court House, Virginia.* Gems, **16**, 1, 7-8, 1984.

A cut stone recently added to the author's collection is described, with some history of the mines in the area. (Author's abstract.) M.O'D.

OHTOMO (J.), TAKAHASHI (M.) (Coloration of Synthetic quartz.) J. Mineralog. Soc. Japan, **15**, 3, 169-75, 9 figs, 1981. (Japanese with English abstract.)

Coloured crystals of quartz of gemstone grade (citrine, amethyst and blue quartz) have been synthesized under hydrothermal conditions ranging 320-330 °C and 1000-1550 kg/cm^2. Conditions for coloration were Fe impurity, K_2CO_3 mineralizer, Ag-lined autoclave for citrine and amethyst; and Co and Al impurities, NaOH mineralizer for blue quartz. These impurities were added in the forms of metals or metallic oxides. Gamma irradiation was necessary for the final coloration of amethyst. IR examination of natural and synthetic quartz crystals were made in the spectral range 2000-4000 cm^{-1}. T.Y.

ORLANDI (P.). *Minerali delle pegmatiti Elbane cinque nuove segnalazioni.* (Minerals of the Elba pegmatite with five new reports.) Rivista Mineralogica Italiana, **7**, 4, 97-112, 23 figs (17 in colour), 1983.

The Elba pegmatite is reviewed with particular reference to tourmaline and beryl. Five new reports (of minerals not of gem quality) are given. M.O'D.

RAMSEY (J. L.). *Brazilian rare and beautiful.* Lapidary J., **37**, 11, 1566-77, 5 figs in colour, 1984.

The present state of gemstone production in Brazil is reviewed. M.O'D.

ROBERTSON (A. D.). *Negative inclusions in zircon from Anakie, Queensland.* Aust. Gemmol., **15**, 5, 164-6, 2 figs, 1984.

Describes rod-like inclusions which are occasionally found in zircons from this sapphire area. They are similar to those in Anakie sapphires. R.K.M.

ROUX (J. E.). *The diamond industry.* Aust. Gemmol., **15**, 5, 143-8, 1984.

Reviews the diamond industry with brief details of various mines selling through the Central Selling Organization of the Diamond Corporation. Explains the complex classification of diamond rough into 'several thousand categories'. The future of the Kimberley pipe mines in Western Australia is discussed. R.K.M.

SAUL (J.), POIROT (J.-P.). *Le premier cristal de taaféite gemme?* (The first gem-quality taffeite crystal?) Revue de Gemmologie, **78**, 28, 4 figs, 1984.

A taffeite crystal from the neighbourhood of Ratnapura, Sri Lanka, shows crystal faces and is of gem quality. Drawings of the crystal and of its absorption spectrum are given. M.O'D.

SCHÄFER (W.). *Die kolumbianischer Smaragdlagerstätten Muzo und Chivor.* (The Colombian emerald locations of Muzo and Chivor.) Lapis, **9**, 4, 9-23, 22 figs (15 in colour), 1984.

An exhaustive and beautifully-illustrated account of the mining of emerald in the two main Colombian sites. M.O'D.

SCHMETZER (K.). *Zur Natur der lapis Lazuli-Imitation von Gilson.* (About the nature of the lapis lazuli imitation of Gilson.) Z.Dt.Gemmol.Ges., **32**, 4, 172-8, 4 figs (1 in colour), 1 table, bibl., 1983.

The author accuses the producer of giving misleading information. The product is manufactured by Gilson, sold as synthetic lapis lazuli and consists of ultramarine and hydrous zinc-phosphates as main constituents with small pyrite crystals added. It is therefore not a synthetic but an imitation. E.S.

SCHMETZER (K.), BANK (H.). *Intensiv gelb gefärbter Tsilaisit (Manganturmalin) von Edelsteinqualität aus Sambia.* (Intensive yellow tsilaisite (manganese tourmaline) of gem quality from Zambia.) Z.Dt.Gemmol. Ges., **32**, 4, 159-63, 1 fig. in colour, bibl., 1983.

An English version of this article is published on pp. 218-23 above. E.S.

SECHOS (B.) *Kashan synthetic ruby.* Wahroongai News, **18**, 2, 10-13, 1984.

A reprint of a paper in N.S.W. Gemmological Review—December 1983, which outlined the difficulties in distinguishing these synthetics from natural rubies and indicated that distinction may depend on several factors, chief of which must be recognition of one of the number of characteristic inclusions, many of which are solid, or filled with flux material. R.K.M.

SHIGLEY (J. E.), STOCKTON (C. M.). *'Cobalt-blue' gem spinels.* Gems & Gemology, **XX**, 1, 34-41, 13 figs (11 in colour), 1984.

An examination of intensely blue spinel of exceptional colour, strongly reminiscent of synthetic spinels coloured by cobalt, which had cobalt related spectra despite high iron content which also showed their absorption. RIs were around 1.717, indicating natural spinel, and many contained natural crystal inclusions. [These stones also give a strong red through the emerald filter. Abstracter was first

to report this rare type of spinel in 1977* and has been taken to task for assuming empirically that the colour was due to cobalt. Present paper seems to vindicate that 'shot in the dark'.] R.K.M.

SHINDO (I.). (Growth of chatoyant single crystals.) J. Mineralog. Soc. Japan, **15**, 3, 136-41, 4 figs, 1981. (Japanese with English abstract.)

It was found for the first time that single crystals of $MgTiO_3$ solid solutions showed chatoyancy and that they could be used as a new imitation cat's-eye gemstone. The crystal growth experiment was made by the travelling solvent float zone method using a halogen lamp image furnace. The crystals tended to grow mostly along the [1010] axis. Boules were dark, when first grown, but became transparent and colourless after annealing at 1300 °C for 24 hours in an oxygen atmosphere and showed distinct chatoyancy along the (0001) plane. T.Y.

SREBRODOL'SKIY (B. I.). *Accumulation of amber.* Doklady, Academy of Sciences of the USSR, Earth Science Sections, **253**, 184-6, 1982. (Translated from Doklady Akademii Nauk SSSR.)

Amber from the Baltic region is fossilized resin that accumulated in 'blue earth', a dark-green glauconite-quartz rock with grit-size quartz particles and phosphorite concretions. The highest amber concentrations are either at the upper or lower parts of the 'blue earth' unit, especially in clayey sediments that indicate a quiescent environment in Palaeogene and Neogene times. S.R.

STACEY (G.). *Mineral of the month. Uvarovite.* Wahroongai News, **18**, 2, 9-10,1984.

Summary of facts on rarest of the garnet sub-species. Crystals usually too small for cutting; larger ones when found, are very dark green, opaque and unsuitable for cutting. Tsavorite [now renamed tsavolite] is also dealt with—a fine green grossular garnet. R.K.M.

STACEY (G.). *Mineral of the month. Andradite.* Wahroongai News, **18**, 3, 21-2, 1984.

A summary of the facts relating to this garnet subspecies which gives us the valuable and rare demantoid, and the less appreciated topazolite, which is probably even rarer. R.K.M.

STOCKTON (C. M.), MANSON (D. V.). *Gem andradite garnets.* Gems & Gemology, **XIX**, 4, 202-8, 7 figs (2 in colour), 1983.

A careful study of the garnet subspecies generally known as demantoid.A range of twenty-one stones was tested and RII 1.880 to 1.883, SGG 3.80 to 3.88 were recorded.These did not include the highly prized rare vivid green. Detailed electron-microprobe chemical analyses underlined the unusually constant composition of the variety. Colour did not directly relate to the small amount of Cr_2O_3 that was found. Manganese and titanium, also in minute amounts, may influence colour. Authors suggest that cutters deliberately orient stones to include characteristic byssolite

*J.Gemm., 1977, XV (7), 356-7.—Ed.

fibres under the table facet. From observation of rough I would say that these usually radiate from the centre of the crystal and the cutter has little choice if size and colour are to be maintained. R.K.M.

THOMPSON (H. M.). *Argyle, De Beers and the international diamond market.* Raw Materials Report, **2**, 3, 25-41, 10 figs, 1983.

A wide ranging view of the prospects of the world diamond market, taking into account new sources of diamond and the production of synthetic material. M.O'D.

VOIGT (S.). *Chrysoberyll-Kristalle aus Niederösterreich.* (Chrysoberyl crystals from Lower Austria.) Lapis, **9**, 4, 26-9, 10 figs (4 in colour), 1984.

Trillings of chrysoberyl are reported from Spitz, between Melk and Krems in Lower Austria. M.O'D.

WADA (K.) (Colour and fine structure of pearls.) J. Mineralog. Soc. Japan, **15**, 3, 143-50, 2 figs, 1981. (Japanese with English abstract.)

It is evident on the base of studies that the colour of pearls is the sum of iridescence and body colour. The iridescence occurs by the interference of light reflected from the superficial and internal laminar structure of nacre, which consists of the accumulation of a crystal layer and a thinner organic sheet parallel to the surface of pearls. The crystal layer is 0.3-0.8 mm thick and consists of a definite aggregate of many small tabular crystals of aragonite in a row. On the other hand, the body colour is due to the absorption of light by pigment, nacreous matter and other material. T.Y.

BOOK REVIEWS

AHRENS (J. R.), MALLOY (R. L.). *Gems and jewellery in Hong Kong: a buyer's guide.* South China Morning Post, Hong Kong, 1984. pp.158. $45.

For those wishing to visit Hong Kong this pocket-sized guide is a most entertaining companion; it is useful as well, since the information given is reliable and sensible. Hints on how to buy are given, as well as details of all the important gemstones, so that the gemmologist will find the book valuable. Few readers will know how to buy ivory in an Oriental country, so if this experience is likely to come your way get the book. M.O'D.

DA CUNHA (C.), DA CUNHA (A.). *Des pierres précieuses aux pierres fines.* (From precious stones to gemstones.) Plon, Paris, 1984. pp.93. Illus. in colour. Fr 135.00.

This is a beautifully produced gemmological textbook since the subject matter is introduced with gem testing in mind. A large portion of the book comes under the section 'how to know as much as the professionals', and it must be admitted that the first stage in learning, the stimulus of the imagination, is successfully accomplished. Preceding this section are descriptions and illustrations of inclusions, all superbly shown. There is a separate chapter on the recognition of synthetic material and an identification table. On the end-paper is a short bibliography and a most useful list of addresses, including those of some of the producers of synthetics. For the student the omission of any discussion or illustration of crystals would be a drawback, but the book is well worth getting if only to remind ourselves that all aspects of gemstones are perennially beautiful. M.O'D.

HENTSCHEL (G.). *Die Mineralien der Eifelvulkane.* (The minerals of the Eifel volcanic region.) Christian Weise Verlag, Munich, 1983. pp.152. Illus. in black and white and in colour. Price on application.

This forms part of the series *Lapis Monographie.* Presumably each part will deal with a particular region or topic, and the standard set by this first issue is very high. It is likely to be of interest to gemmologists, since in the Eifel region are important occurrences of sanidine, peridot and some of the very rare gem materials such as hauyne. Minerals are extensively described, following traditional chemical order and with drawings of many of the crystals. Following this major section come descriptions of the more important localities, a bibliography and an index, both well constructed. M.O'D.

O'DONOGHUE (M.). *Identifying man-made gems.* N.A.G. Press Ltd., London. pp.223. Illus. in black and white, with 61 figs in colour by Edward Gübelin. £14.95.

The basic concept of a book on this aspect of gemmology is a good one, and the publishers have produced a good-looking volume with excellent illustrations accurately captioned in bold type. These are elaborately numbered, although there is little attempt to use these numbers in the text.

The first part of the book deals with 'Methods of Growth'. Here the writer deals mainly with gem crystal production but includes some detail which relates to the much broader aspects of the crystal growth industry concerned with laser crystals, semi-conductors and other non-gem uses. A very short chapter on 'Testing Man-made Gems' and a longer one on 'Photographing Gem Inclusions' seem out of place in this section. The first of these devotes half its length to describing cathodoluminescence, a laboratory research technique which is known to turn some diamonds brown and to cause damage to some other stones, and is a long way out of reach for the ordinary gemmologist.

The second part deals with 'Identification' and covers most methods adequately, although detail seems to be lacking on reflectivity and diamond probe tests, both of which need to be used with some care if errors are to be avoided. Emphasis could have been given to the precautions needed.

Meanings are sometimes rather obscured by using advanced terminology which might confuse rather than enlighten, e.g. on p.107, [GGG crystals] 'are used for magnetic bubble devices which . . . operate by the movements of magnetic domains through a thin epitaxial magnetic layer grown on a non-magnetic, rare-earth, single crystal, garnet substrate.' Apart from the problem of comprehension, this seems to have little to do with gem identification.

There are occasional ambiguities, e.g. on p.191, 'no trace of the "umbrella" marking . . . could be seen, as is common in stones treated by cyclotron.' In some other cases the facts are at variance with those in the source articles, e.g., Knischka rubies on p.126, 'strong phosphorescence . . . long lasting.' The Gübelin report upon which is was apparently based says 'x-ray phosphorescence . . . is neither strong nor of long duration.'

On p.137 RIs are quoted which make Linde emeralds optically positive. The error was in the original GIA paper but was corrected in a note sent out with their next issue. All beryl is optically negative. On p.140 we read of 'A man-made emerald coloured by vanadium *then by* chromium'. That read '*without* chromium' in Dr A. M. Taylor's original paper. The RI of GGG is quoted as 7, which is its SG. Some absorption spectra wavelengths are jumbled and should have been corrected in proof reading.

I have quoted a few examples only and am left with an impression of haste and a feeling that greater care in writing would have produced a more reliable textbook.

R.K.M.

ASSOCIATION NOTICES

OBITUARY
TOINI MIKKOLA
28.3.1907 — 4.2.1984

Mrs Toini Mikkola died in Helsinki on 4th February 1984.

She had graduated as geologist and mineralogist in 1943 and became L.Phil. in 1967. She devoted all her professional life to the Petrological Department of the Geological Survey of Finland, beginning her career as assistant researcher and continuing as a full-time geologist. She specialized in optic mineralogy and published numerous papers on the subject.

In 1960 she passed the Diploma Examination and was elected to the Fellowship of the Gemmological Association of Great Britain, and in the same year she joined the Board of its Finnish counterpart and the team of teachers and instructors at the courses in Finland.

In 1970 she was appointed to be one of the Association's Examiners in Gemmology in respect of the Finnish Candidates, and her comments on the translations of Finnish answer-papers and her lucid explanations of what the candidates were intending to say, when, as sometimes occurred, the meaning of their actual words as literally translated into English was obscure, were of the greatest assistance to her English colleagues in assessing the correct marking of the papers.

Mrs Mikkola was equally well known in the international geological and mineralogical circles, as well as in the International Federation of University Women.

She was widowed in 1940, when her husband (also a geologist) fell in the Finnish Defence War of 1939-40. Her closest surviving relatives are two small grandchildren and their widowed mother.

H.T.
J.R.H.C.

FIG. 1. Mrs Toini Mikkola, L.Phil., F.G.A.

Dr MAX H. HEY
Mineralogist and Microchemical Analyst Extraordinary

Dr Max Hey died peacefully in his sleep, in the early hours of Tuesday, 24th January, 1984. In his 80th year, he had undergone surgery at Reading in November, and was convalescing at the home of his son in Newcastle-upon-Tyne. He is survived by his widow.

Max Hutchinson Hey was born on 11th March, 1904, at Leyland, Lancashire. His father worked with dyestuffs, and from him Max and two of his brothers acquired their interest in chemistry. His schooldays were spent at Leyland Grammar School, and later at Manchester Grammar School. In 1921 he went to Magdalen College, Oxford, graduating in 1925 with first class honours in chemistry and crystallography.

The middle years of the 1920s were not good for employment but, after two years in the Government Chemist's Laboratory and in the Patent Office, he was appointed Assistant Keeper (Second Class) in the Mineral Department of the British Museum (Natural History), with sole responsibility for the running of the chemical laboratory.

His first major task, set for him by the Keeper of Minerals, Dr L. J. Spencer, was to examine and catalogue the many zeolite specimens in the collection. In those days, work on the catalogue was an urgent priority, and all newly-appointed Assistant Keepers in the Department were expected to devote part of their time to a selected group of specimens. Aided on the x-ray side by F. A. Bannister, Max published a now classic series of papers on the zeolites; the new light shed on this complex group earned him both a D.Sc. and an international reputation.

The analysis of small amounts of material was an early challenge, and for qualitative work he enjoyed using reactions that produced characteristic products on a microscope slide. Quantitative analyses were also required, for such minerals as gemstones or the individual grains in a platinum concentrate from the Transvaal. Mineral analyses had previously been made on about 1/10 gram, rarely less, and the purchase of the Department's first microbalance enabled him to get down to the 10 mg scale; he regarded his first true microchemical analyses to have been those on magnesium-zinc-spinels, in 1937.[1] He was also innovative, deviethods for the analysis of the metallic phases of meteorites by chlorination and for the direct determination of ferrous iron in resistant silicates (for kornerupine, 1941).[2]

After the war, he continued his occasional collaboration with B. W. Anderson and C. J. Payne, of the Gem Testing Laboratory, and in the 1950s became known to many of the present generation of gemmologists by the microchemical analyses that he contributed to the descriptions of the newly-discovered gem minerals taaffeite[3], sinhalite[4], and painite[5].

1. 1937: Magnesium-zinc-spinels from Ceylon, by B. W. Anderson and C. J. Payne; with a chemical analysis by M. H. Hey. *Mineral. Mag.*, **24**, 547-54.
2. 1941: Some new data concerning kornerupine and its chemistry, by M. H. Hey, B. W. Anderson and C. J. Payne. *Mineral. Mag.*, **26**, 119-30.
3. 1951: Taaffeite, a new beryllium mineral, found as a cut gemstone, by B. W. Anderson, C. J. Payne and G. F. Claringbull; with microchemical analysis by M. H. Hey. *Mineral. Mag.*, **29**, 765-72.
4. 1952: Sinhalite ($MgAlBO_4$), a new mineral, by G. F. Claringbull and M. H. Hey. *Mineral. Mag.*, **29**, 841-9.
5. 1957: Painite, a new mineral from Mogok, Burma, by G. F. Claringbull, M. H. Hey and C. J. Payne. *Mineral. Mag.*, **31**, 420-5.

Perhaps his best-known work is the 'Chemical Index of Minerals', which grew almost by chance from a wartime request for a listing of all the silicates of magnesium known in nature. He was preparing a third, expanded edition at the time of his last illness. Although he had officially retired in 1969, he remained as busy as ever, working at home and in the Museum as often as the demands of his large garden would permit.

It is impossible here to do more than mention his vast output of about one hundred and fifty publications, since he was master of an amazing range of subjects in both theory and practice: chemistry in its various aspects; crystallography and crystal optics; systematic, topographic, curatorial, and nomenclatural mineralogy; meteoritics; computational and statistical mathematics; and to all of these he made significant and lasting contributions. Yet this is by no means the sum of his professional achievement, since he was never too busy to help others, both in the Museum and in his capacity as Editor of the Mineralogical Magazine. Such was the growth of the subject, that in twenty-five years, from 1956 to 1980, he edited more papers than the redoubtable L. J. Spencer had in fifty-five; there can have been few of their authors who did not benefit from his advice. There is no secret to his success, which was founded in a unique blend of native genius, sound teaching, an ever-inquiring mind and retentive memory, hard work, and above all the ability to keep several problems progressing simultaneously and commit them to paper.

P.G.E.
E.A.J.

* * *

Mr J. A. Fleming, F.G.A. (D.1962), Auckland, New Zealand, died on 3rd May 1984.

MEMORIAL SERVICE FOR B. W. ANDERSON

A Service of Thanksgiving for the life of Basil William Anderson, B.Sc., F.G.A., F.K.C., was held on Tuesday, 24th April, 1984, in the Chapel of King's College London.

The Bidding was delivered by the Dean of King's College, followed by the singing of Charles Wesley's 'Rejoice, the Lord is King' to the music of Handel. The Lesson read by the Secretary of the Gemmological Association, Mr Con Lenan, F.G.A., was from Revelation 21:10-26, followed by Psalm 121, and the Address was delivered by Mr David Callaghan, F.G.A., the Chairman of the Gemmological Association. Two other hymns were sung, 'The King of love my Shepherd is' and 'O

praise ye the Lord', and the prayers were led and the Blessing pronounced by the Dean of the College.

Those present included Mrs (Barbara) Anderson (widow), family friends and more than a hundred gemmologists from the United Kingdom and overseas and members of the trade.

GIFTS TO THE ASSOCIATION

The Council of the Association is indebted to the late Mr John A. Fleming, F.G.A., of Auckland, New Zealand, for a specially made carving in New Zealand nephrite.

NEWS OF FELLOWS

Miss Judith Bannister, F.G.A., who was granted the freedom of the Worshipful Company of Goldsmiths in 1977, was recently elected to the Livery.

Mr Robert Croydon, F.G.A., has recently been granted the freedom of the Worshipful Company of Goldsmiths.

Mr E. A. Jobbins, B.Sc., F.I.M.M., F.G.A., has been elected to the Committee of the Society of Jewellery Historians.

Dr David B. Michaels, LL.B., M.B.A., Ph.D., G.G., F.G.A., who is a Professor of Law and Management at the Community College of Northern Virginia, has been appointed President and Chief Executive of Forensic Gemologists Inc.

On 18th January, 1984, Mr M. J. O'Donoghue, M.A., F.G.S., F.G.A., gave a 30 minute talk on Radio Kent. The subject was man-made gemstones.

On 3rd April, 1984, Mr Peter Read, C.Eng., F.G.A., gave an illustrated talk on 'New gem test instruments and techniques' at the Brazilian Institute of Gems and Precious Metals, in Rio de Janeiro.

MEMBERS' MEETINGS

Midlands Branch

On 30th March, 1984, at the Society of Friends, Dr Johnson's House, Bull Street, Birmingham, Mr A. G. Green gave a talk on lost wax casting as applied to the jewellery trade.

On 17th April, 1984, at the Barn Restaurant, Hockley Heath, a dinner was held for Branch members and guests.

On 27th April, 1984, at the Society of Friends, the Annual General Meeting of the Branch was held, at which Mr C. L. Hundy, F.G.A., and Mr D. M. Larcher, F.G.A., were elected Chairman and Secretary respectively. The meeting was followed by a showing of slides and stones supplied by members.

North-West Branch

On 17th May, 1984, at Church House, Hanover Street, Liverpool, Mr Michael O'Donoghue, M.A., F.G.S., F.G.A., gave a talk on the quartz family of minerals.

ANNUAL GENERAL MEETING

The 53rd Annual General Meeting of the Association was held on Friday, 24th April, 1984, at the Great Hall, Kensington Town Hall, London, W8.

Mr David Callaghan, F.G.A., the Chairman, presiding over the meeting, welcomed members, some of whom had come from as far away as Scotland in the U.K., and from the Netherlands, Italy and Thailand. He referred to some of the items mentioned in the Annual Report, such as the continued high standard of the *Journal,* the Examinations, and the Annual Presentation of Awards, where a Canadian, Douglas Bagnall, and Mrs Fiona Quick, from Zimbabwe, received the Anderson/Bank Prize and the Anderson Medal respectively. These had been presented to them by Professor Dr Hermann Bank, F.G.A., who also had the opportunity of presenting a Diploma to his daughter, Monika.

He proceeded to mention the activity of the Education Committee in redesigning the Correspondence Course, which it was hoped would be ready for 1985, and the formation of an Advisory Committee to help the Chairman and the other Officers (this had proved to be very useful); and he thanked the Branches, which had been busily furthering the interests of gemmology in their areas.

He next referred to the unfortunate absence of the President, Sir Frank Claringbull, who had broken his leg earlier in the year and had sent his apologies, saying he did not feel sufficiently mobile to attend; and finally he welcomed the presence of the Vice-President, Mr Harry Wheeler, and of his brother, Douglas.

Mr Nigel Israel, the Honorary Treasurer, presented the audited accounts for the year ended 31st December, 1983, and the Chairman moved the adoption of the Report and Accounts; the motion was seconded by Mr Peter G. Read, F.G.A., and carried unanimously.

Sir Frank Claringbull, Mr David Callaghan, Mr Noel Deeks, and Mr Nigel Israel were then re-elected as President, Chairman, Vice-Chairman and Honorary Treasurer respectively; and Dr J. B. Nelson and Messrs A. J. French, D. Inkersole, D. M. Larcher, W. Novak and C. H. Winter were re-elected and Mrs E. Stern and Mr D. Morgan were elected to the Council.

The Chairman, after referring to the sad loss suffered by the Association by the death of their senior Vice-President and senior Examiner, Mr B. W. Anderson, then expressed his pleasure in proposing, on the nomination of the Council, the election as a Vice-President of Mr R. Keith Mitchell, F.G.A., and, when duly seconded and put to the meeting, this was carried unanimously.

Messrs Ernst & Whinney were appointed Auditors, and the proceedings then terminated.

COUNCIL MEETINGS

At the Meeting of Council held at the London Tara Hotel, London, W.8., on Tuesday, 21st February, 1984, the business transacted (in addition to the election of Members already reported on p.204 above) included the following:
(1) it was resolved to nominate Mr R. Keith Mitchell, F.G.A., (Tully Medallist 1934) for election at the Annual General Meeting as a Vice-President of the Association;
(2) a request received from the Gemmological Association of South Africa for affiliation with the Association was considered and affiliation was granted.

At the Meeting of Council held on Tuesday, 24th April, 1984, at the Kensington Town Hall, Hornton Street, London, W.8., the business transacted included the election to membership of the following:

FELLOWSHIP

Chamberlain, Roger P., Antwerp, Belgium. 1983
Hutchings, Trevor J., St Saviour, Jersey. 1983
Krikos, Alexandra A., Athens, Greece. 1983
Triantaphyllides, Zoe M., Athens, Greece. 1983

ORDINARY MEMBERSHIP

Alahendra, Jayatilaka, Kandy, Sri Lanka.
Attar, Aviva, London.
Brown, George E., Tucson, Ariz., U.S.A.
Fearn, Ian F., Gillingham.
Francis, Shirley J., Frinton-on-Sea.
Gosling, Robert G., Christies Beach, S. Australia.
Kasparian, Annie, Marseilles, France.
Mehta, Anoop K., London.
Miller, Harward S., Farmington, N. Mex., U.S.A.
Moline, George S., Spokane, Wash., U.S.A.
O'Mahoney, Niamh, Cork, Ireland.
Peavey, Charles A., Norwalk, Ca, U.S.A.
Perea, Hilario L., Farmington, N. Mex., U.S.A.
Potgieter, Ernestine, Cape Town, S. Africa.
Roper, Jane, Madrid, Spain.
Roy, Stephen B., Tucson, Ariz., U.S.A.
Stafford-Smith, Reginald, Brisbane, Qld, Australia.
Stoecklein, Patricia A., Trafalgar, Indiana, U.S.A.
Tippins, Harry, Signal Hill, Ca, U.S.A.
Walker, Gordon S., Belmont, N.S.W., Australia.
Wanigasekera, Vimal, Kandy, Sri Lanka.

THE NEW VICE-PRESIDENT

Mr R. Keith Mitchell, F.G.A., was elected a Vice-President of the Association at the Annual General Meeting as reported above.

In 1928, at the age of 16, R. Keith Mitchell entered the buying department of Mappin & Webb Limited. In these early years he spent his time buying silverware for

export. In 1932 he started at Chelsea Polytechnic, and it was not until 1933 that he obtained a transfer to the jewellery department. He was very interested in gemstones and spent most of his lunch times in the Geological Museum, then situated in Jermyn Street, London, W.1.

In 1934 he passed his Diploma Examination, not only with distinction, but gaining the Tully Memorial Medal, beating very tough opposition from the late Robert Webster, who passed in the same year. It was the practice at that time for Tully Medallists to be immediately seconded to the Council, and until the War he served as a Council Member. Being drafted into the Royal Corps of Signals, he was posted to Singapore where, when it was captured by the Japanese, he was taken prisoner. He was shipped to Japan and spent the remainder of the War in a Japanese Prisoner of War Camp.

Upon his return in 1947 he took up the post of assisting Thorold Jones* with the practical classes at Chelsea Polytechnic. In 1950 he took over the first year correspondence course as Instructor, and a year later in 1952, he took over the second year instructorship as well. He ran both courses single-handed, until Vera Hinton took over a number of first year students. He continued in this position until 1969, when ill health forced his retirement from this work; he had, in fact, run both courses single-handed for over ten years. During the whole of this period he was re-elected to the Council and indeed throughout this period played an active part in setting the high standards that the Gemmological Association enjoys today.

He published his first paper on gemmology in 1935 and has published a total of more than forty papers to date, not to mention the innumerable Abstracts he has provided us with in recent years.

Keith Mitchell ran his own business dealing in gemstones for many years, until his retirement in 1979. During that period he obtained many gemstones, of which a number now form part of the National Collection in the Geological Museum in London. The most notable of the stones he handled and indeed still owns, is the original taaffeite, discovered by Count Taaffe in 1945. This stone is currently on loan to the Geological Museum and is the Type Specimen of the species.

It is now 50 years since he gained the Tully Memorial Medal, serving the Gemmological Association for all his working life, playing an important part in gemmological education, supplying many examples of new materials for the first time in this country, and indeed making many original observations, on new and existing gemstones. C.R.C.

1984 REUNION OF MEMBERS AND PRESENTATION OF AWARDS

The Annual Reunion of Members and Presentation of Awards will take place at Goldsmiths' Hall on Monday, 12th November, 1984.

*See *J. Gemm.*, 1973, **XIII** (7), 26, or *50 Years of Gemmology* at p.29—Ed.

THE BRITISH GEM TESTING LABORATORY

On 12th March, 1984, the name of the Gem Testing Laboratory of the London Chamber of Commerce and Industry, at 27 Greville Street, Hatton Garden, London, E.C.1., was changed to The British Gem Testing Laboratory.

INTERNATIONAL COLORED GEMSTONE ASSOCIATION

At meetings held at Acapulco, Mexico, which took place from 28th January to 2nd February, 1984, and were hosted by the American Gem Trade Association, it was decided to found an International Colored Gemstone Association to foster interest in coloured gemstones and deal with any problems connected with the industry in conjunction with C.I.B.J.O. and national institutions. Founder Members included Messrs Con Lenan and E. A. Jobbins, FF.G.A., from the United Kingdom and Messrs Richard T. Liddicoat, Jr, Hon.F.G.A., and Michael Roman from the U.S.A., as well as Professor Dr E. Gübelin, F.G.A., from Switzerland. Further information may be obtained from Mr Con Lenan, Saint Dunstan's House, Carey Lane, London, EC2V 8AB.

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CORRIGENDA

In *J. Gemm.*, 1983, XVIII (8)—
on p.692, in caption to Fig. 29, for '(verneuil) *c*-axis' read '(Verneuil) ‖*c*-axis'
on p.694, in caption to Fig. 31, for 'Sri Lanka *c*-axis,' read 'Sri Lanka ‖*c*-axis,' and in caption to Fig. 32 for 'Chatham *c*-axis,' read 'Chatham ‖*c*-axis,'
on p.706, in line 8, for 'diffusionbehandelter' read 'diffusionsbehandelter', and, in line 9, for 'difusions behandelten' read 'diffusionsbehandelten'
on p.709, delete the first two lines ('The play of colour . . . create the conditions')
on p.721, in line 22, for 'bam' read 'beam'
on p.748, in Table 3, for 'Marekanite' read '*Marekanite*'
on p.757, Footnote, in line 2, for '$\sqrt{}$k.t' read '$\sqrt{k.t.}$', and, in line 6, for '$A.e^{I/RI}$' read '$A.e^{E/RT}$'
on p.765, in line 19, for '5920A' read '5920Å'

In *J. Gemm.*, 1984, XIX (1)—
on p.21, under third Figure add 'Fig. 9.' and for 'Fig. 9.' read 'Figs 7, 8 and 9.'
on p.67, in line 17, for 'Gems, **5**,' read 'Gems, **15**,'

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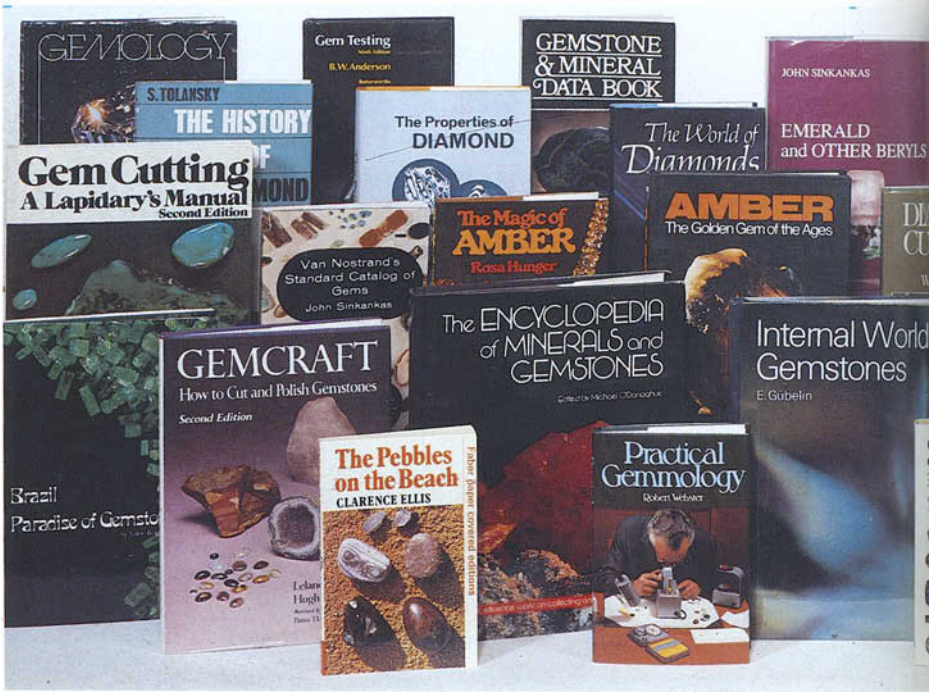

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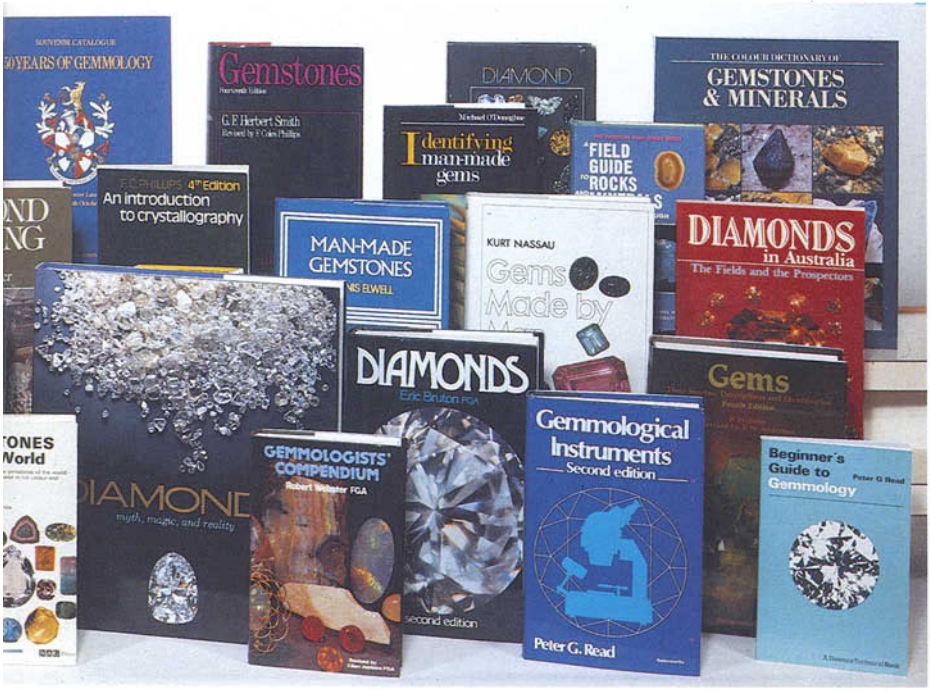

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and

PROCEEDINGS OF THE GEMMOLOGICAL ASSOCIATION OF GREAT BRITAIN

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THE JOURNAL OF GEMMOLOGY
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GLASS INFILLING OF CAVITIES IN NATURAL RUBY

By K. SCARRATT, F.G.A.

The L.C.C.I. British Gem Testing Laboratory

and R. R. HARDING, B.Sc., D.Phil., F.G.A. *

British Geological Survey, Exhibition Road, London, SW7 2DE

Towards the end of April 1984, a rounded triangular-shaped ruby weighing 8.84 cts was brought into the L.C.C.I. Laboratory by a dealer, who having purchased it in Bangkok had since become worried that it had been treated in some way. He was particularly disturbed about a large area on the pavilion of the stone which contained bubbles visible to the naked eye and then recalled that while in Bangkok he had heard that a new process was being used to infill unsightly cavities in natural rubies. The laboratory examination confirmed that an unnatural substance filled what was once a very large open cavity on the pavilion of an otherwise perfectly natural ruby.

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In this instance the dealer was satisfied with the knowledge that the stone had indeed been 'treated' and was not concerned with a positive identification of the type of artificial substance used as the infill. We were, however, in the time permitted, able to establish that the infill had a hardness of less than 6 and a refractive index of 1.512. We were also able to observe a weak greenish fluorescence given off by the infill when the stone was placed under short wave ultraviolet light.

The size of the stone and the extent of the infill material suggested that the first observation to be made during an appraisal would involve the infilled cavity. This being so, it is very unlikely that it would ever be sold for anything more than it was—a treated ruby. What was slightly disturbing to us was the thought of the same process being used on smaller stones with proportionally smaller cavities—especially if the substance was bubble free.

It was not long before our fears were justified. Less than four weeks after our first encounter, one of the participants in a gem identification course being held at the L.C.C.I. Laboratory brought with him two rubies which his firm had recently purchased in Bangkok. Both stones weighed between one and two carats, and when examined on the microscope both were found to have a number of 'infilled cavities' in the pavilion and girdle areas. One of the stones contained three infilled cavities, and in two of these there were bubbles present, but the third was bubble free. In the second stone the infilled cavities were all free of bubbles. It was also noted that a cavity in one of the stones had been left unfilled in its natural state.

Fortunately the owner of the two latter stones was not in a hurry to have one of them returned and as a result (although we were still not allowed to carry out destructive testing) we were able to carry out microprobe analyses of the ruby itself and of the infill material.

The stone analysed weighs 1.21 ct and is an oval modified brilliant/mixed cut. There are two infilled cavities near the culet, but the third and largest lies just below the girdle midway along one long edge of the oval. The latter (see Figure 1) was chosen for analysis because it is the largest and shows a clear junction between the infill material and the host ruby in the middle of a facet. Three analyses of the ruby and five of the infill material were made and the means are given in Table 1.

TABLE 1. Electron microprobe analyses of ruby and infill material

wt%	1	2
SiO_2	<0.2	59.0
Al_2O_3	98.4	28.4
Fe_2O_3	0.5	—
FeO	—	0.7
MgO	<0.2	0.5
Na_2O	<0.2	2.6
K_2O	<0.2	5.4
Cr_2O_3	0.5	<0.2
Total	99.4	96.6

Notes. A Geoscan electron microprobe with Link Systems energy-dispersive attachment and data handling program were used, with an accelerating voltage of 15 kV, a specimen current of 5×10^{-9} amps and an electron beam focused to approximately 5 μm. Elements of atomic number 11 (Na and above) can be measured by this method and the limit of detection for each of the oxides is about 0.2 wt%. Total iron was assigned to Fe_2O_3 in corundum, and to FeO in the infill material.
1. Mean of 3 analyses of ruby. 2. Mean of 5 analyses of infill material.

Although only a small area of the ruby proper was sampled, the three analyses indicate that there was some variation in the minor contents of iron and chromium. The Fe_2O_3 values range from 0.3% to 0.6% and those for Cr_2O_3 from 0.4-0.6%. No other minor elements, with atomic number greater than 11, were detected above the 0.2 wt% level.

Again, although the infill material is small in volume its composition is very consistent. It was found to be essentially an alkali alumino-silicate glass with minor amounts of iron, magnesium and possibly other elements of low atomic number. The low total of about 97% indicates that up to 3% of H_2O, Li_2O or B_2O_3 may be present. Glasses of this composition are generally very viscous and this is consistent with the presence of bubbles in two of the infilled areas.

This new form of ruby treatment may be overlooked quite easily if, firstly, the stones examined are small (*c.* 1.00 ct), and,

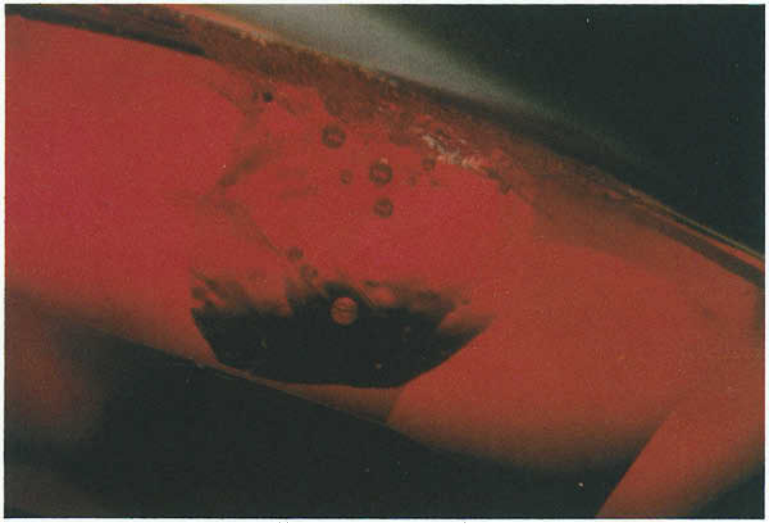

FIG. 1. A cavity in a natural ruby infilled with a glass. Transmitted light.

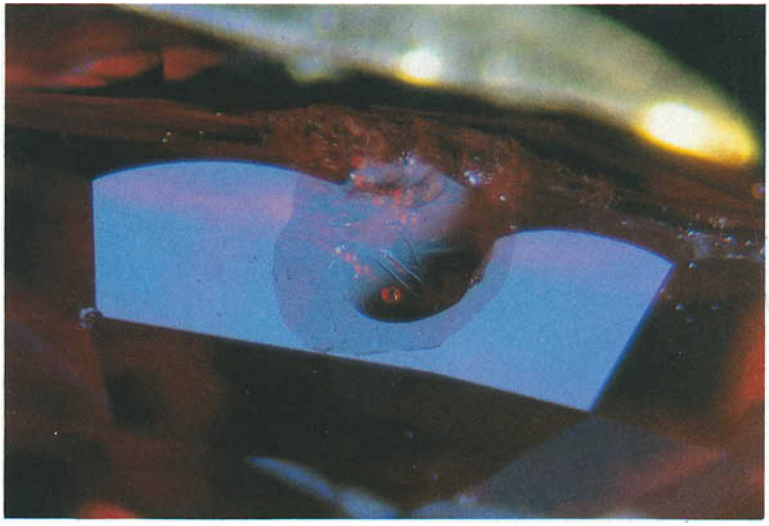

FIG. 2. The same infilled cavity as that in Fig. 1 seen in this case in reflected light. Note the change in lustre between the ruby and the glass.

secondly, if the glass infill is bubble free. When examining rubies it is now recommended that the surface of the stone is examined in reflected light and any changes in lustre (see Figure 2) similar to those seen between the garnet top and glass base of a garnet topped doublet, noted. If seen, then these areas of poor lustre should be more closely examined for evidence of cavity infilling.

[*Manuscript received 23rd June, 1984.*]

CONTRIBUTION TOWARDS THE IDENTIFICATION OF TREATED CORUNDUMS: HEAT AND DIFFUSION TREATED RUBIES

By MAHINDA GUNAWARDENE, F.G.A., D.Gem.G.

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ABSTRACT

Heat and diffusion treatment of rubies are detailed. Even though their identity in certain instances, particularly in heat treatment only, cannot be disclosed to the trade, the aspects mentioned are of useful aid in separations. The dangers of such treatments are discussed. Methods employed in Thailand and Sri Lanka in this connexion are given. Detections of treated rubies by gemmological methods are detailed.

INTRODUCTION

Processes of artificial coloration of corundum varieties have taken a primary position among various improvement operations. The latest to be discussed in this respect is the diffusion treatment of rubies. Following the successful coloration of light blue sapphires from Sri Lanka and lightening of the dark blue of Australian sapphires, the pioneers of 'cooking' corundums, the Thais, operate another heating system on their rubies, and the process has taken a noteworthy position at present.

During a recent visit to the famous gemfield in Thailand, Chantanburi, the author was shown by some dealers how the rubies are subjected to treatment and various steps of the operation. The same practice is also carried out in Sri Lanka today, much more sophisticatedly than previously. Another, recent introduction gaining interest in the trade is the diffusion-treated ruby. Series of research done in this connexion in identifying heat or diffusion treated rubies are detailed.

Under high temperature inducements the colour of blue sapphire is improved and is known to the trade. The technical and gemmological aspects of blue sapphire treatments were described by Jobbins (1971), Harder (1980), Sasaki (1980), Tombs (1980), Nassau (1981), Crowningshield & Nassau (1981), Hänni (1982 a & b) and Gübelin (1982). Further, colour improvement of yellow sapphire and its colour instability were detailed by Schiffman (1981), Schmetzer *et al.* (1982) and Keller (1982). However, only

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very little was mentioned of colour enhancement of ruby (Hänni, 1982 b; Abraham, 1982 and Ohguchi, 1982) during these analytical procedures. Nowadays, the subject is often encountered in identification certificates issued by various gemmological laboratories. Among these two treatment procedures the diffusion treatment needs to be disclosed to the customer according to the rules introduced by the C.I.B.J.O. Coloured Gemstone Commission (1981) here in Europe and the proposals made by Federal Trade Commission Guides for the Jewellery Industry (1981) in U.S.A. Heat treatment, however, does not require disclosure if the detection cannot be made by a gemmological laboratory.

HEAT TREATMENT OF RUBIES

In Thailand the rubies are discovered in an iron-rich basaltic terrain, and the colour is influenced by iron giving a dark brownish-violet hue to the stone. According to the process described by Nassau (1981) the colour can be improved by converting the Fe^{2+} to Fe^{3+} after heating in an oxidizing atmosphere at a temperature between 1000 °C and 1700 °C for many hours. In this conversion ($4FeO + O_2 \rightarrow 2Fe_2O_3$) the darker hue is removed and the stone appears lighter red in colour.

Modern methods are used by Thais in their long noted experiences on the subject. As the first step, suitable stones, with less cracks and fissures, are selected. Rubies with heavy cracks are trimmed by the cutters. Any water concentration within cracks is allowed to evaporate on a preliminary heating process where the material is kept on heated iron trays. The corundums are afterwards packed into a crucible filled with alumina powder (Figure 1). Many of these crucibles, often in different sizes, are then introduced to the main heat treatment utilizing modern ovens. The author was informed by some experienced operators that the use of sophisticated heating plants is more economical and the results are satisfactory. An extensively used electrical furnace is shown in Figure 2. The temperature is gradually increased, followed by periods of raising or lowering the heat which vary among different operators, depending also on the nature and original colour intensity of the stone. An average 8 to 10 hours

FIG. 1. A crucible extensively used in the heat treatment of ruby.

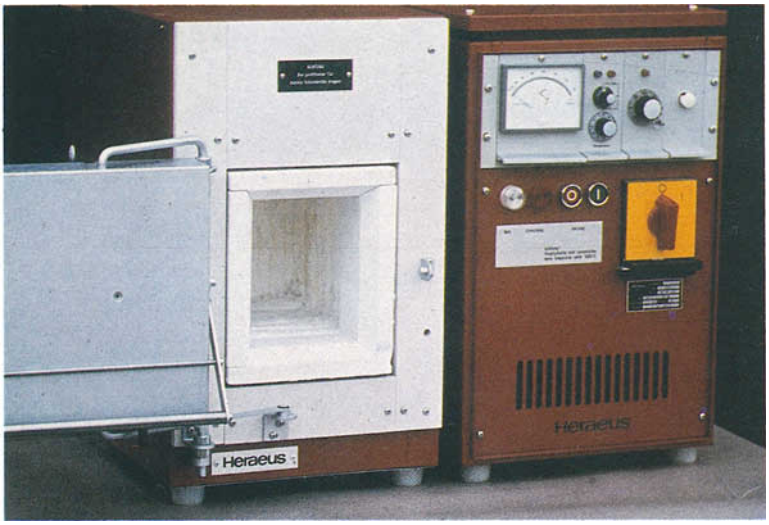

FIG. 2. High temperature chamber furnace manufactured by Hearaeus in West Germany. Owing to rapid heating system it is used in the heat treatment of corundum (after Hearaeus, model number K 1700/1).

FIG. 3. Sorted rough ruby lot weighing 3000 grams just after heat treatment.

FIG. 4. The author, examining rubies after the heating process.

treatment is common. Figure 3, illustrates a lot of 3 kg of heated rubies in the rough state. If the desired colour is not achieved, the process can be repeated several times. In many instances even faceted rubies are heated, if the owner is dissatisfied with the colour. These stones are then sorted out according to various hues of colours and sizes and are marketed in Chantaburi gem market in the Sunday auction (Figure 4).

Frequently encountered colours of corundum in Sri Lanka are the pinkish-violet or pinkish-yellow varieties. These less-priced sapphires are heated to obtain a better pink or, rarely, a reddish hue. The original sapphires of these particular colours often contain rutile within them. It is probable that some titanium causes the violet tinge in such gemstones (see Nassau, 1980; Schmetzer & Bank, 1981). Without disturbing the Cr^{3+}, a heat treatment in reducing atmospheric conditions, at a temperature of 1000 °C to 1500 °C, may result in the removal of rutile.

$$4TiO_2 \rightarrow 2Ti_2O_3 + O_2 \text{ (after Nassau, 1981)}$$

This effects the removal of the blue tinge in the stone, and they appear pink or red in colour after the operation. However, the results of such 'cooking' methods are not very successful. The result is more pink (75% to 85%) than ruby coloration (which may be 5% to 7%).

Only a few dealers in Sri Lanka have adopted Thai methods of heat treatment. The higher temperatures required are achieved by using natural gases or oil (Gunaratne, 1981). Such common oil and gas ovens are sketched in Figures 5a and b respectively. The heat treatment in Sri Lanka is shown to be much more successful than at early stages. According to the discussions had with one of the largest operators the author was informed that only very little treatment is carried out which succeeds in obtaining the 'pure' ruby colour. The attempts made mostly ended up with pink colour as mentioned before. A more primitive process of altering the colour of corundum varieties is the so-called blow-type heating (Gunaratne, 1981). As shown in Figure 6, it is done by coating the gems with clay and by heating, which is obtained by blowing charcoal, in a sand bath. However, this is practised by those dealers who are able and willing to risk the uncertain results of this method.

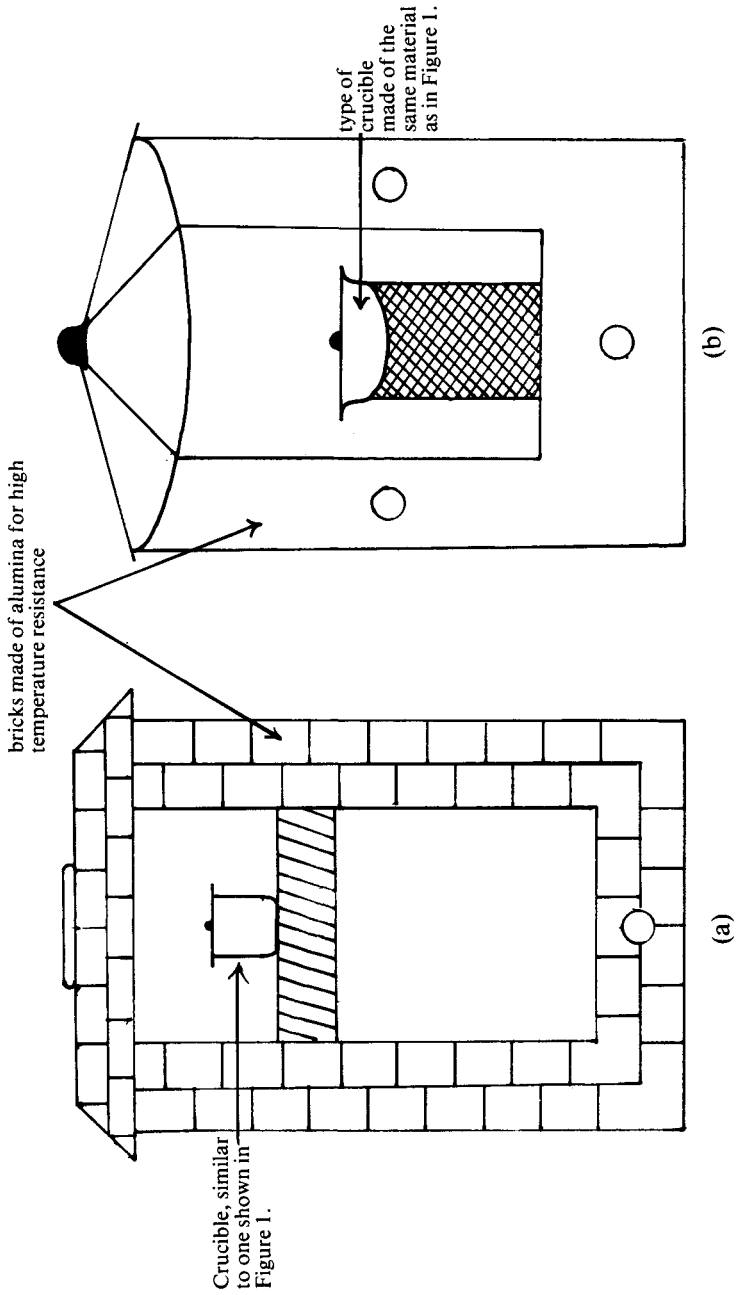

FIG. 5. Typical (a) oil and (b) gas furnaces used in the heat treatment of corundum in Sri Lanka.

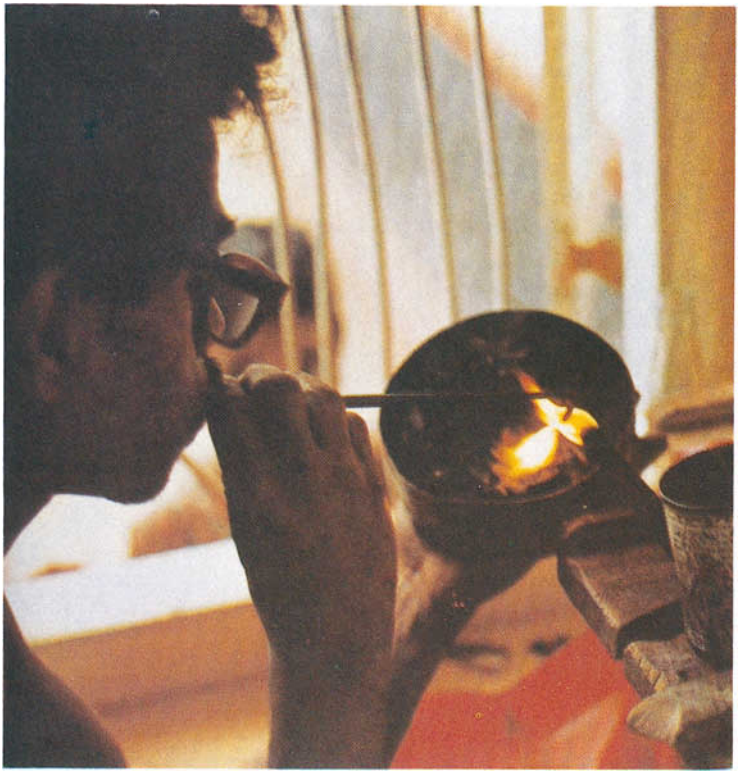

FIG. 6. A historically famous mode of colour alteration—blow type heating—used in Sri Lanka.

DIFFUSION TREATMENT OF RUBIES

The patents introduced by Carr & Nisevich (1975, 1976, 1977) and assigned to the Astrid Corporation Ltd, of Hong Kong, describe glossing of colour in natural or synthetic corundums. Commercially important diffusion treatments related to blue sapphires were mentioned by Nassau (1981) and Crowningshield & Nassau (1981). Those U.S. patents assigned to the Hong Kong company also mention the possibility of diffusion by using oxides other than iron and titanium as in the case of blue sapphires. Nickel, chromium or nickel + chromium oxides are used to give different surface coatings (Carr & Nisevich, 1976 & 1977).

Recognizable amounts of chromium can be induced into pink or colourless sapphires under heat. The mechanism of this is to

move the chromium atoms into the stone under heat. This 'skinning' method, however, is dependent on the temperature and the period of treatment. The process after Carr & Nisevich (1976, 1977) is now practised on most of pink Sri Lanka sapphires, and such colour-coated violet sapphire was detected by Ohguchi (1982). The colour-coated ruby examined by the author was also of Sri Lankan origin. This was confirmed by the inclusions (mentioned below) and the results measured by a UV spectrophotometer (λ 339 nm; λ/W 4.75), a method introduced by Bosshart (1982).

GEMMOLOGICAL IDENTIFICATIONS

The corundum gems now need to be examined with much more intensive gemmological identification methods. The question for gem labs is not only whether the ruby is natural or synthetic but also, if it is natural, whether heat-treated or not. Several investigators provided conclusive answers in this connexion (Crowningshield & Nassau, 1981; Scarratt, 1981; Schiffmann, 1981; Hänni, 1982 a and b; Gübelin, 1982; Schmetzer *et al.*, 1982; Ohguchi, 1982). Some of the characteristics described can be used simultaneously in separating treated rubies.

The most characteristic discrimination features of 'cooked' rubies can be recognized through intensive microscopic studies. These characteristics can be divided as *internal* and *external* alterations. The extensive work done by Gübelin (1973) on the origin of inclusions in coloured gemstones must be taken as a comparison in detecting the epigenetism caused on those treated rubies. This means an alteration of protogenetic and syngenetic inclusions under high temperature conditions. Such syngenetically trapped scenery change to an appearance of epigenetism is shown in Figures 7 and 8 respectively. The liquid droplets of Figure 7 are absent in Figure 8. On some occasions the crystal matter is revealed partly dissolved with surrounding healing feathers. This distinction was made by observing nearly 800 rubies from Thailand before and after heating. However, this is not the only discriminatory criterion for the separability of heat-treated rubies. Also observed were various forms of disc-shaped fissures (Figure 9). Similar healed feathers were observed by Hänni (1982 a and b) and Gübelin (1982) in treated blue sapphires.

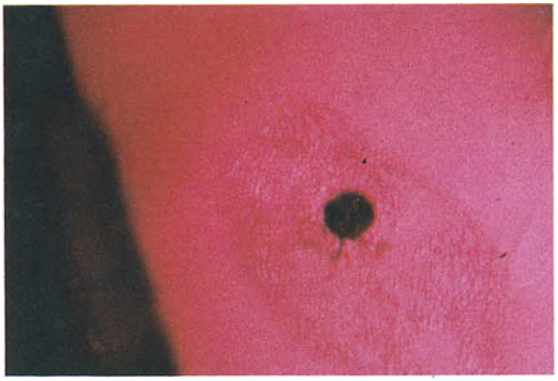

FIG. 7. Locality typical inclusion in Thai ruby; a circular feather with a pyrrhotite crystal at the centre. 25 ×

FIG. 8. Epigenetism caused to the inclusion in Fig. 7 under high temperature. The crystal, after melting, has created a void with a healed feather around. 40 ×

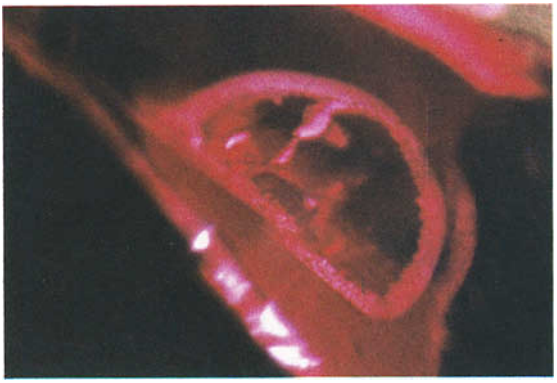

FIG. 9. Healed fissure, often encountered in 'cooked' rubies from Thailand. 60 ×

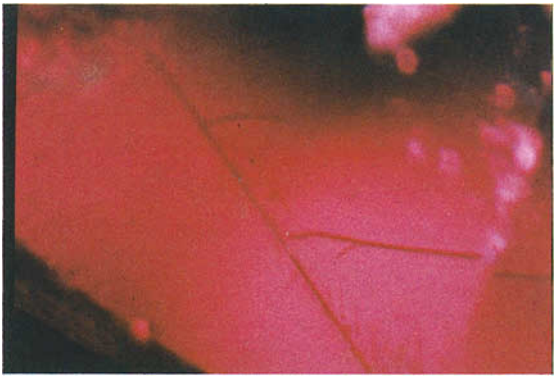

FIG. 10. 'Fire marks' with adjoining hair fine cracks detected as a typical external feature in heat treated Thai ruby. 40×

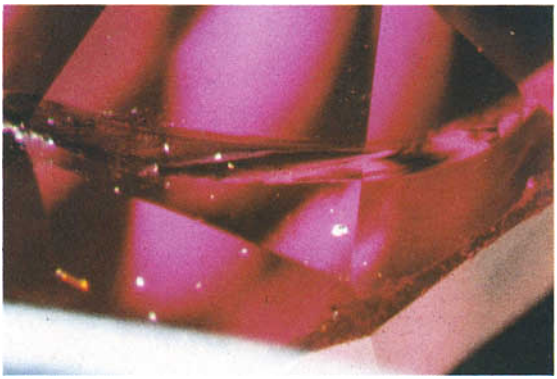

FIG. 11. A fire crack penetrating into the ruby after several repeated heat treatments in Thailand.

FIG. 12. Often seen 'injuries' on the surface of a ruby after high temperature inducement. 30×

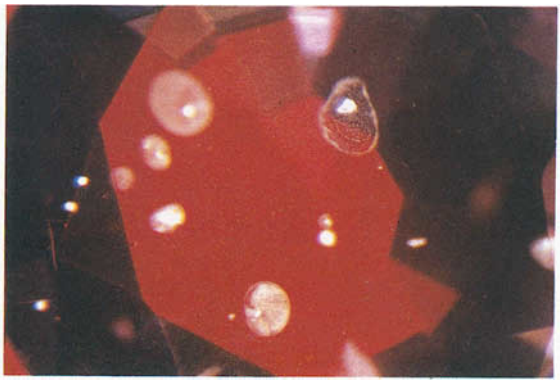

FIG. 13. Typical circular discs of healed fissures seen in a diffusion treated ruby from Sri Lanka. 25 ×

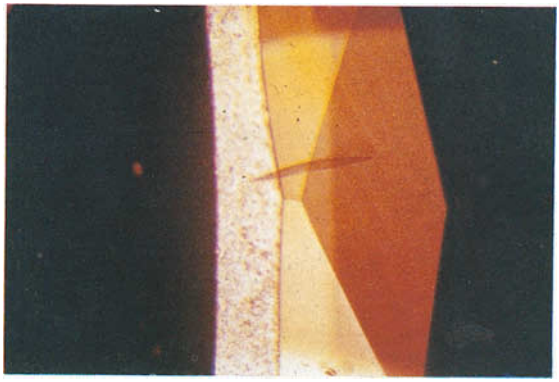

FIG. 14. Different thicknesses of the coating on the two facets and typical 'pock marks' on the inpolished girdle of the diffusion treated ruby investigated. 40 ×

During many observations made it has become apparent that corundum gems need to be examined internally as well as externally. Some noteworthy marks are now encountered on most rubies of Thai origin upon careful surface examinations. Similar surface marks were reported on synthetic corundums made by Verneuil and termed as 'fire marks' (Webster, 1975). The observed rubies from Chanthaburi-Trat province revealed some fire marks (Figure 10), which were, however, dissimilar in appearance to those seen in flame-fusion made rubies. Such fire cracks may penetrate into the stone in repeated heating and appear as in Figure 11. Other features worth mentioning are the strongly damaged surface

'injuries' (Figure 12). These surface markings are caused by multiple reheating at high temperatures. However, they can be minimized, and the stones will present a better surface appearance if repolished before they reach the market.

With the belief of its treated origin in Hong Kong, the author revealed few characteristics in a diffusion treated ruby. The disc shape (the discs were round in this connexion rather than the oval contour of Thai ruby, see Figure 9) and healing fissures (Figure 13) were a common indication in this stone confirming its origin to be Sri Lanka. Under immersion microscopic observation, using methylene iodide ($n_D = 1.74$), the colour concentration on different facets showed (Figure 14) variable thicknesses. The typical 'pock-marks' were present on the unpolished girdle (Figure 14). Recently Ohguchi (1982) mentioned the identification of colour-doped ruby by the use of x-ray fluorescence chemical analysis. He noted different outputs of transmission curves for synthetic, natural and natural colour-coated rubies respectively. It showed that the doped sample contained a higher percentage of colouring material than the non-treated samples.

CONCLUDING THOUGHTS

The colour of ruby can be enhanced by heat or diffusion treatment. The former can occur in nature and may be difficult to detect. The methods introduced by previous investigators can be used simultaneously with the criteria mentioned in this work. However, a steady practical knowledge of internal and external features of rubies is a necessity in such separations. Even though the colour may remain stable, the durability may be disturbed by repeated heating.

Diffusion-treated rubies must be disclosed to the trade. This colour coating procedure is detectable under various gemmological observations by microscope. During the preparation of this paper only very few stones were available in the trade. However, one can expect them to flood the market in future, especially when in those ruby occurring localities they find the best way for them to reach the jeweller.

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[Manuscript received 18th July, 1983.]

ON THE IDENTIFICATION OF A LIGHT PINK PYROPE GARNET AND A KORNERUPINE

By J. M. DUROC-DANNER, F.G.A., G.G.

INTRODUCTION

Recently the writer acquired a parcel of a number of faceted stones. These were mostly sapphires, spinels, and zircons. Some of the stones were not what they were marked, but were easily identified. . . . A small brilliant-cut orange 'spinel' turned out to be a tourmaline, and a deep blue 'zircon' with no double refraction, but with angular markings, was in fact a magnificent blue spinel. Two however were more troublesome and needed a more thorough investigation.

A LIGHT PINK PYROPE GARNET

A light pink stone of 2.46 carats, marked as spinel, was surprisingly clean when viewed under the microscope, except for a few angular-like oriented needles. Since these inclusions are not diagnostic for spinel,[1,2,3,] the stone's identity had to be confirmed.

Anomalous double refraction similar to that seen in some glass imitations was observed under the polariscope, and this according to literature is not at all characteristic of spinel.[1,4]

The refractive index of 1.737 and the specific gravity of 3.738 were much higher than the normal values for a pink spinel.[1,4,5]

No fluorescence could be detected, while pink spinels are said to show a crimson glow under ultraviolet light.[1]

The spectroscope revealed a strong line centred at 432 nm, a broad band at 490-505 nm, two lines at 525 and 570 nm, and weak chromuim lines at 650 and 670 nm. This also is not very characteristic of a pink spinel . . .[1,6]

The strange 'spinel' was in fact a very nice specimen of a light pink pyrope garnet, which was ascertained by its chemical analysis (Table 1).

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TABLE 1

Analytical data and derivation of formula

Chemical analysis wt%			number of ions	
SiO_2	—	45.20	Si	3.04
Al_2O_3	—	25.33	Al	2.00
MgO	—	28.50	Mg	2.88
TOTAL	—	99.03	O	12.00

Empirical formula : $Mg_{2\cdot88}\,Al_{2\cdot00}\,Si_{3\cdot04}\,O_{12}$

Ideal formula : $3MgO.Al_2O_3.3SiO_2$

A KORNERUPINE

Zircons were checked under the microscope for doubling of the facet junctions. All except one, a 3.49 carats oval-cut saturated green stone, showed this effect. It should be mentioned here that, if strong doubling of opposite facets is characteristic of zircons due to their high birefringence, this effect is seen in most varieties except perhaps the green and the very rare orange metamict zircons.[1] Microscopic examination of this green stone with dark-field illumination revealed some very long thin needles (rutile ?) oriented in two directions forming an angle of approximately 147°. Since rutile needles are present in numerous gemstones, and therefore alone are not diagnostic, it was decided to check the physical properties of this stone.

PHYSICAL PROPERTIES

The stone was examined table down in a Gem Illuminator Polariscope, set to its dark position, where the vibration directions of the polarizer and analyser are perpendicular to one another. The stone was rotated in this position, and instead of the typical blinking reaction of anisotropic stones, it remained light with only a slightly darker band moving across the stone as it was turned.

To confirm the anisotropy of this stone, without changing its orientation, and with the polariscope kept in its dark position, the stone was rotated to the position that permitted the maximum of light to pass—a position where the dark band had completely disappeared. Next, the analyser was quickly turned to its light position, and, since simultaneously the stone appeared darker, double refraction was indicated.[7]

The fact that this stone remained light, while rotated between crossed Polaroids suggested that the table facet was probably cut perpendicularly to an optic axis.

To visualize this, and determine whether the stone is uniaxial or biaxial, the polariscope was set to its dark position, and a glass sphere placed on the stone's pavilion. The entire biaxial interference figure could be seen inside the glass sphere (Figure 1).

FIG. 1. Biaxial interference figure made visible by a glass sphere between crossed polars.

By rotating the stone a few degrees, the two brushes corresponding to the two optic axes could be brought closer to each other, and gave rise to a cross-like pattern similar to that of the uniaxial interference figure.

From this test, the stone was proved biaxial, with a very small 2V angle (axial angle), and it was clear that it could not be a green metamict zircon.

The refractive indices determinations were carried out by using a Rayner Dialdex critical angle refractometer with monochromatic sodium light. Only the stone's table facet could be tested to obtain all the refractive indices, since the unsymmetrical narrow step-cut

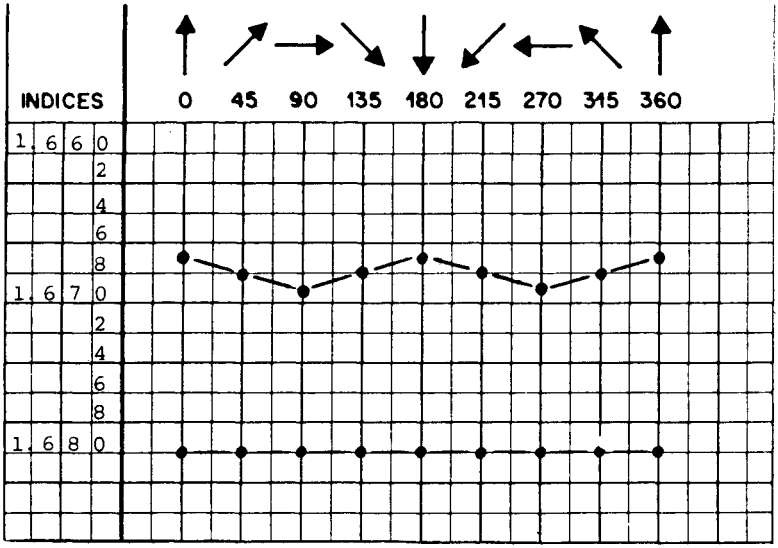

FIG. 2. Refractive indices graph.

faceting of the off-centred pavilion did not permit the stone to sit properly on the refractometer. The stone was rotated every 45° and its indices recorded until a rotation of 180° was obtained, since beyond this point the reading repeats itself. The indices obtained are shown in Figure 2. From these readings it is impossible to tell whether the stone is uniaxial negative, in which case $\omega = 1.680$, $\varepsilon = 1.667$, or biaxial positive with $\alpha = 1.667$, $\beta = 1.669$, $\gamma = 1.680$ (table facet cut perpendicularly to the acute bisectrix), or biaxial positive ? or negative ?, with $\alpha = 1.667$, $\beta = ?$, $\gamma = 1.680$ (table facet cut perpendicularly to the axes planes)[8]. Since the biaxial interference figure was obtained, the stone had to be analysed from another direction to find the value of β and the optic sign. This was done with a minute crystal taken from the stone's girdle and revealed under the polarizing microscope the following indices:

$$\alpha = 1.667 \quad \beta = 1.676 \quad \gamma = 1.680$$

giving a birefringence of 0.013, optic sign (-). By consequence, the table facet of this stone is cut *more or less* perpendicularly to the optic axes planes[8].

The stone remained suspended in methylene iodide of specific gravity 3.32, and hydrostatic weighing of the stone in distilled

water at 4°C using a Mettler PL 300c balance (accuracy ± 0.001 carat) indicated a specific gravity of 3.314.

The pleochroism observed through the pavilion with a Rayner dichroscope was distinct; light green, medium green, and brownish-red (tobacco leaf colour).

The absorption spectrum seen through a Gem Beck Spectroscope Unit, showed only vague indistinct lines in the blue portion of the visible spectrum.

No fluorescence could be seen with a Multispec combined LW/SW Unit (G.A.A.J.).

These physical properties correspond to the complex magnesium iron aluminium boro-silicate, kornerupine.[9,10,11] X-ray powder diffraction and qualitative chemical analysis were undertaken to confirm the identification.

QUALITATIVE CHEMICAL ANALYSIS

The stone was analysed with a P.G.T. energy dispersive analyser coupled to an electron microscope. This showed major contents of Mg, Al, Si, with very little iron. Boron was not detected due to its very light atomic weight, so a final test was undertaken.

X-RAY POWDER DIFFRACTION

A scraping of the stone's girdle was submitted to a beam of monochromatic x-rays (Cu/Ni) in a cylindrical Gandolfi Camera of diameter 114.6 mm. After an exposure time of approximately 7 hours, under working conditions of 40 Kv, and 20 mA, the most important lines were found to be lying at:

d (Å)		I (vis.)
10.35	—	40
6.85	—	35
3.349	—	50
3.003	—	100
2.617	—	100
2.100	—	40
2.080	—	30

and could be matched in the Powder File (J.C.P.D.S. 29-852) to those diagnostic for Kornerupine.

CONCLUSION

With x-ray powder diffraction the identification of kornerupine was confirmed. The physical, optical, and chemical properties are consistent with the range of data quoted in gemmological literature for this mineral.

The main difficulties in the identification of the light pink pyrope garnet and the kornerupine lay in the many possibilities to be considered and the correct interpretation of the information gained from the different tests.

The origin of these two stones, the pyrope and the kornerupine, is unknown to the writer, but according to the cutting style of the kornerupine, this stone could originate from Sri-Lanka.

ACKNOWLEDGEMENTS

The writer is indebted to the Natural History Museum of Geneva, and in particular to Dr H. Sarp, for carrying out the chemical analysis and x-ray powder diffraction, and for confirmation of the physical properties by the polarized microscope.

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CHELSEA, PAWNBROKING AND GEMMOLOGY

By A. E. FARN, F.G.A.

Frinton-on-Sea

I stopped smoking just after the War, not for health reasons, but simply because with a mortgage, smoking was a luxury I had to jettison.

I remember, as a youngster long before the War, a childish interest in collecting 'cigarette cards'. These were issued by the various manufacturers to attract sales. Series such as the 'Flags of the League of Nations', 'The British Army Regiments', were very popular.

One such series I believe was entitled 'Do you know?'. On each card was illustrated in colour a bird, a tower, a symbol, a building, a bridge, and on the other side would be a brief succinct résumé of the details. Some to a small boy would be fascinating, others not so interesting. One which stays in my memory showed three round flat golden-coloured discs. These were said to be three gold bezants representing the 'arms' of money lenders from Lombardy and were said to be the origin of the pawnbrokers' sign of the three golden balls.* Certainly Lombard Street in the City of London is associated with money lending and banking. The three balls mounted two above and one below were facetiously said to signify the odds of two to one against the ultimate redemption of a pledge. In pawnbroking parlance a pledge was something left in pawn against a loan.

Perhaps my continuing memory of the three gold bezants on a cigarette card is due to the fact that my father managed a pawnbroker's shop in inner London, and we lived above the shop. Outside my bedroom window hung three brass balls and later a clock with the name of the shop plus 'Established in 1796'. As a small boy I lay in bed at night unable or unwilling to go to sleep; below me in the main shop a succession of strikes, chimes and cuckoos emanated from the mechanisms of the stock of clocks which in those days were Westminster and Whittington wooden mantel clocks, alarms, cuckoo clocks and sometimes a sonorous grandfather clock.

*'Supposed by some to be derived from the ensign of the wealthy Medici family.' (*O.E.D.*)—Ed.

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Somewhat reluctantly, upon leaving school I started working in the shop as a 'warehouse boy'. This entailed carrying up parcels of clothing, shoes, which had been pawned that day, and stacking or arranging them in date and type order. One room was entirely boots and shoes; the basement was blankets and sheets, and in the loft musical instruments and miscellaneous goods of a very weird and varied nature.

Jewellery was kept downstairs in a compartmentalized safe. The jewellery was usually wedding rings and watches—we didn't live in a wealthy district. After an altercation with my father, who was anxious that *no one* could accuse him of favouring his son, I left and went to yet another pawnbroker in the west of London. Here I lived in as a member of staff. The food was poor. The accommodation consisted of one bedroom shared with two other lads as well as various gramophones, wireless sets, fishing rods and a bicycle—all being pledges.

After a fairly short period I left to join yet another pawnbroking establishment in Chelsea, in the Kings Road near to a now popular pub called 'The Worlds End'.

At the Chelsea shop I heard that my predecessor 'knew all about stones', because according to my junior (17 years) he had been to the polytechnic for stones. Sad to say that at that time Chelsea, its polytechnic and stones meant nothing to me. I was too busy cycling the difficult twelve miles across London daily to think of evening classes.

The employer, a most lugubrious individual, told us all one day that he was going to retire and close the shop—he couldn't sell it and the pawnbroking department had to run down over a year to allow the full term for pledges to elapse.

I found yet another job, this time in the retail jewellery department of a West End pawnbrokers named Jay Richard Attenborough—there were at that time three firms of pawnbrokers carrying the name Attenborough; one only remains in Fleet Street.

At my particular shop I soon found how little I knew—least of all about gemstones. My immediate senior was one George Ratcliffe, F.G.A. (1934): he told me in no uncertain terms that I was extremely ignorant and ought to go to gemmology classes. 'Gemmology, whats that?' was my query, and in practically no time I was at Chelsea Polytechnic with one or two other young chaps, one named Harry Wheeler and another Sam Redknap.

We had an instructor named B. W. Anderson, and another named Thorold Jones. The war years interrupted us for a while, but in September 1946 I enrolled again with others, among whom were Sam Redknap and Harry Wheeler, Bert Clark, Dr Rutland, Dr Stern, all ex-army types.

I never wanted to go into the pawnbroking business, and I didn't expect to get a job in the Laboratory. I felt very much at home though when I made the acquaintance of Robert Webster; he too was ex-army (both wars), still quite young, and equally had an ex-pawnbroking beginning—and strangely enough just outside the Chelsea boundary. There may not be a strong link between Chelsea, pawnbroking and gemmology but at least an interesting one started by George Ratcliffe, who incidentally after the War joined yet another pawnbroking firm.

[*Manuscript received 28th November, 1983.*]

AUSTRALIA'S FIRST EMERALDS

By GRAHAME BROWN, Dip.D.T., F.G.A., F.G.A.A.

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Well respected gemmological texts[1,2,3,4] record that Australia's first commercial emerald deposit was discovered, in 1890, just 9 km to the north-north-east of the small northern New South Wales tin mining town of Emmaville. Emmaville (Figure 1) or Vegetable Creek—to use the original town name, that was derived from the many Chinese market gardens that lined the town's water-course—is located (Map 1) on the western edge of the New England Batholith. Twenty miles to the east of Emmaville lies Deepwater—a country town on the New England Highway, which joins Brisbane to Sydney.

FIG. 1. The town of Emmaville, from the Gulf Road that leads to the Emerald Mine.

HISTORY OF THE EMERALD MINE

David[5], Wynn & Loudon[6] and Mumme[7] have between them provided a relatively complete history of emerald mining at The Glen or Glen Creek area. This history is briefly summarized below.

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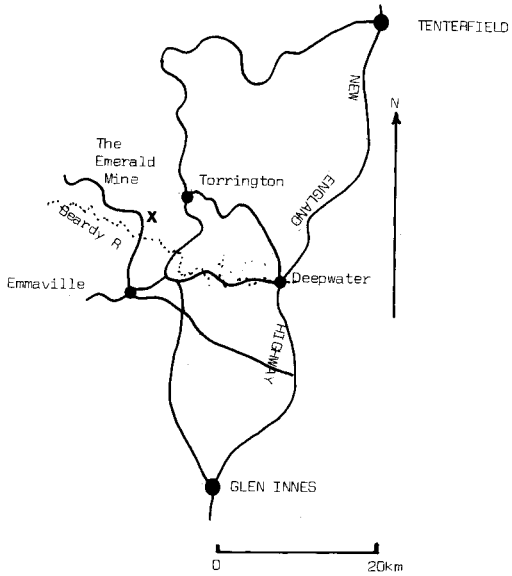

MAP 1. The location of the Emerald Mine at the Summerville (formerly Dakalbin) pastoral property, near Emmaville, N.S.W.

1881 A deposit known locally as De Milhou's Reef or Cleary's Lode was hand mined for cassiterite.

1890 D. A. Porter, an Inspector of Public School Buildings, and an amateur mineralogist, discovered ?emerald, while prospecting the abandoned tin lode at De Milhou's Reef. Porter submitted a small parcel of these green crystals to T. W. E. David—then a Geological Surveyor with the N.S.W. Department of Mines & Agriculture. A report on these samples, by David, concluded: 'they are beryls, of a colour sufficiently emerald green to entitle them to be termed emeralds.'

Porter's find was taken up by the Emerald Proprietary Company, who named the mine they developed on De Milhou's Reef, the Emerald Proprietary or the Emerald Mine. In this same year, the mine was sunk to a depth of 15 m, and an 18 m long drive was completed along the line of the emerald-bearing lode.[8] A parcel of 2250 ct of marketable emerald (both rough and cut) was sent to

London for valuation. Some of the faceted emeralds were sold for £4 per carat.[9]

1891 The Emerald company had sunk two shafts on their lease: the original mine to 15 m, and a new shaft to 30 m. From both of these mines, 25 000 ct of emeralds were recovered. Of the emerald mined, only 0.01 to 0.02 per cent was of gem quality.[10]

1892 About 25 000 ct of emerald, of unknown value, were mined. Due to the hardness of the rock enclosing the emeralds, recovery of emerald, in an undamaged state, proved very difficult.[11]

1893-4 Unprofitable returns for emeralds, sent to London, caused the mine to cease production.[12]

1897 Mining was recommenced, and the main (15 m) shaft was deepened to over 90 m. The purpose of this extension was to test the deposit at depth. No emeralds were recovered at depth.[13]

1898 Sporadic mining was attempted, but no financial return was obtained. The mine again ceased production.[14]

1908-9 The mine was again reopened, and 1000 ct of emerald (valued between £1,600 and £1,700) were recovered from the old drive. The largest emerald rough recovered weighed 60 ct. Of a parcel of rough, that was cut in Europe, the largest stone weighed 6 ct, while the other 49 cut emeralds were determined to be of fair quality, but of pale colour.[15]

1909-63 Only minor prospecting occurred at the Emerald Mine.

1963 A winze was sunk in the drive, at a point 12 m from the main shaft. Unknown quantities of supposedly good quality emeralds were recovered during this mining phase.

1964 The Emerald and its associated mines were surveyed by Wynn & Loudon.[6]

1965-80 No mining activity occurred. The mine was occasionally visited by fossickers.[16]

1981 The main shaft of the Emerald Mine was dewatered and cleaned of accumulated debris. Exploration of the old workings revealed that the mine had a main shaft, 98 m deep, and that two separate drives had been established in a north-easterly direction: a 23 m long drive at the

9 m level, and a 9 m drive at the 37 m level. Plans are believed to be currently in hand for recommencing mining in the drive at the 9 m level.[17]

Recorded emerald production from this mine is incomplete at 53 225 ct,[18] and is most likely to be underestimated.

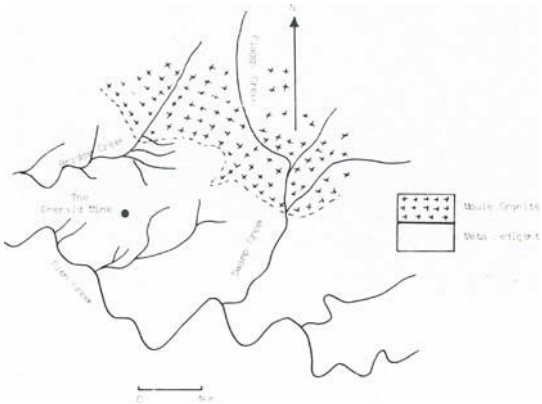

MAP 2. The geology of the emerald deposit at the Emerald Mine, near Emmaville, N.S.W. (*after Wynn & Loudon (1965).*[6]).

GEOLOGY OF THE DEPOSIT

The emeralds occur (Map 2) in a Permian sedimentary sequence that had been intruded by pegmatite and aplite from the nearby Moule Granite.[6] The Emerald Mine (Figure 2)—GR 46693622 Grafton 1:250 000—is sunk into an irregularly shaped lode which dips from the north-east to the south-west from the Moule granitic stock. Although this lode tends to bifurcate, only one emerald-bearing lode has so far been discovered. The emerald-bearing lode is the one that intersects the main shaft of the Emerald Mine at its 9 m level.[19]

The emerald-bearing lode is a quartz-topaz-feldspar-mica pegmatite, that varies in width from 50 mm to 1 m and is a late phase derivative of the nearby Late Permian Moule Granite. This pegmatite has intruded into the surrounding meta-sediments (Permian siltstones, slates, quartzites), along north-east to south-west trending joints.[8]

In the pegmatite, emeralds occur irregularly, as 'bunches', usually firmly embedded in flattened cavities in the quartz-topaz

FIG. 2. The headframe at the Emerald Mine (1982).

vein rock (Figure 3). In these cavities, the generally small (< 1 ct) emeralds are often surrounded by an uncommon kaolin-group mineral—dickite.[20] Minerals frequently associated with the emeralds in the lode are cassiterite (SnO_2), fluorite (CaF_2), arsenopyrite (FeAsS), wolframite (an intermediate member of the series huebnerite $MnWO_4$ and ferberite $FeWO_4$), and rarely quartz.

A recent mineralogical investigation of this emerald-bearing lode[20] indicated that:

- The wall rock was formed from a hard, fine-grained quartz-topaz rock, with a ratio of quartz to topaz of 80:20;
- The narrow alteration zone of the pegmatite was produced by dickitization-type hydrothermal alteration of the topaz content of the host rock; and,
- The lode consisted of major fluorite, beryl, quartz, topaz; with minor cassiterite and arsenopyrite.

Additionally, Mumme[7] has observed that the very small ionic size of the chromophore in this particular emerald prevented its entry into the early stage minerals, that crystallized from the Moule Granite; but this small ionic size allowed the ion to be concentrated in those minerals formed in the late stage pegmatitic veins.

FIG. 3. Emerald crystals in a flattened vugh, in the lode at the Emerald Mine. Note the presence of the minerals that are associated with this lode: fluorite (purplish), dickite (opaque white), arsenopyrite (silvery), quartz (glassy grey).

FIG. 4. Typical habits displayed by the emeralds from the Emerald Mine.

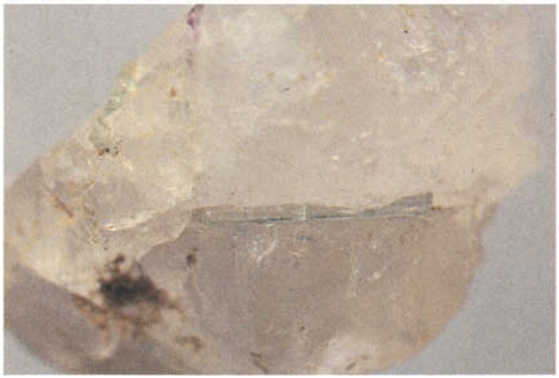

FIG. 5. Specimen of Emerald Mine emerald penetrating quartz.

FIG. 6. Specimen of Emerald Mine emerald penetrating fluorite.

FIG. 7. Specimen of Emerald Mine emerald intergrown with topaz.

FIG. 8. Specimen of Emerald Mine emerald enclosed in its host rock.

GEMMOLOGY OF THE EMERALD

Emerald crystals, from the Emerald Mine, display a decidedly acicular habit (Figure 4), with the hexagonal prism and basal pinacoidal forms dominant. The emerald crystals, which vary in dimension from 1-10 mm in width and up to very rare 3 cm lengths, are found as attached crystals in collapsed dickite-filled cavities within the lode (Figure 3), as well as occurring as crystals penetrating quartz (Figure 5), fluorite (Figure 6), topaz (Figure 7), or the host rock (Figure 8). These mineral associations for the emerald of the Emerald Mine are supported by Stevens's suggested paragenetic sequence,[20] of:

Topaz
Beryl
Quartz
Fluorite

Colours observed in the emeralds, from the Emerald Mine, vary from the faintest greenish hue to a light bright emerald green shade—with a yellowish rather than bluish secondary hue. Stevens's spectrographic analyses clearly attributed the greenish hues of the emerald from the Emerald Mine to their 1000 ppm vanadium and perhaps their 450 ppm copper content, rather than their 350 ppm chromium content. Rather surprisingly no iron was detected in these emeralds.

GEMMOLOGICAL PROPERTIES

Gemmological properties were established for representative samples of gem qualtiy emerald from the Emerald Mine. These properties are listed in Table 1.

CHARACTERISTIC INCLUSIONS

Microscopic examination (×20 and ×50 magnification) of these emeralds revealed a rather common pattern of inclusions, that readily confirmed the pneumatolytic origin of these particular emeralds. The Emerald Mine emeralds displayed many inclusions that could be considered to be typical for beryl—irrespective of its variety.

The inclusions recorded in this investigation into emerald from the Emerald Mine, include:

TABLE 1. The gemmological properties of emeralds from the Emerald Mine, near Emmaville (N.S.W.).

SPECIFIC GRAVITY	2.68
DIAPHANEITY	Transparent
LUSTRE	Vitreous
REFRACTIVE INDEX	ω 1.575, ε 1.57
BIREFRINGENCE	0.005
OPTIC SIGN	U^-
PLEOCHROISM	ω Yellowish green, ε Green
CHELSEA FILTER	Very pale pink
FLUORESCENCE	Inert
ABSORPTION SPECTRUM	A broad absorption band centred at 610 nm, with absorption of the ε ray wider than that of the ω ray. General absorption below 454nm.

.....as Liquid Inclusions[21]

* Two-phase primary tubes oriented parallel to the *c*-axis of the crystal (Figure 9);
* Two-phase primary 'daggers' oriented parallel to the *c*-axis. These inclusions have been produced by a crystal interrupting the rapid growth of the emerald crystal in the direction of its *c*-axis. (Figure 10);
* Partly resorbed parallel oriented tubes, the original two-phase contents of which have been replaced by an epigenetic cavity filling (Figure 11);
* Irregularly outlined two-phase primary polycuspate inclusions oriented parallel to the *c*-axis or the crystal (Figure 12). Occasionally, these inclusions appear to be three-phased (Figure 13);
* Two-phase secondary partly healed incipient cleavages, or 'veils', that are oriented in the basal plane at right angles to the *c*-axis of the crystal (Figure 14). When viewed down the *c*-axis, these secondary inclusions display a net-like form (Figure 15); and

FIG. 9. Photomicrograph of two-phase liquid tubes parallel to the *c*-axis of an emerald crystal from the Emerald Mine. (×20 magnification)

FIG. 10. Photomicrograph of a two-phase primary 'dagger' inclusion included in an emerald from the Emerald Mine. This inclusion has been initiated by an included cassiterite crystal. The 'dagger' is oriented parallel to the *c*-axis. (×20 magnification)

FIG. 11. Photomicrograph of trichite-type inclusions in an emerald from the Emerald Mine. This inclusion has been formed by epigenetic mineral infiltration of resorbed parallel oriented tubular inclusions. (×20 magnification)

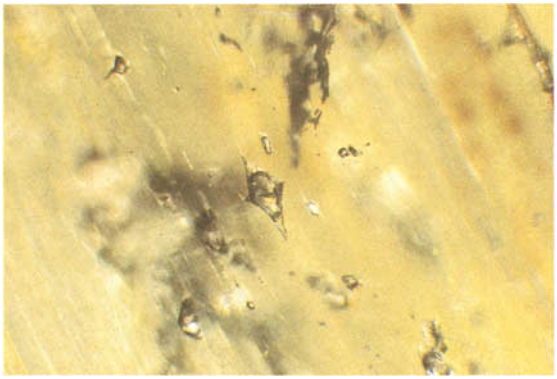

FIG. 12. Photomicrograph of a two-phase polycuspate liquid inclusion, that is oriented parallel to the *c*-axis in an emerald from the Emerald Mine. (×20 magnification)

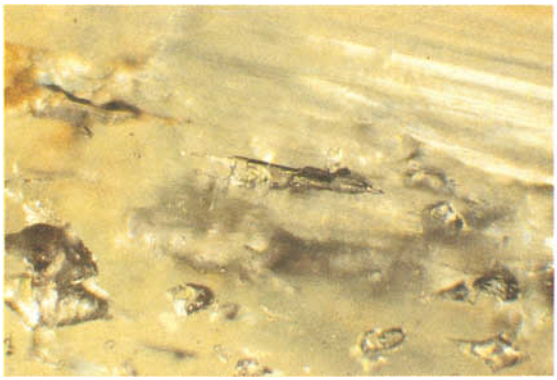

FIG. 13. Photomicrograph of a three-phase (solid phase arrowed) polycuspate inclusion in an emerald from the Emerald Mine. (×20 magnification)

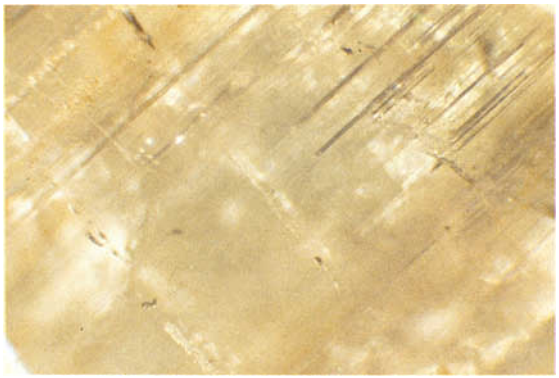

FIG. 14. Photomicrograph of partly healed cleavages in the basal plane of an emerald from the Emerald Mine. Note that these partly healed cleavages are at right angles to the two-phase tubes that parallel the *c*-axis. (×20 magnification)

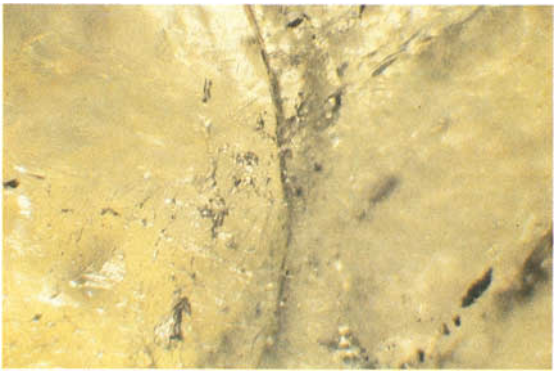

FIG. 15. Photomicrograph of the net-like appearance of the two-phase partly healed basal cleavages in an emerald from the Emerald Mine. (×20 magnification)

FIG. 16. Photomicrograph of randomly oriented partly healed cracks in an emerald from the Emerald Mine. Note the angulation of these cracks to the basal plane of the crystal. (×20 magnification)

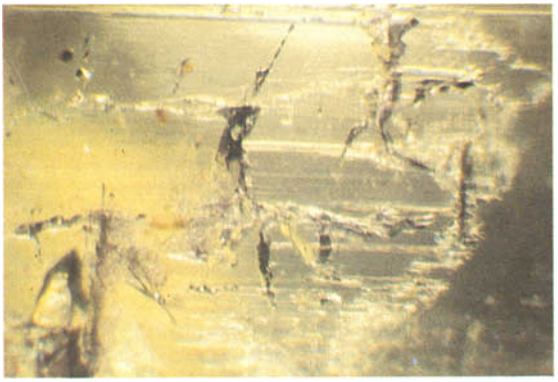

FIG. 17. Photmicrograph of randomly oriented two-phase partly healed cracks in an emerald from the Emerald Mine. (× 20 magnification)

FIG. 18. Photomicrograph of a very irregularly outlined thin film-like partly healed crack in an emerald from the Emerald Mine. (× 20 magnification)

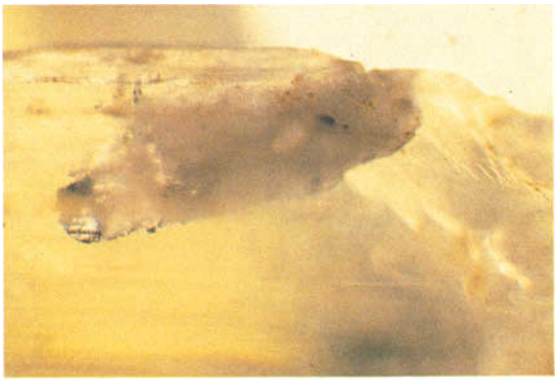

FIG. 19. Photomicrograph of a mass of fluorite that is included in an emerald from the Emerald Mine. (× 20 magnification)

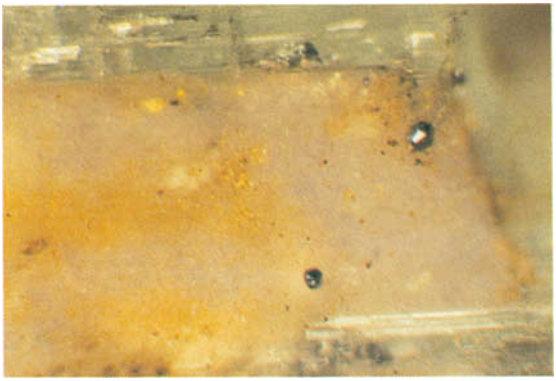

FIG. 20. Photomicrograph of included cassiterite crystals in an emerald from the Emerald Mine. Note the close association between the cassiterite and the fluorite. (× 20 magnification)

FIG. 21. Photomicrograph of an included silvery white mineral, of unknown constitution, in an emerald from the Emerald Mine. (× 20 magnification)

FIG. 22. Photomicrograph of an epigenetically precipitated brownish orange mineral that has infiltrated a crack in a completely grown emerald from the Emerald Mine. (× 20 magnification)

* Randomly oriented secondary partly healed syngenetic internal fractures, the contents of which may be either single-phase (Figure 16) or two-phased (Figure 17). Also in this category are irregular outlined, very thin films, of the trichite-type (Figure 18).

.....and as Mineral Inclusions[21]

* Masses of fluorite (Figure 19);
* Occasional crystals of cassiterite (Figure 20), that were always closely associated with the masses of included fluorite;
* Irregular masses of an unknown silvery white mineral (Figure 21); and,
* Epigenetically precipitated minerals that acted as cavity fillings in cracks that developed after the emerald crystal had formed (Figure 22).

Having completed this microscopic examination, before access was obtained to Stevens's 1971 thesis, it is gratifying to note that the observations recorded above in Figures 9-22 substantially confirm Stevens's[20] classification of inclusions in the emeralds from the Emerald Mine as:

Primary Inclusions

* colour banding
* two-phase hydrosaline tubes parallel to the *c*-axis
* negative crystals
* spherical randomly oriented two-phase inclusions
* very rare three-phase inclusions, and

Secondary Inclusions

* solid inclusions of fluorite, and
* dendritic two-phase striae oriented roughly parallel to the basal plane.

CONCLUSIONS

The emerald-green coloured beryls from the Emerald Mine, near Emmaville, contain vanadium, copper, and chromium as possible chromophores. To classify this beryl as an emerald would seem correct; in spite of its 350 ppm* chromium content.[22,23,25]

*Wood & Nassau (1968) suggest that a minimal 1000 ppm Cr^{3+} content should be present in a beryl before it should be classified as an emerald.

Emeralds from this deposit display a rich suite of liquid and mineral inclusions, that support the hypothesis that these emeralds are late phase derivatives of the nearby Moule Granite. Although the comparatively low refractive indices (1.57-1.575) and specific gravity (2.68) of this emerald fit the existing data[24] for vanadium-rich emeralds, of moderate water and alkali content; these data await ultimate confirmation by subsequent analytical results.

After almost a century of gemmological indifference, it is pleasing to report that at last this historically important emerald deposit has been described in the gemmological literature.

ACKNOWLEDGEMENTS

I wish to express my appreciation to Tony Cope, for allowing me access to his lease at the Emerald Mine; and to Hylda and Harold Bracewell for providing specimens for examination.

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SAPPHIRE FROM LOCH ROAG, ISLE OF LEWIS, SCOTLAND

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PREAMBLE

Occurrences of sapphire in Scotland have long been known (Heddle, 1901; McCallien, 1937; Firsoff, 1971); however, the sizes of all the specimens described to date have been small, mainly in the order of 1 or 2 mm, with thin platelets only rarely attaining a maximum size of 25 mm in diameter. The sapphires from Loch Roag represent a significant find as the crystals are all much larger, reaching 46 mm in diameter.

OCCURRENCE

The sapphires occur as megacrysts in a xenolithic dyke at Loch Roag, Isle of Lewis, Outer Hebrides, Ross and Cromarty, Scotland. The dyke, which varies in width from 0.5 m to 1.5 m, is exposed in a 4.5 m (maximum) vertical section for a length of 24 m, and intrudes almost vertically through rocks of the Lewisian Complex. The dyke is a monchiquite of lamprophyric affinities, and the xenoliths are coarse-grained rocks of presumed mantle and deep crustal origin (Upton *et al.*, 1983). There is a marked variation in the lithology of the dyke. Chilled margins (approx 25 cm wide) characterized by large corroded biotite crystals in a fine-grained matrix grade into a coarser central core containing, in addition to larger corroded biotite crystals and the ball-like xenoliths, corroded megacrysts of augite, apatite, sanidine, anorthoclase and corundum. Biotite and augite megacrysts are abundant, feldspar and grey opaque apatite much less so, whilst corundum megacrysts are scarce.

DESCRIPTION

The corroded sapphire megacrysts occur mainly as striated, distorted, truncated hexagonal pyramids and bipyramids (Figure 1) and occasionally as hexagonal tabular prismatic crystals (Figure 2). The size of the crystals varies, but few are less than 1 cm; the average size is 2-3 cm. All crystals are of gem quality, but the colour is variable even within individual crystals.

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FIG. 1. Pyramidal sapphire crystal, 28 mm long, in matrix.

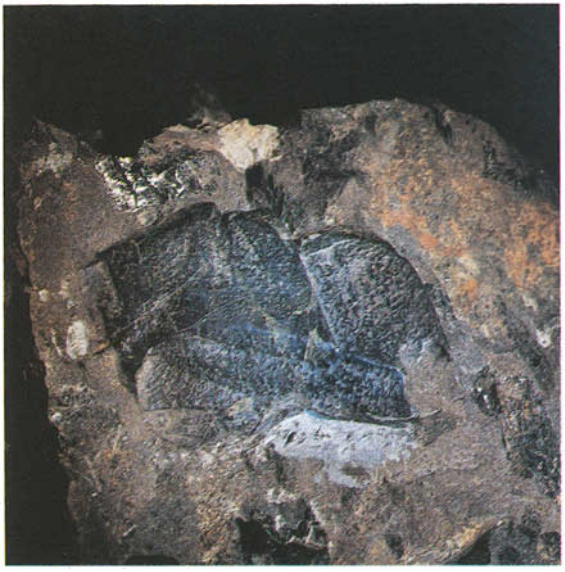

Fig. 2. Tabular sapphire crystal, 43 mm × 27 mm, in matrix.

FIG. 3. Pronounced colour zoning in crystal fragment.

FIG. 4. Hexagonal radial structure with sector zoning in a 22 mm × 27 mm polished crystal cross-section.

FIG. 5. Brilliant cut (8.5 mm dia × 4.5 mm) 2.7 ct dark blue stone with pronounced colour zoning and many fractures.

On balance the smaller crystals are of a fine blue colour, whilst the larger crystals are patchy with areas of blue, green and occasionally yellow. Colour zoning can be seen in some specimens (Figure 3). All of the sapphire crystals show fractures which have in many cases been filled with thin films of secondary iron staining. Some crystals also show well developed parting parallel to {0001}. One specimen in the possession of Edinburgh University Geology Department shows a hexagonal radial structure (Figure 4), with sector zoning. This is caused by symmetrical deposition of exsolution lamellae of haematite micro-inclusions (Upton *et al.*, 1983). As almost all the sapphires are being kept as fine crystal specimens, it was not possible to give a detailed examination of inclusions. Those few polished fragments which were examined proved to be inclusion-free. The single cut stone (Figure 5), 2.7 ct, did however show a large feldspar grain (approx 1 mm) exposed on the crown, and a profusion of micro, opaque breadcrumb-like inclusions and dark wispy veils, the latter two being intimately associated with the large amount of fracturing. Some specimens include grains of a niobium-rich rutile with up to 38% Nb (Aspen P., personal communication).

PROPERTIES

Refractive index:-	ε 1.762—1.767 ω 1.772—1.775 δ 0.008—0.010
Specific gravity:-	3.95—4.05
Absorption spectrum:-	All samples examined showed a medium diffuse broad band centred on 450 nm. No other lines were seen even when using a copper sulphate filter.
Pleochroism:-	Pronounced Because of the patchiness of the colour it is difficult to give the twin colours; suffice to say that they range from violet-blue to yellow-green.
Fluorescence:-	The sapphires exhibited no fluorescence under both long and short-wave ultraviolet.

DISCUSSION

This type of occurrence has similarities with the source rocks of the ruby and sapphire gemfield at Pailin, Kampuchea [Cambodia] (Jobbins *et al.,* 1981) and the sapphire deposit at Chanthaburi-Trat, Thailand (Keller, 1982). Not only are the host basalts of a similar composition, but they also contain nodules and corroded megacrysts of like types. The origin of the sapphires from these SE. Asian localities is regarded as of probable mantle origin (Barr *et al.,* 1978, 1979) as are the Loch Roag sapphires (Upton *et al.,* 1983). The major difference between the deposits is that whilst the Pailin and Chanthaburi-Trat deposits are derived from source rocks formed as a result of outpourings of Tertiary basaltic lavas from volcanic vents and dykes, the Loch Roag deposit is the result of late Palaeozoic intrusive igneous activity and apparently confined to a small area producing *in situ* crystals. A summary examination of the surrounding area revealed one other dyke, but this was not wide enough to have a coarse central core. Because of glaciation, some 10 000 years ago, there can be little likelihood that gem-bearing gravel deposits will exist. Examination of gravels in a nearby burn did not indicate that gem concentrates had formed in the post-glacial period.

Similarities also exist with the 'nodule province' alkali basalts found in Australia at Chinaman Peak, Queensland, and Hill End, New South Wales (Wass *et al.,* 1976). There, corroded corundum (sapphire) megacrysts have been found in Tertiary volcanic plugs and flows respectively. These Australian sources are not worked for sapphires because of the relative rarity of *in situ* crystals, the commercial sources being limited, as with the Kampuchea and Thailand deposits, to alluvial concentrates such as those at Anakie, Queensland, and Inverell, New South Wales.

At Yogo, Montana, U.S.A., sapphires are mined from a Palaeozoic alkali basalt dyke. This is the only mine of its type and one of the very few mines where sapphires are actually extracted from the source rock. The Yogo dyke, whilst being similar in composition to the Loch Roag dyke, does not show the same lithological features. There are no ultra-basic nodule xenoliths, and the rock is essentially fine-grained without megacrysts of the types found in the previously described areas. Most of the sapphires from the Yogo deposit are small; crystals or fragments weighing more than a few carats are extremely rare and the majority of the cut

stones weighed less than one carat (Clabaugh, 1952). The origin of the sapphires differs from those at Loch Roag in that it is attributed to the recrystallization of aluminous rich mudstones picked up at depth by the intrusion (Blodgett, 1981). The Yogo sapphires have a characteristic tabular habit similar to that of the Loch Scridain, Mull, Scotland sapphires, which are derived from baked high alumina shales (Richey, 1961). Yogo sapphires also have a very thin dark spinel coating not found on Loch Roag sapphires.

CONCLUSIONS

The Loch Roag sapphire occurrence strongly resembles those in SE. Asia and Australia, the major difference being the age and type of emplacement; however, the paragenesis is probably the same for them all.

For Scottish mineralogists and gemmologists this is an exciting find, providing as it does gem crystals of cuttable size. However the limited amount of sapphire-bearing rock in this pinch and swell dyke and the scarceness of the sapphires within it suggest that this will be relegated to the 'other occurrences' section in textbooks.

If, as Upton *et al.,* (1983) suggest, these gems are derived from the break-up of peraluminous pegmatoids in the upper mantle or lower crust, then, bearing in mind the loch, rock and bog topography, it is not inconceivable that other similar, and perhaps wider, dykes may lie hidden beneath the thick peat overburden waiting to be discovered. It was only by chance that this dyke was exposed while cutting an access track to peat diggings, for there is no trace of it on the surface.

ACKNOWLEDGEMENTS

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COMPOSITION, PROPERTIES AND ORIGIN OF A NEW TYPE OF HAEMATITE

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ABSTRACT

A new type of haematite which has recently come into use in the gem cutting industry is mineralogically characterized. The new type of haematite ore consists of granular haematite as a main constituent and of magnetite, martite and gangue minerals as minor constituents. The new type of haematite rock originating from Brazil has an Fe content of 69% Fe. Iron ores similar or identical in chemical and mineralogical composition are known and were mined as 'high-grade haematite' for a long time from different localities, e.g., from Quadrilátero Ferrífero area near Ouro Preto, Minas Gerais, Brazil.

INTRODUCTION

In recent months cut and rough material of an obviously new haematite type appeared on the market. Some of the properties of this new type of haematite are different from those of the material used up to now in the gem cutting industry, and, therefore, the attention of the trade was attracted to the new material. The haematite from England or from Morocco, which commonly was used up to now by the gem cutting industry, has a reddish or reddish-brown streak and does not show magnetism. In contrast to this old type, the new type of haematite is bluish grey in colour with a dark brown streak and an evident reaction to the magnet. In addition, the new type of haematite has a granular texture and does not show the radial fibres of orbicular haematite (glaskopf) used in the past.

Due to the properties of the new haematite material mentioned it was assumed by some dealers that the new product might not be haematite but magnetite or even an artificial product. In addition, in some certificates, the new material was indicated as an 'artificial product with a silicon-like binder' or as 'reconstructed haematite' (sintered product of magnetite and haematite as mentioned by Schlossmacher (1969)). In contrast to this certification, the new material was described by Fryer *et al.* (1984) as pure granular haematite. However, no additional details of the properties and composition of the material and no information on its origin are

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available. In the present paper the investigations performed at Heidelberg of this new material are described, which make a more detailed description of the composition of this new haematite ore available.

MATERIALS AND METHODS

For mineralogical characterization of the new haematite type, several cut and polished beads were supplied from different firms in Idar-Oberstein, and occasionally also rough samples of the ore were made available.

For the determination of present phases a great number of samples were investigated by x-ray powder diffraction techniques (Debye-Scherrer cameras, powder diffractometer). Qualitative and quantitative chemical analyses were carried out by electron microprobe, and, for ore microscopy in reflected light, some polished sections were prepared.

RESULTS

All samples investigated, which were assigned to the new type of haematite, consist of granular haematite as a main constituent (Figure 1), which is distinctly different from the orbicular type of haematite (glaskopf) with radial haematite needles or fibres as used by the gem industry in the past. A chemical iron determination of the rough haematite ore resulted in an iron content of 69% Fe, which corresponds to an extremely pure type of iron ore. In all samples investigated by ore microscopy a typical metamorphic fabric with granular haematite and various amounts of minor constituents as magnetite, martite (an alteration product of magnetite with haematite lamellae) and gangue minerals was observed (Figure 1). However, the main constituent in all samples was haematite, which was highly predominant over the content of magnetite, martite and gangue minerals. In one sample, goethite also was determined. By qualitative investigations of the gangue minerals by electron microprobe the rock samples were found to contain Al silicates and K-Al silicates (presumably clay minerals), and Ca phosphates (presumably apatite). The minerals mentioned and their intergrowths are shown in Figure 1.

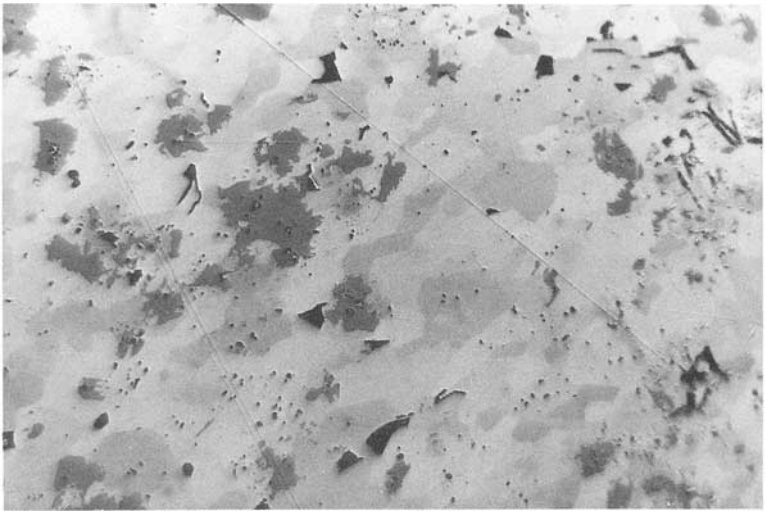

FIG. 1. Photomicrograph of polished section of high-grade haematite ore from Brazil. Greyish-white and light grey: haematite; dark grey: magnetite; black: gangue minerals and voids. (Oil immersion, not exactly crossed nicols, width of the photo approximately 0.35 mm.)

DISCUSSION

As we were informed by the trade, the rough iron ore of the new haematite type originates mainly from two mines in Brazil; however, the exact locations of the mines were not given. In a communication of the Paris Chamber of Commerce, the localities Itabirito and Mariana are mentioned. Both are situated in the mining district of the so-called Quadrilátero Ferrífero near Ouro Preto, Minas Gerais, Brazil. In this mining area, a massive type of haematite ore is known and has been mined for a long time. Due to its mineralogical composition (predominantly granular haematite with admixtures of magnetite, martite, and gangue minerals), its fabric and iron content of 69%, the new type of haematite ore used in the gem industry is similar to, or almost identical with, a massive haematite ore described by various authors from Quadrilátero Ferrífero (e.g., Dorr & Barbosa, 1963; Dorr, 1964, 1965; Reeves, 1966; Eichler, 1976). Therefore, the information of the trade about the origin of the new type of haematite (Brazil) is consistent with the literature about the massive haematite rock, which is mined in

large quantities from various localities in Brazil. For these iron ores with an iron content that averages more than 66% Fe the term 'high-grade haematite' is used in literature (Dorr, 1965).

The magnetic properties of the new type of haematite have to be assigned to the haematite constituent of the ore itself or to its magnetite admixture. On one side, pure haematites without magnetite admixtures are known from different localities, which are distinctly magnetic (Ramdohr, 1980). On the other side, the magnetite constituent of the ore is sure to produce a distinct magnetism.

Though in the samples supplied up to now for investigation purposes no artificial product was found, the use of various materials under the trade name 'hemetine' or 'hematine' as a haematite substitute has been known for a long time. Therefore, materials of unknown origin with questionable properties should be given to one of the gem testing institutes for investigation.

In summary, it could be established that in all properties and composition the new type of haematite ore used now in the gem industry corresponds to a high-grade haematite ore as described from various localities in the world, e.g., from different mines in Quadrilátero Ferrífero, Brazil. The presence of an artificial product was not proven in the material supplied up to now for investigation.

In the last meeting of the nomenclature commission of CIBJO in March 1984 in Milan, Italy, it was decided that for the new type of haematite with 'distinct content of magnetite and martite' the name haematite may be used without any additional remarks (K. Wild, personal communication).

Investigations of a Haematite Imitation

During the investigations of haematite ore from Brazil described in this paper, a haematite substitute of unknown composition was also supplied. Using electron microprobe and x-ray powder diffraction, the material was determined as elemental silicon. From this result, the low density of 2.33 g/cm^3 of the substitute as compared with 5.2—5.3 g/cm^3 for haematite is understood. As learned from further inquiries, the material was occasionally cut during the past 10 years. The rough material is thought to be an impure by-product of the semiconductor industry.

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SIBERIAN DIAMONDS

By R. V. HUDDLESTONE

(being the substance of a lecture delivered to the Gemmological Association of Great Britain at the Central Electricity Generating Board Theatre, Sudbury House, Newgate Street, London, EC1, on 19th October, 1983.)

Diamonds from the Ural Mountains in Russia have been found in small quantities since 1829. Dramatic discoveries by Larisa Popugayeva near Daaldinsk on the Siberian platform in August, 1954, were to prove the opening of a new chapter in the history of the diamond world.

In just 29 years the Soviet Union has become the world's largest diamond producing country. I estimate the total production of diamonds since the Yakutalmaz (Yakutdiamond) company was formed in 1957 to be in excess of 169 million carats, and it is now running at about 10.5 million carats annually—around 25% of total world production. Some observers claim production is 16/17 million carats. I have never seen any evidence for more production than is quoted in my Table 1.

Who were the people involved? What were the difficulties encountered? What were the milestones along the way? How has the market been affected and what of the future? With the aid of some interesting statistics I intend to show new insight into the subject of Siberian diamonds and the amazing developments that I have seen unfold in the last quarter of a century.

In the early 1700s stories were circulating that 'fire stones' had been found in Siberia. In 1736 an early scientist, M. W. Lomonsov, said in St Petersburg that diamonds existed in Siber (Mongolian for sleeping land) and would be found in quantity if men sought with diligence.

The first properly documented diamond in Russia was found on July 5th, 1829, near Krestovozdvizhensk in the Ural Mountains. Between 1829 and 1939 only about 100 stones were found. Alluvial deposits were later found in the River Vishera (1939), Basin of lower Tungusska (1948), River Vilyuy (August 1949), River Markhi (1950/51 Bear Expedition), River Malaya Botuobiya (1953) and Rivers Shugra and Northern Kolchin (early 70s). But what the geologists were seeking was a primary deposit (pipe).

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TABLE 1. Estimated Production

Year:	Total Carats	Gem Carats
1959	800000	Approx 20%
1960	950000	"
1961	1100000	"
1962	N.A.*	"
1963	N.A.*	"
1964	4000000	"
1965	5000000	"
1966	6000000	"
1967	7000000	"
1968	7000000	"
1969	7500000	"
1970	7850000	"
1971	8800000	"
1972	9200000	"
1973	9500000	"
1974	9800000	"
1975	9500000	"
1976	9500000	"
1977	10300000	"
1978	10550000	"
1979	10700000	"
1980	10850000	"
1981	10600000	"
1982	10600000	"
Total	169300000	33860000

Average size of rough just over half a carat. Production Agreement 1960 (De Beers). 1972 Modified. Mir pipe exploitation costs paid off and profitable after 12/13 years from opening.

*Figures for 1962 and 1963 are not available but are assumed to be the same as for 1961 (a conservative assumption).

As long ago as 1937 Vladimir Sobolev (Figure 1) at the 17th International Geological Congress in Moscow had predicted that primary deposits would be found on the Siberian Platform between Lake Baikhal and the Arctic Ocean over 1600 km from Moscow and near the Arctic Circle. In 1941 Sobolev made a full report to Gosplan, the organization responsible for all the five year plans for development of the country. World War II stopped further development.

During 1948 some alluvial deposits were found in the basin of the lower Tunguska river, and Sobolev's plan started to work.

FIG. 1. Vladimir Sobolev.

Gregory Finstein, a Jewish geologist, panned six diamonds on August 12th, 1949, in the 2500 km long Vilyuy river, but dredging did not commence on a commercial scale until 1957. Under the over-all development plan, each year would see a fresh expedition in the search for diamonds, which had now become of strategic importance to Russian industry.

During the Amaka (Bear) expedition in 1950/51, alluvial deposits were found in the Markhi tributary of the Vilyuy river. Under the guidance of A. P. Burov and Professor A. A. Kukharenko, two female geologists Natalya Sardatskikh and Larisa Popugayeva were prospecting, when with great excitement they established that pyrope garnets had been found in their samples (1953)—one of the indicator minerals for primary deposits of diamonds.

During the three to four month summer period in the province of Yakutia the ground unfreezes to a depth of two metres and the tundra becomes a mosquito infested swamp, but this is the only time when conditions are good enough for exploration work, so in that period of 1954 Larisa went out to the new expedition near Daaldinsk. Her painstaking work was rewarded with the find of the first pipe, named Zarnitsa (Thunderflash).

In June 1955 the authorities learned of their success when Yuri Kabardon radioed the message 'HAVE STARTED SMOKING PIPE OF PEACE, TOBACCO GOOD'. The first primary source (pipe) had been discovered not far from where Larisa Popugayeva had walked a few months before. This pipe was named Mir (Peace). I frequently refer to this find as the big hole of Siberia and predict that history will rate this find as being as important as the big hole at Kimberley. There was talk of the Mir pipe production being expected to level off after a decade, yet the mine was only a few years into production. Some pipe mines have operated for a century or so and I expect that the Mir pipe will be a prolific producer for decades to come. In the same year Udachnaya (success or lucky) was discovered and there followed Sputnik 1959, Aikhal (glory) in 1960 (see Figures 2 & 3) and Internationalnaya 1969.

Some geologists began to wonder how the Siberian mine could produce five times more than a comparable mine in South Africa. Geologists now know that there are 450 specific kimberlite pipes on the Siberian platform and that a number of these pipes and some alluvial (secondary) deposits are being worked. Kimberlite is the host material for diamond in the pipe. There are thousands of volcanic pipes in the world. Hundreds contain kimberlite and a few contain diamond in economic quantities—see Tables 2 & 3 and Map.* From this information we see that size of pipe is not

FIG. 2. Workers at Aikhal (Glory) Mine about 1960.

*The Map is printed on the back of Table 6, inserted between pp. 356 and 357.

FIG. 3. The Diamond Road from Aikhal to Mirny.

necessarily an indicator of yield from the pipe, Mir being 23 in the size league while Kimberley ranks 26.

By assessing the age of kimberlite using the method either of U.Pb (Uranium-Lead) dating of zircons or of Rb-Sr (Rubidium-Strontium) dating of micaceous kimberlite matrix, it is possible to arrive at an approximate age of the host materials in a particular pipe and from this deduce that the diamond content is as old as the host material, and probably on current thinking the diamonds are older than the kimberlite. The age of some Siberian deposits, along with comparisons from other continents, can be found on Table 4.

In 1957 Yakutalmaz Trust Company was formed, and in the same year they began to build the town of Mirny. Later a road was built to the town from the Lena River—1958 saw the commencement of construction of a hydro-electric power station on the Vilyuy River, 100 km upstream of Mirny (peaceful). Victor Tikhonov was appointed as the manager of the Mirny diamond administration. Under his guidance production started at Mir in 1958, three years after discovery (see Figures 4, 5 & 6). Udachnaya started producing in 1968 some thirteen years after discovery.

The gestation periods appear to be very long, but when the operating conditions are considered the achievement at Mir (three years) was a heroic feat of man's tenacity in the face of seemingly

TABLE 2. The world's largest known diamond pipes

Order	*Name*	*Country*	*Hectares*	*Acres*
1.	Mwadui	Tanzania	146	360.77
2.	Orapa	Botswana	106.6	261.93
3.	Pipe, Ellendale B	Australia	84	207.48
4.	Camafuca Camazambo	Angola	67.5	166.73
5.	Catoca	Angola	66.2	163.51
6.	Jwaneng	Botswana	54	133.43
7.	Talala	Zaire	50	123.50
8.	Pipe A, Ellendale	Australia	46	113.62
9.	AK1, Argyle	Australia	45	111.15
10.	Pipe C, Ellendale	Australia	36	88.92
11.	Premier	S. Africa	52	79.07
12.	Zarnitsa	Siberia	21.5	53.13
13.	Udatchnaya	Siberia	20	49.40
14.	Kao	Lesotho	19.8	48.90
15.	Massif I	Zaire	18.6	45.94
16.	Finsch	S. Africa	17.9	44.23
17.	Letsang-la-Terai	Lesotho	15.9	39.27
18.	Pipe D, Ellendale	Australia	13	32.12
19.	Koffie-fontein	S. Africa	11.1	27.43
20.	Jagers-fontein	S. Africa	10.0	24.71
21.	Camatue	Angola	9.3	22.98
22.	Leningradkaya	Siberia	9.0	22.23
23.	Mir	Siberia	6.9	17.05
24.	Dainyaya	Siberia	5.4	13.34
25.	De Beers	S. Africa	4.8	11.86
26.	Kimberley	S. Africa	3.6	8.90
27.	Nevidimka	Siberia	2.5	6.18
28.	Dolgodjdannaya	Siberia	2.5	6.18
29.	Ossennyaya	Siberia	1.6	3.95
30.	Molodenjnaya	Siberia	1.5	3.71
31.	Blaauwbosch	S. Africa	1.5	3.71
32.	West End	S. Africa	1.4	3.46
33.	Geophysitchskaya	Siberia	1.2	2.97
34.	Polyarnaya	Siberia	1.0	2.47
35.	Spsuedmmyaya	Siberia	0.5	1.24
36.	Malyutka	Siberia	0.4	0.99
37.	Roberts Victor	S. Africa	0.4	0.99

impossible odds. Yakutia, the coldest province in Siberia, has winter temperatures down to minus 70 °C, rising to 60 °C in the short summer—a range of about 130 °C from one extreme to the other. Under winter conditions iron bars snap like matchsticks, ordinary machinery becomes unusable, and rubber tyres break like brittle crockery (Figures 7 & 8).

TABLE 3.

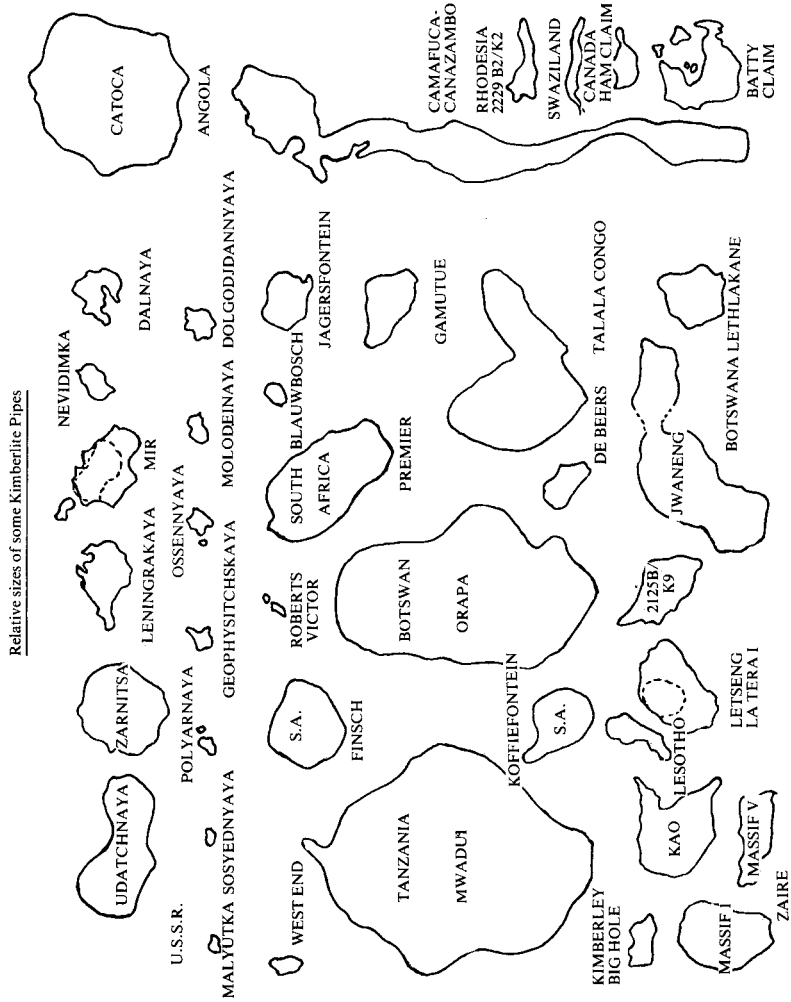
Relative sizes of some Kimberlite Pipes
U.S.S.R.
UDATCHNAYA
ZARNITSA
LENINGRAKAYA
NEVIDIMKA
MIR
DALNAYA
MALYUTKA
SOSYEDNYAYA
POLYARNAYA
GEOPHYSITCHSKAYA
OSSENNYAYA
MOLODEINAYA
DOLGODJDANNYAYA
CATOCA
ANGOLA
WEST END
S.A.
FINSCH
ROBERTS VICTOR
SOUTH AFRICA
BLAUWBOSCH
JAGERSFONTEIN
TANZANIA
MWADUI
BOTSWAN
ORAPA
PREMIER
GAMUTUE
KOFFIEFONTEIN
S.A.
DE BEERS
TALALA CONGO
KIMBERLEY BIG HOLE
KAO
LESOTHO
2125B/K9
JWANENG
BOTSWANA LETHLAKANE
MASSIF I
MASSIF V
ZAIRE
LETSENG LA TERA I
CAMAFUCA-CANAZAMBO
RHODESIA 2229 B2/K2
SWAZILAND
CANADA HAM CLAIM
BATTY CLAIM

TABLE 4. Ages of diamond deposits

Using an age assessment technique based on U.Pb (uranium-lead) dating of zircons, G. Davies, of Geophysics Laboratory, Carnegie Institute, Washington, D.C., and other scientists, estimate the age of some of the Siberian kimberlite as follows:

	Million years
Slyudyanka	148
Pozdnyaya	220
Internatsionalnaya	360
Mir	362
Druzhba	411
Amakinskaya	451
Brazilian Conglomerates	1000
Indian Conglomerates	500
Tanzanian Kimberlites	60
West African Kimberlites	1100
Witwatersrand Conglomerates	2600
Premier Mine	1700
Kimberley Area	90

Using another dating method Rb-Sr (rubidium-strontium) used as the base for dating micaceous kimberlite matrix—the two methods do not always produce the same result:

Premier and National (Transvaal)	1250 and 1180 my respectively
Finsch (Cape Province)	130-170 my
Swartruggens (Transvaal)	150 my
Njoio and Tchivira (Angola)	130 my
Colossus (Central Rhodesia)	490 my
Wesselton (Kimberley)	83-84 my } similar to U.Pb
Monastery (South Africa)	90 my } ages for these pipes
Roberts Victor (South Africa)	127 my

My files contain similar data on another 40 locations whose ages range from 33.9 million years to 2600 million years.

They have since developed special tyres made of polystyrol isoprendivinyl. Buildings have triple doors to preserve internal heat. Some steels shatter or lose hardness, so when building a bridge over the Lena river they used metal pipes filled with kerosene. When working under such extremes of cold it seizes the throat, covers the face with hoar frost and sticks the eyelids together. The first geologists even had to chop their bread with an axe.

According to the 'Institute of Permafrost' in Yakutsk the ground is frozen down to a depth of 5000 feet, which the scientists call 'permafrost' but the locals call 'frozen cement'. There are 22 hours of sunshine during the three summer months, which melts the top six or seven feet and melts the swamps down to about thirty feet. This brings out millions of large *gnoos* (mosquitoes) so that protective clothing (netting) has to be worn (Figures 9 & 10).

The permafrost is so intense that in March 1983 when a 10 000 year old Woolly Mammoth carcass was uncovered, it was so fresh that it was fed straight to the sled dogs after de-icing. The nearest railway, the Trans-Siberian, is over 1000 km away. Supplies first came in by hydroplanes fitted with skis and later by helicopters from the railway depot.

The area is forest (tundra) and swamp. Rivers are ice-free only for about three months of the year. There is now an anchorage at Lensk, and great truck caravans follow the highway that has been constructed. Consider the sheer size of Siberia and the inaccessibility of the mines, which are further than London is from Moscow. The U.S.S.R. has eleven time zones, and there is about ten hours time difference between East and West. The Siberian peoples have over thirty languages. Yakutia has an average of two people for each square kilometre.

FIG. 4. Mirny town, Yakutia, about 1969 (built for the diamond workers).

TABLE 6. World Production of Diamonds
(Thousands of carats)

	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982
Zaire	14752	12504	12432	13155	13140	13423	14087	12520	13390	12940	13000	12000	12000	11213	9683	8734	10235	7500	7500
South Africa	4450	4945	6135	6803	7433	7863	8112	7031	7395	7565	4926	3900	4000	8033	7726	8384	8520	9546	9194
Namibia (S.W. Africa)	1541	1646	1759	1701	1722	2013	1865	1648	1596	1600	1570	1600	1600	2001	1898	1653	1560	1248	1014
Ghana	2668	2273	2819	2537	2447	2391	2550	2562	2659	2317	2573	2000	2000	2300	1950	1253	1258	836	836
Sierra Leone	1463	1489	1462	1400	1410	1989	1955	1935	1800	1404	1670	1500	1500	450	707	885	592	486	485
Angola	1148	1156	1268	1289	1667	2022	2396	2413	2155	2125	2100	2100	2100	353	400	841	1480	1400	1400
Central African Rep.	442	537	540	520	609	535	482	437	524	380	450	450	450	301	284	315	342	312	277
Ivory Coast	200	198	184	175	187	202	213	326	334	300	320	320	320	65	65*	48	—	—	—
Tanzania	664	828	947	987	683	777	703	837	652	501	550	550	550	375	2293	314	274	217	220
Liberia	571	540	555	543	750	746	812	809	890	817	636	650	650	326	308	302	298	336	335
Guinea	72	72	72	50	50	72	74	74	80	80	80	80	80	80	80*	85	39	38	40
Botswana	—	—	—	—	—	200	464	822	2403	2416	2718	2500	2500	2691	2785	4394	5101	4961	7769
Venezuela	115	91	85	69	114	194	509	499	456	778	700	750	750	700	738	803	721	490	500
Brazil*	175	175	150	160	160	160	150	150	155	160	160	250	352	200	200	620	667	1089	1150
Guyana	109	113	96	97	66	52	61	48	49	52	50	50	50	17	17*	16	10	10	9
China	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	N/A	1800	1900	2000
Australia	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	48	205	557
Other W. World	100	110	120	130	140	150	160	170	180	190	190	190	190	65	65*	83	83	84	71
Total W. World +	28470	26677	28624	29616	30578	32589	34593	32281	34718	33625	31693	28890	29092	29170	29399	28730	33027	30658	33357
U.S.S.R.*	4000	5000	6000	7000	7000	7500	7850	8800	9200	9600	9800	9500	9500	10300	10550	10700	10850	10600	10600
Total World	32470	31677	34624	36616	37578	40089	42443	41081	43918	43125	41493	38390	38592	39470	39949*	39430	43877	41258	43957

Source: USBM, IGS
N/A = Figure not available
*Estimate
+ Including statistical discrepancies

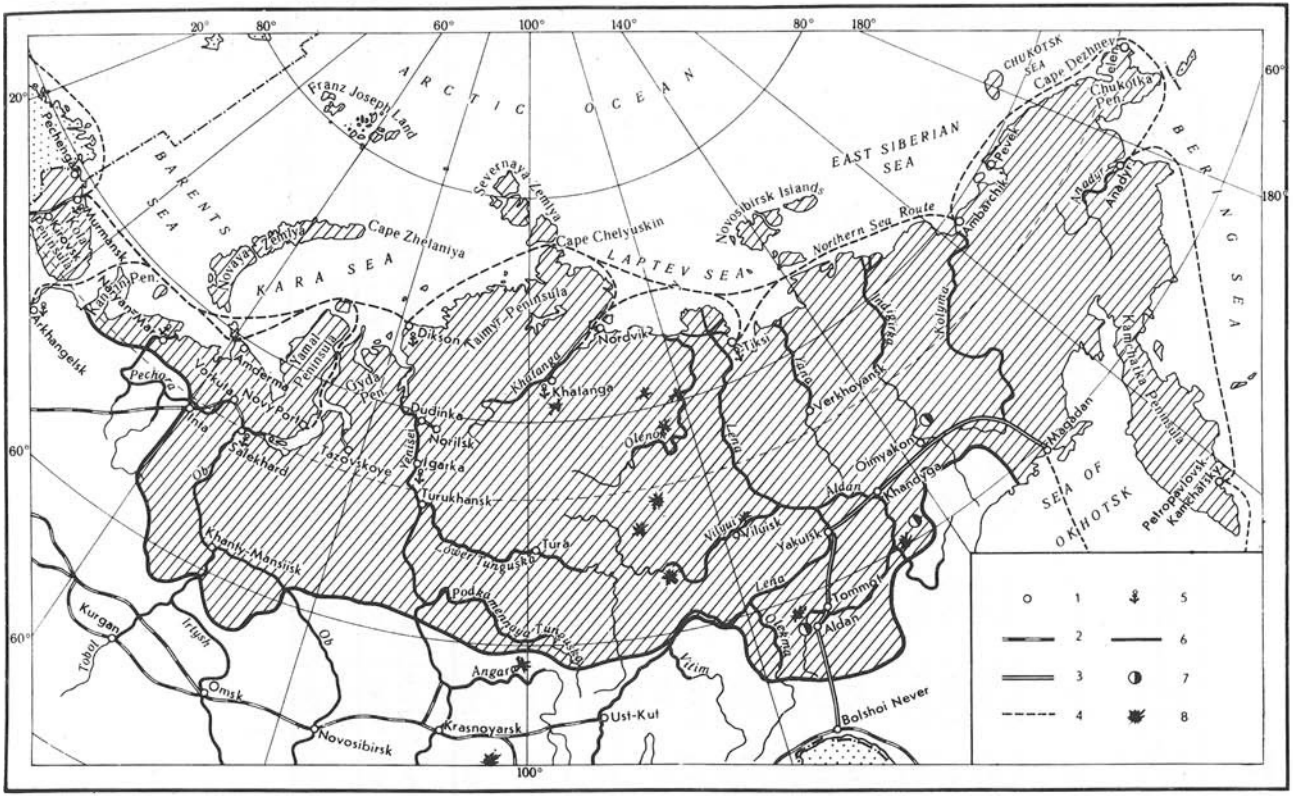
ARCTIC OCEAN
BARENTS SEA
KARA SEA
LAPTEV SEA
EAST SIBERIAN SEA
CHUKOTSK SEA
BERING SEA
SEA OF OKHOTSK
Franz Joseph Land
Novaya Zemlya
Cape Zhelaniya
Severnaya Zemlya
Cape Chelyuskin
Novosibirsk Islands
Northern Sea Route
Cape Dezhnev
Chukotka Pen.
Pevek
Anadyr
Anadyr
Amberchik
Kolyma
Indigirka
Lena
Yana
Olenek
Khatanga
Taimyr Peninsula
Dikson
Nordvik
Tiksi
Verkhoyansk
Oimyakon
Magadan
Kamchatka Peninsula
Petropavlovsk-Kamchatsky
Khandyga
Aldan
Vilyuisk
Yakutsk
Tommot
Olekma
Vitim
Bolshoi Never
Ust-Kut
Angara
Krasnoyarsk
Novosibirsk
Omsk
Irtysh
Ob
Tobol
Kurgan
Khanty-Mansiysk
Salekhard
Tazovskoye
Yenisei
Turukhansk
Tura
Lower Tunguska
Podkamennaya Tunguska
Dudinka
Norilsk
Igarka
Yamal Peninsula
Gydan Pen.
Yamal Pen.
Yenisei
Pechora
Vorkuta
Novy Port
Arkhangelsk
Murmansk
Kola Pen.
Pechenga
Petsamo
Kirovsk
Petrozavodsk
Kuopio
Kemi
Tornio
Vyborg
Leningrad
Moscow
Kiev
Odessa
Sevastopol
Kerch
Rostov
Volgograd
Astrakhan
Kuybyshev
Sverdlovsk
Chelyabinsk
Tashkent
Alma-Ata
Frunze
Dushanbe
Ashkhabad
Tbilisi
Yerevan
Baku
Tehran
Kabul
Karachi
Delhi
Calcutta
Rangoon
Bangkok
Hanoi
Canton
Hong Kong
Shanghai
Nanking
Hankow
Chungking
Kunming
Lhasa
Ulan Bator
Peking
Tientsin
Mukden
Harbin
Tokyo
Osaka
Kyushu
Hokkaido
Sakhalin
Kuril Islands
Aleutian Islands
Bering Strait
Cape Horn
Cape Good Hope
Cape Verde
Cape Hatteras
Cape Cod
Cape Sable
Cape Farewell
Cape Nome
Cape Prince of Wales
Cape Lisburne
Cape Bathurst
Cape Parry
Cape Chidley
Cape Dyer
Cape Ingolfs
Cape Nordkyn
Cape Kolka
Cape Ivanovo
Cape Kanin
Cape Sarych
Cape Ayia
Cape Ayia
Cape Ayia

FIG. 5. Workers' flats at Mirny (summer): about 1980.

FIG. 6. Mirny township (winter): about 1980.

FIG. 7. Building one of the recovery plants in permafrost conditions at Mirny.

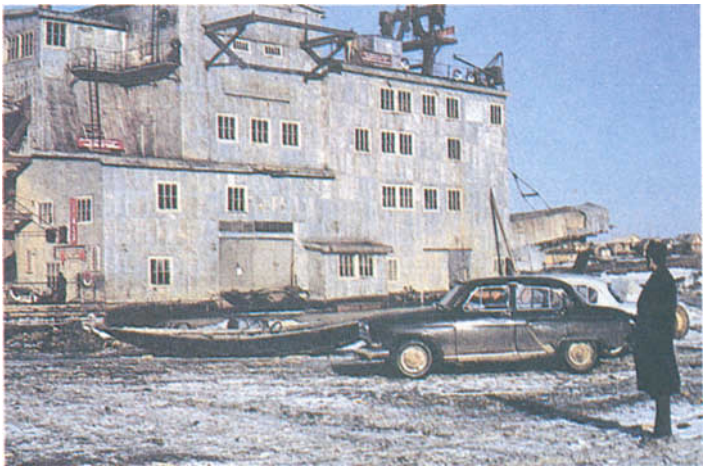

FIG. 8. This huge dredger melts the frozen ice and floats on its own pool: it scoops up the alluvial material, crushes and separates it, and deposits any unwanted material behind it as it moves along.

FIG. 9. Geologists prospecting for diamonds in the short summer period.

FIG. 10. Geologist prospector on the tundra (normally frozen waste) in summer: note the mosquito net.

FIG. 11. Mir pipe, the big hole with opencast galleries.

FIG. 12. Taiga (deciduous forest), Lena River, Lower Yakutia.

The Siberian platform contains three of the world's longest rivers, the Ob/Irtysh at 5410 km, the Yenisi/Angara/Selenga at 5075 km and the Lena at 4400 km. There are over one million lakes, and Lake Baikhal as well as being the deepest in the world at 6365 feet contains 20% of the world's fresh water. During the winters, one of the main motor-roads in the diamond areas crosses this lake on the ice.

In this remote and harsh environment, where it is colder than the North Pole and where snow shoes and reindeer sleds are still the normal mode for personal travel, one Yakut man claims he saw aircraft before he saw his first car and the telephone before there was a mail service. There is no scheduled service to the mines; it takes two hours to fly from Yakutsk to Mir. When drilling holes for blasting they use steam and heat funnelled from the engines of Concordski to prepare the rock for blasting.

It has been said that the mine lacked the facilities necessary to sort and separate large quantities of diamonds. Some years ago Alexei Nicolaievich Stepanov helped to build pilot plant no. 1 at Mirny. Because of his proven skills he was appointed Designer/Manager of plant no. 2 and subsequently became Director of plant no. 3.

The diamond processing/separating plant has been described as the world's largest and is a monstrous, aluminium sheathed, windowless fourteen storey high monolith. The cavernous interior houses gigantic unbelievably noisy machinery which is almost totally automated. The separating processes operate round the clock day and night and sometimes produce enough diamonds in one day to pay the annual operating costs of the plant.

There are now at least seven processing plants in the Mirny area, all of which use vast quantities of water which has to be heated and kept hot in order for the machinery to work. A steel structure built into permafrost ground warms up during the 22 hour days of sunshine in the summer, the metal structure gradually melts the ground and the building slowly sinks. Sometimes they build on stilts to allow biting Siberian wind to take the heat away from the steel.

Due to the problems of constructing, operating and maintaining the engineering plant at the Aikhal (Glory) mine, they decided to build a 'Road' through the tundra from Aikhal in the arctic circle to Mirny, and they set up a team of rugged 30-ton

trucks to carry the diamondiferous material on an all year, round-the-clock relay between the two camps, in order to process it in the relatively better environment at Mirny. The really remarkable fact is that the trip is 250 miles each way. The truck drivers really earn their £1000 plus per month! (see Figures 3, 11 & 12).

By 1972 there were probably about 60 000 people employed in the Mirny area, over 50% of them being female, which sounds like a good arrangement to me! The diamond town of Mirny has forty-six nationalities amongst the workers. The fully electrified town has its own T.V. and radio station and a daily paper. There is a hospital, a brewery and a Vodka distillery, sixteen schools of one type or another and the technical college has about 1000 students. The people live in five to seven storey blocks, which are tinted in differing colours on the outside (see Figures 5 & 6).

There were plans to build a microtown at Udachny, and the planners were thinking of a dome or pyramid structure to cover the whole town but eventually this became a conventional set of structures with a sealed-in environment.

Generally wages are about two and a half times more than equivalent jobs nearer Moscow. Because of the harsh conditions there are bonuses to be earned: 40% extra if North of latitude 58°, 50 and 60% for the Arctic Circle, and 70-100% for the high Arctic. A bonus is paid for remoteness from cities and there is an extra 10% for each year that a worker stays beyond the original agreement.

There are many more facets to producing diamonds in Siberia, where the slang term ice takes on a new meaning.

The world average size of rough diamond produced when I entered the trade in 1944 was about 0.75 to 0.80 ct and gradually dropping. Russian rough diamonds appear to average about 0.50 to 0.55 ct. However, as with all deposits some large Russian stones do turn up. See Table 5: the (unnamed) stone of 120 ct I handled a number of times in my capacity as a technical consultant. That stone was of a good colour, but it exhibited optical stress haloes in the heart of the stone which caused the owner to consult with me. In due course the stone was successfully cut into a number of unnamed stones.

Diamond statistics are notoriously difficult to obtain. Most diamond mining statistics do not include precise gem and industrial production figures, but a generally accepted ratio is 20% gem, 80%

TABLE 5. Large Named/Unnamed Rough Siberian Diamonds

Carats	*Name*	*Comments*
37.56	"Toktogul" (Person's Name)	Found at Mirny
38.72	"Zlata Praga" (Gold Splendour)	Found at Mirny
44.62	"Gornyak" (Miner/Mine-worker)	Found at Mirny
46.36	"Letni" (Summer)	Found at Mirny
51.66	"Valentina Tereshkova" (First Woman Cosmonaut)	Found at Mirny 1963
71.50	"50 Let SSSR" (Fifty Years of the U.S.S.R.)	Found at Mirny
80.66	"Progres" (Progress)	Found at Mirny
105.98	"Mariya" (Name of the best worker at Mirny)	Found at Mirny 1966
114.37	"Bolshaya Medveditsa" (Big/Great Bear)	Found at Mirny
119.55	"Professor Odintsoy"	Found at Mirny 1981 Colourless/Transparent
*120.00	Unnamed	Found at Mirny 1974/5
135.12	"Vetki Pochin" (Great Initiative/Beginning)	Found at Mirny
171.15	"Revolyutsioner I. Babushkin" (I. Babushkin, Revolutionary)	Found at Mirny
200.00 +	"50th Anniversary of Aeroflot"	Found at Mirny 1973
232.10	"Svezda Yakuti" (Star of Yakutia)	Found at Mirny 1973/4 Brownish, transparent, slightly convex facets and rounded edges, no visible inclusions

All the stones (except*) are in the Chamber of Diamonds of the U.S.S.R. in the Treasury at the Kremlin in Moscow.

25.52	"Brilliant"	Found at Mirny Polished—an unusual shape of emerald cut

industrial. The decision as to a specific stone being classed as gem is more commercial than technical. Some of the factors being the obvious one of colour, clarity and shape. However, as the value of gems has risen over the years the dividing line between gem and industrial has been sinking. Many rough stones now sold as low quality gems used to be classed as good industrial. If we take the

estimated 'Russian production' from 1959 to 1982 as 169 300 000 ct, then 20% of that gives us a figure of 33 860 000 during that 24 year period. (See Table 1).

Using other statistics, gathered over the years: during the 19 year period 1964 to 1982 world production of gems was estimated at about 150 007 400 ct, and Russian production of gems was estimated at about 32 850 000 ct or 21% of world production of gems (Table 6*).

During 1982 an article by Edward J. Epstein in *The Sunday Times* made some startling claims about Russian diamonds. He claimed that the Russians were making synthetic diamonds in Moscow and the Ukraine and selling them through the normal channels in London. The newspaper did not allow a reasoned riposte to these claims, which appeared to give them more credence, causing a furore in the trade. His claims are based on the fact that Russian stones have a greenish tint, sharp angular edges, uniform shape and size, and that Soviet scientists had succeeded during the late 1960s in making synthetic gem diamonds up to half a carat in size, yet they were still buying some industrial stones from the West.

Rough diamonds from all deposits can be classified in three basic colour ranges. Cape series (yellow), brown series and green series. Some deposits tend to have a preponderance of one colour: this has no significance to synthetic gem diamonds. Rough diamonds from pipes (primary sources) commonly have octahedrons with sharp angular edges 'brightly polished': they are called glassies and have no significance to synthetic gem diamonds. They are uniform in shape and size; so are the productions from some other mines (Figures 13, 14, 15, 16, 17 & 18).

If the Russians were able to control the manufacturing process to such a degree as implied, then they would also know that the perfect octahedron is not the best shape to make because there is more weight loss when cutting the rough of that shape because of its sharp angular edges. I believe that the ever rising tide of Russian diamonds should not therefore be viewed with such apprehension as has now been generated, and in years to come there could be comforting signs of relief that there will be enough gem stones there, to sell, when the demand returns to the market place.

*Inserted between pages 356 and 357.

FIG. 13. Siberian 'glassy' diamonds (with scale in centimetres).

FIG. 14. Octahedral 'glassies' from Mir.

FIG. 15. Octahedral 'glassy' diamond (about ¾ ct) in kimberlite, from Mir pipe. (Author's collection).

FIG. 16. Chrome diopside inclusion in Siberian diamond.

FIG. 17. Diamond-bearing eclogite with graphite, from Mir (specimen 2 cm long).

FIG. 18. Striated diamond-bearing eclogite from Udachnaya pipe (specimen 3.5 cm long).

Synthetic industrial diamonds were first synthesized by A.S.E.A. of Sweden in 1945 and shortly after that by G.E. of America and De Beers in South Africa and much later by the U.S.S.R. Such stones are now made in most industrialized countries including Russia and China. The Russian factories are based in Kiev, Leningrad, Moscow, Yerevan and Tashkent. There are still some processes in industry where the natural industrial diamond is far superior to the synthetic industrial, and this is why the Russians like everyone else still need to buy on the open market. Even today there are some industrials that are in short supply from natural sources.

In 1970 G.E. of the U.S.A. announced the successful production of synthetic gem diamonds and just a few years ago a story came out that the Russians had made gem diamonds prior to that date. I have never seen this story scientifically substantiated and for the moment it must lie along with a number of similar claims that the Russians were the first in other spheres of endeavour, whereas I believe the Siberian diamond endeavours are to be congratulated.

During 1974/5 I was offered the opportunity to test two of the G.E. synthetic diamonds, which had been cut and polished by Lazare Kaplan of New York. The (D.G.L.) laboratory in Hatton Garden, of which I was the director, carried out exhaustive non-destructive tests on the stones and in the report published were able to demonstrate differences between the synthetic and natural gem diamonds. One of the tests showed rod-like inclusions in the synthetic that we had not, ever, observed in natural stones, and the spectral response on our spectrophotometer was quite unusual: it also exhibited an extremely long phosphorescence decay time after exposure in a dark room to a 365 nm UV light source, which was then extinguished in order to observe the effect.

In 1982 on behalf of another laboratory I borrowed via the Royal Institution one of the stones, that was tested in 1974, and retested the stone for a programme on Télévision Française, (T.V.L.) with the same results. When perusing the records of both laboratories, I found that not one other diamond since 1974 has shown any of these features.

To create a synthetic industrial diamond in the laboratory needs pressures of over 7 million kPa simultaneously with a

temperature of 1353 °C. These conditions must remain stable for many hours, which is not easy to achieve.

To create a synthetic gem diamond in the laboratory needs a pressure of over 21 million kPa and a temperature of 3020 °C. These conditions must be kept stable for nearly one week to produce one rough stone of about one carat. Recently I have spoken with a senior person at G.E., who confirms the view that even today the cost of producing a sythetic gem diamond is at the very least ten times greater than to dig it out of the ground.

As gemmologists will be aware every major gemstone has been synthesized—in the case of ruby and sapphire for over 80 years—and in each case it has increased the market awareness of the natural stone and created a secondary lower-priced market. So there should be no cause for alarm when synthetic gem diamonds do eventually come onto the market.

The diamond cutting and polishing industry in Russia has grown tremendously in recent years and there are cutting factories at Kiev, Moscow, Sverdlovsk near the Vishera River, and Mirny; this last factory is built of ferroconcrete and glass. It has been 'guestimated' that there are up to 10 000 diamond polishers in Russia, which is on a par with Antwerp and Israel for numbers, but it seems more probable that the numbers are in the region of 6000 polishers. One of the plants is so large that it employs about 2000 polishers under one roof. Traditional polishing techniques are used. The average size of polished diamond produced is between 25 and 30 points. Quality control appears to be very strict, and only the well made stones are sorted for export.

A number of times it has been rumoured that the Russians were dumping their polished diamonds on the market, because of the large quantities of Russian diamonds available. From the statistics it can be seen that for every five diamonds in the market place one of them could well be of Russian origin. When Lev Soldatov, a Muscovite who is the Director of the Yakutian Diamond Combine, was asked about dumping, he replied 'If we flooded the market, the ladies of the world would find that their diamonds would lose some of their value. We would not wish to raise the fury of womanhood. I am not sure that even the Soviet Union could cope with that'.

It is also probably fair to say that the marketing of the U.S.S.R. stones does not appear to be fine-tuned to the ebb and

flow of normal market supply and demand and does not act quickly enough to reduce the flow when the market turns down. Of course external currency needs sometimes dictate selling policies.

Moscow appears to market the stones in a number of ways. Originally all output was sold through colleagues of mine. At other times (1960-1972) it was sold by contract through the Central Selling Organization. From 1972 that contract was modified. At the present time there are no contractual agreements. Due to the complex nature of our industry, substantial quantities of Russian rough still appear to find their way by devious routes through the C.S.O.

For a number of years now the Russians have retained substantial quantities of selected sizes of rough for their own polishing operations. The marketing of Russian polished stones is done through Russalmaz in Antwerp, Frankfurt and Geneva. Whatever else may be said, Russian diamonds have mostly been marketed in an orderly fashion, so much so that they have not upset or damaged the industry.

[*Manuscript received 9th March, 1984.*]

GEMMOLOGICAL ABSTRACTS

ALEKSANDROV (V. I.), BATYGOV (S. Kh.), VISHNYAKOVA (M. A.), VORORIKO (Yu. K.), KALABUKHOVA (V. F.), LOMONOVA (E. E.), OSIKO (V. V.). *Optical properties of strontium titanate crystals grown by the Czochralski method from a cold container.* Inorganic Materials, **19**, 2, 238-42, 4 figs, 1983.

Direct high frequency heating of the nonmetallic melt in a cold container has made it possible to grow $SrTiO_3$ by the Czochralski method in air. The colour of the crystals before annealing is determined by the thermal conductions of the growth process. M.O'D.

BAKOŃ (A.), SZYMANSKI (A.). *Morphological qualitative classification of synthetic diamond microcrystals.* Mineralogia Polonica, **13**, 2, 61-8, 30 figs, 1982.

A morphological classification is attempted for synthetic diamonds of different commercial brands, produced by static methods. Five distinct forms were determined for each of two parameters, and three typical grains representing each of the forms is illustrated. These photographs serve as a basis for the qualitative evaluation of diamond grains and allow the selection of an appropriate diamond abrasive for tools with different binders. R.A.H.

BROWN (G.). *Gem feldspars.* Wahroongai News, **18**, 4, 7-14, 1984.

A comprehensive account of all the gem varieties of this the largest group of rock-forming minerals. R.K.M.

BROWN (G.). *The Kashmir sapphire.* Wahroogai News, **18**, 4, 15-16, 1984.

A compilation of facts drawn from several sources on a sapphire often named but very rarely seen or authenticated. R.K.M.

BROWN (G.). *The Cowell nephrite province.* Wahroongai News, **18**, 5, 18-19, 1984.

Describes provenance and material of this large commercially viable deposit of nephrite on the Eyre Peninsular, S. Australia. Occurs in shades from yellow-green to dark green and black, the latter apparently the most valued. There is an estimated 4 million tonnes, 2% of which is thought to be of prime gem quality. R.K.M.

COLE (B.). *Collecting the unusual.* Lapidary J., **38**, 3, 412-3, 7 figs in colour, 1984.

Brief account of the travels and collection of Lowell Jones, a Missouri gemstone dealer. M.O'D.

FRYER (C. W.), ed., CROWNINGSHIELD (R.), HURWITT (K. N.), KANE (R. E.). *Gem Trade Lab Notes.* Gems & Gemology, **XX**, 2, 106-12, 23 figs (19 in colour), 1984.

A 'galaxy' of star inclusions of red goethite in amethyst and a piece of rock with one polished face, found to be partly cummingtonite-grunerite, are described and illustrated; coated diamonds have recently been arriving for test at G.I.A. labs despite legislation which prohibits the practice; natural dendritic holes in diamond resembled laser drilling; a greyish-lavender stone identified as diopside despite unusual colour, constants were normal; nephrite ducks had carved lines enhanced artistically by brown stains resistant to acetone but lifted by 10% HCl solution bead nephrite dyed green by substance similar to that used to dye green jadeite—all are described and illustrated. Realistic imitation 'mabe pearls' proved to be made from some kind of plastic; large flat bouton pearls, x-rayed on edge, showed lentil shaped cavity(?) nuclei, fluoresced strongly in x-rays and were therefore of fresh-water origin; other button pearls fluoresced weakly and were salt-water; a dimpled pearl x-rayed to show that a drilled nucleus had been used—possibly a product of experiments to produce a spherical Biwa pearl, or a Mississippi equivalent.

A fine multiple star quartz of 22 ct and another giant of 170 ct are illustrated, and a heat treated ruby cabochon had patches of blue fluorescence under short UV light; a Verneuil synthetic sapphire showed grain reflection planes similar to grain in diamond, possibly due to heat treatment, not typical of synthetic material—curved colour zoning was also seen; a black stone supposed to be from a meteorite proved to be spinel and not meteorite; a remarkable yellow-brown zircon cat's-eye is illustrated. R.K.M.

GUNAWARDENE (M.). *Identification characteristics of synthetic ruby made by Knischka.* Lapidary J., **37**, 12, 1700-6, 30 figs (29 in colour), 1984.

Translation into English of a paper first published in *Gold & Silver, Uhren & Schmuk,* **36**, 2, 1983. M.O'D.

HÄNNI (H. A.). *Die Echtheitsuntersuchung von Korund-Methoden und ihre Grenzan.* (The true understanding of corundum-methods and limits). Schweizer Uhrmacher und Goldschmiedezeitung, **106**, 5, 17-23, 10 figs (6 in colour), 1984.

Compares the various methods of testing natural and synthetic corundum with illustrations of inclusions and reference to the Ramaura synthetic ruby. M.O'D.

KOIVULA (J. I.). *The first-order red compensator: an effective gemological tool.* Gems & Gemology, **XX**, 2, 101-5, 6 figs (4 in colour), 1984.

An aid to microscopy now available in durable plastic sheet form. The red compensator either enhances of subtracts wavelengths according to its orientation relative to the subject examined. In polarized light this alters intensities of low order interference colours and makes inclusions, etc., more easy to locate. It can shorten exposure times in photomicrography and reduce vibration risks. R.K.M.

KOIVULA (J. I.), ed. *Gem News.* Gems & Gemology, **XX**, 2, 121-2, 1984.

Diamonds: a 260 ct yellow diamond found at Coromandel, Minas Gerais; India implements nationwide diamond exploration starting in Andhra Pradesh; diamond cutting starts in Philippines; Singapore opens own diamond exchange.

Coloured stones: Pakistan reports new emerald deposits found, aquamarine and topaz production continues; someone has rediscovered gem quality amethyst on Rhode Island and gem chrysoberyl at Greenfield, New York State; Zambia consortium is recruiting mining personnel to prospect for emerald and other gems; Tanzania announces easing of government restrictions on individual prospecting; beryllium found in Canadian North West Territories; opal, chalcedony and onyx found at Mt Rudnik, Serbia.

Gold: reported in Ontario and Quebec; mud slides make gold production difficult in Papua, New Guinea; exploratory drilling at Reid Mine, northern California shows up to 1.5 oz per ton, together with silver. R.K.M.

LAURENCE (C.). *Fabled diamond on sale for £5 million.* Daily Telegraph, No. 40, 164, p.11, 1 photo, 4th August 1984.

Put on the market for £5 million by Graff's, Knightsbridge, a 47.29 ct diamond, Golconda 'D', 'has been hailed as the largest "flawless brilliant" in the world'. It is said to have come from Golconda in the seventeenth century, to have disappeared in the eighteenth century, and to have been found recently in Bombay. J.R.H.C.

LOOCK (G.). *Anakie, Zentral Queensland, Australien.* (Anakie, Central Queensland, Australia). Magma, **3**, 36-9, 13 figs (12 in colour), 1984.

The sapphire mines of Anakie are described and some typical crystals illustrated. M.O'D.

NASSAU (K.). *Heat treatment used on gemstone materials.* Lapidary J., *part 1,* **38**, 1, 18-42, 11 figs (7 in colour); *part 2,* **38**, 2, 288-90, 12 figs in colour; 1984.

In part 1 the author outlines the history of heat treatment of gemstones before discussing the methods and equipment used. The mechanisms by which colour is altered are explained with particular reference to quartz and corundum. Part 2 deals with oxidation-reduction in blue sapphire, silk and asterism in corundum, diffusion of colour and asterism into corundum, heat-induced cracking and the reconstruction and clarification of amber. M.O'D.

NIŚKIEWICZ (J.). (Geological setting of the occurrence of chrysoprase and related gemstones in the Szklary massif, Lower Silesia). Geologia Sudetica, **17**, 1/2, 125-39, 3 figs, 1982. (Polish with English summary).

Chrysoprase, chalcedony and opal occur sporadically in serpentine of the Szklary massif in SW. Poland. These minerals are generally found in steeply dipping veins and in irregular lenses a few centimetres in size. They are most often developed in yellowish brown to reddish brown altered serpentine; the chrysoprase is invariably associated with earthy weathered serpentinite relatively rich in Ni, whereas the chalcedony and opal occur in all types of altered serpentinite. On the basis of Ni grades [not given], the author has indicated areas of the least probable occurrence of chrysoprase in the massif. R.A.H.

NOOR DEEN (M.). *Rare gemstones of Sri Lanka.* Lapidary J., **38**, 1, 238-40, 1984.
Brief account of the gem materials found in Sri Lanka. M.O'D.

O'DONOGHUE (M.). *The dealer looks at gemstones—12.* Gems, **15**, 4, 29.
A brief account of the present state of the diamond investment business and of the perils of appraisal related to tax deduction (with reference to some recent cases in the U.S.A.). (Author's abstract) M.O'D.

O'DONOGHUE (M.). *Industrial review: gemstones.* Britannica book of the year, 1983.
The investment boom was fading and the prophesied decline in influence of the Central Selling Organization did not come about. Pakistan emerged as a major gem exporter. Emerald from Brazil was being exploited and some qualities finer than normal were found. Sales at the major auction houses continued to flourish.
(Author's abstract) M.O'D.

PROCTOR (K.). *Gem pegmatites of Minas Gerais, Brazil: exploration, occurrence and aquamarine deposits.* Gems & Gemology, **XX**, 2, 78-100, 17 figs (16 in colour), 1984.
A very full account of the granitic pegmatites of NE. Minas Gerais and, in this paper (the first of a projected series), of the aquamarine, morganite and heliodor production of the region. Early exploration, development, geology, mining methods and sociological effects are explained. All varieties of gem beryl other than emerald are found in these pegmatites, but aquamarine is by far the most important. Different valleys and mines described in detail. Little mining at present, but potential of region is still very great. All aquamarines are heat-treated to change sea-green, or yellow, to fine blue. R.K.M.

REBAN (J.). *Moldavite—the gemmy tektites.* Lapidary J., **38**, 1, 30-6, 10 figs (7 in colour), 1984.
The original author gives a résumé of moldavite from Czechoslovakia, and two other writers describe tektites found in other countries. M.O'D.

ROLANDI (V.). *Edelsteine aus dem Tierreich: Eine gemmologische Untersuchung über das aus Cnidaria (Korallen) stammende Schmuckmaterial.* (Gemstones from the animal kingdom; a gemmological study of Cnidaria (corals) branches used as gem material). Aufschluss, **35**, 251-65, 15 figs (1 in colour), 1984.
The various coral-producing creatures and the structures of the coral are described. M.O'D.

SCANDALE (E.), LUCCHESI (S.), GRAZIANI (G.). *Optical anomalies of beryl crystals.* Physics and Chemistry of Minerals, **11**, 2, 60-6, 7 figs, 1984.
Basal plate sections of natural beryl crystals showed optical anomalies when examined by optical microscope, x-ray topography and electron microprobe analysis. The anomalies were found to be linked with growth history and variation in impurity content. Optical axial plane orientation and 2V values depend on minor element concentration differences in growth sectors. M.O'D.

SHIGLEY (J. E.), KAMPF (A. R.). *Gem-bearing pegmatites: a review.* Gems & Gemology, **XX**, 2, 64-77, 13 figs in colour, 4 tables, 1984.

A good account of these important rock types which are the most prolific sources of many gem minerals, with theories on their formation, the significance of crustal depth and of pneumatolytic solutions. A well-considered paper. R.K.M.

TAGLIAMONTE (N.). *History of shell cameos.* Lapidary J., **38**, 2, 288-90, 13 figs in colour, 1984.

The author gives personal reminiscences of the cameo-making industry of Naples. M.O'D.

ZEITNER (J. C.). *Collect emeralds, diamonds, rubies and more for a fee. Part 1,* Lapidary J., **38**, 1, 62-77, 20 figs (9 in colour), 1984.

Collecting for a fee is common in many parts of the United States. The areas in the states of Maine, New York, Pennsylvania, North Carolina, Arkansas, Missouri and Ohio are listed and described. M.O'D.

Tsumeb. Lapis, **9**, 7/8, 13-63, 85 figs (65 in colour), 1984.

A survey of all the minerals so far found at the copper-lead-zinc mines at Tsumeb, Namibia, with descriptions and notes on occurrence. Some, including malachite, azurite, smithsonite and cuprite, have gem potential. M.O'D.

BOOK REVIEWS

BARNETT (F.). *Opal and how to work it.* Gemcraft Publications Pty Ltd, East Malvern, Victoria, Australia, 1981. pp. iv, 60. Illus. in black-and-white. $3.95.
A useful guide for the amateur prospector and opal cutter. M.O'D.

DAVIES (G.). *Diamond.* Adam Hilger Ltd, Bristol, 1984. pp. x, 255. 81 Illus. in black-and-white. £17.50.

The author has set out with the stated intention of describing the properties and uses of diamond without employing excessive scientific detail, and in doing so he gives us a lively account of the achievements and reports of the various scientists and philosophers down the ages who have become involved with this intriguing gem mineral. The book is certainly not written for the expert, and in over-simplifying some of the more complex aspects of his subject, Dr Davies may occasionally offend both the physicist and the gemmologist.

The opening chapter, entitled 'Fantasy', deals with the use and misuse of the word 'diamond' in ancient manuscripts ranging from the bible to Pliny's 'Natural History'. The curative and magical properties of diamond are also described together with the mineral's early use as an engraving tool for inscribing other gemstones.

The second chapter covers the chemistry of diamond, including an account of Lavoisier's tentative identification of the gas (which resulted from vaporizing diamond) as carbon dioxide, and Tennant's confirmation of this and of the charcoal or carbon composition of diamond. It is amusing to read that Humphry Davy, in attempting to explain away the enormous difference in hardness between charcoal (graphite) and diamond, suggested that this was due to an impurity constituent in diamond. It took another six years before Davy became converted to Tennant's idea that this difference was caused by their differing crystalline structures. Similar insights into the personalities of other scientists who have added to our knowledge of diamond are a feature of subsequent chapters, which include coverage of the structure, synthesis, use and impurity content of diamonds.

A whole chapter is devoted to the diamond stability diagram, which forms the starting point for modern synthesis methods, and this is preceded by a chapter which relates the early unsubstantiated attempts at synthesis, including a graphic report of Hannay's 'explosive' experiments, and the controversy surrounding the later validation of his 'synthetic' diamond specimens. In the chapter on modern synthesis, it is satisfying to see that the Swedish company ASEA is credited with the first confirmed synthesis of diamond (rather than General Electric of America), a fact missing from some books, particularly those by American authors!

In the chapter dealing with diamond impurities, a concise description is given of paramagnetic resonance and other techniques used in the determination of the trace elements present in diamond. In the case of nitrogen impurities, there are clearer descriptions to be found in other textbooks of the differences which exist between Type Ia/b and Type IIa/b diamonds.

The final chapter in this fascinating book is entitled 'Natural gemstones', and briefly covers the history of diamond occurrences, mining, separation techniques, the optics of diamond cuts, and artificial colour enhancement. In the optics section it is disappointing to see the term 'sparkle' in use (as originated in Dodson's PhD Thesis) rather than 'scintillation'. Also disappointing is the scanty coverage of diamond simulants and their detection. Cubic zirconia is produced in top white colour grades as well as yellow, and its dispersion at 0.06 (compared with diamond's 0.044) does not cause its refractive index to change 'rapidly' with the colour of light (there must be some confusion here with strontium titanate which has a dispersion of 0.190; this error is also repeated in the comments on using reflectivity as a test, where it is predominantly the difference in refractive index and *not* dispersion which separates cubic zirconia form diamond).

The final paragraph in this chapter states that the emphasis throughout the book has been on the 'scientific' aspects of diamond, and this is evident from the references given at the end of each chapter, only one of these being taken from a textbook on gemmology.

Despite the minor gemmological inconsistencies, the book is most readable and helps to make a physicist's view of diamond more understandable to the gemmologist. P.G.R.

HOLMES (R. W.), KENNEDY (M. B.). *Mines and minerals of the Great American Rift.* Van Nostrand Reinhold, New York, 1983. pp.xii, 332. Illus.in black-and-white and in colour. £28.60.

The Great American Rift runs from Mexico to Alaska but the states with which the book is concerned are Colorado and New Mexico. Individual mines have been located physically and in the literature, and although some of the descriptions are submitted in a style reminiscent more of the shovel than of the pen a good deal of information can be found. Notes on such minerals as rhodochrosite and fluorite will be interesting to the gemmologist; the bibliography is very comprehensive, the index a little less so (fluorspar and fluorite have separate listings) and the colour photographs are very good. M.O'D.

JACKA (J. D.), HAMMACK (N. S.). *Indian jewelry of the prehistoric southwest.* University of Arizona Press, Tucson, 1975. pp. 48. Illus. in colour. $5.00.

Brief but well-illustrated guide to Indian jewellery with turquoise prominent. M.O'D.

KNEIDL (V.). *Hunsrück und Nahe.* Franckh'sche Verlagshandlung, Stuttgart, 1984. pp. 128. Illus. in colour. DM29.50.

This excellent book covers the geology, mineralogy and fossils of the forested Hunsrück and the Nahe valley of West Germany. Since Idar-Oberstein is in the

Nahe valley the importance of the book to those interested in gem materials is obvious. Lists of specimens, a bibliography and a workable index are provided.

M.O'D.

LEVINSON (O.). *Diamonds in the desert.* Tafelberg, Cape Town, 1983. pp. 172. Illus. in black-and-white and in colour. R24.00.

Set against the background of the discovery of diamonds in the former German South West Africa is the biography of one of the first diamond discoverers and traders, former railway worker August Stauch. A great deal of information is lucidly presented and well researched. Much of the account deals with personalities of the day and their subsequent history; some, though by no means all, made fortunes. Stauch did both but accepted life with admirable equanimity. M.O'D.

NASSAU, (K.). *Gemstone Enhancement.* Butterworths, London, 1984. pp.220. Illus. in black-and-white, with 27 coloured plates. £20.00 (US$34.95 in North America).

In his introductory chapter, Dr Nassau makes the point that the technical details of a number of treatments were discovered during the development of gemstone synthesis. Knowledge of the reversibility of treatments can also be of practical importance where heat is applied during jewellery repair and results in the inadvertent loss of colour in a stone. These opening remarks set the style of the book, which is not only very readable but also achieves a nice balance between theoretical and practical information.

In Chapter 2, 'The History of Treatments', mention is made of Pliny's book written around A.D. 40 to 75, which contains references to gemstone alteration methods, including foiling, oiling, dyeing and the production of composites. Recorded instances of foiling, for instance, go back to at least 2000 B.C. Perhaps the most extensive source of recipes for the falsification of gems is represented by the handwritten 'Stockholm Papyrus', which dates from around A.D. 400. Many examples of these ancient treatments are reproduced, together with extracts from such famous historical gem books as 'The Mirror of Stones' by Camillus Leonardus. The chapter ends with a summary of twentieth-century irradiation techniques.

In Chapter 3, the heat treatment of gems is traced from its very early application in pre-Christian Grecian and Roman times to the sophisticated methods used in the 1970s and 80s. Details of these treatments are given with an explanation of the probable mechanisms of enhancement. Despite the complexity of the associated chemical and valency equations, these mechanisms are easily understandable in Nassau's lucid text.

Chapter 4 deals with 'Irradiation Treatments' and reminds us of the wavelengths in the electromagnetic spectrum and the various sub-atomic particles which are put to use in the service of gemstone enhancement. As with the previous heat treatment chapter, the relevant gems are listed together with their resulting colours and the mechanism of the change (in this case due mainly to the creation of colour centres in the atomic structure).

The simpler processes of chemical staining, bleaching, dyeing and oiling are covered in some detail in Chapter 5, which ends with a description of composites and synthetic overgrowths (e.g. the Lechleitner and Nacken processes).

Of prime interest to the gemmologist and jeweller is Chapter 6, 'The Identification of Treated Gems and the Question of Disclosure', although the author only claims that this contains a brief outline of the subject. The importance of visual inspection is stressed, either by using a 10× hand lens or a modern microscope, and the benefit of using the immersion technique of inspection is also mentioned, as is the possibility that some oils employed for sapphires and rubies may exhibit fluorescence. The chapter ends with a discussion of disclosure regulations applicable to the U.S.A. and to Europe.

The final chapter, 'Specific Gemstone Treatments', contains an alphabetic listing of gems and their various treatments from amber to zoisite. This constitutes nearly 40% of the book, and the author warns that the descriptions of treatments should not be taken as recommendations. The reader should always first try any procedure out on a small fragment of little value!

In this most valuable final chapter, the paragraphs in each alphabetic section are letter-coded to denote the intention of the treatment (e.g., darkening, lightening, clarification, reconstruction, dyeing, coating etc.). The text also contains hints on the recognition of the treatments, and in this respect is a practical adjunct to Chapter 6. Each section is fully referenced enabling the reader to check the original article from which the description has been derived. The reviewer found the corundum section of this chapter the most interesting, as it presented together for the first time all the various treatment processes for sapphire (including geuda material), ruby and the synthetic products.

The Appendices contain information on furnaces and furnace construction, temperature measurement and control (including useful details on thermocouple characteristics), on irradiation figures and hardware, on colour and on suppliers of equipment and services (i.e. heating, irradiation and lasering).

Dr Nassau has performed a valuable service in compiling this definitive work on gemstone enhancement, which will rank as an essential companion volume to the 4th edition of 'Gems'. P.G.R.

NIXON (P. H.), ed. *Lesotho kimberlites.* Lesotho National Development Corporation, [Maseru], 1973. pp.xii, 350. Illus. in black-and-white and in colour. Price on application.

The structural setting of kimberlites and their composition are discussed in a series of studies with the aim of determining the composition, structure and thermal gradient of the earth's mantle and crust. Along with this task information on possible locations for diamond is given, this part of the work being financed by the United Nations Development Programme. Chapters are written by invited contributors. The importance of Lesotho for kimberlite research can be seen when it is realized that there are 17 pipes, 21 dyke enlargements or blows and over 200 dykes. Many of the areas are barren from the diamond prospector's viewpoint, but some of the diamonds which are found are of very high quality.

The first pipe to be described is Letsang-la terae which has produced superb quality diamonds; other pipes are described subsequently, and in each case the

geology is discussed, together with mineralization and morphology of the diamond crystals where appropriate. The book concludes with a bibliography, maps and abstracts in Russian.

Students of kimberlites are exceptionally fortunate to have this major book covering one discrete area. A good deal of information was obtained from satellite imagery and some of this is shown in colour. Gemmologists will be interested to hear that the diamonds from Letseng-la-terae show virtually no octahedra, though transitional forms between octahedra and dodecahedra were observed. Two stones in a sample showed octahedron and dodecahedron on either side of the same crystal. Commonest morphologies were rounded, irregular dodecahedra and rounded, irregular and flattened octahedra. Macles were frequently observed but no cubes or cubo-octahedra. The general colour varied from medium to light brown, progressing into pale yellow and colourless stones with a faint yellow tint. After this come completely colourless stones. Common inclusions were black flakes lying in (111) planes and were probably graphite. No silicate or oxide inclusions were noted on first examination. Diamonds from the Kao kimberlite progress from flat, smooth-faced straight-edged octahedra through rounded forms to rhombic dodecahedra. There is a higher proportion of white varieties among whole crystals compared with irregular stones in which the grey, yellow and brown varieties are more common.

These examples give some idea of the contents of this exceptional book.

M.O'D.

O'LEARY (B.). *A field guide to Australian opals.* Second edn. Gemcraft Publications Pty Ltd, East Malvern, Victoria, Australia, 1984. pp. 159. Illus. in colour. $12.95.

This book is misdescribed as second edition. Only the publisher has changed and the correct designation should be a re-issue as there is no textual change. (Originally reviewed in *J. Gemm.,* 1978, **XVI**, 3, 215). M.O'D.

POHL (W.), NIEDERMAYR (G.). *Geology of the Mwatate quadrangle and the vanadium grossularite deposits of the area.* Kenya Ministry of Natural Resources, Mines and Geological Department, Nairobi, 1979. pp. 55. Map. Price on application.

This study of degree sheet 195/2 forms Report No. 101 of the Mines and Geological Department of Kenya. The occurrence of the vanadium grossular garnet prompted the establishment of a joint Austrian-Kenya Geological Mapping and Mineral Exploration Project whose findings are reported here. Details of the mineral occurrences are given with details of the individual mines. M.O'D.

PEMBERTON (H. E.). *Minerals of California.* Van Nostrand Reinhold, New York, 1983. pp.vii, 591. Illus. in black-and-white. £29.95.

The first list of Californian minerals was compiled by W. P. Blake in 1866, and a mineralogy has appeared eight times since then; in 1966 a centennial volume was published, and the present work is described by the publishers as an update of it.

The total number of terrestrial species described is now 736, and 5 meteoritic species are also included. Arrangement is by chemical composition, and within each category occurrences are described by alphabetical order of county. Each occurrence is given the best or most up-to-date reference, and map coordinates are provided in many cases. There are a first-class bibliography, an index to maps and a subject index. Gemmologists will turn first to the sections on garnet, tourmaline and benitoite in this excellent book. M.O'D.

Chinese ivories from the Shang to the Qing. (An exhibition catalogue organized by the Oriental Ceramic Society jointly with the British Museum). The Society, London, 1984. pp.200. Illus. in black-and-white and in colour. Price on application.

The book opens with a useful discussion of ivory, its properties and colour, and of the way in which it has been worked by the Chinese. The catalogue proper is arranged by period and type of piece; pre-Ming ivory carving is dealt with first, followed by Ming and Qing figure carvings and useful and ornamental pieces. There are a map and a glossary, a short bibliography and a list of lenders to the exhibition. The standard of reproduction is high, especially with the colour plates. M.O'D.

ASSOCIATION NOTICES

JOHN ALAN FLEMING, F.G.A., A.C.A.N.Z.*
A Tribute

Born in the 1920s Alan (as he was known to his friends) was the youngest son of a wealthy gentleman and was educated and brought up in Auckland, New Zealand.

After leaving college Alan entered into training as an accountant, qualifying at an early age as an Associate Chartered Accountant of New Zealand. When war came he served as a sergeant, but never left New Zealand. After the unexpected death of his father in 1948, Alan formed several companies but finally settled in the stamp business, which is still in existence today.

His first experience of London was in 1954, when he and his wife Joy came on holiday. He travelled widely, and it was on a visit to Sri Lanka that he developed a keen interest in gemstones. In 1959 he decided to return to London and shortly after his arrival he enrolled in the gemmology classes and qualified as an F.G.A. in 1962.

From this point onward he specialized in rare and unusual gemstones and mineral specimens. Alan handled a wide range of goods, including some of the first examples of new materials available in this country. He had some of the first 'trillings' of alexandrite from Fort Victoria in Zimbabwe (then Rhodesia), and carried for some time the finest range of blue zoisite (tanzanite) in the country. He was one of the first dealers to obtain the chrome grossular garnet, later to be named tsavolite.

Alan had a keen eye for unusual and interesting items, revelling in their discovery and delighting in teasing the unsuspecting gemmologist with them. Many items were not only made available to the Gem Testing Laboratory and the Geological Museum, but a number were actually donated to their reference collections. During the years a number of these have been published in the *Journal of Gemmology*. Material was also made available to virtually any interested party, who was fortunate enough to think to ask. He gave talks and lectures and never missed an opportunity to spread the message and interest in gemmology.

*Whose death on 3rd May, 1984, was reported above on p.283. –Ed.

Alan remained a one-man business until early 1977, when he together with Peter Hurrell and Christopher Cavey, F.G.A., joined forces to market the first diamonds in kimberlite from Siberia; this was achieved by the acquisition of a company called Rough Gems Ltd. It was one year later that charoite became available, and Alan with his world travels carried news of new materials far and wide. With the decline of the collector market in 1980, Alan expressed a yearning to return to his native New Zealand, finally departing last year, leaving his London business affairs in the hands of Tony French, F.G.A. Unfortunately shortly before leaving London he developed liver trouble and upon his arrival in New Zealand underwent surgery. He never regained his full strength, and, only a few weeks before he died, he was informed that he had terminal cancer.

Alan was a rare man with a wonderful sense of humour; he had a habit of always looking at the best side of people, and was one of the finest intuitive gemmologists I have ever had the pleasure of meeting. He will be sadly missed not only by those who knew him but by the entire gemmological world which has without doubt lost one of its greatest friends.

NEWS OF FELLOWS

On 26th June, 1984, Mr M. J. O'Donoghue, M.A., F.G.S., F.G.A., gave a lecture on 'Recent developments in synthetic gemstones' to the Amateur Geological Society in London.

MEMBERS' MEETINGS

London

On 24th April at Kensington Town Hall, Hornton Street, W.8., a talk was given to members of the Association by Mr Ken Scarratt, F.G.A.

The subjects dealt with during the talk included the jades, amber, pearl, ruby, sapphire, diamond, iolite, haematite and emerald (all of which were illustrated by slides), the common factor amongst them being that the Laboratory had been asked to examine interesting examples of them in the recent past.

On the subject of pearls, a large baroque pearl set as a cigarette holder was described in which the centre had been drilled out to accommodate the tube along which the smoke travelled; also described was a very large orange conch pearl. Mention was also made of naturally coloured natural and cultured pearls as well as the problems associated with differenciating between the modern non-nucleated cultured pearl and the natural pearl.

A collection of amber and related products was then described, which was followed by a report upon the present situation with regard to both the Lennix synthetic emerald, and the Biron synthetic emerald.

Amongst the next items discussed were a necklace of faceted iolite, a nephrite and ivory knife, a blue jadeite vase, diffusion treated corundum and heat altered inclusions in blue sapphire.

The talk then passed on to the problems associated with the natural and the modern synthetic rubies and the way in which, if care is not taken, natural ruby may be mistaken for synthetic. The new Ramaura synthetic ruby and new Seiko synthetic gems were then described.

In conclusion a current problem concerning a new magnetic haematite was related.

Most of the subjects spoken on will, if they have not already, be included in future 'Notes from the Laboratory'.

K.S.

North West Branch

On 19th July, 1984, at Church House, Hanover Street, Liverpool 1, Mrs Val Duke gave a talk on Brazilian gems.

South Yorkshire and District Branch

On 17th May, 1984, at Sheffield City Polytechnic, two films were presented, one on diamonds and one on Orapa, mining in Botswana.

On 21st June, 1984, at Sheffield City Polytechnic, a film evening was held. The first film was on the History of Jewellery. This was followed by two films on the production of gold. The films replaced a talk on valuation by Mr Hugh Ransom, which had to be cancelled because of illness.

On 5th August, 1984, an evening treasure hunt was held in the Peak District.

ASIAN INSTITUTE OF GEMOLOGICAL SCIENCES

The A.I.G.S. is hosting a diamond and emerald seminar in Bangkok from 15th to 17th November, 1984. Participants include Mr Peter G. Read, C.Eng., F.G.A., Mr Roy V. Huddlestone and Dr Peter C. Keller. The attendance fee for the three days is U.S.$100.00. Further details may be obtained from the Registrar, Asian Institute of Gemological Sciences, 987 Silom Road, Rama Jewelry Building (4th Floor), Bangkok 10500, Thailand.

SUBSCRIPTIONS 1985

At the Meeting of the Council held on Tuesday, 24th April, 1984, the business transacted (in addition to the elections to membership recorded on p.286 above) included increases in the subscription rates for 1985 as follows.

Fellows £16: Ordinary Members and Associate £19.

LETTERS TO THE EDITOR

From Mr R. Keith Mitchell, F.G.A.

Dear Sir,

Mrs Barbara Anderson has very kindly drawn my attention to an omission in my obituary notice for her husband.

Among his many honours, Basil Anderson took particular pleasure in having been made a Member of the Indian Academy of Sciences. I should add also that he had been elected to honorary membership of many foreign gemmological organisations and had held office in the Mineralogical Society, served on C.I.B.J.O. committees and so on. A man of many parts, his influence in the world of gemmology was almost universal.

I trust that you will be kind enough to print this letter in the next issue of the Journal.

Yours etc.,
R. KEITH MITCHELL.

31st July, 1984.
Orpington, Kent.

From Mr Richard W. Hughes, A.G., F.G.A.
Asian Institute of Gemological Sciences.

Dear Sir,

Please include this A.I.G.S. Gem Lab Report in the next issue of The Journal of Gemmology.

SURFACE REPAIRED RUBIES—A NEW GEM TREATMENT

Gemologists in the Gem Lab of the Asian Institute of Gemological Sciences in Bangkok, Thailand, have uncovered what appears to be the latest form of corundum treatment to emerge from the ovens of Thailand's skilled gem chefs—the Surface Repaired ruby.

Surface pits and cavities are a common feature on faceted rubies, especially expensive stones. To grind them away completely sacrifices weight. In the ruby business a few extra points may be the difference between profit and loss, and so the pits remain; at least they did until recently. Then a parcel of nine one-carat rubies was brought in for examination. Every stone in the lot was found to have had the surface pits repaired by filling them with a transparent colourless material. These repaired areas stood out in high relief when the stone was immersed in methylene iodide and examined under magnification. Gas bubbles of various sizes were also seen in some of the filled areas. Additional tests proved the filling material to be singly refractive with a 1.52 refractive index, thus suggesting its identity to be some type of glass.

Because the filling material seems to have been fused into the surface pits and cavities, it appears that some type of high temperature heat treatment is involved. Gem cookers have been known to add a wide variety of substances to the crucible,

FIG. 1. Large repaired area (with shaded appearance) in Thai ruby visible under oblique illumination. Note suspended gas bubble. 23 ×.

FIG. 2. Repaired areas (dark contrast at edges) visible in Thai ruby immersed in methylene iodide. Note the gas bubble.

FIG 3. Repaired areas (with shaded appearance) in Thai ruby visible under oblique illumination. Note suspended gas bubble inside repaired area. 38 ×.

and this could be the accidental by-product of the ordinary burning. However, since the initial discovery, other rubies have been found displaying similar repaired features. Thus it seems more likely that the process is being done with the aim of improving the appearance of stones by lessening the visibility of surface flaws.

Regardless of the motives behind this new treatment, the fact remains that in certain cases the surface repairing of rubies could substantially raise the price of a stone, if it were to go undetected. Thus it is of great importance that buyers be presented with full details regarding the absence or presence of surface repair (and its extent) before deciding to purchase a particular stone.

Detection of Surface Repaired Rubies

Detection of the surface repair of rubies should not present too much of a problem to the well-equipped gemmologist. The stone in question should be immersed in pure methylene iodide and examined under magnification with diffused lightfield illumination. Any repaired cavities will be visible as high relief (highly reflective) areas breaking the surface of the stone, especly when viewed at an angle to the surface. Gas bubbles within the filling material are often seen as well. However, care should be taken not to confuse a repaired pit or cavity with a naturally occurring included crystal, which may also break the surface.

A.I.G.S. feels that the sooner the trade becomes aware of this treatment, the better, and we expect to see more of these altered gems in the near future.

Yours etc.,
R. W. Hughes
Laboratory Director.

19th June, 1984.
Bangkok 5, Thailand.

[Although an article on the same subject, received some time before Mr Hughes's letter, appears on pages 293-297 above, his letter also is published in view of the obvious importance to the trade of awareness of this new treatment and to show that it is causing concern in Bangkok as well as in London. The three colour-photographs (Figures 1, 2 and 3) were sent by Mr Hughes at the end of August in the hope that they might accompany his letter. It should be borne in mind that not all infillings contain bubbles.—Ed.]

GEM TESTING EQUIPMENT

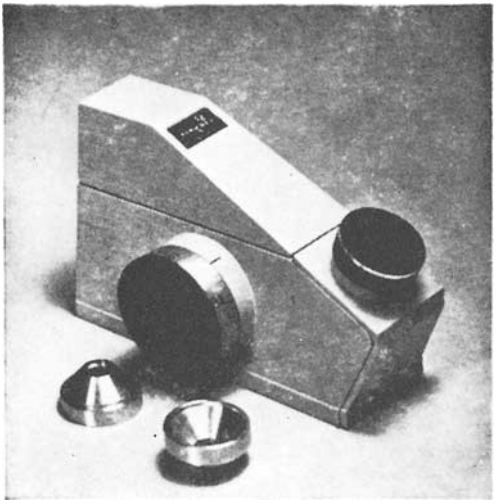

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Historical Note

The Gemmological Association of Great Britain was originally founded in 1908 as the Education Committee of the National Association of Goldsmiths and reconstituted in 1931 as the Gemmological Association. Its name was extended to Gemmological Association of Great Britain in 1938, and finally in 1944 it was incorporated in that name under the Companies Acts as a company limited by guarantee (registered in England, no. 433063).

Affiliated Associations are the Gemmological Association of Australia, the Canadian Gemmological Association, the Gem and Mineral Society of Zimbabwe, the Gemmological Association of Hong Kong and the Gemmological Association of South Africa.

The *Journal of Gemmology* was first published by the Association in 1947. It is a quarterly, published in January, April, July, and October each year, and is issued free to Fellows and Members of the Association. Opinions expressed by authors are not necessarily endorsed by the Association.

Notes for Contributors

The Editor is glad to consider original articles shedding new light on subjects of gemmological interest for publication in the *Journal.* Articles are not normally accepted which have already been published elsewhere in English, and an article is accepted only on the understanding that (1) full information as to any previous publication (whether in English or another language) has been given, (2) it is not under consideration for publication elsewhere and (3) it will not be published elsewhere without the consent of the Editor.

Articles published are paid for, and a minimum of 25 prints of individual articles may be supplied to authors provided application is made on or before approval of proofs. Applications for prints should be made to the Secretary of the Association—not to the Editor—and current rates of payment for articles and terms for the supply of prints may be obtained also from the Secretary.

Although not a mandatory requirement, it is most helpful if articles are typed (together with a carbon copy) in double spacing on one side of the paper, with good margins at sides, top and foot of each page. Articles may be of any length, but it should be borne in mind that long articles are more difficult to fit in than short ones: in practice, an article of much more than 10 000 words (unless capable of division into parts or of exceptional importance) is unlikely to be acceptable, while a short note of 400 or 500 words may achieve early publication.

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and

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IDENTIFICATION CHARACTERISTICS OF FLUX GROWN SYNTHETIC ORANGE SAPPHIRES

By MAHINDA GUNAWARDENE, F.G.A., D.Gem.G.

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INTRODUCTION

During the last few years, the gemstone market has been flooded with many new man-made substances giving effectively similar appearances to those of the natural species. Apart from the historically famous flame-fusion synthetic corundums, which are now abundantly manufactured by V. D. Djévahirdjian SA in Monthey, Switzerland, and the Austrian production of ruby by Professor P. O. Knischka (Knischka & Gübelin, 1981; Gunawardene, 1983 a), most of the new corundum varieties, particularly synthetic rubies, are now made in U.S.A. and Japan. Among many American manufacturers Chatham is credited as being the producer of three prized varieties of corundum synthetically, employing a flux method. His creations are the flux grown ruby, blue and orange sapphires. The latter is made to represent the colour of natural 'Padparadschah' sapphire found in Sri Lanka. However, a vast production of synthetic flux grown orange sapphire sufficient to satisfy the market has not yet been

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TABLE 1. COMPARISON OF PHYSICAL PROPERTIES IN NATURAL AND SYNTHETIC ORANGE SAPPHIRES

	'Padparadschah' sapphire from Sri Lanka	Orange sapphire from Tanzania	'Verneuil' made synthetic orange sapphire	'Chatham' made synthetic orange sapphire	'Inamori' made synthetic orange sapphire
Colour	pinkish-orange to pinkish-yellow with areas of orange-brown and pinkish-orange.	brownish-orange	orange.	reddish-orange with patches of yellowish-orange, orange-brown, pinkish-orange, whitish-yellow.	reddish-orange with purplish-pink, pinkish-orange, yellowish-orange areas.
Refractive indices	e = 1.760—o = 1.768 −0.008 (Gübelin, 1968)	e = 1.763—o = 1.771 −0.008 (Gunawardene, 1984	e = 1.762—o = 1.770 −0.008 (Nassau, 1980)	e = 1.672—o = 1.770 −0.008 (Kane, 1982)	
	e = 1.761—o = 1.769* −0.008	e = 1.765—o = 1.773* −0.008	e = 1.762—o = 1.770* −0.008	e = 1.759—o = 1.767* −0.008	e = 1.760—o = 1.768* −0.008
Specific gravity at 4 °C	3.99±0.01 (Gübelin, 1968)	$4.00^{+0.06}_{-0.02}$* (Gunawardene, 1984)	4.00±0.05 (Nassau, 1980)	4.00±0.03** (Kane, 1982)	
	4.00±0.02*	$4.00^{+0.06}_{-0.02}$*	$4.00^{+0.01}_{-0.02}$*	$4.00^{+0.04}_{-0.01}$**	$4.00^{+0.04}_{-0.01}$*
Dichroism o−ray	yellowish-orange	brownish-orange	orange-brown	pinkish-orange	reddish-yellow
e−ray	pinkish-orange	yellowish-green	light orange	yellowish-orange	yellowish-orange
Luminescence					
Long-wave UV (366 nm)	strong pinkish-orange	inert	weak chalky blue	strong orange-red	strong orange-red
Short-wave UV (254 nm)	weak yellowish-pink	inert	inert	weak pinkish-red	weak pinkish-red
Absorption spectrum	See Figure 2.	See Figure 3.	See Figure 4.	See Figure 5.	(Not measured)
Inclusions	Various crystal inclusions among which rutile needles and zircon with haloes are common. Colour zoning of weak blue and violet. Typical 'Ceylon feathers' forming 'fingerprints'.	Dislocation lines, tiny crystals of zircons. Crossed polars reveal distinct twinning planes. No zoning	'Strain knots' under + polars. Clouds of gas bubbles under high magnification. Rarely curved growth lines.	Flux formation in many forms such as feathers flags and other shapeless flux residues Platinum inclusions.	Less (or no) flux and platinum inclusions than in Chatham product. Fine distribution of a rather thin inclusion. Manufacturer reports a pulling method which causes less inclusions in the finished product.

*Analysed by the author in this investigation.
**Values are considered with faceted samples and not with crystal clusters.

achieved. Further, a similar colour variety of sapphire is made in Japan by Kyocera International Inc., in Kyoto, and marketed under the trade name 'Inamori grown Padparadschah'.

The new varieties of synthetic corundum made in America and Japan are extensively investigated and compared with the natural 'Padparadschah' sapphires and orange sapphires of Sri Lankan and East African origins respectively and with the Verneuil synthetics. The properties such as colour, refractive indices, absorption phenomena, ultraviolet behaviour and the internal characteristics are reported. The comparison stones used and the results obtained are given in Table 1.

GEMMOLOGICAL CHARACTERISTICS

Colour

Both the American and the Japanese synthetic sapphires appeared orange to reddish-orange in colour. They also revealed a distinct reddish-orange tinge in orange-yellow areas of the stone. Further, there can be patches of yellowish-orange, orange-brown, pinkish-orange or whitish-yellow in a single crystal or many such hues in clusters. A cluster of the Chatham product is shown in Figure 1.

FIG. 1. A crystal cluster of flux-grown synthetic orange sapphire marketed by *Chatham Created Gems, Inc.*, San Francisco, U.S.A. (10×).

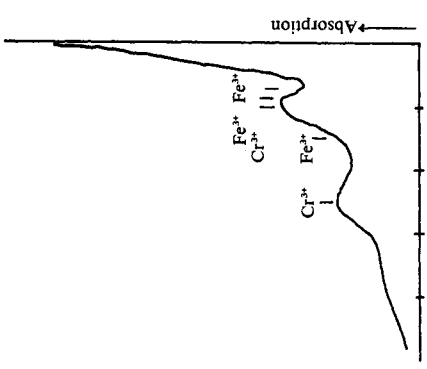

FIG. 2. Absorption spectrum of 'Padparaschah' sapphire from Sri Lanka. (After Schmetzer *et al.*, 1982)

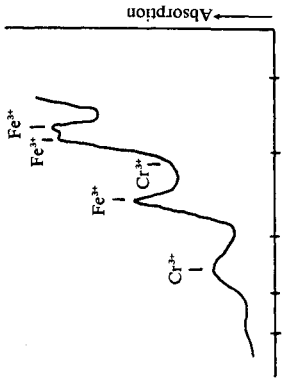

FIG. 3. Absorption spectrum of orange sapphire from Tanzania.

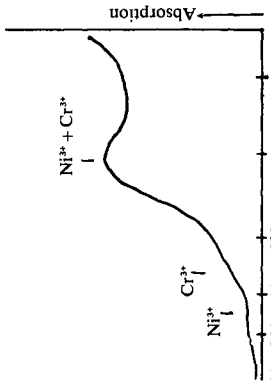

FIG. 4. Absorption spectrum of Verneuil-made synthetic orange sapphire. (After Schmetzer *et al.*, 1982)

The crystals observed were all transparent to translucent and on the clusters a nearly colourless *glossy coating* was evident. This appears to be a ceramic glaze and is found only on the faces of the crystals at the outside of the cluster. Colour zoning, ranging from orange-brown to whitish colour, is visible in cluster crystals much more than in faceted synthetic flux-grown orange sapphires.

Refractive Indices and Specific Gravity Determinations

The standard critical-angle refractometer used with Na_D light of 589.3 nm was used to measure the usual refractive indices for corundum gems. As given in Table 1, the stones used in comparisons gave the same optical refractivities. The specific gravity determinations were made by hydrostatic weighing, employing a Mettler PC 400 electronic balance with specific gravity attachments. The results obtained in five sample stones used in comparisons are listed in Table 1. The results were less certain with the clusters than the individual faceted specimens. The specific gravity was calculated at 3.702 on the crystal cluster. This rather low value may be due to the ceramic glaze coating on the bottom of the cluster. Furthermore, the enclosed gas bubbles in between the crystal groups would have contributed to the low specific gravity, which is very low for corundum. Considering these differences, it is advisable to rely on the common specific gravity value recorded for the fashioned stone rather than on the density of the cluster.

Absorption Spectrum

In regard to the coloration of orange sapphires many investigations are reported (Nassau, 1980; Schmetzer & Bank, 1981; Gunawardene, 1984). One of the most important gemmological determinations of the term 'Padparadschah' is dependent on the extensive analysis of the absorption spectra of orange or reddish-orange corundums. The colouring elements such as Cr^{3+} and Fe^{3+} are mainly responsible for the colour of 'Padparadschah' sapphire. As shown in Figure 2, the absorption peaks recorded for Cr^{3+} and Fe^{3+} are different to those of the curves of other orange sapphires of synthetic or natural origins (see also Schmetzer *et al.*, 1982). The Fe rich orange sapphire from Umba Valley shows dissimilar absorption curves to that of 'Padparadschah' sapphires from Sri Lanka (Figure 3). The Verneuil synthetic orange sapphire owes its colour to Ni^{3+} and Cr^{3+}

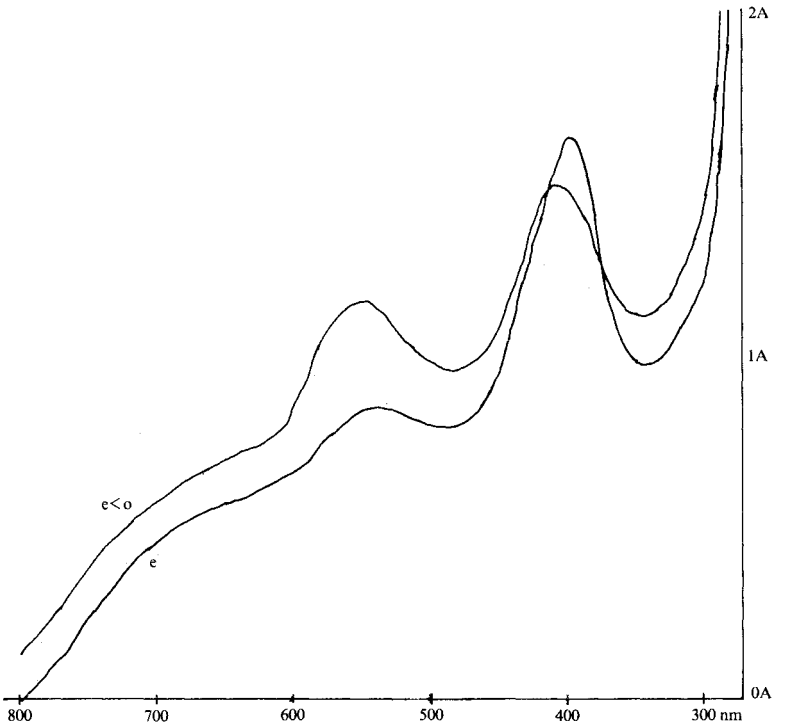

FIG. 5. The recorded absorption spectrum of synthetic orange sapphire made by Chatham using a melt diffusion process. The polarized curves for *o* and *e* rays were analysed by using a Pye-Unicam SP8-100 spectrophotometer.

(Figure 4) and does not cause much difficulty in recognition. As in other orange sapphires, referred to in this work, the absorption spectrum of Chatham-made synthetic orange sapphire measured by using a Pye Unicam spectrophotometer is shown in Figure 5. The absorption curves for *o* and *e* directions are given. It clearly indicates that the absorption spectrum of this new product is caused by Cr^{3+} and Fe^{3+} as in 'Padparadschah' gems of Sri Lankan origin. However, the absorption peaks are at different extinctions.

Therefore, a quantitative absorption spectroscopic analysis may lead to accurate results in discrimination of orange sapphire either of natural or of synthetic origin. Under the usual gemmological spectroscopic investigations, using a prism or diffraction-grating spectroscope, a clear distinction cannot be made in separating natural from synthetic orange sapphires made by Chatham or Kyocera.

Response to Invisible Radiations

In examination under long-wave ultraviolet having a peak wavelength at 366 nm the Chatham-made synthetic orange sapphire exhibited a fluorescence of strong reddish to yellowish-orange of varying intensities. The effect was weaker under short-wave ultraviolet radiation (254 nm). the stones used in the comparison gave the following results. The 'Padparadschah' sapphire from Sri Lanka fluoresced with a strong pinkish-orange glow. The synthetic orange sapphires made by Djévahirdjian were practically inert, as were the natural samples from Tanzania. However, the Japanese product revealed a similar fluorescent response to that of the Chatham-made synthetic orange sapphire. Further comparisons are repeated in Table 1.

Microscopic Examinations

To the gemmologist, the best available instrument within his reach, which can often quite conclusively determine the origin of a gem, is the microscope. For acquiring a positive answer, natural or man-made, the microscope, as most other instruments used in gem testing, has its limitations in certain instances. Most or all of the known natural or synthetic gemstones, particularly corundum gems, must be observed under the microscope and the *Chatham* and *Inamori* products so examined revealed characteristic and interesting inclusions.

The most diagnostic internal characteristics were solid inclusions of *flux* and *platinum*. The former appeared as residual particles or in the form of feathers having wispy veils, curly flags, nets or lace-like appearances. The platinum inclusions observed in these American synthetic orange sapphires revealed pseudohexagonal, trapeziform, triangular, needle-like and many

FIG. 6. Scenery of a lace-like flux feather in *Chatham*-made synthetic orange sapphire. (darkfield, 35 ×).

FIG.7. Irregular flux distribution in the new synthetic orange sapphire from America. They are rather similar to the feathers seen in natural rubies of Thai origin. (darkfield, 30 ×).

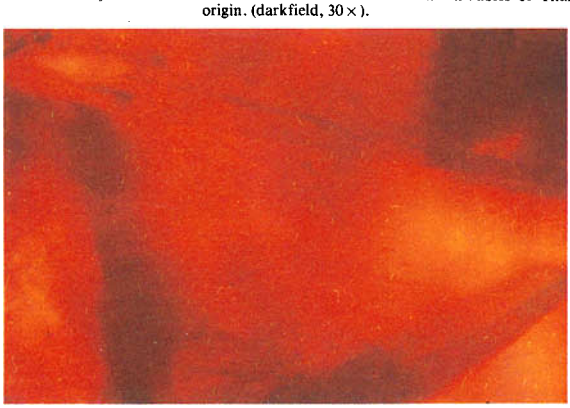

FIG.8. Diffused, branchy formations of a type of inclusion often observed in *Inamori* synthetic orange sapphire. (lightfield, 45 ×).

other irregular shapes. The exact outward appearance of a particular platinum particle can be studied from a definite angle of view, which should be selected after several rotations of the stone. Observed are also the zonal lines, similar to those seen in natural 'Padparadschah' sapphires of Sri Lankan origin, twin-planes and various negative crystal inclusions caused during the diffusion of the used flux.

Flux Inclusions

Developments achieved by many corundum manufacturers (Remeika, 1963; White & Brightwell, 1965) principally employ a type of flux in their synthetics. The dissolving of the flux is mainly dependent on the temperature and the pressure introduced at the time of crystallization. Such variations and extended periods of temperature/pressure environments cause the flux to be distributed in thin feathery formations or as remnants having irregular forms. A typical flux distribution forming a net is shown in Figure 6. Drops of flux, reminiscent of the feathers seen in Thai ruby, as in Figure 7, are commonly encountered in the new Chatham product. However, a lesser amount of inclusions (Figure 8) was noted in the Japanese product in comparison with the available Chatham orange sapphire grown by a flux. Rather confusing 'Ceylon feather' type flags of flux are often seen in the orange flux sapphires made by the American manufacturer (Figure 9). Similar to natural 'Padparadschah' sapphire from Sri Lanka, the colour distribution in the synthetic flux-grown orange sapphire is illustrated in Figure 10. Further, this particular photomicrograph reveals rather fine flux inclusions and rhomb-shaped platinum inclusions. The quite indistinct fingerprint-like flux feather of Figure 11 may mislead the inexperienced professional in identification. Therefore, further examination from different viewing angles is advisable. The flux residues (Figure 12) observed under reflected light clearly indicate the unnatural nature within the interior of the new synthetic orange sapphires. Reflections of the same nature were reported by Gunawardene (1983 a) in synthetic ruby.

Platinum Inclusions

If carefully examined, the recognition of platinum inclusions would provide conclusive means of separating the synthetic flux-

FIG. 9. The flux feather revealed in the *Chatham* product showing an appearance almost similar to the partly healed liquid feather abundantly observed in Sri Lankan 'Padparadschah' sapphires. (darkfield 28 ×).

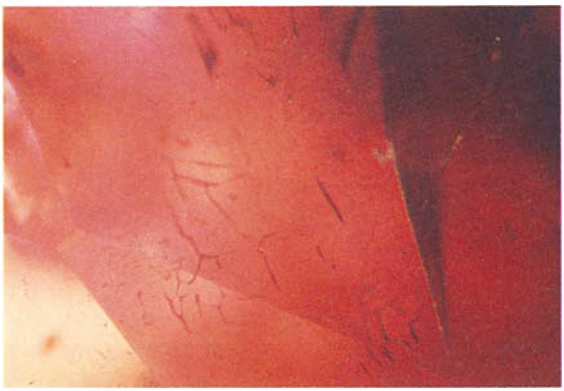

FIG. 10. General view of the new synthetic orange sapphire manufactured by *Chatham*. Flux inclusions, patchy coloration of yellowish-orange, orange and pinkish-purple areas and platinum inclusions. (darkfield and lightfield, 32 ×).

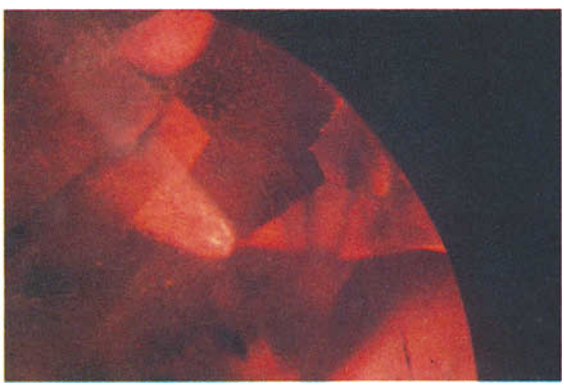

FIG. 11. Distributed flux feathers showing an indistinct appearance in the *Chatham product*. (lightfield, 25 ×).

FIG. 12. Metallic reflections from the residual flux under the microscope light are often encountered in the synthetic orange sapphires created by *Chatham*. (reflected light, 25 ×).

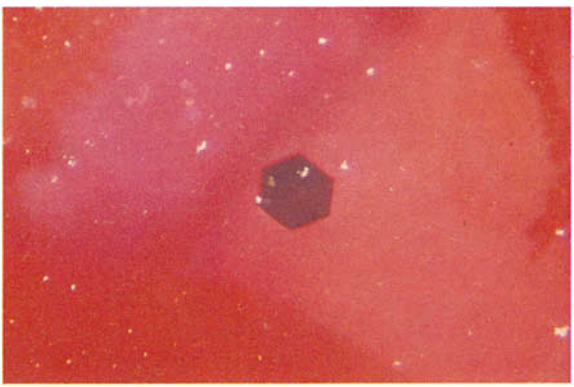

FIG. 13. Pseudohexagonal outward appearance of a platinum inclusion enclosed in a *Chatham* flux-grown orange sapphire. (transmitted light, 46 ×).

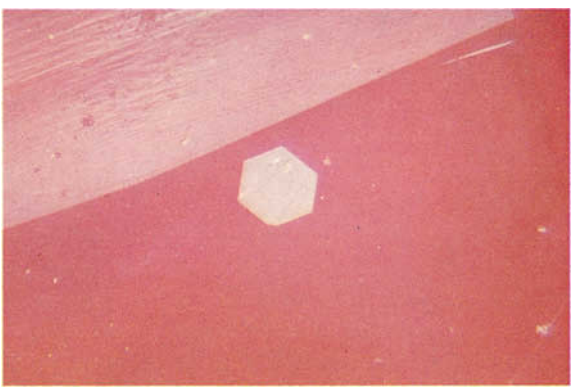

FIG. 14. The same inclusion as in Figure 13, under reflected light. (50 ×).

grown orange sapphires from those of natural origin. They assume various forms much like those seen in ℭ-ruby (Gunawardene, 1983 b). Their appearance under transmitted light is illustrated in Figure 13. As in Figure 14, the platinum platelets tend to reflect with a dull metallic lustre. The thickness of the platinum plate, shown in photomicrographs 13 and 14, was determined by a slow rotation of the stone with the inclusion concerned at a focus. This test revealed the thin nature of the platelets (Figure 15). A similar type of inclusion observable in natural 'Padparadschah' sapphire consists of various mica platelets. Such inclusions are, however, noted only in Sri Lanka corundums and appear characteristically under crossed polarized light. Inamori-made synthetic orange sapphires, as mentioned, contain less or no platinum inclusions and one such internal mark observed is shown in Figure 16. The needle-like platinum inclusions (see Figure 17) may cause difficulties if one is more accustomed to rutile needles, which are often seen in sapphires from Sri Lanka. However, the distinction is easy, if observed under reflected light. The high amount of light reflections from the surface of rutile cannot be compared to the dull metallic appearance of platinum.

Other Inclusions

Orange-brown to whitish zonings are rarely observed in the new orange sapphires made by using a melt-diffusion method. Zoning is more visible in crystal clusters than in faceted samples. Noted also are negative cavities due to dissolving of the flux or platinum. Similar to natural orange sapphires, the new product from Chatham also shows polysynthetic twinning lamellae (Figure 18) under crossed polars.

SUMMARY AND OUTLOOK

The comparison of characteristics in orange sapphires of natural as well as synthetic origin is important to be documented in gemmological literature. The availability of the material from the flux method of production will undoubtedly increase, facilitated by further technical developments in this field. It is probable that larger stones may reach the market in the near future. Special care

FIG. 15. The platinum plate in Figures 13 and 14 now observed from the side. It appears very thin as usual like the plate-like inclusions. (transmitted light, 50×).

FIG. 16. Short, stubby plate-like prisms seen in an *Inamori*-grown synthetic orange sapphire. (reflected light, 32×).

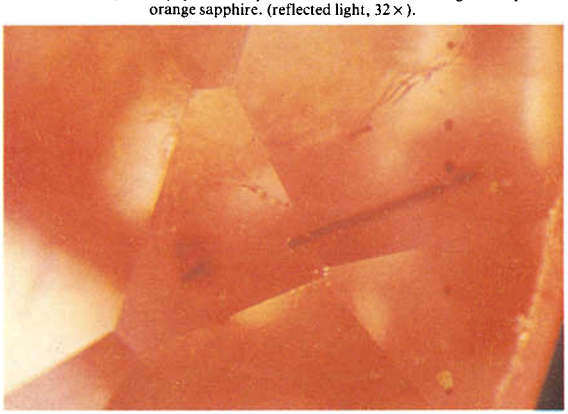

FIG. 17. Needle-like platinum inclusions with dull metallic lustre, embedded in a flux-grown synthetic orange sapphire made by the San Francisco firm. (transmitted light, 30×)

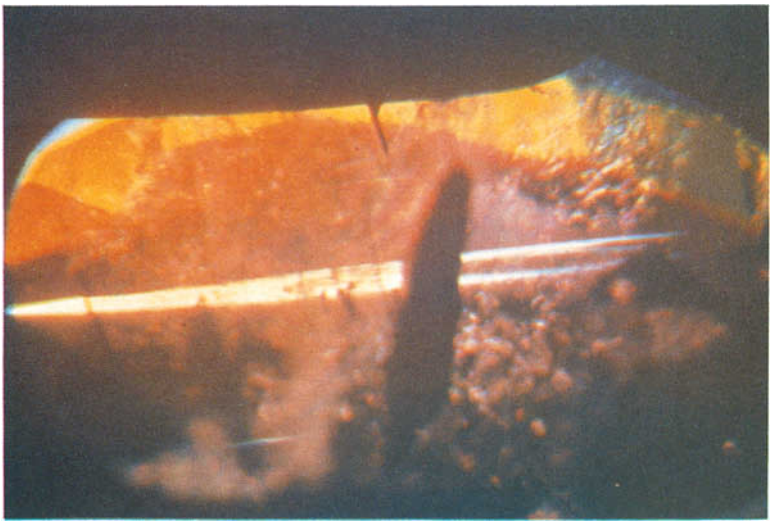

FIG. 18. Distinct twin planes noted in the *Chatham* product under crossed polars. (20 ×).

must be taken in dealing with the 'Padparadschah' colour sapphires in the trade, much more so than before. Those who are purchasing such coloured corundums in Asia or in Africa are advised to have the authenticity certified before the deals are concluded.

ACKNOWLEDGEMENTS

The author wishes to thank K. Arnoldi and Dr G. Lenzen, of the firm Litzenberger and Deutsche Gemmologische Gessellschaft respectively, for providing the Chatham-made synthetic orange sapphire which was presented to them by C. F. Chatham, of San Francisco, U.S.A. Acknowledged also are the excellent spectrophotometric analyses provided by G. Bosshart, Director of the Swiss Foundation for the Research of Gemstones in Zurich, and Dr K. Schmetzer, of Heidelberg University.

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EMERALD AND GREEN BERYL FROM BUCHA, MOHMAND AGENCY, NW. PAKISTAN

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ABSTRACT

Deep bluey green emerald and light green beryl occur sporadically in talc-carbonate-quartz rocks near Bucha (34° 24½′ N, 71° 36′ E). The host rocks have formed along shear zones due to the alteration of enclosing ultramafic rocks; however, the source of solutions responsible for this metasomatic process and introduction of Be is not clear. The beryl and emerald have high iron, the emerald also having higher MgO content and refractive indices than most natural emeralds. The crystals are variable in clarity and reach up to 10 mm in length; gem quality crystals, however, are less than 3 mm long.

INTRODUCTION

Several types of gems and precious stones, some of which are of the top quality, have been found in northern and north-western Pakistan. These include emerald, ruby, red spinel, sapphire, pink and yellow topaz, aquamarine, peridot, tourmaline, idocrase, epidote, garnet (red, green and honey), amethyst, quartz, and green diopside. Ornamental stones such as green (jade-like) rodingite, low quality lapis lazuli, nephrite and several varieties of marble also occur. It is expected that extensive investigations being carried out by various organizations, especially the Gemstone Corporation of Pakistan, will reveal additional occurrences, and Pakistan may emerge as a leading producer of gems and precious stones.

Emerald in Pakistan has been reported from several localities in Swat (Mingora, Charbagh, Alpurai), Mohmand (Prang Ghar, Gandao, Tsapari, Zankhae, and Tora Tigga), and an unconfirmed locality in Bajaur. In this paper we describe a light green beryl and a gem quality emerald recently reported (Rafiq & Jan, 1983) from Bucha (34° 24′ 30″ N, 71° 36′ E), eastern Mohmand Agency. (See Figure 1).

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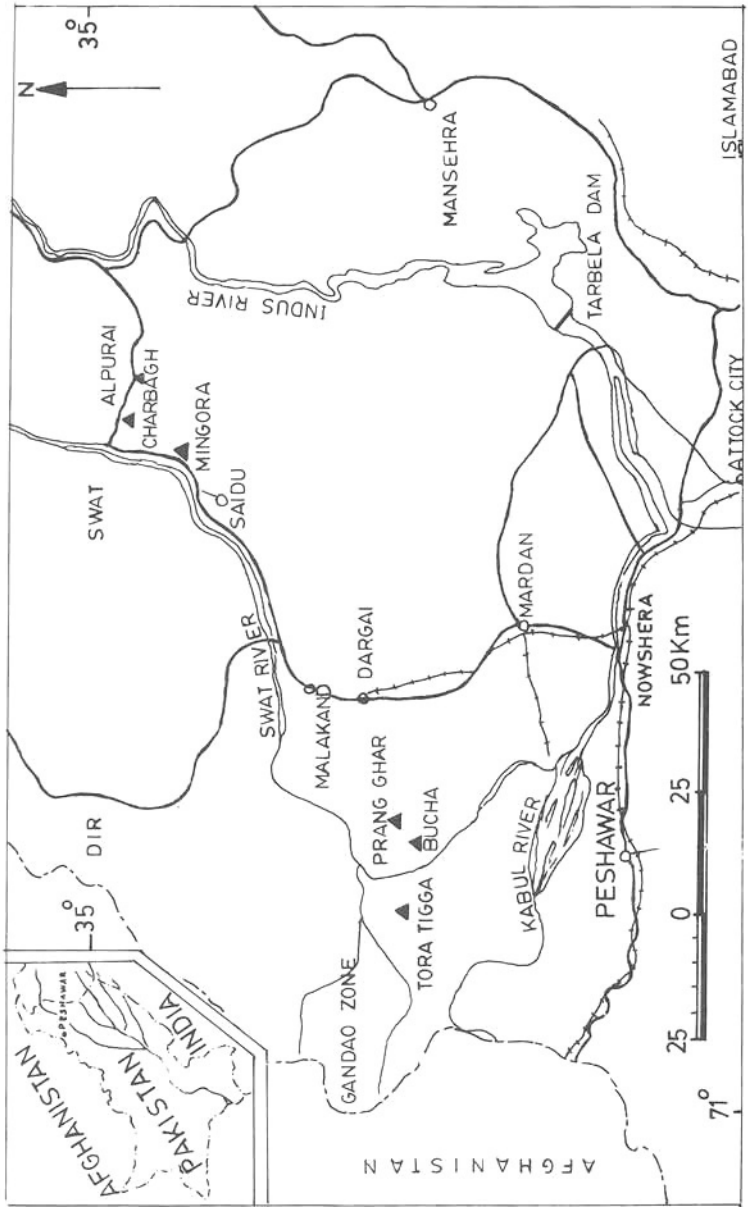

FIG. 1. Emerald localities of NW. Pakistan.

GEOLOGY AND PETROGRAPHY OF HOST ROCKS FOR THE BERYL

The Bucha beryl occurs in talc-carbonate and carbonate-quartz rocks enclosed in ultramafic rocks. Such rocks and associated quartz veins also host emerald and, in one place, a green Cr-rich tourmaline in Swat (Jan *et al.*, 1972, 1981). The Mohmand Agency emerald occurrences, similarly, are found in calcareous rocks and associated quartz veins (Arbab, 1972; Aslam *et al.*, 1982).

Ultramafic rocks in the vicinity of Bucha and Rang Mena are the westerly extension of the Skhakot-Qila-Utmankhel ophiolite complex described by Uppal (1972), Rafiq (1984) and Hussain *et al.* (1984). The complex represents a klippe (Malinconico, 1982), thrust southwards over rocks of the Indo-Pakistan Plate, probably during Late Cretaceous. The ultramafic members of the complex at Bucha contain large bodies, lenses and patches of talc-carbonate and carbonate-quartz rocks. These have a linear distribution and appear to have developed along shear zones. Steatite borders the ultramafics on the south and a black-wall chlorite-magnetite association on the north near Rang Mena. By analogy to other areas of the world, these rocks are regarded by us to be the product of alteration of the ultramafic rocks.

The talc-carbonate and carbonate-quartz rocks are closely associated in the field. They are mostly massive, but the former may locally display a poorly-developed schistose fabric. They are generally light to greenish grey with rusty brown surfaces and at places have the gross appearance of serpentinite. Their appearance, field relations and chemistry (discussed later) suggest that they are the alteration product of the host ultramafic rocks. If so, the carbonate-quartz rock may represent a more advanced stage of alteration than the talc-carbonate rock.

The talc-carbonate rock consists of a fine-grained matrix of talc (with or without opaque oxide) containing abundant aggregates of carbonate and coarse shreds and flakes of talc. A typical specimen of the carbonate-quartz rock consists of about ⅔ carbonate and ⅓ quartz, with small amounts of an opaque oxide (? chromite), dusty magnetite and talc shreds.

TABLE 1. PHYSICAL PROPERTIES OF BUCHA AND SWAT EMERALDS

Specimen	Absorption (in nm)	Strength of Absorption	Chelsea Filter	ε	ω	Inclusions
Light green Beryl (Bucha)	682.8 683.9 585.0	Weak to moderate Weak broad band	Light Brownish red	1.575	1.583	Fluid inclusions Feathers of Fe-oxide Siderite, tremolite/mica
Bluish green emerald (Bucha)	682.8 683.9 585.0	Strong Weak broad band	Dark Brownish red	1.590	1.600	Fluid inclusions Talc fibres Mica plates
Emerald (Swat)*	683 to 680 662, 646, 637 425-430 477-472	Strong Distinct to strong Weak	Red to pink	1.588 to 1.593	1.595 to 1.600	Two-phase inclusions Colour banding and zoning Calcite, dolomite

*Swat emerald values cover the range for seven stones (for details, see Gübelin, 1983).

OPTICS AND CHEMISTRY OF THE EMERALD AND BERYL

The Bucha specimens are highly variable in colour and transparency. They range in colour from light green to grass green and bluish green. In some cases, one end of the crystals is light green and the other (growing direction) is grass green. The crystals are euhedral and reach up to 10 mm in length and 5 mm in breadth, but most are less than 3×2 mm. The smaller crystals are generally transparent, unfractured and more perfect than the large ones, which are translucent, fractured and dull due to impurities, iron staining and (?) alteration along fractures. Some of them contain fluid inclusions, brown iron oxide feathers along fractures, brownish carbonate (? siderite) and, in rare cases, mica flakes, talc and fibry tremolite inclusions.The small grain size of good quality emerald at Bucha does not make it of a high commercial value; the find requires further investigation of the area for possibly more valuable occurrences.

Absorption bands and refractive indices of two crystals are presented in Table 1, together with similar data for the Mingora (Swat) emerald (Gübelin, 1982). The absorption spectrum was determined with a hand spectroscope and RIs by dispersion method on crushed grains. The RIs of the oils were checked by refractometer immediately after each determination and the reported values are accurate to $\pm$ 0.002. The absorption spectrum contains chromium absorption lines (distinct in the case of emerald and weak in light green beryl) in the red region at 6828 Å and 6839 Å. There also are broad but weak Fe-absorption bands for both the varieties in the yellow region at 5850 Å due to their high Fe contents (cf. Gübelin, 1982).

The RIs of the Bucha crystals, especially emerald, are distinctly higher than those of pure beryl due to the high quantity of iron and chromium. Although not very different, the slightly higher values of ω and ε in the Bucha emerald, when compared to Mingora emerald, may be due to a higher Fe_2O_3 content in the former. Bank (1981), for instance, noted that an increase of ferric iron in some Zambian emerald is accompanied by an increase in the ω refractive index. The RIs of the Bucha emerald are higher than those found elsewhere (cf. Gübelin, 1982); the only specimens with comparable δ and refractive indices $\varepsilon = 1.592$, $\omega = 1.602$, according to Bank (1980), are from Kofubu, Zambia. The Bucha emerald, like that of Mingora, is dichroic with ε = light bluey green and ω = yellow green.

The quantities of some minor elements for the light green beryl (analysis 1) and dark bluish-green emerald (analysis 2) are presented in Table 2, along with analytical data for the Mingora emerald (Gübelin, 1982; Schrader, 1983). The analyses were performed in our laboratories, using a Unicam atomic absorption. Total iron was determined as Fe_2O_3; FeO could not be determined due to a scarcity of material. However, step-wise heating of the samples for several hours each at 100, 200, 400, and 500 °C produced no colour change, and we think that iron is mainly present in ferric state. A review of literature also suggests that iron is principally in trivalent form in beryl and emerald analyses.

TABLE 2. MINOR OXIDE CONTENTS OF BUCHA AND SWAT EMERALDS

	Cr_2O_3	Fe_2O_3	MnO	MgO	CuO	NiO	Na_2O	K_2O
1.	0.27	2.25	0.10	2.18	0.41	0.04	1.87	0.27
2.	0.83	2.10	0.10	1.91	0.11	0.02	2.14	0.08
3.	0.66	0.9	—	2.6	—	—	2.1	—
4.	0.8	0.4	0.0	2.7	—	—	2.1	—
5.	1.4	1.4	0.1	2.4	—	—	1.9	—
6.	0.2	0.7	0.002	0.6	—	<0.02	2.0	—

1. Light green beryl from Bucha, Mohmand Agency. } Analyst: M. Tahir Shah
2. Deep bluish-green emerald from Bucha, Mohmand Agency } Analyst: M. Tahir Shah
3. Emerald from Mingora, Swat. Analyst: M. Weibel (Gübelin, 1982).
4. and 5. microprobe analyses of two emeralds from (? Swat) Pakistan (Hänni, 1982). Anal. 4 contains 64.2% SiO_2, 14.8% Al_2O_3 and 0.1% V_2O_3. Anal. 5 contains 63.7% Sio_2 and 13.7% Al_2O_3.
6. Neutron Activation analyses of emerald from (? Swat) Pakistan. Average oxide values calculated from element percentages of two samples (Schrader, 1983). Contains also >0.05% V and 0.14% Sc.

It has been suggested that green coloration in emerald can not only be caused by Cr but also by Mn, Ni, V and Fe (cf. Schrader, 1983). However, a comparison of the analyses of the Bucha crystals suggests that the emerald here owes its colour to the presence of chromium ions. The values for Mn, Fe, and Ni are similar and therefore should have a similar effect on the colour of the two types of crystals. The Mn contents of the two analyses are several times higher than those reported for natural emeralds, as are the Cu

values (especially in analysis 1). If not overestimated, such high values are surprising. Both the specimens have higher Fe_2O_3 than those of natural emeralds from elsewhere (Gübelin, 1982; Hänni, 1982; Schrader, 1983).The Mingora emerald has a slightly higher quantity of MgO than in Bucha. The presence of sideritic carbonate inclusions and iron oxide films along fractures in the Bucha crystals must have added to the high Fe_2O_3 content of the analyses.

PARAGENESIS

Field relations, the high Mg, Ni, Cr contents of the emerald, and the presence of chromite grains in the host rocks suggest that the latter have developed at the expense of the surrounding ultramafic rocks. A talc-carbonate rock with minor accessory minerals contains 445 ppm Mn, 60 ppm Cu, 120 ppm Zn, 6600 ppm Cr, and 1635 ppm Ni. The high values of Cr and Ni and low value of Mn clearly suggest that this rock has an igneous (ultramafic) rather than sedimentary (dolomitic) parentage (cf. Leake, 1972). A similar origin for the talc-carbonate ± fuchsite ± chlorite rock hosting emerald in Swat was proposed by Jan *et al.* (1981). We reject the idea of Gübelin (1982) that the emerald host rocks in Swat were initially dolomitic.

It appears that hydrothermal or pneumatolytic solutions carrying CO_2 penetrated along shear zones and converted the ultramafic rocks into talc-carbonate and carbonate-quartz assemblages. The presence of thick quartz veins about 50 m from the emerald occurrence lends further support to this idea. These solutions, probably, also carried small quantities of Al, Be and Na, wheareas the host rocks supplied Cr, Mg, Fe for the formation of green beryl and emerald. However, the ultimate source of the solutions is not clearly understood. Whether the hydrothermal activity was related to the Cambrian granitic gneisses or alkaline carbonatites (of unknown age) found ~15 km to the north-east is difficult to assess. Butt (in preparation) suggests that in the Swat area the emerald mineralization was caused by hydrothermal solutions related to the granitic gneisses and generated during an (alpine) thermal event. This process cannot be proposed for the Bucha and other emerald occurrences in Mohmand because of the lack of close association between the granitic gneisses and emerald mineralization.

ACKNOWLEDGEMENTS

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CHATOYANCY IN CHRYSOBERYL CAT'S-EYE FROM PEGMATITES OF TRIVANDRUM DISTRICT, SOUTHERN INDIA

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ABSTRACT

Chrysoberyl and its variety cat's-eye occur extensively in innumerable small pegmatite bodies and alluvial gravel beds or Trivandrum district. Investigations of chrysoberyl cat's-eye suggest that chatoyancy may be caused by the presence of acicular the crystals of sillimanite along micro-fractures.

INTRODUCTION

The cat's-eye effect or chatoyancy in minerals is presumed to be caused by the more or less fibrous structure of the minerals (Kraus & Slawson, 1947), inclusions of needle-shaped crystals (Smith, 1972), or short needles and tubes running parallel to the long axis of the crystal (Arem, 1977), In quartz cat's-eye these inclusions have been identified as rutile and amphibole (Smith, 1972). Asterism in quartz from Ratnapura, Sri Lanka, is caused by needles of sillimanite and in sapphire by microscopic cavities (Wuthrich & Weibel, 1981) and rutile needles (Sahama, 1982).

The fibrous inclusions in chrysoberyl cat's-eyes remain at present mineralogically unidentified, although in some instances they represent acicular crystals (Smith, 1972). The present paper reports the findings of studies on chrysoberyl cat's-eyes from pegmatites of Trivandrum district, southern India under SEM with attached microanalyser.

CHRYSOBERYL FROM PEGMATITES OF TRIVANDRUM DISTRICT

Chrysoberyl occurs in innumerable highly weathered small complex pegmatite bodies of early Palaeozoic age in parts of Trivandrum district in Kerala and in the adjoining areas of Tamil Nadu (Soman *et al.*, 1982). The pegmatite field has a strike length of 50-70 km and a width of 30-35 km within Trivandrum district. Rocks of the Khondalite suite, encompassing garnet-sillimanite gneiss and garnet-biotite gneiss, and intermittent bands of enderbites and garnet-bearing granites of Precambrian age are the country rocks.

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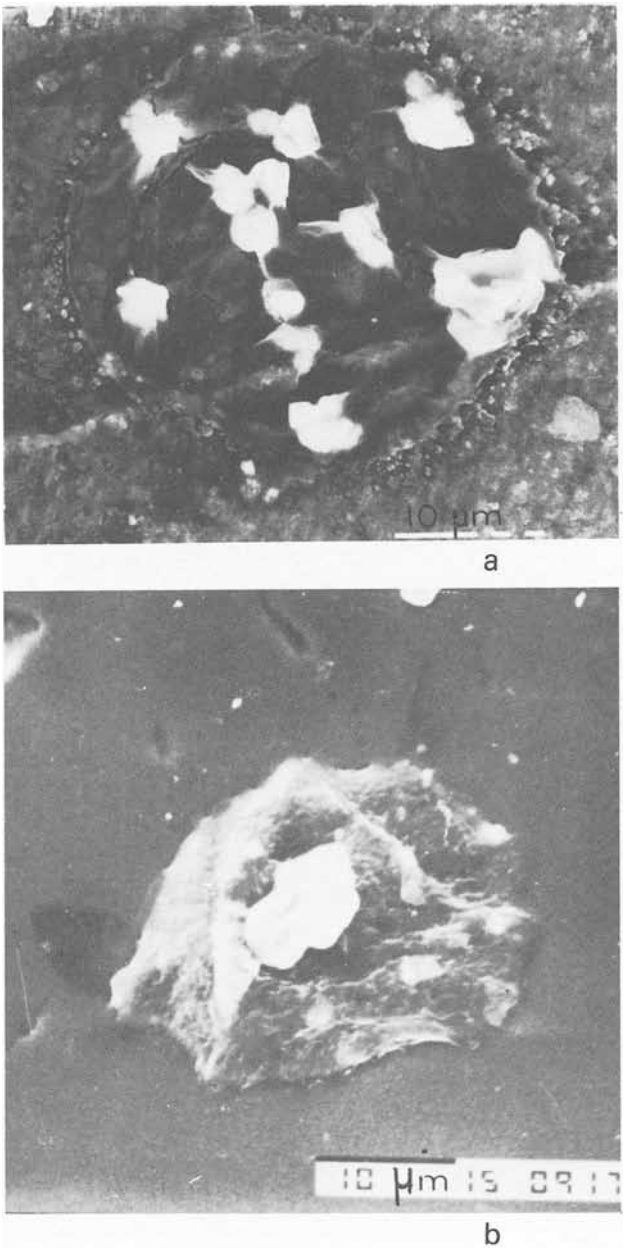

FIG. 1 (a), (b). SEM photomicrographs of mineral inclusions in chrysoberyl cat's-eye (with scales in micrometres).

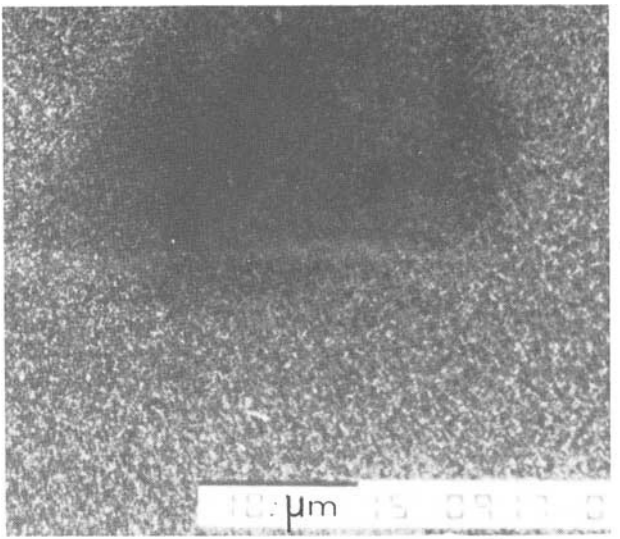

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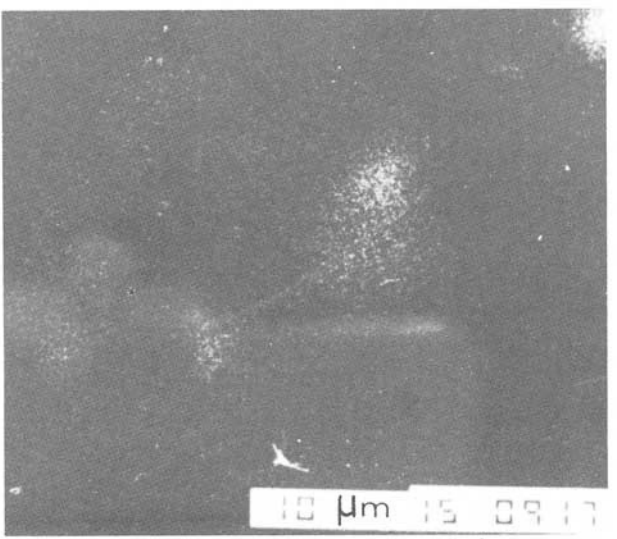

b

FIG: 2 (a). X-ray scanning photograph of Al distribution in chrysoberyl with inclusion as in Figure 1 (b).
(b). X-ray scanning photograph of Si distribution in chrysoberyl with inclusion as in Figure 1 (b). (Scales in micrometres).

The chrysoberyl occurs in pegmatites with potash felspar, smoky and transparent quartz, biotite, plagioclase, muscovite, tourmaline, garnet, beryl, apatite, sillimanite, ilmenite, monozite, cheralite, zircon, corundum, topaz and columbite (Soman & Nair, 1983). It is also recovered from alluvial gravel beds. Chrysoberyl crystals, commonly associated with quartz, are found to be cracked and in some places corroded. Cat's-eye is a very prominent variety of chrysoberyl found in this area.

DISCUSSION

Two specimens of chrysoberyl cat's-eye were examined under a JEOL scanning electron microscope with attached microanalyser.

SEM photomicrographs of chrysoberyl cat's-eye show presence of micro-fractures filled with acicular mineral inclusions (Figure 1 (a), (b)). X-ray scanning of the inclusions showed that they consist of Al and Si (Figure 2). Intensity of Al distribution in the inclusion is less than in chrysoberyl, while Si is higher in the inclusions. Abundance of sillimanite within the country rocks as well as in pegmatites, and its formation in pegmatites after crystallization of chrysoberyl, x-ray scanning data (Figure 2 (a), (b)) and the shape of inclusions (hexagonal acicular crystals, Figure 1 (a)) together suggest that chatoyancy in chrysoberyl cat's-eye from Trivandrum district may be due to the presence of acicular crystals of sillimanite along micro-fractures. This view is further supported by the findings of Wuthrich & Weibel (1981) that asterism in quartz from Ratnapura, Sri Lanka, is caused by needles of sillimanite.

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GREEN SPHALERITE FROM ZAIRE

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ABSTRACT

The cause of colour from dark-green sphalerite from Kipushi, Zaire, investigated by chemical and optical methods is discussed in this paper. The colour is brought about by cobalt, which shows an absorption-maximum at 670 nm in the spectrum of sphalerite. This absorption-maximum is based on a $^4A_2 \rightarrow {}^4T_1(P)$ transition of Co^{2+} in the tetrahedral crystal field of sphalerite.

INTRODUCTION

Several faceted sphalerites from Kipushi, Zaire, with a remarkable dark-green colour, first described by Quintens *et al.* (1984), were investigated. Sphalerite is an important zinc-ore and is only seldom considered worthy to be cut. Based on the minor hardness of 3.5 to 4 and a perfect cleavage to the rhombododecahedron {011} the treatment is difficult, as is the case with many ore-minerals. Sphalerite is in the gem-trade, because of its high refractive index of n = 2.369 and its dispersion of 0.156—an interesting stone for collectors.

At the present time, the most important mines are in Spain and Mexico with stones of mainly yellow and red and infrequent green colours.

The chemical composition of sphalerite is ZnS; it is cubic, and thus each atom is surrounded by 4 neighbour atoms, lying at the edges of a regular tetrahedron. Zinc can be substituted in the sphalerite-structure by elements having a similar ion-radius, in which case iron is the most frequent substitute. Pure sphalerite is colourless and transparent; with higher iron-content the transparency is reduced and the colour gets darker. According to Deer *et al.* (1977) sphalerite can be coloured by certain elements: yellow by Ge, Ca, Cu, Hg, Cd, red by Sn, In, Ag, Mo, and green by Co and Fe.

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ANALYTICAL METHODS AND RESULTS

In order to study the cause of colour, the element contents of ZnS were determined by neutron activation analysis (NAA) and electron-microprobe-analysis (EPMA). The results are listed in Tables 1 and 2. Especially investigated have been cobalt and iron, which according to Deer *et al.* (1977) bring about the green colours in sphalerite.

TABLE 1. Neutron-activation analyses in ppm

	Green Sphalerite from Zaire	Yellow Sphalerite from Spain
Na	20.7	5.9
Mn	22.4	9.8
Co	744.2	n.d.
Cu	972.7	721.3
Ga	2.7	17.9
Pd	145.9	243.7
Cd	3942.9	1509.5

Table 1 shows an enrichment of the elements Na, Mn, Cu and Cd in green sphalerite from Zaire in comparison to a yellow stone from Spain. In the yellow sphalerite from Spain no Co could be found, in the green sphalerite from Zaire the content of Co is with 740 ppm relatively high. To secure the assumption that Co causes the dark-green colour of the sphalerite from Zaire, further specimens from this mine and yellow, orange and red sphalerites from Spain were investigated with EPMA. Wavelength-dispersive analyses were carried out, the detection limit lying at 100 ppm. The results of Table 2 show that along with Co, Fe is present, which cannot be traced back to chalcopyrite inclusions, because EPMA

TABLE 2. Electron-microprobe analyses from green Sphalerites from Zaire in ppm.

	S1	S2	S3
Fe	802.5	682.5	617.5
Co	837.5	890.0	797.5
Cd	4137.5	4372.5	4260.0

can only analyse the surface of the samples. In the yellow, orange and red sphalerites from Spain no Co could be detected and Fe was present only as a trace-element.

For the definitive clarification of the cause of colour a reflection-spectrum from green sphalerite was recorded (Figure 1). This shows a reflection-minimum and thus an absorption-maximum at 670 nm. This maximum is brought about, according to Marfunin (1979), by a $^4A_2 \rightarrow {}^4T_1(P)$ transition of Co^{2+} in the tetrahedral crystal field of sphalerite.

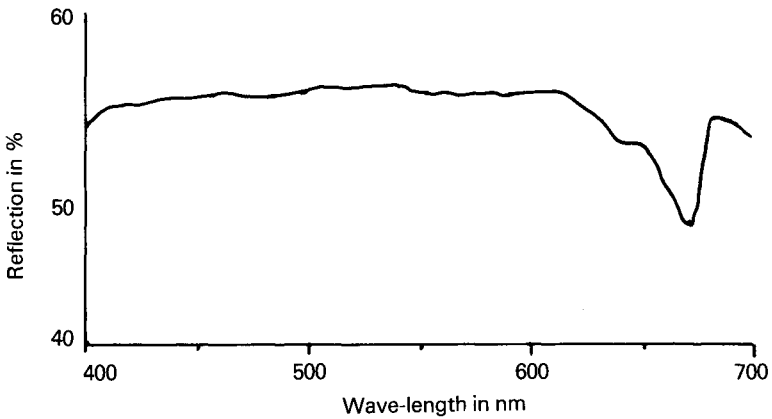

FIG. 1. Recorded absorption curve of Sphalerite.

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COLOURLESS ENSTATITE FROM EMBILIPITIYA, SRI LANKA

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Orthopyroxenes of different colours have been reported from Kenya, Tanzania, India and Sri Lanka. Colourless specimens of this mineral, viz. enstatite, have recently been found in the gem gravels of the Embilipitiya region of Sri Lanka (Figure 1). The mineral was mined near the northern bank of the Chandrika Wewa reservoir at a depth of about one metre (Figure 2). The other gem minerals found with colourless enstatite in these gem gravels were brown enstatite, kornerupine and iolite. The colourless enstatite consisted mainly of fragments and small chips showing easy cleavage (Figure 3). Although the specimens were flawed and contained many inclusions, a few specimens produced attractive gemstones after faceting. The largest tranparent cut specimen was 19.5 ct. Several specimens showed chatoyancy.

The physical and optical properties of the colourless enstatite are given in Table 1.

TABLE 1. Physical and optical properties of Sri Lanka gem enstatite.

	Green and Brown Enstatite of Ratnapura	Colourless Enstatite of Embilipitiya
n_x	1.665 (±0.001)	1.658 (±0.001)
n_z	1.675 (±0.001)	1.668 (±0.001)
DR	0.01	0.01
SG	3.23	3.25

Chemical analysis of the colourless enstatite was done by using an electron microprobe and the results showed a high magnesium content. The iron content was small. (Table 2).

The accompanying microphotographs (Figures 4 to 11) depict typical mineral inclusions in the colourless enstatite. Quartz was the most frequent mineral inclusion observed, and it exhibited well shaped and also partly corroded forms.

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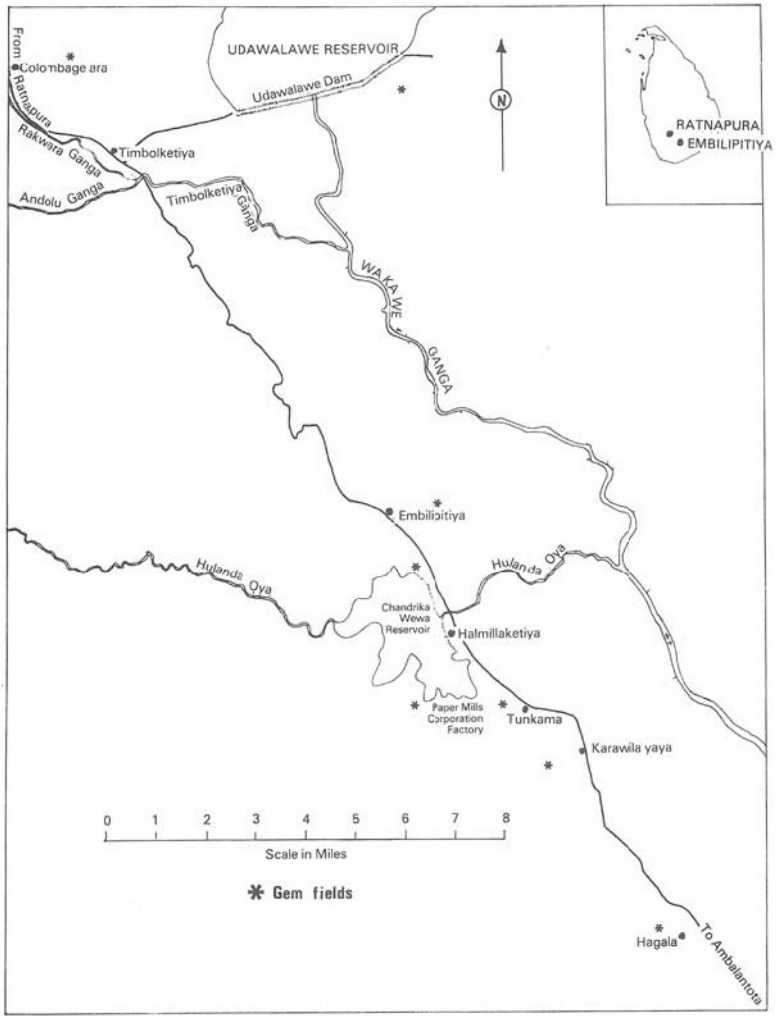

FIG. 1 Gem mining areas in the Embilipitiya district of Sri Lanka.

FIG. 2. Gem mining in Chadrika Wewa.

FIG. 3. Rough fragments of colourless enstatites from Sri Lanka.

FIG.4. Colourless enstatite, Sri Lanka. Partly well shaped, partly corroded crystals of quartz. ×27.

FIG. 5. Colourless enstatite, Sri Lanka. Iron oxides are localized in the brownish-red areas: also present are colourless transparent crystals of quartz. ×15.

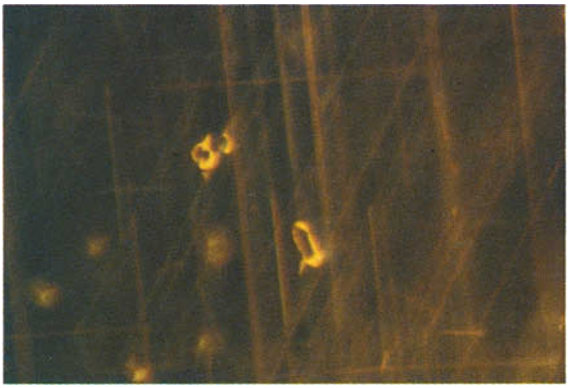

FIG. 6. Colourless enstatite, Sri Lanka. Tiny crystals of zircons with haloes amidst rutile needles. ×45.

FIG. 7. Colourless enstatite, Sri Lanka. Rod-like colourless transparent crystals. ×32.

FIG. 8. Colourless enstatite, Sri Lanka. Healing fractures indicated by iron oxide surfaces, brownish micaceous laminae, and minute two-phase inclusions. ×15.

FIG. 9. Colourless enstatite, Sri Lanka. Minute crystals of apatite among dense silk of rutile needles. × 10

FIG. 10. Colourless enstatite, Sri Lanka. Healing fractures indicated by irregular iron oxide surfaces and elongated minute two-phase cavities. Brassy single crystals of pyrite are present. × 8

FIG. 11. Colourless enstatite, Sri Lanka. At the girdle a large, inside smaller crystals of quartz. × 12

TABLE 2. Electron Microprobe Analyses of Orthopyroxenes, Sri Lanka

Colour	Colourless		Greenish		Pale Brown	
Mineral	Enstatite		Enstatite		Bronzite	
Locality	Embilipitiya		Ratnapura		Ratnapura	
	%	Atomic Ratio	%	Atomic Ratio	%	Atomic Ratio
SiO_2	58.9	1.98	55.0	1.881	56.8	1.964
Al_2O_3	1.7	0.067	6.6	0.266	2.1	0.086
TiO_2	0.03	0.001	0.15	0.004	0.03	0.001
Cr_2O_3	—	—	0.02	0.001	0.31	0.008
FeO	1.0	0.028	5.5	0.157	6.6	1.91
MnO	—	—	0.1	0.003	0.14	0.004
MgO	38.0	1.904	32.8	1.672	33.5	1.727
CaO	0.10	0.004	0.10	0.004	0.21	0.008
Na_2O	0.02	0.001	0.04	0.003	—	—
Total	99.75		100.16		99.69	
Cations calculated to O = 6		3.986		3.987		3.988

The x-ray diffraction pattern of the colourless enstatite was taken using an x-ray diffractometer (model Jeol/JDX 85). Lattice parameters were determined using NaCl as an internal standard. The peaks selected for the lattice parameter determinations were (420), (321) and (610). Instrumental conditions were ¼° per min. scan, Kv, 40mA, 1000 cps. The XRD pattern was identical to that of enstatite, reference J.C.P.D.S. 22-714, the lattice parameters being $A_O = 18.50$ Å, $B_O = 8.75$Å. $C_O = 5.19$Å, space group Pbca.

The writer is grateful to Prof. Dr E. Gübelin, Prof. G. Graziani, Dr Charles Arps, and Mr R. L. Jayasooriya for their valuable assistance and advice.

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AN ACCESSORY FOR GEMMOLOGICAL REFRACTOMETERS

By AGUSTI MOLINÉ SALA, F.G.A.

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This paper describes an accessory to the gemmological refractometer, which makes the handling of stones to be tested easier and permits one to obtain reliable information thanks to the steady working of the attachment.

Continuing new discoveries of materials of interest as gems, synthetics or imitations makes it necessary for the gemmologist to proceed cautiously. Identification of gems must be backed by irrefutable evidence. That is why it is very important to use each instrument to its fullest potential. One of the best and most conclusive is the refractometer, and I have designed and built a very simple device for this instrument, which simplifies considerably the rotation of the tested gem while allowing constant working conditions which give the maximum information in the shortest working time,

The examination of a parcel of gems can be a demanding exercise. Given the technical accuracy of the instrument, it is a paradox that accurate readings must ultimately depend upon the ability of the operator to effect hand movements which will allow correct figures to be obtained. Procedure is usually thus:

(1) Make sure the gem to be tested has a perfectly flat and polished surface with a minimum diameter of approximately 2 mm (cabochons are not considered, as they cannot be tested using the accessory);

(2) Carefully clean the instrument prism and the gem, then apply a droplet of contact liquid to the glass;

(3) The gem must then be centred on the prism, and rotated a few degrees at a time, avoiding any lateral displacement;

(4) To obtain good optical contact it is advisable to maintain light pressure on the gem, especially in the case of small stones which may be raised by the surface tension of the liquid and give inaccurate readings—this must be done with care if the stone is not to scratch the prism;

(5) While carrying out these operations the observer must also look through the eyepiece and write down his observations.

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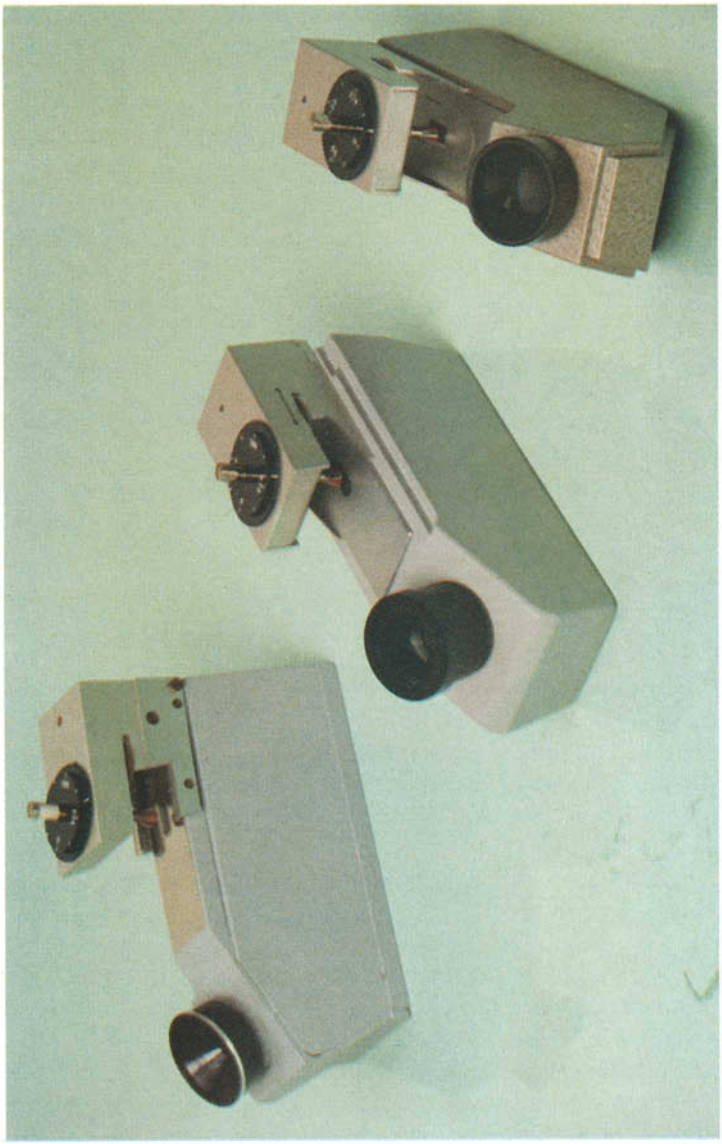

FIG. 1. Any brand of refractometer can be fitted: from left to right, a Rayner 'S', a Shibuya, and a Topcon.

Combining these actions with observations slows down the operation, and if we consider the care needed to obtain correct readings it becomes necessarily a long one. It is therefore useful to have a mechanical device applied to the refractometer which should make it almost an ideal instrument.

This is an accessory applied to the top of the refractometer, after removing the cover, and attached by using the hinge sockets. The contrivance can be lowered or raised like the cover in order to place the stone in position. With a small modification it can be adjusted to any make of refractometer (Figure 1). Its appearance blends with the profile of the instrument. Size is 55 × 30 × 45 mm and weight 38 grams (for a model made to fit Rayner 'S' or 'Dialdex' instruments).

It is built in anodized aluminium. Inside there is a system of gears which transmit movement to a vertical shaft which is held centrally over the glass prism. This shaft has a movement of 7 mm, which allows it to lift high enough to position the gem and adjust to different sizes of unmounted stones. Its lower end is cone shaped and lined with foam rubber so that it will fit the pavilion of most stones. The shaft, and therefore the gem, is rotated by means of a handwheel which protrudes slightly at the right of the device.

The following advantages result:

(1) By not rotating the stone by hand the risk of scratching the glass prism is greatly reduced;

(2) The shaft's weight (5 grams) ensures a constant optical contact between the gem and the prism surface;

(3) The gem is rotated centrally on the prism without displacements of any kind.

Originally the device was made just to rotate the stone. Later someone suggested the idea of measuring the degrees of rotation and I added a couple of wheels to the upper part of the main shaft. The top is graduated in 90° and 45° arcs and rotates with the shaft to which it is attached; the lower wheel is free and is used to zero the top one (Figure 2).

The instrument has been called a 'declinometer' by J. Figueras (1976), whose original work inspired its design, since it measures the rotation of the stone on the refractometer prism surface. But this name is already in use for an instrument connected with compass bearings and to avoid any kind of confusion with the

English translation it may be called a 'rotameter', since the coarse angular measurement facility warrants it.

This device is especially useful when it is necessary to identify a series of stones by establishing RI, birefringence, and optical sign. It will allow the students to make these observations easily in the practical classes when using the refractometer.

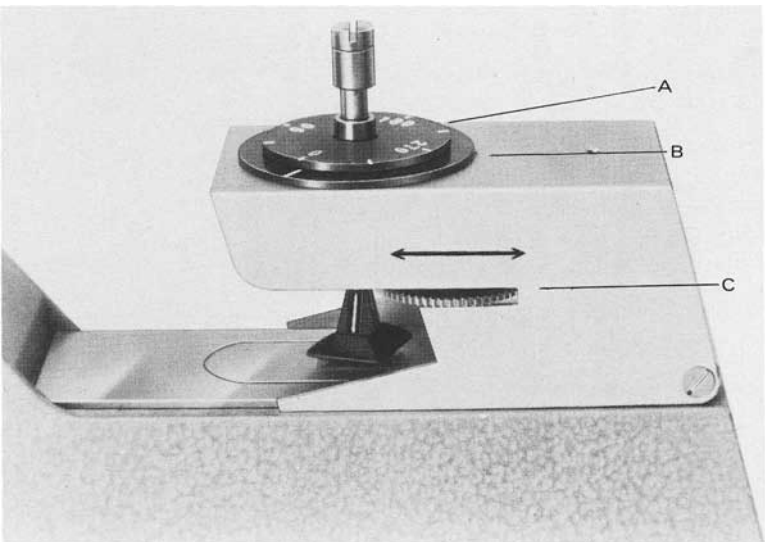

FIG. 2. The accessory fitted on a Topcon refractometer. (a) Graded wheel. (b) Wheel for zeroing the graded wheel. (c) Wheel for operating the device.

The observer can now concentrate on the observation of readings through the eyepiece, since a simple movement of the side wheel will rotate the stone as needed and can be repeated as many times as necessary with the guarantee that the stone will remain correctly adjusted on the prism. This concentration on the refractometer scale will immediately allow uniaxial or biaxial character and optical sign to be seen, separating tones of similar RI, like quartz and cordierite, tourmaline and brazilianite, apatite and topaz, etc. The least movement of the shadow edges on the scale can be observed when the gem is rotated quickly, a move

which is not possible without this device. It also avoids contaminating the fingers with contact liquid and, thanks to the graduated wheel, allows the degree of rotation of the stone to be calculated. If necessary the variations in RI of the test facet can be recorded graphically according to its orientation during a complete rotation.

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ELECTRON SPIN RESONANCE SPECTRA OF NATURAL AND SYNTHETIC SAPPHIRES AT S-BAND (2-4 GHz)

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INTRODUCTION

In a series of previous papers (Troup 1969, Scala & Hutton 1975, Hutton & Barrington 1977, Hutton 1979, Anderson, Hutton & Troup 1981, Troup & Hutton 1983) we have discussed the use of electron spin resonance (ESR) spectroscopy for the identification of gemstones, and in particular, for the distinguishing of natural from synthetic stones. In the last paper of the series we intimated that a wavelength of about 10 cm, corresponding to a frequency of 3000 GHz, might well be more useful to the practising gemmologist, because modern electronic techniques would enable the apparatus to be made much smaller than the 3 cm wavelength (10 GHz) we have been using. Prior to making a prototype apparatus aimed at commercial accessibility, it is of course necessary to verify the possibility of using the lower frequency spectra for gem identification, and perhaps to build up a collection of spectra. We were motivated to do this when we received a 14 ct golden sapphire to test, because it was too large to fit into the 3 cm wavelength resonant cavity.

APPARATUS

The spectrometer was of conventional reference-arm bridge design: the radiofrequency head, capable of operating over the frequency range 2-4 GHz, (S-Band) simply replaced the 10 GHz head of a commercial Varian ESR spectrometer (Froncisz *et al.*, 1979). The cavity was of dimensions approximately $25 \times 10 \times 2.5$ cm; modes at 2.0, 2.9 and 4.0 GHz (nominal) were available. The comparatively large size of the cavity reduces the 'filling factor' (ratio of field in sample volume to total field) but increases the 'Q' ($2\pi \times$ ratio of energy stored to power dissipated per cycle) so that not much sensitivity is lost in comparison with 10 GHz operation because of the lower filling factor. Sensitivity is lost, however, because it also varies roughly as the square of the observation frequency used. However, as will be seen, stones not much above a ct in weight gave adequate signals for identification.

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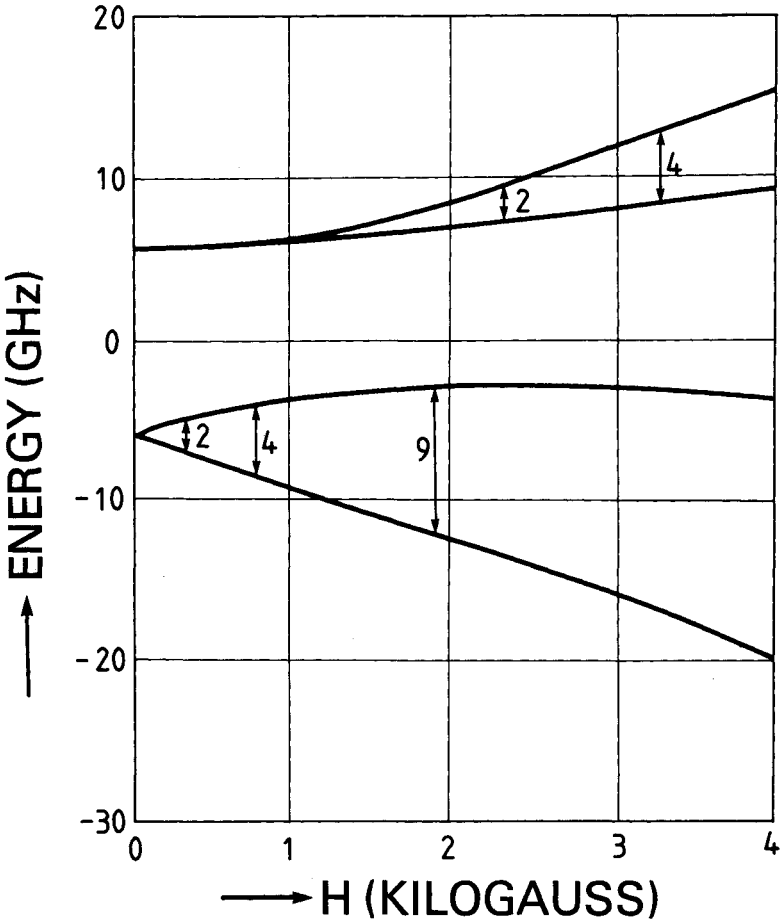

FIG. 1. The ground-state levels of the Cr^{3+} ion in the Al_2O_3 lattice with the steady magnetic field perpendicular to the *c*-axis. The low-field transitions observed at ~9 GHz, ~4 GHz and ~2 GHz are shown.

The samples were placed in a standard 10 mm diameter test-tube, and rotated until the DC magnetic field was perpendicular to the trigonal axis. This is always possible, since sapphires are uniaxial.

SAMPLES

The samples used were (a) synthetic blue sapphire (boule); (b) synthetic yellow sapphire (boule); (c) synthetic pink ruby (boule);

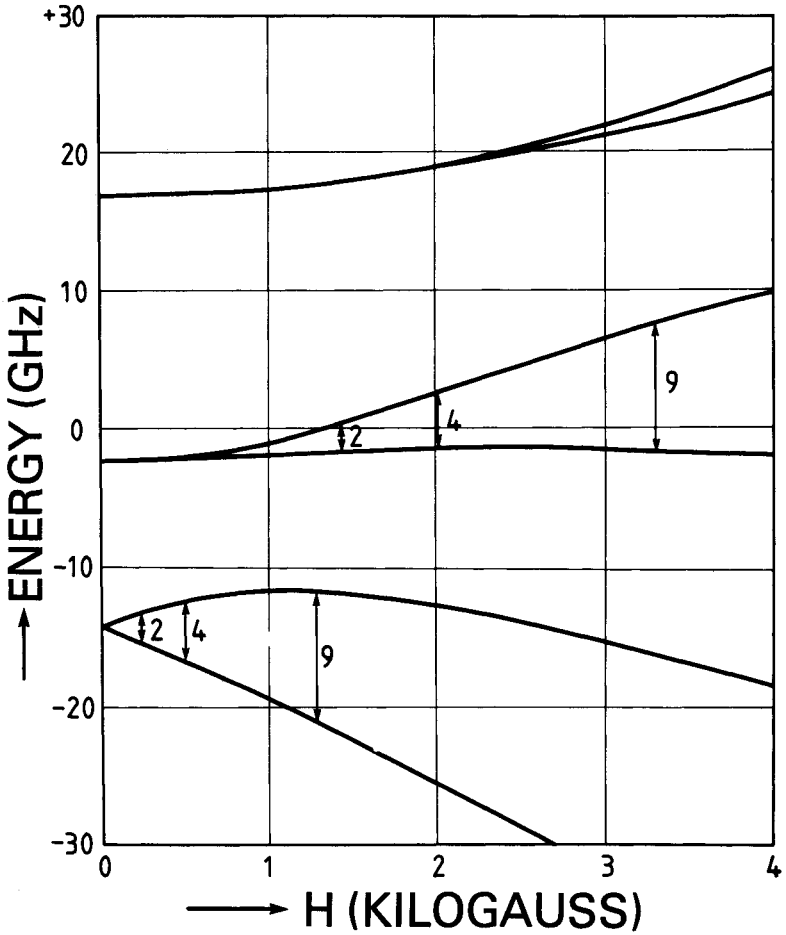

FIG.2. The ground-state energy levels of the Fe^{3+} ion in the Al_2O_3 lattice with the steady magnetic field perpendicular to the *c*-axis. The low-field transitions observed at ~9 GHz, ~4 GHz and ~2GHz are shown.

(d) 3 known natural golden sapphires; (e) the 14 ct golden sapphire (which turned out to be natural) brought to us for testing.

SPECTRA

Figures 1 and 2, respectively, show the lowest energy levels for Cr^{3+} and Fe^{3+} in Al_2O_3, plotted against the steady magnetic field, when this is perpendicular to the *c*-axis. Figure 3 shows the behaviour of the comparatively low-field lines for Cr^{3+} and Fe^{3+} as

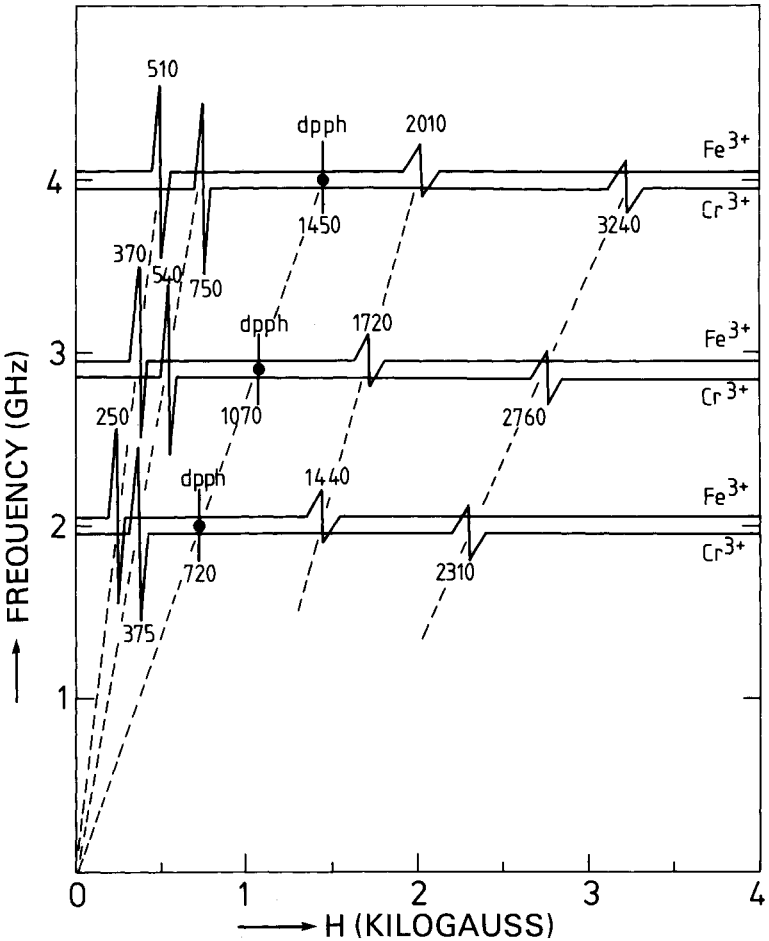

FIG. 3 Behaviour of the comparatively low-field transitions with frequency for the Cr^{3+} (lower lines) and Fe^{3+} (upper lines) in Al_2O_3 with the steady magnetic field perpendicular to the c-axis. Note how the lowest-field Fe^{3+} transition is consistently lower than the lowest field Cr^{3+} transition. 'dpph' means the 'marker' signal from the free radical $\alpha-\alpha$ diphenyl picryl hydrazil, which gives the field value for which $g' = 2$ (see text).

the frequency is changed from ~4 GHz to ~3 GHz to ~2 GHz. 'dpph' ($\alpha-\alpha$ diphenyl picryl hydrazil) is a readily available organic substance which contains one unpaired electron (free radical) per molecule, and which is therefore used as a magnetic field 'marker' and also to verify whether the apparatus is working well. For the sake of brevity, we do not show the signals from all the samples at all the frequencies used in our investigations.

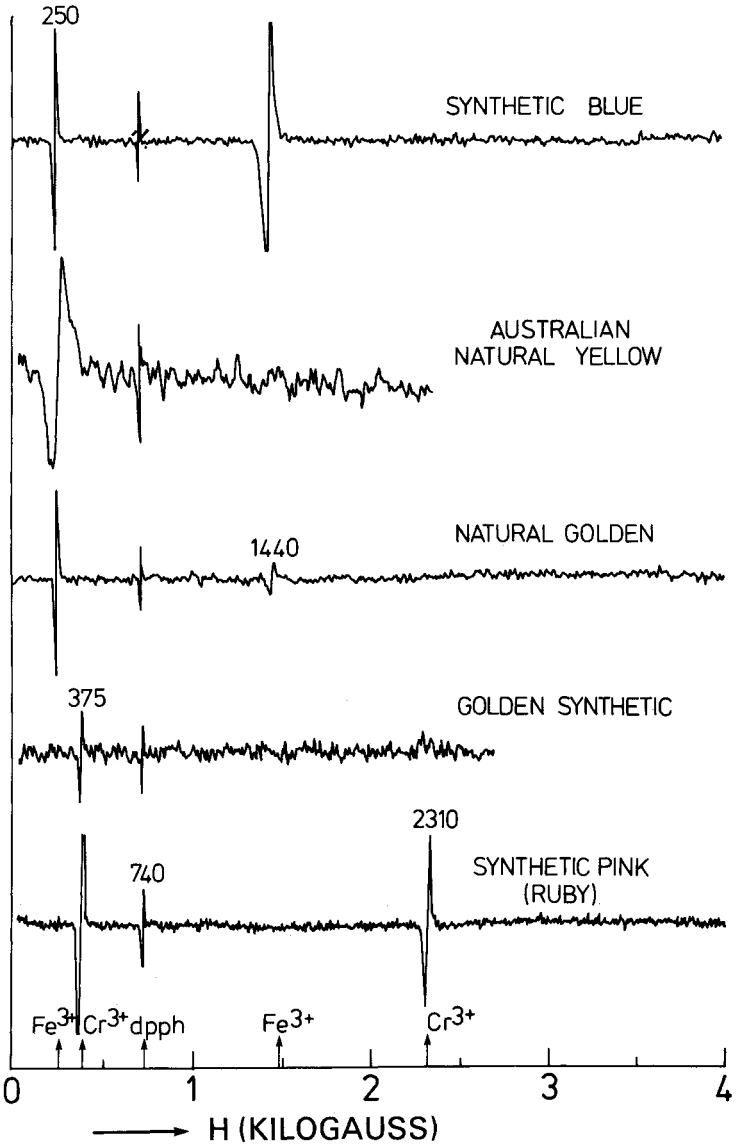

FIG. 4. ~2 GHz spectra of various sapphires: a synthetic blue, an Australian natural yellow, a natural golden, a golden synthetic, and a synthetic pink sapphire. The golden synthetic is of more modern manufacture than the ones used in previous work, shows no Fe^{3+} signal, and a very small Cr^{3+} signal in comparison with the other synthetics (note the signal to noise ratio in the various cases).

The 2 GHz spectra for some of the samples are shown in Figure 4. If the magnetic field (induction) at which a line occurs is B, and the frequency of observation is f, then

$$hf = g'\beta B$$

where h is Planck's constant, β is the Bohr magneton (atomic unit of magnetic moment) and g' is the 'effective g-value'—a constant determined by the ion under observation and the experimental conditions. For dpph, g' is very close to 2. For the lowest field lines in sapphire, when B is perpendicular to the trigonal axis, for Cr^{3+}, $g' \sim 4$, and can go no lower; for Fe^{3+}, $g' \sim 6$, and can go no lower. Thus the presence of a line at $g' \sim 6$, and no (or very low intensity) line at $g' \sim 4$, with B perpendicular to the trigonal axis, is a definitive test for natural golden sapphire.

DISCUSSION

It is quite clear that the 2-4 GHz region can be used to identify gemstones by ESR. In particular, the low magnetic fields necessary for positive characterization of Cr^{3+} and Fe^{3+} in sapphire, required to distinguish natural from synthetic golden sapphire, leads us to the strong belief that a commercial apparatus could be developed. We did not attempt to perform any measurements with *c*-axis parallel to the DC magnetic field, because we did not have the possibility of rotating the magnet about the sample, since the cavity is so large. This could be overcome later by using a different cavity design.

ACKNOWLEDGEMENT

We are grateful to Ms Carole O. Anderson for the loan of three known natural sapphires.

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[*Manuscript received 27th June, 1984*]

GEMMOLOGICAL ABSTRACTS

ALEXANDER (P. O.). *Looking for diamonds? Try geobotany.* Indiaqua, 36 (1983/3), 34-8, 17 figs, 1983.

Author shows that the presence of a kimberlite pipe can be seen in the luxurient plant growth it supports in marked contrast to the poor fertility of the surrounding country rock. R.K.M.

BALFOUR (I.). *Famous diamonds of the world, XVII. The 'Orlov' diamond.* Indiaqua, 36 (1983/3), 127-31, illus., 1983.

Now in the U.S.S.R. Diamond Fund collection in the Kremlin, the origin and history of this 189.6 carat rose-cut stone is 'legend, fact, supposition and theory', and there seem to be connexions with the Great Mogul Diamond. The latter was 'lost', and it is suggested that it was recut either as the Orlov or as the Koh-i-noor. After various robberies and intrigues the stone was purchased in Amsterdam by Count Grigori Orlov, a former lover of Grand Duchess Catherine, wife of Peter III. The latter was deposed and murdered and the crown went to Catherine the Great. Orlov presented her with the diamond but did not regain his former position of favour. It was Catherine who had it set in the Imperial Sceptre, where it rests today. R.K.M.

BALFOUR (I.). *Famous diamonds of the world, XVIII. The 'Star of Sierra Leone'* Indiaqua, 37 (1984/1), 129-31, illus., 1984.

An account of the finding of this 968.9 carat cleavage. Sold to Harry Winston, it was cut to yield a 143.20 carat emerald cut, which was flawed and eventually recut to give seven stones totalling 53.54 carats; a total of seventeen stones was obtained, the largest 53.96 ct and a total weight of 238.48 ct. R.K.M.

BATCHELOR (R. A.), KINNAIR (J. A.). *Gahnite compositions compared.* Mineralog. Mag., **48**, 3, 425-9, 2 figs, 1984.

A blue mineral from Nigeria was identified as the gahnite variety of spinel by wet chemical methods (using atomic absorption spectrophotometry). The composition was found to be 36.7% ZnO, 3.58% FeO and 0.12% MgO. RI was 1.79 and SG between 4.4 and 4.59. The gahnites from different parts of the world appear to fall into two groups, one of metamorphic origin and rich in Mg, and Mg-poor stones showing affinities with igneous rocks. The Nigerian material falls into the latter group. It is possible from the observations made to suggest that there is a diadochy within the zinc spinels between (Zn + Mn) and (Fe + Mg). M.O'D.

BRIGHTMAN (R.). *Chrysoberyl from Anakie, Queensland.* Aust. Gemmol. **15**, 7, 241-2, 2 figs, 1984.

Found among cut sapphires, this yellow-green stone gave RI 1.756-1.768, biaxial birefringence 0.012, SG 3.74, with strong absorption band from 425-458nm, much broader than usual, while constants are higher than expected in normal chrysoberyl. R.K.M.

BROWN (G.). *The diamondiferous kimberlite pipes.* Wahroongai News, **18**, 7, 12-14, 1 fig., 1984.

Discusses nature and origins of kimberlite. Diamondiferous pipes are very rare, may come from 250 km below surface and contain two main types of ultra-mafic nodules, the commoner peridotitic, and eclogitic. Diamonds found in either type, or not at all. Kimberlite thought to act only as transporting medium, not as parent rock. R.K.M.

BROWN (G.). *The problem of colour.* Wahroongai News, **18**, 9, 21-8, 1984.

A paper adapted from 'Colour in fixed prosthodontics' by Prestom (J. D.) in which Mr Brown, himself a dental expert, has drawn parallels with the problems in understanding colour in gemmology. R.K.M.

BROWN (G.). *Some thoughts on lustre.* Wahroongai News, **18**, 9, 17-18, 1984.

An attempt to rationalize and explain this physical characteristic of polished surfaces. It has been poorly defined in some textbooks in the past. R.K.M.

BROWN (G.). *Some interesting reactions in marble.* Wahroongai News, **18**, 7, 20-1, 1984.

Traces reactions from lime to a variety of different marbles, a mass of formulae which may or may not be useful. R.K.M.

CONNELLAN (M.), POZZIBON (L.). *The Australian ideal design for round brilliants.* Aust. Gemmol. **15**, 7, 219-26, 243-6, 16 figs, 1984.

Suggested new proportions for diamond brilliants are justified by elaborate but rather confusing diagrams and mathematics. The one diagram which depicts the side view of the proposed cut shows it without break facets on the base. It is not clear whether this omission is part of the design. The proportions and angles have been arrived at by computer and there is some suggestion that cutting should also be computer controlled. Authors suggest that the design and cutting methods could be used to advantage with coloured stones, with a constant pavilion angle of 39°40′ for all gems. R.K.M.

GRAZIANI (G.), GÜBELIN (E.), LUCCHESI (S.). *Report on the investigation of an emerald from the Kitwe District, Zambia.* Aust. Gemmol., **15**, 7, 227-34, 12 figs in colour, 1984.

An emerald from schist localities near Kitwe established that this highly included material has an origin different from that of the chrome-rich emeralds of the Miku deposits. RI 1.580-1.586, SG 2.794 with variations due to the many

inclusions which were identified as rutile, chrysoberyl (a new inclusion in gems), quartz, apatite, and margarite and muscovite micas. R.K.M.

GURNEY (J.). *Sea diamond developments.* Indiaqua, 36 (1983/3), 13-17, illus., 1983.

A general report on the diamond dredging operations along the Namaqualand coast. Problems have been encountered due to the normally rough seas along the straight coast line, which limit recovery to about five days per month. R.K.M.

JONES (A. K.). *Argyle gathers momentum.* Indiaqua, 37 (1984/1), 19-21, illus., 1984.

Text of address to Belgian Chamber of Commerce in Australia outlining discovery, development and forecast output of AK1 kimberlite pipe at Argyle in N.E. Western Australia. A yield of 7 ct per tonne is offset by small sizes of stones and a 5% fine gem content. R.K.M.

KOIVULA (J. I.). *Mineral inclusions in Zambian emeralds.* Aust. Gemmol., **15**, 7, 235-9, 7 figs in colour, 1984.

Emeralds from the Miku/Kafubu deposit SW. of Kitwe were examined and darvite tourmaline, limonite, magnetite, mica, rutile, haematite and apatite inclusions were found, most of which are illustrated in this author's excellent pictures. RI 1.581-1.588, SG varied from 2.71 to 2.82; chromium absorption was clearly identified. These Miku emeralds would appear to be less included than those from the Kitwe deposit. Author draws parallels with other schist-type deposits such as Habachtal in Austria. [A misprint makes 'rutile' into 'futile'. R.K.M.

LEITE (C. R.), BARELLI (N.), SARDELA (I. A.). *Oriented enstatite inclusions in natural diamond.* Mineralog. Mag., **48**, 3, 459-60, 1984.

A twinned diamond consisting of at least four distinct crystals and coming from the Tibagi River deposits of Paraná, Brazil, showed six colourless euhedral crystal inclusions which were found to be enstatite and forsterite. M.O'D.

LEITHNER (H.). *Topas und Beryll aus Namibia.* (Topaz and beryl from Namibia.) Lapis, **9**, 9, 24-9, 10 figs in colour, 1984.

Gem quality crystals of beryl with well developed faces are found in various locations in Namibia. Beryl of various colours, including aquamarine, is found at Rössing, east-north-east of Swakopmund. M.O'D.

MILLS (M. W.). *Kunzite.* Lapidary J., **38**, 4, 546-52, 7 figs (5 in colour), 1984.

A survey of the kunzite variety of spodumene with special reference to cutting, where the greatest hazard is in sawing. M.O'D.

O'DONOGHUE (M.). *Man-made gemstones.* Gems and Mineral Realm, **16**, 2, 35-6, 1984.

Natural and synthetic spinel are discussed with particular reference to blue material grown by the Verneuil process and recently seen on the market. The colour is much brighter than that usually associated with spinel and resembles that shown by treated blue topaz. Means of distinguishing the natural from the synthetic material are given. (Author's abstract.) M.O'D.

O'DONOGHUE (M.). *Some beryl minerals—3.* Gems and Mineral Realm, **16**, 2, 37-8, 1984.

The emerald deposit at Santa Terezinha, Bahia, Brazil, is discussed.

(Author's abstract.) M.O'D.

O'DONOGHUE (M.). *The literature of mineralogy—9.* Gems and Mineral Realm, **16**, 2, 40-2, 1984.

Among the items discussed are the short course notes published by the Mineralogical Society of America under the title of 'Reviews in Mineralogy': particular attention is paid to the volumes on oxide minerals, pyroxenes and orthopyroxenes. The new Italian journal, 'Rivista Mineralogica Italiana', is also discussed. (Author's abstract.) M.O'D.

O'DONOGHUE (M.). *New light on some old gem friends—zircon.* Gems and Mineral Realm, **16**, 2, 43-4, 1984.

A review of the zircon family of gemstones with particular reference to testing.

(Author's abstract.) M.O'D.

SANDEMAN (D.). *Stones seen—mysterious cabochons.* Aust. Gemmol., **15**, 7, 240, 2 figs, 1984.

Describes two black cabochons supposed to be natural glass from Indonesia. RI 1.525, SG *ca* 2.63, bubbles, inclusions identified as mullite, in radial, sheaf-like and acicular forms with some chatoyance. Not possible to confirm natural origin with any certainty. R.K.M.

STEVENS (E.). *The nature of inclusions, 1.* Wahroongai News, **18**, 7, 7-11, 1 fig, 1984.

Discusses temperature ranges needed for mineral deposition, changes expected at given heats and so on. Quotes Roedder (E.) of U.S. Geological Survey (Scientific American (1970s)) on subject of healed cracks containing fluids. R.K.M.

TABURIAUX (J.). *La perle et la perle de culture. Pt 1.* (Pearl and cultured pearl. Part 1.) Revue de Gemmologie, 79, 21-3, 3 figs in colour, 1984.

Review of the natural and cultured pearl market. M.O'D.

WARD (C. M.). *Titanium and the color of staurolite.* Am. Miner., 69, 541-5, 2 figs, 1984.

The colour intensity of staurolite seems to be related to the titanium content and it is suggested that the colour is caused by Fe^{2+} $-Ti^{4+}$ charge transfer. It is also thought that the titanium is located in the tetrahedrally co-ordinated Fe site. M.O'D.

WRIGHT (P.). *Artificial jade joins list of manufactured gems.* The Times newspaper, No. 62024, p.14, 31st December 1984.

By mixing the constituent materials (sodium, aluminium, silica) in powder form and heating to 2700°F, withdrawing the melt and allowing it to cool to a glassy solid,

then crushing the glass and refiring to the same temperature and exposing to pressures of up to 440 000 lb/in^2 in a diamond-making press in the same laboratory at Schenectady, N.Y., where the first (synthetic) diamonds were made, R. de Vries and J. Fleischer have made cylindrical-shaped pieces of white jadeite, ¼ inch in diameter and ½ inch long: green or lavender synthetic jadeite can be produced by adding traces of chromium or manganese to the starting powder mix, and samples have been made with layered combinations of colours. J.R.H.C.

Russian diamonds. Wahroongai News, **18,** 7, 17-19, 3 figs. 1984.

Discoveries of diamondiferous gravels in Vilyin River basin and pipes at Zarnista, Mir and Udachnaya, with further commercial deposits in basins of Olenk, Muna and Aldan Rivers, all in western Yakutsk region, together make this a major diamond area. Inhospitable swamp lands due to permafrosted subsoil make mining difficult. Product and mode of origin seem to be similar to those for diamonds found in other parts of the world. R.K.M.

Xinhua. Indiaqua, 36 (1983/3), 25, 1983.

News bulletin reports a 92.86 carat diamond discovered at Tancheng, Shandong Province in China. The same area produced 158.78 and 124.27 carat stones in 1979 and 1981. R.K.M.

Zale gem puts others in the shade. The Times newspaper, No. 61993, p.6, 1 fig., 22nd November 1984.

The 890 ct Zale diamond, illustrated surrounded by diamonds totalling 890 ct, is an almost flawless canary-yellow gem from an unknown locality in Africa—a surface stone, not mined. It is expected to weigh 550 ct (larger than Cullinan I), if cutting is successfully finished in eighteen months time, and will be displayed in the Smithsonian Institution, Washington D.C., before and after cutting. J.R.H.C.

BOOK REVIEWS

KITAIGORODSKY (A. I.). *Mixed crystals.* Springer, Berlin, 1984. pp.xiv. 388. DM120.

This book attempts to cover a widening gap between a number of small specialized disciplines, each relying on studies of crystal structures and compositions for their work. The term crystal has widened its meaning to include such topics as cell membrane structures and polymer crystallinity. The book begins with a discussion of phase diagrams and particle packing, continuing with free energy in solid solutions, x-ray scattering and intermetallic compounds. The formation and types of organic solid solutions, polymers and biopolymers complete the book, which has an index and a bibliography. M.O'D.

STEVENS (G.). *Gemmology questions and answers.* Available from Ladybird Gem Merchants, Shop 112, Second Gallery, The Strand, Arcade, Sydney, N.S.W. 2000, Australia. pp.85. $12.

300 simple questions are given to assist the gemmology student. Some of the answers given are too simple and some of them are wrong (for example, the behaviour on the refractometer of a uniaxial stone whose table facet is cut at right angles to the optic axis is to show maximum birefringence during a complete rotation). However, the book, if carefully read and checked, does provide a useful revision tool. M.O'D.

ASSOCIATION NOTICES

OBITUARY

Mr E. R. Bohe, F.G.A. (D. 1956), San Diego, Ca, U.S.A., died on 2nd March, 1984.

Mr Leslie Green, F.G.A. (D. 1961 with Distinction), Rainhill, Prescot, died in July 1983.

NEWS OF FELLOWS

Mr M. J. O'Donoghue, M.A., F.G.S., F.G.A., who is Curator of the Earth Sciences Collections, The British Library, encourages anyone with a serious interest in the literature of gems and minerals to feel free to contact him at the Library (Science Reference Library, 9 Kean Street, London WC2B 4AT: telephone 01-636 1544, extension 674). Enquiries should not be at text-book level. The Science Reference Library is free to all without formality. Collections include all monographs and serials of importance from all countries.

On 16th and 17th June, 1984, at the City University, Mr O'Donoghue and Mr P. G. Read, C.Eng., F.G.A., conducted a course for Precious Stone Training Services Ltd. The course was designed as an instrument pre-Diploma Examination refresher session. On 19th June, 1984, Mr O'Donoghue conducted a one-day Preliminary Examination revision course for the same company.

On 17th September, 1984, Mr O'Donoghue gave a lecture on 'Gemstones', illustrated by specimens of rough and cut stones, to the Merton Scientific Society.

On 16th to 27th October, 1984, Mr O'Donoghue visited Japan and gave lectures on modern developments in synthetic gem materials to audiences of the Gemmological Information Centre of Japan in Tokyo, Fukuoka and Osaka. He also visited the research laboratories of the Seiko company.

MEMBERS' MEETINGS

London

On 18th September, 1984, at the Flett Theatre, Geological Museum, Exhibition Road, South Kensington, S.W.7., Mr J. Rouse, M.A., G.G., gave an illustrated talk on 'Colour grading systems and techniques' and Mr D. McColl, F.G.A.A., gave an illustrated talk on 'The development of a classification and appraisal system for precious opal'.

On 27th November, 1984, at the Flett Theatre, Mr P. G. Reed, C.Eng., F.G.A., gave an illustrated talk on New Instruments and Identification Techniques.

On 27th November, 1984, at the Flett Theatre, an Extaordinary General Meeting was held at which Mr J. R. H. Chisholm was elected a Vice-President of the Association (see page 452 below).

Midlands Branch

On 28th September, 1984, at the Society of Friends, Dr Johnson's House, Birmingham, Miss J. I. Platts, F.G.A., Chairman of the South Yorkshire and District Branch, gave an illustrated talk on her recent visit to the opal fields of Coober Pedy.

On 26th October, 1984, at the Society of Friends, Mr F. Carrigan gave a talk on 'Jewels used in regalia'.

On 30th November, 1984, at the Society of Friends, Mrs Edna Holloway gave a talk on 'Ivory Carving and Netsuke'.

North West Branch

On 20th September, 1984, at Church House, 1 Hanover Street, Liverpool, Mr P. G. Read, C.Eng., F.G.A., gave a talk entitled 'Distinguishing between natural and synthetic gems'.

On 18th October, 1984, at Church House, the Annual General Meeting was held at which Dr John W. Franks, F.G.A., and Mrs Edna Cartmel were re-elected Chairman and Secretary respectively.

On 15th November, 1984, at Church House, Mr R. Wood, F.G.A., and Mr Reynolds gave a talk entitled 'Ruppenthal's, story of and gem display'.

South Yorkshire and District Branch

On 4th October, 1984, at the British Horological Institute, Upton Hall, near Newark, Mr J. A. W. Hodgkinson, F.G.A., gave a talk and demonstration to branch members and a group of retail jewellers on instruments, their uses and limitations.

On 1st November, 1984, at Sheffield City Polytechnic, Mr J. A. W. Hodgkinson, F.G.A., gave a talk entitled 'Keep the moth in your diamond'. The title referred to inclusions which, he urged, should not be regarded necessarily as a detriment, but as a unique feature of added interest in a particular stone.

ANNUAL REUNION OF MEMBERS AND PRESENTATION OF AWARDS

The Annual Reunion of Members and the Presentation of Awards took place in Goldsmiths' Hall on Monday, 12th November, 1984. The Chairman, Mr David Callaghan, F.G.A., presided at the Presentation of Awards in the Livery Hall and opened the proceedings by welcoming all those present, including some who had come a long way—from America, Belgium, France, Germany, India, Spain, Sweden and Switzerland. There had been examination centres in some 30 different countries, including 29 centres in U.S.A. and 22 in the U.K., which had involved a lot of organization by the Association's staff, and throughout the world 715 candidates had sat for the Preliminary Examination and 459 for the Diploma. The Tully Medal—an award difficult to achieve, which had not been won in the last seven years—was to be presented this year to two students, one from Spain, one from U.S.A., and was to be presented—as were the other awards—by Mr Keith Mitchell, F.G.A., who had himself won the Tully Medal fifty years ago—in 1934, a year in which the list of Diploma winners included the names of Norman Harper, later to become a distinguished Chairman of the Association, and Robert Webster, whose outstanding contributions to gemmology were well known: Mr Mitchell had been elected a Vice-President of the Association earlier in the year.

Continuing, Mr Callaghan then said that amongst those in the Hall was Mrs Eunice Robinson Miles, a distinguished gemmologist from America, who was present to receive an Honorary Fellowship. She was born in Connecticut, and after studing mineralogy at university she was Assistant Curator at the Mineralogical Department of the American Museum of Natural History in New York from 1942 to 1952. In 1953 she joined the Gemological Institute of America and was the first—and at that time only—woman working in the G.I.A. laboratory in New York. For some years she taught gemmology and now is primarily concerned with education. She had also written numerous articles, particularly on the colouring of diamonds.

The Chairman then presented Mrs Miles with a framed Certificate, after which he called upon Mr Keith Mitchell to present the awards to the successful examination candidates.

Mr R. Keith Mitchell, F.G.A., Vice-President, then presented the awards and delivered the address which is printed in full below.

The Vice-Chairman, Mr Noel Deeks, F.G.A., thanking Mr Mitchell, said that he had mentioned many other people but had been very modest about himself. He had been in the jewellery trade for fifty-one years* and was still connected with it. He had made a major contribution to gemmology by encouraging hundreds of others to take the examinations. In earlier years he had taught gemmology at the Chelsea Polytechnic and later became the Instructor for the Association's Correspondence Courses. At one time there were 243 students taking the Preliminary subjects and sending in papers every fortnight for him to mark. One of them had the name of Deeks.

Then, before the proceedings were concluded, Mr Callaghan announced the opening of the Basil Anderson Appeal for the purpose of raising £25000 to purchase a spectrophotometer to be placed on permanent loan with the British Gem Testing Laboratory, which will be celebrating its sixtieth year in 1985. Developed by Pye-Unicam Ltd at Cambridge, the instrument is to be known as the Basil Anderson Spectrophotometer in memory of the late B. W. Anderson, who pioneered the use of the specroscope in the identification of gemstones.

*Mr Mitchell was transferred to the Jewellery Department of Mappin & Webb Ltd in 1933.—Ed.

ADDRESS BY MR R. KEITH MITCHELL, F.G.A., VICE-PRESIDENT.

Mr Chairman, Ladies and Gentlemen,

It has given me a lot of pleasure to come here and present Gemmological Diplomas and Diamond Certificates to these successful candidates, at least a dozen of whom have travelled from far countries to be with us tonight. All are most welcome! More than twice their number will receive their Diplomas overseas, for the examinations were held in some 92 different centres in other countries as well as in 22 here in Britain.

Four of the five special prizes have been handed over tonight. Two of these, the Anderson Medal and the Anderson/Bank Prize, were originated by Professor Hermann Bank, of Idar-Oberstein, in honour of the eightieth birthday of our great pioneer gemmologist, B. W. Anderson, in 1981. Sadly, Basil Anderson, guide mentor and friend to so many of us, died early this year, and these two prizes must now be regarded as awards in his memory. The recipients should take great pride in them, for he was a remarkable man.

I am pleased to see that, after a gap of several years in which no Tully Medal was awarded, our examiners have found, not one, but two students whose very excellent work tied for this our highest award. Some of you may wonder about the origin of this medal, for Bristow John Tully died a long time ago in 1929, just a month or two after I first came into the trade.* He was a gem dealer who later opened a Bond Street shop which specialized in rare stones. He was another pioneer of the early days of gemmology, an instructor and lecturer who never actually sat one of our examinations. In the early twenties he ran the Correspondence Courses and was Director of Examinations. He designed a large table refractometer with a rotating dense glass hemisphere which made the observation of birefringent RIs very easy. The switch to arms production killed this off and it was not made again after the war, which was a pity for it was a nice instrument. The dies for the medal were presented by Mrs Tully in 1930 in his memory. For several years it was our only major prize, until Rayners offered the two which are now presented in their name.

Just fifty years ago I, too, walked up on to this rostrum to collect my Diploma, and I am now going to break with tradition to tell you a little about those far off days.

In 1934 the First World War had been over for 16 years. The second instalment lay, quite unsuspected, five years in the future. The world was, as it is today, in the grip of a serious economic depression, known to us then as 'the Slump'. There was no Welfare State and unemployment was a grave problem which a 'dole' of about 50 pence a week did little to alleviate, and it was not finally solved until the Second World War brought full employment. If you had a job, no matter how poorly paid, you worked hard to keep it.

It was a world without many things which we now regard as essential. There was no television. Rayon was the only artificial fibre and nylon, polythene, terylene and a hundred other plastics had yet to be invented. There were no transistors, no tape-recorders, no computers, no radar and no jet aircraft. Nuclear physics was in its infancy, and the atom bomb was eleven years in the future.

*Mr Mitchell entered the buying department of Mappin & Webb Ltd in 1928.—Ed.

In 1934 we had been off the Gold Standard for a couple of years and that metal had rocketed from £4.20 to an unheard-of £6.90 per fine ounce. Silver, which in 1931 had, for one day, reached an all-time low of 5 pence an ounce, had recovered to a slightly more respectable 9 pence. A year or so later dealers were offering beautiful Victorian diamond jewellery at prices based on a figure of £8 per carat for melée stones. Those commodities cost far more today, not because they have increased in true value but because the good old Pound Sterling has been allowed to decline grotesquely in purchasing power until it is roughly equivalent in this respect to a 1934 sixpence (2½ new pence for those who may not remember real money).

Gemmology in 1934 was far simpler in structure than it is today, but we had fewer sophisticated instruments with which to work. The feverish search for laser materials, with its off-spin of new synthetics, was far in the future, and we contended only with synthetic corundums and spinels. Such things as the artificial colouring of diamonds by radiation were almost unknown, for radium was the only source of such particle bombardment. Anderson, our new lecturer, had introduced the 1.81 refractometer liquid, the crossed filter technique and absorption spectroscopy only that year. The course in 'Mineralogy for Jewellers', which was Chelsea Poly's name for gemmology at that time, was restricted to trade members only. But that trade tended to be disinterested, and we had little encouragement from some employers.

In that year twenty-one students, all British, sat the Diploma examination. All of them passed—nine with distinction, a feat which has yet to be equalled.

The enthusiasm of Anderson was contagious and we almost lived for gemmology. Some of our students were to become well-known in later years, like Robert Webster, author of the massive text-book *Gems* and *Practical Gemmology,* and Norman Harper, who was to be Chairman of this Association for some thirteen years. These and others made for fierce competition in our examination, which was probably not all that much easier than those set today. Personally I still have occasional nightmares in which I find myself with three questions to answer and only ten minutes in which to do it. Some of you will know the feeling.

Coming back to the present, I would like first to say a few words to those students who did not achieve a pass grade this year. They are unlikely to be here, but these words will be printed and may get to them one way or another. To them I say 'Don't be down-hearted! No examination is the end of the world, and some well-known gemmologists have had to take more than one shot at this one. Don't give up! If you do have to go over the ground a second time, then your gemmology will almost certainly be better founded as a result. Have another go!'

Successful candidates can forget those few words. You have passed a difficult test, and most of you will be feeling a certain degree of euphoric pride in achieving this milestone which marks the culmination of two or more years of hard, unremitting study—an end in itself, since all of you, both here and elsewhere, are now qualified gemmologists and are to be congratulated most heartily on that fact!

Last year Professor Bank quoted Goethe to make his point. I shall let Churchill underline mine. In no way do I wish to minimize your achievement when I say that your Diploma should be regarded, in his words, as 'the end of the beginning'. The old chap was talking about a very different conflict, but the warning is still apt. We, in the Gem Trade, handle some of the most highly priced substances on this planet, and we must be certain that they are what they are said to be.

Gemmology doesn't stand still. It is a progressive study. New minerals are cut as gems, new synthetics are made, new deceptions are contrived and new ways of dealing with all these things have to be worked out. You will never again be able to look at a stone without seeing it with a gemmologist's eye. You should now have a very valuable basic knowledge—but you haven't finished learning. You never will! In the years to come each gem intelligently examined will add to your experience and possibly teach you more. Use your lens at all times and your other instruments when you can. Read and re-read your Journal until you understand it. Seek out new books on the subject! Ask for information! Cultivate an enquiring mind! If you find something new or interesting, share the discovery by writing about it in the Journal.

In that way you may arrive at the fiftieth anniversary of this evening's ceremony ready to say, as I do now, 'I have never stopped learning about gems!'

That future meeting will be in the year 2034. Doesn't that sound strange? I shall not be there. At the age of 122 I won't be able to get up that marble staircase! But it is possible that one of the younger people who have received Diplomas tonight could stand here in my place. Then he, or she, may perhaps hear a small echo, or a chuckle, from somewhere up there near that wonderful ceiling and possibly will recall my words. I shall do my best to be here in spirit!

Thank you! And good luck to you all!

COUNCIL MEETING

At the meeting of Council held on Tuesday, 9th October, 1984, at the Connaught Rooms, London, W.C.2., the business transacted included the following:

(1) Mr A. E. Farn's resignation from the Council on his appointment as an Examiner in Gemmology was accepted;

(2) Mrs Eunice Miles was elected an Honorary Fellow;

(3) Mr J. R. H. Chisholm was nominated for election as a Vice-President of the Association and it was agreed that an Extraordinary General Meeting on 27th November should be called for the purpose;

(4) the following were elected to membership:

FELLOWSHIP

Adlam, Raymond J., Glasgow. 1984
Altenloh, Jacques C. P. J., Brussels, Belgium. 1984
Anderton, Brian G., Glasgow. 1984
Au-Yeung, Siu Man, Kowloon, Hong Kong. 1984
Baxendale, John F., Widnes. 1984
Beckwith, John M. E., Stockton on Tees. 1964
Blankestijn, Janna G., Leersum, Netherlands. 1983
Boreham, Kevin M., Truro. 1984
Cass, Laurence, Harrow. 1984
Chan, Hung C., Hong Kong. 1984
Chan, Suk H., Victoria, Australia. 1984
Cheung, Chi K., Hong Kong. 1984
Chieveley-Williams, John P. E., Poole. 1984
Chinn, Jeffrey, St Helier, Jersey, C.I. 1984
Corbin, Janet R., Liverpool. 1984
Donoghue, Martin D., Glasgow. 1984
Foote, Lisa A., Brisbane, Qld, Australia. 1984
Fox, Kathleen P., Townsville, Qld, Australia. 1984
Goodchild, Gordon E., Colchester. 1984

Goodchild, Kathleen J., Colchester. 1984
Gould, Henriette, Johannesburg, S.Africa. 1962
Henwood, Amelia R., Basingstoke. 1984
Jennings, Melvyn, Greetland. 1984
Jones, Julia D., Wolverhampton. 1984
Koseki, Norio, Fukushima-Shi, Japan. 1984
Lai Wing-Cheong, Robert, Shatin, N.T., Hong Kong. 1983
Lal, Vispi R., Churchgate, Bombay. 1984
Law, Bik W., Kowloon, Hong Kong. 1984
Leung, Pui F., Yuen, N.T., Hong Kong. 1984
Markus-Pothof, Helga, Wageningen, Netherlands. 1983
Massey, Steven M., Bowden. 1984
Mochan, Yan N., Glasgow. 1984
Morgan, Leon D., Aylesham. 1984
Nial, Brian L., Southport, Qld, Australia. 1984
Nelson, Maja T. A., London. 1984
Palomaki, Jukka Afto J., Katinala, Finland. 1983
Preston, Mitchell R., Morpeth. 1984
Rich, Frederick S., London. 1984
Robertson, Anne N., Gerrards Cross. 1984
Robertson, Neil, Kangaroo Pt, Qld, Australia. 1984
Sanchez Rodriguez, Raul de J., Las Palmas, Canary Is. 1983
Scamp, Colin P. D., Plymouth. 1984
Slack, Richard D., Lower Penarth. 1984
Smith, Clifford N., Leeds. 1984
Tomren, Jan I., Notodden, Norway. 1984
Tudor-Pole, Thomas A. J., London. 1984
van Dijk, Peter, Leimuiden, Netherlands. 1984
van Loenen, Willem J., Lopik, Netherlands. 1983
Wagstaff, Edith H. C., Bury, Lancs. 1984
Wickramasinha, Tudor, London.1984
Wiggin, Richard C., Midland, Texas, U.S.A. 1983
Wightman, David F., Aintree. 1984
Williams, Dawn L., Cheadle Hulme. 1984
Woolf, Tania, London. 1984
Yip, Ki F., Kowloon, Hong Kong. 1984

TRANSFERS FROM ORDINARY MEMBERSHIP TO FELLOWSHIP

Apland, Ken A., Cottage Grove, Oreg., U.S.A. 1984
Asagai, Toshiki, Osaka, Japan. 1984
Bae, Sang K., Seoul, Korea. 1984
Bartlett, Lynne, London. 1984
Bell, Robert D., Durban, S. Africa. 1984
Bennett, Norman P. J., Plymouth. 1984
Berger, Clark J., London. 1984
Beveridge, Ronald R., Adelaide, S. Australia. 1984
Blackburn, Mary-Rose, Pembroke. 1984
Buddington, Jeffrey P., Hyannis, Mass, U.S.A. 1984
Chang, Julius, Hong Kong. 1984
Chang, Yu-Mei, Tokyo, Japan. 1984
Cirone, Monica A., San Jose, Ca, U.S.A. 1984
Coffin, Martin R., Carlisle. 1984
de Vilmorin, Marie, London. 1984
Duguid, Keith B., Eiffel Flats, Zimbabwe. 1984
Dunn, Nigel P., Brierley Hill. 1984
Eaton, Anne, Lymm. 1984
Ehlenbach, Richard J., Winchester, Mass, U.S.A. 1984

Ely, Jana M., London. 1984
Fein, Murray, Whitestone, N.Y., U.S.A. 1984
Fitzgerald, Jennifer G., London. 1984
Gibson, Dorothy, Chatham, N.J., U.S.A. 1984
Gosling, Robert G., Adelaide, S. Australia. 1984
Guinand, François, Neuchatel, Switzerland. 1984
Hennessy, Linda L., Sydney, N.S.W., Australia. 1984
Holden, Patti, Market Harborough. 1984
Hookins, Gary C., Thames Ditton. 1984
Hosaka, Masahiro, Kofu, Japan. 1984
Kamioka, Hitomi, Tokyo, Japan. 1984
Kessler, Paul, Wolverhampton. 1984
Koseki, Norio, Tokyo, Japan. 1984
Kumarasuriar, G. K. K., Colombo, Sri Lanka. 1984
Lewton-Brain, Charles J., Halifax, N.S., Canada. 1984
Lim, Pauline, Kingswinford. 1984
Loup, Daniel L., Geneva, Switzerland. 1984
Maruo, Tatsuzo, Hyogo Pref., Japan. 1984
Moir, Richard C., Sydney, N.S.W., Australia. 1984
Payne, Michael D., Royal Tunbridge Wells. 1984
Peshwa, Krishna V., Pune, India. 1984
Porter, James W., Coventry. 1984
Puig Ovejero, Josep Mª, Barcelona, Spain. 1984
Quam, Maurice D., Saint Paul, Minn., U.S.A. 1984
Quick, Fiona A., Harare, Zimbabwe. 1984
Santiago Gonzalez, Antonia, Tenerife, Canary Is. 1984
Stoecklein, Patricia A., Trafalgar, Ind., U.S.A. 1984
Suzuki, Setsuko, Rokugo, Japan. 1984
Taylor, Caroline H. B., Guildford. 1984
Turner, Starla E., San Francisco, Ca, U.S.A. 1984
Uesugi, Tohru, Osaka, Japan. 1984
Walker, Frank D., Dallas, Tex., U.S.A. 1984
Warriner, E. R., Solihull. 1984
Wong, Christine H., Hong Kong. 1984
Woolley, Joseph G., Nelson, N.Z. 1984
Wurm, Lise A., San Francisco, Ca, U.S.A. 1984
Yap, Ching-Siew, London. 1984

ORDINARY MEMBERSHIP

Abramson, Pamela J., Orlando, Fla, U.S.A.
Ackroyd, Jonathan, L., Dunsfold.
Addison, Nicola E., London.
Aimoto, Masako, Kofu, Japan.
Alexander, Jane E., Singapore.
Anderson, Jeremy F., Northwood.
Anwar, Haroon M. G., Rastanura, Saudi Arabia.
Arias, Antonio, Madrid, Spain.
Armand, Marcel, Auckland, N.Z.
Austen, Susan L., Teignmouth.
Azzopardi, Paul, Kappara, Malta.
Baba, Toshiro, Osaka, Japan.
Biffer, Howard N., New York, U.S.A.
Bracewell, Hylda M., Brisbane, Qld, Australia.
Bram, Carol B., Hong Kong.
Bramlett, Christopher L., Albemarle, North Carolina, U.S.A.
Brasseur, Nathalie P. C., Dusseldorf, W. Germany.

Brinkmann, Hans H., Dickesbach, W. Germany.
Burton, Nicholas J., Fradley.
Carroll, Elizabeth K., Auckland, N.Z.
Castro, Kevin D., Napa, Ca, U.S.A.
Caswell, Amelie M., Hayle.
Chappron, Alan J., Bellevue, Wash., U.S.A.
Cole, John, Blackpool.
Coleman, Rachel R., Newbury.
Costello, Seamus A., Kilkenny, Ireland.
de Ceballos-Romay, J. Fernando, Mazzaine, Mexico.
della Torre, Isabelle, Geneva, Switzerland.
de Witte, Maarten J., Urbana, Ill., U.S.A.
Diyaljee, Wayne V. S., London.
Droste, Gregory S., Evansville, Ind., U.S.A.
Endo, Chiaki, Yamanashi, Japan.
Endo, Katumi, Kofe Yamanashi, Japan.
Fedell, Jean M., Crystal Lake, Ill., U.S.A.
Fessel, Robert P., Paulding, Ohio, U.S.A.
Finkleman, Steven L., Chicago, Ill., U.S.A.
Frank, Anita, Toronto, Ont., Canada.
Furuya, Tsukasa, Yamanashi, Japan.
Gardiner, Margot, Glasgow.
Gemmell, Ian G., Wairoa, N.Z.
Glaveau, Beatrice, Paris, France.
Grant, Louis A. G., Iver Heath.
Green, Gwynneth M., Barnt Green.
Hallier, Michele, Paradise Valley, Ariz., U.S.A.
Holt, Judith A., Chorley.
Homer, Sylvia, New Paltz, N.Y., U.S.A.
Horsup, Alexine, London.
Hyeon-Ka, Tae, Chung Nam, Korea.
Imai, Fumio, Kansas City, U.S.A.
Johnson, Gerald D., Kennewick, Wash., U.S.A.
Jones, Lloyd E., Auckland, N.Z.
Kasai, Kenji, Yamanashi, Japan.
Kienstra, Therese S., Alton, Ill., U.S.A.
King, Adrian J., Walsall.
Landolt, Karin, Beijing, China.
Lee, Alan R., Eastbourne.
Lee, Dong Ho, New Jersey, U.S.A.
Lee, Kay C. R., Seattle, Wash., U.S.A.
Liebermann, Louis B., Joliet, Ill., U.S.A.
Lim-Weissleib, Sin L., Paris, France.
McGlinchey, Kevin C., Derry City, N. Ireland.
Macaulay, Elizabeth A., Windhoek Gooo, Namibia.
Mathews, Paul C., Warmbaths, N. Transvaal, S. Africa.
Maurer, Michael G., Falls City, Nebr., U.S.A.
Mehdi, Jonathan, Herzliah Pituah, Israel.
Melinn, John, Dublin, Ireland.
Mills, Edwin T., Ely.
Mills, Ganny, Hong Kong.
Milton-Stevens, Christopher, Bath.
Mitchell, Virginia C., Shreveport, La, U.S.A.
Mohamed, Mohamed S., Colombo, Sri Lanka.
Mohlemkamp, Margaret I., Gordon, N.S.W., Australia.
Molina, Alfredo J., Phoenix, Ariz., U.S.A.
Mueller, Ralph D., Scottsdale, Ariz., U.S.A.
Munsterman, Henry B., Temple, Tex., U.S.A.
Murrell, Vernon, Croydon.
Nazeer, Mohamed H. M., Colombo, Sri Lanka.
Nechemias, Alan, San Francisco, Ca, U.S.A.
Nielsen, Krystina M., Lorain, Ohio, U.S.A.
Patten, Andrew W., Ilchester.
Pazolides, Constantine A., Thessaloniki, Greece.

Perrott, Christopher J., London.
Ramsay-Rae, Philippa, London.
Rhomberg, Markus, Innsbruck, Austria.
Rock, Barbara A., Athens, Greece.
Root, Charles K., Brownwood, Texas, U.S.A.
Sagar, Jayendra, Muharraq, Bahrain.
Seibert, Jack, Upper Arlington, Ohio, U.S.A.
Senanayake, A. W. Dharma, Singapore.
Shah, Rupam C., Manama, Bahrain.
Shepherd, Frederick J., Chislehurst.
Simmerman, Dianna L., Hong Kong.
Stachura, Joseph P., Jr., Uxbridge, Mass, U.S.A.
Starling, Lynn B., Colorado, U.S.A.
Stewart, Robert M., Swanmore.
Steyn, Johannes J., Chingola, Zambia.
Suhail, Mohamed N., Colombo, Sri Lanka.
Sweeney, Jerome, Kuala Lumpur, Malaysia.
Takeuchi, Masayo, Yamanashi, Japan.
Tezuka, Akira, Yamanashi, Japan.
Tivol, Thomas S., Kansas City, U.S.A.
Tsuruta, Einori, Alameda, Ca, U.S.A.
Tucker, Charles, Swaffham.
Turatti, Maya, Versoix, Switzerland.
Unwin, Derrick J., London.
Wako, Hisashi, Yamanashi, Japan.
Watanabe, Tatuo, Yamanashi, Japan.
Wendon, Jonathan L., Bonvilston.
Whittaker, Maureen J., Halandrion, Greece.
Williams, Bret J., Waikato, N.Z.
Williams, Philippa J., Towcester.
Wolanski, Patricia L., Dallas, Tex., U.S.A.
Wong, Wing K., Telok Kurau, Singapore.
Wood, Francis, Clifton, York.
Wright, John C., Hong Kong.
Xanthopoulou, Celia, London.
Young, Gabrielle E. M., Wareham.
Zanacchi, Lorenzo, Mombasa, Kenya.

EXTRAORDINARY GENERAL MEETING— A NEW VICE-PRESIDENT

John Richard Harrison Chisholm, M.A., F.R.S.A., F.Z.S., M.R.I., F.G.A. was elected a Vice-President of the Association at an Extraordinary General Meeting of the Association on 27th November, 1984.

J. R. H. C. was born in 1905 and educated at Westminster School and Christ Church, Oxford. He practised as a solicitor from 1932 until 1974. His work encompassed a range of legal problems, but life assurance and pension funds were a major interest. He was director of a number of companies and a past Chairman of the Life Assurance Legal Society.

During the last months of the Second World War he spent several weeks in bed with what his doctor called 'a low-grade infection of the lungs' and his wife, Marie-Louise, chanced upon Selwyn's 'Retail Jewellers Handbook' in the local library; they both found it fascinating. Among the advertisements in the end-pages was one for the National Association of Goldsmiths and another on the same page for the Gemmological Association which mentioned the Correspondence Course. In a bantering fashion husband and wife bet each other that they couldn't pass the Diploma examination; both started the correspondence course.

So started the gemmological career of our new Vice-President. He passed the Diploma examination in 1950, but had only seen the gemmological instruments the day before the examination and only learned to cope with them by the end of the practical examination.

In 1955 he was appointed an Examiner in Gemmology (with Dr G. F. (now Sir Frank) Claringbull and Mr B. W. Anderson) and from then on was in sole charge of the Preliminary examination—setting papers and marking the answers. After Dr A. J. Allnutt was appointed as an Examiner in 1963 and took over the Preliminary Examination, J. R. H. C. became primarily responsible for one of the Diploma papers.

In 1953-55 he had written articles for the Journal (as well as some 'Letters to the Editor') and from the late 50s Gordon Andrews (then Secretary of the Association) had been sending him printers' galleys to correct for the Journal. On Gordon Andrews' retiral in 1973, J. R. H. C. was appointed Editor of the Journal—a post he still holds. The present high standing of the Journal worldwide is largely due to his efforts over the past decade. He retired from the post of Examiner in 1982 after 27 years meticulous service.

Chronicled above (in outline only) is a magnificent record of service to the Association, and to this must be added many years of free legal advice on many problems concerned with Association affairs.

There are other sides to this man: he was a Special Constable in 1926, the year of the General Strike in Britain; he served in the Home Guard from 1940-45 and 1952-58, retiring with the rank of Major, and in the Civil Defence Corps from 1950-52 and 1958-68. As late as 1971 he gained his private pilot's licence and lists the Elstree Flying and the Athenaeum as his clubs.

John Chisholm well deserves his election as Vice-President and to the small circle of devoted Fellows who have served the Association so well for so many years.

E.A.J.

GEM DIAMOND EXAMINATION, 1984

In the Post-Diploma Gem Diamond Examination 41 candidates sat and of these 40 succeeded in passing. The following is a list of the names of the successful candidates arranged alphabetically.

Amos, Gillian L., Pontypridd.
Avargues Perles, Antonia, Barcelona, Spain.
Bercott, David S., Glasgow.
Bishop, Ian C., London.
Bisset, Ross, London.
Bolton, Robert G., Menston.
Castell Andujar, Joaquin, Barcelona, Spain.
Collado Castelles, Mª Dolores, Barcelona, Spain.
Collins, Glen M., Glasgow.
Condrup, Jonathon R., London.
Darmudas, Nathaniel R., London.
Doughty, Michelle Susanne, London.
Firth, Barbara, London.
Fryer, Frederick A., London.
Garcia Gisbert, Rocio, Barcelona, Spain.
Genis Perez, Manuel, Barcelona, Spain.
Gonzales Violan, Francesc, Barcelona, Spain.
Guerrero Ramon, Desamparados, Barcelona, Spain.
Houghton, Mark W., Cheshire.

Hutchinson, Marjorie E., London.
John, Bryan C., Carmarthen.
McFarlane, Patricia A., London.
Mehta, Anoop K., London.
Moreno Valero, Eloy, Barcelona, Spain.
Noguera Borel, Agnes, Barcelona, Spain.
Orchant, Lewis, Glasgow.
Pedersen, Julie, Merseyside.
Perera, Priyani A. M., Sri Lanka.
Pike, Corinna A. W., Putney.
Pritchard, Janet M., London.
Salloway, Nigel J., London.
Sanchez Rodriguez, Raúl de J. Barcelona, Spain.
Sealey, Ralf E., London.
Smith, Ian J., Rochdale.
Soni, Anu, London.
Subramaniam, Manoharan, Farnborough.
Wells, Bruce I., Glasgow.
Whittingham, Jill E. A., Farnham.
Woodhouse, M. L., Chatham.
Young, William R., London.

EXAMINATIONS IN GEMMOLOGY, 1984

In the 1984 Examinations in Gemmology 459 candidates completed the Diploma Examination and of these 198 succeeded in passing, 28 of them with Distinction. In the Preliminary Examination 715 sat and 408 passed.

Upon the recommendation of the Examiners the Tully Memorial Medal has been awarded both to Miguel Angel Pellicer Garcia, of Barcelona, Spain, and to Dorothy Gibson, of Chatham, New Jersey, U.S.A.

The Anderson/Bank Prize for the best non-trade candidate of the year in the Diploma Examination was awarded to Jane Francis Cassandra Goad, of London.

The Rayner Diploma Prize for the best candidate of the year whose main income is derived from activities essentially connected with the jewellery trade was awarded to Michael D. Payne, of Royal Tunbridge Wells.

The Anderson Medal for the best candidate of the year in the Preliminary Examination was awarded to Gwynneth M. Green, of Barnt Green, Worcs.

The Rayner Preliminary Prize for the best candidate of the year under 21 years of age whose main income is derived from activities essentially connected with the jewellery trade was awarded to Jill Snider, of Downsview, Ontario, Canada.

The following are lists of the successful candidates arranged alphabetically.

DIPLOMA EXAMINATION

TULLY MEMORIAL MEDAL

Pellicer Garcia, Miguel Angel, Barcelona, Spain.
Gibson, Dorothy, Chatham, N.J., U.S.A.

Anderson/Bank Prize
Goad, Jane F. C., London.

Rayner Diploma Prize
Payne, Michael D., Royal Tunbridge Wells.

QUALIFIED WITH DISTINCTION

Banks-Lyon, Rodney, Bristol.
Barlow, Alice M., Appleton, Wis., U.S.A.
Berger, Clark J., London.
Cahill, Cynthia E., Bangkok, Thailand.
Caracciolo, Marie E., McLean, Va, U.S.A.
Chieveley-Williams, John P. E., Poole.
Chu, K-C. Quinnie, Toronto, Canada.
Dagli, Yogeshkumar P., Bombay, India.
de Vilmorin, Marie, London.
Ehlenbach, Richard J., Winchester, Mass, U.S.A.
Ely, Jana M., London.
Gibson, Dorothy, Chatham, N.J., U.S.A.
Goad, Jane F. C., London.
Jerndell, Bo E. O., Stockholm, Sweden.
Kikano, Margo M., London.
Lal, Vispi R., Bombay, India.
Malkani, Monica, Bombay, India.
Payne, Michael D., Royal Tunbridge Wells.
Pellicer Garcia, Miguel Angel, Barcelona, Spain.
Quick, Fiona A., Harare, Zimbabwe.
Rich, Frederick S., London.
Root, Jerold B., Bethesda, Md, U.S.A.
Stoecklein, Patricia A., Trafalgar, Ind., U.S.A.
Taylor, Caroline H. B., Ripley.
Turner, Starla E., Hillsborough, Ca, U.S.A.
van Wenum, Elbertha G., Amsterdam, Netherlands.
Williams, Dawn L., Cheadle Hulme.
Yin, Anna W. Y., Hong Kong.

QUALIFIED

Adlam, Raymond J., Glasgow.
Alexander, Nicholas A., Johannesburg, S.Africa.
Altenloh, Jacques C. P. J., Brussels, Belgium.
Anderton, Brian G., Glasgow.
Apland, Ken A., Cottage Grove, Oreg., U.S.A.
Asagai, Toshiki, Osaka, Japan.
Au-Yeung, Siu M., Hong Kong.
Bae, Sang K., Seoul, Korea.
Bartlett, Lynne, London.
Bastiaanse, Paul A., Eindhoven, Netherlands.
Baxendale, John F., Widnes.
Bell, Robert D., Pinetown, S.Africa.
Bennett, Norman P. J., Plymouth.
Berger, Joel D., Silver Spring, Md, U.S.A.
Beringen, John J. G., Utrecht, Netherlands.
Bernal Garcia, Jose E., Barcelona, Spain.
Beveridge, Ronald R., Adelaide, S.Australia.
Blackburn, Mary-Rose, Pembroke.
Bonvehi Sola, Joan, Barcelona, Spain.
Boreham, Kevin M., Truro.
Brown, James E., Sheffield.
Buddington, Jeffrey P., Hyannis, Mass, U.S.A.
Budhwani, Amin M., Bombay, India.
Calatayud Llorca, Francisco, Barcelona, Spain.
Calduch Sendra, Mª Esmeralda, Barcelona, Spain.
Calje, Nicoline, Schoonhoven, Netherlands.
Cartmell, Fiona A., Wembley.

Casanovas Ramon, Mª Rosa, Barcelona, Spain.
Cass, Laurence, London.
Chan, Boon T., Penang, Malaysia.
Chan, Hung C., Hong Kong.
Chan, Jacqui B. H., Penang, Malaysia.
Chan, Suk H., Hong Kong.
Chang, Julius, Hong Kong.
Chang, Yu-Mei, Tokyo, Japan.
Cheung, Chi K., Hong Kong.
Chinn, Jeffrey, St Helier, Jersey, C.I.
Cirone, Monica A., San Jose, Ca, U.S.A.
Coffin, Martin R., Carlisle.
Corbin, Janet R., Liverpool.
Courtenay, Jutta W., Hong Kong.
Cox, Jennifer M., Redhill.
D'Cruz, Jeffrey C., Bombay, India.
Dent, Peter J., Guildford.
Dewan, Shobha, Hong Kong.
Dixon Phillip, John G., Wallasey.
Donoghue, Martin D., Glasgow.
Duckett, Karen L., Long Preston.
Duguid, Keith B., Eiffel Flats, Zimbabwe.
Dunn, Nigel P., Brierley Hill.
Eaton, Anne, Lymm.
Ellis, Julia L., Aylesbury.
Fein, Murray, Whitestone, N.Y., U.S.A.
Ferran Estrada, Alejandro, Barcelona, Spain.
Fitzgerald, Jennifer G., London.
Floriach Devant, Mª Teresa, Barcelona, Spain.
Foote, Lisa A., Brisbane, Qld, Australia.
Fox, Kathleen P., Townsville, Qld, Australia.
Franks, Karen M., Manchester.
Gafner, Antoinette, Liestal, Switzerland.
Galindo Merino, Mª del Carmen, Barcelona, Spain.
Giel, Caroline, Schoonhoven, Netherlands.
Glover, Howard N. G., Wallasey.
Gol Perlasia, Jose Mª, Barcelona, Spain.
Goodchild, Gordon E., Colchester.
Goodchild, Kathleen J., Colchester.
Goossens, Xavier A., London.
Gosling, Robert G., Adelaide, S.Australia.
Graham, Kimberley E., Toronto, Canada.
Guinand, François, Neuchatel, Switzerland.
Hall, Michael J. B., Oxshott.
Hansen, Jo Anne, Corvallis, Oreg., U.S.A.
Harding, Richard W., Solihull.
Hennessy, Linda L., Sydney, N.S.W., Australia.
Henwood, Amelia R., Basingstoke.
Hilton, Barbara W., Riverside, Ca, U.S.A.
Ho, Hay-ming J., Hong Kong.
Ho, Frankie K. K., Hong Kong.
Holden, Patti, Market Harborough.
Hookins, Gary C., Thames Ditton.
Hosaka, Masahiro, Kofu, Japan.
Hunt, Jill M., Totnes.
Jacobson, Karl F., Ignacio, Colo, U.S.A.
Jennings, Melvyn, Halifax.
Jhaveri, Prateik R., Bombay, India.
Jones, Julia D., Wolverhampton.
Kamioka, Hitomi, Tokyo, Japan.
Kessler, Paul, Wolverhampton.
Kobesen, Johannes B. A., Amstelveen, Netherlands.
Koseki, Norio, Tokyo, Japan.
Kothari, Prajesh R., Madras, India.
Kotila, Brian W., Don Mills, Ont., Canada.
Kranz, Kurt B. G., Brisbane, Qld, Australia.
Kumarasuriar, Geetha K. K., Colombo, Sri Lanka.
Law, Bik W., Hong Kong.
Leung, Pui F., Hong Kong.
Lewton-Brain, Charles J., Halifax, N.S., Canada.
Lim, Pauline, Kingswinford.

Loup, Daniel L., Geneva, Switzerland.
Lui, Elizabeth S. H., Hong Kong.
MacFadyen, Donald A., Scarborough, Ont., Canada.
McKearney, Michael C., London.
Maruo, Tatsuzo, Hyogo Pref., Japan.
Massey, Steven M., Bowden.
Maughan, Raymond J., Townsville, Qld, Australia.
Mochan, Yan N., Glasgow.
Moir, Richard C., Kenthurst, N.S.W., Australia.
Morgan, Leon D., Aylesham.
Morin Reyes, Maria Luisa, Tenerife, Canary Is.
Muchlinski, Michael, Clacton-on-Sea.
Murray, Jacqueline K., Whalton.
Nancarrow, Peter H. A., West Horsley.
Nelson, Maja T. A., London.
Nial, Brian L., Southport, Qld, Australia.
Parisée, Claudette, Vanier, Ont., Canada.
Paul, Wesley T., Kandy, Sri Lanka.
Payne, Susan E., Sheffield.
Peltonen, Stella P., Stockholm, Sweden.
Peshwa, Krishna V., Pune, India.
Porter, James W., Coventry.
Preston, Mitchell R., Morpeth.
Puig Ovejero, Josep Mª, Barcelona, Spain.
Quam, Maurice D., St Paul, Minn., U.S.A.
Remmereit, Jan, Oslo, Norway.
Rikkoert, Jasper D., Schoonhoven, Netherlands.
Robertson, Anne N., Gerrards Cross.
Roberston, Neil, Brisbane, Qld, Australia.
Rojals Garcia, Montserrat, Barcelona, Spain.
Rooijmans, Eric Frederik T. W. L., Eindhoven, Netherlands.
Ros Hernandez, Julio, Barcelona, Spain.
Rosenblatt, Robert L., Salt Lake City, Utah, U.S.A.
Rundgren, Mats E., Stockholm, Sweden.
Salas Alonso, Jose V., Barcelona, Spain.
Sane, Hemant S., Bombay, India.
Santiago Gonzalez, Antonia, Tenerife, Canary Is.
Scamp, Colin P. D., Plymouth.
Seiz Ortiz, Vicente J., Barcelona, Spain.
Shah, Syed S. A. H., Manchester.
Slack, Richard D., Nantwich.
Smith, Clifford N., Leeds.
Snider, Jill, Downsview, Ont., Canada.
Solis Mariscal, Mª Angeles, Barcelona, Spain.
Sugathapala, Reginal, Zurich, Switzerland.
Suzuki, Setsuko, Yamanashi, Japan.
Tomren, Jan I., Notodden, Norway.
Toole, Michael L. A., Vancouver, Canada.
Trusselle, Richard J., Tring.
Tudor-Pole, Tom A. J., London.
Uesugi, Tohru, Osaka, Japan.
van Dijk, Peter, Leimuiden, Netherlands.
van Grinsven, Helena A., Arnhem, Netherlands.
van Roy, Anne E. J., London.
Visvanathan, Chettiar, Coimbatore, India.
Vogler, Karl J., Basel, Switzerland.
Wagstaff, Edith H. C., Bury, Lancs.
Walker, Frank D., Dallas, Tex., U.S.A.
Warriner, Elizabeth R., Solihull.
Wickramasinha, Tudor, London.
Widmer, Thomas, Aarau, Switzerland.
Widmer, Walter L., Colombo, Sri Lanka.
Wightman, David F., Liverpool.

Witjes de Vaal, Geertje, Oisterwijk, Netherlands.
Wong, Christine H., Hong Kong.
Woolf, Tania, London.
Woolley, Joseph G., Nelson, N.Z.
Wright, Frank A., Riverside, Ca, U.S.A.
Wurm, Lise A., San Francisco, Ca, U.S.A.
Yap, Ching-Siew, London.
Yip, Ki Fung, Hong Kong.
Zwyssig, Urs, Bangkok, Thailand.

PRELIMINARY EXAMINATION

Anderson Medal
Green, Gwynneth M., Barnt Green, Worcs.

Rayner Preliminary Prize
Snider, Jill, Downsview, Ont., Canada.

QUALIFIED

Abrahams, Roy H., Ruislip.
Addison, Nicola E., London.
Advani, Meena, Bombay, India.
Aggarwal, Kamal, New Delhi, India.
Alahendra, Jayatilaka, Kandy, Sri Lanka.
Alexander, Nicholas A., Benoni, S.Africa.
Allen, Vivien, Toronto, Ont., Canada.
Ambrose, Janice M., Brentwood.
Anderson, Vanessa K. A., Hong Kong.
Arno Fece, Nuria, Barcelona, Spain.
Ashraf, Ashfaq A., London.
Ashton, Joan, Hong Kong.
Athanassiades, Emmanouela, Attiki, Greece.
Baimbridge, Andrew C., Manchester.
Balejko, Dominik, Stockholm, Sweden.
Baquero Petricorna, Manuel, Barcelona, Spain.
Batalla Vivas, Francisco C., Barcelona, Spain.
Batalla Vivas, Jose I., Barcelona, Spain.
Bell, Heather L., Formby.
Berger, Joel D., Silver Spring, Md, U.S.A.
Bernadotte, Eva C., Stockholm, Sweden.
Beveridge, Ronald R., Seacombe Heights, S.Australia.
Bhaloo, Shamsudin G., London.
Blankenburg, Hans Ol, Fenwick, Ont., Canada.
Bram, Carol B., Hong Kong.
Brook, Judith M., Leicester.
Brooks, Simon R., Hornchurch.
Brouwer, Marietta H., Utrecht, Netherlands.
Brown, Jayne D., Sheffield.
Budhwani, Amin M., Bombay, India.
Burke, Melody, Camberley.
Buxton, Lynne H., Norwich.
Bydairk, Walter J., Ballston Spa, N.Y., U.S.A.
Cabre Bores, Nuria, Barcelona, Spain.
Cahill, Cynthia E., Bangkok, Thailand.
Calatayud Llorca, Francisco, Barcelona, Spain.
Calvet Pallas, Mª Teresa, Barcelona, Spain.
Campbell, Norma, Hong Kong.
Campillo Pastor, Marina, Barcelona, Spain.

Campos Ruiz, Mª Teresa, Barcelona, Spain.
Carmena Coelho, Jose A., Barcelona, Spain.
Chan, Boon T., Penang, Malaysia.
Chan, Chi K., Kowloon, Hong Kong.
Chan, Immaculata K., Hong Kong.
Chan, Jacqui B. H., Penang, Malaysia.
Chan, Suk H., Victoria, Australia.
Chan, Yiu W. S., Hong Kong.
Chang, Yu-Mei, Tokyo, Japan.
Chaparro Lameda, Daisy A., Barcelona, Spain.
Chau, Hing W., Hong Kong.
Cheng, Bakke P. K., Kowloon, Hong Kong.
Cheng, Alan O. L., Hong Kong.
Cheuk, David H. T., Hong Kong.
Cheung, Chi K., Hong Kong.
Cheung, King W., Hong Kong.
Chilvers, Alan, Guildford.
Ching, Chan Y., Hong Kong.
Chiu, Alan K. Y., Hong Kong.
Choi, Alex S. W., Hong Kong.
Cholat, Nicole B., Hong Kong.
Chooi, Siew T., London.
Chow, Joseph H. K., Hong Kong.
Church, Susan T., New York, U.S.A.
Clancy, Allan W., Queensland, Australia.
Coehoorn, Wilma, Schoonhoven, Netherlands.
Cooper, Berzes, London.
Cox, Jennifer M., Redhill.
Daniell, Mary L. S., Hong Kong.
Davis, Adrienne M., Liphook.
Davis, Howard T., Liphook.
Davis, Simon, Elstree.
D'Cruz, Jeffrey C., Bombay, India.
de Bruin, Ilonka L. J., Amsterdam, Netherlands.
Deelman, Peter J., Schoonhoven, Netherlands.
de Haer, Robert H., Schoonhoven, Netherlands.
de Heer, Petra C., Ede, Netherlands.
Dennis, Stuart G., Bath.
Depyjper, Raphael, Ryn, Netherlands.
Derks, Rudolf, Hettlingen, Switzerland.
Devereux, James P., Toronto, Ont., Canada.
de Vilmorin, Marie, London.
Dewever, Marc L. N., Sittard, Netherlands.
Dias, Mario H., London.
Dimaggio, Joseph C., Centerline, Mich., U.S.A.
Doerr, Bertrand R., Kuesnacht, Switzerland.
Dosanjh, Gurmeet S., New Delhi, India.
Dubbers, Maria T. H., Plasmolen, Netherlands.
Dunstall, Robert, Northampton.
Duque Camp, Susanna Ma, Barcelona, Spain.
Easterbrook, Steven, Bridgend.
Eaton, Anne, Lymm.
Edie, Anmie, Hong Kong.
Ellis, Trevor E., Rugeley.
Elson, Patricia D., Swansea.
Ely, Jana M., London.
Evans, Gareth D., Potters Bar.
Farley, Eileen J., Cabinteely, Dublin, Ireland.
Farre Brugue, Francisco, Barcelona, Spain.
Fernandes, Frank T., Bombay, India.
Fernandez Usac, Teresa, Barcelona, Spain.
Fernando, Ranamukadevege P., Kelaniya, Sri Lanka.
Fixter, Robert H., Lincoln, Nebr., U.S.A.
Fournel, Astrid, Aldeburgh.
Fox-Worthington, Peter J. J. E., Auckland, N.Z.
Frederick, Helen M., Wellington, N.Z.
Fry, Kate E., Bath.

Fujii, Shinichi, Tokyo, Japan.
Gafner, Antoinette, Liestal, Switzerland.
Gambetta, Anthony, Caerphilly.
Gamblen, Philip M., Barrie, Ont., Canada.
Garcia Monge, Jorge, Barcelona, Spain.
Georgopoulou Kyriaki, Marianna, Athens, Greece.
Gerhart, Anna M., San Diego, U.S.A.
Gol Perlasia, Jose Mª, Barcelona, Spain.
Gonggryp, Hendrik S., The Hague, Netherlands.
Goodchild, Kathleen J., Colchester.
Gosling, Robert G., Christies Beach, S.Australia.
Goumas, John, Athens, Greece.
Graupera Olle, Roser, Barcelona, Spain.
Gravett, Marian J., Barnet.
Green, Fionna E., Stonehaven.
Green, Gwynneth M., Barnt Green.
Gregoire, Stanislas, Ghent, Belgium.
Gresswell, Pauline T., Sheffield.
Grievson, Richard P., York.
Grillo Pont, Josep Mª, Barcelona, Spain.
Gualco, Fabiana, Genoa, Italy.
Gualco, Giuseppe, Victoria, Brazil.
Guasch Boliart, Arturo, Barcelona, Spain.
Gunn, Alice K., Burnaby, B.C., Canada.
Haalebos, Maud, Rotterdam, Netherlands.
Hall, Sylvia, Guildford.
Hampton, Malcolm J., Highcliffe.
Harding, Keith J., Worcester, Mass, U.S.A.
Harrison, Margaretha, Geneva, Switzerland.
Hashimoto, Masaki, Osaka, Japan.
Heelas, Anne I., Harare, Zimbabwe.
Heimbuch, Anita A., Flagstaff, Ariz., U.S.A.
Henderson, Mark M., Dundee.
Herold, Richard A. J., Salisbury.
Hildred, Ann B., Thatcham.
Hill, Arthur E., Jersey, C.I.
Hilton, Barbara W., Riverside, Ca, U.S.A.
Hinchliffe, Stanley E., Queensland, Australia.
Hitchman, Caroline A., Sunderland.
Hobbs, Fiona G., Winchester.
Hoi, Josephine B. S., London.
Holland-Grice, Terence H., Stoke on Trent.
Holt, Judith A., Chorley.
Howell, Lindsay J., St Aubins, Jersey, C.I.
Iacovou, Elena, London.
Ichiseki, Zenkoh, Tokyo, Japan.
Imai, Yoshiko, Tokyo, Japan.
Imashiro, Ayano, Tokyo, Japan.
Insa Sales, Juan M., Barcelona, Spain.
Ishizuka, Keiko, Kanagawa Pref., Japan.
Jacobs, Dalia, Kenton.
Jander, Margrit, Geneva, Switzerland.
Jayalath, Roshan J. D., Colombo, Sri Lanka.
Jhaveri, Prateik R., Bombay, India.
Johannessen, Penny M. F., Hong Kong.
Jones, Karen, Bangor.
Jones, Kevin P., Coventry.
Jones, Michael H., Northampton.
Jongenburger, Irma, Schoonhoven, Netherlands.
Joonoos, Roberta A., Colombo, Sri Lanka.
Jordan Figueras, Francisco, Barcelona, Spain.
Joslin, Shirley A., Hong Kong.
Juan Sampablo, Teresa, Barcelona, Spain.
Judge, Susan D., Hong Kong.
Juttmann, Gaby, Rotterdam, Netherlands.
Kai, Kock M., Hong Kong.

Kaleel, Mohamed I., Colombo, Sri Lanka.
Kaller, Douglas, New York, U.S.A.
Kallner, Anders B., Johanneshov, Sweden.
Kamioka, Hitomi, Tokyo, Japan.
Karan, Dorothy C., Ras Tanura, Saudi Arabia.
Kawamoto, Midori, Tokyo, Japan.
Kenny, Alice, Liverpool.
Kirstein, Mark H., Eastbourne.
Kittel, Gerhilde A., Toronto, Ont., Canada.
Knight, Norman H., New Milton.
Kobesen, Johannes B. A., Amstelveen, Netherlands.
Kochhar, Narinder J. S., London.
Kol, Elizabeth A., Schoonhoven, Netherlands.
Kong, Grace W. F., Hong Kong.
Koopman, Peter P., Ryn, Netherlands.
Koster, Anita, Schiedam, Netherlands.
Kotila, Brian W., Don Mills, Ontario, Canada.
Krieger, Sabine M., Stockholm, Sweden.
Krot, Carine, Amsterdam, Netherlands.
Kruithof, Pieter, Amsterdam, Netherlands.
Kuehn, Wolfgang, Surrey, B.C., Canada.
Kumar, Jain J., Delhi, India.
Labastire, Sylvie, London.
Lai, Christina C. K., Hong Kong.
Lambert, Zahava, Willowdale, Ont., Canada.
Langdon, Ingrid, Corpus Christi, Texas, U.S.A.
Lapiccirella Galbiati, Franca, Florence, Italy.
Larson, Len, Thornton, Colo, U.S.A.
Lau, Rosanna W. Y., Hong Kong.
Lau, Yun W., Hong Kong.
Law, Tai S., Hong Kong.
Layhe Cook, Judith A., Warwick.
le Pavoux, Angela D., St Saviour, Jersey, C.I.
Leatham, Claire, Wakefield.
Lee, Chiu W. F. T., Hong Kong.
Levi, Mandy S., Birmingham.
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EXAMINATIONS 1985

The examination dates for 1985 are as follows:

Gem Diamond Examination:

Theory and Practical: Monday, 10th June

Examinations in Gemmology:

Preliminary (Theory): Tuesday, 25th June

Diploma: Theory, Wednesday, 26th June

Practical, Thursday, 27th June (in London the practical examination may be held on other days in that week)

The *last* date for receiving examination entry forms is 31st March.

THE FELLOWSHIP—F.G.A.

It has come to the notice of the Association that a number of candidates who have been successful in the Diploma Examination and received the Association's Diploma in Gemmology have been describing themselves as F.G.A. when they are not entitled to do so. It should be clearly understood that the holder of the Association's Diploma is not automatically entitled to the Fellowship and should not be described as F.G.A. unless he or she has applied for and been elected to the Fellowship and has paid all subscriptions up to date.

CANADIAN GEMMOLOGICAL ASSOCIATION—FIRST GRADUATION CEREMONY

On Friday, 19th October 1984, the Canadian Gemmological Association held its first Graduation Ceremony at the Central Technical School in Toronto. Dr Warren Boyd presided and almost two hundred people were present.

An Honorary Fellowship was awarded to Dean S. M. Field, F.G.A., who was a founder member of the Association and its first President. Mr Harry Wheeler, F.G.A., Vice-President of the G.A. of G.B., was also awarded an Honorary Fellowship for the help and assistance given to the Canadian Association enabling it to set up its own examinations in gemmology.

Mr Wheeler then introduced Mr Eric Bruton, F.G.A., who gave a most interesting talk on diamonds.

Afterwards the D.S.M. Field Gold Medal was awarded to the top students of the year in the First Year Course, Mr A. J. Lewis (1983) and Mrs G. A. Kittel (1984). The W. D. Goodger Award to the top student of the Second Year Course was presented to Mr A. J. Lewis. Then Mr Harry Wheeler handed out British Diplomas to those Canadian candidates who had qualified in the 1984 examinations.

Finally F.C.Gm.A. Diplomas were presented to 1984 candidates who had qualified in the first Diploma examination held by the Canadian Association, followed by the award of Special Diplomas to members of the Canadian Association who had qualified in earlier years in examinations held by the G.A. of G.B., G.I.A., G.A.A. or the German G.A.

Mr W. D. Goodger closed the evening by thanking Eric Bruton and Harry Wheeler for coming to Toronto for the event and everyone else for being present to make the evening such a success.

ASIAN INSTITUTE OF GEMMOLOGICAL SCIENCES

The A.I.G.S. has announced a number of courses in January, February and March 1985. For particulars of courses and other information apply to AIGS Registrar, 987 Silom Road, Rama Jewelry Building, 4th Floor, Bangkok 10500, Thailand.

LETTER TO THE EDITOR

From Peter J. Crowcroft, Ph.D.,
Hong Kong.

Dear Sir,

Several years ago the *Journal* published an article of mine which examined the Beilby flow theory of gemstone polishing (J. Gemm., 1981, XVII (7), 459-65). The Beilby theory has been passed down uncritically through the gemmological textbooks over the last thirty years as the mechanism by which the polishing process occurs. My article showed that the theory is false and that this had been proved conclusively in the 1950s and 1960s. Two groups of workers at that time published detailed scientific papers which specifically examined the theory and concluded that there was no evidence at all to support it. None of this, however, has ever appeared in the gemmology texts or journals. After I finished the Beilby paper I started to examine the texts in more detail on other topics. I soon realized that many things in them were substantially out-of-date or, in some cases like Beilby, wrong. No matter where you looked one could easily find a topic for a paper to bring it up to date.

I concluded that the most recent editions of the traditional gemmology texts* are written at a level of scientific knowledge and philosophy of the 1950s. Gemmology is certainly one of the most multi-disciplined of the sciences: physics, chemistry, geology with some botany and zoology are represented. However, gemmology texts have recognized virtually none of the vast explosion of knowledge which has taken place in each of these fields over the past thirty years. It is incredible to realize that the traditional texts contain no references to any scientific journals and papers. They only reference other gemmology texts and journals which are in a similar state.

So then, if the texts are out of date, what is the status of gemmology today if one looks for progress in its component sciences? The answer is very good. Consider the following journals (to name just eight out of over at least fifty):

Nature
Science
The American Mineralogist
Canadian Mineralogist
Physics & Chemistry of Minerals
Journal of Materials Science
Neues Jahrbuch für Mineralogie Abhandlungen
Applied Spectroscopy

In these journals are to be found literally hundreds of articles over the past twenty years dealing with such items as the origin of colours in sapphire, tourmaline, beryl, emeralds, fluorites and kyanites, the crystal structure and physical properties of topaz, the structure and chemistry of garnets, a crystal and chemical study of kornerupine, the chemistry of amber, the origin of tektites, and so on. These papers use the latest instrumentation, for example, Mossbauer, x-ray fluorescence, infrared and Raman spectroscopy, nuclear magnetic and electron paramagnetic resonance, electron microprobe microscopy, etc. Implicit in these papers are the analysis and discussion of the results in terms of currently accepted scientific theory and

*The Gemmology texts I have used are *Gems, Gemmologist's Compendium* and *Practical Gemmology* by Webster, *Handbook of Gem Identification* by Liddicoat and the recent *Beginners Guide to Gemmology* by Read.

philosophy—for example, general molecular orbital theory, structure of the solid state, crystallography, classic geometric and physical optics, classic electromagnetic theory. As a result of this work the crystal structure, chemistry, optical properties, origin of colour, correlation of structure to spectra, luminescence, etc. for minerals and crystalline solids are basically known and understood.

Thus I believe the challenge for gemmology in 1985 is clear. Gemmology needs to be modernized. This is not because of some abstract search for truth, but it is a very practical requirement, which must take place if gemmologists are to face the new developments such as heat-treated, irradiated and the latest synthetic gem materials. One cannot face these products of the 1980s with the knowledge and methods of an earlier era. Not to modernize could well lead to a loss of confidence by the public in gemmology. There is nothing to be afraid of in this modernization. There is not one theory, technique or concept mentioned above which cannot be explained in a technically correct, easily understandable and nonmathematical manner. There is in fact one excellent example of the type of upgrading and education process I am calling for. This is the work over the past few years by Kurt Nassau. What I am advocating is for a 'Nassau' to be done on the rest of gemmology.

Yours etc.,
Peter Crowcroft.

5th December, 1984
1302 World Trade Centre, Causeway Bay, Hong Kong.

CORRIGENDA

On p.269 above, in line 3, for 'Revista' read 'Rivista'

On p.272 above, in line 21, for 'such clean' read 'such inclusions in clean'

On p.275 above, in line 6, for 'taaféite' read 'taafféite' and, in lines 7 and 8, for 'taffeite' read 'taaffeite'

On p.279 above, in line 24, for 'is was' read 'this was (or is)'

On p.282 above, in line 32, for 'deviethods' read 'devising methods'

On p.287 above, in line 8, for 'until the War' read 'until 1937, when he married,'

On p.288 above, in line 3 from bottom, for 'Rudoe' read 'Ruhoe'

In Vol. XVIII, at head of pp. 782-816 (even numbers), for 'XVII' read 'XVIII'

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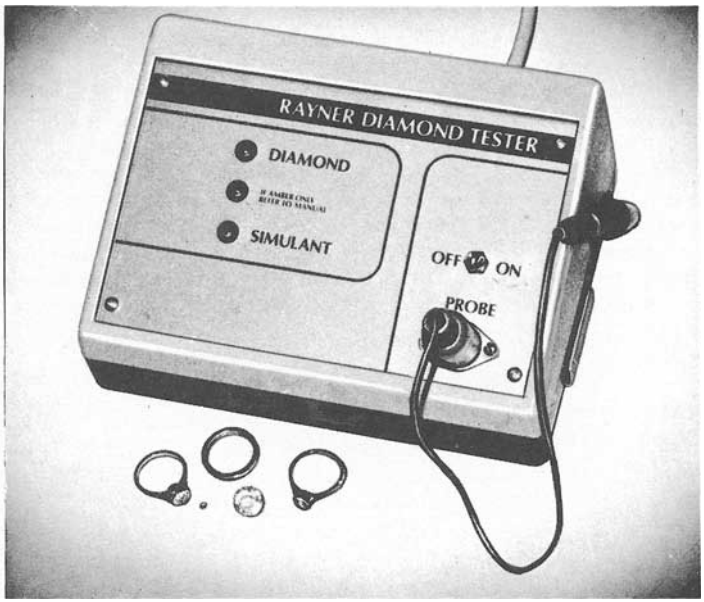

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Historical Note

The Gemmological Association of Great Britain was originally founded in 1908 as the Education Committee of the National Association of Goldsmiths and reconstituted in 1931 as the Gemmological Association. Its name was extended to Gemmological Association of Great Britain in 1938, and finally in 1944 it was incorporated in that name under the Companies Acts as a company limited by guarantee (registered in England, no. 433063).

Affiliated Associations are the Gemmological Association of Australia, the Canadian Gemmological Association, the Gem and Mineral Society of Zimbabwe, the Gemmological Association of Hong Kong and the Gemmological Association of South Africa.

The *Journal of Gemmology* was first published by the Association in 1947. It is a quarterly, published in January, April, July, and October each year, and is issued free to Fellows and Members of the Association. Opinions expressed by authors are not necessarily endorsed by the Association.

Notes for Contributors

The Editor is glad to consider original articles shedding new light on subjects of gemmological interest for publication in the *Journal*. Articles are not normally accepted which have already been published elsewhere in English, and an article is accepted only on the understanding that (1) full information as to any previous publication (whether in English or another language) has been given, (2) it is not under consideration for publication elsewhere and (3) it will not be published elsewhere without the consent of the Editor.

Articles published are paid for, and a minimum of 25 prints of individual articles may be supplied to authors provided application is made on or before approval of proofs. Applications for prints should be made to the Secretary of the Association—not to the Editor—and current rates of payment for articles and terms for the supply of prints may be obtained also from the Secretary.

Although not a mandatory requirement, it is most helpful if articles are typed (together with a carbon copy) in double spacing on one side of the paper, with good margins at sides, top and foot of each page. Articles may be of any length, but it should be borne in mind that long articles are more difficult to fit in than short ones: in practice, an article of much more than 10 000 words (unless capable of division into parts or of exceptional importance) is unlikely to be acceptable, while a short note of 400 or 500 words may achieve early publication.

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GEMMOLOGICAL ASSOCIATION OF GREAT BRITAIN
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THE JOURNAL OF GEMMOLOGY
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Vol. XIX No. 6 APRIL 1985

SOME ASPECTS OF IDENTIFICATION OF KASHAN SYNTHETIC RUBIES

By ULRICH HENN, Dip.Min. and HANS-WERNER SCHRADER, Dip.Min., F.G.A.

Institut für Edelsteinforschung, University of Mainz, W. Germany.

ABSTRACT

Synthetic rubies by Kashan are characterized by inclusions of melt residues. Cryolite was used as flux. The inclusions can be divided into four types. Even in samples looking apparently free of inclusions, these inclusions can be found by microprobe analysis (15 samples). The increased amounts of sodium found with the help of neutron activation analysis (NAA) in two analysed samples are caused by these inclusions of cryolite.

INTRODUCTION

The continual progresses and improvements of the production of synthetic gemstones need always new methods for identification against their natural counterparts, if the criteria for distinction, used up to now, are not sufficient or existent any longer.

As one can imagine, the criteria of identification of a particular synthetic gemstone are not always or totally published in order to avoid the possibility that the producer of this synthetic gemstone may modify the method of growing the crystals, for example by eliminating certain characteristic impurities.

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On the other hand facts which are typical for the method of synthesis of this material and therefore cannot be altered or be prevented, such as, for example, the alterations of the trace elements in flux-grown emeralds (Schrader, 1981, 1983), can be published. The authors of this paper will try to sum up some of the facts on the Kashan synthetic rubies now being offered in a high percentage in the market.

SYNTHESIS OF RUBIES

The development of modern synthetic rubies started after the first successful attempts with flux-fusion synthesis for emeralds. Until then only the easily perceptible synthetic rubies made by the Verneuil process were of considerable importance. Also attempts in the hydrothermal process, developed by the German chemist, Professor Dr Nacken, in the thirties, failed to arouse any commercial interest.

The first method to produce modern synthetic rubies under commercial conditions was flux-fusion synthesis by Carroll F. Chatham from San Francisco at the beginning of the sixties. Investigations proved that he added lithium-molybdates to bring down the temperature of crystallization. Some scientists (Kleber & Fehling, 1965; Arlett *et al.,* 1967; Watanabe & Sumiyoshi, 1974) have been successful in this field by using cryolite.

In 1968 the first synthetic rubies grown from cryolite melts came on the gem-market. These synthetic rubies were produced by Ardon Associates in the United States and have been offered as 'rubies grown by Kashan'.

INCLUSIONS

In spite of the addition of cryolite as crystallizer the temperature of crystallization still reached 892°C to 1041°C (Watanabe & Sumiyoshi, 1977). Therefore only melting residue and perhaps some particles of the crucible and no fluids can be detected as inclusions in the synthetic rubies by Kashan. Investigations done by microprobe analysis proved beside cryolite (Gübelin, 1982) also an alumina phase as part of these heterogeneous melting residues.

If recognizable, these melt residues are typical for synthetic rubies by Kashan. They have been found in different types:

—feathers: these feathers are familiar in their order, their torsion and their mesh-like network.

FIG. 1. Feather of melt residue inclusions in a synthetic Kashan ruby. (65 ×)

—fingerprint inclusions: this kind of inclusion was believed to be a characteristic of natural rubies, mainly from Burma, but Crowningshield (1968) and (Burch 1984) described them in Kashan synthetic rubies too.

—string of pearl-like inclusions: these isolated, threaded-looking inclusions have been seen neither in natural nor in other synthetic rubies up to now.

—comet- or hairpin-like inclusions: these inclusions have been described sometimes (Anderson, 1981; Gübelin, 1982, 1983) to be a typical mark of identification. They occur like a 'V', like rutile, or parallel, like growth striae. But they have been seen now in a fibrous marking, as known with byssolite in garnets, too.

Because all of the inclusions of these kinds are chemically identical and are formed according to the different speed of crystal growth of the host crystal, they all show the same marks of identification. These melt residues appear in brightfield illumination in the microscope nearly opaque and homogeneous, occasionally semitranslucent. In darkfield illumination the strong relief and the heterogeneous, granular character and even a typical metallic reflection are visible.

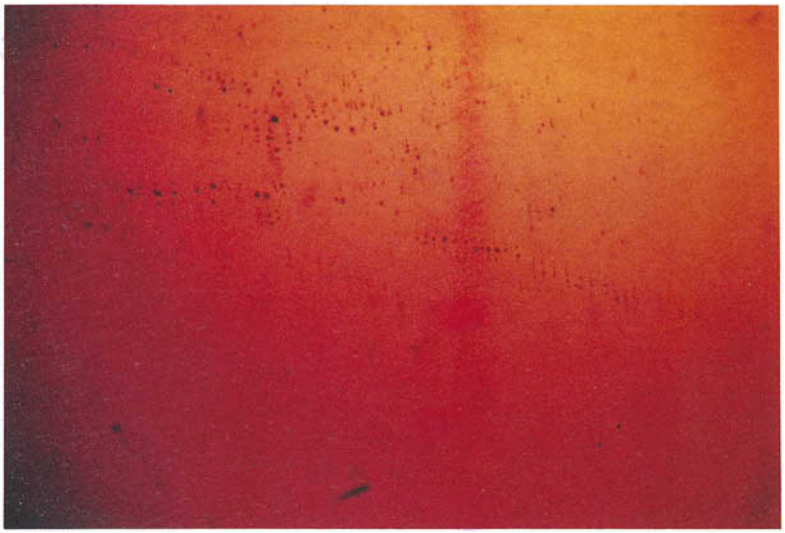

FIG. 2. String of pearl-like inclusions of melt residues in a synthetic Kashan ruby. (18 ×)

FIG 3. String of pearl-like inclusions of melt residues in a synthetic Kashan ruby. (50 ×)

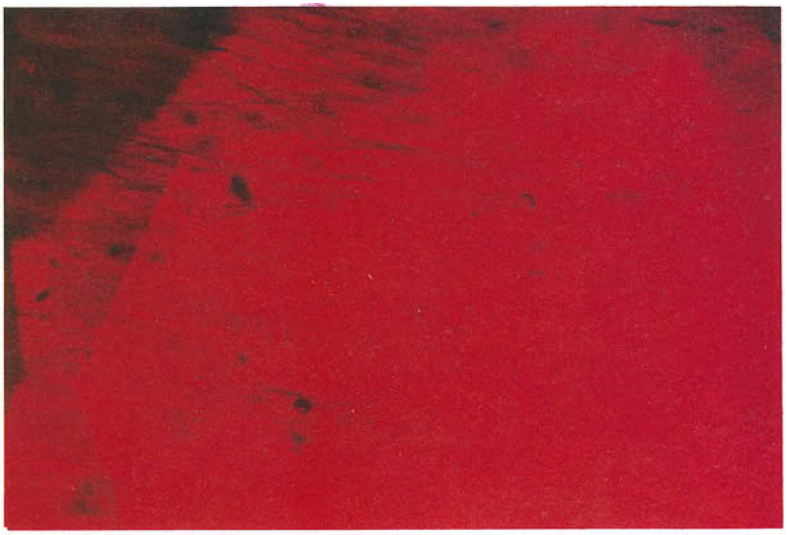

FIG. 4. Comet- or hairpin-like melt residue inclusions in a synthetic Kashan ruby. (28 ×)

FIG. 5. Comet- or hairpin-like melt residue inclusions in a synthetic Kashan ruby. (50 ×)

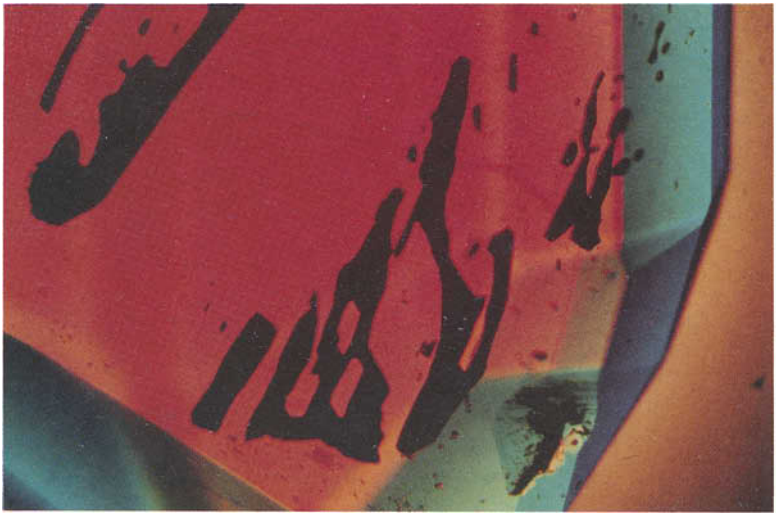

FIG. 6. Melt residues as inclusions in a synthetic Kashan ruby. (28 ×, brightfield illumination)

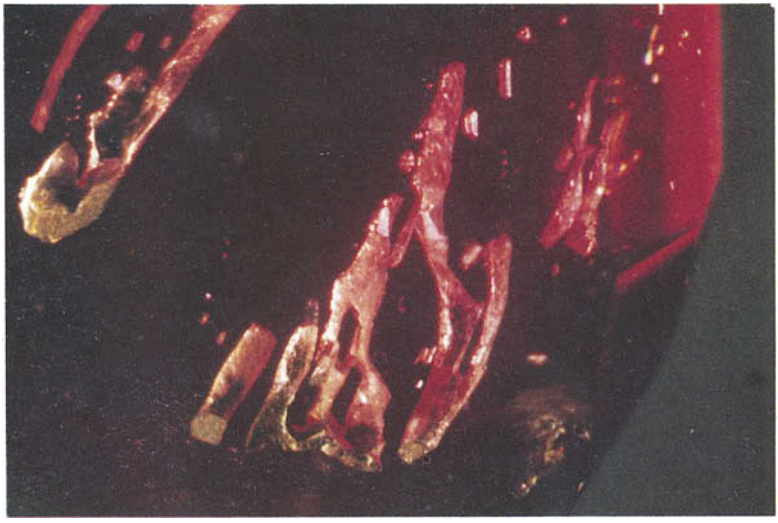

FIG. 7. Melt residues as inclusions in a synthetic Kashan ruby. (28 ×, darkfield illumination)

Unlike a fluid inclusion, the *whole* melt-residue inclusion in flux-grown synthetics may be seen in a reflecting position if moved under the microscope.

CHEMICAL RESULTS

Clearly the identification of gemstones free of any inclusion proves to be difficult. Because of the good results with the analysis of trace elements for distinction (Schneider, 1977; Schrader, 1981, 1983; Hänni, 1982; Kuhlmann, 1983) the Kashan synthetic rubies were determined by neutron activation analysis. From the results, shown in Table 1, a distinctly increased sodium content in Kashan synthetics compared to natural rubies from different occurrences is found.

Apparently these results were not comparable with those of the electron microscope analysis. But the essentially better possibilities of magnification with the microprobe analysis in comparison with the normal (gem) microscope showed that none of the tested synthetic rubies were free of inclusions using a suitable magnification and that always in a statistical distribution submicroscopic inclusions of melt residue have been recognized.

Caused by the system of working, neutron activation analysis reveals the chemistry of the whole sample, and the sodium contents coming from the cryolite inclusions became part of the analysis. With the microprobe analysis it was possible, but only under a higher limit of detection, to find and to analyse sectors sufficiently free of inclusions. These results show no, or hardly increased, sodium contents at the surface.

But, for distinction from natural rubies, in all Kashan synthetic rubies tested very small inclusions of cryolite have been found and analysed. Therefore microprobe analysis makes possible the separation of Kashan synthetic rubies which appear to be free of inclusions. Increased sodium contents of the samples point to the existence of inclusions of cryolite caused by the flux method for synthesis.

ACKNOWLEDGEMENTS

The authors wish to express their thanks to the firm of Gebrüder Goerlitz, Idar-Oberstein, for kindly placing the rubies at their disposal.

TABLE 1

Neutron activation analyses of natural and synthetic rubies (in ppm)

	1	2	3*	4*	5*	6*	7*	8*	9*	10*
Na	410	2631	59	60	60	58	60	69	78	105
Cr	1296	329	4930	2884	957	3125	6484	1858	2297	1436
Mn	0.9	1	3	0.5	0.1	0.1	0.3	0.1	12	0.7
Fe	11	—	<50	3428	86	2278	2232	272	188	818
Ga	—	. 5	1	23	108	29	22	296	145	72

sample No. 1, 2: Kashan synthetic ruby (flux-grown)
sample No. 3 : Chatham synthetic ruby (flux-grown)
sample No. 4 : Ruby from Burma
sample No. 5 : Ruby from Sri Lanka
sample No. 6 : Ruby from Thailand
sample No. 7 : Ruby from Tanzania
sample No. 8 : Ruby from Kenya
sample No. 9 : Ruby from Pakistan
sample No.10 : Ruby from Madagascar

*Analyses from Schneider, 1977.

TABLE 2

Electron microprobe analyses of Kashan synthetic rubies (in wt %)

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Al_2O_3	96.93	96.64	96.73	95.63	94.79	94.92	95.33	95.86	96.24	95.19	95.56	95.59	96.82	95.64	95.46
Na_2O	0.01	0.01	0.01	0.01	0.01	0.02	n.d.	0.01	n.d.	n.d.	0.01	0.01	n.d.	n.d.	n.d.
SiO_2	n.d.	0.02	0.01	0.03	n.d.	0.01	0.02	0.02	0.03	0.01	0.01	0.01	0.01	0.01	0.03
V_2O_5	0.01	0.01	0.08	0.04	0.03	0.02	0.03	0.02	0.02	0.05	0.05	0.05	0.03	0.06	0.06
Cr_2O_3	0.06	0.10	0.10	0.30	0.22	0.26	0.70	0.13	0.32	0.58	0.43	0.55	0.12	1.50	1.10
MnO	0.03	0.01	0.01	n.d.	0.01	0.04	0.02	0.01	0.01	0.07	n.d.	0.02	0.01	0.02	0.02
FeO	0.03	0.07	0.03	0.03	0.03	0.05	0.03	0.01	0.06	0.03	0.02	0.01	0.01	0.03	0.01
CoO	0.01	0.01	0.02	n.d.	n.d.	0.01	0.01	n.d.	n.d.	0.01	0.02	0.01	0.01	0.02	0.01
NiO	0.02	0.03	0.03	0.01	0.01	0.02	0.02	0.02	n.d.	0.02	n.d.	0.04	0.01	0.05	0.01
MgO	0.01	0.01	n.d.	n.d.	0.01	n.d.	n.d.	0.01	0.01	n.d.	0.01	0.01	0.01	0.01	n.d.
Total	97.11	96.91	97.02	96.05	95.11	95.35	96.16	96.09	96.69	95.96	96.09	96.30	97.03	97.34	96.71

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POLYSYNTHETIC TWIN LAMELLAE IN SYNTHETIC VERNEUIL SAPPHIRE

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INTRODUCTION

The writer was intrigued recently, by a 2.35 ct 'native' brilliant-cut stone whose unnaturally intense colour, although attractive, looked not quite right but similar to that of treated sapphires. Since some genuine and synthetic sapphires are known to have their colour enhanced by treatment[1] and since of all the characteristics that permit distinction colour is the least dependable, the stone had to be tested.

EXAMINATION UNDER 10× LENS

Except for a few straight and parallel twinning lines, the stone looked particularly clean. Careful inspection of the girdle did not reveal the characteristic pockmarked 'double girdle' indicating possible heat treatment.[1] The colour, while the stone was immersed in methylene iodide, appeared to be concentrated near the surface, and this is an indication of possible treatment.[1]

ABSORPTION SPECTRUM

The diagnostic iron absorption line at approximately 4500 Å was missing when the stone was observed visually both in transmitted and scattered light on a Gem Beck spectroscope unit.

FLUORESCENCE

With the GAAJ Multispec combined LW/SW unit, under UV 2536 Å and UV 3650 Å, the stone remained inert.

EXAMINATION UNDER THE MICROSCOPE

The stone immersed in methylene iodide was observed on a horizontal Eickhorst stand between crossed polaroids coupled to a Gemolite Bausch & Lomb Mark V microscope, and revealed very easily the straight twinning striations that were observed with the 10× lens (Figures 1, 2, 3).

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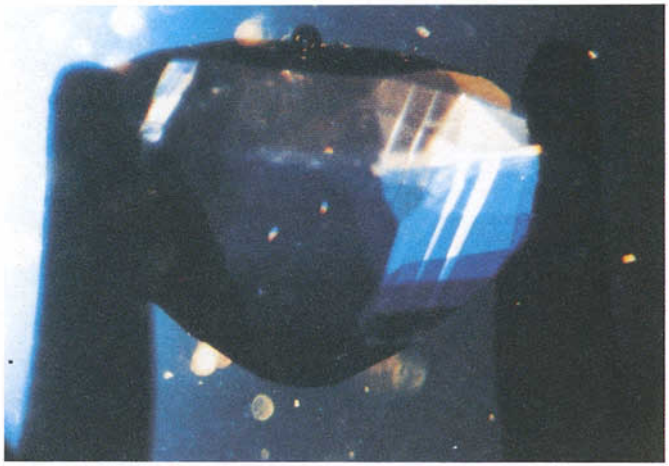

FIG. 1. Side view

FIG. 2. Pavilion view

FIGS 1, 2. Straight twinning striations as they appeared under the microscope when the stone was immersed in methylene iodide.

FIG. 3. Polysynthetic twin lamellae in Verneuil synthetic with interference rings along the twin planes as seen while the stone was immersed in methylene iodide between crossed polaroids. (15 ×)

FIG. 4. 'Plato striation' obtained parallel to the *c* axis while the stone was immersed in methylene iodide between crossed polaroids in their dark position. (15 ×)

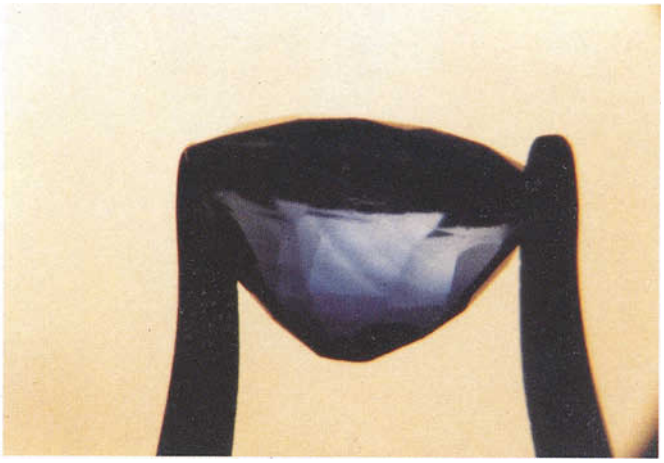

FIG. 5. Curved colour-bands made visible when the stone was immersed in methylene iodide with diffused light source. (15 ×)

It should be noted here that with crystal inclusions, healing planes filled with liquid drops and zonal effects in straight lines, polysynthetic twin lamellae are regarded as one of the characteristics of genuine corundum.* This twinning occurs frequently in ruby, but less so in sapphire.[2] They are also seen, but infrequently and rather as an exception, in their respective Verneuil synthetics.[3,4,5,6] Since this particular sapphire showed no other characteristic but these twinning lines, it was decided while still under crossed polaroids, and in their dark position, to locate the direction of the optic axis of the stone, and try to obtain the lozenge-shaped pattern which is originated by two sets of straight twinning lamellae intersecting each other at 120° and 60° and known as the 'Plato striation'.[5]

The Plato striation effect which betrays 'Verneuil synthetics' was obtained as can be seen in Figure 4. As for the curved coloured bands, these were seen with difficulty, only when the stone was immersed in methylene iodide and the light source masked by a tissue paper (Figure 5).

*Syntheses different from Verneuil's (Knischka, Chatham, Kashan, . . .) can show 'similar' characteristics to those mentioned for natural corundum, and this has to be taken into account if errors of judgement are to be avoided.' [5]

DISCUSSION

The origin of the 'real' polysynthetic twinning must be due to a different phenomenon from the Plato twinning since it does not follow the same direction as can be seen in Figures.1, 2, 3.

These polysynthetic twin lamellae seem to be found in planes slightly inclined to the optic axis. Since this faceted stone does not show crystalline faces, it would be hazardous to guess the precise orientation of the plane containing these twin lamellae. Up to now, all Verneuil synthetics tested by the writer have shown a positive Plato striation, while only this particular synthetic sapphire showed 'real' polysynthetic twinning very similar to that found in natural corundum. Therefore, great care should be taken to obtain either the coloured curves or a Plato striation when such a stone is encountered, if costly mistakes are to be avoided.

Other synthetics, like Kniscka, Chatham, Kashan, . . . and the Ramaura flux ruby, are said to be devoid of this form of 'true' twinning which can be followed deeply inside the gem[7,8,9] (Figure 3).

As for the colour, it was not possible for the writer to test the stone's reaction to re-polishing, but since it did not show the usual characteristic chalky bluish-green glow under short-wave ultraviolet light, and the colour seemed to be concentrated near the surface, it could possibly have been surface diffusion treated.

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A 'THREE-PHASE INCLUSION' IN AN EMERALD FROM SOUTH AFRICA

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Surprises are still possible in specimens from well known occurrences. Some little time ago in a cabochon emerald an unexpected inclusion was found. The occurrence of the emerald, said to be the Cobra Mine* in South Africa, was recognizable by the totality of the inclusions, even though one of the inclusions observed was unexpected and unusual in a South African emerald.

A so called 'three-phase inclusion' was found, such as has been described mainly for Colombian emeralds up to now. Such an inclusion contains, despite its slightly misleading designation (as Gübelin has pointed out), not unconditionally three phases of one substance in the physical-chemical sense, but three substances in different states of aggregation. That means that this inclusion contains the three different substances within it in the three different states of aggregation respectively, namely the gaseous, the liquid and the solid (crystalline) states. In a long, needle-like cavity, a primary inclusion, a gas bubble is included in a liquid (as in a spirit level), together with a cubic crystal.

This observation is unusual in so far as the origin of such inclusions seems to be tied to hydrothermal emerald occurrences. But the South African deposits are described as being of a pegmatitic-pneumatolytic kind and are marked by mica plates, as also in this case.

Although the author remembers a similar observation some years ago, it has not been reported yet, so this seems to be the famous 'exception that proves the rule'. But this exception is not inconceivable, for there are fluent transitions from one phase of the crystallization of magma to another.

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*See Webster's *Gems*, 4th edn (revd B. W. Anderson), 1983, p.110.—Ed

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FIG. 1. Needle-like cavity with a liquid, a gas bubble and a crystal, forming a 'three-phase-inclusion' in a South African emerald (400 ×)

NOTE ON INCLUSIONS IN DIOPSIDE FROM ALA, PIEDMONT, ITALY

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A slightly yellowish green crystal of diopside from an old collection and clearly labelled as coming from Ala, Piedmont, Italy, was recently sent for faceting. The cut gemstone proved to have, in addition to the normal rod like inclusions seen in diopside, inclusions of a type not previously observed in diopside by the author nor apparently described in the literature. The latter occur as extensive curved swirls and veils (Figure 1) which mainly consist of two sets of multiple small parallel two- and three-phase, predominantly euhedral, negative inclusions (Figure 2). Of these sets, one orientation is dominant, the others' presence being minor or in some cases absent altogether. The size of these small inclusions is variable, ranging from 100 to 10 μm. The inclusions are almost certainly pseudosecondary in origin, that is, they are healing fissures formed in the crystal during its growth in the parent fluid. This is deduced from observed necking-down features (Figure 3), connecting tubes and trails (Figure 4), and in addition the orientations of the negative crystals follow crystallographic directions and there is optical continuity, under crossed polars, between the host and the immediate surrounds.

Using a freezing microscope stage, a study of the fluid inclusions was made. A specially prepared sample was frozen to −70°C and then slowly brought up to room temperature. At −37°C the gas bubble contracted and all the liquid froze into a coarse-grained solid. At −36°C partial melting occurred along the grain boundaries and cracks began to appear. This condition persisted until −8°C when further melting occurred. At −1.9°C all the frozen liquid phases had melted. The temperatures at which phase changes took place indicated that the liquid was a saturated mixed saline brine, the major salt being NaCl with only a very minor amount of $MgCl_2$ (Hollister & Crawford, 1981). The isotropic cubic daughter-crystals in the three-phase inclusions are therefore thought to be halite. It was interesting to note that some of the two-phase

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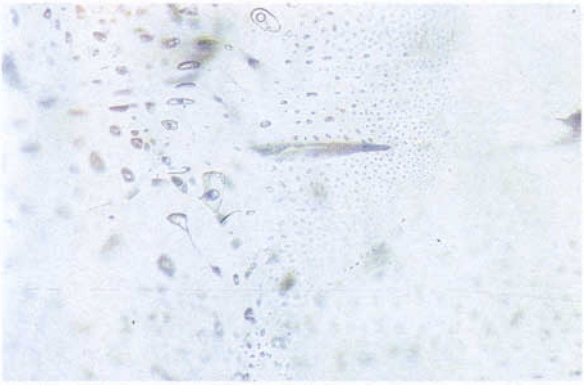

FIG. 1. Curved swirls and veils.

FIG. 2. Parallel alignment of two- and three-phase negative inclusions.

FIG. 3. Necking-down feature.

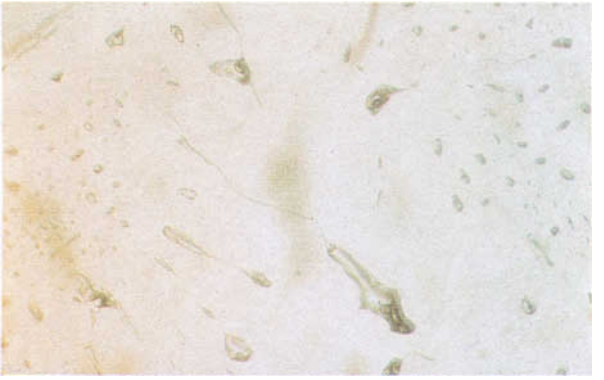

FIG. 4. Connecting tubes and trails.

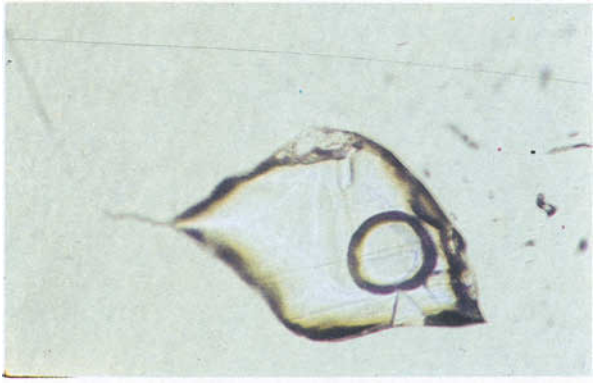

FIG. 5. Some unidentified daughter crystals.

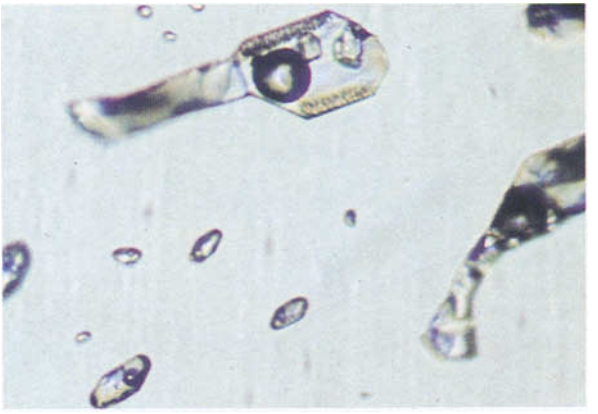

FIG. 6. 'Bearding' lining and negative inclusion.

inclusions when frozen resulted in the nucleation of the stable phase; NaCl crystals. This is due to the withdrawal of water from the solution, thus increasing the degree of supersaturation (Roedder, 1972). Once nucleated, the solid phase persisted.

Several types of unidentified anisotropic microlites are also present in some negative inclusions. These take the form of triangular and prismatic crystals (Figure 5). There is also an unidentified fibrous mineral that forms 'bearding' around the inside of some of the negative inclusions (Figure 6).

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SPECTROPHOTOMETRIC MEASUREMENTS OF FACETED RUBIES

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Spectrophotometric measurements have been proved to be useful for the identification and distinction of natural and synthetic gemstones (Schmetzer & Bank, 1980; Bosshart, 1982). As most of

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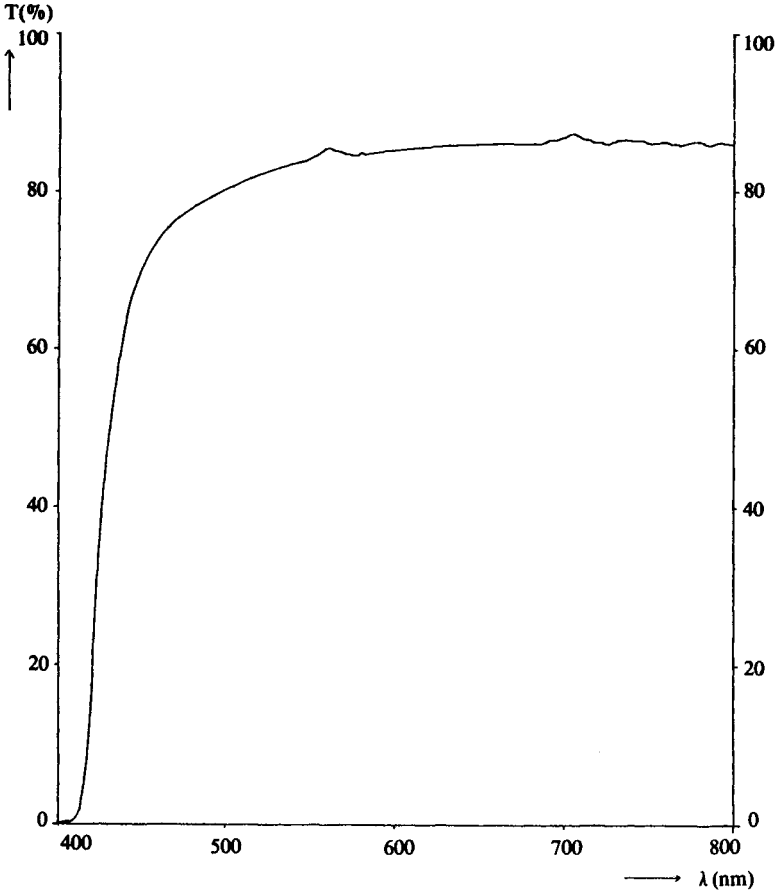

FIG. 1. Transmission diagram of methylene iodide.

the spectral measurements are carried out on thin polished platelets, the results achieved cannot be easily reproduced in the case of faceted gemstones (due to scattering and multiple reflection). The purpose of this short communication is to show how the spectrophotometric method can be applied to faceted gemstones.

In order to eliminate the 'disturbing' factors due to scattering, reflection and refraction, an immersion method has been used and thus the ray of transmitted light passing through the gemstone could be directly measured. The method has been sucessfully tried on faceted rubies.

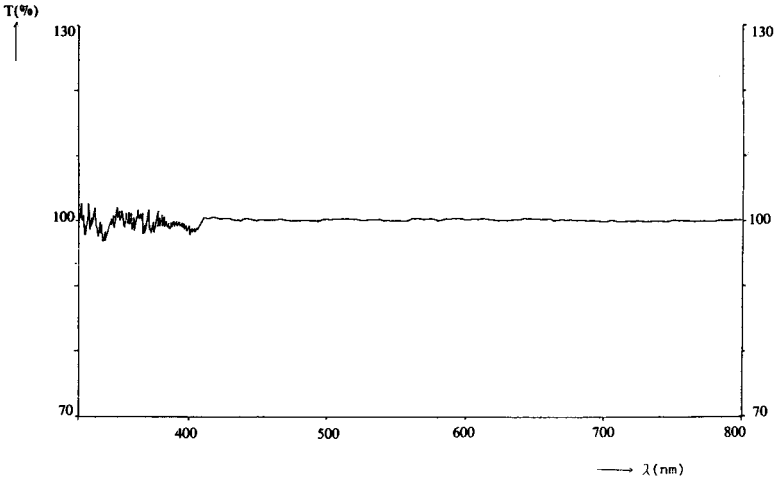

FIG. 2. Transmission diagram after the auto-zero cycle.

The rubies were fixed in a sample holder in an immersion cell filled with methylene iodide (diiodomethane): see Figure 1. The immersion cell was placed in the path of the ray of light. The measurement was performed with a double beam UV-VIS-spectrophotometer (Perkin Elmer 551 S) in the wavelength range from 400 to 800 nm. The colour of the immersion liquid was compensated for by an identical immersion cell filled with methylene iodide placed in the path of the reference beam and by the auto-zero of the spectrophotometer. Figure 2 shows the horizontal transmission curve of the immersion cell filled with

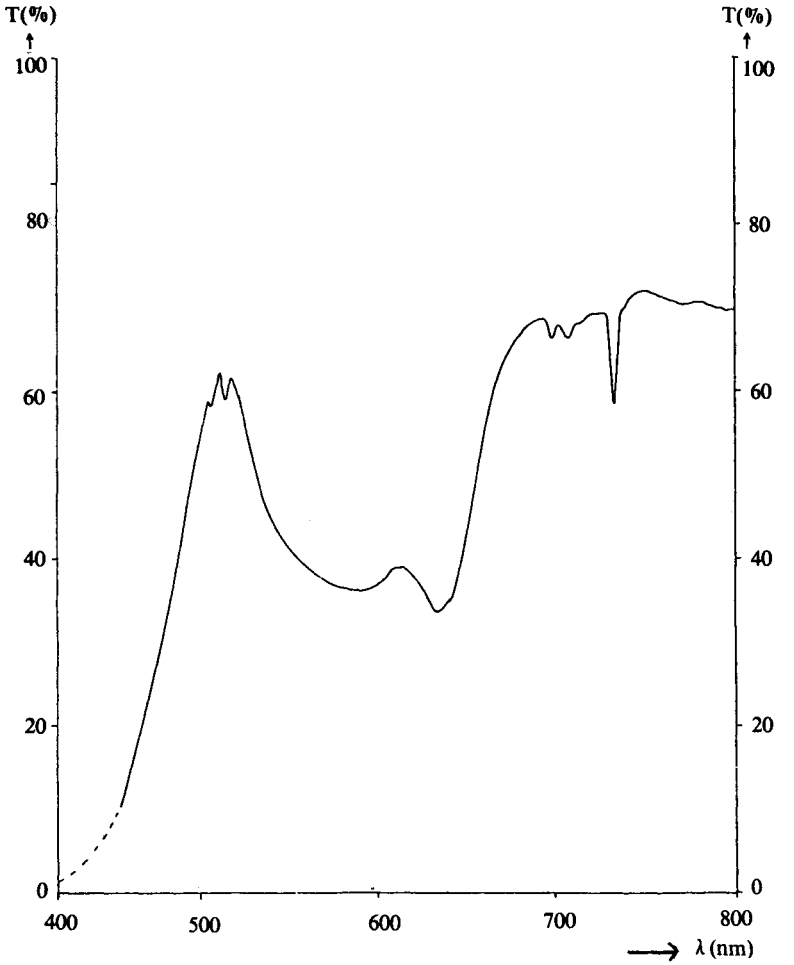

FIG. 3. Transmission diagram of a Burma ruby.

methylene iodide and without any sample after auto-zero cycle. Due to the low UV-transmission of methylene iodide no measurements could be done in the UV. Figures 3 and 4 show the transmittance curves of two rubies.

It is possible to obtain transmission measurements for other gemstones by this method.

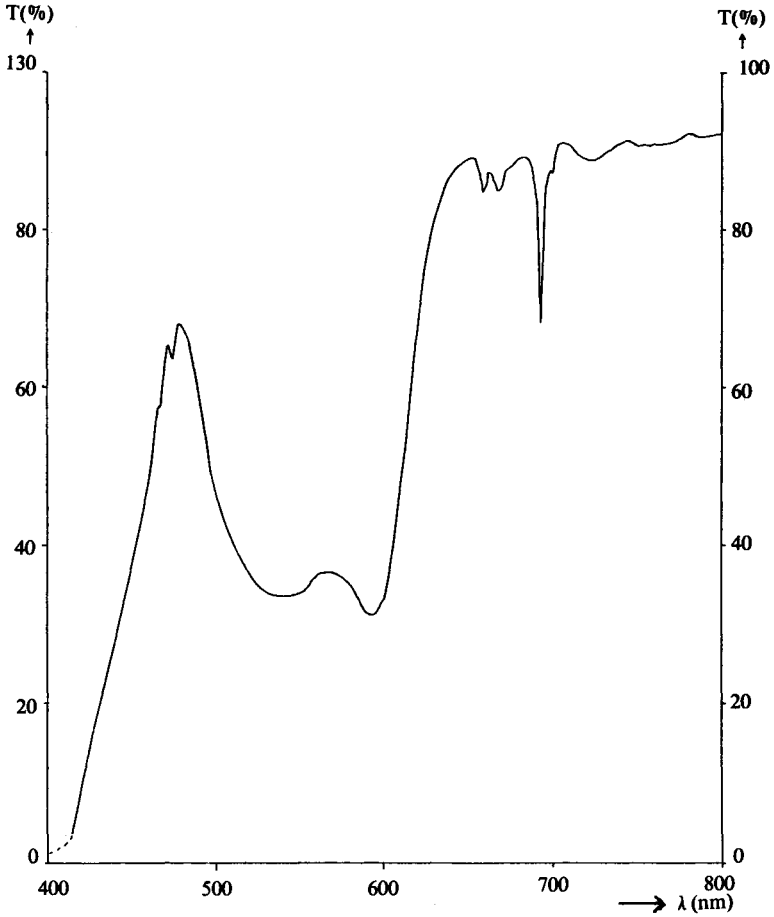

FIG. 4. Transmission diagram of a Siam ruby.

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ZINCIAN TAAFFEITE FROM SRI LANKA

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ABSTRACT

Zinc-bearing taaffeite from Sri Lanka with refractive indices of n_e 1.726, n_o 1.730, and density of 3.71 g/cm^3 is described. The gemstone contains an extraordinarily high zinc content of 4.66% ZnO; the idealized chemical formula of the sample is $Be(Mg, Zn, Fe)_3Al_8O_{16}$ with Mg>Zn, Fe. The reddish-violet colour of the specimen is caused by certain amounts of iron and chromium.

Taaffeite was first described by Anderson *et al.* (1951), and at the time of the original description, only two cut stones of the gem mineral were known, most probably originating from the alluvial gem deposits of Sri Lanka. Until 1974, only two additional cut taaffeites became available; however, Sri Lanka as the most probable origin of the gems was confirmed. During a reinvestigation of the crystal chemistry and structure of the taaffeite group consisting of the minerals taaffeite, musgravite and pehrmanite, 14 cut gemstones and one small fragment of rough taaffeite from Sri Lanka were available to one of the authors for investigation in 1981 and 1982, but about 20 or even more cut taaffeites were known at that time (Schmetzer, 1983a, b, c; Nuber & Schmetzer, 1983). Until now, the authors have investigated more than 50 cut taaffeites, and more than 100 stones are known to be preserved in public or private collections or have appeared in the gem trade. At present, taaffeite from Sri Lanka is still considered as a rare gemstone; taaffeite, however, is no longer one of the rarest gem materials. Recently, one sample of rough taaffeite of gem quality was mentioned. This stone originated from Burma, probably from the Mogok region. In addition, small fragments of rough taaffeite were described from different localities such as U.S.S.R., China, and Australia (*cf.* Schmetzer, 1983a, b, c; Spengler, 1983). These taaffeites were very small and not of gemstone quality and/or size.

Taaffeite is hexagonal with unit cell dimensions of a_o 5.68, c_o 18.3 Å, and space group $P6_3mc$. Taaffeite from Sri Lanka reveals iron and zinc contents between 0.38 and 2.00% FeO and

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up to 0.66% ZnO, corresponding to a chemical formula of $Be(Mg, Fe, Zn)_3Al_8O_{16}$ with Mg>Fe and Mg≫Zn. The refractive indices, double refraction and density vary between n_e 1.717-1.720, n_o 1.721-1.724, Δn 0.004-0.005, and D 3.59-3.62 g/cm^3, respectively. The data of the Burmese gem taaffeite were given as n_e 1.716, n_o 1.720, D 3.59 g/cm^3 by Spengler (1983). Taaffeites from China and U.S.S.R. were found to contain distinct amounts of ZnO (1.89-4.27%) and MnO (0.09-3.03%). According to their somewhat higher manganese and zinc contents, the refractive indices of taaffeite from U.S.S.R. and China were found to be higher compared with the optical data of taaffeites from Sri Lanka.

In general, taaffeites of gem quality from Sri Lanka with FeO contents of about 1-2 wt% are blue or bluish-violet in colour. Some very light, almost colourless specimens with smaller iron contents (<1 wt%) are also known. Only one cut crystal of the red variety of taaffeite with chromium contents of 0.24 wt% Cr_2O_3 and vanadium contents of 0.15 wt% V_2O_3 is described, and some rose-coloured or pinkish taaffeites with smaller chromium and vanadium contents are also known. In summary, the colour of gem taaffeites from Sri Lanka is due to various amounts of iron, chromium and vanadium, and the absorption spectra of gem taaffeites are almost identical with the spectra of iron and chromium containing bluish-violet and red gem spinels (Schmetzer, 1983a).

FIG. 1. Zincian taaffeite from Sri Lanka. Size of the sample approx. 6 × 7mm. *(Photo by O. Medenbach, Bochum).*

The cut taaffeite of 1.25 ct which is described in this paper (Figure 1) has extraordinarily high refractive indices of n_e 1.726, n_o 1.730, which first drew the attention of one of the authors to the stone. The optical data were found to lie still within the range of refractive indices of taaffeites from different localities; however,

the refractive indices mentioned above, are not yet known at present for taaffeites from Sri Lanka. The colour of the sample is an intense reddish-violet, which also is unusual for taaffeites from Sri Lanka.

TABLE 1. Chemical and physical properties of zincian taaffeite from Sri Lanka.

Microprobe analysis (wt%)		cations calculated to 0 = 16		
BeO	4.40*	Be	1.003	
ZnO	4.66	Zn	0.328	2.997
FeO†	1.88	Fe	0.150	
MnO	0.06	Mn	0.005	
MgO	17.69	Mg	2.514	
Al_2O_3	71.10	Al	7.989	8.000
Cr_2O_3	0.15	Cr	0.011	
Σ	99.94			

*assumed from Schmetzer (1983a) †total iron as FeO

optical properties	n_e 1.726(1)
	n_o 1.730(1)
	Δn 0.004
density	D 3.71(2)g/cm^3

Physical and optical properties of the gemstone from Sri Lanka are presented in Table 1. The taaffeite sample was found to contain a distinct zinc content of 4.66% ZnO, which so far was not found in taaffeites from this country. The extraordinarily high refractive indices and density of the specimen are due to the unusual composition of the sample, i.e., the physical data are strongly influenced by the zinc content of the gemstone. The absorption spectrum of the taaffeite is explained by a superposition of the pure iron spectrum, which is known in detail from ordinary bluish-violet taaffeites, and the almost pure chromium spectrum, which is available to the authors from the investigation of the only known red sample with 0.24 wt% Cr_2O_3 and 0.15 wt% V_2O_3 (*cf.* Schmetzer, 1983a). The chemical data of the present sample with

1.88% FeO and 0.15% Cr_2O_3 support this interpretation. In summary, the colour of the zinc-bearing taaffeite with extraordinarily high refractive indices is intermediate between the normal bluish-violet coloration due to iron and the red coloration due to chromium and vanadium. The chemical formula of the zincian taaffeite is given as

$$Be(Mg_{2.51}Zn_{0.33}Fe_{0.15}Mn_{0.01})\,(Al_{7.99}Cr_{0.01})O_{16}$$

or idealized as

$$Be(Mg, Zn, Fe)_3Al_8O_{16} \text{ with } Mg>Zn, Fe.$$

In addition to zinc-bearing spinel, gahnospinel, which has been known for a long time from Sri Lanka (Anderson *et al.*, 1937), zinc-containing taaffeite from Sri Lanka is a second oxide mineral with an isomorphic replacement of magnesium and zinc. In both minerals, zincian spinel and zincian taaffeite, the investigation of the refractive indices will strongly indicate a distinct zinc content in any unknown not yet analysed sample. A complete solid solution between common spinel and gahnite, $MgAl_2O_4$ and $ZnAl_2O_4$, is known to exist in nature. The zincian analogue of taaffeite with the idealized formula $BeZn_3Al_8O_{16}$, however, has not yet been found.

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SOMETHING STRANGE

By R. KEITH MITCHELL, F.G.A.

I have illustrated in Figure 1 one of the most puzzling 'gem' items I have ever found. It is a composite flat plaque-like arrangement, 23 × 19mm, of concretions, most of which resemble halved pearls which have been cemented in place with their sawn side uppermost.

I say 'resemble half pearls' advisedly, for they are brownish in colour and are pearl-like only in their structure of concentric layers around a variety of nuclei. The six larger 'pearls' differ slightly in appearance and in four of them an opaque white layer is seen just below the last 'skin' or layer. The nuclei also differ and in two instances appear to be glassy—possible sand grains. All nuclei are large by comparison with those expected in normal pearls. The six large sections fluoresce white under long ultraviolet wavelengths (365 nm) but their centres are inert.

FIG. 1

In addition there are twelve smaller 'half-pearls', more baroque in shape than the large ones and with even more pronounced nuclei. These are quite brown in colour and do not

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fluoresce. One appears to have formed around a fragment of malachite. The green stone in the centre of the plaque is definitely malachite and there are twelve other mineral fragments embedded in the brown mastic used to hold them all to the base. The latter seems to be a black ceramic of some kind, since there is none of the reaction to acid one would get from black marble used, for instance, in Florentine mosaics. Some of the mineral fragments resemble banded marble and do fluoresce rather faintly. The mastic, which looks resinous and is badly cracked, fluoresces a fairly strong orange brown. The 'pearls' and marble all effervesce with acid but four half circles of brown material do not, and are probably chalcedony of some kind.

It has not been possible to identify the concentric concretions. Short of breaking the thing to examine the uncut surfaces one cannot really determine whether they are indeed unusual pearls or whether they are calculi of mammalian origin. Gall-stones have been suggested, for these form in a similar way and have a pearl-like structure. They could even be sections cut from tubular accretions such as stalagmites, but I am inclined to doubt this. The presence of fairly obviously granular centres argues against it, as does the finely grained concentric layering.

It does seem probable that the larger fluorescing sections are of different nature or origin from that of the smaller non-fluorescing ones.

There seems to be little doubt that the plaque was assembled deliberately to exhibit the marked concentric layering of its components. When new it was probably polished, but wear and age have removed the gloss from all but the harder parts, such as the enigmatical white layer in four of the larger sections, and the 'sand' grain nuclei.

For me this thing is unique. Has any reader seen anything like it? Can anyone throw light upon the 'pearls' that were used and the reason for showing them the wrong way up? The world of the surgical student is prone to a strange sense of humour and I feel that this could be in some way connected with that profession.

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A LOW-COST SPECTROSCOPE UNIT HAVING ADDITIONAL GEMMOLOGICAL APPLICATIONS

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INTRODUCTION

The spectroscope is being increasingly used as a trustworthy diagnostic aid in the characterization of both coloured gemstones and diamonds.

It would appear, however, that students and beginners often encounter difficulties in the effective use of the instrument. The most commonly-voiced complaint is that the instructor could see the spectrum of a given stone quite clearly, but that the student could not. There would probably be no such problem if all students had as much observing time as they wished using one of the many costlier spectroscope-stoneholder-illuminator table units.

The hand-held spectroscopes of both prism and diffraction types are now decreasing in price, so that more students, graduates and jewellers are able and willing to purchase them. However, it is found that the inexpensive penlights often used to 'drive' them are less than satisfactory. They do not provide enough good white light for more than a few minutes observation time. The light rapidly becomes yellower and more feeble. Whilst it requires no manipulative skill to direct the light on to the stone, some dexterity is needed to adjust the spectroscope so as to obtain a satisfyingly uniform spectrum from the light rays which leave the stone. Even when this is accomplished, there is no convenient way to stabilize the image so that other persons are able to inspect the identical spectrum.

This paper describes a spectroscope unit which overcomes these objections. At the same time, with the help of ancillary items, it provides a tool for other kinds of gemmological investigations.

DESCRIPTION OF THE BASIC UNIT

Construction.

The positions of the various components of the basic unit are shown in *Figure 1.* A photograph of the basic unit and some of the optional components is shown in *Figure 2.* The unit consists of a

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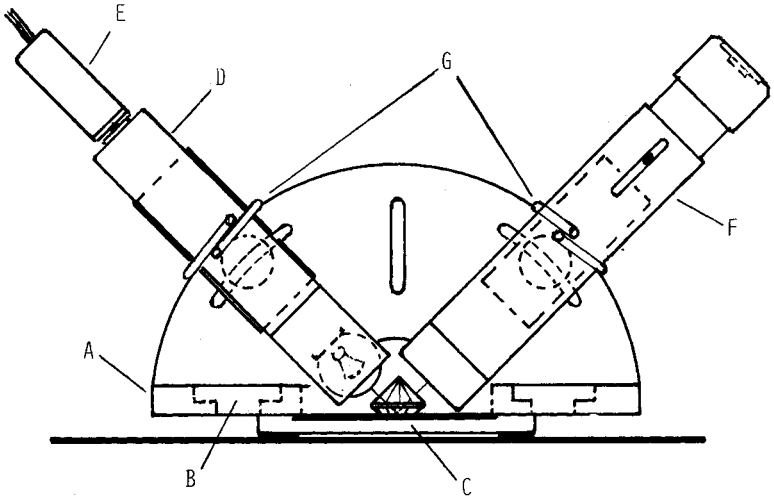

FIG. 1. Sketch of the spectroscope unit.
A., Base. B. Recessed hole for pinhole disc.
C. Gemstone rest: black velvet topside, mirror underside.
D. Barrel light source. E. Jackplug.
F. Fixed slit prism spectroscope.
G. Vee-blocks with wire clamps.

rectangular black Perspex base with a large circular hole at its centre, on either side of which is a smaller hole. A clear Perspex semicircular plate is fixed vertically on this base. Three slots in this plate serve to clamp adjustable vee-blocks, any of which can hold a light source or a spectroscope.

The light-source body is a cylindrical barrel made of a tough black plastic. It has a shielded lamp bulb at one end and an electrical jack-plug socket connexion at the other. It can be firmly held on its vee-block by a finger-release clamp. In this way, the barrel can be rotated on its own axis or slid along the vee-block to suit the lighting conditions required. A thumb-screw in the vee-block allows the barrel to be positioned and tightly clamped on to the vertical plate.

The final component of the basic unit is a glass mirror. The reverse side of the mirror is covered with black velvet, and it is this upon which rests the table facet of the stone under examination.

Lamps and Power Sources.

Two types of lamp are available. Both have identical miniature Edison-screw bases. One is a round, clear bulb, with a straight-coiled filament lamp, rated at 5.5 volts and 1.65 watts. The other is

of the kind used in penlights. It has a tiny condenser lens moulded on the bulb. This gives it a more directed ('collimated') light beam than the first. It has a rating of 2.2 volts and 0.55 watts. Whilst this has a much smaller light energy output than the first lamp, its smaller filament and collimated beam yields a greater light flux at the spectroscope eyepiece.

Both lamps are powered by a 240 volt mains isolating transformer, whose body plugs directly into the standard British 13 ampere mains socket. Through a switch in its base, it delivers three separate voltages.

With the 5.5 volts rated lamp, these settings deliver operating voltages of 2.74, 3.86 and 4.96, yielding operating wattages of 0.54, 0.92 and 1.35 respectively. The lowest voltage setting is used for the 2.2 volt rated lamp, giving an operating voltage of 2.35 and 0.62 watts. This shows it to be over-run by about 13%. Whilst this reduces the rated operating life of some 50 hours, this lamp (and the

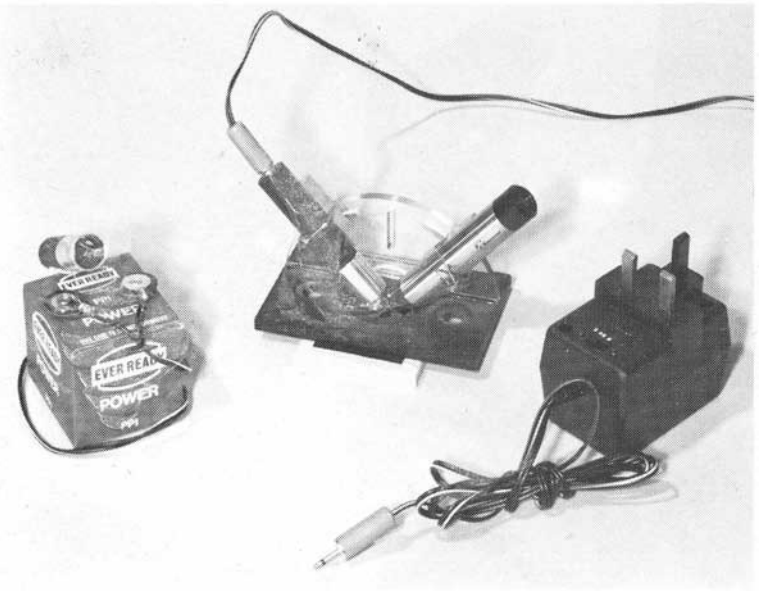

FIG. 2. Photograph of the spectroscope unit.
Centre: Basic unit with fixed slit prism spectroscope.
Right: Mains transformer power supply.
Left: Battery power supply. A slit attachment to the barrel light source which may be used with 'visual optics' is shown resting on top of the battery.

5.5 volt rated one) is quite inexpensive and easy to replace. The resulting greater light flux and the higher ratio of UV light to red light are compensating advantages.

With regard to its possible use in educational institutions, a vital feature of this light source is its complete electrical safety. No direct mains voltage can be reached by the operator's fingers. As it is an isolating transformer, mains voltage cannot be accidently transferred to the flex jack-plug.

The unit may occasionally be needed to examine rough and cut stones before purchase in remote places, where suitable mains supplies are not available. Recourse may then be made to either a mounted penlight for very short periods of observation, or to a large capacity 6-volt dry battery for extended periods. Provision has therefore been made to substitute a standard penlight on the same vee-block as that normally holding the barrel light-source. When the 6-volt battery pack is required, a second shorter flex is available. This has a jack-plug for the barrel light source at one end and a pair of connector clips for the battery pack at the other.

Spectroscopes.

Five types of inexpensive direct-vision spectroscopes may be used. Not unexpectedly, these have different features and, in particular, different diameters. For the basic unit, they are individually fitted with clamping vee-blocks to make them optically co-axial and also co-axial with those of the barrel light source and penlight. Again, like the light sources, the clamps can be released so that their tube axes can be rotated on their vee-blocks or slid along them, as needed.

Two of the spectroscopes are of the diffraction-grating type, and three are of the prism type. The first is an OPL instrument having a fixed, deep-set, but unprotected slit of 37 micrometres width and a focus fixed for normal vision. The second is an Ealing-Beck instrument having a dustproof, glass-protected, fixed slit, also of 37 micrometres width, but with an eyepiece draw-tube giving an adjustable focus.

The third spectroscope is a McCrone compound-Amici prism type having a luminosity at least equal to that of the OPL instrument. It has a glass-protected, fixed slit of 17 micrometres width and a variable focus drawtube. The resolution is high; the sodium doublet can just be discerned. With the two diffraction-type instruments it is not possible to separate the doublet in the blue region of the

ruby spectrum; this can be done comfortably with the prism instrument. This makes it possible to distinguish between a ruby which has been cut with its crystallographic axis parallel to the table and one which has its axis oriented perpendicularly to the table. With the first situation, the 476.5 nm line is the stronger; with the latter, the 475.0 nm line is the stronger.

It could be argued that, with a low-wattage light source, there is a greater need to use a spectroscope having a variable width slit. Experience with the unit using such an instrument generally shows this not to be so. However, if such a facility is needed for some special purpose, such as that described later, a fourth spectroscope (McCrone) is available. Its variable slit is glass-protected and, apart from its greater barrel diameter requiring a different clamping vee-block, its other characteristics are identical to the fixed-slit instrument.

A clamping vee-block is also available as a holder for the well-known Rayner multislit prism spectroscope.

Among the general population, large variations are to be found in the actual focal distances associated with the most comfortable naked-eye viewing. Many of these differences in human vision arise from ageing processes in the crystalline lens of the eye. Apart from this, on using, say, a prism spectroscope, with the ruby doublet at 694.2/692.8 in sharp focus, the ruby doublet at 476.5/475.0 will be seen, but not resolved. For this and other reasons, a focusing eyepiece is one feature of a spectroscope which should be regarded as an important one.

When weak or even medium-strength absorption lines are known to be present in certain spectral regions of the gemstone under examination, the observer is often unable to see them. The reason for this is commonly a failure to obtain the maximum line resolution of the instrument in the desired region. Under these circumstances the three spectral emission lines at 436, 546 and the 577/579 nm doublet seen in any ceiling fluorescent lighting tube are helpful in checking that the slit width, line focus and filter-eliminated 'veiling' or glare have been correctly chosen. The absence of a well-placed emission line in the red end can be overcome by focusing on the group of strong red lines in the neon spectrum. This spectrum is conveniently provided by the small on/off pilot lamps found on many instrument power supplies. Probably the best checking source of all is the spectrum given by the new Philips

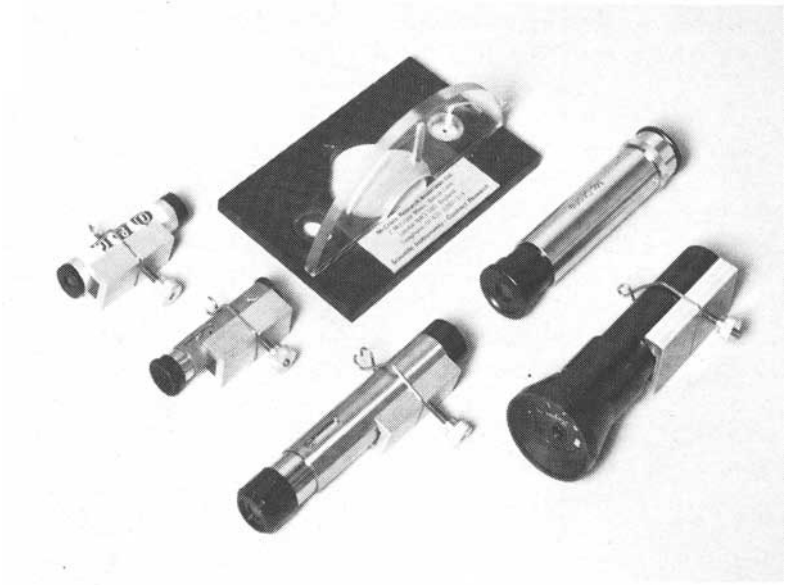

FIG. 3. Photograph of the basic stand with clamp-mounted spectroscopes.

SL*25 fluorescent bulb, intended as a replacement for the ordinary domestic 100 watt tungsten light bulb. Its spectrum shows an abundance of sharp lines from red to violet.

The choice of either a diffraction-type or a prism-type instrument lies with personal preference based on experience with both types. However, it has become the author's invariable practice with an unknown stone to use first the fixed-slit, focusing eyepiece diffraction instrument, followed by the fixed-slit, focusing eyepiece prism instrument. The switching of the vee-block-mounted, pre-aligned instruments takes little time. Details missed by one are often picked up by the other.

Figure 3 shows the basic stand to which can be attached any of the above-mentioned five spectroscopes. From left to right they are:

1. OPL diffraction; fixed slit, fixed eyepiece.
2. Ealing-Beck diffraction; fixed slit, focusing eyepiece.
3. McCrone prism; fixed slit, focusing eyepiece.
4. McCrone prism; continuously variable slit, focusing eyepiece.
5. Rayner prism; six different-width fixed slits, focusing eyepiece.

THE PRINCIPAL REASONS FOR THE NEW UNIT

A commonly held view is that lamps of a power of 150 watts or greater are needed to obtain acceptable spectra. This view was perhaps nourished by the recommendations of B. W. Anderson, who favoured the use of a suitably-housed 240 volt, 500 watt projection lamp.[1] The light from this is conducted to the gemstone by means of a 600 ml spherical, flat-bottomed flask filled with water. This effectively removes all the accompanying heat (infrared) energy and condenses the visible light energy. Alternatively, the flask is filled with a saturated solution of copper sulphate. This also removes the heat, but provides as well a condensed, band-free light source with a much enhanced proportion of violet to red light. This is especially useful in penetrating the 'blue gloom' region, and in eliminating the purple veiling which often obscures the violet region in the spectra of red-to-orange transmitting stones.

This view has been reinforced by the commercial availability of many new 'cold-light' fibre-optics light sources. These are sold as free-standing units or are built into table spectroscopes. Their design and construction are by no means simple and this is reflected in their high cost. The filament of a low-voltage, quartz-halogen lamp of 150 to 250 watts is placed at one focus of an ellipsoidal mirror. The polished entrance face of a shielded glass fibre light guide receives the light energy at the other focus. A toughened glass heat filter is interposed between the two foci. The heat filter only partially absorbs the very large amount of heat energy generated. The heat re-radiated by the filter itself, together with the heat emitted by the rest of the unit, is largely removed by a convector air fan. However, unlike the 500-watt/water-flask arrangement, a considerable amount of heat energy remains and can still reach the gemstone. This has been reported to have caused damage to some heat-sensitive stones, causing minute discontinuities to develop into visible cracks.

Another feature of 'cold-light' sources is one which does not seem to be generally known. An examination of the graph relating percentage transmission to wavelength of a 600 mm length of the standard glass-fibre light-guide cable reveals a fact not unimportant to gemmologists. The graph is shown in *Figure 4*. It can be seen from this that there is an appreciable drop in the light transmitted as it approaches the blue, violet and particularly ultraviolet regions. This yellowing of the white light as it passes through the cable can,

of course, be corrected by the careful choice of a blue glass filter. However, this light-balancing expedient cannot restore the loss of the gemmologically informative ultraviolet components.

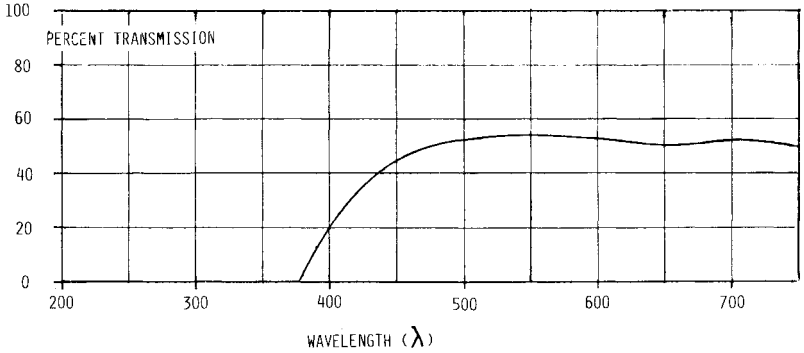

FIG. 4. Spectral transmission curve of a 600 mm long glass-fibre-bundle light guide cable. Percentage transmission versus wavelength (nm).

The results with the spectroscope unit described here have shown that such high wattage sources are not really mandatory. Thus one reason for the new unit is to provide an adequate and cool light flux at low cost. Another is to enable a desired spectrum, once obtained, to be easily recoverable, and, equally important, to be visually stable for inspection by others, again at low cost.

Whilst of lesser importance, the light source with its 5.5 volt rated lamp serves as a mechanically-adjustable illuminant for the critical-angle refractometer* and for the 10× hand loupe. It is particularly convenient when using the technique with faceted stones recommended by Gübelin[2] for distinguishing natural and naturally-coloured sapphires from synthetic and from artificially-coloured sapphires. This present variant consists of placing the stone in a circular glass dish with a flat bottom† and covering it with colourless methylene iodide.‡ The dish is held over or on the vertically-aligned barrel light source, which is fitted with a white

* A refractometer eyepiece filter is available for this; it is fitted with a special 'monochromatic sodium' gelatine filter.
† The glass immersion cell of Gemmological Instruments Ltd (Catalogue No. 1223) is ideal for this purpose.
‡ The free iodine in deeply-coloured methylene iodide can be removed with a piece of clean copper. A few hours' contact will render the liquid almost colourless; after decolorization the copper should be removed.

diffuser cap, and the stone viewed with a 10× hand loupe. Gübelin states: ". . . In the case of a naturally-coloured sapphire, all the facet edges, including the girdle, disappear, and only a blurred blue shimmer remains. Diffusion-coloured sapphires, on the other hand, display a patchy coloration, and all the facet edges, including the girdle, appear sharply defined, just as if the sapphire had been drawn with a blue pen on the bottom of the glass dish . . .".

Compared with viewing the stones directly in air, this immersion technique has proved to be much more informative when viewing inclusions in all transparent coloured stones. It is particularly useful with rough stones and results in a simplification of the usual procedure. Here, a rough stone need not possess a polished flat "window", as is the case for critical examinations in air. Of course, the appropriate RI-matching liquid must be used. In the author's experience, three liquids, glycerine (1.47), benzyl benzoate (1.57) and methylene iodide (1.74) meet the need for low, medium and high RI stones respectively.

There is a further useful feature of the barrel light source. It entails removing the lamp shield and substituting the tiny condenser-lens lamp (rated voltage of 2.2) for that normally used (rated voltage of 5.5). With its more directed (collimated) beam, this hand-held or base-held source can more easily probe into awkward crevices when dealing with large pieces of jewellery having stones in closed- or open-backed settings. Whilst a penlight can do this task just as well, the prolonged viewing times usually needed for spectroscopy make its use impracticable.

The physics of light propagation state that the light intensity varies in inverse proportion to the square of the distance from the source, i.e., it falls off very rapidly with distance. It follows that, if possible, the lamp lens should be brought into near contact with the gemstone surface. The spectroscope slit should also be placed as near to the gemstone as possible. When this is done, it is surprising to see how much cool white light flux is available for visual or spectroscopic examination from a lamp of so small a wattage (0.6 watts).

Other Uses of an Extended Unit

Apart from the above-mentioned applications, the unit can be adapted for other types of gemstone examination with the aid of various accessories.

Polariscope and Conoscope.

An accessory has been designed for converting the basic unit into a polariscope and a conoscope. The polariscope consists of a barrel light source attachment bearing the necessary diffusing and polarizing filters in pre-aligned positions. The transparent gemstone is placed on the glass-protected polarizing filter. As with conventional polariscopes, the stone is rotated and viewed through the crossed analysing filter situated above it (see *Figure 5*).

More often than not, faceted glass gemstone simulants produce effects under crossed polars which indicate that they are doubly-refracting and therefore not glass. With a little experience these distinctive images can be recognized as characteristic of 'frozen-in' internal elastic stresses. It was felt that it would be instructive to include as a polariscope accessory a clear, colourless, rectangular, notched bar of a synthetic resin which possesses a particularly high sensitivity to stress birefringence (piezobirefringence). When the bar ends are held between the fingers and thumbs to produce a bending force, polarizing colours appear. Depending on the degree of pressure applied, the colours vary from grey to purple and first appear at the notch. Releasing the pressure causes the stresses and therefore the colours, to vanish. Within gemstone pastes, the internal stresses are generated during the rapid cooling stage, and at room temperature the elastic stresses are 'frozen-in'. Unlike the carefully 'annealed-out' stresses of optical glass, gemstone pastes are not considered valuable enough to warrant the additional annealing treatment.

Four accessories are needed to convert the polariscope into a conoscope. The first is a small, removable, iris diaphragm cell which is used to support the faceted stone or the windowed 'rough'. The table of the gemstone or flat of the 'rough' is arranged so as to be uppermost. A careful setting of the iris diaphragm allows this to be done so that the specimen does not drop out during any subsequent manipulation. The iris diaphragm cell bearing its stone is then placed on the polariscope table.

The second accessory is a small, well-annealed, polished glass sphere, about 4 mm in diameter. It is attached by epoxy cement to one end of a thin, horizontal metal rod, which in turn is bolted to a small rectangular block. The block, with its supported glass sphere, is able to rotate and to move up and down freely on the vertical rod which connects the analysing filter to the polarizing filter table beneath. With this rod to simplify handling, the sphere is placed in

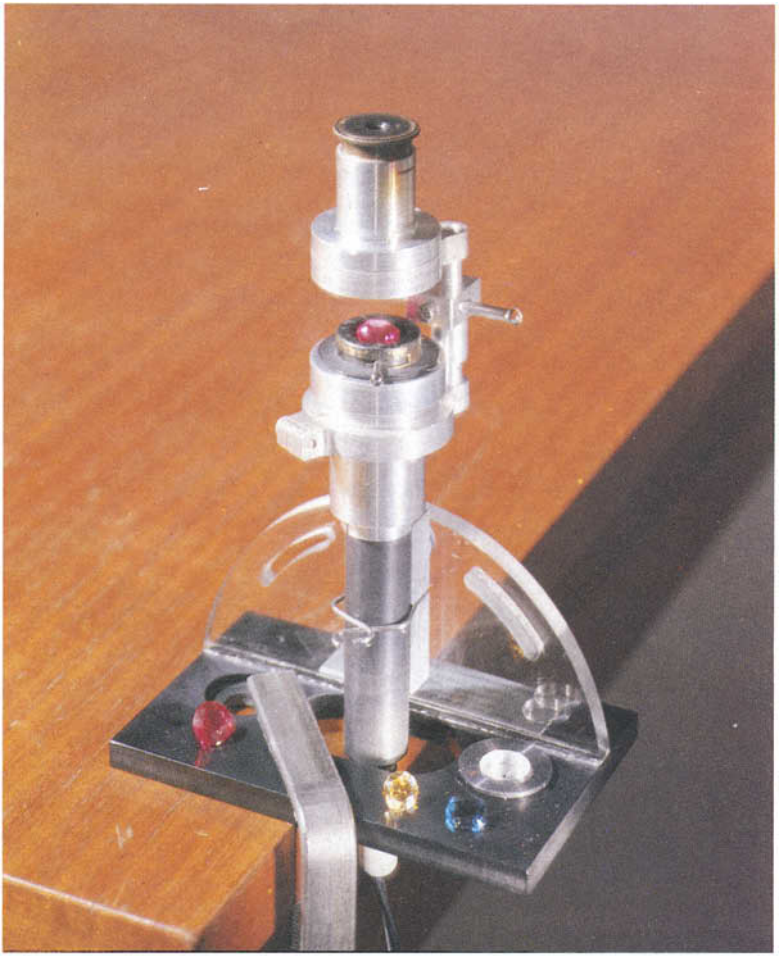

FIG. 5. Photograph of the polariscope-conoscope accessory.
This is shown attached to the barrel light source, which is vertically mounted on the basic stand. To accommodate the projecting jackplug, the whole unit is G-clamped to the edge of a desk or bench. For polariscope (orthoscopic) viewing, the gemstone is placed either directly on the polarizing filter table or supported as shown on the iris diaphragm cell for ease of rotation and tilting. The removable focusing magnifier is used for both orthoscopic and conoscopic viewing.

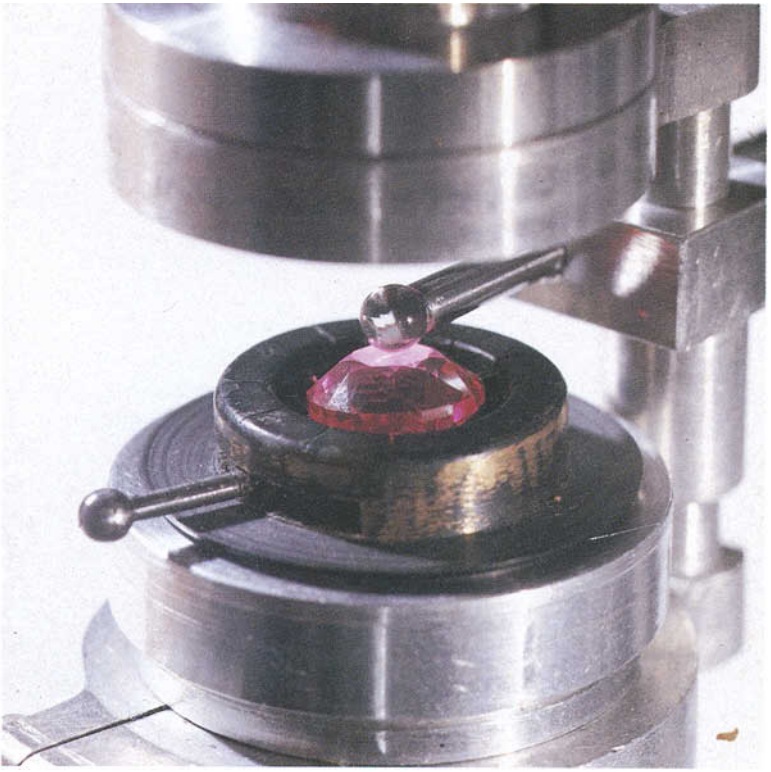

FIG. 6. Enlarged view of the conoscope condenser arm.
The glass sphere condenser is shown resting directly on the table surface of the gemstone. It can be swung in and out of the polariscope's axis as required (see Figure 5). The aperture lever of the iris diaphragm cell also serves to rotate the gemstone on this axis. This rotation is a vital process in following the behaviour of non-centred conoscopic images.

direct contact with the flat surface of the stone (see *Figure 6*). It is then sometimes possible to see at once the image of an optical interference figure lying within the sphere, provided that the stone is of a uniaxial or biaxial character. Unstressed isometric stones or pastes will not, of course, exhibit optical interference figures.

More often than not, no figure appears. However, tilting the stone in the cell about its geometrical axis, with the sphere still in contact, will sometimes coax into view the whole or part of a figure. The presence of a figure gives indisputable evidence that an optical

axis of the gemstone mineral coincides with, or is very close to, the vertical geometrical axis of the gemstone.

For example, it is almost certain that a high quality ruby will display a well-centred uniaxial figure. This is because such a ruby will have been cut so that viewing it directly through the table will exhibit the best possible colour for that stone. This viewing direction is that where only the more reddish omega (ordinary) ray of the ruby will be seen.

The two optic axes of biaxial stones will seldom be seen in the same interference image. Possibly one or other of a single melatope (as the image pattern at the point of emergence of an optic axis is called) will be visible. More probably, the off-centred trace of a melatope will be glimpsed. This will be the case where particular care has been taken by the cutter to present the optimum colour of the stone. Usually, however, no interference figure will be discernible through the table facet. This fact is often related to the practice adopted by native cutters. Their first concern, understandably, is to obtain the maximum weight and clarity from a piece of 'rough', and less to extracting its best colour.

If the gemmologist is sufficiently determined, a recognizable uniaxial or biaxial figure can usually be found. Should the stone possess other largish facets, the search will not be so prolonged. One useful trick discovered by the author is to moisten the glass sphere with the merest touch of any immersion oil. This direct optical coupling between sphere and stone usually helps to intensify and sharpen an otherwise indistinct interference figure. *Figure 7* illustrates the appearances of centred and off-centred uniaxial and biaxial figures.

FIGS 7A to 7L. Uniaxial (7A to 7F) and biaxial (7G to 7L) interference figures ('conoscopic images'). All are of plane-parallel polished sections of single crystals photographed in highly convergent sodium light (wavelength = 589nm) under crossed polars.

FIG. 7A. *Calcite*. Section thickness 0.5 mm; cut at 90° to the optic axis.
FIG. 7B. *Calcite*. Section thickness 3.0 mm; cut at 90° to the optic axis.
FIG. 7C. *Calcite*. Section thickness 1.0 mm; cut at 90° to the optic axis.
FIG. 7D. *Calcite*. Section thickness 0.9 mm; cut at 80° to the optic axis.
FIG. 7E. *Zircon*. Section cut at 90° to the optic axis.
FIG. 7F. *Zircon*. Same section as 7E, but with a superimposed quarter-wave retardation plate having its 'slow' direction oriented north-east to south-west. The image seen is that characteristic of a uniaxial positive crystal.

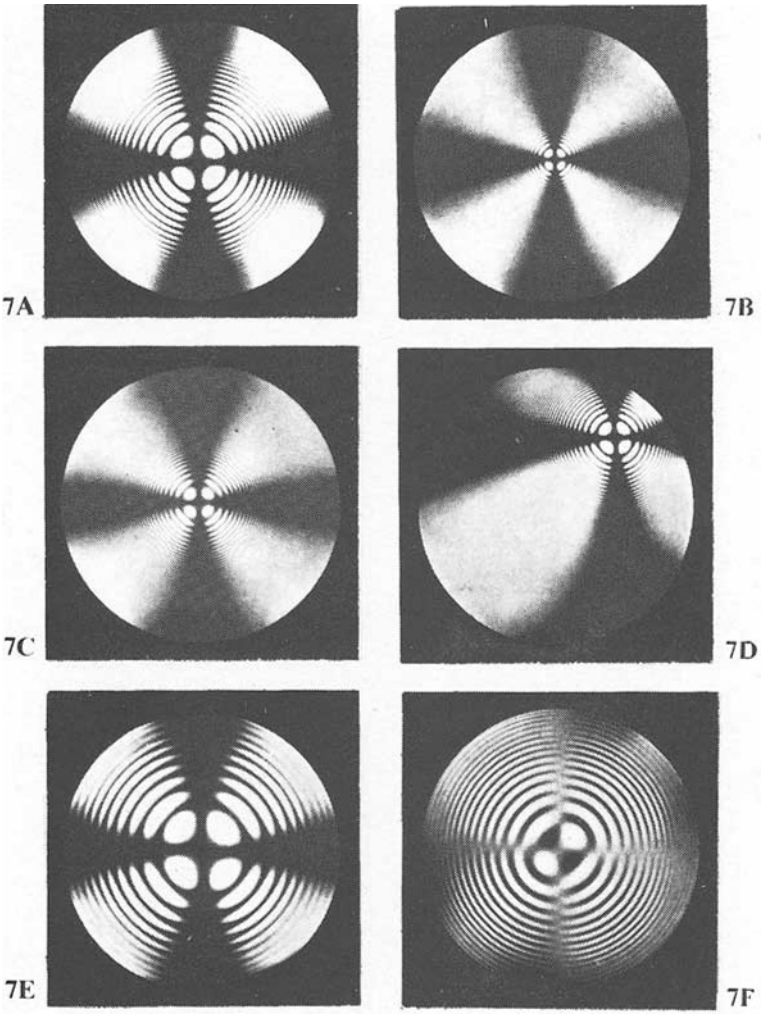

FIGS. 7A to 7F. Uniaxial interference figures ('conoscopic images'). See p. 512 opposite. (For biaxial interference figures see p. 514).

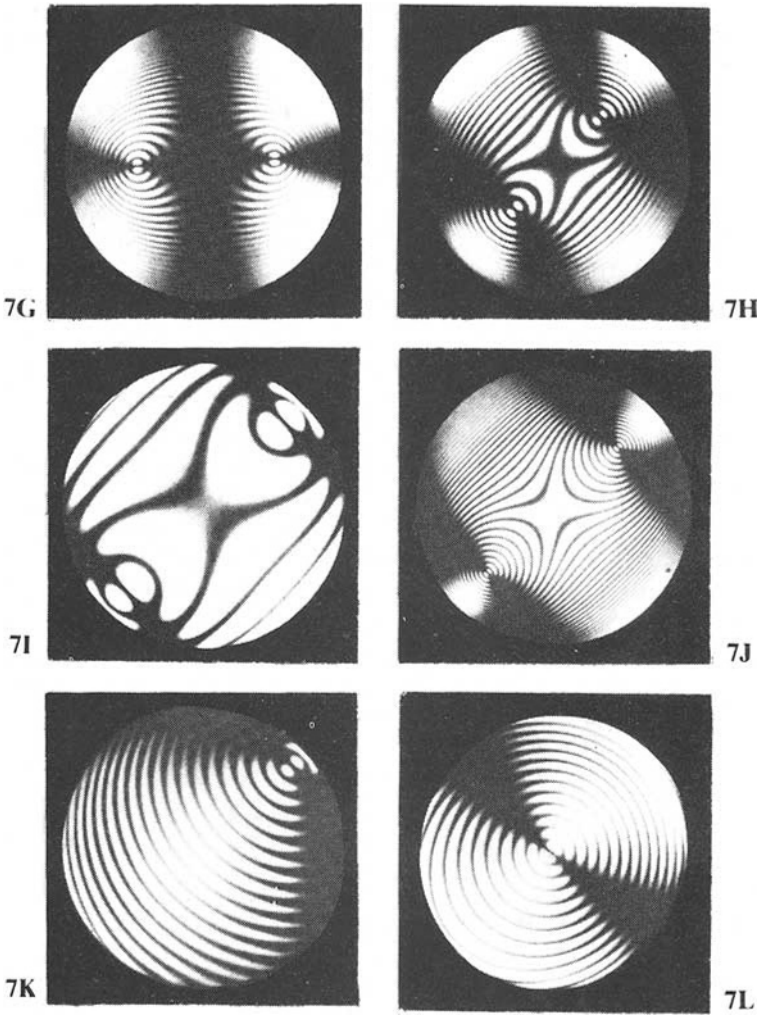

FIGS. 7G to 7L. Biaxial interference figures ('conoscopic images'). See p. 515 opposite. (For uniaxial interference figures see p. 513).

The third conoscope component is a positive eyepiece lens combination mounted in a focusing cell. Its purpose is to magnify the small image seen within the glass sphere. This is needed in order to discern greater detail in the figure. It is perched in a recess on the analysing filter table of the polariscope. Because the height of the glass sphere will vary with the thickness of the gemstone in its cell, provision has been made for focusing the lens.

The final conoscope accessory is a set of three cells similar in dimensions to the iris diaphragm cell. They are intended as aids to the recognition of the image patterns of the optical interference figures. One cell contains a mineral section showing a uniaxial figure. Another is a cleavage slip of muscovite mica, showing both melatopes of a biaxial figure. By both rotating and tilting these cells on the polarizing filter table, one is able to become familiar with the general behaviour of these images. The biaxial figure changes with rotation and orientation in a much more complicated way than the uniaxial one. Without simple standard specimens such as these, the process of recognition of off-centred figures from actual faceted stones would take very much longer.

The last of the three cells contains a quarter-wave plate. This is a device which can be used in conjunction with the conoscope to indicate whether the optical sign of the gemstone (uniaxial or biaxial) is positive or negative. However, the explanation of its use is far from simple. For this reason, the treatment of the subject will be deferred until a later time. Should one wish for a fuller account of conoscopic figures a good introduction is given in the textbook by Gay,[3] or in an excellent article by Robinson.[4]

FIGS 7A to 7L. Uniaxial (7A to 7F) and biaxial (7G to 7L) interference figures ('conoscopic images'). All are of plane-parallel polished sections of single crystals photographed in highly convergent sodium light (wavelength = 589nm) under crossed polars.

FIG. 7G. *Aragonite.* Section thickness 0.5 mm; cut at 90° to the acute bisectrix. Parallel (extinction) position.

FIG. 7H. *Aragonite.* Section as above, but rotated 45° to the 'diagonal position'. Showing 'eyes' (melatopes) and 'brushes' (isogyres). Optic axial angle (2V) = 18°.

FIG. 7I. *Muscovite mica.* Section at 90° to the acute bisectrix (cleavage plate). Diagonal position, showing 'eyes' and 'brushes'. 2V = 39°.

FIG. 7J. *Sphene.* Section cut at 90° to the acute bisectrix. Diagonal position, showing 'eyes' and 'brushes'. 2V = 24°.

FIG. 7K. *Diopside.* Section cut parallel to the 100 plane. Diagonal position, showing a single off-centred 'eye' and 'brushes'. 2V = 58°.

FIG. 7L. *Topaz.* Section cut at 90° to an optic axis. Diagonal position, showing a single centred 'eye' and 'brushes'. The concentric circles are termed 'isochromatic lines'. 2V = 62°.

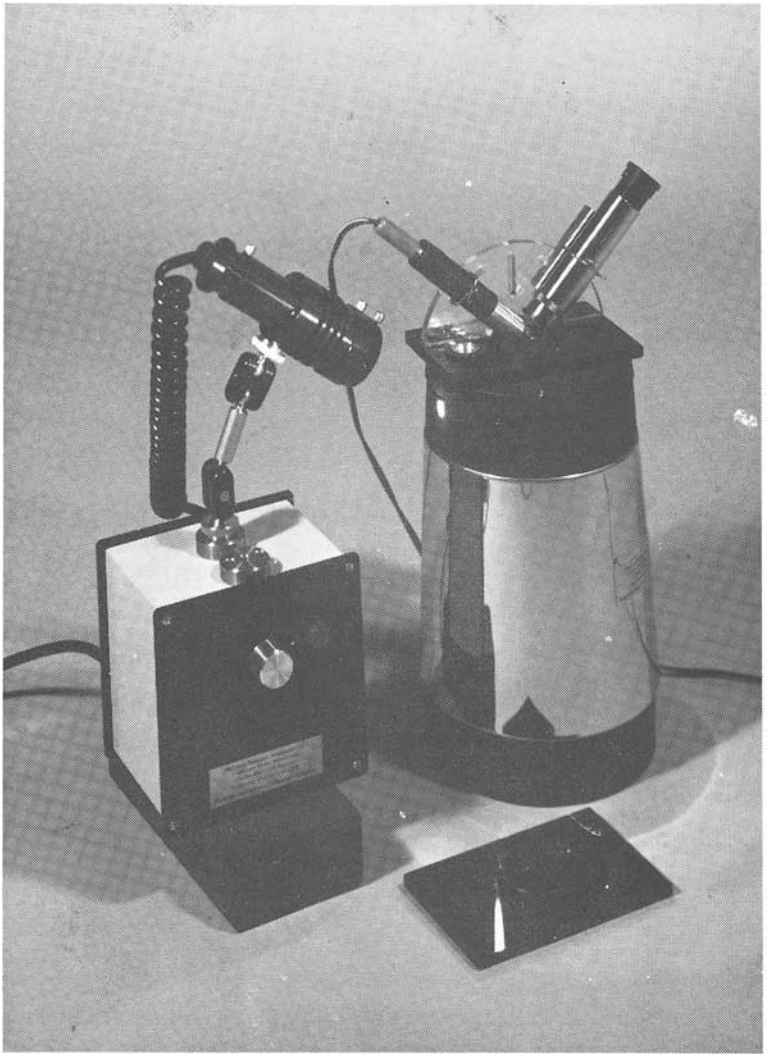

FIG. 8. Photograph of the gemstone cooling unit.
The spectroscope unit is shown in position on top of the vacuum-flask cooling unit. The alternative free-standing light source is shown on the left. A stone alignment jig is shown at the bottom.

Gemstone Cooling Unit

In recent years the hand spectroscope has been found to be an indispensable tool for the characterization of diamonds, whether uncoloured, coloured or artificially coloured. The absorption lines in the visible region are generally narrow and faint. However, by viewing the stone at a sufficiently low temperature, they usually become much enhanced in intensity and sharpness. Additionally, lines which cannot be seen at room temperature often become prominently visible when cooled.

In well-funded gemmological laboratories, low temperature instrumentation has been developed to exploit the effect. Studies utilising this highly complex equipment have elicited many new facts about the properties and histories of faceted diamonds.[5,6,7,8,9,10] These facts now promise to be of routine diagnostic value to the less well-endowed gemmologist, provided low-cost, easy-to-use apparatus is available.

A simple stone cooling device for this purpose has now been developed. It is basically a 'cold-finger' type and can be seen on the right in the photograph of *Figure 8*. The spectroscope unit is shown in position on top of the vacuum-flask cooling unit.

A 13 mm diameter copper heat-conduction rod is fixed centrally in the screw-on insulating lid and reaches almost to the inside bottom of the flask. The upper end of the rod is machined flat and projects slightly above the top of the lid. The gemstone is placed table facet down and centrally on the exposed flat copper surface. No thermal coupling liquid is needed to assist the conduction of heat from the gemstone to the cooled rod.

The top surface of the lid serves as a convenient platform upon which to support the spectroscope unit. The unit is prevented from accidentally sliding off sideways by the presence of a flat metal ring. This ring is attached to the platform so that it lies coaxially with the copper rod. In turn, the ring fits loosely into the large circular hole in the base of the spectroscope stand.

In this way, the gemstone rests directly on its copper rod perch in the normal viewing mode. The gemstone-aligned spectroscope unit can now be placed on the platform or removed from it, without disturbing the gemstone.

Table I shows the temperatures reached by various cooling mixtures, the best of course being liquid nitrogen. Nitrogen gas boils off at −196°C and this becomes the equilibrium temperature

TABLE I. Temperatures of some freezing mixtures

Equilibrium mixture	Temperature °C	Temperature K*
Room temperature	22	295
Crushed ice plus water	0	273
Crushed ice plus sodium chloride crystals (NaCl)	−21	252
Crushed ice plus crushed anhydrous calcium chloride ($CaCl_2$)	−55	218
Crushed ice plus potassium hydroxide pellets (KOH)	−65	208
Crushed carbon dioxide pellets plus methylated spirits†	−78	195
Collins-Scarratt liquid nitrogen evaporator apparatus[5]	−153	120
Boiling point of liquid nitrogen. Collins apparatus[6]	−196	77
Hofer-Manson cryogenic compressor cooling system[7]	−218	55
Absolute zero	−273	0

* K = °C + 273.18

† There are liquids which are as satisfactory, but less inflammable than methylated spirits. They are:

Isopropyl alcohol — Cat. No. 59310
"Dowanol 33-B" (1-Methoxy-2-propanol) — Cat. No. 65280

Obtainable from:
Fluochem Ltd, Peakdale Road,
Glossop, Derbyshire, SK13 9XE, U.K.

Also obtainable from the above suppliers:

Calcium chloride anhydrous lumps — Cat. No. 21080
Potassium hydroxide pellets — Cat. No. 60375

Solid carbon dioxide ice ('Cardice') pellets are obtainable from:
The Distillers Company (Carbon Dioxide) Limited,
Cedar House, 39 London Road,
Reigate, Surrey, RH2 9QE, U.K.

of the copper rod. The body temperature of the gemstone will not be exactly at this point; thermocouple measurements show this to be about 5 to 10°C above it.

A full 25-litre Dewar flask of liquid nitrogen is fairly cheap and can be delivered when requested at one's door. It will take about two months to boil away completely. Admittedly, liquid nitrogen supplies can be a problem for the gemmologist who requires only an occasional examination. However, most gemmologists know a friend in some scientific or medical institution who has ready access to constant liquid nitrogen supplies.

The frosting-over of the gemstone surface becomes a nuisance when the humidity is high. There comes a point when the spectrum becomes less visible. Then the spectroscope unit and the stone are removed, the stone and its perch are rubbed free of the rime, and the stone and unit restored. The alignment is unchanged and the stone's temperature reaches that of the perch in about 15 seconds.

For prolonged frost-free examination, recourse may be made to a separate device. A gentle stream of moisture-free nitrogen is obtained by evaporation from a separate Dewar flask containing liquid nitrogen. The stream is conducted on to the stone by means of a tube, whose holder is bolted on to an existing screw-tapped hole in the base of the spectroscope unit.

With certain diamonds, it can transpire that the blue-violet region requires greater light intensity than the tiny condenser-lens lamp can deliver. This can be supplied by a separate free-standing light source equipped with a heat-absorbing filter. It is shown on the left of *Figure 8*. The condensed spot of cool light can be seen focused on the upper side of the stone cooler unit.

If the use of liquid nitrogen is not feasible, Cardice pellets or even the water/chemical mixtures are still quite effective in sharpening and enhancing the absorption lines.

Here, instead of using a stream of cold, gaseous nitrogen for producing a moisture-free micro-climate for the stone, a slow stream of dried air at room temperature can be used to prevent the formation of rime. All that is required is a small rubber diaphragm pump and a long, wide, glass cylinder with rubber stoppers and glass tubes at both ends. The cylinder is filled with a suitable desiccant, like blue-dyed silica gel. Although the air stream is at room temperature, the temperature of the stone scarcely rises.

With liquid nitrogen cooling, the 415.5 and 478 nm lines of the

Cape series diamonds (Type 1a) and the 497 and 504 bands of the green-fluorescing Brown series become highly visible, as does the 595 band of some treated stones. When the 'Red' colour filter is placed over the eyepiece of the prism spectroscope, even the elusive GR1 line at 741 nm can be discerned in some irradiated stones. This same filter is also helpful in detecting the presence of the radiation-related 637 line in yellow Type 1b stones.

Little work has yet been carried out on the effect of the cooling device on stones other than diamond. A 0.79 carat, colourless zircon showed only a very faint line at 653.5 nm at room temperature. With liquid nitrogen, this line was greatly enhanced and sharp lines were revealed at 589.5, 537.5 and a faint one at 562.5 nm. A puzzling doublet at about 515 nm also appeared.

Observation of the ruby red doublet proved to be instructive. At room temperature, even with some care, the fixed-slit prism spectroscope could not resolve the doublet. With liquid nitrogen, the narrowing and strengthening of the lines made the separation just visible.

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THE RAYNER DIAMONDSCAN— A TEST REPORT

By PETER READ, C.Eng., F.G.A.

When the reflectivity meter was first introduced in the mid-1970s[1,2,3,4], one of the drawbacks in its design was the inability of the instrument to test stones below about 0.15 ct in size. This was due to the need for the main facet of the stone to cover completely the test aperture, whose diameter in some early models was as large as 1.5 mm and is seldom much smaller than 1 mm in more recent models.

Another problem was the difficulty in testing stones which were recessed in their mount. Attempts to overcome this difficulty were made by providing an annular recess to take the stone's setting claws, by forming the test platform into a flat-topped cone or by mounting the infrared light-emitting diode and associated photo-detector in a probe housing. Because of the dimensions of the photo elements, and the need for them to be angled for precise reflection alignment to the surface of the test stone, even the two latter modifications only allowed for the testing of stones of 0.5 ct and upwards.

Although the majority of reflectivity meters are battery-operated and are therefore portable, they do need to be placed on a flat surface for ease of operation, and this is not always possible when making tests away from the workbench (e.g. when checking stones at an auction).

In 1984, following extensive testing of ten prototype units by the jewellery trade, the Rayner Optical Company introduced their DiamondScan model (Figure 1). This version of the reflectivity meter is designed to overcome some of the drawbacks of the more conventional models, and, as its name implies, is specifically developed for identifying diamond and its simulants.

The Rayner DiamondScan is a self-contained battery-operated reflectivity probe, and because of its optical design it is capable of testing stones down to 0.05 ct in size, even if these are recessed in their mount. This has been made possible by coupling the infrared light-emitting diode and its photo-detector via a bifurcated glass-fibre light guide to a stainless steel test tip having an internal diameter of 0.75 mm.

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FIG. 1. View of the Rayner DiamondScan showing (centre, right to left) its bar-graph type indicator, stainless steel test tip, removable test platform and dust cap.

The infrared rays from the diode are effectively collimated by both the fibre optics and the stainless steel test tip. With the stone correctly aligned, the infrared rays impinge on its surface at right-angles (thus satisfying one of the requirements of the Fresnel equation linking reflectivity with refractive index) and are reflected back to the photo-detector.

To reduce the instrument to pocket-size proportions, the output from its photo-detector amplifier is coupled to a bar-graph type display unit rather than a meter. The first segment of this display is labelled 'B', and in the absence of any reflected rays this segment lights to indicate that the battery voltage is adequate for use (if the light extinguishes, the battery needs replacing). The remaining segments are labelled 1 to 9, and the instrument is calibrated (as indicated in Table 1) so that these coincide with the reflectivity of diamond (represented by a diamond symbol against segment 8) and its simulants. A user calibration preset control is accessible through a hole in the side of the unit's case.

TABLE 1

Bar-graph Reading	Identification		
	Diamond	Simulant	Description
B			Battery condition check
1		X	Glass
2		X	Quartz (colourless Beryl, Topaz)
3		X	Corundum, Spinel
4		X	Zircon, YAG
5		X	GGG
6		X	Cubic Zirconia
7		X	Strontium Titanate
♦	X		Diamond (Calibration point)
9		X	Rutile (metals)

The DiamondScan is powered by either a small 7-volt mercury battery or by a 6-volt lithium battery (the latter being available from camera shops and having a shelf life of ten years). With either

battery the operating voltage of the unit's printed circuit board is stabilized at 3.4 volts. To further ensure maximum battery life, the unit is only energized when the pocket clip is pressed against the instrument's body (the clip acts as the on/off switch). Because of the sensitivity of the electronic circuits, a thermal stabilizer has been incorporated to maintain the instrument's calibration over a temperature range of 15 to 25°C.

For operating convenience, a black plastic test platform is provided, and this can be fitted over the probe's test tip to give a reference surface when checking non-recessed stones of 0.25 ct and upwards (Figure 2). When not in use, the probe tip is protected from dust by the test platform and a dust cap. Inadvertent operation of the unit is prevented by inserting it into a carrying sleeve which insulates the pocket clip from the body of the probe.

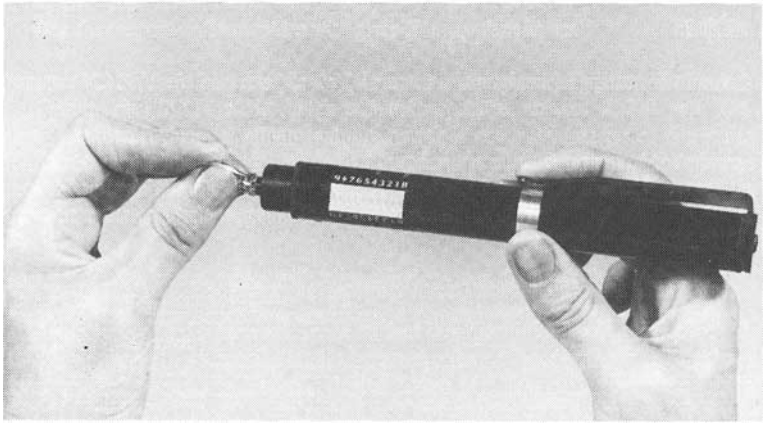

FIG. 2 Using the DiamondScan with the test platform in position.

Besides replacing the battery, the only maintenance required is to keep the test tip and the end of the light guide free from dirt. This is effected by removing the probe tip nozzle and gently dusting the exposed end of the light guide. Any dust particles can then be blown out of the probe tip tube. To maintain calibration, the probe tip nozzle is replaced with its white alignment dot opposite a similar dot on the side of the instrument's case.

During tests made with the DiamondScan using diamonds, diamond simulants and coloured stones, it was clear that some skill was necessary in aligning the probe's test tip squarely (i.e. at right-angles) to the surface of the gem in order to achieve the highest correct reading on the bar-graph indicator. The need for practice in the use of the instrument is emphasized in the operating leaflet, where it is recommended that those users not familar with probe-type reflectivity testers should first attempt to obtain correct readings with a relatively large stone (0.5 ct and upwards) using the black plastic test platform.

Apart from the fact that the DiamondScan is held in one hand, and the stone under test in the other, the use of the test platform makes operation of the instrument similar to that of the conventional desk-type reflectivity meter. The surface of the gem can be easily referenced in the correct orientation against the surface of the test platform, and providing the test aperture in the probe tip is completely covered by the area of the gem's facet, the appropriate maximum reading is obtained without further adjustments.

With much smaller stones (down to 0.05 ct), and with any stone whose mount protrudes beyond the surface of the table facet, it is necessary to use the DiamondScan with the test platform removed. Here, particularly with small stones, care must be taken to ensure that the test tip remains in the centre of the table facet while orientating the stone first in one plane (e.g., horizontally) and then at right-angles to this (e.g., vertically) to obtain the maximum reading.

With unmounted stones, this task is made simpler by first securing the stone in prong tweezers or in a stone display holder. Although it may negate one of the instrument's flexibility features, users have found it easier, at least initially, to sit down and steady both elbows on a horizontal surface when using the DiamondScan, particularly when testing several stones in succession as with an eternity ring. The method of holding the ring or stone against the probe tip (as described in the operating leaflet) using the index finger to steady the hand against the side of the instrument (see Figure 3) certainly makes the testing of stones of any size much easier.

Although the illustrations in Figures 2 and 3 show a right-handed user, left-handed operation simply involves rotating the

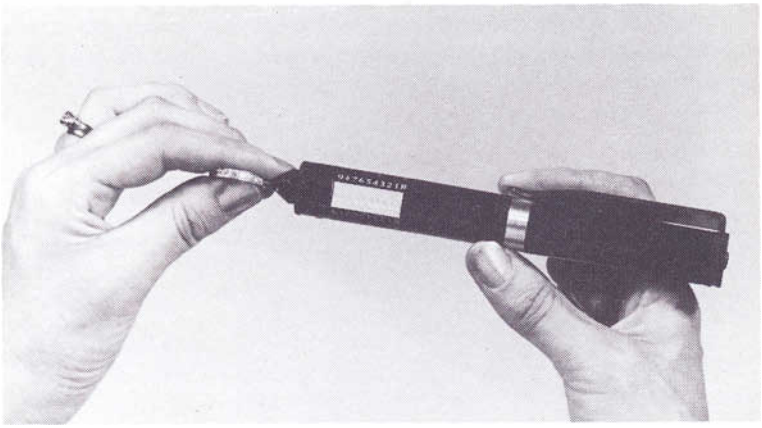

FIG.3 Method of testing small stones with the test platform removed.

pocket clip through 180 degrees (without unscrewing the battery holder) and reading the bar-graph against the alternative scale provided.

As can be seen on the scale of a standard reflectivity meter, the reflectivity values for diamond and the principal diamond simulants (e.g., glass, quartz, corundum, YAG, GGG, CZ, strontium titanate, diamond, rutile) are evenly separated. This fact enables the DiamondScan to be calibrated so that these stones fall into the nine segments of the bar-graph display. Although the instrument has been designed to test for diamond and its simulants, it is also possible, with care, to test for the coloured varieties of some gem materials. This is not recommended, however, because of the possibility of ambiguity caused by the response range of each segment.

As with any reflectivity instrument, one of the most important requirements when testing stones on the DiamondScan is that the surface of the gem is free from dust, grease and scratches. Because it is difficult with this instrument to shield the rear of the stone from ambient light, it is also important that tests are not carried out under high-level lighting. Correct operating procedure is summarized by the following instructions which are printed on the body of the instrument:

'Use in subdued light'

'Clean test surface'

'Adjust angle for maximum reading'

Dimensions of the DiamondScan are 170 mm long by 18 mm diameter. The batteries used are Duracell TR-175 (7-volt) or Duracell PX28L (6-volt).

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GEMMOLOGICAL ABSTRACTS

BALFOUR (I). *Famous diamonds of the world, I – XII,* Indiaqua, 20–31, 1979–1982. (Series continuing – parts XIII (Indiaqua 32, (1982/4)) onwards are separately abstracted.)

The series deals in turn with a celebrated diamond, giving the history and details of the stone where known. Stones discussed in parts I to XII are the Niarchos diamond, the Brunswick blue, the Woyie River diamond, the President Vargas, the Shah diamond, the Jonker, the Dresden Green, the Amsterdam diamond, the Florentine diamond whose whereabouts is at present unknown, the Lesotho brown diamond, the Regent diamond, and the Colenso diamond (stolen from the British Museum (Natural History) in 1965 and never recovered). M.O'D.

BALFOUR (I.). *Famous diamonds of the world, XV. The 'Hastings' diamond.* Indiaqua, 34 (1983/1), 129–33, illus., 1983.

This 101 ct rough diamond was presented as a gift in 1786 by the Indian prince Nizam Ali Cawn to King George III. Because of the involvement of Warren Hastings, the first Governor General of India, in its presentation, a rumour started that the diamond constituted a personal bribe by Hastings to the King, and the resulting scandal caused the stone to be known as the 'Hastings' diamond. Warren Hastings was formally impeached, but was cleared on all counts in April 1795. Although nothing since appears to have been heard of the diamond, the author suggests that the missing stone was part of the Crown Jewels and was mounted in the coronation crown of George IV. He further suggests that subsequently the stone became the principal 32.2 ct diamond in the Westminster Tiara which was made in 1837 for the Marquis of Westminster. In 1959, the tiara was purchased by Harry Winston Inc., and the diamonds sold privately to an undisclosed collector. P.G.R.

BALFOUR (I.). *Famous diamonds of the world, XVI. The 'Excelsior' diamond.* Indiaqua, 35 (1983/2), 131-4, illus., 1983.

The 995.2 metric carat 'Excelsior' diamond, which rates as the second largest rough diamond ever found, was discovered at the open-cast site of the Jagersfontein mine in South Africa's Orange Free State in 1893. The discovery was made by an African boy who was shovelling gravel into a truck (his reward was £500 and a horse with saddle and bridle). The rough stone was of top colour, but contained numerous internal black spots, both features characteristic of Jagersfontein diamonds. The

stone was shipped to the London offices of Messrs Wernher, Beit & Co., the largest of the ten firms that comprised the London syndicate, and was eventually dispatched to Messrs Asscher of Amsterdam for cutting. Possibly because of the numerous inclusions, the 'Excelsior' was cut into twenty-one relatively small stones, the largest being of pear shape and weighing 69.68 metric carats. No single large stone therefore was produced from the rough, a fact which caused some people to believe that the higher commercial rewards associated with a greater number of more saleable small diamonds had outweighed any thought of producing a large stone of historic importance. The author suggests that one of the larger stones cut from the 'Excelsior', a 46.50 ct pear-shaped diamond, was the principal stone in a pendant auctioned at the Park-Bernet Galleries, New York, in 1957. P.G.R.

BALFOUR (I.). *Famous diamonds of the world, XIX. The 'Hope' diamond.* Indiaqua, 38 (1948/2), 127–38, illus., 1984.

The 'Hope' diamond is well known for both its rare colour, a sapphire-like dark blue, and for its reputation as a bringer of misfortune to many of its previous owners. However, as Ian Balfour points out, this gem has not always been unlucky for its owners, nor has it caused their early demise. The Kollur mine, in the vicinity of Golconda, India, is said to have been the source of the stone. What is known is that after Tavernier returned from his final voyage to the Orient he sold a dark blue diamond to Louis XIV of France (the 'Sun King') in 1669. Tavernier himself was certainly not affected by any 'curse' associated with the stone and died of old age in Russia at 84. The 'Tavernier Blue', as the stone became known, was recut in 1673 to a heart-shape which weighed 69.03 metric carats (the original weight being around 110.5 metric carats). In its new form, the diamond was called the 'Blue Diamond of the Crown' and was worn in various ways. Louis XV who succeeded the 'Sun King', had the stone mounted in the decoration of the Golden Fleece insignia, and this was passed to the next King of France, Louis XVI. Although Marie Antoinette (Louis XVI's wife) was said to be 'cursed' by ownership of the blue diamond, there is no record of her ever having worn it.

During the revolution in France, the blue diamond was sent for safe keeping with other Crown Jewels to the Garde Meuble, which was part museum and part furniture store. On 16th September, 1792, the Garde Meuble was broken into and the blue diamond and other gems were stolen. Early in the nineteenth century a dark blue diamond weighing around 44 ct mysteriously made its appearance in London. In 1830, this blue diamond was sold to Henry Philip Hope and acquired the name of the 'Hope' diamond. After the owner died, the stone was inherited by his eldest son, who died at the comparatively early age of 54. The son's wife retained the diamond and in 1887 bequeathed it to her younger grandson with the proviso that he adopt the name of Hope. The grandson, Lord Francis Hope, subsequently attempted to sell the stone to solve his financial difficulties. Francis Hope's eldest sister took legal action to prevent the sale, but in 1901 Hope succeeded in securing permission to dispose of the diamond, which was sold to Adolf Weil of Hatton Garden, London. From 1909 onwards, the diamond passed through many ownerships, some of which were associated with both lurid and bizarre happenings, which added to the legend of the diamond's 'curse'. Finally, in 1949, it was purchased together with other jewellery by the late Harry Winston, who, in 1958 presented the 'Hope' diamond to the Smithsonian Institution in Washington, D.C. P.G.R.

BALFOUR (I.). *Famous diamonds of the World, XX. The 'Cullinan' diamond.* Indiaqua, 39, (1984/3), 123-32, 10 figs, 1984.

A very full account of the finding of the World's largest known diamond, its presentation to King Edward VII, subsequent cutting and eventual incorporation in the British Crown Jewels. R.K.M.

BANK (H.). *Aus der Untersuchungspraxis.* (Notes from the Laboratory.) Z.Dt.Gemmol.Ges., **33**, 1/2, 79–83, 1 photomicrograph in colour, bibl., 1984.

Dark brown chrysoberyl from Sri Lanka was found to show extremely high RI, n_x 1.760, n_y 1.762 and n_z 1.770, while colourless enstatite from Sri Lanka had very low RIs, n_x 1.650, n_y 1.653 and n_z 1.659. Rough 'emerald pieces' were offered on the market, but found to be green dyed quartz. The correct designation of synthetic Knischka rubies as an overgrowth on a seed of Verneuil ruby is discussed. E.S.

BASTOS (F.M.). *Irradiated topaz and radioactivity.* Gems Gemmol., **XX**, 3, 179–80, 1984.

Writer explains method of nuclear treatment to make topaz blue and says that residual radioactivity fades very rapidly. R.K.M.

BEATTIE (R.), BROWN (G.). *Facetable prehnite.* Aust. Gemmol., **15**, 8, 258–9, 3 figs. 1984.

Facet grade material found at Wave Hill, Northern Territory, and cut by R. Beattie. SG 2.92, RI 1.613–1.640, DR 0.027, H 6½. Translucent to transparent. R.K.M.

BOSCH-FIGUEROA (J.M.), FUENTE-CULLELL (C. DE LA). *El color de las gemas.* (The colour of gems.) Gemologia, **20**, 61–2, 18–31, 4 figs, 1984.

The cause of colour in gemstones is explained. M.O.D.

BROWN (G.). *The Snow gemmological spectroscope.* Aust. Gemmol., **15**, 8, 259–62, 2 figs, 1984.

A new spectroscope assembly employing the normal prism instrument but with addition of fibre optic light source for mounted rings. Favourable report. R.K.M.

BROWN (G.). *Topaz.* Wahroongai News, **18**, 10, 27–31, 1984.

An account of this species apparently culled principally from mineralogies and heavily over-weight on atomic structure and crystallography. R.K.M.

BROWN (G.), BRACEWELL (H.). *Harts Range sunstone.* Aust. Gemmol., **15**, 8, 263–74, 26 figs (24 in colour), 1 map, 1984.

Exhaustive account of this feldspar and of the Harts Range mine in Northern Territory. SG 2.57, RI 1.520–1.527. Some identified as aventurine-microcline, others as untwinned microcline-microperthite and one illustration as aventurine-orthoclase, which seems a little unusual. R.K.M.

BROWN (G.). KELLY (S. M. B.). *Alexandrite-chrysoberyl from Zimbabwe.* Aust. Gemmol., **15**, 8, 275–8, 6 figs (1 in colour), map, 1984.

Examination of crystal and poor quality faceted alexandrites from Fort Victoria,

Zimbabwe. SG 3.8, RI 1.749–1.758, DR 0.009. Typical chromium absorption, many inclusions. R.K.M.

BROWN (G.), SNOW (J.). *Two new thermal testers.* Aust. Gemmol., **15**, 8, 281–5, 7 figs, 1984.

Instrument evaluation of Eickhorst Thermolyzer and Diamontron testers. Committee recommends either instrument for thermal testing of diamond if instructions are followed with care. R.K.M.

BURSIL (L. A.). *Small and extended defect structures in gem-quality Type I diamonds.* Endeavour, **7**, 2, 70–7, 4 figs, 1983.

Gem quality diamonds may have up to one atom of carbon per 1000 replaced by nitrogen. The structures formed by the nitrogen in various states of aggregation range from a few atomic diameters up to platelet shapes several microns in size. The understanding of such defect structures may be related to studies of the geological origin and evolution of various diamond species. The ability to control the defect structures may have important practical applications. R.A.H.

CASSEDANNE (J.). *Le chrysobéryl au Brésil.* (Chrysoberyl in Brazil.) Revue de Gemmologie, 80, 7–13, 11 figs (4 in colour), 1984.

Details of 23 occurrences of chrysoberyl in Brazil are given and constants of the stones listed. Some information on mining is also provided. M.O'D.

CAMPBELL (I. C. C.). *The Independent Coloured Stone Laboratory(I.C.S.L.).* South African Gemmologist, **1**, 1, [7–9]*, 1984.

I.C.S.L. is thought to be the only laboratory in S.Africa accredited under the auspices of the Accredited Gemologists Association (U.S.A.). Some stones tested recently include (1) a suspect ruby (slightly over 1 ct) with a triangular inclusion (identity unknown, but looking like some platinum inclusions in some synthetics) not yet definitely identified as natural or synthetic, (2) a heat-treated Verneuil synthetic ruby with a small 'fingerprint' inclusion (curved striae, not visible under 60× magnification, were just seen with immersion in methylene iodide and high intensity lighting reflected and transmitted through an iris diaphragm closed to the size of the stone), (3) another natural-looking Verneuil synthetic ruby with induced fractures (curved striae visible only when immersed), (4) two large apparent aquamarines, which were in fact crown glass coloured by an element other than cobalt, (5) a 3 ct bluish-green stone purchased as tsavorite [*sic*], which was tourmaline coloured mainly by vanadium, (6) a small golden-yellow natural sapphire which faded in direct sunlight, and (7) a round emerald-green doublet from Zimbabwe showing normal Sandawana-type RI on the table and tremolite inclusions, but pavilion was clean glass of surprisingly good colour, and the join (coinciding with the girdle) was free of trapped air. J.R.H.C.

CAVENEY (R. J.). *De Beers Diamond Research Laboratory Report No. 13, Advances in diamond's 'Exotic' applications.* Indiaqua, 35 (1983/2), 125-7, illus., 1983.

Although non-abrasive applications for industrial diamond are small in total economic value when compared with their more common abrasive uses (e.g. in

* Page 7 is not numbered and pages 8 and 9 are numbered 2 and 3. – Ed.

drilling, sawing, grinding, lapping and polishing), there is however a range of more exotic applications where the unique properties of diamond make it the preferred, if not the only, choice of material.

These non-abrasive applications include the diamond window used to protect the spectral analysis equipment in the Pioneer space probe to Venus, the precision diamond knife used in eye surgery and microsurgery, and the diamond high-pressure cells used in the preparation of solid crystalline hydrogen for rocket fuel or as a source of hydrogen for fusion. P.G.R.

CAVENEY (R. J.). *De Beers Diamond Research Laboratory Report No. 17: The origin of diamonds.* Indiaqua, 39 (1984/3), 115–19, 2 figs, 1984.

The growth of diamonds in the depths of the earth and their subsequent emplacement in kimberlite pipes have been the subject of debate for many years. At first it was thought diamond crystallization was associated temporally and spatially with the genesis of kimberlite. More recently, following the laboratory growth of diamond at low pressures and temperatures (known as metastable diamond growth), it has been proposed that diamonds crystallized from kimberlite magma at shallow depths during or after emplacement (known as the 'shallow-earth theory'). However, the study of mineral inclusions in diamond (chromite, olivine, garnet and clinopyroxene) and their phase equilibria has provided clues to both the chemistry of diamond genesis and the conditions under which diamond grew. These studies, and the great difference found in the ages of these inclusions and that of kimberlite (which is comparatively young), confirm that diamond grew under diamond-stable conditions at depths in excess of 150km below the earth's surface. P.G.R.

CHADWICK (J. R.). *Big stones offset low grade at Lesotho's diamond mine.* Indiaqua, 29, 27–33, 17 figs (13 in colour), 1981.

The mine at Letseng-la-Terai in Lesotho lies at 10 500 feet above sea level. At the time of writing 7.6% of the production was larger than 14.7 ct. M.O'D.

COZAR (J.S.). *Contribución al conocimiento de la naturaleza, génesis e identificatión de las inclusions presentes en los rubies sintéticos de fusión Verneuil y de melt-fluxion Chatham y Kashan.* (Contribution to knowledge of the nature, genesis and identification of the inclusions present in Verneuil fusion and Chatham and Kashan flux-melt synthetic rubies.) Bol. Soc. Españ. de Mineralogia, **7**, 31–6, 11 figs, 1983.

Fluid and crystalline inclusions in synthetic rubies are described and illustrated. The rubies grown by the Chatham process frequently contain tabular crystals of platinum. R.A.H.

DABEK (Y.). *L'opale d'Australie.* (Australian opal.) Monde et Minéraux, 65, 32–6, 9 figs (6 in colour), 1985.

Attractively-illustrated general piece on opal from Australia. M.O'D.

DAHANAYAKE (K.). *Modes of occurrence and provenance of gemstones of Sri Lanka.* Mineralium Deposita, 15, 81–6, 2 figs, 1980.

Most of Sri Lanka iiis underlain by Precambrian metamorphic rocks from the amphibole, cordierite and pyroxene facies. Gem minerals are found mostly in the

cordierite and pyroxene facies in the South-western and Highland groups of rocks. Sources of gem minerals are garnetiferous gneisses, cordierite gneisses, marbles and pegmatites. M.O'D.

DANILO DO RIO (S.). *Double production d'émeraudes pour la mine de Sta-Thérèse de Goias (Brésil).* (Emerald production from the mine at Sta Thérèsa in the state of Goias, Brazil, is doubled.) Revue de Gemmologie, 81, 21, 2 figs, 1984.

Production at the mine is increasing and yield is expected to double. The mining area is divided into five zones, Trecho Velho, Trecho Nove, Cata ze Maria, Invasion, Mine des Barbus. Up to 5000 miners are employed. M.O'D.

DESHPANDE (M. L.). *Diamond search in India.* Indiaqua, 26, 27–35, 36 figs (33 in colour), 1980.

The use of Landsat imaging as a technique for identifying potential diamond deposits is suggested, with notes on the history of diamond mining in India. M.O'D.

DORLING (M.), ZUSSMAN (J.). *An investigation of nephrite jade by electron microscopy.* Mineralog. Mag., **49**, 1, 31–6, 8 figs, 1985.

Two specimens of tremolite from Wyoming, and also a richterite from California, all with jade texture, have been examined by TEM using ion-thinning for specimen preparation. The specimens contain clusters of very small lath-like crystallites with their *c* axes approximately parallel but in a range of azimuthal orientations. It is suggested that these clusters, which are themselves in various orientations, are the result of post-tectonic recrystallization of strained amphibole crystals, the new crystals inheriting the *c*-axis orientations of the old. The extreme toughness of nephrite jade is attributed to a number of sub-microscopic features observed, including the sizes, habits and orientations of the crystallites and the nature of the grain boundaries. R.A.H.

EDRISINGHE (B.). *XIX International Gemmological Conference, 1983.* J. Gemmologists Association of Sri Lanka, 1, 41–9, 1984.

An account of the 1983 International Gemmological Conference,* which was hosted by the Gemmologists Association of Sri Lanka, with particular emphasis on the organizational preliminaries and the social side. J.R.H.C.

FAZLI (M. S. M.). *International Coloured Gemstone Association.* J. Gemmologists Association of Sri Lanka, 1, 31–2, 1984.

Records the foundation of I.C.G.A. at a Preliminary Meeting at Acapulco in January-February 1984† and its objects. The next meeting will be at Idar-Oberstein in May 1985. J.R.H.C.

FRYER (C. W.), ed., CROWNINGSHIELD (R.), HURWIT (K. N.), KANE (R. E.). *Gem Trade Lab Notes,* Gems Gemol., **XX**, 3, 167–73, 18 figs in colour, 1984.

A 'phantom' growth plane in diamond; swirled graining in a cubic zirconia and snow-like white (ZrO_2) powder-filled negative inclusions in another are described and illustrated. Green-dyed beryl; a Lechleitner coated 'emerald' with unpolished

* See *J. Gemm.*, 1984, XIX(1), 92–4. – Ed.

† See *J. Gemm.*, 1984, XIX(3), 288. –Ed.

facets and a near colourless enstatite crystal offered as ekanite are also nicely depicted.

Pearls. An abalone pearl of exceptional size (78 x 46 x 12mm) illustrated with its parent shell. Keshi ('accidental' fresh-water pearls) were found to be tissue-nucleated salt-water pearls and probably Australian. White cultured pearl necklace x-rayed showed opaque shadows at drill-holes, reminiscent of silver-stained black pearls. Imitation pearls in Biwa shapes were M.O.P. centred. Seed pearl rope proved to be glass centred imitation. Another seed pearl necklace had imitation pearls intermingled with natural pearls.

Turquoise backed with metal-loaded epoxy-resin matrix in a closed setting brings the comment that stones of this type in such settings should be assessed on a 'so far as mounting permits' basis. R.K.M.

FRYER (C. W.), ed., CROWNINGSHIELD (R.), HURWIT (K.N.), KANE (R. E.). *Gem Trade Lab Notes.* Gems & Gemmology, **XX**, 4, 228–33, 18 figs (17 in colour), 1984.

A small faceted diamond with a *loose* diamond inclusion is illustrated. Indian carved 'emerald' and enamel necklace was found to be carved quartz with green backing. Oolitic opal is compared with sugar-treated opal. The first Tennessee cultured pearls are examined and discussed. Bluish-black cultured pearls proved to be stained with a web-like pattern of colour in some. 'Strawberry' quartz dark brown star owed its star to oriented crystals of goethite, not to reflection. Small corundum bead owed its colour to red substance in drill hole. A 20 ct faceted ruby proved to be a doublet with synthetic colourless spinel top and Verneuil ruby base; reason for such an artefact is obscure. Red-purple and a pinkish-orange sapphire proved by chalky fluorescence to short UV light to be heat-treated stones. Pinkish-purple natural spinel had colour shift to pink in incandescent light, long UV gave moderate chalky yellow-green fluorescence. A brownish-grey tourmaline cat's-eye had large hollow tubes partly filled by a plastic, leaving bubbles. R.K.M.

GARCIA GIMENEZ (R.), GIL SANCHEZ (I.), GARCIA GUINEA (J.), LEGUEY JUMENEZ (S.). *Mineralogía de las maderas silicificades de Palmaces de Jadraque (Guadalajara).* (Mineralogy of the silicified wood of Palmaces de Jadraque, Guadalajara.) Bol. Soc. Españ. de Mineralogía, **7**, 115–22, 1 map, 8 figs, 1983.

The mineralogy of agatized woods in volcaniclastic host rocks on the shore of the Palmaces de Jadraque reservoir, NE. of Madrid, has been studied. The cellular structures have been replaced by chalcedony and iron oxides; 20% of the cells have retained their nucleus, now composed of framboidal aggregates of pyrite cubes 1μm across. The pyrite develops inside the nucleus and the cells are filled with opal while the iron oxides line the cell walls. The colour changes depend on the intensity of this process. R.A.H.

GRIGORIEV (A. P.), Kovalsky (N. V.). *Working of diamond with metal.* Indiaqua, 39 (1984/3), 47-54, 13 figs (2 in colour), 1984.

The authors work at the Institute of Geology in the Yakutian Branch of the Siberian Department of the U.S.S.R. Academy of Sciences, and deal with the problems of natural diamond origin.

A striking phenomenon was observed by these researchers during an experiment on diamond crystallization carried out at atmospheric pressure. When a piece of metal foil was placed on a diamond and heated in a hydrogen atmosphere, the foil progressively sank into the body of the diamond to form a smooth-walled hole. The simplicity of producing various intricate hollows in diamond by use of the technique caused the researchers to explore its possible application to the working of diamond. The resulting project is now in its tenth year, and the method has been patented in several countries, including the U.K.

The mechanics of the technique are quite simple. A suitably shaped piece of iron or nickel foil is placed on the surface of the diamond, and this dissolves the diamond-carbon over the area of contact. The dissolved carbon diffuses through the foil, reacts with hydrogen at the foil's upper surface and is removed as methane. As a result of the dissolving of the diamond on the lower surface of the foil, and its conversion to gas on its upper surface, the foil sinks uniformly into the diamond. Several factors aid the process: diamond readily dissolves in certain metals just as if it were ordinary black carbon; because of carbon's small atom size, it diffuses fairly quickly in a metal; the carbon dissolved in a metal is chemically much more active than diamond and reacts readily with hydrogen.

The authors believe that the possibility of using this thermochemical process to etch an image on to the face of a diamond may bring engraved diamonds into fashion. Other uses for the technique include the improved sharpening of diamond knives used for eye surgery, cutting diamond gear wheels, wire sawing of diamond, the boring of square holes through diamond for wire-drawing applications, and the shaping of synthetic polycrystalline diamond. Rough diamond flats or cleavage fragments, which if it were not for the hardness of their crystal orientation would be an ideal shape for the Princess cut, can now be formed by thermochemical working.

P.G.R.

GÜBELIN (E.). *Opale aux Mexico.* (Opals from Mexico.) Lapis, **10**, 1, 23–30, 25 figs in colour, 1985.

The whole of the Mexican opal industry is reviewed with particular attention to the inclusions found in opal from Queretaro. Much of the included material is cristobalite or goethite. M.O'D.

GUNAWARDENE (M.). *Inclusions in taaffeites from Sri Lanka.* Gems Gemol., **XX**, 3, 159–63, 8 figs in colour, 1984.

46 taaffeites were obtained from nine different gem areas and examined for inclusions. Apatite, phlogopite, spinel, muscovite and negative crystal inclusions were identified. R.K.M.

GUNAWARDENE (M.). *A close examination of platinum inclusions in Chatham blue and orange sapphires.* J. Gemmologists Association of Sri Lanka, 1, 33–7, 6 figs (3 in colour), 1984.

Chatham flux-grown synthetic blue and orange sapphires contain platinum inclusions, which prove their synthetic nature. J.R.H.C.

GURNEY (J.). *Formation of the diamond.* Indiaqua, 23, 63–4, 2 figs in colour, 1979.

A short account of modern theories of diamond formation with reference to kimberlites and mineral inclusions. M.O'D.

GURNEY (J.). *The Monastery mine.* Indiaqua, 29, 21–4, 13 figs in colour, 1981.

The Monastery mine is in the eastern Orange Free State, South Africa. Production is high but the quality very variable. M.O'D.

GURNEY (J.). *What is kimberlite?* Indiaqua, 23, 57–9, 5 figs (3 in colour), 1979.

The composition of kimberlite and its discovery are discussed with reference to diamond mining. M.O'D.

HARDER (H.). *Zur Unterscheidung des Diamanten von Imitationen mit einfachen Mitteln.* (The investigation of imitation diamonds by simple methods.) Aufschluss, 35, 363–73, 2 figs, 1984.

Simple tests for the identification of diamond and its imitations are outlined. M.O'D.

HOFMANN (C.), HENN (U.). *Grüne Sphalerite aus Zaire.* (Green sphalerite from Zaire.) Z.Dt.Gemmol.Ges., **33**, 1/2, 72–4, 1 graph, bibl., 1984.

An English version of this article was published on pages 416–18 above. E.S.

HUGHES (R. W.). *Surface repaired rubies.* Aust. Gemmol., **15**, 8, 279–80, 4 figs in colour, 1984.

Another report on Thai rubies with glass-filled surface holes. R.K.M.

HURLBUT (C. S., Jr.), FRANCIS (C. A.). *An extraordinary calcite gemstone.* Gems & Gemmology, **XX**, 4, 222–5, 4 figs (2 in colour), 1984.

A 1156 carat faceted calcite exhibits multiple coloured images of the lower pavilion facets through the table due to the presence of a twin plane which passes diagonally between table and culet, doubling and quadrupling expected images. The apparent high degree of fire is due to the large size of the stone. R.K.M.

KANE (R. E.). *Natural rubies with glass-filled cavities.* Gems & Gemology, **XX**, 4, 187–99, 15 figs (14 in colour), 1984.

Investigates Thai rubies with large surface cavities in-filled with glass, probably at the same time as they were heated to improve colour. 'Glass-repaired' stones have been reported recently in Britain, United States and Thailand, where the faking probably originated. It enhances weight and appearance of the stone and is considered fraudulent unless openly declared whenever the stone is sold. Filled areas easily detected under magnification by difference in surface lustre when light is reflected from the polished surface. R.K.M.

KOIVULA (J. I.). *Inclusions in a better light.* Z.Dt.Gemmol.Ges., **33**, 1/2, 43–7, 6 figs in colour, bibl., 1984.

In gemmology the separating of natural gemstones from the synthetic counterparts is of utmost importance. The article stresses the tremendous role played by inclusions and the importance of the modern gemmological microscope. E.S.

KOIVULA (J. I.), ed., *Gem News.* Gems Gemol., **XX**, 3, 174–7, 2 figs in colour, 1984.

Diamonds: Indian cutters complain that Australian rough takes longer to facet. De Beers to start drilling for diamond near Kalgoorlie, W. Australia. 400,000 people

now employed in diamond cutting in India, and 100,000 in cutting coloured stones. Aredor Diamond Mine, Guinea, will go into full production.

Coloured stones: A new corundum treatment. Asian Institute of Gemmological Sciences, Bangkok, has noticed rubies in which surface holes have been filled with fused glass to improve appearance and add to weight. RI of glassy in-fill is 1.52, often containing bubbles. Immersed in methylene iodide, filled holes stand out in high relief. [The British Gem Laboratory have also reported finding these – see pp. 293–7 above.]

GEMCP auction in Karachi held in May and emeralds and rubies from Pakistan and lapis lazuli and spinels smuggled from Afghanistan were offered. To decrease problems of illegal mining and smuggling in their own country joint ventures are offered to tribes in mining areas. [Double values with regard to smuggling?]

Zambia. Saudi Arabia emerald contract has not been honoured and is cancelled and a new one signed with a European and South American consortium.

Precious metals: brief reports from East Rand (platinum); Ghana; Japan; Knob Hill, Washington; Val d'Or, Quebec; Philippines and Zimbabwe (all on gold).

Simulated pearls offered in U.S. as 'premature cultured pearls' is unfair trading and rules have been changed to prevent it. Interesting glasses from Iimori Laboratory Ltd included 'maple stone', a dark green glass with leaf-like dendrites of devitrified synthetic cuprite. This is illustrated.

Smithsonian Institution displayed 'Dark Jubilee', Australian black opal of 318.44 ct, donated by Zale Corporation, and Star of Bombay sapphire bequeathed by actress Mary Pickford, for the Centennial of the National Gem Collection in April 1984.

R.K.M.

KOIVULA (J. I.), ed. *Gem News.* Gems & Gemology, **XX**, 4, 242-5, 3 figs in colour, 1984.

Diamonds. A 12 year loan of US$ 32 million to Northern Mining Corporation for Argyle, W. Australia development. 50 ct Golconda D diamond reappeared in Bombay and was bought by Graff Diamonds Ltd. John Sinkankas quotes 1975 report on diamonds in Thailand. At Cornell University a 4000°C laser at 120,000 atmospheres caused accidental melt to a small area of a diamond anvil press. Punch-Jones 34.46 octahedron, found 1928 in West Virginia, sold by Sotheby's. World's largest known uncut diamond displayed at Smithsonian; at 890 ct some think it may cut a larger stone that the Cullinan I (530.20 ct). U.S.S.R. claim to have produced a 2 kilogram synthetic diamond crystal.

Coloured stones. First-sized Mexican opal with fine play of colour found in Queretaro. Golden danburite from Madagascar, pink zircon from Australia and colourless andalusite from Brazil reported by Spanish Gemmological Association. Moroccan anglesite coloured amber-red by dipping in bleach. Fine emerald crystal of 63.70 ct found at Rainbow End mine in North Carolina, another of 1800 ct was of specimen quality only.

Precious metals. High yield of gold and other metals found on west side of Cook's Inlet, Alaska. Refinery opened in Singapore. Sri Lankan gold is to be hallmarked; India, Hong Kong and Singapore make similar arrangements.

Synthetics. General Electric announce the making of the first synthetic jadeite, high temperatures and pressures in diamond synthesis presses were needed. Green, black or lavender shades possible using chromium or manganese dopants. No com-

mercial production planned. Russian hydrothermal emeralds examined and similarity with Zambian natural stones and overlap of testing constants mean that further investigation is needed.

Announcements. Largest faceted diamond currently on display in U.S. is the Ashley 102 ct light yellow at Los Angeles County Museum; once part of Czarist Crown Jewels. Tiffany 'Iris' corsage containing 120 Yogo Gulch, Montana, sapphires is on display in Baltimore. Dates of other shows are given.

American Gem Trade Association recommends that gemstone purchasers be made aware that natural stones are processed by a. cutting and polishing, b. heating to permanently change color, c. application of colourless oil, d. bleaching, e. non-detectable irradiation to permanently change color. It is not acceptable to offer for sale, without full disclosure, gemstones subjected to f. dyeing, tinting, laser drilling, g. irradiation or heating where colour change is not permanent, h. impregnation with wax, paraffin, glass plastic or colored oil, j. composite process, overgrowth and surface diffusion. Other treatments will be considered when notified. R.K.M.

KOIVULA (J. I.), FRYER (C. W.). *Identifying gem-quality synthetic diamonds: an update.* Gems Gemol., **XX**, 3, 146–58, 19 figs in colour, 1984.

A paper to quash American rumours that carat sized synthetic diamonds are now available. Three cut stones (largest 0.40 ct) and five crystals (largest 0.735 ct) were re-examined. No other faceted synthetic diamonds are known.

It was shown that these stones differed from natural diamonds in their inclusions, internal strain patterns, fluorescence and phosphorescence, conductivity and magnetic attraction and could therefore be identified positively as synthetic. New methods of manufacture, should they be found, would mean new products and the identification problem would start afresh, but there seems no reason to believe that those products would not be recognizable as man-made. R.K.M.

KOIVULA (J. I.), FRYER (C. W.). *Green opal from East Africa.* Gems & Gemology, **XX**, 4, 226–7, 4 figs in colour, 1984.

An opal with nickeliferous green body colour from Tanzania, looking very like chrysoprase. RI 1.452, SG 2.125. R.K.M.

MADIGAN (R.). *Diamond exploration in Australia.* Indiaqua, 35, 27–38, 47 figs (46 in colour), 1983.

A history of the discovery and production of diamond in Australia. M.O'D.

MANSON (D. V.), STOCKTON (C. M.). *Pyrope-spessartine garnets with unusual color behaviour.* Gems & Gemology, **XX**, 4, 200–7, 6 figs (4 in colour), 1984.

A further contribution from the research into garnets by these authors deals with 32 stones which showed 'alexandritic' changes of colour under different light sources. [The regrettably misleading trade name 'Malaya' is used.] R.K.M.

MERTENS (R.). *Hauyn, ein seltener Edelstein.* (Hauÿne, a rare gemstone.) Z.Dt.Gemmol.Ges., **33**, 1/2, 65–7, 4 figs in colour, bibl., 1984.

Hauÿne is a beautiful blue gemstone found in pumice in the volcanic Eifel near the lake of Laach. Most crystals are tiny, pea-size crystals being a rarity, but all of a

beautiful blue. They are silicates of a complicated composition, cubic, mostly found as cubes or rhombic dodecahedra, but well crystallized finds are rare. RI 1.502, SG 2.40. Hauÿne is a constituent of lapis lazuli. E.S.

NEUMANN (E.), SCHMETZER (K.). *Farbe, Farbursache und Mechanismen der Farbumwandlung von Amethyst. (Colour, cause of colour and mechanism of colour change in amethyst.) Z.Dt.Gemmol.Ges.*, **33**, 1/2, 35–42, 1984.

The colour in amethyst is caused by Fe^{4+} colour centres incorporated substitutionally on tetrahedral Si^{4+} sites of the quartz structure. Colourless quartz with Fe^{3+} is converted to violet amethyst by ionizing radiation developing Fe^{4+} and Fe^{2+} centres. Both iron centres of amethyst are simultaneously converted by heat treatment to yellow and green colour centres. When citrine is heat treated, the iron centres of amethyst are predominantly converted to iron-containing particles. The mechanism of thermal conversion of colour and colour centres by heat treatment of amethyst is discussed. E.S.

NIXON (P. H.). *The prospect of diamonds in the South-West Pacific.* Indiaqua, 28, 11–16, 25 figs (18 in colour), 1981.

Areas with low temperature gradients at the time of eruption are considered likely sources for primary diamond deposits. The south-west Pacific area is being prospected as being worth investigation. M.O'D.

O'DONOGHUE (M.). *Kashmir sapphires.* Art at Auction, 1983/84, 342–4, 2 figs in colour, 1984.

Some Kashmir sapphires have been seen at Sotheby's during the year under review. This short summary of the occurrence and properties of the sapphires is illustrated by two stones, both fetching well into six figures. (Author's abstract.) M.O'D.

POPKOVA (T. N.). (Microhardness of some amber-like fossil resins.) Zap.Vses. Min.Obshch., **113**, 128–33, 5 figs, 1984. [In Russian.]

The microhardness of amber-like resins from the U.S.S.R. (Sakhalin, Taimyer Island and the Pal'mniken Cape) and France was measured by a diamond pyramid indenter with automatic loading at a load time of 30s. The average values for viscous resins were: rumanite 27.4 – 35.5 and succinite 19.7 – 28.1 N/mm^2. The brittle resins gave: allingite 28.5 – 30.5, plaffeyite 27.4 – 22.6, gedanite 25.2 – 30.1, retinite 23.0 – 24.9 and amber-like retinite 26.1 – 29.6 N/mm^2. With increasing O in the viscous resins the structural bonds weaken, H decreases and brittleness increases whereas in the brittle resins H increases and elasticity improves. R.A.H.

PUNCHIAPPUHAMY (T. G.). *Well known gems of Sri Lanka.* J. Gemmologists Association of Sri Lanka, 1, 17–20, 1984.

There is great potential for exploration of '*in situ*' deposits of gemstones in Sri Lanka, since so far mining has been largely confined to alluvial mining in river beds and flood plains. Varieties of gemstones found in Sri Lanka are listed, and some of the well known Sri Lanka gems displayed in museums in U.S.A. and U.K. and held by the State Gem Corporation are listed and described. J.R.H.C.

PUNCHIHEWA (L. J.). *The Gem Trade Laboratory Quality Grading System for Sri Lanka gemstones.* J. Gemmologists Association of Sri Lanka, 1, 21–30, 1 fig. in colour, 1984.

The GTL Quality Grading System based on three primary scales of assessment – (a) Colour Grading Scale, (b) Perfection Grading Scale and (c) Perfection Grading Scale for Phenomenal Gemstones (Star-stones, Cat's eye, Alexandrite) – is described in detail. J.R.H.C.

RECKER (K.). *Synthetische Diamanten.* (Synthetic diamonds.) Z.Dt.Gemmol.Ges., **33**, 1/2, 5–34, 21 figs, bibl., 1984.

A progress report on diamond synthesis methods, including the catalyst-solvent process, direct graphite to diamond transformation, diamond growth under metastable conditions, growth of larger crystals. Some of the properties of synthetic diamond are listed, and the historical development of diamond synthesis experiments given. The author believes that larger synthetic diamonds will soon be on the market, which up to now have not been economically viable. E.S.

ROSSMAN (G.), KIRSCHVINK (J. L.). *Magnetic properties of gem-quality synthetic diamonds.* Gems Gemmol., **XX**, 3, 163–6, 1 fig. in colour, 1984.

A further investigation of the four larger stones discussed by Koivula and Fryer (see above), together with industrial diamond powders from G.E.C. and from P.R. of China. Natural stones and irradiated natural stones were also examined. Synthetic stones were more magnetic. Cut natural diamonds were magnetic initially but cleaning in hot hydrochloric acid removed traces of scaif iron from the polished surfaces and they became markedly less magnetic. There are fundamental differences in the magnetic properties of synthetic and natural diamonds which could be the basis of a distinguishing test. R.K.M.

RUPASINGHE (M. S.). *Radioactive gem minerals from Sri Lanka.* J. Gemmologists Association of Sri Lanka, 1, 5–12, 3 figs, 3 tables, bibl., 1984.

A new radioactive monazite crystal found in Sri Lanka was studied for its rare element chemistry. Differently coloured zircons were analysed and their chemical differences and similarities noted. Th and U were high in the monazite. J.R.H.C.

SAKUNTALA (S.), KRISHNA BRAHMAM (N.). *Diamond mines near Raichur.* J. Geological Soc. of India, **25**, 12, 780–6, 1 map, 1984.

Information relating to diamond mining in the Raichur area of Karnataka State, India, in the fifteenth century is critically analysed. The localities of Alibenchi and Nelaha, near Raichur, are identified. The 'Raichur diamond' in the museum of the Directorate of Mines and Geology (Govt of Andhra Pradesh) is a colourless octahedral crystal of 2.57 ct. A detailed search for kimberlite pipes is suggested. R.A.H.

SALEH (Z. A.). *Growth of the Gemmologists Association of Sri Lanka.* J. Gemmologists Association of Sri Lanka, 1, 38–40, 1984.

Traces the history of the Gemmologists Association of Sri Lanka from its foundation in 1970 under the Presidency of the late Professor K. Kularatnam to the first issue of its Journal in October 1984. J.R.H.C.

SARBAS (B.), GOERG (U.), AMSTUTZ (G. C.), SCHMETZER (K.), BANK (H.). *Zur Genese ostafrikanischer Grossularvorkommen.* (The genesis of East African grossular occurrences.) Z.Dt.Gemmol.Ges., **33**, 1/2, 48–62, 7 figs (6 in colour), bibl., 1984.

Grossularite and zoisite occurrences in Lualenyi and Mangari, Kenya, and Komolo and Merelani, Tanzania, were investigated petrographically and geochemically. Both gem minerals show green and blue-violet colours, caused by vanadium (0.68–3.3% in grossularite, 0.12% in zoisite). They occur in graphite schists, consisting mainly of quartz, potassium-feldspar, graphite with plagioclase, kyanite, micas, scapolite, diopside, epidote or allanite. A polymetamorphic history is supposed.

E.S.

SAUL (J. M.). *Deposits of coloured gemstones: their distribution in time and space.* J. Gemmologists Association of Sri Lanka, 1, 13–16, 2 maps, 1984.

Coloured gemstones occur in characteristic patterns in regions of metamorphosed sediments alongside deep, thin, long-lived zones of high heat-flow, as observable for gem localities in Brazil, Western Africa, Zimbabwe, Zambia, Mozambique, Tanzania, Kenya, Madagascar, South-western India and Sri Lanka, all parts of pre-drift Gondwanaland, where gem deposits are associated with rift valleys or spreading of continental plates.

Other groups of deposits are in the Urals, the region where U.S.S.R./Pakistan/Afghanistan/Kashmir come together, eastern Nepal, Burma and Thailand/Cambodia/Vietnam; these are on the Asian 'mainland' (N. and E.) side of suture lines, continent-continent collision zones and zones of oceanic subduction, which are not identical to rifts, and proximity would not imply the same heat flow, so a fuller understanding of them will depend on additional geological factors.

Similar reasoning can account for deposts in Australia, North America, Europe, and Asia south-east of Lake Baikal.

Emerald deposits appear to have developed in cooler times or niches within the gemstone regions with greater separation from zones of heat flow. J.R.H.C.

SCARRATT (K.). *How to recognise the new Seiko synthetics.* Retail Jeweller, **22**, 569, 16/26, 7 figs in colour, 1984.

The new Seiko synthetics, made by Matsushiwa Kogyo Co. Ltd, an affiliated company of Suwa Seikosha, who also produce quartz crystals for Seiko watches, include synthetic alexandrite, ruby and sapphire by the 'floating zone' method (the crystals being similar in shape to Verneuil boules) and synthetic emerald (flux-fusion), and at present are marketed only in finished jewellery.

The synthetic alexandrite has a good colour change, and neither it nor the synthetic ruby can be distinguished from natural by RI, SG, fluorescence or absorption spectrum (by hand-spectroscope): the most practical method of identification is by examination of internal features under the microscope, of which many are similar to those of Verneuil synthetics (such as tadpole-like bubbles) but the over-all swirled appearance distinguishes them from the Verneuil type, except that the swirled features may appear similar to the curved lines in the Verneuil synthetic ruby.

The RI and SG of the synthetic orange/pink sapphire are similar to those of the synthetic ruby and their fluorescence and absorption spectrum are similar but weak-

er; their internal features (curved or swirled growth structures) are visible only when immersed in methylene iodide.

Only one synthetic emerald was available for examination: its RI (1.561–1.565) and SG (2.66) were similar to those of other synthetic emeralds on the market, and its absorption spectrum was similar to that of other synthetic and natural emeralds, but its fluorescence under both long- and short-wave UV was green, unlike any so far seen in either natural or synthetic emeralds. The inclusions, such as two-phase feathers and 'Venetian blinds' zoning, were typical of most synthetic emeralds, but viewed without magnification or immersion the stone appeared to have a very dusty surface, the dust particles being in fact within the stone, and if these are common in other samples they should indicate the stone's origin. J.R.H.C.

SCHMETZER (K.). *Pektolith aus der Dominikanischen Republik.* (Pectolite from the Dominican Republic.) Z.Dt.Gemmol.Ges., **33**, 1/2, 63–4, 2 figs in colour, bibl., 1984.

Two rough stones from the Dominican Republic were found to be pectolite. The material is light blue to bluish white, used for cabochons and is known commercially under the name 'Larimar' stone. It is fairly dense (SG 2.74–2.90) and takes a good polish. E.S.

SCHMETZER (K.), BANK (H.). *Zusammensetzung, Eigenschaften und Herkunft eines neuen Hämatitmaterials.* (Composition, properties and origin of a new haematite material.) Z.Dt.Gemmol.Ges., **33**, 1/2, 75–8, 1 fig., bibl., 1984.

An English version of this article was published on pages 343–7 above. E.S.

SCHRADER (H.-W.). *Chromdiopsid aus der UdSSR.* (Chrome diopside from U.S.S.R.) Z.Dt.Gemmol.Ges., **33**, 1/2, 68–71, 2 figs in colour, bibl., 1984.

An English version of this article was published on pages 213–17 above. E.S.

SCHLUSSEL (R.). *Défauts de structure dans les émeraudes naturelles et synthétiques.* (Structural defects in natural and synthetic emeralds.) Revue de Gemmologie, 81, 13–18, 32 figs in colour, 1984.

Crystal and growth structure of a number of emeralds of different origins, both natural and synthetic, are illustrated and discussed together with a table of constants. M.O'D.

SELLSCHOP (J. P. F.). *The gem carbonaceous.* Indiaqua, 26, 95–9, 8 figs (1 in colour), 1980.

Brief form of a paper describing the part played by nuclear physics in diamond studies. M.O'D.

SHIGLEY (J. E.), FOORD (E. E.). *Gem quality red beryl from the Wah-Wah Mountains, Utah.* Gems & Gemology, **XX**, 4, 208–21, 14 figs in colour, 1984.

Described as the rarest of the gem beryls, this red material occurs in small, rather fractured crystals in two of several rhyolite outcrops of this region. RI varies slightly with colour and can be as low as 1.564–1.568 with small birefringence. SG 2.66 to 2.70. No water is present in composition. Manganese is principal cause of colour and well coloured stones have a distinctive absorption spectrum. R.K.M.

SNOW (J.), BROWN (G.). *LED refractometer light sources,* Aust. Gemmol., **15**, 8, 255–7, 4 figs, 1984.

Assessment of two Australian LED 'sodium' light sources, one of three and the other of six components. Both were of limited efficiency owing to broad transmission, and the first was rather under-powered. R.K.M.

SOBOLEV (N. V.). *Siberian diamonds from the earth's mantle.* Indiaqua, 26, 9–15, 18 figs (7 in colour), 1980.

Describes the discovery of diamonds in Siberia with some details of particular features of the stones. M.O'D.

SOBOLEV (N. V.). *What the Siberian diamonds tell us.* Indiaqua, 30, 11–14, 17 figs (7 in colour), 1981.

Inclusions in Siberian diamonds give an indication of the date of formation of the stone. SEM photographs show crystals of various minerals, including garnet and olivine, as inclusions. M.O'D.

SOLANS HUGUET (J.), DOMENECH CASELLAS (M. V.). *Estudio gemologica de la cruz de la Victoria,* (Gemmological study of the cross of Victoria.) Gemologia, **20**, 61/2, 7–17, 6 figs, 1984.

The Cross of Victoria is a jewel in the Cathedral of Oviedo, Spain. Among the stones with which the cross is set are green beryl and quartz. M.O'D.

STACEY (G.). *Almandine,* Wahroongai News, **18**, 10, 23-6, 3 figs, 1984.

A straightforward account of the commonest of the garnets. R.K.M.

STOCKTON (C. M.). *The Chemical distinction of natural and synthetic emeralds.* Gems Gemol., **XX**, 3, 141-5, 1 fig. in colour, 1984.

38 emeralds from 20 localities and 11 synthetics from 6 manufacturers were analysed by electron microprobe for NaO, K_20, MgO, FeO, Al_2O_3, V_2O_3, Cr_2O_3, SiO_2 and Cl, checking by x-ray fluorescence spectrometry. Cl was found in hydrothermal synthetics. Certain trace elements confirmed natural stones.

Ms Stockton envisages future clean synthetics or others controlled to emulate natural emerald more closely, when presently reliable tests may not apply, and has therefore sought chemical differences. Expenses of such testing precludes its use except for important stones when unproven by normal gemmological methods. R.K.M.

STOCKTON (C. M.), MANSON (D. V.). *'Fine green' demantoids.* Gems Gemol., **XX**, 3, 179, 2 figs (1 in colour), 1984.

A short report on the finest quality of demantoid, which was not available at the time of their earlier report (abstracted on p. 185 above). R.K.M.

SWEANEY (J. L.), LATENDRESSE (J. R.). *Freshwater pearls of North America.* Gems Gemol., **XX**, 3, 125–40, 10 figs in colour, 1984.

Excellent account of pearls produced by freshwater Unio mussels, some over 80 ct in weight and astonishingly beautiful. Spherical pearls rare. Different Unio species vary from 1″ to megalonaias gigantea which can span 12″. Most are long lived and can

reach 50 years which accounts for sizes of some pearls. They are often very baroque and wing shapes are common. Colours vary and add charm to the pearl. Pearl culturing is now being carried out by authors in Tennessee, using these bivalves, but water pollution and other problems occur. R.K.M.

THOMAS (A.). *Perspective on Gemmology, Part 1.* South African Gemmologist, 1, 1, 3–6, 1984.

A review of the progress of gemmology up to 1974. A fledgeling in the thirties, it was well established by the fifties. New generation synthetics prompted new techniques for identification. The flux-melt process then coming into commercial use had been pioneered by scientists in the previous century, but industry's demands had been met by the flame-fusion process. After Chatham and Gilson products, loupe and Chelsea filter were no longer sufficient to identify emerald.

Nassau realized the potential for production of new gem materials of the developments in the sixties of solid state physics. By the turn of the decade Zambian emeralds, tanzanites and tsavorites [*sic*] were becoming familiar and the new Czochralski pulling technique was replacing the Verneuil process, and YAG soon superseded strontium titanate as a diamond substitute. J.R.H.C.

WEDLAKE (R. J.). *History of diamond synthesis.* Indiaqua, 24, 23–6, 10 figs (1 in colour), 1980.

The forms of carbon and the history of diamond synthesis are discussed with particular reference to grits. M.O'D.

WILKS (E. M.), WILKS (J.). *The abrasion resistance of brown diamonds.* Industrial Diamond Review, **44**, 2, 82–5, 6 figs, 1984.

Measurements of the abrasion or polish of six brown Type I diamonds show that they have an abrasion resistance appreciably greater than that of white Type I diamonds. It seems probable that this is associated with lattice imperfections revealed by x-ray topography and by the scattering of light in the diamonds. R.A.H.

How Dr Williamson nearly missed finding the Mwadui diamond pipe. Indiaqua, 23, 29–32, 11 figs (2 in colour), 1979.

A brief biographical account of part of the life of Dr John J. Williamson, dealing with his work at Mwadui, Tanzania. M.O'D.

Namaqualand discoveries. Indiaqua, 23, 37–42, 17 figs (2 in colour), 1979.

Describes early prospecting and the first finds of diamond in South-West Africa. Mining scenes are depicted. M.O'D.

'R.J.' study tour to Brazil proves a mine of information. Retail Jeweller, **22**, 569, 6, 1 photo, 1984.

Describes visits to emerald mines (Socoto, in area of Turutiba), lapidary works where mosaics are made from natural gem materials for table-tops, etc., a tourmaline mine called Lavra Golconda, a topaz mine near Rodrigo Silva (about 20 km south-west of Ouro Preto) and the mining methods employed. J.R.H.C.

Synthetic stone. Four Seasons of Jewelry, 54, 30–61, illus. in colour, 1984. [In Japanese.]

A resumé of the present state of synthetic gemstones in Japan. At least two firms are making jewellery set with synthetic stones and quality is very high. M.O'D.

NOTE: during 1984 gemmological literature was increased by the first appearance of two new periodicals – The South African Gemmologist, Vol. 1, No. 1, July 1984, being the official journal of the Gemmological Association of South Africa (Editor, Mr Arthur Thomas, F.G.A., P.O. Box 4216, Johannesburg 2000, S. Africa), and the Journal of the Gemmologists Association of Sri Lanka, No. 1, October 1984 (Editor, Mr E. Gamini Zoysa, F.G.A., Professional Centre, 275/75 Bauddhaloka Mawatha, Colombo 7, Sri Lanka).

BOOK REVIEWS

BLYTH (F. G. H.), DE FREITAS (M. H.). *A geology for engineers,* 7th edn. Arnold, London, 1984. pp.x, 325. £16.50.

This has always been the best of the 'geology for other specialists' books, and this seventh edition incorporates some new features which should help the non-specialist reader to get to grips with the rather large amount of material that it contains. The structure of the book is different from that of previous editions in that it is now divided into two parts, one dealing with fundamental aspects of earth geology and the other the influence of geology upon engineering.

The illustrations have been updated and most are line drawings. Chapters on rocks, minerals and geological maps have been re-worked to provide a basis for independent work on the part of students; text selection, headings and sub-headings and bibliographies at the end of each chapter are all intended to benefit the student even further and enhance what was already an excellent book.

M.O'D.

FUJISAKI (Y.). *Hoseki chu ken kanbi* (Gemstone inclusions.) Fujisaki, Fukuoka, 1980. pp.178. Illus. in black-and-white and in colour. 25000 yen. (In Japanese.)

Even though the language may deter some readers the standard of the photographs is so high that the book should be carefully examined if encountered. A section on imitation jade is particularly valuable.

M.O'D.

GREENBAUM (W. W.). *The gemstone identifier.* Arco Publishing Co. Inc., New York. pp.viii, 184. Numerous line drawings, 4 plates in colour. $7.95 (soft cover), $13.95 (hard cover).

Apparently intended for the 'uninformed' (American) jeweller and for 'John Q. Public', this is a largely superficial book containing many incorrect and confused statements and adds nothing to gemmology.

It advocates hardness testing; dismisses the refractometer as too expensive; but recommends the Gemoscope, which is far from cheap. Some basic facts and descriptions of gems and testing methods are garbled. Many line drawings are both crude and inadequate; one shows a diamond crystal apparently being *sawn* parallel to the octahedral face with a wood saw. *Synthetic* emeralds are said to contain three-phase inclusions. We are told that all SG liquids other than methylene iodide can be diluted with water. One could quote many other inaccuracies. R.K.M.

HERATH (J. W.). *Mineral resources of Sri Lanka.* 2nd edn. Geological Survey Department, Colombo, 1980. pp.iv, 70. Price on application.

A useful guide containing a short section on gemstone production.

M.O'D.

NASSAU (K.). *The physics and chemistry of color.* John Wiley & Sons, New York, 1984. pp.xx, 454. Illus. in black-and-white and in colour. £45.95.

Apart from its admirable lucidity and wide subject coverage this book will be vital for the serious gemmologist on account of its treatment of gem and mineral coloration. The mechanisms of the 15 different ways in which colour can arise in a substance are closely examined and a number of long-held gemmological suppositions are challenged; one is the cause of colour in blue zoisite (tanzanite); formerly held to be due to vanadium substitution, the colour is here reported to be due to intervalence charge transfer between iron and titanium, as is the case with blue sapphire. This process also gives the blue in benitoite and a brown colour to andalusite. Though gemmologists will turn to their own chapters first all the rest should be read; to ensure that readers have paid sufficient attention to the material, questions, not too searching, are given at the end of each chapter and there are bibliographies at the end of the book, preceded by appendices which treat some of the theories in the body of the book in greater detail. This is an elegant treatment of an elegant subject.

M.O'D.

ROBBINS (M.). *The collector's book of fluorescent minerals.* Van Nostrand Reinhold, New York and London, 1983. pp.xiii, 289. Illus. in black-and-white and in colour. £49.50.

This is a very expensive book, by no means large, and the reader is entitled to expect something rather better than the breathless amateur collector style and hasty presentation that he finds. Virtually all examples are from the United States (this should be stated on the title-page) though a few others have been pushed in at the end of the main descriptive section. The introduction, containing some history of the development of UV lamps, is quite interesting. The descriptive section takes up most of the book, the minerals being arranged chemically. Colour work is attractive, but it is hard to illustrate fluorescing specimens in a way that shows more than a few obvious effects. There is a bibliography, index and some identification tables which are not very helpful, since they merely list yellow fluorescing minerals and so on.

M.O'D.

Ivories of China and the East. Spink & Son Ltd, London, 1984. Unpaged. Illus. in black-and-white and in colour. Price on application.

This is a well-produced sale catalogue and contains details of 294 ivories offered during the period 8th–23rd November, 1984. There is a short bibliography and an introductory note on the nature of ivory.

M.O'D.

The world of Kyocera Crescent Vert. Jewelry New Age, Tokyo, 1984. pp.144. Illus. in colour. 1200 yen.

The book is devoted to a review and illustrations of the Kyocera synthetic ruby, alexandrite, emerald, opal, star ruby and orange 'padparadschah' sapphire.

M.O'D.

ASSOCIATION NOTICES

NEWS OF FELLOWS

Messrs Alan Lam, A.G., F.G.A., and Chris Lam, G.G., F.G.A., are respectively Executive Director and Principal of the newly formed Malaysian Institute of Gemological Sciences (see p. 552).

MEMBERS' MEETINGS

London

On 5th March, 1985, at the Flett Theatre, Geological Museum, Exhibition Road, South Kensington, London, S.W.7., Mr Alec Farn, F.G.A., gave an illustrated talk entitled 'Pearls, the first gems of gemmology'.

Midlands Branch

On 25th January, 1985, at Dr Johnson House, Bull Street, Birmingham, a practical evening was held when members were able to use a wide range of gemmological instruments to examine and test gemstones and crystals.

On 22nd February, 1985, at Dr Johnson House, Major A. K. Crisp Jones gave a talk on 'The Jewellery Quarter and the Arts and Crafts Movement in Birmingham'.

North West Branch

On 17th January, 1985, at Church House, Hanover Street, Liverpool 1, Mr K. Scarratt, F.G.A., gave a talk on the work of the British Gem Testing Laboratory.

On 7th March, 1985, at Church House, Mr D. J. Callaghan, F.G.A., gave a talk entitled 'An Evening with the Gemmological Association'.

On 21st March, 1985, at Church House, Mr C. R. Burch, B.Sc., F.G.S., gave a talk on 'Inclusions in Man-made Gemstones'.

South Yorkshire & District Branch

On 8th February, 1985, at the Montgomery Hotel, Montgomery Road, Sheffield 7, the Annual General Meeting was held at which Mr J. I. Reynolds, F.G.A. and Miss J. I. Platts, F.G.A., were elected Chairman and Secretary respectively. The meeting was followed by a buffet supper.

On 21st March, 1985, at the Sheffield City Polytechnic, Pond Street, Sheffield, Mr D. J. Callaghan, F.G.A., gave an illustrated talk entitled 'From gem to jewel'.

COUNCIL MEETING

At a meeting of Council held on Thursday, 21st February, 1985, at the Royal Automobile Club, London, S.W.1., the business transacted included the following:
(1) on the report of the Chairman that the Basil Anderson Appeal had raised approximately £15000 to date, it was agreed that a list of contributors should be issued in due course;
(2) a request received from the Singapore Gemologist Society for affiliation with the Association was considered and affiliation was granted;
(3) Mr J. R. H. Chisholm having indicated his intention of resigning as Editor of the Journal of Gemmology at the end of 1985 following his 80th birthday and the conclusion of Volume XIX, and at his request, the Council appointed Mr E. A. Jobbins to succeed Mr Chisholm as sole Editor of the Journal and meanwhile to act as Editor jointly with him;
(4) Mr C. R. Cavey was appointed Curator of the Association's collection;
(5) the next meeting of Council was agreed to be held on Tuesday, 28th May, 1985, immediately prior to the Annual General Meeting, at the Flett Theatre, the Geological Museum, Exhibition Road, London, S.W.7.;
(6) the following were elected to membership:

FELLOWSHIP

Barlow, Alice M., Appleton, Wis., U.S.A. 1984
Brown, James E., Sheffield. 1984
Budhwani, Amin M., Bombay, India. 1984
Cahill, Cynthia E., Bangkok, Thailand. 1984
Calduch Sendra, Mª Esmeralda, Barcelona, Spain. 1984
Caracciolo, Marie E., McLean, Va, U.S.A. 1984
Chu, K-C. Quinnie, Don Mills, Ont, Canada. 1984
Courtenay, Jutta W., Hong Kong. 1984
D'Cruz, Jeffrey C., Bombay, India. 1984
Dent, Peter J., Normandy. 1984
Dewendra, Rekha, Matara, Sri Lanka. 1982
Gafner, Antoinette, Liestal, Switzerland. 1984
Goad, Jane F. C., London. 1984
Gol Perlasia, Jose Mª, Barcelona, Spain. 1984
Graham, Kimberley E., Toronto, Canada. 1984
Hall, Michael J. B., London. 1984
Hansen, Jo Anne, Corvallis, Oreg, U.S.A. 1984
Ho, Frankie Ka K., Hong Kong. 1984
Hunt, Jill M., Totnes. 1984
Jerndell, Bo E. O., Stockholm, Sweden. 1984

Jhaveri, Prateik R., Bombay, India. 1984
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LETTER TO THE EDITOR

From Mr Peter G. Read, C.Eng, M.I.E.E., M.I.E.R.E., F.G.A.

Dear Sir,

With reference to Dr Peter J. Crowcroft's letter in the January 1985 issue of the *Journal*,* you may be interested to know that I wrote to Basil Anderson following the publication of Crowcroft's article (on the falsity of the Beilby layer theory) in 1981.† As Anderson was beginning to work on the revision of *Gems* for its 4th edition, and I was in the middle of compiling entries for my *Dictionary of Gemmology*, it seemed germane to ask him whether he was going to modify that section of the book which dealth with the Beilby layer. In his reply to my letter he said that he was present at Imperial College, London, during Professor Finch's confirmatory experiments on the existence of the layer, and did not intend to delete the Beilby layer theory from the book. His view on the matter is summarized in the revised section of the book (page 485) as follows:

'Beilby's contention that in general polishing involved surface flow of the polished material has often been attacked, but the account of his meticulous experiments given in his book *Aggregation and Flow of Solids* (London, 1921) and the later confirmation of his theory by modern methods by G. I. Finch (*Science Progress*, April 1937) are in fact entirely convincing.'

*J. Gemm., 1985, XIX (5), 466-7.—Ed. †J. Gemm., 1981, XVII (7), 459-65.—Ed.

Because of Anderson's strong views on the subject, and despite the circumstantial evidence quoted in Crowcroft's article, I decided to hedge my bets. The Beilby layer entry in my *Dictionary of Gemmology* contains the following statement:
'In 1937 Professor G. I. Finch at Imperial College, London, substantiated and extended Beilby's findings using electron diffraction techniques at grazing incidence to the polished surface. At Diamond Grading Laboratories Ltd, London, R. V. Huddlestone confirmed the existence of the Beilby layer by the use of Nomarski interference contrast techniques. Results of this continuing investigation suggest that the production of the layer is influenced by the lap speed and the difference between the hardness of the material and the abrasive. . . . Despite the evidence, however, strong doubt has been expressed over the existence of the Beilby layer and the validity of the theory.'

It is also of interest to note that in the second edition of his book *Diamonds*, Bruton states (p. 405) that when polishing non-diamond gems 'An experienced lapidary can feel when the surface slips as he is polishing a gem.'

Despite the plethora of scientific papers referred to in Crowcroft's article, the majority of the polishing investigations quoted seem to have been carried out on glass, ceramics and metals. In his conclusion, Crowcroft suggests it is high time that a comprehensive theory of *gemmological* polishing is put forward. Until this happens, and our scientific colleagues produced evidence of the polishing mechanism at work in gem materials, most of us will have to content ourselves with the plausibility of the Beilby layer theory.

Yours etc.,
PETER G. READ

25th March, 1985
Bournemouth, Dorset, U.K.

CORRIGENDA

On p.390 above, in line 10 of the 5th column of Table 1, for '1.672' read '1.762'

On p.412 above, in line 8, for 'or' read 'of', and, in line 10, for 'acicular the crystals' read 'acicular crystals'

On p.439 above, in line 16, for 'darvite' read 'dravite'

On p.445 above, in line 22, for 'studing' read 'studying'

On pp. 456 and 460 above, delete 'Hilton, Barbara W., Riverside, Ca, U.S.A.' and on p. 458 above, before line 1 of 2nd column, and on p. 464 above, after 'Wright, Lee P., Birmingham.' in 2nd column, insert 'Wright-Hilton, Barbara A., Riverside, Ca, U.S.A.

On p.467 above, in line 3 of Corrigenda, for '7/and 8,|' read '7 and 8,' and delete whole of line 9 of Corrigenda.

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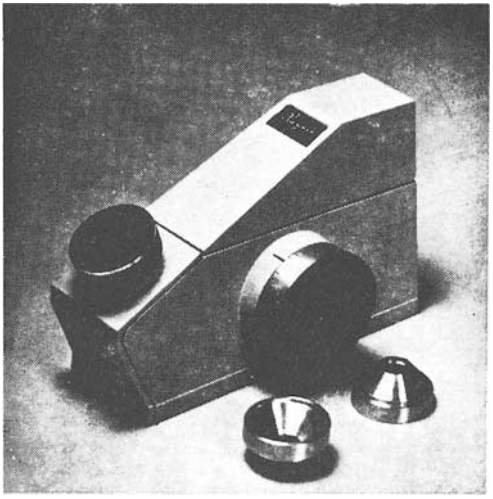

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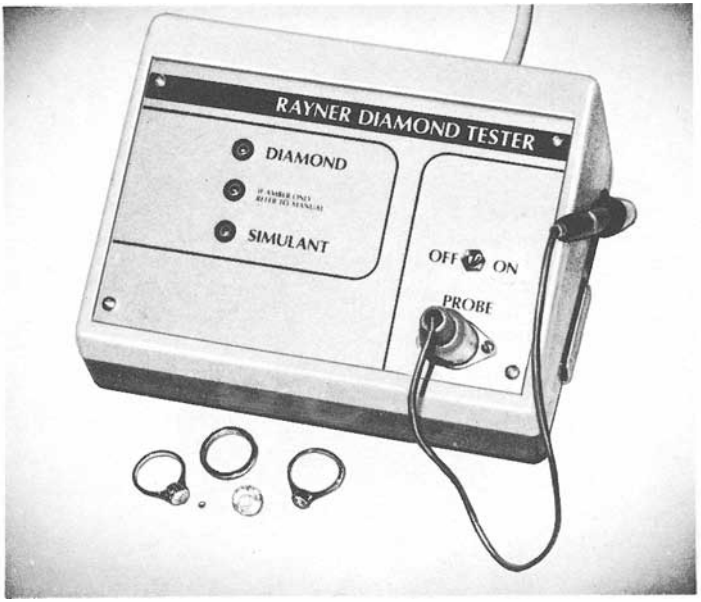

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The *Journal of Gemmology* was first published by the Association in 1947. It is a quarterly, published in January, April, July, and October each year, and is issued free to Fellows and Members of the Association. Opinions expressed by authors are not necessarily endorsed by the Association.

Notes for Contributors

The Editors are glad to consider original articles shedding new light on subjects of gemmological interest for publication in the *Journal*. Articles are not normally accepted which have already been published elsewhere in English, and an article is accepted only on the understanding that (1) full information as to any previous publication (whether in English or another language) has been given, (2) it is not under consideration for publication elsewhere and (3) it will not be published elsewhere without the consent of the Editors.

Articles published are paid for, and a minimum of 25 prints of individual articles may be supplied to authors provided application is made on or before approval of proofs. Applications for prints should be made to the Secretary of the Association—not to the Editors—and current rates of payment for articles and terms for the supply of prints may be obtained also from the Secretary.

Although not a mandatory requirement, it is most helpful if articles are typed (together with a carbon copy) in double spacing on one side of the paper, with good margins at sides, top and foot of each page. Articles may be of any length, but it should be borne in mind that long articles are more difficult to fit in than short ones: in practice, an article of much more than 10 000 words (unless capable of division into parts or of exceptional importance) is unlikely to be acceptable, while a short note of 400 or 500 words may achieve early publication.

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THE JOURNAL OF GEMMOLOGY

and

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Vol. XIX No. 7 JULY, 1985

GEMMOLOGICAL PROPERTIES OF SYNTHETIC CORUNDUMS COATED BY LECHLEITNER

By MAHINDA GUNAWARDENE, F.G.A., D.Gem.G.,
Im Sierling 2, 6581 Hettenrodt, W. Germany

INTRODUCTION

Lechleitner is not a new name in gemmology. He became famous in our science of gems giving an 'emerald coating' to colourless natural beryl. His seeding technique (Figure 1) covered not only beryl seeds, but also quartz and topaz seeds — still, however, providing an emerald appearance (Bank 1976 and 1979). Recently this Austrian manufacturer succeeded in giving a corundum skin to ruby and sapphire seeds.

The initial trials in this new process have been carried out so far only on Verneuil synthetic corundum seeds. The technique is still in the experimental stage. The author was informed by the manufacturer on his achievements about a year ago. However, the author had to endure a great deal of patient waiting before obtaining suitable material for an investigation. The reason is most probably due to the fact that a very few traders are attempting to control the sales of the new product. This was further evident

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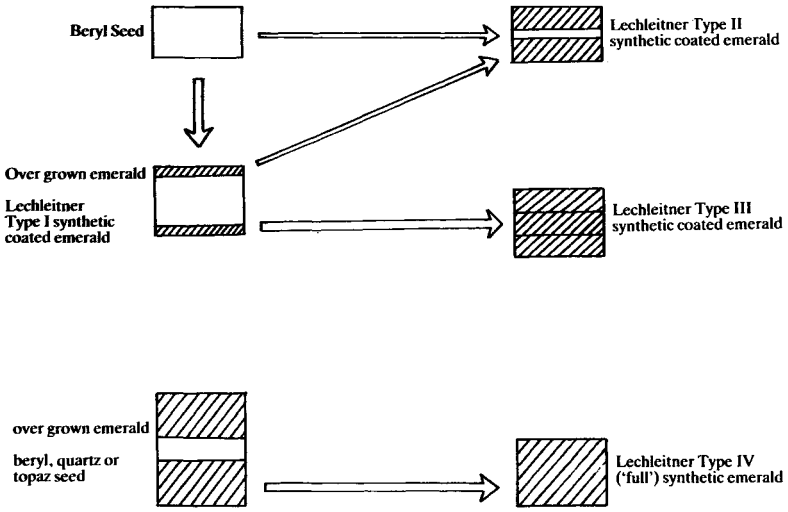

FIG. 1. The famous seeding techniques employed by Lechleitner in emerald.

through the large collection of the material just shown to the author by Mr Lechleitner. Further, the dealers are looking forward to obtaining natural light-coloured sapphires to be used in the process so soon as the manufacturer achieves a considerable success.

The coating is done on all coloured varieties of corundum made by the flame fusion method (Figure 2). The identifications are still easy under gemmological microscopy, with the typical inclusions of Verneuil synthetic corundum. However, if natural seeds are involved, the gemmologist may have to undergo difficulties in determining whether coated or not. Therefore it seemed important to present in detail the characteristics of the material made by Lechleitner. During his studies of the Lechleitner coated synthetic corundums the author observed the importance of the various techniques involved in gem microscopy; and therefore this article aims at describing:

a. different techniques used in gem microscopy, and
b. microgemmology of the material available from the manufacturer.

FIG. 2. These coloured stones are the Lechleitner coated corundums discussed in this article. Weights 1.80 ct to 12.30 ct.

The Microscope and Illumination Techniques

In the course of microgemmological studies two main types of microscope are in use, namely *horizontal* and *vertical*. The illumination techniques used in both these kinds of microscope are basically the same and are known as

a. transmitted illumination,
b. dark field illumination,
c. reflected illumination.

Transmitted Illumination

Figure 3 illustrates typical illumination by transmitted light. In the majority of cases a great deal of the detail of the gem's interior is lost through the transmitted system, especially in corundum gems where the refractive indices of the host gem and air are far different from each other. The light rays passing through the object are mostly lost, and only very few can pass into the microscope system (Figure 4). To avoid such leakage of light the gem must be included in an environment of higher refractive index than that of air. The most suitable for such studies is the immersion technique (Figure 5).

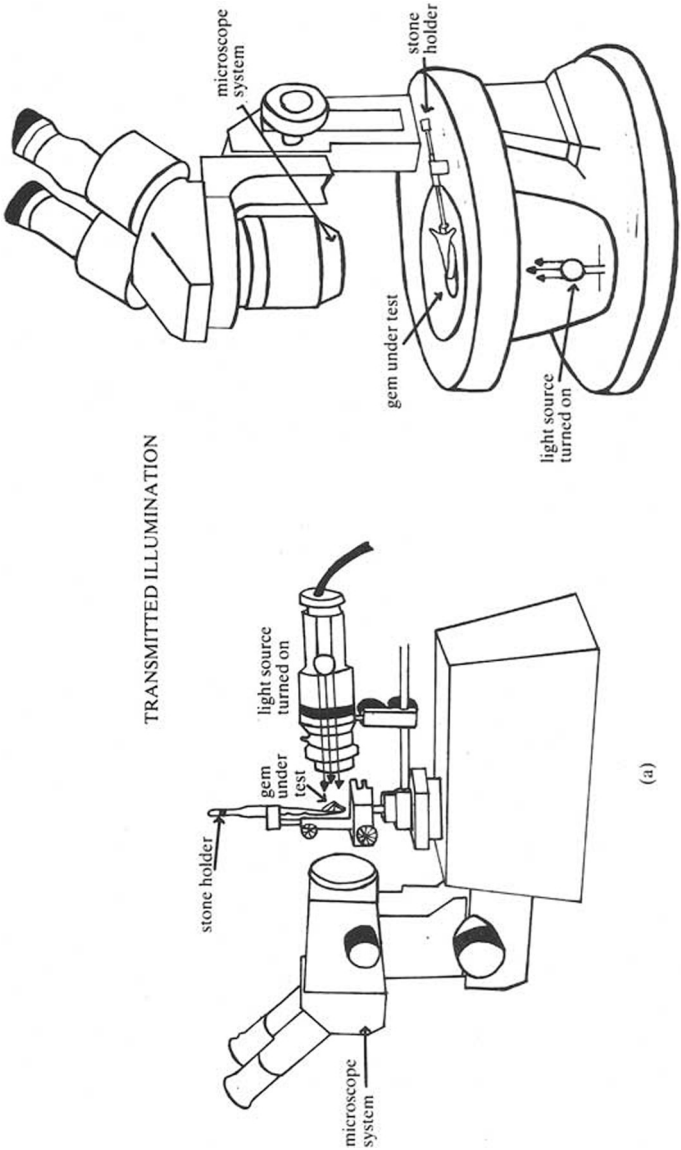

FIG. 3. The transmitted illuminations in (a) *horizontal* and (b) *vertical* gem microscopes. The light passes directly from the light source through the gem to the microscope system. Addition of two polarizers, the polarizer and the analyser, converts the field between to a crossed polarized zone.

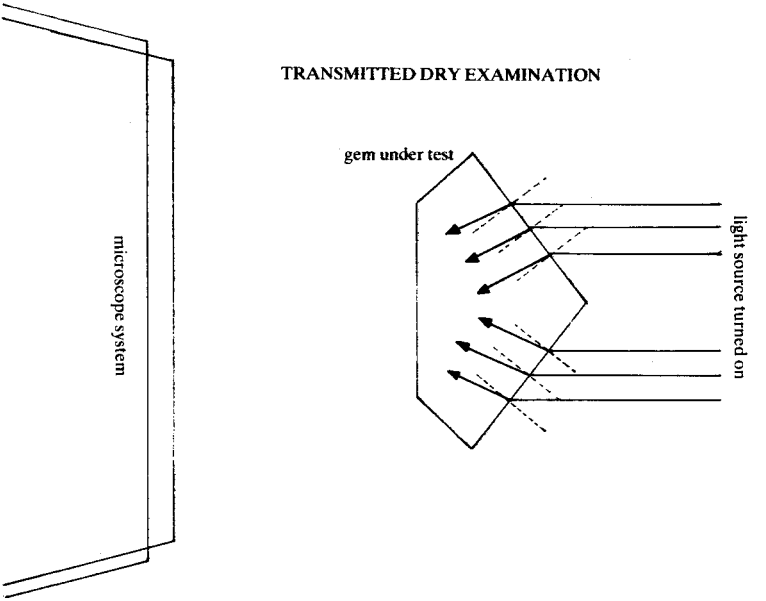

FIG. 4. The velocity of light in air is considerably reduced by the high refractive gem allowing light beams to converge to a limited zone. Only a portion of the gem becomes visible in microscope.

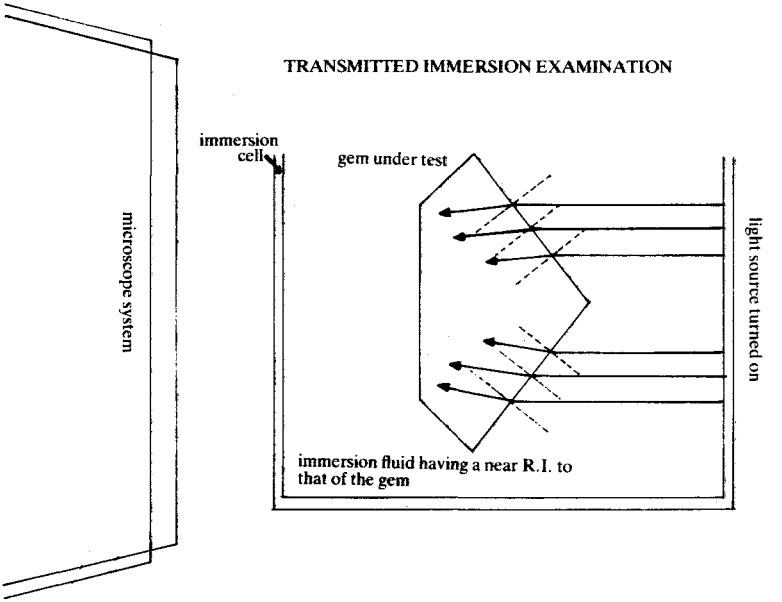

FIG. 5. An alternative method to overcome the problem discussed in Fig. 4. Since the 'optical densities' of two media are similar the velocity of light is not altered considerably. The whole gem is visible.

DARK-FIELD ILLUMINATION

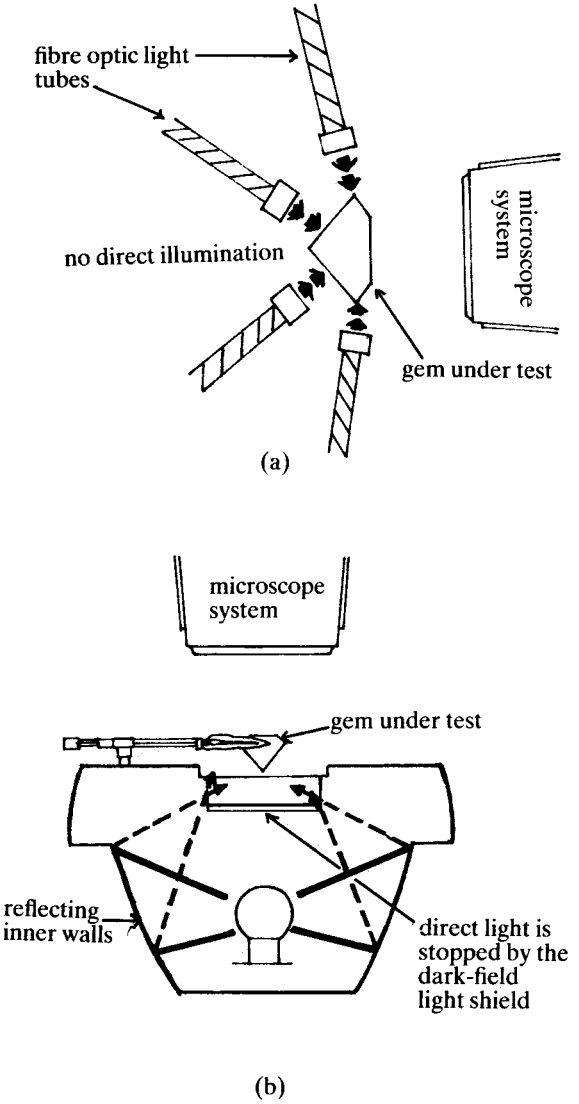

FIG. 6. The dark-field illuminations in (a) *horizontal* and (b) *veritcal* gem microscopes. No direct light is allowed to pass into the microscope system

REFLECTED ILLUMINATION

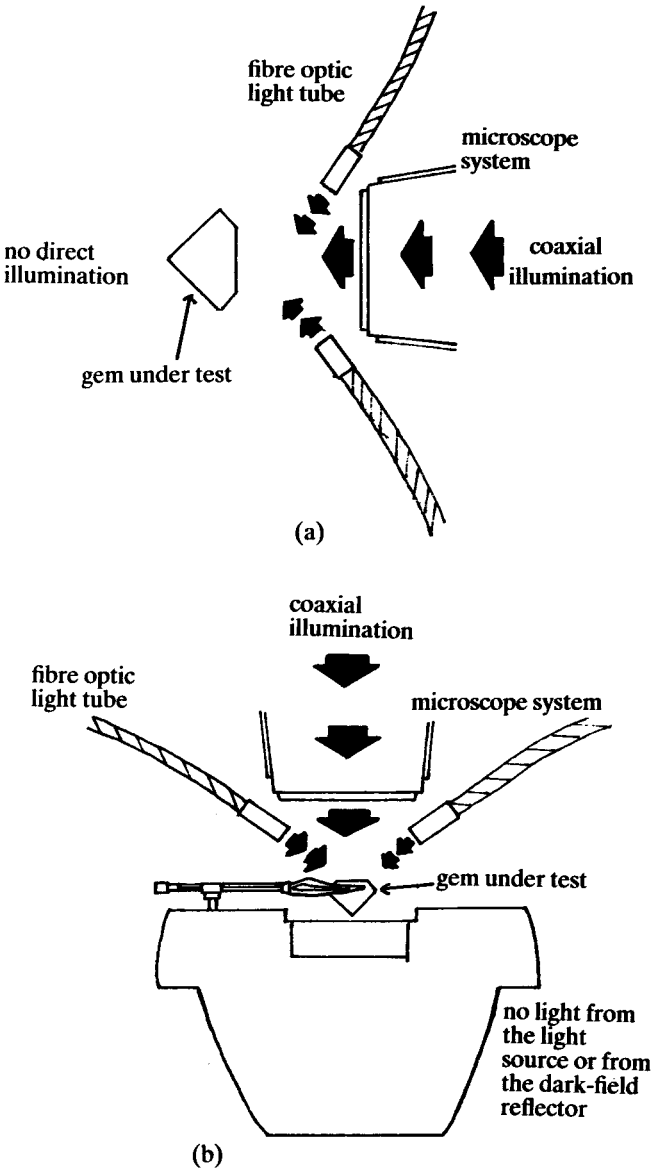

FIG. 7. The reflected illuminations in (a) *horizontal* and (b) *vertical* gem microscopes. The use of vertical or coaxial illumination provides better surface examination possibilities.

This method provided a number of details in new Lechleitner coatings, such as coated contour and various feathers formed in the synthetic (see Figure 8).

Dark Field Illumination

Study of the overall inclusion portrait of the gem under dark field illumination can be informative (Figure 6). In a *horizontal* microscope the dark field lighting can be obtained by the use of a fibre optic illuminator (Figure 6a). The internal characteristics apparent in new coated corundums under similar illumination are illustrated in Figures 14, 15 and 18-24.

Reflected Illumination

Although this method is seldom employed in identification of transparent objects in microgemmology, reflected light was extensively used in studying Lechleitner products. Further deviations such as oblique and/or coaxial illumination are often used in relation to the reflected light method (Figure 7). This light provides ideal conditions for surface examinations, and such observation of new products is shown in Figure 10.

Microgemmology of New Coated Lechleitner Synthetic Corundums

In the course of this study, several characteristics were observed to play a key role in establishing whether the stone in question was coated or not: (a) appearance under immersion, (b) corundum-corundum contact zone, (c) surface appearance and (d) inclusions were of prime importance. The techniques discussed on the use of the gem microscope contribute on a large scale in recognitions.

(a) Appearance Under Immersion

The close refractive indices of methylene iodide ($n=1.74$) and corundum ($n_\omega=1.77-n_\varepsilon=1.76$) provide a clear picture of the coated layer of the Lechleitner corundum (Figure 8). The manufacturer has 'skinned' his product with a thin corundum layer. If precautions are not taken in gem microscopy the observer may miss such features. Practically valuable information is readily obtained by the use of diffused transmitted light with immersion of the stone.

FIG. 8. A coated Lechleitner synthetic ruby seen in immersion microscope with *diffused transmitted light*. The colourless rim visible is the overgrowth. Magnified 20×.

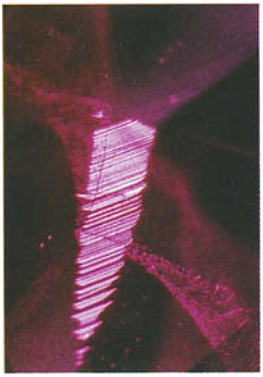

FIG. 9. Often visible unpolished facet plane in Lechleitner coated synthetic corundums. *Reflected illumination*. Magnified 50×.

FIG. 10. Surface cavities on the host corundum during the overgrowth procedure in Lechleitner coated synthetic corundums. *Reflected illumination*. Magnified 22×.

FIG. 11. Typical inclusion portrait of Lechleitner coated Type I synthetic emerald showing the 'net-like' cracks on the coating (see also Fig. 1). *Transmitted illumination*. Magnified 25×.

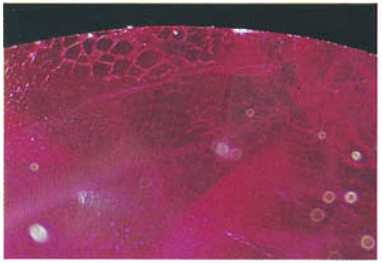

FIG. 12. Very fine 'nets' revealed in Lechleitner coated synthetic ruby. *Dark-field illumination.* Magnified 32×.

FIG. 13. Another ruby exhibiting the typical 'net-like' cracks on the coating. *Dark-field illumination.* Magnified 22×.

FIG. 14. A coated synthetic yellow sapphire with healed feather giving the stone a natural appearance. *Dark-field illumination.* Magnified 45×.

FIG. 15. The healed voids now containing a solid substance in a coated Lechleitner ruby. *Dark-field illumination.* Magnified 25×.

FIG. 16. Healed feathers, similar to those seen in Fig. 15, with included solid substance in a Lechleitner coated synthetic yellow sapphire. *Transmitted illumination.* Magnified 22×.

FIG. 17. The fingerprint cavities clearly exhibiting the dark fillings in synthetic yellow sapphire coated by Lechleitner. *Transmitted illumination.* Magnified 20×.

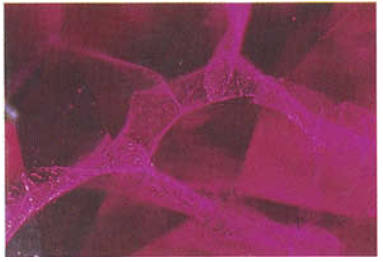

FIG. 18. Feathers resulting under high temperature in coated synthetic ruby appear almost similar to those seen in synthetic flux rubies. *Dark-field illumination.* Magnified 40×.

FIG. 19. Feathers (resembling those seen in heated natural rubies) observed in Lechleitner coated synthetic ruby. *Dark-field illumination.* Magnified 35×.

FIG. 20. Fine 'lace-like' feathers bunched in the central portion of a synthetic ruby 'skinned' by Lechleitner. *Dark-field illumination*. Magnified 38×.

FIG. 21. 'Padparadschah' colour Verneuil synthetic sapphire experimentally coated by Lechleitner reveals fine fingerprint feathers, almost similar in appearance to those observed in Chatham synthetic orange sapphires. *Dark-field illumination*. Magnified 40×.

FIG. 22. Very fine cracks resulting in a Verneuil 'padparadschah' sapphire during the process of coating by Lechleitner *Dark-field* illumination. Magnified 35×.

FIG. 23. Fingerprint feathers resembling those seen in natural 'padparadschahs' from Sri Lanka included within a coated Lechleitner corundum sample. *Dark-field illumination*. Magnified 20×.

FIG. 24. All colours of Verneuil synthetic corundums are 'skinned' by Lechleitner — here a colour-changing type synthetic sapphire exhibiting many feathers internally after seeding techique. *Dark-field illumination*. Magnified 30×.

(*b*) *Corundum-corundum Contact Zone*

The coating of a corundum layer on a corundum base (preform) is done only for faceted stones. However, a good polished surface would not provide a suitable contact zone. Therefore in the majority of cases the facets are left unpolished for successful coating (Figure 9).

(*c*) *Surface Appearance*

It can be established that 'skinning' is done in a high temperature environment. During the process, the secondary corundum layer penetrates somewhat into the host (estimated 3μm deep). By re-polishing the coating can be removed. Such a surface, specially re-polished during this study, is shown in Figure 10; this shows, under reflected light, the surface cavities formed during the coating procedure on the corundum seed.

(*d*) *Inclusions in Coated Synthetic Corundum*

One of the most characteristic inclusions seen in Lechleitner coated emerald is fine *net like* cracks on the coating (Figure 11). However similar quite thin and very fine 'nets' were apparent in some coated rubies (Figures 12 & 13). These inclusions were not distributed in a regular manner over the whole coating in many samples.

Similar in appearance to healed fingerprints, voids were visible just below the surface of coated stones (Figure 14). It is probable that these voids may have resulted during the high temperature evironments of the coating procedure. These are the surface cavities (Figure 10) which may be exposed to the surface by polishing the coating away. In many instances these voids contained a solid substance which exhibited a similar appearance to the over-all heated cavity or fingerprint-like effect (Figures 15, 16 & 17) usually seen in natural gem corundums.

The new Lechleitner coated synthetic corundum revealed fine flags or feathers similar in appearance to those seen in rubies grown by Chatham, Kashan, Knischka and Ramaura and sapphires by Chatham (also Gunawardene, 1983 a; Gübelin, 1983 a & b; Kane, 1983; Gunawardene, 1984 and Kane, 1982; Gunawardene, 1983 b). These may have resulted during the heat inducement in giving corundum skin to the host synthetic. Similar fingerprint inducement was described by Koivula (1983). The observations made by the author on many coloured sapphires coated by Lechleitner are illustrated in Figures 18 to 24 respectively.

Conclusion

The coloured gemstone industry is again being invaded by a new technique of modifying ruby and sapphire. Although it is not known at this time how far the manufacturer has gained success and how widespread such coated materials are, the ruby and sapphire dealer has to undergo a difficult time in dealing with corundum gems. Recent publications on the subject have reported the heat-treatment, synthesising, glass filling of corundum and its surface cavities and now surface coating is added. The gemmologist, jeweller and others who deal with ruby and sapphire should obtain a great amount of practice in detecting such altered stones. Therefore it is author's suggestion that every gem must be viewed through a magnifier. Microgemmology has now taken a vital position in the science as well as in the trade.

This article deals with the first synthetic coated corundum from Lechleitner. It was not possible to gather all details of recognition, especially where natural seeds are involved, due to the absence of such samples to date. On the other hand the nomenclature of this new product still leaves a question. Whether they can be called synthetics or coated material or doublets is still left for discussion.

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THE COMPOSITION OF THE LAPIS LAZULI IMITATION OF GILSON

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ABSTRACT

The product, which is manufactured by Gilson and sold as synthetic lapis lazuli, consists of ultramarine and hydrous zinc-phosphates as main components as well as small pyrite crystals as an accessory constituent. The product does not deserve the synthetic label and has to be called an imitation. The declaration of the producer is incomplete and misleading.

INTRODUCTION

Lazurite, as a mineral species with the general formula $(Na,Ca)_8[(SO_4,S,Cl)_2/(AlSiO_4)_6]$, may be regarded as a natural solid solution consisting of the minerals sodalite $Na_8[Cl_2/(AlSiO_4)_6]$, haüyne $(Na,Ca)_{8-4}[(SO_4)_{1-2}/(AlSiO_4)_6]$ and a component similar to synthetic ultramarine $Na_8[S_{2-4}/(AlSiO_4)_6]$ (Deer *et al.*, 1963; Taylor, 1967; Leithner, 1975). A detailed mineralogical investigation of lazurite was recently published by Hogarth & Griffin (1976). The lazurite-bearing rocks of different localities are given the general name lapis lazuli, though showing often a great variation in their mineralogical composition. The colour in synthetic ultramarine and natural lazurite is assumed to be due to the presence of the radical anion S_3^-. Spectroscopic investigations of lazurite and ultramarine show a strong absorption in the red to yellow area of visible light (broad absorption with maximum at about 600 nm). This absorption is generally accepted to be caused by the S_3^- ion in both crystalline phases, i.e., the intensity of the blue is due to the amount of sulphur which is present as S_3^- (Hofmann *et al.*, 1969; Schwarz & Hofmann, 1970; Wieckowski, 1970; McLaughlin & Marshall, 1970; Seel & Simon, 1972; Chivers, 1974). The mechanism of absorption caused by the S_3^- ion in the visible area, however, is still a subject of scientific investigations (Galimov *et al.*, 1981).

At present, various man-made lapis lazuli substitutes are found on the market. Most of them have to be called imitations due to their chemical composition, e.g., Co-containing synthetic spinel, which was produced by Degussa in Germany. The only man-made

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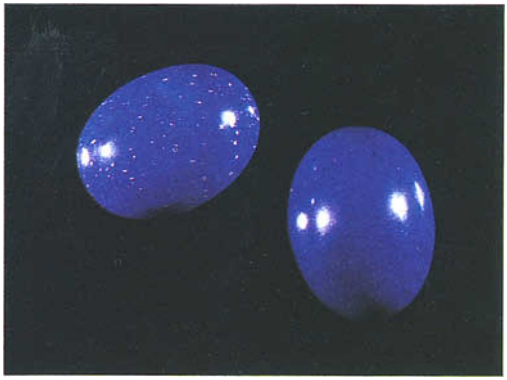

FIG. 1. Lapis lazuli imitations of Gilson; size of the samples approx. 8×6 mm. (*Photo by O. Medenbach, Bochum.*)

product which has been claimed to deserve the synthetic label is said to be the lapis lazuli substitute manufactured by Gilson (Figure 1). For natural and synthetic lazurite an identical formula of $Na_8(AlSiO_4)_6S_2$ is given by the producer, which corresponds to the formula of synthetic blue ultramarine. Small crystals of pyrite are quoted by Gilson to be the only additional admixtures in this "synthetic" lapis (advertisement brochure of P. Gilson). Though some uncertainty in the nature of the man-made lapis substitute of Gilson is mentioned by Nassau (1976, 1977), no detailed investigation of this product is available, which has been sold since about 1975 as true synthetic lapis. In the trade and in some new monographs on synthetic gem materials (Nassau, 1980; Nassau & Nassau, 1980; Sunagawa, 1982) the substitute of Gilson is accepted as synthetic lapis lazuli. The gemmological properties of the lapis substitute of Gilson were described by various authors (Schiffmann, 1976; Andersen, 1976; Mitchell, 1982). In the paper of Andersen an amorphous phase is mentioned, which was found in addition to a crystalline member of the sodalite group. This remarkable observation, however, was only noted in the paper of Gübelin (1981).

Recently, in some of the man-made products of Gilson (turquoise and opal imitations) contrary to the specification of the producer, various additional admixtures were observed. Due to these observations, neither the man-made turquoise nor the man-

made opal of Gilson deserve the synthetic label (Schmetzer & Bank, 1981; Schmetzer, 1984). Therefore, a detailed investigation of the lapis lazuli substitute of Gilson was highly desirable in order to clarify the nature of this product.

RESULTS

The strongest lines in the x-ray powder pattern of the lapis substitute of Gilson are identical within the limits of error with the pattern of natural lazurite (JCPDS Powder Diffraction File # 17-749; Hogarth & Griffin, 1976); some weak lines of pyrite were also observed. Assuming a cubic unit cell with Z=1, the unit cell dimension of the synthetic ultramarine component in the product of Gilson was calculated as a_o = 9.100(2) Å. At the beginning of the investigation some weak diffraction lines, which could not be assigned to ultramarine or pyrite, could not be interpreted without chemical information.

By scanning electron microscope only irregularly shaped particles 5-10 μm in diameter were observed (Figure 2). From this information, however, no information about the number of phases present in the product of Gilson could be deduced.

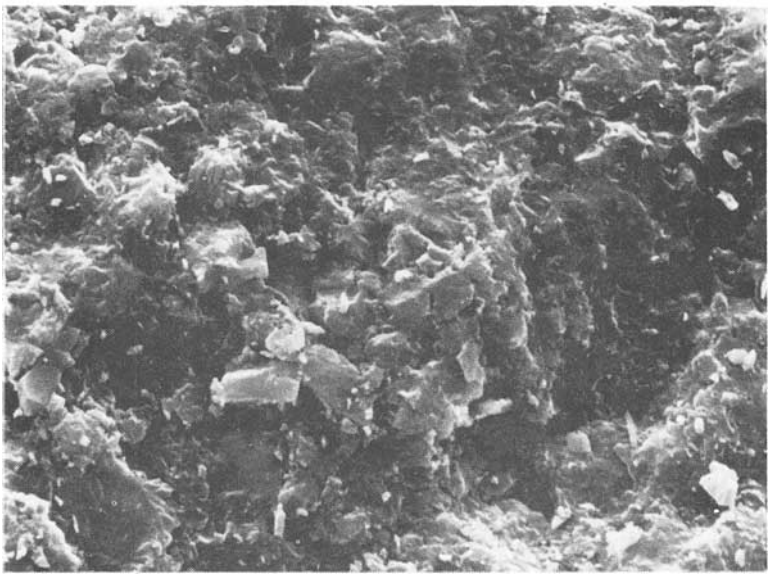

FIG. 2. Lapis lazuli imitation of Gilson; SEM micrograph, 2 300×. (*Photo by H.-G. Röpert, Cologne.*)

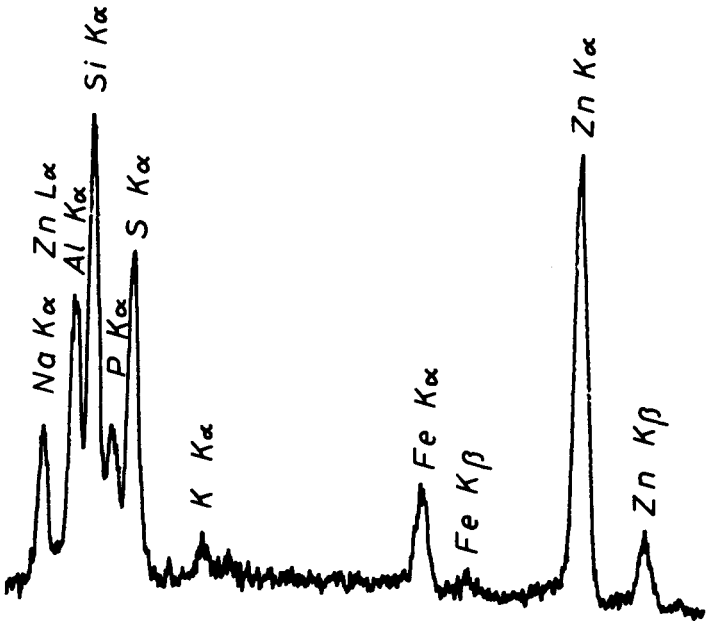

FIG. 3. Energy dispersive x-ray spectrum of lapis lazuli imitation of Gilson.

A qualitative chemical investigation of the lapis substitute by electron microprobe (Figure 3) showed the major elements typical for lazurite (Si, Al, Na, K, S) to be present in the blue areas of the product. In addition, substantial quantities of P, Zn and Fe were found, which are not known to occur in natural lazurite. By investigation of the yellow pyrite crystals in the lapis substitute only Fe and S were found as main elements. A quantitative chemical analysis of a rough piece of the lapis substitute by classical chemical methods is given in Table 1. As a significant result, the percentages of Zn and P were found to fall in the range of the main constituents of the synthetic ultramarine (Si, Al, Na, S). By the analytical method used, the blue matrix and the yellow pyrite crystals were not analysed individually. Therefore, in the analysis given, the value of 1.2 weight % Fe has to be interpreted as sum of the iron content in pyrite and in the other phases of the whole product; sulphur is assumed to be present in both phases, ultramarine and pyrite.

TABLE 1: Chemical data of the lapis lazuli imitation of Gilson

	Chemical composition in weight %
Na_2O	10.8
K_2O	0.7
SiO_2	19.9
Al_2O_3	13.4
SO_3*	17.0
S*	1.4
Fe	1.2
ZnO	20.5
P_2O_5	11.5
H_2O	5.0
Total	100.9

*S and SO_3 calculated from S_{total} = 8.2%

	Ionic ratios calculated to Si+Al = 12		
Na	7.04	7.34	ultramarine
K	0.30		
Si	6.69	12	
Al	5.31		
S*	4.31		
S	0.86	pyrite	
Fe	0.43		
Zn	5.09	$Zn_3(PO_4)_2.4H_2O$ and $Zn_3(PO_4)_2.2H_2O$	
P	3.27		
H_2O	5.61		

*S and SO_4 in ultramarine

By thermogravimetric analysis (Figure 4) a continuous loss of weight was observed between 20 and 350 °C, no additional loss of weight was found between 350 and 750°C. A chemical water determination using titration by the Karl-Fischer method after thermal decomposition of the sample resulted in a water content of 5.0% H_2O.

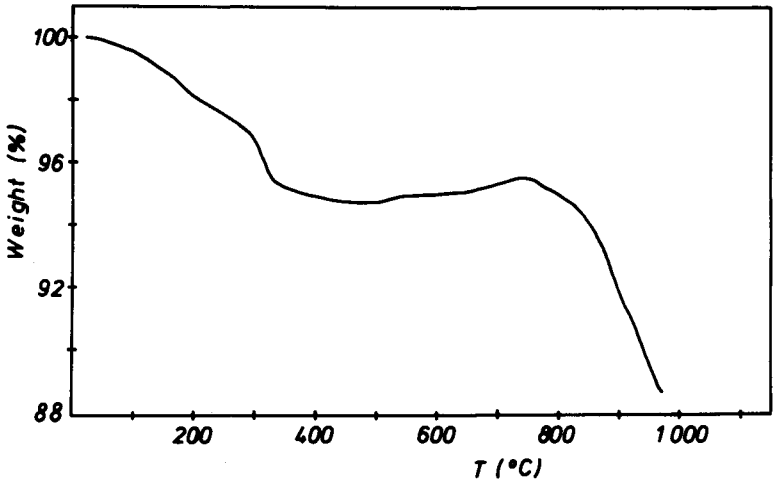

FIG. 4. TG curve of lapis lazuli imitation of Gilson.

In order to characterize the product manufactured by Gilson sufficiently, it had to be determined whether Zn and P could be present in independent crystalline phases. The loss of weight by heating up to 350 °C, as determined by TGA, and the water content of 5.0% present in the sample, as determined by titration, were possibly interpreted as dehydration of a zinc phosphate.

After heat treatment at 300°C for 30 minutes additional information was obtained by the x-ray powder diffraction pattern of the sample. The powder diagram of the heat-treated sample consists of the diffraction pattern of ultramarine and of some weak pyrite lines. The lines in the powder diagram of the untreated sample, which were not yet assigned to a crystalline phase, were not observed in the pattern of the heat-treated sample. However, some

new lines were observed in the powder diagram after heat treatment, which were easily assigned to α-$Zn_3(PO_4)_2$. After dehydration of one or even more hydrous zinc phosphates caused by heat treatment a formation of crystalline α-$Zn_3(PO_4)_2$ was observed. The atomic ratio of Zn:P, as determined by the chemical analysis, was found to be close to 1.5; the ratio of water and zinc is calculated as H_2O:Zn = 1.10 (Table 1). Using all this information, the additional weak diffraction lines in the powder pattern of the untreated sample were assigned to two hydrous zinc phosphates, $Zn_3(PO_4)_2.4H_2O$ and $Zn_3(PO_4)_2.2H_2O$. Consequently, the product of Gilson is considered to consist of ultramarine, pyrite, and two crystalline hydrous zinc phosphates. Supposedly, the amorphous phase mentioned by Andersen (1976) is identical with the hydrous zinc phosphates mentioned above.

Though small amounts of iron and zinc may also be present on Na sites in synthetic ultramarine – synthetic Zn-containing ultramarine was described by Jaeger (1929) – most of the zinc and iron determined by chemical analysis are thought to be present in the form of pyrite and hydrous zinc phosphates. Under this precondition, the formula of the synthetic ultramarine is given as $Na_{7.04}K_{0.30}[(S,SO_4)_{4.31}/Si_{6.69}Al_{5.31}O_{24}]$.

By spectroscopic investigations an absorption band at 17 100 cm^{-1} (585 nm) was determined. Therefore, the colour of the lapis substitute of Gilson, i.e., the colour of the ultramarine component of this product, is thought to be caused by the S_3^- ion.

Conclusion

The lapis lazuli substitute of Gilson consists of three main components, synthetic ultramarine and two hydrous zinc phosphates; small pyrite crystals may also be present. The process of manufacture of this product is unknown, but, for the purpose of this paper, it is not necessary to discuss this process in detail. Due to the presence of crystalline hydrous zinc phosphates as main components, which are not at all associated with natural lazurite or natural lapis lazuli, the lapis substitute of Gilson has to be described as imitation.

Acknowledgements

The investigation of the lapis lazuli imitation of Gilson was initiated by Prof. Dr H. Bank, of Idar-Oberstein. The firms R. Litzenberger and Gebr. Bank of Idar-Oberstein kindly supplied the samples for investigation.

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FRACTURING IN CANADIAN HESSONITES

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ABSTRACT

Repeated oscillatory growth between the rhombic dodecahedral and the trapezohedral crystal habits in hessonite garnets from Québec, Canada, results in considerable internal strain and fracturing. The intensity of this strain is revealed in the microscope by using polarized light and/or the author's shadowing technique.

INTRODUCTION

The Jeffrey mine, at Asbestos, Québec, Canada, has long been known for the splendid pale orange to deep brownish-orange grossular garnets it produces. Externally, the rhombic dodecahedral and trapezohedral habits displayed by these garnets are quite pleasing in their geometric perfection (Figure 1). Yet upon closer inspection these garnets, even in the very finest qualities, are commonly interspersed with numerous small fractures.

While a few of these fractures show distinct signs of secondary healing, trapping small volumes of fluid in the process, as shown in Figure 2, the vast majority appear to be epigenetic in origin showing no evidence of fracture repair whatsoever. Why would these hessonites from the Jeffrey mine contain so many fractures while those from other localitites, such as Sri Lanka and East Africa, are, on a comparative basis, essentially free from similar defects?

PRELIMINARY OBSERVATIONS AND SAMPLE PREPARATION

To investigate the inherent cause of fracturing in the Canadian hessonites, 41 rough crystals and broken crystal sections and seven faceted stones were obtained for this study. When initially examined, it was observed that all 48 specimens, both rough and cut, contained at least a few fractures. Since all of the rough garnets contained fractures, the idea that the fracturing might in some way be caused by heat generated during the lapidary process was ruled out. Ten of the 41 rough crystals and crystal sections were then selected at random, and windows were polished on them so the internal characteristics might be more easily studied.

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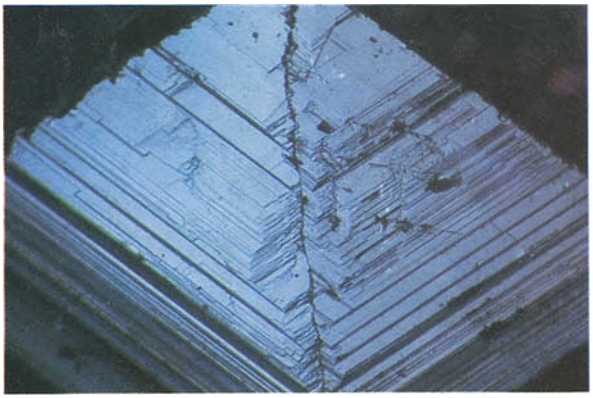

FIG. 1. The surface of this Canadian hessonite grossular garnet displays growth features resulting from oscillation between the rhombic dodecahedral form (dominant) and the trapezohedral form (subordinate). A dislocation that has influenced the crystal's growth runs through the centre. Oblique illumination and shadowing. 35 ×.

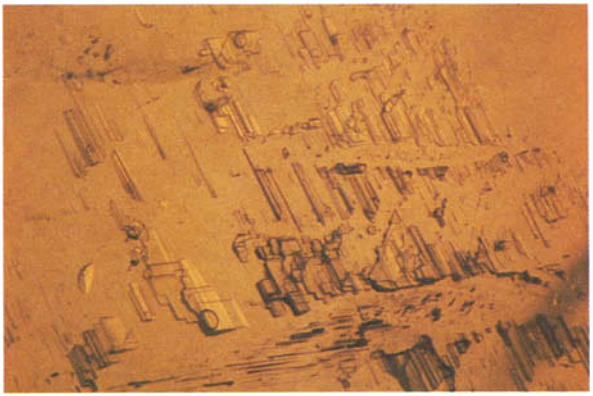

FIG. 2. A somewhat planar secondary partially healed fracture composed of numerous microscopic one-and two-phased inclusions. Transmitted light and shadowing. 110 ×.

FIG. 3. Fracture system in a Canadian hessonite using partial immersion and darkfield illumination. 40 ×.

FIG. 4. The same fracture system using partial immersion and transmitted light. Notice the single tiny acicular diopside inclusion. 40 ×.

FIG. 5. Shadowing is now used and the garnet's rhombic dodecahedral-trapezohedral structure becomes visible. 40 ×.

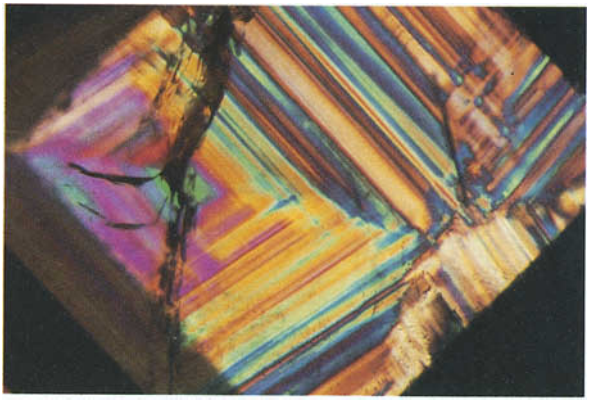

FIG. 6. Under polarized light, strain colours delineate the hessonite's form. 40 ×.

Detailed Microscopic Investigation

Then the ten polished roughs and the seven faceted gems were studied very carefully under the Gemolite microscope using both darkfield and transmitted light to see if perhaps the fractures were the result of thermal expansion of either primary or secondary fluid inclusions. The fractures ran randomly throughout the gems and no such fluid inclusion-to-fracture relationship could be established. The acicular diopside crystals also observed crisscrossing through some of the hessonites (Grice and Williams, 1979; Wight and Grice, 1981) were in no way responsible for the fracturing, as no fractures were directly related to any of these inclusions. It was thought that perhaps shadowing (Koivula, 1982) might reveal some internal features that were not resolved by either darkfield or transmitted light microscopy. A rough crystal section was placed under the microscope and when shadowing was employed the entire original rhombic dodecahdral structure of the garnet became visible just as if the surface features had never been ground and polished away. It was quite obvious at this point that a great deal of strain must be present within these crystals. It was decided that polarized light be used in conjunction with shadowing to see if the strain would produce a polarized light reaction somewhat similar to that observed in synthetic flame-fusion spinels and some diamonds. When polarized light was used, not only was there a reaction, but the strain colours traced the original growth features of the parent crystal. The series of photomicrographs, Figures 3, 4, 5 and 6, illustrate the same hessonite in identical position in darkfield illumination, transmitted light, shadowing, and polarized light. Although hessonites from other localities do show signs of strain in polarised light, no reaction of the strength, vibrant colouration, and clarity shown by these Canadian hessonites had ever before been observed by this author or reported in any of the literature. All of the polished hessonites were studied by shadowing and polarized light, and all showed the same reaction. Even the rough unpolished crystals and crystal sections showed brilliant strain colours in polarized light that delineated the external crystal form. It was now apparent that internal strain was responsible for the fractures commonly observed in the Canadian hessonites from the Jeffrey mine in Québec.

CONCLUSION

Before cutting, the surfaces of these hessonite crystals show a distinctive continuous growth oscillation between both the rhombic dodecahedral and the trapezohedral habits. This intermixing of structural forms results in zoned strain throughout the crystals, which is resolvable even after faceting using shadowing and/or polarized light. In such intensely strained crystals it is not at all surprising to find stress-related fractures.

Gemmologically, it is generally not considered common practice to study singly refractive gem materials, such as garnets, under the microscope using polarized light, but at least in this instance unconventionality proved worthwhile.

ACKNOWLEDGEMENT

The author would like to thank Leon M. Agee, C.G., of Falkenbergs Jewelers in Walla Walla, Washington, for faceting some of the hessonites used in this study.

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'ARTERIES' IN OPAL?

By R. KEITH MITCHELL, F.G.A.

We are accustomed to thinking of Mexican opal as a gem which, unlike precious opal, owes its appeal to a fundamental slightly milky body colour, usually in shades of orange or red, without play of colour.

But this describes only part of the colour range, and it is found almost colourless and transparent, through a butter-milk colour to pale yellow, and on through the familiar orange and red shades. In the finest examples from the Querétaro mines the 'missing' play of colour may occur in quite amazing profusion of greens, blues, reds, yellows and other shades emphasized by their contrast with the saturated body colour of the opal.

FIG. 1. Veining in fire opal.

The opal masses occur enclosed in random and usually rough-surfaced cavities in such rocks as lavas, porphyries and rhyolites, and there is usually considerable wastage when local cutters need to produce clean cabochon gems. Occasionally inclusions may be left in the finished gems, and interesting stones containing a variety of included minerals are known. These can be of goethite, hornblende, quartz, cristobalite, kaolinite, haematite or other associated minerals and may give clues to the original formation of the opal concerned.

Some stones show what appear to be trail or flow markings in their colour structure, which would seem strange in material which has been enclosed totally in cavities of the volcanic rock. One such

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stone is the rather magnificently marked flat cabochon, which I illustrate (Figure 1). Here the blood-red colour is in a reticulated pattern, almost like a medical picture of a circulatory system. The usual assumption is that such colours in a porous gem are due to iron contamination, but it is difficult to envisage just how such a formation could have occurred in this stone. Opal in its early stages may have been a somewhat wet and plastic gel, and I suppose that colorant solutions could penetrate and flow in wisps to form cellular patterns in this way.

Regrettably the stone was not mine, and I no longer recall from whom I begged permission to make this photographic record some ten years ago. If the owner recognizes the stone, I am grateful to him and apologize for my inability to name him.

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A RE-EXAMINATION OF SLOCUM STONE – WITH PARTICULAR EMPHASIS ON INCLUSIONS

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ABSTRACT

The properties of Slocum Stone are reviewed. Six stones were examined microscopically, and their inclusions and optical effects are described and discussed. The commonest inclusions are tinsel-like flakes, which are evidently responsible for the play of colour. No swirl marks were observed, but gas bubbles, many of which display very unusual shapes, are abundant. Evidence is presented to show that at least some of the flakes are the disrupted remnants of what were probably originally continuous sheets produced by a sedimentation process. The distortion of the gas bubbles can probably be attributed to mixing and agitation in a viscous liquid medium (the glass matrix).

INTRODUCTION

Slocum Stone, a beautiful glass imitation of opal, is now well known in gemmological circles. Although not perhaps as convincing as the Japanese latex simulant, it is undoubtedly one of the best opal imitations which has yet appeared. Few experienced observers would be deceived by Slocum Stone, but the general public could easily confuse it with genuine opal.

The manufacturer of this material, Mr John S. Slocum, of Michigan, U.S.A., introduced Slocum Stone in the late 1970s. After several years of experimentation Slocum eventually succeeded in producing a true synthetic opal but was dissatisfied with the result. Although his synthetic material showed the play of colour so desirable in natural opal, it also suffered from the same drawbacks – namely high porosity, sensitivity to moderate heat, susceptibility to cracking and tendency to chip when knocked. Because of the undesirable properties of his synthetic product Slocum embarked on a series of experiments designed to produce an imitation which was tougher and more durable than natural or synthetic opal but which still retained the prized colour flashes. Slocum Stone was the successful outcome of this work and is a tribute to the patience, ingenuity and skill of its originator.

As one would expect, details of the manufacturing process are still secret but the structure, composition and properties of Slocum Stone have been investigated by several workers, including Schowalter (1976), Gübelin (1976), Dunn (1977), Darragh and Sanders (1978), Ball (1978), Farn (1979) and others. Slocum Stone

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is also discussed in the three most recent texts on man-made gemstones — Elwell (1979), Nassau (1980) and O'Donoghue (1983).

Slocum Stone is essentially a silicate glass containing calcium, sodium and magnesium. The water content is negligible compared to that of natural or synthetic opal. The material is made in a range of colours including black, white, amber and green. The specific gravity is between 2.4 and 2.5 and is slightly higher than that of natural opal (2.0 – 2.1). Refractive index is also somewhat higher – 1.49 to 1.51 for Slocum Stone as compared with 1.45 for natural opal. Slocum Stone is inert under all UV wavelengths and x-rays. It is very tough, reasonably hard (H 5½), is resistant to chipping and is unaffected by moderate heating. It is non-porous, does not shrink or expand, and is easily worked by the lapidary. Three types of inclusions have been reported – very thin flakes resembling tinsel or foil, swirl marks and bubbles. Although their precise nature is still uncertain the tinsel-like flakes are evidently responsible for the play of colour, and electron microscope studies (Darragh and Sanders) show that they are composed of a laminated material. Swirl marks and bubbles are to be expected in glass, but, as will be shown later, many of the bubble shapes are very unusual and completely atypical.

The purpose of this paper is to extend previous discussions of Slocum Stone particularly in respect of the inclusions.

A parcel of nine polished Slocum Stones in various colours was kindly loaned to the author by the Gemmological Association of Great Britain. Six of the stones were subjected to detailed microscopic study and the results of that investigation are summarized in this paper. Colour photographs are used extensively to illustrate the article.

Description

The six stones examined are illustrated in Figure 1. Two black, two amber (fire opal imitations) and two white opal simulants are shown. The fire opal simulants have a rather stronger play of colour than is normally associated with that variety of natural opal, but, apart from this slight discrepancy, all of the stones are quite convincing imitations and are undeniably attractive.

FIG. 1. Six Slocum Stones: 1 and 2, black opal simulants; 3 and 4, fire opal simulants; 5 and 6, white opal simulants.

FIG. 2. Blue or purple tinsel-like flakes, some with drawn out gas bubbles adhering to their edges. Black opal simulant. 42×.

(A) INCLUSIONS

According to the literature three types of inclusions occur in Slocum Stone. These are tinsel-like flakes, swirl marks and gas bubbles. Flake inclusions and bubbles are abundant in all of the specimens but typical swirl marks were not observed.

Tinsel-like flakes

These are the most conspicuous inclusions in all of the stones examined; their presence in fact is essential as without them the play of colour is not seen.

Essentially the flakes are flat, extremely thin fragments of widely varying dimensions. Actual sizes range from those which are easily visible to the naked eye (up to several millimetres across the largest diameter) to examples which can just about be seen at a magnification of ×100. Most of the flakes show angular outlines but some are partially rounded. In one of the black opal simulants (No. 1 in Figure 1) the edges of some flakes are accentuated by the presence of drawn out, high relief structures; the latter are assumed to be elongated bubbles adhering to the flake margins (see Figure 2).

The colour of the flakes, as seen in transmitted light, varies according to the simulant. In the black and white imitations they are either bluish or purple (Figures 2 and 3), while green, yellow and orange are the dominant flake colours in the fire opal simulants (Figure 4).

Most of the flakes have featureless surfaces, but one or two show a pattern somewhat resembling lunar cratering (Figure 5).

Under crossed polarized light the flake inclusions show spectacular interference colours (Figure 6).

Close examination of these interesting inclusions suggests that many of them were once part of larger structures; this is evident because boundaries between adjacent flakes are often shaped such that they clearly once fitted together, rather like the pieces of a jig-saw (Figure 5).

Bubbles

Bubble inclusions, presumably air-filled, are common in all specimens. Whilst many of the bubble shapes are perfectly normal for glass (spherical, torpedo shaped, etc.) a considerable number are completely atypical and quite unlike anything the author had previously recorded in glass. The shapes of these unusual bubbles are often so bizarre that it is difficult to describe them adequately in words.

FIG. 4. Yellow, green and orange tinsel-like flakes. Fire opal simulant. 10×.

FIG. 6. Tinsel-like flakes showing spectacular interference colours separated by isotropic (black) glass. Fire opal simulant. Cross polarized light. 10×.

FIG. 3. Blue and purple tinsel-like flakes. White opal simulant. 10×.

FIG. 5. Tinsel-like flakes with surface pattern resembling lunar cratering. Note the jig-saw like relationship between some of the flake margins. Fire opal simulant. 16×.

FIG. 8. Unusual bubble shapes associated with tinsel-like flakes. Fire opal simulant. 42×.

FIG. 10. High relief crescent-shaped bubbles and tinsel-like flakes. Fire opal simulant. 10×.

FIG. 7. Three normal bubble shapes showing high relief. Green flakes in background. Fire opal simulant. 10×.

FIG. 9. Bizarre 'two-pronged' bubble (bottom right), elliptical bubbles and tinsel-like flakes. Fire opal simulant. 10×.

The fire opal simulants (Nos. 3 and 4 in Figure 1) provided the most interesting gas bubbles. Figures 7, 8 and 9 are enlarged views of the stone numbered 4 in Figure 1. In Figure 7, three drawn out, approximately elliptical, high relief bubbles are shown. These are normal shapes for glass. Figure 8, however, illustrates a number of extremely unusual bubbles. The bubbles have the typical high relief (black outlines) but quite atypical shapes.

The two largest bubbles are markedly elongated and taper at their terminations. One of the smaller bubbles (right) resembles a ring while others are crescent shaped. A few minute bubbles are spherical. It is interesting to note the close association between the larger bubbles and the flake inclusions, two of which are shown in the photograph. A variety of bubble shapes are shown in Figure 9 together with flake inclusions (the latter producing colour flashes). The astonishing 'two-pronged' bubble (lower right) is particularly noteworthy. In the other fire opal simulant (No. 3 in Figure 1) crescent, shield or cusp-shaped bubbles are fairly common. Some of these shapes resemble miniature 'Barkhan type' sand dunes which are a feature of certain deserts. Examples are shown in Figures 10, 11 and 12. Flake inclusions are also prominent in Figures 10 and 11.

Bubbles with spikey terminations occur in one of the black opal simulants (No. 1 in Figure 1). These are shown in Figures 13 and 14.

(B) Optical Effects

Although Figure 1 may not suggest it each of the stones studied is transparent to some degree. If transmitted light only is used to illuminate the specimens, they are quite dull and lifeless and show few if any colour flashes. Using overhead reflected lighting, however, the appearance of the stones alters dramatically and a beautiful play of colour, which changes with the viewing angle, appears. The colour flashes are seen at their best when the observer is directly above the specimen but are considerably reduced when the stone is examined from the side.

The optical effects are illustrated in Figures 15-18. These photographs are of the black opal simulant shown as No. 1 in Figure 1. All pictures show an identical field of view but the lighting conditions vary. In Figure 15, photographed in transmitted light only, the body colour of the glass is revealed as a purplish or yellow-orange in which blue or purple tinsel-like flakes are

suspended; colour flashes are non-existent. For Figure 16 overhead reflected light (supplied from a fibre optic light guide) was employed as well as transmitted light, and pure spectral colour flashes, evidently associated with the flake inclusions, can be seen. In Figure 17 the reflected light was retained while the intensity of the transmitted light was markedly reduced resulting in a more pronounced play of colour. Reflected light alone was used to illuminate Figure 18, and the colour flashes are now spectacularly developed against a totally black background.

Discussion

The findings of various workers who have examined Slocum Stone suggest that the production of the material involves a controlled sedimentation process followed by heating in the presence of powdered glass. The fact that some 20 gallons of water are required to produce every carat of Slocum Stone tends to support the view that precipitation is involved.

The purpose of the sedimentation process seems to be to produce a number of multi-layer films. These films, at some stage in the manufacturing process, are apparently disrupted and form the tinsel-like flakes. That many of the flakes are remnants of larger structures, perhaps originally continuous layers, is indisputable (see Figure 5), and it is very likely that all of the flakes were once parts of continuous sheets. The mechanism by which the multi-layer films become fragmented, and their subsequent incorporation as flakes in the glass matrix of Slocum Stone is speculative, but clearly some type of agitation and mixing is involved. The bizarre bubble shapes may well be another manifestation of the mixing process. The high degree of distortion of the bubbles is certainly suggestive of movement of trapped gas (air?) in a viscous liquid medium during agitation. Strangely, clear evidence of mixing of the components, in the form of swirl marks, is lacking in the stones examined. Other workers, however, have recorded swirl marks in Slocum Stone.

Although their exact nature is still conjectural, transmission electron microscope studies by Darragh and Sanders (1978) have shown that the tinsel-like flakes are composed of a laminated or layered material. It has been suggested that the flakes consist of extremely thin layers (about 0.5 μm thick) alternately silica rich and alumina rich. Ball (1978), however, using a scanning electron microscope asserts that the layers are possibly of uniform

FIG. 12. Detail of two crescent-shaped bubbles. Fire opal simulant. 42×.

FIG. 11. Detail of crescent-shaped bubble resembling a 'barkhan' sand dune. Tinsel-like flakes in background. Fire opal simulant. 42×.

FIG. 14. High relief bubbles with spikey terminations. Black opal simulant. 42×.

FIG. 13. High relief bubbles with spikey terminations. Black opal simulant. 42×.

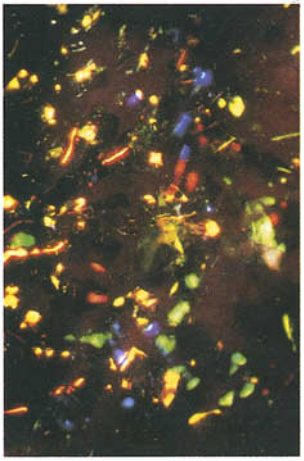

FIG. 16. Black opal simulant showing colour flashes. Transmitted and reflected light. 10×.

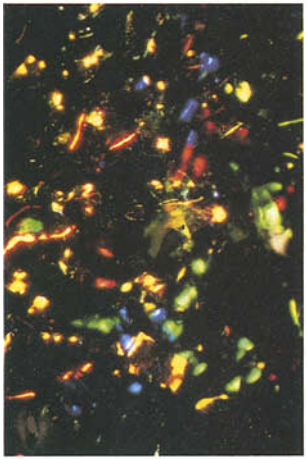

FIG. 18. Black opal simulant showing spectacular colour flashes against a black background. Reflected light only. 10×.

FIG. 15. Black opal simulant without colour flashes. Transmitted light. 10×.

FIG. 17. Black opal simulant showing colour flashes. Reflected light and reduced transmitted light. 10×.

composition. The 0.5 μm thickness of each layer appears to be critical and is sufficient to cause diffraction of reflected light, giving rise to the play of colour in a manner similar to that produced by the silica spheres in natural or synthetic opal. That the flake inclusions are responsible for the colour flashes in Slocum Stone is evident from Figures 15-18. Slocum Stone tends to be fashioned in the cabochon style and normally the material is cut so that the largest surfaces of the majority of the flake inclusions are oriented parallel to the cabochon base. This probably explains why the play of colour is seen at its best from directly above the top of the cabochon. In this position the observer is looking directly down on to the flake surfaces and the effects of diffraction are seen at their best; when they are examined from the side, the viewer sees most of the flakes approximately edge-on, and much of the diffracted light never reaches the eye.

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I should like to thank Mr J.P. Brown, of the Gemmological Association of Great Britain, who kindly loaned me, from the Association's collection, the parcel of Slocum Stones discussed in this paper.

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COLOUR FILTERS AND GEMMOLOGICAL COLORIMETRY

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INTRODUCTION

Colour science is now beginning to assume considerable importance in gemmology. The science is a complex one, because it is a mixture of purely physical and psychophysical components. The attainment of even a minimally useful grasp of the subject for gemmological purposes is not easy, and as much help as possible is needed to assist the learning process.

In a previous article[1] a new spectroscope unit was described which, with a few accessories, enables other kinds of characterizations to be made. A set of colour-filter slides has now been produced for use with this unit. It is felt that this additional combination will help to fill a gap in the practical process of understanding the principles of colour production, perception and measurement.

This article is an attempt to persuade fellow gemmologists that systematically based instruction in colour science is fast becoming a necessary part of their training.

ATTITUDES TO GEMSTONE COLOUR MEASUREMENTS

There is now a strong ground-swell of interest in the internationally accepted method of quantitative colour assessment known as the CIE Tristimulus Colour System.* The interest springs mainly from those research laboratories and teaching institutes which are concerned with gemmological science.

There is, however, also a world-wide awakening of interest in the jewellery, diamond and coloured stone trade. Its collective response covers a range of awareness from a sympathetic but cautious interest to one of declared hostility. The latter stance probably arises from the prevailing and strongly-held belief that it will never be possible to measure quantitatively the body colour of a faceted gemstone.

* CIE is the acronym for the 'Commission Internationale de l'Eclairage', the international governing body for colour science.[2] In the U.S.A., it is sometimes referred to as the ICI System ('International Commission on Illumination').

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At the CIBJO* 1983 executive meeting in Rome, the delegates representing the coloured stone trade of fourteen countries unanimously passed a resolution with the following wording: '*The Coloured Stone Commission of the CIBJO definitely rejects the use of mechanical graduation systems for coloured stones in order to stimulate public sales. The Commission holds that these systems are to the consumer's and to the retail trade's disadvantage*'.[3,4]

This resolution was an answer to the activities of investment firms using coloured stone certificates in order to sell single coloured stones or whole sets for investment purposes. The Commission stated that the trade was aware of several methods for determining the colour of gemstones such as the use of electronic measuring instruments and tables. It had no objection to their development and use, provided that none of the resulting colour measurements were used to ascribe certain commercial values to the measured stones. It believed that such practices would open the way for investment firms to mislead the public into thinking that coloured stones were suitable objects for investment. Reference was made to the fate which faceted gem diamonds have suffered in the last three years. This was in consequence of the issuing by such firms of quantitative colour certificates with their direct linkage to prices.

It might well be thought that those outside the gemstone trade could misconstrue the meaning of the last sentence in the resolution. From the reported general discussion at the Congress, it is abundantly clear that the Commission has no wish to inhibit progress in research studies aimed at the full characterization of coloured gemstones. This included the development of accurate and practical methods of colour measurement.

Trade Problems in the Description of Gemstone Colour

Of the many problems of faceted stone characterization which confront the trade, there are three in particular which spring to mind. They all relate to the now pressing need for an accurate, practical and inexpensive assessment of body colour.

The first is the difficulty experienced by those gemstone miners and merchants who form such an important international coterie

* CIBJO is the acronym for 'Confedération internationale de la bijouterie, joaillerie, orfèvrerie des diamants, perles, et pierres'.

dealing in the highest quality coloured stones. Like diamonds, relatively small colour differences are usually linked to breath-taking price differences. With aquamarines, for example, Ramsey[5] mentions that there is almost an 8000 per cent difference from the cheapest stone to that showing the 'top' colour. The sellers are continually frustrated and baffled by the inability of their buying public to recognize the fine nuances of colour in their own specialist stones. For their part, the buyers are prone to dispute the seller's judgement of colour differences. An internationally-agreed colour standardizing procedure would do much to remove this trading obstacle.

The second is concerned with the widely felt, but largely unexpressed, need to monitor the colour constancy of certain gemstones. These are the stones which are known to have received, or are suspected of having received, laboratory-type treatments to improve their colour appearance. The enhancements could involve irradiation, thermal or chemical operations of a kind which Goethe* could not have imagined. There even exist some natural stones, known to be untreated, which are also subject to colour changes when exposed to white light. Some examples of these are Maxixe beryl, much brown topaz, kunzite from certain localities and zircon.

In current practice, such changes can only be followed by visually comparing the colour appearance of the treated stone with that of a stone of much the same shape and size cut from the untreated homogeneous material. Such comparisons would be made at chosen time intervals, to ensure that the colour was not fugitive over long periods. Intermittent or constant exposure to an intense white light source during these intervals would probably be a requirement of a stringent test for colour stability, or for a check on the absence of tenebrescence.†

When testing a single gemstone of unknown history for light-fastness, by the very nature of the experiment the observer has

* '. . . Colours fixed in glass by fusion, and by nature in gems, defy all time and reaction . . .'. Goethe. *Theory of Colours*, 1810.

† Tenebrescence is a type of reversible photosensitivity. There are certain transparent minerals which darken or beome more deeply coloured on exposure to shortwave UV light (or electrons, neutrons, x-rays, gamma rays). When exposed to white light (e.g. daylight), the irradiated material is bleached or reverts to its previous colour. The process cycle can be repeated endlessly. Hackmanite, a pink sodalite, is the classical model for tenebrescence. Its curious behaviour has been studied by Lee[6] and Medved.[7] Pough and Rogers[8] carried out many experiments on the 'soft' x-ray irradiation of various gemstones and showed that all radiation-treated sapphires exhibited tenebrescence. More recently, Scarratt[9] has reported on the existence of this phenomenon in the so-called 'chameleon' diamonds and in yellow sapphires.

deprived himself of any reliable comparison colour with which to gauge a possible colour shift. Recourse must then be made to some other colour standard with which to match the stone before commencing the light-fastness experiments. This could be chosen from, say, a comprehensive set of similarly coloured pastes, or other standards known to be colour-fast or intrinsically non-fading.

With a system of quantitative colour measurement, this troublesome visual comparison method would be unnecessary. Instead, the colour co-ordinates of the untreated or suspect stone would first be measured by means of a suitable instrument. When the planned treatment of any kind had been carried out on the same stone, the identical measuring procedures would be followed, again at chosen time intervals.

The colour attributes measured would be recorded as three numbers. They would be characteristic of the actual instrument and procedures used; they would probably have little direct meaning to those unfamiliar with the device and its use. If, however, the nature of the device was such as to allow its own particular numbers to be easily converted into those of the CIE System, then a formidable new tool for the gemmologist becomes available. The three derived CIE co-ordinate numbers would serve as a universally-understood international colour description of the stone. They would render quite unnecessary the totally imprecise and crude colour language terms in present use.

Those CIE colour co-ordinate numbers which convey the most meaning in a colour sense are the objective psychophysical terms of dominant wavelenth (λ_d), excitation purity (p_e) and relative luminance Y/Y_o. The more familiar colour terms are the closely-connected perceptual or subjective attributes of hue, colourfulness and lightness, respectively.

The third problem seeking a solution relates to the curious colour change effects seen with some chrysoberyls, corundums, spinels, garnets, monazites, kyanites and fluorites.[10] The higher commercial values, which such alexandrite-effect stones command, no doubt encourages a desire to know more about the fundamental nature of this intriguing phenomenon, and to measure precisely the intensity of the effect to which the value is linked. Here again, the use of a colour measuring device capable of producing CIE co-ordinates for any of the standard light sources could easily dispose of this problem.

GEMSTONE COLORIMETRY

It must be said that so far there appears to be little real understanding in gemmology of the general aspects of colour science. This is rather puzzling. Particularly so, when considering the dominant role that colour plays in the over-all attractiveness and value of a gemstone.

Should teachers now be starting to ask their students certain questions? For example: What are the psychophysical mechanisms of colour vision and colour perception? What does the phrase mean . . . 'Colour exists only in the eye of the beholder'? What is subjective dichroism? How can an absorption or transmission spectrum be qualitatively related to a perceived colour? How can the measured transmittance spectrum of a gemstone be mathematically manipulated so that even a colour-blind person can produce a universally-accepted numerical and objective statement of its colour? How can this same process objectively predict what colour appearance a gemstone will present when viewed with any illuminant of a specified type? What is meant by the rigorous terms 'dominant wavelength', 'excitation purity', 'metric lightness', 'brightness', 'relative luminance', 'metamerism', 'saturation', 'chroma', 'chromaticity', 'colour temperature'? These, some of the terms and concepts used in colour science, would be viewed as unnecessarily arcane matters of little value to practising gemmologists.

At one point the author felt that the greatest obstacle to an eager acceptance by gemmologists of the CIE System was its almost unintelligible profundity. The available literature was written entirely by the same scientists who had invented or developed it. They conceded few departures from the hard road of scientific rigour to simpler pathways which would have helped those who did not have so advanced a technical background. It was, and still is, hard to explain why it is necessary to introduce awkward conceptions such as negative colours. Or to invoke such bizarre quantities as 'supersaturated' or imaginary colour stimuli, which are the X, Y and Z of the CIE Tristimulus Colour System. Such notions are very discouraging to anyone wishing to comprehend the intricacies of colour perception and measurement.

It was therefore the most pleasant surprise to discover, somewhat belatedly, a series of three articles which gave a masterly and lucid treatment of just these two subjects.[11,12,13] Published in

this *Journal* more than 30 years ago, they were a plea by the author, M.D.S. Lewis, to the diamond and coloured gemstone trade, to consider urgently this 'universally adopted system of colour specification and measurement as the basis of a gemmological colorimetry'.

In the last article, the last paragraph is also worth quoting. His last sentence is worth remembering:

'. . . Very recently the writer's attention has been drawn to a remarkable article which appeared in *The Gemmologist* of September 1933 (Vol. 3, No. 26) on the 'Measurement of the Colours of Precious Stones'. A description is given of the Guild Trichromatic Colorimeter (now superseded by the Donaldson instrument) and of the calculations determining the colour quality of a stone. A fascinating and ingenious technique of measuring the light path in a gemstone is also described. It is astonishing to find that even 20 years ago – within two years of the (1931) inauguration of the CIE System – a London firm of scientific instrument makers was ready with an apparatus for the measurement of gemmological colour. Unfortunately the ground was not sufficiently fertile for the idea to take root.'

For the prevailing views on gemmological colorimetry to begin to be changed, at least two things must happen. One is a recognition by examining bodies and teachers to take action soon. It is also necessary for these same individuals to stimulate members of the trade into an awareness of the considerable benefits which can accrue.

Of course, it is equally necessary for the trade itself to deal firmly with retail traders who follow policies of openly encouraging the public to purchase 'colour-certified' stones for investment purposes.

The other matter is the provision of inexpensive teaching material, to allow beginners and mature students to be gradually eased into this new and quite complex subject. The development of the new spectroscope unit has prompted the author to take this latter step.

Colour Filter Slides

Clearly, the simplest and most effective way to begin to do this is to provide a comprehensive series of durable, low-cost, mounted, colour filters. This has now been done. Each of these is relatable to

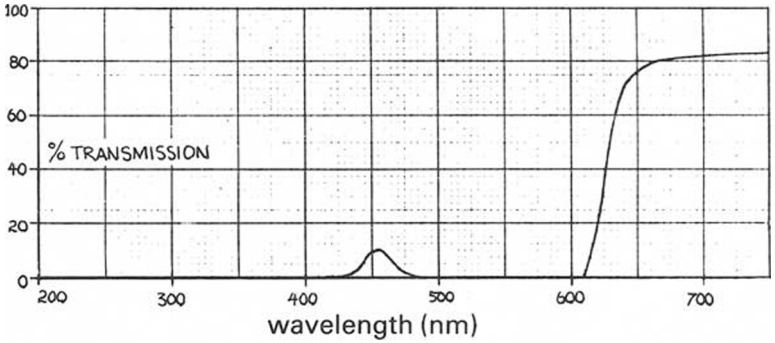

FIG. 1. Example of the spectral transmission graph of a gelatine colour filter. 'Ruby Red' (Filter No. 19, Table I). Percentage transmission versus wavelength (nm).

its own spectral transmission graph provided with the filter set. A typical graph is shown in Figure 1.

Each filter is viewed with the spectroscope unit, either by holding it in front of the spectroscope slit or directly over its eyepiece, whichever is the most convenient. A glance at its corresponding spectral transmission curve allows the student, moving at his or her own pace, to follow the quite complex interactions of white light and coloured filter.

As a rule, in teaching colour science, the lecturer's projection slide explanations are much too fast to permit convincing relationships to be grasped between observation and theory. Although the colour effects on the classroom projector screen can, of course, be seen, the student is often unclear as to exactly what filter or filter combination is being projected.

With each of the new mounted filters, the student's hand and not the lecturer's, is virtually on the projector. The student can follow step-by-step, personally, and at a chosen pace, the direct connexions between the labelled filter, its perceived spectrum, the characteristics of its spectral transmission curve and its perceived colour.

The student then becomes aware that it is the spectral energy *transmitted* by the filter (or stone) that produces the distinctive colour observed. In gemmology, the student has been taught, quite properly, to regard the absorption peaks, rather than the

absorption 'valleys', as the important diagnostic features, simply because they are sharper and more distinctive. It is, however, the shallower absorption valleys (i.e. the transmission bands) that hold the key to an understanding of the production of the resultant colours.

Because of their well-known colour constancy and durability, coloured glasses would be the favoured choice for such a slide collection. However, apart from their high cost, the commercially-available glass colour filters do not embrace a colour range, or colour gamut, as it is called, which is large enough for the present purposes. Coloured gelatine filters are available which do provide an adequate gamut.

The traditional commercially-available gelatine-film filters are usually required for uses which involve frequent handling, as in photography, or for the filtration of strong light sources. They are offered in relatively large standard sizes, varying from a minimum usable diameter of 25 mm to a maximum aperture of 110 mm square. In order to minimize scratching, finger-staining or the buckling arising from changing humidity, it is the practice to sandwich them between optically-flat glass plates. In addition to this, the three components are invariably cemented together with Canada Balsam. This further both improves heat transfer and inhibits humidity-change buckling. However, its main purpose is to reduce the number of parasitically-reflecting air/filter/glass interfaces from six to two, thus increasing the overall light transmission.

The collection of filter slides intended as an accessory to the basic spectroscope unit has been produced with cost very much in mind. They are thin-film (0.1 mm thick) gelatine filters with a protective lacquer overcoating on both sides: they possess sufficiently good colour-fastness. The low cost has been achieved:

(1) By limiting the holder aperture to the smallest diameter which can be conveniently viewed. This reduces humidity buckling and uses less filter material.
(2) By using 'bare' filters. The operations involved in preparing and securing cemented glass sandwiches require costly manipulative time and skills.
(3) By placing the filters in relatively deep recesses in their holders. This decreases the possibilities of scratching or of finger-soiling the surfaces.

TABLE 1. FILTERS MAINLY OF GEMMOLOGICAL INTEREST

Filter No.	Filter name	Purpose
		Crossed filters
1	Fluorescence Exciter* (glass)	Excites chromium fluorescence; absorbs all wavelengths (λ) above 620 nm.
2	High Barrier	Absorbs all wavelengths below 620 nm. Used as a crossed filter to exclude all exciter light.
3	Low Barrier	Absorbs all wavelengths below 530 nm. Used as a less restrictive crossed filter.
		Miscellaneous filters
4	White Diffuser* (glass)	Produces a uniform light source for examinations with 10X loupe and glass immersion cell and for dichroscope observations.
5	Red-End Attenuator	Eliminates the purple glare seen in the spectroscope's blue-violet region.
6	Chelsea	Shows colour effects identical to the Chelsea filter.[17, 18]
7	Colourless Polariser	Colourless filter for use with spectroscope, visual optics, and refractometer.
8	Sodium I	Converts white light to effective 'sodium' light for refractometry.
9	Sodium II	As above, but of higher luminosity for use with the barrel light source.
10	Neodymium (glass)	Shows strong doublet peaking at 744 nm in the far red.
		Filters for demonstrating alexandrite-type colour change effects
11	Standard Daylight	Simulates daylight. Equivalent to CIE Illuminant 'C' (6775K).
12	Standard Tungsten Light	Produces tungsten light equivalent to CIE Illuminant 'A' (2855K).
13	Standard Candle Light	Simulates standard candlelight. Equivalent to a colour temperature of 1950K.
14	Red-Purple Colour Change	Produces large λ_d change. R-P with 'A'; V-P with 'C'.
15	Mid-Purple Colour Change	Produces large λ_d change. M-P with 'A'; V-P with 'C'.
16	Violet-Purple Colour Change	Produces large λ_d change. V-P with 'A'; V with 'C'.
17	Saturation Colour Change	Produces zero λ_d and L* changes. Large p_e change ('A' to 'C').
18	Zero colour Change	Produces zero λ_d,p_e and L* changes ('A' to 'C').
		Colour simulants for some gemstones
19	Ruby Red	Simulates the hue of Sri Lankan and Thai rubies.
20	Spinel Red	Simulates the hue of Burmese spinel and ruby.
21	Imperial Topaz Orange	Simulates the hue of Brazilian 'Sherry-brown' topaz.
22	Heliodor Yellow	Simulates the hue of Namibian heliodor.
23	Peridot Green	Simulates the hue of Zabargad peridot.
24	Emerald Green	Simulates the hue of Colombian emerald.
25	Sapphire Blue	Simulates the hue of Kashmir sapphire.
26	Alexandrite Red	Simulates the hue *changes* of Urals alexandrite.

*This is a thick glass filter enclosed in a metal tube cap which fits on the light source barrel.

TABLE 2. FILTERS MAINLY OF COLOUR SCIENCE INTEREST

Filter No.	Filter name	Purpose
		Additive primary colours
27	Red	These filters are used to produce most colours by simultaneously projecting white light through each. Means have to be provided to vary the relative proportions of coloured light passing through each filter, and to direct each beam on to the same patch of white diffusing mixing screen.
28	Green	
29	Blue	The filters yield the same colours that are produced by the three phosphors used in American television receivers.
		The additive mixing of coloured lights is the principle upon which is based colour printing (half-tone screen letterpress and lithographic process), mosaic art, Impressionist painting, stage lighting and colour television. This principle is also used in the GIA ColorMaster visual colorimeter[27, 28] for the colour measurements of gemstones.
		Also known as:– *Subtractive primary colours*
30	Cyan	(minus-red) By viewing a single white light beam through a pair of these filters at a time, the above red, green and blue colours can be substractively obtained. If the three are used together, no light passes. In principle, by using methods for decreasing each filter's CIE saturation (p_e), most colours can be produced.
31	Magenta	(minus-green)
32	Yellow	(minus-blue)
		The subtractive filtration of white light is the principle upon which is based colour photography, oil-pigment painting, textile dyeing, gravure printing and the Nelson-Lovibond visual colorimeter[29] for the CIE colour measurement of gemstones.
		Narrow-band ('Spectral') monochromatizing filters
33	λ_d = 675 nm	These filters demonstrate how the band-peak wavelength, as shown on the charts, or the CIE dominant wavelength (λ_d), is related to the perceived colour. Spectral observation of each filter should be made using the barrel light source:– (1) alone; (2) with the Standard Tungsten Light filter (CIE Source 'A'), and (3) with the Standard Daylight filter (CIE Source 'C').
34	λ_d = 606 nm	
35	λ_d = 576 nm	
36	λ_d = 538 nm	
37	λ_d = 490 nm	
38	λ_d = 452 nm	
		They can also be used to obtain values of the dispersion of faceted stones. This is accomplished with any gemstone refractometer following the method of Suhner.[30]

(4) By using a single rubber grommet to hold the filter in its cell. Again, this further reduces thermal- or humidity-buckling by permitting small elastic movements of the filter. Should the filter surfaces become soiled or dust-coated, the grommet can be easily removed. The released filter can then be gently wiped with a soft, clean, dry cotton handkerchief and replaced.

(5) By designing easily-machined slide-type filter holders. These are of black Perspex, and are 40 mm in length, 19 mm in width, 6 mm in thickness, and with a viewing aperture of 9.5 mm diameter.

The set contains 38 filters, and except for 3, which are of glass, are of dyed gelatine films. Two of the glass filters are mounted inside metal tube caps; these slide on to the light source barrel. Of the 38 filters, 26 are of direct application to practical gemmology. The remaining 12 are intended to acquaint the student with the elementary principles of colour production, and with the linking of the filter's perceived colour to its observed spectrum and to the corresponding spectral colour transmission curve. They should also help to familiarize the student with the conceptions of dominant wavelength (λ_d), excitation purity (p_e) and metric luminance (L^*). These values are listed for each filter and correspond to the use of the white light of the barrel light source when run at the highest voltage setting and when viewed through the standard Tungsten light filter. This source-plus-filter has been measured experimentally to conform closely to the CIE illuminant A (of colour temperature 2855 Kelvin). This information, together with all the filters, should allow the student, with some practice, to assign numbers, albeit approximately, to the values λ_d, p_e and L^* for an 'unknown' filter.

Brief details of the set of filters are listed in Tables 1 and 2.

A spectrum is viewed by placing the filter over the spectroscope eyepiece. Light from the barrel light source is directed on to the mirror side of the black velvet/mirror sub-base. In this way, light is specularly reflected at 45° into the spectroscope slit, just as it is when reflected from the internal table surface of a gemstone lying on the black velvet side of the stone rest (see Figure 2).

Alternatively, a spectrum can be viewed in a direct transmission mode. This is done by clamping the filter slide on to a fixture attached to the vertical slot of the basic stand. This attachment, with a filter slide in place, can be seen in Figure 3.

The filter storage box and slides are seen in Figure 4.

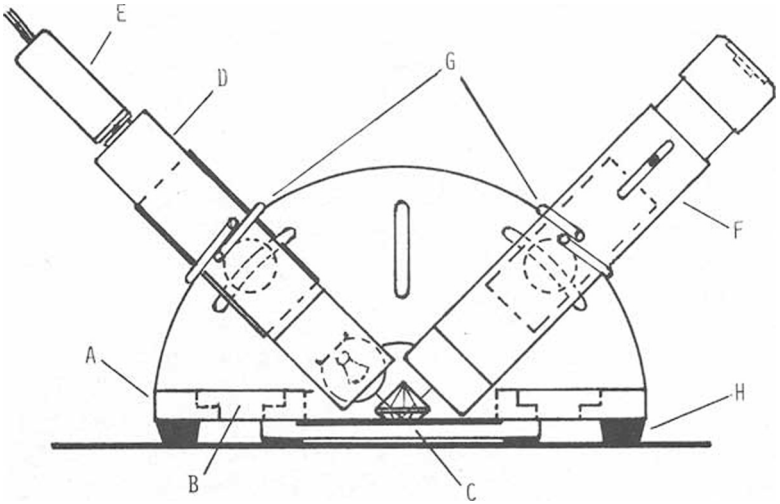

FIG. 2. Sketch of the spectroscope unit.
A. Base. B. Recessed hole for pinhole disc.
C. Gemstone rest; black velvet topside, mirror underside.
D. Barrel light source. E. Jackplug.
F. Fixed slit prism spectroscope.
G. Vee-blocks with wire clamps.
H. Rubber supporting feet.

Comparison Prism Spectroscope

In addition to the five spectroscopes already described,[1] there is now a sixth which has novel features. This is the McCrone comparison spectroscope for viewing two juxtaposed spectra.

It consists of a compound-Amici prism spectroscope, a light source, a standard filter slide holder and an optical arrangement for presenting two spectra side-by-side in the same field of view. It can be mounted on the basic stand in the same manner as the other five instruments. The slit is continuously variable and the eyepiece is focusable.

The advantages of this device over those prism spectroscopes which have externally injected wavelength scales are considerable. There is a complete absence of parallax shift between the two images; this shift is the most troublesome aspect of wavelength scale instruments. Direct spectral comparisons can be made between the faceted test gemstone and a plane-parallel polished section of a chosen orientation of any transparent gemstone material. Sueh sections, mounted in the standard filter slides, serve as permanent

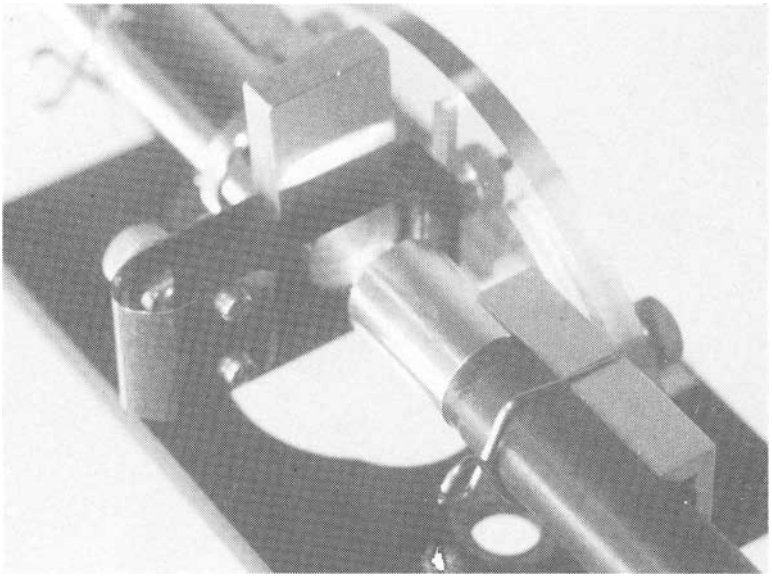

FIG. 3. Prism spectroscope and light source mounted in the direct transmission viewing mode.

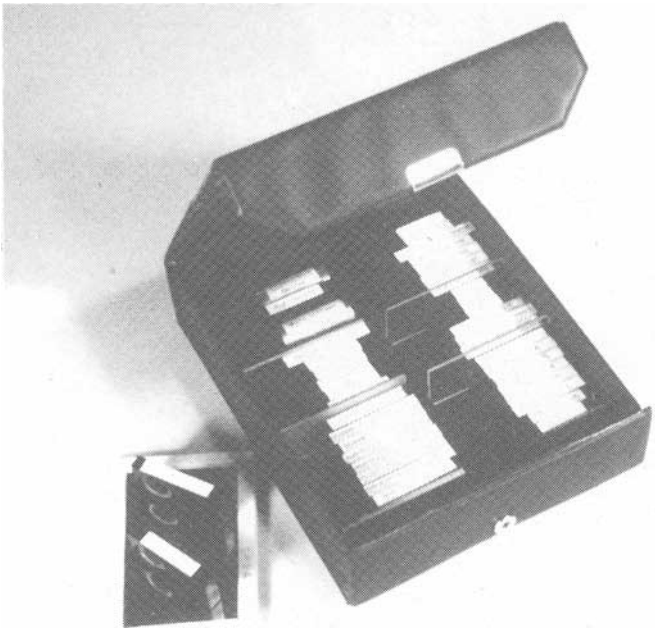

FIG. 4. Filter storage box with filter slides.
Two of the filter slides are shown resting on the mirror side of the gemstone rest.

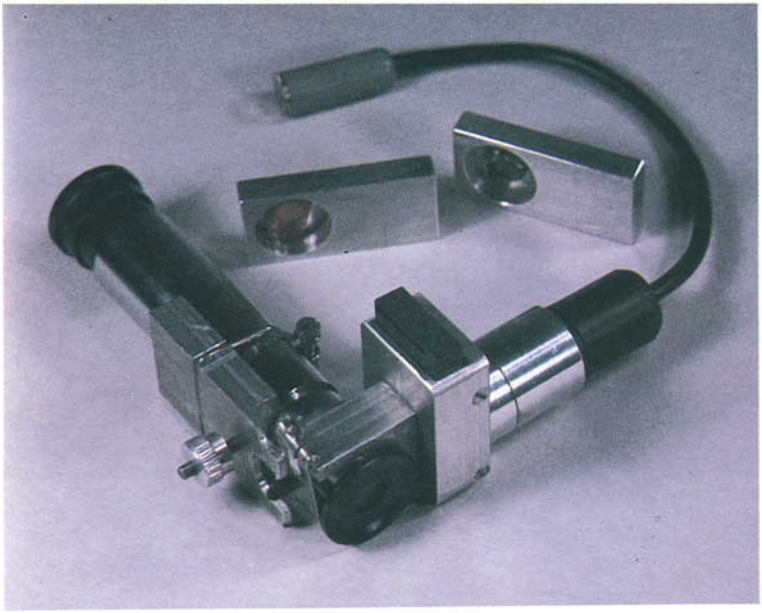

FIG. 5. Comparison prism spectroscope.
Three filter slides are shown; one is in place on the holder. The other two slides contain thick, plane-parallel, polished sections of transparent gemstones. This type of slide serves as a permanent comparison standard for gemstone spectra.

FIG. 6. The comparison prism spectroscope mounted on the basic spectroscope stand.
A black Perspex annulus confining the gemstone can be seen on the gemstone rest. This enables the gemstone's movements to be more readily controlled to obtain the optimum brilliance and uniformity of the spectrum.

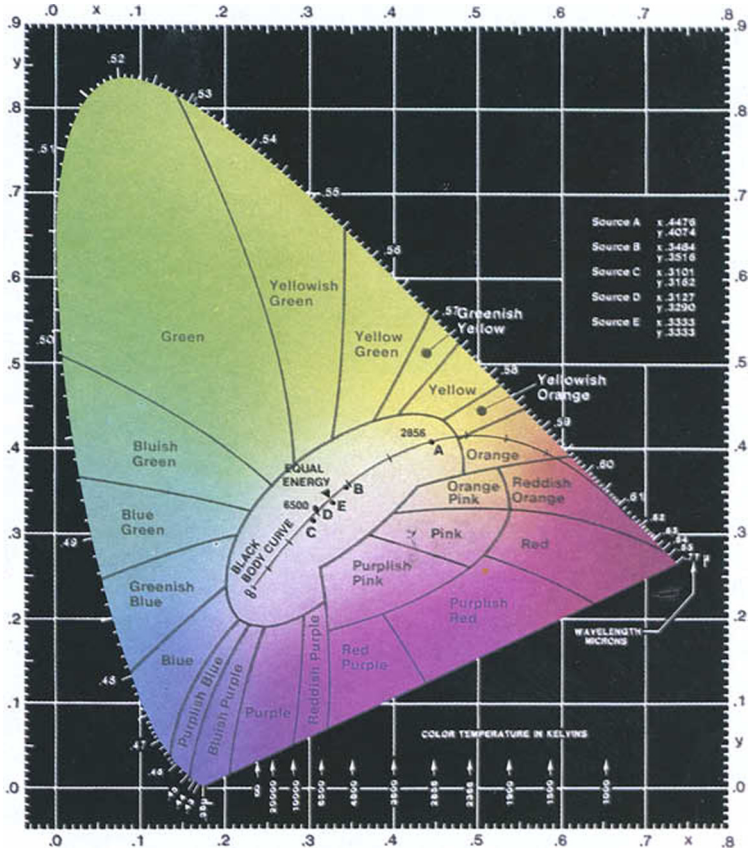

FIG. 7. The CIE (1931) x,y chromaticity diagram.
The chromaticity names allocated to the various zones are those defined for the discriminatory 'Level 1' of the Universal Colour Language System[22] when using the CIE Illuminant 'C' (6775K). The Planckian 'black body' curve and the plots of the various CIE Standard Illuminants (A, B, C, D and E) are also shown.

spectrum references. By suitable choice of materials with known absorption line wavelengths, fairly accurate measurements of the line and band peaks of the test gemstone can be made. Finally any pair of filters, chosen from the collection of gelatine filter slides, can be examined.

The spectroscope is shown in Figure 5. Figure 6 shows it mounted ready for use on the basic spectroscope stand, together with a new type of stone support. This support has been designed so as to permit the stone to be moved about freely on its table surface,

both translationally and rotationally. It enables the stand itself to remain stationary; this can even be bolted to a firmer base.

Several experiments with the comparison spectroscope using this device have persuaded the author that with certain faceted stones, particularly with natural and synthetic emeralds, small but detectable wavelength shifts of the sharp absorption lines in the red do exist. This could of course, be accounted for by crystal axis orientation effects, which only a systematic study could settle. If it proves to be a real effect, it might well have diagnostic significance.

Colorimetric Properties of the Filters

The relevant colorimetric properties of each filter accompany the set. In addition to the spectral transmission graphs which cover the wavelength range from 200 to 750 nanometres, they include the tabulated values of the CIE Tristimulus Colour co-ordinates for each of the three standard illuminants, CIE Illuminant A (colour temperature = 2855K), CIE Illuminant C (= 6770K) and CIE Illuminant D65 (= 6500K). The chromaticity values of the filter for each of the three illuminants are also plotted on two different CIE diagrams. These are the original CIE (1931) x,y diagram and the more recent CIELUV (1976) u′, v′ diagram. The latter yields a more uniform scale of colour differences.

A coloured representation of the CIE (1931) x,y chromaticity diagram is shown in Figure 7, showing the black body (Planckian locus) curve and the plots of the various CIE Standard Illuminants associated with that curve. Examples of two of the six diagrams are shown in Figures 8 and 9. They are the (1931) x,y diagram for Illuminant A and the (1976) u′, v′ diagram for Illuminant D65. The symbols shown against each of the 38 filter plots correspond to the filter name symbols listed in Tables 1 and 2.

It is not appropriate here to give even a short description of the CIE Tristimulus System and its many applications in commerce and industry. For those who seek further information, there are two recent publications,[14,15] which the author believes are among the clearest treatments yet given. An article by Yu,[16] dealing specifically with gemmological colorimetry, retraces some of the paths first blazed by Lewis. Following a brief account of the fundamentals of the CIE System, he proposes the use of any of the well-established collections of standardized colour-graded paint

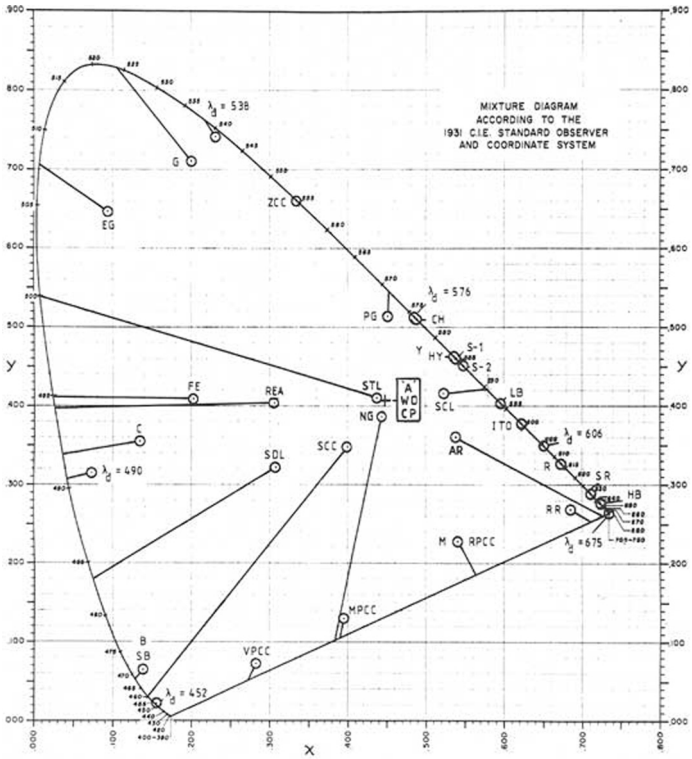

FIG. 8. The CIE (1931) x,y chromaticity diagram.
The chromaticity plots of all 38 colour filters are shown with respect to the CIE Illuminant 'A' (2855K). The filter symbols are given for each plot. The cross corresponds to the identical plots for Illuminant 'A', the white diffuser filter (WD) and the colourless polarizing filter (CP).

chips to match transparent cabochons of ruby, sapphire and other stones. In particular, he mentions the Colour Systems of Munsell, DIN 6164 and others, but neither describes them nor cites actual measurements. A plea is also made for the speedy development of CIE-based techniques to cope with the measurement of transparent faceted stones.

Because of their special interest to gemmologists, the three articles by Lewis have been reproduced and accompany the set of filter slides. Echoing his gentle rebuke, it is to be hoped that the ground has at long last been sufficiently fertilized.

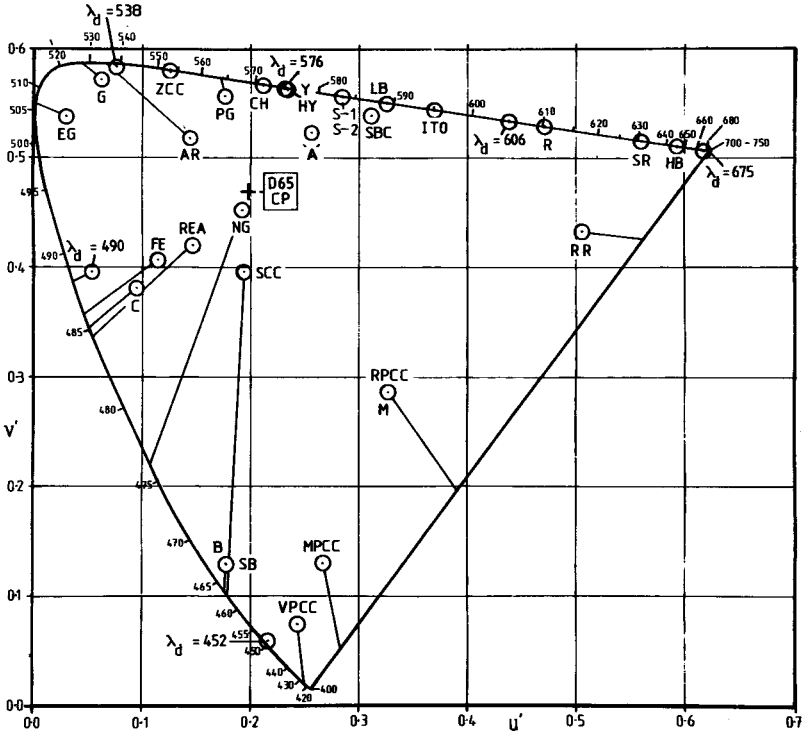

FIG. 9. The CIE (1976) u', v' chromaticity diagram.
The chromaticity plots of all 38 colour filters are shown with respect to the CIE Illuminant 'D65' (6500K). The filter name symbols are given for each plot. The plot for CP is identical to that for D65. Two other illuminants are plotted. They are the CIE Illuminant 'A' and the (non-CIE) illuminant 'SBC', the Standard British Candle (1950K).

Filter Applications

Tables 1 and 2 are more or less self-explanatory, although some amplification is needed for certain filters. The comparison prism spectroscope is an essential device when comparing the spectra of two filters.

While the use of the barrel light source, together with the Standard Tungsten Light filter, is required to render the correct colour appearance of the filters in the set (i.e. with CIE Illuminant A), there are occasions when another, more intense illuminant can be substituted. This is the ordinary unfiltered 100 watt household pearl lamp. It has almost the same colour temperature as the CIE Illuminant A. It is especially useful when viewing the dense filters such as the Chelsea, Sodium I, Alexandrite Red and the Narrow-band ('Spectral') filters.

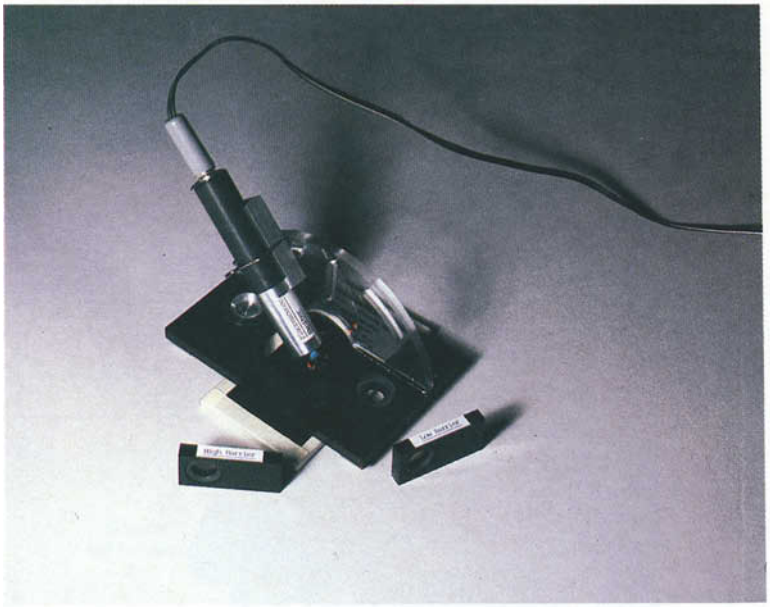

FIG. 10. The 'crossed filters' technique.
The barrel light source is fitted with the glass Fluorescence Exciter filter (No. 1, Table I) to illuminate the ruby gemstone.

In Figure 10, the barrel light source is shown on its stand with one of the cap-mounted glass filters in position. This is the 'Fluorescence Exciter' filter (Table I, No. 1) which transmits all but the red wavelengths. The light emitted from the ruby lying on a velvet-surfaced stone support is seen to be a mixture of two lights. The blue-green light is that specularly reflected from the stone's pavilion facets. The red light is fluorescent light emanating only from the body of the stone. The 'High Barrier' filter (No. 2) completes the crossed filter combination. Placed close to the viewing eye, it behaves as a barrier to the unwanted residual blue-green fluorescence excitation light, but passes all the red fluorescent light.

The Red-End Attenuator filter (No. 5) is useful for detecting faint lines or weak bands in the blue-green, blue and violet regions, particularly when using diffraction grating spectroscopes.

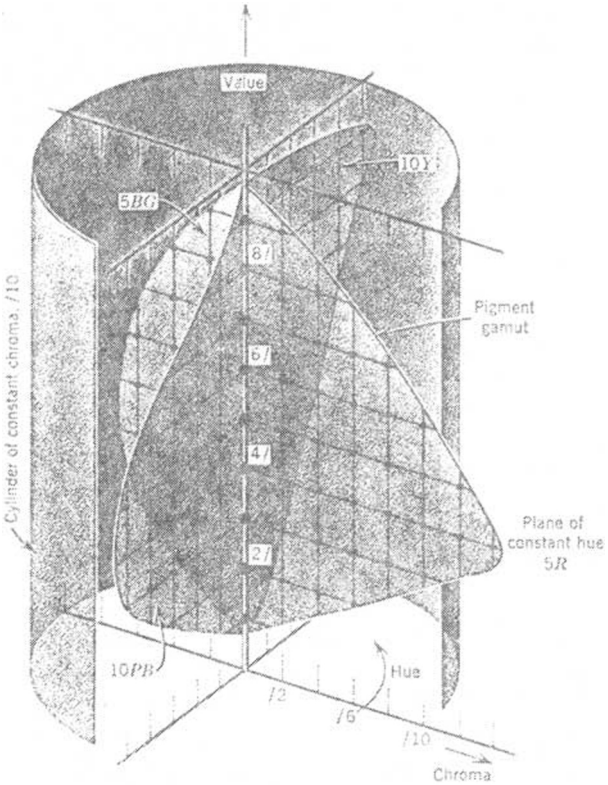

FIG. 11. Schematic diagram of Munsell Colour Space.
This arrangement of a large number of calibrated colour-related surfaces is based on a cylindrical co-ordinate framework. The three attributes of a colour can be represented as a co-ordinate point lying within this space. The attributes are known in the Munsell System as *Hue* (equivalent to the dominant wavelength, λ_d), *Value* (equivalent to the metric lightness, L^*), and *Chroma* (equivalent to saturation, 'colourfulness' or excitation purity, p_e).
The actual colour standards consist of opaque, pigmented films bonded to stiff paper rectangles. They are arranged in a three-dimensional array of orderly scales having visually equal steps. For the sake of clarity, only four vertical planes of constant hue are shown. These are red, yellow, blue-green and purple-blue.

The Chelsea filter (No. 6) has been well documented[17,18] and needs no further comments.

The Alexandrite Red filter (No. 26) gives exactly the same colour response as the new Sterek A filter[19] and indeed performs better in some respects than the Chelsea one. A table listing the observed colour changes for some 26 different stones is supplied with the set.

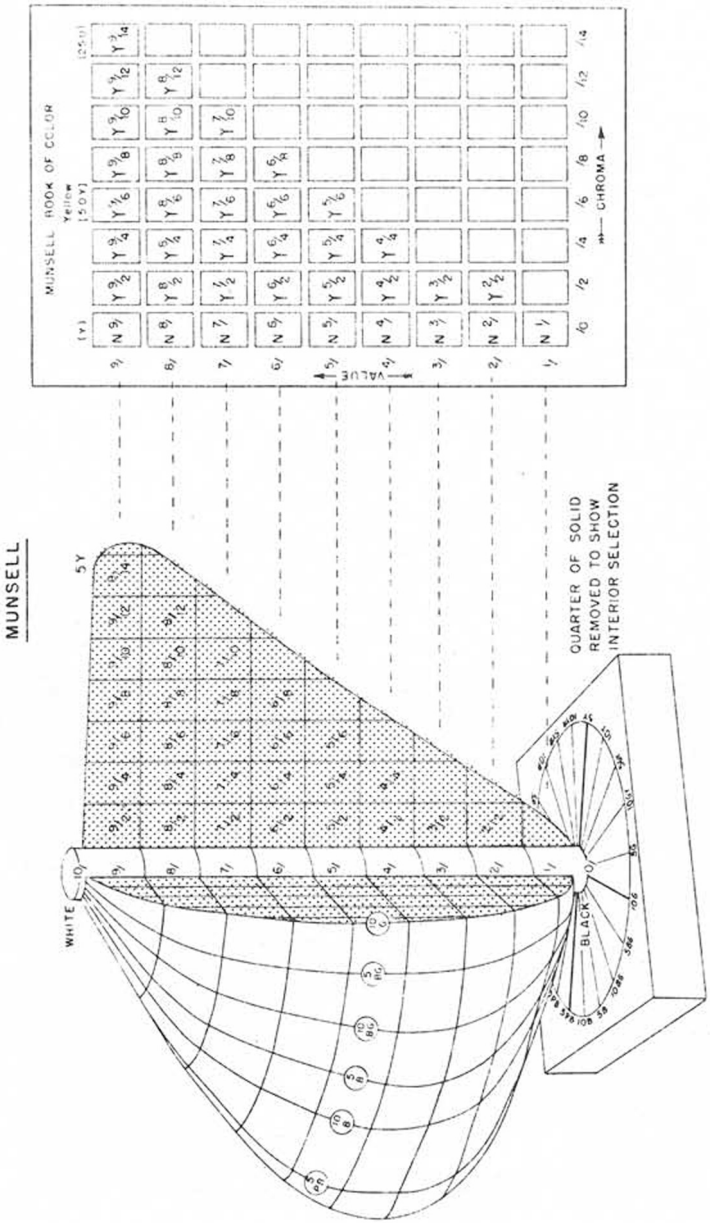

FIG. 12. Munsell Scales of Hue, Value and Chroma.
The Hue (symbol H) circle of this colour space has 20 major hues. It can be expanded to 100 hues, each with its own hue notation. The Value (symbol V) varies from 0 (black) to 10 (white) in relation to the neutral (achromatic) vertical central axis. The Chroma (symbol C) increases radially outwards from the axis. The greater the C, the greater is the colourfulness. The full notation for each of the 38 yellows of the Hue symbol '5 OY' is shown alongside. This page has been taken from the Munsell Colour Atlas. The basic collection of the 'Munsell Book of Colour' has a total of over 1500 painted, detachable colour 'chips'.

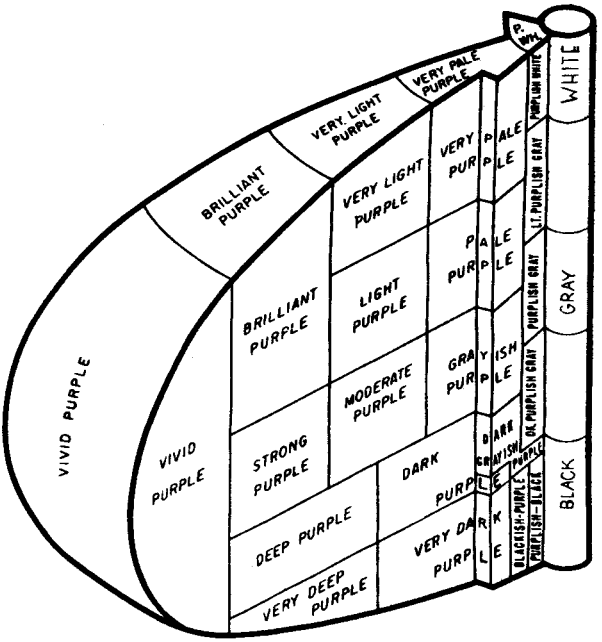

FIG. 13. The purple section of the Universal Colour Language colour space.[22]
This illustrates the colour-name block structure at the discriminatory 'Level 3'. The colour space is identical to that of the Munsell System.

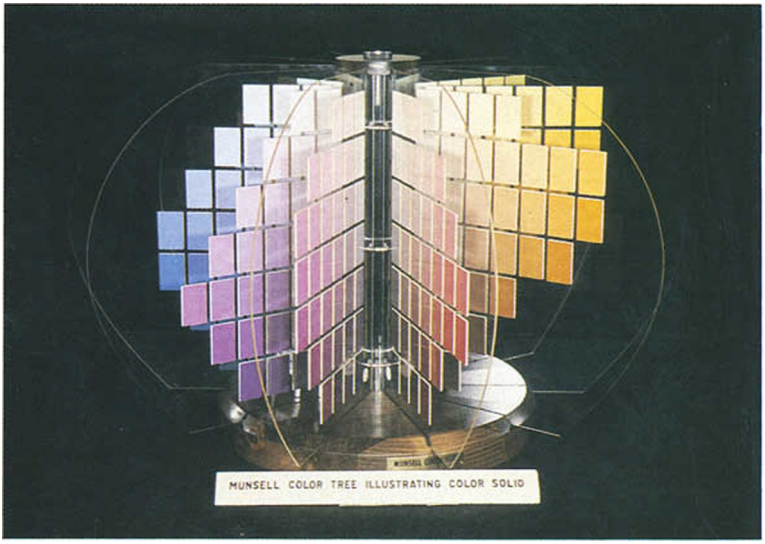

FIG. 14. Munsell 'Colour Tree'.
This is an assembly of standard Munsell colour chips mounted on transparent Hue planes.
To prevent visual overcrowding, only 10 of the standard 40 major Hue planes are shown.

In routine refractometry, when a sodium vapour lamp is not available, a convenient substitute consists of a free-standing, condensing, tungsten light source of about 10 watts in conjunction with a Gemmological Instruments Ltd (1157) Sodium-I filter (No. 8). However, this is too dark a filter to be usable with the barrel light source, particularly when the colourless Polariser filter (No. 7) is also employed. A more luminous filter, Sodium-II (No. 9) is a good substitute, but other monochromatizing filters such as $\lambda_d = 606$ (No. 34) and $\lambda_d = 576$ (No. 35), although darker, can also be used. In operation, the light shield of the mechanically adjustable barrel light source is placed directly and centrally against the light entrance port of the refractometer. The selected filter fits centrally in the flange of the eyepiece. As before, either the mains transformer or a 6-volt battery power supply can be used. The properties and performances of the various monochromatizing light sources are listed in Table 3.

The Neodymium filter (No. 10) serves as a good test of the red sensitivity of normal colour vision. When used with a prism spectroscope and the High Barrier filter (No. 2), a strong doublet peaking at 744 nm in the far red should be discernible. The 'N3' line at 415.5 nm, seen with a yellowish Cape series diamond, is a fair test for visual sensitivity in the far violet if the Red-End Attenuator filter (No. 5) or the Fluorescent Exciter (No. 1) is used with a diffraction instrument.

When exploring the alexandrite-effect colour changes, the three colour temperature filters (Nos 11, 12, 13) should be held together fan-wise in front of a 100 watt pearl lamp. In this way, swift comparisons can be made of the behaviour of any one of the six filters (Nos 14, 15, 16, 17, 18, 26) or indeed of any of the set's other filters interposed in the light path.

The Description of Colour

The colour simulant filters (Nos 19 to 26), named for some of the more important gemstones, are not meant to represent faithfully the commercially- or aesthetically-preferred colour appearance of such stones. As an analogy they are intended simply as colour 'hitching-posts' to which gemstone colours can be tied with different lengths of rein, not just in the two dimensions of

TABLE 3

Monochromatizing light sources obtainable with barrel light source

Filter properties					Performance with refractometer		
Filter name	No. in set	Effective peak λ (nm)	Peak band-width (nm)	Peak transmission (%)	Relative signal sharpness	Relative image intensity	Required correction to instrument reading
$\lambda_d = 606$	34	604	27	6.0	Medium	Moderate	Add 0.0006
(Sodium vapour lamp)	–	589	1	–	Maximum	Intense	Zero
Sodium-I	8	581	20	2.2	Good	Weak	Subtract 0.0004
Sodium-II	9	576	35	36	Fair	Strong	Subtract 0.0007
$\lambda_d = 576$	35	573	25	6.0	Medium	Moderate	Subtract 0.0008

chromaticity (hue and saturation), but in the three complete colour dimensions of hue, saturation and lightness. No one can describe exactly in words how green, grey or dark a particular colour of emerald or peridot appears. The kind of greenness can only be stated as a greater or lesser shift of hue from a given perceived green towards either the blueness of the emerald or the yellowness of the peridot. Or by how much or how little a hue is more colourful or more grey; this is termed its degree of saturation. A shift towards either a lighter or a darker sensation would be described as a lightness difference. In this manner, the filters serve as helpful colour reference points when any of the three light sources (Nos 11, 12, 13) are specified.

In the distant past, gemstones with favoured colours were given biologically poetic names that did little to inform. Nature is ungenerous with her supply of reliably constant colours and Nikon Cooper[20] rightly scorns the continued use of such terms as 'pigeon's blood red' to describe the finest ruby colour. However, many of these optimistically associative and bizarre names are still with us.

In an attempt to seek a more quantitative description for this mysterious red colour known only to hunters and the few fortunate owners of the best Burmese rubies, the author sought the help of the London Zoo. Their Research Department were quick to oblige and sent a specimen of fresh, lysed, aerated, pigeon's blood. A sample of this was promptly spectrophotometered. It yielded a spectral transmission graph which was found to be virtually identical to that for the Spinel Red filter (No. 20). This means that for the first time, good CIE colour co-ordinates for three different light sources now exist for at least one classical gemstone colour. The Burmese bird can at last be safely removed from the realms of gemmology and consigned back to ornithology. The eggshell colour of another bird, the robin, may well be the next one to succumb to CIE scrutiny in the quest for a more acceptable turquoise standard. As the American robin has chosen a different colour scheme for her eggs from that of Britain's national bird, this may present difficulties. The American robin is actually a red-breasted thrush.

While such august bodies as the U.S. National Bureau of Standards has sponsored the development of colour vocabularies,[21] giving sensible English names to specific wedge-shaped zones in colour space, the scheme appears to be too

elaborate and imprecise for widespread acceptance. For example, there are 173 names for the 'light blue' zone. An article by Styne[22] outlines the principles of an extension to this Munsell-System-based method. It is known as the Universal Color Language.

The scheme of the Munsell colour space with its own nomenclature is illustrated in Figures 11 and 12. The Munsell numbers can be converted by computer into CIE co-ordinates corresponding to daylight viewing (equivalent to CIE Illuminant D65). The purple slice of this space is shown in Figure 13, but here the Munsell code-numbers have been replaced by the colour-name blocks of the Universal Color Language. This slice represents a portion of the discriminatory 'Level 3'. The whole colour space at this Level contains 267 colour-name blocks. Coarser divisions are given at Level 1 (see Figure 7) and at Level 2. Tighter descriptions are provided for at Levels 4, 5 and 6. For example, Level 5 yields 100,000 colours by visual matching. Level 6 is divided into 5,000,000 parts, but only a spectrophotometric procedure could hope to attain this kind of accuracy. A Munsell 'Colour Tree' is shown in Figure 14.

It appears to the author (J.B.N.) that the assignment of three CIE numbers per colour has one increasingly important advantage over this method; that of being 'computer-user friendly'. Another is the ease which plus-and-minus tolerances can be assigned to each of the three numbers. This automatically defines the location of a specific volume or zone within any one of the several CIE colour spaces, preferably the uniform and orthogonal colour space, CIE 1976 ($L^*u^*v^*$).[23,24] Thus, colour co-ordinates plotted as points and falling within these boundaries can represent the most favoured gemstone body colours, based either on commercial or aesthetical judgements. There is a further valuable feature. It is the manner by which a consideration of only three numbers allows the gemmologist to conjure up in the mind's eye a fair mental picture of what the unseen colour of a stone will look like. Or conversely, describe a perceived colour with three numbers.

The author fears that the instinctive desire to employ words rather than numbers may sway gemmological colorimetry in this direction. He hopes that Lord Kelvin's view* will prevail.

* '. . . when you can measure what you are speaking about and express it in numbers, you know something about it; but when you cannot express it in numbers, your knowledge is of a meagre and unsatisfactory kind. It may be the beginning of knowledge, but you have scarcely in your thoughts advanced to the state of science, whatever the matter may be'.

Colour Science Experiments

All the filter slides listed in Table 2 and several in Table 1 are components of demonstration material intended as learning aids in the subjects of colour production and colour perception. Both subjects form a necessary preparation for the understanding of practical gemmological colorimetry. Of the systematic experiments which have been brought together, most require detailed explanations. Several other experiments considered important enough to be included require a few simple, low-cost ancillary items. These are large quarter-wave and full-wave retardation filters;[25] 'Dayglo' and UV fluorescent specimens, a pair of wavelength calibration slides, a set of diffusely-reflecting international ceramic colour standards[26] and both ultraviolet- and infrared-transmitting filters.

Descriptions of the experiments and their background explanations are much too lengthy to be included in this article. They will be published in a future paper in this *Journal* under the title 'Some experiments in colour science'. It is also hoped to follow this with an account of the development of a visual gemstone colorimeter.[29]

Acknowledgement

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[*Manuscript received 25th January 1985*]

REFRACTOMETERS WITH BUILT-IN LED ILLUMINATION

By PETER READ, C.Eng., F.G.A.

The use of yellow light-emitting diodes (LEDs) as a convenient and relatively cheap source of refractometer illumination was first proposed by D. Minster[1] in 1979. These miniature solid-state lamps have a peak emission in the region of 585 nm, a wavelength that is sufficiently close to that of the sodium lamp (589.3 nm) to make the yellow LED a useful alternative light source.

The first commercially produced LED unit for refractometer illumination was marketed by the Rayner Optical Company in 1982

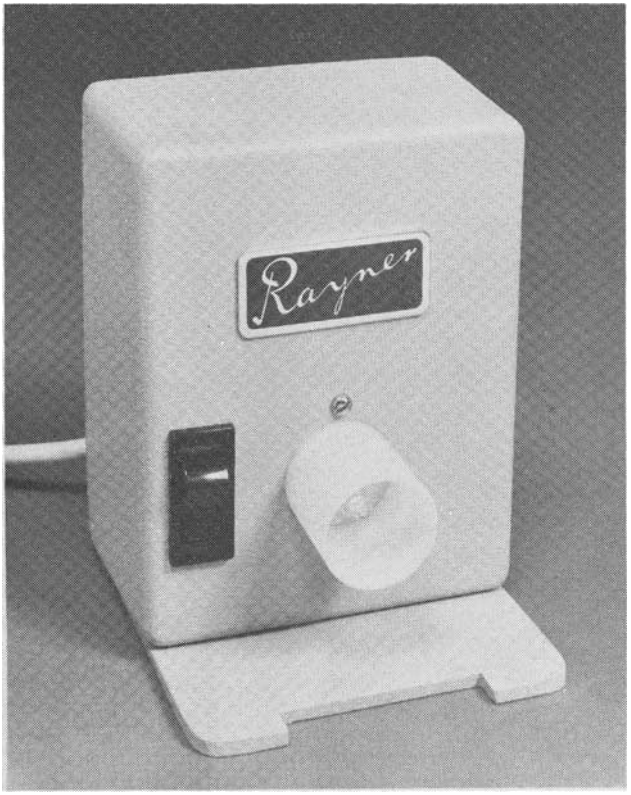

FIG. 1. The Rayner Raylight uses six light-emitting diodes.

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(Figure 1), and this was followed by versions from several other gem instrument manufacturers. The LED illuminator proved to be very popular because of its relatively low cost coupled with the long life of the light-emitting diodes (around 50 000 hours) and the fact that, unlike the sodium lamp, it produced its maximum light output immediately on being switched on. However, in contrast to the sodium lamp, its light is not monochromatic, but includes some green and red wavelengths. As can be seen in Figure 2, the emission bandwidth of the yellow LED (measured at the 50% relative emission points) is 35 nm. In comparison, a medium-quality interference filter (as fitted to high-intensity white light refractometer illuminators) has a bandwidth of between 5 and 20 nm, while the sodium lamp emits the bulk of its energy at the D_1 and D_2 Fraunhofer lines of 589 and 589.6 nm (i.e., it has an effective bandwidth of 0.6nm).

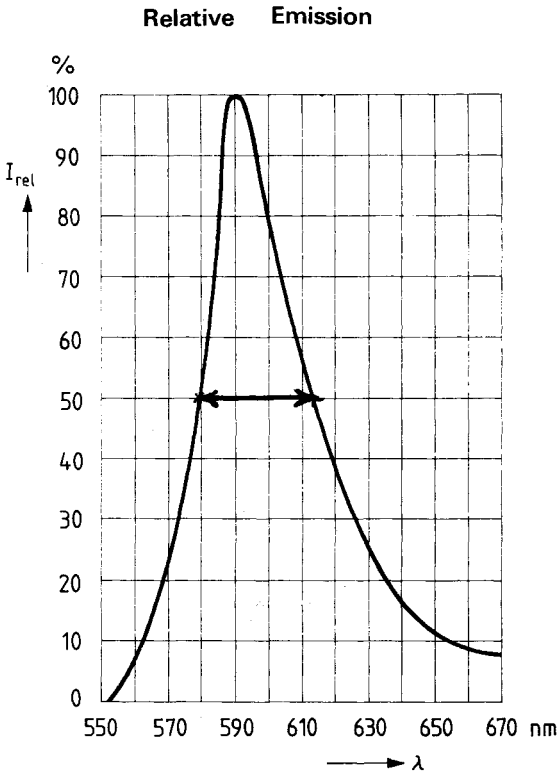

FIG. 2. Relative spectral emission of a yellow LED. The bandwidth at 50%: relative intensity is 35 nm.

In 1983, the Eickhorst company introduced the GemLED refractometer which contained a built-in source of LED illumination.[2] By placing three LEDs in close proximity to the refractometer prism (Figure 3), a sufficiently high level of light was available to enable the refractometer to be used with a polarizing eyepiece filter (with external-LED units the light level is often too low to allow the use of such a filter).

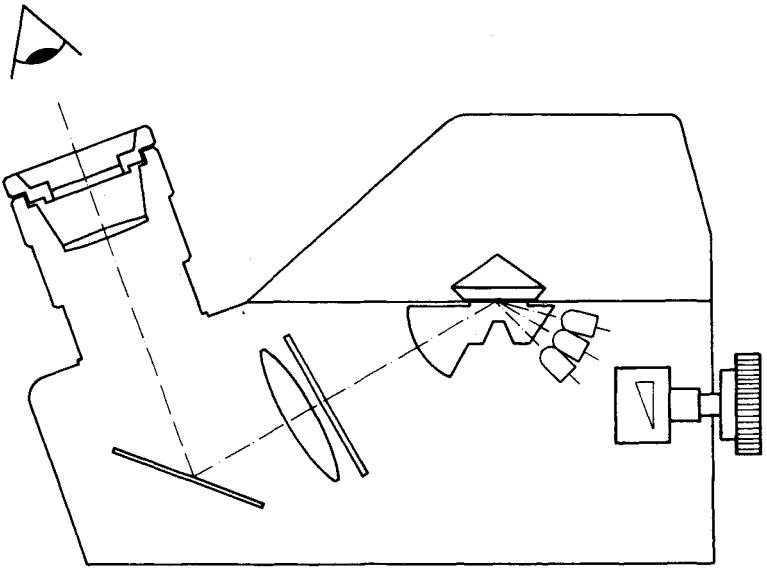

FIG. 3. Diagram showing the position of the three yellow LEDs against the prism in the Eickhorst GemLED refractometer.

The Eickhorst GemLED refractometer (Figure 4) is fitted with a rotary light-level control and because of the low current consumption of the LEDs (around 30mA) can be operated both from a battery supply and, via a 120/240-volt adaptor, from an A.C. mains supply. The battery holder, which can be fitted with either dry batteries or a rechargeable unit, also serves as an operating plinth for the refractometer.

More recently, the Rayner Optical Company has developed a similar LED refractometer (Figure 5). With this unit, the operating plinth contains the mains supply unit, a light-level control and a battery/off/mains switch as well as a PP3-type dry battery. Like the Eickhorst refractometer, the LED illuminator in the Rayner

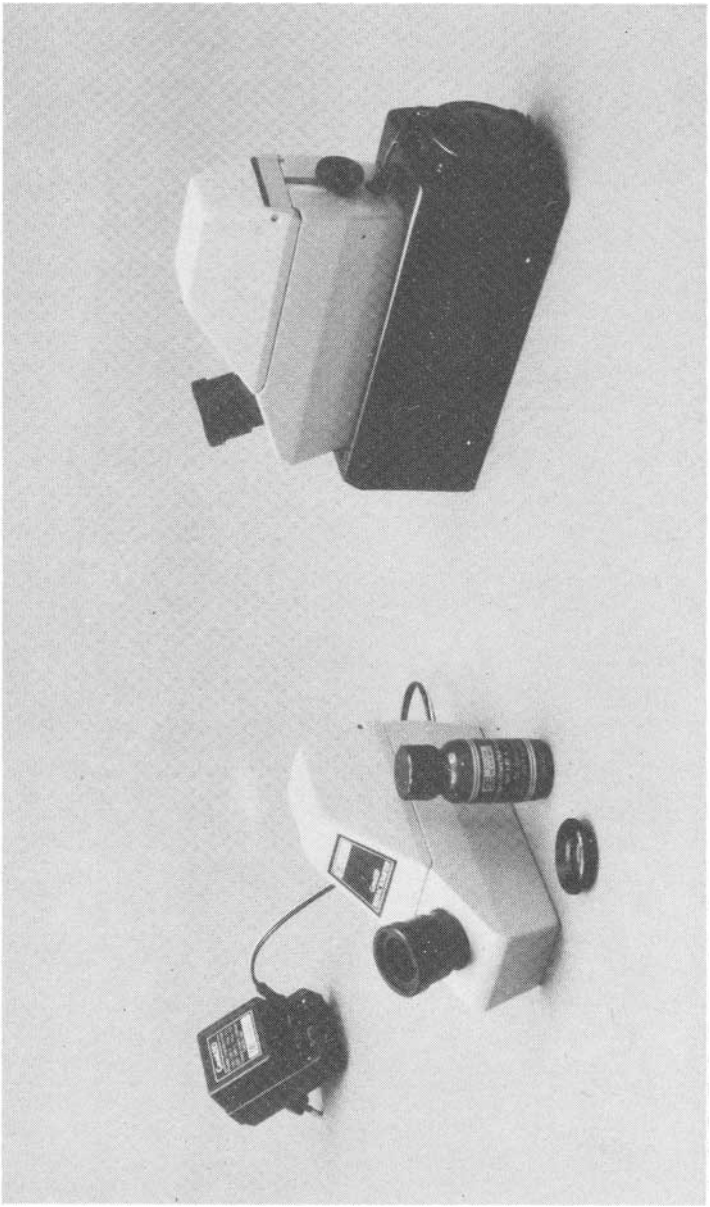

FIG. 4. The Eickhorst GemLED refractometer with a mains adaptor (left) and a battery plinth (right).

FIG. 5. The Rayner LED refractometer uses a 2-LED illuminator which can be withdrawn through the rear of the unit.

model is sufficiently bright to allow for the use of a polarizing eyepiece filter.

In the case of the Rayner model, however, the twin-LED illuminator element can be withdrawn through the rear of the refractometer. This added feature enables the Rayner refractometer to operate with external light sources such as the sodium lamp, which can then be used to provide a truly monochromatic light source when the need arises for very precise RI readings.

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GEMMOLOGICAL ABSTRACTS

ABBOTT (R.N., Jr). *$KAlSiO_4$ stuffed derivatives of tridymite: phase relationships.* Am.Mineral., **69**, 5-6, 449-57, 8 figs, 2 photos, 1984.

The system (K, Na)$AlSiO_4$ includes several stuffed derivatives of tridymite, among them, nepheline, kalsilite and kaliophilite. The phase relations for the potassic side of this system are reassessed in light of (1) theoretical considerations regarding Al/Si order/disorder and displacive transformations, and (2) new analyses of the XRD patterns of some of the polymorphs. J.A.Z.

BALFOUR (I.). *Famous diamonds of the world, XXI. The 'Star of the South'.* Indiaqua, 40 (1985/1), 113-18, illus., 1985.

The author provides a brief survey of the part that three women have played in the history of diamond discoveries; Russian geologist Larisa Popugayeva who was responsible for opening up the U.S.S.R.'s Yakutia diamond field, the diamond geologist Maureen Towie who, with her husband, was the first to find diamonds in the Australian Kimberley Ranges, and a negress slave in Brazil who in 1853 picked up a diamond weighing 268.82 metric carats in the Bugagem diggings in Minas Gerais. The name of the nearby town Bugagem was subsequently changed to 'Estrala do Sul' (Star of the South) in honour of the find.

The negress who found the stone was rewarded with her freedom and a pension for life. Surprisingly, the value of the Brazilian diamond was not immediately recognised, and it was sold for a mere £3000. The fortunate buyer, however, deposited the gem in the Bank of Rio de Janeiro and received an advance of £30000 in lieu of its potential value.

After being the subject of several deals, the diamond was eventually sent to Amsterdam for cutting by Mr Voorzanger of the firm of Coster (who had previously recut the 'Koh-i-Noor'). The Brazilian stone was fashioned into an oval weighing 128.8 metric carats, and because of the stone's 'peculiar prismatic form' this had a rose tint.

The polished gem was bought by a Paris syndicate of dealers who named the stone 'Star of the South', and it was displayed at the London Exhibition of 1862 and at the Paris Exhibition of 1867. The stone was eventually purchased by Mulhar Rao, the Gaekwar of Baroda, for £80000. Following a trial of the Gaekwar for complicity in the attempted poisoning of the British Political Resident at Baroda, the 10-year old son of the Viceroy was placed on the throne. In 1934, the new Gaekwar of Baroda, now an elderly and respected ruler, revealed that the 'Star of the South' was mounted in a necklace among his family's jewels. In recent years it has been reported that the diamond is owned by Rustomjee Jamsetjee of Bombay, but there has been no confirmation of this fact. P.G.R.

BALL (R.A.). *Black opal: a brief review.* Aust.Gemmol., **15**, 9, 310-14, 3 figs, 1985.

Summarizes known facts on this rarest of opals including efforts to define the type more exactly. Carbon from bush fires is suggested as the cause of the black base-colour, but more research is needed on this. R.K.M.

BANK (H.). *Fast farbloser Olivin aus Sri Lanka.* (Nearly colourless olivine from Sri Lanka.) Z.Dt.Gemmol.Ges., **33**, 3/4, 139-40, 2 tables, bibl., 1984.

The author describes a nearly colourless olivine with very low RI 1.640-1.675, SG 3.2, and Fe content only 3.6% of the weight. The author was offered the stone as painite from Sri Lanka and is not absolutely sure of the correctness of the origin. E.S.

BENNETT (J.M.). *A guide to choosing facet rough.* Lapidary J., **38**, 11, 1472-5, 1985.

Advice is given to prospective purchasers of rough gem material. M.O'D.

BREITHAUPT (B.H.). *Goniobasis agate.* Rocks & Minerals, **58**, 5, 247, 1 fig., 1983.

In SW. Wyoming and NW. Colorado, layers of calcareous sediments rich in *Goniobasis* gastropods have been replaced by silica to form an attractive agate. The resulting dark brown to black rock with white fossiliferous markings is popular with lapidaries. The rock is commonly erroneously named turritella agate for its resemblance to the marine-dwelling *Turritella* gastropod. R.S.M.

BRIDGES (C.R.), GRAZIANI (G.), GÜBELIN (E.). *Ein neuer Edelstein aus der Feldspat-Familie.* (A new gemstone of the feldspar family.) Z.Dt.Gemmol.Ges., **33**, 3/4, 104-13, 8 figs in colour, 4 diagrams, 2 tables, bibl., 1984.

The new gem quality feldspar comes from Kioo Hill in Kenya. It occupies central parts of larger common feldspar crystals in a kyanite bearing pegmatite besides vermiculite and quartz. The new gem was found to be a low temperature albite with peristerite structure. RI 1.531-1.539, DR 0.008, SG 2.623 ± 0.002. E.S.

BROWN (G.). *Recording gemstone absorption spectra.* Aust.Gemmol., **15**, 9, 308-9, 2 figs, (1 in colour), 1985.

A brief account of the Snow photographic system for recording colour pictures of absorption spectra. It takes no account of the uneven spectral sensitivity of photographic film or of the inherent absorption of the emulsions. Thirteen spectra are illustrated, but some colours are entirely missing and the built-in scale seems to have a will of its own and wanders some 30nm up or down the spectrum. R.K.M.

BROWN (G.). *Synthetic or imitation: that is the question.* Aust.Gemmol., **15**, 9, 319-21, 1985.

An attempt to sort out the hair-splitting situation in the use of these terms. R.K.M.

CASSEDANNE (J.). *Au pays des émeraudes.* (In the emerald country.) Monde et Minéraux, 66, 16-20, 4 figs (2 in colour), 1985.

The emerald-producing areas of Brazil are reviewed and details given of locations and mining methods. M.O'D.

CHIKAYAMA (A.). *Gem occurrences in India*. Gemmological Review, **6**, 1, 2-7, 9 figs, 1984.

Chrysoberyl cat's-eye is found in the Trivandrum area in Kerala, most specimens being fairly small. Apatite cat's-eye is produced in small quantities from the Kangayam-Karur region, the stones being honey-yellow. Diopside cat's-eye comes from the same area; the stones are black tinged with green. Enstatite cat's-eye from the same area is brown-tinged black. Agate and jasper localities are also quoted. M.O'D.

CHIKAYAMA (A.). *New synthetic vanadium-doped emerald, Biron emerald*. Gemmological Review, **6**, 1, 10-12, 5 figs, 1984.

A synthetic emerald doped with vanadium as well as chromium and with RI 1.577, 1.570, DR 0.007, turned out to be a Biron emerald. SG was 2.72 and the stone displayed straight growth lines and liquid inclusions similar to those already seen in hydrothermal emeralds. M.O'D.

CHIKAYAMA (A.). *Seeking out the sources of some of the newer synthetic gems*. Gemmological Review, **6**, 2/3, 10-12, 1984.

The author discusses Ramaura ruby, C-Ox, Kashan ruby and some new Chatham material. Pink cubic hafnia is being made in the U.S.S.R. and sold as cut stones in the U.S.A. M.O'D.

CHIKAYAMA (A.). *Gem occurrences in India*. Gemmological Review, **6**, 4, 2-4, 7 figs, 1984.

The author discusses cornelian from Jhangadia, Gujarat, calcite from Aurangabad, Maharashtra state, a reported alexandrite occurrence in the Kangayam-Karur gem field in central-southern India. Some tourmaline, kyanite and apophyllite deposits are also quoted. M.O'D.

CHIKAYAMA (A.). *Gem occurrences in India*. Gemmological Review, **6**, 5, 2-5, 4 figs, 1984.

Yellow and brown sphene of gem quality comes from Mettur in Tamil Nadu; no green material has yet been found there. Sillimanite cat's-eye comes from the Bhandada area of Madhya Pradesh which also produces lazulite crystals. Analcime comes from the Poona area and samarskite from Tamil Nadu. Pearl localities are also given. M.O'D.

CHIKAYAMA (A.). *Boulder opal doublets*. Gemmological Review, **6**, 5, 12, 1984.

A boulder opal doublet is made from a white opal on a limonite base with a jagged join. Traces of a dark film of adhesive may be seen on magnification. The opal will show a characteristic bright bluish-white fluorescence under LWUV; this is rarely seen with true boulder opal. M.O'D.

CHIKAYAMA (A.). *Gem occurrences in Sri Lanka*. Gemmological Review: (a) **6**, 6, 2-5, 4 figs; (b) **6**, 7, 2-4, 2 figs; (c) **6**, 8, 2-6, 4 figs; (d) **6**, 9, 2-7, 8 figs; 1984.

(a) A short history of Sri Lanka is given. (b) and (c) The geology is described with a classification of the rock types. (d) The chief mining areas of Ratnapura, Buttala, Meetiyagoda, Pallegama and Kataragama are described. M.O'D.

CONNELLAN (M.), POZZEBON (L.). *Asterism – the great enigma: a study of Austrlian star sapphires*. Aust.Gemmol., **15**, 9, 295-9, 301-6, 9 figs (2 in colour), 1985.

A somewhat aggressive appraisal of asterism which, although extensively illustrated, is neither easy to follow nor completely rational. It seems to be suggested that the arms of a star run parallel with the length of the reflecting crystals, and that star stones are multi-crystalline. A diagram indicates 'Parallel bands of inclusions which act as condensers and store the electric field from incident light-rays which are annulled as they lose photons.' [This may make sense to the writers, but it does not do so to this abstracter.] R.K.M.

DEINES (P.), GURNEY (J.J), HARRIS (J.W.). *Associated chemical and carbon isotopic composition variations in diamonds from Finsch and Premier kimberlite, South Africa.* Geochimica et Cosmochimica Acta, **48**, 2, 325-42, 9 figs, 1984.

The carbon isotopic composition of 66 inclusion-containing diamonds from the Premier kimberlite, S. Africa, 93 inclusion-containing diamonds and four diamonds of two diamond-bearing peridotite xenoliths from the Finsch kimberlite, S. Africa, was measured. The data suggest a relationship between the carbon isotopic composition of the diamonds and the chemical composition of the associated silicates. For both kimberlites, similar trends are noted for diamonds containing peridotite-suite inclusions (P-type) and for diamonds containing eclogite-suite inclusions (E-type): higher $\delta^{13}C$ P-type diamonds tend to have inclusions lower in SiO_2 (ol), Al_2O_3 (opx, gt), Cr_2O_3, MgO, Mg/(Mg + Fe) (ol, opx, gt) and higher in FeO (ol, opx, gt) and CaO (gt). Higher $\delta^{13}C$ E-type diamonds tend to have inclusions lower in SiO_2, Al_2O_3 (gt, cpx), MgO, Mg/(Mg + Fe) (gt), Na_2O, K_2O, TiO_2 (cpx) and higher in CaO, Ca/(Ca + Mg) (gt, cpx). Consideration of a number of different models that have been proposed for the genesis of kimberlites, their xenoliths and diamonds shows that they are all consistent with the conclusion that in the mantle, regions exist that are characterized by different mean carbon isotopic compositions. R.A.H.

DEVRIES (R.C.), FLEISCHER (J.F.). *Synthesis of jadeite for jewelry*. General Electric Technical Information series report (class 1) 84CRD282, 15 pp, 1984.

Different colours of jadeite have been made both by high-pressure synthesis and by a method of reconstitution from natural jadeite powder. Pressures used were about 30-50kb, temperatures 1200-1400°C and the time taken for completion of growth ½ to 24h. M.O'D.

DIETRICH (R.V.). *Michigan's state stone and state gemstone*. Rocks and Minerals, **58**, 3, 97-8, 2 figs, 1983.

'Petoskey stone' is a coral (*Hexagonaria percarinata*) limestone that takes a high polish and is prized by lapidaries for making gems and ornaments. It consists of solid material showing roughly hexagonal-walled units, each with a central dark area from which radial lines extend outward to the walls. This rock was declared the official state stone of Michigan in 1965. The state gemstone (since 1972) is chlorastrolite, an attractive green, chatoyant variety of pumpellyite. R.S.M.

DORLING (M.), ZUSSMAN (J.). *An investigation of nephrite jade by electron microscopy*. Mineralog.Mag., **49**, 1, 31-6, 8 figs, 1985.

Specimens of tremolite and richterite were examined by TEM, the specimens having been ion-thinned. They contained clusters of very small lath-like crystallites with the z-axes roughly parallel but having a range of azimuthal orientations. The clusters may arise from post-tectonic recrystallization of strained amphibole crystals where the new crystals have their z-axes following those of the old. The toughness of nephrite is a function of a variety of submicroscopic features including the sizes and orientations of the crystallites and the nature of the grain boundaries. M.O'D.

EMMETT (J.L.). *Lapis lazuli, the gem of Afghanistan*. Lapidary J., **38**, 11, 1416-19, 2 figs (1 in colour), 1985.

A general survey of the occurrence and use of lapis lazuli with particular reference to the Afghanistan deposits and a note on its colour. M.O'D.

FRYER (C.W.), ed., CROWNINGSHIELD (R.), HURWIT (K.N.), KANE (R.E.). *Gem Trade Lab Notes*. Gems & Gemology, **XXI**, 1, 43-8, 17 figs in colour, 1985.

An amethyst, heated to lighten colour, was left too long and turned brownish-yellow; an almandine star stone had been cut as a cat's-eye by placing the star on the end of the cabochon; a large grossularite carving was identified by RI 1.72 and sinking in methylene iodide [Why not a hydrostatic weighing?]; damaged Mabe pearls evoke warnings of their extreme fragility; 'pearls' cut from hinges of bivalve shells incorrectly offered as 'hinge pearls' (they are shell); a multi-star quartz from Alabama is similar to Sri Lankan stars; Thai ruby had bubble inclusions superficially like those in a glass-filled ruby; a dark-blue doublet consisted of green synthetic spinel top and blue synthetic sapphire base, apparently cemented with super-glue [Difficult to know why such a fake was made]; finally a necklace sold as 'untreated turquoise' was found to be dyed magnesite. All are described and illustrated.

R.K.M.

GRUNDMANN (G.). *Die Mineralien des Smaragdvorkommens im Habachtal*. (Minerals of the emerald deposit in the Habachtal.) Lapis, **10**, 2, 13-33, 22 figs (19 in colour), 1985.

The minerals occurring with emerald, and emerald itself, are described in this exhaustive paper which is also well illustrated. M.O'D.

GUNAWARDENE (M.). *Die innere Paragenese von Taaffeiten aus Sri Lanka*. (The inner paragenesis of taaffeites from Sri Lanka.) Z.Dt.Gemmol.Ges., **33**, 3/4, 91-5, 6 figs in colour, 1 table, 1 map, bibl., 1984.

Taaffeites from eight different localities in Sri Lanka and their typical inclusions are described and shown in photographs. The varying localities produce taaffeites with characteristic inclusions of apatite, phlogopite, spinel, muscovite (?), zircon (?) and garnet (?). The taaffeites in Sri Lanka are found in regional metamorphic rocks together with spinels, corundums and chrysoberyls. E.S.

HEYLMAN (E.B.). *Gem quality spinel in Nayarit, Mexico.* Lapidary J., **38**, 9, 1232, 1984.

A black spinel of gem quality is found in Mexico in the state of Nayarit. The spinel occurs in stream gravels, thought by the author to be in tributaries of the Rio Ameca. M.O'D.

HOFFMANN (K.). *Aufnahme spektraler Remissionskurven von Brillanten und ihre farbmetrische Auswertung.* (Spectral remission curves of brilliant-cut diamonds and their usefulness in determining colour.) Z.Dt.Gemmol.Ges., **33**, 3/4, 96-103, 2 diagrams, 1 table, bibl., 1984.

Reflectance spectra of mounted and unmounted brilliant cut diamonds are obtained using a suitably modified double beam reflectance spectrophotometer interfaced with a computer for colorimetric evaluation. Beside the well-known Cape spectrum, many stones show a broader absorption band in the blue region by which the colour can be graded. For objective grading a colorimetric Yellowness Index is proposed, which is very concise and takes very little time. E.S.

HOWIE (R.A.). *Gemstones.* Transactions of the Leicester Library & Philosophical Society, **78**, 1, 22-7, 1 fig, 1984.

Notes for the author's peripatetic lecture, containing some philosophical (if not literary) musings on gemstones and their simulation, faking and 'value'.

(Author's abstract.) R.A.H.

HOWIE (R.A.), PEGRAM (E.), WALSH (J.N.). *The content of rare earth elements in English fluorites: a preliminary study.* Journal of the Russell Society, **1**, 1, 22-5, 1982.

Ten times more rare earth elements are found in fluorescent fluorites from the Weardale area of north-east England than in non-fluorescent material from Derbyshire. The distribution pattern of the REE also differs between localities. Eleven rare earths and yttrium were checked in eleven fluorites from different English localities and the results tabulated. M.O'D.

HÜBNER (G.). *Ein Kapitel Opalforschung aus dem 18.Jahrhundert.* (Research into opals in the 18th century.) Z.Dt.Gemmol.Ges., **33**, 3/4, 126-7, bibl., 1984.

An early publication by G.Ch. Beireis in the year 1791 on opal and the phenomenon of play of colours is discussed; the scientific content is considered outstanding for its time. The original publication, which took up only four pages of 30 lines each, dealt with the finds in the Carpathian mountains; the chemical composition was unknown at the time, but the author thought the play of colour to derive from a fine lamellar structure reflecting the light in such a way that the colour play is caused. He even spoke of recreating opals artificially. E.S.

JAVOY (M.), PINEAU (F.), DEMAIFFE (D.). *Nitrogen and carbon isotopic composition in the diamonds of Mbuji Mayi (Zaire).* Earth and Planetary Science Letters, **68**, 3, 399-412, 6 figs, 1 map, 1984.

The concentration and isotopic composition of N, measured in large diamonds (g size) from this kimberlite district of Zaire shows a large range of variation ($100 < N < 2100$ ppm; $-11.2 < \delta^{13} N < +6.0$). The ^{15}N-depleted N is associated with the

higher N concentrations. The larger diamonds are individually rather homogeneous in ^{13}C (range of $\delta^{13}C < 0.9\%$) while variations occur within small octahedral diamonds from the same district (range $\leqslant 5.8\%$). The total range of $\delta^{13}C$ variations is about the same for the larger diamonds ($-10.5 < \delta^{13}C < -5.5$), the small octahedral diamonds ($-10 < \delta^{13}C < -4.6$) and the carbonates from local kimberlites ($-11.8 < \delta^{13}C < -5.5$). The diamond carbon isotope data could indicate a complex story of crystallization within a deep-seated system fractionating its carbon isotopes. The N results indicate that N in diamonds is, on average, markedly depleted in ^{15}N (weighted average -5.15%) relative to atmosphere, sediments and upper mantle.

P.Br.

KANE (R.E.). *A preliminary report on the new Lechleitner synthetic ruby and synthetic blue sapphire.* Gems & Gemology, **XXI**, 1, 35-9, 5 figs in colour, 1985.

Two specimens examined and appear to be either flux overgrowth on Verneuil seeds or a larger Verneuil synthetic encased in flux synthetic material and partially altered by the process. No divisions between the Verneuil and flux material were discerned. Process seems entirely different from that used by Lechleitner for emerald overgrowth. Both stones showed very marked wisp-like veil inclusions expected in most flux-grown synthetics. R.K.M.

KELLER (P.C.), KOIVULA (J.I.), GONZALO (J.). *Sapphire from the Mercaderes-Río Mayo area, Cauca, Colombia.* Gems & Gemology, **XXI**, 1, 20-25, 8 figs in colour, 1985.

A new source of gem sapphire visited in 1984. Further visit impossible due to political situation. Crystals are simple hexagonal prisms terminated by parting on (1000), mostly water-worn. Pastel shades; RI and SG normal for corundum; 457nm absorption line in most stones. Boehmite, rutile and apatite inclusions, colour- and growth-zoning and colour changes were found. R.K.M.

KOIVULA (J.I.), FRYER (C.W.). *Interesting red tourmaline from Zambia.* Gems & Gemology, **XXI**, 1, 40-2, 4 figs in colour, 1985.

Strongly birefringent, deep red crystals of tourmaline were found to be very similar to the rare deep red dravite tourmaline reported (1974) from Kenya, despite the two sites in the Great Rift Valley being 1000 km apart. R.K.M.

KOIVULA (J.I.), ed., MISIOROWSKI (E.). *Gem News.* Gems & Gemology, **XXI**, 1, 57-60, 2 figs in colour, 1985.

Diamonds.

Australia – a new, potentially major find near Coanjula, Northern Territory.

Ontario Geological Survey encouraging diamond prospecting following find of Kimberlite boulders near Hearst.

Israel exported 2.3 million carats, mostly small cuts, in 1984.

Sierra Leone buys out B.P. share in National Diamond Mining Co. and gains total control.

Coloured stones.

Australia. New opal locality in northern N.S.W. has yielded a 574.09 carat rough which is known as the 'Big Black'.

Sri Lanka. Australian Haoma North West Group propose to mechanize gem mining on the island.

Turkey. C.A. Schiffmann reports a 157.66 carat gem quality diaspore from Mamaris in Mulga Province.

Precious Metals.

Reports quoted on gold from Colombia, Nova Scotia, Finland, Mali and China, while C.S.I.R.O. in N.S.W. has developed an ultra sensitive test for trace amounts of gold in water. Neutron activation analysis is claimed to detect 1 part in 3 trillion.

Synthetics.

The National Institute for Research in Inorganic Materials in Japan have announced growth of a 3.5 carat gem diamond in 200 hours. De Beers have also grown more large crystals.

Russian hydrothermal synthetic emeralds reported by F.H. Pough had RI 1.574-1.580, SG 2.67+ and unique chevron-shaped internal growth pattern. Iron doping suppresses fluorescence completely [so no response to UV wavelengths or through emerald filter].

Reports on Tucson 1985 Gem Convention, The World Congress of Jewelry Convention, and Hong Kong Jewelry and Watch Fair are printed. R.K.M.

LIND (Th.), SCHMETZER (K.), BANK (H.). *Schleifwürdige blaue und grüne Berylle (Aquamarine und Smaragde) aus Nigeria.* (Cuttable blue and green beryls (aquamarines and emeralds) from Nigeria.) Z.Dt.Gemmol.Ges., **33**, 3/4, 128-37, 13 figs (1 in colour), 2 tables, 2 graphs, bibl., 1984.

The gem quality beryls come from a newly discovered area near Jos in Nigeria. RI 1.570-1.574 to 1.564-1.568, SG 2.66-2.68. Colour zoning. Variable colours and colour intensities are caused by varying concentrations of V, Cr and Fe. Absorption spectra typical for blue beryl aquamarine (coloured by iron) and green beryl emerald (chromium and vanadium). Growth zoning is parallel to the basal pinacoid, the hexagonal dipyramid and parallel to the prism of the first order. Some two-phase inclusions were found. E.S.

MACFALL (R.P.). *Michigan and the Lapidary.* Rocks & Minerals, **58**, 3, 135-6, 5 figs, 1983.

The major gem materials found in Michigan include coral limestone ('Petoskey stone'), pumpellyite (the variety chlorastrolite), datolite (porcelain-like nodules), agates, thomsonite, prehnite, dolomite (pink, brecciated variety), verd antique, conglomerate, and jaspilite (alternating bands of red jasper and haematite). These and their localities are described. R.S.M.

MADSON (M.E.). *Wyoming Jade.* Rocks & Minerals, **58**, 5, 218-22, 5 figs, 1 map, 1983.

The jade (nephrite) fields of central Wyoming include the following areas: Crooks Mountain, Bull Canyon, Pathfinder Reservoir, Horse Creek, and Granite Mountains. The major colours are apple-green, black, olive-green, and snowflake. The latter variety consists of nephrite with coarse-grained tremolite, quartz, epidote or zoisite, and albite. A pink jade owes its colour to zoisite (thulite) and a white jade-like rock is composed primarily of quartz and albite. Three important modes of

occurrence of jade in this area include float, vein and fissure fillings, and ellipsoidal pods. Comments are given on the history and modern development of the deposits.
R.S.M.

MIZOHATA (K.). *Gemmological excursion to Tono*. Gemmological Review, **6**, 7, 5-12, 7 figs, 1984.

This area in Japan is particularly celebrated for topaz crystals which are found in pegmatites. Supplies are now scarce. M.O'D.

NASSAU (K.). *Altering the colour of topaz*. Gems & Gemology, **XXI**, 1, 26-34, 7 figs in colour, 1985.

The past decade has seen the production of deep blue topaz in great quantity. Obviously a treated colour and not a new source. The author and others have established that this colour is the result of irradiation by various sub-atomic particles, followed by heating. Heat treatment of yellow and brown topaz to pink and red is also discussed. R.K.M.

NASSAU (K.). *The early history of gemstone treatment – 1*. Lapidary J., **38**, 11, 1406-12, 9 figs (7 in colour), 1985.

The origins of gemstone treatment are discussed, the text of the article being taken from the author's *Gemstone Enhancement* (Butterworths, London 1984).
M.O'D.

NAZELROD (E.). *Turquoise, inside and out*. Lapidary J., **38**, 9, 1152-90, 1984; **38**, 10, 1304-19, 1985; 24 figs.

A useful survey of turquoise with particular reference to American material and with notes on marketing. M.O'D.

O'DONOGHUE (M.). *The literature of mineralogy – 10*. Gems & Mineral Realm, **16**, 3, 37-9, 3 figs, 1985.

The large illustrated work by Victor Goldschmidt, *Atlas der Krystallformen*, Heidelberg, 1913-1923, 9 vols, is discussed with reproductions and access to large libraries reviewed. (Author's abstract.) M.O'D.

O'DONOGHUE (M.). *New light on some old gem friends – spinel*. Gems & Mineral Realm, **16**, 3, 41, 1985.

An overview of the spinel group of gemstones. (Author's abstract.) M.O'D.

O'DONOGHUE (M.). *Some beryl minerals – 3*. Gems & Mineral Realm, **16**, 3, 42, 1985.

The minerals herderite, vayrynenite and roscherite are described.
(Author's abstract.) M.O'D.

O'DONOGHUE (M.). *Man-made gemstones*. Gems & Mineral Realm, **16**, 3, 43, 1985.

The Ramaura synthetic ruby is described, followed by a note on the absorption spectrum of treated diamonds and of treated yellow sapphire.
(Author's abstract.) M.O'D.

O'DONOGHUE (M.). *The dealer looks at gemstones – 14.* Gems & Mineral Realm, **16**, 3, 44-8, 1985.

The work and writing of Louis Kornitzer are discussed with notes on David Jeffries' *Treatise on diamonds and pearls* (4th edition, 1871), parts of which, dealing with the method then in operation of pricing diamonds, are reproduced.

(Author's abstract.) M.O'D.

PETERSEN (V.), SECHER (K.). *Grönland.* (Greenland.) Magma, 6/84, 3-80, 48 figs in colour, 1984.

A general survey of the mineralogy of Greenland in which several gem species make their appearance. They include tugtupite, ruby, moonstone, lapis lazuli, kornerupine and a fuchsite-bearing quartz, locally known as 'greenlandite' and darkish-green in colour. M.O'D.

PROCTOR (K.). *Gem pegmatites of Minas Gerais, Brazil: The tourmalines of the Araçuaí Districts.* Gems & Gemology, **XXI**, 1, 3-19, 16 figs in colour, 1985.

The second of a series, this deals with mines in the Araçuaí-Salinas districts. Gem crystals found in green, blue, red and other colours, often particoloured, in pegmatite lenses in different localities with topaz, beryl and other minerals. Some pegmatite is hard and unaltered, others in various states of decomposition down to kaolin. R.K.M.

RAMSEY (J.L.). *Pink and precious.* Lapidary J., **38**, 10, 1298-302, 9 figs in colour, 1985.

Red and pink tourmaline, kunzite, pink diamond and pink sapphire are discussed. M.O'D.

SEGNIT (E.R.). *Australian gemstone deposits.* Z.Dt.Gemmol.Ges., **33**, 3/4, 114-25, bibl., 1984.

A general survey of Australian gemstone deposits including history, formation and occurrence, types of gem materials and resources. The more important Australian gems are described and these include opal, sapphire, diamond, emerald, ruby, aquamarine, topaz, zircon, iolite, nephrite, andalusite, tourmaline, garnet, rhodonite, bustamite and a number of quartz varieties such as rock crystal, smoky quartz, amethyst, chrysoprase, tiger's-eye and petrified wood. Many other gemstones have been found in small quantities and the author believes that the future will discover many more and bigger finds. E.S.

SNOW (J.), BROWN (G.). *A red Hi-Superbright LED refractometer light source.* Aust.Gemmol., **15**, 9, 322-4, 1 fig, 1985.

R.L. Burns has suggested the use of a Hi-Superbright ESBR 5001 (Stanley) LED for refractometer readings. This gives about four times more light than a six unit sodium range LED, but is spread from 620 to 690nm. This use of longer wavelengths actually raises the RI readings by about one in the third (estimated) place of decimals. This is not explained although it is known that longer wavelengths are refracted less. The use of such a light-source seems to be acceptable, since trial tests by gemmologists showed that the red readings were only 0.001 too high and well

within the normal margin of error expected in third place observations by different individuals. It is suggested that a small correction could be made, but in abstracter's opinion this would hardly be necessary. R.K.M.

THIMES (J.L.). *Ivory identification*. Lapidary J., **38**, 10, 1320-7, 25 figs, 1985.

A useful and comprehensive guide to ivory and its identification. M.O'D.

WEISE (C.). *Bergkristall-Lagerstätten in Goias und Minas Gerais, Brasilien*. (Rock crystal locations in Minas Gerais and Goias, Brazil.) Lapis, **10**, 3, 13-22, 19 figs (13 in colour), 1985.

The deposits discussed are at Corinto and Diamantina, Minas Gerais and at Niquelandia and San Luis do Tocantins, Goias. M.O'D.

WOENSDREGT (C.F.), WEIBEL (M.), WESSICKEN (R.). *Electron microscopical investigation of oriented magnetite and amphibole in black star diopside*. Schweiz.Mineralog. Petrograph.Mitteilungen, **63**, 2/3, 167-76, 3 figs, 11 photos, 1983.

Investigating the cause of four-fold asterism in black star diopside from Namakkal, Tamil Nadu, India, the authors conducted TEM determinations. The diopside contains oriented inclusions of magnetite parallel to [010] of the diopside host. Magnetite blades cause the asterism effect when the diopside is cut 'en cabochon', perpendicular to its *b*-axis. There are two different orientations of magnetite inclusions, both having [110] of the magnetite parallel to [010] of diopside. While the "Z' type of inclusions have $[111]_{Mt} \| [100]_{Di}$ the "X' type of inclusions are $[111]_{Mt} \wedge [100]_{Di} = 6°$. The oriented inclusions of amphiboles are of minor importance and do not contribute to asterism. W.S.

ZEITNER (J.C.). *Gems named for their colors*. Lapidary J., **38**, 11, 1392-8, 4 figs, 1985.

Some gem name derivations are given but care should be taken since some at least of the derivations are inaccurately referred to classical roots. M.O'D.

ZWAAN (P.C.). *Sapphires and other gems from Sri Lanka*. Proceedings of the International Precious Stone Congress, Tel Aviv, April 10-14, 1983, 8-10, 1983.

Blue sapphire is the most important Sri Lankan gemstone but it is worked only in alluvial deposits. Notes are given on the various localities, mining and cutting methods, and on the other Sri Lankan gemstones; the latter include moonstone (the best from Meetiyagoda), chrysoberyl, spinel, and zircons of various colours (often called tourmalines). R.A.H.

Argyle Diamond Mines Joint Venture. The Rio Tinto Zinc Corporation PLC Annual Report and Accounts (1984), 16-17, one fig. in colour, 1985.

Alluvial ore processed was 38% more than in 1983. Work aimed at production from the kimberlite pipe in early 1986 was more than 50% complete. J.R.H.C.

BOOK REVIEWS

CHHOTILAL (K.). *Diamonds from India.* Revised edn. Gem & Jewellery Export Promotion Council, Bombay, 1984. pp. x, 102. Illus. in black-and-white. Price on application.

An excellent overview not only of Indian diamonds, both industrial and gem, but of the diamond trade in general. Details of the polishing process are given as well as a corpus of useful statistics covering exports from India. M.O'D.

DEWANI (M.D.). *The magic of Indian diamonds.* Gems & Jewellery Export Promotion Council, Bombay, 1984. pp. vii, 36. Illus. in black-and-white and in colour. Price on application.

A short account of Indian diamond production with illustrations of famous stones and some statistics. M.O'D.

NG (J.Y.), ROOT (E.). *Jade for you: value guide to fine jewelry jade.* Jade N Gem Corporation, Los Angeles, 1984. pp. 107. 42 black-and-white illus. and 61 in colour. $45.00.

This book attempts to carry out exactly what its title implies. It relies upon a series of good photographs and a step by step scheme of evaluation.

Following introductory chapters on the jade materials and history, the authors set out their main theme on jade assessment. The beauty of jade is divided into the following elements: colour and tone, texture, translucency or clarity, desirable shape or balance, size and dimensions, polish and finish (which includes the matching or graduation in the case of pairs or beads). A series of explanatory colour photographs follows. Simulants and dyeing are covered next. The detailed evaluation scheme follows – with imaginary examples and a series of photographs illustrating the inspection procedure. Finally there is a comprehensive colour chart illustrating cabochons of various grades and colours with a key showing suggested 1984 prices based upon experience in Hong Kong and U.S.A.

This is a well-produced book amply illustrated with colour photographs, which possibly tend to be a little bright. At $45 it is expensive in Europe, but it should be on the bookshelves of anyone with a serious interest in jade. E.A.J.

Synthesis, crystal growth and characterization. North-Holland Publishing Company, Amsterdam, 1982. pp. xii, 568. Illus. in black-and-white. US$61.00.

This useful volume contains the proceedings of the International School on Synthesis, Crystal Growth and Characterization of Materials for Energy Conversion and Storage, held on 12th to 23rd October, 1981, at the National Physical Laboratory, New Delhi. It comprises papers of a basic nature, designed to present the topic to those whose speciality may be different. The first paper reviews developments in crystal growth and lattice imperfection studies over a period of 30 years; it is followed by papers on the growth and characteristics of crystals with valence instabilities. Succeeding papers review hydrothermal and other techniques with some useful notes on the growth of oxides with very high melting points, including zirconia and hafnia. The remainder of papers deal with characterization and these are useful without breaking very much new ground. An interesting final paper, by Professor D.S. Kothari, comments on the relationship between modern physics and Syadvada. M.O'D.

ASSOCIATION NOTICES

OBITUARY

Mr Tom Ratcliffe, F.G.A. (D.1936), Buxton, died on 13th March, 1985.

GIFTS TO THE ASSOCIATION

The Council of the Association is indebted to the following for their gifts:

Mr R. Holt, F.G.A., London, for rough stones, including pieces of zircon from China, corundum from East Africa, aquamarine from Nigeria and indicolite from South Africa.

Miss P. Lapworth, F.G.A.A., Guildford, Surrey, for sets of the *Australian Gemmologist* for 1983 and 1984.

Mr Ben H. Smith, Jr, F.G.A., Wilmington, North Carolina, U.S.A., for the following: (1) *Mineral collecting sites in North Carolina*, by W.F. Wilson and B.J. McKenzie, Geological Survey Information Circular 24, North Carolina Department of Natural Resources and Community Development (Geological Survey Section), Raleigh, N.C., 1978; (2) *Gold Resources of North Carolina*, by P. Albert Carpenter, III, Information Circular 21, North Carolina Department of Natural and Economic Resources (Office of Earth Resources, Division of Mineral Resources), Raleigh, 1972: (3) mica sheet enclosing flattened garnet, from Mitchell and Yancey Counties, North Carolina: (4) tourmaline in matrix from Crabtree Emerald Mine, Little Switzerland, North Carolina: (5) piece of corundum from Waywood County, North Carolina: (6) piece of a hiddenite crystal from North Carolina: and (7) smoky quartz from North Carolina faceted by the donor.

E.A. Thomson (Gems) Ltd, London, for a piece of silkium (bought from a company making solar panels).

NEWS OF FELLOWS

On 15th April, 1985, Mr M.J. O'Donoghue, M.A., F.G.S., F.G.A., gave a talk on 'The gemstone business' to the Sevenoaks Branch of the British Red Cross.

MEMBERS' MEETINGS

London

On 23rd April, 1985, at the Flett Theatre, Geological Museum, Exhibition Road, London S.W.7., Dr J.W. Harris gave an illustrated talk entitled 'A geologist's perception of diamond'.

On 28th May, 1985, at the Flett Theatre, following the Annual General Meeting (see p. 643) Mr M.J. O'Donoghue, M.A., F.G.S., F.G.A., gave a talk entitled 'The geology of gemstone deposits'.

Midlands Branch

On 29th March, 1985, at Dr Johnson House, Bull Street, Birmingham, Mr G. Jones gave an illustrated talk on microphotography.

On 26th April, 1985, at Dr Johnson House, the Annual General Meeting was held at which Mr C.L. Hundy, F.G.A., and Mr D.M. Larcher, F.G.A., were re-elected Chairman and Secretary respectively.

North West Branch

On 20th June, 1985, at Church House, Hanover Street, Liverpool 1, Mr C.R. Cavey, F.G.A., gave a talk entitled 'Gem crystals, their forms, collectability and associations'.

South Yorkshire & District Branch

On 25th April, 1985, at Sheffield City Polytechnic, a practical evening was held with emphasis on the recognition of diamond.

ANNUAL GENERAL MEETING, 1985

The 54th Annual General Meeting of the Association was held on Tuesday, 28th May, 1985, at the Flett Theatre, Geological Museum, Exhibition Road, London S.W.7.

The Chairman, Mr David Callaghan, F.G.A., opened the meeting by welcoming Mr Howard Rubin, an Ordinary Member, from New York and then expanded on some of the items in the Annual Report, adding the announcement that the Basil Anderson Appeal he had launched in November to raise a fund of £25000 for the purchase of the Basil Anderson Spectrophotometer had nearly reached £20000. 'We are determined to reach the £25000 total', he said, 'but as a result of the substantial amount we have raised the instrument is now installed in the British Gem Testing Laboratory and is in use.'

After thanking Mr John Chisholm for his years of editorship of the *Journal*, the Chairman announced Mr Chisholm's impending retirement at the end of the year, after which the *Journal* would be in the sole charge of Mr Alan Jobbins as Editor.*

Last year it was hoped that the newly designed Correspondence Course in Gemmology would be ready for 1985, but it had been decided to start the Preliminary Course in September 1986 and the Diploma Course in 1987. A Gem Diamond Course was being developed, which would be launched in 1986.

The Association now had three branches—Midlands Branch, North-West Branch and South Yorkshire & District Branch—which held regular meetings of their own, and the Branch Chairmen attended Council Meetings.

Continuing, Mr Callaghan forecast that some interesting new instruments would become available in the next month or so. 'We are always looking to the future', he said. 'It holds a big development for this Association in the not too distant

*See page 549 above, lines 16 to 20.—Ed.

future. We are approaching the end of our tenure at our present premises. In the next year or so, you will be hearing more about this.'

Mr Nigel Israel, F.G.A., the Honorary Treasurer, then presented his financial report with charts on a screen and the adoption of the Report and Accounts was duly proposed, seconded and carried.

Sir Frank Claringbull, Mr David Callaghan, Mr Noel Deeks and Mr Nigel Israel were then re-elected as President, Chairman, Vice-Chairman and Honorary Treasurer respectively: Messrs C. Cavey, L. Cole, P. Daly, A. Hodgkinson, C. Jones and A. Round were re-elected and Mr Robert W. Croydon, F.G.A., and Mr G. Neary, F.G.A., were elected to the Council.

Messrs Ernst & Whinney were re-appointed Auditors, and the proceedings then terminated.

COUNCIL MEETING

At the meeting of Council held on the 28th May, 1985, at the Flett Theatre, Geological Museum, Exhibition Road, London S.W.7., the business transacted included:

(1) receipt of a report from the Chairman that the Basil Anderson Appeal fund stood at £19,111 to date;

(2) decision to increase the subscription for 1986 for all members of the Association (whether Fellows, Associate or Ordinary Members) (a) if residing in the United Kingdom to £25 and (b) if residing outside the United Kingdom to US$50; and

(3) the election to membership of the following:

FELLOWSHIP

Duckett, Karen L., Long Preston. 1984
Banks-Lyon, Rodney, Bristol. 1984
Lui, Elizabeth S-H., Kowloon, Hong Kong. 1984
Malkani, Monica, Bombay, India. 1984
Smiley, Laurianne, Dublin, Ireland. 1982
Zwyssig, Urs, Bangkok, Thailand. 1984

ORDINARY MEMBERSHIP

Calvino, Esperanza, New York, N.Y., U.S.A.
Green, Margaret D.V., Haverfordwest.
Heibrandt, L. Peter, Bro, Sweden.
Hoi, Josephine B.S., London.
Judge, Susan D., Pinecrest, Hong Kong.
Lam, Angela F-H., Shatin, N.T., Hong Kong.
Lippiatt, Irene, Perth, W. Australia.
Lisgarten, John N., Chatham.
Macan Markar, Noorul N., Colombo, Sri Lanka.
Merk, Roger L., San Diego, Ca, U.S.A.
Mohiudin, Syed M., Oman.
Monnas, Edith S., Athens, Greece.
Perera, Cabandugamage L., Colombo, Sri Lanka.
Pongratz, Richard I., Arlington, Tex., U.S.A.
Powell, Warren, Prestwich.
Samaranayake, Ravinda, Colombo, Sri Lanka.
Shah, Nilesh D., Nairobi, Kenya.
Taylor, Anne R.E., Poole.
Tsekouras, Basilio, Athens, Greece.

REPORT ON I.C.A. CONGRESS, IDAR-OBERSTEIN, 1985

The first Congress of the International Colored Gemstone Association was held in Idar-Oberstein from 20th to 22nd May. Some two hundred delegates—dealers, miners and gemmologists—from twenty-six countries attended. The Gemmological Association of Great Britain was represented by Chairman David Callaghan, Chief Examiner Alan Jobbins and Deputy Secretary Jonathan Brown. A team from G.I.A. included Chairman Richard Liddicoat and Vice-President Robert Crowningshield. Among the delegates were Dr Edward Gübelin, famous for his research into gemstone inclusions, Dr Hermann Bank and Mike Roman, of Jewelers of America.

I.C.A. was born largely as a result of the world recession and its effects on the international gem market. For some time the industry has laboured in a trough, beset by increasing problems such as how to deal with new synthetics and treatments, and how to react to the possible extension of the trade into the investment market. Exploratory sessions in 1983 led to a major meeting of dealers in Acapulco early in 1984.* There the resolution was taken to form I.C.A. with the primary aim of promoting the sale of coloured gemstones. Roland Naftule, of Nafco Gems, Phoenix, U.S.A. has worked tirelessly to bring the trade together in this new Association, which owes much to his vision and tenacity. I.C.A. is now to be constituted as an entity under Swiss law, because, says Roland Naftule, that system can best give effect to a democratic constitution, ensuring that the Association responds accurately to the consensus of its membership.

Congress sessions dealt with the major promotional aims of I.C.A., education relative to marketing, gemstone treatments, synthetics, colour nomenclature and grading, investment and appraisal, and international trade and regulations. It was a crowded programme interspersed with much informal discussion and an ambitious entertainment programme. Sessions were lively and exchanges sometimes heated, but observers were impressed by the remarkable extent of agreement that was achieved on all major issues.

Congress did not duck the controversial issues. Maurice Shire, of New York, who generally enhanced proceedings with his forthrightness and wit, called on the Congress to condemn roundly any extension of the coloured gem trade into the investment field. This it did by an overwhelming majority.

Trade ethics were to the fore at several points, but there was a less clear line on the problem of disclosure in relation to treated gemstones. Clearly the heat treatment of corundum was in the minds of all the delegates, and the general opinion appeared to be that almost all corundum gems now coming on the market have been heat treated to enhance their colour. This treatment is permanent and is not required to be disclosed under the terms of the articles of the C.I.B.J.O. Code, which I.C.A. has adopted. Some dealers remained worried by the situation, and strong feelings were expressed in various quarters that full disclosure should be made to the trade and the consumer in all cases where stones are treated. There was deep division over the status of oiled emeralds and complex questions were raised over what the position should be if oiling was developed with a coloured oil, the effect of which would be permanent.

*See p.288 above.—Ed.

On the question of colour communication and grading, a session chaired by Alan Jobbins, it was generally agreed that dealers used to doing business with each other tended to develop a workable colour language of their own. The real problem was communicating down the chain of supply with retailers and consumers. Something should be done towards establishing a colour communication system that would overcome the difficulty, although the technical problems involved had been outlined eloquently in a presentation by Stuart Robinson, of New York. Congress was against the idea of grading certificates for coloured gemstones, but many feared that a widely adopted colour communication system would inevitably lead on to grading and certificates.

Robert Crowningshield, of the G.I.A., gave an entertaining presentation on the current state of affairs over synthetic gemstones. The distinguished panel for this session included Dr Bank and Dr Gübelin. There was much debate on detection methods for some of the new synthetic corundums, and delegates were obviously uneasy about the problems posed by some of these. Dr Henry Hänni, of Zurich, was more confident than most on the issue of detection, stating that about 90 per cent. of the new synthetic corundums could be identified as such by studying their inclusions with an ordinary gemmological microscope. Dr Gübelin was more cautious and felt that traders should make much greater use of the laboratories in their own countries. Congress thoroughly disapproved of such descriptions as 'cultured' being applied to synthetics.

The promotion of the industry is the chief aim of I.C.A., and its leaders have gone on record to the effect that they want the organization to promote coloured gemstones in a way similar to De Beers' world-wide promotion of diamonds. The intensity with which the new association has been formed suggests that this may not be an unreal ambition. Certainly a very positive start has been made, and when Roland Naftule called for donations to a promotional fund, dealers rose to their feet amid resounding applause and pledged nearly a hundred thousand dollars as a 'fighting fund'.

Debate on the subject of promotion extended into the area of education in a session on education relative to marketing, which was chaired by Jonathan Brown. Douglas Hucker, of the U.S.A., gave a stimulating presentation and many issues were explored. The need to educate both trade and consumer was recognized and many ideas were put forward as to how this might be done. It was agreed that support should be given to gemmological and trade associations in members' countries, and that consideration should be given to the use of pamphlets and brochures as an alternative way of disseminating information.

Apart from the Congress sessions, there was an extensive programme of committee meetings, and the board of directors was appointed on the nominations of Congress. The elected officers of I.C.A. are Roland Naftule (U.S.A.) President, Rashmikant Durlabhji (India) First Vice-President, Konrad Wild (West Germany) Second Vice-President, Stuart Robinson (U.S.A.) First Secretary, Israel Eliezri (Israel) Second Secretary, Claud Barguirdjian (France) Treasurer.

HARROW COLLEGE OF FURTHER EDUCATION GEMMOLOGY COURSE

A 30 week course in gemmology for the preliminary examination will commence on Monday, 30th September (afternoon or evening) at Harrow College of Higher Education, Northwick Park, Harrow, HA1 3TP. The lectures will be given by Mr F. A. Fryer, B.Sc, C.Chem., M.R.S.C., F.G.A, from whom further details may be obtained.

LETTER TO THE EDITOR

From R. Keith Mitchell, F.G.A.

Dear Sir,

Mr E. Gamini Zoysa, of the State Gem Corporation, Sir Lanka has given us an interesting and well illustrated account of the recent find of colourless enstatite in the Embilipitiya region of his country.

A single small crystal has come into my possession for a few days, and I am very surprised indeed to find that an almost colourless enstatite (off-white would be my description of it) shows the 506nm sharp absorption line and a less clear broad band centred at 546nm. The 506 line is well known in both green and brown enstatites, but to find that it survives even in the colourless material is something unexpected. Strong spectra in colourless stones are the exception rather than the rule. This particular specimen gives RI of 1.654 and 1.663, slightly lower than the figures quoted by Zoysa and fractionally lower than the lowest figures quoted in Herbert Smith's *Gemstones*. Dana Ford gives even lower figures for an artifically produced pure enstatite. Mr Zoysa mentions that 1% of iron was found in these stonges, but he did not mention the absorption pattern, which is after all a valuable testing factor.

Yours etc.,
R. KEITH MITCHELL

Orpington, Kent.
15th April, 1985.

CORRIGENDA

On p.482 above, the reference at the end of the footnote should read '(7,8)'

On p.483 above, 3rd para., line 1, for 'Kniscka' read 'Knischka'

On p.493 above, top left-hand corner of Fig. 4, for '130' read '100'

On p.529 above, in line 13, for '1948/2' read '1984/2'

On p.532 above, in 2nd line from foot, for 'iiis' read 'is'

On p.537 above, in 12th line from foot, for 'First-sized' read 'Fist-sized'

On p.546 above, in first line of 3rd Book Review, after 'New York' add ', 1983'

On p.553 above, in line 20, for 'produced' read 'produce'

GEM TESTING EQUIPMENT

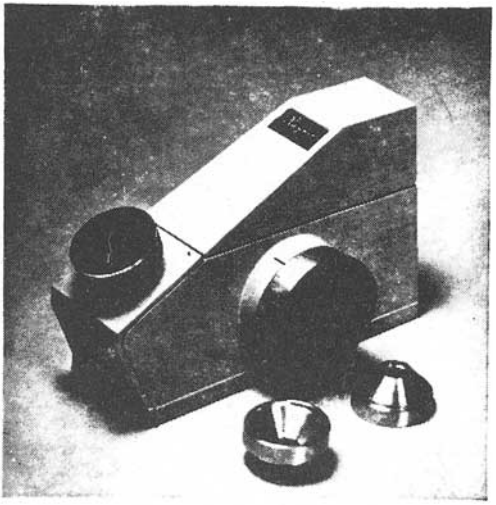

For details and illustrated catalogue write to

Gemmological Instruments, Ltd.

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Historical Note

The Gemmological Association of Great Britain was originally founded in 1908 as the Education Committee of the National Association of Goldsmiths and reconstituted in 1931 as the Gemmological Association. Its name was extended to Gemmological Association of Great Britain in 1938, and finally in 1944 it was incorporated in that name under the Companies Acts as a company limited by guarantee (registered in England, no. 433063).

Affiliated Associations are the Gemmological Association of Australia, the Canadian Gemmological Association, the Gem and Mineral Society of Zimbabwe, the Gemmological Association of Hong Kong, the Gemmological Association of South Africa and the Singapore Gemologist Society.

The *Journal of Gemmology* was first published by the Association in 1947. It is a quarterly, published in January, April, July, and October each year, and is issued free to Fellows and Members of the Association. Opinions expressed by authors are not necessarily endorsed by the Association.

Notes for Contributors

The Editors are glad to consider original articles shedding new light on subjects of gemmological interest for publication in the *Journal*. Articles are not normally accepted which have already been published elsewhere in English, and an article is accepted only on the understanding that (1) full information as to any previous publication (whether in English or another language) has been given, (2) it is not under consideration for publication elsewhere and (3) it will not be published elsewhere without the consent of the Editors.

Articles published are paid for, and a minimum of 25 prints of individual articles may be supplied to authors provided application is made on or before approval of proofs. Applications for prints should be made to the Secretary of the Association—not to the Editors—and current rates of payment for articles and terms for the supply of prints may be obtained also from the Secretary.

Although not a mandatory requirement, it is most helpful if articles are typed (together with a carbon copy) in double spacing on one side of the paper, with good margins at sides, top and foot of each page. Articles may be of any length, but it should be borne in mind that long articles are more difficult to fit in than short ones: in practice, an article of much more than 10 000 words (unless capable of division into parts or of exceptional importance) is unlikely to be acceptable, while a short note of 400 or 500 words may achieve early publication.

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No. 7
July, 1985

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Vol. XIX No. 8 October, 1985

THE JOURNAL OF GEMMOLOGY

and

PROCEEDINGS OF THE GEMMOLOGICAL ASSOCIATION OF GREAT BRITAIN

GEMMOLOGICAL ASSOCIATION OF GREAT BRITAIN
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THE JOURNAL OF GEMMOLOGY
AND PROCEEDINGS OF THE GEMMOLOGICAL ASSOCIATION OF GREAT BRITAIN

Vol. XIX No. 8 OCTOBER, 1985

AVE ATQUE VALE

In this final number of his editorship, the old Editor looks forward with pleasure and with entire confidence to the first number of Volume XX solely edited by his successor, who has been of so much help to him in the last difficult ten months.

The new Volume will be in a new larger format, but not so large as to make it unwieldy when bound. This will remove the constraints of the old (present) format, which served the Association well for 38 years, but which recently made it difficult to accommodate the large Figures, Maps and Tables, which have increasingly been required by contributors. So let us look forward to welcoming the *Journal of Gemmology* in its new livery next year.

It is always sad to preside over an end. I vacate my editorial chair and say farewell to the old-style *Journal* with feelings of some grief, and there have been two sad disappointments in this last year of my editorship. The continued long delays in the issue of each quarterly number of the *Journal,* mainly due to printing difficulties, have been deplorable and the failure of the Basil Anderson Appeal

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Fund to reach its target in a year even more so. When the appeal was launched in October 1984, I confidently expected it to be fully subscribed by Easter 1985. It seemed almost inconceivable that out of the thousands of gemmologists throughout the world there would be less than fifty who would be anxious (and financially well able) to honour the memory of the great man, to whom they owed so much, to the extent of at least five hundred pounds. Apparently not so, however: the fund now stands at £22005 and a list of subscribers to date appears on pages 739 to 742 below—only 266 in all (187 from Great Britain and 79 from overseas)—and a number of well-known names in the world of gemmology and the jewellery trade are conspicuous by their absence. Now is the time for the defaulters to make good their default, so that the new Editor may be able to report in January that the target of £25000 has been reached (and, it is to be hoped, exceeded) and the good name of gemmologists throughout the world redeemed.

The last number of the *Journal* edited by Gordon Andrews was that of January 1973. A comparison of my first number (Vol. VIII, No. 6, April 1973, containing 18 pages of articles with 4 figures in black-and-white, 37 abstracts and book reviews (14 pages) and 8 pages of Association Notices) with this my last number (Vol. XIX, No. 8, October 1985, containing 71 pages of articles with 27 figures/maps in black-and-white and 30 in colour, 68 abstracts and book reviews (13 pages) and 7 pages of Association Notices) exemplifies the remarkable progress made by our science of gemmology in the last twelve years. I am confident that the difference between next January's number and the last of Alan Jobbins's editorship (many years hence, I hope) will be no less significant.

J.R.H.C.

NOTES FROM THE LABORATORY

By KENNETH SCARRATT, F.G.A.

The L.C.C.I. British Gem Testing Laboratory

The nature of some items sent to the Laboratory for examination can at times be a little surprising. In fact two items we received via the National Association of Goldsmiths some months ago for testing must be rated fairly high on anyone's scale of unusuality.

The two items we received (see Figure 1) were described as '... a pearl in two parts which was found in a squid just after the war in Switzerland.' With the unaided eye a superficial examination of the areas along which this 'pearl' had apparently parted, revealed a structure that, whilst not being the same as a normal sectioned pearl structure, was sufficiently close to it for a first impression to be formed that possibly these could be two part pearls (Figures 2 and 3). Try as we might, though, the two 'parts' could not be matched to form a whole sphere.

Both pieces may be described as having translucent high domed 'outer' surfaces and transparent low domed surfaces on what was thought to be the area along which they had parted. The smaller measured 6.60 × 2.18 mm and weighed 0.26 ct, and the larger was 6.84 × 4.56 mm and weighed 0.66 ct.

Upon examination it was found that both allowed x-rays to pass more easily than any known pearl, and that their hardness was less than 3 on Mohs's scale.

Following much discussion about their possible identity and finding ourselves somewhat lost for ideas, one of our number said, in a casual manner, 'they are probably the poor squid's eye-balls'.

With this in mind it was decided that the most probable place we might find an answer was within the molluscs department of the Natural History Museum. Here F. C. Naggs was able, just from our description on the telephone, to say that they were probably the eye lenses of a squid. Following the telephone call Mr Naggs allowed us to compare these with known (somewhat larger) specimens in the Museum which confirmed their identity.

Apparently larger squids' eye lenses were used in Peru to replace the eyes of mummies. The mummies were then left in the sitting position in order that they might gaze upon the public.

* * *

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FIG. 1. Translucent high-domed side of squid's eye lenses; 6.60 × 2.18 mm (left); 6.84 × 4.56 mm (right).

FIG. 2. Transparent low-domed side of squid's eye lenses (see also Figure 1).

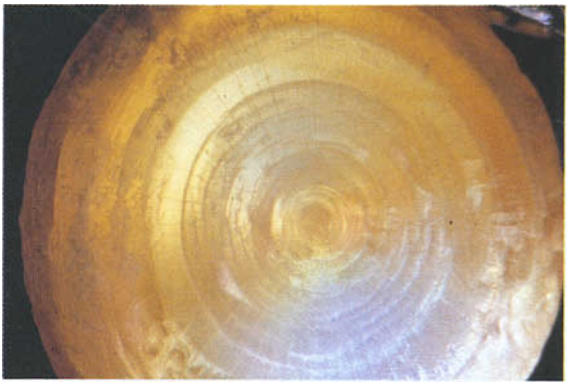

FIG. 3. Structure seen in transparent side of squid's eye lens (see Figure 2).

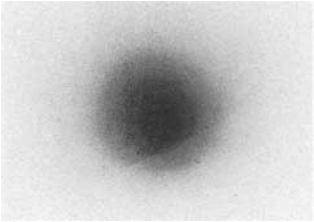

FIG. 4. Autoradiograph of a radium-treated green diamond. The stone was held in contact with x-ray type film for a period of 24 hours.

FIG. 5. A radium-treated green diamond weighing 2.66 ct (see Figures 4 & 6).

Radium treated diamonds are not seen all that often today, but once in a while, particularly when someone's estate is being settled, one does turn up.

One which surfaced recently was radioactive to the extent that it exposed a piece of photographic printing paper to a small degree, after being in contact with it for only 15 minutes. The result of the stone being in contact with an x-ray film for 24 hours is shown in Figure 4. Apart from its degree of radioactivity, though, this stone was interesting also because it was possible to speculate upon its pre-irradiation appearance.

The stone weighed 2.66 ct and measured 8.51 × 8.33 × 5.08 mm and, as may be seen in Figure 5, had a deep green colour. When examined under the microscope, however, what was probably the original colour of the stone became evident in the form of distinct internal brown colour zoning (Figure 6).

With this brown zoning in mind, when the absorption spectrum was examined, whilst quite clear evidence of radiation damage could be seen in that the GR1 (741 nm) band was present (Figure 7), it was also possible to theorize upon the possible cause of the 503 nm band and the associated bands on its short-wave side. If the original colour of the stone was brown, it could be that in this case they are a product of natural causes.

* * *

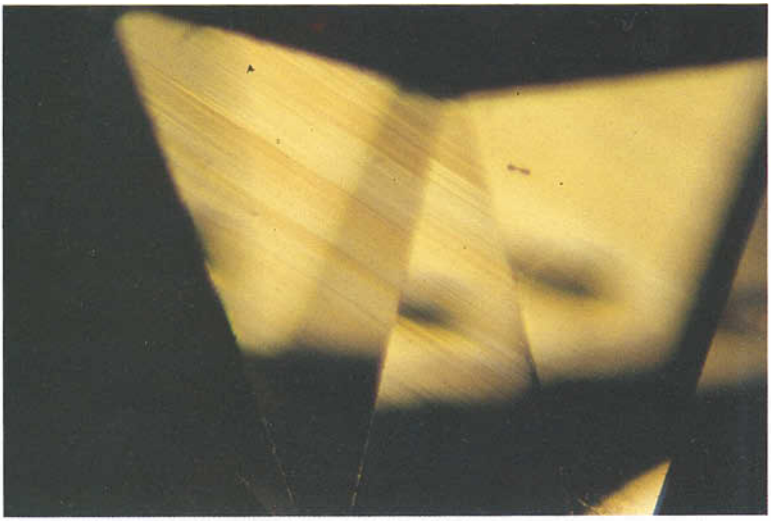

FIG. 6. Brown colour zoning seen below the green 'skin' of the radium-treated diamond in Figure 5.

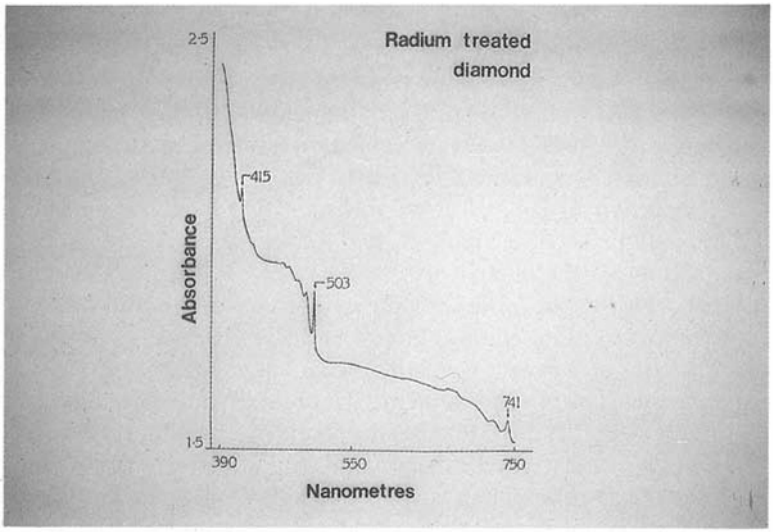

FIG. 7. The absorption spectrum at approximately 120K of the radium-treated green diamond in Figure 5.

FIG. 8. A zircon weighing 2.10 ct in which the colour had altered from blue to a 'dirty colour' which was in parts brown and in other parts green.

FIG. 10. The same zircon as depicted in Figure 8 following heat treatment.

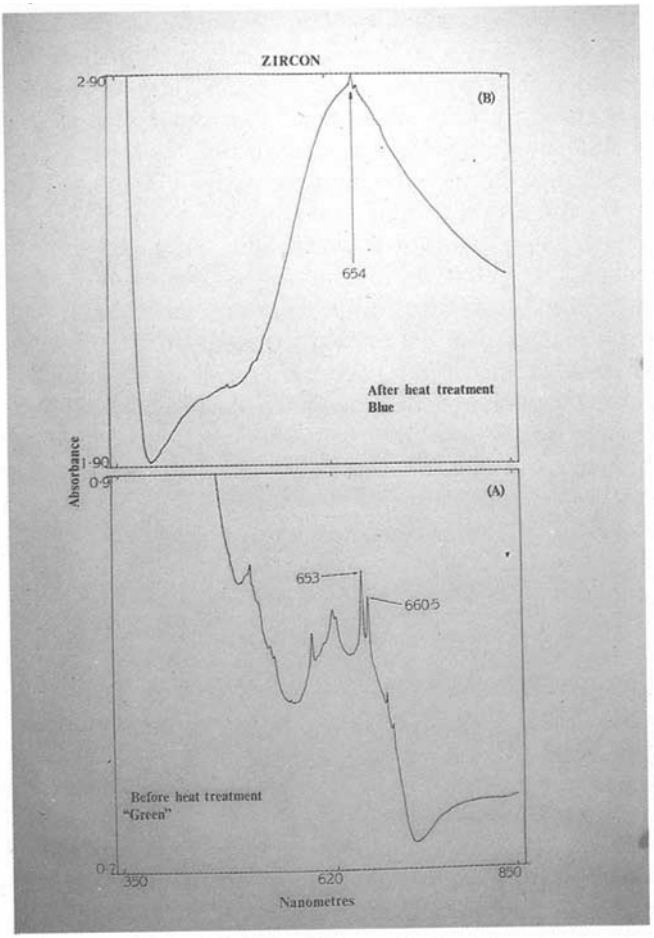

FIG. 9. (a) The absorption spectrum of the zircon as seen in Figure 8 (before heat treatment).
(b) The absorption spectrum of the zircon as seen in Figure 10 (after heat treatment).

As most gemmologists are only too well aware, there have been occasions when heat treated blue zircons have altered from this nice and somewhat characteristic colour to a not so nice 'dirty green or brown'.

Normally we would not involve ourselves in attempting to return such a stone to its previous blue colour, but when we were asked recently (entirely at the owner's risk), we agreed to try. Our main reason for agreeing, though, might be interpreted as a little selfish.

We were, at that time, putting the Basil Anderson (Pye-Unicam PU8800) spectrophotometer 'through its paces', and this seemed a suitable direction in which to take our investigations.

The stone as delivered to us had a fairly 'dirty' colour, as may be seen from Figure 8. Its weight was 2.10 ct and it measured 7.73—5.62 × 4.00 mm. Figure 9a is the recorded absorption curve corresponding to the appearance of the stone in Figure 8. The span of the curve is 0.2A (absorption units).

In the attempt to regain its blue colour, the stone was buried in a charcoal filled small crucible, and this was placed into a furnace. The temperature inside the furnace was raised slowly up to 900°C and then brought down again slowly to room temperature.

When the stone was removed from the charcoal following this treatment, it had the overall appearance of a nice blue, although as may be seen from Figure 10 the colour was concentrated in zones.

Following this alteration to its colour, the stone's absorption spectrum was recorded once more and the somewhat modified curve depicted in Figure 9b was resultant. The span of the curve in this case is 1A.

* * *

Some heat treated rubies and sapphires are providing the gemmologist with a whole new class of inclusions with which he must familiarize himself.

One of the most striking examples of these inclusions was provided recently by a heat treated blue sapphire, which, because of the intense 450 nm complex in its absorption spectrum, is probably of Australian origin.

As may be seen in Figure 11, instead of the blue colour appearing throughout the majority of the stone, in this case the colour has concentrated in small blobs, in areas which probably contained 'silk' and 'feathers' prior to heat treatment.

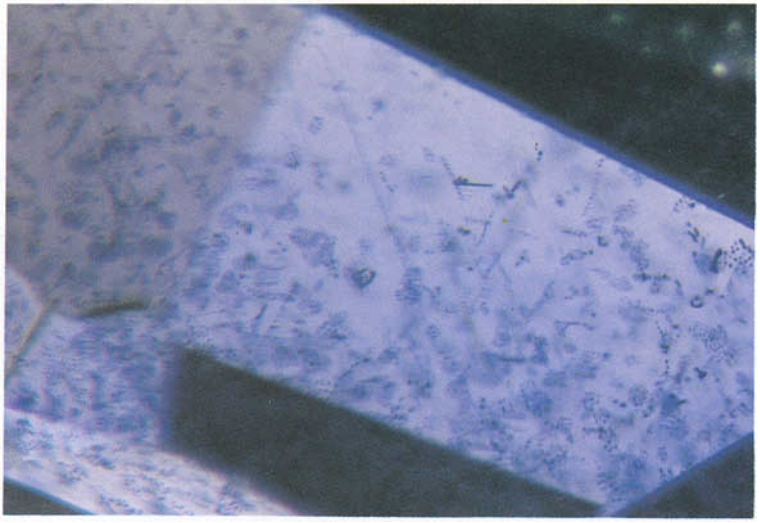

FIG. 11. Inclusions in heat-treated blue sapphire probably of Australian origin.

* * *

In a talk given to members of the Gemmological Association during April 1984 those present were warned of the unusual magnetic properties of a new form of haematite from Brazil, and the material has also been described in this and other journals.[1,2] Apart from being attracted to a magnet this 'magnetic haematite' is also different from the well-known Cumberland material in its type of fracture surface (see Figures 12 and 13) and because the polished surface is usually quite pitted.

Those who deal in haematite now accept this new material as haematite and, whilst there is still the problem of differentiating between magnetic haematite and the haematite imitation 'hemetine',[3] the trade no longer reject material as not being haematite merely because it is magnetic.

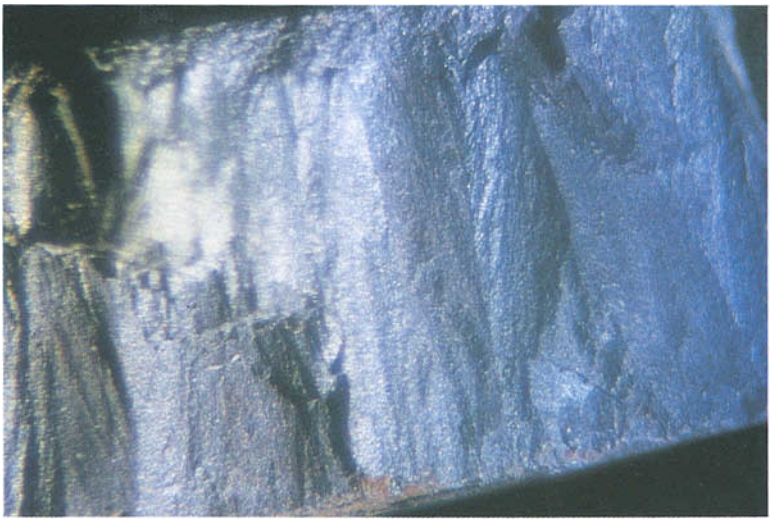

FIG. 12. The fracture surface of Cumberland haematite.

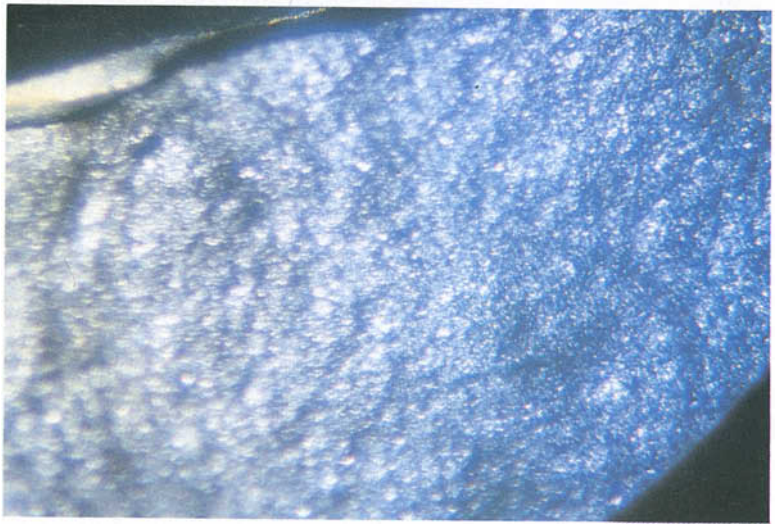

FIG. 13. The fracture surface of 'magnetic haematite.'

Earlier this year two opaque black beads were submitted to the Laboratory for examination as possibly magnetic haematite but in the event were found not to be haematite but a substitute of a kind that we have not met before. Apart from having a good surface polish as compared to the pitted appearance of the magnetic haematite, both beads were distinctly magnetic in that they were strongly attracted to each other and they also attracted iron fillings. The average of three SG determinations on one bead was 4.96, whilst the average for the second was 4.80. The streak in both cases was black.

X-ray powder diffraction analyses carried out by Toby Rappitt pointed towards the beads being a barium iron oxide man-made product similar to that described in JCPDS file 27-1029.

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A NOTE ON THE HISTORY OF DIAMOND SYNTHESIS

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'Is there any other point to which you would wish to draw my attention?'
'To the curious incident of the dog in the night-time.'
'The dog did nothing in the night-time.'
'That was the curious incident,' remarked Sherlock Holmes.
Silver Blaze; Sir Arthur Conan Doyle

INTRODUCTION

In a recent book review of *Diamond*, by G. Davies,[1] P. G. Read comments: '. . . it is satisfying to see that the Swedish company ASEA is credited with the first confirmed synthesis of diamond (rather than General Electric of America), a fact missing from some books, particularly those of American authors!'[2]

Being one of these authors, a clarification may be appropriate. I hesitate to disagree with Mr Read, since he also reviews one of my own books (gratifyingly favourably!) on the very next page.

To begin, let me make two points. First, in my article[3] and in my book [4] (in a footnote on page 179), I did briefly refer to the existence of the ASEA experiments, with at least some explanation of the circumstances, but without attributing priority to their work or considering it to be a significant step in the progress toward a successful synthetic diamond industry. Perhaps I have never been explicit enough in giving the detailed reasoning behind my own, and indeed most scientists', evaluation of this work; hence this brief note to clarify a relatively subtle historical point. Second, Read states that the ASEA synthesis was 'confirmed;' I myself have not been able to locate any report of an independent repetition of the ASEA experiment.

THE BACKGROUND

The setting of these events, as detailed by me elsewhere,[3,4] I consider to be important. Many workers had tried to synthesize diamond over the centuries and a number of these workers had claimed success; most of these claims were made in all sincerity, based on the difficulty of identifying tiny fragments of products. The most persistent worker was Sir Charles Parsons (1854-1931),

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inventor of the steam turbine, who spent a significant part of his fortune over a more than thirty-year period in attempting to duplicate earlier claimed results as well as trying new approaches of his own.[1,4] At first he claimed success, but later came to realize the truth and authorized C. H. Desch to report that no diamonds had ever been made in the laboratory; the details surrounding this confusing report have been given by Lonsdale.[5]

So here we have the setting: many discredited reports and tremendous excitement as ever-improving technology is applied by workers such as P. W. Bridgman at Harvard University and competing groups at industrial research laboratories, such as those of the General Electric, Carborundum, Norton, and ASEA companies.

Work on high pressure synthesis began at ASEA (Allemanna Swenska Elektriska Aktiebolaget) at Västerås in Sweden in 1942. In 1953 Halvard Liander and Erik Lundblad used a high pressure cubic press built by B. Von Platen to contain the ingredients of a *thermite* type reaction to apply high pressure and high temperature to a carbon-containing composition. Only after G.E. had announced their successes did the ASEA group report that this equipment had produced some very small diamond particles.

The Problem

At this point I naturally wish to draw attention to the 'curious incident of the dog' that 'did nothing in the night-time' of the quotation at the beginning of this note. For, what happened after this very significant achievement of the ASEA workers in 1953? Where were the public announcements which would have brought them much acclaim? In this 'curious incident' it appears that, apart from a brief report in the ASEA Journal in 1955,[6] nothing was said in public for seven years until a report was read on 13th April, 1960, and published later that year.[7] By that time there had already appeared a whole series of announcements and publications from G.E. workers starting in 1955;[8] one of these reports[9] is cited in the 1960 ASEA paper. The ASEA workers wrote[7] that they had meanwhile switched to electrical heating, similar to that used by the G.E. workers.

As I have previously written, 'certain principles have been developed over the years for evaluating scientific accomplishments and attributing priorities. For example, the claim of a successful

experiment cannot be fully accepted until it has been duplicated by other experimenters, following the published descriptions of the technique. It is obviously the claimant's fault if inadequate descriptions do not permit a successful duplication, and the claims will then have to be discounted.

'If more than one experimenter claims priority in an achievement, then independent proof of achievement at the time claimed is essential. Patent applications and/or publication of reproducible experimental details, examination of the product by independent experimenters, deposition of the "secrets" in a sealed document (as was done by Verneuil)[3]—all these have been used to establish priority of inventions. The patent system is a protection for the inventor and his firm, so that it is not necessary to resort to keeping one's secret so as to protect an invention.'[3]

It is in view of these considerations that scientists and historians generally do not give priority to the ASEA work, but date the first confirmed synthesis of diamond to the 1955[8] and subsequent G.E. reports, where a process was described in detail that could be and was duplicated, first independently by others at G.E. and soon thereafter by others elsewhere, thus meeting all the criteria for acceptance as a valid achievement. It should be noted that Davies too, in describing the G.E. experiments, says: 'For the first time there could be no doubt that diamonds had been made in the laboratory.'[1] Two pages later he says: 'Ironically, diamonds had already been made . . . two years earlier.' He goes on to describe the ASEA experiments in detail, not, however, explaining what was ironic; possibly he too feels puzzlement at 'the dog' that 'did nothing in the night-time.'

Some Speculations

It is possible to speculate on the reasons why ASEA did not publicly claim success in 1953. There are several possibilities; only the two I consider most probable are here discussed:

1. It may be that the lack of control over the hazardous and unpredictable *thermite* process was so discouraging (and that this process was so destructive to the high pressure equipment) that it was realized at the time that this approach was impractical and not worth pursuing or patenting. Announcement of the achievement may then have been withheld so as not to give competing workers information which might have helped them. From the industrial

research point of view, I consider this the most probable scenario. It is regrettable that the work was not publicized in 1955 after the G.E. news release on 15th February: Lundblad's statement 'we thought we had time' cited by Davies[1] explains the lack of a previous announcement, but the subsequent long delay was critical.

2. It is also possible that the presence of diamond in the product of the 1953 experiment was not recognized at the time and that only after the 1955 announcement of G.E. were the specimens taken off the shelf for re-examination and then identified. Such a sequence has happened often enough in science.

Be all this as it may, these then are the reasons for my attributing priority to the G.E. diamond synthesis work in my writings; it is certainly not from any lack of belief in the ASEA results, nor from any jingoistic attitude. The conventional criteria for the attribution of priority of invention, as discussed above, are merely being followed; in addition, because of the lack of timely publication, the early ASEA work had no effect on the subsequent development of diamond synthesis. Other scientists and historians who have investigated the sequence of events in detail have usually taken the same point of view.

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[*Manuscript received 13th June, 1985.*]

THE KATLANG PINK TOPAZ MINE, NORTH WEST FRONTIER PROVINCE, PAKISTAN.

By WILLIAM H. SPENGLER, A.G., F.G.A.

Asian Institute of Gemological Sciences, Bangkok

Ruins of a civilization two thousand years in the past lie scattered around the hilltops skirting the Katlang valley. The ruins were monasteries, once sentinels in a line stretching from Sarnath to Bamiyan and beyond, in an area where Bhuddism flourished at an early period. In present day Pakistan, the valley floor is covered with lush green fields crossed by irrigation canals, dotted with villages, and accented by mosques and minarets among the houses. From a vantage point on the southern fringe a small hillock surrounded by fields can be seen isolated from the others. It contains a treasure unknown to the ancients – fine crystals of pink topaz.

The hillock would be forgotten like the remaining ruins near its crest but for the recently discovered deposits there. Katlang, near Mardan in the North West Frontier Province, lends its name to the mining project in which the Gemstone Corporation of Pakistan (Gem C P) is now engaged. The deposits on the hill have only been widely known about since the early 1970s and the exact circumstance of their discovery is so far unrevealed. Presumably local farmers from the adjacent village of Ghundow discovered the topaz crystals at the surface near the top of the hillock, where the first trenches were excavated. These easily accessible deposits were privately mined until the Gem C P began seriously considering the project in 1980.

At 68 metres above the valley floor, the top of the knob-shaped hillock is 503 metres in elevation above sea level. The formation is a major eastward plunging anticline consisting of metamorphosed limestones. The limestone strata originated on the bed of the Tethys Sea which at one time lay between the Asian continent and the Indian Subcontinent. Tectonic collision of these two masses resulted in the formation of the surrounding mountains, and the greater Himalayas to the north and east. The dip of the limestone strata is to the north. In combination with related igneous activities, the associated crystals formed from pneumatolytic processes, when

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FIG. 1. View (WNW) of Katlang Valley from the Jamal Ghari Ruins. The foothills in the foreground at the right are the location of the recently discovered Shakertangi topaz deposit.

FIG. 2. View (N) of Katlang Valley from the Jamal Ghari Ruins. The hillock containing the Katlang Mine can be seen at the indicated point near the edge of the valley.

FIG. 3. View (NW) of Katlang Valley from the Jamal Ghari Ruins. The hillock containing the Katlang Mine can be seen at the indicated point near the edge of the valley.

FIG. 4. West side of the hillock. Trenches and tailings can be seen covering the hillside. One of the compressors can be seen in the shed at the base of the hill.

FIG. 5. A small pocket opening at the start of the first tunnel is inspected.

FIG. 6. One of the larger trenches.

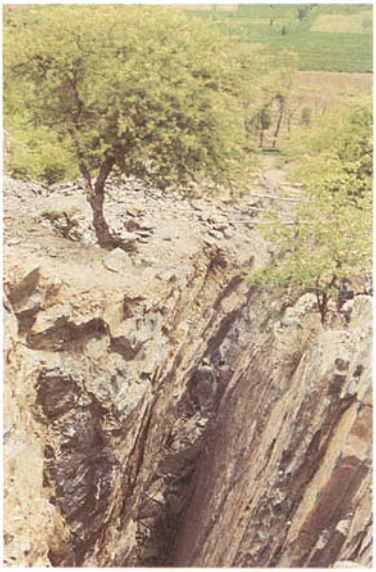

FIG. 7. A trench from the top of the hillock.

FIG. 8. Drilling prior to setting charges.

FIG. 9. A pneumatic drill hose snakes over ruin remains.

the mineralized veins intruded through strike faults and tension gashes into the folded limestone strata. Where growing space permitted, and if spared the pressures of refolding, the topaz is found as euhedral crystals among associated crystalline quartz, calcite, mica and talc.

On the eastern face of the hillock nearly a dozen major trenches have been laboriously carved. Several other minor trenches penetrate to about 15 metres beneath the hill's surface. Due to the depth of the trenches and the possibility of general collapse of the surrounding limestone, further excavation in the larger trenches has become unfeasible. As a result, the Gem C P mining engineers have made the decision to begin tunnelling into the veins. The first tunnel has only recently been started.

The project utilizes an appropriate combination of manual labour and light power equipment. Two compressors on the site power pneumatic drills and hammers. Due to the compaction of the limestone, blasting with dynamite is conducted extensively though care is taken not to set charges near visible veins or pockets. The miners use the pneumatic hammers and hand tools to follow the crystallized veins. Crystals are immediately deposited into lockboxes under supervision of security personnel, while debris is carried off in large wheelbarrows to the dump sites. About two dozen labourers make up the work force. The Gem C P project staff includes a geologist and mining engineer, mechanics, security and administrative personnel.

According to Gem C P staff geologist Syed Iftikhar Hussein, production at the mine has been steadily increasing since the Gem C P started work there. In February '81 – '82 about 10000 ct were recovered. For February '82 – '83 an increase to 17000 ct was accompanied by about 150 crystal specimens of exceptional quality intended for the collector market. Another significant increase in production followed in February '83 – '84 with 28000 ct in addition to 180 collector specimens.

The material mined at the hillock is graded into four categories. Exceptional crystals, unflawed and of a fine pink colour, compose grade A. About 10% of the production is of this quality over all, though some pockets have yielded up to 60% grade A material. Grade B material is transparent, lightly to moderately flawed, with good pink colour: 30% of the production falls into this category. Another 30% being highly flawed pieces of moderate to

FIG. 10. Three euhedral crystals.

FIG. 11. Gem of 37 ct and prismatic crystal. (*Gem Corp. of Pakistan*)

FIG. 12. Large prismatic crystal of 135 grams. (*Mr Issa Jaffar*)

poor colour, are included in grade C, and opaque material classified as Grade D constitutes the balance.

The properties of four pink crystals purchased in the vicinity and tested in the laboratory of the Asian Institute of Gemological Sciences in Bangkok, as well as properties of other specimens reported to have come from the mine, are as follows:

	RI			Birefringence	SG
Author (Four crystals)	1.630	1.632	1.640	0.010	3.52
Petrov, Schmetzer & Bank	1.632	1.633	1.641	0.009	NA
Arem	1.632	1.636	1.641	0.009	3.53

The pleochroism seen in the author's crystals is pink/pink/colourless. There is no distinctive absorption spectrum. Under short-wave ultraviolet light the specimens fluoresce white, and they are inert under long-wave. The euhedral crystals exhibit the ‹110›, ‹120›, ‹140› prism faces, ‹011›, ‹021› brachydomes, ‹111› dipyramid faces, and ‹001› pinacoid. There are no crystal inclusions visible in the specimens though there appears to be liquid contained in cracks.

The colour of the Katlang crystals has been previously described (Petrov, Schmetzer & Bank, 1977) as violet. The pleochroism was noted as yellow, violet with red and violet with blue. Following x-ray examination the material was shown to be OH rich consisting of approximately 15% fluorine. The violet colour was stated to be due to Cr^{+3}. The abundance of OH relative to fluorine is similarly shown by the generally high RI and low SG for topaz.

At the Gem C P Headquarters in Peshawar, there is a fine 37 carat gem, which the Managing Director, Brig. Kaleem ur Rehman Mirza, allowed the author to photograph along with an accompanying crystal. Mr Issa Jaffar, a Karachi dealer, allowed the author to photograph a large prismatic crystal of 135 grams. Dr Joel Arem has two cut pieces pictured in his *Color Encyclopedia of Gemstones*, one of 12.5 ct and another of 36 ct. A 2.4 inch specimen

in matrix is pictured in M. Pierre Bariand's *The Wonderful World of Precious Stones in their Natural State*.

The Katlang mine obviously produces a fine variety of topaz, but, as it is the only producing source for pink material in the region, an erratic supply is to be expected in the near future. Other topaz deposits have been located. Most notably, a recent discovery (summer 1984) of pink and violet material at Shakertangi, 20 kilometres south of Katlang, appears promising. As the highly mineralized mountain areas of northern Pakistan are steadily prospected, further deposits of topaz, as well as deposits of many other gem species, will surely come to light.

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THE OCCURRENCE OF BOTRYOIDAL AND GEM-QUALITY NEPHRITE IN MONTEREY COUNTY, CALIFORNIA.

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ABSTRACT

In an obscure beach cove (see Figure 1) along the California coastline, roughly one hundred kilometres south of the city of Monterey, numerous boulders and pebbles of relatively fine nephrite may be found. The locale is found between the capes of San Martin and Plaskett Point and may be reached by simple trails down steep cliffs. While simple collecting is possible, an understanding of the area's geological history and surface eases the difficulty in locating the nephrite. Discovered as peculiar yet indicative botryoidal masses and weathered chunks, the jade is of a fine quality with minor colour variegation and translucency and an absence of noticeable inclusions.

GEOLOGY

Extending from an area north of San Francisco one hundred and forty kilometres or so, to the south well within the heart of Southern California, the San Andreas Fault zone separates major and distinctive rock groups, each belonging generally to different continental and oceanic plates. The fault system trends north-west to south-east and acts as a plane of movement for these two plates (see Map 1). Excessive fault movement has caused a linear correlating rock displacement of hundreds of kilometres with the westernmost portion aside the fault displaying uplifting of hundreds of metres (Norris *et al*, 1976).

The tremendous turmoil and mobile activity due to the shifting continental and oceanic plates and the intervening fault system has caused a great forced elevation of large masses of sedimentary material into a jumbled, disorderly assemblage of sandstone, shale, chert, limestone and conglomerates termed the Franciscan Formation. Initially, during the Jurassic Period (180 million years ago), aqueous sedimentary rocks were deposited in a stratified manner, composed predominantly of silts, sands and unsorted rock debris. Fifty million years later, however, during the Cretaceous Period, this troughed sedimentary rock collection was disrupted and forced into folded and faulted masses, due to compressional tectonic processes (Page, 1978). During the Jurassic Period, it is believed that the San Andreas Fault zone acted in a more vertical direction, than one currently horizontal, due to confronting and

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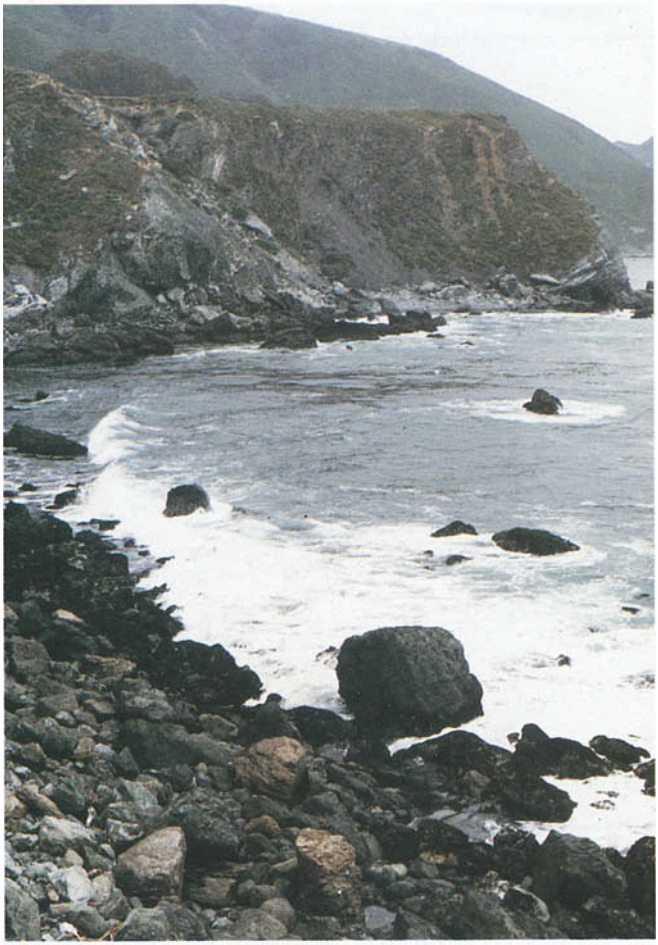

FIG.1. Southward view from Plaskett Point (10.00 a.m.)

disrupting rather than evasive and sliding continental and oceanic plates. With the two plates charging head-on, the eastern plate initially buoyed atop the advancing western oceanic plate. As the western plate, called the Salinian Block, glided beneath, it scoured the ocean's floor unearthing a dark-coloured siliceous rock rich in iron and magnesium (peridotite) and forcing it under high pressures and relatively low temperatures into the Franciscan mélange. Peridotite is the general rock type thought to have derived from the earth's mantle. It is from this material that our nephrite ultimately developed.

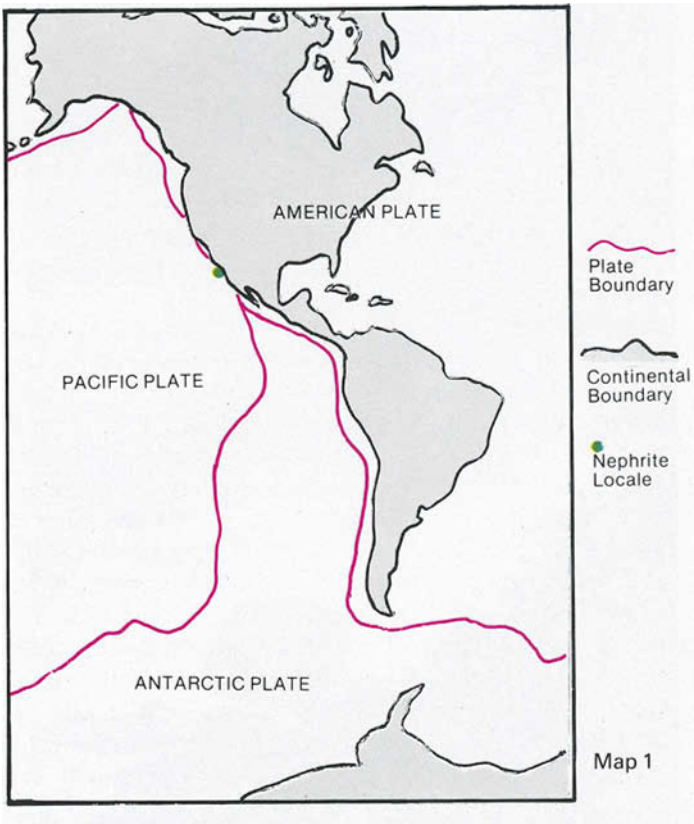

Map 1

The low temperatures and high pressures were responsible for hydration and conversion of the peridotite into serpentinite. The action of local alkaline solutions is believed to be responsible for the subsequent change into nephrite from the serpentinite. In this paper the terms peridotite and serpentinite describe the more massive and general rock units composed predominantly of olivine and serpentine materials.

Mineralogy

The chemical similarities and order of development of the nephrite from the peridotite are easily understood through the examination of the various yet related chemical compositions:

Peridot $(Mg, Fe^{+2}, Ni, Mn^{+2})_2SiO_4$
Serpentine $(Mg, Fe^{+2}, Ni)_3Si_2O_5(OH)_4$
Actinolite $Ca_2 (Mg, Fe)_5, Si_8O_{22}(OH)_2$
Tremolite $Ca_2Mg_5Si_8O_{22}(OH)_2$

Nephrite is a varietal mineral name for a fibrous, compact isomorphic product of the actinolite-tremolite series. Actinolite has an indicative green colour, while the tremolite is typically white or greyish. These two minerals combine to form a complete range from white to greenish-black, depending on the amount of each specific mineral present. Both minerals form in a needle-like habit (acicular), so their combining to form a fibrous variety can be reasonably understood. Ideally, nephrite consists of a randomly oriented intergrowth of crystalline fibres, but in the Monterey County occurrence, it forms in botryoidal masses of the fibred material. Here the rocks found not only contain the nephrite but serpentine, actinolite, tremolite, soapstone and "seminephrite"– a weathered form which exhibits all visual characteristics of the nephrite but lacks the toughness and hardness (Crippen, 1951).

Mylonitization (the relatively high pressure and low temperature grinding of rocks) is a process involved in the complex steps of mineral alteration (see Figure 2). Originally, with the scouring and pushing of the peridotite as well as the great stretching, folding and twisting of the mass, it was forced into a hydrous state because of its oceanic proximity. It was then that subsequent alkaline pore solutions, rich in calcium, magnesium and iron, completed the conversion from the intermediate step of serpentine to the end product—nephrite. Mylonitization caused the physical change and altered botryoidal shape, while the migrating fluids affected only the chemical composition. Mylonitization can manifest itself visually as large rock units (kilometres in size) having a lenticular form or as microscopic particles obviously squeezed together and lamellar in structure or orientation. It is because of this shearing force that the nephrite from the Monterey occurrence shows signs of sliding and/or flattening to some extent. Often the nodules found, either imbedded in the host serpentinite or loose below the cliffs, exhibit an oval or oblate shape. It is also within these zones of shearing and schistosity that the greatest abundance of the nephrite nodules may be found; while in the more solid and less solution-accessible areas of the serpentinite lesser amounts of

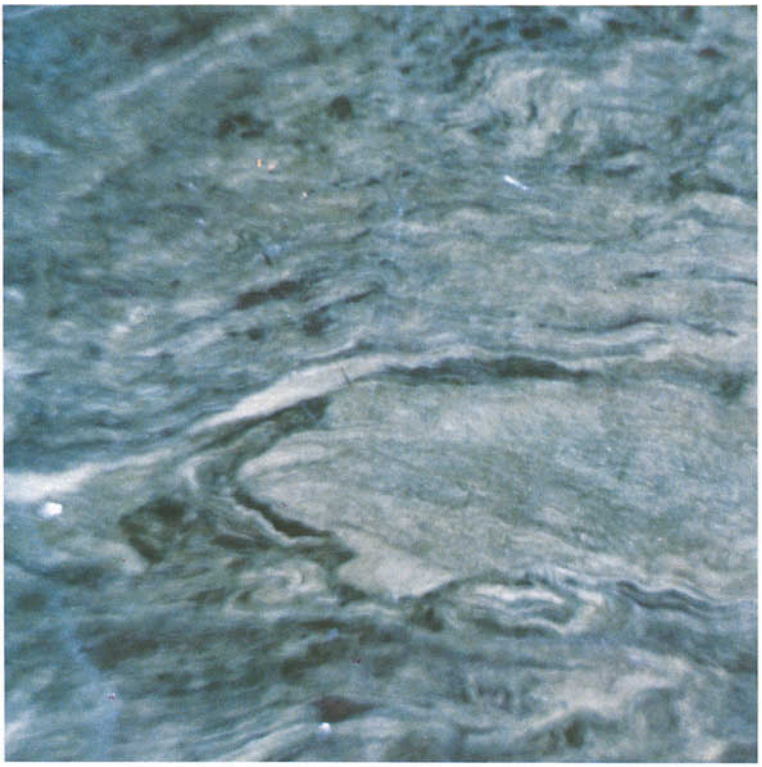

FIG.2. Close up of Mylonite Structure in Nephrite (2x)

the jade are found. The chemical replacement that then occurs is due to the varying accessibility of the serpentines to the mobile alkaline pore solutions (Crippen, 1951).

In the Monterey County nephrite occurrence, with the exception of the nephrite, most of the minerals found in or associated with the serpentinite are found in massive, unsorted and often jumbled groups. The nephrite, however, is consistently located as a compact monomineralic unit. Peculiar yet indicative of the Monterey materials is its botryoidal form. Combined nodular masses of nephrite are found at the beach area typically in the vicinity of its serpentine origin. Having developed its botryoidal habit, it becomes evident under magnification that the nodules either grew outwardly and into one another or were forced

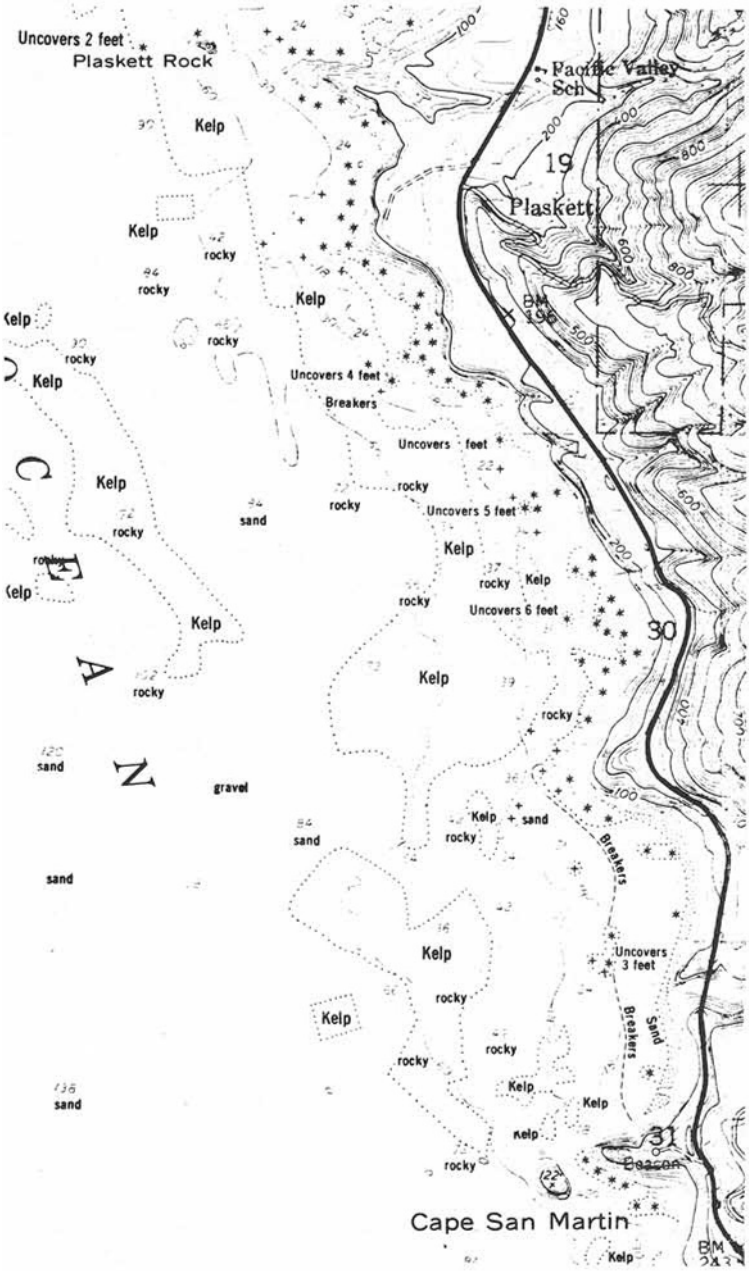

MAP 2. U.S. Topographical map of the area between Plaskett Point and Cape San Martín. (4cm = 1km)

together. It is this compact and unusual grouped nodular mass that has become the trademark of nephrite from this locale. Normal weathering and wave action are subsequently responsible for the separation of the tough nephrite from its less resistant serpentine host.

GEOGRAPHY (see Map 2)

Approximately one hundred kilometres south of the city of Monterey on the California coastline (a fine two hour drive) lies Jade Cove, between Plaskett Point and Cape San Martín. This area extends a distance of roughly three kilometres with the beach varying from sixty to four hundred metres down from the California Highway One. Numerous trails may be taken from the roadway down steep cliffs to the beach area where the nephrite is located. The cliffs vary in height from thirty to eighty metres and are considerably treacherous in some areas. Though a great deal of the area is overlain with soil, it is from the greenish coloured cliff areas that the jade has eroded and may then be found either *in situ* or in the detritus below. It must be noted that the materials may only be legally removed if found below the mean high water level. It is then advisable to visit the area after having carefully studied the tide charts and planning the trip accordingly.

It is a task trying to locate the nephrite nodules, since once wet many of the associated rocks look like the nephrite. Once wetted the typical waxy green appearance of the jade cannot be used as a distinguishing characteristic, so the author found it valuable that the rocks in question be hefted for comparative density and tapped with a hammer for comparative hardness. Most of the associated rocks show inferior characteristics to those of the jade. (See Figure 3.)

Between the two coastal capes, the beaches vary in width from two to twenty metres at low tide, and at this time all of the smaller coves are accessible. Here, the tidal action has separated the tougher jades from the serpentinite and in the process has often given the nodules a polished appearance. In some cases, however, the nephrite has become so weathered that it has taken on a "skin", a layer of reddish-brown oxidized material. The author noted numerous specimens that had been passed over by unknowing collectors because of this weathered surface obscuring the inner nephrite. The skin exhibits a lesser hardness and more granular texture than the nephrite it is concealing.

Gemmology

The nephrite from the Monterey County area shows all the physical properties typical of nephrite from any locality, but its unusual botryoidal form and absence of noticeable inclusions allow it to stand apart. At its best, the botryoidal oddity is said to take on the appearance of a corn cob, though typically the nodular bundles consist of only two to ten nodules each. The Monterey nephrite also exhibits an unusual absence of inclusions. According to Bergsten (1964) nephrite from Alaska and Wyoming both contain numerous and noticeable pyrite and/or chromite octahedra. The jade, however, from this locale seems to contain no crystalline inclusions, only a minor mylonitized/lensed structure apparent under magnification.

The nephrite collected also exhibits typical colour varying from dark and waxy greenish-coloured boulders to light green nodules. Though the nephrite exhibits a moderate to poor translucency, in unusual cases it was located having a very fine semi-transparency in minor thicknesses (see Figure 4). Two oval cabochons of nephrite were cut and both show moderate translucency and fine even colour-distribution with a good polish. It is here that the absence of inclusions allows for little or no micro-particle undercutting, with the micro-mylonite structure affording only minor variable colour, hardness and translucency.

Conclusion

The trek down some California coastal cliffs into the Jade Cove area of Monterey County brings one to not only a beautifully simple place, but one also rich in geological and gemmological history and discovery. Here natural erosion has exposed large serpentine masses and separated from it nodules of nephrite onto the beach or into the sea. Much of the material is found as botryoidal forms, indigenous to this area, or as wave-polished pebbles or weathered chunks. At low tide the keen observer and collector may unearth numerous fine specimens of this unusual and attractive jade. Pieces of various greenish tones, translucency, shape and size make the search rewarding with each new discovery stimulating further search.

FIG.3. View southward showing exposed serpentinite/nephrite cliffs (11.00 a.m.)

FIG.4. Thin section close-up showing nephrite translucency (3mm thickness: 3× magnification)

An understanding of the geology of the area not only makes for a greater appreciation of the mineral development and processes, but also aids in the search for the nephrite. It is through this knowledge that the Monterey County nephrite in its unusual botryoidal form or simple pebble occurrence may be a pleasurable trip and task worth undertaking.

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COLOURLESS CHRYSOBERYL—NATURAL OR SYNTHETIC?

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ABSTRACT

The physical and chemical properties of two colourless chrysoberyl specimens which were said to come from Sri Lanka, were investigated in order to clarify their natural or synthetic origin. The data of the two chrysoberyls were compared with those of natural colourless, yellow, brown, and green chrysoberyl specimens of different localities and with the properties of synthetic alexandrites of three producers. Some of the properties of the two colourless chrysoberyls of unknown origin do not prove them to be either natural or synthetic (refractive indices, colour, chromium and iron contents, inclusions, colour change due to x-ray irradiation). However, unlike all natural specimens which were investigated in this research project, including a natural colourless chrysoberyl from Burma, no Ga was found by x-ray florescence analysis to be present in the two colourless samples under investigation. The results may, therefore, indicate a synthetic origin of the samples.

INTRODUCTION

Chrysoberyl is coloured by various amounts of iron and chromium; traces of vanadium are also present in natural samples. Crystals containing predominantly traces of iron are yellow, yellowish-brown or brown. The colour of the green variety of chrysoberyl, called alexandrite, is due to admixtures of chromium and iron, and yellowish-green crystals also contain certain amounts of both iron and chromium, the colour-producing trace elements. However, the chromium content is significantly smaller in yellowish-green crystals. Colourless chrysoberyl is mentioned as a rare gem material from Burma, and, obviously, only a few specimens are known (Arem, 1977; Webster & Anderson, 1983).

Colourless chrysoberyl, which is said to come from Sri Lanka, was first described as a cut gemstone of 2.13 ct by Müllenmeister (1980). The colourless crystal was identified by optical methods, later confirmed by the author using x-ray powder diffraction. The refractive indices of the colourless chrysoberyl were given as n_x1.740 and n_z1.750. These values are extremely low for chrysoberyl compared to the values of ordinary chrysoberyl and alexandrite crystals of different localities ($n_x \approx 1.744$–1.749,

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$n_z \approx 1.754–1.759$). The low refractive indices of the colourless chrysoberyl are understood assuming extraordinarily low iron and chromium contents, which is self-evident from the lack of colour of the gemstone. However, no definite proof for the natural origin of the sample of H. J. Müllenmeister was given in the publication mentioned.

Discussing this problem with some colleagues, a second colourless chrysoberyl was identified in the collection of Dr E. Gübelin, of Meggen, Switzerland. This gemstone of 8.26 ct, which was bought about ten years ago as a cut gemstone from Sri Lanka, was also submitted for the present investigation.

Looking through the gem material available in the collection of Dr H. Bank, of Idar-Oberstein, two small yellowish chrysoberyl specimens from Sri Lanka were found, but no additional colourless sample from this locality could be supplied for examination.

In fact, no colourless chrysoberyl of undoubtedly natural origin was available at this state of investigation. One very pale green stone of 4.99 ct from Burma was later localized at the Institute of Geological Sciences,* London. Three nearly colourless but very pale green chrysoberyls of Burmese origin are in the collection of the British Museum (Natural History), London. One nearly colourless, very pale green rough tabular crystal, 16×12×4 mm in size and 12.89 ct in weight, is preserved in the collection of the National Museum of Natural History (Smithsonian Institution), Washington, D.C., U.S.A. (NMNH 139974); this specimen was also submitted for the present investigation.

For the sake of comparison, cut gemstones of yellow, yellowish-green and brown coloration from Sri Lanka and Brazil were supplied, as well as alexandrites of various colour intensities from Russia, Zimbabwe, Brazil, and Tanzania.

Synthetic chrysoberyl has been grown by various methods including flux growth, Czochralski, Verneuil flame-fusion, hydrothermal growth, and floating zone techniques (*cf.* Elwell, 1979; Nassau, 1980; O'Donoghue, 1983). Up to now, only chromium-containing alexandrites have been commercially available on the gemstone market. The first stones of cuttable size were produced by the firm Creative Crystals, of Danville, U.S.A. (Liddicoat, 1972-1973) from a flux in the Li_2O-MoO_3 system and by

*Now known as the British Geological Survey.—Ed.

the Czochralski method (Cline *et al.*, 1975; Morris & Cline, 1976). However, the inclusions of the synthetic material indicate that only flux-grown samples were cut for gem purposes (Liddicoat, 1972-1973; Eppler, 1974). The alexandrites grown by the Czochralski method are of great importance in laser devices (Morris & Cline, 1976; Walling *et al.*, 1979; Bukin *et al.*, 1981; Sevast'yanov *et al.*, 1981).

A second type of synthetic alexandrite which is grown by the Czochralski method has been produced since 1976 for gem purposes by the firm Kyoto Ceramic, of Kyoto, Japan (Ohguchi, 1981). Most recently, a third type of synthetic alexandrite was introduced by the firm Suwa Seikosha, of Nagano-Ken, Japan. According to the producer, these crystals are manufactured by the floating zone technique. At present, to the knowledge of the author, no synthetic colourless chrysoberyl has appeared on the gemstone market. However, it is evident that colourless chrysoberyl may be produced by one of the methods mentioned above, omitting the colouring dopants (chromium and iron oxides) in the nutrient material for the production of alexandrite (*cf.* Farrell & Fang, 1964; Bonner & Van Uitert, 1968; Cline *et al.*, 1975). Therefore, an investigation of the two cut colourless chrysoberyls of 2.13 and 8.26 ct available at present to the author in order to clarify the nature of the samples was necessary.

Results

Optical Properties

The refractive indices of the colurless chrysoberyl samples were measured as follows:

cut gemstone of 2.13 ct n_x 1.739, n_z 1.748
cut gemstone of 8.26 ct n_x 1.739, n_z 1.748
rough Burmese crystal n_x 1.738, n_z 1.747.

The very pale green stone of the Institute of Geological Sciences has refractive indices of n_x 1.741, n_z 1.748 (E. A. Jobbins, private communication 1984), the three crystals of the British Museum (Natural History) have refractive indices lower than 1.740 (P. G. Embrey, private communication 1984). All yellow, yellowish-green and green chrysoberyl specimens tested for this investigation have refractive indices in the range which is given in gemmological textbooks.

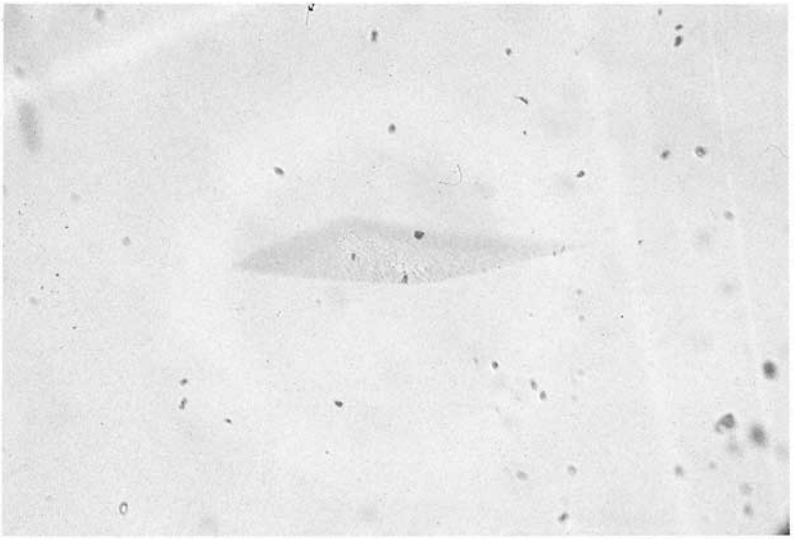

FIG. 1. 'Fingerprint' inclusion consisting of small spherical particles in colourless chrysoberyl of unknown origin (sample of 8.26 ct. collection of E. Gübelin). 55×.

Inclusions

Both colourless gemstones which were said to have come from Sri Lanka are extremely pure crystals. Both samples show straight parallel growth bands, which is common for natural and flux grown chrysoberyl. The gemstone of 8.26 ct has a small 'fingerprint' inclusion (Figure 1) consisting of small spherical particles. No mineral inclusions were observed in either of the two.

The rough Burmese crystal has several mineral inclusions: rounded crystals (zircon?) surrounded by a 'halo' of fractures (Figures 2,3) and double refractive tabular crystals with high interference colours (calcite?) surrounded by a liquid feather (Figures 4,5). In addition, the crystal has a liquid-filled tube and a thin tabular negative crystal.

Spectroscopic Data

In the absorption spectra of the colourless gemstones of unknown origin no distinct absorption bands were observed. The nearly colourless, very pale green Burmese crystal has a very weak chromium spectrum, which is already known in detail from the investigations of alexandrites from different localities.

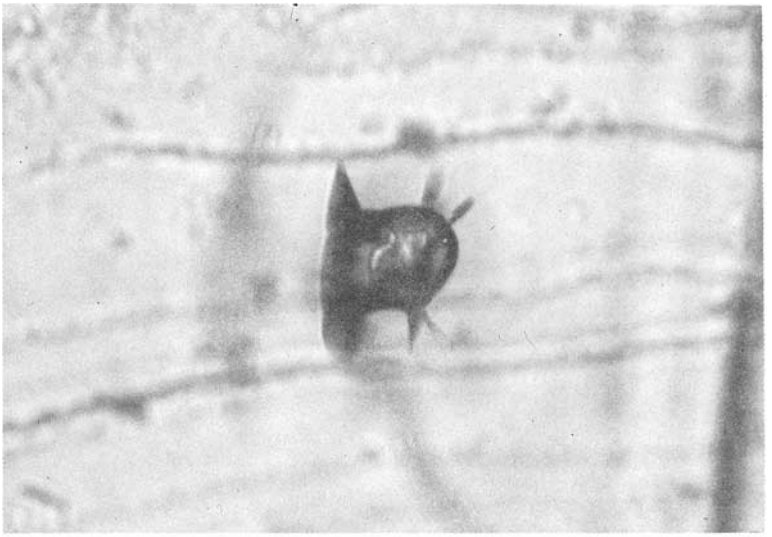

FIG. 2. Rounded crystal (zircon?) surrounded by a 'halo' of fractures in nearly colourless, very pale green chrysoberyl from Burma (tabular crystal, Smithsonian collection). 95×.

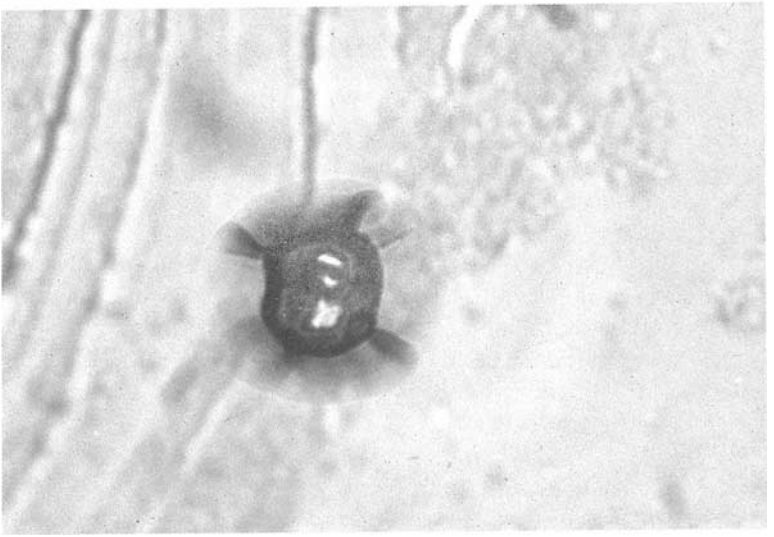

FIG. 3. Rounded crystal (zircon?) surrounded by a 'halo' of fractures in nearly colourless, very pale green chrysoberyl from Burma (tabular crystal, Smithsonian collection). 100×.

The absorption spectra of yellow and brown chrysoberyls show distinct iron bands; all natural alexandrites have absorption bands of chromium and iron, and yellowish-green chrysoberyl specimens show the iron absorption spectrum of yellow or brown samples and weak chromium bands (*cf.* Farrell & Newnham, 1965; Hassan & El-Rakhawy, 1974; Schmetzer *et al.*, 1980).

In synthetic alexandrites the absorption bands of chromium and iron (synthetic alexandrites produced by Creative Crystals and Suwa Seikosha) or a chromium spectrum without iron bands (synthetic alexandrites produced by Kyoto Ceramic) were measured. According to Ohguchi (1981), the synthetic alexandrites of Kyoto Ceramic may also contain certain amounts of vanadium as a dopant.

Chemical Data

Non-destructive chemical analyses by x-ray fluorescence reveal only a very small iron content in the cut colourless gemstone of 2.13 ct. The x-ray fluorescence spectra of both colourless chrysoberyl specimens of unknown origin did not show a distinct signal for Ga. However, in all natural chrysoberyl specimens investigated (the colourless Burmese crystal, yellow, brown and yellowish-green samples from Sri Lanka and Brazil, and alexandrites of the localities mentioned before), in addition to the signals of colouring trace elements (Fe and Cr), a distinct Ga content was observed. In synthetic alexandrites of all three producers, no Ga was found.

Colour Change due to Irradiation

All three colourless samples revealed, after x-ray fluorescence analysis, an intensive golden brown colour. The colour of some light yellow chrysoberyl specimens from Sri Lanka changed to an intensive golden brown after x-ray fluorescence analysis. The colour of dark brown or intensive green samples appeared unchanged to the eye after x-ray fluorescence analysis.

All colour changes were found to be completely reversible after exposure to a fibre optic illuminator for about five minutes. After illumination, the stones were colourless or slightly yellow again.

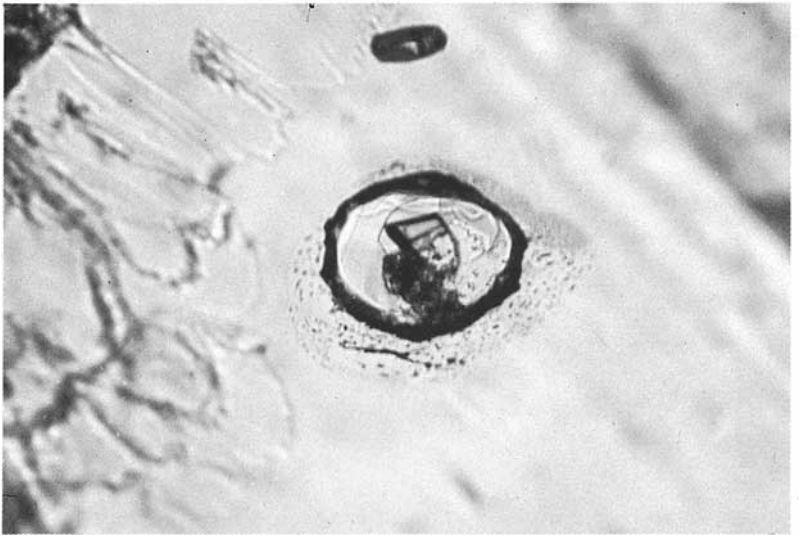

FIG. 4. Tabular crystal (calcite?) surrounded by a liquid feather in nearly colourless, very pale green chrysoberyl from Burma (tabular crystal, Smithsonian collection). 70×.

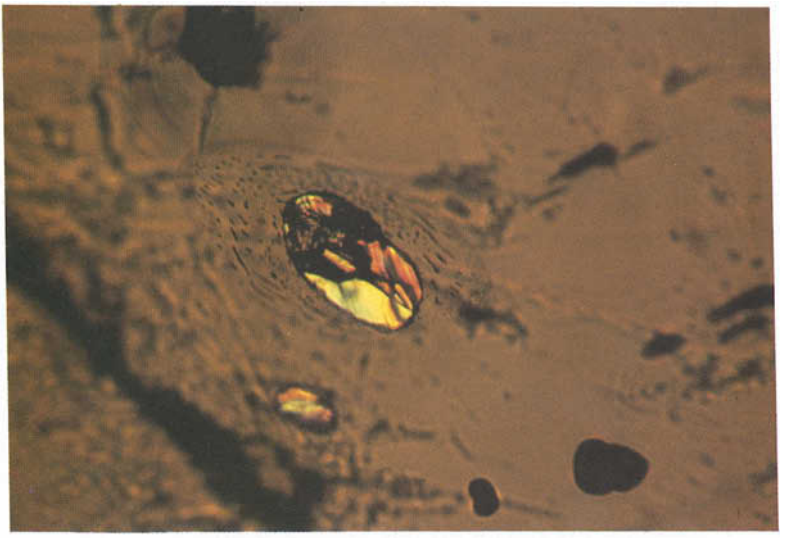

FIG. 5. Tabular crystal (calcite?) surrounded by a liquid feather in nearly colourless, very pale green chrysoberyl from Burma (tabular crystal, Smithsonian collection). Crossed polarizers, 65×.

Discussion

The nearly colourless, very pale greenish chrysoberyl crystal from Burma (Smithsonian specimen NMNH 139974) with mineral inclusions and refractive indices of n_x 1.738, n_z 1.747, is undoubtedly of natural origin. The investigation of this sample indicates that colourless chrysoberyl of natural origin without distinct trace element contents of Fe and Cr and with low refractive indices as determined for the two samples of unknown origin does exist. However, such natural samples, at present, are known to originate only from the Mogok stone tract in Burma. Colourless chrysoberyl from Sri Lanka may exist, too, but has not yet been reported.

The microscopic investigations of the two colourless samples under discussion indicate that the stones could be extremely pure natural materials or extremely pure flux grown samples. The microscopic examination did not reveal the properties of crystals grown by the Czochralski or floating zone technique which are produced by Kyoto Ceramic and Suwa Seikosha of Japan. The synthetic alexandrites of Kyoto Ceramic show curved striations, and the alexandrites of Suwa Seikosha reveal growth inhomogeneities and an irregular shift structure.

The presence of Ga indicates alexandrites of natural origin (Ohguchi, 1981). Quantitative Ga determinations in natural alexandrites reveal an enrichment of about 300-1200 ppm Ga (Ottemann, 1965; Ottemann *et al.*, 1978). As shown in this research project, all natural alexandrite and chrysoberyl samples investigated including the colourless sample from Burma revealed a distinct Ga signal by x-ray fluorescence analysis. On the contrary, both colourless chrysoberyls of unknown origin did not contain Ga in diagnostic quantities. No residues of a flux were found in these samples or in synthetic alexandrite samples of Creative Crystals, which were grown from Li_2O-MoO_3 flux according to the description of the producer (Cline *et al.*, 1975).

The colour change of the two colourless samples after x-ray fluorescence analysis is similar to the colour change described for synthetic alexandrite of Kyoto Ceramic by Bank (1982). Therefore, this colour change was first thought to indicate the synthetic origin of the samples. However, a reversible colour change both of the colourless Burmese crystal and of the yellow or yellowish-green

samples from Sri Lanka also was found after x-ray fluorescence analysis.

In summary, both colourless chrysoberyl samples of unknown origin reveal physical and chemical properties, which may indicate extremely clean natural or flux grown crystals (refractive indices, inclusions, iron and chromium contents, reaction to x-ray irradiation). A distinct Ga content was not found in either of the two samples; Ga, however, was observed in all natural samples investigated. Properties, which indicate an undoubtedly natural origin of the two colourless samples, were not found.

The colourless chrysoberyl in E. Gübelin's collection was bought about ten years ago. At that time, the production of flux grown synthetic alexandrite for gem purposes was already established. Unfortunately, no information about possible production of colourless synthetic chrysoberyl for gem purposes is known by the author to be available, and no information was given by Creative Crystals.

Acknowledgments

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PERIDOT FROM RATNAPURA DISTRICT, SRI LANKA

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INTRODUCTION

Sri Lanka is one of the greatest gemmiferous localities in the world and is famous for the occurrence of common and rare gemstones of various kinds.

Since the discovery of gem sinhalite in the island (Claringbull & Hey, 1952) the great gemmologist B. W. Anderson (1952) found that most of the stones marketed in Sri Lanka as peridot were sinhalite. However, during a recent visit the author discovered a few samples of cut and uncut peridots of gem quality.

The preliminary identification was done after polishing a facet for refractive index determination on a few samples. According to the refractive indices and the quite large birefringence the samples were confirmed as peridot rather than diopside as thought before.

The peridots found in the Ratnapura area, Sri Lanka, were investigated in detail, including a chemical analysis. It was desirable to publish the results of this investigation since the occurrence of gem peridot in Sri Lanka has not yet been reported in the gemmological or mineralogical literature.

FIG. 1. These peridots from Ratnapura represent some of the best colour found in Sri Lanka. The stones range in weight from 5 to 12 ct.

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Chemistry

The chemical analysis of the Sri Lanka peridot was performed by electron microprobe. The results are given in Table 2, in comparison with data of peridots from several other localities, as indicated in Table 1. The calculation of the Fo/Fa ratios show that gem peridots are situated between approximate 92.5%-88.5% Fo with 7.5%-11.5% Fa molecules. The concentrations of Mn and Ca are fairly low. The sample from Sri Lanka contains a slightly higher amount of MnO (0.27%) compared with the other gem peridots. Its composition may be expressed by the formula:

$$Mg_{1.77}\,Fe_{0.22}\,Mn_{0.01}\,Si_{1.00}\,O_{4.00}$$

TABLE 1. *List of peridot samples referred to in this paper.*

1. Arizona	(Dunn, 1974)
2. Arizona, Chinlee Valley	(Dunn, 1974)
3. Arizona, Fort Dèfiance	(Dunn, 1974)
4. Arizona, Rice Station School	(Dunn, 1974)
5. Mexico	(Dunn, 1974)
6. Mexico, Chihuahua	(Dunn, 1974)
7. Island of Zabargad (Egypt)	(Kurat *et al.*, 1982)
8. Island of Zabargad (Egypt)	(Stockton & Manson, 1983)
9. Burma	(Stockton & Manson, 1983)
10. Norway	(Stockton & Manson, 1983)
11. Tanzania, Usambara Mountains	(Stockton & Manson, 1983)
12. Sri Lanka, Ratnapura	(present work)

Physical Properties of Sri Lanka Peridot

The attractive colour of peridot is a distinct olive green, which may vary according to the amount of Mn^{2+} and Fe^{2+} cations present. The Mn^{2+} and Fe^{2+} content is considered responsible for the darkening of the colour (read also Gübelin, 1981). The stone from Sri Lanka (Figure 1) contained a relatively high amount of FeO (10.81 wt %) and MnO (0.27 wt %) compared with other samples.

TABLE 2. *Chemical analyses comparison of Sri Lanka peridot with material from other localities.*

Locality:	Arizona				Mexico		Zabargad		Burma	Norway	Tanzania	Sri Lanka
	1[a]	2[a]	3[a]	4[a]	5[a]	6[a]	7[b]	8[c]	9[c]	10[c]	11[c]	12[d]
Composition												
SiO_2	41.11	41.57	41.39	41.62	41.96	41.32	41.60	41.07	40.25	41.19	40.62	40.62
TiO_2	0.02	0.01	0.02	0.01	*	0.01	*	*	*	*	*	*
Cr_2O_3	0.04	0.03	0.04	0.04	0.06	*	*	*	*	*	*	*
FeO**	9.07	10.37	9.71	8.67	8.67	8.62	9.60	8.14	10.16	6.94	7.74	10.81
MnO	0.09	0.12	0.11	0.18	0.10	0.14	0.10	0.11	0.15	0.06	0.12	0.27
MgO	49.49	48.47	48.50	48.34	49.39	49.80	49.70	50.44	48.90	51.63	51.26	48.11
CaO	0.09	0.09	0.10	0.10	0.16	0.06	*	0.04	*	*	*	0.14
NiO	*	*	*	*	*	*	0.33	0.38	0.31	0.29	0.39	*
Total	99.91	100.66	99.87	99.43	100.34	99.95	100.33	101.18	99.77	100.11	100.13	99.95

(a) Dunn (1974)

(b) Kurat *et al* (1982)

(c) Stockton & Manson (1983)

(d) present work (kindly analysed by Dr H. Hänni)

*below the detection limit of the microprobe

**the total iron is calculated as FeO

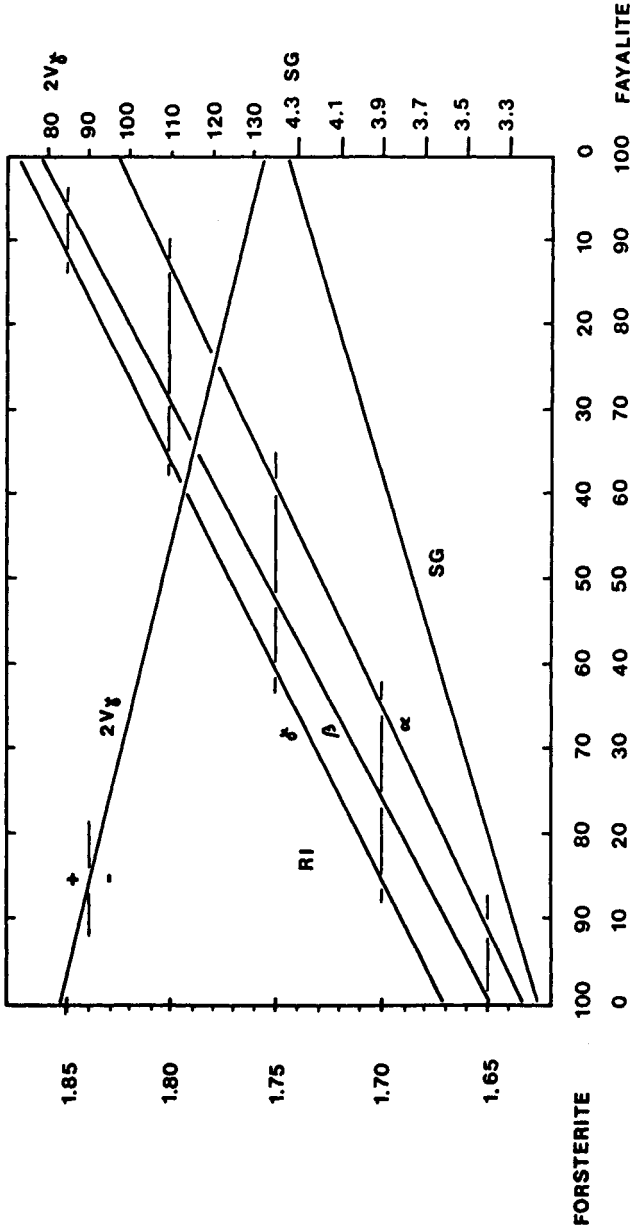

FIG. 2. Variations of 2V angle, specific gravity and refractive indices for the forsterite-fayalite series (after Deer *et al.*, 1982).

TABLE 3. *Optical and physical data of gem peridots from different localities.*

Locality:	Arizona (I)	Arizona (II)	Arizona (III)	Mexico (IV)	Mexico (V)	Zabargad (VI)	Burma (VII)	Australia (VIII)	Tanzania (IX)	Sri Lanka (X)
Refractive indices										
n_α	1.653	1.652	1.652	1.652	1.652	1.652	1.656	1.653	1.650	1.651
n_β	1.669	1.671	1.668	1.671	1.668	1.668	1.671	1.671	1.658	1.660
n_γ	1.690	1.689	1.689	1.688	1.685	1.690	1.692	1.690	1.684	1.690
Birefringence	0.037	0.037	0.037	0.036	0.033	0.035	0.036	0.037	0.034	0.039
Optical character	B+	B−	B+	B−	B+	B−	B+/−	B+	B+	B+
Specific gravity	3.35	3.34	3.34	3.33	—	3.28	3.35	3.39	3.25	3.36
Fo:Fa ratio	91:9	89:11	90:10	91:9	91:9	—	—	—	—	89:11

I-V After Dunn (1975)

VI and X the author

VII after Gübelin (1975 & private communications)

VIII after Brown & Bracewell (1982)

IX after Stockton & Manson (1983)

As well as the colour, the high refractive index of peridot is also caused by the amount of Fe^{2+} percentage. With increasing iron content the axial angle $2V_\gamma$ increases and the optical character turns to negative at 15 molecule % of *fayalite*. Simultaneously n_β is altered slightly away from n_α towards n_γ (Bowen & Schairer, 1935). The relationship between the optic axial angle and the refractive indices after Deer *et al.* (1982) is shown in Figure 2. The refractive

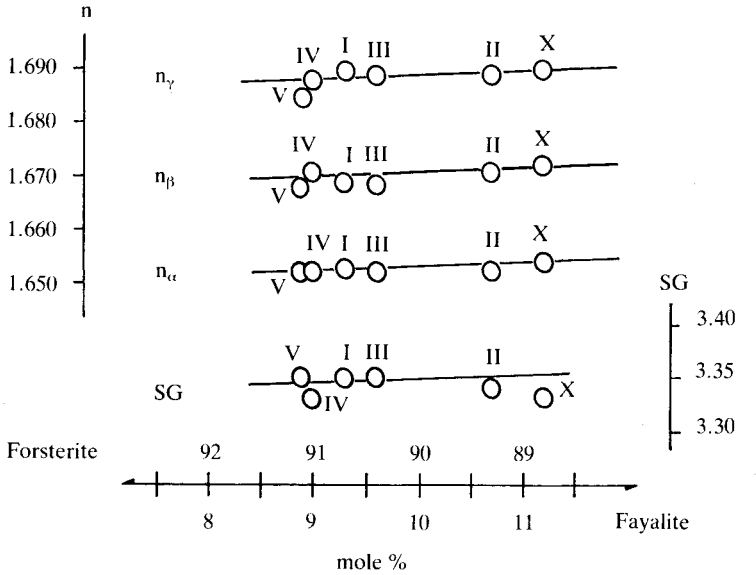

FIG. 3. Some of the samples taken from Table 3 to demonstrate the variations of physical properties in gem peridots in relation to their forsterite and fayalite ratio.

indices and specific gravity are given in Table 3 as are molecule ratios and the physical data comparisons (see also Figure 3). Visible light spectrophotometric examination of the Sri Lanka peridot was conducted on a Pye Unicam SP8-100 UV-VIS spectrophotometer. The recorded spectrum (Figure 4) shows similar peaks to that of tephroite at approximate wavelengths of 610, 550, *500* and *450* nm (Stidham *et al.*, 1976).

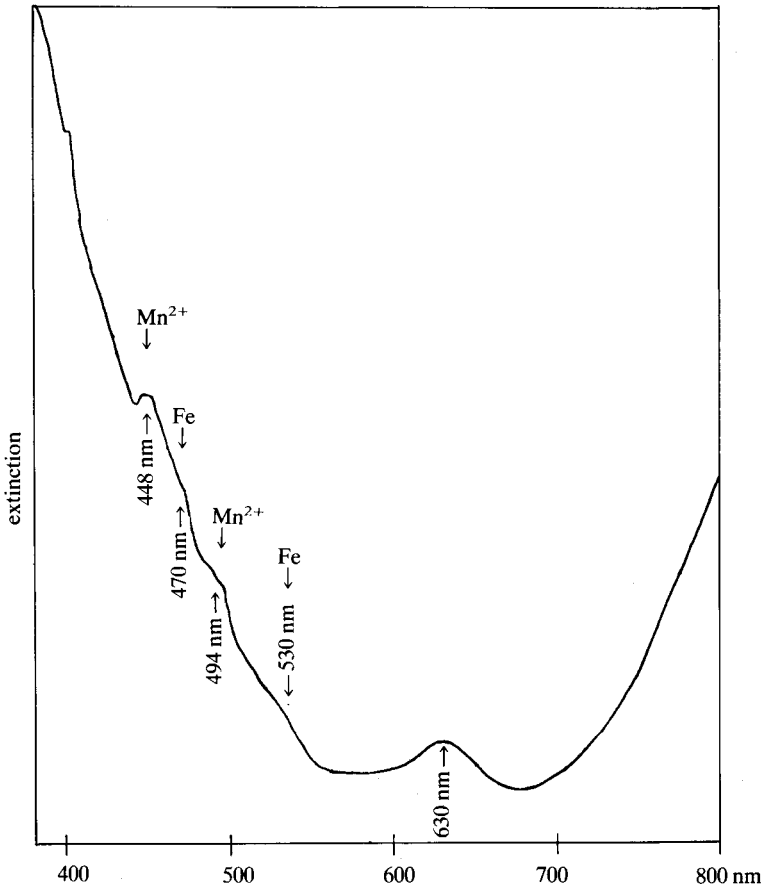

FIG. 4. The absorption spectrum of Sri Lanka peridot within the visible wavelength range of 400 to 800 nm.

Inclusions in Sri Lanka Peridot

Microscope investigations revealed the presence of dark reddish-brown to black euhedral to anhedral crystals as shown in Figure 5. Dunn (1974 & 1978) reported the occurrence of chromian spinel as an inclusion in peridots from Arizona and Mexico. The exposed inclusion just below the surface of the stone from Sri Lanka (Figure 6) was analysed with the electron microprobe and the results obtained are given in Table 4. This analysis showed the inclusions in Sri Lanka peridot to be a member of the spinel mixed

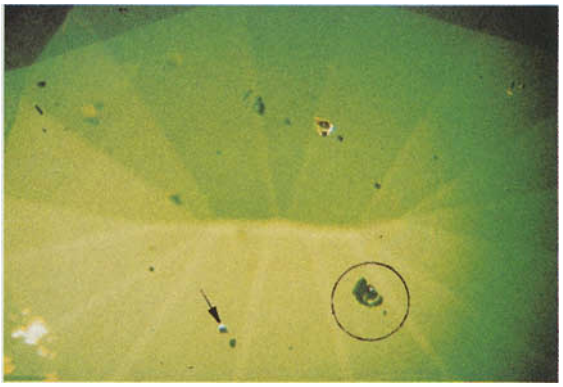

FIG. 5. Euhedral (arrowed) as well as anhedral (circled) spinel inclusions in gem peridot from Ratnapura, Sri Lanka. (15×).

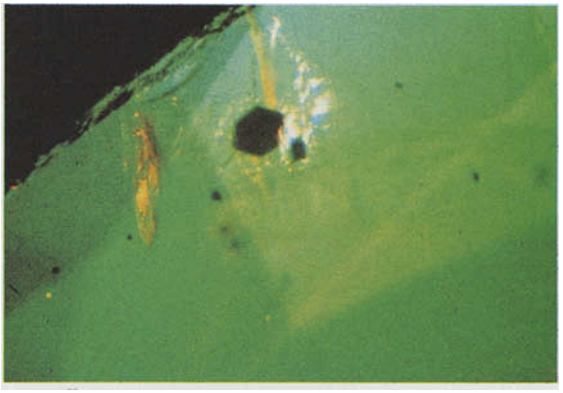

FIG. 6. Flat crystal of iron-rich spinel inclusion showing a pseudohexagonal contour. Note also the tension fissures surrounding the crystal. (40×).

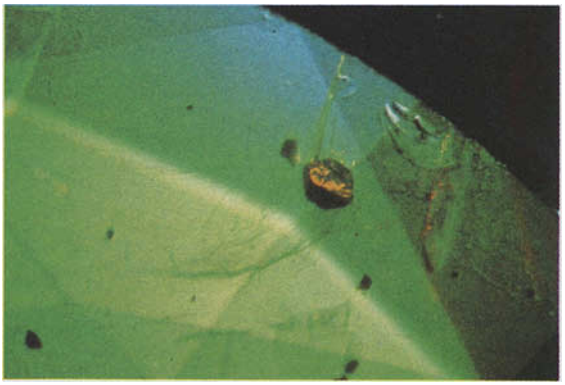

FIG. 7. Smoke-like veiling in Sri Lanka peridot. (40×).

TABLE 4. *Chemical analyses of the spinel inclusions in Arizona, Mexico and Sri Lanka peridots.*

	Arizona sample No: 1	Arizona sample No: 2	Arizona sample No: 3	Arizona sample No: 4	Mexico sample No: 5	Mexico sample No: 6	Sri Lanka sample No: 12
SiO_2	0.12	0.11	0.11	0.10	0.19	—	—
TiO_2	0.27	0.18	0.29	0.52	0.10	0.11	1.11
Al_2O_3	45.46	36.55	34.43	34.91	31.68	46.34	31.93
Cr_2O_3	22.62	33.08	33.11	31.49	34.79	21.60	30.71
FeO	11.95	14.68	14.59	13.75	13.33	12.38	20.32
MnO	0.16	—	0.19	0.18	0.19	0.23	—
MgO	17.71	16.39	15.48	16.57	16.28	18.67	16.31
CaO	0.01	0.03	0.01	—	0.03	—	—
Totals	98.30	101.02	98.21	97.52	96.59	99.33	100.38

samples are from Table 1

the total iron is calculated as FeO

accuracy of data ± 2% relative

crystal series (spinel-magnetite-chromite) similar to those reported in peridots from other localities (Dunn, 1974, 1978; Koivula, 1981). The inclusion is of a platy shape (i.e. an extremely distorted octahedron) showing a pseudohexagonal symmetry resembling mica platelets. The included crystals were often surrounded by tension fissures as shown in Figure 6. Although there were no other typical inclusions present, an effect similar to smoke-like veiling was found (Figure 7). A similar effect was reported by Koivula (1981) from San Carlos peridots. This may be due to lattice dislocations as mentioned by Kohlsted *et al.* (1976) or possibly to unmixing in the subsolidus region (Koivula, 1981).

Occurrence

The occurrence of gem peridot is mainly confined to basaltic rock types as reported from Zabargad Island (Kuart *et al.*, 1981), Arizona (Dunn, 1974), San Carlos (Koivula, 1981) and Mexico (Dunn, 1978).

In Sri Lanka the gem-bearing Highland Group consists mainly of metamorphic rocks of granulite facies. Pelitic, quartzofeldspathic, calcareous, basic and ultrabasic rock types are common in this Group (Munasinghe & Dissanayake, 1981). The presence of spinel inclusions in the gem from the island supports its origin in an ultrabasic igneous environment rather than in a metamorphic region in the Highland Group of rocks.

The exact source is unknown, but field evidence suggests that the locality may be somewhere between Pelmadulla and Kahawatta in the Ratnapura District. During a recent visit the author also examined one colourless olivine said to be found in the same area.

Conclusion

Peridot is not a new gemstone found in Sir Lanka. It is probable that most green sinhalites and/or diopsides found in this locality may be peridots. A careful refractive index determination would distinguish peridot from other confusing species.

Acknowledgement

The author would like to thank Dr Henry A. Hänni, of Basel University, Switzerland, for the microprobe and spectrum analysis and his valuable contributions to the original manuscript.

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[*Manuscript received 30th October, 1984.*]

EXCEPTIO CONFIRMAT REGULUM

By A.E. FARN, F.G.A.

The Laboratory, which celebrates its sixtieth anniversary in 1985, has changed its title. The first described the Laboratory's trade orientation. It was 'The Laboratory of the Diamond, Pearl and Precious Stone Trade Section of the London Chamber of Commerce'. Nearly fifty years later it took a fresh title; this was 'The Gem Testing Laboratory of the London Chamber of Commerce and Industry'. This succinct title lacked the import of the words, Diamond, Pearl, Precious Stones, and Trade. Succinct or not, the Laboratory continued to serve the trade then and now. Its earlier and original members comprised merchants, based chiefly in Hatton Garden with a few in the West End. It is a CIBJO recognized laboratory for the whole of Great Britain. Part of the work of the Director of the Laboratory is to assist in trade matters, particularly with nomenclature, thus maintaining trade and gemmological importance in this capacity with CIBJO. Its third (current) title is 'The British Gem Testing Laboratory'; its functions remain the same as before.

As gemmologists and readers of this *Journal* will appreciate, laboratory problems increase with the 'improvement' of methods of manufacture of synthetic stones and the activities in the bio-mineralization field. In particular large non-nucleated cultured pearls from marine oysters are presently proving troublesome. It must not be forgotten, however, that the original establishment was solely a pearl testing station, set up by a coterie of pearl merchants to combat the threat to the pearl trade by the Japanese spherical cultured pearl. Pearls came before gem testing. Time was available for research in the field of gemmology due to the world trade slump of the late twenties and early thirties of this century. In the pearl world, because of the cultured pearl, the late B.W. Anderson was recruited to find methods to detect them. The gemmological world was fortunate that Anderson could also devote time to the science of gemmology.

One of the most powerful weapons in pearl and gemstone testing is the use of x-rays. The purpose built, 'one-off', x-ray generating set in present use was designed by C.G. Osment, a radiological engineer working in close consultation with B. W.

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Anderson. The set not only affords negative radiographs and lauegrams, but has a built-in viewing chamber. Here can be observed the fluorescence and/or phosphorescence under x-ray excitation of pearls, cultured pearls and other gem materials. The set can record on negative film the degree of transparency or opacity to x-rays that substances may possess.

The well-known transparency of diamonds to x-rays is often seen when a pearl mounted with diamonds is photographed. The diamonds appear as blank spaces, or 'holes', in the precious metal mount, and the pearls being much less transparent show their evanescent structures. C.A. Doelter advocated in 1894 (one year after Röntgen had discovered x-rays) that radiography be used in gem testing, particularly in the case of diamonds. A little later, Dr Herbert Smith produced his portable refractometer in 1905. Had not Dr H. Smith devised his instrument we might well have progressed and become versatile in transparency tests by controlled exposures of gemstones to x-rays. One could say that testing pearls and inadvertently gems as well by x-rays has been a 'revelation'! It was not, however, the primary purpose of this preliminary approach by way of titles or functions of the Laboratory to labour the importance of pearls and pearl testing! Neither was it to accentuate how much gemmology owes to the culturing of pearls. It was in fact to draw attention and interest to some laboratory activities or functions other than just gem testing.

Requests for help and information come from police forensic departments, Customs and Excise (but not the Inland Revenue), local authorities' weights and measures departments, and, of course, the 'media'. In trade enquiries nomenclature features strongly. Work with the G.A., N.A.G. and Coloured Stone Section of the British Jewellery and Giftware Federation helped considerably in the production of the famous C.I.B.J.O. 'Blue Book', and of course help was given to their other publication, 'Rules of Application for the Diamond Trade'.

Despite these efforts to tidy up nomenclature, 'hardy annuals' still put in an appearance. In earlier days we battled against such misuses as 'topaz quartz', where the adjective 'topaz' (for colour) was used to describe the noun 'quartz'. This has now disappeared, but the somewhat hardier 'semi-precious' occasionally surfaces. An obvious illogicality, one wonders how to define half-precious? Yet we know what is meant or implied by the term!

Another 'semi' met with in gemmological contexts is the word 'semi-conductor'. In electronics this is a near insulator. Semi-conductors using germanium, silicon, selenium and silicon carbide are used in thermistors, rectifiers and photo-cells.

In other vein the Laboratory may be asked to advise or to carry out research on the effects certain adhesives have on soft, porous or organic gem materials. Answers are sometimes requested to such questions as 'Why have pearls darkened?', 'Why has a signet ring left a black mark on the wearer's finger?', or even the suitability of a title to a book! Basically, though, the Laboratory's role is gem testing.

Nomenclature must be the order of the day, i.e. the correct naming of stones and materials. Whilst we may regret the passing of a useful or pleasant sounding name, it is better in gemmology to be precise than poetic.

B.W. Anderson, as Director of the Laboratory, was a man dedicated to the correct use of words. In the earlier days of the Laboratory, pen carbon copies of written reports of texts were kept as permanent records. They contained extra details noted of cut, colour, characteristics, inclusions, fluorescence and phosphorescence (these were not on the customer's copy). B.W. Anderson read all of them as part of his administrative duty. All of us benefited by his observations on our descriptions and use of words.

I came across some notes of a talk he gave to his Post-Diploma class many years ago. It was on the subject of jade and jade-like materials, which in their turn had appeared at the Laboratory to be checked hopefully as jade.

The talk he gave was prefaced by a delightful dissertation upon the correct naming of stones; it ran as follows: 'In gemmology we seek so far as is possible to use as names for gemstones only those which can properly be applied to one stone only. In pursuance of this ideal we have had to abandon some attractive and long established names: e.g. 'chrysolite' ('golden stone') was as one time used for topaz, but now means peridot in America and chrysoberyl in England. Therefore it is ambiguous and should be avoided. Olivine is the name for peridot in British mineralogy, but was used so extensively for the green garnet that we find it better to use the terms peridot and demantoid and avoid olivine altogether. Jacinth (for orange zircon or garnet), although a beautiful word and an

ancient name, is also best avoided. One name which covers two distinct minerals, however, we cannot easily avoid using, because of its prestige and unusual appeal. That word is Jade . . .'

Then followed a typically well researched lecture upon the jade-like materials as well as those two fascinating materials nephrite jade and jadeite jade. These two, which have different chemical formulae, and which are two distinct minerals, managed to escape the stringency of nomenclature requirements by worthily exemplifying the maxim 'exceptio confirmat regulum', or, as we might say in English, by being the exceptions that prove the rule.

[*Manuscript received 31st October, 1984.*]

AQUAMARINE FROM MT SURPRISE, QUEENSLAND, AUSTRALIA

By GRAHAME BROWN, F.G.A.A., F.G.A., Dip.D.T., Dip.G.R., F.C.Gm.A.

Gem quality aquamarine is being commercially mined from the Mt Surprise gemfield, of Northern Queensland, Australia. The Mt Surprise gemfield is located (Map 1) 46 km to the ENE. of the small township of Mt Surprise.

The potential that this gemfield possesses, for yielding aquamarine, was first recorded in 1931 by Dunstan.[1] In his *Queensland Mineral Index & Guide*, Dunstan noted:

AQUAMARINE

'300 – Loc. Quartz Hill, on Elizabeth Cr, br of Einasleigh R., Almaden – Georgetown Rd., 130 miles S.W. of Cairns. Co. Tate (ante) Ref B.D.'

The small scale commercial mining operation, that currently yields blue aquamarines, remarkably free from greenish or yellowish overtones, is located near O'Briens Creek. O'Briens Creek is a tributary of Elizabeth Creek, a larger stream that joins the westerly flowing Einasleigh River, which ultimately flows into the Gulf of Carpentaria.

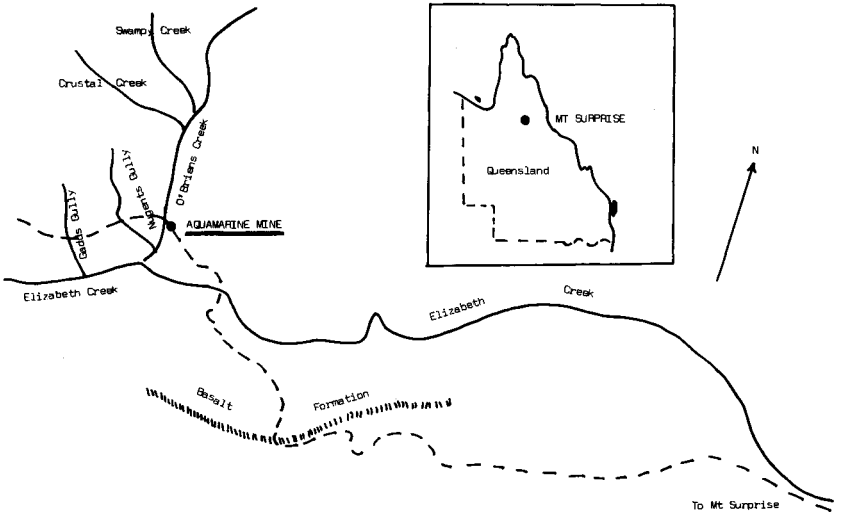

MAP 1. Location of the O'Briens Creek aquamarine mine in the Mt Surprise gemfield of Northern Queensland.

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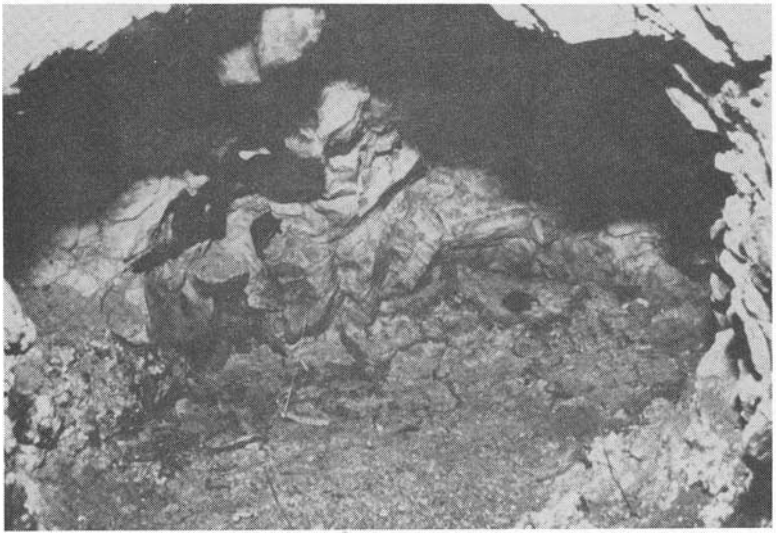

FIG. 1. An aquamarine-bearing vugh (approximately 1 m wide × 0.75m high) in the Elizabeth Creek Granite at O'Briens Creek.

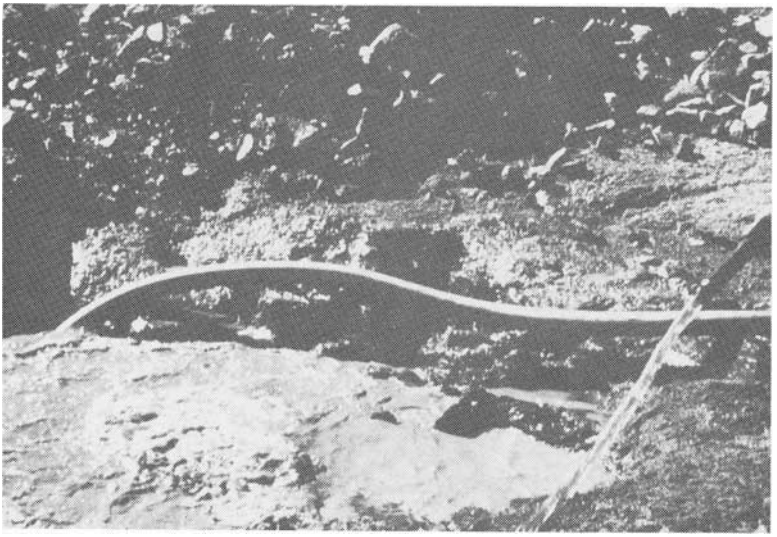

FIG. 2. Hydraulic mining for aquamarine-bearing vughs in the granite at O'Briens Creek. Note (lower right) the 4 cm diameter flexible pipe that was used to create muddy puddles above depressions in the granite surface.

Australian gemmologists should be well aware that the Mt Surprise gemfield is already known as a prolific source of gem-quality colourless, blue, and yellowish topaz.[2]

At the mine site, the aquamarine is found in vughs (Figure 1) in the Elizabeth Creek Granite,[3] which underlies the O'Briens Creek alluvials. To reach the aquamarine-bearing vughs, the overburden of soil, gravel, and small boulders must be completely removed from the underlying granite. This removal is accomplished by using a simple combination of mechanical and hydraulic mining techniques. Initially, light earth-moving equipment is used to remove the gross overburden. Once the granite surface has been roughly exposed, the residual overburden is removed by a simple and inexpensive form of hydraulic mining (Figure 2).

Water from O'Briens Creek is pumped, under pressure, on the surface of the granite, to create muddy puddles above depressions in the granite surface. The contents of these muddy puddles are then evacuated by means of a venturi (vacuum suction) system. Systematic repetition of this puddle creating – puddle evacuating mining cycle rapidly and inexpensively exposes the surface of the granite for inspection by the 2-3 man team that conducts this aquamarine mining operation (Figure 3).

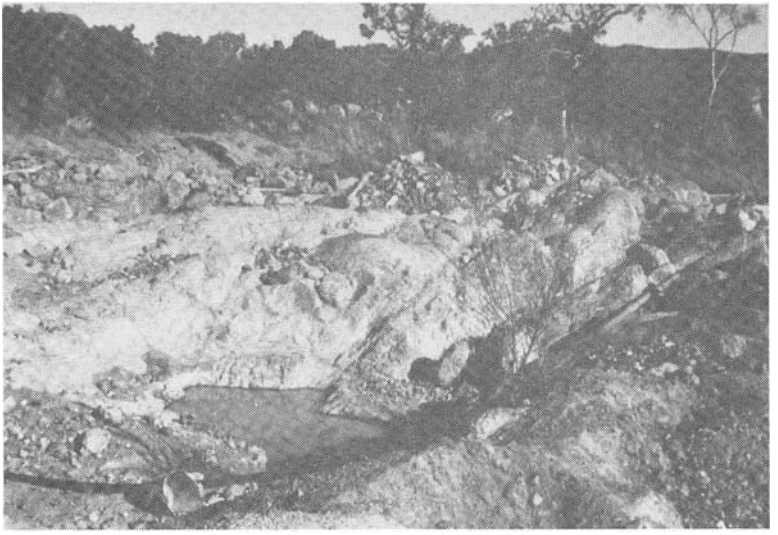

FIG. 3. A worked out portion of the aquamarine mine at O'Briens Creek, Northern Queensland.

If, and when, a vugh is located in the granite surface, its contents are carefully removed by hand and examined in detail for tell-tale evidence of either common beryl (an indicator mineral), or more hopefully aquamarine. Once each vugh has been completely evacuated, its walls are then systematically examined for the presence of any aquamarine crystals that may be attached to the walls of the vugh. Any crystals of aquamarine that are discovered, are carefully removed by hand and bagged for later sorting.

As only one or two aquamarine-producing vughs are usually located per year, the owner of this mine on O'Briens Creek has little difficulty marketing his production either as fine quality aquamarine crystal specimens or else as gem-quality aquamarine faceting rough.

Gemmological Investigations

In order that the gemmology of the aquamarine from O'Briens Creek, in the Mt Surprise gemfield, could be described, the owner of the mine supplied the author with a representative sample of the mine production.

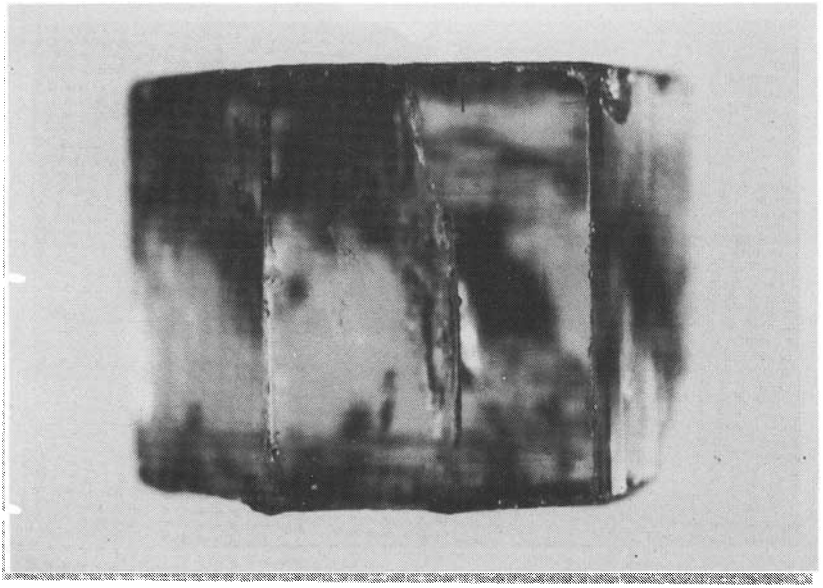

FIG. 4. A euhedral gem quality aquamarine crystal from O'Briens Creek. This crystal measures 30mm × 21mm.

After the specimens were sorted for quality and examined macroscopically, selected specimens were either faceted, or else had inspection facets placed on them. These faceting procedures allowed the selected aquamarines to be critically examined for internal inclusions. Finally, conventional gemmological physical and optical properties were determined for carefully selected specimens of gem-quality aquamarine.

The results of this investigation were then compared with the results of previous investigations into the gemmology of aquamarine from other world-wide localities.

Macroscopic Features

Aquamarine recovered from the O'Briens Creek mine occurred as:

* Well-formed crystals of gem-quality (Figure 4);
* Secondarily resorbed gem-quality crystals (Figure 5);
* Gem-quality crystal fragments;
* Crystals of non-gem quality; and
* Fragments of crystals of non-gem quality (Figure 6).

The euhedral crystals from this mine displayed a simple stoutish prismatic habit, with the hexagonal prism and the basal pinacoid forms predominating (Figure 4). Prism/pinacoid edges were occasionally truncated by small pyramidal forms.

Although 1 to 3ct aquamarines are commonly faceted from the available gem-quality rough, larger sized stones are occasionally obtainable.

Colours of the aquamarine from this mine tended to vary in hue from almost colourless to a medium to deep sky-blue colour. These bluish hues are naturally occurring; so no heat treatment[4] is required to colour-improve the O'Briens Creek aquamarines for the market place.

One rather surprising observation that was made concerning the intensity of the bluish hue displayed by these aquamarines was that both the specific gravity and the refractive index of the O'Briens Creek aquamarine increased with the increasing depth of blue colour.

The mean values reproduced below give some indication of this relationship.

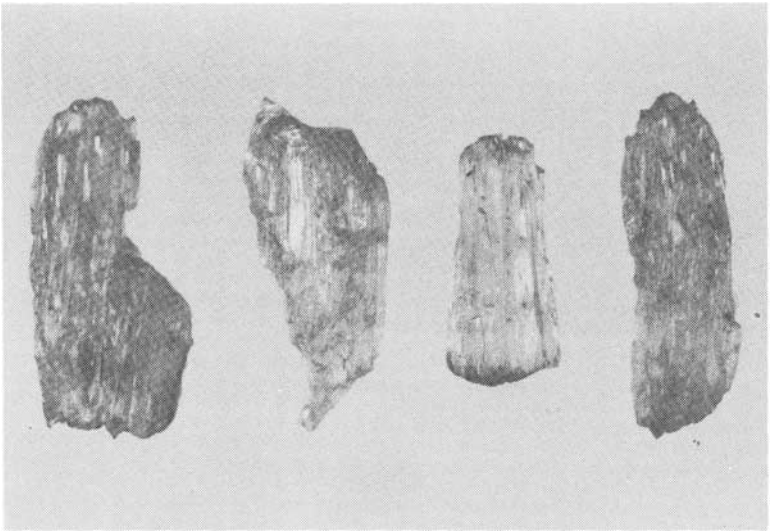

FIG. 5. Secondarily etched gem-quality aquamarine crystals from O'Briens Creek. These crystals average 25 to 30mm in length.

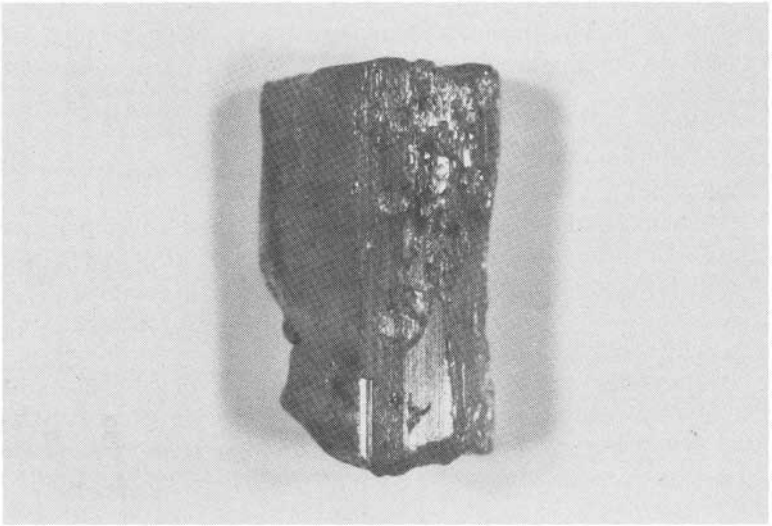

FIG. 6. A large fragment of non gem-quality aquamarine from O'Briens Creek.

	Light blue Aquamarine	Dark blue Aquamarine
Specific gravity	2.68	2.70
Refractive indices	ω 1.567 ε 1.562	ω 1.571 ε 1.566

Gemmological Properties

A detailed examination of the gemmological properties of these aquamarines from the Mt Surprise gemfield revealed no data of great significance as the O'Briens Creek aquamarine displayed physical and optical properties that were almost identical to those of other aquamarines from world-wide localities (see Table 1).

One slight difference in properties was nevertheless noted. Both the refractive index and the specific gravity of the O'Briens Creek aquamarine were located at the lower end of the recognized

TABLE 1. Gemmological properties of aquamarine from O'Briens Creek, compared with the gemmological properties for aquamarine cited by Arem.[6]

	O'Briens Creek Aquamarine	Aquamarine data from Arem[6]
SPECIFIC GRAVITY	2.7	2.68 – 2.80
DIAPHANEITY	Transparent	Transparent
LUSTRE	Vitreous	Vitreous
REFRACTIVE INDEX	ω 1.571 ε 1.566	ω 1.572/90 ε 1.567/8
BIREFRINGENCE	0.005	0.005 to 0.007
OPTIC SIGN	Uniaxial negative	Uniaxial negative
PLEOCHROISM	ω Pale yellowish green ε Blue	ω Colourless ε Blue
CHELSEA FILTER	Distinct green	Distinct green
LUMINESCENCE (UV)	Inert	Inert
ABSORPTION SPECTRUM	Not diagnostic	Not diagnostic

beryl range. Such an observation suggests[5] that the O'Briens Creek aquamarine may not be very rich in either water or alkaline earth elements.

Microscopic Features

To the gemmologist, the most interesting and rewarding feature of the O'Briens Creek aquamarine is the range and diversity of its microscopic inclusions. As most of the gem-quality aquamarine from this mine is at least eye-clean the beautiful patterns of typical beryl inclusions displayed by the O'Briens Creek aquamarine must be observed in included specimens at moderate magnifications. For this investigation, inclusions were recorded on a gemmological microscope, using transmitted light with magnifications that varied from ×20 to ×50.

Common inclusions noted during this microscopic investigation included the typical beryl tube-like inclusions ('tubes') (Figure 7), oriented parallel to the *c*-axis of the aquamarine combined with randomly oriented partly-healed internal fractures that are generally described as either 'feathers', 'veils' or 'fingerprints'.

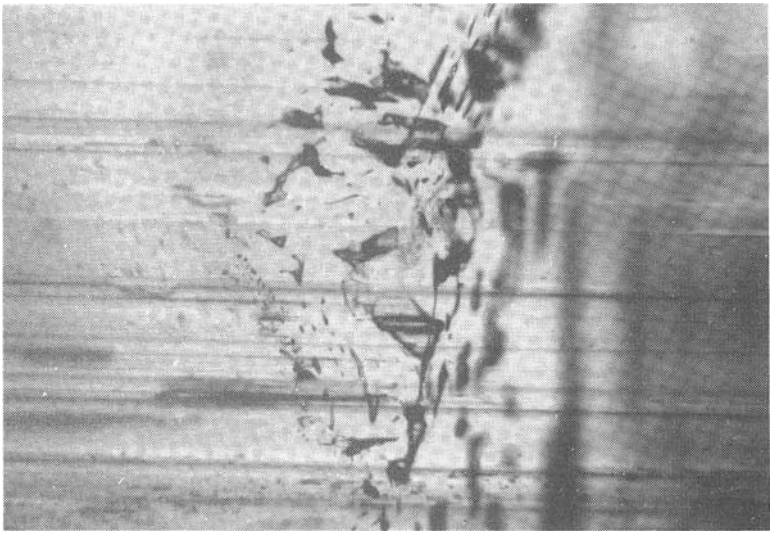

FIG. 7. Photomicrograph of the typical beryl inclusions commonly observed in the aquamarine from O'Briens Creek.
Note: 'tubes' running across the width of the illustration while randomly oriented 'veils' are seen approximately at right angles to the 'tubes'. (×25 magnification).

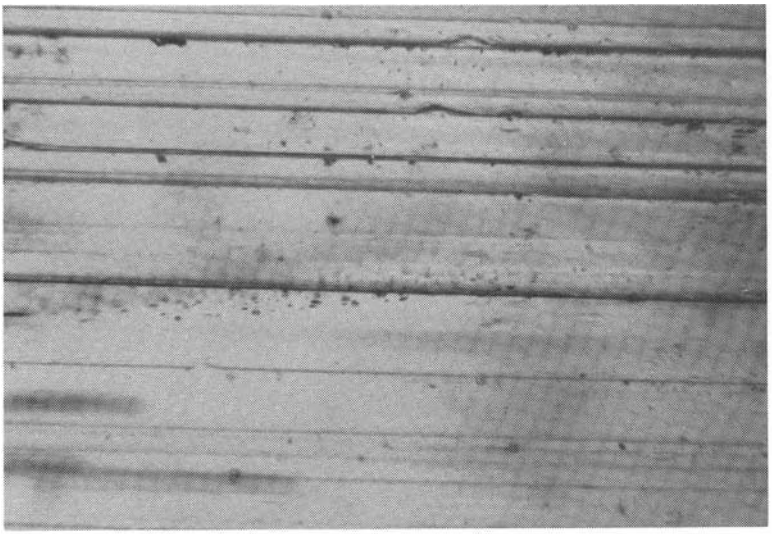

A

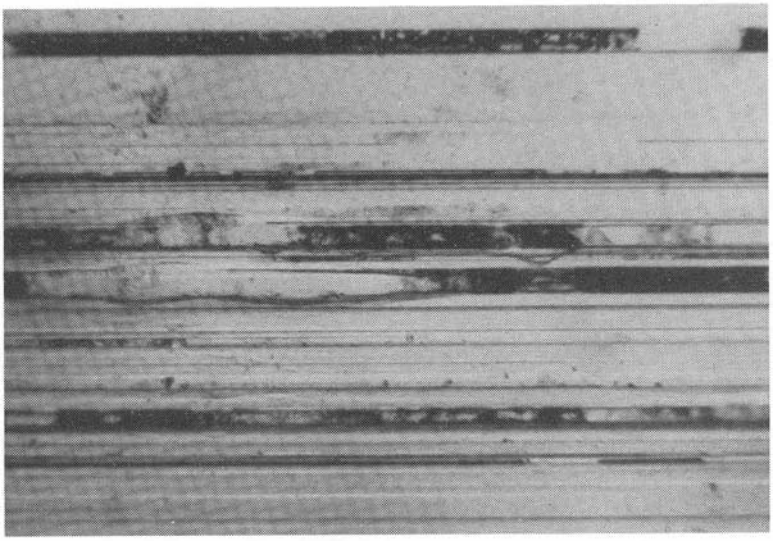

B

FIG. 8. Photomicrographs of aquamarine from O'Briens Creek, showing:
(A) Empty 'tubes' oriented parallel to the *c*-axis of the crystal
(B) 'Tubes' partly filled with epigenetic mineral 'stains'. (×25 magnification).

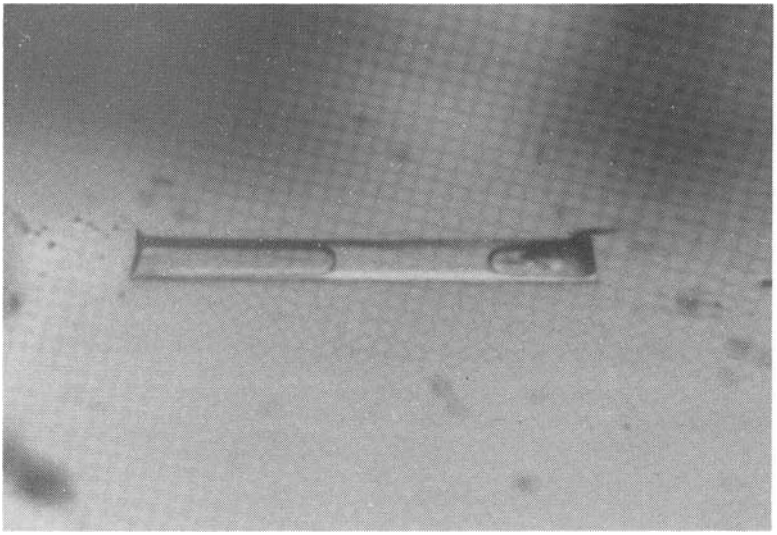

FIG. 9. Photomicrograph of a short two-phase 'tube' segment; such inclusions are responsible for the appearance of 'rain' in aquamarine from O'Briens Creek. (×50 magnification).

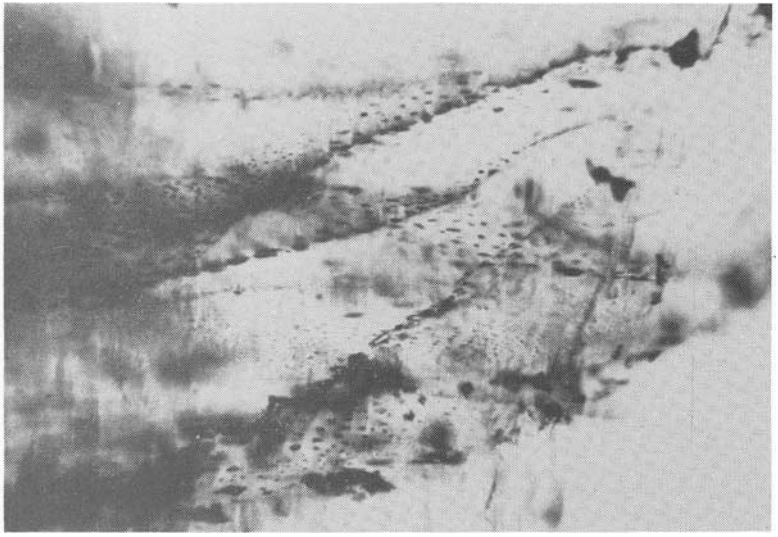

FIG. 10. Photomicrograph of a partly healed internal fracture ('feather', 'veil', or 'fingerprint') found in an aquamarine from O'Briens Creek. (×25 magnification).

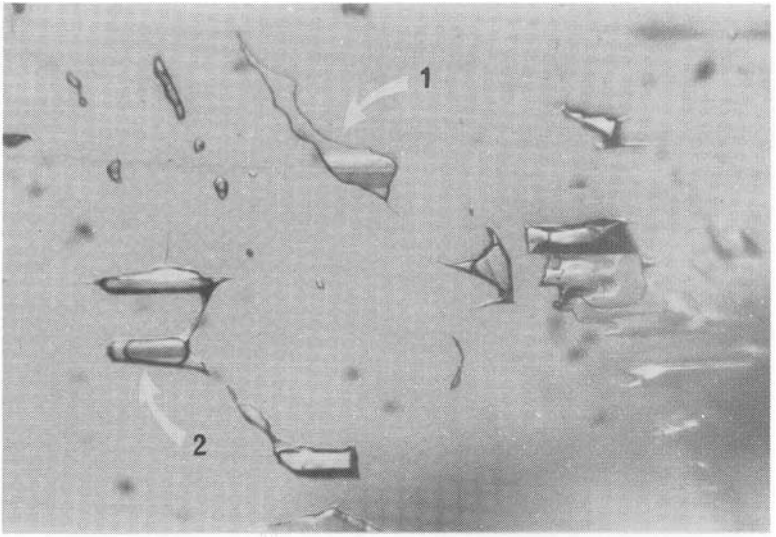

A

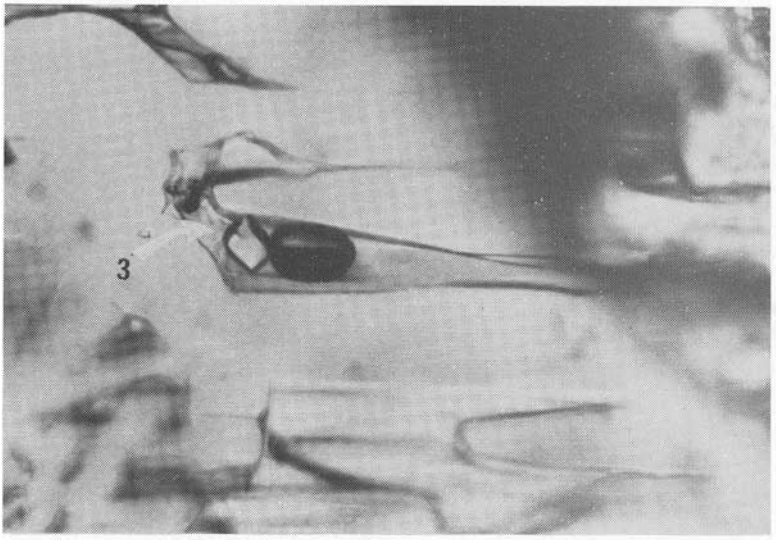

B

FIG. 11. Photomicrographs of the contents of 'veils' in aquamarines from O'Brien's Creek showing:
(A) a single phase inclusion (arrowed 1), and a two-phase inclusion (arrowed 2).
(B) a three-phase inclusion (arrowed 3). (×50 magnification).

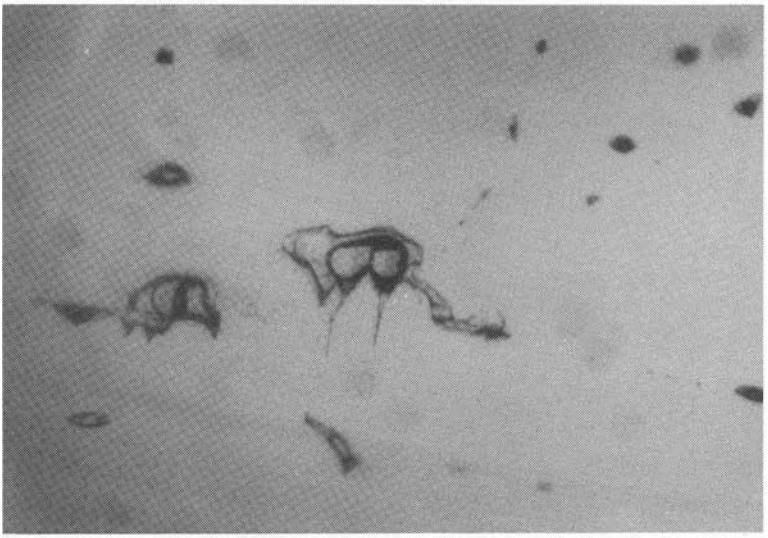

A

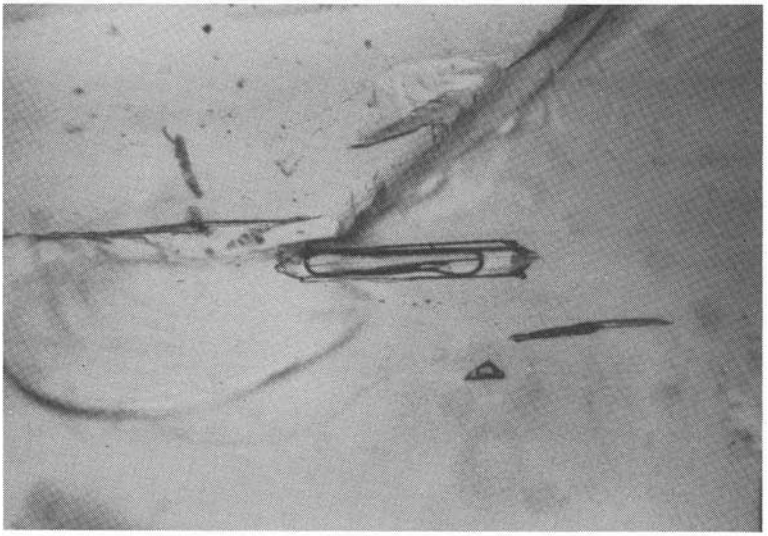

B

FIG. 12. Photomicrographs of aesthetically pleasing 'liquid' inclusions noted in the aquamarine from O'Briens Creek.
(A) Inclusions from a 'veil.'
(B) Inclusions in 'tubes.'
(×50 magnification).

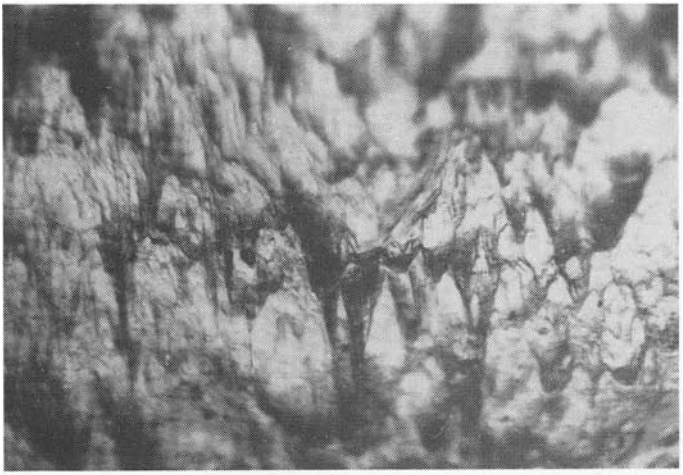

A

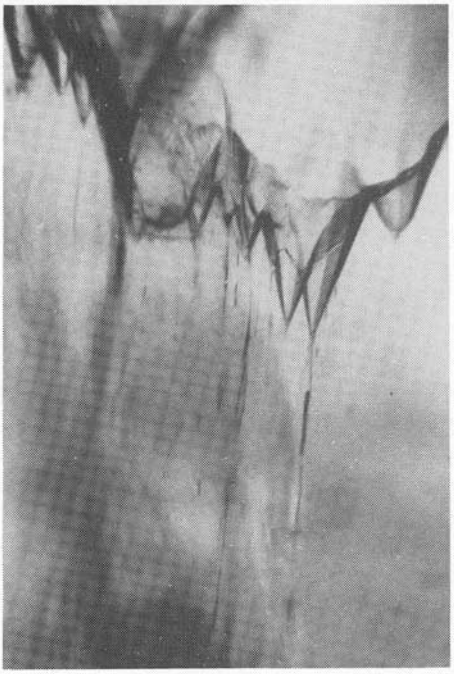

B

FIG. 13. (A) Photograph of the etch hillocks on the basal pinacoid of a secondarily etched aquamarine crystal from O'Briens Creek. (×15 magnification)
(B) Photomicrograph of the genetic relationship between 'tubes' (parallel to the *c*-axis) and etch pits (in the basal pinacoid) of an aquamarine crystal from O'Briens Creek. (×20 magnification).

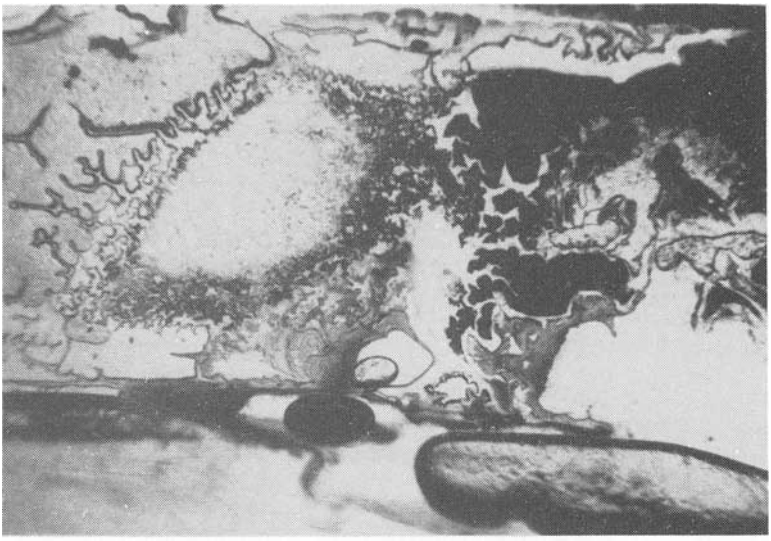

FIG. 14. Photomicrograph of an aesthetically pleasing iron-rich mineral ingrowth in an aquamarine from O'Briens Creek. (×25 magnification).

It was additionally noted that the 'tubes' occasionally appeared to be empty (Figure 8A); but they were also observed to contain epigenetic mineral 'stains' (Figure 8B), or else two-phase (most likely liquid-gas) cavity fillings. Occasionally, these 'tubes' occur as shorter, two-phase segments (Figure 9). It is the frequent occurrence of these shorter 'tubes' that have been rather loosely termed 'rain'.[7]

'Feathers', 'fingerprints' or 'veils' (Figure 10) are the inclusions most frequently observed in O'Briens Creek aquamarine. As is well known, these inclusions are in fact partly healed, randomly oriented, conchoidal fractures which developed within the still growing crystal. Subsequent to their formation, these cracks have been partly repaired by infiltration and deposition from the growth solution that surrounded the growing crystal. In the aquamarine from O'Briens Creek, the cavity fillings in the partly healed internal fractures may be either single phase (liquid, gas, or solid), two-phase (liquid and gas) (Figure 11A), or three-phase (liquid, gas and solid) (Figure 11B).

A close examination of the morphology of the 'tubes' and the 'veils', found in the O'Briens Creek aquamarine, is to be strongly recommended. At the moderate magnifications obtainable with the

gemmological microscope, a great variety of aesthetically pleasing forms will be revealed to the interested observer (Figures 12A, 12B refer).

Another interesting observation made during this microscopic phase of the investigation, concerned the relationship between the etch hillocks, located on the basal pinacoidal faces of the secondarily etched aquamarine crystals (Figure 13A), and the tube-like inclusions that appeared to be genetically related to the apices of these etch pits (Figure 13B). Figures 13A and 13B would seem to indicate that preferential etching does occur in those areas of a growing crystal that can be considered to be structurally weak. In the etched specimens examined, maximum etching seemed to occur when the tube-like inclusions penetrated the basal pinacoidal faces of the crystals. This observation is in accordance with the researches of Roedder.[8]

Although of little gemmological significance, highly coloured ingrowths of iron oxide (?) minerals were frequently associated with some of these etch-induced defects. While aesthetically pleasing (Figure 14), these inclusions would inevitably be removed during faceting; so they are of little practical significance in gem identification.

Conclusion

The O'Briens Creek aquamarine deposit, in the Mt Surprise gemfield of Northern Queensland, yields attractive gem-quality blue aquamarine, that does not require colour improvement by heat treatment. Although the gemmological properties of this aquamarine are not unique, this aquamarine does possess a suite of beryl inclusions that are aesthetically pleasing, and require more detailed investigation.

Acknowledgements

The author wishes to thank the following who have assisted him with this project:
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Provision of photographs and information: H. & H. Bracewell.
Preparation of specimens: R. & S. Kelly.

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[*Manuscript received 25th January 1985.*]

GEMMOLOGICAL ABSTRACTS

AINES (R.D.), KIRBY (S.H.), ROSSMAN (G.R.) *Hydrogen speciation in synthetic quartz*. Physics and Chemistry of Minerals, **11**, 5, 204-12, 9 figs, 1984.

The dominant hydrogen impurity in synthetic quartz is molecular H_2O. H-OH groups are also found. Molecular H_2O concentrations in synthetic quartz crystals studied range from less than 10 to 3300 ppm and decrease smoothly by up to an order of magnitude with distance from the seed. Observed OH^- is probably associated with cationic impurities as in natural quartz. M.O'D.

BAILLARGEAT (C.) *La Granatenkogl.* (The Granatenkogl.) Monde et Minéraux, 68, 16-18, 5 figs (2 in colour), 1985.

The Granatenkogl is in the Tyrolean Alps of Austria and can be reached from the winter resort of Obergurgl. Crystals of pyrope-almandine garnet up to 5cm in size have been found; they show rhombic dodecahedral and icositetrahedral forms with combinations of the two. M.O'D.

BANK (H.). *In memoriam Basil William Anderson*. Z.Dt.Gemmol.Ges., **34**, 1/2, 3-5, 1 fig, 1985.

Obituary, mentioning that Basil Anderson was made an honorary member of the Deutschen Gemmologischen Gesellschaft. E.S.

BANK (H.) *Farblose Cordierite und Cordierit-Katzenaugen aus Sri Lanka.* (Colourless iolites (cordierites) and iolite cat's-eyes from Sri Lanka.) Z.Dt.Gemmol.Ges., **34**, 1/2, 79-80, bibl., 1985.

The iolite cat's-eyes were cut from a grey-colourless piece of rough material, the cat's-eye effect being caused by its fibrous nature: RIs $n_x = 1.530$, $n_y = 1.534$, $n_z = 1.539$, DR 0.009, SG 2.58. The colourless transparent cut iolites showed RIs of $n_x = 1.527$, $n_y = 1.532$, $n_z = 1.536$, DR 0.009, SG 2.55. These seem to be the lowest recorded RIs for iolites. The specimens also have a very low Fe content. E.S.

BRACEWELL (H.), BROWN (G.). *Amazonite from the Koppio district – South Australia.* Aust.Gemmol., **15**, 11, 404-8, 10 figs (6 in colour), 1985.

An account of the Baila Hill deposit on Eyre Peninsula, visited by Bracewell in 1982, which yields a mostly bluish-green amazonite variegated by albite intergrowth, and largely ruined by blast mining methods. R.K.M.

BROWN (G.). *The colours of fluorite*. Wahroongai News, **19**, 4, 18-22, 1985.

Explanations, culled from various sources, of the causes of colour in this material, which has possibly the widest colour range of any mineral. Atomic gap locations entrapping electrons, oxygen atoms which have lost electrons due to natural irradiation, or even the inclusion of stray atoms of yttrium or of samarium are said to be responsible for the different colours. R.K.M.

BROWN (G.). *The abalone and its pearls*. Aust.Gemmol., **15**, 11, 400-3, 1985.

A general account which establishes that such pearls are rare, usually very baroque, and hollow. Illustrated by a tooth-shaped pearl which was compared with sharks' teeth. R.K.M.

BROWN (G.). *Identifying Gilson's polycrystalline lapidary materials*. Aust.Gemmol., **15**, 11, 413-17, 3 figs, 1985.

Gilson turquoise, lapis and coral examined and identified by a number of physical and visual features. R.K.M.

BROWN (G.). *Seiko Synthetics*. Aust.Gemmol., **15**, 11, 418-20, 2 figs, 1985.

Account based on technical information from Suwa Seikosha Co. Japan. Emeralds grown by flux growth; corundum, chrysoberyl, including alexandrite, by floating-zone growth. Floating-zone gives synthetics a swirled colour distribution and irregular flow lines. Seiko rubies display 'rectilinear parting and their padparadscha corundums and alexandrites glow strongly red under LWUV, whereas most natural stones of these species are inert. Flux grown Seiko emeralds fluoresce green in UV light and most stones have RI and SG values within the range expected for flux material. In all cases the microscope will provide the principal clue to their nature. R.K.M.

CASSEDANNE (J.). *Andalousite et scapolite de Espirito Santo (Brésil)*. (Andalusite and scapolite from Espirito Santo, Brazil.) Revue de Gemmologie, 82, 21-5, 11 figs (8 in colour), 1985.

Andalusite is found at Santa Teresa, a small town about 50km north-west of the state capital, Vitória. The site is also known as Serra do Prego. Prismatic crystals are found in gravels and weigh from 2 to 8g. The colour is a yellowish-pink with a green inclining to olive. Scapolite is found at Aracruz and is recovered from a pegmatite. The stones are honey- or caramel-coloured. M.O'D.

COHEN (A.J.), MAKAR (L.N.). *Differing effects of ionizing radiation in massive and single crystal rose quartz*. Neues Jahrbuch für Mineralogie, **11**, 513-21, 3 figs, 1984.

X-irradiation of single crystals of rose quartz intensifies the absorption band due to interstitial Ti^{3+} and gives a deeper rose colour. Massive rose quartz treated in the same way gives three absorption bands related to Al^{3+} trapped-hole impurity colour centres. These grow so intense with increase of irradiation that the specimen turns black. Massive rose quartz has a higher Al^{3+} and alkali (Na^{+} + Li^{+}) content than single crystals. M.O'D.

CURRIER (R.H.). *Natural fading of amethyst*, (letter). Gems Gemol., **XXI**, 2, 115-16, 1 fig. in colour, 1985.

One half of an amethyst crystal group from Rio Grande do Sul, Brazil, kept in dark for three years, retained its colour, the other half, exposed to Californian sun for the same length of time, faded badly. R.K.M.

DIRLAM (D.M.), MISIOROWSKI (E.B.), THOMAS (S.A.). *Pearl fashion through the ages*. Gems Gemol., **XXI**, 2, 63-78, 15 figs (13 in colour), 1985.

A concise review of the use of pearls in jewellery from classical times to the present day. Nicely illustrated. R.K.M.

DREES (B.). *Mineraliensammeln in Australien*. (Mineral locations in Australia.) Lapis, **10**, 6, 13-21, 14 figs (10 in colour), 1985.

Among the species described are sapphire, agate, opal and malachite. M.O'D.

FALLICK (A.E.), JOCELYN (J.), DONNELLY (T.), GUY (M.), BEHAN (C.). *Origin of agates in volcanic rocks from Scotland*. Nature, **313**, 6004, 672-4, 2 figs, 1985.

Isotope ratios are given ($^{18}O/^{16}O$ of silica and D/H of bound water) for agates from Lower Devonian lavas. These differ from those in Tertiary lavas. Data imply that the bound waters associated with the agates have preserved their hydrogen isotope ratios since agate deposition and, as a consequence, that the water content is of genetic significance. The inference is that agates of both ages were formed at low temperature (around 50°C) from fluids with at least a component of meteoric origin. M.O'D.

FRYER (C.W.), ed., CROWNINGSHIELD (R.), HURWIT (K.N.), KANE (R.E.). *Gem Trade Lab Notes*. Gems Gemol., **XXI**, 2, 108-14, 21 figs (19 in colour), 1 table, 1985.

Amber found with metallic sulphide inclusions; amethyst with crystal (natural?) and 'breadcrumb' (synthetic?) inclusions could not be allocated to either category with certainty; five diamonds break in cutting – why?; blue diamond with colour banding conducted electricity more readily along colour zones; a carved fluorite mistaken for amethyst was badly etched by sulphuric acid 'pickle'. Rare cat's-eye hexagonites were examined; a Gilson synthetic opal had outer edges of colourless plastic; a yellow-green Mexican opal, with a marked flow structure and with traces of radioactivity, fluoresced brightly in UV light. Fancy coloured pearls from China were shown to be of tissue-nucleated, cultured, freshwater origin; metal-cored, plastic imitation pearls were found; a dark red-grey quartz cat's-eye also described. A diffusion-asteriated sapphire lost part of its surface star on repolishing; an unusual dark green scapolite cat's-eye is described; a large paste 'pink topaz' had veils of bubbles looking like 'finger-print' inclusions; three small translucent zircons, reputedly from Sri Lanka, had well-developed cat's-eyes, and strong absorption spectra. All are illustrated. R.K.M.

FRYER (C.W.), KOIVULA (J.I.). *The eyepiece pointer: a useful microscope accessory*. Gems Gemol., **XXI**, 2, 105-7, 3 figs (2 in colour), 1985.

Describes a simple device which can easily be built into a microscope eyepiece to

provide a pointer to a specific feature in a stone. The specimen needs to be adjusted to coincide with the pointer which is not itself movable. R.K.M.

FUMEY (P.). *Le pipe d'Argyle.* (The Argyle pipe.) Revue de Gemmologie, 82, 18-20, 5 figs, 1985.

The newly-discovered Argyle diamond pipe in Western Australia is described. M.O'D.

GÜBELIN (E.J.). *Le identificación de los nuevos rubíes sintéticos.* (Identification of the new synthetic rubies.) Gemologia, **21**, 63/64, 5-27, 42 figs (41 in colour), 1984.

An English version of this article was published in *J.Gemm.*, 1983, **XVIII**, 6, 477-99. E.S.

GÜBELIN, (E.). *Identification des nouveaux saphirs synthetiques et des saphirs traites.* (Identification of new synthetic sapphires and of treated sapphires.) Revue de Gemmologie, 82, 9-14, 31 figs (27 in colour); 83, 11-13, 17 figs in colour; 1985.

An article in two parts describing blue and yellow synthetic and treated sapphires with illustrations of characteristic inclusions and immersion phenomena. M.O'D.

GÜBELIN (E.). *Properties of ornamental stones and their gemmological identification.* Aust. Gemmol., **15**, 10, 334-87, 1985.

This important compilation of facts first appeared in Z.Dt.Gemmol.Ges., 30 (1981) and was abstracted by Mrs E. Stern (*J. Gemm.*, **XVIII**, 1, 79) to whom I am indebted for checking this English version against the original German script. A few items have been added and there has been some rearrangement under the heading of cryptocrystalline quartzes. A valuable paper comprising the whole of this issue of the magazine. R.K.M.

HENN (U.) *Eudialyt aus Kanada.* (Eudialite from Canada.) Z.Dt.Gemmol.Ges., **34**, 1/2, 76-8, 1 graph, 1 table, bibl., 1985.

The gem quality eudialite is found in a new locality in Kippaw in Quebec. The transparent crystals were pinkish red, the colour caused by manganese. The high zirconium content might lead to a new source of zirconium. RI varied between 1.600-1.601 and 1.596-1.597, DR 0.004. A graph shows absorption spectrum and a table compares chemical composition of eudialites from Canada and Sweden. E.S.

HENN (U.). *Untersuchungen an Kornerupin und Sinhalit von Elahera, Sri Lanka.* (Examination of kornerupine and sinhalite from Elahera, Sri Lanka.) Z.Dt.Gemmol.Ges., **34**, 1/2, 13-19, 2 graphs, 2 tables, 6 photomicrographs, bibl., 1985.

The new occurrence lies in the Central Province, about 13km south-east of Elahera, yielding mainly garnets, also sapphires, spinels and tourmalines and additionally kornerupine and sinhalite. The kornerupines are bluish-green to greenish-brown crystals with a diameter of about 2cm; SG 3.34-3.36, RI 1.668-1.680, DR 0.012. They show characteristic inclusions for kornerupine from Sri Lanka. The sinhalite is olive green, RI 1.669-1.704, DR 0.035, SG 3.48-3.49; inclusions are liquid or two-phase and clouds of negative crystals. E.S.

HOCHLEITNER (R.) *Dendriten- und Landschaftsachate.* (Dendritic and landscape agate.) Lapis, **10**, 6, 27-9, 9 figs (8 in colour), 1985.

Fine examples of both types of agate are illustrated. M.O'D.

HOISCH (T.D.). *The solid solution chemistry of vesuvianite.* Contributions to mineralogy and petrology, **89**, 2/3, 204-14, 4 figs, 1985.

The solid solution in vesuvianite is examined, taking chemical trends and cation abundances in 22 microprobe analyses. Two structure refinements indicate 50 filled cation sites per formula. Site occupancies have been resolved by optical and Mossbauer studies and stoichiometric abundancies of Si and Ca + Na show 18 and 19 per formula, filling all 4- and 8-fold sites respectively. The four six-fold A sites are filled with Al. Solid solution mainly occurs within the eight 6-fold AlFe sites (Al, Mg, Fe^{2+}, Fe^{3+}, Ti) and one 5-fold B-site (Mg, Fe^{2+}, Fe^{3+}). Eight independent substitutions are known. M.O'D.

HORN (P.). *Moldavite-ihre Entstehung bei der Rieskatastrophe.* (Moldavites – their origin by cataclysm.) Lapis, **10**, 6, 22-6, 6 figs (3 in colour), 1985.

The moldavite area extending from east of Stuttgart to south-east Czechoslovakia is described with illustrations of some of the specimens found. M.O'D.

IACCONI (P.), CARUBA (R.). *Trapping and emission centres in x-irradiated natural zircon. Characterization by thermoluminescence.* Physics and Chemistry of Minerals, **11**, 5, 195-203, 8 figs, 1984.

The TL of natural zircon is characterised by two main peaks at 155± 4 and 378± 7 K. Three kinds of emission have been observed: a band from 400 to 380nm; a series of maxima at 760, 662, 580 and 480nm; and a band at 285nm; These are shown to be due to a host lattice mechanism, Dy^{3+} and OH^- groups respectively. M.O'D.

KANKA (A.). *Achate von Schweighausen im Schwarzwald.* (Agate from Schweighausen in the Black Forest.) Lapis, **10**, 5, 17-21, 8 figs in colour, 1985.

Fine quality agate is found in the Schweighausen area of the Black Forest, West Germany. Specimens are described and illustrated. M.O'D.

KOIVULA (J.I.), KELLER (P.C.). *Russian flux-grown synthetic emeralds.* Gems Gemol., **XXI**, 2, 79-85, 8 figs in colour, 2 tables, bibl., 1985.

A new synthetic using a lead vanadate flux and crucible rotation, this has much in common with other flux-grown synthetic emeralds. Low constants: RI 1.559-1.563, SG about 2.65. Inclusions typical of type: veil-like finger-prints, two-phase, and metallic platinum from the crucible. These stones contained a little MgO, not found in other flux-melt emeralds. Authors warn that changes in growth process, as in all synthetic methods, could affect gemmological testing properties. [Reaction under emerald filter not given, but with 0.2% of iron residual red may be suppressed.] R.K.M.

KOIVULA (J.I.), MISIOROWSKI (E.), eds. *Gem News.* Gems Gemol., **XXI**, 2, 118-20, 1985.

A new diamond area in Guinea contains six pipes and alluvial diggings, high gem-quality yield expected, production scheduled to begin in April this year.

Kimberley (S. Africa) diamonds, dated by radiation analysis of rare earths in contained garnets, are calculated to have formed 3.1 to 3.5 billion years ago. Yield of Australian Argyle diamond mines is falling as the alluvial deposits are depleted. In Canada two kimberlite pipes in British Columbia are to be explored. Australian gemmologists report 'exceptionally beautiful' diamonds discovered in mainland China. Despite some indications of possible kimberlite, a tiny diamond crystal found in a gold placer near Fairbanks, Alaska, is thought to have been transported from afar by geological agencies. R.K.M.

LORENZ (I.), SCHMETZER (K.). *Möglichkeiten und Grenzen der röntgenographischen Untersuchung von Perlen.* (Possibilities and limits in the x-ray investigation of pearls.) Z.Dt.Gemmol.Ges., **34**, 1/2, 57-68, 2 figs, 2 tables, bibl., 1985.

X-ray investigation of pearls uses either direct radiography, x-ray diffraction techniques or the luminescence under x-rays. The authors describe a diffraction camera which allows examination of diffraction patterns in exactly defined angles to each other. A single pearl from a necklace can be looked at by the addition of a special holder. Using all three techniques almost all pearls can be identified. Difficulties were found in distinguishing Keshi cultured pearls from natural sea water pearls, and also in differentiating a small part of non-nucleated cultured freshwater pearls from natural freshwater pearls. E.S.

MATTSON (S.M.), ROSSMAN (G.R.). *Ferric iron in tourmaline.* Physics and Chemistry of Minerals, **11**, 5, 225-34, 10 figs, 1984.

Red Fe^{3+}-rich and black Fe^{3+}, Fe^{2+}-rich tourmalines were examined by optical and Mossbauer spectroscopy, with a view to determining the optical characteristics of Fe^{3+} in tourmaline. Prominent optical absorption features at 485 and 540nm are assigned to transitions of multiple exchange-coupled Fe^{3+} pairs in several site combinations. M.O'D.

MEYER (H.O.A.). *Genesis of diamond: a mantle saga.* Am. Miner., **70**, 3/4, 344-55, 2 figs, 1985.

The author postulates that diamond growth was not always continuous and stones did not always grow in similar chemical environments. A model for diamond growth based on various properties is proposed, and it is suggested that some diamonds may be products of recycled subducted carbon, while others may have been formed by magmatic or metasomatic processes from primordial material. Most diamonds will probably have been formed in the Archaean or Proterozoic. Host rocks are grouped into eclogitic and ultramafic (peridotitic). M.O'D.

MOON (A.R.), PHILLIPS (M.R.) *Asterism – no mystery: A response to 'Asterism – the great enigma'.* Aust.Gemmol., **15**, 11, 395-9, 6 figs, 1985.

Physicists reply to an earlier paper by Connellan & Pozzebon, putting the subject on a much sounder scientific basis. R.K.M.

MOREAU (M.). *Camées et intailles.* (Cameos and intaglios.) Revue de Gemmologie, 83, 15-17, 4 figs, 1985.

A brief résumé of the manufacture of cameos and intaglios. M.O'D.

NASSAU (K.). *Miscellaneous gemstone treatments, part 1*. Lapidary J., **39**, 2, 254-62, 11 figs (7 in colour), 1985.

The paper deals with chemical treatments and impregnation and is based largely on the author's *Gemstone Enhancement* (Butterworths, London, 1984). M.O'D.

NEUMANN (E.), SCHMETZER (K.). *Mechanism of thermal conversion of colour and colour centres by heat treatment of amethyst*. Neues Jahrbuch für Mineralogie Monatshefte, 6, 272-82, 2 figs, 1984.

Heat-treated amethyst shows two absorption bands, that of green prasiolite at $13800cm^{-1}$ and that of yellow or brown quartz centred in the UV. Both bands have been assigned to $Fe^{2+}(I_6)$ colour centres and are probably due to iron-containing particles (Fe_2O_3). It has been found that the relative intensities of the green prasiolite band and the band due to iron-bearing particles and giving the yellow colour are strongly variable. The thermal conversion of colour in amethyst by heat treatment therefore depends upon the relative intensities of both absorption bands. Where the formation of the $13800cm^{-1}$ band dominates over the formation of the band centred in the UV the violet is converted to green. Where the formation of iron-bearing particles dominates the formation of the $Fe^{2+}(I_6)$ colour centres, the yellow or brown colour is developed. It is still not known how both colour centres in different concentrations are developed. M.O'D.

O'DONOGHUE (M.). *Mininoticias*. (Brief notes.) Gemologia, **21**, 63/64, 28-47, 1984.

Spanish translations of extracts from the abstracter's Gemmological Newsletter and Synthetic Crystals Newsletter.

(Author's abstract.) M.O'D

PEARCE (T.H.), THOMAS (M.). *Laser-induced fluorescence in minerals: preliminary results*. Canadian Mineralogist, 22, 379-82, 2 figs in colour, 1984.

Visible radiation from an argon-ion laser induces fluorescence in minerals. From 70 mineral species (150 samples) tested 29 species (61 samples) gave fluorescence. Most minerals showing a fluorescence under UV will show it with laser excitation (488nm line in the argon-ion laser) but colours are usually different.

M.O'D.

PEARSON (G.). *Bush amethyst*. Aust.Gemmol., **15**, 11, 408-9, 1985.

A purple glass from old bottles found in arid regions was shown to contain little iron and up to 0.5% manganese. Similar glass irradiated with x-rays for an hour turned a deep purple. It is suggested that long exposure to UV in sunlight has produced similar coloration. No physical constants are given. R.K.M.

POIROT (J.-P.). *Application de la radiographie en bijouterie-joaillerie*. (Application of radiography to jewellery and the jewellery trade.) Revue de Gemmologie, 82, 15-17, 11 figs, 1985.

A short account of the radiography of pearls is given. M.O'D.

PROCTOR (K.). *Gem pegmatites of Minas Gerais, Brazil; the tourmalines of Governador Valadares District.* Gems Gemol., **XXI**, 2, 86-104, 15 figs in colour, bibl., 1985.

A detailed account of this region and its gem products, illustrating mines, mouth-watering crystals and stones. The third paper in an enthusiastic series by a man who imports and sells such stones. R.K.M.

REBAN (J.). *Bohemian garnets.* Lapidary J., **38**, 12, 18-24, 10 figs (9 in colour), 1985.

The pyrope garnet occurrences in Czechoslovakia are described and illustrated. M.O'D.

ROUSE (J.D.). *Color grading issues: systems and standardization.* Lapidary J., **38**, 12, 1518-30, 9 figs in colour, 1985.

Useful overview of the different methods of colour grading with references to the standards and instruments used. M.O'D.

ROUX (J.E.). *World diamond production today.* Z.Dt.Gemmol.Ges., **34**, 1/2, 24-9, 1985.

The article is in English and is a summary of an address given by the author to the Annual Conference of the Deutsche Gemmologische Gesellschaft on the 30th September, 1984. Diamonds are produced in twenty countries. It has been said that ten million carats more were produced in 1983, but it is shown that most mines produced at the same rate as the previous rate, five produced less and five more, mainly in Australia. The countries producing more than a million carats per year are Angola, Australia, South Africa, Namibia, Botswana and Zaire. Less than that are mined in Brazil, Venezuela, Guinea, Sierra Leone, Liberia, Ivory Coast, Ghana, Central African Republic and Tanzania, and lastly India and Indonesia. E.S.

RUPASINGHE (M.S.). *Anreicherung von radioaktiven Elementen und Seltenen Erd-Elementen in Zirkon und Monazit aus Sri Lanka.* (Enriched radioactive elements and rare earth elements in zircon and monazite from Sri Lanka.) Z.Dt.Gemmol.Ges., **34**, 1/2, 69-75, 1 map, 3 tables, 2 graphs, bibl., 1985.

Due to presence of uranium and thorium some gems from Sri Lanka show measurable radioactivity, namely zircon and monazite, which has earlier been misidentified as zircon. Monazite contains about 40% rare earth elements. E.S.

RUPASINGHE (M.S.), DISSANAYAKE (C.B.). *The rare-earth element abundance in the sedimentary gem deposits of Sri Lanka.* Lithos, **17**, 4, 329-42, 3 figs, 1984.

REE in the gem placer deposits are highly enriched, particularly in the lighter elements. It appears that the progenitors for the REE are magmatic charnockite-granite associations, which are prevalent in the Highland group in which all Sri Lankan gem deposits are found. M.O'D.

SCHMETZER (K.) *Ein verbesserter Probenhalter und seine Anwendung auf Probleme der Unterscheidung natürlicher und synthetischer Rubine sowie natürlicher und synthetischer Amethyste.* (An improved sample-holder and its application to problems of distinguishing between natural and synthetic rubies as well as

between natural and synthetic amethysts.) Z.Dt.Gemmol.Ges., **34**, 1/2, 30-47, 36 figs (30 in colour), 2 tables, bibl., 1985.

The basic principle of the holder is the combination of a vertical and horizontal rotating axis. The vertical axis has a dial with 360° subdivisions. The optical axis of a cut gemstone is placed parallel to the microscope axis facilitating determination of angles between crystal faces. Under crossed nicols, natural and synthetic amethysts show characteristic interference patterns. E.S.

SCHMETZER (K.). *Farbloser Chrysoberyll – natürlich oder synthetisch?* (Colourless chrysoberyl – natural or synthetic?) Z.Dt.Gemmol.Ges., **34**, 1/2, 6-12, 5 figs (1 in colour), bibl., 1985.

An English version of this article is published on pp. 682 – 691 above. E.S.

SCHMETZER (K.). *Minerals of the taaffeite group*, (letter). Gems Gemol., **XXI**, 2, 115, 1985.

Corrects earlier paper by M. Gunawardene (Gems Gemol., XX, 3, 159-63, 1984) in that some material quoted was musgravite and not taaffeite, while Russian samples were from East Siberia and not Lake Ladoga. R.K.M.

SCHMETZER (K.), BANK (H.). *Zink-haltiger Taaffeit aus Sri Lanka.* (Zinc containing taaffeite from Sri Lanka.) Z.Dt.Gemmol.Ges., **34**, 1/2, 20-3, 1 fig. in colour, 1 table, bibl, 1985.

An English version of this article was published on pp. 494-7 above. E.S.

SNOW (J.), SANDERS (J.), BROWN (G.). *Nakazumi star synthetic corundum.* Aust.Gemmol., **15**, 11, 410-12, 6 figs, 1985.

A study club report on several synthetic rubies and sapphires showing stars with tapered arms, irregular whitish opaque inclusions on surfaces, curved colour banding and many gas bubbles among the fine rutile needles. It is stated that ilmenite and haematite needles in natural black star sapphires are oriented at 90° to the lateral crystal axes while rutile needles in these synthetics are expected to orient parallel to those axes. [This may be true of natural stars containing rutile needles, but how do we determine the lateral axes in boule-grown material?] R.K.M.

STOCKTON (C.M.). *Unusual color-change garnet*, (letter). Gems Gemol., **XXI**, 2, 116-7, 1 fig in colour, 1 table, 1985.

A 4.58 carat trapeze-shaped, trap-cut pyrope/hessonite/spessartine garnet changed from yellow-green in fluorescent light to red-brown in incandescent light. RI 1.769, and spessartine spectrum – consistent with other colour-change garnets. Vanadium and not chromium thought to be the colorant. R.K.M.

VAN LAER (N.C.). *Boulder batholith pegmatites.* Lapidary J., **39**, 2, 242-7, 24 figs (12 in colour), 1985.

Describes pegmatite minerals, particularly quartz, occurring in the Butte area of Montana. M.O'D.

VARGAS (G. & M.). *A discussion of the Australian Ideal Design for round brilliants.* Aust.Gemmol., **15**, 11, 421-4, 1985.

Disposes of some arguments put forward by Connellan and Pozzibon in their paper published August 1984. Authors are cutters of long standing and do not accept C & P's computer-based findings. R.K.M.

ZIMMERNINK (W.G.). *Die optischen Anomalien der Granate erläutert an Beispielen aus der Skarnlagerstätte Santander, Peru.* (Optical anomalies of garnets explained with examples from the Skarn occurrence in Santander, Peru.) Z.Dt.Gemmol.Ges., **34**, 1/2, 48-56, 8 figs, 1 table, bibl, 1985.

In spite of their cubic symmetry, garnets often show birefringence. They also often show sector twinning, polysynthetic lamellae, octahedral lamellae, morphological zoning and chemical zoning. All these anomalies can be found in garnets from the Skarn Deposit in Central Peru. In all cases of birefringence, sector or dodecahedral twinning could be observed, although not always very clearly. When the crystals showed chemical zoning, dodecahedral twinning could be observed, at least in the anisotropic grossularite components. Polysynthetic lamellae were only found in crystals with octahedral twinning. E.S.

Gems in unlikely settings. Retail Jeweller, **23**, 601, 12, 1 fig. in colour, 25th July 1985.

The second (concluding) part of the report on the RJ's Study Tour of Pakistan. After flying back to Peshawar the group was received at the Gemstone Corporation H.Q., where the lapidary workshop and gem laboratory are described. The Katlang pink topaz mine was visited and is described. On the way home, a gold jewellery factory in one of the United Arab Emirates was visited. J.R.H.C.

Gem tribute to US girl. The Times newspaper, No.62, 238, p.8, 9th September 1985.

Workers at Mirny have named a Siberian diamond (to be added to the Kremlin collection) after the late Samantha Smith (American schoolgirl invited to Moscow in 1983 after writing to the Kremlin about her fears of war). J.R.H.C.

RJ pioneers new route on Pakistan gems trip. Retail Jeweller, **23**, 600, 4-5, 2 figs in colour, 11th July 1985.

The first part of a report of RJ's Study Tour of Pakistan describes in some detail geological formations and mining activities at the open-cast emerald mine near Mingora in the Swat Valley and adjacent underground Farouk and Islamia mines and the ruby mines in the Hunza area. Other mines in the Swat area, at Gujar Killi, Charbagh and Makhab, and in the Mahmand Agency, at Ar Gandaf, Tora Tiga, Prang Gar and Kirra Killi, are mentioned. J.R.H.C.

BOOK REVIEWS

BANCROFT (P.). *Gem and crystal treasures*. Western Enterprises and Mineralogical Record, Fallbrook, California, 1984. pp. 488. Illus. in black-and-white and in colour. $60.00.

Aimed primarily at the mineral collector, the promotional material preceding this book gave a picture which can now be seen as far from hysterical, since the book is quite magnificent both in conception and content. It covers many (one hundred) of the world's most celebrated mineral locations, including some gemstone ones, giving the mining history, details of the minerals recovered, family details which are particularly interesting, and notes on current access where possible.

The photographs are superb; there are several at each opening and while those in colour are of the high standard we now expect from *Mineralogical Record* those in black-and-white give so fascinating an insight into the way in which fine specimens came to light that they are almost more eye-catching than the coloured ones. The author has taken pains to track down many specimens in collections which are not always generally known, even to specialists, and some of the pieces, once seen, will no doubt be reproduced again. References to each locality are given at the end of the book, where there is also an index.

Since many of the minerals depicted are of gem quality, gemmologists are recommended to get this book, despite its fairly high cost (and weight). The cost is not really excessive when the work done is considered. M.O'D.

BECK (R.J.). *New Zealand Jade*, A.H. & A.W. Rees, Wellington, 1984. pp. 173. Illus. in black-and-white and in colour. Price on application.

An excellent and well illustrated account of New Zealand nephrite covering origins, geography, Maori history and folk-lore, cutting and lapidary in both traditional and contemporary styles, and many other aspects of this lovely material. A successor to Russell Beck's earlier work of the same name which was sub-titled 'The Story of Greenstone'. The author is the director of the Southland Museum and Art Gallery, Invercargill, and is himself a very skilled worker and a foremost expert in nephrite. This will be a valuable addition to the library of any gemmologist interested in this fascinating material. R.K.M.

CHANG (Shih-Lin). *Multiple diffraction of x-rays in crystals*. Springer, Berlin, 1984. pp. xi, 300. DM 148.

Forming number 50 of the Springer series in solid-state sciences this book discusses the implications of the presence in crystals of a three-dimensional arrangement of atoms and molecules giving more than one set of atomic planes which satisfy Bragg's Law and simultaneously diffract an incident x-ray beam. Multiple diffraction gives important information on the structure of the crystal. The treatment, as is inevitable, is largely mathematical but notes on experimental

techniques are provided. Case studies involving gallium arsenide and indium phosphide are useful in bringing the topic to life. There is an extensive bibliography.
M.O'D.

GREENHALGH (P.). *West African diamonds, 1919-83; an economic history.* Manchester University Press, Manchester, 1985. pp. xiii, 306. £25.00.

This survey of the activities of European firms in Ghana and Sierra Leone (and, to a lesser extent, other West African diamond producing countries) is based on a thesis submitted to the University of Birmingham. European firms searching for diamond had considerable effects on the land and labour of these countries and in many cases their own contribution is hard to find. This book examines the records of the companies and concludes that there has been something of a two-way traffic. A postscript outlines the recent, mainly unfavourable, trends in West African economies.

Each chapter has its own bibliography and there is also a general bibliography and an index. M.O'D.

KLEIN (C.), HURLBUT (C.S.). *Manual of mineralogy, after J.D. Dana.* 20th edn. Wiley, New York, 1985. pp. xi, 596. Illus. in black-and-white and in colour. £19.75.

Larger than the previous edition, this weighty paperback includes more pictures, an expansion of the discussion of crystal chemistry, more on the classification of rock types and on crystal properties. There are approximately 200 descriptions of individual mineral species. The authors have based the structure of the whole book on crystal chemistry as an underlying theme.

The book, as before, is very well presented and can be highly recommended. The photographs are attractively reproduced. The bibliographies at the ends of each chapter have been updated and useful information is placed inside the covers at each end of the book; useful conversion tables found here are a boon. M.O'D.

MCGREGOR (A.). *Bone, antler, ivory and horn.* Croom Helm, London, 1985. pp. 245. Illus. in black-and-white. £35.00.

Directed primarily at the archaeologist this book is one of the few attempts to put these organic materials under some sort of close scrutiny in which their nature is related to their use. The book deals specifically with the use of the materials since the Roman period so that there is a large body of documentary evidence to survey and this is well presented here. Drawings in the text are well executed; there is an extensive bibliography, and details of finds are exhaustively given. M.O'D.

NADELHOFFER (H.). *Cartier, jewelers extraordinary.* Thames & Hudson, London, 1984. Illus. in black-and-white and in colour. £25.00.

Hans Nadelhoffer is in a particularly good position in the context of this excellent book, since he is the jewellery expert at Christie's in Geneva, and it is from some of the many sale catalogues that some of the illustrations are taken. The firm of Cartier has been in existence close on one hundred years and the way in which the three main branches (Paris, London, New York) maintained a separate existence until their merger in 1979 is skilfully and even excitingly told. Details of the many

famous designers who have worked for the firm are given but most of all it is the superb sets of colour plates that make this reasonably-priced book an essential member of the private library of the serious gemmologist. It is possible to trace the ways in which various stones rose in and fell from favour; fine details are given in notes to the chapters, and there is a short bibliography. M.O'D.

WEIBEL (M.). *Edelsteine und ihre Mineraleinschlüsse*. (Gemstones and their mineral inclusions.) ABC Verlag, Zürich, 1985. pp. 111. Illus. in colour. Price on appliction.

This most attractively-presented book is written with the assistance of Dr Edward Gübelin, who has supplied some of the photographs. Despite the title the book is not a text on inclusions alone but rather a concise review of the major gemstones with particular reference to their mineral inclusions and with valuable notes on how they were formed. Although the illustrations of inclusions are the first to catch the eye there are many pictures of cut gemstones which give an excellent idea of their colour (and along with this, possible causes of confusion, as is well seen in the plate showing a chrome tourmaline, a demantoid garnet and a tsavolite garnet). Another advantage of the book is the up-to-date information presented on the materials covered. M.O'D.

ZUCKER (B.). *Gems and jewels, a connoisseur's guide*. Thames & Hudson, London, 1984. pp. 248. Illus. in colour. £30.00.

This book gives an overview of the gems best known to the general public with notes on their history, anecdotes on famous stones, details of the best-known stones to come on the market and a certain amount of gemmological detail. Chapters are given to one stone in turn and there is a short bibliography. The coloured illustrations are quite good though the sizes of the objects depicted are not given. Unfortunately the poor knowledge of gemstones shown by the author somewhat militates against any possibilities of the book's being taken seriously in a gemmological context. There are many careless spellings, some of them betraying more fundamental areas of ignorance and many journalistic turns of phrase occupy space where a precise description would have been preferable. M.O'D.

ASSOCIATION NOTICES

OBITUARY

Mr A.F.C. de Klerk, F.G.A. (D. 1962), Bergen op Zoom, Netherlands, died on 13th April, 1985.

Mr W.R. Eldridge, F.G.A. (D. 1980 with Distinction), Kerrville, Texas, U.S.A., died on 23rd November, 1984.

Dr Bernard F. Martin, M.D., M.B., B.Ch., D.Sc., F.G.A., died on 31st August, 1985, aged 67. Dr Martin gained his Diploma and the Tully Medal whilst living in Sheffield in 1966. He later moved to Birmingham where he was Head of the Anatomy Department at the University, and was elected President of the British Society of Anatomists in January 1985. He submitted several papers to the Journal of Gemmology which formed one section of his work that gained him his Doctorate of Science in 1984. D.M.L.

GIFTS TO THE ASSOCIATION

The Council of the Association is indebted to the following for their gifts:

Mrs Bernice Backler, Pinetown, South Africa, for a parcel of mineral specimens for study purposes.

Mr R. Holt, London, for three star sapphires and a garnet with an unusual crystalline inclusion.

NEWS OF FELLOWS

On 15th May, 1985, Dr J.B. Nelson, Ph.D., F.G.S., C.Phys., F.Inst.P., F.G.A., was elected to the Committee of the Colour Group of Great Britain. He hopes to be able to bring gemmologists and colour scientists a little closer together.

On 12th July, 1985, Dr Nelson gave a talk with demonstrations of crystals and crystal models on 'The structure and habit of gem minerals' to the Harrow and Ruislip Geological Society at the Cavendish Pavilion, Eastcote, London.

On 6th September, 1985, Mr M.J. O'Donoghue, M.A., F.G.S., F.G.A., gave a one-day course on gemstone recognition with the 10x lens to the jewellery departments of Liberty & Co. Ltd, London.

MEMBERS' MEETINGS

London

On 18th September, 1985, at the Royal National Hotel, Bedford Way, London, W.C.1, Mr Gerhard Becker gave an illustrated talk entitled 'Gem carving – a short review of the history and every facet of present day carving'.

Midlands Branch

On 27th September, 1985, at Dr Johnson House, Bull Street, Birmingahm, Mr D. Wilkins, F.G.A., gave an illustrated talk entitled 'Rescued from the scrap box'.

Midlands and South Yorkshire and District Branches

On 28th July, 1985, a joint meeting of the Branches was held. Members and friends visited Chatsworth House, near Bakewell, Derbyshire.

North West Branch

On 19th September, 1985, at Church House, Hanover Street, Liverpool 1, Dr R.W. Braithwaite gave a talk entitled 'The cause of colour in Blue John'.

COUNCIL MEETING

At a meeting of Council held on Wednesday, 19th June, 1985, at the Royal Automobile Club, London, S.W.1, the business transacted included discussion of a possible purchase of freehold property (which is not now proceeding).

LETTERS TO THE EDITOR

From Mr R. Keith Mitchell, F.G.A.

Dear Sir,

I have received a number of replies to my query regarding the pearl-like sections in the plaque described in my paper 'Something Strange'*, all of which provide more or less the same answer.

First there was a 'phone call from our Chairman, David Callaghan, who suggested that these might be 'cave pearls'.

This was followed by a letter from Mr A.D. Moss, who suggested that they were oolites, and by another from Dr Michel G.L. Errera, of Brussels, who sent me photostats of two works which described ooliths and pisoliths. (The difference between these is size; an oolith is up to 2mm in diameter, while a pisolith is the same concentric structure up to 10mm. But 'oolite' or 'oolith' is often used regardless of size. 'Cave pearls' are oolites.) Dr Errera also makes the point that human calculi (such as gallstones) are not attacked by dilute hydrochloric acid and do not have sand

*J.Gemm., 1985, XIX (6), 498-9. – Ed.

grains as nuclei. The formations in question have quartz grains and other minerals as centres and do react to acid, so they must be of inorganic origin, i.e. 'cave pearls'.

Finally a letter arrived from Mr Andre Hettena, of the Museum d'Histoire Naturelle, Geneva, which again pressed the claim of oolites, and enclosed a photograph of several specimens from Grotte de Bramabian, Gard, France, and also a most beautiful cross section of a large oolite which had been specially cut by the Museum at the order of their Curator, Dr Jacques Deferne. This handsome specimen is 39mm in diameter. It reacts to acid and is fluorescent under UV light. The quartz nucleus is inert, but the lighter area immediately surrounding this fluoresces white, while the outer rings of the concretion, which are more sandy in colour, fluoresce less strongly. One thing quite evident from this specimen is that such 'pearls' do not have a nacreous outer surface, and so are not very pearl-like in appearance, despite the similarity of their structure to that of the pearl.

I am grateful to these correspondents, and thank all who have taken the trouble to reply to my query.

Yours etc.,
R. KEITH MITCHELL.

24th September 1985
Orpington, Kent.

From Mr D.J. Callaghan, F.G.A.
Gemmological Association of Great Britain

Dear Sir,

THE BASIL ANDERSON SPECTROPHOTOMETER APPEAL

As Chairman of the Appeal Fund I shall be most grateful if you would consider giving space to the publication of the list of subscribers since the Appeal was launched last November. As you will see there have been subscribers from all over the world and the total amount raised now approaches £20000*. The target for the Appeal is £25000 and I am publishing the list now in the hope that any person who may not be aware of the Appeal or who may have overlooked the original request will send a donation to me at the Gemmological Association, Saint Dunstan's House, 2 Carey Lane, London, EC2V 8AB.

I am sure that in general I am preaching to the converted when I say, in the year that sees the 60th anniversary of the foundation of the British Gem Testing Laboratory, how vital this modern British-made sophisticated instrument is to the present day and the future of gem testing.

Yours etc.,
D.J. CALLAGHAN,
Chairman.

9th August, 1985
London.

*At the time of going to press, the amount raised is approximately £22005. – Ed.

THE BASIL ANDERSON APPEAL FUND

LIST OF CONTRIBUTORS

(AS AT THE DATE OF GOING TO PRESS.)

Ackroyd, J.L., Haslemere.
Ahrens, Joan R., G.G., Greensboro, U.S.A.
Akizuki, Ryozo, Osaka, Japan.
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Cooper Scott Ltd, Cheltenham.
Cope, Richard, Nottingham.
Cornell, G., & Son Ltd, Maidstone.
Crabbe, Sylvia, Croydon.
Crawford, Hugh B., Castle Douglas.
Davidsons The Jewellers Ltd, London.
Davies, Percy, & Son Ltd, Gerrards Cross.
Deakin & Francis Ltd, Birmingham.
Deeks, N.W., Luton.
Diamond Trading Company (Pty) Ltd, London.
Dragsted, Ove, Copenhagen, Denmark.
Drewell & Bradshaw Ltd, London.
Duranczyk, Gladys, Hebden Bridge.
Duroc-Danner, J.M., Geneva, Switzerland.
Duyk, Prof. F.M., Brussels, Belgium.
Eadie, John, Glasgow.
Eaton, A., Lymm.
Eliahoo, M., London.
Elson, P.D., Swansea.
Emms, Eric C., Brentwood.
Eton Jewellery Co. Ltd, London.
Evans, W., & Son (Jewellers) Ltd, Matlock.

Fagg, M.N., Wallington.
Fagg, P.M., Wallington.
Faller, Noel P., Londonderry, N. Ireland.
Farber, Ernst, Munich, W. Germany.
Fardon, Robert, St Brelade, Jersey, C.I.
Fillan, Ian, Huddersfield.
Fillans & Son Ltd, Huddersfield.
Fitzgerald, Leslie, London.
Folmer Amtoft Jewellery Ltd, Twickenham.
Franks, Dr. J., Bowden.
Freeman, A., (Precious Stones) Ltd, London.
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CORRIGENDA

On p.569 above, in line 7 from foot, after 'Chatham (' add 'see'

On p.591 above, in line 1 of caption to Fig. 9, for 'right' read 'left'

On p.592 above, in line 15, for 'lower right' read 'lower left'

On p.595 above, Figs. 16 and 17 have been transposed: the redder Figure is Fig. 16 (transmitted and reflected light) and the Figure captioned as Fig. 16 is in fact Fig. 17 (reflected and reduced transmitted light)

On p.633 above, in line 1, for 'Austrlian' read 'Australian'

On p.647 above, in line 23, for 'stonges' read 'stones'

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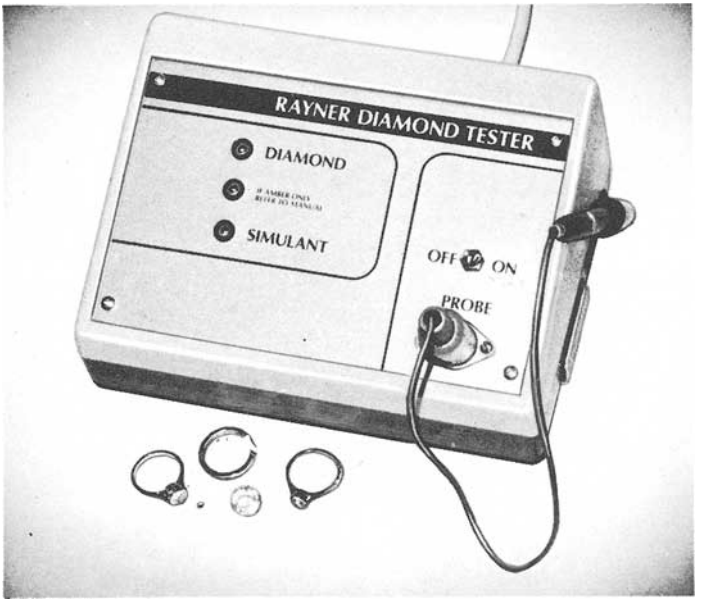

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The *Journal of Gemmology* was first published by the Association in 1947. It is a quarterly, published in January, April, July, and October each year, and is issued free to Fellows and Members of the Association. Opinions expressed by authors are not necessarily endorsed by the Association.

Notes for Contributors

The Editors are glad to consider original articles shedding new light on subjects of gemmological interest for publication in the *Journal*. Articles are not normally accepted which have already been published elsewhere in English, and an article is accepted only on the understanding that (1) full information as to any previous publication (whether in English or another language) has been given, (2) it is not under consideration for publication elsewhere and (3) it will not be published elsewhere without the consent of the Editors.

Articles published are paid for, and a minimum of 25 prints of individual articles may be supplied to authors provided application is made on or before approval of proofs. Applications for prints should be made to the Secretary of the Association—not to the Editors—and current rates of payment for articles and terms for the supply of prints may be obtained also from the Secretary.

Although not a mandatory requirement, it is most helpful if articles are typed (together with a carbon copy) in double spacing on one side of the paper, with good margins at sides, top and foot of each page. Articles may be of any length, but it should be borne in mind that long articles are more difficult to fit in than short ones: in practice, an article of much more than 10 000 words (unless capable of division into parts or of exceptional importance) is unlikely to be acceptable, while a short note of 400 or 500 words may achieve early publication.

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The Journal of Gemmology

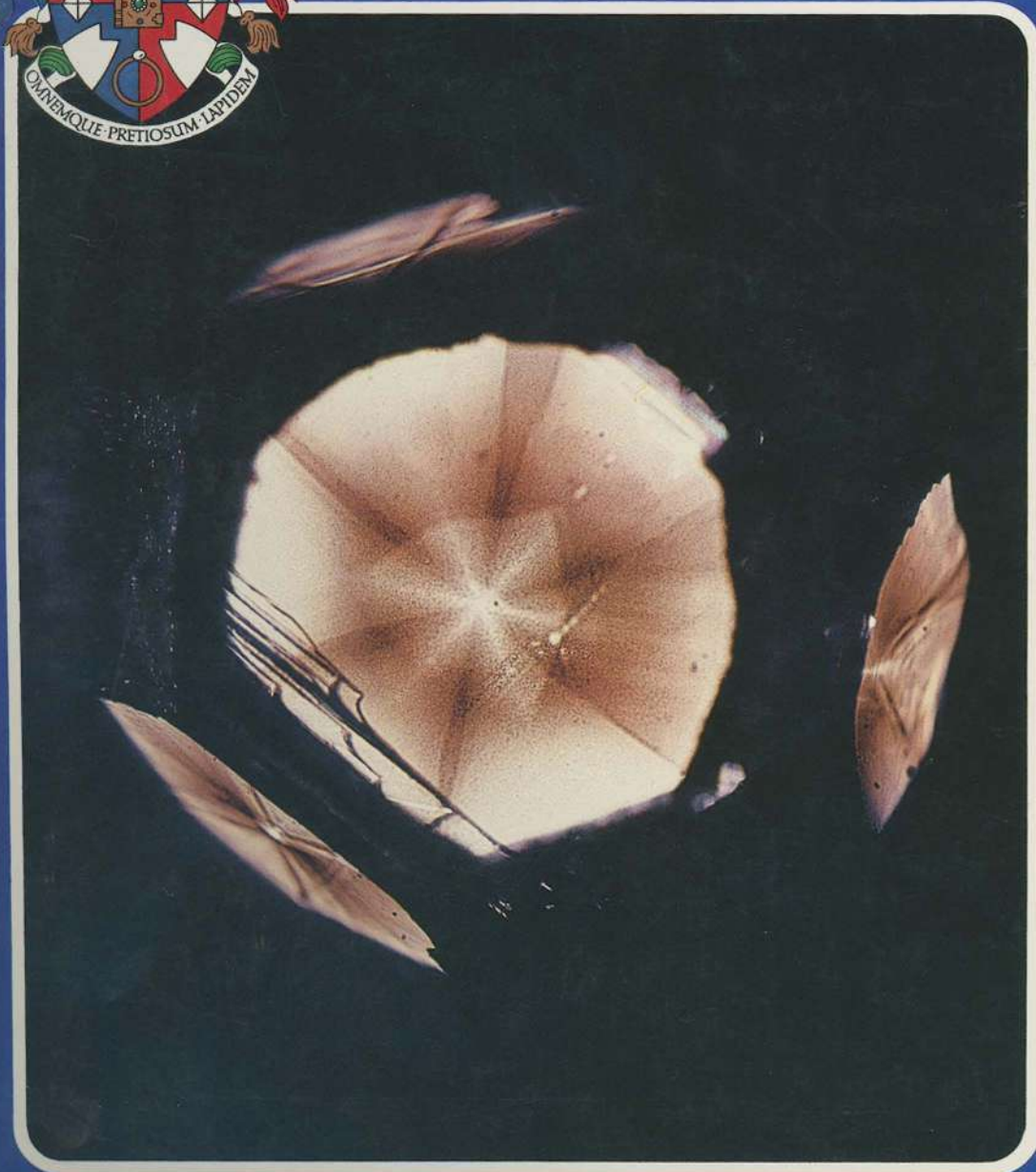

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The Journal of Gemmology

VOLUME 20

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Cover Picture

Photograph of a very unusual cubo-octahedral diamond crystal showing 'stars' through the octahedral faces – see page 52.

Photographed by S.J.A. Currie, F.G.A., New Zealand.

ISSN: 0022–1252

J. Gemm., 1986, 20, 1

JOHN CHISHOLM, Editor 1973–85

John Chisholm relinquished the active Editorial chair at the end of 1985. We wish him well in his retiral and thank him most sincerely for his sagacity and painstaking efforts. We are most fortunate to retain his services as Consultant Editor.

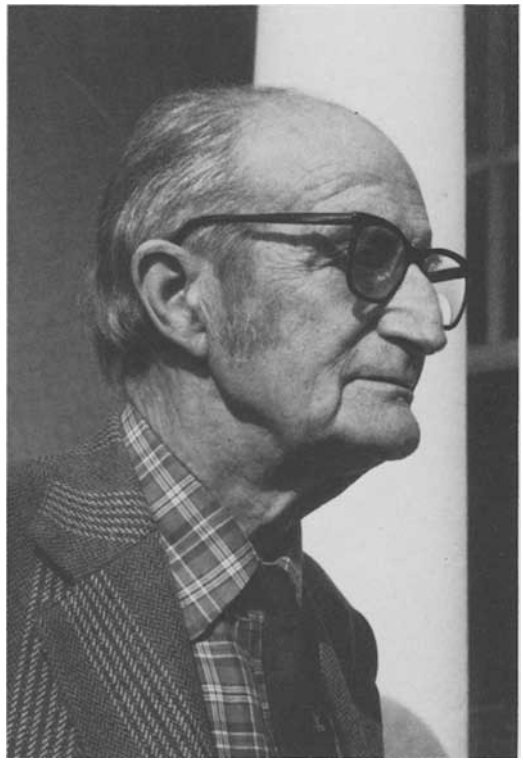

This fine verdite carving of a buffalo*, mounted on a plinth of iroko wood, was presented to John Chisholm as a mark of grateful appreciation for long and wise service to the Gemmological Association over a period of almost four decades.

*A coloured photograph of the buffalo appeared in *J. Gemm.*, 1984, **XIX**, 2, 150.

A description of ruby from Nepal

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[*] British Geological Survey, Exhibition Road, London SW7 2DE, and
[†] British Gem Testing Laboratory, 27 Greville Street, London EC1N 8SU

Abstract

A new occurrence of ruby from Nepal is described. Cut stones, crystals and the matrix minerals surrounding the rubies have been analysed by UV-visible spectrophotometer and by electron microprobe. A variety of inclusions are described and the results are compared with other occurrences of ruby in Asia.

Introduction

Early in 1984 an oval cabochon ruby and a smaller faceted ruby, which were said to come from a new occurrence in Nepal, were brought into the Geological Museum for examination. Both were identified as ruby, but irregularly curved feather inclusions (cf. Gübelin, 1983) in both stones gave rise to some doubt about whether they were natural or synthetic. A short time later the two stones (Fig. 1) were examined at the British Gem Testing Laboratory. Here it was agreed that whilst the inclusions present in these two stones were not characteristic of any particular locality, it was more likely that the rubies were of natural origin. However, it was thought best that specimens of the rough should be obtained to carry out a thorough examination. These duly arrived in late 1984 and this paper describes the nature of the new ruby and its associated minerals. Commercial quality ruby was first reported from Nepal by Toshiro Baba (1982) and he stated that it occurred with topaz in the Taplejung District, Dhankuta Zone of eastern Nepal (see Fig. 2). Cabochon quality sapphire was also reported from the same district by A. Chikayama at the 19th International Gemmological Conference held in Beruwala, Sri Lanka, in November 1983. It is possible that the source of the rubies described in this paper is also Taplejung, but the only information the authors have been given on the whereabouts of the source is that it is 'somewhere in Nepal'.

[‡] Present address: Dept. of Mineralogy, British Museum (Natural History), London SW7 5BD.

Description

Although the two polished stones are not of a particularly good gem quality (Fig. 1), the colour and clarity of the cabochon cut stone which weighs 7.90 cts is somewhat better than the faceted stone. The faceted stone, which weighs 2.17 cts, is heavily included, has a large fracture visible to the unaided eye and is a pinkish-red colour. The cabochon cut stone on the other hand, is clearer, its inclusions are not so easily visible to the unaided eye, and its colour is closer to the 'ideal' ruby red.

Apart from the deceptive curved and twisted feather inclusions two other interesting observations were made during the microscopic examination of both stones. The first was the long sometimes tapering, curved crystals inside the cabochon (Fig. 3), and the second was the presence in both stones of straight bands of blue sapphire.

Two specimens of ruby in matrix were supplied for examination. One is a fine prismatic crystal, 3.5 cm long and 2.3 cm across, in a matrix of white minerals, and the other is a friable dark mica schist (Fig. 4). A slice cut from near the top of the prismatic crystal (Fig. 5) revealed a core of ruby with a colour comparable to that of good Burmese stones. Surrounding the core are zones of paler ruby and some sharply defined bands of blue sapphire with growth lines meeting at 120° (Fig. 6). The crystal is traversed by curved cracks containing minute quantities of fluid, and in some parts these look like undulating films or veils, similar to the features seen first in the cabochon. These inclusions are very similar to those depicted by Gübelin (1983) in Figs. 2 (Chatham ruby). 3 (Kashan), 4 and 7 (Knischka).

Refractive indices and specific gravity

In the first instance refractive index measurements were attempted on the faceted stone, but as the surface was both uneven and broken in many places, the resulting measurement of 1.758–1.766 could only be regarded as approximating the actual refractive indices. Following the slicing and polishing of the crystal specimen, accurate RI measure-

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Fig. 1. Two Nepal rubies. The cabochon weighs 7.90 cts and the faceted stone 2.17 cts.

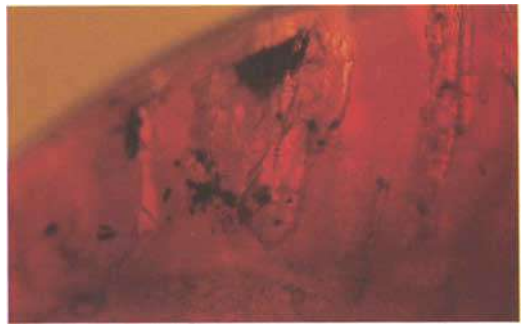

Fig. 3. Prismatic crystal inclusions in cabochon of Nepal ruby.

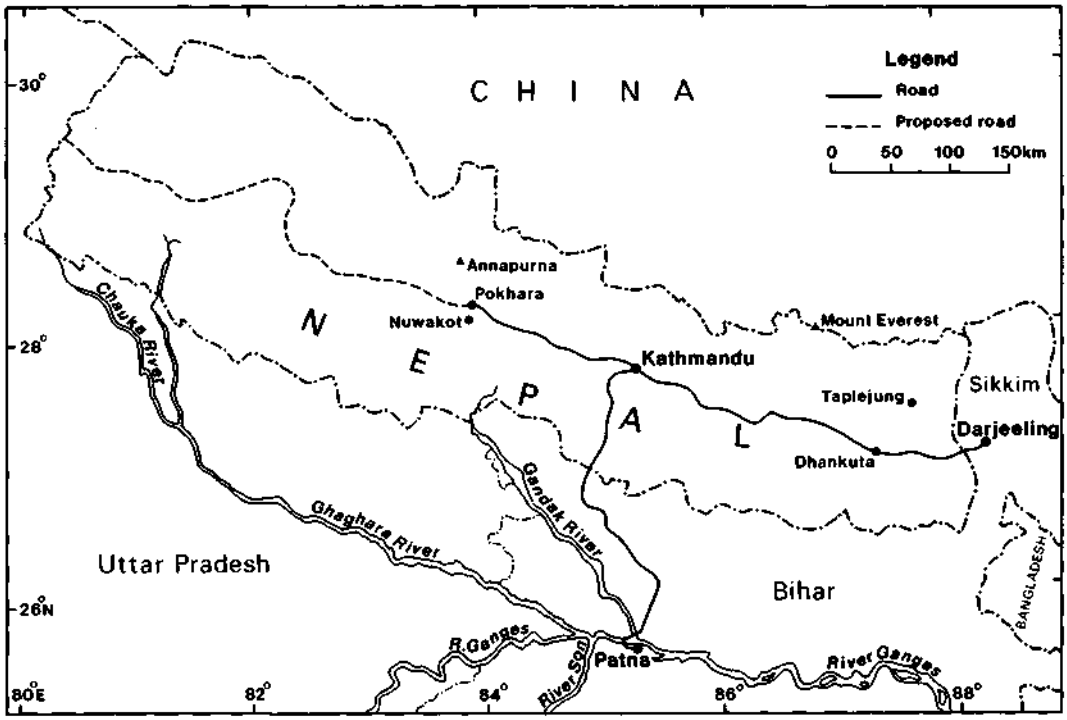

Fig. 2. Map of Nepal.

Fig. 4. Prismatic ruby in matrix of white minerals, and dark mica schist containing ruby and sapphire from Nepal.

Fig. 5. End-on view of prismatic ruby pictured in Figure 4.

Fig. 6. Slice of ruby from the prismatic crystal showing colour zones, banding and inclusions.

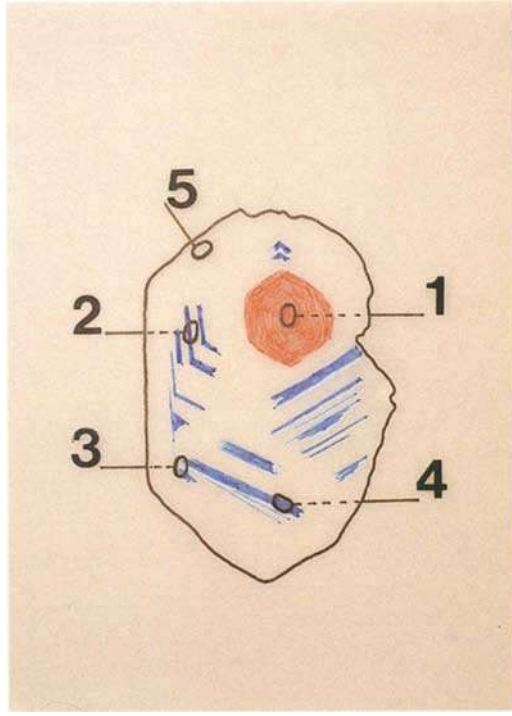

Fig. 7. Sketch of ruby slice indicating colour zones and points where spectrophotometer traces were measured (Fig. 8). See Figs. 10–14.

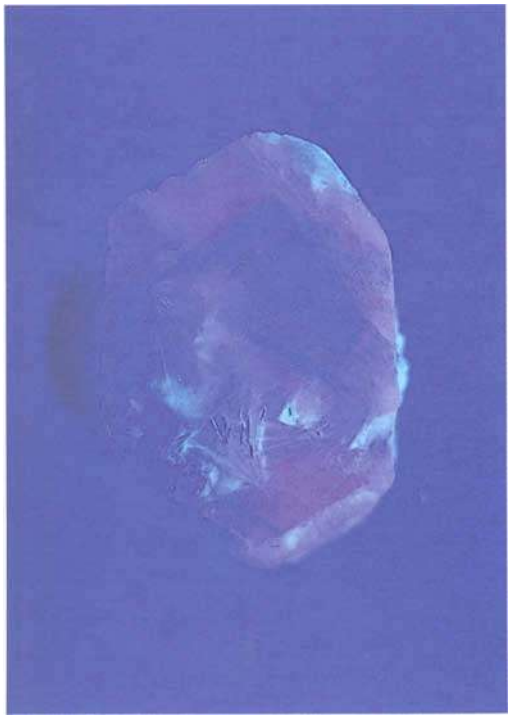

Fig. 18. View of ruby slice in UV light (365 nm). Note the contrast between the zones of ruby and sapphire and the greenish-white fluorescence of the sheaf-like margarite inclusions.

ments of 1.760–1.768 were made on the polished slice using a Rayner Dialdex refractometer and sodium light.

Using the hydrostatic weighing method and distilled water, specific gravity determinations were made on both polished stones and on the crystal slice shown in Fig. 18. The SG of the cabochon was found to be 3.99 and that of the faceted stone 3.98. The slice, however, was found to have the rather low SG of 3.79, and this is probably due to the large amount of included margarite (SG 3.0–3.1).

Absorption spectrum

During the original examination of both polished stones the absorption spectrum was noted for the visible region using a Beck prism-type hand spectroscope. Although the absorption and fluorescence lines were less easily seen in the faceted stone, both stones displayed the typical spectrum for ruby (Anderson 1980).

During the examination of the crystal a more detailed survey of the absorption spectrum was carried out, and five separate areas of the thin slice were examined (see Figs. 6 and 7). The five areas were chosen as examples of the different colours in the slice. Each area examined measured 1.1 × 1.5 mm (see Figs. 10 to 14). A Pye Unicam PU8800/03 (Basil Anderson) UV-visible spectrophotometer was used to examine each area from 190 to 850 nm at room temperature, and for all curves produced the beam passed through the slice in a direction virtually parallel to the optic axis. The span chosen for all curves was 1A (absorbance units), the bandwidth was 0.5 nm and the scan speed was 0.5 nm/s.

The recorded absoption curves for all five areas are shown in Fig. 8. The curves are numbered 1 to 5 and these correlate with the areas numbered 1 to 5 in Fig. 7, and the photographs of these areas in Figs. 10, 11, 12, 13 and 14 respectively. The levels of absorbance for each curve relate in a qualitative way to the other curves. The higher absorbance levels of some of the curves may in part arise from a higher proportion of small flaws or inclusions in the areas examined. In Fig. 8, the baseline of the diagram is 0.85A and the overall absorbance level of each curve is shown as being higher than this figure. However, because the size of the sample beam was reduced by masking to examine the small areas chosen, the absorbance level of each curve is about 0.45A higher than it should be. The path length of light through the ruby slice was small and ranged from 0.94–0.97 mm.

Although in three of the areas examined (Figs. 11, 12 and 13, and curves 2, 3 and 4 respectively) there is a strong blue component present, the curves produced for all five areas are fundamentally those which are expected of ruby (Anderson 1980). Curves 2, 3 and 4 do show, however, that for those areas of the crystal which have a blue component, there is a steeply rising absorbance level from 850 to 620 nm. Whereas, over the same wavelength range in areas which are predominantly red or pink the level of absorbance only rises slightly. Further, the level of absorbance for the band in the 410 nm region is significantly higher than that for the band in the 560 nm region in curves 1 and 5 which apply to the red and pink areas (Figs. 10 and 14), whilst the reverse is so in curves 2, 3 and 4.

Curve 1 was evaluated further according to the method published by Bosshart (1982) for the 'distinction of natural and synthetic rubies by ultraviolet spectrophotometry'. This method uses three parameters to evaluate the UV transmission area. These are the wavelength of the absolute absorption minimum in the UV and the centre position and width of the profile situated at 0.5 absorbance units above the minimum.

In this case it was only possible to measure one of the parameters as the difference between the absolute absorption minimum and the maximum of the absorption band on its long wave side was less than 0.5A (Fig. 9). The measurement of the absorption minimum at 361 nm however placed the stone well into the natural ruby range as described by Bosshart.

Microprobe analyses

Analytical work has been carried out on the faceted ruby, on a slice from the prismatic crystal of ruby in matrix, on a ruby derived from crumbled mica schist, and on a polished thin section of mica schist that contained both ruby and sapphire. Analyses were made using a Cambridge Instruments Geoscan microprobe with Link Systems energy dispersive detector and computer. An accelerating voltage of 15 kV, a specimen current of 5×10^{-9} amps and an electron beam focused to approximately 5μm were used. Elements of atomic number 11 (Na) and above can be measured by this method and the limits of detection for each of the oxides are about 0.2 wt%.

Analyses of selected minerals are given in Table 1. Particular attention was paid to the compositions of the different colour zones in the corundum crystals, and in the reddest parts, the Cr_2O_3 content reached 0.32%. TiO_2 was as high as 0.30% in some zones but the TiO_2 values do not show a good correlation with the intensity of the blue coloration. Iron is below the limit of detection in all the corundum analyses, and an overall mean composition is given in Table 1 column 1. In column 3 the total for apatite is low and this is consistent with

the presence of OH, F, or CO_2 which are not detectable by the microprobe. Similarly the totals for the micas margarite (column 2) and phlogopite (column 4) are low due to the probable presence of OH or F.

Table 1. Analyses of corundum and associated minerals from Nepal.

Wt%	1	2	3	4
SiO_2	0.1	31.6	<0.2	38.8
TiO_2	0.1	<0.2	<0.2	1.0
Al_2O_3	99.7	48.9	<0.2	18.2
Cr_2O_3	0.1	<0.2	<0.2	<0.2
FeO	<0.2	<0.2	<0.2	2.4
MgO	0.2	0.4	0.1	21.5
CaO	<0.2	10.9	55.7	<0.2
Na_2O	<0.2	1.4	<0.2	0.5
K_2O	<0.2	0.2	<0.2	9.9
P_2O_5	<0.2	<0.2	41.6	<0.2
Cl	<0.2	<0.2	0.4	<0.2
Total	100.2	93.4	97.7	92.3

Notes. Total Fe given as FeO.

1. Corundum, mean of 29 analyses from the ruby slice, ruby grain, and polished thin section.
2. Margarite, mean of 8 analyses from ruby slice and polished thin section. Identification checked using X-ray diffraction by R.J. Merriman (B.G.S. X-ray film number X8645).
3. Apatite, mean of 5 analyses from ruby grain and polished thin section. Total takes account of subtraction of oxygen equivalent of chlorine.
4. Phlogopite, mean of 3 analyses from polished thin section. Also contains 0.2% V_2O_3.

The matrix of white minerals surrounding the prismatic crystal of ruby consists largely of calcite, dolomite and the calcium mica, margarite. The margarite occurs as platy sheaves either intergrown with the margins of the ruby or completely included within the crystal. Other inclusions consist of muscovite and zoisite, and associated with margarite at one edge of the ruby slice, are grains of epidote which contain small quantities of rare-earth elements (REE). One black inclusion in the faceted ruby was found by microprobe analysis to be rutile, but other black inclusions, superficially similar to the rutile, present in ruby from the mica schist are apatite coloured black by graphite. The mica schist consists of 80% phlogopite mica, 5% apatite, 3% graphite, 3% corundum (ruby and blue sapphire), 2% margarite and minor quantities of rutile, muscovite, calcite, dolomite, anorthite, zoisite and epidote. Part of the mica schist is shown in Figs. 15, 16 and 17 and shows the intimate intergrowth of phlogopite mica with the corundum, apatite and other minerals. In these Figures it can be seen that the corundum is partly mantled and intersected by patches of margarite. These textures suggest that after the initial growth of corundum, temperature, pressure and chemical conditions changed such that corundum became unstable and was partially converted to margarite before temperatures became so low that alteration was inhibited. In the absence of detailed knowledge of the local geology this interpretation of the textures is only tentative and indeed Okrusch, Bunch and Bank (1976) have argued that for the Hunza Valley (Pakistan) corundum marble, the corundum and margarite formed in an environment of rising temperatures and pressures in place of diaspore, pyrophyllite and calcite.

In ultraviolet radiation the ruby generally displays a bright red to pink glow, stronger in 365 nm than in 253 nm radiation. In the zones of sapphire however the fluorescence is diminished, and where margarite is present, it fluoresces a bright greenish white and commonly shows the sheaf-like structure of the inclusion (Fig. 18).

Discussion

The association of corundum with carbonates, phlogopite, apatite, graphite and calcium aluminium silicates (margarite, zoisite, epidote and anorthite $An_{93}Ab_7$) is similar to that described by Iyer (1953) for parts of the Mogok Stone Tract (see also Keller, 1983). There the Mogok series (Iyer, 1953, p.15) consists of limestones, calciphyres, scapolite-gneisses, calc-granulites and lenticular bands of graphite. Rubies in the Hunza Valley, Pakistan come from a similar geological environment and Okrusch et al. (1976) and Gübelin (1982) describe the host rocks as series of intercalated marbles, schists and gneisses, and the latter shows rubies with calcite, phlogopite and apatite inclusions. Although the range of minerals in the two specimens from Nepal is not as extensive as that in Mogok, two specimens comprise only a very small sample of what is probably a geologically complex area, and further exploration may reveal a much bigger range of minerals and gems.

Acknowledgements

We would like to thank E.A. Jobbins for useful discussion, R.J. Merriman for his X-ray identifications, Dr M.T Styles for advice concerning the microprobe, C.W. Wheatley and R.D. Fakes for making polished thin sections and Charles Mathews Lapidaries for slicing and polishing the crystal. The paper is published by permission of the Director, British Geological Survey (N.E.R.C.).

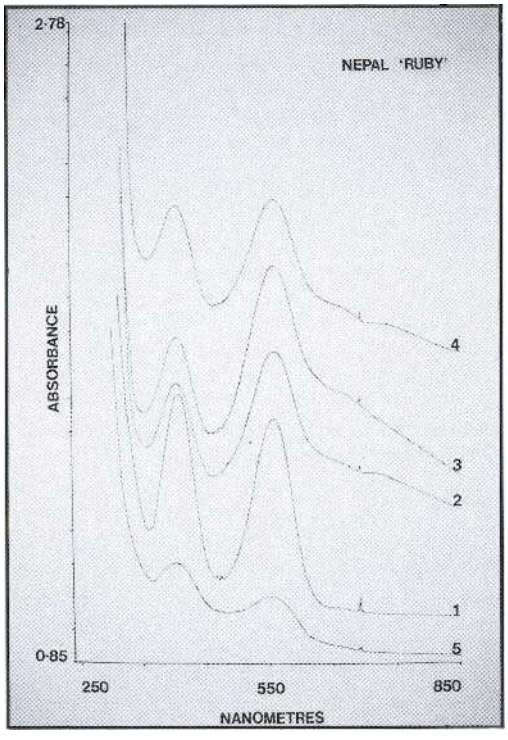

Fig. 8. Absorption curves over the range 250–850 nm measured at five points in the ruby slice (see Fig. 7).

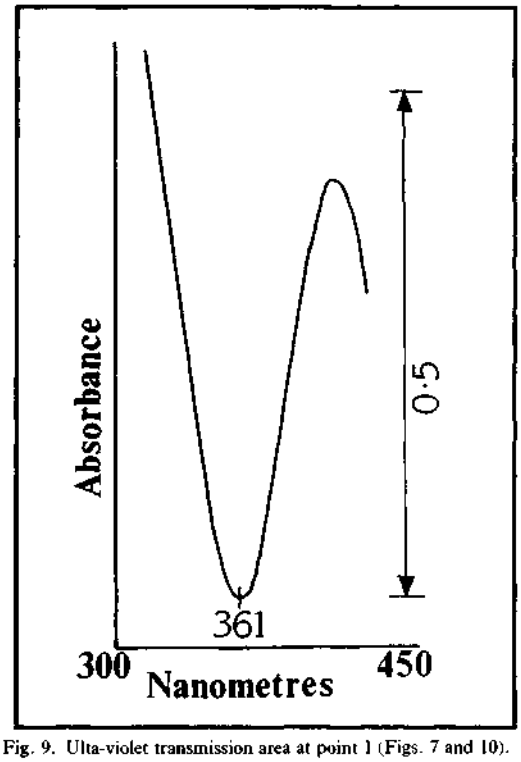

Fig. 9. Ulta-violet transmission area at point 1 (Figs. 7 and 10).

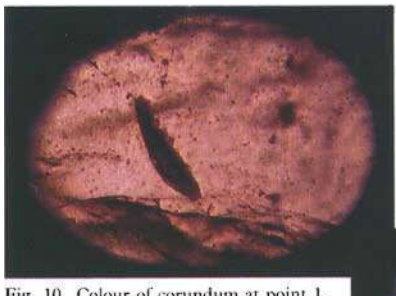

Fig. 10. Colour of corundum at point 1.

Fig. 11. Colour of corundum at point 2.

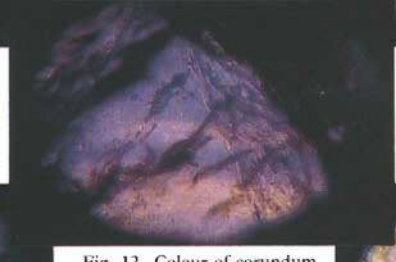

Fig. 12. Colour of corundum at point 3.

Fig. 13. Colour of corundum at point 4.

Fig. 14. Colour of corundum at point 5.

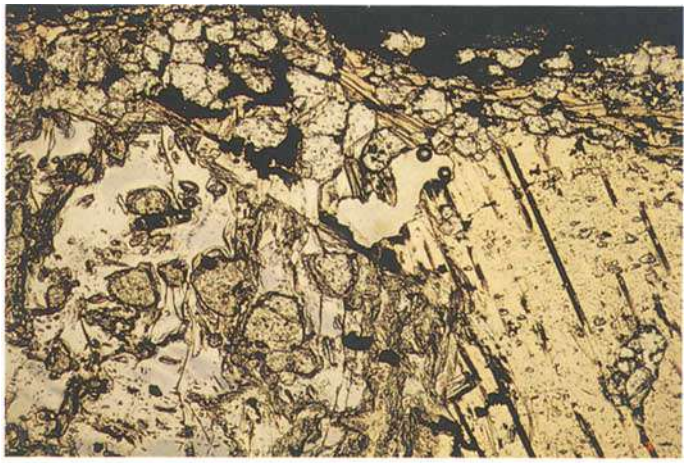

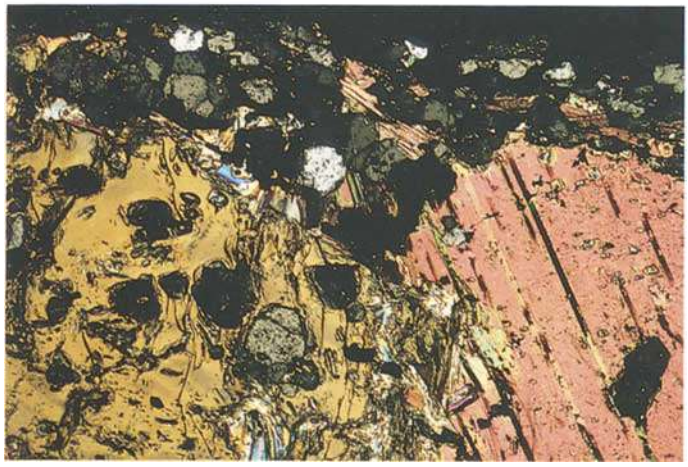

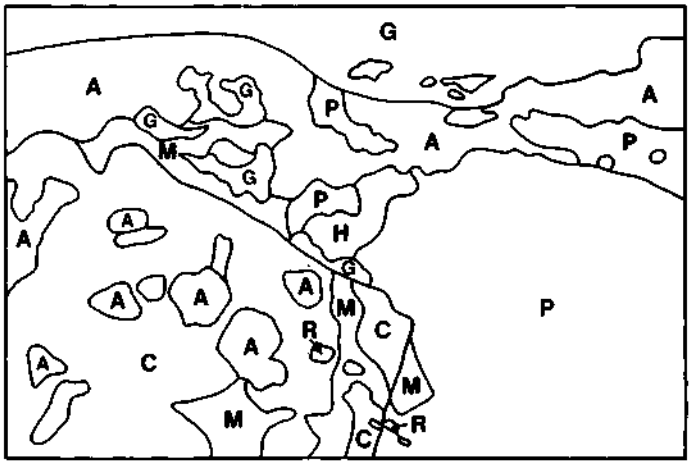

Figs. 15, 16, 17.
Photomicrographs of mica schist containing corundum. Field of view represents 4 mm across. Fig. 15 (top) plane polarised light. Fig. 16 (centre) crossed polarised light. Fig. 17 (bottom) key to minerals shown, apatite (A), corundum (C), graphite (G), margarite (M), phlogopite (P), rutile (R) and (H) is a hole in the slide.

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On the identification of hollow natural pearls and non-nucleated cultured pearls

J.M. Duroc-Danner, F.G.A., G.G.

Hollow natural pearls are seen from time to time[1,2,3], and these can be troublesome to separate from the commonly produced non-nucleated cultured pearls.

A hollow natural pearl

An undrilled baroque pearl (colour plate 1, A) measuring approx. 18.80 × 12.50 × 12.20 mm and weighing 17.07 ct, on all radiographs (Fig. 1 to 4, A) showed a rather large centre of nucleation, sensibly less radiopaque than the ordinary nucleus seen in natural pearls. No circumferential conchiolin deposit could be detected.

The hydrostatic weighing of the pearl in distilled water at 4°C using a Mettler PL 300c balance (accuracy ± 0.001 carat) indicated a density of 2.20 g/cm^3, and confirmed with the X-radiographs that the centre was a large area composed of a void, or less dense material (mud ?). The pearl was identified as natural, and since it did not show any luminescence under X-rays, as a salt water pearl, which due to its large size originates most probably from Australia.

It should be noted here that in gemmological literature, genuine nucleated pearls are said to have densities lying between 2.60 and 2.85 g/cm^3 [4,5]. Densities of non-nucleated or hollow natural pearls are not given due probably to perturbing factors like the irregular shape of the cavities, or of the density of the less dense material composing the nucleus.

A tissue-nucleated cultured pearl

At the same time the writer received the natural hollow pearl described above, a white undrilled baroque pearl (colour plate 1, B) measuring approx. 15.38 × 13.80 × 9.30 mm for a weight of 13.66 ct, came for identification. On the different X-radiographs (Fig. 1 to 4, B) it showed thin radiopaque layers of nacre near the surface, a large and irregular lentil-like shaped centre of nucleation which is very transparent to X-rays, with few fine circumferential lamellae of radiolucent conchiolin. All these structures are typical of non-nucleated cultured pearls. Since this pearl did not show any luminescence under X-rays, it must be a salt water non-nucleated cultured pearl, and due to its large size, originates most probably from Australia[6].

The hydrostatic weighing of this pearl in distilled water under the same conditions as for the natural hollow pearl, indicated a density of 2.718 g/cm^3 which is consistent with that quoted in gemmological literature for non-nucleated cultured pearls.

Discussion

It is interesting to compare the X-radiographs of the two pearls: For the natural hollow pearl, the centre of nucleation is more opaque to X-rays than that of the tissue-nucleated cultured pearl which is very transparent and lentil-shaped. Had the hollow natural pearl been composed of a tissue or other organic nucleus, the resultant X-radiograph would have been similar to that of the cultured tissue-nucleated pearl, and its identification a real challenge.

Density provides little help in separation since this natural hollow pearl had exactly the same as another cultured tissue-nucleated pearl density which showed 2.20 g/cm^3. Densities can overlap both for cultured and natural pearls, either nucleated or non-nucleated.

Colour and shapes in their turn cannot be taken into account to differentiate natural and tissue-nucleated cultured pearls since these vary considerably as well. For these two pearls, only direct X-radiography could make the difference since Lauegrams would in all cases invariably show an hexagonal spot pattern characteristic of natural pearls[7,8].

Acknowledgements

The writer is indebted to the British Gem Testing Laboratory of the London Chamber of Commerce and Industry for taking the X-radiographs, and for their opinion concerning these pearls.

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Plate 1. Pearl A and B

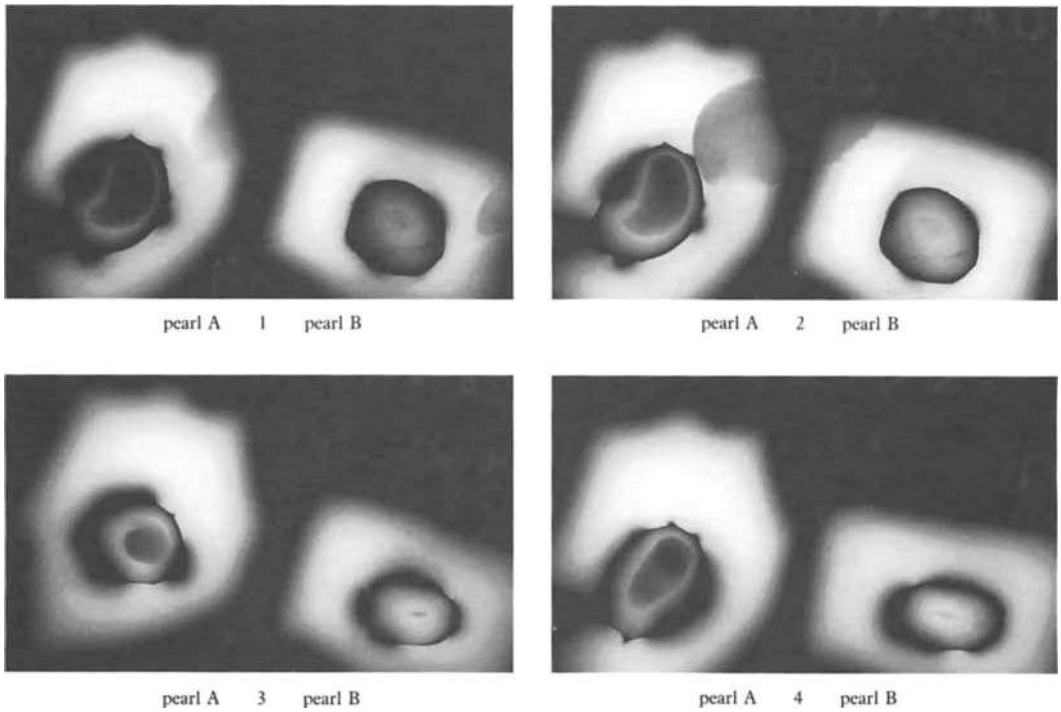

Fig. 1. X-radiographs of Pearl A and B taken from different positions. (The white areas surrounding the pearls represent the masking material.)

For pearl B, note on radiographs 3 and 4 in particular, the small elongated patch near the centre produced by the conchiolin, and the large lentil-shaped nucleus. This is very characteristic of a non-nucleated cultured pearl.

For pearl A, the absence of conchiolin deposits, and the aspect of the nucleus as seen from different positions on the radiographs is characteristic of a natural pearl.

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Seiko synthetic emerald

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The British Gem Testing Laboratory of the London Chamber of Commerce and Industry

Abstract

A new synthetic emerald developed by the Seiko group of companies is described. The features highlighted include the refractive indices (1.560–1.564), the specific gravity (2.655), and the distinctive crystalline inclusions, which are all relevant in differentiating the stone from a natural emerald.

Introduction

The Suwa Seikosha group of companies, renowned in the jewellery trade for its Seiko watches, has moved into the synthetic gem market. The synthetic counterparts of ruby, sapphire (blue, pink, and pink/orange), alexandrite, and emerald are being produced by Matsushima Kogyo Co. Ltd., an affiliated company of Suwa Seikosha.

In November 1983 the Creative Jewel Group of Suwa Seikosha started marketing these stones set in their own line of jewellery, which they have named Bijoreve. Their policy for the present is that the synthetic stones will only be marketed set in their own jewellery. So familiarization with the range of jewellery would be an advantage to anyone concerned with identifying the stones. It would be far better of course to be in a position to recognise the stones themselves without reference to their settings.

Examples from most of the species have already been reported upon[1] but a synthetic emerald subsequently received at the laboratory proved worthy of a further article. The stone was kindly sent to the laboratory at the end of 1984 by Suwa Seikosha, who also confirmed that the stone had been made by a flux-melt method, in contrast to the floating zone technique[2] being used for other Seiko synthetic stones.

Investigation

The synthetic emerald examined is a faceted, marquise-shaped stone, measuring approx. 4.94 × 2.98 × 2.40 mm, and weighing 0.19 ct. The SG of the stone is approximately 2.65 determined by the hydrostatic method. The accuracy of the latter method was limited by the small size of the stone. So this was followed by observing the behaviour of the stone in a heavy liquid in which quartz (SG of quartz 2.651) suspended freely. The stone sank slightly quicker than quartz as the temperature of the liquid increased and hence the SG of the stone was estimated to be approximately 2.665.

The RI of the stone is 1.560–1.564, which was measured on a spinel refractometer using sodium light. The optic axis is parallel to the table along the length of the stone. This was assessed by noting the orientation of the stone on the refractometer prism when a single shadow edge was seen on the scale of the refractometer[3].

The absorption spectra of the Seiko synthetic emerald (Fig. 1) were recorded at room temperature on a Pye Unicam PU 8800/03 UV/visible spectrophotometer (Basil Anderson model). The spectra for the ordinary and extraordinary rays were obtained using a polarizing filter. The relevant operating conditions were a bandwidth of 1 nm, a scan speed of 0.5 nm/sec, and the light path through the girdle of the stone approximates to the width of the stone at 2.98 mm. The salient peaks occur at 476 nm, 637 nm, 680 nm, and 683 nm, for the ordinary ray, and 642 nm, 660 nm, 680 nm, and 683 nm for the extraordinary ray. The areas of general absorption occur below 350 nm, and also are centred at approximately 430 nm and 600 nm. There is nothing exceptional in the visible region but on comparing the spectra (Fig, 1) with the spectrum of a Chatham synthetic emerald recorded under similar conditions (Fig. 2) one notices a difference in the ultraviolet. The Seiko synthetic emerald absorbs radiation below 350 nm, whereas the Chatham synthetic emerald transmits radiation down to 250 nm. This feature of the Seiko synthetic emerald is not definitive as many other synthetic and natural emeralds behave in a similar fashion by absorbing radiation in the same region of the ultra violet[4].

In common with most synthetic emeralds and many natural emeralds the stone appears a strong pinkish-red when viewed through a Chelsea colour

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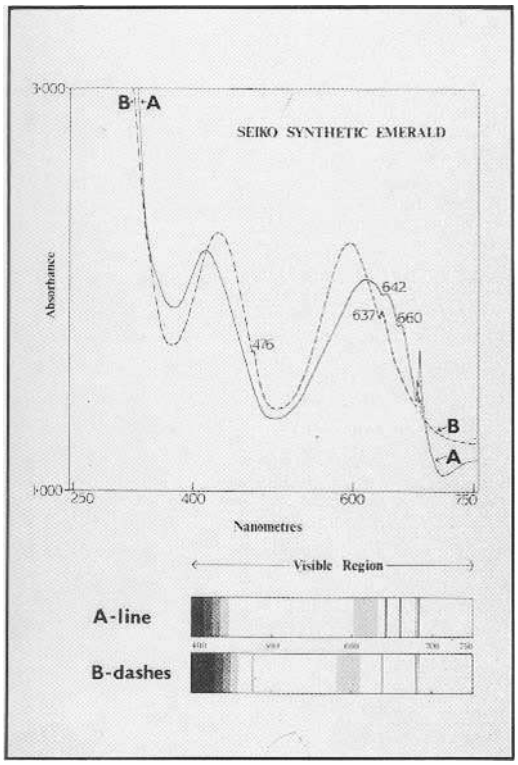

Fig. 1. The absorption spectra of the Seiko synthetic emerald recorded at room temperature on a Pye Unicam PU 8800/03 UV/visible spectrophotometer (operating conditions – bandwidth 1 nm, scan speed 0.5 nm/sec, and light path approximately 2.98 mm) using a polarizing filter to obtain the ordinary ray (dotted curve) and extraordinary ray (solid curve). A comparable representation of what would be seen in a hand spectroscope is illustrated directly below the curves.

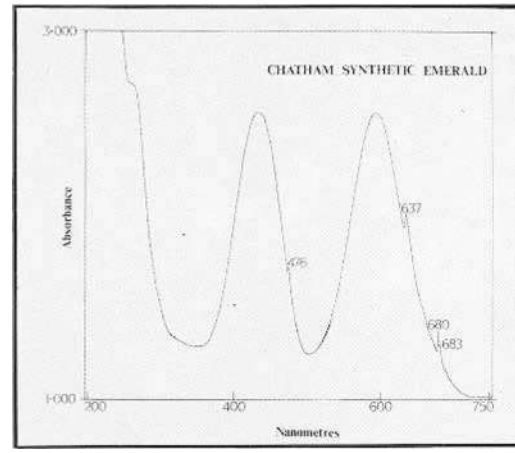

Fig. 2. The absorption spectrum of a Chatham synthetic emerald crystal slice recorded at room temperature on a Pye Unicam PU 8800/03 UV/visible spectrophotometer. (Operating conditions – bandwidth 1 nm, scan speed 0.5 nm/sec, and light path approx. 3.5 mm). The crystal was cut perpendicular to the optic axis and this is the direction through which the recorded ordinary ray was obtained.

filter. This is an inconclusive test for differentiating a natural emerald from a synthetic emerald.

Inclusions

1) Colour zoning of green and colourless growth bands running parallel to the table (Fig. 3). This explains why the observed colour of the stone is better through the table than it is through the girdle.
2) Roughly rectangular inclusions of flux which are oriented in one general direction (Fig. 4) and contained within a plane between the colour zones. There tends to be a concentration of inclusions between these colour zones.
3) Included crystals are situated just above a plane between the colour zones (Fig. 5). The crystals seen in side view in Fig. 5 are the same as those seen in plan view in Fig. 6. A 'star-burst' of three crystals and a rod-shaped crystal make up the complement of included crystals. The 'star-burst' inclusion in Fig 6 appears to be a set of crystals radiating in many directions from a common point. However, the side view reveals that the crystals only radiate above the plane between the colour zones. The positions and general orientations of the crystals in the stone indicate that the crystal occurrences were connected with the local growth conditions. The identities of the crystal inclusions remain unknown since it was not possible to analyse them.
4) Fine dust-like flux, which consists of some 'dot-dot-dot' formations, tends to be oriented perpendicular to the coloured growth zones. This gives the effect of a general orientation of the dust-like flux throughout the stone (Fig. 7).

Conclusions

The refractive indices, the double refraction, and the specific gravity for this synthetic emerald accord to the values for other synthetic emeralds grown by flux-melt methods, as well as being similar to the values recorded for another Seiko synthetic emerald[1]. In common with many flux grown synthetic emeralds the approximate determination of the density of a loose stone using heavy liquids proves a useful means of checking whether a suspect emerald might be a Seiko synthetic, especially if it is impossible to obtain the refractive indices.

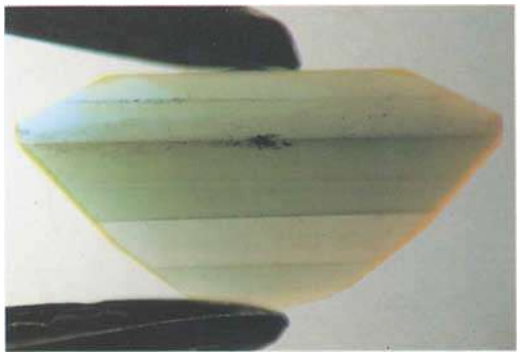

Fig. 3. Coloured growth bands in Seiko synthetic emerald, immersed in benzyl benzoate (length of stone, 4.94 mm).

Fig. 4. Roughly rectangular inclusions of flux oriented in one direction within a Seiko synthetic emerald (approx. 60x magnification).

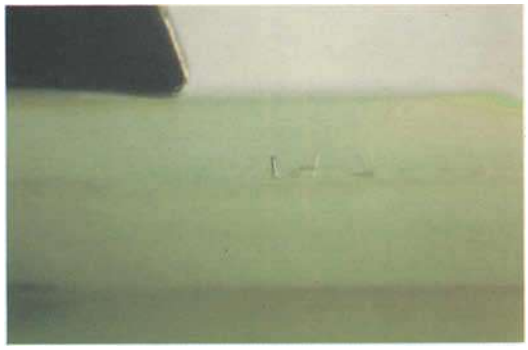

Fig. 5. Crystals in a Seiko synthetic emerald immersed in benzyl benzoate (approx. 60x magnification). This side view shows the association of the crystals with a plane between the coloured growth zones.

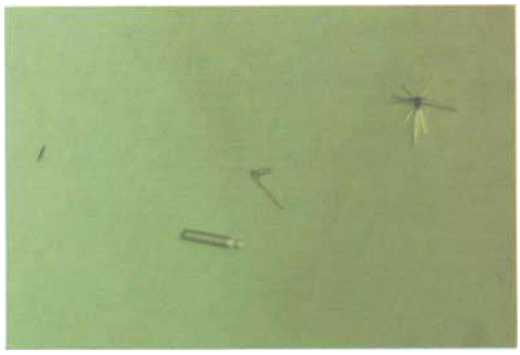

Fig. 6. 'Star-burst' cluster of crystals, a conjunction of two crystals, and a 'two-phase like' crystal in a Seiko synthetic emerald immersed in benzyl benzoate (approx. 100x magnification).

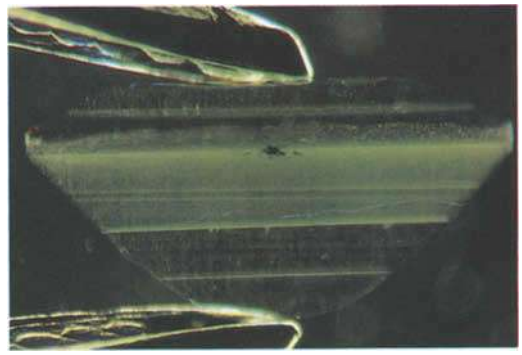

Fig. 7. Fine dot-like flux oriented perpendicular to the coloured growth zones in a Seiko synthetic emerald immersed in benzyl benzoate (length of stone 4.94 mm).

The careful measurement of the refractive indices or a specific gravity determination should differentiate this synthetic emerald from any natural emerald[5]. The identification would be completed by observing the emerald absorption spectrum and examining the stone for the presence of any of the recognizable synthetic-type inclusions already described.

Acknowledgements

On behalf of the laboratory the author acknowledges the gift of the synthetic emerald from Mr K. Yamashita on behalf of the Suwa Seikosha group of companies. The author also acknowledges the help of Mr K. Scarratt and Mr E.A. Jobbins in the composition of this article.

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[*Revised manuscript received 10 May 1985.*]

J. Gemm., 1986, 20, 1

An andalusite anomaly

R. Keith Mitchell, F.G.A.

Every mineralogical textbook I have consulted describes the crystal habit of andalusite unequivocally, and it would seem to be one of most invariable of minerals in this respect. A visit to one of the great museum collections will underline this seemingly inflexible characteristic, for every crystal of this mineral will be found to be in the habit of an almost square orthorhombic prism, usually with broken ends, but when terminated, with the basal pinacoid prominently developed, or perhaps a well-developed simple dome form with the pinacoid as almost a knife-edge. The actual angle between the prism faces is 89° 12′, so close to 90° that only the keenest of eyes would detect the difference in even the best developed crystal.

Well-developed gem-quality crystals of this mineral seem to be quite rare and a water-worn specimen received some twenty years ago from a friend in Ceylon was greeted with some delight. This stone was confirmed beyond all doubt by SG and other tests to be andalusite, and had come from Ceylon gem gravels. But it lacked the requisite 'square prism' habit. This stone is illustrated on the right in Fig. 1.

Fig. 1 Andalusite crystal, Brazil, 8.19 ct (left); water-worn crystal, Sri Lanka, 9.75 ct (right); crystal showing common 'square prism' habit (bottom).

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Fig. 2 Detail of Brazilian andalusite crystal with mm scale.

Then earlier this year Mr C.R. Cavey showed me a euhedral crystal of this mineral which had come from Minas Gerais in Brazil, and which has most of its faces intact apart from minor etching. This is the left-hand crystal in Fig. 1. It will be seen that these two crystals are closely similar in habit. The third specimen in this picture is andalusite in the conventional 'square prism' habit, lying on its side.

Fig. 2 gives an enlarged picture of the Brazilian crystal, which emphasizes the unorthodox habit. Indeed it looks almost monoclinic and it does not take much imagination to see that the Ceylon stone seems to be similarly restricted in symmetry. I am assured that both crystals do, in fact conform to the accepted crystal structure of andalusite, so the discrepancy is apparent rather than real. But I am left wondering at this unusual habit being found in two widely different parts of the world and yet going unrecorded in the highly authoritative mineralogies.

Acknowledgements

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An improved sample holder and its use in the distinction of natural and synthetic ruby as well as natural and synthetic amethyst

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Abstract

An improved sample holder for the gem microscope and its application to problems of the distinction of natural and synthetic rubies and amethysts are described. The basic principle of the sample holder is a combination of a vertical and a horizontal rotation axis. Furthermore, the vertical axis is supplied with a dial having a 360° subdivision. Using this new sample holder the optic axis of a cut gemstone is placed parallel to the microscope axis without having problems, and the determination of angles between structural elements, e.g. between crystal faces, is possible.

Diagnostic criteria useful for a distinction between natural and synthetic rubies are derived from the determination of families of straight parallel growth planes and angular growth banding formed by two families of growth planes. Under crossed polarizers, natural and synthetic amethysts show characteristic interference figures which are also useful for determinative purposes.

Introduction

For the microscopic investigation of gemstones using the horizontal microscope in order to facilitate the application of an immersion cell and immersion liquids, in general, a sample holder is used which has only one vertical rotation axis. The sample under investigation is rotated about this vertical axis through the full angle of 360°. The possibility of the investigation of inclusions is limited in those directions in which the field of view is hidden by the sample holder, e.g. by the crocodile clips, normally used. This disadvantage of the horizontal microscope is partly compensated for by a special sample holder described by Yu (1983), which allows the investigation of inclusions in a cut gemstone during almost the full angle of 360° using the conventional vertical rotation axis.

In order to investigate the inclusions in a cut gemstone in different directions of view, it is necessary to remove the sample from the holder and to place the object under investigation after its rotation back into the sample holder again. According to the geometrical properties of the cut gemstone distinct directions of view in connexion with a 360° rotation about the vertical axis are easily accomplished. In other words, a cut gemstone is easily placed in distinct orientations into the conventional sample holder, e.g. the gem is held by the crocodile clips between its table and culet or at the girdle. However, additional and different orientations of a cut gemstone are very difficult to obtain. Due to this fact, it is very time consuming or sometimes even impossible to adjust the optic axis of a normally faceted gemstone parallel to the microscope axis. The recognition of structural properties, e.g. the exact determination of growth planes, and the verification of the applicability of growth features to a distinction between natural and synthetic gemstones is practically impossible with the conventionally used gem holders.

The development of an improved sample holder was initiated during the investigation of cut flux-grown synthetic rubies of different producers using the gem microscope with a conventional sample holder, in connexion with the determination of crystal faces of rough flux-grown samples of the same producers using a two-circle reflecting goniometer. At present, the recognition of cut flux-grown rubies and the distinction of flux-grown samples from natural rubies is thought to be one of the greatest problems in gemmology. During the investigation of the above mentioned rough crystals of flux-grown ruby it was realized that depending on the producer and the flux material used during crystal growth a characteristic morphology was developed for the crystals investigated. In addition,

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it was realized that distinct crystal faces, which are common in natural ruby (and corundum) were never found in the commercially available flux-grown samples investigated. Furthermore, some distinct crystal faces, which were seldom found in natural crystals, are frequently observed in synthetic rubies of the trade. From these experimental results the question arose, whether these observations were also verifiable in cut rubies and, in addition, if some criteria useful for a distinction between natural and synthetic rubies were derivable from these experimental results.

In the present paper the new improved sample holder is first described. Furthermore, the data of flux-grown and natural rubies, which are easily available by use of the newly developed equipment, are discussed in order to verify a possible application for the distinction of natural and synthetic rubies. Another field of application for the new sample holder is the distinction of natural and synthetic amethyst which is also discussed in this paper.

It is worth mentioning that the criteria for the distinction of natural and synthetic gem materials which are discussed in this paper should be taken as additional possibilities for determinative purposes and supplementary to the conventional methods of microscopy and spectroscopy and *not* as a substitutional method. By the application of the new sample holder for determinative purposes characteristic data useful for a distinction between natural gemstones and their synthetic counterparts are available for a great percentage of samples. However, the data available for distinct samples of the red corundum variety ruby and the violet quartz variety amethyst (as well as for heat-treated amethyst, the so-called citrine) may not be diagnostic for every single sample of these important gem varieties. In other words, the data of some samples may be typical for both natural and synthetic samples and, therefore, are sometimes not useful for determinative purposes. These data, which are typical for both natural and synthetic gem materials, are also discussed in detail.

Description of the improved sample holder for microscopic investigations of gemstones

The most important supplementary alteration of the improved sample holder* (Fig. 1) is the introduction of a second horizontal rotation axis (a) in addition to the normally used vertical rotation axis (b). By use of this new axis which is connected with a set screw, a rotation of the sample about the horizontal axis, through an angle up to about ±40°

*The new sample holder described in this paper is commercially available from Hans-Günter Schneider, Dietzenstr. 41, D-6580 Idar-Oberstein.

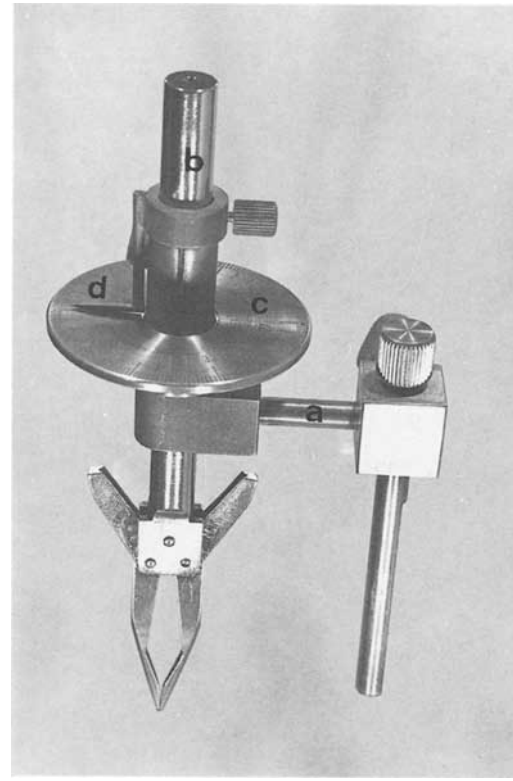

Fig. 1. Improved sample holder for the horizontal microscope (gem microscope with immersion cell); (a) horizontal rotation axis with set screw, (b) vertical rotation axis, (c) dial with 360° subdivision, (d) indicator with set screw.

is practicable. It is self-evident, that the object under investigation may have to be focused again in the microscope and that, in addition, a small displacement of the immersion cell could be necessary at rotation angles above 30°. In general, by this additional possibility of rotation the optic axis of a cut gemstone is found in the gem microscope without problems (Figs. 2–5), starting with different orientations of the cut gemstone held in the gem holder by use of the crocodile-clips. These orientations are normally determined by the cut of the gemstone, i.e. the gemstone is held between the table and the culet or in various positions at the girdle. Further additional equipment of the new sample holder is a dial having a 360° subdivision (c) which is attached to the conventional vertical axis. In addition, it is possible to attach a small indicator with set screw (d) to the 360° dial. By use of this equipment the angle between two structural properties of a gemstone, e.g. the angle between the optic axis and a distinct growth plane is measured.

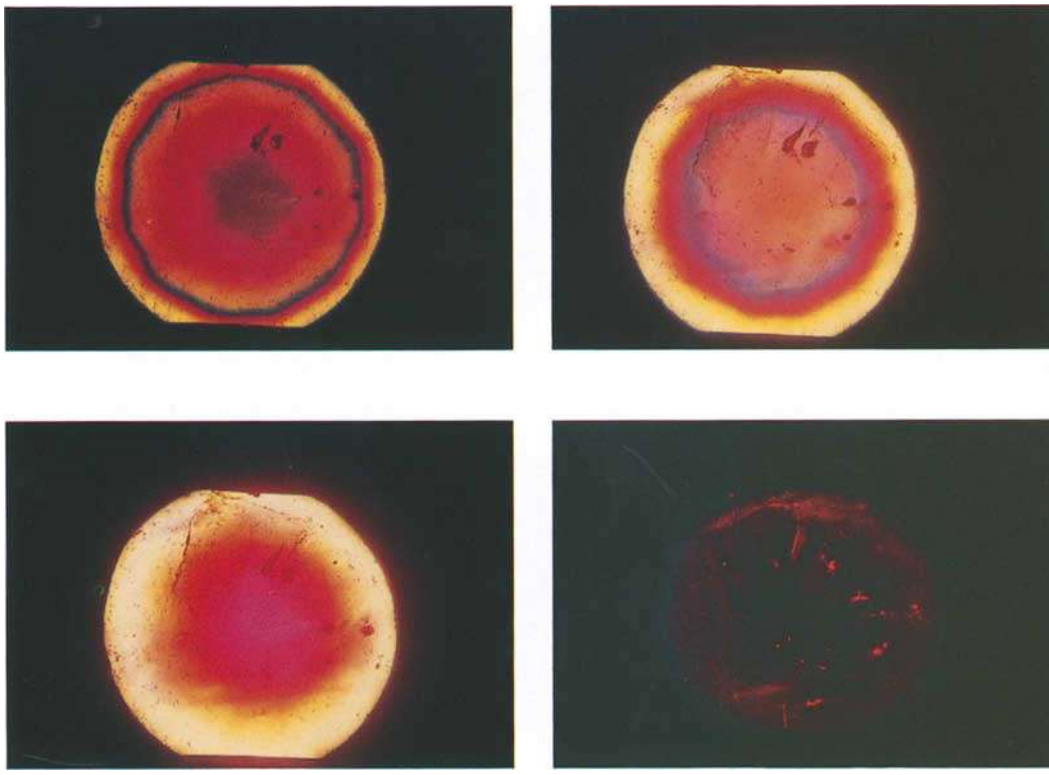

Figs. 2–5. This series describes the variation of interference figures of corundum (Burmese ruby) during a slight rotation of the stone; in Fig. 2 the angle between the optic axis and the microscope axis is about 30°; tilting of the corundum crystal slowly towards positions, in which the angles between optic axis and microscope axis is diminished moves the interference rings towards the centre (Figs. 3 and 4); in Fig. 5 the optic axis is exactly parallel to the microscope axis; further tilting of the corundum crystal slowly towards positions in which the angles between optic axis and microscope axis is enlarged moves the interference rings towards the rim of the interference figure – x pol., 60x.

Applications of the new sample holder

In this paper the applications of the new sample holder to the distinction of natural and synthetic flux-grown ruby as well as natural and synthetic amethyst are described in detail. However, the use of the improved sample holder for routine gemmological investigations is also recommended because of the general enlargement of the field of view by the additional rotation axis. With this additional degree of freedom routine microscopic investigations, i.e. the determination of structural properties and inclusions in gemstones, become much easier.

Distinction of natural rubies and flux-grown synthetic rubies

At present, the recognition of the commercially available types of flux-grown rubies produced by Chatham (Chatham synthetic ruby), Ardon Associates (Kashan synthetic ruby), Knischka (Knischka synthetic ruby), and J.O. Crystals (Ramaura synthetic ruby) is one of the greatest problems of determinative gemmology. The synthetic rubies mentioned above, in general, may have inclusions consisting of feathers with residues of the flux material used in crystal growth (cf. Table 2). In some cases, these feathers are not distinguishable from healing feathers of natural rubies due to their almost identical visual appearance in the gem microscope. In addition, the flux-grown types of commercially produced rubies may show growth features consisting of straight parallel growth bands and even sets of straight growth bands that form an angle. Some years ago, these types of structural properties were taken as indications of undoubted natural origin for unknown samples which were submitted for determinative purposes to gemmological laboratories.

The habit of natural corundum crystals including its red gem variety ruby, in general, is dominated by a number of different crystal forms which are shown in Table 1. These are combinations of the basal pinacoid c (0001) with the second-order hexagonal prism a $(11\bar{2}0)$, the positive rhombohedron r $(10\bar{1}1)$ as well as different second-order hexagonal dipyramids (cf. Goldschmidt, 1918; Niggli, 1927; Palache *et al.*, 1944). The negative rhombohedron d $(01\bar{1}2)$, on the other hand, is developed in natural corundum crystals quite rarely and, if developed, this subordinate crystal form is found in very small faces only and, therefore, the negative rhombohedron is of no importance for the habit of natural crystals. In contrast, the habit of the commercially available gem rubies of the above-mentioned producers is dominated by a more limited number of different crystal forms. A characteristic combination of crystal forms which are typical for every producer (Table 2) was found during the determination of the crystal faces of more than 50 rough crystals with an optical two-circle reflecting goniometer. The predominant crystal faces of synthetic flux-grown ruby are represented in the idealized drawing of Fig. 6. It is important to mention that the second-order hexagonal prism a $(11\bar{2}0)$ was never found in rough crystals of the four most important producers. The negative rhombohedron d $(01\bar{1}2)$, which is a subordinate crystal form in natural corundum (if present at all), was found to be a predominant form in samples of Chatham synthetic ruby, Knischka synthetic ruby and Ramaura synthetic ruby. Three crystal forms, which are predominant in natural ruby, were also determined by the two-circle goniometer as predominant forms in synthetic rubies, the basal pinacoid c (0001), the positive rhombohedron r $(10\bar{1}1)$ and the second-order dipyramid n $(22\bar{4}3)$.

The morphological properties of natural and synthetic rubies are reflected by the internal structure of the crystals, i.e. by straight parallel growth bands visible in natural and synthetic gem rubies by the horizontal microscope in immersion liquid. An exact determination of the angular position of parallel growth planes in ruby vs. the optical axis of the crystal is achievable by use of the new improved sample holder with simple practical training. Please refer to Fig. 7. As a first step, the optic axis of the ruby under investigation is orientated to be coincident with the direction of view (microscope axis) using both the horizontal and vertical axes of the sample holder. By using crossed polarizers in the gem microscope, interference figures consisting of coloured interference rings are observed. Tilting the corundum crystal

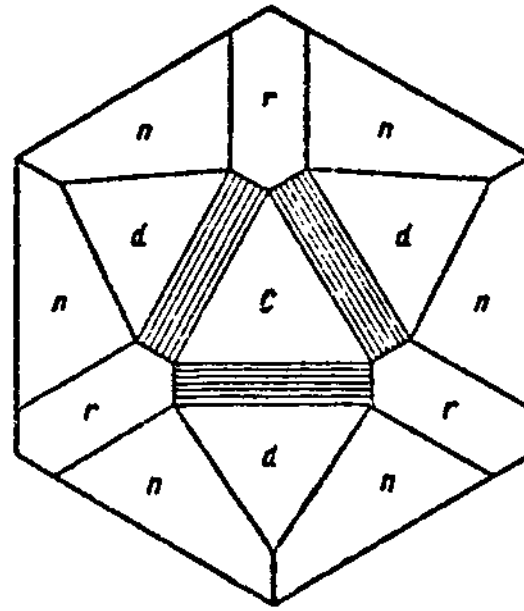

Fig. 6. The most important faces of synthetic corundum: basal pinacoid c (0001), positive rhombohedron r $(10\bar{1}1)$, negative rhombohedron d $(01\bar{1}2)$ and second-order hexagonal dipyramid n $(22\bar{4}3)$; the crystal is viewed in a direction down the c-axis (optic axis); from Timofeeva & Luk'yanova, 1967.

towards a position in which the angle between the optic axis of the sample and the microscope axis is diminished, the interference rings move towards the centre of the interference figure. If the angle between the optic axis of the ruby and the microscope axis is enlarged, the interference rings move towards the rim of the interference figure (Figs. 2–5). After having placed the optic axis in the best achievable position, the indicator attached to the dial of the vertical axis is fixed to 0° by use of the set screw. In a second step of the procedure, the sample is rotated about the vertical axis towards a position, in which sharp parallel growth planes are observed in the microscope, i.e. towards a position in which sharp traces of the growth planes become visible in the gem microscope. By use of the rotation angle δ, which is now readable on the graduated dial, the growth plane under investigation is exactly determined (Table 1). The schematic drawing of the situation is given in Fig. 7., the rotation angle δ is defined as the angle formed by the optic axis of the corundum crystal and the trace of any single growth plane of the crystal.

The recognition of families of straight parallel growth planes which are parallel to crystal faces, and growth planes which do not appear in synthetic rubies of commercial productions, e.g. straight parallel growth planes of the second-order

Table 1. Crystal faces and angles of corundum

Name	Designation	hkl*	angle between c-axis and crystal face (rotation angle δ)**
basal pinacoid	c	(0001)	90°
second-order hexagonal prism	a	$(11\bar{2}0)$	0°
positive rhombohedron	r	$(10\bar{1}1)$	32.4°
negative rhombohedron	d	$(01\bar{1}2)$	51.8°
negative rhombohedron	γ	$(01\bar{1}5)$	72.5°
important second-order hexagonal dipyramids	n	$(22\bar{4}3)$	28.8°
	w	$(11\bar{2}1)$	20.1°
	v	$(44\bar{8}3)$	15.4°
	z	$(22\bar{4}1)$	10.4°
	ν	$(44\bar{8}1)$	5.2°
	ω	$(14\ 14\ \overline{28}\ 3)$	4.5°

*based on the morphological cell with a:c = 1:1.365
**cf. Fig. 7

angles between crystal faces (cf. Figs. 7 and 8)

faces	interfacial angle φ	angle made by the two faces φ'
r ∧ r'	93.9°	86.1°
n ∧ n'	52.0°	128.0°
a ∧ a'	60.0°	120.0°
r ∧ n	26.0°	154.0°
d ∧ n	32.0°	148.0°
r ∧ d	47.0°	133.0°

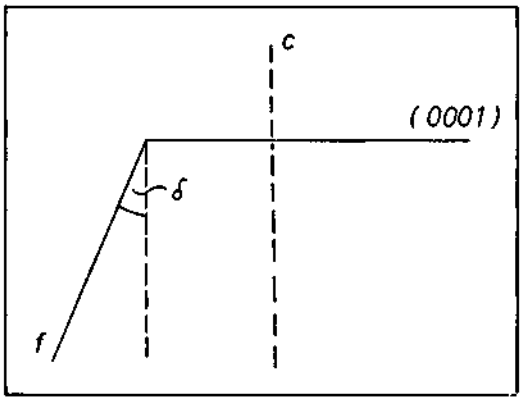

Fig. 7. The determination of growth planes in corundum using the angle between optic axis of the crystal and growth plane; (0001) basal pinacoid, c optic axis, f crystal face or growth plane, δ rotation angle.

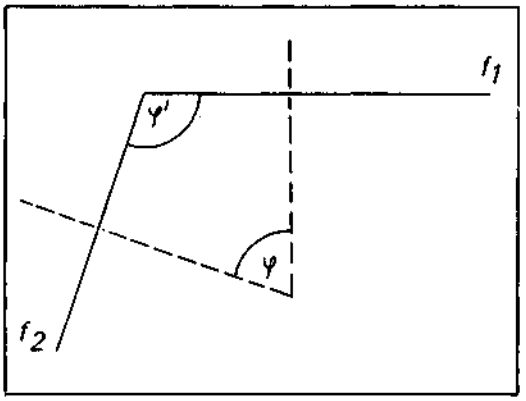

Fig. 8. Straight growth planes that form an angle; f_1 and f_2 growth planes, φ interfacial angle, φ' angle made by the two faces.

Table 2. Crystal forms of synthetic corundum

Producer/trade name	flux*	predominant forms	subordinate forms	frequently observed angular growth bands	twinning* c = common r = rare
Chatham Created Gems of San Francisco, USA (Chatham synthetic rubies)	Li_2O-MoO_3-PbF_2 and/or PbO_2	c, r, d, n		(r, n) (n, n') (d, n)	$(10\bar{1}1)$ r $(10\bar{1}0)$ c
Ardon Associates of Dallas, USA (Kashan synthetic rubies)	Na_3AlF_6	c, r, n		(r, n) (n, n')	$(10\bar{1}1)$ c
P.O. Knischka of Steyr, Austria (Knischka synthetic rubies)	Li_2O-WO_3-PbF_2 and/or PbO_2	c, r, d, n, γ	$(10\bar{1}9)$**	(r, n) (n, n')	
J.O. Crystals of Redondo Beach, USA (Ramaura synthetic rubies)	Bi_2O_3-La_2O_3-PbF_2 and/or PbO_2	c, r, d	n	(r, r') (r, d)	$(10\bar{1}0)$ r

* after Schmetzer (1985)
** after Knischka & Gübelin (1980)

hexagonal prism as well as growth planes parallel to different second-order hexagonal dipyramids with the exclusion of n $(22\bar{4}3)$, strongly indicates rubies of natural origin. On the other hand, the recognition of families of straight parallel growth planes which are parallel to the negative rhombohedron d $(01\bar{1}2)$, or parallel to the negative rhombohedron γ $(01\bar{1}5)$ have to be taken as an indication for a synthetic gemstone of one of the commercial productions. Families of growth planes parallel to the positive rhombohedron $(10\bar{1}1)$ and parallel to the second-order hexagonal dipyramid n $(22\bar{4}3)$ are common in synthetic rubies. However, the recognition of one single family of growth planes parallel to the aforementioned faces alone is of no diagnostic value, because straight parallel growth planes of r and n faces were occasionally observed in natural gem rubies also.

By the investigation of growth planes it is possible to recognize single planes parallel to prism faces in some of the commercially available synthetic rubies also. However, this structural feature, which is often found in Chatham synthetic rubies, is not a single growth plane but a twin boundary (Table 2). This single plane (twin boundary) is quite different in its appearance in the gem microscope from a family of straight parallel growth planes. However, it is important to avoid confusing these two structural properties.

Under these preconditions it is possible to discuss the applicability of angular growth banding in synthetic flux-grown rubies for diagnostic purposes. Parallel growth planes which do not intersect were often described in flux-grown rubies of commercial productions. These growth bands, however, were, until now, assumed not to be of diagnostic value. In particular, families of parallel growth bands that form an angle were taken as identical in natural and synthetic ruby and not diagnostic (cf. Crowningshield, 1969–1970; Kane, 1979, 1983; Knischka & Gübelin, 1980; Gübelin, 1982 a,b). The samples of natural and synthetic ruby which were investigated for this paper, however, strongly indicate distinct differences between families of parallel growth planes that form an angle. Families of parallel growth planes that form an angle of 120°, which are parallel to two distinct faces of the second-order hexagonal prism a $(11\bar{2}0)$, are found to be common in natural rubies of different localities (Figs. 8–10). Characteristic growth planes that form an angle are summarized for synthetic rubies in Table 2. The angle made by the two faces in synthetic rubies (cf. Table 1) is different from 120° (Figs. 8, 11–15). Growth structures of this type might be observed only quite rarely in natural rubies. On the other hand, this type of growth structure is common in synthetic rubies of commercially available productions. The recognition of families of growth planes that form an angle different from 120°, i.e. the angle is not formed by families of growth planes parallel to the prism a $(11\bar{2}0)$, though not unambiguous, could be used as a hint towards synthetic ruby. The recognition of one of these structural features in a ruby, which is assumed to be of natural origin, strongly indicates further investigations in order to find properties which unambiguously solve the problem. In other words, structural features as described above in a sample which is not confirmed as natural by other characteristic properties, strongly indicate great caution because they are typical and common for synthetic stones.

It has to be underlined that the determination of growth planes in rubies of unknown origin with the method described in this paper should be used as an additional investigation supplementary to the routine methods which, in general, are applied to unknown samples of this type in order to prepare certificates for the stones. The possibility of giving general and simple determinative properties, which

Fig. 9. Families of straight parallel growth planes that form an angle, Kenya ruby; planes parallel to prism faces a $(11\bar{2}0)$ form an angle of 120°. – 14x.

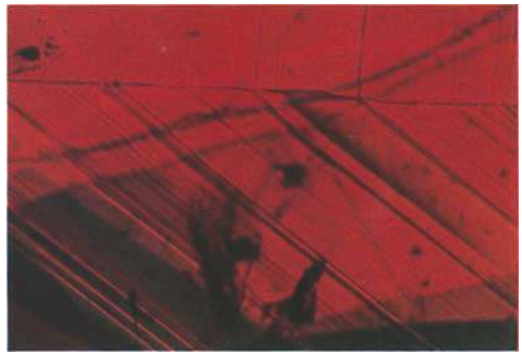

Fig. 10. Families of straight parallel growth planes that form an angle, ruby from Sri Lanka; planes parallel to prism faces a $(11\bar{2}0)$ form an angle of 120°. – 35x.

Fig. 11. Families of straight parallel growth planes that form angles, Chatham synthetic ruby; planes parallel to n $(22\bar{4}3)$, r $(10\bar{1}1)$ and n' $(22\bar{4}3)$ form two angles of 154.0°. – 35x.

Fig. 12. Families of straight parallel growth planes that form an angle, Chatham synthetic ruby; planes parallel to d $(01\bar{1}2)$ and n $(22\bar{4}3)$ form an angle of 148.0°. – 45x.

Fig. 13. Families of straight parallel growth planes that form an angle, Kashan synthetic ruby; planes parallel to r $(10\bar{1}1)$ and n $(22\bar{4}3)$ form an angle of 154.0°. – 28x.

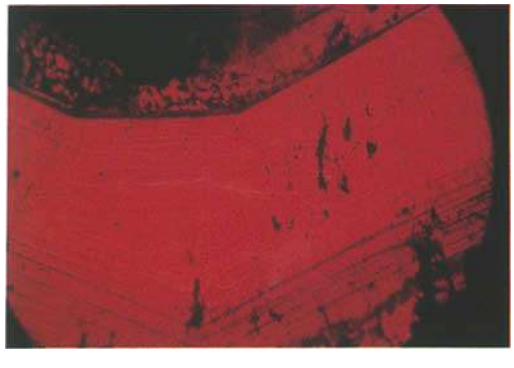

Fig. 14. Families of straight parallel growth planes that form angles, Knischka synthetic ruby; planes parallel to n $(22\bar{4}3)$, r $(10\bar{1}1)$ and n' $(22\bar{4}3)$ form two angles of 154.0° (upper part of the photograph, representing the centre of the crystal); planes parallel to n and n' form an angle of 128.0° (lower part of the photograph, representing the rim of the crystal). – 38x.

Fig. 15. Families of straight parallel growth planes that form an angle, Ramaura synthetic ruby; planes parallel to r and r' $(10\bar{1}1)$ form an angle of 86.1°. – 40x.

are found either in natural rubies from different localities or in synthetic rubies of different producers, is more and more diminished with the appearance of every new type of synthetic ruby. The method for a distinction of natural and synthetic ruby using absorption spectroscopy in the ultraviolet region as described by Bosshart (1981, 1982), for example, was not applicable to the recently produced Ramaura synthetic rubies (Bosshart, 1983). This type of synthetic ruby, however, very frequently shows families of straight parallel growth planes that form an angle of 86.1° (Fig. 15) consisting of two families of growth planes parallel to the predominant positive rhombohedron (r, r′). This structural feature, at present, was neither observed in other synthetic rubies nor in natural stones by the author. In addition, the presence of parallel growth planes parallel to n $(22\bar{4}3)$ in an unknown sample under consideration strongly indicates that the stone is not a Ramaura synthetic ruby.

For the determination of rubies of unknown origin the investigation by conventional microscopic techniques, and the investigation of the absorption spectrum in the ultraviolet region is suggested in addition to the determination of growth features which are described in this paper. By a combination of all methods mentioned an almost complete set of data should be available which enables an unambiguous determination of an unknown sample.

A further possible application of the new sample holder is the distinction of natural and synthetic yellow corundum. Curved growth bands are known to every gemmologist from the investigation of synthetic Verneuil-grown ruby. In synthetic Verneuil-grown yellow corundum, however, these bands are developed very weakly or are not even recognizable by use of the gem microscope. An unambiguous criterion for Verneuil-grown sapphire, however, is the presence of glide planes parallel to the prism a $(11\bar{2}0)$, which are long known in gemmology under the designation Plato lines (cf. Schmetzer, 1985). Plato lines are described as families of intersecting structural planes parallel to the prism face that form an angle of 120°. In order to recognize glide planes in cut samples of doubtful origin it is important to place the optic axis of the sample exactly parallel to the microscope axis using immersion liquid and crossed polarizers. This optical orientation is very easily achievable with the horizontal and vertical axes of the new sample holder. Using the conventional type of sample holder with a vertical axis only, the orientation of the cut sample which is necessary for the recognition of glide planes (Plato lines) is very time consuming and often impossible.

Distinction of natural and synthetic amethysts

The efficiency of several experimental methods suggested for a distinction of natural and synthetic amethyst is discussed in great detail by Lind *et al.* (1983, 1985). The investigation by the gem microscope shows a number of characteristic properties which are recognized in a great percentage of natural amethysts:

- Sharp lamellar structures connected with a distinct colour zoning were, in general, observed parallel to several rhombohedral faces of the cut amethyst crystal.
- Feathers consisting of fluid inclusions and two-phase inclusions, frequently in the form of negative crystals, are common in natural amethyst.
- Mineral inclusions were determined as reddish-brown or black Fe-oxides or Fe-hydroxides.

These properties are used as criteria which indicate amethyst crystals of natural origin. In synthetic amethysts residues of the seed were determined occasionally. In some stones colour zoning consisting of broad bands parallel to one single rhombohedral face, i.e., parallel to the seed used in crystal growth was observed (cf. Lind *et al.*, 1983, 1985). In 1983, Schneider & Dröschel pointed out that a diagnostic polysynthetic twinning on the Brazil law is found in natural amethysts. In contrast, synthetic amethysts of the trade were determined as untwinned single crystals. Unfortunately, the possibility of recognition of an optic axis figure indicating polysynthetic twinning by use of the conventional conoscope is strongly dependant on the direction of the optic axis versus the table of the cut gemstone. Furthermore, natural amethyst crystals generally consist of twinned and untwinned growth sectors, which reduces the applicability of the method (compare a more detailed discussion in the papers of Lind *et al.*, 1983, 1985). The revealing of a finger-print pattern by a repolishing procedure which is interpreted by Schneider & Dröschel (1983) to be due to the bringing-out the lamellar repeated twinning, certainly needs a skilled investigator and two distinct steps of polishing.

The disadvantages in the distinction of natural and synthetic amethysts using the methods mentioned above, which are based on polysynthetic twinning in natural amethyst, are avoidable by the application of the improved sample holder which is described in this paper. With this sample holder polysynthetic twinning is observable in the gem microscope independent of the orientation of the optic axis versus the table of the cut stone and without an additional repolishing procedure.

In order to understand the diagnostic properties of polysynthetically twinned natural amethyst

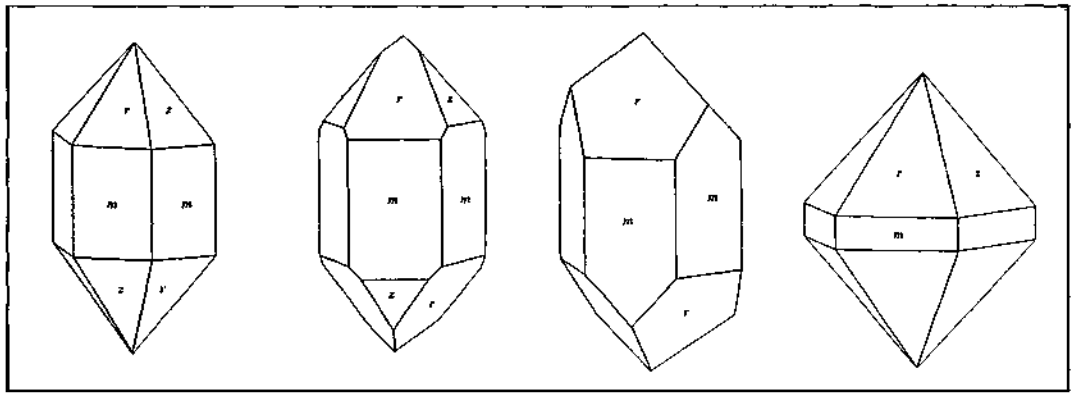

Fig. 16. The characteristic habit of quartz crystals with prism m (10$\bar{1}$0) in combination with the major rhombohedron r (10$\bar{1}$1) and the minor rhombohedron z (01$\bar{1}$1) as dominant forms; from Frondel, 1962.

crystals which are observable by use of the gem microscope, a short description of twinning in natural amethyst is given before the typical interference figures which are presented in this paper. The habit of natural amethyst is characterized generally by the major rhombohedron r (10$\bar{1}$1), the minor rhombohedron z (01$\bar{1}$1) and the prism m (10$\bar{1}$0). The size of both rhombohedral faces, r and z, is different in crystals from various localities (Fig. 16). In a part of the natural amethyst crystals, the major rhombohedron r is dominant over the minor rhombohedron z; in other amethyst crystals both crystal forms are almost identically developed. In addition, a part of the natural amethyst crystals is more or less of distorted habit. In order to understand the observations in the gem microscope it is important to mention that, in general, the sectors confined to the major rhombohedron r (10$\bar{1}$1) consist of polysynthetically twinned lamellae of alternating right-handed and left-handed quartz. The sectors confined to the minor rhombohedron z (01$\bar{1}$1), however, do not show this type of twinning on the Brazil law; only a single twin boundary entering each z growth sector is observed (Fig. 17). The structure of twin boundaries in natural amethyst which is polysynthetically twinned on the Brazil law is extremely complicated. A detailed description was recently published by McLaren & Pitkethly (1982). This paper is suggested for additional reading. The complex interference figures of natural amethyst, consisting of black extinction bands, are known since the extraordinary paper of Brewster (1823), and, therefore, are sometimes also designated Brewster fringes in the literature.

The investigation of polysynthetically twinned amethyst in polarized light under crossed polarizers reveals more or less broad, straight or even curved black interference fringes (extinction bands) provided that the optic axis of the amethyst is arranged exactly coincident with the microscope axis. The extinction bands were found to separate lamellae of right-handed and left-handed quartz. The fringes appear black because light travelling along the optic axis passes through almost equal distances of right-handed and left-handed quartz. This is due to the complicated zig-zag structure of the Brazil twin boundaries as described in detail by McLaren & Pitkethly (1982). For additional reading compare the papers of Brauns (1932), Frondel (1962), Schlössin & Lang (1965), Hassan (1972), Balakirev *et al.* (1975) and Balitsky (1981).

In order to recognize interference figures of polysynthetically twinned amethyst or interference figures of amethyst single crystals for diagnostic determinations, it is only necessary to place the optic axis of the sample coincident with the microscopic axis. This is accomplished using both the horizontal and vertical rotation axes of the improved sample holder. Under these preconditions, tilting the amethyst towards a position, in which the angle between the optic axis and the microscope axis is small, and tilting the crystal back towards the original position again, the interference figure of an amethyst single crystal is found to consist of interference rings moving towards the rim and back towards the centre of the interference figure again (Figs. 18 and 19, compare also the interference figures of corundum in this paper). The interference figures of amethyst single crystals are easily distinguished from interference figures of polysynthetically twinned amethyst crystals (Figs. 20–30). These interference figures of cut amethyst crystals are dependent on the development of growth sectors confined to the major rhombohedron r versus the development of growth

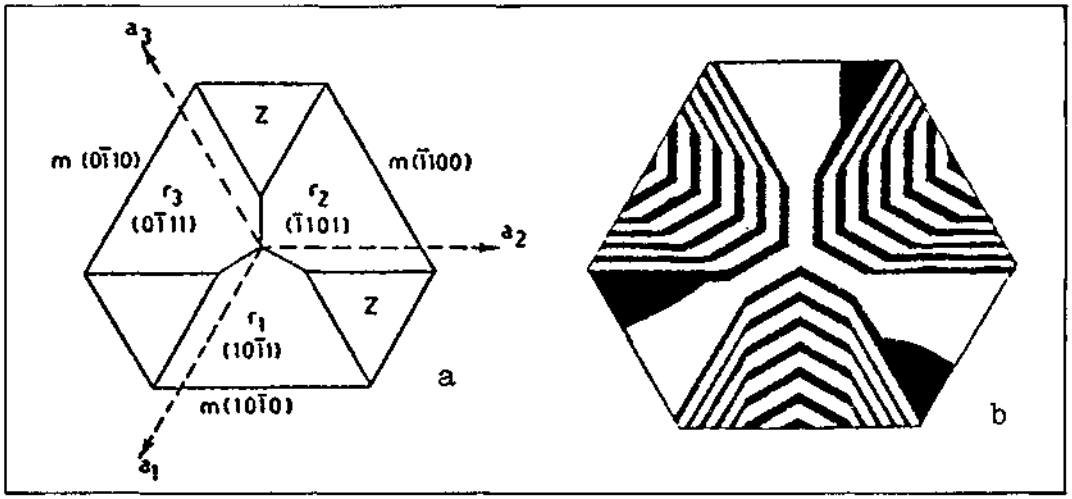

Fig. 17. Polysynthetic twinning in natural amethyst: a) amethyst crystal viewed in a direction parallel to the optic axis showing the major rhombohedron r and the minor rhombohedron z (from McLaren & Pitkethly, 1982); b) amethyst crystal viewed in a direction parallel to the optic axis showing polysynthetic twinning in sectors confined to the major rhombohedron with a single twin boundary entering each z growth sector; right-handed and left-handed quartz is white and black respectively (from Schlössin & Lang, 1965).

sectors confined to the minor rhombohedron z in the crystal under investigation. In addition, it is important from which part of the crystal the cut amethyst sample is originating. Furthermore, the relative distortion of an amethyst crystal may become important for the correct interpretation of the interference figure.

Most of the investigated natural amethyst crystals from different localities were found to be polysynthetically twinned on the Brazil law. Only few natural amethysts showed interference figures of quartz single crystals, e.g. some samples from Ceará, Brazil. These amethysts, however, were easily recognizable as natural samples due to solid state inclusions (reddish-brown Fe-oxides or Fe-hydroxides) in combination with a distinct colour zoning parallel to several rhombohedral faces. The investigated synthetic amethyst samples of commercial Japanese and Russian production, which are available to the author at present, were found to be single crystals not having the characteristic interference figures of polysynthetically twinned natural amethysts as described above. Only one sample of synthetic amethyst from Russian production showed twinning structures similar to a sample which was recently described by Balitsky (1981). In this type of synthetic amethyst a small part of the crystal consists of left-handed

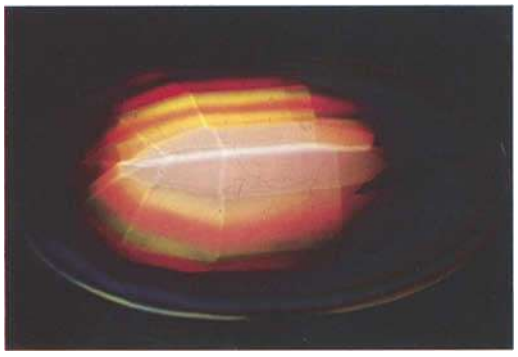

Fig. 18. Interference figure of an amethyst single crystal, the optic axis is nearly perpendicular to the table of the stone; synthetic amethyst of Russian production. – x pol., 12x.

Fig. 19. Interference figure of an amethyst single crystal, the optic axis is nearly parallel to the table of the stone; synthetic amethyst of Russian production . – x pol., 20x.

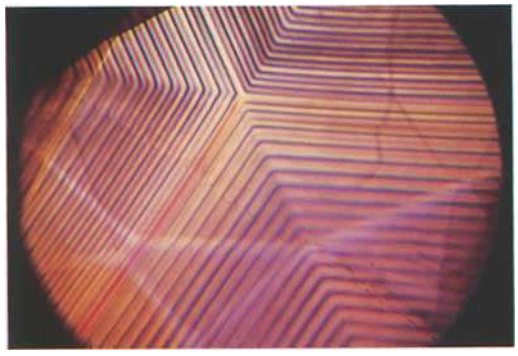

Fig. 20. Interference figure of a polysynthetically twinned natural amethyst, Zambia; twinning is observed in three sectors confined to the major rhombohedron. – x pol., 32x.

Fig. 21. Interference figure of a twinned natural amethyst, Zambia; twinning is observed in three sectors confined to the major rhombohedron. – x pol., 20x.

Fig. 22. Interference figure of a polysynthetically twinned natural amethyst, Montezuma, Brazil; twinning is observed in two sectors confined to the major rhombohedron, a single twin boundary entering one z growth sector. – x pol., 14x.

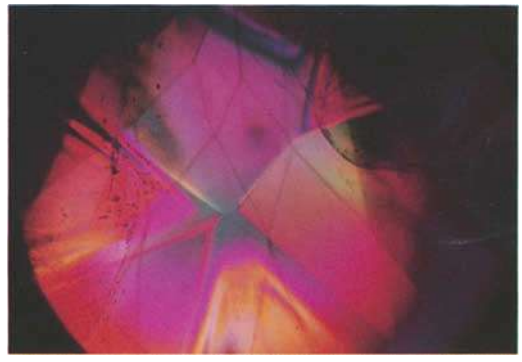

Fig. 23. Interference figure of a twinned natural amethyst, Zambia; twinning is observed only in sectors confined to the major rhombohedron and not in the sectors confined to the minor rhombohedron. – x pol., 20x.

Fig. 24. Interference figure of a twinned natural amethyst, Uruguay; curved extinction bands. – x pol., 28x.

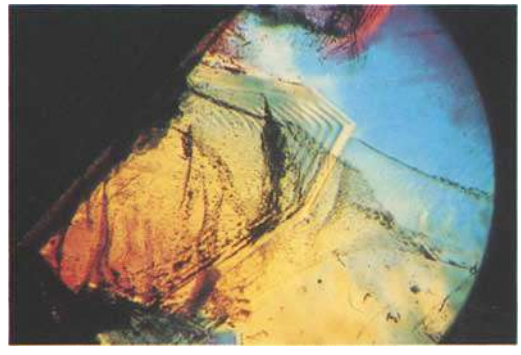

Fig. 25. Interference figure of a polysynthetically twinned natural amethyst, Jakobina, Brazil; twinning is observed in one sector confined to the major rhombohedron. – x pol., 25x.

quartz which is incorporated in a matrix of right-handed quartz in the form of thin triangular plates. Interference figures of samples having this type of twinning are distinctly different from the interference figures of natural amethyst crystals with polysynthetic lamellar twinning on the Brazil law.

The properties of natural and synthetic amethyst which are described in this paper should be taken as supplementary possibilities for a distinction of both types of gem materials. In general, in the opinion of the author, conventional microscopic investigation in combination with the study of the interference figure of a sample reveals enough information to separate natural and synthetic amethyst crystals. For those few samples, which cannot be determined by a combination of both microscopic techniques, infrared spectroscopy is suggested for further investigation (cf. Lind & Schmetzer, 1982, 1983). The study of interference figures is also applicable to the distinction of heat-treated natural amethyst, which is called citrine in the trade, and synthetic citrine crystals, which are also single crystals without a polysynthetic lamellar twinning on the Brazil law (cf. Balitsky, 1981).

Acknowledgements

Numerous ruby and amethyst samples, which were investigated in this paper, were kindly supplied by different firms in the gem trade as well as by private collectors. The comprehensive collections of Prof. Dr H. Bank of Idar-Oberstein, FRG, and of Dr R. Ledig of Stuttgart, FRG, were available for the present investigation. Additional samples were provided by Prof. Dr E. Gübelin of Meggen, Switzerland, and Dr H.A. Hänni of Basel, Switzerland. The author is grateful to the following firms of the gem trade including Gebr. Bank, Gebr. Goerlitz, Gebr. Henn, Gebr. Leyser, R. Litzenberger, J. Petsch, J.Ph. Wild, all of Idar-Oberstein, FRG, Karl Egon Wild of Kirschweiler, FRG, E. Blink of Pforzheim, FRG, and Dr Horst Krupp of Heidelberg, FRG. Gem materials which were not available in the gem trade were kindly given by the producers P.O. Knischka of Steyr, Austria, and T.H. Chatham of San Francisco, USA.

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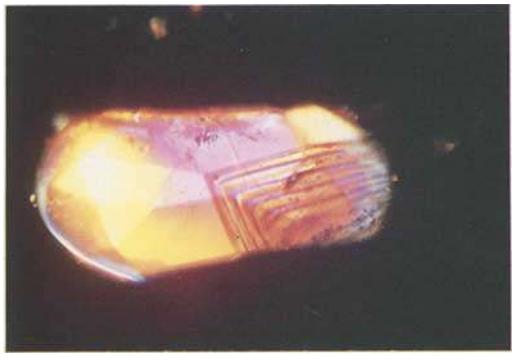

Fig. 26. Interference figure of a polysynthetically twinned natural amethyst, locality unknown; twinning is observed in one sector confined to the major rhombohedron. x pol., 24x.

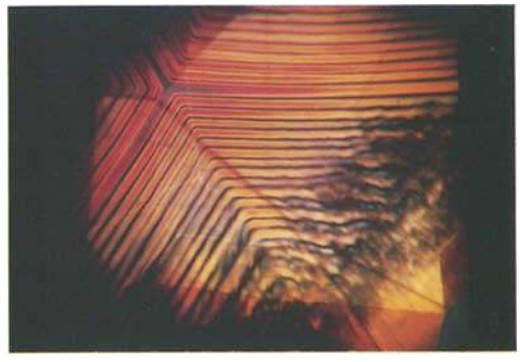

Fig. 27. Interference figure of a polysynthetically twinned natural amethyst, Area, Brazil; twinning is observed in three sectors confined to the major rhombohedron, in the right part of the crystal the straight parallel twin boundaries become irregularly curved lines. x pol., 20x.

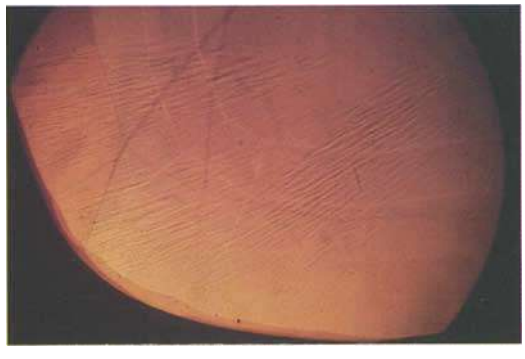

Fig. 28. In the area of Fig. 27 showing irregularly curved lines under crossed polarizers, without crossed polarizers an irregular growth structure is observed. – 28x.

Fig. 29. Interference figure of a twinned natural amethyst, Zambia; irregularly curved extinction bands. x pol., 20x.

Fig. 30. Interference figure of a polysynthetically twinned natural amethyst, Bahia, Brazil; irregularly curved extinction bands. x pol., 30x.

Accidental diamond coatings

Pamela J. Abramson, G.G.

Gemmologists who grade diamonds should be aware of unusual features that I noted recently while examining four diamonds. The four stones, set into two different rings, were in the estate of an elderly woman who had worn the rings constantly for over fifty years while she lived in Deland, Florida.

One diamond of 1.82 ct was set as a solitaire, and the other three stones, 1.23 ct, 1.53 ct, and 1.25 ct (all weights estimated by Leveridge method), were set side-by-side into the second ring. The first unusual feature of these stones was that they all fluoresced a brownish-yellow under short-wave ultraviolet light. The large solitaire showed a strong brownish-yellow fluorescence, while in the second ring the stones showed approximately the same brownish-yellow fluorescence although less intense.

Another unusual feature of the stones was that they showed evidence of a coating even though they had been thoroughly cleaned in a professional ultrasonic unit. At first I supposed that the coating had been nefariously applied, but then realized that it was too haphazardly placed for that to be the case and was most probably accidental. The coating looked like water spotting that had dried in a somewhat scalloped design around many of the facet junctions. Additionally, the coating in all cases covered the table completely.

Other features noted about the coating were: at certain places it seemed thicker than at others and in these thicker areas there was a tinge of a brownish-red colour; the coating could be scratched off with the metal tip of a pointer and had been scratched through wear especially on the tables. Looking through each of the stones, an effect very much like internal graining was quite evident.

With research I found the following information concerning accidental coatings in Eric Bruton's *Diamonds* (second edition, page 385):

> On very rare occasions a cut diamond acquires a coating by accident that depreciates its colour. One such case was reported by Robert Crowningshield, Director of the GIA Gem Trade Laboratory in New York, in 1966. An engagement ring with a stone of less than half a carat had become gradually yellow over eighteen months. Examination showed a brownish-yellowish coating that would not wash off. After treatment with hot acid, the original fine white colour was restored. The coating was apparently caused by the local iron-rich water.

Checking with the trust officer of the estate I found that the owner of the rings had worn them daily for many years in Deland, Florida, and had used well water at her home. Subsequent calls to State water management officials supplied the information that there indeed is a high level of iron in the well water of the Deland area.

Diamond graders and appraisers should be aware of this uncommon yet significant problem in determining colour grades of diamonds. Although I was not given permission to boil these diamonds in an acid bath in order to remove the coating, I am certain that colour grades would be improved with its removal. The most telling evidence of this, of course, is the fact that where the coating thickened a darker colour was quite visible.

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Notes from The Laboratory

K. Scarratt

British Gem Testing Laboratory of the London Chamber of Commerce and Industry

During the course of any one year anything between 80,000 and 150,000 pearls are submitted to the Laboratory for examination. Of these, approximately 80% are found to be natural pearls, and the remaining 20% cultured pearls. Imitation pearls are only rarely submitted. Insofar as our memory serves us, during at least the past ten years we cannot remember having seen pearls with internal structures similar to those depicted in the radiographs (Figs. 1 and 2) taken by Steve Kennedy.

Both radiographs are of single cultured pearls. One appears to show three separate nuclei (Fig. 1) i.e., two mother-of-pearl beads and a non-nucleated (tissue-nucleated) cultured pearl, inside the first pearl. The other (Fig. 2) shows two separate nuclei, both of which are non-nucleated (tissue-nucleated) cultured pearls, inside the second pearl.

Since recording these, we have seen further similar examples and are left wondering whether these pearls are the result of a deliberate culturing process, or whether they were just formed accidentally.

* * *

Some two years ago we were shown a transparent green idocrase by David Kent, F.G.A., which appeared to produce only a single shadow edge on the refractometer at 1.722. For the record, a scraping was taken from this stone to enable the production of an X-ray powder diffraction photograph, and the identification was confirmed. Few gemmological textbooks give the student of gemmology any warning that some idocrases have a very small measurable birefringence. Anderson[1] states, 'a very small double refraction' and gives a figure of 0.005, and Webster[2] does not mention birefringence in specific terms at all. G.F. Herbert Smith[3] on the other hand, states that the optical properties of idocrase are of 'unusual interest because of the remarkably small amount of double refraction displayed. It may be as little as 0.001 and rarely exceeds 0.010'.

In a parcel of three stones submitted to us for examination (Fig. 3) one, a 'pink' zircon, weighing just 0.26 ct was found to owe its colour to a stain which had penetrated its flaws. Another, which was also a small stone of just 0.35 ct, was found to be rutile, and the third, weighing 1.71 cts was found to

Fig. 1. Radiograph of a cultured pearl containing two mother-of-pearl beads and a non-nucleated (tissue nucleated) cultured pearl.

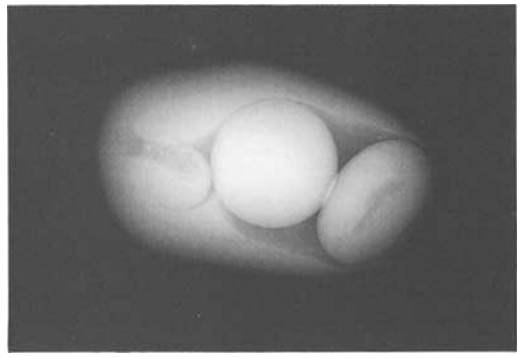

Fig. 2. Radiograph of a cultured pearl containing two non-nucleated (tissue nucleated) cultured pearls.

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Fig. 3. Rectangular natural rutile weighing 0.35 ct, round stained zircon weighing 0.26 ct, and an oval idocrase weighing 1.71 ct.

Fig. 5. A diamond-topped doublet set in a ring.

Fig. 6. Scratch marks seen in the plane of the girdle (junction plane) of the diamond-topped doublet depicted in Fig. 5.

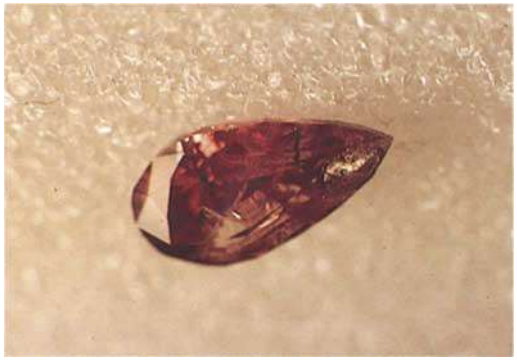

Fig. 8. A naturally coloured deep pinkish-mauve diamond weighing 0.76 ct.

Fig. 10. Three small haüynes weighing 0.152, 0.108 and 0.098 ct, and two larger sodalites, one oval and the other rectangular.

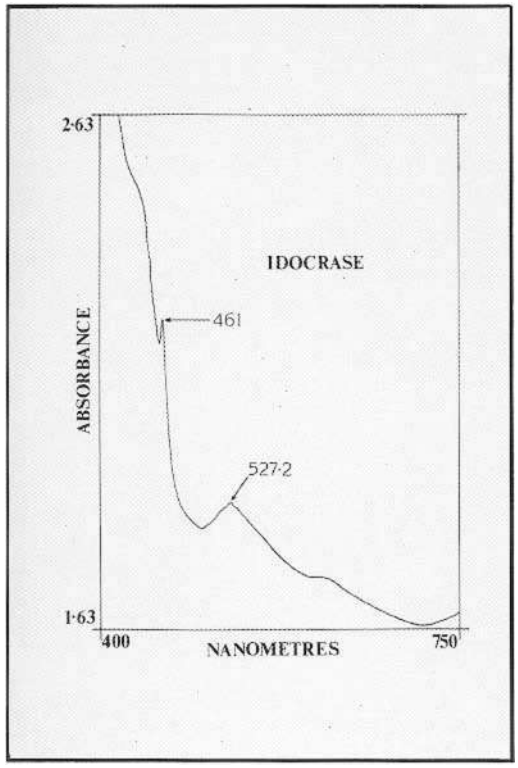

Fig. 4. The absorption curve of the 1.71 ct yellowish-brown idocrase depicted in Fig. 3. The curve was obtained using a Pye Unicam PU8800/03 UV/visible spectrophotometer (Basil Anderson model) with a speed of 0.5 nm/s and a bandwidth of 0.5 nm at room temperature.

be a yellowish-brown idocrase. For the third stone, a birefringence of 0.001 was just perceptible on a Rayner Dialdex refractometer (RI 1.705–1.706). The SG was found, by hydrostatic weighing, to be 3.35. The stone was free of any but the smallest dot-like inclusions, and its absorption spectrum taken with light passing almost parallel to its optic axis was typical for idocrase (Fig. 4).

* * *

Although a number of diamond-topped doublets are held in collections, only rarely are they encountered within the jewellery industry. Thus it may not immediately occur to a trader that the stone set in a ring we were asked to examine (Fig. 5) could be a doublet of this type.

An examination of the stone with a 10x lens though would reveal the many scratch marks and flattened bubbles which can be seen in the plane of its girdle (Fig. 6). With the alteration of the light angle and direction it would be noticed that the crown facets may be mirrored in this same plane; confirming that it is a doublet.

It should be remembered that the results obtained from testing this stone on a reflectivity meter or thermal conductivity probe will only indicate that the portion being tested (the crown) is diamond and not that it might be a composite stone.

* * *

The naturally coloured pink diamonds that have been submitted to the laboratory for examination have, in the main, tended to be of two types. The larger stones (and the majority) which are generally a light pink and have type IIa diamond characteristics. The smaller stones are usually at least partly type Ia, diamonds in which the colour may be seen to be concentrated within planes running through the stone.

A diamond we were asked to examine recently was of the second type in that the colour was located

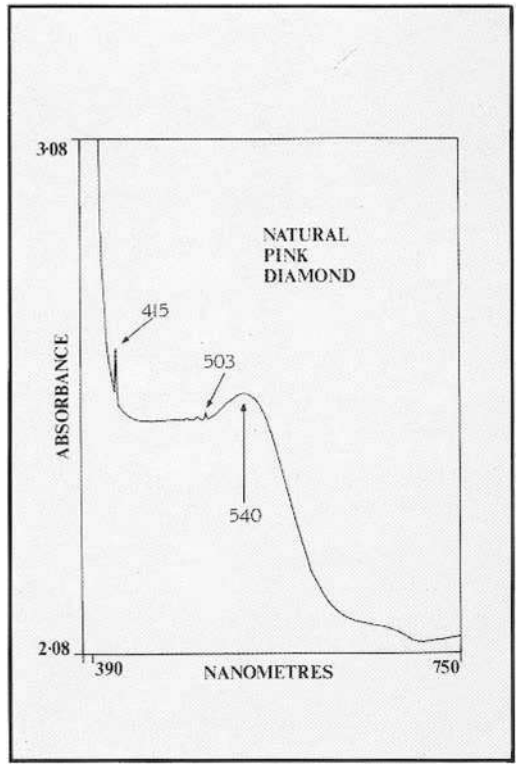

Fig. 7. The absorption curve of the naturally coloured deep pinkish-mauve diamond depicted in Fig. 8. The curve was obtained using a Pye Unicam PU8800/03 UV/visible spectrophotometer (Basil Anderson model) with a speed of 0.5 nm/s and a bandwidth of 1 nm at approximately 120°K. The path length was approximately 4.6 nm.

within planes and as can be seen from Fig. 7 the spectrum had type Ia characteristics. The spectrum is comparable with that of a natural pink diamond published by Collins[4] but the apparent body colour of this stone is remarkable in that it is as close to red as a stone could be without actually being that colour (Fig. 8). The colour is in fact a deep pinkish-mauve. The stone weighs only 0.76 ct.

* * *

Of all the items used in jewellery one would have thought the least likely to have an imitation made of it was the misshapen and individually graceless non-nucleated (tissue nucleated) cultured pearl that is being imported from China and Japan.

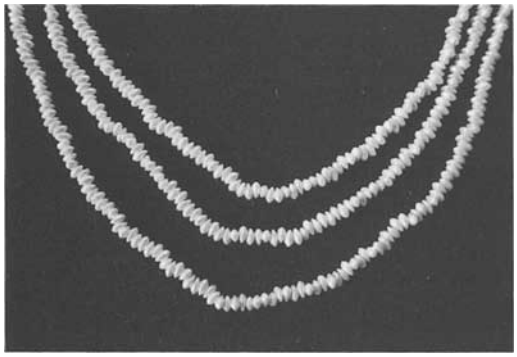

Fig. 9. A necklace of imitation pearls, simulating the appearance of non-nucleated (tissue nucleated) cultured pearls.

However, the current promotional campaign for this type of cultured pearl, which is aimed at the trade, is resulting in them becoming fashionable. As there is a tendency to imitate items in fashion, we should have expected the necklace of imitation pearls shown in Fig. 9 to appear.

* * *

As lapis-lazuli is said to owe its beautiful colour to the presence of haüyne or its sister mineral lazurite the author was pleased to receive three transparent examples of haüyne (Fig. 10) from Alan Jobbins for the purpose of examining their ultraviolet visible spectrum.

The three stones weighed 0.152, 0.108 and 0.098 ct. One fluoresced a weak orange under long-wave ultraviolet light whilst the other two were inert. Under the influence of short-wave ultraviolet light all fluoresced a dull red.

One stone produced only a vague shadow edge on the screen of a Rayner Dialdex refractometer in the region of 1.504, but much clearer readings were obtained for the other two stones, and for both an RI of 1.504 was recorded. A collective SG of 2.48 was obtained by the hydrostatic method.

For comparison purposes, the absorption curves of an oval faceted sodalite (Fig. 10), and a thin slice of lapis-lazuli were also recorded. The sodalite weighed 0.49 ct, gave a clear RI reading of 1.485 and had an SG of 2.327.

Two curves were recorded from two different areas of good blue colour in the lapis-lazuli sample and both revealed similar characteristics. The dotted curve in Fig. 11 shows that lapis-luzuli absorbs light strongly between 700 and 500 nm, has a transmission area centred at 458 nm in the blue and begins to absorb light strongly again at wavelengths shorter than 400 nm.

The curve recorded for the sodalite (dashed curve in Fig. 11) also revealed a strong and wide absorption area from the red through to the green part of the spectrum. However, the transmission area in this case is not in the blue but is centred at 380 nm in the violet. The sodalite also transmits further into the ultraviolet than does the lapis-lazuli.

Curves were recorded for all three of the haüyne samples (solid curve in Fig. 11) and each had similar characteristics. In all cases the absorption area centred at approximately 596 nm, peaked more sharply than did the same area in the spectra of the sodalite and lapis-lazuli samples. The transmission area, as in the lapis-lazuli, is centred in the blue but in these cases at 472 nm. In all of the haüynes an absorption peak was detected at 379 nm

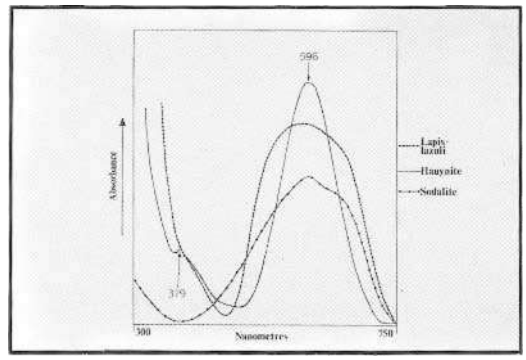

Fig. 11. The absorption curves of lapis-lazuli (dotted), haüyne (solid) and sodalite (dashed). All were obtained using a Pye Unicam PU8800/03 UV/visible spectrophotometer (Basil Anderson model) with a speed of 0.5 nm/s, bandwidth of 0.5 nm and a span of 2A, at room temperature. The path lengths were approximately 2.99 mm (sodalite), 0.46 mm (lapis-lazuli) and 1.87 mm (haüyne).

which was not seen in the sodalite or the lapis-lazuli samples. At wavelengths shorter than this peak the haüynes begin to absorb light strongly.

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Blue and green beryls (aquamarines and emeralds) of gem quality from Nigeria

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Abstract

Beryls of gem quality from a recently discovered mining area near Jos in Nigeria are described. The samples with refractive indices of n_o 1.570–1.574, n_e 1.564–1.568 and densities between 2.66 and 2.68 g/cm^3 show blue or green coloration of variable intensity. Crystals with colour zoning are frequently observed. The variable colours and colour intensities of the beryl crystals are caused by strongly varying concentrations of V, Cr and Fe. By spectroscopic investigations, absorption spectra which are typical for the blue beryl variety aquamarine (coloured by iron) and spectra which are typical for the green beryl variety emerald (coloured by chromium and vanadium) were measured. By microscopic investigations, a distinct growth zoning parallel to the basal pinacoid, the hexagonal dipyramid and parallel to the first-order prism was observed in aquamarines and emeralds, as well as two different types of two-phase inclusions.

Introduction

During 1984, several green beryl crystals and cut gemstones from a new occurrence were submitted for investigation in order to confirm the natural origin of the samples. In addition, some of the samples were used for an investigation of causes of colour in order to verify if the gemstones deserve the designation 'emerald'. From trade information the green beryls come from a mining area near Jos in northern Nigeria, which recently has been supplying large quantities of gem-quality aquamarines. However, at present no detailed information about the geological situation or the paragenesis of the occurrences of the variously coloured beryls are available.

In this paper, a general survey of the chemical, physical and gemmological properties of the new beryls from Nigeria is given. The necessity of a detailed investigation arose from difficulties in proving the natural origin of the first cut gemstones of this new type of beryl, which were not assignable to one of the known occurrences of emeralds according to their microscopical properties.

Materials and methods

For the present investigation about 20 rough crystals and 50 cut beryls of various colours and colour intensities were selected from a great quantity of samples in order to represent the colour variation of the material available.

Chemical data of 20 samples were measured by an automatic electron microprobe (ARL-SEMQ). For determination of the Li_2O, BeO and H_2O contents, which are not available from microprobe examination, two representative samples were selected for wet chemical analysis. A small quantity of powdered material from each of these two crystals was investigated by X-ray diffraction for determination of the unit cell dimensions of the samples (Guinier camera, $CuK_{\alpha 1}$ radiation, internal Si standard). In order to characterize the different types of water incorporated into the channels of the beryl lattice, infrared spectroscopy was applied to several samples (Perkin-Elmer 180). For investigation of the causes of colour, the absorption spectra of a great quantity of chemically analysed samples were recorded (Leitz-Unicam SP 800) in addition to trace element analyses by electron microprobe. Inclusions were determined microscopically in rough and cut samples.

Mineralogical properties

The rough material available for this investigation consisted of transparent crystals with prismatic habit; only the hexagonal prism of first-order $(10\bar{1}0)$ was developed. A small number of crystals were doubly terminated and showed a combination of hexagonal prism and basal pinacoid (0001), occasionally also a small hexagonal dipyramid $(11\bar{2}2)$. Two of the aquamarine crystals were intergrown with black tourmaline (schorl). Additional information concerning the paragenesis of the crystals is not yet available. However, topaz and tourmaline of gem-quality are known to come from cassiterite pegmatites near Jos. It is not quite certain if there is any relationship between these pegmatites and the host rocks of the Nigerian beryls.

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The colour of the samples (Fig. 1) varies from medium blue to light blue and almost colourless (bluish) and from medium green to light green and almost colourless (greenish). A distinct colour zoning, medium blue/light blue/colourless or medium green/ light green/colourless, was observed in a great number of samples. This remarkable colour zoning forms sharp boundaries between different coloured parts of one single crystal. The orientation of these colour boundaries was found to be parallel to the basal pinacoid (0001), or, in other samples, to be parallel to the first-order prism $(10\bar{1}0)$. Quite rarely, a colour zoning with blue and green parts in one single crystal was observed.

The chemical data of the investigated samples reflect the different colour shades and the distinct colour zoning of the beryl crystals. In all samples a strong variation of those trace elements which are responsible for the colour of the crystals, was evident by means of microprobe analysis. However, a direct correlation between the concentrations of the different colouring elements, Fe, V and Cr, was not observed in the samples investigated up to now. On the contrary, the trace elements Fe, V and Cr were found to vary independently in different parts of one crystal. An increase of the chromium concentration may be correlated with both, with an increase or with a decrease of the vanadium concentration. The Fe content, on the other hand, varies independently of an increase or decrease of the Cr- and/or V-concentration.

In Table 1 typical analyses of an intense blue beryl (sample 1) of a light blue, almost colourless crystal (sample 2), of a light green and a medium green coloured gem stone (samples 3 and 4) are quoted. The medium blue coloured sample 1 has a distinct Fe-content and very small amounts of V_2O_3 and Cr_2O_3. Though the Fe-content in sample 2 is almost twice as high as in sample 1, crystal 2 is almost colourless. This situation is explained by different valence states and/or lattice positions of Fe in the samples under discussion. Sample 4, which is medium green coloured, contains distinct amounts of V and Cr, in addition to a Fe-content of 0.13% FeO. The amount of these two colouring trace elements, on the other hand, is extremely low in the light green sample 3. The variation of the colouring trace elements in different beryl crystals from Nigeria is given in Table 2. It is worthwile mentioning that the V_2O_3 and Cr_2O_3 contents in

Fig. 1. Cut beryls from Nigeria. Size of the aquamarine 12 × 18 mm, (*photo by O. Medenbach, Bochum*).

Table 1: Chemical and physical properties of four selected beryl samples from Nigeria

Sample Colour	1 medium blue	2 light blue, almost colourless	3 light green	4 medium green
		Chemical data (wt. %)		
SiO_2	65.17	65.45	65.83	65.53
Al_2O_3	18.84	18.24	18.70	18.39
V_2O_3	0.03	–	0.01	0.06
Cr_2O_3	0.01	–	0.02	0.08
FeO*	0.46	0.89	1.13	0.31
BeO	13.60	13.65**	13.65**	13.70
Li_2O	0.02	0.02**	0.02**	0.01
MgO	0.03	0.04	0.02	0.20
Na_2O	0.10	0.17	0.14	0.15
H_2O	0.95	1.04**	1.04**	1.13
Total	99.21	99.50	100.56	99.56
* total iron as FeO		**average values from the determinations of samples 1 and 4		
		Numbers of ions on the basis of O=18		
Si	5.957	5.982	5.964	5.976
Al	2.029	1.965	1.997	1.977
V	0.002	–	0.001	0.004
Cr	0.001	–	0.001	0.006
Fe	0.033	0.068	0.086	0.024
Be	2.986	2.997	2.970	3.001
Li	0.007	0.007	0.007	0.004
Mg	0.004	0.005	0.003	0.037
Na	0.018	0.030	0.025	0.027
H_2O	0.290	0.317	0.314	0.344
		Physical data		
n_o	1.566(1)	1.566(1)	1.566(1)	1.566(1)
n_e	1.572(1)	1.572(1)	1.572(1)	1.572(1)
D [g/cm³]	2.67(1)	2.68(1)	2.67(1)	2.66(1)
a_o [Å]	9.2198(6)			9.2150(6)
c_o [Å]	9.1924(9)			9.1909(6)

green beryl from Nigeria are low compared with emeralds from other localities.

Emeralds, in which the V and the Cr concentrations are almost in the same range are known, until now, mainly from Colombia. Similar to the trace element concentrations in Nigerian beryls, Colombian emeralds may contain higher amounts of V than Cr or higher amounts of Cr than V (Staatz *et al.*, 1965; Gübelin, 1982 a,b; Hänni, 1981, 1982; Kuhlmann, 1983). The amounts of Na_2O and MgO in Nigerian beryls are very low, compared with the concentrations in beryls, including emeralds, from different localities (Staatz *et al.*, 1982; Franz, 1982; Graziani *et al.*, 1983; Schrader, 1983; Hänni & Kerez, 1983). Again, the Na- and Mg-contents in Nigerian beryls are similar to the contents in Colombian emeralds.

The contents of Na_2O and MgO in Nigerian beryls showed variations in different parts of one crystal or cut gemstone similar to the variation of the colouring trace elements. A correlation of different trace elements, e.g., an isomorphic replacement of the scheme $Al^{3+} \rightarrow (Fe^{2+}, Mg^{2+}) + Na^{+}$, could not be proved experimentally due to the small concentrations of Na and Mg. In addition, the knowledge of the Fe^{2+}/Fe^{3+}-ratios would be necessary to ascertain a correlation between (Fe^{2+}, Mg^{2+}) and Na^{+}. These ratios, however, cannot be determined by electron microprobe.

Investigations of both beryl varieties from Nigeria

Table 2: Variation of chemical and physical properties of beryls from Nigeria

Chemical data (colouring trace elements)	
V_2O_3	0.00 – 0.06
Cr_2O_3	0.00 – 0.08
FeO	0.08 – 1.20
Physical data	
n_o	1.570 – 1.574
n_e	1.564 – 1.568
Δn	0.006
D [g/cm³]	2.66 – 2.68

(medium blue aquamarine and medium green emerald) by infrared spectroscopy in the area between 4000 and 3000 cm^{-1} showed absorption bands at 3695, 3655 and 3590 cm^{-1}. According to Wood & Nassau (1967, 1968), these absorption bands are caused by two different types of water molecules incorporated into the channels of the beryl structure. In general, both types of water are present in natural beryl. The amounts of water, which were determined by chemical analyses in two selected samples (0.95 and 1.13 wt%, respectively) are found to be within the normal range of natural beryls.

The values of the refractive indices and densities for beryl samples from Nigeria (Tables 1, 2), are found to lie close to the lower limit of values which were published for natural beryls of different localities Černý & Hawthorne, 1976; Schrader, 1983). Only a small variation of the physical properties was measured in the Nigerian beryls investigated (Table 2).

The unit cell dimensions of both samples, which were investigated by X-ray powder diffraction, were found to be similar to the values of beryls with low contents of Fe, Mg and Na (Bakakin *et al.*, 1970; Filho *et al.*, 1973; Franz, 1982).

Absorption spectroscopy and naming of the beryl varieties investigated

The absorption spectra of the beryl samples from Nigeria are subdivided into three basic types. The medium blue beryls reveal a typical "aquamarine spectrum" (Fig. 2) with absorption bands of Fe^{3+} in the bluish-violet and in the ultraviolet area, absorption bands in the near infrared (with polarization ∥ and ⊥ *c*) due to Fe^{2+} on two different lattice positions and an absorption band in the red area (with polarization ∥ *c*), which is assigned to a Fe^{2+}/Fe^{3+} charge transfer process (cf. Samoilovich *et al.*, 1971; Price *et al.*, 1976; Parkin *et al.*, 1977; Goldman *et al.*, 1978; Platonov *et al.*, 1978, 1979; Blak *et al.*, 1982).

In light blue beryls (aquamarines) the intensities of the Fe^{2+}/Fe^{3+} band (with polarization ∥ *c*) in the red area and the Fe^{2+} absorption (with polarization ∥ *c*) in the near infrared are weak compared to medium blue samples. This decrease of the intensities of both absorption bands is explained by a decrease of the concentration of one of the two Fe^{2+} types. Both absorption bands are not observed in nearly colourless beryls. The spectra of such colourless crystals, however, show the Fe^{3+} absorption bands in the bluish-violet and the ultraviolet area and the Fe^{2+} absorption band (with polarization ∥ *c*) in the near infrared, none of which need be considered in the coloration of beryl.

In green beryl from Nigeria (Fig. 2), in addition to the Fe^{3+} and Fe^{2+} bands of colourless samples, strong absorption bands of V^{3+} and Cr^{3+} are observed in the red and bluish-violet area. In the absorption spectra of Colombian emeralds (Schmetzer *et al.*, 1974) and in the spectra of other oxides and silicates with similar V- and Cr-contents (Schmetzer & Ottemann, 1979; Schmetzer, 1982), a superposition of the V^{3+} and Cr^{3+} absorption bands is observed in the visible area. In general, both absorption bands in the visible area, which are responsible for the colour of the V- and Cr-containing minerals, e.g., for the colour of Colombian emeralds, and also for the colour of the new green beryls from Nigeria, are caused by both trivalent trace elements V^{3+} and Cr^{3+}. The influences of Fe^{3+} and Fe^{2+} on the colour of Colombian and Nigerian beryls are negligible. The only differences in the spectra of Colombian and Nigerian beryls are the variable intensities of the Fe absorption bands, e.g., the low intensity of the Fe^{2+} band in the near infrared (with polarization ⊥ *c*) in the spectra of Colombian emeralds. Therefore, the designation emerald for the medium green beryls from Nigeria is an appropriate one for these crystals.

A continuous transition between well coloured and almost colourless crystals is observed for both beryl varieties from Nigeria. A light green sample, for example, contained only 0.01% V_2O_3 and 0.02% Cr_2O_3 (cf. Table 1, sample 3). Bluish-green beryls with a distinct aquamarine and emerald component, reported to be common for crystals from Zambia (Schmetzer & Bank, 1980, 1981), are quite rare in the Nigerian material available at present.

Inclusions in beryls from Nigeria

In general, the beryl samples investigated (aquamarine and emerald) show prominent growth zoning parallel to three crystal faces: the basal pinacoid, the hexagonal dipyramid and the prism of first-order (Figs. 3–8). Mineral inclusions have not yet been observed in the material available.

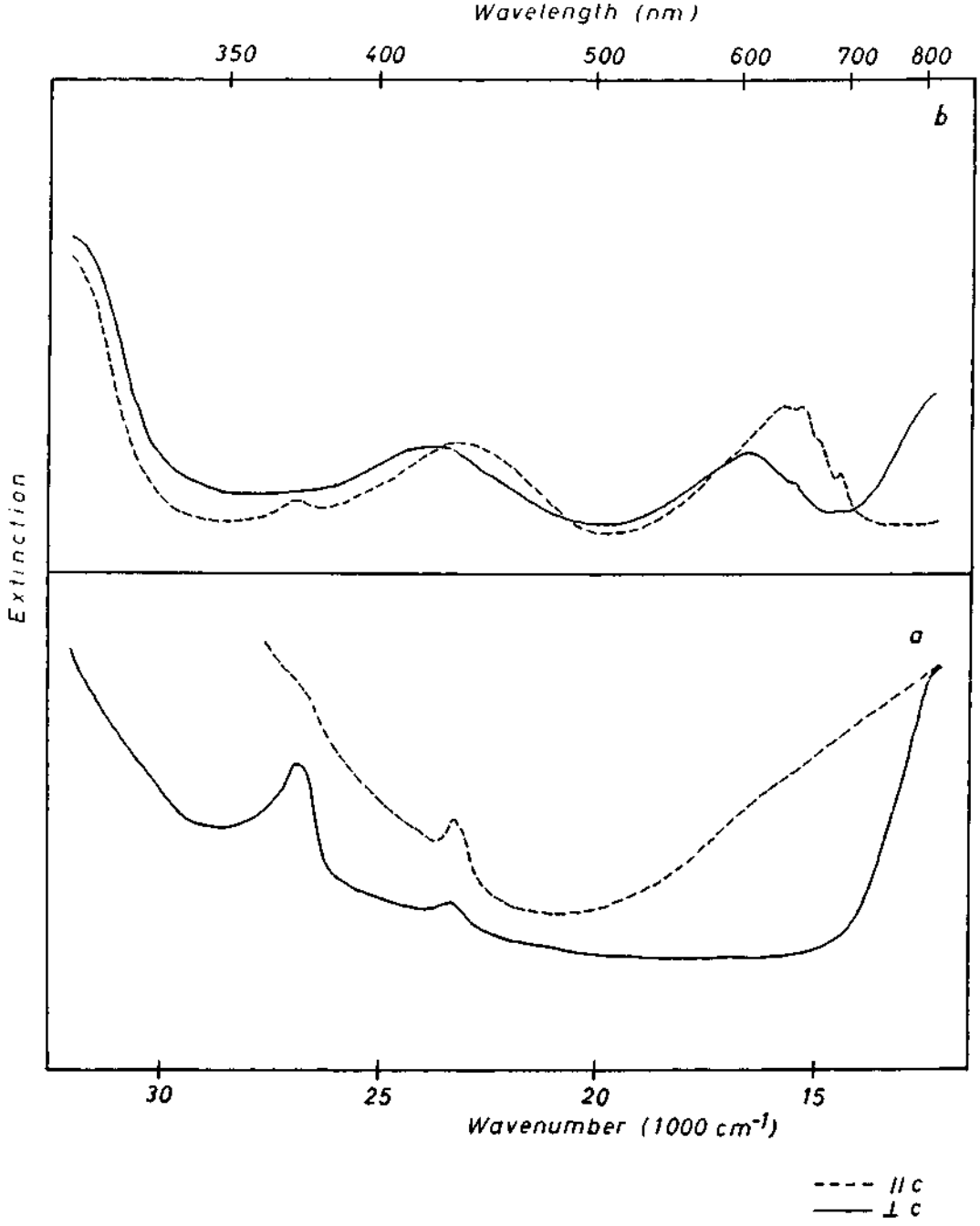

Fig. 2. Absorption spectra of beryls from Nigeria; a. aquamarine, not heat treated (analysis 1); pleochroism || *c* blue, ⊥ *c* almost colourless, light greenish. b. emerald (analysis 4); pleochroism || *c* bluish green, ⊥ *c* yellowish green.

Frequently, however, two different types of two-phase inclusions were found. The first type forms irregular feathers, in most cases in the cores of the crystals (Figs. 4, 9–11). The second type of two-phase inclusions was generally observed at the rims of beryl crystals with growth zoning parallel to the prism faces. This second type forms elongated, often jagged cavities parallel to the prism face (Figs. 12–14).

Acknowledgements

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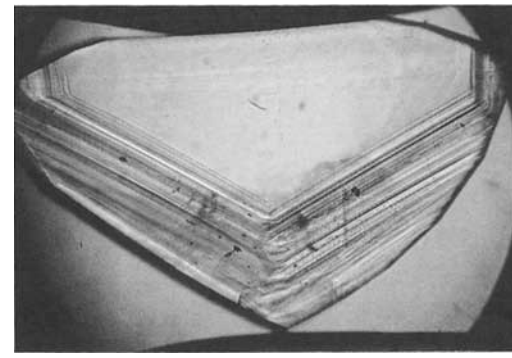

Fig. 3 Beryl from Nigeria: growth zoning parallel to the prism face ($10\bar{1}0$); view parallel to the *c*-axis. 20 x.

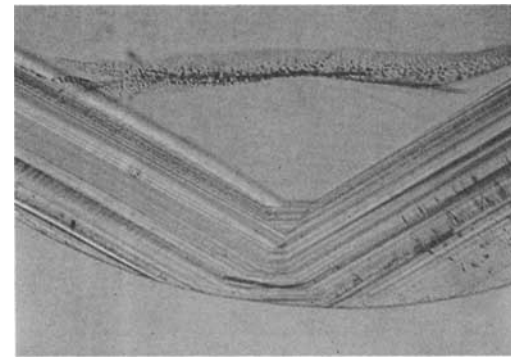

Fig. 4. Beryl from Nigeria: growth zoning parallel to the prism face ($10\bar{1}0$); view parallel to the *c*-axis; in the core of the crystal feather of fluid-inclusions and two-phase inclusions. 30 x.

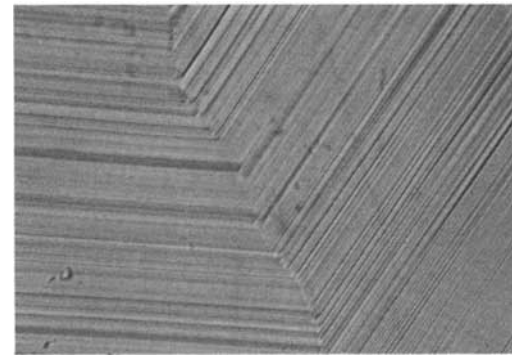

Fig. 5. Beryl from Nigeria: growth zoning parallel to the prism face ($10\bar{1}0$); view parallel to the *c*-axis. 30 x.

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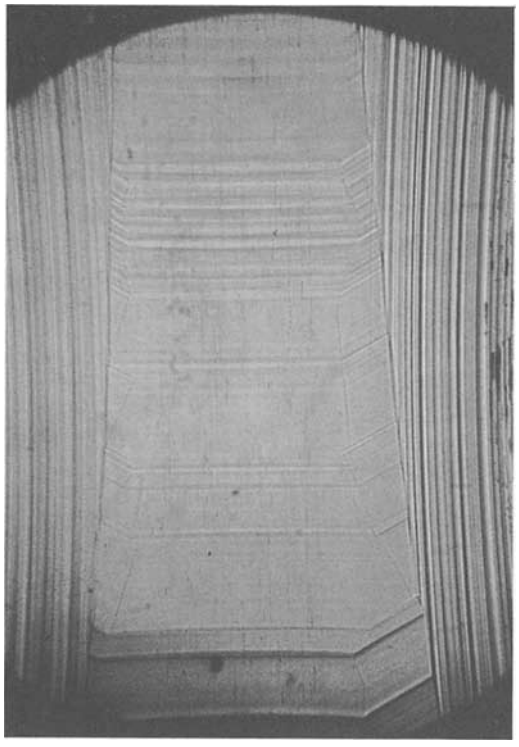

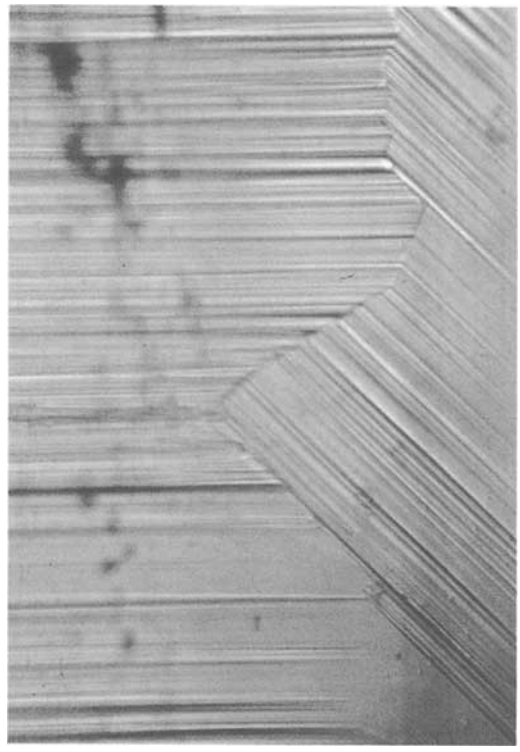

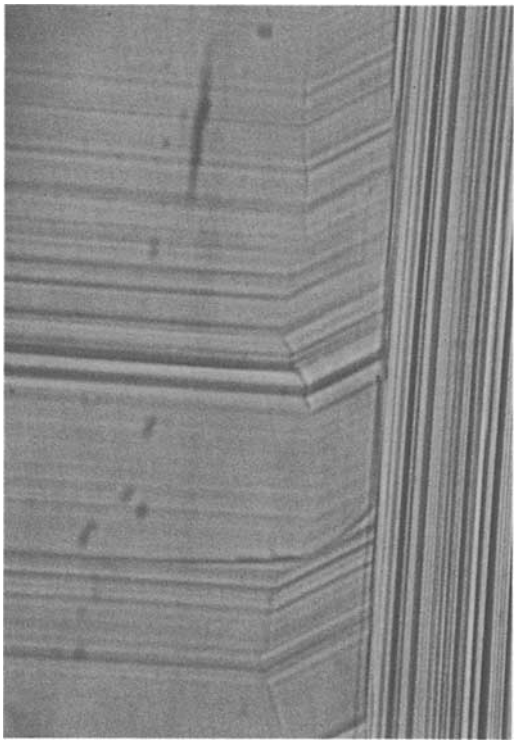

Fig. 6. (Above left.) Beryl from Nigeria: growth zoning parallel to the basal pinacoid, the hexagonal bipyramid and the prism faces; view perpendicular to the *c*-axis; the *c*-axis runs vertically. 22 x.

Fig. 7. (Above right.) Beryl from Nigeria: growth zoning parallel to the basal pinacoid, the hexagonal bipyramid and the prism faces; view perpendicular to the *c*-axis; the *c*-axis runs vertically. 50 x.

Fig. 8. (Left.) Beryl from Nigeria: growth zoning parallel to the basal pinacoid and the hexagonal bipyramid; view perpendicular to the *c*-axis runs vertically. 30 x.

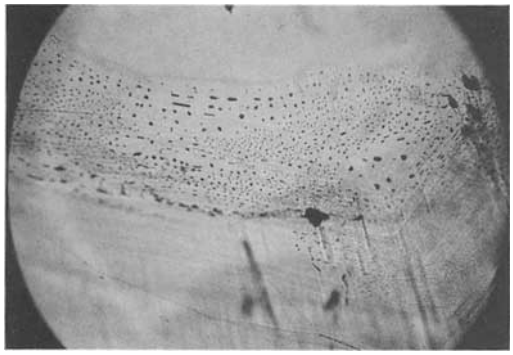

Fig. 9. Beryl from Nigeria: feather consisting of fluid inclusions and two-phase inclusions without orientation in the beryl lattice. 38 x.

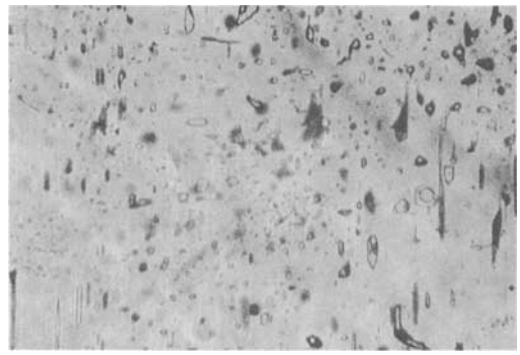

Fig. 10. Beryl from Nigeria: feather consisting of fluid inclusions and two-phase inclusions without orientation in the beryl lattice. 90 x.

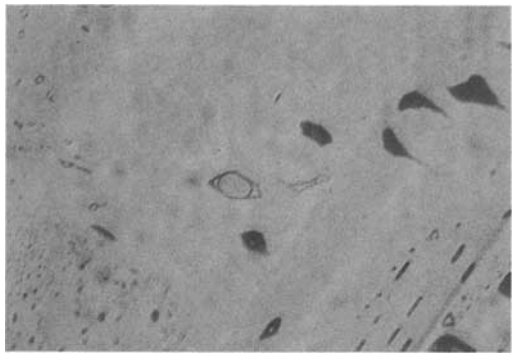

Fig. 11. Beryl from Nigeria: feather consisting of fluid inclusions and two-phase inclusions without orientation in the beryl lattice. 100 x.

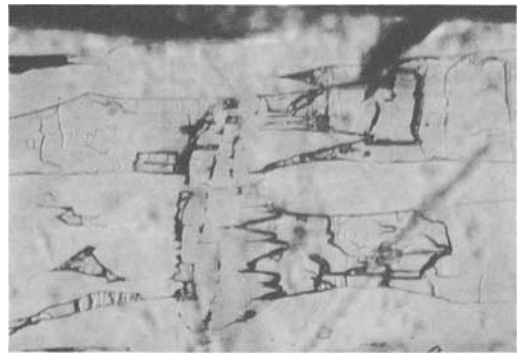

Fig. 12. Beryl from Nigeria: fluid and two-phase inclusions with orientation parallel to the prism $(10\bar{1}0)$. 55 x.

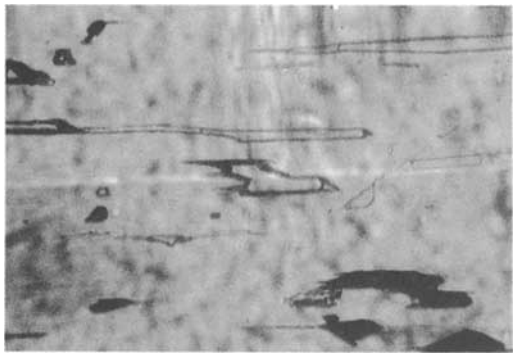

Fig. 13. Beryl from Nigeria: fluid and two-phase inclusions with orientation parallel to the prism $(10\bar{1}0)$. 70 x.

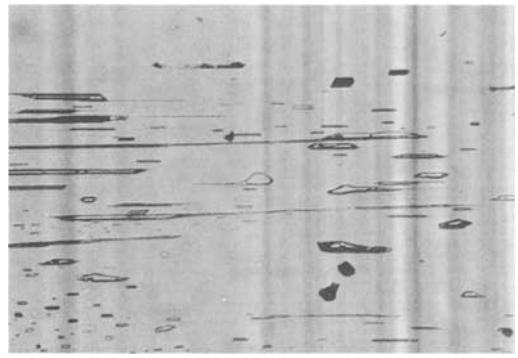

Fig. 14. Beryl from Nigeria: fluid and two-phase inclusions with orientation parallel to the prism $(10\bar{1}0)$. 55 x.

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Visual optics without the gloom

James B. Nelson, Ph.D., F.G.S., F.Inst.P., C.Phys., F.G.A.

The Hodgkinson method

A simple method was described by Crowningshield and Ellison[1] about 35 years ago which yielded useful information about the optical properties of gemstones.

This 'through-the-stone' testing method was, surprisingly enough, not followed up by gemmologists until its usefulness was 'rediscovered' recently by Hodgkinson[2]. He gave it the name 'visual optics' and showed in some detail how it could provide information on any faceted gemstone concerning its refractive index, birefringence, dispersion and spectral appearance. What is particularly intriguing about it is that this information, although highly approximate, can be obtained without the aid of instruments. In principle, all that is needed is a darkened room, a solitary, clear, small light source, and experience of the visual effects acquired from looking through known stones. The effects seen are quite independent of the size of the stone.

The technique, which has now come to be known as the Hodgkinson Method, is simplicity itself. It involves closing one eye and holding the stone between thumb and forefinger.

The table facet is presented to the seeing eye, so that it virtually touches the eyeball. If the source used is a *clear* domestic electric light bulb, then the stone is best held some three to six metres from it.

It is prudent to start with a brilliant-cut stone of low refractive index, like amethyst or citrine. When the stone's table is approximately perpendicular to the line-of-sight of the lamp's filament, concentric rings of tiny white or coloured images will be seen against a dark background. These spots are the spectral reproductions of the lamp's filament, arising from refraction through each of the stone's pavilion facets.

In such a stone of low refractive index, the complete inner ring of images can be seen by looking straight towards the light source. As the refractive index of the chosen stone is progressively increased, this ring of images becomes larger and larger. When the higher refractive indices are approached, only a portion of the innermost ring can be seen, and this by looking, not directly through the stone, but aslant.

For stones having the same pavilion angles, the diameter of the innermost ring of images is directly related to the refractive index. With a little practice, it is quite an easy task to estimate the refractive index of an unknown stone to an accuracy of ± 0.1 (e.g. 1.4, 1.5, 1.6, 1.7, 1.8). The diameter of the circle is mentally assessed, and compared with what has been observed for standard reference stones. Much experience is needed to judge the indices to an accuracy of, say, ± 0.02. Pavilion angles which depart greatly from those of brilliant-cut stones, such as those of 'fish-eye' or 'lumpy' cuts, can cause some initial confusion. However, with an awareness of this situation, suitable corrections can be made.

Birefringence is estimated from the appearance of the two tiny spectral images which constitute each facet spot.

Doubly refracting stones generally display two such images. For the low-dispersion stone, quartz, the two spectra overlap, producing some white. In the case of the highly birefringent peridot, the two spectra are widely separated. The gap between the same two spectral colours, say red, represents a measure of the birefringence.

Depending on the orientation of the optical axis/axes within the stone with respect to the viewing direction, the observed gap may be a maximum, zero or somewhere between the two. The latter situation is the one most commonly encountered.

Nevertheless, each stone must be rotated and tilted in different directions to ensure that it approaches, or attains, its diagnostic and maximum birefringence. Again, a range of reference stones is essential to guide the beginner.

Unlike birefringence, dispersion is virtually unaffected by the stone's optical axis orientation. The dispersion is estimated from the spread of the spectral images. The spectra are single for isometric

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stones or in pairs for uniaxial and biaxial stones. Overlapping spectra are easily coped with.

In an informative and entertaining article, Hanneman[3] suggested that the estimated birefringence: dispersion ratio (B ÷ D) could be a helpful variable. This article and a subsequent more theoretical one[4], together of course, with Hodgkinson's original paper, are required reading for anyone intending to explore the technique. His repeated view is that the mastery of the Hodgkinson Method ought to be a requirement in postgraduate courses in gemmology. This view is a sensible one, considering that with about ten minutes' practice, it is possible to recognize instantly a ruby, peridot or zircon, and this in a darkened room. With only a little more experience, diamond and cubic zirconia can be confidently distinguished. This is done by making use, not of the usual primary images, but of the faint, centrally-located secondaries, caused by internal total reflections.

The writer has found it possible to make the same distinction between ring-mounted stones using the crescent moon as a less prosaic light source. This moonlight experiment by a fiancée might well mark the collapse of a not-too-robust betrothal, if she happened to possess only this small piece of gemmological knowledge.

The method scores highest marks when the use of the normal range of instruments (apart from the 10X hand loupe and the Chelsea filter) is troublesome and awkward, is not rapid enough, or is frowned upon. These situations arise at the jeweller's shop-counter, the auction room, the valuers' premises and at the gem and jewellery shows. It also arises when collectors or commercial buyers are in certain foreign markets, especially in south-east Asia, where well-intentioned, but ill-informed traders can sometimes be encountered.

Difficulties in popularizing the method

What, one might ask, has the discussion of this still little-used technique to do with the subject of this article's title? It is this. In the formal teaching of a new procedure, difficulties always seem to be greatest at the beginning. If the method is to win widespread adoption, the most serious obstacles must be overcome. The main obstacle here, as it appears to the writer, is that of having a classful of beginners working in almost total darkness for more than a few minutes at a time. Each student will be labouring at different rates, levels and times, so that out of necessity the room will have to remain in the dimmest possible gloom for long periods. This hampers the normal classroom activities, such as 10X loupe stone-viewing, stone identity checking and exchange, note-taking, blackboard-explaining and the now, more frequent recovering of dropped stones. More importantly, this very different regime will find little favour with most instructors.

The other learning impediment concerns the single shared light source itself. The preferred source is a bare, non-frosted, 40-watt domestic bulb having a shallow "C"-shaped filament. It always comes as a surprise when looking through a stone to discover that this relatively weak illuminant can produce such a host of confusing and distracting images. These spring from mirror-like objects which are normally unobserved in a bright room. Also, the white walls and ceiling raise the background level of the stone's image from the desired velvety black to a disturbing white veiling or glare. When greater experience and confidence have been gained, such perturbances become much less important. Secondary and even large or multiple primary sources eventually come to be accepted as mild nuisances. However, they can cause beginners to regard the method as too complicated and stop them from investing the effort required to master it.

Modifications to the method

Both teaching obstacles could be overcome if it were found to be possible to carry out visual optics in a well-lit classroom. This is indeed practical if the source is sufficiently small and bright and is seen against a jet black background. Apparent source smallness is purely a matter of angular subtense (θ). Here θ is the angle seen at the eye, bounded by the actual size of the source (S) at a distance (D). For example, the full moon has a value of θ = 0.52°*.

A few experiments made by the writer with known faceted stones showed that quite acceptable spectral resolutions could be obtained with a θ value equal to about one-tenth of this (θ = 0.05°). Therefore an illuminated slit, 0.218 mm wide (S) and say, 3.0 mm long, viewed at the convenient distance of 250 mm (D) would subtend an angle of θ = 0.05°. Or a pinhole of 0.50 mm diameter (S), viewed at D = 573 mm, would yield the same θ of 0.05°. The intrinsic source brightness is proportional to the aperture dimensions. Thus the slit has fifty-five times the actual brightness of the pinhole for the same spectral resolving power. The higher efficiency slit is more costly to make, so a choice is available.

The barrel light source of the spectroscope unit described by the author[5] is used to illuminate either of these two apertures. The electroformed slit

* The moon's diameter = 3,476 km. Its mean distance from the earth (eye) is = 384,400 km. Its angular subtense is therefore $\theta = \frac{S \times 57.3^\circ}{D} = 0.518^\circ$.

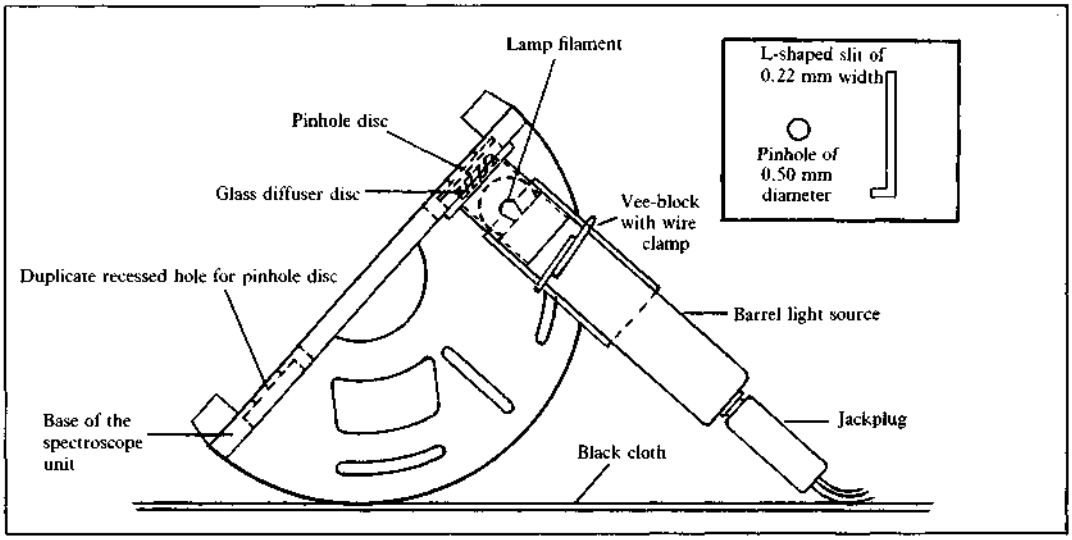

Fig. 1 Arrangement for viewing pinhole source

is enclosed in a cap containing a ground glass diffusing disc, which slides on to the barrel. As before, the vee-block clamp on the spectroscope unit's base allows the slit unit to be directed as desired. It can, of course, be used without the base.

For these situations 'in the field' already mentioned, it can be carried about with its pocket six-volt battery and flexible leads. See Fig. 2 of Reference 5.

The pinhole alternative consists of a small aluminium alloy disc with a pinhole drilled in its centre and with a glass diffuser filter disc cemented onto it. It is fitted to one of the two recessed holes in the unit's base. The disc can be seen in Fig. 5 of Reference 5.

The barrel light source is directed on to the pinhole disc and clamped. The unit as a whole can then be perched on end as shown here in Fig. 1. If the upturned unit is placed in the middle of a 400 mm square of black cloth, the beginner will see only the single, small, intense source of white light issuing from either the slit or the pinhole. There will be no other distracting light sources, so that when a stone is viewed, the tiny spectral images will be seen in sharp contrast against a truly black background.

Unlike the image of the C-shaped filament of the 40 watt light bulb, that of the pinhole is strictly symmetrical. This feature provides additional information about a stone. It enables the observer to judge the quality of flatness of the pavilion facets, provided that the refractive index (or indices) of the stone is uniform. Conversely, if the facets are seen to be reasonably flat, then mishapen, blurred or discontinuous spectral images may be observed. These are sure evidence of the presence of small local refractive index differences. These 'swirl marks' or striae effects are best seen with Sri Lankan hessonites and to a much lesser degree with many Burmese rubies. In the case of pastes, both features are usually present. Instant judgements can also be made as to the degree of angular regularity of the pavilion facets.

The slit source yields more intense and better quality spectra. The Oughton spectra[6] are easily visible with blue sapphires (except those from Sri Lanka), almandines, and didymium-bearing stones. The asymmetric shape of the slit permits distinctions to be made between primary and secondary images. Primary images will all have the same orientations; secondary images will have random orientations.

It is hoped that this review of the method and the suggestions for teaching aids might persuade more gemmologists to 'educate the eyeball' as Hanneman so succinctly puts it.

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[*Manuscript received 23 March 1985.*]

An Unusual Star Diamond

(Cover photograph)

S.J.A. Currie, F.G.A., New Zealand

The star diamond illustrated on the front cover is thought to be one of only four known specimens and this one takes the form of an exquisitely symetrical cubo-octahedron, with eight glassy octahedral faces and six rectangular hexahedral faces which are covered with small four-sided pits, giving them a superficially rough appearance.

The weight of the specimen is 0.21 ct, and the octahedral face diameter approximately 2.5 mm. The crystal is of generally light brown colour with the rays of the star a rather stronger brown. It has no major inclusions other than the minute 'bread-crumbs' which when illuminated yield the star effect. The crystal was described previously by R. K. Mitchell[1].

The specimen was brought to New Zealand by the late Mr Alan Fleming and since his death its whereabouts are uncertain. There is an unconfirmed report that it was sold to a Sydney (Australia) museum collection, but Mr Fleming treasured this stone so much that the writer's great fear is that it might still be in the pockets of his Sunday-best waistcoat, never to see the light of day again.

Orientated four-sided etch pits on the tetrahexahedral faces of the 0.21 ct 'star diamond' described.
Photograph by S.J.A. Currie.

The cover photograph was taken using a single flash on to one of the octahedral faces. The camera was a Nikon FM2 body fixed to the eye-tube of a Kyowa stereo-zoom microscope.

Reference

1. Mitchell, R.K. 1981. Star inclusion in diamond. *J. Gemm.*, **XVII**, 8, 584–8.

Gemmological Abstracts

ANDERSON, B. W. 1985. The search for the ideal high index refractometer. *Lapidary J.*, **39**, 4, 45-6.

A posthumous paper describing the history of attempts to manufacture a critical-angle refractometer from blende and diamond. M.O'D.

ATKINSON, D., KOTHAVALA, R. Z. 1985. Kaschmir-Saphir. (Kashmir sapphire.) *Lapis*, **10**, 10, 11-22, 22 figs (20 in colour).

An account of the recovery of blue sapphire from the Zanskar range in Kashmir, with references to other gem minerals found in the vicinity. These include tourmaline and aquamarine. M.O'D.

BALFOUR (I.). 1985. Famous diamonds of the world, XXII. The 'Eureka' diamond. *Indiaqua*, **41**, 2, 123-27, illus. in black and white and in colour.

Although the 'Eureka' diamond was found in late 1866 on the 'De Kalk' farm near Hopetown in the most northerly part of the South African Cape Colony, it is possible that several earlier finds may have preceded it and contributed to the realisation of the area's diamondiferous potential.

It was thought at the time that the diamond was discovered by Erasmus, son of Jacobs the farm owner, but later reports indicate that it was Jacobs' daughter who found the stone.

Early in 1867, the 'Eureka' passed through several hands before it was acquired and verified as a diamond by O'Reilly, a hunter and trader. O'Reilly tried to use the 'Eureka' as a means to persuade Parliament to reward him for being instrumental in the discovery of diamonds in South Africa, but he met with no success. Finally, he was persuaded to send the stone to Dr Atherstone, a well-known amateur geologist. Atherstone checked the stone and verified it as a 21.25 carat diamond woth £800.

After further verification in London, and the stone's inspection by Queen Victoria, who doubted South Africa as its country of origin (diamonds were only known to come from India or Brazil), it was purchased by Sir Philip Wodehouse who was Governor of the Cape Colony during the period of the 'Eureka's' discovery. The cut stone was eventually purchased in 1967 by De Beers and presented to the Speaker of the South African House of Assembly. The historic 10.73 carat cushion cut stone is now on permanent loan to the Kimberley Mine Museum. P.G.R.

BALFOUR (I.). 1985. Famous diamonds of the world, XXIII. The 'Star of South Africa'. *Indiaqua*, **41**, 2, 129-34, illus. in black and white and in colour.

The finder of the 83.5 carat 'Star of South Africa' was a young Griqua called Zwartboy. He made the discovery in 1869 near the De Kalk farm (where the 'Eureka' was found in 1866), and sold the gem to van Niekerk for 500 sheep, 10 head of cattle and a horse. The stone was initially valued at around £25000. Van Niekerk sold the stone to Lilienfeld Bros. for £11200.

The sale resulted in legal proceedings, as the Diamond Metal and Mineral Association had obtained a concession from Waterboer, Chief of the Griqua, for the sole prospecting rights to the territory. However, the judges of the Supreme Court in Cape Town found in favour of Lilienfeld, and the stone was sent to Amsterdam where it was cut into a 47.69 carat pear-shape. It was purchased by Lady Dudley, and after her death the stone reappeared at a Christie auction in 1974 where it was sold for £225000 to an unnamed purchaser. P.G.R.

BASSETT, A. M. 1985. The tourmalines of Nepal. *Mineralogical Record*, **16**, 5, 413-18, 5 figs (3 in colour).

Fine crystals of tourmaline up to 20cm in length have been found in two pegmatite mines in the Sankhuwa Sabha district of the Kosi zone of eastern Nepal. Some are bright grass-green elbaite, others are yellow-amber Mn-rich elbaite and still others are pink, lemon-yellow and green multi-coloured crystals. M.O'D.

BENESCH, F., WÖHRMANN, B. 1985. Toramalli: a short history of the tourmaline group. *Mineralogical Record*, **16**, 5, 331-8, 16 figs.

A summary of the references to tourmaline made by ancient writers and later. M.O'D.

BREUER, G., RATH, R. 1985. Influence of oblique illumination on the BECKE line. *Neues*

Jahrbuch für Mineralogie. Monatshefte, **6**, 251-4.
The Becke line is best observed using parallel light and with a small magnification. A mathematical reasoning supporting this is given.
M.O'D.

BURSILL, L. A., GLAISHER, R. W. 1985. Aggregation and dissolution of small and extended defect structures in Type Ia diamond. *American Mineralogist*, **70**, 5/6, 608-18, 15 figs.
The structure formed by nitrogen at various states of aggregation in diamond is reviewed. The structure ranges from a few atomic diameters to platelet shapes several microns in size. M.O'D.

CHERMETTE, A. 1985. La couleur des mineraux et des gemmes. (The colour of minerals and gemstones.) *Monde et Mineraux*, 67, 20-4; 69, 12-19. 22 figs (11 in colour).
The various ways in which minerals and gemstones get their colour are discussed with some high quality photographs and useful diagrams. A short bibliography is appended. M.O'D.

DESHPANDE, M. L. 1978. Gemstones and semi-precious stones. *Indian Minerals*, **32**, 1, 1-17, 1 fig.
Brief details of the more important gemstones are given, followed by lists of Indian deposits with future prospects. M.O'D.

DIETRICH, R. V. 1985. The tourmaline group: a résumé. *Mineralogical Record*, **16**, 5, 339-51, 22 figs (8 in colour). Taken from a recently published monograph* by the same author (and with the same title) the paper gives an up-to-date account of the chemistry and properties of the tourmaline group of minerals. There is a useful bibliography. M.O'D.

FISCHER, K. 1985. Peridot-Olivin in Edelstein qualität. (Peridot – gem quality olivine.) *Lapis*, **10**, 9, 31-40, 11 figs (10 in colour).
Gem varieties of olivine are described and beautifully illustrated. The various localities are reviewed. M.O'D.

FRANCIS, C. A. 1985. Maine tourmaline. *Mineralogical Record*, **16**, 5, 365-88, 30 figs (12 in colour).
Detailed account of the occurrence of tourmaline in the pegmatites of Androscoggin, Oxford and Sagadahoc counties, Maine. Separate localities are described and there is a useful bibliography.
M.O'D.

*DIETRICH, R. V. 1985. The tourmaline group. Van Nostrand Reinhold.

FRITSCH, E. 1985. La couleur des mineraux et des gemmes. (The colour of minerals and gemstones.) *Monde et Mineraux*, **70**, 12-22, 13 figs (8 in colour).
Discusses alteration of colour on irradiation, colour centres, diffraction colours, Tyndall scattering, asterism and chatoyancy. M.O'D.

HALL, A. M., THOMAS, M. F., THORP, M. B. 1985. Late Quaternary alluvial placer development in the humid tropics: the case of the Birim diamond placer, Ghana. *Journal of the Geological Society*, **142**, 5, 777-87, 6 figs.
Three chronostratigraphic units have been identified by radiocarbon dating of the diamondiferous sediments of the Birim River floodplain, Ghana; dates are 13000-11000, 9000-7000, and 21000 years BP to the present. Diamond grade is influenced by bedrock consistency, gravel thickness, gravel calibre and stratigraphic position, along with other external factors. M.O'D.

HEFENDEHL, K. 1985. Mineralien aus Sudkorea. (Minerals from South Korea.) *Lapis*, **10**, 9, 21-30, 20 figs (11 in colour).
Among the minerals found in South Korea are rhodochrosite, aquamarine, scheelite and fluorite, all of which may occur in gem quality. M.O'D.

HOFMEISTER, A. M., ROSSMAN, G. R. 1985. A spectroscopic study of irradiation colouring of amazonite: structurally hydrous, Pb-bearing feldspar. *American Mineralogist*, **70**, 7/8, 794-804, 14 figs.
Irradiation-induced colour in amazonite can develop only when both structurally bound H_2O and Pb impurities are present. The colour is caused either by an absorption minimum in the ß spectrum between three overlapping bands in the UV and a broad band in the area from 643 to 625nm (giving blue) or by a combination in the ß spectrum of one UV band and a broad band at 720nm giving a green colour or by both elements superimposed giving a blue-green body colour. All optical variations are correlated with an EPR pattern indicative of trivalent or monovalent Pb. M.O'D.

IVANKIN, P. F., ARGUNOV, K. P., BORIS, Ye.I. 1984. Changing environments of diamond formation in kimberlites. *International Geology Review*, **26**, 7, 795-802.
A relationship between injective and explosive processes of kimberlite formation is found and discussed. M.O'D.

KAZMI, A. H., PETERS, J. J., OBODDA, H. P. 1985. Gem pegmatites of the Shingus-Dusso

area, Gilgit, Pakistan. *Mineralogical Record*, **16**, 5, 393-411, 34 figs (13 in colour).

Very fine crystals of multi-coloured tourmaline, aquamarine, sherry-brown topaz and almandine-spessartine have been found in the pegmatites of the Western Himalayas, Gilgit District, Pakistan. The location is along the suture zone of the Indo-Pakistan and Asian crystal plates. M.O'D.

LINDSTEN, D. C. 1985. Emerald – the rarest beryl. *Lapidary, J.*, **39**, 5, 25-32, 6 figs (5 in colour).

Misleadingly-written and predictable article on emerald. M.O'D.

MARCUSSON, C. R. 1985. Recent work at the Himalaya mine. *Mineralogical Record*, **16**, 5, 419-24, 8 figs (5 in colour).

Fine crystals of tourmaline are again being recovered from the Himalaya mine in the Mesa Grande district, 83km north-east of San Diego, California. The crystals occur in pegmatites. The most spectacular ones are bi-coloured pink and green. M.O'D.

MUSCAT, B. 1984/1985. Sri Lanka – island of gems. *South African Gemmologist*, **1**, 2, 5-9; **1**, 3, 8-10.

An account of gem mining, with a historical emphasis, on Sri Lanka. M.O'D.

NASSAU, K. 1985. Miscellaneous gemstone treatments. Part 2. *Lapidary J.*, **39**, 3, 30-40, 10 figs (7 in colour).

This part of a continuing paper deals with dyeing, oiling and other methods of altering colour. A useful bibliography is given. M.O'D.

NASSAU, K. 1985. Gemstone enhancement. *Lapidary J.* **39**, 4, 16-23, 13 figs (9 in colour).

Describes the coating and foiling of gemstones, composites and synthetic overgrowth. M.O'D.

O'DONOGHUE, M. 1985. Industrial review – gemstones. *Britannica book of the year*, 274.

The state of the world gemstone trade is discussed with notes on the influence of political developments on gemstone supply.

(Author's abstract) M.O'D.

ORLANDI, P., SCORTECCI, P. B. 1985. Minerals of the Elba pegmatites. *Mineralogical Record*, **16**, 5, 353-63, 19 figs (5 in colour).

Fine tourmaline is well-known from the pegmatites of the Isle of Elba and is described here, along with other minerals. The occurrence is at Monte Capanne where it occurs as prismatic crystals in veins. Many crystals have black terminations (these are particularly common from the Graziano veins near San Ilario in Campo). Recently crystals with pale pink tips and green bases have been found in a vein at Fonte del Prete. M.O'D.

POUGH, F. H. 1985. Spectral gemstones – frozen rainbows. *Lapidary J.*, **39**, 6, 19-21, 2 figs in colour.

A brief account of the cause of colour in gemstones and how some of the colour-causing phenomena were first observed. M.O'D.

POUGH, F. H. 1985. General Electric's synthetic jadeite. *Lapidary J.*, **39**, 7, 42-4, 4 figs (3 in colour).

Synthesis of jadeite was announced by General Electric in 1984. The product was made solely for temperature and pressure studies and not for commercial use, though this may develop later. A Japanese synthetic jadeite is being worked on. Up to 40 kilobars pressure would have been needed for successful synthesis. M.O'D.

RUMYANTSEVA, Ye.V. 1983. Chromdravite – a new mineral from Karelia. *International Geology Review*, **25**, 8, 989-92.

Chromium up to 31.6 wt % is found in a tourmaline emanating from the Onezhskiy depression, central Karelia, U.S.S.R. RI is (ω) 1.778 ± 0.005, (ϵ) 1.722 ± 0.005, SG 3.40 ± 0.01. Pleochroic colours are dark green and yellow-green. M.O'D.

SCHMETZER, K., BANK, H. 1985. Crystal chemistry of zincian spinels (gahnospinels) from Sri Lanka. *Neues Jahrbuch für Mineralogie. Monatshefte*. 8, 353-6.

Chemical composition and physical properties of zincian spinels from Sri Lanka are discussed. Samples chosen were from the solid solution series spinel-gahnite within a compositional range from 95-45% spinel and from 0.2-50% gahnite. A complete solid solution series between aluminous spinel and an intermediate gahnospinel with about 50% of the gahnite end-member was confirmed. M.O'D.

SCHUMANN, W. 1985. Sculpting in precious stone. *Optima*, **33**, 2, 61-6, 7 figs in colour.

Short article, beautifully illustrated, about gem carving in Idar-Oberstein. Four of the illustrations depict cameos on show at the local gem museum. E.S.

SHOR, R. 1985. What if India offers quality diamonds at bargain rates? *Jewelers' Circular*

Keystone, **156**, 8, 187-201, 12 figs in colour.

A report on the growth of the Indian diamond cutting industry which is threatening those of Israel and Belgium in its low-cost turnover of fair-quality small stones. A bourse has been established at Bharat but it has not yet been recognized by the World Federation of Diamond Bourses. M.O'D.

THOMAS, A. 1984/1985. Perspective on gemmology. *South African Gemmologist*, **1**, 1, 3-6; **1**, 2, 3-4; **1**, 3, 3-5.

A survey of the current gemmological scene with particular reference to synthetic productions. M.O'D.

THOMAS, M. F., THORP, M. B., TEEUW, R. M. 1985. Paleogeomorphology and the occurrence of diamondiferous placer deposits in Koidu, Sierra Leone. *Journal of the Geological Society*, **142**, 5, 789-802, 8 figs.

The Koidu alluvial diamond field in Sierra Leone is examined on the basis of diamond distribution and geomorphology to give some idea of the emplacement of placers during the later Cenozoic. M.O'D.

ZEITNER, J. C. 1985. Gem fraud: problem for all. *Lapidary J.*, **39**, 3, 76-9.

Discusses the commoner frauds with particular reference to false appraisals. M.O'D.

ZEITNER, J. C. 1985. Gem chrysocolla. *Lapidary J.*, **39**, 6, 28-33, 4 figs (1 in colour).

Brief account of the ornamental stone chrysocolla with particular reference to North American deposits. M.O'D.

IDCA Newsletter is the official journal of the Indian Diamonds and Colour Stone Association, 22 West 48th Street, New York, NY 10036. U.S.A. Issue 2 of volume 1 contains a variety of short informative pieces on diamond and on the trade. M.O'D.

Jewellery studies, 1983/1984, 1, contains papers on a Phoenician earring; a sardonyx cameo acquired recently by the British Museum; Jewish marriage rings; Mughal jewellery; Royal wedding jewellery; the Layard family with particular reference to Lady Layard and her penchant for the work of Cortelazzo and Castellani, with other shorter papers. M.O'D.

Book Reviews

BARIAND, P., POIROT, J.-P. 1985. *Larousse des pierres precieuses, fines, ornamentales, organiques.* Larousse, Paris. pp.261. Illus. in colour. Price on application.

Most of this attractive book consists of gem materials described in alphabetical order but preliminary chapters deal with the symbolism of gemstones, their origin and historical use, their properties (in this section are some very fine photographs of inclusions) their fashioning and synthesis. At the end of the book are identification tables and a short bibliography. Details of important collections are also given. Few of the photographs have been published before and the book is worth buying for the illustrations alone.

M.O'D.

BECK, R. J. 1984. *New Zealand jade.* A. H. & A. W. Reed, Wellington. pp vi, 174. Illus. in colour. NZ $24.95.

This fascinating and readable book is concerned with all aspects of New Zealand jade. The author is Director of the Southland Museum, Invercargill (South Island) and is a jade lover, carver and explorer.

Following a brief introduction there is a short chapter on terminology which includes descriptions of the varieties of nephrite recognized by the Maoris. A major part of the book (52 pages) is devoted to accounts of the various jade fields in the South Island. Their geology is clearly explained and is supplemented by descriptions of the Maori and European discovery and exploitation of the deposits. A short chapter on the local bowenite follows. Maori history and legends concerned with jade are outlined and this is succeeded by a most interesting chapter on Maori lapidary methods. The stages in the manufacture of the Maori implements themselves are described next. The history and methods of European exploitation is followed by a chapter on lapidary hints.

Four appendices describe the origin of nephrite, the physical properties of New Zealand nephrite, the jade substitutes and world sources of jade. The glossary, bibliography and index are all extensive and admirably complement the excellent text. This is a very well illustrated paperback which promises to become a 'mini-classic'.

E.A.J.

BECKER, V. 1985. *Art nouveau jewelry.* Thames and Hudson, London. pp.240. Illus. in black-and-white and in colour. £25.00.

Printed in Japan, this is a well-presented study of a field in which there is a growing interest. The author, who has already produced excellent surveys of antique and twentieth-century jewellery, starts with an introduction to the conception of art nouveau before turning to France, Germany and Austria, Great Britain and the United States, each of which has its own chapter. Developments in other countries are also covered. Particularly useful are biographies of the major jewellers and a section on makers' marks and signatures. There is an adequate bibliography and an index.

The publishers are to be congratulated on producing so attractive a book at so low a cost. Standards of reproduction are high and the text is easy to read.

M.O'D.

CLIFFORD, D. *Anne Clifford's jewellery: antique.* Nottingham Court Press, London. pp.49. Illus. in colour. £14.95.

Anne Clifford was an authority on cut steel and Berlin ironwork jewellery though many other types feature in this pleasant catalogue whose entries give provenance as well as description. The standard of reproduction is generally good though by no means outstanding and the catholic taste displayed by the collector has given a selection of pieces which cover many dates and styles. Reasonably priced, this would be a good introduction to jewellery for a beginner.

M.O'D.

EPPLER, W. F. 1984. *Praktische Gemmologie. 2nd edn.* (Practical gemmology.) Rühle-Diebener-Verlag, Stuttgart. pp. xi, 504. Illus. in black-and-white. DM 158.

Almost all the book is taken up by descriptions of species and details of testing methods are left until the end. This does not matter since there are already plenty of teaching manuals; fewer books go to such trouble to provide detailed descriptions of all gem

species. Photographs of inclusions, as in the first edition, are particularly noteworthy and care has been taken to bring the accounts of major species up-to-date. In addition there is a good deal of information on synthetic stones which are placed in the text with their natural counterparts. Though Knischka ruby is mentioned the Ramaura product is not; on the other hand there are some excellent photographs of alexandrite trillings grown from the melt with a flux of lithium molybdate. It is, in fact, to the photographs that the reader returns and the book is well worth having for these alone. The remainder of the text is unexceptionable; identification tables, a glossary, drawings of absorption spectra and an index completing the book. The only serious desideratum is an adequate bibliography.

M.O'D.

PSCHICHHOLZ, D. 1979. *Diamant: gradierung, gewinnung, kauf.* (Diamond: grading, recovery, cost.) Rühle-Diebener-Verlag, Stuttgart. pp. 152. illus. in black-and-white. DM. 42.60.

A simple and attractively-presented guide to diamond with useful diagrams, especially clear on grading. This would make a good textbook for a preliminary diamond study course. M.O'D.

VAN LANDINGHAM, S. L. 1985. *Geology of world gem deposits.* Van Nostrand Reinhold, New York. pp. x, 406. Illus. in black-and-white. £51.15.

The book is divided into three sections, the first two of which contain 22 papers of a benchmark nature covering the general topics of the origin and development of gemstone deposits and their exploration, evaluation and occurrences. None are from obscure journals. The third section is a review of the geology of world gem deposits and consists of 126 pages of references preceded by a world survey, by continent, of the literature. This can only be selective as are the papers in the first two sections and I have been unable to find a linking thread. The references are useful as are the author and subject indexes but from the title I had hoped for a geological text. M.O'D.

ZEISS, W. 1984. *Setting of gemstones.* Rühle-Diebener-Verlag, Stuttgart. pp. 124. Illus. in black-and-white. Price on application.

The details of how to set gemstones are carefully and lucidly described, the author illustrating each stage with text diagrams. I know of no other book in which the techniques of the mounter and setter are so well covered and can strongly recommend it for those professionally engaged in setting and for those gemmologists who would like to know more about a topic so closely allied with their own. A bibliography would have been useful. M.O'D.

1984. *Goldschmiede- und Uhrmacher Jahrbuch 1985.* (Yearbook for the goldsmith and watchmaker.) Rühle-Diebener-Verlag, Stuttgart. pp. 176. Illus. in black-and-white and in colour. DM 17.20.

This issue of the valuable series contains papers on the history of platinum, the engraving of rock crystal, the colours obtainable from titanium, niobium and tantalum metals, together with papers chiefly of interest to the watchmaker. M.O'D.

Proceedings of the Gemmological Association of Great Britain and Association Notices

GIFTS TO THE ASSOCIATION

The Council of the Association is indebted to the following for their gifts:

Mrs P. M. Goldie, London, for a copy of The Macdonald Encyclopedia of Rocks and Minerals, Macdonald & Co. Ltd, 1983, the Gemmologists' Compendium by Robert Webster, N.A.G. Press Ltd, London, 1979, and some back copies of the Journal of Gemmology.

Mr R. Lucas, F.G.A., Barnet, for a sovereign and half sovereign brass balance, and a small hand-held cased gem balance.

The Rayner Optical Co., Hove, for a copy of Dana's Textbook of Mineralogy, John Wiley & Sons, Inc., New York, 1966.

Mr Harry Wheeler, F.G.A., Chigwell, for a specimen of peridot from El Golfo Sands, Lanzarote, Canary Islands.

NEWS OF FELLOWS

Mr M. J. O'Donoghue, M.A., F.G.S., F.G.A., recently spent some time with the Gemstone Corporation of Pakistan visiting many of the gemstone mines and prospects.

Mr P. Read, C.Eng., M.I.E.E., M.I.E.R.E., gave two talks at the 2nd European Precious Stones Conference in Antwerp from 18th–20th October, 1985. His first talk illustrated the use of a computer gem data base as an aid to gem identification, and his second talk described the latest gem test instruments.

MEMBERS' MEETINGS

London

On 26th November, 1985, at the Flett Theatre, Geological Museum, Exhibition Road, South Kensington, London S.W.7., Mr J. I. Koivula, B.A., B.Sc., C.G., F.G.A., of the Gemological Institute of America, gave an illustrated talk entitled 'Microscopic characteristics of natural, synthetic and treated corundums'.

Midlands Branch

On 25th October, 1985, at Dr Johnson House, Bull Street, Birmingham, Mr E. Emms, F.G.A., of the British Gem Testing Laboratory, gave an illustrated talk entitled 'Inclusions and diamond grading'.

On 29th November, 1985, at Dr Johnson House, Mr D. J. Callaghan, F.G.A., gave a talk entitled 'From gem to jewel'.

North West Branch

On 17th October, 1985, at Church House, Hanover Street, Liverpool 1, the Annual General Meeting was held, at which Mr S. Hill, F.G.A., was elected Chairman and Mrs E. Cartmel re-elected Secretary.

On 21st November, 1985, at Church House, Mr P. Harrison gave a talk entitled 'The Blue John mines'.

South Yorkshire and District Branch

On 15th October, 1985, at Sheffield City Polytechnic, Pond Street, Sheffield, Mr D. Price, F.G.A., gave a talk entitled 'The cutting of gemstones'.

On 19th November, 1985, at Sheffield City Polytechnic, Mr D. H. Ariyaratna gave a talk entitled 'The gemstones of Sri Lanka'.

ANNUAL REUNION OF MEMBERS AND PRESENTATION OF AWARDS

The Annual Reunion of Members and Presentation of Awards took place at Goldsmiths' Hall on 28th October, 1985. The Chairman of the Association, Mr David Callaghan, F.G.A., opened the meeting by welcoming those present. He explained that this year 1184 students had taken their examinations in 26 countries. It was a great challenge to the Association's staff to organize this and he thanked and congratulated them.

He continued that it was a special evening because for the first time since 1974 someone from the U.K. had been awarded the Association's top

award, the Tully Medal. The winner, Gwynneth Mary Green of Barnt Green, Birmingham, had won the Anderson Medal last year and was the first person ever to receive both awards.

An Honorary Fellowship had also been awarded, which was, Mr Callaghan explained, another rare event as there were only six altogether. It went to Mr Ted Thomson who had been in the coloured stone trade for many years. Mr Thomson, he continued, was a major figure in the London trade and was a past president of the Colour Stone Section of C.I.B.J.O.

He then called on Mr Richard T. Liddicoat, Jr, Hon. F.G.A., Chairman of the Board of the Gemological Institute of America, to present the awards.

After the presentations Mr Callaghan announced that the Basil Anderson Appeal for a spectrophotometer was now only £3000 short of the target figure of £25000. He thanked all those who had sent in donations.

Mr Liddicoat then delivered his address. He took the opportunity to congratulate all those who had passed their examinations. It took an effort, he said, as the G.A. courses were rigorous and demanding – it was a task that needed perseverance. Home study graduates, he said, were a 'special lot', rare people who had the perseverance to carry out such a programme without falling by the wayside. They were 'above the crowd', he added, and many employers looked for that extra something – people likely to get ahead and be successful employees.

But, he warned, do not be over-confident or arrogant, it was not helpful with peers. It was, in any case, imperative to regard the F.G.A. as a foundation on which to build a career, a start to which years of experience should be added. Basil Anderson, he reminded the audience, had never stopped learning.

It was important to keep abreast of what was going on by reading publications that gave material in enough depth to be of value to the F.G.A. Another aspect, he felt, was to establish if possible a communication network of peers in the locality. Although the large cities had association meetings, a closer relationship was really needed, especially for those outside the towns. Such links he felt, maintained contact, built credibility and could even be an early warning system too.

The trade, he said, was 'ever changing and never boring'. Not only was it one of the most exciting professions, he continued, it was dealing with people who were looking for beauty for a loved one. It was a happy profession and a constant challenge. Every day of his 45 years he'd enjoyed the thought of going to the G.I.A. and 'seeing what was new'. He hoped that those newly qualified would find it as enjoyable.

Thanking Mr Liddicoat, Mr Noel Deeks, Vice-Chairman of the Gemmological Association, said that he hoped those present would find time to give to the Association. Gemmology was like a garden – you only got out what you put in.

In conclusion Mr Callaghan told the audience that the Association was looking at the possibility of creating a new home study course for the Diamond Diploma. They were definitely revamping the whole G.A. examination course, and the Preliminary section would be available by September 1986.

COUNCIL MEETINGS

At the meeting of the Council held on 25th September, 1985, at the R.A.C. Club, London S.W.1, the business transacted included the following:

(1) Mr Ted Thomson were elected an Honorary Fellow;
(2) it was agreed that a warning about the dangers of using Clerici solution should be published in the Journal of Gemmology (see p.69 below);
(3) the following were elected to membership;

Fellowship

Abrahams, Roy H., Ruislip. 1985
Alexander, Nicholas A., Linden, S. Africa. 1984
Ambrose, Janice M., Enfield. 1985
Bateley, Linda A., Tenterden. 1985
Brook, Judith M., Knighton. 1985
Cooper, Berzes, London. 1985
Ellis, Trevor E., Rugeley. 1985
Evans, Gareth D., Potters Bar. 1985
Green, Fiona E., Stonehaven. 1985
Groves, Lesley C., Eastbourne. 1985
Helton, Janet L., Calgary, Alta, Canada. 1983
Herold, Richard A. J., Salisbury. 1985
Iacovou, Elena, London. 1985
Jacobs, Dalia, Harrow. 1985
Jones, Karen, Bangor. 1985
Jones, Kevin P., Coventry. 1985
Klimek, Karol S., Tunbridge Wells. 1966
Knight, Norman, New Milton. 1985
Kothari, Prajesh R., Madras, India. 1984
Layhe Cook, Judith A., Tiddington. 1985
Lewis, Doreen E., Monmouth. 1985
Loveday, Elsje, St Martins, Guernsey, C.I. 1985
Osborne, Malcolm G., Bordon. 1985
Ramsey-Rae, Philippa A., London. 1985
Sanders, Adam F., Ware. 1985
Savin, Vincent G., Rickmansworth. 1985
Sayers, Claire L., Twickenham. 1985
Shankar, Sangeeta, Luton. 1985
Stead, William A., London. 1985
Sturman, Nicholas P. G., London. 1985
Wilkinson, Richard C., Prestbury. 1985
Young, Gabrielle E. M., Wareham. 1985

Transfers from Ordinary Membership to Fellowship

Abe, Kazumi, Kofu, Japan. 1985
Ashraf, Ashraq A., London. 1985
Bell, Heather L., Formby. 1985
Brinkmann, Hans H., Idar-Oberstein, W. Germany. 1985
Broad, Arline E., Thames, New Zealand. 1985
Caycedo, Miguel J., Bogota, Colombia. 1985
Chilvers, Alan, Guildford. 1985
Chiu, King-Yip A., Hong Kong. 1985
Clancy, Allan W., Brisbane, Qld, Australia. 1985
Derks, Ruedi, Hetlingen, Switzerland. 1985
Doerr, Bertrand R., Kusnacht, Switzerland. 1985
Emmanuel, Michael R., St Helier, Jersey, C.I. 1985
Francis, Shirley J., Frinton-on-Sea. 1985
Fry, Kate E., Bath. 1985
Fujii, Shinichi, Tokyo, Japan. 1985
Gerhart, Anna M., San Diego, Calif., U.S.A. 1985
Gonggryp, Hendrik S., The Hague, Netherlands. 1985
Green, Gwynneth M., Birmingham. 1985
Hallier, Michele, Paradise Valley, Ariz, U.S.A. 1985
Harding, Keith J., Worcester, Mass., U.S.A. 1985
Harrington, Christine M., Seattle, Wash., U.S.A. 1985
Henderson, Mark M., Dundee. 1985
Hill, Arthur E., St Saviour, Jersey, C.I. 1985

Imai, Yoshiko, Tokyo, Japan. 1985
Kawamoto, Midori, Tokyo, Japan. 1985
Kirstein, Mark H., Eastbourne. 1985
Kochhar, Narinder, J. S., London. 1985
Kruithof, Pieter, Amsterdam, Netherlands. 1985
Larson, Len, Thornton, Colo., U.S.A. 1985
Ly, Khai, Sydney, N.S.W., Australia. 1985
McKee, Catherine A., London. 1985
Minton, Annie P., London. 1985
Moore, Elaine P., London. 1985
Morrison, Stephen P., London. 1985
Murakami, Ryutaro, Osaka, Japan. 1985
Ohshiro, Kenji, Tokyo, Japan. 1985
Or, Wai Lam, Hong Kong. 1985
Perrott, Christopher J., London. 1985
Quy, Caroline E., Chalfont St Giles. 1985
Roach, Michael P., Howell, N.J., U.S.A. 1985
Sasaki, Kiyoshi, Ehime Pref, Japan. 1985
Shum, Chan H., Kuala Lumpur, Malaysia. 1985
Stather, Memory H., Hong Kong. 1985
Stephenson, Timothy, Creetown. 1985
Taank, Avinash, Ilford. 1985
Taylor, Alec E., Lasswade. 1985
Thomis, Helen M., Halifax. 1985
Thornley, Joan A., Green Bay, Wis., U.S.A. 1985
Voce, Elizabeth M., Topsham. 1985
Wackan, Susan K., London. 1985
Waddington, Clive, Harrogate. 1985
Watson, Thomas N., London. 1985
Yoshiyama, Masaru, Chiba, Japan. 1985

Ordinary Membership

Akers, Patrick J., Wimborne.
Bonsor, Gordon L., Colchester.
Bowers, Barbara J., Borrego Springs, Calif., U.S.A.
Campbell, Norma, Repulse Bay, Hong Kong.
Castora, Loretta C., New York, N.Y., U.S.A.
Chooi, Siew-Thim, London.
Corcoran, Jocelyn M., New Plymouth, New Zealand.
Corliss, James C., Chalmette, La, U.S.A.
De'Ath, David, Luanshya, Zambia.
De Bevere, Dirk, Coogee, N.S.W., Australia.
Finnegan, Robin S., Stockton-on-Tees.
Gambini, Elena, Milan, Italy.
Gardiner, Kenneth, Lanchester.
Grumser, Pierre, Lausanne, Switzerland.
Hamawi, George, Nairobi, Kenya.
Hawkhead, Carol, Bournemouth.
Henderson, Paul T., Auckland, New Zealand.
Hinchliffe, Stanley E., Lota, Qld, Australia.
Hirst, Lindy M., Johannesburg, S. Africa.
Hossen, Iqbal H., Port-Louis, Mauritius.
Huntington, Richard C., Las Vegas, Nev., U.S.A.
Jakob, Beatrice, London.
Kennedy, Aleta J., Staines.
Kneip, John R., London.
Kwan, Patrick C., London.
Lamb, Walter R., Leighton Buzzard.
Leith, Harold B., Golden, Colo., U.S.A.
Lloyd, Susannah M. D., Abergavenny.
McCarthy, Raymond C. Jr., Chattanooga, Tenn., U.S.A.
MacGregor, Douglas I., Brazil.
McGurn, Walter E., Huntingdon.
Maclean, Mimi, Cherry Hinton.
Maetzener-Levy, Lydia, Zurich, Switzerland.
Markov, Mark, London.
Michaels, Amy J., Montgomery, Ala., U.S.A.
Michons-Bordes, Helena, Uppsala, Sweden.
Mitchell, Christopher, Leigh-on-Sea.
Murphy, David R., Haverhill.
Nielsen, Lolita A., Nairobi, Kenya.
Niklewicz, Danusia, Santa Monica, Calif., U.S.A.
Osmond, Mark E., Salisbury.
Pettinger, Richard H., Bristol.
Pozzi, Amelia, Appiano Gentile, Italy.
Pretty, Eric J., South Auckland, New Zealand.
Ravagnani, Daniele, Gromo, Italy.
Redcliffe, Jacqueline, Hove.
Roebuck, Joy A., Beckenham.
Rothon, Jeremy, Randburg, S. Africa.
Schloss, Sindi J., Scottsdale, Ariz., U.S.A.

Silvennoinen, Pirjo P., Sevenoaks.
Sinclair, Lyall W., Burwell.
Sinderholm, Evelyn W., Poway, Calif., U.S.A.
Smith, Adrian S., Portsmouth.
Stradling, Zoe V., Lausanne, Switzerland.
Suchcicki, Eugeniusz M., Nairobi, Kenya.
Sylvester, Elizabeth M., Seend.
Tripp, Julia M., Seoul, Korea.
Van Gelder, Lizbeth, London.
Wheeldon, Hayley, D., Ryde.
Witlin, Holly, Ambler, Pa, U.S.A.
Wong, Bambi, San Francisco, Calif., U.S.A.
Yandle, Lorna R., Bethesda, Md, U.S.A.
Yasui, Eleanore, Arlington, Va, U.S.A.
Yeo, Clarisse, Singapore.
Young, Roy T., Dunedin, New Zealand.
Yu, Stephen, London.

At a meeting of the Council held on 19th November, 1985, at the Marlborough Crest Hotel, Bloomsbury Street, London W.C.1., the business transacted included the election to membership of the following:

Fellowship
Ashton, Joan P., Hong Kong. 1985
Bolin-Möller, Anita, Taby, Sweden. 1985
Bosch, Coert E., Arnhem, Netherlands. 1985
Bram, Carol B., Hong Kong. 1985
Bryson, Varaphorn P., Washington Township, N.J., U.S.A. 1985
Carter-Van Roy, Anne E., London. 1984
Chan, Chi K., Hong Kong. 1985
Cheng, Bakke P., Hong Kong. 1985
Cheng, Oi L. A., Hong Kong. 1985
Cheung, King W., Hong Kong. 1985
Choi, Shu W. A., Hong Kong. 1985
Cholat, Nicole B., Hong Kong. 1985
Comber, Takako K., Hong Kong. 1985
Devereux, James P., Toronto, Ont., Canada. 1985
Dewever, Marc L. N., Sittard, Netherlands. 1985
Fang, Jin K., Kaohsiung, Taiwan. 1985
Farley, Eileen J., Dublin, Eire. 1985
Grafin von Francken Sierstorpff, Monika, Cologne, W. Germany. 1985
Hall, Sylvia, Guildford. 1985
Harrison, Margaretha, Geneva, Switzerland. 1985
Inamochi, Sachiko, Niigata Ken, Japan. 1985
Johannessen, Penny M., Hong Kong. 1985
Kallner, Anders B., Frolunda, Sweden. 1985
Kuehn, J. Wolfgang, Vancouver, B.C., Canada. 1985
Levy, Stephen A., Washington DC, U.S.A. 1985
Lloyd-George, Kim A., Hong Kong. 1985
Lovering, Paula G., Alexandra, New Zealand. 1985
MacLennan, David J., Glasgow. 1985
Manorotkul, Wimon, Bangkok, Thailand. 1985
Mulder, Mieke, Amsterdam, Netherlands. 1985
Nakazawa, Hiromi, Tokyo, Japan. 1985
Ng, Koon Y., Hong Kong. 1985
Nurminen, Tuija P. A., Helsinki, Finland. 1985
Ocampo, Antonieta R., Hong Kong. 1985
Olsen, John R., Dhahran, Saudi Arabia. 1985
Olsen, Sandra A., Dhahran, Saudi Arabia. 1985
Patterson, Shannon, Gahanna, Ohio, U.S.A. 1985
Poelen, Ellen B., Molenhoek, Netherlands. 1985
Ross, Howard D., Harare, Zimbabwe. 1985
Rowley, Phillip L., Vienna, Va, U.S.A. 1985
Scandella, Stefano, Liestal, Switzerland. 1985
Siegel, Paul L., Port Jefferson, N.Y., U.S.A. 1985
Skytta, Martti V., Kouvola, Finland. 1985
Snare, Melanie J., Toronto, Ont., Canada. 1985
Strick, Frank, Miami Beach, Fla, U.S.A. 1985
Squelch, Bruce C., Toowoomba, Qld, Australia. 1985
Taylor, William W., Brisbane, Qld, Australia. 1985
Teramae, Kiyomi, Chiba Ken, Japan. 1985
Tsaktanis, Michael, Athens, Greece. 1985
Van der Giessen, Wilma, The Hague, Netherlands. 1985
Vikamsey, Shilpa J., Bombay, India. 1985
Wakabayashi, Hisao, Tokyo, Japan. 1985
Watanabe, Masahiro, Tottori Ken, Japan. 1985
Wong, W. Y. Eva, Hong Kong. 1985

Transfer from Ordinary Membership to Fellowship
Molina, Alfredo J., Phoenix, Ariz., U.S.A. 1985

Ordinary Membership
Archer, Mary C., Edinburgh.
Arthur, Lynne, Denny.
Bellers, Veronica O., Horsham.
Browne, Dudley M., Great Missenden.
Buxton, Lynne H., Norwich.
Chang, Hwei, London.
Chang, Ming C., London.
Chino, Hiroaki, Kofu, Japan.
Christensen, Cherie, San Jose, Calif., U.S.A.
Cook, Alan C., Epping.
Dawson, Kathryn L., Leighton Buzzard.
Elkins, Heather, Nairobi, Kenya.
Furuya, Tsukasa, Kofu, Japan.
Gay, Michael, Romsey.
Horiuchi, Yuzi, Kofu, Japan.
Ito, Masahiro, Kofu, Japan.
Jack, Barbara M., Dunblane.
Kirk, Helena, Milton Keynes.
Kramer, Stephen A., Bradford.
McManus, Andrea, Sausalito, Calif. U.S.A.
Manning, G., Middletown, Ohio, U.S.A.
Muran, Holly L., Reno, Nev., U.S.A.
Muratore, Rosanilla, London.

Ortenburger, Thomas, Lake City, Fla., U.S.A.
Polycarp, Qkoro, Imo Stata, Nigeria.
Sample, Fiona J., Morpeth.
Schorn, Terence F., West Vancouver, B.C., Canada.
Stewart, Robert, London.
Trusch, Alec, Dartford.
Underdown, Derek W., Partridge Green.
Van Hoffman, Geraldine, Hove.
Watanabe, Tatsuo, Kofu, Japan.
Yamase, Toshifumi, Kofu, Japan.
Yung Ho Yang, Robert, Sao Paulo, Brazil.

GEM DIAMOND EXAMINATION, 1985

In the Post-Diploma Gem Diamond Examination 44 candidates sat and all succeeded in passing. The following is a list of the successful candidates arranged alphabetically.

Adlam, Raymond J., Glasgow.
Anderton, Brian G., Glasgow.
Bird, Nigel G., Epsom.
Brown, James E., Banner Cross.
Bugg, John R., Tettenhall.
Calduch Sendra, Ma. Esmeralda, Barcelona, Spain.
Carter-van Roy, Anne E., London.
Chieveley-Williams, John P. E., Poole.
De Vilmorin, Marie E., London.
Dent, Peter J., Normandy.
Donoghue, Martin D., Glasgow.
Dunn, Nigel P., Brierley Hill.
Ely, Jana M., London.
Ferran Estrada, Alejandro, Barcelona, Spain.
Floriach Devant, Ma. Teresa, Barcelona, Spain.
Franks, Karen M., Prestwich.
Gilmour, Kevin D., Shiregreen.
Gol Perlasia, Joseph Ma., Barcelona, Spain.
Hinchliffe, Brian, Sheffield.
Holden, Patricia, Market Harborough.
Hookins, Gary C., Thames Ditton.
Housley, John G., Sheffield.
Hu, Shirley, London.
Judez Martinez, Gregorio, Barcelona, Spain.
Liggett, Sonia A., Penylan.
Lim, Pauline, Kingswinford.
Morris, Kelsey, Hayling Island.
Payne, Susan E., Sheffield.
Pellicer Garcia, Miguel, Barcelona, Spain.
Percival, Colin A., Netherthorpe.
Porter, James W., Coventry.
Puig Ovejero, Joseph Ma., Barcelona, Spain.
Rich, Frederick S., London.
Ros Hernandez, Julio, Barcelona, Spain.
Seiz Ortiz, Vicente J., Barcelona, Spain.
Shah, Syed S., Fallowfield.
Shaikh, Leela, London.
Sulis Mariscal, Ma. Angeles, Barcelona, Spain.
Taylor, Caroline H., Ripley.
Tudor-Pole, Tom J., London.
Warriner, Elizabeth R., Solihull.
Wickramasinha, Tudor, London.
Woolf, Tania, London.
Yap, Ching S., London.

EXAMINATIONS IN GEMMOLOGY, 1985

In the 1985 Examinations in Gemmology, 716 candidates sat the Preliminary Examination and 396 (55%) passed, and 468 sat the Diploma Examination and 209 (45%) passed, 27 with Distinction.

The Tully Medal has been awarded by the Examiners to Mrs Gwynneth Mary Green of Barnt Green, Birmingham.
The Anderson/Bank Prize has been awarded to Mr Hans-Heinrich Brinkmann of Idar-Oberstein, West Germany.
The Rayner Diploma Prize has been awarded to Mr Roland Schlüssel of Colombier, Switzerland.
The Anderson Medal has been awarded to Mr Reinholdt Ziegler Unhjem of Oslo, Norway.
The Rayner Preliminary Prize has been awarded to Mr Reinholdt Ziegler Unhjem of Oslo, Norway.

The names of the successful candidates are as follows:

DIPLOMA

Qualified with Distinction

Bell, Heather L., Formby.
Brinkmann, Hans-Heinrich, Idar Oberstein, W. Germany.
Brook, Judith M., Leicester.
Cheng, Bakke Pik-Kit, Hong Kong.
Clancy, Allan W., Brisbane, Qld, Australia.
Ellis, Trevor, E., Rugeley.
Fujii, Shinichi, Tokyo, Japan.
Green, Gwynneth M., Birmingham.
Halton, Elizabeth M., Huddersfield.
Jander, Margrit A. J., Geneva, Switzerland.
Kochhar, Narinder J. S., London.
Levy, Stephen A., Washington DC, U.S.A.
Lovering, Paula G., Alexandra, New Zealand.
Manorotkul, Wimon, Bangkok, Thailand.
Molina, Alfredo J., Phoenix, Ariz., U.S.A.
Nakamura, Kayoko, Tokyo, Japan.
Ohshiro, Kenji, Tokyo, Japan.
Olsen, John R., Dhahran, Saudi Arabia.
Or, Wai L., Hong Kong.
Patterson, Shannon F., Gahanna, Ohio, U.S.A.
Pickrell, Rupert J., Turramurra, N.S.W. Australia.
Scandella, Stefano, Basel, Switzerland.
Schlüssel, Roland, Colombier, Switzerland.

Skoropad, John D., Bangkok, Thailand.
Teramae, Kiyomi, Tokyo, Japan.
Voce, Elizabeth M., Topsham.
Young, Gabrielle E. M., Wareham.

Qualified

Abbot, Anita M., Phoenix, Ariz., U.S.A.
Abe, Kazumi, Kofu, Japan.
Abrahams, Roy H., Ruislip.
Allen, Viven, Toronto, Ont., Canada.
Ambrose, Janice M., Oakwood.
Arno Fece, Nuria, Barcelona, Spain.
Arroyo Llorens, Ma Cristina, Barcelona, Spain.
Ashraf, Ashfaq Ahmed, London.
Ashton, Joan P., Hong Kong.
Athanassiades, Emmanouela, Athens, Greece.
Baquero Petricorena, Manuel, Barcelona, Spain.
Batalla Vivas, Jose I., Barcelona, Spain.
Bateley, Linda A., Tenterden.
Bau Martinez, Ma Luisa, Barcelona, Spain.
Benser, Eugenie M., Baltimore, Md., U.S.A.
Bernad Soria, Pedro J., Barcelona, Spain.
Biosca Bas, Ma de los Angeles, Barcelona, Spain.
Bloodworth, Roy N., Ossett.
Bodifee, Brigitte K., Naarden, Netherlands.
Boermans, Antoon Peter E. M., Venlo, Netherlands.
Bolin-Moller, Anita M. H., Taby, Sweden.
Bosch, Coert E., Arnhem, Netherlands.
Bram, Carol B., Hong Kong.
Broad, Arline E., Thames, New Zealand.
Bryson, Varaphorn P., Bangkok, Thailand.
Cabre Bores, Nuria, Barcelona, Spain.
Campos Ruiz, Ma Teresa, Barcelona, Spain.
Canas Aguilar, Jose V., Barcelona, Spain.
Capar, Allan P., Springfield, Va, U.S.A.
Carmena Coelho, Jose A., Barcelona, Spain.
Caycedo, Miguel J., Bogota, Colombia.
Chan, Chi K., Hong Kong.
Chaparro Lameda, Daisy A., Barcelona, Spain.
Cheng, Oi Lun Alan, Hong Kong.
Cheung, King-Wing, Hong Kong.
Cheung, Lee, Hong Kong.
Chilvers, Alan, Guildford.
Chiu, King-Yip Alan, Hong Kong.
Choi, Shu-Wing Alex, Hong Kong.
Cholat, Nicole, Hong Kong.
Comber, Takako K., Hong Kong.
Cooper, Berzes, London.
Derks, Ruedi, Hettlingen, Switzerland.
Devereux, James P., Toronto, Ont., Canada.
Dewever, Jan A., Sittard, Netherlands.
Dewever, Marc L. N., Sittard, Netherlands.
Dickey, Timothy B., Ontario, Calif., U.S.A.
Doerr, Bertrand R., Kusnacht, Switzerland.
Dubbers, Maria-Theresia H., Plasmolen, Netherlands.
Emmanuel, Michael R., St Helier, Jersey, C.I.
Evans, Gareth D., Potters Bar.
Fang, Jin-Kuon, Kaohsiung, Taiwan.
Farley, Eileen J., Dublin, Eire.
Ferreira, Anslem C., Colombo, Sri Lanka.
Fournier-Laroque, Maryse M., Geneva, Switzerland.
Fox-Worthington, Peter J. J. E., Auckland, New Zealand.
Francis, Shirley J., Frinton-on-Sea.
Fry, Kate E., Bath.
Gabarro Val, Marta, Barcelona, Spain.
Gamblen, Philip M., Barrie, Ont., Canada.
Gascon Cuello, Fernando, Barcelona, Spain.
Georgopoulou-Kyriaki, Marianna, Athens, Greece.
Gerhart, Anna M., San Diego, Calif., U.S.A.
Gonggryp, Hendrik S., The Hague, Netherlands.
Gräfin von Francken Sierstorpff, Monika, Cologne, W. Germany.
Green, Fiona E., Stonehaven.
Grotenhuis, Ingrid, Winterswijk, Netherlands.
Groves, Lesley, Eastbourne.
Hall, Sylvia, Guildford.
Hallier, Michele, Paradise Valley, Ariz., U.S.A.
Harding, Keith J., Worcester, Mass., U.S.A.
Harrington, Christine M., Seattle, Wash., U.S.A.
Harrison, Margaretha, Geneva, Switzerland.
Henderson, Mark MacArthur, Dundee.
Herold, Richard A. J., Salisbury.
Hill, Arthur E., St Saviour, Jersey, C.I.
Iacovou, Elena, London.
Imai, Yoshiko, Tokyo, Japan.
Inamochi, Sachiko, Niigata Ken, Japan.
Insa Sales, Juan M., Barcelona, Spain.
Jacobs, Dalia, London.
Johannessen, Penny M. F., Hong Kong.
Jones, Karen, Bangor.
Jones, Kevin P., Coventry.
Jongenburger, Irma, Ede, Netherlands.
Juan Sampablo, Teresa, Barcelona, Spain.
Kai, Kock M., Hong Kong.
Källner, Anders B., Johanneshov, Sweden.
Kawamoto, Midori, Tokyo, Japan.
Kirstein, Mark H., Eastbourne.
Kittel, Gerhilde A., Toronto, Ont., Canada.
Knight, Norman, New Milton.
Kothari, Rekha Y., Bombay, India.
Kruithof, Pieter, Amsterdam, Netherlands.
Kuehn, Johann W., Vancouver, B.C., Canada.
Larson, Len, Thornton, Colo., U.S.A.
Layhe Cook, Judith A., Stratford-upon-Avon.
Lewis, Doreen E., Monmouth.
Liyanaarachchi, Tudor P., Colombo, Sri Lanka.
Lloyd-George, Kim A., Hong Kong.
Llucia Aguilera, Rosa, Barcelona, Spain.
Loveday, Elsje, St Martins, Guernsey, C.I.

Ly, Khai, Sydney, N.S.W., Australia.
McKee, Catherine A., London.
MacLennan, David J., Glasgow.
Major, Christine B., Sydney, N.S.W., Australia.
Marti Martinez, Nicolas, Barcelona, Spain.
Minton, Annie P. London.
Moore, Elaine, London.
Morrison, Stephen P., London.
Mulder, Mieke, Amsterdam, Netherlands.
Murakami, Ryutaro, Osaka, Japan.
Nakazawa, Hiromi, Tokyo, Japan.
Ng, Raymond Koon Yung, Hong Kong.
Ngai, Ramon Pui Chun, Hong Kong.
Niklewicz, Danusia, Santa Monica, Calif., U.S.A.
Nurminen, Tuija P. A., Helsinki, Finland.
Ocampo, Antonieta R., Hong Kong.
Olsen, Sandra A., Dhahran, Saudi Arabia.
Osacar Soriano, Ma Cinta, Barcelona, Spain.
Osborne, Malcolm G., Bordon.
Overbeek, Louise A.-M., Leiden, Netherlands.
Pajaron Gamon, Ma Loreto, Barcelona, Spain.
Papadopoylos, Fatalas C., Athens, Greece.
Parker, Claire E., Worthing.
Pascual Torres, Jose L., Barcelona, Spain.
Payette, Francine, Sillery, Que., Canada.
Penfold, Reginald C., Maidstone.
Perrott, Christopher J., London.
Platon Davila, Susana, Barcelona, Spain.
Poelen, Ellen B., Molenhoek, Netherlands.
Prezio, Anthony, Toronto, Ont., Canada.
Quy, Caroline E., Chalfont St Giles.
Radan, Milan, Toronto, Ont., Canada.
Ramsey-Rae, Philippa A., London.
Roach, Michael P., Howell, N.J., U.S.A.
Rodriguez Pellicer, Antonia L., Barcelona, Spain.
Ross, Howard D., Harare, Zimbabwe.
Rowley, Phillip L., Vienna, Va., U.S.A.
Ruiz Roser, Emilio, Barcelona, Spain.
Sanders, Adam F., Ware.
Sasaki, Kiyoshi, Ehime Pref., Japan.
Savin, Vincent G., Rickmansworth.
Sayers, Claire L., Plymouth.
Shankar, Sangeeta, Luton.
Shimizu, Yoshimi, Yamanashi, Japan.
Shum, Chan Hui, Kuala Lumpur, Malaysia.
Siegel, Paul L., Patchogue, N.Y., U.S.A.
Skyttä, Martti V., Kouvola, Finland.
Snare, Melanie J., Toronto, Ont., Canada.
Snijders, Adriana C. M., Mapert, Netherlands.
Spreckley, Vaughan G. M., London.
Spuida, Bernhard H. A. A., Pfronten, W. Germany.
Squelch, Bruce C., Toowoomba, Qld, Australia.
Stather, Memory H., Hong Kong.
Stead, William A., London.
Stephenson, Timothy, Creetown.
Strick, Frank, North Miami Beach, Fla., U.S.A.
Sturman, Nicholas P. G., Marlborough.
Taank, Avinash, Ilford.
Tam, Man Wai, Hong Kong.
Taylor, Alec E., Lasswade.
Taylor, William W., Brisbane, Qld., Australia.
Tetteroo, Caroline C. B. O., Nootdorp, Netherlands.
Thomis, Helen M., Halifax.
Thornley, Joan A., Green Bay, Wis., U.S.A.
Tsaktanis, Michael, Athens, Greece.
Van Dergiessen, Wilma, The Hague, Netherlands.
Van Oyen, Jean-Paul, Wijchen, Netherlands.
Vassiliades, Dionyssi, Athens, Greece.
Vikamsey, Shilpa J., Bombay, India.
Wackan, Susan K., London.
Waddington, Clive, Harrogate.
Wakabayashi, Hisao, Tokyo, Japan.
Watanabe, Masahiro, Tokyo, Japan.
Watson, Thomas N., London.
Wilby, Christine A., Birmingham.
Wilkinson, Richard C., Prestbury.
Wong, Wai Yuk Eva, Hong Kong.
Yoshiyama, Masaru, Chiba Pref., Japan.
Young, Pak Chee Patrick, Hong Kong.
Zandvoort, Christine J. M., Rotterdam, Netherlands.

PRELIMINARY

Qualified

Abe, Kazumi, Kofe, Japan.
Abear, Marga, Northwood.
Abell, Alison M., Nairobi, Kenya.
Abramson, Pamela J., Orlando, Fla., U.S.A.
Adams, Amanda C., Leicester.
Agrawal, Nirmal, Aldershot.
Akers, Patrick J., Wimborne.
Albers, Hermina J., Vinkeveen, Netherlands.
Alexander, Jane E., Singapore.
Alford, Audrey E., Oslo, Norway.
Alliance, Alma B., Manchester.
Andrews, Olive M., Hong Kong.
Arias, Garnacho A., Madrid, Spain.
Armand, M., Auckland, New Zealand.
Arnold, Gillian M., London.
Arroyo Llorens, Ma Cristina, Barcelona, Spain.
Arthur, Lynne, Denny.
Artz, Rudolf J. M., Antwerpen, Belgium.
Axelson, Glenn N., Wawa, Ont., Canada.
Barber, Roxey L., Encinitas, Calif., U.S.A.
Barber, Susan A., Cowfold.
Bartholomew, Jurgen C., Shoreham-by-Sea.
Bateman, Linda D., Vancouver, B.C., Canada.
Bau Martinez, Ma Luisa, Barcelona, Spain.
Baz Seguido, Ma Luisa, Barcelona, Spain.
Beighton, Philip D., Sheffield.
Beljaars, Maria M. J., Schoonhoven, Netherlands.
Bellers, Veronica O., Horsham.

Benser, Eugenie M., Baltimore, Md., U.S.A.
Blackburn, James O., Winchester.
Blake, Nicholas P., Southampton.
Bolland, Marian W., Hong Kong.
Booth, Ian M., Leeds.
Borden, Parker A., Lakeside, Calif., U.S.A.
Bragg, Moira A., Bolton.
Braid, Robert N., Prestwich.
Bramlett, Christopher L., Albemarle, N.C., U.S.A.
Brelsforth, Jane, Chadderton.
Bres, Klesine N., Boxtel, Netherlands.
Brill, Douglas, Halifax.
Brinkmann, Hans-Heinrich, Idar Oberstein, W. Germany.
Brophy, Mark S. J., Gatley.
Brouwers, Godfried W. C., Valkenburg, Netherlands.
Brown, Malcolm R., Wigan.
Bruggeman, Renate F., Almelo, Netherlands.
Bryson, Varaplforn P., Bangkok, Thailand.
Buescher-Hain, Jane, Seattle, Wash., U.S.A.
Buglass, James J., Uckfield.
Burns, Gail P. L., Bethesda, Md., U.S.A.
Burton, Nicholas J., Fradley.
Butfoy, Carol A., Kenton.
Butler, John J., South Shields.
Caballeria Surinach, Ma Assumpta, Barcelona, Spain.
Capar, Allan P., Springfield, Va, U.S.A.
Carmody, Justine L., Thames Ditton.
Carnes, John E., Trowbridge.
Carroll, Elizabeth K., Auckland, New Zealand.
Casanova Guillen, Luis M., Barcelona, Spain.
Chalandon, Tohra, London.
Chan, Pik Yuk Addy, Hong Kong.
Chan, Richard Ki-Mun, London.
Chang, Nancy A., Hong Kong.
Chard, Duncan, London.
Chavan, Satish G., Bombay, India.
Cheung, Lai Chun Mercedes, Hong Kong.
Chow, Winston Wun-Sing, Hong Kong.
Chowdhury, Iqbal K., Solihull.
Chu, Veronica, Stockport.
Chung, Stephen Wui Kwong, Leeds.
Clark, Berenice M., Hobart, Tasmania.
Clarke, Anthony, Bromley.
Coleman, Rachel R., Newbury.
Colvin, Moranna, Hong Kong.
Cooney, Tracy J., Birmingham.
Corniplas, Elias L., Agincourt, Ont., Canada.
Courtenay, Penelope A., Barton-le-Clay.
Cox, Simon A., Blackpool.
Crowley, Deborah K., London.
Cullen-Spellman, Rosemary, Ennis, Eire.
Curwen, Ruth E., Tonbridge.
Cuthbert, Richard A., London.
Dangedara, Dezinzige A. N., Colombo, Sri Lanka.
Davidson, Helen, Durham.
Dawes, Percival E., Stevenage.
De Boer, Gerrit-Jan, Schoonhoven, Netherlands.
De Bruno, Philip, Clifton, N.J., U.S.A.
De Grafte, Hendricus A. M., Geldrop, Netherlands.
De Jong, Anna M. C., Boskoop, Netherlands.
Dean, John A., Ossett.
Delgado Chaubell, Cristina, Barcelona, Spain.
Dickey, Timothy B., Ontario, Calif., U.S.A.
Dieste Torres, Jose L., Barcelona, Spain.
Dikhoff, Frederikus J., Castricum, Netherlands.
Domenech Lahoz, Christiane, Barcelona, Spain.
Droste, Gregory S., Evansville, Ind., U.S.A.
Dworschak, Francis, Ottawa, Ont., Canada.
Ebrahim, Nazma R., Nairobi, Kenya.
Ekman, Lars A., Malmoe, Sweden.
Elkins, Heather, Nairobi, Kenya.
Endo, Takako, Kofu, Japan.
Epa, Widanagamage S. D., Mt Lavinia, Sri Lanka.
Eriksson, Brita A., Helsinki, Finland.
Fang, Jin-Kuon, Kaohsiung, Taiwan.
Fedell, Jean M., Crystal Lake, Ill., U.S.A.
Fernandez Nunez, Francisco J., Barcelona, Spain.
Fernandez Sanchez, Fernando, Barcelona, Spain.
Fernando, Malnaidelage T. W., Katunayaka, Sri Lanka.
Ferrer Verdasco, Marta, Barcelona, Spain.
Fessel, Robert P., Paulding, Ohio, U.S.A.
Fitzgerald, Trevor M. P., Folkestone.
Fu, Milal M., Hong Kong.
Gabarro Vall, Marta, Barcelona, Spain.
Gampola, Hennayake M. T., Katunayake, Sri Lanka.
Gardiner, Margot, Glasgow.
Garrigos McCarthy, Carlos L., Barcelona, Spain.
Gentsidou, Fotini, Athens, Greece.
Geolat, Patti J., Dallas, Tex., U.S.A.
Gillett, Graham, Bexhill-on-Sea.
Gillings, J., Croydon.
Girard, Patricia A., Kirn Dunoon.
Glaveau, Beatrice, Paris, France.
Glenister, James E., Eastbourne.
Glover, Andrew M., Horsham.
Gold, Francine, Markham, Ont., Canada.
Gollance, Caryl I. P., London.
Goodall, Andrew M., Rickmansworth.
Goodlin, Fran, Toronto, Ont., Canada.
Graham, Robert C. P., London.
Greeno, Philip M., Hastoe.
Gronlund, Tuulikki I., Espoo, Finland.
Grote, Isabelle, London.
Gunawardena, Warrussapperuma A. D., South Croydon.
Gunawardene, Kingsley de Silva, Dehiwala, Sri Lanka.

Hagen, Jeannette A., Leidschendam, Netherlands.
Hagnas, Lloyd, San Diego, Calif., U.S.A.
Hakanpaa, Miika J., Lahji, Finland.
Hall, Nicholas R., Bath.
Hallier, Michele, Paradise Valley, Ariz., U.S.A.
Halloran, Ellen M., New York City, N.Y., U.S.A.
Haque, Mohammed M., London.
Hash, Daniel W., Watrous, Sask., Canada.
Hatjis, John H., Athens, Greece.
Hawkhead, Carol, Bournemouth.
Heindorff, Judith H., Arana Hills, Qld, Australia.
Hellqvist, Ing-Britt E., Tumba, Sweden.
Helmore, Peter R., London.
Hemachandra, Chamindri, Colombo, Sri Lanka.
Hepburn, John A., Orpington.
Hewitt, Peter R., Horsforth.
Higgingson, Clare M., Colne.
Hinds, Andrew F., Rickmansworth.
Hirst, Susan C., Palmerston North, New Zealand.
Hodges, Mark C., Bristol.
Hogben, Richard N., Dumfries.
Holopainen, Outi T., Helsinki, Finland.
Holton, Yvonne, Edinburgh.
Horsup, Alexine, Birmingham.
Howell, Elizabeth J., Saffron Walden.
Hudson, Carole A., Ware.
Hui, Yat Sun K., Hong Kong.
Huiskamp, Eveline A., The Hague, Netherlands.
Humpage, Susan A., Birmingham.
Hyrsky, Kaisa M., Lahti, Finland.
Inestal Hermida, Susana, Barcelona, Spain.
Iwaki, Takakazu, Hyogo, Japan.
Jackson, Sarah E., Chorleywood.
Jain, Monica, Bombay, India.
Jokipii, Vesa E. K., Turku, Finland.
Jongeleen, Johannes T., Delft, Netherlands.
Kahari, Eeva P. K., Lahti, Finland.
Kalannayake, Lenaduwa L. Y. R., Kegalle, Sri Lanka.
Kallitsis, Henrietta, Athens, Greece.
Karunanayake, Sarath P., Dehiwala, Sri Lanka.
Keerthi, Koku H. U. J., Gampaha, Sri Lanka.
Kievit, Wouter, Rotterdam, Netherlands.
Kiewiet, Jantine A., Hong Kong.
King, Geoffrey R. G., Maidstone.
Kingshott, Clifford J., Brookmans Park.
Kirkland, Vanda J., Brighton.
Kishi, Masaki, Hiratsuka, Japan.
Kittilsen, Harald, Stathelle, Norway.
Klein, Linda S., Saltsjo-Boo, Sweden.
Knox, George T., South Harrow.
Kojima, Yaeko, Choufu City, Japan.
Kolick, Donald, North Olmsted, Ohio, U.S.A.
Koski, Jouko I., Helsinki, Finland.
Kotewall, Pik Y., Hong Kong.
Kothari, Rekha Y., Bombay, India.
Kubota, Kazuyuki, Tokyo, Japan.
Kuwahara, Chizu, Yokosuka City, Japan.
Laaksonen, Susanna M., Saltsjobaden, Sweden.
Lam, Fung-Han A., Hong Kong.
Lam, Keturah, London.
Lampinen, Heikki S. J., Jyvaskyla, Finland.
Landholt, Karin, Beijing, P. R. of China.
Lash, Vincent S., Chevy Chase, Md., U.S.A.
Lau, Yim M. T., Hong Kong.
Lee, Mei-Ying, Hong Kong.
Leichtenstein, Cess H., Neuhof, Austria.
Leigh, Nancy E., Brisbane, Qld., Australia.
Lenting, Heike A., Purmerend, Netherlands.
Leung, Marilyn S., Hong Kong.
Levy, Stephen A., Washington D.C., U.S.A.
Lewis, Robert C., Redbourn.
Linley, Mark A., Worcester.
Liu, Chi W. R., Hong Kong.
Lo, Jeanette, Hong Kong.
Lode, Lillian, Egersund, Norway.
Loh, Man-Pak V., Hong Kong.
Loohia, Bhavendra B., London.
Luk, Woon C., Hong Kong.
McArthur, Niven R., Southland, New Zealand.
MacGregor, Douglas I., Brazil.
McKee, Catherine A., London.
McQueen, Colin F., Lincoln.
Manders, Andrew P., Gloucester.
Manorotkul, Wimon, Bangkok, Thailand.
Martens, Judocus M., Deurne, Netherlands.
Martin, David J., Warrington.
Martinez Garcia, Eva M., Barcelona, Spain.
Maskonen, Seija S., Helsinki, Finland.
Mehta, Smita D., Flushing, N.Y., U.S.A.
Merk, Roger L., San Diego, Calif., U.S.A.
Merry, Neil J., Broxbourne.
Meyot, Eline G., Huizen, Netherlands.
Michiels, Marina J. M., Bengambucht, Netherlands.
Michon-Bordes, Helena M. J., Uppsala, Sweden.
Millage, Michael D., Manchester.
Mills, Edwin T., Ely.
Mills, Ganny, Hong Kong.
Mitchell, Irene E., Worcester.
Molina, Alfredo J., Phoenix, Ariz., U.S.A.
Moreno Ribot, Ignasi, Barcelona, Spain.
Morishita, Sachie, Tokyo, Japan.
Musa, Dorothy J., Hong Kong.
Nakamura, Kayoko, Tokyo, Japan.
Navarro Garcia, Rodolfo, Barcelona, Spain.
Neumand, Marion J. S., Richmond.
Ng, Sunny G. S., London.
Nicholls, Sarah, Manchester.
Nishimori, Yoshie, Tokyo, Japan.
Norcott, Susan C., Bristol.
Nystrom, Kauko E., Tammela, Finland.
O, Yan K. R., Hong Kong.
O'Neill, Jan D., Hong Kong.

Offermans, Mathieu J. W. M., Amsterdam, Netherlands.
Onishi, Hirokazu, Osaka, Japan.
Ouyang, Tak C. C., Hong Kong.
Overton, Jayne H., Salford Priors.
Owen, Margaret C., Dallas, Tex., U.S.A.
Padley, James, Bromyard.
Palombi, Robert J., Toronto, Ont., Canada.
Panis, Suzanne H., Beverwijk.
Pares Montane, Rosendo, Barcelona, Spain.
Parker, Martin A., Kings Lynn.
Parsons, Julie E., Hayes.
Patel, Devika S., Nairobi, Kenya.
Pathirana, Nishan D., London.
Peek-V.D. Peet, Maria J. M., Heiloo, Netherlands.
Peiris, Malalage N. P., Kolonnawa, Sri Lanka.
Perera, Frances H. J. S., Maharagama, Sri Lanka.
Perera, Shobana, Nugegoda, Sri Lanka.
Peries, Rosamund C., Bristol.
Pfneisl, Thomas, Vienna, Austria.
Phillips, Glenys J., Brighouse.
Pickrell, Rupert J., Turramurra, N.S.W., Australia.
Plumb, Helen L., Prestbury.
Poblador Cerezo, Luid M., Barcelona, Spain.
Ponti, Caroline, Geneva, Switzerland.
Potter, Christopher, Whitstable.
Potter, Ruth, Liverpool.
Powell, Gregory J., Prestatyn.
Powell, Warren, Manchester.
Prats Mustaros, Pere, Barcelona, Spain.
Premadasa, Jayasinghage D., Gona Junction, Sri Lanka.
Prime, Steven P., Swindon.
Pring, Amanda L., Torquay.
Pring, Jacqueline A., Torquay.
Pumarola Ciria, Ma Pilar, Barcelona, Spain.
Punt, Marianne E. M., Apeldoorn, Netherlands.
Quddus, Abdul, Athens, Greece.
Radan, Milan, Toronto, Ont., Canada.
Rafols Garrit, Yolanda, Barcelona, Spain.
Redman, David A., London.
Reijneker, Bernarda, Drachten, Netherlands.
Remmelink, Willemina H., Hummelo, Netherlands.
Rensen, Albertus T., Breda, Netherlands.
Reponen, Seppo J., Lahti, Finland.
Rice, Karen L., Solihull.
Rice, Michael, Humbleton.
Rickard, Patricia L., South Laguna, Calif., U.S.A.
Ripatti, Pekka P., Lahti, Finland.
Robinson, Timothy, Port Sunlight.
Rock, Barbara A., Athens, Greece.
Rodewijk, Nicolas G. A. M., Waalwijk, Netherlands.
Rogers, Stephen M., Folkestone.
Ronsmans, Bruno, Brussels, Belgium.
Rubies Sender, Federico, Barcelona, Spain.
Ruiz Rodriguez, Gustavo A., Barcelona, Spain.
Sabeti, Elham, Manipal, India.
Sandberg, Anne L., Kjeller, Norway.
Sankar, David, London.
Sato, Kazuo, Fussa City, Japan.
Saumell, Corie, Stamford, Conn., U.S.A.
Sayer, Linda, Weston-Super-Mare.
Sayers, Claire L., Twickenham.
Schoo, Derk J. W., Arnhem, Netherlands.
Schorn, Terence F., West Vancouver, B.C., Canada.
Schreier Lawrence, Skokie, Ill., U.S.A.
Seibert, Jack, Colombus, Ohio, U.S.A.
Serra Palau, Carles, Barcelona, Spain.
Seweuster, Theodorus J. W. M., Hilvarenbeek, Netherlands.
Shah, Ajay, Mombasa, Kenya.
Shah, Nilesh D., Nairobi, Kenya.
Shaw, Patricia V., Leeds.
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EXAMINATIONS 1986

The examination dates for 1986 are as follows:

Gem Diamond Examination:
Monday, 9th June.

Examinations in Gemmology:
Preliminary, Theory, Tuesday, 24th June
Diploma: Theory, Wednesday, 25th June
Practical, Thursday, 26th June (in London the practical examination may be held on other days in that week).

The last date for receiving examination entry forms is 31st March.

CLERICI SOLUTION A WARNING

In view of the extremely dangerous nature of Clerici solution and the possible hazards when used by individuals not accustomed to handling dangerous chemicals, the Council has decided that the Association (1) should not support its use in gem testing and (2) would not supply the solution in future.

LITERATURE GUIDES

The Science Reference Library hopes to publish two literature guides, one to mineralogy, the other to gemmology, over the next few months. Will anyone interested please write to External Relations Section, Science Reference Library, 25 Southampton Buildings, London WC2A 1AW – this will help the market assessment.

20th INTERNATIONAL GEMMOLOGICAL CONFERENCE, SYDNEY, AUSTRALIA

This very successful conference was held from 29th September to 4th October, 1985, at the Manly Pacific Hotel on the shores of Sydney Harbour. Delegates from 17 countries attended.

Authors and titles of papers are listed below in order of presentation.

Chalmers, R. O. Australian gem and ornamental minerals.
Sobolev, N., Efrimova E. S. Some physical and chemical characteristics of diamonds from Copeton, New South Wales.
Tombs, G., Sechos, W. Surface and internal features of Argyle diamonds, Kimberley Region, Western Australia.
Pienaar, H. Gemmology of 'Blue Lace' agate, Namibia.
Zoysa, G. Recent Sri Lankan gems.
Sherman, G. The Australian opal fields.
Arps, C. E. S. In search of the source rocks of Sri Lanka's gemstones: a progress report.
Zwaan, P. C. Gemmological news from the Embilipitiya and Kataragama areas in Sri Lanka.
Schiffmann, C. A. Note on a large rough taaffeite.
Vochten, I. R., de Grave, E., Zwaan, P. C. Characterization of some scapolite, corundum and spinel crystals from Kochipadana and Amarawewa, Sri Lanka.

Eliezri, I. Colombian emeralds.
Graziani, G. The effect of internal characteristics on the resulting aspect of gem minerals.
Kanis, J. Zambia's gemstones.
Dragsted, O. Numite from Greenland.
Myers, J. The Western Australian synthetic emerald.
Gübelin, E. Mexican opal and its inclusions.
Coldham, T. Inclusions in Australian sapphires before and after heat treatment.
Franklin, B., Giles, A. Use of electron microscope in gemstone determination.
Birch, W. D. Gemstones from Beechworth, Eldorado, Victoria.
Brown, G. Australian gem feldspars.
Lishmund, S., Pecover, S. Tertiary volcanoclastic rocks in New South Wales and the genesis of Australian sapphires.
Adrian, J. Geology as an aid to gemmology in New South Wales.
Kovac, C., Birch, W. D. Gem minerals of Pakistan.
Sutherland, F. L., Hollis, J. High pressure gem minerals in Eastern Australia.
Katz, M. Review of the geology of the gemstones of Sri Lanka.
Gordon, J. Gem minerals of the Harts Range, Northern Territory, Australia.
Darragh, P., Hill, R. E. T. The Warda Warra Emerald Deposit, Western Australia.
Mumme, I. Emerald occurrence in Australia.
Chikayama, A. Gemstones in China, especially jade and similar stones.
Superchi, M. An Italian gem material: the Chalky Alabaster from Volterra, Tuscanny, Italy.
Harding, R. R., Scarratt, K. A description of ruby from Nepal.
Segnit, E. R. A decorative serpentine from Western Australia.
MacGregor, E. The beneficiation and treatment of Brazilian emeralds.
Sunagawa, I. Why ruby and sapphire take different crystal habits.
Remau, G. Gem quality apatite from Transvaal, South Africa.
Scarratt, K., Harding, R. R. Ruby and sapphire with glass infillings.
Becker, G. Gem carving.
Ponahlo, J. A new identification method for synthetic emeralds, rubies and other highly valued gemstones.
Sato, K. Paper read by Sunagawa, I. and Shida, J. Gem testing based on the characterization of crystal defect and texture.
Schiffmann, C. A. Limitations of the spectroscopic identification of a treated diamond.
Jobbins, E. A. A.C.D. Pain and the gemstones of Burma.

Letters to the Editor

From Peter J. Crowcroft, Ph.D.

Dear Sir,

Peter Read's recent letter in the *Journal*[1] has made me realise that I completely underestimated the depth of feeling that traditional gemmologists have for the Beilby theory of polishing when I wrote my paper "Demise of the Beilby-Bowden Theory of Polishing" in 1981[2]. I thought that presenting a summary of the accepted scientific view today (that the theory is incorrect) would be sufficient to bring gemmology up to date on this rather small technical point. Comprehensive references were deliberately given so that interested readers could follow up the story for themselves (and also because the gemmology texts are so lacking in providing references to the scientific literature). I find Read's dismissal of these references as 'circumstantial' to be quite unscientific, particularly as neither he nor Anderson seem to have even examined them! Does Read or (did) Anderson seriously believe that there has been no significant work done on the nature of the polished non-metal surface since Finch (fifty years ago) or Beilby (eighty years ago)? I would encourage readers to search out the references I gave at their nearest University library and make up their own minds.

Read's letter is an excellent illustration of why the gemmology texts are out-of-date. This was the main point of my letter in the January 1985 edition of the *Journal*[3]. Gemmologists have not kept up with the huge explosion in scientific knowledge over the past 20–30 years. Consequently today they do not fully realise how far behind they are.

The Beilby theory is not the only example in gemmology of an 'emotional' attachment by gemmologists to a nice but incorrect theory. A second example is the idea that Hannay and others were successful in their attempts to produce synthetic diamonds at the turn of this century. This matter *should* have been decided in 1976. It was B. W. Anderson himself who wrote in this *Journal* reviewing a paper by Prof. A. T. Collins:

'These latest results thus reinforce the generally held judgement that Hannay's diamond fragments could not have been synthesised as the results of his experiments. . . The most probable explanation of the mystery seems to be that the starting materials were accidentally contaminated with particles of diamond dust'[4]. Earlier in the same review Anderson wrote: 'In 1959 and in 1962 the Hannay specimens were again examined by X-ray methods by Professor Lonsdale and her colleagues, and they now became convinced that the fragments consisted of *natural* diamonds'. (Italics in the original).

Yet when Anderson revised the 4th edn of *Gems* his previous conviction deserted him. He not only left Webster's text about Hannay unchanged ('Thus on the face of things the earliest experiment on diamond synthesis was successful'), but he allowed the crucial word 'natural' to remain omitted from in front of 'diamonds' in the description of Lonsdales work (page 374). Anderson even added an additional full page account of another 1900's attempt to produce synthetic diamonds. This addition was commended (and described as 'apparently successful') when Chisholm reviewed the 4th edn in 1984[5]. The 'forgetting' of Prof. Collins work, the misrepresentation of Prof. Lonsdales work and the continued propagation of the idea that Hannay and others were successful in their experiments in the face of conclusive evidence to the contrary is reprehensible.

Both these examples demonstrate a reluctance by traditional gemmologists to accept scientific results when it does not suit them. This is not the way a Science works. Thus I am sceptical of Read's call to his scientific colleagues to produce evidence for him. I see little indication that the Gemmology of today would either welcome or even consider such results. Gemmology is in urgent need of academically qualified people to 'translate' the relevant sections of current day physics, chemistry, etc. into gemmological language. This will eventually happen but maybe the process will not start until the older generation of traditional gemmologists have passed from the scene.

Yours etc.,
Peter Crowcroft

19th August 1985
1302 World Trade Centre, Causeway Bay, Hong Kong.

(1) *J. Gemm.*, 1985, XIX(6), 552.
(2) *J. Gemm.*, 1981, XVII(7), 459.
(3) *J. Gemm.*, 1985, XIX(5), 466.
(4) *J. Gemm.*, 1976, XV(3), 138.
(5) *J. Gemm.*, 1984, XIX(1), 70.

From G. Bosshart, M.Sc., G.G. and Dr K. Schmetzer

Dear Sir,

With reference to the article 'Spectrophotometric measurements of faceted rubies' by A. Banerjee, J. Himmer and H.-W. Schrader, *J. Gemm.*, 1985, **XIX**, 6, 489–93, we would like to make the following comments.

The normal practice in both our laboratories is to record the absorption spectra of *faceted* stones (in this case rubies) and not thin sections or polished platelets. We therefore wish to state that the spectra described in both of the papers quoted in the above publication (Schmetzer & Bank, 1980, and Bosshart, 1982) were not, as implied by Banerjee *et al.*, those recorded for polished thin sections but for faceted stones.

However, a problem not discussed by the authors of the above publication, is the measurement of polarized spectra in faceted anisotropic gems which may be difficult (in particular complete polarisation).

Furthermore, the immersion method described by Banerjee *et al.* has one main disadvantage: the absorption of methylene iodide is very high in the ultraviolet area. This spectral region, on the other hand, is assumed to be of diagnostic value for the distinction of natural and synthetic rubies. Methylene iodide would therefore mask all available spectral information.

One of us (G.B.) will submit an article discussing the measurement and presentation of absorption spectra for faceted gemstones, for publication in the *Journal* in the near future.

Yours etc.,
G. Bosshart*
K. Schmetzer†

6th December 1985

*Swiss Foundation for the Research of Gemstones, Zurich, Switzerland.
†Institute of Mineralogy and Petrography, University of Heidelberg, Heidelberg, West Germany.

THE JOURNAL OF GEMMOLOGY BACK NUMBERS

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Wanted
A member wishes to acquire copies of *The Journal of Gemmology*, volumes 1, 2 and 3. Box No. HC1.

For Sale
The Journal of Gemmology, volumes 8–19 inclusive are offered for sale. Also copies of The Gemmologist, Gems and Gemcraft. Box No. HC2.

DATES FOR 1986

Tuesday, 4th March
Talk by Prof. Pieter C. Zwaan, F.G.A. The Flett Theatre, Geological Museum, Exhibition Road, South Kensington, London SW7.

Tuesday, 22nd April
Talk by Dr Charles E. Arps, F.G.A. The Flett Theatre.

Tuesday, 13th May
Annual General Meeting.

Tuesday, 27th May
Talk by Mr Gunnar Raade. The Flett Theatre.

Tuesday, 16th September
Talk by Mr Kenneth Scarratt, F.G.A. The Flett Theatre.

Tuesday, 14th October
Talk by Dr Johann Ponahlo. The Flett Theatre.

Monday, 10th November
Reunion of Members and Presentation of Awards. Goldsmiths' Hall, Foster Lane, London EC2.

Instructors in Gemmology

In September 1986 the Gemmological Association plans to launch the first part (Preliminary Section) of a new correspondence course in gemmology to replace the existing course which has remained substantially unchanged for many years.

In anticipation of an increased number of students annually, the G.A. wishes to recruit some additional instructors in order to spread the work load.

The minimum qualification is the Diploma of the Association (F.G.A.), but additional relevant academic qualifications and trade experience are desirable. It also will be an advantage to hold professional teacher/trainer qualifications and to have experience in these fields.

The work of an instructor is demanding both in terms of knowledge and commitment, but can also be very enjoyable.

Anyone who wishes to apply to be an instructor should apply in writing, as soon as possible, with detailed C.V., to the Secretary, Gemmological Association of Great Britain, St. Dunstan's House, Carey Lane, London. EC2V 8AB.

GEMMOLOGICAL ASSOCIATION OF GREAT BRITAIN

The Arms and Crest of the Association, conferred by a grant of Arms made by the Kings of Arms under royal authority. The cross is a variation of that in the Arms of the National Association of Goldsmiths of Great Britain and Ireland. In the middle is a gold jewelled book representing the study of gemmology and the examination work of the Association. Above it is a top plan of a rose-cut diamond inside a ring, suggesting the scrutiny of gems by magnification under a lens. The lozenges represent uncut octahadra and the gem-set ring indicates the use of gems in oranmentation. The lynx of the crest at the top was credited, in ancient times, with being able to see through opaque substances. He represents the lapidary and the student scrutinising every aspect of gemmology. In the paws is one of the oldest heraldic emblems, an escarbuncle, to represent a very brilliant jewel, usually a ruby. The radiating arms suggest light diffused by the escarbuncle and their tips are shown as jewels representing the colours of the spectrum.

Historical Note

The Gemmological Association of Great Britain was originally founded in 1908 as the Education Committee of the National Association of Goldsmiths and reconstituted in 1931 as the Gemmological Association. Its name was extended to Gemmological Association of Great Britain in 1938, and finally in 1944 it was incorporated in that name under the Companies Acts as a company limited by guarantee (registered in England, no. 433063).

Affiliated Associations are the Gemmological Association of Australia, the Canadian Gemmological Association, the Gem and Mineral Society of Zimbabwe, the Gemmological Association of Hong Kong, the Gemmological Association of South Africa and the Singapore Gemologist Society.

The *Journal of Gemmology* was first published by the Association in 1947. It is a quarterly, published in January, April, July, and October each year, and is issued free to Fellows and Members of the Association. Opinions expressed by authors are not necessarily endorsed by the Association.

Notes for Contributors

The Editors are glad to consider original articles shedding new light on subjects of gemmological interest for publication in the *Journal*. Articles are not normally accepted which have already been published elsewhere in English, and an article is accepted only on the understanding that (1) full information as to any previous publication (whether in English or another language) has been given, (2) it is not under consideration for publication elsewhere and (3) it will not be published elsewhere without the consent of the Editors.

Papers should be submitted in duplicate on A4 paper. They should be typed with double line spacing with ample margins of at least 25mm all round. The title should be as brief as is consistent with clear indication of the content of the paper. It should be followed by the names (with initials) of the authors and by their addresses. A short abstract of 50–100 words should be provided. Papers may be of any length, but long papers of more than 10,000 words (unless capable of division into parts or of exceptional importance) are unlikely to be acceptable, whereas a short paper of 400–500 words may achieve early publication.

Twenty five copies of individual papers are provided on request free of charge; additional copies may be supplied at cost, but they must be ordered at first proof stage or earlier.

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The Journal of Gemmology

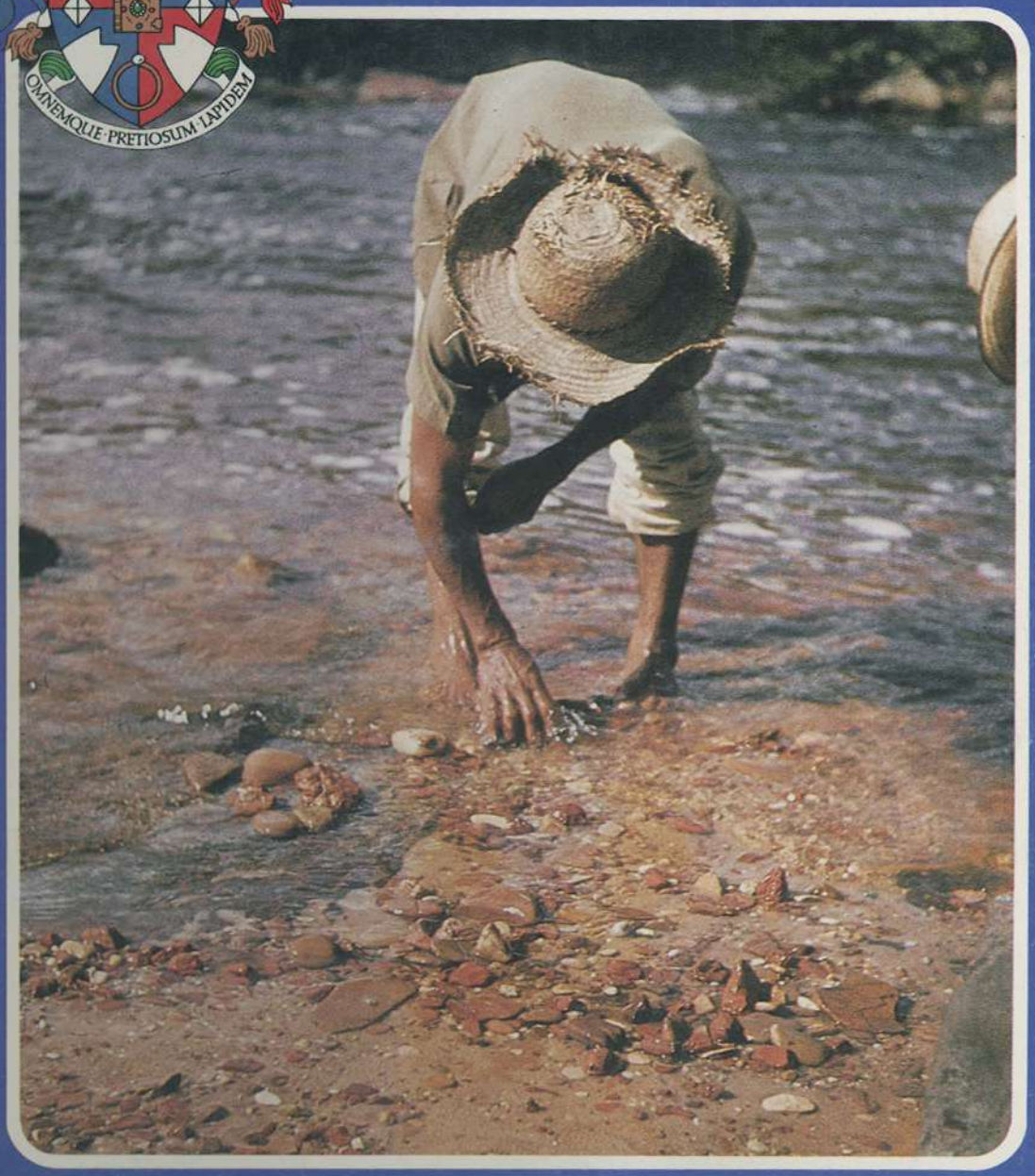

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The Journal of Gemmology

VOLUME 20

NUMBER TWO APRIL 1986

Cover Picture

Amerindian named 'Joseph' collecting jasper in the Ireng River at one of the Orinduik falls in Guyana, South America – see page 91.

Photograph by J.G. Gosling, F.G.A.

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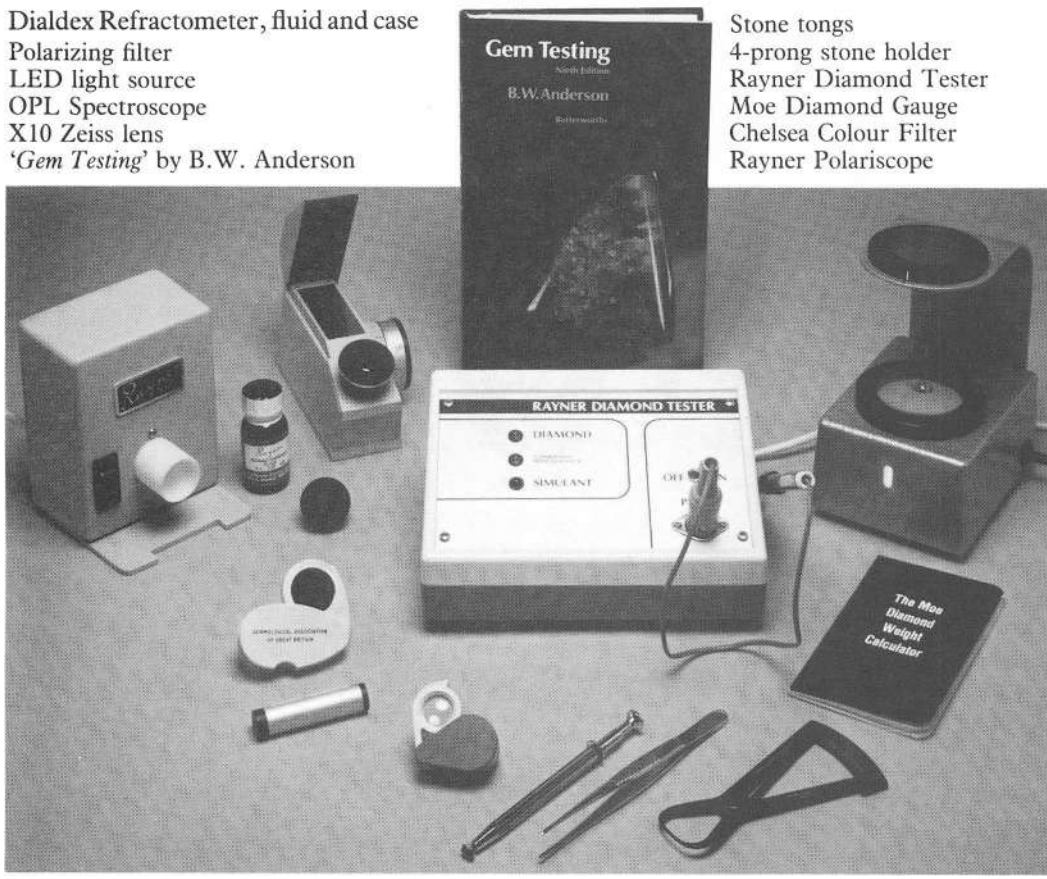

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New developments in spectroscopic methods for detecting artificially coloured diamonds

G.S. Woods and A.T. Collins†*

* CSO Valuations Ltd, 17 Charterhouse Street, London, EC1N 6RA
† Wheatstone Physics Laboratory, King's College, London, WC2R 2LS

Introduction

Four parameters ('the four Cs') normally determine the value of a polished diamond gemstone: the carat weight, the cut, the clarity and the colour. For a diamond of a given weight, with a well-proportioned cut and a high clarity grade, the colour has a profound influence on the value of the stone.

Diamonds which appear completely colourless are very rare and command the highest prices. However, a large proportion of gem quality diamonds, belonging to the so-called Cape Series, exhibit various degrees of yellowness down to a pale straw colour. Even a hint of this yellow coloration – so faint that a layman would not notice it – significantly reduces the value of the diamond. As the yellow colour becomes more and more pronounced, so that it becomes obvious even to the untrained eye, the value of the diamond falls further. Occasionally, however, diamonds are found in nature which are of excellent gem quality and which have a *full-bodied* yellow, golden or amber colour. Such stones are termed 'fancies'. These diamonds, when properly cut and polished, are on grounds of both rarity and attractiveness generally more valuable than those with the less definite pale yellow colours of the lowest categories of the Cape Series. In Fig. 1 we represent in a schematic way how market forces determine the value of diamonds having different depths of yellow coloration. We notice that, although the strongly-coloured yellow fancy diamonds are nowhere near as valuable as otherwise comparable colourless stones, they can command a price well above some of the diamonds near the middle of the distribution.

Research work on diamond during the 1950s, notably by Dugdale[1] and Clark and co-workers[2,3], showed that it was possible artificially to colour diamonds yellow or golden by subjecting them to radiation damage in a nuclear reactor, or in a van de Graaff accelerator, or by using very intense γ-ray sources, and then heating the specimens to about 800°C. This pioneering work led to three very fruitful decades of fundamental research on physical properties of diamond, including investigations of the point defects which are the origins of colour, and this is still an active field of investigation in many laboratories.

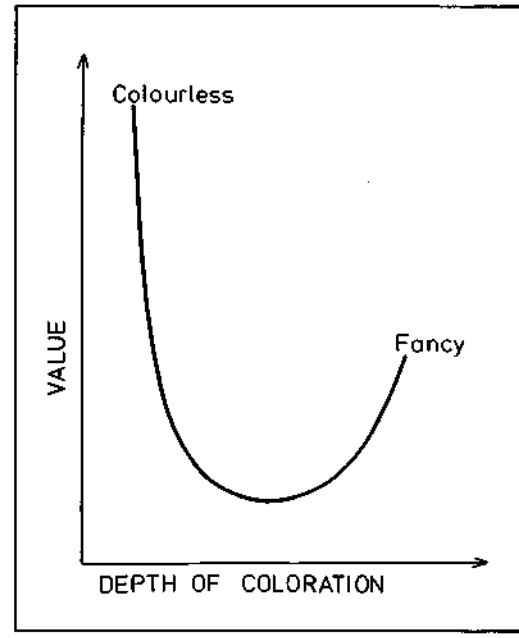

Fig. 1. This diagram illustrates, in a schematic way, how the value of a cut and polished diamond varies with the depth of yellow coloration.

The colour produced by irradiation and heating (called 'treatment' in the gem trade) adds to that already present in the diamond. Hence, considering diamonds from near the minimum point in Fig. 1, the effect of treatment is to intensify their colour, and thus potentially to enhance their value. Although many customers would be unable to tell, by eye, whether a fancy yellow diamond was naturally or artificially coloured, market forces decree that the natural product is more valuable than the artificial one. (Indeed, this is true for most gem materials.) A

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further advantage of treatment in increasing the value of a stone is that the deeper colour can hide small cracks and inclusions, and so diamonds with a relatively low clarity grade can be selected in the first instance.

These points were, of course, all appreciated at an early stage by the gem industry: consequently gem-testing laboratories world-wide now often have the responsibility of deciding whether a particular diamond has been treated. It should be noted that many treated diamonds are in fact legitimately sold as such, with certificates stating that the colour is artificial. However, problems arise when attempts are made to pass off treated stones as natural yellow fancy diamonds.

Spectroscopic techniques

Although many diamonds may appear to have a similar yellow colour, the way in which they absorb light may be very different. These differences can be partially revealed using a simple hand-held spectroscope, and very considerable advances in examining diamonds were made by Anderson[4] with such an instrument. Absorption lines in diamond become much sharper if the diamond is cooled to about −150°C or lower, and Scarratt[5] obtained far greater sensitivity with a hand spectroscope when the diamonds were at low temperature. The hand spectroscope, however, has many limitations, and the major gem-testing laboratories now use spectrophotometers which provide a plot, or spectrum, showing how strongly the diamond is absorbing over a wide range of wavelengths. It is often advantageous to record a spectrum with the diamond cooled to liquid nitrogen temperature (−196°C) or slightly above.

In Fig. 2 we show absorption spectra, recorded at room temperature, of four different yellow diamonds – a canary yellow, a deep Cape yellow, an amber yellow and a treated yellow. At first sight two things may seem surprising. The first is that the diamonds have a similar hue; and the second is that there should be any problem in detecting the treated stone.

The reason for the similarity of colour is related to the response of the human eye, which has its maximum sensitivity at about 550 nm and can detect virtually nothing at wavelengths below 380 nm or above 750 nm. Moreover, the colour receptors in the eye respond only to the average light level and cannot sense sharp absorption lines or subtle variations in the light level. As far as the eye is concerned, therefore, all four diamonds are simply absorbing light at the blue/violet end of the visible spectrum and so appear yellow.

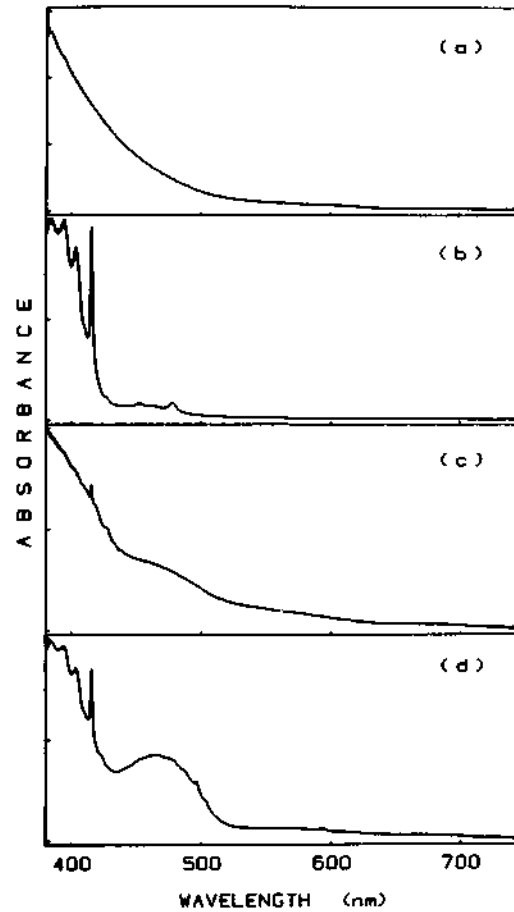

Fig. 2. Absorption spectra of four yellow diamonds, recorded with the samples at room temperature. (a) is a type Ib diamond classified as canary yellow, (b) is a Cape series diamond, (c) is an amber diamond and (d) is a treated diamond.

A precise assessment of the colour can be obtained by taking the data of Fig. 2 and calculating the chromaticity coordinates[6]. These are numbers which locate the colour in a two-dimensional colour space, and which are an objective measurement of the colour of an article, as would be recorded by a standard observer under standardized conditions of illumination. (The interested reader is referred to books by Billmeyer and Saltzman[7], Graham[8] or Wyszecki and Stiles[9] for a more thorough discussion of this topic than can be given here.) The chromaticity coordinates would again show the similarity between the colours of the four diamonds, placing them in fairly close proximity in colour space.

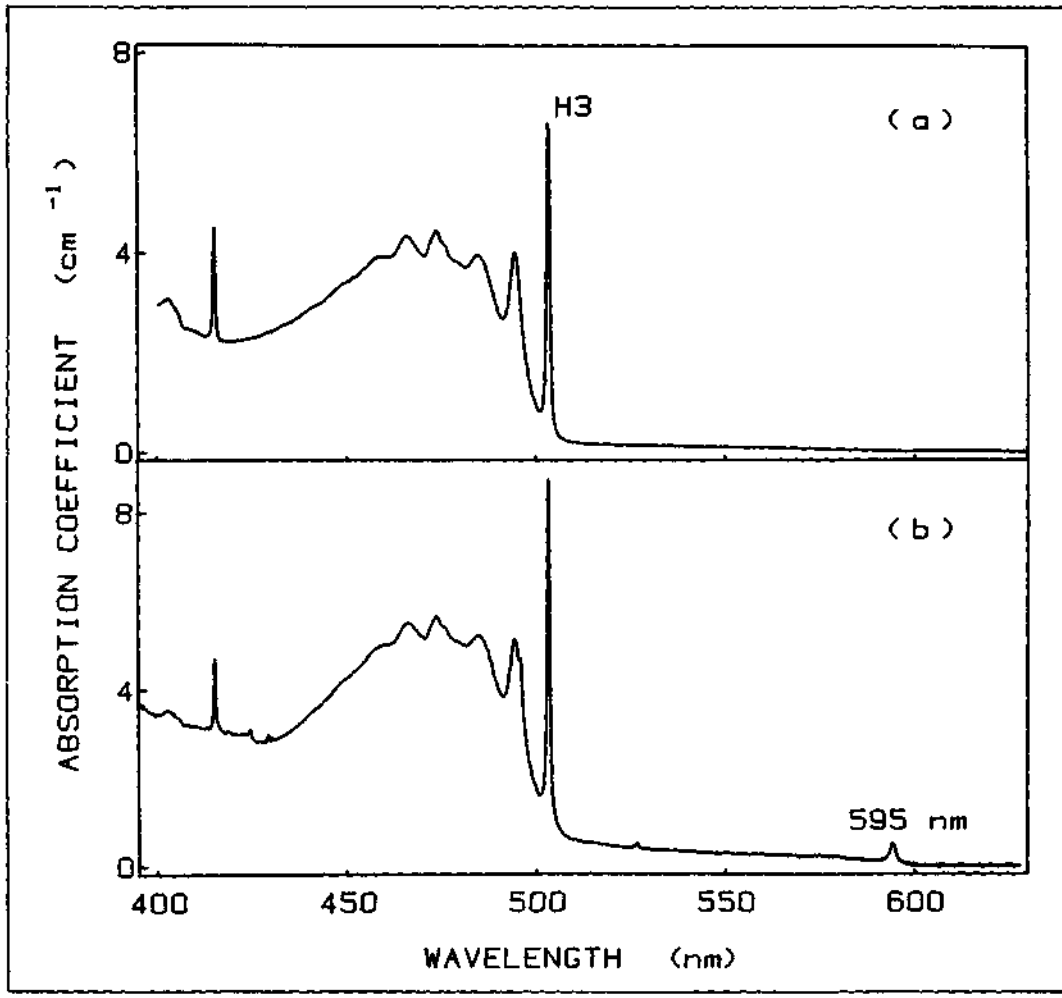

Fig. 3. Absorption spectra, recorded with the samples at liquid nitrogen temperature, of (a) a natural fancy yellow diamond and (b) a treated yellow diamond.

As noted above, the differences between the spectra shown in Fig. 2 should make it very easy to identify a treated diamond. The problem which arises is that the dominant absorption band produced in some diamonds by treatment is also found to occur naturally in certain stones[10]. In Fig. 3 we show absorption spectra, recorded at liquid nitrogen temperature, of a natural fancy yellow diamond and an artificially coloured diamond. In both cases the colour is caused by the H3 absorption band which has a sharp line at 503 nm. It is diamonds containing this absorption band which can pose the greatest problem to gem-testing laboratories. Inspection of Fig. 3 shows that there is an absorption line at 595 nm in the spectrum of the treated diamond that is not present in the naturally coloured stone. Studies by Crowningshield[11] in 1957 on a large number of treated and untreated diamonds indicated that the presence or absence of this absorption line could be used to indicate whether the colour of a cut and polished diamond was artificial or natural. However, in 1978, high temperature annealing studies by Collins[12] showed that the 595 nm absorption line can be destroyed (by heating treated diamonds to about 1000°C) without significantly changing the colour. It is possible that this phenomenon has been known for many years by those operators who colour diamonds artificially and try to sell them as natural fancy stones. The fact that the 595 nm absorption line is not a reliable indicator of the history of a diamond has caused considerable anxiety, since 1978, in the gem-testing centres.

Research work on treated diamonds has continued in our laboratories, and as a result of this work we can now set out a series of spectroscopic measurements which will indicate with a very high degree of reliability whether a yellow or brown fancy coloured diamond is naturally or artificially coloured. In the rest of this paper we deal with the relevant point defects in diamond, summarizing previous work and incorporating our present results at the appropriate points. Useful background reading may be found in articles by Anderson[13], Collins[14] and Woods[15].

Point defects in diamond

In this section we shall be concerned with the nitrogen impurity which is present in most diamonds, with the vacancies and interstitials which result from irradiation and with the effects of heat treatment. It is believed that nitrogen is first incorporated in the diamond crystal, as it grows, in the form of single nitrogen atoms on substitutional lattice sites (i.e. at those points in the diamond lattice normally occupied by carbon atoms). For a small proportion of natural diamonds most of the nitrogen is still present in this form, and the crystals have a characteristic yellow colour. These are classified as type Ib diamonds and in some cases the colour may be described as a canary yellow[16]. The absorption spectrum in the visible region for type Ib diamonds is typified by that shown in Fig. 2a.

For most diamonds the high temperatures (around 1000–1200°C) experienced over geological time-scales result in the nitrogen atoms moving around in the crystal, ultimately forming small aggregates. The first stage of aggregation produces A-centres, which are made up of two nearest-neighbour nitrogen atoms. The next dominant stage of aggregation is the formation of B-centres, which are believed to contain four nitrogen atoms. Neither the A-aggregates nor the B-aggregates produce absorption in the visible region, so neither contributes to colour; however the conditions that result in the formation of B-centres also produce N3 centres. It is the N3 centre, believed to contain three nitrogen atoms, which, when present in different concentrations, produces the yellow colours of the Cape Series stones. The spectrum of the N3 centre is that shown in Fig. 2b.

From this brief summary, we can make an important generalization: pale yellow diamonds selected for treatment almost certainly have some nitrogen present in the B form.

Radiation damage

Immediately after damage by high energy electrons or fast neutrons, diamonds have a blue or green colour, primarily associated with absorption in the GR1 band[14], due to the vacancy. As the diamonds are heated at progressively higher temperatures for a standard time interval (typically one hour) the following behaviour of certain absorption bands is noted:

a. At about 275°C the 595 nm line is first detected. So, too, is an absorption line at 1450 cm^{-1} (6897 nm) in the infrared spectral region. The interstitial atom produced by the irradiation is believed to be involved in the formation of both of these centres. As the temperature is raised the 595 nm line reaches its maximum intensity by about 800°C, and is reduced to zero after heating to about 1000°C[12]. The 1450 cm^{-1} line reaches its maximum intensity at about 400°C and remains at this strength until about 1300°C. Prolonged heating at temperatures around 1400°C is necessary to eliminate this absorption[15].
b. At about 500°C the vacancies begin to move and the GR1 absorption begins to decrease, finally disappearing after heating at about 800°C. As the intensity of GR1 decreases, so, in a complementary fashion, do the intensities of the H3 (503 nm) and H4 (496 nm) lines increase. Spectra of diamonds containing the H3 and H4 bands have been shown previously in reference 14, and it was emphasised there that it is necessary to make measurements at high resolution with the diamond at low temperature if the H4 line is to be distinguished from the side-band of the H3 absorption system. The H3 centre is a vacancy trapped at a nitrogen A-centre and the H4 centre is a vacancy trapped at the nitrogen B-centre, and, for diamonds heated at temperatures up to 1200°C, the ratio of the H3:H4 line strengths is proportional to the ratio of the A:B nitrogen concentrations. It has been reported previously, and confirmed in the present investigation, that the relative strength of the H4 line may be substantially reduced by heating the diamond at temperatures above about 1200°C. Four hours heating at 1400°C can completely eliminate the H4 band in some diamonds.
c. The most important finding to emerge from our research[17], as far as gem-testing laboratories are concerned, follows on from the preliminary work of Woods[15] on the H1b and H1c lines in irradiated and annealed diamonds. These absorption lines in the near infrared spectral region, at 2024 and 1936 nm respectively, are shown in Fig. 4. The value of these lines in the examination of treated diamonds stems from their annealing behaviour. Fig. 5a shows the decay of the GR1 and the growth of the H3 band as the diamond is heated at temperatures between 400°C and 800°C, and we see that the intensities of these bands behave in a comple-

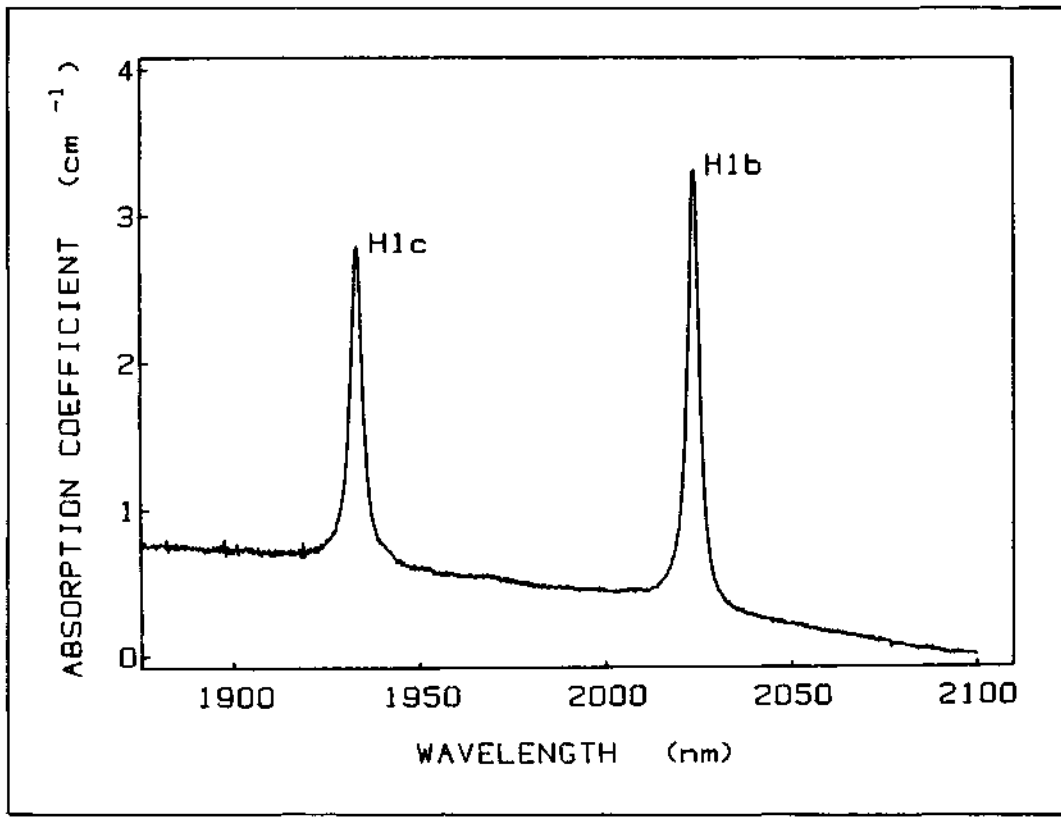

Fig. 4. Absorption spectrum, recorded with the sample at liquid nitrogen temperature, showing the H1b and H1c lines in a treated diamond.

mentary fashion. The H4 band, although not shown for the sake of clarity, behaves like the H3 band. Fig. 5b shows that, at a somewhat higher range of temperatures, exactly the same complementary effect is observed for the decay of the 595 nm band and the growth of the H1b line (the H1c line behaves identically). In particular we note that for annealing temperatures up to 1325°C it is not possible to produce a treated yellow or brown diamond that has not present either the 595 nm line on the one hand, or, on the other, the H1b and/or H1c lines.

Our work[17] shows that the ratio of the H1b:H1c line strengths is proportional to the ratio of the H3:H4 line strengths. However there is no relationship between the intensities of H1b and H3, nor of H1c and H4. These results indicate that H1b and H1c centres are formed when some or all of the constituents of the 595 nm centre become trapped at the A-form or B-form of nitrogen, respectively.

Prolonged heating at 1400°C substantially reduces, or eliminates, the H1b and H1c lines. However, we have found that this drastic treatment results in an unattractive appearance of the diamond, partly because of an absorption often produced at the red end of the spectrum (illustrated in Fig. 6) which imparts a drab, unappealing green colour; and also because of internal graphitization often occurring at micro-inclusions. Moreover, it is very difficult to prevent the polished facets on the stone from becoming frosted. Thus, although it is possible, with care, to heat a treated diamond to 1000°C to destroy the 595 nm line, it is not possible to destroy the H1b or H1c lines without ruining the diamond as a gem.

Natural fancy diamonds

We have examined a large number of diamonds in which the H3 band occurs naturally and, apart from one diamond which we discuss later, we find the following:

a. There is little evidence for an absorption line at 1450 cm^{-1} in any of the diamonds;
b. None of the diamonds showed an H4 line, regardless of the A to B nitrogen ratio;
c. None of the diamonds had a 595 nm line;
d. None of the diamonds had an H1b or H1c line.

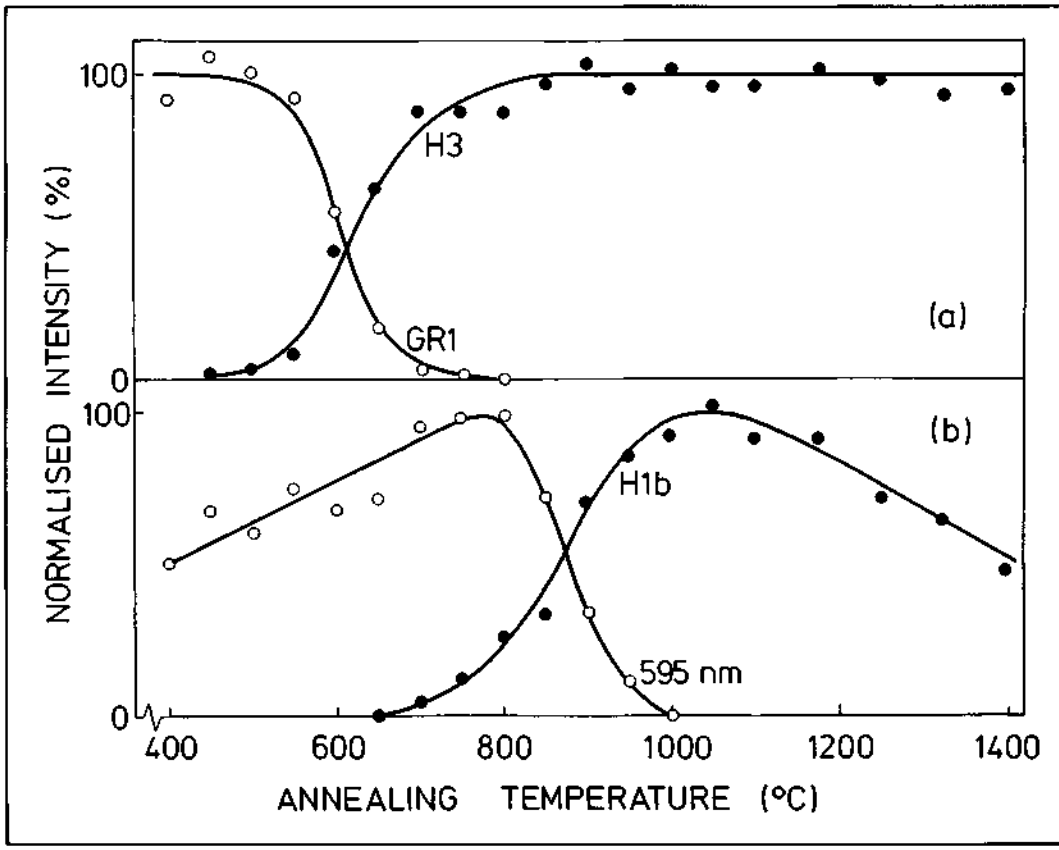

Fig. 5. Annealing curves showing (a) the decay of the GR1 absorption and the growth of the H3 (503 nm) absorption, and (b) the decay of the 595 nm absorption and the growth of the H1b line. The diamonds were heated for one hour at each temperature.

As we have noted above, the 1450 cm^{-1}, H4, 595 nm, H1b and H1c lines can be virtually eliminated in a treated diamond by heating for about four hours at 1400°C, although only at the cost of spoiling the diamond as a gem. In nature the lower temperatures acting for millions of years, on stones in which vacancies have been produced by natural processes, also result in diamonds showing only the H3 absorption band: in this case, however, the stones will not have suffered the deleterious effects which we have described as being a result of the higher temperatures used in the laboratory.

Spectroscopic assessment of diamonds

The presence or absence of the 1450 cm^{-1} infrared line, taken on its own, is not a satisfactory indicator of the origin of the colour of a diamond. Some diamonds which have not been irradiated have an absorption which may be confused with the radiation-induced 1450 cm^{-1} line. Furthermore, Woods[15] found that this line was *not* present in one of his treated stones, for reasons not yet fully understood. However, a clearly defined 1450 cm^{-1} line would strongly suggest that a diamond had been artificially coloured.

The absence of the H4 line does not unambiguously mean that a diamond has not been treated. It is perfectly possible, starting with a diamond which does not contain B-centres, to produce an artificial colour with no H4 absorption present. (See Fig. 3b for example.) However, as we have noted earlier, diamonds selected for treatment generally have at least some nitrogen present in the B-form, and the H4 line will therefore be present after treatment. The presence of this line would again strongly suggest that the diamond has been artificially coloured.

The most reliable indicator of the lack of authenticity of the colour of a diamond turns out to be the 595 nm line used until 1978, *taken in conjunction with* the H1b and/or H1c lines. Fig. 5 shows that for an annealing temperature around 700°C, the 595 nm line would be near its maximum strength, but the H1b and/or H1c lines would be

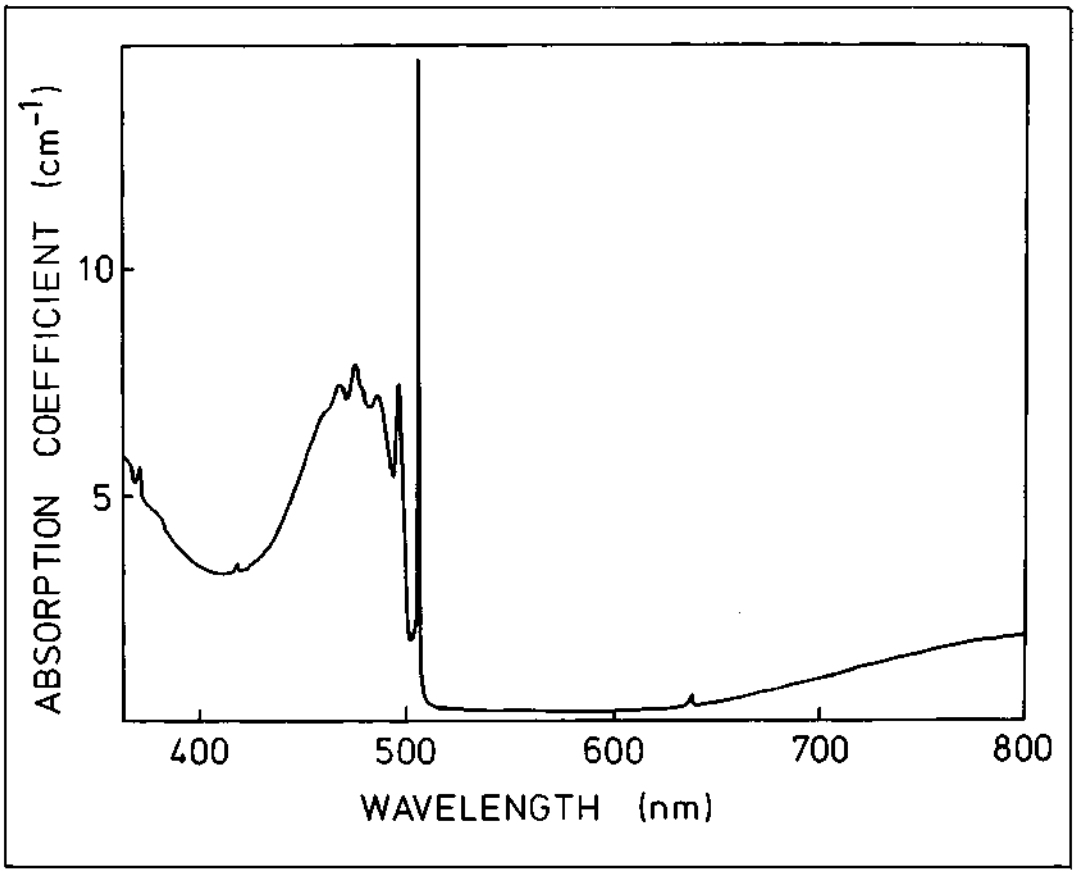

Fig. 6. Absorption spectrum, recorded with the sample at liquid nitrogen temperature, of a treated diamond that has been heated at 1400°C for four hours to destroy the H1b and H1c absorption lines. Note the absorption at the red end of the spectrum (wavelengths above 630 nm) which gives the diamond a drab, unattractive appearance.

barely detectable; whereas for an annealing temperature greater than 1000°C the 595 nm line would be completely absent, but the H1b and/or H1c lines would be relatively strong. An intermediate situation is observed for temperatures between 700 and 1000°C.

An exception

A diamond owned by the late Basil Anderson has been referred to previously in this journal[14]. Because it was purchased before 1950 Anderson was certain that the colour was natural. However, the diamond has both H3 and H4 absorption bands with the H3:H4 ratio proportional to the A:B nitrogen ratio, and a well-defined 595 nm line. In our present measurements we have shown that, for this stone, the H1b and H1c lines are very weak indeed, and the spectra are, at face value, all characteristic of a treated diamond that has been annealed at about 750°C.

We must assume that the natural annealing received by this diamond was relatively mild compared with that received by all the others we have examined (in much the same way as type Ib diamonds have experienced a milder degree of heating and nitrogen aggregation than the vast majority of type Ia diamonds). Diamonds like Anderson's are however extremely rare and we believe our method of assessing the origin of the colour of diamonds will be correct in 99% of cases examined. No treated diamonds should be mistaken as naturally coloured, but it is possible that very occasionally a naturally coloured diamond may be classified as treated.

Conclusions

Latest developments in research on artificially coloured yellow and brown diamonds have been described. We have shown that it is not possible to colour a diamond artificially using radiation damage

and heat treatment, without producing at least one of the absorption lines at 595 nm, 1936 nm (H1c) or 2024 nm (H1b). When all three are absent the diamond may safely be categorized as 'naturally coloured'. It is desirable to measure the spectra in the visible region with the sample cooled with liquid nitrogen. The H1b and H1c lines, however, are reasonably sharp at room temperature, and in many cases cooling will not be necessary to record the near infrared spectrum.

Very occasionally one or more of the above lines may be present in a naturally coloured stone. In any diamond in which the 595 nm band is absent, but the H1b and H1c lines are present, the strengths of the latter should therefore be compared with those of a known treated diamond which has an H3 band of similar intensity to that of the stone being investigated. If the H1b and H1c lines are very weak compared with the standard stone, then the colour of the diamond under test is probably of natural origin. This conclusion could be firmer if the H4 line is absent or very weak.

Even after completing a detailed series of tests there may be very rare occasions when a naturally coloured diamond is wrongly classified, but it should not in future be possible fraudulently to obtain a 'naturally coloured' certification for a treated diamond that has been heated at 1000°C to destroy the 595 nm line.

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Green aventurine quartz: mineralogical characterization

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Introduction

Quartzite, a metamorphic rock consisting of interlocking grains of quartz, may contain small crystals of mica or other minerals. When these accessory minerals impart an appealing colour, sheen or glitter to the quartzite, then it is known as aventurine quartz. Green aventurine quartz is one variety reportedly containing platey crystals of a green chromium-bearing muscovite mica, fuchsite[1]. It is commonly used for beads or set in rings, brooches and other articles of jewellery as well as being used in making bowls, vases and other ornamental objects. Most of the green aventurine comes from India; hence the misnomer, Indian jade. Some localities where it occurs are Belvadi in the Hassan district of Mysore and the Coimbatore,

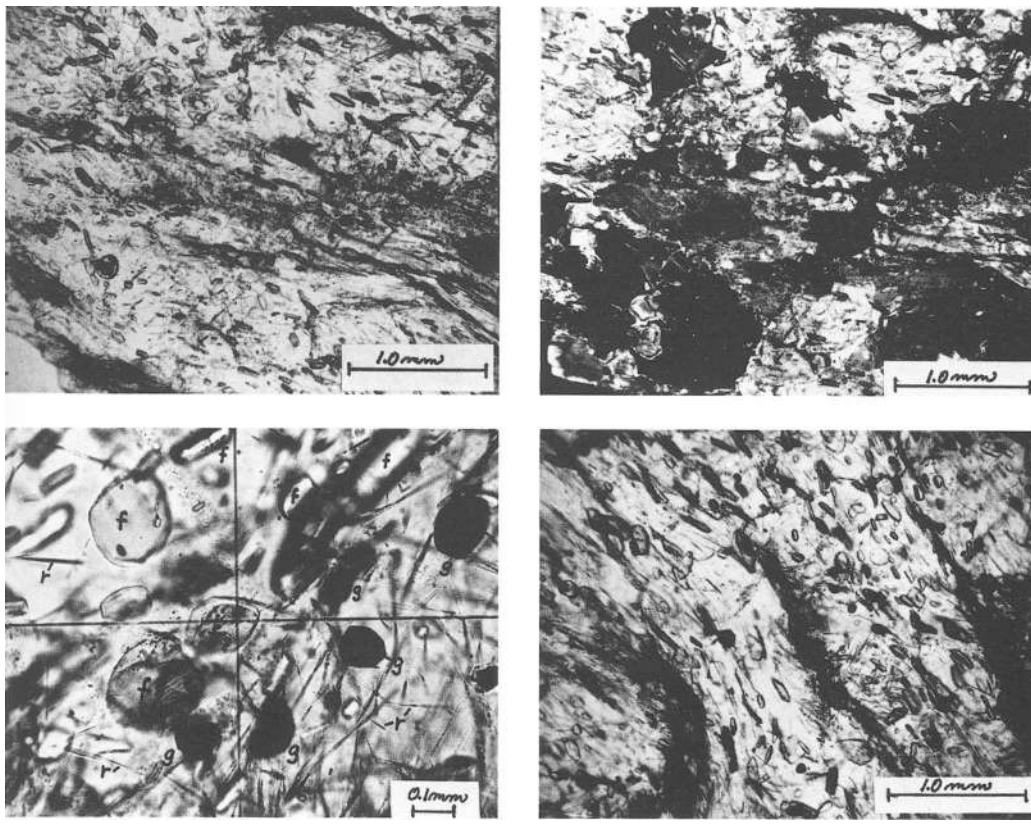

Fig. 1. Transmission light micrograph of a thin-section of green aventurine showing the various mineral components.
1a. Normal light. 1b. Crossed-polarized light.
1c. Normal light. f=fuchsite, g=garnet, r=rutile. 1d. Normal light.

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Bellary and Nellore districts of Madras. Other sources are Siberia, Tanzania, China, and Rutland County, Vermont, USA.[1,2]

Previous studies on the mineral description of green aventurine were not found to be reported in the literature. However, Webster[1] states that this material gives a chromium-type optical absorption spectrum, but with the lines in the red rather vague and the broad absorption in the yellow-green region not pronounced.

Green aventurine from the Bellary district, India, was studied in order to determine the mineral constituents present and their microstructural arrangement. These analyses were conducted by means of petrographic microscopy, scanning and transmission electron microscopy, X-ray diffraction and electron microprobe spectroscopy.

Petrographic microscopy

Thin sections showed the aventurine to be composed of a complex array of four crystalline minerals. Interlocking, irregularly-shaped grains of quartz, SiO_2, formed the bulk of the specimen. Associated with the quartz were three accessory minerals, fuchsite mica, $K(Al, Cr)_2(AlSi_3O_{10})(OH)_2$; rutile, TiO_2; and almandine garnet, $Fe_3Al_2(SiO_4)_3$.

Figs. 1a and 1b show this microstructure using normal light transmission and the same field using cross-polarized light. The relatively large polyhedral quartz grains can be seen best in Fig. 1b where some of these grains up to about 1.0 mm in size are at partial or complete extinction (black). The smaller 0.1–0.2 mm transparent green euhedral crystals of fuchsite are in abundance as are the grey hair-like fibres of rutile which are aggregated into bundles in some areas. Small dark red crystals of garnet, less than 0.1 mm, occur with less frequency. At the higher magnification of Fig. 1c some of these minerals are marked with identifying labels. The subparallel texture of the rutile fibres and fibre bundles as well as the platey fuchsite mica crystals imparts a schistosity to this metamorphic rock which is readily observed in Fig. 1d.

Electron microscopy

Transmission and scanning electron microscopes were used to examine fracture surfaces of the aventurine. These instruments revealed the granular texture of the quartz along with the accessory crystals of mica. The rutile and garnet crystals were not identified by these methods.

Fig. 2a shows the granular texture of the quartz on a fracture surface of the aventurine observed by scanning microscopy. A fracture crevice travelling through the quartz contains fuchsite mica.

Transmission electron microscopy using the replication method also revealed the granular nature of the specimen. Fig. 2b shows one region at high magnification where a small crystal of fuchsite mica is located at the grain boundaries of three relatively large grains of quartz. The mica crystal displays a parallel step-like topography reflecting the perfect cleavage inherent in this mineral.

X-ray diffraction

The powder X-ray diffraction pattern of aventurine obtained using a diffractometer showed peaks assignable to quartz and mica. Although almandine garnet and rutile were indicated by light microscopy, their volume percentage in the

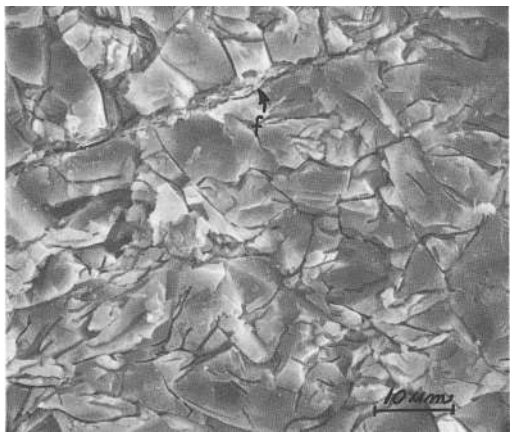

Fig. 2a. Scanning electron micrograph of the surface of green aventurine. Etched with NaOH. The grains of quartz are clearly discernible. Fuchsite (labelled f) occurs in a fracture crevice.

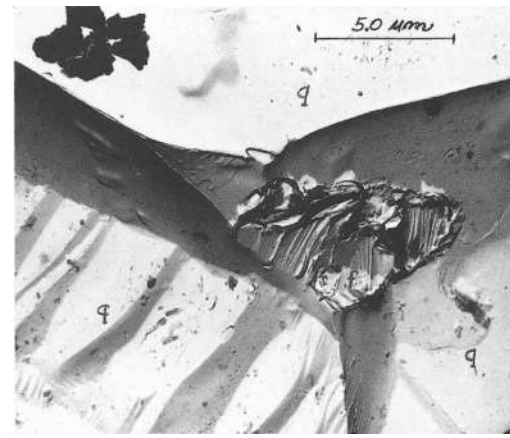

Fig. 2b. Transmission electron micrograph of the surface of green aventurine. Replication. Crystals of quartz and fuchsite mica are present in this field. q=quartz; f=fuchsite.

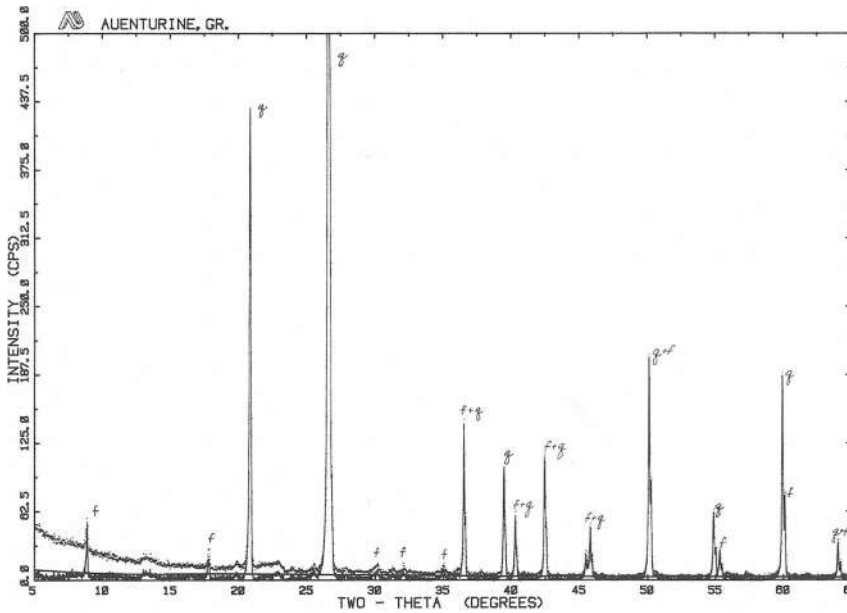

Fig. 3. X-ray diffraction pattern of green aventurine. CuKα radiation. Diffraction maximas identified by q=quartz and f=fuchsite mica.

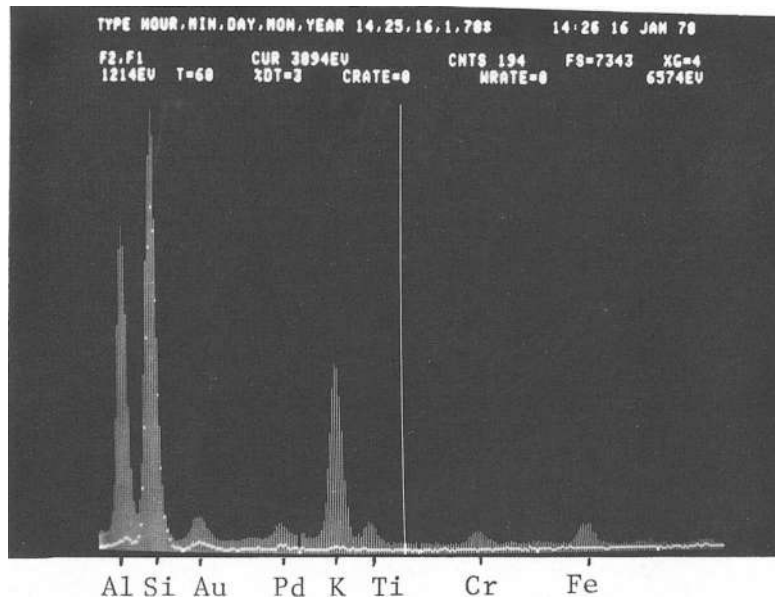

Fig. 4. X-ray spectrum emitted from green aventurine during electron microprobe analysis. Elements corresponding to the X-ray peaks are given by chemical symbols.

aventurine was too low to be detected by X-ray diffraction. These X-ray results are presented in Fig. 3.

Electron microprobe spectroscopy

Chemical analysis of the elements present in the aventurine was carried out by identifying the X-rays emitted from the sample when bombarded by an electron beam.

Fig. 4 shows the X-ray spectrum which was obtained. The various X-ray peaks are identified as to their corresponding chemical element. With the exception of the elements of gold (Au) and palladium (Pd), which were derived from the electron-conductive metal coating that was applied to the aventurine surface, all the elements detected corresponded to the various mineral species present.

Taking the elements in the order they appear on the graph in Fig. 4, aluminium (Al) occurs in almandine garnet, $Fe_3Al_2(SiO_4)_3$, and in fuchsite mica, $K(Al, Cr)_2 (AlSi_3O_{10})(OH)_2$. Silicon occurs in quartz, SiO_2, as well as in the garnet and mica. Potassium is found in the mica, titanium occurs in rutile, TiO_2, chromium occurs in the mica and iron occurs in the garnet.

Acknowledgement

The US National Museum, Division of Mineralogy, supplied the mineral specimens used in this study.

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Locating gem deposits by computer

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The information explosion about which so much is heard today is no passing phenomenon. The range and amount of literature (not always in book or journal form) with relevance to gemstones is surprisingly large and often appears to be growing exponentially. After nearly twenty-six years in national libraries, during which time I have examined virtually every piece of information on gemstones ever published, I am no closer to claiming close acquaintance with the whole field. The growth of information is matched, too, by growth in those interested in it and the interest shown manifests itself at a number of levels. As Curator of the largest European collection of earth science books and journals one of my chief tasks is to supply precise or general information from the collections as well as to build it up and maintain its eminence.

Sources of information

The readership of such an institution as the Science Reference Library (part of the British Library) has changed since its physical separation from the British Museum in the early 1970's. Readers even in those days would have been content to check gemmological points in the standard textbooks of the time and though there were in fact many other sources to which they could turn even then, few were aware that much useful data could be found in physical and chemical texts and journals as well as in mineralogical and geological ones. There seems to have been an unwillingness on the part of writers on gemmological topics to refer to outside sources, so that until very recently even the better monographs provided inadequate bibliographies with few citations of pieces other than those which most readers would already have known about. Even today almost all the gemmological texts are found wanting in this area. This may partly be due to the readership aimed at, since if a book can be addressed to the beginner, time and scholarship do not need to be spent on extensive literature searching. Another explanation may be that many writers are themselves unfamiliar with the scale of the resources now available and it is true that, unless a conscious effort is made to find out what is there, useful, even vital material will be missed.

Much of the elusive material is concerned with the location of minerals since many finds are first communicated to those needing to know and for obvious commercial reasons publication in high-relief texts would not be contemplated. Again, many gem minerals are found during prospecting for something else – a good example is the discovery of gem spodumene in the lithium mines of southern California. Recovery of strategic minerals may pay for the recovery of otherwise uneconomic gem specimen material and only the mineral may be thought worth recording. Those who do the recording will send details to a mineralogical or economic geology journal and may not think of *The Journal of Gemmology*.

Maps

Further useful information can be found in geological maps and in the maps produced for a limited and specific purpose. Again, access to maps is a specialized skill and finding out who actually holds a particular map is not always easy. Major libraries hold standard surveys, including geological ones, but many gem locations are not shown, either because they are too insignificant as places or the name used by miners is too local to get further than the immediate area. Many gem locations are known by more than one name and when a name is used it may refer to the nearest place of significance which may be some miles away from the actual mine (e.g. Sandawana). Where a name is used on a map and the deposit is described in the literature it ought to be possible to locate both even when the two names used are different. How this can be done will be seen later.

In the absence of definite detail about existing gem locations, possible ones can also be predicted if the right map is to hand. This will in all cases be a geological map since these are the only ones upon which elements are shown. If beryllium is seen on a

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map (usually as Be) then the possibility of the presence of one of the beryl gemstones is there.

The overall picture then is one of a mass of information, much of it fairly easily predictable and obtainable but with an underlying mass of data which is at once both valuable and unsuspected. The value of this type of information is that it is usually more specific and first-hand, being taken from workers in the field.

As anyone who has used *Chemical Abstracts* will know to their cost, the fear that something important may be overlooked through inadequate searching technique can be considerable and it is now unreasonable to expect anyone to search an increasingly large footage of small-type paperwork. To be sure of finding all there is on a particular topic at least a dozen journals need to be consulted and although *Mineralogical Abstracts* covers the earth science side well, many searchers for details of gem deposits may need to look in mining or economic sources or even in general science journals such as *Nature*.

Clearly some form of mechanized retrieval system is as necessary in the location of gem deposit information as it is in subjects with a wider background.

Databases

Fortunately today we have at least two databases concerning themselves with geology, mineralogy and allied topics. The databases GEOREF and GEOARCHIVE (American and British-based respectively) can be accessed through the Lockheed DIALOG host which itself is easily obtainable by subscribers to British networks with access to PSS (Packet Stream Switching). The technique of searching is not hard to master, but the real skill comes in avoiding unnecessary expense, since a lot of time can be spent pondering the next move while the system is actually live. There are ways of getting round this, as will be seen below. For greater ease of understanding, search qualifiers are not included in the descriptions below. Intending searchers will need to learn the qualifiers appropriate to the database host they select.

Searching

Searching for a topic means that the computer will look for given words, phrases, map coordinates or the names of authors and present them to the user in the form of "hits". A large number of hits is not necessarily helpful since the word GEOLOGY will appear so often in a geological database that to ask for it is a waste of time. We need to know how to avoid this waste by giving the system more specific words and combinations so that it will be able to narrow the search, remembering also that the material loaded into the system may be in different languages: if we expect a paper in German about emerald to include the word EMERALD rather than SMARAGD we may lose that paper. One way to bear this in mind is to reflect on the history of the country in which we are interested: former French colonies will be more likely to have papers written about them in French (EMERAUD). Again, the computer is literal and if you ask it for references including the word RUBY it will ignore RUBIES.

The two main databases are loaded (stored) with material in the form of abstracts so that the searcher's hits will include not only the title of relevant papers but abstracts of them. The most economic way to check whether or not a paper will be worth printing out is to get the system to type the title or the paper in précis form; only after this need the searcher opt for the full abstract (which is more expensive). It is hoped that *Mineralogical Abstracts* will be loaded on to GEOARCHIVE during 1986.

It is relatively easy to locate a paper on a particular gemstone; the name of the species can be keyed in accompanied by country name where known or by the name of the author (be careful with spelling) in addition:

RUBY AND MOGOK AND IYER

will give any paper whose keywords include the three (not any other paper and not any which contain only two or one keywords out of the three). For less certain searches it would be preferable to key

RUBY OR MOGOK

so that the system would look for papers with either keyword. Should the searcher already know about the Iyer paper and therefore not want to spend money on it he would key

RUBY OR MOGOK AND NOT IYER

The use of AND, OR and AND NOT is known as Boolean logic and is familiar to all computer users: without this conditioning searches would be hugely unwieldy, producing vast amounts of repetitive information.

If we wish to range in our search for ruby a little more widely we can key

RUB?

– this device is known as a truncation and will give hits for ruby, rubis (French) and rubies. A similar strategy for diamond might be

DIAMON?

but this would lead to an oversize response, since the terms diamond, diamondiferous and even Diamonair would be retrieved. In the latter case the use of AND NOT is indicated. In the same way PERIDOT? would give both the gem of that name and peridotite.

For more general concepts we need to be able to use the term that a system prefers. What these

terms are can be found in a dictionary-like work produced by the originators of the database and known as a thesaurus. Here we can find whether the database recognizes the term 'synthetic' in the sense that gemmologists give to it or whether 'man-made' is preferred. All thesauri are large because they contain so many cross-references and in addition some may carry numerical codes for geographical areas as well as for some general concepts.

Many papers are written for the more popular journals and in such cases may have rather fanciful titles. The searcher will not be able to guess that a paper on peridot has the title *Green gems from the Red Sea* but RED SEA is acceptable as a phrase, as is MAFIC ROCKS. Keying in RED SEA OR MAFIC ROCKS OR GEM? would give us the Gübelin paper on Zabargad, the spelling of which is romanized in different ways, this making it an uncertain search term on its own.

Searching coordinates

There is no detailed map of world gemstone deposits apart from that produced in the 1960s by the French Bureau de Recherches Géologiques et Minières. This uses an equiareal projection and a scale of 1:40000000. This does not allow for much distinction between rock types, and in fact eight different types of gem deposit are distinguished:

deposits enclosed in volcanic rocks and their vents
decay deposits of volcanic rocks
pegmatite deposits
lode deposits
metamorphic deposits
endomorphic deposits
decomposition deposits
other types.

A careful study of the deposits as shown on the map will show where they fit into the map coordinates (latitude and longitude). The two main databases will accept map coordinates as search terms and these can be combined with country names, deposit type names as listed above (consult the thesaurus to see if these are acceptable phrases for your database) and species names:

Lat. 22° 50′ 45″ N to 23° 5′ 15″ N and Long. 96° 19′ to 96° 35′ E would give us the Mogok Stone Tract in Burma: they should be combined with GEM? or RUB? or SAPH? or CORUND? or KORUND

to give one search. Results of this (the number of hits) could be combined with shifts in the coordinates to see if further corundum gems were reported from neighbouring areas. On the whole these areas are well reported and stones from them have been the subject of papers for many years. A deposit of significance for strategic elements as well as for gem material can be found by searching on

Lat. 15° to 25° 8′ S and Long. 22° to 28° E

and adding the term MANGAN? (for both English and German spellings of manganese). The deposit is the Kalahari manganese orefield from which magnificent orange-pink rhodochrosite has been recovered. As the ore is likely to be of more importance than the gem material it may be worthwhile using a metals database rather than a geological one. Since this deposit was located partly at least by the use of remote sensing using the LANDSAT satellites, a look at the 16 mm browse film produced from their orbits will show useful areas with coordinates worth inputting.

For those interested in getting the most up-to-date information on a prospect the date of publication of particular papers can be significant, and when the subject is a popular one a cut-off date can eliminate large quantities of paper. In most databases this is done by keying in PY=1960–1980, for example, so that any paper with a publication date not falling in that range is not brought up.

Likely prospects for gemstones can be checked by inputting the names of features which have been found to be common accessories to known deposits of the desired species. For a deposit similar to that in the Pala area of southern California we could try coordinates plus GRAPHIC GRANITE OR SCHORL OR MUSCOVITE to see if these have been reported as occurring together (it would be surprising if they did not). We could add lithium as a concept by typing Li? or the full word.

Chemical data

Chemical formulae can in fact be entered in addition to the terms already mentioned, providing that they are mentioned in the papers abstracted. Normally chemical searches would take place in *Chemical Abstracts* (which contains a good deal of geological information), but this is a very large database which needs skilful handling. We know that there are 2331890 possible quaternary compounds (i.e. having four elements) and 109736 ternary ones. As the total number of known mineral species is only about 3000 some kind of selection is clearly operating and possible compounds can easily be found by using the computer. A paper describing calcium and oxygen will not normally mention that no CaO forms naturally on earth since Ca and O combine more efficiently with CO_2 to form $CaCO_3$ but once such sources as *Chemical Index to Minerals*, *Glossary of Mineral Species* and lists of new and discredited minerals are loaded into a database it will be possible to search on various elements and their compounds to see which combine.

In a similar way optical and physical constants

will be able to be searched in conjunction with species names, place names and chemical terms to see whether there can be a red tourmaline with abnormally high refractive index; whether there can be gem materials which include boron and whether this is linked with any particular type of rock formation.

I should like to encourage gemmologists to visit the Science Reference Library to see what we can already provide and to conceive what may be possible in future. Anyone who has regularly scoured the tiny print of the hard-copy *Chemical Abstracts* or *Index Medicus* will know how much easier it is to use the computer, and it does provide opportunities for bringing together concepts which no hard-cover work could afford to do.

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A description of the jasper found at the Orinduik Falls in Guyana, South America

(Cover photograph)

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In the north-east of South America between Venezuela and Surinam and to the north of Brazil lies Guyana. The name comes from an Amerindian word which means 'Land of Waters', and this is an apt description since great rivers dominate the country.

One of these is the river Ireng which is the natural boundary between Guyana and Brazil. On this river lies the tiny community of Orinduik with its air strip, two stores and Amerindian settlement where guides and helpers may be hired. On these settlements live Wapisianas and Macusi Indians, who are a sturdy, small built people with a tremendous capacity for hard work and fun.

From the early days of geological exploration it has been recorded that certain areas of Guyana had a wide range of ornamental stones. Among these was a very handsome red jasper that was found in large quantities around Orinduik in the Pakaraima Mountains. In the early 1970s both the quantity and quality found encouraged the Ministry of Energy and Natural Resources to set up a new industry based on the utilization of these materials. This project was assisted by British Technical Aid arranged by the Ministry of Overseas Development and the author was privileged to carry out the scheme for the people and Government of Guyana.

To reach Orinduik from Georgetown could take about two weeks by river and land since much of the journey would be through miles of the most beautiful jungle scenery, which is still largely unexplored. Normal access with Georgetown is by Guyana Airways, which takes only a few hours, and once there overland communications are good.

The area is the habitat of a small fly called locally Kaboura, which produces a maddeningly itchy bite – fortunately it yields to insect repellents.

Orinduik lies in the south-western part of the Pakaraima Mountains, which are underlain by the geological unit known as the Roraima Formation. This consists of a great thickness of current-bedded, pink and red ferruginous sandstones and arkroses together with shales and conglomerates. Mount Roraima is not too far from Orinduik and rising sheer out of the jungle gave Sir Arthur Conan Doyle the geological basis for his popular classic 'The Lost World'.

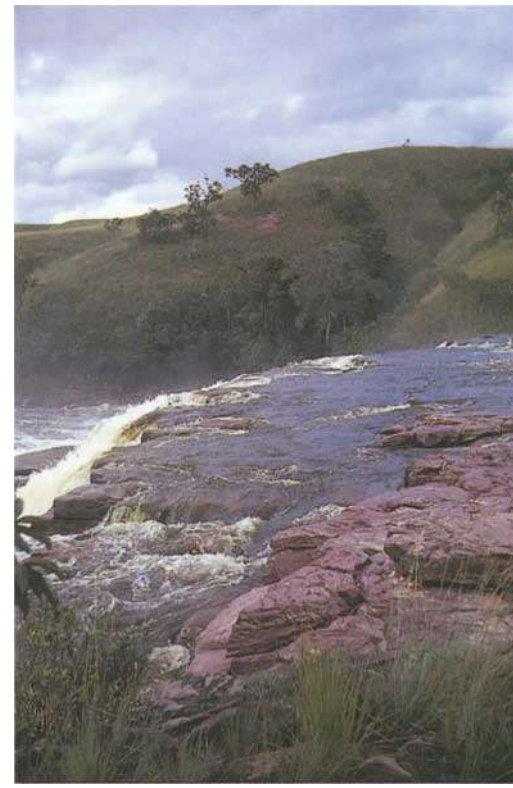

Fig. 1. Falls at Orinduik showing red jasper and blocky sandstone outcrop. *Photograph by J.G. Gosling.*

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At first sight from Orinduik the Falls appear as a series of vast steps at the head of the valley, but from the air one is aware of three major falls and about a dozen minor drops. The overall effect is one of breath-taking beauty, since all the rock faces of the falls are formed of dusky red quartzitic sandstone and interbedded jaspers. These quartzitic sandstones are fine to very fine grained and often break with conchoidal fractures but are fairly easily distinguished from the true micro- to cryptocrystalline jasper used as an ornamental stone.

Large boulders are also found rolled along in the Ireng river and were particularly fine above the last major fall, and it was discovered that the best jasper for tumbling or cutting was found just below the last major fall. (Photograph on front cover.)

This seemingly idyllic spot can hide a few dangers, as just above the Falls are beautiful sheltered pools but one must be aware of the deep holes there, since these may host a very powerful electric eel, which has a sting sufficiently powerful to stun a man and allow him to drift over the edge of the Falls.

There are many interesting animals, birds and insects in the area, but the fireflies, or candleflies as they are called locally, leave a lasting impression because of the brilliance of their blue-green light emission at night.

Farther away from the Ireng river and out on the savannas another interesting jasper formation is to be found. Here strange forms are created by wind erosion. In this type of erosion sand is whipped up by the wind and cutting its way into the jasper produces weird shapes and strange angular castles of all sizes.

In other areas of the Roraima Formation many varieties of jasper have been found including grey, purple, brown, green, spotted and banded forms.

After these materials had been collected and sorted, they were transported back to the small industrial unit in Georgetown and fashioned into clockfaces, paperweights, jewellery units and a host of other objects for sale locally and for export.

This project continues to flourish and has been expanded to other areas in the interior.

Fig. 2. Searching for red jasper pebbles by a brownish-red sandstone outcrop, Orinduik Falls. *Photograph by J.G. Gosling.*

[Manuscript received 16 February 1986.]

Notes from the Laboratory – 6

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On occasions, because of his cunning and artistry, the perpetrator of an attempt at gemmological skulduggery might be thought of as a person deserving a little of our admiration. This should be far from the case. Any intended dishonesty must be looked upon in the light of the knowledge that the person involved is attempting to sully the reputation of the gemmologist and others who handle jewellery.

An example of this cunning and artistry was seen when we were asked to examine the marquise-shaped opal set in the ring seen in Figs 1 and 2. The stone was clearly a synthetic showing the typical 'lizard skin' structure and columns of colour. In fact there cannot be a gemmologist who would have been in any doubt as to its identity. On this occasion the attempted deceit was, we believe, aimed at the 'antique' dealer/collector who perhaps has only a limited knowledge of gemstones, rather than the pure gemmologist who might not have much knowledge of old jewellery. The ring had been made up from several parts of old rings and one section included part of a hallmark with a date letter similar to that used for the period 1916–17 (Fig. 3) – many years before the production of synthetic opal!

* * *

Fig. 1. A synthetic opal in a ring made up from several parts of old rings.

Fig. 2. A synthetic opal in a ring made up from several parts of old rings (side view).

Fig. 3. The hallmark in the shank of the ring seen in Figs 1 and 2.

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Fig. 4. Natural opal 11.49×8.31×2.11 mm (see Figs 5, 6 and 8 for structure).

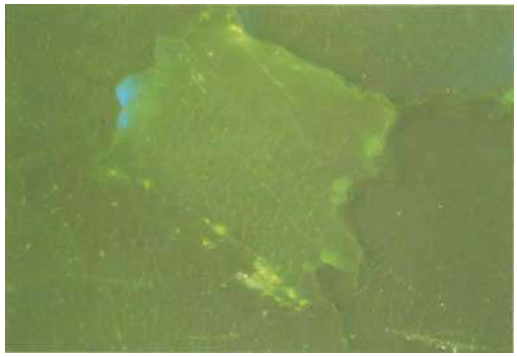

Fig. 5. 'Chicken wire' type structures in the natural opal seen in Fig. 4.

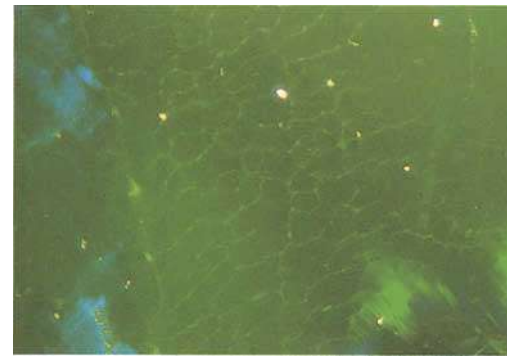

Fig. 6. A closer view of the 'chicken wire' type structures seen in Fig. 5 in a natural opal.

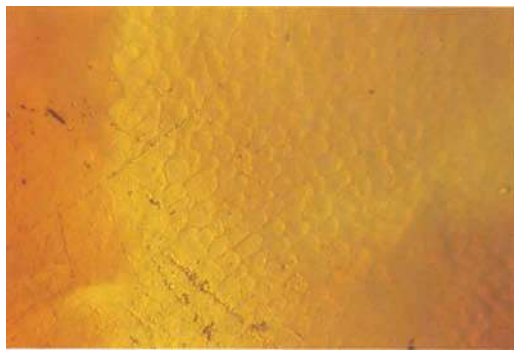

Fig. 7. 'Chicken wire' structures in Gilson synthetic opal.

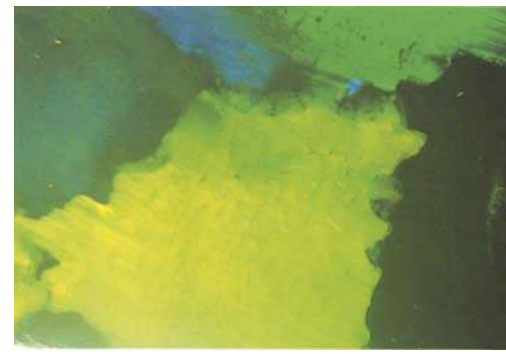

Fig. 8. Dark matrix veins in the natural opal in Fig. 4 giving an appearance similar to an opal that has been sugar-acid treated.

Some years ago when the first papers were published detailing the diagnostic structures of synthetic opal[1,2], an eminent British gemmologist stated that he had seen similar structures in natural opals. In the intervening period we have noted a number of peculiar structures in natural opals. Many of these have resembled the structures seen in sugar-acid treated opals but have revealed themselves to be, for example, oolitic opal. We have never seen a natural opal in which the structures are identical to those seen in the Gilson material.

Amongst those which we have examined the closest we have come to a synthetic-like structure in a natural opal was seen towards the end of 1985. The structure was seen in the 1.50 ct stone depicted in Fig. 4. The stone measured 11.49×8.31×2.11 mm and was backed by its matrix. The matrix travelled through the opal in veins and these were arranged in a pattern (Figs. 5 and 6) which was similar in some ways to the 'chicken wire' structure seen in transmitted light in some synthetic opals (Fig. 7). In reflected light (Fig. 8) the dark colour of the matrix in the veins gives the impression that the stone has been sugar-acid treated, which it has not.

* * *

In 1984[3] details of a large hollow baroque pearl were reported upon in which the cavity had been 'filled' with a number of beads. The beads had 'an opacity to X-rays comparable with that of the setting'.

Two further examples of large hollow pearls with their cavities filled with artificial materials have been examined recently. The first pearl measured approximately 18×15 mm and, as can be seen in Fig. 9, had a very large internal cavity. The pearl had been drilled in one place and through the drill hole the cavity had been filled with what appears on the radiograph to be wire. Upon looking into the drill hole some form of adhesive substance could also be seen in the cavity.

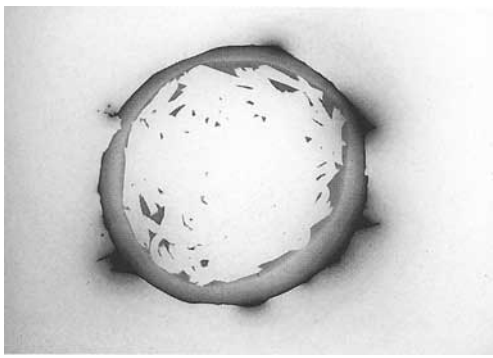

Fig. 9. Radiograph of a large hollow pearl in which the void appears to have been filled with wire.

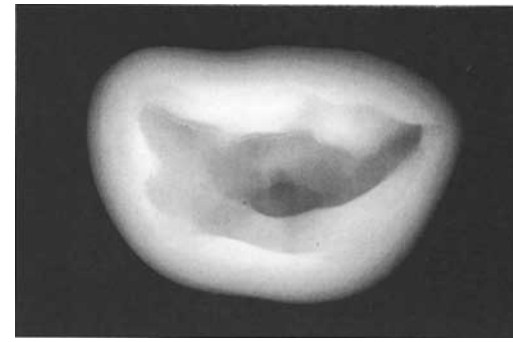

Fig. 10. Radiograph of a large hollow pearl in which the void appears to have been filled with a resin-like substance.

The second example weighed 28.58 ct and as can be seen in Fig. 10 it also had a large internal cavity. The pearl had been drilled in one place and this time the cavity had been filled with a soft substance similar in appearance to a dry resin. The substance was heated with a hot point and the odour produced was similar to a burning plastic when smelt in close proximity, but at a greater distance the smell was similar to frying bacon.

* * *

If one looks back through the gemmological journals of recent years it will be realized that quite a number of manufacturers are either producing or have the capability of producing synthetic rubies. Mostly if these manufacturers market their stones they do so openly and make various announcements about them. It is quite unusual to have placed before you a number of obviously synthetic ruby crystals, the manufacturer of which nobody seems to know.

This happened recently when we were shown the crystals depicted in Figs 11 and 12. The crystals in Fig. 11 had a lot of included orange flux and those in Fig. 12 had platinum wire protruding from them.

* * *

An interesting and effective amber 'treatment' was brought to our attention during the latter part of 1985. A dealer who purchased an 'amber' drop with a view to repolishing it was surprised to find that the colour of the material was located in the surface area only and that beneath the surface it was colourless (Fig. 13). The colour penetrates the colourless material along flaws (Fig. 14) and these when viewed side on (Fig. 15) bore a close resemblance to the stress figures seen in much clarified amber[4].

The material has an SG of 1.04 and an approximate RI of 1.55–1.56. There are numerous included

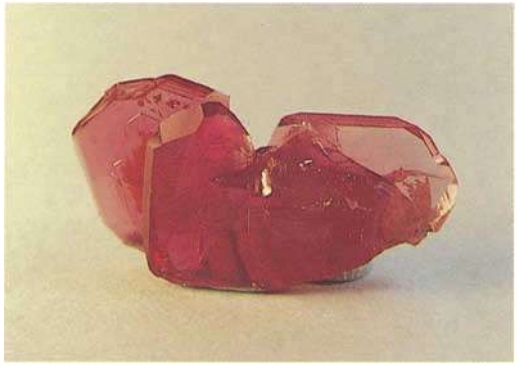

Fig. 11. A group of synthetic ruby crystals with included orange flux.

Fig. 12. Two synthetic ruby crystals with platinum wire protruding.

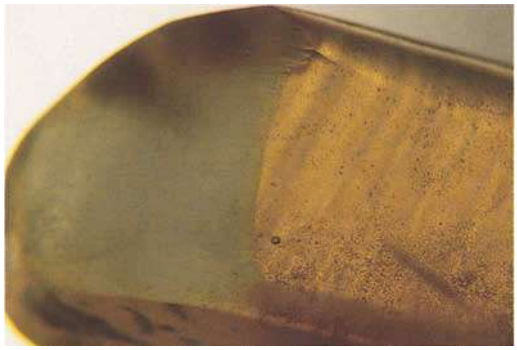

Fig. 13. Amber in which part of the surface yellow colour has been polished away revealing the colourless material beneath.

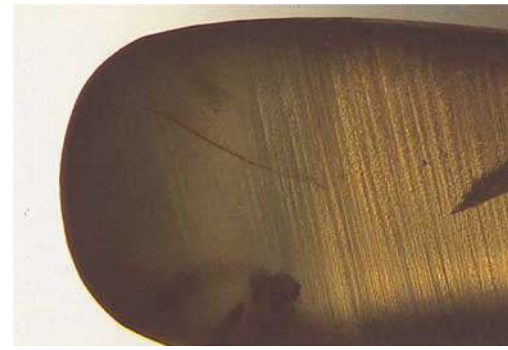

Fig. 14. Amber in which the surface coloration (see Figs 13 and 15) also penetrates the colourless underlying material along flaws.

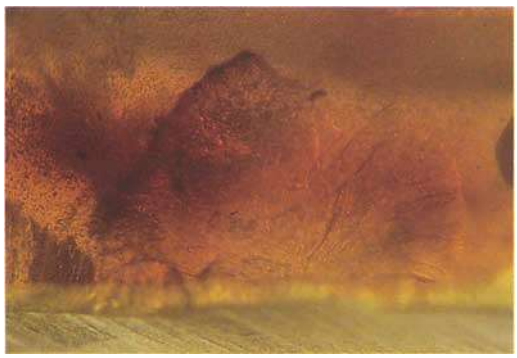

Fig. 15. A flaw in the amber of Figs 13 and 14 which resembles the stress figures seen in much clarified amber.

Fig. 16. A 4 mm broken natural pearl.

bubbles, the greater number of which are just under the surface (see Figs 13 and 15). The colour is not a discrete coating on the surface, such as a paint or a varnish, but appears to have been diffused into the surface of the material by gentle heating. The colourless area in Fig. 13 fluoresces a bright light blue under ultraviolet light whilst the yellow area fluoresces a mustard-yellow/green. The material is very soft, sectile, and when heated with a hot point produces a smell similar to that produced by amber. Additional pieces of this material are now being examined and more details will be published in a future number.

* * *

The 4 mm broken pearl in Fig. 16 was strung in a necklace of natural pearls. The owner of the necklace assumed that the apparent 'bead' revealed by the break indicated that it was a cultured pearl. In fact radiographs of the pearl proved it to be natural.

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An unusual needle-like inclusion in gem sinhalite from Elahera, Sri Lanka

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Elahera, the north-east gem field of Sri Lanka is well known for the occurrence of near colourless, yellowish, brownish or greenish-brown sinhalites of gem quality. The internal paragenesis of these sinhalites often exhibit mineral inclusions such as zircon, apatite and mica, and liquid feathers including two-phase cavities. However, to date sinhalite with rutile or similar needle-like inclusions is not known. While collecting sinhalites from this gem locality it was evident that one sample contained needle-like inclusions which are orientated in certain crystallographical directions of the host gem (Fig. 1).

Since it was the opinion of some gemmologists that the inclusion was rutile, further investigations were needed to confirm the nature of these needle inclusions.

The gem microscope provided noteworthy information during the investigations. It revealed the orientation of the needles parallel to the three main rhombic crystal axes. Under cross-section examination the needles were of tetragonal symmetry (Fig. 2). However, the distinct surface lustre of rutile was absent when observed under reflected light. Along the length of these needles there were portions transparent enough to show the enclosed iron oxide concentrations (Fig. 3). This is not the case in rutile inclusions seen in many other gemstones. Further, immersion microscopy revealed the clear transparent nature of the needles.

A suitable optical flat was available on one of the rear facets with an exposed portion of the inclusion. Under these conditions the electron

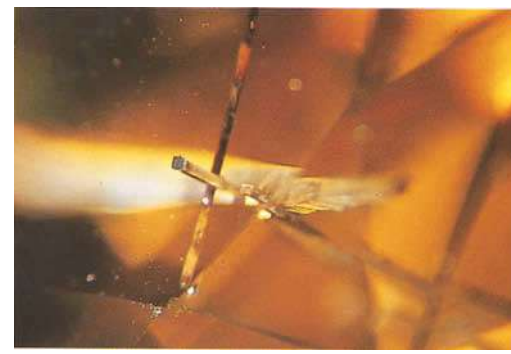

Fig. 2. Apparent tetragonal symmetry of the needle-like inclusion under cross-section examination. Dark field 40x.

Fig. 1. Gem sinhalite of 8.43 ct from Elahera, Sri Lanka, with orientated needle-like inclusions.

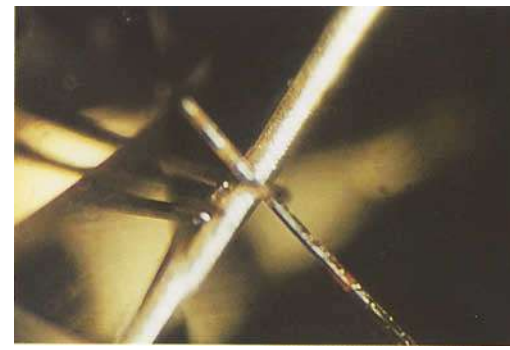

Fig. 3. Transparent areas of the needles clearly showing the iron-oxide concentrations. Dark field 55x.

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beam of the microprobe signalled the Fe and Si peaks. However, these chemical components did not show any crystalline nature nor any X-ray diffraction patterns.

Both the gemmological and chemical investigations have contributed in recognizing the needle-like inclusions in Elahera gem sinhalite. Neither the microscope nor the microprobe provided any clue that the inclusion was rutile. Furthermore, the chemical component without any crystalline nature suggested that the inclusion was a secondary cavity filled with iron oxide. These hollowed needles probably formed in the gem sinhalite during growth and were related to the main crystallographical directions of the host. They were then filled with iron oxide and other chemical components from the neighbouring rocks.

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Gem hornblende from Baffin Island, NWT, Canada

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Introduction

Baffin Island is situated north of the province of Quebec, on the southern fringe of the Arctic region, in the District of Franklin, Northwest Territories, Canada. Field parties from the National Museum of Natural Sciences and the University of Ottawa have investigated mineral deposits on southern Baffin Island with an emphasis on lapis lazuli. D.D. Hogarth (1971) studied the lapis lazuli deposits in detail as a potential source of gem material. These deposits have been known to the local Inuit (Eskimos) for decades, and are presently under claim with them, but there has been no development of the property. The paper 'Lapis Lazuli from Lake Harbour, Baffin Island, Canada' (Grice and Gault, 1983) gives a good overview of the situation regarding travel and collecting in the area, and describes some of the minerals that have been collected. Travel is difficult because it is an isolated area with only a short ice-free period (July and August), and variable weather including erratic fog banks.

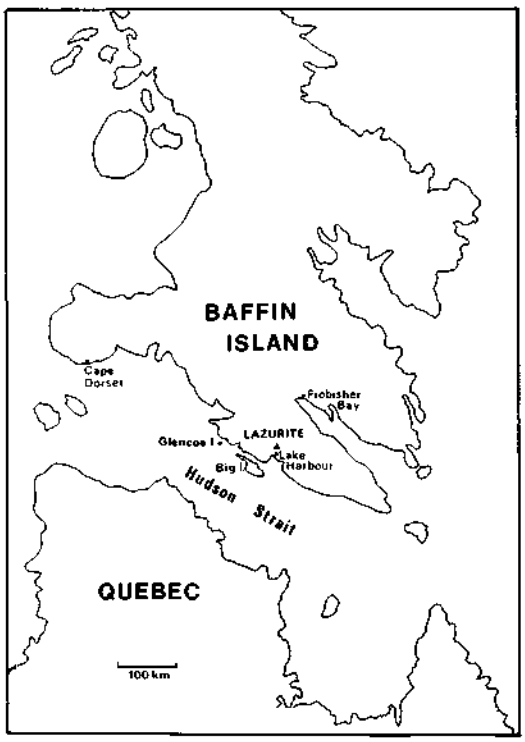

Fig. 1a. Location map for southern Baffin Island.

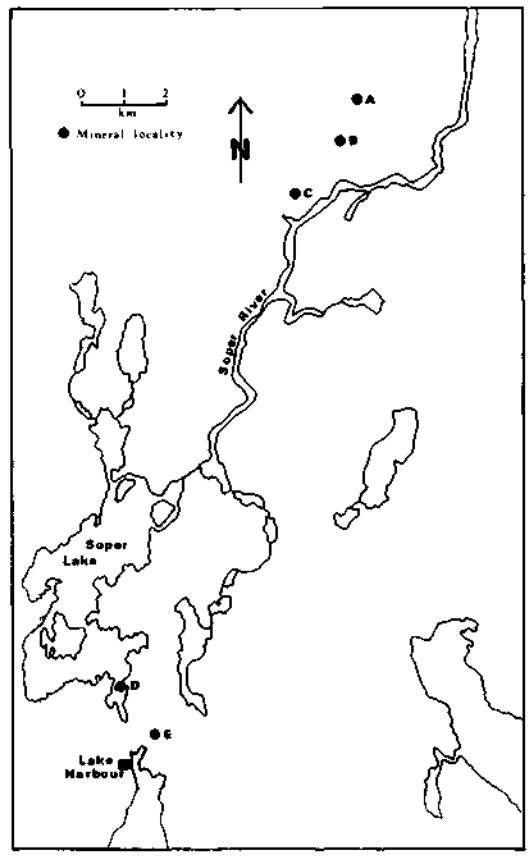

Fig. 1b. Soper River mineral localities: B – north lapis lazuli deposit; C – south lapis lazuli deposit and hornblendes.

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Fig. 2. Camp at Soper River, Baffin Island, NWT, looking north to the lapis lazuli deposits (in white marble).

Fig 3. Phlogopite mica pit near the south lapis lazuli occurrence where facetable hornblende was found in 1980.

Geology

The lapis lazuli of southern Baffin Island lies within a series of highly metamorphosed sedimentary rocks, the most abundant being garnet-biotite gneiss and marble. The dolomitic marble, which is coarse grained and almost white in colour, commonly contains diopside, amphiboles, phlogopite and clinohumite, as well as lazurite deposits. Other minerals such as meionite, uvite, spinel, graphite, forsterite and titanite occur more rarely in the marble.

Hornblende occurrence

One of the areas visited by Grice and Gault in 1980 was along the Soper River some 15km north of Lake Harbour (see Figs. 1 and 2), near the previously known 'south lapis occurrence' and 'north lapis occurrence'. Hornblende is common there in the marbles as stubby, prismatic, greenish-brown crystals averaging 2–3 cm long. Fragments of large crystals were found in a phlogopite mica pit a short distance from the south lapis occurrence (Fig. 3). Some of these fragments were transparent enough to facet.

Gem hornblende

Hornblende is a monoclinic, calcium magnesium aluminium silicate in the amphibole group. Chemical analysis is essential to determine the identity of a particular member of the amphibole group since there is much overlap in values of physical and optical properties; even X-ray data are inconclusive. See the 'Amphiboles-General' section of this article for an explanation of this most complicated group of minerals.

Chemical analyses on specimens from several locations on Baffin Island (Grice and Gault, 1983) showed minor variations in composition, but all were within the edenitic to pargasitic hornblende range, using Leake's (1978) amphibole classification. The faceting-grade fragments are pargasitic hornblende (NMNS 46664). Analyses are given in Table 1. Note that the facetable hornblende contains traces of vanadium and chromium. The presence of vanadium was unexpected, as it was absent in analyses of other minerals from the same area. Vanadium is not usually reported in amphiboles (Deer, Howie and Zussman, 1963; Hawthorne, 1983). In this case, the vanadium and chromium (along with low iron content) are likely to contribute to the pleasing greenish-brown colour, since most hornblendes are very dark and unattractive.

Four gems were faceted for the National Gem Collection by Mr Arthur T. Grant, a noted faceter with considerable experience in handling unusual gem materials. He used silicon carbide laps for cutting, and chromium oxide on an ultralap for polishing. The pavilion main facet was placed at 41°; the crown main angle was 42° with 5° splits when possible. Some difficulty arose when cutting across the cleavages, as fraying tended to occur. The material chipped easily during polishing. Orientation of the rough required careful consideration of the cleavage planes and the pleochroism. Mr Grant's opinion is that faceting this material is 'not terribly difficult'. The four stones are fashioned in various styles and weigh between 1.62 and 3.03 ct:

NMNS 20896 emerald step cut 3.00 ct
10.4×6.8×6.3 mm
NMNS 20897 marquise step cut 1.62 ct
16.9×4.1×3.9 mm
NMNS 20900 octagonal step cut 1.91 ct
12.2×5.0×4.0 mm
NMNS 22129 pear-shaped brilliant 3.03 ct
12.5×7.5×5.4 mm

One (NMNS 20897) appears a more greenish-brown than the others, because of pleochroism. See Figs 5 and 6.

Table 1. Composition of Baffin Isalnd Hornblendes

	Pargasitic Hornblende 46664	Pargasitic Hornblende 46677	Edenitic Hornblende 46608
SiO_2	45.0	43.8	46.5
TiO_2	0.73	0.45	1.1
V_2O_5	0.11	0.0	0.0
Al_2O_3	14.1	14.7	11.7
Cr_2O_3	0.10	0.08	0.0
FeO*	0.62	1.3	0.31
MnO	0.0	0.0	0.0
MgO	20.1	19.3	20.7
ZnO	0.0	0.0	0.0
CaO	12.1	12.7	12.1
Na_2O	3.0	2.3	3.4
K_2O	1.3	1.6	0.50
F	1.4	1.6	1.1
Cl	0.07	0.12	0.01
H_2O**	2.0	2.6	3.0
	100.00	100.00	100.00

*total iron expressed as FeO
**by difference
A simplified chemical formula derived from analysis of 46664 is $(Na, K)(Ca, Na)_2(Mg, Al)_5(Si, Al)_8O_{22}(OH, F)_2$.
Calculated density 3.09 g/cm³.

minerals make the precise correlation of their chemical composition and optical properties practically impossible.

Identification

If gem hornblende is encountered unexpectedly, it is quite likely to be mistaken for brown tourmaline (dravite or uvite). The refractive indices, birefringence and specific gravity are very similar, and they both show strong pleochroism. However, tourmaline is uniaxial, not biaxial, and shows only two dichroic colours.

Other gems that may appear in shades of brown have either lower refractive indices e.g. quartz, or much higher indices. Grossular (hessonite) garnet, sphalerite, and diamond are singly refractive. Cassiterite, scheelite, titanite (sphene), and zircon are all over the limits of a standard refractometer, and are not likely to be mistaken for hornblende. A number of other brown gemstones with which hornblende could be confused are listed in Table 2.

Description of gem hornblende

Crystal system: Monoclinic.
Habit: Stubby, prismatic.
Inclusions: Veils of healing feathers; colourless crystal inclusions.
Colour: Greenish-brown.
Lustre: Vitreous.
Fluorescence: Moderate – yellow in shortwave ultraviolet; inert in longwave.
Hardness: 5½–6.
Tenacity: Brittle.
Cleavage: Two good, {110} at 56°; {100} {001} parting.
Twinning: {100} simple, lamellar, common.
Specific gravity: 3.09 ±0.01.
Optical properties

Refractive index:	α 1.625–1.627
(sodium light,	β 1.632–1.633
Rayner Dialdex	γ 1.644–1.647
refractometer)	
average	1.626–1.645

Birefringence: 0.020 Biaxial positive.
Pleochroism: Strong; green/orange/brownish-orange.
Absorption spectrum: Weak; a line in the blue.
Note the wide range of values listed for common hornblendes in Deer, Howie and Zussman (1963): α1.615–1.705; β1.618–1.714; γ1.632–1.730; birefringence 0.014–0.026; optic sign positive or negative; SG 3.02–3.45.

Generally, refractive indices of amphiboles are increased by the substitutions of ferrous iron for magnesium, and aluminium for silicon. The varied and extensive substitutions in the hornblende

Fig. 5. Hornblende gem: 3.00 ct, emerald cut (NMNS 20896) from Baffin Island, NWT, Canada.

Fig. 6. Hornblende gems: 3.00 ct, emerald cut (NMNS 20896) and 3.03 ct, pear-shaped brilliant cut (NMNS 22129), from Baffin Island, NWT, Canada.

Table 2. Identification of Gem Hornblende

Gemstone	RI	DR	SG	Pleochroism	Other
Pargasitic Hornblende	1.625–1.645	0.020 B(+)	3.09	S: G/O/Br-O	low dispersion
Very similar, and likely to be confused with hornblende					
Tourmaline (Dravite or Uvite)	1.62–1.64	0.020 U(−)	3.06	S: Y-Br/dk Br	
Vesuvianite	1.70–1.71	0.005 U(−)	3.3–3.5	S: G/O-Br	abs. spectrum
Similar, but less likely to be confused					
Topaz, brown	1.630–1.638	0.008 B(+)	3.53	D: Br-Y/Y/O-Y	
Andalusite	1.63–1.65	0.016 B(−)	3.15	S: Y/G/R	
Barite	1.636–1.648	0.012 B(+)	4.3–4.6	Wk: Y/Y/V	
Danburite	1.630–1.636	0.006 B(−)	3.00	None	
Siderite	1.633–1.873	0.240 U(−)	3.8–3.9		
Enstatite-Hypersthene Series	1.65–1.66 to 1.76–1.77	0.008 B(+) 0.012 B(−) to 0.021	3.25 3.4 to 3.5	D: G/Y-G/Br-G Pink to G	abs. spectrum
Peridot, brown	1.65–1.69	0.036 B(+)	3.4	Weak	abs. spectrum
Diopside-Hedenbergite Series	1.664–1.694 to 1.72–1.75	0.024 B(+) to 0.031	3.29 to 3.56	Weak or none lt G/G-Br	
Sinhalite	1.67–1.71	0.038 B(−)	3.48	D: lt Br/G-Br/dk Br	abs. spectrum
Axinite	1.678–1.680	0.01 B(−)	3.29	S: Br/V/G	high dispersion
Epidote	1.736–1.770	0.034 B(−)	3.4	S: G/Br/Y	abs. spectrum
Chrysoberyl, brown	1.75–1.76	0.01 B(+)	3.72	D: Y/Br	abs. spectrum

D distinct; lt imperceptible; S strong; Wk weak.
Colours by initial letters.
Data extracted from Webster, 1983, and Arem, 1977.

Vesuvianite (idocrase) from Laurel, Quebec has a similar golden-brown colour, but its refractive indices are significantly higher. Topaz has an RI in the same region, but it has a higher SG and a lower birefringence. Andalusite might be tricky, but it is usually more greenish or reddish in appearance.

Conclusions and future prospects

The number of Canadian gemstones in the National Gem Collection of Canada has been augmented significantly in recent years by arranging to have suitable pieces of field-collected minerals faceted into gems. This increase has been both in number and, more importantly, in the number of species. The Mineral Sciences Division of the National Museum of Natural Sciences has continued a long tradition of collecting in the field – one that was begun by the Geological Survey of Canada in the 1880s at the beginning of the development of Canada. Very few mineral museums today have personnel who actually go out to collect mineral specimens.

The pargasitic hornblende from Baffin Island, when properly cut to take advantage of its pleochroism, is an attractive gemstone with its warm brown colour showing glints of green and orange. Additional material may very well be obtained on future field trips to look specifically for faceting material. It was simply a lucky chance that some of the small amount brought back in 1980 was suitable for faceting.

Although faceted hornblende will never be a commercial success with its relative softness and limited supply, it is definitely a mineralogical rarity, a desirable collector's stone, and another contribution to Canada's mineral and gemstone heritage.

Amphiboles – General

The amphibole group consists of extremely important rock-forming minerals, occurring in a wide variety of igneous and metamorphic rocks throughout the world. Because they are so common, these silicate minerals are present in most mineral

collections, and have been rigorously investigated by mineralogists.

The name 'amphibole' is derived from the Greek, *amphibolos*=ambiguous. It was used first by Haüy in 1801, referring to the great variety in composition and appearance of these minerals. Many of the amphiboles share common physical properties and appear alike externally, but internally there is great diversity in chemical composition, with many atomic substitutions possible giving rise to extensive solid solution series. Many amphiboles are, therefore, often misidentified, since a visual identification based on the usual characteristics of colour, crystal habit, specific gravity etc. is invalid. Even optical and X-ray data may be inconclusive because of overlapping values between various members of the group. Amphiboles are one of the most complicated groups of minerals, and are a challenge to all who encounter them.

The advent in the 1960s of the electron microprobe enabling rapid, accurate chemical analysis of small samples of minerals did much to promote understanding of the amphiboles, because knowledge of their chemistry is essential. A general classification of the amphiboles, based on crystal chemistry, was compiled by Leake (1978), after years of work by a committee of the International Mineralogical Association. A précis of this highly technical work was presented by Robinson (1981) for mineral collectors, with particular reference to a number of well-known amphibole localities in Ontario and New York. General background information on amphiboles is given by Deer, Howie and Zussman (1963).

Until now, gemmologists have not had much reason to be concerned about the amphibole group. The only group members commonly known in gemmological circles are tremolite and actinolite, mostly because nephrite jade is a variety of them. Tremolite-actinolite-ferroactinolite form a solid solution series varying from tremolite ($Ca_2Mg_5Si_8O_{22}(OH, F)_2$), with increasing amounts of ferrous iron substituting for magnesium, to ferroactinolite ($Ca_2Fe_5Si_8O_{22}(OH, F)_2$). These are simple amphiboles.

The essential feature of the structure of amphiboles is the presence of $(Si, Al)O_4$ tetrahedra linked to form double chains with the composition $(Si_4O_{11})_n$. These double chains are oriented parallel to the *c*-axis, and run 'lengthwise' in most amphibole crystals (see Fig. 7). This helps explain the prismatic crystal habit and the splintery 56° and 124° cleavage commonly found in amphiboles. The chains are separated and bonded laterally by planes of cations plus hydroxyl radicals. The crystal system may be either monoclinic or orthorhombic. When aluminium substitutes for

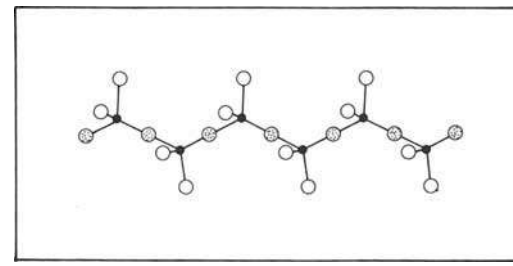

Fig. 7a. Each silica tetrahedron (SiO_4) may share two oxygen atoms to form a chain. This single chain $(SiO_3)_n$ is found in pyroxenes.

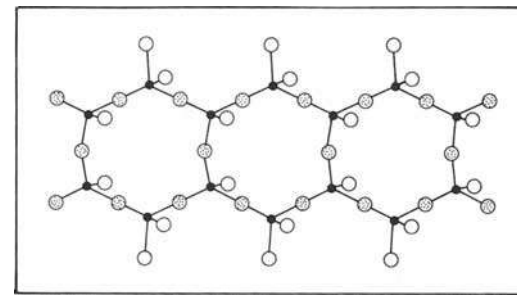

Fig. 7b. A double chain $(Si_4O_{11})_n$ occurs in amphiboles. Two parallel single chains may form a double chain by sharing oxygen atoms between alternate tetrahedra.

some of the silicon in the Si_4O_{11} chain, the net charge balance is usually maintained by substitution of the type $Mg^{2+}Si^{4+} \leftrightarrows Al^{3+}Al^{3+}$.

The general formula of an amphibole is given in Leake (1978) as $A_{0-1}B_2C_5{}^{VI}T_8{}^{IV}O_{22}(OH, F, Cl)_2$. We are concerned here with hornblendes, which are monoclinic, and in the calcic amphibole sub-group (one of four), which contains substantial calcium in the B position. Then, most commonly,

A is sodium or potassium

C is magnesium, with some ferrous iron, etc. in six-fold co-ordination.

T is silicon, aluminium, ferric iron, etc. in four-fold co-ordination.

The classification is made on the basis of which elements are in B, the number of silicon atoms (silicon/aluminium ration), the magnesium/iron ratio, and other chemical considerations, resulting in 57 recognized end-members.

A simplified version of Leake's classification of calcic amphiboles is shown in Fig. 8. Note that common usage of the term hornblende includes calcium-rich amphiboles having a wide range in proportions of magnesium/iron and silicon/aluminium. The formula of our Baffin Island amphibole was determined from its chemical analysis to be $(Na_{0.65}K_{0.23})$ $(Ca_{1.81}Na_{0.16})$

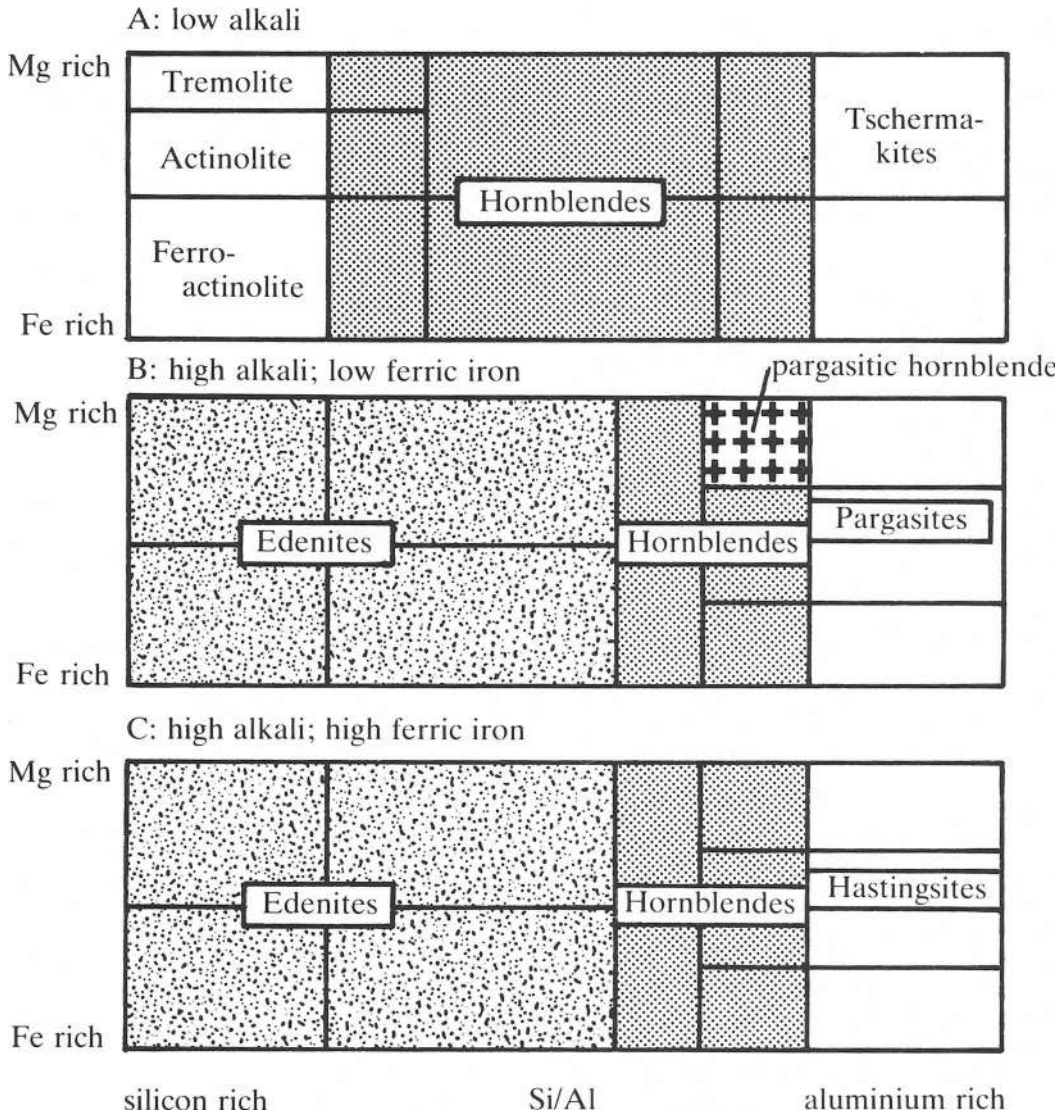

Fig. 8. Classification of calcic amphiboles (after Leake, 1978).

$(Mg_{4.17}Fe_{0.07}Al_{0.58}Ti_{0.08}Cr_{0.01}V_{0.01})$ $(Si_{6.27}Al_{1.73})$ $O_{21.52}$ $(OH_{1.84}F_{0.62}Cl_{0.02})$. Because its water content was determined only by difference, the value for OH is probably too high. Vanadium was arbitrarily assigned to position C based on its ionic radius. The calculated density for this formula is 3.09, compared to the observed density of 3.088 g/cm³. This formula places our amphibole in the pargasitic hornblende region, as shown by the + in Fig. 8, since it contains very little iron, and moderately high aluminium versus silicon. Because such complicated calculations are necessary to pinpoint the exact identity of an amphibole, there will still be many occasions when a broader terminology will have to be used.

Acknowledgements

The author wishes to thank her colleagues at the National Museum of Natural Sciences, Ottawa, Canada, for their support during this project: R.A. Gault, for bringing the material to her attention after his field work on Baffin Island, and for providing photographs and descriptions of the locality; Drs J.D. Grice and G. Robinson, for many helpful discussions, and critical reading of the manuscript. Special thanks are due to Mr Arthur T. Grant, of Hannibal, N.Y., for his careful skill in faceting the hornblende gems.

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On the problems of using the gallium content as a means of distinction between natural and synthetic gemstones

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Abstract

In the past Ga-contents have been used to distinguish natural and synthetic gemstones. The Ga contents of 32 emeralds, 18 corundums and 16 chrysoberyls have been analysed by neutron activation analysis (NAA). It is shown that a distinction of natural and synthetic gemstones on the basis of their Ga contents is not possible.

Introduction

The title of this paper may already imply the kind of equipment which is currently used to distinguish natural and synthetic gemstones. The continuous development of techniques and the methods of production of synthetic gemstones necessitate new methods of distinction. In particular gemstones need special treatment, in that methods transferred from geochemistry have to work without destroying the stone. In spite of this limitation the trace element analysis, for example, can be extremely useful. This kind of analysis is able to indicate the environment of the origin of a gemstone, whether it be natural or synthetic. The crystal growth in a crucible of platinum means that in many cases very small traces of this element (Pt) are incorporated in the synthetic crystal, and, in few favourable cases, microscopically small plates of platinum.

Investigation by trace element analysis of gemstones containing aluminium indicate various contents of gallium. This fact is not surprising, for it has been known for some years that in nature gallium is camouflaged by aluminium. The similar ionic radii and the same state of valence of aluminium and gallium explain this behaviour. The amount of gallium in the earth's crust is very small compared with aluminium, and Rösler and Lange (1976) give a proportion of Al:Ga=4235:1 for an average composition of the Earth's crust. This ratio differs in some rocks because gallium can be enriched at the end of a magmatic cycle. Table 1 shows the theoretical gallium contents of some gemstones.

Certain investigations (Ottemann *et al.* 1978, Horiuchi 1979, Ohguchi 1981, Hänni and Stern 1982, Schmetzer 1985) on synthetic and natural gemstones yielded the following 'rules', whose accuracy should be tested:

- corundum: gallium contents greater than 50–200 ppm prove a natural origin,
  gallium contents smaller than 50–200 ppm indicate a synthetic origin,
- alexandrite: 'measurable' gallium contents signify a natural origin.

Method

Requirements of methods used to investigate gemstones include:

- the method has to work without destruction;
- the method must not cause any alterations such as discoloration.

Normally the following methods are applicable:

- X-ray-fluorescence-analysis (XFA) with wavelength-dispersive and energy-dispersive measurements;
- electron microprobe analysis (EPMA) with wavelength-dispersive and energy-dispersive measurements;

Table 1: Gallium contents of some gemstones theoretically calculated on the geochemical proportion of Al:Ga of the Earth's crust:

Emerald	$Be_3Al_2(Si_6O_{18})$	10.2% Al	24 ppm Ga
Corundum	Al_2O_3	52.9% Al	124 ppm Ga
Chrysoberyl	$BeAl_2O_4$	42.5% Al	100 ppm Ga

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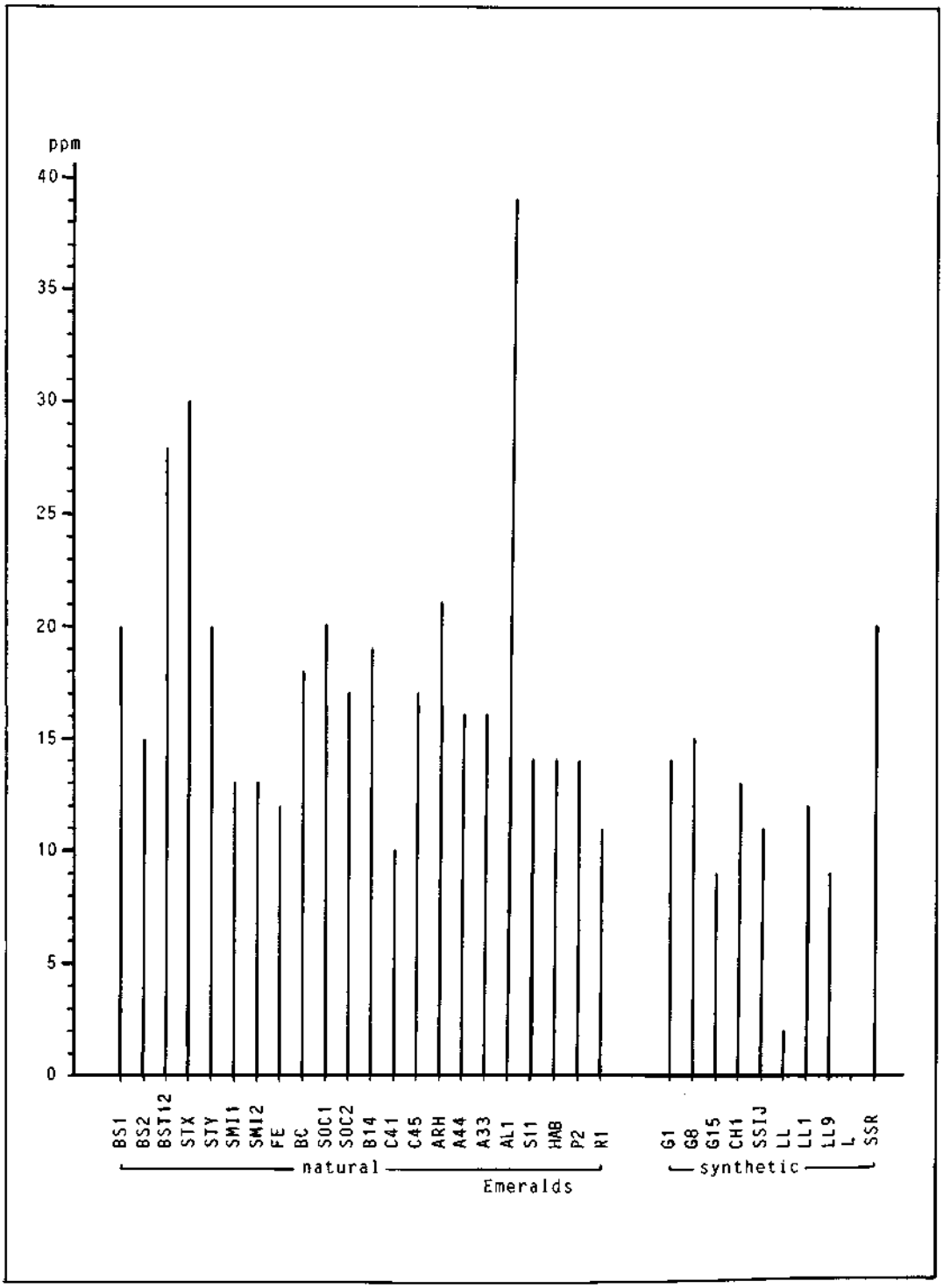

Fig. 1 : Gallium contents of natural and synthetic emeralds

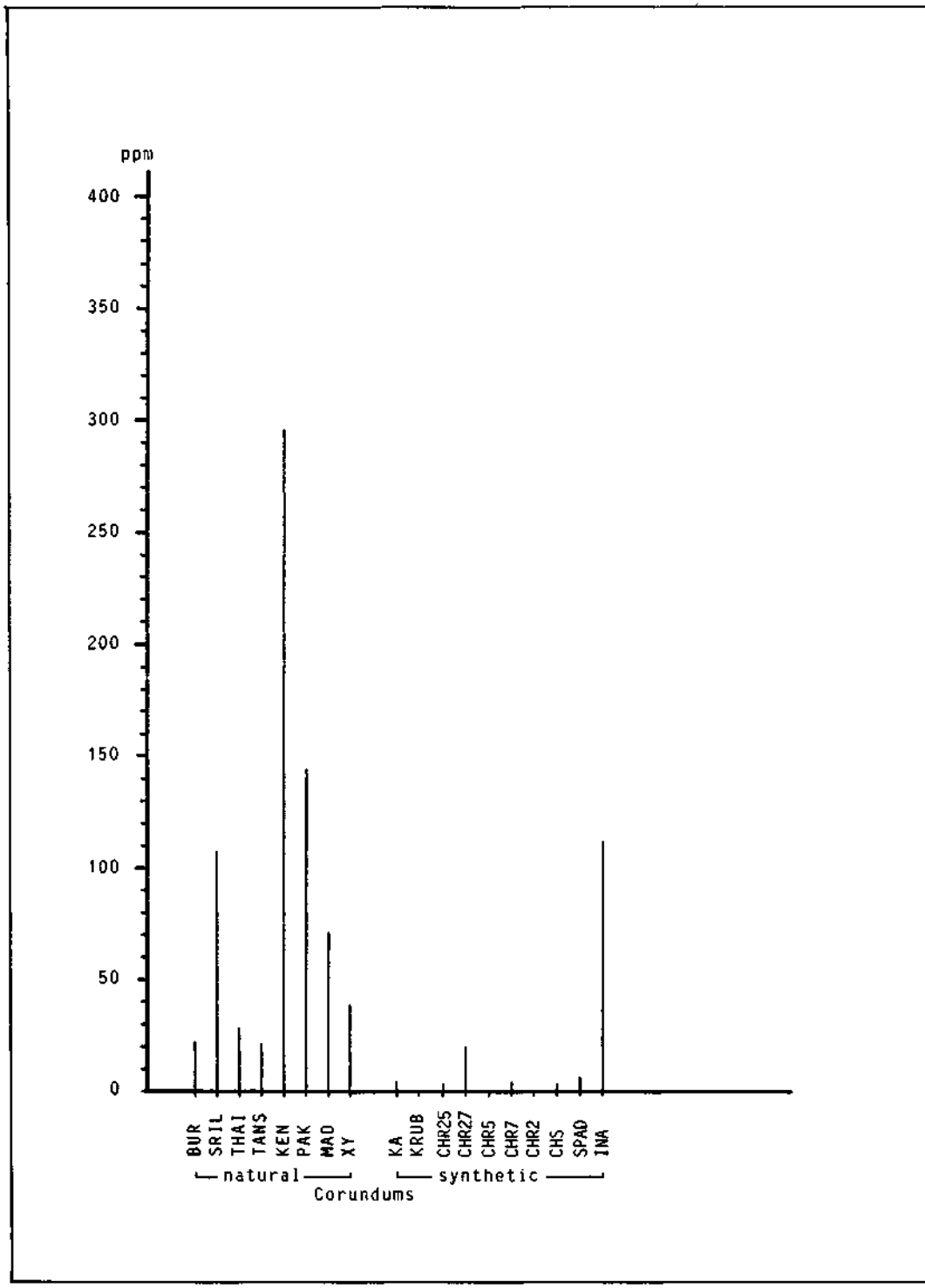

Fig. 2 : Gallium contents of natural and synthetic corundums

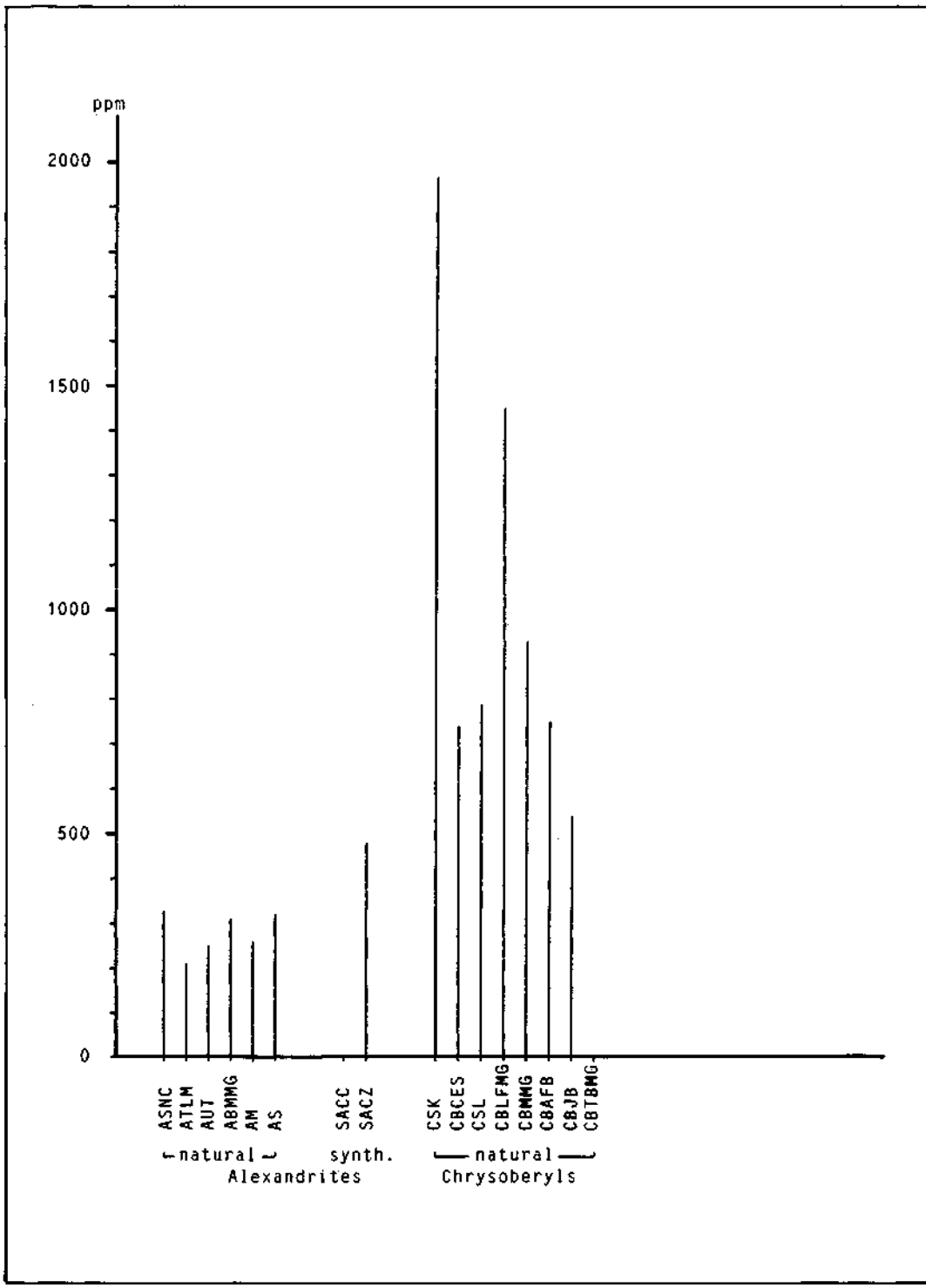

Fig. 3 : Gallium contents of natural and synthetic chrysoberyls

Table 2: Samples investigated by NAA gallium contents from Figs 1 to 3:

BS1	Emerald, Salininha, Brazil	20 ppm
BS2	Emerald, Salininha, Brazil	15 ppm
BST12	Emerald, Sta Terezinha de Goias, Brazil	28 ppm
STX	Emerald, Sta Terezinha de Goias, Brazil	30 ppm
STY	Emerald, Sta Terezinha de Goias, Brazil	20 ppm
SMI1	Emerald, Sta Maria de Itabira, Brazil	13 ppm
SMI2	Emerald, Sta Maria de Itabira, Brazil	13 ppm
FE	Emerald, Ferros, Brazil	12 ppm
BC	Emerald, Carnaiba, Brazil	18 ppm
SOC1	Emerald, Socotó, Brazil	20 ppm
SOC2	Emerald, Socotó, Brazil	17 ppm
B14	Emerald, Brazil	19 ppm
C41	Emerald, Chivor, Colombia	10 ppm
C45	Emerald, Chivor, Colombia	17 ppm
ARH	Emerald, Zimbabwe	21 ppm
A44	Emerald, Cobra Mine, Transvaal, South Africa	16 ppm
A33	Emerald, Cobra Mine, Transvaal, South Africa	16 ppm
AL1	Emerald, Leydsdorpdistrict, South Africa	39 ppm
S11	Emerald, Zambia	14 ppm
HAB	Emerald, Afghanistan	14 ppm
P2	Emerald, Pakistan	14 ppm
R1	Emerald, Takowaja, Siberia, USSR	11 ppm
G1	Synthetic emerald, flux-method, Gilson	14 ppm
G8	Synthetic emerald, flux-method, Gilson	15 ppm
G15	Synthetic emerald, flux-method, Gilson	9 ppm
CH1	Synthetic emerald, flux-method, Chatham	13 ppm
SSIJ	Synthetic emerald, flux-method, Inamori	11 ppm
LL	Synthetic emerald, hydroth.-method, Lechleitner	2 ppm
LL1	Synthetic emerald, hydroth.-method, Lechleitner	12 ppm
LL9	Synthetic emerald, hydroth.-method, Lechleitner	9 ppm
L	Synthetic emerald, hydroth.-method, Linde	0
SSR	Synthetic emerald, hydroth.-method, USSR	20 ppm
BUR	Corundum, ruby, Burma	23 ppm*
SRIL	Corundum, ruby, Sri Lanka	107 ppm*
THAI	Corundum, ruby, Thailand	28 ppm*
TANS	Corundum, ruby, Longido, Tanzania	22 ppm*
KEN	Corundum, ruby, Kenya	295 ppm*
PAK	Corundum, ruby, Pakistan	144 ppm*
MAD	Corundum, ruby, Madagascar	71 ppm*
XY	Corundum, ruby, unknown origin	39 ppm
KA	Synthetic ruby, Kashan	5 ppm
KRUB	Synthetic ruby, Kashan	0
CHR25	Synthetic ruby, Chatham	4 ppm*
CHR27	Synthetic ruby, Chatham	20 ppm*
CHR5	Synthetic ruby, Chatham	0.6 ppm*
CHR7	Synthetic ruby, Chatham	5 ppm*
CHR2	Synthetic ruby, Chatham	1 ppm*
CHS	Synthetic sapphire, Chatham	4 ppm*
SPAD	Synthetic sapphire, Chatham	7 ppm
INA	Synthetic ruby, Inamori	112 ppm
ASNC	Alexandrite, Novello Claims, Zimbabwe	330 ppm
ATLM	Alexandrite, Lake Manyara, Tanzania	210 ppm
AUT	Alexandrite, Takowaja, USSR	250 ppm

* after Schneider (1979)

ABMMG	Alexandrite, Malacacheta, MG, Brazil	310 ppm
AM	Alexandrite, Madagascar	260 ppm
AS	Alexandrite, Zambia	320 ppm
SACC	Synthetic alexandrite, (flux) Creative Crystals	5 ppm
SACZ	Synthetic alexandrite, Czochralski	480 ppm
CSK	Chrysoberyl, Kapoi, Zimbabwe	1970 ppm
CBCES	Chrysoberyl, Colatina, Espirito Santo, Brazil	740 ppm
CSL	Chrysoberyl, Sri Lanka	790 ppm
CBLFMG	Chrysoberyl, Lonego de Fogo, MG, Brazil	1450 ppm
CBMMG	Chrysoberyl, Malacacheta, MG, Brazil	930 ppm
CBAFB	Chrysoberyl, Agua Fria, Bahia, Brazil	750 ppm
CBJB	Chrysoberyl Jaqueto, Bahia, MG, Brazil	540 ppm
CBTBMG	Chrysoberyl, Tres Barras, Brazil	2 ppm

- scanning electron microscope (SEM) with energy-dispersive measurements;
- neutron activation analysis (NAA) with energy-dispersive measurements.

Investigation of gemstones by wavelength-dispersive XFA is risky because the high excitation energy may cause irreversible discoloration of gemstones (Bank, 1982).

Energy-dispersive measurements by SEM and EPMA have a relatively high detection limit of about 2wt.% for Ga and are not sensitive enough to measure the Ga contents of gemstones. Energy-dispersive XFA and wavelength-dispersive EPMA may detect the levels of Ga present in some gemstones (EDS-XFA: ±200 ppm, WDS-EPMA: ±100 ppm). However, these values are close to the detection limits, so inaccurate figures must be accepted. Besides this, in both methods only the surface of the sample can be analysed and so possible variation in content caused by the structure or zoning in the material are not detected. Currently the best method for measuring Ga is NAA as its detection limit is 0.5 ppm and accuracy is 3–10% of the Ga value. However, this kind of analysis is not suitable for a large number of investigations because radioactivity decreases slowly, and a lot of time is needed for the whole investigation and thus the costs are consequently high.

Results

Gallium contents have been obtained by the authors and Schneider (1979) using NAA for:
32 emeralds (22 natural, 10 synthetic);
18 corundums (8 natural, 10 synthetic); and
16 chrysoberyls (6 natural alexandrites, 2 synthetic alexandrites, and 8 natural chrysoberyls).

The results are given in Table 2 and displayed in Figs. 1–3. Four natural corundums were found with Ga <50 ppm, and only one with >200 ppm. One synthetic alexandrite with high Ga and one natural chrysoberyl with only 2 ppm Ga were found. In the emerald analyses the range of Ga contents is similar for both natural and synthetic stones.

These results indicate that the proposals concerning use of Ga content for distinguishing between natural and synthetic gemstones, put forward by authors listed above, must be treated with caution, and any conclusions indicated by Ga contents should be corroborated by further tests.

Acknowledgements

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Possibilities and limitations in radiographic determination of pearls

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Abstract

The main types of pearls available at present in the trade are characterized by radiographic features. Systematic investigations of pearls were conducted using direct radiography as well as X-ray diffraction techniques. In addition the luminescence under X-ray excitation was examined. A simple diffraction camera was developed which enables the investigation of diffraction patterns of pearls in exactly defined angles to each other. By use of an additional sample holder the production of diffraction patterns of one single pearl from a necklace is possible. During the investigation of freshwater pearls (natural and cultured freshwater pearls) with X-ray diffraction techniques a dark spot is generated on the pearl's surface by radiation defects.

Using a combination of all three radiographic techniques available at present, an unambiguous identification of almost every type of pearl found in the trade is possible. Due to overlapping of their characteristic radiographic features it is difficult to distinguish some Keshi cultured pearls from natural seawater pearls and some non-bead-nucleated cultured freshwater pearls from natural freshwater pearls.

Schematic diagrams for determining pearls of unknown origin using the three radiographic methods are presented.

Introduction

Since the middle of the 1920s radiographic techniques have been used extensively for the distinction of natural and cultured pearls. By use of the X-ray diffraction method, which is also known as the Laue-technique, natural pearls are distinguishable from bead-nucleated cultured pearls. Using direct radiography internal structures of pearls may become visible on the X-ray film which lead to a conclusive identification of the pearl's origin. The luminescence of pearls under X-ray excitation depends on the growth environment of the pearl (freshwater or seawater).

Detailed descriptions of systematic investigations of pearls with radiographic techniques were recently published by Hänni (1982, 1983) and Brown (1979, 1983). Hänni (1982, 1983) investigated the diffraction patterns of natural and bead-nucleated cultured pearls, and studied the influence of the external shape of non-spherical pearls on the diffraction patterns of the pearls, especially the relationship between the direction of the primary X-ray beam with respect to the external shape of the pearl, i.e. the direction in which a non-spherical pearl is placed in the X-ray beam (cf. also Webster, 1957; Schiffman, 1971; Duroc-Danner and Yvon, 1983). Brown (1979, 1983) gave a systematically arranged compilation of direct radiographs of natural pearls, cultured pearls and imitation pearls (cf. also Webster, 1957; Brown, 1980, 1981a, 1981b; Brown and Mendis, 1984).

In the literature dealing with identification of pearls by radiographic techniques – including gemmological textbooks – one finds only few hints on possible ambiguities in radiographic results of pearl investigation, i.e. on possible overlappings of diagnostic features of pearls of different origin. The aim of the present paper is to make a contribution to this important and still problematic field of pearl identification. The applicability of different radiographic techniques on the characterization of pearls of unknown origin is discussed in regard to overlapping diagnostic features of different types of pearl which are available on the international market.

The composition and internal structure of pearls is described in detail by different authors, e.g. Wada (1970), Korago *et al.* (1976), Götting (1979) and Simkiss and Wada (1980). Only those types of pearls which mainly consist of small tubular crystals of aragonite (nacre) exhibit those optical properties which are the precondition to use the pearls for jewellery, i.e. for necklaces or rings. Pearls which mainly consist of organic matter (conchiolin) or of prismatic crystals of aragonite or calcite are not useful for jewellery and are therefore of no commercial value.

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Experimental details

At present the types of pearls given in the summary below are found on the international market:

Natural pearls

1. spherical, pear-shaped, button-shaped or baroque-shaped from seawater
2. spherical, pear-shaped, button-shaped or baroque-shaped from freshwater
3. blister pearls (removed from the shell of the oyster, with or without shell fragments) from seawater

Cultured pearls from seawater

1. bead-nucleated cultured pearls
2. cultured blister pearls (e.g. Mabe composite cultured pearls)
3. non-bead-nucleated, non-tissue-implanted cultured pearls (Keshi cultured pearls); pearls of this type (adventitious pearls) are accidentally formed in bead-nucleated oysters (cf. Brown, 1980).

Cultured pearls from freshwater

1. bead-nucleated cultured pearls
2. cultured blister pearls
3. non-bead-nucleated cultured pearls
   a) tissue-implanted cultured pearls ('first crop' Biwa cultured pearls, Chinese cultured freshwater pearls)
   b) non-tissue-implanted cultured pearls ('second crop' Biwa cultured pearls) (cf. also Farn, 1975; Brown, 1981a, 1981b).

For the present paper several necklaces and single pearls (not mounted in jewellery) of each type mentioned above were examined:

The following numbers indicate (a) necklaces used for direct radiography and luminescence tests (pearls from necklaces used for X-ray diffraction), (b) single pearls used for direct radiography and luminescence tests (single pearls used for X-ray diffraction).

	(a)	(b)
Natural pearls		
from seawater	12 (10),	90 (8)
from freshwater	– – ,	24 (4)
blister pearls from seawater	– – ,	2 –
Cultured pearls, seawater		
bead-nucleated pearls	25 (15),	55 (10)
blister pearls	– – ,	2 –
Keshi pearls	2 – ,	30 (8)
Cultured pearls, freshwater		
bead-nucleated pearls	– – ,	2 (2)
blister pearls	– – ,	– –
non-bead-nucleated pearls	30 (5),	20 (8)

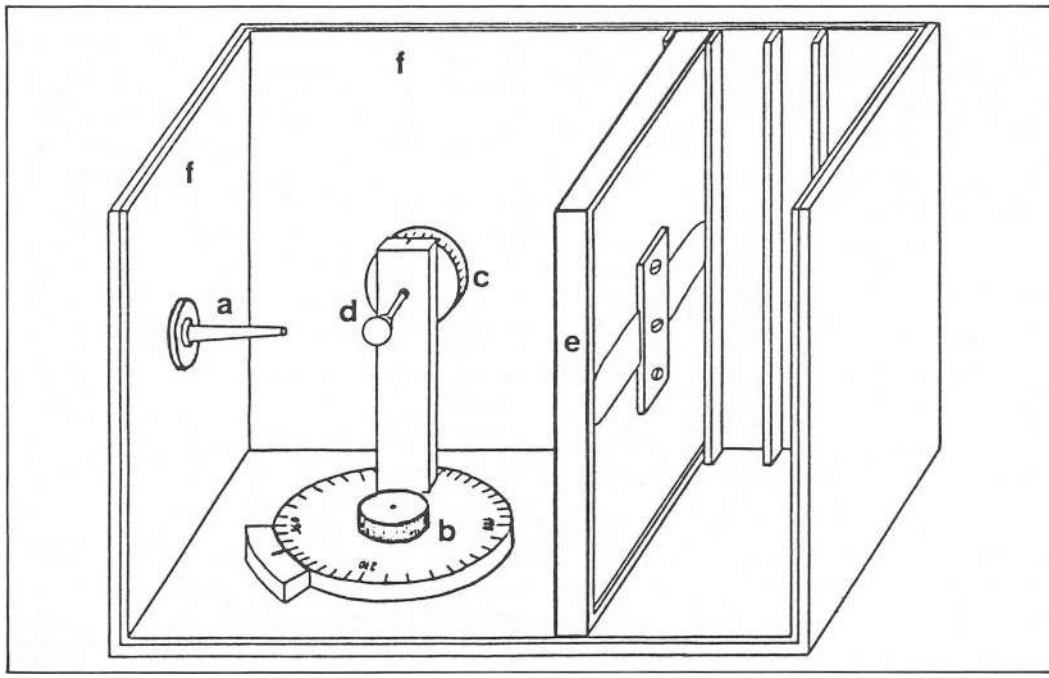

Fig. 1. X-ray diffraction camera (Laue-camera) for pearls; (a) collimator, (b) vertical rotation axis with a dial having 360° subdivisions, (c) horizontal rotation axis with a dial having 360° subdivisions, (d) pearl, (e) film cassette, (f) camera box covered inside with lead sheet; length of the camera approximately 25 cm.

Direct radiography was performed according to the experimental conditions already described in detail by Webster (1957) using immersion liquids. These experimental conditions (Webster, 1957) are principally different from the method of Brown (1983), who investigated pearls and pearl necklaces by direct radiography without using immersion liquids. Mainly carbon tetrachloride and tetrachloroethylene were used. Direct radiography with immersion liquids, in general, gave better results in pearl testing than without.

The luminescence of pearls under X-ray excitation was investigated before the pearls were placed in the immersion liquid for direct radiography. The reaction of the pearl under the primary X-ray beam was observed in an absolutely darkened room through a window of lead-bearing glass in the camera used for direct radiography. In this time-saving procedure both methods were performed in one single working step.

Experimental conditions: copper target, 35 kV, 24 mA; pearl to target distance variable 20–80 cm (mainly a distance of 20 cm was used); exposure time 30 seconds.

The X-ray diffraction patterns of pearls were photographed in a specially developed diffraction camera (Fig. 1). The camera works according to the principle of a two-circle goniometer. The pearl is placed at various exactly defined angles with reference to the primary X-ray beam using both a horizontal and a vertical rotation axis. For the investigation of single pearls in necklaces an additional sample holder is used (Fig. 2), which enables the attachment of the necklace in front of the collimator of the X-ray beam. By using this sample holder X-ray diffraction photographs of single pearls in necklaces are possible in all directions which are adjustable by a rotation of the pearl with the string of the necklace as a rotation axis.

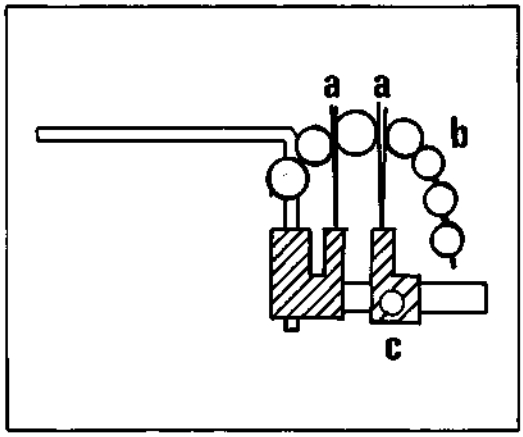

Fig. 2. Additional sample holder for X-ray diffraction photographs of single pearls from necklaces; (a) forks to support the necklace, (b) necklace, (c) movable fork with screw set adjustable according to the diameter of the pearl; length approximately 8 cm.

Experimental conditions: two different tubes were used for diffraction experiments, copper target, 40 kV, 20 mA or iron target, 36 kV, 26 mA; pearl to target distance 12 cm, pearl to collimator and distances 0.5, 1.5 or 2.5 cm) three different collimators), pearl to film distances 8, 12 or 16 cm; exposure times 2–16 h; film type Agfa OSRAY M3.

Results

Generally, the results of our experimental investigations confirm the data widely scattered in the literature as well as the results of the most recent systematic examinations by Hänni (1982, 1983) and Brown (1979, 1983). Some results complete the data available in the literature, especially the data of certain types of pearls which were not previously investigated by a combination of all three experimental methods used in our study.

Imitation pearls and cultured blister pearls are often recognizable without the application of radiographic techniques (Webster, 1973). Imitation pearls are distinguishable from natural and cultured pearls by examination of the surface structure and/or by their different density. Cultured blister pearls (e.g. Mabe composite cultured pearls) are identifiable due to their characteristic external form and due to their artificial supplement on the backside of the sample. Therefore these two types of material are not discussed in further detail.

The characteristic properties of natural pearls and cultured pearls which are determinable by radiographic techniques are summarized in Table 1.

Direct radiography

The diagnostic features in direct radiographs of pearls are due to the different X-ray transparency of calcium carbonate (mainly aragonite with low X-ray transparency) and organic matter (conchiolin with high X-ray transparency). The not absorbed fractions of the primary beam cause the blackening of the X-ray film. In order to recognize unambiguously characteristic structures of pearls, several X-ray pictures in various orientations generally have to be taken. The best method to hold pearls steady is to use small patches of paper tissue.

The direct radiographs of a fraction of natural pearls (seawater and freshwater pearls) and of some Keshi cultured pearls reveal circles, arcs or regular cavities close to the centre of the pearls. These diagnostic structures in the X-ray film are caused by conchiolin in the centre or between the concentric layers of aragonite crystals.

Table 1. The different types of pearl and their radiographic properties of diagnostic value

Type of pearl	Direct radiographs*	Luminescence under X-ray excitation	X-ray diffraction patterns**	Radiation defects
natural freshwater pearls	fine circles or arcs close to the centre	variable: weak to strong	identical at different angles to each other, consisting of a system of descrete spots having a six-fold symmetry or of a diffuse halo	medium to strong
natural seawater pearls		not observed		not observed
Keshi cultured pearls				
non-bead-nucleated cultured freshwater pearls	large irregular patches of variable radiolucency	variable: medium to strong		medium to strong
bead-nucleated cultured freshwater pearls	external circles or arcs, radio-opaque bead in the centre	strong	different at right angles to each other, consisting of a system of discrete spots having a two-fold symmetry (first direction) or of a system of discrete spots having a six-fold symmetry or of a diffuse halo (second direction)	
bead-nucleated cultured seawater pearls		variable: not observed to medium		not observed

* diagnostic features are not observable for all pearls
** for spherical or almost spherical pearls

Cultured pearls with mother-of-pearl nuclei (bead-nucleated cultured seawater and freshwater pearls) are recognizable on the direct X-ray picture by an almost circular structure closer to the rim of the pearl. In general, this circular structure is interrupted and sometimes only short parts are visible. The diagnostic features of bead-nucleated cultured pearls are caused by a layer of conchiolin coating the mother-of-pearl bead in a first step of growth after the seed is inserted into the oyster. Therefore an outline of the bead which may be coated by a conchiolin layer of irregular thickness becomes visible on the X-ray picture.

The direct radiographs of non-bead-nucleated tissue-implanted freshwater pearls (Biwa cultured pearls and Chinese freshwater cultured pearls) and most of Keshi cultured pearls yield irregularly formed structures of variable X-ray transparency in the centre of the pearls. In the case of freshwater cultured pearls, these structures are caused by cavities and irregularly deposited conchiolin layers. In the case of Keshi cultured pearls, the reason for similar structures is thought to be due to irregular concentrations of organic matter occasionally associated with shell fragments (cf. Brown, 1980, 1981a, 1981b).

Luminescence under X-ray excitation

The different reaction of pearls under X-ray excitation is explained by their different manganese contents assumed to be caused by different manganese concentrations in seawater and freshwater (Waldeck and Baier, 1970; Webster, 1975).

Under the experimental conditions used in this study, natural pearls grown in a seawater environment do not show luminescence under X-ray excitation. The luminescence behaviour of the bead-nucleated cultured seawater pearls is different. Dependent on the thickness of their skin (layer of nacre) around the mother-of-pearl nucleus (which is artificially produced from shells grown in freshwater), a weak luminescence is observed in thin-skinned pearls. In pearls with a great thickness of the layer of nacre grown in seawater, no reaction

under X-ray excitation was observed. On the contrary, pearls grown in freshwater – natural freshwater pearls and cultured freshwater pearls – reveal a distinct reaction under X-ray excitation. This greenish luminescence of freshwater pearls is of variable intensity (weak, medium or strong) and is thought to be dependent on growth conditions, i.e. the trace element content of the growth environment. A strong luminescence under X-ray excitation was observed from Biwa cultured pearls as well as from natural freshwater pearls from Scotland.

X-ray diffraction

The application of the Laue-method for pearls is based on the different arrangements of small calcium carbonate crystals (mainly aragonite) in the layers of natural pearls and bead-nucleated cultured pearls, respectively. The symmetry of the diffraction pattern is dependent on the symmetrical relationship in the pearl parallel to the primary X-ray beam. In almost spherical natural pearls with a concentric layered structure of aragonite platelets, identical relationships are found in different orientations of the pearl with respect to the X-ray beam. In contrast, the symmetrical relationships in bead-nucleated cultured pearls are different in directions parallel and perpendicular to the orientation of the nearly straight parallel aragonite layers of the nucleus.

A concentric layered structure is found in all natural pearls (natural seawater and freshwater pearls), in non-bead-nucleated cultured freshwater pearls and in Keshi cultured pearls. In these groups, assuming the X-ray beam passes through the centre of an almost spherical pearl, the diffraction pattern consists of a system of discrete spots having a six-fold symmetry or of a nearly concentric halo. Every transition between both basic types of pattern is observable.

The diffraction pattern of bead-nucleated cultured pearls (seawater or freshwater) is identical with the diffraction pattern of pearls with a concentric layered structure under the precondition that the direction of the primary X-ray beam is perpendicular to the aragonite layers of the nucleus. However, in other directions, especially parallel to the aragonite layers of the nucleus, the diffraction pattern of bead-nucleated cultured pearls, in general, consists of a system of discrete spots having a two-fold symmetry.

Under the precondition that the first diffraction pattern of a pearl of unknown origin shows a six-fold symmetry (as described above), a second Laue-pattern in a direction perpendicular to the first orientation of the pearl has to be conducted in order to determine the possible presence of a nucleus. Therefore, in general, at least two or even more diffraction photographs have to be taken at exactly defined angles to each other. This procedure is easily practicable using the diffraction camera described in this paper (Fig. 1), which enables different discrete orientations of the pearl without the necessity of removing the pearl from the camera.

The diffraction patterns of non-spherical pearls are extremely complex depending on the orientation of the pearl in the X-ray beam (cf. Hänni, 1982, 1983). In such cases an identification of a pearl of unknown origin with the Laue-method only may become very difficult or even impossible.

The Laue-pattern of a thick-skinned cultured pearl with a relatively small mother-of-pearl nucleus consists of a pattern with a six-fold symmetry (caused by the skin) which is superimposed on a pattern with a two-fold symmetry (caused by the nucleus). The pattern of the nucleus, however, was clearly visible in the diffraction patterns of all samples investigated in our laboratory.

Radiation defects

Having investigated the diffraction pattern of freshwater pearls (natural and cultured freshwater pearls of all types) under the experimental conditions mentioned above a dark circular spot was incidentally observed on the surface of the pearl. Radiation defects were never observed during the investigation of luminescence under X-ray excitation or after direct radiography of freshwater pearls. After the investigation of seawater pearls by X-ray diffraction techniques no radiation defects were observed. Similar radiation defects were also produced on the surface of a bead-nucleus (grown in freshwater!) from which the skin of nacre had been removed. The radiation defects were found to be reversible. They disappeared after exposing the pearl to direct sunlight for several weeks, e.g. on a window seat. Nevertheless, the application of the X-ray diffraction method for the determination of freshwater pearls should be avoided if possible. The identification of freshwater pearls can be made from observations of luminescence under X-ray excitation.

Possibilities of radiographic determination of pearls of unknown origin

The most important result of our systematic investigations is the fact that most pearls available in the trade are adequately characterizable and sufficiently identifiable by a combination of the three radiographic techniques described in this paper (Table 1). The application of only one of the methods mentioned above allows the unambiguous determination of only a minor part of the pearls found on the market.

As already described, diagnostic internal structures of a pearl may become visible on the X-ray film by the application of direct radiographic techniques. However, structures which are suitable for an unambiguous determination of the sample were recognized in only 10–20% of natural pearls.

About 60% of direct radiographs of bead-nucleated cultured pearls (seawater and freshwater) revealed diagnostic structures on the X-ray film, i.e. the characteristic circle close to the rim of the pearl (or at least part of it) became visible. The percentage of pearls which showed diagnostic structures on their X-ray photograph, however, was extremely variable between different necklaces, e.g. the percentage of diagnostic structures was found to vary between 16 and 94%. In baroque-shaped or non-spherical bead-nucleated cultured pearls, the mother-of-pearl nucleus was recognizable on the X-ray photograph in almost 100% of all pearls investigated. These results indicate that the application of the diffraction method to non-spherical pearls is rarely required. In thin-skinned spherical pearls, however, the outline of the mother-of-pearl nucleus was seldom recognizable. The best experimental condition was a horizontal orientation of the drill hole; under this precondition, the outline of the nucleus became visible close to the drill hole. Therefore, the investigation of the diffraction pattern is of great importance for the determination of thin-skinned bead-nucleated pearls.

In our study the direct radiographs of Keshi cultured pearls yielded, in about 80% of the samples investigated, diagnostic structures which are similar to those of non-bead-nucleated tissue-implanted cultured pearls. In about 10% of the X-ray pictures diagnostic structures were recognized which are close to those only seen in the radiographs of natural pearls.

Non-bead-nucleated cultured freshwater pearls from China are, in general, recognizable due to their external shape as well as to their characteristic surface structures. A large proportion of non-bead-nucleated cultured freshwater pearls from Japan (Biwa cultured pearls) is easily recognizable by their external shape. In addition, both types of cultured pearls reveal typical radiographic features in the X-ray photograph. Spherical or nearly spherical non-bead-nucleated cultured freshwater pearls (Biwa cultured pearls), however, are easily mistaken for natural pearls or bead-nucleated cultured pearls. The direct radiographs of this type of Biwa cultured pearls revealed in only 20% of the samples the diagnostic blacking of irregular formed structures of high X-ray transparency. These results indicate that this second type of non-bead-nucleated Biwa cultured pearls without characteristic properties in the direct X-ray photograph was grown without tissue implantation (cf. Brown, 1981a, 1981b; 'first crop' and 'second crop' Biwa cultured pearls). Both types of non-bead-nucleated cultured pearls, however, are recognizable due to an intense and diagnostic luminescence under X-ray excitation.

The luminescent behaviour of pearls under X-ray excitation was examined in one single working step together with the direct radiographic exposure. The information obtainable from this test alone is not sufficient to characterize a pearl of unknown origin. However, the luminescence under X-ray excitation is suitable to give important clues which are useful to complete the information from the direct radiograph and, if necessary, the diffraction pattern. In addition, the investigation of luminescence under X-ray excitation is important for the recognition of freshwater pearls in order to avoid radiation damage caused by the Laue-method.

The investigation of the diffraction patterns can prove the presence or absence of a mother-of-pearl nucleus in pearls of unknown origin (seawater and freshwater pearls). The Laue-method is not able to distinguish between natural pearls, non-bead-nucleated cultured pearls and Keshi cultured pearls. However, it is very useful to characterize pearls without diagnostic properties in the direct radiograph, e.g. thin-skinned bead-nucleated cultured pearls as well as extremely thick-skinned bead-nucleated cultured pearls.

Determinative procedure for the characterization of pearls of unknown origin

In general, only those pearls which are not determinable according to their external features, e.g. surface properties or external shape, are submitted for radiographic examination. Without application of radiographic procedures the following types of pearl are often recognizable: cultured blister pearls (e.g. Mabe composite cultured pearls), most non-bead-nucleated cultured freshwater pearls from China, a fraction of non-bead-nucleated cultured freshwater pearls from Japan (Biwa cultured pearls), and imitation pearls.

It is suggested that the determination of pearls of unknown origin begins with several direct radiographs in various orientations of the pearl. In the same step the luminescence of pearls under X-ray excitation is investigated. Assuming that the direct radiographs reveal structures of diagnostic value, i.e. structures which unambiguously indicate the internal structure of the pearl, an unequivocal identification of most of those samples is possible by combining direct radiography with luminescence. A schematic diagram for determinative purposes of pearls with diagnostic structures in the direct radiograph is given in Fig. 3. For those pearls mentioned above, diffraction photographs can be

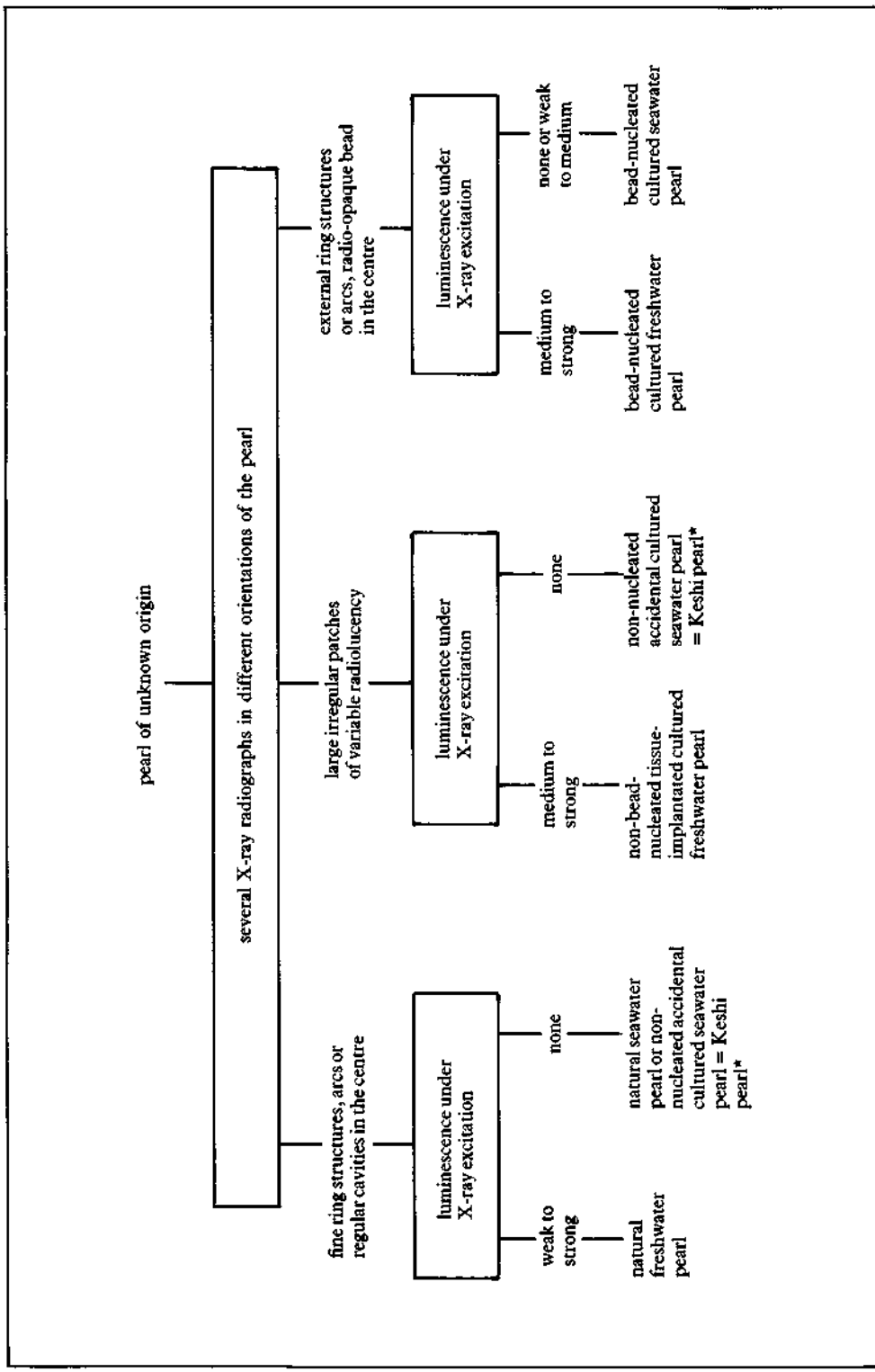

Fig. 3. Schematic diagram for determining pearls of unknown origin using direct radiography and luminescence under X-ray excitation (for pearls having diagnostic structures in the direct radiograph).

* About 10% of Keshi cultured pearls investigated in this study revealed structures in the direct radiograph which are similar to the structures of natural pearls.

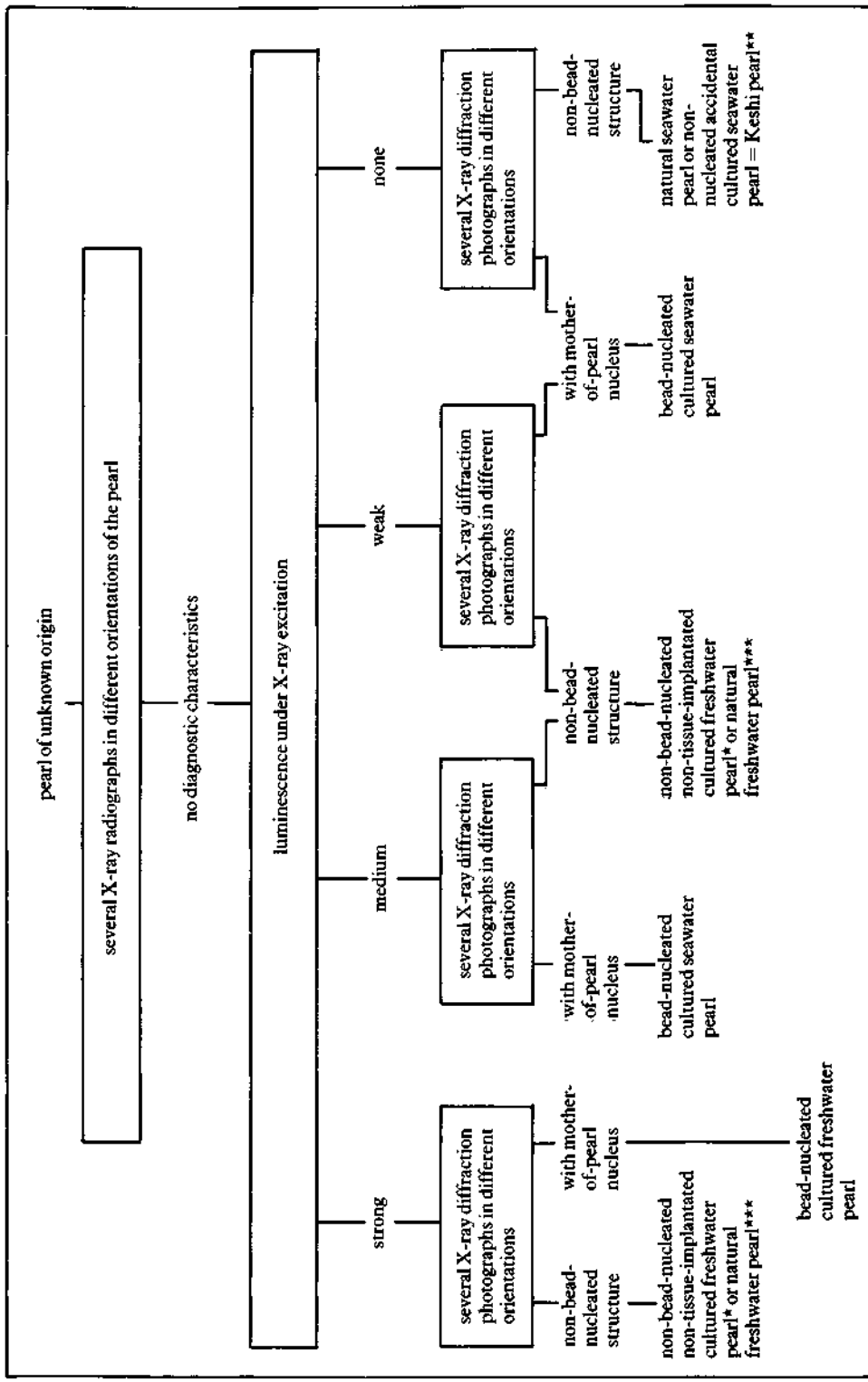

Fig. 4. Schematic diagram for determining pearls of unknown origin using X-ray diffraction and luminescence under X-ray excitation (for pearls without diagnostic structures in the direct radiograph).

* Pearls with the properties indicated are supposedly 'second crop' Biwa cultured pearls.

** About 80% of Keshi cultured pearls in this study were recognizable by direct radiography. The direct radiographs of about 10% revealed structures similar to natural seawater pearls, and those of about 10% were of no diagnostic value.

*** Natural freshwater pearls were often distinguishable by visual appearance from cultured freshwater pearls; natural freshwater pearls without diagnostic properties in the direct radiograph and having the strong luminescence of Biwa cultured pearls are extremely rare.

taken as a supplementary test although in those cases the application of this method is not necessary. Difficulties arise in the determination of some Keshi cultured pearls which reveal no structures in the X-ray photograph or show diagnostic structures indicating a natural pearl. The application of the Laue-method in addition does not solve these determinative problems.

In addition to the luminescence under X-ray excitation, diffraction photographs are necessary for those pearls without determinative features in direct radiographs. The investigation of freshwater pearls by the diffraction technique can cause radiation damage. Thus, the diffraction method should be avoided for those pearls which are recognized by luminescence as freshwater-grown. Without positive results of direct radiography an unequivocal identification by the combination of luminescence and diffraction radiography is possible only for a fraction of the pearls. A schematic diagram for this situation is given in Fig. 4. By the application of luminescence investigation and diffraction radiography only, natural seawater pearls are not distinguishable from Keshi cultured pearls. Also a fraction of natural freshwater pearls cannot be distinguished from non-bead-nucleated tissue or non-tissue-implanted cultured freshwater pearls by this approach. According to the results of this study, about 80% of Keshi cultured pearls are recognizable by direct radiography. For the remaining 20%, the three types of radiographic techniques are not suitable for an unambiguous distinction from natural seawater pearls. Natural freshwater pearls without diagnostic features in the direct radiograph but with a strong luminescence are easily mistaken for spherical or nearly spherical Biwa cultured pearls without diagnostic structures (non-bead-nucleated non-tissue-implantated cultured freshwater pearls). However, natural pearls having these properties are extremely rare.

Additional remarks

During this study it became evident that necklaces found in the trade may consist of both natural pearls and bead-nucleated cultured pearls, which are often thin-skinned cultured pearls. It is self-evident that an unequivocal characterization of necklaces composed of natural and cultured pearls is extremely difficult. If a necklace of unknown origin consists, e.g. of 100 pearls, and if furthermore by direct radiography about 10% of the pearls were recognized as natural and about 10% of the pearls were recognized as cultured pearls, the determination of the remaining 80% of the pearls without diagnostic structures in the direct radiograph will be extremely time consuming although X-ray diffraction photographs of every pearl of the necklace can solve this problem (diffraction photographs of pearls from necklaces can be done by use of the sample holder pictured in Fig. 2). Only those pearls of the necklace having a diameter of at least 3 mm can be investigated by X-ray diffraction photography.

In conclusion it can be stated that necklaces of uniform composition, i.e. necklaces consisting of one type of pearl only, are easily determinable by a combination of all three methods discussed in this paper. On the contrary, the determination of mixed necklaces, i.e. necklaces consisting of pearls of different origins, may be extremely complicated and time consuming.

In general, single pearls of distinct size are also determinable by a combination of all three X-ray techniques, though difficulties may arise from certain types of pearls. The determination of small pearls by radiographic methods, however, may become difficult or even impossible.

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The authors are grateful to Mr H. Hahn and Mr E. Hahn, of Idar-Oberstein, West Germany, for information about the pearl market and for a critical discussion of the experimental results presented in this paper. The firms of Ph. Becker & Co., J. Graef & Co. and A. Hahn, of Idar-Oberstein, and E. Eugster, of Zürich, Switzerland, submitted pearls and necklaces.

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Gemmological Abstracts

ALEXANDER, P.O. 1985. Looking for diamonds? Try geobotany. *Wahroongai News*, **19**, 7, 18–20.

The strongly mineralized ultramafic rocks of kimberlite have been found to promote vegetation so that it stands out in contrast to the sparse cover of the surrounding rock, which is also ultramafic but less rich in phosphorus and potassium.

Geobotanical studies of the Hinota kimberlite pipe have shown that the vegetation in the form of large and healthy trees is in such marked contrast as to be discernible from a distance or from the air. It is suggested that these differences in vegetation may be useful in locating buried kimberlite pipes in areas of known potential, with particular reference to the Panna diamond belt of Central India. R.K.M.

BAGUENA RUIZ, C. 1985. Estudio comparativo de tres tipos de 'hematites'. (Comparative study of three types of 'hematites'.) *Gemologia*, **22**, 65/66, 48–59, 9 figs (6 in colour).

Three types of material which have been given the name hematite are examined. X-ray diffraction is used to determine crystal structure and electrical conductivity studies establish the identity of the specimens conclusively. M.O'D.

BALFOUR, I. 1985. Famous diamonds of the world, XXIV. The 'Nassak' diamond. *Indiaqua*, 42, 3, 133–5, illus.

The diamond known as 'Nassak' was named after the town of Nasil situated 110 miles north of Bombay. It was 'liberated' in 1818 by British forces as part of the booty in the last of the Mahratta Wars, and was handed over to the East India Company. Its shape then was triangular, and it weighed around 89 carats. After passing through many hands it was purchased by Harry Winston who had it re-cut to its present shape as an emerald-cut weighing 43.38 carats. It was finally acquired by the King of Saudi Arabia in 1977. P.G.R.

BANCROFT, P. 1985. The story behind the book. *Lapidary J.*, **39**, 9, 26–37, 8 figs (3 in colour).

The book is *Gem and Crystal Treasures** and the article gives some of the anecdotes amassed by the author while preparing the book. M.O'D.

* Reviewed in *J. Gemm.*, 1985, **XIX**, 8, 733.

BANK H. 1985. Farbloser Skolezit aus Indien. (Colourless scolecite from India.) *Z. Dt. Gemmol. Ges.*, **34**, 3/4, 167–8, bibl.

The transparent colourless crystals were offered as natrolite, but were shown to be scolecite, SG 2.21, RI n_x 1.512, n_y 1.518, n_z 1.523. E.S.

BANK, H., KNIEWALD, G. 1985. Farbloser Hyalophan von Busovača, Jugoslawien. (Colourless hyalophane from Busovača, Yugoslavia.) *Z. Dt. Gemmol. Ges.*, **34**, 3/4, 169–70.

The material comes from Busovača in central Bosnia, about 50 km north-west of Sarajevo. It is colourless, transparent, density 2.89 g/cm^3, RI n_x 1.541–1.543, n_y 1.546–1.549, n_z 1.549–1.551, DR 0.007–0.008, and was found to be hyalophane. E.S.

BOUŠKA, V., FRYDRYCH, M., TURNOVEC, I. 1985. Moldavites as precious stones. *Z. Dt. Gemmol. Ges.*, **34**, 3/4, 83–91, 8 figs (3 in colour).

Prehistoric man was already attracted by moldavites, found near Willendorf in Austria and Oslavany in Czechoslovakia. There are no medieval reports on moldavites. They were used as decorative stones from the 18th century. Examples of cut moldavites set in gold were shown at the National Exhibition in Prague in 1891. Two of the authors work in the co-operative 'Granat' in Czechoslovakia which produces modern moldavite jewellery, mainly set with uncut stones, but moldavite is also cut and two artists are mentioned as specializing in engraving moldavites. E.S.

BOWERSOX, G.W. 1985. A status report on gemstones from Afghanistan. *Gems Gemol.*, **XXI**, 4, 192–204, 14 figs in colour.

Report on production of emerald, tourmaline, kunzite and ruby, at the western end of the Himalayas in NE Afghanistan, which has increased dramatically since the Russian invasion greatly increased the need for foreign currency. Fine emerald from the Panjshir Valley (bombs sometimes reveal new localities), RI and SG are high comparable with those for South African stones. Nuristan region produces fine aquamarine, tourmaline in pink, blue, green and multi-coloured. Some of the finest kunzite comes from this region. Fine rubies occur in marble in Sorobi District at Jegdalek, but

war precludes serious mining. Considerable quantities of fine lapis lazuli are also coming across the border to Pakistan. The gems are back-packed out, the miners often walking hundreds of miles through remote and difficult country. The need for foreign exchange is great. R.K.M.

CARUBA, R., BAUMER, A., GANTEAUME, M., IACCONI, P. 1985. An experimental study of hydroxyl groups and water in synthetic and natural zircons: a model of the metamict state. *American Mineralogist*, **70**, 1224–31, 8 figs.

Zircon has been synthesized between 200 and 800°C at 1 kbar in a fluorinated environment. It is a solid solution in which the $(OH,F)_4$ group takes the place of a SiO_4 tetrahedron and is of the type $Zr(SiO_4)_{1-x}(OH,F)_{4x}$ with $0.2<x<0.8$. It is thought that natural zircons are formed at low temperature in a hydrous and fluorinated environment enriched by heavy rare earth and radioactive elements whose particles destroy the hydroxylated crystal lattice. F is thought to be present in the $(OH)_4$ tetrahedra. M.O'D.

CAVENEY, R.J. 1985. De Beers Diamond Research Laboratory Report No. 20. The strength and performance of diamond depends on many factors. *Indiaqua*, 42, 3, 123–5, illus.

It has been discovered that, when a narrow beam of laser light is passed through a diamond which is visually free from foreign inclusions, the beam experiences scattering. A direct relationship has been established between the intensity of light scattered and the performance of the diamond as a cutting tool. It is concluded that many of the previously unexplained differences in mechanical properties of diamond can now be explained by the presence of inclusions which are invisible even under a microscope. P.G.R.

COHEN, A.J. 1985. Amethyst colour in quartz, the result of radiation protection involving iron. *American Mineralogist*, **70**, 1180–5, 3 figs.

Fe^{3+} in interstitial positions in the growth loci of the major rhombohedron in quartz crystals will prevent the development of smokiness if the amount of Fe is larger than the Al^{3+} impurity content. The Al impurity is responsible for the smoky colour through the operation of a trapped hole centre when ionizing radiation is used. Growth loci of the minor rhombohedra may be smoky even when there is an excess of substitutional Fe^{3+} over Al^{3+}. When interstitial Fe^{3+} is oxidized to Fe^{4+} an electron becomes available for quenching the trapped hole centres on oxygens adjoining substitutional Al^{3+} sites as they form. In these circumstances the smoky colour is not developed. Amethyst colour is produced by an absorption band of the Fe^{4+}. In nature Fe^{3+} only predominates over Fe^{4+} in quartz formed under shallow-growth conditions such as cavities or geodes. Amethyst coloration is found in these conditions only. M.O'D.

COHEN, A.J., MAKAR, L.N. 1985. Dynamic biaxial absorption spectra of Ti^{3+} and Fe^{2+} in a natural rose quartz crystal. *Mineralogical Magazine*, **49**, 354, 709–15, 4 figs.

The absorption spectrum of Ti^{3+} in quartz is characteristic for Ti in an octahedral site. However. the high oscillator strength of the band indicates intensive charge transfer, and this is most likely to take place between a substitutional Ti^{4+} and an interstitial Ti^{3+}. The band shows biaxial anisotropy similar to that shown by that of octahedral Fe^{2+} in the same crystal, which suggests that the Ti^{3+} occupies the same site – an interstitial site at the intersection of the 3-fold axis with the two 2-fold axes. When the crystal is *X*-irradiated and then bleached by UV light or heat the dynamic nature of the Ti and Fe can be observed. Ti^{4+} ions are acceptors of electrons donated by Fe^{2+} during *X*-irradiation. This can be seen in an increase of the 2.4eV band intensity with decrease of the Fe^{2+} band intensities and the appearance of Fe^{3+} charge transfer bands in the UV region. The heat and UV treatment diminish the Fe^{3+} charge transfer bands and increase the Fe^{2+} crystal field bands, together with decrease in the 2.4eV band related to Ti. M.O'D.

COLDHAM, T. 1985. Sapphires from Australia. *Gems Gemol.*, **XXI**, 3, 130–46, 21 figs in colour.

A good account of the sapphire fields at Inverell, NSW, and at Anakie in Queensland, including geology, mining methods, processing, sorting and grading. Almost all the output is sold to Thai merchants skilled in heat treatment to improve colour and remove silk. Blues and yellows predominate, while pinks, purple and mauve stones are rare. Colour zoning is common, often alternating blue and yellow. These two fields are showing signs of exhaustion, but the vast area of basalts in eastern Australia probably hides other potential mining areas of considerable significance. R.K.M.

DONTENVILLE, S., CALAS, G., CERVELLE, B. 1985. Etude spectroscopique des turquoises naturelles et traitées. (Spectroscopic study of natural and treated turquoise.) *Revue de Gemmologie*, **85**, 8–10, 6 figs. First part.

Spectra for natural turquoise from the United States, plastic impregnated turquoise with added colour, plastic-impregnated turquoise with no

added colour, Gilson synthetic turquoise and 'turquoise morte' (material whose colour has been lost through exposure to sunlight) are described and illustrated. M.O'D.

FRUITMAN, C. 1985. The ultima cut. *Lapidary J.*, **39**, 8, 25–32, 9 figs (1 in colour).

A cut designed to increase dispersion in a variety of coloured stones is described. Loss of weight is avoided as far as possible. M.O'D.

FRYER, C.W. (Ed.), CROWNINGSHIELD, R., HURWITT, K.N., KANE, R.E. 1985. Gem Trade Lab notes. *Gems Gemol.*, **XXI**, 3, 171–7, 19 figs in colour.

Black star sapphire doublets and two corundums with surface-induced stars, one natural, the other a flux-grown synthetic, are described. A gambling dice cut from an industrial diamond; strontium titanate and cubic zirconia mistaken for diamonds, were totally destroyed by heat in repairs; an apparently new low grade synthetic emerald with considerable inclusions of parallel needles (RI 1.555–1.560, SG 2.67); a green and white carved bell with plagioclase and green muscovite mica as major constituents; a demantoid cat's-eye identified by its single refraction and absorption spectrum; a fine jadeite with unidentified hair-like inclusions; another with a large white single jadeite crystal as an inclusion; plastic imitations of lapis lazuli and a purplish-pink faceted sapphirine are all described and illustrated. R.K.M.

FRYER, C.W. (Ed.), CROWINGSHIELD, R., HURWITT, K.N., KANE, R.E. 1985. Gem Trade Lab notes. *Gems Gemol.*, **XXI**, 4, 232–8, 18 figs in colour.

Reports on bi-colour aquamarine/goshenite; diamond turned yellow-brown by heat of laser sawing; diamond with internal natural radiation staining; and the composite (piggy-back) setting of two yellow diamonds. Off-colour yellow diamonds are being re-cut as modified octagonals to enhance the colour; and a cubic zirconia was similary cut. Garnet/glass doublet, mistaken for ruby, melted under heat of repair work (low temperature soft glass). A fine jet urn is illustrated. Lapis lazuli beads had been oiled to improve colour. An interesting collection of rare pink conch 'pearls' described. A large collection of three-quarter blister pearls from Hong Kong were shown to be plastic. A pinkish-purple natural spinel had colour change to purplish-pink. Synthetic alexandritic type spinels are
rarely seen. Synthetic zincite described and illustrated. Another oddity was identified as the boiled lens of a fish's eye. R.K.M.

GÜBELIN, E. 1985. La identificación de los nuevos zafiros sintéticos y tratados. (Identification of the new synthetic and heat-treated sapphires.) *Gemologia*, **22**, 65/66, 5–34, 49 figs (44 in colour).

Translation into Spanish of a paper first published in *J. Gemm.*, 1983, **XVIII**, 8, 677–706. M.O'D.

HENN, U., SCHRAMM, M. 1985. Untersuchungen an braunen Turmalinen von Elahera, Sri Lanka. (Investigation of brown tourmalines from Elahera, Sri Lanka.) *Z. Dt. Gemmol. Ges.*, **34**, 3/4, 98–100, 1 fig. in colour.

The brown tourmalines from Elahera were classified as uvites and dravites. Photomicrograph shows rounded zircon crystals in a brown tourmaline. E.S.

HOFER, S.C. 1985. Pink diamonds from Australia. *Gems Gemol.*, **XXI**, 3, 147–55, 12 figs in colour.

Pink diamonds have been regarded as among the rarest of the colour varieties and it is considered unusual to encounter actual parcels of natural pink diamonds. But a surprisingly large number of these stones have come in to the New York Gem Trade Lab this year, all originating from material produced in the newly discovered Argyle deposits in NW Australia. Most stones are heavily included. 138 were examined in detail by this author.

Colour was an unusual smoky purplish-pink, deeper than most pink diamonds. Nuances of brown and other colours were found. The spectrum showed the Cape absorption line at 415 nm and the weak band at 520–580 nm, markedly different from the spectra of known irradiated pinks. UV fluorescence was blue but varied in strength. Colour is thought to be due to plastic deformation of crystal lattice and is unevenly distributed in the form of 'brush stroke' grain lines throughout the stone, best seen under low power magnification. 'Frosted' cleavage cracks and a pitted, sugary crystal surface seem to be characteristic of these Australian diamonds. It is thought that 'etching' is due to the crystal surfaces being dissolved by heat. [The author does not say whether the observed pitting was in reverse to the octahedral edge or parallel to it. In abstracter's experience the latter is always the case when a diamond has been burnt.] Solid inclusions had mostly assumed shapes which accorded with the morphology of the diamond. It is considered that the features described would be sufficient to identify the provenance of these Australian pinks with fair certainity. R.K.M.

KANE, R.E., LIDDICOAT, R.T., Jun. 1985. The Biron hydrothermal synthetic emerald. *Gems Gemol.*, **XXI**, 3, 156–70, 18 figs in colour.

New hydrothermal synthetic emeralds grown in Western Australia were subjected to careful gemmological tests. Colour varied from green to slightly bluish-green with good saturation and high transparency, often apparently free from inclusions. Dichroism and absorption were as expected for synthetic emeralds and fine natural stones. Red transmission was observed under suitable lighting, but this again is seen in some of the finer Colombian stones. A strong red was seen through the Chelsea colour filter.

SG varied slightly around 2.70 so that they overlapped the values for natural emeralds, confirming these are hydrothermally produced stones. None of the stones examined exhibited any fluorescence under either type of UV light. Iron was not found in these stones and the quenching in this instance must be due to the high concentration of vanadium, which exceeded the chromium content by more than two to one. RIs of 1.569 and 1.573 were obtained giving a birefringence figure of 0.004–0.005, low values which suggest the synthetic origin, and rather more like those of a flux-grown stone than a hydrothermal synthetic.

The authors concentrate on inclusions, which are the identifying features in most synthetic emeralds. Healed fissures of the fingerprint and veil type are typical, and often consist of two-phase inclusions of bubble and liquid. Inclusions are by no means prolific, and careful illumination is often needed to bring out the tell-tale features. A variety of other inclusion forms is described and illustrated, including nail-head spicules stemming from phenakite crystals, or gold crystals which have come from the lining of the steel autoclave, both proving the synthetic origin of the stones.

Dark-field illumination shows growth irregularities and 'flows' of colour which would not otherwise be obvious. Some of these consisted of 'comet tails' of minute white particles. White specks were almost the only inclusions to be seen in the cleanest stones. A few stones showed what appeared to be seed-plates.

Chemically the presence of chlorine in these synthetics can be regarded as proof of synthesis. This element does not occur in flux-grown synthetics or in natural emeralds.

The authors suggest that the characteristic inclusions and the low refractive indices and birefringence provide principal identifying clues to these stones. Identification is not considered to be difficult provided the gemmologist is familiar with the inclusions to be expected, and uses that knowledge to the full. The presence of chlorine is another valuable final proof for such laboratories as have facilities to test for this.

The manufacturer claims to be able to control the clarity and is concentrating on 'clean' material.

R.K.M.

KOIVULA, J.I., MISIOROWSKI, E. 1985. Gem news. *Gems Gemol.*, **XXI**, 3, 185–7, 1 fig. in colour.

News of diamond mining in Australia, Botswana, Ghana, Namibia, Sierra Leone (three diamonds over 100 carats found) and United States (kimberlites under glacial deposits in northern Michigan are being explored).

A new amethyst area in Para, Brazil, is now producing significantly. Aquamarine from the Jos region of Nigeria continues to reach Idar-Oberstein. Other supplies are coming from various African localities and Brazil. Phantom quartz with 'ghost' outlines apparently due to green chlorite inclusions is being mined at Buenopolis in Minas Gerais.

Triangular growth markings on the basal pinacoids of a very thin Yogo Gulch, Montana, sapphire were in the expected reverse orientation and so close together as to give a perfect Star of David formation when viewed along the *c* axis.

R.K.M.

KOIVULA, J.I. 1985. Gem news. *Gems Gemol.*, **XXI**, 4, 247–9, 2 figs in colour.

Reports on diamond mines in Shandong Province, China; on high potential of Indian alluvial deposits; and on UK Diamond Futures market which is mooted. Two rare 'pineapples' of opal, replacing glauberite crystals, found at White Cliffs. A new Pakistan source of emerald at Sassi in the Haramosh Mountains gives clean light-coloured stones. Alan Macnow reports that all cultured pearls are treated with mild oxidizing agent to prevent discoloration, some dyed pink or other colours. Smuggling of gems from Burma to Thailand continues. Kenyan rubies are sent to Bangkok for heat treatment to clarify them.

Pailin mines in Cambodia closed by military activity, miners cross to similar deposits in Thailand. Sapphire-bearing regions in Fujian, China, are being explored. An aquamarine crystal from Yogo Gulch, Montana, had growth pattern on basal pinacoid forming a six-pointed 'Star of David'.

R.K.M.

LIND, Th., SCHMETZER, K. 1985. Neue Untersuchungen an in Japan hergestellten synthetischen Amethysten. (New investigations of the Japanese synthetic amethysts.) *Z. Dt. Gemmol. Ges.*, **34**, 3/4, 160–4, 6 figs in colour, bibl.

Synthetic Japanese amethysts are now available in the gem trade. Certain diagnostic properties such as inclusions, growth structures, twinning and infrared spectra are discussed. The gemstones frequently have feathers consisting of liquid-filled and two-phase inclusions, sharp growth zoning parallel to one rhombohedral face as well as twin structures, which can easily be distinguished from the polysynthetic lamellar twinning in natural amethysts. E.S.

MÜLLENMEISTER, H.J. 1985. Zirkon-Katzenauge aus Sir Lanka. (Zircon cat's-eye from Sri Lanka.) *Z. Dt. Gemmol. Ges.*, **34**, 3/4. 165–6, 1 fig. in colour, bibl.

The stone described is a yellowish zircon cat's-eye with blue adularescence, cut as cabochon weighing 5.52 ct with strong chatoyancy. It is from Sri Lanka and was originally offered as moonstone. SG 4.62. The chatoyancy is caused by layered inclusions of needles; the nature of these inclusions was not determined. E.S.

NASSAU, K., HANSON, A.E. 1985. The pearl in the chicken: pearl recipes in Papyrus Holmiensis. *Gems Gemol.*, **XXI**, 4, 224–31, 7 figs. in colour.

Authors have found and tried ancient recipes for repolishing and/or cleaning pearls by feeding them to a chicken. Pearls remain in the bird's crop for an hour or so only and are then abstracted by killing the chicken. Some experiments failed, other succeeded. [From the chicken's viewpoint they all failed miserably.] R.K.M.

NUBER, B., SCHMETZER, K. 1984. Structural refinement of tsilaisite (manganese tourmaline). *N. Jb. Miner. Mh.*, **7**, 301–4.

The crystal structure of the Na-(Al,Mn,Li)-tourmaline tsilaisite was refined to a R-value of 2.9%. The structure is closely related to the crystal structures of elbaite and schorl, and manganese was found to occupy exclusively Y sites in the tsilaisite structure. Author's abstract. B.N.

O'DONOGHUE, M. 1985. Crystals as ornament. *Gems and Mineral Realm*, **16**, 4, 11–23.

An exhaustive outline of the progress of gemstone synthesis since the middle of the last century, with a bibliography. Author's abstract. M.O'D.

O'DONOGHUE, M. 1985. Pakistan. *Gems and Mineral Realm*, **16**, 4, 35–7.

An account of the author's trip to Pakistan as adviser to the State Gem Corporation. The geology of the major gem deposits is outlined.

Author's abstract. M.O'D.

PIZANI, P.S., TERRILE, M.C., FARACH, H.A., POOLE, C.P. 1985. Color centers in sodalite. *American Mineralogist*, **70**, 1186–92, 9 figs.

Natural sodalite subjected to various radiation and heat treatments is studied with ESR, NMR, optical absorption spectroscopy, ionic thermal currents and electrical conductivity. It is proposed that the colour centres which are involved in coloration and bleaching are associated with interstitial oxygen. M.O'D.

PONAHLO, J., KOROSCHETZ, T. 1985. Quantitative Kathodolumineszenz – ein neues Verfahren zur Unterscheidung echter von synthetischen Smaragden und Rubinen. (Quantitative cathodoluminescence – a new method of differentiating between natural and synthetic emerald and ruby). *Z. Dt. Gemmol. Ges.*, **34**, 3/4, 132–42, 9 figs (7 in colour), bibl.

Quantitative cathodoluminescence is the method of microphotometric measuring of luminescence-intensities emitted during bombardment with fast travelling electrons (cathodorays). Natural rubies from Thailand show one tenth of CL intensities compared with synthetic rubies. E.S.

ROSENBERG, P.E., FOIT, F.F. 1985. Tourmaline solid solutions in the system MgO-Al_2O_3-SiO_2-B_2O_3-H_2O. *American Mineralogist*, **70**, 1217–23, 3 figs.

A narrow range of tourmaline solid solutions in this system has been synthesized in the presence of excess silica, B_2O_3 and H_2O in the temperature range 400–800°C at a pressure of 1 kbar. In nature tourmalines approaching the alkali-free composition are rare, most not coming even close to it. The synthesis shows that the narrow range can exist and the principal substitutions are identified. M.O'D.

ROTTLÄNDER, R.C.A. 1985. Der chemische Abbau des Bernsteins bei seiner Aufbewahrung an der Luft. (The chemical decomposition of amber when exposed to air.) *Z. Dt. Gemmol. Ges.*, **34**, 3/4, 143–51, 7 figs, bibl.

Amber is of interest to gemmologists as well as archaeologists. It is known that when exposed to air and light amber decomposes with an uptake of oxygen. This was quantitatively tested over 14 years, during that time solubility increased up to 40% (among the soluble substances 65% terpenes). It was calculated that there were about 25% resin acids of the abietic acid type present as parent substances. The infrared spectra reflect oxidation of amber. E.S.

SCHMETZER, K. 1985. Distinction of natural and synthetic rubies by ultraviolet absorption spectroscopy – possibilities and limitations of the method. *Z. Dt. Gemmol. Ges.*, **34**, 3/4, 101–29, 45 figs, bibl.

The article discusses possibilities and limitations of UV absorption spectroscopy for the differentiation between natural and synthetic rubies. For determination of rubies of unknown origin a direct comparison of the spectra of unknown samples with standard spectra of natural samples of known origins and of synthetic samples of known producers is necessary. For a great number of unknown samples, UV spectroscopy gives unambiguous information about locality of natural or producer of synthetic rubies. It may also reduce possible options regarding locality or producer. It does not provide definite information for determining each possible unknown ruby, but it is helpful when combined with microscopy and trace element analysis. E.S.

SCHMETZER, K., BANK, H. 1985. Gahnospinelle aus Sri Lanka. (Gahnospinel from Sri Lanka.) *Z. Dt. Gemmol. Ges.*, **34**, 3/4, 92-7, 8 figs (1 in colour), bibl.

The examined samples of zincian spinels (gahnospinels) from Sri Lanka were found to represent intermediate members of the spinel-gahnite series with minor components of hercynite. The investigations confirmed results published by Anderson in 1937. E.S.

SCHRADER, H.W. 1985. 'Dreiphaseneinschluss' in einem Smaragd aus Südafrika. (A three-phase inclusion in an emerald from South Africa.) *Z. Dt. Gemmol. Ges.*, **34**, 3/4, 130–1, 1 fig in colour.

An English version of this article was published in *J. Gemm.*, 1985, **XIX**, 6, 484-5. E.S.

SCHRADER, H.-W., HENN, U. 1985. Über die Problematik der Galliumgehalte als Hilfsmittel zur Unterscheidung von naturlichen Edelsteinen and synthetischen Steinen. (About the problems of using the gallium content to differentiate between natural and synthetic stones.) *Z. Dt. Gemmol. Ges.*, **34**. 3/4, 152–9, bibl.

An English version of this article appears on p. 108 above. E.S.

SHIGLEY, J.E., KOIVULA, J.I. 1985. Amethystine chalcedony. *Gems Gemol.*, **XXI**, 4, 219–23, 7 figs (6 in colour).

A new amethystine chalcedony from Arizona, offered as 'damsonite', has normal constants for crypotocrystalline quartz, occurs in greyish, slightly reddish-purple, opaque masses varying from dark to light in colour. Heating to 550°C changed colour to a citrine orange. R.K.M.

SOLANS, J., DOMENECH, M.V. 1985. Los materiales gemológicos de Asturias. (Gemmological materials from Asturias.) *Gemologia*, **22**, 65/66, 35–43, 3 figs.

Among the ornamental minerals found in the Spanish province of Asturias are chiastolite, beryl, fluorite, jasper, amber and quartz with some jet. M.O'D.

SOMAN, K., NAIR, N.G.K. 1985. Genesis of chrysoberyl in the pegmatites of southern Kerala, India. *Mineralogical Magazine*, **49**, 354, 733–8, 2 figs.

Chrysoberyl had been found in association with quartz in alkali feldspar in granitic pegmatites in southern Kerala, India. It is thought to crystallize earlier than beryl and sillimanite. A model explained in detail in the paper may serve to explain the genesis of chrysoberyl in Sri Lanka. M.O'D.

STOCKTON, C.M., MANSON, D.V. 1985. A proposed new classification for gem-quality garnets. *Gems Gemol.*, **XXI**, 4, 205–18, 8 figs (4 in colour).

Published work by these authors suggests a redefining of the garnet group into categories of grossular, andradite, pyrope, pyrope-almandine, almandine, almandine-spessartine, spessartine, and pyrope-spessartine. Varietal categories (e.g. tsavorite, chrome pyrope, rhodolite and malaia) are defined. These suggestions are argued convincingly and backed by gemmological data and electron-probe chemical analyses. The result is a paper on vexed questions of definition which must give grounds for further discussion. R.K.M.

ZEITNER, J.C. 1985. Facet a stone from home. *Lapidary J.*, **39**, 8, 42–51, 4 figs in colour.

Describes some classic gemstones from North American localities and gives brief information on the gemstone market. M.O'D.

ZEITNER, J.C. 1985. Merry Christmas gems. *Lapidary J.*, **39**, 9, 19–24, 4 figs in colour.

Describes red and green gemstones, including alexandrite, iris agate, unakite, tourmaline, bloodstone, ruby in zoisite and others. M.O'D.

Book Reviews

BARDET, M.G. 1974. *Geologie du diamant. Deuxieme partie: gisements de diamant d'Afrique.* (Geology of diamonds. Second part: deposits of diamond in Africa.) BRGM, Paris. Pagination irregular. Illus. in black-and-white. Price on application.

Forming *Memoire No. 83* of the Bureau de Recherches Géologiques et Minères, this book discusses the diamond occurrences in Africa giving simplified geological maps of each of the major sites and covering the Kimberley area in some detail. Each of the major mines is discussed and its production and features described in tables. Each major area (South, West, East and Central Africa) is provided with its own bibliography. This is one of the few books on diamond to cover the geological and mineralogical aspects of its occurrence and is essential for the mineralogist. M.O'D.

BERRY, F.J., VAUGHAN, D.J., (Eds.) 1985. *Chemical bonding and spectroscopy in mineral chemistry.* Chapman & Hall, London. pp. x, 325. £35.00.

Chapters in this book are: quantum mechanical models and methods in mineralogy; X-ray spectroscopy and chemical bonding in minerals; electronic spectra of minerals; mineralogical applications of luminescence techniques; Mössbauer spectroscopy in mineral chemistry; electron spin resonance and nuclear magnetic resonance applied to minerals; spectroscopy and chemical bonding in the opaque minerals and mineral surfaces and the chemical bond. Almost all the chapters have something of interest for the gemmologist but I would particularly recommend the one dealing with the electronic spectra of minerals, since it contains a good deal of information on mineral coloration. Although this topic has long been prominent in the appropriate journals it is here updated and presented lucidly with a useful reference section (all the chapters have one). Luminescence techniques are also valuable and the section on the opaque minerals should also be consulted when needed. M.O'D.

CONTENT, D.J. 1985. *Glyptic arts – ancient jewelry: an annotated bibliography.* Crow Hill, Houlton, Maine 04730, USA. pp. 158. Price on application.

This is the comprehensive catalogue of a bookseller specializing in engraved gems, jewellery and the art of the goldsmith. The seventh in a series, it contains several hundred entries giving short bibliographical details of each item but no description of the text. M.O'D.

FORTHUBER, W. 1978. *Diamant, die härteste Währung der Welt.* (Diamond, the hardest currency in the world.) Verlag Atelier Oehri, Vaduz. pp. 131. Illus. in black-and-white. Price on application.

A pleasantly presented text on diamond with particular reference to diamond grading. Proportions and clarity grading are illustrated as are a number of instruments. M.O'D.

KALDIS, E. (Ed.). 1985. *Current topics in materials science.* Vol. 11. North-Holland Physics Publishing, Amsterdam. pp. 453. Price on application.

Garnets grown as thin layers and as crystals grown from high temperature solutions are discussed in the first chapter of this valuable book. Details of growth methods and the composition of melts are given. Special attention is paid to interfacial kinetics and to the correlation between growth kinetics and growth-induced magnetic anisotropy. Considerable detail on the growth of YAG, GGG and their analogues is given. The second chapter deals with substrates for epitaxial garnet layers and discusses dislocations.

The growth of iron borate, $FeBO_3$, is described in the third chapter and the growth and properties of lanthanum hexaboride in the fourth and last chapter. Readers are advised to consult this series where it can be found (for example in the Science Reference Library). Details of crystal formation and growth appear here long before reaching mineralogical or gemmological texts. M.O'D.

KALDIS, E. (Ed.). 1985. *Current topics in materials science.* Vol. 12. North-Holland Physics Publishing, Amsterdam. pp. 483. Price on application.

Four topics are covered by the latest volume in this useful series. The first is metallic, ionic and Van der Waals clusters, the second covers metastable phases in the bulk and on substrates, the third describes vapour pressure investigation of P-T-X phase equilibria and non-stoichiometry in binary systems. The final paper covers the mechanical

properties of brittle materials, with modern theories and experimental evidence.

Readers who wish to find out more about the metastable phases of such materials as diamond will find the second paper of particular interest. R. Kern of CNRS (France) makes the point that a metastable phase of a substance means that it is quenched and transforms at so slow a rate that nobody sees any tendency to transform during a lifetime. Diamond, silica glass and amorphous semiconductors are strongly metastable rather than unstable. The thesis is developed in the paper. M.O'D.

KOSKOFF, D.E. 1981. *The diamond world.* Harper & Row, New York. pp. viii, 356. Illus. in black-and-white. Price on application.

This covers very similar ground to Timothy Green's *The world of diamonds* (Weidenfeld & Nicolson, 1981) but is longer and more anecdotal. The history of the stone from mine to piece of jewellery is well outlined with useful and interesting side-lights on aspects of the diamond trade, particularly that of New York. There are some very welcome bibliographical notes and the whole book is conceived in a scholarly fashion. M.O'D.

METZ, R. 1985. *Antlitz edler Steine.* (The faith of precious stones.) Prisma Verlag, Gütersloh. pp. 188. Illus. in colour. DM 39.00.

This most beautifully illustrated book first came out in 1964, but this is a new printing with greatly enhanced colour reproduction. It is very competitively priced and can be highly recommended. It gives a simple introduction to the science of minerals with notes on the crystal systems with form and habit and valuable notes on how mineral crystals are formed. Various types of formation are described, including Alpine clefts, pegmatites and hydrothermal deposits. All through the book appropriate full-page-sized colour photographs by Arnold E. Fanck accompany the text; particularly noteworthy for me are those of blue salt crystals from the classic locality of Stassfurt and chalcanthite from Coquimbo.

The book ends with an exciting reproduction of the yellow Tiffany diamond and with a bibliography. Diagrams illustrating the basic symmetry of the crystal systems are provided. Although in German the text should present little difficulty and in any case the pictures are the main reason for buying the book. M.O'D.

SANCHEZ CABELLO, A. 1978. *El interes por las piedras preciosas.* (Interest in precious stones.) Artes Graficas Vicent, Paterna, Valencia. pp. 167. Illus. in black-and-white and in colour. Price on application.

A well illustrated book on diamond with some of the major gemstones, probably written (from the style and the date) for the prospective investor. The illustrations are of very variable quality, some being excellent, others less so. There is a short bibliography. M.O'D.

TABURIAUX, J. 1985. *Pearls, their origin, treatment and identification.* NAG Press, Ipswich. pp. 247. Illus. in black-and-white and in colour. £14.95.

Translated from the French *La perle-et ses secrets* this is one of the very few books to appear on pearl in the past few years. The author is professionally concerned with pearls and has visited a number of the more important areas of pearl recovery.

Much of the book is taken up by anecdotes, charming and instructive in themselves but still without the cited basis in fact that this type of book should provide. Since no references are given and there is no bibliography, the reader has to take much on trust and with the lack of serious literature on pearl for so long, it is a pity that the publishers did not try to get a more solid book. The details on the different pearl fisheries are interesting but we have no way in which to establish their accuracy or topicality without citations. The author is scarcely happier when describing the structure of pearls and is clearly not at home with the scientific basis of pearl testing. Proof-reading by the publishers, if there was any, should have picked up the description of aragonite crystals as triclinic. In this section the choice and size of chapters is capricious to say the least (if this were a stronger book and citations appropriate, such lack of arrangement would be a major drawback to the abstracter. A set of questions, useful in conception, suffers because the answers are so terse that students (who have no other book on which to draw) will take them as gospel; readers looking at the description of orient, in which light is said to be 'distorted' will be excused for feeling apprehensive about the rest of the book.

All this is a pity as the idea behind the book was good and the illustrations adequate (though some appear to have been reproduced from xerox). The lack of bibliography completely vitiates the use of the book as a serious text though the general reader will find it interesting. M.O'D.

Proceedings of the Gemmological Association of Great Britain and Association Notices

OBITUARY

Mr J.G. Shenton, F.G.A. (D.1934), Cheltenham, died on 30th September, 1985.

Mr F.S.H. Tisdall, F.G.A. (D.1936 with Distinction), Birmingham, died on 23rd January, 1986.

GIFTS TO THE ASSOCIATION

The Council of the Association is indebted to the following for their gifts:

Mr John S. Burda, Unionville, Conn., USA, for a piece of peridot and green Transvaal garnet.

Mr R. Holt, London, for an oval emerald.

MEMBERS' MEETINGS

London

On 4th March, 1986, at the Flett Theatre, Geological Museum, Exhibition Road, South Kensington, London S.W.7, Prof. Pieter C. Zwaan, F.G.A., gave an illustrated talk entitled 'Gemstones from the Kataragama area in Sri Lanka'.

Midlands Branch

On 31st January, 1986, at Dr Johnson House, Bull Street, Birmingham, Mrs H. Muller, M.Sc., F.G.A., gave a talk entitled 'Jet and its simulants'.

On 28th February, 1986, at Dr Johnson House, Mr Christopher Cavey, F.G.A., gave a talk entitled 'Some historical aspects of gemstones'.

North West Branch

On 16th January, 1986, at Church House, Hanover Street, Liverpool 1, Dr G. Durant gave a talked entitled 'Lapidaries, leechcraft and lore'.

On 20th February, 1986, at Church House, Mr Rex Bingham gave a talk entitled 'Gold prospecting'.

South Yorkshire and District Branch

On 24th January, 1986, at the Montgomery Hotel, Sheffield, the Annual General Meeting was held, at which Mr J.I. Reynolds, F.G.A., and Miss J.I. Platts, F.G.A., were re-elected Chairman and Secretary respectively.

On 13th February, 1986, at Sheffield City Polytechnic, Mr David Wilkins, F.G.A., gave an illustrated talk entitled 'Rescued from the scrap box'.

On 18th March, 1986, at Sheffield City Polytechnic, Mrs M.S. Carson, Deputy Assay Master at the Sheffield Assay Office, gave an illustrated talk entitled 'The history and work of the Sheffield Assay Office'. The talk was followed by a demonstration of the testing of gold, silver and platinum.

COUNCIL MEETING

At the meeting of the Council held on 22nd January, 1986, at the Royal Automobile Club, 89 Pall Mall, London S.W.1, the business transacted included the election of the following:

Fellowship

Allen, Vivien, Toronto, Ont., Canada. 1985
Bloodworth, Roy N., Wakefield. 1985
Georgopoulou Kyriaki, Marianna, Athens, Greece. 1985
Halton, Elizabeth M., Huddersfield. 1985.
Higham, Joyce R., Southport. 1973
Kittel, Gerhilde A., Toronto, Ont., Canada. 1985
Kothari, Rekha Y., Bombay, India. 1985
Kotila, Brian W., Don Mills, Ont., Canada. 1984
Major, Christine B., St. Ives, NSW, Australia. 1985
Pickrell, Rupert J., Turramurra, NSW, Australia. 1985
Roser, Emilio Ruiz, Valencia, Spain. 1985
Tam, Man Wai, Kowloon, Hong Kong. 1985

Ordinary Membership

Averbrook, Jeffrey I., Everett, Mass., USA.
Chase, Moya, Hong Kong.
Clark, Berenice, Hobart, Tas., Australia.
Grange, Margaret D.J., Hong Kong.

Hulm, Valerie A., Hong Kong.
McArthur, Niven R., Gore, New Zealand.
McCulloch, Georgina K., London.
McSporran-Wirepa, Margaret, Gisborne, New Zealand.
Manning, Gerald E., Middletown, Ohio, USA.
Meister, Adrian, Zollikon, Switzerland.
Moreau, Jean M., Toulon, France.
Rich, Elizabeth, London.
Streit-Stalder, Martha V., São Paulo, Brazil.
Sullivan, Maeve D., Kowloon, Hong Kong.
Trobec, Martin B., Calgary, Alta., Canada.

EDUCATION ADMINISTRATOR DESIGNATE

On 10th February, 1986, Mr David Eagle joined the Gemmological Association of Great Britain and the National Association of Goldsmiths to take up the position of Education Administrator Designate to take over responsibilities for education and training on the retirement of Mr Leslie Fitzgerald, F.G.A.

For twenty years Mr Eagle held senior positions with the Chartered Association of Certified Accountants, mainly in relation to their examinations, and was responsible for the establishment, development and maintenance of an accountancy diploma scheme for non-accountants.

POOL OF SPEAKERS

The Association has formed a 'pool of speakers' from gemmologists around the world who have indicated their willingness to travel to London to give an evening presentation to members of the Association.

This pool contains a large variety of speakers but the Programme Secretary, Tony French, F.G.A., is keen to expand it. Would any gemmologists who have had experience of speaking before large groups of people, and would like their names included in the pool, please contact the Secretary at Saint Dunstan's House giving full details of their topic(s) and the times of the year when they would be available to speak.

THE JOURNAL OF GEMMOLOGY BACK NUMBERS

The Association has a number of back-dated issues of the *Journal* for sale. For a complete list of those available please write to the Gemmological Association, Saint Dunstan's House, Carey Lane, London EC2V 8AB.

Letters to the Editor

From J.R.H. Chisholm, M.A., F.G.A.

Dear Sir,

In his Letter to the Editor (*J. Gemm.*, 1986, 20(1), 70–1) Dr Crowcroft had evidently misunderstood what I wrote in reviewing the 4th edition of Webster's *Gems* as indicating that I believe that de Boismenu (and presumably Hannay too) had succeeded in making synthetic diamonds, which, of course, I don't. What I found (and still find) surprising was that, at a time when Hannay's (*then* apparently successful) attempts to make diamonds made a considerable stir, de Boismenu's attempts (*then* apparently equally successful) appeared to have passed practically unnoticed. In the light of subsequent developments we all now know that neither Hannay's nor de Boismenu's attempts to make diamonds were (or could have been) successful.

I think that in considering such a work as Webster's *Gems* Dr Crowcroft should bear in mind the readers for whom it was written – mainly members of the trade, to far too many of whom 'scientific' and 'academic' are dirty words. There must be a lot more educational work carried out before some members of the trade are ready to accept the rigours of scientific method.

Turning to something quite different, I feel that apologies are due both to the authors and to their readers for two particularly unfortunate pieces of printing in the *Journal* of October last. (1) The arrows indicating the position of the 'hillock' in Figures 2 and 3 on page 665 are misplaced (they had been correctly shown on the originals and were again correctly placed by the author on the final colour proof): to place them correctly, the arrow at the top of Figure 2 should be moved 3.5mm to the left, with the arrow at the side moved up 7mm, and the arrow at the top of Figure 3 should be moved 5.5mm to the right, with the arrow at the side moved up 6mm. (2) The very poor quality of the Map on page 677, in which the coastline together with much other detail has disappeared, is most regrettable, the author having supplied an excellently clear coloured original as well as an equally clear black-and-white copy.

Yours etc.,
J.R.H. Chisholm

10th March, 1986
The Athenaeum, London, S.W.1.

From Peter G. Read, C.Eng, M.I.E.E., M.I.E.R.E., F.G.A.

Dear Sir,

I refer to Peter Crowcroft's recent letter in the Journal[1] in which he claims there is 'a reluctance by traditional gemmologists to accept scientific results when it does not suit them'.

I am neither one of the older generation of traditional gemmologists that Crowcroft implies in his letter, nor do I have an 'emotional' attachment to the Beilby theory of polishing. However, as with my own discipline, I am reluctant to abandon one theory before an alternative has been formulated. The statement in the Crowcroft article[2] that 'There is no reason to believe that these mechanisms (relevant to the polishing of glass and metal surfaces) do not also apply to the polishing of all gemmological material', and the following comment that 'it still remains for a comprehensive theory to be put forward' do not seem to me to be good enough reasons to disregard the Beilby theory. The crux of the argument seems to lie with the conflict of views on the confirmatory work done by Bowden in 1954 and 1958. Indeed, Crowcroft himself seems guilty of ignoring facts which do not suit his argument (NB, the absence under Nomarski interference contrast microscopy of crystallographic features on the polished surfaces of non-diamond gem materials).

I also think it is expecting rather too much for the average gemmologist (who is usually a busy practising jeweller) to 'search out the reference at their nearest University library' in order to convince themselves of the arguments in Crowcroft's article. Very few gemmologists are physicists, and in the relatively new science of gemmology they have to rely on well-reasoned articles printed in the journals of the various gemmological associations to keep themselves informed of new techniques and theories.

My call for experimental evidence of the polishing process in *gemstones* is therefore not unreasonable in this context. When a comprehensive theory of gemmological polishing is eventually proposed, I am sure that despite Crowcroft's pessimism it will be accepted by even the older generation of traditional gemmologists.

Yours etc.,
Peter G. Read

4th March, 1986
68 Forest House, Russell-Cotes Road, Bournemouth, Dorset.

(1) *J. Gemm.*, 1986, 20, 1, 70.
(2) *J. Gemm.*, 1981, XVII, 7, 459.

From Dr Erik G. Lundblad

Dear Sir,

In his article 'A note on the history of diamond synthesis'[1], Dr Nassau describes why he and some other authors do not attribute the priority of diamond synthesis to ASEA in 1953 and why they do not consider the ASEA work to be a significant step in the progress towards a successful synthetic diamond industry. The main reason is that ASEA did not publish at the time claimed any descriptions of the technology to permit independent experimenters to duplicate the process. This is true.

We at ASEA made no public announcement in 1953, mainly because we wanted to improve on the size and quality of the diamonds and also to gain more detailed knowledge of the conditions of diamond formation. We also had evidence to believe that no other teams were engaged in synthesis attempts and that we therefore had time to wait. There we were apparently misled.

Although we recognized the scientific value of the first diamond synthesis we basically considered the commercial prospects to be of greater importance.

How could we now best protect our know-how? We arrived at the conclusion that only the equipment could be patented but not the process due to a number of prior publications. To keep our know-how in house, very tight security measures were applied while work continued on the development of suitable production facilities.

It was too late to change this policy, when some seven years later we realized that GE contrary to our expectations, had filed a patent application of the process, which also was granted, despite heavy opposition, in some important countries.

The 1953 synthesis was made in a complex spherical high-pressure apparatus using a thermite mixture for heating the carbon-iron matrix. Dr Nassau is quite right in describing this process as being so destructive to the high-pressure equipment that it was not worth pursuing. Thermite was used not only for heating but also basically to provide a good isostatic pressure in the very large high-pressure reaction chamber (800 cm^3). In later runs the matrix was also heated by electrical means.

The 'sphere' was patented but never used in production. As early as 1955 a piston-and-cylinder apparatus had been developed. Although the reaction chamber was now much smaller (5 cm^3) the apparatus was more practical for development work. A version of this apparatus developed in steps was subsequently used in the diamond production.

The confirmation of the 1953 synthesis and some of the following ones were made at the Institute of Inorganic Chemistry, University of Stockholm, under the supervision of the late Professor Arne

Ölander, Dean of the Chemical Faculty and also a member of the Royal Swedish Academy of Sciences. Professor Ölander was the only independent consultant that had had a full insight of the work since the 1940s. The X-ray analyses were made and confirmed by two of his assistants. However, only Professor Ölander was informed about the origin of the diamonds.

It is not for me to judge what influence our early work had on the subsequent development of diamond synthesis. Commercial production started in the early 1960s and since then the plant has been one of the world's leading producers of high-grade industrial diamonds and other sophisticated super-high-pressure products.

In 1965 a separate company was founded, Scandiamant AB, jointly owned by ASEA and De Beers, and in 1975 the operations were completely taken over by De Beers. ASEA has not been engaged in diamond synthesis since then, but whatever historians may say we were certainly involved in 1953.

Yours etc.,
Erik G. Lundbald
Vice President, ASEA AB
(former member of the diamond development team in 1953).

20th February, 1986.
ASEA AB, S-721 83 Västerås, Sweden.

(1) *J. Gemm.*, 1985, XIX, 8, 660.

From Mrs E. Stern, F.G.A.

Dear Sir,

I read with amazement the article 'An unusual star diamond' (*J. Gemm.*, 1986, 20, 1, 52) in which S.J.A. Currie states that the star diamond described is thought to be one of only four known specimens.

It is quite true that the phenomenon is rare, but I know of a collection in Germany belonging to Dr U. Kurz-Tesch comprising 56 stones, total weight 46.55ct; the smallest weighing 0.19ct, the largest 2.14ct. They are all transparent with a slight olive-beige hue (raincoat colour), some lighter, some a little darker. The quality of the stars also varies somewhat, but all show distinct asterism. All the stones are octahedra, some without 'points'. It is presumed that the origin is Venezuela.

Yours etc.,
Evelyne Stern

3rd March, 1986.
90 Carlton Avenue East, Wembley Park, Middlesex, HA9 8LY.

From Tony French, F.G.A.

Dear Sir,

I am pleased to be able to clarify a small doubt expressed by Mr S.J.A. Currie in the first edition of your superb new journal, regarding the star diamond[1].

Alan Fleming willed his personal collection of gems, minerals and carvings to the Auckland Museum in New Zealand. The star diamond was not, however, part of his collection.

As the person responsible to his executors in New Zealand for the disposal of his estate in this country, I knew Alan wanted this crystal to go to a museum. Having checked that the crystal was still in his New Zealand stock, I asked his executors whether they would agree to it being added to his collection in the Museum. They have since written to me confirming that this has been done.

I am sure Alan would have been delighted to know that Mr Currie's photograph of this crystal adorned the cover of the first edition of the new journal.

Yours etc.,
Tony French

10th February, 1986.
82 Brookley Road, Brockenhurst, Hants. SO4 7RA.

(1) *J. Gemm.*, 20, 1, 52.

From Dr A. Banerjee and Dip. Min., H.-W. Schrader, F.G.A.

Dear Sir,

We are concerned at the less than objective style of the letter from G. Bosshart and K. Schmetzer, published in the January 1986 number of this *Journal*[1]. As a response to our paper 'Spectrophotometric measurements of faceted rubies'[2] we should have expected and hoped for a more critical discussion.

In the articles quoted by us (Schmetzer and Bank, 1980[3] and Bosshart, 1982[4]) the authors only describe that they have investigated '154 natural sapphire crystals' and 'ninety-four rubies' respectively. No specific information was given that they used faceted gemstones. Therefore we wrote: 'as most of the spectral measurements are carried out on thin polished platelets, the results achieved cannot be easily reproduced in the case of faceted gemstones'. We tried to introduce a general additional technique. It was neither our intention to describe how to solve minor problems on orientation

or polarization of the samples, nor to find a method of disctinction between natural and synthetic rubies.

We recognize the 'disadvantages' of methylene iodide and would refer Mr Bosshart and Dr Schmetzer to the Gems and Gemology abstract[5] where C.M. Stockton comments 'As the authors point out, methylene iodide absorbs virtually all light below about 440nm, but very clean spectral diagrams are obtained and illustrated for the rest of the visible range. Thus, the immersion method is shown to have distinct advantages'.

We wish to express thanks to the Editor of the *Journal of Gemmology* for allowing us space to publish our ideas.

Yours etc.,
Arun Banerjee
Hans-Werner Schrader

20th February, 1986.
Institut für Edelsteinforschung, Institut für Geowissenschaften, Johannes Gutenburg-Universität, Mainz, West Germany.

(1) *J. Gemm.*, 1986, 20, 7, 71.
(2) *J. Gemm.*, 1985, XIX, 6, 489–93.
(3) *Neues Jahrbuch für Mineralogie*, 139, 2, 216–25.
(4) *J. Gemm.*, XVIII, 2, 145–60.
(5) *Gems Gemol.*, 1985, XXI, 3, 182.

From Mr D.J. Callaghan, F.G.A.
Gemmological Association of Great Britain

Dear Sir,

THE BASIL ANDERSON SPECTROPHOTOMETER APPEAL.

I am happy to advise you that the target figure of £25,000 for the Spectrophotometer Appeal launched in the name of the late Basil Anderson in November 1984, has now been achieved. I shall be grateful if you will allow me to express my thanks on behalf of the Council of the Gemmological Association of Great Britain to all those people throughout the world who have contributed to the Appeal.

A supplementary list to that issued in *J. Gemm.*, XIX(8), 739–42, is being compiled, and I would be pleased if it could be published in a future issue of the *Journal*.

Yours etc.,
D.J. Callaghan
Chairman.

19th March, 1986.
London.

CORRIGENDUM

In *J. Gemm.*, 20, 1, p.35, the radiographs for Figures 1 and 2 were transposed.

GEMMOLOGICAL ASSOCIATION OF GREAT BRITAIN

The Arms and Crest of the Association, conferred by a grant of Arms made by the Kings of Arms under royal authority. The cross is a variation of that in the Arms of the National Association of Goldsmiths of Great Britain and Ireland. In the middle is a gold jewelled book representing the study of gemmology and the examination work of the Association. Above it is a top plan of a rose-cut diamond inside a ring, suggesting the scrutiny of gems by magnification under a lens. The lozenges represent uncut octahedra and the gem-set ring indicates the use of gems in ornamentation. The lynx of the crest at the top was credited, in ancient times, with being able to see through opaque substances. He represents the lapidary and the student scrutinizing every aspect of gemmology. In the paws is one of the oldest heraldic emblems, an escarbuncle, to represent a very brilliant jewel, usually a ruby. The radiating arms suggest light diffused by the escarbuncle and their tips are shown as jewels representing the colours of the spectrum.

Historical Note

The Gemmological Association of Great Britain was originally founded in 1908 as the Education Committee of the National Association of Goldsmiths and reconstituted in 1931 as the Gemmological Association. Its name was extended to Gemmological Association of Great Britain in 1938, and finally in 1944 it was incorporated in that name under the Companies Acts as a company limited by guarantee (registered in England, no. 433063).

Affiliated Associations are the Gemmological Association of Australia, the Canadian Gemmological Association, the Gem and Mineral Society of Zimbabwe, the Gemmological Association of Hong Kong, the Gemmological Association of South Africa and the Singapore Gemologist Society.

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Notes for Contributors

The Editors are glad to consider original articles shedding new light on subjects of gemmological interest for publication in the *Journal*. Articles are not normally accepted which have already been published elsewhere in English, and an article is accepted only on the understanding that (1) full information as to any previous publication (whether in English or another language) has been given, (2) it is not under consideration for publication elsewhere and (3) it will not be published elsewhere without the consent of the Editors.

Papers should be submitted in duplicate on A4 paper. They should be typed with double line spacing with ample margins of at least 25mm all round. The title should be as brief as is consistent with clear indication of the content of the paper. It should be followed by the names (with initials) of the authors and by their addresses. A short abstract of 50–100 words should be provided. Papers may be of any length, but long papers of more than 10 000 words (unless capable of division into parts or of exceptional importance) are unlikely to be acceptable, whereas a short paper of 400–500 words may achieve early publication.

Twenty five copies of individual papers are provided on request free of charge; additional copies may be supplied, but they must be ordered at first proof stage or earlier.

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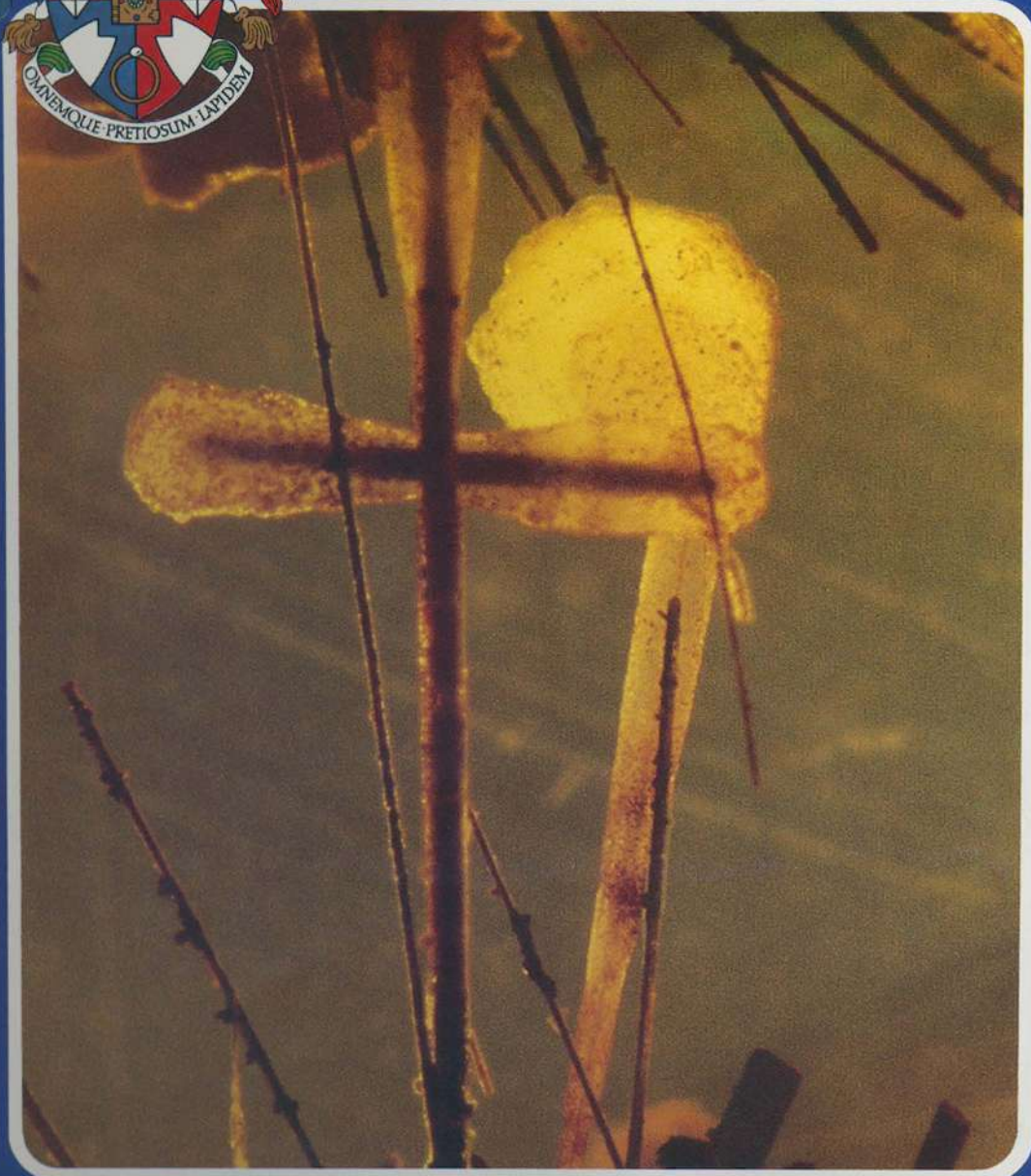

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Cover Picture

Protogenetic crystals of altered hornblende were first coated with an initial layer of opal and then later were completely engulfed by this Mexican opal. Transmitted and oblique illumination. 45x. See 'Inclusions in opal', pp. 139–44.

Photograph from 'Photoatlas of inclusions in gemstones'.

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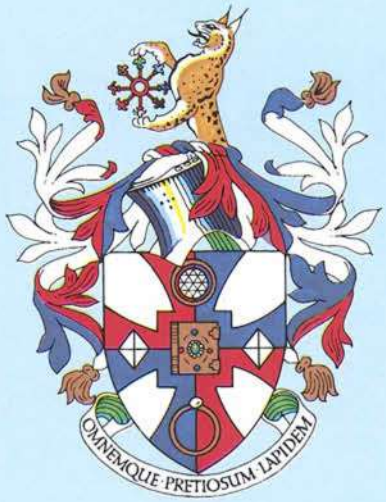

NEW GEMMOLOGY COURSE

The Gemmological Association of Great Britain is proud to announce that from September 1986 it is introducing a new home study course in gemmology. This will prepare students for the examinations leading to the award of the Association's Fellowship Diploma.

The new course is radically different from other gemmological courses, and presents a new, friendly, step-by-step approach to learning that should be welcomed by students all over the world.

For further details, contact the Education Department, Gemmological Association of Great Britain, Saint Dunstan's House, Carey Lane, London, EC2V 8AB. Tel: 01-726 4374. Cables: GEMINST.

The long-awaited new book about inclusions in gemstones by Dr E. Gübelin and Mr J.I. Koivula will appear on the market this Autumn under the title of 'Photoatlas of inclusions in gemstones'† and we are delighted to learn that this book is dedicated to Basil W. Anderson.

Dr E. Gübelin has been successful in securing the co-operation of Professor H.O.A. Meyer and Dr E. Roedder in the United States, and of Professor Dr H.A. Stalder in Switzerland.

The volume resulting from this collaboration reveals a spectacular triumph of colour photomicrography, and the work is obviously destined to become a classic in the field. We are therefore pleased to publish a foretaste of this work in the form of the chapter on inclusions in opal. It is especially appropriate to include it here, since the subject has not been presented in the Journal *before.*

We congratulate Dr Gübelin and his team on their great achievement.

The Editor

Inclusions in opal

Dr Edward Gübelin, C.G., F.G.A. and John I. Koivula, C.G., F.G.A.***

*Ratna Mahal, Benzeholzstrasse 11, CH-6045 Meggen LU, Switzerland
**Gemological Institute of America, Santa Monica, CA 90406, USA

Precious opal, prized for its spectral play of colour, is commonly described as an amorphous silica gel. But the amorphous state of opal's structure is questionable. It is now known that opal is structurally composed of a more-or-less orderly, close-packed arrangement of submicroscopic spheres of two crystalline minerals – cristobalite and tridymite. In Mexican opal, which formed at higher temperatures than its Australian cousin, the spheres consist rather of cristobalite. In the Australian opal they are more commonly tridymite. The size of these spheres and the interstitial spaces between them dictate, through the diffraction of white light, the play of colours an opal will display. Formed in sedimentary or volcanic rocks, through the invasion of low-temperature silica-bearing solutions, opal is essentially composed of silica, with variable water of hydration. Opals may, in time, loose their water and dehydrate to chalcedony. A small percentage of additional elements such as aluminium, iron, calcium, magnesium and sodium in the form of submicroscopic mineral grains, may also be present.

The body colour of precious opals ranges from near colourless to milky-white, yellow, orange, red, grey to nearly black, and brown. As rapturously enchanting as the contrasts of the gay kaleidoscopy and the satisfying harmony of the lively colour-play, is the contemplation of the manifold unique inclusions – mainly in opal from Mexico. This is especially so since the great majority of opals found all over the world either have no inclusions or these cannot be seen because the host gem is too opaque.

The brownish opal termed hyalite, found in Mexico, contains white spherulites as large as one millimetre in diameter. This hyalite is called iris opal when it displays an iridescence resulting from a finely layered internal botryoidal structure. Brazilian white opals may contain tiny dark grey octahedra of the nickel iron sulphide, bravoite. Fine particles of sand-like matrix and an uneven distribution of body-colour are noted in some Australian stones. As a result of their translucent to clear transparent opal-medium, one can see that the fire opals found in Mexico are alive with inclusions. Needles of hornblende, which once protruded from the rhyolite matrix, are often trapped. Quartz, goethite and even two- and three-phase inclusions are but a few of the inclusions identified. The following richly varying photomicrographs of opal inclusions offer an impressive show of their unsuspected beauty and wide variety.

[*Manuscript received 31 March 1986.*]

†Gübelin, E., Koivula, J.I. 1986. *Photoatlas of inclusions in gemstones.* ABC Edition, Zurich.

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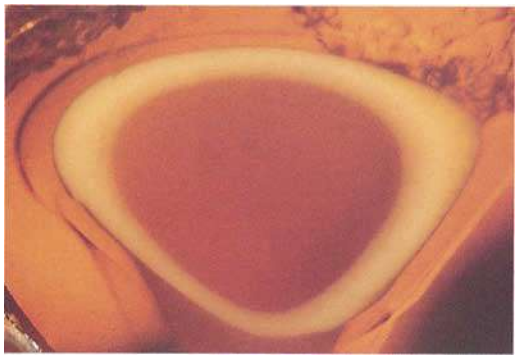

Fig. 1. Microscopic image showing the *flow-structure* in an opal from Querétaro, Mexico. Although usually present to some degree, flow zones are rarely as pronounced as here. Transmitted and oblique illumination. 15x.

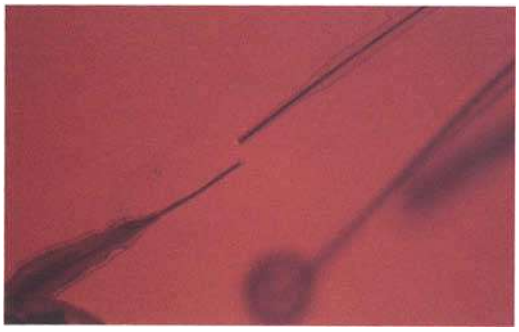

Fig. 2. The flowing motion of the silica-gel which produced this Mexican opal, had enough viscosity and force to break this *needle-like crystal* inclusion. Transmitted light. 40x.

Fig. 3. A confusing mass of *acicular crystals of hornblende*, all displaying an *opal coating*. The entire grouping now resides in this Mexican opal as a protogenetic jumble. Transmitted and oblique illumination. 20x.

Fig. 4. Here, it is clearly apparent how, in the first phase of solidification, a 'sock' of *white opal* enveloped a *goethite needle* before the flaming Mexican fire opal enclosed this primary formation with a secondary growth-phase. Darkfield with overhead lighting. 20x.

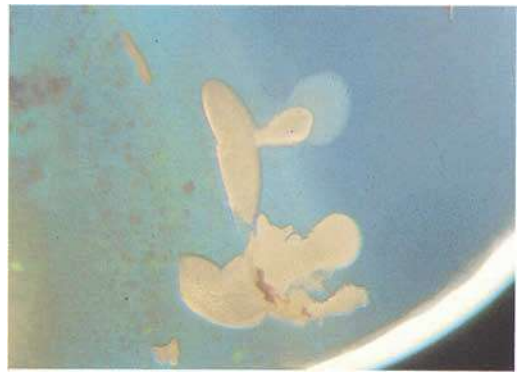

Fig. 5. Botryoidal shapes, like these in blue opal from Mexico, are preferred by *chalcedony inclusions*. Darkfield illumination. 18x.

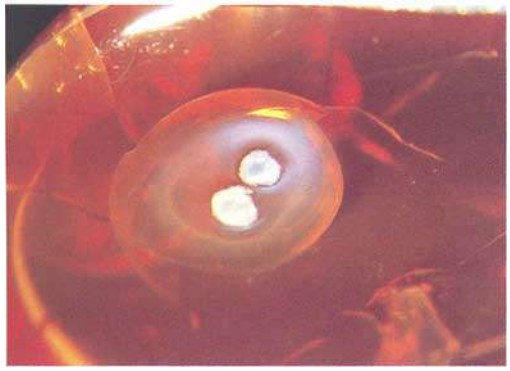

Fig. 6. A fire opal from Querétaro, Mexico, has equipped itself with an unmistakable identity-mark with the help of this pair of white *chalcedony* 'eyes'. Darkfield with overhead illumination. 10x.

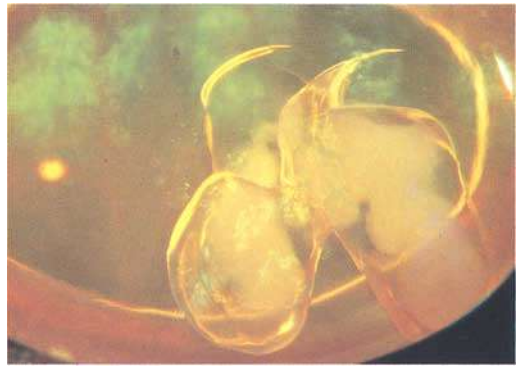

Fig. 7. *Chalcedony inclusions*, commonly resident in Mexican opal, often surround themselves with curved fissures as a result of internal tension. Darkfield illumination. 20x.

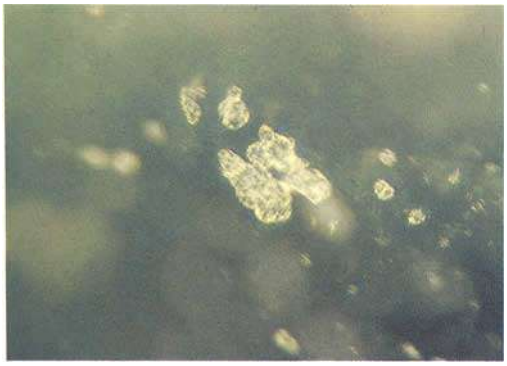

Fig. 8. Looking like glass, small aggregates of tiny plate-like *cristobalite crystallites* hover in a water opal from Querétaro, Mexico. Darkfield illumination. 150x.

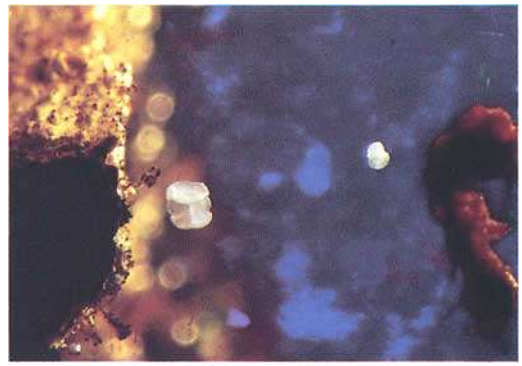

Fig. 9. Translucent white *cristobalite* inclusions in a Mexican opal, are suspended against a background of a deep blue/orange/red play of colour. Oblique illumination. 20x.

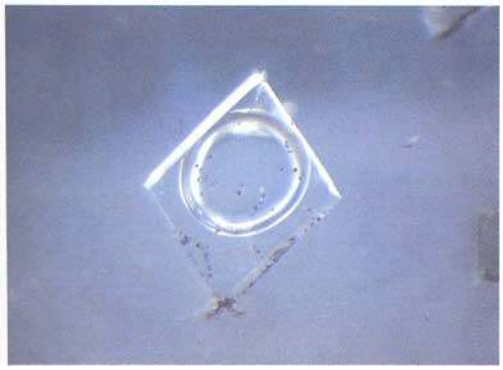

Fig. 10. This *three-phase inclusion* in a Mexican opal now occupies the area once filled by a rhombohedral crystal of a mineral such as calcite or dolomite. A volume of liquid, a large gas bubble and numerous small red solid phases now fill the void. Darkfield and oblique illumination. 35x.

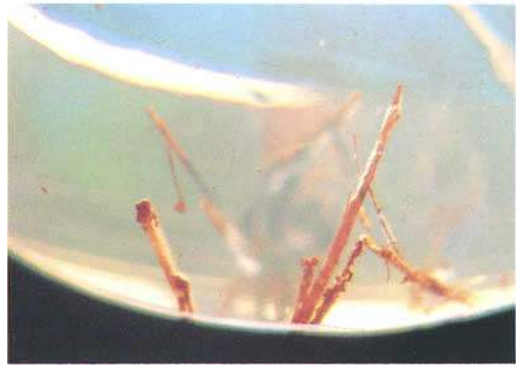

Fig. 11. Limonitized *goethite needles* once reached from the walls of the cavity in which this Mexican water opal solidified, thereby being embraced as protogenetic inclusions. Dark-field illumination. 20x.

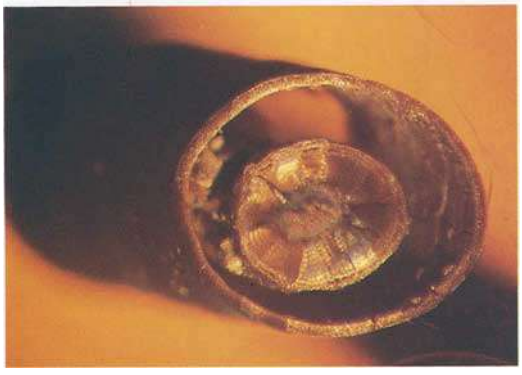

Fig. 12. Earthy-brown inclusions in a Mexican opal, of the iron hydroxide *goethite*, illustrate the 'tree-ring' form produced by the repeated cycles of opal deposition on pre-existing crystal inclusions. Transmitted and oblique illumination. 50x.

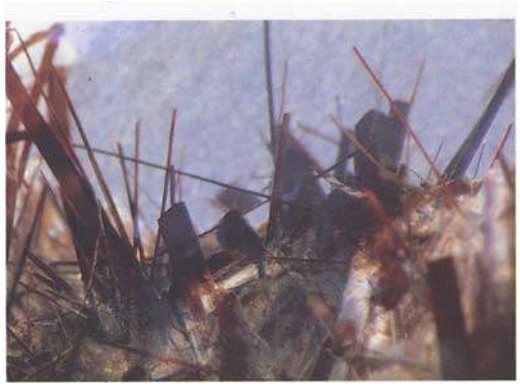

Fig. 13. A jumble of acicular crystals and thick black *hornblende crystals* projecting from the rhyolite matrix into the Mexican opal. Oblique illumination. 30x.

Fig. 14. A green-black *hornblende crystal* is covered with a *crust of limonite*. Note the thickness of the limonite layer at the top, near the fracture. Darkfield illumination. 34x.

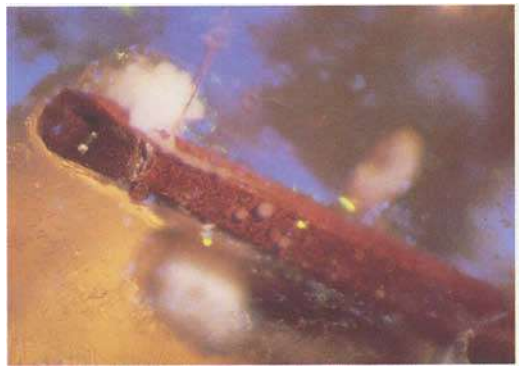

Fig. 15. Looking like billowy clouds, the dull white opaque masses associated with this brown *pseudomorph of limonite* after hornblende are inclusions of kaolinite, a clay mineral, in this Mexican opal. Oblique illumination. 40x.

Fig. 16. In a Mexican water opal, an unusual combination has occurred through the intergrowth of *hornblende-fragments and kaolinite-platelets with some rhyolite-matrix*. Darkfield illumination. 34x.

Fig. 17. *Limonite pseudomorphs* after hornblende, create a speleological image of stalagmites in a Mexican sherry opal. Darkfield with side illumination. 8x.

Fig. 18. A yellow opal from Tanzania is charmingly enlivened by numerous dendrites of *manganese oxide*, varying in size. Transmitted illumination. 25x.

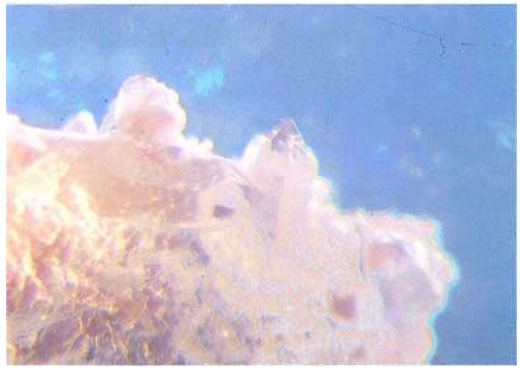

Fig. 19. Clear, transparent *pinnacles of rock-crystal* protrude from a crude mass of *kaolinite* in a Mexican blue opal. Darkfield. 50x.

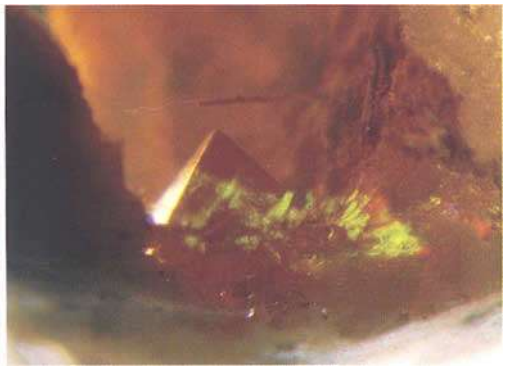

Fig. 20. A limonite-coated *rock-crystal peak* with flaming green colour-play, conjures up an ancient-Egyptian scene in a fire opal from Querétaro, Mexico. Darkfield with side illumination. 12x.

Fig. 21. Premising Nature has sketched the Pyramids of Gizeh, long before the Pharoahs of the IVth Dynasty erected them: peaks of *rock-crystal* coated with limonite, and *limonite rods*, pierce a Mexican fire opal from the rhyolite matrix. The reflection offf the light-source gives the impression of a rising moon behind the pyramids. Darkfield with side illumination. 12x.

Fig. 22. An epigenetic pattern was produced when *iron-rich fluids* invaded the *fracture* in this Mexican opal and dried out. Transmitted light. 40x.

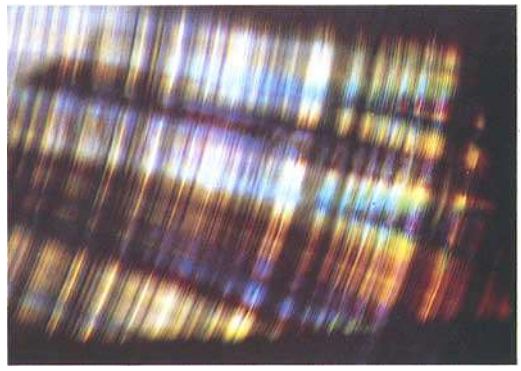

Fig. 23. The botryoidal finely *laminated structure* found in Mexican hyalite opals behaves as a diffraction grating and gives rise to bright interference colours. Darkfield illumination. 45x.

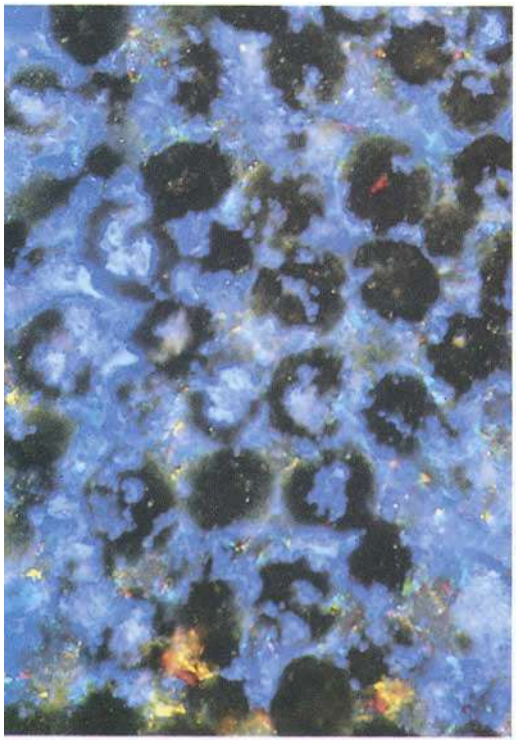

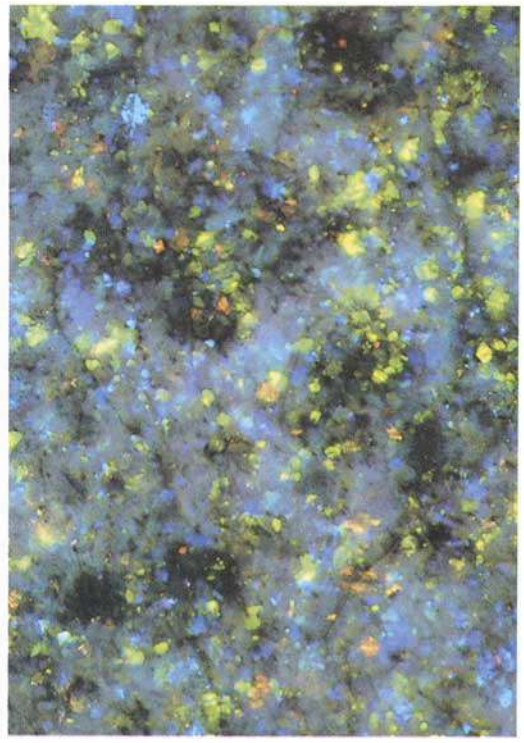

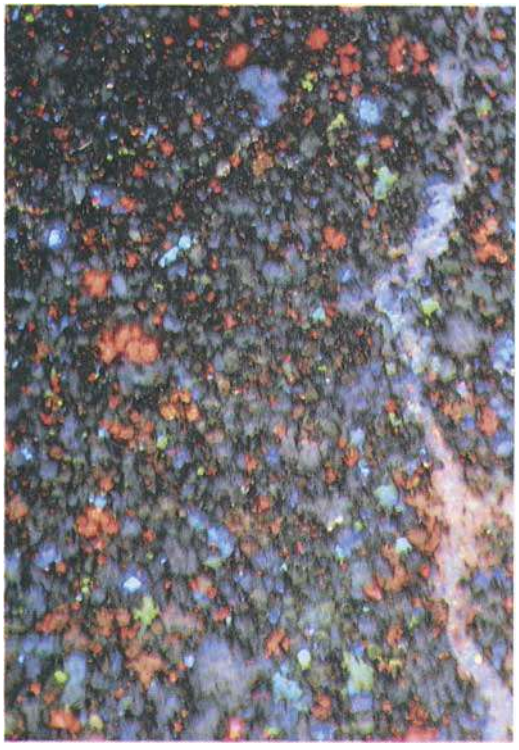

Fig. 24. (Top left.) The characteristic *circular structure* of Australian oolitic opal should not be confused with treated opals. Oblique illumination. 20x.

Fig. 25. (Top right.) The *black cloud-like patches* of subsurface soot characteristic of *smoke-treated* Mexican opals, are visible in this photomicrograph. Oblique illumination. 30x.

Fig. 26. (Left.) Porous Australian opals *treated* with sugar and sulphuric acid to give them a black body-colour. Under the microscope, such 'sugar-treated' opals have a *pepper-like* character. Oblique illumination. 30x.

Notes from the Laboratory – 7

Kenneth Scarratt, F.G.A.

The Gem Testing Laboratory of Great Britain,
27 Greville Street, London, EC1N 8SU

It has been said that as the Author has written 'Notes from the Laboratory' from what appear to be three different laboratories over the last five years, some explanation is needed.

It is not, as might be thought, that the author likes to flit from one laboratory to another, indeed he has remained in just one. It is the Laboratory's name that has changed, firstly from 'The Gem Testing Laboratory of the London Chamber of Commerce and Industry' and then to 'The British Gem Testing Laboratory of the London Chamber of Commerce and Industry'. The Laboratory is now known as 'The Gem Testing Laboratory of Great Britain'.

This latest change, however, has been a little more than just a change in name. The Laboratory is now no longer a part of the London Chamber of Commerce. It is an entity on its own and is administered by a committee made up from the Laboratory's members, and representatives from the Gemmological Association of Great Britain, the National Association of Goldsmiths and the British Jewellers Association. It is financed by its members and the above Associations, as well as the London Diamond Bourse, the London Diamond Club and others. The Laboratory, initially directed by B.W. Anderson from 1925 and then by A.E. Farn from 1972 to 1981 has now entered a new era in which the Associations have more influence over its operations.

* * *

Whilst reading a newly published book on pearls[1] we noted a half page description of one of the most intriguing of all 'pearls', the 'Southern Cross'. This reminded us of our examination in 1981 of a group of pearls which were reputed to be the 'Southern Cross'.

The Book of the Pearl by Kunz and Stevenson[2] describes the 'Southern Cross' as '. . . nine attached pearls forming a Roman Cross about one and one half inches in length, seven pearls constituting the shaft or standard, while the arms are formed by one pearl on each side of the second one from the upper end'.

The group of pearls examined in 1981 meets with this description (Figures 1a,1b). Its length is approximately 37.2 mm, the width is approximately 18.3 mm and its weight is 24.79 ct.

The 'Southern Cross' is said to have been found in one piece by a boy named Clark, but before he could hand it over to his employer, James Kelly, it had broken into three distinct pieces.

Kunz and Stevenson further credit Henry Taunton as making a 'positive statement' that 'there were only eight pearls in the cluster when it was sold by Kelly in 1883, and to make it resemble a well-proportioned cross – the right arm being absent – another pearl of suitable size and shape was subsequently secured at Cossack and attached in the proper place to the others, which in the meantime, had been re-fastened together by diamond cement, thus making three artificial joints . . . .'

If the group of pearls examined in 1981 is the 'Southern Cross', whilst all the pearls forming the cross are natural, there are now only two natural joints between the pearls (A and B in Figure 2). Joint 'A' has been strengthened by the addition of some adhesive on one side and all the remaining joints are now artificial.

The internal natural structures in the individual pearls are fine, and therefore the detail in the radiograph of this group will not reproduce well. The radiograph in Figure 3 displays the junctions between the pearls.

* * *

At least to the unaided eye, glass can provide one of the most convincing imitations of jadeite. In the past this has been particularly true of glass which has a mottled green colouring and a profusion of spherical bubbles. This type was often used for bead necklaces.

Another glass which is proving to be a popular substitute for jadeite is the devitrified type. This material can be made to resemble jadeite closely in both colour and general appearance. When cabochons are set in rings they can be very convincing.

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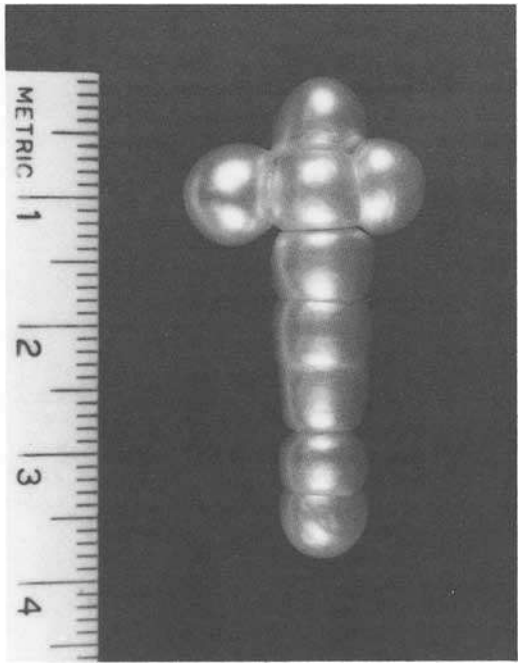

Fig. 1. (a) Group of natural pearls said to be the 'Southern Cross' (front).

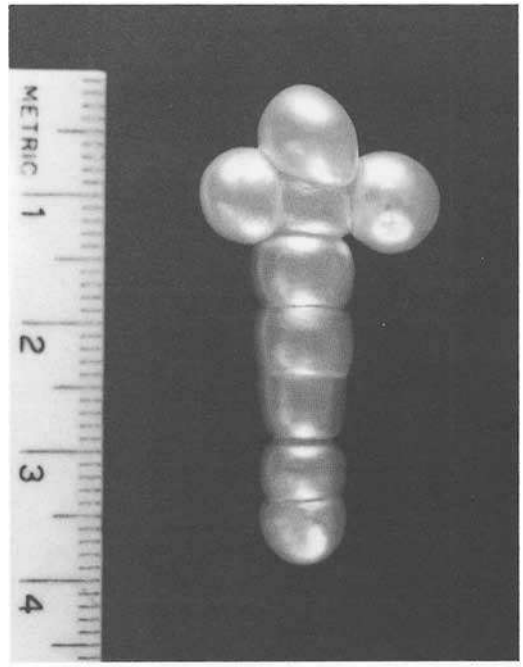

(b) Group of natural pearls said to be the 'Southern Cross' (back).

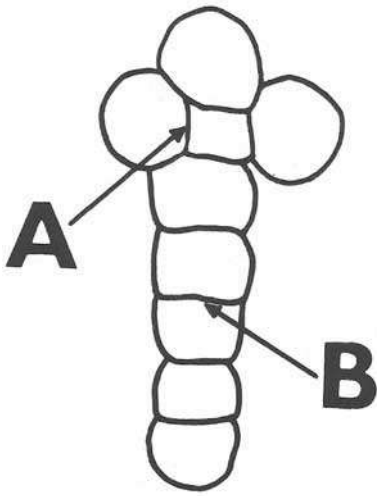

Fig. 2. Diagram of 'Southern Cross' (see Figure 1b) indicating the remaining natural junctions between the pearls (A and B). All the remaining joints are artificial.

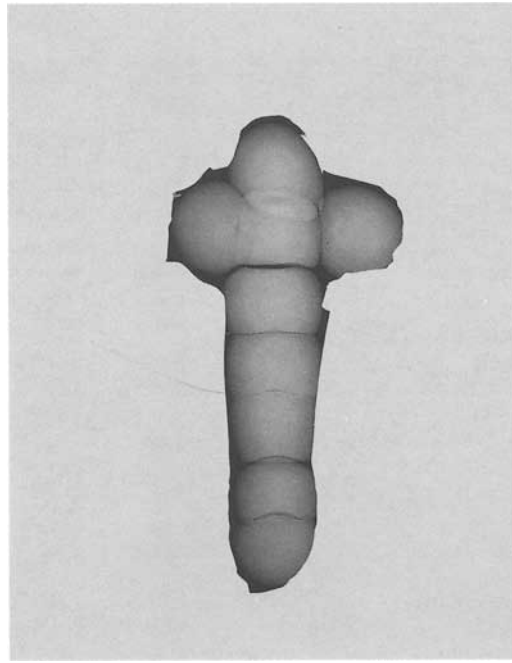

Fig. 3. Radiograph of the 'Southern Cross' displaying the junctions between the pearls.

The stones set in the ring in Figure 4 are examples of how plausible this material can be, particularly when seen in the 'correct' setting. Both cabochons are glass with RIs in the region of 1.52 and fibrous inclusions (Figure 5).

Fig. 4. Two pieces of devitrified green glass, cut as drop-shaped cabochons and set in a ring. The setting is similar to that commonly used for jadeite.

Fig. 5. Fibrous inclusions in the devitrified glass of Figure 4.

* * *

The introduction of the cultured pearl could have spelled disaster for the economies of the Gulf States which were reliant upon the pearl as one of their main sources of income. However, the discovery of oil and gas relegated the pearl, in terms of proportion of national income, to a much lower level, and therefore all was saved.

Even with this wealth, the old pearling nations have not altogether forgotten the traditions associated with producing some of the world's finest pearls. The pearling families have not deserted the pearl, and much of the trading flow in natural pearls is now in the opposite direction. The pearls that were fished in the Gulf and sold on the European markets are now returning to the Gulf.

Amongst the modern buildings which are the Bahrain of today, merchants can still be found trading in the age old way (Figure 6) and even a humble rubbish skip makes a passer-by aware of the country's history (Figure 7). Bahrain was one of the greatest pearling centres and is still a centre for natural pearls" it is said to be illegal to import a cultured pearl.

In about 1915, Qatar, a close neighbour of Bahrain and another of the great pearling nations, had 350 pearling boats based in its main town Doha. At that time Doha was a town of some 12 000 people with a *suq* of about 50 shops and a Ruler's palace. There were also 60 sea-going trading boats running to Oman and nearly 100 fishing boats.

This may seem a little out of place in 'Notes from the Laboratory', but many gemmologists make the journey to Sri Lanka or Thailand at least once in their lives, if not on a regular basis. Sadly only a few have taken the opportunity to break their flights either in Bahrain or Qatar, or any of the other Gulf States which are regular stops for most aircraft flying between the UK and the Far East.

There is much of gemmological interest in both Bahrain and Qatar. The National Museum in Qatar boasts an excellent display of the many qualities of natural pearl (Figure 8) and pearl diving and trading equipment (Figures 9 and 10). In the same museum a large aquarium brings home to the visitor the many natural dangers faced by the pearl divers each time they entered the Gulf waters.

Simply, this 'note' is a reminder to the organizers of gemmological tours which pass through the Gulf, and to the regular traveller, that a large slice of gemmological history evolved in the area.

* * *

A green diamond brought into the Laboratory for testing (Figure 11) was found to be radioactive, and it was possible to detect this radioactivity through a sheet of lead 0.1 mm in thickness. Monitor measurements indicated that the degree of radioactivity in the pavilion area was much greater than that in the crown area.

Whilst still in its setting the stone was placed on its side, as in Figure 12, on a piece of X-ray film for 118 hours. This produced the autoradiograph in Figure 13.

As the stone aroused a little curiosity the client was asked if he would give his permission for it to be unset. This was necessary in order to obtain a clearer view of its pavilion surface and to record its spectrum.

Fig. 6. A pearl merchant in Bahrain with his natural pearls and the tools of his trade.

Fig. 7. Insignia on rubbish skips in Bahrain display the importance the pearling industry has had for the country.

Fig. 8. Yakkah or second quality natural pearls on display at the museum in Doha.

Fig. 9. Pearl diving equipment on display at the museum in Doha.

Fig. 10. Pearl merchants equipment on display in the museum in Doha.

Fig. 11. Radioactive green diamond set in a ring.

Fig. 12. Radioactive green diamond set in ring (as Figure 11), side view. Refer to Figure 13.

The spectrum displayed a weak GR1 band (Figure 14), and unlike a previously reported stone[3], which had brown diamond characteristics, this appeared to be a Cape series stone.

When examined with a microscope, it could be seen that the green colour was located at and just below the surface of the pavilion facets. There was no green coloration in the crown facets. The colour in the pavilion facets was blotchy with many pin-point sized, and some slightly larger, near colourless areas (Figure 15). In addition there were many small deep green marks, which varied in size and shape, in the same area.

It would seem that this diamond had been treated on the pavilion only and not on the crown. This was confirmed by two further autoradiographs, the first of which (Figure 16) was taken with the table facet down on X-ray film. Here it can be seen that there has barely been any exposure of the film in the area which was in contact with, or close to, the crown of the stone. The second autoradiograph (Figure 17) was taken with one of the pavilion facets resting on the film. In comparing Figures 16 and 17 it should be noted that the exposure time for Figure 16 is 16½ hours whilst that used for Figure 17 is only 30 minutes.

With the stone in the same position, a similar and only slightly weaker exposure to that in Figure 17 was obtained in only 15 minutes.

A close examination of Figure 17 will reveal a number of intense black spots which appear to be associated with the deep green marks on the surface of the stone.

The stone measured 8.23–8.50 × 4.52 mm and weighed 1.91 ct.

* * *

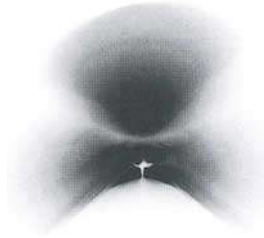

Fig. 13. Autoradiograph produced by the green diamond of Figure 11 when positioned on X-ray film in the manner of Figure 12 for a period of 118 hours.

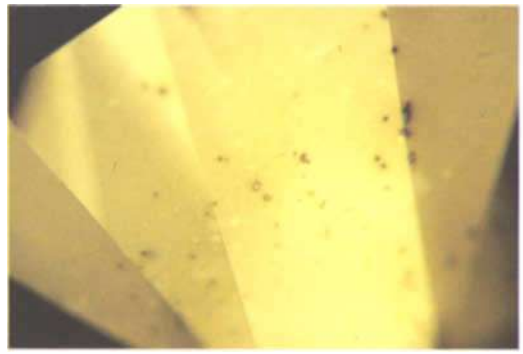

Fig. 15. The blotchy coloration on the pavilion facets of the radioactive diamond in Figure 11. Note also the intense green spots.

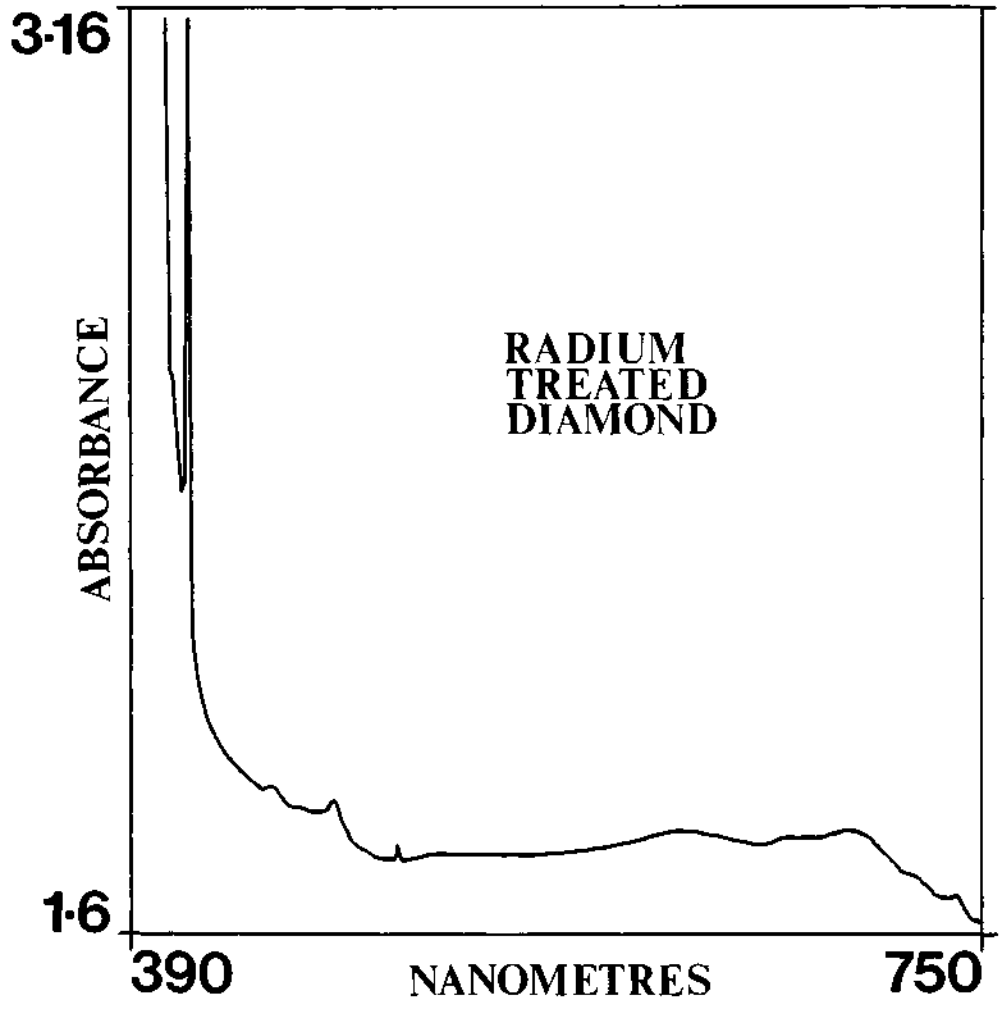

Fig. 14. The absorption curve of the radioactive green diamond in Figure 11 displaying a Cape series spectrum and a weak GR1 band. The curve was obtained using a Pye Unicam PU8800/03 UV/visible spectrophotometer (Basil Anderson model) with a speed of 0.5 nm/s and a bandwidth of 0.5 nm at approximately 120 K.

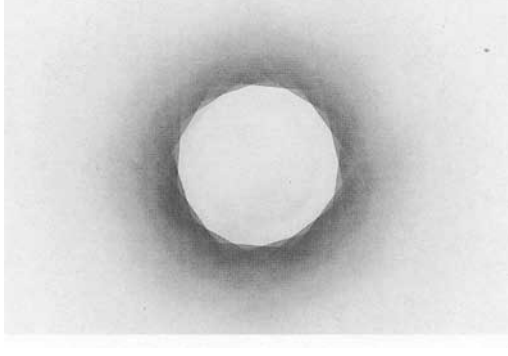

Fig. 16. Autoradiograph produced by the green diamond in Figure 11 when positioned with its table in contact with X-ray film. Exposure time 16½ hours.

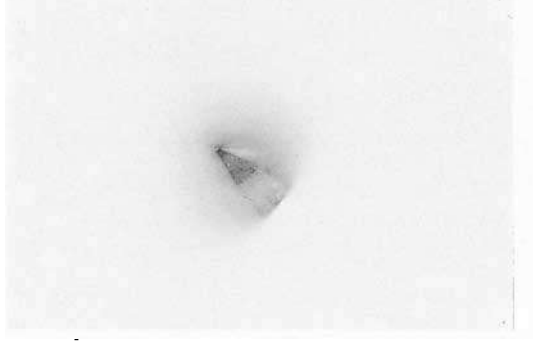

Fig. 17. Autoradiograph produced by the green diamond in Figure 11 when positioned with a pavilion facet in contact with X-ray film. Exposure time 30 minutes.

A recent gift to the Laboratory collection is seen in Figure 18. It is a fibrolite (sillimanite), the identity of which has been confirmed by X-ray powder diffraction.

The specimen is a 1.48 ct slice taken from a light yellowish water-worn crystal. The SG as determined by hydrostatic weighing, is 3.30 and the RIs are 1.660–1.682. Whilst the RI readings as determined on a Rayner Dialdex refractometer appear to be biaxial positive the difference between α and β is so small as to make this determination difficult.

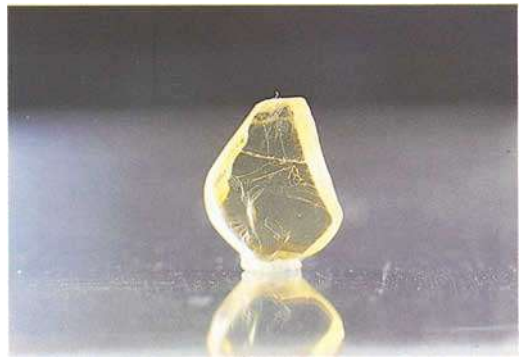

Fig. 18. A 1.48 ct fibrolite specimen given to the Laboratory collection.

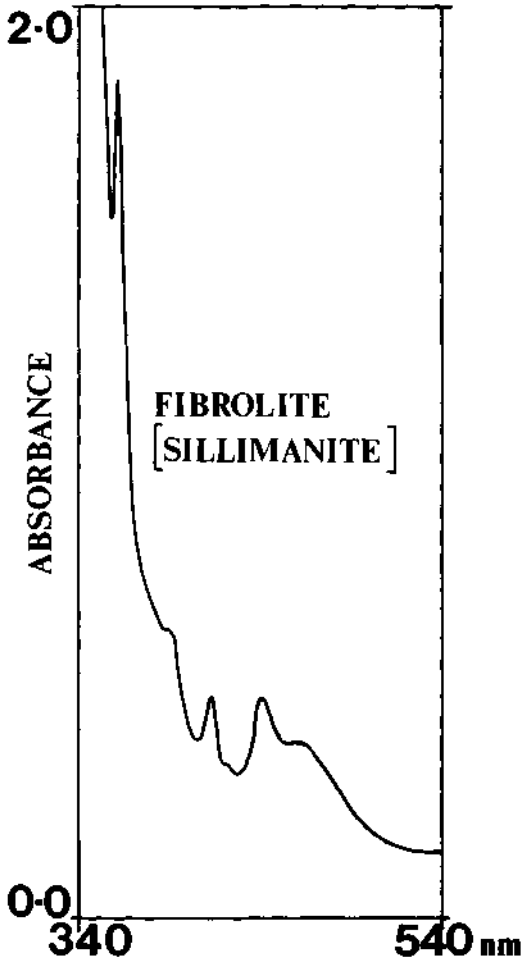

Fig. 19. The absorption curve of the fibrolite in Figure 18. The curve was obtained using a Pye Unicam PU8800/03 UV/visible spectrophotometer (Basil Anderson model) with a speed of 0.5 nm/s and a bandwidth of 0.5 nm at room temperature. The path length was 2.39 mm. The main peaks in the curve are at 460.2, 440.8, 412.8, 389 and 360.8 nm.

Under both long-wave and short-wave ultraviolet light the stone fluoresces a weak orange. This fluorescence is stronger under long-wave ultraviolet than short-wave.

The pleochroism is strong, the colours being yellow, light yellow and colourless. The absorption spectrum is shown in Figure 19 and the main absorption peaks are at 460.2, 440.8, 412.8, 389 and 360.8 nm.

* * *

We are fortunate in that at the same time as our benefactor donated the fibrolite to the Laboratory collection, he also gave us the opportunity to examine an interesting specimen of taaffeite.

The stone, which is a bluish, smoky grey colour in daylight, is shown photographed in artificial light in Figure 20. It weighs 0.70 ct and measures 5.19 × 4.68 × 2.78 mm.

Fig. 20. Four examples of taaffeite. (i) A round faceted stone weighing 0.86 ct from the British Museum (Natural History) collection (BM 1967.309). (ii) A 0.70 ct stone belonging to Mark L. Jones, F.G.A. (iii) Rough material weighing 2.78 cts from the BM (NH) collection (BM 1979.417). (iv) The 0.56 ct cushion-shaped, type specimen, owned by R.K. Mitchell, F.G.A. and on loan to the Geological Museum.

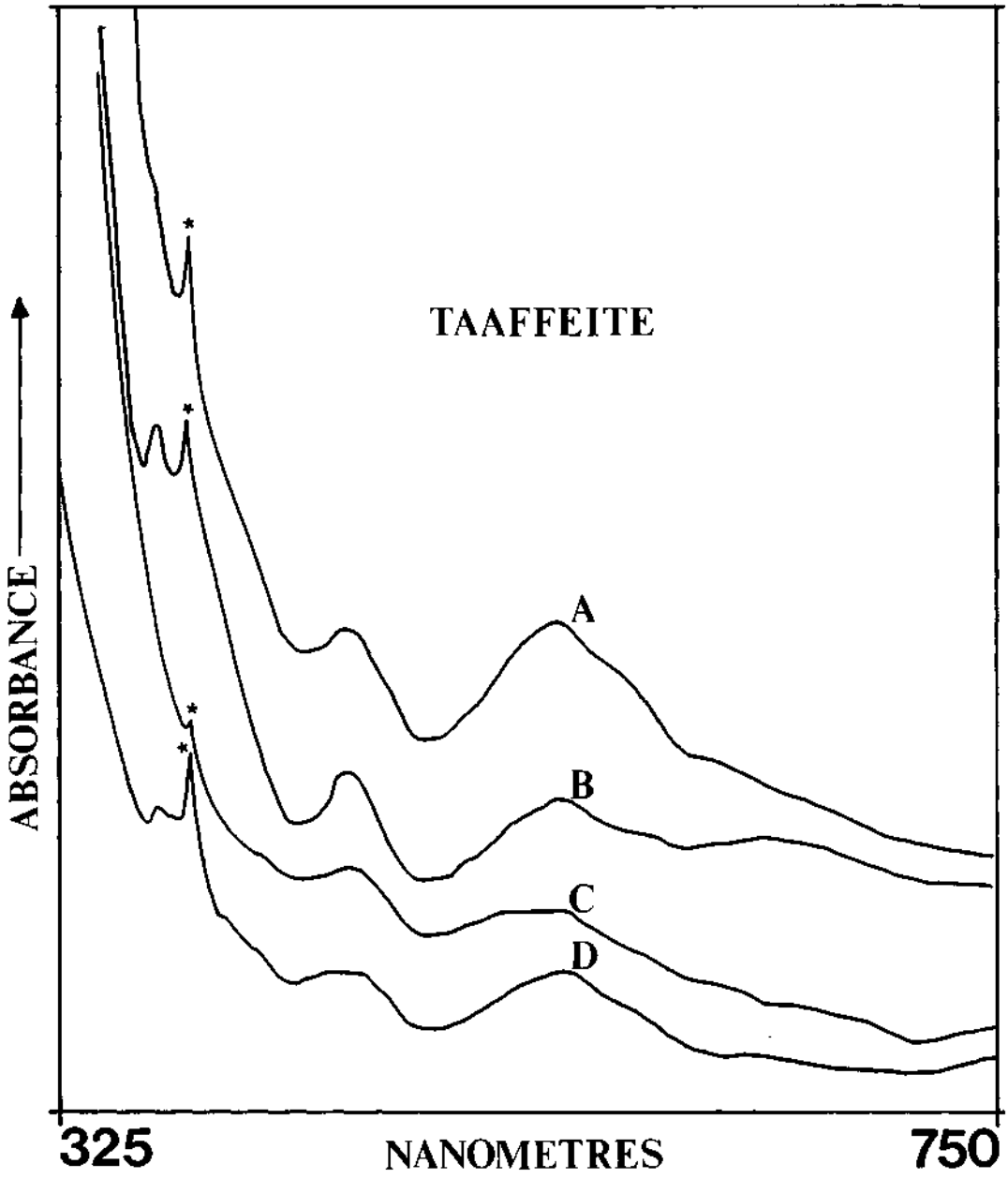

Fig. 21. The spectra produced by the four taaffeites in Figure 20. Curve A is that of the rough specimen (Figure 21 iii), curve B is that of the specimen belonging to Mark L. Jones, F.G.A. (Figure 21 ii), curve C is that of the type specimen (Figure 21 iv), and curve D is that of the round faceted stone (Figure 21 i). The peaks indicated by * are at a slightly different wavelength for each specimen. These are, A.385 nm, B.383.4 nm, C.384.4 nm, D.384.8 nm. All curves were recorded under similar conditions using a Pye Unicam PU8800/03 UV/visible spectrophotometer (Basil Anderson model) with a speed of 1 nm/s for curves A, C and D and 0.5 nm/s for curve B. The bandwidth for each curve was 0.5 nm, the span 2A and each was recorded at room temperature. The path lengths were approximately A, 7.1 mm, B, 2.78 mm, C, 4.89 mm and D, 5.28 mm.

The refractive indices as determined with a Rayner Dialdex refractometer are 1.718–1.724 and the SG obtained by hydrostatic weighing is 3.67.

There is very little difference between the absorption spectrum produced by the ordinary ray and that produced by the extraordinary ray. The spectrum recorded at approximately 90° to the optic axis is reproduced as (B) in Figure 21. By way of comparison the spectra of three further taaffeites, including the type specimen, (Figure 21), were examined under similar conditions. These spectra are also reproduced in Figure 21.

* * *

Fig. 22. Heavily included synthetic diamond grit with an average grain-size of 0.4 mm.

As explained by Anderson in his book *Gem Testing*[4] the Laboratory on many occasions has been asked to examine diamond grits and powders, when dealers in industrial diamond have been concerned about the purity or grit size of lots they propose to purchase.

Although we are not asked quite so often nowadays to examine these grits and powders, when we are they are usually composed of very fine-grained natural diamond and only occasionally are they synthetic diamond. When they have been synthetic diamond, the grain size has also been very small.

Recently we were asked to examine a sample of synthetic diamond grit weighing 1.33 ct in which the average grain size was 0.4 mm (Figure 22).

The sample was attracted to a hand magnet and, as is normal for synthetic diamond grit, the individual crystals were heavily included (Figure 22). It appeared also that the greater the amount of inclusions the greater the reaction there was to the magnet.

The examination to estimate the percentage of impurity present was carried out in the manner described by Anderson[4]. Two small samples from the larger sample were examined and the impurity percentages were found to be 9.78% and 0.78%. The impurity reacted strongly to a magnet.

Acknowledgements

It is with pleasure that the Laboratory gratefully acknowledges the gift of the fibrolite from Mark L. Jones, F.G.A. We are also indebted to Mr Jones for the sight of his taaffeite specimen, and to Dr R.R. Harding, and Mr R.K. Mitchell, F.G.A., for allowing us to examine the spectra of the other three specimens of taaffeite. Figures 1 and 2 were taken by Mr T.J. Rappitt, F.G.A., in 1981.

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Some observations on brown tourmalines from Elahera, Sri Lanka

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Abstract

This paper deals with the description of brown tourmalines from Elahera, Sri Lanka. They were classified as uvite and dravite as a result of their chemical and optical properties.

Introduction

In the Sinhalese linguistic usage, the name tourmaline is applied as a generic term to a number of coloured gemstones. But the mineral tourmaline itself is relatively rare and it occurs exclusively in the brown variety. Until now the known deposits are located in the Uva region, in the Ratnapura district and in the Tissamaharma area (Dunn, 1977 and Zwaan, 1982). These occurrences are always alluvial deposits.

All tourmalines are members of solid solution series with the general composition: XY_3Z_6 $[(OH)_4(BO_3)_3(Si_6O_{18})]$ with X=Na, Ca; Y=Li, Al, Mg, Fe, Mn; Z=Al, Fe, Mg.

Analyses from Dunn (1977) classified the brown tourmalines from Sri Lanka as uvite and dravite:

$Ca\ Mg_3\ (Al_5, Mg)\ [(OH)_4(BO_3)_3(Si_6O_{18})]$ – Uvite

$Na\ Mg_3\ Al_6\ [(OH)_4(BO_3)_3(Si_6O_{18})]$ – Dravite

The occurrence of brown tourmalines of gemstone quality in the Elahera area was mentioned by Henn (1983), but more detailed studies were not made earlier.

Results

For the analyses orientated slices from brown to dark brown tourmaline crystals were cut and polished. The following values for the refractive indices and densities were measured:

Dravite	Uvite
$n_o=1.640$	$n_o=1.635-1.648$
$n_e=1.623$	$n_e=1.619-1.631$
$n_e-n_o=-0.017$	$n_e-n_o=0.016-0.021$
$D=2.922\ g/cm^3$	$D=2.85-3.24\ g/cm^3$

Under the microscope the tourmalines show their characteristic unorientated feathers, consisting mostly of elongated fluid and two-phase inclusions. Furthermore orientated hollow tubes are present, which are often filled with two immiscible fluids. As

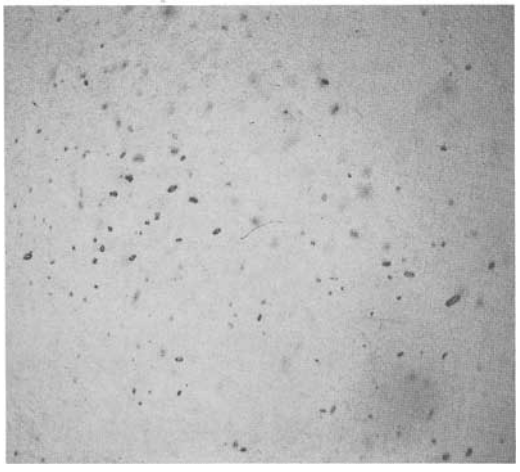

Fig. 1. Rounded zircon crystals in a brown tourmaline from Elahera, Sri Lanka. (25x)

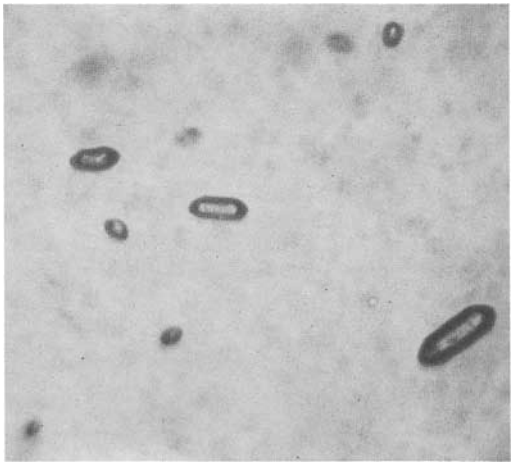

Fig. 2. Rounded zircon crystals in a brown tourmaline from Elahera, Sri Lanka. (125x)

mineral inclusions rounded zircon crystals (Figs. 1 and 2) were observed and their chemical compositions analysed with the electron microprobe. The results are listed in Table 1.

Table 1. Electron microprobe analyses of zircon inclusions in brown tourmalines from Elahera, Sri Lanka (Wt %)

	Inclusion 1	Inclusion 2	Inclusion 3
SiO_2	29.76	32.42	29.80
Al_2O_3	0.03	0.06	0.08
Na_2O	0.01	–	0.02
CaO	–	0.04	–
TiO_2	0.19	0.03	0.03
V_2O_3	–	0.10	0.04
MnO	–	0.29	0.05
FeO	0.51	0.60	0.54
ZrO_2	71.74	68.68	68.34
Total	102.25	102.19	98.90

Table 2. Electron microprobe analyses of brown tourmalines from Elahera, Sri Lanka (Wt %)

	Uvite variation out of 11 samples	average	Dravite
SiO_2	36.95–37.76	37.45	37.13
Al_2O_3	29.01–30.21	29.60	32.24
Na_2O	0.77– 0.98	0.88	1.59
K_2O	0.03– 0.15	0.07	0.06
MgO	11.22–13.45	12.23	11.27
CaO	3.80– 4.13	3.93	1.96
FeO	0.64– 1.50	1.11	0.78
MnO	n.d.– 0.07	0.04	0.04
TiO_2	0.34– 1,06	0.63	0.59
Total	84.37–87.68	85.93	85.66

Chemical analyses of the tourmalines were also determined by the electron microprobe (Table 2). With one exception, all examined samples are uvites (Ca>Na) with the uvite forming 60.0 to 77.8% of the crystal. Only one sample was analysed as a dravite (Ca<Na), consisting of 62.5% dravite. The schorl variety forms between 2.9 and 6.9% of the uvites and 10% of the dravite. The terms Ca>Na and Ca<Na are related to the number of atoms. From the chemical analyses the following specific formulae for uvites and dravites from Elahera were calculated:

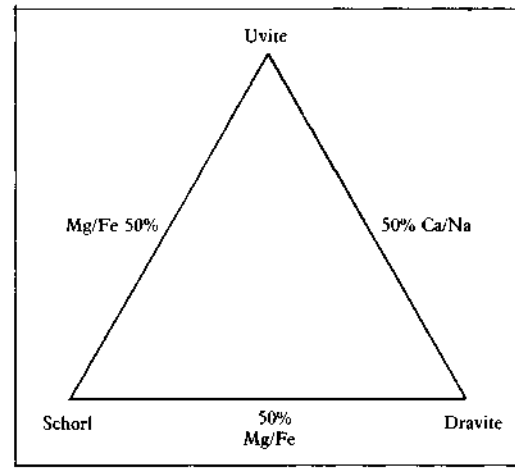

Fig. 3 System uvite-dravite-schorl with samples from Elahera plotted.

Uvite:
$(Ca_{0.6-0.7}, Na_{0.2-0.4})\ (Mg_{2.7-3.4}, Fe_{0.1-0.2})\ Al_{5.4-6.0}\ [(OH)_4(BO_3)_3(Si_6O_{18})]$
Dravite:
$(Ca_{0.3}, Na_{0.5})\ (Mg_{2.7}, Fe_{0.3})\ Al_{6.1}\ [(OH)_4(BO_3)_3(Si_6O_{18})]$

Fig. 3 shows the place of the tourmaline samples from Elahera in the system uvite-dravite-schorl.

Absorption spectra of tourmalines were described by Faye *et al.* (1968), Manning (1968), Faye *et al.* (1974) and Smith (1978). Fig. 4 shows absorption spectra with varying orientations of uvites from Elahera in polarized light. The absorption maxima and the corresponding charge-transfer processes are listed in Table 3. The absorption band, caused by the charge-transfer process $Fe^{2+} \rightarrow Fe^{3+}$ has one maximum at 760 nm for E‖*c* and one at 690 nm for E⊥*c*. These absorption bands were observed in

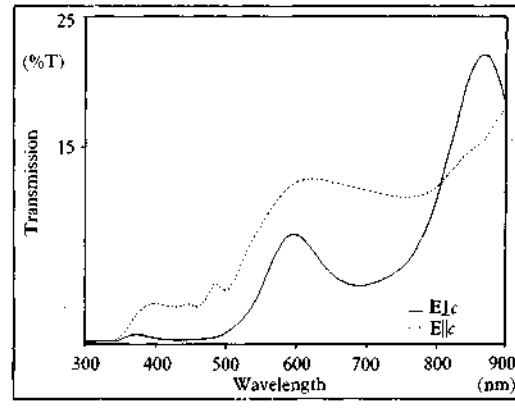

Fig. 4. Absorption spectra of a uvite from Elahera, Sri Lanka, in polarized light and different orientations.

Table 3. Absorption maxima and charge-transfer processes of brown uvites from Elahera, Sri Lanka

	absorption maxima (nm)	charge-transfer processes
E‖*c*	760	$Fe^{2+} \rightarrow Fe^{3+}$
	500	
	460	$Fe^{2+} \rightarrow Ti^{4+}$
	430	
E⊥*c*	690	$Fe^{2+} \rightarrow Fe^{3+}$
	440	$Fe^{2+} \rightarrow Ti^{4+}$

brown and green tourmalines (Smith, 1978) and have only slight influence on the colour (Manning, 1968). The absorption responsible for the brown colour has a maximum at 440 nm for E⊥*c*. At E‖*c* this band split in three maxima at 500, 460 and 430 nm. It is caused by the charge-transfer process $Fe^{2+} \rightarrow Ti^{4+}$ (Smith, 1978).

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A re-investigation of gahnospinels from Sri Lanka

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Abstract

The chemical composition and physical properties of zincian spinels (gahnospinels) from Sri Lanka were re-investigated. The samples were found to represent intermediate members of the spinelgahnite solid solution series with minor components of hercynite. Refractive indices and densities of the samples are closely correlated to the molecular proportions of the gemstones. Colour, absorption spectra, and inclusions of zinc-bearing gahnospinels were found to be similar to the properties of ordinary zinc-free spinels from Sri Lanka. The data published by Anderson *et al.* (1937) as well as the existence of a continuous solid solution series between spinel and gahnite, which was also assumed by Anderson and his co-workers, were confirmed by these investigations.

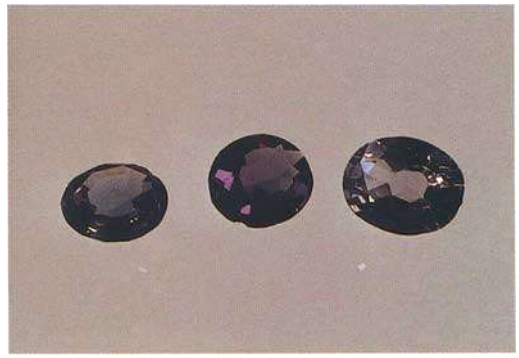

Fig. 1. Gahnospinels from Sri Lanka. Size of the samples approx. 8 × 10 mm. *Photo by O. Medenbach, Bochum, FRG.*

Table 1: Selected physical and chemical properties of gahnospinels from Sri Lanka*

	d (g/cm^3)	n	ZnO (wt%)	FeO (wt%)
1	3.60	1.716	0.14	2.34
2	3.60	1.715	0.86	1.34
3	3.72	1.723	7.18	1.92
4	3.75	1.724	7.36	1.69
5	3.77	1.731	10.27	2.52
6	3.80	1.733	11.55	1.74
7	3.86	1.737	12.98	1.47
8	4.00	1.741	18.74	0.78
A	3.967	1.7465	18.21	1.93
9	4.05	1.752	24.81	1.90
B	4.060	1.7542	not analysed	

* for complete chemical data see Schmetzer & Bank (1985)

A sample analysed by Anderson *et al.* (1937)

B sample described by Anderson (1964) with extraordinarily high values for density and refractive index

Aluminous magnesium-zinc-spinels from Sri Lanka were first described by Anderson *et al.* (1937). The densities and refractive indices of 22 samples were found to range from 3.584 to 3.981 g/cm^3 and from 1.7153 to 1.7469, respectively. One sample was chemically analysed containing major amounts of Al_2O_3, ZnO and FeO (Table 1). The analysis represents a member of the aluminous spinel solid solution series with dominant molecular percentages of the idealized end members spinel $MgAl_2O_4$ (62.4%) and gahnite $ZnAl_2O_4$ (33.5%), as well as subordinate percentages of hercynite $FeAl_2O_4$ (4.1%). According to a proposal of Anderson *et al.* (1937), zinc-bearing spinels are termed zincian spinels or gahnospinels in the literature.

Since that time gahnospinels have been frequently encountered in the gemmological laboratory of the London Chamber of Commerce. However, only one sample was recognized after 25 years of research, which exceeded the range for refractive indices and densities as described in the (1937) paper (Anderson, 1964). This sample showed outstandingly high figures for density and refractive index (Table 1) indicating an intermediate member of the isomorphous spinel-gahnite solid solution

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series with molecular proportions of approximately 50% each of the gahnite and the spinel end member.

According to the physical data of Anderson *et al.* (1937), there is no evidence for a miscibility gap between both end members of the solid solution series, spinel and gahnite. However, chemical data of only one sample are available in the literature. Therefore, further investigations of chemical and physical properties of gahnospinels from Sri Lanka were carried out in order to complete the present knowledge on intermediate members of the spinel-gahnite solid solution series (Schmetzer & Bank, 1985).

All samples available to the authors were transparent, cut blue, bluish-violet or violet materials of gem quality (Figure 1). Most of the material was selected from cut gem spinels of ordinary parcels originating from Sri Lanka. Therefore, no further details about the exact localities for the zincian spinels are available.

Selected chemical and physical data of the samples are summarized in Table 1. Refractive indices and densities are found to be within the range of the values published by Anderson *et al.* (1937) and Anderson (1964). The consistency of these properties (Figure 2) may indicate samples of similar chemical compositions in both investigations. Our microprobe analyses indicate that the spinels represent intermediate members of the spinelgahnite series within a compositional range of the predominant end members spinel (95.1–45.3 mol%) and gahnite (0.2–50.4 mol%) with minor components of hercynite (1.7–5.4 mol%). The physical properties are closely correlated to the molecular proportions of the samples, i.e. an increase of both density and refractive index is caused by an increasing Zn-component in the spinel-gahnite solid solution series. These physical data are also influenced by the slightly variable hercynite percentages of the samples (Table 1, Figure 2).

The colour of gahnospinels from Sri Lanka (Figure 1) is identical with the colour variation observed for ordinary blue, bluish-violet and violet

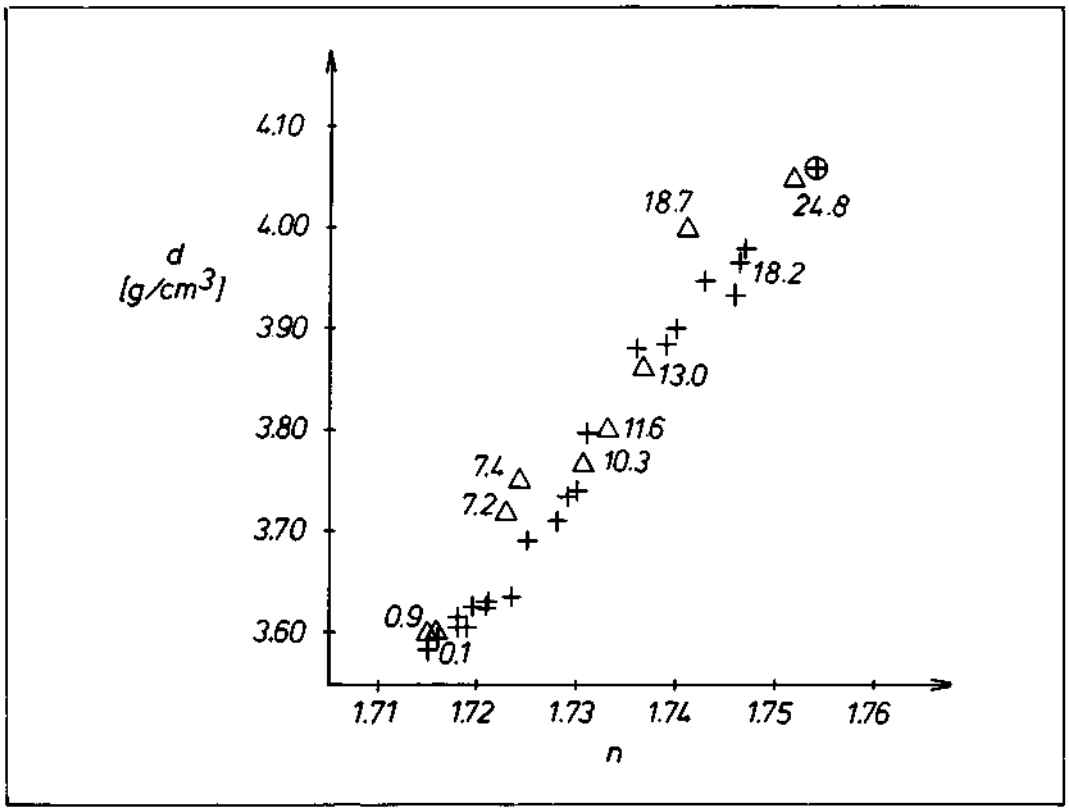

Fig. 2. Plot of densities vs refractive indices of gahnospinels from Sri Lanka; + indicates samples described by Anderson *et al.* (1937), ⊕ indicates the sample with extraordinarily high values for density and refractive index described by Anderson (1964), △ indicates samples of Schmetzer & Bank (1985); the figures indicate weight percentages of ZnO.

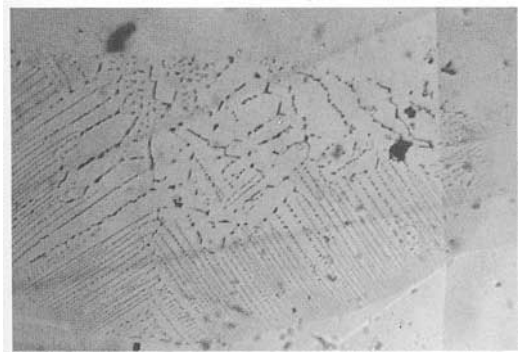

Fig. 3 Stringers of small particles in gahnospinel from Sri Lanka. 45x.

Fig. 4. Stringers of small particles in gahnospinel from Sri Lanka. 50x.

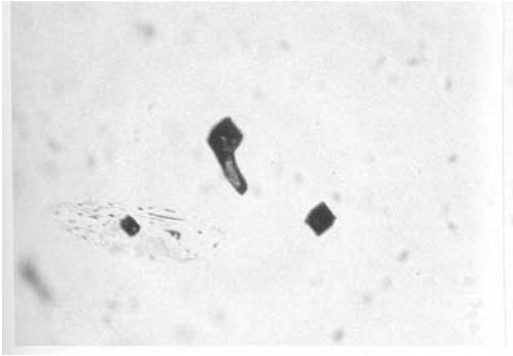

Fig. 5. Two octahedral crystals, one of them surrounded by a liquid feather, and one negative octahedron (middle) in gahnospinel from Sri Lanka. 60x.

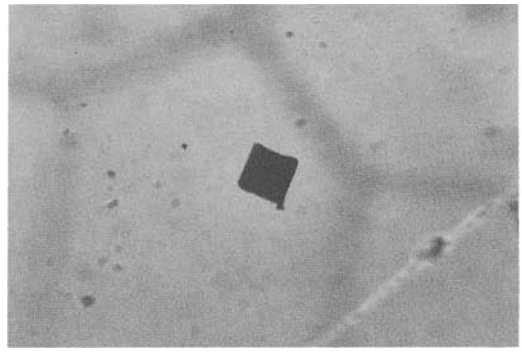

Fig. 6. Octahedral crystal in gahnospinel from Sri Lanka. 80x.

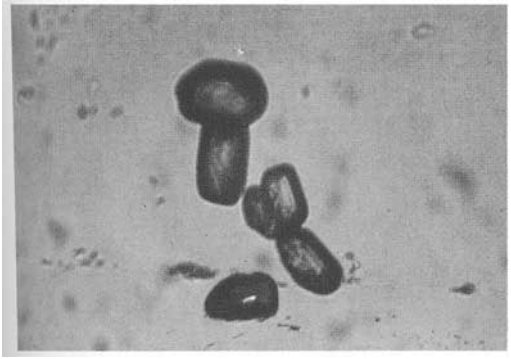

Fig. 7. Rounded mineral inclusions, most probably apatites, in gahnospinel from Sri Lanka. 100x.

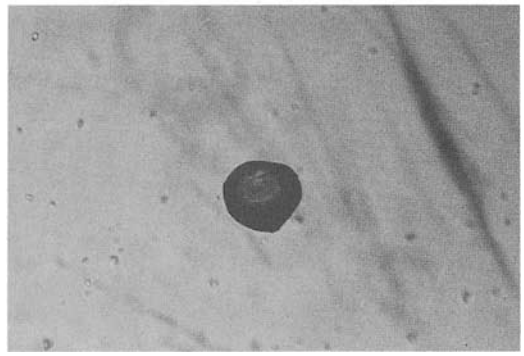

Fig. 8. Rounded mineral inclusion in gahnospinel from Sri Lanka. 65x.

gem spinels from Sri Lanka. The absorption spectra of gahnospinels and ordinary spinels do not show any significant differences. According to Dickson & Smith (1976) the absorption bands of natural blue spinels in the visible area are mainly due to spin-forbidden transitions of tetrahedrally co-ordinated Fe^{2+}. Thus, the colour of spinels of unknown composition, e.g. of rough spinels, is of no diagnostic value for a distinction between ordinary spinels and gahnospinels.

The inclusions observed in gahnospinels from Sri Lanka do not reveal any extraordinary properties compared to the inclusions which are common for ordinary gem spinels from this country (Figures 3–8). Most frequently stringers of small particles, either in straight lines or as fingerprints, were found. Individual octahedra, occasionally surrounded by a liquid feather, as well as mineral inclusions of various shapes were observed. In two samples, one solid inclusion was exposed on the table of the cut gemstone in each case. Both inclusions were determined as apatite by microprobe analysis.

The chemical composition and the physical data of gahnospinels from Sri Lanka confirm the assumptions of Anderson *et al.* (1937). These authors suggested that transparent blue or violet gem spinels from Sri Lanka with extraordinary high densities and refractive indices are members of a complete solid solution series with major components of spinel and gahnite and minor components of hercynite. At present, the compositional range of gahnospinels from Sri Lanka is found to vary within the aluminous spinel solid solution series from about 95 to 45 mol% spinel, and from aout 0.2 to 50 mol% gahnite with hercynite components of about 2–5 mol%. No significant difference is found between the absorption spectra and colour of gahnospinels and ordinary gem spinels from Sri Lanka nor between the inclusions in zinc-containing and zinc-free samples.

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Some unusual cat's-eyes

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Chatoyancy adds beauty and rarity to a gemstone. Some chatoyant gems, such as zircon, tanzanite and opal, may command a very high price, but they are not necessarily beautiful. In this short report I shall describe three unusual cat's-eyes from my collection.

Sillimanite cat's-eyes (which are now available) are mostly from India. Serious collectors can usually obtain them. They are commonly greyish-green in colour, with black inclusions proved to be magnetite and hematite (Zwaan, 1982). There 'eyes' are usually broad and dull, and they can often be identified at sight and without the use of instruments.

In 1984 I obtained a 0.73 ct stone, reputedly from Sri Lanka. This has a beautiful yellowish-green colour and a very sharp eye due to a good fibrous structure (Figure 1). The stone resembles chrysoberyl cat's-eye of good quality, so chatoyant sillimanite now has to be considered as a chrysoberyl simulant. The stone was identified as sillimanite from the refractive index (1.67 by the distant vision method) and its X-ray diffraction data.

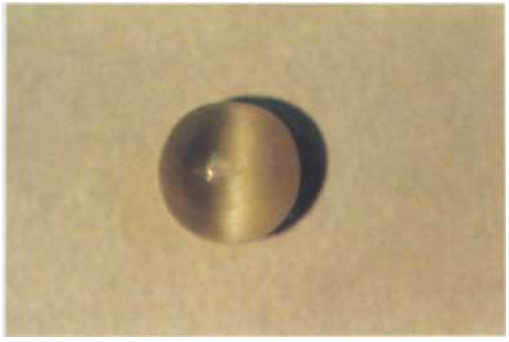

Fig. 1. Sillimanite (fibrolite) cat's-eye, 0.73 ct.

Fig. 2. Kyanite cat's-eye with tubular inclusions.

Fig. 3. Tubular inclusions in kyanite cat's-eye.

Fig. 4. Petalite cat's-eye possibly from South Africa, 17.03 ct.

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Kyanite cat's-eye came into my possession in 1984 when I bought a few cabochons. They all had a royal blue colour but were of low quality due to heavy cleavage and inclusions. One flat cabochon weighing 5.26 ct (Figure 2) shows chatoyancy. It shows prominent cleavages and tubular inclusions running at right angles to the cleavages (Figure 3). The chatoyancy could be due to the tubular inclusions, and as these are coarse the 'eye' is not very sharp, although it can be seen under a normal fluorescent lamp without a penlight. Such a stone is a collectors' item only and is useless for jewellery on account of its fragility and inclusions.

Petalite cat's-eye was sold to me as analcime from an unknown locality. This pretty pale pink stone weighs 17.03 ct, is almost opaque and massive, but possesses a sharp but superficial chatoyancy. The refractive index was determined as 1.50 by the distant vision method. The X-ray diffraction data proved the stone to be petalite.

Petalite in the gem market is usually colourless and transparent, but massive pink material from South Africa is sometimes cut en cabochon and may show chatoyancy. Petalite-analcime cat's-eyes, translucent and pinkish-brown in colour, have been found (Bank, 1982) in Zimbabwe. My stone (Figure 4) is pink, and no analcime lines were found in the X-ray diffraction pattern. Thus, this stone may be described as petalite cat's-eye, maybe from South Africa.

I wish to thank Mr S. Kinoshita, Mr S. Kihara and Mr K. Kuraya for their kind and useful advice, and Mr S. Fujiwara for taking X-ray diffraction photographs.

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A peculiar inclusion in a yellow corundum from Malawi

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In an investigation of a yellow crystal of Malawi corundum (gemmological and chemical characteristics are summarized in Table 1), a syngenetic inclusion, where 'necking-down' took place after trapping, was observed. The necking-down process can take place after the formation of crystals and primary inclusions, but at high temperature and pressure only (Roedder, 1984).

Indeed inclusions with large surface areas very often tend to split into two or more separate parts, and even to cause apparently isolated inclusions in the host mineral. Such inclusions may contain solid, liquid or gaseous phases or their mixtures.

Figure 1 schematically shows the development of necking-down with time by decreasing the temperature. On the left one can see the primary inclusion at temperature T_4; when temperature decreases the necking-down process takes place [T_3 and T_2] and causes the formation of separate inclusions which in our case contain both a liquid and a gaseous phase [T_1].

Such inclusions are not unusual; they have been observed in amethysts from North Carolina (USA), sapphires from Montana (USA), and in many other minerals.

Figures 2–7 show photographs of the corundum taken under different conditions studied. From the necking-down process two cavities connected by a thin hollow and surrounded by other small cavities, apparently isolated, were formed.

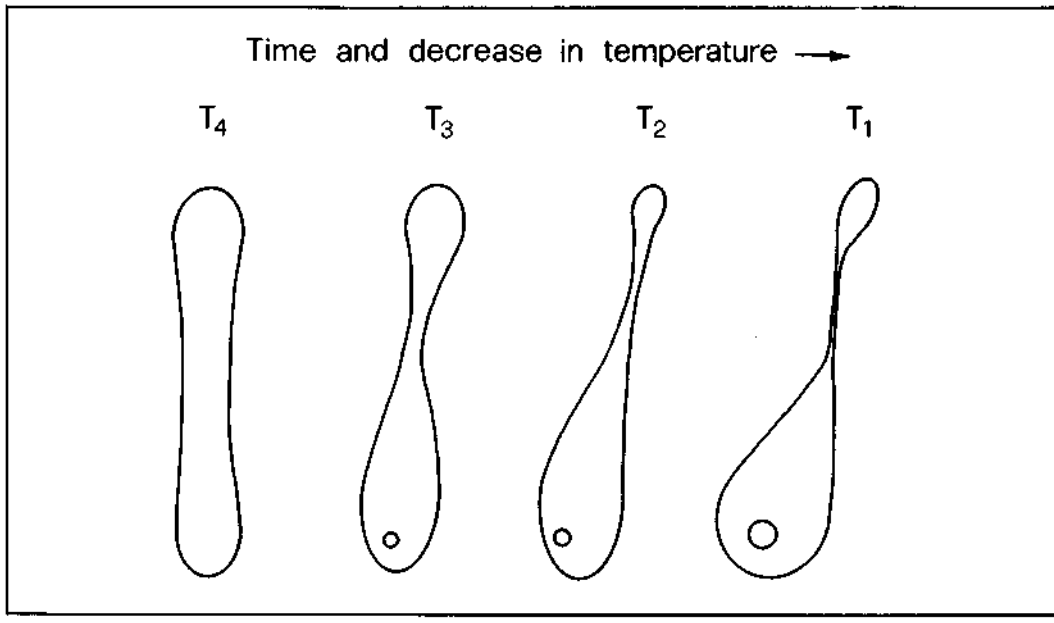

Fig. 1. Schematic development of 'necking-down' inclusion.

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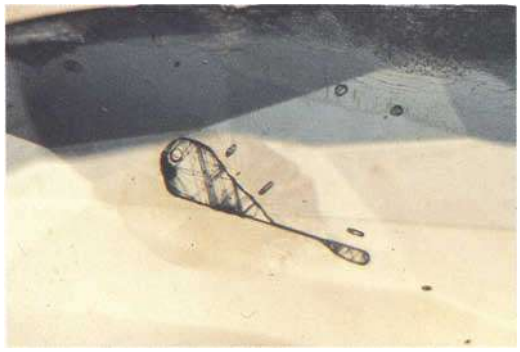

Fig. 2. The 'necked-down' three-phase inclusion. Within the cavity are seen the thin radiating needles, the gaseous phase and the small nuclei of crystallization. A fingerprint surrounds the three-phase inclusion. Direct illumination. 18x.

Fig. 3 The external fingerprint inclusion and the triangular or tetrahedral nuclei of crystallization show better. Reflected illumination. 20x.

Fig. 4. This picture shows the moving of a vapour bubble nearer the trapping. Direct illumination, polarized light. 40x.

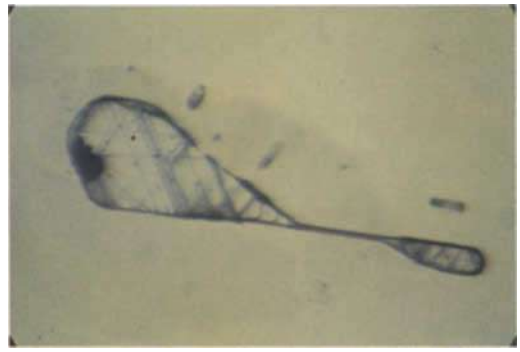

Fig. 5. The vapour bubble disappears owing to its re-absorption in the canal connecting the two cavities. Direct illumination, polarized light. 40x.

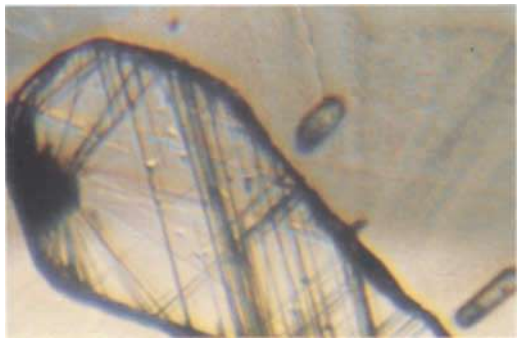

Fig. 6. The bigger part of the 'necked-down' inclusion, with thin radiating and crossed needles and small traingular or tetrahedral nuclei of crystallization. Direct illumination, closed diaphragm. 70x.

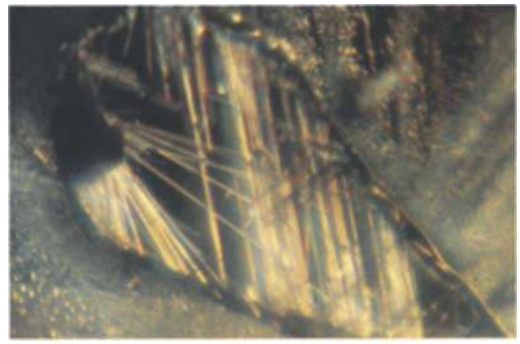

Fig. 7. The same subject as Figure 6. The needle-shaped inclusions are a reddish-golden colour; they are probably rutile. Reflected illumination. 70x.

Table 1: Properties of yellow corundum (Malawi)

COLOUR	: yellow
LUSTRE	: vitreous
HARDNESS	: 9
DENSITY	: 4.00 g/cm^3
OPTICS	: n_o = 1.769 n_e = 1.759
BIREFRINGENCE	: 0.010
PLEOCHROISM	: none
ABSORPTION/ SPECTRUM	: absorption band at 690-700 nm (hand spectroscope)
LUMINESCENCE	: UVL–yellow weak: UVS –none
INCLUSIONS	: three-phase inclusion, cavities, fingerprint inclusion, fractures, twins

Chemical analysis EDAX

Al_2O_3	97.83
Fe_2O_3	0.82
MnO	0.02
MgO	0.89
Na_2O	0.22
CaO	–
K_2O	0.03
Cr_2O_3	0.04
NiO	0.02
CuO	0.10
CoO	–
H_2O	–
Total	99.97

The two largest cavities, surrounded by a fingerprint, can be considered as a single inclusion. It contains three phases: a solid phase formed by thin radiating birefringent needles (possibly TiO_2); a liquid phase (possibly CO_2) and a gaseous phase outlined by a moving bubble (upper left in Figure 2) which disappears (homogenizes) by heating at 31°–32°C.

Within the largest cavity, small triangular or tetrahedral markings (Figures 5, 6) can be seen; they are likely to be small nuclei of crystallization.

Acknowledgements

The Authors wish to thank Professor E. Roedder for helpful suggestions. The work was supported by Centro di Mineralogia e Petrologia delle Formazioni Ignee, C.N.R., Italia 1984.

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Roedder, E. (ed.). (1984) *Fluid inclusions*. Reviews in Mineralogy. Min. Soc. of America.

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The very sphinx of diamonds

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As a gemmologist I have always had a love of both coloured and colourless stones. I believed in my early days that gemmology was principally about coloured stones. Colourless stones, such as pure examples of beryl, quartz, topaz and corundum, lack that subtle touch of impurity so carelessly and inadequately bestowed by nature. Just a little touch of chromium alters considerably the beryl, the corundum or the topaz. However, as a gemmologist, I found that trade laboratory practice demanded a knowledge of all kinds and colours of gemstones, whether amorphous or crystalline, opaque or transparent, organic or inorganic. In the Laboratory I had a lovely long run of testing coloured stones year after year and became proficient in the use of the microscope, spectroscope and the ×10 lens. Because I was so busy with coloured stones I was somewhat detached from what was really our *raison d'etre*, that is to say, *pearls*.

My world though was of gemstones, coloured for preference, with hard to find inclusions which were hallmarks in that sphere. The absorption spectra of gemstones examined by the hand spectroscope (Beck prism) and measured by the Beck wavelength measuring spectroscope were the tools of the trade.

We were testing around 60 000 pearls annually, with a tremendous peak of some 100 000 pearls in one particular year. Pearls were, and still are, a very important part of the Laboratory work and income. However, with the retirement of Anderson, Payne and Webster, my enjoyable gemmological (stone testing) days were numbered. I switched to pearl testing, simply because at that time with Laboratory moves and staff retirements there was no one else to do the job.

In my annual report I wrote of the 'wind of change', borrowing the phrase from one of our Prime Ministers who shall be nameless. The wind of change certainly blew, and one wonders whether change is sometimes for better or is to be deplored. For the major portion of my gem testing life and for the entire length of that of my colleagues Anderson, Payne and Webster, we never gave opinions or examined diamonds for colour or purity. That was a Laboratory rule. I was faced with two major changes to accept, and to teach to new staff. Fashions change in gems, commercial outlook and in policies. In my earlier days we seldom looked at diamonds because diamond merchants did not need our help to tell them their stones were diamonds. Yellow or brown diamonds were not very saleable anyway. Much of the early work by Anderson on the absorption spectra of diamonds, together with C.J. Payne's contribution on the zoning of natural brown diamond, and Webster's work on fluorescence and phosphorescence under X-ray excitations formed a tremendous fund of knowledge. This knowledge was put to good use later when people became more aware of colour in diamonds. Or was it diversion of money to a new form of hedge against inflation?

Two factors for me had changed. Pearls *had* to be my metiers and we *had* to accept diamond grading as part of a Laboratory service. We became the CIBJO recognized Laboratory for diamond grading, and pearl and coloured stone testing, in Great Britain.

In pearl testing by X-ray methods, that is to say radiography, we often X-rayed pieces of jewellery set with pearls. On the negative film, due to the mass density of metal, i.e. gold or silver, the mount itself would stand out in sharp relief compared with the greater transparency of the pearls (calcium carbonate). The striking feature of many of these pieces of jewellery which contained diamonds also, was that the diamonds were all transparent to X-rays. This gave the picture or radiograph the appearance of empty settings. In this manner although not requested, we inadvertently proved the diamonds. The pearls could be much more difficult! Because of so much concentration on pearl testing by optical and X-ray methods I became specialized and in my retirement have given talks on pearls.

Writing recently upon pearls, I consulted various of my old books upon gemstones including 'Pearls and Pearling Life', by Edwin W. Streeter (London, 1886). Later, needing to consult this book again, I

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inadvertently picked from my bookshelves another Edwin W. Streeter book, 'The Great Diamonds of the World' (London, 1882). Both books have gold leaf edging and somewhat similar sombre binding. I opened it out of curiosity, and as I turned the pages my eye was attracted to 'The Sancy Diamond'. Although not a diamond man, still less a diamond grading advocate, I was nevertheless intrigued because I remembered having personally handled the Sancy with Alan Jobbins. Readers will remember Alan Jobbins's article in the *Journal of Gemmology*, 1977, XV, 5, 240–2, entitled 'A brief look at the Sancy'.

In a report by De Beers dated 1966 the stone is stated to be 55ct, white, pear-shaped, named Sancy (Astor), an Indian stone belonging to the Astor family, England. Alan Jobbins's very full report giving accurate measurements and weight plus luminescent characteristics is dated 1976. The report which triggered my memory was in Edwin Streeter's book of 1882. Streeter describes the Sancy as 'the very Sphinx of diamonds'. He says 'the Sancy seems to be wrapped in a dense cloud of mystery, defying the most subtle analysis and impenetrable to the attacks of the keenest processes of reasoning'. The Sancy was purchased in 1892 by William Waldorf Astor, first Viscount Astor. He gave it as a wedding present to his son, whose wife Nancy, Lady Astor, wore it on state occasions in a tiara. It passed to her son after her death in 1964. It was on show in Paris in 1962.

This brings it almost up to date, or at least to January 1976 when tested by Alan Jobbins at the Geological Museum laboratory in full view of its then owner, Lord Astor. A good record now exists of its luminescent characteristics, density, weight and a contact immersion photograph showing its light transmission.

It rests now in France*, where the authorities are active in re-assembling their own historic and notable jewels.

I cannot help hoping that the Sancy has reached its logical resting place, for if it cannot be England it must surely be Paris. Despite Edwin Streeter's description of 'the very Sphinx of diamonds' it does, nevertheless, have a truly French connection.

In 1976, during my time as Director of the Laboratory, I was invited to participate in the accurate recording of the Sancy diamond. It was a great honour, a considerable compliment to our Laboratory, and for me a feeling of excitement to feel that 'I was there'.

One of the smallest and least known vicissitudes suffered by the Sancy in its meandering occurred on that occasion. For a few seemingly endless moments in an unfamiliar dark room (cell) about the size of a telephone kiosk I was preparing to expose the Sancy to short-wave ultraviolet exposure to form a contact immersion photograph. I lost the stone in the complete darkness and fumbled around with adrenalin-charged imagination working overtime trying to locate it. Perhaps my colleagues never even noticed the pause which to me seemed endless. I finished the exposure and added metaphorically one more fascinating facet to the Sancy travelogue.

[*Manuscript received 27 January 1986.*]

*The Sancy has been in the Louvre since 1978 – Verlet (Pierre), Le 'Sancy' rentre au Louvre, *Gazette des Beaux Arts*, November 1978, pp. 165–8. – Ed.

A treatment procedure for improving colour and quality of zircons

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There are some types of gem minerals that appear in the jewellery market only after some kind of treatment which makes them more attractive or saleable than in their natural state.

Blue and colourless zircons occur in nature, they are not found in sufficient quantity, and rarely in good enough quality, for commercial purposes. But with the development of new methods, gemmologists have been able to convert less attractive zircons into colourless and also coloured stones.

For more than one hundred years workers have suggested the possibility of using zircons in place of diamonds. Today this industry is progressing on a very large scale.

Table I. Treatment combinations

Colours	TREATMENTS 1000°C, 15 hrs.			
	T 1	T 2	T 3	T 4
Yellow (a)	YT 1	YT 2	YT 3	YT 4
Green (b)	GT 1	GT 2	GT 3	GT 4
Violet (c)	VT 1	VT 2	VT 3	VT 4
Dark Green (d)	DGT 1	DGT 2	DGT 3	DGT 4

← oxidation →← reduction →

T1 and T3 – rapid cooling at room temperature
T2 and T4 – slow cooling inside the oven

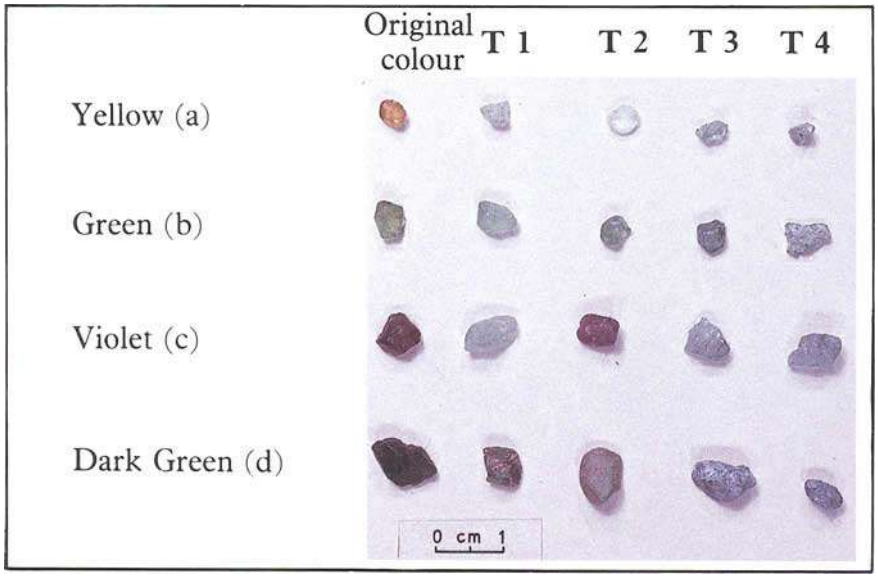

Fig. 1. Results of the treatments. (see Table I).

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Table II Concentrations of important elements in zircons from Sri Lanka

Colour	No. of analyses	Si%	Fe%	Zr%	Hf%	Th%	U%
Yellow	36	15.67	0.02	48.25	1.19	0.07	0.14
Green	63	15.87	0.07	47.69	1.44	0.12	0.41
Violet	33	16.02	0.02	48.65	1.01	0.09	0.11

As an accessory mineral in rocks, zircon has been extensively studied by many previous workers (Vithanage 1957; Vance & Anderson 1972; Sahama 1981). Due to its wide range of occurrences in igneous and metamorphic rocks, it has also been used as an indicator mineral in petrogenesis.

In the present study, authors have experimented on the colour and quality variation in zircons of four different colours placing them in high temperature, under oxidizing or reducing conditions (Table I). The results obtained were fascinating and the findings have proved the success of producing high gem-quality stones from less valuable zircons.

Materials and methods

Sediment samples from different locations in Ratnapura gemming district of Sri Lanka were collected, washed and the zircon grains carefully selected using the following techniques in addition to visual identification.

geiger – müller counter
density measurements
refractive index (RI) measurements
X-ray diffractometer.

Separated zircon grains were then further divided into four different colours and representative specimens were finally analysed chemically using an electron-microprobe instrument (Cameca; Camebax microbeam). From each grain 3 points have been analysed and also great care has been taken to avoid inclusions and tiny holes on surfaces.

Three stones from each colour group were then subjected to the following heat treatment procedure.

To create an oxidizing environment, the alumina crucible, in which the stones were treated, is kept open. In the case of reducing treatments, stones were covered with a thin carbon and a thick alumina layer successively and the crucible kept tightly closed.

Results and Discussion

Colour and Chemistry

Table II clearly illustrates the compositional dependance of colours in zircons. Green zircons usually have higher (about 3 times) amounts of iron and uranium, while the other two shows similar chemical properties. The Th content in green stones is relatively higher than that of the other two.

Green zircons represented nearly 50% of the sample population subjected to analysis. The majority of them are of metamict type and one can expect maximum compositional irregularities, and hence an unusual correlation among elements in them. Their high representation in the present study may have masked the true correlations in other coloured stones (Table III) Sommerauer (1976) reported a possible tolerance of substitution of an element with ± 15% ionic size into the zircon lattice (Goldschmidt law). However the relationship between green colour and the U content is unmistakable, and therefore the relationships between colours and Th,Hf, and U content in zircons should be thoroughly investigated.

Table III. Correlation coefficient matrix for the elements studied

	Si	Fe	Zr	Hf	Th	U
Si	1.000					
Fe	+ 0.287	1.000				
Zr	− 0.308	− 0.329	1.000			
Hf	− 0.128	− 0.024	− 0.171	1.000		
Th	− 0.007	+ 0.017	+ 0.010	− 0.068	1.000	
U	− 0.049	−0.041	− 0.166	+ 0.455	+ 0.040	1.000

Quality of treated stones

The combination YT2 (see Table I and Fig. 1) is the most successful result obtained from the treatment, in order to produce a colourless and substitute for diamonds. The high reflective nature and the brilliant lustre are the attractive improvements made by this method on zircons. Yellow zircons which have been used for this combination of treatments are very often found in alluvial sediments. The cost of treatment is also very low and proves its economic feasibility.

By the treatment T2 the authors have been able to produce a reddish-violet stone from a honey-brown zircon, which shows an improved lustre.

Treatment T3 has been able to produce an aquamarine-type light blue and high lustre stone from a green zircon.

Further, dark green unattractive metamict zircons can also be changed by T3 into blue, translucent stones which possibly can be used as beads in jewellery.

The effects of these treatments on differently coloured stones can be seen in Fig. 1 and one can notice that the other treatment combinations do not improve the quality of stones. However, it is very interesting to note that all treatment combinations have been able to change the original colour, though they do not improve the quality.

The results of the present study and earlier studies suggest that the phenomenon behind the colour change is the variation in oxidation state and the sites of substitution of impurity ions (e.g. Fe^{2+}, Fe^{3+} etc).

Acknowledgements

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The brilliant cut – analysis of weight by calculation

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In the daily work of most gemmologists, who are involved in the jewellery trade, the requirement of having to calculate the weight of a mounted, round brilliant-cut diamond crops up all too regularly.

A look through the literature will reveal a variety of equations that have been used over the years and at first glance they look diverse and confusing.

It was the very appearance of these equations that first aroused the writer's interest with the thought that they cannot all be right.

After a very detailed study, in which the writer tried to forecast the most appropriate Shape (S) Factor for a variety of proportions, a method evolved in which the accuracy of the calculation is limited only by the ability of the gemmologist to measure the parameters of the stone.

Nowadays, the weight of a round brilliant-cut diamond is usually calculated using one of the following six equations, where D is the diameter, H is the total height and R is the radius of the stone.

1. *Grodzinski's Equation*

Wt of stone in carats = $(D/6.42)^3$ (D measured in mm)

Grodzinski's equation represents a straight proportion calculation on a 1 ct brilliant-cut diamond and is quite accurate over a considerable range of sizes, but it takes no account of the actual depth, so it should be limited to diamonds of very good make.

2. Wt of stone in carats = $D^3 \times 0.59 \times 0.0060$ (D in mm)

This equation uses 0.0060 as a Shape (S) Factor and assumes that the depth is 0.59 times (59%) the girdle diameter, a fair assumption for well-cut stones.

3. Wt of stone in carats = $D^2 \times H \times 0.0060$ (D and H in mm)

This is a refinement, where H, the total depth, is included as a measurement in its own right, overcoming earlier objections.

4. *Anderson's Equation*

Wt of stone in carats = $D^2 \times H \times 6$ (D and H in cm)

Anderson's equation is the same as 3. but as the measurements are in cm the 0.0060 factor becomes 6.0.

5. Wt of stone in carats = $D^2 \times H \times 3.52 \times 0.0018$ (D and H in mm)

In this case the 'S' factor is split into the general shape factor for round brilliant-cut stones and multiplied by the specific gravity (3.52) of diamond. The product of these two is 0.006336, some 5.6% greater than 0.0060.

6. *Leveridge's Equation*

Wt of stone in carats = $R^2 \times H \times 0.0245$ (R and H in mm)

Although Leveridge's equation looks quite different, the use of the 'radius' instead of the usual 'diameter' produces the 0.0245 factor, which when divided by '4', equals 0.00615, making the answer 2.5% greater than if 0.0060 was used.

Essentially the carat/weight problem is one of elementary mathematics as the round brilliant-cut can, if the facets are disregarded, be represented by a series of three cones and a thin cylinder, as in Figure 1.

Where – R_G = the radius at the girdle.
H_P = the depth of the pavilion.
H_G = thickness of the girdle.
R_T = the radius of the table.
h_1 = total height of cone of crown.
h_2 = the height of the cone removed, the base of which is the table.

therefore $h_1 - h_2 = H_c$ the height of the crown.

By calculating the volume of each of the solids, i.e. the pavilion cone, the girdle cylinder and two crown cones, the volume of the stone may be obtained. The volume of the crown is the volume of the whole top cone less that of the smaller cone, the

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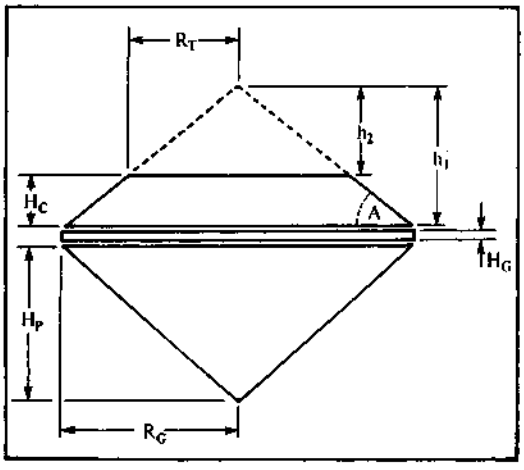

Fig. 1. Diagram illustrating that, if the facets are disregarded, a round brilliant-cut diamond may be represented as a series of cones and a thin cylinder.

base of which is the table.

Using this method, two equations, A and B, may be obtained. One of them (A) uses the crown angle whilst the other (B) makes use of the crown height.

Equation A – using the crown angle

Wt of stone in carats = $0.03686\,(D/2)^3\,[(H_P + 3H_G + 0.5 \tan \hat{A}) - (T_b^3 \times 0.5 \tan \hat{A})]$

Where – D = diameter of girdle in mm
H_p = % depth of pavilion written as a decimal (43%=0.43)
H_G = % thickness of girdle written as a decimal (3%=0.03)
$\hat{A}$ = crown angle in degrees
T_b = diameter of table as a decimal of the girdle (65%=0.65)

Equation B – using the crown height

Wt of stone in carats = $0.03686\,(D/2)^3\,[H_P + 3H_G + (H_C/1 - T_b)\,(1 - T_b^3)]$

Where H_C = % height of the crown written as a decimal (12%=0.12).

All of the other symbols remain the same as in Equation A.

It should be noted that in both equations, the term H_G, the girdle thickness is multiplied by three and shows that the volume, and consequently the weight, is three times as sensitive to changes in girdle thickness as it is to changes in the other heights.

The following example will serve to demonstrate the use of these equations.

Example: Find the carat weight of a round brilliant-cut diamond of the following dimensions – Diameter, 6.5 mm, Crown angle 34.5°, Table 60%, Pavilion 43.1%, Girdle 2.3%.

Substituting in equation A where
D=6.5 mm, H_p=0.431, H_G=0.023, $\hat{A}$=34.5°, T_b=0.60 then

$0.03686\,(6.5/2)^3 \times [(0.431 + (3 \times 0.023) + 0.5 \times \tan 34.5°) - (0.6^3 \times 0.5 \times \tan 34.5°)] = 0.9736$ ct.

The total depth can be extracted from this equation by the calculation –
$(H_P + H_G + (0.5 \times \text{Tan } 34.5°)) - (T_b \times 0.5 \times \text{Tan } 34.5°) = 0.591$ (expressed as a decimal of the girdle diameter)

Replacing the 0.59 in equation 2 with the figure 0.591 and rearranging, the correct 'S' factor can be calculated –

$(6.5)^3 \times 0.591 \times$ 'S' factor = ct wt
Therefore
'S' factor = $0.9736/(6.5^3 \times 0.591) = 0.005999$

It must be appreciated that, in using calculators, answers are given to many places of decimals. The accuracy of the results obtained is limited by several factors.

1. The regularity of the shape of the stone.
2. Slight variations in the SG of diamond.
3. The accuracy of the method of measurement.
4. The assumptions made in the derivation of the equations, e.g. ignoring the facets when calculating the volume of the cones.

By using a programmable calculator it is possible to investigate the effect on both the carat weight and the 'S' factor when any of the dimensions are changed either singularly or simultaneously.

Taking the previous example. Investigate the effect of a pavilion range from 39% to 47%.

Note: as the carat weight increases the 'S' factor decreases.

Pav.	39%	41%	43%	45%	47%
Ct Wt	0.9208	0.9461	0.9714	0.9966	1.0219
'S' factor	0.00609	0.00604	0.00599	0.00595	0.00592

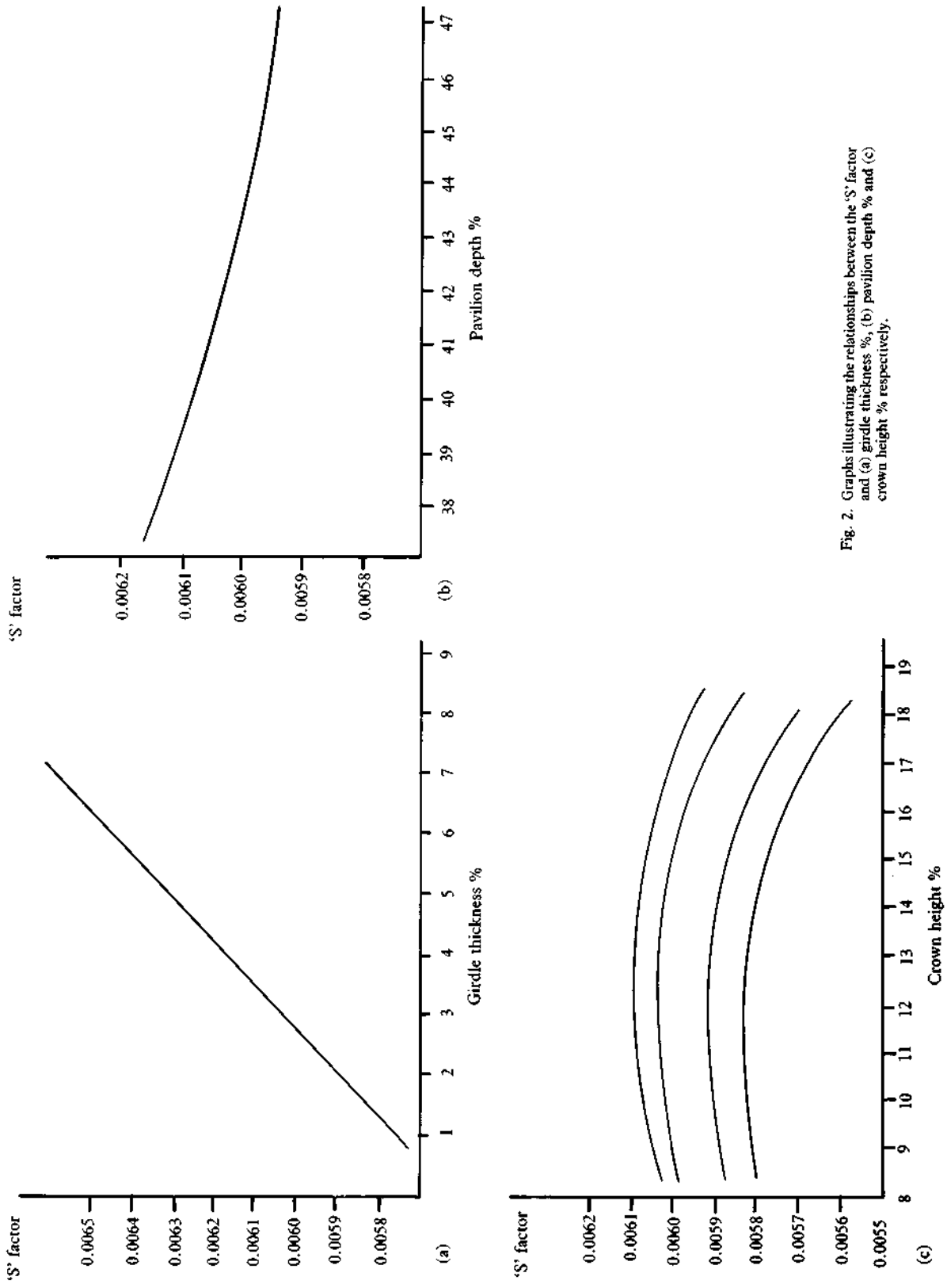

Fig. 2. Graphs illustrating the relationships between the 'S' factor and (a) girdle thickness %, (b) pavilion depth % and (c) crown height % respectively.

Tables of this type can be produced for the variation of the girdle thickness, crown height and crown angle but the results are easier to appreciate if presented in graph form as illustrated.

The graphs show clearly that the weight and the 'S' factor respond rapidly to changes in girdle thickness and crown angle. A small progressive change occurs in the factor with increasing pavilion depth, while simple changes to the crown height percentage are almost self-neutralizing as far as the 'S' factor is concerned. With a reduction in crown angle both the weight and the factor decrease rapidly.

It should be realized that each of the above graphs features only one variable at a time, i.e. the one featuring the pavilion variations from 37% to 47% relates only to a diamond with crown angle 34.5°, table 60%, girdle 2.3% but is irrespective of girdle diameter.

The author set out originally to establish a method of weight estimation by adding the separate components of these graphs but although this proved to be a mathematical nonsense, the graphs can be used independently.

The graph of the girdle thickness will probably find the greatest application as it applies to an otherwise well cut stone and can be used in conjunction with equation No. 3.

The diameter and total depth are inserted in the equation, and the 'S' factor for the appropriate girdle thickness is read off the graph and inserted in the equation instead of 0.0060, thereby making allowance for the one stone dimension which has the greatest single influence on the 'S' factor and consequently the weight.

The graphs also show that 0.0060 is quite accurate for any diamond within the following limits:

Pavilion between 41% and 44.5%.
Girdle between 2.0% and 2.7%.
Table between 55% and 75% provided the angle is 34.5°.

The 'S' factor of 0.0060 should not be applied to any diamond with a crown angle less than 34.5°.

There is also a practice in the cutting industry to thicken the girdle on smaller stones, which has the benefit of reducing the fragility of the stone for the setter. If diamonds of 3.0 mm, 4.0 mm, 5.0 mm and 6.0 mm are calculated out, the 'S' factor will be seen to start at approximately 0.0063 for 3.0 mm and 4.0 mm diamonds, reducing gradually to 0.0062 at 5.0 mm and 0.0061 at 6.0 mm.

Hence it can be seen that all of the equations Nos 1 to 6 can produce reasonably accurate results within limited circumstances and provided the crown angle is not less than 34.5°. The use of these equations on spread cut stones introduces serious errors.

The particular value of the two equations A and B is that any diamond that can be measured as for a certificate, with either the crown angle or the crown depth, can be calculated to quite accurate limits. Experience has shown that an error less than 0.5% can be considered normal for diamonds of good symmetry.

As an aid to using the equations, any programmable calculator that can accommodate fifty steps and five variables, like the Sharp EL-5100, or equivalent Casio models, can be used to program–store and recall the equations at the touch of a button.

Equation B for instance can be stored in the EL-5100 in this form:

$$f(ABCDE) = 0.03686 \times (A \div 2) Y^x 3 \times (B + (3 \times C) + (D \div (1 - E)) \times (1 - EY^x 3))$$

Where – A = diameter in mm
B = pavilion depth % expressed as a decimal
C = girdle thickness % expressed as a decimal
D = crown height % expressed as a decimal
E = table % expressed as a decimal

The term Y^x3 appearing twice in the equation is the terminology used by this particular machine to raise a function to the cube power.

Once stored, this equation can be recalled, the five measurements entered and the answer is delivered almost instantaneously.

The next problem is that of actually making the measurements. The obvious way would be with a Proportionscope, and the 'View-through' type might be suitable provided the culet and the girdle thickness can be seen and measured. A better method would be the use of a microscope with a Vernier calibrated stage. This would necessitate the taking of measurements and subsequently converting them to decimals of the girdle diameter.

The writer's preferred method is to use a zoom microscope fitted with a reticle in the eye-piece. The most convenient form of reticle is one that is divided into one hundred divisions and numbered one to ten. The piece of jewellery is clamped on the stage with the crown of the diamond under examination facing squarely upwards. The optics are then zoomed until the scale length exactly coincides with the girdle diameter.

Under these conditions the girdle diameter equals 100 divisions and the piece can then be moved or rotated so that the table, crown, girdle and pavilion can all be read directly in percentages

of the girdle diameter under the magnification of the microscope. It only remains to take a measurement of the girdle in mm to be able to solve equation B.

One final comment about the measuring of the table diameter and the girdle thickness. As the junction points of the star and girdle facets are outside the cone of the crown main facets, the table diameter can be taken as the 'point to point' distance. For the girdle it is necessary to take an average of several measurements at the base of the main facets.

Although this technique is not for the smaller stones, any set diamond of 0.75 ct or more, where the girdle and culet are visible, could warrant the full analysis of proportions. In this case the gemmologist would have all the information necessary to make an accurate calculation of carat weight by this method.

Appendix

The equations A and B are derived as follows: referring to Figure 1 –

(a) pavilion volume is $\frac{1}{3}\pi R_G^2 H_P$

(b) the girdle volume is $\pi R_G^2 H_G$

The volume of the crown is represented by the whole top cone minus the smaller cone, the base of which is the table – e.g., $\frac{1}{3}\pi R_G^2 h_1 - \frac{1}{3}\pi R_T^2 h_2$

Although the girdle DIAMETER is the measurement that gemmologists prefer to start with, the mathematics become awkward working with the term $(D/2)^2$, so it is better to stay with R (radius) for the time being.

Adding the four terms together and factorizing,

$$\text{Volume} = \tfrac{1}{3}\pi\,[R_G^2(H_p + 3H_G + h_1) - (R_T^2 \times h_2)] \quad \ldots(X)$$

To convert this volume, which is expressed in cubic mm, to weight in carats, it is necessary to –

(a) Divide by 1000 to convert it to cubic cm

(b) Multiply by 3.52 (SG of diamond) to convert the volume to grams

and finally

(c) Multiply by 5 to convert grams to carats

i.e. $1/1000 \times 3.52 \times 5 = 0.0176$

Thus

$$\text{Ct wt} = 0.0176 \times \frac{\pi}{3}\,[R_G^2(H_p + 3H_G + h_1) - (R_T^2 \times h_2)] \quad \ldots(Y)$$

Unfortunately this equation still includes the terms 'h_1' and 'h_2', neither of which can be measured as they both originate from a point beyond the top of the stone.

Conversion of equation Y into equations A and B for use with the crown angle and the crown height respectively are shown below.

Details of proof of Equation A (crown angle) (see Figure 3).

$$\text{Volume} = \tfrac{1}{3}\pi R_G^2 H_P + \pi R_G^2 H_G + \tfrac{1}{3}\pi R_G^2 h_1 - \tfrac{1}{3}\pi R_T^2 h_2$$

Substituting for R_T^2 equals $R_G^2 \times T_b{}^2\%$ and factorizing,

$$\tfrac{\pi}{3} R_G^2\,[(H_P + 3H_G + h_1) - (T_b{}^2 \times h_2)$$

Now in the right angle triangle ABC representing the crown –

$$h_1/\sin A = R_G/\sin B$$

$$\therefore h_1 = R_G \sin A/\sin B$$

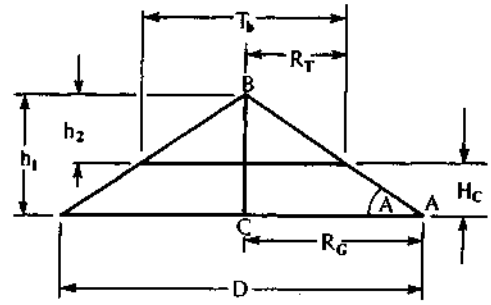

Fig. 3.

As $\angle A$ and $\angle B$ are complementary,
$\sin B = \sin(90° - A) = \cos A$
and $\sin A/\cos A = \tan A$

Therefore $h_1 = R_G \tan A$ and $h_2 = h_1 \times T_b\% = R_G \times \tan A \times T_b\%$

Substituting for h_1 and h_2,

$\therefore$ Volume =

$$\frac{\pi}{3} R_G^2\,[(H_P + 3H_G + (R_G \times \tan A)) - (T_b^2 \times T_b \times R_G \times \tan A)]$$

At this stage H_P and H_G are in the form of actual measurements (mm), so if they are each divided by D (girdle diameter) they are in a much more usable form for the gemmologist.

Volume =

$$\frac{\pi}{3} R_G^2\,[(H_p \times D)/D + (3H_G \times D)/D + (R_G \times \tan A)\,D - (T_b^3 \times R_G \times \tan A)/D]$$

Substituting D/2 for R_G and extracting D,

Volume =

$$\frac{2\pi}{3}(D/2)^3\,[(H_p + 3H_G + 0.5 \tan A) - (t_b^3 \times 0.5 \tan A)]$$

Converting this volume in cubic mm to carat weight and also taking in the $\frac{2\pi}{3}$ gives the final multiplying constant of 0.03686.

$$\therefore \text{Ct Wt} = 0.03686 \times (D/2)^3 [(H_P + 3H_G + 0.5 \tan A) - (T_b^3 \times 0.5 \tan A)] \quad \ldots(A)$$

Details of proof of Equation B (crown height)

Using the same diagram and introducing H_C to replace $h_1 - h_2$ and starting at line No. 2 in the previous proof,

$$\text{Volume} = \tfrac{1}{3}\pi R_G^2 (H_P + 3H_G + h_1 - (T_b^2 \times h_2))$$

As $H_C = h_1 (1 - T_b\%)$, then $h_1 = H_C/(1 - T_b\%)$ and $h_2 = h_1 \times T_b\%$

Substituting for h_1 and h_2,

$$\text{Vol.} = \tfrac{1}{3}\pi R_G^2 [H_P + 3H_G + (H_C/(1 - T_b)) - ((T_b^3 - H_C)/(1 - T_b))]$$

$$\text{Vol.} = \tfrac{1}{3}\pi R_G^2 [H_P + 3H_G + (H_C/(1 - T_b))(1 - T_b^3)]$$

Now taking each of the measurements H_P, H_G and H_C and representing them as a decimal of the diameter (Table has already been treated),

$$= \tfrac{1}{3}\pi R_G^2 [(H_p \times D/D) + (3H_G \times D/D) + \frac{H_C \times D/D}{(1 - T_p)} (1 - T_p^3)]$$

Extracting the D and substituting (D/2) for R_G,

$$\text{Vol} = \frac{2\pi}{3} (D/2)^3 [(H_P + 3H_G + ((1 - T_b)H_C/(1 - T_b^3))]$$

Converting this volume in cubic mm to carat weight and also taking in the $\frac{2\pi}{3}$ gives the final multiplying constant of 0.03686.

$$\therefore \text{Ct Wt} = 0.03686 \times (D/2)^3 [(H_P + 3H_G + ((1 - T_b)H_C/(1 - T_b^3))] \quad \ldots(B)$$

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Light, heavy and rare minerals in the washed gem gravels of Sri Lanka

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Abstract

Light, heavy and some rare minerals as found in the washed gem gravels from Sri Lanka have been studied for their abundance and chemical compositions. Among the rare minerals found were fergusonite, geikielite, niobian-rutile, radioactive rutile, allanite and thorite/thorianite. Analyses for rare-earth elements and 25 other elements were made, and among the noteworthy features are the abundances of Th and U in zircon and monazite.

Introduction

Sri Lanka (Ceylon) is an island with an area of 69450 sq.km and is essentially a part of the shield area of peninsular India. Geologically and physically Sri Lanka is the southern continuation of the Indian sub-continent. It is believed to have separated in recent geological times due to shallow tectonic movements.

The greater part of the island (90%) is made up of Precambrian metamorphic rocks, which can be divided into four major divisions, viz. Highland Group, South-west Group, Eastern and Western Vijayan Complexes (Munasinghe and Dissanayke, 1982). Apart from the two small Jurassic sedimentary basins (Fig. 1) (together 8–10 sq.km) the rest of the island (10%) is covered by Tertiary (Miocene limestone), Quaternary (red beds, clastic sediments) and Recent (alluvial) sediments.

The Highland Group occupies the entire hill country of the island and is comprised of granulite facies metasediments, while the Vijayan complexes are comprised of granitoids, migmatites and migmatitic gneisses. The South-west Group is also made up of granulite facies metasediments and as indicated by the presence of cordierite (Katz 1972) represents different pressure/temperature conditions.

The high rate of weathering in this tropical island has denudated the land for the past few million years and given rise to thick and extensive piles of sediments in flood plains of all major rivers. One can also see buried streams, rivers and sediment-filled lakes. These vast alluvial plains are very fertile and most of them have been cultivated for the past two thousand years.

The accidental discovery of gemstones in these deposits attracted people into gem mining and this practice has continued unbroken for more than a thousand years.

There are two main gemming areas in Sri Lanka, namely Ratnapura and Elahera, and also a few scattered locations; Rakwana, Tissamaharama, Okkampitiya and others. A noteworthy feature is that all these regions are located in the Highland and South-west Group meta-sedimentary formations.

The aim of this study is to identify all types of gemstones and other heavy minerals in the gem-bearing gravels from these areas, and also to identify the major differences among these deposits.

Geology of the area studied

Fig. 1 illustrates the major gemming areas of Sri Lanka, and Fig. 2 illustrates the geology of the Ratnapura and Rakwana gem fields. Scattered alluvium is found lying on charnockite-meta-sedimentary rocks; namely charnockites, garnet-sillimanite granulites, amphibolites, and perthite-bearing garnet-biotite-granulitic gneisses. Here charnockite and pelitic garnet-sillimanite granulites are the predominent rock types. Further the occurrence of zircon granites, vein-quartz and pegmatites is a notable feature of the region.

Fig. 3 illustrates the geology of the Elahera gem field, situated in the north-east foot slopes of the Central Highlands, where a ridge and valley topography is predominent. Quartzite, marble, garnet-sillimanite-biotite gneisses, with tourmaline (Rupasinghe *et al.,* 1984) and charnockite are the major rock types lying in this region.

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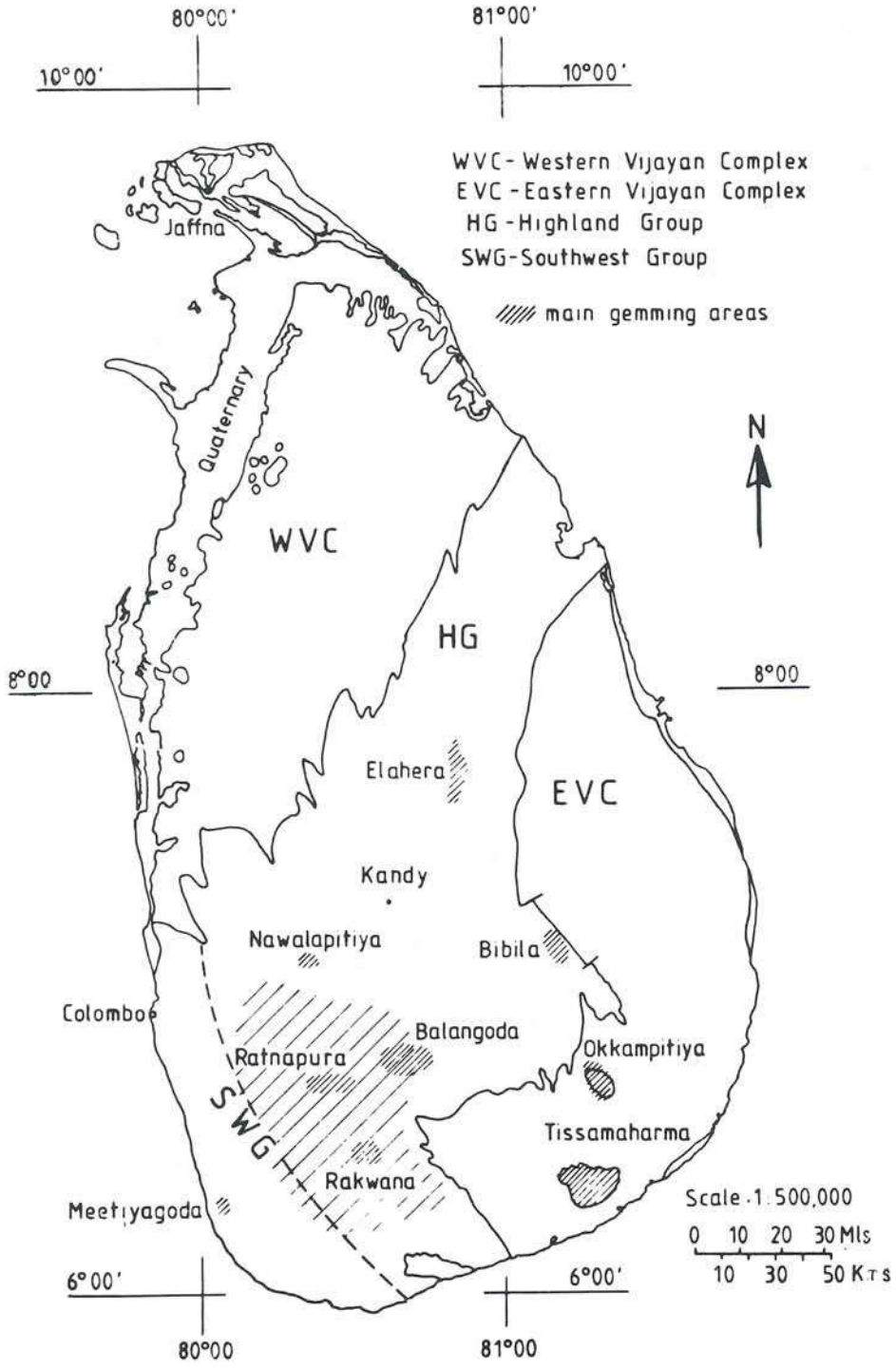

Fig. 1. Generalized geological map of Sri Lanka with major gemming areas.

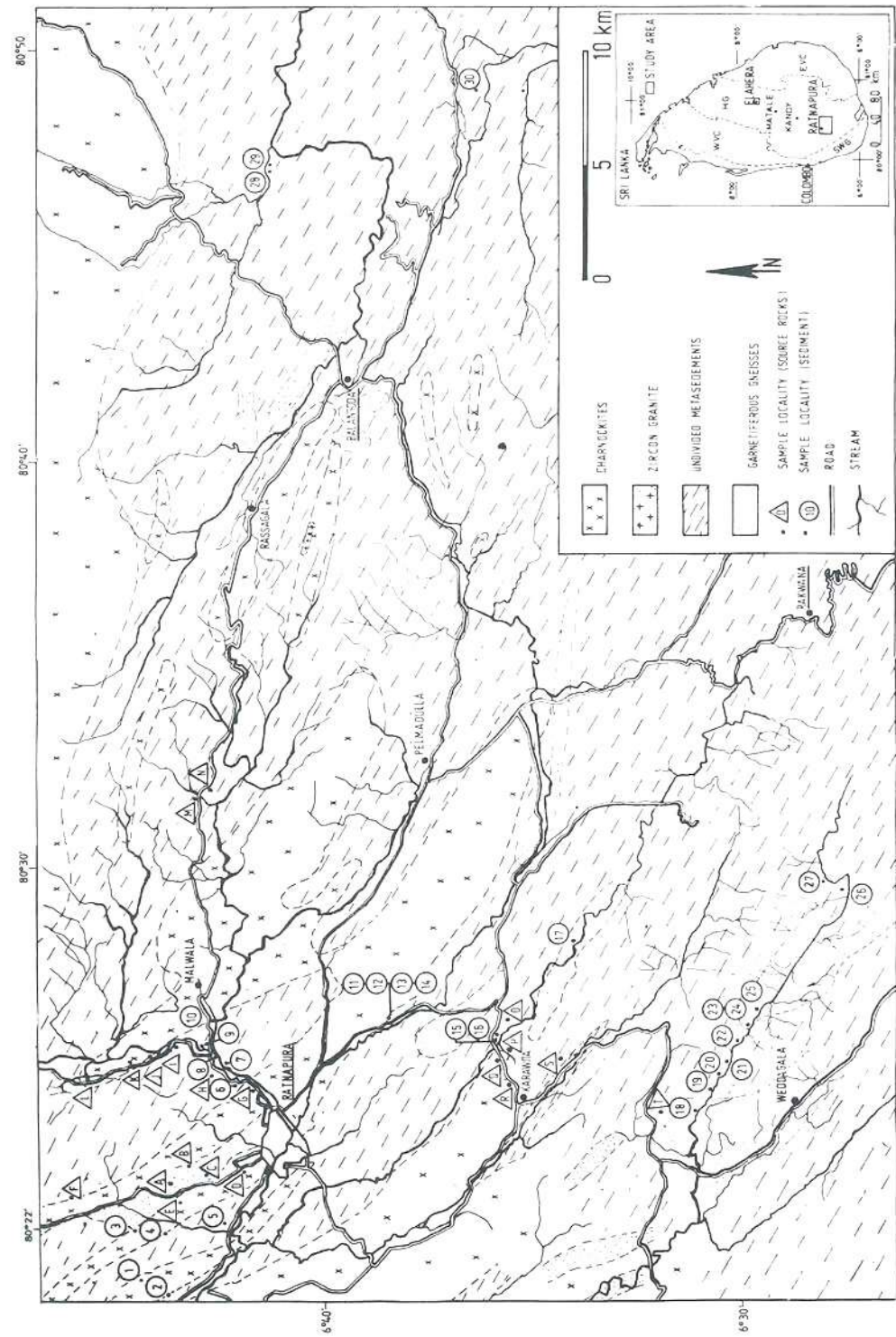

Fig. 2. Generalized geological map of the Ratnapura and Rakwana areas.

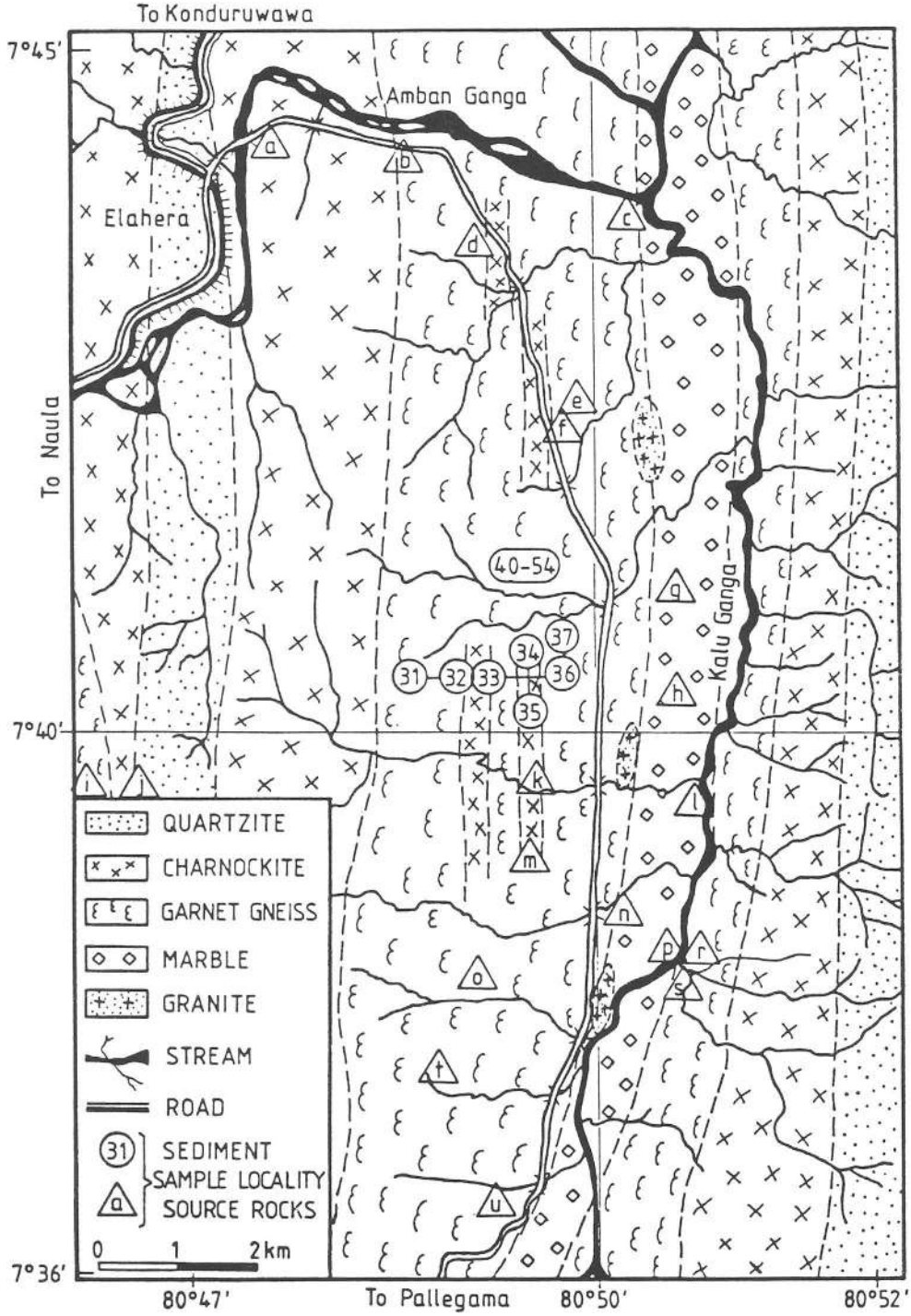

Fig. 3 Generalized geological map of the Elahera area.

Materials and methods

Sampling methods

Samples were collected from locations shown in Figs 2 and 3. All samples were taken from existing gem pits. The pay gravel layers, locally termed 'illam', are usually composed of rounded or subangular pebbles or boulders of quartz, heavy minerals and also gemstones.

15–25 buckets of clayey gravel (illam)* were taken from each pit and washed until clay was removed. The remaining portion, locally termed 'nambuwa', was collected in polythene bags. The weight of an average sample varied in the range of 10–15 kg. However, during the process of washing light gem minerals such as beryl (SG 2.7), and amethyst (SG 2.65) are often washed away with other light minerals.

Analyses

A quarter of a sample was taken for heavy/light mineral separation (Fig. 4) and the percentages of heavy and light fractions measured. Here the minerals having higher densities than tetrabromethane (SG 2.96) were considered as heavy minerals while the others were treated as light minerals.

Other liquids of varying densities are also used in determining densities of minerals. The remaining material of each sample was used in the following series (Fig. 5) of investigations (physical and chemical), for identification and also in the understanding of the processes involved in their formation.

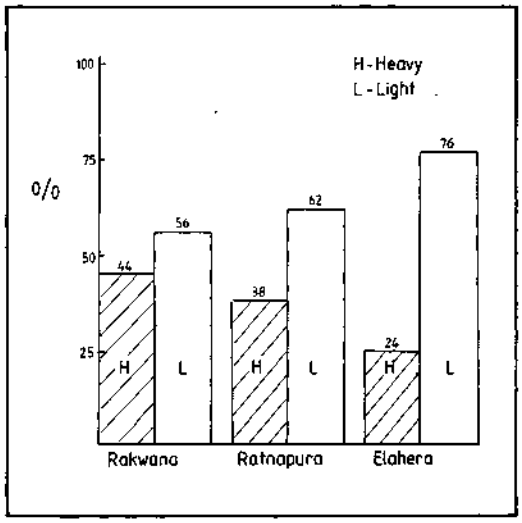

Fig. 4 Percentage of heavy and light minerals in the sediments from the three major gem fields.

*Local miners use a cane basket shaped like a gold prospector's steel pan, which is easily rotated in water even when it is full of 'illam'.

Heavy and light mineral contents of the gem sediments

The heavy mineral content of the Rakwana sediments is higher than that in Elahera. However a marked similarity exists between sediments from Rakwana and Ratnapura the heavy mineral content of the Rakwana sediments being approximately twice as high as that in Elahera (see Fig. 4).

The greater abundance of pegmatites in the SW region could well be a cause for the presence of high amounts of heavy minerals in that area. Minerals, very often found in pegmatites and in rocks associated with cordierite gneisses (Katz, 1972; Wadia and Fernando, 1944; Coomaraswamy, 1906), are found in greater amounts in sediments from the Rakwana and Ratnapura regions.

In the Elahera area, pegmatites are more felsic and the heavy mineral content is very low. Further, the area is flat and covered by thick alluvial sediments and the accumulation of heavy minerals is comparatively less. In the hilly southwest region, the high rate of errosion and transportation washes away the light minerals resulting in high concentrations of heavy minerals in the sediments.

Radioactive minerals

The following minerals found in this study, were categorized as radioactive minerals: monazite; zircon; thorianite; thorite; allanite.

Among these, zircons are widely used in jewellery. It is of interest to note that radioactive zircons have also been found in jewellery. Jobbins *et al.* (1977) have reported a monazite crystal with high radioactivity found in a piece of Sri Lankan jewellery.

The radioactivity of gem-quality zircons varies according to their thorium and uranium contents.

Table 1. Th and U concentration of differently coloured zircons from Sri Lanka

Colour	Th %	U %
Green	0.11176	0.4095
Violet	0.0840	0.1131
Yellow	0.0740	0.1360
Rose	0.0600	0.1190

(Rupasinghe, 1984)

Table 1 shows the Th and U contents of some zircons from Sri Lanka. It is apparent that the green zircons contain greater amounts of Th and U. An average monazite contains about 8% Th and 0.4% U.

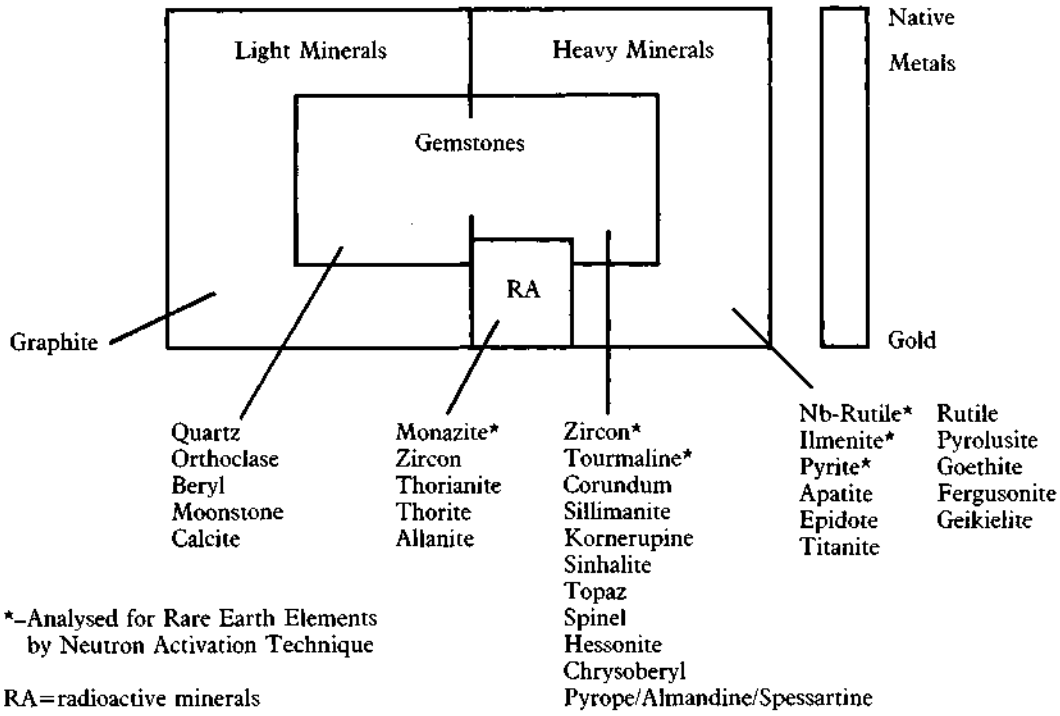

Fig. 5. A general classification of minerals found in washed gem sediments ('nambuwa').

Rare minerals

The following minerals found in the gem gravels of Sri Lanka can be grouped as rare minerals on the basis of their abundance: fergusonite; geikielite; niobian rutile; and also radioactive rutile; allanite; thorite/thorianite.

Fergusonite ($Yt(Nb, Ta)O_4$)

This mineral locally termed 'Gurupachcha'. This is found only in the south-west region. Coomaraswamy (1906) found some fergusonite containing about 2% thoria and over 4% of U_3O_8, and believed to be derived from granites and pegmatites. Generally fergusonite is found as rounded grains, black to brown in colour, and very rich in elements such as Nb, Ta and Be (Rosler, 1980).

Geikielite ($Mg\ Ti\ O_3$)

This mineral is only found in the Ratnapura gem sediments. It is black in colour, and has a fleshy-red streak. This may have been derived from the South-west Group calc-silicates. The X-ray diffractometer pattern is very similar to that of ilmenite and only chemical analysis or specific gravity tests enable one to distinguish this mineral from ilmenite.

Allanite

$(Ca, Ce)_2 (Fe^{3+}, Fe^{2+}) Al_2[O/OH/SiO_4/Si_2O_7]$

This mineral is found in the Elahera, Ratnapura and Rakwana gem sediments, but in small amounts. They are generally rounded in shape and are considered to be derived from pegmatites. It is worthy of note that allanites found in South-west Group sediments are less radioactive than those found in the Highland Group sediments.

Thorite/thorianite ($ThSiO_4/(Th, U)O_2$)

These minerals are found only in the South-west Group sediments and do not generally travel far away from source. Occurrences of rich sources of these minerals were found by previous workers (Coormaraswamy, 1906), in the Bambarabotuwa area. Searle (1962) reported thorianite with about 71.45% of ThO and 22.5% U_3O_8.

Niobian rutile

Niobian rutile in sediments was reported for the first time in Sri Lanka and is found only in the Rakwana sediments. It is very rich in Nb, and Ta, and also contains large amounts of Ce and La (270 ppm, 91 ppm respectively). The chemical composition of this mineral is shown in Table 2.

Table 2. Microprobe analysis of six different points in a 'Niobian rutile'

%	i	ii	iii	iv	v	vi
TiO_2	58.19	50.27	49.66	48.57	58.44	49.36
FeO	8.08	10.53	10.05	10.44	8.43	10.68
Nb_2O_5	24.23	29.67	30.63	31.04	23.23	30.00
Ta_2O_5	9.50	9.54	9.59	9.95	9.90	9.96

Table 2 illustrates the compositional inhomogeneity in a single grain of niobian rutile. The specific gravity of this mineral varies according to the chemical composition, in the range of 4.2–5.6. The Nb content in this mineral is approximately three times higher than that of lunar Nb rutile (Hlava *et al.*, 1972).

Table 3. Nb concentrations (ppm) in rocks and washed sediments ('nambuwa') from Ratnapura and Elahera

	Rocks average Nb	Nambuwa average Nb	Accumulation Factor
Ratnapura	12	166	14
Elahera	10	88	9

Table 4. Nb concentrations in different rock types from Ratnapura and Elahera

Rock sample	No. of samples	Average Nb content
Ratnapura		
Acid charnockite	7	17 ppm
Basic charnockite	6	10 ppm
Intermediate charnockite	2	12 ppm
Biotite gneisses	3	17 ppm
Qtz Felds. Gneisses	2	4 ppm
Sediments	30	22 ppm
Elahera		
Charnockite	4	8 ppm
Gneisses	11	12 ppm
Marble	4	1 ppm
Sediments	6	24 ppm

Tables 3 and 4 show the Nb contents of 'nambuwa' and various rocks respectively. It can be seen from these tables that:–

1 acid charnockites contain nearly twice as much Nb as basic charnockites (17 ppm and 10 ppm respectively).
2 biotite gneisses contain Nb amounts similar to acid charnockites (17 ppm).
3 Nb content in Elahera nambuwa is less than that in Ratnapura and Rakwana (88 ppm, 113 ppm and 158 ppm respectively).
4 the accumulation factor (Table 3) indicates that Nb minerals accumulate in the Ratnapura sediments more than in Elahera sediments.

The differences in physical, mineralogical and geochemical properties of sediments may be due to their geological, geomorphological and hydrological historics.

The Nb contents in the size fraction $<0.63\mu m$ of gem sediments from Ratnapura, Rakwana (SW Group) and Elahera are about the same. But Nb in 'nambuwa' from SW region is higher than in 'nambuwa' from Elahera by a factor of two.

Cuprite (CuO)

This mineral has also been found for the first time in Sri Lanka, in the Rakwana sediments. This porous and earthy-grey mineral has been tested by X-ray diffractometry and its identification confirmed. Coomaraswamy (1906) has reported a few occurrences of native copper in the Pelmadulla area. These were found in laterites with ferruginous concretions. The presence of cuprite in this area is a clear indication of a possible occurrence of native copper.

Gold

The 'Mahawangsaya' (the written history of Sri Lanka – which runs back some 2600 years) states that Sri Lankans have used gold in their jewellery, religious monuments and thrones, for thousands of years.

Dissanayake and Karunaratne (1984) in their geo-archaeological study state that the ancient Sinhalese obtained native gold from many different locations throughout the island. During the course of this study, three native gold nuggets of about 0.6 g were found in 'nambuwa' from the SW region and the people in certain villages (e.g. Omatta) had made jewellery from this locally found gold. In the seventeenth century, planters in these areas found gold in some alluvial sediments, but due to technological constraints this industry has been abandoned. In order to evaluate the economic feasibility of these gold-bearing sediments, a detailed study is essential.

Rare-earth element distribution in minerals

Nb-rutile, monazite, zircon, tourmaline and pyrite have been analysed by neutron activation analysis for REE and 25 other elements (see Table 5). Zircon and monazite are rich in the REE as well as Th and U.

Acknowledgements

Grateful thanks are due to Messrs S.M.B. Amunugama, K. Dunuhappawa and Mrs J. Wijesekera for their assistance.

Table 5. Neutron Activation Analytical data of some important minerals found in Sri Lankan gem sediments

	Zircon	Ilmenite	Nb-rutile	Pyrite	Tourmaline	Monazite
Nb_2O_5	–	–	24.23%	–	–	–
Ti	–	32.6%	30.00%	–	–	–
Fe	0.1%	36.1%	8.25%	47.58%	11.65%	–
Na	6	18.4	370	29	1.86%	538
K	15	18	120	25	150	1.01%
Sc	11.6	53	130	25	162	2
Cr	–	350	–	9130	44	20
Mn	4	2300	154	4	4215	85
Co	3	55	–	158	–	100
Zn	–	470	–	–	360	–
Ga	–	4	33	–	383	–
As	–	1	–	13	3	–
Se	–	–	–	12	–	–
Br	–	–	44	5	3	–
Sr	–	–	40	–	–	–
Zr	47%	–	–	–	–	1.35%
Mo	–	15	–	–	–	–
In	–	–	2	–	–	–
Sb	–	1	–	1	1	25
Ba	–	–	220	–	–	5000
La	0.4	11	91	1	2	12
Ce	–	26	270	–	2	26%
Sm	–	1	–	0.04	436	1%
Eu	0.5	0.1	0.5	0.14	–	104
Tb	2.2	–	–	–	–	437
Dy	19	0.5	–	–	–	1032
Ho	8	–	–	–	–	–
Yb	74	0.3	–	–	–	123
Lu	16	0.9	–	–	–	35
Hf	2%	4.5	447	–	–	–
Ta	1	78	7%	–	1.40	–
W	–	22	2844	–	–	–
Au	–	–	–	0.03	–	–
Th	425	4	25	–	–	8.34%
U	2410	–	254	0.17	–	3640

Note: All values in ppm except those indicated as %.

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[*Manuscript received 4 April 1985.*]

Gemmological Abstracts

ALIPRANDI, R. 1984. Qualche osservazione sulla presenza di inclusioni in rubini sintetici da fondente di recente produzione. (Observations on the presence of inclusions in synthetic ruby from the beginning to the latest productions.) *La Gemmologia*, **10**, 3/4, 15–19, 5 figs in colour.

Characteristic inclusions in different types of synthetic ruby are described and illustrated. M.O'D.

ALIPRANDI, R., GUIDI, G. 1985. Berillo bicolore dell'Orissa (India). (Bi-colour beryl from Orissa, India.) *La Gemmologia*, **10**, (sole issue of 1985), 27–31, 8 figs (3 in colour).

A cut stone from Orissa, India, had colourless and golden yellow sections. RI of the two sections were 1.570, 1.575 and 1.574, 1.580, respectively. SG was 2.73–2.74. A much higher Fe^{3+} content was found in the golden sections (0.67% compared with 0.13%). M.O'D.

BENAVIDES, M.E. 1985. Gemología. (Gemmology.) *Gaceta Mineralógica, Sociedad Mexicana de Mineralogía*, **1**, 3, 12–14, 1 fig.

A short account of what constitutes a gemstone. M.O'D.

BORELLI, A. 1981. La 'turquerenite' o 'turchese afgana' (magnesite colorata artificialmente) un sostituto minore della turchese. ('Turquerenite' or 'Afghan turquoise' (artificially coloured magnesite) a minor turquoise substitute.) *La Gemmologia*, **7**, 3/4, 14–17, 3 figs (2 in colour).

Dyed magnesite with an SG of 2.69–2.77 and a hardness of between 4 and 5 has been used as a turquoise imitation. A strong absorption band at about 590nm is illustrated and there is also absorption in the violet with fainter bands in the blue. M.O'D.

BORELLI, A. 1983. Turchese: porposta di classificazione e nomenclatura gemmologico-merceologica. (Turquoise: proposals for a classification and nomenclature for gemmology and commerce.) *La Gemmologia*, **9**, 1/2, 22–8.

A system of classification and nomenclature for turquoise is outlined which includes treated and imitation material as well as synthetic stones. M.O'D.

BORELLI, A. 1984. Metodo rapido per la distinzione dell'ambra dai suoi sostituti naturali o artificiali. (A quick method of distinguishing amber from its natural and artificial substitutes.) *La Gemmologia*, **10**, 3/4, 10–14.

Simple tests are outlined. M.O'D.

BORELLI, A., SBRANA, G. 1981. Uso della spettrografia I.R. per distinguere la turchese naturale da quella sintetica e dagli altri sostituti e per rilevarne eventuali sofisticazioni. (Use of infrared spectrography to distinguish between natural turquoise and synthetic material and various substitutes with means of increasing sophistication.) *La Gemmologia*, **7**, 3/4, 9–13, 2 figs.

Infrared spectroscopy can help to distinguish between natural and synthetic turquoise and some of its imitations. IR spectra are illustrated. M.O'D.

BORELLI, A., TROSTI FERRONI, R. 1981. Metodo non distruttivo per la determinazione al diffratometro a R.X. di gemme policristalline tipo giada e tipo turchesse, delle loro imitazioni naturali e di certi sostituti artificiali. (A non-destructive method for the X-ray diffraction study of jade- or turquoise-like polycrystalline gems, their natural imitations and some artificial substitutes.) *La Gemmologia*, **7**, 1/2, 5–10, 4 figs (1 in colour).

X-ray diffraction has been used to identify natural, natural imitations and man-made imitations of jade- and turquoise-like polycrystalline minerals. Diffraction patterns are given. M.O'D.

BORELLI, A., TROSTI FERRONI, R. 1981. Un inconsueto materiale tipo giada. (An unusual jade-like material.) *La Gemmologia*, **7**, 1/2, 11–12, 3 figs (1 in colour).

A green material resembling jade was found to be an amphibole of the glaucophane type. X-ray diffraction was used and the spectra obtained are given. M.O'D.

BOSCARDIN, M., COLMELET, G., VIOLATI TESCARI, Q. 1982. Xonotlite: un nuovo minerale italiano di interesse gemmologico. (Xonotlite, a

new Italian mineral of gemmological interest.) *La Gemmologia*, 8, 3/4, 12–16.

Xonotlite, a calcium silicate with the composition $Ca_3Si_3O_8(OH)_2$ and a member of the monoclinic crystal system, has been found in an area of contact between monzonitic rocks and Triassic dolomites at Contrada, Molini di Laghi, Vicenza, Italy. The hardness is 6 and the colour pink and white veining. RI is $\alpha = \beta = 1.583, \gamma = 1.593$. M.O'D.

Bosch-Figueroa, J.M. 1985. Caracteristicas morfologicas de los diamantes. (Morphological characteristics of diamonds.) *Gemologia*, 23, 67/68, 14–22, 2 figs.

Characteristics of diamond crystals from a number of South African mines are given. M.O'D.

Bosch-Figueroa, J.M. 1985. Tratamientos empleados para modificar el color del topacio. (Treatment used to modify the colour of topaz.) *Gemologia*, 23, 67/68, 23–8, 4 figs.

The treatment of topaz by a variety of methods resulting in alteration of colour is described. M.O'D.

Breiter, K., Pasava, J. 1986. Bohemian quartz. *Lapidary Journal*, 39, 11, 54–5, 4 figs.

Ferruginous quartz is found in some Ordovician volcano-sedimentary iron ore deposits south-west of Prague, Czechoslovakia. A star-like red and yellow quartz can be found on dumps near the mines at Zajecov and Svata Dobrotiva. M.O'D.

Brown, G. 1985. Conversion kits for built-in LED refractometer light sources. *Australian Gemmologist*, 15, 12, 456–8, 3 figs.

An evaluation of Snow kits supplied for use with different makes of refractometer. Fitting in some instances requires disassembly of the instrument which might invalidate a guarantee. R.K.M.

Brown, G., Hamid, D., Kelly, S.M.B. 1985. Some information on the Kashmir sapphires. *Australian Gemmologist*, 15, 12, 448–9, 2 figs in colour.

Features extracts from diary of Melbourne dealer, George Hamid, who visited the area in 1982 but found no Kashmir sapphires. Suggests that the day of the Kashmir sapphire is over. R.K.M.

Brown, G., Snow, J. 1985. Green dyed 'crackled beryl'. *Australian Gemmologist*, 15, 12, 454–5, 6 figs.

An 8.1 ct leek-green beryl which owed its colour to heating and quenching in green dye. R.K.M.

Brown, G., Snow, J. 1985. The Relite refractometer light source. *Australian Gemmologist*, 15, 12, 458–9, 1 fig.

An evaluation of an extra-bright LED source for use with batteries or 9V DC mains converter. Height of LED is adjustable. R.K.M.

Burls, J. 1985. Diamonds from the Emerald Isle. *Optima*, 33, 169–79, 5 figs.

Historical survey of the development of the De Beers Shannon plant synthesizing diamond grit, producing syndite and syndie (for wire drawing) occasioned by its Silver Jubilee. E.S.

Butini, E., Aliprandi, R. 1981. Corallo: imitazioni e trattamenti. (Coral: imitation and treatment.) *La Gemmologia*, 7, 1/2, 13–17.

Descriptions and a table of coral and its imitations, including treated material, are given. Among the natural simulants palygorskite is suggested as a possibility. M.O'D.

Caucia, F., Sacchetti, A., Setti, M., Veniale, F. 1984. Studio di opali naturali e sintetici. (A study of natural and synthetic opal.) *La Gemmologia*, 10, 1/2, 16–21, 2 figs.

Natural and synthetic opals were examined by X-ray diffraction, thermal analysis, IR spectrometry, electron microscopy and the electron microprobe. Different types of structure are identified. M.O'D.

Collins, A.T., 1983. Centri di colore nei diamanti. (Colour centres in diamond.) *La Gemmologia*, 9, 3/4, 20–46, 19 figs.

A detailed review of the role played by colour centres in the coloration of diamond with reproduction of absorption spectra. M.O'D.

Couty, R., Velde, B. 1986. Pressure-induced band splitting in infrared spectra of sanidine and albite. *American Mineralogist*, 71, 99–104, 6 figs.

In the infrared spectra of sanidine and albite under pressures of up to 40 kbar convergence was noted. New bands were seen in the sanidine spectra and these are attributed to changes in the position of the alkali ion in the structure as it influences the oxygents of the tetrahedral network. M.O'D.

Cozar, J.S. 1981. Alejandrita sintetica. (Synthetic alexandrite.) *Boletin del Instituto Gemológico Español*, 21, 31–5, 8 figs in colour.

Cut specimens of synthetic alexandrite grown by Creative Crystals Inc. of Concord, California, were examined. RI was 1.740–1.749 and SG 3.70. A

normal absorption spectrum for alexandrite was observed. Flux inclusions indicated the origin. M.O'D.

COZAR, J.S. 1984. Enstitita 'Ojo de Gato' en el olivino de la isla de Lanzarote. (Cat's-eye enstatite in the olivine of the island of Lanzarote.) *Boletin del Instituto Gemológico Español*, 25, 30–50, 26 figs in colour.

Cat's-eye green enstatite is found at Lanzarote in the Canary Islands where olivine of gem quality occurs. The enstatite is found as macroscopic inclusions in the olivine. M.O'D.

COZAR, J.S., RIVAS, P., FERNADEZ, M. 1985. Alteraciones hidrotermales caracteristicas de la kimberlita de la chimenea Dutoitspan. (Characteristic hydrothermal alterations of the Dutoitspan kimberlite pipe). *Boletin del Instituto Gemológico Español*, 26, 5–24, 12 figs (11 in colour).

A kimberlite sample from the Dutoitspan diamond mine and its composition assessed; pectolite is among the minerals identified. M.O'D.

DE MICHELE, V. 1981. Materiali gemmiferi italiani. (Italian gem materials.) *La Gemmologia*, 7, 3/4, 17–25.

A list with brief descriptions of Italian gem and ornamental materials is given. Among them are adularia, albite, amber, andalusite, anglesite, apatite, axinite, beryl, varieties of quartz, chrysoberyl, datolite, diopside, epidote, euclase, garnets, leucite, olivine, opal varieties, prehnite, serpentine, tourmaline, vesuvianite and zircon. M.O'D.

DONTENVILLE, S., CALAS, G., CERVELLE, B. 1986. Etude spectroscopique des turquoises naturelles et traités. (Spectroscopic study of natural and treated turquoise.) *Revue de Gemmologie*, 86, 3–4, 3 figs.

Second part* of a paper covering the spectra of Gilson turquoise and plastic-impregnated turquoise. M.O'D.

DRAGSTED, O. 1985. Nummite. *Australian Gemmologist*, **15**, 12, 461, 2 figs in colour.

A new ornamental variety of gedrite found at Godthab Fjord, Greenland, is brown with golden inclusions. R.K.M.

FJORDGREN, O. 1986. Infrared detective. *Lapidary Journal*, **39**, 12, 39–41, 1 fig.

Infrared photography can be used to detect heat treatment of geuda corundum. M.O'D

* The first part was abstracted in *J.Gemm.*, 1986, **20**, 2, 125–6.

FLAMINI, A., GASTALDI, L., GRUBESSI, O., VITICOLI, S. 1983. Contributo della spettroscopia ottica ed EPR alla distinzione tra smeraldi naturali e sintetici. (The contribution of optical spectroscopy and EPR to the distinction between natural and synthetic emerald.) *La Gemmologia*, **9**, 1/2, 6–11, 3 figs.

Studies using optical absorption spectroscopy and EPR on natural and synthetic emerald are discussed. Work was carried out in a wide temperature range. Spectra are reproduced and distinction said to be nearly conclusive. M.O'D.

FLAMINI, A., GASTALDI, L., GRUBESSI, O., VITICOLI, S. 1983. Sulle caratteristiche particolari del berillo rosso dell'Utah. (Particular characteristics of red beryl from Utah.) *La Gemmologia*, **9**, 1/2, 12–20, 20 figs (12 in colour).

Cut stones and crystals of red beryl from Wildhorse Spring and Wah Wah, Utah, USA, were studied with a variety of methods. Colour is related principally to divalent manganese and shows in cut stones in a variety of characteristic patterns. Concentric pyramidal zoning of colour is noted in many cut stones; the pyramids have orange cores with purple and light pink showing as the edges are reached. M.O'D.

FLAMINI, A., GASTALDI, L., GRUBESSI, O., VITICOLI, S. 1983. Risultati preliminari di sintesi di smeraldi. (Preliminary results on the synthesis of emeralds.) *La Gemmologia*, **9**, 3/4, 6–9, 6 figs (4 in colour).

Single crystals of emerald were grown from a $Li_2Mo_2O_7$ flux. Transition metal ions were used as dopants. Cell dimensions are reported and optical absorption spectra given. A strong band was seen at 825nm and ascribed to iron. M.O'D.

FLAMINI, A., GRUBESSI, O., MOTTANA, A. 1984. Il sistema chimico del berillo e le sue conseguenze sulle proprietà fisiche. (The chemical system of beryl and its significance for its physical properties.) *La Gemmologia*, **10**, 1/2, 6–15, 6 figs.

Synthetic emeralds have smaller unit cell parameters than natural ones and in this paper the presence of water molecules is suggested as one of the causes of this. M.O'D.

FRANCIS, P. 1986. Indian antiquity. *Lapidary Journal*, **39**, 12, 45–55, 3 figs.

An account of the mining in India of amethyst and citrine and their shipment to the West as far back as the first century AD. M.O'D.

FUENTES, J.C., ROSELLO, E.A. 1986. Topacios en la provincia de Catamarca, Argentina. (Topaz

from the province of Catamarca, Argentina.) *Boletin del Instituto Gemológico Española*, 27, 25–8, 5 figs (4 in colour).

Topaz is found at the contact between a metamorphic rock and the host rock of the granitic Papachacra formation in the Belén Dept of Argentina. The mineral is formed hydrothermally; some crystals are up to 50mm in length, euhedral to subhedral and light greenish-yellow. M.O'D.

FUMEY, P. 1986. L'opale precieuse en territoire du Sud-Australien: Coober Pedy. (Precious opal from South Australia: Coober Pedy.) Revue de Gemmologie, 86, 17–20, 4 figs (2 in colour).

An account of the history and geology of the Coober Pedy opal deposit with a diagram of the formations in which it is found. M.O'D.

GARCÍA GIMENEZ, R., LEGUEY JIMENEZ, S. 1981. Influencia de elementos cromóforos en elbaitas zonadas. (Influence of chromophores in zoned elbaites.) *Boletin del Instituto Gemológico Español*, 21, 21–8, 4 figs (2 in colour).

Iron and manganese are shown by spectroscopy to be responsible for the different colours of elbaite tourmaline. Electron microscopy was used to examine the crystals. M.O'D.

GARCÍA GUINEA, J. 1983. Materiales gemológicos españoles, minerals, perspectivas generales. (Spanish gemmological materials, minerals, general overview.) *Boletin del Instituto Gemológico Español*, 24, 9–18, 7 figs (6 in colour).

Spanish gemmological minerals include beryl, topaz, olivine, rose quartz, citrine and variscite. M.O'D.

GARCÍA GUINEA, J. 1986. Materiales gemológicos españoles: los zafiros de Goyán (Pontevedra). (Spanish gemmological materials: sapphires from Goyán (Pontevedra).) *Boletin del Instituto Gemológica Español*, 27, 16–24, 14 figs (9 in colour).

Blue sapphires are found in andalusite masses in mica schist segregation veins at Goyán, Pontevedra, Spain. M.O'D.

GARCÍA GUINEA, J., GALÁN HUERTOS, E. 1985. Materiales gemológicos españoles: yacimientos de cuarzo. (Spanish gemmological materials: quartz deposits.) *Boletin del Instituto Gemológico Español*, 26, 27–40, 18 figs (12 in colour).

The main Spanish quartz deposits of gemmological importance are listed and described. Some examples are analysed. M.O'D.

GARZON JIMENEZ, J. 1983. El color de las gemas. (The colour of gems.) *Boletin del Instituto Gemológico Español*, 24, 21–47, 22 figs in colour.

A comprehensive review of the various causes of colour in gemstones with diagrams of the processes involved. M.O'D.

GAUTHIER, J.-P. 1986. L'opale noble au microscope électronique. (Precious opal under the electron microscope.) *Revue de Gemmologie*, 86, 21–6, 20 figs.

A study of the structure of precious opal as seen with the electron microscope. High quality illustrations are provided. M.O'D.

GRAETSCH, H., FLÖRKE, O.W., MIEHE, G. 1985. The nature of water in chalcedony and opal-C from Brazilian agate geodes. *Physics and Chemistry of Minerals*, 12, 300–6, 10 figs.

Water species $H_2O_{(SiOH)}$ and $H_2O_{(mol)}$ in chalcedony and opal-C (a type of opal occurring with chalcedony in Brazilian agates) were studied by a variety of techniques. Both chalcedony and opal-C have fully hydrated surfaces at the open porosity and contain additional water at inner surfaces which are closed micropores in the case of opal-C and regions of accumulated defects in chalcedony. Tests indicated that chalcedony is formed at low temperatures. M.O'D.

GRECO, S. 1982. Notizie sull'ambra di Santo Domingo. (Note on amber from Santo Domingo.) *La Gemmologia*, 8, 1/2, 25–34, 8 figs in colour.

Characteristics of amber from Santo Domingo (Dominican Republic) are described and illustrated. M.O'D.

GÜBELIN, E. 1985. Il riconoscimento dei nuovo rubini sintetici. (The recognition of the new synthetic rubies.) *La Gemmologia*, **10**, (sole issue of 1985), 6–18, 42 figs (41 in colour).

Translation into Italian of a paper first published in *J. Gemm.*, 1983, **XVIII**, 6, 477–99. M.O'D.

GÜBELIN, E. 1986. Deux nouveaux produits artificiels sur le marché des pierres précieuses: le rubis synthétique 'Ramaura' et le gallo-aluminate d'yttrium. (Two new artificial products on the gem market: Ramaura synthetic ruby and yttrium gallium aluminate.) *Revue de Gemmologie*, 86, 15, 8 figs in colour.

Second part of a paper translated from the German and covering characteristic inclusions in the materials concerned, which are illustrated. M.O'D.

GUILLÉN, P. 1986. El coral. (Coral.) *Boletin del Instituto Gemológico Español*, 27, 6–15, 14 figs in colour.

An attractively illustrated account of the use of coral as an ornamental material. M.O'D.

HOFMEISTER, A.M., ROSSMAN, G.R. 1985. A model for the irradiative coloration of smoky feldspar and the inhibiting influence of water. *Physics and Chemistry of Minerals*, 12, 324–32, 6 figs.

Radiation induced smoky colour and associated EPR signals were found to develop in potassium feldspar when free from structurally bound water. Fluid inclusion water does not affect coloration. M.O'D.

HOFMEISTER, A.M., ROSSMAN, G.R. 1986. A spectroscopic study of blue radiation coloring in plagioclase. *American Mineralogist*, **71**, 95–8, 4 figs.

Blue in sodic plagioclase arises from electronic transitions of Pb: a similar transition gives the colour in amazonite. Both types of feldspar have elevated Pb concentrations, structurally incorporated hydrogen, similar response of the colour to heating and irradiation and similar features in the absorption spectrum, including band shape, position and polarization. M.O'D.

HUANG, Z.H., GANDAIS, M. 1985. Some physical properties of a labradorite single crystal from Mexico. *Bulletin de Mineralogie*, 108, 829–33, 3 figs.

A gem-quality labradorite crystal was shown to have a plagioclase structure and refractive indices of γ 1.5689, β 1.563 and α 1.5598. These values correspond to a composition of An_{62} which was confirmed by the electron microprobe. Some albite twin lamellae were seen but otherwise the crystal was transparent with no compositional zoning or inclusions. The size was $2 \times 2 \times 1$cm. M.O'D.

KANKA, A. 1986. Achate von Waldhambach. (Agate from Waldhambach.) *Lapis*, **11**, 4, 25–7, 7 figs (6 in colour).

Fine agate, with some amethyst, is found at Waldhambach, north-west of Karlsruhe, West Germany. M.O'D.

KOURIMSKY, J. 1980. Pietre preziose della Cecoslovacchia. (Precious stones of Czechoslovakia.) *La Gemmologia*, **6**, 3/4, 5–13, 11 figs.

The different geological areas of Czechoslovakia are reviewed: amethyst, rose quartz and agate, aquamarine and golden beryl, are found as well as moldavite which is probably the best-known ornamental material. M.O'D.

LANDAIS, E. 1981. Assorbimento del berillo nell-infrarosso: suo contributo alla distinzione fra smeraldi naturali e sintetici. (Absorption of beryl in the infrared: its role in distinguishing between natural and synthetic emerald.) *La Gemmologia*, 7, 3/4, 5–14, 6 figs.

Details of the IR absorption spectra for a number of natural and synthetic emeralds are given. It is possible to distinguish the natural and hydrothermal product from that grown by the flux-melt method, since the latter shows no water IR spectrum, whereas the other two show the characteristic bands. M.O'D.

LEGUEY, S., MORANTE, M., MEDINA, J.A. 1982. Inclusiones piramidales en berilos relacionades con fenomenos de corrosion. (Pyramidal inclusions in beryl related to corrosion phenomena.) *Boletin del Instituto Gemológico Español*, 23, 17–27, 14 figs (6 in colour).

Inclusions in a beryl crystal from Minas Gerais, Brazil, show pseudo-pyramidal form. Some also display zoning and others a differing coloration and degree of transparency. The differences observed are related to the degree of corrosion encountered during formation. M.O'D.

LIND, T., SCHMETZER, K., BANK, H. 1985. Methods for the distinction of natural and synthetic amethyst. *Australian Gemmologist*, **15**, 12, 463–70, 7 figs in colour.

Several methods are discussed: conoscopic examination for complete uniaxial centre cross; angular colour zones; polysynthetic twinning; fluid, two-phase and ripple-fracture inclusions; sharp lamellar and angular colour zoning; fingerprint pattern on lightly polished surfaces – all denote natural amethyst. Synthetics are untwinned and show none of these features. Infrared spectroscopy shows that absorption line in region of $3500^{cm^{-1}}$ occurs only in the synthetic amethyst. Further methods of discrimination are being sought. R.K.M.

MANGIAGALLI, G., ROSEO, I. 1985. Una rodingite a vesuviana della Valtournenche (Aosta) come materiale di interesse gemmologico. (A vesuvianite rodingite from Valtournenche (Aosta) as a material of gemmological interest.) *La Gemmologia*, **10** (sole issue of 1985, 19–23, 8 figs in colour.

A vesuvianite rodingite resembling jade is reported from Valtournenche (Aosta). RI is about 1.700; SG ranges from 3.07 to 3.32 and there is an absorption line near 460nm. The colour is light to dark green. M.O'D.

MARENSI DE MOURA, O.J., GARCÍA GUINEA, J. 1984. Pegmatitas españolas con berilo y otras similares de Minas Gerais (Brasil). (Beryl-bearing Spanish pegmatites and other similarities with Minas Gerais, Brazil.) *Boletin del Instituto Gemológico Español*, 25, 9–28, 6 figs.

Spanish beryl-bearing pegmatites are related to the Centro Iberica and Ossa-Morena structural units. Beryl occurs in the intermediate zones associated with microcline-perthite, quartz and muscovite, or in metasomatic phases. Similarities with beryl-bearing pegmatites in Minas Gerais, Brazil, are recorded. M.O'D.

MOLINE SALA, A. 1985. Aparato para la observación de fluorescencias en materiales gemológicos. (Apparatus for the observation of fluorescence in gem materials.) *Gemologia*, **23**, 67/68, 5–13, 7 figs.

A device operating with intermittent production of long-wave and short-wave ultraviolet light and of white light is used for gem testing. Construction and results are described. M.O'D.

NASSAU, K. 1982. Quarzo ametista-citrino naturale, trattato e sintetico. (Natural amethyst-citrine quartz, treated and synthetic.) *La Gemmologia*, **8**, 3/4, 17–28, 9 figs (7 in colour).

A translation into Italian and adaptation of papers by the author in *Lapidary Journal*, 1981, **35**, 1, 52–60*. M.O'D.

O'DONOGHUE, M. 1986. Gems and gemmology. *Watchmaker, Jeweller and Silversmith*, March 1986, pp. 54–7, 3 figs in colour.

The first of a new series, this column includes notes on jade and its simulants, the gem minerals of Pakistan, impregnated opal and some new synthetic materials. (Author's abstract.) M.O'D.

O'DONOGHUE, M. 1986. Gems and gemmology. *Watchmaker, Jeweller and Silversmith*, April 1986, pp. 46–8.

The gemstones of Pakistan, methods of gemstone weighing, notes on new synthetic materials and on freshwater pearls from China, are included in this month's column. (Author's abstract.) M.O'D.

PEARSON, G. 1985. The role of water in cracking of opal. *Australian Gemmologist*, **15**, 12, 435–45, 3 figs.

In an attempt to assess cracking potential in Australian opal the author used samples from Coober Pedy (3 areas), Mintabie, Lightning Ridge and White Cliffs (2 areas) in a series of experiments which included heating in various fluids. At 100°C, held for four hours, no cracking occurred. At 200°C cracking occurred quickly in all specimens, the more so in that from the Coober Pedy Eleven Mile mine. Unresolved anomalies were found and the experiments do not appear to have contributed answers as to why some opals crack at ambient temperatures. R.K.M.

POIROT, J.-P. 1986. Pierres précieuses. (Precious stones.) *Monde et Minéraux*, **71**, 28–41, 12 figs in colour.

First part of a very general though beautifully-illustrated guide to the gem varieties of minerals. M.O'D.

POUGH, F.H. 1986. Ammolite: grandmother of pearl. *Lapidary Journal*, **39**, 10, 35–41, 9 figs in colour.

Fossilized ammonite shell from a location near Lethbridge, Alberta, Canada, shows an attractive play of colour and has been used ornamentally. The play of colour is more directional than that shown by opal and the spectral succession is less pronounced. Stones have been capped with synthetic spinel. M.O'D.

PRING, A., DIN, V.K., JEFFERSON, D.A., THOMAS, J.M. 1986. The crystal chemistry of rhodizite: a re-examination. *Mineralogical Magazine*, 50, 355, 163–72, 6 figs.

An analysis of rhodizite using high-resolution electron microscopy, magic angle spinning nuclear magnetic resonance, single crystal X-ray structure refinement and fresh chemical investigation has given the formula $(K_{0.46}Cs_{0.36}Rb_{0.06}Na_{0.02})\ \Sigma_{0.90}\ Al_{3.99}Be_4(B_{11.35}Be_{0.55}Li_{0.02})O_{28}$. M.O'D.

PROUT, B.A.W. 1986. Jet. *Wahroongai News*, **20**, 1, 6–7.

A brief account of the history and rise and fall in fashion of this rather gloomy mourning gem. The introduction of the cheaper black glass, vulcanite and ebonite contributed to its decline as much as did changes in fashion. R.K.M.

SAMUELS, S.K. 1986. Burma's jade. *Lapidary Journal*, **39**, 12, 20–5, 1 fig.

Short account of Burmese history as it affects jade recovery and use. M.O'D.

SARMIENTO CARPINTERO, L. 1985. La importancia de las inclusiones en la gemología. (The importance of inclusions in gemmology.) *Boletin del instituto Gemológico Español*, 26, 41–9, 11 figs in colour.

A well-illustrated survey of the more important inclusions in gemstones. M.O'D.

* Abstracted in *J.Gemm.*, 1981, **XVII**, 8, 638.

SAVASCIN, Y. 1986. Anatolia. *Lapidary Journal*, **39**, 12, 42–4, 5 figs in colour.

Gem materials found in Anatolia (Turkey) include fire opal from Simaw and chalcedony from Eskisehir-Saricakaya. Obsidian is also found. M.O'D.

SCHMETZER, K., BANK, H. 1984. Crystal chemistry of tsilaisite (manganese tourmaline) from Zambia. *N. Jb. Miner. Mh.*, 2, 61–9.

Chemical, optical and X-ray data of manganese-bearing tourmaline from Zambia are given. The tourmalines have manganese contents of approximately 6–7% MnO and iron contents 0.1% FeO, and they represent intermediate members of a solid solution series between the idealized end members elbaite, $Na(Li_{1.5}Al_{1.5})Al_6(BO_3)_3Si_6O_{18}(OH,F)_4$, and tsilaisite, $Na(Mn_{1.5}Al_{1.5})Al_6(BO_3)_3Si_6O_{18}O_{1.5}(OH,F)_{2.5}$. An isomorphic replacement of $Li^+ + (OH)^- \rightarrow Mn^{2+} + O^{2-}$ is found to be dominant in natural manganese tourmalines over a second type of coupled substitution $Al^{3+} + O^{2-} \rightarrow Mn^{2+} + (OH)^-$, which is present only in a minor amount. Tourmaline from Zambia has a composition of about 70% of the tsilaisite end member, and the physical properties of this intermediate tourmaline (a_o 15.915, c_o 7.123 Å; n_e 1.623, n_o 1.647; D 3.13 g/cm^3) are close to the data published for members of the elbaite-schorl solid solution series. Author's abstract. K.S.

STELLER, E.T. 1985. Angles. *Australian Gemmologist*, **15**, 12, 450–3, 1 fig.

Criticism of the Australian Ideal Design for round Brilliant for diamond (*Australian Gemmologist*, 1984, **15**, 7, 219–26, 243–6*) which presented the peculiar idea of sixteen pavilion facets. Dr Steller, a retired University mathematician, also criticises a paper by Dr Suzuki (*Australian Gemmologist*, 1970). † R.K.M.

SUNAGAWA, I. 1983. Diamanti, naturali e sintetici. (Natural and synthetic diamond.) *La Gemmologia*, **9**, 3/4, 10–19, 3 figs.

A general review of natural and synthetic diamonds with discussion of their formation. M.O'D.

SWOBODA, E.R. 1986. Green phantoms. *Lapidary Journal*, **39**, 11, 19–24, 4 figs (1 in colour).

Phantom inclusions in various types of quartz are described with anecdotes of the author's field trips in Brazil. M.O'D.

* Abstracted in *J.Gemm.*, 1985, **XIX**, 5, 438.
† Abstracted in *J.Gemm.*, 1971, **XII**, 5, 180–1.

TALAVERA ESCUDERO, A. 1981. Perlas cultivadas de agua dulce. (Freshwater cultured pearls.) *Boletin del Instituto Gemológico Español*, 21, 9–10, 4 figs in colour.

A brief description of freshwater cultured pearls with a note on Spanish occurrences. M.O'D.

THEMELIS T. 1986. Oven fresh sapphires. *Lapidary Journal*, **39**, 11, 49–53, 3 figs in colour.

The author describes the heating of colourless corundum to produce blue sapphire in Sri Lanka. M.O'D.

TOMBS, G. 1985. Jade: the gemstone material enigma. *Australian Gemmologist*, **15**, 12, 445–7.

The author describes this as an appreciation exercise. It is little more. R.K.M.

TURREL, M. 1986. Découverte de l'Autriche. (Discovered in Austria.) *Revue de Gemmologie*, 86, 16, 1 fig. in colour.

A short review of Austrian minerals which include emerald from the Habachtal. M.O'D.

VINK, B.W. 1986. Stability relations of malachite and azurite. *Mineralogical Magazine*, **50**, 355, 41–7, 4 figs.

Azurite is formed only under relatively acid conditions at fairly high carbonate activities, these taking place under basic conditions. Malachite is thus the commoner form of copper carbonate. Small changes in carbonate/bicarbonate activities explain the common alteration of azurite to malachite. Eh-pH diagrams show stability relations of the two minerals. M.O'D.

WALTERS, J. 1986. Agate, fact and fantasy. *Lapidary Journal*, **39**, 11, 38–9.

A brief introduction to agate lore. M.O'D.

WOODRUFF, R.E. 1986. Larimar. *Lapidary Journal*, **39**, 10, 26–32, 8 figs (4 in colour).

The name is given to a blue mineral of volcanic origin tentatively identified as a variety of pectolite. It is found in the Dominican Republic about 10km north of the road from Barahona to Bahoruco. M.O'D.

YAMAMOTO, T. 1982. Ostras perliferas Akoya. (Akoya pearl oysters.) *Boletin del Instituto Gemológico Español*, 23, 8–16 6 figs in colour.

A useful review of the various activities of Japanese cultured pearl manufacturers. M.O'D.

ZANCANELLA, R. 1981. Nuovi metodi di analisi degli elementi qualitativi del diamante. (New methods of analysis of qualitative elements in diamond.) *La Gemmologia*, 7, 3/4, 18–24, 1 fig.

A method of plotting and assessing the role of inclusions in the clarity of diamond is suggested. Micron-sized inclusions are noted using appropriate microscopic techniques and are placed in arbitrary shapes (circle, rectangle, square, rhombus) to form a basis for clarity assessment. M.O'D.

ZAPATERO RAMOS, L. 1981. Diapositivos que aumentan el contraste microscópico y su utilización en gemologia. (The use of diapositives to augment microscopic contrast and its utilization in gemmology.) *Boletin del Instituto Gemológico Español*, 21, 13–19, 11 figs in colour.

An explanation of the use of phase contrast microscopy for the study of gemstones. M.O'D.

ZEITNER, J.C. 1986. Quartz, the lapidary favorite. *Lapidary Journal*, 39, 11, 26–32, 5 figs in colour.

A brief introduction to the quartz minerals with special reference to their ornamental usage. M.O'D.

ZEITNER, J.C. 1986. Rare among rare. *Lapidary Journal*, 39, 12, 26–34, 4 figs in colour.

A short illustrated survey of some of the less common gemstones to be found in Asia. Stones discussed include painite, manganotantalite, kornerupine, sinhalite, cymophane, zircon, jadeite, sapphirine, demantoid garnet, iolite, cassiterite and spodumene. M.O'D.

Gem Bulletinen. 1986. 1. Published by Stockholms Gemmologiska Förening, Stockholm, Sweden.

This new journal is reproduced from typescript and contains papers on turquoise and andalusite, with shorter notes. M.O'D.

Book Reviews

BRICE, J.C. 1986. *Crystal growth processes*. Blackie, Glasgow: Halsted Press, New York, pp. x, 298. Illus. in black-and-white. £29.00.

Before this book was published there was no single place in which the student could look for detailed accounts of crystal growth processes; the literature contains many such descriptions but they are nearly always in expensive journals which are hard to locate or in even more elusive conference proceedings. Many descriptions assume some degree of prior knowledge on the part of the reader and most are concerned with specific materials.

In this book the processes themselves are examined after an introductory section dealing with the need for single-crystal materials and with the basic concepts of crystallization. Up to 15 000 tonnes of single crystals are produced world-wide each year for electronics and similar applications as well as for ornament in jewellery. There is thought to be an annual increase in the rate of demand for these substances in the order of 7%. The chapter on basic concepts explains the nature of crystals, their structures and imperfections, and gives particularly valuable notes on phase relations, growth kinetics and transport processes.

Descriptions of the different growth processes come next and deal with the Bridgman and related processes first, followed by the Czochralski and other melt growth techniques. Apparently overall 80% of melt-grown crystals are available from Bridgman and Czochralski methods of growth, but the other 20% can only be obtained by other methods (flux-melt growth, skull-melting, Verneuil, chemical vapour transport, hydrothermal, growth from solid phases). All these methods are described and each section has its own bibliography.

A useful and interesting concluding chapter explains why particular methods of growth are chosen and a postscript suggests that while the demand for single crystal materials is likely to increase, automation of much of the growth process will mean that there will not be a corresponding increase in the number of workers in the field. Those already in it will be concerned with furthering study on the complex interactions of growth parameters on the characteristics of the crystal that they grow. These topics are treated in the book which is highly recommended for anyone with an abiding interest in the formation of crystals. The text is not too rigorous for general consumption. M.O'D.

BURCH, C.R. 1986. *Gemstone inclusions*. Sunderland Polytechnic, Sunderland. Unpaginated. Price on application.

This is a short descriptive catalogue of an exhibition of photographs of gemstone inclusions, the display being held at the Geological Museum, London, from 25 March to 31 May 1986. Exhibits were 100mm × 120mm on Kodak Ektachrome 50 Professional EPY 135 transparency film. M.O'D.

DIETRICH, R.V. 1985 *The tourmaline group*. Van Nostrand Reinhold, New York. pp. xiii, 300. Illus. in black-and white and in colour. £38.45.

There has been no separate monograph on the tourmaline group of minerals since the two books by A.C. Hamlin, *The History of Mount Mica* and *The tourmaline*, both published in the last century and now highly desirable collectors' pieces. Both were enthusiastic reports by a collector and as the state of mineralogy at the time did not allow for the grouping of the tourmaline group minerals into the classes which we know today the present book is particularly welcome. With all the techniques of modern laboratories at his disposal, the author briefly reviews nomenclature and then outlines the different species comprising the tourmaline group. Gemmologists may be surprised to learn that there are eight species with distinct compositions and many more names which have been assigned to colour varieties and hypothetical end-member compositions. The author feels that some old-established names, particularly the colour-based ones, should now be abandoned in the interests of clarity.

Crystal form and habit are treated next and some interesting diagrams have been taken from several early authorities. Structure and chemical composition are then discussed with a most useful account of solid solutions – a topic still not completely understood. Inclusions and the intergrowth of tourmaline with other minerals have a chapter of their own, which is followed by a

discussion of colour. In this and the following sections on physical and optical properties a number of useful tables and diagrams are provided; in particular those of absorption spectra should be consulted when the question of colour alteration arises. The remainder of the book deals with the occurrence of tourmaline; there are appendices, one of them listing localities which have yielded notable specimens or gem quality material, and a fine bibliography of nearly 1,000 general and cited references. A more complete bibliography, of some 2,500 entries, can be consulted on cards at the Department of Mineral Sciences at the National Museum of Natural History, Washington, DC.

This is a book which I hope will be the forerunner of others dealing in this kind of depth with individual gem species. The quality of production is high and the colour pictures, though few in number, quite magnificent. M.O'D.

MAI, P. 1983. *La connaissance des gemmes et de leurs subsituts*. Part 1. (The knowledge of gems and their substitutes.) Published by the author at Anvers. pp. 158. Price on application.

This work forms part of a course on gemmology and is unexceptional. M.O'D.

SINKANKAS, J. (READ, P., ed.) 1986. *Beryl*. Butterworths, London. pp. xiii, 225. Illus. in black-and-white and in colour. £24.00.

This is an abridgement of the author's *Emerald and other beryls**, 1981, Chilton Book Co., Radnor, Pa., USA. The material has been up-dated in some places and the over-all emphasis is on the gemmological aspects of the beryl minerals. The abridgement has been very successful and the presentation and price are very good. M.O'D.

* Reviewed in *J.Gemm.*, 1982, XVIII, 3, 252–3.

Proceedings of the Gemmological Association of Great Britain and Association Notices

OBITUARY

FRANCIS SIDNEY HOPE TISDALL was born on 10 August, 1899, and died on 23 January, 1986. To his colleagues and friends he was known as Sid, and will be well remembered by that name. He was born in England, but his family emigrated shortly after his birth to New Zealand where he lived until he was 14 years old. During this time he attended Wellington College where 'mens sana in corpore sano' (as he would have said) was the rule.

His father being in the sports outfitting business, Sid needed no encouragement to become the keen cyclist and walker that characterized him during the whole of his life.

He also showed considerable scholastic ability. Just before the First World War he returned to England where he attended Four Oaks College, near Sutton Coldfield, Warwicks. Although a good academic scholar, he was attracted to a more adventurous life, and giving his age as 16, in 1914 he enlisted in the Forces so that he could join an Army Band and enjoy his pursuits of drum, piccolo and flute playing. He was on active service for four years and may have remained longer in the army, but his grandfather, the jeweller Samuel Hope, wrote to his Commanding Officer telling him that a job for young Sidney was awaiting him in the family business.

Sid duly joined the family company, but to quote from a personal letter, he says '. . when Works Manager, Gem Ring Department Manager, Designer and Gemmologist (yes the lot!) at my late grandfather's firm . . . I preferred to be a "back-room" boy'.

In 1939 he left the company to start his own business buying and selling second-hand jewellery in Manchester and Liverpool. At the end of the Second World War he moved to Rhos-on-Sea which enabled him to be nearer to his beloved mountain scenery, but after an unsuccessful business venture returned to Walmley. Here he worked as a jewellery designer and consultant, retiring from the firm of Deakin and Francis at the age of 67.

Sid was a man of many parts. Although a fine athlete winning awards for ice dancing, acrobatic diving and walking 50 miles on his 60th birthday, in common with many others denied the luxury of a university education, he continued to pursue his studies with great diligence and concentration. He obtained the Fellowship Diploma with Distinction in 1935, and the Diamond Diploma in 1966. In 1938 he was awarded the Certificate of Merit for Jewellery Design at the then Vittoria Street School for Jewellers and Silversmiths, Birmingham.

Sid Tisdall

His keen interest in gemmology enabled him to obtain the post of Lecturer in Gemmology at this College and he began teaching in 1938. This activity, although to be his main interest for the rest of his life, did not prevent him from teaching classical Greek, taking vigorous exercise hill walk-

ing, pursuing his keen interest in photography and forming the North Birmingham Cycling Club.

He was a prolific writer. Many of his old students will recall his beautifully written RI and SG tables and his 'full answers to questions likely to appear in the next examinations'. The latter would sometimes occupy three pages of meticulous handwriting. As would be expected, bad spelling was an anathema to him and he was much troubled by the decline in the writing ability of his students.

As gemmological correspondent of the *British Jewellery and Watch Buyer*, he contributed many useful and interesting articles and published many papers in *The Gemmologist*, *The Journal of Gemmology* and *Gems*. He was a thorough gemmologist of the old practical school, being a great advocate of the X10 lens and down-to-earth commonsense. In some circles in London he was known as the 'Robert Webster of the Midlands'.

In 1977 on the 25th Anniversary of the formation of the Birmingham Branch of the Gemmological Association, he was given the Sir James Walton Memorial Library Award 'in sincere recognition of many years hard work for gemmology in Birmingham'.

His wife Violet died in 1979 after a long period of decline during which time Sid attended devotedly to her needs. He was a religious, God-fearing man, who knew his Bible well and did his best to live by its teaching.

Those of us who knew him closely will remember his intense interest in and dedication to his subject, his enthusiasm for teaching, his forthright manner and his kindness.

An attack of shingles in later life dealt a severe blow since his eyesight became impaired. This was followed shortly by a severe stroke. He struggled to continue with an active life for three years, but died peacefully from heart failure.

He leaves two sons, Neil and David, and a daughter Barbara. Sid was buried on 30 January at Sutton Coldfield Cemetary. He will be missed by his many friends, but he will not be forgotten.

A.D.M.

* * *

Miss Jean Isobel Platts, F.G.A. (D.1970), Sheffield, died in hospital on 25 February, 1986.

Jean was a founder member of the South Yorkshire and District Branch of the Gemmological Association which was formed in 1977. She gave continuing and devoted service as a committee member, Secretary and Chairman.

She was formerly a teacher of Gemmology and Diamond Diploma courses at the Sheffield City Polytechnic, where she was directly responsible for the increase and improvement of the specimen collection and the instrumentation in the department.

Jean was the principal organizer for the South Yorkshire Branch and a diplomatic co-ordinator. Her quiet efficiency and gentle manner will be greatly missed by all the members.

* * *

It is with great regret that we announce the death of Mr Harry Wheeler, F.G.A., former Secretary of the Association, on 5 June, 1986. A full obituary notice will appear in the October issue of the *Journal*.

GIFTS TO THE ASSOCIATION

The Council of the Association is indebted to Mr R. Holt, London, for the following gifts: an agate engraved with the head of a queen; a specimen of rough African emerald of 103.5 ct; an andradite variety melanite garnet crystal group on matrix from Italy; a cleavage piece of chrome fluorite from Zambia; garnet and tourmaline rough from Africa.

NEWS OF FELLOWS

Mr Alan Hodgkinson, F.G.A., toured Hong Kong and Bangkok in March 1986. He organized two two-day practical gemmology courses, as well as giving several lectures to the Hong Kong Gemmological Association and the Asian Institute of Gemmology.

On 9 May, 1986, Dr J.B. Nelson, Ph.D., F.G.S., C.Phys., F.Inst.P., F.G.A., gave a lecture with demonstrations using large scale atomic structure models on 'The structure and chemistry of gemstone minerals' to the Sussex Mineral and Lapidary Society at Haywards Heath.

On 4 June, 1986, Dr Nelson gave a talk to the Brent Geological Society, Brent, entitled 'Diagnostic inclusions in faceted gemstones'. He employed a gemstone immersion microscope of his own design to project images of the internal microstructures of some thirty stones directly on to a screen. Its most valuable feature proved to be its ability to isolate a particular image from the general 'optical noise' by making controlled movements of the stone while immersed in the matching liquid.

On 28 May, 1986, at the Annual Conference of the National Association of Goldsmiths held at the Hythe Imperial Hotel, Hythe, Mr Kenneth Scarratt, F.G.A., gave an illustrated lecture entitled 'Contrasting gem mining techniques'.

MEMBERS' MEETINGS

London

On 22 April, 1986, at the Flett Theatre, Geological Museum, Exhibition Road, South Kensington, London S.W.7, Dr Charles E.S. Arps, F.G.A., of the National Museum of Geology and Mineralogy, Leiden, The Netherlands, gave an illustrated talk entitled 'Gemstones from Indonesia'.

On 13 May, 1986, at the Flett Theatre, following the Annual General Meeting (see p.198), a Gemmological Forum was held, chaired by Mr David J. Callaghan, F.G.A., Chairman of the Association. The panel consisted of the following: Mr Alan Jobbins, B.Sc., F.I.M.M., F.G.A., Dr Roger Harding, B.Sc., D.Phil., F.G.A., Mr Kenneth Scarratt, F.G.A., Dr George Harrison-Jones, B.Sc., Ph.D., F.G.A., Ms Diana Foley and Mr Christopher R. Cavey, F.G.A. Subjects covered included the following: how to identify jade in the shop; the glass infilling of rubies and sapphires; understanding the relationship between the various ways of presenting absorption spectra; faceting easily cleavable material; eighteenth and nineteenth century cut steel jewellery as a substitute for gold and diamonds; and how one might attempt to date carved intaglios.

On 27 May, 1986, at the Flett Theatre, Mr Gunnar Raade, Curator of Minerals at the Mineralogisk-Geologisk Museum, Oslo, Norway, gave an illustrated talk entitled 'Gemstones of Norway'.

Midlands Branch

On 21 March, 1986, at Dr Johnson House, Bull Street, Birmingham, Mr Alec Farn, F.G.A., gave an illustrated talk entitled 'Jade and its simulants'.

On 25 April, 1986, at Dr Johnson House, the Annual General Meeting was held, at which Mr P. West, F.G.A., was elected Chairman and Mr D.M. Larcher, F.G.A., re-elected Secretary. Following the Annual General Meeting, Mr Owen Smyth, of Town Talk Polish, gave an illustrated talk entitled 'The scientific approach to cleaning metals and gemstones'.

North West Branch

On 17 April, 1986, at Church House, Hanover Street, Liverpool 1, Dr J.B. Nelson, Ph.D., F.G.S., C.Phys., F.Inst.P., F.G.A., gave a talk entitled 'How can I identify this transparent euhedral crystal?'. Using a vertical optical goniometer, he was able to demonstrate the practical measurement of all the interfacial angles of a crystal, thus leading to its identification by the Barker Method. The same device was used to show how the RIs and dispersions of faceted stones could be determined by means of the minimum deviation method. He also illustrated the optical ray paths followed within a polished perspex model of the profile of a brilliant-cut gemstone.

On 15 May, 1986, at Church House, Mr Alec Farn, F.G.A., gave a talk entitled 'Gemmological recollections'.

South Yorkshire and District Branch

On 22 May, 1986, at the Sheffield City Polytechnic, Pond Street, Sheffield, Mr G.A. Massie gave a practical demonstration of his lapidary skills. There was also a range of gemstones available for identification.

Mrs Susan E. Payne, B.A., F.G.A., has succeeded Miss Jean Platts (see Obituary p.196) as Hon. Secretary of the Branch.

COUNCIL MEETING

At the meeting of the Council held on 22 April, 1986, at the Royal Automobile Club, 89 Pall Mall, London S.W.1, the business transacted included the election of the following:

Fellowship

Abbot, Anita M., Phoenix, Ariz., USA. 1985
Arroyo Llorens, Maria C., Madrid, Spain. 1985
Coleman, Walter D., Valley Falls, Kan., USA. 1968
Ellis, John R., Norwich. 1961
Gascon Cuello, Fernando, Zaragoza, Spain. 1985
Kai, Kock M., Kowloon, Hong Kong. 1985
Little, Derek, Dundee, Scotland. 1981
Liyanaarachchi, Tudor P., Colombo, Sri Lanka. 1985
Spreckley, Vaughan G.M., London. 1985

Transfers from Ordinary Membership to Fellowship

Niklewicz, Danusia, Santa Monica, Calif., USA. 1985
Perera, G.H.A.P., Mount Lavinia, Sri Lanka. 1979
Waddington, Clive, Harrogate. 1985

Ordinary Membership

Amemiya, Tamami, Saitama Pref., Japan.
Asano, Kimiko, Bromley.
Barber, Roxey L., Encinitas, Calif., USA.
Bateman, Linda D., Vancouver, BC, Canada.
Becker, Thomas, Berlin, Germany.
Beever, Richard H., Orpington.
Beizer, Sameul, New York, NY, USA. 1985
Blake-Eckstein, Adrienne, Indianapolis, Ind., USA.
Bonds, Bobbye F., Magnolia, Ariz., USA.
Bramsden, Manny, Maidenhead.
Canty, Jess, London.

Chapman, Janet E., Poole.
Collin, Alan A., Billingshurst.
Cooper, Malcolm D., Standon.
Davoudi, Vivien, Troinex, Switzerland.
Doland, Gregory S., Farnham.
Edwards, Charlton T.K., Harpenden.
Eguchi, Yukio, Osaka City, Japan.
Ekman, Anders, Malmoe, Sweden.
Epa, Widanagamage, Mount Lavinia, Sri Lanka.
Fatalas Papadopoulos, Costas, Athens, Greece.
Furukawa, Junko, Kyoto City, Japan.
Genot, Luc, Brussels, Belgium.
Goddard, John D., Hastings.
Gordon, Don D., Warwick, WA, Australia.
Hagnas, Lloyd, San Diego, Calif., USA.
Hagon, Clive L., London.
Hallinan, John W., Crecora, Co. Limerick, Ireland.
Harrison, Rouer F.J., Kings Langley.
Head, Judy E., Newdigate.
Hirai, Junko, Tokyo, Japan.
Hirama, Katsunori, Tokyo, Japan.
Hirose, Sairi, Nagasaka Pref., Japan.
Holmes, Christopher W., Stockport.
Ishimoto, Kazuko, Hyogo Pref., Japan.
Kato, Kuniako, Osaka City, Japan.
Kenna, Sean N., Leixlip, Co. Kildare, Ireland.
Kent, Jeni, Hyde Park, SA, Australia.
Kinder, Lawrence V., Bangor, Co. Down, N. Ireland.
Kunishima, Ikuko, Osaka City, Japan.
Logan, Joan A., Hounslow.
Masuoka, Yoshima, Matsubara City, Japan.
Matsubara, Yoshiko, Hirakata City, Japan.
Matsuyama, Yasuo, Osaka City, Japan.
Mellor, Karen, Pinner.
Miyabayashi, Yuki, Kawachi-negano City, Japan.
Mochinaga, Schoichi, Aira-gun, Japan.
Morrison, Laurence, Upminster.
Murata, Fumiko, Osaka, Japan.
Nakagawa, Kyoko, Kobe City, Japan.
Nonaka, Chikako, Kuki City, Japan.
Ono, Takahiro, Tokyo, Japan.
Ozaki, Keiko, Kawanishi City, Japan.
Pay, Duncan L., Fife, Scotland.
Penfold, Edward,, Jeddah, Saudi Arabia.
Perkins, Sarah, London.
Pitre, Judith M., Imperial Beach, Calif., USA.
Rockwell, Alan M., Southfield, Mich., USA.
Rubilotta, Michel, Rousset, France.
Sano, Jun, Hiroshima Pref., Japan.
Shaw, Patricia V., Leeds.
Silvestre, Jean-Claude, Nimes, France.
Skinner, Graham D., Worthing.
Spuida, Bernhard, Pfronten, W. Germany.
Takizawa, Toshiko, Tokyo, Japan.
Tohyama, Masuo, Osaka, Japan.
Twigg, Fiona, Mount Kennedy, Co. Wicklow, Ireland.
Ushio, Tsutae, Fukuoka Pref., Japan.
Ushio, Yoshiko, Tokyo, Japan.
Wackerlig, Marc O., Winterthur, Switzerland.
Yaku, Mihoko, Osaka, Japan.
Yamasa, Toshiko, Tokyo, Japan.
Yoshimoto, Misako, Munakata-gun, Japan.

ANNUAL GENERAL MEETING 1986

The 55th Annual General Meeting of the Association was held on Tuesday, 13 May, 1986, at the Flett Theatre, Geological Museum, Exhibition Road, South Kensington, London S.W.7.

Mr David J. Callaghan, F.G.A., the Chairman of the Association, presided over the meeting. He referred to some of the items mentioned in the Annual Report, and announced that the Basil Anderson Appeal launched in November 1984 for the purchase of the Basil Anderson Spectrophotometer had reached its target figure of £25 000.

Referring to the examinations, Mr Callaghan said that he was pleased to report that the Tully Medal had been awarded two years consecutively. In 1985 this Medal was awarded to Mrs Gwyneth Green, who is the first student to be awarded both the Anderson and Tully medals. The awards had been presented by Mr Richard T. Liddicoat, Jr., Hon. F.G.A., Chairman of the Board of the Gemological Institute of America.

The Chairman paid tribute to the work of Mr J.R.H. Chisholm for his years of editorship of the *Journal*, who retired at the end of the year. He then thanked Mr Alan Jobbins who had succeeded John Chisholm as Editor, and referred to the new format of the *Journal*, which had been well received by members.

Continuing, Mr Callaghan reported that the Preliminary section of the new home study course in gemmology would be commencing in September 1986. He thanked Mr Jonathan Brown for his tremendous achievement in obtaining a grant of £30 000 for the course from the Distributive Industry Training Board Trust.

During the year a new Executive Committee had been formed, and the Chairman thanked all members of the Council, Examiners and Instructors, for their help and support during the year.

Mr Nigel Israel, the Honorary Treasurer, presented the audited accounts for the year ended 31 December, 1985, illustrated by coloured charts. The adoption of the Report and Accounts was duly proposed, seconded by Mr Alan Jobbins and carried.

Sir Frank Claringbull, Mr David Callaghan, Mr Noel Deeks and Mr Nigel Israel were then re-elected as President, Chairman, Vice-Chairman and Honorary Treasurer respectively. Mrs S. Hiscox and Messrs. D. Inkersole, B. Jackson, M.

O'Donoghue, P. Read and C. Winter were re-elected to the Council.

Messrs. Ernst and Whinney were reappointed Auditors, and the proceedings then terminated.

GEMSTONES UNDER THE MICROSCOPE

An exhibition of photographs by Mr C.R. Burch, B.Sc., F.G.S., was held at the Geological Museum, Exhibition Road, South Kensington, London S.W.7, from 25 March to 31 May, 1986. Characteristic inclusions occurring in both natural and man-made gemstones were illustrated in 30 full-colour enlargements.

GEMMOLOGICAL COURSES

Retail Jeweller

The *Retail Jeweller* continues its residential courses on gem identification this autumn at Upton Hall, Newark, Notts. Mr Alan Hodgkinson, F.G.A., is the course leader, assisted by Mr Patrick Daly, F.G.A. The dates are as follows:

29–30 September, 1986. Two-day introduction to practical gem identification.

1–3 October, 1986. Three-day practical gem identification for second year students and refresher course for Diploma holders.

Full details from the *Retail Jeweller*, 100 Avenue Road, London NW3 3TP.

Genesis

Courses for overseas students or those home students wishing to complete the full course for the Gemmological Association's Diploma examination in one year are offered by Genesis. Courses start in mid-September and continue to the following June. Tuition occupies two full days per week and is intensive. Courses are limited to eight students and include visits to gem centres such as Idar-Oberstein and Antwerp. Full details from Colin Winter, F.G.A., Genesis Design Jewellery Ltd, 21 West Street, Epsom, Surrey, KT18 7RL.

INDIA GEMS AND JEWELLERY FAIR

The 1986 Fair is to be held from 4 to 8 September at the Taj Mahal Hotel, Bombay, India. For details contact IGJ Fair 1986, c/o Hindustan Diamond Co. Ltd, 15 Atlanta, Nariman Point, Bombay 400 021, India. Telex 011-4710 HDCL IN.

FAKED EMERALD CRYSTALS FROM AMERICA

Three 'emerald' crystals weighing 52, 33 and 20 grams were offered to Bernice Backler, a jeweller in Pinetown, South Africa. The locality was given as Chitanti District, Zambia. The crystals appeared to have a coating of mica-schist and on cutting a 'window' and drying a specimen on paper a vivid yellow stain was noted and an acidic liquid oozed from the crystal. Washing the specimen with dilute detergent caused it to come apart, revealing a green dye on flat pieces of quartz(?) which had been gummed together to form the fake. Readers should beware of such imitations.

CORRIGENDA

On p. 52 above, the caption to the photograph uses the term 'etch pits'. In fact, they are raised tetrahexahedral formations sometimes known as 'quadrons'.

On p. 103 above, the caption to the photograph at the top of the left-hand column has been omitted. It should read: 'Fig. 4. Paragasitic hornblende crystal (NMNS 46661) from Soper River, Baffin Island, NWT, Canada, with facetable rough and 3.00 ct emerald cut hornblende (NMNS 20896)'.

On p. 116 above, right-hand column, line 11, for 'and' read 'end'.

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GEMMOLOGICAL ASSOCIATION OF GREAT BRITAIN

The Arms and Crest of the Association, conferred by a grant of Arms made by the Kings of Arms under royal authority. The cross is a variation of that in the Arms of the National Association of Goldsmiths of Great Britain and Ireland. In the middle is a gold jewelled book representing the study of gemmology and the examination work of the Association. Above it is a top plan of a rose-cut diamond inside a ring, suggesting the scrutiny of gems by magnification under a lens. The lozenges represent uncut

octahedra and the gem-set ring indicates the use of gems in ornamentation. The lynx of the crest at the top was credited, in ancient times, with being able to see through opaque substances. He represents the lapidary and the student scrutinizing every aspect of gemmology. In the paws is one of the oldest heraldic emblems, an escarbuncle, to represent a very brilliant jewel, usually a ruby. The radiating arms suggest light diffused by the escarbuncle and their tips are shown as jewels representing the colours of the spectrum.

Historical Note

The Gemmological Association of Great Britain was originally founded in 1908 as the Education Committee of the National Association of Goldsmiths and reconstituted in 1931 as the Gemmological Association. Its name was extended to Gemmological Association of Great Britain in 1938, and finally in 1944 it was incorporated in that name under the Companies Acts as a company limited by guarantee (registered in England, no. 433063).

Affiliated Associations are the Gemmological Association of Australia, the Canadian Gemmological Association, the Gem and Mineral Society of Zimbabwe, the Gemmological Association of Hong Kong, the Gemmological Association of South Africa and the Singapore Gemologist Society.

The *Journal of Gemmology* was first published by the Association in 1947. It is a quarterly, published in January, April, July, and October each year, and is issued free to Fellows and Members of the Association. Opinions expressed by authors are not necessarily endorsed by the Association.

Notes for Contributors

The Editors are glad to consider original articles shedding new light on subjects of gemmological interest for publication in the *Journal*. Articles are not normally accepted which have already been published elsewhere in English, and an article is accepted only on the understanding that (1) full information as to any previous publication (whether in English or another language) has been given, (2) it is not under consideration for publication elsewhere and (3) it will not be published elsewhere without the consent of the Editors.

Papers should be submitted in duplicate on A4 paper. They should be typed with double line spacing with ample margins of at least 25mm all round. The title should be as brief as is consistent with clear indication of the content of the paper. It should be followed by the names (with initials) of the authors and by their addresses. A short abstract of 50–100 words should be provided. Papers may be of any length, but long papers of more than 10 000 words (unless capable of division into parts or of exceptional importance) are unlikely to be acceptable, whereas a short paper of 400–500 words may achieve early publication.

Twenty five copies of individual papers are provided on request free of charge; additional copies may be supplied, but they must be ordered at first proof stage or earlier.

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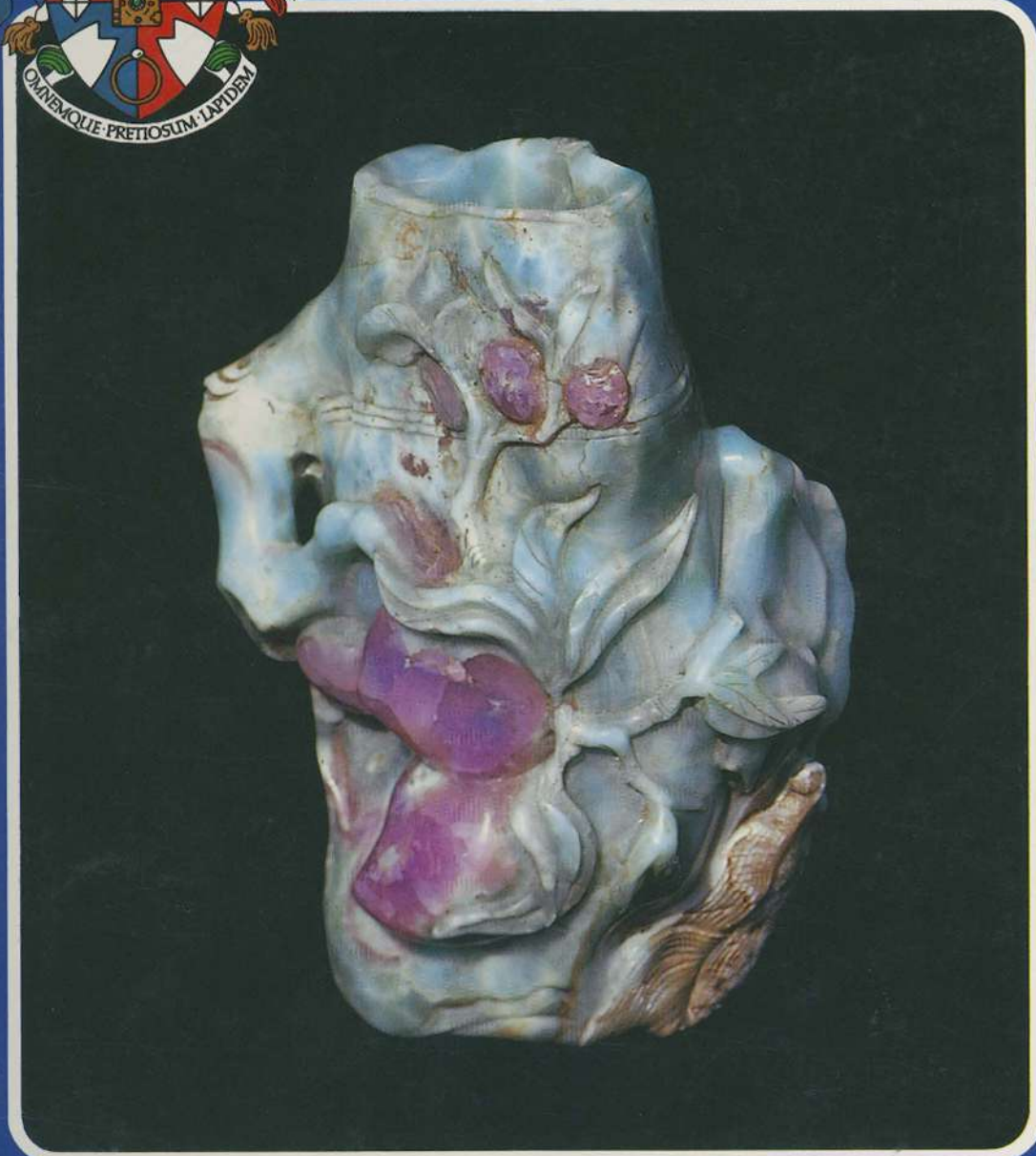

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The Journal of Gemmology

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Cover Picture

Chinese vase carved in banded blue aragonite and purple cobaltocalcite. Kindly lent for many years for display to the Geological Museum, London, by Mr and Mrs J.H. Common.

Photograph by E.A. Jobbins

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AVE ATQUE VALE*

HARRY WHEELER, Secretary 1973–1982

We report with great sadness the death of Mr H.J.B. Wheeler on 5 June 1986. He had served the Association (and the National Association of Goldsmiths) with distinction for almost half a century and his friendly face and ever ready advice will be greatly missed by his friends. During his period of office the Association broadened its international connections and its world-wide prestige was recognized by the support given to its Jubilee celebrations in 1981. A full obituary appears on page 256.

By courtesy of Mr J. Goodall.

JONATHAN BROWN, Secretary 1986–

We welcome Mr J.P. Brown as the new Secretary of the Association, following the resignation of Con Lenan to take up another post. Jonathan Brown joined the Association in 1972, working with former Secretaries Gordon Andrews and Harry Wheeler. In 1971 he gained his F.G.A. with distinction and won the Tully Medal. In 1979 he left the GA to study law and was called to the Bar in 1980. He rejoined the Association in 1983 and has since made a very significant contribution to the education services of both Associations. We wish him well in the broader responsibilities of his new posts, Secretary of the Gemmological Association and Chief Executive of the National Association of Goldsmiths.

* Hail and farewell, Catullus, *Odes*, ode ci, 1.10.

Glass fillings in sapphire

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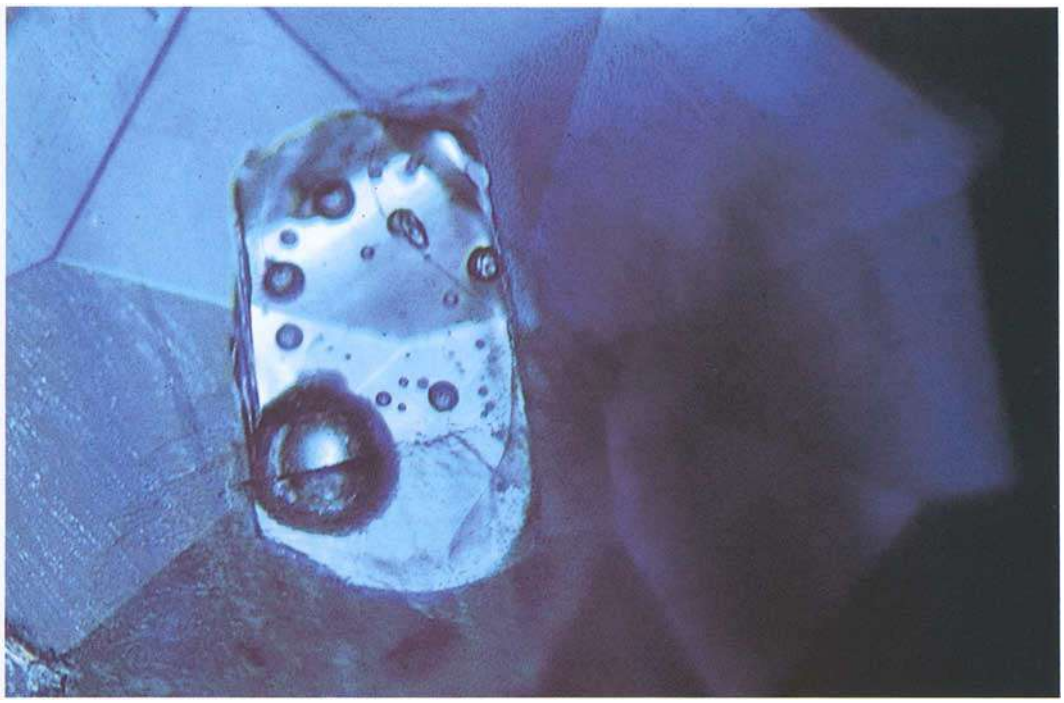

Fig. 1. Area of glass containing bubbles near culet of 1.28 ct sapphire. The largest bubble is 0.5 mm in diameter.

Abstract

Electron microprobe analyses of a filling at the surface of a faceted sapphire indicate that it is an aluminosilicate glass. Its composition is compared with a range of glasses found in rubies, and the possibilities of a natural or of a man-made origin are discussed. It is concluded that the glass in this sapphire is man-made.

Introduction

Rubies and sapphires 'repaired' with glass have been described recently by Scarratt (1983), Hughes (1984 a:b.), Kane (1984), and Scarratt and Harding (1984). The glass fillings generally appear on the surface of cut stones, and in a very interesting account of the phenomenon Kane concluded that the simplest way to detect fillings in such stones is to examine them carefully in reflected light or to immerse them in liquid and look for small areas in the stone which contain bubbles.

Sapphires with glass fillings are much rarer than filled rubies but the stone described by Scarratt (1983) and dating from 1976 has what appears to be a vitreous inclusion containing many bubbles. This inclusion does not break the surface. The 1.28 ct sapphire described below does have a vitreous inclusion at its surface and this stone has a known history since 1979. Kane (1984, p.199) argued that

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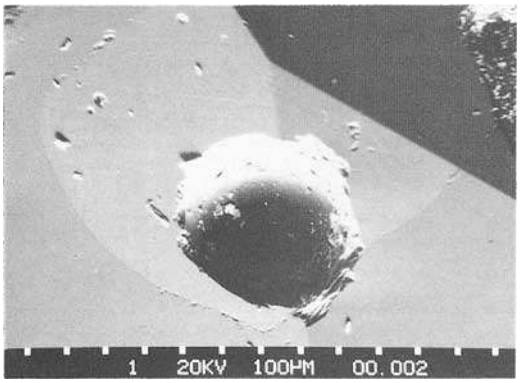

Fig. 2. Glass filling with hemispherical cavity (bubble) as seen using Cambridge Instruments Microscan 9. Compare with Figures 3 and 4.

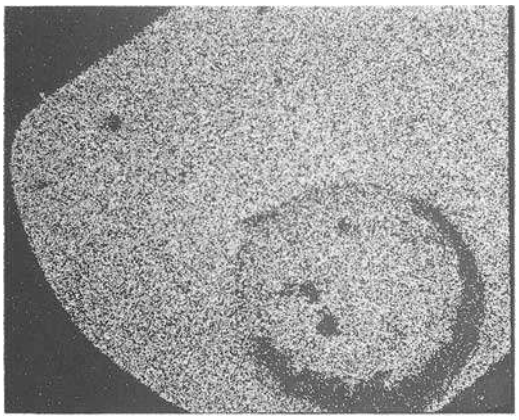

Fig. 3. X-ray picture of distribution and concentration of silicon in the glass and host sapphire. The sharp boundary between glass and sapphire is well shown, and the shape of the area and position of the bubble (0.5 mm diam.) may be compared with Figure 2.

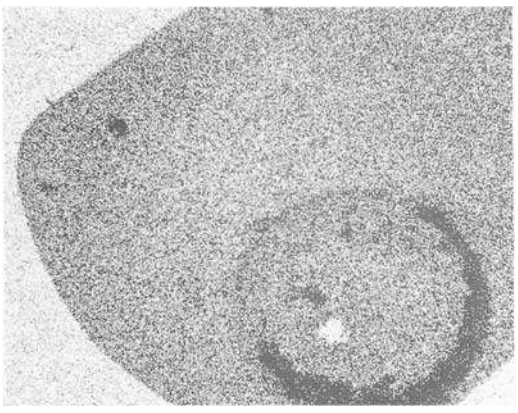

Fig. 4. X-ray picture of distribution and concentration of aluminium in the glass and host sapphire. Note the sharp boundary between the glass and sapphire.

determination of the nature of small fillings in rubies was of minor importance, but the present authors feel firstly that sapphires present a different problem because of their different geological origins, and secondly that identification of fillings is important in building up a comprehensive picture of the inclusions and treatments found in sapphires. The 1.28 ct stone mentioned above is a round mixed-cut stone and features relating to the glass filling in it are shown in Figures 1–4.

Composition of the glass filling

Electron microprobe analyses of the glass were made using a Cambridge Instruments Geoscan with Link Systems energy dispersive detector and computer. An accelerating voltage of 15kV, a specimen current of 5×10^{-9} amps and an electron beam focused to approximately 50μm (i.e. a defocused beam for glass analyses) were used. Elements of atomic number 11 (Na) and above can be measured by this method and the limits of detection for each of the oxides are about 0.2 wt%. Figures 2, 3 and 4 were obtained using a Cambridge Instruments Microscan 9 with an electron beam focused to 1μm.

The glass filling is located close to the culet, measures less than 1mm across, and contains numerous small bubbles. Analyses of four different spots were made and show that the major elements may vary between different areas by up to 10 wt%. The range of analyses and the mean are given in Table 1, and show that it is essentially an alumino-silicate glass. It should be noted that such elements as Li, Be or B, and the water content have not been determined, but the totals of the other oxides of 97–99% indicate that, should they be present, their amounts are not large.

The composition of the glass in the sapphire compares closely with that found in the ruby described by Scarratt and Harding (1984) and for comparative purposes this is shown in Table 1, column 3. The main differences are higher CaO and Na_2O contents of the glass in the sapphire. The analyses in columns 2 and 3 are dissimilar from Stockton's analyses of glasses in rubies A and B (Kane, 1984, p. 197) but compare more closely with her analyses C and D (op. cit.) which are reproduced in Table 1. Analyses A and B both have high CaO and MgO contents and the natural glass (Table 1, column 5) is notable for its low content of alkali metals.

There are three possible origins for the glass found in a ruby or sapphire. It may be (1) a natural volcanic glass, or (2) a man-made synthetic glass, or it may be (3) the result of melting of natural inclusions. Let us consider these in more detail:

Table 1. Electron microprobe analyses of glass.

Wt%	1	2	3	4	5
SiO_2	53-64	57.5	59.0	56.9	56.8
TiO_2	<0.2	<0.2	<0.2	0.1	0.4
Al_2O_3	23-32	29.4	28.4	31.9	26.4
FeO	1.5-2.7	2.1	0.7	0.3	1.5
MgO	0.3-0.9	0.6	0.5	0.1	1.9
CaO	1.1-1.8	1.5	<0.2	0.1	6.5
Na_2O	6.5-7.2	6.7	2.6	1.7	0.4
K_2O	0.6-0.9	0.7	5.4	3.5	0.6
MnO	<0.2	<0.2	<0.2	<0.1	<0.1
Total		98.5	96.6	94.6	94.5

Notes. Total iron is given as FeO.
1. Range of oxides in glass filling in the 1.28 ct sapphire.
2. Mean of 10 analyses of glass filling in the 1.28 ct sapphire.
3. Mean composition of glass filling in ruby (Scarratt and Harding, 1984).
4. Glass C (artificially induced) in ruby (Stockton in Kane, 1984).
5. Glass D (natural) in ruby (Stockton in Kane, 1984).

1. Most natural glasses occur in volcanic environments either as lavas or as fragments in volcanic ashes and tuffs. Rubies are only rarely associated with lavas and there is only one major volcanic province – that of Thailand and Kampuchea (Cambodia) – where rubies are mined. Sapphires are much more commonly associated with volcanic activity (Figures 5 and 6) and occur notably in the basaltic provinces in New South Wales, Thailand-Kampuchea and the Jos Plateau, Nigeria. In these districts the sapphires have rounded lustrous surfaces (Figure 5) which are not a result of cold mechanical abrasion but more likely of hot magmatic corrosion or partial resorption. It is probable that at some stage these sapphire crystals were part of a deep crustal rock that was invaded and shattered by upward moving basaltic magma. Fragments of rock and sapphire were incorporated in the magma flow and some were eventually extruded at the Earth's surface. Those that did make it to the top survived a hostile chemical environment which left its mark in the form of rounded corrosion edges and pits in the crystals. It is quite possible that in this eruptive environment glassy lava may adhere to the sapphires.

Although as yet we have not seen any sapphires with undisputed volcanic glass, it is nevertheless relevant to inquire into what kinds of volcanic glass one might expect in the Australian, Thai or Nigerian provinces.

The basalts in these provinces are classed as alkali basalts, and, in comparison with other basalts, they have low SiO_2 and high alkali and TiO_2 contents. An example of an alkali basalt from northern Thailand is given in Table 2, column 1, and rocks of this composition may also be found in the Australian and Nigerian sapphire provinces mentioned above.

If this analysis is compared with that of the glass filling (Table 2, column 4) the most striking differences are the lower values of SiO_2 and Al_2O_3 in the basalt. These differences rule out any likelihood that the glass filling resulted from quenching of a magma of this composition. However, this composition is not the only one that can be found in basalts. Some basalts are completely microcrystalline, but others consist partly of crystals and partly of residual glass, and this glass has a composition which differs quite considerably from the overall composition of the basalt.

In 1966 Wilkinson described residual glasses in basalts from New South Wales (see Table 2, column 2) and these compositions compare more closely with those of the glass fillings. However they still differ quite considerably in Al_2O_3 content.

Having examined the compositions of basalts and some residual glasses in naturally occurring rocks, is there any prospect of finding a natural glass with the SiO_2 and Al_2O_3 contents of that found in the sapphire? There are not yet enough experimental

Table 2. Analyses of basalt.

Wt%	1	2	3	4	5
SiO_2	46.0	52.8	55-62	57.5	59.5
TiO_2	2.1	1.1		<0.2	<0.2
Al_2O_3	15.0	20.6	15-25	29.4	24.3
Fe_2O_3	3.5	1.2		n.d.	n.d.
FeO	6.2	2.7		2.1	0.4
MgO	8.3	0.5		0.6	0.6
CaO	8.2	2.6		1.5	0.8
Na_2O	3.0	5.1		6.7	14.4
K_2O	2.9	5.1		0.7	<0.2
H_2O	3.3	7.2		n.d.	n.d.
MnO	0.2	<0.1		<0.2	<0.2
P_2O_5	0.6	0.9		<0.2	<0.2
Total	99.3	99.8		98.5	100.0

Notes. n.d. means not determined.
1. Basanite, northern Thailand (Barr and Macdonald, 1979).
2. Alkali basalt, New South Wales (Wilkinson, 1966).
3. Range of SiO_2 and Al_2O_3 in glass compositions obtained from melting basalt (Helz, 1976).
4. See Table 1, Note 2.
5. White jadeite, Burma. MI 16820. (Anal. R. R. Harding).

data to state categorically that glasses with 57% SiO_2 and 30% Al_2O_3 can occur in nature, but Helz (1976) has shown that glasses with 62% SiO_2 and 25% Al_2O_3 are possible (Table 2, column 3). Her melting experiments were carried out on Hawaiian basalts at 5 kb water pressure (equivalent to conditions 15 km deep in the crust). With magmas of this or other alkaline compositions it may be possible that under different conditions of pressure and gas composition, liquids of even higher Al_2O_3 content may be generated.

Fig. 5. Weathered alkali basalt containing sapphire from the Jos Plateau, Nigeria. The sapphires have rounded edges, possibly from magmatic corrosion, and exhibit a high lustre. *Photo: E.A. Jobbins.*

Fig. 6. Lamprophyre containing sapphire from Montana, USA. *Photo: E.A. Jobbins.*

2. In considering whether the glass fillings in rubies were of artificial origin, Kane (1984) commented that rubies with glass fillings showed evidence of heat treatment, and that some rubies contained very many tiny glass fillings whose over-all weight was insignificant compared with that of the host. In addition he referred to a practice of coating rubies and sapphires with different substances (pastes) prior to their heat treatment and suggested that the compositions of the glass fillings were directly related to the oxide present in either the crucible material or the coating material. These oxides include those of Ca, Mg, Na and Si. In the glass analyses of both Kane and ourselves Al_2O_3 also is a major constituent and this may well be derived from crucible material which, in some cases, is known to be corundum.

Element maps showing the distribution of Si and Al in the glass, host sapphire and the boundary between the two are shown in Figures 3 and 4. They show that the glass is essentially chemically homogeneous (similar patterns were obtained for Na and Fe distributions), and that there is a sharp change in composition at the sapphire-glass boundary. Any possibility that Al in the glass had been derived from the sapphire is not supported by these results. If Al in the glass had come from the sapphire, a higher concentration of Al would be expected nearer the sapphire and the glass would be inhomogeneous.

Silicate glasses high in alumina are known to have higher melting temperatures, to be more viscous and difficult to clear of bubbles than many other

glasses, and they seem an odd choice for the purpose of filling tiny cavities in rubies and sapphires.

3. A third possible origin for glass inclusions is by the melting and quenching of natural crystal or crystal and liquid inclusions. The commonest inclusions in ruby and sapphire are acicular crystals of rutile (TiO_2). Other crystal inclusions recorded are spinel ($MgAl_2O_4$), zircon ($ZrSiO_4$), mica ($KMg_3AlSi_3O_{10}(OH,F)_2$), apatite ($Ca_5(PO_4)_3(OH,F,Cl)$), calcium aluminium silicates such as zoisite, anorthite and margarite, and amphiboles. Some glassy substances in heat-treated rubies from east Africa show spinel and zoisite compositions (Dr H.A. Hänni, personal communication). Many rubies and sapphires also contain healed feathers with tiny amounts of trapped brine solutions.

Some zeolites or clay minerals resemble the composition of glass D given by Kane (1984, p. 197), but none is directly comparable with the glass in the 1.28 ct sapphire. This is essentially a sodium aluminium silicate and the proportions of Na: Al: Si do not correspond precisely with those of any known mineral. The minerals closest in composition to the glass are jadeite ($NaAlSi_2O_6$), and albite ($NaAlSi_3O_8$) but both have higher Na and lower Al. Pilot experiments of heating powdered jadeite at temperatures of 1200°C, 1400°C and 1600°C for different periods up to four hours were carried out to ascertain whether sodium was depleted relative to Si and Al. The analyses of glasses quenched from the different melts indicate that the Na_2O content of the quenched glasses is within 2 wt% of that in the original jadeite powder (Table 2, column 5), and there is no significant volatilization of sodium. It is therefore most unlikely that this NaAlSi glass was derived from a natural NaAlSi mineral with different porportions of these elements.

Conclusions

(i) The glass fillings in rubies and sapphires have a range of compositions, some of which correspond to mineral compositions. Others do not and are probably artificial and deliberately manufactured to 'enhance' the stone.

(ii) It is unlikely that any glass inclusions reported to date are natural volcanic glass, although sapphires in particular occur in geological environments where natural glass inclusions are a distinct possibility.

Acknowledgements

We would like to thank Miss F. Wall and Dr R. F. Symes for advice concerning the microprobe analyses and for taking the Microscan pictures, Mrs E. Brunton for carrying out a computer search of the literature, and Mr E.A. Jobbins for supplying pictures of sapphires from Montana and Nigeria. We had useful discussions with Dr A. Wilson (Laboratory of the Government Chemist) and with Mr T.S. Coldham.

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Solution coloration of smoky quartz

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Abstract

This paper discusses the possible coloration of smoky quartz by naturally occurring radioactive hydrothermal fluids. The smoky brown colour of the quartz crystals described here is confined to a surface layer only a few millimetres in thickness. The greatest depth of colour is concentrated around surface solution cavities and near-surface fluid inclusion chambers.

Introduction

While examining several hundred smoky quartz crystals imported from Minas Gerais, Brazil, it was noticed that a few dozen of the larger crystals, some as large as 20cm in longest dimension, showed an unusual outlined or shadowed, uneven smoky brown coloration. In these crystals the colour seemed to be confined to the outer surface with depth of colour extending into the crystal's surfaces a maximum of only 2.0mm. The colour was concentrated at crystal-face junctions and in and around solution pits, as shown in Figure 1, while the broad, flat rhombohedral and prism faces showed virtually no colour penetration. This gave the crystals an unusual type of skeletal phantom coloration. It has been well established that irradiation of colourless rock crystal quartz will produce smoky quartz (Rossman, 1981, and Nassau, 1984). It was therefore obvious that a source of radiation had played a major role in the colour enhancement of this material. But why the colour was distributed in the manner described above, rather than disseminated relatively evenly throughout these crystals as is usually the case, was still to be learned.

Microscopic examination

One of the crystals, measuring 9.5 × 7.8 × 4.1cm, was given to the author for a closer examination, to see if any evidence of the possible colouring mechanism could be discovered. Using a stereo zoom microscope it was observed that, without exception, wherever a near-surface fluid inclusion or cavity existed it was surrounded by a smoky brown halo or cloud. As illustrated in Figure 2, most of the near-surface cavities were very slightly open at the surface. The quartz had not grown sufficiently to seal them completely. Therefore, they contained no liquid, but only a gas phase.

However, a few of these cavities were sealed during growth and did contain both liquid and gas (Figure 3). A closer detail of this cavity and its two-phase contents is provided in Figure 4. The tip of this fluid inclusion, where the gas bubble is resting

Fig. 1. A large pit in quartz, measuring approximately 1cm in length, surrounded by a rim of smoky colour resulting from a radioactive hydrothermal solution.

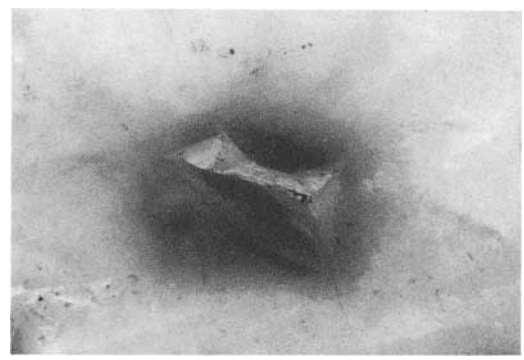

Fig. 2. Near-surface cavity in the quartz crystal, very slightly open at the surface and now containing only a gas. Note the smoky brown cloud surrounding the cavity. 5x.

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Fig. 3. Two-phase fluid inclusion containing the once-radioactive liquid that caused the brown smoky quartz halo. 5x.

Fig. 4. Close detail of the two-phase inclusion shown in Figure 3. The bubble is free to move in its void. The solution was checked with a Geiger counter and is no longer detectably radioactive. 15x.

in the photomicrograph, appeared to be less than a tenth of a millimetre from the crystal's surface. Even a slight abrasion along that surface area could have caused this fluid inclusion to rupture. After judging the fragile nature of this inclusion, it was not at all surprising that liquid and gas fluid inclusions, in this near-surface zone of smoky coloration, were rare.

A probable mechanism

The phantom-like, surface confined, smoky brown colour displayed by these quartz crystals together with the way face junctions and solution pits are delineated suggests that the hydrothermal solution responsible for the last millimetre of crystal growth was radioactive. The radioactivity was probably the result of submicroscopic radioisotopes suspended in the silica-rich hydrothermal solution. The solution was not isotope-potent enough to produce a smoky brown colour throughout the crystals, so a surface-only colour alteration resulted. Although no reaction was expected, as a final testing step the crystal was checked for residual radiation using a Victoreen survey meter capable of detecting alpha, beta, or gamma radiation. The results of this radiation check were negative.

Concluding thoughts

No direct mention of radioactive hydrothermal solutions as colouring agents for natural smoky quartz could be found in the literature, nor have smoky quartz crystals of this type been described before. Nature is an excellent source of radiation. So, although this theory is plausible, it is still only a theory. Reader observations are welcome.

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Notes from the Laboratory – 8

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There can be no doubt that when a diamond is cut into a perfectly proportioned modern brilliant, whether the stone is coloured or colourless, the magnificent response this mineral can have to light is seen at its best. We should not assume though, that those diamonds which are not cut to produce this response, or were cut in an older style, are any less impressive. They have a beauty and a character of their own.

Fig. 1. Large flat blue diamond set in a heavy ring.

A large flat diamond was reported in this Journal in 1984 (Jobbins *et al.*, 1984). Of those who have seen this stone few would deny its historical interest, and even fewer would deny that in its own right it is a spectacular diamond. All those who have viewed the Crown Jewels in the Tower of London cannot fail to be stunned by the effect produced by thousands of old-cut diamonds.

The Laboratory was asked to examine another flat diamond in May 1986 and whilst this one did not have the size of that reported in 1984, it did have a recognizable colour. The diamond, surrounded by smaller old-cut diamonds, was impressively set in a heavy ring (Figure 1) which displayed its fancy blue colour effectively. When removed from the setting (Figure 2) the colour, which was still apparent through the table, could be seen to be quite deep when the stone was viewed edge on.

Like the 1984 flat stone, the high surface lustre of this stone gave it a character of its own and the fact that it was a distinct blue colour added to its impressive appearance.

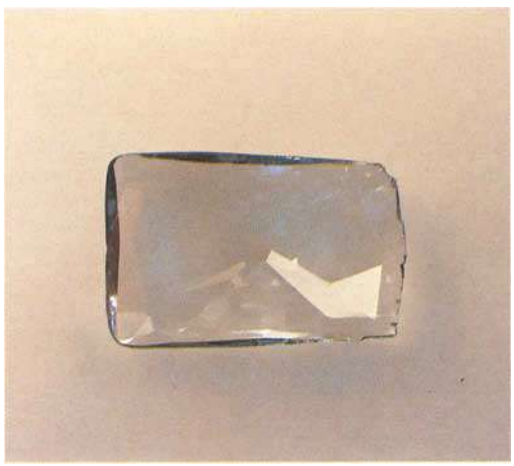

Fig. 2. The large flat blue diamond of Figure 1 after being removed from its setting.

The stone measured approximately 19.27–12.52 × 1.86 mm and weighed 4.36 cts. In clarity grading terms the stone, which had surface crazing and was chipped at the girdle (Figure 2), could be described as vsl.

The stone conducted electricity and was inert to long-wave ultraviolet, and only fluoresced a slight chalky colour under short-wave ultraviolet light. In common with other naturally coloured blue diamonds, this stone transmitted ultraviolet light down to 235.6 nm (Figure 3).

Today, as in the past, in producing a faceted diamond the cut chosen for a particular piece of

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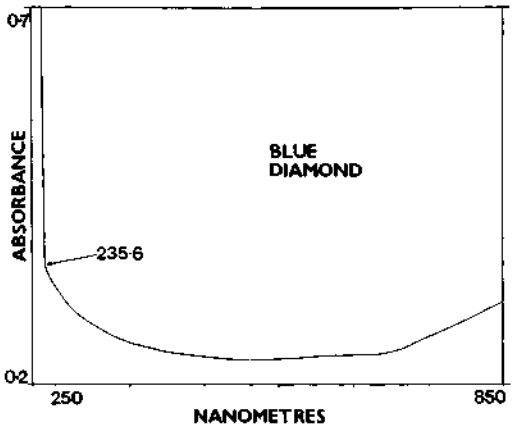

Fig. 3. The absorption curve of the blue diamond in Figures 1 and 2. The curve was obtained using a Pye Unicam PU8800/03 UV/visible spectrophotometer (Basil Anderson Model) with a speed of 0.5 nm/s and a bandwidth of 0.5 nm at room temperature. The path length was approximately 1.8 mm. The stone transmitted light down to 235.6 nm.

rough is the one which will maximize its potential both in terms of beauty and economics. This means that the vast majority of facted diamonds are cut in the modern round brilliant form or some fancy variation.

To the gemmologist who appreciates the unusual, not only in the form of a rare gemstone but also in the presentation of any gem material, it is a pleasure to see a diamond fashioned in an unconventional manner. These flat diamonds are unusual and this can also be said of another diamond we had the pleasure of examining recently. This was a very tastefully set stone cut in the style of a briolette (Figure 4).

Fig. 4. A tastefully set diamond cut in the style of a briolette.

* * *

Diamond in its natural state is an easily recognizable material, but even so the Laboratory has on many occasions had the unhappy task of having to inform the owners of large lots of colourless stones that what they have is topaz or quartz, and not a fortune in diamonds.

A short while ago there were rumours amongst the London diamond trade that synthetic cubic zirconia was being fashioned into octahedra and that the producers had even engraved 'trigons' on the faces. At about the same time we were asked to examine a parcel of rough stones which, it was said, were being offered to the trade as diamonds. If we were hoping to see the synthetic cubic zirconia 'crystals' our expectations were not realized. What was actually placed before us was a parcel of small pieces of quartz, each of which was coated with an adhesive containing numerous small squares of silver coloured foil (Figure 5)!

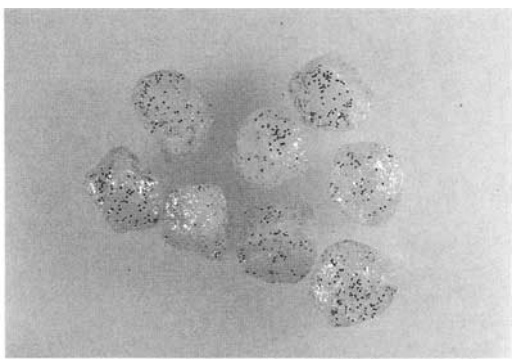

Fig. 5. 'Imitation diamond crystals' fashioned in quartz.

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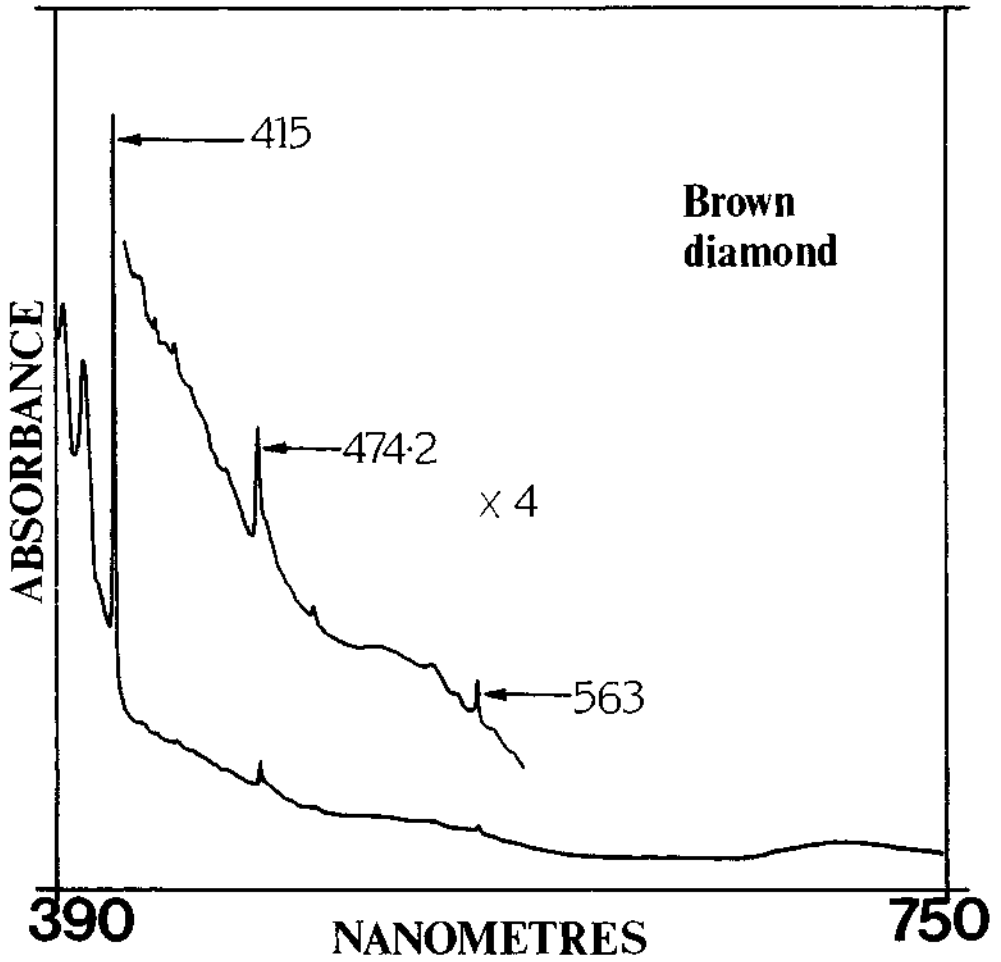

Fig. 6. The absorption curve of a brown diamond. The curve was obtained using a Pye Unicam PU8800/03 UV/visible spectrophotometer (Basil Anderson Model) with a speed of 0.5 nm/s and a bandwidth of 0.5 nm at approximately 120K. The path length was approximately 7 mm.

On rare occasions since 1977 we have noted the occurrence of a sharp fine absorption line in the area of 478 nm and a further group of three lines in the 560 nm region of the spectra of some brown diamonds. Owing to the proximity of the 'N2' band (at 120K, the N2 is at 477.2 nm) of the 'Cape series' spectrum, to the line seen in these stones, it is easy to mistake one for the other. When viewed with the hand spectroscope though, it will be seen that the N2 in the normal Cape series spectrum is much wider and is not as sharp as the line in the spectra of these brown stones.

At approximately 120K the wavelength of the line in the blue in the brown stones has varied between 474.2 nm and 474.9 nm but when recorded on a spectrophotometer the peak shape has been characteristic (Figure 6). The peak in each case is sharp and has a shoulder on its long-wave side. The wavelength of the main peak of the group in the green area has varied between 562.2 nm and 563 nm (Figure 6). The other two peaks have been at 554 and 544 nm.

In the past year we have examined three diamonds in which the colour changes from brown in artificial light to green in daylight. The spectra of these stones were recorded at 120K and each produced curves similar to that in Figure 6. However, one stone (Figure 9) recorded a spectrum (Figure 7) in which both the N2 and the '474' peaks were clearly present. In the hand spectroscope this combination is seen as a wide dark band with a sharp edge on its short-wave side.

For comparison purposes a normal Cape series spectrum (recorded at approximately 120K) of a

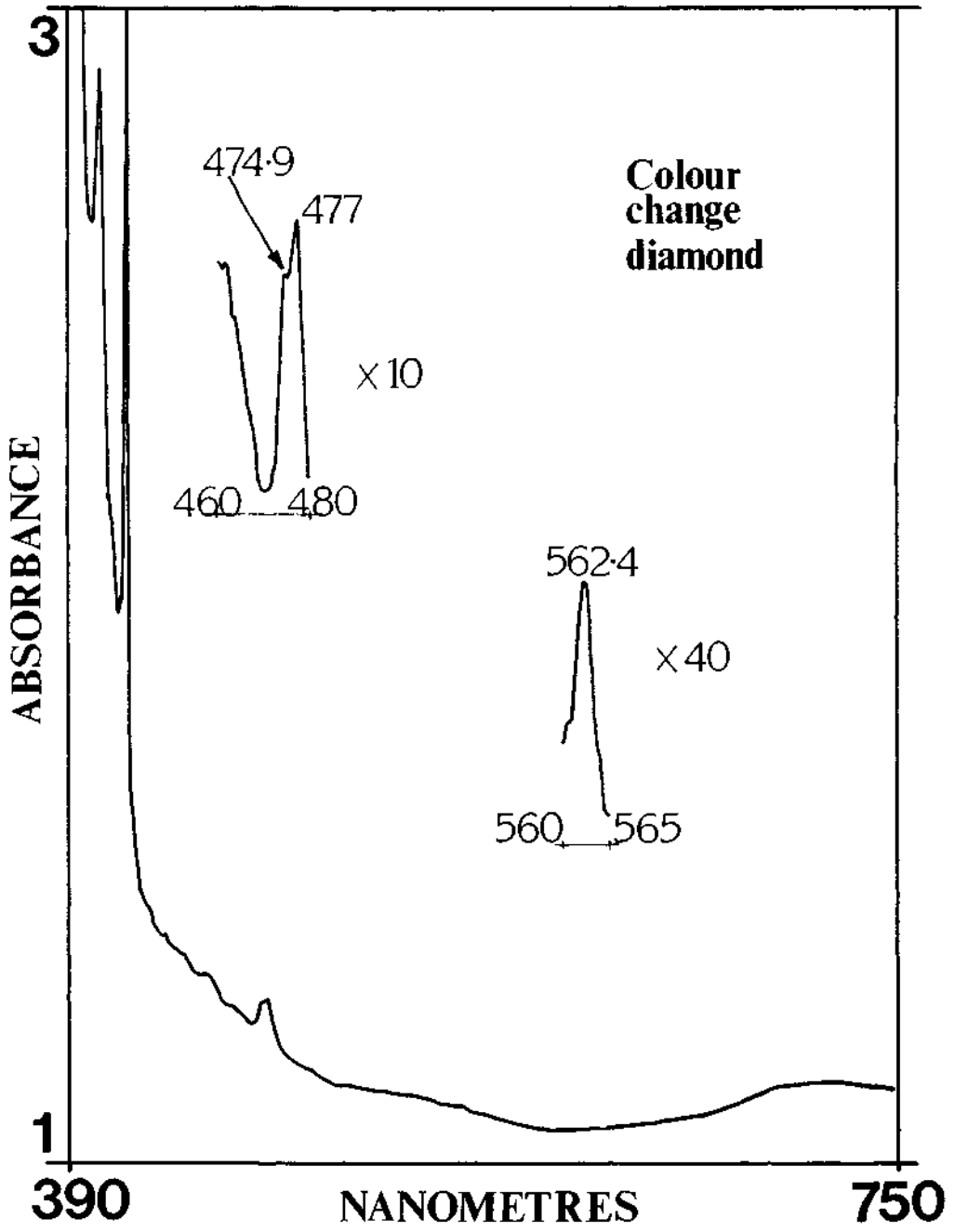

Fig. 7. The absorption curve of a diamond which changes colour from brown in artificial light to green in daylight. The curve was obtained using a Pye Unicam PU8800/03 UV/visible spectrophotometer (Basil Anderson Model) with a speed of 0.5 nm/s and a bandwidth of 0.5 nm at approximately 120K. The path was approximately 9.17 nm.

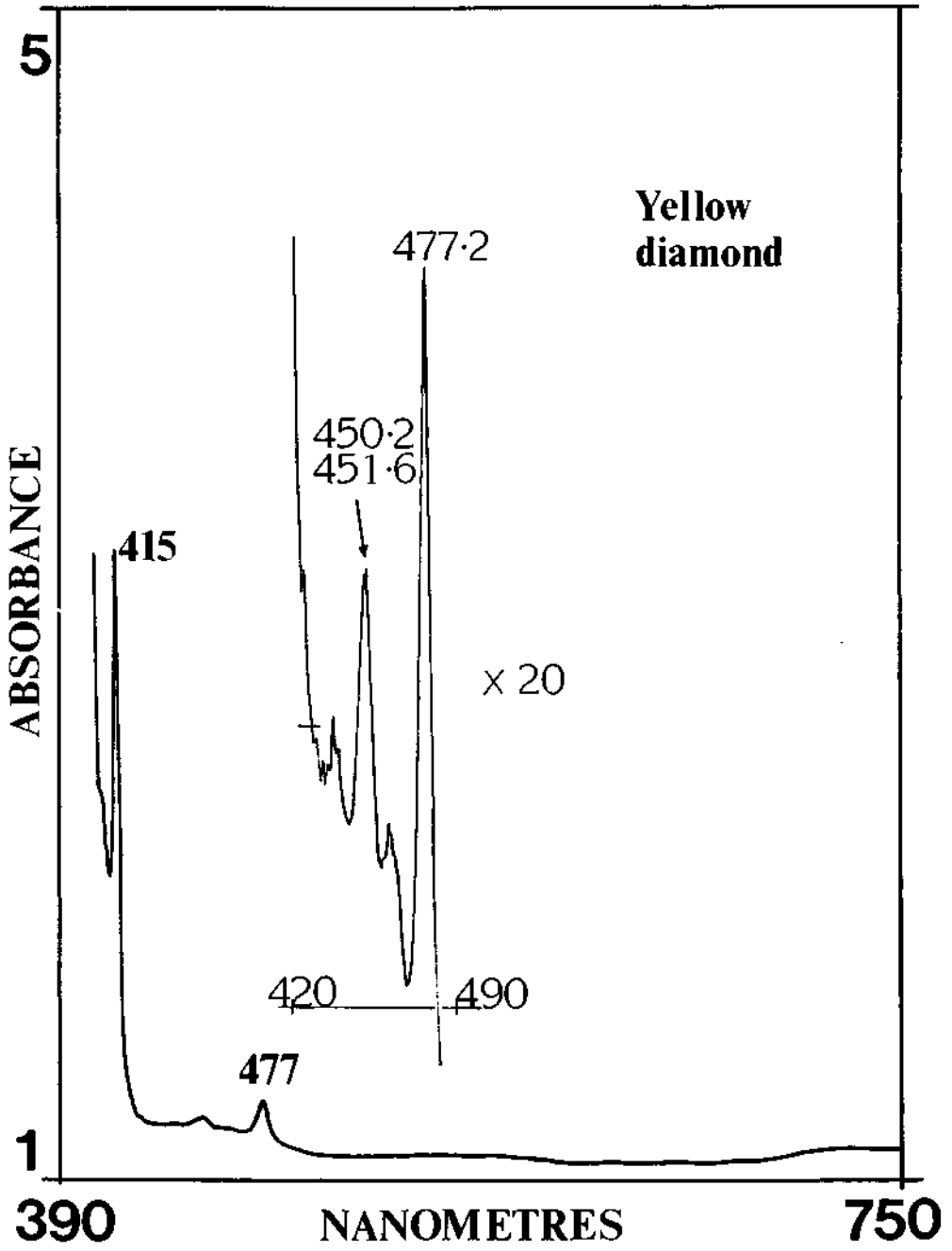

Fig. 8. The absorption curve of a Cape series yellow diamond. The curve was obtained using a Pye Unicam PU8800/03 UV/visible spectrophotometer (Basil Anderson Model) with a speed of 0.5 nm/s and a bandwidth of 0.5 nm at approximately 120K. The path length was approximately 6.8 mm.

Fig. 9. A diamond which changes colour from brown in artificial light to green in daylight.

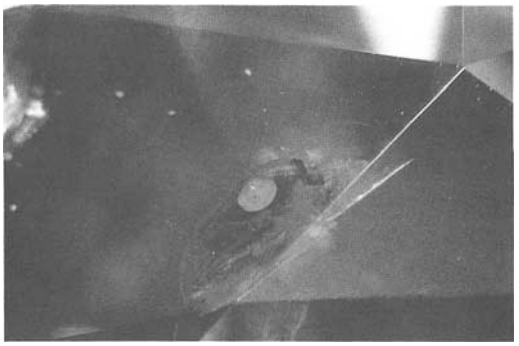

Fig. 10. A short laser hole in a diamond extending from a crown facet to a cleavage.

yellow diamond is reproduced in Figure 8. It will be noted that at 120K a group of extra sharp peaks are seen in the spectrum of Cape series stones at 424.2, 430.2, 432.8, 435, 437 and 439.8 nm and that the peak at '451' is a doublet with peaks at 450.2 and 451.6 nm.

The reason for the 'colour change' in the stone in Figure 9 became clear following a microscopic examination which revealed that it contained large areas of dust-like cloud. The cloud fluoresced a bright yellow-green under ultraviolet light whilst the remainder of the stone fluoresced blue. This combined fluorescence was strong enough to change the colour of the stone from brown in artificial light to green in daylight.

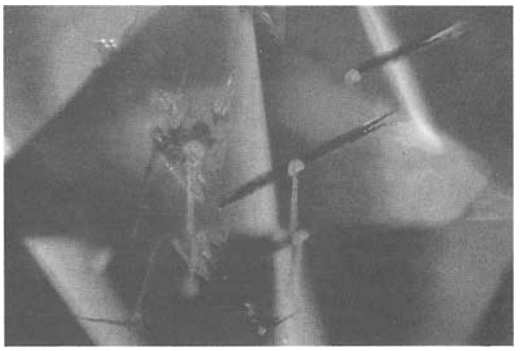

Fig. 11. A laser hole in a diamond extending down to a long black inclusion.

* * *

The laser drilling of diamonds is carried out in order to reduce the visibility of black inclusions and thereby possibly improve the chances of the stone being saleable. There is very little, if any, chance of the clarity grade being improved by such treatment.

A diamond submitted for examination recently had seven drill holes present, each extending down to an inclusion or a cleavage area. However, the treatment had not been entirely successful. Whilst the drill holes were on target, in a few cases only a small area of the inclusion had been made less visible by conversion from black to white.

Figure 10 shows a very short laser hole in the stone extending from the table facet to a cleavage. The cleavage extends from a crown facet into the stone and at an angle with the table. Where the drill hole meets the cleavage there is a round white area, which is where the treatment has been effective, but otherwise it is still a mostly black cleavage. Figure 11 shows a similar result on a long black inclusion in the same stone.

* * *

Some years ago a number of parcels were being offered for sale containing cabochons of a pink material which had a porcelain-like surface, and was said to be pink opal. In recent years very little has been seen of this material, however, some merchants have kept small amounts in stock.

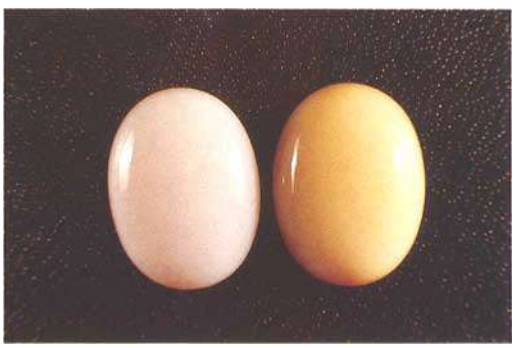

Fig. 12. Opal which has changed colour from pink to a much darker shade approaching orange.

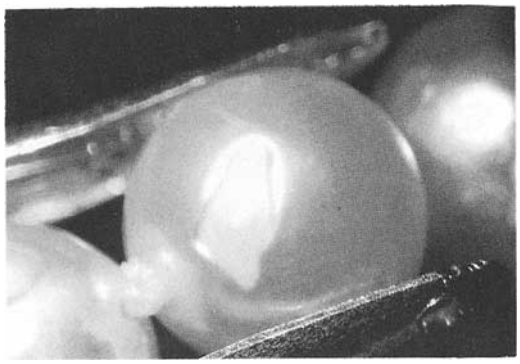

Fig. 13. Poor quality cultured pearls.

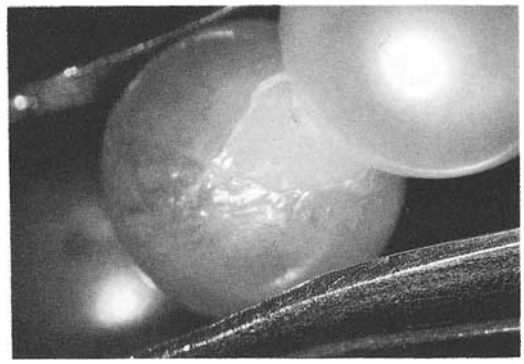

Fig. 14. Poor quality cultured pearls.

On a recent visit to one of these merchants we were informed that some of their stock of this material had changed from a light pink to a much darker shade which approaches orange (Figure 12). The stock had been stored in a safe and inside normal stone papers. At present the reason for this colour change is not known.

* * *

The quality of some cultured pearls being offered for sale to the public over the past few years falls short of that which hitherto has been an acceptable standard. It almost appears that because of the current increase in demand for cultured pearl necklaces, an 'anything goes' attitude is prevalent in some quarters.

Recently the Laboratory has been asked to examine rows of cultured pearls in which the nacre has either separated from the mother-of-pearl bead or is in the process of doing so. In some other cases (Figure 13) part of the mother-of-pearl bead has *never* been covered, or the nacre that is present is of very low quality (Figure 14). Following complaints from members of the public various Trading Standards Authorities are now investigating this problem.

Reference

Jobbins, E.A., Harding, R.R., Scarratt, K. 1984. A brief description of a spectacular 56.71 ct tabular diamond. *J. Gemm.*, **XIX**, 1, 1–7.

[*Manuscript received 9 August 1986.*]

The colour bar in the gemstone industry

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Abstract

The current general attitudes in the gemstone industry towards quantitative descriptions of the body colours of coloured diamonds and gemstones are discussed in some detail. Instruments and systems which are suitable for making such measurements are described. It is shown that practical and adequate procedures already exist and could be deployed at once if the industry wished to do so.

The body colours of a number of faceted gemstones were measured by means of a visual tristimulus colorimeter, using a new gemstone mounting technique developed by the author. From this experience and other considerations, there is evidence that an international agreement on gemstone colour grading could be reached more quickly if visual measurements were abandoned in favour of photoelectric ones.

Physical colour standards, such as painted chip collections, would still be required, but not for measurement. They would be needed to translate the incomprehensible CIE colour space notations produced by spectrocolorimeters into meangingful colour appearances.

Introduction

A previous article[1] presented a number of reasons for gemmologists to consider the adoption of a particular and internationally-used system of colour measurement for the numerical colour decription of faceted gemstones.

The arguments followed were similar to those given in earlier papers by Lewis (1952)[2,3,4,], who made the same plea to use this system without delay. Then (as now), suitable instrumentation was available for measuring these three numbers (CIE Tristimulus Colour Co-ordinates) for any diamond or coloured gemstone. His description of the CIE (1931) System, which has since been greatly extended [CIE 1976 (L*u*v*) colour space][5], still remains for the gemmologist one of the best accounts of this daunting subject.

This article outlines the use of visual comparison methods for gemmological colorimetry. It lists 17 obstacles which seem to be hindering the acceptance by the gemstone industry of gemstone colour measurement. A visual colorimeter designed by the author is described, together with the results of CIE measurements made by it on 38 faceted stones and 'windowed' rough. Proposals are made for taking the first steps towards establishing international standards for the quantitative description of gemstone body colour.

Colour grading charts

Colour is *what we see*. It does not exist without eyes to perceive the sensation. For this reason, it is those procedures which allow the direct visual comparison of pairs of colour stimuli which may be the most appealing, although not necessarily the most appropriate.

With these methods, an acceptable colour match can be made between the calibrated (reference) stimulus and that of the gemstone (test) stimulus. Three numbers taken from the matching reference stimulus then serve as a complete colour description of the gemstone. In principle, although perhaps not always in practice, these numbers can be transformed into CIE colour co-ordinates. The CIE values are much more universally understood than the miscellaneous sets of numbers produced by each of many systems which have so far been marketed. This is especially so if the CIE co-ordinates are expressed, not as the basic Tristimulus Co-ordinates (X,Y,Z), or as the chromaticity and luminance co-ordinates (x,y,Y), but as the dominant wavelength (λ_d), the percent excitation purity (p_e) and the metric lightness (L*). With only a little experience, these last-named co-ordinates permit a good mental image to be formed of what a colour will look like.

At the moment of writing, there are some five colour-grading chart systems being offered to gemmologists[6]. They are mostly based on the long-established Munsell Colour Atlas[1,4,7,10,13,19,24]. This atlas is a collection of over 1,500 colour-related paint 'chips', marketed as the 'Munsell Book of Colour'. Each chip is labelled with its own Munsell notation (H,V,C) relating to the CIE Illuminant 'C' (colour temperature=6775K). Tables or graphs (see Figure 1) are supplied which give the corresponding CIE co-ordinates, x,y,Y, which in turn can

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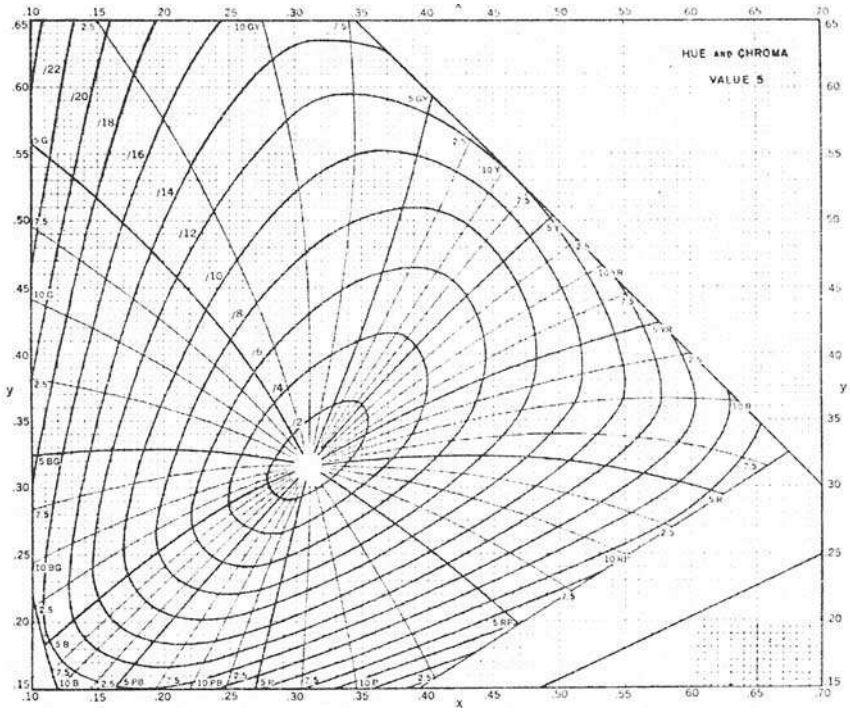

Fig. 1. Munsell loci of constant hue (H) and constant chroma (C) superimposed on a CIE (1931) chromaticity chart (x,y). For chart with value (V=5). CIE Source C.

be instantly converted into the more comprehensible numbers, λ_d, p_e and L^*. A characteristic of the Munsell System is that the gaps between the calibrated chips have approximately equal colour spacings. Its most important feature is the prime position it holds amongst the world's colour scientists.

Trade objections

Resistance to the adoption of these relatively inexpensive chart systems by gemstone miners, dealers, jewellers and teachers is almost total. Academically-minded gemmologists and collectors are for the most part fairly sympathetic.

It is perhaps useful to list the main objections:–

1. The existing colour-grading charts do not compare like with like. A brilliant-type cut (no 'window') transparent stone has to be compared with a calibrated opaque, painted chip, or, less commonly, with a white-backed coloured acetate filter. In practice, matching is found to be confusing and awkward: this leads to poor accuracy.
2. There is much concern about the proliferation of notations, symbols, codes and numbers for each chart system. Each system has its own nomenclature, so that quantities generated by the use of one system cannot be instantly understood by the users of another. Cross-referencing is impossible.
3. There is also frustration about the multiplicity of terms used to describe the three precise and separable attributes of colour. They are referred to as metric hue (h_{uv}), metric chroma(C^*_{uv}) and metric lightness (L^*) and are the three co-ordinates in the orthogonal colour space known as CIE 1976 (L^*,u^*,v^*), often abbreviated to CIELUV[5,8,15]. Examples of these common usages are:–

   Hue is the original Munsell term (H). It is also the term for metric hue (h_{uv}) in CIELUV space. It is the attribute of a visual sensation according to which an area appears to be similar to one, or to proportions of two, of the perceived colours red, orange, yellow, green, blue and purple. It is virtually equivalent to the CIE (1931) 'dominant wavelength' (λ_d), and corresponds to the

'farbton' (T) of the West German DIN 6164 System. It is often incorrectly referred to as 'shade' or 'colour'.

Chroma is the term for metric chroma (C^*_{uv}) in CIELUV space. It is associated with the CIE (1931) 'excitation purity' (p_e), the 'sättigung' (S) of DIN 6164 and the Munsell 'chroma' (C). It is the attribute of a visual sensation according to which an area appears to exhibit more or less chromatic colour. It has been variously described as 'saturation', 'colourfulness', 'intensity', 'vividness', 'vivacity', 'paleness', 'liveliness', 'purity', 'brightness', 'strength', 'cleanliness', 'grayness' and 'dullness'.

Lightness is the term for metric lightness (L^*) in CIELUV space. It is associated with the CIE (1931) 'luminous factor' (Y), the value (V) of Munsell and the 'dunkelstufe' (D) of DIN 6164. It is the attribute of a visual sensation according to which an area appears to reflect diffusely or transmit a greater or smaller fraction of incident light. It is often referred to as 'tone', and erroneously as 'brightness'.

4. The existing colour ranges, or 'gamuts', as they are called, are regarded as too restricted for gemstone grading. In general, gemstones have much more saturated hues than the colour charts provide. The more saturated paints are impermanent; they are therefore not included in the gamut of the long-established colour grading charts of Munsell.
5. Even with a set of over 1,500 chips, the colour spacings between chips are felt to be inconveniently large. The task of interpolating the gemstone's colour between a set of four or six chips is viewed as being both an uncertain and a fussy estimation. The CIE 'Standard Observer' can discern differences between some five million different colours when pairs of uniform fields are viewed side-by-side[7]. This incredible, effortless feat of human vision explains why the steps between the chips in the available collections are regarded as too large.
6. There is much understandable unease about the varied and unreliable performance of the many different light sources used at present for stone-and-chart matches.
7. It is a strongly-held belief that two or more observers cannot agree about a given match or about the resulting colour numbers. Indeed there is a prevailing conviction that no colour-measuring procedure or apparatus will ever be able to yield an accurate and sensible statement about the body colour of a gemstone.
8. There is a widespread feeling that trained male colourists and women (either trained or untrained) possess much superior colour-matching abilities to those untrained males who have no colour vision defects.

Apart from these purely 'nuts-and-bolts' considerations, there are other aspects of colour grading (see below) which worry gemmologists.

9. The fear of possible misuse of gemstone certificates which include colour grading numbers. This includes the temptation to switch stones and certificates.
10. The high cost of non-subjective (i.e. non-visual) colour measuring equipment, such as spectrophotometers and photoelectric colorimeters.
11. The dread of a market collapse in high-quality coloured stones. Memories are still fresh of the massive slump in diamond prices, largely caused by the vigorous sales promotions of investment firms using price-linked colour-grading certificates.
12. An aversion to any national or international agreement which would allocate specially-defined volumes or zones in a given CIE colour space to certain groups of stones such as rubies, emeralds and sapphires. From this, it is believed, would surely follow the setting-up of plus-and-minus limiting tolerances for each of the co-ordinates λ_d, p_e and L^* for the most commercially-valuable or aesthetically-preferred stones.
13. Having set out upon this course, miners, dealers and jewellers would be fearful of another problem. They would expect to encounter difficulties in disposing from their inventories many of the larger number of stones which would necessarily be now excluded from the preferred zones. They feel that a new generation of colour-educated buyers would probably resist purchasing goods which were 'out-of-specification'.
14. Those gem cutters who aim for maximum weight and clarity, rather than optimum colour, would scarcely welcome any such convulsive changes in their traditional ways of working.
15. The use of many related sets of master (colour-calibrated) stones is now an internationally accepted practice for diamonds of the Cape series. Although costly, the reason that this is practicable is because the colour range is not three-dimensional (λ_d,p_e, L^*) as with diamond fancies and coloured stones, but is virtually one-dimensional (p_e). All the colours embraced by the 11 commercially-important GIA colour grades, D to N, have a constant λ_d of 576 nm.

The most yellow of these, N, has the incredibly low p_c value of 5.0%![9] As few as seven master stones are considered sufficient to cover this tiny gamut. This would hardly be possible with coloured stones, as the sheer economics would preclude such large collections.

Nevertheless, many dealers do indeed possess sizeable ranges of their specialist coloured stones. They would be likely to rebel against changes which would threaten the trading advantage which the possession of such 'standards' would endow.

16. It would appear to be advantageous to jewellers, valuers, auction houses, insurers and insurance brokers to arrange to have CIE colour measurements made routinely on their higher quality gemstones when they become their temporary custodians. This practice would almost certainly confer total legal protection to themselves and their clients in the event of losses, price disputes or allegations of stone- or certificate-switching, colour fading or various chicaneries and deceits. Let it be supposed that a single valuable emerald has been lost from its setting and has no similar companions to help judge its colour. How can the jeweller supplying the replacement, which itself will be either poorer or finer in colour, negotiate a solution satisfactory to the owner, the valuer, insurer and himself? As litigation is now a major growth industry, one would imagine that prior colour measurement would be the answer.

One would imagine wrongly. As an American gemmologist friend with a taste for Goldwynisms put it, "They are agog with indifference". He reports sadly that the cost of measurement and the fuss of sending goods back and forth to an accredited laboratory is thought to be hardly worth the degree of protection gained.

A final obstacle which does not worry gemmologists, but which does worry the author is this:–

17. Many gemmologists, especially those involved with jewellery, have strongly-developed artistic temperaments. Like the archetypal easel painter, they have little patience with 'finicky measurements' and are prone to feel that an analytical approach to a quantitative colour selection of stones is nonsensical.

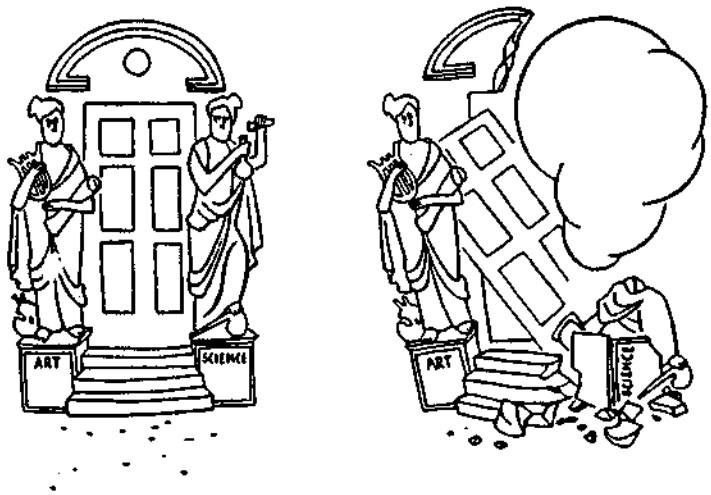

Fig. 2. The archetypal artist's view of the archetypal scientist.

Most successful artists possess only a rudimentary scientific grasp of colour production and the simpler mechanisms of perception; almost none have any knowledge of colour measurement. If reproached about this, they will offer a scornful retort, such as "I know my own colours (meaning colorants, dyes or pigments), so I don't need to paint by numbers, thank you". Their general feeling about science is fairly well summed up in the cartoon in Figure 2.

A brave attempt was made some years ago by an extremely talented artist and teacher, Joy Turner Luke [10], to coax and cajole her fellow artists into learning something about colour

science. She suggested several novel ways by which they might perhaps gain inspiration and fresh insight into their work. From all accounts it was not a great success. The poet Keats has encapsulated this curious sentiment that the appreciation and savouring of beautiful objects is diminished if even the smallest attempts are made to describe their nature:–

> Do not all charms fly
> At the mere touch of cold philosophy?*
> There was an awful rainbow once in heaven:
> We know her woof, her texture: she is given
> In the dull catalogue of common things.
> Philosophy will clip an Angel's wings,
> Conquer all mysteries by rule and line,
> Empty the haunted air, and gnoméd mine –
> Unweave a rainbow.
>
> Lamia, II, page 472.

As an unashamed, hard-core, card-carrying physicist, the author is both puzzled and irritated by these views. He cannot believe that knowledge has to be paid for by the loss of wonder. Gübelin's magnum opus 'The internal world of gemstones'[11] provides the most beautiful and elegant proof of the absurdity of the Keatsian view.

Commercial perspectives in colour control

The vital question which must be posed is this. Is the gemstone industry unique in its apparent hostility to colour grading, with respect to other successful enterprises who have been compelled to use high-quality colour control procedures for industry-wide standardisation?

The answer to this question is an unequivocal yes.

Since the beginning of the 1950s, the worldwide penetration of colour into the manufacturing and marketing processes has been truly massive and will continue to increase. No consumer product, commercial package, sales promotion or entertainment activity is now without its colourful message.

Most industries now require means for rigorously controlling the colour appearance of their products. These are organizations which supply such diverse commodities as paints and coloured coatings, clothing and furnishing textiles, dyed leatherware, plastics, paper and packaging materials, printing inks and photographic films, artistic and architectural products, coating phosphors for television sets and fluorescent light tubes, anodised-and-dyed deposits on metals, dental protheses, coloured glasses, pottery and ceramics, skin and hair cosmetics, industrial mineral oils, waxes and resins, foodstuffs, flowers, beverages and pharmaceuticals.

It is therefore not surprising to discover that there now exists a large variety of instrumental means for predicting, formulating and monitoring the precise amounts of colorants to be added to various matrices to achieve the desired colour of the final product. Or to accept or reject the natural products of the forests, fields, mines and seas. All such assessments make use of any one of the several colour spaces associated with the CIE Tristimulus Colour System.

The earliest commercial method of colour control originated in the textile dyehouse. Here, a textile swatch of three dyed yarns was supplied to the dyer. One was the colour to be aimed at; the other two represented the limiting colours. Finished goods lying outside this colour bracket were returned by the customer. Unfortunately, the dyehouse soon discovered that this kind of simple quality control was no longer able to meet the wishes of their customers. Some of the most complex and sophisticated arrangements now in use consist of spectrophotometers linked on-line to large-memory computers. Their success in trimming the skilled labour force and in reducing the proportion of rejected dyehouse products vastly compensated for the high capital costs.

In all these cases, the suppliers saw no need to change from their simple colour controls to the much more rigorous and costly ones. As with all competitive market forces, it was the customers who were the driving force. It was only after the customers' needs were satisfied that the suppliers discovered the benefits. The paint industry has been by far the quickest to have risen to the challenge; manufacturers can now paint to within incredibly narrow colour tolerances.

A recent survey of colour grading issues has been given by Rouse[12]. As a teacher at the Asian Institute of Gemmological Sciences in Bangkok, Thailand, his views carry much authority in a country which is one of the world's most important gemstone producers and traders. His concluding paragraph is worth quoting:–

'Colour grading should be viewed as a valuable tool for creating a communication system where none exists; as a means to standardize the colour stone industry, and as a vehicle to generate confidence and sales in an industry that needs both. Dealers, therefore, should not be alarmed at the emerging systems of colour grading. Given the proper framework, they can open up a new era for the gemstone industry: an era of colour communication standardization which will result in an

* Science was an unfamiliar word in the time of Keats. It was then better known as natural philosophy.

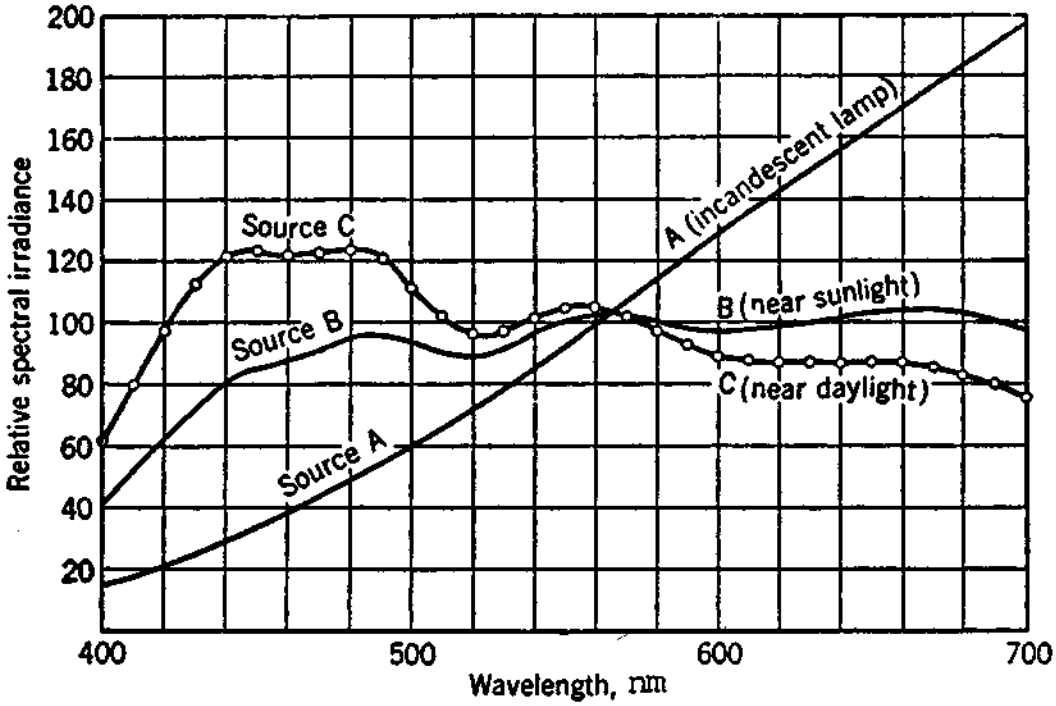

Fig. 3. Relative spectral energies from standard CIE Sources, A, B and C.

upgraded cutting industry, a new public confidence in gemstones, and a thriving marketplace for dealers.'

Methods and instruments for gemstone colorimetry

Apart from the colour-matching charts and colour sample collections, there are two other fundamentally different methods currently used in gemstone colorimetry. They are termed 'visual tristimulus colorimetry' and 'photoelectric colorimetry'.

These devices, whilst much more costly, have many important advantages over the colour reference charts. They can embrace a larger colour gamut; they require no awkward interpolations since the reference colours are stepless; they possess built-in, or can produce, CIE-approved light sources and viewing arrangements; they have no need of sets of calibrated reference gemstones, and they yield less subjective and more accurate and realistic measurements of a gemstone's body colour.

Visual CIE Tristimulus colorimeters. These instruments depend on the visual comparison of two coloured object surfaces (or of transparent bodies) or their optically-manipulated images. One of these is the gemstone under test. The other is that of the calibrated reference standard. The CIE conditions of viewing for colorimetry in general are quite rigorous. They are:–

a. The two structureless comparison fields must be separated by a sharp dividing line.
b. This bi-partite field of view must be restricted so as to have an angular subtense not greater than 4°.
c. The white light illuminating the pair of objects must conform to one of only three light sources approved by the CIE. These are described as Source A(S_A), Source B(S_B) and Source C(S_C). Their relative power emissions as a variation with wavelength are shown in the graph of Figure 3. It can be seen from this that S_C has a much higher proportion of violet-blue light (λ=400 to 480 nm) to red light (λ=630 to 700 nm) than S_A (see Appendix 1 for more details).
d. The illuminating and viewing geometries must conform to any one of four specified arrangements.

When the above conditions are fulfilled, observers with normal colour vision show an extremely high sensitivity to minute colour differences. There are usually few serious discrepancies in field matches

between different observers who have passed a colour vision test.

Further details of the CIE requirements are outlined in various publications[7,13,14,15].

Photoelectric colorimeters. These instruments should be of particular interest to those who prefer their colour measurements to be undertaken by a dispassionate machine. Their use would remove all the eight 'nuts-and-bolts' objections already mentioned. The devices are so contrived that an individual's colour-measuring decisions are taken over by a hypothetical 'eye', so that even a colour-defective operator can produce accurate measurements.

This mathematical ideal eye is the creation of the CIE and is termed the 'CIE Standard Observer'. It consists of a table of numbers which represents a statistical account of the visual colour responses of some 52 actual colour-normal observers. These numbers are called 'CIE colour-matching functions' or distribution coefficients, $\bar{x}_\lambda, \bar{y}_\lambda, \bar{z}_\lambda$. They are shown plotted against their wavelengths in Figure 4. These curves are really the basic data of the CIE system and in effect define how the 'standard observer' sees any given colour. All else in the CIE system can be derived from them, including the extremely useful chromaticity diagrams[1,5,7,15,16].

The contrivance which makes use of these curves is the recording spectrocolorimeter which is the most fundamental of several of these psychophysical, non-subjective instruments. Its purpose is to break down first the component spectral energies of the light received from the coloured object, whether it be from a reflecting surface or from a transparent body. The instrument used by research gemmologists to carry out this task is called a spectrophotometer. A diagram of its usual form, operating in the transmission mode, is shown in Figure 5. The results of an operating run made by it on a faceted Thai ruby is presented as the print-out reproduced in Figure 6. Such a graph contains all the basic information needed to build up a complete picture of the gemstone's colour *under any specified kind of illumination*.

Table 1: Colour appearance systems and colour atlases

Name of colour-order system and atlas	Country of origin	Year of intro-duction	Colour space notation	Number of colour samples	Approx. cost (1986)	References
CIE Tristimulus Colour System	International	1931	X,Y,Z,	none	—	1,3,4,13,14,19
Munsell Book of Color*	USA	1943	H,V,C	1566	£700	1,4,7,10,13, 19,24
DIN-6164 Colour Chart	W. Germany	1960	T,S,D	585	£150	13,19
ISCC-NBS Centroid Colors	USA	1964	H,V,C	251	£30	1,20,21
Munsell Limit Color Cascade	USA	1974	H,V,C	816	£40	Tintometer Ltd.
CIE 1976 ($L^*u'v'$) Colour Space	International	1976	L^*,u',v'	none	—	5,8,15,16
CIE 1976 ($L^*u^*v^*$). Known as 'CIELUV'	International	1976	L^*,u^*,v^*	none	—	1,5,8,15,16
OSA Uniform Color Scale	USA	1977	L,j,g	558	Unknown	22
Natural Colour System. Known as 'NCS'	Sweden	1979	s,c,ø	1412	£140	23
SVF Formula Colour Space	Norway	1986	Vy,F_1,F_2	none	—	24

* The Munsell Color Notation was first published by A. Munsell in 1905 and the first Atlas of the Munsell Colour System was made commercially available in 1915. However, it was not until 1943 that a new renotated Munsell Book of Color was linked to the CIE (1931) system, as indeed are all the other systems and atlases listed above.

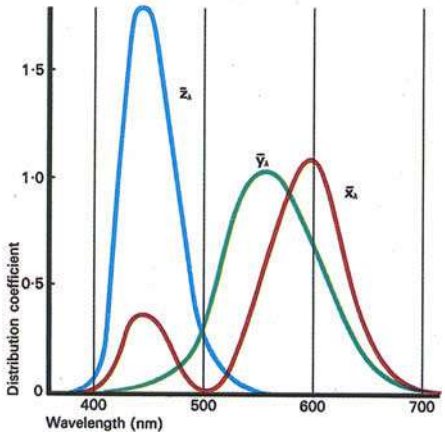

Fig. 4. CIE colour matching functions for an equal-energy white light (CIE Illuminant E).

This is accomplished by mathematically combining the three fundamental elements needed to produce the CIE tristimulus colour values, X,Y,Z[13,14,16]. These three elements which are essential in producing the sensation of colour, listed together with their numerical expressions, are:–

1. The light source. This is expressed as the spectral power distribution of the chosen CIE standard or non-standard illuminant. It is important to appreciate that actual CIE *sources* are not required here, only illuminants (see Appendix 1).
2. The object's colouring characteristics. This is expressed as the percent transmittance (or reflectance) of the object with respect to wavelength (λ) and is obtained by means of the spectrophotometer (see Figure 6).
3. The 'eye' of the CIE 'Standard Observer'. This is expressed as the CIE distribution coefficients $\bar{x}_\lambda, \bar{y}_\lambda, \bar{z}_\lambda$ (see Figure 4).

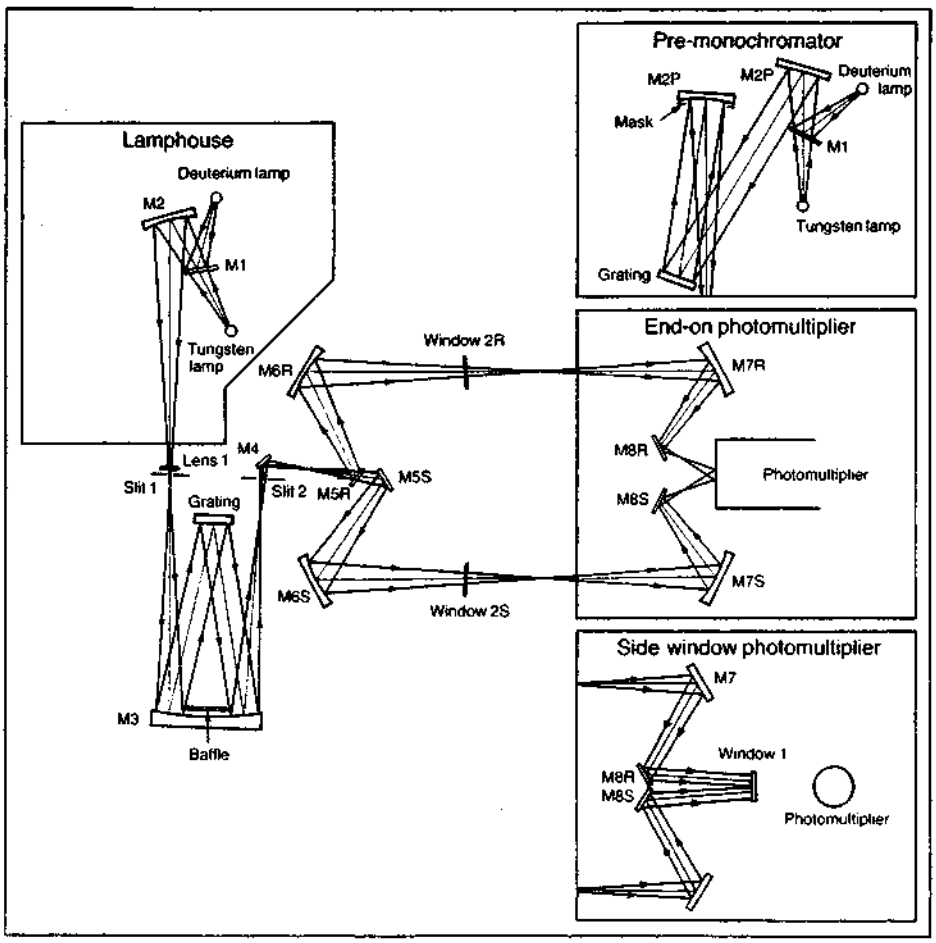

Fig. 5. Optical design details of the Pye Unicam (PU8800/03) UV-visible spectrophotometer (Basil Anderson model).

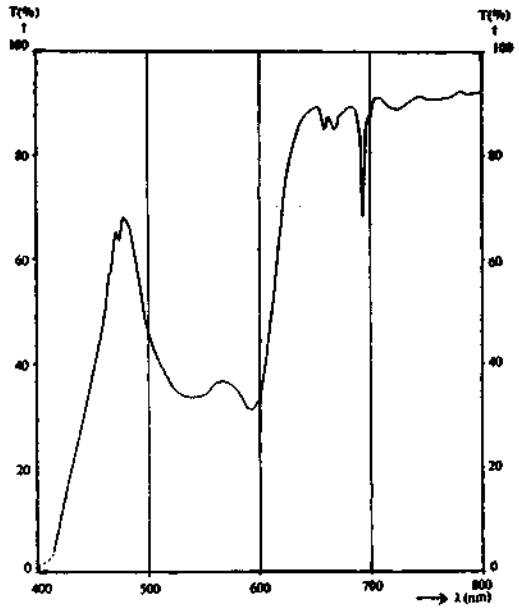

Fig. 6. Results of a spectrophotometer transmission scan through the visible region. The specimen was a faceted Thai ruby immersed in a cell filled with methylene iodide (di-iodomethane). Reference No. 38.

A microcomputer is attached 'on-line' to the spectrophotometer; the combination now becomes a spectrocolorimeter. All the relevant CIE data and computing instructions are stored in the memory. Once the object's colour characteristics have been measured and transferred to the microcomputer, the instrument automatically delivers the X,Y,Z co-ordinates for the selected light source.

Up to this point, only a spectrum and three colour co-ordinates have appeared in the VDU of this 'black box'. As colour is something which is seen, some means must therefore be provided for visualising the actual colour appearance which these raw, quite incomprehensible numbers represent. To this end, the microcomputer can be programmed to transform the X,Y,Z, co-ordinates into those of the many colour-appearance spaces and three-dimensional systems now in current use. With the exception of the CIE system itself and that of the SVF notation, the perceptual colour order systems shown in Table 1 have material colour standards associated with them. These are in the form of collections of systematically-ordered painted or printed colour samples or chips.

Each colour-space system has its own virtues and shortcomings, so that a suitable one must be selected for the purpose in hand. Useful guidance is given by Judd and Wyszecki[13], Wright[17] and Tonnquist[18].

Photoelectric tristimulus colorimeters. These operate on a quite different principle from that of the spectrocolorimeter. They are devices which automatically evaluate the CIE tristimulus values of a given sample without making use of the human eye.

In practice, the sample is suitably positioned so as to receive white light from a stabilised source. The light passing from the sample, either by transmission or reflection, is conducted to specially-designed red, green and blue filters. Photocells lying behind them are used to measure their transmitted light intensities. The combinations of the spectral characteristics of the light source, the filters and the photosensors are so chosen that their separate responses match exactly those of the 'Standard Observer' curves of Figure 4. A white reference sample is used to balance the photocurrents of the sensors so that the three readings obtained on a test sample are directly proportional to its X,Y,Z values.

To produce such a device which is reliable, flexible in use, accurate and of a low cost, is a very tall order indeed. Since the first attempt was made in 1915[27], enormous efforts have been made in trying to attain this goal. The degree to which commercial instruments have been successful in duplicating the desired distribution coefficients has varied greatly from one to another. Maintenance of the calibration is especially difficult. As only one kind of illuminant is possible, alexandrite effects cannot be measured. In no manner can even the best be compared in accuracy with that of the spectrocolorimeter.

An attempt to use this kind of colorimeter for gemstone colorimetry has recently been described[25,26], but no results have yet been reported.

Existing visual CIE tristimulus gemstone colorimeters

Returning to these types of instruments, so far only two have been developed for gemstone colorimetry. They are the GIA 'ColorMaster' and the Nelson-Lovibond Gemstone Colorimeter.

The GIA ColorMaster. This instrument uses the principle of additive coloured lights (red, green, blue) for generating a colour-matching field and comparing this with the body colour of a gemstone. It does this by flooding a colourless translucent gemstone representation with a mixture of red, green and blue lights. The relative intensities of these lights can be controlled and the resulting colour-matching photocell values presented as digital readouts. The device is illustrated in Figure 7.

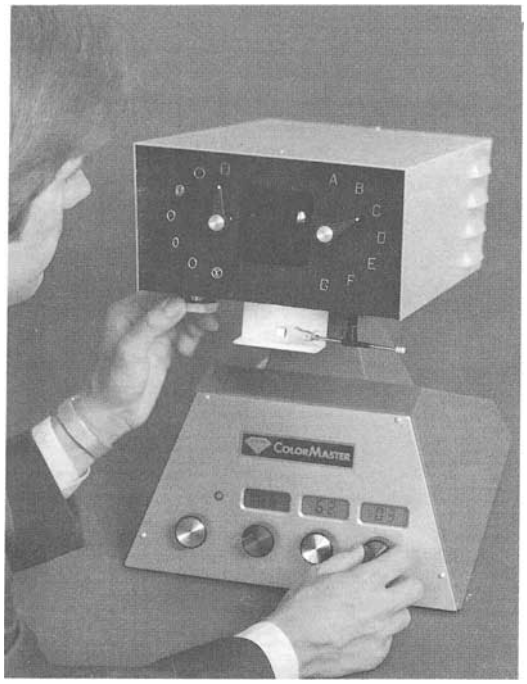

Fig. 7. The 'GEM' ColorMaster of the GIA.

In the patent declaration of the invention[28], its stated main purpose was to enable two jewellers to exchange by telephone a numerical description of the colour appearance of a selected gemstone. For this to happen, both jewellers were obliged to possess identically-calibrated ColorMasters, one to analyse and one to synthesize. In an effort to surmount this limitation, the manufacturers supplied instructions for transforming these ColorMaster readings into CIE co-ordinates, x,y,Y, for either 'tungsten' or 'daylight' viewing. However, as none of the four CIE requirements are even remotely fulfilled, such co-ordinates have no scientific validity.

A recent article on a proposed new classification scheme for gem-quality garnets[29] presented a CIE chromaticity diagram showing plots for 202 garnets. Apart from possessing no basis in colour science, the diagram also possessed no achromatic ('white') plot! Thus one is unable to learn whether an S_A or S_C light source was used, if indeed it were possible to achieve either with this apparatus.* This unfortunate omission means that the values of x and y cannot be transformed into the more comprehensible colour-appearance quantities, λ_d and p_e. Even

* An earlier article[30] places the neutral point used as x=0.3604; y=0.3483. This corresponds to a light source having the properties of a reddish-purple S_R.

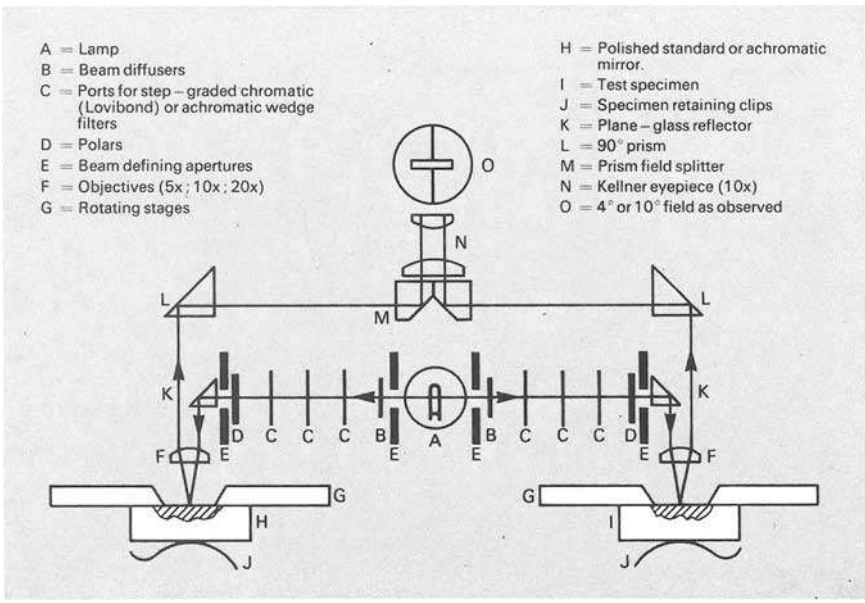

Fig. 8. Illuminating and imaging beam paths in the Nelson-Lovibond visual tristimulus microcolorimeter. Specular reflection mode.

those numbers do not provide all the information needed to convey the full colour appearances. The third necessary co-ordinate, Y, was also omitted. As these multiple errors have been compounded by describing the diagram contents as having a 'tone level 5', whatever that might mean, this item in an otherwise superb contribution should not go undeplored.

Happily, most of the many users of the Color-Master seem to have decided not to use the CIE conversion formulae. The main uses in the U.S.A. appear to be that of a jewellery sales promotional aid, a component of the new computer-trading networks for gemstone exchanges and as a rather expensive colour educational tool for trainee gemmologists. A frank and informative discussion of the instrument and its use has been given by Federman[31].

The Nelson-Lovibond Gemstone Colorimeter. This device uses the principle of subtractive coloured lights (cyan, magenta, yellow) for producing a colour-matching field. The Lovibond Tintometer instrument and its derivatives have had a long and successful history in their many industrial applications. Their construction and use are well documented[7,13], so there is no need for further descriptions.

Some 10 years ago, with the kind co-operation of Tintometer Ltd, the author used the basic heart of the system, the calibrated glasses, to produce an apparatus for the rapid identification of any of approximately 300 metallic ore minerals[32,33]. This was done by measuring the specular colour of a minute area on the polished section of a polycrystalline ore. It was the first visual tristimulus colorimeter to yield the CIE co-ordinates, x,y,Y for the Sources, S_A and S_C for coloured areas down to 30 micrometres diameter. This could be done for both the reflection and transmission modes. The illuminating and imaging beam paths for this microcolorimeter, shown in the specular reflection mode, are illustrated in Figure 8.

The instrument was then modified to measure not the specular, but the diffusely reflecting light from similarly minute areas. For example, it was found possible to measure the colours of the individual paint layers on automobile body finishes. The up-ended and polished multiple-layered paint fragments from say a hit-and-run accident could easily be measured, and numbers rather than words, fed into a central police computer data base. Another successful application was the colour measurement of certain groups of flower pigments. The colour of an area of only about four plant cells across could be measured before chemical deterioration took place[34].

Encouraged by these and other successes, the author decided to grasp the gemstone nettle. The general difficulties which Lewis predicted[4] soon became apparent, but the greatest problem was to find the only acceptable way to guide the measuring light beams into and out of the gemstone.

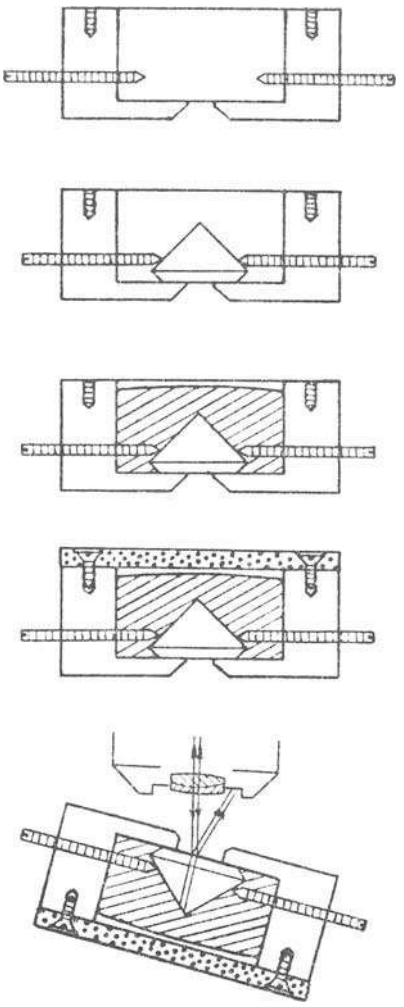

Fig. 9. Mounting and illuminating-viewing details of the Nelson FMIR gemstone mounting technique.

A physicist would probably describe a brilliant-type cut gemstone as 'a wavelength-dispersive, off-axis, retroreflector'. This means that for the stone to perform its task, the light striking or entering the crown should be returned to the eye of the beholder, bringing with it any 'fire' but not returning any desaturating external specular reflections. After much pondering and experimenting the author stumbled on a rather neat way of doing this,

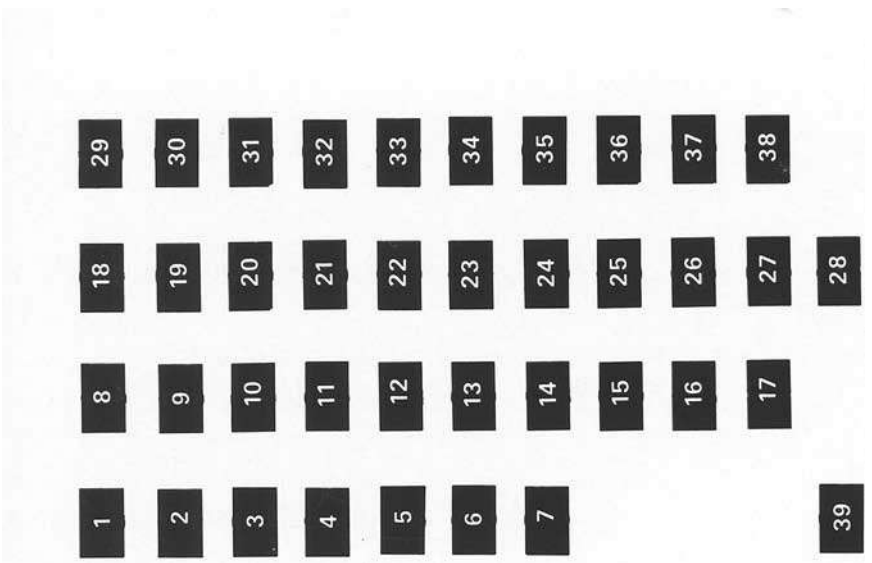

Fig. 11. Photograph of the 38 gemstones measured on the Nelson-Lovibond Gemstone Colorimeter.

Table 2: CIE Tristimulus Colour Co-ordinates of 38 gemstones measured with the Nelson-Lovibond gemstone colorimeter

CIE source A (x=0.4475; y=0.4074) Colour space,x,y,L*

Stone No.	Gemstone	Origin	Weight	Polar Co-ordinates			Colour Classification	Dominant Wavelength range
			Carats	λ_d (nm)	p_e	L*		λ_d (nm)
1	Spinel	Burma	3.45	635.0	75.7	31.2	Red	700 to 630
2	Garnet rough	Kenya	6.03	620.0	33.9	56.6	Orange	630 to 590
3	Garnet, hessonite	Sri Lanka	8.65	611.0	92.6	26.4		
4	Fire opal	Mexico	1.98	604.5	92.5	45.2		
5	Quartz, smoky	Switzerland	3.86	599.5	26.4	42.3		
6	Cornelian	India	2.11	596.0	54.6	42.6		
7	Topaz	Brazil	10.21	590.5	54.2	86.5		
8	Amethyst, H.T.; citrine simulant	Brazil	1.76	589.0	90.0	73.4	Yellow	590 to 570
9	Rutile, synthetic	Linde, USA	8.65	586.0	26.1	61.6		
10	Zircon, normal density	Sri Lanka	5.96	585.0	67.8	64.2		
11	Chrysoberyl	Sri Lanka	1.95	583.2	59.8	78.9		
12	Sphalerite	Mexico	5.45	581.8	75.0	39.9		
13	Zircon, low density	Sri Lanka	7.44	578.0	78.3	33.4		
14	Beryl	Madagascar	4.78	576.5	25.7	95.7		
15	Peridot	Zabargad	3.87	571.5	48.9	69.2		
16	Demantoid	USSR	1.60	561.0	59.4	55.4	Yellow-green	570 to 550
17	Tsavorite	Kenya	0.88	552.1	28.7	50.4		
—	None		—	—	—	—	Green	550 to 510
18	Emerald, synthetic	Linde, USA	1.35	505.0	49.6	49.9	Blue-green	510 to 480
19	Spinel, synthetic, simulated tourmaline	Unknown	10.00	499.2	18.8	31.6		
20	Spinel, synthetic, simulated tourmaline	Unknown	3.77	493.5	35.6	11.3		
21	Zircon	Cambodia	0.67	492.3	20.3	47.0		
22	Spinel, synthetic, aquamarine simulant	Unknown	8.92	489.0	24.4	83.3		
23	Spinel	Sri Lanka	1.08	481.1	7.8	55.6		
24	Tanzanite	Tanzania	0.73	480.4	17.9	65.7		
25	Spinel, synthetic, sapphire simulant	Unknown	2.81	480.0	65.9	32.3		
26	Sapphire	Australia	1.55	479.3	59.0	19.6	Blue	480 to 450
27	Glass, sapphire simulant	Unknown	2.06	474.0	73.6	28.6		
28	Spinel	Sri Lanka	3.80	472.0	24.3	26.4		
—	None			—	—	—	Violet	450 to 400
29	Tanzanite, oriented cube, 'C' axis	Tanzania	5.73	C577.8	29.5	31.9	Violet-purple	C579 to C575
30	Spinel	Sri Lanka	6.54	C571.8	44.3	13.8	Mid-purple	C575 to C555
31	Amethyst	Tanzania	2.01	C567.1	48.5	43.5		
32	Amethyst	Thailand	5.08	C561.5	19.8	61.0		
33	Spinel	Sri Lanka	3.00	C554.5	17.6	49.0	Red-purple	C555 to C504
34	Sapphire, alexandrite simulant	Unknown	13.69	C535.5	35.6	47.2		
35	Ruby, pink	Sri Lanka	1.30	C521.0	31.2	60.5		
36	Almandine	Sri Lanka	0.90	C511.0	51.8	32.3		
37	Almandine, rough	Kenya	20.03	C509.0	64.8	28.4		
38	Ruby, synthetic	Unknown	7.23	C504.5	76.6	32.5		
39	Spinel, synthetic (Reference)	Unknown	4.27	None	0.0	100.0	Colourless	—

Note: C579.0=400 nm; C503.9=700 nm

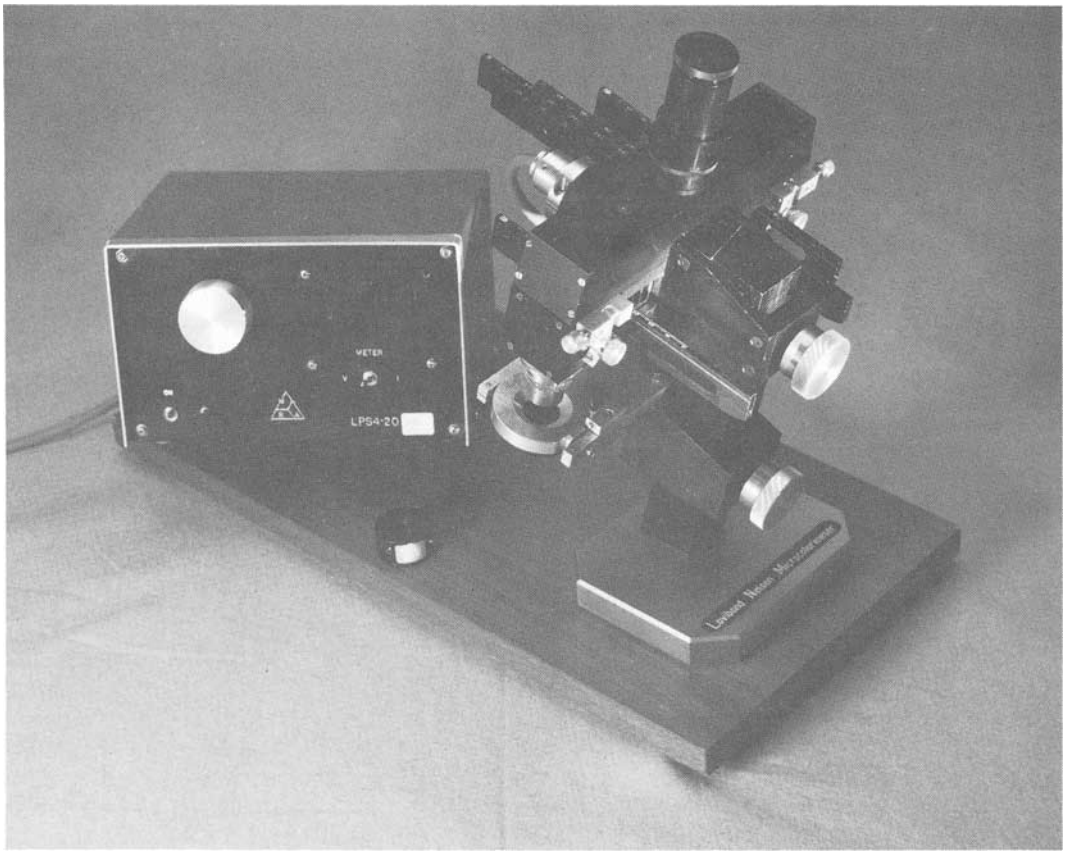

Fig. 10. The Nelson-Lovibond Gemstone Colorimeter. Five colour-matching slides containing the calibrated Lovibond filter glasses can be seen inserted into the beam paths. A constant-intensity CIE Source A is maintained by the mains-stabilised power supply. A FMIR mount can be seen beneath this.

but excluding the 'fire'. The method, which he has termed 'frustrated multiple internal reflection' (FMIR) is best explained by way of Figure 9.

The stone, of any shape or size, is placed in the empty metal cell. The cell has four loosely-fitting screws which serve to centre and hold the stone in position. A thick silicone rubber monomer suspension of a pure-white pigment such as barium sulphate, or the anatase form of titania, is poured into the cell so that it entirely surrounds the stone, except for the table facet. The gentlest of pressures on the screws is enough to prevent leakage through the cell's bevelled aperture. When the silicone rubber has polymerised, through the prior addition of several drops of curing liquid, a lid is screwed on top of the cell to prevent any disturbance of the gelled but flexible rubber.

The cell is now inverted and placed on one of the tilting substages of the colorimeter shown in Figure 10. The cell is tilted at an angle just sufficient to direct the specular reflection from the table facet so that it does not enter the objective lens and is trapped in the objective's annulus (see Figure 9).

In operation, the well-defined and directed light beam, descending from the microscope objective, enters the mounted stone. Here it is deflected slightly by refraction and passes through the stone until it meets the interface between the stone and the white rubber. As the flexible rubber is in direct optical (i.e. 'wetted') contact with the stone, the normal internal total reflection does not take place (i.e. it is frustrated). Instead, the light enters the white rubber near to the culet and is diffused. This diffuse patch of light is able to return back along the original beam path and is collected by the objective. The collected light is then delivered to the comparison eyepiece. Here, it is joined with a similar structureless patch of white light received from a colourless reference stone. This stone has been mounted in an identical manner to that of the test stone and held on the other tilting substage. In this manner, the total ray-path length is much the

same as that met with in the normal viewing aspect of a gemstone.

The matching procedure itself can be better seen from Figures 8 and 10. Before the white light reaches the eyepiece, it is intercepted by the calibrated coloured Lovibond glass filters. These are mounted in nine metal slides, each bearing 10 filters. A colour match in the eyepiece is achieved by sliding into the beam path the appropriate combinations of pairs of the Lovibond chromatic filters (magenta plus yellow; yellow plus cyan; cyan plus magenta) together with neutral (achromatic) density wedges. The subsequent procedures for converting the matching Lovibond glass numbers and the visual optical density readings into the CIE co-ordinates, x,y,Y are thoroughly dealt with in Reference 7.

The colorimeter was used to obtain the CIE co-ordinates for S_A of 38 coloured stones, mostly faceted, but some as cabochon-cut and some as rough pebbles with a polished window. They are shown in Figure 11. They were mounted using a proprietary pure-white preparation known as 'Silcoset 105'. A colourless, brilliant-cut synthetic spinel was used as the white, neutral reference stone (Stone No 39). The results are presented in Table 2, with the measured x,y,Y Cartesian co-ordinates converted into the λ_d, p_e, L^* colour-appearance polar coordinates. The stones are also shown in Figure 12 positioned within this colour space and occupying the point positions representing their body colours. The envelope of optimal colours, known as the MacAdam limits[13,19] is shown in Figure 13 as a Perspex model of the same S_A colour space. The boundaries of this model represent the maximum possible value of L^* for a given chromaticity (x,y), assuming that the objects do not fluoresce. All the colours of the gemstones are seen to lie within this most interesting and useful colour volume. A chromaticity chart projection of it is given in Figure 14.

When these modifications and measurements were first described[35], the author naively believed that as gemstones were usually displayed sold and worn under tungsten lighting conditions, S_A would be the ideal source. He learned later that traders insisted upon a daylight source or its (non-CIE) simulant. (See Appendix 1). An attempt was then made to convert the instrument's S_A source to S_C by means of a Davis-Gibson liquid filter[14,19], but it proved to be much too absorbing to cope with stones of low L^*. Rather than design a more luminous and complex optical system, it was decided to abandon further marketing of the colorimeter for gemstone use. However, the invention of the 'FMIR' mounting technique during this period has since been put to good use in the construction of a low-cost spectrocolorimeter. This is now in the preproduction stage.

The FMIR mount†

The considerable advantages of the FMIR mounting technique are worth listing:–

1. The microscopical examination of the gemstone's illuminated surface and interior allows the user to detect the presence of both surface and internal imperfections. This makes it possible to move the cell across the substage so as to keep these scattering or obscuring centres well out of the narrow beam path. False results are more likely to ensue when a stone's table facet is applied blindly to an instrument's entrance port.
2. The microscopic control also allows the incident light beam to be directed as closely as possible to the culet. It ensures that the total chromophore path length is virtually the same as that encountered in everyday viewing. A coloured stone is judged by the buyer only when it is table face up as in gem-set jewellery. This is not the situation with conventional transmitted light spectrophotometry. Here, the shorter ray path options are few because gemstones are designed as retroreflectors. Figure 15 illustrates the fact that the only practicable pathway through most stones is by an entry through a crown facet and an exit through a nearly parallel pavilion facet.
3. Other means for collecting radiation from faceted gemstones for spectrophotometry have been proposed. The integrating sphere is one such technique, but Collins[37] has shown that this is not without its own colour-distorting perils. In another, the stone is supported on a clamp in a liquid immersion cell, using an optically-compatible liquid. This has been employed for investigating both visible[38] and infrared[39] spectra.
   The FMIR technique is free from the various constraints imposed by these methods. It should also be able to cope with ultraviolet measurements.
4. In the above 'crown facet ⟷ pavilion facet' beam paths, incident polarised light is often used in academic studies for isolating pleochroic colours. Polarised light has absolutely no place in colour grading work as human vision cannot detect it without the use of an analysing polar. If

† The author has decided not to exercise his patent rights on this invention. If gemmologists or other designers of spectrocolorimeters find it useful, they may feel free to use it. If they do so, all that is wished for is that due reference be made to this article.

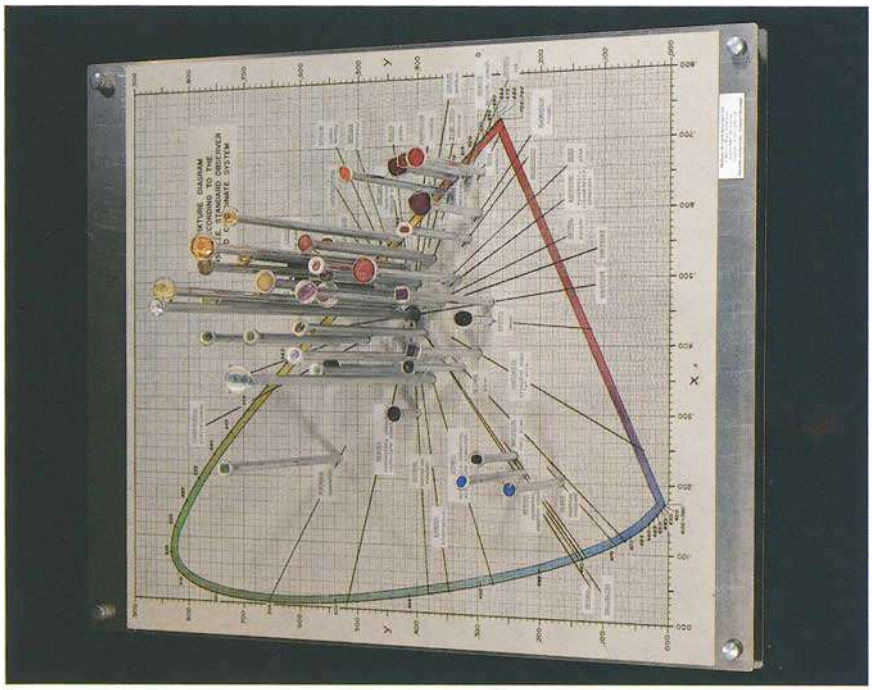

Fig. 12. The 38 measured gemstones arranged to show their colour point locations within the CIE colour space, x,y,L*. CIE Source A. The topmost stone is that of the colourless white spinel used as the white (neutral) reference standard (p_x=0,0). Its co-ordinates are x=0.4475; y=0.4070; L*=100.0.

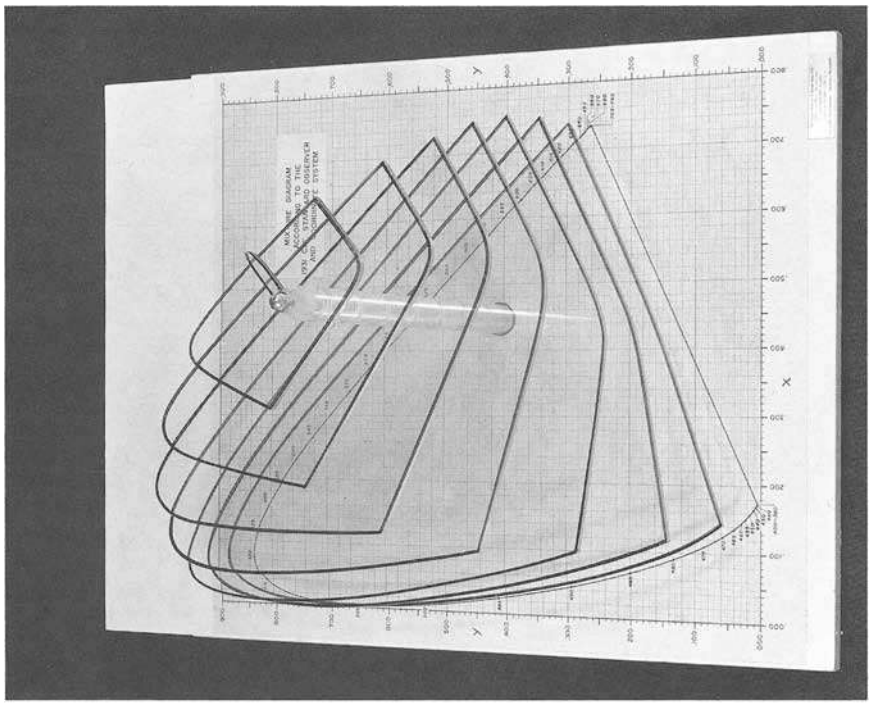

Fig. 13. A perspex model of the MacAdam Limits (optimal colours) for x,y,L* colour space. CIE Source A.

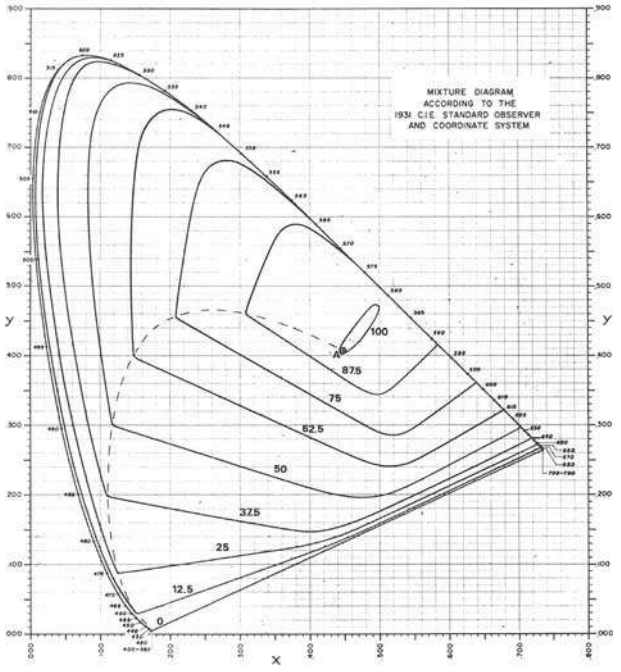

Fig. 14. Chromaticity loci of optimal colours.

pleochroic colours are present in the 'trans-reflected' or 'remitted' beams from FMIR mounts, the eye itself or the photosensor will mix these colours quite effectively.

5. The technique eliminates falsely enhanced hue and saturation measurements arising from stray dispersion effects. Dispersion 'fire' is quenched by the frustration of all multiple internal total reflections. Also, the removal of all specular surface reflections and all internal reflections means that desaturation of the observed body colour cannot occur.
6. The absence of a bulky metallic gemstone support ensures the absence of disturbing scattering effects.
   The four small metallic points of contact in the FMIR mount are virtually invisible. Indeed, it was found possible to measure a gemstone set in a gold finger-ring which had been invested with the white silicone rubber.
7. The size and shape of the stone is unimportant. All that is required is a single polished flat face having a diameter slightly greater than that of the cell's aperture of 2.5 mm. This could be helpful in assessing the potential of costly gem mineral rough before commencing faceting.
8. There is a useful by-product of the technique. After measurement, the stone is easily parted from the mounting, using only the fingers. The two parts of the separated mount are fitted together and secured with plasticine. This now becomes a mould. If this is filled with a two-part epoxy cement, preferably mixed with a little flake aluminium powder, a positive replica is obtained. This constitutes a faithful, permanent, geometrical record of the girdle and all the pavilion facets. Using an optical goniometer, the author found an exact correspondence between the interfacial angles of an emerald's pavilion facets and those of its aluminium-pigmented epoxy casting.
9. Within the recommendations laid down by the CIE for the illuminating and viewing conditions, it must be said that this technique does not comply strictly with any of the four specified arrangements. The two which most closely approach it are termed the 0°/45° and 45°/0° geometries whereas the FMIR mount would be

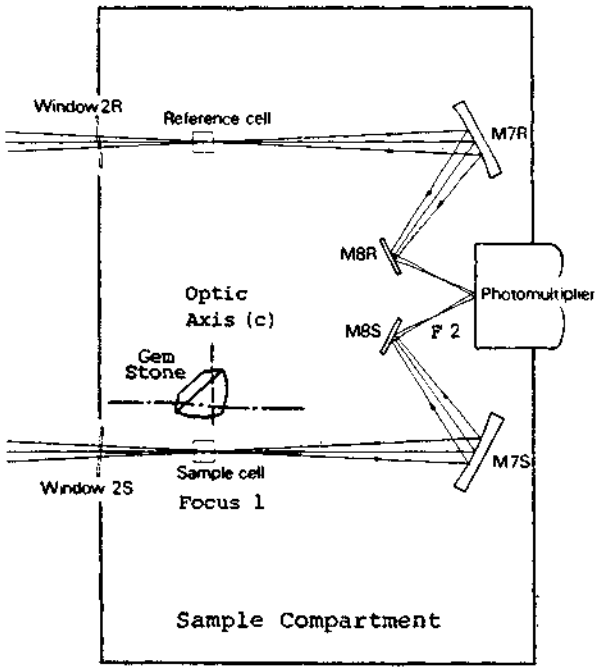

Fig. 15.
The sample compartment of a spectrophotometer showing the only possible transmitted light beam path in air through a well-cut faceted stone. The position of the stone is shown at the first focus (Focus 1) of the incident beam. An alternative position for small stones is at the second beam focus (F2). Reference 36.

described as an approximate 45°/45° geometry. To see if the FMIR mount gave comparable results, three of the 12 tiles of the second series of the Ceramic Colour Standards[40] were measured using a 45° tilt angle and S_A source. The chosen tiles were Deep Blue (No 1), New Yellow (No 4) and Bright Red (No 6). Good, acceptable agreements were obtained.

Discussion

From the views expressed and the instrumentation described here, there are several conclusions which can be drawn which are almost self-evident.

It is clear that the tools needed to characterise numerically the body colour of a gemstone are already in place. When any of the currently available spectrophotometers are linked to a suitable sampling arrangement, such as the microscope/FMIR mount unit or some similar device, together with a computer, then this combination becomes the tool par excellence, the gemstone spectrocolorimeter. Photoelectric tristimulus colorimeters should be regarded with caution.

The existing spectrophotometers were designed mainly for biological and health-care laboratories. As they represent only one component of a gemstone spectrocolorimeter, they are unnecessarily elaborate and therefore costly (about £25,000 with ancillaries). With the imminent appearance of a new generation of gemstone spectrocolorimeters, designed purely for gemstone colorimetry, prices will fall dramatically. For example, it is envisaged that a complete unit, yielding CIE values of X, Y, Z; x, y; λ_d, p_e; u',v'; L^*,u^*, v^* for the Illuminants A, C and D65, will cost about £3,500 and be in production within 18 months.

In practice, the obscure CIE numbers from spectrocolorimeters require transforming into actual colour-appearance samples. Although some of the gemstone colour-grading charts (Appendix 3) are no doubt useful, the low-price alternative forms of the American Munsell and the Swedish Natural Colour chart systems are easily the best choices. Curiously, both contain more of the saturated colours than their costlier parent systems. The little-known Munsell Limit Colour Cascade costs £40 as against £700. The NCS Index costs £47 against £140. (Table 1).

It is an open question as to which is the preferable colour collection. The Munsell atlas has sold over 50,000 units and this guarantees it a durable future. Although the NCS atlas is only but two years old, it has the greater advantage of having a simple, valid, numerical 'language' by which it can call to mind and describe the perceptions of colour and colour combinations. Because of the low costs, both can be tested together, so that experience alone can decide which is best for use in gemstone colorimetry.

The only reason to refer to the Universal Color Language[20,21] is to demonstrate its clumsiness and imprecision. As in a previous plea[1], it is to be hoped that the desire to employ numbers rather than words will prevail in gemmological colorimetry.

In spite of the existence of suitable hardware, almost impenetrable barriers still exist in the trade to the ready acceptance of gemstone colour measurement. Most of the reasons which prop up these barriers have been touched upon here.

Nevertheless, there is evidence of the beginning of some activity towards their removal. An 'International Gemstone Standards Committee' has been inaugurated which is concerning itself with colour grading issues. Several conferences and seminars have recently been held which dealt with this topic, although rather cautiously. Interest seems to be the greatest in America where gemstone computer networks are proliferating. South East- and Far East- Asian countries are following closely behind, but both apathy and hostility still prevail in the European marketplace. Rouse's rousing clarion call has not been heard there.

It is highly probable that it will be the international buyers and customers, as always, who will ultimately cause the barriers to come down.

Appendix 1

Light sources

The terms 'CIE Illuminant' and 'CIE Source' have caused much misunderstanding. To draw the crucial distinction, the CIE sanctions the use of four standard *illuminants* for colorimetry[14]. Three are described as 'standard light *sources*' and directions are specified for their production. The first, S_A, represents an incandescent tungsten lamp operating at a colour temperature of 2855K. The second and third sources, S_B and S_C, are produced by filtration of the source S_A through rigorously specified liquid filters. They are intended to simulate 'direct noon sunlight' (correlated colour temperature of 4875K) and 'north noon diffuse daylight' (correlated colour temperature of 6775K) respectively. All are relatively easy to produce[1,7,13,14]. (See Figure 3).

The fourth standard illuminant, D65, is not a real source. It consists simply of a numerical table of the spectral power distribution representing a particular phase of daylight having a correlated colour temperature of 6500K. It is used in conjunction with spectrophotometers to calculate the CIE Tristimulus co-ordinates of object colours, and plays no part whatever in practical visual colorimetry.

Other non-standard illuminants simulating other phases of daylight are sanctioned. These cover a correlated colour temperature range of 4000K to 25000K (e.g. D55, D75...). Because of serious practical obstacles, the CIE is highly unlikely in the foreseeable future to recommend the use of an actual light source as a simulant to any of the 'D' series of illuminants. Indeed, it has even withdrawn its recommendation for the use of 'S_B'.

A good example of this common misapprehension is given in the CIBJO publication 'Rules for the Diamond Trade' (1980). Article 3(3) requires that the stones must be colour-graded "...under normalized artificial light equivalent to approximately 5500° Kelvin (D55)". As Article 3(6) states that "Photometric measurements have no determinative value", it is difficult to see how these conflicting requirements can be reconciled.

Appendix 2

Comments on 'Trade objections'

As with objections (1) to (5), that of (6) requires little further comment. It is enough to repeat the necessity of using only S_A or S_C light sources; those employing gas discharge lamps must be avoided at all costs.

Given an almost universal non-compliance in gemmology with one or more of the CIE requirements, the views relating to objection (7) are not unexpected. In addition, there is the possibility that the two fields may exhibit 'metamerism'[7,13,19], a colour phenomenon related to the alexandrite effect. It can be present when there is a good colour match under a given light source, but a poor match when using a different source. This situation could arise when fairly saturated purple stones are being examined. Adherence to the use of a single stated CIE source would eliminate this problem.

The feelings expressed under objection (8) spring from a misconception and have no scientific basis. Female colorists are undoubtedly more aware or more conscious of colour sensations than those males who have no colour vision defects. However, it has been found that both groups possess the same colour discriminatory abilities, which is an entirely different matter.

This misconception has arisen because of the fact that 8.1% of the male population have colour vision defects against only 0.4% for the female population. Expressed differently, it means that for every female who has defective colour vision, there are 20 males similarly affected. Thus it would be prudent for the gemstone industry to require those of its

male members who are active in the marketing of diamonds and coloured stones to submit to a colour vision check. Normal colour vision can be assumed if an observer is able to pass one of the established and well-conducted colour vision tests, such as those using the Ishihara Charts, the Farnsworth D15 Test or the Lovibond Colour Vision Analyser[7]. Those whose colour vision is sufficiently abnormal to be a handicap should not be encouraged to work in situations where critical colour judgements have to be made.

Appendix 3

Commercially-available charts currently used for the colour grading of coloured gemstones

Colour Chart	Supplier
GIA Color Grading Manual	Gemological Institute of America, 1660 Stewart Street, P.O. Box 2110, Santa Monica, California 90406, USA
Gem Dialogue	Kassoy, 32 West 47th Street, New York, N.Y. 10036, USA
Gem Color Manual	Gemlab Research and Technology Group, Box 69024, Vancouver, British Columbia, V5K 4W3, Canada
Gem Color Guide	Gemological Technology Inc., Costa Mesa, California, USA
AGL Color Scan	American Gemological Laboratories, Inc., 645 Fifth Avenue, New York, N.Y. 10022, USA

Note: See also the CIE-linked colour-appearance systems listed in Table 1.

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Spectrophotometric measurements of faceted rubies: critical review of an immersion technique

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Referring to the paper 'Spectrophotometric measurements of faceted rubies' by A. Banerjee, J. Himmer and H.-W. Schrader (*J. Gemm.*, 1985, **XIX**, 6, 489–93) and to the abstract of this article by C.M. Stockton (Gems & Gemology, 1985, **XXI**, 3, 182) and in reply to the Letter to the Editor by Banerjee and Schrader (*J. Gemm.*, 1986, **20**, 2, 135–6), four critical notes must be added to the discussion. For this purpose, a transmittance diagram of two faceted Burma rubies is used to compare the immersion spectra published by Banerjee *et al.* (one of them, Figure 3, shown here as curve A) with a spectrum recorded in air by G. Bosshart (curve B).

1) Banerjee *et al.* (1985) intended to demonstrate immersion in methylene iodide as an advantageous general technique for getting straylight-free absorption diagrams of faceted gemstones in the 400 to 800 nm range. While, for the visible area, we do not negate the feasibility of good-quality absorption spectra of faceted gemstones immersed in certain colourless, light-stable heavy liquids, the two published ruby curves (Figures 3 and 4, pages 492 and 493) do not prove the advantages of the method and should not be termed 'clean spectral diagrams' (Stockton, 1985): both spectra are misleading in part. They show a strange additional transmission peak roughly where the slender chromium absorption band is positioned in any undisturbed ruby diagram (see curve B). The phantom transmission in curve A is an unexplained artefact most likely caused by the methylene iodide immersion technique.

In addition, Figures 3 and 4 are insufficiently resolved: the chromium doublets at 475/476 nm and at 693/694 nm in fact are wide singlets. The alert spectroscopist also notes that the abscissa in Figure 3 (here as curve A) is in error by at least +40 nm. This would be the transmittance diagram of a greenish or colour-changing corundum and not of a ruby.

2) It is not correct to state that absorption curves of faceted gemstones in air in general are negatively affected by 'refraction and reflection of the light beam' and 'cannot be easily reproduced'. Recording in air is successfully done by an increasing number of gemmological laboratories around the world (for the sake of comparability, however, preferably in the absorbance and not in the transmittance mode). In fact, a skilled operator is able to record detailed and fully polarized absorption spectra in air, all the way down to 280 nm and unpolarized curves even down to 200 nm.

3) Immersion techniques require a set of wide, fairly expensive UV silica glass cells and are cumbersome in terms of fine adjustments of the stone in the light beam. Immersion does not eliminate scattering effects caused by condensed tiny inclusions nor by strong internal growth inhomogeneities and fluorescence.

According to the authors' experience, immersion does not even improve the UV/Visible spectra of cut stones with inferior polish, nor of rough stones, in an obvious manner.

4) Among the *liquids* a gemmologist usually knows, methylene iodide is the least suited for immersion. It is not entirely colourless and it reacts to light and heat by darkening. Transmission ends at approximately 440 nm at best (and thus is completely inappropriate for UV spectra of rubies). Dispersion of light into the spectral colours is high (a problem encountered in immersion microscopy of inclusions also). Like other heavy liquids, it has a strong and unpleasant odour, is expensive and not totally harmless with respect to toxicity. The only property of methylene iodide which is advantageous for the recording of gemstones like rubies, is its high refractive index (n_D 1.734 at 23°C).

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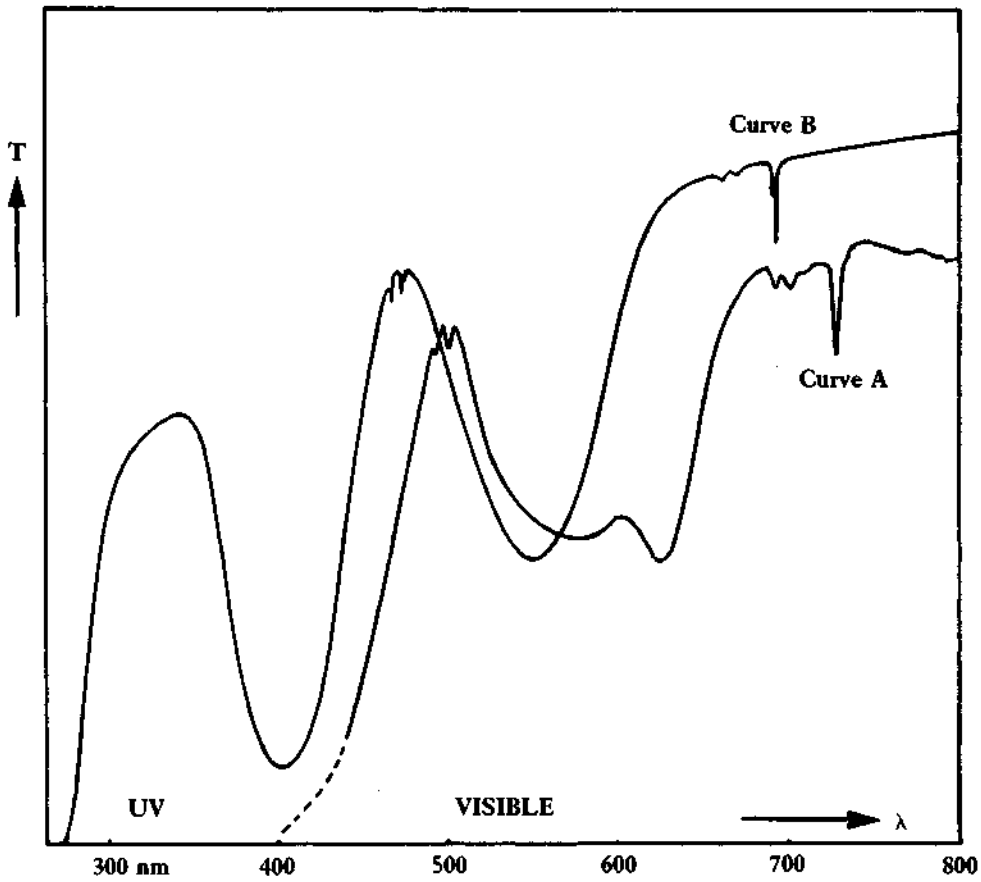

Comparative transmittance spectra of two faceted rubies from Burma, recorded at ambient temperature in methylene iodide immersion by Banerjee *et al.* (1985), Curve A, and in air by G. Bosshart, Curve B.

Bromoform has better transmittance (down to 350 nm) but a markedly lower refractive index (n_D 1.590 at 23°C).

Perchloroethylene (C_2Cl_4), a colourless liquid of medium refractive index (n_D 1.505 at 23°C) and of lower toxicity than carbon tetra-chloride (therefore used in dry cleaning), can be considered as an option for extraordinary cases, since it transmits at least to 300 nm and is stable.

Own immersion experiments dating back to 1974 and correspondence of one of the authors (GB) with the late B.W. Anderson as early as January 1978, showed distilled water to be that 'very useful dream liquid' with the most favourable combination of properties. It is colourless, transmits to at least 240 (210) nm, is stable to light, ultraviolet radiation and heat (during recording and storage), has low dispersion, is universally available, cheap, non-toxic, odourless and non-fluorescent. The low refractive index (n_D 1.329 at 23°C), however, even disqualifies this liquid as an ideal immersion medium.

Conclusion

From our own observations, we therefore conclude that immersion is an unnecessary complication during absorbance measurements on rough and cut gemstones and especially is of no advantage for the recording of UV spectra of faceted rubies.

Experience in properly positioning the stones, varying from specimen to specimen in the degree of difficulties presented by the external and internal properties, efficiently replaces the need for immersion techniques.

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J. Gemm., 1986, 20, 4

Some low cost accessories

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Abstract

In an attempt to save money the following devices were constructed with wood at a total cost of approximately £2.00. None are claimed to be original ideas.

Gemstone holder for the refractometer

This holder is easily constructed given the use of normal carpentry tools. It consists of a piece of ¾in. thick blockboard, 2in. long by 1⅛in. wide, with a 3/16in. hole in the centre. It is important that the long sides are exactly parallel. The two cheek pieces, either side, are 4mm plywood, 2⅜in. by 2in. Cut outs are made by holding both in a vice, and using a 1⅛in. wood bit and a coping saw. The width apart is governed by the dimensions of the table of the refractometer. The sides are glued and pinned to the base, and, if necessary, dressed with a plane. A 3/16in. flat-headed brass machine screw 2¾in. long with two 3/16in. hexagonal nuts to fit, a small piece of aluminium sheet bored and filed to a point, and a small blob of Blu-Tack, complete the assembly. Lines at 45° intervals are drawn on the top surface as an aid to the determination of refractive indices. The machine screw is inserted upwards as shown in Figure 1. Blu-Tack is quite effective in controlling the gemstone while it is on the prism of the refractometer. Total cost 50 pence.

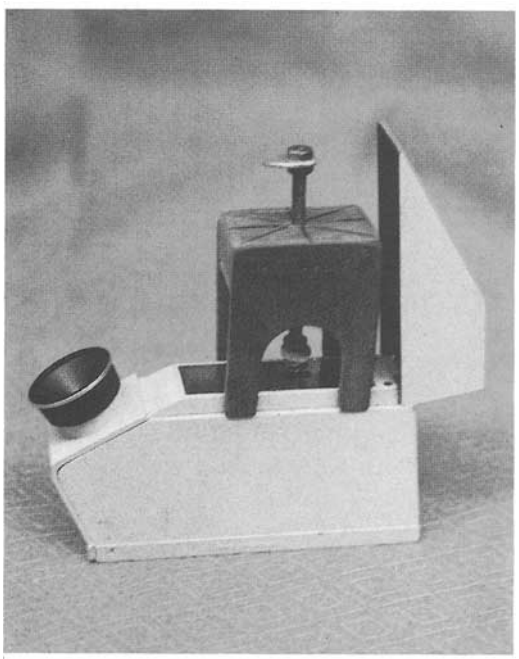

Fig. 1. Gemstone holder for the refractometer.

Holder for heavy liquid bottles

Spilt methelyne iodide and bromoform, besides being obnoxious and smelly, are also quite effective paint removers, so a holder for the heavy liquid bottles was devised. It was made from a piece of scrap wood, 2½in. by 2½in. by 8in. long. The bottles are 1in. in diameter by 2¼in. high. The holes, bored into the wood, should be 1⅛in. in diameter and 1¾in. deep. Six holes were drilled to take the normal range of four specific gravity testing liquids plus extra bottles of specialized dilutions. The finished holder is shown in Figure 2; cost 25 pence.

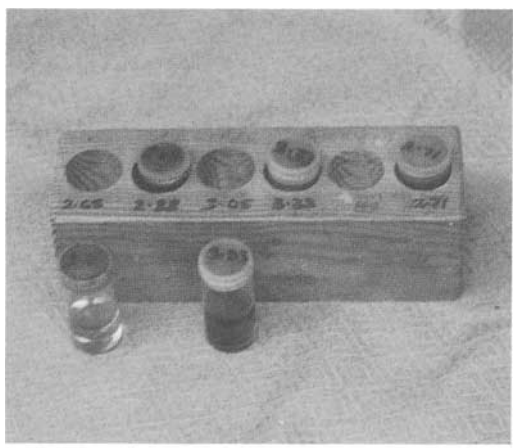

Fig. 2. Holder for heavy liquid bottles.

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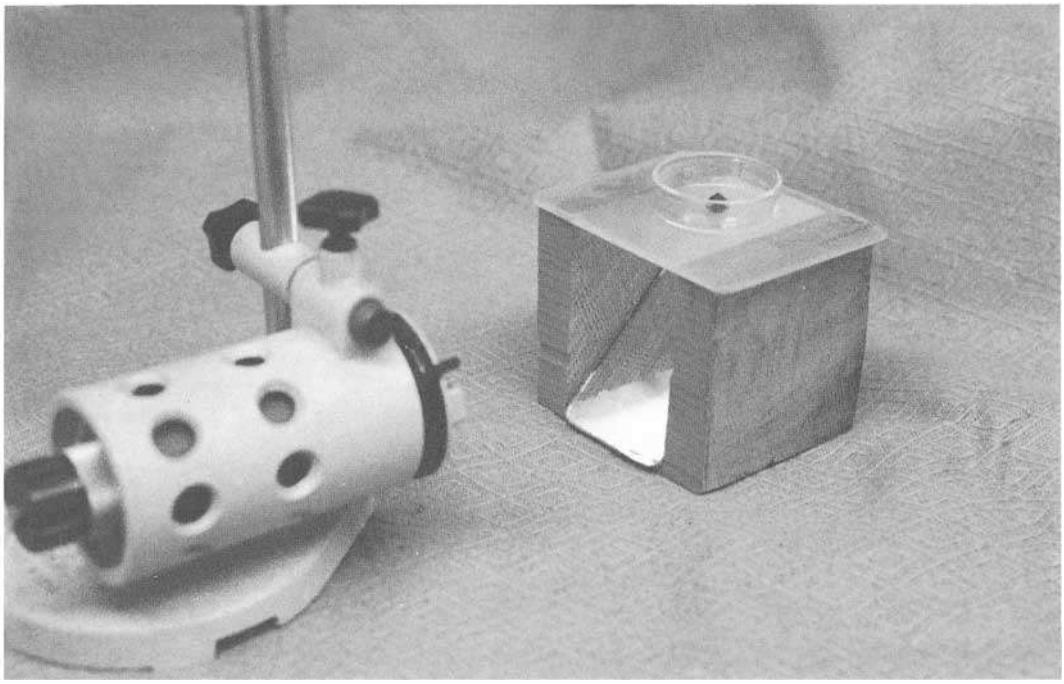

Fig. 3. Angled mirror device for immersion contrast.

Angled mirror device for immersion contrast

This is also easily constructed. It consists of a block of wood 3in. × 3in. × 4in. long, a mirror and a piece of ground glass. Holding the wood in a vice, two diagonal cuts are made with a tenon saw, corner to corner, 2in. apart (the width of the mirror). The 45° slope is obtained by removing the wood with a sharp chisel. The mirror, purchased from Woolworths, was originally too large, and was cut to size with a diamond saw, but a glass cutter would work equally well. It should be 2in. wide by 4¼in. long. It is glued to the inside diagonal of the wood with Evostik, or any other good adhesive. The ground glass top 4in. × 3in. is made by rubbing together two pieces of window glass with silicon carbide 260 grit and water, until an acceptable degree of opacity is obtained. The sharp corners are reduced with 'Wet and Dry' paper or on grinding wheels. It is glued into place, as shown in Figure 3; cost £1.00.

If interested persons are dubious about their technical ability to construct these accessories, an approach to a local joiner asking him to make them in his spare time would keep down the cost.

* * *

The Editor would be pleased to receive contributions from other readers who feel that they have made inexpensive accessories for use in gem testing.

[*Manuscript received 6 May 1986.*]

The Gem-trak gemstone identifier – a test report

Peter Read, C.Eng., F.G.A.

There are many thermal conductivity testers on the market which can distinguish diamond from its various simulants, but until recently only two of these have been capable of identifying any other gemstone. The reason for this becomes clear when the design requirements for both types of thermal tester are examined.

In the case of the diamond/diamond simulant instrument, it is only necessary to discriminate between diamond (with a thermal conductivity ranging from 1,000–2,600 W/m/degree C) and corundum (which, compared with diamond, has the next highest conductivity of 40 W/m/degree C). Because of the large difference in these two thermal conductivities, the design problems involved in the production of a suitable thermal tester are relatively simple.

In contrast, it is considerably more difficult to identify non-diamond gems by this method as their thermal conductivities span the very much smaller range from glass at 1.0 W/m/degree C to sapphire/ruby at 40 W/m/degree C.

The first commercial instrument specifically to cover both diamond and the non-diamond gems

The Omnitest 'Gem-trak' thermal conductivity gemstone identifier.

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was the Gemtek 'Gemmologist' in 1983[1]. This was followed in 1984 by the 'Alpha-test'[2]. Both instruments used a technique which measured the time taken for the heated probe test tip to fall between two preset temperature levels. This time interval was displayed as a direct analogue indication of the gem's thermal conductivity (a low reading indicating a high conductivity).

The 'Alpha-test' instrument represented a significant improvement on the earlier 'Gemmologist' in that the temperature of its probe tip was automatically stabilized. In addition, its digital display was automatically zeroed each time a new test was initiated.

The operating constraints, which were necessary because of the very small differences between the thermal conductivities of the non-diamond gems, remained the same, however, for both instruments. This meant that the testers had to be operated in a draught-free environment having an ambient temperature between 18 and 25° C (64–77° F), the gem under test had to be at body temperature, and the probe tip had to be applied at right-angles to the test surface with just enough pressure to cause the tip to retract by 3mm. To users who were more familiar with the less rigorous test requirements of the simpler diamond/diamond simulant tester, these operating constraints proved troublesome.

In April 1986, a third generation thermal gemstone tester was introduced. This new instrument, the 'Gem-trak', uses the same basic measuring technique as its two predecessors (indeed, the probe together with the principal gemstone readings and the sapphire/emerald calibration adjustments appear to be identical to those of the 'Alpha-test').

The 'Gem-trak' gemstone identifier is housed in a stylish electronic-type instrument case whose carrying handle can be used as a stand to tilt the unit at a convenient operating angle. In comparison to the 'Alpha-test', one practical improvement is a test probe that can be disconnected from its control box by means of a plug/socket on the front panel. This facilitates the replacement of a damaged probe.

During tests on diamonds and a range of other gems, the 'Gem-tek' produced consistent readings within the ranges quoted in the operating manual (as with the 'Alpha-test', it was found that high zircons produced much lower readings than low zircons – 52 compared with 400). Repetitive tests on the same gemstone were essential to establish a valid reading, and some users of this type of instrument have complained of the time taken between tests for the probe tip temperature to stabilize and the 'Ready' lamp to light (approximately 10–15 seconds depending on the conductivity of the gem).

While acknowledging the technical ingenuity incorporated in the design of instruments such as the 'Gem-trak', it should be remembered that (as with the reflectivity method of gem identification) there are several stones which cannot be positively identified because they have similar thermal conductivities). Bearing this in mind, the 'Gem-trak' is mainly suitable for the identification of diamonds, diamond simulants and a limited range of non-diamond gems (particularly where the latter are small and are mounted so that they cannot be checked on either a refractometer or a reflectivity meter).

The 'Gem-trak' is manufactured and distributed by Omnitest Ltd., Highcliffe House, 411–413 Lymington Road, Highcliffe, Dorset BH23 5EN.

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[*Manuscript received 3 July 1986.*]

Gemmological Abstracts

ADRIAN, J. 1986. Geology as an aid to gemmology in New South Wales. *Australian Gemmologist*, **16**, 2, 80.

Abstract advocating changes in gemmology in line with changes in geological thinking. R.K.M.

BAKER, C.R. 1986. The hardness of Australian diamonds. *Australian Gemmologist*, **16**, 1, 11–12.

Investigates the generally held belief that Australian diamonds are harder to cut than those from other sources because of inclusions, twinning, type of crystal, etc. Stones from the new Argyle AK1 pipe, which is a lamprolite and not a kimberlite, are affected in this way. R.K.M.

BALFOUR, I. 1986. Famous diamonds of the world, XXV. The 'Sancy'. *Indiaqua*, **43** (1986/1). 127–32, illus.

Although there have been at least three diamonds known as the 'Sancy', the one which is now recognized as the authentic stone is a pear-shaped briolette weighing 55.23 ct and is displayed in the Louvre, Paris.

It is possible that Nicolas de Sancy acquired the stone during his travels in the Far East, but the author admits that the 'Sancy' has probably the most confused history of all the famous diamonds. Among the stone's owners were James I, Cardinal Mazarin, Marie Antoinette, the Russian Prince Demidoff, the Maharaja of Patiala, and Lady Astor. In 1978 the 'Sancy' was re-sold for a reputed $1,000,000 and is now on view in the Louvre Museum, Paris. P.G.R.

BARTON, M.D. 1986. Phase equilibria and thermodynamic properties of minerals in the $BeO–Al_2O_3–SiO_2–H_2O$ (BASH) system, with petrologic applications. *American Mineralogist*, **71**, 277–300, 12 figs.

Phase relations and thermodynamic properties of behoite, bertrandite, beryl, bromellite, chrysoberyl, euclase and phenakite are quantitatively evaluated from new measurements with data from the literature. M.O'D.

BEATTIE, R., BROWN, G. 1986. Facetable bowenite. *Australian Gemmologist*, **16**, 1, 25–6, 5 figs in colour.

A translucent yellowish-green bowenite of 0.84 ct was cut from New Zealand material. RI 1.560–1.562. SG 2.59. H 5–6. R.K.M.

BEESLEY, C.R. 1986. Pakistan's emeralds. *Jewelers' Circular Keystone*, **157**, 2, 358365, 9 figs in colour.

An outline of the mining of emerald from a number of sites in Pakistan. M.O'D.

BERAN, A., ZEMANN, J. 1986. The pleochroism of a gem-quality enstatite in the region of the OH stretching frequency, with a stereochemical interpretation. *TMPM Tschermaks Mineralogische und Petrografische Mitteilungen*, **35**, 19–25, 3 figs.

The enstatite examined was almost colourless and of gem quality, of a few millimetres in size. Two sharp absorption bands were seen at 3410 and $3510 cm^{-1}$ and these were attributed to OH stretching vibrations. The absorption coefficients were larger parallel to the direction of the silicate chains so that the OH dipoles must be oriented approximately parallel to [001]. A stereochemical interpretation of the incorporation of the OH groups into the structure is given. M.O'D.

BIRDSALL, M.C. 1986. Lightning Ridge, black opal capital of Australia. *Lapidary Journal*, **40**, 3, 26–32, 5 figs in colour.

A general history of the Lightning Ridge opal fields. M.O'D.

BROWN, G. 1986. Presidium DiaMeter. *Australian Gemmologist*, **16**, 1, 17, 2 figs.

A slide-rule type gauge which is said to be useful, with limitations, for comparing weight/diameter of brilliant-cut diamonds. R.K.M.

BROWN, G. 1986. Letter. *Australian Gemmologist*, **16**, 1, 18.

Quotes Dr Birch's microprobe analysis of the Hart's Range aventurine feldspar from Koppio,

discussed in *Australian Gemmologist*, 1984, **15**, 8, 263–74, defining it as a potassium aluminium silicate, with sodium and barium described as a minimum microcline with bulk composition of about $Or_{88}Ab_{12}$. R.K.M.

BROWN, G. 1986. Australian gem feldspars. *Australian Gemmologist*, **16**, 2, 81.

Abstract calling attention to andesine-labradorite from the Hogarth Range, NSW, and to an anorthoclase-cryptoperthite antiperthite from Moonstone Hill, N. Queensland, which have gem potentials. R.K.M.

BROWN G., SNOW, J., TAYLOR, B. 1986. The Gemlusta GL500P reflectometer. *Australian Gemmologist*, 16, 1, 9–10, 1 fig.

A further version of earlier Gemlusta instruments, this one had additional facilities. Not all claims made by the maker could be substantiated. R.K.M.

CAMPBELL, I. 1986. On the subject of gemstone treatments. *South African Gemologist*, **2**, 1, 11–13.

Yellow sapphire and the nomenclature to be used for treated stones are discussed. M.O'D.

CASSEDANNE, J. 1986. La kunzite au Bresil. (Kunzite in Brazil.) *Revue de Gemmologie*, 87, 5–8, 10 figs (8 in colour).

Various sites for kunzite in Brazil are described and mapped. A list of known sites is given and there is a short bibliography. M.O'D.

CHIKAYAMA, A. 1986. Gemstones in China – especially jade and similar stones. *Australian Gemmologist*, **16**, 2, 60–3, 1 map.

A brief account concerned with nephrite and with other ornamental minerals used by the Chinese carver. R.K.M.

DAHANAYAKE, K., RANASINGHE, A.P. 1985. Geology and mineralogy of gemming terrains of Sri Lanka. *Bulletin of the Geological Society of Finland*, **57**, 1–2, 139–49, 5 figs.

Gem recovery in Sri Lanka is carried out in river valleys and on hill slopes underlain by high grade Precambrian metasediments. Corundum is the most important of the gem minerals found and occurs in assemblages which also contain garnet, spinel, topaz, tourmaline and zircon. These assemblages may be residual, alluvial or eluvial deposits. Gem minerals are derived from garnetiferous gneisses, granulites and charnockites and their formation is attributed to a desilification process under conditions of high temperature and pressure, since the charnockites in particular are poor in quartz though rich in corundum, hypersthene and sillimanite. M.O'D.

DEVRIES, R.C., FLEISCHER, J.F. 1986. Synthesis of jadeite for jewellery. Wahroongai News, 20, 6, 8–11, 1 fig. A reprint from General Electric Technical Information No. 84, CRD282 November 1984*.

Explains the difficult experimental method of synthesis from a powdered glass which is sintered at high temperatures and at pressures equivalent to those used in diamond synthesis. Some lamination of the product occurred. Reconstitution of natural jadeite from its powder was also achieved. An optional lower pressure method is mooted. R.K.M.

FLAMINI, A., GASTALDI, L., VITICOLI, S. 1986. Crystal growth and characterization of beryl doped with transition metal ions. *Materials Research Bulletin*, 21, 1–6, 6 figs.

The growth of beryl crystals containing the transition metal ions Cr^{3+}, Fe^{3+}, Fe^{2+} and Mn^{2+}, from a flux of $Li_2Mo_2O_7$ is described together with notes on the characterization of the crystals. M.O'D.

FRYER, C.W. (Ed.), CROWNINGSHIELD, R., HURWIT, K.N., KANE, R.E. 1986. Gem Trade Lab notes. *Gems Gemol.*, **22**, 1, 46–53, 24 figs in colour.

An alexandrite of fine colour had coarse silk of unusual type; calcite marble and magnesite bead necklaces were identified; a fine danburite, thought to be the first from Sri Lanka, resembled very fine yellow sapphire. An alphabet of letters cut by laser from diamond is illustrated and would have been impossible to make by conventional cutting methods; three ekanites examined in the past year were all hazy with inclusions and were highly radioactive; a tarnished or coated emerald gave an RI of 1.48 on the coated area but normal Zambian emerald readings where cleaned; glass microspheres were found at Nogales, Arizona, possibly connected with the Winslow meteoric crater; an amphibole ring was tentatively identified as magnesian hastingsite, a hornblende; white quartzite, dyed blue to imitate lapis lazuli was distinguished by higher RI and dye concentrations; a large oolitic opal had chalcedony matrix; several tissue nucleated salt-water cultured pearls seen recently in which drilling has attempted to eliminate evidence of tissue nucleation, the salt-water version seems to be new; freshwater bead-nucleated pearls were found to have pre-drilled nuclei, making insertion into the less accessible mussel body simpler; four 'pad-paradscha' sapphires cut from a 1126 ct crystal

* Abstracted in *J. Gemm.*, 1985, **XIX**, 7, 633.

discussed in *Gems Gemol.*, Spring 1983 issue, were examined, one stone of 16.92 ct had been heat treated to an unnatural orange colour altering its fluorescence and absorption; yttrium aluminium gallium garnets of a deep vanadium green colour were found to have reddish-brown flux melt inclusions and wispy veils, a marked absorption similar to green YAG, RI 1.885, SG 5.05. All are described and illustrated. R.K.M.

FRYER, C.W. (Ed.), CROWNINGSHIELD, R., HURWIT, K.N., KANE, R.E. 1986. Gem Trade Lab notes. *Gems Gemol.*, 22, 2, 108–13, 14 figs in colour.

A devitrified cobalt glass imitation of black onyx from Hong Kong tested and identified. Green glass cabochons represented as natural showed devitrification and a large bubble suggesting artificial origin. Dyed and wax-sealed lapis lazuli beads showed patchy red fluorescence under long-wave UV in some beads while others showed normal chalky green expected in natural coloured lapis lazuli, swab tests defeated by paraffin wax seal, Chelsea filter gave brownish-red colour brighter than expected in natural coloured lapis.

A shaped bead necklace had been veneered with opal, using black adhesive to give superficial appearance of black opal. Green opal cabochons with black dendrites resembled green grossularite garnet. Raised area around drill-hole of a cultured pearl was due to the erosion by skin acids of all surface unprotected by the mount. Mantle-tissue nucleated freshwater pearls had large drill holes intended to remove tell-tale 'voids', but X-ray fluorescence revealed them as cultivated – sometimes used to replace natural pearls in old jewellery.

Two opaque black cabochons with sharp reddish-brown 'eyes' were found to be a massive fibrous form of rutile which has not previously been reported. 'Cobalt-blue' spinels, reportedly from Okkampitiya in Sri Lanka, were tested, RI 1.720, inert to UV, very little anomalous birefringence, absorption bands as 434, 460 and 480 nm were diagnostic. An opaque greenish-blue carving was identified as paraffin-wax treated Chinese turquoise. RI 1.58 was due to wax. Black wax used to simulate matrix.

All stones are illustrated. R.K.M.

FRYER, C.W., KOIVULA, J.I. 1986. An examination of four important gems. *Gems Gemol.*, 22, 2, 99–102, 5 figs in colour.

The star of Bombay sapphire (182 ct), the Portuguese Diamond (127.01 ct) and the two large diamonds of Marie Antoinette's earrings (approx. 19 and 13 ct), all supplied by Harry Winston Inc., were examined gemmologically. R.K.M.

FUMEY, P. 1986. Étude des émeraudes synthètiques. (Study of synthetic emeralds.) *Revue de Gemmologie*, 87, 19–20.

A brief summary of the methods by which synthetic emeralds are produced. M.O'D.

GÜBELIN, E. 1986 Deux nouveaux produits artificiels sur le marché des pierres précieuses: le rubis synthètique 'Ramaura' et le gallo-aluminate d'yttrium. (Two new artificial products on the gem market: Ramaura synthetic ruby and yttrium gallium aluminate.) *Revue de Gemmologie*, 87, 15–16, 14 figs in colour.

Describes the physical and optical properties of yttrium gallium aluminate with photographs of characteristic inclusions. M.O'D.

GÜBELIN, E. 1986. Opal from Mexico. *Australian Gemmologist*, 16, 2, 45–51, 14 figs in colour.

An excellent account of the great variety of opals found in the mountainous regions, the richest area being the State of Queretaro. Dr Gübelin illustrates and lists many minerals included in these opals. R.K.M.

GÜBELIN, E., WEIBEL, M., WOENSDREGT, C.F. 1986. Some unusual sillimanite cat's-eyes. *Gems Gemol.*, 22, 2, 96–8, 3 figs (1 in colour).

Some blackish sillimanite cabochons with sharp chatoyant streaks are claimed to be Sri Lankan. Under SEM examination about 0.5% of Fe_2O_3 was found. RI 1.660–1.680, SG 3.257. R.K.M.

GUNAWARDENE, M., RUPASINGHE, M.S. 1986. The Elahera gem field in central Sri Lanka. *Gems Gemol.*, 22, 2, 80–95, 19 figs in colour.

This has been an active gem centre for centuries, but modern exploitation began in the 1950s and became large scale in the late 1970s. Mining is by open pit and gem gravels are extracted by pick and chunkel shovel. Corundum in a great variety of shades is found together with spinel, garnets, chrysoberyl (alexandrite and cat's-eyes), zircon and sinhalite. R.K.M.

HARDER, H., 1986. Naturliche kobaltblaue Spinelle von Ratnapura, Sri Lanka. (Natural cobalt blue spinel from Ratnapura, Sri Lanka.) *Neues Jahrbach für Mineralogie, Monatshefte*, 3, 971–100.

Natural Co-bearing spinels have recently been found in the gem gravels of Paradise mining area, NE of Ratnapura, Sri Lanka. XRF partial analysis of a sapphire-blue spinel gave Co 0.09, Ni 0.04, Fe 0.29, Mn 0.01, Cr 0.025, V 0.035, Ti 0.01, Zn 0.001, Ca 0.1, K 0.2, Ga 0.01%; the presence of Ga may be useful in distinguishing natural from synthetic Co-bearing spinels. The natural blue spinels have *n* 1.715–1.720, SG 3.58–3.61. R.A.H.

HARDER, H., SCHNEIDER, A. 1986. Isomorpher Einbau von Eisen und Titan zur Erklärung der blauen Farbe von Rutilund Spinellhaltigen seidig weißen Korunden nach einer Wärmbehandlung. (Isomorphic inclusion of iron and titanium as an explanation of the blue colour of rutile and spinel-bearing silky white corundums after heat treatment.) *Neues Jahrbuch für Mineralogie, Monatshefte*, 5, 209–18.

In natural sapphires the blue colour is due to electron transition between Fe^{2+} anf Fe^{3+}, whereas in synthetic sapphires the Fe^{2+}/Ti^{4+} electron transition is responsible. The matrix of rutile-bearing silky/milky natural corundum crystals is poor in Ti and Fe, but in the samples studied Fe also occurs in inclusions of ceylonite (spinel). Samples of this rutile-bearing corundum on heating to 1600°C for 30 minutes are changed to a fine sapphire blue caused by the Fe^{2+}/Ti^{4+} electron transition now possible in the corundum lattice. The sum of transition elements Fe and Ti in the corundum was almost tripled by such heat treatment. R.A.H.

HEILMANN, G., HENN, U. 1986. On the origin of blue sapphire from Elahera, Sri Lanka. *Australian Gemmologist*, **16**, 1, 2–4, 6 figs in colour.

An examination of chemistry and inclusions verifies that the sapphires have eroded from garnetiferous gneiss rocks of the Highland Group. R.K.M.

HEYLMUN, E.B. 1986. Opal from Magdalena. *Lapidary Journal*, **40**, 3, 49–53, 6 figs (3 in colour).

Magdalena is an important location for opal in the state of Jalisco, Mexico. Various mines in the area are described. M.O'D.

HOLMES, I. 1986. Fireworks at midnight. *Lapidary Journal*. **40**, 3, 20–4, 1 fig. in colour.

A short review of the opal found in Indonesia; many are a pronounced black and have a fine play of colour. A pinpoint pattern of colour is characteristic. M.O'D.

KATZ, M.B. 1986. Review of the geology of gemstones in Sri Lanka. *Australian Gemmologist*, **16**, 2, 52–6, 1 map.

A concise geological account concerned largely with theories of origin. R.K.M.

KELLER, A.S., KELLER, P.C. 1986. The sapphires of Mingxi, Fujian Province, China. *Gems Gemol.*, **22**, 1, 41–5, 6 figs in colour.

Research and exploration of this remote sapphire source suggests that the occurrence is similar to those in New South Wales. The corundum is alluvial or eluvial and is mined by hand from the stream bed. Sapphires vary from yellowish green through green to very dark blue. Heat treatment has so far done little to improve the colour. There is potential for increased production. R.K.M.

KELLER, P.C., WAN, G-D. 1986. The Changma diamond district, Mengyin, Shandong Province, China. *Gems Gemol.*, **22**, 1, 14–23, 13 figs in colour.

Diamond bearing areas are known in Shandong, Hubai, Liaoning and Hunan Provinces, and at Changma, in Shandong, kimberlites exhibit great potential. Mining is by terraced open cast pit which from the illustrations is of vast size. Victory No. 1 pipe gives about one carat per ton, with around 20% of gem quality which are faceted at the State-owned Shanghai Diamond Factory, or at the Beijing Diamond factory, a collective venture. Rough is also imported from Antwerp. Chinese production is in its infancy when compared with other sources.

Changma diamonds tend to be yellowish, but some very large crystals have been found and some fine whites, fancy yellows and browns were seen. R.K.M.

KELLER, P.C., WANG, F. 1986. A survey of the gemstone resources of China. *Gems Gemol.*, **22**, 1, 3–13, 10 figs in colour.

A general overview of deposits of amber from Fushun coalfield; cinnabar from Wanshanchang; corundum from Fujian and Hainan Island; diamond from Sichuan, Xinjiang Uygur and Yunnan; garnet from Jiangsu, including pyrope, grossular, demantoid, rhodolite and spessartine; nephrite from Kunlun mountains and other places. Altay Mountains yield most expected pegmatite gem minerals including large beryl crystals of industrial quality. Gemmy peridot is found in basalt lava in Hebei Province, and fine turquoise in Hubei and Shaanxi Provinces. Many other species are found and China can be expected to become a source of many gems. R.K.M.

KELLY, S.M. 1986. Bowesite – a new lapidary material from Australia. *Australian Gemmologist*, **16**, 1, 5–8, 6 figs in colour, 1 map.

This is an attractively patterned green rock mixture of diopside, epidote, grossularite, actinolite, plagioclase, quartz, sphene, iron oxide and calcite in varying amounts. RI 1.57, SG 2.78 to 3.10. Opaque, light green to dark rich green and near black. Volcanic detritus product suitable for carving. R.K.M.

KEMP, D.E. 1986. Whitby jet. *Lapidary Journal*, **40**, 2, 37–41, 4 figs.

A short useful account of the occurrence and fashioning of jet from Whitby, Yorkshire, England. M.O'D.

KOIVULA, J.I., FRYER, C.W. 1986. The gemmological characteristics of Chinese peridot. *Gems Gemol.*, **22**, 1, 38–40, 7 figs in colour.

Six peridot nodules were available for this report and three of these were faceted to stones of various sizes, light to dark yellowish-green in colour. RI 1.653–1.689, SG 3.36, with typical peridot absorption. Inert to UV light. Hardness approaches 7. Inclusions plentiful and typical of alkali basalt material and similar to those found in Arizona peridot. R.K.M.

KOIVULA, J.I., MISIOROWSKI, E. 1986. Gem News. *Gems Gemol.*, **22**, 1, 54–5, 2 figs in colour.

Diamonds. India: New deposits reported from Tanna and Chatarpur districts. Japan: Largest synthetic industrial diamond crystal (3.50 ct) claimed by National Research Institute at Tsukuba. South Africa: Pyrope with diamond inclusions (reversing the normal order) has been found. Sri Lanka: Geological Survey are drilling to locate possible diamond occurrences.

Coloured stones. Dr Kurt Nassau says that heating to 200°C for an hour will determine colour stability in gems, but should not be used for yellow sapphires which will lose colour under this test. Pala International has begun dredging in Sri Lanka, output is cut in California. Two strongly parti-coloured Sri Lankan sapphires in yellow and blue were seen from Mr Ben Hoo of Singapore.

Synthetics. Adachi Shin Industrial Co. Ltd of Japan are producing a 'water-melon' synthetic beryl with a heavily zoned pink core surrounded by a green 'rind'. Dopants appear to be manganese and chromium. Other colours have been grown by what is said to be a new method. R.K.M.

KOIVULA, J.I., MISIOROWSKI, E. 1986. Gem news. *Gems Gemol.*, **22**, 2, 114–16, 3 figs in colour.

Among many fine natural gems at the Tucson show cat's-eye kunzite, covellite, lepidolite cabochons, magnesite dyed to imitate turquoise, pectolite, 'rainbow' moonstone, spurrite and two taaffeite crystals (one of 46.17 ct is largest on record) were seen, as well as many other rarities.

A 2.12 ct purple twinned spinel from a private collection showed two separate six-rayed stars. A rock crystal quartz had been cut skilfully to reflect a single vertical acicular tourmaline crystal inclusion in a perfect wheel formation. A fine emerald crystal from the Sams collection at the Houston Museum of Natural Science is also illustrated. R.K.M.

KOVAC, D. 1986. Minerals and gemstones of Pakistan. *Australian Gemmologist*, **16**, 2, 57–9.

Gemstone mining is a young industry in Pakistan but its origins are ancient and its potential is great. Emerald is the most important gem and is mined in the Swat valley, near Mingora. Ruby comes next in importance and is from the Hunza valley high in the Karakoram ranges. Other gems are topaz, aquamarine, chrome diopside, kunzite, garnets, spinel, tourmaline and various ornamental chalcedonies. R.K.M.

LANDAIS, E. 1986. Le trésor de la 'Voûte verte' de Dresde. (The treasure of the 'Green Vaults' at Dresden.) *Revue de Gemmologie*, **87**, 4.

A brief summary of the contents of the Green Vaults at Dresden, German Democratic Republic. M.O'D.

LIVSTRAND, U. 1986. Black pearls of Manihi. *Lapidary Journal*, **40**, 2, 26–34, 5 figs in colour.

An account of pearl fishing at Manihi in the Tuamotu Archipelago in the South Pacific. M.O'D.

LONDON, D. 1986. Formation of tourmaline-rich gem pockets in miarolitic pegmatites. *American Mineralogist*, **71**, 396–405, 6 figs.

Pocket development in tourmaline-rich, miarolitic, rare-element pegmatites occurs between approximately 475 and 425°C and between 2800 and 2400 bars. This observation arises from the examination of fluid inclusions in spodumene, beryl, tourmaline and quartz from the miarolitic pegmatites of Afghanistan. It is possible that the formation of gem pockets may depend upon the timing of tourmaline crystallization since an alkali borate component is removed from the residual pegmatic melt when it is formed so that other alkali alumino-silicate and oxide-forming minerals are deposited and a large amount of H_2O exsolved. If crystallization of tourmaline is inhibited until a late stage of pegmatite consolidation the liberated H_2O may form pegmatite pockets. M.O'D.

MEDOFF, R.S. 1986. Value added: selecting organic gemstone material. *Lapidary Journal*, **40**, 2, 42–9, 4 figs in colour.

A guide to the purchase of amber, coral, pearl and other organic ornamental materials. M.O'D.

MOON, A.R., PHILLIPS, M.R. 1984. The physics of asterism in sapphire. *Schweizerische mineralogische und petrographische Mitteilungen*, **64**, 329–34, 5 figs.

The star in asteriated sapphire arises from the incoherent superposition of reflected Fraunhofer diffraction patterns which arise when light is scattered from precipitates strictly oriented within the host. Long, thin precipitates give sharper stars than shorter, wider ones. M.O'D.

NASSAU, K. 1986. Green glass made of Mount Saint Helen's ash? *Gems Gemol.*, 22, 2, 103–4, 2 figs in colour.

A green glass, said to have been made from the volcanic ash of this eruption, was analysed and compared with a black glass made from known St Helen's ash. They differed significantly and the green glass must contain only a small proportion of that ash, if any. R.K.M.

NEWSOME, D. 1984/85. Colors and spectral distributions of fluorescent minerals. Part III. *Journal of the Fluorescent Mineral Society*, **13**, 2–28, 13 figs.

The gem species benitoite and scheelite are among the minerals whose luminescence is discussed. M.O'D.

NIEDERMAYR, G. 1986. Mineral localities in Austria. *Mineralogical Record*, **17**, 2, 105–10, 8 figs (6 in colour).

Beryl, including emerald and aquamarine, epidote, apatite, amethyst, euclase, scheelite, datolite, sphene and garnet, are among the minerals of gemmological interest described. M.O'D.

O'DONOGHUE, M. 1986. Gems and gemmology. *Watchmaker, Jeweller and Silversmith*, May 1986, 54–7, 3 figs in colour.

Topics considered this month include determination of the source of rubies, gemmology in Italy, examination preparation courses, trips to field areas of gem interest, sugilite, synthetic diamond and how to tackle examinations in gemmology. (Author's abstract.) M.O'D.

O'DONOGHUE, M. 1986. Gems and gemmology. *Watchmaker, Jeweller and Silversmith*, June 1986, 58–60.

Synthetic gem diamond, Lechleitner solid synthetics, coloured and faceted strontium titanate, YAG, GGG and $YAlO_3$ and the writing of Pliny on beryl, are among the topics discussed this month. (Author's abstract.) M.O'D.

O'DONOGHUE, M. 1986. Gems and gemmology. *Watchmaker, Jeweller and Silversmith*, July 1986, 39–42, 1 fig.

This month the topics discussed include the varieties of chrysoberyl, hints for students taking gemmological examinations, with particular reference to the available literature, reviews of the first three Butterworth gem books and details of rare stones and synthetics, including pink-orange sapphire and gemstones from China. (Author's abstract.) M.O'D.

O'DONOGHUE, M. 1986. Industrial review – gemstones. *Britannica Book of the Year* – 1986, 274.

1985 saw little change in the world gem markets and arguments over whether or not treatment should be disclosed were still unresolved. Details of the country of origin for major stones are increasingly being requested by buyers in the saleroom.

The Internal Revenue Service in the United States has cracked down on the practice of making tax-shelter donations of gemstones to major collections whose acquisitions have declined as a result. Indian production of cut diamonds threatened to undercut traditional sources and the Israeli industry in particular could be affected. The Aredor field in Guinea was producing diamonds, 95% of which are said to be of gem quality. (Author's abstract.) M.O'D.

PARTLOW, D.P., COHEN, A.J. 1986. Optical studies of biaxial Al-related color centers in smoky quartz. *American Mineralogist*, **71**, 589–98, 7 figs.

Three absorption bands associated with trapped hole centres develop when quartz containing trivalent Al in a substitutional trivalent Si site is subjected to ionizing radiation. Studies of the directional anisotropy of two of the bands in the quartz basal plane show that they may interchange orientations from crystal to crystal in major rhombohedral growth. M.O'D.

PONAHLO, J., KOROSCHETZ, T. 1986. Quantitative cathodoluminescence of gemstones. *Australian Gemmologist*, **16**, 2, 64–71, 13 figs (9 in colour).

A detailed account of this method of gemmological testing between natural and synthetic stones. [In 1976 the GIA found that this method of testing could produce colour changes and damage in some stones.] R.K.M.

POUGH, F.H. 1986. Gem treatment: pearl. *Lapidary Journal*, **40**, 3, 16–18.

A short review of the various methods by which the appearance of pearl can be improved. M.O'D.

RINGSRUD, R. 1986. The Coscuez mine: a major source of Colombian emeralds. *Gems Gemol.*, **22**, 2, 67–79, 11 figs in colour.

Coscuez, a small mine high in the Andes about 10 km from Muzo, is second most productive in Colombia, its emeralds being sold as Muzo stones. They are found in calcite veins in distorted Lower Cretaceous carbonaceous shales. Mined by adit tunnelling and latterly by bulldozer and dynamite to expose calcite which is then worked by hand pick. Locals poach tailings. RI 1.574–1.580, SG 2.68–2.71, pink to red under emerald filter, inclusions mainly part-healed fractures with fewer three phase cavities than in Muzo stones. R.K.M.

ROSSMAN, G.R. MATTSON, S.M. 1986. Yellow, Mn-rich elbaite with Mn-Ti intervalence charge transfer. *American Mineralogist*, **71**, 599–602, 3 figs.

Yellowish-green to yellowish-brown Mn-rich tourmaline from Zambia and Nepal owes its colour to an Fe^{2+}–Ti^{4+} (brown) and Mn^{2+}–Ti^{4+} (yellowish-green) intervalence charge transfer. A band at 325 nm is caused by a Mn–Ti interaction and is especially well developed in the Zambian material. M.O'D.

ROTSTEIN, A.H. 1986. Fossil ivory, stable and usable. *Lapidary Journal*, **40**, 2, 35–6, 3 figs.

A solution is offered to the problem of cracking as found in mammoth and walrus ivories which are stabilized by an undescribed process. M.O'D.

SHEILS, K.C. 1986. Ultraviolet recovery. *Lapidary Journal*, **40**, 3, 36–40, 1 fig.

Ultraviolet light is used to find opal at the Coober Pedy field in South Australia. Orange-fluorescing gypsum has been found to be a guide to localities for good quality opal. M.O'D.

SHIGLEY, J.E., KAMPF, A.R., ROSSMAN, G.R. 1986. New data on painite. *Mineralogical Magazine*, 50, 267–70, 3 figs.

The third painite specimen to be found turned up in 1979 in a parcel of rough Burmese gem quality spinel. Composition echoed that of the type crystal but trace amounts of Fe, Cr, V, Ti, Na and Hf were also found. The colour is believed to arise from the presence of Cr^{3+} and V^{3+} as optical absorption spectra of these elements were observed. M.O'D.

SMITH, J.V. 1985. Can Yogo sapphire firm survive? *Jewelers' Circular-Keystone*, **156**, 13, 146–52, 3 figs in colour.

Describes the current financial troubles of Intergem Inc., owner of the main source for Montana blue sapphires. M.O'D.

SMITH, J.V. 1986. Gem synthetics: options and outlook. *Jewelers' Circular-Keystone*, **157**, 4, 206–24, 28 figs (25 in colour).

A review of the present part played by synthetic gemstones in the jewellery trade, their method of manufacture and ways to identify them. Photographs of inclusions complete the article. M.O'D.

STERN, L.A., BROWN, G.E., BIRD, D.K., JAHNS, R.H. FOORD, E.E., SHIGLEY, J.E., SPAULDING, L.B. 1986. Mineralogy and geochemical evolution of the Little Three pegmatite-aplite layered intrusive, Ramona, California. *American Mineralogist*, **71**, 406–27, 7 figs.

The Little Three pegmatite is a celebrated source of spessartine, tourmaline and topaz. Several layered pegmatite-aplite intrusives exposed at the mine show closely associated fine-grained to giant-textured mineral assemblages thought to have co-evolved from a hydrous aluminosilicate residual melt with an exsolved supercritical vapour phase. M.O'D.

SWANSON, S.E., FENN, P.M. 1986. Quartz crystallization in igenous rocks. *American Mineralogist*, **71**, 331–42, 12 figs.

The transition from euhedral to dendritic growth in quartz depends upon the degree of undercooling and does not have any particular relationship to bulk composition, water content of the melt or pressure. M.O'D.

THOMAS, L.H. 1986. Elusive in Louisiana. *Lapidary Journal*, **40**, 3, 54–6.

A location for precious opal near Leesville in south-west Louisiana is described. The material has been reported to be an opalescent sandstone consisting of irregular particles of quartzite from 0.1 mm to 1 mm in size; these are cemented by pieces of precious fire opal. M.O'D.

THOMAS, S.A., LEE, H.W. 1986. Gemstone carving in China: winds of change. *Gems Gemol.*, **22**, 1, 24–34, 11 figs (5 in colour).

Traces the history of stone carving from Paleolithic times, through Sung, Ming and Ch'ing Dynasties to Emperor Ch'ien Lung who encouraged the art by establishing workshops in the Imperial Palace at Beijing and importing Moslem gem carvers. Jadeite first used in 1784. Today the industry is being encouraged in many ways and power tools are replacing many, but not all, of the foot-treadle lathes, with diamond dust used for polishing. R.K.M.

TOMBS, G.A., SECHOS, B. 1986. Examination of surface features of Argyle diamonds from Western Australia. *Australian Gemmologist*, **16**, 2, 41–4, 9 figs in colour.

Diamonds from the Kimberly, Western Australia, area occur in potassium-rich lamprolite pipes and not in kimberlites, and it is suggested that the alkali has attacked the contained diamonds which tend to be highly misshapen, etched and corroded. Some etch-pits on octahedral faces are hexagonal rather than the normal trigon shape and it may be that growth and etch conditions have combined. Garnet inclusions have been found. R.K.M.

VAHLDIEK, B.W. 1976. Bernstein aus den eozänen Braukohlen von Helmstedt (Budesrepublik Deutschland, Niedersachsen) Stratigraphie und Ausbildung. (Amber from the Eocene brown coal of Helmstedt (Lower Saxony, Federal Republic of Germany) stratigraphy and formation.) *Aufschluss*, 37, 165–77, 3 figs (1 in colour).

Amber from an Eocene lignite at Helmstedt is described and details of its stratigraphical relationships and formation given. M.O'D.

VANCE, B. 1986. The angel of Yowah. *Lapidary Journal*, **40**, 3, 33–4, 2 figs in colour.

Describes a specimen of opal found in the Yowah Valley of central Queensland and thought to resemble the figure of an angel. The stone weighs 1280 ct. M.O'D.

WANG, F. 1986. A gemmological study of turquoise in China. *Gems Gemol.*, **22**, 1, 35–7, 4 figs in colour.

Turquoise of a quality to compare with material from other countries is mined in Hubei Province. Colour ranges from sky-blue to bluish-green depending upon the amount of ferrous iron present, with constants within the normal range for the species, and the expected absorption. R.K.M.

WILSON, M.M. 1986. Expeditions. Big sky sapphires. *Lapidary Journal*, **40**, 1, 26–36, 6 figs in colour.

An interesting account of the sapphire mines of Montana, USA. M.O'D.

WILSON, W.E. 1986. What's new in minerals? *Mineralogical Record*. **17**, 2, 147–52, 10 figs (6 in colour).

Describes specimens seen at the Detroit and Munich mineral shows. Items of gemmological interest include cobaltian calcite from Mupine, Shaba province, Zaire; golden topaz from near Mimosa, Espirito Santo, Brazil; aquamarine from Lavra da Invreja, Marambainha, Minas Gerais, Brazil; elbaite crystal groups from the Genipapo mine, Aracuai, Minas Gerais, and more tourmaline specimens from the well-established localities of the Cruzeiro mine (water-melon crystals) and Itinga (olive-green crystals with brownish-green or yellow terminations). M.O'D.

ZEITNER, J.C. 1986. Opal in the United States. *Lapidary Journal*, **40**, 3, 42–8, 6 figs in colour.

Opal from Idaho, Nevada, California, New Mexico, Oregon and Texas is described. M.O'D.

ZWAAN, P.C. 1986. Gem minerals from the Embilipitiya and Kataragama areas of Sri Lanka. *Australian Gemmologist*, **16**, 2, 35–40, 5 figs.

An account of two comparatively new gem areas where deposits are thought to be eluvial rather than alluvial. Crystals are often euhedral and well formed. The first locality is noted for rarer gems like brown to colourless enstatite, cordierite and kornerupine. Kataragama lacks these but has corundum, spinel, almandine, hessonite and tourmaline. Apatite, brown sphene, actinolite, diopside and hiddenite are also reported. R.K.M.

New artificial diamond developments in Japan. 1986. *Production Engineering Research Association*, PERA-OTIS 86/5549. Unpaged.

More than one Japanese firm is working on the production of artificial diamond; Sumitomo Chemical claim to be able to produce a low cost mass production method for stones up to 1 ct in size and are also developing smaller stones (about 0.5 mm) for use as semiconductor heat sinks. Offprints of several papers from a variety of journals accompany this report. M.O'D.

Book Reviews

ANDERGASSEN, W. 1982. *Il diamante oggi*. (The diamond today.) Paleani Editrice, Rome. pp.278. Illus. in black-and-white and in colour. Price on application.

This book provides an excellent introductory text on the diamond from its formation, recovery, history, fashioning, testing, grading and simulation. The most prominent feature is a set of coloured photographs of diamond surfaces showing their features in interference colours. Grading is explained and questions are posed in some of the chapters. There is a glossary and a short bibliography.

M.O'D.

ANDERSON, B.W. 1983. *Gemmologia practica*. (Practical gemmology.) Traduzione di Carlo Trossarelli. Istituto Gemmologica Italiano, Milan. pp.xvi, 551. Illus. in black-and-white. Price on application.

This is a well-produced and somewhat enlarged translation of the 9th edition of *Gem testing* (1980)*. Additions include extra illustrations and improved tables (those in the original were a disappointment).

M.O'D.

CHRISTIANSEN, E.H., SHERIDAN, M.F., BURT, D.M. 1986. *The geology and geochemistry of Cenozoic topaz rhyolites from the western United States*. Geological Society of America, Boulder, Colo. Special Paper 205. pp.82. Price on application.

Cenozoic topaz-bearing rhyolites rich in silica are found widely distributed across the western United States and Mexico. They are enriched in fluorine and the topaz was formed in post-magmatic vapour-phase alteration. Details of the various deposits are given with maps and diagrams. M.O'D.

CIPRIANI, C. 1986. *The Macdonald encyclopedia of precious stones*. Macdonald, London. pp.384. Illus. in colour. £7.95.

Translated from the Italian, this book is a handy guide to a large number of gem materials and contains a good deal of information which is carefully put together and which will be useful for students. The system used to find particular species (colour depictions in diagrammatic form in the text margins) appears a little complicated but this does not matter and they are not really needed. The arrangement appears to be in order of importance but this is quite sensible in so small a book. The quality of the reproductions is high, though the spessartine looks too yellow. M.O'D.

FARN, A.E. 1986. *Pearls: natural, cultured and imitation*. Butterworths, London. pp.150. Illus. in black-and-white and in colour. £25.00.

Of all the members of the new series of Butterworths Gem Books this is to me the most welcome. Not only has there been a dearth of serious literature on pearls (and on ornamental organic materials in general) but in this instance the only possible author has arisen to take up pen and responsibility so that readers can be assured that use of the book really will enhance their knowledge of the material, which is once more gaining in popularity after years of comparative neglect. Mr Farn cut his teeth on pearls (perhaps literally) and no one living knows more about them. The book follows the pattern set for the series in having a section of colour photographs in the centre and in providing adequate references at the back. There is also a glossary. After a general introduction which ends with a list of pearl occurrences, Mr Farn goes on to discuss how pearls come to be formed. He lists some theories held in antiquity (flashes of lightning is one of them) and enlarges on the charming notion that pearls are formed from dewdrops, concluding regretfully that they are not. There are, in fact, several possible causes of pearl formation; grains of sand are now known to be a very rare cause but parasitic intrusions are more likely agents. A chapter on the history of pearls (i.e. the recorded use of pearls in early times) is followed by an outline of the structure and anatomy of the pearl oyster. Here there are some excellent and necessary

* Reviewed in *J. Gemm.*, 1980, **XVII**, 3, 193.

diagrams accompanied by a description of how the oyster works. The next chapter outlines the places where pearls have been found and good-sized clear maps are provided. A good deal of history is included in this quite long chapter (which also covers freshwater pearls) and this is lucidly introduced.

Cultured pearls form the subject of the next section of the book. Here again the history of the processes used are recounted and readers should be clear when they have read the section exactly what processes have been used in the past and which ones are likely to be in use now. Testing of pearls comes naturally at this point and the section contains useful diagrams and photographs.

Lastly the subject of imitation pearls is introduced, followed by notes on pearl pricing (the complicated method of arriving at the price of good quality pearls at least is still in use); a pot-pourri on the staining and other treatment of pearls and famous pearls. An excellent summary of a difficult subject – my only criticism is that (in my copy at least) the binding is flimsy, one gathering coming out on first handling of the book. M.O'D.

GAUTIER, G. 1983. *Cartier, the legend*. Arlington Books, London. pp.253. Illus. in black-and-white and in colour. £19.95.

The story of the various branches of the firm of Cartier is recounted from 1808 to the present day. Many photographs of Cartier products are included with the well-written text. The original French text was entitled *Rue de la Paix* and was published in 1980 by Juillard, Paris. M.O'D.

KALDIS, E. (Ed.) 1985. *Crystal growth of electronic materials*. North-Holland, Amsterdam. pp.x, 384. Illus. in black-and-white. Dfl 235.00.

This volume which is full of features relevant to the growth of gem-quality crystals, covers the lectures given at the 5th International Summer School on Crystal Growth and Materials Research (ISSCG–5) held at Davos in September 1983. It provides useful updates on techniques of crystal growth and gives details of materials composition which were unsuspected before.

An introductory section gives an overview of fundamental aspects of crystal growth which would be useful for anyone approaching the topic for the first time and subsequent sections deal with the growth of substances of extreme dimensions, with growth from high and low temperatures and with the growth of silicon. Growth of III–V compounds, miscellaneous materials and crystal characterization complete the book. Those with an interest in the growth of such materials as YAG, GGG and corundum will find interesting points on the conditions needed for the growth of the best quality crystals. The growth atmosphere is particularly important.

Each chapter is provided with extensive references and readers are recommended to consult the book where possible; even if many of the details are hard to understand it is always useful to know why certain materials are grown and why some cost more than others. M.O'D.

LEONE, E., CUMO, C. 1985. *Gemme naturali e artificiali*. (Natural and artificial gems.) Editrice Elleci, Valenza. pp.575. Illus. in black-and-white and in colour. L.90 000.

This large book is intended to cover all the varieties of minerals that can be used ornamentally. It begins with a description of the principles behind the classic tests and an account of the causes of colour. There are short sections on gemstone occurrence and on inclusions and how they arise. Diamond begins the long account of the gemstones themselves and there are some excellent colour photographs illustrating luminescence and the polishing process. The first-class colour pictures follow the text through the book; there are some fine black-and-white ones, too, particularly illustrating emerald and its synthetic and composite counterparts. There is a fairly short bibliography and identification tables.

For the Italian reader this provides an excellent introduction to gemmology and the language does not seriously impede the English reader from finding out a good deal about the subject. M.O'D.

MAY, E. 1979. *Jade for beginners*. Times Books International. Singapore. Illus. in black-and-white and in colour. pp.57. Price on application.

A short but well-written guide to the jade minerals as used in ornament. The use of jade in the past is discussed with particular reference to China. M.O'D.

MILLER, R.McG. 1985. *Departmental report on the mining and production of diamonds at CDM 1945 to 1983*. Namibian Department of Economic Affairs and the Geological Survey, Windhoek. pp.28. R3.50.

This report was commissioned to refute long-standing arguments that CDM (Consolidated Diamond Mines) were increasing diamond production in contravention of the Halbscheid Agreement. It was alleged that high-grade ore was mined in preference to low-grade ore and that over-burden and waste were dumped on top of diamondiferous gravel. Statistics are used in the refutation as are day-by-day accounts of the actual production.

M.O'D.

MEDENBACH, O., WILK, H. 1986. *The magic of minerals*. Springer-Verlag, Berlin. pp.204. Illus. in colour. DM128.

A translation by John Sampson White of *Zauberwelt der Mineralien*, 1977*. M.O'D.

MENZHAUSEN, J. (Text.) 1983. *The Green Vault*. An introduction. The State Art Collections in Dresden, Dresden. pp.119. Illus. in colour. 15M.

Though much of the area of the Green Vaults was destroyed by bombing in 1945, some of the contents were in safe keeping and in fact much of the total stock was eventually brought back to the City and will in due course be rearranged in some of the rooms which were unaffected by the raid and by later vicissitudes in other countries. This attractively illustrated guide depicts many artefacts of gemmological interest, mostly from the period and illustrating the style known as Dresden Baroque. As always with books from the German Democratic Republic, the price is amazingly low. M.O'D.

MITCHELL, R.S. 1985. *Dictionary of rocks*. Van Nostrand Reinhold, New York. pp.xi, 228. Illus. in black-and-white and in colour. £32.95.

This most useful reference book forms a companion to the author's *Mineral names – what do they mean?* (Van Nostrand Reinhold, 1979)†. Rocks are arranged alphabetically and some related materials are also included. These are migmatites, tektites, impactites and major meteorite types. Cave rocks and formations, organic resins, ambers, bitumens and major coal varieties can also be found. On the gem and ornamental material side, a number of gem-rock terms are included and many local and trade names are explained as well as non-English terms often found in English-language publications. Some terms not found in the main alphabetical section can be found in the glossary; these include structural and textural terms often used in petrology and microscopic petrography. The origins of rock names have been investigated and as many as possible are explained; where names relate to individuals brief biographies are given. A section of coloured pictures provides a welcome break in the text.

The author claims that this is the first book of its kind and I have no evidence of any other one as comprehensive as this. M.O'D.

* Reviewed in *J. Gemm.*, 1979, **XVI**, 7, 488.

† Reviewed in *J. Gemm.*, 1980, **XVII**, 2, 136.

ROUSE, J.D. 1986. *Garnet*. Butterworths, London pp.x, 134. Illus. in black-and-white and in colour. £22.00.

Forming part of the Butterworths Gem Books series, this is a well-presented study of the gem varieties of the garnet group of minerals. The history of use of garnet is discussed first, with references to classical and later authors and this section which, like those following, contains a list of references, is succeeded by a chapter on garnet chemistry, physical properties, colour and classification. A table giving the main characteristics of each gem variety of garnet is included and will prove useful as a quick reference guide for students.

Each garnet variety is now discussed in turn following the order pyrope, almandine, spessartine (given here as spessartite), grossular and andradite. Intermediate (rhodolite) garnets are treated between the almandine and spessartine sections and rarer varieties (yellow andradite, uvarovite) are discussed in the andradite chapter.

The contents of these chapters cover the members of the family exhaustively and major locations are shown on maps. A section of colour pictures depicts inclusions in garnet.

This is an excellent book and I was particularly pleased to see the number of references appended to each chapter. M.O'D.

SAMSONOV, J.P. TURINGUE, A.P. 1984. (Gems of the USSR.) Nedra, Moscow, pp.335. Illus. in black-and-white and in colour. 4r. 50c (In Russian.)

This is a well-produced survey written with the general supervision of an Academician (V. I. Smirnov) and thus amounts to an official guide. Occupying so large an area the USSR contains examples of almost every variety of gem mineral and the range of these minerals can be seen in the important collections in Moscow and Leningrad which have been drawn upon for the illustrations to this book. Some years ago I was able to examine some of the gem specimens in the reserve collections of the A.E. Fersman Mineralogical Museum in Moscow and some of the stones seen on that occasion are represented here.

The book begins by introducing and classifying gem minerals and then explains how they are formed. Gems suitable for collecting are described and there is a chapter on gemstone synthesis; this section also contains details of gem testing practices. Later chapters describe the manufacture of ornamental pieces and jewellery.

The last chapter is one of the most interesting; it explains how gemstone deposits are evaluated and how they may best be worked; it also describes the operation of Western gem markets and gives some

ideas on the way in which similar industries might be developed in the USSR. There is a short bibliography and an index of gemstone deposits. There are many good quality colour pictures and even for those with no Russian these make the book well worth getting. As always with Soviet books, the price is within the reach of all; a sensible policy which we could well copy. M.O'D.

SCHMETZER, K. 1986. *Naturliche und synthetische Rubine*. (Natural and synthetic rubies.) Schweizerbart'sche Verlagsbuchhandlung, Stuttgart. pp.vi, 131. Illus. in black-and-white and in colour. DM38.

In a major survey of ruby, Dr Schmetzer begins with a discussion of the mineralogy and crystallography of corundum with a table showing the chemical composition of rubies from eleven localities. The growth methods and composition of synthetic rubies follows.

The next part of the book (which is not divided into chapters which can easily be distinguished from one another) covers inclusions and continues virtually to the end. The accompanying coloured and black-and-white photographs are superb and the book is worth buying for these alone. There is an extensive bibliography preceded by notes on fluorescence and fluorescence spectroscopy. The book is up-to-date and includes notes on Knischka and Lechleitner ruby and it is to be hoped that further works on other stones, of a similar standard, will be forthcoming. M.O'D.

SCHÜTT, R.-W. 1984. *Die Entdeckung des Isomorphismus*. (The discovery of isomorphism.) Gerstenberg Verlag, Hildesheim. pp.324. DM68.

This study of the gradual recognition of the phenomenon of isomorphism in mineralogy and chemistry forms part of the series *Arbor scientiarum*, taking the number IX of Reihe A, *Abhandlungen*. Much of the text is given over to the work of Haüy and his contemporaries and particular reference is made to isomorphism in emerald and other beryls, apatite, calcite, calcite and aragonite, diamond and graphite; the mechanism of crystallization and the concepts of 'masse chimique' and 'melange chimique' are also discussed before the study turns to the work of Mitscherlich and Berzelius. There is a comprehensive bibliography and the study is an invaluable guide to early thoughts on the formation of minerals. M.O'D.

SINKANKAS, J. 1985. *Gem Cutting*. 3rd edn. Van Nostrand Reinhold, New York. pp.xvii, 365. £51.20.

First published in 1955, this familiar tall book is still the best account of the fashioning of gem materials in English. Over the years the general presentation has not varied much; the author makes the point in his preface to the current edition that one of the few notable developments in faceting is the widespread use of diamond polishing agents for almost all types of work from the original rough to the finished piece. There has been a large increase in the number of substances which can be cut, particularly man-made ones and details of these are given in a large section at the end of the book. As always with John Sinkankas, the style is enviably lucid and the diagrams unmatchable. M.O'D.

VOYNICK, S.M. 1985. *The great American sapphire*. Mountain Press Publishing Co., Missoula, Mont. pp.xi, 199. Illus. in black-and-white and in colour. US$9.95.

This is a well-written and interesting account of the discovery and marketing of the sapphires from Yogo, Montana, USA. The first sapphires were recognized as such in the 1860s and mining has suffered many vicissitudes up to the present. Though the account of the mining operations forms the main part of the book, there are many gemmological asides and an account of the effects of heat treating corundum in general. The author has consulted many sources and it would have been pleasing to have had a bibliography in a book which is otherwise well worth reading and very reasonably priced. M.O'D.

ZANCANELLA, R. 1980. *Il diamante: manuale pratico*. (The diamond: a practical manual.) Istituto Gemmologico Italiano, Milan, pp.195. Illus. in black-and-white and in colour. Price on application.

This is a useful and well-produced book dealing primarily with diamond grading and cutting, though there is also a good deal of introductory information on the properties of diamond. Particularly useful are the coloured diagrams which illustrate how a stone is polished to give the best optical effects. Final chapters describe how stones are tested and there is a short bibliography.

For those interested in the path of light through a diamond this book gives outstanding diagrams and the labelling of the diagrams with figures giving various sets of proportions are also valuable as a guide for those unfamiliar with the importance for the final stone of adherence to sets of proportions. M.O'D.

Proceedings of the Gemmological Association of Great Britain and Association Notices

OBITUARY

Henry James Blackburn Wheeler

It is with very deep regret that we report the death, from a heart attack on 5 June 1986, shortly after returning from holiday in China and Hong Kong, of Mr H.J.B. Wheeler, former Secretary of the Gemmological Association and of the National Association of Goldsmiths.

Harry and Rene Wheeler

Harry Wheeler served the two Associations all his working life, joining them as a shorthand-typist at the age of 16 in 1934. He first attended gemmology classes at the old centre at Chelsea Polytechnic in 1939, but war disrupted that effort and it was not until after some six years with the Royal Army Service Corps, which took him to many places including North Africa and Sicily, that he was able once more to take up these studies. He passed the Diploma examination with Distinction in 1947, a year which produced two Tully Medallists and eleven distinctions out of a total of 22 successful students. Harry was an excellent gemmologist.

With two associations to serve, Mr Wheeler emulated his predecessor, Mr Gordon Andrews, in his efficient approach to these and other responsibilities. The two men had worked together for so long that the transition could only be smooth, with a minimum of reorganization. In both capacities he had a broad and total understanding of the problems involved. Over the years the scope and coverage of the associations had grown enormously, due largely to the collaborative efforts of Andrews and Wheeler in the near thirty years since the end of the war and to the quiet efficiency of Harry himself when he was eventually alone at the secretarial helm.

Harry Wheeler was an excellent and popular speaker who enjoyed the challenge of conferences and award ceremonies which brought successful students each year from many parts of the world. His relations with staff were meticulous and fair. He expected work to be done well, but showed appreciation of effort at all times.

He was a Freeman of the Worshipful Company of Goldsmiths, a Freeman of the City of London, an Honorary Fellow of the Canadian Gemmological Association, a Honorary Member of the Gemmological Association of All Japan and, since retiring in 1982, a Vice-President of our own Gemmological Association. Already a widely travelled man, he used that retirement to journey even further afield and was an excellent ambassador for Britain's gemmologists. His hobby was bowling,

something requiring a different skill but rather similar concentration to that which served him so well in his long career.

A director of Gemmological Instruments Ltd, with his brother, Douglas Wheeler, who served the two associations for a similar length of time, and others, Harry was influential in fostering the introduction of new and improved instruments and in furthering the development of correspondence teaching at all levels.

Those of us who knew him well will remember him for his ability to grasp and understand detail, and his innate shrewdness in all things requiring judgement.

Harry is survived by his wife Rene, two sons and a daughter and six grandchildren, to whom our most sincere condolences are expressed. His wife was a familiar and popular figure at GA (and NAG) events and gave Harry and the Associations very active support throughout his career. One son is employed in the gem stone trade. It is a well-known platitude to say that a death brings an era to an end, but in the case of Harry J. Wheeler the feeling of loss is tempered only by the three years since he dropped out of active participation in Trade affairs. His delightful personality is still fresh in memory and will be greatly missed by all who knew him.

* * *

PATRICIA MARGARET STATHAM died peacefully in Derby on 13 August 1986 in her sixty-fifth year.

Pat Statham gained a B.Sc. degree at Reading University. She joined the Department of Health in Scotland for a short time, but then transferred to the Geological Survey in Edinburgh. Her work there was mainly on fossils but on her transfer in 1956 to the (then) Geological Survey and Museum in London she worked with E.A. Jobbins on minerals and gemstones. This very successful partnership continued for some 23 years until her retiral in 1979. Her first task in London, requiring meticulous application, was the rearrangement, on crystal chemistry lines, of the mineral collection of some 80 000 specimens. One of the responsibilities of a curatorial mineralogist is dealing with enquiries. She answered many thousands on minerals, gemstones and hardstone carvings, and became one of a dying breed of specimen mineralogists who could identify the species and locality of a considerable range of mineral specimens at sight. She was the epitome of down-to-earth reliability, intensely loyal and unassuming.

She gained her F.G.A. in 1969 and with her superb attention to detail became an excellent proof reader of gemmological and mineralogical texts. The new Guide '*Gemstones in the Geological Museum*' was jointly revised by Pat Statham and E.A. Jobbins and appeared under her authorship. She helped with the Index of Volume XIX of this *Journal* only a few months before her death from lung cancer.

Devotion to duty, as exemplified by Pat Statham, is not so common a trait today.

* * *

Mr H.J. Korevaar, F.G.A. (D.1972), Zwanenlaan, Netherlands, died on 30 June 1985.

Mr M.D.S. Lewis, Brighton, died on 8 July 1986. Mr Lewis gained his Diploma and the Tully Medal in 1944, and was the first recipient of the Research Diploma of the Gemmological Assocation in 1945. A full obituary will appear in the January 1987 issue of the *Journal*.

GIFTS TO THE ASSOCIATION

The Council of the Association is indebted to Mr Leslie Cole, F.G.A., for a set of hand-held weighing balances in the original wooden box.

CON LENAN
Secretary 1982–1986

Con Lenan will relinquish his post as Secretary of the Gemmological Association on 1 November 1986 to take up an appointment as Marketing Director of the London Commodity Exchange. We thank him for his significant contribution to the progress of the GA and particularly for his efforts in refurbishing and polishing the Association's image.

NEWS OF FELLOWS

Mr M.J. O'Donoghue, M.A., F.G.S., F.G.A., has been appointed Editor of the Newsletter of the Geological Information Group of the Geological Society and to membership of the Geological Society's Library Committee.

Messrs O'Donoghue and Read, with Mr R. Huddlestone, conducted a one-day course for Preliminary Examination candidates at 100 Hatton Garden, London E.C.1, from 17–19 June 1986.

MEMBERS' MEETINGS

London

On 16 September 1986 at the Flett Theatre, Geological Museum, Exhibition Road, South Kensington, London S.W.7, Mr Ken Scarratt, F.G.A., Director of the Gem Testing Laboratory of Great Britain, gave an illustrated talk entitled 'Happenings at the Lab'.

Midlands Branch

On 19 September 1986 at Dr Johnson House, Bull Street, Birmingham, Mr A. Hodgkinson, F.G.A., gave a talk entitled 'New sources of gemstones and new synthetics'.

North West Branch

On 19 June 1986 at Church House, Hanover Street, Liverpool 1, Mr D. Durham gave a talk entitled 'From rough to finished gem'.

On 18 September 1986 at Church House, Mr A. Hodgkinson, F.G.A., gave a talk entitled 'New sources of gemstones and new synthetics'.

COUNCIL MEETINGS

At the meeting of the Council held on 26 August 1986 at Saint Dunstan's House, Carey Lane, London EC2V 8AB, Mr Jonathan P. Brown, Barrister-at-Law, F.G.A., was appointed successor to Mr Con Lenan as Secretary of the Association (see p.202).

At the meeting of the Council held on 16 September 1986 at the Royal Automobile Club, 89 Pall Mall, London S.W.1, the business transacted included the formal appointment of Mr J.R.H. Chisholm, M.A., F.G.A., as Consultant Editor. A list of members elected will appear in the January 1987 issue of the *Journal*.

NEW GEMMOLOGY COURSE

On 31 August 1986 at the International Watch, Jewellery and Silver Trades Fair, Earls Court, London, a champagne reception was held to mark the official launching of the New Gemmology Course (Preliminary section).

GEMMOLOGICAL ASSOCIATION INAUGURAL DINNER, NEW YORK CITY

The Inaugural Dinner of the Gemmological Association of Great Britain in the United States was held on 9 June 1986 in New York City, where approximately 60 people gathered at the New York Athletic Club. People from various parts of the country were present and the Gemmological Association was honoured to have among its guests recognized leaders of the gemmological profession and representatives of the nation's leading gem trade associations. Guests were welcomed by Dorothy Gibson, F.G.A. (Tully Medallist, 1984), and the speaker was David Callaghan, F.G.A., Chairman of the Gemmological Association, who, of course, was already well-known to many of the guests. All enjoyed his talk on the Association and also on jewellery.

The Gemmological Association plans to hold similar dinner meetings in different parts of the United States when the Chairman or other Officers of the Association are in the country.

SEMINAR ON GEOLOGICAL AND MINERALOGICAL LITERATURE

The Science Reference and Information Service will be holding a one-day seminar on the use of geological and mineralogical literature on 3 December 1986. It is intended for those dealing professionally with the extensive literature of the earth sciences for librarians and research workers and anyone who needs to become familiar with the very large amount of information now available on such topics as prospecting, mineral testing, details of new minerals and of particular rock and mineral groups such as ores and gemstones. The needs of the oil and mining industries will also be covered.

The seminar will be held at the Science Reference and Information Service, 25 Southampton Buildings, Chancery Lane, London WC2A 1AW. The price of the seminar is £43.50 (plus VAT) to include lunch and refreshments.

Application forms can be obtained from Marketing and Public Relations Section, Science Reference and Information Service, 25 Southampton Buildings, London WC2A 1AW. Telephone 01-405 8721, ext. 3427.

GEMOLOGICAL INSTITUTE OF AMERICA

The Institute has announced the appointment of Bill Boyajian as acting President following the resignation of Glenn Nord to take up another appointment.

EXAMINATIONS 1987

The examination dates for 1987 are as follows:

Gem Diamond Examination:

Monday 8 June.

Examinations in Gemmology:

Preliminary: Theory, Monday 29 June.

Diploma:

Theory, Tuesday, 30 June.

Practical, Wednesday, 1 July (the practical examination may also be held on Thursday 2 July and Friday 3 July)

The last date for receipt of examination entry forms is 31 March.

Letter to the Editor

From R. Keith Mitchell, F.G.A.

Dear Sir,

I read with sadness Mr Morgan's obituary for Mr F.S.H. Tisdall whom I first encountered as a student in the mid 1960s. This sounds strange when we realize that he actually took his Diploma with Distinction in 1936 (not '35).

It is not generally known that this quite remarkable man, feeling that his gemmology might perhaps have rusted a little, actually applied for permission to sit the GA examinations, which he had already passed so brilliantly, a second time. It was not possible to allow this but the Council did not prevent him from working through the entire two years of the correspondence course again. I undertook to be his instructor and must admit that he gave me quite a run for my money. He had a shrewd and enquiring mind which he exercised to the full, and our exchanges were very lively at times.

Later, when I had an office in Holborn from 1967 to 1979, he would turn up from time to time, often quite unheralded, and start further discussions even before he was properly through the door. A man of considerable character in more senses than one. I have not heard him described as a Midland's Robert Webster but, having known the latter extremely well, I can confirm that they were alike in many ways.

Yours etc.,
Keith Mitchell

11 August 1986
21 Bark Hart Road, Orpington, Kent.

CORRIGENDA

In *J. Gemm.*, 1985, **XIX** (7), on p.620, Table 3, last column: for 'Add 0.0006' read 'Subtract 0.0017'; for 'Subtract 0.0004' read 'Add 0.0010'; for 'Subtract 0.0007' read 'Add 0.0015'; and for 'Subtract 0.0008' read 'Add 0.0020'

On p.152 above, in the caption to Figure 21, for 'Figure 21' given in brackets throughout the caption, read 'Figure 20'

On p.173 above in fig. 2 (c) the crown angles were omitted. The values to be inserted on the four curves are 24°, 30°, 34.5° and 37°, reading from the lowest curve upwards.

On p.196 above, 1st column, in line 12 from foot, for 'cemetary' read 'cemetery'

On p.199 above, 1st column, last heading, for 'America' read 'Africa'

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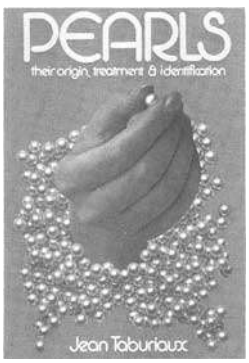

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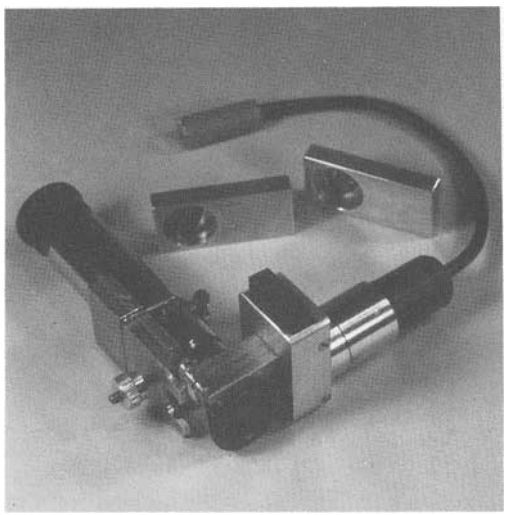

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Historical Note

The Gemmological Association of Great Britain was originally founded in 1908 as the Education Committee of the National Association of Goldsmiths and reconstituted in 1931 as the Gemmological Association. Its name was extended to Gemmological Association of Great Britain in 1938, and finally in 1944 it was incorporated in that name under the Companies Acts as a company limited by guarantee (registered in England, no. 433063).

Affiliated Associations are the Gemmological Association of Australia, the Canadian Gemmological Association, the Gem and Mineral Society of Zimbabwe, the Gemmological Association of Hong Kong, the Gemmological Association of South Africa and the Singapore Gemologist Society.

The *Journal of Gemmology* was first published by the Association in 1947. It is a quarterly, published in January, April, July, and October each year, and is issued free to Fellows and Members of the Association. Opinions expressed by authors are not necessarily endorsed by the Association.

Notes for Contributors

The Editors are glad to consider original articles shedding new light on subjects of gemmological interest for publication in the *Journal*. Articles are not normally accepted which have already been published elsewhere in English, and an article is accepted only on the understanding that (1) full information as to any previous publication (whether in English or another language) has been given, (2) it is not under consideration for publication elsewhere and (3) it will not be published elsewhere without the consent of the Editors.

Papers should be submitted in duplicate on A4 paper. They should be typed with double line spacing with ample margins of at least 25mm all round. The title should be as brief as is consistent with clear indication of the content of the paper. It should be followed by the names (with initials) of the authors and by their addresses. A short abstract of 50–100 words should be provided. Papers may be of any length, but long papers of more than 10 000 words (unless capable of division into parts or of exceptional importance) are unlikely to be acceptable, whereas a short paper of 400–500 words may achieve early publication.

Twenty five copies of individual papers are provided on request free of charge; additional copies may be supplied, but they must be ordered at first proof stage or earlier.

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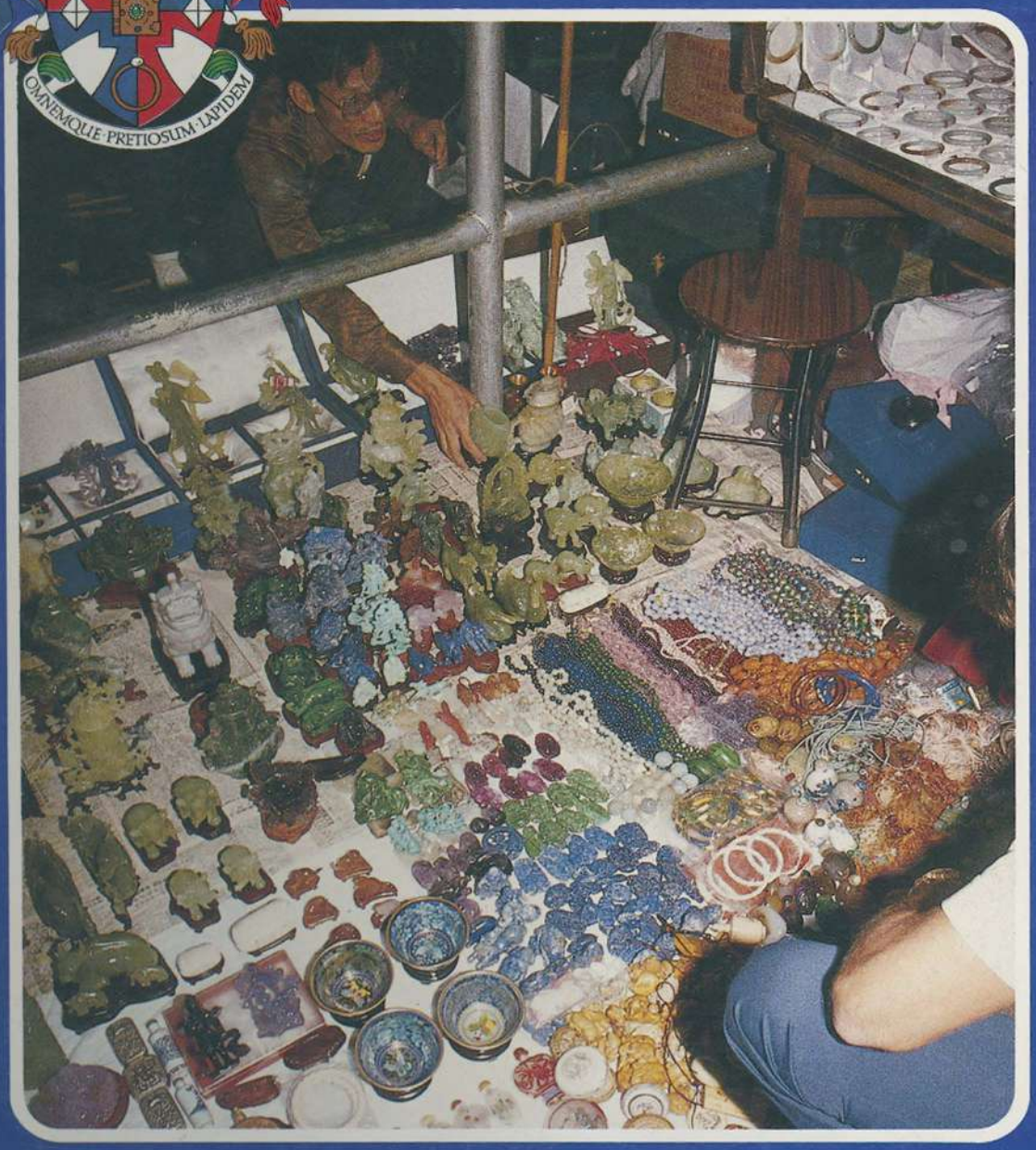

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The Journal of Gemmology

VOLUME 20

NUMBER FIVE JANUARY 1987

Cover Picture

A typical stall in the 'jade market' in Hong Kong.
Note the wide range of jade and other hardstone carvings available
(see 'A visit to Hong Kong', pp.270–1).
Photograph by E.A. Jobbins

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J. Gemm., 1987, 20, 5

A Major Presentation to the Gemmological Association of Great Britain.

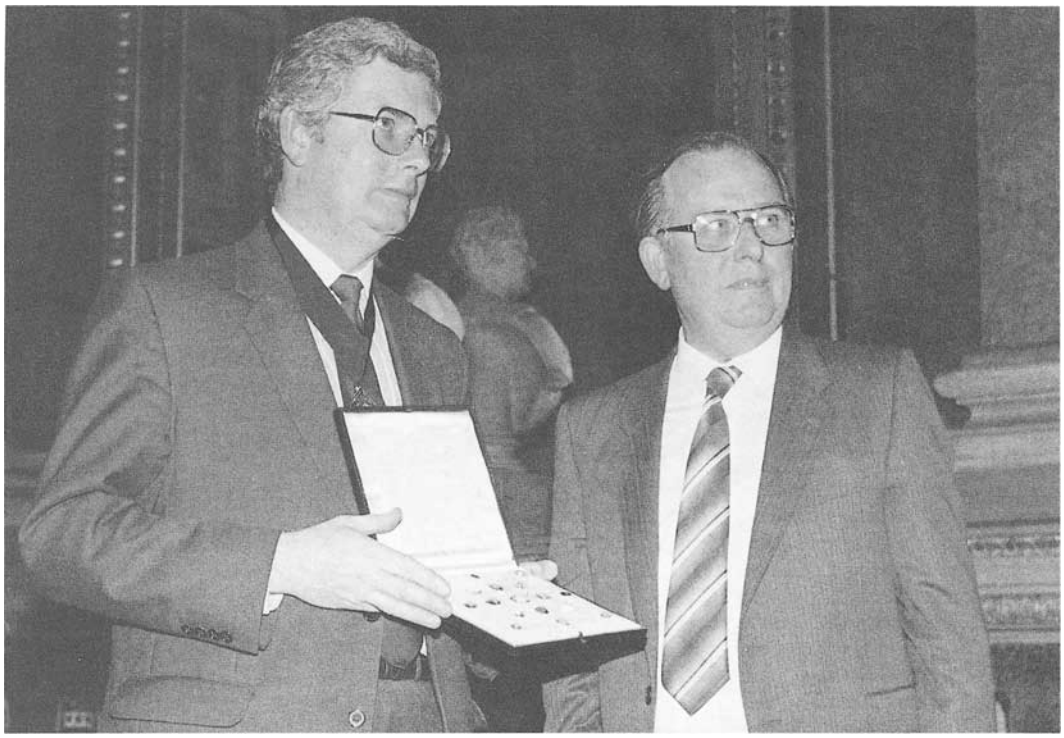

The late Basil Anderson assembled a fine collection of cut stones during his near sixty years at the gemmological helm. This collection was auctioned recently at Christie's in London and was purchased anonymously.

The collection has now been presented to the Gemmological Association by this anonymous purchaser. We sincerely thank our generous benefactor on behalf of all Fellows and Members of the Association. The collection will be studied and catalogued by our Curator, Christopher Cavey, F.G.A., and full details will be given in a paper to be published in a future issue of the *Journal*.

The picture shows Mr A. Middlemiss, F.G.A., of Christie's, when he passed over part of the B.W. Anderson collection to the Chairman of the Association, Mr David Callaghan, F.G.A., at the Annual Presentation of Awards ceremony at Goldsmiths' Hall on 11 November 1986.

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ISSN: 0022-1252

Metallic inclusions in Chatham synthetic corundums

C.R. Burch, B.Sc., F.G.S.

Senior Lecturer in Gemmology and Geology, Sunderland Polytechnic

Abstract

Metallic inclusions in coloured flux-grown Chatham synthetic corundums are described and illustrated. The inclusions are probably composed of platinum metal, derived from the walls of the crucible in which crystallization took place. Apart from the 'normal' triangular and hexagonal crystal shapes these inclusions may occur as plates, needles, spicules, daggers, blades, rods, bars, pyramids or in irregular forms. Several of the inclusions showed etched surfaces and some were closely associated with solid flux.

Description

A parcel of coloured synthetic corundums, kindly loaned by 'Chatham Created Gems' was recently subjected to detailed microscopic examination. The parcel included red, blue and orange-pink ('padparadscha' colour) rough material and crystal clusters (weighing a total of 1046 carats) together with 12 faceted stones (five orange-pink sapphires, four blue sapphires and three rubies).

Inclusions of solid flux, in various forms, were present in all of the specimens studied and many of the samples contained a wide range of beautifully developed metallic inclusions. Although the latter are almost certainly composed of platinum metal, the general term 'metallic' is used to describe them here since crucibles composed of rhodium or iridium may sometimes be used for flux growth.

The characteristics of flux inclusions in Chatham synthetic corundums have been discussed elsewhere (Gübelin 1983; Kane 1982, 1983; Scarratt 1977) and this short paper is primarily concerned with the visual appearance, particularly crystal shapes, of the metallic inclusions in these synthetic gemstones. As expected, all the metallic inclusions examined were strongly reflecting when suitably oriented and illuminated. Colours observed in reflected light were silvery, grey or yellowish. What was unexpected was the very considerable diversity of form which the inclusions displayed. The commonest shapes were triangles or hexagons although these were rarely perfectly symmetrical. Less common, but still fairly abundant, were forms resembling thin plates, needles, spicules, daggers, blades, rods, bars and pyramids. In addition some of the inclusions were quite irregular in outline. Another interesting feature shown by a number of the inclusions was the development of pitting or etching on one or more of their surfaces – an effect perhaps due to corrosion by the molten flux before the inclusion became incorporated in the growing corundum host. In a few cases the metallic inclusions were partly coated by a layer of white flux of variable thickness.

The features noted above are illustrated in the accompanying photographs.

Conclusion

Careful observation of the shapes of metallic inclusions could prove, in conjunction with flux inclusions, extremely helpful in determining the synthetic nature of a doubtful corundum. Although this paper has dealt exclusively with Chatham stones, it is reasonable to assume that equally diverse metallic crystal forms may occur in other gemstones produced by the flux melt process.

Acknowledgement

I am most grateful to Thomas Chatham of 'Chatham Created Gems', San Francisco, who kindly loaned me the synthetic corundums discussed in this paper. The parcel, which included synthetic emeralds as well as corundums, weighed in total 1333 carats and contained some of the finest examples of synthetic gem material I have ever seen.

References

Gübelin, E. 1983. Identification of the new synthetic and treated sapphires. *J. Gemm.*, **XVIII**, 8, 677–706.

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[*Manuscript received 5 August 1986.*]

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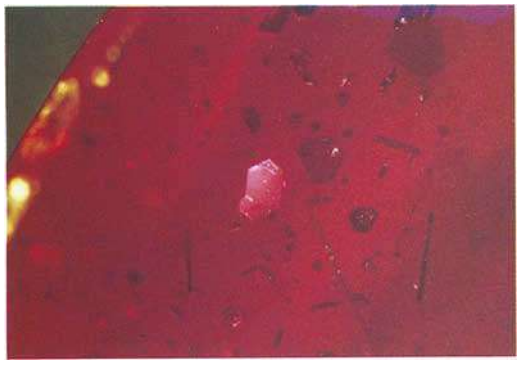

Fig. 1. Hexagonal plates (one strongly reflecting), triangles with truncated corners, bar and needle-like metallic inclusions. Chatham ruby cabochon (1.8 ct). Reflected light. 16x.

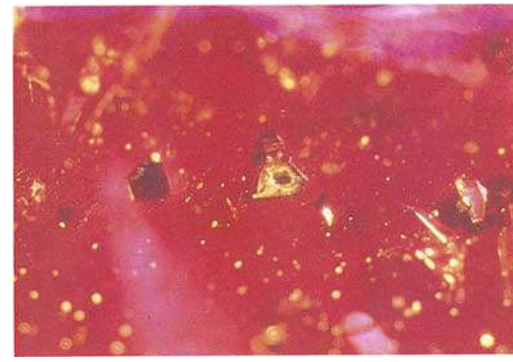

Fig. 2. Triangular inclusion (with attached white flux) pseudo-hexagonal and irregular metallic crystals. Chatham ruby crystal cluster (284 ct). Transmitted and reflected light. 16x.

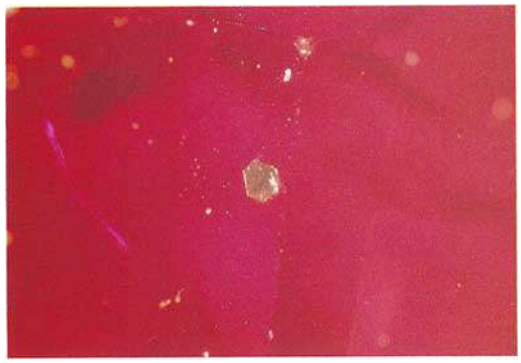

Fig. 3. Almost symmetrical, hexagonal metallic crystal with etched surface. Chatham ruby rough (189 ct). Transmitted and reflected light. 10x.

Fig. 4. Etched hexagonal metallic inclusions with some attached white flux. Chatham orange-pink ('padparadscha' colour) sapphire rough (425 ct). Reflected light. 10x.

Fig. 5. Dense concentration of metallic blades, spicules, plates and irregular forms. Chatham blue sapphire rough (45.8 ct). Transmitted and reflected light. 10x.

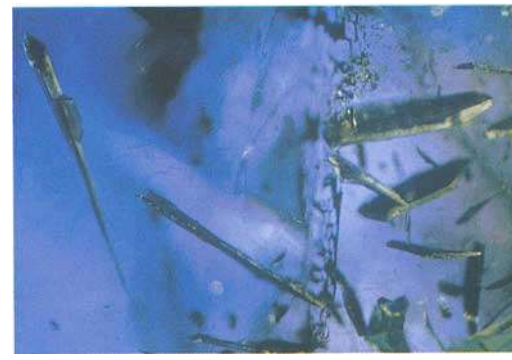

Fig. 6. Hexagonal plates, bars and dagger-like metallic inclusions. Chatham blue sapphire rough (45.8 ct). Transmitted and reflected light. 10x.

Fig. 7. Elongate, thin metallic blade (note 'feather' and white flux also). Chatham blue sapphire rough (45.8 ct). Transmitted and reflected light. 10x.

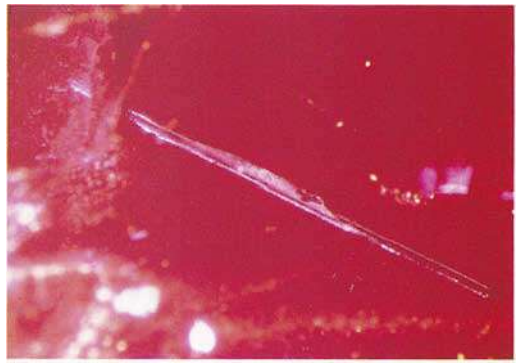

Fig. 8. Elongate metallic blade, partially coated with white flux. Chatham ruby rough (189 ct). Transmitted and reflected light. 10x.

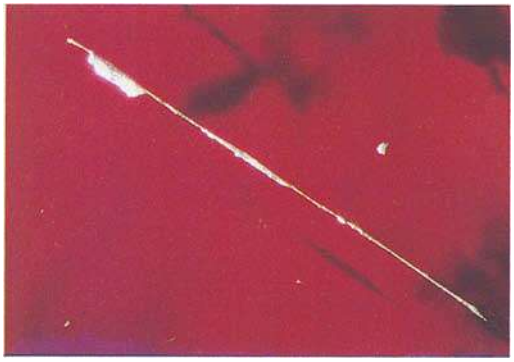

Fig. 9. Needle-like metallic inclusion coated with strongly reflecting white flux. Chatham ruby rough (189 ct). Transmitted and reflected light. 10x.

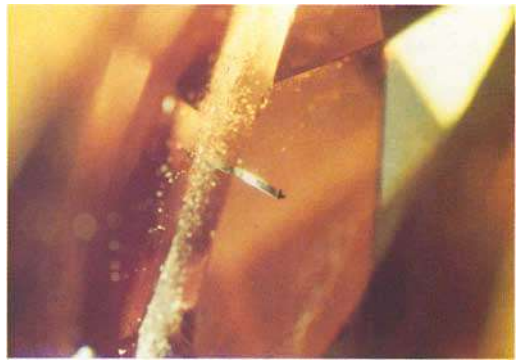

Fig. 10. Metallic bar with triangular cross-section immediately beneath girdle. Chatham orange-pink ('padparadscha' colour) faceted sapphire (0.89 ct). Transmitted and reflected light. 10x.

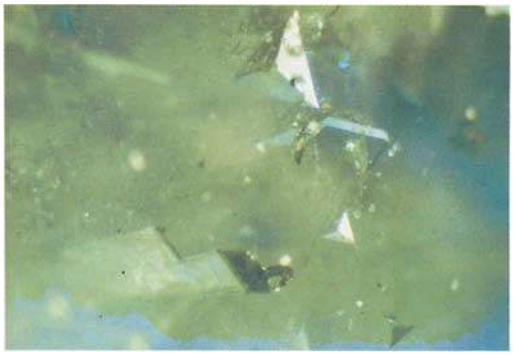

Fig. 11. Metallic pyramids, plates and irregular inclusions. Chatham blue sapphire crystal cluster (102 ct). Transmitted and reflected light. 16x.

Fig. 12. Irregular silvery, metallic inclusion. Chatham blue sapphire rough (45.8 ct). Transmitted and reflected light. 10x.

A visit to Hong Kong

L.E. Fitzgerald, F.G.A.

Education Administrator, Gemmological Association of Great Britain, London

One of the highlights of being Education Administrator for the Association, and there are many, is having visitors from literally all over the world – Alaska, Canada, the United States of America, Finland, Sweden, Holland, France, Belgium, Switzerland, Italy, Spain, the Canary Islands, Lebanon, Israel, Dubai, Kenya, Zimbabwe, South Africa, India, Sri Lanka, Thailand, Singapore, Hong Kong, Japan, The Philippines, Australia, New Zealand and Tasmania.

Each and every one of them is welcomed and ushered into the Education Department and I often wonder how they view the desk untidily littered with paper and the rather confined area reserved for visitors. Discussions often range from politics to religion or to personal matters, but the one bond that unites us all is the love of gemmology.

Many are the invitations to 'look me up when you are in . . .'. One of the most consistent and insistent of these was from Mrs Melinda Tilley, who lives in Kowloon, to visit Hong Kong and meet the gemmologists there. Many and varied had been the reasons which prevented me from accepting these invitations, but in 1985 I decided to go, much to Melinda's delight. With hindsight I can truthfully say that it was one of the best decisions I have made.

My pleasure was increased by the knowledge that Melinda's husband Frank was to be Flight Engineer on the Boeing 747 which conveyed me from this part of the globe to a land 7000 miles away and eight hours in advance on the clock, and by being invited into the cockpit for the take off from Gatwick.

I was met at Kai Tak airport by Mrs Tilley and quickly divested myself of the raincoat and jacket that had been necessary in London. I would not need these for two whole weeks, weeks that were packed with activity. My first impression was that of all first-time visitors to Hong Kong – the high buildings, the busy streets, the banners stretching across the roads – and the heat.

The next morning I was able to meet the class that gathers at the Tilleys' home for general studies in gemmology and to be amazed to see them looking through diffraction grating spectroscopes and talking about 'two lines in the blue'. General study group! They were ready to enrol in the serious business of the Course in Gemmology conducted by the GA of GB and in fact one of them has now taken the plunge.

Three of Mrs Tilley's past students are now established jewellers in Kowloon and proudly display the Diploma in Gemmology alongside other certificates from the USA and Hong Kong itself. Sometimes a whole wall is covered with framed certificates. Gemmology is a serious business in Hong Kong and I was pleased to note how greatly esteemed is the Diploma of the GA of GB.

One of these past students, Sunny Tsui, who has a small but well-filled shop and is proud of his stock of gems and jewellery, very kindly invited us to a Chui Chow Garden restaurant together with his wife, three children and his niece, who is a designer of fine jewellery. We sampled Chinese hospitality and some strange but delightful delicacies, beautifully presented. A truly memorable evening.

I felt very proud to represent the Gemmological Association of Great Britain and also to meet once again Mrs Kitty Wong, who is the co-ordinator of studies at the Hong Kong Baptist College. It was Kitty Wong who, in 1985, undertook the administration of the Examinations in Gemmology in Hong Kong on our behalf and with over 100 candidates – easily the largest centre outside the UK – made an admirable job of it.

The Hong Kong Baptist College is a large complex with many students. Gemmology is only part of the curriculum but the college possesses a fine range of equipment. Classrooms are airy and air-conditioned as are the laboratories with the gem-testing instruments. This is an important factor especially during the summer months. I also saw the large hall where the examinations are held and met senior academic staff, including Dr David Lovett and Dr Mary Wang. It is always a pleasure to meet the people who are responsible for providing accommodation and invigilation on our behalf for

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the Examinations in Gemmology and to establish lasting contacts with them. I feel it is of great benefit to all of us.

Alan Jobbins arrived in Hong Kong on Sunday and the next evening we had an enjoyable evening at Anne Paul's home, where we met representatives from the Gemmological Association of Hong Kong and the Hong Kong Baptist College. Alan soon found himself being cross-examined on topics ranging from colour in gemstones to the expectations of the Examiners in such subjects as the Diploma practical examination. We were able to assure these keen teachers of gemmology that the examiners are anxiously looking for marks to help students pass the examinations and not, as many think, trying to take away marks and fail them.

There were too many things to see and my time was fully occupied. Alan managed to visit the 'jade market' (see front cover illustration), but, regrettably, I was engaged on other business.

The next evening was an important occasion – the Annual Dinner of the Hong Kong Gemmological Association and Alan and myself were guests of honour. Alan gave an illustrated talk on the gemfields in Burma, Indo-China and Australia and answered many questions. After dinner the students who had been successful in' the Diploma Examination and had received their Diplomas, were presented with scrolls welcoming them to membership of the Gemmological Association of Hong Kong. Later we were able to talk to them and also to past students who had corresponded but never met us. Altogether another never-to-be-forgotten occasion.

The following day we both left the warm, welcoming people of Hong Kong for the long journey home to the cloudy, cold shores of the UK but our minds were filled with many happy memories and invitations to return.

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Chalcopyrite in peridot: a first observation

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Abstract

This paper describes, for the first time, inclusions of the copper-iron sulphide chalcopyrite in peridot. The peridot host was analysed for traces of copper to determine if copper might be playing a role in the coloration of this gem. No copper was detected.

Introduction

A small parcel of faceted Arizona peridot was recently donated to the Gemological Institute of America for use in the reference collection and for student study sets. While examining these peridots under magnification, it was noticed that one of them contained a few tiny rounded obviously protogenetic, metallic-looking, dark inclusions. One of these inclusions had been cut through during faceting and was now exposed at the host's surface. In the past, the authors had noticed similar metallic-looking grains as inclusions in Arizona peridot (Figure 1), but the inclusions were never before so conveniently laid out for analysis as they were in this gem. It was therefore decided that both X-ray diffraction and microchemical testing could be carried out to determine the identity of these inclusions.

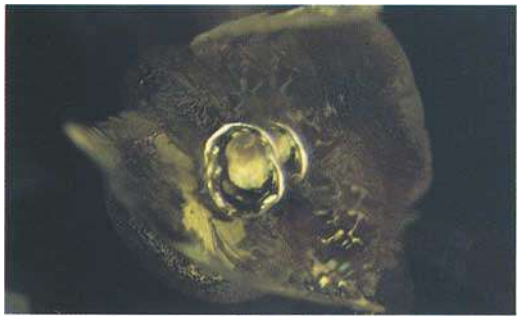

Fig. 1. Protogenetic chalcopyrite inclusion surrounded by a healed fracture system in an Arizona peridot. Dark-field illumination. 50x.

Description of the host

The peridot host (GIA collection number 14576) is a yellowish-green oval modified brilliant cut of medium intensity (Figure 2) weighing 1.29 ct and measuring approximately 7.98 × 6.11 × 3.83 mm.

The gemmological properties exhibited by this stone fell within the range of properties already established for Arizona material (Koivula, 1981). Using sodium vapour light, the refractive index was measured at 1.652 alpha, 1.670 beta, and 1.689 gamma with a birefringence of 0.037. The specific

Fig. 2. Oval faceted 1.29 ct peridot that was the subject of this study.

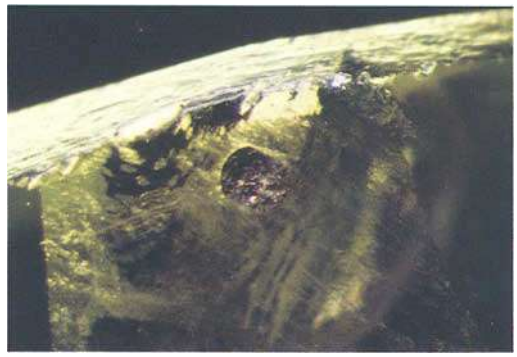

Fig. 3. Chalcopyrite inclusion analysed for this study, exposed at the surface of the gem shown in Figure 2. Oblique illumination. 50x.

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gravity was determined hydrostatically using a Voland double-pan balance. The average for three runs was 3.33. The gem's specific gravity was also checked using pure methylene iodide with a specific gravity of 3.32. The peridot sank very slowly in this liquid.

The visible light absorption spectrum was studied next using a Beck prism spectroscope and fibre optic, white light, illumination. The observed absorption pattern is typical for peridot from Arizona (Koivula, 1981). The gem shows a band in the blue-green with its strength at 496.0 nm and a weaker zone at 488.0 nm. A line is visible at 473.0 nm, while a weak band, centred at 452.0 nm is also present.

Preparation for analysis

The analysed inclusion breaks the peridot's surface on the pavilion, near the girdle, within the first row of facets (Figure 3).

To ensure a contaminant-free surface for analysis the facet containing the inclusion was freshly ground using a diamond-charged, 360 grit, grinding lap (not a copper lap). The gem was then placed in warm fresh distilled water, ultrasonically cleaned for five minutes, and then allowed to air dry.

Analysis of the inclusions

Once cleaned, it was apparent that the inclusion had a metallic appearance and a brassy colour when viewed in surface reflected light (Figure 3). Because of this, it was felt that the inclusion was probably a sulphide of iron, possibly pyrite. A decision was made that X-ray powder diffraction be used to identify the inclusion positively.

A spindle was prepared under magnification from a minute amount of powder obtained from the inclusion. The spindle was then mounted in a Debye-Scherrer powder camera and exposed to X-rays generated from a copper target tube at 46 kV and 26 mA for five hours. After developing the X-ray film, the pattern produced was measured for d-spacing with a Nies overlay scale corrected for film shrinkage. The strengths of the lines were estimated visually. This pattern was then compared with our standards for several different sulphides. A pattern match was obtained with the chalcopyrite standard.

Since chalcopyrite is easily decomposed by concentrated nitric acid, yielding free sulphur and a green-coloured copper-iron solution, it was decided that this simple microchemical test could be used to chemically test for the presence of copper in the inclusion. The test was carried out while viewing the inclusion microscopically in incident illumination. A tiny droplet of nitric acid was placed on the inclusion surface and within moments the expected reaction occurred and a green solution formed, although no distinct yellow sulphur crystals were visible at the low magnification that was used.

Analysis of the host for copper

With the discovery of protogenetic chalcopyrite in peridot, the question was raised that perhaps some of the copper present in the environment that precipitated the chalcopyrite might also have been incorporated structurally in the host peridot, at least in trace amounts. It was even thought that, if present, copper may be playing a partial role in the coloration of the peridot. It was therefore felt that, because of these questions, an analysis for trace-copper, within the peridot itself, was needed.

The gem was thoroughly cleaned and then was taken to the California Institute of Technology in Pasadena, California, for analysis using a Kevex energy dispersive X-ray fluorescence unit. Concerning copper analysis, the detection limit of this instrument is in the parts per million range. The table facet was analysed but no trace of copper was detected within the peridot.

Conclusion

The identification of chalcopyrite as an inclusion in peridot is the first observation of this nature known to the authors. As such, it adds to the cumulative gemmological knowledge we have concerning this gem material. A lack of trace copper in the peridot ruled out the possibility that copper may be playing a partial role in the coloration of the peridot.

Acknowledgements

The authors would like to thank Carol M. Stockton, senior research gemmologist at the Gemological Institute of America in Santa Monica, for the trace elemental analysis for copper, and the California Institute of Technology for use of their energy dispersive X-ray fluorescence unit. Ruth Patchick deserves thanks for typing this manuscript.

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New investigations of synthetic amethysts produced in Japan

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Abstract

Synthetic amethysts of Japanese production, which are now available in the gem trade, are characterized with respect to their diagnostic properties such as inclusions, growth structures, twinning, and infrared spectra. The gemstones frequently have feathers consisting of liquid-filled and two-phase inclusions, sharp growth zoning parallel to one rhombohedral face as well as twin structures. This twinning, however, can be distinguished from polysynthetic lamellar twinning in natural amethysts.

Introduction

Some comprehensive papers on the distinction of natural and synthetic amethyst using infrared spectroscopy and microscopy were recently published (Lind and Schmetzer 1982, 1983; Lind *et al.* 1983). Since that time, the authors have continuously investigated parcels of natural and synthetic amethysts with the methods thought to be useful for determinative purposes. The proposal for a determinative procedure for the distinction of natural and synthetic amethysts, as published by Lind *et al.* (1983), includes (I) investigations by the conoscope and (II) microscopic investigations as well as (III) infrared spectroscopy. This method was introduced in 1982 by the authors as a routine investigation for the measurement of faceted amethysts. The application of infrared spectroscopy was suggested for those samples which are still of doubtful origin after steps (I) and (II) of the determinative procedure. A practical method for an easy recognition of polysynthetic lamellar twinning in amethyst which is important for a distinction of natural and synthetic samples was developed by Schmetzer (1985 a,b), using an improved sample holder with a horizontal and vertical rotation axis for the immersion microscope. This additional investigation is practicable for everyone after a short time of training with typical samples of natural and synthetic origin.

It is self evident that the criteria for a practical distinction of natural and synthetic amethysts, which were worked out until the publications mentioned above were written and published, referred to the types of natural and synthetic amethyst which were available at that time in the trade. Synthetic amethysts then mainly originated from commercial production in the USSR. From the morphology of the rough crystals as well as the infrared spectra of those samples, the synthetic amethysts from USSR were identified by the authors of the present paper as being grown from highly K-alkaline solutions as described in 1975 by Chadshi *et al.* (cf also Balitsky, 1981). In the above investigations, however, some synthetic amethysts of other producers were also included. In addition to the synthetic amethysts produced in the USSR by the method of Chadshi *et al.* (1975), synthetic amethysts produced in Japan became more and more important for the trade. The first samples of this commercial production were already taken into consideration for the study of Lind *et al.* (1983). Meanwhile, the percentage of synthetic amethysts produced in Japan has increased compared with the percentage of synthetic amethysts produced in the USSR, which formerly were dominant in the trade.

In the last few months, an increasing number of synthetic amethysts of Japanese production showing extraordinary gemmological properties were found during routine investigations. Only some of the diagnostic characteristics of those synthetic amethysts are included in the papers published at present. Therefore, in order to avoid misinterpretations during the distinctions of natural and synthetic amethysts in the gemstone trade, the publication of the determinative properties of this new type of synthetic amethyst appears to be highly necessary in the opinion of the authors. Supposedly, the different structural properties as well as feathers consisting of fluid and two-phase inclusions which are now frequently observed in this new type of synthetic amethyst are caused by alternating growth conditions. Thus, the increase of commercial production techniques causes a permanent necessity of revising and enlarging the diagnostic criteria useful for a distinction of natural gemstones and their synthetic counterparts. These revising and enlarging investigations, in general, have to be carried out with normal samples available in the trade.

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Unlike the synthetic amethysts investigated in the past, samples of the new type of synthetic amethyst produced in Japan frequently reveal feathers consisting of fluid inclusions and two-phase inclusions (Figure 1).

For each gemmologist it is evident that fluid and two-phase inclusions may be found in all crystals grown under hydrothermal conditions, i.e. in natural as well as in synthetic amethysts. Feathers in synthetic amethysts, however, were found to be extremely rare in the samples investigated previously (cf. Lind *et al.*, 1983, 1985).

In synthetic amethysts from commercial Japanese production, which are described in the present publication, sharp lamellar structures connected with a distinct colour zoning were commonly observed by use of the immersion microscope (Figure 2). These lamellar structures are parallel to one rhombohedral face of the synthetic amethyst, which is parallel to the seed used for the growth of the synthetic amethyst crystal (i.e. perpendicular to the growth direction). In synthetic amethysts investigated in the past broad colour bands parallel to one rhombohedral face were rarely observed, whereas in natural amethysts generally sharp lamellar structures are observable parallel to several rhombohedral faces.

The different types of commercially grown synthetic amethysts of the trade, which were previously investigated by the authors, in general did not reveal polysynthetic twinning on the Brazil law. These results were consistent with the data published by Balitsky (1981) and Schneider and Dröschel (1983), who recognized the great importance of polysynthetic lamellar twinning in natural amethyst for a distinction of natural stones from their man-made counterparts (cf. also the determinative procedure of Lind *et al.*, 1983, 1985). In contrast, twinning on the Brazil law in synthetic amethysts was described by different authors (Melankholin and Tsinober, 1963; Chentsova *et al.*, 1966; Balakirev *et al.*, 1975; Balitsky, 1981). This type of twinning, however, is only confined to distinct areas of the synthetic crystal. By use of the gem microscope, these twinned areas are recognizable between crossed polarizers as triangular shaped zones which are incorporated into a main crystal. Balakirev *et al.* (1975) demonstrated that this type of twinning reveals a certain twin structure on the microscopic scale and, thus, is different from the twin structure on the macroscopic scale which is common in natural colourless quartz.

The investigation of samples of the new type of synthetic amethyst from commercial Japanese production by the authors showed twinning in triangular shaped zones which are incorporated into the main crystal in about half of the faceted synthetic amethysts studied. By use of the immersion microscope with the newly developed sample holder as a supplement, these acute-angled areas are easily recognizable between crossed polarizers as incorporations into the main crystal of synthetic amethyst which is not twinned on the Brazil law (Figures 3–6). A similar structure was found only in one sample of the recently investigated types of synthetic amethyst; this sample was from the commercial production in the USSR. Due to the microscopic appearance of this type of twinning in synthetic amethyst, a distinction from the different forms of polysynthetic lamellar twinning in natural amethyst, in general, is avoidable by careful investigations. For this purpose, a detailed knowledge of the various properties of polysynthetically twinned natural amethysts on the Brazil law as described comprehensively by Schmetzer (1985 a,b) is necessary.

Some samples of the new type of synthetic amethyst of Japanese production were investigated by infrared spectroscopy using an immersion cell which was especially developed for the study of faceted gemstones (Lind and Schmetzer, 1982, 1983). The infrared spectra of samples of the new type of synthetic amethyst reveal the additional absorption band which was recently found to be of diagnostic value for the distinction of natural and synthetic amethyst. This additional absorption band in the infrared area was first detected in synthetic amethysts produced in the USSR. Later, identical spectroscopic features were found also in the first synthetic amethysts from Japan. However, it is worth while mentioning that the additional absorption band in some synthetic amethysts from commercial Japanese production was only of low intensity. Additional investigations of synthetic amethysts of all types of commercial production available in the trade are continuously carried out.

The distinction of natural and synthetic amethysts now as ever before is based on a detailed microscopic investigation of the samples of unknown origin. This investigation includes the microscopic determination of a possible presence of growth structures, twinning and inclusions. For samples which are still doubtful supplementary investigations by infrared spectroscopy have to be performed (cf. the determinative procedure in Lind *et al.*, 1983, 1985). At present, by a combination of those methods which are recognized to be of diagnostic value in most cases it will be possible to find diagnostic properties which are suitable to characterise the sample of unknown origin. Each gem variety including amethyst, however, occasionally reveals samples without diagnostic properties of unambiguous value. Problems for a distinction between natural and synthetic amethysts, especially for small

Fig. 1. Synthetic amethyst from new Japanese production; feather consisting of fluid and two-phase inclusions. 30x.

Fig. 2. Synthetic amethyst from new Japanese production; sharp lamellar growth structures, connected with a distinct colour zoning (pictured above) parallel to the seed of the synthetic crystal (pictured below); feather consisting of fluid and two-phase inclusions. 20x.

Fig. 3. Synthetic amethyst from new Japanese production; acute-angled twinned area incorporated into the main crystal which is not twinned on the Brazil law. Crossed polarizers. 24x.

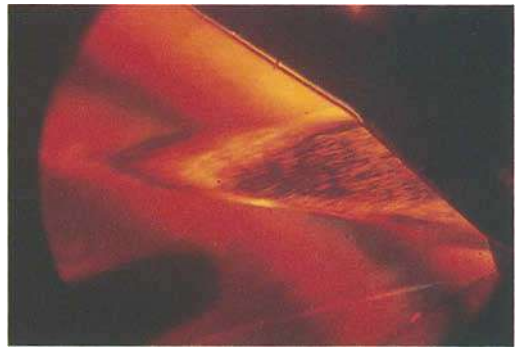

Fig. 4. Synthetic amethyst from new Japanese production; acute-angled twinned area incorporated into the main crystal which is not twinned on the Brazil law. Crossed polarizers. 40x.

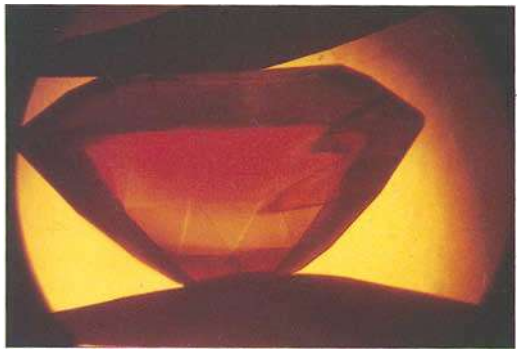

Fig. 5. Synthetic amethyst from new Japanese production; acute-angled twinned areas incorporated into the main crystal which is not twinned on the Brazil law. 16x.

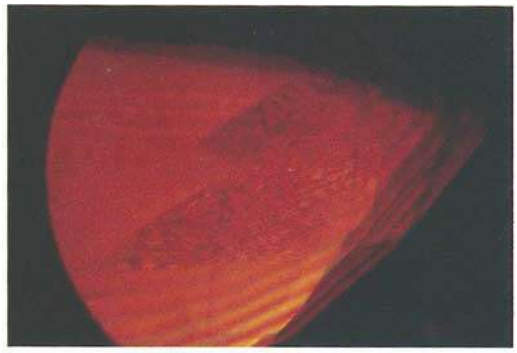

Fig. 6. Synthetic amethyst from new Japanese production; acute-angled twinned areas incorporated into the main crystal which is not twinned on the Brazil law. Crossed polarizers. 34x.

samples, may arise due to the fact that natural amethysts reveal polysynthetic lamellar twinning only in areas confined to the major rhombohedron of the crystals.

Acknowledgements

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On corundums from Umba Valley, Tanzania

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Abstract

The many colours exhibited by corundums from Umba Valley in Tanzania are related to their varying contents of Fe, Ti, Cr and V. Ni and Co could not be detected by the EDS-XRF technique used. The presence of abundant inclusions distinquishes these gemstones, and the following were found: zircon, rutile(?), apatite, hematite, mica, monazite, plagioclase, calcite, pyrrhotine and graphite. Healed fractures, negative crystals, colour zoning, twinning with traces of intersecting lamellae and boehmite(?) laths were noted. Techniques for the identification of inclusions are discussed. The densities (3.98-4.01 g/cm^3) and refractive indices (n_e: 1.761-1.768, n_o: 1.769-1.778) were also determined. Spectral features are given.

Introduction

Corundum is economically the most significant of the many unusal gemstones of East Africa. Numerous occurrences of ruby in Kenya and Tanzania (Longido, Lossogonoi, Mangari and Morogoro) have supplied the gem-cutting industry with raw material for a long time, but corundum from the Umba Valley is unique for the large range of colours exhibited by the mineral.

The aim of this study is to describe the properties and characteristics of the corundum from Umba Valley, and to supplement and confirm data and information from earlier publications.

Rubies from alluvial deposits were discovered in the vicinity of the River Umba in north-eastern Tanzania in 1960 (Solesbury, 1967). The host rock of the corundum was found not far from this location in a pegmatite which intrudes a greyish-green serpentinite. The pegmatite varies mineralogically, but where it hosts corundum it contains vermiculite and a calcic plagioclase. Gneisses (in part graphitic), amphibolites and marbles are geologically associated with these rocks. The geology of the area was described by Solesbury (1967). The erosive action of the River Umba resulted in the exposure of these rocks and the formation of alluvial deposits. Many corundum crystals were thus extracted from the host rock and accumulated in pockets and depressions.

Habit and colour of the crystals

The crystals or crystal fragments usually occur in tabular, hexagonal forms without pyramid faces. Generally, the basal faces seem to be corroded and, as with the prism faces, perforated with 'packets' of vermiculite. Intersecting furrows occur on the basal faces, often forming regular triangles. These originate where the traces of the rhombohedral cut the basal faces. The furrows are also exit positions of the fine twin lamellae which also lie parallel to the rhombohedral faces. In many ways, the corundum from Umba resembles that from the Missouri River in Montana (USA), especially as far as colour, habit and inclusion patterns are concerned. However the Umba corundum exhibits colours which are much more varied; all conceivable colour combinations of blue, red, yellow and colourless occur (Pough, 1972; Naftule, 1982). However, pure (spectral) colours are virtually never encountered and variations of bluish-green, bluish-grey, violet, pink, yellowish-green, brownish-yellow, orange or brown predominate. The best colour is exhibited in the direction of the *c*-axis, often paler in the centre of the crystal and more strongly coloured towards the crystal rims. Colour zoning in two different colours within the same crystal sometimes occurs.

Two colour varieties of Umba corundum have attracted particular attention. Firstly, the bright orange to yellowish-brown stones and secondly, the colour-changing alexandrite-like types (Naftule, 1982). At this stage, it should be pointed out that with respect to colour, the superb orange corundum from Umba Valley differs chemically from the padparadschas of Sri Lanka as far as the causes of the colour are concerned. The trace elements chromium (Cr) and iron (Fe) are mainly responsible for the colour of the orange Umba corundum, whereby Cr^{3+} is the cause of the red component, and Fe^{3+} of the yellow. The padparadschas of Sri Lanka owe their colour to a combination of chromium and lattice defects (the latter acting as colour centres), as well as to trace quantities of iron. In the latter case the chromium is the cause of the

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red colour component, but the yellow component of the orange stems mainly from the colour centres (Schmetzer *et al.*, 1982). As the two varieties of corundum are dissimilar both in appearance and as to the origin of their colour, there is no cause to designate the orange corundum from Umba as padparadscha (Gunawardene, 1984).

Many authors have studied the causes of colour in corundum (Harder, 1969, Lehmann *et al.*, 1970, Schmetzer *et al.*, 1981). The following data from corundums from Umba originates from the work of Harder (1969), who investigated a large number of differently coloured corundums from all over the world, using wavelength-dispersive X-ray fluorescence techniques (Table 1).

Table 1. Colouring effect of trace elements in corundum from Umba Valley. (after Harder, 1969)

	Cr	V	Fe	Ti
Red	0.03	–	0.05	0.006
Violet	0.04	0.002	0.1	0.009
Bluish	0.014	–	0.6	0.006
Yellowish-green	0.007	–	0.5	0.006
Greenish	0.002	–	0.4	0.009

(Values in weight %)

As can be seen in Table 1, the four main trace elements in Umba corundum occur in concentrations covering a wide range. Lattice position and oxidation state of Fe as well as its association with other trace elements play an important role in colour considerations. Basically, the following rules apply (after Schmetzer and Bank, 1981): *Yellow* corundum is either coloured by the presence of trivalent iron (Fe^{3+}) or by defects in the crystal lattice (colour centres). The iron in *blue* sapphire is mainly divalent and together with quadrivalent titanium it forms the blue colour of the mineral as (Fe^{2+}/Ti^{4+}) pairs. *Green* corundum probably possesses its colour through mixing of yellow and blue, the latter two colours resulting from the reasons given above. *Red* corundum (ruby) contains trivalent chromium (Cr^{3+}) and often also vanadium (V^{3+}) and iron. *Violet* stones can be expected to contain a mixture of Cr with Fe and Ti, as violet may be considered to be a mixture of red and blue. Vanadium plays a major role in the colour-changing alexandrite-type corundum (Hänni, 1983). On the other hand, the colour effect of such natural stones is often masked by further trace elements resulting in the predominance of other colours. Particularly in the case of Umba Valley corundum, the combined effect of different colour-giving trace elements can be observed. Depending on which combination of elements are present and their relative proportions, a rich palette of colour results.

Twelve corundum samples from Umba exhibiting a wide range of colours, were analysed for the four chromophore elements Cr, V, Ti, Fe by W. B. Stern (Basel). Using an energy-dispersive X-ray fluorescence unit (Stern and Hänni, 1982), the results of Harder (1969) were confirmed qualitatively. Measurable quantities of nickel or cobalt were not detected. Signals from Zr, Pb, Cu, Zn were registered in specimens containing numerous inclusions. There, Zr and Pb is explained by zircon crystals which in many cases reach the surface of the faceted stones. The Cu and Zn signals are most probably due to metal remainders stemming from the cutting wheels. The metal particles are fixed in fractures and open pores in the sample.

Physical Properties

The specific gravity of corundum varies only within a small range; any values outside this range are probably due to the presence of lighter or heavier inclusions. Table 2 shows a compilation of values of specific gravity and refractive indices also exhibit only small variations. The maximum values attained are extremes for corundum, and were measured on an orange-coloured specimen (see also Bank, 1972).

The absorption spectra reflect the many colour varieties and are combinations of the three basic spectra of ruby, sapphire and yellow corundum. Even very small amounts of Cr result in the fluorescence doublet at 693nm. On the other hand, the presence of vanadium or titanium when combined with other chromophores is hard to detect from the spectrum (Bossart, 1981). The Fe^{3+} in blue and bluish-green stones results in a strong band at 450nm. This can be so broad and strong in orange stones, that it merges with the absorption shoulder in the violet. This means that under the spectroscope, darkness occurs with such specimens after violet, below 470nm.

Four typical colour varieties of corundum from Umba exhibit the following absorption spectra (recorded using a Pye-Unicam SP8-100 spectrophotometer):

Orange: 700, 693, 688, 674, 657, 554 (wide, **470** general absorption.

Bluish-green: (693), 560 (wide;, 466, **450**, 388, 376, 360 general absorption.

Olive: (693), 650, 468, 456, **450**, 388, 376, 360 general absorption.

Light violet: **693**, 657, (560 wide), (466), 450, 388, 373, 320 general absorption.

Weak lines are in brackets, strong lines are in bold-faced type, and the last values represent the beginning of general absorption. Values are in nanometres (nm).

Table 2. Physical data of the Umba Valley corundums.

	This study	Zwaan (1974)	Gunawardene (1984)
Density (g/cm^3)	3.98_0-4.01_0	3.97_5-3.99_3	3.99-4.06
Refractive indices			
n_e	1.761-1.769	1.760-1.765	1.763-1.765
n_o	1.768-1.778	1.768-1.774	1.771-1.773

Mineral inclusions and their determination

Of the gemstones which occur in the Umba Valley, garnets have undergone the most in-depth study of their inclusions. Investigations by Schubnel (1972), Zwaan (1974) and Gübelin (1981) have shown that the following inclusions exist in the pyrope-almandine-spessartine-grossular mixed crystals of the garnet group:– apatite, monazite, zircon, rutile, pyrite, pyrrhotine, quartz.

With the exception of quartz, all the above minerals as well as some others can be found in corundum. The following is a list of minerals determined by Zwaan (1974), identified mainly by using X-ray powder techniques: apatite, graphite, pyrrhotine, rutile, spinel, vermiculite, zircon.

Observations of the occurence of a number of these minerals were made previously by Eppler (1973).

Unfortunately, results in publications seldom mention how mineral inclusions were identified. Nowadays, numerous techniques are available, and the commonest are briefly described below.

X-ray powder technique

A small amount of powdered sample material is usually used for this relatively simple investigation. After removal of included grains exposed on a surface or scraping off of powder using a diamond file, the characteristic diffraction pattern of the sample is compared with those of known phases.

Electron beam techniques

The study of tiny areas such as inclusions lying on the surface of a gemstone can be undertaken by means of two similar instruments: the scanning electron microscope (SEM) and the electron microprobe (EMP). Utilizing a fine beam of electrons, the atoms of the area studied are excited and generate characteristic X-rays. They are typical in terms of energy or wavelength for each element present in the sample. The emitted (fluorescence) radiation may be sorted using an energy-dispersive system (EDS) attached to the SEM or EMP. The resulting energy spectra enable one to read the chemical composition at least qualitatively (Figure 10). The SEM has the advantage that it can magnify strongly the analysed area and produce pictures of the surface. The EMP on the other hand is used primarily for fully quantitative chemical analysis rather than for imaging. Both techniques work non-destructively but possess the inherent disadvantage that the lightest elements cannot be analysed.

Raman-laser probe

Using this equipment, solid, liquid ot gaseous inclusions within gemstones can be analysed. A monochromatic (wavelength, e.g., 488nm) laser beam is focused on an inclusion. The laser beam undergoes a frequency change characteristic of the material excited, through interaction with oscillating molecules. The spectra recorded in the infrared region are compared with reference spectra for known solid, liquid and gaseous phases.

Of the three methods discussed above, Raman spectroscopy is still a novel technique in the field of gemmology (Delé *et al.*, 1985).

Optical techniques

Inclusions are often solely identified by their appearance under the microscope (form, colour, relief, etc.) and compared with known phases, especially when other techniques cannot be applied through lack of equipment. On the other hand, identifications purely on the basis of optical comparison are relatively unreliable. Information on inclusions would be more valuable if the technique used for the determination was described.

There are, however, certain types of inclusions, although widely distributed and well-known, whose determination poses great problems: for example, the identification of fine rutile needles in corundum. It can be difficult to decide in certain cases whether, we are dealing with rutile needles, or with hollow cavities (the titanium detected can either occur in the corundum lattice, or as segregated rutile).

In corundum from Umba Valley, ruby from Thailand and Kenya, sapphire from Missouri River deposit (Montana, USA) and corundums from other sources, characteristic inclusions resembling scaffolding are found. These have not been definitely identified due to differing results obtained by various investigators. These linear elements which cross through the corundum in sets parallel to the rhombohedral edges have been described as:

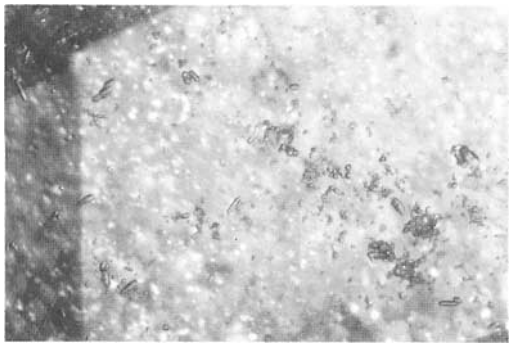

Fig. 1. The most common inclusions in corundum from Umba Valley are zircons. 25x.

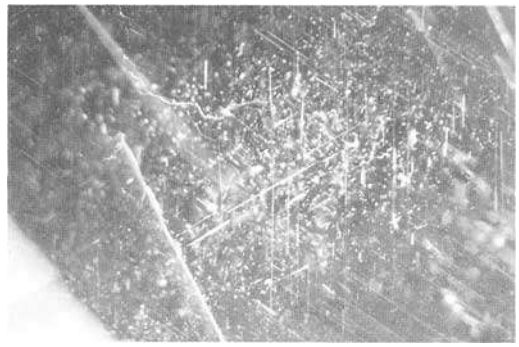

Fig. 2. Short and long needles of rutile, partly lanciform as twinned forms. Reflected light showing interference colours. 25x.

Fig. 3. Idiomorphic crystals of apatite with unidentified dark inclusions. 50x.

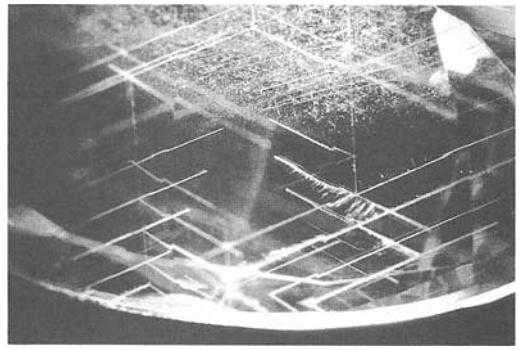

Fig. 4. Twin lamellae intersections and boehmite laths respectively, with fine fissures. Below: fine rutile segregations. 10x.

(a) needles of corundum (Eppler, 1973).
(b) traces of intersecting twin- or dislocation lamellae (Gübelin, 1974; Schubnel, 1972).
(c) boehmite (Keller *et al.*, 1985).

Regardless of the importance of these inclusions (sometimes wrongly taken for rutile) general discussions on their nature have as yet not taken place. The extensive treatment in Schmetzer (1985) will lead hopefully to a generally accepted and used term for this type of inclusion.

The different inclusions found in Umba corundums, as well as structural phenomena exhibited, are described in order of abundance below. The abbreviations following the mineral names denote the method of identification used for this study:
EMP Electron microprobe technique.
OM Optical microscopy.
SEM Scanning electron microscopy.
XRD X-ray diffraction (powder techniques).

Identified inclusions

Zircon (SEM) Figure 1. Small to very small crystals of slightly rounded tetragonal prisms, partly intergrown in groups. They exhibit no preferred orientation in corundum, but are often surrounded by stress fissures. A zoned structure is often observed. The ratio of length: width varies from 2:1 to 30:1. The colourless zircon crystals have a positive relief relative to the surrounding corundum.

Rutile (OM) Figure 2. Very fine, oriented needles, often occurring in three intersecting systems. Mainly very loose and short. Due to the small amounts present and the minute exit positions to the corundum surface, rutile could not be confirmed either chemically or by X-ray techniques.

Apatite (SEM) Figure 3. Individual large to small crystals which occur frequently in reddish corundum and themselves often contain minute dark brown unidentified inclusions. Their hexagonal and prismatic forms with multi-faced to rounded terminations are usually readily recognizable. The mineral grains are colourless and possess a negative relief relative to corundum. Apatite is much rarer than zircon in the blue and green corundum varieties.

Boehmite-laths (OM) Figure 4. Fine to substantial lathlike to track-like structures run through the

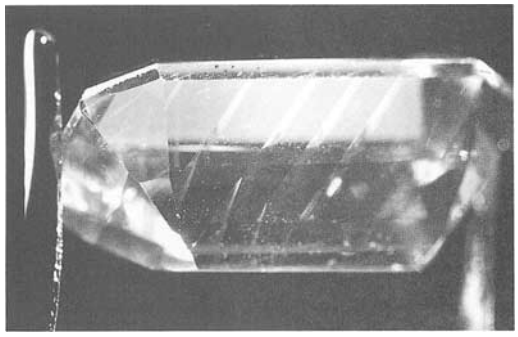

Fig. 5. Polysynthetic twinning, wide and narrow bands alternating. 10x.

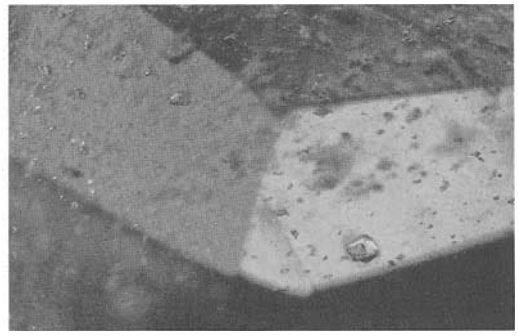

Fig. 6. Tabular greenish-yellow crystal of monazite, together with numerous small grains of zircon. 20x.

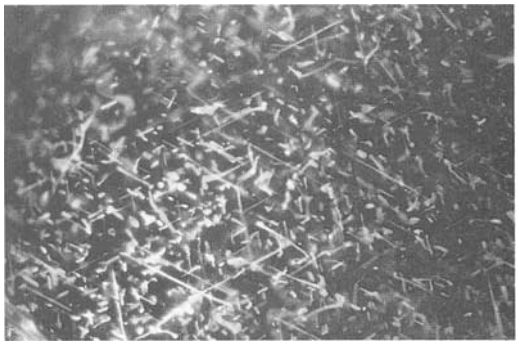

Fig. 7. Needles and thin platelets of hematite coloured brown in transmitted light. The regular pattern corresponds to the arrangement of the rutile-silk. 35x.

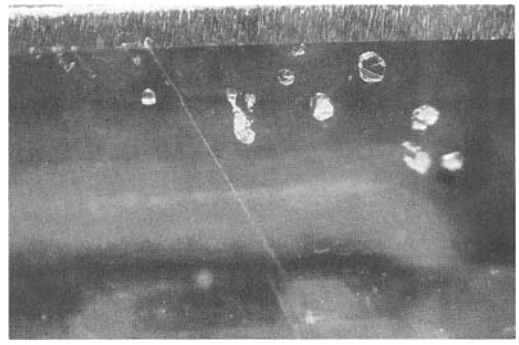

Fig. 8. Flat negative crystals, parallel to the basal face of corundum, in part exhibiting trigonal symmetry. 30x.

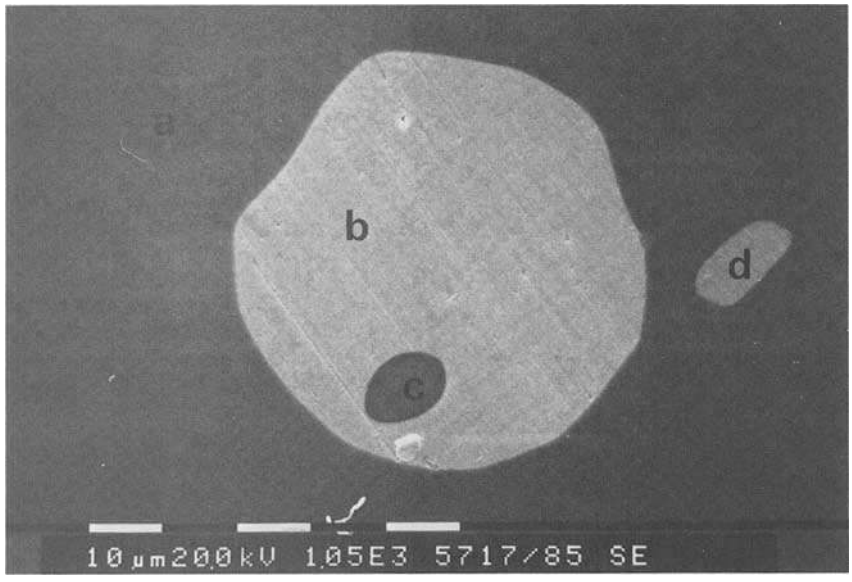

Fig. 9. SEM micrograph of a surface of corundum, showing intersected inclusions. The latter were identified on the basis of their EDS spectra: *a:* corundum, *b:* monazite, *c:* plagioclase, *d:* zircon.

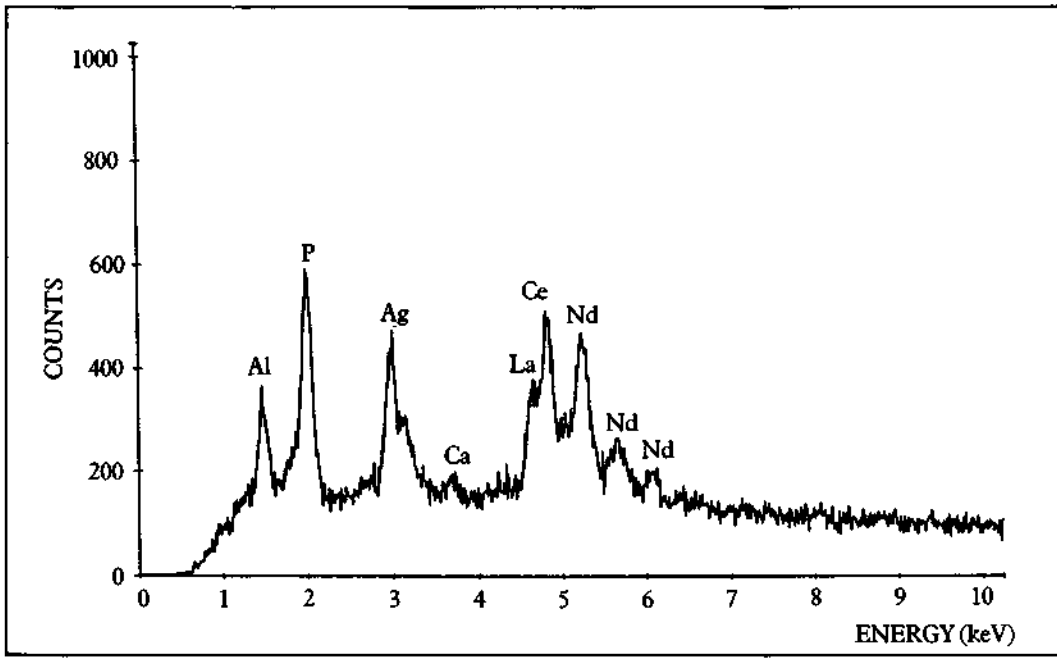

Fig. 10. EDS spectrum of the monazite grain in Figure 9. The Ag line is due to the necessary coating of the sample with a conductive material. The fact that monazite often contains rare earth elements is supported by this EDS spectrum.

corundums parallel to the rhombohedral edges. They occur mostly in three spatial directions and intersect each other at nearly right angles. Often very fine fissures emanate from these lines. The boehmite laths run within the traces of systems of intersecting twin lamellae. The impression arises that the laths are either hollow or filled with polycrystalline material (Delé, pers. com., 1984). As mentioned above, different names have been applied to this type of inclusion.

Twinning (OM) Figure 5. Polysynthetic twinning occurs very commonly in all the colour varieties, mainly in the form of alternating, very fine and broader lamellae. Two other common growth features often encountered are colour zoning, and zoning whereby differing amounts of mineral inclusions occur in definite zones.

Monazite (SEM) Figures 6 and 9. Yellowish-green tabular crystals, containing plagioclase inclusions (SEM). Monazite ($CePO_4$) usually contains different elements of the rare earth group, in this case lanthanum and neodymium (Figure 10).

Hematite (EMP) Figure 7. Very thin, parallel oriented transparent brown platelets to lanciform habits. These are very similar to the hematite inclusions in the brown star corundum of Ban Kha Cha, Thailand (Weibel and Wessicken, 1981). These hematite platelets are the main cause of colour in most of the brown corundums from Umba.

Negative crystals (OM) Figure 8. Flat, crystallographically shaped cavities (?), arranged parallel to each other, have been found, which exhibit interference colours when viewed with oblique illumination. They could also be regarded as liquid films.

Mica (XRD) Colourless and also greenish-brown scales or flakes, presumably vermiculite from the host rock, occur mainly in the reddish varieties.

Calcite (XRD) Whitish rounded crystals, identified in blue corundum.

Pyrrhotine (XRD) Dark brown to golden lustrous round or stepped crystals, identified in reddish corundum.

Graphite (XRD) Very shiny, opaque, black platelets or flakes, flexible, identified in reddish-violet corundum.

Mineral dust (OM) Minute unidentified dots in zones or as 'comets', often clouding the whole stone.

Healed fractures (OM) More or less well-healed fissures containing liquid droplets.

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The author is grateful to K.E. Wild, Kirschweiler, who supplied study material, Professor W.B. Stern (Geochemical Laboratory, University of Basel) for the numerous EDS-XRF analyses, and M. Düggelin (Laboratory for Scanning Electron Microscopy, University of Basel) for his collaboration in the determination of inclusions.

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Notes from the Laboratory – 9

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We were recently sent a number of pieces of a blue material from Hong Kong for examination with the comment that they were the result of a 'joint venture' which was attempting to produce lapis lazuli. The pieces were in the form of a round, drilled bead weighing 9.53 ct, an oval cabochon weighing 5.03 ct and a number of pieces of rough material (Figure 1).

The material appeared to take a good polish and whilst the colour varied from piece to piece the combination of polish and colour in the drilled bead was pleasing. Some pieces displayed a schiller which was easily visible to the unaided eye and this was the first indication of the fibrous and radiating inclusions that could be seen in all the specimens with the aid of a 10x lens (Figure 2).

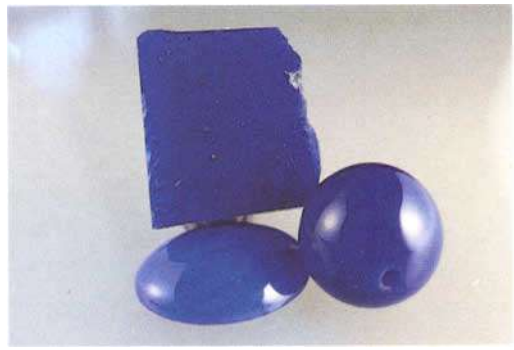

Fig. 1. Blue devitrified glass imitating lapis lazuli. One round drilled bead weighing 9.53 ct, an oval cabochon weighing 5.03 ct and one piece of the rough material.

Table 1: Electron microprobe analyses of blue devitrified glass from Hong Kong: mean of five points.

SiO_2	68.08
Al_2O_3	5.03
FeO	trace
MgO	0.18
CaO	15.21
Na_2O	7.65
K_2O	1.99
Cu_2O	1.45
S	trace
Cl	trace
	99.59%

Analyses were carried out on a Cambridge Instruments Geoscan with Link Systems energy dispersive detector and computer. The electron beam was defocused to 50–100μm diameter, and an accelerating voltage of 15kV and a specimen current of approximately 5.10^{-9} amp were used. Five spots were analysed and the mean is given in the table.

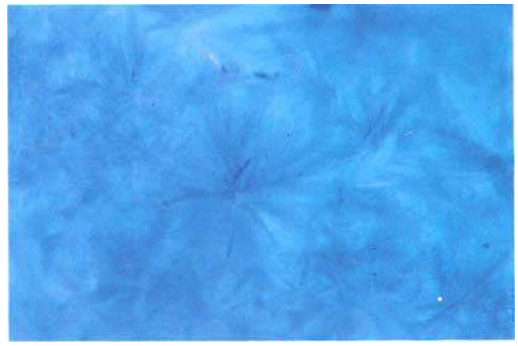

Fig. 2. Fibrous and radiating inclusions in blue devitrified glass imitating lapis lazuli.

One surface on each of three specimens was polished flat in order to facilitate refractive index measurements. RIs were then obtained using a Dialdex refractometer in sodium light. Even with flat, polished surfaces the RI readings were still not sharp, though it is possible to state that the refractive indices for the three specimens varied between 1.506 and 1.508.

The specific gravity was determined for each of four specimens by hydrostatic weighing in distilled

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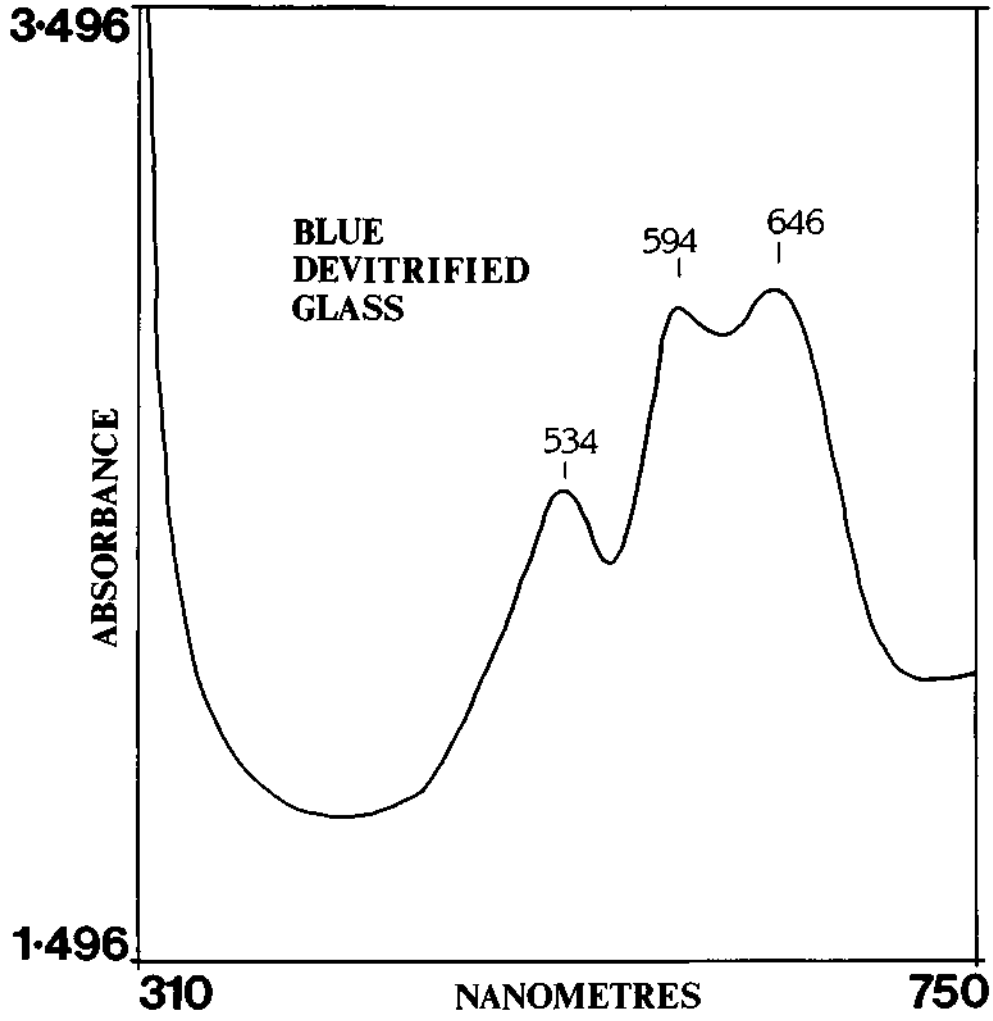

Fig. 3. The absorption curve of the blue devitrified glass in Figure 1. The curve was obtained using a Pye Unicam PU8800/03 UV/visible spectrophotometer (Basil Anderson model) with a speed of 1 nm/s and a bandwidth of 0.5 nm at room temperature. The path length was 0.5 mm.

water at room temperature and the results were 2.51, 2.54, 2.55 and 2.56. The Mohs hardness for each of three specimens was found to be 5–5½.

A thin slice was cut and polished from a rough sample in order to facilitate absorption measurements on the spectrophotometer and a curve between 750 and 310 nm was obtained (Figure 3). The curve appears to be typical of cobalt although no trace of this element was detected during electron microprobe analyses. Five spots were examined by electron microprobe analyses and a mean of the results is given in Table 1.

All pieces contain fibrous and radiating inclusions. In some pieces, e.g. the bead, these inclusions are fine and in others they are coarse. A small scraping was taken from one of the rough samples and this produced an X-ray diffraction pattern typical of wollastonite ($CaSiO_3$). In our opinion the material is a devitrified calcium alkali silicate glass containing fibrous wollastonite (Gübelin and Koivula, 1986, p.439).

A different devitrified blue glass imitating lapis lazuli was reported by Bosshart in 1983 (Bosshart, 1983).

* * *

Generally, pearls examined in the Laboratory conform in their internal and external structures to the arrangement of stacked aragonite platelets described by Webster and others (Webster, 1983, p.506; Hanni, 1983). When seen with the aid of a 10x lens or a microscope, the surface of most pearls, be they natural or cultured, will be resolved as a

series of overlapping platelets. The observation of the serrated edges to these platelets is a welcome sign to anyone wishing to distinguish natural and cultured pearls from the various imitations.

However, not every pearl conforms with the *standard*, and differing internal and external structures are possible. The pink conch pearl is, with its flame structure (Farn, 1986), a good example of this. Another good, if not striking example of the abnormal, was sent to us recently. It was sent from Scotland for our observations, and it was thought to be a natural black freshwater pearl which had fallen apart, revealing an interesting internal as well as a peculiar external structure. The surface structure is seen in Figure 4 and the internal structure in Figures 5 and 6.

The pearl is composed of long, slender crystals of aragonite all radiating from a central point; and the structure seen on the surface consists of the cross sections of these crystals. This structure was compared with various examples of pearl thin sections in the Laboratory's collection and it was found to resemble most closely that of a natural freshwater pearl (Figure 7).

* * *

Probably one of the most difficult tasks the Laboratory undertakes is the issuing of Damage Reports on gemstones that were not submitted for examination before the damage occurred. An example of a typical question might be 'Has the flaw in this diamond occurred recently?' Sometimes it is possible to answer the question but often it is not.

A few years ago I reported in '*Notes from the Laboratory*' (Scarratt, 1983) a most unfortunate case where a fine piece of lapis lazuli had been ruined by being placed in an acid bath for cleaning. We have examined the results of similar accidents both before and since that report, but none have displayed quite the devastation that resulted from the immersion of an amethyst necklace in hydrofluoric acid!

An enamelled necklace from which five hexagonal, faceted, amethysts were suspended, was sent to a workshop for the enamel to be recreated. During the course of the work the whole item was immersed in hydrofluoric acid. The outcome of this immersion was the severe etching of every facet on each amethyst, examples of which are shown in Figures 8 and 9.

* * *

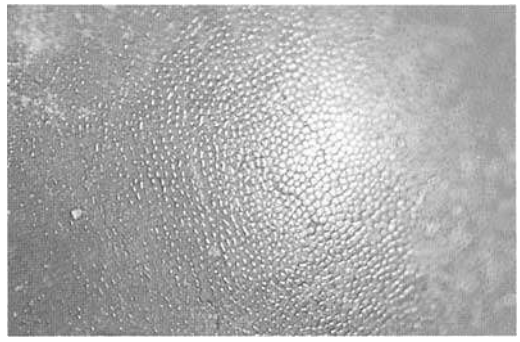

Fig. 4. The surface structure of a freshwater pearl from Scotland.

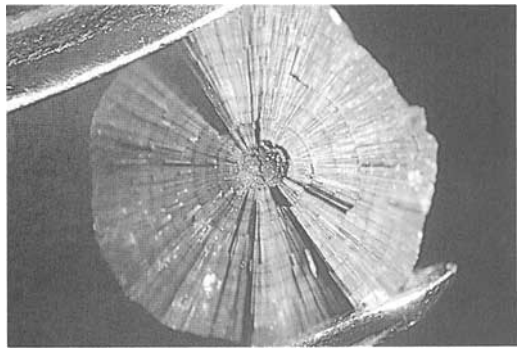

Fig. 5. The internal structure of a freshwater pearl from Scotland which was revealed when the pearl fell apart.

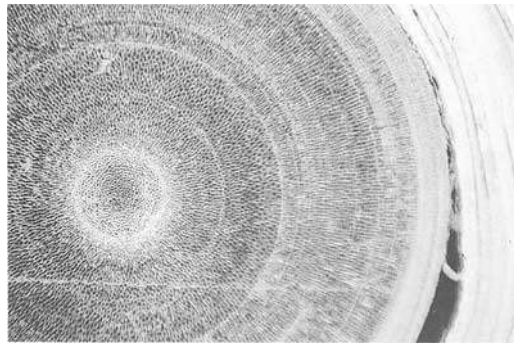

Fig. 6. A closer view of the internal structure of a freshwater pearl seen in Figure 5.

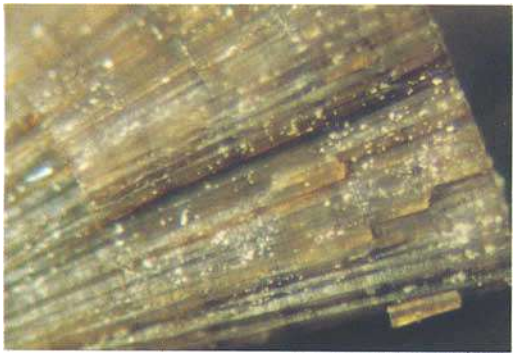

Fig. 7. The thin section of a natural freshwater pearl (Laboratory collection).

The difficulties concerning the identification of the cause of the colour in many green diamonds make even the most experienced gemmologists think more than twice before putting pen to paper. Bearing this in mind and the fact that nowadays laboratories are usually only requested to identify the problematic items, it was a most satisfying feeling to be able, almost immediately upon picking up a green diamond recently, to identify in a most positive fashion the cause of colour as being due to artificial irradiation. Around the culet area was the 'opened umbrella' pattern resembling a water mark and typical of cyclotroned diamonds. (Figure 10), and in the girdle area there was a clear ring of dark green coloration (Figure 11) (Webster, 1983, p.693).

* * *

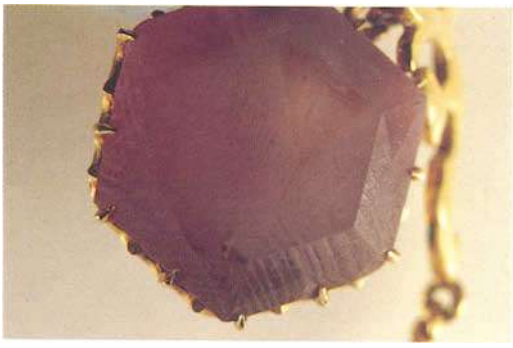

Fig. 8. One of five amethysts after being etched by hydrofluoric acid.

Fig 9. Close-up view of the etched surface on the amethyst.

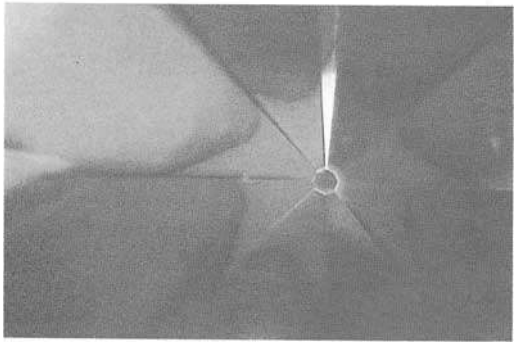

Fig. 10. The water-mark like opened umbrella pattern seen in the culet area of a cyclotroned green diamond.

Fig. 11. Colour concentration at the girdle of a green cyclotroned diamond.

During August 1981 we were asked to examine three loose rectangular, faceted, green stones which, it was said, were being offered in Switzerland as natural emeralds. It was further stated that these stones had been mined in Australia.

The stones, which weighed 1.07, 2.21 and 3.12 ct, had refractive indices of 1.571–1.576 and SGs ranging from 2.693 to 2.709. As the stones were green and had the typical RIs and SGs of beryl the obvious next step was to examine their absorption spectra for the presence of chromium lines. The spectrum observed consisted of the absorption of the violet, with an edge at approximately 466 nm, and a general absorption of the area between 582 and 620 nm. There was no indication of the normal emerald chromium lines in the red although a very weak single absorption line was seen in the deep red, i.e. at a much longer wavelength than is normal

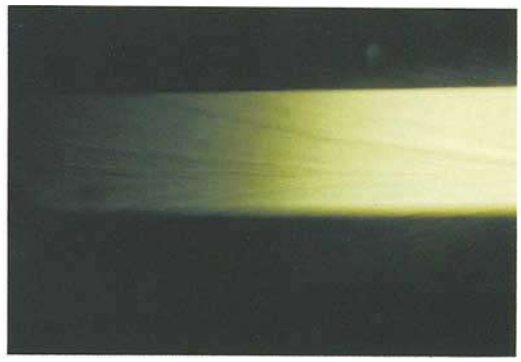

Fig. 15. A 'mountain peak' feature seen when looking down the optic axis of a 1.81 ct synthetic emerald.

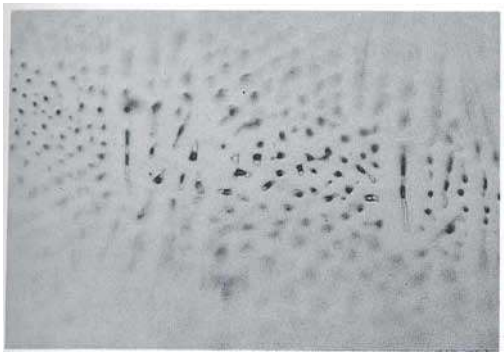

Fig. 12. Feather of two phase inclusions in a Biron synthetic emerald examined in 1981.

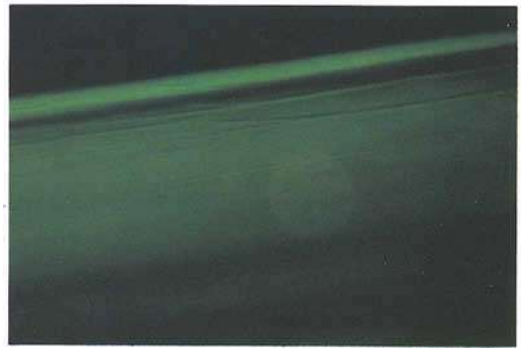

Fig. 16. The peaks and valleys of the 'mountain peak' feature seen in Figure 15 are revealed as long streaks passing along the length of the stone when viewed at right angles and through the girdle.

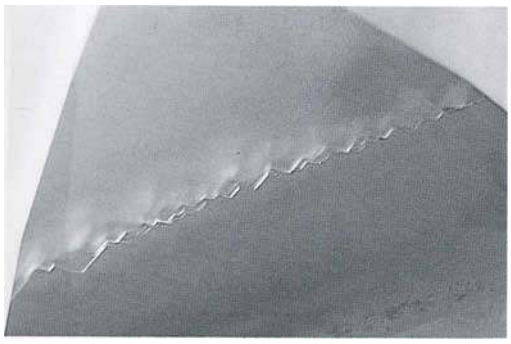

Fig. 13. Spear of arrow-point growth features seen in a Biron synthetic emerald examined in 1981.

Fig. 17. One of the possible appearances of the 'mountain peak' feature in the 1.81 ct synthetic emerald, as seen through the table facet.

for emerald. The line was too weak to measure with the hand spectroscope. All that could be established at that stage was that the material was green beryl.

A microscopic examination revealed that the stones were remarkably free from inclusions. However, in one stone a small feather of two phase inclusions could be seen (Figure 12) and a very small nail-head inclusion was seen after a prolonged search. The most notable feature of all three stones was a peculiar form of growth structure which may be likened to a spear or arrow-point (Figure 13).

Electron microprobe analyses were carried out on one of the stones. This confirmed a very low (<0.10%) chromium content, and a comparatively high vanadium content (0.61–0.51%).

After examining a number of Australian-grown synthetic vanadium beryls (Taylor, 1967) from the Laboratory collection, we were of the opinion that these stones were of synthetic origin.

Only a few weeks after our examination, fellow gemmologist G.A. Tombs, F.G.A.A., of Sydney, Australia, informed us that there was indeed a new synthetic 'emerald' being produced in Australia. He had examined some of these new synthetics and later reported upon them in *The Australian Gemmologist* (Tombs, 1983). His description of the material matched ours in most respects except that he had been able to observe chromium, if weakly, in the spectrum of his samples.

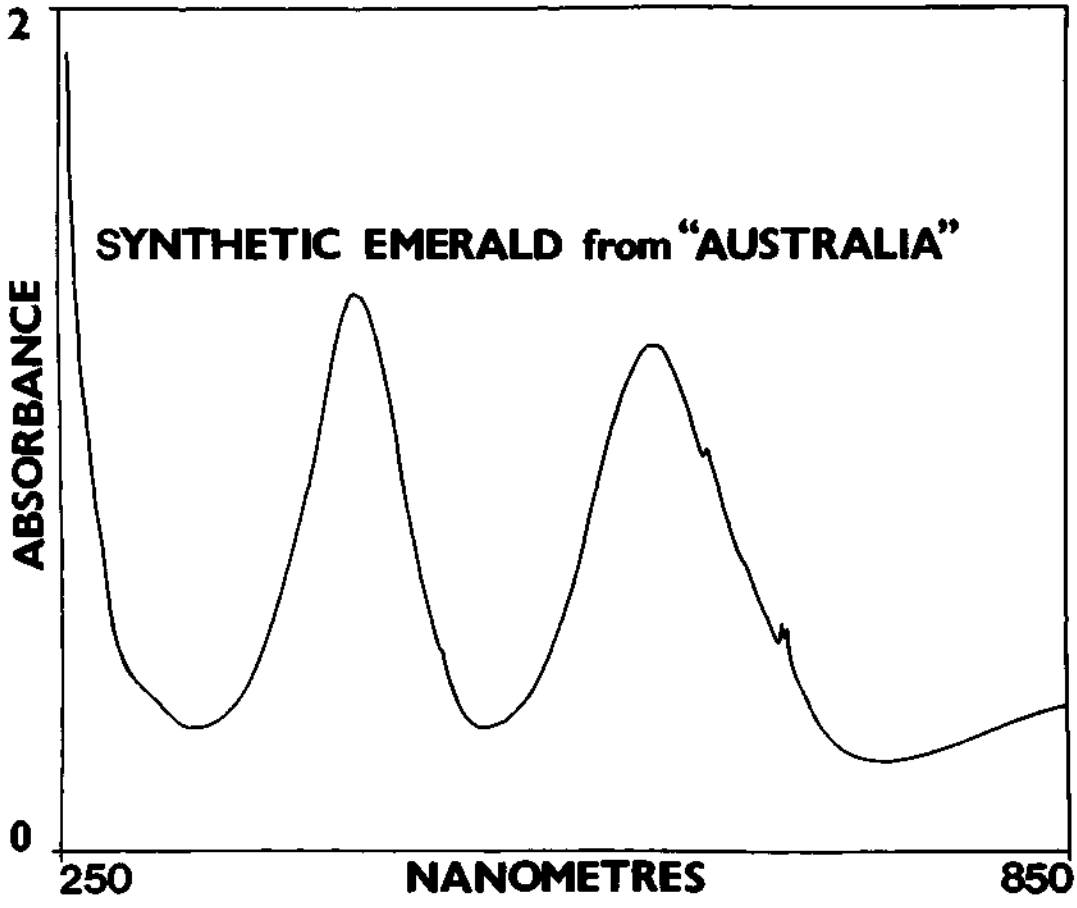

Fig. 14. The absorption curve of a 1.81 ct synthetic emerald said to come from Australia, taken at right angles to the optic axis. The curve was obtained by using a Pye Unicam PU8800/03 UV/visible spectrophotometer (Basil Anderson model) with a speed of 1 nm/s and a bandwidth of 0.5 nm at room temperature. The path length was approximately 6 mm.

Since that time the Biron synthetic emerald, as we now know it, has been well documented, and whilst the internal appearance seems now to differ from the original material its RIs and SG, as reported by Kane and Liddicoat, remain within the same range as that of the original material and, of course in the same range as that of some natural emeralds (Kane and Liddicoat, 1985).

Recently we were asked to examine one stone as a sample from a parcel of green stones that had been purchased as synthetic emeralds grown in Australia. The stone weighed 1.81 ct, was emerald cut, and was of a particularly pleasant emerald green colour. The refractive indices of this stone at 1.571–1.576, differ slightly from those reported by Kane and Liddicoat as being characteristic of the Biron synthetic emerald (1.569–1.573, [+ 0.001]) but they are the same as those reported by Darragh and Willing (Darragh and Willing, 1982), and the same as those of the stones examined by us in 1981. The ultraviolet fluorescence of this stone also differed from that described by Kane and Liddicoat, in that their stones were inert, whilst this one fluoresced a weak red under long-wave, and a much weaker red under short-wave ultraviolet light.

The SG of this stone was found by hydrostatic weighing in distilled water to be 2.702; it was deep red under the Chelsea colour filter, fluoresced red when exposed to a strong pin-point of visible light, and the dichroism was strong – yellowish-green/bluish-green. These four characteristics conform with those described by Kane and Liddicoat as being typical of the Biron synthetic emerald.

The recorded absorption curve of this stone, taken at right angles to the optic axis, is reproduced in Figure 14. The chromium peaks at 679.9 and 682.4 nm, are clearly present in this unpolarized curve and it can be seen that the stone transmits ultraviolet down to 250 nm.

From the foregoing, it is fair to state that the gemmological constants of this 1.81 ct stone are similar to those of the Biron synthetic emerald, but they are also within the same range as other hydrothermally grown synthetic emeralds, as well as being in the same range as some natural emeralds. Taking into account the information published so far on the internal features of the Biron synthetic emerald, and apart from a small feather formation and a minute nail-head inclusion which are similar to those observed in the first Biron synthetics, the other internal features of this stone appear to be more typical of the Linde synthetic emerald rather than the Biron (Gübelin and Koivula, 1986, pp.461–74).

The optic axis was parallel to the table facet and along the length of the stone. With the stone immersed in benzyl benzoate, upon looking down the optic axis a distinctive feature like mountain peaks could be seen (Figure 15). Similar features have been recorded in both natural and synthetic emeralds. Viewed at right angles and through the girdle, the peaks and valleys of the feature reveal themselves as long streaks passing down the length of the stone (Figure 16). Viewed through the table, the appearance of the 'mountain peak' features depends upon the lighting used and the angle of view. Figure 17 shows one of the possible appearances.

* * *

Acknowledgement

Thanks are due to Dr R.R. Harding for his advice and assistance and particularly for producing the electron microprobe analyses of both the blue glass and the Biron synthetic emerald.

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Some unusual cat's-eyes – 2

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Osaka, Japan

After the publication of my previous paper (Ito, 1986), I was able to obtain some more rare cat's-eyes, including zircon, diopside, scapolite and kunzite. They are described in this short paper.

Zircon cat's-eye

When I paid a visit to Sri Lanka in 1984, I found a zircon cat's-eye in the stock of a dealer in Colombo, which had a dark green colour (maybe untreated) and weighed more than 5 ct. Of course I asked the dealer to sell it to me, but it was impossible for me to get it because he demanded a totally unreasonable price. This stone resembled that described in *Gems & Gemology*, Winter 1983 (Fryer (ed.), 1983).

Fig. 1. Two zircon cat's-eyes, 3.73 and 2.78 ct.

At the beginning of 1986, I got two zircon cat's-eyes (Figure 1), weighing 3.73 ct and 2.78 ct, brownish-grey and yellowish-brown in colour, which were said to be heat-treated. They showed sharp eyes and more than ten zircon lines under the spectroscope. I believe that zircons of other colours, such as blue, orange and colourless, can show chatoyancy. My stones came from Sri Lanka, but I think that stones from other localities, such as Canada, Burma, and USSR, can also show chatoyancy.

Diopside cat's-eye

From the point of view of jewellery, the chromium variety (dark green in colour) is the most popular of all kinds of diopside. Star diopside of almost black body-colour is also famous and much cheaper. In Sri Lanka there occurs light yellowish or greyish-green diopside which may be less attractive but is much less expensive than Cr-diopside. Some show chatoyancy very clearly because of compact tubular inclusions (Figure 2); generally they have a rather sharp eye.

Fig. 2. Sri Lankan diopsides. Cat's-eye and faceted stone.

I am not sure if diopside of other types and from other localities, such as Burma and USA, happen to show chatoyancy similar to that in my specimen from Sri Lanka, but I do think it would be splendid if Cr-diopside showed chatoyancy.

My collection has a stone of 3.45 ct but, of course, larger stones could be available. Refractive index is 1.68 (distant vision), and inert under ultraviolet rays.

Fibrolite (sillimanite) cat's-eye

In my previous paper, I reported on a nice greenish-yellow fibrolite cat's-eye which closely resembled chrysoberyl cat's-eye. Recently I obtained

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Fig. 3. Fibrolite cat's-eyes, 1.54 and 0.82 ct.

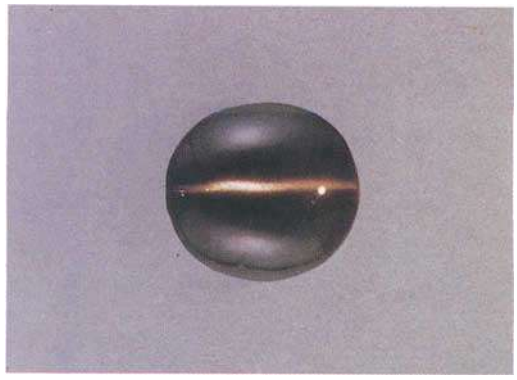

Fig. 4. Scapolite cat's-eye of black body-colour (from Sri Lanka).

another one from Sri Lanka which seems to be a more typical type for fibrolite. This weighs 1.54 ct and has a very attractive green colour. Many fibrous inclusions can be seen – which is appropriate for the name 'fibrolite'. Faceted fibrolite also occurs in Sri Lanka, some of which looks like aquamarine. Figure 3 shows two types of gem-quality fibrolite cat's-eye. The smaller is the stone reported in the previous paper, and the larger is described in this paragraph.

Scapolite cat's-eye

Colourless, violet and orange-brown scapolite cat's-eyes are popular, and often attractive. I obtained a black body-colour scapolite cat's-eye in March 1986 from Sri Lanka (Figure 4). This stone weighs 3.52 ct and is translucent. The refractive index is 1.55, and it is inert under ultraviolet rays.

Kunzite cat's-eye

In 1984 I had a chance to get rough material weighing one ounce which was described as 'kunzite cat's-eye', but from its appearance I doubted if it showed chatoyancy. As a result of cutting, three cabochons were made and one of them weighing 35.9 ct has a very sharp eye (Figure 5). The locality of this rough is unknown, but it has a rather attractive pinkish colour. Generally speaking the colour of kunzite tends to fade in sunlight. It will be interesting to see if the body colour of this stone will fade in the future. The stone has a massive structure, and shows purplish-pink colour under both long and short wave ultraviolet rays.

Fig. 5. Kunzite cat's-eye 35.9 ct.

Acknowledgements

I would like to thank Messrs S. Kihara and T. Fujiwara for useful advice.

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On twinning in natural and synthetic flux-grown ruby

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Abstract

Twinning in natural and synthetic flux-grown ruby is described with respect to its use in the distinction of natural and synthetic rubies.

Natural rubies rarely reveal contact twins on the basal pinacoid *c* (0001) or on the positive rhombohedron *r* $(10\bar{1}1)$ with macroscopically developed individuals in twin position. Repetitive twinning on *r* $(10\bar{1}1)$, consisting of thin lamellae of corundum in twin position intercalated parallel to one, two or three rhombohedral faces of a dominant individual, however, is common for natural ruby. Intersecting lamellae parallel to two rhombohedral faces form nearly rectangular chequered patterns.

In Chatham synthetic rubies contact twins on the prism faces $(10\bar{1}0)$ or $(11\bar{2}0)$ were frequently found. Ramaura synthetic rubies reveal penetration twinning about the *c* axis [0001]. In Kashan synthetic rubies as well as in Chatham synthetic rubies repetitive twinning of intercalated lamellae on *r* $(10\bar{1}1)$ was found, even intersecting lamellae forming angles of 93.9° were observed.

Introduction

In mineralogical and gemmological textbooks various forms of twinning are mentioned as being common for natural corundum including the gem varieties ruby and sapphire. In scientific papers dealing with flux-growth of corundum and ruby a different type of twinning is described. In some original descriptions of new types of flux-grown rubies twinning, in general, is not quoted. In other papers as well as in some gemmological textbooks (e.g. Webster and Anderson, 1983), twinning of synthetic flux-grown rubies is mentioned without a detailed description and without any conclusions about the diagnostic applicability of twinning to problems of the distinction of natural and synthetic rubies.

The aim of the present paper is to report some properties of natural and synthetic ruby which are related to the different types of twinning observable in natural and synthetic corundum. In addition to the application of families of straight parallel growth planes to problems of the distinction of natural and synthetic rubies (Schmetzer, 1985a, 1986), twinning is the second important structural property which needs attention. In some cases twinning can be applied to problems of the distinction of natural and synthetic rubies. In other cases, the knowledge of all types of twinning which can occur in natural and synthetic ruby, e.g. the possible presence of repetitive rhombohedral twinning in Kashan synthetic rubies, is essential to avoid misinterpretations of microscopic observations.

Definitions

The following definitions of twinning and related conceptions are given by Bloss (1971):

'Two crystals of a given crystalline material are said to be twins if they occur intergrown so that all crystallographic directions of the first (for example, axes a_1, b_1 and c_1) are related to the corresponding directions of the second (for example, axes a_2, b_2 and c_2) by the operation of either (1) a mirror plane of symmetry, (2) a two-fold axis of symmetry or less frequently a three-, four-, or six-fold axis, or (3) a centre of symmetry $\bar{1}$. A twin plane or axis can never coincide in direction with any symmetry operation (in the untwinned crystal structure) for which this twinning operation is either identical or a subgroup. According to which of the above three types of symmetry relate the two individuals, the twins are called (1) *reflection twins*, (2) *rotation twins*, or (3) *centrosymmetric twins*, respectively. The plane of symmetry relating reflection twins is called the *twin plane*; the axis of symmetry relating rotation twins is called the *twin axis*; and the centre of symmetry relating centrosymmetric twins is called the *twin centre*. In *reflection twins* the twin plane is always parallel to a possible lattice plane (hkl). The twin plane's crystallographic direction is thus defined by stating the indices for this plane (in relation to either of the twinned individuals). For *rotation twins* the twin axis may generally be specified by designating the indices [uvw] of the one to which it is parallel.

'Twins are also classified and named according to the way they are intergrown. If the two twinned individuals are in contact along a well-defined plane so that a cut along this plane would entirely separate the two, they are called *contact twins* and the plane of contact is called the composition *plane*. On the

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other hand, two twinned individuals may either be in contact along an irregular surface or be so intergrown that no compositional plane exists along which a cut could be made to separate cleanly the two twinned individuals, each to its own side of the plane. Such twins, in which a composition plane is lacking, are called *penetration twins* or *interpenetrant twins*. In some materials the twin-producing symmetry operation may occur repeatedly so that numerous individuals and composition planes occur even within one relatively small grain. If the several composition planes are mutually parallel, the twinning is called *polysynthetic twinning.'*

Basic types of twinning in corundum

Corundum crystallizes in the hexagonal (rhombohedral) system and possesses the crystal class $\bar{3}$ 2/m (D_{3d}). In crystal class $\bar{3}$ 2/m the second-order hexagonal prism $(11\bar{2}0)$ is parallel to a mirror plane, and hence $(11\bar{2}0)$ cannot be a twin plane but a composition plane of twinned corundum crystals. In crystal class $\bar{3}$ 2/m a 180° rotation about the *c* axis [0001] is symmetrically equivalent to a reflection across the first-order hexagonal prism $(10\bar{1}0)$ or the basal pinacoid (0001).

In natural corundum, two types of twinning are described:

(a) Contact twinning on the basal pinacoid *c* (0001), with *c* (0001) as both the twin plane and composition plane.

(b) Contact twinning on the positive rhombohedron *r* $(10\bar{1}1)$ with *r* $(10\bar{1}1)$ as both the twin plane and composition plane.

Though twinning in natural corundum generally is mentioned as being common, contact twins on *c* (0001) or *r* $(10\bar{1}1)$ consisting of two or more well developed crystals are extremely rare (for a summary of the literature compare Spencer, 1927). Occasionally, symmetrical groups of three individuals around a central crystal due to twinning on three rhombohedral faces are observed (Drugman, 1943).

Lamellar twinning on *r* $(10\bar{1}1)$, however, is found in a great number of natural corundum crystals. In this type of twinning, often also designated as polysynthetic twinning, thin lamellae or lamellar layers of corundum in twin position are intercalated with *r* $(10\bar{1}1)$ as both the twin plane and composition plane into the dominant corundum individual. Due to an interfacial angle of 93.9° between two rhombohedral faces, intersecting lamellar seams of corundum are macroscopically observed as nearly rectangular striations on well developed prism faces of natural corundum (see Lasaulx, 1885; Judd, 1895; Melczer, 1902; Palache *et al.*, 1944).

Lamellar twinning on *c* (0001) is rarely mentioned in the literature. An unequivocal distinction of intercalated thin lamellae in corundum crystals with *c* (0001) regarded as both the twin plane and composition plane from basal parting, which is also known to occur parallel to *c* (0001) in corundum, however, is rarely found. Thus, the basal pinacoid *c* (0001), in general, is regarded as a structural plane, which can be either twin plane or parting plane (Judd, 1895; Bauer, 1896; Kronberg, 1957; Scheuplein and Gibbs, 1960).

In synthetic corundum, two types of twinning are described in papers dealing with growth conditions and properties of flux-grown crystals:

(a) Contact twinning on the first-order hexagonal prism $(10\bar{1}0)$ or the second-order hexagonal prism $(11\bar{2}0)$ as composition planes with $(10\bar{1}0)$ as twin plane.

(b) Penetration twinning along irregular surfaces with 180° rotation about the *c*-axis [0001] as twin axis.

Due to the fact that both types of twinning (reflection and rotation twinning) are symmetrically equivalent, they can be observed within one single flux-grown corundum individual. In such samples more complex twin-boundaries than one single line were found on etched (0001) planes of flux-grown corundum crystals. Even twin boundaries changing direction frequently and irregularly as well as splitting boundaries were observed. In such cases the boundaries of three or more crystals twinned by 180° rotations about [0001] and/or by reflections across $(10\bar{1}0)$ were found to meet at one single point. In other samples, several parallel twin bands were observed. In general, however, the twin boundaries tend to favour the $(11\bar{2}0)$ and/or $(10\bar{1}0)$ planes (Melczer, 1902*; Stephens and Alford, 1964; White and Brightwell, 1965; Janowski *et al.*, 1965; Champion and Clemence, 1967; Voronkova *et al.*, 1968; Lillicrap and White, 1976). No evidence of rhombohedral twinning is known by the present author from the literature for flux-grown corundum and ruby.

In gemmological literature, twinning is sometimes assigned only to natural rubies, e.g. in the description of Kashan synthetic rubies (Kane, 1979), and in the description of Kashan, Chatham and Knischka synthetic rubies (Gübelin, 1982a, b), or is not mentioned in the description of important new types of synthetic ruby, e.g. Ramaura synthetic rubies (Bosshart, 1983; Kane, 1983, Gübelin, 1984). Only for Chatham synthetic rubies, twinning or 'pseudo-twinning' is briefly mentioned without a detailed description (Fryer *et al.*, 1981; Brown, 1984).

* Melczer investigated an early type of Fremy's synthetic flux-grown rubies (cf. Elwell and Scheel, 1975).

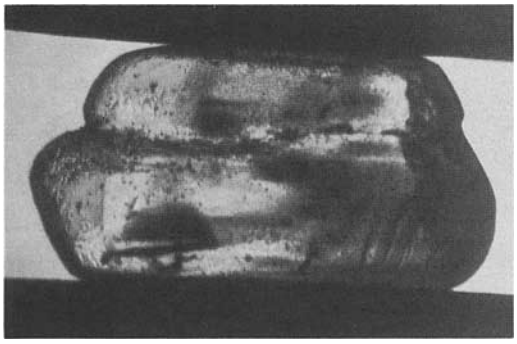

Fig. 1. Natural ruby from Sri Lanka, contact twin on (0001). 30x.

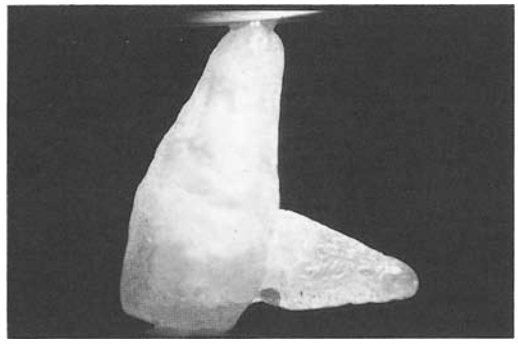

Fig. 2. Natural corundum from Sri Lanka, contact twin on $(10\bar{1}1)$. 12x.

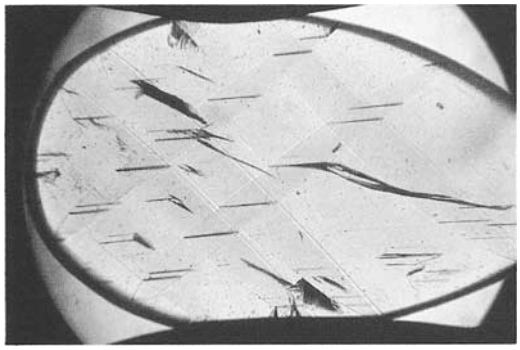

Fig. 7. Natural ruby from Umba, Tanzania, intercalated lamellae of corundum in twin position on $(10\bar{1}1)$ parallel to two rhombohedral faces. 24x.

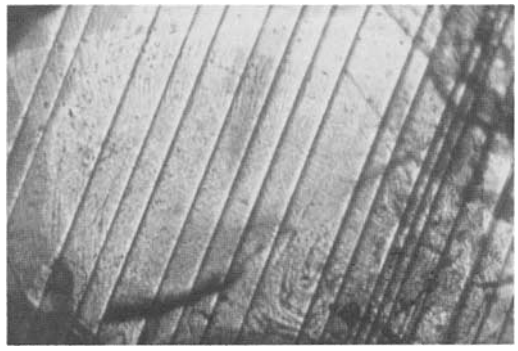

Fig. 8. Natural ruby from Burma, intercalated lamellae of corundum in twin position on $(10\bar{1}1)$. 30x.

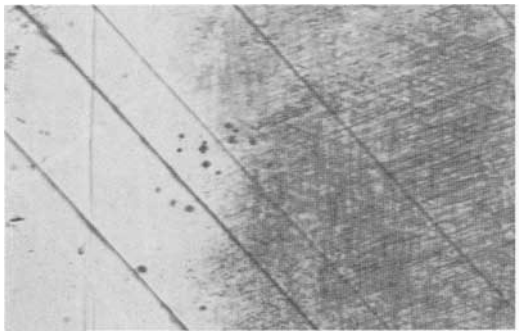

Fig. 9. Natural ruby from Sri Lanka, intercalated lamellae of corundum in twin position on $(10\bar{1}1)$. 45x.

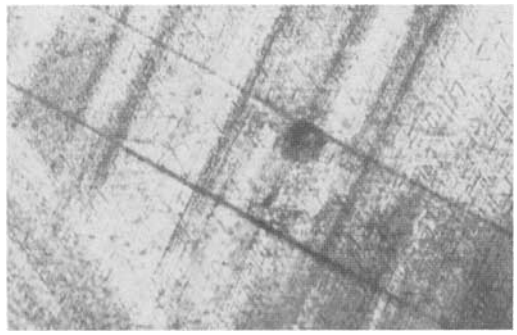

Fig. 10. Natural ruby from Sri Lanka, intercalated lamellae of corundum in twin position on $(10\bar{1}1)$. 35x.

Fig.3. Natural ruby from Sri Lanka, contact twin on $(10\bar{1}1)$ with three crystals in twin position around a central crystal. x pol., 40x.

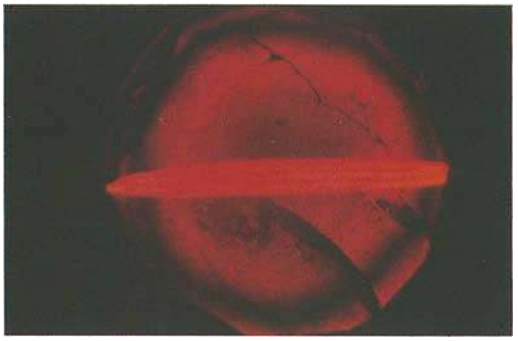

Fig. 4. Natural ruby from Sri Lanka, intercalated lamellae of corundum in twin position on $(10\bar{1}1)$. x pol., 20x.

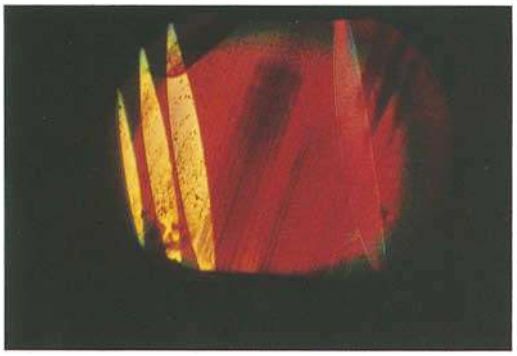

Fig. 5. Natural ruby from Burma, intercalated lamellae of corundum in twin position on $(10\bar{1}1)$. x pol., 24x.

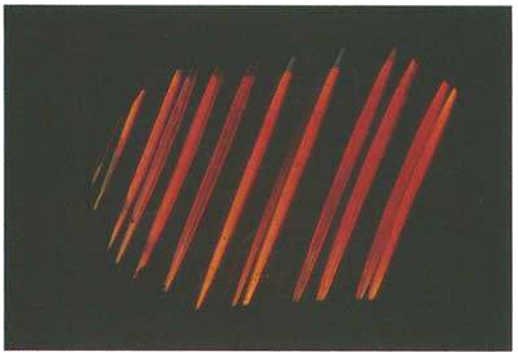

Fig. 6. Natural ruby from Burma, intercalated lamellae of corundum in twin position on $(10\bar{1}1)$. x pol., 26x.

Fig. 13. Natural ruby from Sri Lanka, intercalated lamellae of corundum in twin position on $(10\bar{1}1)$; the lamellae showing interference striations. x pol., 25x.

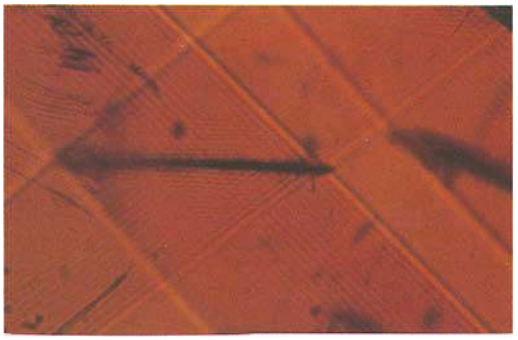

Fig. 14. Natural ruby from Umba, Tanzania, intercalated lamellae of corundum in twin position on $(10\bar{1}1)$ parallel to two rhombohedral faces; the lamellae showing interference striations. 80x.

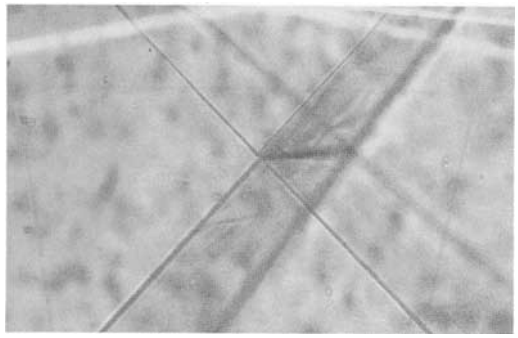

Fig. 11. Natural ruby from Burma, intercalated lamellae of corundum in twin position on $(10\bar{1}1)$ parallel to two rhombohedral faces. 40x.

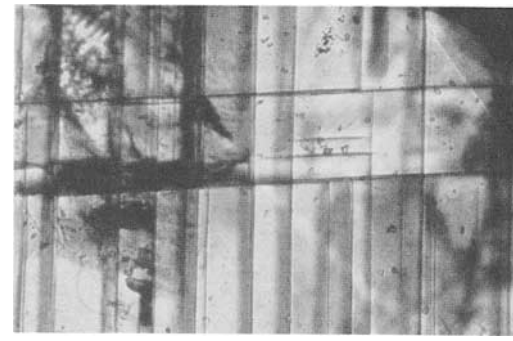

Fig. 12. Natural ruby from Thailand, intercalated lamellae of corundum in twin position on $(10\bar{1}1)$ parallel to two rhombohedral faces. 35x.

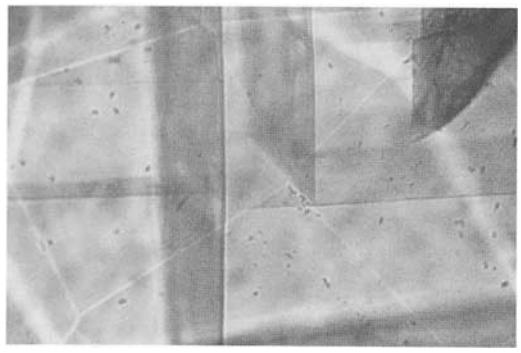

Fig. 20. Natural ruby from Thailand, intercalated lamellae of corundum in twin position on $(10\bar{1}1)$ parallel to two rhombohedral faces; one lamella ends at another lamella running through the crystal in nearly rectangular direction. 50x.

Fig. 21. Natural ruby from Thailand, intercalated lamellae of corundum in twin position on $(10\bar{1}1)$ parallel to two rhombohedral faces; single lamellae end at other lamellae running through the crystal in nearly rectangular direction. 100x.

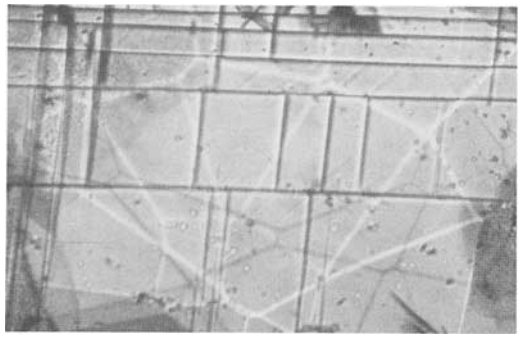

Fig. 22. Natural ruby from Thailand, intercalated lamellae of corundum in twin position on $(10\bar{1}1)$ parallel to two rhombohedral faces; single lamellae end at other lamellae running through the crystal in nearly rectangular direction. 50x.

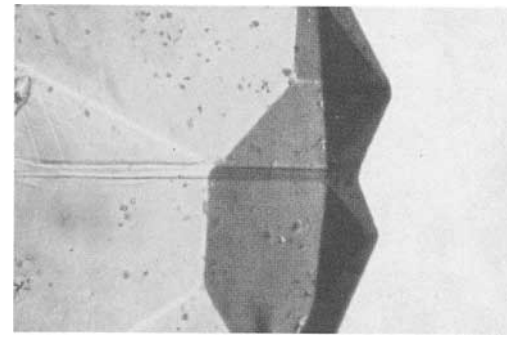

Fig. 26. Chatham synthetic ruby, contact twin on $(10\bar{1}0)$ with composition plane, view parallel to the optic axis. 40x.

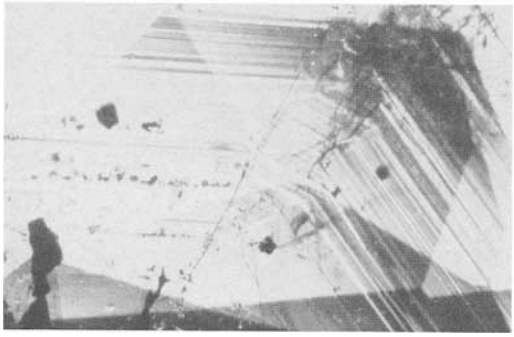

Fig. 27. Chatham synthetic ruby, contact twin on $(10\bar{1}0)$; the composition plane and families of straight parallel growth planes parallel to $n(22\bar{4}3)$ and $r(10\bar{1}1)$ are visible. 20x.

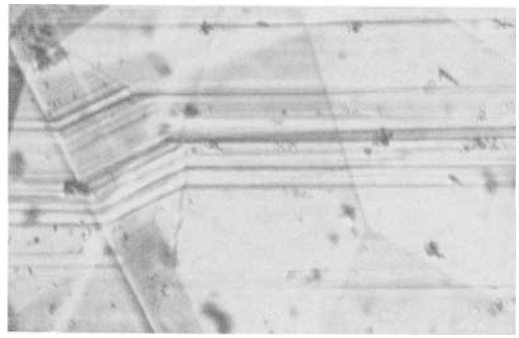

Fig. 28. Chatham synthetic ruby, contact twin on $(10\bar{1}0)$; the composition plane and families of straight parallel growth planes parallel to $n(22\bar{4}3)$ and $r(10\bar{1}1)$ are visible. 50x.

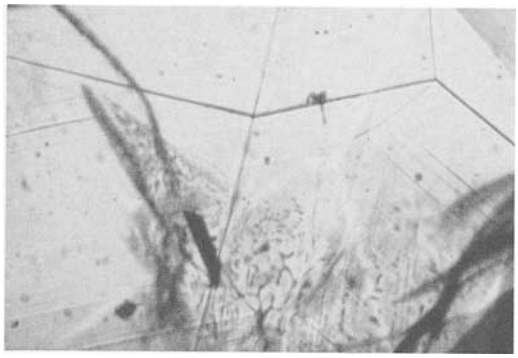

Fig. 29. Chatham synthetic ruby, contact twin on $(10\bar{1}0)$; the composition plane and families of straight parallel growth planes parallel to $n(22\bar{4}3)$ and $r(10\bar{1}1)$ are visible. 30x.

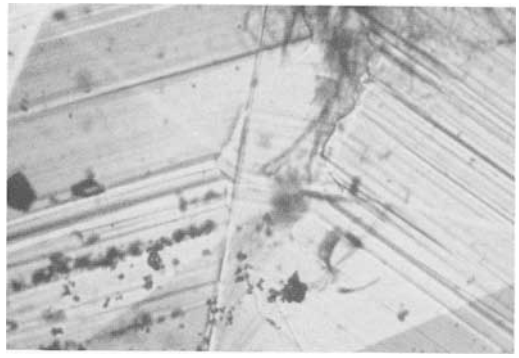

Fig. 30. Chatham synthetic ruby, contact twin on $(10\bar{1}0)$; the composition plane and families of straight parallel growth planes parallel to $n(22\bar{4}3)$ and $r(10\bar{1}1)$ are visible. 30x.

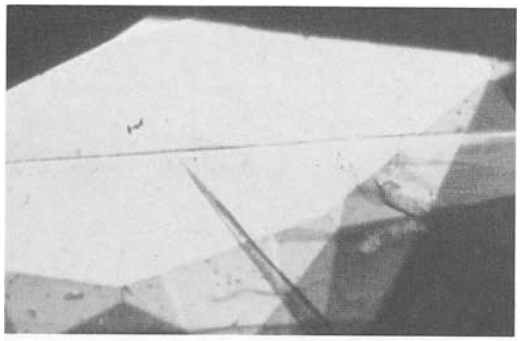

Fig. 31. Ramaura synthetic ruby, contact twin on $(10\bar{1}0)$ or penetration twin along [0001]; the composition plane runs parallel to the prism zone. 30x.

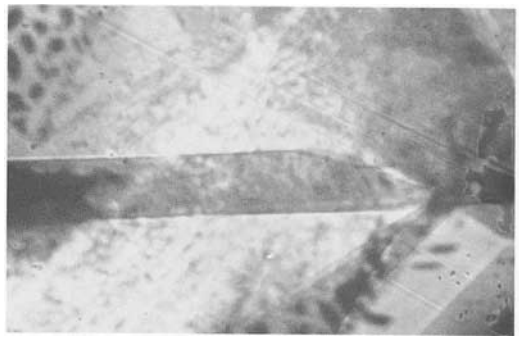

Fig. 32. Ramaura synthetic ruby, penetration twin along [0001], view nearly parallel to the optic axis. 40x.

Fig. 15. Natural ruby from Burma, intercalated lamellae of corundum in twin position on (10$\bar{1}$1) parallel to two rhombohedral faces; the lamellae showing interference striations. x pol., 35x.

Fig. 16. Natural ruby from Thailand, intercalated lamellae of corundum in twin position on (10$\bar{1}$1); the lamellae showing interference striations. x pol., 30x.

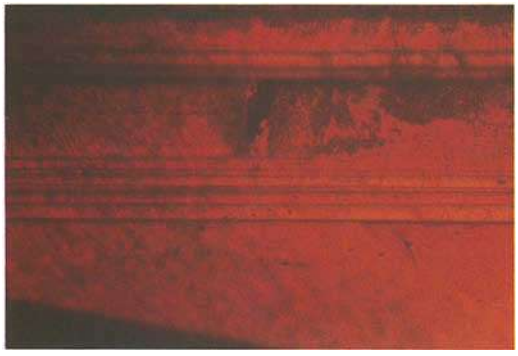

Figs. 17, 18. Natural ruby from Sri Lanka, polysynthetic twinning on (10$\bar{1}$1). Using plane polarized light, in different orientations of the polarizer the pleochroism of polysynthetically twinned ruby becomes visible. 80x.

Fig. 19. Natural ruby from Sri Lanka, polysynthetic twinning on (10$\bar{1}$1). Plane polarized light. 80x

Fig. 23. Natural ruby from Burma, one intercalated lamella of corundum in twin position on (10$\bar{1}$1) ends irregularly within the dominant crystal. x pol., 32x.

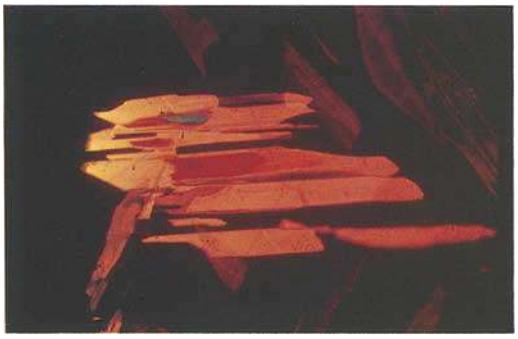

Fig. 24. Natural ruby from Thailand, intercalated lamellae of corundum in twin position on (10$\bar{1}$1) parallel to three rhombohedral faces end irregularly within the dominant crystal. x pol., 35x.

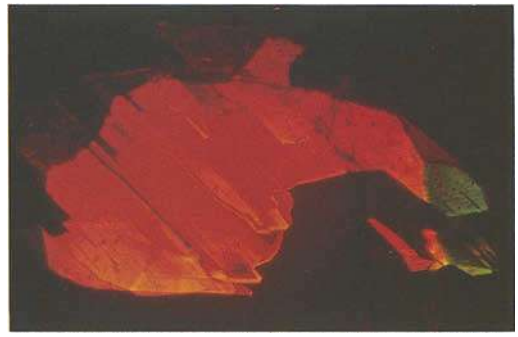

Fig. 25. Natural ruby from Thailand, intercalated lamellae of corundum in twin position on (10$\bar{1}$1) end irregularly within the dominant crystal. x pol., 35x.

Fig. 35. Chatham synthetic ruby, intercalated lamellae of corundum in twin position on (10$\bar{1}$1). x pol., 35x.

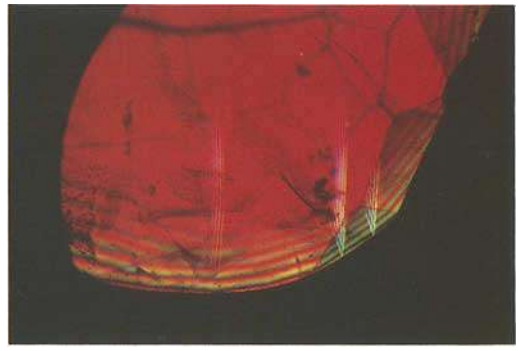

Fig. 38. Kashan synthetic ruby, intercalated lamellae of corundum in twin position on (10$\bar{1}$1). x pol., 40x.

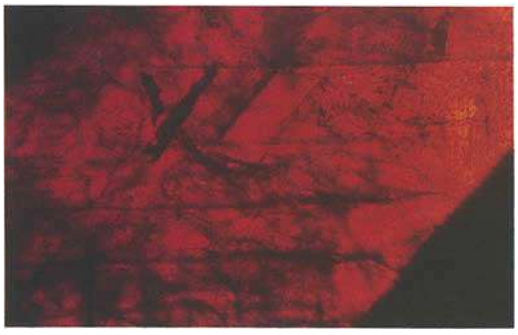

Fig. 39. Kashan synthetic ruby, intercalated lamellae of corundum in twin position on (10$\bar{1}$1). x pol., 45x.

Fig. 41. Kashan synthetic ruby, one intercalated lamella of corundum in twin position on (10$\bar{1}$1) ends irregularly within the dominant crystal. x pol., 24x.

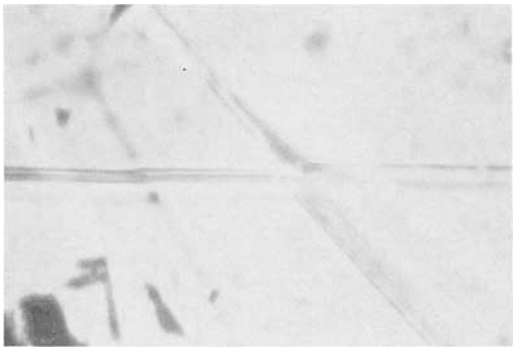

Fig. 33. Chatham synthetic ruby, intersecting structural planes (twin boundaries?). 95x.

Fig. 34. Chatham synthetic ruby, three structural planes (twin boundaries?) meeting at one point. 80x.

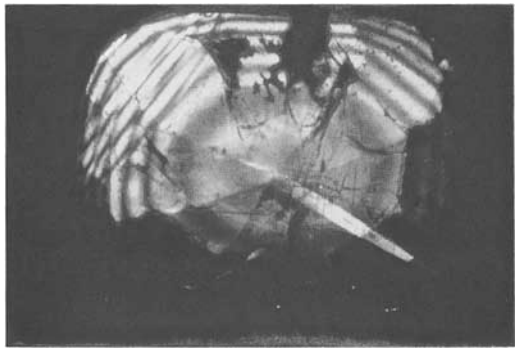

Fig. 36. Chatham synthetic ruby, intercalated lamellae of corundum in twin position on (10$\bar{1}$1) parallel to two rhombohedral faces. x pol., 20x.

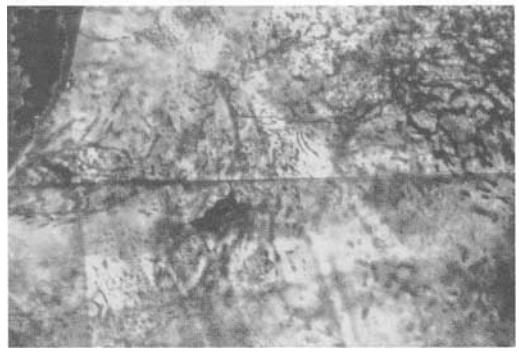

Fig. 37. Chatham synthetic ruby, intercalated lamellae of corundum in twin position on (10$\bar{1}$1). 70x.

Fig. 40. Kashan synthetic ruby, intercalated lamellae of corundum in twin position on (10$\bar{1}$1) parallel to two rhombohedral faces. 50x.

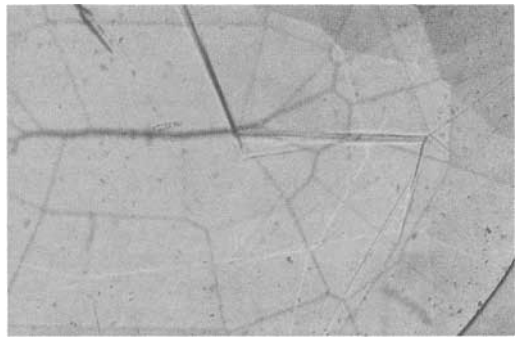

Fig. 42. Ramaura synthetic ruby, irregular structural surface. 30x.

Results

Twinning in natural ruby

(a) Contact twinning on *c* (0001)

In rough samples, contact twinning on (0001) is very rarely recognizable by the morphology of the sample (fig. 1). Due to an identical optical orientation of corundum crystals which are related by reflection twinning on the basal pinacoid (0001), no optical interference figure is observable in the microscope. Thus, the unambiguous recognition of contact twinning on (0001) to cut natural rubies, i.e., a distinction of a twin boundary parallel to (0001) from growth planes or from glide planes parallel to (0001), is extremely difficult or even impossible without etching.

(b) Single contact twinning on *r* $(10\bar{1}1)$

Contact twins on the positive rhombohedron *r* $(10\bar{1}1)$ which are macroscopically developed are known to the author from parcels of rough corundum crystals from Sri Lanka (fig. 2). During the investigation of cut rubies from Sri Lanka by the microscope, contact twins consisting of two or more macroscopically developed individuals were rarely recognized due to the different optical orientation of the twinned corundum crystals. Occasionally, a central crystal which is twinned on three rhombohedral faces was found (fig. 3).

(c) Repetitive twinning on *r* $(10\bar{1}1)$

Repetitive twinning on the positive rhombohedron *r* $(10\bar{1}1)$ is common in natural rubies from different localities. In general, thin lamellae of corundum in twin position are intercalated parallel to one, two or even three rhombohedral faces of the dominant crystal (figs. 4–12). Intersecting lamellae parallel to two or even three rhombohedral faces form two- or three-dimensional patterns of lamellae intersecting at angles of 93.9°. Under crossed polarizers, intercalated lamellae of corundum are recognizable by interference striations caused by the different orientation of the dominant crystal from the intercalated lamellae (figs. 13–16).

In some gemmological textbooks dealing with microscopic features of natural corundum (e.g. Gübelin, 1953, 1974) intercalated lamellae of corundum are mostly regarded as twin boundaries between polysynthetically twinned crystals. However, in more than 95% of corundum crystals, investigated by the present author, these 'twin boundaries' are recognized as intercalated thin lamellae parallel to the rhombohedral faces of a dominant crystal. Only some rubies from Sri Lanka and Burma were found to consist of unusually thick lamellae of corundum in different crystallographic orientations, which are easily recognized in plane polarized light due to the pleochroism of various parts of the corundum crystal in different optical orientations (figs. 17–19). Only in such cases, the term polysynthetic twinning *sensu stricto* should be applied to corundum, which implies repeatedly twinned parts of similar thickness.

Intercalated lamellae in twin position in natural rubies often run through the whole cut sample. Lamellae parallel to one rhombohedral face are common for some important localities of gem rubies, e.g. Sri Lanka or Burma. Intersecting lamellae parallel to two faces forming an angle of 93.9° are less common in samples from these localities. Rubies from other countries, e.g. Thailand, Tanzania or Kenya, on the other hand, tend to have intercalated lamellae mostly parallel to two or even three rhombohedral faces.

In some rubies of different localities, single lamellae were found to end at another corundum lamella which runs through the ruby in nearly rectangular direction (figs. 20–22). In other samples, lamellae were found to end irregularly within the dominant crystals (figs. 23–25).

Twinning in synthetic ruby

(a) Contact twinning on $(10\bar{1}0)$ and $(11\bar{2}0)$ and penetration twinning about [0001]

Macroscopic contact twinning on the first-order hexagonal prism $(10\bar{1}0)$ or the second-order hexagonal prism $(11\bar{2}0)$ was occasionally observed in rough Chatham synthetic rubies (fig. 26). Under the microscope, single twin boundaries parallel to $(10\bar{1}0)$ or $(11\bar{2}0)$ are frequently observed in this type of synthetic ruby (figs. 27–30). Due to an identical orientation of the optic axes of the twinned individuals, no interference figures are observed under crossed polarizers. In synthetic rubies available at present in the gem trade, no growth planes parallel to the prism faces are observed (Schmetzer, 1985a, 1986). Thus, by a recognition of one single straight plane parallel to the prism faces reflection twinning in synthetic ruby is obvious. On the other hand, a family of straight parallel planes indicating prism faces is conclusive for growth planes parallel to $(11\bar{2}0)$ in natural corundum.

In Ramaura synthetic rubies occasionally more or less irregular boundaries nearly parallel to prism faces were observed (figs. 31–32). Obviously, these irregular boundaries are due to penetration twinning with a 180° rotation about [0001]. Similar structural properties were never found in natural rubies.

In synthetic rubies, frequently in Chatham synthetic rubies and Ramaura synthetic rubies,

distinct types of structural properties were observed which possibly are also due to penetration twinning. In the immersion microscope, three or more lines are observed which meet at one point with different angles (figs. 33–34). These structures are similar to twin boundaries as described in the literature, which were observed after etching of (0001) faces of synthetic flux-grown rubies. Thus, these structures are possibly also caused by penetration twins. Another possible interpretation is a combination of growth planes and contact or penetration twinning. However, further examination without non-destructive methods, e.g. etching of cut faces in various orientations, is necessary.

(b) Repetitive twinning on *r* $(10\bar{1}1)$
Repetitive twinning consisting of thin intercalated lamellae which are running through a dominant crystal was frequently observed in Kashan synthetic rubies and occasionally in Chatham synthetic rubies (figs. 35–40). In Kashan synthetic rubies intercalated lamellae of corundum in twin position were found to run parallel to one or two rhombohedral faces of the dominant crystal, and even patterns of intersecting lamellae were observed. In Chatham synthetic rubies, intercalated lamellae mostly were found to run parallel to one rhombohedral face, in different parts of some crystals occasionally lamellae parallel to a second $(10\bar{1}1)$ face were found. However, no intersecting lamellae forming nearly rectangular structures were found so far in Chatham synthetic rubies. In addition, no combination of reflection twinning on $(10\bar{1}0)$ or $(11\bar{2}0)$ and intercalated lamellae was observed. In synthetic rubies, an irregular ending of intercalated lamellae within the dominant crystal was found to be more common than in natural ruby (fig. 41).

Discussion

Different types of twinning were found to be common in both natural and synthetic rubies. The recognition of intercalated lamellae parallel to *r* $(10\bar{1}1)$ in natural and synthetic rubies is possible without difficulty by use of the immersion microscope (between crossed polarizers interference striations become visible). The recognition of twinning on *c* (0001), i.e. the distinction of twin boundaries from growth planes or glide planes parallel to (0001) is almost impossible with the microscope. The recognition of contact twinning on faces parallel to the prism zone with twin boundaries parallel to the first-order and/or second-order hexagonal prism in synthetic ruby, in general, is easily done with the microscope (in natural rubies families of straight parallel growth planes parallel to $(11\bar{2}0)$ are observed; a single line parallel to the faces of the prism zone, however, indicates reflection twinning in synthetic ruby). The recognition of penetration twinning about [0001] is dependent on the direction and form of the more or less irregular twin boundary. In some cases, e.g. in some Ramaura synthetic rubies (fig. 42), designation of irregular surfaces as irregular twin boundaries or irregular growth structures is impossible by investigations with the immersion microscope alone.

For a distinction of natural and synthetic rubies complete knowledge of properties of each type of natural or synthetic ruby is necessary. By a combination of several experimental methods of investigation, e.g. microscopy and UV absorption spectroscopy, a complete set of data should be available to identify positively a certain type of natural or synthetic ruby and, in addition, to exclude positively all other possibilities. In the opinion of the author a complete set of data for ruby identification consists of, at least, the knowledge of structural properties (twinning and growth planes), inclusions, and of the full information available for the UV absorption spectrum (cf. Schmetzer, 1985a, b, 1986).

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Schmetzer, K. 1985a. Ein vervesserter Probenhalter und seine Anwendung auf Probleme der Unterscheidung natürlicher und synthetischer Rubine sowie natürlicher und synthetischer Amethyste. *Z. Dt. Gemmol. Ges.*, **34**, 29–46.

Schmetzer, K. 1985b. Distinction of natural and synthetic rubies by ultraviolet absorption spectroscopy – possibilities and limitations of the method. *Z. Dt. Gemmol. Ges.* **34**, 3/4, 101–29.

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Webster, R. 1983. *Gems, their sources, descriptions and identification*, 4th edn. (revised B.W. Anderson) London: Butterworths.

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[*Manuscript received 1 June 1985.*]

Gemmological Abstracts

ARPS, C.E.S. 1986. In search of the source rocks of Sri Lanka's gemstones, a progress report. *Australian Gemmologist*, **16**, 3, 117.
Abstract delineates localities. R.K.M.

BANK, H. 1986. Gemmologische Kurinformationen. (Short gemmological notes.) *Z.Dt.Gemmol.Ges.*, 35, 1/2, 69–71.
The author reports on incidents where glass has been offered as aquamarine and as amethyst. Also fluorite of an intense green colour, mainly 'rolled' (water-worn?) flat and longish stones, has been offered as emerald. In the autumn of 1984, the author was offered a six-rayed greenish-black, cut star diopside, from Nammkal, South India. Star diopsides are usually only known to have a four-rayed star. A so-called star corundum has been offered on the market, not with the usual angles between rays of 60°, but irregular angles between 51–64°. This was found to be a star bronzite. The notes also contain some further data on the colourless yugawaralite from India, a tecto silicate. E.S.

BECKER, G. 1986. Gem carving. *Australian Gemmologist*, **16**, 3, 120.
Abstract outlines history and methods of carving. R.K.M.

BIRCH, W.D. 1986. Gemstones of the Beechworth area. *Australian Gemmologist*, **16**, 3, 101–6, 5 figs (4 in colour).
Museum collections show that this largely depleted area has produced diamond, corundum, schorl tourmaline, garnet, zircon, quartz and some rarer gem minerals. R.K.M.

BORELLI, A. 1986. Osservazioni sulle inclusioni solide degli smeraldi di Santa Terezinha di Goias (Brasile). (Observations on solid inclusions in emeralds from Santa Terezinha de Goias, Brazil.) *La Gemmologia*, **11**, 3, 6–10, 9 figs in colour.
Energy dispersive X-rays coupled with a scanning electron microscope were used to investigate inclusions in emerald from Santa Terezinha, Goias State, Brazil. The chief mineral inclusion was found to be a ferroan magnesite; talc and a chrome hercynite were also found. M.O'D.

BULVNINA, G.P. 1986. A skilful selection of gems, a perfect composition. *Gem world*, **14**, 1, 31–3, 2 figs.
The work of the Moscow jewellery factory is described. M.O'D.

CAMPBELL, I.C., 1986. Notes from the laboratory. *South African Gemmologist*, **2**, 2, 14–15.
Dyed quartz crystals in a capsule and offered as Sandawana emerald are reported as well as bowenite beads offered as jadeite. M.O'D.

CAMPBELL, I.C., THOMAS, A.E. 1986. Lennix, an African synthetic emerald. *South African Gemmologist*, **2**, 23–7, 3 figs (1 in colour).
Twenty-four specimens were tested giving an average SG of 2.62–2.63 and RI of 1.559 (at its lowest) and 1.564 (at the highest). Average DR was 0.004. Twisted smoke-like veils, coarse hollow voids, some containing apparent flux residues, flux traceries, granular whitish inclusions, some concentrated in planes and fine feather-like structures, perhaps of a relatively transparent solid, are found in the stones. M.O'D.

CASSEDANNE, J.-P., BARROS, J.-C. 1986. Quelques gîtes d'émeraudes de Goias. (Some emerald sites in Goias.) *Revue de Gemmologie*, 88, 9–12, 6 figs (2 in colour).
The main emerald-producing sites in the Brazilian state of Goias are described. M.O'D.

DE GRAVE, E., VOCHTEN, R., ZWAAN, P.C., CRAENEN, J. 1986. Characterization of some scapolite, corundum and spinel crystals from Kochipadana and Amarawewa, Kataragama area, Sri Lanka. *Z.Dt.Gemmol.Ges.* 35, 1/2, 47–57. 5 figs, 2 tables, bibl.
The composition and the nature of the inclusions of some scapolite, corundum and spinel gemstones from Kochipadana and/or Amarawewa, Sri Lanka, have been determined by microprobe analysis. Eight spinels with Fe substitutions have been studied in detail by X-ray powder diffraction, EDX and ^{57}Fe Mössbauer spectroscopy at 80 and 300K. All samples contain 4–8% Fe^{3+} relative to the total iron content. The major part of the Fe^{2+} ions are located on tetrahedral sites but the broad quadruple

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splitting distributions indicate a partially inverse spinel structure. E.S.

DELÉ-DUBOIS, M.-L., POIROT, J.-P, SCHUBNEL, H.-J., 1986. Identification de micro-inclusions dans des rubis et émeraudes de synthèse par spectroscopie Raman. (Identification of micro-inclusions in synthetic ruby and emerald by Raman spectroscopy.) *Revue de Gemmologie*, 88, 15–17, 12 figs in colour.

Raman spectroscopy is suggested as a means of identifying synthetic ruby and emerald by their inclusions. M.O'D.

DEREPPE, J.-M., MOREAUX, C. 1986. Appication de la résonance magnétique nucléaire à l'etude des gemmes. (Application of nuclear magnetic resonance to the study of gems.) *Revue de Gemmologie*, 88, 7–8, 2 figs.

NMR techniques already widely used in mineral studies are suggested for the testing of gemstones, particularly emerald. M.O'D.

FEDERMAN, D. 1986. Inside Europe's coloured gem capital, Idar-Oberstein. *Modern Jeweler*, March 1986, 44–8, 7 figs (2 in colour).

The author traces Idar-Oberstein's development through the ages and describes its place in the gem trade today. The rise and decline of the diamond cutting industry is historically explained. The two colour plates show (a) amethysts, faceting pavilions with intaglios on top, and (b) so-called gem sculptures, i.e. fantasy cuts of large citrine, green tourmaline, yellow beryl and amethyst. E.S.

FETTEL, M. 1986. Mineralfundstellen bei Kasern im inneren Ahrntal/Südtirol. (Mineral locations around Kasern in the inner Ahrntal, South Tirol.) *Lapis*, **11**, 9, 11–15, 9 figs (7 in colour).

Gem minerals found in this area of Austria include quartz, sphene and euclase. Crystals are illustrated. M.O'D.

FRANKLIN, B.J., GILES, A.D., 1986. Scanning electron microscope and polarizing microscope techniques used in identification of inclusions in sapphire. *Australian Gemmologist*, **16**, 3, 121.

Abstract describes methods used. R.K.M.

FRENZEL, G., STÄHLE, V., BANK, F.H. 1986. Ein oktaedrischer Gahnospinell-Rohstein von Ratnapura, Sri Lanka. (An octahedral gahnospinel from Ratnapura, Sri Lanka.) *Z.Dt. Gemmol.Ges.*, **35**, 1/2, 39–46, 7 figs (1 in colour), bibl.

The gahnospinel crystal weighed 4.53g and was found in Ratnapura. The diameter was approximately 15 mm. It is the first well-defined idiomorphous gahnospinel crystal described in detail. Definite steps could be observed on the crystal surface which changed slightly from blue towards red. The edges and corners were a little rounded, probably caused by transport by river. Some opaque zinc-iron-aluminate spinel inclusions, some negative crystals, elliptic healing cracks caused by tension. E.S.

GHERA, A., GRAZIANI, G., LUCCHESI, S., MARTINI, M. 1986. Colour zoning in natural and synthetic materials. *Australian Gemmologist*, **16**, 3, 125–7, 3 figs in colour.

Uneven colour is often seen in gems. Kyanite and Chatham synthetic sapphire were used in this study. R.K.M.

GORDON, J.L. 1986. Gem minerals of the Harts Range. *Australian Gemmologist*, **16**, 3, 121–8.

Abstract: garnet, ruby, iolite, beryl, etc., are found. R.K.M.

GÜBELIN, E. 1986. Les opales mexicaines. (Mexican opal.) *Revue de Gemmologie*, 88, 3–6, 11 figs in colour.

A historical and technical review of the various types and locations of opal in Mexico. M.O'D.

GÜBELIN, E.J. KOIVULA, J.I. 1986. Einschlüsse im Quarz. (Inclusions in quartz.) *Lapis*, **11**, 9, 19–26, 42 figs in colour.

The paper presents a series of colour pictures of inclusions in quartz from the authors' book *Photo-atlas of inclusions in gemstones**. M.O'D.

HÄNNI, H.A. 1986. Korunde aus dem Umba-Tal, Tansania. (Corundums from the Umba Valley, Tanzania.) *Z.Dt.Gemmol,Ges.*, **35**, 1/2, 1–13, 10 figs (2 in colour), bibl.

An English version of this article is published on p.278 above. E.S.

HARDING, R.R. SCARRATT, K. 1986. Description of a ruby from Nepal. *Australian Gemmologist*, **16**, 3, 116.

Short abstract on a new ruby source. R.K.M.

HENN, U. 1986. Saphire aus Nigeria und von Sta Terezinha de Goias, Brazilien. (Sapphires from Nigeria and from Santa Terezinha de Goias, Brazil.) *Z.Dt.Gemmol.Ges.*, **35**, 1/2, 15–19, 4 figs in colour, bibl.

Lately blue sapphires from Nigeria have reached the market, supposed to come from a new

*See review on page 312–3.

occurrence 50km north of Jos in northern Nigeria, but nothing exact is known. The rough crystals show flat prismatic to pinacoidal habit, are dark blue to inky. SG 3.96–4.00; RI 1.760–1.764, 1.770–1.772; DR 0.008–0.010. The sapphires from Brazil come from the well-known emerald mine at Santa Terezinha de Goias, are bluish-grey with frequent definite colour zoning from greyish-blue to dark blue. RI 1.758–1.760, 1.765–1.767; DR 0.007; SG 3.91–4.35, depending on inclusions which can be muscovite and margarite; these inclusions are found along the cleavage planes and detract from the transparency of the stone. There are also liquid inclusions present. E.S.

HENN, U. 1986. Sugilit aus Südafrika. (Sugilite from South Africa.) *Z.Dt.Gemmol.Ges.*, **35**, 1/2, 65–7, 2 figs in colour, bibl.

Since 1982 this gem has been traded in the USA under the name of 'royal lavulite' and 'royal azel'. It is a complicated silicate. Only three occurrences are known; Iwagi Islet in SW Japan, Madhya Pradesh in Central India, but all cuttable material comes from the Wessels Mine, 23 north-west of Hotazel in Cape Province, South Africa. Sugilite can easily be mistaken for sogdianite, with practically the same RI, SG, spectrum and UV reaction, but sugilite contains no zirconium, while sogdianite contains up to 9.8% in weight of ZrO_2. Both may be violet to purple. E.S.

HEYLMUN, E.B. 1986. Tantalizing turquoise. *Lapidary Journal*, **40**, 6, 49–50, 1 fig.

Describes turquoise deposits near Courtland, Arizona. M.O'D.

JOBBINS, E.A., COUPAR, A.G. 1986. A.C.D. Pain and the gemstones of Burma. *Australian Gemmologist*, **16**, 3, 116.

Short abstract of biographical paper. R.K.M.

KANIS, J. 1986. Zambian gemstones. *Australian Gemmologist*, **16**, 3, 128–9.

Abstract: Kafubu emeralds better than Miku stones. Aquamarine, tourmaline and amethyst found. R.K.M.

KELLY, S.M.B. 1986. Bowesite – a new lapidary material from Australia. *Wahroongai News*, **20**, 7, 8–10.

An opaque green rock containing diopside, epidote, grossularite, actinolite, plagioclase, quartz, sphene, iron oxide and calcite, which gives a patterned material similar to nephrite in appearance and suitable for carving. RI 1.57, SG 2.78 to 3.10. R.K.M.

KOSMOWSKA-CERANOWICZ, B. 1986. Bernsteinfunde und Bernstein-lagerstätten in Polen. (Amber finds and amber occurrences in Poland.) *Z.Dt. Gemmol.Ges.*, **35**, 1/2, 21–6, 4 figs (3 in colour), bibl.

The author describes a new deposit of Baltic amber near Chlapowo and other fossil resin finds in Poland. Age and genesis of resin-bearing sediments are discussed. Some of the pieces recovered seem to be quite large, one photograph depicting a piece of amber weighing 880g. E.S.

MACGREGOR, E. 1986. The beneficiation and treatment of Brazilian emeralds. *Australian Gemmologist*, **16**, 3, 120–1.

Abstract of paper. Beneficiation means concentration and sorting of rough. R.K.M.

MATHUR, S.M. 1986. Panna mine revisited. *Indiaqua*, 44, 2, 23–7, 21 figs in colour.

The Panna diamond mine in India is described. Work on diamond recovery is still in progress. M.O'D.

MOLINÉ SALA, A. 1986. Un equipo-accesorio acoplado a balanza, para determinación del peso especifico. (Accessory apparatus with a balance for the determination of specific gravity.) *Gemologia*, **24**, 69/70, 5–11, 2 figs.

Details are given of an apparatus for SG determination combined with a simple balance. M.O'D.

MÜLLENMEISTER, H.J. 1986. Untersuchung radioaktiver Edelsteine und Mineralien. (Investigating radioactive gemstones and minerals.) *Z.Dt. Gemmol.Ges.*, **35**, 1/2, 59–63, 2 tables, 2 graphs, bibl.

Various uranium minerals and radioactive gemstones, mainly zircons and ekanite from Sri Lanka, were investigated with regard to their γ and β radiation. A colourless chrysoberyl was used as the comparison stone for induced radioactivity. The dark green zircons were found to have most active radioactivity, while the originally brown zircons from Kambodscha which have had their colour changed to blue have neither γ nor β radiation. E.S.

MUMME, I.A. 1986. Modes of occurrence of emeralds in Australia. *Australian Gemmologist*, **16**, 3, 106–8.

Emerald has been mined in New South Wales and in Western Australia. R.K.M.

O'Donoghue, M. 1986. Rubi y zafiro sinteticos de Lechleitner y corindon recubierto de Lechleitner. (Lechleitner synthetic ruby and sapphire and reconstructed Lechleitner corundum.) *Gemologia*, **24**, 69/70, 12–16.

A summary, taken from the author's *Synthetic crystals newsletter* and *Gemmological newsletter* of the features of recent Lechleitner production of solid ruby and sapphire and of a so-called reconstructed corundum. (Author's abstract.) M.O'D.

O'Donoghue, M. 1986. Pakistan. *Gemologia*, **24**, 69/70, 17–22, 1 fig. (In Spanish.)

An account, translated from the author's paper in *Gemmological newsletter*, of gemstone deposits in Pakistan. (Author's abstract.) M.O'D.

O'Donoghue, M. 1986. Diamante-gema sintetico. (Synthetic gem diamond.) *Gemologia*, **24**, 69/70, 23–6.

An account of recent progress in the synthesis of gem quality diamond taken from the author's *Synthetic crystals newsletter*.

(Author's abstract.) M.O'D.

O'Neill, K. 1986. Roses of the sea. *Lapidary Journal*, **40**, 5, 49–52, 2 figs in colour.

A short account of rhodonite from the Sea Rose mines off the coast of British Columbia. M.O'D.

Read, P.G. 1983–1985. (1) Reflectivity versus Thermal Conductivity. *Gem Instrument Digest*, May 1983, **1**, 1, 2–3, 2 figs: (2) Gem Instrument Reports, *ibid.*, 3–12, 13 figs. 1 table: (3) The Kashan Identification Myth, *id.*, August 1983, **1**, 2, 15–17, 2 figs: (4) Gem Instrument Reports, *ibid.*, 17–25, 12 figs, 1 table: (5) Challenge of the new synthetic emeralds, *id.*, November 1983, **1**, 3, 30–1, 2 figs: (6) Gem Instrument Reports, *ibid.*, 31–42, 18 figs: (7) The Identification of Precious Metals, *id.*, February 1984, **1**, 4, 47–8, 1 fig: (8) Gem Instrument Reports, *ibid.*, 48–58, 17 figs: (9) Electronics in Gemmology, *id.*, May 1984, **1**, 5, 64, 1 fig: (10) Gem Instrument Reports, *ibid.*, 65–71, 10 figs.

(1) Reflectivity and thermal instruments give different and complementary test information: it is advisable to test a suspect diamond with both.

(2) Reports on Rayner 'Raylight' (LED refractometer light source); CUEL 20 W (fibre-optic light source); two thermal conductivity testers (GEM Mini-DiamondMaster/Presidium Fact; Eickhorst Thermolyzer Diamond-Tester); two gem microscopes (Correct SJM-2, Krüss Gemstone-Microscope KA13); Okuda DC-530A Diamond Color-Tester and Presidium Master Program for calibrating it; Krüss UV Gem Spectroscope 1303; Kalnew/GAAJ 'Gemcolor 2' diamond spectrophotometer.

(3) The Kashan Synthetic Ruby is not unique in needing a little more than average care for its identification.

(4) Reports on Kassoy 'Xtra-Vue' 10X loupe; S & T CubiCZ refractometer; two fibre-optic light sources (TBL 50 watt; GemLab high intensity System C illuminator); Rayner DiamondScan reflectivity probe; two electronic diamond scales (Kassoy portable; Haigis CE40); two colour comparison systems (GemLab Research 'Gem Color Manual'; 'GemDialogue' charts); HRD BL70-1 stereo-zoom microscope; Wedgewood gold touchstone; Mitsubishi ultrasonic gold bar tester Type FD-410G.

(5) For some years flux-grown synthetic emeralds such as Gilson, Chatham and Zerfass were detectable by their low RI, DR and SG due to absence of iron oxides (which would have eroded the platinum apparatus): later Gilson used ceramic apparatus for his 'N' synthetic emerald, with constants nearer to the natural. Flux-melt 'Lennix' by Lens, hydrothermal products such as Nacken and Lechleitner, 'Regency Created Emerald' (Vacuum Ventures) and 'Crescent Vert' (Kyocera Co. of Japan) are also mentioned. As with Kashan synthetic rubies, identification depends on colour (and zoning), luminescence, S.W.UV transparency, RI, DR, SG, and, in particular, inclusions.

(6) Reports on Presidium Gem Weight Computer; Ceres CZecker thermal diamond checker; instruments by Theo Muller (LED refractometer light source; spectroscope; polariscope; fibre-optic cold-light; microscope); Gemlab spectrometer; Japanese microscopes (GAAJ DX and SP; GSM890 and GSM1080 from Gemprint; EMT (turret) and EMZ (zoom); Microtec magnifiers; fine metals testing kit by Pure Metals Corporation of Australia; Kassoy's CU5 and MP4 polaroid systems for jewellery photography; computer systems for the jeweller-gemmologist (NAG Computer Package, NAG Plan and NAG Writer, by Duncan Bransom Office Systems Ltd; Retail Jewellery Stock Analysis and Control Program, by A.J. Hales Computers; Jewel Manager, by Gemlab Gemmological Services Research and Technology group; Polygon Automated Diamond Trading Network; American Gem Market System; CompuGem, by Gemological Research Corporation; GemData 1, by P.G. Read Consultancy Services Ltd.

(7) Refers to Wedgewood Gold Touchstone (streak), Mitsubishi gold bar tester (acoustic velocity), and testing kit by Fine Metals Corporation of Australia (dilute acids) and to author's use of Ceres Diamond Probe; Gemtek (UK) and Presidium Diamond Pte Ltd (Singapore) understood to be

working on a thermal conductivity instrument calibrated to give caratage of gold alloys; Gemlust Pty Ltd (Australia)'s Model GS500PGS is a reflectivity gem tester with extra control unit and probe for testing gold.

(8) Reports on Duogemmeter; Alpha-test Electronic Gemstone Indicator; Gemlab Multi-function Polariscope; Krüss UV Gem Spectroscope 1303; E.Ö.G.G. Grading Lamp Unit; two microscopes (Eickhorst Mini-Diascope; Kassoy Gem Microscope); Krohn Fluxed-flame Torch; Kalnew Gemcolor 2 Diamond Spectrophotometer; Rayner Opticaids; CUEL Cold-Light Illumination Equipment; Rubin CZ Masterstones.

(9) Starting about ten years before with the reflectivity meter (a simple device with infrared LED, photodetector, resistors and a meter – later with voltage regulator circuit and a circuit producing infrared pulses) and followed by the thermal conductivity tester, both instruments have become increasingly sophisticated, with the aid of microprocessors and computers.

(10) Reports on Presidium 'Duotester'; GfD 'Gemexpert'; CCTV Spectroscope Camera System by Gemlab; S & T Dichroscope; two electronic balances (Trans-American TA620 Multi-mode; Shimadzu ED-1400C/G Electronic); Gemlab Immersionscope; Gemlab Inclined-Scope; two jewellery cleaners ('Connoisseurs' vibratory unit; Medelco MD-5 ultrasonic unit). J.R.H.C.

REMAUT, G., VOCHTEN, R. 1986. Blue-green apatite from Gravelotte, South Africa. *Australian Gemmologist*, **16**, 3, 115–6, 2 figs.

Bluish-green apatite has been found among emerald deposits. The infrared spectrum printed lacks an abscissa scale. R.K.M.

ROBERT, D. 1986. A propos de turquoises plus ou moins fausses. (About turquoise more or less false). *Revue de Gemmologie*, 88, 18–20, 5 figs in colour.

The author provides a general survey of natural, synthetic and treated turquoise. M.O'D.

SCARRATT, K., HARDING, R.R. 1986. Ruby and sapphire with glass infillings. *Australian Gemmologist*, **16**, 3, 119.

Abstract says that alkali aluminosilicate glasses are used. R.K.M.

SCHIFFMANN, C.A. 1986. Limitations to the spectroscopic identification of a treated diamond. *Australian Gemmologist*, **16**, 3, 108–9, 3 figs.

Outlines difficulties in assessing origin of colour in fancy diamond using standard equipment. Laboratory testing may be necessary. R.K.M.

SCHIFFMANN, C.A. 1986. Note on a large rough taaffeite. *Australian Gemmologist*, **16**, 3, 118, 2 figs.

Abstract of report on a taaffeite of 11.07 ct. R.K.M.

SCHMETZER, K. 1986. Production techniques of commercially available gem rubies. *Australian Gemmologist*, **16**, 3, 95–100, 12 figs in colour.

The title is misleading. Author deals only with synthetics, covering known manufacturing processes. R.K.M.

SCHMETZER, K. 1986. Färbung und Bestrahlungsschäden in elektronenbestrahlten blauen Topasen. (Coloration and radiation damage in electron treated blue topaz.) *Z.Dt.Gemmol.Ges.*, 35, 1/2, 27–38, 8 figs (2 in colour), 2 tables, bibl.

The material investigated was two lots of fairly heavily damaged topaz from Nigeria, treated in the USA and compared with material treated with gamma rays and electrons, heat-treated blue topaz of various origins, and treated as well as natural blue topaz from Brazil, Nigeria and Zimbabwe. The electron irradiated samples revealed cracks and parting planes parallel to the basal pinacoid. Also, a shell-like structure was observed which consisted of a blue rim, a colourless intermediate zone with various irradiation-induced defects, and a colourless zone; this may be due to the temperature gradient from the surface to the topaz centre. The temperature gradient is formed during the irradiation process by all-round cooling with running water. E.S.

SEGNIT, E.R. 1986. Decorative serpentine from Marble Bar area, Western Australia. *Australian Gemmologist*, **16**, 3, 120.

Abstract describes a chlorite serpentine which can be chatoyant. R.K.M.

SEVERI, P. 1986. Zaffiri stellati. (Star sapphires.) *Gemmologia*, **11**, 3, 16–21, 17 figs in colour.

A description of the effects of asterism in the blue sapphire variety of corundum. M.O'D.

SHERMAN, E.G. 1986. The Australian opal fields. *Australian Gemmologist*, **16**, 3, 129.

Abstract: commercial fields are Cretaceous and lie in the Great Artesian Basin. R.K.M.

SOBOLEV, N.V., SOBOLEV, E.V., YEFIMOVA, E.S. 1986. Some physical and chemical characteristics of diamonds from Copetown, New South Wales. *Australian Gemmologist*, **16**, 3, 119.

Abstract gives nitrogen content and inclusions. R.K.M.

SUNAGAWA, I. 1986. Morphology of ruby and sapphire. *Australian Gemmologist*, **16**, 3, 119.
Abstract suggests that habits are controlled by the growth media. R.K.M.

SUPERCHI, M. 1986. Gypsum alabaster from Volterra, Tuscany; an Italian gem material. *Australian Gemmologist*, **16**, 3, 118–19.
Abstract describes this as high quality alabaster. R.K.M.

TERRENCE, S., COLDHAM, B.A. 1986. Inclusions in Australian sapphire before and after heat treatment. *Australian Gemmologist*, **16**, 3, 122–5. 7 figs in colour.
Contributes to the difficult problem of identification of heat-treated sapphires. R.K.M.

THEMELIS, T. 1986. Spectroscope comparison. *Lapidary Journal*, **40**, 5, 42–8, 9 figs in colour.
A simple, lucidly presented account of the main types of hand spectroscopes available to the gemmologist and hints on their use. M.O'D.

VOCHTEN, R., DE GRAVE, E., ZWAAN, P.C. 1986. A study of scapolite, corundum and spinel crystals from the Tissamaharama area, Sri Lanka. *Australian Gemmologist*, **16**, 3, 91–4, 5 figs.
Chemical composition and inclusions were examined. R.K.M.

WANG, F. 1986. (A gemmological study of some garnets in China.) *Acta Geologica Sinica*, **16**, 2, 151–63, 10 figs (7 in colour). (Chinese with English abstract.)
Chemical analyses and optical and physical properties (including the visible transparency, chromaticity coordinates, dominant wavelength and degree of colour saturation) are reported for seven garnets from China. These garnets occur in magmatic and pegmatitic rocks, skarns and placer or drift deposits and include pyrope (2), pyrope-almandine (2), spessartine (1), and grossular (2). The visible absorption spectra of these garnets are shown and colour photographs are presented, one of these showing two-phase inclusions. Some details are given of cutting styles, the round brilliant-cut and oval brilliant-cut being the most favoured. R.A.H.

WEINER, K.L. 1986. Ein besonderer Quarz-Kristall aus Brazilien. (An unusual quartz crystal from Brazil.) *Lapis*, **11**, 10, 30–3, 8 figs (1 in colour).
A rock crystal from Diamantina, Minas Gerais, Brazil, showed a number of unusual features, including trigon-like markings on some of the faces. M.O'D.

ZOYSA, E.G.G. 1986. Gem deposits in Sri Lanka with special emphasis on recent discoveries. *Australian Gemmologist*, **16**, 3, 110–14, 1 map, 3 tables.
An abstract listing about thirty species. R.K.M.

Argyle Diamond Mines Joint Venture, 1986. *The Rio Tinto Zinc Corporation PLC Annual Report and Accounts (1985)*, 19.
Slightly more ore was processed than in 1984 and 24% more diamonds produced. Alluvial operations ceased, but the kimberlite mine and plant started up in December and output should achieve target level of 25 000 000 ct by late 1986. J.R.H.C.

The paradise of gems. 1986. *Gem World*, **14**, 1, 38–43, 1 fig.
A short summary of the present position of the Brazilian gemstone industry with a list of the gem species currently produced. M.O'D.

NOTE: *The Australian Gemmologist*, 1986 (May), **16**, 2, and (August), **16**, 3, included the Proceedings of the 20th International Gemmological Conference and contained both some complete papers and abstracts of others.

Indian Gemmologist. The first number of this new Journal was published in November 1986. Subscription rates are US $10 for sea mail and US $25 for airmail. Further details from Forum of Indian Gemmologists, 29 Gurukul Chambers, 187–9 Mumbadevi Road, Bombay 400 002, India.

Book Reviews

FINOT, L. 1986. *Les lapidairies indiens.* (Indian lapidaries.) Adidom, Paris, pp.179. Price on application.

Reprint of a work first published in Paris in 1896, this simply-produced book describes some Indian lapidaries with a comprehensive introduction.

M.O'D.

GÜBELIN, E.J., KOIVULA, J.I. 1986. *Photoatlas of inclusions in gemstones.* ABC Edition, Zurich, pp.532, 15 illus. in black-and-white, 1,449 in colour. £110 from Gemmological Instruments Ltd, London.

This book is the successor to Gübelin's *Internal World of Gemstones* published in 1974. In this volume the superb photography by Gübelin is reinforced by the innovative photographic genius of Koivula, who has won awards for his photographic research and is a senior research gemmologist with the Gemological Institute of America. The result is a photographic feast coupled with the results of their own research work and enhanced with chapters by other leading scientists. Despite the scientific input the average reader will find everything explained in lucid, not too technical, terms.

Essentially the book is divided into six uneven parts. Part I (30 pages) contains the introduction and a very informative section (with good diagrams) on photomicrography and the specialized illumination of the gemstone. The uses of phase-contrast microscopy and the shadowing technique are described here. Part II (68 pages) discusses the genesis of mineral inclusions in gemstones, and this is followed by three specialist contributions from Dr E. Roedder on 'The origin of fluid inclusions in gemstones', Prof. Henry O.A. Meyer on 'The inclusions in diamonds and the genesis of diamond' and 'The formation of quartz and its inclusions' by Prof. Dr H.A. Stalder. These sections are accompanied by a series of fine colour photographs.

Parts III (102 pages) and IV (218 pages) form the real core of the Photoatlas. Part III (arranged alphabetically as is Part IV) deals with a series of individual mineral species inclusions found in a variety of host gemstones. The species described include (among many others) amphibole, apatite, chromite, feldspar, glass, goethite, graphite, ilmenite, magnetite, quartz, sphene, tourmaline and multiple inclusion scenes, aggregates and twins. The fantasy of inclusions and their odd shapes in gemstones leads the authors to create in the imagination an old fashioned stove, a shrew and a prehistoric bird amongst other extraordinary resemblances. Part IV (the largest) is the most important part of the book and deals with 25 host species and their varieties. Some idea of the comprehensive nature of the treatment provided may be gauged by the section on emerald. The inclusions in stones from Brazil (several localities), Habachthal, Ajmer, Colombia (several mines), Lake Manyara, Mozambique, Pakistan, Sandawana, Transvaal, Urals, Zambia are all described and usually with several different photographs for each locality. Each photograph is provided with a concise description of the various inclusions and details of the type of lighting and the magnification. Ruby, sapphire and other important commercial gemstones are given comparable treatment and there is a very fine section on treated corundums. This part and the following Part V will be of crucial importance to the practising gemmologist.

Part V (88 pages) deals with the inclusions of man-made stones. It opens with a short review of the development of the various methods of gemstone synthesis and discusses the use of the terms imitation, artificial and synthetic. Over 40 photographs are used to illustrate inclusions in a wide variety of glasses. Synthetic emeralds (50 photographs) receive full treatment and photographs of several types, such as Lennix, Biron and Regency-created are included. Synthetic ruby (90 photographs) is described and figured comprehensively and includes details of the latest Knischka, Kashan and Ramaura types. Synthetic sapphire of various colours are also illustrated very fully.

Part VI (15 pages) – the 'concluding thoughts' – includes a geological timetable, a glossary of scientific expressions used, an extensive bibliography and a list of works cited. A very welcome addition to this volume is the provision of an index.

This *magnum opus* is exactly that. The provision of some 1,400 photographs and descriptions could be confusing, but here they have been logically arranged and a good contents list and index provided. The book is not just beautiful, it is also a comprehensive laboratory manual for those (most gemmologists!) who do not have access to the enormous range of natural stones from numerous localities or the range of very clever fakes which are now produced. Criticisms can be few, the reviewer (and some of his friends) find the outer cover disappointing in its near monochrome appearance, and the page margins somewhat ungenerous for the superb contents. It it to be hoped that binding will stand up to the very hard usage that many copies will receive. At £110 (in London) the book is expensive, but this is understandable when one considers the very extensive use of colour and the superb reproduction. The reviewer recommends buying the book first and affording it afterwards. It is the ideal gift for the gemmologist, jeweller, mineralogist, geologist (or anyone else for that matter) who has everything else. E.A.J.

LÉMERY, N. 1986. *Dictionnaire universel des drogues simples*. 3rd edn. (Universal dictionary of simple drugs.) Adidom, Paris, pp.124. Price on application.

Reprint of a work first published in 1733 and dealing with the medicinal and curative powers of drugs obtained from minerals. Typescript index. M.O'D.

Proceedings of the Gemmological Association of Great Britain and Association Notices

OBITUARY

M.D.S. Lewis was born in London on 1 March, 1901 and died on 8 July, 1986. He was probably best known to gemmologists and jewellers as the author of the definitive work 'Antique Paste Jewellery' and from his articles in the *Journal*.

He took his B.Sc. in 1921 at London University. There were few openings for science graduates at that time and he was unable to obtain a suitable post which could make use of his particular talents, which were mathematics and physics. His uncle was the proprietor of the jewellery manufacturing firm of Lazarus and Co., in Fitzroy Square, London, and offered him an opening as a jewellery designer. He found it to be very much to his liking and remained there for most of his working life. He was married in 1930 and the couple lived in Hampstead. From all accounts, he was a superb performer in both amateur ballroom dancing and ice-dancing.

Shortly before the war he began to be intrigued by the gemstones which were so much a part of his work and decided to enrol in the Chelsea gemmology classes. During the war his firm became wholly involved in the manufacture of various optical-mechanical components for aircraft. Because of this he was not called up for active service, but his scientific background led him into becoming a Gas Identification Officer, based in London.

He was awarded the F.G.A. and Tully Medal in 1944. In 1945 the G.A. Council decided to initiate an international Research Diploma to encourage and recognise post-graduate work of merit. A thesis submitted by Lewis entitled 'Some Surface Properties of Gemstones' convinced the Council that he should be the first recipient of the G.A. Research Diploma.†

†The succeeding Diploma awards were made in 1946 to R. Webster (London), in 1953 to G.F. Leechman (Falmouth, Cornwall), in 1957 to E. Gübelin, Ph.D. (Meggen, Switzerland), in 1959 to L.C. Trumper, B.Sc. (Devizes, Wiltshire), and in 1976 to the last recipient Pete J. Dunn, (Washington, DC, USA).

In 1947 the Gemological Institute of America awarded him their Graduate Gemologist Diploma. The photograph was taken at about this time.

When the firm resumed their jewellery manufacturing after the war, his uncle died and he took over the management of the business. In 1960 his salesman, who was a close personal friend, was killed in a car accident. This shock, coupled with the fact that he had not particularly enjoyed his new role, which had taken him away from the designing and production side of the business, made him decide to abandon jewellery manufacturing altogether. He was then able to devote himself fully to those pursuits closest to his heart. His researches resulted in the scholarly and authoritative survey *Antique Paste Jewellery* which was published by Faber and Faber in 1970 and sold in the Victoria and Albert Museum bookshop.

It was an earlier series of articles to the *Journal*, however, which most impressed the writer. These dealt with the effects and mechanisms of the interaction of light with transparent, coloured, faceted gemstones. The extremely unusual fusion of artistic and scientific abilities allowed him to describe these complex optical phenomena in a startlingly lucid manner. In his assertion of the

importance to gemmologists of a clear understanding of colour production, perception and measurement, he was decades in advance of his time. His explanations of the almost unintelligible intricacies of the internationally-adopted method of colour measurement known as the CIE Tristimulus Colour System are by far the best the writer has seen. A list of his contributions to the *Journal* is given below.

During the later part of his life he wrote many articles for the *Connoisseur* magazine and was a consultant for both Sotheby's and Christie's on antique jewellery. His advice was frequently sought by producers of historical cinema films. A rather shy and retiring person, he never delivered lectures, but when approached was massively generous with his time and knowledge. He possessed an intense love of fine antique jewellery and displayed a warmth of feeling towards those who shared it. This is very evident in a tribute to Mosheh Oved, the proprietor of the 'Cameo Corner' in Holborn's Museum Street, which was published in the November 1958 issue of *Goldsmiths Journal*. It is the writer's lasting regret that he never had the opportunity of talking to or meeting with so remarkable a man.

Latterly, he suffered from a debilitating illness, together with a serious eye affliction which greatly impaired his enjoyment of life. He leaves a son, Mr Graham Lewis and a daughter, Mrs Jennifer Parkhouse, both of Brighton.

Articles by M.D.S. Lewis in the *Journal of Gemmology*:

Selective reflection, 1947 **I**, 4, 10–14.
Speculations on lustre, 1948, **I**, 8, 9–17.
Paste, 1949 **II**, 4, 141–50.
Hardness tests, 1950, **II**, 6, 221–6.
Colour perception in gemmology, 1952, **III**, 6, 249–67.
Measurement of colour, Part 1, 1952, **III**, 7, 289–304.
Measurement of colour, Part 2, 1952, **III**, 8, 341–50.
The first half of the 19th century, 1955, **V**, 1, 17–28.

J.B.N.

JOHN GEORGE RAE, M.B.E., F.G.A., Weisdale, Shetland, died in November 1985 at the age of 80. Mr Rae passed the Diploma examination in 1934, and was amongst the first in Scotland to do so. He worked in Edinburgh until 1945 when he went to Shetland as a lay agent of the Church of Scotland. In 1955 he resumed his trade and founded the manufacturing business of Shetland Silvercraft and then the retail business of J.G. Rae Ltd. He was a member of the County Council and numerous local committees. He received the M.B.E. from the Queen in 1980.

* * *

GORDON W. WHITEHEAD, F.G.A. (D.1949 with Distinction), Surbiton, died on 19 September 1986.

GIFTS TO THE ASSOCIATION

The Council of the Association is indebted to the following for their gifts:

Creative Gemcrafts Pty Ltd, Adelaide, Australia, for two hessonite garnets.

Mr H.G. Stonley, F.G.A., Aylesbury, for a selection of gemstones including peridot, aquamarine, topaz, garnet and tourmaline.

Mr I. Thomson, of E.A. Thomson (Gems) Ltd, London, for a beryl doublet imitating a ruby.

NEWS OF FELLOWS

Mr E. Alan Jobbins was invited to lecture in Milan on 15 October 1986 in the series 'Gemmologia Europa' organized by CISGEM (Centro Informazione e Servizi Gemmologici) on behalf of Azienda Speciale della Camera di Commercio Industria Artigianato e Agricoltura di Milano. His subject was 'Gemstones of south-east Asia' and four other lectures followed at fortnightly intervals given by Prof. E. Gübelin, Switzerland, Dr J. Kanis, Portugal, Dr H. Schubnel, France, and Prof. P. Zwaan, Netherlands. The whole series was conceived to celebrate the sexcentenary of Milan Cathedral.

On 23 October 1986 Mr M.J. O'Donoghue, M.A., F.G.S., F.G.A., presented a paper on crystal growth information at a seminar on new materials held by the Science Reference and Information Service of the British Library.

MEMBERS' MEETINGS

London

On 14 October 1986 at the Flett Theatre, Geological Museum, Exhibition Road, South Kensington, London S.W.7, Dr J. Ponahlo, F.G.A., of the Austrian Gemmological Association, gave an illustrated talk entitled 'Quantitative cathodoluminescence of gemstones'.

Midlands Branch

On 17 October 1986 at Dr Johnson House, Bull Street, Birmingham, a talk was given by Mr Frank Diesch, of Mikimoto Pearls. He gave an account of the history of Mikimoto and of present day culturing, and concluded with a guide to the valuation of pearls.

On 21 November 1986 at Dr Johnson House, Mr Ken Scarratt, F.G.A., Director of the Gem Testing Laboratory of Great Britain, gave an illustrated talk entitled 'Gems from the Laboratory'. A selection of the latest instruments and books was displayed by representatives from Gemmological Instruments Ltd.

South Yorkshire and District Branch

On 6 November 1986 at the Sheffield City Polytechnic, Pond Street, Sheffield, Mr Eric Emms, F.G.A., of the Gem Testing Laboratory of Great Britain, gave an illustrated talk on the workings of the Laboratory.

ANNUAL REUNION OF MEMBERS AND PRESENTATION OF AWARDS

The Annual Reunion of Members and Presentation of Awards was held on 10 November 1986 at Goldsmiths' Hall, London. The Chairman, Mr David J. Callaghan, F.G.A., presided at the Presentation, and welcomed those present. Mr Callaghan noted that nearly 1000 students had taken the Association's examinations in 1986 and among those before him were award winners from Cyprus, Dubai, Kenya, Netherlands, Norway, Portugal, Spain, Sweden, Sri Lanka and the USA.

The Chairman then called upon Mr Herbert Tillander, F.G.A., of Finland, to present the awards to the successful candidates. After making the presentations, Mr Tillander delivered the address which is printed in full below.

The Vice-Chairman, Mr Noel Deeks, F.G.A., gave the vote of thanks, paying tribute to Mr Tillander's work.

Mr Callaghan then announced that part of the gemstone collection of the late Basil Anderson was being donated anonymously to the Gemmological Association. The collection was presented to Mr Callaghan on behalf of the Association by Mr A. Middlemiss, F.G.A., of Christie's, a full report of which appears on p.266.

ADDRESS BY MR HERBERT TILLANDER, F.G.A.

Ladies and Gentlemen,

It is a great day for all of us invited to join the officers, members of the Council, examiners and instructors of the world's oldest gemmological organization.

For those who have just received their awards this ceremony marks the start of a hopefully long and successful career.

For the officials of the Association it certainly means a great deal of satisfaction if they win applause from the audience in recognition of their voluntary and very worthy contributions in promoting gemmology world-wide.

For me it is a delight to have over-generously been invited to meet all of you and share your enthusiasm. Twenty-five years have passed since I was first honoured with this same privilege and just over half-a-century since I received my Diploma.

I congratulate those who have gained awards and sympathize with those who have unfortunately for some reason not been successful, but have at least acquainted themselves well with the subject. Since the standard of the diploma is *very* high and since few students are able to devote more than their spare time for study, there is no question about it being a real achievement to qualify for a Diploma. It could be said without much exaggeration that a normal student has less chance to pass than to fail. In some cases, also, factors outside the control of the student may have disturbed the normal rhythm of studies and practice in gem-testing. It really needs enthusiasm and sacrifice of time during two long years and a very good head for study to pass the present stiff examination with distinction.

There is a tendency among some overseas members of the Gemmological Association to strive after recognition as gem experts by the public and even the courts of justice. A very dangerous ambition indeed, since theoretical knowledge must be coupled with long experience in the trade and constant handling of such gems that have to be competently tested and in addition correctly appraised.

You need constant practice with gems in order to know them better and this is now possible without the strain of an examination ahead of you. I am sure you will get very much pleasure from such a study.

You will have to keep well informed about new developments in the gemmological field in order to remain up to date. This, in my opinion, involves not just thoroughly studying every issue of our excellent *Journal of Gemmology* but also other publications. The 'Gemmological Abstracts' and the 'Book Reviews' of the British journal will guide you well in this respect. Personally I have found the American *Gems and Gemology* and the Conclave issues of *Guilds* well worth reading and memorizing.

The Diploma alone does not make you an expert. In every profession, in every science and even in a hobby you are more or less a beginner when you have received your Diploma, but you have all the qualifications to achieve the reputation of a real expert if you proceed.

Much, obviously, depends on the type of occupation you are engaged in or look for. It may be, for instance, testing, grading, appraising or research work or any other job which permits you in connection with your work to keep abreast of the times.

During the hectic studies for the examinations many of you will have paid attention to some narrow sector which caught your specific interest but which was not dealt with in detail. Why not start proper research on this or any other subject as an earnest hobby and gradually qualify yourself as an expert. This is what I decided about twenty years ago. I gave up overall gemmology and my preceding hobby, diamond grading, and began a serious research on the history of diamond cuts. My treatise with over 1000 line drawings and as many photographs is still in manuscript, and it remains to find a publisher. But on account of a vast correspondence, a number of articles published and lectures held in various countries I appear to be a universally recognized specialist in this field. This research with numerous exciting discoveries has filled all my spare time with joy and contentment.

Gemmology has indeed a very wide scope and many sectors of this science have yet been only cursorily handled. The range for new discoveries is still substantial and I do hope some of you at least will decide to fill such gaps.

COUNCIL MEETINGS

At the meeting of the Council held on 16 September 1986 at the Royal Automobile Club, Pall Mall, London S.W.1, the business transacted included the election to membership of the following:

Fellowship

Adams, Amanda C., Leicester. 1986
Aloupas, Phiros, Nicosia, Cyprus. 1986
Bellers, Veronica O., Crawley. 1986
Blackburn, James O., Winchester. 1986
Booker, Martin, Chester. 1986
Cooney, Tracy J., Birmingham. 1986
Davidson, Helen, Chester le Street. 1986
Dean, John A., Ossett. 1986
Emerson, Michael E., Auckland, New Zealand. 1983
Goodall, Andrew M., Abbots Langley. 1986
Helmore, Peter R., London. 1986
Hudson, Carole A., Ware. 1986
Iwahori Mitsuo, Tokyo, Japan. 1975
Jackson, Sarah E., Chorleywood. 1986
Jayasundera, Amarasekera B., Kandy, Sri Lanka. 1970
Kenny, Ian P.A., Tralee, Co. Kerry, Ireland. 1986
King, Barry J., Bury St Edmunds. 1986
Klimek, Bettina A.L., Tunbridge Wells. 1986
Linley, Mark A., Worcester. 1986
Magudia, Ratilal H., St Albans. 1986
Nalliah, Selliah, Victoria, Australia. 1970
Neumand, Marion J.S., Richmond. 1986
Parker, Claire E., Worthing. 1985
Potter, Christopher, Whitstable. 1986
Robinson, Timothy, Wirral. 1986
Salmon, Shereen B., Preston. 1986
Schlussel, Roland, Colombier, Switzerland. 1985
Simpson, Geoffrey P., Marple. 1986
Spencer, Jonathan P., Bristol. 1986
Thompson, Howard W., New Malden. 1986
Topitz, Ursula A., Los Angeles, Calif., USA. 1983
Tyler, Karen, Blackpool. 1986
Waldeck, Stephen J., Ringwood. 1986
Walsh, Claire E., London. 1986
Watson, Margery E., London. 1986
Welch, Mark G., Taunton. 1980
White, Robert, Northampton. 1986

Transfers from Ordinary Membership to Fellowship

Abramson, Pamela J., Orlando, Fla., USA. 1986
Akers, Patrick J., Wimborne. 1986
Amemiya, Tamami, Tokorozawa City, Japan. 1986
Anderson, Vanessa K.A., Hong Kong. 1986
Armand, Marcel, Auckland, New Zealand. 1986
Bartholomew, Jurgen C., Shoreham-by-Sea. 1986
Burton, Nicholas J., Lichfield. 1986
Butfoy, Carol A., Kenton. 1986
Campbell, Norma B., Hong Kong. 1986
Carroll, Elizabeth K., Auckland, New Zealand. 1986
Chung, Stephen W.K., Leeds. 1986
Coleman, Rachel R., Newbury. 1986
Deeley, Peter J., Birmingham. 1986
Elkins, Heather, Nairobi, Kenya. 1986
Fedell, Jean M., Crystal Lake, Ill., USA. 1986
Fessel, Robert P., Paulding, Ohio, USA. 1986
Gardiner, Margot, Glasgow. 1986
Geolat, Patti J., Dallas, Tex., USA. 1986
Glaveau, Beatrice, Paris, France. 1986
Hamawi, George, Nairobi, Kenya. 1986
Hawkhead, Carol, Bournemouth. 1986
Hirama, Katsunori, Tokyo, Japan. 1986
Hirose, Sairi, Nagasaki Pref., Japan. 1986
Jones, Michael H., Northampton. 1986
Kato, Kuniaki, Osaka, Japan. 1986
Kent, Jeni, Hyde Park, SA, Australia. 1986
Kuittinen, Raili, Helsinki, Finland. 1982
Martin, David J., Warrington. 1986
Meister, Adrian, Zurich, Switzerland. 1986
Mellor, Karen, Amersham on the Hill. 1986
Merk, Roger L., San Diego, Calif., USA. 1986
Mills, Edwin T., Ely. 1986
Powell, Warren, Prestwich. 1986
Reynolds, Gerald N., Arlington, Tex., USA. 1986
Seibert, Jack, Arlington, Tex., USA. 1986
Shaw, Patricia V., Leeds. 1986
Smith, Adrian S., Portsmouth. 1986
Stewart, Robert M., London. 1986
Taylor, Anne R.E., Poole. 1986

Taylor, Roger J., Kings Norton. 1986
Van Gelder, Lizbeth S., London. 1986
Williams, Bret J., Matamata, New Zealand. 1986
Xanthopoulos, Celia, London. 1986
Yandle, Lorna R., Bethesda, Md, USA. 1986

Ordinary Membership
Agrawala, Das S.K. Orissa, India.
Atkinson, Gordon, Caithness.
Best, Gwendoline, Bridport.
Booth, Christine, Oldham.
Brown, Douglas C., Singapore.
Brown, Lee N., Nimes, France.
Browne, Andrew J., Caterham.
Caithness, Sharon M., Harare, Zimbabwe.
Carry, Peter D., Aberdeen.
Chan, Chi Wa, Hong Kong.
Choo, Boo Seng S., Singapore.
Craddock, Joan, Loughborough.
David, Ian G.H., Dunmow.
Durham, Dennis, Hull.
El-Sirgany, Adel A., Freeport, Ill., USA.
Evans, Elma B.H., Spring Valley, Minn., USA.
Ferris, Alan, Banbridge, Co. Down, N. Ireland.
Ferry, John M., Norwich.
Gay, Bernice M., Romsey.
Godwin, James G., Brighton.
Gollance, Caryl I.P., London.
Hage-Chahine Sawaya, Nayla, Paris, France.
Hansen, Gary R., St Louis, Mo., USA.
Hawke, Thelma C., Newquay.
Hayashi, Masahiko, Tokyo, Japan.
Horiuchi, Satoru, Tokyo, Japan.
Houbail, Ahmed J., Manama, Bahrain.
Jack, Barbara M.H., Glasgow.
Kent, David W., London.
Kim, Won Sa, Chungnam, Korea.
Kneip, John R., London.
Korevaar, Marianne, Ter Dar, Netherlands.
Leung, Marilyn S., Hong Kong.
Lewis, Anthony J., Toronto, Ont., Canada.
Lombardi, Armando, Alessandria, Italy.
Mansell, Luke E., Cambridge.
McGill, Robert, London.
McGregor, Celia, Turramurra, NSW, Australia.
Meurice, Alison S., Hythe.
Miller, Marvin D., Fairfax, USA.
Moralee, Jean M., Saltburn.
Palfreyman, William D., ACT, Australia.
Petersen, Allen C., Granby, Conn., USA.
Pintz, Frank E., Northbrook, Ill., USA.
Pyzowski, Carl C., Frackville, Penna., USA.
Rennes, Michael D., London.
Serret, Michel, Paris, France.
Sherwood, Peter H., London.
Smith, Michelle, Paris, France.
Sosnowski, Javier, Barcelona, Spain.
Spiro-Haccou, Geertruida J., Jakarta, Indonesia.
Stocker, Betty, Chipping Campden.
Sulaiman, Zahari, Selangor, Malaysia.
Sultan, Rebecca, Borehamwood.
Taylor, Helen M., Whitby.
Turner, John F., Wakefield.
Vasquez, Tomas, Barranquilla, Colombia.
Wallace, Janice M., Johannesburg, S. Africa.
Woolley, Shirl L., San Diego, Calif., USA.
Youens, Philip A., Bristol.

At the meeting of the Council held on 18 November 1986 at the Royal Automobile Club, the business transacted included the election to membership of the following:

Fellowship
Abear, Marga, Ottawa, Canada. 1986
Andrews, Olive M., Gateshead. 1986
Arnold, Gillian M., London. 1986
Bennett, David W., Royston. 1980
Bruciak, Thomas M., Lanham, Md, USA. 1986
Burns, Brian, Huddersfield. 1986
Chalandon, Tohra, London. 1986
Chan, Pik Yuk Addy, Hong Kong. 1986
Choopojcharoen, Chatchai, Bangkok, Thailand. 1986
Clarke, William R., Toronto, Ont., Canada. 1986
Cowell, Gawin, Hobart, Tasmania. 1986
Dagli, Yogesh P., Bombay, India. 1984
Daniell, Mary L.S., Hong Kong. 1986
de Haer, Robert H., Stuttgart, Germany. 1986
de Maesschalck, Alexandra A., Amsterdam, Netherlands. 1986
Essex, Philip E., Toronto, Ont., Canada. 1986
Fitzgerald, Trevor M.P., Folkestone. 1986
Gillett, Graham, Bexhill On Sea. 1986
Gold, Francine I., Markham, Ont., Canada. 1986
Gumuchdjian, Michael A., Teufen, Switzerland. 1986
Hamilton, Ann, Paisley. 1986
Hepburn, John A., Orpington. 1986
Ho, Frankie K.K., Hong Kong. 1984
Hoefer, William D., San Jose, Calif., USA. 1986
Holton, Yvonne, Edinburgh. 1986
Hopkins, Corrinne B., Singapore. 1986
Klein, Linda S., Stockholm, Sweden. 1986
McGregor, Robert G., Nepean, Ont., Canada. 1986
McQueen, Colin F., Lincoln. 1986
Masin, Roy P.A., Soestdijk, Netherlands. 1986
May, Jasper B. St J., Banbury. 1986
Mazza, Deborah R.H., Idar Oberstein, W. Germany. 1986
Merry, Neil J., Broxbourne. 1986
Nishimori, Yoshie, Fukui-Ken, Japan. 1986

Norcott, Susan C., Bristol. 1986
Onishi, Hirokazu, Osaka, Japan. 1986
Palombi, Robert J., London, Ont., Canada. 1986
Payette, Francine, Sillery, Que., Canada. 1985
Pfneisl, Thomas, Vienna, Austria. 1986
Phillips, Glenys J., Brighouse. 1986
Pieris, Ishita K., Nawala, Sri Lanka. 1986
Powell, Gregory J., Prestatyn. 1986
Rice, Karen L., Solihull. 1986
Rickard, Patricia L., South Laguna, Calif., USA. 1986
Smith, Gillian M., Wetherby. 1986
Smith, Susan A., Hendon. 1986
Swinkin, Barry D., Toronto, Ont., Canada. 1986
Tatlock, John F., Washington DC, USA. 1986
Tidswell, Linda A., Bingley. 1986
Unhjem, Reinholdt Z., Oslo, Norway. 1986
Vara, Pradip, Stanmore. 1986
Witschard, Peter R., Stockholm, Sweden. 1986
Wong, Kai S., Hong Kong. 1986
Woodward, Elizabeth, London. 1986
Yu Fuk Kau, David, Hong Kong. 1986
Zainuddin, Nisreen A., Deira-Dubai, UAE. 1986

Ordinary Membership

Abrahams, Ashley H., Kenley.
Adam, Adam, London.
Anwar, Pasha, London.
Ash, Brian G.V., Kings Lynn.
Baumann, Yvonne, Dungarvan, Waterford, Ireland.
Best, Jean H., Wimborne.
Booley, Timothy J., Wakefield.
Burbridge, Colin D. Birmingham.
Ching, Estella S.T.T., Hong Kong.
Coward, Stephanie J., Colchester.
Dibbens, Ian J., Christchurch.
Dormer, Colin L., Sutton.
Drukker, M., Amsterdam, Netherlands.
Esser, Clara L.M., Singapore.
Findlay, Caroline E., London.
Fitzmaurice, Karl M., Dublin, Ireland.
Hamid, Jeffery A.B.A., Perak, W. Malaysia.
Hossen, Iqbal H., Port Louis, Mauritius.
Kabamba, Bujitu M., Leven.
Kasler, Jesse M., Chula Vista, Calif., USA.
Krysler, Clement, London.
Liechtenstein, Helene, Steiermak, Austria.
Lind, Thomas, Idar Oberstein, W. Germany.
Loube, Lynne P., Washington DC, USA.
McCleland, Susan M.F., Haslemere.
Maddens, Claudine Z., Belgium.
Mahaux, Jacques R., Overijse, Belgium.
Malin, Dianne M., Wembley.
Moldes, Rhyna, Miami, Fla., USA.
Ng, Avis L., London.
Nunes, Michel, George, S. Africa.
Reynolds, W.A.G., Sydney, NSW, Australia.
Richner, Sally J., Grosse Pointe, Michigan, USA.
Schneirla, Peter C., New York, NY, USA.
Scott Young, Rosemary S., Glasgow.
Straub, Bernard C., Reading.
Sumpster, Antony M., London.
Talberg, Judy, Burkina Faso, W. Africa.
Theriault, Peter J., Camden Maine, USA.
Tong, James P.T., Hong Kong.
Treloar, Karl R., Banwell.
Van Rooyen, Brent A., Glenstantia, S. Africa.
Vest, Geraldine M., London.
Vincent, Patricia J., Wokingham.
Wagner, Martin K., Gerrards Cross.
Woodward, Zena P., London.

GEM DIAMOND EXAMINATION 1986

In the Post-Diploma Gem Diamond Examination 39 candidates sat and 38 qualified. The following is a list of the successful candidates arranged alphabetically.

Ambrose, Janice M., Enfield.
Arno Fece, Nuria, Barcelona, Spain.
Ashraf, Ashfaq A., London.
Baquero Petricorena, Manuel, Barcelona, Spain.
Batalla Vivas, Jose I., Barcelona, Spain.
Bernad Soria, Pedro J., Barcelona, Spain.
Biosca Bas, Ma de los Angeles, Barcelona, Spain.
Cabre Bores, Nuria, Barcelona, Spain.
Campos Ruiz, Ma T., Barcelona, Spain.
Carmena Coelho, Jose A., Barcelona, Spain.
Evans, Gareth D., Potters Bar.
Francis, Shirley J., Frinton-on-Sea.
Gascon Cuello, Fernando, Barcelona, Spain.
Goad, Jane F.C., London.
Herold, Richard A.J., Salisbury.
Hutton, Andrew J., Sanderstead.
Iacovou, Elena N., Nicosia, Cyprus.
Insa Sales, Juan M., Barcelona, Spain.
Jones, Karen, Bangor.
Juan Sampablo, Teresa, Barcelona, Spain.
Lewis, Doreen E., Monmouth.
McKearney, Michael C., London.
Marti Martinez, Nicolas, Barcelona, Spain.
Medniuk, Melanie A., Witham.
Moore, Elaine, Northwood.
Morling, Anthony J.D., St Mary, Jersey, CI.
Morrison, Stephen P., London.
Pajaron Gamon, Ma L., Barcelona, Spain.
Parker, Claire E., Goring-by-Sea.
Pascual Torres, Jose L., Barcelona, Spain.
Platon Davila, Susana, Barcelona, Spain.
Ramsey-Rae, Philippa, London.
Spreckley, Vaughan G.M., London.
Stead, William A., London.
Sturman, Nicholas P.G., London.
Taank, Avinash, Ilford.

Wackan, Susan K., London.
Wilson, Andrew R., Goring-by-Sea.

EXAMINATIONS IN GEMMOLOGY 1986

In the 1986 Examinations in Gemmology 704 candidates sat the Preliminary examination and 456 (65%) passed, 466 sat the Diploma examination and 187 (40%) passed, 13 with distinction.

The Tully Medal, to be awarded to the candidate (trade or non-trade) who submits the best set of answers in the Diploma examination, has not been awarded this year.

The Anderson/Bank Prize for the best non-trade candidate of the year in the Diploma examination has been awarded to Lizbeth Sara Van Gelder of London.

The Rayner Diploma Prize for the best candidate of the year whose main income is derived from activities essentially connected with the jewellery trade has been awarded to Karen Lindsey Rice of Birmingham.

The Anderson Medal for the best candidate of the year in the Preliminary examination has been awarded to Eeva Katri Harjula of Finland.

The Rayner Preliminary Prize for the best candidate under the age of 21 years on 1 June whose main income is derived from activities essentially connected with the jewellery trade was awarded to Mei Po Mak of Hong Kong.

The names of the successful candidates are as follows:

DIPLOMA

Qualified with Distinction

Abell, Alison M., Nairobi, Kenya.
Amemiya, Tamami, Tokorozawa City, Japan.
Haque, Mohammed, London.
Helmore, Peter R., London.
Hirama, Katsunori, Tokyo, Japan.
Meister, Adrian, Zurich, Switzerland.
Rice, Karen L., Solihull.
Robinson, Timothy, Wirral.
Simpson, Geoffrey P., Marple.
Stewart, Robert M., London.
Tyler, Karen, Cleveleys.
Unhjem, Reinholdt Z., Oslo, Norway.
Van Gelder, Lizbeth S. London.

Qualified

Abear, Marga, Ottawa, Ont., Canada.
Abramson, Pamela J., Orlando, Fla., USA.
Adams, Amanda C., Burstall.
Aggarwal, Kamal K., Patiali, India.
Akers, Patrick J., Wimborne.
Aloupas, Phivos, Nicosia, Cyprus.
Amarasiri, Sujatha, Colombo, Sri Lanka.
Anderson, Vanessa K.A., Hong Kong.
Andrews, Olive M., Hong Kong.
Armand, Marcel, Auckland, New Zealand.
Arnold, Gillian M., London.
Batholomew, Jurgen C., Shoreham-by-Sea.
Beckett, Michael J., London.
Bellers, Veronica O., Horsham.
Blackburn, James O., Winchester.
Bolland, Wendy M., Hong Kong.
Booker, Martin, Chester.
Bruciak, Thomas M., Lanham, Md, USA.
Bruggeman, Renate F., Almelo, Netherlands.
Buis, Jan D.B., Lopik, Netherlands.
Burns, Brian, Huddersfield.
Burton, Nicholas J., Lichfield.
Butfoy, Carol A., Kenton.
Campbell, Norma B., Hong Kong.
Campillo Pastor, Marina, Barcelona, Spain.
Carroll, Elizabeth K., Auckland, New Zealand.
Casanova Guillen, Luis M., Barcelona, Spain.
Chalandon, Tohra, London.
Chan, Pik Y.A., Hong Kong.
Chandrasena, Vishwakanthie, Idar-Oberstein, W. Germany.
Chard, Duncan, London.
Cheung, Yiu W.D., Hong Kong.
Choopojcharoen, Chatchai, Bangkok, Thailand.
Chow, Winston W.S., Hong Kong.
Chung, Stephen W.K., Leeds.
Clarke, William R., Toronto, Ont., Canada.
Coleman, Rachel R., Newbury.
Cooney, Tracy J., Birmingham.
Cowell, Gawin, Hobart, Tasmania.
Daniell, Mary L.S., Hong Kong.
Davidson, Helen, Chester-le-Street.
Dean, John A., Ossett.
Deeley, Peter J., Birmingham.
de Haer, Robert H., Zwolle, Netherlands.
de Maesschalck, Alexandra A., Amsterdam, Netherlands.
Domenech Lahoz, Christiane, Barcelona, Spain.
Duque Camp, Susanna Ma, Barcelona, Spain.
Elkins, Heather, Nairobi, Kenya.
Essex, Philip E., Toronto, Ont., Canada.
Fedell, Jean M., Crystal Lake, Ill., USA.
Fernandez Nunez, Francisco J., Barcelona, Spain.
Fernandez Sanchez, Fernando, Barcelona, Spain.
Fessel, Robert P., Paulding, Ohio, USA.
Fitzgerald, Trevor M.P., Folkestone.
Gardiner, Margot, Glasgow.
Gentsidou, Fotina, Athens, Greece.
Geolat, Patti J., Dallas, Tex., USA.
Gillett, Graham, Bexhill-on-Sea.
Glaveau, Beatrice, Paris, France.
Gold, Francine, Markham, Ont., Canada.
Goodall, Andrew M., Abbots Langley.
Goodlin, Fran, Toronto, Ont., Canada.
Gumuchdjian, Michael A., Teufen, Switzerland.

Hamawi, George, Nairobi, Kenya.
Hamilton, Ann, Bridge of Weir.
Hawkhead, Carol, Bournemouth.
Hepburn, John A., Orpington.
Hirose, Sairi, Nagasaki Pref., Japan.
Hoefer, William D., San Jose, Calif., USA.
Holton, Yvonne, Edinburgh.
Hopkins, Corrinne B., Bangkok, Thailand.
Hudson, Carole A., Ware.
Indrebø, Solveig, Oslo, Norway.
Jackson, Sarah E., Watford.
Jain, Monica, Bombay, India.
Jones, Michael H., Northampton.
Kalannayake, Lenaduwa L.Y.R., Colombo, Sri Lanka.
Kato, Kuniaki, Osaka, Japan.
Kenny, Ian P.A., Tralee, Co. Kerry, Ireland.
Kent, Jeni, Hyde Park, SA, Australia.
Kievit, Wouter, Rotterdam, Netherlands.
King, Barry J., Bury St Edmunds.
Klein, Linda S., Stockholm, Sweden.
Klimek, Bettina A.L., Tunbridge Wells.
Kotewall, Pikyee, Hong Kong.
Krot, Carine A.P., Amsterdam, Netherlands.
Lam, Keturah M.H., Hong Kong.
Lee, Mei-Ying, Hong Kong.
Leung, Marilyn S., Hong Kong.
Linley, Mark A., Worcester.
Lloyd, Jeremy J., Birmingham.
McGregor, Robert G., Nepean, Ont., Canada.
McIntosh, Stewart F., Glasgow.
McQueen, Colin F., Lincoln.
Magudia, Ratilal H., St Albans.
Mak, Yim Ming, Hong Kong.
Malhotra, Kapil, Bombay, India.
Marazzi, Roberto, Lugano, Italy.
Marti Beltran, Fernando, Barcelona, Spain.
Martin, David J., Warrington.
Masin, Roy P.A., Soestdijk, Netherlands.
Maskonen, Seija S., Helsinki, Finland.
Mavridou, Angelika, Thessalonika, Greece.
May, Jasper B. St J., Birmingham.
Mazza, Deborah R.H., Idar Oberstein, W. Germany.
Mellor, Karen, Amersham-on-the-Hill.
Merk, Roger L., San Diego, Calif., USA.
Merry, Neil J., Broxbourne.
Mills, Edwin T., Ely.
Murano, Fumiko, Osaka, Japan.
Neumand, Marion J.S., Richmond.
Ng, Li Neng, Penang, Malaysia.
Nidharak, Gurdip S., Solon, Ohio, USA.
Nishimori, Yoshie, Tokyo, Japan.
Norcott, Susan C., Bristol.
Onishi, Hirokazu, Osaka, Japan.
Palmer, Valerie G., London.
Palombi, Robert J., London, Ont., Canada.
Pfneisl, Thomas, Vienna, Austria.
Phillips, Glenys J., Brighouse.
Piedvache, Roland, Paris, France.
Pieris, Ishita K., Colombo, Sri Lanka.
Poblador Cerezo, Luis M., Barcelona, Spain.
Potter, Christopher, Whitstable.
Powell, Gregory J., Prestatyn.
Powell, Warren, Prestwich.
Preston, Karen L., Burnley.
Rafols Garrit, Yolanda, Barcelona, Spain.
Rehbinder, Anne C.M., Stockholm, Sweden.
Reynolds, Gerald N., Arlington, Tex., USA.
Rickard, Patricia L., South Laguna, Calif., USA.
Salmon, Shereen B., Preston.
Seibert, Jack, Columbus, Ohio, USA.
Senaratne, Amal C., Colombo, Sri Lanka.
Serra Palau, Carles, Barcelona, Spain.
Shah, Manoj D., Bombay, India.
Shaw, Patricia V., Leeds.
Smidt, Margot, Voorburg, Netherlands.
Smith, Adrian S., Emsworth.
Smith, Alan, Blackpool.
Smith, Gillian M., Wetherby.
Smith, Susan A., Hendon.
So Nai Leung, Jimmy, Hong Kong.
Spencer, Jonathan P., Bristol.
Swinkin, Barry D., Toronto, Ont., Canada.
Tai, Anissa M., Singapore.
Tassabehji, Basima, Manchester.
Tatlock, John F., Washington DC, USA.
Taylor, Anne R.E., Poole.
Taylor, Roger J., Kings Norton.
Thethy, Avtar S., London.
Thompson, Howard W., New Malden.
Tidswell, Linda A., Bingley.
Torrance, Claire H., Auckland, New Zealand.
Tortosa Domingo, Ramon, Barcelona, Spain.
van Dijk-Pietrzak, Jolanta A., Rijswijk, Netherlands.
Vara, Pradip, Stanmore.
Vilanova Cardona, Elvira, Barcelona, Spain.
Vittachi, Nedra, Colombo, Sri Lanka.
Waldeck, Stephen J., Ringwood.
Walsh, Claire E., Hendon.
Watson, Margery E., London.
Wezel, Annemarie, Alkmaar, Netherlands.
White, Robert, Northampton.
Williams, Bret J., Waikato, New Zealand.
Winter, Kim M., Toronto, Ont., Canada.
Witschard, Peter R., Stockholm, Sweden.
Wong, Kai S., Hong Kong.
Woodward, Elizabeth, London.
Xanthopoulos, Celia, Athens, Greece.
Yandle, Lorna R., Bethesda, Md, USA.
Yu Fuk Kau, David, Hong Kong.
Zainuddin, Nisreen A., Deira, Dubai, UAE.
Zaveri, Narendra I.Z., Bombay, India.

PRELIMINARY

Qualified

Aketa, Haruo, Tokyo, Japan.
Alegria Oses, Ma Roas, Barcelona, Spain.
Allen, Elizabeth A., London.
Amemiya, Tamami, Tokorozawa City, Japan.
Amiel Fresneda, Josefa, Barcelona, Spain.
Aresti, Anthony, Barnet.
Armangue Martinez, Ma Angeles, Barcelona, Spain.
Arnold, Patricia, F., Amersham.
Arratia San Hueza, Antonio, London.
Asensi Marti, Ma Victoria, Barcelona, Spain.
Asensi Rolland, Asuncion G., Barcelona, Spain.
Ashby, Paul J., Dover.
Asiain De Los Angeles, Jorge J., Barcelona, Spain.
Atkinson, Mavis W., Bradford.
Atkinson, Morris, Bradford.
Atkinson, Timothy C., Ripon.
Au Yeung, Kwai H., Hong Kong.
Axell, Anita C., Stockholm, Sweden.
Baker, Sylvia V.J., Bangkok, Thailand.
Bargilis, George C., Limassol, Cyprus.
Barlow, R.M., Hong Kong.
Barnes, Joyce J., Marazion.
Baron, Raymond, Liverpool.
Baumann, Yvonne, Dungarvan, Waterford, Ireland.
Beale, Evelyn M., Beamsville, Ont., Canada.
Beattie, Paul J., Liverpool.
Becker, Kim A., Francistown, Botswana.
Bernat Serra, Marcos, Barcelona, Spain.
Bertran Codina, Xavier, Barcelona, Spain.
Bettridge, Howard E., Keston.
Biffer, Howard N., New York, NY, USA.
Billingham, Carole J., Richmond.
Birch, Claire A., Sacramento, Calif., USA.
Birchall, Steven, Hyde.
Bishop, Lyndall, A., Hong Kong.
Blackford, Peggy, Harare, Zimbabwe.
Boardman, Chat Ngoc, McLean, Va, USA.
Bode, William E.G., Harrogate.
Boe, Olav A., Alhus, Norway.
Boot, Maria, Cotgrave.
Borreda Hernandez, Frederico, Barcelona, Spain.
Bosch Lucia, Pilar, Barcelona, Spain.
Bourke, Mary, Enniscorthy, Wexford, Ireland.
Bowis, Mark L., London.
Braithwaite, Doris, Farsley.
Bramham, Kathleen, London.
Bramsden, Manny, Maidenhead.
Brandligt-van der Hoed, Maria A.G., Bussum, Netherlands.
Brasok, Nadia, Toronto, Ont., Canada.
Bristow, Peter H., Whitley Bay.
Bruciak, Thomas M., Lanham, Md., USA.
Brummer, Pieter, Almelo, Netherlands.
Burbridge, Colin D., Birmingham.
Burdett, Martin A., London.
Burman-Roy, Chaya R., Glasgow.
Burques Montserrat, Ma J., Barcelona, Spain.
Burt, Peter O.K., Great Mongeham.
Canty, Jesse, London.
Carpmael, Malcolm P., Shoreham-by-Sea.
Cartmill, Edith L.L., Bangor, N. Ireland.
Cass, Elliott, London.
Castoro, Loretta C., New York, NY, USA.
Caulfield, Gwendolyn R., King City, Ont., Canada.
Chan, Leung F.P., Hong Kong.
Chan, William T.W., Hong Kong.
Chan, Yiu Chung, Hong Kong.
Cheeseman, Alan S., Birmingham.
Cheng, Shik-Ching Lilian, Hong Kong.
Cheng-Lau, Kwai L.K., Kowloon, Hong Kong.
Cheung, Paul K.K., Hong Kong.
Ching, Estella S.T.T., Hong Kong.
Chiu, Sin Y., Hong Kong.
Choopojcharoen, Chatchai, Bangkok, Thailand.
Choy, Boo S.R., Hong Kong.
Christensen, Cherie A., San Jose, Calif., USA.
Christensen, Hanne L., Oslo, Norway.
Chu, Chi H., Hong Kong.
Chung, Ying K., Hong Kong.
Churcher, Mark, Kettering.
Clarke, Deborah L., Tenterden.
Clarke, William R., Toronto, Ont., Canada.
Collings, Faith, Liskeard.
Cook, Nigel V., Chatham.
Corduff, Rosalie P., Stoke-on-Trent.
Cosman, Maria A., Montfoort, Netherlands.
Coward, Stephanie J., Colchester.
Cros, Jean-Marc, London.
Curran, Paul H., Brighton.
Currant, Paula, Bath.
Dabell, Louise C., Nottingham.
Dallas, James A., London.
Dalmau Bafalluy, Ma N., Barcelona, Spain.
Davis, Howard A., West Haven, Conn., USA.
De Diego Prieto, Manuel, Barcelona, Spain.
de Jong, Peter, Zwijndrecht, Netherlands.
de Jong-Flick, Diana, Zwijndrecht, Netherlands.
de Maesschalck, Alexandra A., Amsterdam, Netherlands.
de Visser, Irene M., Rotterdam, Netherlands.
De'Ath, David, Luanshya, Zambia.
Della Torre, Isabelle, Geneva, Switzerland.
den Haring, Wilhelmina M., Schoonhoven, Netherlands.
Dewever. Nicole J.M., Sittard, Netherlands.
Dhalla, Akbar, London.
Diaz Vaquero, Ma J., Barcelona, Spain.
Dodani, Manoj B., Hong Kong.
Dominy, Geoffrey M., Edmonton, Alta., Canada.

Drukker-Loth, Julia M., Huizen, Netherlands.
Dufficy, Margaret H., San Francisco, Calif., USA.
Dunkley, Teresa A., Kingsthorpe.
Dunn, Wendy S., London.
Duranczyk, Gladys, Hebden Bridge.
Edwards, Nicholas L., Ingleton.
Elias Berdalet, Ma E., Barcelona, Spain.
Ellis, Maxwell, Duffield.
Engberg, Eleonor K., Solna, Sweden.
Esser, Clara L.M., Hurth, W. Germany.
Essex, Philip E., Toronto, Ont., Canada.
Esufali, Joher M., Colombo, Sri Lanka.
Evangelou, Andreas, London.
Faustmann, Asuncion M.S.Q., Manila, Philippines.
Fenton, Neil D., Greasby.
Fernandez Fernandez, Joesp Ma, Barcelona, Spain.
Ferrer Coma, Montserrat, Barcelona, Spain.
Findlay, Caroline E., Kirkliston.
Forsberg, Pierre G.C., Kisa, Sweden.
Foster, Brenda C., St Albans.
Foster, Janice G., Oshawa, Ont., Canada.
Foster, Paul R., Enfield.
Fox, Julie A., Rochester.
Franklin, Neil, Newcastle-upon-Tyne.
Gambini, Elena, Milan, Italy.
Gashinski, Ron, Burlington, Ont., Canada.
Gay, Bernice M., Romsey.
Gay, Michael, Romsey.
Gaynor, David, Ryton.
Gelabert Tremoleda, Carina, Barcelona, Spain.
Genot, Luc P.A., Brussels, Belgium.
Gervilla Linares, Fernando, Barcelona, Spain.
Gibbs, Stuart L., London.
Glover, Graham D.B., London.
Gomez Molina, Miguel A., Marbella, Spain.
Gonzalez Molinera, Carlos, Barcelona, Spain.
Graham, Lee V., Farnham.
Greenwold, Lynn, Stow-on-the-Wold.
Griffiths, Sarah J.C., London.
Gual Balmanya, Concepcio, Barcelona, Spain.
Guarino Alemany, Ma T., Barcelona, Spain.
Gumuchdjian, Michael A., Teufen, Switzerland.
Gunaratne, Ananda L., Kundasale, Sri Lanka.
Gunaratne, Dhammika D., Moratuwa, Sri Lanka.
Hackenberg, Astrid M., Schoonhoven, Netherlands.
Hagon, Clive L., London.
Hakola, Arto K., Tornio, Finland.
Hall, Warren S., Croydon.
Hamawi, George, Nairobi, Kenya.
Hare, Michael, South Woodham Ferrers.
Harjula, Eeva K., Helsinki, Finland.
Harper, Fleur, Chester.
Hart, Claudette V., Toronto, Ont., Canada.
Hawke, Thelma C., Newquay.
Hawkins, Philippa L., London.
Hawkins, Richard A., Sutton.
Hayes, Alan G.J., Stockport.
Hazel, Dougal, Clondalkin, Dublin, Ireland.
Head, Judy E., Newdigate.
Heibrandt, Lars P., Stockholm, Sweden.
Henderson, Paul T., Auckland, New Zealand.
Hewett, Leslie, Dartford.
Higgs, Samantha M., Cuffley.
Hilton, Holly A., London.
Hirama, Katsunori, Tokyo, Japan.
Hirose, Sairi, Nagasaki Pref., Japan.
Hirst, Lindy M., Johannesburg, S. Africa.
Hitcham, Peter J., Kingston-upon-Thames.
Ho, Chi F., Hong Kong.
Hoefer, William D., San Jose, Calif., USA.
Holbech, William H., London.
Hoogenboom, Maria A., Woubrugge, Netherlands.
Hook, Natalie A., Accrington.
Hopkins, Corrinne B., Bangkok, Thailand.
Horn, Erna, Sellingen, Netherlands.
Horrocks, Anthony J., Sidmouth.
Hossen, Iqbal H., Port Louis, Mauritius.
Howard, Anthony K., London.
Howat, Denise, Hong Kong.
Hud, Julie A., Nottingham.
Hud, Michael, Nottingham.
Hughes, Stephen N., Cardiff.
Hulm, Valerie A., Hong Kong.
Huntingdon, Richard C., Las Vegas, Nev., USA.
Huppach, Friedrich H., Earby.
Huuskonen, Kari O., Helsinki, Finland.
Iguaz Esteban, Yolanda, Barcelona, Spain.
Ilines, Janice A., London.
Imaya, Rika, Osaka, Japan.
Jack, Barbara M.H., Glasgow.
Jackson, Robert M., London.
Jarvelainen, Raila T., Helsinki, Finland.
Je, Jim J.T.M., Toronto, Ont., Canada.
Jefferson, Gareth W., London.
Jessop, Susan F., London.
Johnson Smith, Susanne A., London.
Jones, Hilary J., Wombourne.
Jones, Margaret E., Stockport.
Kacinari, Elizabeta, Antwerp, Belgium.
Kallioniemi, Anne M., Helsinki, Finland.
Kang, Min-Woong, Toronto, Ont., Canada.
Kangashniemi, Risto I., Tampere, Finland.
Karvinen, Jyrki P., Tampere, Finland.
Kato, Kuniaki, Osaka, Japan.
Kendrew, Sharon R., London.
Kenna, Sean N., Leixlip, Co. Kildare, Ireland.
Kenny, Ian P.A., Tralee, Co. Kerry, Ireland.
Kent, Jeni, Hyde Park, SA, Australia.
Killeen, Kevin V., Dublin, Ireland.
Kim, Won-Sa, Chungnam, Korea.

Kiyono, Masako, Tokyo, Japan.
Kneip, John R., London.
Knight, James H., Godalming.
Kolbach, Gerrigje E.A., Goudswaard, Netherlands.
Kramer, Stephen A., Bradford.
Krill, Sarah, Wisbech.
Laakso, Tarmo S., Helsinki, Finland.
Labastida Gaspar, Juan A., Barcelona, Spain.
Lacklison, Stephen R., Paignton.
Lai, Chun C., Hong Kong.
Lai, Shuk C., Hong Kong.
Lam, Cecilia S.L., Hong Kong.
Lam, May K.J., Hong Kong.
Lambert, Roslyn, Shirley.
Lander, Angelique M., 't Harde, Netherlands.
Lang, Matti P., Lahti, Finland.
Lange, Karin E., Kitchener, Ont., Canada.
Latre Gonzales, Jose, Barcelona, Spain.
Lau, Miu W., Hong Kong.
Lee, Lap T., Hong Kong.
Lee, Luen H., Hong Kong.
Lee, Mary T.H., Hong Kong.
Lee, Yin M., Hong Kong.
Lekamge, Neil S., Kandy, Sri Lanka.
Leung, Tak L., Hong Kong.
Levy, Laurence M., London.
Lewis, Rachel, Stockport.
Leyens, Richard, London.
Lightfoot, Paul, Ottery St Mary.
Ligterink, Angenita, Waddinxveen, Netherlands.
Lindquist, Airi B., Helsinki, Finland.
Lindquist, Maria T., London.
Lloyd, Florence M., Harpenden.
Lloyd, Susannah M.D., Abergavenny.
Lloyd-Jones, John H.T., Ware.
Lo, Suet M., Hong Kong.
Lopez Gonzales, Gloria, Barcelona, Spain.
Lowe, Patrick A., Sligo, Ireland.
Lu, Lucy S.G., Hong Kong.
Lucia Lambea, Teresa, Barcelona, Spain.
Luk, Kwok Yi, Hong Kong.
Luong, Vinh Du, Toronto, Ont., Canada.
McBride, Phillip, Radcliffe.
MacDonald, Moira, Glasgow.
McDonald, Richard G., Edinburgh.
McGregor, Robert G., Nepean, Ont., Canada.
McSporran-Wirepa, Margaret, Gisborne, New Zealand.
Maenpaa, Risto Y., Jarvenpaa, Finland.
Maheshwari, Sudha, Kenton.
Mak, Mei Po, Hong Kong.
Mak, Wing H.W., Hong Kong.
Mak, Yim M., Hong Kong.
Makredes, Mary B., Hong Kong.
Malet Hernandez, Christine, Barcelona, Spain.
Malhotra, Kapil, Bombay, India.
Malhotra, Ravi, Bombay, India.
Malmsten-Ghazaw, Scharon L., Masala, Finland.
Marazzi, Roberto, Lugano, Italy.
March, Debra A., Toronto, Ont., Canada.
Markov, Mark, London.
Marks, Jan H., Dordrecht, Netherlands.
Marriott, Janet A., Amersham.
Martin Martinez, Victor, Barcelona, Spain.
Martine-Leyland, Eric, Vancouver, BC, Canada.
Masuoka, Yoshimi, Osaka, Japan.
Matsubara, Suzuko, Nara Japan.
Matsubara, Yoshiko, Osaka, Japan.
Matthews, Andrew, Bury.
Maupu, Francoise R.J., Lagnieu, France.
Mavridou, Angelika, Thessalonika, Greece.
May, Jasper B. St J., Birmingham.
Mazza, Deborah, Idar Oberstein, W. Germany.
Meigh, Melanie J., Painswick.
Meister, Adrian, Zurich, Switzerland.
Melian de Gasson, Maria I., Bangkok, Thailand.
Menegatti, Brigitte, Hong Kong.
Metaxas, George, London.
Michaels, Amy J., Montgomery, Ala., USA.
Millar, Ewan, Paisley.
Milton-Stevens, Christopher, Bath.
Miura, Masatoshi, Osaka, Japan.
Miyabayashi, Yuki, Osaka, Japan.
Mohideen, Zaheem, Colombo, Sri Lanka.
Molina Torreblanca, Amparo, Barcelona, Spain.
Moore, Laura J., Colombo, Sri Lanka.
Moralee, Jean M., Staithes.
Morena Garcia, Roas Ma, Barcelona, Spain.
Moritz, Tatjana J.S., St Michielsgestel, Netherlands.
Morris, Vincent P., Leeds.
Morrison, Laurie J., Upminster.
Murano, Fumiko, Osaka, Japan.
Myers, Angela M., Liverpool.
Nakamori, Katsuyuki, Tokyo, Japan.
Nakata, Hideyuki, Tokyo, Japan.
Ng, Avis L., London.
Ng, Gordon K.T., Hong Kong.
Ng, Li N., Penang, Malaysia.
Ng, Siu L.A., Hong Kong.
Ng, Wai Y., Hong Kong.
Nidharak, Gurdip S., Solon, Ohio, USA.
Nikula, Marja-Leena A., Lahti, Finland.
Norton, Robert, Warrington.
Nottingham, Peter, Leeds.
Oostendorp, Hendrina A.I., The Hague, Netherlands.
Oostwegel, Gabrielle C.W., Shinnen, Netherlands.
Orrey, Russell A., Barrowby.
Ors Griera, Sonia, Barcelona, Spain.
Ortoli Lockwood, Dominique M.J., London.
Oudenes, Hendrik, Papendrecht, Netherlands.
Ozaki, Keiko, Osaka, Japan.

Pak, Lai B.L., Hong Kong.
Palacios Muro, Juan L., Barcelona, Spain.
Pallares Marina, Berta, Barcelona, Spain.
Palmer, Lorraine F., Goring-by-Sea.
Parker, Christine A., Hong Kong.
Parker, Vaughan A., King's Lynn.
Parkin, Ann E., New York, NY, USA.
Pasenen, Pirjo H., Toivala, Finland.
Pattni, Unnat N., London.
Payne, Angela J., Frinton-on-Sea.
Pearce, Maxine L., Pudsey.
Perez Dominguez, Mercedes M., Barcelona, Spain.
Phillip, Tony J., Niagara Falls, Ont., Canada.
Pick, Velma M., London.
Piedvache, Roland, Paris, France.
Pinker, Stuart J., London.
Pitkanen, Risto A.I., Lahti, Finland.
Platt, Karen K., London.
Pombo Mota, Ana Ma, Barcelona, Spain.
Powell, Philip V., Cheltenham.
Pridham, Michelle A., Maldon.
Ramchandani, Devika M., Hendon.
Raskin, David A., Glasgow.
Ravagnani, Daniele, Gromo, Italy.
Rayner, John C., Nottingham.
Redmann, Markus, Idar-Oberstein, W. Germany.
Riley, Mark J., Chorley.
Roebuck, Joy A., Enfield.
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This year an exhibition will be on loan at the Fair entitled 'Treasure trove – jewellery presented to the Nation through the National Art-Collections Fund'.

Further information from the organizers, Brian and Anna Haughton, 3B Burlington Gardens, Old Bond Street, London W1X 1LE.

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INTERNATIONAL COLORED GEMSTONE ASSOCIATION

The second congress of the Association will be held in Bangkok, Thailand, from 18 to 20 May 1987. Further details from ICA, 22643 Strathern Street, Canoga Park, CA 91304, USA.

GEM IDENTIFICATION COURSE

This year Mr Alan Hodgkinson, F.G.A., will be running two-day gem identification basic courses, and three-day refresher courses for those with some knowledge and experience. They will be held under the sponsorship of the *Retail Jeweller* at the British Horological Institute, Upton Hall, Newark, Notts. The dates are 23/24 February and 28/29 September for the two-day, and 25–27 February and 30 September to 2 October for the three-day courses.

Full details from the *Retail Jeweller*, 100 Avenue Road, London NW3 3TP.

DATES FOR 1987

Tuesday, 31 March
Talk by Mr K. Wild, The Flett Theatre, Geological Museum, Exhibition Road, South Kensington, London S.W.7.

Thursday, 10 September
Talk by Professor I. Sunagawa, The Flett Theatre.

Tuesday, 13 October
Talk by Mr C.R. Burch, The Flett Theatre.

Monday, 9 November
Annual Reunion of Members and Presentation of Awards, Goldsmiths' Hall, Foster Lane, London E.C.2.

GEMMOLOGY AND JEWELLERY STUDY TOUR OF LONDON NOVEMBER 1986

A group of fifteen American gemmologists, most of whom are engaged in the jewellery trade, began their highly successful study programme with an illustrated talk on antique jewellery by Jack Ogden, followed by a tour of the British Museum jewellery collections, including the Hull Grundy Gift. They attended a seminar on 'Synthetics and gemstone enhancement' with Ken Scarratt and his colleagues at the Gem Testing Laboratory of Great Britain, and took a special 'behind the scenes' tour of the London Assay Office. Other visits and guided tours included De Beers Diamond Information Department, Monnickendam's diamond cutting workshops at Hove, near Brighton, the Museum of London with a detailed view of the jewellery of the Cheapside Hoard, the Jewellery Gallery at the Victoria and Albert Museum, and the Gemstone Gallery at the Geological Museum. There were also illustrated talks on 'Jade' by Alan Jobbins and 'Glyptic gems' by Christopher Cavey. The final day included a visit to view the Crown Jewels, and the highlight of the evening was the attendance at the Presentation of Awards.

Other social events included a celebration dinner at the Royal Automobile Club, Pall Mall, London S.W.1, and visits of the tour included Windsor and Hampton Court, the Lord Mayor's Show, and attendance at the Service of Remembrance at the Cenotaph, Whitehall.

Members of the Study Tour group at Goldsmiths' Hall.

The party included the following Fellows and wives: Ellamae Anderson, James Coote, Murray Feine, Bob and Nancy Fessel, Dorothy Gibson, Eunice Miles, Jeanne Miller, Chuck Pollack, A. Rider, Jack and Margaret Seibert, Charles and Lillian Sharp, and Dan Simpson.

Letter to the Editor

From Kurt Nassau

Dear Sir,

My attention was drawn to the article 'A treatment procedure for improving colour and quality of zircons' by M.S. Rupasinghe and A. Senaratne (*J. Gemm.*, **20**, 3, July 1986) by an editor who wondered if his readers should be alerted to this work in his magazine. My comment had to be that it is certainly useful to have accessible the heat-treatment behaviour of Sri Lankan zircons of different colours; however–

1. This is hardly a 'new method' since zircons have been successfully heat-treated to colourless and various colours for a century or more; Bauer mentions heated zircon 'Matura diamonds' in his 1904 (1896) treatise and Webster details the heating of Sri Lankan zircons in his. No reference is given in the article to relevant older reports, e.g. those by W.F. Eppler (*Goldschmiede Zeitung*, **51**, 531, 1936), G.O. Wild (*Gemmologist*, 7, 98, 1938), and W.C. Buckingham (*J. Gemm.*, 2, 177, 1950) or to recent reviews such as that by K. Nassau in *Gemstone Enhancement*, Butterworths, 1984, pp. 172–3.

2. Colourless zircon long ago ceased to be an important commercial diamond substitute because synthetics supply a much more convincing simulation.

3. As discussed in the above-cited review and elsewhere, some heat-treated zircons may revert partially or completely to their original colour in the sun or even in the dark, a behaviour apparently not checked or at least not mentioned in this article.

4. Irradiation usually restores the original colour and it is rather doubtful whether this simple oxidation-state explanation referred to can cover the many colours and colour changes in zircon.

5. The authors' comment on the 'unmistakable' relationship between an elevated uranium content and a green colour implies cause and effect; note, however, that the iron content is equally elevated in the green samples, a result on which no comment is made. And so on.

Yours etc.,
Kurt Nassau

4 October 1986
170 Round Top Road, Bernardsville, NJ 07924, USA.

CORRIGENDUM

On page 202 above, in the footnote, for '**Odes**, ode ci, 1.10.' read 'CI, 10.'

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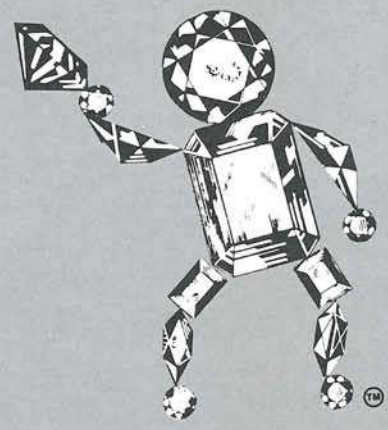

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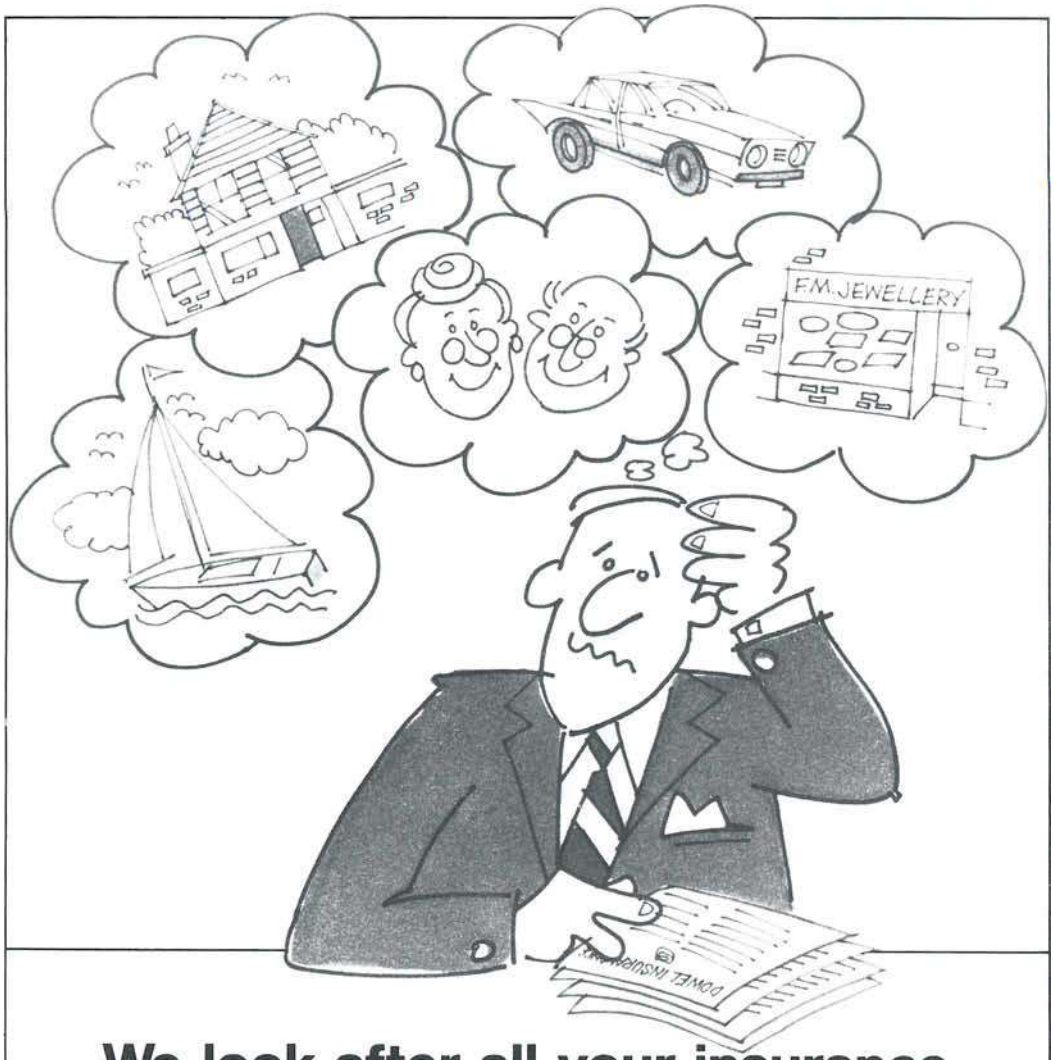

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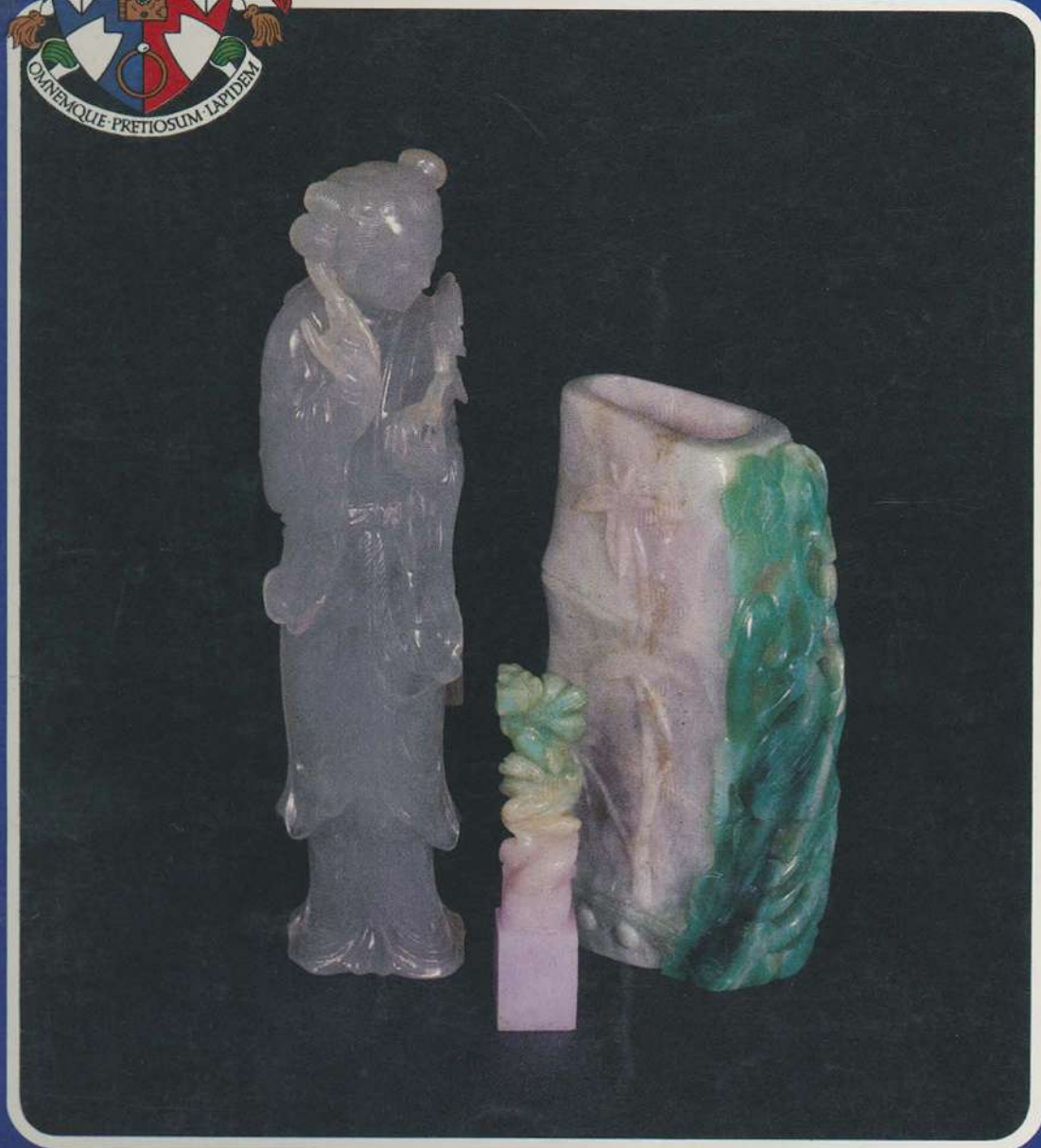

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Cover Picture

An unusually translucent jadeite figurine and other jadeite carvings showing colour variation (see 'Some colour variation in jadeite', p.376).
Photograph by E.A. Jobbins.

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A major new initiative in gemmological education

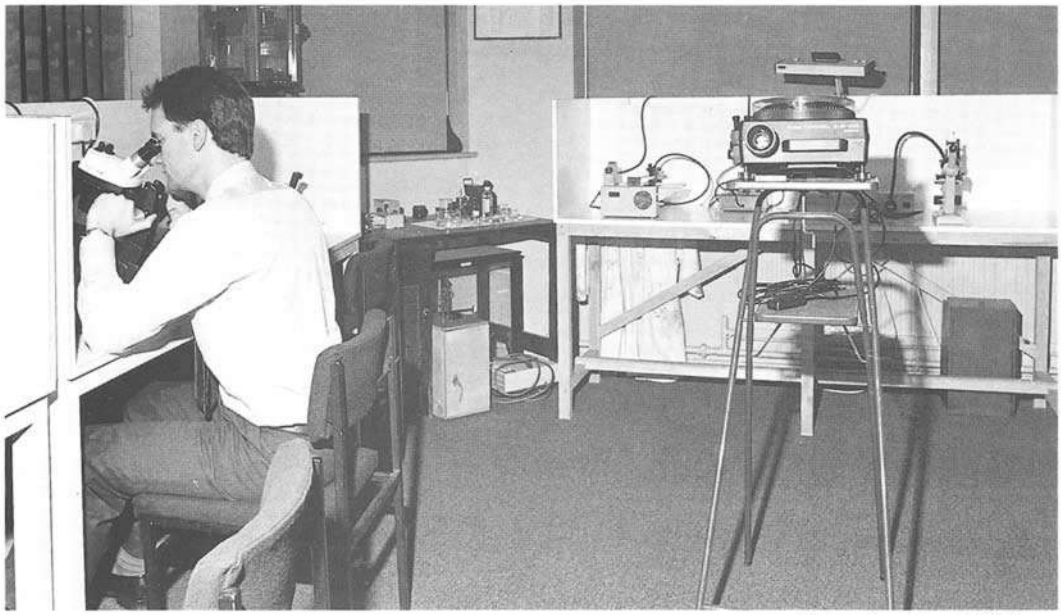

Photograph courtesy of K. Blakemore

The Gemmological Association has collaborated with the Gem Testing Laboratory of Great Britain to launch a programme of one-day courses.

The courses have been designed for the Association by Ken Scarratt and will be held at the Gem Testing Laboratory in London.

The aim is to give practical instruction and experience to students studying gemmology, particularly those preparing to take the FGA examination by home study, and updates specialized courses for all gemmologists.

Various courses are being offered, the dates of which are:

1 and 29 May	**Practical gemstone identification – General**
3 July	**Practical identification – Pearls**
17 July	**Practical identification – Jade, amber and their simulants**
31 July	**Practical identification – Synthetic ruby and sapphire**
28 August	**Practical identification – Synthetic emerald and amethyst**
2 October	**Introduction to diamond grading (of particular interest to students preparing to take the Gem Diamond examination.)**

Each course is limited to 12 participants and is offered at the especially low charge of £55 plus VAT (including lunch). The courses are open to all students and members of the Association who would like to take a short refresher course. Further information from Paula Jennings on 01-726 4374.

To book for the courses please use the coupon given on page 397 and enclose the necessary remittance.

Damage to cut diamonds

Dr H.A. Hänni, FGA, and G. Bosshart, GG

Swiss Foundation for the Research of Gemstones (SSEF)*, Zurich, Switzerland

Abstract

Diamonds are generally considered as extremely resistant gems. Thermal or mechanical damage is, nevertheless, possible during various stages of working (cutting, setting, soldering) or wearing the stones. Thus many cut diamonds reach the jeweller's counter with minor to distinct damage. Only a relatively small proportion of the observed injuries result from wearing. Minor blemishes can be removed with minimal weight loss by a specially trained cutter.

Chemical resistance

A diamond's high resistance to chemical attack derives from the strong covalent bonding between the carbon atoms in the diamond lattice. At low temperature and pressure conditions, it effects a strong inertia against all standard acids, caustics and solvents. However, at high temperatures, and in the presence of certain melts or gases, the diamonds do not comport themselves with such invulnerability any longer.

In our laboratory, several experiments were carried out on cut diamonds (Bosshart, in preparation) to shed light on their thermal behaviour. Exposed to air, the stones were heated in an electric laboratory furnace without any coating. Already during an annealing cycle of 30 minutes at 650°C, or after two hours at 600°C, a whitish turbidity appeared on the faceted surfaces. No transformation to (black) graphite or amorphous carbon was observed. Obviously alteration of the diamonds' outermost layers of carbon atoms by the oxygen in the air takes place as low as 600°C. During this oxidation process, the diamonds transform directly into gaseous carbon dioxide (CO_2). Whitish, shallow but rough burn marks are left behind. Considerably deeper burn pits are produced at higher temperatures and longer annealing.

In comparison with our static annealing experiments in the electric laboratory furnace, the turbulent supply of oxygen under the soldering torch of the goldsmith certainly leads to more serious burn marks at 600°C, if the mounted diamond has not, or not entirely, been coated by a borate (boric acid, Liquobor, borax, etc.). The function of the borate melt is to coat the diamond in order to prevent oxygen from reaching the surface of the stone. However, if the diamond has not been degreased, openings may form in the borate coating. Then corrosion of the diamond can start (Figure 10).

A borate melt is able to corrode corundums but not diamonds. The latter can be attacked only by the hot melts of metals like platinum, iron, tungsten, or by some strongly oxidizing compounds (De Beers Industrial Diamond Division: Properties of Diamond, special publication). Yet under all normal chemical conditions, diamonds do not react.

Mechanical Resistance

The hardness of a diamond, or more precisely its extremely high resistance to abrasion, is the prominent physical property which makes a diamond to be for ever. It is seldom that blemishes can be recognized by eye, even after decades of wearing the stone as a solitaire. A diamond occupies the uppermost level of the Mohs' scale of scratch hardness. This means that it is not scratched by any other mineral except by its own kind. The hardness depends on the direction of scratching on the crystal (hardness anisotropy). There are harder and slightly softer directions. This fact is taken into account during cutting because diamond surfaces can be worked successfully only in the softer directions.

The longevity of a diamond is limited by its tendency to split along very definite atomic layers when struck precisely parallel to them. This quality of developing flat separation planes is termed cleavage. Diamond possesses a perfect cleavage parallel to the eight octahedral crystal faces and less pronounced ones parallel to some other faces.

Another limitation is its sensitivity to knocks in any other direction, on facet edges and corners especially; bruises and percussion cracks are liable

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to form. Their size depends on the force of impact. Inversely, static pressure on surfaces does not harm a diamond at all.

Large inclusions represent yet another hazard for diamonds. However, it is a fairly rare accident when a piqué diamond with extended cleavages, or incorporating foreign mineral inclusions surrounded by tension haloes, breaks into pieces under mechanical or thermal stress.

Damage during cutting and polishing

Industrial cutting of diamonds cannot always be carried out with sufficient care, probably for reasons of time. Many a diamond cutter is entirely aware neither of the brittleness of all diamonds and of the internal strain inherent in many diamonds, nor of the corresponding vulnerability of the goods he is cutting. Consequently, many diamonds leave the cutting works with minor blemishes. The most frequent of these negative characteristics are small cleavages, pressure and percussion cracks, as well as burn marks.

An excessively strong pressure during the bruting process creates groups of tiny fissures parallel to the cleavage direction (Figure 1). They traverse the girdle and often appear at four different positions around the circumference, separated from each other by 90° (in the normal case of a 4-point brilliant). Finely bruted girdles show these tiny cleavages in a much less conspicuous manner than coarsely bruted girdles. In earlier days, these fissures were harmlessly designated bearding and wrongly considered external characteristics. Usually they can be removed; in these instances, the removal is easier and more complete by faceting of the girdle rather than by polishing it. Thus internal blemishes are eliminated and this results in an improvement of the clarity.

A further injury of the first hour, which is encountered quite frequently, consists of pressure cracks. They probably stem from the use of the dop, the tool which holds the diamond tight during cutting (Figures 2 and 4). The blemishes occur as small cracks, roughly on the same level of the pavilion, running across facet edges. They are caused by a too strongly tightened dop or by knocking vibrations (Figure 5). We also sometimes observe more or less circular fissures, mainly on pavilion facets, the origin of which we cannot yet explain. Possibly, however, there is a connection with the dop as well (Figure 3).

When a diamond is turned in the dop, scratches in the form of concentric arcs may occur on the table (Figure 6). The finger-like piece of metal pressing the pavilion of the brilliant into the dop causes these scratches when it is contaminated with diamond paste (Figure 4).

If diamonds are heated too much during the cutting operation, rough burn marks are incurred, especially on lower girdle facets, star facets and on the table. A build up of heat in the metal of the dop is responsible for this. As mentioned earlier, the superficial corrosion of the diamond already starts at 600°C with the formation of roundish to annular burn marks.

The view that fissures across facet edges are generated on diamonds as they are pressed against each other in a stone paper may be correct in certain cases. Stones in lots of considerable weight are particularly endangered. As a rule, however, the cause of the damage lies in the too strongly tightened dop. In order to form pressure cracks on diamonds in a stone paper, a greater force is required than that applied to such wrappings in general.

On the other hand, large diamonds merit individual packing because blemishes, like scratches and abraded facet edges can happen relatively easily.

The unpopular large culet of old-cut diamonds today has an equally extreme analogue in the pointed culet of the modern brilliant-cut (a pointed pavilion without any facet). The danger to this type of culet can be deduced from the fact that, during grading, we encounter less than ten undamaged pavilion pyramids for every one hundred diamonds originally with pointed culets. Usually the exact time of damage cannot be determined.

Damage during setting

Prominent parts of a cut diamond, i.e. not only the pointed culet but also the girdle, are especially sensitive to injuries. A girdle of medium thickness shows little tendency to cleave under the normal forces of impact during setting. However, the thinner the girdle, the easier it can chip under the influence of knocks, pressure or scratching. Thereby cleavage is stimulated if the direction of the destructive stress acts roughly parallel to it. Actually, irregularly formed fracture surfaces are encountered more frequently. Off to the sides, they readily change into short cleavage fissures.

Greater damage is occasionally caused by slipped punches, or by the stone-setter's electric hammer, and has a characteristic appearance. Mostly they are cataract fractures extending into the pavilion and are situated close to a prong (claw). In the central part of the depression, they have a conchoidal form and continue in cleavage steps towards the edge of the fracture (Figure 7).

Fig. 1. Fine cleavage fissures running across the slightly polished girdle of a brilliant-cut diamond. Darkfield illumination. 11x.

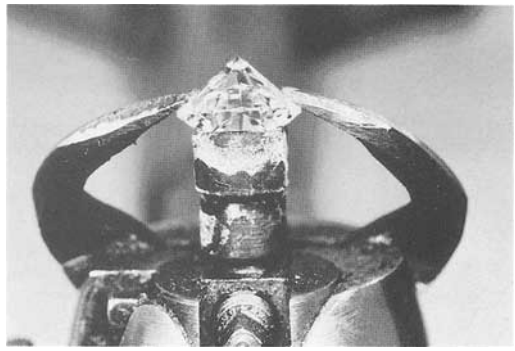

Fig. 2. Diamond fixed in a cutter's dop. Burn marks may appear at both points of contact on the pavilion.

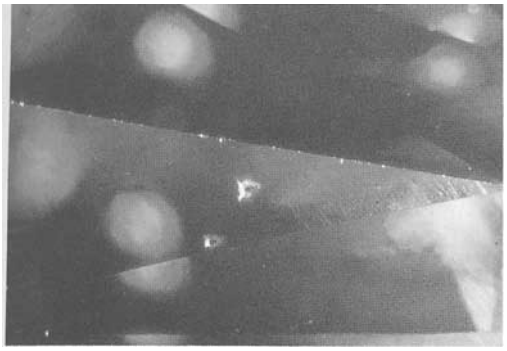

Fig. 3. Roundish cracks caused by percussion or pressure on a lower girdle facet. Darkfield illumination. 28x.

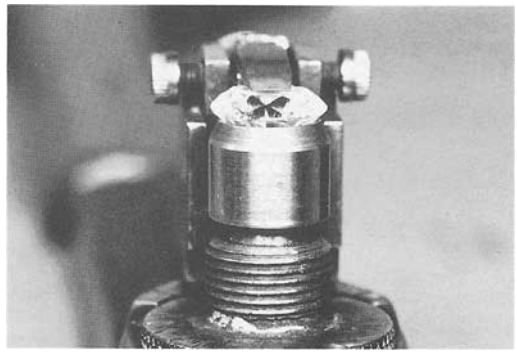

Fig. 4. Brilliant-cut diamond of 2 ct tightly mounted in the dop. Heat accumulation in the finger-like piece of metal sometimes leads to burn marks on the table.

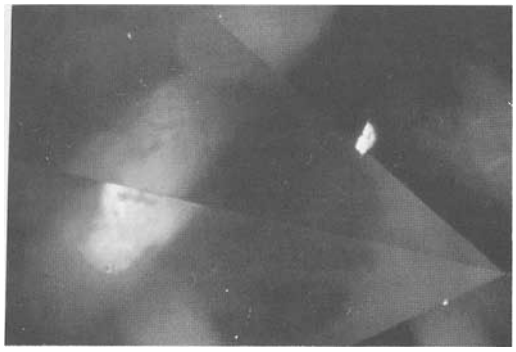

Fig. 5. Pressure crack across a pavilion facet edge of a brilliant-cut diamond. Darkfield illumination. 34x.

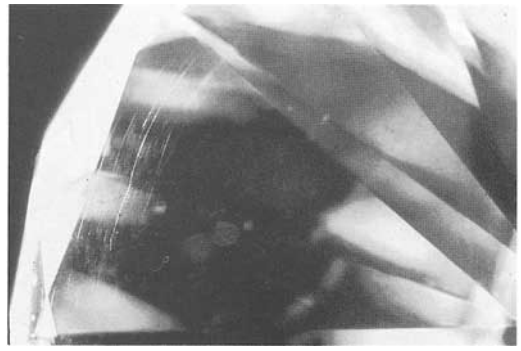

Fig. 6. Arc-shaped scratches on the table of a brilliant-cut diamond viewed from the pavilion side. Darkfield illumination. 17x.

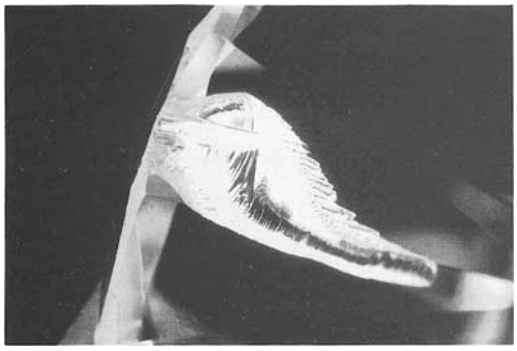

Fig. 7. Complex cataract breakage in the pavilion of a brilliant-cut diamond, generated by shock impact from the crown side on to the girdle zone. Darkfield illumination. 17x.

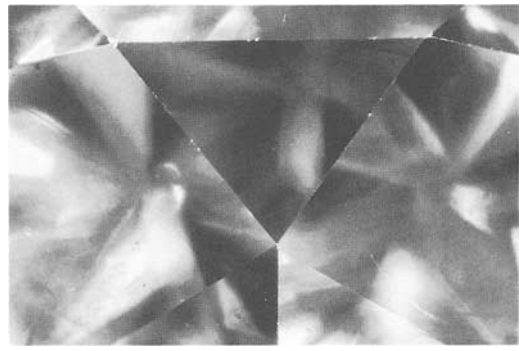

Fig. 8. Wear marks in the form of small shallow bruises on the edges and corners of a star facet and a fine scratch on an adjacent main facet. Darkfield illumination. 22x.

Damage during wear

Several types of blemishes are observed on mounted diamonds. The most widespread damage originates from knocking the set diamond against other objects. They consist of small, but loupe-visible, bruises and percussion cracks. They appear on edges and corners around the table and the crown facets. These wear marks demonstrate clearly that diamonds are slightly sensitive to the influence of shocks (Figures 8 and 9).

Larger breakages in the girdle region also occur, particularly on big diamonds with a very thin girdle (e.g. on old-cut diamonds). These cases, however, are less frequent than generally assumed in the jewellery trade. Stone settings with widely separated prongs favour the formation of such fractures. While ordinary percussion cracks effect a reduction of the clarity grade of loupe-clean stones only, larger fractures may easily lower a VS and even an SI clarity grade.

Further damage develops when a solitaire ring is worn next to a diamond-studded eternity ring. Since the ring on the neighbouring finger may rotate, it usually scratches the solitaire diamond at two opposite places according to how the ring has been placed on the finger. Rough, whitish abrasion marks result from this. They are also occasionally of fissure-like character.

Bruises and percussion cracks on the pavilion side of set diamonds are probably not the result of wearing jewellery. The pavilion is protected by the mounting and the finger. These blemishes are not recent and usually have been produced in the diamond factory, as mentioned earlier. Scratches may occur whenever diamonds touch, not only on stones in a lot but also in the mounted state, for example in the jewellery box.

Damage in repairing and transforming diamond jewellery

According to the introductory statements, superficial burn marks are produced under the goldsmith's torch if the mounted diamond has not been sufficiently degreased. The borate coating then cannot offer complete protection and burn marks are the consequences (Figure 10).

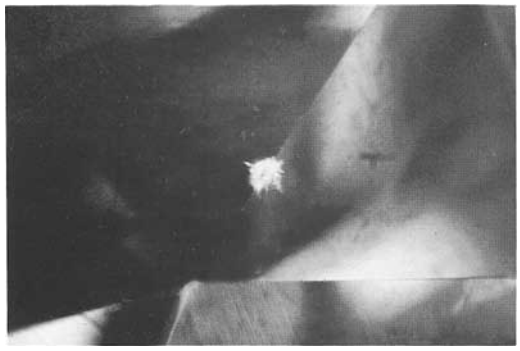

Fig. 9. Bruise on a table edge accompanied by fairly deep percussion cracks, radiating out to both sides of the facet edge. Darkfield illumination. 34x.

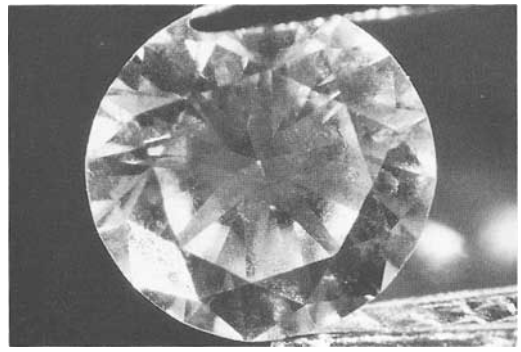

Fig. 10. Brilliant-cut diamond with whitish surface due to extensive burning. Brilliance grossly reduced. Darkfield illumination. 13x.

Repair of damaged diamonds

Most of the blemishes listed here can be removed with minor weight loss by a carefully executed repolishing operation. Damages of considerable depth demand a more complete recutting of the stone and cost more than just a few points of weight. Buying loupe-clean diamonds with weights like 1.00 ct is not recommended, for the simple reason that even a slight touch up of such a stone will decrease its weight below the critical limit.

The skills of a specialized diamond cutter are needed for a successful repolishing operation. He does not treat diamonds like the hardest material in the world but works gently and cautiously as if handling raw eggs. If this approach would take hold and prevail in all diamond workshops, a much larger portion of loupe-clean diamonds would reach the market.

In the damaged state, diamonds are mainly graded between VVS 1 and SI 2 if they do not contain any internal characteristics other than new cracks. SSEF clarity grading always assesses the possibility of improving the stone and a corresponding recommendation for repolishing, plus a precise sketch for the specialized cutter are provided. Thus, the repolishing operation finally raises such stones up to the clarity level which they could have had from the beginning or which they once possessed.

If, apart from the clarity, the cut can be ameliorated in the same operation, the recommendation for repolishing includes a comment for the cutter with respect to symmetry, polish, girdle or culet.

Conclusion

It can be stated that a precise microscopic examination of damage on cut diamonds in certain cases enables the recognition of the causes. The SSEF Laboratory has been in a position to carry out this type of analysis for many years. Insurance companies and other interested parties have regularly made use of this service.

Acknowledgements

We wish to extend our gratitude for technical comments and suggestions to the following professionals in Zurich: Messrs B. Christen, A. Guichon, F. Loosli, D. Roux, and P. Widmer. Figures 2 and 4 were kindly placed at our disposal by Mr Guichon.

[*Manuscript received 30 December 1986, revised 26 January 1987.*]

GIA INSTRUMENTS

The Gemmological Association now stocks a range of superb quality gem-testing instruments manufactured by the Gemological Institute of America.

DiamondLite

Included in the range is a diamond light which is designed to provide a constant, uniform, colour-corrected light source in an instrument that facilitates the rapid, accurate colour grading of diamonds. This DiamondLite also incorporates an ultraviolet light source to detect fluorescence in diamonds.

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Confusing colourless stones

David Kent, FGA

London

Before retirement I was employed by a London firm of jewellers as an appraiser and buyer of second-hand jewellery. One day in 1976 a client offered for sale a gentleman's flush-set 18 ct gold gypsy ring, set with three brilliant-cut colourless stones. The ring carried the London hallmark for 1975. Additionally there was a valuation, also dated 1975, from a Hatton Garden firm for a three stone flush-set diamond gypsy ring, stating that it should be insured for £980. The client intimated that he would be prepared to sell the ring for about half that amount.

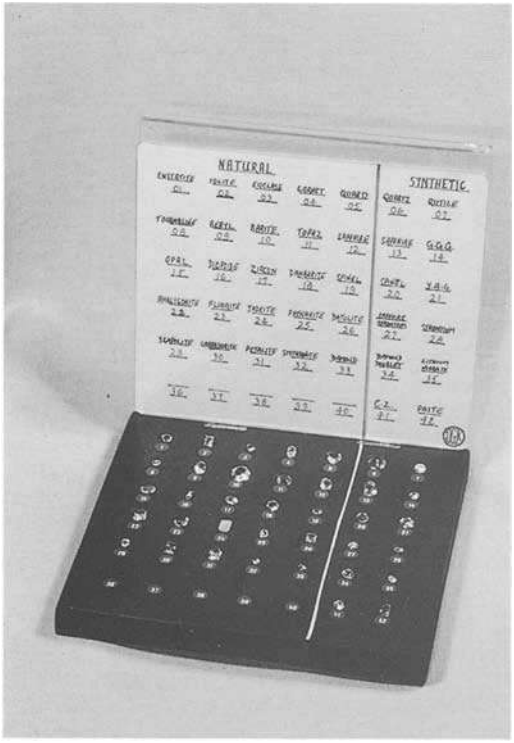

Fig. 1. Box constructed by the author to display and house his collection of colourless stones.

I was impressed by the apparent good quality of the stones, which I roughly estimated as weighing 0.50 ct for the centre and 0.25 ct for each of the two side stones. Using my lens and Moe gauge, I inspected the ring in our very good, north-facing, 'buying' daylight. I suddenly realized that the stones showed too much dispersion, and being taken aback, refused to offer, and handed the ring back to the client.

Being already familiar with simulants such as YAG and GGG, I was puzzled and immediately sent a message around the branches warning the staff that a new simulant appeared to be to hand. Two or three weeks later I learned that a number of jewellers had been defrauded of considerable sums by the use of a new diamond simulant – cubic zirconia!

Having quite a good private collection of gemstones, I resolved to display as many colourless stones as possible in one case for comparison purposes. Since this time I have been able to add to the original display, some stones being kindly presented by good friends.

The collection is housed in a purpose-made display box constructed by the author (Figure 1). A piece of hardwood (an old breadboard!) was cut to size (204 × 184 × 17 mm) and smoothed with abrasive paper. The positions of the holes to locate the stones were carefully measured out and then marked with a centre punch and a hammer. The small holes so formed were then enlarged using twist drills of suitable size to form shallow cups. A chisel was used to make rectangular holes. After smoothing the wood was stained using black leather dye, or it could be sprayed with grey primer followed by matt black, both paints being available in aerosol form from paint shops or car accessory stores. The self-adhesive numbers are available from any good stationer. A hinged lid of clear Perspex was provided to keep the stones in position.

A few years ago A.D. Morgan, FGA, made for me an efficient infrared reflectometer, and it may interest fellow gemmologists to see how closely the

Table 1. Infrared reflectometer readings on colourless gemstones in the David Kent collection. Diamond calibrated at 70.

Meter reading	Mean RI	Species	Weight (ct)	SG
17	1.434	Fluorite	2.91	3.18
17	1.438	Opal	1.96	2.00
19	1.505	Paste	1.15	2.44
20	1.506	Petalite	2.06	2.39
22	1.549	Quartz	2.67	2.65
22	1.549	Synthetic quartz	4.67	2.65
23	1.540	Iolite	1.19	2.58
23	1.555	Beryllonite	0.84	2.82
23	1.560	Scapolite	0.39	2.60
23	1.561	Labradorite	1.25	2.68
23	1.583	Beryl	1.48	2.74
25	1.615	Topaz	3.95	3.56
25	1.622	Amblygonite	2.58	3.03
25	1.629	Tourmaline	0.60	3.00 (approx)
25	1.640	Baryte	8.01	4.49
25	1.647	Datolite	0.96	2.90
26	1.633	Danburite	1.58	2.98
27	1.655	Jadeite	1.77	3.34
27	1.660	Enstatite	1.03	3.22
27	1.662	Euclase	0.43	3.10
28	1.660	Phenakite	0.85	2.98
29	1.65 vague	Smithsonite	044	4.19 (approx)
29	1.678	Diopside	0.51	3.22
30	1.712	Spinel	0.96	3.61
30	1.725	Synthetic spinel	1.68	3.65
31	1.736	Grossular	1.27	3.60
32	1.782	Benitoite	0.44	3.65
33	1.764	Sapphire	2.73	4.00
33	1.764	Synthetic sapphire	3.93	4.00
38	1.830	YAG	2.90	4.57
39	1.764	Synthetic sapphire/ strontium titanate doublet	1.12	4.66
42	1.95	Zircon	2.52	4.66
42	2.03	GGG	1.67	7.10
56	2.17	Cubic zirconia	1.51	5.80
62	2.25	Lithium niobate	0.64	4.70
64	2.41	Strontium titanate	1.21	5.14
70	2.42	Diamond	0.48	3.52
76	2.42	Diamond/synthetic sapphire doublet	1.68	3.82
80	2.62	Synthetic rutile	1.55	4.20

meter readings follow the refractive indices, shown in the Table 1. The RI values above 1.81 are approximate, having been determined by the real and apparent depth method. The specific gravities were determined by the hydrostatic method using water.

[*Manuscript received 13 February 1986, revised 9 January 1987.*]

Investigation of a sapphire cat's-eye from Burma

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Abstract

A sapphire cat's-eye from Burma is described and the cause of chatoyancy was investigated. The sample does not show needle- to rod-like inclusions, which are in general responsible for chatoyancy of gemstones. The Burmese sapphire is not a single crystal but consists of two sectors which are slightly inclined against each other: the inclination angle equals 11°. In both sectors, growth planes parallel to the hexagonal dipyramid $(22\bar{4}1)$ as well as glide planes parallel to the basal pinacoid (0001) are observed. Chatoyancy is caused by total internal reflection at irregular patch-like fissures on basal glide planes.

Introduction

Rubies and sapphires from certain occurrences, e.g. Burma and Sri Lanka, frequently show asterism when the crystals are cut in the cabochon form. The most common six-rayed stars are caused by needle- to rod-like inclusions of rutile or other iron-titanium oxides. The needle axes of these inclusions are lying in the basal plane (0001) in three different orientations parallel to traces of the prism faces of the host crystal. If only one set of parallel orientated needle-like inclusions is present in corundum, a cat's-eye is produced. This condition, however, is extremely rare if existing at all in natural corundum. On the other hand, corundum cabochons revealing less than six rays on the curved surface exhibit needle-like inclusions in three orientations but are not cut in the appropriate direction, i.e. with the base of the cabochon at right angles to the *c*-axis of the crystal.

The present paper describes a small blue sapphire cat's-eye from Burma. A preliminary microscopic investigation disclosed that a light effect resembling chatoyancy is not due to needle-like inclusions parallel to one direction in this extraordinary sample. Therefore, a detailed study of the stone was undertaken in order to clarify the cause of the optical properties of the sapphire.

Microscopic investigations

The blue sapphire from Burma was cut as an oval cabochon of 4.0 × 5.5 mm in size and weighed 0.53 ct. The sample disclosed a chatoyancy-like effect on the curved surface: the direction of the reflected ray is orientated parallel to the long 5.5 mm axis of the oval stone. Microscopic investigation in methylene iodide disclosed that the sapphire consists of two parts which are separated by an irregular step-like surface looking like a landscape with a dense distribution of hillocks (Figure 1). In each part of the sample, one set of straight parallel planes is observable, the two sets of planes are slightly inclined against each other forming an angle of ≈ 169° (Figure 2). The orientations of the two sets of planes are determined to be parallel to the basal planes of the two parts of the sapphire crystal. Consequently, the sample is not a corundum single crystal but consists of two sectors, the *c*-axes of which are slightly inclined to each other: the inclination angle equals 11°. Under crossed polarizers, interference striations and interference colours are observable at the irregular boundary between both parts of the corundum crystal (Figure 3). This optical effect is due to the different crystallographical orientations of these sectors. In each part of the corundum crystal, a second type of sets of straight parallel planes is observed forming angles of 100° with the first type of straight parallel planes described above (Figure 4). By rotation of the corundum crystal about various axes, especially about the short 4.0 mm axis of the oval stone, only the first type of structural plane reveals irregular spots or patches, which display total internal reflection when the angles of the incident ray with the normal are greater than 35° (Figure 5). Transparency is observed at smaller inclinations of the face normal versus the microscope axis, i.e. when the angle of the incident ray with the primary ray of light is smaller than 35°. This critical angle of ≈ 35° corresponds with the critical angle of corundum in contact with air or vacuum, which equals 34.4° (cf. Schmetzer, 1986).

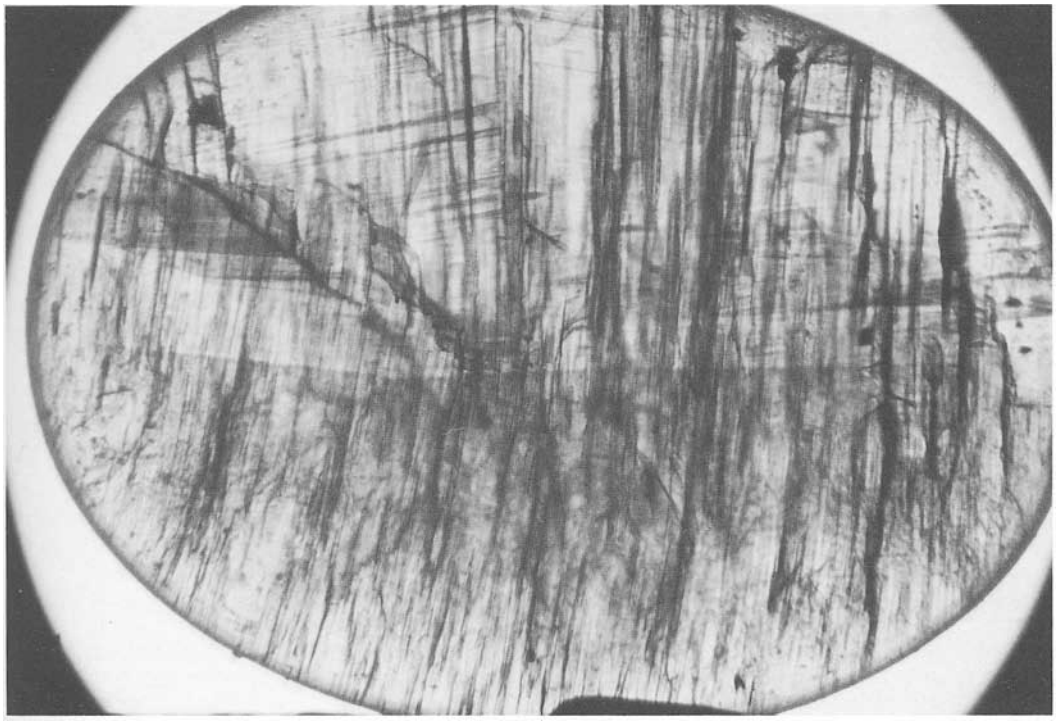

Fig. 1. General survey of sapphire cat's-eye from Burma; the sample consists of two parts which are separated by an irregular surface, each part reveals glide planes parallel to the basal pinacoid (0001). In the upper part two sets of growth planes parallel to the hexagonal dipyramids (2241) are present. 36x.

Discussion

In general, untwinned natural ruby and sapphire crystals are single crystals without different crystallographical orientations of different parts of the crystals. Natural corundum of the particular type, which is described in the present paper, is extremely rare. In the experience of the authors, only one non-single crystal of corundum has been observed in the past. This sample from Sri Lanka, however, was only available for a limited time and thus was not studied in detail.

On the other hand, in synthetic corundum crystals which were produced by the Verneuil technique, slight inclinations of different growth sectors against each other are common. The irregularly curved surfaces between these sectors,

Fig. 2. Sapphire cat's-eye from Burma; the two parts of the stone, which are separated by an irregular surface, reveal glide planes parallel to (0001). The glide planes are inclined against each other forming angles of ≈ 169°. 50x.

Fig. 3. Sapphire cat's-eye from Burma; interference striations and interference colours are observable at the irregular boundary between the two parts of the crystal. Crossed polarizers. 20x.

Fig. 4. Sapphire cat's-eye from Burma; two sets of growth planes parallel to the hexagonal dipyramids (2241) intersect with glide planes parallel to the basal pinacoid (0001). 40x.

Fig. 5. Sapphire cat's-eye from Burma; irregular spot- and patch-like fissures on basal glide planes showing total internal reflection at distinct angles. 70x.

which are called small-angle grain boundaries, display interference striations and interference colours under crossed polarizers (cf. Schmetzer, 1986). A second characteristic property of Verneuil-grown corundum is the presence of intersecting glide planes parallel to the second-order hexagonal prism $(11\bar{2}0)$. These prismatic glide planes are formed at extremely high temperatures [above 2000°C] (Scheuplein and Gibbs, 1960; Stephens and Alford, 1964).

In natural or synthetic corundum, glide planes parallel to basal faces are produced by external stress at temperatures above 900°C (Kronberg, 1957; Scheuplein and Gibbs, 1960) or even at room temperature (Johnsen, 1917; Veit, 1922). Both types of basal and prismatic glide planes are shown in Figure 6. A third type of structural separation plane parallel to the rhombohedral face $(10\bar{1}1)$ is limited to natural corundum with intercalated lamellae of boehmite along these so-called parting planes (White, 1979; cf. also the paper of Judd, 1895).

The microscopic observations of two types of intersecting structural planes in the non-single crystal sapphire from Burma, which is described in this paper, suggest that at least one set of these planes are not growth structures. Growth structures in natural corundum are commonly observable parallel to the basal pinacoid (0001) as well as parallel to the second-order hexagonal prism $(11\bar{2}0)$, parallel to the rhombohedron $(10\bar{1}1)$, and parallel to different hexagonal dipyramids $(hh\bar{2}\bar{h}l)$. Growth planes, however, do not display irregular patches with total reflection at distinct angles. These facts support an interpretation of both types of structural planes in the cat's-eye sapphire from

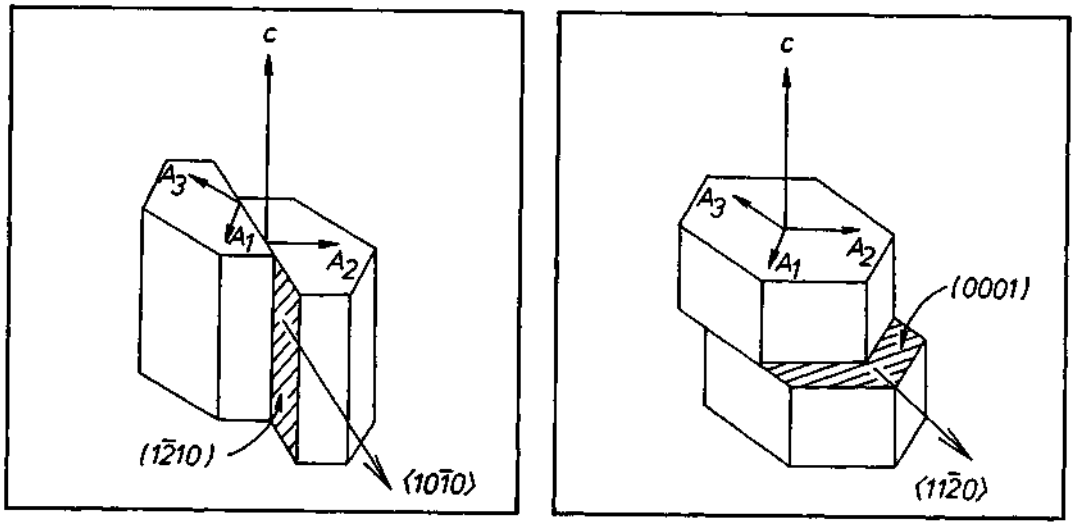

Fig. 6. Schematic drawing of basal and prismatic glide planes and glide directions in corundum (after Scheuplein and Gibbs, 1960).

Burma as growth planes parallel to the hexagonal dipyramid z $(22\bar{4}1)$ and glide planes parallel to the basal pinacoid c (0001). The different crystallographical orientation in both parts of the crystal is caused by an inclination of structural planes, which is presumably generated during the glide process. Details of the mechanism of formation of the irregular boundary between both parts of the crystal, however, are unknown at present. A possible explanation of the formation of this structural feature is a combination of basal and prismatic gliding, which was artificially produced in synthetic Verneuil-grown corundum by Scheuplein and Gibbs (1962).

The presence of irregular patch-like fissures with total reflection at distinct angles is responsible for the optical effect of the cabochon-cut stone, which is similar to a cat's-eye in other well known gemstones such as chrysoberyl and tourmaline. These irregular fissures are presumably formed on the basal glide planes during the slip process.

Acknowledgements

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On the colour of gemstones and Nelson's 'body colour'

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Dr Nelson's article on the measurement of colour in gemstones (Nelson, 1986) covers many of the complexities involved in this perplexing problem and gives his views of a solution for '. . . taking the first steps towards establishing international standards for the quantitative description of gemstone body colour'. In his article a number of important aspects of colour measurements are discussed. I do not agree with all the statements he makes and feel that some significant matters have been omitted, but I wish to comment here only on one specific aspect of his approach.

It appears to me that Nelson has fallen into a trap to which we scientists unfortunately are rather prone. Let us call it the *irrelevant model trap* and clarify this as follows. Frequently, in scientific and technological research, one proposes a 'model', an idealized approach to what one is trying to achieve. Such a model is usually an interpretation of what one feels are the most important aspects of the problem and includes the relationship of these aspects to characteristics that can be measured. The next step involves a study on how to perform these measurements and from these measurements to deduce the nature of the important aspects.

At this point the model is complete. The task is, however, not yet finished, for it remains to be demonstrated that the model does indeed correspond to the reality it was intended to represent. This last step has not been performed by Nelson and it is easy to show that there are fatal flaws in attempting to move from his model back to reality. These flaws involve one concept discussed by Nelson at length and one other which is never specifically discussed, although it is at the centre of his approach.

Nelson clearly recognizes that 'Colour is *what we see*' (his emphasis). It is curious therefore that he does not explain why the colour that is measured in his model is the 'body colour'. And here is the problem: when we look at a faceted gemstone, we see much more than just a body colour.

Before going any further, we need to know exactly what Nelson means by 'body colour', a term which he does not define. Part of his Figure 9, shown here as Figure 1, appears to give the answer. If a beam of white light enters the table facet near its centre at a small angle and is returned along the same path by frustrated reflection from a diffusing white rubber* in contact with the back of the stone, then the colour carried by this beam emerging from the table is Nelson's 'body colour'. Presumably this term is intended to distinguish the colour seen near the centre of the table facet from that perceived near the edges or rim of the stone. There are three separate problems with this approach, any one of which is fatal to the validity of this model.

First, '*what we see*' when looking at a gemstone does include the edge or rim region; if this is different in hue or in intensity from the central region of the gem, as it usually is, it will clearly influence the overall colour perception our brain receives from our eyes and thus can hardly be ignored. Two stones could easily have the same 'body colour' with significantly different edge colours and therefore give quite different overall colour impressions.

Second, the 'body colour' approach as used by Nelson excludes the effects of dispersion and of pleochroism (Nassau, 1983). These are, however, a part of '*what we see*'. As one example, the pleochroism is present as dichroism in the case of ruby; a piece of ruby rough shows its best colour when the cut is oriented so that the purple-red of the ordinary ray is dominant rather than the orange-red of the extraordinary ray. This aspect also makes any such measurement technique not particularly useful for rough, as suggested by Nelson, since a range of colours could be obtained depending on the orientation of the windows on the rough with respect to the optic axes.

*Even if the white rubber were to act as an integrating sphere does (possibly implied by Nelson's use of the word *multiple* in 'frustrated multiple internal reflection' but apparently negated by subsequent statements), the remarks following would still apply, although with minor modifications.

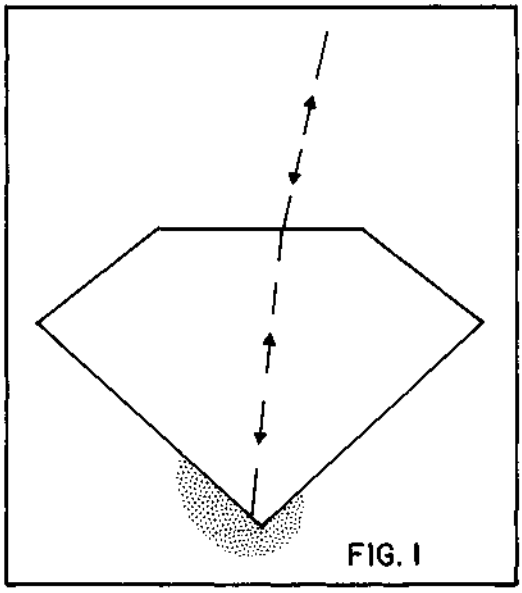

Fig. 1. The path through a gem in Nelson's 'body colour' technique.

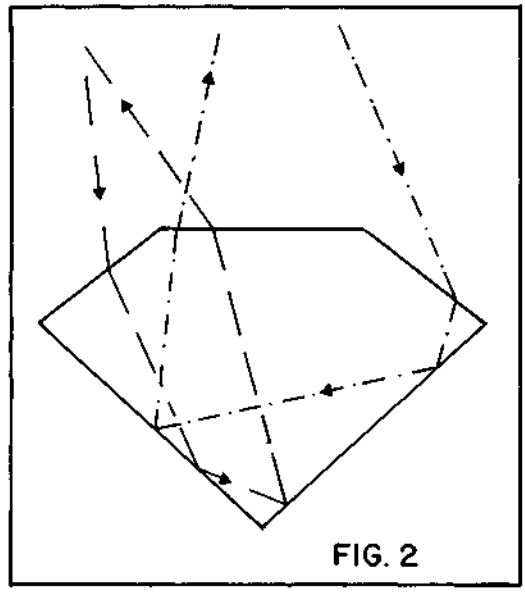

Fig. 2. Typical viewing paths in a gem, illustrated for a diamond; both paths can be traversed in either direction.

The third vitiating aspect is the question of the optical path within the gemstone. This might not matter if just a single optical path were involved, but it is not. The exact returning path of Figure 1 as used by Nelson is not present under normal viewing conditions because (a) the head of the viewer blocks that light which could produce a precise returning path and (b) frustrated reflection is not present. There is a wide range of actual paths contributing to the perceived colour, only two of which are shown schematically in Figure 2. This involves not only paths approximately perpendicular to the table, but also paths at least partially near parallel to the table, thus sampling different parts of the pleochroism. Note that paths emerging from the table may have entered the gemstone near the edge and vice versa. Also note that pleochroism does produce significant colour variation, even though the light is not polarized.

Except in rare and unusual circumstances, the result of these three effects will be that the 'body colour' determined by following Nelson's procedure will not be the same as the overall colour impression produced by the gemstone under ordinary viewing conditions. Yes, it would indeed be convenient if colour measurement could be taken over by what Nelson calls a 'dispassionate machine', but this would be useful only if it gave an answer relevant to the question being asked: '*what colour do we see?*'

These are the reasons why I believe it to be obvious that it will always be necessary to use the eye to compare the overall colour impression produced by a gemstone viewed *as a whole* with some other kind of reference material, be it a light-produced image, a set of master stones, or an opaque or transparent pigmented chart of some type. There are, admittedly, problems in each of these approaches, and a very specialized training will be required so that centre colour, edge colour, pleochroism, refractive index, dispersion, and all other optical effects present can be incorporated into a single visually-perceived colour *on which different observers can agree*. The colour measurement problem has been satisfactorily solved in many other systems, as mentioned by Nelson; he should, however, not permit himself to be taken in by the deceptively simple gemstone which poses problems far more complex than do any of these other systems.

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The two-colour beryl from Orissa, India

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Introduction

Numerous gemstones show different colours in the same crystal, sometimes differing from end to end, at other times in concentric layers as witness to the varying chemical-physical processes involved in their formation. 'Water melon' tourmaline is a well-known example of a gemstone showing different chromatic zones, colours ranging from red to pink and green in many different shades.

The corundum group sometimes produces specimens of different colours of yellow, blue and pink, occasionally mixed by the reflection of the facets in the faceted stones. Recently two-coloured quartzes have made their appearance in the trade, their colour being correlated with different oxidation states of iron. As in quartz, iron and its oxidation state is responsible for the colour of beryl, a mineral incapable of possessing any colour in its pure state.

The occurrence of beryl in the Pulbani district of Orissa State was limited to a few localities in the Eastern Ghats region, and the particular samples were mined in the Gopalbur and Lukapara area. The region is characterized by a complex of metamorphic rocks such as charnockite-khondalite-leptynite associated with rocks rich in hydrous minerals. The charnockite shows intrusive relationship towards the khondalite and has itself undergone post-magmatic changes such as albitization and myrmekitization (Crookshank, 1938). The charnockites have also formed hybrid gneisses with khondalites and sometimes with other ancient gneisses. In this region crystalline limestones, cordierite gneisses, sapphirine bearing rocks, and nepheline-syenite are also found.

The beryl-bearing and mica pegmatite bodies of variable size are probably localized along the fracture planes of the metamorphic rocks. Green shales and medium to coarse-grained yellowish sandstones, having pebbles and conglomerates of Gondwana group of rocks, also occur in the basin with faulted boundaries on east and west (Krishnan, 1982).

Orissian deposits furnish gem beryls which occur in colourless and yellow, and occasionally the crystals show lighter hued yellow colour zones, parallel to the basal plane.

Experimental

The origin of colour in beryl has recently been revised by Goldman *et al.* (1978), supporting the conclusion that iron is responsible for different colours in beryls when located primarily in the aluminium site, though the colour is derived mainly from the amount of ions located in the channels formed by the silicon ions. Less often specimens of natural origin showing sectored variation in colour and properties like the two samples from the Orissa State are reported.

The two beryls examined occurred in pegmatite bodies in the Pulbani mining area and are associated with cordierite, corundum, garnets, quartz and chrysoberyl (cat's-eye and alexandrite). The investigated specimens (Figure 1) weighing respectively 4.13 and 3.97 ct, were cut with an octagonal outline with long parallel facets (step cut) clearly showed the two-colour separation line running across the middle of table (Figure 2).

With the intent of a preliminary checking of the greatest variation between the yellow and colourless areas of each sample, the refractive indices were evaluated using oriented laminae cut parallel to the optical axis of the crystals. Preliminary optical observations led to recognition of elongated fibrous inclusions, strictly following the direction of the *c*-axis, referable to growth-tubes which are spread through the entire volume of the beryl, and are filled by birefringent material.

Cavities of different sizes with prismatic habit orientated with elongation direction parallel to *c*-axis of the beryl matrix are also present. It seemed appropriate to conduct the present study to determine the mineralogical characteristics of these two-colour beryls to define their formational conditions.

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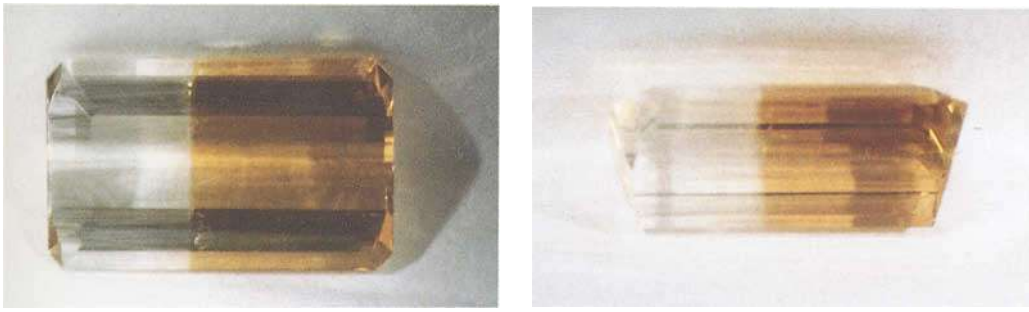

Figs. 1 (a) and (b). Two-coloured beryls from Orissa.

Table 1 summarizes the gemmological properties of one of the two samples probably cut from the same crystal. The density measured by the hydrostatic method gave a value of 2.699 ± 0.002 g/cm^3 while the RI reading taken with a hemisphere refractometer using monochromatic sodium light, turned out to show different values corresponding to the different regions of the specimen. The shadow edge gave indices for extraordinary ray n_ϵ at 1.574 and for the ordinary ray n_ω at 1.580 on the yellow portion, n_ϵ 1.570 and n_ω 1.575 on the colourless portion.

An additional reading taken across the interface of the colours gave the values of 1.570, 1.573 and 1.580. Microscopic examination of the specimens immersed in benzyl benzoate revealed a barrier of acicular growth-tubes all oriented parallel to the main growth axis. They seem to originate from the same plane parallel to the (0001) pinacoid protruding from a layer of blocking guest microlites. Further electron microprobe analysis (EPMA) investigation confirmed the presence of acicular parallel growth tubes, some of them breaking the surface of the specimen, having the same composition as the host crystal. A section of a tube-like inclusion breaking the surface of the beryl is shown in Figure 3.

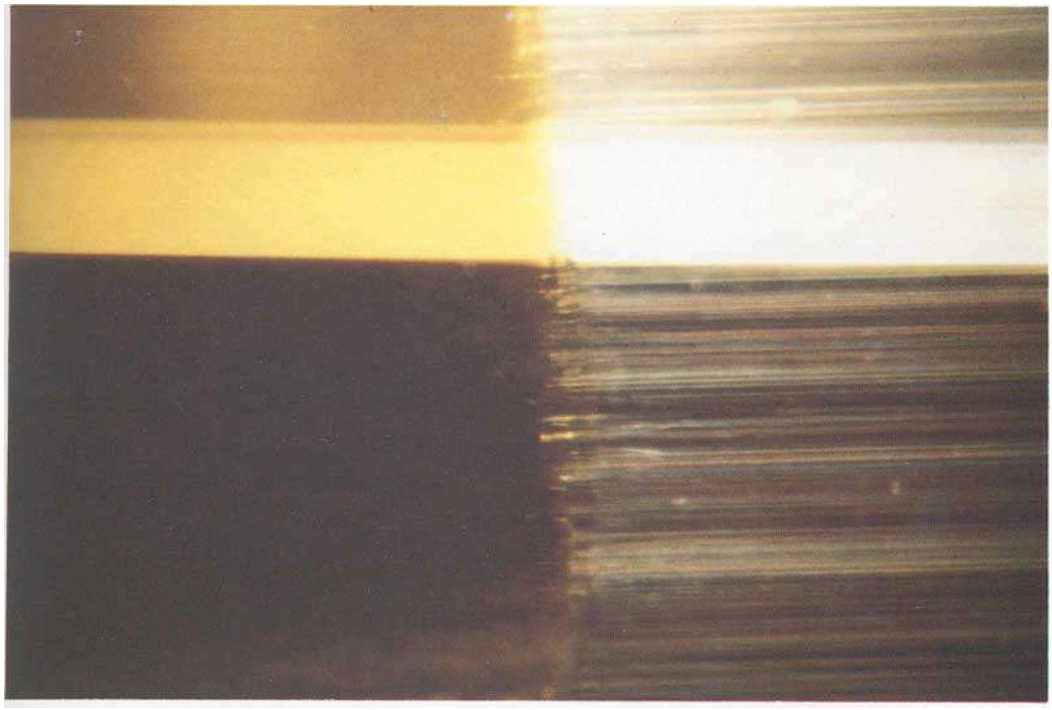

Fig. 2. Photomicrograph of some acicular inclusions reaching the middle of table and forming the border-line between yellow and colourless areas. 45x.

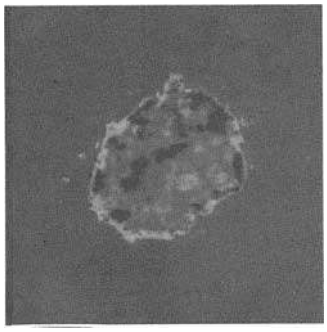

Fig. 3. Section of an acicular inclusion protruding through the (0001) plane. SEM photograph, 1000x.

EPMA quantitative analysis performed on both colourless and yellow sectors has shown different chemical compositions. The yellow area reveals a higher concentration of iron, 0.67 wt.%, against 0.13 wt.% in the colourless area, while a higher percentage of aluminium is reported in the colourless, 19.90 wt.%, against 19.32 wt.% in the yellow area (Table 2). Figure 4 shows a quantitative elemental distribution of Al_2O_3 and FeO through the two different coloured areas.

Table 1. Gemmological properties of two-coloured beryl from Orissa

Crystal system	Hexagonal	
Hardness	7½ (Mohs)	
Toughness	Strong but brittle	
Cleavage	Poor	
Fracture	Conchoidal	
Density	2.699±0.002 g/cm^3	
Transparency	Good	
Optical character	Uniaxal negative	
Pleochroism	Absent	
Long-wave ultraviolet (365 nm)	Inert	
Short-wave ultraviolet (253.7 nm)	Inert	
Visible spectrum	540 nm (Fe)	
Optical observation	Elongated fibrous inclusions, minute unidentified inclusions, some K-feldspar	
Birefringence	Colourless area 0.005	
	Yellow area 0.006	
RI	Colourless area	n_ϵ 1.570±0.002
		n_ω 1.575±0.003
	Yellow area	n_ϵ 1.574±0.004
		n_ω 1.580±0.002

Table 2. Chemical analyses of two-coloured beryl from Orissa

	Colourless	Yellow
SiO_2	64.16	64.53
TiO_2	tr.	tr.
Al_2O_3	19.90	19.32
Cr_2O_3	—	—
FeO†	0.13	0.67
BeO*	12.96	12.94
MnO	—	—
MgO	0.10	0.11
CaO	0.12	0.09
Na_2O	0.13	0.12
K_2O	0.16	0.12
Li_2O	nd	nd
Cs_2O	nd	nd
Numbers of ions on the basis of 36 (O)		
Si	11.571	11.594
Ti	—	—
Al	4.225	4.102
Cr	—	—
Fe	0.022	0.097
Be	5.612	5.581
Mn	—	—
Mg	0.022	0.032
Ca	0.022	0.022
Na	0.022	0.022
K	0.022	0.011
Li	—	—
Cs	—	—
Σ	9.947	9.867

Σ = sum of metal ions other than Si

†total iron as FeO
*dosed with pyrophosphate

Conclusion

The pair of unusual gemstones reported in this paper have been cut in order to place the interface, where the colours turn from colourless to yellow, exactly in the middle of the table facet producing a pleasant chromatic effect. Such interface proved to be formed by a barrier of included crystals pre-existing at the start of growth of the beryl crystal, some of them identified as K-feldspar. Such barrier of guest microlites produced a blocking effect in the growing beryl causing crystallization of growth tubes within the embedding crystal.

Acknowledgements

The constructive suggestions of Prof. G. Graziani, Dept of Earth Sciences, University of Rome, are gratefully acknowledged.

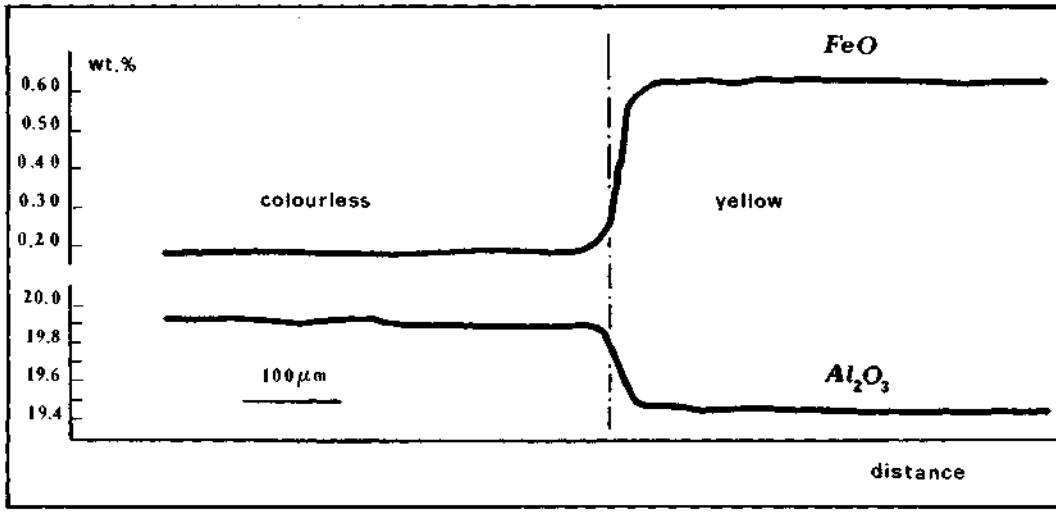

Fig. 4. Diagram showing the increased concentration of FeO in the yellow portion of the bi-coloured beryl compared with the colourless part, and the greater concentration of Al_2O_3 in the colourless compared with the yellow part.

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Notes from the Laboratory – 10

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Saussurite, a rock composed essentially of albite and zoisite and which can closely resemble jadeite and nephrite, is usually described only in brief terms in the sections of textbooks which deal with the jades rather than under its own heading, say in the sections dealing with 'unusual minerals' (e.g., Webster, 1983; G.F. Herbert Smith, 1972). Saussurite's representation in these works tends firstly to indicate that it will only be met with rarely, and secondly that the position it holds in the gemmological world is one of a substitute for the jades and that it is not regarded as a material to be considered in its own right. However, a description of saussurite in 1974 (Jobbins and Rutland, 1974) which includes colour photographs, adequately fulfils the need for more detailed information of this material.

Fig. 1. A string of one hundred saussurite beads showing the variations in colour.

Jobbins and Rutland examined six carvings in an attractive green material over a period of two years at the Institute of Geological Sciences, London. Some of these had been sold in Hong Kong or China as jade or 'new jade', but a detailed examination proved that they were composed of either dominant or very significant proportions of saussurite. Their report on the properties of these six items and two standard specimens from the collections, as well as on the properties revealed by many analyses of saussurite since it was described by H.B. de Saussure in 1780, emphasises the possible variations in the composition of this material, SG, RI, hardness, absorption spectrum and general appearance. Using X-ray diffraction their examination revealed compositions which included the presence of zoisite, Ca-rich plagioclase, clino-enstatite, diopside and chlorite, whilst their normal gemmological examination revealed SGs ranging from 2.85–3.22, RIs ranging from 1.55–1.56 for the white areas to 1.68–1.70 for the darker areas (although the latter

Fig. 2. A saussurite carving of a seated lady, mostly white in colour but with several areas of green varying in shade from light to very dark.

Fig. 3. The back of the carving in Figure 2.

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Fig. 4. A saussurite carving of two birds in a tree showing the variations in colour, cf. Figures 1, 2 and 3.

results were not felt to be reliable), a hardness of between 5 and 7, and absorption spectra varying from being 'not distinctive', to 'Cr lines in red' with 'absorption of blue/violet', to a 'line in deep violet'.

It is clear then that saussurite, unlike the majority of materials handled by gemmologists, does not have convenient constants by which it may be identified; indeed it is its variable properties coupled with its mottled green and white appearance that first give hints towards its identity. However, these are only hints and as stated by Jobbins and Rutland thirteen years ago in remarking about the specialized equipment needed to identify their specimens, 'The material will create problems in the future for many gemmologists and dealers'. A mottled green and white rock which had some properties similar to those of saussurite was examined by Robert E. Kane in 1985 (Fryer *et al.*, 1985). In this case X-ray diffraction revealed the major constituents to be a white plagioclase feldspar and a green muscovite mica and the material was therefore only reported upon as being a rock consisting of two or more minerals.

After not having examined any examples for some time, we were recently asked to examine three mottled green and white items which, following X-ray powder diffraction analyses, were identified as saussurite. The first, which was submitted by a different client to the other two, was a string of one hundred round drilled beads with a total weight of 422.74 ct (Figure 1). The second was a carving of a seated lady (Figures 2 and 3) with a weight of 445 gm and dimensions of 12 cm height, 14 cm width, and 5 cm depth. The third was a carving depicting two birds in a tree (Figures 4 and 5) which weighed 380 gm and had dimensions of 15 cm height, 17 cm width and 10 cm depth.

Fig 5. A close view of the saussurite carving in Figure 4.

The general appearance and colour distribution of the three items examined recently, are adequately displayed in Figures 1 to 5. Whilst zoisite was proved to be present by X-ray diffraction, several distant vision RI readings failed to produce a value greater than 1.60. The approximate RIs for the three items varied between 1.57 and 1.60. The absorption spectrum as seen with the hand spectroscope varied greatly, not only between the items but also between areas on each item. The absorption spectrum of the beads in Figure 1 revealed only a vague band in the blue and this was also true of some areas of the carving in Figures 4 and 5, but in other areas of this same carving the spectrum typical of chromium could be observed in the red. In the absorption spectrum of some of the areas in the carving in Figures 2 and 3 a strong band could be seen centred at 442.1 nm.

* * *

During 1986 we were fortunate to be shown a rather large rough diamond, which appeared to be a light brownish colour. The crystal which weighed 73.50 ct can be seen in Figure 6. Upon examination it was found that the surface was spotted with brown radiation marks, and the degree of influence these had on the actual colour of the crystal was not fully understood until after the crystal had been cut. The first finished stone to be cut from the crystal was a 4.75 ct pear shape (Figure 7) and when this was graded for colour and clarity it was found to be a 'Fancy Light Pink', and 'Internally Flawless'. None of the brown radiation marks were left on the cut stone and the 'light pink' was in fact the true body colour of the diamond and not the light brownish colour of the uncut crystal.

In following our routine testing procedures for coloured diamonds we noted that the fluorescence and absorption characteristics of this stone were similar to those of two pink diamonds described by Anderson twenty seven years ago (Anderson, 1960). They were similar also to those of ten natural pink stones examined in the Laboratory over the past ten years, but these were by no means characteristic of pink diamonds in general. This new stone fluoresced a very strong orange under short-wave ultraviolet light and a medium strength orange under long-wave ultraviolet. The first of the two stones described by Anderson in 1960 weighed 34.64 ct and he stated the fluorescence to be 'a strong orange-yellow or "apricot" '; the second stone was smaller at only 2.83 ct but had similar fluorescence characteristics. When Anderson examined the fluorescence of his stones with a hand spectroscope interesting and similar emission spectra were revealed for both. He described the spectrum as a series of bright lines extending towards the red end, and in diminishing strength from the end member of the series. He recorded the wavelength of this main line as 5750Å. Our observations were similar for the 4.75 ct stone. The spectrum which we obtained by bathing the stone in white light filtered through copper sulphate solution may be described as a clear and sharp bright line at 575 nm and a bright 'patch' between 590 and 650 nm.

Anderson stated that it was possible that the larger of his stones came from the old Golconda mines of India and that experiments had revealed the stone to have the ultraviolet transparency characteristics of a type II diamond. It is said that this new crystal was also found in India, and, as with Anderson's stone, ultraviolet transparency tests revealed type II diamond characteristics.

As always the Laboratory's main interest with coloured diamonds is in the area of colour origin – is the diamond coloured naturally or artificially? It is particularly interesting to be able to observe any coloured diamond both before and after cutting and even more so when the original rough shows clear signs of having been *naturally* in the presence of radioactivity as some stage in its history.

When a type Ib diamond is irradiated and annealed, depending upon the strength of the original yellow body colour and how heavy an irradiation is used, either a pink or a mauve artificially coloured diamond will be produced. Such treated pink diamonds are easily identified because the irradiation and annealing changes the typical Ib absorption spectra and induces a strong sharp line at 637 nm and further lines at 595, 575 and 503 nm, the last three of which sit on a broad absorption band centred near 560 nm. The 637 line is reported to be associated with isolated substitutional nitrogen (Collins, 1982).

On many occasions over the last ten years, both with the hand spectroscope and the spectrophotometer, we have recorded the 637 nm line in many naturally coloured yellow and brown type Ib diamonds when they have been held at low temperatures. Even at 120K, though, the 637 line in such stones is generally very weak (Scarratt, 1984, p110). Until now, only on one occasion have we observed a naturally occurring 637 line in other than a yellow or brown stone and in that case it was a 'green' stone, in which the colour was due to included material. However, when the 4.75 ct light pink stone was examined at low temperatures on the spectrophotometer, despite it appearing to have type II diamond characteristics in its ultraviolet transparency and in general terms also in its visible spectrum, this naturally coloured pink diamond recorded peaks, if only very weakly, at 637, 575, and 503 nm (Figure 8).

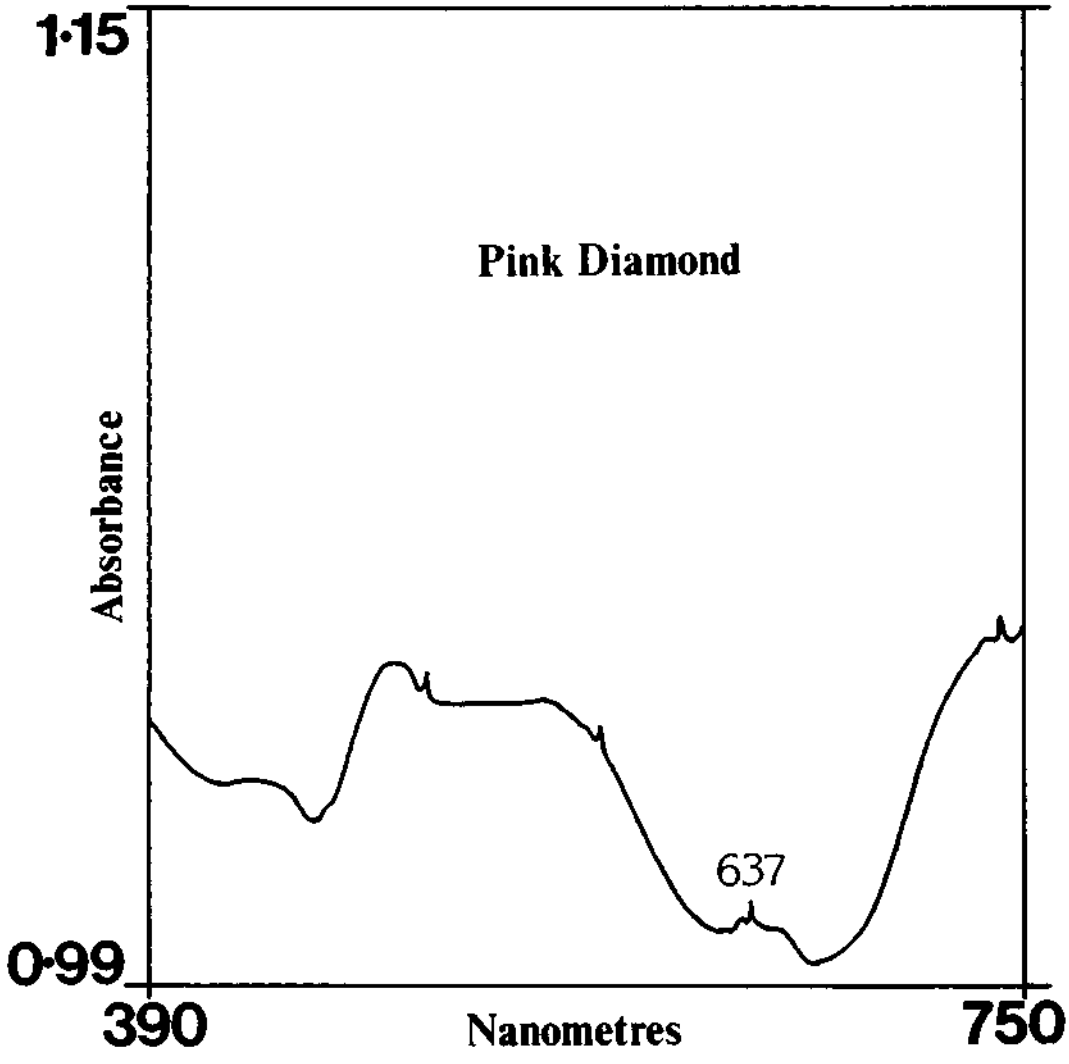

Fig. 8. The absorption curve of the 'Fancy Light Pink' pear-shaped diamond in Figure 7. The curve was obtained using a Pye Unicam PU8800/03 UV/visible spectrophotometer (Basil Anderson model) with a speed of 0.5 nm/s and a bandwidth of 0.5 nm at approximately 120K. The path length was approximately 9 mm.

Fig. 6. A 73.53 ct rough 'light pink' diamond with brown natural radiation marks on the surface. *Photograph by Mr M. Gould of M. Vainer Ltd.*

Fig. 7. A plastic model of the diamond in Figure 6 from which the three unfinished stones and the 4.75 ct pear-shaped diamond in front were cut.

Fig. 9. Brown natural radiation marks on the 'skin' of one of the partly polished diamonds in Figure 7.

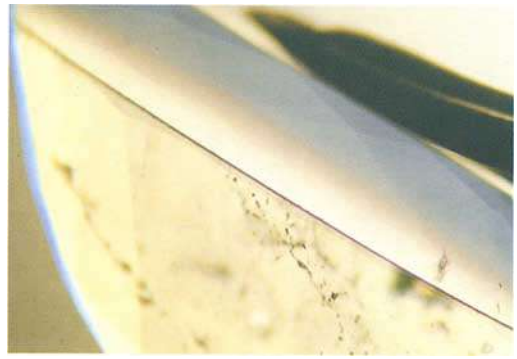

Fig. 10. A 'red' beryl-on-beryl composite stone seen here immersed in benzyl benzoate. The rich red junction can be seen following the girdle.

To our knowledge this is the first time that a line at 637 nm has been observed in a naturally coloured pink diamond: in all other cases of pink diamonds where a line has been recorded at this wavelength the coloration has been due to man-induced irradiation and annealing.

For the record we asked if we could examine the remaining pieces of the crystal before they became finished stones, these can be seen in Figure 7 with a plastic model of the crystal in the background. Brownish radiation marks could still be seen on the uncut surfaces of the three unfinished stones (Figure 9): all behaved in the same way as the 4.75 ct stone when bathed in ultraviolet light, and similar emission spectra were also produced.

* * *

An interesting and quite effective ruby imitation was given to the Laboratory collection recently. It was a composite stone in which both the crown and pavilion were made from near colourless beryl (Figure 10) and these were joined at the girdle with a rich red adhesive. The refractive indices were 1.580–1.586 for the crown and 1.584–1.590 for the pavilion. Internally the crown was comparatively free from inclusions, whereas included in the pavilion were innumerable two-phase inclusions (Figure 11).

Fig. 11. The crown of the composite stone in Figure 10 is relatively free of inclusions whereas the pavilion, as seen here, contains innumerable two-phase inclusions. The edge of the junction can be seen as a curved red line at the top of the figure, and the pinkish coloration below this is in the plane of the junction. The stone is photographed immersed in benzyl benzoate.

Acknowledgements

Thanks are due to Mr S.J. Kennedy for the production of the absorption curve of the 4.75 ct pink diamond and to Mr I. Shenker for the production of the X-ray powder diffraction details of the saussurite. Figure 6 was taken by Mr M. Gould of M. Vainer Ltd. We are also indebted to the firms of M. Vainer Ltd for allowing us to examine the large pink diamond and to E.A. Thomson Ltd for the gift of the beryl composite stone.

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Colour and irradiation-induced defects in topaz treated with high-energy electrons

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Abstract

In topaz irradiated with electrons in the 10 to 20 mega-electronvolt range different colour centres are present in variable concentrations. Due to their strong polarization dependency the colour centres are designated as X- and Y-centres, the colour of which is blue and bluish-violet respectively.

The electron irradiated samples reveal cracks and parting planes parallel to the basal pinacoid *c* (001). In addition, a shell-like structure is observed consisting of a blue rim, a colourless intermediate zone, which is characterized by a high concentration of irradiation-induced defects, and a colourless core. This shell-like structure is explained by a temperature gradient from the surface to the centre of the topaz crystals. This temperature gradient is formed during the irradiation process of the samples which are cooled all-around with running water.

Colour, spectroscopic properties and colour causes of natural blue topaz are compared with features of topaz crystals which were artificially irradiated with gamma rays, electrons and neutrons.

Introduction

Colourless topaz has been irradiation-treated commercially for about ten years in different procedures in order to produce a more or less intense blue coloration. Under exposure to gamma rays, e.g. on irradiation to gamma rays produced by Co-60 within a gamma cell, in general only a blue coloration of low intensity is acquired. The treatment of topaz with high-energy electrons by the use of linear accelerators or with neutrons in nuclear reactors causes a more intense blue colour. By the use of gamma rays or electrons, the irradiation-treated topaz turns a more intense brown or greenish-brown colour. The desired blue coloration is produced by subsequent heating at about 200°C for a few hours in order to bleach the brown unstable colour centres in topaz.

Neutron-irradiated stones in general reveal an intense blue coloration without heat treatment. However, heating of neutron-irradiated stones is applied to remove an inky or steely hue, i.e. in order to produce lighter shades of blue (cf. also Nassau and Prescott, 1975; Nassau, 1985).

The absorption spectra of natural and artificially irradiated blue topaz crystals in the visible area were studied by different authors (Nassau and Prescott, 1975; Petrov, 1977). According to these papers, the coloration of all different types of natural and artificially induced blue topaz is caused by a broad absorption band at about 15 200 – 16 100 cm^{-1} ≙ 658 – 620 nm (cf. also Nassau, 1984, 1985).

By the use of low-energy gamma radiation, e.g. with the gamma radiation of Co–60 having energies of 1.33 and 1.17 MeV, neither radioactivity nor radiation defects are induced. The disadvantage of neutron irradiation in nuclear reactors is the generation of radioactive nuclides by neutron activation, partly with long half-lifes (in topaz mainly Sc–46 and Ta–182 are produced, subordinate amounts of Co–60 and Cs–134 are also observed after irradiation). These radioactive nuclides cause an irradiation-induced radioactivity, which is not acceptable to the trade. Therefore, according to the individual conditions of treatment as well as to the trace element contents of an individual crystal, a cooling off period between one and four years is necessary for the decay of radioactivity. After this time, the induced radioactivity has almost completely disappeared, the remaining activity being in the range of the natural background. By treatment with electrons of energies between 10 and 20 mega-electronvolts, which are commonly used for the irradiation of topaz, certain types of radiation defects are occasionally produced. This irradiation-induced cracking and damage may diminish the quality of the treated crystal or make the topaz completely useless for jewellery purposes.

The aim of the present paper is a detailed description of the coloration and different types of electron-induced defects in irradiated topaz. In addition, the study presents the first description of different types of blue colour centres in topaz, which were discovered during this research project.

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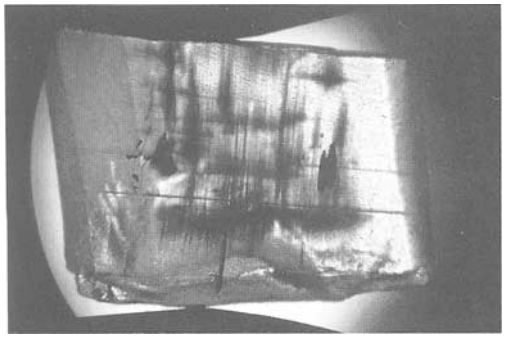

Fig. 1. Topaz from Nigeria irradiated with high-energy electrons; the sample reveals parting parallel to the basal pinacoid (above): in addition, parallel cracks are developed. At a distance of about 3 mm from the surface, an intermediate zone with a high defect concentration is formed. View perpendicular to the *c*-axis. 12x.

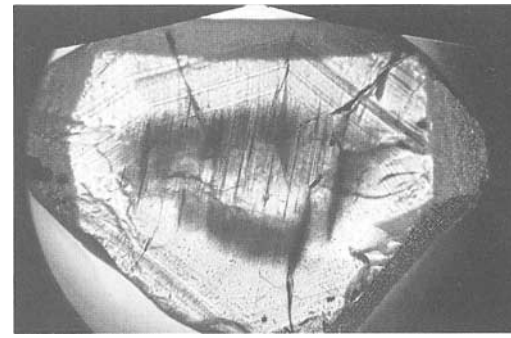

Fig. 2. Topaz from Nigeria irradiated with high-energy electrons (identical stone to that in Figure 1); all-around shell-like structure consisting of a light blue rim (about 3 mm broad), a colourless intermediate zone, which is characterized by a high concentration of defects, and a colourless core; growth planes parallel to the prism faces *m* (110) and *l* (120) are developed. View parallel to the *c*-axis. 14x.

Experimental details

For the present study, two parcels of hardly damaged topaz crystals were available. According to the information given by the supplier, both parcels of stones were recently treated by different linear accelerators in the USA. All samples were pre-shaped topazes, which had been mined in various (?) localities in Nigeria. For comparisons sake, different parcels of topaz from various localities which were treated by the author by the use of gamma rays and high-energy electrons and converted to blue after subsequent heating, neutron-irradiated samples from different occurrences as well as naturally blue coloured topaz from Brazil, Nigeria and Zimbabwe, were spectroscopically investigated.

Results

The topaz crystals from Nigeria irradiated with high-energy electrons exhibit a blue coloration of variable intensity. By examination with the naked eye, most of the stones reveal plane parallel cracks, and part of the samples were broken parallel to one or even two of these planes (Figure 1). The orientation of these parting planes is parallel to the known cleavage of topaz, i.e. parallel to the basal pinacoid *c* (001).

All topaz crystals of both parcels exhibit a shell-like zoning, which was found to be independent from the crystallographical orientation of the individual sample (Figures 2, 3). This shell-like structure was observable in all samples however, the best investigations were possible in cracked samples with one or two parting planes parallel to *c* (001). The rim of the stones reveals a uniform blue coloration beginning directly at the surface of the pre-shaped stones. The depth of this zone is also very uniform and measures about 3 mm. This uniform and all-round light blue coloration in the rim of the samples is superimposed by an irregular and spot-like bluish-violet colour, which is generally developed only in one side or in one area of the rim (Figures 3, 4). The irregular and patch-like distribution of the bluish-violet coloration is comparable with the irregular zoning of the brown colour of Nigerian topaz samples, which were irradiated in the gamma cell with Co–60 or in a linear accelerator with high-energy electrons before the stones are heat treated. In both types of samples, i.e. in heat treated and non-heat treated irradiated stones, the irregular and patchy bluish-violet or brown coloration of topaz in most cases does not follow crystal faces and varies even among crystallographical zones. In some samples growth planes parallel to the prism faces *m* (110) and *l* (120) were observable in immersion liquids. However, only in a few cases was the colour zoning found to follow this clearly developed growth zoning (Figures 2, 4). The pleochroism of the intensely coloured zones or patches is different from the pleochroism of the light blue uniformly coloured zones (Table 1). The pleochroism of these light blue zones is identical with the normal pleochroism of natural blue topaz as well as identical with that of topaz which was irradiated in a gamma cell and heated subsequently (Table 1, cf. also Petrov, 1977). In topaz from different localities which was irradiated in nuclear reactors with neutrons, the pleochroic colours are somewhat different (Table 1). Colour zoning was never observed in samples which had been treated in this manner.

The absorption spectra of natural (untreated) blue topaz as well as the spectra of topaz irradiated by neutrons, electrons or gamma rays, reveal

Table 1. Pleochroism and absorption maxima in blue topaz

	natural untreated blue topaz, Brazil, Nigeria, Zimbabwe		blue topaz irradiated in the gamma cell, subsequently heat-treated	blue topaz irradiated in linear accelerators, subsequently heat-treated		blue topaz irradiated in nuclear reactors	
colour zoning	distinct colour zoning rarely observable		no colour zoning observed	light blue, all-around developed zone	darker blue, irregularly developed zone	no colour zoning observed	
pleochroism							
X‖a	distinctly blue		distinctly blue	distinctly blue**	distinctly blue**	very intense blue to bluish-black****	
Y‖b	colourless, grey		colourless, grey	colourless, grey	intense bluish-violet	colourless, grey	
Z‖c	colourless, yellowish		colourless, yellowish	colourless, yellowish	colourless, yellowish	light bluish	
absorption maxima [in cm^{-1} and nm]							
X‖a	15200–16000 ≙ 658–625***	23800 ≙ 420	16000 ≙ 625	16000 ≙ 625**	16000 ≙ 625**	15200–16000 ≙ 658–625****	23800 ≙ 420
Y‖b	—*	—*	—*	—*	16600 ≙ 602	16600 ≙ 602	—*
Z‖c	—*	—*	—*	—*	—*	15200 ≙ 658	23800 ≙ 420
intensity ratios	X ≫ (Z,Y)	X ≫ (Z,Y)	X ≫ (Z,Y)	X ≫ (Z,Y)	X ≈ Y ≫ Z	X ≫ Z ≫ Y	X ≫ Z ≫ Y

* the presence of an absorption maximum was not confirmable for samples up to 2 cm in thickness.
** colour or intensities of the absorption bands are identical in both zones.
*** absorption maximum variable in different stones from different localities.
**** colour and absorption maximum variable according to various exposure times to neutrons and gamma rays in the reactor.

different absorption bands with maxima in the area between 15 000 and 17 000 cm^{-1} ($\approx$ 667 – 590 nm), the intensities of all absorption bands being distinctly dependent on the polarization of the electric vector E (parallel to the three indicatrix axes X, Y, and Z). These spectroscopic investigations confirm that the absorption scheme of natural blue topaz is almost identical with that of topaz treated with gamma rays as well as with the absorption scheme of the uniformly coloured and all-round light blue area of electron-irradiated topaz. In neutron-irradiated stones, this absorption scheme is strongly intensified. In these dark blue samples, absorption bands in the Y- and Z-spectra are observed, which cannot be measured with certainty in the light blue coloured samples mentioned above. Furthermore, additional absorption maxima in the violet area of the visible region are observed in neutron-irradiated topaz (Table 1). These maxima were also present in the spectra of the darkest blue samples of natural blue topaz crystals from different localities, which were available for the present study.

In the irregular and spot-like bluish-violet areas of electron-irradiated topaz, which are, in general, developed only in one side or region of a pre-shaped sample, a distinct absorption band in the Y-spectrum is observed. This band of high intensity is not observable in natural or gamma-irradiated stones, and is found in neutron-irradiated samples only with low intensity. The intensity of the absorption band in the X-spectra of electron-irradiated topaz is identical in different areas of these crystals, i.e. in light blue and intense bluish-violet regions. These results of spectroscopic measurements confirm the visible observations, which show a homogeneous colour distribution and intensity in electron-irradiated topaz for polarized light with an electric vector E parallel to X. Strong colour zoning, however, is observable for polarized light with an electric vector E parallel to Y.

Inwards from the blue rim of the topaz crystals, which were recently irradiated by linear accelerators in the USA, a colourless zone of about 1 mm in depth is observed. This colourless zone is characterized by a high concentration of structural defects (Figures 1–5). Following this second intermediate shell (fissure zone) a colourless core is observed, which is almost free of structural defects (Figure 2). Independently from the three concentrically

Fig. 3. Topaz crystals from Nigeria irradiated with high-energy electrons; the samples reveal parting planes parallel to the basal pinacoid (001). An all-around shell-like structure consists of a light blue rim, a colourless intermediate zone, which is characterized by a high concentration of defects, and a colourless core. The uniform light blue colour of the rim is superimposed by an irregular and spot-like bluish-violet coloration. Size of the left sample approx. 17.5 × 13 mm. (*Photo by O. Medenbach, Bochum.*)

Fig. 4. Topaz from Nigeria irradiated with high-energy electrons; irregular bluish-violet coloration developed at one side of the rim of the sample, intermediate zone with high defect concentration; growth planes are parallel to the prism faces *m* (110). View parallel to the *c*-axis: polarized light with E parallel to Y. 20x.

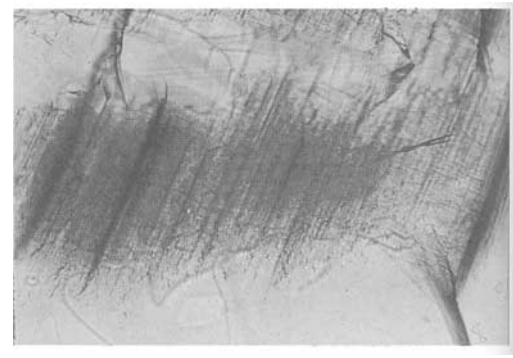

Fig 5. Topaz from Nigeria irradiated with high-energy electrons; intermediate zone with high concentration of needle-like defect structures, the orientation of the needle axes is parallel to the *a*-axis of the crystal. View parallel to the *c*-axis. 30x.

Fig. 6. Topaz from Nigeria irradiated with high-energy electrons; intersecting needle-like defect structures orientated with the needle axes parallel to the *a*- and *c*-axes of the crystal; isolated patches of cracks parallel to the basal pinacoid *c* (001). 55x.

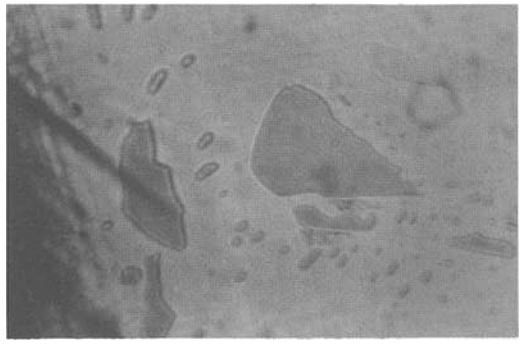

Fig. 7. Topaz from Nigeria irradiated with high-energy electrons; isolated patches of cracks parallel to the basal pinacoid *c* (001). 80x.

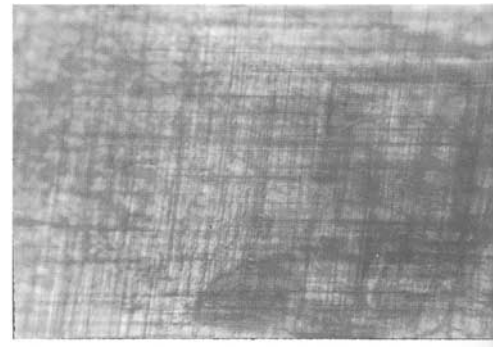

Fig. 8. Topaz from Nigeria irradiated with high-energy electrons; intersecting needle-like defect structures orientated with the needle axes parallel to the *a*- and *c*-axes of the crystal. 65x.

arranged shells or zones, the samples often revealed sets of parting planes parallel to the cleavage of topaz (Figure 1), which is parallel to the basal pinacoid *c* (001). In some areas, these cracks are not developed in the form of continuous planes, but in the form of isolated patches (Figures 6, 7), i.e. they enclose only parts of a continuous plane parallel to the basal pinacoid *c* (001).

The fine structure of the second intermediate shell of electron-irradiated topaz, which is characterized by a high defect concentration, is formed by two systems of linear fissures, which are arranged parallel to two crystallographic directions in topaz. The orientations of the needle-like defect structures were determined to be parallel to the crystallographic *a*- and *c*-axes of the samples (Figures 3, 6, 8). In some areas, the two dominant systems of needle-like defect structures intersecting at right angles (Figures 6, 8) are connected by a third subordinate system of irregular fissures.

Discussion

In some recently published papers dealing comprehensively with colour and colour causes of natural (untreated) and irradiated brown and blue topaz (Nassau, 1984, 1985), only one blue colour centre is mentioned for all types of blue topaz. The experimental results described in this paper as well as further investigations (Schmetzer, 1987), however, confirm the development of several different blue colour centres, or more precisely, the development of at least two blue X-centres and one bluish-violet Y-centre in topaz. The relative concentration of these colour centres is mainly dependent on the type of irradiation used for the coloration of the stone (cf. Figure 9). The blue X-centres with a polarization of X ≫ (Z, Y) are predominant in natural blue topaz, in gamma-and neutron-irradiated topaz, and in the uniform all-round light blue area of electron-irradiated topaz. The concentrations of the X-centres in neutron-irradiated samples strongly exceed the concentrations of the X-centres in all other types of blue topaz. Only in the dark bluish-violet patchy areas of electron-irradiated topaz, is the intensity of the absorption band of the Y-centre with a polarization of Y ≫ (X, Z) comparable with the intensity of the absorption band of the X-centres (Figure 9). The presence of both X- and Y-colour centres in this type of irradiated topaz, however, is absolutely necessary to bring the intensity of the blue coloration to a commercially usable level. In neutron-irradiated topaz, the presence of small concentrations of the bluish-violet Y-centre was confirmed by spectroscopic investigations (cf. Table 1, Figure 9).

Due to the similar position of their absorption maxima, the distinction of X- and Y-centres in irradiated blue topaz has to be conducted with polarized absorption spectroscopy. In the paper of Nassau and Prescott (1975), an absorption maximum at 620 nm in stones irradiated with Co–60 was measured; no information about the polarized spectra of these samples was published. Presumably, these stones mainly contained small concentrations of X-centres. The only polarized spectra of natural blue coloured topaz crystals were published by Petrov (1977). This paper contains adequate data on the X-centres. A connection between the concentration of part of the X-centres in dark blue, naturally coloured as well as in neutron irradiated topaz and the intensity of the new absorption band in the bluish-violet area is conceivable (Table 1). This connection, however, needs further experimental confirmation.

Presumably, the irregularly distributed and patchy bluish-violet coloration in electron-irradiated and subsequently heat-treated topaz from Nigeria, i.e. the irregular concentration of Y-centres after treatment, is caused by an irregular distribution of

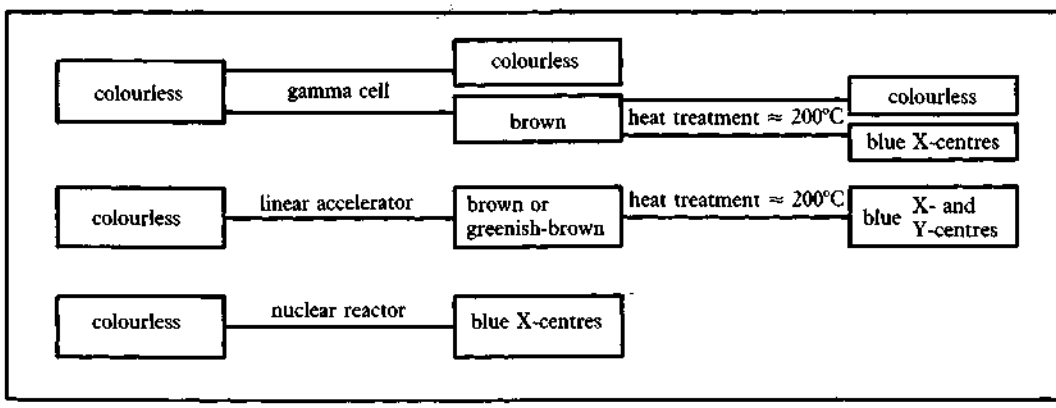

Fig. 9. The development of blue and bluish-violet X- and Y-centres in topaz by irradiation processes and subsequent heat treatment.

one or several trace elements in different areas of those crystals. Unfortunately, the colour causes of the X-centres and the newly described Y-centre in topaz as well as the different mechanisms of stabilization of colour centres, i.e. the reaction mechanisms by irradiation and heat treatment (Figure 9), are almost unknown. A first attempt to clarify some of these problems was made by Petrov (1983). Thus, the most probable connection between the irregular colour distribution and one or several trace elements has still to be confirmed analytically. Most probably, the irregular distribution of the brown coloration in gamma- or electron-irradiated, non-heat treated samples from Nigeria is also due to variable trace element concentrations in those crystals, and a connection with the irregular concentration of bluish-violet Y-centres after heat treatment of electron-irradiated samples is also conceivable.

Due to the more regular distribution of X-centres in gamma- and electron-irradiated and subsequently heat treated as well as in neutron irradiated non-heat treated topaz (Figure 9), the concentration of X-centres is less dependent on various trace element concentrations in the individual topaz crystal. Most probably, the precursor elements or precursor centres for the generation of blue X-centres in topaz are found in uniform distributions within the crystals or are not present at all (referring to topaz crystals which are uniformly coloured in X polarization by irradiation with gamma rays or high-energy electrons and to topaz crystals which are colourless in X polarization after irradiation and heat treatment; (Figure 9). By neutron irradiation, an extremely high concentration and uniform distribution of X-centres is developed, and the concentration exceeds that in gamma ray and electron-irradiated samples (among several thousands of neutron-irradiated topaz crystals, no sample was observed which remained colourless).

In order to explain the radiation induced defects in topaz two mechanisms have to be discussed. For the development of a commercially usable blue coloration in topaz an electron beam with particles in the 10 to 20 mega-electronvolt range is applied. These high-energy electrons interact in a different manner with the atoms of the topaz structure. One of these interactions is the build-up of electrical charge in topaz, causing the formation of parting planes parallel to the basal pinacoid *c* (001), which is the ordinary cleavage plane of this mineral. This process is caused by the limited penetration of electrons in topaz, which is approximately calculated for electrons with an energy of 15 MeV to ≈ 2.27 cm for the maximum range of penetration and to ≈ 0.69 cm for the half-thickness. In addition, the high-energy electrons, which are slowed down by interaction with the atoms of the topaz structure, cause the generation of heat. Therefore, the topaz crystals have to be cooled continuously with running water during the irradiation process. These facts can help to explain the all-around shell-like structure of the crystals with radiation induced defect structures. Due to the contact of the surface of the irradiated topaz crystals with running water an all-around temperature gradient from the rim to the core of the topaz is generated. Presumably, shell-like zones having different temperatures and thus zones with different thermal expansion are formed. The anisotropic heat conduction of orthorhombic topaz as well as the anisotropic thermal expansion, which is also zoned from the surface to the centre, probably causes stress in the topaz structure. As a result, the characteristic systems of defect structures described above are formed.

The absence of blue or bluish-violet colour centres in the intermediate zone and in the core of the topaz crystals is also explainable by increased temperatures in these areas. In general, the blue coloration of natural untreated as well as that of irradiated topaz is removed at temperatures between 200 and 500°C. The exact temperature is dependent on the unknown conditions of colour causes and stabilization mechanisms in an individual sample. Therefore, the temperatures in the intermediate fissure zone and in the core of the crystals are assumed to exceed 200°C during the irradiation process. Obviously, the all-around cooling by running water was inadequate to protect the whole samples. Under the experimental conditions of the irradiation process, which are unknown in detail, the cooling was only sufficient in a rim zone of 3 mm in depth for the generation and stabilization of the blue and bluish-violet X- and Y-colour centres.

Acknowledgements

Both parcels of electron-irradiated topaz from the USA were kindly submitted by Dr H. Krupp of Heidelberg, FRG. Financial support was given by grants of the Wirtschaftsministerium des Landes Rheinland-Pfalz, FRG.

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Sapphirine (not sapphire) in a ruby from Bo Rai, Thailand

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Abstract

This note describes inclusions of the magnesium aluminium silicate, sapphirine, discovered in a Thai ruby. The inclusions were identified by X-ray powder diffraction. This is the first report of sapphirine as an inclusion in any gem material.

A small broken rough ruby crystal containing three dark greenish-blue crystalline-appearing inclusions was given to the authors for examination. The host ruby was a purplish-red tabular etched crystal that weighed 0.91 carats. It was collected by Dr Peter C. Keller while studying the Bo Rai ruby mines in the Trat Province of Thailand (Keller, 1982).

Fig. 1. Dark greenish-blue sapphirine inclusion exposed at the surface of a broken Thai ruby. Dark-field illumination. 30x.

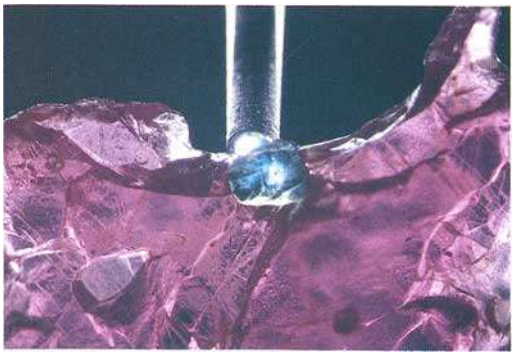

Fig. 2. A pinpoint illuminator highlights the sapphirine inclusion for optical examination. 10x.

The ruby had been broken across its centre, exposing the largest of the three inclusions to the surface for easy X-ray powder diffraction analysis (Figure 1). Since inclusions of this appearance had never before been reported in ruby, it was decided that identification would be attempted.

Testing

After gemmological verification that the host crystal was ruby, the inclusions themselves were examined optically to see what could be learned before X-ray analysis was performed.

As shown in Figure 1, the inclusions were anhedral rounded grains. This suggested a protogenetic origin in relation to their host. An 80-watt pinpoint fibre-optic illuminator was needed to get enough light through the exposed inclusion (Figure 2) to examine for pleochroism. The inclusion proved to be birefringent and the green and deep blue pleochroic colours that were observed suggested that the inclusions might be sapphire.

The inclusion was then scraped using a fine-point diamond-tipped scraper until a minute amount of powder was obtained to make a spindle for X-ray powder diffraction.

The spindle was mounted and centred in a Debye-Scherrer powder camera and exposed to X-rays generated at 46 kV and 26 mA from a nickel-filtered copper target tube for a time of 4.5 hours.

The resulting pattern was compared with our sapphire (corundum) standard pattern. It was immediately obvious that the inclusion was not sapphire. The unknown's pattern was then measured

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for d spacing using a Nies overlay scale corrected for film shrinkage, while the line intensities were visually estimated.

Using our Mineral Powder Diffraction File Search Manual (JCPDS, 1980), we found an exact pattern match with the monoclinic mineral sapphirine (ASTM File Number 21–549), chemical formula $(Mg, Al)_8 (Al, Si)_6 O_{20}$ (Fleischer, 1980).

This came as a complete surprise because although sapphirine had been reported as a cut stone (Fryer, 1985), it had not been reported as an inclusion. So in this respect it is a first observation.

Conclusion

Because of their colour, pleochroism and close proximity to ruby, these inclusions were at first thought to be sapphire. Where sapphire vs. sapphirine is concerned, this is a common mistake. Sapphirine gets its name from sapphire because small grains of the two minerals look very much alike. Even though they are completely different minerals chemically and physically, they are still easily confused. So, on the basis of looks, it is logical, if given the choice, to pick the much commoner sapphire over the rarer of the two, sapphirine.

Acknowledgements

The authors would like to thank Peter C. Keller, Ph.D., GG, Associate Director of the Los Angeles County Museum of Natural History, for the gift of the ruby with sapphirine inclusions. Thanks are also given to Ruth Patchick for typing this manuscript.

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Diaspore, a rare faceted gem

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Abstract

In recent years, a number of gemmological laboratories have reported the appearance of gem quality diaspore*.

The writer has had the opportunity to examine some rough crystals, and six faceted stones cut from them, the measurements, weights and properties of which are described below.

Appearance

The rough diaspores examined by the writer were found in two different forms:

1) Long, flattened, prismatic crystals, occasionally twinned (Figure 1), characterized by deep vertical striations on (001) (similar to those seen in spodumene), most often showing fractured terminations, or more rarely terminated at one end by faces (110) and (111), and at the other end a flat or fractured base (Figure 2).
2) Tabular crystals with mica-like cleavage, consisting of a number of thin plates superimposed on each other. Although the cleavage (010) is perfect, it is much less facile than that of micas which it resembles.

The large emerald-cut diaspore was cut from a similar tabular crystal to the one described above, which measured approximately 77.40 × 75.50 × 43.30 mm, for a total depth of 26.80 mm, and a weight of 210 g (Figure 3).

As can be seen from Figure 3, the stone was rather heavily flawed by a number of oriented elongated canal-like inclusions running in parallel bands, and the faceted stone cut from this rough crystal attained a weight of only 7.632 g (38.16 ct).

According to the lapidary who cut the six stones from six different crystals, no particular difficulties were noticed in relation to the perfect (010) cleavage, or for fashioning and polishing the different gems which take a very good polish with a vitreous lustre.

A remarkable characteristic of these faceted diaspores is their colour change (Figure 4), comparable with that observed in alexandrite. Their colour is brownish-green in daylight, Colormaster notations BD-11/100/45 for the majority, but one stone of a deeper green colour gave ED-15/100/21. In tungsten light, the majority showed a moderate change of colour which could best be described as pinkish-brown, with Colormaster notations BD-22/100/34. The deeper green stone showed a very distinct colour change to pinkish-red, Colormaster notations ED-33/100/21.

Hardness

The hardness on Mohs' scale, taken on rough crystals with hardness points and plates, revealed that face (010) is not scratched by 6½, but slightly scratched by 7. Against polished plates, the same face was found to scratch easily GGG (gadolinium

Shape, measurements and weight

Stone No.	Shape	Approximate Measurements	Weight
1	Emerald-cut	23.76 × 16.01 × 11.13 mm	38.16 ct
2	Oval cabochon	14.65 × 10.34 × 8.22 mm	12.55 ct
3	Rectangular step-cut	12.86 × 11.23 × 7.43 mm	8.89 ct
4	Emerald-cut	11.62 × 7.68 × 5.34 mm	4.32 ct
5	Brilliant-cut	7.06 × 5.75 mm	1.87 ct
6	Round cabochon	5.92 × 4.11 mm	1.18 ct

*Diaspore is hydrogen aluminium oxide, $HAlO_2$, which crystallizes in the orthorhombic system.

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Fig. 1. Diaspore crystal showing twinning. Approximate measurements of crystal: height 68.40 mm, width 32.20 × 27.00 mm, weight 92.34 g.

Fig. 2. Gem-quality, flattened, prismatic crystal of diaspore deeply striated parallel to its length, with one end terminated by a flattened pyramid and the other end by a fractured base. Approximate measurements of the crystal: 64.92 × 34.48 × 17.06 mm, weight 64.14 g.

Fig. 3 (a) The rough crystal of diaspore weighing 210 g from which the 38.16 ct emerald-cut stone was faceted.

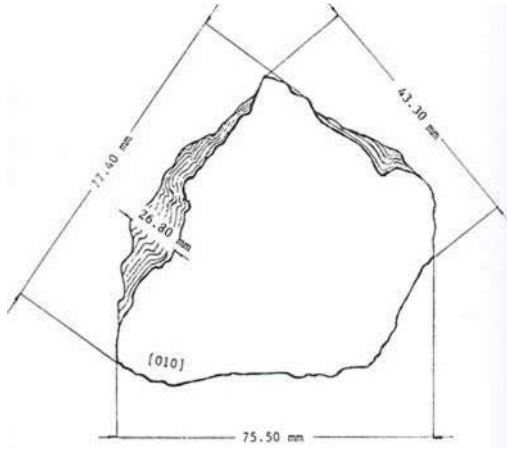

Fig. 3 (b). Sketch of the rough crystal, showing its measurements and cleavage direction.

Figs. 4 (a) and (b). The six cut diaspores studied, as they appeared under (a) fluorescent light, and (b) tungsten light.

gallium garnet), but could hardly scratch quartz. At 90° to this plane, the same hardness was found, giving a hardness of 6½–7 for this mineral.

Chemical testing

Under the action of hydrochloric and sulphuric acids, the surfaces of the stones were not etched, and their colour was unaltered.

Density

The densities were obtained by hydrostatic weighing of the stones in distilled water using a Mettler PL 300c balance (accuracy ± 0.001 carat), and gave the following results corrected to 4°C for the six different stones:

Stone Nos.	Density
1, 5 and 6	3.382 g/cm^3
2	3.402 g/cm^3
3	3.404 g/cm^3
4	3.415 g/cm^3

Refractive Indices

The refractive index determinations were carried out using a Rayner Dialdex refractometer and monochromatic sodium light. Only the table facets were tested and it was only possible to get a value for the intermediate β index on stone No. 4. In this case the upper and lower shadow edges obtained on the refractometer reached the same 1.723 value as the stone was rotated indicating that this was the value for β. In the other cases the upper and lower shadow edges did not reach a common value.

The author has observed that many faceted biaxial stones have their table facets cut parallel to critical directions, such as the table cut parallel to an optic axis or to optic axial planes or cut parallel to an acute or obtuse bisectrix. These orientations do not facilitate the determination of the β value using the table facet alone.

In many cases it is not possible to obtain readings from other facets, e.g. when the stone is set or where the style of faceting does not allow the stone to sit properly on the refractometer. For such stones cut according to critical directions, it is always a good idea to obtain an interference figure whilst the stone is being observed under the polariscope with the aid of a conoscope.

The indices obtained from the six stones are: $\alpha = 1.702$, $\beta = 1.723$, $\gamma = 1.750$, giving a birefringence of 0.048, with optic sign (+). Stone 6, the round double cabochon, gave only one reading: 1.70 (spot reading).

Pleochroism

The pleochroism of the stones, observed through the pavilion with a Rayner calcite dichroscope, was distinct; medium pinkish-brown, light greenish-brown and light brown.

Absorption spectra

The absorption spectra seen through a Gem Beck Spectroscope Unit, showed lines in the blue portion of the visible spectrum, not dissimilar to those seen in Australian sapphires.

Stone No.	Absorption spectra
1	Very strong band, 438–465 nm
2	Strong broad lines, 445, 450, 458, 465 nm
3	Strong broad band, 440–468 nm
4	Strong broad band, 440–465 nm
5	Strong broad band, 445–468 nm
6	Strong broad band, 445–460 nm

Ultraviolet fluorescence

The stones, examined with a Multispec combined LW/SW unit, revealed only a moderate green glow under the radiation of 253 nm.

Colour filter

The stones remained green when viewed through a Chelsea colour filter.

Microscopic examination

The inclusions were examined under a Bausch & Lomb Mark V Gemolite binocular microscope using dark field illumination or overhead lighting, depending on whether internal or external features were to be examined.

Five types of inclusions have been observed in the six diaspores examined:

1) Disc-shaped fingerprint-like inclusions consisting of a multitude of very small, oriented, squarish, two-phase inclusions.
2) Isolated small, squarish, two-phase inclusions, reminiscent of those seen by the writer in emeralds from Mozambique.
3) Long oriented canals filled with two-phase inclusions (Figure 5).
4) A mobile bubble was seen in a negative crystal. At room temperature the bubble, which was spherical, rested in one corner of the negative crystal (Figure 6). After a few seconds, the heat from the 30W, 115–125V light bulb used for examination of the stone, made the bubble move slowly from one corner to the other (Figure 7). A few seconds after the light was turned off the

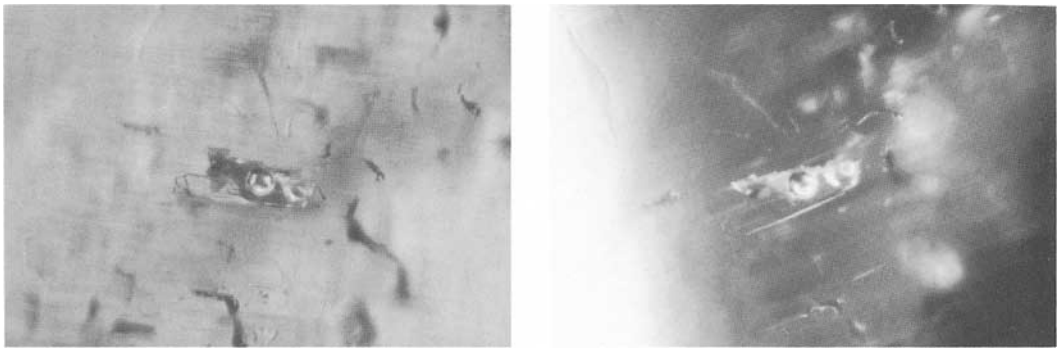

Figs. 5 (a) and (b). Long, two-phase inclusions, one of the most characteristic features, seen under high magnification (125x), (a) in transmitted light, and (b) with dark-field illumination.

Fig. 6. A negative crystal with a gas bubble resting at one end.

Fig. 7. After a few seconds, the heat from the 30W light bulb of the microscope makes the bubble shown in Figure 6 move slowly to the other end of the negative crystal. 125x.

bubble returned to its original position. The phenomenon can be reproduced under the same conditions as many times as one wishes.

5) Internal fractures, cleavages and tension cracks.

Conclusion

As can be seen from this article, gem diaspore would have all the characteristics to qualify as a highly valuable and desirable stone. Unfortunately, only very few crystals of sufficient transparency, clarity and colour have so far been reported. Some occasionally show terminations or are twinned, and these should not be cut; others are so small that they would probably only produce faceted stones under one carat. If this is the true situation, the stones analysed in this article should be considered in view of their size and beauty as exceptional.

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Some colour variation in jadeite

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Jadeite is a material which is often encountered during the normal course of commerce by the trade gemmologist. Variations of the same colour in one object are not uncommon, but two distinct colours in adjoining zones are not so often seen. This latter type of variation is most often encountered in material where the outer skin of a rough boulder has been subjected to weathering. These colour variations are commonly from greens to browns and brownish-orange. In the cover illustration two interesting examples of colour variation are seen.

Fig. 1. Upper part of a jadeite figurine (Kuan Yin) showing unusual translucency and mirror-like polish, achieved by the use of diamond. *Photograph by E.A. Jobbins.*

The brush pot is in the shape of a bamboo stem with a margin of good emerald green colour; the bulk of the pot consists of whitish to pale lavender jadeite with a little green interspersed. The dimensions are 10 × 3 × 2 cm. The pot was probably carved during the early nineteenth century, and the surface polish was achieved without the use of diamond powder.

The carved desk seal shows colours varying from medium green, through a whitish zone to a fine lavender. This item is typical of material carved in China for export to Europe during the latter part of the nineteenth century. The base of the seal is engraved with a European armorial crest. The dimensions are 6 × 1.2 × 1.1 cm. Refractive index measurements were easily made on the flat surface of the lavender coloured base.

The third object (see cover picture and Figure 1) is a very unusual type of jadeite of a pale blue/grey/green colour, depending upon the type of illumination in which it is viewed. In daylight it is an icy bluish-grey colour and is much the same colour in tungsten light, but in fluorescent light it appears a pale celadon (pale green) colour. The material is of exceptional translucency and is virtually transparent around the fingers and on the thinner edges. Normal fibrous, granular jadeite structure is visible but only when searched for carefully and then only evident in small areas. The carving is of the Goddess Kuan Yin and is thought to be of modern workmanship. The polish is mirror-like and no 'orange-peel' effect is visible, which would indicate that it has been achieved using diamond powder. Refractive index and birefringence measurements were easily taken from the base, and it shows a remarkably strong absorption band at 437.4 nm. The dimensions are 14.5 × 3 × 2.3 cm.

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On the inclusions in emeralds from Santa Terezinha de Goiás, Brazil

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Abstract

Inclusions in emeralds from Santa Terezinha de Goiás, Brazil, are investigated by electron microprobe analysis (EPMA). The inclusions are determined as pyrite, magnesioferrite and mica (possibly biotite).

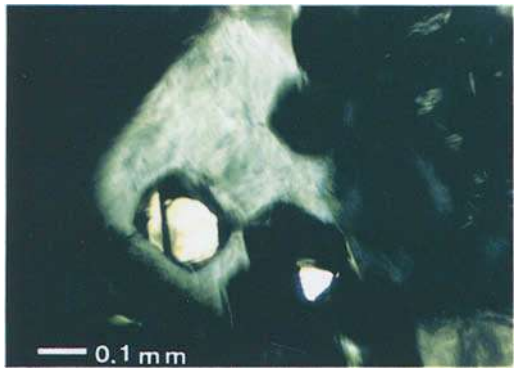

Fig. 1. Pyrite inclusion in emerald; diameter of pyrite approximately 0.2mm.

Introduction

The Santa Terezinha emerald has been reported firstly by Liddicoat (1983), and comprehensively by Cassedanne and Sauer (1984). They reported on locality, history, geology and gemmological properties including inclusions. On inclusions, they listed chromite, pyrite, biotite, calcite and two-phase inclusions. Special regard must be paid to pyrite and chromite. For pyrite, the locality is the only one except Colombia whose emeralds include pyrites. For chromite, the basis of their identification relies on the presence of chromium detected by X-ray fluorescence. There may be some doubt as to whether chromium was due to the inclusion or the host crystal, because of the rather broad analysing area of the method.

Fortunately, we obtained some cut samples in which a few inclusions appeared on facets and were able to investigate the inclusions without damage to the faceted stones.

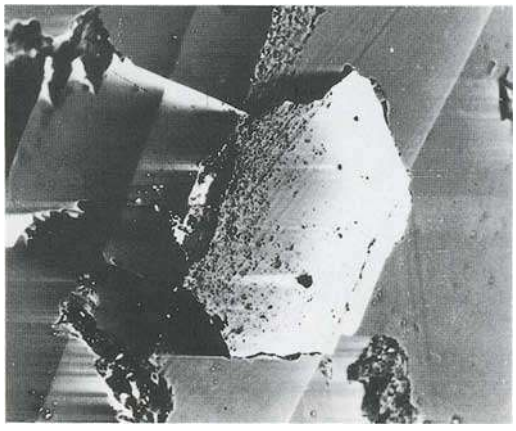

Fig. 2a. SEM photograph of the pyrite appearing on a facet.

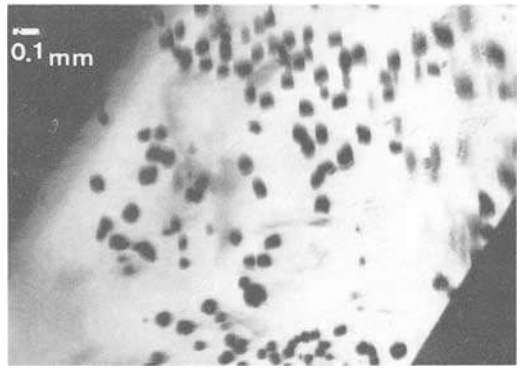

Fig. 2b. Characteristic X-ray image (sulphur). The same position as Figure 2a.

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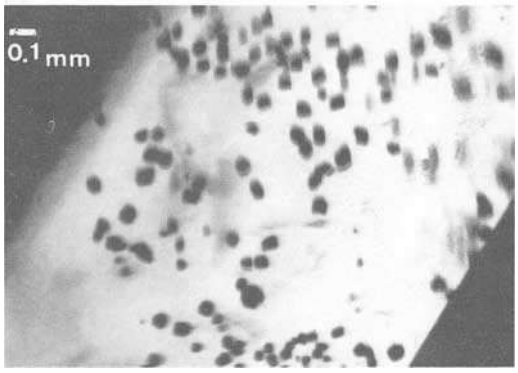

Fig. 3. 'Coal-like' inclusions in emerald. Each crystal is about 50μm~100μm.

Results

Two specimens of emerald were examined by microprobe EPMA (JEOL – 733). Experimental conditions were: acceleration voltage 25 kV; absorption current 1.0×10^{-8} amperes.

Figure 1 shows inclusions in the Santa Terezinha emerald. They occur as well-formed or slightly rounded cubes with metallic lustre. Their diameters are about 0.2mm and one (lower left) appears on a facet edge. We detected iron and sulphur, but cannot detect zinc by EPMA.

Figures 2a and 2b show a scanning electron microscope (SEM) image and a characteristic X-ray image (for sulphur) of the inclusion. Further semi-quantitative analysis of the inclusion revealed that the ratio or iron to sulphur was ½ and the inclusion can be concluded to be pyrite.

Figure 3 shows typical inclusions in Stanta Terezinha emerald which we describe as 'coal-like'. They are present as rounded crystals and distributed as clouds. Each individual crystal is 50~100μm in size. A few of them occasionally appeared on the table facet (Figure 4); one shows a rod-like shape on the facet. An SEM photograph is shown in Figure 5. Compositions were analysed at three points on the included crystal. Elements Mg, Fe. Cr and traces of Ni, Cu were detected. Chromium was also detected by EPMA which has an analysing area much smaller than X-ray fluorescence analysis. Figures 6a and 6b show the concentration of magnesium and lack of aluminium in the included crystal. These results suggest that the inclusion is magnesioferrite [$Mg(Fe,Cr)_2O_4$] or magnesio-chromite [$(Mg,Fe)(Al,Cr)_2O_4$] rather than chromite [$FeCr_2O_4$]. All belong to the spinel series.

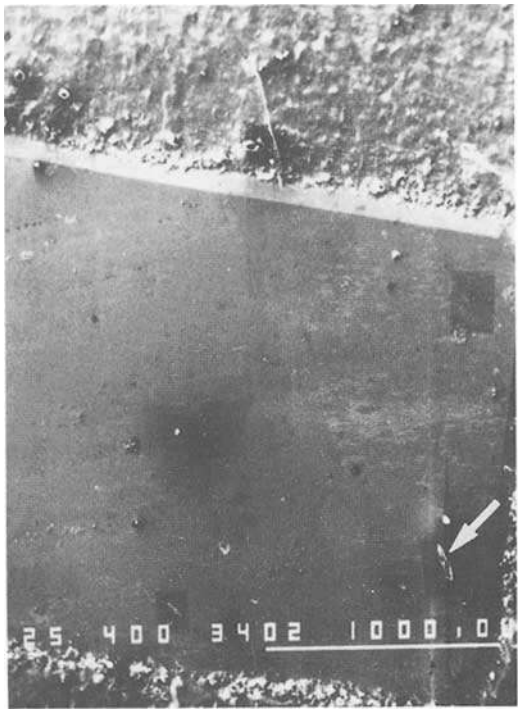

Fig. 4. One of the 'coal-like' inclusions on a facet which shows rod-like shape (arrow indicates). White bar represents 1000μm.

Fig. 5. SEM photograph of the rod-like crystal. The white bar represents 10μm.

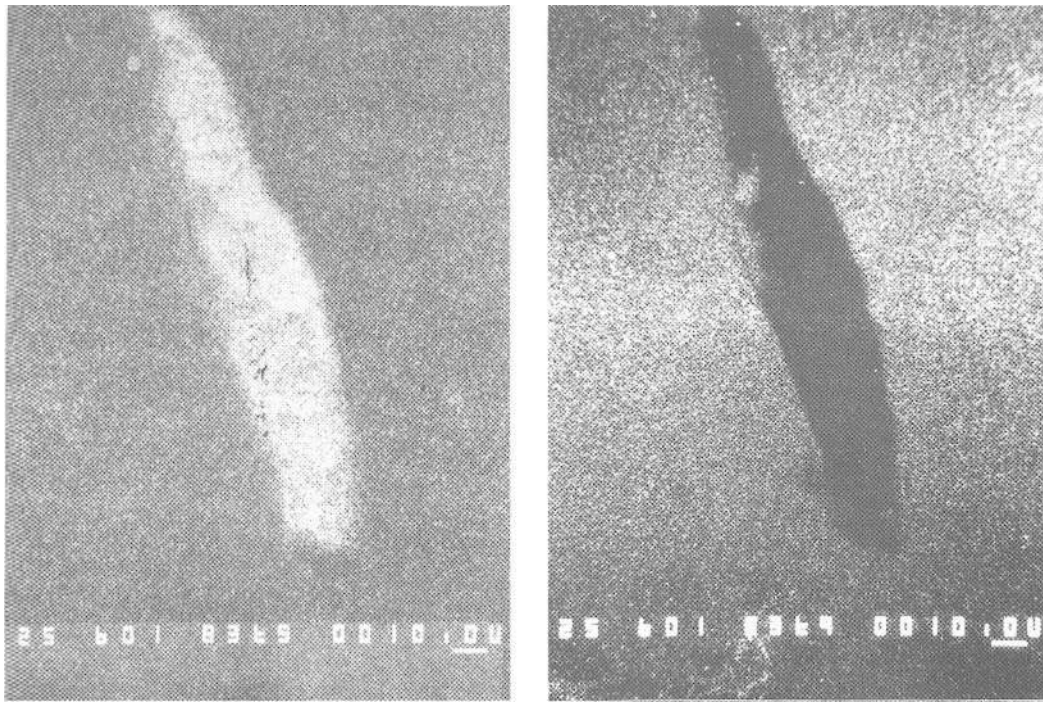

Fig. 6a. and 6b. Characteristic X-ray images (Mg and Al) of the same crystal as in Figure 5. These photographs reveal the concentration of Mg and the lack of Al in the crystal. White bar represents 10μm.

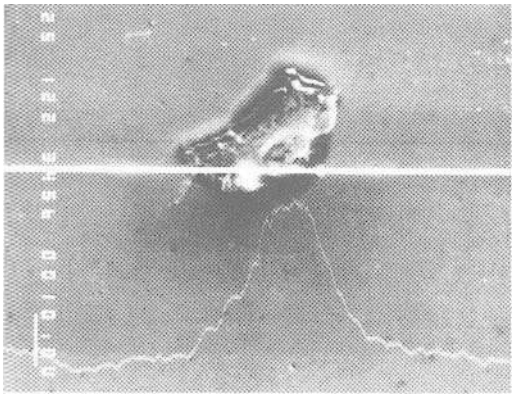

Fig. 7. SEM photograph and the line profile of K concentration on the other included crystal. This crystal may be biotite. White bar represents 10μm.

Figure 7 shows a SEM image and line profile of the potassium content of another included crystal. The crystal was determined as mica (possibly biotite) by the high concentration of potassium together with aluminium and magnesium.

Conclusion

In emeralds from Santa Terezinha, three types of inclusion minerals can be identified by EPMA. They are pyrite, mica and magnesioferrite. The existence of pyrite in these emeralds is very important, since no other locality except Colombia has provided emeralds with pyrite inclusions. Hereafter we cannot conclude that an emerald must come from Colombia simply because it contains pyrite as an inclusion.

References

Liddicoat, R.T., jr, 1983. New emerald mines at Santa Terezinha de Goiás, Brazil. *Proc. of the 19th International Gemmological Conference, Sri Lanka.*

Cassedanne, I.P. and Sauer, D.A. 1984. The Santa Terezinha de Goiás emerald deposit. *Gems Gemol.*, **20**, 1–13.

[*Manuscript received 5 June 1986*]

Gemmological Abstracts

BALFOUR, I. 1986. Famous diamonds of the world, XXVI. La Belle Helene. *Indiaqua*, **44** (1986/2), 125–7.

Found early in 1951 in one of the Consolidated Diamond Mine's southernmost workings along the inhospitable Namibia coast, La Belle Helene was a perfect blue-white stone weighing 160 ct. It was bought by Mr Romi Goldmuntz and cut in his New York premises to yield three gems: two pear-shaped stones of 30.38 and 29.71 ct, and a marquise of 10.50 ct, all of which were sold through Cartier's to private buyers. P.G.R.

BALFOUR, I. 1986. Famous diamonds of the world, XXVII. The Vainer Briolette. *Indiaqua*, **44** (1986/2), 129–30.

Although the origin of the 202.58 ct rough diamond that yielded the 116.60 Vainer Briolette is not known, it is believed to be a South African stone. In its rough state, the diamond was yellowish, lightly spotted, and of an almost perfect octahedral shape. It was cut in London in 1985/6 by the firm of M. Vainer Ltd. to produce a principal stone (which has the distinction of being the largest diamond briolette in the world) plus five other gems weighing a total of 14.93 ct. The Vainer Briolette was purchased by the Sultan of Brunei. P.G.R.

BALFOUR, I. 1986. Famous diamonds of the world, XXVIII. Matan. *Indiaqua*, 45 (1986/3), 123–4.

The Matan (or 'Mattam') takes its name from a town in West Borneo. The diamond was discovered there in the local diamond mines in the early 1800s, and was said to weigh 367 ct. When cut, the stone was described as being about the size of a walnut and drop-shaped. The present whereabouts of the gem is unknown, but it may have been part of the cargo of diamonds shipped out of Borneo by the Japanese during World War II. The cruiser carrying the shipment was sunk off the coast of Eastern Sumatra. P.G.R.

BALFOUR, I. 1986. Famous diamonds of the world, XXIX. Emperor Maximilian. *Indiaqua*, **45** (1986/3), 126–8.

Acquired by Archduke Maximilian (younger brother of Joseph I, Emperor of Austria) when he was visiting Brazil in 1860, the Emperor Maximilian was a cushion-cut stone weighing 41.94 ct, and was so named after the Archduke became Emperor of Brazil in 1864. The diamond survived Maximilian's execution in 1867, and after being bought by a Chicago diamond dealer in 1919, was eventually sold by him to a private collector in New York in 1946. P.G.R.

BANK, H., 1986. Gemmologische Kurzinformationen. (Short gemmological notes.) *Zeitschrift der Deutschen Gemmologischen Gesellschaft*, **35**, 3/4, 185–9.

Four short articles, each with its own bibliography. The first note deals with an olivine from the Eifel, between Mayen and Gerolstein, from the volcanic limestones present there. These local stones are of interest only to collectors as they are too small to be cut. An olivine of brownish-olive colour was discussed that had an exceptionally high RI, n_x 1.670, n_y 1.688, n_z 1.706, SG 3.43. Dr Bank then discusses Brazilian scheelite (yellowish-white, or grey to brown and colourless), H 4.5–5, and senarmontite. The other two notes have been worked on by Dr Bank with Th. Lind and U. Henn and deal with emeralds from Sta Terezinha de Goias, Brazil, with relatively high RI, and with synthetic emeralds produced hydrothermally in the USSR, showing growth irregularities and 'nail-like' inclusions. E.S.

BRIGHTMAN, R., SANDEMAN, D., 1986. Boulder opal triplet imitating natural solid boulder opal. *Australian Gemmologist*, **16**, 4, 151–2, 4 figs in colour.

Several opals were found to be triplets made by cementing a layer of fine crystal opal, with a mixture of powdered ironstone and resin, to a genuine boulder opal base. These are convincing imitations but may show bubbles in the cement layer, which will soften under a hot needle. They originate from Hong Kong. R.K.M.

BROWN, G., 1986. An unusual keshi pearl. *Australian Gemmologist*, **16**, 4, 139–40, 2 figs.

Describes a large adventitious bouton pearl with a non-nacreous back. Thought to be tissue nucleated. R.K.M.

BROWN, G., 1986. The gemmology of the shell cameo. *Australian Gemmologist*, **16**, 4, 153–61, 19 figs in colour.

An excellent account of various shell cameos. R.K.M.

BROWN, G. 1986. Benitoite. *Wahroongai News*, **20**, 12, 4–7, 4 figs.

A good summary of the known facts of this rare gemstone. Normally blue, a 'reddish' variety is mentioned.

This may stem from a report of a pink benitoite mentioned by Anderson in the fourth edition of Webster's *Gems*. Abstracter believes that the pink stone was reported from one of the West Indian islands and that nothing more was heard of it. R.K.M.

CASSEDANNE, J. 1986. L'améthyste de Pau d'Arco (Pará-Brésil). (Amethyst from Pau d'Arco (Pará, Brazil). *Revue de Gemmologie*, 89, 12–15, 9 figs (8 in colour).

Two new locations for amethyst have been discovered in the Amazonian forest in the state of Pará, Brazil. The locations are known as Pau d'Arco and Maraba. Colour banding, goethite crystals and fibres are all prominent inclusions. SG is 2.66 and RI 1.544 and 1.553 with a DR of 0.009. An absorption band exists between 560 and 520 nm. There is no luminescence and stones will lose colour when heated to 450°C, passing through a grey-violet colour at 350°C. M.O'D

ELLIOTT, J. 1986. Contemporary intarsia: the Medvedev approach to gem inlay. *Gems & Gemology*, **XXII**, 4, 229–34, 6 figs in colour.

A revival, by a Russian artist lapidary, of skilled inlay of stone in contrasting colours. Nicolai Medvedev now works in the United States, producing remarkably fine, high quality work in thin veneers of opaque stone such as malachite, lapis lazuli, sugilite, opal and rhodochrosite, each piece selected, sawn, cut and polished to an exact fit in a highly intricate design, whether for boxes or for flat pendant pieces. A remarkable skill reminiscent of earlier times. R.K.M.

FITZGERALD, S., RHEINGOLD, A.L., LEAVENS, P.B. 1986. Crystal structure of a Cu-bearing vesuvianite. *American Mineralogist*, **71**, 1011–14.

A blue Cu-bearing vesuvianite from Franklin, New Jersey, was determined and the formula given. M.O'D.

FRYER, C.W. (Ed.), CROWNINGSHIELD, R., HURWIT, K.N., KANE, R.E. 1986. Gem Trade Lab Notes. *Gems & Gemology*, **XXII**, 4, 235–40, 19 figs in colour.

A natural amethyst showed Brazil twinning even in unpolarized light. A synthetic amethyst had a 'nailhead' hydrothermal-type inclusion. A natural andalusite with curved growth lines was seen. Faceted orange clinohumite, cut and rough (RI 1.631–1.668, biaxial positive, SG 3.18) were donated to the GIA. A diamond with a heart-shaped cloud inclusion was seen.

Synthetic spinel soudé stones with sintered glass coloured layers investigated and one found which gave an RI of 1.682 for the glass, as well as the expected 1.724 for the spinel crown. A white 'breadcrumb' inclusion was seen in a hydrothermal synthetic emerald. 'Lapis' beads were proved to be surface-dyed dolomite. Natural pearl was badly eroded by skin acid. 'Coques de perle' imitations were found to have been worked from nautilus shell. A large weakly chatoyant pink cabochon represented as analcime was identified as petalite. A necklace of dark beads was found to be quartz heavily included with pyrite crystals. All items are illustrated. R.K.M.

GAUTHIER, J.-P. 1986. Synthese et imitation de l'opale noble. (Synthesis and imitation of precious opal.) *Revue de Gemmologie*, 89, 16–23, 12 figs.

A useful review of the known facts about the synthesis of opal and the nature and manufacture of its various imitations. Electron microscopy of opal structure is described and illustrated. M.O'D.

GÜBELIN, E. 1986. Die diagnostischen Eigenschaften der neuesten Synthesen. (Diagnostic features of the latest synthetics.) *Goldschmiede Zeitung*, **81**, 11, 69–76, 47 figs in colour.

Characteristic inclusions are described and illustrated for emerald (Lennix, Biron, Russian hydrothermal and flux and Seiko), ruby (Lechleitner) and sapphire (Seiko and Lechleitner). A yellowish and an alexandrite-like Lechleitner product are also illustrated. M.O'D.

GÜBELIN, E.J., 1986. The distinguishing criteria of the garnet family with special emphasis on inclusions. *Indian Gemmologist*, **1**, 1, 5–14, 16 figs in colour.

A full account of the characteristic inclusions to be found in gem species of garnet with high-class colour illustrations. M.O'D.

GÜBELIN, E., KOIVULA, J.I., 1986. Inklusen im Bernstein. (Inclusions in amber.) *Zeitschrift der Deutschen Gemmologischen Gesellschaft*, **35**, 3/4, 73–86, 45 figs in colour.

The article consists of a short introduction and 45 beautiful photographs of plant and animal inclusions in mainly Dominican and Baltic amber (a couple of illustrations are of copal resin from Colombia and Africa), including a photograph of a rare scorpion inclusion. E.S.

HÄNNI, H.A., 1986. Behandelte Korunde mit glasartigen Füllungen. (Treated corundums with glassy fillings.) *Zeitschrift der Deutschen Gemmologischen Gesellschaft*, 35, 3/4, 87–96, 8 figs (5 in colour).

During thermal treatment of corundums, chemicals are applied which may form glassy coatings or fillings of cavities and fissures. This is practised in increasing measure mainly in Thailand. The applied glasses vary in their Si, Al, Mg, Ca, Na and K content. The introduction of these glasses into cracks can improve the transparency of the stone significantly, but, if the cooling rate is low, partial recrystallization of the glass may occur, leading to an opaque filling. E.S.

HAZEN, R.M., AU, A.Y., FINGER, L.W. 1986. High-pressure crystal chemistry of beryl ($Be_3Al_2Si_6O_{18}$) and euclase ($BeAlSiO_4OH$). *American Mineralogist*, **71**, 977–84, 2 figs.

Objectives of the study were to determine pressure-volume equation-of-state parameters and compression anisotropies by measuring the pressure variation of unit cell dimensions; to calculate polyhedral bulk moduli from high-pressure structure data, to test the effects of structure on the moduli and to identify geometrical changes in the beryl and euclase structures. Findings are given in tabular form. M.O'D.

IYER, J.P., 1986. Panna diamonds in the world context. *Indian Gemmologist*, **1**, 1, 31–5, 5 figs.

Panna diamonds are generally of a high standard of quality, size and crystal perfection. Diagrams of the commoner forms are provided. M.O'D.

JHAVERI, K., 1986. Diamond grading. *Indian Gemmologist*, **1**, 1, 19–25, 10 figs.

The first part of a promised series of papers, this one deals with the path of light in a cut diamond and with styles of cutting. M.O'D.

KIEFERT, L., SCHMETZER, K., 1986. Morphologie und Zwillingsbildung bei synthetischen blauen Sapphiren von Chatham. (Morphology and formation of twinning in Chatham synthetic blue sapphires.) *Zeitschrift der Deutschen Gemmologischen Gesellschaft*, 35, 3/4 127–38, 10 figs (2 in colour).

The article discusses morphological and crystallographic properties of Chatham blue synthetic sapphires. Most crystals show contact twinning. Internal structural properties such as straight parallel growth planes and twin boundaries applied to the differentiation between natural and synthetic corundum are discussed. E.S.

KIEFERT, L., SCHMETZER, K., 1986. Rosafarbene und violette Sapphire aus Nepal. (Pink and violet sapphires from Nepal). *Zeitschrift der Deutschen Gemmologischen Gesellschaft*, 35, 3/4, 113–25, 16 figs (6 in colour).

The exact occurrence of these sapphires from Nepal is unknown. The colour is caused by chromium (pink) and a combination of chromium, iron and titanium (violet). Associated minerals found were calcite, phlogopite, margarite and rutile. The samples show intercalated lamellae of corundum in twin position and straight parallel growth planes. Small platelets of mica seem to be the most characteristic inclusion of this new locality. The sapphires also show healed and unhealed fractures, making them somewhat unsuitable for jewellery purposes. E.S.

KOIVULA, J.I., 1986. Three-phase inclusions in 'Regency' synthetic hydrothermal emerald. *Zeitschrift der Deutschen Gemmologischen Gesellschaft*, 35, 3/4, 97–9, 2 figs in colour.

The paper describes the discovery of true three-phase inclusions in Vacuum Ventures 'Regency-created' hydrothermal synthetic emeralds. The three separate phases comprising these inclusions are contained within the spike-shaped voids commonly associated with hydrothermal synthetic emeralds. The solid daughter crystals display the habit of phenakite and are birefringent. E.S.

KOIVULA, J.I., FRYER, C.W., 1986. Hollandite in quartz: a first observation. *Australian Gemmologist*, **16**, 4, 141–2, 3 figs.

A rare black sub-metallic barium-iron-manganese oxide was found as radial formations in a large faceted rock-crystal from Minas Gerais. R.K.M.

KOIVULA, J.I., FRYER, C.W., 1986. Blue-green zircon in Pakistani beryl. *Zeitschrift der Deutschen Gemmologischen Gesellschaft*, 35, 3/4, 101–3, 1 fig in colour.

Idiomorphous crystals of translucent blue-green zircons were identified for the first time as inclusions in a pale blue aquamarine crystal derived from a pegmatite in northern Pakistan, situated near the Afghanistan, Russian and Chinese borders. The crystal was 2cm long. E.S.

KOIVULA, J.I., MISIOROWSKI, E. 1986. Gem news. *Gems & Gemology*, **XXII**, 4, 246–8, 4 figs in colour.

Irradiated green amblygonite seen. Bicolour green/orange beryl from Minas Gerais heats to blue/pink. Chalcedony stained blue with copper salts develops copper dendrites when treated electrically. Chrome-green sphene from Baja,

California, is being marketed as Mexican emerald. Green amazonite crystals found in Teller Co., Colorado. Pink/green West African tourmalines used in carvings for Intergem '86 exhibition in Idar-Oberstein. Kenyan rubies are exported to Thailand for heating to improve their transparency: results are said to be 'dramatic'. A green jade-like cabochon was shown to be meta-variscite. A new find of elbaite tourmaline reported from Minas Gerais. R.K.M.

MISIOROWSKI, E.B., DIRLAM, D.M. 1986. Art nouveau: jewels and jewelers. *Gems & Gemology*, **XXII**, 4, 209–28, 22 figs in colour.

A beautifully illustrated paper on a fantasy art style which was largely killed by the grim realities of the 1914–18 war. The paper deals briefly with a number of the leading designers and makers of jewellery which was often characterized by whip-lash lines and somewhat distorted naturalistic forms very skilfully executed in gems, precious metals and enamels. Today these pieces are eminently collectable. R.K.M.

MOON, A.R., PHILLIPS, M.R., 1986. Inclusions in sapphire and heat treatment. *Australian Gemmologist*, **16**, 4, 163–6, 6 figs.

A further examination of important features related to the current practice of heating sapphire rough to improve colour and/or asterism. R.K.M.

NAGIN, T., NAGIN, I., 1986. Quartz crystals of Colombia. *Lapidary Journal*, **40**, 8, 38–41, 6 figs.

A useful account of a quartz deposit at Alto de Cruces, Colombia, with descriptions of the crystals and of their mode of formation. An Arkansas company is marketing them. M.O'D.

O'DONOGHUE, M., 1986. Gems and gemmology. *Watchmaker, Jeweller and Silversmith*, November, 45–7, 1 fig.

The whole column is devoted to a detailed review of Gübelin's *Photoatlas of inclusions in gemstones* from which a number of extracts are taken, dealing in particular with diamond, emerald and ruby. (Author's abstract.) M.O'D.

O'DONOGHUE, M. 1987. Gems and gemmology. *Watchmaker, Jeweller and Silversmith*, January 1987, 47–9.

Among the topics discussed are the partially restored Green Vaults at Dresden, glass made from volcano ash, gem and mineral nomenclature and cobalt-coloured natural blue spinel.

(Author's abstract) M.O'D.

PANJIKAR, J., 1986. Gem resources of India. *Indian Gemmologist*, **1**, 1, 15–17, 1 fig.

The first part of a promised series of papers on Indian gem minerals, this section outlines the geology of the beryl deposits with special reference to aquamarine. M.O'D.

PATTANI, H. 1986. The precious metal gold. *Indian Gemmologist*, **1**, 1, 27–30.

A short account of some of the uses for jewellery during the last 6000 years of gold and its various standards/alloys – also of rolled gold and gold plating. J.R.H.C

PEARSON, G., 1986. Opal pineapples from White Cliffs. *Australian Gemmologist*, **16**, 4, 143–50, 13 figs in colour.

A detailed account of a new finding of these pseudomorphs of glauberite, usually described as 'pineapples' and here referred to also as 'fruit'. Difficult hand mining conditions are described. Better specimens found in powdery white clay. Cleaning of specimens presented difficulties. Some 'pineapples' are available for sale. R.K.M.

POUGH, F.H., 1986. Gem treatment: opal. *Lapidary Journal*, **40**, 7, 16–18.

Brief summary of the various treatments applied to opal and notes on some imitations. M.O'D.

POUGH, F.H. 1987. Garnet. *Lapidary Journal*, **40**, 10, 16–18.

A brief and general discussion of the garnet gem species. M.O'D.

POUGH, F.H. 1986. Zircon. *Lapidary Journal*, **40**, 9, 15–18.

A short review of the various treatments applied to gem-quality zircon. M.O'D.

READ, P.G., 1984–1985. (1) Spotting the Fakes, *Gem Instrument Digest*, August 1984, **1**, 6, 76–7, 1 fig: (2) Gem Instrument Reports, *ibid.*, 77–84, 14 figs: (3) Disclosure of Gemstone Treatments, *id.*, November 1984, **1**, 7, 90–1, 1 fig: (4) Gem Instrument Reports, *ibid.*, 91–8, 11 figs: (5) Gem Instrument Design Trends, *id.*, February 1985, **1**, 8, 103–4, 1 fig: (6) Gem Instrument Reports, *ibid.*, 104–11, 12 figs:

(1) Diamond seems to be the only stone identifiable with some certainty without the use of expensive research equipment: the risk of mistaken identification increases as each new synthetic coloured stone is introduced. As each new effective test is discovered, manufacturers seem to go out of their way to defeat it, and we are back to using a gem's distinctive internal features to separate the genuine from the fake.

(2) Reports on Rayner LED-illuminated Dialdex refractometer; OPL Wavelength Spectroscope; Presidium DiaMeter; Eickhorst Uviscope Pocketlite;

Gemlab Digital Spectroscope; Eickhorst Gemlyzer; Diamontron thermal tester; Demetron UV curing adhesives and lamps; Diamond Mounting Gauge by Centennial Casting Co.; Master Pearl Grading Sets (Midwest Gem Lab.); three new light sources (Illuminator/Magnifier by Beech & Son Ltd; Aristo Mic-O-Lite illuminators; Omnilite high-intensity fibre-optic probe).

(3) The disclosure rules of the Federal Trade Commission (USA) and CIBJO are compared and discussed.

(4) Reports on GemPro Digital Analyser; Rayner Polariscope with Konoscope attachment; SKS Macroscopes; Eickhorst LED-Lite Refractometer Illuminator; widefield lens for Rayner S Refractometer; battery/stand unit for Eickhorst Thermolyzer; Prior ZS2500 stereo-zoom microscopes; JDN FireScope; Leveridge gauge for melée weight estimation; Mettler CE150 and AE500C electronic balances.

(5) No major innovations in last two years other than the GemPro, but some unusual features introduced and existing instruments improved to reduce cost and improve ease of handling. Queried whether Rofin 6010 unit (light source, scanning monochromator, sample holder/photodetector, with absorption spectrum shown on standard oscilloscope) is 'poor man's version' of spectrophotometer.

(6) Reports on Eickhorst Microlab; Spectroscope Unit M-1 (McCrone Research Associates); Kassoy Gemmological Microscope; two light sources (Krüss fibre-optic units KL5120, KL5130; Kassoy halogen Jeweller's Lamp); static elimination (Zerostat 3; 3M Anti-static mat; ASP40 Anti-static spray); Nelson Ray-path Unit; GRC Gem Color Analyzer; Pye Unicam PU8800 UV-Vis Spectrophotometer ('Basil Anderson Spectrophotometer'). J.R.H.C.

READ, P.G. 1986. A question of colour. *Canadian Jeweller*, November 1986, 25–7, 9 figs in colour.

The mechanism of colour production in gemstones is discussed (transition elements in allochromatic and ideochromatic gems, pleochroism, interference and diffraction effects, and colour centres). The second part of the article comprises a series of product knowledge profiles covering the characteristics and occurrence of twenty-two gem species. (Author's abstract) P.G.R.

READ, P.G. 1986. Grading coloured stones. *Canadian Jeweller*, November 1986, 11.

A review is made of the politics and techniques of instrumental colour grading for both diamonds and coloured gemstones. Instruments for diamond colour grading (Eickhorst Diamond Photometer, the Okuda Diamond Color Checker and the Kalnew GemColor 2) are briefly described as are two instruments used for grading coloured stones (GIA Colormaster and Zeiss spectrophotometer). Mention is made of the computer-based 'expert' network developed by American Gem Market System (AGMS). (Author's abstract) P.G.R.

READ, P.G. 1986. Fancy diamonds: treated or not? *British Jeweller*, September 1986, 39.

Contains a brief historical review of the alteration of a diamond's colour by irradiation and heating, together with the methods of discriminating between treated and untreated diamonds. Since the discovery that the diagnostic 595 nm absorption line in a treated diamond can be eliminated if the stone is heated to around 1000°C, identification problems have existed. Drs Collins and Wood have solved these problems by detecting two more diagnostic lines in treated diamonds at 1,936 and 2.024 nm. (Author's abstract) P.G.R.

ROHRBACH, R.P., 1986. Stars and stripes forever. *Lapidary Journal*, **40**, 7, 20–30, 8 figs in colour.

Non-rigorous account of asterism and chatoyancy in gemstones. M.O'D.

ROOT, E., 1986. Gems and minerals of the USSR. *Lapidary Journal*, **40**, 8, 42–7, 6 figs (5 in colour).

A brief account of some of the gem materials to be found in the Soviet Union, based on a tourist visit. M.O'D.

ROUX, J. 1986. The information revolution – thirty years on. *Indiaqua*, **45**, 1986/3, 97–9.

The author, formerly Information Officer of De Beers Central Selling Organization in London, contrasts the early days, when diamond knowledge and lore were jealously guarded and passed down from father to son, with the printed information explosion of the present day. P.G.R.

SCHLUSSEL, R. 1986. Nouveau traitement de rubis naturels. (New treatment for natural rubies.) *Revue de Gemmologie*, **89**, 4–8, 13 figs in colour.

This paper forms the second part of an account of methods used to improve the appearance of natural rubies. Cavity filling is the technique mainly described. M.O'D.

SCHMETZER, K., KIEFERT, L., 1986. Untersuchung eines Sapphir-Katzenauges aus Burma. (Investigation of a sapphire cat's-eye from Burma.) *Zeitschrift der Deutschen Gemmologischen Gesellschaft*, **35**, 3/4, 105–11, 6 figs (1 in colour).

The chatoyancy was examined in a sapphire cat's-eye from Burma which did not show any needle or rod-type inclusions. The crystal was shown to be twinned, inclination angle about 11 degrees. Both 'twins' have growth planes parallel to the hexagonal dipyramid as well as glide planes parallel to the

basal pinacoid. Chatoyancy is presumed to be caused by total internal reflection at irregular patch-like fissures on basal glide planes. E.S.

SHIGLEY, J.E., FRITSCH, E., STOCKTON, C.M., FRYER, C.W., KANE, R.E. 1986. The gemological properties of Sumitomo gem quality synthetic yellow diamonds. *Gems & Gemology*, **XXII**, 4, 192–208, 20 figs in colour.

In 1985 Sumitomo Electric Industries produced gem quality yellow synthetic diamond crystals in quantity. They now make them up to 2 carats in weight, primarily for the industrial market as heat sinks and for precision cutting tools. But some have been faceted as gems, the largest to date being a brilliant of 0.8 carat. Grown at high temperatures and pressures in a metal flux solvent around seed crystals of synthetic diamond, giving crystals which are consistent in their properties. Yellow colour is due to dispersed nitrogen which is carefully controlled in amount.

The twenty samples examined were all deep yellow, cleavage-free and with no prominent inclusions. Growth trigons were absent. All were type Ib and their spectra lacked the strong lines of the natural type Ia yellow diamond. Inert to LWUV, the crystals glow greenish-yellow under SWUV. They are non-conducting of electricity, but their thermal conduction is similar to that of natural diamond. Specific gravity (3.505) is slightly lower than that for most natural stones. Inclusions: random pinpoints of whitish material and some opaque crystals of flux. Some crystals had colourless thread-like veins near their surfaces which were not retained in the cut stones; these are not seen in natural diamonds. Parallel colour graining is a prominent feature of these synthetics, while a 'Maltese Cross' of wedge shapes is seen in some of them. Polarizing microscope showed an interference pattern of a twisted dark cross. Two crystals were slightly magnetic.

Identification: the inert reaction to LWUV and the bright yellow under SWUV provide an easy test. Sharp absorption lines in the blue will confirm natural yellows, but their absence cannot be taken to indicate a sure synthetic. Large stones of deep yellow, at this stage, are unlikely to be synthetic. Pale yellows also seem unlikely to be made. A valuable paper on a significant synthetic. R.K.M.

SHIGLEY, J.E., KANE, R.E., MANSON, D.V., 1986. A notable Mn-rich gem elbaite tourmaline and its relationship to 'tsilaisite'. *American Mineralogist*, **71**, 1214–16, 1 fig.

A tourmaline with an uncommon yellowish-green colour was found to have the most Mn-rich composition ever reported for tourmaline. The postulation is of a possible solid-solution series between elbaite and a hypothetical Mn analogue 'tsilaisite'. RI was 1.621, 1.649 with a DR of 0.028; SG was 3.13. The stone is thought to have come from Zambia. M.O'D.

SLAHOR, S., 1986. Mysterious moonstone. *Lapidary Journal*, **40**, 7, 37, 1 fig.

Single page note on the legend and lore of moonstone. M.O'D.

SOBOTT, R.J., 1986. Gemmologisches Wissen im christlich geprägten Kulturraum zur Zeit des Frühund Hochmittelalters (7.–12.Jh.n.Chr.). (Gemmological knowledge in the sacred arts between the 7th and 12th centuries AD.) *Zeitschrift der Deutschen Gemmologischen Gesellschaft*, 35, 3/4, 139–59, 4 figs in colour.

Much work was done by medieval goldsmiths for the church making extensive use of gemstones. Monks and bishops also wrote treatises on gems which are of great interest, but because of their lack of knowledge of the subject, do not contribute to the progress of gemmology. The author lists many such works and also quotes a number of original texts in Latin with translations; the stones discussed by these medieval authors are mainly sapphires, emeralds, amethysts and carbuncles. E.S.

STRIPP, D.M. 1986. Beginner's luck. *Lapidary Journal*, **40**, 9, 24–31, 4 figs in colour.

The article describes a visit to the gem-hunting grounds at Spruce Pine, North Carolina, USA, and the emerald crystals recovered. M.O'D.

STRUNZ, H., WILK, H., 1986. Die modernen Edelstein-Refraktometer. (The modern gem refractometer.) *Zeitschrift der Deutschen Gemmologischen Gesellschaft*, 35, 3/4, 161–77, 13 figs.

The article is sub-titled 'Basis, shape and materials of refractometers, how they are handled, their history and corrections'. European refractometers generally use Rayner reflectors, American ones a semi-cylindrical reflector. Indicatrix used since 1910 gives rise to some misunderstandings which are corrected. The author points out that the light entering the modern refractometer does not graze, but enters at an angle from below; also that the depth of the light from the reflector into the gemstone measures only a few wavelengths (589nm). E.S.

THEMELIS, T., 1986. Synthetic stars. *Lapidary Journal*, **40**, 7, 46–8, 6 figs in colour.

Straightforward account of the manufacture of starstones. M.O'D.

THEMELIS, T. 1986. Urano-pyrochlore in sapphire. *Lapidary Journal*, **40**, 9, 19, 2 figs in colour.

A short description, with references, of the uranium pyrochlore found as a reddish inclusion in sapphire crystals from Pailin, Khmer Republic. M.O'D.

VOGLER, K., 1986. Neue Untersuchungen an einem farblosen Chrysoberyll. (New investigation of a colourless chrysoberyl.) *Zeitschrift der Deutschen Gemmologischen Gesellschaft*, **35**, 3/4, 179–83, 2 figs.

A colourless chrysoberyl of 8.2 ct of doubtful origin, previously examined by K. Schmetzer (*Zeitschrift der Deutschen Gemmologischen Gesellschaft*, 1985, **34**, 1/2, 6–12*) has been re-examined by non-destructive, chemical analysis (EDS XRF) and the presence of gallium was clearly shown. This and other internal features showed the specimen to be of natural origin. E.S.

WINKLER, R. 1987. Berylliummineralien aus der Umgebung von Böckstein. (Beryllium minerals from the neighbourhood of Böckstein.) *Lapis*, **12**, 2, 11–14, 11 figs (8 in colour).

Among the crystals found in the area of Böckstein are aquamarine and phenakite; the location is in the eastern Austrian alps. M.O'D.

ZEITNER, J.C., 1986. Phenomenal gems – find them in the USA. *Lapidary Journal*, **40**, 7, 32–6, 3 figs in colour.

Useful account of some gem minerals found in the United States. M.O'D.

ZHOU, Y. 1986. Growth of high quality large Nd:YAG crystals by temperature gradient technique (TGT). *Journal of Crystal Growth*, 78, 31–5, 6 figs.

Though usable laser rods of YAG doped with Nd are usually grown by the Czochralski pulling technique, such crystals often show an optically inhomogeneous core region due to the convex interface attained during growth. TGT growth allows the whole crystal rather than outer regions only to be used. M.O'D.

Book Reviews

BRUTON, E. 1986. *Legendary gems or gems that made history*. NAG Press, Ipswich (and Chilton Books, Radnor, Pennsylvania). pp.xii, 239. 23 colour plates, 75 figures. £15.95.

This is essentially a narrative book, but it will also serve as a reference book on legendary gems. The author has written authoritatively on diamonds, clocks and many other subjects, and can truly list his professions as writer, publisher, horologist, gemmologist and restorer of old houses.

Chapters one and two deal in fascinating detail with the history of the Koh-i-Noor diamond from its probable source in the Kollur mines in India, through its acquisition by the Moguls and other rulers, to its unfortunate re-cutting in the nineteenth century and its incorporation in the British Royal Regalia. Chapter three relates the stories of the diamonds which have now vanished, including the Great Mogul, the Moon of the Mountains, the Mirror of Portugal, the Pigot and the Great Table (although the Persian Darya-i-Noor is now thought to be part of this stone). Chapter four includes the story of the Great Blue diamond from which the extant Hope diamond may have been cut. Chapter five explains the French connections of the Sancy, Regent (Pitt) and Hortensia diamonds and tells of the wars and other international machinations associated with them. Chapter six is a fascinating mixture of history with science and includes accounts of the Florentine, De Beers, Red Cross, Kimberley, Tiffany, Wittelsbach, Dresden Green and other coloured diamonds. Chapter seven, entitled 'The greatest gem of all time', is mainly devoted to the Cullinan diamond but inclusion of the Excelsior and Star of Sierra Leone completes the descriptions of the three largest known rough gem-quality diamonds. Chapter eight is devoted to 'rubies' and sapphires – in particular to the Black Princes and Timur rubies, which are, of course, red spinels. The legends surrounding the St Edwards and Stuart sapphires are covered in some detail and

*Abstracted in *Journal of Gemmology*, 1985, **XIX**, 8, 731.

the modern sapphire carvings of the heads of various American presidents receive attention. Chapter nine is largely devoted to legendary emeralds, but famous aquamarines, alexandrites, amethysts and opals, are also covered. Chapter ten relates the stories of famous pearls from 2560 BC to the present day. Chapters eleven and twelve complete the narrative with 'Legends in the making' and the stories of dealers and collectors of great gems.

The foregoing summary of the chapters in this book cannot convey the extremely interesting way in which the various legends (and facts) surrounding the fabulous gems are recounted. Access to information in the book is facilitated by the gemstone species arrangement, but the provision of a good index is an even better way of finding a specific topic. The author provides a good bibliography and freely acknowledges his debt to the authors of the source books listed.

It would be surprising if no errors were to be found, and apart from minor typographical mistakes the reviewer could draw attention to the following points. On page 139 it states that spinel is 'an oxide of aluminium and manganese' and on page 161 that 'ruby and sapphire have a lower relative density' than diamond! Figure 9–7 shows a celebrated gem-quality aquamarine crystal some 25cm high and *not* the Devonshire emerald, which has been clipped from the bottom of the picture.

The book was manufactured in the USA and the spelling is American, but this should not detract from its good narrative flow and the assemblage of so much gemstone history and legend in one convenient volume. E.A.J.

HICKLING, J. 1986. *Practical jewellery repair*. NAG Press, Ipswich. pp.vi, 192. Over 200 black and white illustrations. £9.95.

Well known for their range of practical books, NAG Press Ltd, of Ipswich, have just published *Practical jewellery repair*, which is sure to become a standard textbook for the amateur restorer of jewellery, as well as the working professional and apprentice.

Starting where it all begins – in the workshop or workroom – the author shows how a wide range of repair work can be undertaken with even quite a modest set-up, that can be extended as finances and the skills of the user permit.

There is a very thorough grounding in the various processes and materials required, including working with precious metals and solders and stocking some of the less expensive gemstones. Basic skills such as soldering, casting, wire-drawing, polishing, sawing and filling, are fully explained and illustrated throughout with many clear line drawings. Based on his own wide experience, the author introduces some effective and ingenious methods and short cuts that save both time and cost or improve the work entailed.

With over 30 years' experience, in the UK, Australia and New Zealand, the author provides tried and tested advice on restoring all kinds of antique and modern jewellery, with particular emphasis on the making and repairing of rings. He also describes some of the more unusual repairs to lockets, bracelets, earrings, brooches and watch-cases, including the making of joints, safety catches, pins, respringing and polishing. The appendices also include a useful and comprehensive 'Jeweller's guide to gemstone handling' using a lathe and, increasingly important these days, workshop security. P.R.

MITCHELL, R.H. 1986. *Kimberlites, mineralogy, geochemistry and petrology*. Plenum, New York. pp.xv, 442. $78.00.

The book is concerned primarily with the petrology of kimberlites rather than prospecting for them. Though the occurrence of minerals in kimberlite is described in chapter six, the main aim of the book is to give a survey of the advances made in kimberlite studies over the past 25 years. For this reason the discussion of diamond with respect to kimberlites is left to a short section towards the end of the book. Discussion turns upon whether diamonds are xenocrysts in kimberlite; if they are, then the role of the kimberlite is merely one of transportation. Diamond is regarded as a mineral which can occur in a variety of parageneses in the upper mantle so that several modes of origin are possible. These are briefly discussed. M.O'D.

TAYLOR, L. 1985. *Struck by lightning*. Jon the Printer Pty Ltd, Ashmore, Queensland. pp.183. Illus. in black-and-white and in colour. $5.15.

Now published by the author at Box 675 PO, Surfers Paradise, Queensland, this cheerful book consists mostly of anecdotes and poems, all with an opal mining background and theme. Among the tales are sections on the mining, selling and nature of opal. M.O'D.

Some semi-precious and ornamental stones of South Australia. Geological Survey of South Australia, Adelaide, 1980. pp.159. Illus. in colour. Price on application.

This is a useful survey with a considerable amount of detail given about the mines, their owners and their production. Opal is not included. There is a map in a pocket at the back of the book. M.O'D.

Proceedings of the Gemmological Association of Great Britain and Association Notices

GIFTS TO THE ASSOCIATION

The Council of the Association is indebted to Mr Peter Read for the gift of the computer installation used by him to develop his Gemdata programs (Read, 1980 and 1983), which is now installed in the Association's library at Saint Dunstan's House.

The Gemdata program provided for use with the computer has five sections:

(1) Gem identification, using test inputs for RI values, optic sign, SG, etc.
(2) Gem data tables, arranged in alphabetic, RI and SG orders.
(3) Gem data comparisons, enabling side-by-side comparisons of selected gems.
(4) Gem data pages, comprising an encyclopaedia of over 200 gem materials with information on their constants, characteristics and principal occurrences.
(5) Gem calculations, for the determination of SG, reflectivity, critical angle and Brewster angle.

The computer donated by Mr Peter Read, with the Gemdata programs.

The computer, with its Gemdata program, constitutes a means of rapid access to gemmological data for both exam, revision and gem identification purposes. It is available for use, on request, to both students of gemmology and to visiting gemmologists, particuarly those who wish to evaluate the use of the computer for gemmological purposes.

References

Read, P. 1980. Computer-aided gem identification. *Journal of Gemmology*, **XVII**, 4, 239–49.

Read, P. 1983. A computer program for gem identification. *Gems & Gemology*, **XIX**, 3, 157–63.

NEWS OF FELLOWS

The Association's Honorary Treasurer, Mr Nigel Israel, of Nibris Books, is moving in April. His new address will be 1 Simon Lodge, 76 Victoria Drive, Wimbledon, London SW19 6HJ. Telephone 01-789 0200.

Mr Michael O'Donoghue chaired a seminar on 'Geological and mineralogical literature' at the British Library's Science Reference and Information Service on 3 December 1986. Mr Nigel Israel presented a paper on 'The literature of gemmology' at the seminar.

MEMBERS' MEETINGS

Midlands Branch

On 20 February 1987 at Dr Johnson House, Bull Street, Birmingham, a talk was given by Mrs Carole Gibbs on the subject of tortoiseshell, including its recovery and marketing.

On 20 March 1987 at Dr Johnson House, Mr Alec E. Farn gave a talk on pearls.

North West Branch

On 16 October 1986 at Church House, Hanover Street, Liverpool 1, the Annual General Meeting was held, at which Mr S.G. Hill, FGA, was re-elected Chairman and Mrs I. Knight, FGA, elected Secretary.

On 20 November 1986 at Church House, Mr J. Dickson gave a talk entitled 'Microscopy, equipment and specimens'.

On 21 January 1987 at Church House, Mr J. Condrupt of Sotheby's gave a talk on jewellery that had been auctioned.

On 18 February 1987 Dr G. Trecise arranged a special viewing of gemmological specimens at Liverpool Museum.

On 18 March 1987 at Church House, Mr John Pyke, Sen., gave a talk on his newly catalogued collection of gemstones.

EXTRAORDINARY GENERAL MEETING

An Extraordinary General Meeting was held at the Royal Automobile Club, 89 Pall Mall, London SW1, on 28 January 1987, at which special resolutions were passed making a number of changes in the Memorandum and Articles of Association.

COUNCIL MEETING

At a meeting of Council held at the Royal Automobile Club immediately following the Extraordinary General Meeting on 28 January 1987 the business transacted included

(1) the appointment to the Council and nomination for election to the Council at the next Annual General Meeting of the following Fellows, namely Drs A.J. Allnutt, G. Harrison Jones and R.R. Harding and Messrs E.M. Bruton, A.E. Farn, E.A. Jobbins, D.G. Kent, P.G. Read and K. Scarratt.
(2) the establishment and terms of reference of an Executive Committee in accordance with the new Article 61.
(3) the appointment to serve on the Executive Committee of Sir Frank Claringbull (President), Mr David Callaghan (Chairman), Mr Noel Deeks (Vice-Chairman), Mr Nigel Israel (Honorary Treasurer), Dr G. Harrison Jones (Chairman of the Education Committee), Mr E.A. Jobbins (Chairman of the Board of Examiners), Drs A.J. Allnutt, R.R. Harding and J.B. Nelson, and Messrs E.M. Bruton, C.R. Cavey, A.E. Farn, P.G. Read, K. Scarratt and C.H. Winter.
(4) receipt of a report of the recent satisfactory business of Gemmological Instruments Limited.
(5) the election to membership of the following:

Fellowship

Abell, Alison M., London. 1986
Gentsidou, Fontini, Serres, Greece. 1986
Goodlin, Franceen D., Toronto, Ont., Canada. 1986
Lloyd, Jeremy J., Birmingham. 1986
McIntosh, Stewart F., Glasgow. 1986
Malhotra, Kapil, Bombay, India. 1986
Rowell, Unni G., Bloomington, Ind., USA. 1960
Skoropad, John D., Edmonton, Alta, Canada. 1985
Torrance, Claire H., Auckland, New Zealand. 1986
Van Dijk-Pietrzak, Jolanta A., Utrecht, Netherlands. 1986

Ordinary Membership

Andersen, Aud N., Grimstad, Norway.
Aoki, Yuka, Osaka, Japan.
Arthur, Lynne, Denny.
Atkins, Tristan A., Banstead.
Attar, Simon, London.
Axell, Anita, Stockholm, Sweden.
Barber, Susan A., Horsham.
Blain, Raymond E., Ashton-under-Lyne.
Burns, Brenda, Edinburgh.
Chadwick, Valerie, Brighton.
Chang, Kim, Taipei, Taiwan.
Charrington, Rosa M., Beckenham.
Curran, Paul H., Brighton.
Damiani, Michael, London.
Dawes, Percival E., Stevenage.
Dominy, Geoffrey M., Edmonton, Alta, Canada.
Draper, Geoffrey J., Brighton.
Edie, Anmie W., Ditchling.
Foster, Brenda C., St Albans.
Fox, Anthony H., Maidenhead.
Francis, Richard, London.
Fukuda, Yoshie, Yokohama City, Japan.
Gray, Thelma, Burnley.
Hara, Yoshiko, Osaka, Japan.
Hilton, Holly A., London.
Hiramatsu, Ikuo, Tokyo, Japan.
Hirano, Masato, Tokyo, Japan.
Hong, Chi-Won, Osaka, Japan.
Hori, Takeaki, Kyoto City, Japan.
Hsieh, Chiun-in, Tokyo, Japan.
Iwasawa, Koichi, Tokyo, Japan.
Jessop, Paul R., Glenrothes.
Kamei, Tsukumi, Osaka, Japan.
Kanodia, Jai P., London.
Katz, Raffi, London.
Keast, Edmund J., Sanderstead.
Kingsley, Serena, Eastbourne.
Larsson, Thomas, Järfälla, Sweden.
Lau, Kwok Hung, Kowloon, Hong Kong.
Leyens, Richard, London.
Loveday, Dawn E., Caterham.
McDonagh, Bernard, Wrightington.
Manning, Mark J., North Lancing.
Marumo, Kayo, Osaka City, Japan.
Matsumoto, Akira, Honjo City, Japan.
May, James G., Belfast, N. Ireland.
Millar, Ewan, Paisley.

Mohsinali-Esufali, Joher, Colombo, Sri Lanka.
Montgomery, Keith B., Leeds.
Mumabe, Atsuhiro, Tokyo, Japan.
Nimry, Lina, London.
Nordby, Anita, Oslo, Norway.
Ogawa, Yoko, Kana Gawa Pref., Japan.
Olivares, Rosana, Gibraltar.
Owen, Margaret E., Pietermaritzburg, South Africa.
Ozier, Stephen M., Bournemouth.
Raskin, David A., Glasgow.
Reavell, David, Dunstable.
Roberts, Charles, San Antonio, Tex., USA.
Rodwell, Peter F., Malmesbury.
Routledge, Hylton M., Bromsgrove.
Sabel, Sara, London.
Sarna, Rajesh, Nairobi, Kenya.
Sato, Hitoshi, Tokyo, Japan.
Saunders, Geoffrey P., Transvaal, South Africa.
Sayers, Charlotte A., London.
Shread, Andrew, Beeston.
Steedman, Pauline, London.
Stone, Anthony R., Poole.
Stone, Emma E., Derby.
Straitouri, Sophia, London.
Tabeling, Raymond W., Wilmington, Del., USA.
Tajima, Hidemasa, Osaka, Japan.
Tajima, Tomie, Kamakura City, Japan.
Taylor, David J., Cowes, IOW.
Uchibori, Satoru, Tokyo, Japan.
Usui, Kenichi, Tokyo, Japan.
Wadia, Aneeta, London.
Warrington, Jeffrey T., Brighton.
Wege, Joyce, Leeds.
Weiss, Anthony S., Bushey.
Winterbottom, Martin, Watford.
Yanagi, Narue, Tohka-Machi City, Japan.
Yang, Richard K. K., Kelantan, Malaysia.

ANALYSIS AND TECHNOLOGY OF ANCIENT GEMSTONES

The European University Centre for the Cultural Heritage is organizing an international symposium on 'Analysis and technology of ancient gemstones', to be held in Ravello, Italy, from 13 to 16 November 1987. Further details from Prof. T. Hackens, European University Centre for the Cultural Heritage, Villa Rufolo, I 84010 Ravello, Italy.

GEM TRADE RESTRICTIONS IN KENYA

As from 30 December 1986 anyone trading in minerals or gemstones in Kenya must have a licence. As a result of the enactment of the Statute Law (Miscellaneous Amendment) Act 1986, it is now illegal and an offence to be in possession of or trade in gemstones and/or other minerals without registering and having obtained a mineral dealers licence from the Commissioner of Mines and Geology.

GEM QUALITY SYNTHETIC DIAMOND IS BEING MARKETED

A synthetic diamond, identified at GIA's Gem Trade Laboratory in New York, is the first indication that new synthetic diamonds are circulating in the gem market. GIA broke the news of the new synthetics in January in the Institute's quarterly journal, *Gems & Gemology*. The article, entitled 'The gemological properties of the Sumitomo gem-quality synthetic yellow diamonds', was prepared by GIA's research department in Santa Monica, California.

The colour of the 23 point stone, submitted by a gem dealer, was a very intense yellow. Jewellers should definitely be wary of any fancy yellow diamonds they come across in the trade.

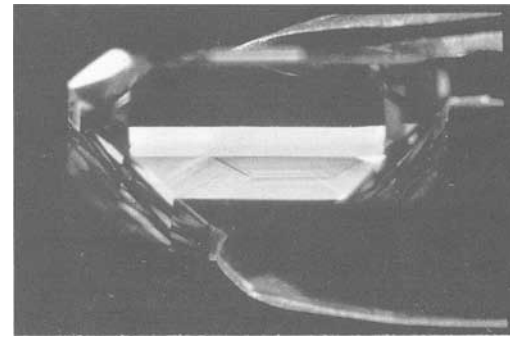

An emerald-cut synthetic Sumitomo diamond. The distinctive hourglass-shaped internal graining pattern has not been observed in any of the rough crystal sections studied.
Photomicrograph by John Koivula, from *Gems & Gemology*, Winter 1986.

GIA Board Chairman, Mr Richard T. Liddicoat, is not surprised at the appearance of the new synthetics in the diamond market. 'As I wrote in *Gems & Gemology*', Mr Liddicoat says, 'we knew they would show up. The question was when, and it turns out to be sooner rather than later. But then, our labs are always among the first to see new synthetics whenever they appear'.

The first synthetic diamonds were two stones submitted by a customer on 18 February, with a request for an origin of colour report. The smaller stone was identified as a diamond using a thermal inertia instrument, a standard test. It was then found to match the characteristics described in *Gems & Gemology*.

GEM IDENTIFICATION COURSE

Two- and three-day courses on gem identification run by Mr Alan Hodgkinson will be held at the British Horological Institute, Upton Hall, Newark, Notts., in the autumn.

Full details from the *Retail Jeweller*, 100 Avenue Road, London NW3 3TP.

LETTER TO THE EDITOR

From Bernice Backler
Barnscott Gemological & Metallogical Laboratory

Dear Sir,

Further to your request in Vol. 20, No. 4, p.241, re low cost accessories, we have pleasure in submitting the following:

Let there be light in your darkness

The attached sketch (we may be many things but not artists) shows that a light-source can be made with a minimal amount of expenditure and effort. We do not claim that the idea is original, only that we put brain in gear and got the pumpkin pip moving after reading an article by Hugh Crawford.

The sketch is virtually self-explanatory except to say that the transformer and fan are connected into the same electric line where the switch will operate both when it is activated.

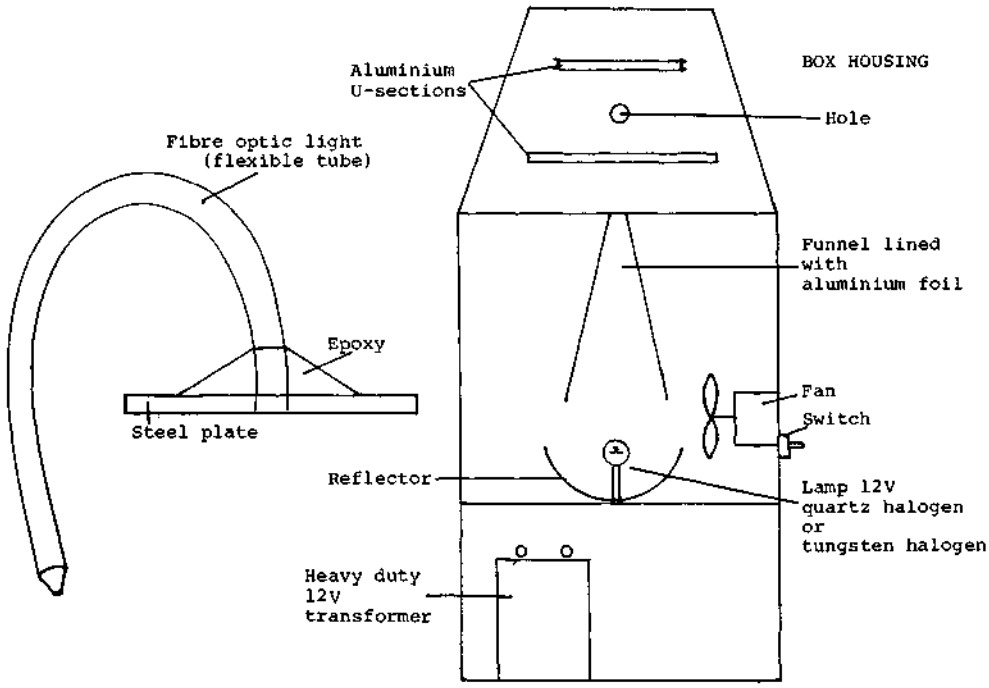

Getting the parts is fairly simple – you scrounge them – the flexible fibre optic tube can be obtained from any abominable surgeon, or hospital, who throw them out when they break. The fan is obtainable from a refrigeration engineer who also throws out and replaces with new; this is a cold counter fan. The quartz halogen headlamp and reflector comes from a motor scrapyard, the electric cable is nicked from your wife's iron* and the box can be anything handy.

Words of warning – before switching on the quartz halogen lamp wipe it off with a cloth dipped in benzine, which disposes of any oddities your sweaty paws have left on it. If you don't do this your lamp will go 'bang'.

The use of this light box is manifold – you will note that the hole in the top through which the light escapes has two pieces of aluminium U-section (with a gap of approximately ⅛ inch). Into this U-section are placed strips of black plastic with holes (to correspond to the box hole) ranging from 1mm up to what you need. Here you can check rough stones for flaws, cracks, inclusions, etc. Another word of warning – unless you want to make your doctor rich, don't look directly into the light – it is powerful – view obliquely.

For instance, you can check garnet for flaws, inclusions, etc., pearls, aquamarine, you name it. To check a diamond against a simulant, place a piece of ground glass in the U-section, position the diamond table down and if a dark star appears in the culet you have a diamond, if not, you have something else.

Cement, with epoxy, the fibre optic into a sheet of steel and you have a totally movable light source.

*This could be dangerous on at least two counts! – Ed.

With a bit of ingenuity (and anyone who is a member of the GA is ingenious) a clamp can be made so that this light source is used, for instance, on the microscope.

With felicitations from the mad professor. If you publish this I'll send you more, if you don't I'll use my alchemy to turn you into something that shivered in your recent cold spell.

Yours etc.,
Bernice Backler
19 January 1987
2c Medical Centra, 79 Compton Street,
PO Box 1692, Pinetown 3600, South Africa.

ANNUAL GENERAL MEETING

The Annual General Meeting of the Association is to be held on Tuesday 16 June 1987 at the Flett Theatre, Geological Museum, Exhibition Road, South Kensington, London SW7, at 6.30 for 7.00 pm. This will be followed by a Gemmological Forum, when a panel of experts will be answering questions on a number of subjects.

THE JOURNAL OF GEMMOLOGY COMBINED ISSUE

The Editor is pleased to announce that following the successful launch of the present volume of *The Journal of Gemmology* in its new format, plans are underway to develop the contents of the *Journal* further in a way to maximize the interest and benefit to the readership. As a result of these plans, a combined issue will appear in September/October this year. This issue will comprise numbers 7 and 8 of the current volume which means that members will *not* receive a journal in July.

CHALCOPYRITE IN PERIDOT

In the paper by J. Koivula and C.W. Fryer, (*Journal of Gemmology*, **20**, 5, 272–3), this was claimed to be the first recorded occurrence of chalcopyrite in peridot. We have been informed, however, by Dr H.J. Schubnel of Paris, that he described chalcopyrite in peridot in a paper published in 1968 (Giraud, R., Picot, P., and Schubnel H.J., 1968. Les inclusions sphéroïdales des gemmes de roches ultrabasiques. *Revue de Gemmologie*, No. 14, 9–11). We apologize to Dr Schubnel for this error.

CORRIGENDA

On p. 176 above, 1st column, line 15, for '$(T_b^3 - H_c)/(1 - T_b)$' read '$H_cT_b^3/(1 - T_b)$'.

On p.176 above, 2nd column, lines 2, 3 and 8, for '$(1 - T_b)H_c/(1 - T_b^3)$' read $H_c(1 - T_b^3)/(1 - T_b)$'.

On p.287 above, the caption to the last figure in the 2nd column should read 'Fig. 7. The thin section of a natural freshwater pearl (Laboratory collection).'

On p.288 above, the caption to the first figure in the 1st column should read 'Fig. 6. A closer view of the internal structure of a freshwater pearl seen in Figure 5.'

On p.289 above, the illustrations to figures 13 and 15 have been transposed.

On p.309 above, in first column, line 27, for '1983–1985' read '1983–1984'.

ADVERTISING IN THE JOURNAL OF GEMMOLOGY

The Editors of the *Journal* invite advertisements from gemstone and mineral dealers, scientific instrument makers, publishers and others with interests in the gemmological, mineralogical, lapidary and jewellery fields.

Rates per insertion, excluding VAT, are as follows:

Whole page £180
Half page £100
Quarter page £60

Enquiries to Mrs M. Burland, Advertising Manager, Gemmological Association, Saint Dunstan's House, Carey Lane, London EC2V 8AB.

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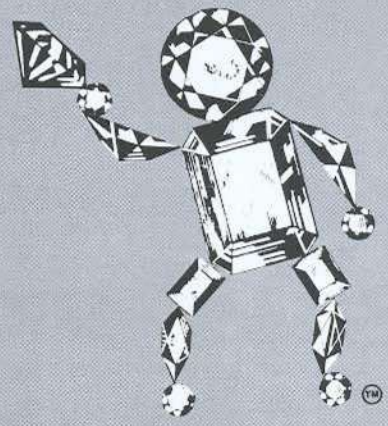

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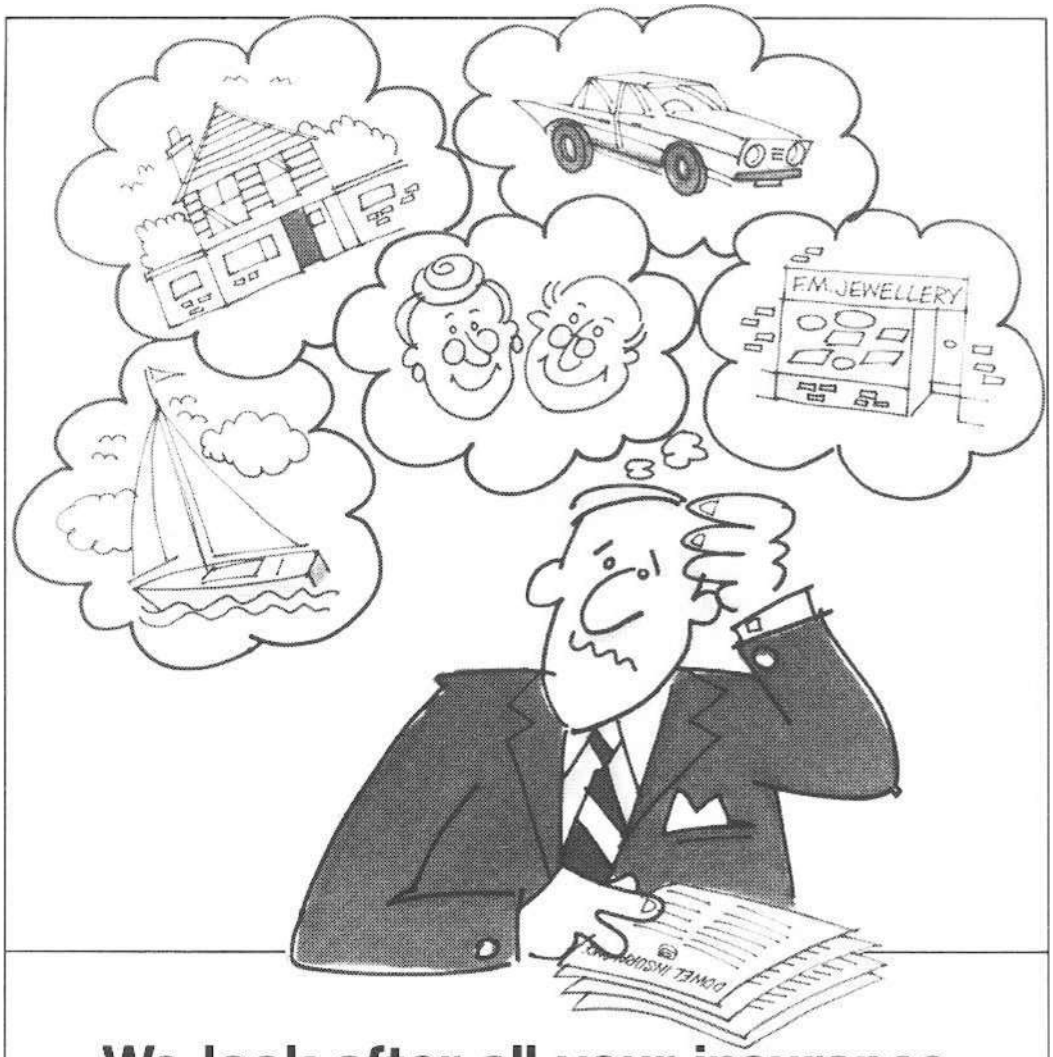

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You can't beat Experience

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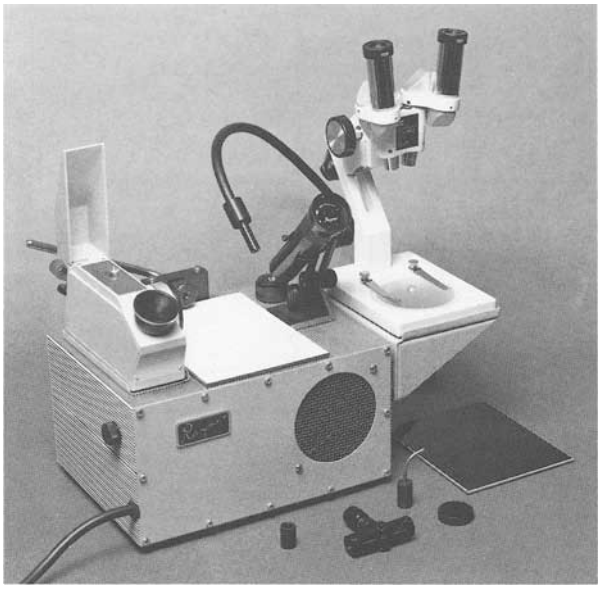

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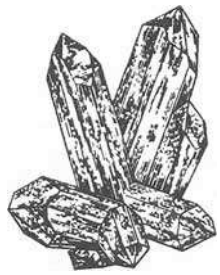

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Twenty five copies of individual papers are provided on request free of charge; additional copies may be supplied, but they must be ordered at first proof stage or earlier.

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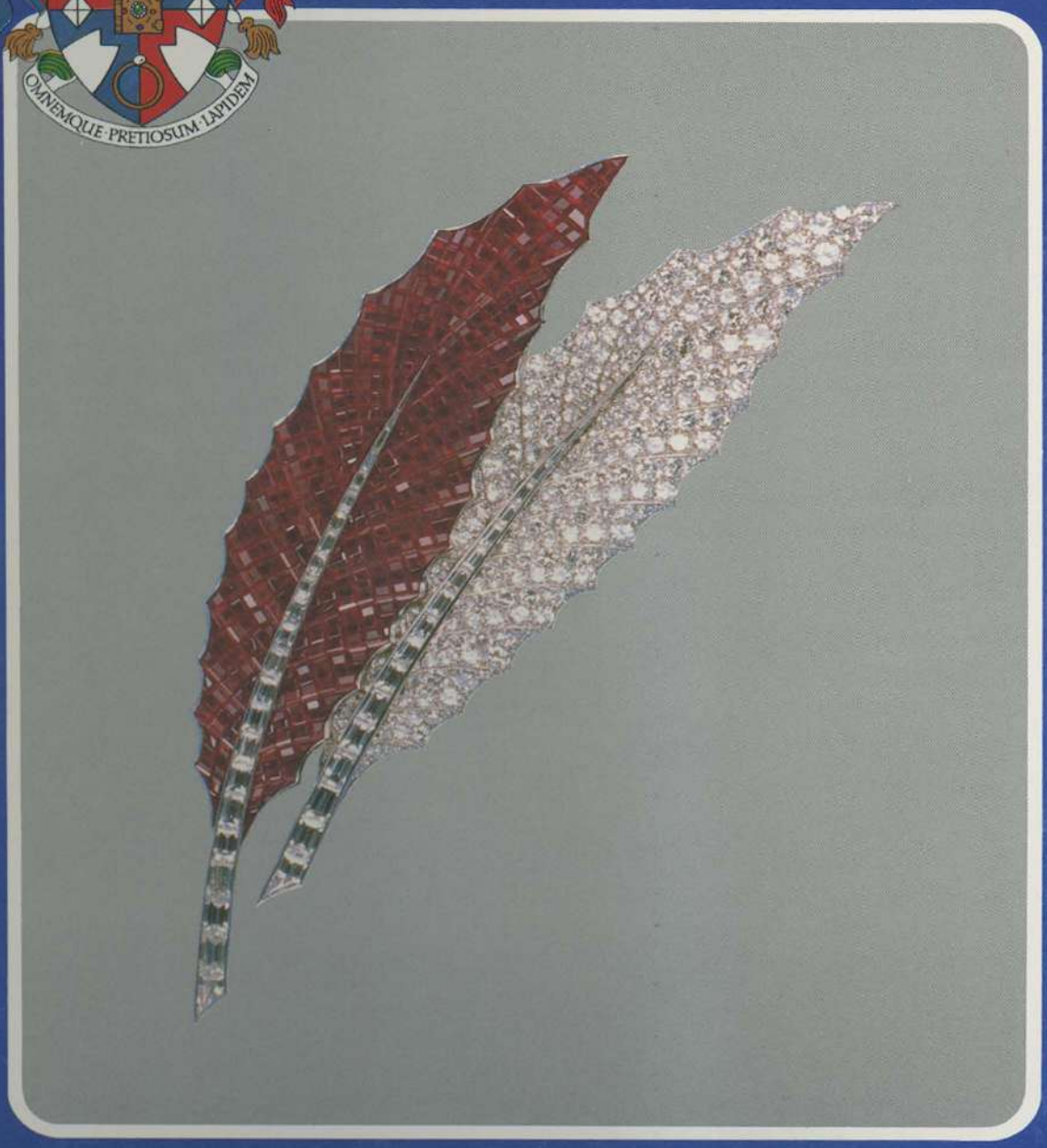

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JULY AND OCTOBER 1987

Cover Picture

An 'invisibly set' ruby and diamond clip by Van Cleef and Arpels, Paris. Designed as two holly leaves, from the Duchess of Windsor's collection (see 'The sale of the Windsor jewels', pp. 423–426).
Photograph courtesy of Sotheby's.

ISSN: 0022–1252

Editorial

This combined issue comprising numbers seven and eight concludes volume 20 of the redesigned *Journal of Gemmology*. The cover, with its colourful (and, we hope, educational) front and its readily informative back has earned more plaudits than brickbats. The papers (the 'meat' of the Journal) sometimes have a highly scientific content, but this is to be expected when we are tackling gemmological 'education' at the frontiers. However, we also try to include lighter material, and in this combined issue we hope we are approaching a balance between science (in the field and in the laboratory), commerce (in the auction rooms and in diamond grading), light biography (which includes the development of books and journals) and 'do-it-yourself' gemmology among other topics.

The production of the *Journal* poses many problems including late or non-arrival of copy, unsuitable submissions, and the complexities of modern printing technology. Material published depends upon material submitted, and the Editor looks back nostalgically at articles such as those written by Louis Kornitzer for *The Gemmologist* in the thirties. These anecdotal and narrative papers covered travel in the gem-producing areas prior to the advent of air travel, combined with accounts (often humorous) of his experiences, good and bad, in the Hatton Garden of yesteryear. There must be many merchants and retailers with like experiences over the years – the Editor would greatly welcome some articles from a few of them.

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Blue spinel from the Hunza valley, Pakistan

R.R. Harding and F. Wall

Department of Mineralogy, British Museum (Natural History), Cromwell Road, London SW7 5BD.

Abstract

The spectral features of blue spinels from the Hunza valley, Pakistan, are described. Microprobe analyses indicate variable contents of Ti and Cr in the spinels and this, in addition to iron, probably gives rise to a range of colours from blue to pink.

Introduction

Parcels containing blue octahedral crystals of spinel mixed with rubies have recently arrived from the Hunza valley, Pakistan. Although small, the crystals are of gem quality and since the blue spinels described by Shigley and Stockton (1984) and Kane (1986) were thought to come from Sri Lanka, a description and chemical analysis were undertaken to characterize the Hunza crystals more precisely.

The crystals are single or twinned octahedra, black or dark blue in reflected light, but in strong transmitted light, a range of blue, lilac and pink colours. They are inert in both long- and short-wave ultraviolet radiation and show no fluorescence under crossed filters ($CuSO_4$ solution and Chelsea filter).

Colour zoning in the crystals appears diffuse and no sharp colour variations were seen. Feathers with liquid or gas in irregular patches are common inclusions but solid crystal inclusions are rare or absent. The spinel crystals occur in a matrix of white carbonates which also contain crystals of pink corundum, dark golden-yellow corundum, brassy pyrite and black opaque minerals. The identities of the corundums and pyrite were checked using X-ray diffraction analysis by S. Somogyi (film numbers: corundum 6400F, 6401F; pyrite 6399F).

Spectrum

The spectrum shown by each crystal through a Beck prism spectroscope is similar in pattern to those depicted by Shigley and Stockton (1984) for natural blue spinel. They show absorption at 650–630 nm, 600–590 nm, 580–565 nm, 555–540 nm, 470 nm tailing off to about 455 nm, and 440 nm tailing off to about 425 nm (Figure 1). In addition, the lilac and pink crystals show absorption at 680 nm with some fluorescence on the long-wave side of this band, indicating the presence of chromium. There is a qualitative correlation between the intensity of pink in the crystal and the strength of the chromium absorption.

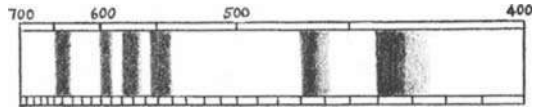

Fig. 1. Spectrum of blue spinel from Hunza valley through Beck prism spectroscope.

In Figure 2, trace 2 shows the absorption pattern of a Hunza spinel measured on a Pye-Unicam PU8800/03 UV-Visible spectrophotometer. The path length of light through the crystal measured 1.93 mm and wavelengths 380-750 nm were scanned at 1 nm/sec. The bandwidth was 0.5 nm and the recorder was set on a range of 2A (absorption units). For comparison a synthetic blue spinel was run under the same conditions except that the wavelength scan was extended into the ultraviolet (trace 3), and although the absorption pattern is similar in the 500–700 nm region, the natural spinel absorbs strongly in the ultraviolet below 400 nm. In contrast the synthetic spinel transmits radiation down to 290 nm. In comparison with the spectra shown by Shigley and Stockton (1984, p. 39) the pattern of absorption of the Hunza valley spinel most resembles that of the type I – natural although the centres of the absorptions between 500 and 700 nm are not identical.

Microprobe analysis

A flat octahedral surface of a spinel crystal measuring 8 mm across was chemically analysed using a Cambridge Instruments Microscan IX microprobe. Nine wavelength-dispersive spot

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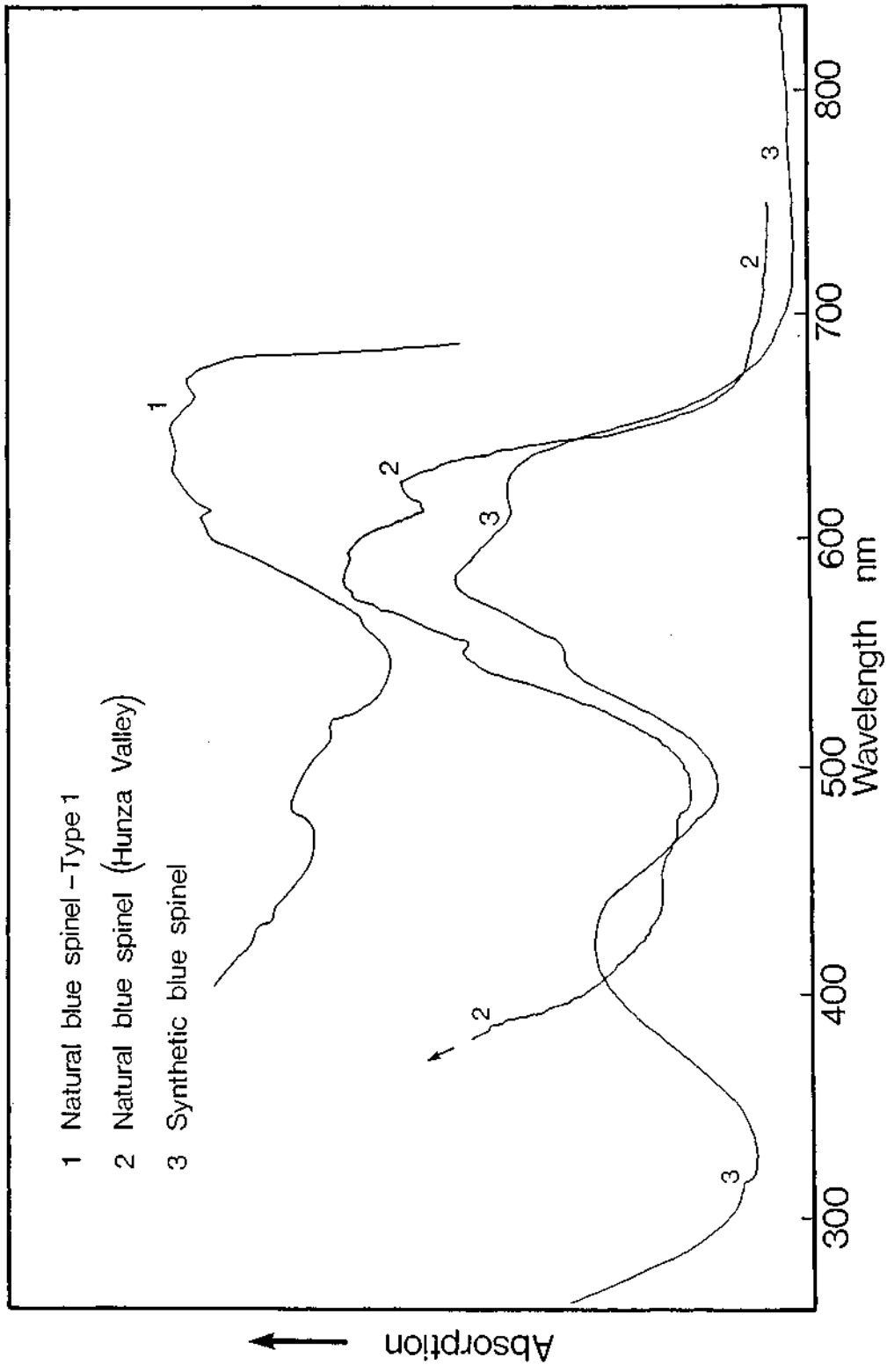

Fig. 2. Spectrophotometer traces of blue spinel from Hunza valley (2) compared with type I – Natural spinel (1) (converted from transmission trace of Shigley and Stockton, 1984, p. 39) and synthetic blue spinel (3).

analyses were carried out at 20 kV and 25 mA with a beam diameter of 1 μm, and the results are given in Table 1.

Table 1. Electron microprobe analyses of blue spinels.

Wt%	1		2
	Mean	S.D.	
MgO	24.6	0.32	25.45 – 27.88
Al_2O_3	69.3	0.26	70.20 – 71.61
SiO_2	0.05	0.01	n.r.
TiO_2	0.18	0.26	n.d. – < 0.04
V_2O_5	0.05		n.d. – 0.07
Cr_2O_3	0.73	0.14	n.d. – < 0.04
MnO	< 0.05		n.d. – 0.07
FeO	3.75	0.05	0.69 – 3.53
ZnO	0.35	0.04	< 0.04 – 0.44
CoO	< 0.05		n.d. – 0.05
NiO	< 0.05		n.d. – 0.14
Total	99.01		

Notes:
Total Fe as FeO; n.d. not detected; n.r. not reported. The standards used were: Eagle Station olivine (Mg, Fe), jadeite (Na, Al), manganese metal, chromium metal, zinc metal, vanadium metal, rutile (Ti), and wollastonite (Si,Ca).

1. Mean and standard deviation (S.D.) of nine analyses of different spots on octahedral face of blue spinel from Pakistan.
2. Range in composition of 18 natural blue spinels, Shigley and Stockton, 1984, Table 1.

The analyses show spinel with a consistent major element composition of Mg and Al, minor Fe, and small amounts of Cr, V, Mn, Si, Ti and Zn. The Ti distribution is heterogeneous and varies between 0.01 and 0.77% in different parts of the crystal. In one area a rounded patch measuring 200 × 100 μm shows a consistent content of 12.1% TiO_2. Material from this area was extracted and analysed by X-ray diffraction and a spinel pattern was obtained (film 6383F). However, the total analysis is not consistent with spinel proportions and further material must be sought.

Although the composition of the Hunza spinel compares closely with the spinels studied by Shigley and Stockton (1984) and reproduced in Table 1 column 2, it differs in two ways. Firstly there is significant Ti in the Hunza crystal while Shigley and Stockton (op. cit. pp. 38 and 41) state that there is considerably less than 0.04% TiO_2 in the stones they studied; and secondly there is significant Cr in the Hunza spinel. Cobalt was sought in the Hunza crystal but, if present, is below the detection limit for this analytical method of 0.05% CoO.

Conclusion

To summarize, spinels with spectral characteristics similar to those for blue spinels described previously are being extracted from rocks in the Hunza valley. They do, however, contain significant Ti and Cr, and these elements are probably responsible for the slightly different spectral features and wider colour range of the Hunza crystals. The range includes blues, lilacs and pinks comparable with those found in fine quality sapphires.

Acknowledgements

We would like to thank C. Cavey for the donation of Hunza spinel crystals to the museum; and we are grateful both to S. Somogyi for carrying out the X-ray diffraction analysis, and to K. Scarratt for results from the Anderson spectrophotometer at the Gem Testing Laboratory.

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[*Manuscript received 24 July 1987.*]

Notes from the Laboratory – 11

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On 18 April 1985 Sumitomo Electric Industries Ltd issued a news release entitled: 'World's first mass production process for synthesizing large diamond monocrystals'. The news release starts with the following paragraph:

> 'Sumitomo Electric has succeeded, for the first time in the world, in mass-producing large synthetic diamond monocrystals. The company is beginning to market them for various industrial applications.'

The news release further stated that Sumitomo's synthetic diamond monocrystals are high-quality stones largely free of impurities and defects and range in size up to 1.2 ct (about 6 mm in diameter).

At the 20th International Gemmological Conference, which was held in Sydney, Australia, between 30 September and 4 October, 1985, I was able to obtain two specimens of the Sumitomo synthetic diamond (Figure 1) with the assistance of Ms Yunko Shida. Whilst both these specimens were interesting, little in terms of normal gemmological identifying characteristics could be obtained, and relied upon, from so few examples.

During 1986 the Laboratories of The Gemological Institute of America examined more than twenty examples of this new synthetic diamond and they subsequently published their findings in the form of an excellent paper in the winter 1986 issue of *Gems & Gemology* (Shigley *et al.*, 1986).

This report compares the results published by Shigley *et al.*, with observations made on our specimen crystals and one faceted Sumitomo synthetic diamond loaned to us by Mr J. Schlussel of The Diamond Registry, New York.

As with the GIA specimens, Mr Schlussel's specimen may be described as very deep, intense or pure yellow, its weight was 0.23 ct and its measurements were 3.95 – 3.95 × 1.62 mm. The stone was faceted as a shallow emerald-cut.

The colour of the faceted stone was such an intense yellow that this observation possibly plants the first seeds of suspicion in one's mind, i.e. if the possibility of a synthetic is not thought of, then an irradiated stone should be. When observed under magnification, particularly from the pavilion, whilst the intense yellow was found to be the dominant colour, areas of a lighter yellow and other areas which were colourless could be seen easily. These colourless and yellow patches formed a definite pattern which, when viewed through one of the four largest pavilion facets, might be described as either a 'bow tie' or 'hourglass' structure (Figure 2). Figure 3 shows this same structure under slightly different lighting conditions. As the stone was turned to examine the other three largest pavilion facets a similar structure was found to be present in each and it was seen that the 'bow ties' share a wedge-shaped light yellow area situated under the corner facets (Figure 4).

When bathed in long-wave ultraviolet radiation the faceted Sumitomo synthetic diamond was almost inert, but under the influence of short-wave the effect was markedly different. Short-wave ultraviolet produced a bright yellow fluorescence which when observed under magnification was sharply zoned. When viewed from the crown (Figure 5a) there was an octagonal area under the table facet which fluoresced a bright yellow and radiating from the edges of this were four lighter yellow fluorescing areas. The areas radiating from the corners of the bright yellow area were inert (see Figure 5). When viewed from the pavilion the fluorescence could be seen to be both zoned and layered (Figure 5b); close to the area of the culet was an almost square layered zone of bright yellow and below this was a layer of a lighter yellow. When placed in a beam of X-rays (Diffraction tube, Mo target, at 45kV/20mA) the Sumitomo synthetic diamond fluoresced a strong greenish-yellow and this was followed by a prolonged yellowish-blue phosphorescence.

The absorption spectrum of the faceted stone as seen with the hand spectroscope revealed no sharp changes in transmission, i.e. there were no absorption lines present. However, the blue and violet areas of the spectrum appeared to be increasingly

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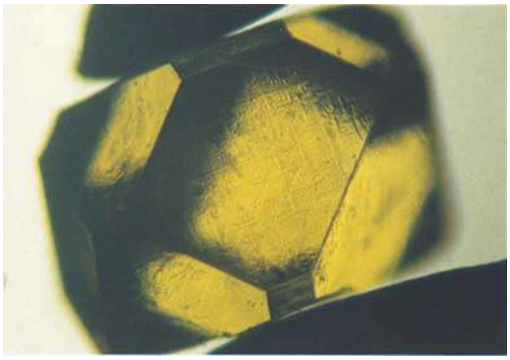

Fig. 1. Sumitomo synthetic diamond crystal obtained in late 1985 weighing 0.08 ct.

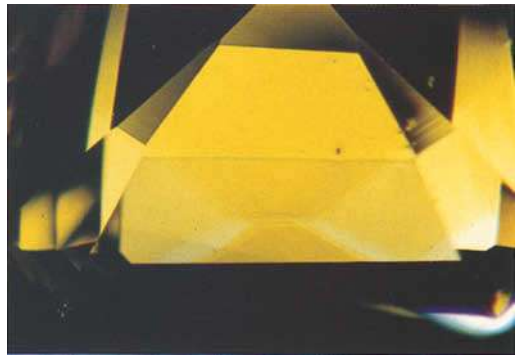

Fig. 2. 'Bow-tie' or 'hourglass' structure seen through a pavilion facet of the faceted Sumitomo synthetic diamond belonging to Mr Schlussel.

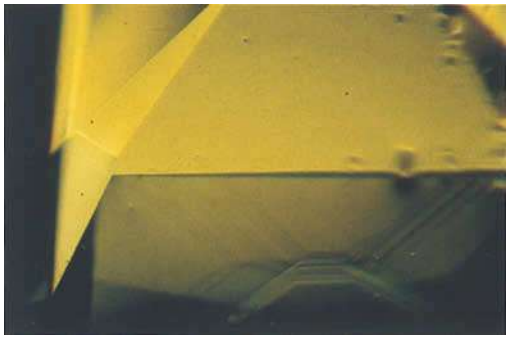

Fig. 3. 'Bow-tie' or 'hourglass' structure in the faceted Sumitomo synthetic diamond as in Figure 2, but in different lighting conditions.

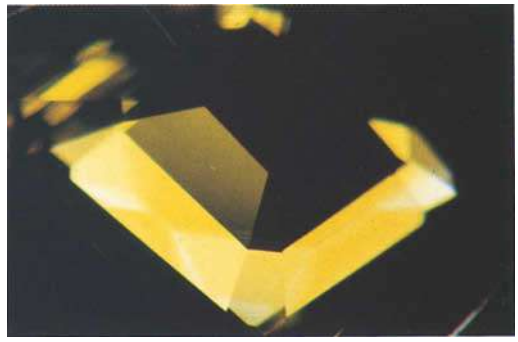

Fig. 4. Two 'bow-tie' structures in the Sumitomo synthetic diamond share a light yellow wedge-shaped area under a corner facet.

absorbed the shorter the wavelength (Figure 6b), and this was confirmed when the spectrum was examined between 750 and 390 nm on a spectrophotometer. Here, even at approximately 120 K, no absorption peaks were recorded, only a gradual increase in absorption from 560 nm.

Dr J. Milledge, of University College, London, carried out infrared measurements on the faceted Sumitomo synthetic diamond and these determined it to be type Ib.

The properties of the stone belonging to Mr Schlussel compare well with those of the twenty-three stones reported upon by Shigley *et al.*; both the visible and IR spectra reveal the same characteristics and the zoned short-wave ultraviolet fluorescence patterns show a remarkable similarity. The almost inert response to long-wave ultraviolet radiation is also similar to that reported by Shigley *et al.*, and both the colourless-yellow zones present in Mr Schlussel's stone, and those examined by the GIA appear to produce a similar regular ('bow-tie', 'hourglass') pattern.

The surface features of the Sumitomo synthetic diamond crystals described by Shigley *et al.*, are

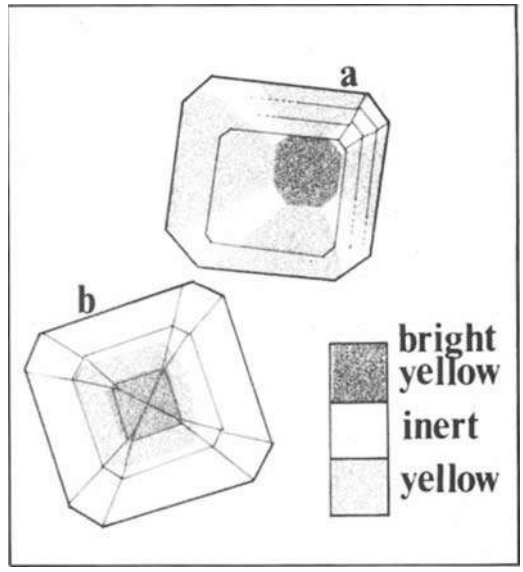

Fig. 5. The short-wave ultraviolet induced fluorescence of the Sumitomo synthetic diamond (a) as seen from the crown, and (b) as from the pavilion.

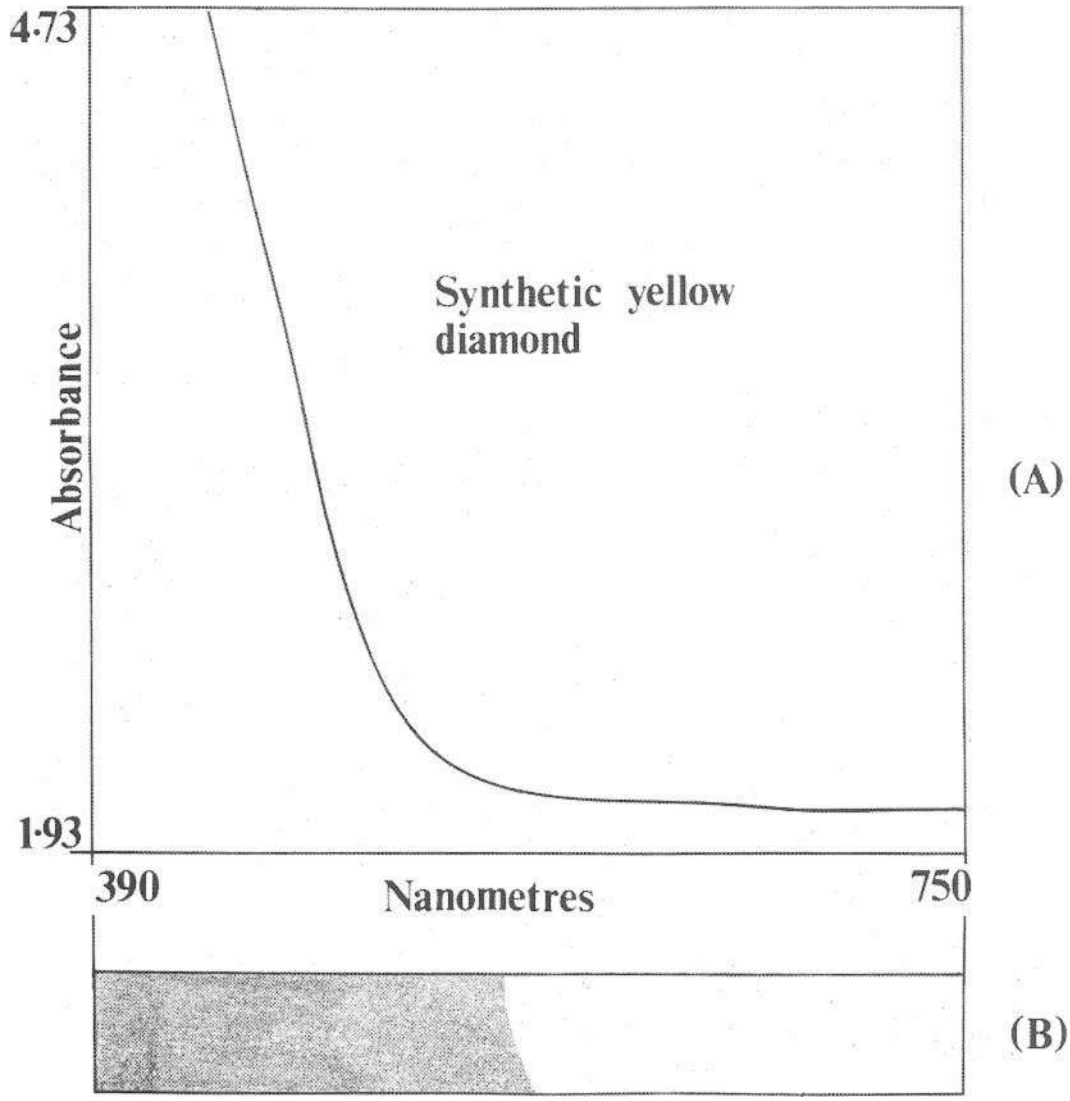

Fig. 6. The absorption spectrum of the Sumitomo synthetic diamond (A) as recorded at 120 K on a Pye Unicam PU 8800/03 UV/visible spectrophotometer (Basil Anderson model) with a speed of 1 nm/s, a bandwidth of 0.5 nm and a path length of approximately 1.6 mm, and (B) as seen with the hand spectroscope.

similar to those observed on the crystals obtained in late 1985 (Figure 1).

Richard T. Liddicoat, Jr., ended his editorial to the Winter 1986 edition of *Gems & Gemology* by stating that what is perhaps the 'last great barrier' in gemmology 'has been breached' and that the role of the gemmologist has never been more important. These few words cannot be ignored; we have indeed reached a very important point in the development of our science.

At the moment Sumitomo are only producing synthetic type Ib diamonds and these have a canary yellow body colour; it is also stated that they are only being produced for use as heat sinks in industry. However, even if Sumitomo's policy changed and large amounts of their presently produced material became available to the jewellery market, this should not create an insurmountable problem to jewellers.

All those who handle coloured diamonds must now be aware of this extra hazard, and when they become involved with an intense yellow diamond

they have not only to think of the possibility of an irradiated diamond but also of the Sumitomo synthetic. Identification of these stones, judging from the few samples so far examined, should not be too difficult.

The infrared (IR) spectrum of the Sumitomo synthetic is typical of this type of synthetic diamond in that it reveals pure type Ib characteristics, and this could assist in separating it from the natural type Ib diamond which may have Ia charactersitics also present. As the equipment needed to record IR spectra is not normally available to the 'average gemmologist' information in this area would at first seem surplus to the requirements of most gemmologists. There is a connection, however, for the visible spectra of Ib diamonds (natural or synthetic) is quite different from that of the majority of natural yellow diamonds. Most natural yellow diamonds are type Ia and these, at the very least, show an absorption band at 415 nm and possibly others in the violet and blue parts of the spectrum (Anderson 1985, 174), which are not seen in type Ib diamonds (the Sumitomo synthetic). The visible spectrum of a Ib diamond (natural or synthetic) is one of increasing and gradual absorption with shorter wavelengths from about 560 nm (Figure 6): therefore the observation of a 415 nm band is sufficient to identify the stone as natural. However, if the 415 nm band is not seen, this does not prove the diamond to be synthetic.

The response of the Sumitomo synthetic diamond to ultraviolet radiations is unusual and can serve as an aid to identification, particularly when the short-wave fluorescence is examined closely and its zoned nature is seen. We have never seen the 'bow tie' or 'hourglass' zoning (observed under magnification in normal lighting) in any natural yellow diamonds and this may prove in time to be a useful identifying feature.

* * *

Late in 1985 we received an enquiry from Sri Lanka for information about sapphirine $(Mg,Fe,Al)_8O_2[(Al,Si)_6O_{18}]$ as it was felt by the enquirer that gem quality material might be available in that country. Shortly after replying to that enquiry we received the Fall 1985 issue of *Gems & Gemology* in which there was a report of a purplish-pink faceted sapphirine (Fryer *et al.*, 1985). More recently sapphirine has been described as an inclusion in ruby (Koivula and Fryer, 1987).

Earlier this year we were sent an oval blue stone (Figure 7) measuring 5.86 – 7.40 × 2.74 mm and weighing 0.90 ct which had been bought as 'blue idocrase' in Sri Lanka. The stone was strongly pleochroic and had an SG of 3.45. The minimum and maximum refractive indices, as determined on the table facet in sodium light and with a Rayner Dialdex refractometer, were 1.704 and 1.710 with a variation for the lower reading up to 1.705 and for the higher reading down to 1.707, indicating a biaxial stone. Whilst 'biaxial' readings have been reported for idocrase (vesuvianite) (Larsen and Berman, 1964), as it is a tetragonal material uniaxial readings are usual and this anomaly along with the lack of any recognizable features in its absorption spectrum (Figure 8) raised some curiosity about the true identitiy of this stone.

Permission was sought to take a small scraping from the stone and an X-ray powder diffraction pattern was obtained. After comparison with standard JCPDS file 21-549, the stone was identified as sapphirine and this was further corroborated by comparison with the powder diffraction pattern produced from a specimen in the collection of the British Museum (Natural History) – BM 23304 – which comes from Friskernaes, Greenland, and was purchased by the museum in 1849.

* * *

Two interesting pearls both originating from the British Isles have been donated to the Laboratory collection recently. The first is from Scotland and weighs 13.36 grains and measures 8.06 mm in diameter and, as can be seen from Figure 9, only part of its surface is nacreous, the rest being a dull brown. Whilst much of the line where the nacreous coating and the brown surface meet is in the form of a 'step down' towards the latter, a large portion blends smoothly from one to the other with no visible demarcation line. The nacre has only an indistinct platelet structure at normal magnifications, whilst much of the brown area has a similar cross-section to that reported for another Scottish pearl in *Notes from the Laboratory – 9* (Scarratt, 1987). A radiograph of this latest pearl revealed the typical ring structure of a natural pearl (Figure 10).

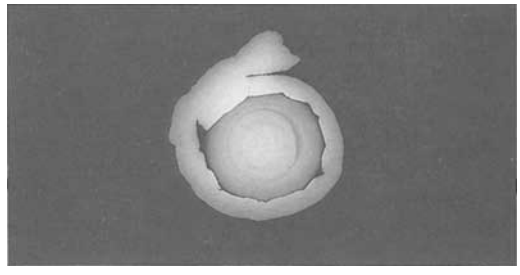

Fig. 10. A radiograph of the pearl in Figure 9 showing the typical ring structures. N.B. the opaque (white) area around the pearl is a lead mask.

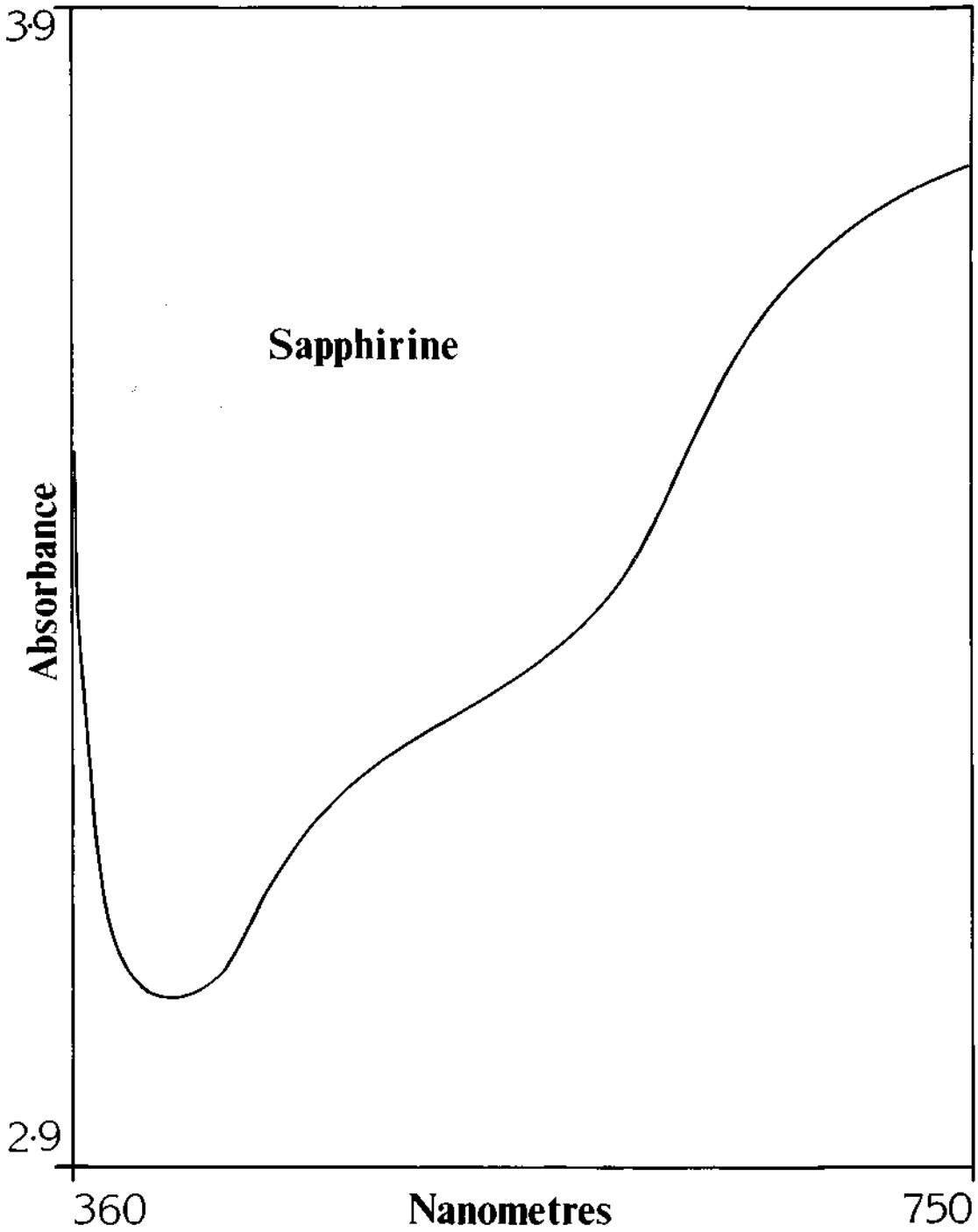

Fig. 8. The absorption spectrum of a 0.90 ct blue sapphirine. The curve was obtained using a Pye Unicam PU 8800/03 UV/visible spectrophotometer (Basil Anderson model) with a speed of 1 nm/s and a bandwidth of 1 nm at room temperature.

Fig. 7. An oval blue sapphirine weighing 0.90 ct.

Fig. 9. A 13.36 grain pearl with only a small surface area of nacre.

Fig. 11. A 8.20 grain salt-water mussel pearl found by a fisherman from Cromer, Norfolk.

Fig. 12. The network of cushion shaped 'holes' seen in a 10.56 ct opal. Transmitted light.

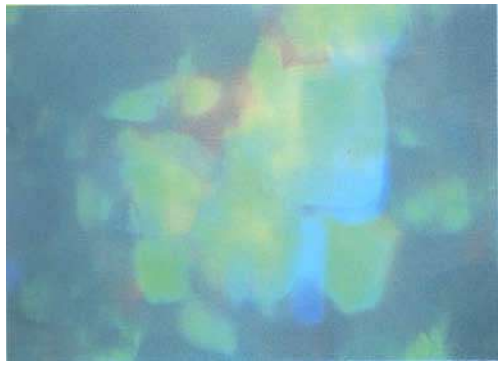

Fig. 13. The same structure in a 10.56 ct opal as seen in Figure 12 but in reflected light.

Fig. 14. Lapis-lazuli-like bead necklace.

The second is a slightly baroque button-shaped 8.20 grain 'salt-water mussel pearl' found by a Cromer fisherman, the colour of which varied from a dark to a bright blue (Figure 11). No overlapping platelet structure was seen on the surface and no internal structures were revealed by X-radiography although indications of a layered structure within could be seen on the surface. The surface has a high lustre, is uneven and dimpled, and in one of the larger dimples there is an area of brown organic-like matter. Using the X-ray powder diffraction technique the pearl proved to be composed of calcite.

* * *

As superbly illustrated by Gübelin and Koivula in their paper *Inclusions in Opal* (Gübelin and Koivula, 1986), the interior of opal can be as fascinating as any other gem material and there can be few more interesting than a 10.56 ct stone we examined towards the end of May this year.

The stone measured 19.21 – 15.06 × 6.72 mm, had a very fine play of colour and constants typical for opal (RI 1.44, SG 2.10). Internally a large number of worm-like needles were present, the cross-sections of some showing clear ring structures, but in addition to these and covering approximately two thirds of the stone, was a peculiar honeycomb-like structure. In transmitted light this structure appeared as many cushion-shaped 'holes' in a brownish network (Figure 12). Figure 13 shows this same structure but in reflected light.

* * *

Sometimes when we come across an item we have not encountered before, such as a new synthetic or imitation, we are allowed a reasonable amount of time to carry out a complete examination. Often though, the owner or his intermediary require the item to be returned by a specific time and when the period allowed is short and the item appears to be interesting a certain degree of frustration is experienced. Nevertheless an attempt is made to gain as much information as possible.

Such was the case when a single row of 43 blue lapis-lazuli-like beads was submitted for examination earlier this year. Each was similarly carved (Figure 14) and the colour, were it *lapis-lazuli*, was quite even (apart from a darkening on the high ridges of each of the beads that had been worn in contact with the skin) and fairly well matched. The structure, the like of which I have not seen in natural lapis-lazuli or the Gilson product, was fine grained although the surface was pitted and there was a profusion of pyrite-like inclusions of all shapes and sizes, including slivers. However, the colour of this pyrite was of a somewhat deeper yellow than one might expect to see in any natural material.

Under both long- and short-wave ultraviolet rays the beads weakly fluoresced a greenish cast which was quite unlike that produced by natural lapis-lazuli. The material was quite soft in that a cut was easily made into the area inside a drill hole with a steel blade but the powder produced by this cut was a very bright blue. In many cases when a 'hot point' was held close to the beads the surface appeared to either melt or sweat and in areas where this did not occur, when the hot point was brought into contact with the bead the surface appeared to be slightly 'sticky'. The application, on a small piece of cotton wool, of a small drop of dilute hydrochloric acid to the surface of one bead produced a strong smell of 'rotten eggs' and the colour of the bead (blue) was transferred to the cotton wool.

The necklace was compared with many known samples of natural lapis-lazuli, the Gilson produced material and many imitations, as well as reconstructed and stained material from the Laboratory collection. No match was found and unfortunately it then had to be returned to the owner without any further work being carried out.

* * *

Late in 1986 Alan Hodgkinson FGA, sent two 'new Russian hydrothermal synthetic emeralds' to the Laboratory for the examination of their absorption spectra. The first was a piece of partly polished rough weighing 1.43 ct and measuring 7.47 mm in length (Figures 15 and 16) and the second was an emerald-cut stone weighing 0.88 ct and measuring 5.49 – 4.96 × 4.63 mm (Figure 15).

The constants of the two pieces varied slightly in that the SG (determined hydrostatically in distilled water at room temperature) for the faceted stone was found to be 2.71, whilst that of the polished rough was 2.68. The RIs for the faceted stone (determined on the table facet and using a Rayner spinel model refractometer in sodium light) were 1.580–1.585, but those for the polished rough were found to vary significantly according to the face on which they were measured. Face 'A' (see Figure 16) gave RIs of 1.567 – 1.571, whilst face 'B' gave 1.580 – 1.587.

Under the influence of both long- and short-wave ultraviolet rays the stones produced virtually no response. There was also no response when the stones were viewed through the Chelsea colour filter.

The stones were examined under magnification, both dry as well as immersed in benzyl benzoate (RI 1.569 to 1.570). The growth features seen in the

faceted stone, in general over-view, had a distinctive '*water in whisky*' appearance (Figure 17) which in some directions was crossed with almost parallel growth banding (Figure 18). Upon closer examination very distinctive 'arrow-head' and 'quill' structures could be seen (Figures 19 and 20). Similar features were seen, if a little more graphically, in the polished rough sample (Figures 21 and 22) along with equivalent near-parallel growth banding (Figure 23). At one end of the polished rough sample there was a layer of reddish/brownish platelets (Figures 16 and 24), which was close to the surface and not of great depth (Figure 25). The reason for the differing RIs produced for face 'A' of the polished rough became apparent when the stone

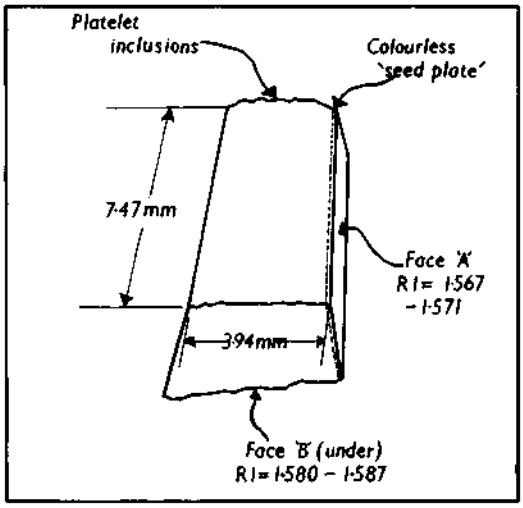

Fig. 16. Detail of the Russian synthetic emerald polished rough specimen seen in Figure 15.

was immersed in benzyl benzoate. Face 'A' was in fact a colourless seed plate (Figure 26) and the interface between this and the synthetic emerald had a cobbled appearance.

These features (Figures 17 to 26) help to identify these particular samples as being of synthetic origin and this goes some way to alleviating the problems created by the high RIs. However, some of the most interesting and indeed characteristic features of both stones were contained in their absorption spectra.

The two stones were, both for natural and synthetic emerald, unusually highly absorbing in the red portion of the spectrum (Figures 27, 28, 29 and 30). The 'normal' emerald absorption curves are presented in Figure 31 as examples '1' (Australian hydrothermal synthetic emerald) and '2' (Natural Colombian Emerald). These two curves clearly show the typical emerald chromium doublet in the red, with peaks at 679.9 and 682.4 nm in the case of the Australian synthetic and at 679.6 and 682.4 nm for the natural emerald from Colombia. Whilst the relative intensity and, to some degree, the wavelength of these peaks may vary according to the direction in which the curve is recorded, they commonly sit on the slope of a band to the short-wave side which allows some red to be transmitted (see also Sinkankas 1981).

Figure 27 shows the absorption curve for the polished rough specimen as recorded through face 'A' and this reveals a strong, sharp, chromium absorption peak at 683.6 nm. However, apart from a slight shoulder at 680.4 on the short-wave side and a more visible shoulder at 688 nm on the long-wave side of this main peak, there is no indication of the 'normal' emerald chromium doublet. Figure 29 reveals similar features in the curve recorded through the shorter, girdle to girdle, distance in the emerald-cut stone. In each case the peak is sitting on an area of absorbance that is gradually increasing from 500 nm through to the deep red, which is different from curves '1' and '2' in Figure 31.

Figures 27 (b) and 29 (b) indicate the direction in which those curves were recorded and the significant angle these were at to the optic axis of each stone. When further spectra were taken in a direction at approximately 90° to the first, no chromium peaks were recorded (Figures 28 and 30), but the general absorbance in the area where they might have occurred was particularly strong. In Figure 28 a shoulder occurs at 684 nm which may be related to the 683.6 nm chromium peak. However, if the spectrum of either of these stones were observed using a hand spectroscope, a strong chromium line would be observed amidst the general absorption of the red in one direction, and at 90° to this, most of the red will be strongly absorbed and no chromium lines will be visible.

Regardless of direction, a similar group of peaks was recorded for both polished rough and the emerald-cut stone, in the violet and ultraviolet. These are shown in Figure 29 as being a doublet at 368.6 and 372 nm and a strong peak at 425 nm with a shoulder on its long-wave side at 440 nm. This group compares well with those recorded in the spectrum of a greenish aquamarine from Pakistan and seen as example '3' in Figure 31, and also with those recorded in an emerald from Madagascar and seen as example '4' in Figure 31, as well as that reported for the Gilson 'N' series synthetic emerald (Anderson 1985, 134).

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Fig. 15. Two Russian synthetic emeralds, the polished rough weighing 1.43 ct (see also Figure 16) and the emerald-cut stone weighing 0.88 ct.

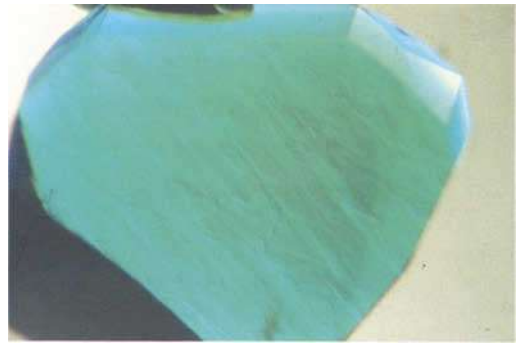

Fig. 17. 'Water in whisky' appearance seen in the emerald-cut Russian synthetic emerald of Figure 15.

Fig. 18. 'Water in whisky' appearance seen in the emerald-cut Russian synthetic emerald of Figure 15, crossed by parallel growth banding.

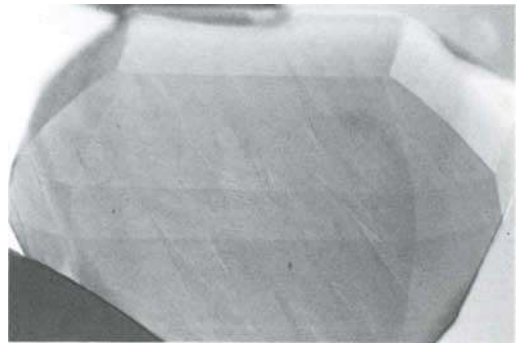

Fig. 19. 'Arrow-head' and 'quill' structures seen in the emerald-cut Russian synthetic emerald of Figure 15.

Fig. 20. A closer view of the 'arrow-head' and 'quill' structures seen in Figure 19.

Fig. 21. 'Water in whisky' appearance seen in the Russian synthetic emerald polished rough specimen of Figure 15.

Fig. 22. 'Arrow-head' and 'quill' structures seen in the Russian sysnthetic emerald polished rough specimen of Figure 15.

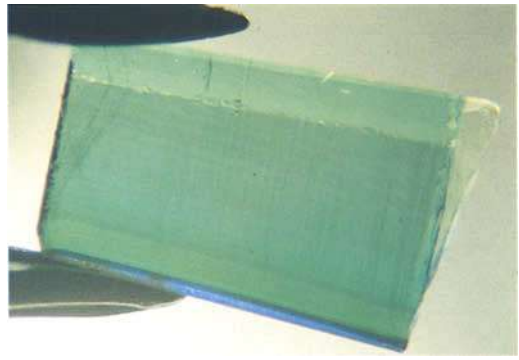

Fig. 23. The Russian synthetic emerald polished rough specimen of Figure 15 viewed through face 'B' (see Figure 16) showing parallel growth banding.

Fig. 24. Reddish/brownish platelets seen at one end of the Russian synthetic emerald polished rough specimen of Figure 15 (see also Figure 16).

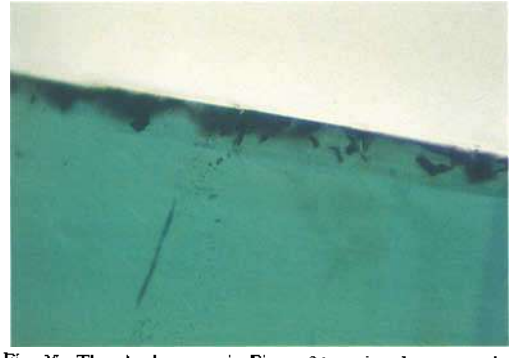

Fig. 25. The platelets seen in Figure 24 are in a layer near the surface which is not of great depth. The layer is seen here in side view.

Fig. 26. Colourless seed plate at the surface of the Russian synthetic emerald polished rough specimen of Figure 15.

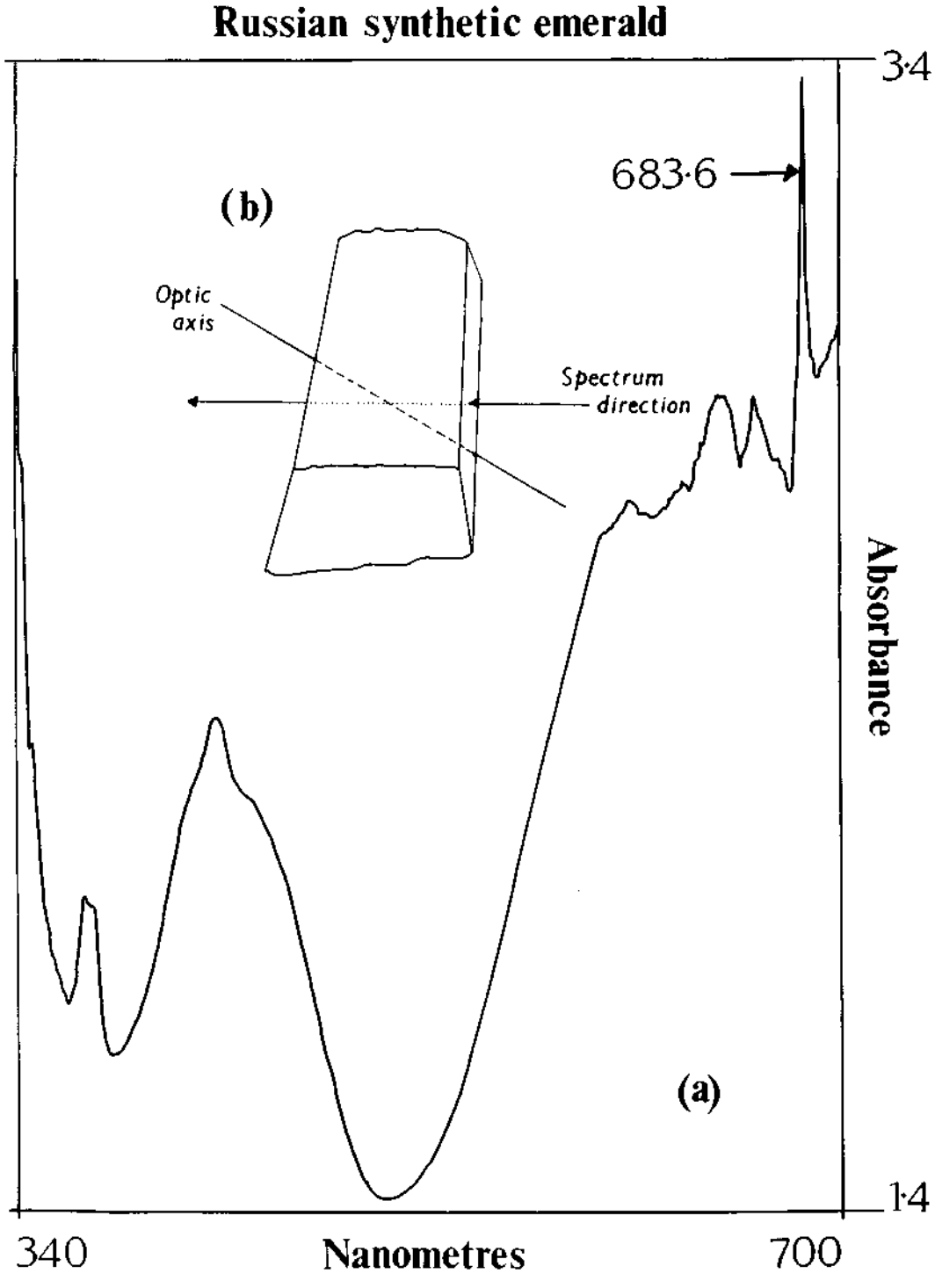

Fig. 27. The absorption curve of the Russsian synthetic emerald polished rough specimen of Figures 15 and 16 taken in the direction indicated by (b). The curve was obtained using a Pye Unicam PU 8800/03 UV/visible spectrophotometer (Basil Anderson model) with a speed of 1 nm/s and a bandwidth of 0.5 nm at room temperature. The path length was 4.3 mm.

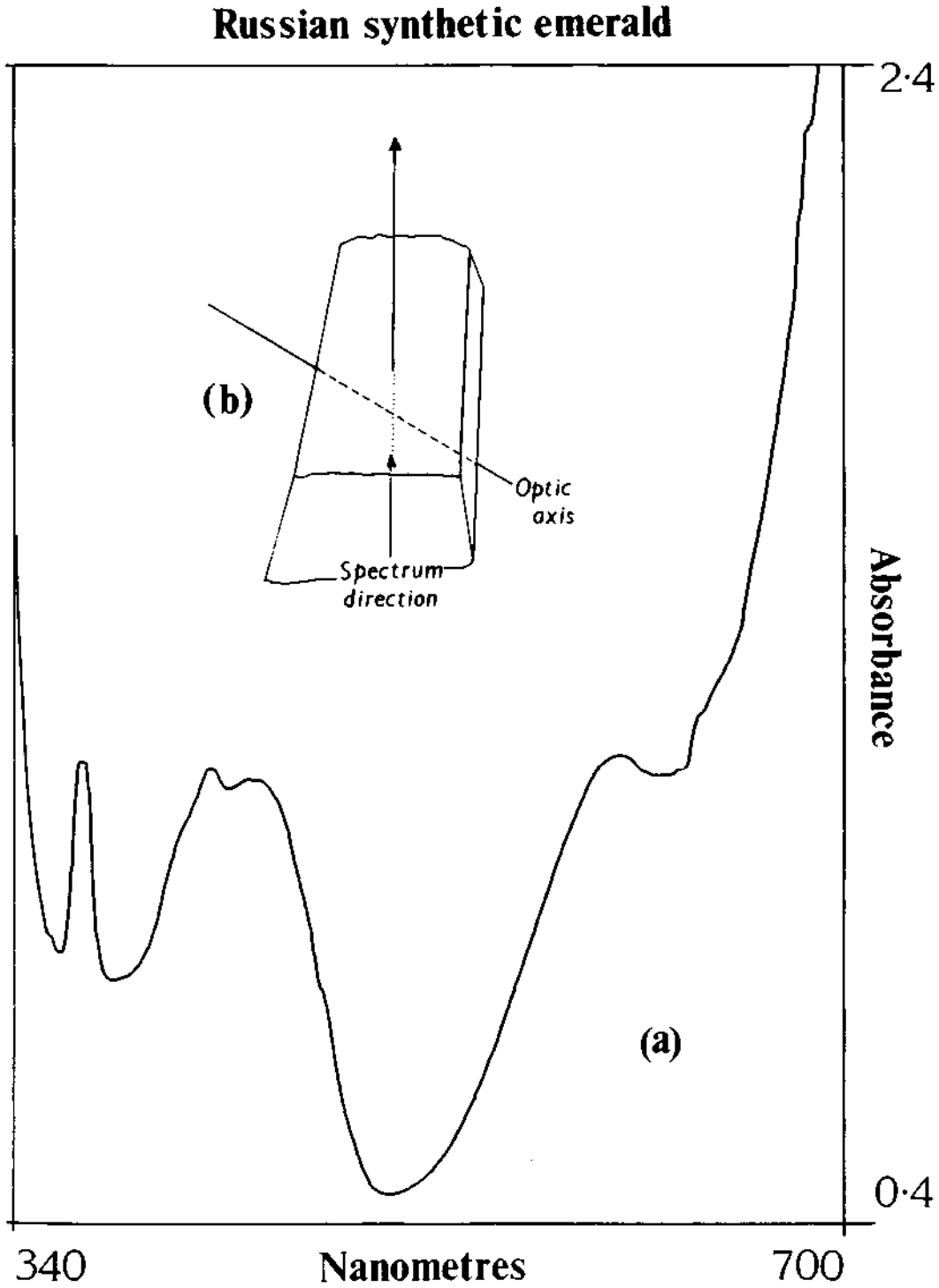

Fig. 28. The absorption curve of the Russian synthetic emerald polished rough specimen of Figures 15 and 16 taken in the direction indicated by (b). The curve was obtained using a Pye Unicam PU 8800/03 UV/visible spectrophotometer (Basil Anderson model) with a speed of 1 nm/s and a bandwidth of 0.5 nm at room temperature. The path length was 3.6 mm.

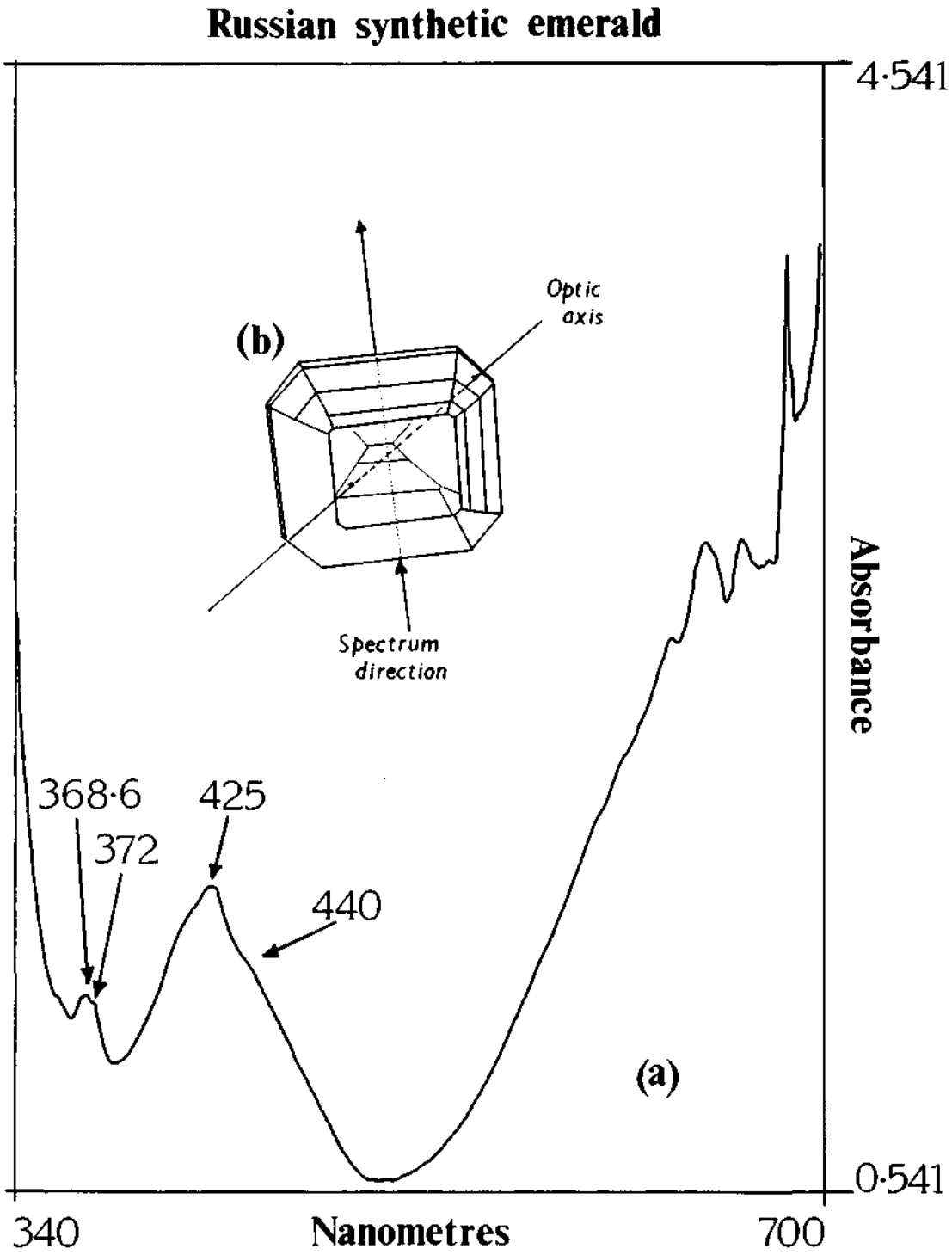

Fig. 29. The absorption curve of the emerald-cut Russian synthetic emerald of Figure 15 taken in the direction indicated by (b). The curve was obtained using a Pye Unicam PU 8800/03 UV/visible spectrophotometer (Basil Anderson model) with a speed of 1 nm/s and a bandwidth of 0.5 nm at room temperature. The path length was 4.96 mm.

Russian synthetic emerald

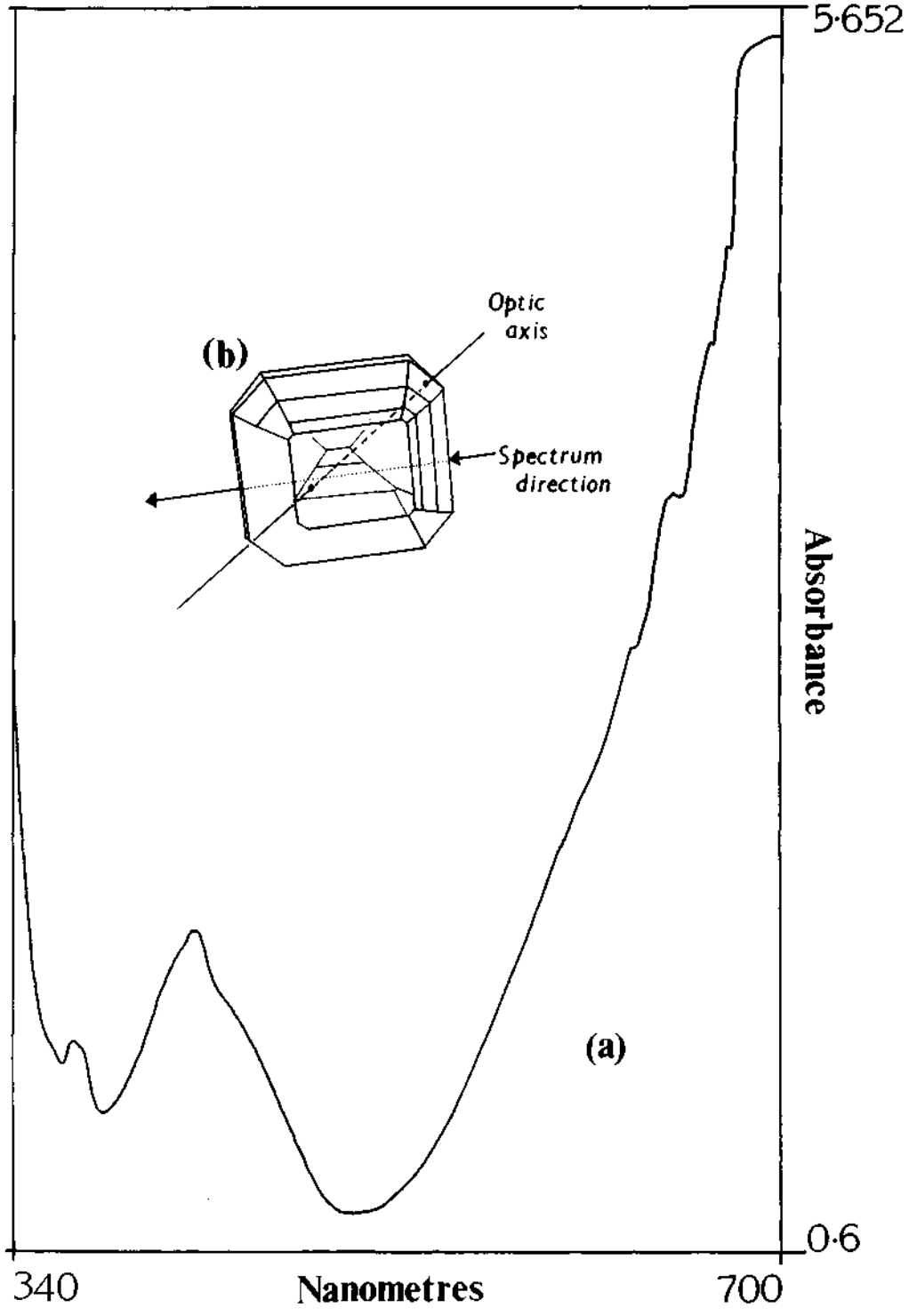

Fig. 30. The absorption curve of the emerald-cut Russian synthetic emerald of Figure 15 taken in the direction indicated by (b). The curve was obtained using a Pye Unicam PU 8800/03 UV/visible spectrophotometer (Basil Anderson model) with a speed of 1 nm/s and a bandwidth of 1 nm at room temperature. The path length was 5.49 mm.

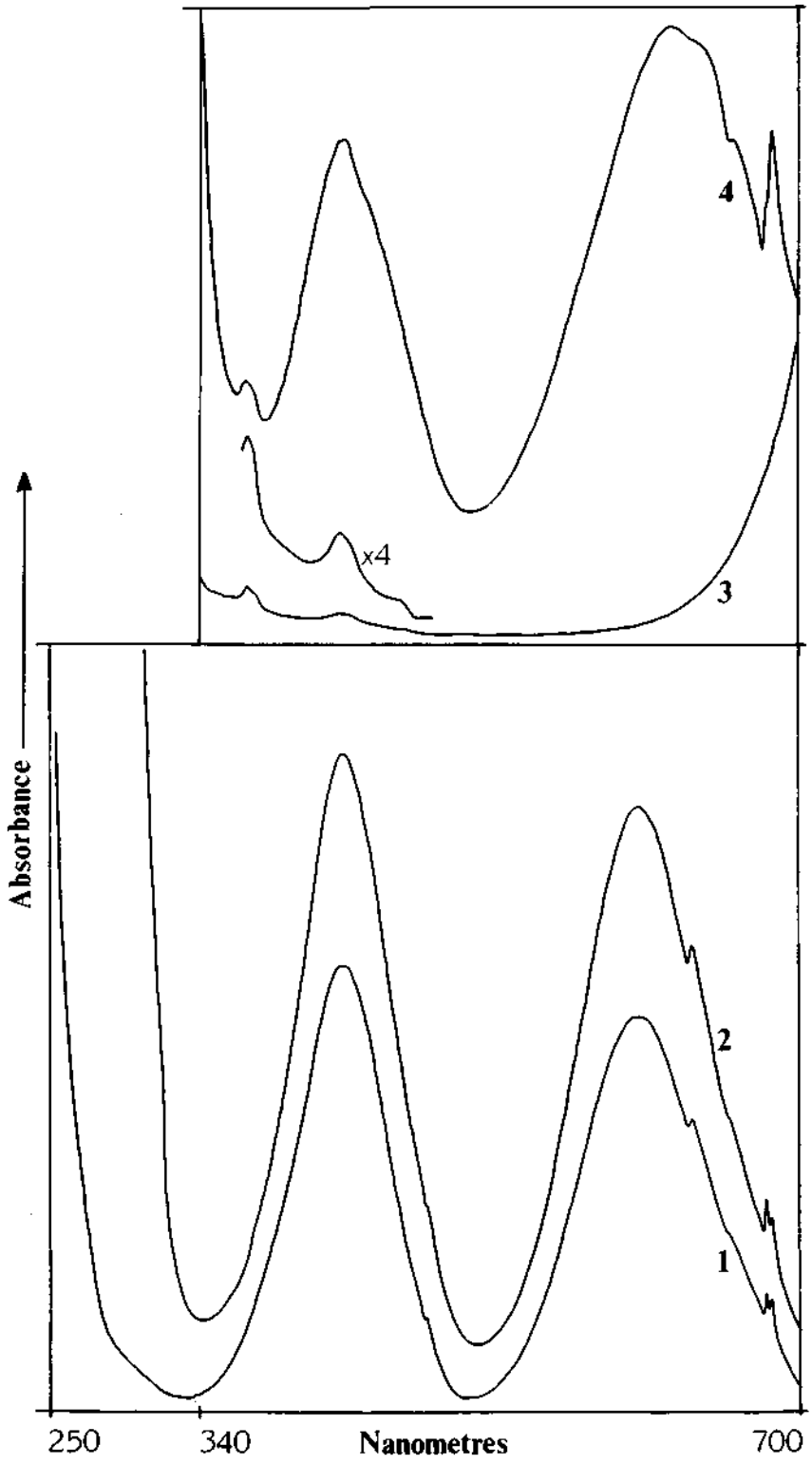

Fig. 31. Example absorption curves of (1) Australian hydrothermal synthetic emerald, (2) natural emerald from Colombia, (3) greenish aquamarine, (4) natural emerald from Madagascar.

Fig. 32. A 17.81 ct synthetic ruby with infilled cativies. The cavities are seen here looking through the crown to the bottom of the stone, positioned at the lower right corner and at the top edge of the table.

Fig. 33. An infilled cavity in the synthetic ruby of Figure 32 seen here from the bottom of the stone.

In recent times a number of papers have been published giving information on the glass infilling of cavities in ruby and sapphire (Scarratt and Harding, 1984; Kane, 1984; Scarratt, Harding and Din, 1986). In all instances the ruby or sapphire in question has, apart from the filling, been of natural origin.

A 17.81 ct red stone (Figure 32) sent for examination recently displayed the typical curved structures seen in stones produced by the Verneuil growth process and as a result was found to be a synthetic ruby. In addition to the curved growth structures though, there appeared to be a number of partially formed 'twin planes' which formed needle-like structures where their paths crossed, and a number of 'induced feathers', all of which might cause a little confusion to the uninitiated.

Somewhat amazingly though, on the bottom of the stone two holes appeared to have been manufactured, one on a side, and the other on a corner, and then filled with a colourless material (Figures 33 and 34) to imitate the cavity infillings of natural ruby. On the same corner as one of the infills two further cavities have been 'scooped out' and left in a similar manner to cavities that are left unfilled in natural rubies where infilling of other cavities has taken place.

The filling in this case is easily scratched by steel and against the brightly fluorescing background of the synthetic ruby it is inert to long-wave and green to short-wave ultraviolet rays. It also has a profusion of bubbles and, unlike the infilling seen in the natural material, the junction between the infill and the synthetic ruby at the surface is far from perfect.

The stone has now been placed on long-term loan in the Laboratory Collection.

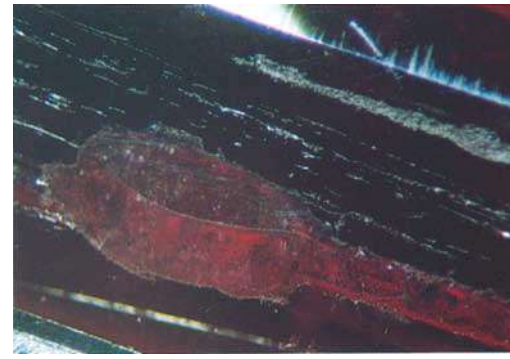

Fig. 34. A closer view of the infilled cavity seen in Figure 33.

Acknowledgements

It is with particular gratitude that the author acknowledges, on behalf of the Laboratory, firstly the good spirit of Mr Schlussel of The Diamond Registry, New York, in loaning to the Laboratory his faceted Sumitomo synthetic diamond and secondly, as always, the ready assistance of David Hargett for allowing the examination of the Sumitomo material that was in the New York Gem Trade Laboratory, in February of this year. Grateful thanks also go to Dr J. Milledge, of University College, London, for recording the infra-red spectrum of Mr Schlussel's stone.

Over the past few years Mr Mark L. Jones, FGA, has been a constant source of information to the Laboratory and he has made some very generous donations to the Collection, including the blue pearl described above. In this instance we are also indebted to him for sending the blue faceted sapphirine specimen for examination. We are

grateful also in this respect to J.G. Francis and S. Somogy of the British Museum (Natural History) for supplying the details of their sapphirine and providing a copy of its powder diffraction pattern for the Laboratory files.

The Laboratory is once again indebted to Alastair Cairncross, FGA, for his generosity, and on this occasion we thank him for the donation of the unusual brown (partly nacre-covered) pearl described above.

Finally we thank Alan Hodgkinson, FGA, for allowing us to examine his Russian synthetic emerald samples and Dr R.R. Harding and his colleagues at the British Museum (Natural History) for much discussion on the reasons for the peculiar absorption characteristics of these stones.

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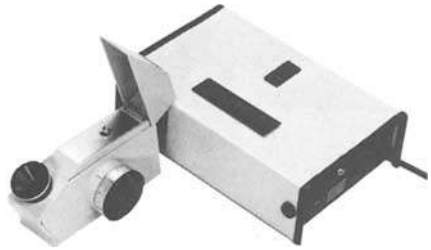

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The sale of the Windsor jewels

Amanda Gray, FGA

London W.8

Apart from creating international headlines, the April sale held in Geneva by Sotheby's of the Windsor jewels was a unique opportunity to see a collection of pieces of both gemmological interest and 'social' appeal. The Wallis and Edward romance attracted to the sale both the serious collector and the jet set.

Viewing the sale from the gemmological perspective it produced pieces of considerable interest, ranging from a matching pair of canary diamonds weighing 93 ct to a natural pearl necklace (Figure 1) graduating from 16.8 to 9.2 mm, and included many examples of fine craftsmanship by the well-known jewellers of the time.

The pear-shaped canary diamond lapel clips were exceptional due to the large size of the stones (40.81 ct and 52.13 ct), their good natural colour, and the fact that they were such a well-matched pair. They were very effective visually and Harry Winston put them into simple twisted wire diamond-set mounts. The Duchess had a pair of ear-rings to wear with the lapel clips; they each had two canary diamonds, one pear-shaped and one circular, in pavé-set mounts made by Cartier in 1968. These were of a deeper colour than the lapel clips.

The Duchess's most famous diamond was the 31.26 ct cushion-cut McLean diamond (Figure 2). This previously belonged to an American, Mrs Evalyn Walsh McLean, who had also owned the Hope diamond and the Star of the East, as well as many other pieces which were bought by Harry Winston after her death. He sold the McLean diamond to the Duke and Duchess in 1950. It was a beautifully proportioned stone and displayed considerable fire. A GIA report stated that it was 'D' colour, clarity VS2. The stone was claw-set with a single tapered baguette diamond on each shoulder; the ring sold for £1.8m. (before buyer's premium), the highest price in the sale, and was purchased by a Japanese diamond dealer.

On viewing the ruby pieces one was aware of their incredible vibrancy. The necklace (Figure 3) made by Van Cleef and Arpels for the Duchess's fortieth birthday, was in a design of twisted ribbons of cushion-shaped Burmese rubies and baguette diamonds with a tassel of rubies falling at the side of the neck. The whiteness of the diamonds provided a good contrast, making the rubies glow very intensely, creating a stunning effect overall. There were two large rubies weighing together 36.15 ct, in a Cartier bangle of 1938. These also appeared to be of Burmese origin; they were heavily included and had iron stains, patches of silk, and there was an interesting area of chatoyancy at the edge of one of the stones.

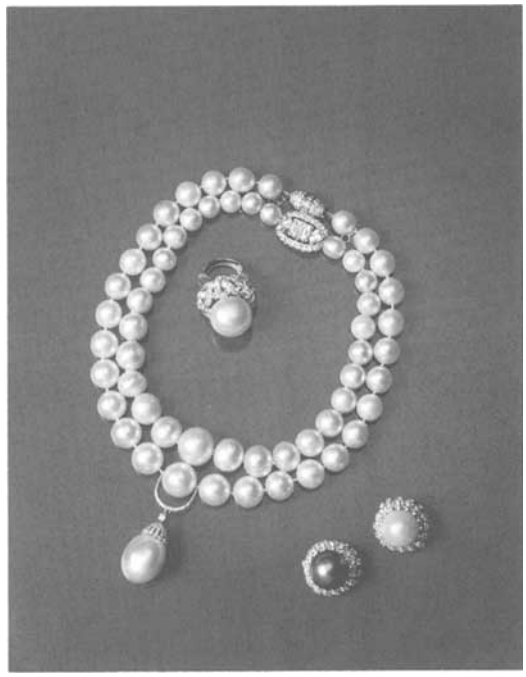

Fig. 1. Inner necklet: natural pearls graduated from 16.8 to 9.2 mm, diamond set clasp. Outer necklet: cultured pearls graduated from 15 to 11 mm, with detachable pearl drop. Ring set 18 mm natural pearl. Ear clips, set pearls (one black and one white) and diamonds.
Photo by courtesy of Sotheby's.

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Fig. 2. (Above) Flexible diamonds and sapphire set bracelet. 31.26 ct McLean diamond.
Photo by courtesy of Sotheby's.

Fig. 3. (Right) Ruby and diamond set necklet.
Photo by courtesy of Sotheby's.

Fig. 4. (Left) Five of the famous cat jewels.
Photo by courtesy of Sotheby's.

Fig. 5. (Below) Gem-set flamingo brooch.
Photo by courtesy of Sotheby's.

One of the most interesting pieces of ruby-set jewellery from the design point of view was a double-leaf clip (cover picture) which was one of the first pieces in which Van Cleef and Arpels used the 'invisible setting'. The calibré rubies were cut with such precision that they slotted together and were held in place by channels of gold on the reverse of the piece so that no gold was visible at the front. The Duchess's wedding present from the Duke, a bracelet (Figure 2) in the form of a wide flexible band of diamonds, with an invisibly-set sapphire bow-shaped clasp, was also made by Van Cleef and Arpels. The cushion-shaped sapphires were of an incredibly intense blue. Her drop-shaped cabochon sapphire earrings were one of the most attractive pieces in the sale. The sapphires weighing 75 ct were suspended from diamond-set clips designed as Prince of Wales feathers. The sapphires had round dot-like inclusions and fine silk, and were probably of Burmese origin. The largest sapphire in the sale was a 206 ct cushion-shaped stone which was of an intense colour and simply mounted by Cartier in 1951 in a border of baguette and brilliant-cut diamonds with a detachable loop so that it could be worn as a pendant and also as a brooch. This was bought for £210,000 by Mr Marvin Mitchelson, purportedly on behalf of Miss Joan Collins. The Duchess often wore the pendant hanging from a diamond rivière which sold for eight times its estimated price.

There were various large emerald pieces in the Duchess's collection. The Duke is said to have swapped a couple of the Duchess's emerald and diamond necklaces for the 48.95 ct emerald and diamond pear-shaped pendant which once belonged to King Alphonso III of Spain. Although this was heavily included it must have looked very effective, particularly when worn suspended from the Cartier necklace which had five pear-shaped emeralds weighing 41.50 ct. Her engagement ring also had an interesting origin. It is said to have belonged to the Grand Mogul and was one half of a fantastic stone purchased by a member of Cartier on a stone-finding mission to Baghdad. He had wired home for a large sum of money which he spent on one enormous emerald. This stone was cut in half and repolished making two spectacular stones, one of which was bought by an American millionaire and the other by the Duke. The setting for the emerald was redesigned many times before the 1958 Cartier mount was settled on; the 19.77 ct stone is set in yellow gold with a diamond-set leaf border.

The Duchess owned some exceptionally large pearl pieces (Figure 1). She had a graduated natural pearl necklace with 28 pearls ranging from 16.8 mm to 9.2 mm, and a detachable pearl drop weighing 190 grains. Her pearl ring made by Cartier in 1964 was set with a single 18 mm natural pearl. She sometimes wore several pearl necklaces together; she also had a cultured pearl necklet by Van Cleef and Arpels of 29 pearls graduating from 15 to 11 mm, all of a fine lustre and well matched, compared with the natural pearl necklace which was of a greyish tinge and had small grain markings.

Among the highlights of the sale were the Cat jewels (Figure 4), inspired by Jeanne Toussain of Cartier. She had been a close companion of Louis Cartier and was made responsible for the Haute Joaillerie in 1934. She had a liking for panthers which resulted in the appearance of these jewels. The Duchess owned one of the first of these, made in 1948; it was an enamelled panther sitting on a 90 ct cabochon emerald. She also had another panther with a pavé-set diamond and calibre sapphire body with yellow diamond eyes, seated on a 152 ct cabochon sapphire. This sapphire was of a deep translucent cornflower-blue colour with some interesting inclusions; some small crystals with halos, other fine dots and a big patch of crystal inclusions on one side. This sapphire was originally purchased by the Duke for £5,000 and the finished piece sold for £576,000.

Jeanne Toussaint also designed the flamingo brooch (Figure 5) which the Duchess was often photographed wearing. It was made up by Cartier in 1940 using calibré-cut rubies, emeralds and sapphires in the plummage, a cabochon citrine and sapphire in the beak, a similarly cut sapphire in the eye, with a pavé-set body. The stones were of a fine colour; they were said to have come from other pieces of jewellery which had been broken up. It was exquisitely made and even had hinged legs.

As was widely publicized, the prices of these fantastic pieces far outreached all expectations. The estimate for the sale total had been £5m. but the final figure, including buyer's premium, was £31m. Pieces which incorporated the Prince of Wales feathers motif naturally fetched high prices. There was one particularly astonishing result – a dress suite comprising a pair of cufflinks, each link pavé-set with brilliant-cut diamonds, one with the letter 'W' and the other with the letter 'E', and three buttons and a stud with the letter 'E', estimated to sell for £4,800 to £6,400 realised £240,000! Elizabeth Taylor was said to have bid £350,000 'from her Los Angeles poolside' for the Prince of Wales feathers clip. These are just two indications of how the history outweighed the intrinsic value of the majority of pieces in this unique collection of jewellery.

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Blue and yellow sapphire from Kaduna Province, Nigeria

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and Deutsche Stiftung Edelsteinforschung, Idar-Oberstein, West Germany

Abstract

Blue and yellow sapphires from Kaduna province near Jos, Nigeria, were characterized by mineralogical and gemmological investigations and the diagnostic properties of the samples are given. The rough sapphire crystals with tabular, barrel-shaped or prismatic habit originate from a secondary weathering horizon. The mineral assemblage consists of quartz, kaolinite, goethite, hematite and gibbsite. The blue or yellow colour of the samples is caused by various amounts of Fe^{3+}, Fe^{2+}, Ti^{4+}, Ti^{3+} and Cr^{3+}. Microscopic investigations reveal characteristic properties such as growth structures associated with intense colour zoning, fissures on basal parting planes, mineral inclusions with or without primary liquid feathers (albite, uranpyrochlore, zircon), negative crystals, as well as pseudosecondary healing fissures and secondary inclusions in unhealed fractures.

Introduction

Dark blue sapphires from Nigeria have been known for about 15 years. They have been increasingly offered on the gem market since the beginning of the 80s and meanwhile have reached a certain economic significance. These sapphires are mostly dark blue, and although the majority are cut

Fig. 1. E. Petsch at a visit to the sapphire occurrence in Kaduna province, north-east of Jos, Nigeria.

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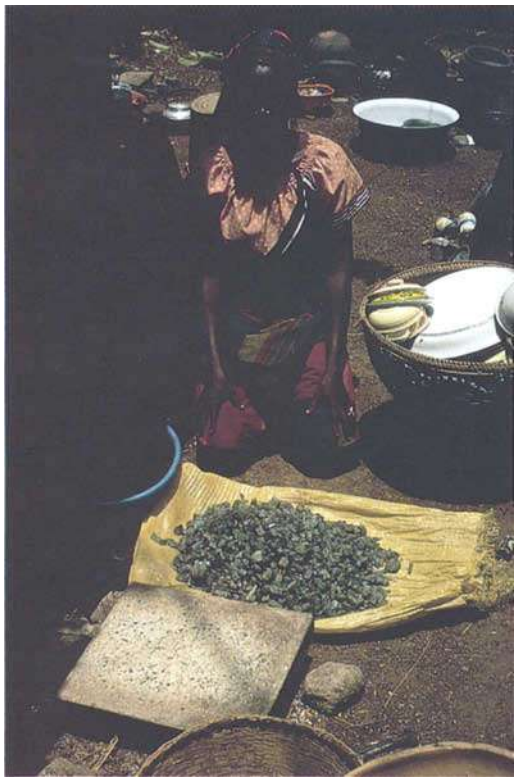

Fig. 2. Rough sapphire crystals from Kaduna province, north-east of Jos, Nigeria.

as cabochons, some are faceted. From time to time, yellow sapphires from Nigeria are offered as well.

Even though rough and cut sapphires from Nigeria have been available for a long time only one short contribution by Henn (1986) has been published until now with initial information about physical properties and inclusions.

38 rough crystals and 31 sapphires cut as cabochons from Nigeria have been at the authors' disposal in connection with systematic investigations of sapphires from different localities. Thus we had enough material to conduct detailed investigations of the diagnostic properties of the sapphires from this locality. Some interesting properties of these corundums caused the authors to publish a more detailed description of the Nigerian sapphires.

Occurrence and paragenesis

According to Petsch (1986, private communication), the sapphires described in this article originate from Kaduna province, about 45 km north-east of the city of Jos in Nigeria. The sapphires of the trade are derived, according to information given, from a secondary source. They are mined from an alluvial weathering rock, in holes and depressions up to a depth of about 0.5 to 1 m (Figures 1, 2). The sapphires show a dull, slightly corroded surface, which is a hint towards a magmatic rock as native host rock of the corundums, for the crystals were obviously in direct contact with a melt. There is only a slight rounding of the crystals, a sign for a relatively short transportation of the primary material to the secondary deposit.

In order to characterize the surrounding rock more exactly, the weathering minerals, which were existent on the faces of some rough samples, were determined by microprobe investigations and X-ray powder diffraction. In general, this very fine aggregate consists of quartz as well as the ferralitic weathering minerals goethite and kaolinite; subordinate minerals are gibbsite and hematite. These results reveal that this sapphire deposit in Nigeria is an occurrence in a secondary weathering horizon.

In literature Falconer (1911) describes a lateritic weathering horizon in the district where the investigated sapphire deposit occurs. Reyment (1965) mentions kaolinitic clays on the Jos plateau, and Turner (1977) characterizes lateritized Tertiary basalts from several localities in the whole area of the Jos plateau.

Scarratt *et al.* (1986) describe a weathered alkali basalt as primary mother rock of blue sapphires on the Jos plateau (cf. Figure 5 in Scarratt *et al.*, 1986). These authors also mention the slightly corroded surface of the crystals. Unfortunately, there is no information obtainable about the distance between the primary and the secondary occurrence. It is also unknown if the sapphire-bearing mother rock is exploited for gems commercially.

Morphology and appearance of the crystals

As mentioned above, the rough sapphires from Nigeria have dull, slightly corroded surfaces with slightly rounded edges. This appearance is typical for crystals which are brought up to the Earth's surface together with volcanic activity. The corroded crystal faces show a dull greasy lustre.

Furthermore, the crystals reveal smooth, highly lustrous faces parallel to the basal pinacoid *c* (0001) besides faces showing the typical conchoidal fracture of corundum. Those smooth faces are glide planes parallel to the basal plane *c*, a specific property of corundum, which causes basal parting of the crystals.

Due to the high number of crystals with well developed crystal faces, a typical morphology of the Nigerian sapphires was determined as follows: the majority of the crystals reveal tabular habit with the basal pinacoid *c* (0001) and the hexagonal dipyramid *z* $(22\bar{4}1)$ or with the crystal faces *c*, *z* and the positive rhombohedron *r* $(10\bar{1}1)$ (Figures 3a, b). Besides the

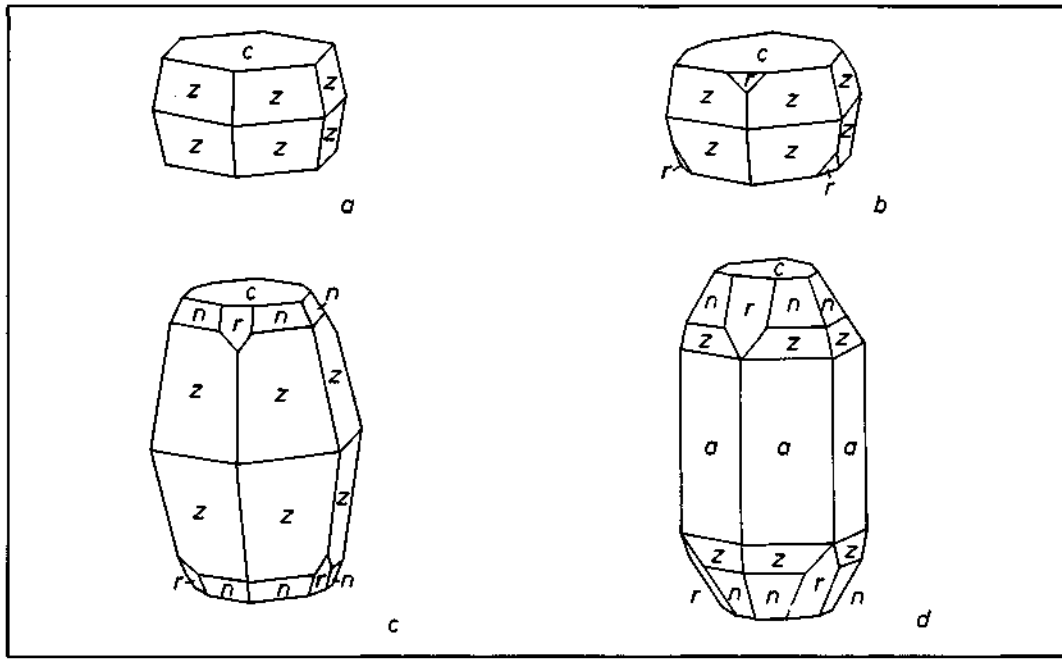

Fig. 3. Habit of blue sapphires from Nigeria, (a, b) tabular, (c) barrel-shaped, (d) prismatic; crystal faces are the basal pinacoid c (0001), the hexagonal prism a $(11\bar{2}0)$, the positive rhombohedron r $(10\bar{1}1)$, and the hexagonal dipyramids n $(22\bar{4}3)$ and z $(22\bar{4}1)$.

Fig. 4. Cut blue sapphires from Nigeria. *Photo by O. Medenbach, Bochum.*

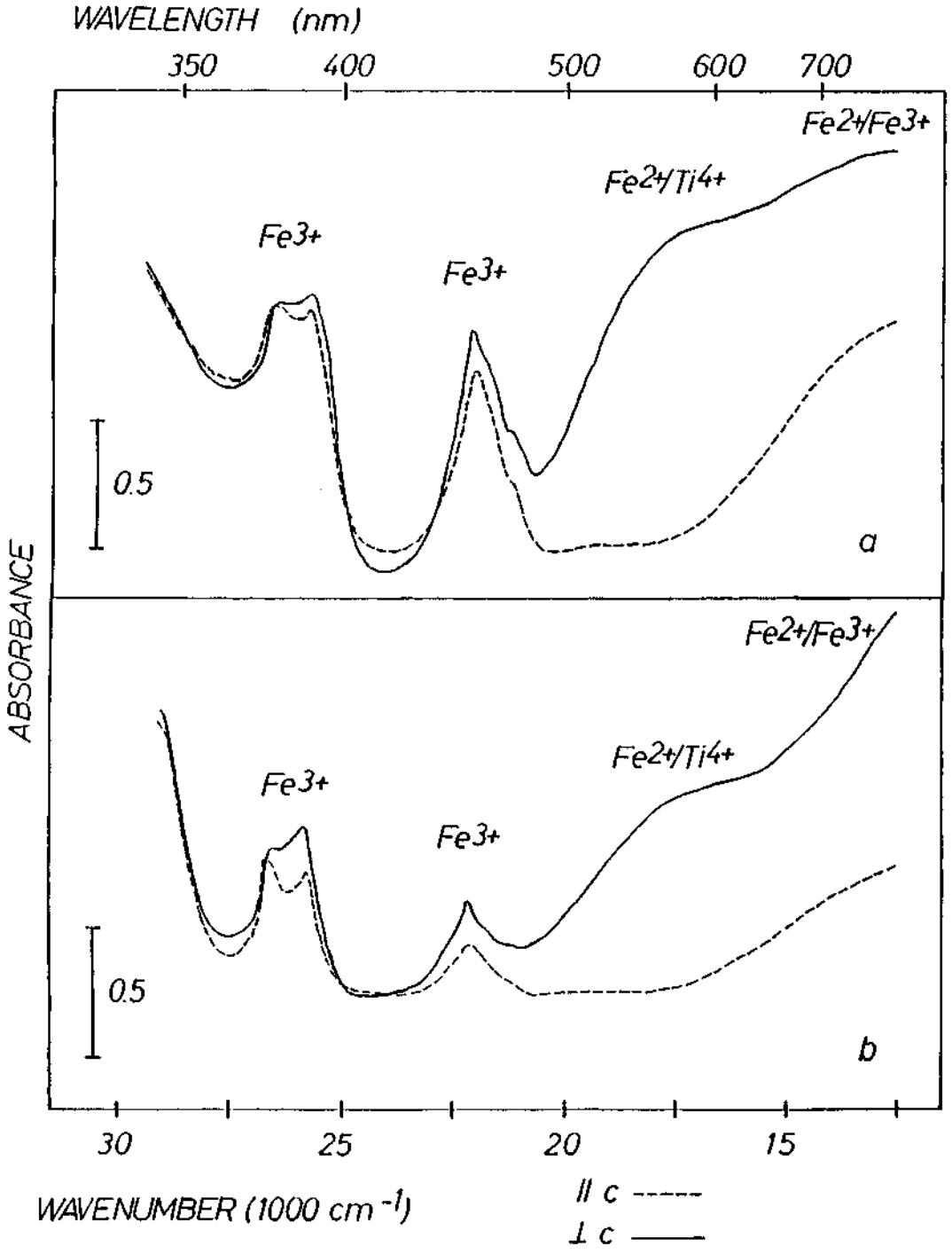

Fig. 5. Absorption spectra of blue sapphires from Nigeria without Cr^{3+}-component; pleochroism ∥ c yellowish-green, ⊥ c bluish-violet; hues in colour are caused by variable intensities of the Fe- and Fe-Ti-bands.

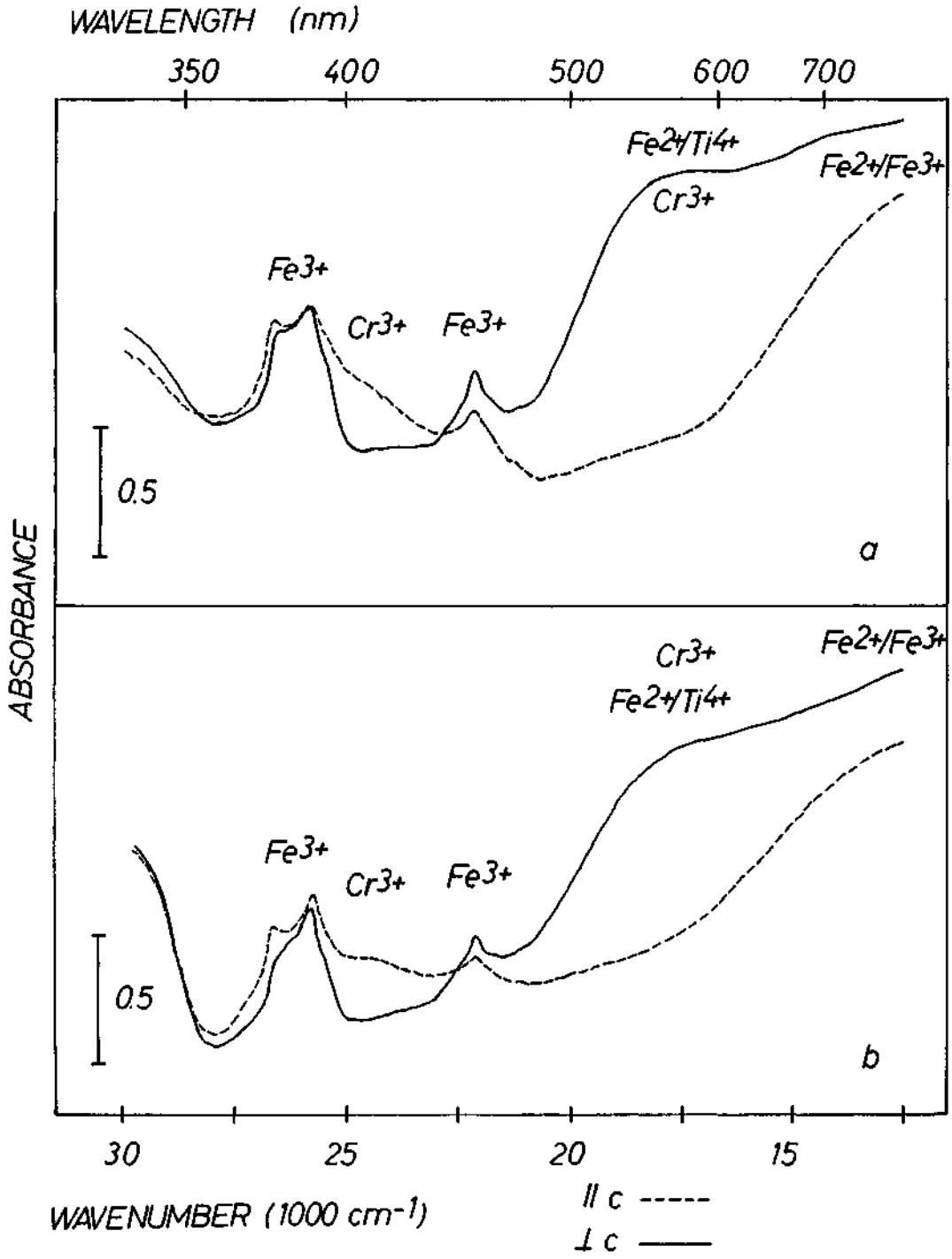

Fig. 6. Absorption spectra of blue sapphires from Nigeria with Cr^{3+}-component; pleochroism ∥ c bluish-green or green ⊥ c bluish-violet; hues in colour are caused by variable intensities of the Cr-, Fe- and Fe-Ti-bands.

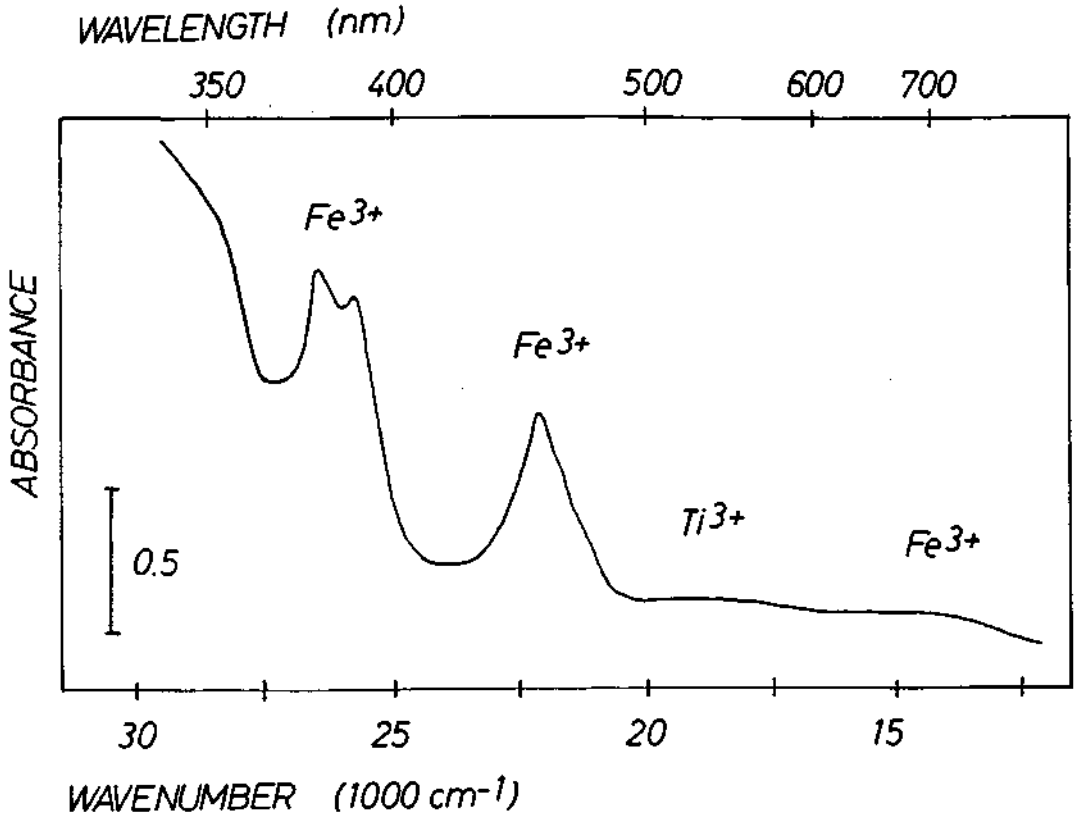

Fig. 7. Absorption spectra of a yellow sapphire from Nigeria without Fe^{2+}/Ti^{4+}- and Fe^{2+}/Fe^{3+}-component, weak pleochroism.

crystal faces as mentioned above, additionally sapphires with barrel-shaped habit reveal the hexagonal dipyramid *n* $(22\bar{4}3)$ (Figure 3c). Crystals with prismatic habit display the hexagonal prism *a* $(11\bar{2}0)$ in addition to the forms mentioned above (Figure 3d).

Physical properties

The density of some of the sapphires was determined to range from 3.99 to 4.01 g/cm^3. The refractive indices vary between 1.759 and 1.761 for n_e and between 1.768 and 1.770 for n_o; the double refraction equals 0.009. These data reveal the typical values for corundum (cf. also Henn, 1986).

Colour and spectroscopic data

Part of the sample of cut sapphires from Nigeria shows a very dark, inky blue, and part discloses a dark blue colour with a light greenish hue (Figure 4). Rough crystals reveal an especially distinct pleochroism. The Nigerian sapphires show bluish-violet colours perpendicular to the *c*-axis, and bluish-green, green or greenish-yellow colours parallel to the *c*-axis. Occasionally, the rough crystals show macroscopically a very distinct colour zoning parallel to the outer crystal faces.

In order to clarify the colour causes, absorption spectra of all available samples were recorded in the area of 11 500 to 30 000 cm^{-1} (870–333 nm) using a double-beam Leitz-Unicam SP.800 spectrophotometer. Some of the samples were measured in polarized light, i.e. the absorption spectra parallel and perpendicular to the *c*-axis could be measured separately.

The blue sapphires from Nigeria reveal a distinction into two main types of spectra (for the assignment of the absorption spectra of natural blue, bluish-green, green and yellow sapphires cf. the papers of Schmetzer and Bank, 1980, 1981, a, b; Burns and Burns, 1984; Schmetzer, 1987): samples that appear yellowish-green parallel to the *c*-axis and bluish-violet perpendicular to the *c*-axis show only the absorption bands of Fe^{3+} and the intervalence absorption bands of Fe^{2+}/Fe^{3+} and Fe^{2+}/Ti^{4+}. Perpendicular to the *c*-axis the band of Fe^{2+}/Ti^{4+} is much more intense in the yellow spectral range compared with the spectrum parallel to the *c*-axis, which causes the different pleochroism

of the crystals (Figures 5a, b).

Sapphires that show bluish-green to green colours parallel to the *c*-axis and bluish-violet colours perpendicular to the *c*-axis have, besides the already mentioned sapphire-spectra with Fe^{3+}, Fe^{2+}/Fe^{3+} and Fe^{2+}/Ti^{4+}, distinct Cr^{3+} bands in the yellow and bluish-violet ranges, respectively. This Cr^{3+}-component of the spectrum is more distinct in the direction parallel to the *c*-axis than perpendicular to *c*. It weakens the yellow and bluish-violet transmission parallel to *c* and leads to a strengthening of the green component (Figures 6a, b).

For both types of spectra, the presence of the Fe^{3+}, Fe^{2+}/Fe^{3+} and Fe^{2+}/Ti^{4+} bands is characteristic, but their relative intensities in different samples may, however, vary considerably. This wide range in variation is responsible for the different hues of blue Nigerian sapphires.

The spectrum of the less common yellow sapphires, which were available to the authors only as cut samples, is dominated by Fe^{3+}, and there is also a weak Ti^{3+} absorption band (Figure 7). The intervalence absorption bands of Fe^{2+}/Fe^{3+} and Fe^{2+}/Ti^{4+} were not observed in yellow samples.

Microscopic properties

Corundum samples from Nigeria which are described in this paper commonly reveal small lamellae of corundum in twin position, which are intercalated parallel to the positive rhombohedron *r* $(10\bar{1}1)$ of the dominant corundum crystal in one, two or three directions intersecting at angles of 93.9° (Figures 8, 9, 10). The distances between different twin lamellae vary widely; occasionally they end irregularly in the dominant corundum crystal. Frequently, the intersecting lines between two sets of intercalated corundum lamellae reveal lath-like structures consisting of polycrystalline material (most probably boehmite) (Figures 10, 11; cf. Schmetzer, 1986b).

As a characteristic feature, the crystals disclose families of straight parallel growth planes; repeatedly two or more sets of straight parallel growth planes that form an angle are observable. Nearly always there is a strong colour zoning between darker and lighter, almost colourless areas connected with growth structures. This colour zoning is due to different growth conditions, i.e. due to a different incorporation of the colour-causing elements Fe and/or Ti in concentration and/or valence. The determination of growth structures according to the method of Schmetzer (1985, 1986a) reveals that the planes are, according to the morphology of the rough crystals, mainly parallel to dominant crystal faces like the hexagonal dipyramid *z* $(22\bar{4}1)$, parallel to the positive rhombohedron *r* $(10\bar{1}1)$ and parallel to the basal pinacoid *c* (0001). In addition, crystal faces parallel to the hexagonal dipyramid *n* $(22\bar{4}3)$ and parallel to the hexagonal prism *a* $(11\bar{2}0)$ may occur (Figures 12–17). In connection with growth structures and colour zoning the sapphires from Nigeria may contain zones with different concentrations of extremely small particles ('mineral dust') (Figure 18) or, rarely, with tiny needle-like mineral inclusions.

There is a strikingly high number of samples with unhealed plane fissures orientated parallel to the basal pinacoid *c*. These fissures are arranged so that they are intersecting right-angled with the prism faces *a* $(11\bar{2}0)$ and under an angle of 79.6° with the dominant pyramid faces *z* $(22\bar{4}1)$. They appear transparent in a view parallel to the *c*-axis, but expose total internal reflection under distinct angles in the microscope (Figure 19). This proves that these are fissures on glide planes parallel to the basal pinacoid *c*, which are due to a plastic deformation of the corundum crystals (cf. Schmetzer and Kiefert, 1986). As indicated in laboratory experiments, glide planes, or partings, respectively, parallel to the basal pinacoid *c* may be generated already at low temperatures, i.e. at about 900°C (Kronberg, 1957; Scheuplein and Gibbs, 1960). Glide planes and partings parallel to *c* are common in natural corundum from different localities.

Mineral inclusions are not present in all sapphires from Nigeria. However, part of the investigated samples reveal characteristic solid inclusions like hexagonal platelets, crystals with tension cracks, crystals with rosette-like fluid inclusions parallel to the basal pinacoid *c* as well as grains surrounded by irregularly orientated rosette-like fluid inclusions. These orientated and not orientated fluid inclusion rosettes are, as well as the mineral inclusions, of primary origin. They were included in the host crystal together with the mineral grains during the formation of the corundum host.

In one sample, opaque, hexagonal-shaped platelets, that are partly corroded, were observed (Figure 20). These platelets, which could not yet be determined exactly, reveal a certain similarity to hexagonal Pt-particles in flux-grown Chatham synthetic rubies and sapphires (cf. Kane, 1982; Schmetzer, 1986b). Furthermore, short-prismatic to columnar mineral inclusions with small stress cracks were observed and identified by electron microprobe as zircons (Figure 24). Red to reddish-brown, slightly rounded grains with irregularly orientated stress cracks and rosette-shaped fluid inclusions are frequently observed (Figures 21, 22, 23). These inclusions were exposed at the surface of two cut samples. They were determined by microprobe investigations as uranpyrochlore (cf. also Hogarth, 1977). Furthermore, occasionally

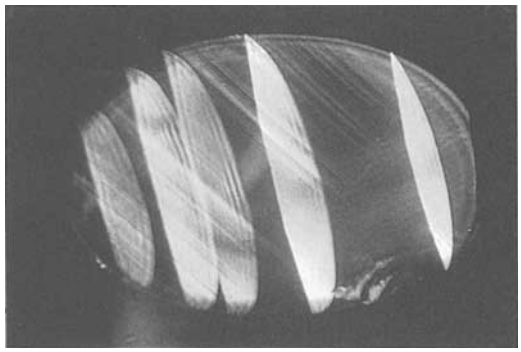

Fig. 8. Blue sapphire from Nigeria; intercalated lamellae of corundum in twin position parallel to one rhombohedral face r $(10\bar{1}1)$. Crossed polarizers. 20x.

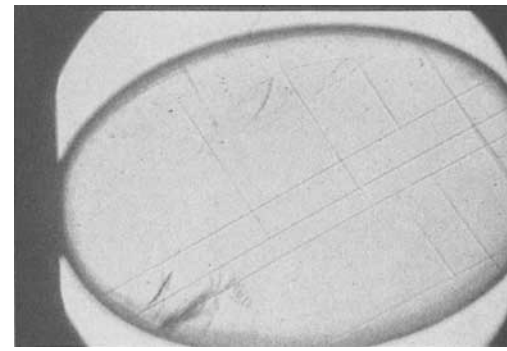

Fig. 9. Blue sapphire from Nigeria; intercalated lamellae of corundum in twin position parallel to two rhombohedral faces r and r' $\{10\bar{1}1\}$ intersecting at angles of 93.9°. 30x.

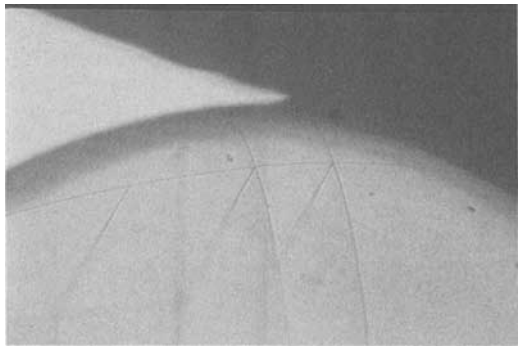

Fig. 10. Blue sapphire from Nigeria; intercalated lamellae of corundum in twin position parallel to two rhombohedral faces r and r' $\{10\bar{1}1\}$; polycrystalline material, most probably boehmite, at the intersecting lines of both lamellar systems. 65x.

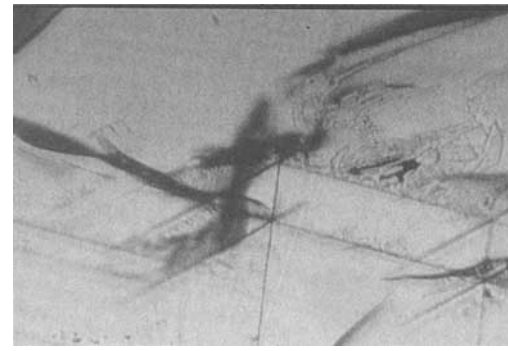

Fig. 11. Blue sapphire from Nigeria; rectangular three-dimensional lattice of polycrystalline material, most probably boehmite, at the intersecting lines of twin lamellae intercalated parallel to the three rhombohedral faces r, r' and r'' $\{10\bar{1}1\}$. 85x.

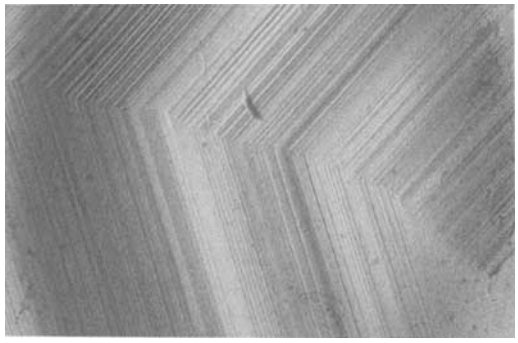

Fig. 12. Blue sapphire from Nigeria, view 10.4° inclined to the c-axis; angled growth structure, the faces z and z' $\{22\bar{4}1\}$ are forming an angle of 121.1°. Crossed polarizers. 30x.

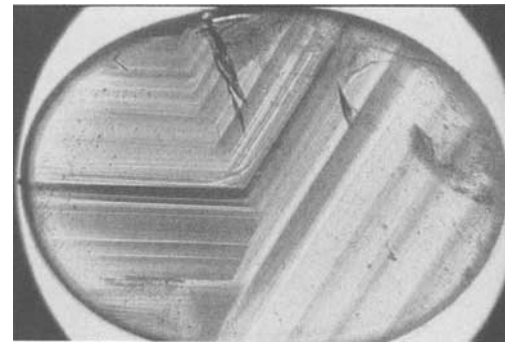

Fig. 13. Blue sapphire from Nigeria, view ∥ to the c-axis; angled growth structure, the faces a and a' $\{11\bar{2}0\}$ are forming an angle of 120°. 30x.

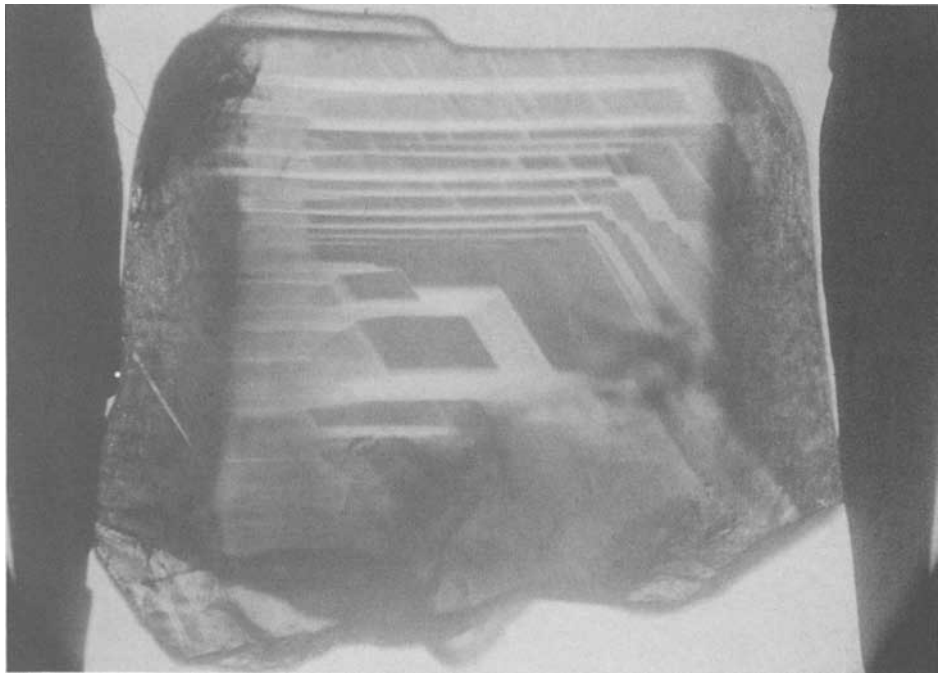

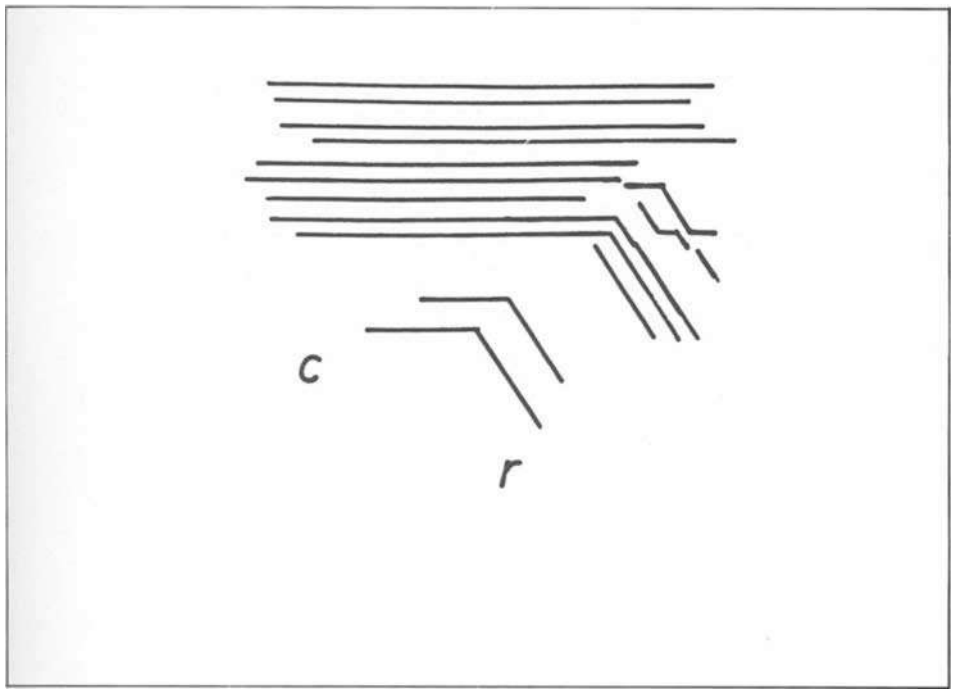

Fig. 14. Blue sapphire from Nigeria, view ⊥ to the *c*-axis; growth- and colour zoning parallel to the basal pinacoid c (0001) as well as parallel to the positive rhombohedron r $(10\bar{1}1)$. Above: microphotograph, 16x; below: drawing of growth planes.

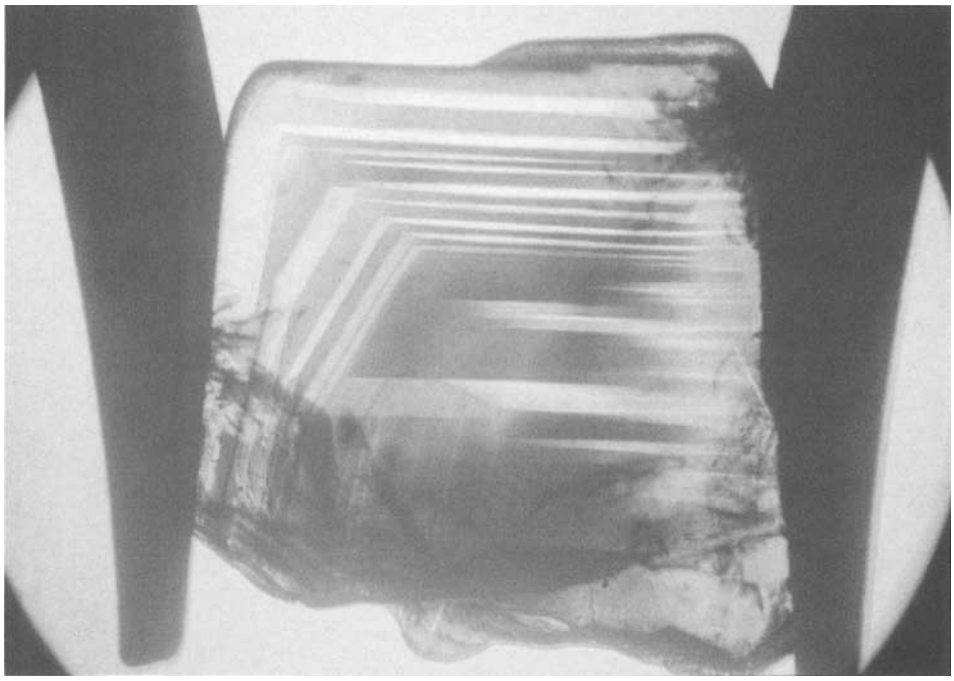

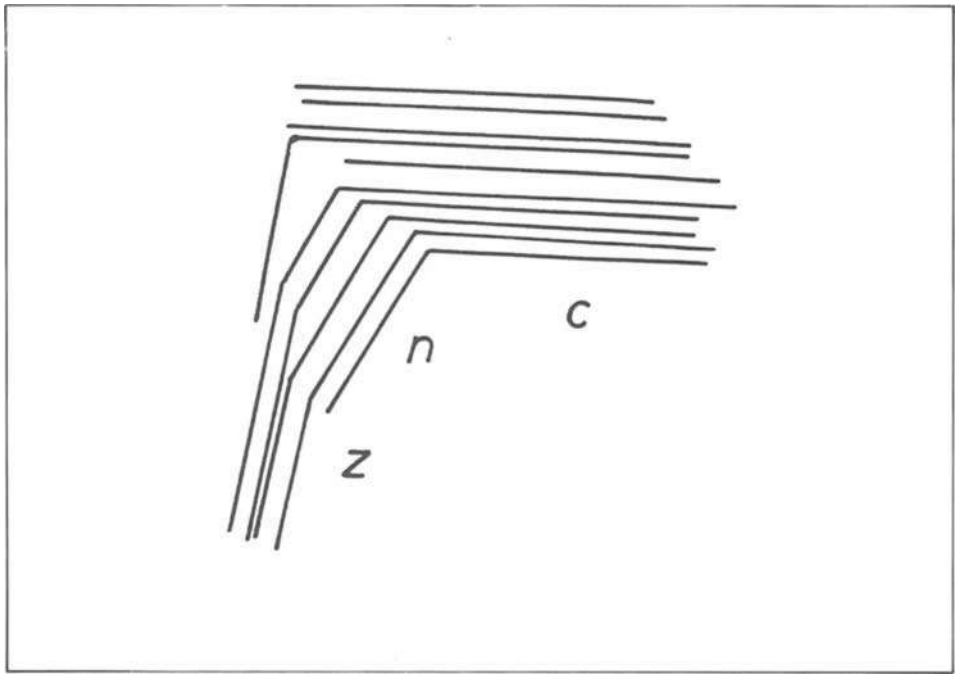

Fig. 15. Blue sapphire from Nigeria, view ⊥ to the c-axis; growth- and colour-zoning parallel to the basal pinacoid c (0001) as well as parallel to the hexagonal dipyramids n $(22\bar{4}3)$ and z $(22\bar{4}1)$. Above: microphotograph, 16x; below: drawing of growth structures.

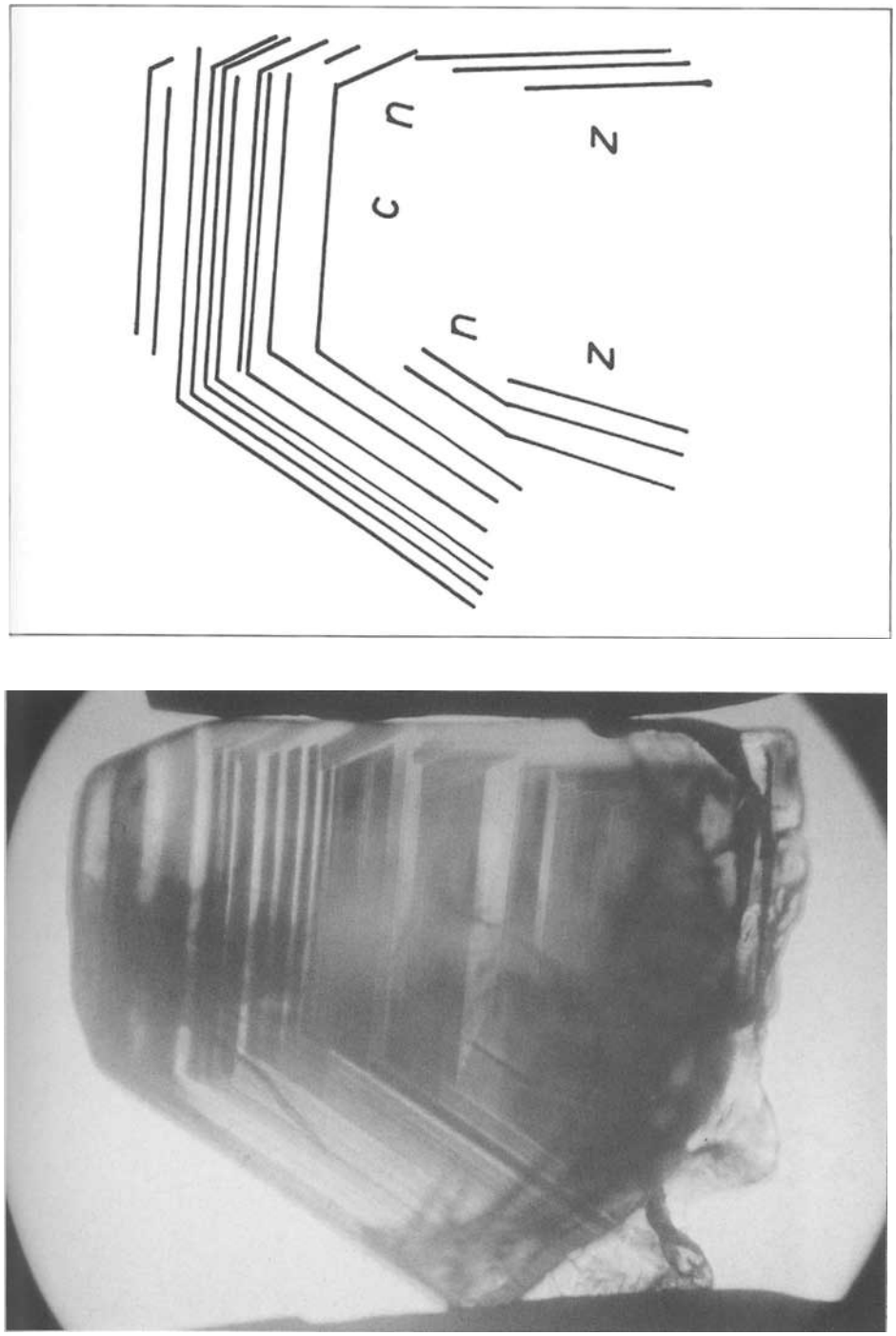

Fig. 16. Blue sapphire from Nigeria, view ⊥ to the *c*-axis; growth- and colour-zoning parallel to the basal pinacoid *c* {0001} as well as parallel to the hexagonal dipyramids *n* {$22\bar{4}3$} and *z* {$22\bar{4}1$}. Left: microphotograph, 18x; right: drawing of growth structures.

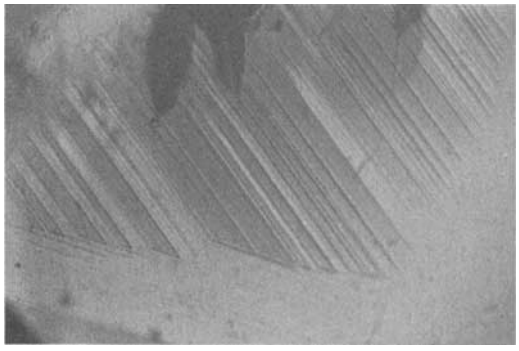

Fig. 17. Blue sapphire from Nigeria, view 32.4° inclined to the c-axis; growth structure parallel to the positive rhombohedron r (10$\bar{1}$1). 30x.

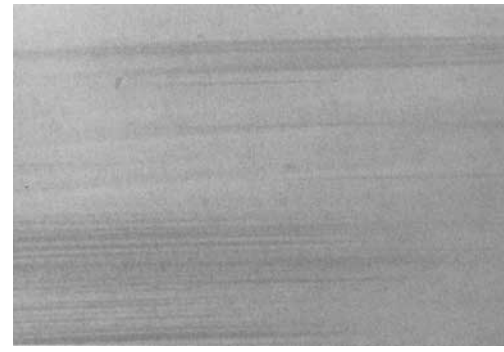

Fig. 18. Blue sapphire from Nigeria, view ⊥ to the c-axis; growth structure parallel to the basal pinacoid *c* (0001), connected with areas of different concentrations of extremely fine mineral inclusions. 45x.

Fig. 19. Blue sapphire from Nigeria; fissures showing internal reflection due to glide planes parallel to the basal pinacoid *c* (0001). 50x.

Fig. 20. Blue sapphire from Nigeria; corroded, hexagonal-shaped mineral platelet. 100x.

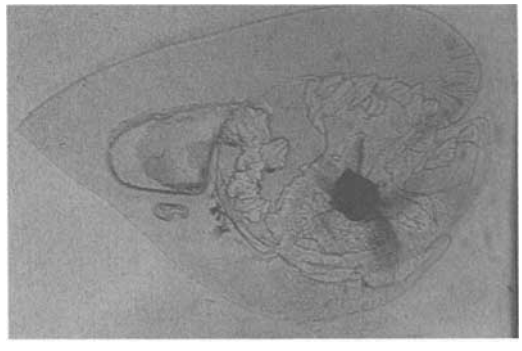

Fig. 21. Blue sapphire from Nigeria; uranpyrochlore with stress cracks and irregularly orientated primary rosette-like fluid inclusions. 45x.

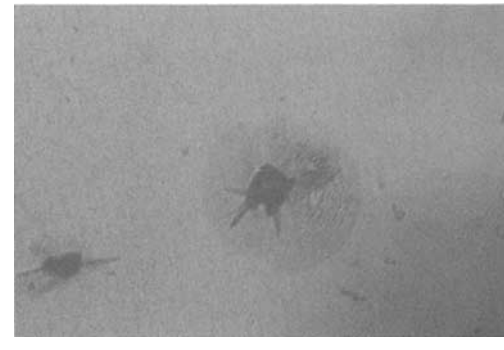

Fig. 22. Blue sapphire from Nigeria, uranpyrochlore with stress cracks and irregularly orientated primary rosette-like fluid inclusions. 100x.

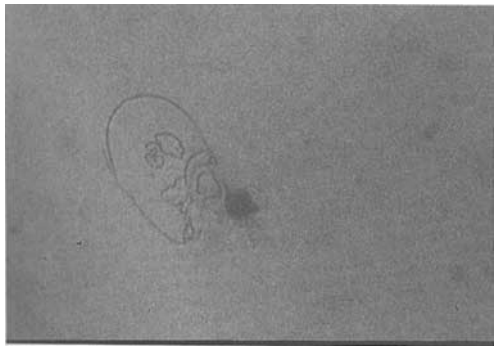

Fig. 23. Blue sapphire from Nigeria; uranpyrochlore with stress cracks and irregularly orientated primary rosette-like fluid inclusions. 85x.

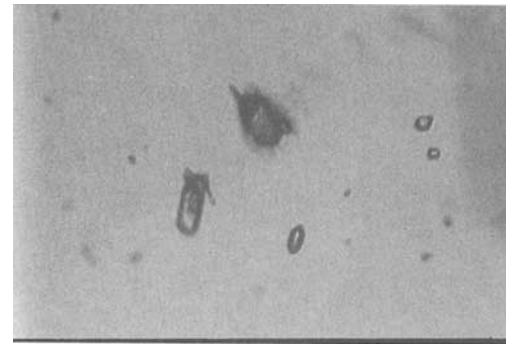

Fig. 24. Blue sapphire from Nigeria; rounded uranpyrochlore with stress cracks (above), prismatic albite (right), zircons (below and left). 100x.

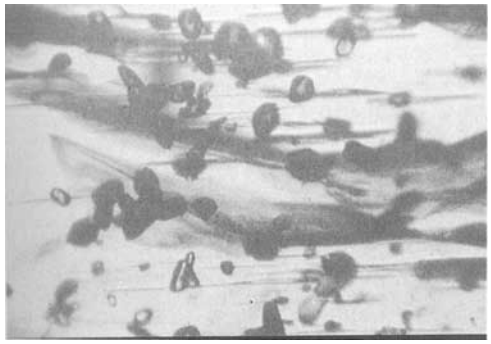

Fig. 25. Blue sapphire from Nigeria; prismatic to rounded albite crystals with rosette-like fluid inclusions parallel to the basal pinacoid *c* (0001). 65x.

Fig. 26. Blue sapphire from Nigeria, view ⊥ to the *c*-axis; prismatic to rounded albite crystals with rosette-like fluid inclusions parallel to the basal pinacoid *c* (0001). 75x.

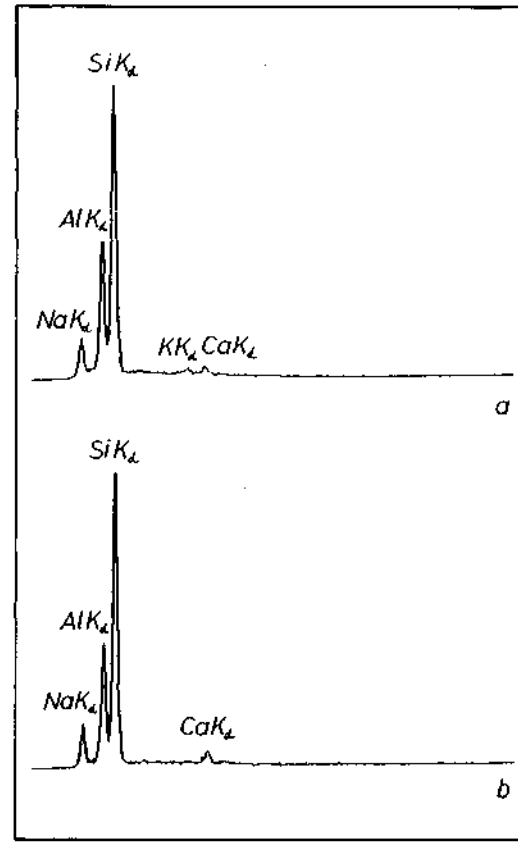

Fig. 27. Energy dispersive X-ray spectra of an albite crystal in a blue sapphire from Nigeria (a) as well as of an albite-standard of the Institute of Mineralogy and Petrography, University of Heidelberg (b).

slightly rounded, double-refracting prisms were observed with rosette-like fluid inclusions, which are orientated parallel to the basal pinacoid *c* (Figure 24). Similar fluid inclusion rosettes around grains or negative crystals with an identical orientation on faces parallel to the basal pinacoid are frequently observable in rubies from Thailand and should be known to all gemmologists.

In one specimen of the available investigation material, a greater number of such slightly rounded, prismatic mineral inclusions with rosette-like fluid inclusions parallel to the basal pinacoid was observed (Figures 25, 26). This sample was cut and polished several times and the inclusions exposed at the surface were investigated by microprobe. These investigations revealed partly irregularly formed cavities and negative crystals, but also five crystals of identical chemical composition. They were identified as a Na-Al-silicate. By comparison with the energy dispersive X-ray spectra of an albite-standard, the inclusions in the blue sapphire from Nigeria could be determined as albite (Figures 27a, b).

Besides the different mineral inclusions (zircon, albite, uranpyrochlore) and the above-mentioned irregularly formed cavities and negative crystals, the sapphires from Nigeria frequently show cavities partly filled with microcrystalline substances or two-phase inclusions, which are also surrounded by healing fissures (Figures 28, 29, 30).

Whereas the orientated and non-orientated rosette-like fluid inclusions around mineral grains are certainly of primary origin, the corundums from Nigeria frequently reveal pseudosecondary healing fissures (Figures 31, 32) and not healed fissures. Furthermore, the investigated sapphires show occasionally fissures secondarily filled with brown mineral substances (Figure 33). Presumably, these brown fillings consist of Fe-oxides or -hydroxides, that were deposited in the fissures during the weathering process of the rock. Probably they are the same weathering minerals, which build the surrounding weathering rock, i.e. goethite or hematite.

Healing fissures of one kind are worth mentioning in particular because they are so far observed in this form in corundum from Nigeria only: these healing fissures show an initial pseudo-secondary healing at the rims of the cracks. Later on, no subsequent formation of corundum took place until the fissure was completely healed. However, the crack desiccated, because obviously no adequate growth conditions, e.g. no adequate nutritive solutions, were available for the formation of corundum. Substances which were contained in the residual or later newly infiltrated solution were precipitated in dendritical form during the desiccation of the fissure (Figures 34, 35). The designation for this type of healing fissure is proposed to be pseudo-secondary – secondary according to its formation in two subsequent parts.

Discussion

The blue and yellow sapphires from Kaduna province, Nigeria, are characterized by a considerable number of diagnostic properties which are suitable for the recognition of samples from this occurrence in contrast to blue sapphires from different localities, as well as to distinguish Nigerian sapphires from synthetic blue and yellow sapphires. Macroscopically, in addition to the characteristic morphology of the samples, which is frequently connected with colour zoning parallel to the crystal faces, the corroded surfaces of the crystals and the parting planes parallel to the basal pinacoid are worth mentioning. The density and optical data of

Fig. 28. Blue sapphire from Nigeria; elongated negative crystal with two-phase inclusion, healing fissure. 100x.

Fig. 29. Blue sapphire from Nigeria, primary negative crystals surrounded by primary or pseudosecondary healing fissures. 40x.

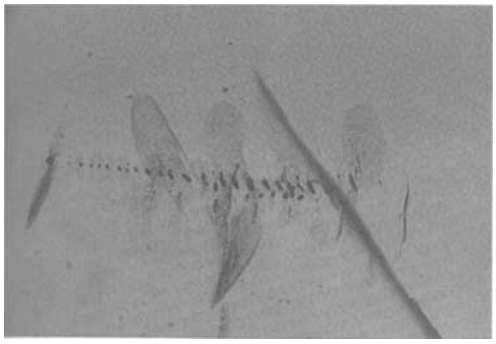

Fig. 30. Blue sapphire from Nigeria, primary negative crystals surrounded by primary or pseudosecondary healing fissures. 40x.

Fig. 31. Blue sapphire from Nigeria; healing fissure. 40x.

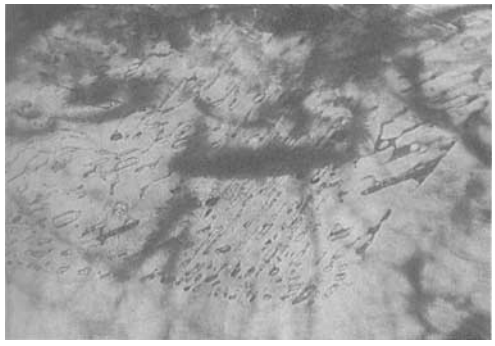

Fig. 32. Blue sapphire from Nigeria; healing fissures with two-phase inclusions. Crossed polarizers. 30x.

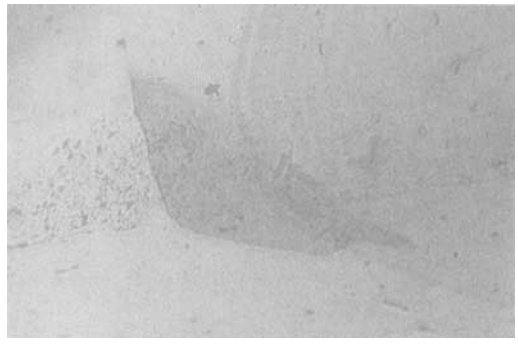

Fig. 33. Blue sapphire from Nigeria; fissure with secondary filling of a brownish substance, most probably Feoxides or hydroxides. 70x.

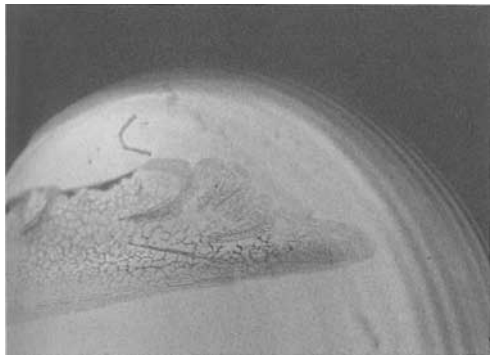

Fig. 34. Blue sapphire from Nigeria; fissure, partly healed pseudosecondarily at the rims of the cracks, partly filled secondarily with a dendritical substance. 16x.

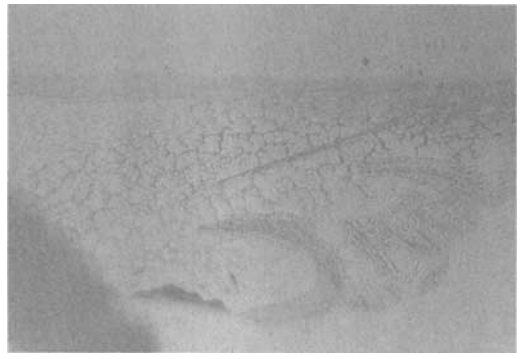

Fig. 35. Blue sapphire from Nigeria; fissure, partly healed pseudosecondarily at the rims of the cracks, partly filled secondarily with a dendritical substance. 80x.

the sapphires as well as colour, pleochroism and absorption spectra are less suitable for a determination of the locality, because similar properties are observable in samples from other localities, e.g. Australia and Thailand.

Some important microscopic properties that are especially worth mentioning are the intense growth- and colour-zoning correlated with the morphology of the crystals. The frequently observable parting planes parallel to the basal pinacoid are reflected by unhealed fissures that reveal total internal reflection under distinct angles in the microscope. Inclusions of zircon, uranpyrochlore and albite crystals are frequently surrounded by stress cracks (zircon, uranpyrochlore) or primary unorientated rosette-like fluid inclusions (uranpyrochlore) as well as by rosette-like fluid inclusions orientated preferably parallel to the basal pinacoid (albite). These mineral inclusions frequently appear together with primary cavities and negative crystals. Opaque lamellar mineral inclusions could not yet be determined exactly. Besides the healing fissures and the unhealed fissures secondarily filled with Fe-oxides and -hydroxides, which are observable also in sapphires from other occurrences, Nigerian sapphires reveal a mixed type of partly pseudosecondary healed fissures with dendritical secondary relicts in the unhealed areas.

The determination of uranpyrochlore crystals as primary mineral inclusions besides albite and zircon supports the indication of Scarratt *et al.* (1986), who mentioned alkali basalt as mother rock of blue Nigerian sapphires. Uranpyrochlore was first determined by Gübelin (1969) in blue sapphires and was reputed to be a typical characteristic property of blue sapphires from Pailin, Cambodia (Gübelin, 1974). Recent investigations identified their mother rocks as Tertiary to Quarternary alkali basalts (Jobbins and Berrangé, 1981). However, inclusions of uranpyrochlore were also determined in Australian sapphires (Coldham, 1986; Moon and Phillips, 1986), whose mother rocks are alkali basalts, too. Obviously, the distribution of sapphires with inclusions of uranpyrochlore is more abundant than supposed previously. This inclusion is not, therefore, any longer characteristic for sapphires from Pailin, but it seems to occur frequently in sapphires from alkali basalts.

Acknowledgements

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In the witness box

Eric Bruton, FGA

Great Bentley, Essex, CO7 8QG

How did you become involved in gemmology?

The simple answer is 'By chance.' I was offered a job as group training officer in the then new Pakistani Air Force, but instead started up a farm machinery business with a friend in the UK. Our RAF gratuities ran out, so I applied for a job with a small firm, NAG Press in Hammersmith, and was interviewed on a Thursday by the owner, Arthur Tremayne, who to my surprise said I could have it if I started on Monday. I did, to find AT in hospital after a heart attack. Another young man wandering through the office, a converted shop, said 'If you're Eric Bruton, I'm your new assistant, Malcolm Henderson'.

There were four monthly publications, *The Gemmologist, Goldsmiths Journal, Horological Journal,* and *Industrial Diamond Review,* all running at least a month late. Worse was to come AT: had sacked the printers as well as his editorial staff. We were in very deep water. That was in 1947.

Did you know anything at all about gemmology?

Nothing. I knew how a clock worked and something about the use of industrial diamonds, but I'd not even heard the word gemmology. We'd got the four journals settled at a new printer and coming out regularly by the time AT returned. His first instruction was, 'Get to know Gordon Andrews of the GA and Major Cowen of the Horological Institute'. I did and fortunately quickly became friends with both. Not much later I was able to count Robert Webster and then Basil Anderson as friends. Robert gave me private lessons to supplement the teaching of Thorold Jones at the Chelsea Polytechnic gemmology classes; just as well, since my diploma exam coincided with getting married to Anne and finding somewhere to live in 1950. Courting inhibits swatting constants, but at least Anne got to know some basic gemmology.

Later, a course in silversmithing at the Central School of Arts and Crafts and studying more advanced horology at home with the help of a correspondence course helped with the other subjects. AT was a partly spent force by then and I took over much of his work as Editor, even to ghosting his vituperative trade gossip page, not a particularly pleasant job.

Eric Bruton, FBHI, FGA, when President of the National Association of Goldsmiths in 1983–85.

Did NAG Press publish books as well at that time?

Oh yes, nearly all of them textbooks, but a few odd ones, like one on film stars! AT asked Basil Anderson, Robert Webster and C.J. Payne if they would co-operate in writing the definitive book on gemmology, but I might have left by then. About this time I intended to leave to avoid getting too specialized, but AT promised me a share in the business.

When he died in 1954 he left everything to the company secretary, Miss Edith Palmer. After much heart searching, I stayed on, taking over AT's office. In the meantime, Robert Webster finished

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his section of *Gems,* while neither of the others had started. Eventually they agreed to let Robert finish the book himself. After I'd subbed it and sorted out the pictures, format, paper, binding, etc. I asked Edith for £1000 to set it in motion. That was in 1961. 'We haven't got the money,' she said. So I had to help Robert find another publisher. Butterworths took it and are now our main rivals (my own company acquired NAG Press Ltd in 1986) in publishing gemmological books.

Was that when the Thomson Organization took you over?

Yes. Robert's book was the crunch. We offered ourselves to Thomson in 1961. It's a fascinating story, but out of place here. They gobbled up so many small firms there were more of us directors than there were staff. In less than two years our overheads had been doubled and we were losing money. I was asked what I was going to do about it. The outcome was the fortnightly quality newspaper, *Retail Jeweller,* a concept I'd had for some years without the finance to launch it. Fortunately it was a winner from the start. *The Gemmologist,* which had ceased publication, was incorporated in it, and while I was *RJ* publisher and editor we kept up a good gemmology content with the help of Basil Anderson, Alec Farn, and later Alan Hodgkinson.

One objective was to encourage the jeweller to promote himself more effectively as a specialist, and it struck me one day that the best way would be to take a group of jewellers and gemmologists to visit the Kimberley diamond mines for first-hand experience. No party had done it before. I rang Lionel Burke of De Beers, who enthusiastically promised plenty of help. 'How many?' Ten, I thought.

A page one paragraph in RJ brought 96 enquiries, but we had to limit numbers to 45. In SA it was red carpet treatment all the way with access to everything. Many of the group gave series of slide or cine lectures afterwards which helped their images and businesses. The study tours soon became established yearly, and I have taken groups to mines and trading centres in Australia, Brazil, Colombia, Ceylon, Hong Kong, India, Israel, Namibia, Pakistan, South Africa, Thailand and elsewhere, several times to some countries. But they were not for a month each time like the first one!

Weren't you in the trade at one time?

Yes. One day Northampton jeweller, Michael Jones, declared, 'Eric, in *RJ* you're always advising us, but seriously, what do you know about retailing? Have you ever sold a ring over the counter or locked up the safe for the night?' He was right. I went home and asked Anne, 'What do you think about starting a jewellers' shop?'

To her credit, she didn't even blink. So we did, with Diamond Boutique in Maidenhead in 1967, selling only gold and natural gemstones. That worked too, thanks largely to Anne's drive. Soon she was elected to the council of the National Association of Goldsmiths. I sold the business, regretfully, about eighteen months after she died aged 46 in 1976. Starting such a business from scratch is like walking along the parapet of the Empire State Building in a high wind!

A lot of things were happening about this time. Norman Harper had started a diamond grading course in Birmingham, and I kept nagging him to get one started in London, as I wanted to learn. Eventually he told me he'd say something at the next GA meeting. He gave me one of the worst frights ever by announcing that *I* was to run it. It was useless trying to protest. The next day Fate took a hand, when a stranger arrived in the office. He was D.C.B. Jones, who graded diamonds for Monnickendam and wanted to help. Edward Gübelin was exceptionally supportive with encouragement and arranging for me to be an observer at a Frankfurt course in which he was the key figure.

Someone said Sir John Cass College might have space for us, so I went to see the head, Mr Greenman, who liked the idea. Asked if he had a safe for our valuable diamonds, he took me to see a large Victorian contraption in which he kept bottles of sherry safe for governors' meetings. When he tried to open it, the handle came off in his hand! This also resulted in the silversmithing and other jewellery departments going to Cass when squeezed out of the Central School, followed later by gemmology when Chelsea wanted them out.

The first grading courses in 1967 attracted a lot of the 'top brass' from gemmology and the diamond trade, and we never failed to have a waiting list from retailers thereafter for many years. One day Professor Font-Altaba and Dr Bosch-Figueroa from Barcelona University suggested we set up a course there, so Andy Taylor (who graded for Tanzania and succeeded David Jones) and I prepared for a week of instruction to a class of top jewellers as well as the Spanish teachers-to-be.

We could only manage tiny stones for grading, and when one day we asked the students to bring some of their own stones, the open parcels presented a staggering sight. One paper alone held over a million pounds' worth of three and four carat stones. Almost every cut and colour was there. Perhaps the jewellers felt safe because the students were on strike and the campus was full of riot police.

Professor S. Tolansky, whom I got to know through editing his book, *Microstructures of Diamond*

Surfaces, agreed to becoming our first examiner. There was no suitable course book, one covering the whole field of diamonds, so I was forced to write one. De Beers were immensely generous, giving me flights and access to mines in various parts of Africa as well as introductions to key people and I went to mines in other countries under my own steam. Having a background in mechanical engineering was a great help. Fate again got the timing right because the book *Diamonds* (somewhat shorter than its original 130000 words in manuscript) still sells well all over the world.

That's about it, except that a powerful team of specialists, of which I'm fortunate to be chairman, is in the later stages of preparing the first GA home study course in gem diamonds, including grading, that we confidently expect to broaden membership into the diamond trade.

You haven't mentioned how you started writing.

It's something I've done as long as I can remember, articles then books, fact and fiction. May I add an odd footnote? De Beers gave me a very friendly send-off party when I retired recently from being publisher of *RJ*, and *Diamond Trading Company* director, Michael Grantham, presented me with a silver half-octahedron surmounted by an octahedral diamond crystal, designed by Gerald Benney. Sometimes an unguarded comment slips out before I can stop it. 'Some of the trigons are wrongly orientated!' To my relief, it caused a laugh. Later I was looking up something in Tolansky's book and to my horror I spotted an incorrect drawing which was obviously the reference source. I'd been the culprit in the first place!

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The emeralds of the Belmont Mine, Minas Gerais, Brazil

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1. Introduction

Although Brazil was for many years renowned for its agate, tourmaline and aquamarine, emerald can be considered today to be its most important gemstone.

The search for the 'Serra das Esmeraldas', a mythical country in the north-east of present-day Minas Gerais, significantly helped the development of the interior of the country by the Bandeirantes in the sixteenth and seventeenth centuries. The first large discoveries of emerald, however, were not made until 1963, in Bahia. The discovery of further occurrences in the states of Bahia, Goiás and Minas Gerais, has resulted in Brazil becoming one of the leading producers of emerald.

At the present time, emerald mines in production are Carnaíba and Socotó (both in Bahia state), Santa Terezhina (Goiás) and Itabira (Minas Gerais). In addition, there are a number of other occurrences whose yields were never, or only temporarily, of economic significance (Figure 1).

The Belmont mine lies near Oliveira Castro (Itabira district, MG), about 13km south-east of the town of Itabira and 120km north-east of Belo Horizonte, the state capital of Minas Gerais.

The first emeralds were discovered in 1978 at Itabira, near the railway line joining Belo Horizonte with Vitoria. Using primitive tools, garimpeiros set about exploiting an area of about 60 by 120 metres to a depth of 6 metres. From this initial stage of mining, about 40 kg of emeralds were extracted from about 20 000 cubic metres of rock, and marketed.

Since 1981, the workings have been extended using modern machinery. A few hundred metres from the workings is the plant, and within this a water cannon is used to wash away the finer components. Coarser pebbles of waste material are then removed before the remaining material is transported to a large hall by conveyor belt. In this hall the emerald is removed and sorted manually.

The average emerald-content of the biotite schist is 165 s/ton. The Belmont mine is probably the richest emerald occurrence in Brazil so far as emerald-content of the parent rock in relation to the average quality of the emeralds is concerned.

2. Geology

The following remarks concerning the regional and local geology are based on the works of Schorscher (1973), Schorscher and Guimarães (1976) and Schorscher *et al.* (1982) – see Figure 2.

2.1. Regional Geology

The stratigraphy of the Itabira region is characterized by two rock series of Precambrian age: the crystalline basement (after Pfulg, 1968: 'Série pré-Minas'), underlying meta-sediments ('Supergrupo Minas').

The (crystalline) basement is mainly composed of paragneiss and poly-metamorphic migmatites. The rocks, which show a mainly granitic character, are subdivided according to their origin into 'primary' and 'secondary' components (Schorscher *et al.*, 1982).

The 'primary' components comprise mainly meta-tectic gneisses and anatectic migmatites. Granitic intrusions are rare. Amphibolites occur within these and, depending on their origin, are designated either 'basic' or 'ultramafic'. The 'ultramafic' amphibolites are made up of over 95% (vol.) of a green clino-amphibole as well as accessory chromite (further minerals: tremolite, talc, clinozoisite, epidote and magnetite). Two samples analysed by Schorscher *et al.* (1982) exhibit a peridotitic composition with high Cr- and Ni-contents (ca. 2000 ppm Cr and 1500 ppm Ni).

The 'secondary' components mainly comprise metasomatic crystalline rocks, low-grade meta-sediments (serpentinites to chloritites and talc schists) and non-metamorphic rocks. Granitic intrusions are common. Pegmatoids, meta-ultramafites as well as meta-basic and basaltic rocks are

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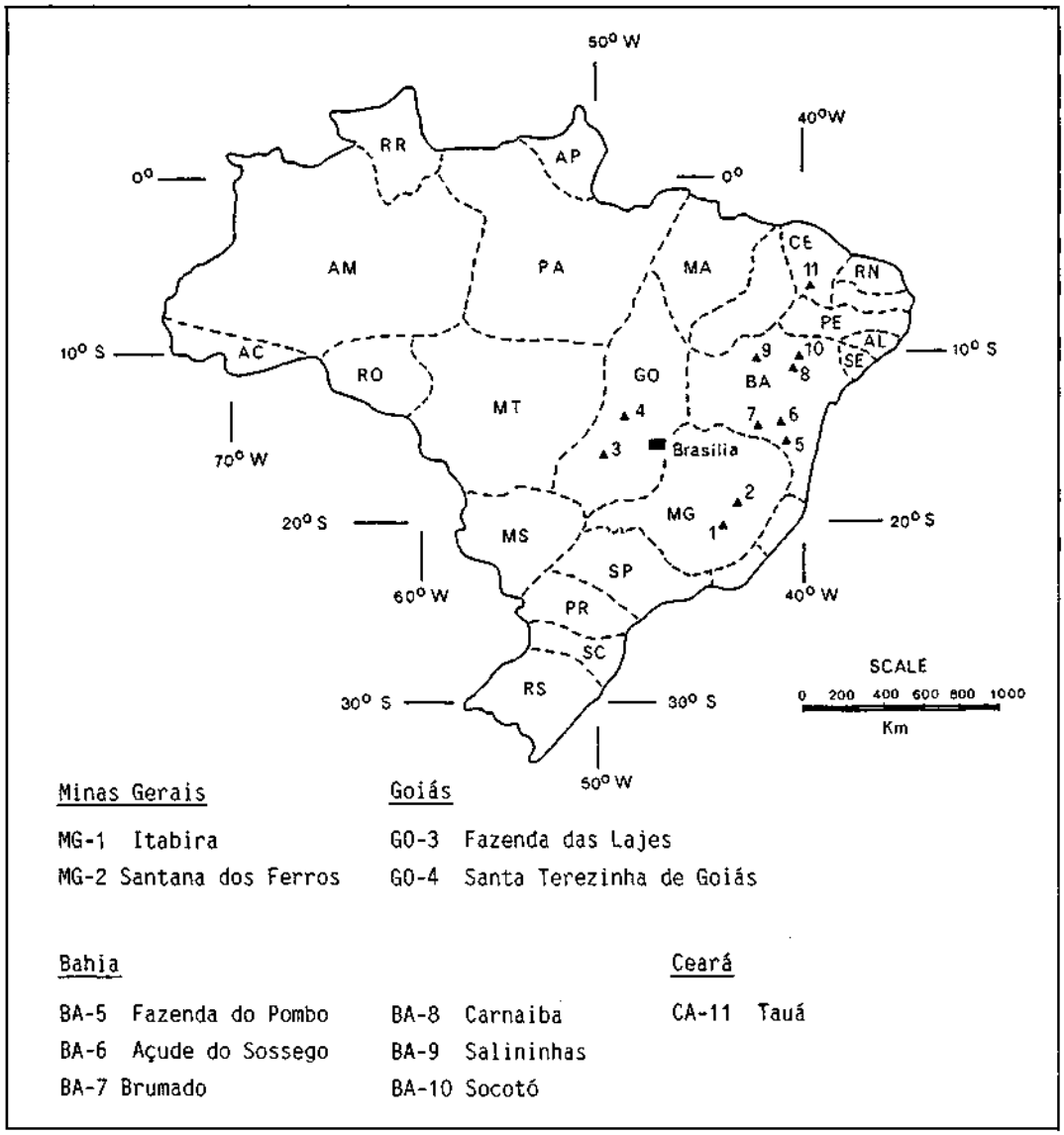

Fig. 1. The emerald occurrences in Brazil.

also present, albeit to a lesser degree.

The meta-ultramafites contain high Cr and Ni values (>1000 ppm) and are younger than the 'primary' rocks.

2.2. Local Geology

In the Itabira region (MG), the 'Supergrupo Minas' is made up of the following sub-groups, from the lowest to the uppermost: paragneisses, greenschists, the Caraca group, the Itabira group and the Piracicaba group. The three last-named groups are separated from the basement ('Série pré-Minas') by a structural and metamorphic discontinuity.

The paragneisses were formed through the metamorphism of greywackes and other sandstones. The Caraca group is composed of micaceous quartzites and, to a lesser extent, phyllites. The Itabira group is economically the most important unit of the Minas Series, due to its itabirite- and hematite-iron ore contents. Quartzites, sericites and phyllites dominate the Piracicaba group.

The 'Supergrupo Minas' sequence is structurally characterized by folds with horizontal or nearly

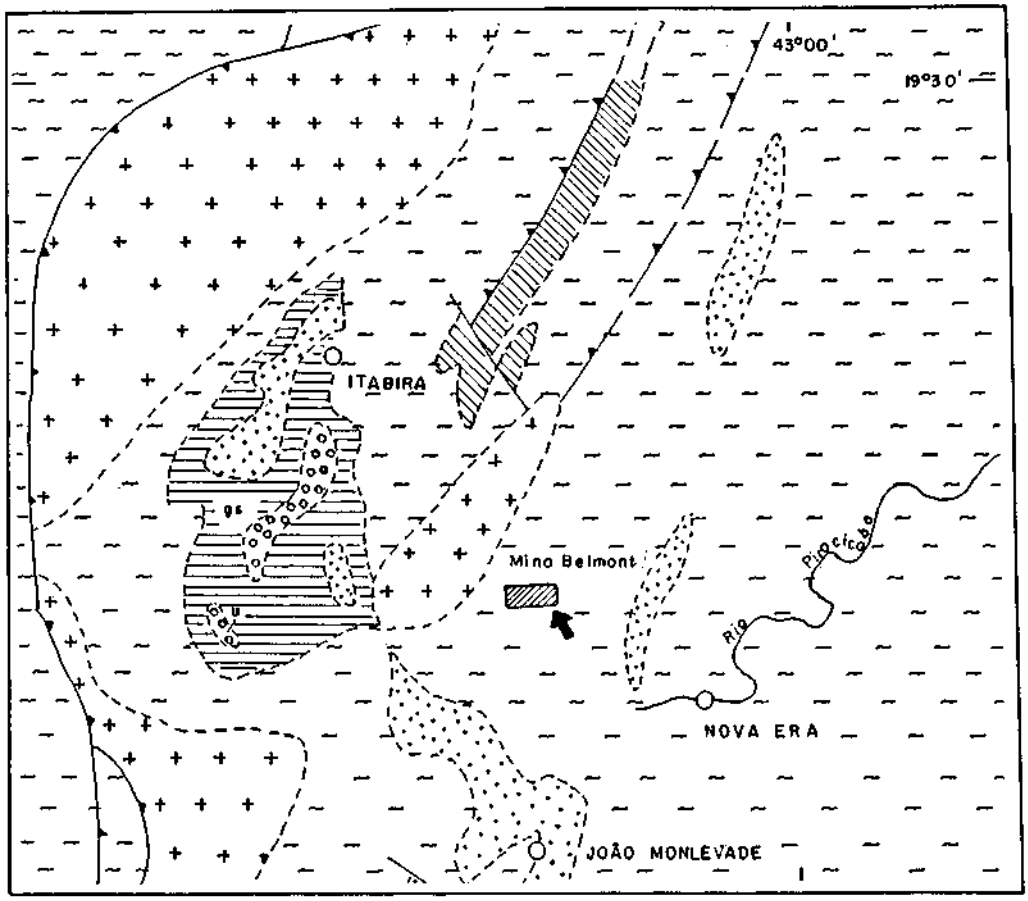

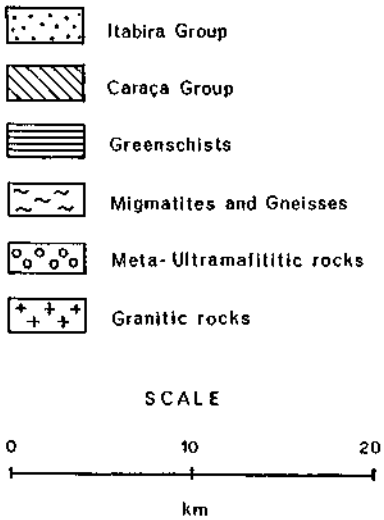

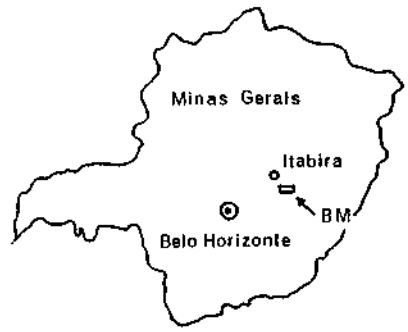

Fig. 2. Regional geology of the emerald occurrences at Belmont Mine, Itabira, Minas Gerais, Brazil.

Fig. 3. The present workings of the Belmont Mine in the emerald occurrence near Itabira.

horizontal axes. The whole sequence was subjected to a regional metamorphism.

In the area of the emerald occurrence, a belt of schists dominates, stretching in a north to north-easterly direction. The width of the belt varies between 750 and 1200 metres. Leucogneisses occur symmetrically on both sides of this belt. The schist belt, together with the mafic rocks, is stongly folded, with axes generally trending north to north-east.

The gneisses and the schists are riddled with small pegmatite bodies in the form of pockets of quartz and kaolin. These are concentrated between the gneisses and the schist belt. The largest pegmatite body is a vein (ca 10 metres wide) which cross-cuts the gneiss and schist structures at right-angles.

No emeralds are found in the gneisses, although these occasionally contain pegmatites with beryl and/or aquamarine.

Emeralds mined from the present workings (Figure 3) occur in black biotite/phlogopite schists, in green chlorite schists or in kaolin masses (altered pegmatite). They are occasionally accompanied by chrysoberyl or alexandrite. Crystals of lower quality are also found in quartz masses.

3. Optical and chemical properties of Itabira emerald

Optical data of Itabira emerald determined by different authors are presented in Table 1. The measured density values range between 2.72 and 2.74 g/cm^3.

Table 1. Refractive indices and birefringences of Itabira emeralds.

n_e	n_o	Δ_n	References
1.580	1.589	−0.009	Muller-Bastos (1981)
1.580±0.01	1.589±0.01	−0.009	Sauer (1982)
1.574−1.578	1.580−1.583	−0.004−0.006	Schwarz (1986)a
1.581−1.582	1.589−1.590	−0.007−0.008	Schwarz (1986)b

Table 2. Microprobe analyses of Itabira emeralds. Total iron as FeO. CaO-content <0.01 Wt%.

Sample number:	1	2	3	4	5	6	7	8	9
SiO_2	64.00	67.58	65.46	66.00	65.59	66.99	66.48	66.35	68.05
Al_2O_3	15.83	17.79	18.25	18.25	18.42	16.66	16.21	16.09	18.92
Cr_2O_3	0.39	0.20	0.00	0.05	0.18	0.91	0.07	0.08	0.06
V_2O_3	0.00	0.11	0.00	0.02	0.00	0.07	0.02	0.00	0.00
FeO	0.98	0.33	0.40	0.32	0.19	0.76	0.64	0.62	0.43
MnO	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.07	0.08
MgO	1.86	0.56	0.66	0.62	0.52	1.69	1.84	1.79	0.97
Na_2O	1.29	0.29	0.40	0.34	0.26	0.99	1.18	1.18	0.37
Total	84.35	86.86	85.17	85.60	85.16	88.07	86.47	86.18	88.88
Chemical formula (normalized: Si = 6)									
Si	6.000	6.000	6.000	6.000	6.000	6.000	6.000	6.000	6.000
Al	1.749	1.862	1.972	1.956	1.986	1.759	1.724	1.715	1.966
Cr	0.029	0.014	0.000	0.004	0.013	0.064	0.005	0.006	0.004
V+	0.000	0.008	0.000	0.001	0.000	0.005	0.001	0.000	0.000
Fe++	0.077	0.024	0.031	0.024	0.015	0.057	0.048	0.047	0.032
Mn	0.000	0.000	0.000	0.000	0.000	0.000	0.002	0.005	0.006
Mg	0.260	0.074	0.090	0.084	0.071	0.226	0.248	0.241	0.127
Na	0.234	0.050	0.071	0.060	0.046	0.172	0.206	0.207	0.063
Total	8.349	8.032	8.164	8.129	8.124	8.283	8.234	8.221	8.198

The microprobe analyses (Table 2) were carried out using an ARL-SEMQ instrument, with wavelength dispersive (WD) spectrometers and an energy dispersive system (EDS, TN 2000) (Schwander and Gloor, 1980). Beam diameter was 2 microns, accelerating voltage 15 kV and specimen current 30 mA. Standards used for the analyses comprised synthetic oxides and some simple silicate minerals.

Franz *et al.* (1986), in their work on beryl in regionally metamorphosed rocks, discussed in detail the problems which may arise during the calculation of the beryl formula. For this reason, the emerald analyses given in Table 2 were normalized both cationically (Si = 6) and anionically (O = 15); as the lighter elements such as Be or Li cannot be analysed with the microprobe, 3BeO was not taken into consideration during the anionical normalization.

Both methods of normalization resulted in virtually identical chemical formulae.

Structural and chemical considerations indicate that the following substitutions in the Itabira emeralds could be applicable:

(a) Al^{3+} (octahedral) = $(Mg,Fe)^{2+}$ + Na^{+} (channel site).

(b) Al^{3+} (octahedral) = $(Cr,Fe,V)^{3+}$.

The mineral formulae calculations (Table 2) indicate substitution type (a) is mainly present. Through this substitution, channel positions are also occupied and the difference in charge between Mg^{2+} and Fe^{2+} versus Al^{3+} is compensated for by Na^{+}.

Figure 4, showing a gradient of less than 1, demonstrates a slight excess of (Mg+Fe) over Na. This can be explained by a small amount of Fe^{3+}, which is not compensated charge-wise by Na^{+}.

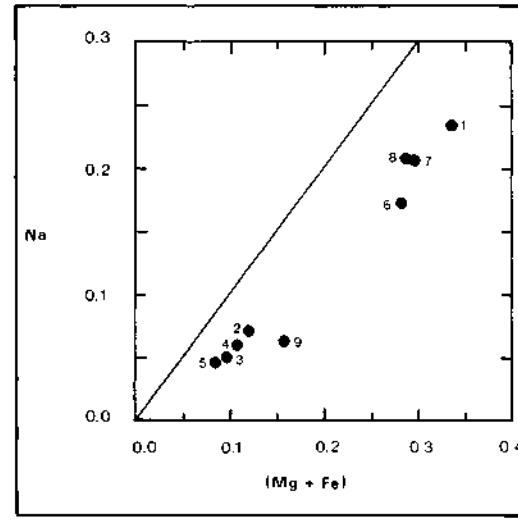

Fig. 4. Plot of (Mg + Fe) v. Na for the Itabira emeralds showing the slight excess of (Mg + Fe) over Na. Numbers refer to analysis numbers in Table 2.

According to (b), Cr^{3+} is accommodated into the lattice at the same time (the analyses show Cr_2O_3-values from 0.00 to 0.91).

The emerald analyses show relatively low values for FeO, MgO and Na_2O when compared with similar material from biotite schists (Hänni 1982, Hänni and Klein, 1982, Hänni and Kerez, 1983).

4. Inclusions

In general, emeralds from the Belmont mine at Itabira, Minas Gerais, can be easily distinguished from those from Santa Terezinha, Goiás, Carnaiba, Bahia, and Socoto, Bahia, on the basis of inclusion studies.

Under the optical microscope Itabira emeralds are found to contain relatively few inclusions. By far the most common inclusions are of mica, which occurs in a diversity of form and colour.

Not only does the colour of the mica inclusions vary from emerald to emerald, but also within the same gemstone itself. The colour is mainly various shades of brown, from a yellowish brown through grey-brown to nearly black. Greenish shades also occur, albeit seldom.

The mica flakes are usually strongly rounded or irregular (Figures 5, 6), although elongated forms or nearly ideal pseudo-hexagonal crystals (Figure 7) can be observed. Two generations can be seen, the first indicating formation before that of the emerald (protogenetic), and the second indicating formation at the same time as that of the host crystal (syngenetic). The protogenetic micas exhibit irregular, or strongly rounded forms, and usually possess a deep brown colour. This colour can be so deep that platelets thick enough may appear opaque. These inclusions are irregularly distributed within the emeralds and show no preferred orientation (Figure 5). The syngenetic micas on the other hand, are thin, transparent flakes which either are elongated or partly exhibit a distorted pseudo-hexagonal shape (Figure 7). These flakes usually show a preferred orientation within the emerald: the elongated crystals lie sub-parallel to the *c*-axis, and the pseudo-hexagonal sections lie parallel to the basal plane.

Microprobe analyses have shown that these micas are members of the biotite-phlogopite series. The fluorine-contents of these micas are about 2–3 wt% (Table 3). This indicates that complex fluorine phases played a role during the formation of the emeralds, especially during the formation of ion complexes capable of migration.

Apart from intergrowth of mica crystals with other mineral inclusions (Figure 8), interesting phenomena can be observed, apparently related to dissolution and re-crystallization processes. Figure 9 shows a mica crystal whose narrower end has been either partly dissolved or altered to another mineral species. At the other end, apart from signs of resolution, the 'birth' of a (new?) mineral can be observed in the form of dendrites.

Table 3. Microprobe analyses of some mineral inclusions in Itabira emeralds.

	Andesine	Biotite/ Phlogopite	Fe-Dolomite
SiO_2	59.95	38.15	0.12
TiO_2	0.00	0.86	0.00
Al_2O_3	25.64	15.01	0.00
Cr_2O_3	0.00	0.35	0.00
FeO	0.06	9.26	6.32
MnO	0.00	0.11	0.69
MgO	0.20	16.65	16.62
CaO	7.99	0.10	33.40
Na_2O	7.35	0.35	0.00
K_2O	0.14	9.15	0.01
F	0.00	3.09	0.00
Total	101.33	93.08	57.16
	An 37.2% Ab 62.0% Or 0.8% Andesine		

As mentioned above, inclusions other than mica in the Itabira emeralds are much less abundant. Apart from an opaque mineral (hematite or molybdenite), the following minerals have been identified using either X-ray diffraction or micro-X-ray spectroscopy techniques: quartz, tremolite, dolomite, andesine and apatite.

Andesine (see chemical analyses in Table 3) occurs as colourless, transparent, tabular crystals (Figure 10). Quartz occurs colourless to brownish, mainly as crystals rounded by corrosion. Similarly corroded forms are also normally exhibited by the beryl and carbonate inclusions (Fe-dolomite: Table 3). The latter occur in groups of colourless crystals. Tremolite generally forms transparent needle-like crystals, and apatite occurs as rounded hexagonal forms. The opaque (?pseudo-) hexagonal crystal inclusions shown in Figure 8 intergrown with a mica flake have not been positively identified. These could be molybdenite or hematite.

The claim of Gübelin and Koivula (1986) that 'biotite, chromite and pyrite preferably determine the inner paragenesis of the emeralds from Itabira' could not be confirmed by our investigations, although we studied about 300 emeralds from this location, also using the gemmological microscope.

The very commonly-occurring growth tubes in the Itabira emeralds are of greater diagnostic value than the mineral inclusions. These tubes are tiny

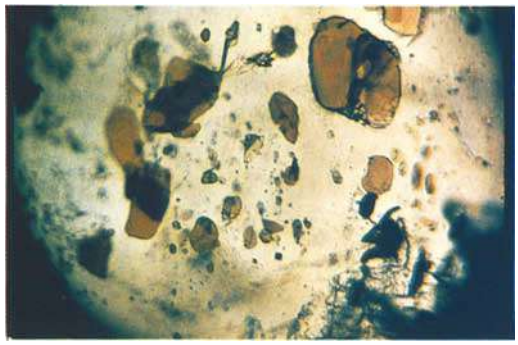

Fig. 5. Protogenetic mica inclusions (biotite/phlogopite) with irregular/rounded outlines. These crystals possess no preferred orientation to the host crystal. 20x. (Note: all photographs were taken using immersion liquids).

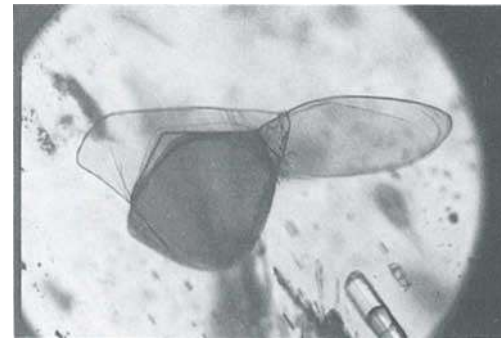

Fig. 6. Biotite/phlogopite inclusions with a protogenetic origin. The crystals exhibit rounded forms and their colour varies from light to dark brown. 100x.

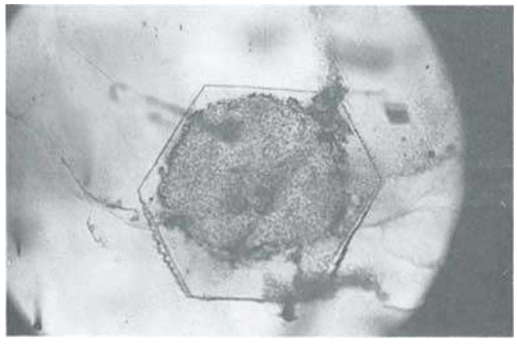

Fig. 7. Mica flakes with a syngenetic origin showing nearly ideally-formed pseudo-hexagonal shapes. Orientation parallel to the basal plane of the emerald host crystal. Partly corroded surface. 100x.

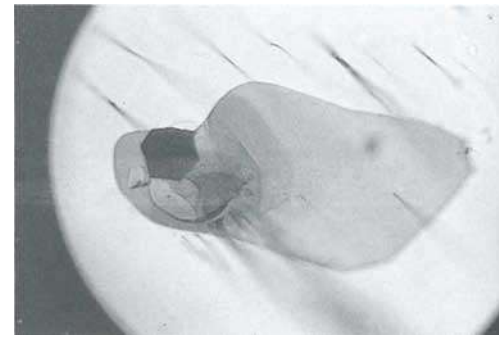

Fig. 8. Intergrowth of a mica crystal with an opaque mineral platelet, which possesses a (pseudo-) hexagonal form (probably hematite or molybdenite). 70x.

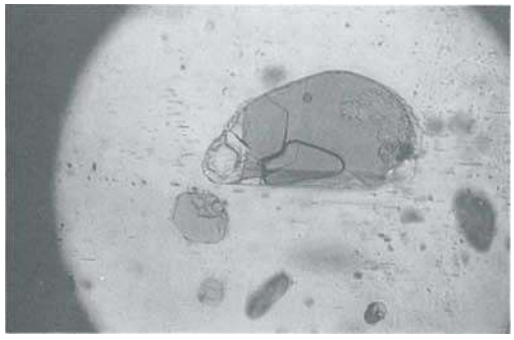

Fig. 9. Mica flake exhibiting solution and recrystallization phenomena. 100x.

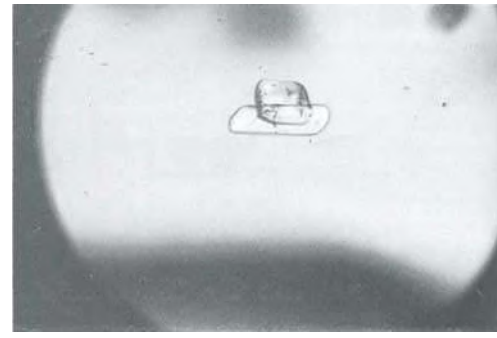

Fig. 10. Colourless, transparent, tabular crystal inclusion (andesine). The other inclusions could not be identified due to their loss during preparation. 70x.

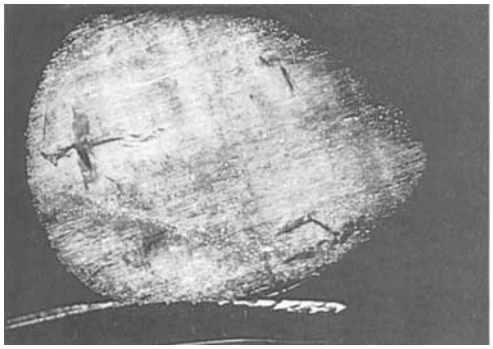

Fig. 11. Itabira emeralds containing numerous fine growth tubes, and exhibiting a slightly turbid, silken appearance. 20x.

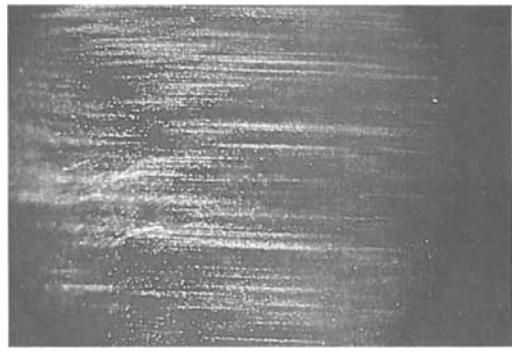

Fig. 12. Growth tubes are often arranged in parallel strings which produces the so-called 'Rain Effect' leading to chatoyancy. 35x.

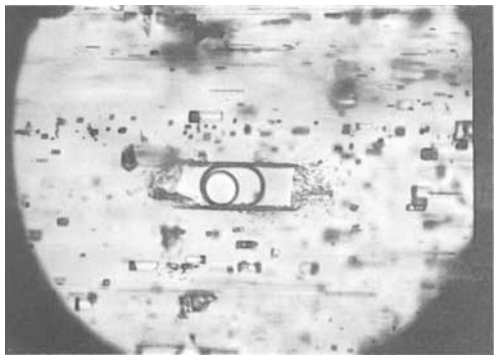

Fig. 13. Rectangular cavity oriented in the direction of the *c*-axis, with a fluid three-phase filling of the type liquid/liquid/gas ('l-l-g'). 70x.

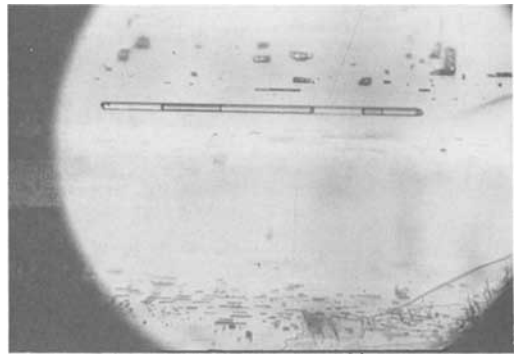

Fig. 15. Elongated cavity oriented parallel to the *c*-axis, with an interesting filling: the phase sequence from left to right is: l_1-g-l_2-l_1-g-l_2. 70x.

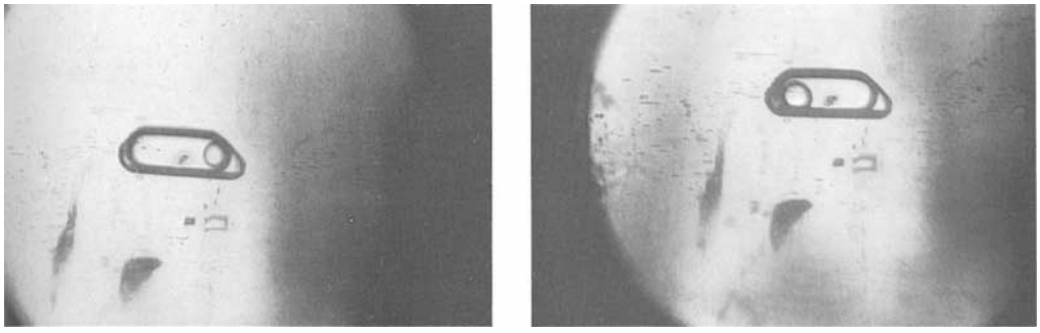

Fig. 14. Negative crystal with an 'l-l-g' three-phase filling. Note the mobile gas bubble seen once on the right-hand side of the cavity. 70x.

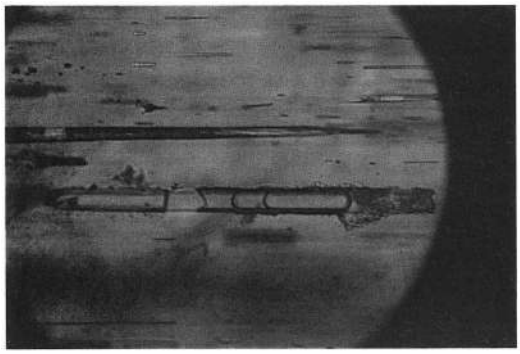

Fig. 16. Elongated multiphase inclusion, oriented parallel to the c-axis of the emerald. 100x.

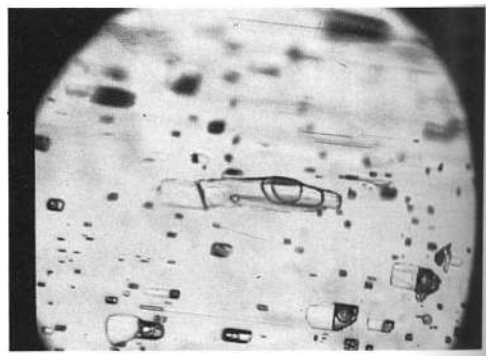

Fig. 17. Common and characteristic inclusion type in the Itabira emerald: birefringent crystals accompanied by cavities containing a variety of fillings (i.e. various fluid inclusions). 100x.

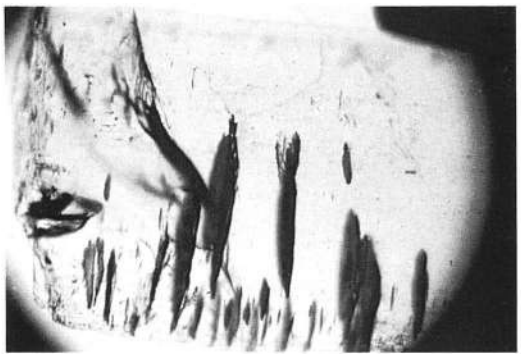

Fig. 18. Cluster of unhealed fissures, parallel to the basal plane. 20x.

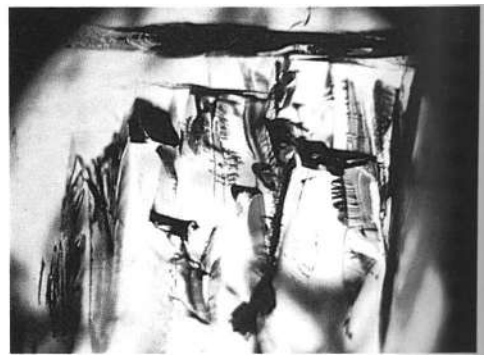

Fig. 19. Unoriented unhealed fissures. 20x.

Fig. 20. Disc-like fissures are characteristic of the Itabira emeralds. Their centres usually possess a cavity containing a variety of fillings (Fig. 19). 70x.

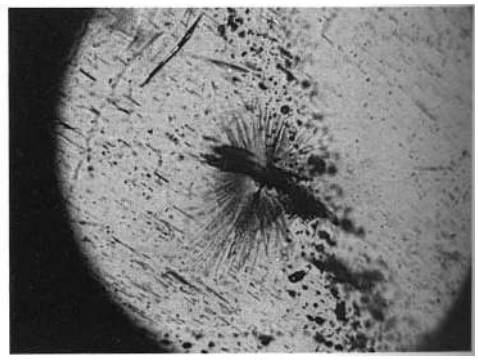

Fig. 21. The fissures shown in Figure 19 often form swarms more or less parallel to the basal plane. 35x.

channels oriented parallel to the *c*-axis of the emerald and are filled with a variety of material. These tiny tubes are sometimes so abundant that they impart a turbid appearance to the emerald or a nearly silken lustre (Figure 10). Their arrangement in parallel strings gives rise to the so-called 'Rain Effect', which has also been observed in many Brazilian aquamarines (Figure 12).

The tiny growth tubes are often concentrated in planes or layers which run parallel to the basal plane of the emerald. These growth tubes could have formed in the crystallization 'shadow' of extremely fine particles of other minerals on the basal plane. These growth tubes are often accompanied by a large number of much larger tubes or channels which can contain various fillings: one or two liquids, possibly combined with a gas bubble and/or a solid phase (see below). When an abundance of fine growth tubes is present, the gemstones, when cut as cabochons, will display the cat's-eye effect termed chatoyancy.

The most abundant group of inclusions in the Itabira emeralds are those with two-, three- and multi-phase inclusions, and these exhibit an extraordinarily large variety of forms (Figures 13–17). This indicates a complex and multiphase formation history of the emeralds. Apart from their occurrence in the various-sized growth tubes, these inclusions can be observed in irregular or regular/rectangular-bordered cavities (Figure 13), as well as in more or less perfectly-formed negative crystals (Figure 14). Analogous to the 'classical' solid/liquid/gas (s-l-g) three-phase inclusions in the Colombian emeralds, they can be sub-divided by virtue of their formation history into primary and secondary inclusions, originations as residues from the mother liquid. The 's-l-g' three-phase inclusions can be observed occasionally, while liquid-gas inclusions (i.e. l-g two-phase inclusions at room temeprature) also occur widely distributed. Other phase combinations, however, are more interesting and of greater diagnostic value.

1. Cavities containing two immiscible liquids (fluid 'l-l two-phase inclusions).
2. Cavities containing two immiscible liquids and a gas bubble (fluid 'l-l-g' three-phase inclusions; Figure 13)
3. Cavities containing two immiscible liquids, a gas bubble and a crystal (fluid 's-l-l-g' four-phase or multi-phase inclusions)

Typical inclusions in the Itabira emeralds are composed of white, birefringent crystals usually associated with a rectangular cavity (Figure 17). The cavity filling can be variable (mainly 'l-g' or 'l-l-g' type). The crystal inclusions could not be positively identified. They normally have short- to long-prismatic forms and seem to show a hexagonal symmetry (apatite?). These inclusions are often abundant, normally oriented parallel to the *c*-axis of the emerald (with primary cavities), but also in healed fractures.

The final types of inclusion to be described from the Itabira emeralds are the various fissure types. Of special note is the relatively large number of unhealed fissure planes (Figures 18, 19). This indicates that these fissures have an epigenetic origin and were only formed after the emerald crystal had finished growing, when it was no longer in contact with any mother liquid. For this reason, the fissures and cracks were often filled with other solutions (mainly water containing Fe or Mn). The relatively fast rate of crystallization resulted in the formation of skeletal or dendritic crystals. In contrast, the 'healing' of a fissure takes place through the crystallization within it of material similar to that of the host crystal. The mother solution generally possesses a complex chemical composition and it contains additional components which are not needed for the formation of further host crystal. These remaining components normally concentrate in small cavities. They seldom form single-phase fluid inclusions, and two-, three- or multi-phase inclusions are more common. The healed fissures so formed have a characteristic appearance and play an important role in the discrimination between natural and synthetic gemstones.

Another type of inclusion, which has not yet been observed in other Brazilian occurrences and which is thus specific to Itabira emeralds, occurs in disc-like stress fissures. Generally, these contain a cavity in the centre with a variable filling (Figures 20, 21). These small fissures mostly occur in swarms, are parallel to each other and also run parallel to the basal cleavage face of the emerald.

5. Formation Conditions

Genetically, the emerald occurrence at Itabira is linked to the association between mafic-ultamafic rocks (or their metamorphic derivatives) and pegmatites. The pegmatites provide the beryllium, and the (ultra-) mafites the Cr and Fe necessary for the green colour of the emerald. Vanadium (stemming from the metasediments) could also contribute to this colour. On the basis of the inclusion-type specific to the Itabira emeralds, this deposit may be regarded as a specific sub-type when considering the occurrence of emerald systematically (Schwarz, 1986).

On the basis of microthermometric determinations on a chosen sample containing 25 four-phase inclusions, a minimum formation temperature of 380°C and a minimum formation pressure of 1400 bars has been calculated (Mullis, 1979). The

pressure was calculated on the basis of the temperature of homogenization, with the aid of the PVT data relating to the system H_2O-CO_2-NaCl, after Bowers and Helgeson (1983).

The Itabira deposit is unique in the apparently low conditions of formation (P,T) when compared with other emerald occurrences associated with metamorphic schists. These low conditions are probably responsible for the inclusion and chemical characteristics of the emeralds.

The formation of the Itabira emeralds cannot be directly connected to the intrusion of the pergmatite masses. The emeralds are more likely to have been formed as a result of a later metamorphic or retrograde episode.

The occurrence of various types of gas-liquid inclusion within the same crystal indicates a complex formation history involving more than one event.

Acknowledgement

We wish to thank Ronaldo Fonseca Ribeiro of the Belmont Gemas Ltda for his kind cooperation during our visit to the mine, as well as for the provision of sample material and a number of unpublished reports.

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We would like to thank Professor H. Schwander, Basel, for his support during the microprobe investigations, and Dr J. Mullis, Basel, for his gas-liquid inclusion studies.

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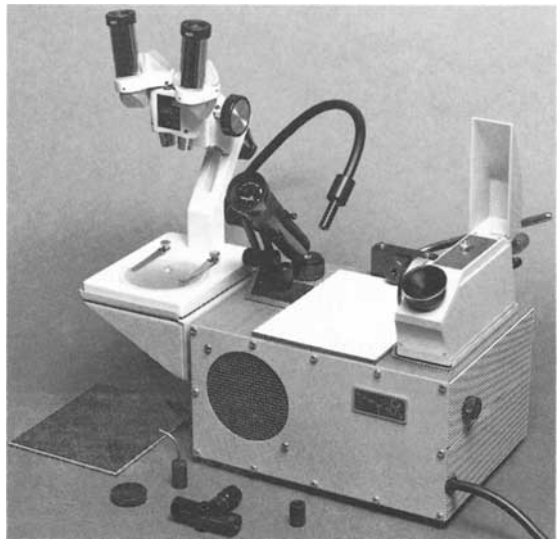

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The separation of natural from synthetic diamonds using the Barkhausen effect

David Minster, FGA, DgemG

Pretoria 0002, South Africa

According to various sources in current gemmological literature (Koivula and Fryer, 1984; Rossman and Kirschvink 1984; Shigley *et al.*, 1986), synthetic diamonds currently produced by both the General Electric and Sumitomo processes are affected by externally induced magnetic fields. This is due mainly to the presence of ferromagnetic particles or inclusions in the stones which are artefacts of the current synthesis methods.

In order to understand the effect produced when a ferromagnetic material is subjected to an external magnetic field, the theory of magnetic domains has been postulated (Graf, 1978). Figure 1 illustrates the separate magnetic domains in an unmagnetized polycrystalline ferromagnetic sample. The domains are orientated at random, so no external magnetic field is observed, but within each domain there exist completely aligned atomic or molecular dipoles (magnets). The arrows in the diagram indicate the random orientation of these dipoles in the crystals that make up the solid. (There are methods of observing these domains directly but they fall outside the scope of this article.) When a non-magnetized ferromagnetic sample is moved through a strong magnetic field, the non-aligned dipoles try to align themselves with the field. This alignment occurs as a series of small abrupt steps (known as Barkhausen jumps). They are caused by the discontinuous movements of mobile magnetic boundaries between magnetic domains. When this happens we can detect the electrical 'noise' produced by the sudden irregular motion of the domain boundaries as the favoured domains grow at the expense of their neighbours. This noise is known as Barkhausen noise after the person who first observed the phenomenon.

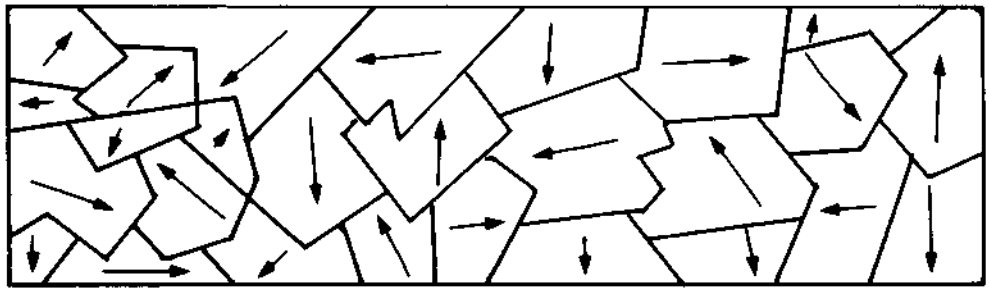

Fig. 1. Diagrammatic representations of magnetic domains in an unmagnetized polycrystalline ferromagnetic sample.

Practical application

A very strong, small magnet is placed opposite a sensitive pick-up coil (Figure 2). The coil in turn is connected to a very high-gain low-noise amplifier, the output of which is connected to a pair of headphones. The gap between the coil and magnet should be 1 cm. If a diamond containing ferromagnetic particles is swung to and fro between the magnet and coil a 'swishing' sound will be heard in the headphones, which is due to the changing of the magnetic domains in the ferromagnetic inclusions in the diamond. Until now synthetic diamonds have shown much higher levels of magnetism (due to ferromagnetic particles) but near-colourless, inclusion-free synthetics do occasionally display less magnetism than some natural stones (Rossman and Kirschvink, 1984).

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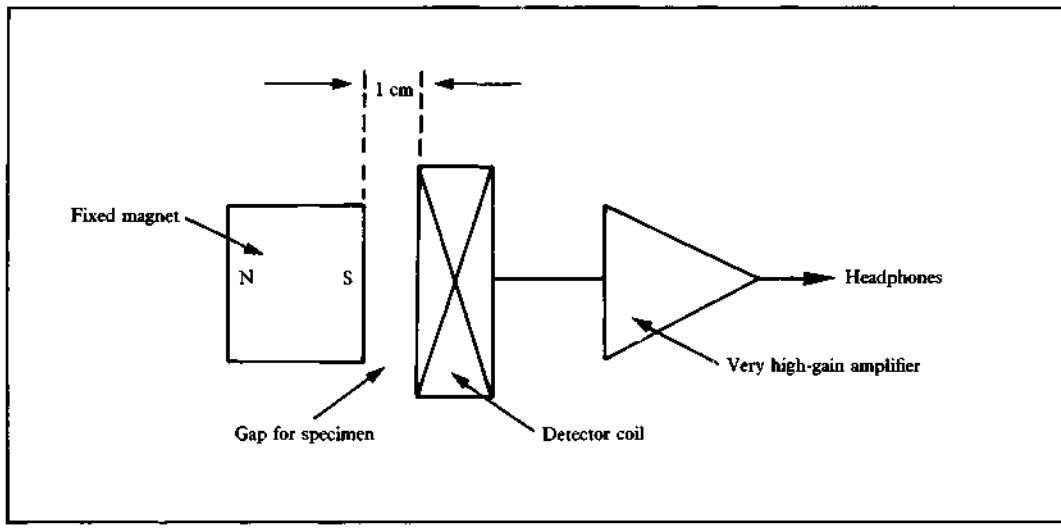

Fig. 2. Diagram illustrating a possible circuit for detecting the Barkhausen effect when synthetic diamonds are placed in a magnetic field.

NB. The stone *must* be in motion for the effect to be observed. The longer the arc of the swing, the more pronounced the effect is.

Precautions

Obviously the effect is less pronounced in stones that contain fewer ferromagnetic particles. Also, for more accurate results, the stones should be boiled in acid beforehand to clean off any external ferromagnetic particles. The stones to be tested can be enclosed in a clean stone-paper and this can be held in the hand and waved through the detector taking care not to touch either the magnet or the coil in the process, otherwise false results can be produced due to the noise caused by the paper striking the detector apparatus. Do not use metal tweezers to hold the stone!

In keeping with standard gemmological practices, other tests should be conducted, i.e. microscope examination of inclusions, etc. before a final conclusion is reached.

Note: Excellent results have been achieved with the tests that I have conducted. These have, however, only been carried out on synthetic industrial diamonds, since gem quality synthetics are unavailable to me in this remote locale, but I see no reason why this method of testing should not work on the latter, provided they contain ferromagnetic particles.

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The body colour of gemstones

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Abstract

This article is a response to a previous article by Dr K. Nassau who discussed the relation of gemstone 'body colour' to gemstone colour appearance.

It affirms that the author (J.B.N.) has made no claim to link 'FMIR body colour' with Nassau's 'overall colour impression produced by the gemstone under ordinary viewing conditions'.

Reasons are given why it is both practically and theoretically unlikely that *gemstone colour appearance* will ever be capable of being expressed in numerical terms. On the other hand, *gemstone body colour* can be so expressed and the three numbers measured represent an intrinsic property of a particular polished gemstone.

Discussion

In the last issue of the *Journal*,[1] Dr Kurt Nassau raised doubts about one specific aspect of my article 'The colour bar in the gemstone industry'.[2] He stated that . . . 'this aspect comprises at least three separate problems, any one of which is fatal to the validity of this model'. He concludes by advising me . . . 'not to permit myself to be taken in by the deceptively simple gemstone which poses problems far more complex than do any of these other systems' (non-gem applications which the author touched upon).

I dearly wish that Nassau could speak with many of these other colour scientists who think that their own successful industrial application of colour measurement, process control and their customers' colour perception of their product was initially anything other than an ulcer-producing activity.

His doubts hinge upon the term 'gemstone body colour' and its connection with the visual colour appearance of a gemstone. He expresses fears about the possible survival of my 'idealized model'. In these notes I hope to persuade him that his fears may not be so firmly based as he first imagined. In any event I am most grateful to him for giving me the opportunity of a further discussion of this most fascinating subject.

Firstly, it seems to me that he does little service to the scientific approach to gemmological problems by suggesting that 'we scientists unfortunately are rather prone to build a 'model' which is usually an interpretation of what one feels are the most important aspects of the problem without demonstrating that the model does indeed correspond to the reality it was intended to represent'.

This kind of utterance will bring much comfort to those gemmologists who already believe that physicists are very odd people indeed and certainly these modern bogeymen should not be allowed to frighten gemstone traders. Compared with other professionals, I have found scientists to be so much concerned with their need to unite theory with experiment that they often shrink from advancing quite sensible explanatory models. The reason for their timidity lies in the fact that most scientists are harsh and unforgiving judges of their own and their colleagues' work if they feel that proposed models do not exactly fit the observed facts. It is this simple process which keeps science cleansed of much theoretical litter.

Dr Nassau claims that I have fallen into his own imaginative invention, the *'irrelevant model trap'*. I feel that I am a little too sure-footed to have stumbled blindly into such a hole. Indeed, I fear that it is he who has slipped into another kind of trap and this of his own making.

If he will re-read the relevant parts of my article, together with an earlier one,[3] he might be surprised to discover that in neither article have I claimed that the methods and measurements which I describe provide the observer with a description of the *colour appearance* of a gemstone. The claims made relate only to establishing that my visual tristimulus colorimeter yields CIE co-ordinate measurements of a particular kind of volume body-colour, a kind automatically defined by the description of the FMIR technique. The reason for attempting to measure body colour of this kind is that it serves to characterize the colouring properties

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of any faceted† stone. Up to the present time such measurements do not and cannot convey the *colour appearance* of a stone, either in isolation, or in the company of neighbouring stones or metal mountings. Therefore I have no need of any kind of 'model'.

Unlike Dr Nassau, a diamond merchant does not confuse 'body colour' with 'total colour appearance.' Nassau describes the latter as 'the overall colour impression produced by the gemstone under ordinary viewing conditions'. When a merchant is assessing the 'show of colour' of a faceted stone, he takes steps to avoid those colour disturbances arising from differences in 'fire', lustre-orientation, size, shape and imperfections.

When very small body-colour differences between stones first became recognized as an important value factor* in trading, it soon became a common practice among merchants to produce a fine condensed mist over their standards and test stones by breathing upon them.[6] This matt water-droplet coating 'quenched the fire' by frustrating the multiple total internal reflections and allowed the body colours alone to be isolated and compared. The other components contributing to the total colour appearance could then be separately assessed. These are the size, perfection of cut, shape (defining brilliance and dispersion) and external and internal scattering discontinuities. So far as is known, traders have not yet attempted to describe the 'total colour appearance' of a diamond or give it a number or 'figure-of-merit'. This may be because the only way open to them to assess the body colour is by viewing the stone across the girdle (or effectively, the light path illustrated in Figure 15 of Reference 2). The most desirable viewing aspect would be approximately normal to the table, but the disturbing spectral fire precludes this choice.

It might be mentioned here that the writer has already measured the FMIR-type body colour on a number of Cape Yellow Series diamonds. The stones were the seven colour master stones of the Diamond Trading (Propriety) Ltd, and were measured using the Nelson-Lovibond Gemstone Colorimeter at the London Laboratory of the De Beers Central Selling Organisation, with the kind cooperation of the Head of the Laboratory, Dr G.S. Woods. The CIE Illuminant used was the 'A' Source and the measurements placed the stones in the correct order of yellow-saturation (all with λ_d = 587nm ± 1). However, as the master set of stones was calibrated against CIE Illuminant 'C' no direct comparison with the colorimeter's performance could be made.

Nassau has curiously and wrongly assumed that I am attempting to link body colour with total colour appearance. I have never dreamed of entering that awesome minefield. The aims are much more modest. It might be helpful here to describe the bones of the method again and its sole purpose.

By means of a microscope, a narrow, well-defined beam of incandescent white light, mains-stabilized and calibrated to attain the colour temperature of a CIE 'A' Source, is directed through the table to a spot near the culet of the specially-mounted test stone. The focused spot of now semi-coloured light is diffused by a pure white elastomer adhering optically to the stone's pavilion. The diffuse patch of light then retraces the same optical pathway as it entered. On leaving the stone, this trans-reflected (remitted) light is collected by the microscope's objective lens and delivered to the colour sensor. The sensor may be an eye or a suitable electronic photosensor, preferably the latter. For the purpose of comparison, visual colour matching or electronic colour measuring, an identical parallel system of optics is employed, using a colourless faceted stone as the primary calibrant. With the help of a calculator or a microcomputer, the measured light intensities are converted into CIE colour co-ordinates for the CIE Illuminant used.

These three co-ordinates represent the body colour of the test stone only, *and nothing more*. To quote from my article[2] (page 231) 'The stones are also shown in Figure 12, positioned within this colour space and occupying the point positions representing their body colours.'

Like the diamond merchant's body-colour assessment, colour appearance effects such as specular reflection, spectral dispersion and multiple internal reflections are eliminated. In the case of birefringent stones exhibiting pleochroism, an effective mixing of the two polarized coloured beams is accomplished without effort by the sensor, whether it be eye or photodetector. Even the curious dichroic phenomenon seen in certain tourmalines, which the author would like to propose to be known as the 'Mitchell effect', after its discoverer,[6] would yield the correct perceived body colour.

†Nassau refers to the measurement of FMIR-mounted windowed rough as being 'not particularly useful'.

The author (J.B.N.) has assumed that the sensible faceter usually chooses his window so that it will yield the best hue and that it will lie parallel to the same plane as the table of his finished stone. The measurement will be useful because it will allow the faceter to measure the metric luminance (L*) of the darker kinds of valuable rough. This provides him with precise information about the optimum depth to aim at for his finished stone, thus bringing it into a favourable L* range for displaying the maximum liveliness.

*The commercial importance of diamond body colour becomes clear when considering the current wholesale cost of a round, brilliant-cut, one-carat, flawless, well-proportioned stone.

A 'D-colour' stone is valued at $10,000, and an 'E-colour' stone at $5,500.[4] The excitation purity (p_e) of the 'A' stone is 0.35% and that of the 'E' stone is 0.79%.[5] The p_e difference (0.44) at this chromaticity value lies almost at the threshold level of visual colour discrimination!

An important feature of the FMIR mount is that the ray-paths are chosen by microscopical viewing. In this manner, gross light-absorbing or light-scattering centres can be easily avoided by a sliding or rotational movement of the stone on its stage. Small scattering centres and those similar to the colloid-size liquid inclusions present in Kashmir sapphires or in 'sleepy' stones will contribute, as they must, to the final observed body colour coordinates. Again, by successive angular positionings of the stone on its stage between individual measurements, colour discontinuities can be assessed. Such controlled and recorded variations serve as a further useful characterization of a valuable stone's body colour. The variations can be of the diffuse patchiness variety or of the sharp-zoned kind. It will be argued that zoning will distort the instrument's assessment of body colour. It depends entirely on the nature of the colour discontinuity.

The author recalls seeing a huge, stunning, clean, round, brilliant-cut blue sapphire on a Sri Lankan dealer's finger ring. The dealer was most reluctant to allow a closer inspection, but finally consented. It turned out that all of the crown and most of the pavilion were quite colourless. A thin, flat, 'sandwich-filling' of deep blue colour lay just below the girdle and was parallel to it. The measured body colour of such a stone would not conflict with its perceived body colour if measured by the FMIR method.

A word of explanation is necessary here with respect to Nassau's puzzlement about the use of the word 'multiple' in the FMIR acronym.

The optical coupling of the stone with the white elastomer frustrates any further possible occurrence of *multiple* total internal reflections.

He has also suggested that the white elastomer might act as a classical integrating sphere. Curiously enough, it does not. Some simple tests bore this out. Three round, brilliant-cut, colourless, synthetic spinels were drilled with small holes which entered the culet and were aligned along the axis of symmetry. The holes were about 0.8mm diameter and of a depth of about one-quarter that of the total depth of the stone, similar to that shown in 'Abb. 2' of Figure 1.[7] The holes were filled with epoxy resins dyed strongly in red, green and blue. When the beam was focused near the culet but not touching the dyed epoxy-filled cavities, only the faintest tint of any of the three well-saturated colours could be discerned. When focused directly on the filled cavities, the fully-saturated colours showed up strongly. Figure 1 has been taken from a description of a US patent. Its claim rests on the fact that colourless synthetic stones can be transformed into uniform, strongly-coloured ones simply by providing a saturated dyed or pigmented small plug as a culet insert. This trick works very well because the (unfrustrated) multiple total internal reflections repeatedly interact with the plug. It is in effect a good integrating sphere!

Returning to the method and its purpose, it should be said again that the quantity which is being measured is solely the colouring power of a particular cut and polished stone. It is simply another intrinsic property of a coloured stone that can be measured visually or by an electronic machine. It differs from the measurement of refractive indices or B–G dispersions, or weights, or specific gravities, or scratch hardnesses, only because its quantitative assessment requires a more complex device than a refractometer with its monochromatic light source or sources, or a chemical balance, or a set of hardness testing pencils.

What indeed is the value of such colour measurements to gemmologists? Some of the problems confronting the gemstone industry which it is believed these measurements could help to solve have already been discussed.[3] They should be of value to those engaged in mining and gemstone rough production, in the cutting and marketing of unset stones, in controlling gemstone colour enhancements, in assessing alexandrite-type colour changes and in monitoring colour stability, fading and tenebrescence effects.

The measurements will be of little or no importance to jewellery designers and jewellery house sales-personnel. Their interests are concerned more about total colour appearance and not with body colours. Having said this, they should nevertheless be made aware of some of the colour mixing perils that jewellery design could entail, such as metamerism and simultaneous contrast.

Up to this point, the discussion has focused mainly on body colour, which is purely a matter of *colour grading*.

Turning now to the matter of *colour appearance*, it is important to know if this aspect can be quantitatively assessed in a similar manner. Since numbers are being sought, can the CIE Tristimulus Colour System quantify the colour appearance of an isolated gemstone or an array of set stones?

The core-data of this system is the CIE 1931 Standard Colorimetric Observer. Measured and standardized sixty years ago using trichromatric colorimetry, the system describes proportions of two calibrated colour stimuli which match a third (the test colour). Although examined and re-examined on many occasions since that time, the original core-data have been fully substantiated and have stood the tests of more advanced experimental techniques. It forms the basis of technologies such as colour television, colour photography and a host of industries that produce coloured objects to match

a designer's conception. The system has demonstrated its complete validity for quantifying the colours of the great majority of objects seen under the quite different surroundings occurring in everyday life.

In spite of its unbelievable successes, among its limitations are the facts that it does not predict colour appearance, nor does it predict colour discriminability. There are also two situations where the perceived colour is not reliably quantified by its tristimulus values. The first is known as *simultaneous contrast*, whose effects can only be assessed visually. The second involves a visual phenomenon known as *chromatic adaptation*.

However, recent advances in colour science are providing some remedies for these ailments. It must be noted that the new formulae and indices are no more than approximations to the truth. More significant improvements must be forthcoming before it can be claimed that the colour appearance can be measured realistically.

There are two very recent developments which promise a closer convergence between the CIE system and colour appearance predictions. The first[8] describes a new model of colour vision for predicting colour appearance. A supportive work[9] shows that this physiologically plausible model of colour vision, based on the CIE 1931 Standard Colorimetric Observer, can provide reasonably good predictions of the colour appearance of surface colours seen either in simulated daylight illumination (CIE Illuminant C) or in tungsten light (CIE Illuminant A).

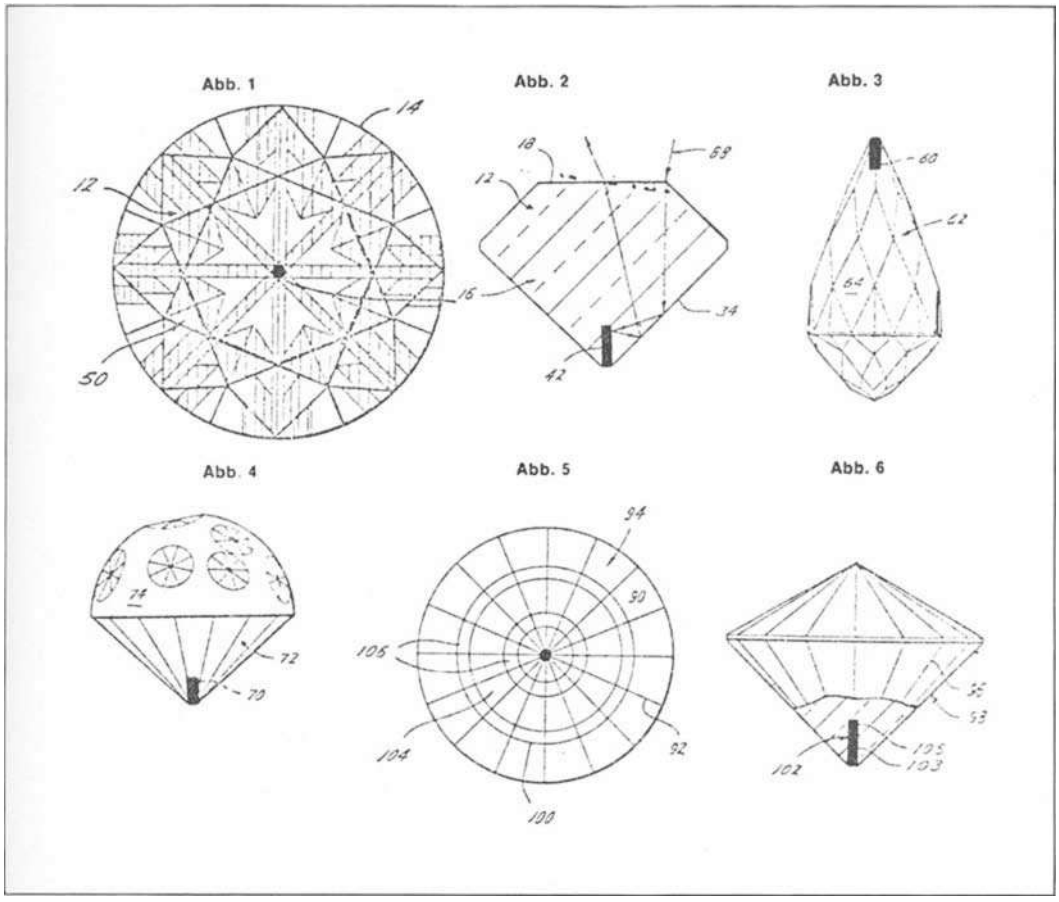

Fig. 1. Illustration showing the method of changing colourless articles into highly coloured ones by internal reflections from coloured inserts. Taken from US Patent Declaration 3 835 665 (13.4.1973).

The second advance concerns a colour order and notation system developed by the Swedish Color Center Foundation. Called the Natural Color System (NCS)[10] it is a psychometric model for colour description. The system has an associated collection of 1412 colour samples, which employs

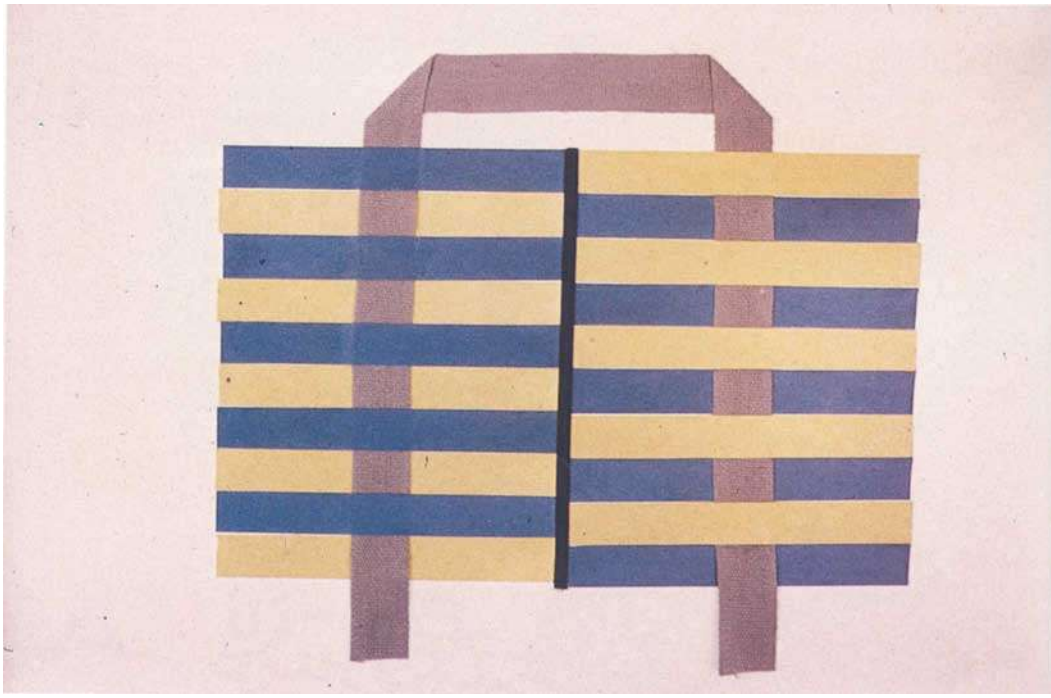

Fig. 2. The brown tape is the same colour throughout, but appears to change colour against the diffetent coloured backgrounds.

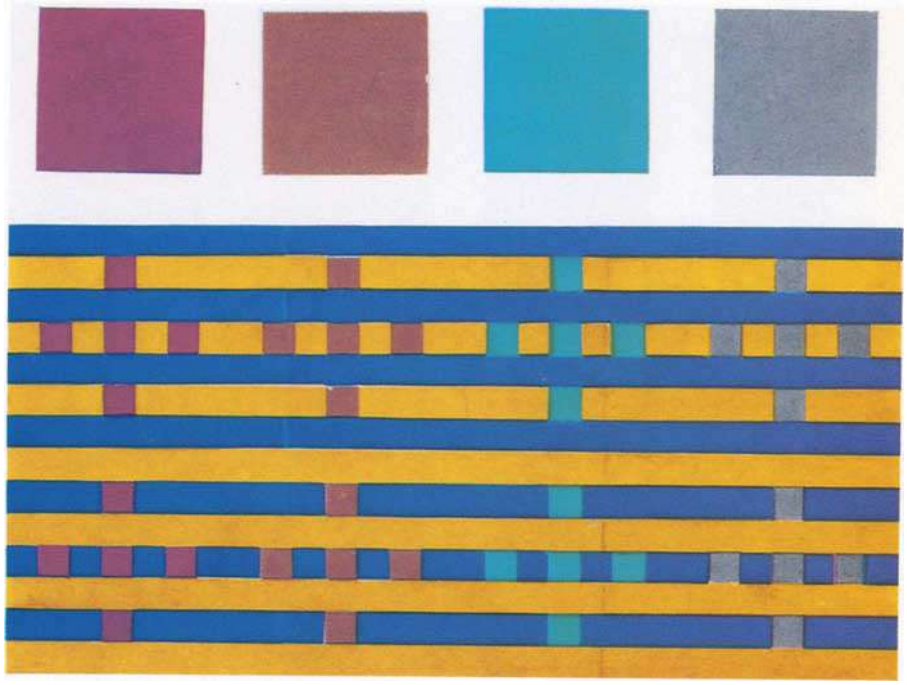

Fig. 3. Changes in colour due to the condition of viewing. Only the four colours shown in the large squares have been used in this photograph. The changes are best seen by tilting the illustration away from the viewer.

the same NCS symbol language; this is particularly easy to comprehend and use. The language is expressed both by graphical illustrations and by letter-digit notation and more importantly can also be expressed in CIE colour co-ordinates. It is therefore a good unifying visual system for describing colours and for approximately quantifying colour appearance, or 'what we actually see'. Indeed, the origin of the system in 1964 sprang from this underlying need of a phenomenological philosophy. One serious shortcoming for gemmologists is the lack of highly saturated samples, although of course, the notation system itself can deal with the most saturated colours. Another is the usual difficulty of visually comparing test stones with painted surfaces. Like is not compared with like, so that there are increased risks that different observers cannot agree about their matches.

The most remarkable fact about human colour vision is not that we fail to agree on colour matches, but that the level of general agreement is so high. There is such a multitude of complex physical and chemical processes and mechanisms constantly at work in the retina and visual cortex that it appears incredible that there can be such universal agreement. The mundane act of seeing with a fleeting glance that a crumpled piece of cloth is uniformly dyed must be immensely complicated. There is clearly more to seeing than just looking.

A good example of the complexities of colour vision with which no colour appearance model can yet cope is that of simultaneous contrast. Figure 2 is a photograph of a 'woven fabric' made by the author to illustrate the effect. It consists of alternating warps of blue and yellow ribbons and a brownish woof which can be seen to be woven into the warps. If this illustration is tilted away from the viewer so to foreshorten the image, it will be seen that the woof colour changes with respect to the warp. Perhaps a more spectacular example is shown in Figure 3. The effect is widely exploited in art in the form of neo-impressionistic paintings, in mosaic tile assemblies and in tapestries. A most effective display of the phenomenon was a carpet in which twelve colours were easily recognized in the geometrical design. As the carpet was a Wilton, which meant that only five yarns were used, the other seven colours resulted from simultaneous contrast.

Examples of jewellery exploiting this effect are not known to the author. However, there is the well-publicized failure of a regalia designer to recognize the phenomenon.[11] It concerned the design of the ceremonial sword presented to the people of Stalingrad in recognition of the heroic stand made by the city in the Second World War. A photograph (not in colour, regrettably) of the

Fig. 4. The Wilkinson Sword of Stalingrad.

Wilkinson sword is shown in Figure 4. The pommel was made from a Scottish quartz crystal. The hilt was bound with silk thread dyed to a brilliant turquoise colour and overlaid by Welsh pure gold wire. The combination had a pink colour reminiscent of inexpensive ashtrays of the time, made of dyed anodised aluminium. This example of a material substance converted into a sensory effect was quite dramatic, but this proved to be an inadequate reason to spare the design. Many fruitless experiments were made in attempts to restore the hue of the gold.

Acknowledgements

Thanks are due to Adam Hilger Ltd, for permission to reproduce Figure 3 from *The measurement of colour* by W.D. Wright, 1969. Also to Mr George Bull-Diamond of Charles Mathews Ltd. for a gift of the photograph of the Stalingrad Sword.

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Further development of a computer program for gem identification

Peter G. Read, C.Eng., MIEE, MIERE, FGA

Seven years ago, I made the following comment in an article[1] in this *Journal* describing my first two computer programs for gem identification:
'From the results of this work I believe that with a larger memory (perhaps of 64K) and with faster data storage loading peripherals, both programs can be expanded to a point where they would make a useful contribution to gem identification.'

Two years later I had achieved this goal by expanding the memory of the computer and by replacing the tape cassette storage with a floppy disk reader. This enabled me to increase the number of gems covered by the programs from 80 to over 200, and to extend the program features and the variety of data displayed.[2]

The added features included an option to allow a gem's specific gravity to be input to the computer in the form of a number code which accommodated approximations made with the aid of heavy liquids (see Figure 7). Another feature was the provision of an input for a gem's optic sign as an extra identification criterion. In addition, when search limit 2 was chosen, the mismatch tolerance for refractive index was automatically widened to ±0.1 for those stones with an RI above the 1.80 limit of a standard refractometer. This allowed for the errors associated with the 'direct' or 'apparent depth' method of determining refractive index using a microscope. A further section, called 'Gem Calculations', was also added and this enabled hydrostatic weighing derived SGs, reflectivity values, critical angles and Brewster angles to be calculated for any gem. Finally, the program data was modified to contain the total possible range of RI and SG values associated with each gem.

Although the ability to input the expanded program from a magnetic disk rather than a tape cassette greatly speeded up the loading of the program, the greater number of gems covered and the increased amount of data to be searched by the program meant that the average identification time was as long as 20 seconds with the 8-bit computer then in use. A finite limit to the maximum memory capacity of the computer (52K) also prevented the program from being expanded any further or for any additional gems to be added. In particular, the test input criteria for gem identification had to be limited to RIs, optic sign, optical character and SG. This restriction sometimes resulted in the program finding and displaying additional identifications in which the colour and transparency were not in agreement with the specimen being tested.

Fig. 1. The author's IBM-compatible Amstrad PC1512DD computer installation used to develop the GEMDATA program.

By 1987, the specifications and costs of personal computers had vastly improved, and taking advantage of these changes I replaced my original equipment with a 16-bit Amstrad PC1512DD (Figure 1) whose larger memory (512K) then allowed me to expand further the gem identification section of the program.

Apart from the benefits of faster operation afforded by the 16-bit central processor unit in the new computer, and the availability of multi-coloured texts (Figure 2), the larger memory has now permitted a gem's colour and transparency to be taken into account as identification criteria (Figures 3–5). With the updated GEMDATA program, it is possible to input a choice of ten colours (plus colourless) and to specify the gem as

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Fig. 2. The GEMDATA 'menu' gives a choice of three program sections.

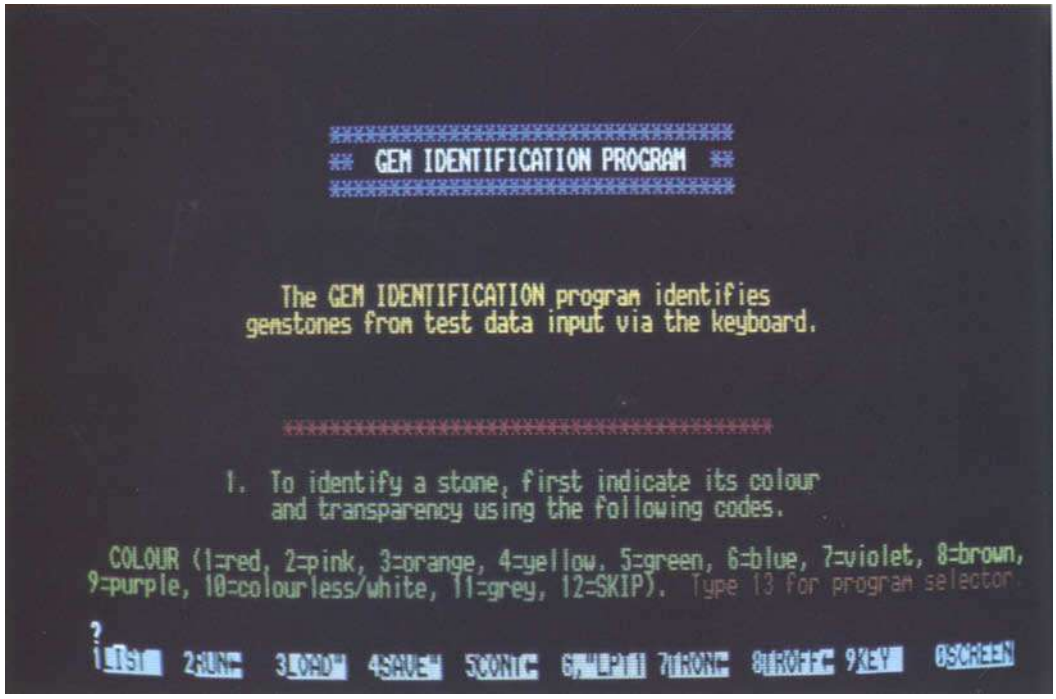

Fig. 3–5. 'Gem Identification' has been selected and the inputs '1' (colour = red), '2' (translucent), '1.6' (a single refractive index as measured on a standard refractometer), '1' (the gem under test shows doubly refracting on a polariscope) and '3.6' for SG have been typed in. The program displays the identification 'Rhodochrosite' (whose upper refractive index of 1.82 was 'off scale' on the refractometer). Identification time was three seconds.

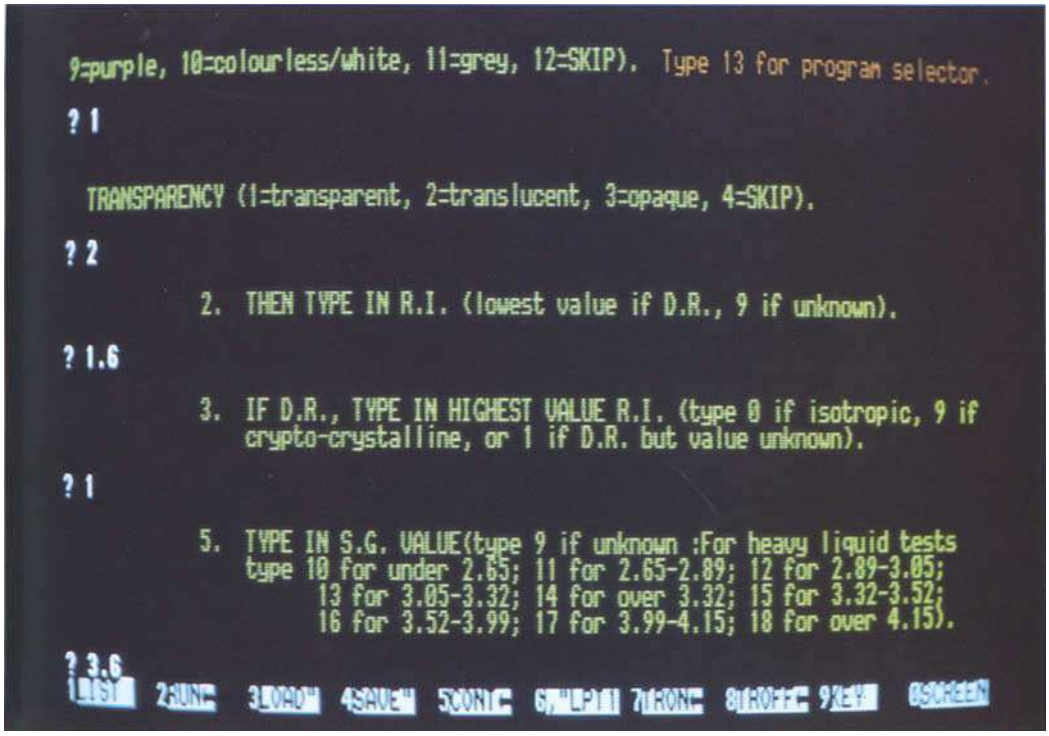
9=purple, 10=colourless/white, 11=grey, 12=SKIP). Type 13 for program selector.
? 1
TRANSPARENCY (1=transparent, 2=translucent, 3=opaque, 4=SKIP).
? 2
2. THEN TYPE IN R.I. (lowest value if D.R., 9 if unknown).
? 1.6
3. IF D.R., TYPE IN HIGHEST VALUE R.I. (type 0 if isotropic, 9 if crypto-crystalline, or 1 if D.R. but value unknown).
? 1
5. TYPE IN S.G. VALUE(type 9 if unknown :For heavy liquid tests type 10 for under 2.65; 11 for 2.65-2.89; 12 for 2.89-3.05; 13 for 3.05-3.32; 14 for over 3.32; 15 for 3.32-3.52; 16 for 3.52-3.99; 17 for 3.99-4.15; 18 for over 4.15).
? 3.6
1LIST 2RUN 3LOAD" 4SAVE" 5CONT 6"LPT1 7TRON 8TROFF 9KEY 0SCREEN

Fig. 4.

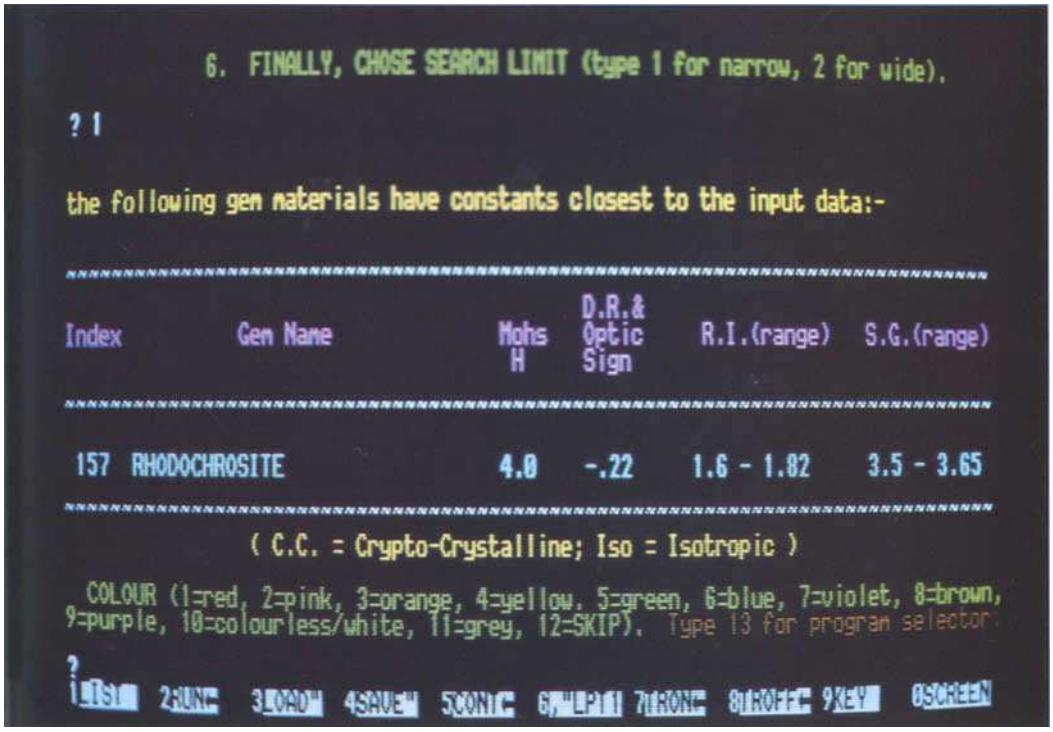
6. FINALLY, CHOSE SEARCH LIMIT (type 1 for narrow, 2 for wide).
? 1
the following gem materials have constants closest to the input data:-
Index Gem Name Mohs H D.R.& Optic Sign R.I.(range) S.G.(range)
157 RHODOCHROSITE 4.0 -.22 1.6 - 1.82 3.5 - 3.65
(C.C. = Crypto-Crystalline; Iso = Isotropic)
COLOUR (1=red, 2=pink, 3=orange, 4=yellow, 5=green, 6=blue, 7=violet, 8=brown, 9=purple, 10=colourless/white, 11=grey, 12=SKIP). Type 13 for program selector.
?
1LIST 2RUN 3LOAD" 4SAVE" 5CONT 6"LPT1 7TRON 8TROFF 9KEY 0SCREEN

Fig. 5.

the following gem materials have constants closest to the input data:-

Index	Gem Name	Mohs H	D.R.& Optic Sign	R.I.(range)	S.G.(range)
29	BOWENITE	4.0	C.C.	1.56	2.58 - 2.59
41	CHALCEDONY	6.5	C.C.	1.53 - 1.54	2.58 - 2.64
46	CHRYSOCOLLA	4.0	C.C.	1.5	2 - 2.45
98	JADEITE	6.5	C.C.	1.65 - 1.68	3.3 - 3.36
127	NEPHRITE	6.5	C.C.	1.6 - 1.641	2.9 - 3.02
201	VARISCITE	5.0	C.C.	1.56	2.4 - 2.6

(C.C. = Crypto-Crystalline; Iso = Isotropic)

COLOUR (1=red, 2=pink, 3=orange, 4=yellow, 5=green, 6=blue, 7=violet, brown, 9=purple, 10=colourless/white, 11=grey, 12=SKIP). Type 13 for program selector

?

1LIST 2RUNC 3LOADW 4SAVEW 5CONIC 6PLEPI 7TRONC 8TROFFC 9KEY 0SCREEN

Fig. 6. The program has been instructed to display all green translucent crypto-crystalline stones (the inputs for RI and SG have been bypassed by using the program options).

Index	Gem Name	Mohs H	D.R.& Optic Sign	R.I.(range)	S.G.(range)
3	ALMANDINE	7.5	Iso.	1.77 - 1.81	3.8 - 4.2
54	CUBIC ZIRCONIUM OXIDE	8.0	Iso.	2.09 - 2.18	5.54 - 6
55	CUPRITE	4.0	Iso.	2.85	5.85 - 6.15
121	MICROLITE	5.5	Iso.	1.93	5.5
150	PYROPE(garnet)	7.5	Iso.	1.75 - 1.77	3.7 - 3.8
176	SPESSARTITE(garnet)	7.0	Iso.	1.8	4.16
180	SPINEL(natural)	8.0	Iso.	1.718	3.6
186	STRONTIUM TITANITE	6.0	Iso.	2.41	3.13
212	YAG	8.5	Iso.	1.832	4.58
221	GLASS(man-made)	4-6	Iso.	1.47 - 1.77	2.3 - 5

(C.C. = Crypto-Crystalline; Iso = Isotropic)

COLOUR (1=red, 2=pink, 3=orange, 4=yellow, 5=green, 6=blue, 7=violet, 8=brown, 9=purple, 10=colourless/white, 11=grey, 12=SKIP). Type 13 for program selector

?

1LIST 2RUNC 3LOADW 4SAVEW 5CONIC 6PLEPI 7TRONC 8TROFFC 9KEY 0SCREEN

Fig. 7. Here, the program was instructed to display all red transparent singly-refracting gems having an SG of 3.32 and above.

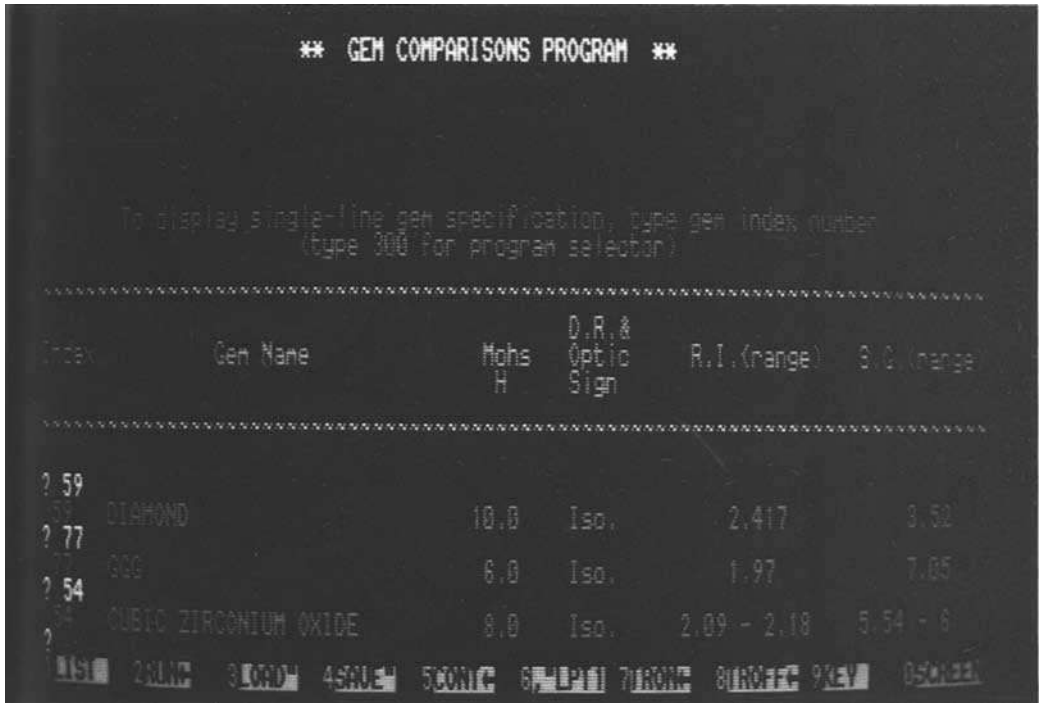

Fig. 8. The 'Gem Comparisons' section of the program allows for side-by-side display of the constants of gems selected from an index list.

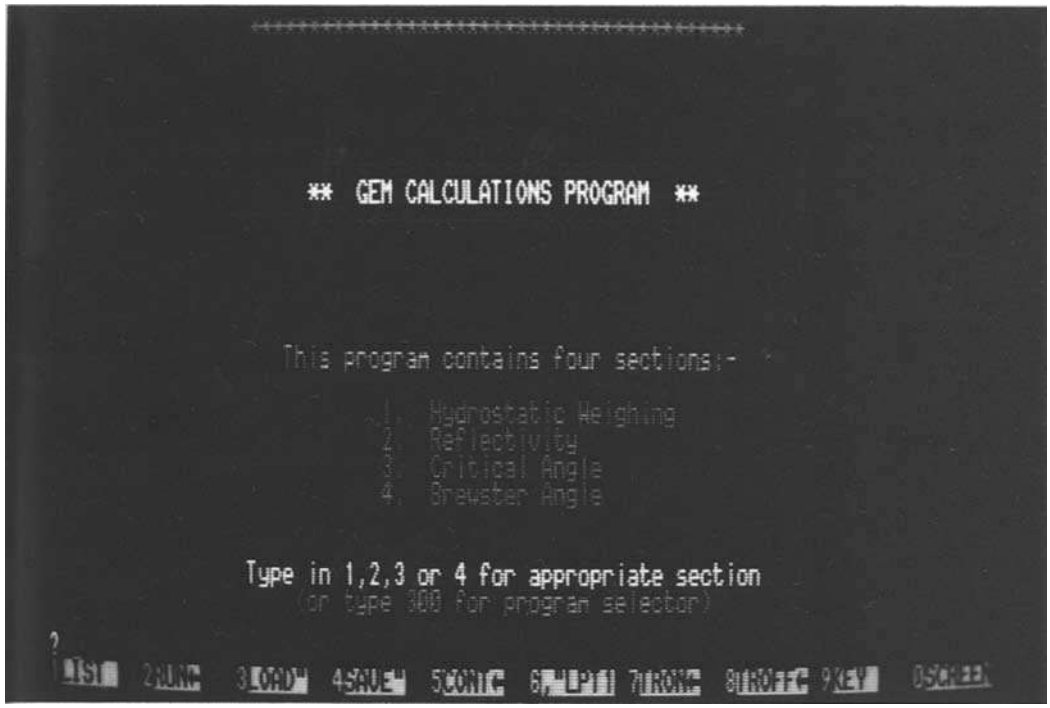

Fig. 9–12. The 'Gem Calculations' menu, and examples of its use for checking the reflectivity, critical angle and Brewster angle of diamond.

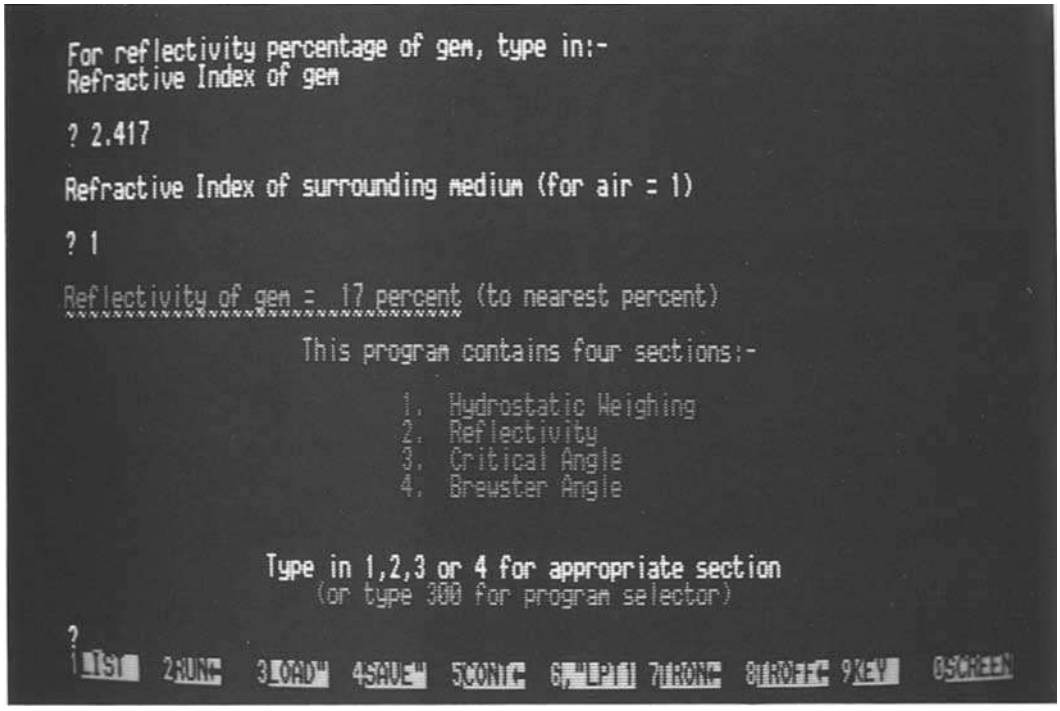
For reflectivity percentage of gem, type in:-
Refractive Index of gem
? 2.417
Refractive Index of surrounding medium (for air = 1)
? 1
Reflectivity of gem = 17 percent (to nearest percent)
This program contains four sections:-
1. Hydrostatic Weighing
2. Reflectivity
3. Critical Angle
4. Brewster Angle
Type in 1,2,3 or 4 for appropriate section
(or type 300 for program selector)
?
1LIST 2RUN" 3LOAD" 4SAVE" 5CONT 6LPRINT 7RON 8ROFF 9KEY 0SCREEN

Fig. 10.

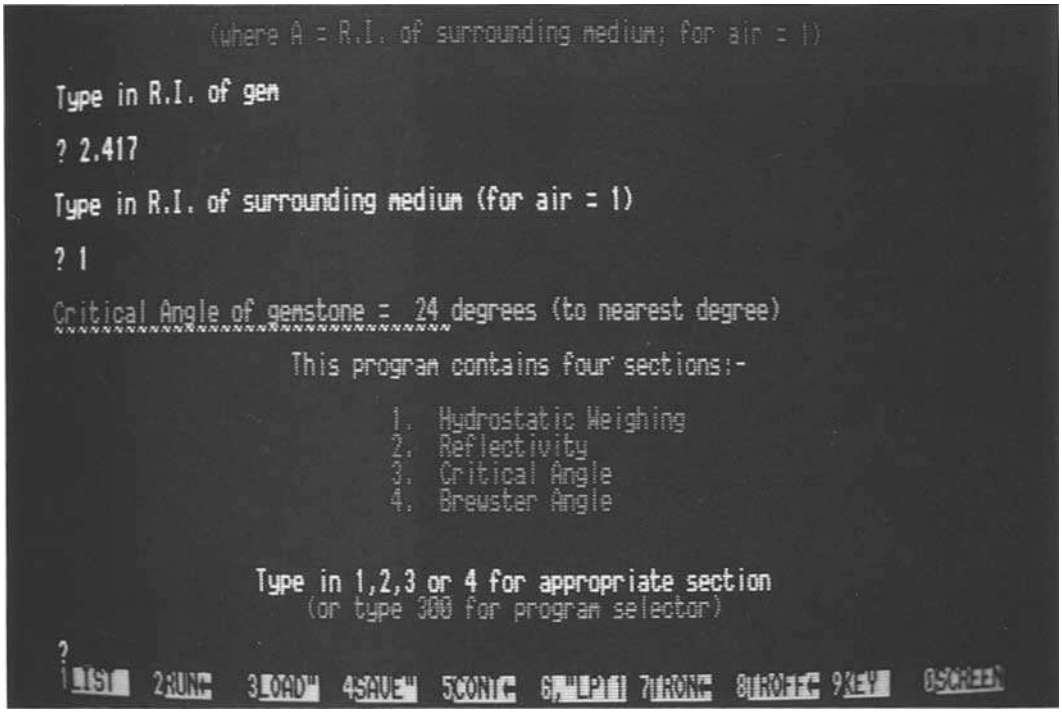
(where A = R.I. of surrounding medium; for air = 1)
Type in R.I. of gem
? 2.417
Type in R.I. of surrounding medium (for air = 1)
? 1
Critical Angle of gemstone = 24 degrees (to nearest degree)
This program contains four sections:-
1. Hydrostatic Weighing
2. Reflectivity
3. Critical Angle
4. Brewster Angle
Type in 1,2,3 or 4 for appropriate section
(or type 300 for program selector)
?
1LIST 2RUN" 3LOAD" 4SAVE" 5CONT 6LPRINT 7RON 8ROFF 9KEY 0SCREEN

Fig. 11.

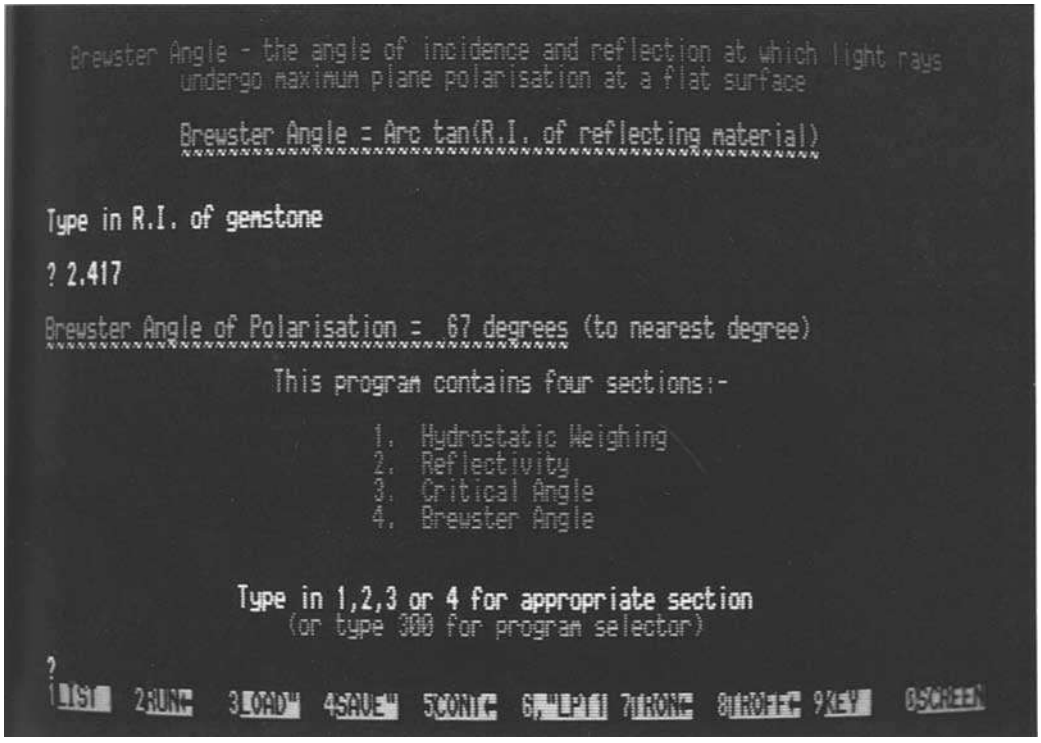

Fig. 12.

transparent, translucent or opaque. For flexibility, it is also possible to bypass or 'skip' the inputs for colour and/or transparency (as can be done for RI, optic sign and SG). This 'skip' facility has the added advantage of making it possible to display specific groups of gemstones. For example, the program can be asked to display all green translucent crypto-crystalline gems having any value of RI and SG (Figure 6), or to list all red transparent singly-refracting stones having an SG of 3.32 and upwards (Figure 7).

The facility for calling up separate program sections from a 'menu' is retained and allows a choice of 'Gem Identification' (using input test data), 'Gem Comparisons' (providing side-by-side displays of the constants of selected gems in the form of single-line specifications – Figure 8) and 'Gem Calculations' (hydrostatic weighing, reflectivity, critical angle and Brewster angle – Figures 9–12).

Additionally, the single-line gem specifications displayed in both the gem identification and comparison sections of the program have been modified to show Mohs hardness, optic sign/DR (or 'Iso.' for isotropic; 'C.C' for crypto-crystalline), RI range and SG range.

With the previous equipment, because of the incompatibility between disk operating systems, it was only possible to make the program accessible to would-be users in the form of a printed listing (which was some 700 lines in length). The Amstrad PC1512DD, however, is IBM-compatible, and the new GEMDATA program can be fed directly into similar computers which accept 5¼-inch double-density, double-sided floppy disks and have a minimum memory of 120K to accommodate both the program and the BASIC language in which the program is written.

As an increasing number of jewellers are turning to the computer as an aid to stock control and accounting, the addition of a program such as GEMDATA would make it possible to expand the clerical uses of the installation into the realms of gem identification and appraisal.

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Internal diffusion

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Abstract

Some minerals, such as rutile, hematite and ilmenite, found as inclusions in sapphires are capable of imparting body-colour to their host during high temperature heat treatment. The inclusions are cannibalized by the host sapphire for the chromophoric elements they contain. If the inclusions are not completely consumed by their host this 'internal diffusion' results in a zone of intensely coloured sapphire surrounding the remaining inclusions.

Introduction

The elemental causes at the atomic level of both the blue and the stable yellow colour in sapphires have been known and at least partially understood for some time. Over the past several years some excellent articles have been written by a number of well known and highly regarded gemmologists and research scientists that document these coloration mechanisms and the trace elements responsible for the resulting colour (Crowningshield and Nassau, 1981; Gunaratne, 1981; Nassau, 1981 and 1984; Keller, 1982; Schmetzer, Bosshart, and Hänni, 1983).

However, although the colour producing mechanism is generally understood and the colouring agent(s) is/are known, the exact source of the colouring agent(s) themselves is usually not mentioned and still remains, at least in some cases, unknown.

It seems to be generally accepted that the agents responsible for the blue and stable yellow colours in heat treated sapphires are either already naturally present as trace elements at the submicroscopic lattice level, as in the case of Sri Lankan 'geuda', or must be added in artificially from the exterior of the gem through a high temperature diffusion treatment.

In the case of a high temperature diffusion treatment the sources of the various colouring elements are jars of readily available purified laboratory chemicals, usually in oxide form, that are painted on to the prefaceted gem's surfaces just before treatment. The question of colouring element source only arises when we consider those gems that require no externally applied chemicals to attain body colour when they are subjected to a high temperature treatment. Are all these colouring agents, in, as an example the Sri Lankan geuda, already present throughout the gems as trace elements, or is there some other natural source that provides at least some of the colouring ions from within the gems?

In his paper on geuda sapphire coloration written in 1981 Herbert S. Gunaratne of the Sri Lankan State Gem Corporation hinted at a possible chromophore source with the following statement:

'Titanium and iron are both colouring elements to which is attributed responsibility for imparting colour to blue sapphires. These elements have been found in varying proportions as insignificant impurities which are jointly or by themselves responsible for the colour. In the geuda of the ideal stone the rutile present has remained, so to say, in a state of inactivity, in the sense that its true function as a colouring element has not fully revealed itself. On the other hand, the faint powder-blue tint in such a stone could be attributed to iron in some form, which, if subject to heat, totally disappears at certain temperatures, making the stone visibly whitish. On being subject to still higher temperatures (temperature closer to the melting point of titanium), the titanium begins to melt within the host while the host is still in a solid state. In this state the atoms of the rapidly melting titanium not only begin to readjust themselves once again in relation to crystallographic laws, but also to bring out its colouring properties which gradually diffuse into the host.'

Although Mr. Gunaratne does not specifically say so, from the paragraph quoted above it can be reasonably inferred that when he writes of titanium melting he is referring to the mineral rutile in the form of exsolution needles and not to metallic titanium in uncombined elemental form. In the last sentence he speaks of the colouring properties of the melting titanium (rutile) gradually diffusing into the stone. Although no mention as to where the iron (also needed for blue colour) is coming from, this still strongly suggests that he felt that the solid microscopically visible inclusions present in Sri

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Lankan geuda sapphires were responsible, at least in some way, for the resulting blue colour by diffusion into the surrounding corundum host.

With respect to yellow coloured sapphires from sources such as Australia and Thailand it has also been theorized more than once that inclusions may at least play a partial role in the colorizing process during heat treatment.

An excellent paper on gem corundum from Thailand written by Dr Peter C. Keller, Associate Director of the Los Angeles County Museum of Natural History, and published in 1982, points out one possible colouring element source in colour-stable heat-treated yellow and orange sapphires. This particular discussion on colour-cause is quoted as follows:

'The actual mechanism for the appearance of the golden yellow colour in the sapphire is open to speculation until the extensive research required to provide a conclusive answer can be completed. According to George Rossman. of the California Institute of Technology (personal communication, 1982). Trivalent iron alone will produce a pale yellow colour, but cannot be called upon for the rich golden colour observed in many of the treated stones seen in Chanthaburi. Rossman suggests that perhaps we are seeing incipient exsolution of the trivalent iron as sub-microscopic iron oxides in the corundum lattice. This mechanism would be very similar to the exsolution of hematite in plagioclase feldspar giving rise to the golden colour of sunstone. In the case of plagioclase, the hematite may become coarse enough to result in aventurescence. This phenomenon has not been observed in sapphire, although the process is not unlike the exsolution of titanium oxides (rutile) in corundum to produce the familiar silk inclusions. As noted above, however, detailed research will be needed to answer this question for certain.'

Here it was stated that the colour intensification of some golden yellow heat treated sapphires is in part thought to be the direct result of the presence of inclusions.

Another noteworthy paper discussing yellow and orange-brown heat-treated sapphires, authored by Dr Karl Schmetzer of West Germany, and George Bosshart and Dr Henry A. Hänni from Switzerland, was published in 1983.

In this paper the authors point out that although temperatures in excess of 1550°C are reportedly used in the annealing of yellow sapphires no explanation as to the cause of the heat treatment-generated yellow coloration can be given at this time. They then go on to speculate:

Possibly is it related to the resorption of pre-existent mineral inclusions during annealing. Chemical analyses (microprobe, X-ray fluorescence) indicate limited contents of Fe and sometimes also of Cr and Mg. Already before the heat treatment, these elements were present in some form inside the crystal (as incusion constituents or on Al sites of the corundum lattice) and become colour-efficient by the strong annealing.

Here again it is suggested that perhaps some inclusions in sapphires will supply their host with colouring ions during high temperature heat treatment.

In his definitive book *Gemstone enhancement* (1984) Dr Kurt Nassau also mentions inclusion caused colour in explaining that if pale to medium yellow corundum containing Fe^{3+} ions in the form of Fe_2O_3 is strongly heated it could aggregate the Fe_2O_3 to form particles of hematite and in this manner produce a deeper yellow-to-brown colour in the gem. One of the colour illustrations (by this author) in *Gemstone enhancement* (plate number XVI) shows orange-yellow halos in a heat-treated sapphire taken in diffused transmitted light at 25×.

What was not shown in the book was the matching companion micrograph taken in the same position, at the same magnification but under dark-field conditions. This second photomicrograph (Figure 1), when compared to the original photo shown in *Gemstone enhancement* (Figure 2), shows that for every orange-yellow halo there is a corresponding acicular inclusion at the centre of the halo. The connection here between inclusions, colour and heat treated host is obvious. The colouring agent (iron) has diffused from the inclusions into the surrounding sapphire.

Observations

After discovering this 'internal diffusion' colouring mechanism (Figure 3) twelve additional heat-treated yellow sapphires were examined very closely in both diffused transmitted and dark-field illumination using magnifications as high as 160×. In nine of the twelve treated sapphires tiny whitish appearing acicular inclusions, surrounded by yellow colour rinds, were observed. In the remaining three sapphires no specific source for the colour could be established.

Rutile (TiO_2: often containing at least some iron), hematite (alpha-Fe_2O_3: sometimes containing titanium) and ilmenite ($Fe^{+2}TiO_3$) have all been recognized as mineral inclusions in sapphires from various localities. Chemically they are also very closely related. Other chemically related inclusions such as pyrite (FeS_2), pyrrhotite ($Fe_{1-x}S$) and chalcopyrite ($CuFeS_2$) have also been identified in sapphires. Even though each of these compounds is universally acknowledged as a separate and distinct mineral, when studying their chemical formulas a common gemmological link is discovered. The

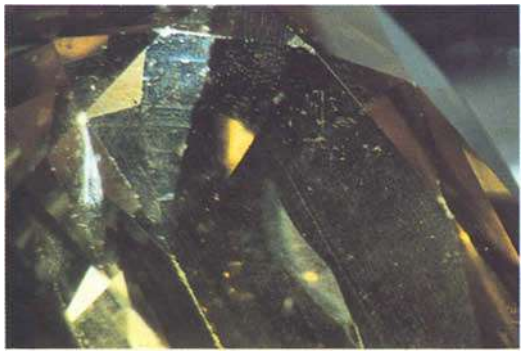

Fig. 1. Heat-treated orangish-yellow sapphire containing a multitude of tiny acicular (hematite?) inclusions. Dark-field illumination. 25x.

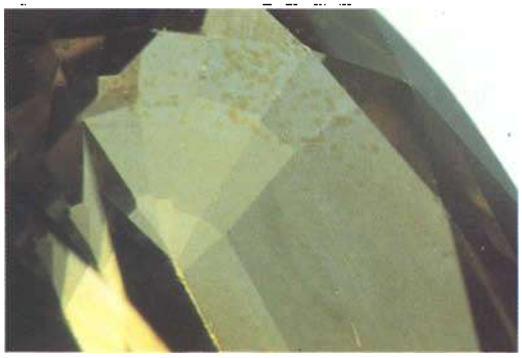

Fig. 2. Using diffused transmitted light on this same sapphire reveals an orangy-yellow coloured halo surrounding each of the minute whitish-appearing acicular inclusions. 25x.

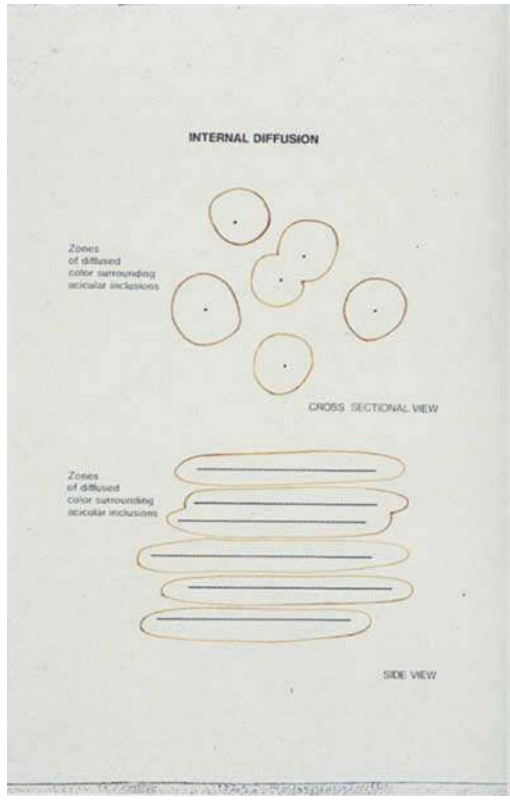

Fig. 3. Schematic diagram of the 'internal diffusion' mechanism showing both cross sectional and side views.

metallic elements that compose them, either separately or together, have the capacity of causing yellow to blue colour in corundum. So perhaps if both iron and titanium (which are both necessary to create blue colour in sapphire) were present at the same time as the chemical components of an inclusion then a blue-coloured halo would be generated around that inclusion during high temperature heat treatment if the temperature was high enough to volatilize the inclusion without melting the host.

Just such an inclusion cannibalizing mechanism apparently does exist. An extensive microscopically-aided search through a number of pale to dark blue heat-treated sapphires from the Phillipsburg area of Montana in the United States (47 faceted stones) and from Sri Lanka (38 faceted stones) yielded a few gems (6 from Montana and 2 from Sri Lanka) that showed obvious evidence of blue internal-colour-diffusion haloing generated by thermally activated inclusions. Examples of this visual evidence of inclusion caused coloration in one of the heat-treated Phillipsburg sapphires is shown in Figure 4 while this same effect in a Sri Lankan gem is shown in Figure 5.

Additional examples of 'internal diffusion' have also been found while studying blue flame-fusion (Verneuil) synthetic sapphires. When the powdered chemicals which are melted to grow these synthetic sapphires are unevenly mixed small pockets of the chromophoric oxides used to produce the blue colour may become concentrated and trapped in the melt layers. When this happens, as shown in Figure 6, colour diffuses away from these pockets into the successive growth layers creating blue-phantoms extending from the oxide-pockets.

Conclusion

From the visual evidence presented in this study it is apparent that microscopically visible inclusions provide at least some of the colouring ions in some high temperature heat-treated sapphires through 'internal diffusion'. What percentage of the colour in a given gem can actually be attributed to this

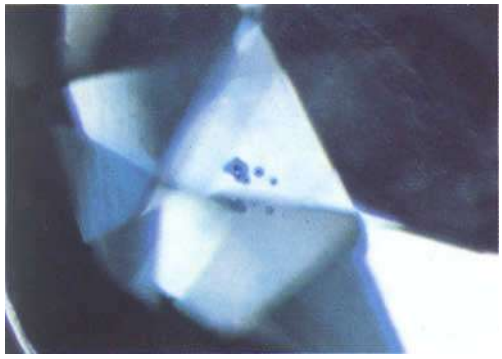

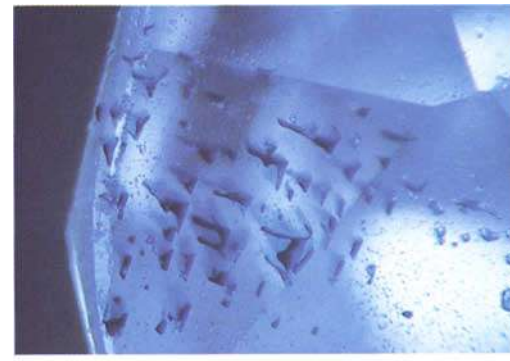

Fig. 4. (Above) Small cluster of anhedral black submetallic ilmenite inclusions encircled by blue 'internal diffusion' clouds in a pale blue sapphire from Phillipsburg, Montana. Diffused transmitted light. 45x.

Fig. 5. (Above right) This tight grouping of irregular titaniferous hematite crystallites has released both titanium and iron during heat treatment resulting in the surrounding zone of blue colour in this Sri Lankan Sapphire. Diffused transmitted light. 40x.

Fig. 6. (Right) Chromophoric oxide-pockets with internal diffusion generated blue-phantoms in a flame-fusion synthetic sapphire. Diffused transmitted light. 35x.

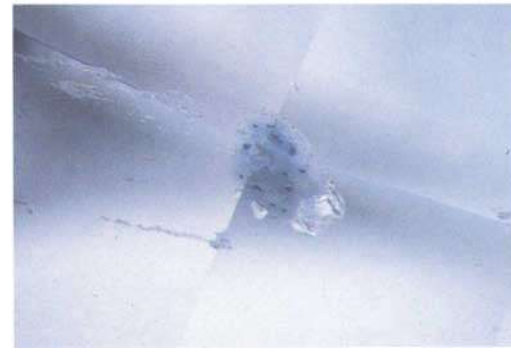

mechanism is open to speculation and will differ from stone to stone. It is probable that most of the colour in heat-treated yellow and blue sapphires results from the presence of either trace elements or submicroscopic inclusions, neither of which can be observed with a microscope.

Acknowledgements

The author would like to thank Mr William C. Kerr, GG, of Long Beach, California, for providing some of the Montana sapphires used in this study.

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The background to diamond grading

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Abstract

The background to the assessment of diamond quality is given with emphasis on the present grading systems.

Introduction

When considering the purchase of any commodity, be it a house, a car, a kilo of fruit or a diamond, one naturally wants to know whether the price being asked is reasonable for the quality of the item offered. To judge whether value for money is being obtained, one has to find a means by which the quality can be appraised. In the case of a polished diamond, quality is decided by reference to the so-called 'Four Cs', i.e. Carat weight, Colour, Clarity and Cut.

This article is an introduction to a series which will review the present status of laboratory-based diamond grading and the methods used to assess the 4 Cs. Subsequent articles will examine the systems and nomenclature used in greater detail. The author recognizes that throughout the world many systems have been devised, used locally, but are not necessarily known on the international market.

For centuries the sole criterion used by the trade to assess diamond quality was that of size (weight). In 1750, David Jeffries[1] stated: *'The principle, or rule is, that the proportional increase, or value of Diamonds is the square of their weight, whether rough or manufactured.'*

The background to diamond grading

The formula used by the trade was $n^2P = R$, where n is the weight in carats, P the price of a stone of one carat and R the total value.

An example Jeffries quotes is *'a rough diamond of two carrats [sic], at the rate of £2 per carat . . . multiply 2 by 2, the square of its weight then multiply the product of 4 by £2 . . . that makes £8 which is the true value of a rough diamond of 2 carats'.*

The square weight rule appears to have applied as late as 1877[2], although by 1918 the rule had fallen out of favour as J.R. Sutton shows in his book *Diamond*[3]. He quotes some diamond values of that year which illustrate the relationship between price and size which still holds true today, i.e. as the weight increases, the price *per carat* increases.

Example: Bultfontein (a mine in South Africa) *Diamond Values Sept 1918.*

Market Value in Shillings (20 shillings = £1)

Weight (ct)	*Price per carat*	*Price per stone*
1	*146*	*146*
2	*242*	*484*
4	*296.5*	*1186*
7	*325.5*	*2278*

With the increase in the number of diamonds coming on to the market at the turn of the century, many from the Cape area of South Africa, interest became focused on the *colour* of the stones. At this time colour (or more correctly the lack of colour) in diamond was described in quite vague terms. A jeweller in Paris (at that time the centre of the diamond trade) might describe the colour of an exceptional diamond as *'of the best first water'*; a reference to the water-like transparency of the stone. Poorer colours might be described as *'of the second water'*. It became apparent that many stones from the Cape were not of the best colour. There was and still is a tremendous variation of colour, from the absolutely colourless stones, very few in number hence in great demand, to the more common pale yellow stones. Certain South African mines were noted for certain quality stones. For example the Jagersfontein mine in the Orange Free State was known to produce many fine water-white crystals thus such stones were called 'Jagers'. Such names were incorporated into an *international* colour grading scale in use in the 1930s (see Table 1).

These terms, known as 'old terms' or 'old Engish terms' still survive in certain quarters of the trade but have been superseded by other nomenclatures (see Table 2).

An interest in the internal characteristics, flaws or inclusions in diamonds only arose when the construction of a reliable jewellers' eye-glass (or loupe) had been perfected.

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Table 1. Colour grades of 'white' diamonds used in the 1930s.

Jager (the best colour)
River
Top Wesselton
Wesselton
Top Crystal
Crystal
Top Cape
Cape
Light Yellow
Yellow (the worst colour)

At the beginning of this century two clarity grades were in use in Paris, *'piqué'* used to describe the major proportion of diamonds containing visible flaws, and *'clean'* for the much rarer hence greatly prized diamond devoid of flaws or inclusions. By the 1920s the terms 'very, very slight imperfect' and 'very slight imperfect' were being used to describe stones with minor inclusions.

By the 1930s a progression of grades was established in which the number and size of the inclusions affected the clarity grade. The Gemological Institute of America (GIA), established in 1931, had devised the following scale:–

Flawless
Very, very slightly imperfect
Very slightly imperfect
Slightly imperfect
Imperfect

By now the term 'piqué' had fallen out of favour in the United States and was replaced by the word 'imperfect' or just 'I'.

At present this scale has been modified and extended as can be seen in Table 2.

The best clarity grade used in the GIA system is 'internally flawless' – a phrase invented in 1968. 'Loupe clean', a term coined at the turn of the century, is used in other systems.

The importance of *Cut* in diamond quality is the subject of a separate article but it can be noted that its importance has only recently been appreciated. Even today the aspect of cut is often ignored when a diamond is valued.

We have seen how the interest in diamond quality has resulted in size, colour, clarity and then cut being appreciated.

Anyone with the required knowledge and experience can grade the quality of a diamond. However, the remainder of this article will concentrate on the grading systems and the independent laboratories that issue diamond reports and certificates.

Table 2. The three diamond grading systems.

	GIA	IDC	CIBJO
COLOUR			
scale	D	Exceptional white (+)	Exceptional white (+)
	E	Exceptional white	Exceptional white
	F	Rare white (+)	Rare white (+)
	G	Rare white	Rare white
	H	White	White
	I–J	Slightly tinted white	Slightly tinted white
	K–L	Tinted white	Tinted white
	M–N	Tinted colour 1	Tinted colour
	O–P	Tinted colour 2	Tinted colour
	Q–R	Tinted colour 3	Tinted colour
	S–Z	Tinted colour 4	Tinted colour
CLARITY			
scale	Internally flawless	Loupe clean	Loupe clean
	vvs 1	vvs 1	vvs 1
	vvs 2	vvs 2	vvs 2
	vs 1	vs 1	vs 1
	vs 2	vs 2	vs 2
	si 1	si	si 1
	si 2	si	si 2
	I 1	Piqué I	Piqué I
	I 2	Piqué II	Piqué II
	I 3	Piqué III	Piqué III

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The Gem Testing Laboratory of Great Britain

Officially approved by the

INTERNATIONAL CONFEDERATION *of* JEWELLERY, SILVERWARE, DIAMONDS, PEARLS AND STONES

CIBJO

DIAMOND REPORT

Carat weight:	1.17
Colour grade:	Rare White (G).
Clarity grade:	vs1
Shape and cut:	Round brilliant.
Measurements:	approx. 6.79 x 6.89 x 4.08 mm.
Proportions: Height:	59 % Table: 64 %
Finish: Symmetry:	Good-medium.
Finish: Polish:	Good.
Girdle:	Thin-thick, bruted.
UV-fluorescence:	None.
Comments:	External characteristics.

This diamond report is based on the Rules of application decided upon by CIBJO up to 1978, in particular on grading with the ten-power aplanatic and achromatic lens and on colour comparison with the CIBJO master diamonds.

The diamond has been tested independently in an absolutely objective way by at least two experts according to the present knowledge in the field of diamond grading.

The report does not make any statement with respect to the monetary value of the diamond.

Only the original report with signatures and embossed stamp is a valid identification document. Misuse of this document will lead to prosecution.

The Gem Testing Laboratory of Great Britain

Date 30th July 1987.

Signed E.C. Emms.

Eric C. Emms.

The Gem Testing Laboratory of Great Britain, 27 Greville Street, London, EC1N 8SU

Figure 1. A London CIBJO Diamond Report.

In 1953 the GIA held its first diamond grading class for jewellers. Its diamond grading certification service arose in New York from a demand from GIA students to have their stock diamonds graded by the GIA. The GIA diamond grading system evolved from this demand. By the mid 1950s their certificate or diamond report had been formalized. Diamonds graded at this time were of exceptional quality (of the top two colours and top clarity). Crowningshield[4] states that only since the 1970s have lower qualities been graded.

In Europe, other efforts were made to standardize diamond grading. In 1969 the Trade Associations of Jewellers in Denmark, Finland, Norway and Sweden published the Scandinavian Diamond Nomenclature and Grading Standards (Scan. D.N.) This was a grading manual which laid down clarity and cut standards as well as defining colour grades. Scan. D.N. was revised in 1980.

In 1971 the Diamond Commission of the International Confederation of Jewellery, Silverware, Diamonds, Pearls and Stones (CIBJO) was established, ten years after CIBJO was founded. The aim of the Commission was to harmonize diamond grading terminology throughout Europe and eventually the world. In 1979 CIBJO produced its Rules for the Diamond Trade in which it laid down standards for diamond grading. The CIBJO grades are given in Table 2.

Also established at this time was another European organization, the International Diamond Council (IDC). The Council was originally a joint committee comprising members of the World Federation of Diamond Bourses and the International Diamond Manufacturers' Association, formed in 1975. After several meetings, IDC produced its 'International Rules for Grading Polished Diamonds' in 1978.

By the end of the 1970s, we see that three organizations existed with their own diamond grading systems and terminologies. The differences between the systems lies in the grading procedures of each system and not in their nomenclatures. These differences will be explored in further articles.

The independent laboratories throughout the world subscribe to one of these systems. Laboratories in London (The Gem Testing Laboratory of Great Britain), Switzerland, Germany, Austria, Spain, Japan and other countries follow the CIBJO Rules. The GIA have two diamond grading establishments in the US (New York and Los Angeles). Laboratories in Antwerp (the Diamond High Council – HRD), Johannesburg (Jewellery Council of South Africa) and Tel Aviv follow the IDC Rules. Each laboratory issues a written report on loose polished diamonds. An example of a CIBJO Diamond Report is shown in Figure 1.

As to the future, it is obviously desirable that there should be not three, but one universal grading system used by all laboratories. One may also see a move to a more automated grading procedure. This aspect will be reviewed in a later paper.

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Some DIY gemmological instruments

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Abstract
Some simple and inexpensive DIY gemmological instruments are described, namely a polariscope, a dichroscope and a light intensity unit.

Use it up, wear it out;
Make it do, or do without.

New England maxim.

Introduction

I suspect that many gemmologists will at some time have made an aid for the diagnostic investigation of gemstones, and one often finds that the construction and design of the completed instrument is dictated by the ready availability and proximity of so-called 'bits and pieces'. Such diverse items used for the construction of the instruments have been a circular eyeglass from welding goggles, a moulded plano-convex lens from a signal box, a plastic container for 35 mm film, a watchmaker's eyeglass, a disco light, an on/off switch from an electric blanket and a ring with flange of unknown origin.

Polariscope

Components required for the polariscope (Figures 1 and 2):

Box – length 5", height 4½", breadth 3¼". Made from ½" plywood. Glued and panel-pinned except base where wood screws were used to facilitate base removal. Hole diameter on top of box 1¼".

Light source – 25W 240V pigmy lamp.

Bottom polaroid – lower polaroid sandwiched between 1¾" diameter glass and glued centrally with hole in top of box.

Top polaroid – polaroid film is cut to give a snug fit in a light batten holder and fitted in crossed position to

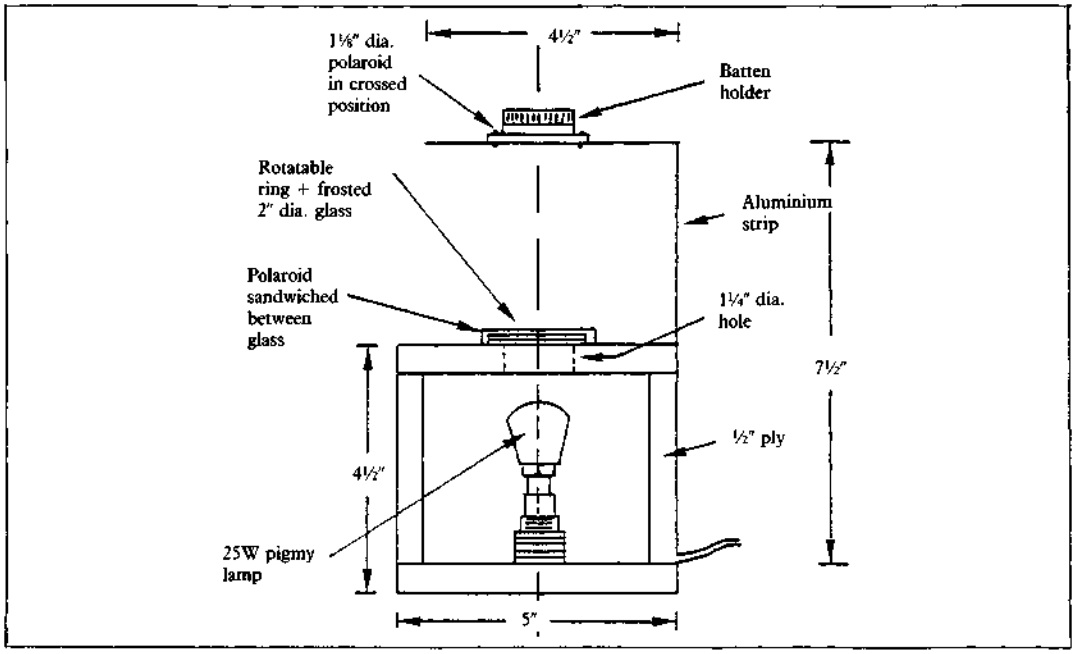

Fig. 1. Diagram of polariscope.

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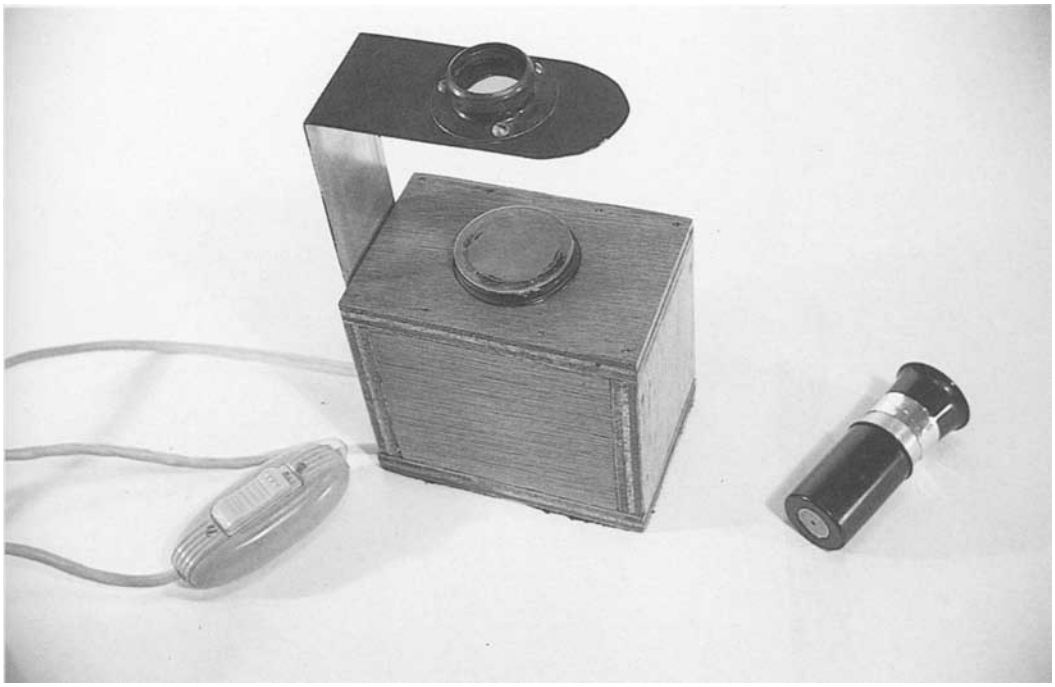

Fig. 2. Polariscope and dichroscope.

bottom polaroid. The top polaroid and holder is held by an aluminium supporting strip which was painted matt black.

Turntable – a 2″ diameter piece of glass (from welding goggles) was frosted with silicon carbide grit and glued with Araldite to a metal ring with flange (similar to a jam pot cover with hole).

Switch – on/off switch.

Dichroscope

Components required for the dichroscope (Figures 2 and 3):

Black plastic container – type used for 35 mm film.

Aluminium tube – 2¼″ in length and a snug fit inside the plastic container.

Watchmaker's eyeglass – 4″ focal length.

Calcite rhomb – held in the aluminium tube by a cork ring.

Plastic tape – used to bind eyeglass to aluminium tube.

Paper disc – with the aid of a low-power microscope a square hole of 2 mm wide was cut with a razor blade. If on viewing the resultant images of opening overlap, a smaller hole should be cut. If images are

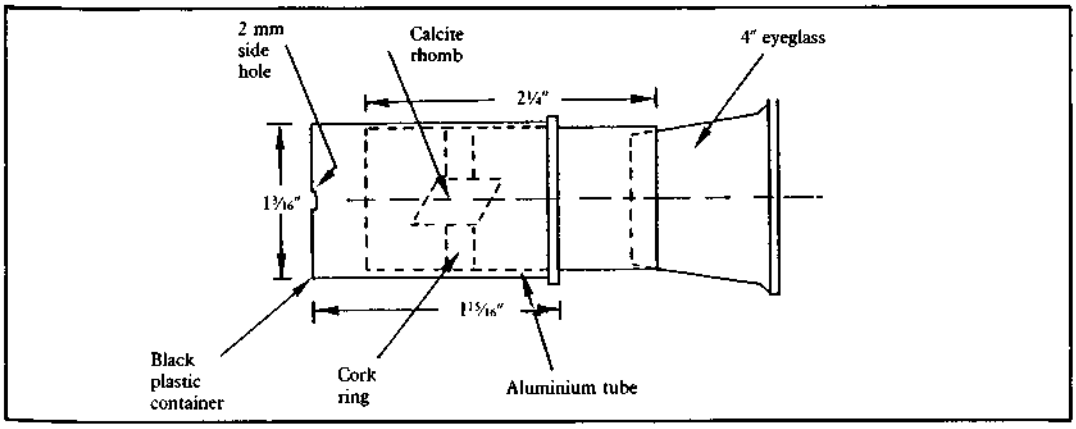

Fig. 3. Diagram of dichroscope.

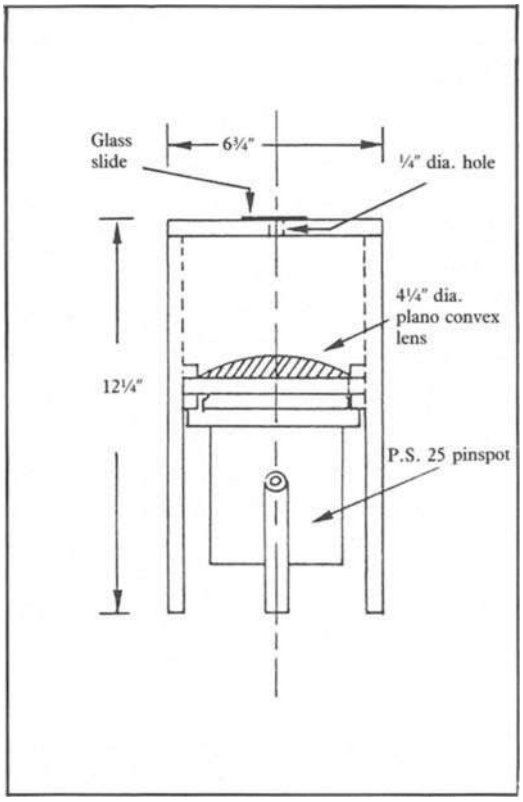

Fig. 4. Diagram of light intensity unit.

Fig. 5. Light intensity unit.

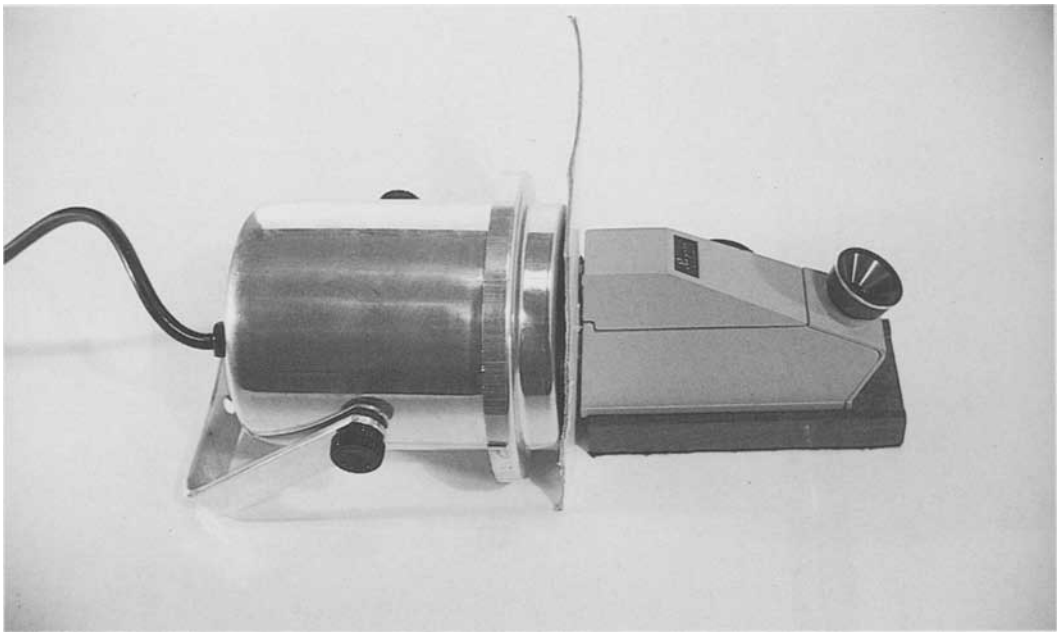

Fig. 6. Light intensity unit used horizontally with the refractometer.

insufficiently close to one another then a larger square should be cut.

All surfaces inside the tube were painted matt black to minimize spurious reflections. Some secondary images of the opening were seen on viewing, perhaps due to the absence of glass prisms at either end of the rhomb. However, the instrument works – and thus justifies its use.

Light intensity unit

Components required for the light intensity unit (Figures 4, 5 and 6):

Box – height 12¼", depth 6¼", breadth 6¾", constructed from ½" plywood. Glued and pinned. Box is open at base and part side for insertion of light source.

Light source – P.S. Pinspot 25W 5.5V from Sis Ltd, 57 St Andrews Road, Northampton.

Lens – 4¼" diameter moulded plano convex lens.

Glass slide – microscope slide taped to top of box.

The pinspot disco lamp may be used vertically as a light source in conjunction with the box for spectroscopic work (Figure 5) or used horizontally with a yellow/green filter for refractometer work (Figure 6).

[*Manuscript received 2 February 1987.*]

A cheap dichroscope

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Abstract

A method of making a dichroscope using polaroid sheet.

Description and use

As mentioned by G.F. Herbert Smith*, a simple and effective dichroscope can easily be constructed using polaroid sheet. Cut two squares of polaroid; approximately 1.50 cm on edge is adequate. These are cemented (an epoxy resin is suitable) to a glass microscope slide in contact down one edge and with the directions of polarization at 90°C (see Figure 1). The edge in contact should be as flush as possible. A second glass slide can be cemented on the top for protection if desired.

To use: large stones can simply be placed over the join and rotated to achieve maximum effect.

Small stones can be examined by placing them under a microscope so that they are out of focus and the field of view is saturated with colour. The dichroscope can then be rested on the top of the microscope and rotated for best effect. Removing the eyepiece may be helpful here.

The blue-grey tint of the polaroid may mask very weak dichroism but presents little trouble with most stones.

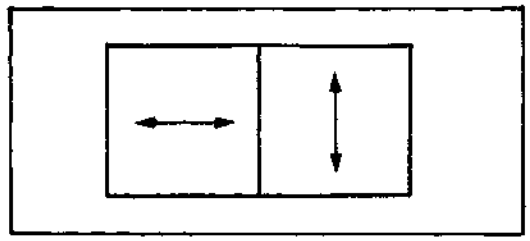

Fig. 1. Plan of dichroscope showing microscope slide with two squares of polaroid cemented to it with directions of polarizations at 90°.

*G.F. Herbert Smith, 1972. *Gemstones*, 14th edn, 108. Chapman & Hall, London.

[*Manuscript received 28 January 1987.*]

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An account of chrysoberyl-bearing pegmatite near Pattara, Sri Lanka

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Introduction

The genesis of gemstones in Sri Lanka has been a subject for much discussion. Gems are mostly mined from alluvial deposits underlain by Precambrian metamorphic rocks. Blue corundum crystals have been discovered in crystalline limestone at Kolonné (Gunaratne, 1976); the origin of these was undoubtedly during the metamorphism of crystalline rocks within the island. Chrysoberyl of dark green colour has also been found near Ulvita in a pegmatite body (personal communication from Mr D. Jayawardena, Director, Geological Survey Department), but this material is not suitable for faceting. Recently a pegmatite bearing gem-quality chrysoberyl was located near Pattara in the Morawaka area. Gem mining fields in the Morawaka area are shown in Figure 1. Figure 2 shows mining activities at the pegmatite deposit. The detailed exploration of the deposit is in progress.

Fig. 2. Mining activities at Pattara chrysoberyl-bearing pegmatite deposit.

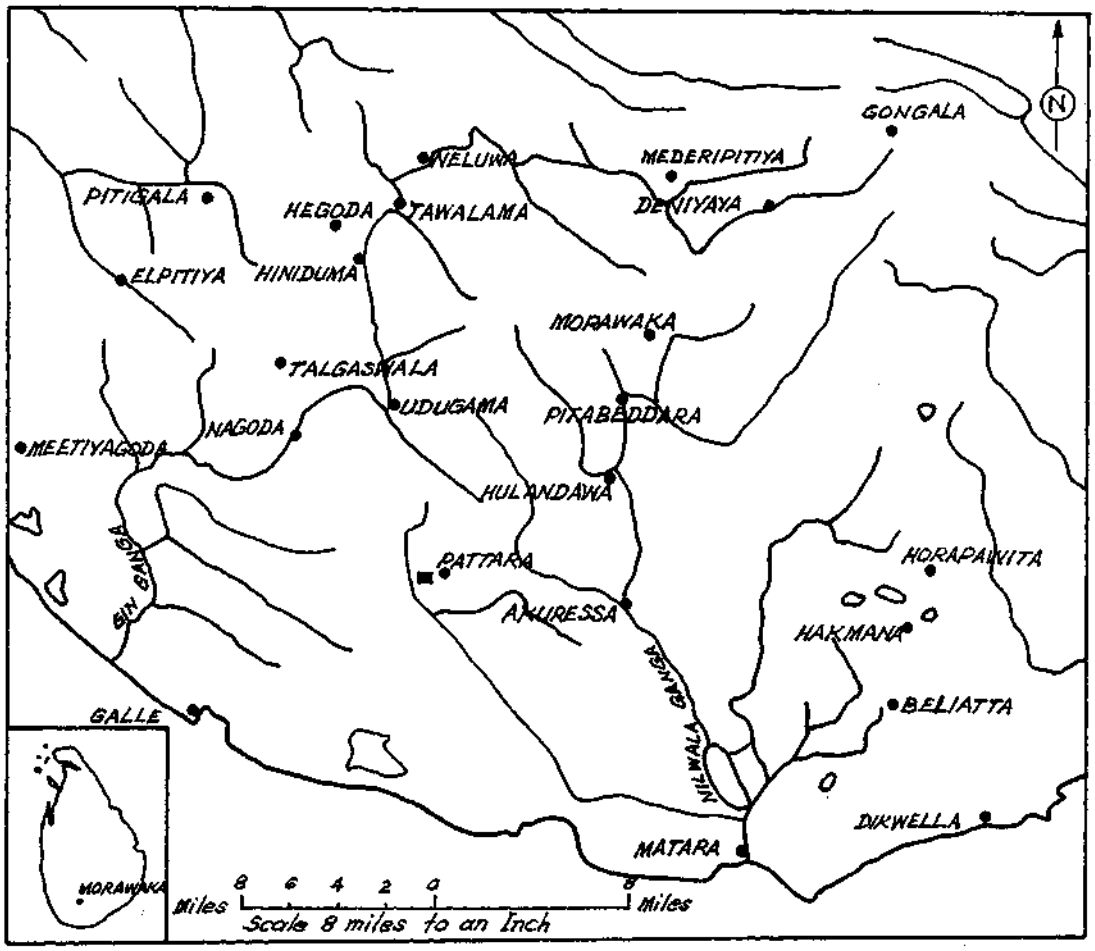

■ Chrysoberyl pegmatite.

● Gem mining areas.

Fig. 1. Distribution of gem deposits in Morawaka area.

Geology

The occurrences of chrysoberyl, including alexandrite and cat's-eyes, are more frequently found in and around Morawaka and Deniyaya than in the other gem mining areas in Sri Lanka. A notable feature of the gem gravels in this part of the island is the higher concentration of green zircons than other minerals and the absence of corundum.

The geology of the Pattara area is shown in Figure 3. The pegmatite body is horizontal and cylindrical in shape, with a diameter of about 30 cm. It is located at a depth of about 8 m (see Figure 4). In the zone of pegmatite mineralization pyrite, columbite-tantalite, muscovite and phlogopite were identified as associated minerals. Mineralization of this chrysoberyl pegmatite body is within the biotite-gneiss and the pegmatite body occurs parallel to the axis of the syncline.

Chemical and physical properties

Chrysoberyl mined from the pegmatite is transparent, apple green in colour, and varies in size from 1 mm to 8 mm. Some worked specimens displayed chatoyancy, whilst a few possessed sufficient colour change to be termed alexandrite.

(Source: Geological Survey Department)

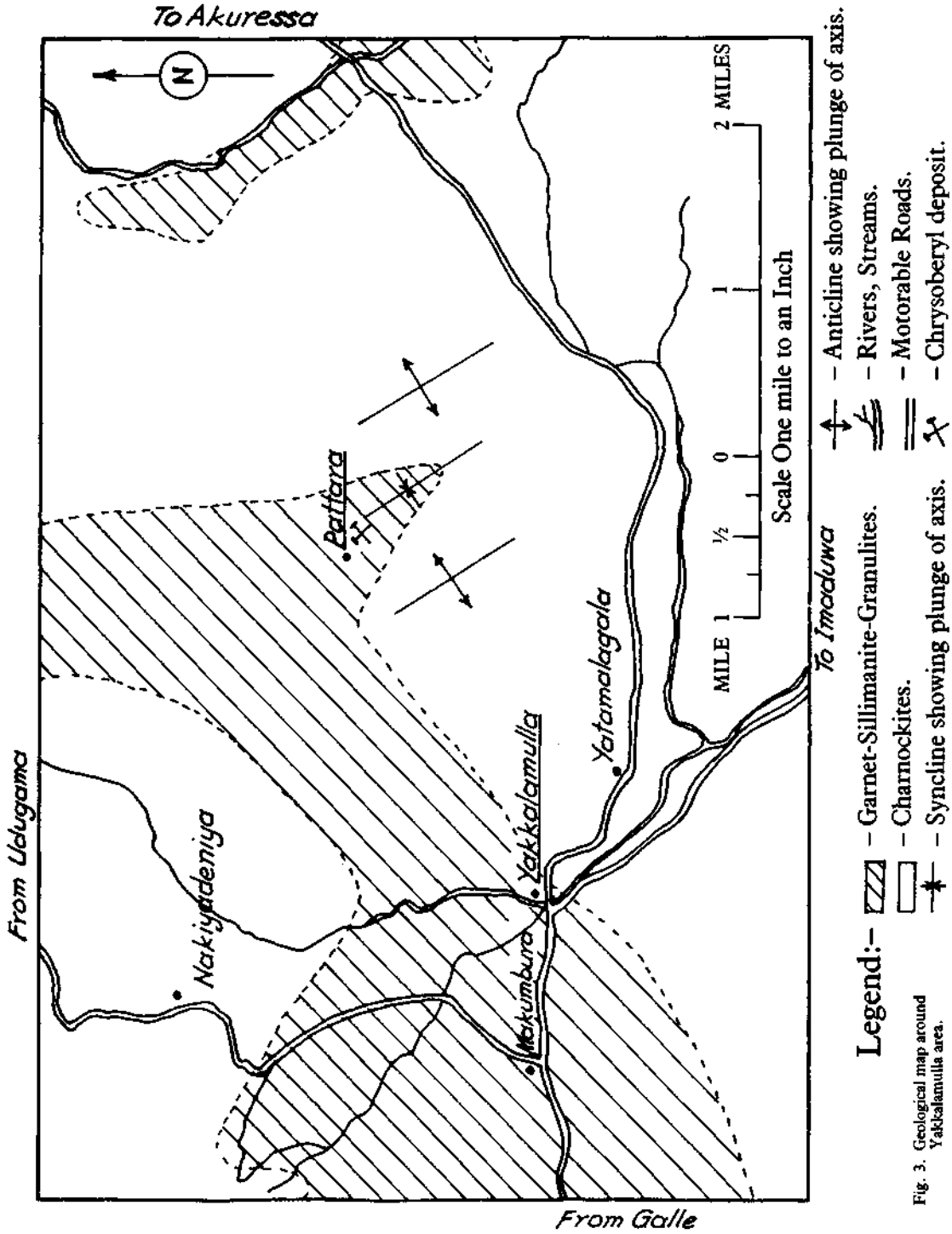

Fig. 3. Geological map around Yakkalamulla area.

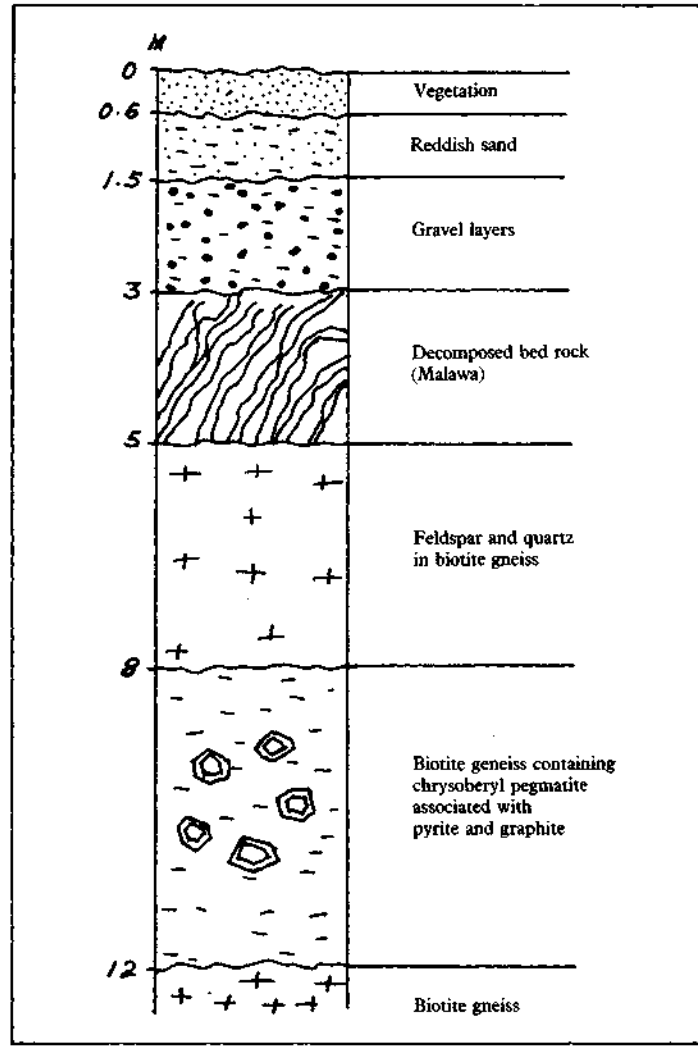

Fig. 4. Cross section of chrysoberyl pegmatite at Pattara.

The identity of the Pattara chrysoberyl was confirmed by X-ray diffraction analysis at the British Museum (Natural History). Atomic absorption analysis by V.K. Din gave the following results in percentages by weight: AL_2O_3 80.9, Fe_2O_3 1.04 (total Fe), BeO 17.3; total 99.24. The chrysoberyl contains as trace elements 600 ppm chromium and 700 ppm gallium.

References

Gunaratne, H.S., 1976. On the occurrence of gem corundum in Kolonné. *Journal of Gemmology*, XV, 1, 29–30.

[*Manuscript received 24 June 1986, revised 19 February 1987.*]

Gemmological Abstracts

ALMQUIST, A., 1987. Minnesota's thomsonite. *Lapidary Journal*, **41**, 1, 57–62, 2 figs in colour.

Thomsonite, whose properties are given, can be found at a number of beach locations along the north shore of Lake Superior in Minnesota. M.O'D.

APPEL, P.W.U., JENSEN, A., 1987. A new gem material from Greenland: iridescent ortho-amphibole. *Gems and Gemology*, **23**, 1, 36–42, 7 figs in colour.

Describes an ornamental grey to black mineral with iridescent spangles or patches, reminiscent of labradorescence, oriented parallel to a pinacoid face. Composition is complex, but basically a Mg/Fe hydrated silicate with Na and Al in varying amounts.

Biaxial, RI varying around 1.64–1.66. SG from 3.18 to 3.37. Fluoresces dark violet in UV. Marketed in Greenland as Nuummite, from Nuuk, its place of origin. R.K.M.

BALFOUR, I., 1987. Famous diamonds of the world, XXX. Pigot. *Indiaqua*, **46** (1987/1), 149–53.

Named after George Pigot, controversial Governor of Madras, the oval 48.63 ct diamond was probably acquired as a gift, and as such was partly the reason for Pigot's arrest and imprisonment in 1776. After his death in jail in 1777, the stone was sold for around £10,000, and later became the cause of three law suits following an abortive attempt to sell the stone to Napoleon. The Pasha of Egypt acquired the Pigot in 1822 for £30,000, but since that time the stone's whereabouts are unknown. P.G.R.

BALITSKY, V.S., BALITSKAYA, O.V. 1986. The amethyst-citrine dichromatism in quartz and its origin. *Physics and chemistry of minerals*, **13**, 415–21, 5 figs.

The amethyst-citrine dichromatism was studied as a function of the growth conditions of the specimens. The origin of the coloration is related to the variable way in which the colour-producing impurities are incorporated into the crystal; the impurities are dependent on growth direction and growth rate. The charge compensators also affect the thermal stability of the amethyst colour centres. M.O'D.

BANCROFT, P., 1987. Burnished splendor. *Lapidary Journal*, **41**, 2, 25–32, 5 figs (1 in colour).

Two celebrated mines, Charcas, San Luis Potosi, Mexico, and Morro Velho, Minas Gerais, Brazil, are described, with particular reference to silver and gold mining respectively. M.O'D.

BECK, C.W., LAMBERT, J.B., FRYE, J.S. 1986. Beckerite. *Physics & Chemistry of Minerals*, **13**, 6, 411–4.

Beckerite, a minor component of the amber fossil resins of northern Europe, has previously been classified as being mineralogically distinct from common Baltic amber, or succinite, on the basis of physical properties such as density, and chemical properties such as saponification number. It is shown here that beckerite and succinite are spectrographically identical, according to IR and 13C NMR methods. The deviations of beckerite are attributed to the presence of low levels of contaminants, such as decomposed wood and insect excrement. P.Br.

BERK, M., 1987. Wearable science. *Lapidary Journal*, **40**, 12, 25–31, 1 fig in colour.

General review of the use of man-made stones and their commercial relationship to natural ones. M.O'D.

BORELLI, A., CIPRIANI, C., INNOCENTI, C., TROSTI, R., 1986. Caratterizatione del lapis lazuli. (Characterization of lapis-lazuli.) *La Gemmologia*, **11**, 4, 24–7, 4 figs.

The minerals which together constitute lapis-lazuli are named and described; diopside, phlogopite, potassium feldspar, sodalite, calcite, wollastonite and pyrite occur with lazurite. Lazurite and wollastonite occur together in Chilean material

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while lazurite and diopside are found in lapis from Siberia and Afghanistan. M.O'D.

BROWN, G., 1986. Sphene. *Wahroongai News*, **20**, 11, 7–9, 3 figs.

A concise account of sphene, written from the point of view of the mineralogist. M.O'D.

BROWN, G., 1987. Chatham synthetic yellow sapphires. *Wahroongai News*, **21**, 1, 10.

Yellow sapphires are reported to have been made by the San Franciso firm of Chatham. SG is said to be 4.0 and RI 1.762–1.770 with a DR of 0.008. No other details are given apart from inclusions normal in flux-grown material. M.O'D.

BROWN, G., 1987. Peridot. *Wahroongai News*, **21**, 1, 11–14, 3 figs.

A concise comprehensive account of olivine and the peridot gem variety. M.O'D.

BROWN, G., 1987. Gem scapolite. *Wahroongai News*, **21**, 2, 13–17, 4 figs.

A detailed account of the mineralogy and gemstone potential of the scapolite family. M.O'D.

BROWN, G., 1987. Opal. *Wahroongai News*, **21**, 3, 14–25, 11 figs.

A useful overview of precious and synthetic opal. M.O'D.

BROWN, G., SNOW, J., 1987. Ivorina – a new ivory imitation. *Australian Gemmologist*, **16**, 5, 178–80, 3 figs.

An American imitation ivory is shown to be formulated casein, a milk derivative which is far from new. H 2 to 3, easily peeled, SG 1.34, RI 1.55; fluoresces white to bluish-white; mouldable under heat. R.K.M.

BROWN, G., SNOW, J., KELLY, S.M.B., 1987. A gemmological study club miscellany. *Australian Gemmologist*, **16**, 5, 195–8, 13 figs in colour.

A jet bead with SG 1.182 was lower than values quoted in most textbooks, but within the 1.10 to 1.40 range for brown coal, of which jet is a variety. A string of coated plastic beads imitating Biwa cultured pearls was found to show no central cavity under X-rays and was easily detectable by lens. A 1.08 ct sapphire, probably from Anakie, Queensland, changed from khaki-green in daylight to brownish-mauve in incandescent light – microscope revealed needles or fibres in straight bands. Orissa garnets, from Sarif International of Jaipur, were shown to be of the pyrope-almandine series. A home-made Australian 'synthetic' opal was found to be a bullet-shaped clear plastic dome filled with opal fragments embedded in a thermo-setting plastic; it did not have the normal characteristics of synthetic opal; bubbles were present and the container was easily recognized from the back. R.K.M.

BUKIN, G.V., GODOVIKOV, A.A., KLYAKHIN, V.A., SOBOLEV, V.S., 1986. Growth of emerald single crystals. *Growth of Crystals*, **13**, 251–60, 13 figs.

A short account of the various growth methods for emerald. M.O'D.

CAI, X., CAO, J., FU, Y., TANG, R. 1985. (ESR study of 'Guizhou jadeite'.) *Acta Mineralogica Sinica*, **5**, 3, 221–8. (Chinese with English abstract.)

An investigation of the green gemstone known as 'Guizhou jadeite' by electron spin resonance spectroscopy shows it to be a mixture of white quartz, green dickite and an organic substance. The green colour in the dickite is shown to be due to the presence of Cr^{3+}. R.A.H.

CAVENEY, R.J., 1987. De Beers Diamond Research Report No. 23. *Indiaqua*, **46** (1987/1), 141–5.

This review of the technical achievements at the Johannesburg Diamond Research Laboratory includes the improvement of diamond recovery by grease and X-ray sorting, the optimization of rock crushers at Kimberley where feedback control systems have been introduced, and a method of reducing the operating costs and water consumption at the mines by the identification and rejection of waste rock from the ore as early as possible in the treatment process. P.G.R.

DE MICHELE, V., 1986. La bilancia idrostatica, un'invenzione giovanile di Galileo Galilei. (The hydrostatic balance, a youthful invention of Galileo Galilei.) *La Gemmologia*, **11**, 4, 28–35.

The hydrostatic balance was invented by Galileo Galilei in 1586 and his account of the instrument is reproduced. M.O'D.

FEDERMANN, D. 1986. Der Iolith: der neue 'Billig'-Saphir. (Iolite, the new inexpensive blue sapphire.) *Goldschmiede Zeitung*, **81**, 11, 104, 1 fig in colour.

Suggests iolite as an alternative to blue sapphire for jewellery use. M.O'D.

FOORD, E.E. 1986. Le pegmatiti di Mesa Grande, San Diego County, California. (The Mesa Grande pegmatites, San Diego County, California.) *Rivista mineralogia Italiana*, **9**, 3, 111–26, 19 figs (14 in colour).

An account of the tourmaline and other pegmatitic

gem and other minerals found in San Diego County, California. First published in *Mineralogical Record*, 8, 6. M.O'D.

FRITSCH, E., STOCKTON, C.M., 1987. Infrared spectroscopy in gem identification. *Gems and Gemology*, **23**, 1, 18–26, 12 figs, mostly in colour.

Organic molecules give sharpest absorption bands in infrared and provide a safe test for opals impregnated with organic polymers, and for turquoise, for water in hydrothermal synthetics and for identifying types Ia, Ib, IIa and IIb in diamond. Experimenting continues, particularly with coloured diamonds, natural/synthetic amethyst and corundum, impregnation of gems other than opal and with gem identification by infrared means.

A separate account of the Nicolet 6SX Transform Infrared Spectrophotometer is given. R.K.M.

FRYER, C.W. (Ed.), CROWNINGSHIELD, R., HURWIT, K.N., KANE, R.E., 1987. Gem Trade Lab notes. *Gems and Gemology*, **23**, 1, 43–9, 19 figs in colour.

A large light green paste with RI 1.529 and SG about 2.50 with straight parallel strain banding on polariscope was deceptive if accepted on sight. A diamond with unusual bright green inclusions (probably diopside or enstatite) and a yellow diamond with a large rectangular prism knot are described. Of two diamonds colour tested, one was a natural fancy brown, the other, yellow (0.23 ct), fluoresced chalky-blue in short-wave UV and was inert in long-wave UV, showed no absorption lines and had an hour-glass pattern of graining, identified as one of the new Japanese synthetic diamonds, the first encountered in a Trade situation.

A faceted diaspore was seen with a colour change from yellow-green to yellow-brown, RI 1.702–1.750 with typical absorption lines in the blue and violet. Opaque black water-worn pebbles from diamond localities in South America identified by X-ray diffraction as goethite-like although SG and H did not match that mineral, possibly partially altered. A hematite tested by its strong magnetic polarity was identified as lodestone, a form of magnetite which can oxidize to hematite. A 'nephrite' necklace with RI 1.55, SG 2.65 and H 7, was shown to be green dyed quartzite.

A black calcareous 'pearl' from a clam had 'golf ball' surface patterning resembling black *Hexagonaria* coral and fluoresced a faint orange in long-wave UV. A colour picture of pearls against two contrasting backgrounds demonstrated that apparent pearl colour is affected by background.

A fossiliferous chalcedony was identified as *Turritella* agate, the result of quartz replacing the original limestone of included shells, this one contained flecks of gold. A range of three cat's-eye and star quartzes exhibited variations of the normal phenomena. A ruby doublet was identified in which both parts were natural material, a bezel setting would make this difficult to detect [polariscope and unmatched extinction?]. A number of heat treated rubies had smooth shallow oval or round spalling depressions in pavilion facet surfaces. A sapphire, probably heat-treated 'geuda', showed a small zone of brown colour. Report mentions that Australian stones heated to lighten colour do not need repolishing and are, so far, undetectable: many are sold mixed in Thai parcels. Most items are illustrated. R.K.M.

GARCIA, R., LEGUEY, S. 1986. Gemmological study of minerals from the spodumene group. *Morphology and Phase Equilibria of Minerals*, Sofia: IMA, 2, 421–31.

Chemical analyses and cell parameters are given for spodumene kunzite and hiddenite from Minas Gerais, Brazil. R.A.H.

GARCIA-GIMENEZ, R., LEGUEY-JIMENEZ, S., 1987. Co-ordonnees chromatiques C.I.E. sur les tourmalines de Tanzanie. (CIE chromatic co-ordinates for Tanzanian tourmalines.) *Revue de Gemmologie*, **90**, 17–19, 6 figs (1 in colour).

The various columns shown by Tanzanian tourmalines are evaluated using CIE colour co-ordinates. M.O'D.

GARCÍA GIMÉNEZ, R., MORANTE, M., MEDINA, J.A., LEGUEY, S. 1985. Posibilidades gemológicas de los ópalos y materiales silíceos de la zona de Esquivias Valdemoro en la cuenca de Madrid. (Gemmological possibilities of the opal and siliceous materials of the zone of Esquivias Valdemoro in the Madrid basin.) *Boletín de la Sociedad Española de Mineralogía*, 8, 65–72.

The mineralogical, optical and textural characteristics of siliceous opaline minerals with diverse coloration are analysed from the gemmological viewpoint. The samples studied are located at different levels and in thicknesses varying 0.15–0.20 m and 0.59–0.8 m, associated with sepiolite and palygorskite deposits in the Esquivias and Cerro Batallones zone south of Madrid. Black and white opals are found, with cristobalite as the principal component in both. Organic matter with paramagnetic activity and the laminate texture are the causes of the coloration and iridescence in the black variety. The Al impurities and the globular texture explain the nacreous whiteness and fluorescence in the wite opals. The organic content

and high porosity of these opals permit modification of their colour by thermal treatment of dyeing.
P.Br.

GUO, J., CHEN, F., DEN, H., TAN, Y., RONG, Z., DEN, E., 1986. (The colour of placer diamonds in Hunan.) *Acta Mineralogica Sinica*, 6, 2, 132–8. (Chinese with English abstract.)

In these yellow, brown and green diamonds there are two types of colour centre; one is represented by nitrogen atom centres (single N atoms and N3 centres) and the other by irradiation damage centres (GR 1, 637, 595, H3, H4 and 3H). The geological implications of these centres are discussed. The 595 centre is quite common in these natural diamonds of Hunan and should not be used as the only criterion to distinguish untreated stones; the 3H centre has been detected in irradiated natural diamond. R.A.H.

HÄNNI, H.A., BOSSHART, G., 1987. Schäden an geschliffenen Diamanten. (Damage to cut diamonds.) *Goldschmiede und Uhrmacher Zeitung*, 85, 5, 83–5, 9 figs.

An English version of this article was published in the *Journal of Gemmology*, 20, 6, 339–43. M.O'D.

HARDER, H., 1987. Das Brennen von Saphiren. (Heating of sapphire.) Lapis, 12, 4, 15–19, 6 figs (3 in colour).

The heat treatment of mainly colourless corundum to give a blue colour is described. M.O'D.

HARDER, H., SCHNEIDER, A. 1986. Isomorpher Einbau von Eisen und Titan zur Erklärung der blauen Farbe von Rutil- und Spinell-haltigen seidig weissen Korunden nach einer Wärmebehandlung. (Solid solution of iron and titanium as the explanation of the blue in rutile and spinel containing corundum with silk-rich or milky appearance after heat treatment.) *Neues Jahrbuch für Mineralogie*, 5, 209–18, 5 figs.

Silk-rich and milky corundum has been altered to a sapphire blue after heating to temperatures above 1550°C. The blue in natural sapphire is ascribed to electron transition between Fe^{2+} and Fe^{3+} and in synthetic blue sapphire to the transition between Fe^{2+} and Ti^{4+}. A rutile and spinel matrix containing milky corundum rich in silk had a low Ti and Fe content. Heating the matrix to 1600°C for only 30 minutes sufficed to resolve almost all the Ti and Fe of the rutile and spinel into the corundum, causing a fine sapphire blue by the transition between Fe^{2+} and Ti^{4+} which was now possible.
M.O'D.

KATO, M., 1987. (Scintillation.) Journal of the Gemmological Society of Japan, 12, 1/4, 12–19, 9 figs. (In Japanese.)

The author postulates that scintillation consists of radiation and reflection from facets with the greater part being played by the former. Angular measurements are made and discussed. M.O'D.

KATO, M., 1987. (Star facet brilliancy.) Journal of the Gemmological Society of Japan, 12, 1/4, 20–3, 6 figs. (In Japanese.)

An attempt was made to increase the brilliancy of a diamond by cutting additional star-type facets on the pavilion. Results found that the brilliancy was somewhat improved though there was some twinkling and no flash. M.O'D.

KOIVULA, J.I., 1987. Gems news. *Gems & Gemology*. 23, 1, 52–5, 4 figs in colour.

A 'diamond' ring, reported by a South African laboratory, was proved to be a cubic zirconia with a diamond coating and was said to have fooled a thermal diamond probe. A reference to O'Donoghue's 'identifying man-made gems' is inaccurate here.

Tucson Gem and Mineral Show '87 is reported in short paragraphs under different gem headings. Iris agate, colour-zoned fluorite sold as amethyst, a fine carved quartz container and a red-purple scapolite are illustrated. R.K.M.

KOIVULA, J.I., 1987. Inclusion related iron theft in amethyst. *Australian Gemmologist*, 16, 5, 191–2. 3 figs in colour.

Acicular inclusions of iron minerals, goethite and lepidocrocite, viewed end-on, were found to be surrounded by zones of colourless quartz, indicating iron-depletion by the inclusions which had the greater need for the metal. R.K.M.

KOSNAR, R.A. 1986. La Montagna Italiana del Colorado. (Italian Mountain, Colorado.) *Rivista Mineralogica Italiana*, 9, 3, 131–5, 7 figs (6 in colour).

Among the gem minerals found at this location are yellow andradite, vesuvianite, hessonite and epidote. M.O'D.

LAHTI, S., SAIKKONNEN, R., 1986. Kunzite from the Haalpaluoma pegmatite quarry, western Finland. *Bulletin of the Geological Society of Finland*, 58, 2, 47–52, 1 fig. in colour.

A purple transparent kunzite crystal of about 7 cm in length has been found at the Haalpaluoma feldspar quarry in western Finland. The kunzite is embedded in a purple, fine-scaled lepidolite. RI is given as 1.660, 1.665 and 1.679. M.O'D.

LEUNG, C.S., MERIGOUX, H., POIROT, J.P., ZECCHINI, P. 1986. Use of infrared spectrometry in gemmology. *Morphology and Phase Equilibria of Minerals*, Sofia: IMA, 2, 441–8.

IR spectroscopy offers a rapid technique for checking whether a stone is natural or synthetic. Both reflection and transmission methods are useful: the first gives mineral identification (even while mounted in jewellery) and the second allows a distinction to be made between natural and synthetic stones. Examples are given for beryl, chrysoberyl, quartz and topaz. R.A.H.

LICHANG, Q., 1985. Synthetic diamond in China. *Progress in Crystal Growth and Characterization*, **11**, 4, 245–61, 1 fig.

A short account of work done on the synthesis of diamond in China; deals mainly with organization and staffing with notes on a number of possible techniques for diamond growth. M.O'D.

MALISA, E., KINNUNEN, K., KOLJONEN, T., 1986. Notes on fluid inclusions of vanadiferous zoisite (tanzanite) and green grossular in Merelani area, northern Tanzania. *Bulletin of the Geological Society of Finland*, **58**, 2, 51–8, 9 figs (3 in colour).

Tanzanite crystals occur mainly in boudinaged pegmatic veins and hydrothermal fracture fillings in a brecciated and hydrothermally altered graphite-bearing diopside gneiss. There appear to be two generations, one (brown) being older than the other (blue) type; the latter has more pronounced pyramidal faces. Negative crystal-shaped primary inclusions may be surrounded by liquid or gas filled microcracks in the tan-coloured tanzanites, but are not reported from the blue ones. It may be that the blue crystals were originally tan coloured and were altered to blue as temperature rose in the surrounding rocks after crystallization.

Graphite flakes and secondary fluid inclusion cavities are found in gem-quality green grossular associated with the tanzanite. M.O'D.

MATTSON, S.M., ROSSMAN, G.R., 1987. $Fe^{2+}-Fe^{3+}$ interactions in tourmaline. *Physics and Chemistry of Minerals*, **14**, 163–71, 11 figs.

Colour and spectroscopic properties of Fe-bearing tourmalines do not vary smoothly with Fe concentration. Details of a possible new cause of the manifestation of the interaction between two states of Fe are given. M.O'D.

MYAKYU, K., 1987. Le jade birman. (Burmese jade.) *Revue de Gemmologie*, **90**, 4–6, 2 figs in colour.

A short account of the jade-bearing localities in Burma, with geographical co-ordinates. M.O'D.

NASSAU, K., 1987. The current decade: synthetic gemstones in the 1980s. *Lapidary Journal*, **40**, 12, 32–42, 6 figs in colour.

The present position of man-made gem materials is reviewed. Details and references to the products are given, together with means of identification. M.O'D.

NASSAU, K., SHIGLEY, J.E. 1987. A study of the General Electric synthetic jadeite. *Gems & Gemology*, **23**, 1, 27–35, 10 figs in colour.

GE have synthesized small discs of jadeite in white, grey, green, lavender and black, by means of high pressure apparatus used in the synthesis of diamond. Process took up to 24 hours at 30 to 50 kilobars of pressure and at temperatures of 1200°C to 1400°C. Samples were rather harder than natural jadeite, but fluoresced similarly. RI about 1.65+, SG by hydrostatic weighing around 3.27. Spectra resembled those for natural jadeite but 437 nm line was missing. The illustrations suggest that the synthetic discs lack somewhat in homogeneity and resemble poor quality fissured natural jadeite. Might be improved upon, but extreme cost of process suggests that this is unlikely. R.K.M.

O'DONOGHUE, M., 1986. Kamienie szlachetne i ozdobne wysp brytyjskich. (Gem minerals of Great Britain.) *Mineralogia Polonica*, **17**, 1, 111–14.

Gem quality and ornamental minerals from the British Isles are described and discussed. M.O'D.

O'DONOGHUE, M., 1987. Gems & Gemmology. *Watchmaker, Jeweller and Silversmith*, May 1987, 37–9, 3 figs.

Subjects reviewed include the sale of the Duchess of Windsor's jewels, inclusions in amber and corundum, recent books and information on opal and on instruments. Notices of papers in the *Journal of Gemmology*, 1987, 20, 5, are included. (Author's abstract) M.O'D.

O'DONOGHUE, M., 1987. Poland as a gemmological centre. *Indian Gemmologist*, **1**, 2, 31–3.

A visit to Poland in 1981 included the Skawina plant where synthetic corundum is manufactured. Other Polish minerals include chrysoprase. (Author's abstract) M.O'D.

O'LEARY, B., 1987. Some more on crystal opal. *Australian Gemmologist*, **16**, 5, 175–7.

An anecdotal history of the vexed term 'crystal' which has become attached to certain fine specimens of the amorphous gem opal. R.K.M.

ORLOVA, M.P., CURANOVA, V.N., SOSEDKO, T.A., CHEREPANOV, V.A., SHADENKOV, E.M. 1986. Mineralogy and genesis of chrome-diopside from the Inagli Massif (Aldan). *Morphology and Phase Equilibrium of Minerals*, Sofia: IMA, **2**, 449–60, 1 map.

Gem varieties of chrome diopside from the pegmatites of the Inagli alkaline ultrabasic massif, Siberia, have Cr_2O_3 0.07–1.58% with total Fe as Fe_2O_3 1.3%. The crystals are often zoned, with Mg and Cr decreasing towards their margins. With increasing Cr content, there is a tendency for the *c* parameter to increase while *b* decreases slightly. In some of the transparent emerald-green varieties appreciable Na_2O marks the entry of the acmite molecule. R.A.H.

PETROSYAN, A.G., 1986. General method of formulation and crystal growth of ornamental garnets. *Crystal Research and Technology*, **21**, 11, 1375–81, 5 figs.

The shift of absorption lines from Eu^{2+}, Yb^{2+} and Zr^{3+} ions resulting from crystal field variations in c-sites of the garnet lattice is considered with regard to the possible growth of ornamental garnets with a smooth colour range from violet to red. M.O'D.

POUGH, F.H., 1987. Trophy tourmalines. *Lapidary Journal*, **40**, 11, 20–32, 4 figs in colour.

A general account of the tourmaline group of gemstones with beautiful illustrations. A table of end-member compositions is given. M.O'D.

POUGH, F.H., 1987. Amethyst. *Lapidary Journal*, **40**, 11, 16–18.

A short account of the amethyst gemstones, including comments on synthetic material and the commercial role of the stone. M.O'D.

POUGH, F.H., 1987. Gem treatment: lapis lazuli. *Lapidary Journal*, **41**, 1, 18.

A brief note on the ways in which lapis-lazuli can be imitated and treated. M.O'D.

POUGH, F.H., 1987. Moonstone and feldspars. *Lapidary Journal*, **41**, 2, 15–18.

Some of the ways in which the feldspar gemstones can be treated should have been discussed as the article forms part of a continuing series on such matters but the author correctly says that feldspars are not usually altered in any way. M.O'D.

PROUT, B.A.W., 1986. Cut steel jewellery. *Wahroongai News*, **20**, 12, 10.

A short account of the manufacture of a diamond substitute from cut steel. M.O'D.

RAYMOND, J., 1987. Down in the dumps. *Lapidary Journal*, **40**, 11, 65–70, 2 figs (1 in colour).

The writer describes working on the dumps at Mount Mica, Maine, where tourmaline and quartz crystals are occasionally found. M.O'D.

READ, P.G., 1987. Thermal conductivity versus reflectivity. *Indian Gemmolgoist*, **1**, 2, 21–4, 4 figs.

The Gemtek thermal conductivity diamond tester is described. M.O'D.

READ, P.G. 1987. The gemmologist's mecca. *Canadian Jeweller*, January 1987, 12.

Contains a description of the gem displays in the headquarters of A. Ruppenthal KG at Idar-Oberstein, Germany, with a brief history of how the surrounding district developed into one of the gem centres of Europe. (Author's abstract). P.G.R.

READ, P.G., 1987. The chameleon gems. *Canadian Jeweller*, February 1987, 14.

Colour change in gems such as alexandrite and the rare colour-change varieties of spinel, corundum, tourmaline ('chameleonite' and diamond are discussed. Colour change simulants of alexandrite are listed together with identifying features. (Author's abstract) P.G.F.

READ, P.G., 1987. High-tech enhancements. *Canadian Jeweller*, March 1987, 14.

Several gem enhancement processes, which are spin-offs from high-tech industries, are listed including the recently publicized process of diamond coating (currently being developed for use in machine tools and for the production of radiation-proof microchips required in the USA Star Wars programme), A warning is given that identification methods may have to be revised if the process is used to coat diamond simulants such as cubic zirconium oxide. (Author's abstract) P.G.R.

READ, P.G., 1987. Balancing acts. *Canadian Jeweller*, April 1987, 14.

Traces the history of the development of the jeweller's electronic balance, and compares the weighing specifications and costs of typical precision and portable versions. (Author's abstract) P.G.R.

ROSEN, E., 1987. Appraising multi-coloured tourmaline. *Lapidary Journal*, **40**, 11, 50–6, 2 figs (1 in colour).

Criteria for assessing the commercial potential of multi-coloured tourmalines are given. M.O'D.

SCHMETZER, K., 1987. Production techniques of commercially available Knischka synthetic rubies – an additional note. *Australian Gemmologist*, **16**, 5, 192–4, 6 figs in colour.

Chemical investigation of flux and crucible residues reveals that platinum platelets and needles, from the crucible, and oxides of sodium, tungsten and tantalum, from the flux, may be found in commercial productions of Knischka synthetic rubies. These do not occur in natural rubies and provide a basis for routine identification of the synthetics. The commercial runs are spontaneously nucleated and seed crystals are not used. R.K.M.

SCHMETZER, K., 1987. Microscopic observation of twinning microstructure in natural amethyst. *Neues Jahrbuch für Mineralogie Monatshefte*, **1**, 8–15, 8 figs.

Micro-twinning in natural amethyst was investigated by optical methods. In one extraordinary sample from Brazil direct observation of twin boundaries was possible. In agreement with the model of McLaren and Pitkethly (1982)* polysynthetic Brazil twin boundaries in each growth sector confined to one of the major rhombohedral faces, e.g. r $(10\bar{1}1)$, are found to be orientated parallel to the two remaining major rhombohedral faces, e.g. r′ $(\bar{1}101)$ and r″ $(0\bar{1}11)$. In subsequent composition planes an alternating orientation of the predominant twin boundaries was observed. The external forms and orientations of liquid and two-phase inclusions in healed fractures of natural amethyst reflect the internal structure of the polysynthetically twinned crystals. The inclusions which are located within growth sectors confined to one major rhombohedral face form striations consisting of inclusions without particular elongated cavities. These stripes alternate with striations consisting of inclusions without particular external forms in the sequence abab. In one healing fracture located within growth sectors confined to two rhombohedral faces, striations with two different orientations of parallel elongated inclusions alternate with striations consisting of inclusions without dominant external forms in the sequence ababacac. The striations are located within the zones of Brewster fringes which are identical with the zones of continuous composition surfaces with lamellar microstructures parallel $\{10\bar{1}1\}$. These surfaces separate lamellae of right-handed and left-handed quartz. (Author's abstract.) K.S.

*McLaren, A.C., Pitkethly, D.R. 1982. The twinning microstructure and growth of amethyst quartz. *Physics and Chemistry of Minerals*, 8, 128–35.

SEGNIT, E.R., 1987. Decorative serpentinite from the Marble Bar area. *Australian Gemmologist*, **16**, 5, 182–3, 198, 4 figs in colour.

Marketed unfortunately as 'Pilbara jade', this soft material, found in the north-west of Western Australia, adds to the list of decorative stones. Dark green with grey-white areas and chrysotile veins. R.K.M.

SIBER, H.J., 1987. Peru heute. (Peru today.) *Lapis*, **12**, 6, 17–28, 22 figs (11 in colour).

In recent years minerals from Peru have appeared frequently on the market. Fine quartz and rhodochrosite specimens are among those of gem quality. M.O'D.

SIMONTON, T.C., ROY, R., KOMARNENI, S., BREVEL, E. 1986. Microstructure and mechanical properties of synthetic opal: a chemically bonded ceramic. *Journal of Materials Research*, **1**, 5, 667–74.

Using optical, scanning and electron microscopy plus X-ray, chemical and DTA, it is concluded that synthetic opal is composed of non-crystalline silica and crystalline (tetragonal) zirconia balls. K.A.R.

SLIWA, A.S., NGULWE, C.A. 1984. Geological setting of Zambian emerald deposits. *Precambrian Research*, **25**, 1–3, 213–28.

The Kafubu emerald deposits occur within rocks of the Muva supergroup which form the youngest part of the pre-Katangan basement immediately SW of the well-known Copperbelt of Zambia. Within the Muva supergroup are persistent bands of talc-chlorite-amphibole (tremolite/actinolite) -magnetite schist, which are intruded by pegmatites. These pegmatites are believed to be related to neighbouring granite rocks which originated or were rejuvenated during early stages of Pan-African orogeny. Pegmatites occur as feldspar-quartz-muscovite bodies or as minor quartz-tourmaline veins. Contact aureoles of the pegmatitic veins with the ultramafic schists are usually altered to phlogopite-biotite-tourmaline aggregates and the minor veins are often concordant to the foliation of the country rocks. The emeralds are found in the contact zones, and sometimes within the quartz-tourmaline veins. The emerald fields are considered comparable in quantity and quality of material to the well-known Colombian fields, but their lithological setting differs considerably. Striking similarities were found between the Zambian occurrences and those of South Africa and Zimbabwe. R.A.H.

STRIPP, D.M., 1987. More on Morefield. *Lapidary Journal*, **41**, 1, 21–6, 3 figs (2 in colour).

The Morefield mine at Amelia, Virginia, produces amazonite and other ornamental minerals, including agate, apatite, beryl and zircon. M.O'D.

SUNAGAWA, I. 1986. Morphology of diamonds. *Morphology and Phase Equilibria of Minerals*, Sofia: IMA, 2, 195–207.

Observations on morphology and surface microtopography of diamond crystals of three different origins are summarized and the observations are critically analysed in the light of present understanding of the growth mechanisms and morphology of crystals. The three types of diamonds are: (1) natural diamonds, including both single-crystals and polycrystalline aggregates. Both ultramafic suites (in kimberlite) and eclogite suites are discussed. All natural diamonds are grown from the solution phase of silicate compositions under diamond stable conditions; (2) synthetic diamonds grown by static high P under diamond stable conditions. They are grown from metal-carbon solution phases; (3) synthetic diamonds grown by pyrolysis or chemical vapour deposition processes of CH_4 or C_2H_2 under $P < 1$ atm. and high T conditions. They are grown under diamond unstable conditions from the vapour phase. Analysis of growth rates vs chemical potential provides information concerning the mutual relations among polycrystalline aggregates, dendritic, hopper and polyhedral crystals. Analysis of morphological characteristics of single crystalline diamonds and their surface microtopographs are based on the extent to which their morphologies deviate from the theoretical morphology. J.M.H.

TAY, T.S., 1987. Structural aspects of fingerprint inclusions in corundum. *Australian Gemmologist*, **16**, 5, 188–90, 5 figs in colour.

Microscopic examination showed that 'fingerprints', partially healed cracks in natural corundum, are often oriented in alignment with parting planes. Synthetic flux-grown corundum also shows 'fingerprints', but not in parallel alignment. R.K.M.

THEMELIS, T., 1987. Quenched cracked. *Lapidary Journal*, **40**, 11, 19, 2 figs in colour.

Describes the practice of heating and quenching certain transparent stones, with particular reference to ruby. Low-grade Chatham and Kashan stones are said to be regularly heated and quenched to give natural-looking inclusions. M.O'D.

THEMELIS, T., 1987. Idaho geuda. *Lapidary Journal*, **40**, 11, 57–62, 3 figs in colour.

Whitish corundum from central-east Idaho can be treated to give a blue colour as with some Sri Lankan material. The Idaho crystals come from a site called Floodwood Blue in Clearwater County. Details of mining and constants of the stones are given. M.O'D.

THEMELIS, T., 1987. Seed in synthetic ruby. *Lapidary Journal*, **40**, 12, 19, 2 figs in colour.

Two photographs of Chatham rubies are described with respect to their inclusions. M.O'D.

THEMELIS, T., 1987. Inclusion of the month: Lechleitner synthetic emerald. *Lapidary Journal*, **41**, 1, 19, 2 figs in colour.

Characteristic inclusions of the Lechleitner emerald are illustrated. M.O'D.

THEMELIS, T., 1987. Trapiche emerald. *Lapidary Journal*, **41**, 2, 19, 3 figs in colour.

The formation and structure of trapiche emerald are briefly discussed. M.O'D.

THOMAS, S.L., 1987. 'Modern' jewelry: Retro to Abstract. *Gems & Gemology*, **23**, 1, 3.17, 15 figs in colour.

A nicely illustrated account of the broader themes in jewellery design from the strangely named 'Retro' style in about 1940, onwards to the less easily identified styles of recent years. Many famous names are mentioned. R.K.M.

TORIWAKI, J., YOKOI, S., 1987. Rendering gems by computer graphics. *Journal of the Gemmological Society of Japan*, **12**, 1/4, 3–11, 17 figs (1 in colour). (In Japanese.)

The fashioning of gemstones can be helped by plotting the proportions and angles on a computer using a graphics package. M.O'D.

TROSSARELLI, C., 1986. Alessandrite sintetica prodotta in URSS. (Russian synthetic alexandrite.) *La Gemmologia*, **11**, 4, 6–22, 32 figs in colour.

Synthetic alexandrite made in the USSR is examined and its internal features illustrated in a bilingual paper. From an examination of rough and cut material it appears that they are produced by different methods, the cut by flux growth and the rough by crystal pulling. M.O'D.

VIKAMSEY, I., 1987. Kohinoor – the famous diamond. *Indian Gemmologist*, **1**, 2, 25–33, 7 figs.

The history of the Koh-i-Noor diamond is given. M.O'D.

VON KNORRING, O., CONDLIFFE, E., TONG, Y.L., 1986. Some mineralogical and geochemical aspects of chromium-bearing skarn minerals

from Northern Karelia, Finland. *Bulletin of the Geological Society of Finland*, **58**, 1, 277–92, 8 figs.

Characteristic chrome-bearing minerals from the skarn association at Outukumpu, northern Karelia, Finland, are re-examined. They include uvarovite, chrome tourmaline and chrome diopside. Uvarovite from this location is low in Fe, unlike examples described from other places. The best developed uvarovite crystals are found in a quartz-banded, chromian diopside-sulphide skarn. The crystals show dodecahedral and trapezohedral forms in a glassy quartz matrix. M.O'D.

WATANABE, K, 1987. Inclusions in flux-grown crystals of corundum. *Crystal Research and Technology*, **22**, 3, 345–55, 13 figs.

Flux-grown corundum has been found to contain flux inclusions, negative crystals and cavities. The process of inclusion formation is described. M.O'D.

YELLIN, J, 1987. Amber glow. *Lapidary Journal*, **40**, 11, 46–7, 5 figs in colour.

A short photographic essay on amber. M.O'D.

ZEITNER, J.C., 1987. Enter China. *Lapidary Journal*, **40**, 11, 42–5, 3 figs in colour.

Gem material is coming on to the international market from China, including coral, jade, quartz and turquoise. M.O'D.

ZEITNER, J.C., 1987. Tourmalines of Pala. *Lapidary Journal*, **40**, 11, 34–41, 3 figs (2 in colour).

Tourmaline from the pegmatites in the Pala area of San Diego County, southern California, are described with notes on the history of mining in the area. M.O'D.

ZEITNER, J.C., 1987. No 'sin' in synthetics. *Lapidary Journal*, **40**, 12, 20–4, 3 figs in colour.

A short account of the better-known man-made gemstones. M.O'D.

ZEITNER, J.C., 1987. Riotous thundereggs of Madras, Oregon. *Lapidary Journal*, **41**, 1, 27–32, 2 figs in colour.

Fine plume agate and thundereggs are found at mines in the Madras area of Jefferson County, Oregon. The locality and access are described. M.O'D.

ZHANG, D.B., HE, X.M., CHEN, J.P., WANG, J.C., TANG, Y.F., HU, B.L., 1986. Research on crystal growth and defects in cubic zirconia. *Journal of Crystal Growth*, **79**, 336–40, 6 figs.

Cubic zirconia grown by the skull melting method is investigated. Specimens had distribution coefficients of stabilizers Y_2O_3 and CaO greater and less than 1 respectively. Nearly colourless large single crystals were obtained using 10–12 mol% Y_2O_3 as stabilizer. SEM studies show that Si, Ca, Mg, Y, etc., occur mainly at the ends and in the centre of the crystal. M.O'D.

ZHANG, L.H., 1985. GGG and related compounds. *Progress in Crystal Growth and Characterization*, **11**, 1, 283–9, 2 figs.

Gives notes on the growth and structure of GGG with a list of possible dopants. M.O'D.

ARGYLE DIAMONDS JOINT VENTRE, 1987. *Rio Tinto Zinc Corporation Review*, 2 (June 1987), 13.

Full production from Argyle (world's largest diamond mine) began in March 1986. J.R.H.C.

ARGYLE DIAMOND MINE in AUSTRALIA, 1987. *Rio Tinto Zinc Corporation PLC Annual Report and Accounts for 1986*, 10.

The Argyle Mine, much the largest diamond mine in the world, completed its first full year of production with 29 200 000 ct output (mainly industrial, but also gems, including the rare pink). J.R.H.C.

AUSTRALIAN COLOURED DIAMONDS, 1987. *Wahroongai News*, **10**, 1, 17.

A system of listing reference colours for Australian diamonds is proposed with forty different descriptions. Many Australian diamonds show faint colours. M.O'D.

BERYLL. (Beryl.), 1987. *Goldschmiede und Uhrmacher Zeitung*, 85, 4, 98–115, 28 figs (18 in colour).

The beryl gems are reviewed by a number of authors. M.O'D.

BLUE JOHN. 1986. *Wahroongai News*, **20**, 12, 17–19.

An account of the Blue John variety of fluorite largely taken from Ollerenshaw and Harrison, *The history of Blue John stone*, 2nd edition. M.O'D.

FLUORESCENCE 1986. *Wahroongai News*, **20**, 11, 12–13.

A table of the fluorescent effects seen in gem minerals. It is taken from the *Information Sheet* of the New South Wales Department of Mineral Resources. M.O'D.

Book Reviews

AREM, J.E., 1987. *Colour encyclopedia of gemstones.* 2nd edn. Van Nostrand Reinhold, New York. pp. vii, 248. Illus in colour. £39.75.

The updated edition of this book is as attractive as the first and with about 30 new species of gemstone to add, as well as some new varieties of already established ones, the text is again of considerable importance to the gemmologist. Moreover it is so arranged as to be quite easily assimilated by the discriminating reader who may not know much about the minerals from which the gemstones are fashioned.

As before, the gem species are arranged alphabetically though attention has been paid to the grouping of minerals in families where appropriate. Such groupings go far to explain the small differences in constants which so baffle the student, who often finds it hard to grasp the interplay of different elements in a mineral belonging to a group. This and other mineralogical matters are lucidly discussed in the preceding chapters, which also include useful explanations of colour measurement and specification. Details of the alteration of colour are specifically omitted, however. I would recommend the early portions of the book as an excellent study of the geology and mineralogy of gemstones.

In the descriptive portion of the book, entries take the same form as before with all important features provided, as well as notes on the commercial significance of the stones. Tables give the constants of some major gemstones which occur in a wide variety of environments, and this makes it easier for the reader to find the details he wants at a glance. Particularly welcome to this reviewer is the continuation of this section into the field of man-made products – the first time that they have received just this kind of well-deserved recognition. They are also illustrated in colour.

It is, of course, the colour pictures which were so great a feature of the previous edition and they are even more beautiful this time round – and there are more of them. All that expert positioning and lighting can do has been done and the specimens thus look their best. It is idle to criticize this as some have, as gemstones, unlike minerals in general, are meant to look beautiful and these superb pictures are completely successful. I recommend readers to look first at the coloured pictures of the man-made stones (bismuth germanium oxide and cadmium sulphide, for example) to see what a man-made product can look like.

There are several lists and tables as well as a bibliography and index. For such a book the price is amazingly reasonable and it will lift the spirit as the stones themselves do. M.O'D.

BECKER, V., 1987. *The jewellery of Rene Lalique.* Worshipful Company of Goldsmiths, London. pp.192. Illus. in colour. Price on application.

This most attractive book is the catalogue of an exhibition held from 28 May to 24 July 1987. Each piece carries a short caption and there is a short glossary and a bibliography. The permanent location for each piece is given, where appropriate. Quality of the illustrations is very high and the author and publishers are to be congratulated. M.O'D.

CLARK, G., 1986. *Symbols of excellence.* The University Press, Cambridge. pp.x, 126. 12 colour plates, 43 figures. £12.95.

Professor Grahame Clark has written a delightful and scholarly book (the printing of Pubic instead of Punic on p.10 is unfortunate!). After a first Introductory chapter, the following five chapters cover respectively Organic materials, Jade, Precious metals, Precious stones and The symbolic roles of precious substances, and Professor Clark's novel treatment of familiar subjects is most refreshing.

Rather unusually, the dust cover is worthy of careful preservation, as it bears an admirable and impressive illustration in colour of the fourteenth century silver-gilt gem-set and enamelled reliquary bust of Charlemagne (in the Aachen Cathedral Treasury), which is not reproduced inside the book. J.R.H.C.

DESAUTELS, P., 1987. *The jade kingdom.* Van Nostrand Reinhold, New York. pp. viii,118.

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Illus. in black-and-white and in colour. £31.45.

It is not easy to discuss the jade minerals without writing too academically or in so general and journalistic a manner that the book will have little to attract the reader. This book manages to avoid both extremes and though it does go a little overboard with diagrams in the text the general level and appearance should command a respectable readership.

Sensibly the book begins with a definition of jade and introduces nephrite and jadeite with some of their simulants, the latter having a short chapter to themselves. Jade testing comes next and is followed by sources of jade. I was particularly pleased to see the complex topic of jade occurrence succinctly dealt with here and a table at the end of the chapter gives a surprisingly large number of countries in which worked jade objects from prehistoric times had been found.

We then begin to survey the significance of jade to the Chinese and to look at Chinese symbolism in artefacts generally. One important point is missed here; an object was particuarly venerated by the Chinese if it could be inscribed. Many jade artefacts are so inscribed, and I should have liked to see some examples of this, as the choice of character can often give a clue to the dating of a piece. Such a section could have displaced the somewhat tedious series of whole-page drawings of figures and objects which are not particularly well executed, nor is their significance really adequately explained.

Jade in the New World deals with Mesoamerican jade, and subsequent chapters cover New Zealand and Asian material. The book ends with a discussion of jade fashioning (again with over-large diagrams) and with a bibliography and index.

Apart from the loose and breathless style so often found in books of this level, I found this well worth reading and can recommend it. The colour pictures are first class. M.O'D.

FRAQUET, H., 1987. *Amber*. Butterworths, London. pp.xii. 176. Illus. in black-and-white and in colour. £25.00.

Amber differs from other gem materials in that it usually forms the whole of an artefact. For the researcher this means that a good deal of time and attention has to be devoted to the development of the artefacts, which in the case of amber go back to Palaeolithic times. Chapter 2 of the book (the first chapter is the profile, a feature common to the *Butterworths Gem Book series*) deals with the use of amber in antiquity up to a time felicitously called 'Unsettled Europe', the first millennium AD. This period has a chapter to itself, including its own bibliography; the other chapters also have short bibliographies. The Renaissance period and artefacts dating from the thirteenth to the eighteenth centuries are described in chapter 4. Before the marked increase in the use of amber for ornament in the nineteenth and twentieth centuries and the simultaneous development of substitutes, a short chapter on the medicinal use of amber is inserted. Gemmologists will find the book interesting up to this point and both interesting and important thereafter. Considerable research has been carried out into commercial history, both of amber and its imitations, and provides welcome notes of authenticity in a field notoriously subject to conjecture. Later chapters deal with amber from Asia, Sicily, Romania, the Dominican Republic and Mexico. Then follow chapters on resins, amber identification, more advanced identification techniques, the botanical parentage of resins and inclusions. Three appendices are devoted to the geological ages, amber in the USA and infrared spectra of amber samples respectively.

This book should be purchased by all practising gemmologists who will read it with ease and great enjoyment. It is no small feat to produce a book with so much authenticated material and the English is lucid. The colour pictures, occupying a section to themselves, have reproduced well. M.O'D.

JENSEN, D.E., 1978. *Minerals of New York State*. Ward Press, Rochester. pp.220. Illus. in black-and-white and in colour. £7.95.

This is a professionally-written state mineralogy in which the minerals are arranged alphabetically after introductory material giving details of mining history and mineralogy in the state. There is an excellent bibliography. Minerals of gemmological interest include lapis-lazuli and labradorite. M.O'D.

JORIS, A., 1986. *A destiny in diamonds*. Boolarong Publications, Brisbane. pp.vi, 113. Illus. in black- and-white. £18.00.

This autobiography of a well-known figure in the Australian industrial diamond world contains a good deal of anecdote and useful information written in an easy style. Those with an interest in the Australian diamond scene and in its history should buy the book. M.O'D.

KESSE, G.O., 1985. *The mineral and rock resources of Ghana*. Balkema, Rotterdam. pp.xiv, 610. Illus. in black-and-white. Fl 150.00.

Pages 362-400 describe Ghana's diamond deposits with details of diamond discoveries and mining. The mode of occurrence of the diamond crystals is discussed and production statistics included. M.O'D.

LONECK, A. 1986. *Opals, rivers of illusions*. Gemcraft, East Malvern, Victoria. pp.64. Illus. in black-

and-white and in colour. Price on application.

This attractive book can be recommended; though written in a breathless style with a multiplicity of paragraphs and though too many varietal and other names are thrown up and left unexplained, the text none the less is well worth reading and very informative. Details of recent research on the cause of play of colour were new to me and could well be expanded elsewhere. Notes on production in countries other than Australia are also welcome.

M.O'D.

LOUDERBACK, G.D., 1985. *Benitoite, California state gemstone*. The Gemmary, Redondo Beach, California. Irregular pagination. Illus. in black-and-white. £5.00.

This is a most interesting and useful reprint of two papers on benitoite first published in 1907 and 1909. They appeared in the *Bulletin* of the Department of Geology of the University of California and deal with the discovery, composition, properties and crystallography of the mineral. M.O'D.

MEARS, K., 1986. *The crown jewels, Tower of London*. Department of the Environment, London. pp.44. Illus. in colour. £1.95.

A new popular guide to the crown jewels in always welcome. This is attractively presented, with just enough history and the emphasis on the excellent colour pictures of the regalia. M.O'D.

MULLER, H., 1987. *Jet*. Butterworths, London. pp.ix, 149. Illus. in black-and-white and in colour. £22.50.

This is the only monograph on jet to have been published and is particularly welcome on that account alone. One of the series *Butterworths Gem Books* it gives not only the description of the material and its properties that we have come to expect from this series but also goes into considerable detail on the working and distribution of jet. This in-depth survey is possible because the handling of jet has traditionally been confined to one place in the world, Whitby in North Yorkshire.

The book opens with a profile of jet, following the convention of the series. Details of geology and mining follow, with a chapter on jet in history and another on the Whitby jet industry. Notes on the care of jet are included in this chapter.

The general reader will probably find the next chapter the most immediately appealing as it describes the many types of ornament that have been fashioned from jet. Dating of jet pieces is notoriously difficult but the author does her best to give dates for the major styles,and this alone is most useful.

Jet is then followed through the rest of the world before details of the simulants are given. Some of these, I have to admit, have their own attraction, and I have often sought a piece of worked vulcanite! Appendices give short notes on where jet may be found; on jet fashioning; a list of Whitby jet ornament manufacturers 1849, and of jet merchants and ornament manufacturers 1867 from the same town; similar lists are given for 1890 and 1905. There is an index and each chapter includes its own bibliography. The central section of colour pictures is successful, especially when we bear in mind that jet is black.

All who are concerned with the study of ornamental materials should buy this very reasonably-priced book. M.O'D.

O'DONOGHUE, M., 1986. *The literature of gemstones*. British Library, Science Reference and Information Service, ISBN 0-7123-0738-9. pp75 plus 2 pages of crystal diagrams. £12.00.

This is an extremely useful little book (booklet would, I think, be a better description), by the Curator of Earth Sciences at the British Library. Starting with a general preface and introduction, it attempts, quite successfully, to list the more important works on gemmology under the following categories: encyclopaedic works, general comprehensive surveys, gem testing, gem testing instruments, quick reference publications, textbooks, synthetic gemstones, fashioning, works on individual species, jewellery, gemstones of particular localities, bibliographies, abstracts, journals, gemstone prices, guides to collections, and regalia.

The works are listed with their publication details, including if and where held by the British Library, and, in many cases, with helpful descriptions by the author. The book ends with a useful index, followed, inexplicably, with two pages of beryl and corundum crystal diagrams.

The literature of gemmology is extremely large, so the selection is necessarily a personal one by the author. Many people will, I suspect, be surprised by the omission of some of their favourite works. The reviewer was personally most surprised by the exclusion of *Diamonds and precious stones* by Emanuel, 1865 and 1867, as this book contains an extremely extensive bibliography of historic books on gemstones.

I would, however, certainly recommend *The literature of gemstones* (together with the author's companion work *The literature of mineralogy*) to anyone interested in gemmology, in spite of the unfortunately high price of a soft covered booklet of little more than photostat quality. N.B.I.

O'Donoghue, M., 1985. *Putevoditel po mineralam.* (Beginner's guide to minerals.) Nedra, Leningrad. pp.206. Illus. in black-and-white and in colour. C.50.

Translation of a work first published by Newnes-Butterworth in 1982. (Author's review) M.O'D.

Panczner, W.D., 1987. *Minerals of Mexico.* Van Nostrand Reinhold, New York. pp.xiii, 459. Illus. in black-and- white and in colour. £38.65.

Mexico, a leading producer of a large number of metal ores, is also important to the gemstone trade for its fine opals, topaz and rarer minerals such as smithsonite and chrome sphene. A useful guide was published by G.F. Kunz in 1902 but this lengthy paper, in *Transactions of the American Institute of Mining Engineers,* is now one of gemmology's rare pieces.

The present book lists the minerals in alphabetical order after chapters giving details of the geography, geology, mineralogy and mining history. At the end there is a gazetteer, particularly useful for those with access to geological maps of the country. Reproduction of the descriptive section is, successfully, from typewriting which helps to keep the price manageable for these days. The bibliography is large and welcome. M.O'D.

Roedder, E., 1984. *Fluid inclusions.* Mineralogical Society of America, Washington. pp.vi, 644. Illus. in black-and-white. Price on application.

This volume forms no. 12 of the series *Reviews in mineralogy,* formerly *Short course notes.* The latter series title indicates the aim of the publishers to present the latest information on a variety of mineralogical topics, and the author in this case introduces studies of all types of inclusions, gas, liquid or melt. Unlike other books in the series, this is a single-author work, and the author has carried out a very comprehensive survey of the subject.

After an introduction to fluid inclusions, the author describes how they arise and how they may be altered by trapping in their host. Then come chapters on inclusion identification and on the interpretation of their presence. Chapters on various environments follow, and there are subject and locality indexes and a very comprehensive set of references. Gemmologists will find much bearing on their subject; students of diamond formation, in particular, will turn to chapter 17, on upper mantle environments, in which there are several sections on diamond. M.O'D.

Sobolev, N.V., 1977. *Deep-seated inclusions in kimberlites and the problem of the composition of the Upper Mantle.* American Geophysical Union, Washington. pp.viii, 279. Illus. in black-and-white. Price on application.

Though published some time ago, this is so important a text that readers should be aware of it, since it gives an insight into the formation of and inclusions in diamond. The Russian edition was published in 1974. There is an extensive bibliography. M.O'D.

Vargas, G., and Vargas, M., 1985. *Descriptions of gem materials.* 3rd edn. Vargas, Thermal, California. pp.x, 180. Price on application.

Descriptions of gem materials has now become a standard work. Two alphabetical sequences cover natural and synthetic, materials and there are useful appendices giving stones arranged by their hardness, their specific gravities and their refractive indices, for the book is aimed primarily at the lapidary. Each entry gives chemical composition and other customary details, together with mode of occurrence and short details of place of origin and outstanding market features. Among the newcomers to this edition are clinohumite and sugilite. Virtually all minerals of possible ornamental significance are included and the section on synthetic stones includes some intriguing items. For the sake of academic completeness the crystal system of most synthetic tellurium oxide is tetragonal (the natural material is paratellurite). There is a short bibliography. As a general reference book the work succeeds admirably and is well worth obtaining. M.O'D.

Woodward, C., and Harding, R., 1987. *Gemstones.* British Museum (Natural History), London. pp.60. Illus. in colour. £4.95.

This is a most welcome and very well produced guide to the newly united gemstone collection of the British Museum (Natural History) and the Institute of Geological Sciences (now British Geological Survey). The standard of the coloured illustrations equals and even exceeds that of similar productions from overseas, and it is with considerable pleasure that we can now say that the world's best gemstone collections have a fitting guide. After introducing simple crystallography, light, cutting and the general rarity of gemstones, the book goes on to describe the major gem species, rarities and synthetics. Inclusions, gemstone deposits, gem testing and famous gems conclude this excellent book which could easily serve as an introductory gemmology text. M.O'D.

Proceedings of the Gemmological Association of Great Britain and Association Notices

OBITUARY

Mr Geoffrey Nicholls Betts, FGA (D.1959), died unexpectedly on 3 March 1987, aged 66.

His first occupation was in the legal profession and throughout his career he retained the elegant handwriting and attention to detail which he learned there.

He later entered the family jewellery and pawnbroking business in Birmingham, gaining considerable experience dealing in second-hand goods.

Following a period of wartime service in the Army, he studied gemmology at the Birmingham Jewellery School, obtaining his FGA in 1959.

In 1960 he joined Fattorini & Sons in Bradford as manager, diamond buyer and valuer, later becoming a director. There he developed his undoubted skills in the appraisal of gemstones. His encouragement and guidance to younger people who were making their way in the profession will be remembered with affection by those who came under his influence. He was well known and respected throughout the trade.

In his private life Geoff was an enthusiastic golfer, a keen bridge player and a former member of the Heaton Amateur Operatic Society. He will be sadly missed by his many friends.

He leaves a widow, a son, two daughters and six grand-children. D.M.L.

Mr Maurice L. Butterfield, FGA (D.1949), Stockport, died on 31 August 1986.

Mr Neville Deane, FGA (D.1954, Tully Medallist), Bewdley, died on 1 March 1987 aged 88. A full obituary will appear in the next issue of the *Journal*.

Mr Arthur Kermeth, FGA (D.1929), London, died on 2 October 1986 aged 76.

Mr Eric Renfrey, DFC, JP, FGA (D.1967 with Distinction), Ormskirk, died in March 1987.

Mr John Rogers, FGA (D.1980), Portrush, died on 2 September 1986.

GIFTS TO THE ASSOCIATION

The Council of the Association is indebted to Mr Julian R. Dimayaakyak, Naga City, Philippines, for a sample of tektite glass.

NEWS OF FELLOWS

On 20 May 1987 at the Annual Conference of the National Association of Goldsmiths held at the Grand Hotel Excelsior, Valetta, Malta, Mr Kenneth Scarratt, FGA, gave an illustrated lecture entitled 'Gemstone enhancement'.

On 27 May 1987 at Northwick House, Owles Road, Bournemouth, Mr Peter G. Read, C.Eng., MIEE, MIERE, FGA, gave an illustrated talk to the Wessex Branch of the National Association of Goldsmiths entitled 'The design of gem test instruments'. After the talk he gave a demonstration of prototypes of the new Rayner sodium lamp unit and a thermal version of the Rayner DiamondScan.

From 23 to 25 June 1987 Mr Michael O'Donoghue, MA, FGS, FGA, lectured during a series of courses given by the Precious Stone Training Services.

On 8 July 1987 at The British Library Mr O'Donoghue chaired a Seminar on New Materials Information Sources.

MEMBERS' MEETINGS

London

On 31 March 1987 at the Flett Theatre, Geological Museum, Exhibition Road, South Kensington, London SW7, Mr Konrad Wild gave a lecture entitled 'Gem cutting in Idar-Oberstein'.

On 16 June 1987 at the Flett Theatre, following the Annual General Meeting (see p.505) a Gemmological Forum was held, chaired by Mr David J. Callaghan, FGA, Chairman of the Council. The panel consisted of the following: Mr Christopher R. Cavey, FGA, Dr Jamie B. Nelson, Ph.D., FRMS, F.Inst.P., FGS, FGA, Mr Michael J. O'Donoghue, MA, FGS, FGA, Mr Peter G. Read, C.Eng., MIEE, MIERE, FGA, Miss Judy Rudoe and Mr Kenneth Scarratt, FGA. The subjects covered were as follows: how different types of animal ivory can be distinguished; why people see gemstone colours differently; how gemstone crystal growth began and why some growth methods are chosen in preference to others; developments in the use of the computer for gemmology; what we can learn from contemporary portraits about eighteenth and nineteenth century jewellery that looks rather cumber-

some or impractical to wear; and the position today with regard to synthetic gem-quality diamond.

On 10 September 1987 at the Flett Theatre Professor I. Sunagawa of the Institute of Mineralogy, Petrology and Economic Geology, Tohoku University, Japan, gave a lecture entitled 'Gemmology and the science of crystal growth'. In addition to slides, Professor Sunagawa illustrated his presentation with two films entitled 'Wonders of crystals' and 'In-situ observation of crystal growth in aqueous solution and high temperature silicate solution'.

Midlands Branch

On 24 April 1987 at Dr Johnson House, Bull Street, Birmingham, the Annual General Meeting was held, at which Mr Peter J. West, FGA, and Mr David M. Larcher, FGA, were re-elected Chairman and Secretary respectively. This was followed by an illustrated talk by Mr Gwilym Jones, FGA, with an emphasis on diagnostic inclusions in gemstones.

North West Branch

On 20 May 1987 at Church House, Hanover Street, Liverpool 1, Mr Alan Williams, FGA, introduced the controversial topic of the value of gemmological knowledge to the salesman in multiple jewellery shops. This evoked a lively discussion.

On 17 June 1987 at Church House Mrs Helen Muller, FGA, gave an illustrated talk on jet, its origin, history and artefacts, and the identification of jet from its substitutes.

On 1 July 1987 at Church House Mrs Valerie Duke presented a beautifully photographed illustration of the development of jewellery fashions to complement costumes from 1066 to the 1900s. The latter section of the evening was a display of Brazilian gemstones.

On 16 September 1987 at Church House Dr J.W. Harris, B.Sc., M.Sc., Ph.D., of the Department of Applied Geology, University of Strathclyde, gave an illustrated lecture entitled 'The characteristics and ages of mineral inclusions in diamonds'.

South Yorkshire and District Branch

On 20 May 1987 at the Sheffield City Polytechnic, Pond Street, Sheffield, the Annual General Meeting was held at which Mr George Massie, FGA, was elected Chairman and Mrs Susan E. Payne, BA, FGA, re-elected Secretary. This was followed by an illustrated talk by Mrs Helen Muller on jet and its simulants.

On 24 June 1987 at Sheffield City Polytechnic, Mr G. Millington gave an illustrated talk on gemstone inclusions.

COUNCIL MEETING

At the meeting of the Council held on 27 April 1987 at the Royal Automobile Club, 89 Pall Mall, London SW1, the business transacted included the election to membership of the following:

Fellowship

Amarasiri, Sujatha, Colombo, Sri Lanka. 1986.
Chandrasena, Vishwakanthie, Colombo, Sri Lanka. 1986.
Dirlam, Dona M., Santa Monica, Calif., USA. 1982.
Lam, Keturah M.H., Kowloon, Hong Kong. 1986.
Rehbinder, Anne C.M., Vallentuna, Sweden. 1986.

Ordinary Membership

Albizi, Eva D., Bangkok, Thailand.
Allison, Rudie J., Fort Madison, Iowa, USA.
Arington, Stanley C., Auburn, Ala., USA.
Ashton, David, London.
Bauco, Robert, London.
Belson, Timothy E., Harrogate.
Bjelke-Weis, Anine N., Andorra.
Boyce, Jeremy P., Zurich, Switzerland.
Bradley, Peter F., Fort Myers, Fla., USA.
Brown, Charlie N., Cambridge.
Clelland-Brown, John, Edinburgh.
Dash, Suzanna, London.
Davis, Simon, Watford.
Eldredge, Anan, Anchorage, Alas., USA.
Franklin, Neil, Newcastle-upon-Tyne.
Fricker, Alan J., London.
Glynn, Peter J., Oman.
Hajdukiewicz, J., Northolt.
Harris, Jeffrey W., Glasgow.
Hughes, Brian R., Bangkok, Thailand.
Huppach, Friedrich H., Colne.
Isackson, Earl T., Seattle, Wash., USA.
Jeanneret, Charles, London.
Jefferies, Barrie W., Lewes.
Jefferies, Zhora, Lewes.
John, Christine, Sunningdale.
Keen, Paul, London.
Knight, James H., Godalming.
Lekamge, Neil S., Kandy, Sri Lanka.
Lloyd, Florence M., Harpenden.
Mantilla, Armando, Beaverton, Oreg, USA.
Mirakaj, L., Brussels, Belgium.
Moore, R. Joy, Rochester, USA.
Muston, Nicholas J., Hove.
Pattni, Unnat N., London.
Phyall, A.P., London.
Richter, Dudley C., Nashville, Tenn., USA.
Schatzle-Parisod, Arlette, Kaiseraugst, Switzerland.
Sneeringer, Margaret R., Co. Dublin, Ireland.
Stromberg, Anders N., Enskede, Sweden.
Stromberg, Ingrid M., Enskede, Sweden.
Vildiridis, Athanassios, London.
Wasilewski, Igor, Brussels, Belgium.
Williamson, David D., St Clair Shores, Mich., USA.

ANNUAL GENERAL MEETING 1987

The 56th Annual General Meeting of the Association was held on 16 June 1987 at the Flett Theatre, Geological Museum, Exhibition Road, South Kensington, London SW7.

The Chairman, Mr David Callaghan, FGA, presided over the meeting. He expanded on some of the items in the Annual Report and emphasized that 1986 had been a year of change for the Association. He reminded members that it was a year since the sudden death of Mr Harry Wheeler, former Secretary of the Association.

He announced that the Preliminary section of the new home study course was launched in the autumn, and that the Diploma section would be ready by September 1987.

1986 had been a tough year financially for the Association. This resulted in a review of all systems at headquarters and a much tighter control over spending and planning. As a result of the new course, a further grant had been received from the Distributive Industry Training Trust of nearly £20,000.

In November Mr Jonathan P. Brown, FGA, was appointed Secretary following the resignation of Mr Con Lenan, and Mr John Russell took over as Financial Controller to the Association.

Mr Callaghan then thanked members of the Council and the staff at headquarters for their help and support during the year. Mr Nigel Israel, Treasurer of the Association, presented the audited accounts for the year ended 31 December 1986, illustrated by coloured charts. The adoption of the Report and Accounts was duly proposed, seconded by Mr Christopher Cavey, and carried.

Sir Frank Claringbull, Mr David J. Callaghan, Mr Noel W. Deeks and Mr Nigel B. Israel were re-elected President, Chairman, Vice-Chairman and Honorary Treasurer respectively. Mrs E. Stern, Dr J. Nelson and Messrs A. French, D. Larcher, A. Morgan and W. Nowak were re- elected, and Drs A. Allnutt, R. Harding, J. Harris, G. Harrison Jones, Messrs E. Bruton, A.E. Farn, E.A. Jobbins, D. Kent, P. Read and K. Scarratt elected, to the Council.

Messrs Ernst and Whinney were reappointed Auditors, and the proceedings then terminated.

LETTERS TO THE EDITOR

From A.E. Farn, FGA

Dear Sir,

The first article I read when I receive my copy of *The Journal of Gemmology* is 'Notes from the Laboratory'. These give me great pleasure and enjoyment. One article in particular in the April 1987 issue which interested me was on saussurite*. In Ken Scarratt's excellent article he mentions the work done by yourself and our mutual and late friend Dr E.H. Rutland on saussurite in 1974†. This triggered my memory of what may well have been one of the bird carvings mentioned. When shipments of these kinds of materials come over a demand occurs for testing both by buyers and vendors who specialize in jade-like materials. Some end up at the Geological Museum, others arrive at the Laboratory.

In September 1973 the Laboratory received a carving in what appeared to be jadeite-jade of a bird similar to many we had tested over the years. The carving very closely resembled jadeite-jade in texture and variegated colour. We did a density test in a large plastic tub and obtained a result of 2.85; a distant-vision refractive index reading was taken at 1.57; a line in the blue at 455.0 nm indicated some zoisite in the chemical composition – we had no powder camera at that time.

Dr Rutland, who was acting Head of Department in your absence, confirmed our findings. I was pleased at the conclusion since I no longer had my old colleagues Anderson, Payne and Webster to call upon. My new and enthusiastic staff were also new to saussurite as indeed was I.

I wrote a short article giving details of the test, which appeared in the *Retail Jeweller* for 5 September 1973. Whilst not on the lines of 'Notes from the Laboratory', it did, however, record the interesting material saussurite which was so new to us all.

During a courtesy call to the Paris Laboratory very shortly after, I was shown a carving of a bird in what appeared to be jadeite-jade. Armed with my recent knowledge and borrowing a hand spectroscope, I suggested it to be saussurite, and they too had arrived at the same result using their powder camera.

I shall continue to read 'Notes from the Laboratory' by Ken Scarratt with enjoyment, respect and a touch of gemmological nostalgia.

Yours etc.,
A.E. Farn
23 June 1987
Seaford, E. Sussex.

From J.R.H. Chisholm, MA, FGA

Dear Sir,

M.D.S. Lewis, B.Sc., ARCS, FGA, CG

The late Malcolm D.S. Lewis was a rather more prolific writer than his Obituary (*J.Gemm.*, 1987, **20**, 5, 314–15) seemed to indicate, and he had more

*Journal of Gemmology, 20, 6, 356-8. – Ed.

†Journal of Gemmology, XIV, 1, 1-7. – Ed.

articles to his credit than the eight in the *Journal* listed there.

I do not pretend that the following list is complete, but it comprises his articles in *The Gemmologist* so far as I can trace them on my shelves: and, of course, besides his articles in *The Gemmologist* and the *Journal* he contributed to other periodicals as well.

Articles in *The Gemmologist*:

Chemical tests for paste and quartz, 1946, **XV**, 175, 37–8.

Feigl's test for amorphous silica as applied to opal and turquoise, 1947, **XVI**. 192, 217–18.

Bauer's test for paste and real stones and other aspects of adhesion, 1947, **XVI**, 196, 324–6.

The structure of gemstones, Part I. Introduction, 1948, **XVII**, 199, 27–31.

The structure of gemstones, Part II. Hardness, cleavage, 1948, **XVII**, 200, 53–7.

The structure of gemstones, Part III. Isomorphous replacement, symmetry and temperature, 1948, **XVII**, 201, 86–9.

The structure of gemstones, Part IV. Optical properties. 1948, **XVII**, 202, 103–6.

The structure of gemstones, Part V. Polishing, Beilby layer, abrasion, 1948, **XVII**, 203, 141–51.

The structure of gemstones, Part VI. Adhesion, drop tests, 1948, **XVII**, 204, 163–7.

The structure of gemstones, Part VII. Conductivity, the glassy state, feel, 1948, **XVII**, 205, 190–2/210.

The historical background of English jewellery (Anglo-Saxon and Mediaeval), 1948, **XVII**, 206, 220–30.

The historical background of English jewellery (2. Renaissance, Elizabethan), 1948, **XVII**, 207, 254–63.

The historical background of English jewellery (3. 17th and 18th centuries), 1948, **XVII**, 209, 321–7.

I cannot trace that he ever used the letters GG after his name, and I do not think he sought or obtained the Graduate Gemologist Diploma of the Gemological Institute of America as stated in the Obituary, but after successfully completing the necessary examinations he was awarded the title of Certified Gemologist by the American Gem Society in 1947.

It is recorded in the *Journal* (I, 3, 36) that in that same year (1947) he attended the GA's first Annual Dinner at the Waldorf Hotel on 15 May and (*J.Gemm.*, I, 3, 34) he made a donation to the Association of £2.2.0, which was then, of course, of much greater value than £2.10 would be now (indeed it was substantially more than the Association's then annual subscription).

Yours etc.,
J.R.H. Chisholm
7 April 1987
Holly Lodge, Lytham St Annes, FY8 3HP.

CORRIGENDUM

On p.380 above, second column, line 4, for 'Brazil' read 'Mexico'. This typing error is regretted, both by the abstractor and the editor.

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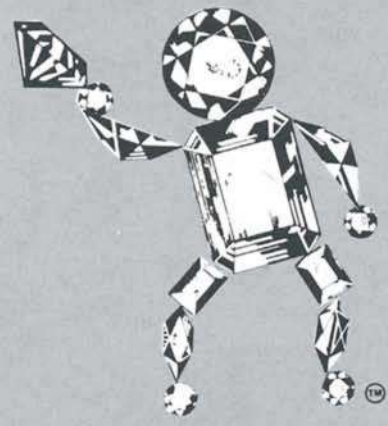

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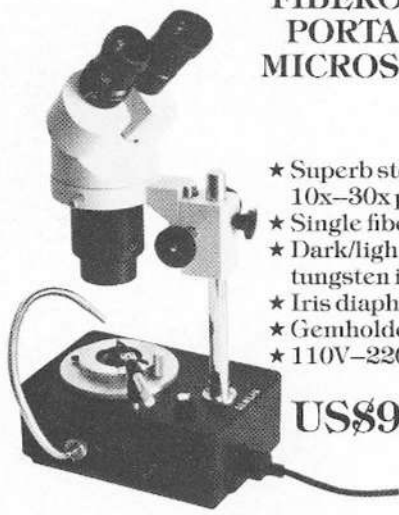

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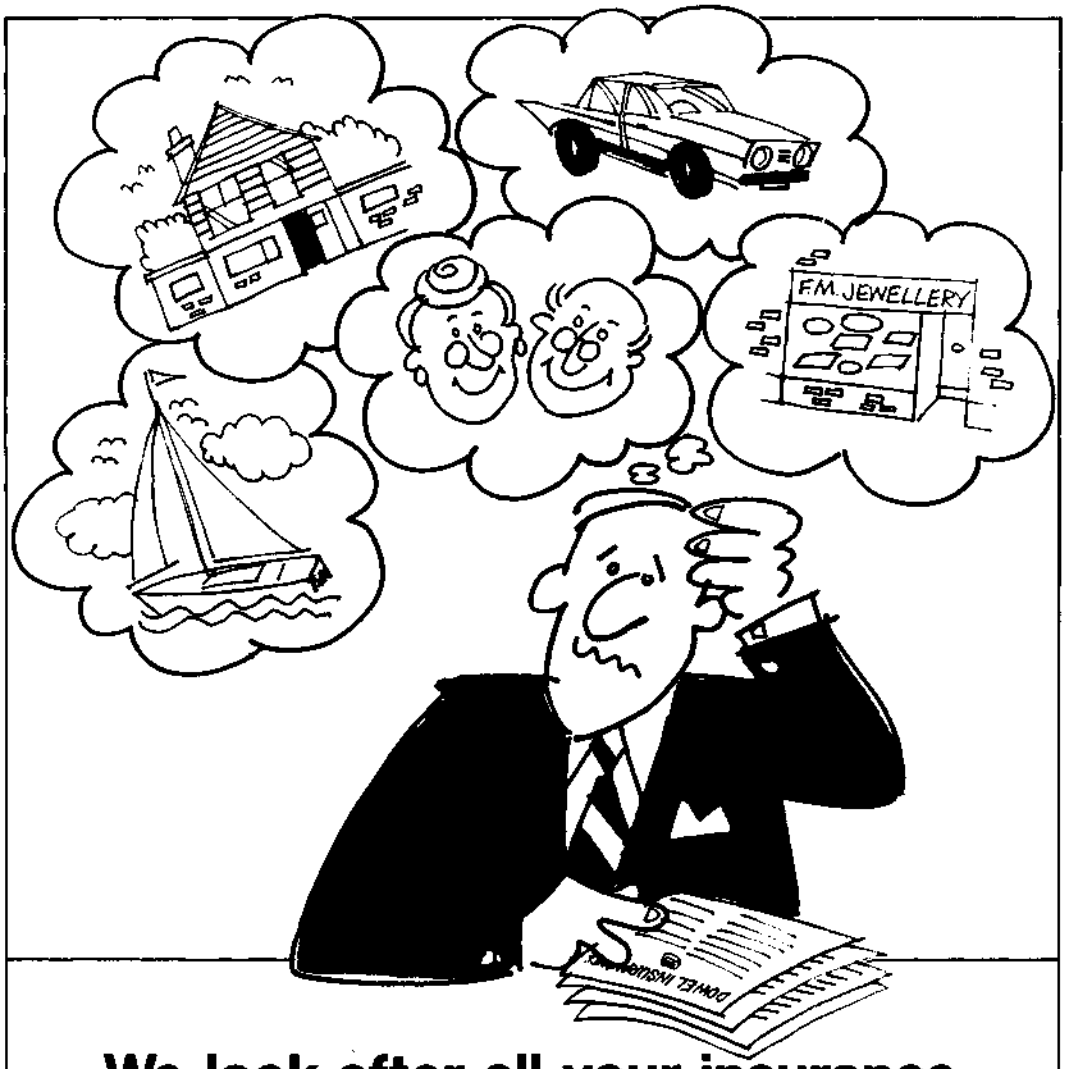

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octahedra and the gem-set ring indicates the use of gems in ornamentation. The lynx of the crest at the top was credited, in ancient times, with being able to see through opaque substances. He represents the lapidary and the student scrutinizing every aspect of gemmology. In the paws is one of the oldest heraldic emblems, an escarbuncle, to represent a very brilliant jewel, usually a ruby. The radiating arms suggest light diffused by the escarbuncle and their tips are shown as jewels representing the colours of the spectrum.

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The Gemmological Association of Great Britain was originally founded in 1908 as the Education Committee of the National Association of Goldsmiths and reconstituted in 1931 as the Gemmological Association. Its name was extended to Gemmological Association of Great Britain in 1938, and finally in 1944 it was incorporated in that name under the Companies Acts as a company limited by guarantee (registered in England, no. 433063).

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The Editors are glad to consider original articles shedding new light on subjects of gemmological interest for publication in the *Journal*. Articles are not normally accepted which have already been published elsewhere in English, and an article is accepted only on the understanding that (1) full information as to any previous publication (whether in English or another language) has been given, (2) it is not under consideration for publication elsewhere and (3) it will not be published elsewhere without the consent of the Editors.

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The jewelled hilt of a Maharajah's sword. (See Harding and Stronge p.3.) *Photograph by Frank Greenaway.*

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John Chisholm 1905-1987

It is with great sadness that we report the death on Friday 13 November of John Chisholm, Editor of the *Journal* from 1973 until 1985 and then Consultant Editor.

John Richard Harrison Chisholm, MA, FRSA, FZS, MRI, FGA, born 27 November 1905, was one of three sons of Hugh Chisholm, who was City Editor of *The Times* and Editor of the *Encyclopaedia Britannica* and was a considerable literary figure in the early decades of this century. John obviously inherited his father's ways with words and their precise meanings, a trait which led to his very successful career as a lawyer and, subsequently, as Editor of this *Journal*.

He was educated at Westminster School and then went up to Christ Church, Oxford, where he took his BA in 1929 (MA 1943). He practised as a solicitor from 1932 to 1974. He had a long association with the Equity and Law Life Assurance Society and was a past Chairman of the Life Assurance Legal Society. He was a director of a wide range of companies.

During the last months of the Second World War he spent several weeks in bed with what his doctor called 'a low-grade infection of the lungs' and his second wife, Marie-Louise, chanced upon Selwyn's *Retail Jewellers Handbook* in the local library; they both found it fascinating. Among the advertisements in the end-pages was one for the National Association of Goldsmiths and another on the same page for the Gemmological Association which mentioned the Correspondence Course. In a bantering fashion husband and wife bet each other that they couldn't pass the Diploma examination; both started the correspondence course.

Following an apprenticeship reading (for Gordon Andrews, the first Editor) the proofs of articles for the *Journal of Gemmology*, it soon became evident that his gemmological knowledge and dedication to the intricacies of proof reading were fitting qualifications for appointment as an Examiner for the Association. He took up this post in 1955 with Dr (now Sir) G.F. Claringbull and Mr B.W. Anderson. He was in sole charge of the Preliminary Examination, setting papers and marking them. This continued until 1963 when Mr (later Dr) A.J. Allnutt was appointed. Since then he was concerned with the Diploma examinations,

usually marking Part 1. He retired from the post of Examiner in 1982 after 27 years devoted service.

When Gordon Andrews retired as Secretary of the Association and Editor of the *Journal* in 1973 John Chisholm was the obvious successor – a man of scholarship with a trained legal mind and the ability to check manuscripts in the minutest detail. A manuscript paper checked by J.R.H.C. would be covered with numerous corrections and improvements, which his eagle eyes had sought out – lesser mortals commonly missed many of the errors. Over the years he improved the layout of the *Journal* and gradually increased the number and quality of the papers. It was not unknown for him to pay himself for colour illustrations which he could see would improve the understanding and quality of a particular paper.

Since he gained his Diploma in 1950 the Officers of the Association have consulted him regularly on legal matters – a source of advice, given gratuitously, over a period of nearly forty years. John was elected a Vice-President of the Association in November 1984 (see *J.Gemm.*, XIX, 5, 452) – a fitting tribute to a man who has given superlative service to the Association for very many years.

J.R.H.C. is survived by his three sons and their families, to whom we extend our deepest sympathy.

E.A.J. with the earlier assistance of J.R.H.C.

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The gemstones in a Maharajah's sword

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and

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Abstract

A brief summary of the history surrounding a Maharajah's sword is followed by a brief description of the diamonds, rubies, emeralds and onyx which decorate the hilt. The diamonds are compared with other diamonds cut in Indian styles, and the rubies and emeralds tentatively ascribed to Burmese and Colombian origins respectively.

Introduction

One hundred years ago in 1888 a sword with a jewelled hilt was bought for £150 by the South Kensington Museum (now the Victoria and Albert Museum) from Miss Malcolm. Miss Malcolm was a niece of Sir John Malcolm (almost certainly a daughter of one of his brothers) to whom the sword had been presented after it had been taken by the army from the Maharajah Holkar at the battle of Mehidpur in 1817. Details of the historical events of those times have been described elsewhere (Stronge and Harding, 1988) and in this article they are summarized briefly before the description of the gemstones which decorate the sword.

Historical background

After Aurangzeb's death in 1707 the Mughal empire in India disintegrated and many groups struggled to fill the resulting power vacuum. In 1674 Shivaji had founded an independent Maratha state which developed to play an important role in the eighteenth century. The Maratha houses, like that of Holkar, were established when Shivaji allowed his military leaders to retain any conquered lands as hereditary property. Meanwhile the trading interests of the British East India Company had been growing and their protection eventually involved the British Government and the appointment of a Governor-General in 1793. Some Maratha houses co-operated with the British but others, including Holkar, were not ready to relinquish their power without a fight, and so, in 1817, after two periods of inconclusive conflict Lord Hastings gathered a large army at Mehidpur to crush the opposition. Part of this force comprised the army of the Deccan under the command of Sir Thomas Hislop with Malcolm as his political agent. The battle took place on 21 December and was won by the British forces. The jewels of Holkar's family were captured from the fleeing cavalry and among them was the Maharajah's sword. The Rajah of Mysore presented the sword to Malcolm 'in acknowledgement of the kindness and consideration with which he treated the auxiliary troops' (Wilson, 1888, p.198). The sword then became an heirloom in the Malcolm family.

The sword

The total length of the sword is 92 cm and the curving blade has clearly had a certain amount of use; originally it must have broadened slightly in the last quarter of its length where it becomes double-edged but re-grinding has reduced the width. Just below the languet of the hilt on one face (Figures 1 and 2) is a gold-inlaid umbrella or *chatr* which indicates royal ownership. The gold hilt is richly decorated with flower and leaf motifs and the tilted disc-pommel is ornamented with a floral scroll on each face; these surfaces are studded with rubies, diamonds and emeralds (Figures 2, 3 and 4) and the only plain surface is at the back of the knuckle guard which terminates in the stylized tiger-head. In all, there are 378 rubies, 276 diamonds, 38 emeralds and the tiger's eyes are onyx, a total of 694 gemstones.

a) *Ruby*

The rubies comprise table-cuts, cabochons or pieces of polished rough, most being rounded but some of quite irregular shape, although this variation is masked by the geometry of the settings. One point cut ruby terminates the spike at the end of

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HILT

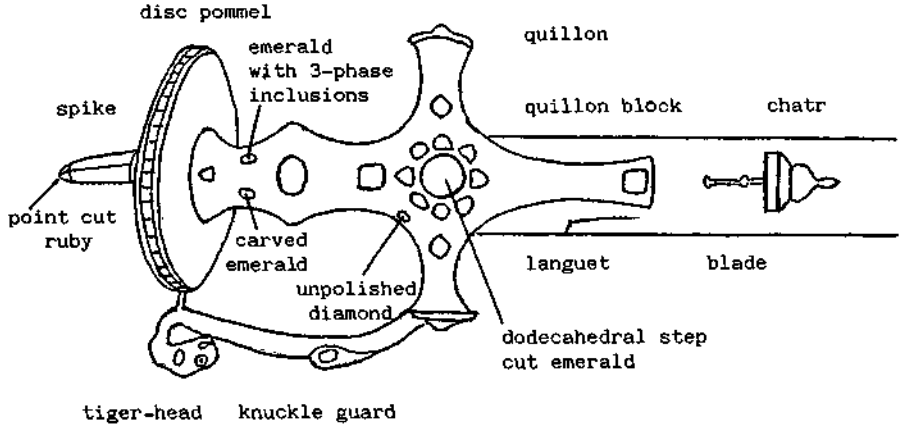

Fig. 1. Sketch of right-hand side of the sword with nomenclature of different parts and positions of some notable stones.

Fig. 2. The right-hand side of the hilt.

Fig. 3. The left-hand side of the hilt.

Fig. 4. The outside of the disc pommel.

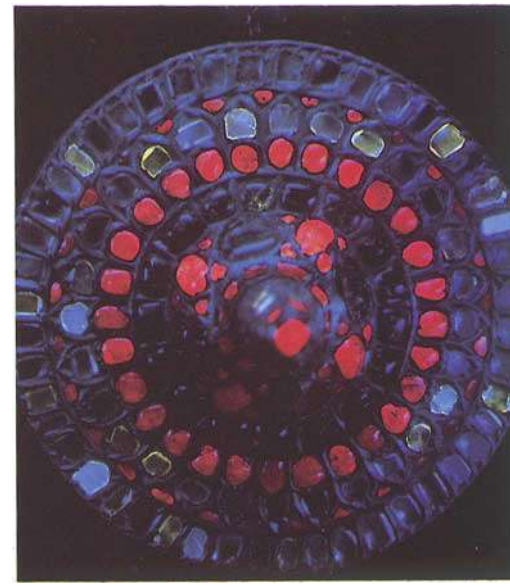

Fig. 5. The outside of the disc pommel in ultraviolet radiation.

the hilt. In general the rubies are a fine rich red comparable with good Burmese stones and they show a strong chromium spectrum, but some are paler red with a backing of orange enamel or foil, a colour that makes one suspect at first that the stone may be spinel or paste. However, their chromium spectra indicate that they are rubies, and their inclusions of fine rutile needles, silk, twin planes, colourless rounded crystals and liquid-filled feathers are also found in the more richly coloured rubies. Strong fluorescence in long-wave ultraviolet radiation is shown by the richly coloured rubies but the response is weaker in the paler foiled stones. Some rubies contain drill holes, of different diameters in different stones, and have either been used in necklaces or earrings or were at one time destined for such use. An oval star ruby of fine colour is set next to the hexagonal emerald in the quillon block.

b) *Diamond*

The diamonds range in size from tiny chips to cut and polished stones 9 mm across at the girdle. Most are polished cleavage pieces more or less rectangular, oval or triangular but in detail some are quite irregular in outline, and in places these irregularities have been used to advantage in the floral and leaf designs. The margins of the irregular

Fig. 6. The carved emerald on the knuckle guard and adjacent diamond terminating the quillon.

Fig. 7. The diamond terminating the quillon opposite the knuckle guard.

stones have commonly been left unpolished but many of the more regularly shaped stones have small girdle facets. Most of the latter have polished flat table facets and flat bases but a few have table facets that are slightly curved and this gives a rippled effect in reflected light. A similar effect was observed on the pavilion facets of the 56.71 ct tabular diamond described by Jobbins *et al* (1984) and may either be a feature of a particular style or period, or a consequence of the Indians' use of steel polishing wheels rather than the iron ones favoured by European cutters. Some diamonds are set in cavities which themselves have curved reflecting surfaces and this further enhances the play of light from the sword hilt. One stone on the quillon block above the *chatr* is an unpolished flat octahedron of high lustre and quality and could be termed a glassy. In ultraviolet radiation the diamonds show a range of fluorescence from pale bluish white to pale yellowish green to inert (see Figure 5).

Two unusual diamonds terminate the quillon (see Figures 6, 7 and 8). Both have roughly circular girdles averaging 9 mm in diameter which are close to or coincident with a flat base. At the knuckle guard end of the quillon the diamond has a row of 16 rectangular facets above the girdle and these are surmounted by 16 triangular and 16 elongate pentagonal facets which rise to a small table facet 2.5 mm in diameter. In the other diamond the row of rectangular facets is absent, and 21 triangular facets and 21 elongate facets rise to a table facet 2.8 mm in diameter. The form of the cut in the two stones compares with parts of Indian-cut stones figured by Tavernier (1889), and resembles the upper part of the Koh-i-noor as drawn by Professor Tennant and published in Ball's translation of *Travels in India* by Tavernier (see Figure 8c). The cut is also similar to one depicted by Tillander (1980), reproduced in Figure 8d, which is an example of one of more than 200 cuts of diamond known by the end of the fifteenth century.

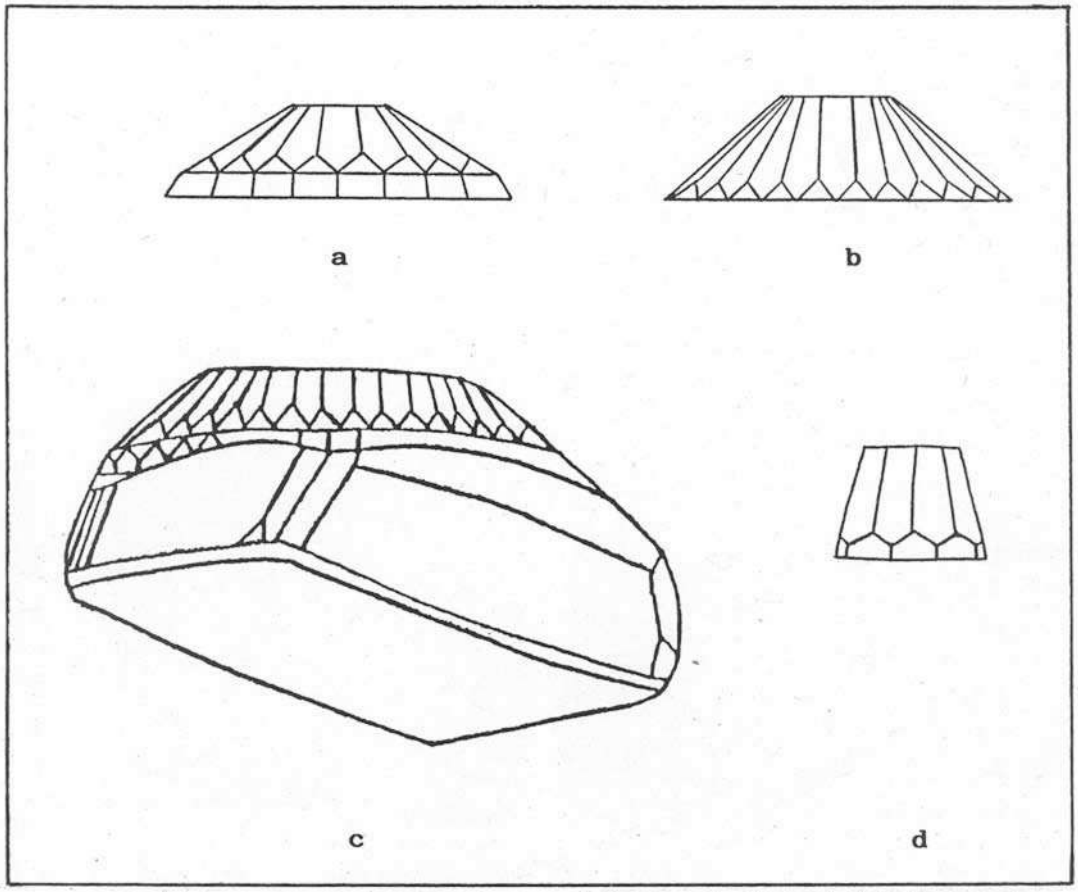

Fig. 8. Sketches of diamonds terminating the quillon: (a) next to knuckle guard, and (b) at opposite end of quillon. Sketch of Koh-i-noor (c) after Tennant, and diamond with pentagonal facets (d) after Tillander (1980, p.208).

c) *Emerald*

The green stones are all backed by green foil or enamel and this disguises a considerable range of intensity of the stones' body colours. The two largest emeralds at the centre of the quillon block on either side of the hilt are emerald-cuts, the one above the *chatr* being dodecahedral (15 mm across) and the other hexagonal (11 mm across). Both stones are set pavilion outwards, and both show a distinct chromium spectrum and have typical emerald inclusions.

Apart from the two emerald cut stones on the outer surface of the disc pommel, the remaining emeralds comprise rounded polished fragments, oval cabochons and four carved stones. The carved stones illustrate simple or floral designs and lie in positions in the overall pattern which fulfil the dictates of colour symmetry rather than emphasize any significance the carving may have. The largest carved emerald is set on the knuckle guard but is of rather poor quality with a weak chromium spectrum. Two green stones on the outside of the pommel do not show a chromium spectrum and should be called green beryl. In contrast some stones show good emerald colour and one on the hilt near the disc pommel is typical of fine Colombian stones. It and many others contain spiky two-phase inclusions but only one stone with three-phase inclusions was seen.

d) *Onyx*

Two hemispherical pieces of onyx with circular black centres and white rims constitute the eyes in the tiger-head on the knuckle guard.

Discussion

The stones have some characteristics which can be explained by reference to the past history of Holkar. There is a considerable variation in quality although this does not relate to their position in the decorative composition. In the imperial products of the Mughals the stones of exceptional size, shape or colour would be given a place of prominence, and those which were especially treasured became effectively part of the emperor's insignia, being set and re-set as each successive emperor wished. One example of this was the Koh-i-noor which was owned successively by Mir Jumla, Shah Jahan, Aurangzeb, Nadir Shah, and a succession of Persian and Afghan emperors until 1813 when Shah Sujah lost it to Ranjit Singh, the Lion of the Punjab. His headquarters were in Lahore, bordering the Maratha territory to the northwest, but he kept a neutral stance and did not become involved in the disputes between the Marathas and the British.

The house of Holkar did not have resources to compare with those of Ranjit Singh, and although there are a few high quality stones in the sword, others are not so fine, and some stones have served other purposes in the past. One example is the carved emerald on the knuckle guard which is of poor quality and is not one which would have been given prominence had a better choice of stones been available.

The date of manufacture of the sword is not known; all that can be said is that it is pre-1817. The provenance of the stones is also problematic. Some emeralds are almost certainly from Colombia but others may be European; the rubies do not have diagnostic inclusions but stones with similar characteristics are known from Burma, Afghanistan and possibly other parts of the Himalayas. The diamonds are probably Indian or Brazilian, but again distinctive inclusions are lacking. However, despite the mixed quality of the individual stones, they have all been combined on the sword to create an effect of opulence and splendour.

Acknowledgement

We would like to thank Frank Greenaway (British Museum (Natural History)) for taking the photographs.

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Surface repaired corundum – two unusual variations

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In 1984, gemmologists in London (Scarratt and Harding, 1984) and Bangkok (Hughes, 1984) reported on an entirely new type of ruby treatment, dubbed 'surface repair', involving the filling of surface pits with glass. Since that time large numbers of rubies and even some sapphires (Scarratt, *et al*, 1986) have been seen treated in this way.

In June of 1987 two unusual variations of surface repair were submitted to the laboratory of the Asian Institute of Gemological Sciences in Bangkok for identification. The first of these was a 2.24 ct ruby. Microscopic examination revealed the stone to be a very unusual assembled gem in which a small chunk of natural Burmese ruby was fused with glass to the side of a larger piece of Verneuil synthetic ruby. The stone was then faceted to hide the junction of the two pieces.

An unusual feature of this stone is the use of glass to join the two pieces together. Figures 1 and 2 show the stone as it appears with overhead lighting in the microscope (10x). Notice the difference in lustre between the corundum/synthetic corundum and the glass separating them. Higher magnification reveals the colourless nature of the glass, as well as spherical gas bubbles. This is shown in Figure 3. Note also the dense white patch of silk in the upper right corner of the stone in Figure 3.

With regard to the stone's manufacture, it appears that the natural and synthetic pieces were roughly shaped and put together. Glass was then used to fix them together, and the stone faceted to hide the join. Evidence of this is shown by the facets, which stretch across all three materials.

Identification of this stone was not a problem. Although the natural portion contained natural inclusions such as rutile silk, the Verneuil section contained gas bubbles and curved striae. Also found in the synthetic portion were induced fingerprints and feathers. Gas bubbles were found in the glass portion.

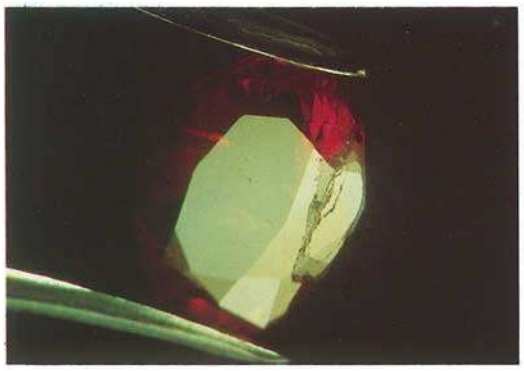

Fig. 1. Overhead lighting reveals a small piece of natural Burmese ruby (right) held to a much larger piece of Verneuil synthetic ruby (left) with glass. The slightly more dull lustre of the glass filling reveals its true nature. 10x. Photo by Wimon Manorotkul, AIGS.

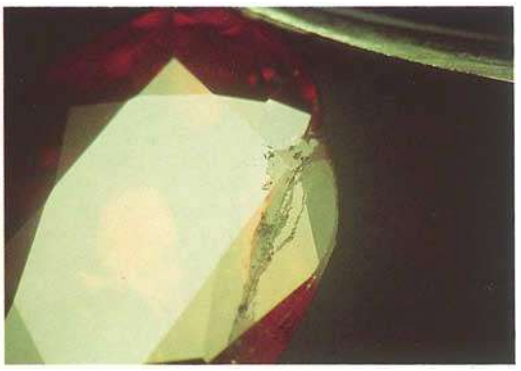

Fig. 2. An enlarged view of the same stone as in Fig. 1. Again, the glass is visible in overhead lighting due to its poorer lustre. 30x. Photo by Wimon Manorotkul, AIGS.

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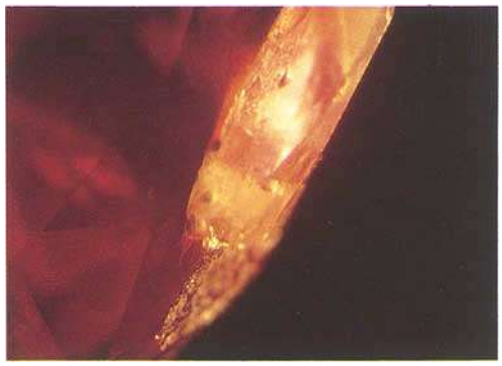

Fig. 3. Dark field illumination reveals the glassy material used to bind a small piece of natural ruby to a larger piece of synthetic ruby. Gas bubbles are visible in the glass portion while a dense white cloud of rutile silk is visible in the upper right corner of the natural piece at right. 50x. Photo by Wimon Manorotkul, AIGS.

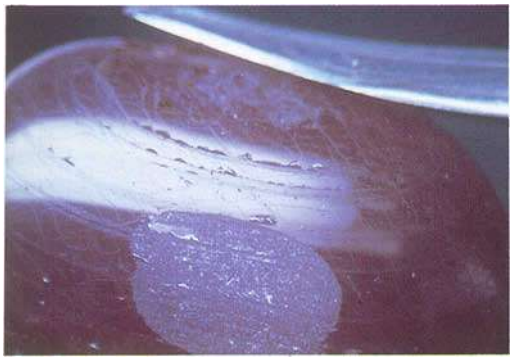

Fig. 4. Each of the cracks in this heavily included natural ruby has been filled with glass. The glass is visible with overhead lighting, due to its lower lustre. 25x. Photo by Wimon Manorotkul, AIGS.

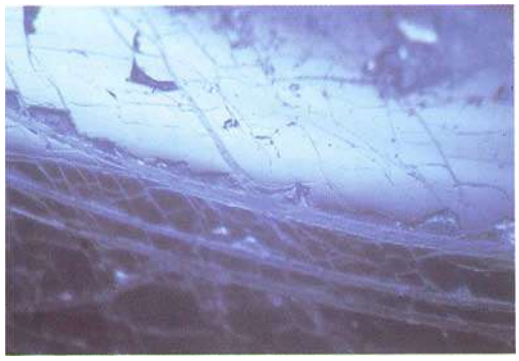

Fig. 5. Same as Fig. 4, but with slightly higher magnification. 50x. Photo by Wimon Manorotkul, AIGS.

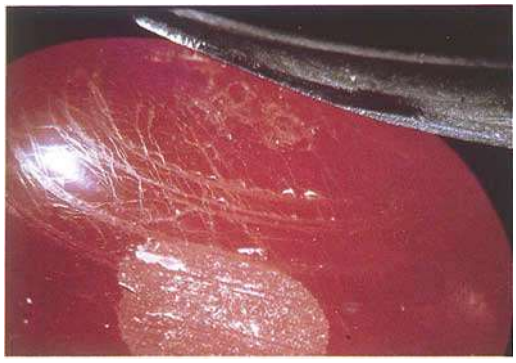

Fig. 6. Same as Fig. 4, but with a more yellowish light source. 25x. Photo by Wimon Manorotkul, AIGS.

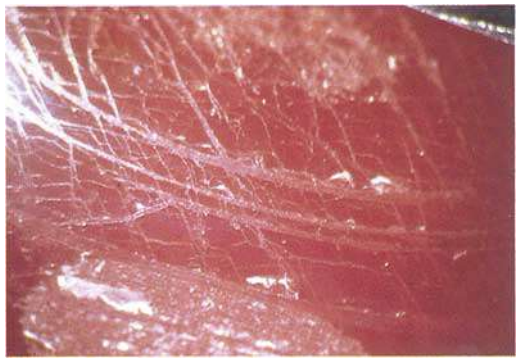

Fig. 7. Same as Fig. 5, but with a more yellowish light source. 50x. Photo by Wimon Manorotkul, AIGS.

During the recent ICA Congress held in May 1987 in Bangkok, Dr Henry Hänni of Switzerland described to the author a new treatment used on rubies. This consisted of introducing glass into the fractures of low-grade ruby cabochons from Africa. It differed from ordinary surface repair in that the glass actually penetrated into the fractures.

The first stone of this type seen in Bangkok was brought in during June 1987. It was a heavily included 13.74 ct ruby cabochon, as shown in Figures 5-8. Overhead lighting or immersion in methylene iodide revealed each of the cracks to be filled with a glassy substance. It was not possible to determine how deep the glass penetrated into the cracks, but it did appear to extend a fair distance under the surface.

Detection of this treatment is the same as for ordinary surface repair. Overhead lighting reveals the glass, due to its lustre being lower than the surrounding corundum. Immersion in methylene iodide also allows the glass to be seen, as it appears in high relief compared with the surrounding corundum, due to the lower RI of the glass. Gas bubbles may also be seen in the glass filling.

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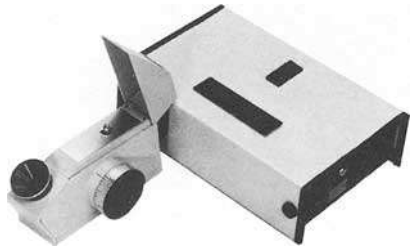

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The Gemmological Association has collaborated with the Gem Testing Laboratory of Great Britain to arrange a programme of one-day courses.

The courses have been designed for the Association by Ken Scarratt and will be held at the Gem Testing Laboratory in London. The aim is to give practical instruction and experience to students studying gemmology, particularly those preparing to take the FGA examination by home study, and updates specialized courses for all gemmologists.

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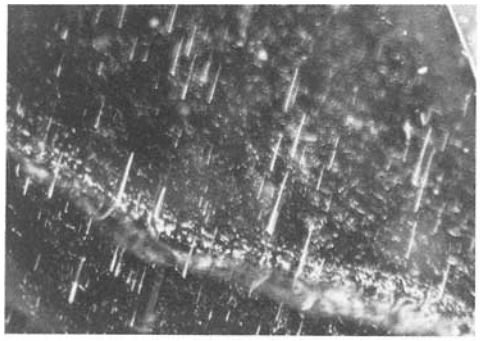

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Various types of one-day courses are being offered during 1988, the dates of which are:

24 March	**Basic practical gem testing techniques**
21 April	**Emerald, amethyst and opal**
19 and 20 May	**Practical diamond grading examination revision**
16 and 17 June	**Practical gem testing examination revision**
5 July	**Organic gem materials, including amber and pearls**
29 September	**Diamond grading**
27 October	**Jade, turquoise, lapis lazuli and their simulants**
24 November	**Ruby and sapphire**

The National Association of Goldsmiths are also arranging courses on practical gemstone knowledge at the Laboratory. **These are to be held on 4 March, 13 May, 7 July and 7 October 1988.**

Each course is limited to 8 participants and is offered at the low charge of £55 plus VAT (including lunch). The courses are open to all students and members of the Association who would like to take a short refresher course. For further information contact Paula Jennings on 01-726 4374.

A doublet made of a natural green sapphire crown and a Verneuil synthetic ruby pavilion

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Abstract

With all the concern to recognise the modern synthetics (Knischka, Chatham, Kashan, Ramaura, Inamori), one would tend to give too quickly a natural origin to a stone presenting at first sight unequivocal inclusions, and thus forget to check for a possible doublet.

The two rubies received recently by the writer for identification fall into this category.

Ring A

Ring B

Fig. 1. The two rings received for testing the quality and origin of the rubies.

Appearance

Two oval-cut ruby and diamond cluster rings (Figure 1) were received for testing the quality and origin of the rubies.

At first sight, the rubies were of a beautiful red colour not dissimilar to that found in Burmese stones. The diamonds and rings were also of a very good make and quality.

Under the microscope

Under the microscope, and in dark-field illumination, many rutile needles giving rise to 'silk', long canals, strong straight colour zonings, 'feathers', were easily seen, but surprisingly seemed to be concentrated in one zone near the surface. The rings were tilted in order to view the ruby's pavilion, which appeared abnormally free of inclusions.

At this stage it was decided to take a closer look at the girdle and to change the lighting conditions of the microscope to reflected light.

In reflected light, the rubies proved to be doublets since a groove could be seen in the middle of the girdle. The stones were again tilted in the face up position, and they appeared green under the microscope.

With both lightings on, dark-field illumination and reflected light, and by just slightly inclining the stones, the two colours green and red appeared (Figures 2, 3). From this point it was decided to check the refractive indices, absorption spectrum, and ultraviolet fluorescence of these composite stones.

Refractive indices

The refractive index determinations were carried out using a Rayner Dialdex refractometer and monochromatic sodium light. Only the table facet was tested since the stones were mounted and that

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Fig. 2. Ring A

Fig. 3. Ring B

Figs. 2 and 3. The two rubies seen under the microscope in dark-field illumination and reflected light, showing clearly the two different materials composing these stones.

their owner did not allow the writer to have them unmounted.

The indices obtained were 1.773 1.765, giving a birefringence of .008, with optic sign (–), confirming the crown to be corundum, variety green sapphire.

Absorption spectrum

The light reflected from the stone's table was analysed through a Gem Beck spectroscope unit, and revealed a strong band centred at 450 nm. This, the rather high refractive indices for corundum, and the inclusions observed are characteristic of Australian green sapphires.

The same procedure was carried on the pavilion of the stones and revealed bands and lines centred at 440-450, 468, 472, 477, 500-610, 630-670, 695 nm. This absorption spectrum is characteristic of ruby, either natural or synthetic.

Ultraviolet fluorescence

The stones were examined with a Multispec combined LW/SW unit, and revealed two different behaviours for the crown and pavilion.

In the table facet up position, the stones remained inert to LW and SW. On the contrary, the pavilion when presented horizontally, fluoresced a strong brick-red to LW.

Since some natural rubies can have similar behaviours (Sri Lanka, Burma, Africa), it was decided to try and obtain a Plato or curved striae by immersing the stones in methylene iodide between crossed polaroids.

Examination in methylene iodide

The stones immersed in methylene iodide were observed on a horizontal Eickhorst stand between crossed polaroids coupled to a Gemolite Bausch & Lomb Mark V microscope, and revealed strong

Fig. 4. Strong straight colour zones in the crown, and curved growth lines in the pavilion made visible when the stone is immersed in methylene iodide.

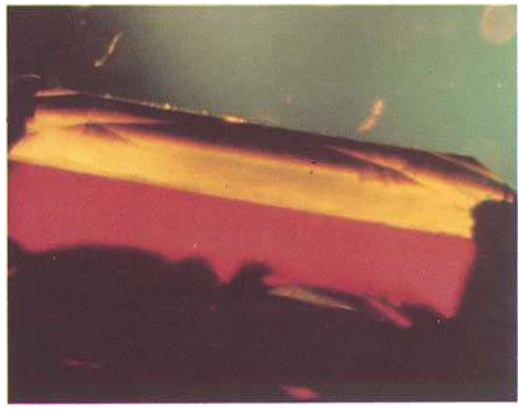

Fig. 5. The two different corundums composing this doublet show even more clearly when the stone is immersed in methylene iodide.

straight colour zones in the crown, and curved growing lines in the pavilion (Figure 4).

The Plato striations which also betray 'Verneuil synthetics' were not secured due to the mounting.

Also of interest is to visualize how the two different corundum layers composing this doublet react when immersed in methylene iodide and between crossed polaroids (Figures 4, 5).

Conclusion

These very convincing ruby doublets of an excellent colour, made of a natural green Australian sapphire crown and a Verneuil synthetic pavilion, should encourage every gemmologist to take great care to observe the inclusions in detail as to where they lie, if they are distributed with a certain logic. If, as for these stones, they seem to be confined in one zone of the stone, or if they are of different constitution for the crown and pavilion, on or near the surface, and do not traverse the stone, then a doublet should be suspected, and the stone thoroughly checked.

[*Manuscript received 9 July 1987.*]

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Morphology and twinning in Chatham synthetic blue sapphire

L. Kiefert and Dr K. Schmetzer

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Abstract

Morphological properties of Chatham synthetic blue sapphires are described. The crystals reveal tabular to rhombohedral habit with *c* {0001}, *r* {10$\bar{1}$1}, *d* {01$\bar{1}$2} and *n* {22$\bar{4}$3} as predominant crystal forms as well as Y {01$\bar{1}$5} as subordinate form. Most crystals disclose contact twinning by reflection across {10$\bar{1}$0} with *a* {11$\bar{2}$0} as composition plane. Single and repeated (cyclic) twinning is observed. The application of internal structural properties such as families of straight parallel growth planes and twin boundaries on the distinction of natural and synthetic corundum is briefly discussed.

Fig. 1. Crystal group of Chatham synthetic blue sapphires, 9.45 ct in weight, consisting of five untwinned and six twinned individuals. Size approx. 13 x 16 mm (*photo by O. Medenbach, Bochum*).

Fig. 2. Crystal group of Chatham synthetic blue sapphires, 7.02 ct in weight, consisting of two untwinned and one twinned individual. Size approx. 10 x 15 mm (*photo by O. Medenbach, Bochum*).

Introduction

Chatham synthetic blue sapphires were first reported by Bank (1977), Scarratt (1977), and Koivula (1981) and more detailed descriptions of this new synthetic gem material were written by Gübelin (1982, 1983) and Kane (1982). Additional papers dealing with gemmological properties of flux-grown Chatham synthetic sapphires were published by Gunawardene (1983) and Brown (1984). In the papers cited above, emphasis is laid on microscopic description of diagnostic features, eg. inclusions of small needles or platelets of platinum as well as 'fingerprint' feathers consisting of residual flux. Only limited information is available about structural features such as morphology and growth structures as well as about the possible presence of twinning. These features, however, are incidentally of diagnostic value for the distinction of natural and synthetic rubies (cf. Schmetzer 1985, 1986a,b, 1987). Therefore, a crystallographic investigation of structural properties of Chatham synthetic sapphires was undertaken by the present authors.

Materials and methods

For the determination of structural properties of Chatham synthetic blue sapphires, both rough crystals and faceted stones were available. The group of five rough samples under investigation was found to consist of single individuals as well as of irregularly intergrown crystal groups and clusters (Figures 1, 2). One sample was formed by four individuals which were irregularly intergrown. On one side of the sapphires a glaze-like layer of transparent material was attached to the crystals, presumably in order to improve the stability of the crystal group. This coating was amorphous to

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X-rays, and by electron-microprobe the material was found to contain, K, Ca, Pb, Al and Si as major components (cf. Scarratt 1977, Kane 1982, Brown 1984). A similar coating was observed on one side of one of the sapphire clusters which consisted of 11 sapphire crystals.

In order to determine the morphology and twinning of Chatham synthetic sapphires the crystal faces of all five rough samples including individuals from crystal groups and clusters were first examined with an optical two-circle reflecting goniometer and later identified by means of the stereographic projection. In a second step, families of straight parallel growth planes as well as twin boundaries were microscopically investigated immersed in methylene iodide with the aid of a sample holder with horizontal and vertical rotation axes. This method (Schmetzer, 1985, 1986a) allows an easy microscopic determination of structural features in rough and faceted gemstones. Thus, in addition to the five samples of rough individuals, eight faceted stones of various sizes were also included in the present study.

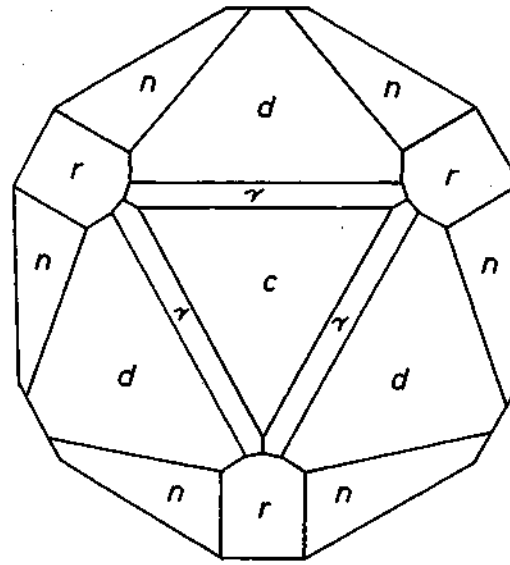

Fig. 3. Idealized single crystal of Chatham synthetic sapphire viewed in a direction parallel to the *c*-axis.

Results

The five rough samples were found to consist of single crystals and twinned individuals. Twinning is caused by one single reflection, or even by repeated reflections across the first-order hexagonal prism $(10\bar{1}0)$, which is easily recognizable due to the re-entrant angles of the samples. In general, twinned and untwinned individuals are irregularly intergrown. The five samples investigated in this study are described as indicated below:

Sample	Number of individuals	Untwinned individuals	Twinned individuals
1	11	5	6
2	1		1
3	4		4
4	3	2	1
5	1		1

The crystal faces which were identified in both untwinned and twinned crystals are identical, the samples displayed tabular to rhombohedral habit with the basal pinacoid *c* $\{0001\}$, the positive rhombohedron *r* $\{10\bar{1}1\}$, the negative rhombohedron *d* $\{01\bar{1}2\}$ and the hexagonal dipyramid *n* $\{22\bar{4}3\}$ as predominant forms, as well as the negative rhombohedron γ $\{01\bar{1}5\}$ as subordinate form (Figure 3). Occasionally, an oscillatory development of both negative rhombohedrons *d* and γ was observed causing parallel striations on these crystal faces. No prism faces were detected.

All single and repeatedly twinned individuals (cyclic twinning) were contact twins with the second-order prism *a* $\{11\bar{2}0\}$ as composition plane (Figures 4, 5). In the crystal class of corundum $\bar{3}^2/_m$, the second-order hexagonal prism *a* $\{11\bar{2}0\}$ is parallel to a mirror plane. Thus, this face cannot be a twin plane but is a composition plane of two single crystals twinned by a reflection across the first-order hexagonal prism $\{10\bar{1}0\}$, which is not a mirror plane in crystal class $\bar{3}^2/_m$. In repeatedly twinned individuals, which are also called cyclic twins, all twin boundaries intersect in a straight line. Hence, the twinned crystals are more distorted than the untwinned individuals, especially the negative rhombohedral faces *d* $(01\bar{1}2)$ and γ $(01\bar{1}5)$ vary significantly in size.

In the immersion microscope, families of straight parallel growth planes were determined which reflect the external growth faces of the crystals. These growth faces are parallel to the predominant forms *c* $\{0001\}$, *r* $\{10\bar{1}1\}$, *d* $\{01\bar{1}2\}$, and *n* $\{22\bar{4}3\}$. The most frequently observed angles, which are made by two families of straight parallel growth planes, equal 154° (made by the faces *r* and *n*), 148° (made by the faces *d* and *n*), 128° (made by the faces *n* and *n'*), and less commonly 133° (made by the faces *r* and *d*). The composition planes *a* $\{11\bar{2}0\}$ of the individuals, which are related by reflection twinning on $\{10\bar{1}0\}$ are also observable in the gem microscope without having problems (Figures 6, 7, 8).

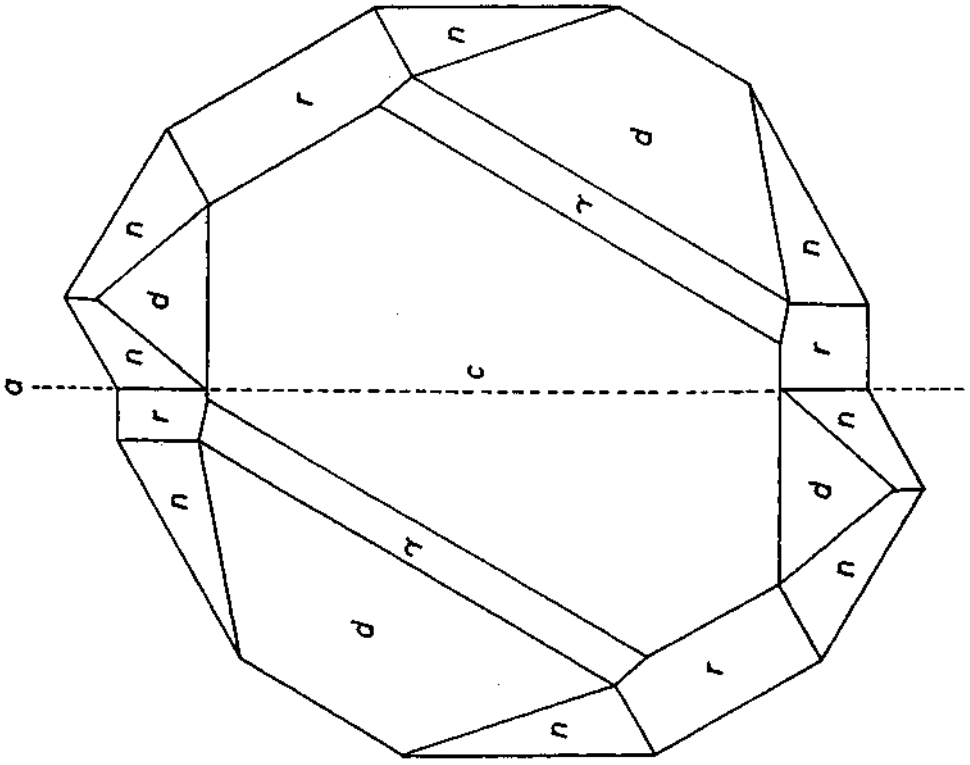
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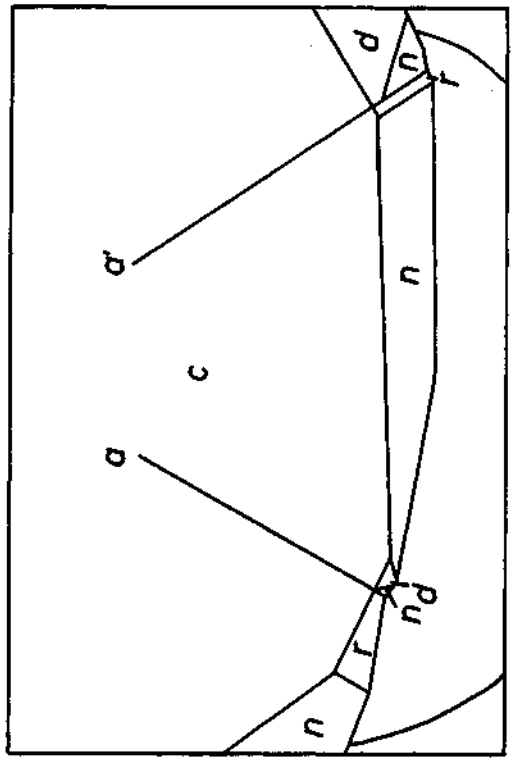

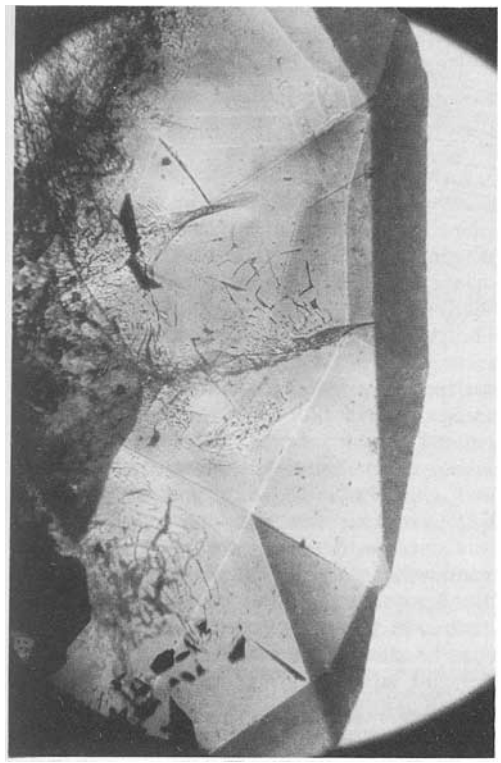

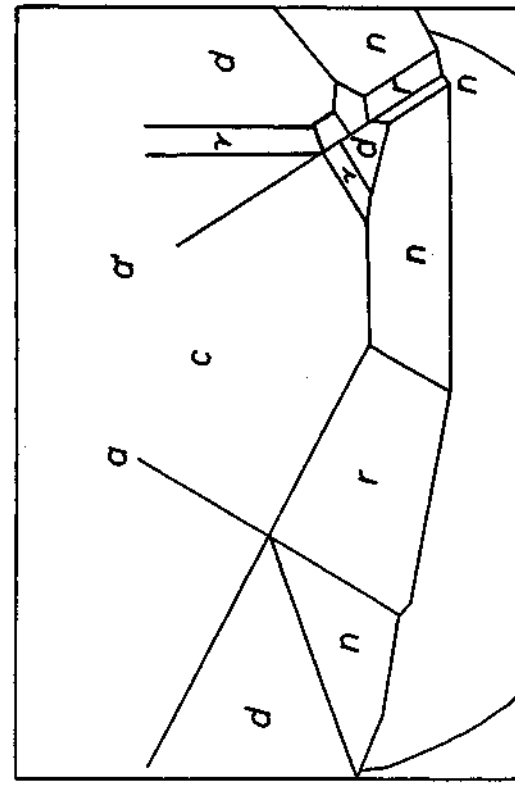

Fig. 6. Distorted crystal of Chatham synthetic sapphire viewed in a direction parallel to the *c*-axis. The crystal reveals repeated (cyclic) twinning across {10$\bar{1}$0} with *a* {11$\bar{2}$0} as composition planes; two composition planes *a* and *a'* are observable; re-entrant angles are formed by the faces *n* and *r*. Top left: microphotograph, 24 x; top right: drawing of crystal faces and twin boundaries, viewed in a direction parallel to the +*c*-axis; left: drawing of crystal faces and twin boundaries, viewed in a direction parallel to the −*c*-axis.

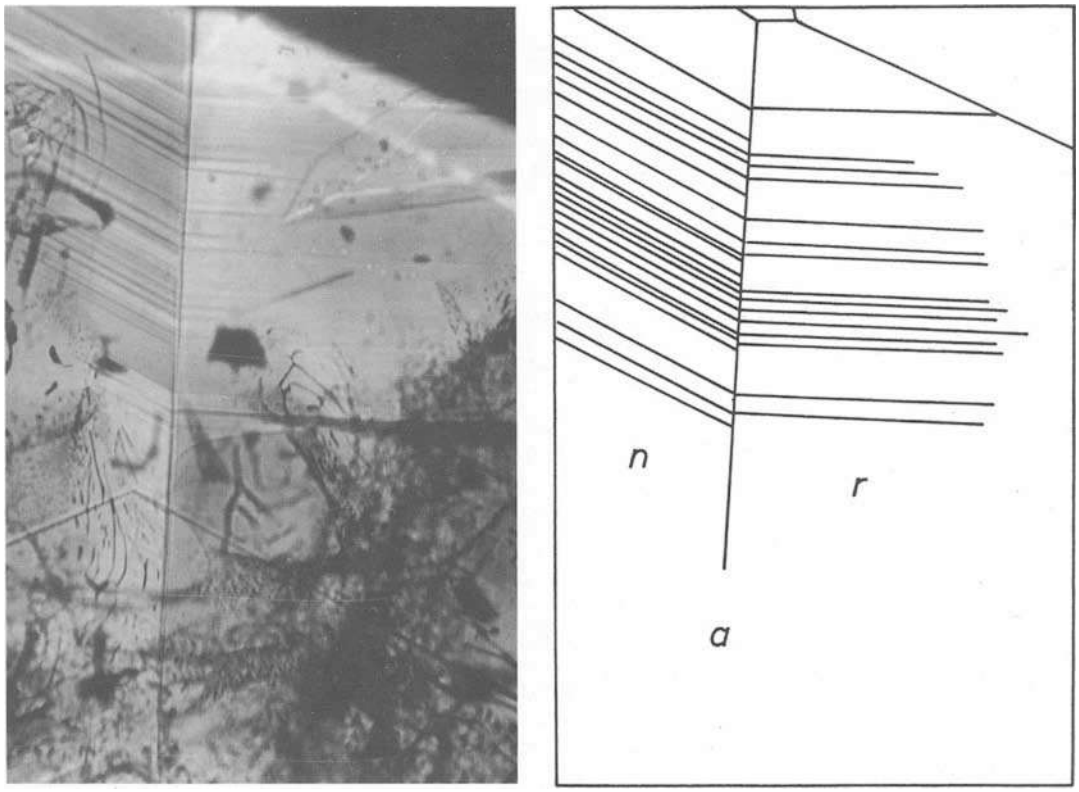

Fig. 7. Families of straight parallel growth planes in Chatham synthetic sapphire, growth sectors confined to the positive rhombohedron r $(10\bar{1}1)$ [right part] and the hexagonal dipyramid n $(22\bar{4}3)$ [left part] are divided by a twin boundary parallel to a $(11\bar{2}0)$; a re-entrant angle is formed by the faces n and r. Left: microphotograph, 40 x; right: drawing of growth and composition planes.

Discussion

The habit of Chatham synthetic blue sapphire is similar to the habit of Chatham synthetic ruby (cf. Schmetzer, 1985, 1986 a, b). In both varieties, the predominant forms are the basal pinacoid c $\{0001\}$, the positive rhombohedron r $\{10\bar{1}1\}$, the negative rhombohedron d $\{01\bar{1}2\}$, and the hexagonal dipyramid n $\{22\bar{4}3\}$. In Chatham synthetic blue sapphire, an additional negative rhombohedron γ $\{01\bar{1}5\}$ was observed, which was previously mentioned for Knischka synthetic rubies, too (Knischka, 1980; Knischka & Gübelin, 1980). Most Chatham synthetic blue sapphires are twinned by a reflection across $\{10\bar{1}0\}$ with $\{11\bar{2}0\}$ as composition plane. Single and repeated (cyclic) twinning was observed. According to the knowledge of the authors, cyclic twinning of corundum has not yet been described in the literature though single twinning across $(10\bar{1}0)$ with $(10\bar{1}0)$ or $(11\bar{2}0)$ as composition planes is already known for flux-grown ruby and corundum (cf. Schmetzer, 1986 b, 1987). Twinning and internal growth structures in Chatham synthetic blue sapphire are closely related to internal structural features of Chatham synthetic ruby and thus, similar growth conditions, e.g. the compositions of fluxes, are evident for both varieties.

The results which are described in this paper disclose some discrepancies with literature data. Prism faces, growth planes parallel to prism faces forming angles of 120° (which is also described as hexagonal zoning) as well as polysynthetic twin lamellae, which are briefly mentioned by Kane (1982), Gübelin (1982, 1983) and Gunawardene (1983), were never observed. Unfortunately, in the papers cited no detailed informations about the determinative procedures of these structural properties are quoted, and thus no final explanations of these discrepancies are possible.

For the distinction of natural and synthetic rubies and sapphires, the application of growth structures and twinning may lead to conclusive results in some cases. In natural corundum, families of straight parallel growth planes parallel to the

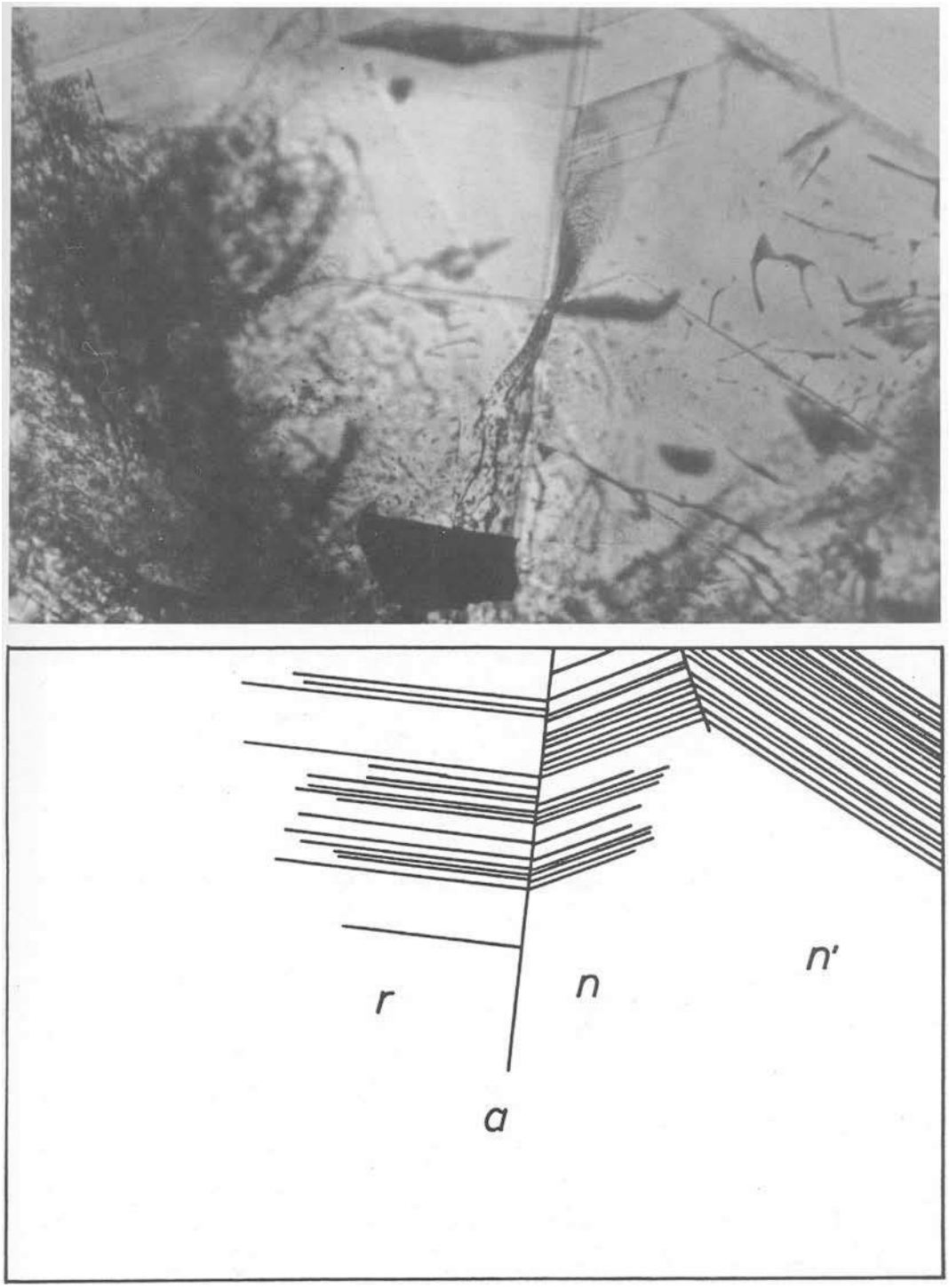

Fig. 8. Families of straight parallel growth planes in Chatham synthetic sapphire, growth sectors confined to the positive rhombohedron r $(10\bar{1}1)$ [left part] and the hexagonal dipyramid n $(22\bar{4}3)$ [right part] are divided by a twin boundary parallel to a $(11\bar{2}0)$; a re-entrant angle is formed by the faces n and r [centre]; planes parallel to n and n' $\{22\bar{4}3\}$ form an angle of 128° [right part]. Upper part: microphotograph, 30 x; lower part: drawing of growth and composition planes.

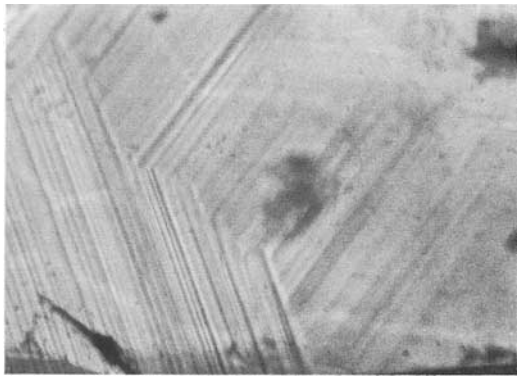

Fig. 9. Families of straight parallel growth planes that form an angle in natural ruby from Sri Lanka viewed in a direction parallel to the *c*-axis; planes parallel to prism faces *a* and *a'* $\{11\bar{2}0\}$ form an angle of 120°. 30 x.

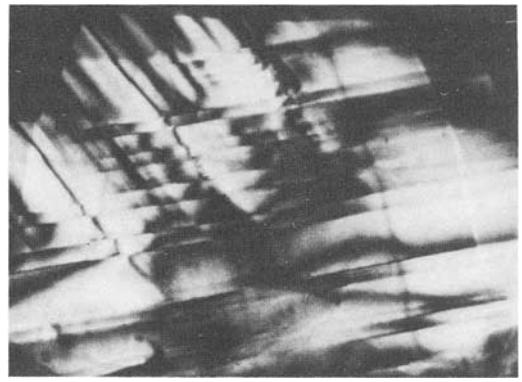

Fig. 10. Families of intersecting glide planes parallel to prism faces *a*, *a'* and *a''* $\{11\bar{2}0\}$ in synthetic orange sapphire which was produced by the Verneuil technique; view in a direction parallel to the *c*-axis. Crossed polars 25 x.

prism faces *a* $\{11\bar{2}0\}$ forming angles of 120° are frequently observable (Figure 9). In synthetic sapphires which were grown by the Verneuil technique, intersecting glide planes (the so-called Plato lines) parallel to *a* $\{11\bar{2}0\}$ are often present (Figure 10). Flux grown synthetic corundum of particular producers is recognizable by the presence of a single twin boundary parallel to *a* $\{11\bar{2}0\}$ (Figures 6, 7, 8). For a more detailed discussion of these problems, the reader is referred to the recent papers of Schmetzer (1985, 1986 a, b, 1987).

Acknowledgements

Chatham synthetic blue sapphires which were investigated in the present study were kindly supplied by the firm R. Litzenberger of Idar-Oberstein, West Germany. Financial support was given by grants of the Wirtschaftsministerium des Landes Rheinland-Pfalz, West Germany.

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Identifying yellow sapphires – two important techniques

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Abstract

The author discusses two new techniques for identifying yellow/orange sapphires.

1. Placing a blue filter between the light source and immersion cell provides the contrast necessary to resolve the colour banding (straight or curved) in natural and synthetic yellow/orange sapphires.

2. Heat treatment in Sri Lankan yellow to orange sapphires can be identified by exposing the stones to the heat and light of a strong bulb. Upon heating up slightly, the colour of heat-treated specimens will become darker and more brownish. As it cools back to room temperature the colour returns to normal.

The blue filter as a gemmological tool

In dealing with the corundum gemstones, yellow sapphires are often thought to be among the most difficult to identify. This is largely because yellow sapphires are frequently completely free of inclusions and the colour banding is more difficult to find in this colour than almost any other. The author has developed a new technique which makes it possible to locate the colour banding (straight or curved) in virtually all natural and synthetic yellow sapphires, thus greatly aiding their identification.

Natural yellow sapphires are produced primarily from four sources: Sri Lanka, Thailand, Australia and Tanzania. All of these stones contain straight growth lines (colour bands). Synthetic yellow/orange sapphires are of two types: Chatham has begun producing a flux-grown product, and this contains straight growth lines, but is extremely rare; the vast majority of all synthetic yellow/orange sapphires are produced by the Verneuil process, and, as such, contain curved growth lines. It must be stressed that all yellow/orange sapphires, synthetic or natural, possess these lines. The trick is simply to find them, and to see if they are straight or curved.

Although the presence of other inclusions or an iron absorption spectrum will allow identification, frequently these features are absent. This makes it imperative to locate the growth lines for positive identification. The traditional technique has been to immerse the stone in methylene iodide and examine it in the microscope with light field illumination. Some gemmologists suggest that a piece of tissue paper be placed over the light to provide diffusion. A better method is to use a piece of frosted white plastic or glass, as it won't catch fire. This is readily available from shops making plastic signs for less than $1.00.

The main problem with this technique, however, is that one is looking for yellow lines in a yellow stone immersed in a yellow liquid over a yellowish light (tungsten filament). Is it any wonder that they are hard to find? Some have suggested twisting the overhead fluorescent light under the microscope and placing the immersion cell on top of this. It is a definite improvement, but still not good enough. One day in 1981, while pulling my hair out in frustration at my inability to locate the bands in a yellow sapphire, I stumbled across a solution. Prior to this, on a lark, I had bought thin pieces of plastic of different colours in Bangkok's finest sign shop. On that fateful day, rather than lose more hair, I decided to see what would happen if these were placed under the immersion cell. One by one I tried them: red, green, yellow and then blue. Lo and behold, when the blue filter was placed under the cell (with the white one), the colour bands appeared! I broke it in half and tried a double thickness. Even better! Since that day we at AIGS have taught of and used the blue filter for the testing of all yellow and orange sapphires, and have been able to locate the colour banding in perhaps 98-99% of all stones.

I wish I could tell you that I knew what I was doing from the start, but such was not the case; the discovery was pure accident. However, it is possible to explain the effect. With the white filter only, the bands are difficult to see because they are the same colour as the stone; immersion in a yellow liquid

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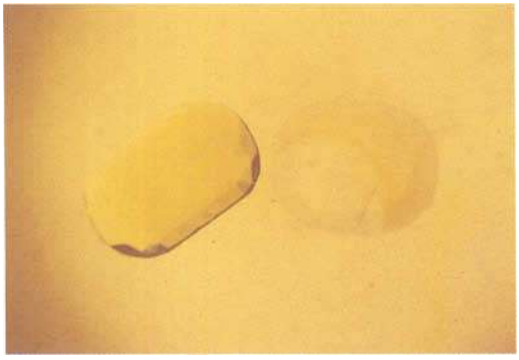

Fig. 1. Two yellow sapphires: a natural (left) and a Verneuil synthetic (right) are shown immersed in methylene iodide with diffuse light-field tungsten illumination. Due to the lack of contrast between the stone and the background, the colour zoning is difficult to see.

Fig. 2. The same two stones from Fig. 1, but now with a blue filter placed below the immersion cell. The blue filter provides contrast between the colour zoning and the background, making it much easier to resolve.

hardly improves the situation very much. The addition of a blue filter (a frosted blue filter allows elimination of the white filter), although cutting down on the available light, provides the contrast necessary to see the lines. Experimentation has shown that deep blue filters work better than light blue ones, up to a point. Experiment to find the best combination. The effect is not subtle; the blue filter provides an improvement of several magnitudes.

Not only does the blue filter work for yellow and orange sapphires, but other colour filters work for other corundums. It has been found that the colour of the filter should match the absorption maxima (wavelength of maximum absorption) of the stone. Thus, for rubies a filter of a yellow-green colour works best.

The effect of the blue filter on a yellow sapphire is shown in Figures 1 and 2. Figure 1 shows two stones over a white filter only; Figure 2 shows the same stones over a frosted blue filter.

Identifying heat treatment in Sri Lankan yellow and orange sapphires

Prior to 1981, to the best of the author's knowledge, heat treatment was not practised on Sri Lankan yellow/orange sapphires. The technique of deepening the colour of yellow/orange Sri Lankan sapphires by the appropriate heat treatment first came to our attention in 1981, when Bangkok gem dealer Robert Stevenson of Gem Resource showed the author a Sri Lankan orange sapphire of unbelievably rich colour. He claimed that it was treated in a new way (later learned to be a new heat treatment) and gave it to us to check the colour stability.

At this point we must pause for a moment to describe the methods used for checking colour stability. For several years prior to 1981, we had been routinely checking the colour stability of all Sri Lankan yellow/orange sapphires brought in for testing. This meant placing the stone on a metal platform and bringing a very hot 150 watt spotlight to within 1 cm of the stone, for up to one hour. (Note: Mr Cap Beesley (1983) of the American Gemological Laboratories has previously described a fade test for stones consisting of exposing the specimen to unfiltered ultraviolet light. If unfiltered short-wave ultraviolet were to be used with Sri Lankan yellow/orange sapphires, this will have exactly the opposite effect, deepening the colour, not lightening it.) The colour in those stones which had been irradiated to deepen the colour would always fade, usually well within one hour. If the stone was naturally coloured there would be no change. (However, reliable sources have reported in Sri Lanka that some yellow/orange stones will fade slightly, or a lot, right after being unearthed. Still, this does not negate the fade test as described above, as a customer wants to know the colour stability, whether irradiated by man or naturally coloured. The AIGS refuses to test Sri Lankan yellow/orange sapphires unless permitted to do this test.) We had tested a number of naturally coloured very deep yellow/orange Sri Lankan sapphires prior to 1981 which showed no change in colour during the fade test. Thus, you can imagine our surprise when, on performing the fade test on Mr Stevenson's stone, we noticed that the colour became much darker and more brownish. As it cooled back down to room temperature, the colour returned to normal. Amazing, but true!

Since that fateful day we have had the opportunity to observe first-hand the treatment process and can testify that it involves only heat (heat to 1800-1900°C in an oxidizing atmosphere). We have

Fig. 3. A heat-treated Sri Lankan yellow/orange sapphire is shown face-down at room temperature.

Fig. 4. The same stone from Fig. 3 is now shown just after it was exposed within 1 cm to the heat and light of a 150 watt spotlight for 15 minutes. The colour has become much darker and more brownish. After it returns to room temperature the colour will return to that in Fig. 3.

performed the fade test on literally thousands of stones and have found the following:

Origin	Reaction during fade test
Natural Sri Lankan yellow/orange sapphires	No change in most. Some may show some fading.
Natural or heat-treated yellow/orange sapphires from Thailand, Australia, Tanzania	No change
Irradiated Sri Lankan yellow/orange sapphires	The colour fades within one hour.
Heat-treated Sri Lankan yellow/orange sapphires	The colour temporarily becomes darker and more brownish. As the stone cools to room temperature, the colour returns to its original state. See Figures 3 and 4 for before and after representations.

In order to detect even slight changes in colour, comparison stones should be used. In other words, select two stones of similar colour. Perform the fade test on one only. While it is still hot (use tweezers!) compare its colour to the other. If it is a heat-treated Sri Lankan yellow/orange sapphire, its colour will have darkened noticeably. As for the reasons that this test works, the author can only speculate. The colour in natural Sri Lankan yellow/orange sapphires appears to be due mainly to colour centres. In the heat-treated Sri Lankan yellow/orange sapphires, however, it appears to be some type of mechanical coloration due to the exsolution of reddish Fe-rich mineral particles (hematite?). Apparently the colour of the particles is temperature dependent; hence the change as the stone is heated during the fade test.

We have found that there is a direct correlation between the original depth of colour before the fade test and the amount of change during the test. In general, the darker and more orangy/brownish the colour is to start with, the more change will be noticed during the test; the lighter the colour is to start with, the less change will be noticed during the test. It is not necessary to use only a 150 watt spotlight. Experiments have shown that almost any source of gentle heat will do, even a microscope bulb. Avoid overheating the specimen, however, for this could damage certain natural stones containing carbon dioxide inclusions.

The author feels that this test is extremely important for it represents the first *simple* test for detecting heat treatment in any type of corundum. It is believed that, in the future, as the gem markets begin to realize the vital importance of detecting *all* treatments in gemstones, tests such as this will come into widespread use.

References

Beesley, C.R. Cap, 1983. What you must know – A primer on treatment I.D. *Jeweler's Circular Keystone*, May, 48-56.

[*Manuscript received 17 September 1987.*]

Post Diploma

David Kent, FGA

London

We are very fortunate in London to have an evening class especially for Post Diploma students. I believe I can claim to be the oldest inhabitant and still a student!

In 1946, after six years' wartime army service in India and Germany, I wished to attend evening classes in order to improve my scanty knowledge of the German language. I consulted *Floodlight*, the educational booklet issued by the (then) London County Council, to see where German classes were held. However, I saw that 'Gemmology' was the subject listed before 'German' and decided to study gemmology instead. I had already returned to the retail jewellery trade, in which I had been employed since leaving school in 1929, and gemmology would be useful for my future career.

Having managed to obtain my Diploma in 1948, I immediately joined the class which was then held at the Chelsea Polytechnic. Our instructors were Basil W. Anderson and Alec Farn. Mr Anderson used to alternate a practical evening, using stones from his extensive collection, with talks on all subjects keeping us up-to-date with the latest gemmological information.

For instance we were given instruction on the distant vision or spot method of determining the refractive index of cabochon-cut stones very soon after Lester B. Benson devised it in America.

B.W.A. was very interested in emeralds and would inform us on all newly discovered sources during the 1950s and 1960s. Great strides were made in producing synthetic gem materials and we were given every opportunity to learn the different methods of manufacture. Glass, natural and artificial, was another favourite topic for interesting evening talks.

The class was treated to a series of articles on spectroscopy which B.W.A. and C.J. Payne had studied over many years. Their results were then published in 40 monthly instalments in *The Gemmologist* between 1953-1957.

At Christmas time and end of term we would be set light-hearted competitions. Prizes would be awarded and ranged from an orange to a bar of chocolate or a small group of crystals. Sometimes individual members would be called to the front of the class to give two-minute lecturettes on a subject of the master's choice – two minutes seemed a very long time.

The evening class moved from Chelsea in 1957 to the Northern Polytechnic and again in 1969 to the City of London Polytechnic (Sir John Cass College, Aldgate) where we now meet once a week.

During 1966 Basil Anderson moved to the west of England. Before he left he entertained us by recounting his experiences in a lecture entitled '40 years a gemmologist', starting in 1925 when he opened the gem laboratory in a small Hatton Garden room with a commissionaire, a balance and a telephone.

B.W.A. and Alec Farn were also keen on teaching us gemmological identification without instruments, with perhaps a lens only, using eyes, tongue, heft and even sound (natural and cultured pearls rattle differently together).

There have been many jewellers in the class as well as taxi drivers, doctors, solicitors and other professions. Members would sometimes speak on subjects close to their hearts.

Werner Stern was most interesting on the history of Idar-Oberstein, also on various methods of hardness testing.

I remember particularly talks given by that epitome of an English gentleman, Sir James Walton, eminent surgeon and later our Chairman/Curator and President of the National Association of Goldsmiths. He was interested in ways of testing specific gravity. He once gave us a long talk on atomic structure – any little knowledge I had at the start had evaporated at the end!

Sir James once confounded us all by bringing to class a collection of 52 jade and jade-like minerals

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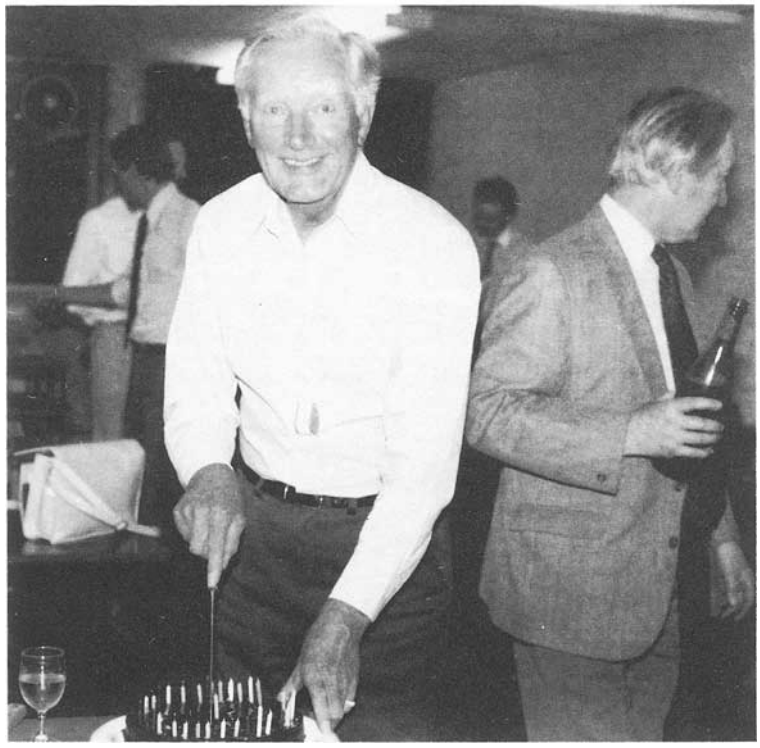

Surprise 70th birthday party for David Kent at a Post Diploma class, June 1985. *Photo by Rosemary Ross.*

housed in a box with a Plaster of Paris bed. Since then I have never been wholly confident of jade recognition.

Another member was Keith Mitchell who would advise us with his extensive knowledge of coloured gemstones.

We occasionally had lectures by visiting experts in various fields and I still have notes of those given by Robert Webster, Thorold Jones, Ernest Rutland and many others. For instance I remember talks on microscopy by Colonel Sprague; Mrs Alice Sumner-Tait on her exciting journeys when gem hunting in Brazil and East Africa; Elsie Ruff, a great enthusiast on sources of jade and C.J. Payne once came and gave us a very full description of the goniometer and how to use it. I have never quite recovered from the experience. I also have notes and charts on an occasion when we conducted an experiment in class on the relative volatility of mixed heavy liquids and the change in specific gravity at room temperatures. I must mention that this was under the guidance of Robert Webster.

In 1966 Alan Jobbins took over as instructor and has continued the good work. The class continues to thrive with most of the thirty members attending regularly. Therefore it tends to be a gemmologists' club and a great deal of specimen stone swapping takes place. We still have practical evenings alternating with talks mostly by E.A.J., usually illustrated with beautiful slides from photographs taken by him in various parts of the world. These lectures could include exotic birds and plants since Alan is a keen ornithologist as was B.W.A. Some of his lectures are also presented to international audiences. Occasionally we have a special evening on subjects such as jade, ivory or jewellery, when members bring pieces from their own collections for inspection and discussion.

In 1986 a party of American gemmologists visited the class and they returned to the USA wishing they had similar opportunities there.

[*Manuscript received 1 September 1987.*]

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Emerald-coloured rough

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On 15 July last year two specimens of 'emerald looking' rough were handed to us for testing. These weighed 95 and 19.5 grams (see Figure 1). They had been brought back from Zambia and apparently there was considerably more of this material available.

It appeared to be of a very good colour, but almost too good to be true. The surface consisted of patches of sandy material mixed with patches of pyrite. Examination with fibre optic lights in the transparent areas revealed inclusions not compatible with those found in emerald and under the Chelsea filter only green light was visible. The surface of the specimens looked too loose to make a good SG determination.

We expressed our doubts to the customer who really could not believe that they were not genuine emeralds. In order to get nearer to the truth we suggested polishing a flat on the small stone. This revealed a quartz reading. Emerald-green quartz – maybe this was a new deposit? The customer insisted that the large one was natural emerald, and demanded more tests.

It was not feasible to polish a flat on this specimen so that it could balance on the refractometer, so we suggested cutting off a section. This

Fig. 1. The two specimens of 'emerald looking' rough with a centimetre scale.

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Fig. 2. The larger specimen cut in two. The surface has been scraped to show where the sand and pyrite had been stuck on.

Fig. 3. A close-up of the larger of the two cut pieces.

Fig. 4. A piece of metal (possibly aluminium) can be seen in the cavity in the top left-hand corner. Transmitted light.

was agreed and all was revealed (see Figures 2, 3 and 4). The stone consisted of a central body of colourless quartz that had a green lacquer all over it. This was wrapped in slabs and many pieces of clear quartz also painted with green lacquer, which can be seen peeling off where we had disturbed it with the saw. It was all held strongly together with a softish gum and the sand and pyrite had been stuck on (Figure 2 shows where we had scraped off this layer). Also there was a piece of softish metal (possibly aluminium) which can be seen in Figure 4 in the large cavity in the top left-hand corner.

It was now obvious that this was a composite stone and a fake.

[*Manuscript received 7 August 1987.*]

The XXI International Gemmological Conference, Brazil 1987

Report by Alan Jobbins

The conference, which was superbly organized by Elizabeth and Ian MacGregor and their Brazilian helpers, was held in the Hotel Atlantico Sul some 35km WSW of Rio de Janeiro. The conference, held from 20–24 September, was followed by an excursion starting on 26 September and finishing on 4 October. Some 45 delegates (from 19 countries), local observers, wives and guests attended. The excursion route took in the following towns: Belo Horizonte, Diamantina, Aracuai, Teofilo Otoni, Governador Valadares, Itabira and Ouro Preto. The mining operations visited included: Sampaio and Boa Vista diamond mines; Tejucana diamond dredging operations; Urubu feldspar and lithium pegmatite mine; Marambaia Valley aquamarine and chrysoberyl mines; Golconda feldspar pegmatite mine; Hematita alexandrite and Belmont emerald mines; Capão topaz mine.

The papers read are listed below, broadly in the order in which they were presented.

MacGregor, B.I. (Brazil). Introduction to the Conference and Brazil.

Sauer, D., and Cassedanne, J.P. (Brazil). Classification of the gemstone deposits of Brazil.

Koivula, J. (USA). Mirror image reversals: inclusions as symmetrical art.

Chikayama, A. (Japan). Recent report from Burma: gem occurrences and gem emporium.

Chalmers, O. (Australia). The opal fields of South Australia.

Poirot, J.P. (France). Coatings of imitation pearls.

Pienaar, H.S. (South Africa). A numerical approach to gem identification.

Kanis, J. (Portugal). A new emerald deposit in Zimbabwe 'Machingwe Mine'.

Barros, J.C. (Brazil), and Kinnaird, J. (UK). Emeralds from Goias State, Brazil.

Schwarz, D. (Brazil). A locality review of known Brazilian emerald occurrences and a mineralogical comparison of emeralds from major producing areas.

Gübelin, E. (Switzerland). Recently observed inclusions in gemstones.

Zwaan, P.C. (The Netherlands). Gemstones from Cuba.

Saul, J.M. (France). An unusual glass specimen from East Africa.

Graziani, G. (Italy). Blue corundum analyzed by unusual techniques.

Ripoll, V.M., de Brum, T.M., Hofmeister, T., and Juchem, D. (Brazil). Mineralogical and gemmological characteristics of corundum from Santa Catarina.

Shida, J. (Japan). The colour of padparadscha sapphires.

Arps, C.E.S. (The Netherlands). Observations on gem gravels from Sri Lanka.

Juchem, P.L., Hofmeister, T., and de Brum, T.M. (Brazil). Gemstones in the State of Rio Grande do Sul, Brazil.

Segnit, E.R. (Australia). Some notes on tourmaline, black opal and 'treated matrix' from Autralia.

Pie Roger, R.M. (Spain). Gemmological materials found in Spain.

Jobbins, E.A., Scarratt, K., and Harding, R.R. (UK). The British Crown Jewels.

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Fig. 1. Hand sorting emerald concentrate on a moving belt at the Belmont emerald mine near Itabira, Minas Gerais, Brazil.

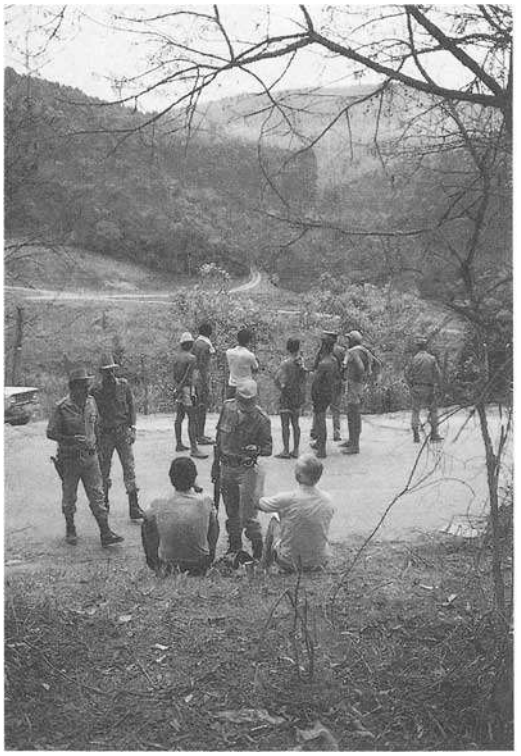

Fig. 2. The Hematita alexandrite deposit (background) with members of the Conference (seated) discussing gemstone rough with military police guarding the deposit. Garimpeiros (free-lance miners) are standing behind the police.

Becker, G. (West Germany). Apatite – colour change by heat treatment.

Middleton, R.C. (Brazil). The geology around the Virgem de Lapa gem–bearing pegmatite bodies.

Castelo Branco, R.M.G., de Menezes, J.S. (Brazil). Occur rences of gems in the State of Ceara, north–eastern Brazil.

Superchi, M. (Italy). An Italian ornamental material: the 'pot stone' from Valmalenco (Lombardy).

Eliezri, I.Z. (Israel). Geological evidence supporting identification of the gemstones in the breastplate of the High Priest in the Bible.

Zoysa, J. (Sri Lanka). A chrysoberyl–bearing pegmatite near Pattara, Sri Lanka.

Schiffmann, C. (Switzerland). Subjects of topical interest raised and discussed.

Svisero, D.P. (Brazil), and Meyer, H.O.A. (USA). Diamonds and kimberlites in continental Brazil: a review.

Haralyi, N.L.E. (Brazil). Considerations concerning flat tened and elongated diamonds.

Sobolev, N.V. (USSR). Comparative study of crystalline inclusions in diamonds from the USSR and India.

Koivula, J.I. (USA). Visual evidence of elastic deforma tions in diamonds.

Meyer, H.O.A. (USA). Diamonds deposits of Venezuela.

Hughes, R.W. (Thailand). Gemmological developments in Bangkok – new treatments, techniques, etc.

Saul, J. (France). The origins of diamonds and the exist ence of porosity and carbonate–rich fluids deep in the crust.

Miyata, T., and Hosaka, M. (Japan). On the synthesis of rose quartz.

Schmetzer, K. (West Germany). Methods of distinction of natural and synthetic citrine.

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The refractometer – distant vision and awkward specimens

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Distant vision is one of those grey areas which lurk in the gemmological shadows.

It is easy enough to go over the prescribed routine (see Figure 1) but when a keen student is bold enough to say 'I don't find it easy because the blob is generally too vague to see exactly, when bisected by the shadow', what can one do?

Knowing that communication arises from the communicant seeing and understanding, and not in the instructor's teaching, one can either hope for the bell, repeat the exercise more thoroughly, or search for inspiration. In searching for inspiration I took one of the nearby fibre optic lights and directed the light on to the stone under test, whilst leaving the Rayner monochromatic light source in the conventional position (see Figure 2). The vague blob produced by the monochromatic light source acting on a green jadeite suddenly registered bright green as the fibre optic light transmitted the green of the stone down through the refractometer optics to register within the liquid blob shadow on the scale (Figure 3). The bisection position could now be seen quite positively and a usefully accurate refractive index obtained. Most gems submitted to distant vision techniques are generally transparent to semi-opaque and therefore permit the fibre optic light to penetrate the specimen and project its colour on to the scale.

The technique is also successful with the occasional opaque stone, when the fibre optic light can be aimed horizontally at the liquid interface of the specimen under test and the refractometer prism.

While this method may not achieve third place decimal accuracy with distant vision, one point in its favour is that we only need to bring the test

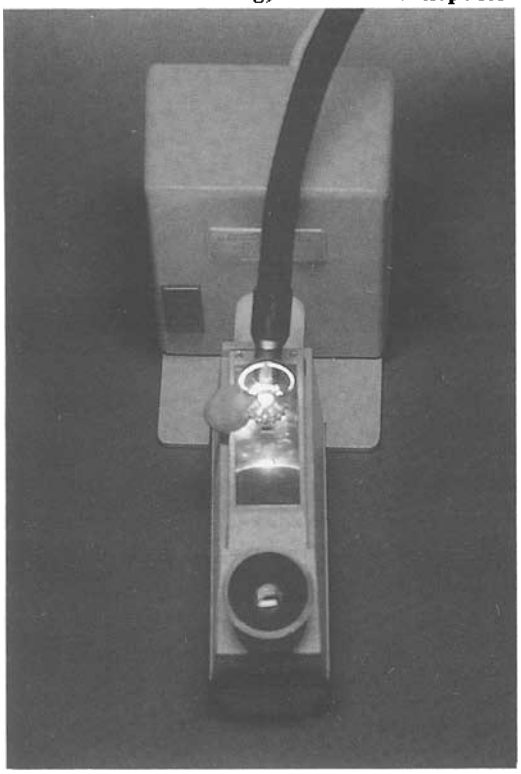

Fig. 2. Fibre optic light source directed on to the stone under test.

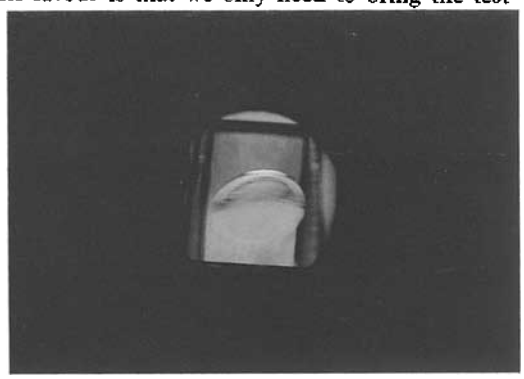

Fig. 3. Bright green blob seen when fibre optic light was directed through jadeite.

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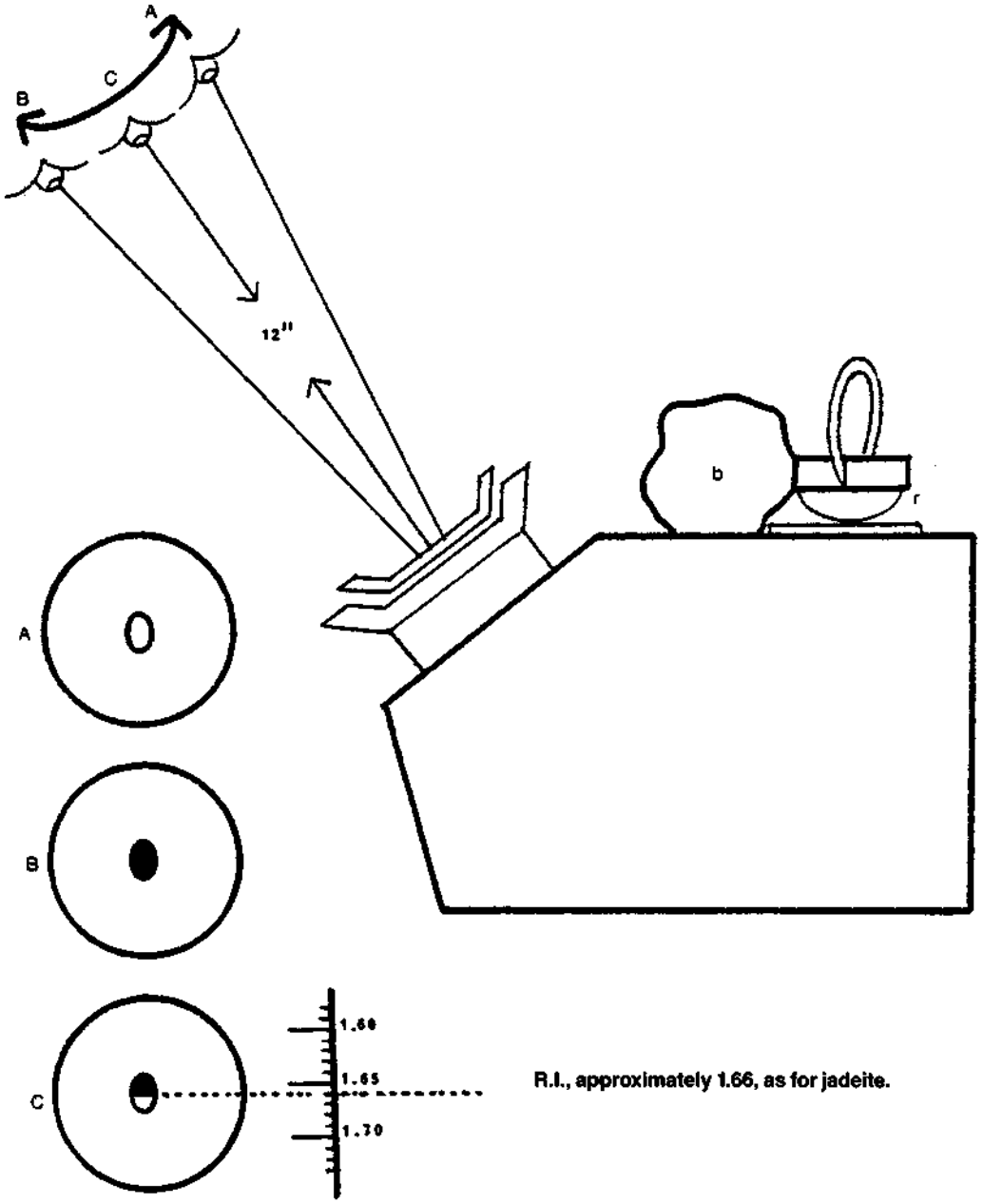

b. Blu-tack or plasticine to support the ring, etc.

r. Ring, set with cabochon gemstone.

Fig. 1. Distant vision technique for cabochons, etc.

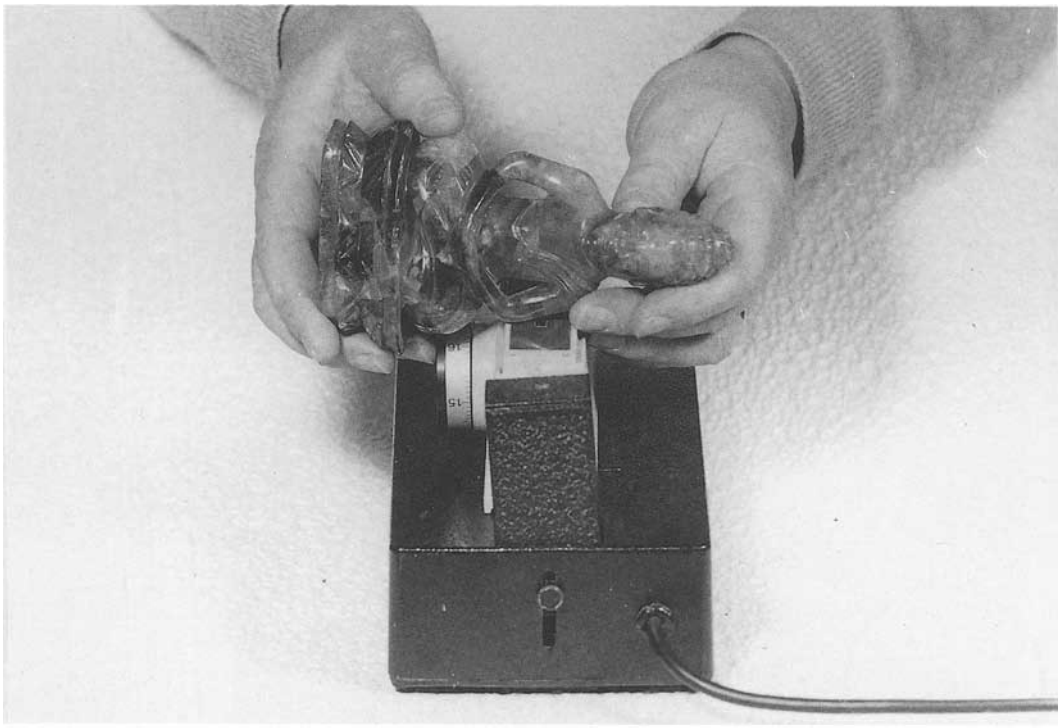

Fig. 4 A fluorspar Buddha carving on the refractometer.

material into contact with the refractometer prism, and virtually all cabochon gems oblige by projecting beyond the setting, thus facilitating such contact. What is not generally appreciated from this is that all sorts of sizes and shapes can be tested in this way and therefore beads, baroque shapes, carvings, bangles and the like, can be accommodated. Figure 4 shows a Buddha carving in fluorspar being tested. I feel it important to mention that the best results for distant vision with a refractometer are gained in the 1.50 to 1.70 range of refractive indices. Above and below these values the determinations become extremely cramped and difficult to extract accurately. The difficulty outside this central range is in obtaining a blob bisection position. The critical bisection is aided in much higher or lower refractive gems by sliding the specimen gently off the central position of the prism, but while this enables the bisection position to be achieved, it also introduces a slight error.

To illustrate this, select the flat table facet of a cut rock crystal and position it centrally on the refractometer as for a normal direct scale reading. The ordinary ray should register 1.544. While watching the shadow reading, slide the specimen gently toward the eyepiece of the instrument and the reading will lower to about 1.540, and when it is slid gently towards the back of the instrument the ordinary ray will rise to about 1.548. It is good refractometer practice to keep such a specimen handy in your refractometer case as it keeps an eye on the accuracy of your instrument, and if you should find a slight error of, say, 0.003 when the rock crystal is centrally located on the prism, then this can be added to, or subtracted from, all subsequent readings to counterbalance the constant error.

Chunky bracelets, earrings and faceted bead necklets, can cause some difficulty in arriving at a 'safe' RI measurement; the main concern being to protect the instrument from the jewellery 'running off' the refractometer and chipping the prism. Large blobs of Blu-Tack or plasticine are useful in acting as control holds over the jewellery and so permit gentle contact to be made between gem and the soft and brittle prism (see Figure 5, the bead necklace, and Figure 6, the faceted stone bracelet).

The above details are abstracted from 'The refractometer technique', a highly informative chapter in a forthcoming book *Practical diamond and gem identification* to be published by NAG Press Ltd.

[*Manuscript received 26 October 1987.*]

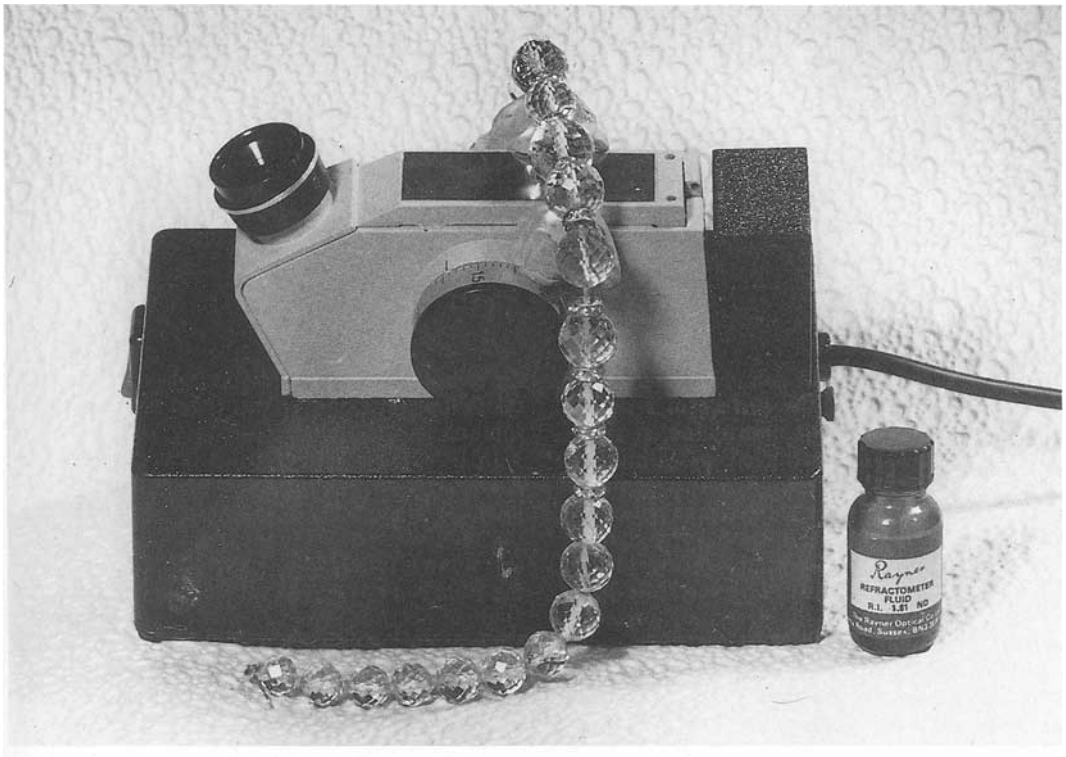

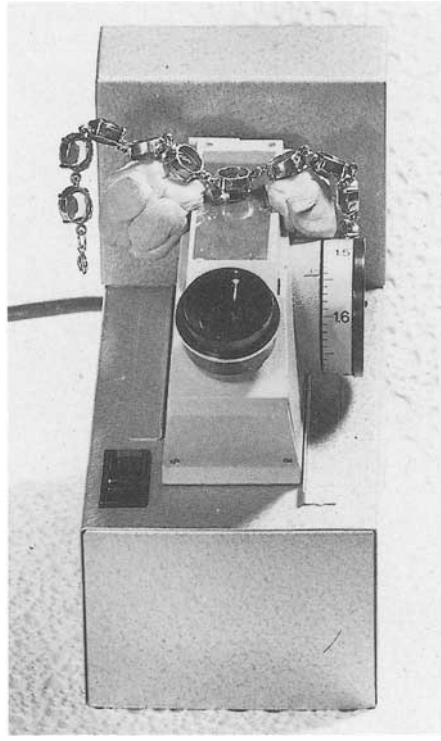

Figs. 5 and 6. Large balls of Blu-Tack are positioned on the flanks of the refractometer. These take a firm hold of the necklet and bracelet and allow them to be straddled across the prism so that one gem at a time may be carefully lowered into contact with the prism.

Further development of the Brewster-angle refractometer

Peter Read, C.Eng., FGA

Brewster's law states that complete polarization of a ray reflected from the surface of a denser medium occurs when it is normal (i.e. at right-angles) to its associated refracted ray within that medium (Figure 1). If the Brewster angle of polarization is A, then the refractive index of the reflecting medium is equal to *tan A*. (The plane of polarization is the same as the plane of the reflecting medium, which is why vertically polarized sunglasses cut down the glare from horizontal surfaces such as the sea.)

Although B.W. Anderson proved that a gemstone's refractive index could be derived by utilizing the Brewster angle of polarization,[1] he told the writer that this method of measurement was not developed by him into a usable instrument because of the mechanical difficulty involved in rotating a beam of light about the facet surface of a gemstone while simultaneously following the movement of the reflected ray with a suitable polarization detector (although, in hindsight, there was a simpler solution!).

In 1979, the writer built his first experimental Brewster-angle refractometer[2] which used a high-intensity beam of collimated white light and passed the rays reflected from the polished surface of a gemstone through a vertically-orientated polarizing filter onto a translucent screen. The Brewster angle of polarization was detected by varying the angle of the incident ray until the light spot on the screen was extinguished, and this angle was translated via a scale into an RI reading. Limitations of this simple optical model were two-fold. Because white rather than monochromatic light was used, the extinction of the light spot on the screen was not total at the Brewster angle; the sensitivity of the instrument was further limited by the low intensity of the imaged light spot (this was due partly to the

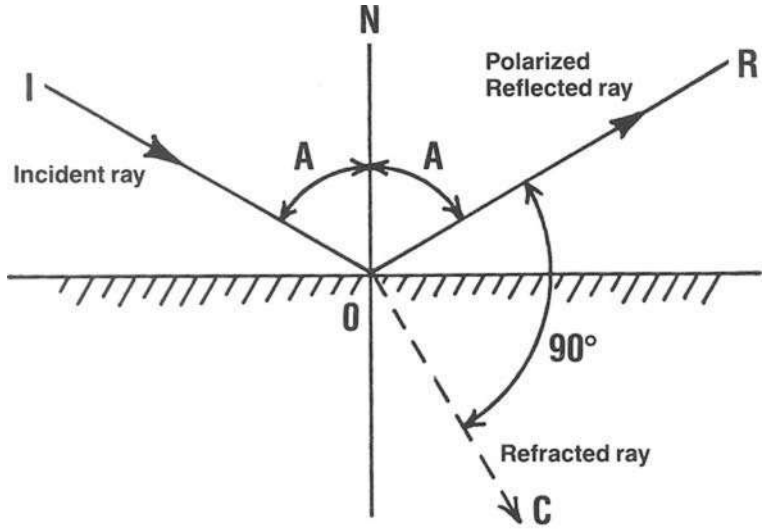

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light absorbed by both the polarizing filter and the screen, and partly to the reflectivity of the gem's surface – particularly in the case of low RI stones).

By coincidence, while the writer was evaluating this first model, Dr R.M. Yu (of Hong Kong University) was also exploring the possibility of using the Brewster-angle phenomenon as a means of measuring a gem's RI. With Yu's method,[3] a graduated transparent scale is illuminated by a fluorescent lamp whose light is diffused by means of a strip of translucent white plastic. Light from the illuminated scale is reflected from the polished surface of the gem and viewed through an appropriately orientated polarizing filter. As the various points on the scale subtend different angles to the reflecting surface of the gem, the observer sees a dark band on this otherwise evenly illuminated scale, this band occurring at angles of viewing close to the Brewster angle for the gem. The position of the band on the scale can therefore be used as an indication of the gem's RI, and the scale can be calibrated accordingly.

The recent availability of a small, relatively low-cost, laser using a helium-neon plasma tube with a vertically-polarized output of 0.5 mW at 632.8 nm has enabled the writer to develop a more sophisticated electronic version of his original optical model.

In this redesigned version (Figures 2-4) the laser is mounted so that it can be pivoted through 20 degrees beneath a 1 mm diameter gemstone test aperture, with the pivot fulcrum coincident with the aperture position (Figure 5). When a gemstone is placed in position over the aperture, the beam reflected from the polished surface of the gem is detected by a photodiode. To ensure that the reflected laser beam is detected over the full range of angles, a photodiode was chosen that has a light sensitive area of at least 9 mm^2, and this is placed close to the point of reflection.

The photodiode output is amplified and displayed on a panel meter. Because of the high polarization ratio of the laser (500:1), a very positive null is obtained on the meter reading when pivoting the beam through the gem's Brewster angle. To avoid the necessity of fitting a mechanical scale to translate the beam/laser angle into an RI reading, a small transducer has been fitted to the laser pivot shaft. This converts the angular movement of the laser into a voltage which, via a 'Null/RI' change-over switch, is then displayed as an RI reading on the same panel meter. While the original model covered the RI range of 1.43 to 2.90 (fluorspar to rutile), the new version has been designed to include high-RI materials such as hematite and has

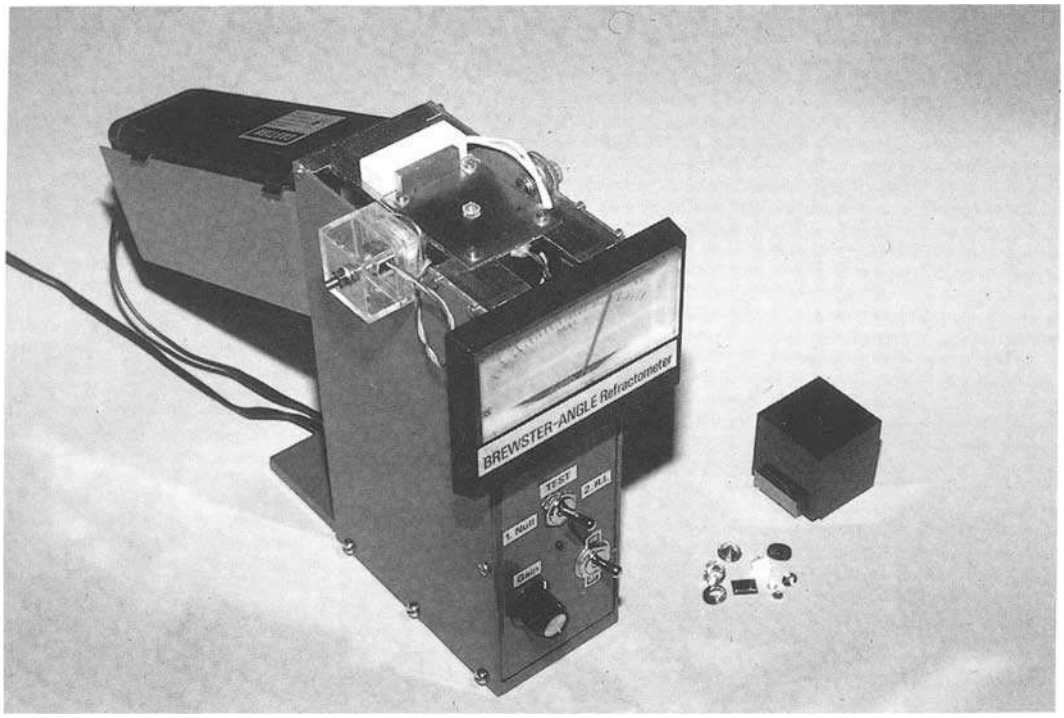

Fig. 2. General view of the experimental Brewster-angle refractometer. The magnetic interlock has been by-passed and the safety cover removed to show a synthetic rutile specimen illuminated by the laser beam.

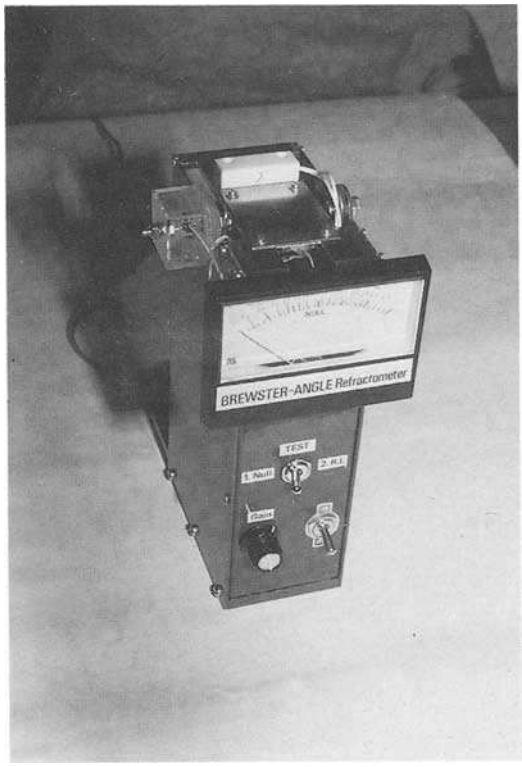

Fig. 3. (Left). View of the instrument's control panel. The panel meter is used via the two-position 'TEST' switch for both null indication when pivoting the laser beam, and for direct readout of a gem's RI when the null is found.

Fig. 4. (Below). Side view of the refractometer showing the angle/voltage transducer fitted to the laser pivot and the safety cover in position over the test platform.

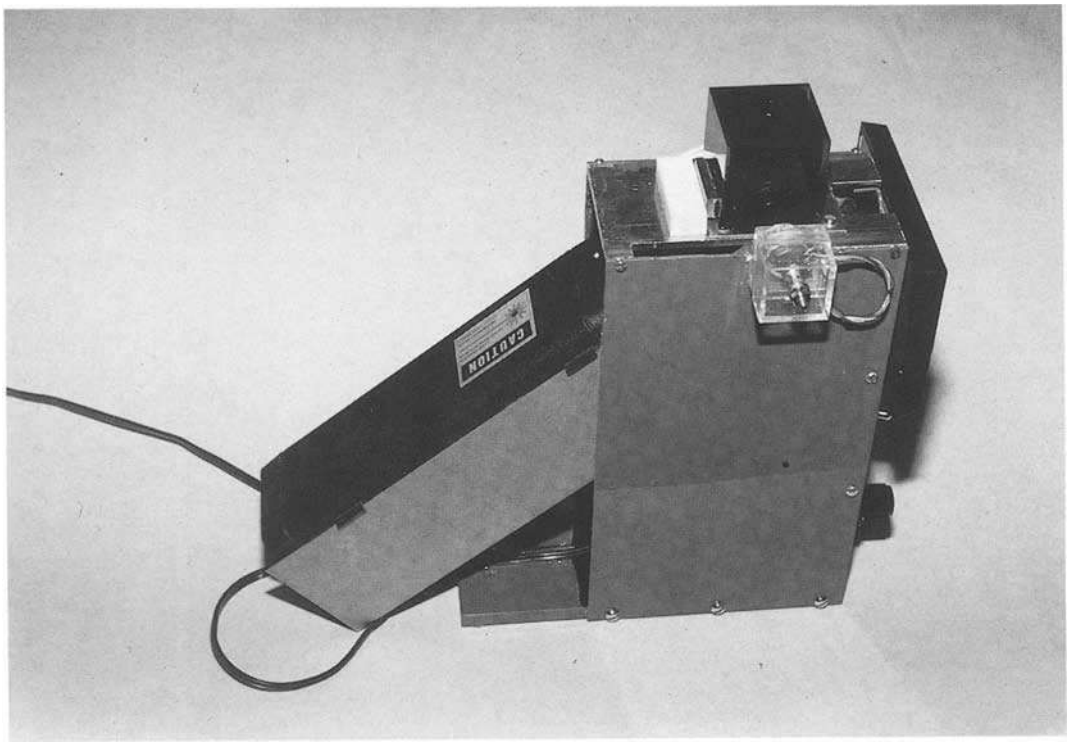

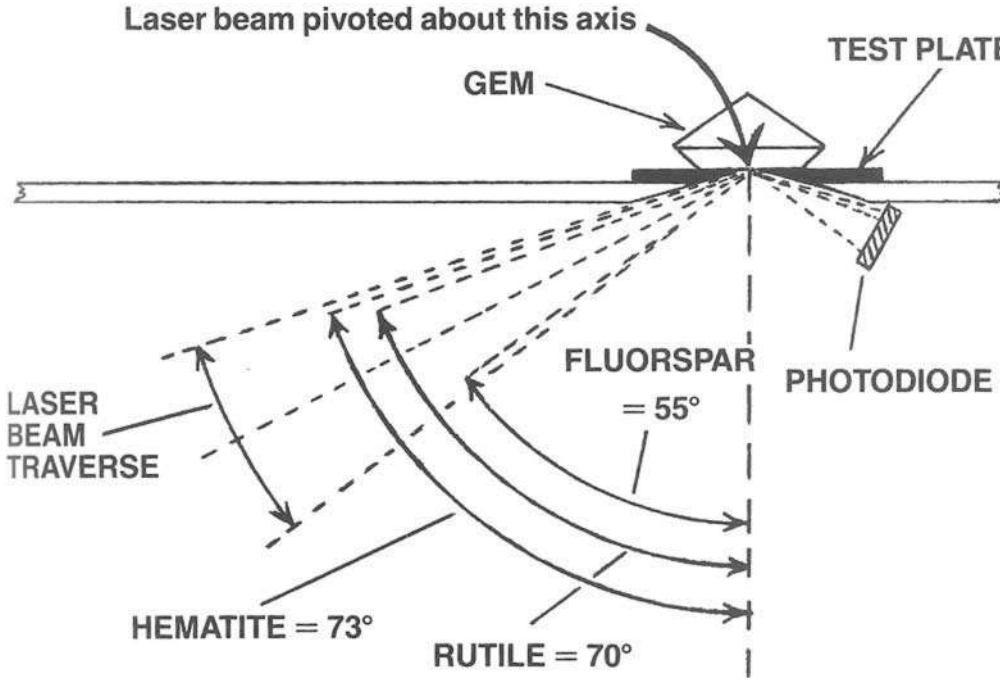

Fig. 5. Sketch showing the optics of the experimental refractometer.

a measuring range of 1.40 to 3.3.

To allow for possible non-linearities in the angle/voltage transducer, the RI scale of the panel meter was calibrated by first measuring a series of ten gemstones with RIs ranging from 1.43 to 3.2. From a graph relating these RIs to the scale readings on the meter, evenly spaced calibration points were derived (1.4, 1.5, 1.6 etc) and marked on the meter scale.

To avoid overloading the null meter when testing high reflectivity stones such as CZ, diamond and rutile, a 'Gain' control is fitted to reduce the amplification of the photodiode output until the vicinity of the Brewster angle is reached. As a further safeguard, this time to the operator's eyes, a light-tight box, painted on the inside with matt black paint to absorb the laser beam, is placed over the gem during testing. This safety cover is fitted with a small bar magnet which operates a magnetic reed switch to turn off the laser beam when the cover is removed from the test platform.

While this instrument cannot yet resolve refractive indices to an accuracy better than ±0.01 at the lower half of its range, and ±0.1 towards the top end of its scale, it is hoped that a further version with improved laser pivot bearings, a friction-lock control to adjust the laser beam angle (at the moment, the laser is pivoted by hand and cannot be locked in position at the null point), and a 1:5 gearing of the angle/voltage transducer drive, will further improve its capability.

Finally it should be mentioned that one of the main advantages of the Brewster-angle refractometer over the reflectivity meter is that provided the facet of the gem to be tested is reasonably flat, the accuracy of reading is not affected by the degree of polish as this only affects the sharpness of the null and not its angular position. In use, the Brewster-angle refractometer is a much quicker means of determining RI than by measuring the angle of minimum deviation on a table spectrometer. Unlike high-range critical-angle refractometers (using strontium titanate or cubic zirconium oxide tables) the Brewster-angle model also has the advantage of not requiring toxic contact fluids.

Acknowledgement

In conclusion, the writer would like to acknowledge the assistance afforded by the Rayner Optical Company in constructing the mechanical section of the experimental model.

References

1. Anderson, B.W., 1941. Brewster angle, Gemmologist, **X**, 61-3.
2. Read, P.G., 1979. An experimental Brewster-angle refractometer. *Journal of Gemmology*, **XVI**, 8, 537-41.
3. Yu, R.M., 1979. The Brewster-angle refractometer. *Gems & Gemology*, **Winter**, 245-7.

[*Manuscript received 2 September 1987.*]

Gemmological Abstracts

AHRENS, J.R., 1987. The Burma emporium. *Lapidary Journal*, **41**, 4, 42–50, 4 figs in colour.

The article describes a visit to the government-run gem auctions in Rangoon. M.O'D.

ATKINSON, W.J., 1987. The exploration and development of Australian diamond. *Industrial Diamond Review*, **47**, 1, 1–8, 2 maps.

Alluvial diamonds have been known in Australia since 1851 but the most significant event was the setting up of the Ashton Joint Venture in 1972 to explore for diamonds in the Kimberley region of Western Australia, which has resulted in the location of ~90 kimberlite and lamproitic bodies and two alluvial diamond deposits. The diamondiferous Ellendale olivine lamproites (25 m.y.) was discovered in 1977. Diamondiferous kimberlite, although theoretically predictable, had yet to be found on the Australian continent, and a separate suite of indicator minerals had to be identified as characteristic of the olivine lamproites within the leucite lamproites; this suite, of fine grain size, is dominated by chromite. The richly diamondiferous Argyle lamproite was discovered in 1979. These olivine lamproite diatremes have large surface areas but extremely narrow feeder pipes. The Argyle diatreme (1100 ≃ 1200 m.y.) is infilled with sandy lapilli–tuff consisting of ~40% rounded quartz grains together with lamproite clasts. The Argyle pipe contains 3 ppm diamonds, mostly as brown, frosted, irregular shaped stones with inclusions of graphite; they are generally heavily resorbed dodecahedra, i.e. predominantly industrial quality currently averaging $6.50 carat, but with some gem material, including very rare pink stones. Two associated alluvial deposits average 4 carats/tonne. R.A.H.

BALFOUR, I., 1987. Famous diamonds of the world, XXXI. Eugénie. *Indiaqua*, **47**, (1987/2), 117–19.

The rough from which the Eugénie was cut weighed more than 100 carats and was found around 1760 in the province of Minas Gerais, Brazil. It is said that the stone was cut in Holland into an oval-shaped brilliant of 51 ct. It was given by Catherine II, Empress of Russia, to Prince Potemkin (for a time the stone was known as the 'Potemkin' diamond). After Prince Potemkin's death, the diamond was bought by Napoleon III for his young bride, Empress Eugénie. The diamond had two further owners, but its whereabouts now are unknown. P.G.R.

BALFOUR, I., 1987. Famous diamonds of the world, XXXII. Kimberley. *Indiaqua*, **47**, (1987/2), 120–1.

The Kimberley diamond, allegedly from the Kimberley Mine in South Africa, weighing 490 carats in the rough, was initially fashioned into a 70 carat emerald-cut stone in 1921. In 1958 it was recut to its present weight of 55.09 carats. The Kimberley was sold to a private Texas collector in 1971. P.G.R.

BANK, H., 1987. (a) Schwarzer Turmalin als Glas bestimmt. (Black tourmaline identified as glass.) *Zeitschrift der Deutschen Gemmologischen Gesellschaft*, **36**, 1/2, 88–90; (b) Schleifwürdige Spinelle aus Nigeria. (Gem quality spinel from Nigeria.) Id., 90; (c) Zu den optischen Daten von Phenakit. (On the optical data of phenakite.) Id., 90–2.

(a) An opaque black cabochon of 0.106ct, that had been certified by an overseas gemmological laboratory as being glass, was found to be tourmaline after careful testing. (b) The second note deals with gem quality spinels from Nigeria. The crystals were of a pale violet colour. (c) The last note deals with phenakite and compares optical data of stones from Brazil, Madagascar, Nigeria and the USSR. E.S.

BANK, H., LEYSER, K.-G., MAES, J., 1987. Grüne Diopside aus Ostafrika als Grossulare bzw. Kornerupine angesehen. (Green diopsides from East Africa wrongly identified as grossularites and kornerupines.) *Zeitschrift der Deutschen Gemmologischen Gesellschaft*, **36**, 1/2, 86–8.

Details of the method of correct identification of green diopsides are described. E.S.

BOSE, M., 1987. Dearer diamonds. *The Times Newspaper*, No. 62873, 15 September 1987, p.33.

Diamond prices have been rising owing to big

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buying by the Japanese, probably due to the strength of the yen against the dollar. Diamonds should be valued not as investments but for their beauty, rarity and long-lasting quality. J.R.H.C.

BRIGHTMAN, R., WILLHELM, M.-L., 1987. Resin bonded malachite. *Australian Gemmologist*, **16**, 6, 239–40, 2 figs in colour.

A bangle from Tanzania had been made from malachite fragments set in matrix of resin and malachite dust. Resin fluoresced blue/green under ultraviolet light and contained bubbles. RI 1.54–1.55 was due to resin. Bubbles and fragments obvious with lens. R.K.M.

BROWN, G., 1987. The Kruss UV spectroscope (model UVS-2000). *Wahroongai News*, **21**, 1, 18–19.

A new instrument using mercury vapour light w/l 250 to 600nm and a fluorescent integrating screen to display unabsorbed emission lines. Report says that one would expect a little more diagnostic and discriminatory potential for the price (DM6860). R.K.M.

BROWN, G., BRACEWELL, H., 1987. 'Citron chrysophrase'. *Australian Gemmologist*, **16**, 6, 231–3, 4 figs in colour, 1 map.

A massive lime-green material associated with common opal, magnesite and chrysoprase, found at Yunamindera, a gold mining area of Western Australia, had hardness about 4½, SG 2.90, spot RI 1.60 with large DR. Slow solubility in hydrochloric acid suggested a carbonate, probably a nickeloan magnesite. Chrysoprase is a misnomer. R.K.M.

CLANCEY, A., 1987. Rocks in gemmology. *Wahroongai News*, **20**, 10, 24–9.

A considered attempt to relate gem species to their types of parent rock, a subject for a larger book here reduced to six pages. R.K.M.

CYR, K.R., 1987. Pride of the Philippines. *Lapidary Journal*, **41**, 4, 51–8, 1 fig. in colour.

Ornamental materials from the Philippines include shells of various kinds and varieties of quartz. M.O'D.

FRYER, C.W., ED., CROWNINGSHIELD, R., HURWIT, K.N., KANE, R.E., 1987. Gem Trade Lab notes. *Gems & Gemology*, **23**, 2, 104–10, 20 figs in colour.

An epidote with tremolite needle inclusions and opals which proved to be a new type of assembled stone, opal chips cemented into a glass dome, are described. A cultured pearl drop filed or otherwise 'worked' at one end, lost its 'orient' and turned milky – no explanation could be offered. A sphere from the Upper Cretaceous era had been called a fossil pearl; confirmed to have a concentric structure but the absence of nacre precluded calling it other than a calcareous concretion.

A nice peridot cat's-eye is illustrated – these are rare. Dyed yellow quartzite, offered in all innocence as jadeite at the 1987 Tucson Gem and Mineral show, gave a spot reading of 1.55 and dye came off on an acetone swab.

An exceptionally deep-cut pale blue sapphire resembled a 'native-cut' Ceylon stone. Colour was entirely in the culet and curved zoning was detected there. A Plato test confirmed this as synthetic. A large yellow sapphire showed clearly visible curved zoning which is unusual in synthetics of this colour. A blue sapphire had discoid fractures which confirmed heating, and irregular misty 'smoke-ring' inclusions which have not been seen before.

A small brownish-green stone from Thailand was identified as sapphirine by RI, 1.711 and 1.718. These very rare gems are more normally a deep sapphire blue. Carved beads offered at Tucson by dealers from Beijing were shown to be surface dyed serpentine when sawn in half and polished – dye was soluble in acetone. A bi-colour drop topaz was purplish-pink and orange-yellow either side of a twin plane. All items are illustrated. R.K.M.

FUHRBACH, J., 1987. Want to buy a 'hot diamond'? – a letter. *Gems & Gemology*, **23**, 2, 111, 2 figs.

A 'black diamond' in a ring caused redness and a sore on the wearer's finger. Unset, the stone had an SG of 5.272 but no RI was obtained. A Geiger counter confirmed that there was strong gamma radiation and the amorphous substance was identified as pitchblende. R.K.M.

GALIA, W., 1987. Eine neue Generation synthetischer Rubine von P.O. Knischka unter Verwendung natürlicher Nährsubstanz. (A new generation of synthetic rubies from P.O. Knischka grown without the use of seeding crystals.) *Zeitschrift der Deutschen Gemmologischen Gesellschaft*, **36**, 1/2, 19–31, 21 figs (4 in colour), 1 table, 1 graph, bibl.

The synthetic ruby crystals were produced without seed crystal by spontaneous nucleation from flux according to US patent 4 525 171. These crystals are now being produced commercially. The author describes a ruby prism of 328.5 ct. Growth takes eighteen months with hardly any platinum inclusions. No curved growth marks can be seen. There are some milky or cloudy dispersions. Traces of Pt, Na, W and Ta were detected, showing that the crucible was platinum and the flux contained

$Na_2W_2O_7$ and Ta_2O_5. The UV absorption was found by using a recording double-beam Leitz Unicam spectrophotometer as well as a Krüss UV spectroscope. The new material yields stones of up to 5 ct of high transparency. The colour leans towards purple. RI 1.762–1.770, DR 0.008. SG 3.97–4.01. Definite dichroism from reddish-orange to saturated purplish-red. E.S.

GNEVUSHEV, M.A., ZIL'BERSHTEIN, A.H., KRASHENNIKOVA, G.E., 1986. (Birefringence of diamonds from shock metamorphosed rocks.) *Zapiski Vses. Min. Obshch.*, **115**, 4, 442–6.

Birefringent plates (⊥[111]) of diamond from shock metamorphosed gneisses were studied by optical crystallographic methods. Two of the plates have their optic axis oriented along [100] of the diamond and their birefringence must be due to deformation. The latter is calculated to have required a residual mechanical stress of 21 and 41 kbar. The fact that the elongation of these plates corresponds with the lowest *n* is further evidence of a deformation origin of the birefringence. R.A.H.

HAUGEN, S.O., 1987. A system for evaluation of opal. *Australian Gemmologist*, **16**, 6, 213–15.

A precis of a suggested points system of evaluation for this immensely variable gem. R.K.M.

HEINDORFF, J., 1986. Transparent plagioclase feldspar. *Wahroongai News*, **20**, 10, 21–3.

Ms Heindorf says [gemmological] reference books give little information on plagioclase gems, so she has condensed some available facts to remedy this. R.K.M.

HENN, U., 1987. Inclusions in yellow chrysoberyl, natural and synthetic alexandrite. *Australian Gemmologist*, **16**, 6, 217–20, 12 figs in colour.

Inclusions can indicate origin but need microprobe to identify. Natural alexandrites usually show phlogopite regardless of sources. Some Japanese synthetics are clean, others show flux, platinum, and fingerprint 'veils' ('rumpled feathers'). Origins difficult or impossible from inclusions. R.K.M.

HEYLMUN, E.B., 1987, Virgin Valley. *Lapidary Journal*, **41**, 3, 33–44, 5 figs (3 in colour).

Fine dark opal pseudomorphous after wood is found in the Virgin Valley area of Nevada, USA. M.O'D.

INGELSON, A., 1987. Western Canada's finest. *Lapidary Journal*, **41**, 4, 20–6, 6 figs in colour.

A short account of mineral museums in western Canada and their contents. M.O'D.

KANE, R.E., 1987. Three notable fancy-colour diamonds: purplish red, purple pink, reddish purple. *Gems & Gemology*, **23**, 2, 90–5, 9 figs in colour.

A gemmological report on three diamonds sold early this year at Christie's, New York, for quite astonishing record prices – the highest, an 0.95ct purplish-red with surface blemishes, for $880,000. All three stones are strongly coloured, and are said to have originated from Brazilian mines more than thirty years ago. A 415.5nm absorption line was seen at room temperature in the largest stone and again in the other two when moderately cooled. LW UV fluorescence was bluish-white in all three stones but less intense in the largest one. X-rays gave similar fluorescence. No phosphorescence. Polariscope showed interference indicating patterns of considerable strain mottled in linear forms, sometimes cross-hatched. The 0.59ct stone was colour grained corresponding with the strain patterns. Inclusions of olivine and graphite were found. R.K.M.

KELLY, S.M.B., BROWN, G., 1987. A new synthetic emerald. *Australian Gemmologist*, **16**, 6, 237–8, 7 figs in colour.

Five stones were thought to be Japanese made by the Gilson process. RI 1.533–1.588, SG 2.64, with small variations. Heavily included, transparent to semi-transparent. Chelsea filter, red. No fluorescence to UV. Variable strength absorption spectra. R.K.M.

KIEFERT, L., SCHMETZER, K., 1987. Pink and violet sapphires from Nepal. *Australian Gemmologist*, **16**, 6, 225–9, 16 figs in colour.

Rough, faceted and cabochon specimens examined, exact origins unknown. Crystals had calcite, phlogopite, margarite and rutile adhering. Constants normal for corundum. Colours pink to light red and reddish-violet, sapphires rather than rubies. Low quality because extensive inclusions preclude faceting other than in very small sizes. R.K.M.

KIEFERT, L., SCHMETZER, K., 1987. Blaue und gelbe Sapphire aus der Provinz Kaduna, Nigeria. (Blue and yellow sapphires from the province of Kaduna, Nigeria.) *Zeitschrift der Deutschen Gemmologischen Gesellschaft*, **36**, 1/2, 61–78, 35 figs (3 in colour), bibl.

An English version of this article was published in the *Journal of Gemmology*, 1987, **20**, 7/8, 427–42. E.S.

KOIVULA, J.I., 1987. The rutilated topaz misnomer. *Gems & Gemology*, **23**, 2, 100–3, 7 figs in colour.

Needles in colourless topaz, incorrectly identified as rutile, are shown to be hollow growth tubes

stained by iron oxide. R.K.M.

LIND, TH., HENN, U., BANK, H., 1987. Nach dem Hydrothermalverfahren hergestellte synthetische Smaragde aus der UdSSR. (Hydrothermally produced synthetic emeralds from the USSR.) *Zeitschrift der Deutschen Gemmologischen Gesellschaft*, **36**, 1/2, 51–60, 9 figs (2 in colour), bibl.

The authors had the opportunity to examine 50 synthetic emeralds produced in the USSR by hydrothermal method. SG 2.68–2.7, RI n_o1.578–1.584, n_e1.571–1.581. DR 0.005–0.008. Absorption spectrum showed strong iron bands causing strong pleochroism of yellowish–green to blue. E.S.

LIVSTRAND, U., 1987. The black opals of Lightning Ridge. *Lapidary Journal*, **41**, 3, 49–56, 4 figs (1 in colour).

A brief guide to the mining of opal at Lightning Ridge, New South Wales, Australia, is given. M.O'D.

MARTIN, D.D., 1987. Gemstone durability: design to display. *Gems & Gemology*, **23**, 2, 63–77, 18 figs in colour.

An excellent summary of many causes of damage to gemstones in manufacture, display, cleaning, repair and wear. A valuable paper! R.K.M.

PECOVER, S.R., 1987. New concepts on the origin of sapphire in northeastern New South Wales. *Australian Gemmologist*, **16**, 6, 221.

Associates sapphire with explosive volcanic formations and with the rare diamond occurrence. Suggests that recognition of tuffaceous rock formations as primary sources of sapphire could lead to major expansion of the mining industry in this area. R.K.M.

POUGH, F.H., 1987. Gem treatment: scapolite. *Lapidary Journal*, **41**, 4, 14–17.

This is a general description of the scapolite mineral group. M.O'D.

POUGH, F.H., 1987. Anhydrite. *Lapidary Journal*, **41**, 5, 16–18.

Occurrences of anhydrite are described with notes on fashioning possibilities. M.O'D.

POUGH, F.H., 1987. Actinolite and tremolite, a couple of amphiboles. *Lapidary Journal*, **41**, 6, 16–18.

Brief description of the ornamental amphiboles. M.O'D.

READ, P.G., 1987. Light effects. *Canadian Jeweller*, May 1987, 22.

The use of photoluminescence in gem identification, ranging from the cross–filter method of excitation by means of LW/SW UV and X–rays, is described. Mention is made of the use of UV to distinguish between natural and synthetic diamonds, particularly in the case of the Sumitomo product. (Author's abstract) P.G.R.

READ, P.G., 1987. Polarised light. *Canadian Jeweller*, June 1987, 9.

Contains a brief history of the development of polarising devices, and then describes the use of the konoscope attachment to the polariscope. (Author's abstract) P.G.R.

ROBERT, D., 1987. Topazes bleus aprés traitement. (Blue topaz after treatment.) *Revue de Gemmologie*, 91, 17–20, 6 figs in colour.

Topaz is frequently irradiated to give a deep blue colour. The process of treatment is described. M.O'D.

SCHMETZER, K., 1987. Ein neuer Typ orientierter leistenförmiger Einschlüsse in Spinell. (A new type of lath–like inclusion in spinel.) *Zeitschrift der Deutschen Gemmologischen Gesellschaft*, **36**, 1/2, 11–17, 7 figs, bibl.

The blueish–violet spinel from Sri Lanka with orientated inclusions was tested microscopically, with X–ray single crystal diffraction and by electron microscope. The sample showed four sets of lath–like doubly refracting crystal inclusions, orientated parallel to the three–fold axes of the host. The guest mineral is a Al_2SiO_5 polymorph, probably sillimanite. The new type of inclusion is quite different from the orientated rutile needles or titanium crystals described in Sri Lankan star spinels. E.S.

SCHMETZER, K., 1987. (a) Dreiphaseneinschlüsse in einem gelben Sapphir aus Sri Lanka. (Three phase inclusions in a yellow sapphire from Sri Lanka.) *Zeitschrift der Deutschen Gemmologischen Gesellschaft*, **36**, 1/2, 79–81; (b) Zur Nomenklatur und Bestimmung von Südsee–Zuchtperlen. (Nomenclature and determination of South Sea cultured pearls.) Id., 83–6.

(a) The three–phase inclusions were found in an untreated yellow sapphire from Sri Lanka. The inclusions form tabular negative crystals, orientated with their table parallel top the basal face of the host crystal. They are filled with doubly refractive crystals, as well as liquid gas. Identification of crystal inclusions was not possible, but mica is a possibility with liquid and gaseous CO_2 a probability. (b) Cultured South Sea pearls are either nucleated with round or irregularly– shaped mother–of–pearl beads, or are non–bead nucle-

ated. When seen in X–ray radiographs these so–called Keshi pearls have structures identical with non–bead nucleated tissue–implanted cultured freshwater pearls (Biwa). It can therefore be assumed that these Keshi pearls are non– bead nucleated tissue–implanted. E.S.

SCHMETZER, K., BANK, H., 1987. Synthetische Lechleitner–Rubine mit natürlichen Kernen und synthetischen Überzügen. (Synthetic Lechleitner rubies with natural core and synthetic coating.) *Zeitschrift der Deutschen Gemmologischen Gesellschaft*, **36**, 1/2, 1– 10; 21 figs (4 in colour), bibl.

A new type of Lechleitner ruby was investigated. This consisted of a natural core of light–coloured ruby or colourless corundum from Sri Lanka covered by a thin layer of flux–grown synthetic ruby. The natural cores of the examined stones were partly rough crystals, partly bruted or cut stones. A very careful microscopic examination is called for, especially of the contact zone, which can resemble the first generation of the so–called 'Knischka' rubies. Determination of trace elements, especially those of the residue of the flux, as well as X–ray fluorescence, microprobe analysis and spectroscopic examination can help in final determination. E.S.

SCHRAMM, M., HENN, U., 1987. Schleifwürdige grüne Diopside aus Indien. (Cuttable green diopsides from India.) *Zeitschrift der Deutschen Gemmologischen Gesellschaft*, **36**, 1/2, 81–3. bibl.

The prismatic crystals from India have a length of about 3cm, SG 3.27–3.32. RI n_x1.669–1.670, n_z1.698–1.700, DR 0.029–0.030. The relatively high iron content of 2.51 and 4.13% respectively show that the crystals are not pure diopside, but very near to diopside, which is confirmed by the RI. E.S.

SHIGLEY, J.E., KOIVULA, J.I., FRYER, C.W., 1987. The occurrences and gemmological properties of Wessel Mine sugilite. *Gems & Gemology*, **23**, 2, 78–89, 13 figs in colour.

The purple mangoan form of the rare mineral sugilite is found in small amounts at the Wessel Mine in the Kalahari region of South Africa, some of it intermixed with chalcedony of similar hue. An excellent material for cabochons or for carving, the best is purple or blueish–purple in colour, which looks redder in incandescent light. RI 1.607, massive and multi–crystalline, it shows no birefringence (1.544 for chalcedony when it occurs). SG varies from 2.80, to 2.70 for the chalcedonic material. H 5½ to 6½, tough. Often attractively banded or grained. Absorption band is seen at 419nm, with other narrow manganese bands in darker material, but not in sugilite with high chalcedony content. R.K.M.

STEVENS, E., 1986. The diploma course – adequacy or inadequacy. *Wahroongai News*, **20**, 10, 10–15.

A criticism of gemmological teaching in Australia, suggesting objectives which might improve this, including an examination requirement for 100% accuracy in identification. Author is concerned at extreme breadth of educational background among students, from lowest to highest qualifications, and suggests, among other reforms, a pre–entrance education standard. R.K.M.

STOCKTON, C.M., 1987. The separation of natural from synthetic emeralds by infrared spectroscopy. *Gems & Gemology*, **23**, 2, 96–9, 2 figs in colour.

A laboratory test which is unlikely to be available to the ordinary gemmologist, Fourier transform infrared spectroscopy can distinguish synthetic from natural emerald nondestructively in less than five minutes. Flux synthetics lack water and therefore do not have the strong absorption band between 3400 and 4000^{cm-1} which is present in all natural emeralds. Hydrothermal synthetics contain water and their infrared spectra at those wavelengths are rather similar to those of the natural stones. Other spectral lines will distinguish these. Infrared absorption is greatest in the extraordinary ray so cut stones should be tested in more than one direction to ensure positive identification. R.K.M.

ZEITNER, J.C., 1987. Queretaro opals. *Lapidary Journal*, **41**, 3, 20–4, 3 figs in colour.

Occurrences of opals in the Mexican state of Queretaro are described. M.O'D.

ZOYSA, E.G., 1987. New gems from the Ratnapura area, Sri Lanka. *Australian Gemmologist*, **16**, 6, 239–40, 3 figs in colour.

Describes chatoyant fibrolite, scheelite and green orthoclase. R.K.M.

ANON. 1987. Gem news. *Gems & Gemology*, **23**, 2, 122–4, 4 figs in colour.

A 14.33 ct rough diamond found when washing for gold in north California is the largest yet from that state. A 1.06 ct alexandrite from a new Brazilian locality has a colour–change to rival that of the finest Russian stones. A 320 ct rough ekanite has been found in Sri Lanka. Chinese pictorial marble tiles from Yunnan are illustrated. A large pink pearl was shown to be coral. R.K.M.

Book Reviews

ARNOTH, J., 1986. *Achate, Bilder im Stein.* (Agate, pictures in stone.) Naturhistorisches Museum Basel, pp.103, illus. in black–and–white and in colour. Price on application.

This is the most attractive book I have yet to see on agate. Using the landscape format, the publishers manage to present over fifty pages of coloured pictures after introductory chapters dealing with agate formation. It is largely a picture book but of the highest quality. M.O'D.

BOYLE, R.W., 1987. *Gold: history and genesis of deposits.* Van Nostrand Reinhold, New York. pp. xvii, 676. Illus. in black–and–white and in colour. £39.95.

The literature of gold is now so large and diffuse that a set of benchmark papers is very welcome. The first chapter deals with the general history of gold and the types of auriferous deposits; it is followed by a large number of papers classified into eighteen chapters. Most papers are accompanied by lists of references and there is an author and a subject index. The editor has provided summaries and comments on the papers which give the book a continuity which it would otherwise lack. The book can, in fact, be read through without too much difficulty though it is fair to say that the level is graduate at least, thus placing it out of the reach of many who might otherwise profit by it. On the other hand the price is reasonable for a work of this size and the standard of production is good. M.O'D.

FLEISCHER, M., 1986. *Glossary of mineral species.* Fifth edn. Mineralogical Record, Tucson, pp.227. Price on application.

Now the established reference book for mineral names and compositions, the *Glossary* includes about 340 new names for this edition. Additionally, about 750 entries have been changed in some respect about 13 additional mineral groups are added. Following established practice each entry gives chemical composition, crystal system and colour where appropriate. M.O'D.

HABSBURG, G. VON, 1986. *Faberge, Hofjuwelier der Zaren.* (Fabergé, jeweller to the Tsars.) Bayerische Nationalmuseum, Münich, pp.359, illus. in black–and–white and in colour. Price on application.

This is a beautifully produced catalogue of an exhibition of the work of Fabergé, held in 1986 at the Bayerische Nationalmuseum. Fabergé's life and work are described in preliminary chapters. M.O'D.

LANGE–MECHLEN, S., 1982. *Diamanten.* 3rd revised edn. (Diamonds.) Belser Verlag, Stuttgart, pp.120, illus. in black–and– white and in colour. £14.95.

This short book concentrates upon the cutting and grading of diamond, but also comments briefly upon other important stones in the final chapters. There is a short bibliography. M.O'D.

SUHNER, B., 1984. *Infra–rot Spektren von Mineralien.* (Infrared spectra of minerals.) The author, Basel, 2 vols, pagination irregular. Limited edition of 150 copies. Price on application.

Infrared spectra of 300 minerals are depicted and described. The work, a thesis submitted to the University of Basel, can be consulted at the British Library's Science Reference and Information Service. M.O'D.

VAN PELT, H., VAN PELT, E., 1987. *Birthday book of gems.* Published by the authors, Los Angeles. pp. 126. Illus. in colour. Price on application.

Arranged with a diary page facing a colour picture of a gemstone, this book can be used over the years without confusion as the specific days of the week are not given. However, many, if not most, readers will want to keep the book clean for the sake of the superb illustrations which are as good (at least) as any I have seen previously. It is difficult to single out a particular one, but the black opal (for the first week of October) is quite magnificent. Each picture carries a detailed caption on the diary page. M.O'D.

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Proceedings of the Gemmological Association of Great Britain and Association Notices

OBITUARY

It is with great regret that we announce the death of Mr J.R.H. Chisholm, MA, FRSA, FZS, MRI, FGA, a Vice– President of the Association and past Editor of the *Journal*. A full obituary is given on p.2 above.

Mr Leslie F. Cole, FGA (D.1937 with Distinction), London, died on 6 December 1987. A full obituary will appear in the next issue of the *Journal*.

GIFTS TO THE ASSOCIATION

The Council of the Association have received recently several substantial gifts which will greatly augment the teaching and display collections. Our most sincere thanks to these generous donors.

The late Neville Deane, FGA, bequeathed his extensive collection of some thousands of natural and synthetic cut stones. The scope and variety of the collection, built up over many decades, reflects his wide interests, both as a teacher and a collector. It will be of enormous help to future students.

Mr George Lindley, FGA, who recently retired from the precious stone trade, has donated his collection of historic books to mark this event. These are a most welcome addition to the library.

Mr W.C. Buckingham, FGA, has retired from the gem trade after spending fifty years with the firm of George Lindley & Co. Ltd. To mark his retiral he has presented to the Association his large collection of rough zircons from many localities. He sees the gift as a tribute to former colleagues including George Lindley, Ted Thomson, John Shotton and Jim Hallet among others; also to the new owners of his former firm. To mark the occasion further he wishes to fund a bursary to promote research on the rough zircons by Post Diploma student(s) with a view to publishing the results as a paper(s) in this *Journal*. It is envisaged that there will be a monetary award for suitable papers. Details of the scheme have yet to be finalized, but interested students are invited to write to the Association marking their letters 'The Buckingham Bursary'.

Mr Jerry Johnson, FGA, of J. & J. Gems, USA, has kindly donated several specimens of cut stones and crystal fragments of pleochroic labradorite from Oregon, USA.

NEWS OF FELLOWS

On 17 September 1987 Mr Eric C. Emms, B.Sc., FGA, gave an illustrated talk on the workings of the Gem Testing Laboratory of Great Britain to members of The Academy (a group of young people involved in the London jewellery trade). He was assisted by Mr Nicholas Sturman, FGA.

On 9 September 1987 Mr Michael O'Donoghue, MA, FGS, FGA, gave a lecture entitled 'The origin of gemstones' to the King's Lynn Society of Arts and Sciences.

On 16 September 1987 Mr P.G. Read, FGA, gave an illustrated talk on 'The design of gem testing instruments' to the Yorkshire Centre of the National Association of Goldsmiths in Leeds. After the talk he demonstrated his newly developed Brewster–angle refractometer which uses a polarized laser light source and electronic read–out.

On 23 September 1987 Mr A.E. Farn, FGA, gave a talk to the Wessex Branch of the National Association of Goldsmiths entitled 'The history of pearls'.

During a visit to the Far East last autumn, Mr P.G. Read gave illustrated talks on 'The design of gem testing instruments' to the Singapore Gemologist Society on 4 October, to the Sydney branch of the Australian Gemmological Association on 7 October, and to the Brisbane branch on 14 October. After each talk he demonstrated his Gemdata gem identification program and his Brewster–angle refractometer with laser light source.

MEMBERS' MEETINGS

Midlands Branch

On 18 September 1987 at Dr Johnson House, Bull Street, Birmingham, Dr J.B. Nelson, Ph.D., FGS, FRMS, F.Inst.P., FGA, gave a presentation

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on 'A new gem–testing optical bench'.

On 16 October 1987 at Dr Johnson House Mr Grenville Millington, FGA, gave an illustrated talk entitled 'Inclusions in gemstones'.

On 20 November 1987 at Dr Johnson House Mr Michael J. O'Donoghue, MA, FGS, FGA, gave a lecture entitled 'The geological occurrence of gem minerals in Pakistan'.

North West Branch

On 21 October 1987 at Church House, Hanover Street, Liverpool 1, Mr Bill Ford of the Wirral Lapidary Society gave a demonstration of gemstone faceting.

On 18 November 1987 at Church House the Annual General Meeting was held at which Mr R. Perrett, FGA, was elected Chairman and Mrs I. Knight, FGA, re–elected Secretary.

ANNUAL REUNION OF MEMBERS AND PRESENTATION OF AWARDS

The Annual Reunion of Members and Presentation of Awards was held on 9 November 1987 at Goldsmiths' Hall, London. The Chairman, Mr David Callaghan, presided and welcomed those present. The 1987 examinations had been held in 32 countries throughout the world in over 95 centres. This had involved a great deal of organization by the Education Department of the Association. Mr Callaghan paid tribute to Mr Leslie Fitzgerald and his team for all the work they do. He announced that the Tully Medal had been awarded to Mr Duncan Lamont Pay, a former employee of A. & G. Cairncross, Perth, and that the President of the National Association of Goldsmiths, Mr Jimmy Cairncross, was present to see him receive his award. Over a hundred candidates were present to receive their Gem Diamond Certificates and Diplomas, including those who had come from Canada, Cyprus, Finland, Holland, Hong Kong, Spain, Sri Lanka, Sweden, USA and West Germany.

Mr Callaghan then called upon Dr George Harrison Jones, Chairman of the Education Committee, to present the awards.

After the presentations, Dr Jones delivered his address. He began by thanking the Chairman and members of the Council for according him the privilege of presenting the awards, a privilege which he accepted, with great pleasure, on behalf

Figs 1 and 2. The Tully Medallist, Duncan Lamont Pay, and the Rayner Diploma Prize winner, Henry Chan–Fan Cheng, receiving their awards from Dr George Harrison Jones.

of those members of the Association and those members of the staff who had worked so hard to produce the new correspondence courses.

He continued by congratulating all the candidates who received their certificates and diplomas, awards which were highly regarded throughout the world and which represented a great deal of hard work and application. He further congratulated those who had gained their awards with distinction as this required a mark of 80% or more and was a considerable achievement. He finally congratulated the tutors and lecturers of the successful candidates, who had managed to cover the Diploma course in the short time of one academic year.

The considerable developments in science and technology had produced new materials, new synthetics, new processes and new methods of gemstone treatment, and one had only to look at the examination papers over the years to realize that the course content is continually expanding. With this in mind, the Association had introduced a degree of flexibility into their correspondence courses, so that students may take up to four years to complete the two sections, Preliminary and Diploma. Dr Jones considered that colleges would have to review their systems in the near future with a view to extending their courses.

It was emphasized that the courses and examinations were designed to provide and test for a sound basis for the continuing study of gemmology. It was essential for all gemmologists to keep up–to–date with current developments and as textbooks tend to become out–dated, Dr Jones strongly recommended the reading of current published material such as the *Journal of Gemmology*. He stated that the Association was very fortunate in having the services of Mr Alan Jobbins as Editor and Mrs Mary Burland as Editorial Assistant but that neither the Editor nor his assistant wrote the *Journal*. The *Journal* attempts to cater for all tastes and to keep its readers up–to–date and therefore any member who came across something of interest to fellow gemmologists should write it up and submit it to the Editor for his consideration.

Those wishing to continue their studies would be interested to know that the Association will be launching the new Gem Diamond Home Study Course, produced by Mr Eric Bruton and his team, during 1988.

Dr Jones concluded by saying that the Association was a group of people with a common interest – gemmology – and that he hoped that those present would enjoy a long association with the GA. He also hoped that they would derive as much pleasure from gemmology as he does.

The Vice–Chairman, Mr Noel Deeks, gave the vote of thanks, paying tribute to the work Dr Jones had done on the Home Study course. He said that he hoped that many of those present would become active members of the Association.

In conclusion Mr Callaghan thanked Mr Jonathan Brown, Secretary of the Association, and his staff for their work on the new courses.

COUNCIL MEETING

At the meeting of the Council held on 22 September 1987 at the Royal Automobile Club, Pall Mall, London S.W.1, the business transacted included the following:

(1) the subscription rate for 1988 for Fellows and Ordinary members in the UK was increased to £27.00 and the rate for overseas members fixed at US $65.00;

(2) the following were elected to membership:

Fellowship

Allen, Elizabeth A., London. 1987
Ashby, Paul J., Dover. 1987
Atkinson, Mavis W., Queensbury. 1987
Barnes, Joyce J., Marazion. 1987
Bourke, Mary, Enniscorthy, Wexford, Ireland. 1987
Brummer, Pieter, Almelo, Netherlands. 1987
Carmody, Justine L., Thames Ditton. 1987
Chang, Nancy A., Hong Kong. 1987
Chanter, James E., Newton Abbot. 1987
Cheng, Henry C.F., Kowloon, Hong Kong. 1987
Cheng, Lau K.L.K., Kowloon, Hong Kong. 1987
Dodani, Manoj B., Kowloon, Hong Kong. 1987
Dunstall, Robert, Northampton. 1987
Forsberg, Pierre G., Kisa, Sweden. 1987
Fox, Julie A., Maidstone. 1987
Griffiths, Sarah J., Carshalton. 1987
Groenenboom, Peter, Amsterdam, Netherlands. 1979
Hawkins, Philippa L., London. 1987
Hayes, Alan G.J., Stockport. 1987
Hud, Julie A., Nottingham. 1987
Hud, Michael, Nottingham. 1987
Humpage, Susan A., Edgbaston. 1987
Indrebø, Solveig, Oslo, Norway. 1986
Johnson, Jane, Headcorn. 1976
Kangasniemi, Risto I., Tampere, Finland. 1987
Lightfoot, Paul, Ottery St Mary. 1987
Lindquist, Maria T., London. 1987
McDonald, Richard G., Edinburgh. 1987
Manzi, Michael J., Penzance. 1987
Martick, Barbara A., London. 1981
Martine–Leyland, Eric, Vancouver, BC, Canada. 1987
Orrey, Russell A., Barrowby. 1987
Osborne, David L., Canvey Island. 1969
Padley, Stanley J., Bromyard. 1987

Powell, Philip V., Cheltenham. 1987
Richards, David, Ruddington. 1983
Riley, Mark J., Quedgeley. 1987
Shah, Manoj D., Bombay, India. 1986
Smith, Marilyn L., London. 1987
Sokhal, Baljender, Cannock. 1987
Thomas, David D., Cheam. 1987
Tsotros, Alex, Johannesburg, South Africa. 1987
Vilpas–Vesterinen, Leeni A., Helsinki, Finland. 1987
Watts–Goodearle, Gwendolyn R., Toronto, Ont., Canada. 1987
Wightman, Janice T., Burbage. 1987
Woodhouse, Neville, Chesterfield. 1974
Wren, Rebecca J., Ware. 1987
Yau, Vivian, Lantau, Hong Kong. 1987
Youngs, Michael A., Felixstowe. 1987
Zandvoort, Christien, Rotterdam, Netherlands. 1985

Transfers from Ordinary Membership to Fellowship
Arias Garnacho, Antonio, Madrid, Spain. 1987
Arthur, Lynne, Denny. 1987
Birchall, Steven, Hyde. 1987
Brillo, Douglas, Halifax. 1987
Canty, Jess, London. 1987
Ching, Estella S.T., Hong Kong. 1987
Coward, Stephanie J., Colchester. 1987
de Cosse Brissac, Helene, Princess of Liechtenstein, Steiermak, Austria. 1987
Dominy, Geoffrey, Edmonton, Alta., Canada. 1987
Elson, Patricia D., Swansea. 1987
Esser, Clara L.M., Singapore. 1987
Gambini, Elena, Milan, Italy. 1987
Gay, Michael, Romsey. 1987
Genot, Luc P.A., Brussels, Belgium. 1987
Greenwold, Lynn, Stow on the Wold, 1987
Hage–Chahine–Sawaya, Nayla, London. 1987
Hall, Warren S., Purley. 1987
Hilton, Holly A., London. 1987
Hulm, Valerie A., Hong Kong. 1987
Huppach, Friedrich H., Colne. 1987
Judge, Susan D., Hong Kong. 1987
Keast, Edmund J., Sanderstead. 1987
Kneip, John R., London. 1987
Knight, James H., Godalming. 1987
Knox, George T., South Harrow. 1987
Kramer, Stephan A., Bradford. 1987
Kubota, Kazuyuki, Tokyo, Japan. 1987
Lekamge, Neil S., Kandy, Sri Lanka. 1987
McArthur, Niven R., Dunedin, New Zealand. 1987
McCleland, Susan M.F., Haslemere. 1987
Michaels, Amy J., Montgomery, Ala., USA
Millar, Ewan, Paisley, 1987
Miyabayashi, Yuki, Osaka, Japan. 1987
Monnas, Edith S., Athens, Greece. 1987
Ng, Avis L., London. 1987
Nimry, Lina, London. 1987
Pay, Duncan L., Newport–on–Tay. 1987
Perera, Callistus R., Colombo, Sri Lanka. 1987
Rothon, Jeremy, Blairgowrie, South Africa. 1987
Schneirla, Peter C., New York, NY, USA. 1987
Shread, Andrew, Beeston. 1987
Straitouri, Sophia, London. 1987
Straub, Bernard C., Reading. 1987
Sullivan, Maeve D., Kowloon, Hong Kong. 1987
Tajima, Hidemasa, Osaka, Japan. 1987
Takizawa, Toshiko, Tokyo, Japan. 1987
Talberg, Judy, Burkina, West Africa. 1987
Tambuyser, Paul B., Schoorl, Netherlands. 1987
Taylor, Helen M., Whitby. 1987
Van Moppes, Michael, Crowhurst. 1987
Vest, Geraldine M., Lafayette, Ind., USA. 1987
Vincent, Patricia J., Wokingham. 1987
Watson, Charles E., Jakarta, Indonesia. 1987
Yanagi, Nurue, Niigata Pref., Japan. 1987

Ordinary Membership
Agoren, B. David, London.
Bruno, Roberta, Torino, Italy.
Dada, Timothy A., London.
Dangedara, Deunuge A.N., London.
England, Corey J., Moline, Ill., USA.
Forester, Nanette M., Beverly Hills, Calif., USA.
Geach, Julian C., London.
Gordon, Jillian, Christchurch, New Zealand.
Gouverneur, Keith, Tamanaco, Caracas, Venezuela.
Griffith, Pritpal, Wembley.
Hochberg, Naomi, Ramat Gan, Israel.
Jarvis, Hilary A., London.
Jefferson, Gareth, London.
Kastritseas, Iraclis P., Rhodes, Greece.
Kops, Doreen A., Perth, WA, Australia.
Laurie, John J.W., Monte Carlo, Monaco.
Levy, John, London.
Lilley, Elaine, Hull.
Liyanage, Penny, Ashford Common.
McIlwraith, Philomena M., Kowloon, Hong Kong.
Rhoades Walkley, Barrie, Tadley.
Ross, William C., Norwich.
Search, Martin J., St Peter Port, Guernsey, CI.
Sullivan, David C.K., Durban, S. Africa.
Taylor, Frederick W., Tewkesbury.
Tociapski, Paul, Bogota, Colombia.
Turner, David B., Benwell.
Van Camp, Coralie A., Auckland, New Zealand.
Wiles, Susan, Hull.
Williams, Ann R., Caithness.

EXECUTIVE COMMITTEE MEETING

At a meeting of the Executive Committee held on 28 October 1987 at Saint Dunstan's House the

business transacted included the election of the following:

Fellowship

Anckar, Bjorn H., Gothenburg, Sweden. 1987
Andrews, Robert E., Birch Vale. 1969
Arratia Sanhueza, Juan A., London. 1987
Bishop, Lyndall A., Kowloon, Hong Kong. 1987
Brophy, Mark S.J., Cheadle. 1978
Chan, Richard K.M., London. 1987
Chan, William T.W., Kowloon, Hong Kong. 1987
Choy, Boo S.R., Hong Kong. 1987
de Gasson, Maria I.M., Bangkok, Thailand. 1987
de Jong, Peter, Zwyndrecht, The Netherlands. 1987
Dunham Lord, Rosemary M., Bangkok, Thailand. 1987
Fox Worthington, Peter J.J.E., Auckland, New Zealand. 1985
Gaynor, David, Ryton. 1987
Glenister, James E., Tunbridge Wells. 1987
Graham, Peter D., Liverpool. 1981
Gunaratne, Dhammika D., Moratuwa, Sri Lanka. 1987
Heindorff, Judith H., Brisbane, Qld., Australia. 1987
Hirst, Susan C., Palmerston North, New Zealand. 1987
Ho, Chi F.P., Kowloon, Hong Kong. 1987
Hutchings, Beverly J., Willowdale, Ont., Canada. 1987
Huuskonen, Kari O., Helsinki, Finland. 1987
Kallioniemi, Anne M., Helsinki, Finland. 1987
Lambert, Roslyn, West Wickham. 1987
Lee, Lap T., Kowloon, Hong Kong. 1987
Leung, Tak L., Kowloon, Hong Kong. 1987
Luk, Kwok Y.S., Hong Kong. 1987
Luk, Woon C., Kowloon, Hong Kong. 1987
Madden, Denise E., Hong Kong. 1987
Malmsten–Ghazawi, Scharon L., Masala, Finland. 1987
Manders, Andrew P., Longlevens. 1987
Marks, Jan H., Dordrecht, The Netherlands. 1987
Menegatti, Brigitte, Hong Kong. 1987
Nath, Meenakshi, Bombay, India. 1987
Pak, Lai B.L., Hong Kong. 1987
Parker, Vaughan A., King's Lynn. 1987
Parkin, Ann E., New York, NY, USA. 1987
Rayner, John C., Hinckley. 1987
Reponen, Seppo J., Kouvola, Finland. 1987
Rouhselang, Coleen A., Austin, Tex., USA. 1987
Sanghvi, Smitesh H., Bombay, India. 1987
Stanbury, Derek C., Bartley Green. 1987
Straton–Ferrier, Sophie L., Edinburgh. 1987
Tidswell, Eric, Bingley. 1987
Tovey, Kevin G., Newport. 1987
Tsang Ngai, Wing G., Hong Kong. 1987
Turnbull, Daniel A., Glasgow. 1987
Van Dyk, Delene, Cape Town, South Africa. 1987
Visser, Frederiik, Annaparochie, The Netherlands. 1987
Webster, William J., Glasgow. 1987
Whittle, Helen M., Clevedon. 1987
Wolfsbergen, Margaretha T., The Hague, The Netherlands. 1987
Wong, Qui L.S., Hong Kong. 1987
You, Yun B., Inchon, South Korea. 1987

Ordinary Membership

Abdel Shaheed, Gale, Newark.
Beaty, Harold W., Spokane, Wash., USA.
Bourdillon, Catriona C.C., London.
Collingwood, Mark A., Leeds.
Collins, Barry M., Kempston.
Cousins, Nigel T., Deal.
Cox, Vann S., Leeds.
Crombie, Sylvia, Hemel Hempstead.
Cross, Margaret J., Leeds.
Dickinson, Julie, London.
Eyles, Joan M., London.
Fisher, Dorothy A., Surbiton.
Gau, Robert B.R., Taiwan.
Hartley, John M., Blackpool.
Kenney, George T., Lihue, Hawaii, USA.
Kirby, Marcus D., Leeds.
Leddicoat, Andrew, Guiseley.
Lowe, Paul A., Truro.
McCallum, Simon L., Newbury.
McKenna, Joseph T., London.
O'Sullivan, Susan A., London.
Ridgeway, Elizabeth J., London.
Rowlands, Alan F., London.
Silverthorne, Bernard C., London.
Theodorou, Theodoros, Limassol, Cyprus.
Tock, Graham B., Hull.
Vanhefflin, Keith, Kirton Lindsey.
Yuill, J. Martin, Lanark.

GEM DIAMOND EXAMINATION 1987

In the Post–Diploma Gem Diamond Examination 38 candidates sat and 38 qualified. The following is a list of the candidates arranged alphabetically.

Abrahams, Roy H., Ruislip.
Adams, Amanda C., Leicester.
Bartlett, Lynne, London.
Casanova Guillen, Luis M., Barcelona, Spain.
Deeley, Peter J., Birmingham.
Domenech Lahoz, Christiane, Barcelona, Spain.
Fernandez Sanchez, Fernando, Barcelona, Spain.
Gardiner, Margot, Glasgow.
Green, Gwynneth M., Worcester.

Hall, Michael J., London.
Hamilton, Ann, Paisley.
Haque, M. Manzurul, London.
Henderson, Mark M., Guildford.
Hepburn, John A., Orpington.
Horne, Allan R., Brighton.
Jones, Kevin P., Coventry.
Layhe–Cook, Judith A., Stratford–upon–Avon.
Linley, Mark A., Worcester.
Lloyd, Jeremy J., Birmingham.
Magudia, Ratilal H., St Albans.
Marti Beltran, Fernando, Barcelona, Spain.
Neumand, Marion J.S., Richmond.
Palmer, Valerie G., London.
Phillips, Glenys J., Brighouse.
Poblador Cerezo, Luis M., Barcelona, Spain.
Rafols Garrit, Yolanda, Barcelona, Spain.
Rice, Karen L., Solihull.
Ruiz Roser, Emilio, Barcelona, Spain.
Serra Palau, Carles, Barcelona, Spain.
Simpson, Geoffrey P., Stockport.
Smith, Gillian M., Sheffield.
Smith, Susan A., London,
Stewart, Robert, London.
Thompson, Howard W., New Malden.
Tortosa Domingo, Ramon, Barcelona, Spain.
Vara, Pradip, London.
Vilanova Cardona, Elvira, Barcelona.
Walsh, Claire E., Hendon.

EXAMINATIONS IN GEMMOLOGY 1987

In the 1987 Examination in Gemmology 530 candidates sat the Preliminary Examination and 305 (57.5%) passed, 512 sat the Diploma Examination and 222 (43.6%) passed, 21 with distinction.

The Tully Medal for the candidate (trade or non–trade) who submits the best set of answers in the Diploma Examination has been awarded to Duncan Lamont Pay of Newport–on–Tay, Fife, Scotland.

The Anderson/Bank Prize for the best non–trade candidate of the year in the Diploma Examination has been awarded to Julia Drukker–Loth of Huizen, The Netherlands.

The Rayner Diploma Prize for the best candidate of the year who derives his main income from activities essentially connected with the jewellery trade has been awarded to Henry Chan–Fan Cheng of Kowloon, Hong Kong.

The Anderson Medal for the best candidate of the year in the Preliminary Examination has been awarded to Betty Stocker of Chipping Campden, Gloucestershire.

The Rayner Preliminary Prize for the best candidate under the age of 21 years on 1 June whose main income is derived from activities essentially connected with the jewellery trade has been awarded to David Webster of Glasgow.

The names of the successful candidates are as follows:

DIPLOMA

Qualified with Distinction

Cheng, Henry C.F., Hong Kong.
Chiu, Man Kam, Hong Kong.
Cosman, Maria A., Montfoort, Netherlands.
Coward, Stephanie J., Colchester.
Dominy, Geoffrey, Edmonton, Alta, Canada.
Drukker–Loth, Julia M., Huizen, Netherlands.
Guarino Alemany, Ma T., Barcelona, Spain.
Hash, Daniel W., Watrous, Sask., Canada.
Keast, Edmund J., Sanderstead.
Knight, James H., Godalming.
Lam, Cecilia S.L., Alberta, Canada.
Lau, Rosanna W.Y., Hong Kong.
Madden, Denise E., Hong Kong.
Pay, Duncan L., Newport–on–Tay.
Riley, Mark J., Cheltenham.
Straub, Bernard C., Reading.
Tambuyser, Paul B., Antwerp, Belgium.
Thevathasan, Nuala A., London.
Vest, Geraldine M., W. Layfayette, Ind., USA.
Visser, Frederik, St Annaparochie, Netherlands.
Zwack, Geraldine M., Bangkok. Thailand.

Qualified

Allen, Elizabeth A., Southgate.
Anckar, Bjorn H. Gothenburg, Sweden.
Aresti, Anthony, London.
Arias Garnacho, Antonio, Madrid, Spain.
Arratia San Hueza, Antonio, London.
Arthur, Lynne, Falkirk.
Ashby, Paul J., Dover.
Asiain De Los Angeles, Jorge J., Barcelona, Spain.
Atkinson, Mavis W., Bradford.
Au Yeung, Kwai H., Hong Kong.
Aziz, Khalid, Idar–Oberstein, W. Germany.
Baker, June, Ottawa, Ont., Canada.
Baker, Sylvia V.J., Bangkok, Thailand.
Barnes, Joyce J., Marazion.
Bernad Serra, Marcos, Barcelona, Spain.
Billingham, Carole Jane, London.
Birchall, Steven, Hyde.
Bishop, Lyndall A., Hong Kong.
Bourke, Mary, Enniscorthy, Wexford, Ireland.
Brill, Douglas, Halifax.
Brophy, Mark S.J., Manchester.
Brouwer, Mariette H., Utrecht, Netherlands.
Brummer, Pieter, Almelo, Netherlands.
Burgues Montserrat, Ma Jesus, Barcelona, Spain.
Canty, Jesse, London.
Carmody, Justine L., Thames Ditton.
Chan, Richard Ki–Mun, London.

Chan, William T.W., Hong Kong.
Chang, Nancy A., Hong Kong.
Chanter, James E., Newton Abbot.
Cheng, Lau K.L.K., Kowloon, Hong Kong.
Ching, Estella S.T., Hong Kong.
Choy, Boo S.R., Hong Kong.
Corduff, Rosalie P., Stoke–on–Trent.
Cros, Jean–Marc, London.
Dale, Ann F., Silver Spring, Md., USA.
Dallas, James A., London.
Dalmau Bafalluy, Ma N., Barcelona, Spain.
de Cosse Brissac, Helene, Princess of Liechtenstein, Steiermak, Austria.
de Jong, Peter, Zwijndrecht, Netherlands.
Dodani, Manoj B., Hong Kong.
Dufficy, Margaret H., San Rafael, Calif., USA.
Dunham Lord, Rosemary M., Sunbury–on–Thames.
Dunn, Wendy S., Putney.
Dunstall, Robert, Northampton.
Elson, Patricia D., Swansea.
Esser, Clara L.M., Singapore.
Ferrer Coma, Montserrat, Barcelona, Spain.
Filion, Marie Marchand, Montreal, Que., Canada.
Forsberg, Pierre G.C., Stockholm, Sweden.
Fox, Julie A., Maidstone.
Fu, Milai M., Hong Kong.
Gambini, Elena, Milan, Italy.
Gay, Michael, Romsey.
Gaynor, David, Crawcrook.
Genot, Luc P.A., Brussels, Belgium.
Gervilla Linares, Fernando, Barcelona, Spain.
Girard, Patricia A., Dunoon.
Glenister, James E., Eastbourne.
Glover, Graham D.B., London.
Greenwold, Lynn, Stow–on–the–Wold.
Griffiths, Sarah J.C., London.
Gunaratne, Dhammika D., Moratuwa, Sri Lanka.
Hage–Chahine Sawaya, Nayla, London.
Hakola, Arto K., Outokumpu, Finland.
Hall, Warren S., Croydon.
Hawkins, Philippa L., London.
Hayes, Alan G.J., Bramhall.
Heindorff, Judith H., Brisbane, Qld, Australia.
Hellqvist, Ing–Britt E., Stockholm, Sweden.
Hilton, Holly A., London.
Hirst, Susan C., Palmerston North, New Zealand.
Ho, Chi F.P., Hong Kong.
Hud, Julie A., Nottingham.
Hud, Michael, Nottingham.
Huiskamp, Eveline A., The Hague, Netherlands.
Hulm, Valerie A., Hong Kong.
Humpage, Susan A., Birmingham.
Huppach, Friedrich H., Barnoldswick.
Hutchings, Beverly J., Toronto, Ont., Canada.
Huuskonen, Kari O., Helsinki, Finland.
Iguaz Esteban, Yolanda, Barcelona, Spain.
Judge, Susan D., Hong Kong.
Kangasniemi, Risto I., Tampere, Finland.
Kiallioniemi, Anne M., Helsinki, Finland.
Kneip, John R., London.
Knox, George T., Harrow.
Kramer, Stephen A., Bradford.
Kubota, Kazuyuki, Tokyo, Japan.
Lai, Chun C., Hong Kong.
Lam, Mau K.J., Hong Kong.
Lambert, Roslyn, Shirley.
Latre Gonzalez, Jose, Barcelona, Spain.
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PROGRAMME OF LONDON EVENING MEETINGS 1988

The following meetings have been arranged to take place in London in 1988. Full details will be circulated, to those members in the South East of England only, nearer the relevant dates. Those members outside the circulation area should contact the Association if they require further details.

Tuesday, 8 March
'News from the Gem Testing Laboratory of the Chamber of Commerce in Milan, Italy' by Dr Margherita Superchi, Italy.

Tuesday, 24 May
'The colour treatment of zircon oxide' by Jesus Garzon, B.Sc., Spain.

Tuesday, 11 October
'A review of inclusions in synthetic gemstones' by Clive R. Burch, England.

Tickets will be available for each of the above meetings at a cost of £2.50 per ticket per meeting.

The 1988 Annual General Meeting will take place on **Wednesday 15 June.** Full details will be published in the 1987 Annual Report and Accounts of the Association, which will be sent to all members residing in the United Kingdom. Copies are available to overseas members on request. A Gemmological Forum will be held following the AGM based on the successful meetings held in 1986 and 1987.

Whilst every endeavour will be made to adhere to the planned schedule of events, these may be subject to alteration without prior notice and we apologize for any inconvenience such an alteration may cause.

Letter to the Editor

From R. Keith Mitchell, FGA

Dear Sir,

I am wondering whether I have achieved a 'first' in the field of gemmology.

For a long time I have been aware that refractive indices are obtainable from only a limited area of my refractometer prism, and small stones need to be pushed along its length until such time as they arrive at the optimum position. When doing this with really small stones a certain degree of manual skill was called for.

Gradually I have noticed that stones with a low RI tend to give readings when placed towards the top end of the prism, i.e. farthest away from the eyepiece, while those with a high RI give the information when they are closer to the bottom end, nearer the user's eye.

Today, in a pioneering spirit, it occurred to me to see whether it was possible to test two stones of differing RIs at one and the same time. Accordingly I placed a small chalcedony on a Topcon refractometer, in the required position for a low reading, and a synthetic sapphire on the other end of the prism. Both readings were quite clearly visible, 1.535 for the crypto–crystalline quartz, and 1.76–1.77 for the sapphire. It was necessary to move the head a little to see them, but they were most definitely there at the same time.

As a check, I changed their positions around and found that while the chalcedony could be made to give a reading in the sapphire position, although it was not a very good one, and was possibly a little lower than that obtained in the optimum position, the sapphire would not 'read' at all in the far position.

It occurs to me that this could also account for the indistinct RI shadow edges seen in gem materials which are recognized as mixtures of minerals, e.g. nephrite or jadeite. The instrument is, in effect, reading for a large area of the stone and not just for a small spot.

This achievement will hardly revolutionize gemmology, but I do rather think it has to be a 'first', even if it has taken me some 55 years to arrive at it!

Yours etc.,
R. Keith Mitchell

PS I have just tried putting an emerald, a tourmaline and a spinel on the refractometer at one time. This was really crowding the instrument prism and readings were not as clear as one would have wished, but again with a little head movement three separate sets of RIs were to be seen. Again a rather useless achievement, but perhaps an amusing one.

19 November 1987
21 Bark Hart Road, Orpington, Kent BR6 0QB.

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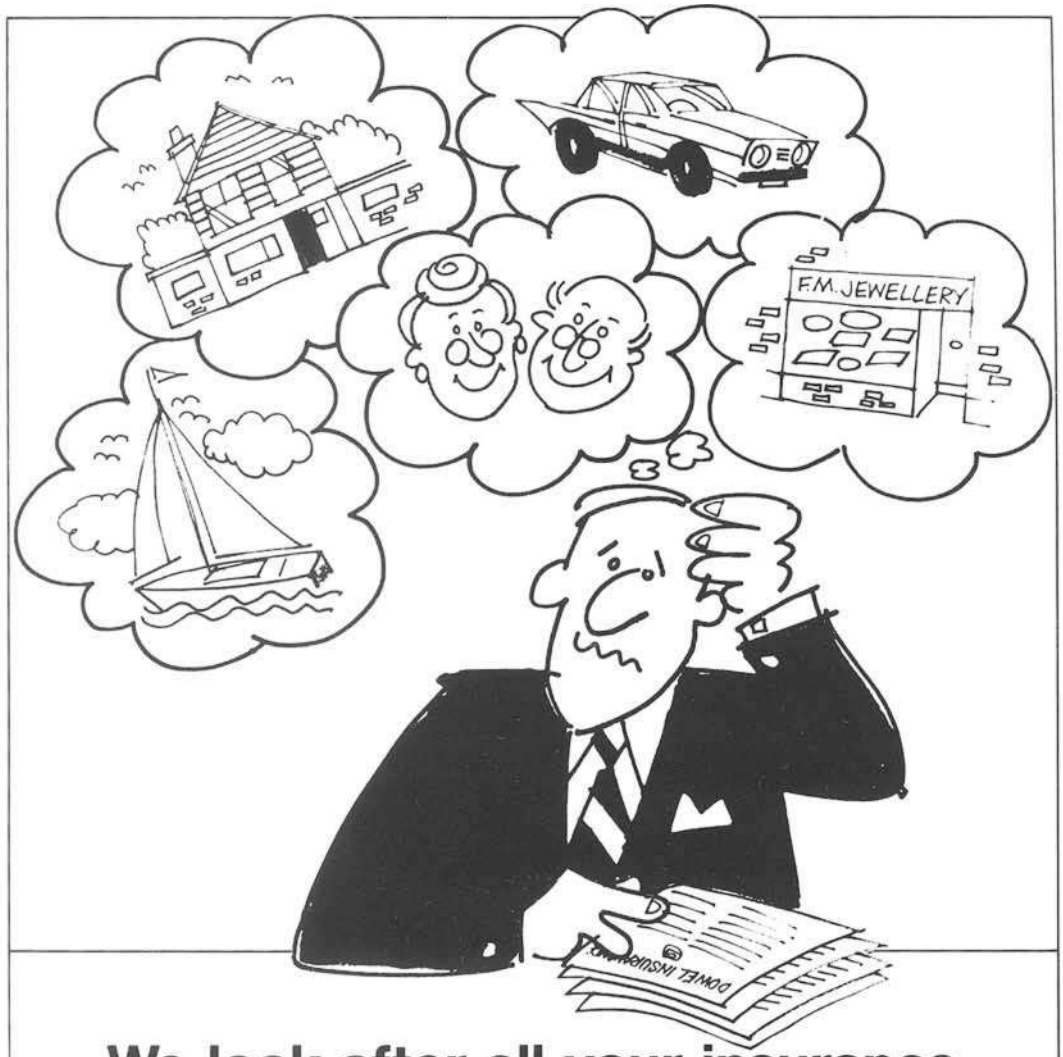

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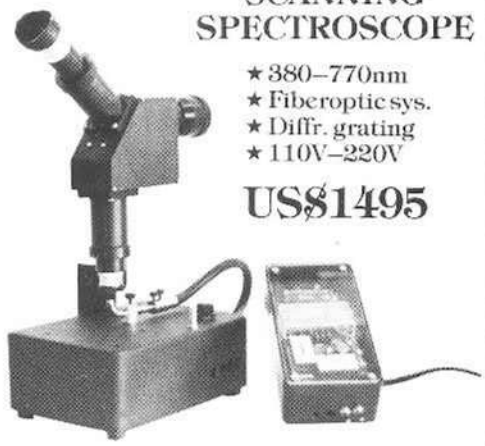

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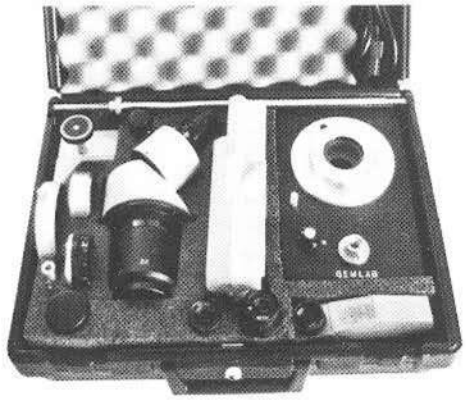

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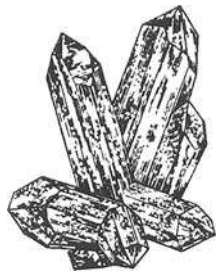

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octahedra and the gem-set ring indicates the use of gems in ornamentation. The lynx of the crest at the top was credited, in ancient times, with being able to see through opaque substances. He represents the lapidary and the student scrutinizing every aspect of gemmology. In the paws is one of the oldest heraldic emblems, an escarbuncle, to represent a very brilliant jewel, usually a ruby. The radiating arms suggest light diffused by the escarbuncle and their tips are shown as jewels representing the colours of the spectrum.

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Twenty five copies of individual papers are provided on request free of charge; additional copies may be supplied, but they must be ordered at first proof stage or earlier.

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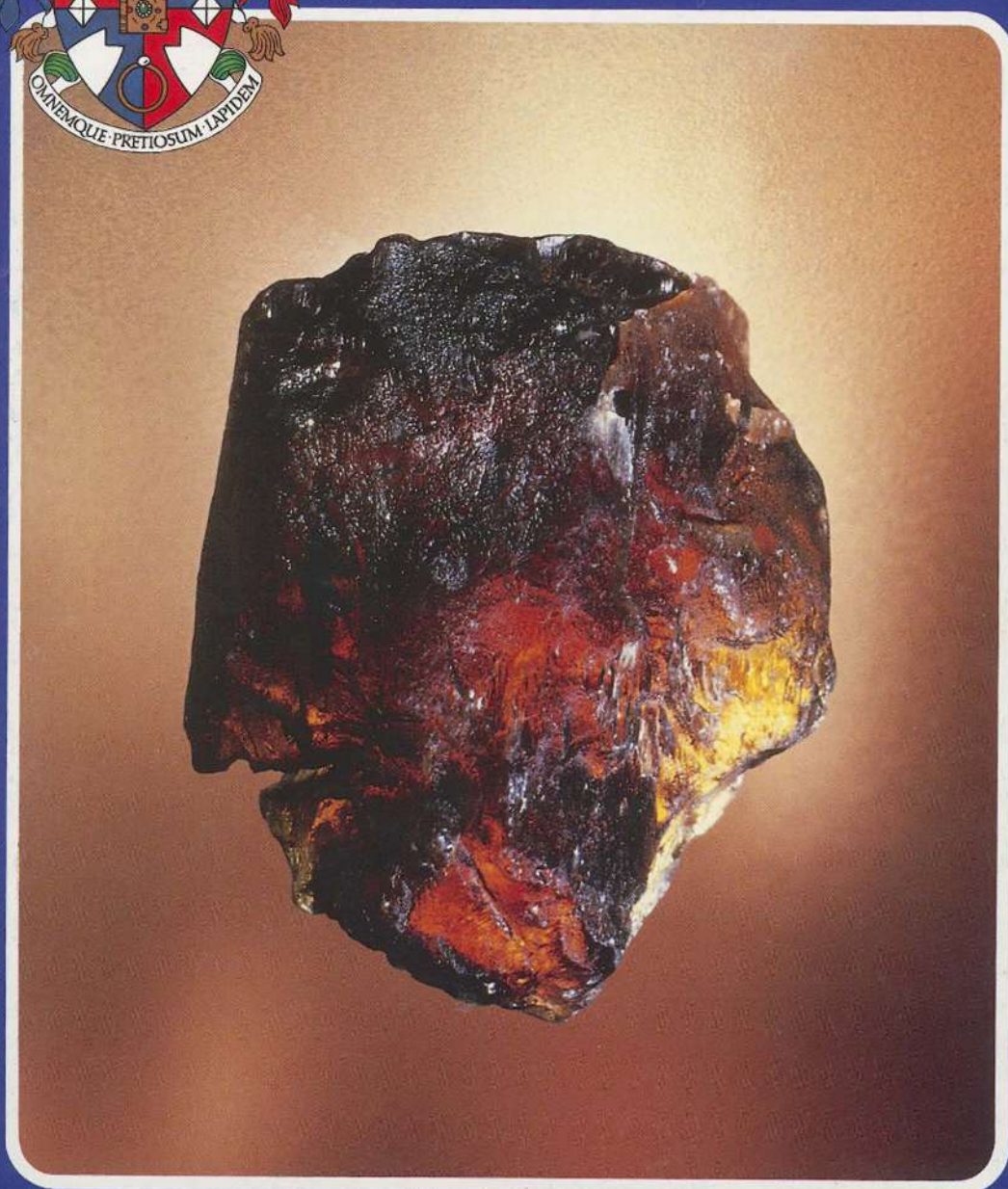

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Cover Picture

Tanzanian enstatite rough
(see 'Gemmological investigation of a large faceted east African enstatite', p.92).
Photograph by Tino Hammid.

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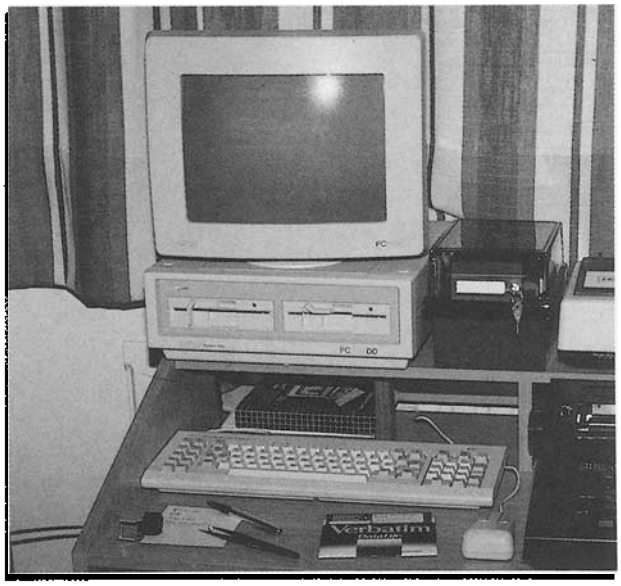

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An important Australian contribution to gemmology

R. Keith Mitchell, FGA

Almost forty years ago the late Lester B. Benson Jnr, a brilliant innovator with the Gemological Institute of America, hit on the 'distant vision' or 'spot' method of obtaining approximate refractive index readings from cabochon or other curved polished surfaces. Ever since then successive students have struggled to put this method to use.

With the instrument scale viewed from a distance of about 30cm (1 foot) the exercise involves a good deal of head-movement, both vertically and from side to side, for the tiny image of the spot of contact fluid slides out of sight with remarkable ease and it is often necessary to re-position the stone on the instrument, and to jiggle the head endlessly before the required half shadow, half light, position is obtained. Then, with the elusive disc image hovering precariously in sight and nicely bisected, one realises to one's total disgust, that the instrument scale is completely out of focus!

For the present writer, who has severe astigmatism and wears bifocal glasses, this last problem was easily solved. The bisected spot image was located using the distance vision section of the spectacle lens, and the head then held rigidly steady in that position while the right hand raised the specs to the point where the scale could be seen, *in focus*, through the 'reading' section of the lens. But most people do not have this simple solution to hand.

However, the August 1987 issue of the *Australian Gemmologist* prints an excellent paper by Gordon S. Walker, ASTC, FIO, FGAA, in which he describes a remarkably simple device which very largely overcomes the difficulties which have brought misery and frustration to so many.

Mr Walker is an optician as well as a gemmologist, and is obviously familiar with the pinhole diaphragm as a primitive device to overcome focusing problems including either long or near sight. Some readers may have experimented with a pinhole camera which, *without a lens*, can give a picture in which a scene is always in focus, regardless of the distance of the subject from the pinhole. In this the only limiting factors are the size of the pinhole, which regulates the sharpness of the picture, since the latter consists of an infinite number of images of the tiny hole, and the long exposure needed if a small enough hole is used. The same principle is used in more elaborate lensed cameras, when stopping down to a very small aperture increases the depth of focus very substantially. But in these the increased focal depth is still limited by the presence of a lens. The pinhole camera suffers no such limitation.

Mr Walker has cleverly used the universal focus principle to improve the Lester Benson distant vision RI method.

Using a pinhole rather less than a millimetre in diameter, held as close as possible to the eye and at a distance of no more than 6cm (2½ inches) from the refractometer eyepiece, he sees both the scale and the contact spot nicely in focus at one and the same time. This closer viewpoint also means that far more of the scale is now visible and the spot no longer plays its devilish hide and seek game with the viewer. An approximate RI can be obtained with no difficulty at all. Mr Walker even suggests that this so simplifies the procedure as to make accurate estimates to a third place of decimals possible.

I have now tried this little device exhaustively and can heartily recommend it. My pinhole was made in a developed, unexposed (black) photographic transparency by the simple expedient of pushing the point of a very fine stringing needle a short way through it. This gave me a reasonably clean hole of about 0.5mm in diameter. (The black surface is advisable to avoid distracting reflections from one of a lighter colour.) I placed a cabochon stone on a suitably small spot of contact fluid on the prism of the refractometer. Removing my spectacles, without which I can focus nothing, I brought the pinhole close to my right eye at a distance of about 7.5cm (three inches) from the instrument eyepiece. Both scale and spot were nicely in focus and a slight movement of my head brought the spot image to the position where it was bisected equally into light and dark areas. A reading of 1.54 for chalcedony was obtained immediately and with the utmost ease.

The previous need to stand up and move around

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rather like an animated blancmange, while ogling the instrument from a distance, is obviated. The whole test can be carried out while sitting at the bench or table.

This very simple procedure adds so much to cabochon stone testing by making a difficult and rather elusive method absurdly easy, that one is left wondering why no one has hit upon it before in the many years since Lester Benson published his method in 1948. I do, however, take leave to doubt whether the reading facility is improved to the point where a reliable third place of decimals could be estimated. This has still to depend on the ability of the individual observer to judge when the spot is exactly bisected. That judgement may be easier, but the spot image is still very mobile with the slightest movement of the head and such accuracy would still be difficult.

But the fact remains that Mr Gordon Walker has found a way to make a rather tricky testing procedure almost as simple as the test for a faceted stone. All gemmologists should try it!

It is only fair to mention that distant vision testing is usually less difficult with the Rayner Dialdex refractometer because the black screen which moves down to mark the shadow-edge reading is always easily visible. But there is a tendency among students to assume that they can still estimate readings to three places of decimals when using the calibrated knob of this instrument to read the RI. In point of fact the method is no more accurate with the Dialdex than it is with the standard scale refractometer, and readings should still be regarded as rather approximate. The pinhole device still helps here since it allows the shadow edge to be seen from a closer viewpoint when the head can be held much steadier without undue strain, and a wider field of view allows one to judge much more easily when the spot is accurately bisected.

Reference

Walker, G.S., 1987. A new 'spot reading' technique for the refractometer. *Australian Gemmologist*, **16**, 7, 253-6.

[*Manuscript received 8 January 1988*]

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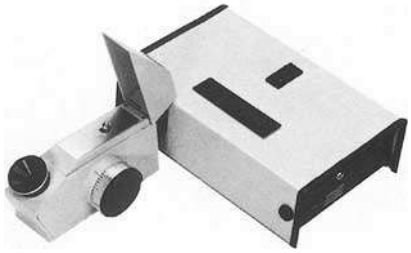

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Orientated lath-like inclusions of a new type in spinel

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Abstract

A bluish-violet spinel from Sri Lanka with orientated inclusions was investigated by microscopy, X-ray single crystal diffraction, and electron microprobe techniques. The sample reveals four sets of lath-like double refracting crystal inclusions which are orientated parallel to the three-fold axes of the host. The guest mineral is one of the Al_2SiO_5 polymorphs, most probably sillimanite. A general survey of the literature dealing with orientated inclusions and asterism in spinel is given.

Orientated inclusions in spinel

In the present paper, orientated inclusions of a new type in spinel are described. The sample investigated did not show asterism. This fact is due to the dimensions of the lath-like guest crystals. Nevertheless, a summary of the literature dealing with orientated inclusions and asterism in spinel is presented for comparison as well as in order to avoid confusion with other types of orientated needle- to rod-like guest minerals in spinel.

The presence of orientated inclusions in natural spinel was of certain interest to gemmologists because asterism in spinel results from diffraction of light from these minerals. Asteriated spinels from Sri Lanka and Burma were described by different authors, e.g. Anderson and Payne (1954), Switzer (1955), Gübelin (1957) and Eppler (1958). In general, alternating six- and four-rayed stars are observed along the curved surface of the spinels which are cut in the cabochon form. The axes passing through the centre of each six-rayed star are parallel to the four three-fold axes of the cubic spinel; the axes passing through the centre of each four-rayed star are parallel to the three four-fold axes of the crystal. This common type of asterism in spinel is caused by triangular sets of needle-like inclusions (Figures 1, 2), which are orientated parallel to the six edges of the octahedron faces <110>. According to the symmetry of the cubic system in each plane parallel to the eight octahedron faces of the spinel with inclusions parallel to <110>), three intersecting sets of needles at 120° intervals are observed (Figures 1, 2). Each triangular set of inclusions will produce a six-rayed star if the crystal is cut cabochon and viewed in directions parallel to the four three-fold axes, i.e. at right angles to the octahedral faces. The light bands of two different six-rayed stars intersect at 90° at each of the poles of the three four-fold axes of the spinel forming four-rayed stars if the crystal is viewed at right angles to the cube faces (cf. Switzer, 1955).

Extremely rare are spinels which disclose only one single six-rayed star on the surface of the cabochon. In these spinels, only one triangular set of intersecting needle-like inclusions is present lying in one single plane parallel to one octahedral face of the spinel (Gübelin, 1968; Gübelin and Koivula, 1986).

The nature of the orientated needle-like inclusions is described by different authors with some controversy. This is due to the fact that both types of asterism in spinel mentioned above were not clearly separated in each publication. The needle-like inclusions which are present in the common type of asteriated spinels showing alternating six- and four-rayed stars, are most probably small rutile crystals. This opinion was already published by Eppler (1958) and Strunz (1968) and was also confirmed by Gübelin and Koivula (1986). However, the only known experimental proof for the presence of rutile in asteriated spinel was made by the present author by X-ray powder diffraction (cf. Bank, 1980, 1983).

The cause of a single six-rayed star in the second rare type of asteriated spinel (cf. Gübelin 1957, 1968; Eppler, 1958) is due to the presence of orientated needle-like inclusions of sphene (Gübelin and Koivula, 1986). In that case, only one single plane with three sets of parallel inclusions is observable.

Experimental procedures and results

In the present paper, a faceted bluish-violet spinel from Ratnapura, Sri Lanka, was studied. This sample was submitted to the author by a gem collector in order to determine the nature of some

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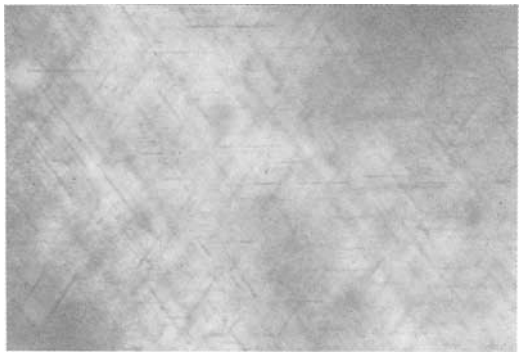

Fig. 1. Asteriated red spinel from Sri Lanka; view in a direction parallel to one of the three-fold axes <111>; the axes of three sets of needle-like inclusions, most probably rutile, are orientated parallel to one octahedron face <111> at 120° intervals. 75x.

Fig. 2. Asteriated red spinel from Sri Lanka; various sets of parallel orientated needle-like inclusions, most probably rutile. 75x.

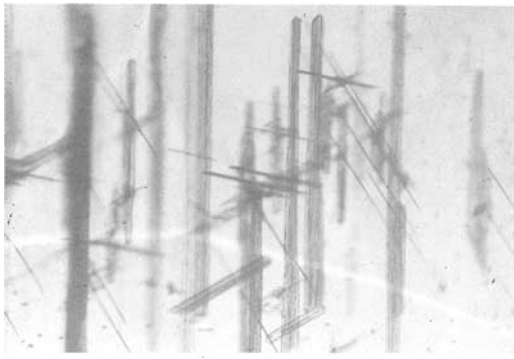

Fig. 3. Bluish-violet spinel from Sri Lanka containing four sets of parallel orientated lath-like inclusions, most probably sillimanite. 50x.

Fig. 4. Bluish-violet spinel from Sri Lanka containing four sets of parallel orientated lath-like inclusions, most probably sillimanite. 70x.

Fig. 5. Bluish-violet spinel from Sri Lanka; view in a direction parallel to one of the three-fold axes <111>; cross-sections of one set of lath-like crystals the axes of which are orientated parallel to the direction of view; three sets of parallel inclusions are observable parallel to the remaining three-fold axes <111>. 75x.

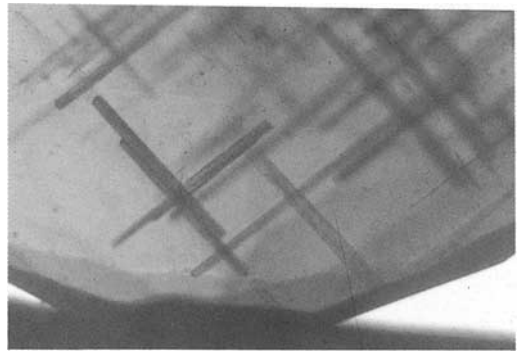

Fig. 6. Bluish-violet spinel from Sri Lanka; view in a direction parallel to one of the four-fold axes <100>; four different sets of parallel lath-like inclusions are orientated parallel to the four three-fold axes <111>; the crystals are orientated against each other according to the body diagonals of a cube. 35x.

needle-like inclusions. The stone was bought during a trip to Sri Lanka in 1980.

The microscopic investigation of the sample revealed four sets of parallel lath-like inclusions to be present (Figures 3, 4). The orientation of the axes of the double refracting crystals was determined to be parallel to the four body diagonals of a cube (Figures 5, 6). According to the symmetry of the host, the orientation of the axes of the lath-like guest minerals was assumed to be parallel to the four three-fold axes of the cubic spinel. This was confirmed by a combination of microscopy and X-ray single crystal diffraction.

Firstly, the host spinel was affixed with rubber to a goniometer head. Then, the direction of one set of lath-like guest crystals was orientated microscopically almost parallel to the primary X-ray beam of a precession camera. The deviation between the crystal axes and the X-ray beam was assumed to be less than 5°. After three orientation photographs and some small corrections with the two arcs of the goniometer head, one plane of the reciprocal lattice of the host crystal was adjusted perpendicular to the primary X-ray beam. A direct X-ray photograph of this reciprocal lattice plane revealed the orientation of the plane to be parallel to one of the octahedron faces {111} of the host crystal. This investigation disclosed that one set of inclusions was parallel to one of the three-fold axes <111> of the spinel. Thus, the axes of all four different sets of lath-like inclusions, which are related to each other as the body diagonals of a cube, are confirmed to be orientated parallel to the four three-fold axes <111> of the cubic spinel (cf. Figures 5, 6).

Parallel to each of the four three-fold axes of a spinel, three symmetry equivalent orientations of the cross-sections of lath-like crystals are possible. However, parallel to each of the three-fold axes of the spinel investigated, only one single direction of the cross-sections of the guest crystals was observed

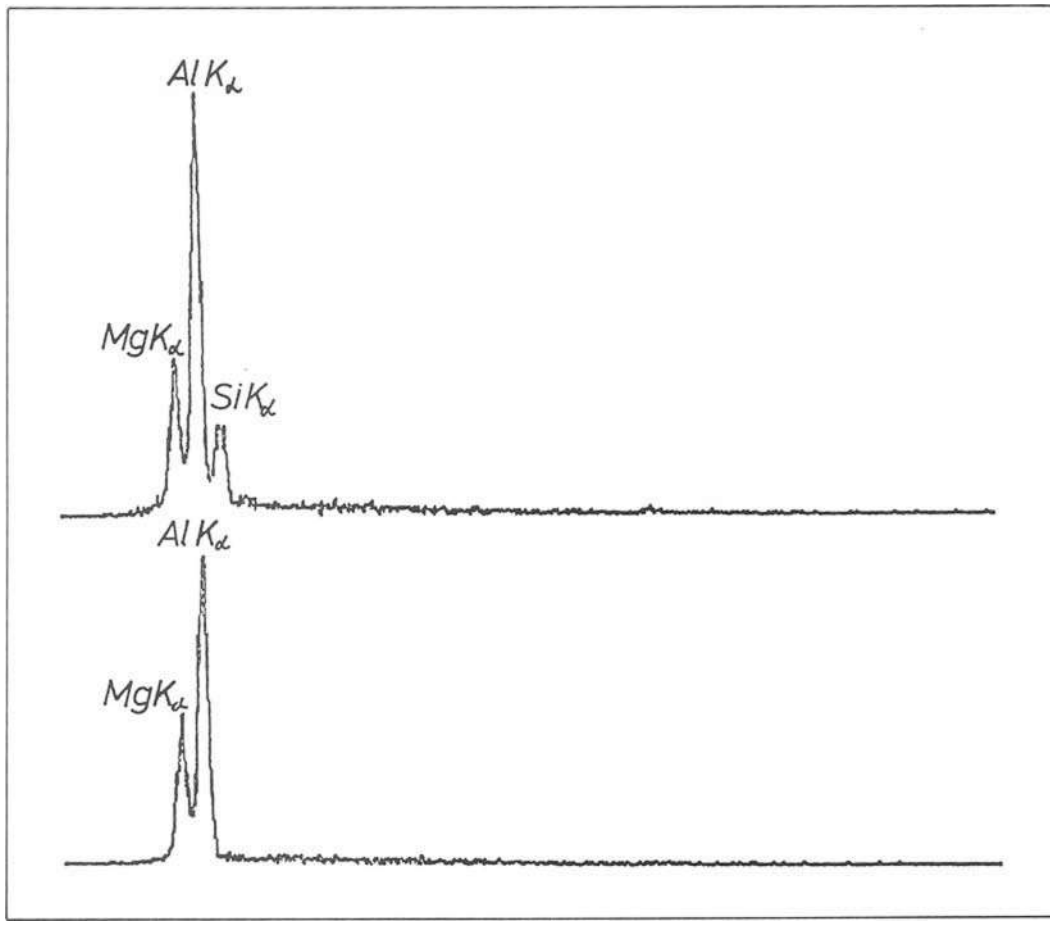

Fig. 7. Energy dispersive X-ray spectrum of bluish-violet spinel from Sri Lanka (below) and superimposed X-ray spectrum of the host spinel and the guest phase, most probably sillimanite (above).

(Figures 3–5). At present, the reasons for this restriction is not understood by the author.

A chemical investigation of the inclusions was undertaken by electron microprobe techniques. Due to the fact that the widths of the cross-sections of the lath-like inclusions (Figure 5) which were exposed to the surface on different facets were smaller than the diameter of the electron beam, quantitative analyses of the inclusions were not performable. However, semiquantitative investigations using the energy dispersive analysis system of the microprobe disclosed the composition of the lath-like mineral. In Figure 7 the energy dispersive X-ray spectrum of the host spinel is compared with the superimposed X-ray spectra of the host spinel and the guest mineral. In both diagrams, the intensities of the Mg signals were made comparable using appropriate counting times. The superimposed X-ray spectrum of both host and guest mineral, shows an additional line of Si as well as an increased intensity of the Al signal, compared with the intensity of Al in the pure host spectrum. Thus, the presence of Al and Si as main components in the guest mineral are disclosed. This interpretation is based on the assumption that Mg is not present in the guest compound, which was proved by the X-ray scanning technique (X-ray images for MgK_{α}, AlK_{α} and SiK_{α}) for several cross-sections of the guest phase exposed to the surface of one facet.

From these chemical data, the orientated inclusions in spinel are determined as one of the Al_2SiO_5 polymorphs andalusite, sillimanite, and kyanite. According to the morphology of the lath-like guest minerals in spinel, only sillimanite and andalusite form needle- to lath-like crystals, while kyanite in general is found in tabular plates. Two arguments favour the determination of the inclusions as sillimanite: orientated needle-like inclusions of sillimanite were recently determined in asteriated quartz from Sri Lanka as well as in chrysoberyl cat's-eyes from India (Woensdregt *et al.*, 1980; Soman and Nair, 1985). According to recent petrological studies of PT conditions of spinel-bearing mother rocks from Ratnapura area, Sri Lanka, sillimanite is the only common Al_2SiO_5 polymorph in these Precambrian metamorphic rocks (Dahanayake *et al.*, 1980; Munasinghe and Dissanayake, 1981; Dahanayake and Ranasinghe, 1981).

Conclusions

In summary, the bluish-violet host spinel from Ratnapura, Sri Lanka, contains four sets of lath-like inclusions. The axes of these doubly refracting minerals are orientated parallel to the four three-fold axes <111> of the cubic spinel. The main components of the crystals are Al and Si. Morphological and petrological arguments support the determination of the inclusions as the Al_2SiO_5 polymorph sillimanite. This new type of inclusion is different from orientated rutile and sphene crystals in asteriated spinels from Sri Lanka.

Acknowledgements

The author is grateful to Mr H.J. Müllenmeister of Markt Schwaben, West Germany, who submitted the bluish-violet spinel for investigation. Asteriated spinels from Sri Lanka were kindly supplied by Prof. Dr H. Bank of Idar-Oberstein, West Germany. Financial support was given by grants of the Wirtschaftsministerium des Landes Rheinland-Pfalz, West Germany.

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Synthetic opal

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Early in the 1980s there arrived in London a range of attractive opals with a very natural looking prismatic play of colour within the stones. The yellows, greens, oranges and reds were seen against a general pale bluish semi-transparency, and when illuminated from behind by a fibre optic light the stones showed a pale orangy colour. This whole appearance is compatible with certain natural opals and there was no 'chicken wire' as with the Gilson synthetic opal. The material gained some ground until identified later as synthetic.

The material is apparently synthesized in Japan, and it is helpful to note that when examined by immersion microscope between partly or totally crossed polars, a distinctive stratification is seen as in Figure 1. The effect is very similar to that noted as 'venetian blinds' in synthetic hydrothermal emeralds, and a similar occurrence in Colombian hydrothermal emeralds. The large dark area in the microphotograph is the drill hole of a part-drilled 4 mm bead – the materials ranging from 3 mm beads to 16 x 14 mm oval cabochons.

A support test for the opal material is that ultraviolet long-wave radiation produces little fluorescent and no phosphorescent response with the synthetic opal described, whereas similar natural opal invariably fluoresces and phosphoresces strongly.

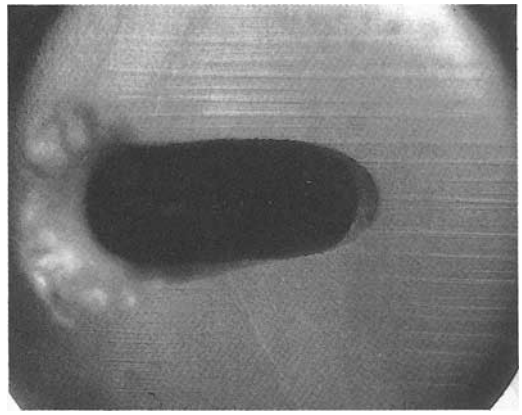

Fig. 1. Synthetic opal examined by immersion microscope. Crossed polarizers. 25x.

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Observations on turquoise, lapis-lazuli and coral, and some of their simulants

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Abstract

Various aspects of the chemical, physical and gemmological properties of natural, Gilson stimulants and imitations of turquoise, lapis-lazuli and coral have been described by Crowninghshield (1974), Williams and Nassau (1976), Schiffmann (1976), Nassau (1977, 1979) and Schmetzer (1985). In this paper the results of X-ray diffraction (XRD) and X-ray fluorescence (XRF) analysis on Gilson simulants and other imitations (which were rectangular blocks imported from West Germany) are compared with those from natural materials. In addition the broken surfaces of these materials are viewed by scanning electron microscope (SEM) and the patterns obtained compared with those resulting from the natural materials. The effects of acid treatment on the surfaces are also photographed.

Results

The X-ray powder diffraction patterns of the Gilson simulants of turquoise, lapis-lazuli and coral matched those of the natural materials. However, in the case of the Gilson lapis-lazuli significant amounts of zinc were detected by X-ray fluorescence analysis (compare Schmetzer, 1985). The imitation turquoise, lapis lazuli and coral consisted essentially of calcite and polystyrene. Their specific gravities (hydrostatic method) were in the 1.65–1.70 range. XRF analysis showed the presence of copper, cobalt and antimony in the turquoise, lapis-lazuli and coral imitations respectively. These elements may act as colouring agents in the respective imitation gems.

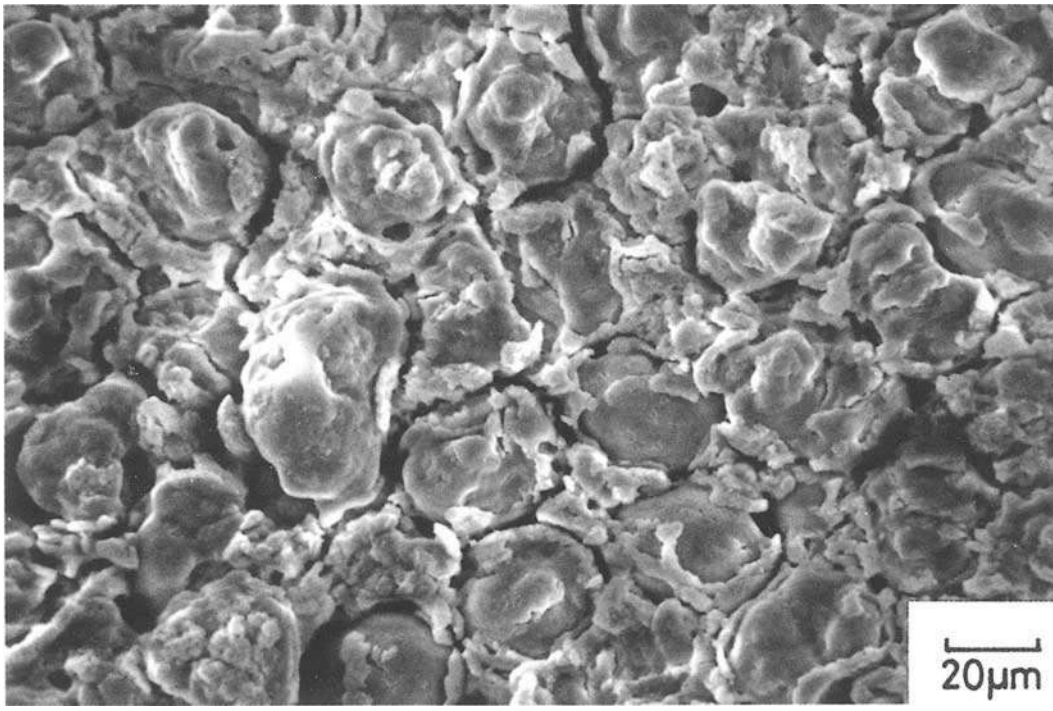

Fig. 1. Gilson turquoise after HF acid treatment; the obvious grains of about 20 μm in size and the matrix, which may be different from the composition of the grains, appear.

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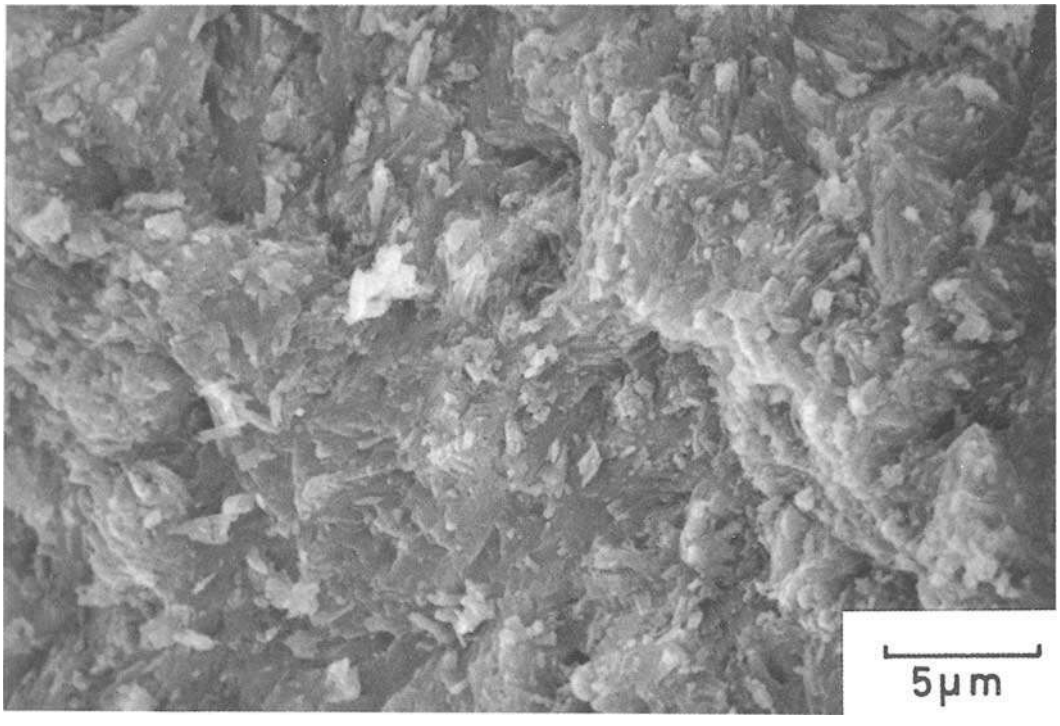

Fig. 2. Natural turquoise before acid treatment; the pillar-shaped crystal of about 0.4 × 2 μm in size.

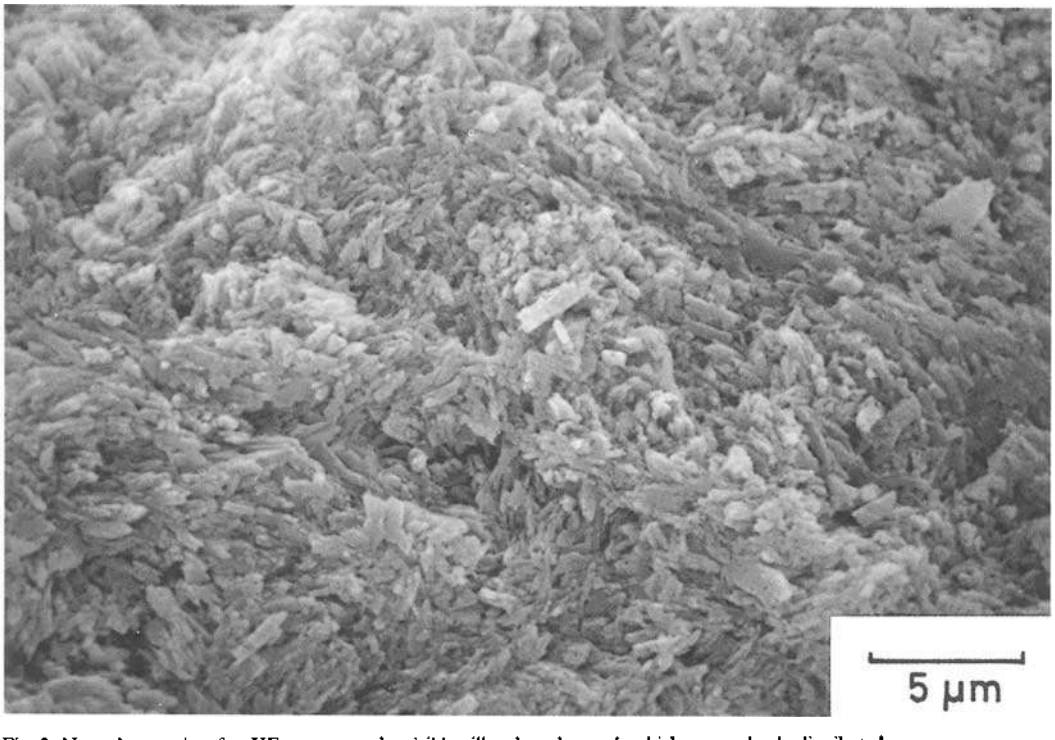

Fig. 3. Natural turquoise after HF treatment; the visible pillar-shaped crystals which are randomly distributed.

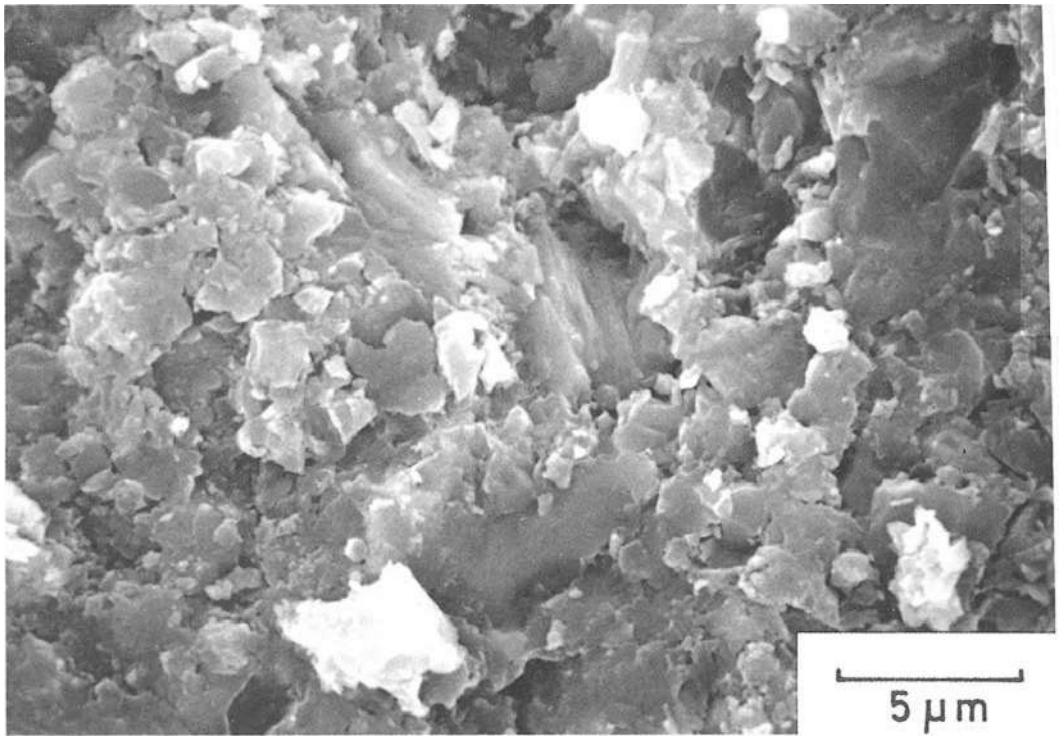

Fig. 4. Gilson lapis lazuli before acid treatment; the particles of various sizes.

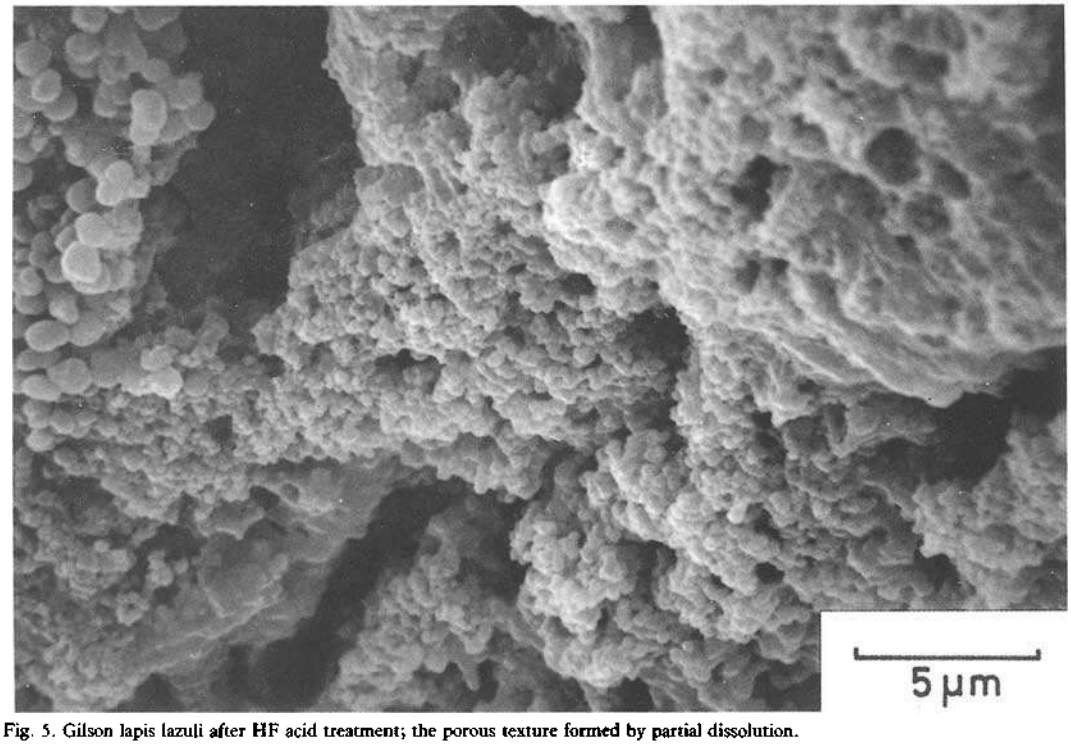

Fig. 5. Gilson lapis lazuli after HF acid treatment; the porous texture formed by partial dissolution.

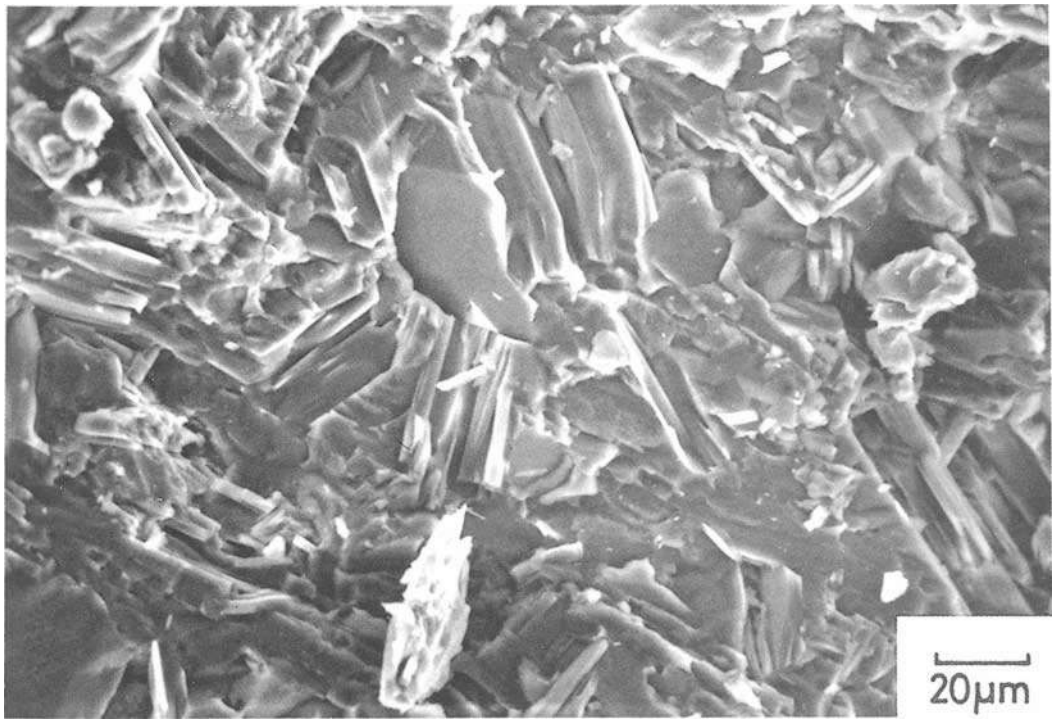

Fig. 6. Natural lapis lazuli before acid treatment; the plate-like crystals of about 10–30 μm in length.

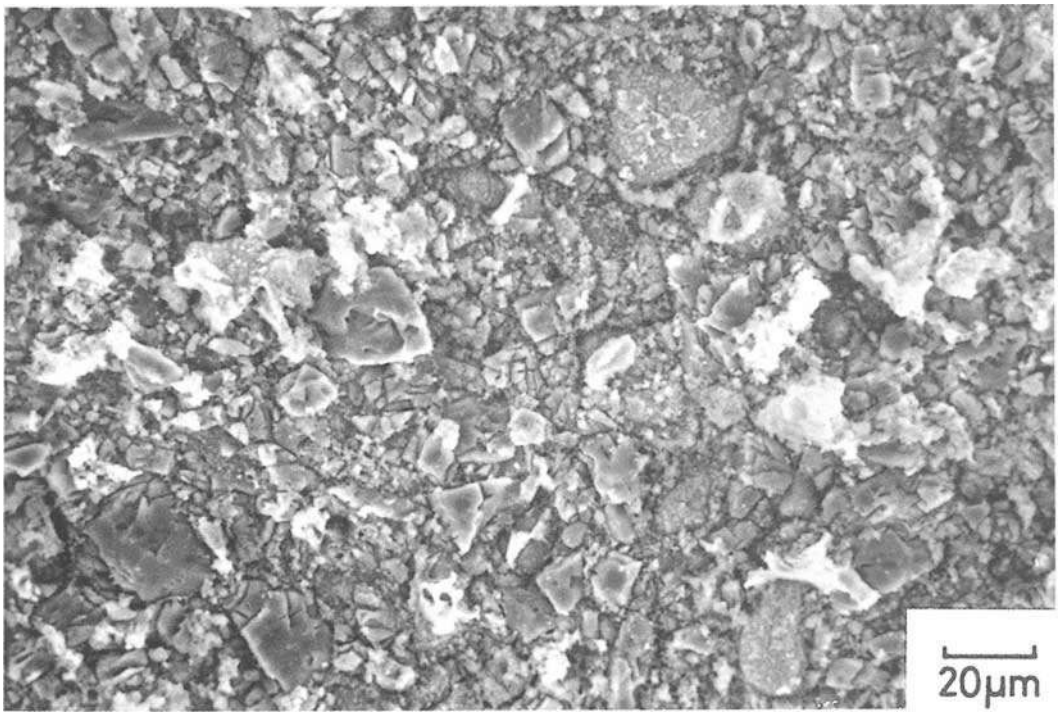

Fig. 7. Gilson coral before acid treatment; the angular particles of about 2–20 μm in size and the rounded particles rather larger than the angular particles.

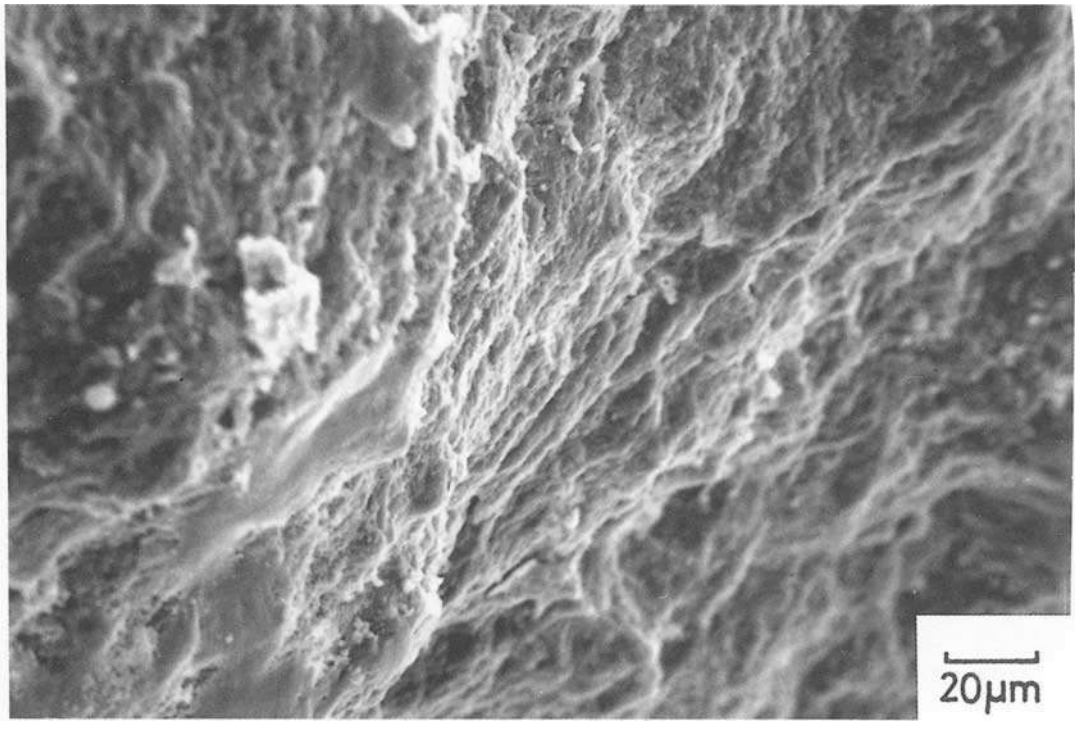

Fig. 8. Natural coral before acid treatment; the wave-like pattern showing the marks of growth.

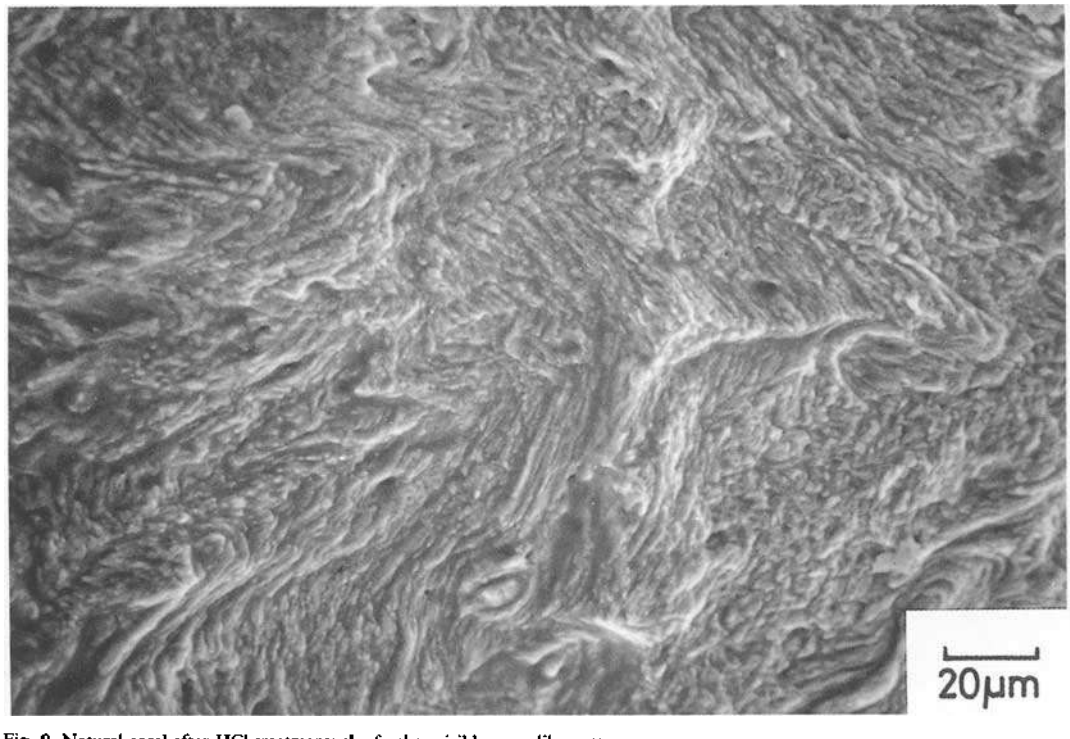

Fig. 9. Natural coral after HCl treatment; the further visible wave-like pattern.

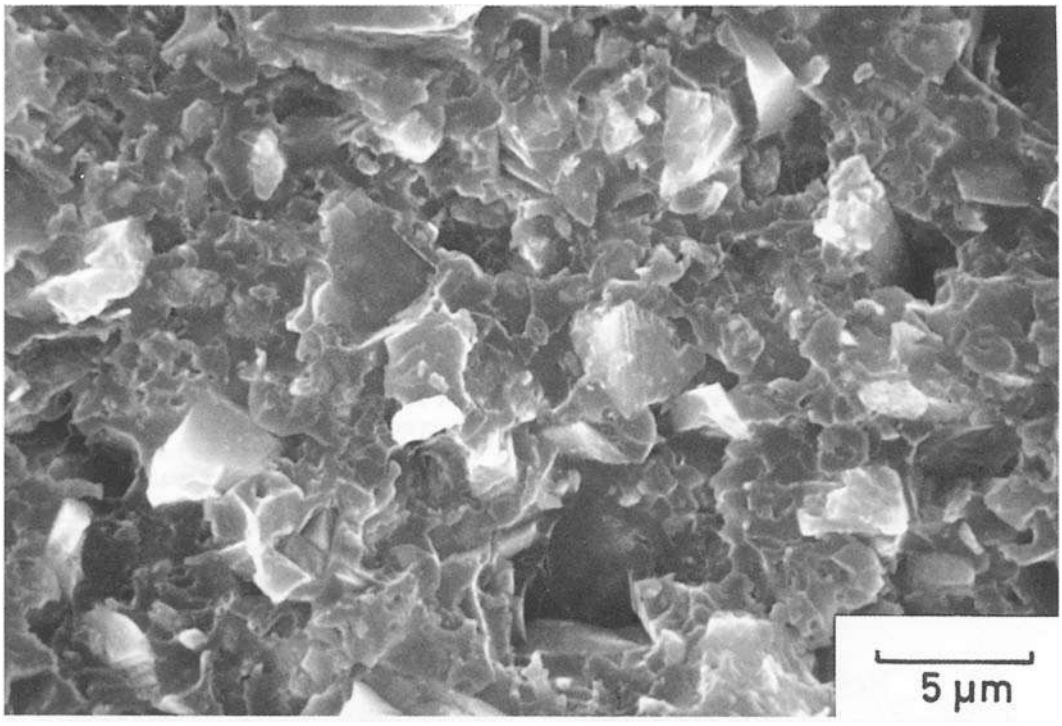

Fig. 10. Imitation turquoise, lapis lazuli, and coral before acid treatment; the complex broken-surface with plastic and calcite particles.

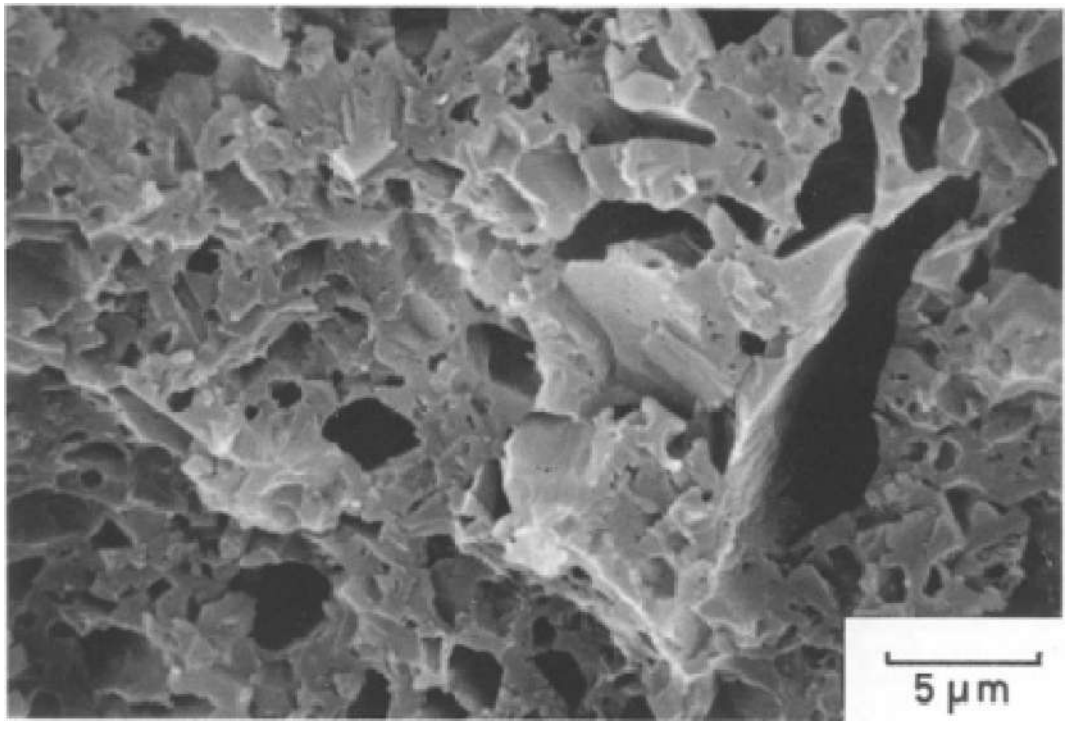

Fig. 11. Imitation turquoise, lapis lazuli, and coral after HCl acid treatment; many holes are formed by the dissolution of $CaCO_3$ as one component.

Under the SEM Gilson turquoise shows a similar pattern (slightly deformed spheres) to that described by Eppler (1974). However, the greater magnification (X500) gives a better three dimensional picture than the thin-section (X246) of Eppler taken with a conventional microscope.

[*Manuscript received 22 January 1987, revised 25 June 1987*]

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A fishy 'gem'?

R. Keith Mitchell, FGA

In 1985 I wrote a short paper about a small man-made oval plaque, or plate, with thin pearl-like sections of what were eventually identified as ooliths, pisoliths or 'cave pearls'. This was published in *Journal of Gemmology*[1].

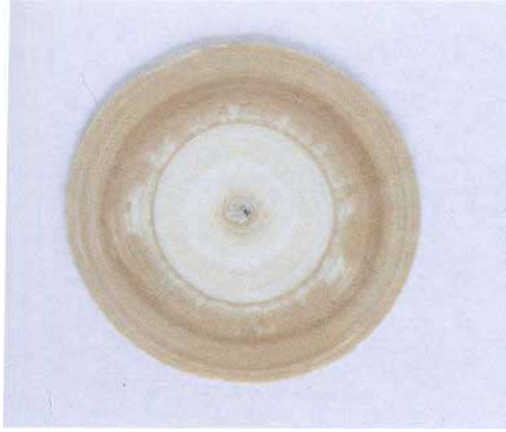

Fig. 1. A section through a large 'cave pearl'.

Fig. 2. A polished fragment of 'musselcracker' palate.

A letter in a subsequent issue[2] mentioned that Dr Jaques Deferne, of the Museum at Grotte de Bramabian, Garde, France, had cut a fine section from a much larger cave pearl, which Mr Andre Hettena, of Geneva, sent on to me. This 'pearl' section, which I now illustrate in Figure 1, was 39mm in diameter, and fluoresced very white in its lighter areas and a sandy yellow in the outer darker rings under long UV light.

A year later I received a letter from Dr H. Schreuders, of Cape Town, enclosing another strange ornamental 'stone' which he thought looked like my original illustration.

I have to agree that there is a strong resemblance, but this new specimen, Figure 2, is a homogeneous organic solid and is natural, whereas my plaque is a composite object assembled by man from a number of separate thin inorganic sections cemented with a resin to a slate backing.

Dr Schreuders has given me details of the new specimen and tells me that it is actually a polished fragment of the bony palate of a large fish known colloquially as a 'musselcracker'. This is the common name for two species, *Sparadon durbanensis* and *Cymatoceps nasutus*, both members of the family *Sparidae*. They feed mostly on hard black mussels or on crustacea, sea urchins and other hard-shelled sea animals. They need powerful jaws and a strong bone structure to crush such prey and the palate apparently develops protuberant knobs which, when polished flat, give rise to the well-marked, tessellated pattern of my illustration, a pattern which carries through to the underside of the specimen. There is a suggestion of a silky radial growth pattern on some of the surfaces sectioned by polishing, but there is no sign of the concentric 'onion ring' structure seen in pearls and in 'cave pearls'.

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I think that this is one of those materials which are simple enough to recognize by sight once one is aware of their existence. Tests for bone or tooth substances, including slight reaction to acid may help, but the material really does not resemble mammalian bone. The polish and slight translucency is more like that of fine porcelain, quite different from the dull surface and opacity of the plaque in my original paper.

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[*Manuscript received 22 January 1988*]

More on Nelson's 'FMIR Body Colour'

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With the Editor's permission, let me add to the exchange between Dr James B. Nelson[1,2] and me[3]. I promise to be brief and, so as to sharpen the focus, will cover only essentials (which, in my opinion, were not answered by Nelson[2]).

Yes – colour measurements have triumphed in the many fields Nelson listed[1], but all have this in common: their measurements correspond very closely to the colour that is visually perceived.

Nelson clearly states[2] that the FMIR body colour* of a gemstone is not the same as the colour perceived by the eye, although I do feel that his original article[1] continuously gives the impression that the two are at least very closely related.

Consider one simple example. A diamond coloured by green 'naturals', or a colourless diamond turned green by cyclotron irradiation at the girdle, both appear green to the eye because internal reflections spread the colour throughout the stone. The FMIR body colour would, however, not show any traces of green according to Nelson's own descriptions[1,2].

I conclude, as previously[3], that Nelson's model† just is not appropriate to the real world of gemstones.

Footnote: *For the sake of clarity, one should always distinguish between 'FMIR body colour' and 'body colour', since gemmologists often use 'body colour' to designate the visually-perceived colour near the centre of a stone – as for one example, in the GIA courses. It is, I think, imperative to adhere fully to the terminology of the gemstone discipline.

†I realize that Nelson states[2] "I have no need for any kind of 'model'". I am, of course, using this word as science epistemologists do (see any of Karl Popper's writings, for example), who recognized that every measurement, no matter how simple, is not an absolute, but merely 'models' some aspect of reality.

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3. Nassau, K., 1987. On the colour of gemstones and Nelson's 'body colour'. *Journal of Gemmology*, **20**, 6, 350-1.

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Notes on the inclusions in a greyish kyanite

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Abstract

A greyish kyanite and its numerous inclusions were studied. Optical observations were made and X-ray diffraction and electron microprobe analyses were performed. The recognized inclusions are: andalusite, apatite, calcite and zircon. The tubular inclusions or channels are sometimes made evident by fillings consisting of andalusite and kyanite as well as iron oxides and hydroxides.

Approximate P-T conditions for the formation of this kyanite sample are estimated.

Key words

Kyanite, mineral inclusions, andalusite, apatite, calcite, hematite, lepidocrocite, maghemite, zircon, channels, electron microprobe data, X-ray diffraction.

Introduction

A greyish-blue, gem quality kyanite sample (12 × 9 × 3mm) was examined (Figure 1). The colour of the sample is not homogeneous, as a greyish hue is distributed unevenly in the crystal (White and White, 1967; Faye and Nickel, 1969), resulting in numerous intensively coloured areas which are large and undefined.

Furthermore, numerous mineral inclusions were noted inside the crystal. These are euhedral, often aggregated, forming bunches of prismatic, sometimes elongated, transparent crystals (Figure 2).

Besides sporadic transparent fibrous inclusions, rare minute opaque minerals were observed also.

The former are colourless, birefringent slim rods, developed parallel both to the groups of needle-like grooves or channels, and to the *c* axis of the host crystal (Figure 3). Such features produce a moderate cat's-eye effect. The unusual characteristics of this sample warranted various investigations and a thorough description of these features.

Analytical results

Kyanite:

Chemical composition and physical data are reported in Table 1.

Fig. 1. Numerous transparent crystal inclusions and bunches of narrow channels, cause an evanescent cat's-eye effect. 10x.

Optical properties were determined by means of a universal stage. Pleochroism is barely noticeable, with α: colourless, β: violet-grey and γ: cobalt blue-grey. The refractive indices were determined by means of the immersion method, yielding: $n_\alpha = 1.712 \pm 0.004$; $n_\beta = 1.720 \pm 0.003$; $n_\gamma = 1.728 \pm 0.003$; $n_\Delta = 0.015$; $2V_\alpha = 83°$.

The density was measured by a Mettler H_2O scale with distilled water as displacement liquid, and it was found to be equal to 3.670 ± 0.004 g/cm^3.

It was possible to calculate the unit cell parameters by means of X-ray powder diffractometry, using Ni filtered, $Cu_{K\alpha}$ radiation with five oscillatory scans at 1/4° 2θ per minute from 10° to 80° 2θ. Pure semiconductor grade crystalline silicon metal (Jarrel Ash JM, spectroscopy impurity less than 300 ppm) was used as an internal standard.

The lattice constants were estimated using a least-squares refinement (De Angelis *et al.*, 1977) of the X-ray data, indexed by comparison with the data listed by the JCPDS, card No. 11-46.

It was also possible, based on the lattice constants, to calculate the density of this kyanite as if it were totally free of inclusions. The value obtained was considerably higher than the measured one.

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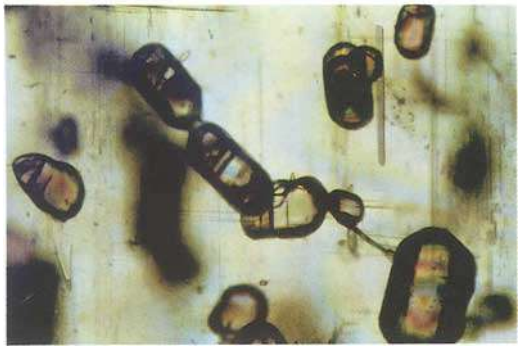

Fig. 2. Various large andalusite and anhedral transparent calcite crystals. 20x.

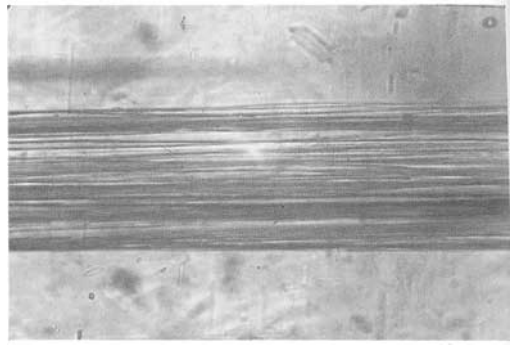

Fig. 3. Groups of channels, rigorously orientated parallel to the *c* axis of the host kyanite, are mainly responsible for the chatoyancy effect. 200x.

In order to investigate the chemical composition of this sample, some inclusion-free areas were analysed by means of a Jeol-50A electron microprobe, using natural and synthetic standards. Matrix corrections were performed using the EMPADR VII program (Rucklidge and Gasperrini, 1969).

A noticeable amount of inclusions made it possible to determine the ignition loss. The iron and titanium contents corresponded with the expected values, while the MnO content is a little higher and the alkali content is quite low (Pearson and Shaw, 1960; Albee and Chodos, 1969).

Table 1. Microprobe analysis, optical properties and X-ray data of greyish kyanite.

		Number of ions on the basis of 20 (0)		
SiO_2	37.58 wt.%	Si	4.049	4.05
Al_2O_3	62.19	Al	7.898	
TiO_2	0.07	Ti	0.006	
FeO*	0.21	Fe	0.019	
MnO	0.20	Mn	0.018	
MgO	–	Mg	–	
Cr_2O_3	–	Cr	–	
BaO	tr.	Ba	–	7.95
SrO	–	Sr	–	
CaO	–	Ca	–	
K_2O	0.05	K	0.007	
Na_2O	–	Na	–	
H_2O^+ } **	–	H	–	
H_2O^- }				
TOTAL	100.30			

n_α	= 1.712 ± 0.004	*a*	= 7.059 ± 0.002 Å
n_β	= 1.720 ± 0.003	*b*	= 7.907 ± 0.007 Å
n_γ	= 1.728 ± 0.003	*c*	= 5.571 ± 0.003 Å
birefringence: ± ± 0.016			
$2V_\alpha$	= 83°	α	= 89.1° ± 0.3°
ϱ (g/cm^3)	= 3.670 ± 0.004	β	= 101.6° ± 0.3°
ϱ_{cal}^{obs}	= 3.783 ± 0.004	γ	= 105.6° ± 0.6°

* All iron as FeO.
** Not determined.

Table 2. Microprobe analyses of the inclusions of greyish kyanite.

	Andalusite		Apatite		Calcite		Zircon
SiO_2	37.64	SiO_2	–	CaO	55.34	SiO_2	33.34
Al_2O_3	61.52	Al_2O_3	0.05	MgO	0.17	ZrO_2	63.18
TiO_2	0.05	FeO*	0.16	FeO*	0.03	TiO_2	0.08
FeO*	0.28	MnO	0.01	MnO	0.08	Al_2O_3	1.07
MnO	0.04	MgO	0.26	CO_2†	43.91	FeO*	0.60
MgO	–	CaO	53.25			R.E.	tr.
Cr_2O_3	–	BaO	–			MnO	tr.
CaO	–	SrO	–			MgO	0.22
BaO	tr.	Na_2O	0.24			CaO	0.65
SrO	–	P_2O_5	41.36			P_2O_5	–
Na_2O	–	CO_2	–			H_2O^+ } **	–
K_2O	–	F	–			H_2O^- }	
H_2O^+ } **	–	Cl	0.19				
H_2O^- }		H_2O^+ } **	–				
		H_2O^- }					
TOTAL	99.53 wt.%		95.52		99.53		99.14

* All iron as FeO
** Not determined
† Calculated

Inclusions

The numerous inclusions were analysed by the electron microprobe (Table 2).

Conspicuous euhedral, prismatic crystals (up to 0.70 × 0.40mm), characterized by high relief and low birefringence, were observed (Figure 2).

These inclusions are roughly aligned with the *c* axis of the host kyanite. The microanalyses show the presence of Si and Al in the same ratio as is found in kyanite, and of other minor elements. Therefore these crystals were identified as polymorphs of Al_2SiO_5, probably andalusite, based on their morphology (Figure 4). Moreover, a Rigaku X-ray microdiffractometer MDG2193V was used. The microdiffractograms revealed the reflections of andalusite and concurred well with the crystallographic data reported by JCPDS, card No. 13-122. Thus the guest mineral was confirmed as *andalusite*, the low-temperature, low pressure polymorph of Al_2SiO_5 (Brown and Fyfe, 1971).

Other transparent and colourless inclusions were then examined. Some anhedral greyish crystals (up to 0.20 × 0.15mm) show a composition very close to pure $CaCO_3$, with small amounts of MgO, FeO and MnO. The CO_2 content was calculated by difference, bearing in mind the crystallochemical formula.

Long, prismatic crystals (up to 0.03 × 0.05mm) are also present, with refractive indices lower than those of kyanite. The microprobe analyses indicated that they are *apatite*. The absence of fluorine and the presence of small amounts of chlorine suggest that they may be carbonate or hydroxyapatite (Figure 5).

Sporadic thin non-pleochroic long prismatic crystals (up to 0.017 × 0.003mm) were also noted, with very high relief, and refractive indices higher than the host kyanite. Electron microprobe scans revealed that the crystals are euhedral and prismatic. Their composition was found to be essentially ZrO_2 and SiO_2 with small amounts of Al_2O_3, CaO and FeO. This indicates therefore that they are *zircon*, characterized by the lack of Rare Earths and phosphorus (Figure 6).

Iso-orientated to the elongated crystals just described, are thin needle-like euhedral channels (up to 3 × 0.005mm). These *channels* are parallel to the *c* axis of the host kyanite and their presence is made evident by fillings consisting of minute andalusite crystals (Figure 7), and yellow or brownish-red minute crystalline material (Figure 8). Moreover various little transparent crystals are visible (up to 0.002 × 0.001mm). These channels are sometimes caused by the traction of some inclusions, mainly

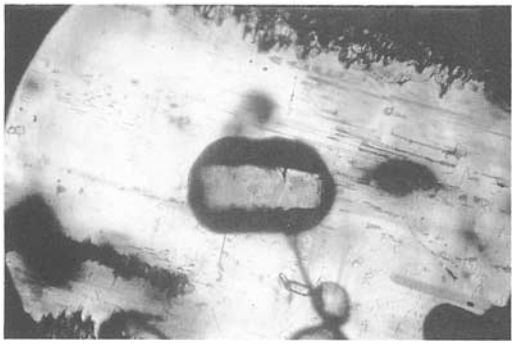

Fig. 4. Euhedral andalusite crystal with an outstandingly well-developed association of the {110} and the {011} prisms. 30x.

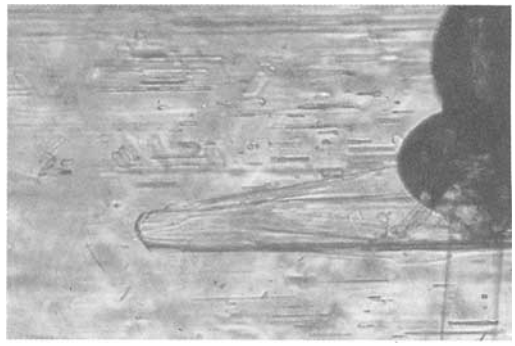

Fig. 5. Elongated prismatic apatite crystals are distributed among the thin channels. 200x.

Fig. 6. Long euhedral prismatic crystal of zircon. SEM photograph. 3000x.

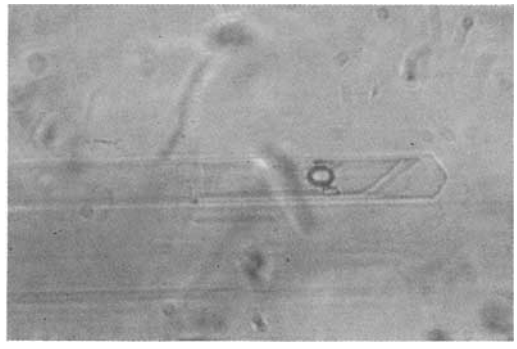

Fig. 7. Rare presence of minute euhedral andalusite crystals inside the channels. 250x.

Fig. 8. A channel filled with yellow lepidocrocite plates, unusually mixed with iron oxide slabs displaying a bright red colour. 250x.

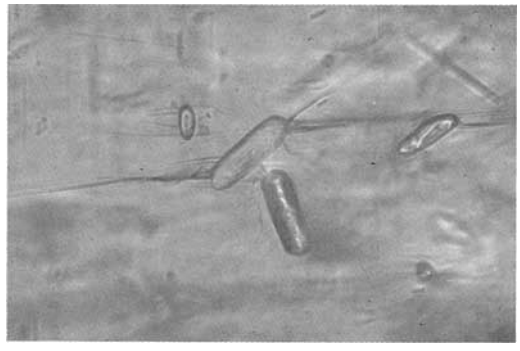

Fig. 9. The channels are sometimes caused by the traction of minute andalusite crystals. 250x.

the minute andalusite crystals (Figure 9).

Among the above mentioned mineral inclusions are yellow slabs formed by thin lamellae. Sometimes these are intergrown with brownish-red minute lenticular platelets (up to 0.003 × 0.001mm). The electron microprobe analyses disclosed the exclusive presence of iron in both these kinds of inclusions, indicating that they are *iron oxides* and *hydroxides* respectively.

The yellowish lamellae appear to be similar to *lepidocrocite* laminae containing *hematite, maghemite* and *Fe hydroxides* described by Graziani and Gübelin (1981).

The optical characteristics of the small transparent colourless crystals are very similar to those of the host kyanite. This suggests that kyanite also is present as a filling material of the channels.

The electron microprobe analyses show the presence of Si and Al and other elements in identical proportions to those of the kyanite crystals. The concurrence of the optical observations and the chemical analyses reveals that the described crystalline material is always *kyanite*.

Very minute, elongated, slightly reddish needles (up to 0.014 × 0.002mm) were observed; these are intergrown with the apatite prismatic crystals. These needles are randomly aligned and often angular. They may be one of the three polymorphs of titanium oxide.

Discussion

The characteristic features of this greyish kyanite and the presence of numerous inclusions of different kinds lead to the following considerations:

The sample is remarkable for its unusual greyish-blue colour and by noticeable amounts of one of the minor elements (i.e. manganese).

Particular mention is made concerning the difference between the measured and calculated density values. Such a difference should be attributed to the large amount of inclusions of lower density such as andalusite, calcite and apatite in the kyanite. Consequently, values as high as 3.78 g/cm^3 could be expected in an inclusion-free greyish kyanite of the kind analysed in this study.

The numerous parallel channels and fine fibrous inclusions are responsible for the weak chatoyant effect. The presence of syngenetic andalusite in the kyanite allows the individual plotting of the kyanite-andalusite equilibrium curve in the Al_2SiO_5 system as a first clue to define the P-T conditions under which this sample formed (Holdaway, 1971). On the other hand, the impossibility of defining the exact reaction boundary curve on the diagram allows only the emphasis of 4 Kbar and temperature of 500°C as a maximum. In fact, the field in which these two polymorphs coexist can be extended over a large P-T range (Richardson *et al.*, 1969).

In any case, the absence of pyrophyllite in the sample would suggest lower temperature and pressure values in this kyanite-andalusite assemblage, i.e. 350°–400°C and 2.5–3.0 Kbar respectively.

The presence in some channels of kyanite together with iron oxides and hydroxides, indicates that the latter iron minerals crystallized after a subsequent filling up of the channels with an iron-rich fluid. Lepidocrocite dehydration is proved by the presence of reddish iron oxides, probably hematite or maghemite, which could have formed at temperatures around or above 300°C, depending on pressure conditions (Kulp and Treites, 1951).

Acknowledgements

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Investigation of cat's-eye zircons from Sri Lanka

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Introduction

Zircon, the most common radio-active gemstone, is found abundantly in the sedimentary gem beds of Sri Lanka. The chemical and structural aspects of zircon were detailed by Gottfried *et al.* (1956); Vitanege (1957); Vance and Anderson (1972); Sahama (1981) and recently by Rupasinghe (1984). There have been many reports in gemmological literature on zircon with chatoyancy effect in the past as well as in recent years (see Eppler, 1958; Fryer *et al.*, 1983, 1984 and 1985). During the last few months the authors were informed of an occurrence of zircon cat's-eye in Bibilé, Sri Lanka. Investigating this information during a recent visit of one of the authors to the 'Gem Island', it became apparent that a large number of zircon cat's-eyes were available in the local gem market. The sudden occurrence of phenomenal zircons from Sri Lanka aroused the authors' interest to research in detail whether there is an actual natural occurrence or whether some type of enhancement is carried out to produce a chatoyancy effect.

The author's visit to Sri Lanka yielded the answer to the problem of zircon cat's-eye effect in that country. The chatoyancy can occur either naturally or after heat treatment to the gem. However, the former is rare (Figure 1). The majority of stones now available are subjected to a process of heating (Figure 2). This article aims therefore at describing the gemmological and chemical properties of 'natural' and 'treated' cat's-eye zircon. Particular details on the cause of the chatoyancy in both types are discussed.

Gemmological properties

Several gemmological tests were conducted to determine the properties of two types of cat's-eye zircons, especially to distinguish between treated and untreated.

Colour

The zircon cat's-eyes shown in Figures 1 and 2 exhibit overall light brown and whitish-grey colours respectively. The cat's-eye effect in 'natural' zircon was rather weak in appearance compared with the remarkable chatoyancy in heat-treated samples. The treated stones exhibited a slight bluish-sheen under reflected light.

Fig. 1. Zircon exhibiting a 'natural' cat's-eye effect found in Bibilé, Sri Lanka. Weight 3.43 ct.

Fig. 2. Heat-treated zircon exhibiting a chatoyancy effect, Most of the stones investigated in this study are of this type. Weight 5.52 ct.

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Fig. 3. Growth tubes which are arranged parallel to one direction in the 'natural' zircon cat's-eye from Sri Lanka. Photographed by using colour filter to enhance the tube-like inclusions. Transmitted and reflected light illumination. 50 x.

Fig. 4. The growth tubes seen in 'natural' zircon cat's-eye from Sri Lanka are often filled with minute mineral matter. Dark-field illumination. 55 x.

Refractive index and specific gravity

Because of the high refractive index of zircon it was necessary to use the Riplus type refractometer and this provided, with great difficulty, the usual shadow-edges for high and intermediate type zircons. The 'natural' cat's-eye zircon provided the intermediate type values, whereas the treated ones gave the values for high type (Table 1). The specific gravities of the samples were determined hydrostatically on a Sartorius balance at room temperature. The cat's-eye zircons revealed specific gravities ranging from 4.00 to 4.69.

Spectroscopic and ultraviolet radiation analysis

The absorption spectra of these zircons were determined by the use of hand-held prism-type spectroscope. The most diagnostic 653.5 nm absorption line accompanied the other lines at 660.5, 662.5, 621.0, 615, 589.6, 562.0, and 516.2 nm.

None of the samples exhibited any noteworthy luminescence when illuminated under either ultraviolet radiations.

Gem microscope observations

Under high magnifications a clear-cut answer to the origin of the zircon cat's-eye can be obtained. The 'natural' chatoyant zircon contained numerous growth tubes arranged parallel to one direction in the gem (Figure 3). These tubes seem to be quite large in diameter (Figure 4) and are often filled with mineral matter. Although the mineral plates have not contributed to the effect of chatoyancy they were identified as biotite mica (Figure 5).

The inclusions in heat-treated cat's-eye zircons were in no way similar to those described above,. In appearance they were comparatively free from inclusions. However, with magnification fine disc-shaped fissures were visible (Figure 6). These ultra-thin tension fissures were arranged in a parallel

Table 1. The gemmological properties of 'natural' and heat-treated zircon cat's-eyes from Sri Lanka.

	Refractive index	Specific gravity	Absorption spectrum in nm	Inclusions
'Natural' zircon cat's-eye (1 sample)	1.83	4.04	660.5, 653.5, 621, 589.5	Hollow tubes parallel in one direction and often filled with biotite mica inclusions.
Heat-treated zircon cat's-eyes (10 samples)	1.92-1.97	4.60-4.69	660.5, 691.0, 662.5, 653.5, 621, 615, 589.6 562, 537.6, 516.2.	Fine disc-shape tension fissures arrange in one orientation. Cracks on the unpolished surfaces.

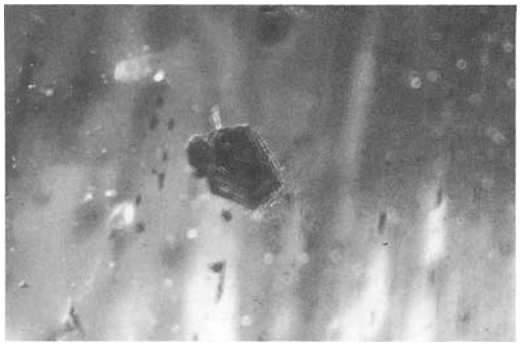

Fig. 5. The enclosed minerals within the tubes were identified as biotite mica in zircon cat's-eye of untreated origin. Dark-field illumination. 80 x.

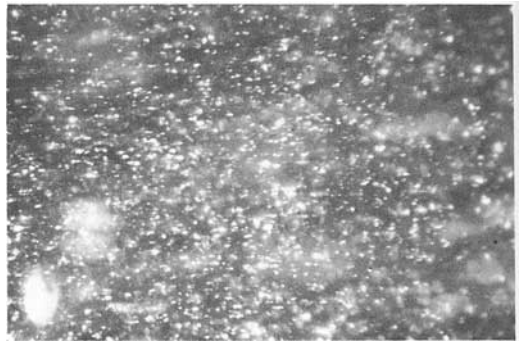

Fig. 6. Fine disc-like tension fissures arranged in parallel orientation in heat-treated zircon cat's-eyes are now available in the trade. Dark-field illumination. 60 x.

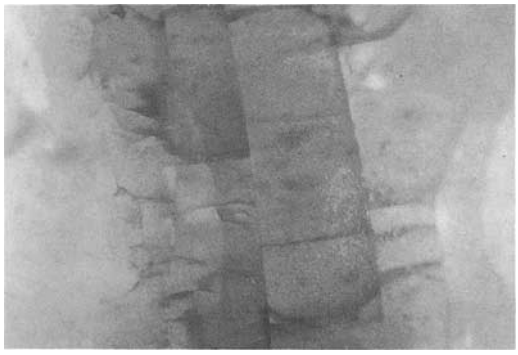

Fig. 7. Visible fire cracks often seen on unpolished surfacts of heat-treated zircons from Sri Lanka. Transmitted light illumination. 53 x.

orientation in the stone and when such zircons are cut en-cabochon they provide a chatoyancy with a bluish-sheen under reflected light. Many heat-treated zircon cat's-eyes observed exhibited fire cracks (Figure 7) on unpolished surface areas.

Chemical analysis

Microprobe analysis were conducted on two cat's-eye zircons of natural and heat-treated origins. The treated zircons contained no iron and showed less percentags of the common radio-active elements such as Hf, Th, and U. The results obtained in this analysis are given in Table 2.

The cause of chatoyancy

The chatoyancy in zircons from Sri Lanka described in this paper is caused by the parallel arrangement of hollow or growth tubes or ultra-thin disc-like fissures. In natural zircon cat's-eyes the arrangement of growth tubes takes place in one direction. If the needle-like inclusions orient compactly within the gem the effect is pronounced. However, in many instances, as one shown in Figure 1, the included tubes are rather far apart from each other and this causes somewhat indistinct chatoyancy.

The fine disc-shape fissures can also produce a cat's-eye effect if the arrangement takes place in a regular manner. Heat-treatment influences such arrangements within zircons and this leads to chatoyancy.

Heat treatment of zircon cat's-eye

Heat-treating zircon is well-known and is reported in detail by Webster (1975). The majority of zircons found in Sri Lanka are often subjected to heat. However, it was only quite recently that treaters began to produce a cat's-eye in zircon. The process is similar in practice to that of heat-treating

Table 2. Chemical data (in wt%) for 'natural' and heat-treated zircon cat's-eyes from Sri Lanka.

	SiO_2	FeO[a]	ZrO_2	HfO_2	ThO_2	UO_2
'Natural' zircon cat's-eye	34.28	0.04	63.70	1.40	0.25	0.67
Heat-treated zircon cat's-eye	33.96	nd[b]	65.10	1.19	0.22	0.34

[a] Total iron calculated as FeO [b]nd = not detected

amethyst to set in a schillerization. At the request of the operators the authors have kept the exact details of the process secret. It was apparent however, that the temperature used in this instance was lower than in the amethyst treatment. The lowering of temperature causes the result of fine fissures and often cracking of the stone. A similar sheen to that of moonstone-like quartzes often results in treated zircons. However, as has been observed by one of the authors it is not at all an easy task to treat zircons to show chatoyancy.

Conclusion

Zircon with a cat's-eye effect is not a new occurrence to either gemmology or to the trade. However, heat-induced zircon cat's-eyes have not been mentioned previously in literature Such stones are now encountered often in the trade. Therefore the properties mentioned in this article are of value in future determinations of the origin of cat's-eye zircons.

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Gemmological investigation of a large faceted east African enstatite

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Abstract

This article describes the identification and scientific documentation of a large, gem-quality, faceted Tanzanian enstatite that was presented to the Gemological Institute of America. The results of chemical analysis, X-ray powder diffraction, and various gemmological tests, carried out on this gemstone, are reported.

Introduction

GIA was recently given a large, gem-quality, orangish-brown, rough crystalline mass, mined in Tanzania, that weighed approximately 75 carats. Shown in Figure 1, the rough, presented to the GIA as hypersthene, was superficially covered with numerous extremely fine parallel striations (Figure 2) that resulted from the surface exposure of abundant, minute, acicular growth tubes. The growth tubes were so fine and evenly disseminated that they gave the rough crystal a directionally-dependent translucency that complemented its rather strong pleochroism. The pleochroism and the general appearance were what one might expect of a pyroxene.

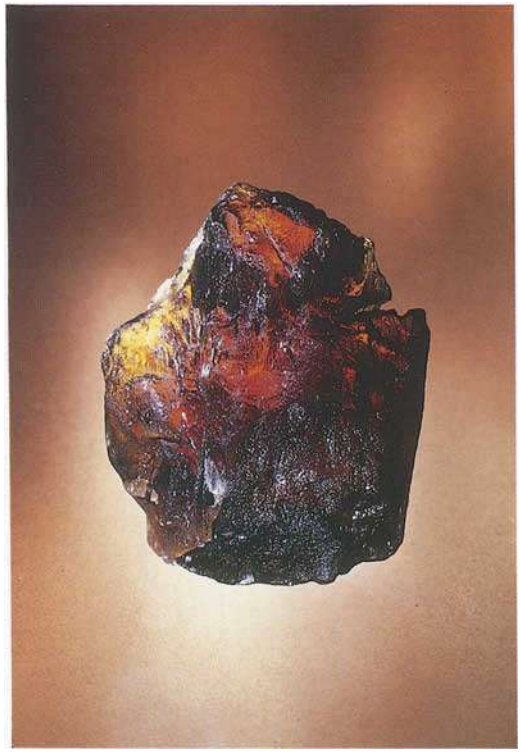

Fig. 1. Tanzanian enstatite rough before faceting. *Photo by Tino Hammid.*

The rough crystalline mass was subsequently cut by Mr Michael Gray of Los Angeles, California, into a large, antique cushion modified step cut, shown in Figure 3, weighing 46.56 carats. We believed this to be perhaps the largest known faceted pyroxene. Once faceted, the gem and a remaining fragment of the rough crystal were subjected to a variety of testing techniques to determine its properties and correct identity, which proved to be enstatite.

Gemmological properties

Microscopy

Examination of the faceted stone with a gemmological microscope revealed a multitude of extremely fine acicular inclusions as well as a few coarse ones (Figure 4). The inclusions, all lying parallel to one another in a single direction, were thickly disseminated throughout the stone. Had a decision been made to fashion the rough crystal in a properly oriented cabochon form, it would probably have resulted in a fine cat's-eye stone displaying excellent chatoyancy. Distinct colour and growth zones, of a light yellowish-brown hue, running in a direction perpendicular to that of the acicular inclusions, were also visible through the microscope. One of these is shown bisecting the acicular inclusions in Figure 5.

Refractive index

Using a sodium vapour light source and a Duplex II refractometer the refractive index of the faceted stone was observed to be $\alpha = 1.662$, $\gamma = 1.673$, and

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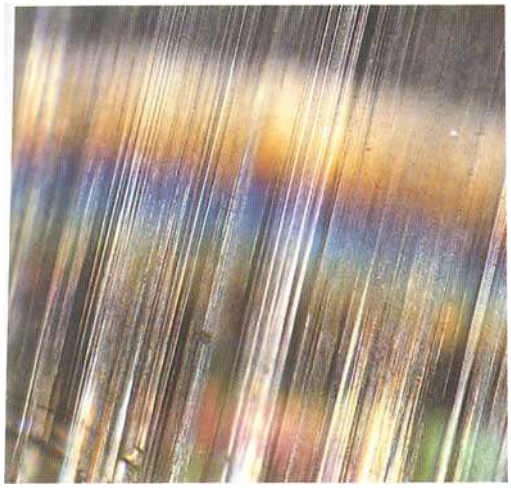

Fig. 2. Fine parallel striations on surface of rough enstatite crystal. Magnified 85x.

Fig. 3. Faceted antique cushion step cut enstatite weighing 46.56 carats (possibly the world's largest), size 21.52 × 20.34 × 13.73 mm. *Photo by Tino Hammid.*

the intermediate reading $\beta = 1.667$. Because β was determined to be slightly closer to α, the stone exhibited a biaxial positive optic character. The birefringence is 0.011. This was the first indication that the gemstone might be enstatite since hypersthene is biaxial negative with a higher birefringence (0.012–0.021).

Specific Gravity

The specific gravity of the faceted stone and the rough crystal were determined in two ways. Using pure methylene iodide with a known specific gravity of 3.32 as a heavy liquid, it was found that both the faceted stone and rough crystal section sank slowly. On the basis of this observation the specific gravity was estimated to be approximately 3.35. Next, utilizing a Voland double pan diamond balance the specific gravity was determined by the hydrostatic method. The values so obtained on the two pieces ranged from 3.33 to 3.41.

Spectroscopy

A GIA-GEM spectroscope unit with a Beck prism spectroscope was used to check the visible light absorption characteristics of this faceted gem. The spectroscopic examination, carried out at room temperature, showed a textbook spectrum for brown enstatite (Liddicoat, 1981). A strong sharp line at 506.0 nm, flanked closely by two weak lines at 503.0 and 507.5 nm are readily visible. The stone also shows a single band located between 547.5 and 550.0 nm as well as a series of weak bands in the blue.

Pleochroism

The presence of strong pleochroism in this stone was first noted during microscopic examination. Strong pleochroism is a characteristic feature of many coloured pyroxenes. Since the material was determined to be biaxial it was thought that perhaps three distinct pleochroic colours might be observed

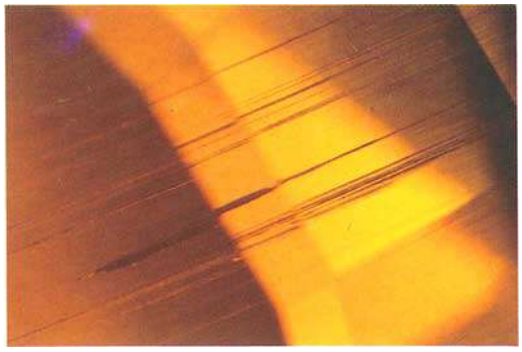

Fig. 4. Some of the coarse and fine acicular inclusions observed in the faceted enstatite. Magnified 50x.

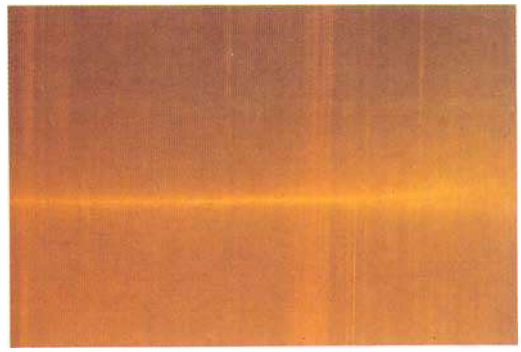

Fig. 5. Colour-growth zone, bisecting the acicular inclusions at a right angle, as seen in the faceted enstatite. Magnified 50x.

through a calcite dichroscope. A strong fibre-optic light source was used during testing. As suspected, through the dichroscope, three distinct pleochroic colours were observed: (1) greenish-brown, (2) yellowish-brown, and (3) reddish-brown.

Luminescence

The reaction of this gem material to both long-wave (366.9 nm) and short-wave (253.7 nm) ultra-violet radiation is negative.

Hardness

Using a set of hardness points, a microscope, and oblique incident illumination, the hardness of both the rough crystal section and the faceted stone was determined. The tests, carefully performed on inconspicuous areas, showed a hardness of approximately 5½ to 6 on the Mohs' scale.

X-ray diffraction

Using a sharp-edged diamond scribe, a tiny amount of powder was carefully scraped from the girdle edge of the faceted stone. The powder was used to prepare a spindle for X-ray powder diffraction. The sample was mounted in a Debye-Scherrer powder camera and exposed for eight hours to X-rays generated at 46 kV and 26 mA from a copper target tube. The diffraction pattern obtained matched that of orthopyroxene in the area of the enstatite-hypersthene portion of a complex six-member solid solution series between enstatite and orthoferrosilite based on the magnesium/iron ratio (Deer *et al.*, 1978).

Chemical analysis

In order to establish where the faceted stone and rough crystal section fit into this solid solution series, it is necessary to determine, through chemical analysis, the percentages of both iron and magnesium that are present.

Using the electron probe microanalyser at the California Institute of Technology, Carol Stockton, GIAs senior research gemmologist, found average weight per cent values as follows: SiO_2 56.99, MgO 33.78, FeO 7.45, Al_2O_3 0.74, CaO 0.36, TiO_2 0.04, Cr_2O_3 0.08, MnO 0.18, sum: 99.62 wt%. Pyroxenes such as enstatite and hypersthene belong to a solid solution series in which magnesium and iron substitute for one another in varying amounts. The series extends from pure end member enstatite ($Mg_2(SiO_3)_2$) to pure end member orthoferrosilite ($Fe_2(SiO_3)_2$). The series is arbitrarily divided into six regions, each with a mineral name and range of composition. The names and ranges (numbers refer to percentage of $Fe_2(SiO_3)_2$ in formula) are as follows: enstatite (0–12), bronzite (12–30), hypersthene (30–50), ferrohypersthene (50–70), eulite (70–88), and orthoferrosilite (88–100). The chemical analysis and measured properties of this gemstone indicate that it is enstatite with approximately 11% $Fe_2(SiO_3)_2$ in its composition.

Conclusion

Properties obtained from the battery of standard gemmological tests, such as refractometry, spectroscopy, and specific gravity, together with the results obtained by X-ray powder diffraction and electron microprobe analysis, prove this gemstone to be the orthopyroxene enstatite. It is close to the borderline between enstatite and bronzite. At 45.56 carats it is much larger than any faceted enstatite previously reported (Arem, 1977) and may be the largest faceted enstatite yet reported.

Acknowledgements

The authors thank Mr and Mrs Hyman Savinar of Los Angeles for donating this gem to the GIA for its research and display collection (GIA # 14512 A,B).

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Lechleitner synthetic rubies with natural seed and synthetic overgrowth

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Abstract

A new type of Lechleitner synthetic ruby was investigated with respect to determinative properties useful for distinction from natural samples. The new synthesis consists of natural seeds of corundum from Sri Lanka, which are coated by a thin layer of flux-grown synthetic ruby. Spectroscopic, chemical and microscopic properties are given.

Introduction

Lechleitner synthetic rubies and sapphires were first announced by Bank (1983) and later described by Kane (1985) and Gunawardene (1985). According to the publications mentioned, faceted samples of Lechleitner synthetic rubies and sapphires reveal curved growth striations and flux material in the form of wispy veils and fingerprints (Kane, 1985) as well as various forms of flux residues (Gunawardene, 1985). Due to the investigation of rough and faceted samples of Lechleitner synthetic corundum by one of the present authors (Schmetzer, 1986a, b), it is evident that faceted and pre-shaped forms as well as irregular fragments of Verneuil-grown synthetic corundums were used by the producer as seeds for his synthesis. The synthetic Verneuil seeds were overgrown with a thin layer of synthetic corundum in a flux process. This method of synthesis is generally described by Koivula (1983). Most probably, the flux used by Lechleitner for crystal growth is in the system Li_2O-MoO_3-PbF_2 and/or PbO. Due to the small thickness of the synthetic flux-grown layer of Lechleitner synthetic rubies and sapphires, the complete overgrowth or at least part of it was removed during the faceting process. The remaining samples consisted of the Verneuil seed with induced fingerprint patterns of residual flux material and, in some cases, with a thin flux-grown coating. Similar samples of Verneuil grown synthetic ruby with induced fingerprint pattern and thin flux-grown coating were formerly produced and marketed by Chatham and Knischka and recently by an unknown producer (cf. Schmetzer, 1986a,b).

With the basic knowledge of Lechtleitner's process, some of the observations of Kane and Gunawardene become more easily understandable. Most probably, the two cut camples revealing curved growth striations, which were available to Kane (1985), consisted only of Verneuil-grown seeds, the overgrowths of which were completely removed during the cutting process. The visual appearance of various forms of flux residues pictured in the paper of Gunawardene (1985) are in part typical for flux inclusions in the overgrowth (e.g. Figures 14-17) as well as for induced fingerprint patterns in the Verneuil-grown seeds of Lechleitner synthetic corundums (e.g. Figures 18-24). However, without a detailed investigation of the Verneuil-grown corundum versus flux-grown corundum contact zone as well as without an investigation of the areas with and without curved growth striations in each sample, which is most conveniently performable with the immersion microscope using methylene-iodide as immersion liquid, the assignment of inclusions to the seed or the overgrowth is connected with some uncertainty. Unfortunately, curved growth striations were not mentioned in the paper of Gunawardene and therefore, a more detailed interpretation of his figures is extremely difficult.

Not long ago, the first samples of a new type of Lechleitner synthetic ruby were made available for investigation. In contrast to the stones mentioned above, this new synthesis consists of natural corundum crystals from Sri Lanka which were used as seeds, with thin layers of synthetic flux-grown corundum as overgrowth. Due to the presence of

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natural inclusions in the seed crystals as well as due to the visual appearance of the irregular boundary between natural seed and synthetic overgrowth, samples of this synthesis are more difficult to recognize compared to the old type of stone with Verneuil-grown seeds. Thus, a description of this new type of synthetic ruby appears necessary and helpful in order to avoid misinterpretations in determinative procedures.

Colour and spectroscopic properties

For the present investigation six faceted samples of the new type of Lechleitner synthetic ruby were available. The colour of the stones (Figure 1) is red with a light violet hue, which is equal to the coloration of the well known pink to violet series of natural rubies from Sri Lanka. In some samples, the coloration of the zone confined to the girdle of the cut stones is more intense compared to the coloration of the zone confined to the table of the synthetic ruby (Figure 2). This visual appearance resembles the colour zoning known from sapphires which are diffusion treated in order to improve the intensity of the blue coloration (Hänni, 1982). In Lechleitner synthetic rubies the strengthened colour intensity of some samples in the girdle area is due to an increased thickness of the flux overgrowth in the rim area compared to the lighter zone confined to the table of the sample. This visual appearance of the faceted samples indicates the use of very light reddish or even colourless samples as seed crystals.

Absorption spectra of Lechleitner synthetic rubies with natural seeds reveal the typical absorption bands of Cr^{3+} in corundum which are superimposed by a weak Fe^{2+}/Ti^{4+} absorption in the red area of the visible region (Figure 3). This type of absorption spectrum with a strong ruby component and a weak blue sapphire absorption superimposed is normally observed in pink to violet rubies from Sri Lanka and confirms the similarity in colour of Lechleitner synthetic rubies of the new type with the common type of rubies from Sri Lanka as already mentioned above.

The absorption spectra of Lechleitner synthetic rubies in the ultraviolet area are less uniform than the spectra in the visible region (Figure 3). This result is understandable by various percentages of seed versus overgrowth in different samples; the influences of both are added to the ultraviolet spectra of the samples. Furthermore, different types of corundum from Sri Lanka may have been used as seed crystals. Samples from this country reveal extremely variable transparencies in their ultraviolet spectra (cf. Schmetzer, 1985). For both reasons mentioned, the contribution of the natural seed of corundum from Sri Lanka to the spectroscopic properties of the entire overgrown sample is variable and cannot be separated from the contribution of the synthetic overgrowth.

Fig. 1. Lechleitner synthetic rubies with natural seed and synthetic overgrowth. Size of the samples approx. 6 mm. (*Photo by O. Medenbach, Bochum, West Germany.*)

Fig. 2. Colour zoning in Lechleitner synthetic rubies with natural seed and synthetic overgrowth; in one sample the 'silk' of the natural seed is visible. – Size of the samples 8 x 9 and 7 x 7 mm. (*Photo by O. Medenbach, Bochum, West Germany.*)

Chemical properties

Investigations of residues of the flux material in Lechleitner synthetic rubies with natural seeds using X-ray fluorescence and electron microprobe techniques yielded the presence of traces of Mo. This result is consistent with chemical investigations of Lechleitner synthetic rubies with Verneuil seeds (Schmetzer, 1986a,b) and indicates crystal growth by the flux method with fluxes in the system Li_2O-MoO_3-PbF_2 and/or PbO.

Microscopic properties

All six samples available at present to the authors consist of natural seeds with an all-around thin

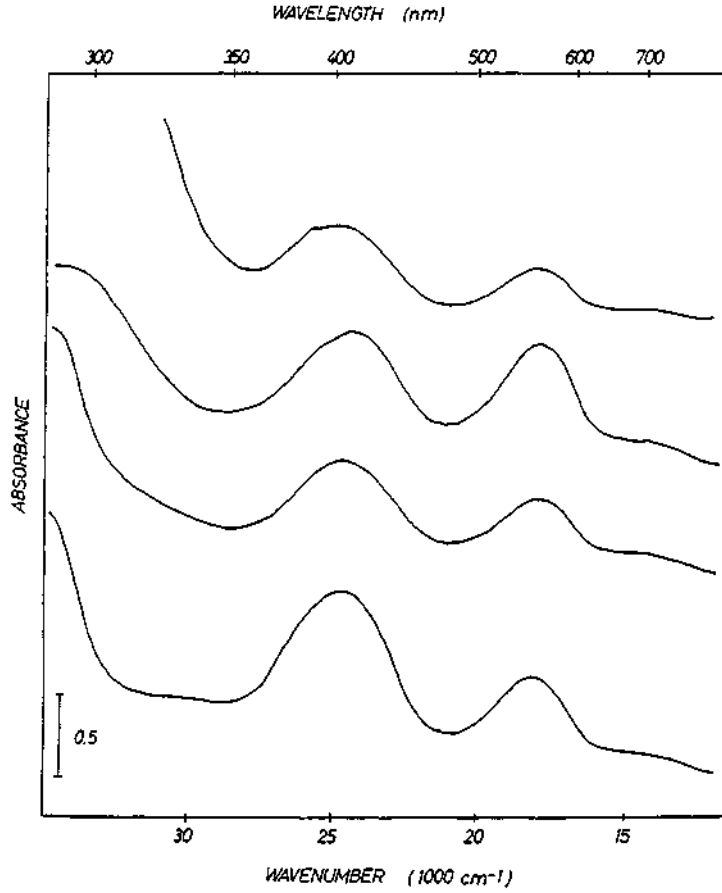

Fig. 3. Absorption spectra of Lechleitner synthetic rubies with natural seeds and synthetic overgrowth; the Cr^{3+} absorption bands have weak Fe^{2+}/Ti^{4+} intervalence absorption bands in the red area superimposed.

overgrowth of synthetic ruby (Figure 4). Obviously, pre-shaped or cut samples as well as roundish or irregularly shaped seeds were used by Lechleitner (Figures 4-9). In some cases it is evident that very light or even colourless corundum seeds were selected by the producer (Figures 6-8). If irregularly formed seeds are used for the process, the contact zone between natural seed and synthetic overgrowth (Figure 8) resembles swirl-like irregular growth structures in natural rubies from Burma or Sri Lanka, which are known to gemmologists as 'treacle'. Similar growth structures with irregularly shaped seeds are also known to the authors from the first generation of Knischka synthetic rubies.

The natural seeds used by Lechleitner display various forms of structural properties and inclusions, which are common for rubies and sapphires from Sri Lanka: intercalated lamellae of corundum in twin position (Figure 10), families of straight parallel growth planes that form an angle (Figure 11), irregularly shaped and rounded cavities as well as negative crystals (Figure 12), rounded mineral inclusions (Figure 13), rutile needles or 'silk' (Figure 2), tabular mineral inclusions surrounded by liquid feathers (Figure 14), as well as partly healed fissures with liquid and two-phase inclusions (Figure 15). In unhealed cracks within the seed, residues of the flux material are incidentally observed (Figure 16), which are induced during the period of crystal growth by the flux method.

In the synthetic overgrowth of Lechleitner synthetic rubies, various forms of flux residues are included (Figures 6-9, 17, 18). Doubly refracting crystals are occasionally observed at the boundary between natural seed and synthetic overgrowth (Figures 13, 19). According to investigations of

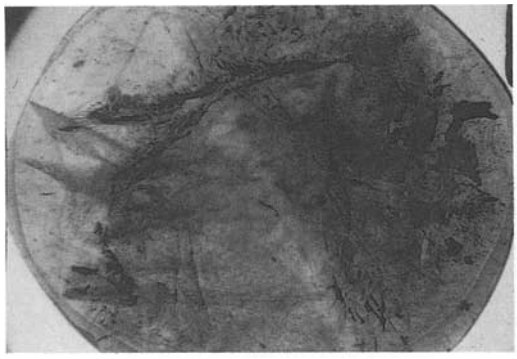

Fig. 4. Lechleitner synthetic ruby; rounded natural seed and all-around synthetic overgrowth. 26x.

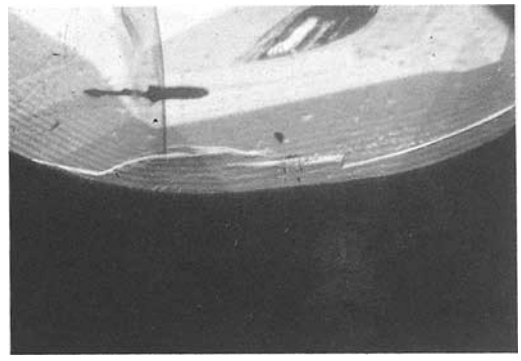

Fig. 5. Lechleitner synthetic ruby; contact zone between natural irregularly shaped seed and synthetic overgrowth. Crossed polars, 35x.

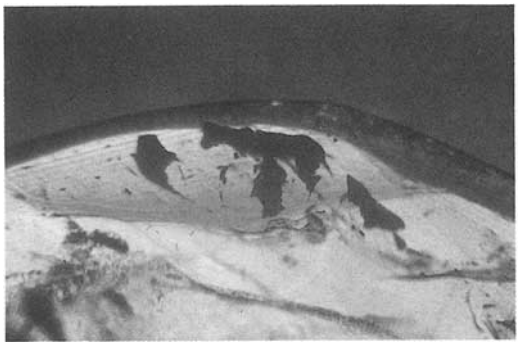

Fig. 6. Lechleitner synthetic ruby; contact zone between irregularly shaped natural seed and synthetic overgrowth resembling swirl-like irregular growth structures ('treacle') in natural ruby; flux residues are trapped in the overgrowth. Crossed polars, 45x.

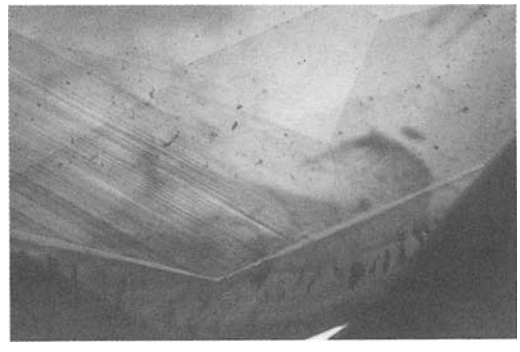

Fig. 7. Lechleitner synthetic ruby; contact zone between pre-shaped or faceted natural seed and synthetic overgrowth. 25x.

Fig. 8. Lechleitner synthetic ruby; contact zone between pre-shaped or faceted natural seed and synthetic overgrowth; flux residues are trapped in the synthetic overgrowth. Crossed polars, 45x.

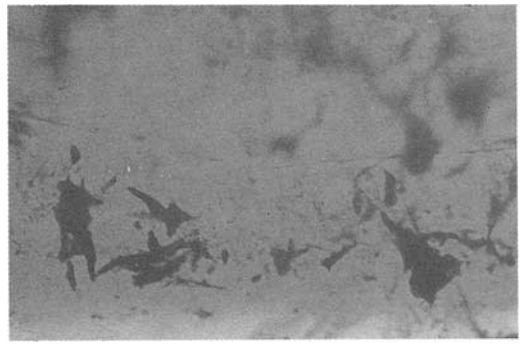

Fig. 9. Lechleitner synthetic ruby; contact zone between pre-shaped or faceted natural seed and synthetic overgrowth; flux residues are trapped in the synthetic overgrowth. 65x.

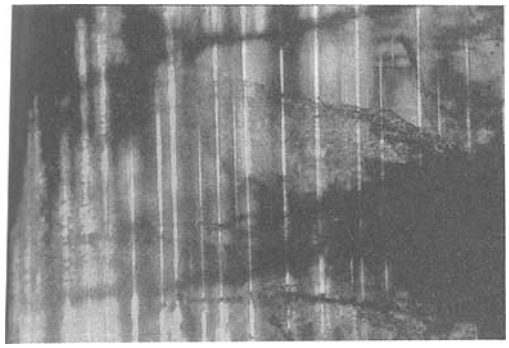

Fig. 10. Lechleitner synthetic ruby; natural seed with intercalated lamellae of corundum in twin position on r $(10\bar{1}1)$. Crossed polars, 50x.

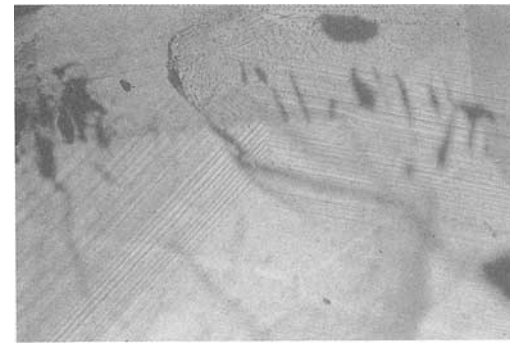

Fig. 11. Lechleitner synthetic ruby; natural seed with families of straight parallel growth planes parallel to w $\{11\bar{2}1\}$ that form an angle of 124°; flux residues in the synthetic overgrowth. 40x.

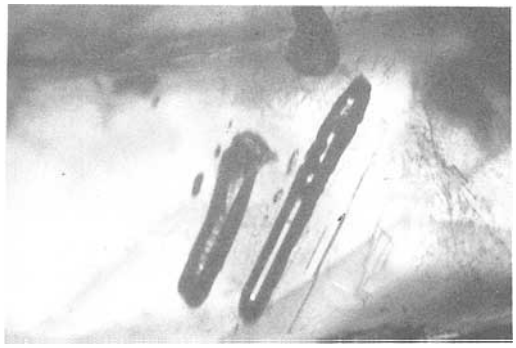

Fig. 12. Lechleitner synthetic ruby; natural seed with negative crystals. 60x.

Fig. 13. Lechleitner synthetic ruby; natural seed with rounded doubly refracting mineral inclusion (centre); doubly refracting crystals (most probably corundum) confined to the contact zone between natural seed and synthetic overgrowth (left). Crossed polars, 35x.

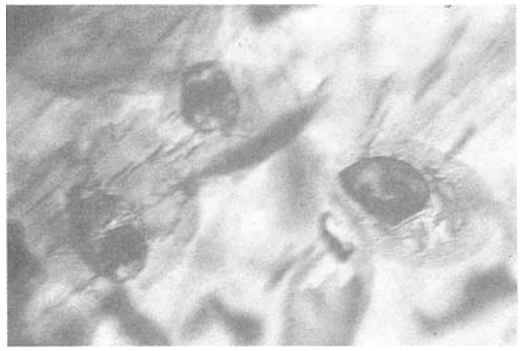

Fig. 14. Lechleitner synthetic ruby; natural seed with platy mineral inclusions (most probably mica) surrounded by liquid feathers. 85x.

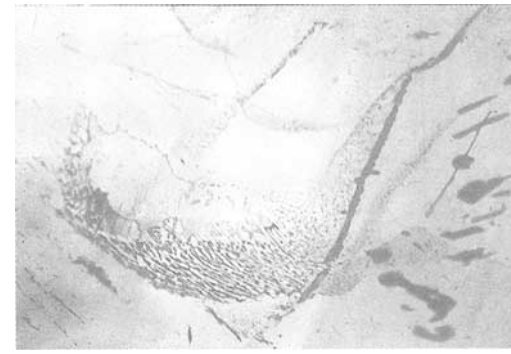

Fig. 15. Lechleitner synthetic ruby; natural seed containing healed fissures with liquid and two-phase inclusions (centre); synthetic overgrowth with residues of the flux (right). 40x.

Fig. 16. Lechleitner synthetic ruby; natural seed with induced flux material. 55x.

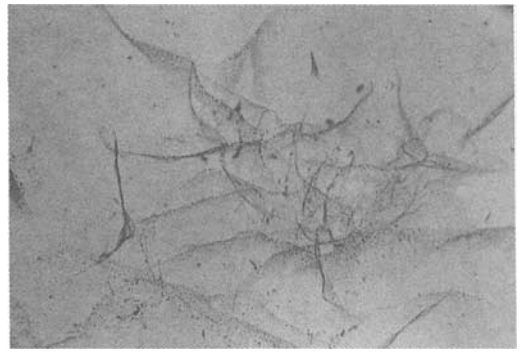

Fig. 17. Lechleitner synthetic ruby; synthetic overgrowth with residues of the flux. 45x.

Fig. 18. Lechleitner synthetic ruby; synthetic overgrowth with residues of the flux. 60x.

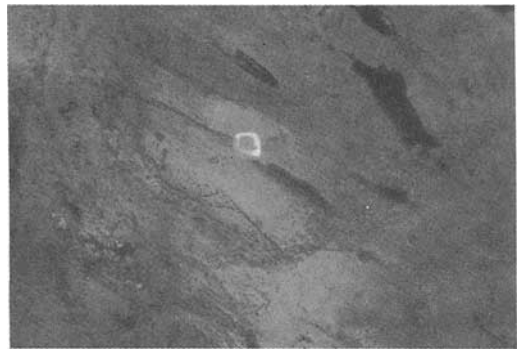

Fig. 19. Lechleitner synthetic ruby; doubly refracting crystal (most probably corundum) confined to the boundary between natural seed and synthetic overgrowth. Crossed polars, 75x.

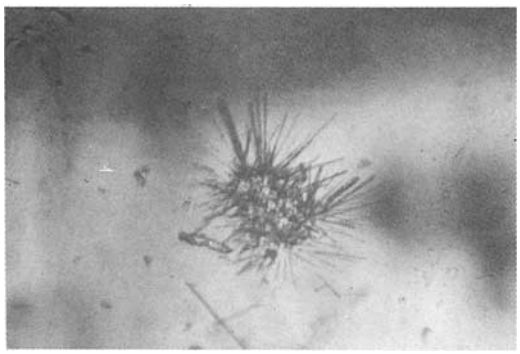

Fig. 20. Lechleitner synthetic ruby; synthetic overgrowth with needle-like inclusions. 100x.

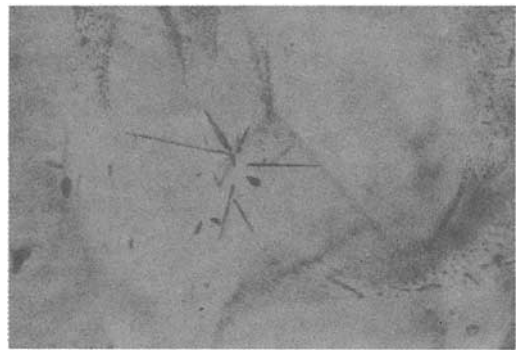

Fig. 21. Lechleitner synthetic ruby; synthetic overgrowth with needle-like inclusions. 95x.

Chatham synthetic rubies as well as Knischka synthetic rubies (Schmetzer, 1986a), similar inclusions which are also confined to the boundaries between subsequent growth zones were identified as corundum formed by spontaneous nucleation. This explanation is also applied to the identical type of inclusion in Lechleitner synthetic rubies. A new form of needle-like inclusion, which was not observed before in Lechleitner synthetic rubies containing Verneuil seeds, is pictured in Figures 20 and 21. At present, the composition of these needles is unknown.

Conclusions

The new type of Lechleitner synthetic ruby consists of natural seeds of light coloured or colourless corundum, which are coated by a thin layer of synthetic flux-grown ruby. Due to the fact that natural inclusions are present in the seeds of the stones, a careful investigation of the synthetic overgrowth and the contact zone between natural and synthetic corundum has to be performed in order to determine the samples unequivocally. The investigation of trace elements, i.e. the chemical determination of residues of the flux by electron microprobe or X-ray fluorescence analysis as well as spectroscopic investigations are helpful in identification procedures.

Acknowledgement

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Colour-changing chromiferous tourmalines from East Africa

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East Africa is well known as a producer of various coloured tourmalines of gem quality. Occurrences of elbaite (Voi, Kenya), dravite (Osarara, Kenya) and uvite (Magadi, Kenya; Moshi and Gerevi Hills, Tanzania) are mentioned by Dietrich (1985). Furthermore red (Bank, 1974), light-brown, yellow, green (Bank, 1975) and golden-yellow (Hänni *et al.*, 1981) as well as red dravite (Dunn, *et al.*, 1975) from Kenya are described in gemmological literature.

Occurrences of green tourmalines in East Africa are commercially important. Three groups can be distinguished by their type of coloration:

1. vanadiferous green tourmalines from Gerevi Hills, Tanzania (Bassett, 1953; McKie, 1955; Webster, 1961);
2. chromiferous green tourmalines (Bank and Berdesinski, 1967; Crowningshield, 1967/1968); and
3. vanadium-chromium-tourmalines from Umba Valley, Tanzania (Zwaan, 1974).

Most of the green tourmalines from East Africa were described as vanadium-coloured members of solid-solution-series between dravite and uvite (Schmetzer and Bank, 1977)

dravite $Na\,Mg_3\,Al_6$ $[(OH,F)(OH)_3(BO_3)_3\,Si_6O_{18}]$
uvite $Ca\,Mg_3\,(Al_5Mg)$ $[(OH,F)(OH)_3(BO_3)_3\,Si_6O_{18}]$

formed by replacement of sodium and aluminium by calcium and magnesium.

Schmetzer (1978) mentioned green vanadiferous and chromiferrous dravites from Tanzania (Gerevi Hills, Umba Valley) and Kenya (Kwale District, Tsavo Park, Lualenyi) as well as uvite from Landanai, Tanzania. Bluish-green dravites from East Africa are described by Dunn (1978).

In a large number of green tourmalines from East Africa (probably from Lelatema, Tanzania) one of the authors (H.B.) has found some stones showing a distinct change of colour from green in daylight to brownish-red or red in artificial light.

This special optical effect, found in gemstones like alexandrite, garnet, corundum, spinel, zircon, fluorite, kyanite and diaspore, has, to the authors' knowledge, never before been described in tourmalines.

The colour-changing tourmalines from East Africa show the following gemmological properties:

$n_o = 1.644 - 1.645$
$n_e = 1.622 - 1.623$
$\Delta n = -0.022$
$D = 3.04 - 3.06\ g/cm^3$

pleochroism: brownish-green or yellowish-green to emerald-green

For chemical analyses with an electron microprobe (Cameca microbeam) two samples of 5.41 and 1.73 ct were selected:

	sample 1	sample 2
	5.41 ct	1.73 ct
SiO_2	35.29	34.87
Al_2O_3	33.57	31.73
MgO	11.13	11.40
CaO	1.95	2.63
Na_2O	1.53	1.39
Cr_2O_3	0.36	0.64
V_2O_3	0.04	0.06
TiO_2	0.18	0.48
total	84.07	83.20

Data in wt.−%

The results of chemical investigations proved the samples to be chromiferous dravite-uvite mixed crystals with slight excess of uvite. The uvite portions amount to 55 and 65% respectively. The vanadium contents are low but in the range of detection limit of the microprobe.

Spectroscopical studies yielded typical absorption spectra of chromiferous minerals. Absorption bands caused by Cr^{3+} possess maxima at 606 and 450 nm.

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[*Manuscript received 14 January 1988*]

A note on the Barkhausen effect

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Minster's technique of using the Barkhausen effect to identify synthetic diamonds[1] is a very ingenious approach. The ferromagnetic nickel inclusions causing this effect are, of course, derived from the solvent used in diamond synthesis[2]. It should be noted, however, that the literature shows that it is possible to synthesize diamond by using non-ferromagnetic solvents such as platinum[2] which would then give a false negative result. In addition, one might obtain a false positive result from the reaction of a natural diamond containing ferromagnetic inclusions such as magnetite[3]. Accordingly, great caution must be used in interpreting the results of a Barkhausen-effect test.

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Crystalline and organic

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Talking to a mixed audience of retail jewellers and gemmologists recently on the history of pearls, I found myself explaining that, for the major part of my laboratory career, I had concentrated upon coloured stones in jewellery. I considered myself fortunate to have what I then considered the most interesting aspect of practical gem testing in a trade laboratory. Despite my concentration upon coloured stones, it was inevitable that some pearl lore penetrated. Our purpose-built X-ray generating set was constantly in use for pearls, YAGs, diamonds, green grossulars, Vernueil synthetics and so on.

During the holiday periods I did a certain amount of X-ray pearl testing so that, despite my emphasis that I was a coloured stone man, I did in fact know something about pearls.

Following the retirement and death of colleagues, it was inevitable that the important section of laboratory work, pearl testing, should continue, and I became the 'pearl man' at the laboratory. Having now embraced the pearl testing side of the laboratory's activities I found that I was achieving a name and some expertise in this particular discipline. I enjoyed watching the details appear in the developing dish as the negatives yielded their exposure secrets. These were mostly shadowgraphs or radiographs. The lauegrams could be even more exciting. When a large suspect pearl weighing close to a hundred grains was sent for testing accompanied by a request for urgent treatment, tension mounted as the negatives showed a worrying 'halo' pattern.

Negative, yet an indication that I was dealing with a blending of two distinct components, just as surely as if they were as different as crystals and organics.

At the talk to the mixed audience I hoped to stimulate an interest in the history of pearls and an appreciation of the marvel of nature which the lowly pearl-bearing oyster achieves. The origin of pearls has been to a very considerable extent well defined. The 'grain of sand' theory is fast disappearing, in company with other die-hard phrases such as semi-precious.

What has always impressed me in the history of a pearl's arrival is the part played by the epithelial cells of the thin-skinned mantle which covers the soft viscera of the oyster. These cells produce a waterproof organic covering of conchiolin, which has an SG of 1.34. They then secrete the secondary layer of bio-mineralized calcite as a prismatic layer with an SG of 2.71. The inner lining of nacreous mother-of-pearl (aragonite) has an SG of 2.93.

This feat of producing both crystalline and organic materials of quite different specific gravities by the skin tissues of this lowly creature with no head, no brain, no eyes and very elementary nervous system, is truly a wonder of nature.

If by chance the oyster is invaded by a parasitical worm (cestode/trematode) it entombs in it a sac or cyst. It covers the skeletal remains with conchiolin which hardens to become the nucleus of a pearl. The subsequent overlapping layers which envelope the nucleus are platelets of rhombic aragonite in groups of three. These have a pseudo-hexagonal structure which, when penetrated by a beam of X-rays, yield the well-known six spot pattern seen in lauegrams of natural pearls.

As gemmologists we tend to think in terms of crystals and gemstones. I like to think that from 1925 when Basil Anderson was invited to investigate the problem of the new Japanese cultured pearl that here began the real assault and study of both crystalline and organic materials.

B.W. Anderson was brought up with a background of mineral and geological knowledge and a family link with the nitrate deposits of Chile. Nevertheless he was a man who appreciated organic products. Like other keen gardener/gemmologists he preferred food from soil unadulterated by chemicals, not even powdered apatite as a fertilizer! Having inherited B.W. Anderson's role in the laboratory I turned from crystalline gemstones to the first gems in gemmology, pearls. They are unique in requiring no aid from man, being ready furnished with beauty, rarity and 'orient'. They remain unique examples of a crystalline/organic homogenous gem.

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Another low cost accessory

The late J.R.H. Chisholm, MA, FGA

At the end of the recent article by Hugh Crawford, FCA (*Some low cost accessories*, J.Gemm., 1986, 20, 4, 240-1), the Editor expressed his willingness to receive descriptions of other inexpensive gem-testing accessories made by readers. Thirty-three years ago I described one such in a paper (Simple photomicrography, *J.Gemm.*, 1954, **IV**, 5, 217-23) illustrated by my then thirteen year old eldest son (now FRPS, but still an amateur), and two years before that I had described another inexpensive accessory (Live-box techniques, *J.Gemm.*, 1952, **III**, 7, 279-81), but it was not made by me and second-hand "live-boxes" are probably not obtainable so cheaply now as they were then.

The present article describes a piece of apparatus also made more than thirty years ago. As can be seen from the photographs (Figures 1 and 2) the ultraviolet light box is simply constructed of plywood (glued together). The object it is desired to illuminate is placed in the lower (open) half of the box, which is loosely lined with black velvet: the UV light bulb is in the upper half of the box underneath a bent sheet-aluminium reflector and the light passes from the upper to the lower half through a 2½ x 1⅛ inch opening: under this is fixed a holder into which a piece of Wood's glass can be slid. I fear that the UV light bulb and Wood's glass may not now be obtainable so cheaply as they were thirty years ago, but to make the rest of the apparatus should not even now cost many pennies.

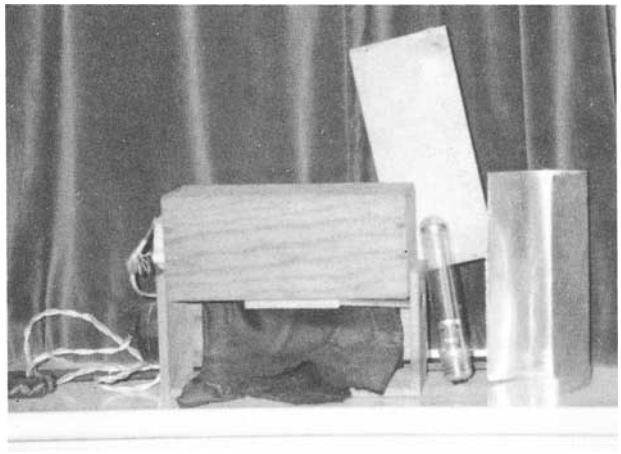

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Gemmological Abstracts

BALITSKI, V.S., BUBLIKOVA, T.M., SOROKINA, S.L., BALITSKAYA, L.V., SHTEINBERG, A.S., 1987. Man-made jewelry malachite. *Gems & Gemology*, **23**, 3, 152-7, 9 figs (3 in colour).

Silky, banded and bud-like [botryoidal] malachite is being made in the USSR by crystallization from aqueous solutions in sizes ranging upwards from 0.5kg. Vases up to 8kg, produced in Sverdlovsk, were exhibited in 1984. This material is an exact counterpart of natural malachite and can be detected, so far, only by thermal analysis – a destructive test. [Abstracter is puzzled that a mineral which is mined in great quantity to be smelted as an ore of copper should be worth synthesizing. The mineral is surely plentiful?] R.K.M.

BANK, H., HENN, U., BANK, F.H., 1987. A new alexandrite deposit in Brazil. *Goldschmiedezeitung*, 9, 91-2.

A find of alexandrite has been made at Era Nova, near Belo Horizonte, Minas Gerais, Brazil. Some stones show a colour change from green, blueish-green, blue or brownish-green to violet or red. RI is given as 1.741-1.745 and 1.751-1.755 with a DR of 0.007-0.010. The SG is 3.71-3.78. The deposit is reported to be secondary, the specimens being recovered from river gravel. M.O'D

BERNER, R.A., LANDIS, G.P., 1987. Chemical analysis of gaseous bubble inclusions in amber: the composition of ancient air. *American Journal of Science*, 757-62.

Gaseous inclusions in two separate samples of amber from the Dominican Republic were analyzed by quadrupole mass spectrometry. It is concluded that the inclusions represent ancient air modified by the partial reaction of O_2 with amber to produce CO_2, by the addition of small amounts of hydrogen gas and hydrocarbons from amber decomposition and, in the case of the Dominican amber, the addition of excess argon during burial in sediments. This effect was not shown in control samples of Baltic amber. It is suggested from the data that Eocene and Oligocene atmospheres were not appreciably different from those of today as far as N_2,O_2 and Ar are concerned. M.O'D.

BROWN, G., 1987. Spodumene. *Wahroongai News*, **21**, 4, 25–7, 3 figs.

A compilation from authoritative sources of facts on this interesting gem species, including the new deep violet–blue variety from Afghanistan. [RIs are incorrectly summarized as 1.66–1.75, gamma reading should be 1.675.] R.K.M.

BROWN, G., 1987. Jade and opal news from South Australia. *Wahroongai News*, **21**, 4, 28, 1 map.

Estimated 60,000 tonnes of nephrite, including a rare black variety, considered recoverable at Cowell, SA.

New opal finds at Zorba and Halley's Comet mines in Coober Pedy area are shown roughly, and none too readably, on a sketch map. Brief news of productive areas at Mintabie and Andamooka from *Mineral Industry Quarterly (S. Australia)* No. 43. R.K.M.

BROWN, G., 1987. Iolite. *Wahroongai News*, **21**, 5, 20–3. 6 figs.

Facts on iolite or cordierite, a gem blessed with more names than most, from several authorities. R.K.M.

BROWN, G., 1987. Taaffeite – an update. *Wahroongai News*, **21**, 5, 25–7.

Facts of this rare gem, discovered in 1945 by Count Taaffe of Dublin, and the confusion between the original rather erroneous micro–chemical analysis and the more accurate electron–probe assessment by Karl Schmetzer in 1983, thanks to which the 'new' gem, taprobanite, is now identified as a red form of taaffeite. R.K.M.

BROWN, G., 1987. Rhodochrosite. *Wahroongai News*, **21**, 5, 16–19, 5 figs.

Facts on another ornamental gem species culled from half a dozen reputable sources. Usually massive, it cuts handsomely as pink and white cabochons, but scalenohedra and rhombohhedra are found which will facet, allowing for softness (4) and three directions of perfect cleavage. [The ordinary ray (1.812) is above the range of the refractometer and the extraordinary ray (here

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quoted as 1.60) can appear disconcertingly as a single reading at any point between 1.60 and the top of the scale, depending on the direction tested.] R.K.M.

BROWN, G., 1987. Fluorite. *Wahroongai News*, **21**, 12, 22-5, 5 sketched figures.

A good account of this common but beautiful mineral which is the no. 4 standard for Mohs' hardness and too soft for convenient use in jewellery. It is best known in the form of massive purple/white Blue John, which comes from Derbyshire. Rare gem qualities in other colours are cut for collectors. [Green massive material is often used for carved figures in China. A drawing of interpenetrant cubes has shading suggesting diagonal striation which does not occur in this mineral. Vicinal striation does occur, but approximates to cube edge directions.] R.K.M.

BROWN, G., 1987. Gem enstatites. *Wahroongai News*, **21**, 7, 23-5.

A rather complex compilation of facts from two authoritative sources. R.K.M.

BROWN, G., 1987. A new opalized fossil find. *Wahroongai News*, **21**, 12, 5.

The editor of WN quotes from Mineral Industrial Quarterly that an opalized part of a skeleton of a 3 metre long plesiosaur has been found near Coober Pedy. He speculates whether this invaluable scientific find will succumb to commercial considerations and end as calibrated opal cabochons? [A pity if it does!] R.K.M.

BROWN, G., KELLY, S.M.B., 1987. An interesting copal resin necklace. *Australian Gemmologist*, **16**, 7, 263-6, 7 figs in colour.

Various inclusions and other features seemed natural and suggested copal, but distant vision RI was approximately 1.60, instead of 1.54, and reactions to LUV and SUV light were not as expected. Possible explanations are offered, but doubt must remain. R.K.M.

BROWN, G., SNOW, J., 1987. Gemmological jottings. *Australian Gemmologist*, **16**, 7, 267-70, 12 figs in colour.

Deals with natural turquoise beads colour-enhanced by dyeing and waxing; a plastic imitation walrus tusk scrimshaw, proved by blebs of plastic left in recesses; a Japanese synthetic opal which did not readily show 'lizard skin' or 'chicken wire' colour patches, or the columnar structure seen in Gilson type stones; imitation gold coral found to be a plastic-coated mixture of golden, 'thorny' coral and colourless plastic, with included bubbles; a thermal diamond probe, the Diamond Beam (batteries or mains), which identified diamond efficiently (beep and red light) while simulants give no response, but are not identified. R.K.M.

BROWN G., SNOW, J., 1987. Gemmological study club reports. *Australian Gemmologist*, **16**, 8, 287-92, 18 figs in colour.

Describes a white opal triplet; a bog oak cameo; unusually translucent turquoise; a plastic imitation ivory brooch; coated plastic imitation pearls and a Biwa cultured pearl necklace. R.K.M.

BROWN, G., SNOW, J., LAMB, J., 1987. A new treatment for turquoise. *Australian Gemmologist*, **16**, 8, 307-9, 6 figs in colour.

Paraffin wax treatment for porous turquoise has been known for a long time although not much seems to have been written about it. This paper describes further deception by painting on black 'matrix veins' with a mixture of wax and Indian ink, which can be scraped off. R.K.M.

CAMPBELL, I.I.C., 1987. Four stones of interest. *South African Gemmologist*, **2**, 4, 3–5, 4 figs in colour.

Four stones recently examined and illustrated are two simulations of emerald, a Zambian emerald with interesting inclusions and a tanzanite with unusual surface features. M.O'D.

CASSEDANNE, J.P., SAUER, D.A., 1987. La topaze impériale. (Imperial topaz.) *Revue de Gemmologie*, 91, 2–9, 16 figs in colour.

Occurrences of fine quality topaz in the Brazilian state of Minas Gerais are described. M.O'D.

CLUNAS, C., 1987. Jade carvers and their customers in Ming China. *Transactions of the Oriental Ceramic Society*, **50**, 69– 85, 7 figs.

A study of textual material not long known in the West has provided new light on the work of the jade carver in the Ming period, 1368–1644 and on the people who commissioned work from him. No references have been found to the tactile importance so often ascribed to jade – that seems to have been a later fashion – but visual effects are clearly of great importance. M.O'D.

FALLICK, A.E., JOCELYN, J., DONNELLY, T., GUY, M., BEHAN, C., 1985. Origin of agates in volcanic rocks from Scotland. *Nature*, **313**, 6004, 672–4, 2 figs.

Isotope ratios, $^{18}O^{16}O$ of silica and D/H of bound water are presented for agates from Lower Devonian lavas. These ratios are distinct from those obtained from agates from Tertiary lavas but the

two ratios are linearly correlated and plot along a single line approximately parallel to the line defined by present–day meteoric waters. The data suggest that bound waters associated with the agates have preserved their hydrogen isotope ratios since agate deposition: this supports arguments that the water content is of genetic significance.

M.O'D.

FENNER, C., 1987. Blackfellow's buttons. *Wahroongai News*, **21**, 6, 6–7.

Abstracted from *Mostly Australian*, a book published in 1945, this deals with the black glass tektites found in southern and western Australia, and makes a case for their origin having been a single meteoric shower. R.K.M.

FRITSCH, E., MISIOROWSKI, E.B., 1987. The history and gemology of Queen conch 'pearls'. *Gems & Gemology*, **23**, 4, 208-21, 15 figs in colour.

An excellent and well illustrated paper on this infrequently encountered rare 'pearl'. Although usually below 10 carats in weight, they have occasionally been found up to 45 carats. Apart from colour the most valuable feature is the so-called 'flame' structure seen beneath the surface of the best 'pearls' which are found in the Queen conch, *Strombus gigas*, which is now a protected species so supplies are diminishing. 'Conch' is correctly pronounced 'konk' [despite the fact that most people seem to use the soft 'ch' ending]. They are non-nacreous and should not be regarded as true pearls, hence the quotes used for 'pearl'. Colour ranges from deep to pale pink, through brown and yellow to white, with a regrettable tendency for the pinks to fade on prolonged exposure to strong sunlight. A broad absorption around 500nm indicates an organic colour, so fading should be no great surprise. SG averages at 2.85, higher than for coral (2.65) which can be confused with conch 'pearl'. This paper deals only with the *S. gigas* 'pearls', although there are other univalves known as conchs which, with other pink shells, may produce pink or other coloured 'pearls'. R.K.M.

FRITSCH, E., ROSSMAN, G.R., 1987. An update on color in gems. Part 1: introduction and colors caused by dispersed metal ions. *Gems & Gemology*, **23**, 3, 126-39. 15 figs in colour.

This first of three parts explains a difficult subject in reasonably simple terms. Quantum mechanics are mentioned but not explained. Colour is different according to the nature of the colorant ion, its valency, and the composition of the host mineral. The co-ordination with 4, 6, or 8 neighbouring atoms also affects it. Differences in these factors in various crystal directions are among the causes of pleochroism. R.K.M.

FRYER, C.W., ED., CROWNINGSHIELD, R., HURWIT, K.N., KANE, R.E., 1987. Gem Trade Lab notes. *Gems & Gemology*, **23**, 3, 164-8, 12 figs in colour.

Alexandrite from a new find in Minas Gerais, colour change similar to fine Russian stones, properties consistent with published figures, some cat's-eyes seen, illustrated in *Gems & Gemology*, **23**, 2. A 2.67ct green marquise diamond had small darker green areas and was highly radioactive, suggesting recent exposure to radium and that the stone could be a health hazard. An intense yellow, treated diamond showed strong Cape absorption; fluorescence in chalky greenish-yellow; chilled in liquid N, the stone showed 594nm line strongly proving radiation treatment; probably a natural Cape treated to increase the colour.

Spectacular triple link 'Imperial' jadeite earrings proved natural in colour; unusual quality to use in such a wasteful design. X-rays proved silver nitrate used to colour black cultured pearl necklace; natural blacks fluoresce under LUV, these were inert. A large button-shaped pearl had a diamond watch inset into its back; question whether this was a blister pearl or a whole pearl not resolved.

A scenic quartz from Massachusetts, with a three dimensional 'picture' caused by jasper-like inclusions is illustrated. A deep orangeish-yellow, heat-treated sapphire is described and illustrated.

An extremely rare cat's-eye sillimanite (fibrolite) was almost black in colour, with RI 1.66-1.68; these can be nearly colourless, violet, grey or this dark form. An unusual brownish-grey taaffeite of 0.61ct was examined by the Los Angeles laboratory, RI 1.720-1.726 [high birefringence?]. A green cat's-eye chrome tourmaline from Umba River, Tanzania, gave a strong red through the Chelsea filter. Most items illustrated. R.K.M.

FRYER, C., ED., CROWNINGSHIELD, R., HURWIT, K.N., KANE, R.E., 1987. Gem Trade Lab notes. *Gems & Gemology*, **23**, 4, 232-7, 13 figs in colour.

A modified brilliant faceted amber is described as unusual; another amber was shown to be composite, pieces of broken (amber?) beads held in a plastic matrix. 'Riverstone' beads, neither coral nor marble, were shown to be calcium carbonate. Corundum doublets were found in two important, bezel-set cluster rings, synthetic ruby and sapphire pavilions with natural sapphire crowns. Red fluorescence of synthetic emeralds to LUV is discussed and a specimen in which flux inclusions fluoresced yellow is illustrated; yellow fluorescing oil suggests an oiled natural emerald, but some synthetic emeralds are known to have been oiled.

Dyed quartzite beads simulated mottled jadeite; another dyed quartzite necklace resembled fine

green jadeite. A natural black Tahitian cultured pearl (20 x 18mm) was the largest seen by that Lab. Another calcareous, non-nacreous, concretion was from a 'thorny oyster' and had 'flame' structure as seen in clam and conch shells. A very large drop cultured pearl with a 12mm pre-drilled centre was proved to be of freshwater origin by its strong X-ray fluorescence. Heat treated natural rubies showed shallow spall cavities where material had 'blistered' off in treatment, some filled with a glass-like substance, one had acquired a spot of gold probably during setting. Synthetic rubies are not often heat-treated but some may be quench cracked to imitate fractures in natural stones, unusually these may spall and show other signs of the treatment apart from cracking [which does not require very high temperatures].

A new feature is added to this edition of Lab notes, quoting abstracts from items 25, 15 and 5 years ago. R.K.M.

GRAZIANI, G., GÜBELIN, E., MARTINI, M., 1987. The Lennix synthetic emerald. *Gems & Gemology*, **23**, 3, 140-7, 10 figs in colour.

Grown by flux-fusion at atmospheric pressure, the crystals are described as short hexagonal prisms with predominant basal pinacoids. [The one illustrated, and all those seen earlier by abstracter, were octagonal and provided excellent preforms for emerald-cut stones. So far no one seems to have queried this unnatural shape for a hexagonal crystal, or offered any explanation of how it was achieved.] RIs vary slightly around 1.559 for *e* and 1.562 for *w*; birefringence 0.003 to 0.004, darker areas had the higher values; SG about 2.66; absorption similar to that of natural emerald plus 477nm in the *c* direction; good red through Chelsea filter. Inclusions plentiful, wisp-like veils, irregular opaque flux often with peripheral 'frames' of included crystals, tubes or rods parallel to the *c* axis, colour zones due to growth stages, included phenakite, etc. Superficial resemblance to poor quality, heavily-included natural emerald can cause problems. Veils and wisp-like inclusions are diagnostic. R.K.M.

GÜBELIN, E., 1987. Diagnose des nouvelles synthéses d'émeraude. (Diagnosis of new syntheses of emerald. *Revue de Gemmologie*, 92, 5–7, 11 figs in colour.

Features of the Lennix synthetic emerald are described and illustrated (the first of a set of papers). M.O'D.

GÜBELIN, E., 1987. Diagnose des nouvelles synthèses d'émeraude. 2nd part. (Diagnosis of new synthetic emeralds.) *Revue de Gemmologie*, 93, 7-11, 19 figs in colour.

Emeralds of artificial origin are discussed. Those illustrated are the Biron and two Soviet products, one flux-grown, the other hydrothermal. M.O'D.

GÜBELIN, E.J., 1987. The genesis of mineral inclusions in gemstones. *Gem Bulletinen, Stockholms Gemmologiska Förening*, 2, 1–28, 31 figs.

A chapter from the author's book *Photoatlas of inclusions in gemstones** is reproduced. M.O'D.

GÜBELIN, E., 1988. Lightning Ridge. *Lapis*, **13**, 2, 15-30. 37 figs (34 in colour.

A beautifully illustrated and exhaustive account of the classic Australian opal field at Lightning Ridge in New South Wales. M.O'D.

HÄNNI, H.A., SCHWARZ, D., FISCHER, M., 1987. Die Smaragde der Belmont–Mine bei Itabira, Minas Gerais, Brasilien: Vorkommen und Charakteristika. (The emeralds of the Belmont Mine near Itabira, Minas Gerais, Brazil: their occurrence and characteristics.) *Zeitschrift der Deutschen Gemmologischen Gesellschaft*, **36**, 1/2, 33–49, 22 figs (3 in colour), 4 tables, bibl.

An English version of this article was published in the *Journal of Gemmology*, 1987, **20**, 7/8, 446–56. E.S.

HOCHLEITNER, R., WEISE, C., 1987. Die Himalaya Mine dei Mesa Grande in Kalifornien. (The Himalaya Mine near Mesa Grande in California.) *Lapis*, **12**, 10, 11-32, 20 figs (12 in colour).

The Himalaya mine in southern California is now once more producing fine quality pink and multi-coloured tourmaline crystals. Details of the history of the mine are given. M.O'D.

HUGHES, R.W., 1987. The plastic coating of gems. *Australian Gemmologist*, **16**, 7, 259-61, 9 figs in colour.

Among cheap stones from Burma were faceted quartz, colourless star corundum, and pale jadeite coated with red or green plastic to imitate much more valuable gems. Magnification revealed peeling of plastic, gas bubbles, swirls of colour, etc. R.K.M.

KANE, R.E., 1987. Inamori synthetic cat's-eye alexandrite. *Gems & Gemology*, **23**, 3, 158-62, 5 figs in colour.

Kyocera Corporation has produced the first commercial cat's-eye alexandrite. History of chrysoberyl synthesis is outlined. This cat's-eye is probably from a Czochralski pulled crystal. Broad eye of moderate intensity, greyish-green in daylight, dark purplish-red in incandescent light, slightly oily dullness, otherwise apparently clean. Faint

*Reviewed in *Journal of Gemmology*, 1987, **20**, 5, 312–3.

six-ray star seen down eye-streak direction, this does not occur in the natural stone. Microscope showed vague rippled striations parallel to the long axis of the stone. Natural cat's-eyes contain ultra-fine growth tubes or needles quite different from anything seen in these synthetics. R.K.M.

KELLY, M.B., 1987. Notes from the Lab. *Wahroongai News*, **21**, 3, 13, 1 fig.

An antique gold mounted suite was set with foil-backed yellowish-green and green cabochons which were identified as prehnite – possibly imitating chrysoprase. R.K.M.

KELLY, R., 1987. The art and skill of the lapidary: cabochon cutting. *Wahroongai News*, **21** : (a) part 1, 2, 18– 19; (b) part 2, 3, 10–11; (c) part 3, 5, 17–19.

(a) The first paper of the series. (b) Advice on selection of rough. (c) Selecting the best equipment for cabbing. Some sound advice from a very expert cutter. R.K.M.

KELLY, R., 1987. Facets. *Wahroongai News*, **21**, 6, 10–11.

Brief but sensible advice on this subject. R.K.M.

KEMP, J., 1987. Jade. *Wahroongai News*, **21**, 8, 15-20, 1 fig.

An interesting paper which deals with nephrite and jadeite and with a long list of imitants. R.K.M.

KOIVULA, J.I., 1987. Gem news. *Gems& Gemology*, **23**, 3, 172-6, 8 figs in colour.

A heavily cracked and included diamond had apparently been filled to minimize cracks. Reportedly treated in Israel by high temperature and pressure, with a secret filler; a number of such stones have been seen. A 64.83 ct pear-shaped diamond auctioned by Christie, Manson & Woods in New York is illustrated. No price quoted.

An iridescent andradite cabochon was bought in Hong Kong as black opal; colour play is in zones which echo the original rhomb-dodecahedron; a 44.59ct example is illustrated; this new gemmological material is thought to come from Sonora, Mexico; iridescent garnet was known before, but this seems to be an outstanding example. Emeralds impregnated with plastic have been found by a Japanese laboratory; more durable than oiling, the unknown plastic can still penetrate only where cracks reach the surface of the stone. Kunzite from a new source in Sri Lanka is reported. 'Rainbow moonstones' from India have been identified, by Dr Hänni of Basel, as labradorite feldspars. Orangeish-brown quartz cat's-eyes from Belo Horizonte, Minas Gerais, show exceptionally fine chatoyancy, sometimes with a hint of asterism.

Quartz with included marcasite, pyrite, chalcopyrite, silver and gold, from Zacatecas, Mexico, is being cut as beads and sold as solvernite. A new ruby locality in Afghanistan is reported. Mr Bleck says that Sri Lankan rubies are being heated in an open fire to drive off blue over-tones; and that some cat's-eye zircons have had the eye induced by melting feldspar onto the rough back of the zircon cabochon. R.K.M.

KOIVULA, J.I., Ed., 1987. Gem news. *Gems & Gemology*, **23**, 4, 238-42, 6 figs in colour.

Diamonds from a kimberlite pipe are reported from Mato Grosso, the first such mine in Brazil. A rare and complex diamond Mohs-Rose twin is illustrated. The 64.83 ct diamond described in Gem news (*Gems & Gemology*, **23**, 3) fetched US$6,380,000 at Christie's.

Itabira mine, Minas Gerais, is producing an impressive quantity of fine alexandrites when not interrupted by strife among the local miners. 'Siberian' amethyst has been found at Rainbow Lode mine at Red Feathers Lakes, Colorado, some in gem quality. Adularescence in amethyst from Artigas, Uraguay, has been called the 'Lowell' effect after its discoverer. H.S. Pienaar has introduced the 'Stellenbosch Index', or SGI, as a new method of teaching the basics of gemmology. A star sapphire also had colour change from blue to blueish-purple in incandescent light. Natural strontium titanate has been found in Mongolia. Thaumasite, a complex hexagonal compound of hydrated calcium silico-carbide and sulphur was found, in a South African shipment of minerals, in gem quality, but a hardness of 3.5 makes it unsuitable for jewellery. A pocket of gem topaz has been found at Conway, New Hampshire.

We are warned that short-wave UV filters can deteriorate with time and become opaque. Newest short UV lamps have 'life-time' filters. Efficiency can be checked with scheelite, benitoite or [hopefully] 'even a small synthetic yellow Ib diamond'.

R.K.M.

KOIVULA, J.I., 1987. Goethite inclusion alteration during heat conversion of amethyst to citrine. *Australian Gemmologist*, **16**, 7, 271-2, 2 figs in colour.

Heating amethyst to 350°C changed golden goethite inclusions to brown/red hematite with some fracturing of the host quartz due to release of water. Such hematite pseudomorphs plus fracturing indicate heat treatment. R.K.M.

KOIVULA, J.I., 1987. Pronounced flow structure in Australian opal. *Australian Gemmologist*, **16**, 7, 257-8, 1 fig. in colour.

A boulder opal showed clear evidence of flow

structure with curved layering of colour-play areas. The phenomenon is not uncommon, but is rarely as obvious as this. R.K.M.

KOIVULA, J.I., 1987. Pyrite in Canadian ammonite. *Australian Gemmologist*, **16**, 8, 304-7, 4 figs in colour.

Pyrite is sometimes the replacing mineral in these beautiful fossils [cf Dorset Lias, England]. The author describes it in ammonites from Alberta, Canada, and has taken the trouble to prove the mineral chemically. The Canadian fossils are protected by law, so complete fossils may not be used for jewellery, although broken ones can be so used. R.K.M.

LOOCK, G.W., 1987. Chrysoberyll aus Orissa, Indien. (Chrysoberyl from Orissa, India.) *Lapis*, **12**, 12, 11-15, 14 figs (8 in colour).

Fine crystals of chrysoberyl, mostly twinned, are found at a number of mines in the State of Orissa, India. Well-formed trillings are fairly common and other minerals of ornamental interest include amethyst, zircon and topaz. M.O'D.

NASSAU, K., 1987. Irradiated gemstones – could the ice be hot? *Lapidary Journal*, **41**, 5, 41–6, 3 figs (1 in colour).

The possibilities of gemstones retaining latent radioactivity after treatment to alter or enhance colour are discussed. Actual amounts of radiation so far observed are minimal but care needs to be taken with some topaz, spodumene and diamond. M.O'D.

NASSAU, K., VALENTE, G.K., 1987. The seven types of yellow sapphire and their stability to light. *Gems & Gemology*, **23**, 4, 222-31, 8 figs in colour.

Deals in detail with (1) light stable natural yellows; (2) natural or irradiated yellows with fading colour centre; (3 & 4) iron-containing unheated and heated yellows which are stable; (5) yellows obtained by surface diffused Fe or Ni – stable; (6) synthetic yellows – stable; (7) irradiated synthetics – unstable. Unexpectedly natural yellows can fade when heated to less than 200°C, but colour can be restored by exposure to light. R.K.M.

NIEDERMAYR, G., 1986. Bleiberg, Carinthia, Austria. *Mineralogical Record*, **17**, 6, 355–69, 33 figs (12 in colour).

Bleiberg is one of Europe's classic locations for lead and its minerals. The gemmologist, however, will be most interested in the occurrence of lumachelle, first described in 1793. This material, whose play of colour comes from fossil shell fragments, is found in the argillaceous Raibler beds which overlie the Wetterstein complex. M.O'D.

OBENAUER, K., 1987. Uber Merkmale des Quellens und Schwindens bei der Chalcedon– Bildung. (On the role of swelling and contraction in chalcedony formation.) *Aufschluss*, **38**, 247–52, 5 figs (1 in colour).

Details of the formation of chalcedony are given with especial reference to the way in which growth allows the material to expand and contract. M.O'D.

O'DONOGHUE, M., 1987. Gems and gemmology. *Watchmaker, Jeweller & Silversmith*, September 1987, 51–3.

Chief attention is paid to amber, jet and their simulants; there are also notes on synthetic jadeite and synthetic ruby, a substitute for lapis lazuli and details of interesting specimens on display at the 1987 Tucson gem and mineral fair. At the fair it was reported that tsavolite had virtually disappeared from the market and that chatoyant kornerupine was being offered as chatoyant quartz.

(Author's abstract.) M.O'D.

O'DONOGHUE, M., 1987. Adelstenar som Försvinner i Natten. (Gemstones that pass in the night.) *GME Bulletinen, Stockholm Gemmologiska Förening*, 1987/1, 12–13.

A brief description of manganoan sugilite is given.

(Author's abstract.) M.O'D.

OLLIVER, J.G., 1987. A review of jade in South Australia. *Australian Gemmologist*, **16**, 8, 283-6, 9 figs, 6 in colour.

This deals with Cowell nephrite deposits. Geology; estimated potential of this 6 × 3km area are discussed optimistically. R.K.M

READ, P.G., 1987. Birth of a science. *British Jeweller*, June 1987, 74–7, 90, 5 figs in colour.

To coincide with the hundredth anniversary of the *British Jeweller*, this article traces the development of the science of gemmology over the last 100 years in terms of the personalities of the period, the emergence of gem test instruments, newly discovered gem species and the evolving techniques of gemstone synthesis and identification.

(Author's abstract) P.G.R.

ROBERT, D., 1987. A propos d'une analyse d'émeraude synthétique. (Concerning an analysis of a synthetic emerald.) *Revue de Gemmologie*, 93, 12.

Further notes on the Lennix emerald are given to supplement the points made by Gübelin in his

paper in *Revue de Gemmologie*, 92. M.O'D.

ROUGHGEMS LTD., 1987. Charoite. *Wahroongai News*, **21**, 12, 29.

An account of this rare, one locality, attractively grained violet-purple hydrated calcium-potassium-silicate metasomatic rock. A beautiful addition to the ornamental materials list which could be more widely exploited. R.K.M.

RUNDLE, F.A., 1987. Colour grading coloured stones. *Wahroongai News*, **21**, 7, 2-8.

An excellent review of the problems and difficulties of this subject, and of two American colorimetric methods of defining colour: the GIA ColorMaster and the American Gemological Laboratories' Color Scan Charts. R.K.M.

RUSKONE, E., 1987. La taille des pierres de couleur. (The cutting of coloured stones.) *Revue de Gemmologie*, 92, 15.

The first part of a paper on the cutting of coloured stones. The history of the process is introduced. M.O'D.

RUSKONE, E., 1987. La taille des pierres de couleur, 2nd part. (The cutting of coloured stones.) *Revue de Gemmologie*, 93, 13-17, 4 figs in colour.

General discussion of the history and techniques employed by the lapidary. M.O'D.

SCHÄFER, W., 1987. Himmlische Tränen. (Heavenly tears.) *Schmuck und Uhren:* 10, 35-8; 11, 36-8, 7 figs (1 in colour).

A description of the emerald mines of Colombia. M.O'D.

SCHMETZER, K., HENN, U., 1987. Synthetic or imitation? An investigation of the products of Kyocera Corporation that show play-of-color. *Gems & Gemology*, **23**, 3, 148-51, 3 figs in colour.

Investigates whether these are synthetic opal or opal simulants. Authors found that they contained no water and therefore do not match natural opal. They propose they should be called simulants and not synthetics. R.K.M.

SHIGLEY, J.E., FRITSCH, E., STOCKTON, C.E., KOIVULA, J.I., FRYER, C.W., KANE, R.E., HARGETT, D.R., WELCH, C.W., 1987. The gemological properties of De Beers gem-quality synthetic diamonds. *Gems & Gemology*, **23**, 4, 187-206, 23 figs in colour.

With so many eminent authors this has to be an important paper.

GIA Research Department examined 14 synthetic type 1b diamonds grown by De Beers, 8 crystals up to 5.23 ct and 6 faceted stones up to 0.90 ct. The paper is the first report on these in gemmological literature.

Colours range from dark brownish-yellow, through bright yellow to greenish-yellow, grown in a multi-metal melt which is both flux and catalyst. De Beers say that no faceted stones have been marketed, nor do they intend doing so. Growth experiments have been directed entirely towards high technological needs. However, some Sumitomo synthetic diamonds have appeared on the open market so identification has considerable significance.

Gemmologically the De Beers diamonds can be detected as synthetic by short-wave fluorescence, which is yellow in the brownish and greenish stones, with slight phosphorescence in the latter; by absence of absorption lines expected in natural yellow stones; by geometric zoning of colour and of internal graining; by clouds of minute white inclusions which fog some of the darker stones; by some larger inclusions of flux metal; and by crystal surface defects, which may be found as naturals on cut stones, which are specific to the synthetics. Infrared spectra indicate that the synthetics are all type 1b, rare in natural yellow diamonds, which are usually type 1a.

The authors are confident that synthetic diamonds of this type can be detected with ease, but express some reservations whether diamonds with lower nitrogen content, e.g. the more difficult colourless stones, should they ever be made on a commercial scale, would be detectable. [It seems only fair to emphasize that production of synthetic diamonds in cuttable gem quality does seem still to be a very expensive undertaking, possibly justified only for use in vastly important scientific applications. To date that seems to be the object of these exercises.] R.K.M.

SNOW, J., 1987. Care and use of gemmological instruments. *Wahroongai News*, **21** : (a) 2, 10–11; (b) polariscope, 3, 9–11; (c) the figure–o–scope, 4, 14–15, 3 figs; (d) the refractometer, 5, 14–15; (e) the microscope, 6, 10–11.

(a) Logically, Mr Snow starts with the eye, for without this natural organ gemmology could hardly exist. He then gives sound advice on the use of the hand lens. (b) Sound, basic instruction on the polariscope and good advice. (c) An Australian version of the conoscope, similar to the polariscope but using oblique light to give interference figures. Line drawings do not convey the expected figures too well. (d) More very sound advice, this time on the refractometer, from an expert gemmologist. (e) Brief but sensible advice on the microscope. R.K.M.

SNOW, J., 1987. The Chelsea filter. *Wahroongai News*, **21**, 8, 8.

A short account of this well-known gemmological aid. The author says that natural emeralds appear pink or *green* through the filter. [In my experience emeralds which do not show pink give an ash-grey residual colour, not green, despite what textbooks may say. Any 'emerald' appearing green through the filter is not an emerald!] R.K.M.

SNOW, J., 1987. Helpful hints with practical work. *Wahroongai News*, **21**, 9, 26-7.

Logical approach to testing three different stones with further suggestions for such problems. All good sound advice. R.K.M.

SNOW, J., 1987. The Kerez effect. *Wahroongai News*, **21**, 12, 15-18.

A full account of a multiple RI effect seen in certain tourmalines, which the abstracter reported in 1967 and named after the friend who had first noticed it. Others have written about it since and are quoted here. Suggestions are made for a possible further investigation, including attempts to reproduce the effect by controlled heating of tourmalines. [The dark green tourmalines exhibiting this multiplicity of readings are rare, possibly from a unique locality, and it is perhaps unwise to assume that heat, however applied, will necessarily give rise to the effect in any suitably coloured tourmaline.] R.K.M.

SNOW, J., BROWN, G., 1987. LWUV fluorescence of gemstones: a photographic review. *Australian Gemmologist*, **16**, 8, 269-300, 16 figs in colour.

About 100 gems were grouped by species with their imitants and photographed in white fluorescent light and then in long-wave UV light. The resultant pairs of slides are often informative – possibly of the variability of fluorescent colour, which may be responsible for the often differing descriptions of the phenomenon in various tests. R.K.M.

STEIN, I., 1987. Opal triplets. *Wahroongai News*, **21**, 8, 21-2.

An account which suggests that moulded glass tops (frangible!) are largely being used in place of quartz in making these cheap versions of opal. R.K.M.

STEIN, I., 1987. Opal triplets, cutting by hand. *Wahroongai News*, **21**, 9, 15-17, 4 figs.

Advice on cutting and assembly. R.K.M.

STEIN, I., 1987. Machine cutting of opal triplets. *Wahroongai News*, **21**, 10, 17-18, 5 figs.

Describes the Bilki saw which has 120 close-set blades vibrating 1400 times a minute, producing opal slices about 0.25mm thick. The ultra-thin blades are charged with silicon carbide grit and wear very rapidly. Basically this is an update of the primitive mud-saw. [The line diagrams would be more readily understood if annotations could be typed instead of scribbled freehand!] R.K.M.

SUNAGAWA, I., 1986. Morphology of diamonds. *Morphology and Phase Equilibria of Minerals*, Sofia: IMA Vol. 2, 195–207.

Observations on morphology and surface microtopography of diamond crystals of three different origins are summarized and the observations are critically analysed in the light of present understanding of the growth mechanisms and morphology of crystals. The three types of diamond are: (1) natural diamond, including both single–crystals and polycrystalline aggregates. Both ultramafic suites (in kimberlite) and eclogite suites are discussed. All natural diamonds are grown from the solution phase of silicate compositions under diamond stable conditions; (2) synthetic diamond grown by static high P under diamond stable conditions. They are grown from metal–carbon solution phases; (3) synthetic diamond grown by pyrolysis or chemical vapour deposition processes of CH_4 or C_2H_2 under $P < 1$ atm. and high T conditions. They are grown under diamond unstable conditions from the vapour phase. Analysis of growth rates *vs* chemical potential provides information concerning the mutual relations among polycrystalline aggregates, dendritic, hopper and polyhedral crystals. Analysis of morphological characteristics of single crystalline diamonds and their surface microtopographs are based on the extent to which their morphologies deviate from the theoretical morphology. J.M.H.

THEMELIS, T., 1987. Diamonds from Venezuela. *Lapidary Journal*, **41**, 4, 59–69, 5 figs (1 in colour).

Maps and descriptions are given for Venezuelan diamond. M.O'D.

THEMELIS, T., 1987. Burmese taaffeite. *Lapidary Journal*, **41**, 5, 19, 2 figs in colour.

Among the inclusions noted are red crystals, perhaps of spinel; various parallel acicular crystals of unknown species and fingerprint or feather–like droplets resembling those in Burmese blue sapphire. Colourless transparent hexagonal crystals with a slightly rounded outline were noted in another specimen. M.O'D.

THEMELIS, T., 1987. Girasol effect. *Lapidary Jour-*

nal, **41**, 6, 19, 2 figs in colour.

A particular colour effect seen in some Mexican opal is described. M.O'D.

THROWER, C., STEANE, D., 1987. Notes on Tasmanian gemstones. *Australian Gemmologist*, **16**, 6, 223–4.

Large very dark sapphires from Weld River area were too flawed and twinned for heat treatment to lighten colour. Upper Gordon River stones also strongly twinned with some asterism. No gem quality. Colours light blue to black.

Fragments of alexandrite found with sapphires at Weld River, some with chatoyancy.

Low quality turquoise found at Back Greek, at Beaconsfield and on north–west coast, usually as thin veins in slate, porous with white soft patches.

R.K.M.

TILLANDER, H., 1987. Diamantschliff im 17.Jahrhundert. (Diamond cutting in the seventeenth century.) *Jahrbuch der Kunsthistoriken Sammlungen in Wien*, 81, 169-84, 191 figs.

The essay describes the development of diamond cuts in the 17th century. Cuts developed during the period include the Taille en Seize, V-cut and the Hybrid half-rose cut. The rose cut itself is also discussed. M.O'D.

TRT'IYAKOVA, L.I., BENAVIDES, K.S., 1987. (Mineralogical and spectral colorimetric studies of emeralds from Chivor and Muzo deposits, Colombia.) *Zapiski Vses. Min. Obshch.*, **116**, 6, 713-18. (Russian with English abstract.)

A series of emeralds from the Chivor and Muzo deposits has been studied and their chromatic characteristics established. Although there is some overlap, spectral differences are clearly seen between the emeralds from these two Colombian deposits. The chromophores are Cr+ and V+.

R.A.H.

WALKER, G.S., 1987. A new 'spot reading' technique for the refractometer. *Australian Gemmologist*, **16**, 7, 253-6, 2 figs.

For distant vision RI tests, suggests using a pinhole diaphragm held close to the eye and viewing from about 6cm instead of 30cm. Spot and scale are both in focus and more of the scale is seen. R.K.M.

WARD, F., 1987. Jade, stone of heaven. *National Geographic*, **172**, 3, 282–315, 37 figs in colour.

Attractively illustrated general overview of the jade minerals and methods of fashioning them.

M.O'D.

WILKS, E.M., WILKS, J., 1987. Cleavage surfaces of diamond. *Industrial Diamond Review*, **47**, 1, 17–20.

The (111) cleavage surfaces are generally smoother on the so–called Type II diamonds than on the much more common Type I diamonds. Such variations are due to the quite large variations of crystal structure arising from the presence of impurity atoms, and reflected in the irregular pattern of growth banding. R.A.H.

WILKS, E.M., WILKS, J., 1987. An unusual form of coated diamond. *Mineralogical Magazine*, **51**, 5, 743–6.

On polishing an (001) surface on a colourless dodeca hedral diamond of gem quality from Zaire, a marked step was observed between the central and outer regions. This distinction into core and coat was confirmed by X–ray topography and SEM techniques, and by differences in abrasion resistance and orientation of cleavage. These differences are ascribed to quite different growth conditions.

R.A.H.

Book Reviews

APOSTOLESCU, R., 1987. *Caleidoscop mineralogic.* (Mineral kaleidoscope.) Editura Technica, Bucuresti, pp.246, illus. in black–and–white and in colour. Lei 22.50. [In Rumanian.]

Depite the popular sound of the title, this is a serious mineralogical textbook with very valuable references to Romanian minerals and their localities. Gem quality minerals are described and illustrated in colour at the end of the book. There is a bibliography and a chapter with questions and answers. M.O'D.

BALFOUR, I., 1987. *Famous diamonds.* Collins, London, pp224, illus. in black-and-white and in colour. £15.00.

Based on a series of articles appearing in *Indiaqua*, this excellent book covers many of the best-known diamonds with illustrations and copious historical notes. There is a table to the world's largest stones, giving details of the stones and their whereabouts where known, a glossary and a useful bibliography. Although there are many accounts of celebrated diamonds extant, this one is carefully written and is based on records whose authenticity is sound. The price is most reasonable for so attractive and interesting a book. M.O'D.

BIRĂU, O., CIUHANDU, A., VANGHELI, D.A., 1986. *Safirul si rubinul.* (Sapphire and ruby.) Editura Facla, Timisoara, pp.170, illus. in black–and–white. Lei 19.50. [In Romanian.]

An exhaustive treatise on the ruby and sapphire varieties of corundum with particular reference to crystal structure as determined by X–rays. There is an excellent bibliography. M.O'D.

FIELD, L., 1987. *The Queen's jewels.* Weidenfeld and Nicolson, London, pp.192, illus. in black-and-white and in colour. £18.00.

More than one book has been assembled from photographs of the personal jewellery of Her Majesty the Queen but this is the most satisfactory one to appear so far. This book, too, includes a section on jewellery which is properly the property of the state as the crown jewels are also described.

The jewellery is described by stone so that there are sections on rubies, sapphires and diamonds, among others. Considerable historical material is provided and the photographs are of high quality. Many are themselves of historical interest as their subjects include personages of previous generations. This is a well-produced book and well worth the very reasonable price. There is an excellent bibliography. M.O'D.

HADDLETON, M.E., 1987. *The Jewellery Quarter history and guide.* YBA Publications, Birmingham, pp.39, illus. in colour. Gratis.

A most delightfully produced guide to the happily rejuvenated Jewellery Quarter of Birmingham. M.O'D.

HARTMAN-GOLDSMITH, J., 1986. *Chinese jade.* Oxford University Press, Hong Kong, pp. xvi, 81, illus. in black-and-white and in colour. £6.95.

Forming part of the series *Images of Asia*, this short book is of good quality, describing the main features of the use made of the jade minerals by the Chinese. Particular reference is made to the nature of the artefacts and there is a useful bibliography. M.O'D.

LUZZATTO-BILITZ, O., 1987. *Antique jade.* Cassell, London, pp.153, illus. in colour. £4.95.

Translated from *Antiche giade*, published in 1966, this is a good short guide to jade artefacts and is well illustrated. M.O'D.

MATTHES, S., 1987. *Mineralogie.* (Mineralogy.) Springer-Verlag, Berlin, pp. xvii, 444, illus. in black-and-white. DM69.00.

The second edition of a work first published in 1983, the text deals not only with the major mineral species but gives a detailed account of mineral formation and rock types. Thus it is in no sense a replacement of Dana's *Manual of mineralogy* but rather a text which guides the reader through a good deal of material found normally only in journals. The section describing minerals starts the book and the remainder of the text covers the three major rock types, their petrology and mineralogy.

Each section has its own bibliography and there are some useful crystal drawings as well as high-quality photographs. M.O'D.

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PIETRACAPRINA, A., BRIZZI, G., 1986. *La Sardegna e i suoi minerali.* (Sardinia and its minerals.) Editrice Mediterranea, Cagliari, pagination irregular, illus. in colour. Price on application.

Minerals from Sardinia are described in alphabetical order, each entry containing full details of the mineral concerned with notes on occurrences. Gem minerals include amethyst, fluorite and vesuvianite. Maps of important occurrences follow the descriptive section and then come notes on minerals and crystals in general, with a glossary. There is a short bibliography. The book is very well produced and particularly welcome. M.O'D.

SCHUBNEL, H.-J., 1987. *Pierres de lumiere et objets precieux.* (Shining stones and precious objects.) Editions Arthaud, Paris, pp.257, illus. in colour. F 495.00.

Though there are a number of books presenting fine jewelled artefacts with a general supporting text, this one is very well produced with many of the pictures new to publication. The book commences with a description of the use of gemstones in prehistory and among primitive societies, proceeding to the introduction of later objects from both East and West; particular attention is paid to the pieces emanating from Central America and this section also contains an account of gemstone carving. The remainder of the book discusses gemstones themselves with a useful note on gemstones in commerce. There is a short bibliography. M.O'D.

SPENCER, C., 1986. *Mineral wealth of Saudi Arabia.* Immel Publishing, London, pp.128, illus. in colour. £23.50.

Among the minerals with possible ornamental application found in Saudi Arabia are peridot, fluorite, selenite, gold, azurite, malachite, chrysocolla, tourmaline, garnet, amazonite and quartz. M.O'D.

SYCHOVA, N., 1984. *Traditional jewellery from Soviet Central Asia and Kazakhstan.* Sovetsky Khudozhnik, Moscow, pp.179, illus. in colour. Price on application.

This is a well-illustrated and printed book with a text in Russian and English. Coral and turquoise are widely used and many stones are set in silver. A wide variety of styles has been chosen to give the reader a good idea of the range used over the period described and there is a short bibliography, in Russian only. M.O'D.

SUNAGAWA, I., 1987. *Materials science of the earth's interior.* Terra Scientific Publishing Company, Tokyo, and D. Reidel Publishing Company, Dordrecht. pp. xv, 653. Illus. in black–and–white. Price on application.

This major work contains chapters on the mechanism of crystal growth and on the morphology of natural and synthetic diamond crystals. These chapters are followed by others on surface microtopographic and X–ray topographic study of octahedral crystal of natural diamond from Siberia and on synthesis researches of diamond. M.O'D.

Proceedings of the Gemmological Association of Great Britain and Association Notices

OBITUARY

Mr E.J. Burbage, FGA (D.1927 with Distinction), London, died on 18 January 1988, after a long illness. His collection of gemstones and minerals will remain on display at Haslemere Museum.

Mr Leslie F. Cole, FGA (D.1937 with Distinction), London, died on 6 December 1987 within a few days of his 81st birthday. A service was held at St Anthony's Church, Nunhead.

Fifty years ago Leslie Cole passed his examination in gemmology with distinction. It was a year when the list of successful candidates was almost entirely male and represented the coloured stone trade in many aspects of collectors, dealers and specialists. It was the era when Chelsea Polytechnic was the venue of trade gemmology, the classes were entitled 'Mineralogy for jewellers'. Leslie was acquainted with not only Chelsea Polytechnic but also with the Northern Polytechnic and Sir John Cass College. A close associate and friend of Robert Webster, he assisted at classes over a very long period and to within a year or so of his death.

He was also a member of the Council of the Gemmological Association for many years; one could say that Leslie Cole served the trade and gemmology for a lifetime. During the war years he served as a Special Constable in the war-torn capital. His retail experience included Wordleys the specialist shop in Birchin Lane in the City of London. His daughter has happy memories of accompanying her father on his Saturday morning clock winding tours of duty. After the closure of Wordleys he joined the old established jewellers Jay Richard Attenborough in Oxford Street. His last position was with Arthur Saunders of Southampton Row.

He will be remembered by generations of students of the London scene and by fellow Council members. His lifetime as a gemmologist spanned the vintage years of Anderson, Payne, Webster, Andrews and Wheeler, embracing the very gamut of gemmology. A.E.F.

Mr Xaver Saller, FGA (D.1960 with Distinction), died on 18 December 1987.

With the death of Xaver Saller gemmology has lost one of its brightest stars. Very knowledgeable, always helpful, his death is a sad loss to all those who knew and worked with him and to the industry as a whole. He is survived by his wife, Doris, and daughter Silvia.

Xaver Saller was a self-made man. He was born in Schmiedeweiden in Bavaria on 26 May 1904, lost his mother at the age of seven and his father at the age of twelve during the First World War. After leaving grammar school in Nürnberg, he went to the Technical Goldsmiths College in Pforzheim, and from then on worked in the jewellery trade. In 1951 under Professor Schlossmacher he took his German gemmological examinations and in 1960 he became an FGA. Xaver Saller was an Honorary President of the German Gemmological Association, and an honorary member of the Finnish and Japanese gemmological associations. He also contributed to various committees, including the nomenclature commission of CIBJO.

Together with his wife Doris he offered generous hospitality to his many friends. His house in Rottach/Egern is a delight. I am very saddened by the loss of an honourable man and good friend. E.S.

GIFTS TO THE ASSOCIATION

The Council of the Association is indebted to E.A. Thomson (Gems) Ltd, London, for the gift of two oval fluorolith cabochons.

NEWS OF FELLOWS

After 38 years with the Gemological Institute of America and the GIA Gem Trade Laboratory, Bert Krashes announced his retirement near the end of 1987. He will continue to serve on the Board of Governors of the GIA.

Bert Krashes was born in New York City on 23 April 1923. He is married to Charlotte Frankel and has three sons and a daughter.

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Mr Krashes was a bombardier in the United States Eighth Air Force during World War II. He became a prisoner of war, after being shot down and wounded over Europe. His formal education included the New York City public school system, New York University, and the Gemological Institute of America, from which he was graduated in 1949. Mr Krashes joined the staff of the GIA and the GIA Gem Trade Laboratory in 1949. He soon developed a reputation as an outstanding teacher, and became a much sought after speaker for the American Gem Society conclaves and for jewellers' groups all over the United States and Canada.

Bert Krashes.

In addition to earning his Graduate Gemologist diploma from the GIA, he also became a Certified Gemologist through the American Gem Society. In 1953 Krashes passed with Disinction the Diploma Examination of the Gemmological Association of Great Britain. In 1970 he was made an honorary vice president of the Gemmological Association of Canada. Together with his longtime colleague, Robert Crowningshield, Bert Krashes was honoured by the American Gem Society in 1983, by the presentation of its prestigious Robert M. Shipley award.

In his many years of dedicated service Bert Krashes searned the respect and admiration of those who had the opportunity to work with him. The diamond and jewellery industries have been enriched by his presence.

* * *

On 18 November 1987 Mr Michael O'Donoghue, MA, FGS, FGA, organized and chaired a British Library Seminar on Earth Science Information Sources.

On 5 March 1988 Mr O'Donoghue gave a lecture entitled 'Gemstones' to the Kent Group of the British Iris Society.

MEMBERS' MEETINGS

London

On 8 March 1988 at the Flett Theatre, Geological Museum, Exhibition Road, South Kensington, London SW7, Dr Margherita Superchi gave an illustrated lecture entitled 'The treasures of Milan Cathedral, the use of a pot-stone from Val Malenco and the alabaster of Volterra'. Dr Superchi's presentation was dedicated to the memory of Xaver Saller of Munich, West Germany, who died in 1987 (obituary p.117).

Midlands Branch

On 15 January 1988 at Dr Johnson House, Bull Street, Birmingham, Mr Alan Jobbins, FGA, gave an illustrated lecture entitled 'The gemstones of Brazil'.

On 19 February 1988 at Dr Johnson House Mr Alan Clark, FGA, of the Gem Testing Laboratory of Great Britain, gave an illustrated lecture entitled 'Future gemmology?'.

On 18 March 1988 at Dr Johnson House Mr D.J. Callaghan, FGA, Chairman of the Gemmological Association, gave an illustrated lecture entitled 'From gem to jewel'.

North West Branch

On 20 January 1988 at Church House, Hanover Street, Liverpool, Mr W. Stringer gave a talk entitled 'Diamonds'.

On 17 February 1988 at Church House Mr Jonathan Condrup of Sothebys gave a talk entitled 'Antique cameos'.

On 16 March 1988 at Church House Dr John Franks gave a talk on the Munich Gem Fair.

COUNCIL MEETING

At a meeting of the Council held on 18 February 1988 at the Royal Automobile Club, Pall Mall, London SW1, the business transacted included the election to membership of the following:

Fellowship

Aresti, Tony, London. 1987
Bernat, Marcos, Barcelona, Spain. 1987
Brennan, John D., Birmingham. 1969
Chiu, Man K.A., Kowloon, Hong Kong. 1987
Corduff, Rosalie P.T., Stoke-on-Trent. 1987
Dale, Ann F., Kenner, La., USA. 1987

Dalmau Bafalluy, Mo Nieves, Barcelona, Spain. 1987
Drukker-Loth, Julia J.M., Huizen, Netherlands. 1987
Dufficy, Margaret H., San Rafael, Ca., USA. 1987
Ferrer Coma, Montserrat, Barcelona, Spain. 1987
Filion, Marie M., Montreal, Que., Canada. 1987
Hakola, Arto K., Tornio, Finland. 1987
Lam, Jim M.K., Kowloon, Hong Kong. 1987
Marsh, Lesley F., Harare, Zimbabwe. 1987
Maupu, Francoise J., St Rambert en Bugey, France. 1987
Metaxas, George C., London. 1987
Minner, Loren M., Belen, New Mexico. 1987
Nakamori, Katsuyuki, Saitama-Ken, Japan. 1987
Offord, Nigel J., Chandlers Ford. 1987
Pitkanen, Marja-Leena A., Lahti, Finland. 1987
Roucouna, Catherine, Athens, Greece. 1987
Saminathan, Kannika, Ipoh, Malaysia. 1987
Scott, Doreen M., Liverpool. 1987
Silverman, Sivan J., Watertown, Ma., USA. 1987
Tang, Ho C.M.T., Hong Kong. 1987
Tapia Canadell, Laura, Barcelona, Spain. 1987
Thevathasan, Nuala A., Colombo, Sri Lanka. 1987
Wirman, Anna L., Saltsjo-Boo, Sweden. 1987
Zwack, Geraldine M., Bangkok, Thailand. 1987

Ordinary Membership
Admet, Alessandro, Milan, Italy.
Ahad, Sayed, Brentford.
Alfano, Angelo, London.
Andrews, Fern A., London.
Bassett, Marlene J., London.
Bignotti, Fabrizio, London.
Brink, Carl F., Crystal Falls, Mich., USA.
Cerrone, Mo., Hitchin.
Clark, Diane E., Letchworth.
Coote, George E., Sevenoaks.
Coulthard, Joan M., Windermere.
De Bevere, Dirk, Sutton.
De Michele, Vincenzo, Milan, Italy.
De Silva, Edirimuni J.B., Singapore.
Dryden, Kenneth E., Spalding.
Duprez, Bruno, Linselles, France.
Elliott, Lucy E.C., London.
Emden, Lee, High Wycombe.
Fong, Phoay H., Penang, Malaysia.
Foster, W. James, Arroyo Grande, Ca., USA
Gaston, Giuliani, Brasilia, Brazil.
Genis Sol, Eduard, Girona, Spain.
Gower, Sarah-Jane, Yiewsley.
Graham, Barry D., Glasgow.
Gullerud, Hanne, Nesoddtangen, Norway.
Hamblin, Frederick T., Brighton.
Hanna, David, Inverness.
Hirst, Jenny E., London.
Holmes, Irene V., Tadworth.
Hughes, Thomas H., Castro Valley, Ca., USA.
Ishikawa, Kyoko, Richmond.
Jain, Sanjay, London.
Jassinger, Alexandre I.J., Epsom.
Kwok, Suk Har, Hong Kong.
Kyriakidou, Katerina A., London.
Law, Patricia M., Cambridge.
Lipton, Lindsay, London.
Liyanage, D.C.S., Ashford Common.
McGowan, Marion, London.
Meade, Christopher, Cleckheaton.
Mussche, Eduard, Brussels, Belgium.
Newbould, Hans P.M., Surbiton.
Nunn, Robert A., Chesham.
Page, Steven, Hillingdon.
Parsons, Ann S., Kemsing.
Pattni, S., Southall.
Pedersen, Gunhild, Nattland, Norway.
Petty, Mary A., London.
Piyasirikul, Soonthorn, Bangkok, Thailand.
Pople, Cecilia, Godalming.
Roberts, Anne M., Crawley.
Sadler, Anthony, Loughton.
Schunko, Christian, Oslo, Norway.
Shukla, Manjot, London.
Sim, Evelyn, London.
Sinclair, Anne L.K., Haslemere.
Skrablin, Lada-Lucia, London.
Slater, Garth, Hallingbury.
Solheim, Jan, Bønes, Norway.
Soriano Clemente, Marta, Spain.
Sparks, Deborah A., Ruislip.
Speake, Michael H., Tadworth.
Spencer, Stephen R., Nottingham.
Suzuki, Yoshio, Tokyo, Japan.
Teixeira, Luis F.C., Woking.
Thurlow, Stephen N.G., Billingshurst.
Torrens, Robert M., Crieff.
Tsouji, Nao, Richmond.
Urvik, Hilde, Oslo, Norway.
Whitby, Victoria M., Hindhead.
Winblad, Cathrine, Stockholm, Sweden.
Wu, Mei, London.

MEETING OF OFFICERS

At a meeting of the Officers of the Association held on 1 March 1988 the following were elected to membership:

Fellowship
Gotoh, Takeshi, Amsterdam, Netherlands. 1977
Harding, Richard W., Solihull. 1984
Hash, Daniel W., Watrous, Sask., Canada. 1987

Ordinary Membership
Baxter, Graham S., Plymouth.
Bucy, Rodger, Ellicott City, Ma., USA.

Butler, David J., Malmo, Sweden.
Carter, Geoffrey J., Carshalton.
Crevoshay, George, Newton, Mass., USA.
Doran, Sean F., Liverpool.
Harris, Raymond H.L., London.
Misson, Gary P., Oxford.
Monachino, Melinda, San Francisco, Ca., USA.
Nootenboom, Apollonius, Kingsland.
Nyah, Koufie, London.
Ogden, Anne-Marie, Bristol.
Pender, Patricia, Southport.
Pyne, Anne M., Bristol.
Rana, Ghulam A., London.
Schwarz, Dietmar, Ouro Preto, Minas Gerais, Brazil.
Thevanayagam, Michael A.H.K., Washington.

CORRIGENDA

On p.49 above, first column, for 'Brillo, Douglas', read 'Brill, Douglas'.

On p.52 above, 2nd column, Katsuyuki Nakamori, Saitama-Ken, Japan, was omitted from the list of those who qualified in the Diploma section of the 1987 Examinations in Gemmology.

AMENDMENT TO PROGRAMME OF LONDON EVENING MEETINGS 1988

Would members please note that the meeting that was to have been held on Tuesday 24 May has been cancelled.

The October meeting at which Clive R. Burch will be giving a lecture entitled 'A review of inclusions in synthetic gemstones' will be held on **Monday 10 October 1988** and not on 11 October as notified in the January issue of *the Journal*.

Letter to the Editor

From James E. Shigley and Carol M. Stockton

Dear Sir,

The article 'Blue spinel from the Hunza valley, Pakistan' by R.R. Harding and F. Wall that was published in the July/October 1987 issue of *The Journal of Gemmology* includes a comparison of the spectra of these new blue spinels with that of a cobalt-containing one published in our article 'Cobalt-blue gem spinels' in the Spring 1984 issue of *Gems & Gemology*. Figure 2 of Messrs Harding and Wall's article clearly shows that their spectra and our do not correspond. However, this is because the spectrum from our 1984 article has a non-linear wavelength scale similar to that seen in a prism spectroscope. The spectra published in the 1984 article were obtained from an old single-beam spectrophotometer system that has since been superseded at GIA Research by a Pye-Unicam 8800 dual-beam instrument. Nevertheless, we must apologize for having neither explicitly stated that the scale in our 1984 article was non-linear nor having provided a better scale (simplified for lack of space, as we recall) in our original figure, although the non-linearity could be deduced by correlating labelled bands with those of the hand spectroscope images printed alongside.

In order to set the record straight, we are sending you linearly-scaled spectra (in absorption, this time) from the same four stones originally illustrated. We would be grateful if you could publish this letter and these four spectra in order to provide a better comparison for those obtained by Harding and Wall as well as for future gemmological researchers. As far as we can tell, under the circumstances, comparison of the spectra of the Hunza valley blue spinels with that (now comparable) of the type I cobalt-containing blue spinel from Sri Lanka reveals the presence of cobalt as a colouring agent as well as chromium and (possibly) titanium, as stated by Harding and Wall.

Yours etc.,
James E. Shigley and Carol M. Stockton

10 December 1987
GIA Research Department, Santa Monica, Ca., USA.

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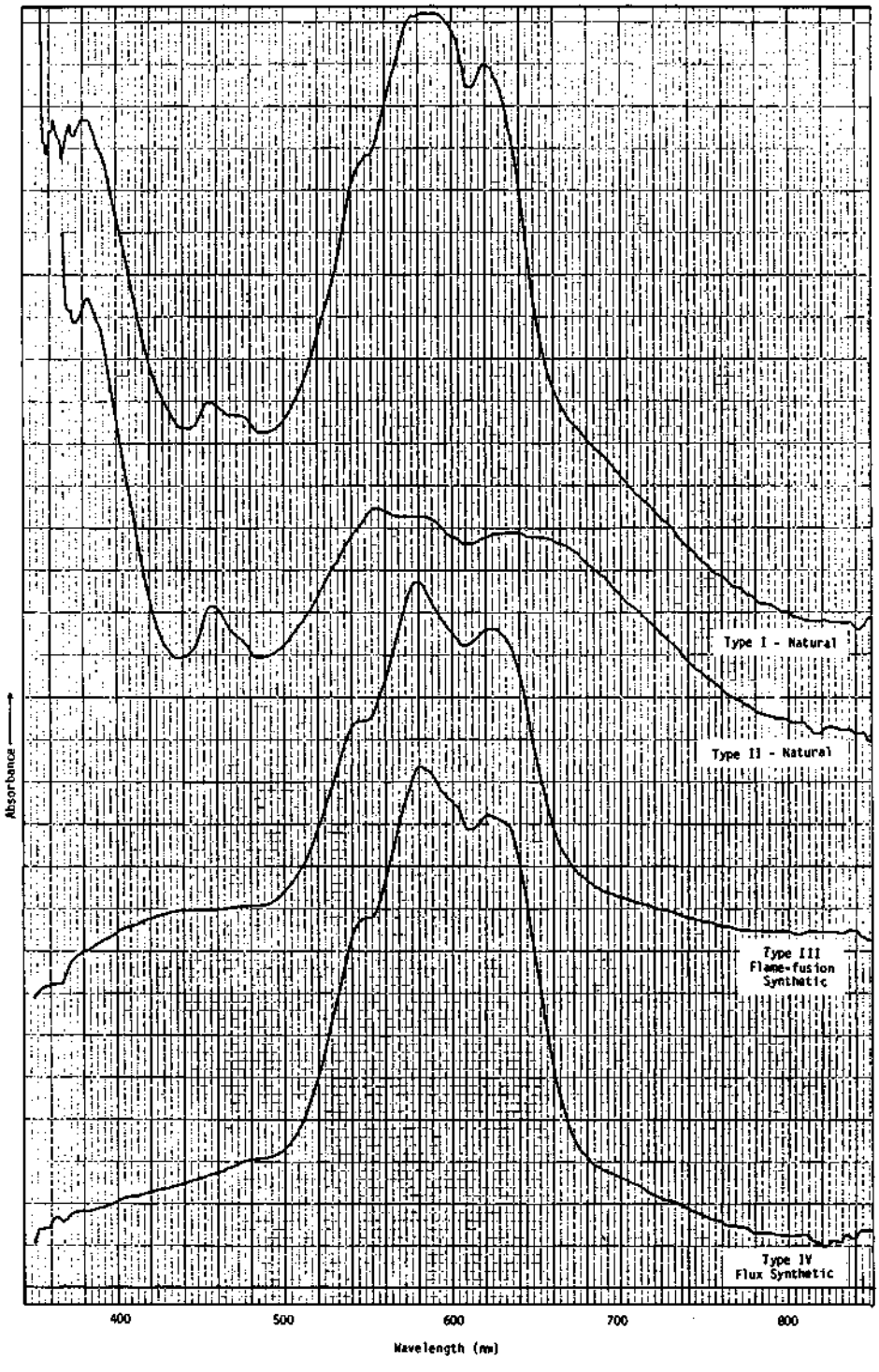

Absorption spectra of four blue spinels.

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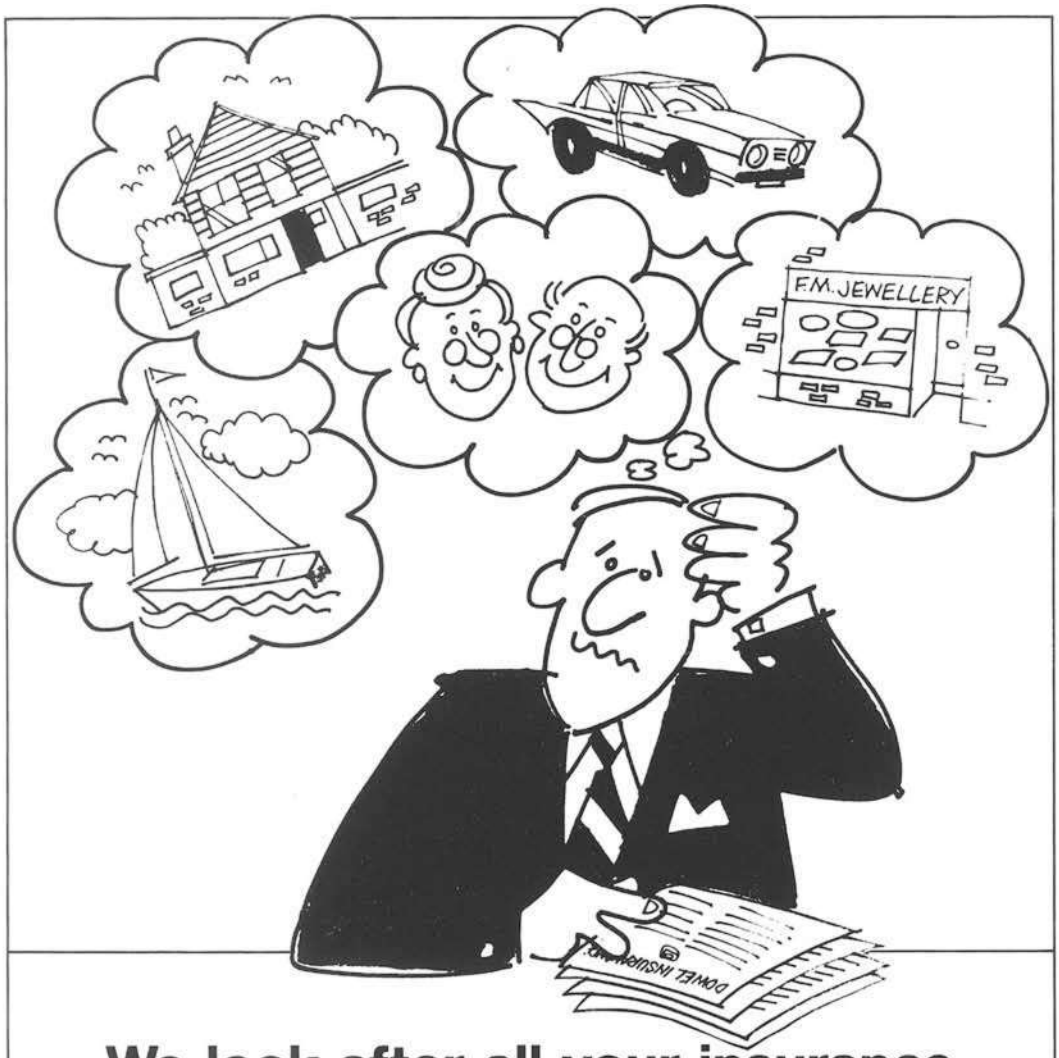

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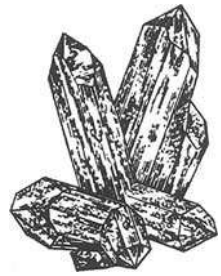

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ADVERTISING IN THE JOURNAL OF GEMMOLOGY

The Editors of the *Journal* invite advertisements from gemstone and mineral dealers, scientific instrument makers, publishers and others with interests in the gemmological, mineralogical, lapidary and jewellery fields.

Rates per insertion, excluding VAT, are as follows:

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Enquiries to Mrs M. Burland, Advertising Manager, Gemmological Association, Saint Dunstan's House, Carey Lane, London EC2V 8AB.

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Strasbourg	Smithsonian Institution	Royal Ontario Museum

A number of invited speakers will also take part in these sessions which will be followed by an open session. Poster displays are welcomed.

Registration will be £15 for members of the Mineralogical Society, otherwise £20.

Further details from:

Dr Paul Henderson, Mineralogy and Museums Conference, Department of Mineralogy, British Museum (Natural History), Cromwell Road, London SW7 5BD

AN EXCITING NEW OPPORTUNITY IN GEMMOLOGICAL EDUCATION

The Gemmological Association has launched a whole new programme of short practical courses in gremmology.

The courses have been designed for the Association by Ken Scarratt and will be held at the Gem Testing Laboratory in London. The aim is to give practical instruction and experience to students studying gemmology, particularly those preparing to take the FGA examination by home study, and updates specialized courses for all gemmologists.

Various types of one-day courses are being offered during 1988, the dates of which are:

19 and 20 May	**Practical diamond grading examination revision**
16 and 17 June	**Practical gem testing examination revision**
5 July	**Organic gem materials, including amber and pearls**
29 September	**Diamond grading**
27 October	**Jade, turquoise, lapis lazuli and their simulants**
24 November	**Ruby and sapphire**

The National Association of Goldsmiths are also arranging courses on practical gemstone knowledge at the Laboratory. **These are to be held on 13 May, 7 July and 7 October 1988.**

Each course is limited to 8 participants and is offered at the low charge of £55 plus VAT (including lunch). The courses are open to all students and members of the Association who would like to take a short refresher course.

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The Arms and Crest of the Association, conferred by a grant of Arms made by the Kings of Arms under royal authority. The cross is a variation of that in the Arms of the National Association of Goldsmiths of Great Britain and Ireland. In the middle is a gold jewelled book representing the study of gemmology and the examination work of the Association. Above it is a top plan of a rose-cut diamond inside a ring, suggesting the scrutiny of gems by magnification under a lens. The lozenges represent uncut octahedra and the gem-set ring indicates the use of gems in ornamentation. The lynx of the crest at the top was credited, in ancient times, with being able to see through opaque substances. He represents the lapidary and the student scrutinizing every aspect of gemmology. In the paws is one of the oldest heraldic emblems, an escarbuncle, to represent a very brilliant jewel, usually a ruby. The radiating arms suggest light diffused by the escarbuncle and their tips are shown as jewels representing the colours of the spectrum.

Historical Note

The Gemmological Association of Great Britain was originally founded in 1908 as the Education Committee of the National Association of Goldsmiths and reconstituted in 1931 as the Gemmological Association. Its name was extended to Gemmological Association of Great Britain in 1938, and finally in 1944 it was incorporated in that name under the Companies Acts as a company limited by guarantee (registered in England, no. 433063).

Affiliated Associations are the Gemmological Association of Australia, the Canadian Gemmological Association, the Gem and Mineral Society of Zimbabwe, the Gemmological Association of Hong Kong, the Gemmological Association of South Africa and the Singapore Gemologist Society.

The *Journal of Gemmology* was first published by the Association in 1947. It is a quarterly, published in January, April, July, and October each year, and is issued free to Fellows and Members of the Association. Opinions expressed by authors are not necessarily endorsed by the Association.

Notes for Contributors

The Editors are glad to consider original articles shedding new light on subjects of gemmological interest for publication in the *Journal*. Articles are not normally accepted which have already been published elsewhere in English, and an article is accepted only on the understanding that (1) full information as to any previous publication (whether in English or another language) has been given, (2) it is not under consideration for publication elsewhere and (3) it will not be published elsewhere without the consent of the Editors.

Papers should be submitted in duplicate on A4 paper. They should be typed with double line spacing with ample margins of at least 25mm all round. The title should be as brief as is consistent with clear indication of the content of the paper. It should be followed by the names (with initials) of the authors and by their addresses. A short abstract of 50–100 words should be provided. Papers may be of any length, but long papers of more than 10|000 words (unless capable of division into parts or of exceptional importance) are unlikely to be acceptable, whereas a short paper of 400–500 words may achieve early publication.

Twenty five copies of individual papers are provided on request free of charge; additional copies may be supplied, but they must be ordered at first proof stage or earlier.

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The Journal of Gemmology

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July 1988

The Journal of Gemmology

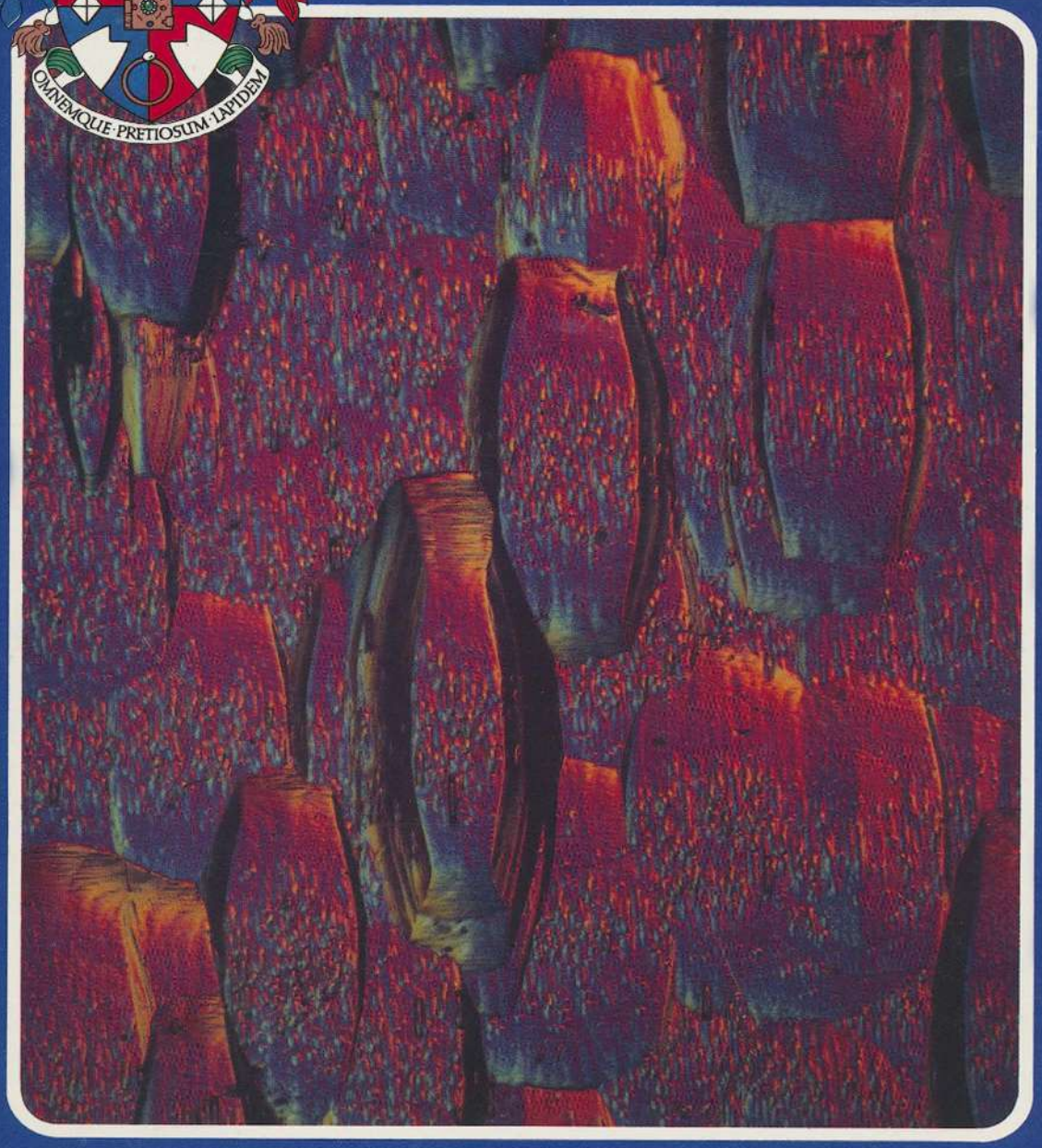

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Cover Picture

Boat-shaped etch figures on a first order prism face of a green beryl crystal from the Soviet Union. The *c*-axis runs in the long direction. Nomarski Differential Interference Contrast. 80x. (See 'Etch figures on beryl', p. 142.)
Photograph by John I. Koivula.

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Douglas Wheeler

It is with deep regret that we report the death on Saturday 7 May 1988 of Douglas Wheeler, former Assistant Secretary of the Gemmological Association of Great Britain and Deputy Secretary of the National Association of Goldsmiths.

Douglas was born on 15 May 1922 in East Ham, London, and joined the staff of the GA and NAG in 1936 at the age of 14. He served both associations continuously except for a period of five years in HM Forces. On his 19th birthday he volunteered for the RAF and after flying training in Canada saw active service in Europe. He was commissioned at 21. Douglas returned to civilian life in 1946 and rejoined the Associations, working alongside the late Gordon Andrews and his brother, the late Harry Wheeler, both of whom had also returned from the services.

He studied at Chelsea Polytechnic as an evening class student and became an FGA in 1948. He was appointed Assistant Secretary for the GA in 1973 and Deputy Secretary of the NAG in 1976.

Douglas retired from business in November 1983. He said at that time that he had greatly enjoyed his years with the two Associations and had been lucky in the people he had met and worked with. He looked forward to a new life of retirement in Norfolk.

He leaves his wife, Kathleen, two sons, Michael and Stephen and grandchildren.

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Notes from the Laboratory – 12

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The Lennix synthetic emerald, an update

Farn first described the Lennix synthetic emerald in 1980 (Farn, 1980) following a gift in 1979 of a number of sample crystals to the Laboratory. Little has been seen of this synthetic in the market since Farn's first report, however, last year a further gift of three crystals was made to the Laboratory by Szemes Attila of *Enterprise Française de Fabrication D'emeraude de Culture* (Figure 1) and another description (Graziani, *et al.*, 1987) was published in *Gems & Gemology*.

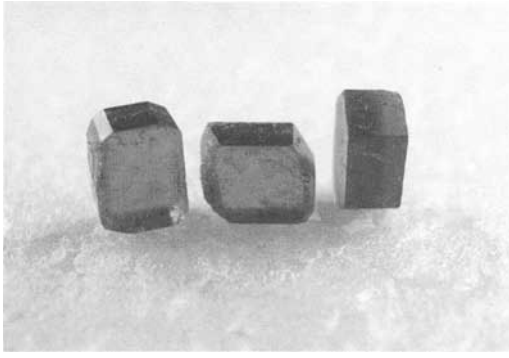

Fig. 1. Lennix synthetic emerald crystals.

The three crystals recently donated weigh 0.81, 0.71, and 0.82 ct, the 0.81 ct stone measuring 4.34 – 5.66 x 2.84 mm. All fluoresce red when irradiated with either long-wave or short-wave ultraviolet rays and also X-rays (diffraction tube, Mo target at 40 kV and 15 mA). Following the slicing and polishing of the 0.81 ct specimen refractive index measurements of 1.561-1.565 were made and these are both consistent with flux grown synthetic emeralds in general and similar to those reported by Farn (1.562-1.566) and Graziani, *et al.* (1.559-1.562).

It is often difficult to obtain accurate results when determining the SGs of stones in the size range of these crystals if the hydrostatic method is used. To determine the SGs of these crystals a liquid was mixed in which an inclusion free and colourless quartz was suspended at room temperature. When the Lennix crystals were placed into the same liquid with the quartz 'marker' each behaved in the same way as the quartz, i.e. at room temperature they were suspended in the same position, as the temperature was gradually raised they slowly sank at the same rate as and with the quartz marker, and as the temperature was lowered they slowly floated to the surface at the same rate and with the quartz marker.

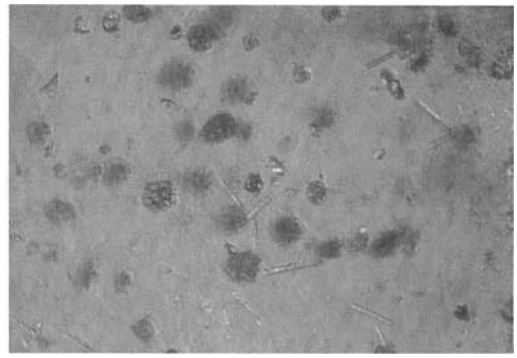

Fig. 2. Crystal aggregates and needle-like inclusions in the Lennix synthetic emerald.

This indicates an SG of 2.65 (somewhat below the value that is normally expected of a natural emerald) which is also consistent with the findings of both Farn (2.65) and Graziani, *et al.* (2.65-2.66).

The inclusions and growth features are similar to those of the original 1979 samples, in that the Lennix synthetic emerald is both heavily included and zoned. As one has come to expect a synthetic emerald to be of a high quality (at least in terms of clarity) the faceted Lennix synthetic emerald poses a threat to the over-confident. When examined in the direction along the *c* axis (Figure 2) a multitude of small crystal aggregates are seen which are similar to those described by Farn (Farn, 1980. Figures 5

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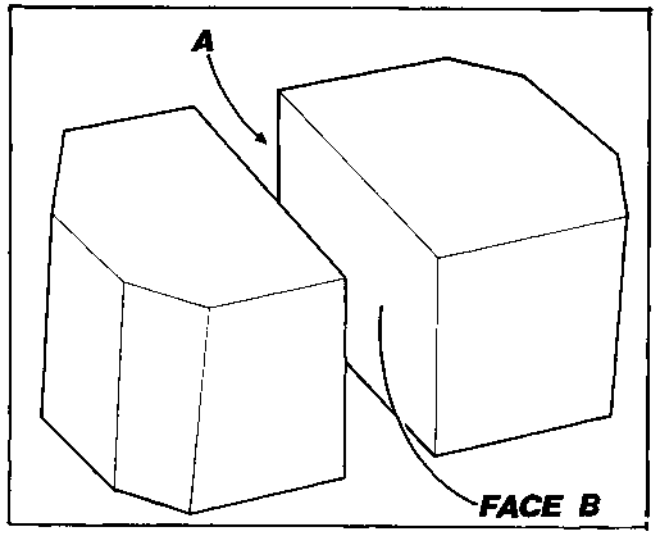

Fig. 4. Line drawing showing the direction in which the 0.81 ct Lennix synthetic emerald was sawn (A) and polished.

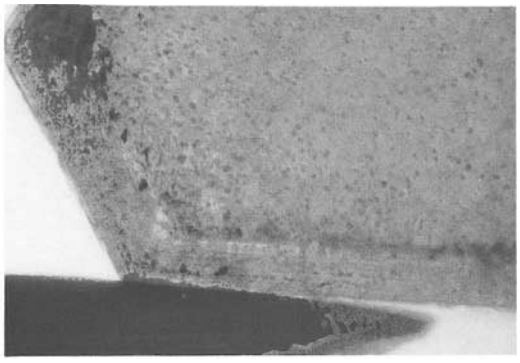

Fig. 3. Crystal aggregates and zoning in the Lennix synthetic emerald.

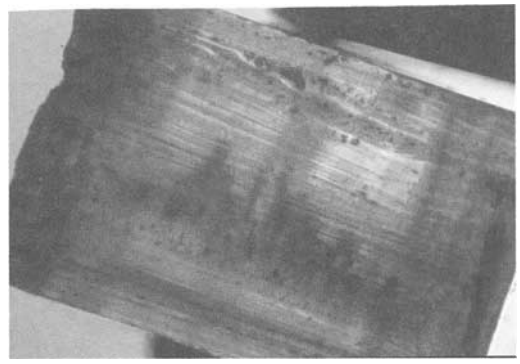

Fig. 5. Zoning in the Lennix synthetic emerald.

Fig. 6. 'Two phase' inclusions in the Lennix synthetic emerald.

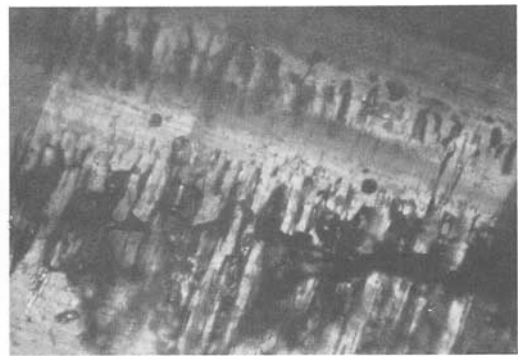

Fig. 7. 'Two phase' and other needle-like inclusions in the Lennix synthetic emerald.

and 6) and a clearly visible zoned structure can be observed within a limited area close to the edge of the crystal. This zoning running 'parallel' with the outer shape of the crystal can be seen in Figure 3.

Upon looking into these crystals one gains the impression that a large 'seed' is contained within. In order that this might be further investigated the 0.81 ct specimen was sliced and polished in the direction indicated by Figure 4. Figure 5 is taken through face 'B' of Figure 4, and this clearly reveals two distinct growth periods. The first characterized by a layered colourless or near-colourless and green area which forms the greater part of the crystal and the second by an outer skin which is layered roughly parallel with the four sides of the crystal. As observed with the crystals reported on in 1980, these later crystals contain large two- and sometimes three-phase inclusions (some of which show a distinct red colour), Figure 6. However, also contained within the more recent crystals are multitudes of small needle-like inclusions, Figures 2 and 7.

The absorption spectrum is typical of that to be expected from 'emerald'. As can be seen in Figure 8, the Lennix synthetic emerald transmits ultraviolet down to 275 nm.

The filling of cavities and feathers in ruby

Rubies in which cavities have been filled with glass are no longer an uncommon sight in the Laboratory. However, upon sorting through a parcel of rubies recently we came across two interesting forms of filling. The first was a plastic filling and was observed in several cabochon-cut rubies (Figure 9) and the second was a fracture that had been filled (at least partially) with glass (Figures 10 and 11). This latter type of infilling could be somewhat more difficult to detect than the 'normal' cavity infilling as the finished product looks, at first glance, to be similar to a 'normal' feather.

Inclusions in heat treated corundum

A heat treated sapphire recently submitted for examination displayed, in transmitted light, the not uncommon sight of an altered guest mineral and associated tension halo (Figure 12). In reflected light though, this inclusion revealed its 'hi-tech' origins by bearing a close resemblance to a 'compact disc' (Figure 13).

The two penny pieces test

An interesting book was loaned to us recently by R. J. Bridges, its title being, *Familiar Lessons on Mineralogy and Geology*. It is the 'twelfth edition'

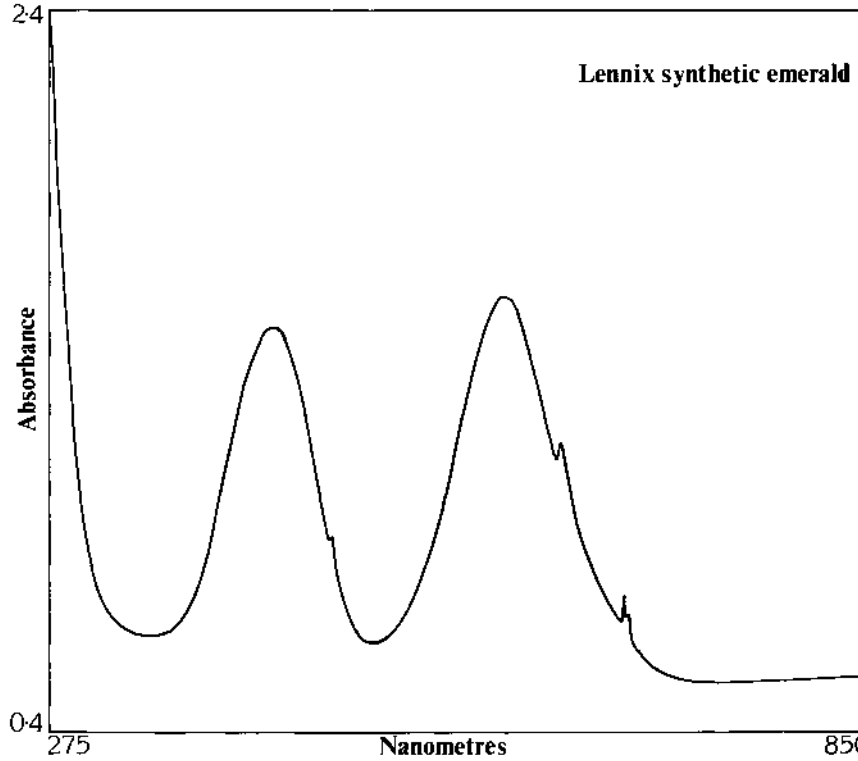

Fig. 8. Absorption spectrum of Lennix synthetic emerald. The curve was obtained using a Pye Unicam PU 8800/03 UV/visible spectrophotometer (Basil Anderson model) with a speed of 1 nm/s and a bandwidth of 0.5 nm at room temperature. The path length was 2.54 mm.

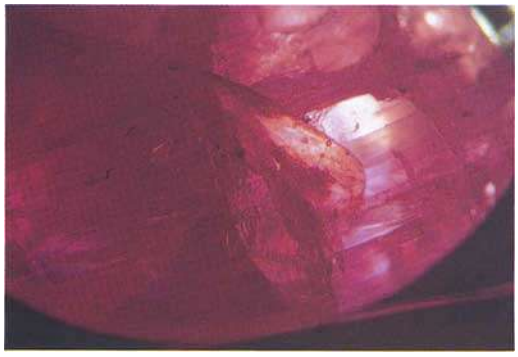

Fig. 9. Plastic infill in a cabochon-cut ruby.

Fig. 10. Partially glass-filled feather in a natural ruby.

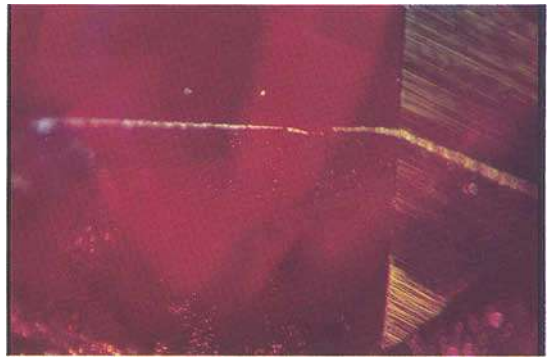

Fig. 11. Partially glass-filled feather in a natural ruby.

Fig. 12. Altered inclusion and tension halo in a heat treated sapphire, transmitted light.

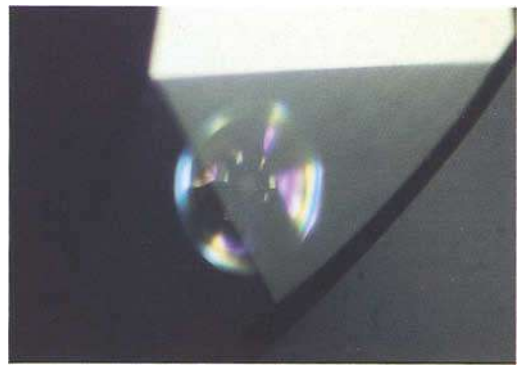

Fig. 13. Altered inclusion and tension halo in a heat treated sapphire, reflected light.

and is dated 1830. There are a number of interesting 'tests' described (many of which cannot be recommended today), one of which is described as follows '*... if the substance be small, place it betwixt two penny pieces, and strongly press them with the thumb and finger, when, if it is not a diamond, it will break and be reduced to powder;...*' Apart from its intended use as currency, we have heard of many uses for the humble penny and now we have yet another.

ANICS, synthetically grown beryl

During the International Gemmological Conference held in Brazil in September/October 1987, the author was given a group of four synthetic beryl crystals. They were given via Dr Miyata of the Institute of Gem & Jewellery Art, Kofu, Japan, by Naosuke Adachi of the manufacturing company, Adachi New Industrial Co. Ltd, of Osaka, Japan. The method of growth is by chemical vapour deposition and the following types of material are said to be produced: emerald, reddish beryl, sky blue beryl, pink beryl, violet beryl, yellowish-green beryl, colourless beryl and watermelon beryl. It is reported (Yagi and Adachi, 1979) that the doping agents involved in producing these colours are: Co, Mn, Ni, Cu, Nd, Ag, Ti, Fe, Ce, Cr and their combinations.

The four stones given are red, violet/mauve, sky blue, and 'watermelon' with a mauvish centre and green skin (Figure 14). The latter weighs 0.64 ct and its dimensions are 7.7 x 3.5 x 2.8 mm. The 'watermelon' type, which closely resembles tourmaline, has been described by Koivula (1986) as having a specific gravity of 2.66 and refractive indices of 1.559 and 1.564. The company give the mean refractive indices and specific gravity for each type as: emerald 1.57 and 2.63-2.70, reddish 1.568 and 2.66, sky blue 1.575 and 2.67, pink 1.569 and 2.66, and violet 1.573 and 2.67 respectively. These figures largely agree with those obtained on the specimens in Figure 14, although the SG obtained on the violet/mauve sample was a little less, at approximately 2.64, than that quoted by the manufacturer of 2.67, and the refractive indices of the 'watermelon' specimen differed fractionally, at 1.560-1.563, to those obtained by Koivula. The colour in three of the specimens is clearly zoned and the most common inclusions are twisted 'veil-like' feathers and diffuse clouds.

Fig. 14. ANICS synthetic beryl group.

'Fluorolith'

Every now and then peculiar 'fashion stones' appear on the market such as the 'mood stones' of about a decade ago. A short time ago we were given the two stones in Figure 15 and were told that they were being marketed as 'fluorolith'. They are interesting in that they phosphoresce quite strongly and for a considerable length of time, after exposure to light. Figure 16 shows this green phosphorescence after exposure to an optical fibre light.

Fig. 15. Two cabochons of 'Fluorolith'.

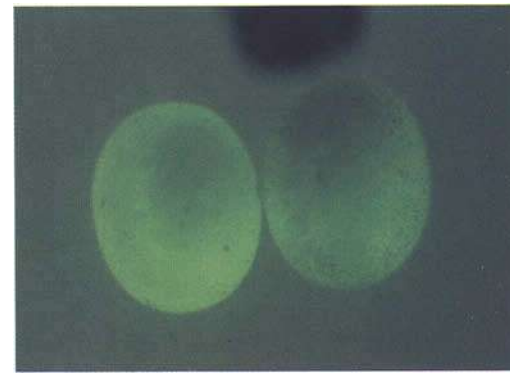

Fig. 16. The two cabochons of Figure 15 phosphorescing after exposure to light.

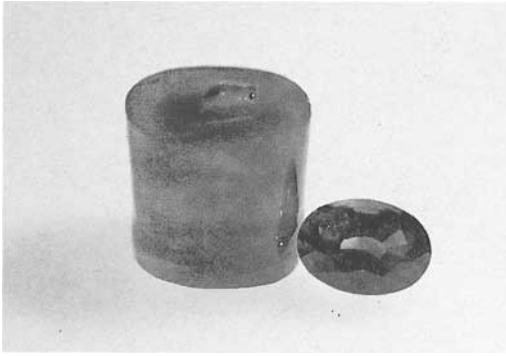

Fig. 17. Kyocera synthetic blue sapphire.

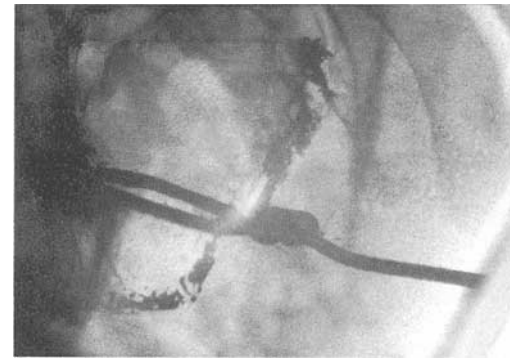

Fig. 21. Platinum wire and seed in the Kyocera synthetic emerald crystal of Figure 19.

Kyocera synthetics

The Laboratory has obtained through the UK offices of the Kyocera Corporation an up-to-date range of their synthetic stones. This includes: blue sapphire, white and black 'opal', emerald, star ruby, alexandrite and alexandrite cat's-eye (Figures 17, 18, 19, and 20).

The emerald crystal seen in Figure 19 weighs 22.15 ct and measures 13.19 x 16.37 x 10.05 mm. The seed is clearly visible in the crystal and a platinum wire can be seen looped through it (Figure 21). Twisted and veil-like feathers, typical of synthetic emeralds in general, are present within the crystal, however, little in terms of the 'usual' inclusions are present in one of the faceted stones. This is a 1.22 ct emerald-cut stone measuring 7.01 x 6.04 x 4.35 mm and those inclusions present consist of many needles (Figure 22) running parallel to the optic axis – which is perpendicular to the table facet. The refractive indices for this emerald-cut stone are 1.560-1.565 but another brilliant-cut stone weighing 1.20 ct, had indices of 1.562-1.565. The SG for the emerald-cut stone was found to be 2.64 and that of the crystal 2.66. Using a prism-type hand-held spectroscope, in all cases a strong chromium spectrum was seen. Under long-wave ultraviolet light the stone's fluorescence is a very weak orange-red or it is inert and under short-wave ultraviolet the fluorescence is a dull or weak orange-red. When viewed through a Chelsea colour filter the stones appear a strong red and under an intense light, such as that provided by the optical fibre type, they glow a bright red (Figure 23).

The star ruby (Figure 20) is a nicely proportioned oval cabochon of 1.42 ct which when observed with a prism-type hand-held spectroscope displays the normal chromium spectrum for ruby. Its SG and RI (distant vision) are also within the range for corundum. The star is formed from a mass of silk-like inclusions (Figure 24) which in themselves could prove deceptive but the 'smoky' or 'flame-like' structures so often seen in the surface areas of

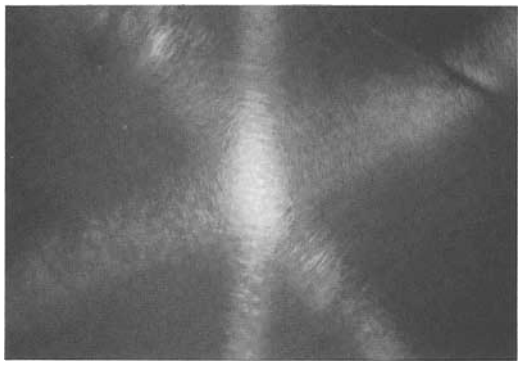

Fig. 24. The silk-like inclusions responsible for the star effect in the Kyocera synthetic star ruby.

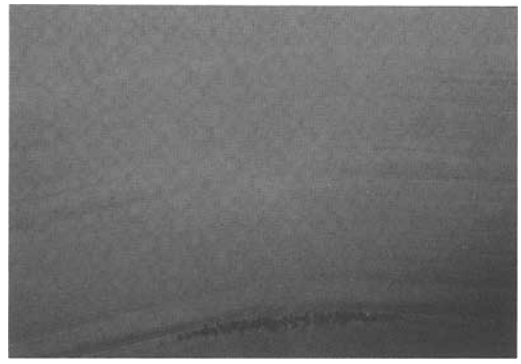

Fig. 26. Zoning in a Kyocera synthetic alexandrite.

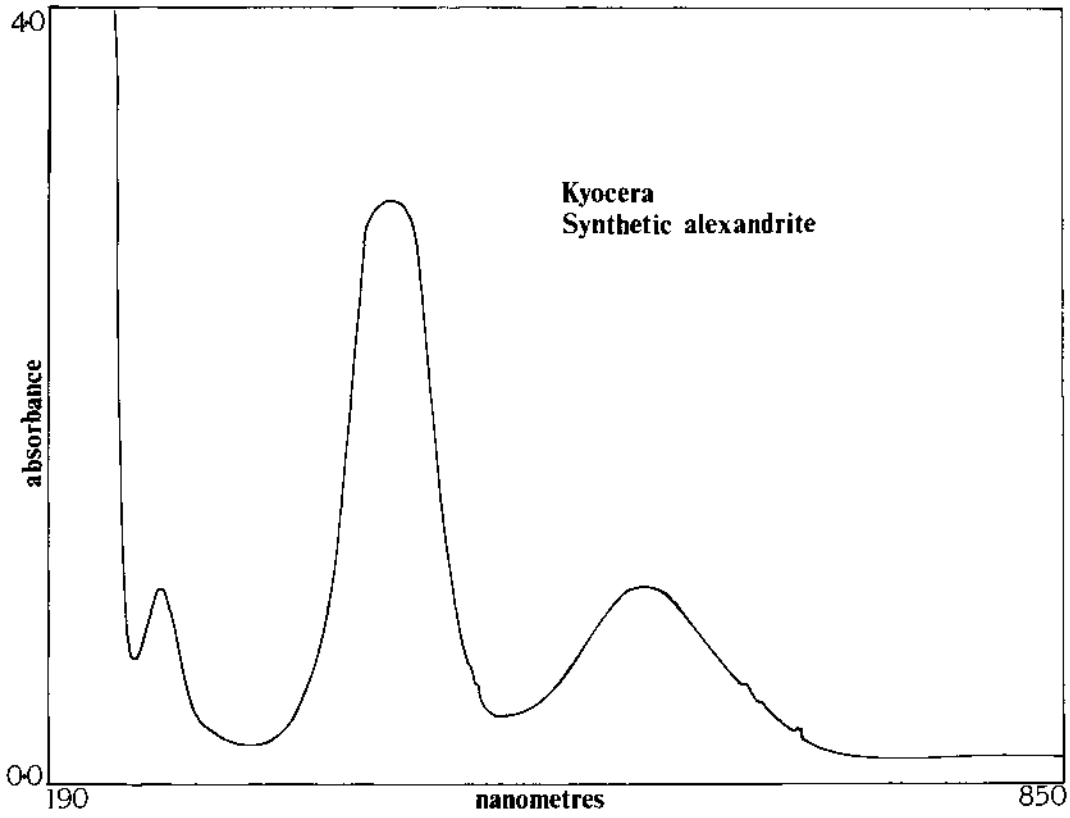

Fig. 25. Absorption spectrum of the synthetic alexandrite crystal. The curve was obtained using a Pye Unicam PU 8800/03 UV/visible spectrophotometer (Basil Andersom model) with a speed of 1 nm/s and a bandwidth of 0.5 nm at room temperature. The path length was 6.5 mm.

synthetic star corundum give away the origin of this material.

Figure 18 shows the synthetic alexandrite and synthetic alexandrite cat's-eye produced by Kyocera. The uncut alexandrite specimen weighs 18.13 ct and measures 17.02 x 13.30 x 6.53 mm and the cabochon-cut cat's-eye weighs 0.97 ct. The refractive indices obtained from the round faceted stone are 1.740-1.748, and the absorption spectrum of the crystal is reproduced in Figure 25. The uncut synthetic alexandrite has easily visible growth structures which at first glance may appear to be 'curved lines'. However, as the angle of view is changed slightly, it can be seen that they are in fact angular (Figure 26), and similar growth features can be seen in the round faceted stone. The cat's-eye cabochon has a clear 'fibrous' structure (Figure 27) which is dissimilar to that seen in the natural material (see Kane 1987). The uncut cat's-eye material has similar structures but many bubbles are present close to the surface.

The faceted synthetic blue sapphire in Figure 17 has refractive indices of 1.760-1.768, but the colour distribution of the uncut material is most distinctive (Figures 28 and 29). Bubbles are also present.

The Kyocera opal product is similar in its structural characteristics to the Gilson material, i.e. a chicken wire or mesh-like structure is clearly visible in both the black and white material (see Schmetzer and Henn, 1987).

Acknowledgements

It is with pleasure that the author acknowledges the assistance of all the members of staff at the Gem Testing Laboratory of Great Britain in compiling these 'Notes'. In particular, S. J. Kennedy, I. Shenker and N. Sturman, provided much information concerning the Kyocera synthetics. The fluorolith was shown to us by E. A. Thomson Gems, who continue, as always, to provide the Laboratory with

Fig. 18. Kyocera synthetic alexandrite and synthetic alexandrite cat's eye.

Fig. 19. Kyocera synthetic emerald crystal.

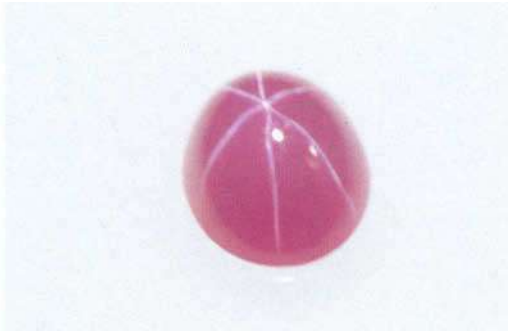

Fig. 20. Kyocera synthetic star ruby.

Fig. 22. Needle-like inclusions in the Kyocera synthetic emerald.

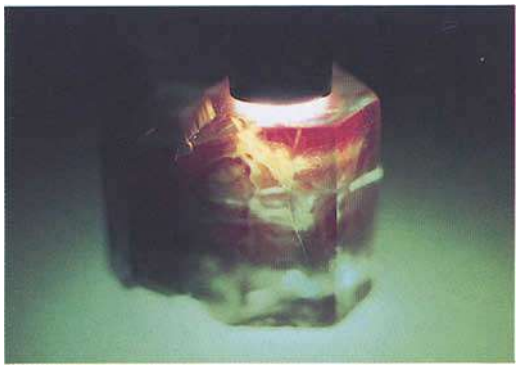

Fig. 23. Kyocera synthetic emerald glowing red in the light produced from an optical fibre light unit.

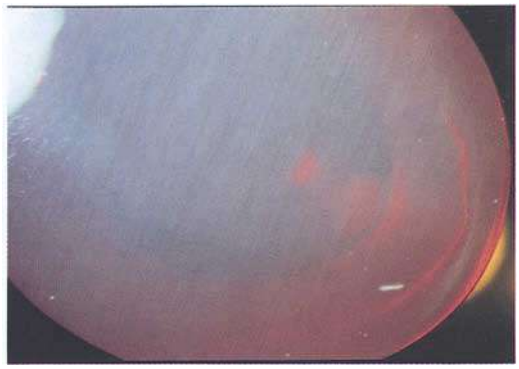

Fig. 27. 'Fibrous-type' structure in a Kyocera synthetic alexandrite cat's-eye.

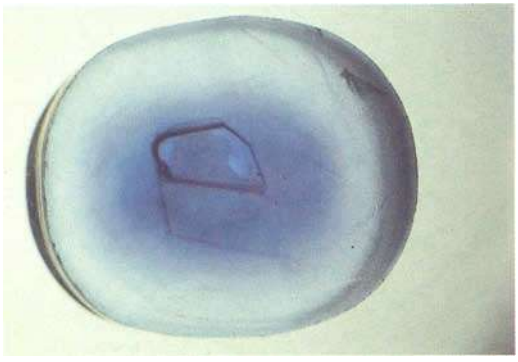

Fig. 28. Colour distribution in a Kyocera synthetic blue sapphire crystal.

valuable information for which we are most grateful. We owe a debt of thanks to Szemes Attila of *Enterprise Française de Fabrication D'emeraude de Culture*, for the Lennix synthetic emerald specimens and to Naosuke Adachi of Adachi New Industrial Co. Ltd, of Osaka, Japan for the ANICS synthetic beryl specimens and state further, that we wish some other manufacturers of synthetic gem materials could find their way to being as generous. Our thanks also go to R. J. Bridges for the loan of *Familiar Lessons on Mineralogy and Geology*.

Fig. 29. Colour distribution in a Kyocera synthetic blue sapphire crystal.

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The 10x lens

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It was not entirely inappropriate that the July/October *Journal* arrived on Remembrance Day, 11 November 1988. I was encouraged by the editorial which indicated that there was room for some lighter material other than the 'meat' of the *Journal's* highly scientific content which it quotes as 'tackling gemmological education at the frontiers'. I noted and was particularly warmed by the nostalgia expressed in the Editorial for the Louis Kornitzer style of writing. Kornitzer certainly holds a special place in the dealer/traveller world of gemstones. His style reveals a deep appreciation and love of gemstones. He was, however, a man who earned his living by buying and selling gems. Without this commercial appreciation and profit motive our world of gemmology would be less well provided for.

Fortunately for students of gemmology stones which are heavily included or indeed flawed are relatively cheap and provide ideal material upon which to practise.

In these retirement days there is time for reflection, retrospection and a reading of papers previously published, plus periodicals to peruse. Having moved house and home several times recently in fairly rapid succession I am somewhat geared to clearing out and generally reducing the accumulation of old papers, periodicals and the like.

When these occasions occur I start with determination and enthusiasm to discard some of the papers and books, but they all suddenly acquire interest and importance. Very few are jettisoned, at worst they are 'relegated'. My industry soon grinds to a halt, held up by my immersion in an absorbing article by Basil Anderson, or one of his informative yet entertaining letters. These 'pearls of wisdom', evoke memories of the old days, the old lab and old friends. The *Journal* editorial, in like manner, directed my thoughts to one of the most delightful writers of the gemmological scene. Someone who revels in the structures of gemstones and who has over many years explored the interiors of gemstones with a poetic eye.

In the old days our opposite number was the Service Public du Controle des Diamants, Perles Fines, et Pierres Précieuses de la Chambre de Commerce et d'Industrie de Paris. We of course were The Laboratory of the Diamond, Pearl and Precious Stone Trade Section of The London Chamber of Commerce. Mademoiselle Dina Level is possibly one of the longest serving members of the Paris Laboratory. She started in 1929 and retired in July 1969 completing 40 years of service for which she received the Médaille d'or du Travail, the gold medal of industry. She is also Présidente d'Honneur Association Française de Gemmologie and an Honorary Fellow of The Gemmological Association of Great Britain. She is now retired from the Paris Laboratory but not from the world of gemmology. In her earlier days she was a welcome visitor to our laboratory. We enjoyed her enthusiastic and truly gallic reactions to the luminescent effects in the X-ray viewing chamber and other optical phenomena.

At one time not many gemmologists had seen adequately displayed the fluted or 'organ pipe' group of bright red lines in the spectrum of natural red spinel. When we demonstrated this effect to Dina Level many years ago we used a small colourless glass bottle packed tight with hundreds of tiny octahedral crystals of red spinel. A flask of copper sulphate solution served to cool and concentrate the beam of light on to the microscope. The spectroscope sat on top of an old brass microscope used solely as a light gathering source. Basil Anderson, well over six feet tall, looked comfortably down through the mounted spectroscope, but as Dina is petite, we stood her on a strong low stool for better viewing. Success was achieved, but on viewing this extremely fascinating sight for her first time Dina nearly came over backwards with delighted reaction. She has a very genuine love and appreciation for the many beautiful inclusions and optical effects seen in natural, synthetic and imitation stones.

Mlle Level has written many fascinating articles for the 'Revue française de gemmologie' in a lively

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but learned manner. Her appearance on National Television literally swept audiences off their feet with her exuberant enthusiasm for the hidden beauties of gemstones.

In a report of her talk on television, the writer uses as a heading Dina's own words, 'Pierre tu vas me dire quelque chose' (gemstone you are going to tell me something); quoting and translating loose subtle nuances such as the intimate 'tu' for a gem. It is difficult to convey the feeling expressed by Dina Level. These are the kind of papers which stop me when I start to tidy up. They can be easily assimilated by readers who may enjoy a break from the heavier 'meat', mentioned in the *Journal's* editorial.

In an article entitled 'Les Mystères de la Coupe Verte, racine d'émeraude ou?' Mlle Level gives a description of an oval green cup on show in the Louvre Museum, Paris. It is exhibited among the 'Agates' of Monseigneur le Dauphin. It has an oval bowl, baluster stem and oval foot, all three pieces being of the same material. It has simple classic lines and has an overall lightly scratched appearance. The foot and stem are ornamented by twisted enamelled cordons of gold. Three earlier inventories in 1723, 1791 and 1876 gave precise details but failed to agree on the correct nature of the material. The first entry in 1723 stated, *prime d'émeraude;* this is old style French used wrongly for prase, fluor or jade. According to M. J.P. Poirot, Director of the Paris Laboratory, Prime d'émeraude is untranslatable. The second description in 1791 described the cup as prase but with an interior crystallization not yet determined. Both descriptions stated that the cup had been repaired (cassée et remastiquée). The third description of 1896 described the cup as prase and attributed it to the reign of Henri IV, but made no mention of included crystallization.

Members of the Société Française de Gemmologie were able to make a detailed examination of the cup and produced the following details. Softer than quartz, old conchoidal fractures, inert to ultra violet rays and inert through the Chelsea Filter. Examination by progressive magnification with the microscope revealed furrow-like scratches all over; some appear to come from within. Polishing has cut across and sectioned some furrows. Intersecting lines in the interior have a star-like effect with clear rounded green centres. The material is slightly translucent. The chevron or star effect is unlike that of any natural material, or even purpurine glass. Eventually an analysis proved it to be lead glass which was surprising considering its low refractive index of 1.54.

Where the high power of the microscope failed Mlle Level succeeded – with a detailed examination using a 10x lens. She was looking for 'the natural signature of the artificial' – a bubble. A 10x lens is more manoeuvrable than a microscope. Dina Level found a small milky bubble typical of glass and then two more. She finishes her discussion and describes the deception afforded by the cup; it is no less interesting because of the material, in itself rare, its manufacture unknown. She writes of the cup's own soliloquy, 'for a century and a half you have described me as *prime d'émeraude*, then prase (with reservations), then prase again. Almost a century after, the year of grace 1973, is the year of my disgrace. What would Monseigneur le Dauphin have said?' Dina Level apologises to the cup saying 'excuse me little cup for upsetting you; gemmology thanks you for allowing the examination and the sight in your furbelows of those precious "pearls" – your bubbles'.

Mlle Level writes of, and talks to gems; she delves with delight into the world of moss, needles, doubling, dichroism and shatter marks; she is poet, enthusiast and scientist. As a respite from the heavier going, hers is the kind of gemmology that stops me in my tracks.

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Level, D., 1973. Les mystères de la Coupe Verte, racine d'émeraude prase ou? *Revue de Gemmologie*, 35, 8-9.

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Etch figures on beryl

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Abstract

The surface features of several natural solution-etched beryl crystals were photomicrographically documented using Nomarski Differential Interference Contrast microscopy (Brightman, 1982). The observed etch figures are characteristic for the mineral beryl and can be useful in the identification of even badly corroded crystals.

Solution etched beryl

When examining rough crystals of the mineral beryl it will be noticed that the condition of the individual faces on those crystals varies greatly from crystal to crystal, and even from face to face on the same crystal. While some entire crystals, or separate faces on certain crystals, will appear to be mirror smooth, others will be quite obviously pitted or corroded looking. This apparent corrosion, or etching, is the result of dissolution or the dissolving away of previously formed crystal faces.

Dissolution is a term that can be applied to any solution-etched crystal. Natural crystals, such as beryl, that grow in solution, are always susceptible to solution etching or dissolution should the chemical environment change sufficiently.

If one closely examines the corroded looking surfaces of a solution-etched beryl crystal, the apparently haphazard irregular appearance gives way to a delightful array of geometric patterns known to mineralogists as etch figures.

These etch figures, decorating the surfaces of the solution-attacked beryl, reflect the internal symmetry of the crystal's underlying structure. But the three-dimensional structural framework of beryl varies with direction in the crystal. So it follows that crystal faces which are identical would display similar etch figures. And, those etch features would be visibly different from the etch figures found on dissimilar faces. Therefore each facial plane (or crystal form) on a solution-etched beryl would have its own set of characteristic etch figures.

In his excellent book, *Emerald and Other Beryls* (1981) John Sinkankas illustrates, through a series of black-and-white line drawings, some of the possible etch figures that have been observed on the various faces of beryl. He shows twenty two different figures for the prism faces alone. While another eighteen drawings serve to show some of the patterns that have been found and described on the pyramidal and pinacoidal faces.

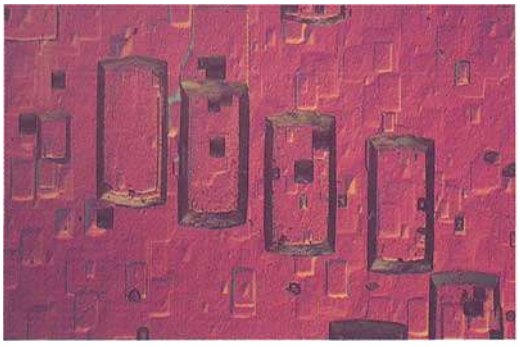

Fig. 1. Rectangular etch figures on a first order prism face of a Brazilian aquamarine. Nomarski Differential Interference Contrast. The *c*-axis runs in the long direction. 80x.

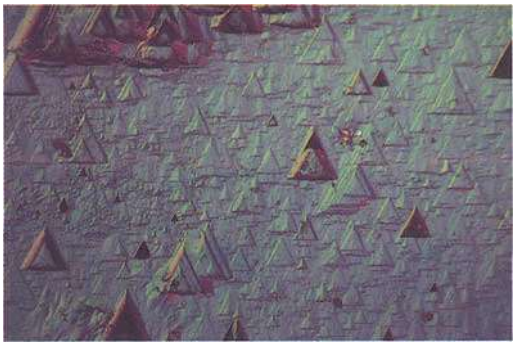

Fig. 2. Triangular etch patterns on a first order bypyramid of a Brazilian aquamarine Nomarski Differential Interference Contrast. 80x.

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Fig. 3. Shield-shaped etch figures on a second order bypyramid of a Brazilian goshenite. Nomarski Differential Interference Contrast. 80x.

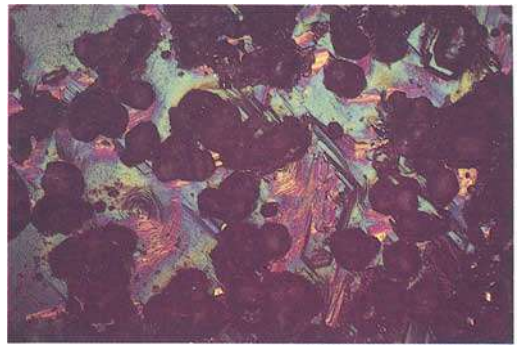

Fig. 4. Hexagonal solution cavities on the basal pinacoid of an aquamarine from Brazil. The *c*-axis is perpendicular to the image. Nomarski Differential Interference Contrast. 80x.

It would be beyond the scope of this article, and the budget of most journals, to provide colour photomicrographs depicting all the etch figures illustrated by Sinkankas in *Emerald and Other Beryls*. So only the most common etch figures observed on the prism (Cover Photomicrograph and Figure 1), pyramid (Figures 2 and 3) and pinacoid faces (Figure 4) are shown.

It is hoped that these few colourful photomicrographic images will excite others to microscopically explore the dissolution hallmarks of beryl.

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[*Manuscript received 3 March 1988*]

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Characterization of Russian hydrothermally-grown synthetic emeralds

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Abstract

Russian hydrothermally-grown synthetic emeralds are characterized with respect to chemical, physical, and spectroscopic properties, growth structures and inclusions. Physical properties such as specific gravity, refractive indices, colour and pleochroism, as well as absorption bands in the visible and infrared region are caused by the extraordinary chemical composition of the samples containing high amounts of Cr_2O_3, Fe_2O_3, Ni_2O_3 and CuO. Microscopic features such as growth structures and inclusions are due to the experimental conditions of crystal growth. In summary, all features of diagnostic value are explainable with respect to the details of synthesis applied to the growth process of this exceptional type of synthetic emerald by Russian scientists. All properties determined are compared with features of natural emeralds from different sources.

I. Introduction

Synthetic emeralds have been manufactured in Russia by hydrothermal techniques since 1965 (Emel'yanova *et al.*, 1965). Commercially produced faceted samples were first mentioned in gemmological literature by Fryer *et al.* (1983) and Koivula (1984, 1985). Chemical data were published by Hofmann *et al.* (1985), Gübelin (1986) and Lind *et al.* (1987). In all three papers cited, exceptional high iron contents for beryl or emeralds between 3.07 and 5.32 wt.% Fe_2O_3 were mentioned. In addition, a remarkable nickel content of 0.62 wt.% NiO was found by Hofmann *et al.* (1985).

Spectroscopic data were published by Gübelin (1986), Lind *et al.* (1987) and Scarratt (1987). The first author briefly mentions absorption lines and absorption bands which are typical for Cr^{3+} in beryl. In the paper of Lind *et al.* (1987), the absorption bands found in the spectra which were recorded for several samples of Russian hydrothermally-grown synthetic emeralds were assigned to Cr^{3+}, Fe^{3+} and Fe^{2+} ligand field transitions as well as to a Fe^{2+}/Fe^{3+} charge-transfer absorption. In other words, the absorption spectrum was interpreted to be typical for emeralds containing a distinct aquamarine component in addition to the chromium-vanadium spectrum of emerald. Beryl samples of this type reveal a pleochroism of blue $\parallel c$ and yellowish-green $\perp c$, and emeralds of this particular colour originating from Miku, Zambia, were first described by Schmetzer & Bank (1980, 1981). In the paper of Scarratt (1987), non-polarized absorption spectra of two samples are pictured, which were recorded at angles of 90° to each other, but oblique to the optical axis of the rough and faceted stone, respectively. Some extraordinary features of the spectra are mentioned, but no explanation for these properties could be given.

Microscopic observations were described in all papers cited above dealing with information on seed plates, irregular growth structures, reddish-brownish and opaque platelets as well as two- and three-phase inclusions.

During a systematic study of absorption spectra of natural and synthetic emeralds, the present author was able to record the spectra of some faceted samples of Russian synthetic hydrothermally-grown crystals which were made available as a loan from Prof. Dr E. Gübelin of Meggen, Switzerland in December 1986. The first spectroscopic results indicated the presence of some absorption bands, which were not able to be assigned to the known chromium, vanadium and iron absorptions of emerald (cf. Lind *et al.*, 1987; Scarratt, 1987). In addition, using X-ray fluorescence analysis, traces of nickel and, most surprisingly, copper were found to be present. From these preliminary results, a more comprehensive study of chemical, physical and spectroscopic properties as well as microscopic features of this exceptional type of synthetic emerald was initiated. All characteristics observed are in good agreement with Russian literature dealing with properties of hydrothermally-grown synthetic beryl doped with traces of chromium, iron, nickel and copper. In addition, most observations are useful for determinative purposes, i.e. for a recognition of samples of unknown origin as well as for distinction of natural and synthetic emeralds.

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II. Materials and methods

For the present study, 13 faceted samples of Russian hydrothermally-grown synthetic emeralds were available for non-destructive investigations. Eleven square cut samples in the range of 0.35 to 0.52 ct in weight and about 4 × 5 mm in size (Figure 1) originally came to Europe as pre-shaped or cut samples via Hong Kong in 1986. One faceted sample 0.88 ct in weight and 5 × 5.5 mm in size came to Great Britain in 1986 and was already described by Scarratt (1987). Another cut sample 2.34 ct in weight and 6.5 × 10 mm in size was given to a private collector in 1979 during a visit to the Institute of Geology and Geophysics, Siberian branch of the USSR Academy of Sciences, Novosibirsk, USSR.

By scientists of this research institute, the complete development of growth processes for hydrothermal synthesis of emeralds was undertaken and complete descriptions of chemical, physical and spectroscopic properties as well as growth structures of this research material were published in the Russian language (Solntsev *et al.*, 1976, 1978; Il'in *et al.*, 1980; Klyakhin, 1980; Lokhova *et al.*, 1980; Bukin *et al.*, 1980, 1981; Shatsky *et al.*, 1980, 1981; Klyakhin *et al.*, 1981a,b; Solntsev, 1981a,b; Lebedev & Askhabov, 1984; Lebedev & Dokukin, 1984; Pugachev, 1984; Lebedev *et al.*, 1986). However, according to Russian literature, the commercial production of hydrothermally-grown synthetic emerald, which was reduced to practice on jewellery plants in Sverdlovsk, Leningrad, L'vov and Estonian (Lebedev, 1987), is performed at L'vov, Ukraine, USSR (Godovikov *et al.*, 1982). At present, hydrothermally-grown synthetic emerald is produced in limited amounts of nearly 1-2 kg a year on contract with private businessmen from the USA and Canada. Only limited information about properties of this commercially produced type of synthetic emerald is available to the present author from Russian literature (Godovikov *et al.*, 1982; Granadchikova *et al.*, 1983), but according to the features of the material available for this study, growth conditions and properties of the Russian scientific research material and the commercial Russian production are similar or almost identical. One important difference, i.e. the different materials used for autoclave walls, will be discussed later in this article (cf. section IV).

Fig. 1. Faceted Russian hydrothermally-grown synthetic emeralds. Size of samples approx. 4 × 5 mm (*Photo by O. Medenbach, Bochum, West Germany*).

For the present study, all samples available were spectroscopically examined in the range of about 11,500 to 32,500 cm^{-1} using a double-beam UV-VIS spectrophotometer (Leitz-Unicam, model SP.800). Five samples representing the complete variability of spectroscopic properties were selected for chemical analysis by electron microprobe (ARL,

model SEMQ, used for main and trace elements) and X-ray fluorescence techniques (Siemens, model SRS 300, used for trace elements). As internal reference materials, samples of synthetic emeralds grown by Chatham, Gilson and Lechleitner were included in the chemical study, and fragments of the identical crystals were simultaneously analyzed for colour causing trace elements by destructive techniques using inductively coupled plasma atomic emission spectrometry (Perkin-Elmer, model ICP 6000). For the determination of unit cell dimensions as well as for infrared spectroscopy small amounts of powder were scraped from the girdle of one faceted stone. This powder was used in order to obtain an X-ray powder diffraction pattern for the calculation of unit cell dimensions (Debye-Scherrer camera, diameter 114.6 mm, FeK_{α} radiation) as well as for the preparation of a KBr pressed disk for infrared spectroscopy using a double-beam IR spectrophotometer (Perkin-Elmer, model IR 180).

III. Results

III.1 Chemical and physical properties of Russian hydrothermally-grown synthetic emeralds

Chemical data of Russian hydrothermally-grown synthetic emeralds obtained by non-destructive techniques are presented in Tables 1 and 2. The analytical results indicate remarkably low values of MgO and Na_2O compared with most sources of natural emeralds (Hänni 1981, 1982; Schrader, 1983; Stockton, 1984), but surprisingly high, but varying amounts of colour-causing trace elements such as Cr_2O_3, Fe_2O_3, Ni_2O_3 and CuO (cf. Figure 2). The valence states and lattice positions of these transition metal elements are determined by an

Table 1. Chemical and physical properties of Russian hydrothermally-grown synthetic emerald (sample a)

Chemical properties						Physical properties	
Chemical analysis [wt.%]		Cations calculated to Si=6			Lattice Site	Unit cell dimensions [Å] (refined from 20 d-values)	
CuO	0.10	Cu	0.007	3.000	tetrahedron	a_0	9.234 (3)
BeO[1]	13.58	Be	2.993			c_0	9.197 (4)
						Specific gravity [g/cm^3]	
MgO	0.04	Mg	0.005	2.021	octahedron	$d_{obs.}$	2.69 (1)
MnO	<0.01	Mn	——			$d_{calc.}$	2.703
Al_2O_3	16.05	Al	1.736				
V_2O_3	<0.01	V	——			Refractive indices	
Cr_2O_3	0.35	Cr	0.025				
Fe_2O_3[2]	3.00	Fe	0.207			n_o	1.580 (1)
Ni_2O_3[3]	0.72	Ni	0.048			n_e	1.573 (1)
SiO_2	65.38	Si	6.000		tetrahedron	Δn	0.007
Li_2O	n.d.	Li	0.x		channel		
Na_2O	0.03	Na	0.005				
K_2O	0.03	K	0.004				
H_2O[4]	0.98	H_2O	0.300				
Σ	100.26						

n.d. not determined, but present according to infrared spectroscopy
1 calculated for Σ Be+Cu = 3.00
2 total iron as Fe_2O_3
3 total nickel as Ni_2O_3
4 calculated for H_2O = 0.30

Crystal chemical formula:
$(Cu_{0.01}Be_{2.99})(Mg_{0.01}Al_{1.74}Cr_{0.03}Fe_{0.21}Ni_{0.05})Si_6O_{18}(Li_{0.x}Na_{0.01}K_{0.01}H_2O_{0.30})$

Table 2. Colour-causing trace elements in Russian hydrothermally-grown synthetic emeralds [ppm]

Sample	V	Cr	Fe	Ni	Cu
e	<100	2580	21700	3050	6760
d	<100	4240	30100	2310	4240
c	<100	2740	20300	4260	3470
b	<100	4070	19600	6100	1080
a	<100	2400	21000	5100	800

assignment of absorption bands in the visible and ultraviolet area (compare section III.3). According to these data, copper was found in the divalent state replacing beryllium in tetrahedral sites. Chromium, iron and nickel are found exclusively in the trivalent state in octahedral aluminium sites.

The value for BeO was calculated according to crystal chemical principles as Σ Be + Cu = 3.00. However, due to a possible presence of small amounts of lithium replacing beryllium in tetrahedral sites, the calculated BeO content is assumed to be an approximation only.

The presence of water was established by infrared spectroscopy (see section III.4), and the total amount of water was calculated for a reasonable value of 0.3 water ions in the formula unit. This value represents an average for hydrothermally-grown Russian beryl, which was found to contain between 0.10 and 0.62 water ions in the formula unit

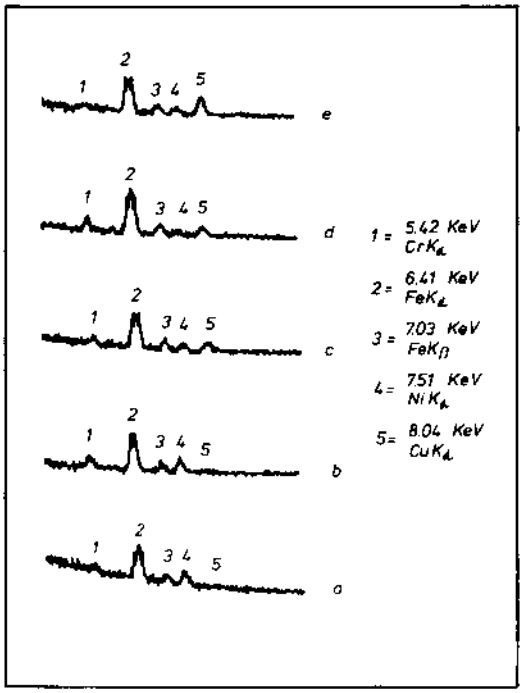

Fig. 2. Energy-dispersive X-ray fluorescence spectra of colour causing trace elements (Cr, Fe, Ni, Cu) in samples (a) to (e) of Russian hydrothermally-grown synthetic emeralds (cf. Table 2).

(Il'in *et al.*, 1980; Klyakhin *et al.*, 1981a,b; Shatsky *et al.*, 1981; Lebedev & Dokukin, 1984; Pugachev, 1984; Lebedev *et al.*, 1986).

The presence of distinct amounts of lithium in channel sites of the beryl lattice is derived indirectly from infrared spectroscopical investigations in connection with the low quantities of Na_2O, which were analytically determined by electron microprobe analysis (cf. section III.4). However, the quantitative amount of Li_2O in Russian synthetic emerald was unable to be determined by non-destructive methods. The crystal chemical formula of one specimen (sample a) reads $(Cu_{0.01}Be_{2.99})(Mg_{0.01}Al_{1.74}Cr_{0.03}Fe_{0.21}Ni_{0.05})Si_6O_{18}(Li_{0.x}Na_{0.01}K_{0.01}H_2O_{0.30})$. Samples of hydrothermally-grown synthetic beryl which are similar or almost identical in chemical and physical properties were recently described by Klyakhin *et al.* (1981b) and Lebedev *et al.* (1986).

From the 13 faceted gemstones of Russian synthetic emeralds investigated in the present study, microscopic investigations revealed the presence of residues of colourless seed plates in six of the samples. Three of the synthetic emeralds were cut in a direction leaving the residue of the seed plate as table facet of the stone (cf. Figure 6), and in three of the samples part of the seed plate was found to form the culet of the cut synthetic emerald (cf. Figure 7). Thus, refractive indices of hydrothermally-grown emeralds were obtainable from the table facets of ten samples using a standard Rayner refractometer, and the refractive indices of seed plates were obtainable for three cut stones. Specific gravities of Russian synthetic hydrothermally-grown emeralds were measured for those seven samples without residues of seed plates.

The results (Table 3) indicate a slight variability for optical data as well as for specific gravities of the synthetic emerald material and constant values for the optical properties of seed plates. According to gemmological standard reference books, these values are within the range of natural emeralds from different localities. On the other hand, specific gravities and refractive indices of these Russian synthetic hydrothermal emeralds are found in the upper part or even slightly above the range known for synthetic emeralds with the exception of Lechleitner synthetic emeralds (emerald-coated natural

Table 3. Range of refractive indices and specific gravities for Russian hydrothermally-grown synthetic emeralds

Synthetic emerald			
n_o	n_e	Δn	d[g/cm^3]*
1.580 to 1.586	1.573 to 1.579	0.006 to 0.007	2.68 to 2.70

*for samples without seed plate

Seed plate			
n_o	n_e	Δn	d[g/cm^3]
1.571	1.565	0.006	not available

beryl cores). The values were also found to be distinctively higher than Russian flux-grown synthetic emeralds (cf. Koivula & Keller, 1985).

In general, in natural and synthetic beryl and emerald, increasing amounts of alkali metal oxides such as Li_2O, Na_2O, K_2O, Rb_2O, and Cs_2O (with Li^+ in tetrahedral Be sites as well as in channel sites, and all other alkalis located in channel sites of the beryl structure), as well as increasing amounts of MgO and transition metal oxides such as V_2O_3, Cr_2O_3, MnO, FeO, Fe_2O_3, CoO, Co_2O_3, NiO, Ni_2O_3, CuO (located in octahedral and/or tetrahedral sites of the beryl structure) cause increasing values of unit cell dimensions (especially of a_0, dependent on replacements of octahedral sites, and of c_0, dependent on replacements of tetrahedral sites), refractive indices and specific gravities (Pavlova, 1963; Bakakin *et al.*, 1967, 1970; Filho *et al.*, 1973; Černý & Hawthorne, 1976; Solntsev *et al.*, 1976; Rodionov & Pavlyuchenko, 1980; Bukin *et al.*, 1980; Klyakhin *et al.*, 1981a,b; Shatsky *et al.*, 1981; Franz, 1982; Pugachev, 1984; Lebedev *et al.*, 1986; Deer *et al.*, 1986).

Increasing amounts of transition metal elements in general are responsible for increasing refractive indices and specific gravities in synthetic emerald. The differences in physical properties of Russian synthetic hydrothermal emeralds compared with other synthetic emeralds of various producers are due to the high amounts of colour-causing trace elements such as Cr, Fe, Ni, and Cu in the Russian material (compare section III.3), which exceed the amounts of transition metal elements found in other flux-grown or hydrothermally-grown synthetic emeralds. An exception is observed for Lechleitner synthetic emeralds (emerald-coated beryl seeds) with extraordinarily high refractive indices. The thin overgrowth of this synthetic emerald may contain up to 10.01 wt.% Cr_2O_3 causing refractive indices up to n_o 1.610, n_e 1.601 (Schmetzer *et al.*, 1981a,b).

The amounts of colour-causing trace elements in Russian hydrothermally-grown synthetic emeralds also exceed the range which is generally found in natural emeralds from different localities. According to these data alone, the refractive indices of the Russian material should also exceed the values of natural emeralds. On the other hand, most natural emeralds reveal higher amounts of MgO and alkali metal oxides (especially Na_2O contents) than the samples described in this paper. In general, an increase of alkali metal contents in natural and synthetic emeralds is responsible for an increase of refractive indices. Thus, in Russian hydrothermally-grown synthetic emeralds, the influence of high amounts of colour-causing transition metal oxides is partly compensated by the low contents of MgO and alkali metal oxides. Regarding these facts, refractive indices and specific gravities in the range of natural emeralds become understandable.

The unit cell dimensions of Russian synthetic hydrothermally-grown emeralds (Table 1) are found to lie within the range of natural beryls as well as within the range of hydrothermally-grown samples described in Russian literature, which contain transition metal oxides between 2.0 and 5.0 wt.% in octahedral aluminium sites and lower lithium and/or copper contents in tetrahedral beryllium sites (Bakakin *et al.*, 1967, 1970; Filho *et al.*, 1973; Solntsev *et al.*, 1976; Il'in *et al.*, 1980; Bukin *et al.*, 1980; Klyakhin *et al.*, 1981a,b; Shatsky *et al.*, 1981; Franz, 1982; Pugachev, 1984; Lebedev *et al.*, 1986). Samples of this type of natural and synthetic beryl, in which octahedral replacement of Al^{3+} is dominant over tetrahedral replacement of Be^{2+} are called o-beryls (Bakakin *et al.*, 1967, 1970).

All samples investigated were inert to long- and short-wave ultraviolet radiation. This result is understandable in view of the high concentrations of iron in the synthetic material, which is responsible for the quenching of chromium fluorescence.

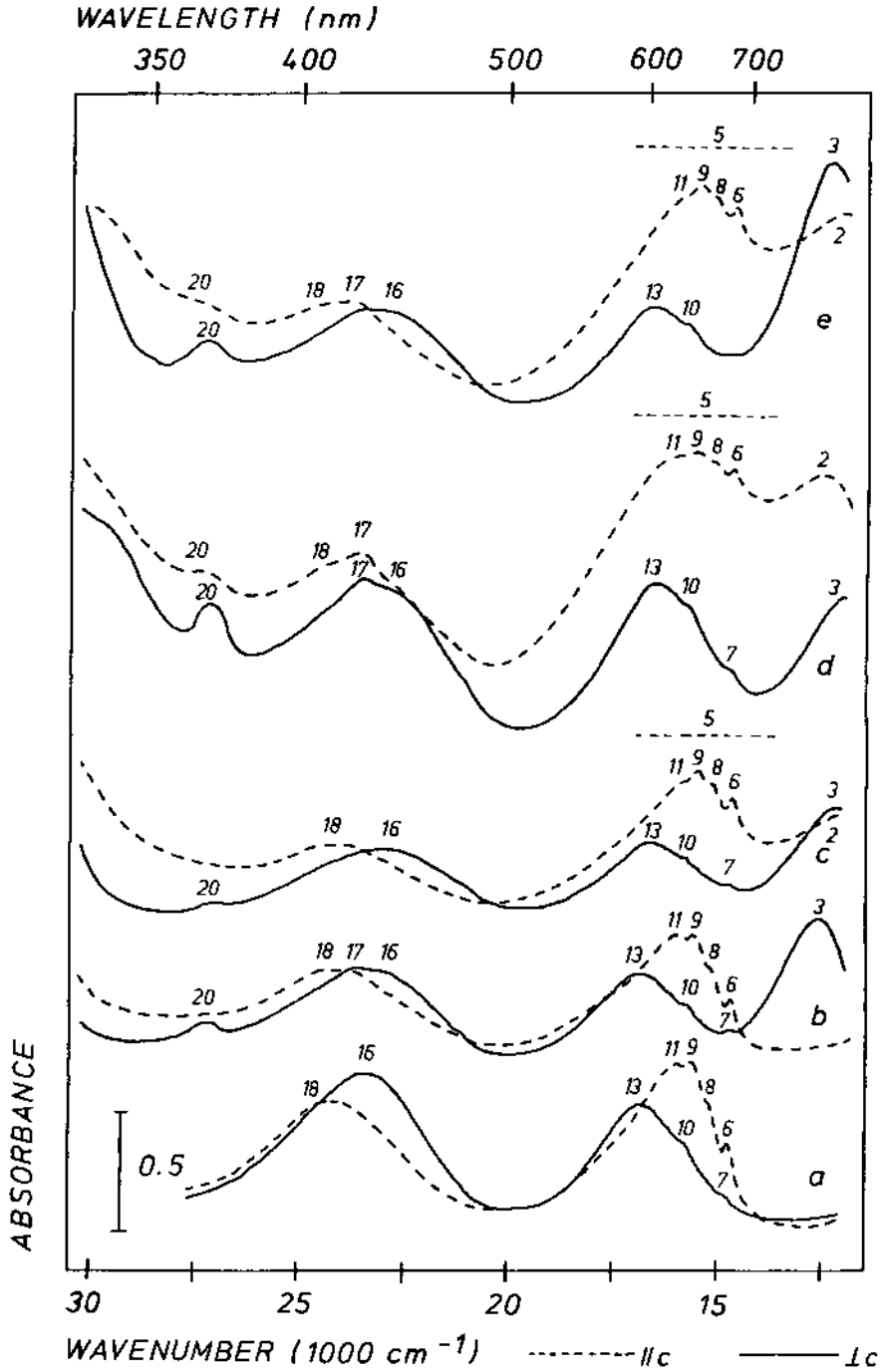

Fig. 3. Polarized absorption spectra of natural emeralds from different sources; sample (a) from Chivor, Colombia, representing a typical chromium-vanadium emerald spectrum without distinct Fe absorption bands; sample (b) from Jos, Nigeria, representing a typical chromium-vanadium emerald spectrum with an Fe^{2+} absorption band in the near infrared (polarization ⊥ *c*) and two Fe^{3+} bands in the bluish-violet and ultraviolet; sample (c) from Ankadilalana, Madagascar, sample (d) from Sta. Terezinha de Goiás, Brazil, and sample (e) from Miku, Zambia, representing the superimposed spectra of chromium-vanadium emerald and aquamarine in various intensity ratios (the aquamarine spectrum consisting of two Fe^{2+} absorption bands in the near infrared [polarization ∥ and ⊥ *c*], two Fe^{3+} bands in the blueish-violet and ultraviolet, and an Fe^{2+}/Fe^{3+} intervalence transition in the red area [polarization ∥ *c*]); the positions of absorption minima and pleochroism of the samples are given in Table 4, the positions and assignments of absorption maxima are given in Table 5.

III.2 Absorption spectroscopy and colour of natural and synthetic emeralds

In gemmological nomenclature it is generally accepted that emerald is the green variety of beryl, the colour of which is caused by traces of chromium or by traces of vanadium and chromium. In natural and synthetic beryl, the two spin-allowed strong absorption bands of Cr^{3+} in octahedral Al^{3+} sites are located in the red and blue range of the visible region. The two spin-allowed strong absorption bands of V^{3+} in octahedral sites of the beryl structure reveal similar absorption maxima (Wood & Nassau, 1968; Beckwith & Troup, 1973) and, thus, in samples bearing both transition metal elements, chromium and vanadium, the absorption bands of Cr^{3+} and V^{3+} are superimposed and no separated absorption maxima are observable (Schmetzer, 1982).

Natural emeralds from most sources show distinct amounts of both colour-causing trace elements, chromium and vanadium, and in samples from some localities, e.g. in some emeralds from Muzo, Colombia, the amount of V_2O_3 even exceeds the amount of Cr_2O_3 (e.g. Nassau & Jackson, 1970; Franz, 1982). But in general, the intensities of both absorption bands of Cr^{3+} in the red and blue areas are increased due to the presence of V^{3+}. Only one commercially interesting source of vanadium-bearing, chromium-free green beryl is known (Salininha, Bahia, Brazil), and some samples of a similar type were also described from other localities (e.g. from Kenya; cf. Schmetzer, 1982; Ghera & Lucchesi, 1987). For samples of this type of green beryl, their acceptance as emerald in gemmological nomenclature is still in discussion.

In synthetic emeralds which are commercially produced, in general the amount of chromium exceeds the amount of vanadium, but samples with $V_2O_3 > Cr_2O_3$ were also described in literature (e.g. Biron synthetic emeralds; Kane & Liddicoat, 1985).

In natural and synthetic iron-bearing beryl, three basic types of spectra are observed, which are assigned to three types of iron in the beryl lattice. Though different authors came to various models for the assignment of iron absorption bands in beryl (e.g. Wood & Nassau, 1968; Samoilovich *et al.*, 1971; Schmetzer *et al.*, 1974; Price *et al.*, 1976; Parkin *et al.*, 1977; Goldman *et al.*, 1978; Platonov *et al.*, 1978, 1979; Blak *et al.*, 1982; Solntsev *et al.*, 1984, 1985), the positions of absorption maxima are not in discussion.

In general, two absorption maxima in the near infrared (maximum I at 12,000 cm^{-1} $\parallel c$, and maximum II at 12,200 cm^{-1} $\perp c$) are assigned to bivalent iron in two different lattice sites. Two absorption bands in the bluish-violet and the ultraviolet range (maximum I at 23,500 cm^{-1}, $\parallel c > \perp c$; and maximum II at 27,000 cm^{-1}, $\perp c \gg \parallel c$) are assigned to Fe^{3+} replacing Al^{3+} in octahedral coordination. A broad absorption band in the red area (from 16,700 to 13,300 cm^{-1}, $\parallel c$) is assigned to a Fe^{2+}/Fe^{3+} charge-transfer process. This intervalence transfer absorption in the red is not observed in samples revealing distinct absorption bands of Fe^{3+} in the bluish-violet (at 23,500 cm^{-1}) and ultraviolet (at 27,000 cm^{-1}) range and the Fe^{2+} absorption with polarization $\perp c$ (at 12,200 cm^{-1}) in the near infrared. However, in all samples which show an additional absorption of Fe^{2+} with polarization $\parallel c$ (at 12,000 cm^{-1}) in the near infrared, the Fe^{2+}/Fe^{3+} charge-transfer absorption in the red is also observable. This absorption band is responsible for the blue colour of aquamarine.

In the most recent papers of Solntsev *et al.* (1984, 1985), the band with polarization $\perp c$ (at 12,200 cm^{-1}) is assigned to Fe^{2+} in tetrahedral Be^{2+} sites and the 12,000 cm^{-1} band with polarization $\parallel c$ is assigned to Fe^{2+} in octahedral Al^{3+} sites. Consequently, the charge-transfer absorption in the red between 16,700 and 13,300 cm^{-1} with polarization $\parallel c$ is assigned to a Fe^{2+}/Fe^{3+} intervalence absorption within Fe^{2+} and Fe^{3+} ions, both located in adjacent octahedral sites of the beryl structure.

In natural emeralds from different sources, all types of iron absorption bands which are known in colourless to intense blue beryls are also observable. In samples from some localities, e.g. in part of natural emeralds from Colombia or Pakistan, no absorption bands of ferrous or ferric iron are observable by spectroscopic investigations (Figure 3a). The pleochroism of these samples is described as green or slightly bluish-green $\parallel c$ and yellowish-green $\perp c$, absorption maxima are given in Table 4.

Natural emeralds from other localities, e.g. some samples from Jos, Nigeria; Sandawana, Zimbabwe; Lake Manyara, Tanzania; Itabira, Brazil or Ural Mountains, USSR, reveal the presence of a dominant absorption band of Fe^{2+} in the infrared at 12,200 cm^{-1} with polarization $\perp c$ and two strong absorption bands of Fe^{3+} in the bluish-violet and ultraviolet area at 23,500 and 27,000 cm^{-1} (Figure 3b). Both types of iron do not influence the visible part of the absorption spectrum and, thus, do not influence or change the chromium-vanadium colour and pleochroism of the samples (cf. Table 4). In these emeralds, an absorption of Fe^{2+} in the infrared with polarization $\parallel c$ is not observable or is found to be very weak in intensity, and no intervalence transfer absorption of Fe^{2+}/Fe^{3+} in the red area with polarization $\parallel c$ is present.

In a third type of natural emerald, variable amounts of bivalent iron are present in two sites (tetrahedral and octahedral) and trivalent iron is

Table 4. Examples for absorption minima in the visible range and pleochroism of natural emeralds as well as Russian hydrothermally-grown synthetic emeralds

Natural emeralds Locality/ sample	Pleochroism ‖c	⊥ c	Position of absorption minima ‖c[cm^{-1}]	[nm]	⊥ c[cm^{-1}]	[nm]	Spectrum
Miku, Zambia (e)	blue	yellowish-green	20,600	485	19,800	505	Fig. 3e
Sta. Terezinha de Goiás, Brazil (d)	blue	yellowish-green	20,400	490	19,700	508	Fig. 3d
Ankadilalana, Madagascar (c)	blue	yellowish-green	20,400	490	19,700	508	Fig. 3c
Jos, Nigeria (b)	bluish-green	yellowish-green	20,100	498	19,900	503	Fig. 3b
Chivor, Colombia (a)	bluish-green	yellowish-green	20,000	500	19,800	505	Fig. 3a

Russian hydrothermally-grown synthetic emeralds Sample	Pleochroism ‖c	⊥ c	Position of absorption minima ‖c[cm^{-1}]	[nm]	⊥ c[cm^{-1}]	[nm]	Spectrum
(e)	blue	yellow-green	20,400	490	19,900	503	Fig. 4e
(d)	blue	yellow-green	20,300	493	19,900	503	Fig. 4d
(c)	blue	yellow-green	20,300	493	19,800	505	Fig. 4c
(b)	greenish-blue	yellow-green	20,200	495	19,800	505	Fig. 4b
(a)	greenish-blue	yellow-green	20,200	495	19,800	505	Fig. 4a

present in octahedral sites (Figure 3c,d,e). These emeralds reveal a complete absorption spectrum of aquamarine consisting of two Fe^{2+} bands in the infrared (at 12,000 cm^{-1}, polarization ‖ *c*, and at 12,200 cm^{-1}, polarization ⊥ *c*), two Fe^{3+} bands in the bluish-violet and ultraviolet (at 23,500 and 27,000 cm^{-1}) as well as a Fe^{2+}/Fe^{3+} intervalence transfer absorption band in the red (between 16,700 and 13,300 cm^{-1}; polarization ‖ *c*). Like in natural aquamarines, the amounts of all these types of ferrous and ferric iron may be variable, and thus the Fe^{2+}, Fe^{3+} and Fe^{2+}/Fe^{3+} absorption bands are found to vary in intensity, too.

This complete aquamarine spectrum is superimposed on the ordinary chromium-vanadium spectrum of emerald, causing a distinct shift of the absorption minimum in the spectrum ‖ *c* from green to bluish-green, greenish-blue or blue, i.e. towards higher wave numbers (lower wavelengths; cf. Table 4). This principle was first described for emeralds from Zambia with a strong aquamarine and a weak emerald component, revealing a pleochroism of blue ‖ *c* and yellowish-green ⊥ *c* (Table 4). Meanwhile, similar types of absorption spectra consisting of an aquamarine component as well as of a chromium-vanadium (emerald) component, were found by the present author in additional samples from different sources, e.g. in emeralds from Santa Terezinha, Carnaiba, Itabira and Socotó, Brazil; Ankadilalana, Madagascar; Lake Manyara, Tanzania; Gravelotte, South Africa; Habachtal, Austria; Maria Mine, Mozambique; Machingwe, Zimbabwe. The pleochroism of these samples varies according to the intensity ratio of the aquamarine and emerald components (Figure 4c,d,e) from bluish-green to greenish-blue and blue ‖ *c*, with yellowish-green ⊥ *c* (cf. Table 4).

In commercially available synthetic emeralds from different producers with the exception of Lechleitner synthetic emeralds (emerald-coated colourless natural iron-bearing beryl seeds), no absorption bands of bivalent iron in the infrared with polarization ‖ or ⊥ *c* are found to be superimposed to the chromium-vanadium emerald spectrum. In Russian and Gilson flux-grown synthetic emeralds, absorption bands of Fe^{3+} are found in the bluish-violet and ultraviolet range. According to Nassau (1980), this type of iron-bearing synthetic emerald was produced by Gilson for a short period of time. Consequently, the presence of iron bands

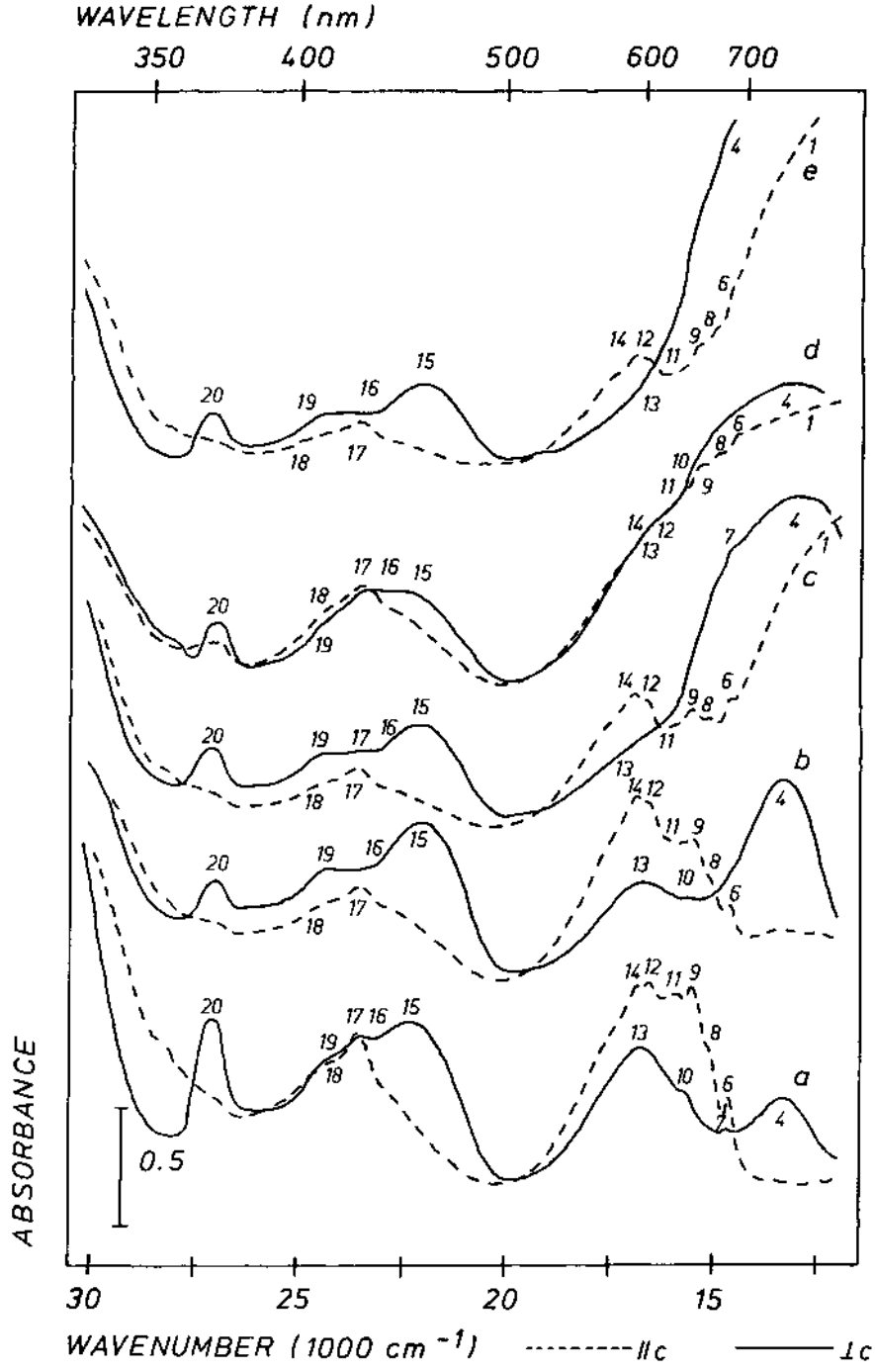

Fig. 4. Polarized absorption spectra of samples (a) to (e) of Russian hydrothermally-grown synthetic emeralds; the spectra reveal a superimposition of absorption bands of Cr^{3+}, Fe^{3+}, and Ni^{3+} in octahedral sites and Cu^{2+} in tetrahedral sites, all four colour-causing trace elements being present in variable amounts in different samples (for analytical data cf. Table 2); the positions of absorption minima and pleochroism of the samples are given in Table 4, the positions and assignments of absorption maxima are given in Table 5.
The orientation of the *c*-axis of sample (d) versus the facets of the cut stone was very unfavourable in order to obtain polarized spectra of good quality; only in this special case spectrum ---- represents a condition with polarization $\parallel c$ > polarization $\perp c$, and spectrum —— represents a condition with polarization $\perp c$ > polarization $\parallel c$.

Table 5. Spectroscopic data of natural emeralds and Russian hydrothermally-grown synthetic emeralds

Position of absorption maxima natural emeralds [cm^{-1}]	[nm]	synthetic emeralds [[cm^{-1}]	[nm]	Polarization of absorption bands	Assignment	Designation in Figs. 3 and 4
		10,900*	917*	$\parallel c$	Cu^{2+} tetr.	1
12,000	833			$\parallel c$	Fe^{2+} oct.	2
12,200	820			$\perp c$	Fe^{2+} tetr.	3
		13,300	752	$\perp c$	Cu^{2+} tetr.	4
13,300–16,700	752-599			$\parallel c$	Fe^{2+}/Fe^{3+}	5
14,600	685	14,600	685	$\parallel c$	Cr^{3+} oct.	6
14,700	680	14,700	680	$\perp c$	Cr^{3+} oct.	7
15,100	662	15,100	662	$\parallel c$	Cr^{3+} oct.	8
15,500	645	15,500	645	$\parallel c$	Cr^{3+} oct.	9
15,700	637	15,700	637	$\perp c$	Cr^{3+} oct.	10
15,900	629	15,900	629	$\parallel c$	Cr^{3+} oct.	11
		16,500	606	$\parallel c$	Ni^{3+} oct.	12
16,600	602	16,600	602	$\perp c$	Cr^{3+} oct.	13
		16,800	595	$\parallel c$	Ni^{3+} oct.	14
		22,000	555	$\perp c$	Ni^{3+} oct.	15
23,200	431	23,200	431	$\perp c$	Cr^{3+} oct.	16
23,500	426	23,500	426	$\parallel c > \perp c$	Fe^{3+} oct.	17
23,800	420	23,800	420	$\parallel c$	Cr^{3+} oct.	18
		24,200	413	$\perp c$	Ni^{3+} oct.	19
27,000	370	27,000	370	$\perp c \gg \parallel c$	Fe^{3+} oct.	20

*after Solntsev (1981a,b), Lebedev *et al.* (1986)

assigned to bivalent iron or to bivalent as well as trivalent iron in an emerald sample of questionable origin is sufficient to prove the stone as natural emerald.

Though nickel was determined in natural emeralds from Cobra mine, Transvaal, South Africa, in concentrations up to 0.025 wt.% (Schrader, 1983), nickel absorption bands (for the position of absorption maxima confer Table 5) were found neither in the spectra of samples from Cobra mine nor in spectra of emeralds from other localities. Thus, the influence of nickel on the colour of natural emeralds of known sources is negligible.

III.3 Absorption spectroscopy and colour of Russian hydrothermally-grown synthetic emeralds

According to chemical data (section III.1; Tables 1, 2; Figure 2), samples of Russian hydrothermally-grown synthetic emeralds investigated in this paper contain variable but high amounts of four colour-causing transition elements: chromium, iron, nickel and copper. As described in section III.2 in detail, natural emeralds, in general, contain traces of vanadium, chromium and, in most instances, iron. The pleochroism of Russian hydrothermal synthetic emeralds varies from greenish-blue to blue $\parallel c$, with yellow-green or greenish-yellow $\perp c$ (Table 4). The absorption spectra of all samples consist of several absorption bands in the infrared, visible and ultraviolet range (Figure 4a-e) which are assigned to Cr^{3+}, Fe^{3+} and Ni^{3+} in octahedral sites and to Cu^{2+} in tetrahedral sites (Table 5). These assignments are based on the known positions of Cr^{3+} and Fe^{3+} absorption bands (e.g. Wood & Nassau, 1968; Solntsev, 1981a, Klyakhin *et al.*, 1981b) and on the positions of Ni^{3+} and Cu^{2+} absorption bands as published in the most recent Russian literature (Solntsev, 1981a,b; Klyakhin *et al.*, 1981b; Lebedev *et al.*, 1986).

Only in some older papers, the nickel doublet at 16,500 and 16,800 cm^{-1} (polarization $\parallel c$) is assigned to Ni^{2+} (Solntsev *et al.*, 1978; Il'in *et al.*, 1980; Bukin *et al.*, 1981), but in the samples investigated in the present paper no further spectroscopic criteria for the presence of Ni^{2+} were found. These data support the assignment of this doublet to Ni^{3+} as published in the most recent Russian publications. Obviously, under the oxygen partial pressures used for hydrothermal synthesis of emerald by Russian scientists, iron, nickel and chromium ions predominantly substitute Al^{3+} in octahedral sites as

Fe^{3+}, Ni^{3+} and Cr^{3+} and copper is found to replace Be^{2+} in tetrahedral sites as Cu^{2+}. Consequently, only subordinate amounts of Fe^{2+}, Ni^{2+} and Cu^{+} ions are assumed to be incorporated into the beryl structure during crystal growth (cf. Klyakhin *et al.*, 1981b).

Non-polarized absorption spectra of hydrothermally-grown Russian synthetic emeralds and the pleochroism of these beryls are similar with spectra and pleochroism of natural emeralds revealing a chromium-vanadium (emerald) and aquamarine component. Due to these similarities overlooking the high amounts of nickel and copper in the samples as well as additional absorption maxima, the absorption spectra of Russian synthetic hydrothermally-grown emeralds were assigned to Cr^{3+}, Fe^{3+}, Fe^{2+} as well as to an intervalence transfer absorption of Fe^{2+} and Fe^{3+} (Lind *et al.*, 1987). However, spectra recorded in polarized light (cf. Figure 4a-e) clearly indicate the presence of absorption bands of both trace elements, Ni and Cu (Table 5), which is confirmed by chemical data (Table 2; Figure 2). No evidence has been found up to now either for the presence of bivalent iron in tetrahedral or octahedral coordination or for the presence of the Fe^{2+}/Fe^{3+} charge-transfer absorption band in the red region of visible light.

In the absorption spectra of Russian hydrothermal synthetic emeralds the absorption bands of chromium and nickel are found to be dominant in the visible area, and the influence of iron and copper bands is subordinate. The colour of synthetic nickel-doped beryl is described as yellowish-green with a pleochroism of blue $\parallel c$ and yellow-green or yellow $\perp c$ (Emel'yanova *et al.*, 1965; Solntsev, 1981a; Lebedev *et al.*, 1986). Due to the presence of a strong nickel absorption doublet at 16,500 and 16,800 cm^{-1} (polarization $\parallel c$), the absorption minimum of the ordinary chromium-vanadium (emerald) spectrum is shifted from green or bluish-green to greenish-blue and blue (cf. Table 4). On the other hand, the presence of an absorption band of Ni^{3+} at 22,000 cm^{-1} (polarization $\perp c$) causes an increase of yellow in the spectrum $\perp c$. Thus, due to the presence of high amounts of nickel, the pleochroism of ordinary chromium-vanadium emerald (bluish-green $\parallel c$, yellowish-green $\perp c$) is increased and changed to greenish-blue or blue $\parallel c$ and to yellow-green $\perp c$ (Table 4). This interpretation of colour and pleochroism in chromium- and nickel-bearing emeralds is consistent with Russian literature (Lokhova *et al.*, 1980; Bukin *et al.*, 1981; Solntsev, 1981a,b; Lebedev *et al.* 1986).

The influence of iron and copper on the colour of Russian hydrothermally-grown synthetic emeralds is subordinate. In samples containing lower amounts of copper, the absorption bands of Cu^{2+} do not influence the visible part of the absorption spectrum and the colour of the crystals (cf. Figure 4a,b). With increasing copper contents, a distinct influence on the visible part of the absorption spectra becomes evident (Figure 4c,d,e), especially in polarization $\perp c$. The influence of copper, however, does not distinctly shift absorption minima in the yellow to blue range (cf. Table 4) and thus, the influence of copper on the colour of Russian chromium- and nickel-bearing synthetic beryls is subordinate. The absorption band of Fe^{3+} in the bluish-violet area at 23,500 cm^{-1} is superimposed on the maxima of Cr^{3+} and Ni^{3+} in this spectral range, and thus the influence of Fe^{3+} on the colour of the samples is negligible.

Consequently, the colour and pleochroism of Russian hydrothermally-grown synthetic emeralds is due to the presence of high amounts of chromium and nickel. In samples of this type, additional high amounts of trivalent iron and bivalent copper do not remarkably contribute to the colour of these beryls.

III.4 Infrared spectroscopy and types of water in Russian hydrothermally-grown synthetic emeralds

Two types of water molecules were characterized in channel sites of natural and synthetic beryls and emeralds using infrared spectroscopy. Type-I water molecules have their two-fold symmetry axis perpendicular to the crystallographic six-fold axis of the beryl crystal and are not adjacent to alkali ions. Type-II water molecules have their two-fold symmetry axis parallel to the crystallographic six-fold axis of the beryl crystal and are adjacent to alkali ions. In high alkali natural emeralds, predominant absorption bands of type-II water are observed and only subordinate bands of type-I water are found. In low alkali natural emerald, e.g. in Colombian emeralds, absorption bands of both types of water are present. Up to 1980, in synthetic hydrothermally-grown emeralds, e.g. in Linde synthetic emeralds, only type-I water molecules were found. Flux-grown synthetic emeralds do not contain any water molecules and thus do not reveal water absorptions in the infrared (Wood & Nassau, 1967, 1968; Flanigen *et al.*, 1967; Nassau, 1976, 1980; Nassau & Nassau, 1980).

However, in the papers of Klyakhin *et al.* (1981b), Shatsky *et al.* (1981), Kodaira *et al.* (1982) and Lebedev *et al.* (1986), hydrothermally-grown synthetic beryl containing alkalies as well as type-I and type-II water molecules were described. According to the most comprehensive work of Shatsky *et al.* (1981), high concentrations of type-II water were incorporated only in sodium- and lithium-bearing synthetic beryl, bot not in potassian, rubidian and cesian beryls. Most recently, high pressure hydrothermal treatment of flux-grown

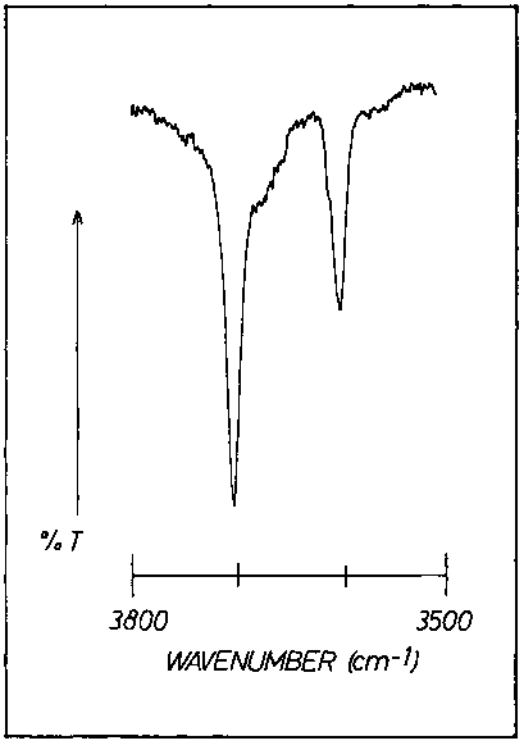

Fig. 5. Infrared spectrum of Russian hydrothermally-grown synthetic emerald indicating the presence of type-I and type-II water molecules.

beryl was described and the incorporation of type-I and type-II water molecules was observed (Kodaira *et al.*, 1984).

Infrared spectra of the commercially grown type of Russian hydrothermal synthetic emerald (Figure 5) clearly reveal two strong absorption bands at 3,595 and 3,698 cm^{-1} and, consequently, the incorporation of water molecules of types I and II is indicated. According to the presence of sodium only in very small amounts (Table 1), type-II water molecules obviously are adjacent to lithium ions in channel sites of the beryl structure.

Due to the presence of both types of water molecules, the infrared spectra of Russian hydrothermally-grown synthetic emeralds are identical with those of low alkali natural emeralds, e.g. with part of natural emeralds from Colombia. Therefore, infrared spectroscopy is unable to distinguish between these particular varieties of natural and synthetic emeralds. These results are consistent with the paper of Stockton (1987), in which similarities between infrared spectra of Russian synthetic hydrothermal emeralds and natural emeralds are described. Unfortunately, no explanation for these similarities or identities is given or discussed in the paper cited.

III.5 Microscopic features of Russian hydrothermally-grown synthetic emeralds

In half of the cut synthetic emeralds investigated residues of the seed plate consisting of colourless beryls were found (Figures 6-8). In all samples, the angle between the boundary seed plate/synthetic emerald and the optical axis of the synthetic emerald was determined by means of an especially developed sample holder (Schmetzer, 1985, 1986). For all samples, this angle was measured between 30 and 32°, indicating that for all samples seed plates parallel to $(5\ 5\ \bar{10}\ 6)$ were used which form an angle of 31.05° with the optic axis of beryl (calculated for hexagonal beryl with $a:c = 1:0.9967$).

In all samples with seed, families of parallel growth lines connected with colour zoning were found parallel to the boundary seed plate/synthetic emerald (Figures 6-8). In faceted samples without residues of the seed plate, families of parallel growth lines connected with colour zoning were also present (Figures 9-10), and the angle between these faces and the *c*-axis of the synthetic emerald was measured to be equal to 31°. Thus, all 13 samples examined were grown from beryl seeds parallel to $(5\ 5\ \bar{10}\ 6)$. This detail of growth conditions is mentioned in some Russian publications (e.g. Klyakhin *et al.*, 1981b; Lebedev & Askhabov, 1984; Lebedev *et al.*, 1986) to be one of the standard techniques suitable for hydrothermal synthesis of beryl (cf. growth conditions for Linde hydrothermally-grown synthetic emeralds; Flanigen, 1971; Flanigen & Mumbach, 1971). Samples which are grown from seed plates parallel to $(11\bar{2}0)$ were also mentioned in the Russian papers cited above, but obviously no synthetic emerald of this type was available for the present investigation. Since growth zoning parallel to $(5\ 5\ \bar{10}\ 6)$ is subordinate in natural emeralds, if present at all, the recognition of this structural feature by microscopic examination is sufficient to characterize a sample of unknown nature as synthetic emerald.

The application of colourless beryl seeds which are cut parallel to $(5\ 5\ \bar{10}\ 6)$ causes the development of additional characteristic growth microstructures which are never found in natural emeralds (Figures 6-11, 13-16). These growth structures, which partly resemble growth structures in Linde hydrothermally-grown synthetic emeralds, are easily observable with the gem microscope using immersion liquids. Similar or almost identical structures were already mentioned by Russian authors (Klyakhin *et al.*, 1981b; Granadchikova *et al.*, 1983; Lebedev & Askhabov, 1984; Lebedev *et al.*, 1986). In general, the observations described in the papers cited are confirmed by the investigations of the present author, and a small part of this information is also found in gemmological papers published so far.

Microscopic investigations of the boundary seed plate/synthetic emerald as well as the examination of growth lines parallel to (5 5 $\overline{10}$ 6) at high magnifications reveals the presence of a distinct type of step-like microstructure. The boundary between the seed plate and the synthetic emerald does not reveal a plane surface but shows a cobbled appearance. This boundary consists of a cellular pattern which is formed by several crystal faces with slightly oblique orientation with respect to the seed plate (Figure 11). From each of these cellular centres of nucleation, sub-individuals of synthetic emerald are grown with a preferred subparallel orientation oblique to the seed plate (Figure 12). The size of these sub-individuals and the form of the polycentrically growing step-like surface (Figures 7-10) is continuously changed during the growth process.

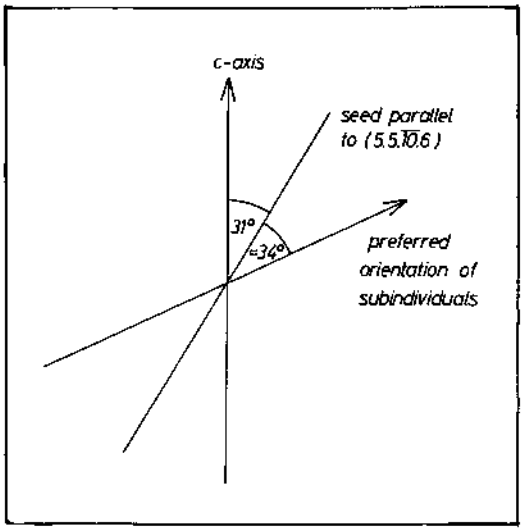

Fig. 12. Schematic representation of the orientation of the seed plate parallel to (5 5 $\overline{10}$ 6) in Russian hydrothermally-grown synthetic emerald versus *c*-axis and preferred orientation of sub-individuals.

In a certain direction which is inclined about 34° versus the seed plate, a characteristic block structure of subparallel orientated sub-individuals with curved surfaces is observable (Figures 13, 14). In some synthetic emeralds a distinct colour zoning was observable between different sub-individuals, and interference striations were found confined to the subgrain boundaries. These boundaries between sub-individuals of variable size are characterized by growth features, forming angular growth patterns with the edges of the sub-individuals as bisectors of the respective angles (Figures 15, 16). Irregular growth structures, which are not consistent with that general scheme are rare (Figure 17).

Confined to the boundaries between seed plates and synthetic hydrothermally-grown emerald, small opaque particles were observed (Figure 18), which were obviously trapped at the start of the growth process. The synthetic emeralds themselves were found to be extremely pure, and in some faceted samples, only growth structures but no foreign inclusions were observable.

In several gemmological papers, opaque hexagonal-shaped platelets are mentioned as inclusions in Russian hydrothermally-grown synthetic emeralds (Gübelin, 1986; Lind *et al.*, 1987) and some inclusions of this type were also found in the 13 samples investigated by the present author (Figure 19). The presumption of Gübelin (1986), that these particles are platinum platelets seems unlikely according to growth conditions of commercially produced samples (cf. section IV). In the publication of Granadchikova *et al.* (1983) these platelets are also pictured, and a possible explanation is found in the paper of Klyakhin *et al.* (1981b), who mentioned hematite as an inclusion in hydrothermally-grown synthetic emerald. This explanation seems more reasonable according to growth conditions of the samples using oxide buffers in the equilibrium field hematite-magnetite.

In addition, Klyakhin and his co-workers also mentioned two- and three-phase inclusions, which were occasionally found in the samples examined for this paper. Typical are double refractive crystal inclusions confined to growth tubes with liquid or two-phase fillings (Figures 20, 21) or similar multiphase-inclusions, which are not confined to a small crystal (Figure 22). Some of the synthetic emeralds also contained feathers consisting of liquid, two-phase and three-phase inclusions (Figures 23, 24), probably filled with two immiscible liquids and one gaseous phase.

IV. Growth conditions and properties of Russian hydrothermally-grown synthetic emeralds

Two papers in Russian dealing with growth conditions and properties of industrially-grown synthetic hydrothermal emeralds are available to the present author. In the paper of Godovikov *et al.* (1982), some details about industrial growth processes of synthetic gem materials in USSR are described. In the publication of Granadchikova *et al.* (1983), properties of natural emeralds from Ural mountains, flux-grown and hydrothermally-grown research material and synthetic emeralds of the industrial hydrothermal production in USSR are compared. According to Godovikov *et al.* (1982), industrial growth of hydrothermal synthetic emerald in USSR is performed at L'vov, Ukraine. The

Fig. 6. Russian hydrothermally-grown synthetic emerald; faceted sample with residue of the seed parallel to the table, growth lines and colour zoning parallel to the boundary colourless seed/synthetic emerald. Crossed polarizers. 20x.

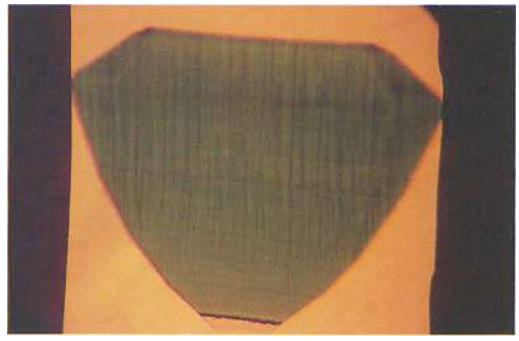

Fig. 7. Russian hydrothermally-grown synthetic emerald; faceted sample with residue of the seed at the culet, step-like growth lines and colour zoning parallel to the boundary colourless seed/synthetic emerald, irregularly changing subgrain boundaries almost perpendicular to seed plate and colour zoning. 38x.

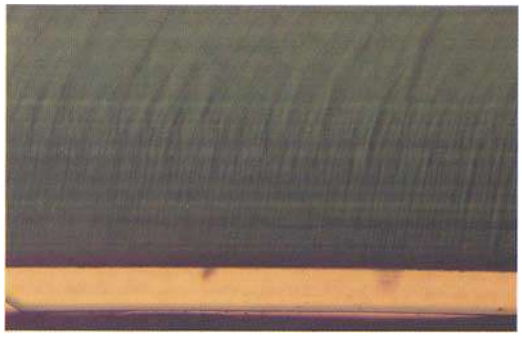

Fig. 8. Russian hydrothermally-grown synthetic emerald; faceted sample with residue of the seed parallel to the table, step-like growth lines and colour zoning parallel to the boundary colourless seed/synthetic emerald, irregularly changing subgrain boundaries almost perpendicular to seed plate and colour zoning. Crossed polarizers. 40x.

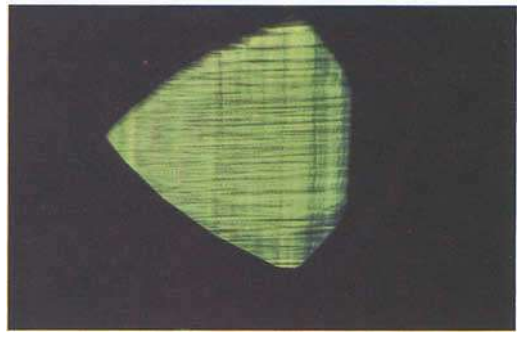

Fig. 9. Russian hydrothermally-grown synthetic emerald; faceted sample without residue of the seed, step-like growth lines and colour zoning, irregularly changing subgrain boundaries almost perpendicular to the colour zoning. Crossed polarizers. 20x.

Fig. 10. Russian hydrothermally-grown synthetic emerald; faceted sample without residue of the seed, step-like growth lines and colour zoning, irregularly changing subgrain boundaries almost perpendicular to the colour zoning. Crossed polarizers. 40x.

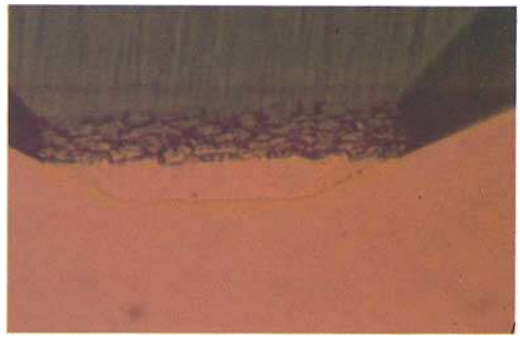

Fig. 11. Russian hydrothermally-grown synthetic emerald; faceted sample with residue of the seed at the culet, cellular pattern of the boundary seed plate/synthetic emerald, subgrain boundaries between subindividuals originating from each of this cellular nucleation centres with cobbled appearance. 90x.

Fig. 18. Russian hydrothermally-grown synthetic emerald; opaque particles confined to the boundary colourless seed/synthetic emerald. View in a direction perpendicular to the boundary. 40x.

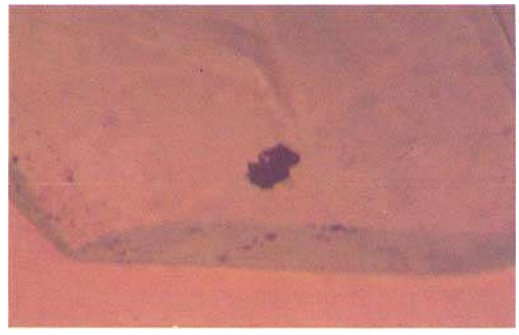

Fig. 19. Russian hydrothermally-grown synthetic emerald; inclusions of opaque hexagonal platelets, most probably hematite. 100x.

Fig. 20. Russian hydrothermally-grown synthetic emerald; inclusion of a double refractive crystal. Crossed polarizers. 100x.

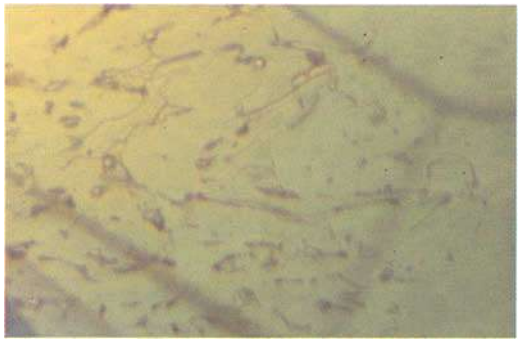

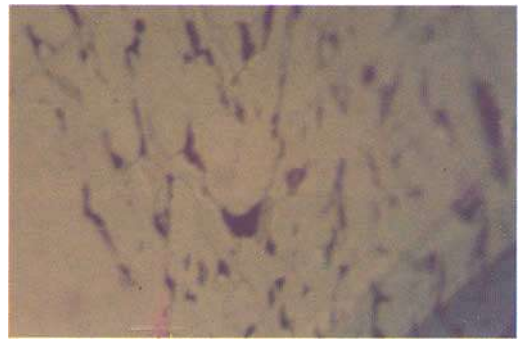

Figs. 23, 24. Russian hydrothermally-grown synthetic emerald; feather with three-phase inclusions, probably consisting of two immiscible liquids and one gaseous phase; dependent on the direction of view, all three phases show transparency (Figure. 23), or two liquid phases show transparency and the gaseous phase shows total internal reflection, or one liquid phase shows transparency and one liquid and one gaseous phase show total internal reflection (Figure 24). Figure 23, 70x; Figure 24, 95x.

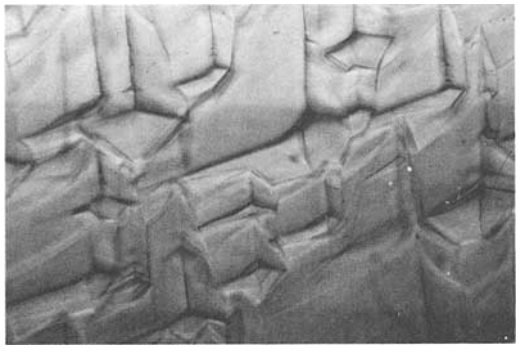

Fig. 13. Russian hydrothermally-grown synthetic emerald; block structure of subparallel orientated sub-individuals with curved surfaces. 30x.

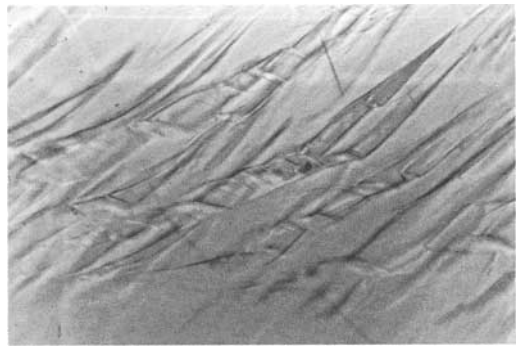

Fig. 14. Russian hydrothermally-grown synthetic emerald; irregularly changing subgrain boundaries between sub-individuals with preferred orientation. 35x.

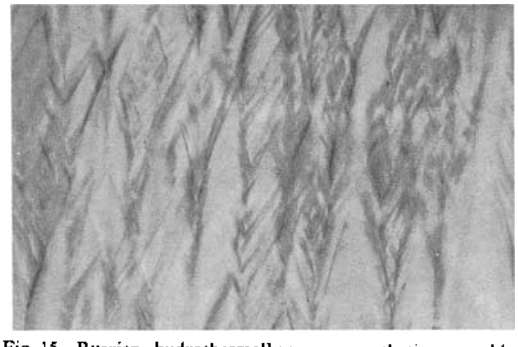

Fig. 15. Russian hydrothermally-grown synthetic emerald; angular growth patterns with the edges of sub-individuals as bisectors of the angles. 45x.

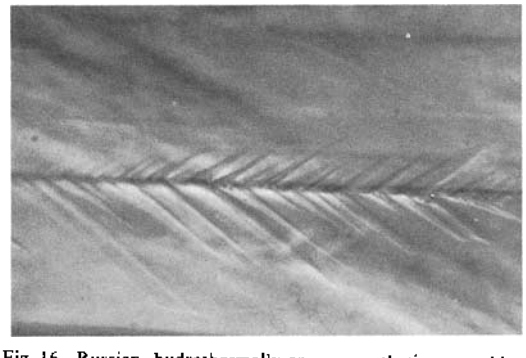

Fig. 16. Russian hydrothermally-grown synthetic emerald; angular growth pattern with the edge of a sub-individual as bisector of the angles. 50x.

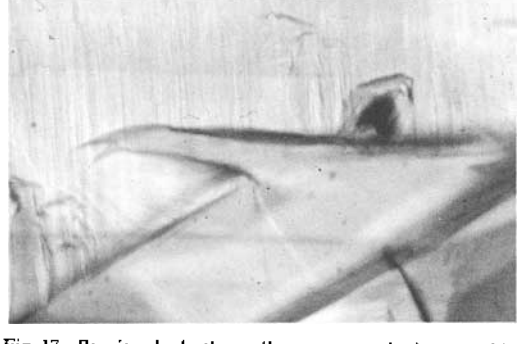

Fig. 17. Russian hydrothermally-grown synthetic emerald; irregular growth structure. 45x.

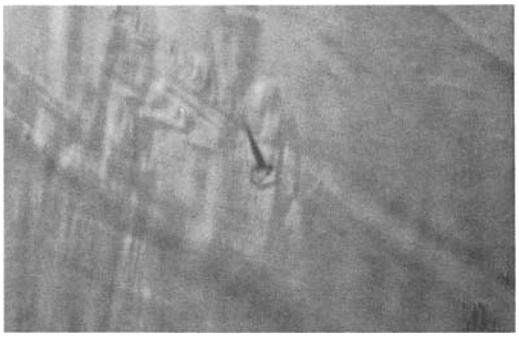

Fig. 21. Russian hydrothermally-grown synthetic emerald; the identical inclusion of Figure 20, consisting of a double refractive crystal and a growth tube with liquid filling. 100x.

Fig. 22. Russian hydrothermally-grown synthetic emerald; three-phase inclusion, probably consisting of two immiscible liquids and one gaseous phase. 100x.

following growth conditions are mentioned: temperature range 550-620°C, temperature gradient method, pressure 1000 bars, stainless steel autoclaves 200-800 ml in volume without precious metal liners are used, growth rate of synthetic emerald 0.2-0.3 mm per day, in 20-30 days from seed plates of about 6 cm^2 in size synthetic emerald crystals of 10-20 grams in weight are grown, the thickness of synthetic emerald layers attains 5-7 mm, natural beryl or oxides of Be, Al and Si are used as nutrients.

No details about the exact composition of the solutions used for the growth process and no information about the temperature gradient applied are given. However, temperature and pressure are in the range of growth conditions mentioned for scientific research material, and growth features of the research material (Klyakhin *et al.*, 1981b; Lebedev & Askhabov, 1984; Lebedev *et al.*, 1986) are identical with properties of industrially-grown samples as described in this paper and by Granadchikova *et al.* (1983). Thus, the compositions of solutions and the temperature gradients mentioned in scientific research papers are assumed to be similar or almost identical with the conditions used for the industrial process.

The solutions are characterized as 'acidic solutions' or as 'fluor-bearing solutions of complex compositions' as well as 'acidic solutions of complex compositions', temperature gradients mentioned are $\Delta T = 45°C$, $\Delta T = 20\text{-}100°C$, or $\Delta T = 70\text{-}130°C$, at growth temperatures between 590 and 620°C and pressures between 800 and 1500 bars (Solntsev *et al.*, 1976, 1978; Il'in *et al.*, 1980; Klyakhin, 1980; Bukin *et al.*, 1980; Solntsev, 1981a; Shatsky *et al.*, 1981; Lebedev & Askhabov, 1984; Pugachev, 1984; Lebedev *et al.*, 1986). According to the valence states and lattice sites of iron, nickel, and copper as they are indicated from absorption spectra (cf. section III.3; Table 5), the samples were grown under oxygen partial pressures in the $Fe_3O_4 - Fe_2O_3$ equilibrium field (cf. Klyakhin *et al.*, 1981b).

In the opinion of the present author, the most striking difference between part of the samples grown for research purposes and specimens of the industrial production is the lack of precious metal (platinum or gold) inserts in the industrial process (Godovikov *et al.*, 1982; Granadchikova *et al.*, 1983), which are mentioned in some research papers (e.g. Shatsky *et al.*, 1981; Klyakhin *et al.*, 1981b; Lebedev *et al.*, 1986). According to Granadchikova *et al.* (1983), this experimental detail of growth conditions is responsible for the incorporation of high amounts of iron and nickel in the synthetic emerald crystals, originating from the walls of the steel autoclaves. In the opinion of the present author, the lack of precious metal inserts could also be responsible for the copper contents of the samples. However, it is also possible that certain amounts of iron, nickel and copper are added to the nutrient material, too.

Due to the fact that the influence of chromium and nickel is dominant for the colour of the samples (which is certainly known to the producers), the iron- and copper contents of these synthetic emeralds are most presumably more or less accidental. However, since the influence of nickel on the colour of nickel- and chromium-bearing synthetic emeralds as well as the interpretation of absorption spectra of chromium- and nickel-bearing synthetic emeralds was the subject of various Russian research papers (e.g. Lokhova *et al.*, 1980; Bukin *et al.*, 1981; Klyakhin *et al.*, 1981b), the incorporation of nickel is assumed to be most presumably non-accidental. As described in section III.3 in detail, this nickel content is responsible for a colour and pleochroism of the synthetic emeralds, which resembles that of natural emerald from particular occurrences, e.g. from Zambia, Brazil or Madagascar (cf. Table 4).

The high contents of transition metal oxides are

also responsible for some physical properties of the synthetic hydrothermally-grown emeralds, e.g. for specific gravities and refractive indices, which are found to be within the natural range. The presence of both type-I and type-II water molecules in Russian industrially-grown synthetic emeralds, which is typical for natural samples, is also due to growth conditions. Most probably, lithium ions in the channels of the beryl lattice cause the stabilization of type-II water molecules.

The choice of seed plates of colourless beryl, which were cut parallel to (5 5 $\overline{10}$ 6), obviously dominates growth structures in the synthetic emerald crystals, e.g. growth zoning parallel to the seed plate as well as the typical block structure of sub-individuals forming the hydrothermally-grown beryl crystals (cf. Lebedev & Askhabov, 1984). Both features are of high diagnostic value; they were never found in natural emeralds before and they are easily recognizable in the immersion microscope.

V. Conclusions

The industrial production of Russian hydrothermally-grown synthetic emeralds is performed in steel autoclaves without precious metal inserts using seed plates of colourless beryl, which are cut parallel to (5 5 $\overline{10}$ 6). Due to these growth conditions, distinct amounts of chromium, iron, nickel and copper are incorporated in the synthetic crystals and characteristic microstructures are formed. Both features are of high diagnostic value, they are easily recognizable by non-destructive techniques such as trace element analysis, by absorption spectroscopy in the visible and ultraviolet range and by microscopic examination using immersion liquids.

The chemical composition of the samples, i.e. the high amounts of transition metal oxides present, are responsible for the high values of refractive indices and specific gravities, as well as for the high unit cell dimensions. The colour and pleochroism of the samples is caused by traces of both dominant transition metal elements, chromium and nickel, and the influence of iron and copper is subordinate. The presence of type-I and type-II water molecules, which was regarded to be diagnostic for natural emerald up to now, is explainable by growth conditions, in which alkali ions were incorporated into the channels of the beryl structure. The synthetic emerald crystals consist of sub-individuals, the formation of which is due to the growth conditions applied, especially due to the orientation of the seed plate. With a detailed knowledge of all properties of this exceptional type of hydrothermally-grown synthetic emerald, no difficulties should arise with the recognition of samples of unknown origin.

VI. Acknowledgements

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Radiation induced structural damage in beryl

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Abstract

Stress-induced structural defects in beryl, similar to those first reported in irradiated topazes, are described and illustrated. As with topaz, the build-up of excess electrical charge and heat in the beryl, during irradiation, is thought to be the cause of these defects.

Introduction

For several years now, colourless topaz has been imported into the United States from Nigeria. Large quantities are brought in annually for the sole purpose of treatment, by a combination of irradiation and heating, to turn the topaz blue.

During linear accelerator (linac) treatment, when high-energy electrons in the 10 to 20 mega-electronvolt range are used, a great deal of heat is generated together with an excessive negative charge within the topaz. Due to the limited depth of penetration of the electrons both the heat and the electric charge are unevenly distributed within the topaz structure (Nassau, 1985; Schmetzer, 1987). This results in strain.

Further, the surfaces of the topaz crystals are cooled with running water during irradiation which sets up extreme temperature gradient, from the outer surface to the core, in the crystals (Nassau, 1985, Schmetzer, 1987). This causes even more internal strain which, in the most severe cases, relieves itself through cleavage along the basal pinacoid and through the formation of needle-like structural defects parallel to the *a*- and *c*-axes (Schmetzer, 1987). In some crystals these defects may take on a bold 'fish skeleton' or 'fern-like' form (Figure 1). But in all cases involving topaz these defects mirror the orthorhombic symmetry of their host.

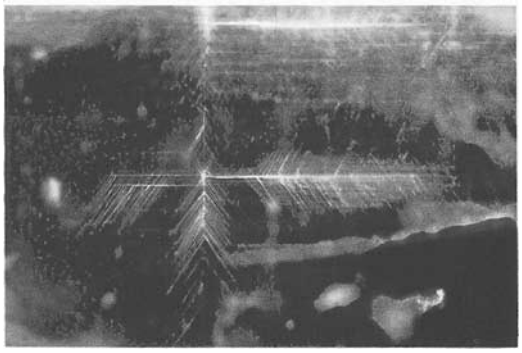

Fig. 1. Electron-induced structural damage showing the orthorhombic symmetry of the irradiated blue topaz host. Viewed perpendicular to the *c*-axis, at an angle inclined to the *a*-axis. 20x.

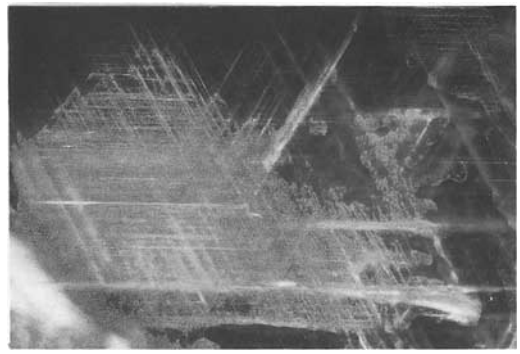

Fig. 2. Electron-induced structural damage showing the hexagonal symmetry of the irradiated yellow beryl host. Viewed parallel to the *c*-axis direction. 35x.

When shipments of topaz are received from Nigeria it is common to have a few crystal sections and fragments of colourless 'goshenite' beryl mixed in with the colourless topaz (Peter and Bobbi Flusser, Personal Communication). But, because of the quantities of rough involved, and the commercial nature of this mass-treatment process, the few

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pieces of beryl are never separated from the bulk of topaz before irradiation... but only after the operation.

Description of the beryl

When the treated topaz is removed from the linac it is then relatively easy to spot any beryl 'ringers' that may have been present. Since all the colourless beryl has turned to a golden yellow, it now stands out in stark contrast with the brownish-to-blue topaz.

Three linac-treated yellow, anhedral crystal fragments of Nigerian beryl, weighing betwen 8.92 and 21.05 carats, were recovered from a recent treatment run of topaz and examined using a standard gemmological microscope. Just like some of the electron-treated topazes previously described by Schmetzer (1987), which showed radiation-induced defects that delineated their orthorhombic symmetry (Figure 1), two of these beryls exhibited similar structural defects that mirrored the hexagonal symmetry of their host (Figure 2). Defects such as these have never before been reported as inclusions in beryl from any locality.

In a follow-up examination of several hundred carats of un-irradiated Nigerian beryl no such defects were observed. This suggests that linac generated electron-irradiation is responsible.

Conclusion

Of three linac-treated Nigerian beryls examined, two of them showed the prominent hexagonal defect structure. If these beryls were to be treated on a commercial basis, using a strong beam of electrons generated by a linear accelerator, then perhaps as many as two-thirds of them would develop this internal hexagonal pattern.

The fineness of these defect 'needles', together with their dense, close-packed nature (Figure 2), is reminiscent of the rutile needles found in Sri Lankan star corundums. This suggests that perhaps six-rayed star beryls could be cut from the best of these treated stones.

Acknowledgements

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The emeralds of Fazenda Boa Esperança, Tauá, Ceará, Brazil: occurrence and properties

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Abstract

The emerald-producing Fazenda Boa Esperança (Tauá, Ceará) in Brazil, the regional and local geology, and the properties of the emeralds are discussed.

The emerald occurrence is situated in biotite schists and tremolite-bearing schists containing phlogopite and chlorite. Its formation is closely related to anatectic pegmatites which have intruded into the rock series. The emeralds are associated with very large apatite crystals and locally, with corundum.

Chemical analyses show low contents of Cr_2O_3 and V_2O_3 (<0.25 wt.%) and rather high contents of FeO (0.91-1.17 wt.%), MgO (2.42-2.69 wt.%) and Na_2O (1.69-1.96 wt.%).

The following substitutions explain the low Al-contents:-

$Al^{3+,VI} = (Mg,Fe)^{2+} + Na^{+}$

$Al^{3+,VI} = (Fe,Cr,V)^{3+,VI}$

The Tauá emeralds contain many mineral inclusions. So far, phlogopite, tremolite, molybdenite, allanite and apatite have been identified. In addition, accumulations of very small fluid droplets and/or mineral dust and plane cavities occur, mostly exhibiting a one-phase filling. The concentrations of these inclusions lower the gemmological quality of the emeralds.

1. Introduction

The Fazenda (farm) Boa Esperença lies 40 km NNE of Tauá, a small town in the south-east of the federal state of Ceará (Figure 1). The region is one of the driest in Brazil, and the caatinga vegetation typical of this arid area known as the Sertao, consists essentially of low thorny bushes, stunted trees and numerous species of cacti.

The emerald deposit of Fazenda Boa Esperança, which lies less than 1 km east of National Highway BR 020 (linking Fortaleza with the capital Brasilia), has been known for a long time. Since the early 1950s, emeralds (and/or green beryls) have been extracted by garimpeiros (Brazilian freelance miners). At the beginning of the 1970s, the mining company Mineração Sao Pedro Limitada began serious mining operations on a larger scale, but soon gave up due to the high development costs involved. In 1983, the company Mineração Brasileira Ltda. undertook detailed geological mapping of the area (Andrade, 1983; Korpershoek, 1983).

2. Geology

Figure 2 presents the regional geology in which the emerald deposit at Fazenda Boa Esperança is situated.

The following presentation of the regional and local geological conditions of the emerald deposit is based on the work of Gomes *et al.* (1981), Mello *et al.* (1978) and Korpershoek (1984).

2.1 *Regional Geology*

Over 80% of the surface of Ceará State is mainly composed of Precambrian crystalline rocks. Apart from this, granitic and dioritic-gabbroidal intrusive rocks and pegmatites also occur.

At the end of the Brazilian orogenesis (ca. 650-600 million years), the main geological structures including the characteristic faults, had been formed. Tectonic movements along some of the faults during the Palaeozoic-Mesozoic eras led to a partitioning of the crystalline basement into numerous fault blocks. Thus, Fazenda Boa Esperança lies on the southern border of the Bloco Santa Quiteria, which is described in Figures 2 and 3 as Unit II. In the north, the Bloco Santa Quiteria overlies leptites and, to a lesser degree, biotite gneisses of Unit III. On the other hand, in the more southern area the Bloco Santa Quiteria underlies a polymetamorphic volcano-sedimentary unit, the Complexo de Pedra Branca (Unit I in Figures 2 and 3).

The latter is lithologically very varied and is composed of quartzites, leptites, mica schists, para- and ortho-gneisses, migmatites, amphibolites, serpentinites etc. The Complexo de Pedra Branca is

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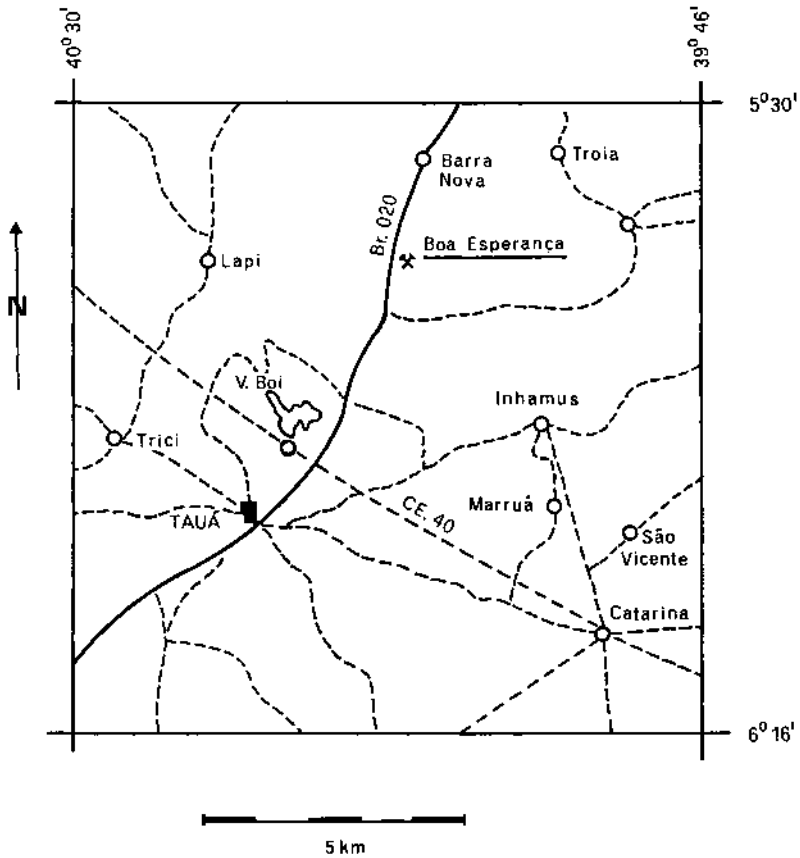

Fig. 1. Geographical situation of the emerald deposit at Boa Esperança, Tauá, Ceará.

regarded as a 'Nucleo Antigo'* at least 2000 million years old, and overprinted by the Brazilian orogenesis.

In the Bloco Santa Quiteria, several diorite massifs occur whose age and stratigraphical correlation are still unknown. Furthermore, several gabbro bodies occur with a minimum age of 1900 million years, and two granite intrusions occur within the largest diorite massif (Diorito de Tauá). The intrusions are considered to be syntectonic with the Brazilian orogenesis.

A system of rhyolitic to dacitic dykes appear in the south-western portion of the Bloco Santa Quiteria, which cut both the Complexo de Pedra Branca and the Tauá diorite. These dykes can be up to 300 metres wide and several kilometres long. Other dykes belonging to the same lithological type, fill concentric fractures in the syntectonic granites near Tauá. The age of these late-tectonic dykes is given as about 600 million years.

*Blocks which split a folded region into different zones. They may have been formed during an earlier period, or originated from the same deformation phase which folded the region but, however, had already consolidated (Khain & Sheynaann, in Gomes *et al.*, 1981).

2.2 *Local geology and genetic aspects*

Tectonically speaking, the Fazenda Boa Esperança lies on the southern border of the Bloco Santa Quiteria (Unit II in Figures 2 and 3). This area is mainly composed of biotite gneisses and -schists and leptites, as well as ultramafic rocks, amphibolites and a large number of pegmatites (Figure 3).

Emerald is found in the biotite schists near the pegmatite veins. This unit lithologically presents a very varied development and comprises ultramafic rocks (metamorphosed to talc-schists, tremolites etc.), metabasites, amphibolites (often undergoing transformation to hornblende-gneiss), leptites, as well as biotite gneisses and emerald-bearing biotite schists. The latter are, at least partially, described as 'tremolite schists with phlogopite and chlorite' (Cassedanne and Mello, 1979). Additionally, numerous dykes and pegmatite veins occur.

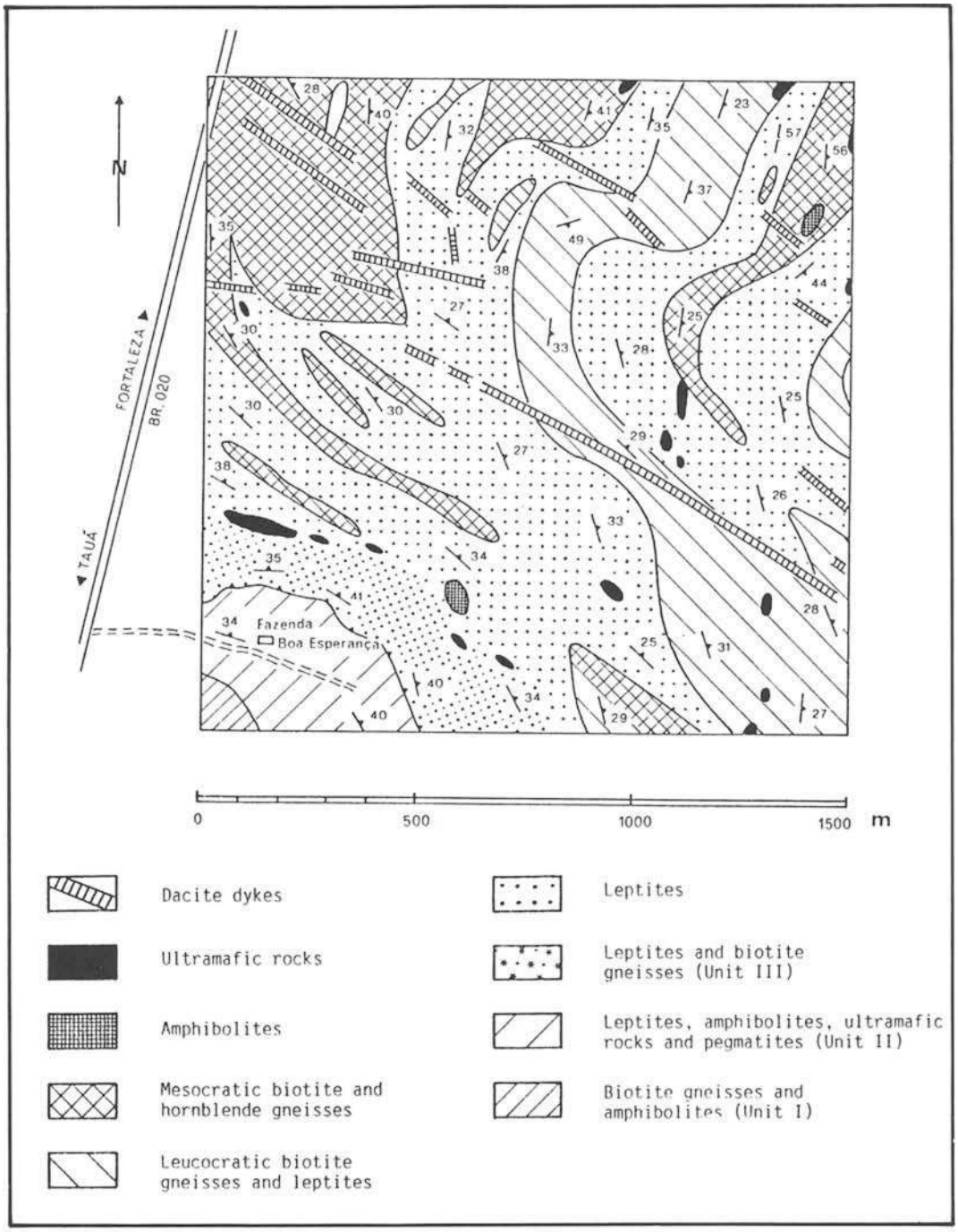

Fig. 2. Regional geology of the emerald deposit.

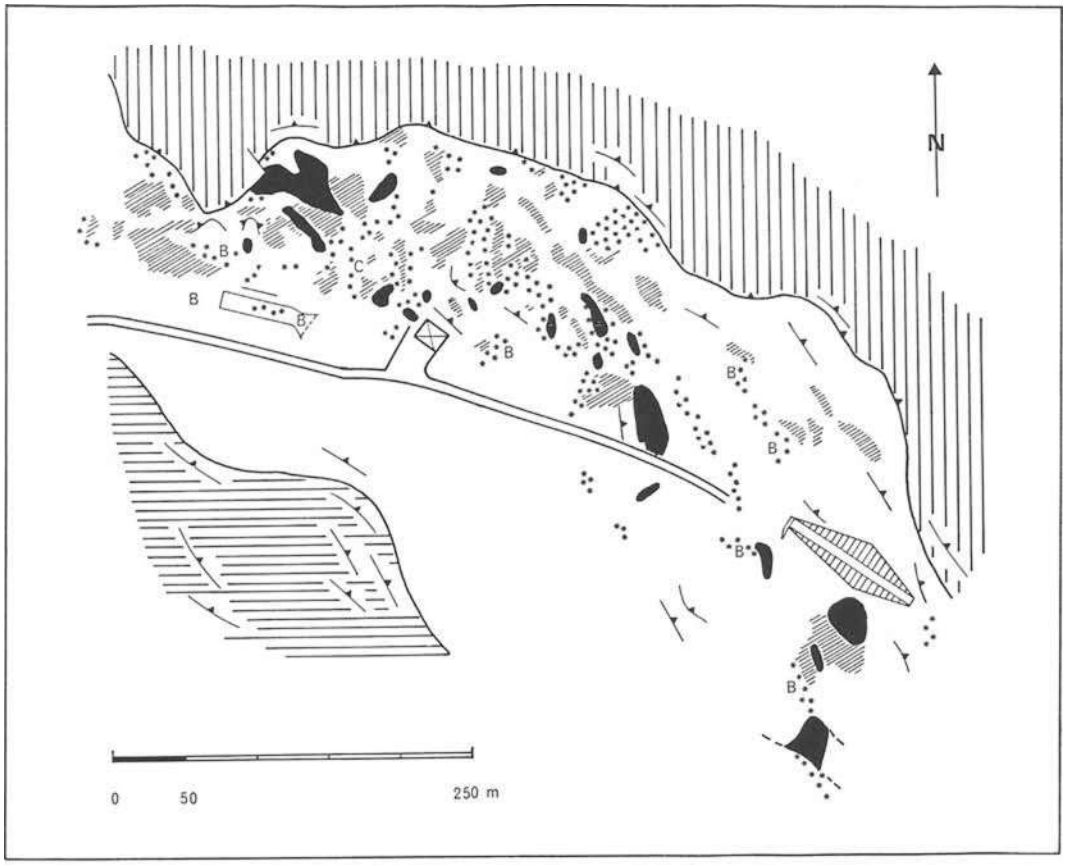

Leptites and (to a lesser degree) biotite gneisses — Unit III

Pegmatites

Ultramafic rocks

Amphibolites

Biotite gneisses and -schists

Unit II

Biotite gneisses and (to a lesser degree) amphibolites — Unit I

B = beryl, emerald

C = corundum, sapphire

Fig. 3. Local geology of the emerald deposit.

The complete volcano-sedimentary sequence as well as the layers directly overlying it were intensively folded; the volcano-sedimentary unit underwent at least three deformation phases.

The ultramafic rocks occur as oval, lenticular or irregular bodies. These, as did the other rocks of the unit, experienced a regional metamorphism and were transformed to talc-schists, talc-tremolite schists, and tremolitites. Some of the ultramafic rocks contain grains of magnetite and are considerably magnetic.

The numerous pegmatites form long and irregular bodies, and also concordant intrusions. They usually have a simple composition mainly of quartz and albite. They are coarse- to fine-grained, with the latter appearing to be the predominant type.

Cassedanne and Mello (1979) suggest that this fine-grained facies originates from the cataclasis during the tectonic deformation. The pegmatites as well as the leptites contain minute red grains of garnet.

The pegmatites are mainly quite homogeneous. Where differentiated, muscovite-rich portions occur, or, in some, finely-layered biotite can be present. Sometimes, concentrations of quartz are developed. Apart from these, the following minerals are present: beryl, columbite-tantalite, tourmaline, apatite, molybdenite and native bismuth or bismutite (Cassedanne and Mello, 1979).

The pegmatites do not seem to be directly derived from late magmatic processes, which usually are accompanied by significant hydrothermal activity. Such an origin would seem to be improbable, because their unusual composition can only with difficulty be linked to a simple granitic origin. They were probably locally mobilised during the regional metamorphism, when pressure and temperature rose notably. This led to a partial anatexis and to the formation of Na-rich pegmatites, determined by the nature of the host-rock. Their composition differs from the K-rich pegmatites in the hanging wall, reflecting the composition of the neighbouring leptites (Korpershoek, 1983).

The emerald-bearing biotite schists (or tremolitic schists with phlogopite and chlorite) neighbouring the 'anatectic' pegmatites are products of chemical reactions (metasomatism) between the pegmatites and the basic or ultrabasic rocks. By exometamorphic processes, i.e. through the change of the original rock by the addition of components of another surrounding chemical medium, the necessary elements for the formation of beryl can reach the biotite schist and crystallize in the form of exometamorphic beryl (or emerald). Most of the beryls so-formed correspond to those which are found in the pegmatites themselves, i.e. they are mostly pale green; the beryl variety emerald is only formed where an adequate supply of colour-providing elements from the basic or ultrabasic rocks is available. Chromium is possibly supplied by some of the chromian magnetite in the ultramafic rocks.

The emeralds are generally small and seldom longer than 2 cm. Occasionally, fragments of larger crystals have been found. The prismatic crystals (combination of six-sided prisms and basal pinacoid) exhibit different shades of green, whereby an apple-green seems to be the most abundant colour. According to Cassedanne and Mello (1979), this green colour in the Tauá emeralds stems from the addition of vanadium. The authors' chemical analyses could not confirm this, and their work suggests rather that Cr and Fe are responsible for the colour (see section 3).

In a preliminary classification of emerald deposits (Schwarz, 1987), the Tauá occurrence was assigned to the 'classical' type of genesis, characterized by the association of mafic-ultramafic rocks and pegmatites (Be-supplier). As the Tauá pegmatites cannot be considered to be 'true' pegmatites containing light elements, but rather as mobilisations, i.e. anatectic pegmatites, the question as to the origin of the Be has still to be answered. The question of whether this deposit and other similarly-formed emerald mineralizations should be considered to be a sub-type of the classical emerald genesis, or rather as a specifically separate class of genesis, will only be resolved after further detailed studies are carried out.

The emerald is occasionally associated with unusually large (up to 15 cm), beautifully formed apatite prisms. These are dark green to bluish in colour and often so clear and free of inclusions as to make them of great interest to the gem cutter.

Apart from emerald, corundum has been observed in Unit III in three habits (Figure 3) (Korpershoek, 1984). Firstly, the mineral occurs as minute (<0.1 mm) xenomorphic grains of the blue variety of corundum – sapphire, which occurs as an accessory mineral in the tremolite-talc schist. Also, colourless to blue corundum crystals have been found in a contact metamorphic rock mainly composed of oligoclase (20-22% An). These corundums are characterized by a nearly right-angled parting of the rhombohedron $(10\bar{1}1)$. The third habit of the corundum is as colourless, prismatic crystals, originally up to 3 mm long, which have largely been replaced by sericite, and which occur together with black tourmaline in muscovite schists.

3. Optical and chemical data of the Tauá Emeralds

Optical data stemming from a number of authors

Table 1. Refractive indices and birefringences of the Tauá emeralds

n_e	n_o	Δn	Reference
1.580 ± 0.001	1.586 ± 0.001	0.006	Cassedanne & Mello (1979)
1.579	1.587	0.008	Branco *et al.* (1984)
1.579 – 1.582	1.585 – 1.589	0.006 – 0.008	Schwarz (1987)*
1.570 – 1.574	1.577 – 1.581	0.007 – 0.008	Schwarz (1987)**

*Range of optical data in dark emeralds
**Range of optical data in light emeralds

concerning the emeralds from Fazenda Boa Esperança are presented in Table 1.

The electron microprobe analyses (Table 2) were carried out with an ARL-SEMQ instrument, in which the WDS spectrometer was used in combination with an energy dispersive system (EDS, TN 2000) (Schwander and Gloor, 1980). The instrumental working conditions were 15kV accelerating voltage, 30mA beam current with a beam diameter of about 2 micrometres. The standards used for the analyses comprised synthetic oxides and simple silicate minerals.

The analyses were cationically normalized to Si = 6 atoms. Low Cr_2O_3 and V_2O_3-values (<0.25 wt.%) contrast with high values for FeO (0.91 – 1.17 wt.%), MgO (2.42 – 2.69 wt.%) and Na_2O (1.69 – 1.96 wt.%). The low Al contents are compensated by Mg and Fe^{2+} through the reactions:

(a) $Al^{3+,VI} = (Mg,Fe)^{2+} + Na^{+}$

Cr, V and Fe (Figure 4) likewise compensate:

(b) $2Al^{3+,VI} = Fe^{3+,VI} + (Cr,V)^{3+,VI}$

(see Franz *et al.*, 1986).

The calculations at the bottom of Table 2 show that principally substitution-type (a) occurs in the case of these emeralds, and differences in charge between Mg^{2+} and Fe^{2+} versus Al^{3+} are compensated by Na^{+}. Figure 4, exhibiting a gradient <1 shows a slight excess of (Mg+Fe) over Na. This can be explained by a small amount of Fe^{3+} which need not be compensated chargewise by Na^{+}. Probe analyses cannot indicate oxidation state nor position of the ions within the lattice and as the Fe can occur either as Fe^{2+} or Fe^{3+} in the octahedral or tetrahedral positions, a certain degree of uncertainty in the crystal chemical treatment of this element can occur. Figure 4 compares chemical plots between the Tauá and Itabira emeralds (Hänni, *et al.*, 1987). The Tauá samples are characterized by a larger

Table 2. Microprobe analyses of Tauá emeralds

SiO_2	66.92	67.13	65.99	63.16	63.76	63.75
Al_2O_3	15.83	15.57	14.84	14.66	14.93	14.84
Cr_2O_3	.10	.19	.06	.23	.10	.23
V_2O_3	.00	.00	.06	.00	.00	.00
FeO	.91	1.17	1.05	1.03	1.00	1.11
MgO	2.46	2.69	2.42	2.46	2.47	2.55
Na_2O	1.69	1.73	1.91	1.85	1.96	1.87
Total	87.91	88.48	86.33	83.39	84.22	84.35
Formula On the basis of 6 Si atoms						
Si	6.000	6.000	6.000	6.000	6.000	6.000
Al	1.673	1.640	1.591	1.654	1.656	1.646
Cr	0.007	0.013	0.004	0.017	0.007	0.017
Fe^{2+}	0.068	0.087	0.080	0.081	0.079	0.088
Mg	0.329	0.358	0.328	0.348	0.346	0.358
Na	0.293	0.300	0.336	0.341	0.358	0.342
Σ	8.370	8.398	8.339	8.441	8.446	8.451

Total Fe calculated as FeO

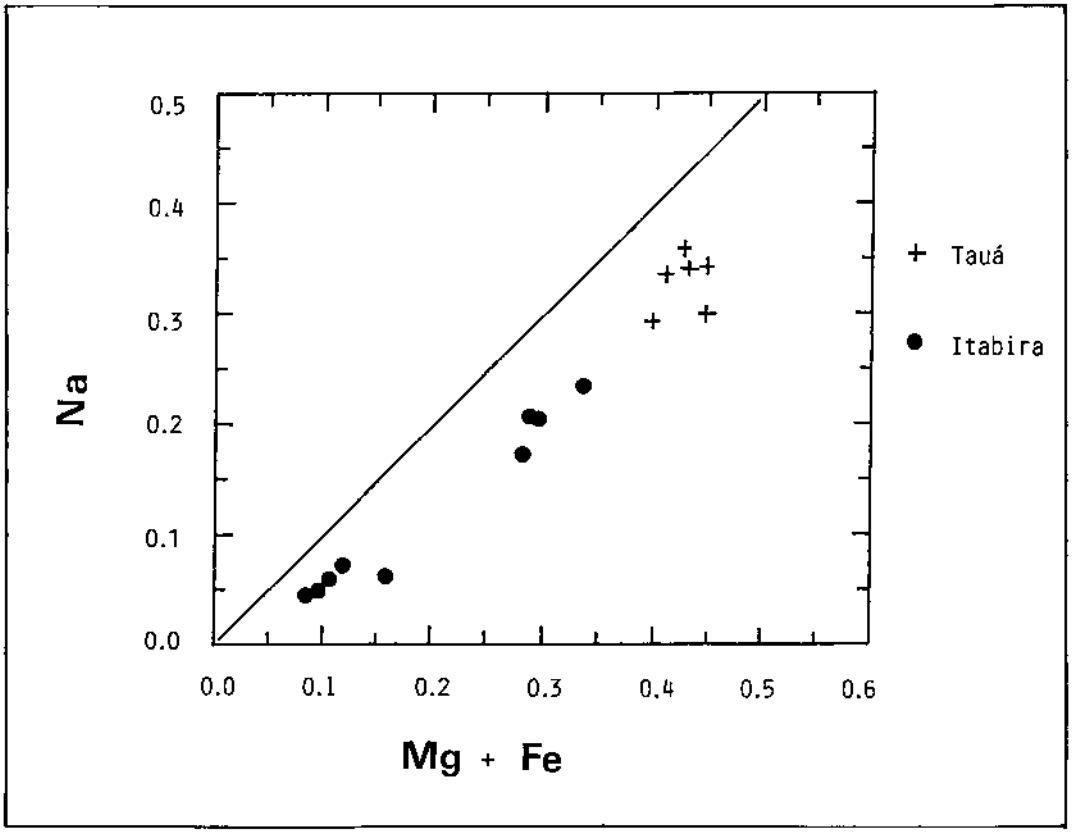

Fig. 4. Comparison between the relationship Na vs. (Mg+Fe) in emeralds from Tauá and Itabira.

amount of Na, Mg and Fe, substituting for Al, than in the Itabira material.

4. Inclusions

The most conspicuous property exhibited by the Tauá emeralds is the presence of numerous mineral inclusions, which strikingly reflect the mineralogy and geology of the area at the time of the formation of the emerald. So far, the following mineral inclusions have been identified:

Biotite/phlogopite

The probe analyses in Table 3 show that the mica inclusions in the Tauá emeralds are phlogopite (Mg/Fe>2). Their distribution pattern in the host crystal as well as variations in habit and colour indicate the occurrence of two distinctively different genetic types; firstly, of protogenetic inclusions mainly of a dark brown colour with irregular or rounded shapes and which are irregularly distributed within the emerald (Figures 10, 11). In contrast to these, mica crystals of syngenetic origin are crystallographically oriented. These are in the form of thin pseudohexagonal platelets lying either parallel to the basal plane of the emerald or parallel to the prism planes of the emerald, intersecting each other at angles of 60 and 120° (Figure 11). Their colour is usually a light brown.

Tremolite

The habit of the tremolite crystals varies from prismatic needles to thick stalks or 'bamboo-like' forms (Figures 5, 6). The crystals are colourless through weakly green to dark green, are randomly oriented throughout the emerald crystal, and sometimes form dense aggregates. These are typical protogenetic inclusions, and are often broken at one or both ends, or 'sharpened' to a pencil-like form (Figure 7). Table 3 gives two typical analyses. The chemical analyses of the amphiboles correspond to tremolite or tremolitic hornblende respectively.

Molybdenite

Although molybdenite (Figure 8) occurs in part as perfect although often warped (pseudo-) hexagonal platelets with a metallic lustre, partially

Table 3. Microprobe analyses of mineral inclusions in Tauá emeralds

	Phlogopite		Tremolite*	Allanite**
SiO_2	42.58	41.68	52.41 – 56.04	31.28
TiO_2	.32	.31	.00 – .12	.00
Al_2O_3	12.44	12.35	2.42 – 4.48	14.43
Cr_2O_3	.11	.17	.22 – .47	.00
V_2O_3	.00	.00	.00 – .03	.00
FeO	6.70	7.68	6.45 – 7.00	10.60
MnO	.04	.00	.12 – .40	.00
MgO	22.90	21.90	19.06 – 20.33	1.27
CaO	.04	.06	11.40 – 12.17	9.71
Na_2O	.63	.56	.63 – 1.17	.21
K_2O	8.74	8.68	.00 – .05	.13
F	~2.4	~2.7	.90 – 1.20	n.d.
Total	96.90	96.10		67.63

* Range encountered in 8 inclusions of tremolite; fluorine not quantitatively determined in all crystals.

** Partial analysis. Cerium was qualitatively determined; usually about 30 wt.% in allanites.

corroded crystals are more common and these then take on irregular 'ink stain' or skeletal forms (Figure 5).

Allanite (orthite)

Allanite appears both as zoned prismatic and thick 'stems' (stalks), and as fibrous columnar crystals with a dark brown colour, mainly arranged in sheaf-like aggregates (Figure 8). Table 3 presents a partial chemical analysis of an allanite crystal.

Apatite

Apatite forms colourless and transparent crystals, occurring mainly as short prisms.

Other mineral inclusions

One of the mineral inclusions could not be identified. This is a strongly orangeish-red coloured irregular crystal (Figures 5, 14).

The Tauá emeralds can contain numerous tremolite crystals (with very little or no mica), but can also be totally free of tremolite. This depends on the composition of the respective host rock of the emerald, i.e. whether the latter is mainly a biotite/phlogopite schist or a tremolite-bearing schist with phlogopite and chlorite.

In general, the Tauá emeralds produced nowadays are not of a high quality, mainly due to the large number of inclusions in them. Apart from the mineral inclusions described above, many minute particles exist which, in part, form dense clouds resulting in reduced transparency. These collections of minute liquid droplets and/or mineral dust are more or less evenly distributed throughout the emerald (Figure 12).

Shallow cavities (mainly containing a single phase) and numerous cracks add to the general opacity (Figure 13).

Acknowledgements

We wish to acknowledge the generous cooperation of the Mineração Brasileira Limitada (MBL) and Mr Peter Bartholomew, during the investigation at the Fazenda Boa Esperança, as well as for the use of maps and unpublished material. Mr Raimundo Mariano G. Castelo Branco kindly supplied material for the chemical analyses and the mineral inclusion studies. One of the authors (D.S.) is grateful to the following institutions for financial support and the provision of materials: Deutscher Akademischer Austauschdienst (DAAD), Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ), Deutsche Forschungsgemeinschaft (DFG) and the Fritz Thyssen Foundation. We also wish to thank Professor H. Schwander for his support during the microprobe studies.

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Fig. 7a

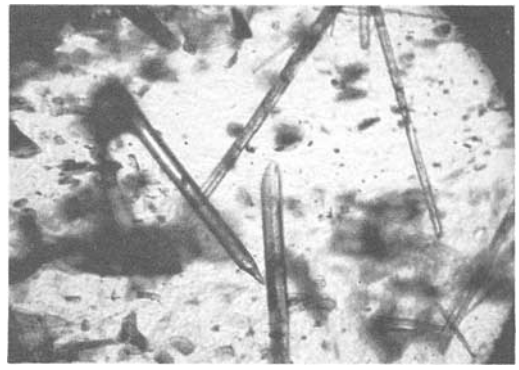

Fig. 7b

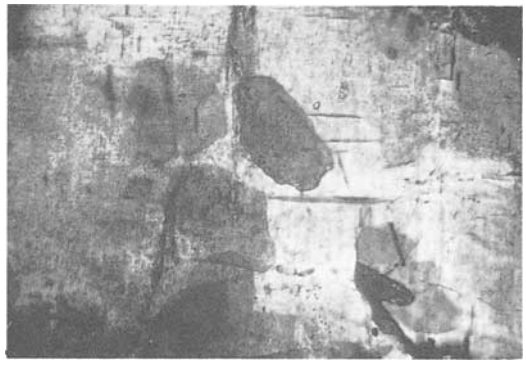

Fig. 10

Fig. 12

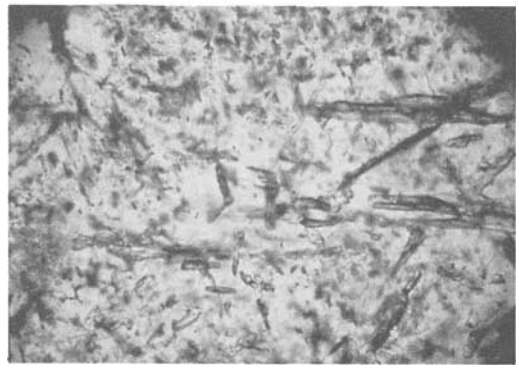

Fig. 13

Fig. 5. Tauá emeralds with numerous protogenetic mineral inclusions. Apart from columnar-prismatic or bamboo-like tremolite crystals with a light- to dark-green colour, brownish, mainly rounded, micas and opaque molybdenite can be seen. The latter mineral is usually strongly corroded when it then forms ink-spot or skeletal textures. On the left of the figure, a strongly orange-red unidentified crystal can be seen. 35x.

Fig. 6. Prismatic crystal of tremolite with a dark green colour, at one end intergrown with molybdenite. 50x.

Fig. 7a. Protogenetic crystal of tremolite. These are broken at one or both ends, indicating the effects of mechanical influences (transport, tectonic movements) prior to inclusion in the emerald. A further indication of the protogenetic origin of these crystals is supplied by the totally random orientation to that of the host crystal. 50x.

Fig. 7b. Pencil-shaped protogenetic tremolite crystals, randomly oriented within the emerald. 50x.

Fig. 8. Perfectly formed, (pseudo-) hexagonal platelet of molybdenite (black, opaque) with dark brown columnar crystals of allanite, which usually occurs in sheaf-like aggregates. 70x.

Fig. 9. Association of mineral inclusions in a Tauá emerald shown in polarized light (crossed nicols): columnar-prismatic tremolite crystals next to mica platelets and opaque molybdenite. 35x.

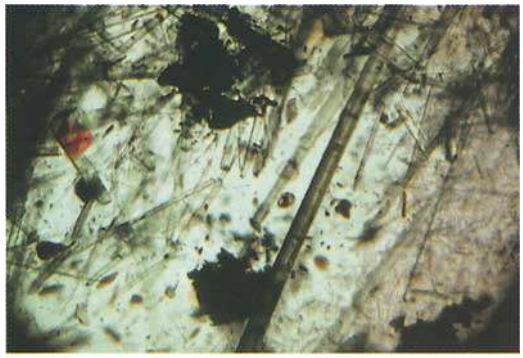

Fig. 5

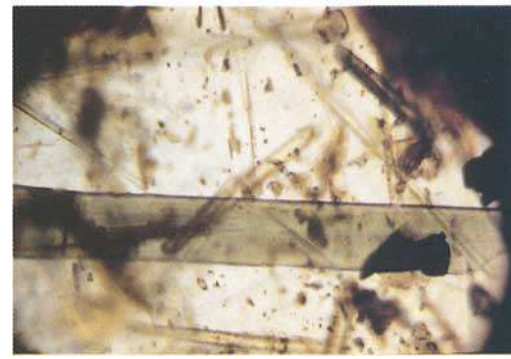

Fig. 6

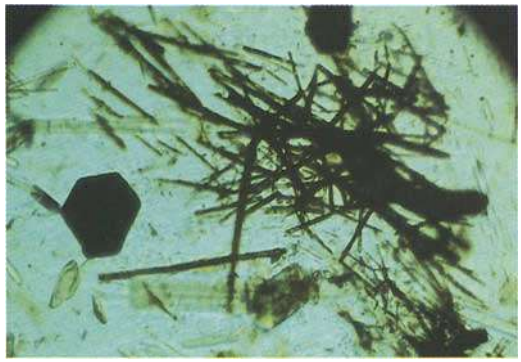

Fig. 8

Fig. 9

Fig. 11

Fig. 14

Fig. 10. Protogenetic dark brown mica inclusion (phlogopite). The crystals are irregularly bordered and randomly oriented in the emerald. 50x.

Fig. 11. This Tauá emerald contains numerous mica crystals which can be classified into two genetic types:
a) mica crystals with a protogenetic origin, and which are characterized by their usually dark colour and irregular forms. They are randomly oriented in the emerald host crystal;
b) syngenetic mica crystals are transparent, light brown platelets usually with a definite pseudo-hexagonal outline. They lie either parallel to the basal plane of the emerald, or parallel to the prism face of the emerald (the crystals appear as dark streaks in the Figure, which intersect at angles of 60 and 120°).

Fig. 12. Numerous minute particles (liquid droplets and/or mineral dust), the large number of which lead to a distinct reduction in the transparency and therefore the gemmological quality of the Tauá emeralds. 50x.

Fig. 13. The reduction of transparency in the emeralds can be caused by the numerous shallow cavities, which often contain a single-phase filling (liquid or gas). 70x.

Fig. 14. Strongly orange-red unidentified crystals on the left/right border of the photograph. 70x.

Note: All photographs were taken using immersion liquids.

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Hallmarked synthetic emerald

Alan Hodgkinson, FGA

Clarkston, Glasgow G76 7JD

The flux-grown Lennix emeralds probably provide the most interesting range of synthetic emerald inclusions to date – so much so that their appearance to the inexperienced eye gives a convincing impression of Nature's own handiwork. They were first reported in this *Journal* by Farn (1980) and described in more detail later by Graziani *et al.* (1987). The first specimen seen by the author was loaned in 1983 by Dennis Price, the Midlands lapidary and gemmologist. The latest were received from Monsieur Lens himself in 1987. The author is grateful to both.

The refractive indices for stones of both periods coincide: ray ω 1.564 and ε ray 1.560, DR 0.004. The specific gravity is 2.655. Under ultra-violet light they show a good red response in long-wave radiation and a slightly reduced response in short-wave. Through the Chelsea filter they show a bright raspberry red. These fluorescent effects, due to chromium, are more obvious in the later specimens.

The absorption spectrum shows a strong chromium pattern in the red, but the 477nm line in the blue was more fugitive and showed better when the yellowish-green ω ray was isolated by the polarizer drawing back the chromium cut-off at the violet end of the spectrum.

The crystals seen showed well-developed pinacoids from 5-16mm, whilst the prism faces were from 2.5-5mm in length.

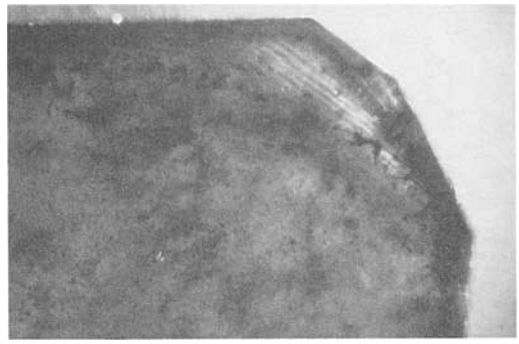

Fig. 1.

Fig. 2.

Figure 1. A view through a pinacoid face reveals part of the hexagonal crystal plan emphasized by chrome variations near the edge with a series of growth lines not always parallel to the outside prism walls. The growth lines repeat perhaps seven or eight times but are only peripheral, while the central area has every appearance of being natural by lens (no pun intended!). Certainly there are various veil-like inclusions floating about, but we see such general apparitions in natural as well as synthetic stones. A horizontal immersion microscope using benzyl benzoate RI 1.57, gave a closer look at the intriguing inclusion repertoire.

Figure 2. (25x) Stockings on a washing line are cavities which hang from the pinacoid washing lines, and the contents beckon you closer with higher magnification.

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Fig. 3.

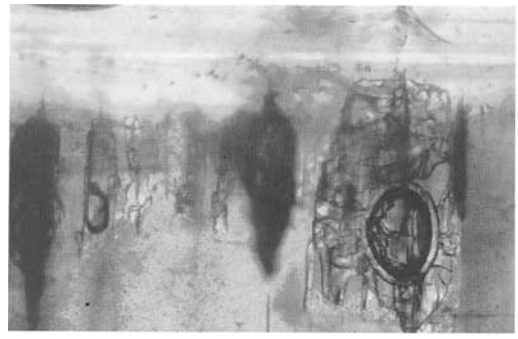

Fig. 4.

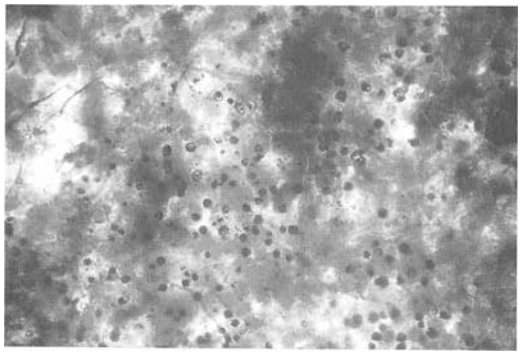

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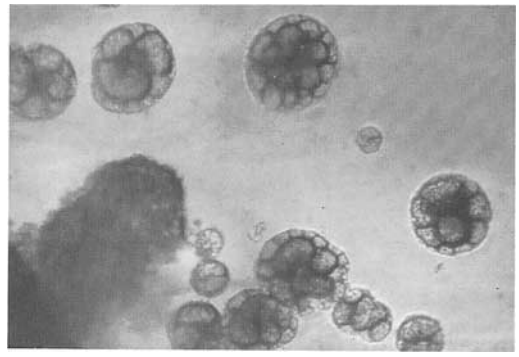

Fig. 6.

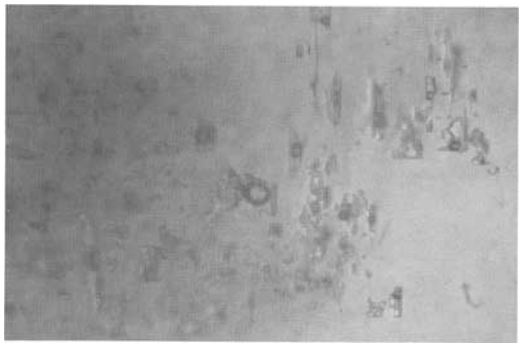

Fig. 7.

Figure 3. (56x) Seems to present three and even multi-phase inclusions cramming all available space in the stocking-like shapes.

Figure 4. (120x) Shows the contents in greater detail and now it can be appreciated that the gas phase is not free living in a liquid filled cavity as in nature, but marooned by the entrapped flux and haloed by what is possibly a glass surround wall which is in turn enclosed by a mosaic of phenakite crystals all enclosed within the one stocking. Note the washing line of chrome variations from which it is suspended.

Figure 5. A general aspect of the Lennix emerald is a series of small diffused spots such as we see in natural stones where mica pages have been unable to precipitate out complete crystals or have been largely devoured by the hostile resorbing growth environment. Closer examination of these diffuse spots in the earlier specimen revealed a curious phenomenon.

Figure 6. (240x) 'Primitive life cells'. The inclusions look for all the world like some living cells in the process of dividing and multiplying into more complex living material. In fact the ball-like aggregate are a multiple generation of daughter phenakite crystals. In the more recent emeralds these seem to be more like a badly broken pavement area.

Figure 7. (120x) 'Indian emerald'! Surely this must be an Indian emerald with the typical feature of parallel negative prism cavities topped or bottomed with a flat pinacoid face and oppositely terminated by a stepping down of the cavity, while the gas phase only adds fidelity. Again we have to gasp at the achievement of Monsieur Lens, that his emerald should so closely mimic the inclusions of the Ajmer province emerald.

Figure 8. Crossed polarized light revealed a shoal of colourful alien crystals swimming parallel and close to the prism walls. The bright interference colours indicate their birefringent crystalline nature. It occurred to me that they too were phenakite crystals. However, the *Photoatlas of inclusions in gemstones* (Gübelin and Koivula, 1986) shows what appears to be an identical feature in a Lennix emerald which the authors identified as beryl crystals.

Figure 9. (50x) 'Duty mark'. Islands of flux trapped in this Lennix emerald show a characteristic ripple growth circular and oval frames. The chance likeness to the head of George III and the oval frame are similar to the duty marks on sterling silver made in the UK between 1786 and 1820 which signified that the precious metal duty had been paid. Note even the Teuton nose and periwig. Some would welcome a system of 'hallmarking' which would separate the natural from the synthetic gemstone, but this would spoil all the pleasure of our gemmological sport and it should be mentioned that there are unfortunately those who have transposed hallmarks in the past and doubtless the same fraternity would play gemmological tricks also. It is perhaps fortunate that the Lennix is a flux grown product and as such produces the normally low RI readings below those recorded in nature.

I feel I owe much of my fascination with gemmology to Dr Gübelin's exploration of these largely unplumbed crystal depths. In the same way that we owe so great a debt to the late B.W. Anderson for charting the arena of spectroscopy, so must Dr Gübelin be credited with being somewhat of a Jacques Cousteau in venturing into the subterranean world of gemstones and mapping the way with his masterfully educative photography.

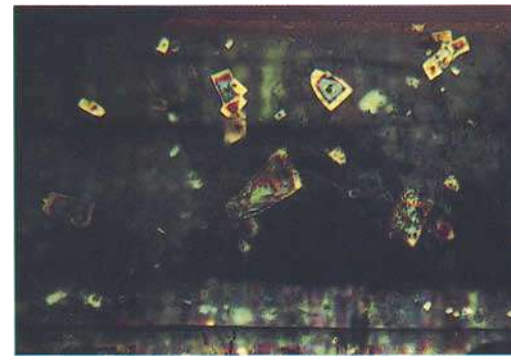

Fig. 8.

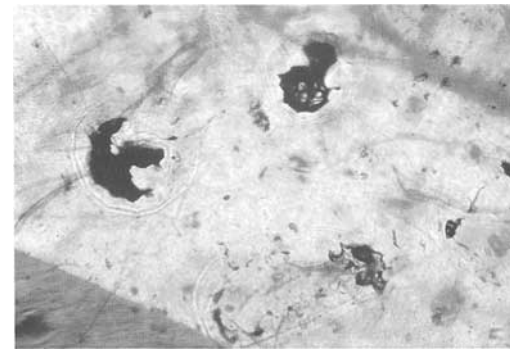

Fig. 9.

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J. Gemm., 1988, 21, 3

Quantitative cathodoluminescence – a modern approach to gemstone recognition

Dr. Johann Ponahlo

Austrian Gemmological Research Institute, Vienna, Austria

Introduction

The use of cathodorays is well known among physicists, dating back more than one century. But the use of cathodoluminescence (CL) as a means for gemstone recognition is not so well established among gemmologists of today.

It was an Italian mineralogist, A. Pochettino[6], who, apparently, was the first to investigate the CL-effects in minerals, observing and measuring them as early as 1910. At about the same time the Austrian mineralogist, H. Michel[5], then keeper of the mineralogical department of the Austrian Museum for Natural History, also one of the first gemmologists of central Europe, began, by visual inspection of CL-colours, to differentiate between genuine and synthetic gemstones. Later on CL of gemstones, unfortunately, became a nearly forgotten or discredited method. Its renaissance in gemmology started when Gaal[1] published his work in the seventies. Besides books by Marfunin[4] and Lumb[3], information on CL of minerals is still sparse and papers are widely scattered among numerous periodicals. Practically nothing is published on CL of gemstones.

Luminescence apparatus

There are two different ways used to generate electrons

a) by using a 'hot cathode' or,

b) by using a 'cold cathode' device.

The 'hot cathode' apparatus requires a high vacuum and precise alignment of the filaments. Samples need a conductive coating as a pretreatment to prevent surface charges. But the

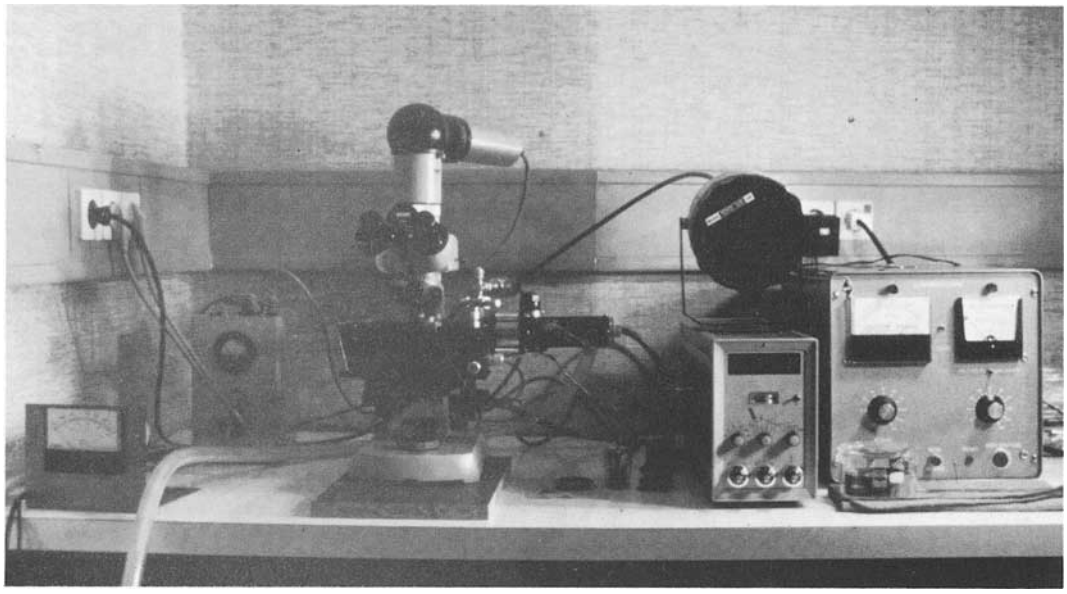

Fig. 1. Luminoscope® mounted on a Zeiss-Standard WL microscope with Zeiss-photomultiplier SF and amplifier. On the right a box for the generation and regulation of accelerating high voltage and current, with coil-current regulator for the electron-beam and vacuum meter.

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apparatus can be operated at voltages above 60 kV.

The 'cold cathode' technique demands less sophisticated equipment which can operate in a low vacuum at voltages up to 20 kV. During its operation enough positive ions are produced to neutralise any electrostatic charging.

The CL-investigations described later were carried out by means of a 'cold cathode' equipment, called a Luminoscope®, supplied by the Nuclide Corp., Acton, USA. The research was undertaken by the Austrian Gemmological Research Institute of the Erste Österreichische Gemmologische Gesellschaft e.V., Vienna, Austria. Details of the apparatus were already published by Ponahlo & Koroschetz[7,8]. Figure 1 shows the Luminoscope® mounted on a microscope Zeiss-Standard WL.

A few words on CL-theory

We know that CL-effects in solids depend on the existence of so-called '*centres*' which are capable of absorbing energy from photons or electrons that are impinging on their surfaces. The centres can be divided into '*intrinsic*' and '*extrinsic*' ones. Primarily the former are lattice imperfections. The latter are caused by certain impurity elements present in the host-crystals. When considering CL-effects of emeralds or rubies attention should be paid to extrinsic centres only.

The impurity elements can roughly be grouped into

a) '*activators*' which give rise to spontaneous CL, even when present in trace amounts. With most gemstones these are the transition metal ions: V^{+3}, Cr^{+3}, Mn^{+3} and/or Mn^{+2}.
b) '*quenchers*' which impede any spontaneous luminescence process to take place, even in the presence of some activator material in the same crystal. Of the 3d-elements, the transition metal ions Fe^{+2}, Co^{+2} and Ni^{+2} are considered to act in such a way.

When measuring CL-intensities of emeralds and rubies the following relationship (1) was found to exist between I = intensity of the emitted CL-colour (red with emeralds and rubies) and W = i.V = power of excitation of electrons; i = exciting current and V = exciting voltage.

$$I = a + b.W + c.W^2 + d.W^3 \qquad (1)$$

This cubic equation results from statistical polynomial regression of the experimental data. With d>0 equation (1) is characterized by a curve showing a convex form with respect to the abscissae at low values and a maximum at high values of power of excitation. The former is known as dark voltage effect which results when electrons of an activator element are lacking enough energy for a quantum jump. The latter arises as an effect of saturation at high power of excitation when no more electrons are available for quantum jumps. With emeralds equation (1) was simplified to become equation (2)

$$I = a + b.W \qquad (2)$$

This is the equation of a straight line. Such straight lines are shown in Figure 4 having different gradients (or angles of inclination).

When measuring the CL-intensities of rubies an exponential equation (3) was found to give the best fit with experimental data:

$$I = a.W^b \qquad (3)$$

which for ease of statistical treatment and presentation of results (in Figure 8) was used in its logarithmic form (4):

$$\log I = \log a + b.\log W \qquad (4)$$

Results of CL-measurements on emeralds

From Figure 4, it is evident that with emeralds there exist two different areas of CL-intensities that can be clearly separated from each other, if the values of I (measured in arbitrary units, proportional to the amplifier photocurrent) are plotted as ordinate figures against the values of the power of excitation W (measured in watts) on the abscissa. Within certain predetermined conditions of power of excitation, the values of I decrease linearly with decreasing W. The results are straight lines for each emerald tested, with '*steep gradients*' representative of synthetic stones, and with '*low gradients*' exclusively characteristic of each genuine emerald tested so far, regardless of origin.

For ease of comparison of data for a larger number of both genuine and synthetic emeralds – including each time the measurement of the same reference stone – the entire data were saved on magnetic tape of a Hewlett Packard HP-41CV pocket calculator with HP-Digital Cassette Drive and HP-Thermal Printer plus HP-Interface module. These data were then subjected to statistical treatment. By means of a coordinate transformation program any slight change of the gradient of the straight line of the reference stone could easily be corrected to standard conditions previously fixed. The same procedure was applied, with equally good results, to the logarithms of the CL-intensities versus power-of-excitation data obtained with rubies as will be shown later.

Growth lines were easily observed in many Gilson synthetic emeralds. The new Lennix synthetic emeralds exhibited a blueish tinge of CL-colour with a rather brilliant brick red showing through. Figure 3 gives an example for both features. In previous studies on such synthetic emeralds an even more intense blueish overcast could be observed.

Lower gradients than for all other synthetic emeralds resulted from measurements of hydrothermally man-made Lechleitner emeralds. But

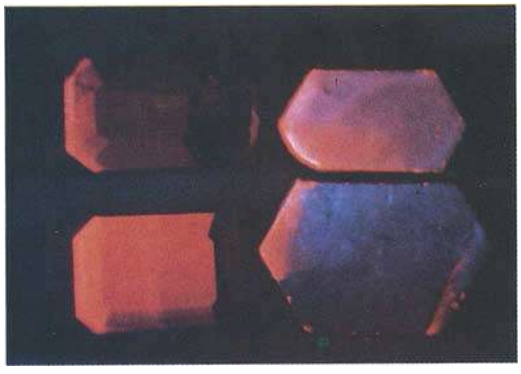

Fig. 2. CL of emeralds: upper left (dark) a genuine Colombian emerald (reference stone 0.85 ct), lower left a synthetic Gilson emerald showing growth-lines (0.86 ct), upper and lower right two synthetic Lennix emeralds with bluish overcast on scarlet-red basic CL-colour (0.96 and 1.67 ct); 7.5 kV at 0.8 mA.

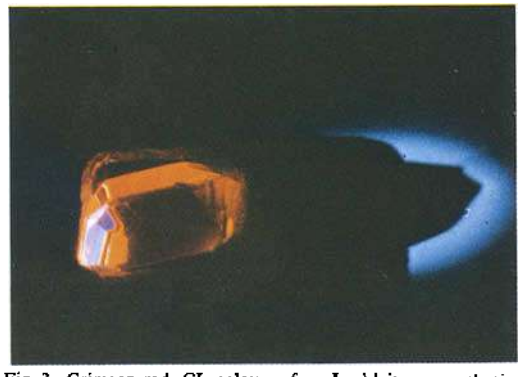

Fig. 3. Crimson-red CL-colour of a Lechleitner synthetic emerald with bluish and white blots; 8.5 kV at 0.9 mA.

Fig. 5. Seven rubies placed in vacuum-chamber of the Luminoscope® (flashlight); for details see text.

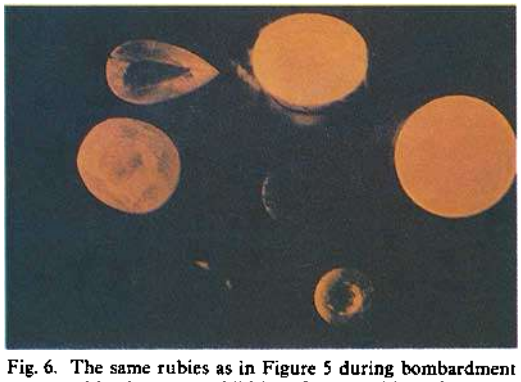

Fig. 6. The same rubies as in Figure 5 during bombardment with electrons exhibiting CL-intensities of marked differences; for details see text.

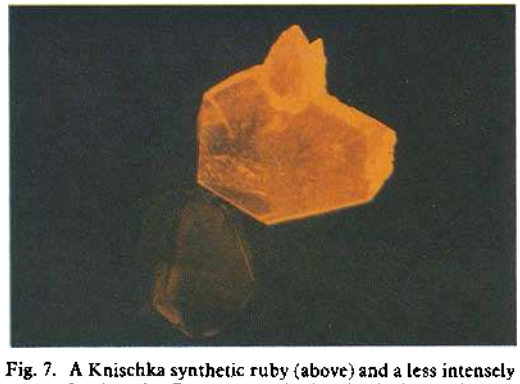

Fig. 7. A Knischka synthetic ruby (above) and a less intensely luminescing Ramaura synthetic ruby during the impact of electrons; for details see text.

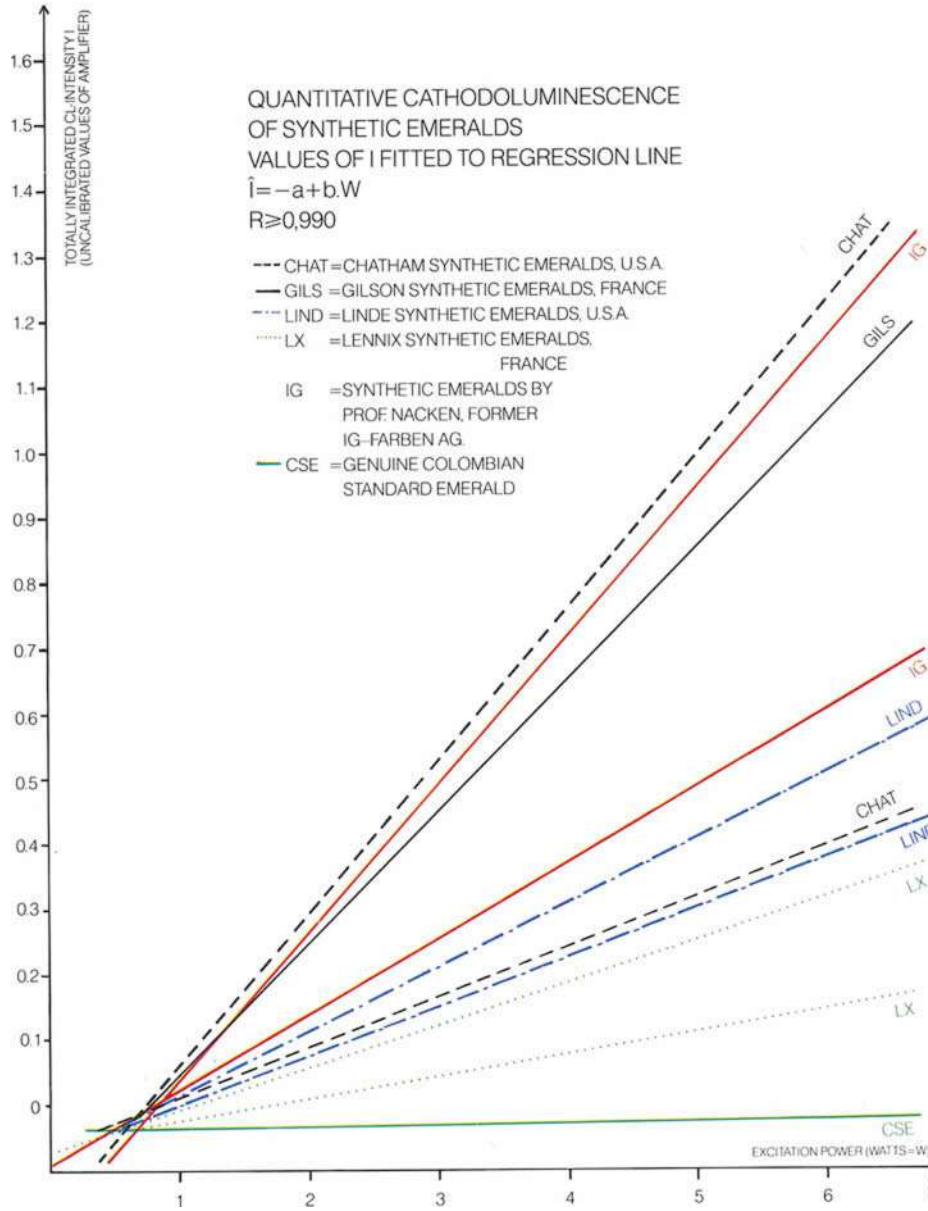

Fig. 4. Quantitative cathodoluminescence of synthetic emeralds.

these stones showed different CL-colours than those observed on any of the natural emeralds tested. Furthermore, their CL-intensities were not uniformly distributed over the entire irradiated surface, as can be seen from Figure 3.

Recent measurements on a newer synthetic stone, the Regency-created emerald, indicated strong CL-intensity, nearly as intense as that obtained with any of the old or new Chatham man-made emeralds tested.

Thus, each 'I-versus-W-plot' of data obtained from quantitative CL-tests would reveal quickly either the genuine or the synthetic origin of the stone depending on the 'gradient' of the straight line relative to the gradient of the genuine Colombian emerald reference stone (compare Figure 4).

Results of CL-measurements on rubies

Similar results were obtained with quantitative CL-intensity measurements on rubies. Pronounced differences could be found between all genuine rubies from Thailand tested so far and their synthetic counterparts regardless of their producers. Man-made stones by Kashan, Chatham, Ramaura, Knischka, Lechleitner and old and new Verneuil synthetics were investigated.

To present the entire data a plot based on formula (4) was used. Three different logarithmic ordinate scales, each differing by one order of magnitude (10) from the other, and one logarithmic scale on the abscissa had to be chosen as can be seen from Figure 8. Outer left is the logarithmic ordinate scale with the lowest figures. It was used to plot the (log I)-values of CL-intensities of genuine Thai rubies with their (log W)-values on the abscissa. The 95% confidence band results from regression analyses of data measured on more than forty Thai rubies. Note the narrow confidence band of these data in the diagram (hyperbolae drawn as solid lines from uppermost left to lowest right in Figure 8).

The inner left-hand logarithmic scale of (log I) has ten times greater values than the left-hand outer scale. Such higher values were consistenly found when measuring CL-intensities of synthetic Kashan rubies. The two broken lines enclose a broad band valid for all Kashan synthetic rubies that could be investigated. So far no exception has been found.

In order to plot the data for Knischka synthetic rubies another tenfold increase of the logarithmic ordinate scale was necessary. This scale is projected on the outer right-hand ordinate of Figure 8. Because of the few Knischka synthetic stones available one dotted straight line is reproduced in Figure 8. It is located in the middle of a broad band (dash-dotted lines) results of measurements on synthetic Chatham rubies. From Figure 8 it is evident that both Knischka and Chatham rubies show up to *hundred times stronger* CL-intensities than genuine rubies from Thailand.

Ramaura synthetic rubies exhibited distinctly weaker CL-intensities than the Chatham man-made products, somewhat between those of Knischka and Kashan rubies. Figure 7 gives a visual impression of the CL-intensities of a Ramaura and a Knischka synthetic ruby.

Recent tests made with new synthetic Lechleitner rubies furnished nearly the same results as found with Kashan synthetic rubies.

The photomacrograph of Figure 5 showing seven rubies was taken in incandescent light: two genuine rubies from Thailand (centre and lower left), one drop-shaped Knischka synthetic ruby (upper left), one brilliant-cut Ramaura synthetic ruby (lower right), two oval stones, one a Chatham synthetic (in the middle of the uppermost row), the other a Lechleitner synthetic ruby (second left in the middle row), and a round disc of a Verneuil ruby. Figure 6 shows these stones in identical arrangement luminescing during a bombardment with electrons. Note the subdued CL-intensity of the two genuine Thai stones. A distinctly higher CL-intensity is displayed by both the Ramaura and the Knischka synthetics. A more intense glow is displayed by the Lechleitner synthetic ruby. A marked increase in CL-intensity becomes obvious when observing the CL-intensities of the two oval stones, one a Chatham synthetic and the other a Verneuil ruby.

Other genuine rubies from Burma, India, Kenya, Sri Lanka and Tanzania, which were included in these measurements, gave inconsistent results of CL-intensities. Therefore, at present, genuine rubies from these localities *cannot* be differentiated from their synthetic counterparts by means of this method.

CL-spectra of jadeites and some jade-like minerals

'Jade' in its proper sense comprises two minerals only: jadeite, a clinopyroxene, and nephrite, an amphibole. But there exists numerous other green ornamental stones frequently mixed up with both of these minerals. Among them green grossulars (erroneously called 'Transvaal jade') and amazonites are often met with in gemmologial laboratories. Each of these ornamental stones can be separated from the other by making use of their CL-colours and/or CL-spectra, as will be described below.

Figure 9 is a photomacrograph of a broken cabochon-jadeite, (centre), flanked by a round green translucent African grossular (above) and a dyed green agate (below). Figure 10 demonstrates the vivid CL-colours of two of these minerals. The jadeite luminescing canary-green and the grossular intensely orange-yellow with a brownish tint. Figure 11 shows a polished translucent mottled-green jadeite ring in its natural colour. This ring was mistaken for grossular because of its rather strong yellowish-green CL-colour (compare Figure 12). However, when more specimens had been tested, it was realized that the lack of a brownish tint in the CL-colour shown could be considered an indicator for jadeite. With grossular, the orange-yellow CL-colour and its brownish tint were always already noticeable at exciting energies as low as 5 kV. Nevertheless, such subtle differences in CL-colours called for an improvement of the method; the more so since cut and polished true jadeites are costly objects. Finally, when it became obvious that

CL-spectra of gemstones are practically unknown to gemmologists and in the literature, preliminary tests were started.

Basic requirements for recording and analysing CL-spectra of gemstones were the installation of additional and more complicated apparatus. The SF photomultiplier mounted on the body tube of the Zeiss-Standard WL microscope had to be replaced by a newly developed fibre-optic system (Zeiss-Schott) to guide the light emitted from the irradiated specimen through the microscope to a VIS-NIR-monochromator. Then the photomultiplier had to be flanged to the exit slit of the monochromator. The CL-light could thus be diffracted into its spectral components which, in turn, were converted into electric signals by means of the photomultiplier. Finally, the electric signals of the entire CL-spectrum were amplified (at low noise level) by means of a Zeiss-amplifier MPC 64. By this means, then, the CL-colours emitted from the surface of the irradiated specimen could be recorded as spectral components in a wavelength range between 380 and 1000 nm. The whole assemblage was automated and operated by a Hewlett-Packard 2000 S computer. Spectra could be stored in a double-floppy disk and reproduced using both a printer and a plotter.

Figure 15 shows two jadeite CL-spectra: the one with higher peaks originating from the canary-green luminescence of the broken cabochon of Figure 10 (centre). The other spectrum was taken from a jadeite exhibiting a pinkish CL-colour. The natural colours of the latter were a vivid green and white. The peaks of both spectra are centred at 407, 557 and 692 nm. Such CL-spectra seem to be typical of many natural green or white translucent or opaque jadeites.

However, some green jadeites displayed royal blue CL-colours, visible only under bombardment with highly energized electrons above 12 kV. Sometimes, after prolonged irradiation, the blue CL-colour would change into a pinkish-red. Then, the peaks originally found at 407, 557 and 692 nm, gave way to a new strong and broad band with a peak maximum at 766 nm (NIR). This follows from Figure 16 which contains one spectrum of Figure 15 for comparison.

One green jadeite luminesced in a rather intense blueish-violet CL-colour; Figure 17 shows its CL-spectrum. If the peak wavelengths of this spectrum are compared with those of the spectra of Figures 15 and 16, they are found to occur at the same wavelengths. This would indicate that the different CL-colours of the specimens tested so far are caused by different peak-intensities relative to each other.

The CL-spectrum of the jadeite-ring of Figure 12 with its canary-green CL-colour is reproduced in Figure 18. The peaks in the bluish-violet range are no longer visible, whereas the weak band in the yellowish-green range has more than doubled its intensity. No obvious change of peak-wavelengths has occurred. The medium strong band in the (NIR) at 766 nm is found again, as in the spectrum of the white jadeite whose blue CL-colour turned into pink (see Figure 16). This band in the NIR may exert some influence on the CL-colour of jadeites.

The sharp lines visible in many CL-spectra are emission lines of the helium gas used to generate a plasma with a steady leak of gas in the cold cathode tube during experiments. Besides a carrier gas of electric charges helium exerts a cooling effect of the samples under test.

Quite different CL-spectra were recorded from the green grossulars tested so far. In Figure 19 three CL-spectra typical of grossulars are presented. They differ from each other in their peak intensities only. All specimens were luminescing with an orange colour and brownish tint. A grossular CL-spectrum, thus, consists of two distinct bands with peak-wavelengths at 590 and 719 nm. Considering EPR-studies made on African grossulars (cf. Hage, Zabinski & Amthauer [2]) the band at 719 nm could be due to Cr^{+3}, a trace element which has always been found in these green grossulars.

Another type of CL-spectrum occurred when amazonites from both South Africa and Brazil were tested. This is demonstrated in Figure 20. Such spectra consist of three peaks occurring at 506, 690 and in the range 830 to 840 nm; one in the blue and one in the orange part of the visible spectrum and another one in the NIR. According to the high intensity of the 506 peak the corresponding CL-colour of all the amazonites tested was a brilliant sky-blue. But there seems to be a subtle difference between the amazonites from South Africa and from Brazil which might become obvious in further investigations. The spectrum contained in Figure 20 belongs to that Brazilian amazonite whose photomacrograph of blue CL-colour is shown in Figure 14. The spectrum of the amazonite from South Africa is reproduced in Figure 21. In this CL-spectrum the 690-band is missing. Yet, it is noted that this amazonite exhibits nearly the same blue CL-colour, if one compares Figure 14 with Figure 13. With regard to the sparse information published on activator elements in amazonites and the contradictory results found (Marfunin[4]) more detailed studies on this peculiar feldspar seem to be necessary and are under way.

Conclusion and summary

In view of the striking results obtained by quantitative CL of emeralds and rubies, i.e. measurements of the variation in the integral intensity of the red CL-colour of these gemstones

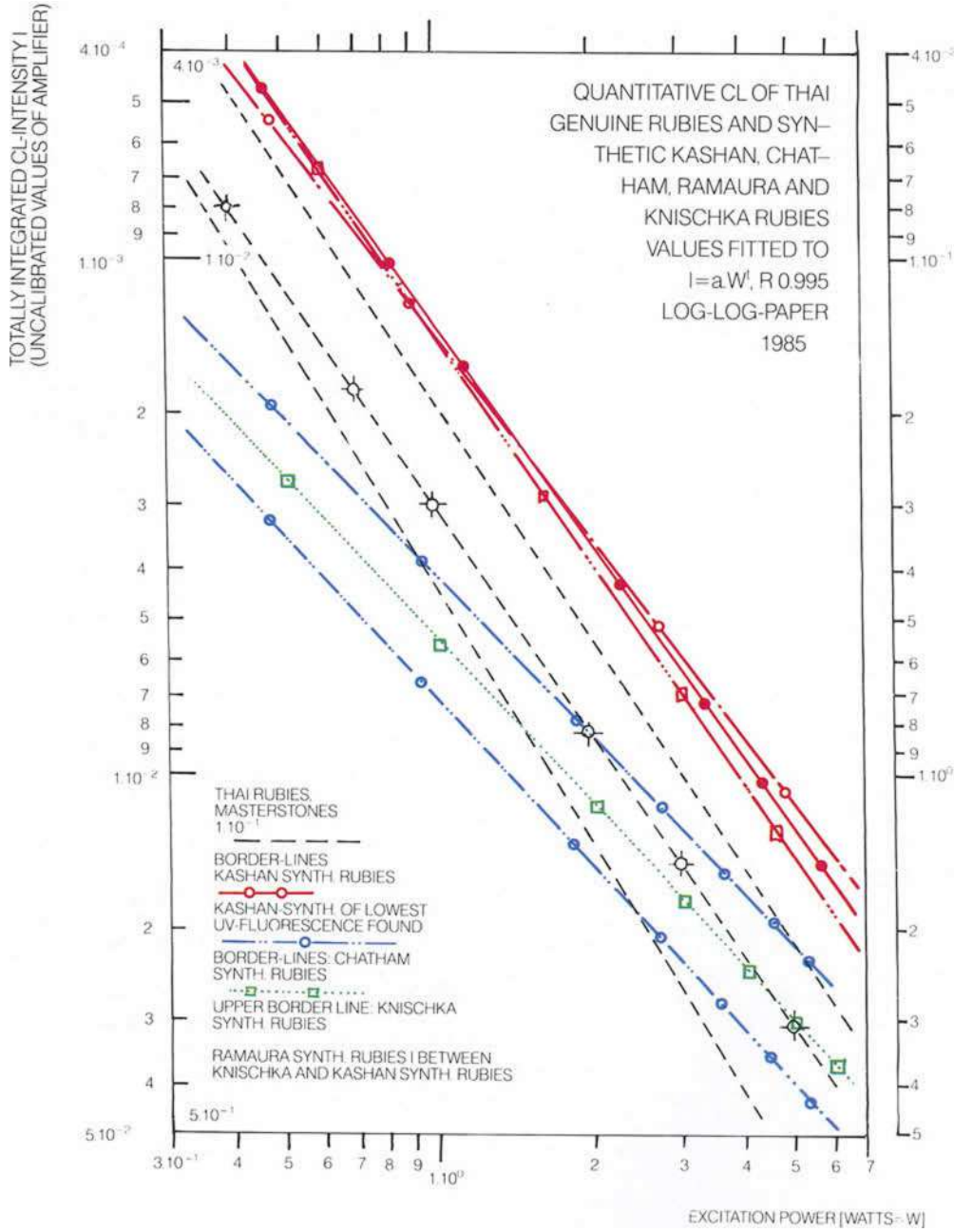

Fig. 8. Quantitative cathodoluminescence of natural and synthetic rubies.

Fig. 9. Translucent green grossular (top), broken drop-shaped green jadeite (middle) and dark green translucent dyed agate ready for CL-test in vacuum-chamber of the Luminoscope® (flashlight).

Fig. 10. The upper two cabochons of Figure 9 under the impact of electrons (10.5 kV at 1.0 mA); note orange-yellow CL-colour of the grossular against canary-green CL-colour of jadeite; dyed agate is non-luminescing.

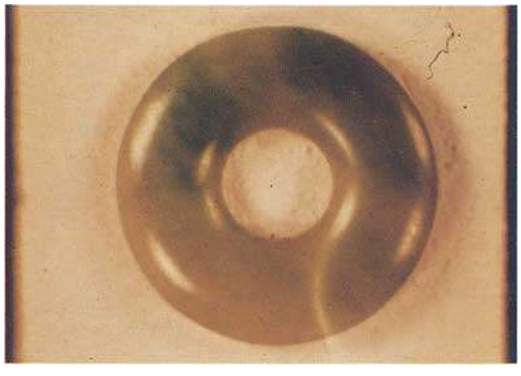

Fig. 11. True jadeite-ring, erroneously identified as green grossular by visual inspection in daylight.

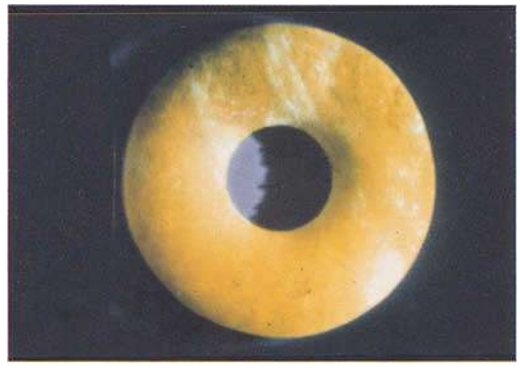

Fig. 12. The same ring showing yellow CL-colours with greenish tint, rather similar to the orange-yellow of the grossular; but note the conditions of test 14.0 kV at 1 mA.

Fig. 13. Plate of green non-translucent African grossular exhibiting numerous small luminescing dots of yellowish-brown CL-colour (left piece) against bright violet-blue CL-colour of a South African amazonite (faceted) with 12.5 kV at 0.7 mA.

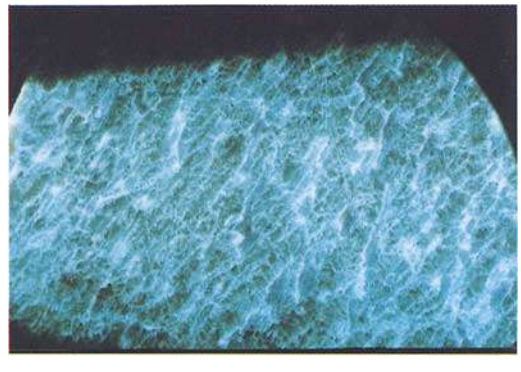

Fig. 14. Brazilian amazonite displaying a vivid blue CL-colour with white twisted bands similar to its natural appearance. The emitted blue CL is strongly polarized. 7.0 kV at 1.0 mA.

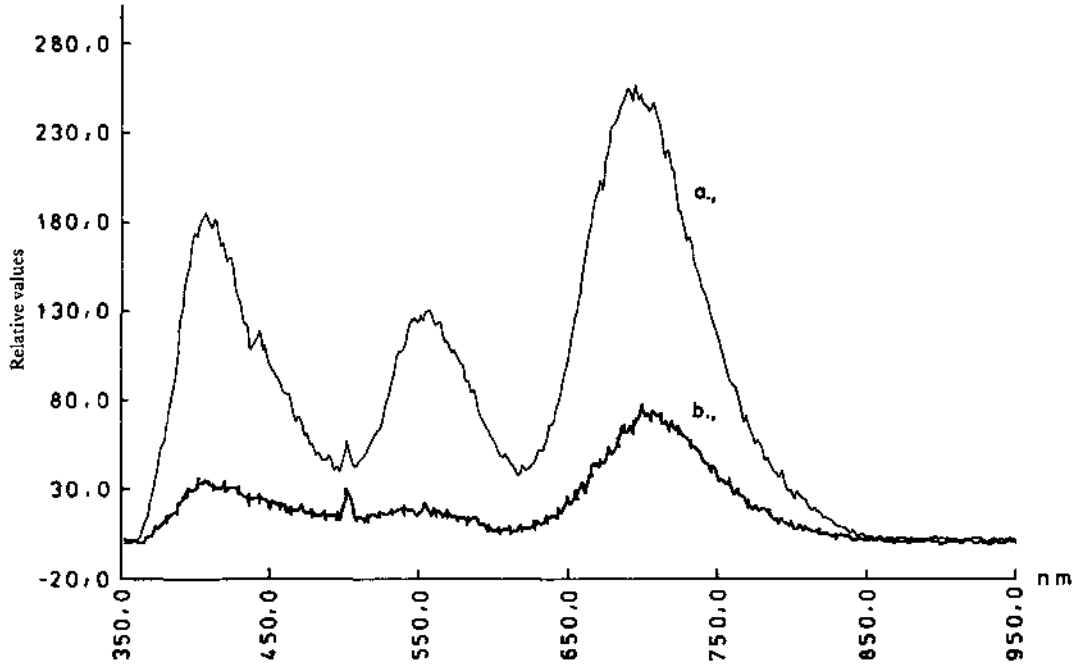

Fig. 15. Two CL-spectra of jadeites, (a) with strong bands typical of canary-green CL-colour, (b) with weaker bands resulting from a white jadeite showing pinkish CL-colour.

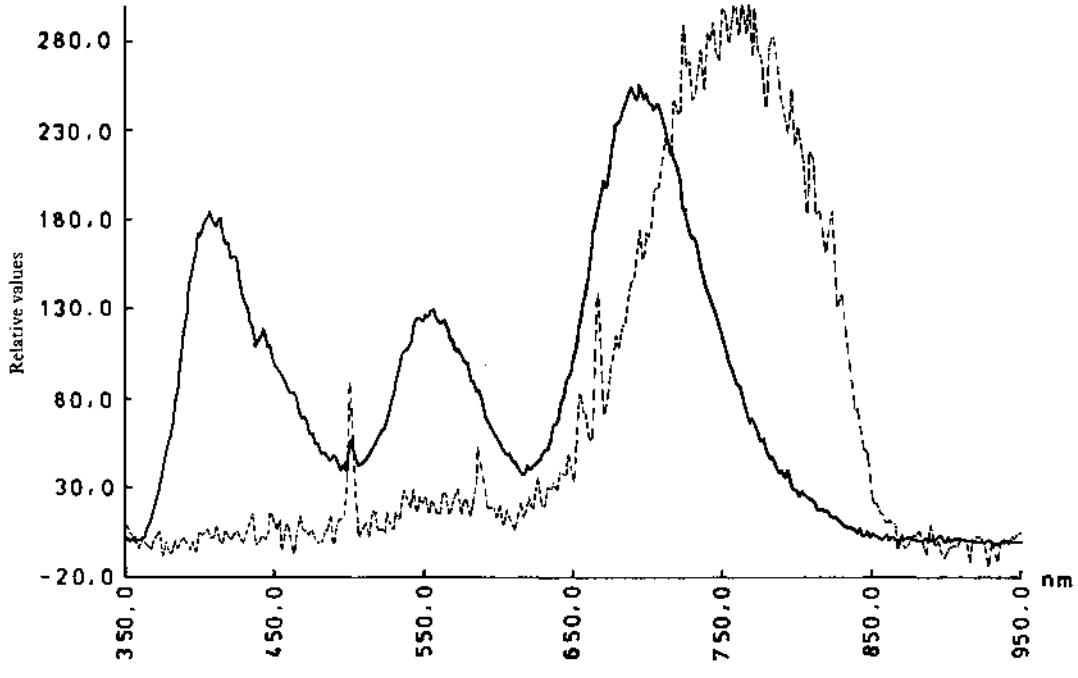

Fig. 16. CL-spectrum of a jadeite showing pinkish-red CL-colour after prolonged irradiation (broken line); CL-spectrum of the canary-green luminescing jadeite of Figure 15 (full line); spectrum was taken by steps of 2 nm.

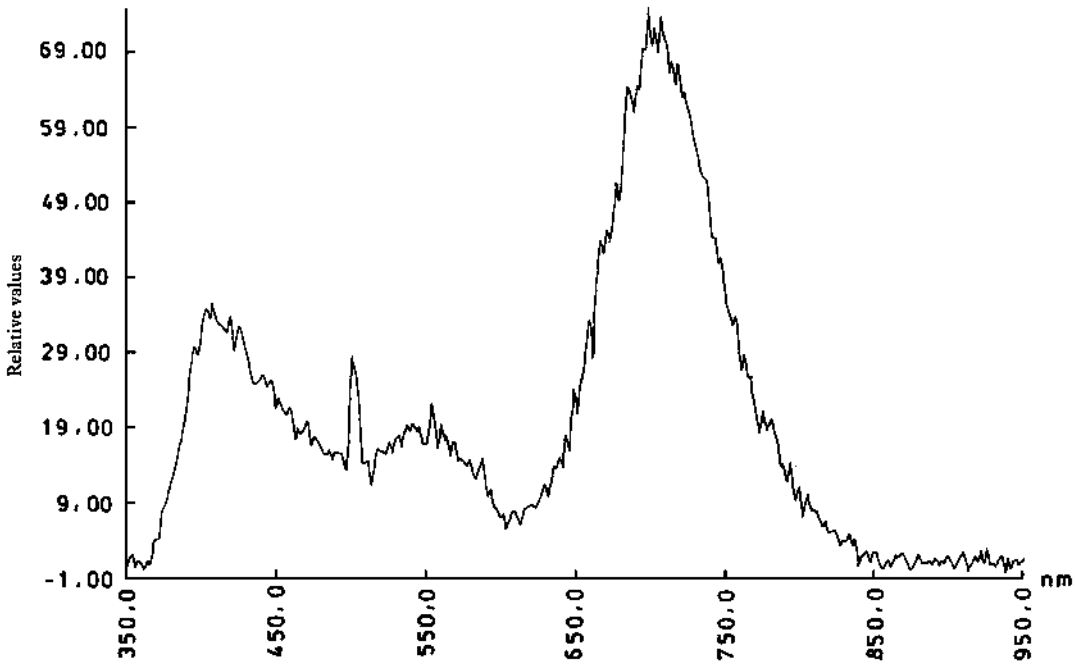

Fig. 17. CL-spectrum of a bluish-violet luminescing green jadeite; spectrum was taken by steps of 3 nm.

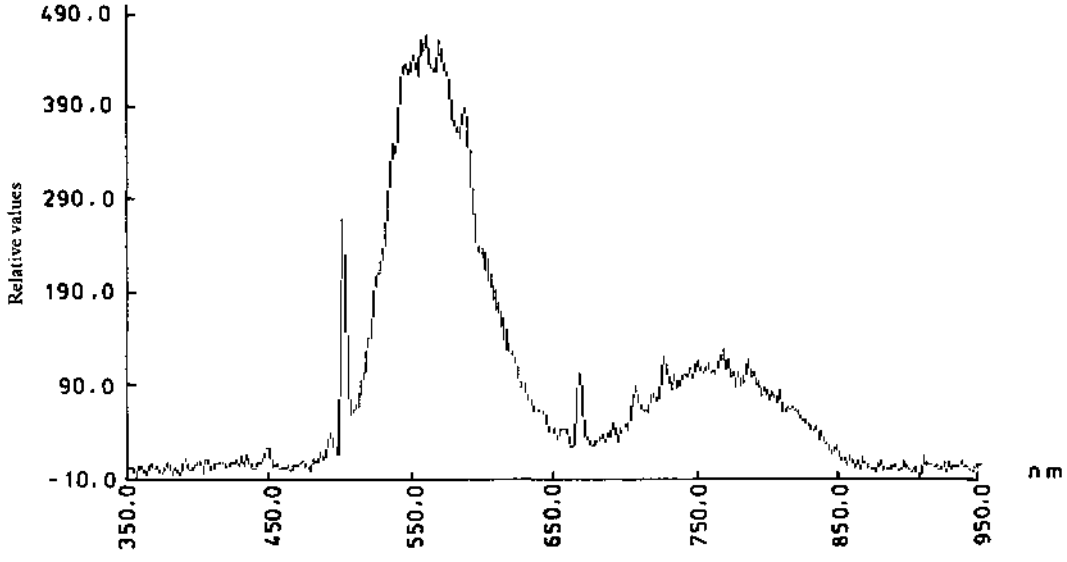

Fig. 18. CL-spectrum of the greenish-yellow luminescing mottled green jadeite-ring of Figures 11 and 12. Spectrum was taken by steps of 4 nm.

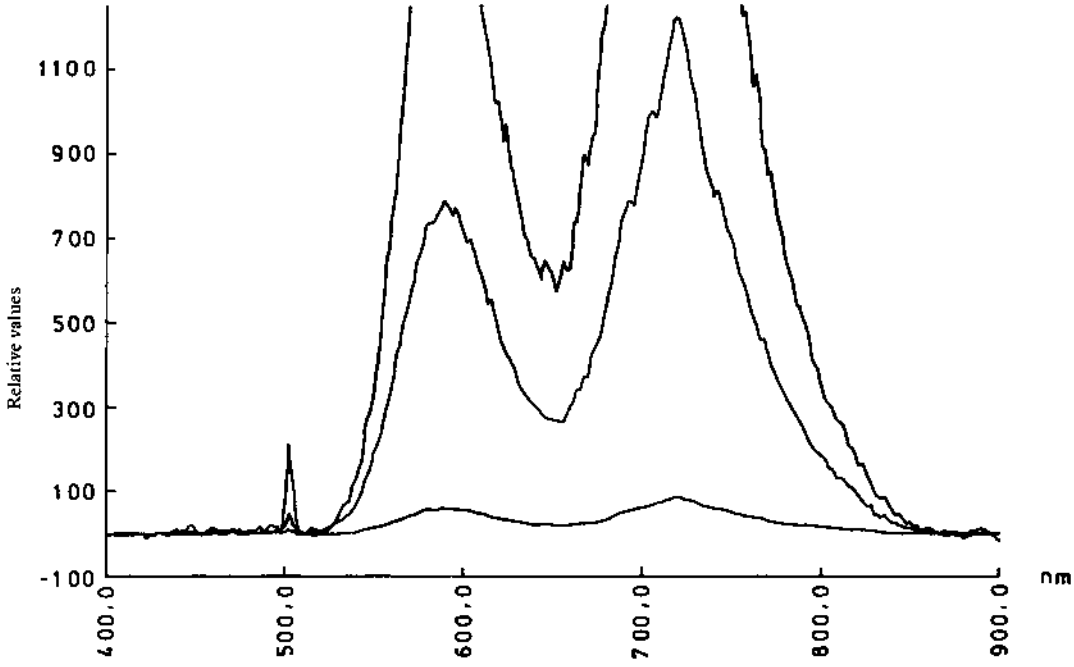

Fig. 19. Three CL-spectra of green African grossulars. Note the different CL-intensities. The two strong bands are characteristics of this mineral with its brownish-tinted orange CL-colour. Spectra were taken by steps of 1 nm.

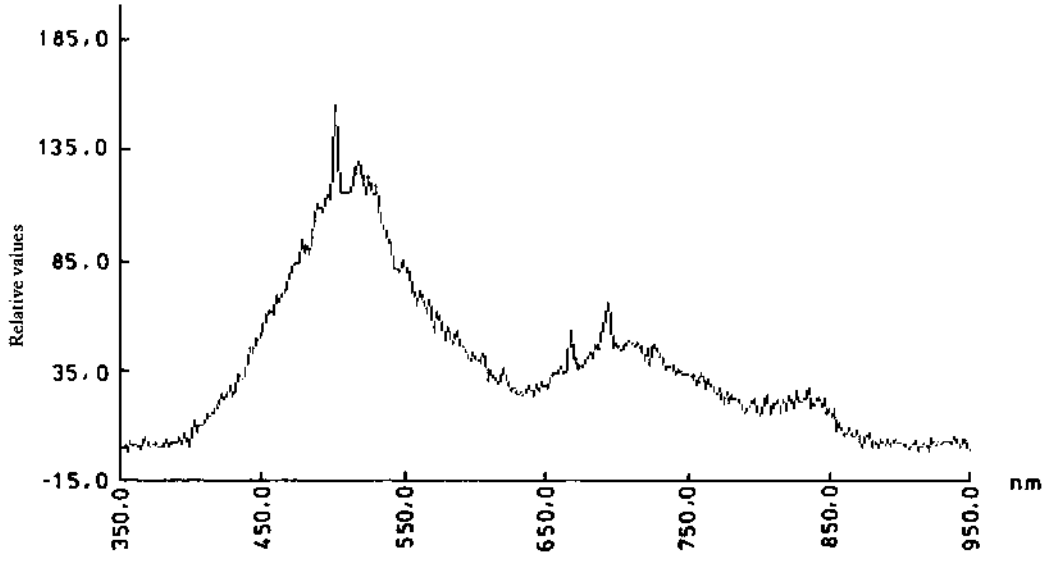

Fig. 20. CL-spectrum of a sky-blue luminescing Brazilian amazonite, taken by steps of 2 nm.

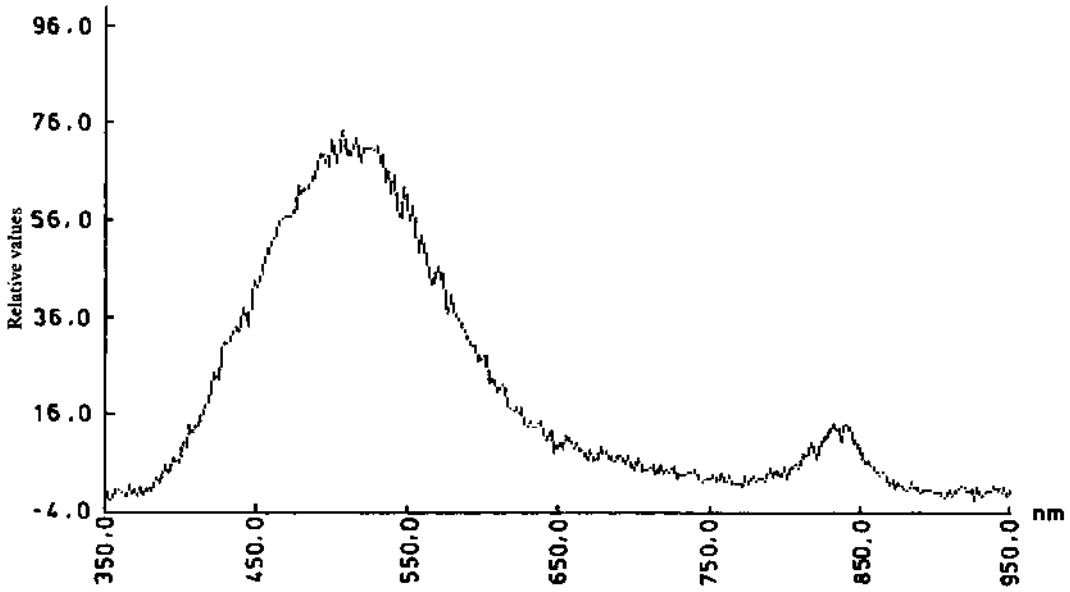

Fig. 21. CL-spectrum of a sky-blue luminescing South African amazonite, taken by steps of 2 nm.

with diminishing exciting power, this method seems to have the potential to develop into a routine procedure in larger gemmological laboratories where new secure diagnostic methods are required to differentiate between genuine and synthetic emeralds and, especially, between genuine Thai rubies and their difficult-to-analyse synthetic counterparts. Considering the high prices of these gemstones which can now safely be separated from any synthetic material, the costs of the whole equipment: microscope, photomultiplier and amplifier, Luminoscope®, vacuum pump and a few accessories, will certainly be of minor importance.

Recording CL-spectra may seem to be a more costly as well as a more sophisticated method. But taking into account the enormous amount of research work, technical experience and monetary investment involved in the crystal growing industry a computerized modern instrument for microspectrophotometry of CL might become a necessity in a gemmological research laboratory within the next few years. Admittedly, there is a long way to go in taking CL-spectra of gemstones. The present work should be considered a first step towards better gemstone recognition.

There are a number of other gemstones containing chromium as an activator element besides the one described in this paper. Spinel, alexandrite, chrome-diopside, hiddenite – to mention a few – are being tested at present. The methods described in this paper will also be tested for application to genuine and synthetic sapphires – some results have already been obtained with treated and untreated corundums – and to many other synthetic gemstones that have no natural equivalent. Future work may be carried out on the application of CL-microspectrophotometry to the location of the origin of certain gemstones.

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In the opinion of the author, the amethyst-citrine combination known as ametrine has not so far been found naturally. M.O'D.

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Describes the collections, locations, history and access details of fifteen museums in eastern Europe and the USSR. Many collections include fine gemstones. M.O'D.

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A description of the Argyle mine in Western Australia which claims to be the world's largest producer of diamonds, and of a remarkable collection of its fancy coloured diamonds ranging from yellow to blue, with various pinks, champagnes and cognac browns, mounted in exotic jewellery by Stuart Devlin for the Champagne Diamond Exhibition. [Where is it held?] R.K.M.

BROWN, G., 1988. Crystalline quartz. *Wahroongai News*, 22, 3, 26-9, many sketched figures.

An exhaustive account of this abundant mineral, which takes the subject rather beyond normal gemmological requirements, compiled from a number of well-known authorities. The 'figuroscope' (conoscope) patterns for colourless quartz and amethyst have been transposed. R.K.M.

BROWN, G., 1988. Using the quartz wedge in gemmology. *Wahroongai News*, 22, 3, 26-9, many sketched figures.

An explanation of this accessory to the polarizing mineralogical microscope, advocating its use. R.K.M.

BUENO DE CAMARAGO, M., ISOTANI, S., 1988. Optical absorption spectroscopy of natural and irradiated pink tourmaline. *American Mineralogist*, 73, 172-80, 16 figs.

Natural pink Brazilian tourmaline irradiated by gamma rays from ^{60}Co was studied with a spectrophotometer for the purpose of making optical absorption measurements at different concentrations of irradiation, the maximum dose being 20MGy. Optical absorption bands observed were 8500 and 14,800cm^{-1} assigned to d-d transitions of Fe^{2+} in b and c sites respectively; 19,500 and 25,500cm^{-1} assigned to $^5E \rightarrow {}^5A_1$ and $^5B_2 \rightarrow {}^5A_1$ d-d transitions of Mn^{3+} respectively. M.O'D.

CASSEDANNE, J., 1988. L'améthyste au Brésil. (Brazilian amethyst.) *Revue de Gemmologie*, 94, 15-18, 8 figs (1 in colour).

First part of a survey of Brazilian amethyst deposits classified according to type. M.O'D.

COZAR, J.S., 1987. La falsa cacoxenita. (False cacoxenite.) *Boletin del Instituto Gemológico Español*, 29, 30-43, 30 figs (18 in colour).

Inclusions in Moroccan hyaline quartz and in amethyst from Uruguay, though originally believed to be cacoxenite, were found by the electron microprobe to be rutile or goethite. M.O'D.

DEELMAN, J.C., 1986. Opal-CT in bamboo. *Neues Jahrbuch für Mineralogie, Monatshefte*, 9, 407-15, 3 figs.

Direct X-ray diffraction study has shown that the opal in the culm of the bamboo *Bambusa blumeana* is opal-CT. Precious opal is designated opal-A in a system of terminology that postulates opal-A as highly disordered, nearly amorphous opaline silica, opal-CT as disordered α-cristobalite, α-tridymite and opal-C as well-ordered α-cristobalite. M.O'D.

FRITSCH, E., ROSSMAN, G.R., 1988. An update on color in gems. Part 2: Colors involving multiple atoms and color centres. *Gems and Gemology*, **24**, 1, 3-15, 11 figs in colour.

Discusses in detail colour caused by electron interchange between adjacent atoms, e.g. oxygen→metal charge transfer, as in yellow and blue beryl. Some interchanges skip an oxygen atom and occur between metal atoms of different valency, e.g. $Fe^{2+} \rightarrow Ti^{4+}$ in blue sapphire. $Fe^{3+} \rightarrow Fe^{3+}$ gives yellow in corundum and deep red in tourmaline. Delocalization of electrons cause intense colour in amber and lazurite. Colour centres caused by atoms wholly or partially removed by natural or artificial

radiation also cause colour, e.g. green diamond. A most informative paper. R.K.M.

FRYER, C.W., ED., CROWNINGSHIELD, R., HURWIT, K.N., KANE, R.E., 1988. Gem Trade Lab notes. *Gems and Gemology*, **24**, 1, 47-52, 18 figs in colour.

Czochralski pulled synthetic alexandrites were free from inclusions and fluoresced more strongly than the natural stones under UV. Chalcedony with dendrite stain painted on; clinohumite; diamond with green luminescence also had cyclotron 'umbrella' effect; diamond was seriously scratched by hardness test with a diamond point; and an unusual banded structure in lapis lazuli, are all illustrated and described.

Examples of early cultured blister pearl found, possibly dating from 1890, backing of saltwater shell did not fluoresce. A fine tiara (comb) had pearls proved natural by their non-fluorescent reaction and by X-radiography. Heat treated sapphire had spalled and had an unusual dark hexagon as an inclusion. Another sapphire had intact, well-formed silk undamaged and was therefore considered not to have been heat treated. Pink, yellow and purplish-red tourmalines from Nepal were examined, RI 1.619-1.637 for the pink, and 1.620-1.648 for the yellowish-green; birefringence varies with colour. Turquoise necklace looked good quality, but found to be gibbsite bonded with plastic. R.K.M.

GARCIA GUINEA, J., LUQUE DE VILLAR, F.J., 1987. Análisis de las posibilidades de existencia de diamantes en España. (Analysis of the possibilities of the existence of diamonds in Spain.) *Boletin del Instituto Gemológico Español*, 28, 37-44, 6 figs in colour.

No kimberlite occurrences are yet recorded for Spain and most reports of diamond have proved to be quartz. A useful bibliography is appended. M.O'D.

GARZÓN, J., 1987. Inclusiones de corindones sinteticos. (Inclusions in synthetic corundum.) *Boletin del Instituto Gemológico Español*, 29, 6-28, 110 figs in colour.

A very well-illustrated up-to-date account of the inclusions found in synthetic corundum of all types. M.O'D.

GARZÓN, J., 1987. Pruebas diferenciales del diamante y de sus imitaciones. (Proofs distinguishing diamond from its imitations.) *Boletin del Instituto Gemológico Español*, 28, 6-14, 20 figs in colour.

A useful account of the present position of diamond identification. M.O'D.

GAUTHIER, J.-P., FUMEY, P., 1988. Une gemme metamicte: l'ékamite. (Ekanite, a metamict gem.) *Revue de Gemmologie*, **94**, 3-7, 7 figs (1 in colour).

A survey of ekanite, including a review of the literature and assessments of the mineral's radioactivity. M.O'D.

GRAY, M., 1988. Faceting large gemstones. *Gems and Gemology*, **24**, 1, 33-42, 9 figs in colour.

With new and improved machines and techniques, larger and larger size gems are cuttable and a topaz of 22,898 ct and a citrine of 19,548 ct are currently the world's heaviest and largest faceted stones respectively. Such sizes are cut for prestige rather than as wearable gems. Describes giant equipment, saws, grinders, laps and dops needed. Cold dopping is best. Table cut and polished first, then pavilion facets, then crown. An interesting paper on problems which few commercial lapidaries need to face. R.K.M.

GÜBELIN, E., 1988. The diagnostic properties of the latest synthetic stones. *Australian Gemmologist*, **16**, 9, 329-34 and 344-5, 46 figs in colour.

This paper deals with Lennix, Biron, Sovient and Seiko synthetic emeralds and with Seiko, Lechleitner and Knischka (rubies) synthetic corundums in considerable detail and with great efficiency. Detection is almost always dependant on recognition of characteristic inclusions. Dr Gübelin is the prime expert in these. R.K.M.

HARDER, H., 1986. Natürliche kobaltblaue Spinelle von Ratnapura, Sri Lanka. (Natural cobalt-blue spinels from Sri Lanka.) *Neues Jahrbuch für Mineralogie, Monatshefte*, 3, 97-100.

Dark blue spinel containing cobalt is described from the Ratnapura area of Sri Lanka. In addition to Co, traces of Fe, Ni, V and Ga are found in the specimens. No Ga has yet been reported from the synthetic product. In the analysed sample the high Co content is 0.09 and this gives too dark a blue for a good quality gemstone. M.O'D.

HARDER, H., SCHNEIDER, A., 1986. Isomorpher Einbau von Eisen und Titan zur Erklärung der blauen Farbe von Rutil-und Spinell-haltigen seidig weissen Korunden nach einer Wärmebehandlung. (Solid solution of iron and titanium as an explanation of the blue colour of rutile and spinel containing silky corundum after heat treatment.) *Neues Jahrbuch für Mineralogie, Monatshefte*, 5, 209-18, 5 figs.

Sample of rutile-bearing corundum annealed to 1600°C for 30 minutes were changed to a fine sapphire blue from milky-white. The change is

ascribed to electron transitions between Fe^{2+} and Ti^{4+} now possible in the corundum lattice. M.O'D.

HARDER, H., SCHNEIDER, A., 1987. Die Abkühlungsgeschwindigkeit als Ursache für die Bildung entweder von Sternkorunden oder von kornblumenblauen Saphiren. (The influence of cooling history on the formation of star corundum or cornflower-blue sapphire.) *Neues Jahrbuch für Mineralogie, Monatshefte*, 8, 344-6.

Describes the cause of colour and star formation in blue corundum. M.O'D.

HUDSON, S., 1988. North Georgia's fairy crosses. *Lapidary Journal*, **41**, 11, 55-9, 2 figs (1 in colour).

Staurolite crystals are found at the Hackney Farm near the town of Blue Ridge, Georgia, USA. M.O'D.

KARANTH, R.V., 1988. Silica bead industry in Cambay, Gujarat State, India. *Journal of the Geological Society of India*, **31**, 4, 426-31.

The manufacture of silica beads in Cambay has a tradition going back more than 2000 years. Today it forms an important cottage industry in Gujarat. Mechanised grinding and tumbling processes have been adopted recently but details are given of more primitive methods of shaping, grinding and drilling using a bow drill. Colour enhancement of chalcedony is procured by heating nodules in a covered earthern pot buried in paddy husk which produces a reducing atmosphere. Black onyx is produced by boiling the chalcedony in sugar solution followed by treatment with H_2SO_4. R.A.H.

KOIVULA, J.I., KAMMERLING, R.C., 1988. Gem news. *Gems and Gemology*, **24**, 1, 56-9, 8 figs in colour.

A report on Tucson '88 Gem and Mineral Show; theme mineral beryl; carved gems, charoite, alexandrites from Hematita, Brazil; 'hot pink' sapphires from several places, some heat-treated; star sapphire, one a fine purple, 23.97 ct, with an excellent star; tsavorite garnets, possibly from new locality; spessartines from Ramona, California; various other garnets; scapolite cat's-eye; Sri Lankan faceted sillimanite 12.23 ct claimed to be the world's largest [Geological Museum in London has one of 19.85 ct]; various synthetics are described. R.K.M.

LINDSTEN, D.C., 1988. But will it last? *Lapidary Journal*, **41**, 12, 57-60.

A description of the role played by hardness and durability in gemstones. M.O'D.

MITCHELL, R.K., 1988. El and high ice. *Wahroongai News*, **22**, 2, 2-3.

A guest editorial which explains the reason for density of water increasing as temperature goes below 4°C, and for ice floating. (Author's abstract) R.K.M.

NASSAU, K., 1988. The 13 colors of gems and minerals. *Lapidary Journal*, **41**, 11, 32-73, 13 figs (6 in colour).

An abbreviated account of the causes of colour in gemstones taken from the author's *Physics and chemistry of color*, 1983.* M.O'D.

NIEDERMAYR, G., 1988. Mineralien und Smaragdbergbau Habachtal. (The minerals and the emerald-bearing rocks of the Habachtal.) *Emser Hefte*, **9**, 1, 2-48, 39 figs (23 in colour).

The minerals and the emerald deposit of the Austrian Habachtal are described. M.O'D.

POUGH, F.H., 1988. Gem treatment: andalusite. *Lapidary Journal*, **41**, 11, 14-17.

General overview of the varieties of andalusite. M.O'D.

POUGH, F.H., 1988. Apatite. *Lapidary Journal*, **41**, 12, 14-18.

A general survey of the apatite group of minerals with particular reference to those of gem quality. M.O'D.

POUGH, F.H., 1988. More or less altering the color of diamonds. *Lapidary Journal*, **41**, 12, 28-32, 4 figs in colour.

An account of the history and present state of the art of diamond enhancement by one of the original practitioners. M.O'D.

PROCTOR, K., 1988. Chrysoberyl and alexandrite from the pegmatite districts of Minas Gerais, Brazil. *Gems and Gemology*, **24**, 1, 16-32, 16 figs in colour.

A further paper by an author importing gems from these sources. Alexandrites found recently in the Hematita area rival or surpass the original Uralian material in colour and quality and include some fine alexandrite cat's-eyes. Describes localities with maps and excellent photographs. Overcrowding of the worked areas has resulted in disputes and gun-fights. Minas Gerais chrysoberyl mines are probably the world's most productive. R.K.M.

ROBERT, D., 1988. L'émeraldolite, une nouvelle matière. (Emeraldolite, a new material.) *Revue de Gemmologie*, 94, 9-10, 8 figs (2 in colour).

Emeraldolite is an undesirable name given to an overgrowth of emerald on beryl. Eye examination is

*Reviewed in *Journal of Gemmology*, 1985, **XIX**, 6, 547.

sufficient to detect the deception. M.O'D.

ROBERTSON, R.S., SCOTT, D.C., 1988. Precious opal and the weathered profile at Coober Pedy. *Australian Gemmologist*, **16**, 9, 323-7, 2 maps, 10 figs (8 in colour).

A detailed account of the locality, geology and geological history of this important opal area. R.K.M.

SAPALSKI ROSELLO, C., 1987. La esfalerita de los Picos de Europa, Santander (España). (Sphalerite from Picos de Europa, Santander, Spain.) *Boletin del Instituto Gemológico Español*, 28, 6-14, 20 figs in colour.

Gem quality sphalerite from Picos de Europa, Santander, Spain, is described and analyses given. M.O'D.

SCHMETZER, K., 1987. Zur Deutung der Farbursache blauer Saphire-eine Diskussion. (The cause of colour in blue sapphire – a discussion.) *Neues Jahrbuch für Mineralogie, Monatshefte*, 8, 337-43, 5 figs.

In blue sapphires from different localities a distinct Fe^{2+}/Ti^{4+} charge transfer absorption is always observed with the spectroscope. Natural untreated or heat-treated sapphires without the Fe^{2}/Ti^{4} bands are green. M.O'D.

SCHUHBAUER, E., 1988. Mineraliensuche in Nevada und Utah. (Mineral seeking in Nevada and Utah.) *Lapis*, **13**, 5, 11-27, 31 figs (19 in colour).

Red beryl and topaz from a number of locations in the south-western United States are described with excellent colour reproductions and occurrence details. M.O'D.

SNOW, J., BROWN, G., 1988. Sri Lankan ekanite. *Australian Gemmologist*, **16**, 9, 346-8, 7 figs (6 in colour).

An investigation of an 0.512 ct specimen of this extremely rare metamict gem, which was discovered by the late F.L.D. Ekanayake of Colombo in 1953. The constants and absorption spectrum of this stone are slightly at variance with those published for the species, but such variation is to be expected in a metamict substance. R.K.M.

STOCKTON, C.M., KANE, R.E., 1988. The distinction of natural from synthetic alexandrite by infrared spectroscopy. *Gems and Gemology*, **24**, 1, 44-6, 2 figs (1 in colour).

Characteristic inclusions separate most natural alexandrites from their synthetic simulants, but in the absence of such features infrared spectroscopy gives markedly different absorption between the natural and synthetic stones. R.K.M.

THEMELIS, T., 1988. Appraising colored stones. *Lapidary Journal*, **41**, 11, 43-8, 1 fig. in colour.

The writer gives an account of his work as a gemstone appraiser and illustrates the documentation he uses. M.O'D.

THEMELIS, T., 1988. Photomicrography. *Lapidary Journal*, **41**, 11, 53-4, 2 figs in colour.

An introductory discussion of the use of photomicrography in gem testing. M.O'D.

THEMELIS, T., 1988. Flashes in black opal. *Lapidary Journal*, **41**, 12, 19, 2 figs in colour.

Brief account of the cause of the play of colour in opal. M.O'D.

VARGAS, G., VARGAS, M., 1988. Orienting color in quartz gems. *Lapidary Journal*, **41**, 11, 49-52, 4 figs (3 in colour).

The authors illustrate the best methods of obtaining optimum colour from a given piece of quartz rough. M.O'D.

WESTMAN, B.J., 1988. The enigmatic Hope. *Lapidary Journal*, **41**, 12, 42-105, 3 figs in colour.

A brief history of the blue Hope diamond now in the National Museum of Natural History, Smithsonian Institution, Washington DC. M.O'D.

WIGMORE, G., 1988. An uncommon material. *Australian Gemmologist*, **16**, 9, 351, 2 figs in colour.

Describes manganoan sugilite, a massive purple mineral from Kalahari, South Africa, which is being sold as Royal Lavulite, or Royal Azel. [A suggestion that this is the world's rarest gem is surely an exaggeration?] R.K.M.

WILSON, W.E., 1988. The Iron Cap mine, Graham County, Arizona. *Mineralogical Record*, **19**, 2, 81-7, 16 figs (7 in colour).

Fine gem-quality sphalerite is found at the Iron Cap mine, Graham County, Arizona, USA. Crystals are yellow to yellowish-green and may measure up to 2.5cm across. The colour darkens to black with increasing iron content. M.O'D.

ZEITNER, J.C., 1988. US diamond prospects. *Lapidary Journal*, **41**, 12, 21-7, 3 figs in colour.

The history of diamond occurrence in the Unites States is summarized. Diamonds have recently been discovered in Wyoming, Colorado and Michigan, and the use of remote sensing techniques may help future prospectors. M.O'D.

1988. Abalone pearls. *Lapidary Journal*, **41**, 11, 40-1, 4 figs in colour.

Good quality pictures of abalone from the Lowell Jones collection. M.O'D.

Book Reviews

DRITS, V.A., 1987. *Electron diffraction and high-resolution electron microscopy of mineral structures.* Springer, Berlin. pp. xii, 304. Illus. in black-and-white. DM248.

Though somewhat advanced for most gemmologists, this translation from a Russian original gives a useful insight into practices of mineral surface examination with the most sophisticated techniques and equipment. After an introduction to crystal structures and the basic mechanism of electron scattering by crystals the book goes on to discuss the geometrical analysis of point electron-diffraction patterns. Several chapters deal with various aspects of electron diffraction with electron microscope techniques. Minerals are introduced with the micas in the eighth chapter and layer minerals are examined after this point. The last chapter deals with chain silicates and there is an extensive bibliography. M.O'D.

GRAMACCIOLI, C.M., 1986. *Il meraviglioso mondo dei cristalli.* (The wonderful world of crystals.) Calderini, Bologna. pp. X, 291. Illus. in colour. L50,000.

Despite the title this is a serious study of the forms and habits of a wide range of minerals. The crystals are shown in three-colour diagrams with axes and named faces. Photographs of mineral specimens show examples mostly from Alpine regions. M.O'D.

LEEDER, O., THOMAS, R., KLEMM, W., 1987. *Einschlüsse in Mineralien.* (Inclusions in minerals.) Enke Verlag, Stuttgart. pp.180. Illus. in black-and-white. DM48.

Chapters describe the nature of inclusions, the H_2O, CO_2 and various binary and ternary systems, continuing with notes on the use of thermobarometry and other diagnostic techniques. The remainder of the book is devoted to different types of inclusion with notes on the minerals concerned. There is an extensive bibliography and several pages of good quality black-and-white photographs at the back. M.O'D.

MILLER, A.M., 1988. *Gems and jewellery appraising, techniques of professional practise.* Van Nostrand Reinhold, Wokingham. Illus. in black-and-white and in colour. £9.50.

To the best of my knowledge this is the first of its kind, and of course it has to be American. They say what happens first in the USA follows on to this country, sometimes for the good of us all. This book will benefit all those FGAs involved in valuation/appraisal work. Of particular merit are the chapters on setting up as an appraiser which show how important even your stationery can be, including letters, etc., to prospective clients. It even deals with your general appearance; not only should you be good at your work, you must look as if you can do it too!

To me Chapter 7 dealing with court appearances and the whole area of expert witnesses is worth the price of the book. To others it may be something else. What it will not be are the chapters dealing with gemstones and antique jewellery. These are a little basic and have probably been done this way to give the book a broader sales area.

However much of the book, although mainly about the American appraiser and his work, is very professional. It will prove to you that we are some way behind and although the National Association of Goldsmiths' Valuers Scheme is up and running we will have to sprint to catch up. P.S.

VARGAS, G., VARGAS, M., 1987. *Diagrams for faceting. Vol. 3.* Vargas, Thermal, California. pp. xxiv, 149. Illus. in black-and- white. Price on application.

This third volume of faceting styles sent to the compilers from correspondents consists of suggestions from Australia. Words and numbers are used to describe the cuts. M.O'D.

1987. *Diamonds 1988.* The Economist, London. pp. iii, 38. Price on application.

The report while confident that the diamond market has recovered from the slump of the 1970s and early 1980s states that diamond investment activity is still subdued. World production is not expected to increase very much and there will be a continuing swing to low cost centres of manufacturing. M.O'D.

Proceedings of the Gemmological Association of Great Britain and Association Notices

OBITUARY

Mr Alistair D. Cairncross, JP, FGA (D.1948), Perth, died suddenly on 7 March 1988. He will be missed by many people and particularly by those whom he knew in the trade he loved. A man of many loveable traits, so generous and happy in nature that it has been a privilege for me and our staff at Cairncross Limited to work with him. His talents as an artist and designer, in addition to his exceptional expertise in the Scottish fresh water pearls, made him almost unique. He leaves his wife, Mary, and two children. J.K.C.

Mrs Christina J. Sanders (née Hollander), FGA (D.1950), died in March 1988. She was a partner in the Hollander family gemmology business for very many years and was still actively interested at the time of her death.

Mr John Sopp, FGA (D.1937 with Distinction), Pinner, died suddenly on 20 February 1988. Mr Sopp spent his whole career with J.H.Lucas Ltd, manufacturing jewellers, late of Kirby Street, London EC1, apart from serving in the Royal Artillery during the Second World War. He joined the company as an apprentice designer, studying design at the Central School of Art and gemmology at Chelsea Polytechnic. He then moved to the sales and administration side and finally became Managing Director, largely responsible for the export trade.

It is with great regret that we announce the death of Mr Douglas Wheeler, FGA, former Assistant Secretary of the Gemmological Association of Great Britain, on 7 May 1988. A full obituary is given on p.130 above.

GIFTS TO THE ASSOCIATION

The Council of the Association is indebted to the following for their gifts:

Sir Frank Claringbull for three books: *Precious stones – a popular account of their characteristics, occurrences and applications, with an introduction to their determination, for mineralogists, lapidaries, jewellers, etc., with an appendix on pearls and coral*, by Dr Max Bauer; *Edelsteinkunde Dritte Auflage, vollkommen new bearbeitat von*, by Dr Max Bauer and Dr Schlossmacher; *Der Diamant*, by Fersmann and Goldschmidt.

Mr R. Holt of R. Holt & Co. Ltd., London, for the book *Precious stones and gems* by Edwin W. Streeter, Chapman and Hall, London, 1877.

Dr Margherita Superchi, Milan, Italy, for *Analisi Gemmologica del Tesoro del Duomo di Milano* (Gemmological analysis of the Milan Cathedral treasure), by Centro Informazione e Servizi Gemmologici, Camera di Commercio, Industria, Artigianato e Agricoltura di Milano.

NEWS OF FELLOWS

On 4 June 1988 Mr Peter Read gave a talk on the development of his experimental Brewster-angle refractometer to the German Gemmological Association at their headquarters in Idar- Oberstein. After the illustrated talk he demonstrated the ability of the refractometer to measure the refractive index of stones over a range of 1.40 to 3.3. When questioned on the future development of the instrument, he told the audience that the Raynor Optical Company had nearly completed their work on a pre-production version and that it was hoped that the refractometer, complete with a polarized laser light source, would be available commercially through Gemmological Instruments Limited by the end of the year.

MEMBERS' MEETING

London

On 15 June 1988 at the Flett Theatre, Geological Museum, Exhibition Road, South Kensington, London SW7, following the Annual General Meeting (see p.201) a gemmological forum was held, organized by Mr Christopher Cavey, FGA, and chaired by Mr David Callaghan, FGA, Chairman of the Council. The panel consisted of Dr Roger Harding, B.Sc., D.Phil., FGA, Mr Alan Hodgkinson, FGA, and Dr Jamie Nelson, Ph.D., FRMS,

F.Inst.P., FGS, FGA. The subjects covered, illustrated by slides, models and practical demonstrations, were as follows: the reasons for maintaining and up-dating collections in museums, visual optics and the body colour of gemstones.

Midlands Branch

On 15 April 1988 at Dr Johnson House, Bull Street, Birmingham, the Annual General Meeting was held at which Mrs Janet S. Leek, FGA, and Mr John R. Bugg, LL B, FGA, were elected Chairman and Secretary respectively. This was followed by a talk by Mr Doug Morgan, FGA, and Mr Dennis Price, FGA, entitled 'Gem cutting and polishing for the amateur lapidary'.

North West Branch

On 18 May 1988 at Church House, Hanover Street, Liverpool, Mr Nigel Grist, FGA, gave a talk about his work as a designer jeweller. Members were able to view samples of his work, in particular specimens of his 'Faberge type' flowers.

On 2 June 1988 members of the Branch visited De Beers Consolidated Mines Limited in Charterhouse Street, London EC1.

JOINT ACTIVITIES WITH OTHER ORGANIZATIONS

Society of Jewellery Historians

On 23 March 1988 at the Geological Museum, Exhibition Road, South Kensington, London SW7, an introduction to practical gemmology was held for members of the Association and the Society of Jewellery Historians.

On 16 April 1988 a symposium entitled 'Glass in jewellery'was held at the Society of Antiquaries, Burlington House, London, by the Association and the Society of Jewellery Historians.

The symposium comprised seven lectures, many given by experts in their field, and looked initially at the composition and structure of glass (Dr Ian Freestone), its identification with respect to gemstones (Ken Scarratt), and its use in ancient jewellery (Jack Ogden). This was followed by a comprehensive talk on glass intaglios and cameos (Gertrud Seidmann), a look at the 17th and 18th century pastes at the Museum of London (Amanda Herries), a fascinating study made on 19th century glass mosaic jewellery (Judy Rudoe), and a lecture on 20th century costume jewellery (Jane Stancliffe).

The Mineralogical Society

On 22 April 1988 a half-day meeting entitled The economic mineralogy and petrology of pegmatites' was held at the Geological Society, Burlington House, Piccadilly, London W1V 4BR, by the Association and the Mineralogical Society.

The meeting comprised the following lectures: Rare metals in pegmatites (Dr P. Moller, Hah-Meitner Institut, Berlin, East Germany); Fluid processes during lithium mineralization in pegmatites from SE Ireland (Mr M. Whitworth, Imperial College, London); Exotic minerals in Gondwana pegmatites (Dr J. Kinnaird, St Andrews University, Scotland); The classification of pegmatitic rocks in SW England and aspects of the pneumatolytic transition (Mr Lin Yucheng and Dr C. Halls, Imperial College, London); Gemstone-bearing pegmatites from Central and Southern Africa (Dr J. Kanis, Cascais, Portugal); Gem-bearing pegmatites of the Pala district, San Diego County, California (Mr M. O'Donoghue, British Library, London); Inclusions in gemstones from pegmatites (Dr E.J. Gübelin, Meggen, Switzerland). During the tea break there was a poster display on pegmatites and their relationship to the chemical evolution of the Galway granite, Western Ireland (Mr M. Whitworth, Imperial College, London, and Dr M. Feely, University College, Galway, Ireland). The meeting was opened by Dr D.J. Vaughan, President of the Mineralogical Society and concluding remarks were given by Mr D.J. Callaghan, Chairman of the Gemmological Association.

MEETINGS OF THE EXECUTIVE COMMITTEE

At a meeting of the Executive Committee held on 6 April 1988 at Saint Dunstan's House, Carey Lane, London EC2, the business transacted included the election to membership of the following:

Fellowship

Aziz, Khalid, Karachi, Pakistan. 1987
Bowers, Norman, Manchester. 1967
Markov, Mark, London. 1987

Ordinary Membership

Bøe, Olav A., Alhus, Norway.
De Winter, Rene, Amsterdam, Netherlands.
Donaldson, Geralyn A., Brussels, Belgium.
Foxwell, Russell N., London.
Harada, Kenji, Tokyo, Japan.
Ishii, Tomoyuki, Tokyo, Japan.
Jinnai, Kouji, Kanagawa Pref, Japan.
Karunanayake, Sarath P., Dehiwala, Sri Lanka.
Kelley, Kellie J., Clinton, Wash., USA.
Lee, Bea W., Seoul, Korea.
Lee, Hung K., Taipei, Taiwan.
Longden, Sharon D., Eckington.
McKay, Kenneth D., Swanage.
Mogi, Masako, Tokyo, Japan.
Nakamura, Chiyo, Hokkaido, Japan.
Neomoto, Naoki, Tokyo, Japan.
Ohmura, Keiko, Tokyo, Japan.
Ohshima, Takako, Osaka, Japan.

Oshima, Hirotomo, Tokyo, Japan.
Otsuka, Masae, Chiba Pref, Japan.
Oudenes, Hendrik, Papendrecht, Netherlands.
Petrides, Eugene, London.
Sekiguchi, Kazuyoshi, Tokyo, Japan.
Shah, Anurag D., Nairobi, Kenya.
Shimizu, Terukazu, Tokyo, Japan.
Sugihara, Kaori, Tokyo, Japan.
Urata, Nami, Osaka, Japan.
Washi, Shoichi, Chiba Pref, Japan.
Yim, Tae Y., Tokyo, Japan.
Yokoyama, Haruaki, Fukuoka Pref, Japan.
Yoshimoto, Misako, Fukuoka Pref, Japan.

At a meeting of the Executive Committee held on 11 May 1988 at Saint Dunstan's House, the business transacted included the election to membership of the following:

Ordinary Membership
Colucci, Thomas R., Chatham, NJ, USA.
Gainer, Pamela, Wokingham.
Hampton, John S., Lancaster.
Moulder, Robert P., Sandbach.
Thompson, Neil C., Maidenhead.
Tirat, Pierre, Poitiers, France.

COUNCIL MEETING

At a meeting of the Council held on 3 May 1988 at the Royal Automobile Club, Pall Mall, London SW1, the business transacted included the election to membership of the following:

Fellowship
Aloy, Richard N., San Jose, Calif., USA. 1976
Gemayel, Farid, Jounieh, Lebanon. 1982
Hellqvist, Ing-Britt E., Tumba, Sweden. 1987
Leung, Wai Hung, Kowloon, Hong Kong. 1987
Verjee, Nasim K., Nairobi, Kenya. 1982

Ordinary Membership
Archard, Trevor J., Hove.
Baldridge, Stephanie A., San Jose, Calif., USA.
Kanis, Jan, Cascais, Portugal.
Langridge, John P., Sompting.
Mulkern, Michael P., Brewster, NY, USA.
Tracy, Joseph M., Kansas City, Mo, USA.

ANNUAL GENERAL MEETING 1988

The 57th Annual General Meeting of the Association was held on 15 June 1988 at the Flett Theatre, Geological Museum, Exhibition Road, South Kensington, London SW7.

The Chairman, Mr David Callaghan, FGA, opened the meeting by welcoming members. He referred to the sad news of the death of Mr Douglas Wheeler, FGA (obituary p.130 above). The late Gordon Andrews and Harry and Douglas Wheeler formed a team that did so much for building the name of the Gemmological Association throughout the world, and Douglas's death marks the passing of the trio.

As a result of the poor financial position the previous year, stringent economies had been imposed by the Executive Committee and the Council. Mr Callaghan was pleased to report that there had been a considerable improvement, and this dramatic change was due to the Secretary, Mr Jonathan Brown, and his team. He thanked Jonathan and the staff for all they had achieved during the year, and particularly Sandra Page for her work on the Diploma course.

Mr Callaghan then thanked the Officers and Council for their help and support during the year.

He announced that there will be a change of venue for the Presentation of Awards this year, due to the closure of Goldsmiths' Hall for alterations. The Presentation is to be held on 25 November 1988 at the original Guildhall in the City of London.

Mr Nigel Israel, Treasurer of the Association, presented the audited accounts for the year ended 31 December 1987. The adoption of the Report and Accounts was duly proposed, seconded by Mr Kenneth Scarratt, and carried.

Sir Frank Claringbull, Mr David J. Callaghan, Mr Noel W. Deeks and Mr Nigel B. Israel were re-elected President, Chairman, Vice-Chairman and Honorary Treasurer, respectively. Messrs. C.R. Cavey, P.J.E. Daly, J.A.W. Hodgkinson, D. Inkersole, B. Jackson and M.J. O'Donoghue were re-elected and Mrs Gwyneth Green elected to the Council. Messrs C.B. Jones and A.W. Round retired from the Council and Mr Callaghan thanked them for the help and support they had given.

Messrs. Ernst and Whinney were reappointed Auditors, and the proceedings then terminated.

GEM TESTING LABORATORY OF GREAT BRITAIN

On 13 June 1988 the Gem Testing Laboratory opened an office at 10 Vyse Street, Birmingham. A qualified gemmologist is in attendance on Monday and Tuesday of each week to provide a 'While you wait' testing service with a verbal report for most types of gemstone. The service is available to members of the Association and further details may be obtained from Alan Clark, FGA, at the London laboratory on 01- 405 3351.

CORRIGENDA

On p.83 above, second column, 7th line, for '0.015', read '0.016'

On p.84 above, second column, first line, for 'possible', read 'impossible'

On p.84 above, in Table 1, the ± signs should have been omitted after 'birefringence'

Letter to the Editor

From Gordon S. Walker, ASTC, FIO, FGAA

Dear Sir,

In reference to a paper in the April 1988 issue of the *Journal*, by R. Keith Mitchell, FGA, entitled 'An important Australian contribution to gemmology', I would like to make the following observations, if I may.

I quite understand Mr Mitchell's doubts concerning the third decimal place accuracy, particularly in reference to the mobility of the spot.

So very often, in my field of study and practice, I find that the actual problems which occur have within themselves their own solutions – and such is the case here.

When in deep water, I can either drown or become a diver!

With the refractometers I use, the spot takes on a rugby ball shape which is made as small as possible.

The technique is as follows:

Using the point of the 'rugby ball' direct your gaze away from this and towards the scale side and even beyond this to utilize more of the peripheral vision of the eye's retina. The central vision of the eye has a high proportion of cones which produce high visual acuity whereas the periphery has more rods which have a higher sensitivity for movement.

By using the mobility of the image, it is easy after some practice to judge equal swings with slightly peripheral vision and record the higher and lower shadow edges of these swings, and taking the middle position of such swings as the third decimal place – such swings should be as small as practical.

This method is not so easy with the Dialdex, but still possible.

It is important to stress that not everyone will be able to get an accurate third decimal place in a short space of time and such should never be expected from a student sitting for an examination is gemmology!

The mobility principle combined with the peripheral vision technique is not new; for this is the very method used by gemmologists who get better than average results with a spectroscope.

The main difference here is that the mobility and peripheral vision technique is horizontal in application instead of vertical in reference to the absorption lines and scale.

I know a gemmologist who has a layman's way of putting it. He says, 'I look around the corner of the edge of the spectrum and then I see the absorption lines'.

It should be noted that the matter of the third decimal place is quite useless unless we address two other considerations which are of paramount importance: for unless we do this, the whole exercise is useless and the results will be at the best very approximate indeed!

The first is to achieve an accurate second decimal reading by using the control of several singly refractive cabochons with flat ground and polished bases which are used as a check on the second (and third) decimal place read.

The result is that 0.01 to 0.02 must be added to the spot reading to give the same result as is achieved on the flat surface. The amount added appears to be standard for each operator.

The second matter that needs to be mentioned is the need of a check on all commercially sold refractometers, for some leave much to be desired. It is wise to check all instruments from time to time with a material with a known RI, such as a flat ground and polished piece of optical crown glass, having an RI of 1.523 (or whatever the manufacturer's specifications are).

In conclusion please thank Mr R. Keith Mitchell for his comments and opinions regarding the original paper.

Yours etc.,

Gordon S. Walker
June 1988
PO Box 37, Belmont, NSW 2280, Australia.

References

Mitchell, R.K., 1988. An important Australian contribution to gemmology. *Journal of Gemmology*, 21, 2, 67-8.

Walker, G.S., 1987. A new 'spot reading' technique for the refractometer. *Australian Gemmologist*, 16, 7, 253-6.

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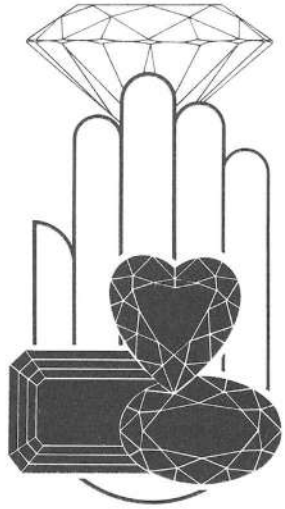

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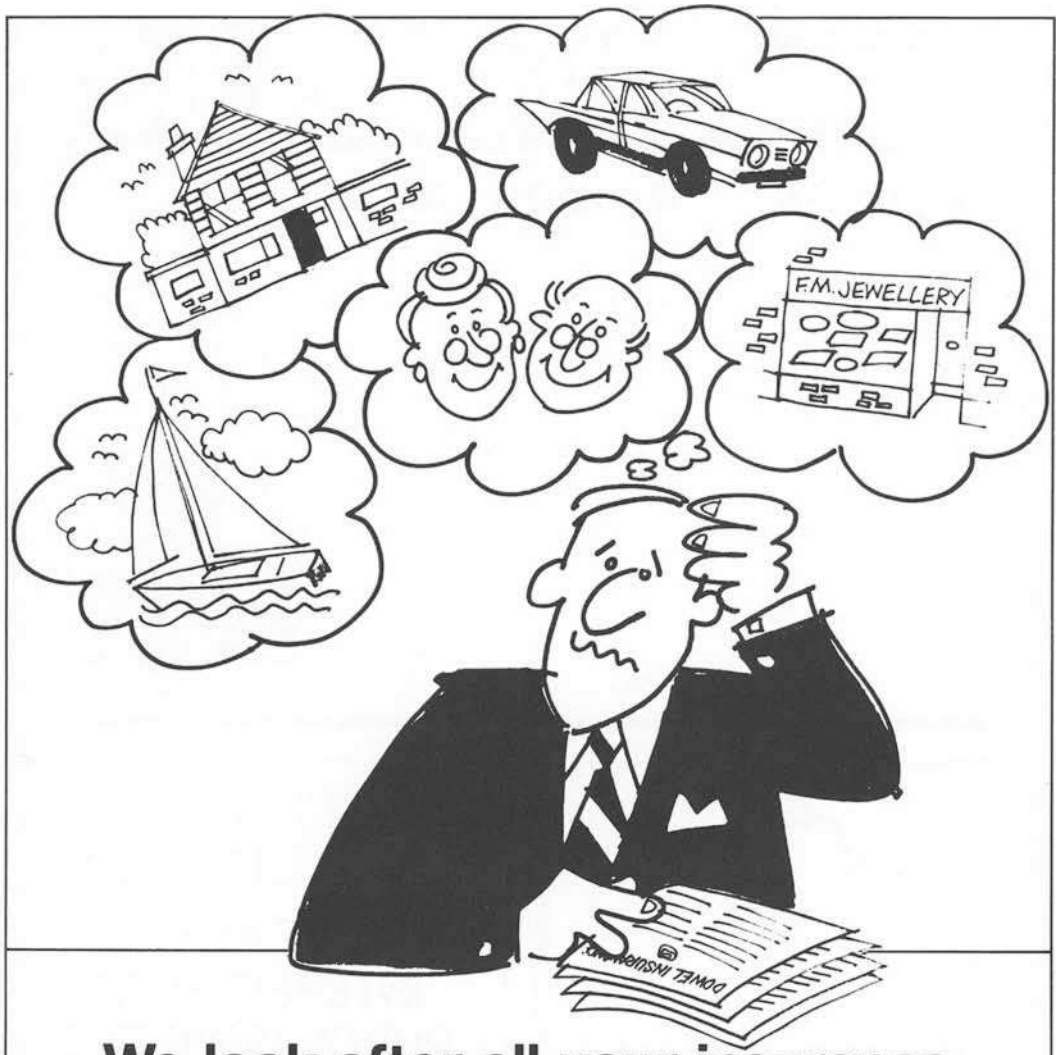

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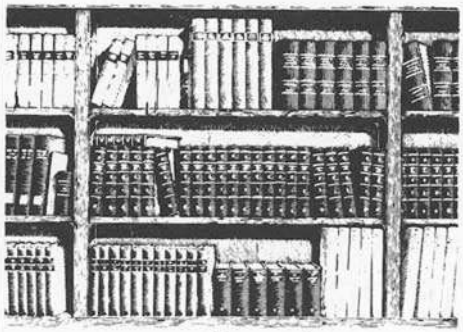

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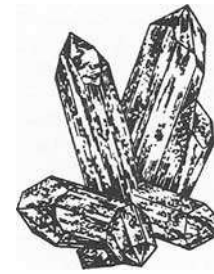

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GEMMOLOGICAL ASSOCIATION OF GREAT BRITAIN

The Arms and Crest of the Association, conferred by a grant of Arms made by the Kings of Arms under royal authority. The cross is a variation of that in the Arms of the National Association of Goldsmiths of Great Britain and Ireland. In the middle is a gold jewelled book representing the study of gemmology and the examination work of the Association. Above it is a top plan of a rose-cut diamond inside a ring, suggesting the scrutiny of gems by magnification under a lens. The lozenges represent uncut octahedra and the gem-set ring indicates the use of gems in ornamentation. The lynx of the crest at the top was credited, in ancient times, with being able to see through opaque substances. He represents the lapidary and the student scrutinizing every aspect of gemmology. In the paws is one of the oldest heraldic emblems, an escarbuncle, to represent a very brilliant jewel, usually a ruby. The radiating arms suggest light diffused by the escarbuncle and their tips are shown as jewels representing the colours of the spectrum.

Historical Note

The Gemmological Association of Great Britain was originally founded in 1908 as the Education Committee of the National Association of Goldsmiths and reconstituted in 1931 as the Gemmological Association. Its name was extended to Gemmological Association of Great Britain in 1938, and finally in 1944 it was incorporated in that name under the Companies Acts as a company limited by guarantee (registered in England, no. 433063).

Affiliated Associations are the Gemmological Association of Australia, the Canadian Gemmological Association, the Gem and Mineral Society of Zimbabwe, the Gemmological Association of Hong Kong, the Gemmological Association of South Africa and the Singapore Gemologist Society.

The *Journal of Gemmology* was first published by the Association in 1947. It is a quarterly, published in January, April, July, and October each year, and is issued free to Fellows and Members of the Association. Opinions expressed by authors are not necessarily endorsed by the Association.

Notes for Contributors

The Editors are glad to consider original articles shedding new light on subjects of gemmological interest for publication in the *Journal*. Articles are not normally accepted which have already been published elsewhere in English, and an article is accepted only on the understanding that (1) full information as to any previous publication (whether in English or another language) has been given, (2) it is not under consideration for publication elsewhere and (3) it will not be published elsewhere without the consent of the Editors.

Papers should be submitted in duplicate on A4 paper. They should be typed with double line spacing with ample margins of at least 25mm all round. The title should be as brief as is consistent with clear indication of the content of the paper. It should be followed by the names (with initials) of the authors and by their addresses. A short abstract of 50–100 words should be provided. Papers may be of any length, but long papers of more than 10'000 words (unless capable of division into parts or of exceptional importance) are unlikely to be acceptable, whereas a short paper of 400–500 words may achieve early publication.

Twenty five copies of individual papers are provided on request free of charge; additional copies may be supplied, but they must be ordered at first proof stage or earlier.

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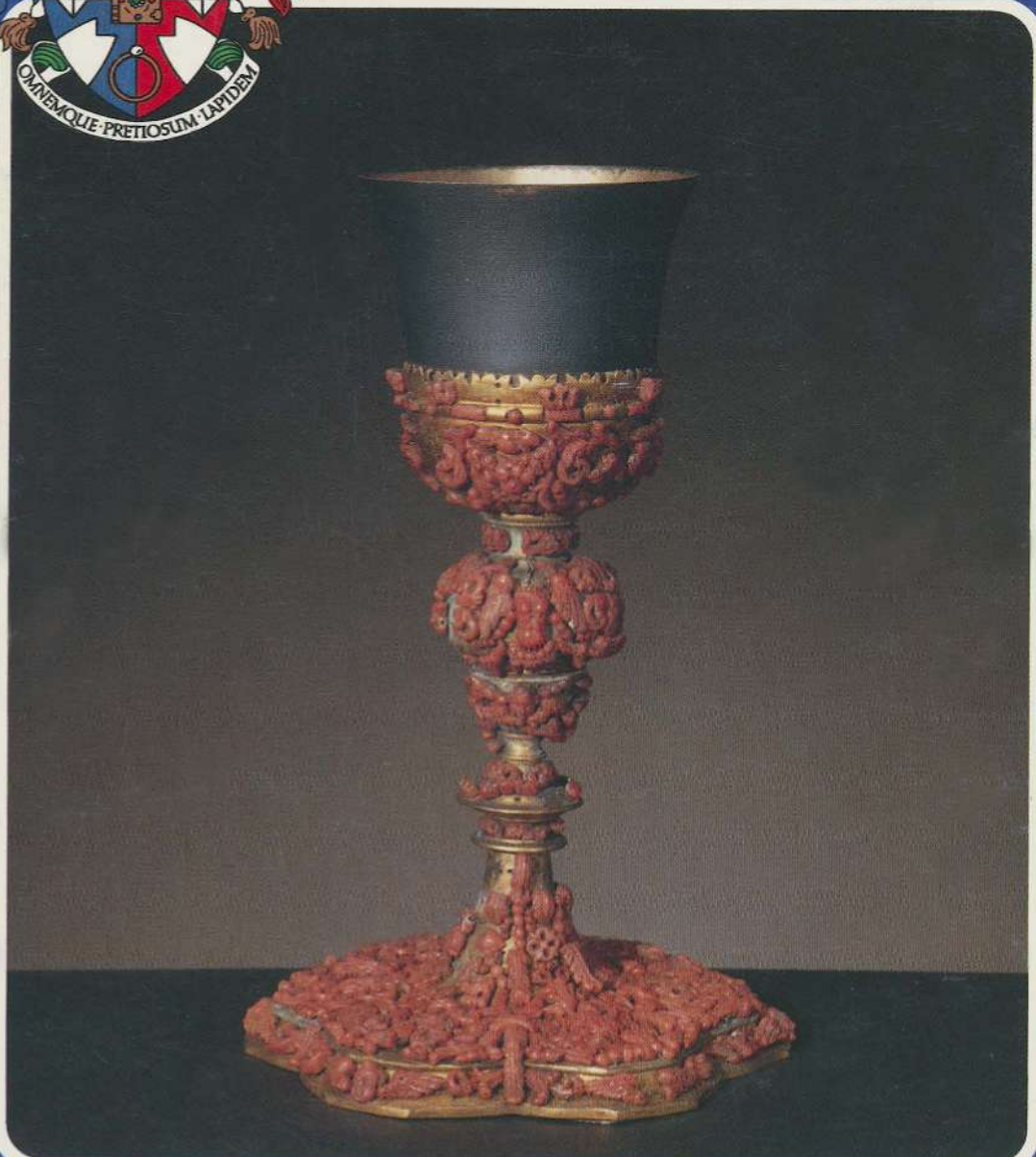

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The Journal of Gemmology

VOLUME 21

NUMBER FOUR OCTOBER 1988

Cover Picture

The Airoldi Chalice; silver and gold plate, decorated with red coral carved as angel and cherub heads and leaf motifs. Sicilian workmanship, XVII century; height 230mm.
Photograph courtesy CISGEM, Milan

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The Buckingham Award

Mr W.C. Buckingham, FGA, has very generously donated his fine collection of zircon rough to the Gemmological Association of Great Britain to mark his retiral after fifty years from the firm of George Lindley & Co. Ltd. He is also offering an award to newly-qualified Fellows of the Association who carry out research on samples from the collection.

The criteria for the research are:

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2. Having carried out the research programme, the Fellow must present the results in the form of a paper which would, in the opinion of the Editor, be worthy of publication in *The Journal of Gemmology*.
3. A Fellow whose research and paper satisfy these criteria will be awarded the sum of £100 or books and/or instruments to that value.
4. The Fellow must first apply in writing to the Secretary of the Association, setting out his proposed research and methodology and the instruments he proposes to use. The time to be taken must also be specified.

Research materials provided by the Association must be returned within the time stipulated.

The Association reserves the right to authorize or reject research projects at its sole discretion and will not enter into the reasons for any decision made.

Those interested in the Award are invited to write to the Secretary of the Gemmological Association, Saint Dunstan's House, Carey Lane, London EC2V 8AB, giving the information set out in item 4 above.

Imitation pearl coatings

S.J. Kennedy, J.G. Francis** and G.C. Jones***

*Gem Testing Laboratory of Great Britain, 27 Greville Street, London EC1N 8SU.
**Dept. of Mineralogy, British Museum (Natural History), London SW7 5BD.

Abstract

The coating on an imitation pearl was studied by a variety of techniques. The nacreous effect of the coating was found to be due to minute platy hexagonal crystals of basic lead carbonate suspended in a clear nitrocellulose lacquer. The form of the crystals was studied by scanning electron microscopy while their composition was revealed by infrared spectroscopy and electron microprobe analysis.

Introduction

A single-row, ungraduated bracelet of 24 'pearls' and 6 round, black beads with 3 colourless, stone-set metal spacers (Figure 1) was submitted to the Gem Testing Laboratory of Great Britain by a trading standards authority with the request to test both beads and 'pearls'.

Identification of the black beads as onyx was not difficult – the X-ray powder diffraction pattern obtained was that of quartz. A cursory examination of the pearls with a 10x loupe showed a form of the granular structure typical of imitation pearls. A radiograph of the necklace demonstrated clearly that these were not nacreous pearls. The radiograph (Figure 2) shows that the 'pearl' consists of a bead that is partly transparent to X-rays, surrounded by an X-ray opaque coating. This coating shows up as a lighter rim to the greyish disc of the bead.

This information would normally be sufficient, and a report would be issued to the effect that the beads were imitation pearls. However, in this case, because questionable claims had been made about the composition of the imitation pearls, it was necessary to identify the materials used in their manufacture. One 'pearl' was subjected to further examination.

Glass bead

The bead which formed the body of the 'pearl' was found to be glass by X-ray diffraction and electron microprobe techniques. The only point of interest here was that the glass was semi-transparent to X-rays, whereas coated imitation pearls have tended to be made of a glass that is opaque to X-rays. This difference can be

Fig. 1. Imitation pearl and onyx bead bracelet – the milky white bead next to an onyx bead (top right) is the glass bead from which the nacreous coating has been removed.

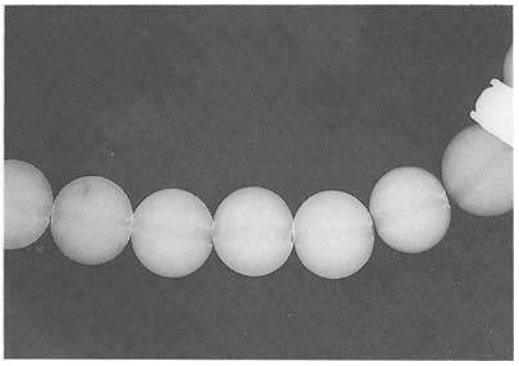

Fig. 2. Radiograph of imitation pearl from bracelet.

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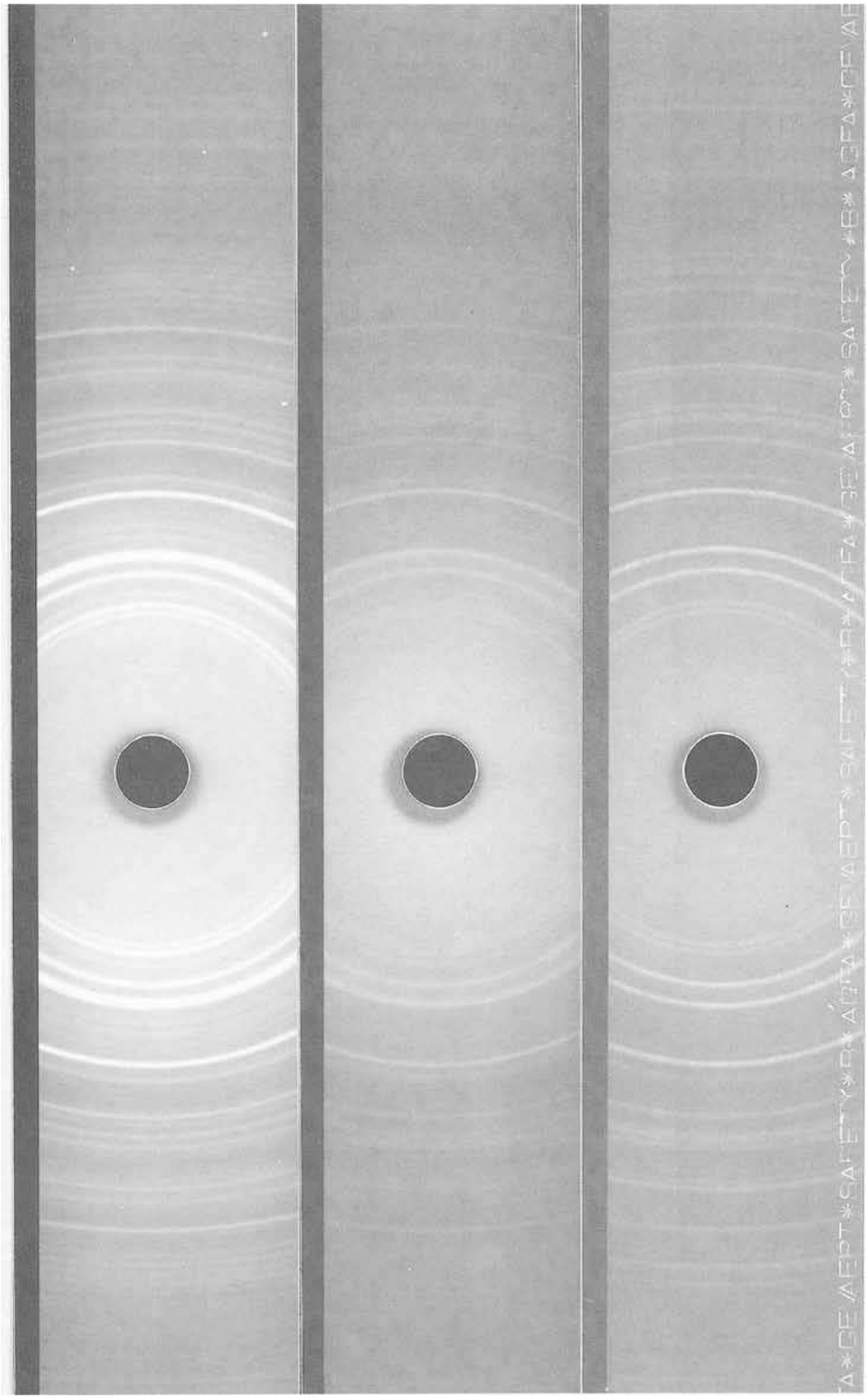

Fig. 3. X-ray powder diffraction patterns of: (top) material coating imitation pearl; (middle) commercial grade 'white lead'; (bottom) hydrocerussite; Ashover, Derbyshire, UK.

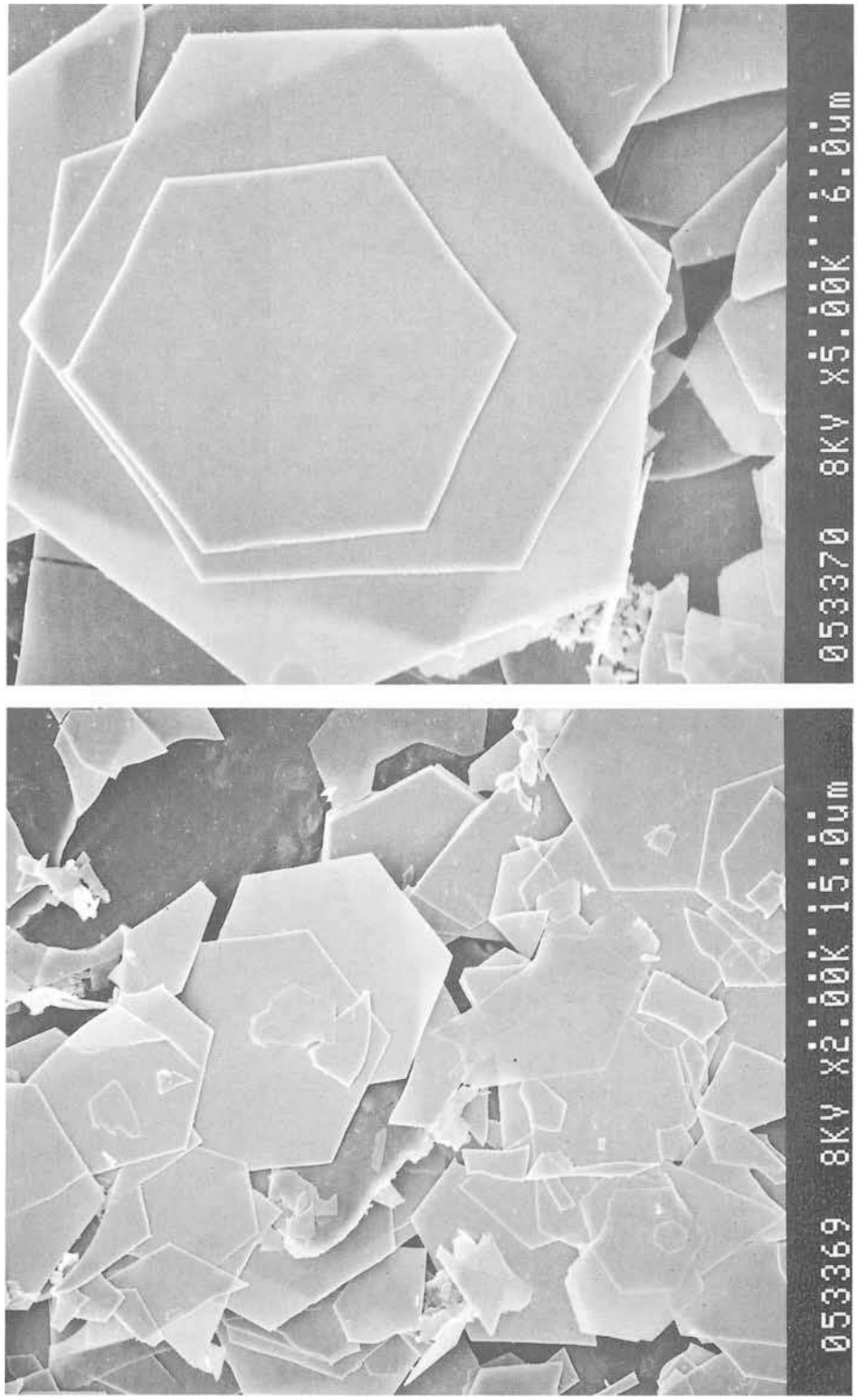

Fig. 4. Scanning electron microscope image of nacreous filler from imitation pearl coating (left) 2000x, (right) 5000x.

accounted for by the relatively low lead content (approx. 1% PbO) as found by electron microprobe analysis.

Coating

The X-ray powder diffraction pattern of the pearl coating obtained at the Gem Testing Laboratory (Figure 3a) was close to that of the mineral hydrocerussite (Figure 3c), but did not match it exactly. The use of hydrocerussite as an imitation pearl coating has been documented[1], but the anomaly in the diffraction photograph led us to pursue the matter further, using a variety of techniques available at the Department of Mineralogy, BM(NH).

An infrared spectrum of the coating material showed a mixture of nitrocellulose and another component. During an unsuccessful attempt to dissolve the coating in dichloroethane, it separated into two layers, i.e. a nitrocellulose 'sandwich' with nacreous inner surfaces. Acetone dissolved the nitrocellulose lacquer completely and allowed further infrared spectra to be run on the separated soluble and insoluble materials (approx. 56 wt% insol.). These spectra confirmed the identification of nitrocellulose and a hydrocerussite-like filler. Under the optical and scanning electron microscopes, the acetone-insoluble nacreous filler appeared as minute hexagonal plates of average size 15 × 0.25 micrometres (Figure 4). These plates were also examined in the electron microprobe, which revealed lead as the only detectable element (elements lighter than sodium are not detectable by this instrument).

Hydrocerussite or lead dihydroxydicarbonate has been produced synthetically by many different methods, some of which are quoted as giving rise to hexagonal nacreous plates[2].

The exact chemical composition of these synthetic products is in doubt, as is the composition of the pigment 'white lead' which is another form of hydrocerussite[3]. A specimen of white lead gave an X-ray diffraction pattern and an infrared spectrum both of which matched much more closely those of the pearl material than the mineral hydrocerussite (see X-ray patterns, Figures 3b & 3c).

Further background

After these investigations were completed, M. Jean Paul Poirot presented a paper at the International Gemmological Conference in Brazil in 1987 entitled 'Imitation pearls and their coatings'. He noted the following crystalline materials as being present in the nacreous coatings of imitation pearls and visible on microscopic examination of an acetone extract of the coating:

(1) rods of guanine approx. 5 × 30 micrometres – this is a component of the well-known 'essence of orient' extracted from fish scales and one of the longest-used pearl simulants; or
(2) square plates of bismoclite (bismuth oxychloride) approx. 10 micrometres across – this compound is also used in 'pearl' cosmetics such as nail varnish, etc.; or
(3) hexagonal plates of hydrocerussite approx. 15 micrometres across; or
(4) fragments of mica crystals, sometimes coated with titanium dioxide.

Conclusion

The imitation pearls in question are coated with a synthetic, basic lead carbonate in the form of minute hexagonal plates, suspended in and coated by clear nitrocellulose lacquer.

The anomalies in the X-ray powder diffraction patterns and infrared spectra are the result of the variable nature of the basic lead carbonate, the exact composition of which depends on its method of production.

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Alexandrite: natural or synthetic?

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Since the appearance on the market of great quantities of rough and faceted alexandrites from Brazil (Bank *et al.*, 1987a; Bank *et al.*, 1987b; Gübelin and Schiffmann, 1988), the differentiation between these (to a great extent relatively inclusion-free) gemstones, and synthetic alexandrites, has naturally been pushed into the foreground of gemmological investigations. Recently a dark green-to-violet changing to red-violet stone of 1.34 ct (faceted, oval, 7.2 × 6.4 × 3.5 mm) arrived for investigation, which had been identified by a laboratory as a synthetic alexandrite. Yet the owner of the stone doubted this outcome, since he had purchased it personally in the rough at the mine in Brazil and had also cut it himself (which, however, does not prove that it is genuine).

The stone was doubly-refractive on the polariscope and biaxial on the conoscope. The standard gemmological values were as follows:
$n_x = 1.745$, $n_y = 1.748$, $n_z = 1.754$, $\Delta n = 0.009$, $D = 3.71$ g/cm^3.
These all indicate the mineral variety chrysoberyl ($BeAl_2O_4$), which crystallizes in the orthorhombic system. With the aid of spectroscopic analyses, the stone could be identified as an alexandrite through the presence of chromium lines. Yet the question of natural versus synthetic still remained unsolved.

Microscopically, step-like growth striations were observed – which are also no indication of natural origin – as well as 'fingerprint-feathers' of bizarre-shaped cavities (Figure 1). Some of the latter contained a solid substance which between crossed polars displayed interference colours, and was thus founded to be doubly-refractive. With overhead illumination, these inclusions reflect strongly (Figure 2) and are thus reminiscent of the flux residues in synthetic alexandrite (Gübelin and Koivula, 1986, Trossarelli, 1986, Henn, 1987).

Several inclusions were exposed to the surface of the faceted stone, allowing further investigations as to their identity with the help of more sophisticated methods. Qualitative energy-dispersive analyses with the aid of a scanning electron microscope (SEM), identified very diverse substances in the fissures surrounding the exposed inclusions. Figure 3 shows such an area of fissures; the white streak measures 50 μm. The white spherical grain could be identified as tin. Similar solid substances present in these fissures proved to be copper, nickel and lead. Lead-oxide was detected by means

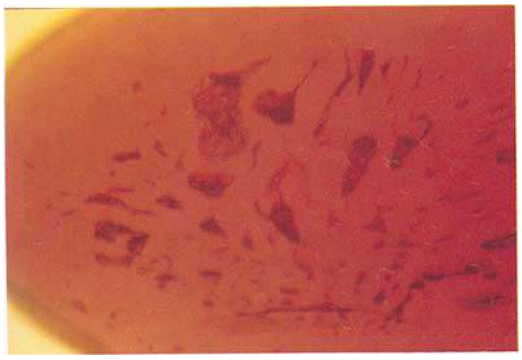

Fig. 1. Bizarre-shaped cavities, partly filled with solid substance. 15x.

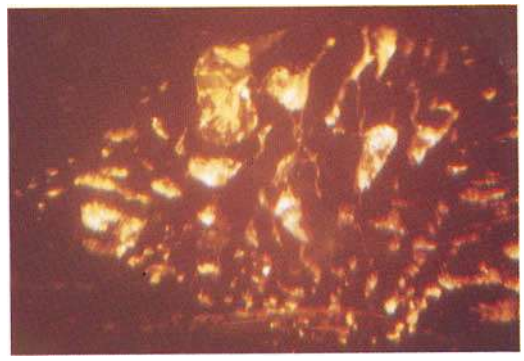

Fig. 2. Bizarre-shaped cavities, partly filled with solid substance. Reflected light. 20x.

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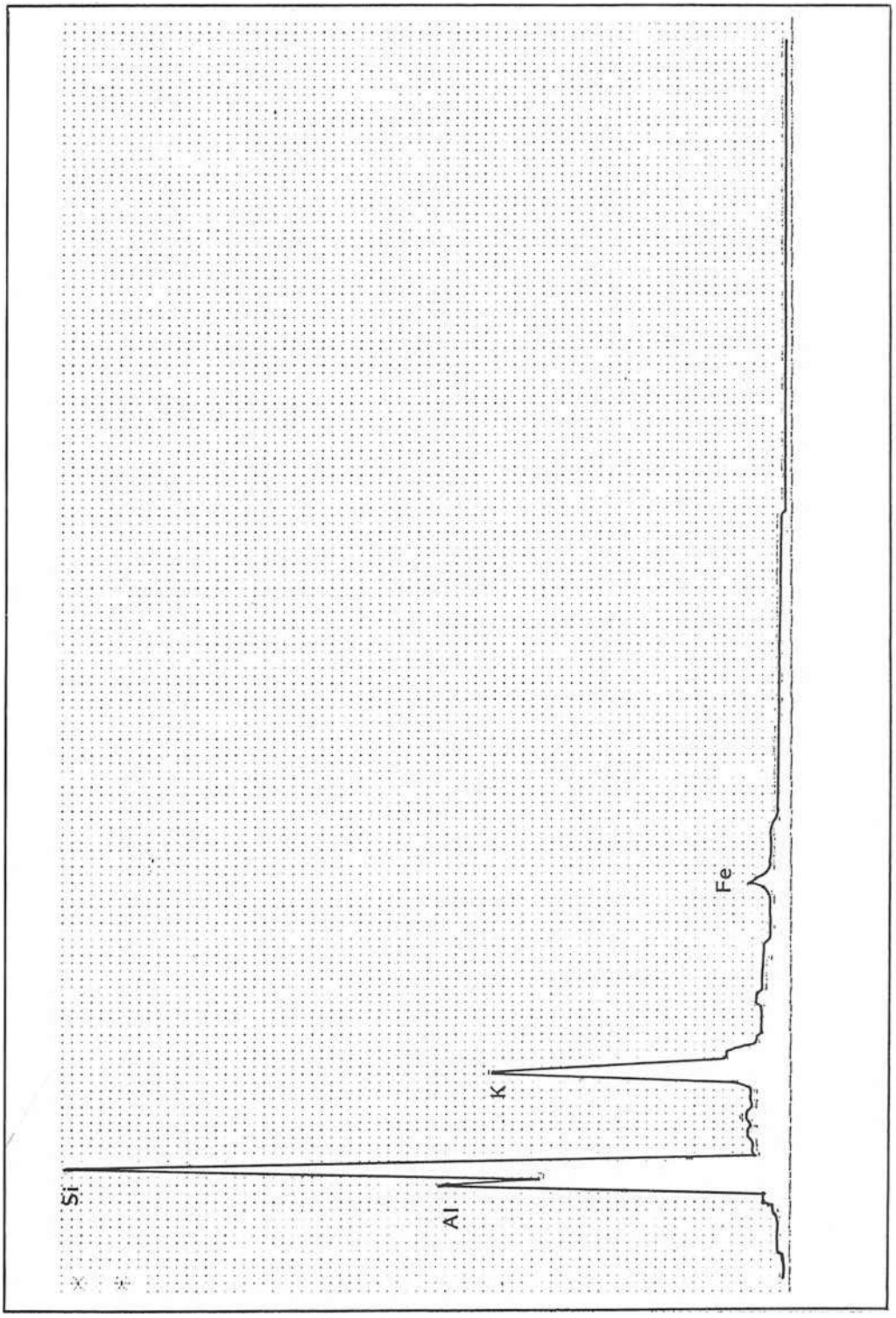

Fig. 4. Energy-spectrum of alkali-feldspar inclusion.

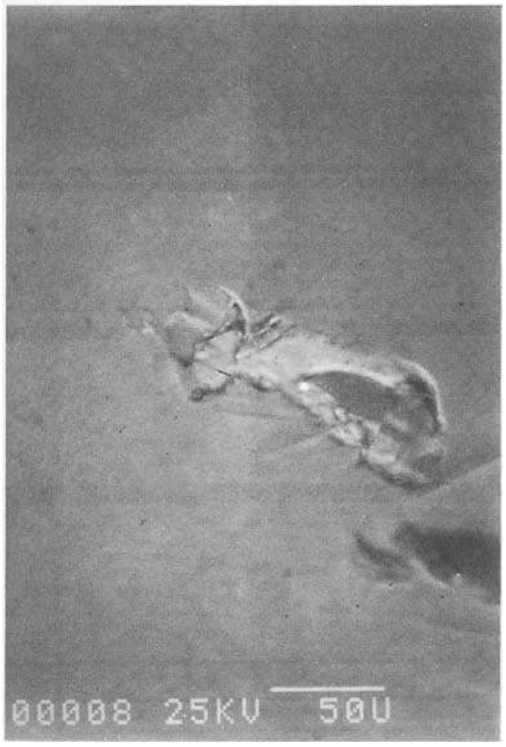

Fig. 3. SEM-photograph: fissure with solid substances.

of the Raman spectroscope. The latter was quoted as proof that the investigated stone was a synthetic alexandrite. These spherical metal grains, however, were not securely lodged in the fissures, and are probably remnants left by the cutting or polishing discs, which were forced into the fissures during these processes.

A more precise investigation of the solid fillings of these fissures revealed the presence of potassium-rich aluminium silicates – probably potassium feldspar (Figure 4). This definitely proves the natural origin of the stone.

Acknowledgements

Scanning electronic microscope analyses were carried out at the Max-Planck-Institut für Chemie, Abt. Kosmochemie, Mainz, West-Germany. Financial support was given by grants of the Wirtschaftsministerium des Landes Rheinland-Pfalz, FRG, within a project for applied research.

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A new type of twinning in natural sapphire

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Abstract

A new type of twin structure in natural sapphire from Sri Lanka is described. The samples reveal inserted irregularly shaped bodies of subordinate corundum individuals, which are confined to intercalated lamellae parallel to rhombohedral faces *r* $(10\bar{1}1)$ and related to the dominant crystal by reflection across $(10\bar{1}1)$.

In some cases, the recognition of certain types of twinning in ruby and sapphire is applicable to the distinction of natural and synthetic corundum. In general, a detailed knowledge about twin structures occurring in natural ruby and sapphire as well as in different types of synthetic corundum is necessary in order to avoid misinterpretations of structural properties during microscopic examination of samples of unknown origin. A general survey dealing with twin structures in natural rubies from different localities is given by Schmetzer (1987), and the results described in the paper cited are also valid for natural sapphires without any restriction. Twinning in flux-grown gem quality synthetic ruby and sapphire was described in detail by Schmetzer (1987) and Kiefert & Schmetzer (1988).

In natural corundum, three types of twinning are observable: contact twins on the basal plane *c* (0001) or on the positive rhombohedron *r* $(10\bar{1}1)$ with two macroscopically developed individuals are rare. Repetitive twinning on *r* $(10\bar{1}1)$, on the other hand, is common in natural ruby and sapphire but, in general, only thin lamellae of corundum in twin position are intercalated parallel to one, two or three rhombohedral faces of the dominant ruby or sapphire crystal. In some samples, intercalated lamellae were found to end irregularly within the dominant corundum individual. The new type of twin structure to be described in this paper is confined to intercalated lamellar twinning on *r* $(10\bar{1}1)$. Up to now, twinning of this particular type was observable only in natural corundum, but never in synthetic rubies or sapphires of different producers.

The new type of twin structure was observed in the course of microscopical examination of some hundreds of light yellowish or bluish untreated (i.e. non-heat treated) natural sapphires from Sri Lanka. In about 50 of these cabochon cut samples, bodies of corundum crystals were found to occur in an orientation different from the dominant sapphire individual. Due to their different crystallographic orientation, these corundum crystals inserted into the dominant individual are clearly recognizable under crossed polarizers, but not in plane polarized light (Figures 1–6). Part of these inserted bodies reveal only irregular surfaces as boundaries between dominant and subordinate corundum individuals (Figures 1, 2). Both crystals differing in orientation, in general, are not related by reflection across the positive rhombohedron *r* $(10\bar{1}1)$ and, at present, it is unknown to the author if both parts of the crystals are connected by an unknown twin law or not.

Samples of the second part of sapphire crystals with inserted bodies of corundum reveal at least one plane surface as boundary between dominant and subordinate individuals (Figure 3). A thorough microscopic examination indicates that, in all cases, these contact planes are parts of intercalated lamellae on *r* $(10\bar{1}1)$ [Figures 4, 5, 6]. The remaining boundaries between main crystals and inserted irregular bodies, i.e. those boundaries which are not confined to an intercalated lamella on *r*, may consist of either irregular surfaces or of plane crystal faces (Figures 3–6).

In part of the crystals investigated, up to five inserted bodies of corundum were observed, which are confined to several intercalated lamellae parallel to one rhombohedral face *r* $(10\bar{1}1)$. In two samples, inserted bodies of corundum in twin position were found which are confined to intercalated lamellae parallel to two rhombohedral faces *r* and *r'* $\{10\bar{1}1\}$.

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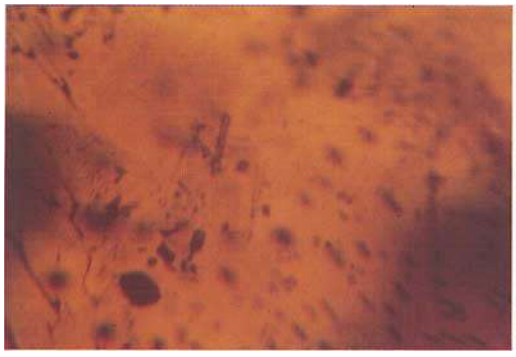

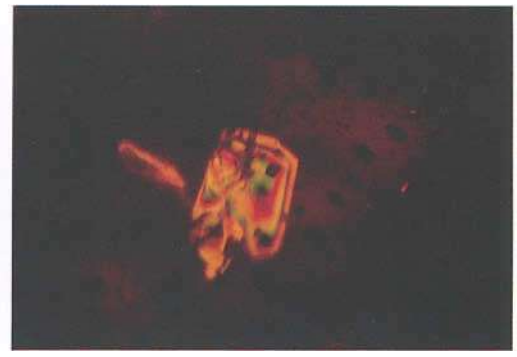

Figs. 1, 2. Natural sapphire from Sri Lanka; inserted bodies of corundum revealing irregular surfaces as boundaries between subordinate crystals and the dominant individual. Fig. 1, plane polarized light; Fig. 2 crossed polarizers. 100x.

Fig. 3. Natural sapphire from Sri Lanka; inserted bodies of corundum revealing plane boundaries between dominant and subordinate individuals. Crossed polarizers. 30x.

Fig. 4. Natural sapphire from Sri Lanka; inserted body of corundum [below] confined to an intercalated lamella on the positive rhombohedron r $(10\bar{1}1)$ [above] as boundary between dominant and subordinate individuals. View almost perpendicular to the intercalated lamella, crossed polarizers. 20x.

Fig. 5. Natural sapphire from Sri Lanka; inserted body of corundum confined to an intercalated lamella on the positive rhombohedron r $(10\bar{1}1)$ as boundary between dominant and subordinate individuals. View parallel to the intercalated lamella, crossed polarizers. 20x.

Fig. 6. Natural sapphire from Sri Lanka; inserted bodies of corundum confined to an intercalated lamella on the positive rhombohedron r $(10\bar{1}1)$ as boundary between dominant and subordinate individuals. View almost parallel to the intercalated lamella, crossed polarizers. 40x.

According to its properties, the new type of twin structure in corundum described combines both single types of rhombohedral twinning, i.e. contact twinning on r $(10\bar{1}1)$ [consisting of two macroscopically developed individuals] and lamellar twinning on r $(10\bar{1}1)$ [consisting of intercalated thin lamellae]. Consequently, this type of twinning is classified as combined rhombohedral twinning.

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[*Manuscript received 22 February 1988.*]

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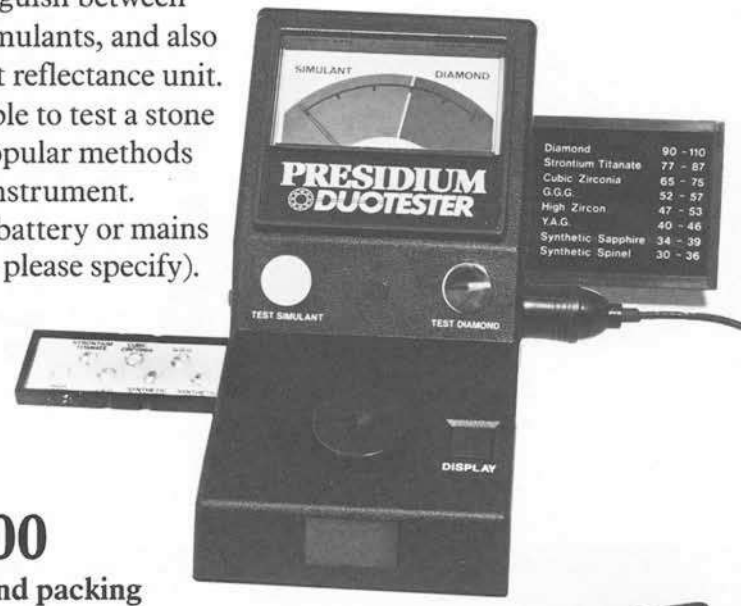

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An unusual ruby from Nepal*

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Abstract

A high quality ruby from Nepal is described. The stone, weighing 1.288ct, revealed extraordinary growth structures connected with colour zoning as well as mineral inclusions (phlogopite), feathers consisting of two- and most probably three-phase inclusions and ultra-fine fluid films, as diagnostic characteristics.

Introduction

A purely gemmological routine investigation can sometimes result in a false diagnosis, or at least create difficulties, especially when the problem concerns the differentiation between natural gems and synthetic stones. This is particularly so if the inclusions observed are not clearly indicative, but

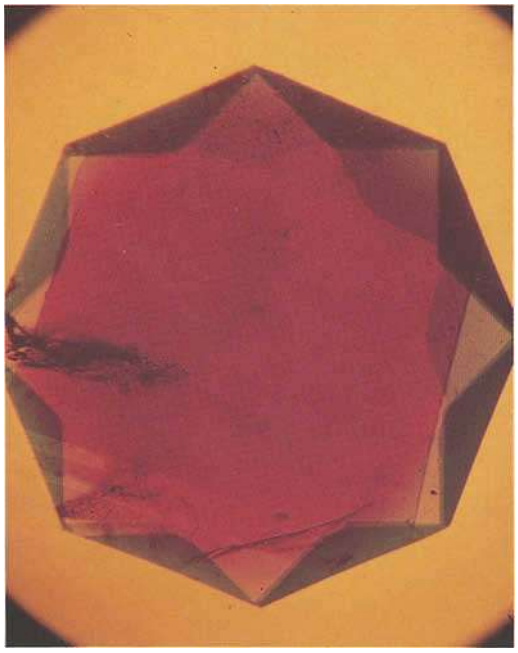

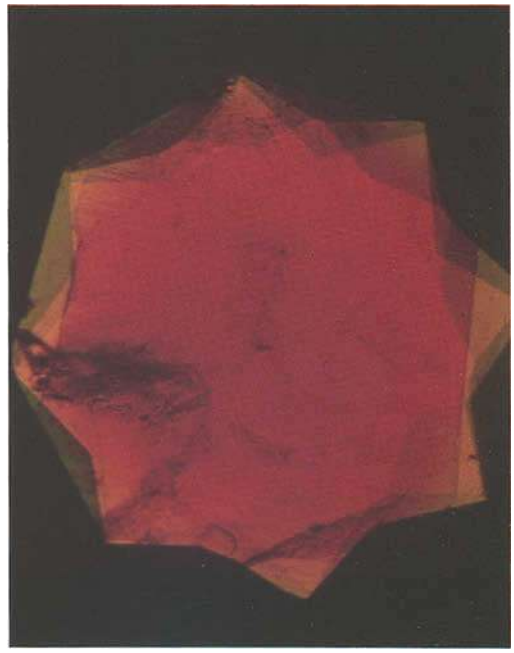

Figs 1 and 2. Growth structures and colour zoning in a natural ruby from Nepal; view almost perpendicular to the *c*-axis; broad alternate colourless and red bands parallel to the basal pinacoid *c* (0001) forming the lower edge of the sample, colourless parts confined to growth structures parallel to the hexagonal prism *a* $(11\bar{2}0)$ on the left side of the sample and parallel to the hexagonal dipyramid *v* $(44\bar{8}1)$ on the right of the sample, spindle-like growth structures in the dark red central part of the stone. Transmitted light using methylene iodide as immersion liquid. 22x. *(Photos by K. Schmetzer.)*

*The Editor received two papers on this subject on the same day. They have been combined to form this paper.

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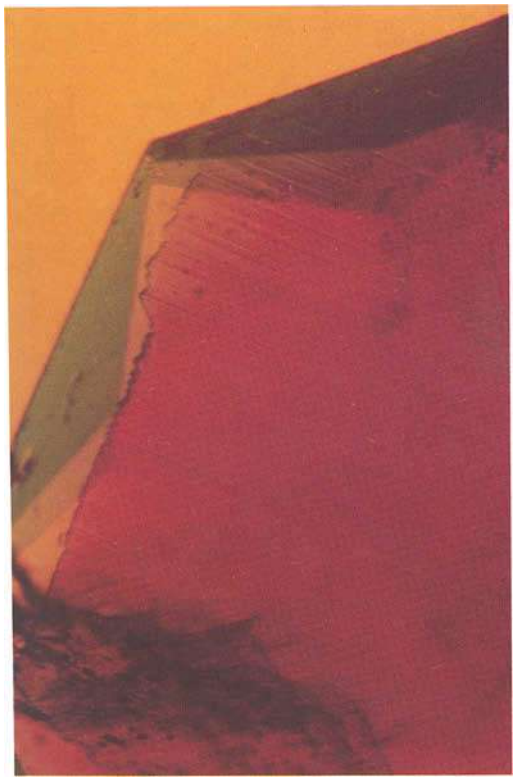

Fig. 3. Growth structures and colour zoning in a natural ruby from Nepal; view almost perpendicular to the *c*-axis; growth structure parallel to the hexagonal prism *a* $(11\bar{2}0)$ visible as boundary between colourless edge and dark red central part, spindle-like growth structures in the central part, parallel to the basal face *c* (0001). Transmitted light using methylene iodide as immersion liquid. 30x. *(Photo by K. Schmetzer.)*

Fig. 4. Spindle-like growth structures in the dark red central part of a natural ruby from Nepal; view almost perpendicular to the *c*-axis. Transmitted light using methylene iodide as immersion liquid. 25x. *(Photo by K. Schmetzer.)*

ambiguous, i.e. if they could be found in both natural and synthetic stones and are not typical of either. This happened recently during the investigation of a faceted red stone, whereby the question was raised whether it was a natural or a synthetic stone, and whether it originated from the Kingdom of Nepal.

Ruby, as well as pink, violet and purplish sapphires, from Nepal were recently described by Harding and Scarratt (1986) and Kiefert and Schmetzer (1986, 1987). Most of the material available until now has been of cabochon quality and any faceted samples of notable transparency have been few. Thus, the authors were surprised to receive a faceted sample of more than one carat, with excellent purity, a good 'Burmese red' colour, and which was said to originate from Nepal. Under the microscope the ruby revealed characteristics which closely resembled some of the properties seen in Ramaura and Kashan synthetic rubies and which had not been observed previously in Nepalese rubies. So the stone was examined in detail using spectroscope, microprobe and further microscopic investigations.

Investigation

The faceted ruby weighs 1.288 ct and is cut as an almost equilateral octagon (6.00 × 6.00 × 4.15 mm). The physical properties of the sample are within the range known for both natural and synthetic ruby, i.e. $n_o = 1.770$, $n_e = 1.762$, $\Delta n = 0.008$, $D = 3.98$ g/cm^3, and with the hand spectroscope the normal chromium spectrum of ruby was detected.

The absorption spectrum of the sample in the visible and ultraviolet regions, as examined with the aid of a UV/VIS spectrophotometer, is similar to the spectra already published for ruby and sapphire from Nepal by Harding and Scarratt (1986) and Kiefert and Schmetzer (1986, 1987),

but does not contain a significant Fe^{2+}/Ti^{4+} charge transfer absorption in the red region of the visible spectrum. Due to the absence of iron and/or titanium in distinct amounts, the sample reveals a good ruby colour without any purplish hue, i.e. without an additional sapphire component.

Using methylene iodide as an immersion liquid, a microscopic examination of the ruby, in a direction normal to the table facet, revealed a dark red central area, two well-defined and near-colourless areas situated close to the girdle and on opposite sides and another area, also bounded at one edge by the girdle, in which there was strong colour zoning (Figures 1, 2 and 3). In the latter area the alternating broad colourless and red zones (Figures 1 and 2) are parallel to the basal pinacoid *c* (0001), and the two near-colourless areas form angles of 90° and 85° respectively, with the growth structures connected with this colour zoning. Consequently, these colour zones are confined to growth structures parallel to the hexagonal prism *a* $(11\bar{2}0)$ and parallel to the hexagonal dipyramid *v* $(44\bar{8}1)$. Similar almost rectangular growth structures connected with colour zoning have been observed previously by the authors in Ramaura synthetic rubies. However, in such stones the growth zones forming angles of 86° are made by two different rhombohedral faces *r* and *r'* $(10\bar{1}1)$.

Many of the microscopic observations disclosed ambiguous features which could neither be attributed clearly to a natural nor a synthetic ruby. Amongst the most confusing characteristics of this 1.288 ct ruby are the spindle-like growth structures in the dark red central part of the stone. These are parallel to the basal pinacoid *c* (0001) (Figures 1 and 4), and are connected with the colour zoning. These structural characteristics resemble features often observed in synthetic flux-grown rubies.

Both at the girdle and near the culet of the stone several small, solid inclusions are exposed at the surface. Examination by electron microprobe both in London and Heidelberg indicated that these inclusions are phlogopite (Figure 5), a mica which has already been identified in the paragenesis of ruby and rose and violet sapphire from Nepal.

Further microscopic examination revealed the presence of dark 'feathers' consisting of small more

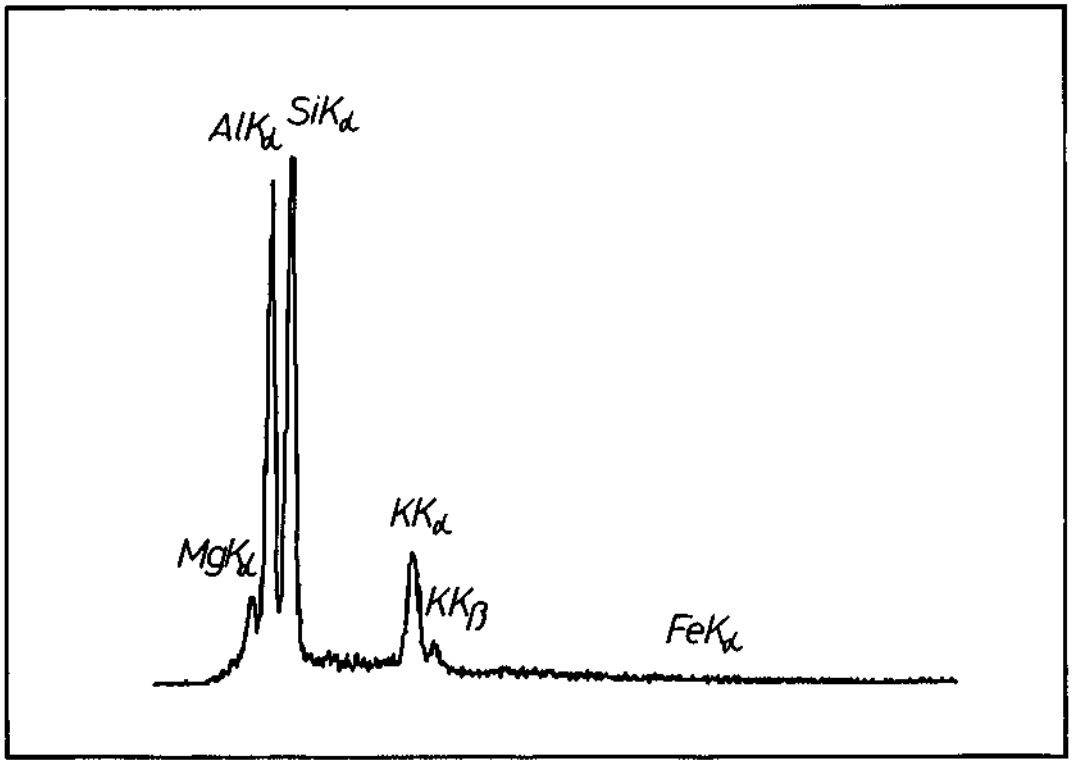

Fig. 5. Energy-dispersive X-ray spectrum of phlogopite in natural ruby from Nepal. This spectrum was performed by K. Schmetzer confirming results of R. R. Harding.

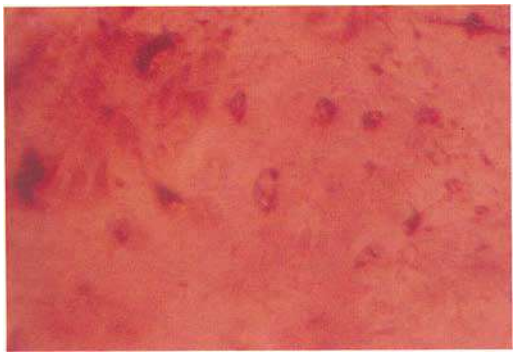

Fig. 6. 'Feather' consisting of irregular cavities and negative crystals with liquid and two-phase filling. Transmitted light using methylene iodide as immersion liquid. 75x. *(Photo by U. Henn.)*

Fig. 7. 'Feather' consisting of liquid, two- and most probably three-phase inclusions in natural ruby from Nepal. The solid components (probably margarite) show interference colours. Transmitted light using methylene iodide as immersion liquid, crossed polarizers. 80x. *(Photo by K. Schmetzer.)*

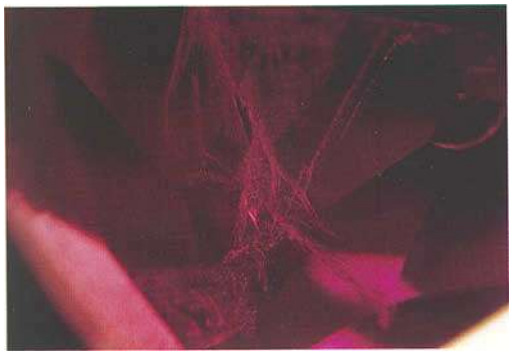

Fig. 8. 'Feather' consisting of small irregularly shaped cavities and negative crystals with multi-phase filling in natural ruby from Nepal. Darkfield illumination. 40x. *(Photo by K. Scarratt.)*

Fig. 9. 'Feather' consisting of small irregularly shaped cavities and negative crystals with multi-phase filling (lower left part) and ultra-thin liquid and two-phase inclusions showing interference colours under suitable illumination (central and upper right part). Transmitted light using methylene iodide as immersion liquid, crossed polarizers. 100x. *(Photo by K. Schmetzer.)*

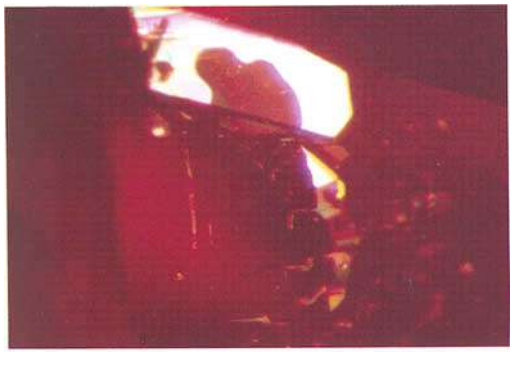

Fig. 10. Ultra-fine liquid films, partly also two-phase (liquid/gaseous) in natural ruby from Nepal; these fluid inclusions reveal interference colours under suitable illumination. Darkfield illumination. 50x. *(Photo by E. Gübelin.)*

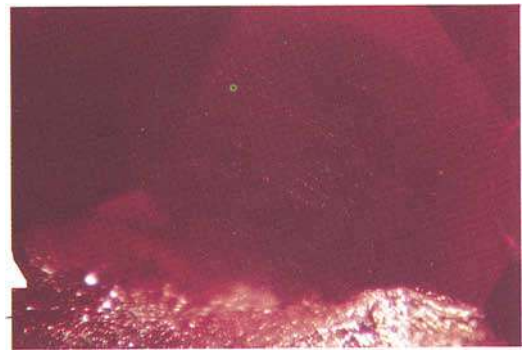

Fig. 11. Fine and bright dust-like 'fog' particles in natural ruby from Nepal. Reflected light. 60x. *(Photo by K. Scarratt.)*

or less irregularly shaped cavities as well as small crystals (Figures 6 to 9). The filling of the small cavities is liquid, two-phase (solid/liquid or liquid/gaseous) and, most probably, also three-phase (solid/liquid/gaseous). The solid parts of the inclusions displayed interference colours under crossed polarizers (Figure 4). Such feathers, which have been observed previously in Nepalese rubies of a much lower quality, closely resemble residual flux in flux-grown synthetic rubies. In addition, ultra-fine liquid films, sometimes also as two-phase inclusions (liquid/gaseous) were observed in the natural ruby from Nepal (Figures 9, 10). Under suitable illumination, these filmy inclusions glow with interference colours. The ultra-fine films testify – together with the phlogopite inclusions examined by electron microprobe – to the natural origin of the ruby. However, another type of inclusion was quite ambiguous at first sight; these are dust-like 'fog' striations (Figure 11), which are reminiscent of Kashan synthetic rubies.

Conclusion

In summary, the presence of phlogopite, two- and, most probably, three-phase inclusions, as well as ultra-fine fluid inclusions in this high quality, 1.288 ct ruby, on the one hand, proves the sample to be of natural origin, and, on the other, confirms its locality as Nepal. Until now the exceptional growth structures of this ruby had not been observed in natural rubies either from this or any other locality.

Acknowledgement

We would like to thank Ms F. Wall, Department of Mineralogy, BM(NH), for Microscan IX microprobe analyses of the ruby and its phlogopite inclusions.

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[*Manuscript received 28 April, 1988.*]

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ESR and optical spectra of Mn^{2+} sapphire

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Introduction

In our studies of the Electron Spin Resonance (ESR) spectra of natural sapphires (Troup and Hutton, 1983) we observed in many cases, a large number of small lines covering a large magnetic field range: an example is given in Figure 1. The hypotheses we put forward to explain these lines were: (a) that they could be due to pairs of Cr^{3+} or Fe^{3+} ions; (b) that they could be due to radiation damage; and (c) that they could be due to Mn^{2+}.

Although the Spin-Hamiltonian (ESR spectral parameters and behaviour) of Mn^{2+} in sapphire have been published previously (Low and Suss, 1960; Folen, 1962), no illustrations of spectra were given. It would have been possible to calculate the appearance of the spectra, but this involves assumptions about line-shapes. Accordingly, it was decided to synthesize some Mn^{2+} sapphire, in order to record the ESR spectra, and compare the appearance and line positions with the extended, small line spectra mentioned above.

Synthesis of Mn^{2+} sapphire

Crystals of Mn sapphire were grown in PbO–Pb F_2 flux (Chase and Osmer, 1970). Analytical reagent grade chemical compounds were used, and the composition was: 17 mol % of Al_2O_3, 30 mol % of PbF_2, 53 mol % of PbO and 0.05 mol % of MnO_2. These amounts of the compounds were mechanically mixed in an alumina container by shaking with a mixing pulsator for two hours.

Subsequently the mixture was placed in a 60ml platinum crucible which was then closed with a platinum plug. The filled crucible was placed in a closed-end alumina tube and covered with alumina bubbles. A ceramic cap was used to close the open end of the tube. (Figure 2).

The alumina tube containing the Pt crucible was placed in the furnace and heated to 1270°C, held for 4 hours and cooled at 4°C/h to 900°C.

The crucible was then cooled with the furnace. The crystals which grew on the melt surface were removed from the solidified flux by leaching in hot

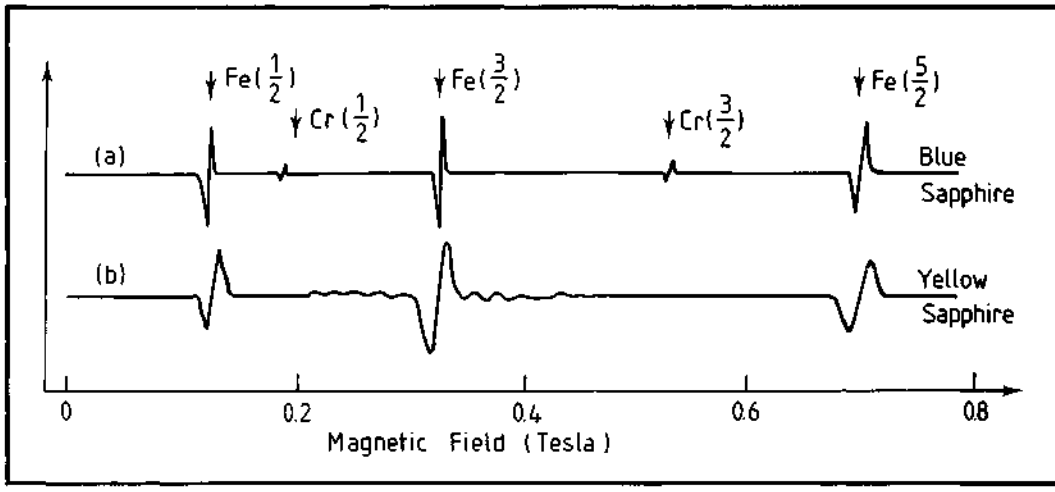

Fig. 1. ESR spectra of blue and yellow sapphire at ~ 3 cm wavelength with the steady magnetic field perpendicular to the trigonal axis.

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25% HNO_3. They were in the form of pink pseudo-hexagonal or irregular platelets, which proved to have the large faces perpendicular to the c-axis. Most crystals had flux inclusions, and a somewhat irregular distribution of the pink coloration. Some of them are shown in Figure 3.

Optical spectrum

The optical (visible) spectra to be presented and discussed below were taken with a Varian DMS100 UV-Visible spectrophotometer. Because the Mn^{2+} sapphire crystals were thin basal pinacoids, only the ordinary ray spectrum, shown in Figure 4, could be obtained. A comparison spectrum of Cr^{3+} sapphire ('pink ruby') is shown in Figure 5. Because the spectrophotometer has an unpolarized light source, and because of the cut of the synthetic Cr^{3+} sapphire sample available to us, its spectrum is a 'mixture' of ordinary and extraordinary ray spectra.

However, the familiar absorption bands in the blue and green are clearly displayed, as is the ultraviolet absorption edge. The feature labelled 'D', in the red, results from the usually fluorescent 'ruby doublet'; in this case, because the dispersive element in the spectrophotometer comes immediately after the *source*, so that *monochrome* light falls on the sample, the lines are in absorption.

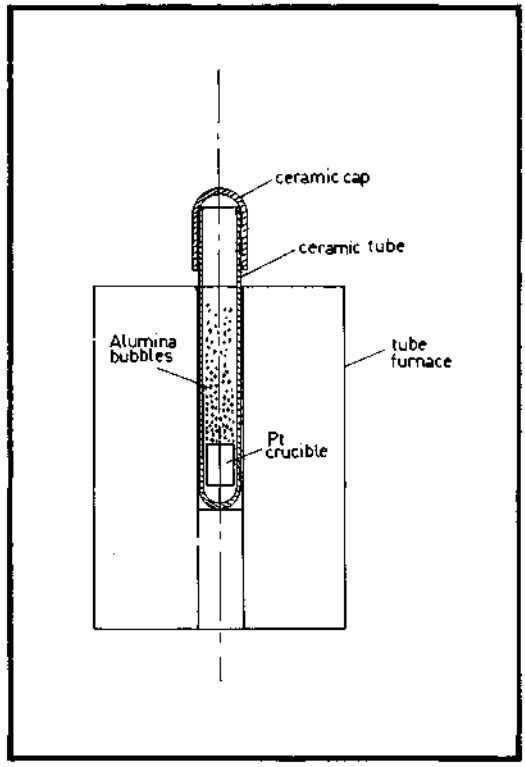

Fig. 2. Details of the arrangement used in the furnace in order to synthesize Mn^{2+} sapphire.

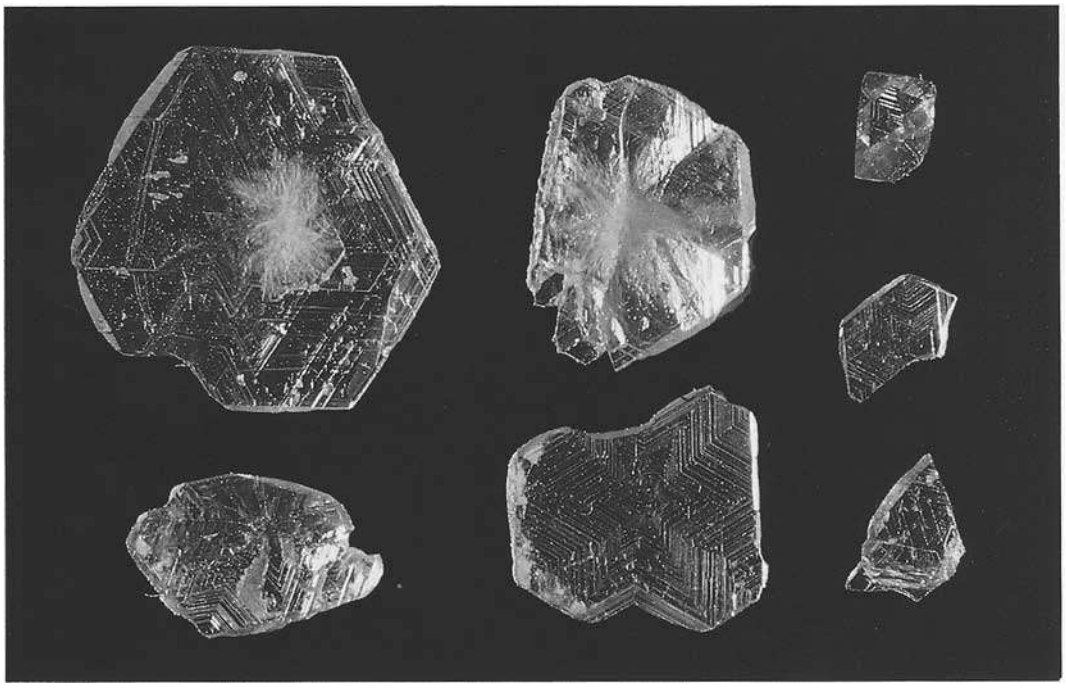

Fig. 3. Some crystals of Mn^{2+} sapphire. The largest crystal is ~ 1 cm across.

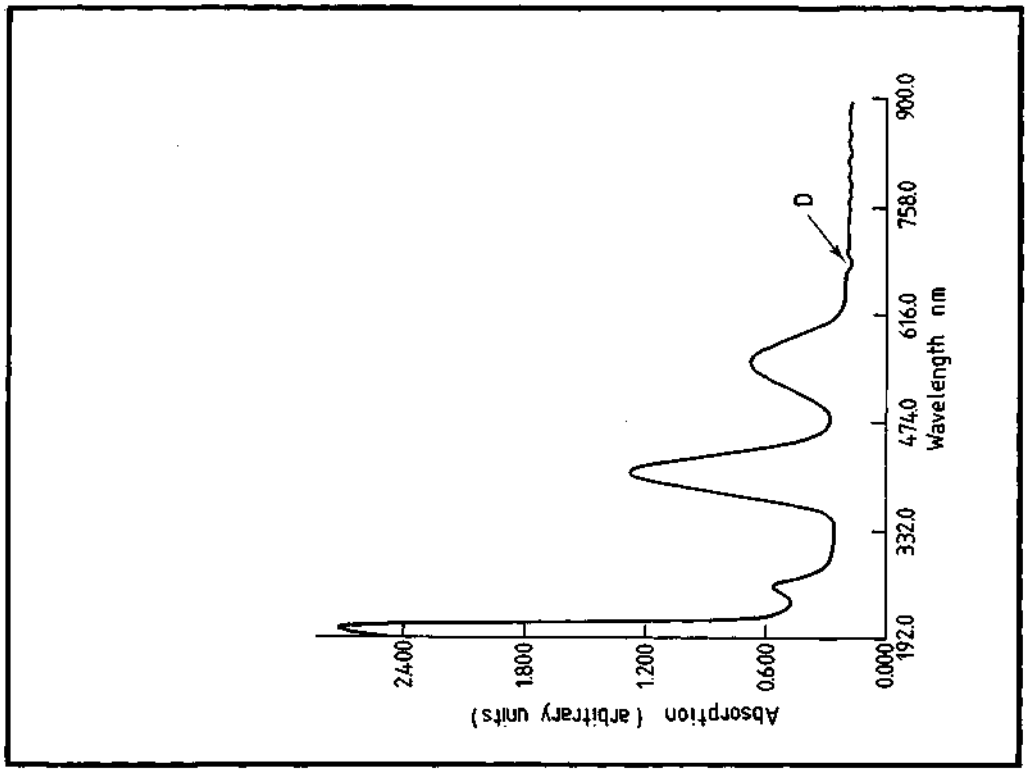

Fig. 5. Optical spectrum of synthetic ruby: 'mixture' of ordinary and extraordinary ray.

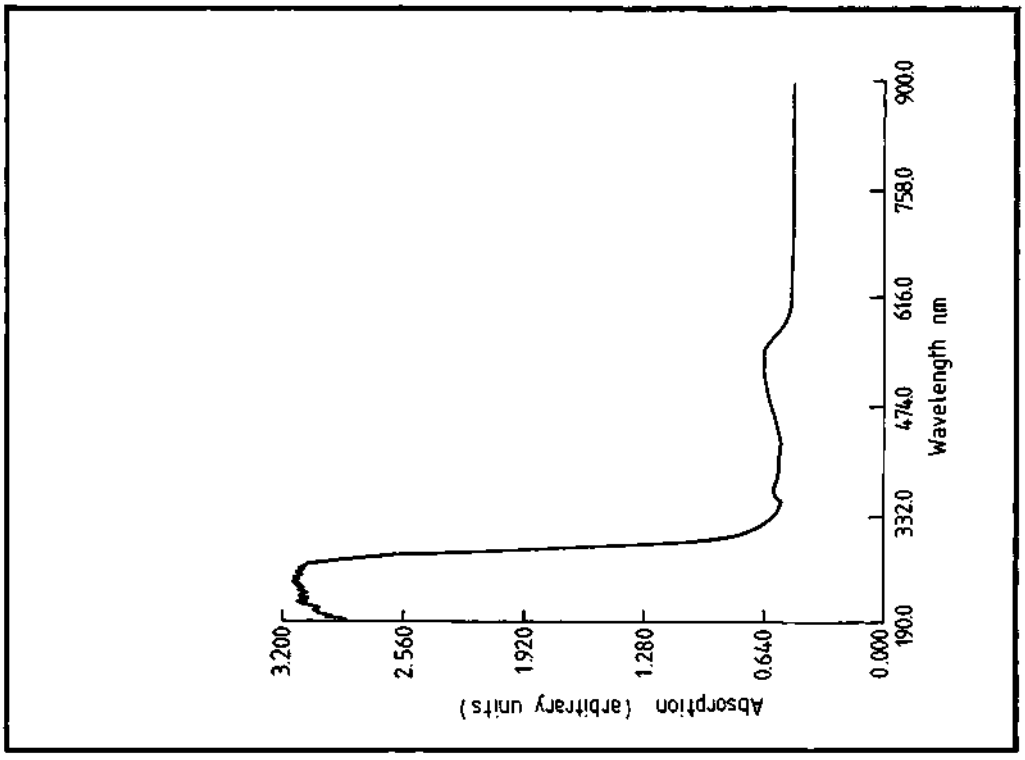

Fig. 4. Optical spectrum of Mn^{2+} sapphire: ordinary ray only.

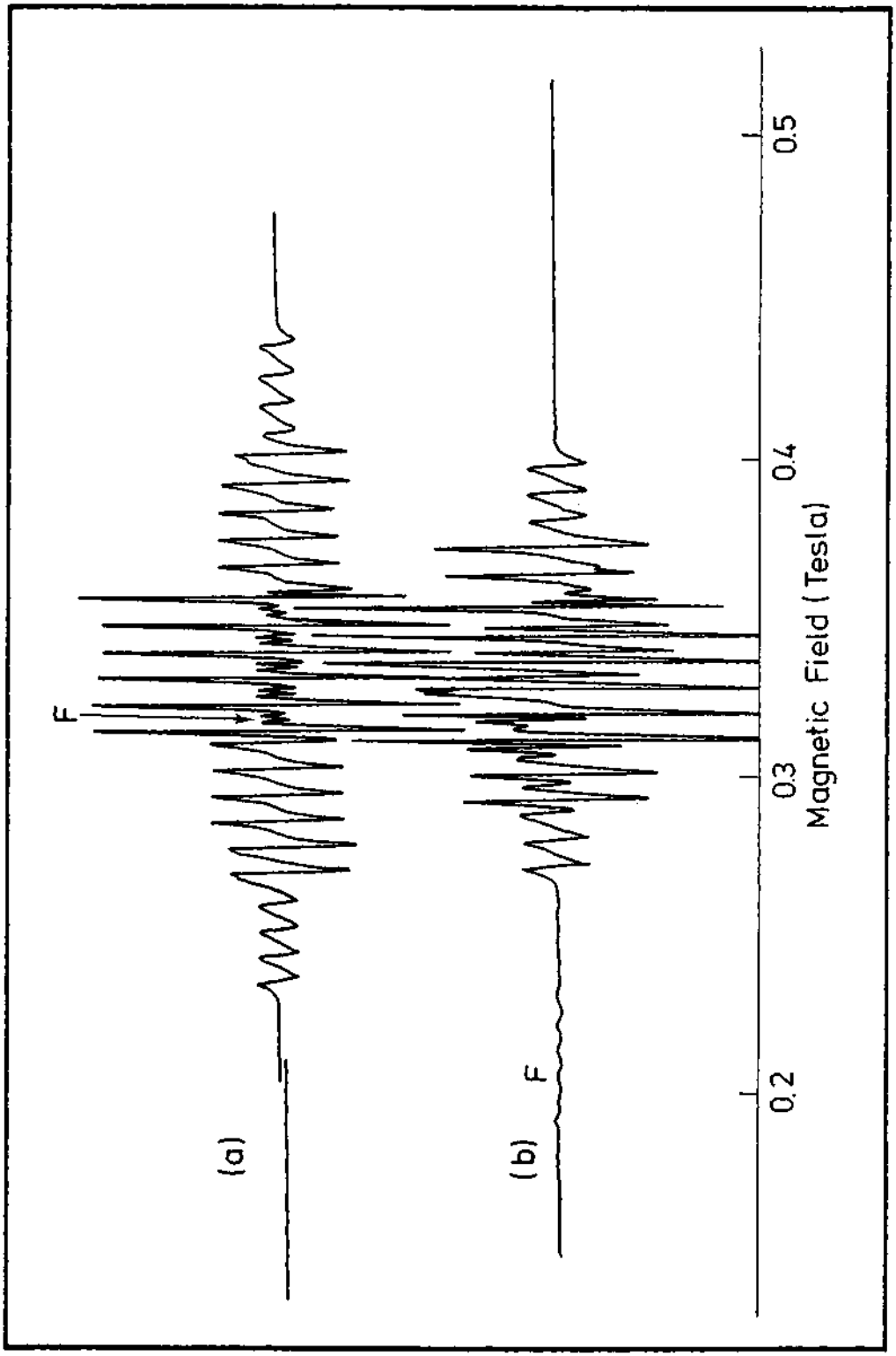

Fig. 6. ESR spectrum of Mn^{2+} sapphire at ~ 3 cm wavelength. Curve (a): static magnetic field parallel to the trigonal axis. Curve (b): static magnetic field perpendicular to trigonal axis.

The Mn^{2+} sapphire shows little absorption in the visible: what there is, occurs in a region not occupied by the ruby absorption bands. Further, the ultraviolet (UV) absorption edge is shifted, towards longer wavelengths, quite considerably. Because of the reduction process used to synthesize this material, it will contain not only Mn^{2+}, but charge compensation centres as well, and also some Mn^{3+}. Any or all of these may be the cause of the shift of the UV absorption edge.

The Mn sapphire fluoresces under UV light, appearing pink to the eye. A gemmological hand-held spectroscope showed a broad fluorescent line on the yellow-green edge of the spectrum.

ESR spectrum

The ESR spectrum of Mn^{2+} sapphire is shown in Figure 6: curve (a) for the static magnetic field parallel to the *c*-axis, curve (b) for the field perpendicular to the *c*-axis. The spectrum is complicated, and spread over quite a large region of magnetic field, in comparison to the Fe^{3+}-and CR^{3+}-sapphire spectra (static magnetic field perpendicular to the *c*-axis) shown in Figures 1(a) and (b). This spread comes about because the nucleus of Mn has a spin of 5/2, and this interacts with the total electron spin of 5/2. The phenomenon is known as 'hyperfine splitting'. The small lines in Figure 6, labelled F, in between the large lines, are due to 'forbidden transitions'. So is the group of lines, at comparatively low field, labelled 'L' in Figure 6(b).

Discussion

To our knowledge, pure Mn^{2+} sapphire does not occur naturally. Our hypothesis, that the ESR lines in the g = 2 region (near 0.3 Tesla) might be due to the presence of Mn^{2+} in natural sapphire is, for the most part, not supported, because the spread of the Mn^{2+} lines about this region is almost symmetrical. For reasons of space, we do not reproduce the spectra given in Troup and Hutton, 1983 here: these spectra, we believe, show that Mn^{2+} is *absent*. Thus the lines arising in many natural sapphires must be due to some other impurity ion, to radiation damage centres, to close pairs of Fe^{3+} ions, or a combination of these three.

However, there may be a good case for the natural yellow sapphire of Figure 1(a) containing Mn^{2+}, since the small lines appear approximately at equal strength on either side of the g = 2 Fe^{3+} line, for the appropriate field spread. The Fe^{3+} lines are very broad in this particular specimen, and magnetic interaction (known as 'anisotropic exchange interaction') is possible between the Fe^{3+} and Mn^{2+} ions. This would broaden the Mn^{2+} lines, thus including the small lines (labelled F in Figure 6) under the broadened large lines. The lower Mn^{2+} field lines of Figure 6(b) would simply be smeared out by this broadening, and thus would not be easily detected. However, the breadth of the Fe^{3+} lines could indicate a high Fe^{3+} concentration, in which case the small lines in the yellow sapphire could be due to close Fe^{3+} pairs. More work, including quantitative analysis, is necessary to resolve this question.

It is clear that either optical or ESR spectra will discriminate easily between (synthetic) Mn^{2+} and Fe^{3+} or Cr^{3+} sapphire. While Mn^{2+} sapphire is a pleasing pink colour, different from the colour of 'pink (Cr^{3+}) sapphire', it is unlikely to become a competitor on the synthetic sapphire market, because it is much more difficult to make.

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The gemmological characteristics of Inamori synthetic cat's-eye alexandrite chrysoberyl

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Abstract

Kyocera Corporation of Kyoto, Japan, has successfully synthesized, and is currently marketing, a chatoyant colour change material that gemmologically tests as cat's-eye alexandrite chrysoberyl. With the exception of microscopic characteristics, all the gemmological properties shown by this material are essentially the same as those encountered in natural alexandrite cat's-eyes. For those gemmologists without access to sophisticated testing equipment, the internal characteristics are the only universally available means of identifying this new synthetic product.

Fig. 1. The two largest synthetic Kyocera alexandrite chrysoberyl cat's-eyes described in this report. Incandescent fibre-optic illumination.

Introduction

Since late 1986 Kyocera America Corporation's 'Inamori' gemstone and jewellery division has been marketing, as 'Inamori', a new chatoyant colour change material that gemmologically tests as alexandrite cat's-eye chrysoberyl. This new synthetic is manufactured by their parent company, Kyocera Corporation, which has headquarters in Kyoto, Japan.

In an effort to provide the gemmological community with information on their new product, Kyocera recently loaned the Gemological Institute of America, in Santa Monica, California, some samples of these new colour change cat's-eyes for gemmological examination. The results of this detailed examination comprise the body of this report.

Description

The two largest stones supplied by Kyocera (Figure 1) were semi-transparent, well polished, oval double cabochons that weighed 3.27 and 3.31 carats respectively, with corresponding measurements of 9.00 × 7.01 × 5.55 mm and 8.92 × 7.11 × 5.61 mm. The remaining bulk of the test sample consisted of ten smaller uniform-cut 6 × 5 mm double cabochons with a total weight of 10.86 carats.

With the aid of a single overhead incandescent light source all the stones displayed a relatively sharp, moderately intense, bluish-white chatoyant band running across their length (Figure 1).

The stones showed a moderate change of colour that complemented their near transparency. The body-colour in incandescent light (Figure 1) was a vivid, slightly-dark, purplish-red. Under the sun, or in fluorescent light, the colour changed to a very

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slightly brownish purple-green. In addition to the colour change, under all lighting conditions, the stones possessed a somewhat greyish milky overtone which is also shown in Figure 1.

In transmitted incandescent light these cat's-eyes showed a columnar cone of milky pink light (Figure 2). Its diameter was controlled by the size of the aperture placed between the light source and the stone.

Gemmological properties

The properties listed by Kyocera in the promotional brochure for their new 'Inamori Created' alexandrite cat's-eye are provided, for reasons of comparison, in the table below.

Classification	Chrysoberyl
Chemical composition	$BeAl_2O_4$
X-ray diffraction	Same as natural alexandrite cat's-eye
Spectograph	Same as natural alexandrite cat's-eye
Crystal system	Orthorhombic
Hardness (Mohs)	8½
Specific gravity	3.72
Melting point	1,870°C
Transparency	Transparent/semi transparent
Refractive index	1.743-1.752
Double refraction	0.008
Change of colour	Distinct
Average dispersion	0.015
Pleochroism	
Daylight	Strong green/yellowish green/dark red
Incandescent light	Reddish purple
Chelsea colour filter reaction	Red
Inclusion	Solidus

The results of the laboratory testing done by the authors on Inamori's alexandrite cat's-eyes are reported as follows:

Refractive index

Using the largest possible 'spot' contact area on the refractometer, and sodium light, the refractive index of these cat's-eyes was read as 1.747 to 1.753. Because the stones' surfaces were curved, more precise readings and accurate birefringence determination were not possible.

Pleochroism

Alexandrite chrysoberyls are trichroic and these stones were no exception. They showed brownish green, brownish yellow and slightly brownish red.

Reaction to ultra violet radiation

When exposed to long-wave ultraviolet radiation the cat's-eyes fluoresced a uniform dull, chalky red colour of moderate intensity. The short-wave reaction appeared to be a slightly stronger, very chalky, brownish-orange. Phosphorescence was not observed in any of the stones.

Specific gravity

Using the hydrostatic method the specific gravity of the two largest stones was determined. The average value for six tests was calculated as 3.74.

Colour filter reaction

As expected, the colour of these synthetic colour change cabochons appeared red when viewed through the Chelsea colour filter.

Spectroscopy

The visible light spectrum, obtained by transmitting white light through the domes of the cabochons, was typical of those recorded previously for alexandrite (Liddicoat, 1981). The observed lines were located at 680, 650, 625, 616 and 471 nanometres. In addition there was a smudged band between 590 and 535 nanometres, and a cut-off in the blue at 445 nanometres. It was also noticed that the largest of the stones showed a weak cat's-eye in transmitted light.

Microscopy

When microscopically examining these synthetic cat's-eyes the first thing noticed is the transmitted light appearance of a multitude of apparently parallel colour zones (Figure 3) that run perpendicular to the chatoyant band (Figure 1). At first these zones appear to be perfectly straight, but close scrutiny, in combination with shadowing, shows that they are very slightly undulating. This suggests that these cat's-eyes are crystallized from a high temperature melt rather than grown as euhedral crystals by a flux or hydrothermal process.

When incident illumination is used, numerous thin, purplish blue-white, milky zoned bands appear where the colour zones are (Figure 4). The precise directional relationship between these milky bands and the colour zones is revealed when the stones are examined, directly through the cabochon's dome, using both fibre optic and shadowed transmitted light in combination (Figure 5).

These zoned bands are composed of tiny white particles which are far too small to be individually resolved microscopically. They are the cause of the

chatoyancy, and their appearance suggests that they may be the result of a controlled annealing and exsolution process: much the same as the chemical precipitation mechanism that was used by Union Carbide's Linde division in making its synthetic star corundums.

Another feature worth mentioning is the limited visibility of these zones. When looking straight down on the edges of the colour zones or milky bands they are easily seen (Figures 3, 4 and 5). But even a very slight change in the viewing angle and these important diagnostic features will no longer be clearly visible. So, in addition to the proper illumination technique, viewing direction is equally important.

The microscope reveals significant features that are contrary to what one expects from nature's environment. In general, the internal motif observed in Kyocera's product in no way resembles the suite of characteristic inclusions recognized so far in natural chrysoberyls (Gübelin and Koivula, 1986).

Spectrophotometry

Using a Pye Unicam PU8800 spectrophotometer, the ultraviolet-visible absorption spectrum of one of these synthetic cat's-eye alexandrites was taken in a direction normal to the cabochon girdle. The result is shown in Figure 6 (top). The very strong absorption background towards the UV is in fact due to the diffusion of light by the inclusions that cause the chatoyancy. The sharp 'chromium lines' situated around 680 nanometres, are also detectable with the hand-held spectroscope.

Two broad absorption bands, with maxima around 440 and 560 nanometres, separate two transmission windows, one in the blue-green, the other in the red. Such a spectrum is responsible for the colour change effect.

The emission spectrum of sunlight has a maximum in the green, so in daylight there is more light transmitted through the window in the blue-green, and the crystal appears bluish green. Longer wavelengths predominate in incandescent illumination and the red body colour results from more light transmitting through the window in the red.

Comparing the spectrum of this synthetic cat's-eye (Figure 6 top) with the spectrum of a natural alexandrite from Tanzania, also shown in Figure 6 (bottom), one notices the absence of the 375 nanometres absorption in the synthetic. This band in the natural stone is due to the presence of Fe^{3+} ions (Farrell and Newnham, 1965) and is present in all optical directions. Iron is a common impurity in natural alexandrite but it is absent from the synthetic cat's-eyes tested so far. Therefore, if a gemmologist has access to a UV-visible spectrophotometer, then this Fe^{3+} related absorption band can be used as an additional means of separating natural from synthetic cat's-eye alexandrite.

One of the synthetic cabochons was also run on the GIA's Nicolet 60SX Fourier Transform Infrared Spectrometer to check for the possible presence of water within the structure. No water was found.

This total lack of water adds support to the premise that Kyocera's alexandrite cat's-eyes are crystallized from a high temperature melt.

X-ray diffraction

All the standard gemmological tests pointed to the conclusion that this synthetic material was chrysoberyl. And in Kyocera's promotional brochure they list chrysoberyl as the result of their X-ray diffraction testing.

However, since this is a new form of synthetic, it was decided to confirm the chrysoberyl identification by means of our own X-ray powder diffraction test.

A glass fibre spindle was prepared and mounted in a Debye-Scherrer powder camera. Then the sample was exposed for 9 hours to X-rays generated from a copper target tube by a voltage of 46 kilovolts and a current of 26 milliamperes.

The exposed X-ray film was developed and allowed to air-dry. The resulting pattern was compared to our standard pattern for chrysoberyl and the two X-ray films matched.

Conclusion

This study of the new Inamori synthetic alexandrite chrysoberyl cat's-eye was based on the examination of only twelve stones.

Although very close, the important gemmological properties, as listed by Kyocera, are not an exact match with those obtained by the authors during testing, and probably reflect average values for a great number of stones. The gemmological properties may vary slightly in a larger test sample and might possibly more closely reflect those reported by Kyocera.

With the exception of microscopy, all the other gemmological properties shown by these Inamori cat's-eyes, such as ultraviolet fluorescence and specific gravity, overlap with those shown by natural alexandrite chrysoberyls. Therefore, unless one has access to a UV-visible spectrophotometer, the microscope is the only means available to the gemmologist for the positive identification of Kyocera's newest synthetic.

How much of this synthetic cat's-eye alexandrite will enter the gem market is open to speculation.

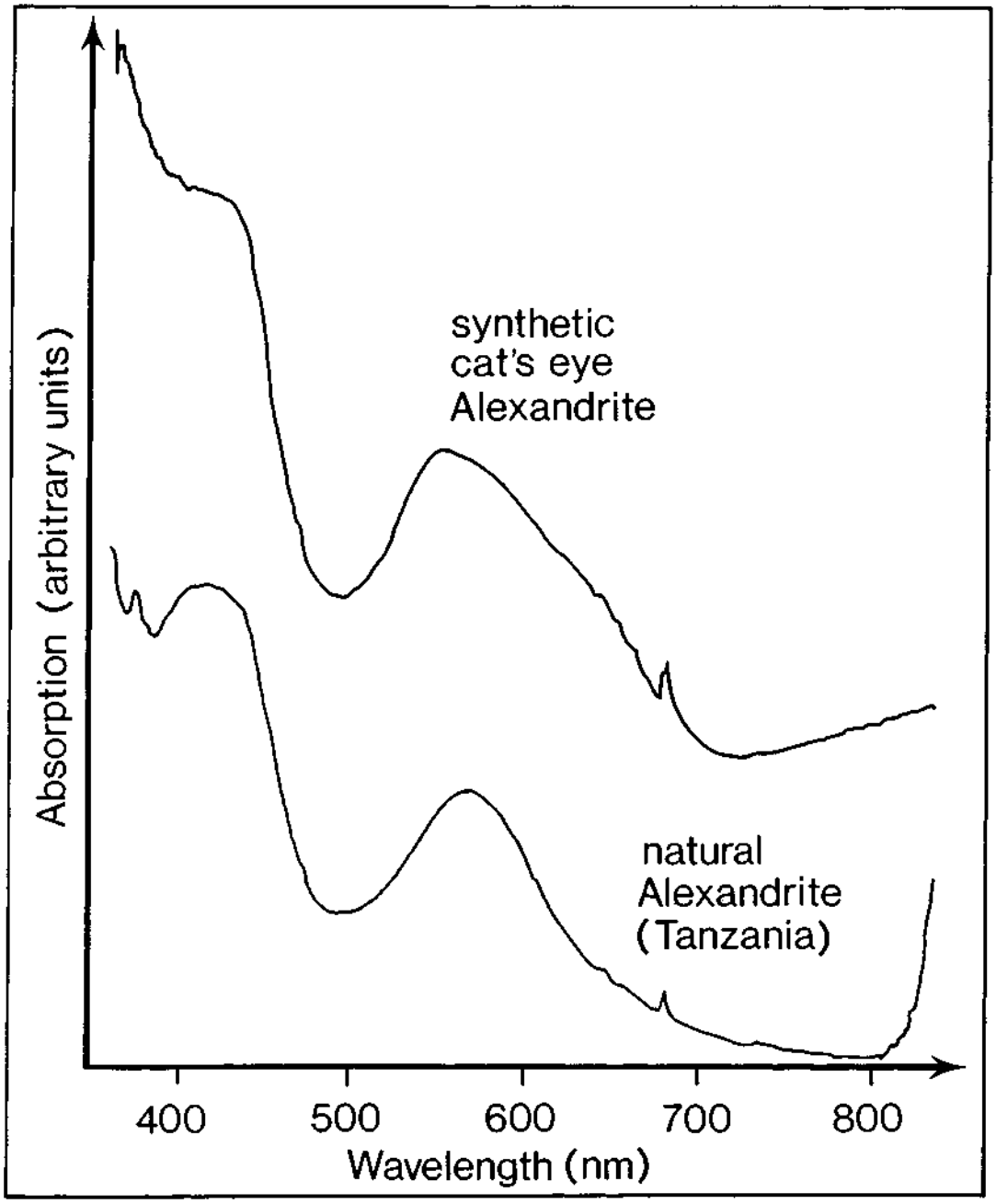

Fig. 6. Top: Ultraviolet-visible absorption characteristics of a synthetic alexandrite cat's-eye, run perpendicular to the girdle plane of the stone. Bottom: Ultraviolet-visible absorption characteristics of a natural alexandrite from Tanzania, run in a random direction. Drawing by Peter Johnston.

Fig. 2. The typical conical-shaped milky light transmission effect shown by the Inamori alexandrite cat's-eyes.

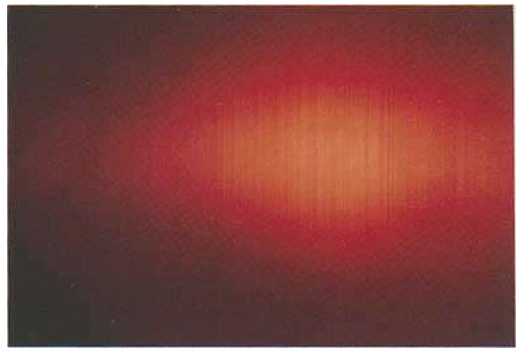

Fig. 3. The very slightly undulating growth-colour zones, shown here in shadowed transmitted light, are the single most important diagnostic feature of Kyocera's new product 30x.

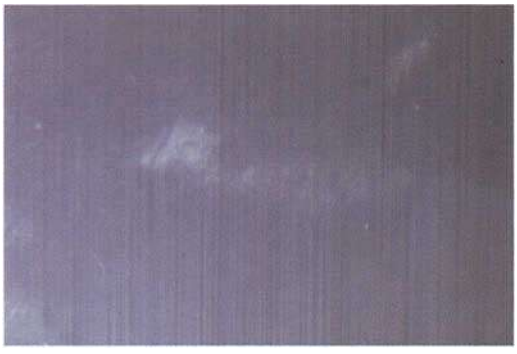

Fig. 4. In oblique incident light these characteristic growth features show up as a series of fine laminated milky layers. 30x.

Fig. 5. The directional relationship between the milky bands and the colour zones is shown in this photomicrograph. Oblique incident and shadowed transmitted light. 30x.

But, according to their brochure, Kyocera is currently selling their rough, and two grades of the cut material as 'Gemstones for the 21st Century – Created by Science and Technology' under the trade name Inamori.

Acknowledgements

The authors are grateful to Mr Ken Takada, director of the jewellery division of Kyocera America, Inc., for supplying the 'Inamori' cat's-eye alexandrites examined in this report. Thanks are also extended to Mr Dino DeGhionno, supervisor of the Gemological Institute of America's resident coloured stones programme, for his assistance in obtaining the stones.

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Violet emeralds?

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Abstract

Colour changes induced by ionizing radiation on synthetic emeralds from green to smoky or to violet are attributed to colour centres and are similar to those of irradiated quartz. These kinds of colour centres may also be present in natural emeralds. Electron microprobe analyses (EMPA) presented in cations per formula unit show the replacement of Si-cations by Al and other elements.

Introduction

In order to distinguish between natural and synthetic gemstones such as emeralds, extensive chemical analyses at a high technical level may be required. In analytical methods, such as X-ray fluorescence analyses (XFA) or neutron activation analyses (NAA) used for the detection of trace elements, samples are exposed to ionizing radiation which may cause changes in colour.

During investigation by NAA synthetic emeralds were found to change from green to smoky or to violet and these colours were found to be of variable stability. Corresponding colour changes in synthetic emeralds have been reported by Bank (1982) and Lind *et al.* (1986). A similar colour change was also observed in a natural emerald during X-ray fluorescence analyses, so these colour changes do not seem to be restricted to synthetic emeralds.

As heat treatment at different temperatures and for different durations may cause the total restoration of the colour, colour centres are probably involved in the transformations.

Ionizing radiation causes the following colour changes:

– from green to smoky colours in hydrothermal synthetic emeralds (Figure 1), and even – from green to violet colours in flux-grown synthetic emeralds (Figures 2 and 3),

both being demonstrated by polarized UV-visible spectra. These transmission spectra still show the typical absorption of emeralds, for instance the chromium bands, on which are superimposed additional, stronger absorptions caused by the neutron radiation. Exposing these violet samples to normal daylight for five months bleaches them but still leaves them with smoky colours.

Colour centres by the replacement of Si

These colour changes suggest an analogy with radiation-induced colour changes of colourless quartz to smoky quartz or amethyst involving one of the following mechanisms:

- the irradiation of quartz showing a coupled replacement of Si by Al together with a corresponding charge compensation in the lattice forms activated $[AlO_4]^{4-}$ centres by the loss of an electron (Nassau and Prescott, 1977). These colour centres cause the well known smoky colour;
- the irradiation of quartz showing a corresponding replacement of Si by Fe^{2+} forms activated $[FeO_4]^{5-}$ centres with citrine colours (Nassau, 1984);
- the continuing irradiation of these citrine centres or those with a replacement of Si by Fe^{3+} activates $(FeO_4]^{4-}$ amethyst colour centres (Nassau, 1984).

  The stability of such amethyst centres is correlated to the absence of water as shown in natural amethrines (amethyst/citrines) by Aines and Rossman (1986).

Considering that the Si_6O_{18} rings of the beryl structure present quartz-like surroundings, corresponding radiation effects on emeralds might be caused by corresponding mechanisms:

- water containing, i.e. hydrothermal, synthetic emeralds on radiation only develop smoky colours. Possible citrine colour centres are not perceptible visually;
- among the water free, i.e. flux-grown, synthetic emeralds violet amethyst colour centres may be developed;
- the wavelengths of these additional absorptions resemble those of irradiated quartzes. An insignificant shift to shorter wavelengths corresponds to shorter metal-oxygen bonds of beryl com-

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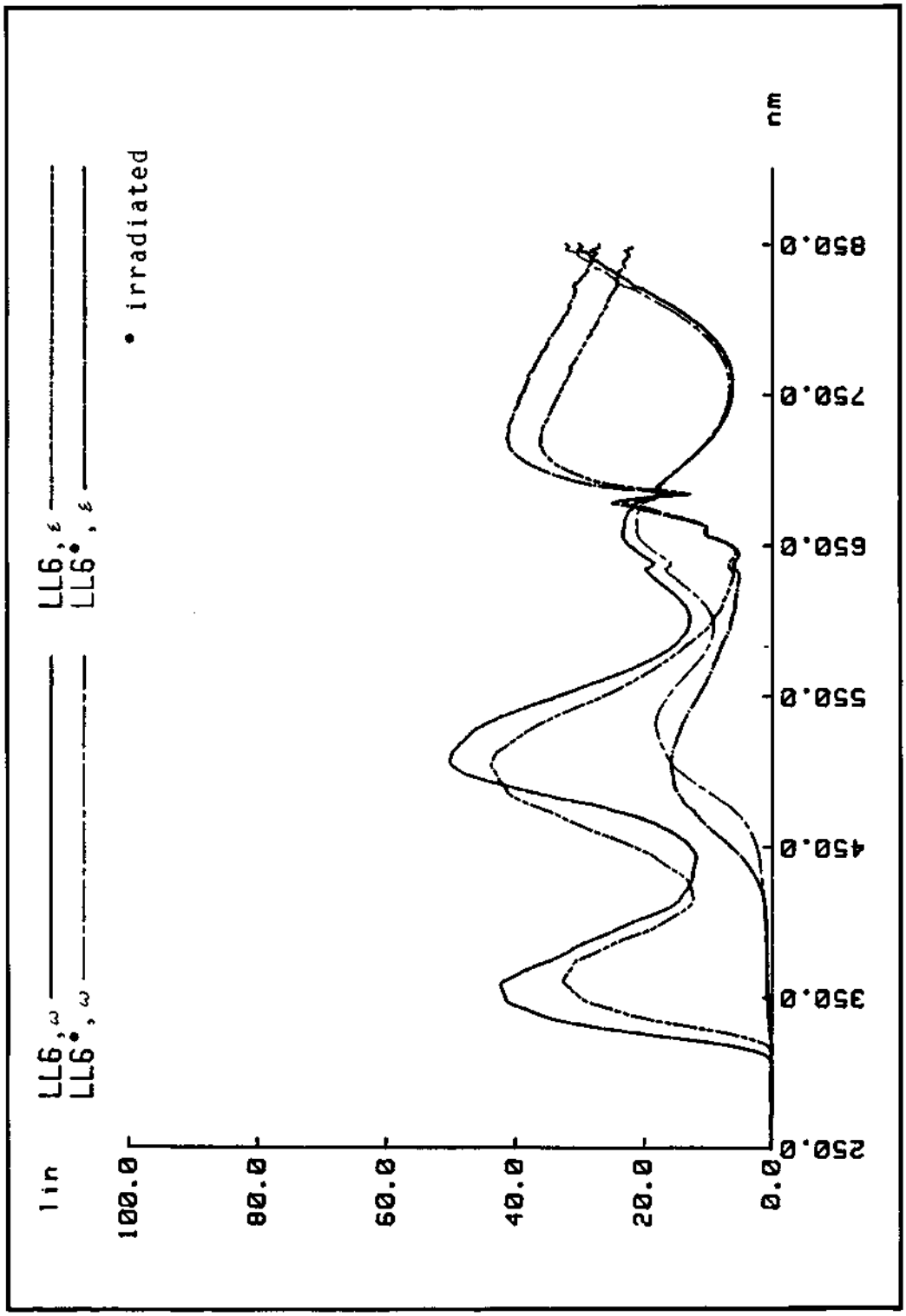

Fig. 1. Transmission spectrum of a *Lechleitner* synthetic hydrothermal emerald (LL 6) before (ε ——, ω ——) and after (ε ——, ω ——) irradiation.

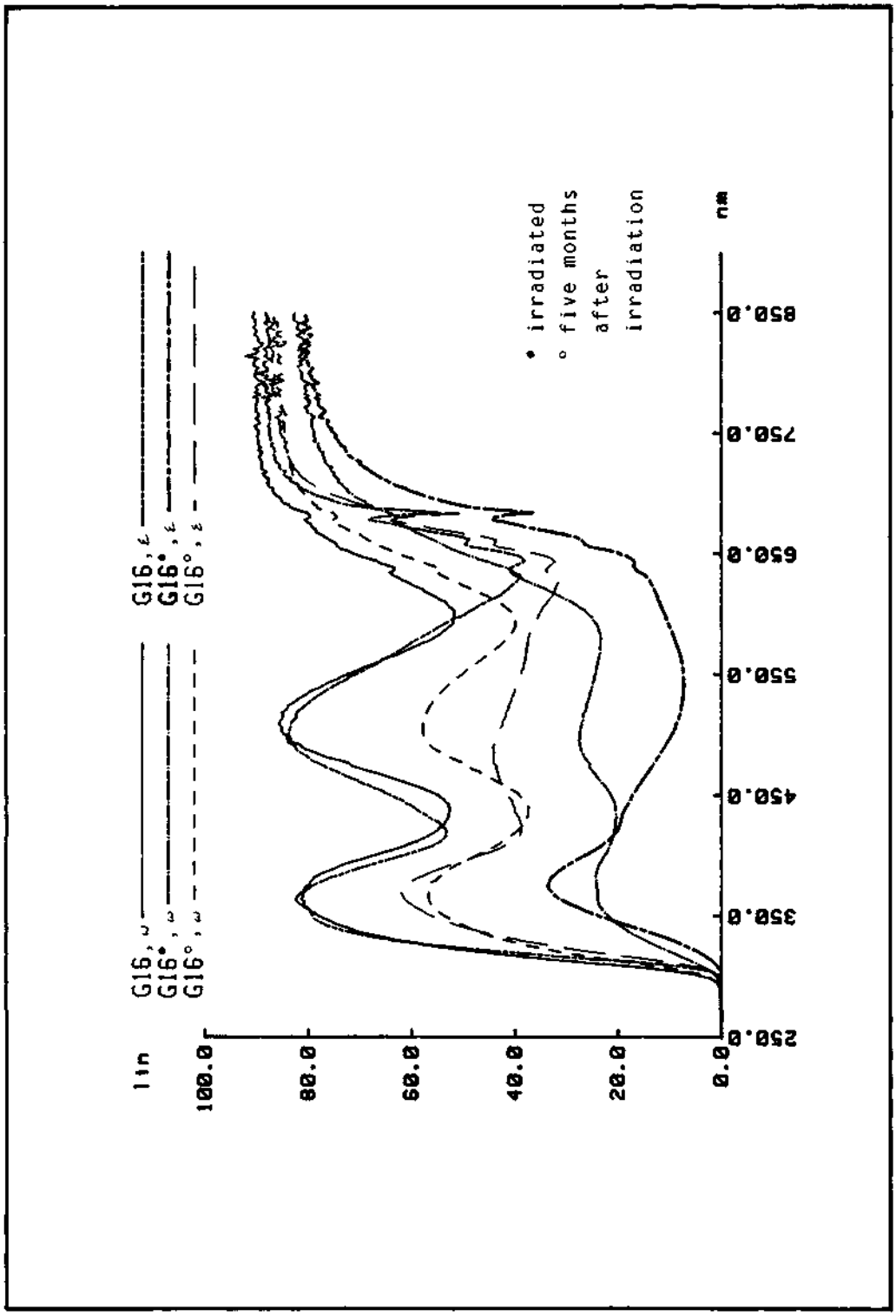

Fig. 2. Transmission spectra of a *Gilson* synthetic flux-grown emerald (G 16) before (ε —·—·—, ω ——), after ε —·—·—, ω —·—·—) irradiation, and after five months after irradiation (ε ——, ω ——).

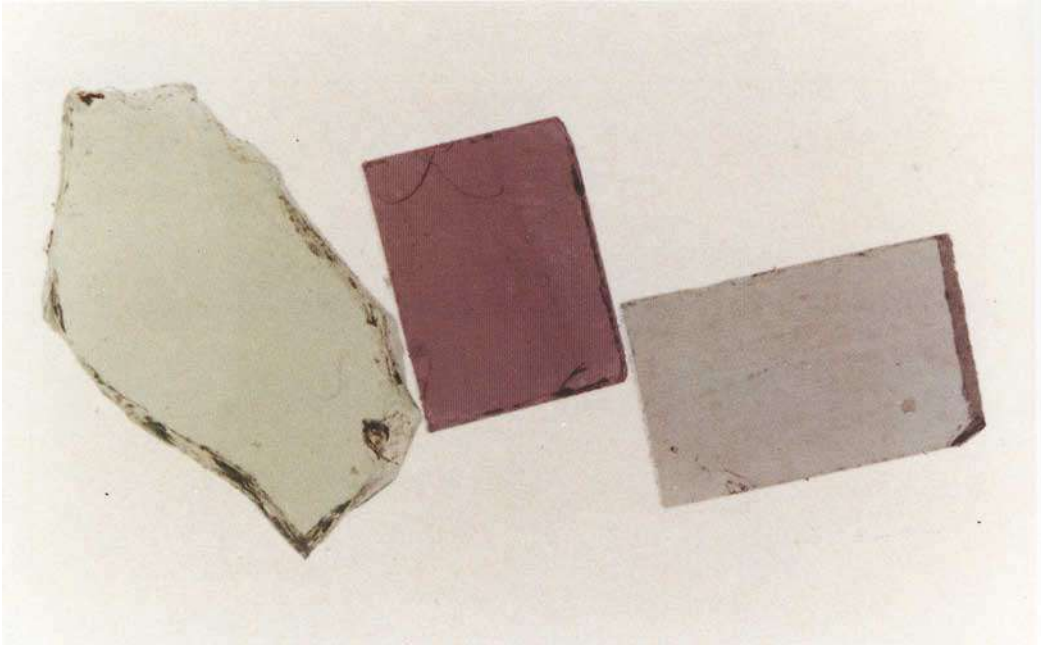

Fig. 3. Slices of a *Gilson* flux-grown synthetic emerald (G 16), thickness ~ 1.1 mm, green (left, irregular shaped) before – violet (middle, rectangular shaped, 2.6 × 3.5 mm) after irradiation and smoky (right, rectangular shaped, 2.6 × 4.2 mm) five months after irradiation.

pared to quartz according to the crystal field theory.

The possibility of the replacement of Si in the beryl structure by Al ($Si^{4+} \rightarrow Al^{3+} + R^{+}$) has been already demonstrated by Shatskiy, *et al.* (1981) and by Nassau and Nassau (1980) only as an example for the incorporation of alkalies ($Si^{4+} \rightarrow Al^{3+} + Na^{+}$). But the consequences of irradiating centres associated with these replacements have not been recognized up till now.

Chemical analyses

The presence of the replacement of Si by Al and Fe in emeralds is demonstrated by electron microprobe analyses (EMPA) of:

- 16 natural emeralds of different origin;
- 8 different flux-grown; and
- 6 different hydrothermal synthetic emeralds (Table 1).

From these three groups a representative example of each is represented by its chemical analyses

Table 1. Origin and label of samples of natural and synthetic emeralds analysed by EMPA.

Origin	Label
Natural emeralds:	
Colombia, Chivor	C 69
Colombia, Chivor	C 75
Colombia, Chivor	C 85
Colombia	SMG C
Brazil, Sta. Maria de Itabira	SMI 2
Brazil, Carnaiba	BC 9
Brazil, Socotó	SOC 41
Brazil, Saliniha	BS 2
Brazil	B 24
Brazil	BX
Nigeria	N 4b
South Africa, Cobra-Mine	A 39
Mozambique, Morrua	M 3
Zambia	S 47
USSR, Urals	R 8
Afghanistan, Pandjir-Valley	HAB
Flux-grown synthetic emeralds:	
Gilson	G 16
Gilson	GMT
Gilson	GDT
Lennix	Lens
Inamori	IJ 1
Lechleitner	LL 10
Lechleitner	LL 11
Lechleitner	LL 12
Hydrothermal synthetic emeralds:	
Linde	L1
Lechleitner	LL 14
Lechleitner	LL 16
Lechleitner	LL 67
USSR	SSR
Biron	BIR 2

Table 2. Chemistry of a Colombian emerald (C 85), 40 points analysed by a line-scan EMPA, distance 2μm.

	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.	14.	15.	16.	17.	18.	19.	20.
SiO_2	64,842	64,536	64,369	63,926	64,268	63,826	64,345	64,136	64,134	64,200	64,433	64,117	64,179	64,467	64,179	64,153	64,189	64,125	64,076	64,048
Al_2O_3	17,670	17,693	17,649	17,407	17,498	17,513	17,558	17,449	17,498	17,523	17,596	17,500	17,432	17,649	17,258	17,337	17,574	17,536	17,487	17,583
Cr_2O_3	,172	,193	,243	,219	,191	,244	,172	,229	,210	,213	,232	,250	,209	,193	,174	,246	,215	,196	,208	,221
V_2O_3	,062	,034	,046	,057	,088	,057	,046	,077	,085	,115	,072	,056	,021	,069	,072	,021	,038	,062	,088	,043
FeO	,010	,021	,090	0	,050	,040	,021	,085	,021	,071	,030	0	,066	,005	,060	,085	0	,024	,040	,010
ZnO	0	0	,045	0	,045	0	,037	,075	0	0	,103	,015	,030	,097	0	,111	0	,103	0	0
MgO	,156	,161	,177	,126	,158	,207	,186	,176	,177	,184	,162	,172	,189	,182	,187	,172	,184	,196	,158	,164
Na_2O	,168	,174	,159	,159	,173	,208	,166	,162	,194	,170	,156	,177	,204	,129	,190	,170	,155	,190	,205	,159
CaO	0	,020	,003	,027	0	0	0	,018	0	,010	0	0	0	0	,003	,007	,011	0	0	0
I	83,081	82,830	82,780	81,922	82,471	82,095	82,531	82,406	82,320	82,485	82,786	82,286	82,328	82,793	82,123	82,301	82,366	82,432	82,261	82,228
Si	6,013	6,004	5,997	6,013	6,008	5,993	6,008	6,004	6,004	6,001	6,003	6,005	6,009	6,003	6,023	6,013	6,005	5,998	6,004	6,002
Al	1,931	1,940	1,938	1,930	1,928	1,939	1,932	1,925	1,931	1,930	1,932	1,932	1,924	1,937	1,909	1,915	1,937	1,933	1,931	1,942
Cr	,013	,014	,018	,016	,014	,018	,013	,017	,016	,016	,017	,018	,015	,014	,014	,018	,016	,015	,015	,016
V	,005	,003	,003	,004	,007	,004	,003	,006	,006	,009	,005	,004	,002	,005	,006	,002	,003	,005	,007	,003
Fe	,001	,002	,007	0	,004	,003	,002	,007	,002	,006	,002	0	,005	,001	,005	,007	0	,002	,003	,001
Zn	0	0	,003	0	,003	0	,003	,005	0	0	,007	,001	,002	,007	0	,008	0	,007	0	0
Mg	,021	,022	,025	,018	,022	,029	,026	,025	,025	,026	,023	,024	,026	,025	,026	,024	,026	,027	,022	,023
Na	,030	,032	,029	,029	,031	,038	,030	,029	,035	,031	,028	,032	,037	,023	,035	,031	,028	,035	,037	,029
Ca	0	,002	0	,003	0	0	0	,002	0	,001	0	0	0	0	0	,001	,001	0	0	0

	21.	22.	23.	24.	25.	26.	27.	28.	29.	30.	31.	32.	33.	34.	35.	36.	37.	38.	39.	40.
SiO_2	64,318	64,395	64,634	64,373	64,872	64,621	64,277	64,504	65,143	64,555	64,709	64,275	64,551	64,333	64,585	64,673	64,324	64,442	64,628	64,718
Al_2O_3	17,583	17,483	17,275	17,541	17,587	17,651	17,715	17,598	17,317	17,405	17,504	17,388	17,630	17,670	17,823	17,553	17,409	17,679	17,711	17,919
Cr_2O_3	,205	,183	,203	,228	,273	,200	,235	,256	,229	,292	,189	,279	,263	,222	,238	,199	,194	,203	,151	,186
V_2O_3	,028	,022	,062	,062	,063	,085	,106	,046	,069	,106	,049	,057	,063	,075	,065	,075	,063	,040	,034	,026
FeO	,015	0	,040	,045	,015	,140	,030	0	,100	,055	0	,050	,040	,060	0	,035	,060	0	,066	,015
ZnO	,030	0	0	,156	,015	0	,007	0	0	0	,037	,045	0	,037	,022	0	,067	0	0	,037
MgO	,191	,159	,179	,167	,169	,141	,171	,189	,192	,204	,194	,154	,158	,166	,158	,164	,164	,148	,181	,194
Na_2O	,183	,173	,177	,178	,173	,152	,181	,220	,205	,174	,209	,174	,174	,179	,171	,174	,167	,177	,189	,182
CaO	,001	,007	0	,006	0	,010	0	,008	0	0	,004	0	,008	,001	,017	,021	,011	,014	,013	0
I	82,554	82,421	82,570	82,756	83,167	83,001	82,722	82,820	83,256	82,792	82,894	82,423	82,887	82,753	83,079	82,893	82,461	82,702	82,971	83,278
Si	6,004	6,018	6,032	6,001	6,013	6,004	5,990	6,002	6,032	6,013	6,015	6,013	6,004	5,994	5,992	6,013	6,015	6,004	6,002	5,989
Al	1,934	1,926	1,900	1,927	1,921	1,933	1,946	1,930	1,890	1,911	1,918	1,918	1,917	1,941	1,949	1,923	1,918	1,941	1,939	1,954
Cr	,015	,014	,015	,017	,020	,015	,017	,019	,017	,022	,014	,021	,019	,016	,018	,015	,014	,015	,011	,014
V	,002	,002	,005	,005	,005	,006	,008	,003	,005	,008	,004	,004	,005	,006	,005	,006	,005	,003	,003	,002
Fe	,001	0	,003	,003	,001	,011	,002	0	,008	,004	0	,004	,003	,005	0	,003	,005	0	,005	,001
Zn	,002	0	0	,010	,001	0	,001	0	0	0	,003	,003	0	,003	,002	0	,005	0	0	,003
Mg	,027	,022	,025	,023	,023	,020	,024	,026	,026	,028	,027	,022	,022	,023	,022	,023	,023	,021	,025	,027
Na	,033	,031	,032	,032	,031	,027	,032	,040	,037	,031	,038	,032	,031	,032	,031	,032	,030	,032	,034	,033
Ca	0	,001	0	,001	0	,001	0	,001	0	0	,001	0	,001	0	,002	,002	,001	,001	,001	0

Table 3. Chemistry of a *Gilson* flux-grown synthetic emerald (G 16), 40 points analysed by a line-scan EMPA, distance 2μm.

	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.	14.	15.	16.	17.	18.	19.	20.
SiO_2	65,103	64,855	65,139	65,265	64,861	65,246	64,891	65,103	64,889	65,066	65,047	65,084	65,049	64,974	65,133	64,910	64,395	64,970	65,486	65,094
Al_2O_3	19,095	19,183	18,707	18,781	19,021	19,079	19,032	18,953	18,862	19,008	18,974	18,741	19,051	18,783	18,726	18,758	18,811	18,745	19,015	18,985
Cr_2O_3	,284	,326	,346	,295	,380	,256	,336	,341	,294	,289	,358	,326	,304	,402	,390	,364	,269	,399	,339	,224
V_2O_3	,021	,009	,026	,018	,026	,026	,015	0	0	,046	0	,003	0	0	0	0	,003	0	0	0
FeO	,005	,040	,055	,040	0	,045	,114	,075	,021	,060	,060	,035	,075	,010	,024	,030	,021	0	0	0
ZnO	0	,215	0	0	0	,060	,060	,052	0	,096	,045	0	0	,037	0	0	,052	,075	,045	0
MgO	0	,010	,003	0	,007	,010	,008	,003	,002	,005	0	,012	,027	0	0	,015	0	,003	0	0
Na_2O	,077	,109	,078	,074	,074	,084	,116	,071	,062	,082	,080	,116	,067	,098	,081	,094	,074	,074	,059	,086
CaO	0	0	,027	,008	,008	,024	,003	,007	,004	,001	,013	0	,011	,024	0	,020	,004	0	0	,007
Σ	84,583	84,747	84,383	84,482	84,378	84,830	84,575	84,605	84,133	84,654	84,576	84,316	84,584	84,329	84,354	84,191	83,629	84,266	84,944	84,396
Si	5,932	5,908	5,953	5,955	5,927	5,932	5,920	5,936	5,945	5,930	5,933	5,951	5,930	5,943	5,954	5,945	5,937	5,947	5,944	5,943
Al	2,051	2,060	2,015	2,020	2,049	2,044	2,047	2,036	2,037	2,042	2,040	2,019	2,047	2,025	2,017	2,025	2,044	2,022	2,034	2,043
Cr	,021	,024	,025	,021	,027	,018	,024	,025	,021	,021	,026	,024	,022	,029	,028	,026	,020	,029	,024	,016
V	,002	,001	,002	,001	,002	,002	,001	0	0	,003	0	0	0	0	0	0	0	0	0	0
Fe	,001	,003	,004	,003	0	,003	,009	,006	,002	,005	,005	,003	,006	,001	,002	,002	,002	0	0	0
Zn	0	,015	0	0	0	,004	,004	,003	0	,006	,003	0	0	,003	0	0	,003	,005	,003	0
Mg	0	,001	,001	0	,001	,001	,001	,001	0	,001	0	,002	,004	0	0	,002	0	,001	0	0
Na	,013	,019	,013	,013	,013	,014	,020	,012	,011	,014	,014	,020	,011	,017	,014	,016	,013	,013	,010	,015
Ca	0	0	,002	,001	,001	,002	0	,001	0	0	,001	0	,001	,002	0	,001	0	0	0	,001

	21.	22.	23.	24.	25.	26.	27.	28.	29.	30.	31.	32.	33.	34.	35.	36.	37.	38.	39.	40.
SiO_2	65,126	65,017	65,757	65,041	64,908	65,214	65,368	65,135	64,673	65,154	65,638	65,002	65,263	64,910	65,000	65,280	65,197	65,469	65,261	65,188
Al_2O_3	18,917	19,138	18,756	19,146	19,015	19,055	19,021	19,208	19,144	19,219	18,722	18,892	19,117	19,098	19,062	19,263	19,374	19,138	18,870	19,155
Cr_2O_3	,303	,278	,425	,301	,313	,351	,272	,284	,285	,282	,362	,365	,311	,310	,292	,278	,330	,355	,384	,412
V_2O_3	,022	,016	0	0	0	0	0	,026	,003	0	,013	,012	0	0	0	0	0	,024	0	0
FeO	,045	,015	,060	,030	0	,035	,105	,005	0	,066	,045	,010	0	,075	,045	,060	0	,090	,030	,066
ZnO	,060	0	,082	,022	0	0	0	0	,052	0	0	0	,022	0	,045	,030	,082	0	,045	0
MgO	0	,015	0	,005	0	,010	0	,017	0	0	0	0	,010	,013	0	0	,003	0	0	0
Na_2O	,092	,046	,040	,066	,104	,066	,073	,063	,062	,050	,055	,063	,085	,063	,061	,070	,054	,063	,055	,062
CaO	,004	,001	,004	,027	,010	0	,011	,017	0	,028	,011	0	,007	,010	,011	,008	0	,010	,028	,034
Σ	84,568	84,527	85,126	84,637	84,350	84,730	84,850	84,755	84,219	84,799	84,847	84,345	84,816	84,479	84,517	84,990	85,041	85,148	84,673	84,917
Si	5,940	5,929	5,961	5,925	5,932	5,934	5,940	5,924	5,920	5,924	5,965	5,942	5,932	5,925	5,930	5,923	5,913	5,931	5,945	5,922
Al	2,033	2,057	2,004	2,056	2,048	2,044	2,037	2,059	2,065	2,059	2,005	2,035	2,048	2,054	2,050	2,060	2,071	2,043	2,026	2,051
Cr	,022	,020	,030	,022	,023	,025	,020	,021	,021	,020	,026	,026	,022	,022	,021	,020	,024	,025	,028	,030
V	,002	,001	0	0	0	0	0	,002	0	0	,001	,001	0	0	0	0	0	,002	0	0
Fe	,003	,001	,005	,002	0	,003	,008	,001	0	,005	,003	,001	0	,006	,003	,005	0	,007	,002	,005
Zn	,004	0	,006	,002	0	0	0	0	,003	0	0	0	,001	0	,003	,002	,006	0	,003	0
Mg	0	,002	0	,001	0	,001	0	,002	0	0	0	0	,001	,002	0	0	,001	0	0	0
Na	,016	,008	,007	,011	,018	,011	,012	,011	,011	,008	,009	,011	,014	,001	,010	,012	,009	,011	,009	,011
Ca	,001	0	,001	,002	,001	0	,001	,001	0	,002	,001	0	,001	,001	,001	,001	0	,001	,002	,003

Table 4. Chemistry of a *Linde* hydrothermal synthetic emerald (L 1), 40 points analysed by a line-scan EMPA, distance 2μm.

	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.	14.	15.	16.	17.	18.	19.	20.
SiO_2	67,463	67,692	66,907	67,586	67,820	67,696	67,636	67,572	67,815	68,181	67,477	67,910	66,675	67,580	66,286	67,899	67,905	67,657	67,738	67,728
Al_2O_3	18,583	18,577	18,677	18,745	18,987	18,771	18,762	18,441	18,335	18,516	18,412	18,573	18,295	18,445	17,851	18,148	18,333	18,462	18,520	18,641
Cr_2O_3	,152	,158	,193	,345	,297	,254	,284	,248	,215	,172	,235	,232	,275	,275	,345	,411	,263	,229	,238	,248
V_2O_3	0	,060	0	0	,043	,024	0	,021	,021	0	,032	,046	,006	,018	,018	0	,035	,054	0	0
FeO	,011	,060	,027	0	,050	,022	,044	0	,012	0	,022	,072	,094	,012	0	,005	,033	0	,005	0
ZnO	,170	,014	,156	0	0	0	0	0	0	,044	0	0	,044	,029	,129	0	,015	0	,057	0
MgO	0	0	,028	0	,012	,007	,010	0	,020	,013	0	0	,010	0	,012	,002	0	,008	0	,007
Na_2O	,019	,041	,076	,030	,024	,032	,047	,024	,059	,044	,009	,009	,042	,044	,019	,031	,016	,015	0	,011
CaO	0	0	0	0	,022	,004	0	,004	0	0	,018	,007	0	0	,006	,018	0	0	,015	0
I	86,397	86,602	86,064	86,706	87,254	86,810	86,782	86,310	86,477	86,971	86,207	86,849	85,440	86,402	84,665	86,513	86,601	86,426	86,575	86,635
Si	6,019	6,023	5,997	6,008	5,994	6,010	6,008	6,030	6,040	6,037	6,029	6,025	6,018	6,027	6,037	6,047	6,040	6,030	6,028	6,021
Al	1,955	1,948	1,972	1,964	1,978	1,964	1,964	1,939	1,925	1,932	1,939	1,942	1,946	1,939	1,916	1,905	1,922	1,939	1,942	1,953
Cr	,011	,011	,014	,024	,021	,018	,020	,017	,015	,012	,017	,016	,020	,019	,025	,029	,018	,016	,017	,017
V	0	,005	0	0	,003	,002	0	,001	,001	0	,002	,003	,001	,001	,001	0	,003	,004	0	0
Fe	0	,005	,002	0	,004	,002	,003	0	,001	0	,002	,005	,007	,001	0	,001	,003	0	,001	0
Zn	,011	0	,009	0	0	0	0	0	0	,003	0	0	,003	,002	,009	0	,001	0	,004	0
Mg	0	0	,005	0	,001	,001	,001	0	,003	,002	0	0	,001	0	,002	0	0	,001	0	,001
Na	,002	,007	,014	,005	,004	,006	,008	,004	,010	,008	,002	,002	,007	,008	,003	,005	,003	,003	0	,002
Ca	0	0	0	0	,002	,001	0	,001	0	0	,002	,001	0	0	,001	,002	0	0	,002	0

	21.	22.	23.	24.	25.	26.	27.	28.	29.	30.	31.	32.	33.	34.	35.	36.	37.	38.	39.	40.
SiO_2	68,168	67,942	67,441	67,651	67,728	67,240	67,758	63,627	62,681	63,188	67,807	67,610	66,724	67,090	67,247	67,161	67,428	67,356	67,189	66,977
Al_2O_3	18,628	18,641	18,951	18,688	18,598	18,904	18,397	18,575	18,418	18,630	18,639	18,877	19,062	18,758	18,328	18,476	18,291	18,552	18,421	18,419
Cr_2O_3	,172	,175	,266	,402	,320	,314	,269	,232	,266	,235	,161	,158	,142	,368	,238	,196	,157	,220	,181	,205
V_2O_3	0	0	0	0	0	0	,024	0	0	,043	0	,018	,024	,044	0	0	,017	,006	0	0
FeO	0	0	,022	0	0	0	0	0	,028	,012	0	,044	,044	0	0	,027	0	,027	0	,038
ZnO	,086	0	,015	0	,144	,187	,115	0	0	0	0	0	0	,086	0	,113	,297	,057	,113	0
MgO	,025	0	,018	0	,015	,013	,002	0	,002	,008	0	0	,022	0	,012	0	0	,006	,001	,001
Na_2O	,046	,042	,085	,027	,061	,050	,039	,047	,040	,023	,011	,069	,001	,050	,012	,078	,044	,035	,039	,064
CaO	,004	,006	,003	0	,018	,004	0	0	0	0	0	,001	,011	0	,020	,010	,002	,001	,006	,005
I	87,129	86,805	86,801	86,768	86,884	86,716	86,603	82,481	81,436	82,139	86,618	86,777	86,030	86,397	85,857	86,060	86,236	86,260	85,950	85,709
Si	6,028	6,027	5,992	6,010	6,014	5,986	6,031	5,950	5,939	5,935	6,027	6,004	5,978	5,992	6,031	6,018	6,033	6,019	6,023	6,022
Al	1,941	1,949	1,984	1,957	1,946	1,983	1,930	2,047	2,057	2,063	1,953	1,976	2,013	1,975	1,938	1,951	1,927	1,953	1,946	1,951
Cr	,012	,012	,019	,028	,023	,022	,019	,017	,020	,017	,011	,011	,010	,026	,016	,014	,011	,016	,014	,014
V	0	0	0	0	0	0	,002	0	0	,003	0	,001	,002	,003	0	0	,002	0	0	0
Fe	0	0	,002	0	0	0	0	0	,002	,001	0	,003	,003	0	0	,002	0	,002	0	,002
Zn	,006	0	,001	0	,009	,012	,008	0	0	0	0	0	0	,006	0	,007	,021	,005	,007	0
Mg	,003	0	,002	0	,002	,002	0	0	0	,001	0	0	,003	0	,002	0	0	0	0	0
Na	,008	,007	,014	,005	,011	,009	,007	,009	,007	,004	,002	,012	0	,009	,002	,014	,007	,007	,007	,012
Ca	,001	,001	0	0	,002	,001	0	0	0	0	0	0	,001	0	,002	0	0	0	0	0

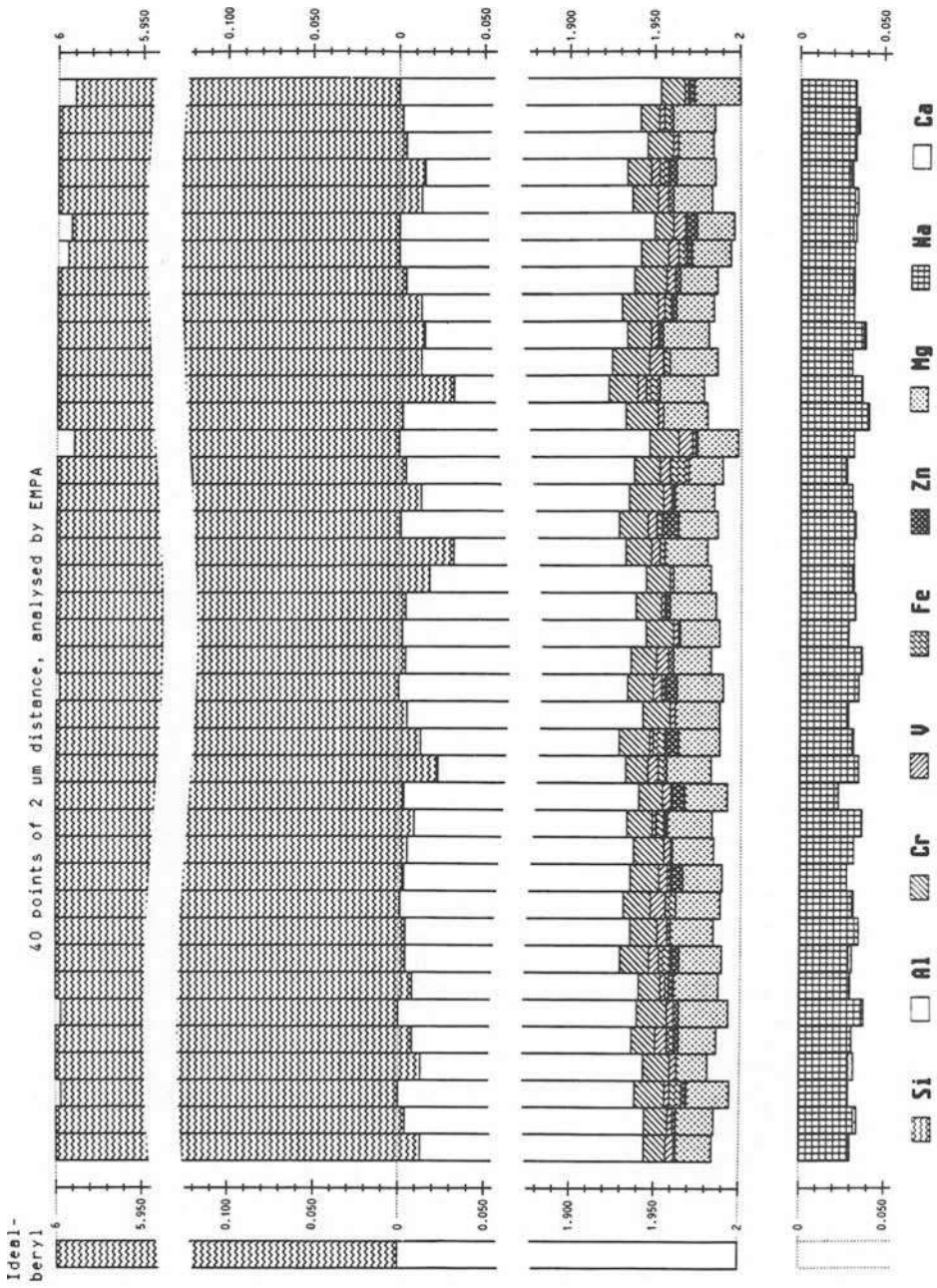

Fig. 4. Elements occupying the Si-, the Al-, and the interstitial structural channel positions of a Colombian emerald (C 85) presented in cations per formula unit. The distance from point to point is 2 μm.

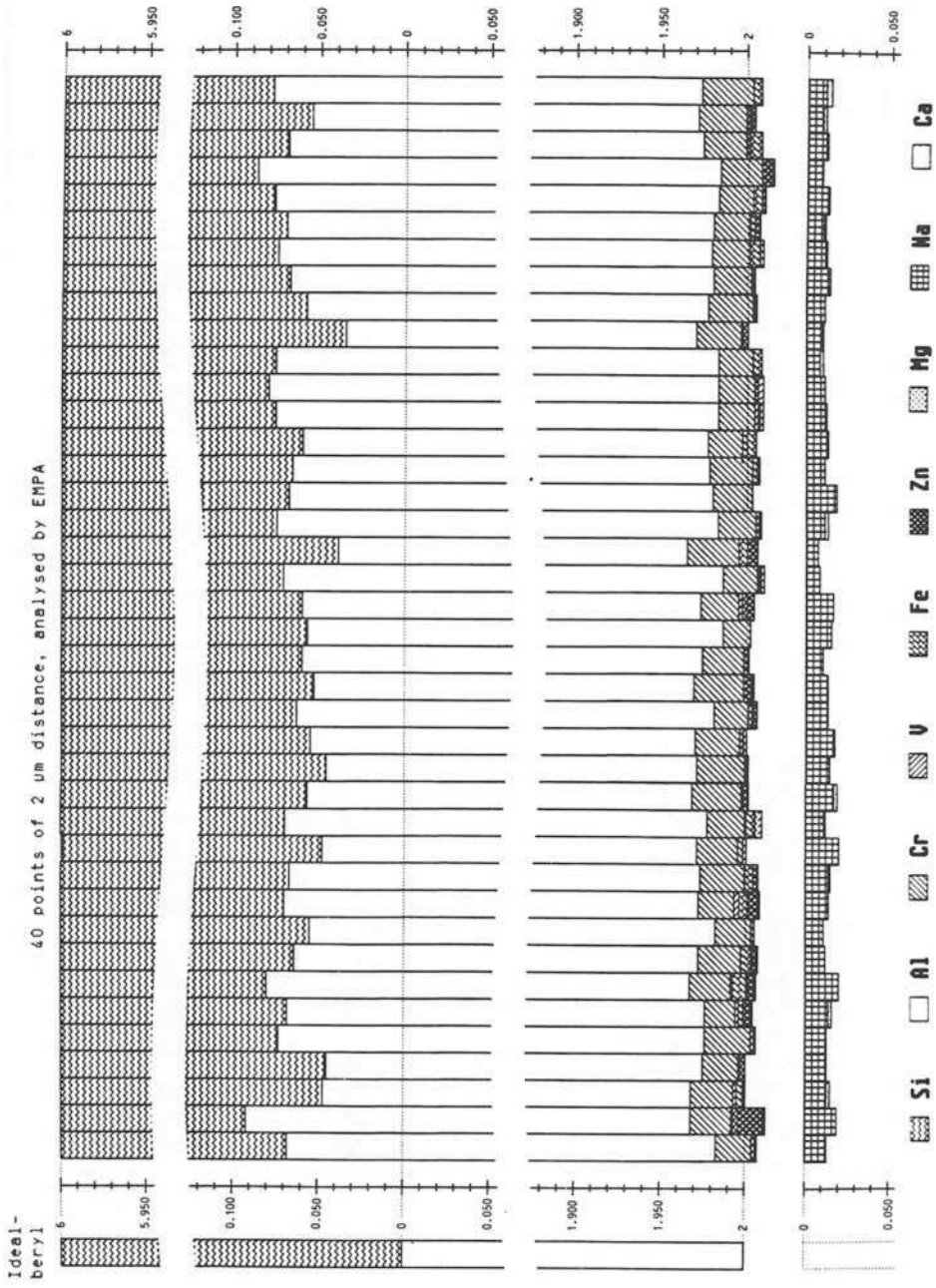

Fig. 5. Elements occupying the Si-, the Al-, and the interstitial structural channel positions of a *Gilson* flux-grown synthetic emerald (G 16) presented in cations per formula unit. The distance from point to point is 2 μm.

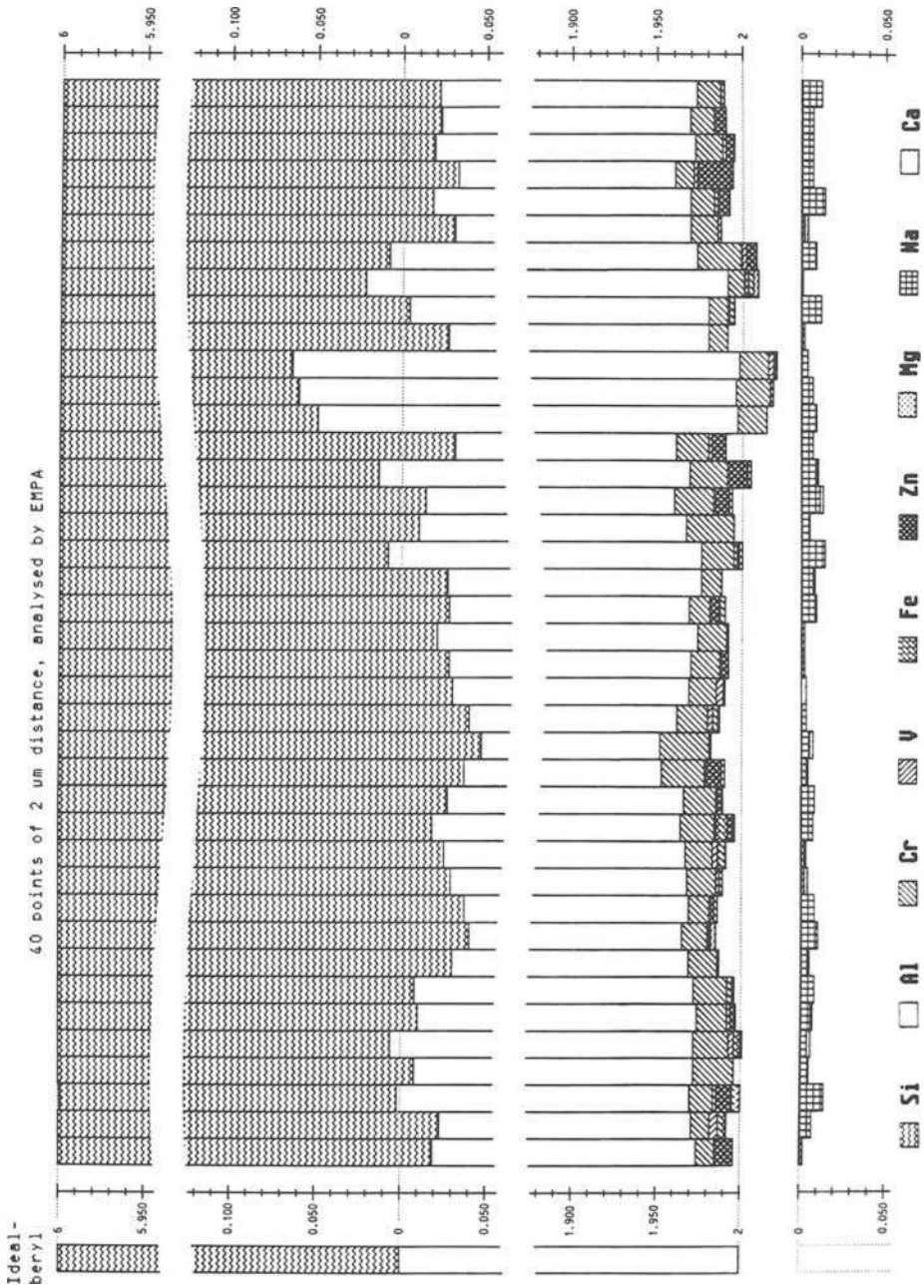

Fig. 6. Elements occupying the Si-, the Al-, and the interstitial structural channel positions of a *Linde* hydrothermal synthetic emerald (L 1) presented in cations per formula unit. The distance from point to point is $2\mu m$.

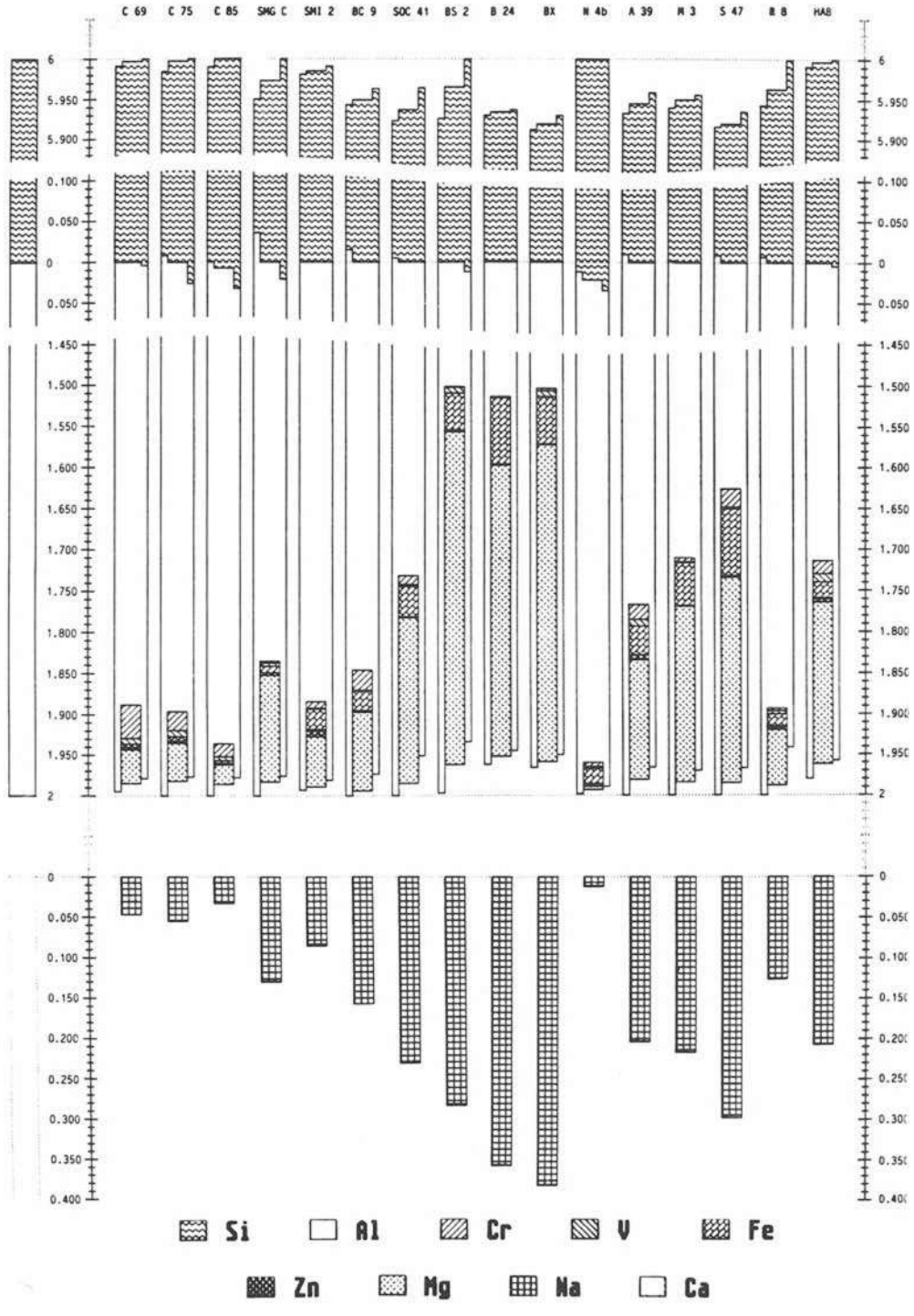

Fig. 7. Average chemistry of 16 natural emeralds presented in cations per formula unit attached to their lattice position (including their maximum deviation).

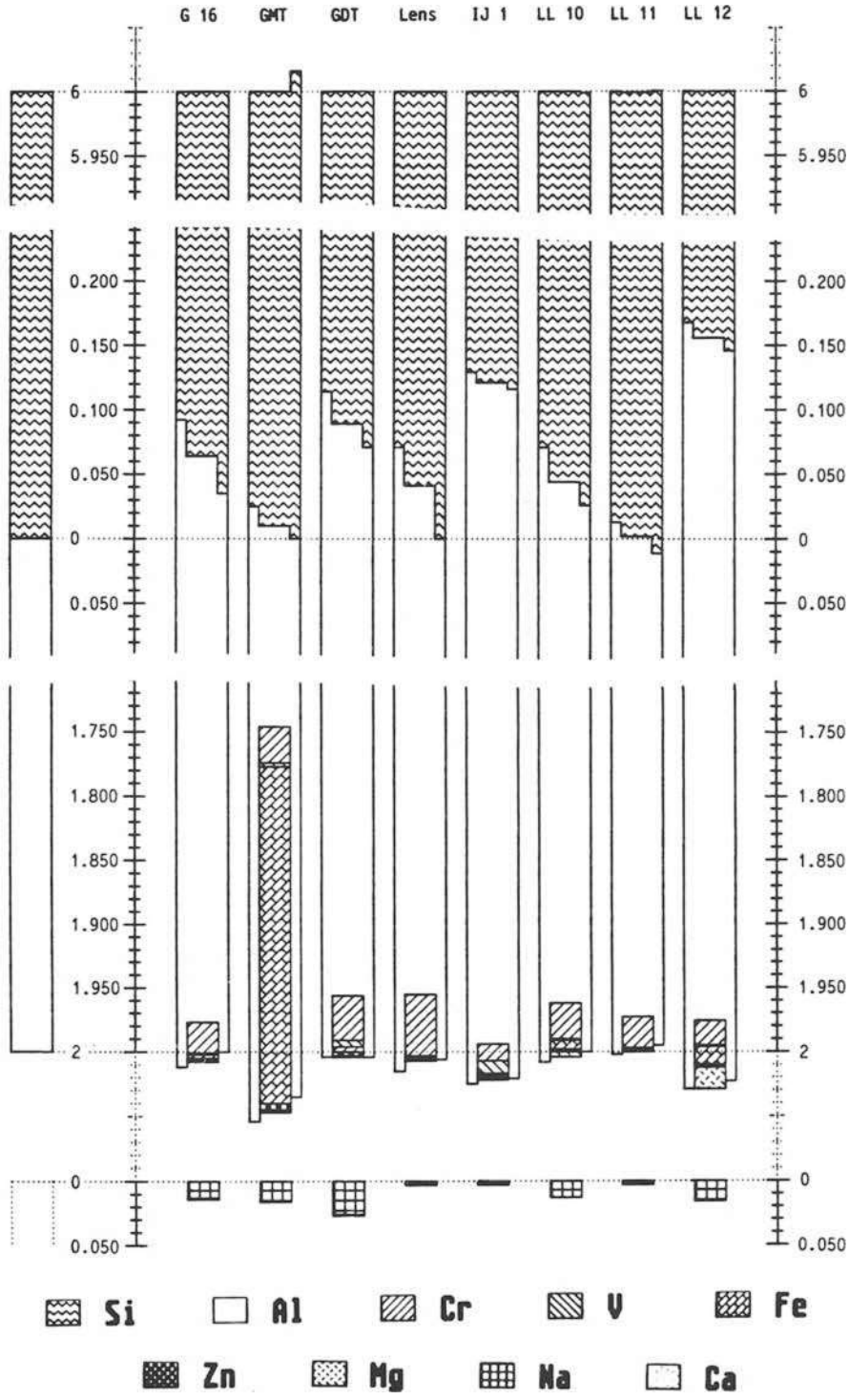

Fig. 8. Average chemistry of 8 flux-grown synthetic emeralds presented in cations per formula unit attached to their lattice position (including their maximum deviation).

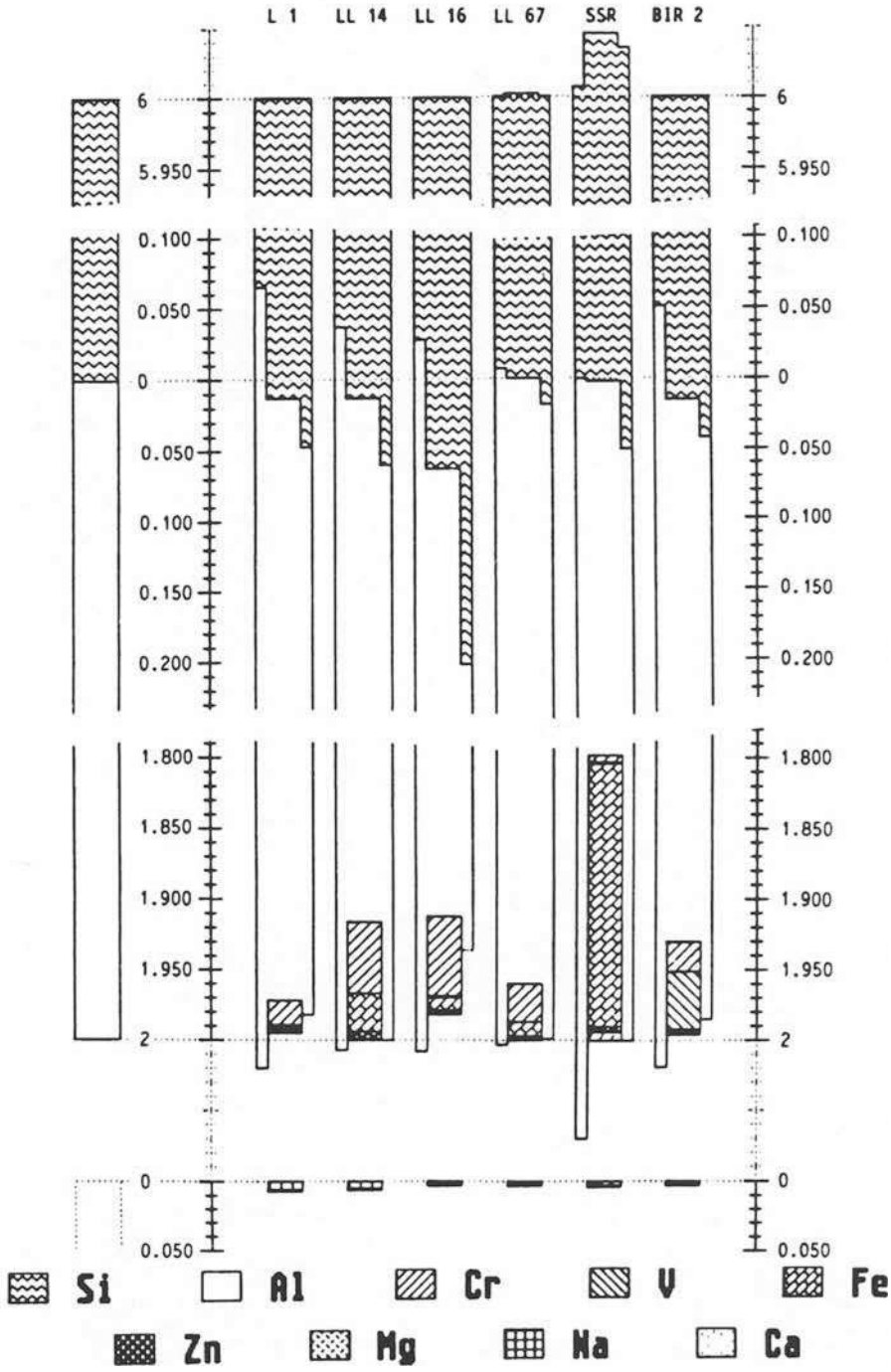

Fig. 9. Average chemistry of 6 hydrothermal synthetic emeralds presented in cations per formula unit attached to their lattice position (including their maximum deviation).

using a line scan EMPA of 40 points 2μm apart perpendicular to the zoning. The analysed values have been converted to cations per formula unit (Tables 2 to 4) so that variation can be considered on an atomic basis.

The converted Si-cations were allocated to the Si-positions of the lattice and the converted Al-, Cr-, Fe-, Zn-, and Mg- cations to the Al-positions. In Figures 4 to 6 the Si-cations are shown with Al- and replacement cations. Excess cations in one position were used to compensate deficiencies in the other; remaining excess values are shown in the diagrams. The amounts of alkali- and alkali earth-cations located in the structural channels are also presented.

All measurements by EMPA yielded totals between 82 and 86 wt% which is within the stochiometric range of beryl, assuming that Be, Li and water not detectable by EMPA make up the remainder.

Natural emeralds:

All natural emeralds (Figures 4 and 7) show Al-deficiencies. In some emeralds from deposits in Brazil and Africa these deficiencies are accompanied by Si-deficiencies. The Al-deficiencies are partly compensated by contents of Cr, V, Fe, Zn, and Mg and even Si. The number of alkali cations corresponds very closely with the number of divalent cations and this is consistent with coupled replacement.

Flux-grown synthetic emeralds:

These synthetic emeralds show a general deficiency in Si (Figures 5 and 8). The deficiencies may be partly compensated by Al-cations and the minor quantities of Cr, V, Fe, Zn, and Mg, for their number distinctly exceeds the number of Al-positions in the beryl structure (=2). The necessary charge compensation is provided by the alkalies in excess of those assigned to the divalent cations in the coupled replacement.

Hydrothermal synthetic emeralds:

These synthetic emeralds reveal regions with Al-deficiencies next to regions with Si-deficiencies (Figures 6 and 9). The content of alkalies is not sufficient to satisfy charge compensation requirement and show likely that H-cations are incorporated. Located in the structural channels they have been confirmed by infra-red spectroscopy (Schrader, in prep.).

These investigations indicate the replacement of Si by Al and other cations in synthetic emeralds which form colour centres when subjected to intense radiation. The direct proof will probably come from electron paramagnetic resonance (EPR) investigations later on.

Colour centres in natural beryls

Fe-cations replacing Si in natural beryls have already been proven as:

- Fe^{3+} in Si-positions (Wood and Nassau, 1968);
- Fe^{3+} in the tetrahedral lattice position (= Si) by EPR (Samoilovich *et al.*, 1971);
- Fe^{2+} in the tetrahedral lattice position (= Si) by Mössbauer-spectroscopy (Price, *et al.*, 1976).

Therefore the possibility of the activation of corresponding colour centres in natural beryls should not be excluded. For instance the Colombian emerald (Figure 4) reveals some regions with Si-deficiencies. But in these cases the Al-deficiencies are hindering the replacement of Si by Al. Further the observation of X-ray luminescence from natural beryls by Kuznetsov, *et al.* (1979), caused by the replacement of Si, may also indicate the existence of colour centres.

However, activated centres will be destroyed immediately by atomic hydrogen because of its high reactivity. The H_2O-contents of natural beryls are sufficient to enable development of atomic hydrogen on ionizing radiation as proven by EPR by Koryagin and Grechusnikov (1966), Bershov (1970), and Anderson (1974).

Acknowledgements

For providing facilities for the NAA thanks are due to the Max-Planck-Institute, Mainz, Dept. of Cosmochemistry, and for the microscopic spectral measurements the German Bundeskriminalamt (Federal Criminal Police Office), Wiesbaden, Dept. of Criminal technology is thanked.

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[*Manuscript received 5 May 1987, revised 13 January 1988.*]

The Presidium 'Duotester' – a test report

Peter Read, C. Eng., FGA, Dia.Dip.

In the first issue of the 'Gem Instrument Digest'[1] I made the following observations on the use of reflectivity and thermal methods for the identification of gemstones:-

'Apart from differences in measuring technology between reflectivity and thermal instruments, there is also the difference in test *information*. With the reflectivity meter it is possible to identify the nature of the stone even if it is not a diamond. The thermal conductivity tester, however, with one interesting exception . . ., only proves that the stone is, or is not, a diamond.

'What is perhaps more important is the fact that the advantages and disadvantages of each type of instrument conveniently *complement* each other. For example, the reflectivity of strontium titanate is uncomfortably close to that of diamond, and with a small error in instrument calibration could result in a wrong identification. The thermal conductivity of strontium titanate, however, is so much smaller than that of diamond that no error of identification could occur even with the simplest type of thermal conductivity meter. Similarly, corundum's thermal conductivity is closer to diamond's than any other simulant, with the result that a large cold sapphire may produce a diamond indication on some of the simpler thermal conductivity testers. Fortunately, however, it is not possible (even with a reasonable degree of miscalibration) to confuse sapphire with diamond on a reflectivity meter as their relative lustres are conspicuously different. It is sound gemmological practice to base an identification on the results of more than just one type of test. For this reason it makes good sense to exploit the complementary features of these two types of instrument and check a suspect diamond with both reflectivity and thermal conductivity tests. Whatever instrument is used, it is equally important that its calibration is checked both before and during use by reference to known comparison stones.'

Perhaps these observations did not go unnoticed, as some time later the Presidium company of Singapore introduced their Duotester instrument which not only combined a reflectivity meter in the same case as their original 'Gem Tester' instrument (this was one of the earlier thermal testers) but also provided a set of diamond simulants for calibration checking.

In this new combined instrument, the probe of the thermal tester section has been redesigned and has a metallized barrel which is used to activate a

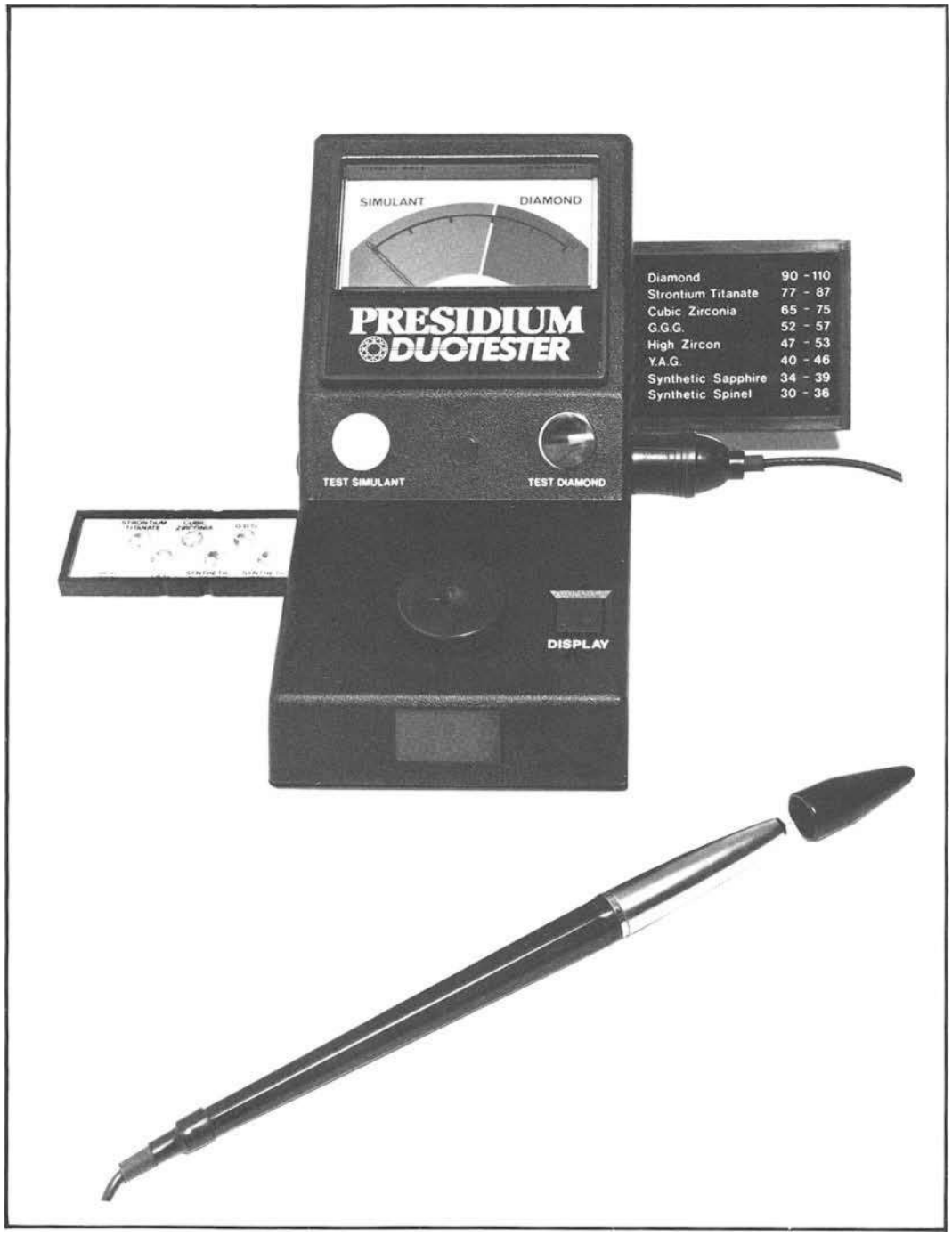

The Presidium Duotester is a combined thermal and reflectivity meter. Seven diamond simulants are provided in a tray which extends from the left side of the unit's case. The typical reflectivity ranges for diamond and the seven simulants are displayed on a panel which slots into the right-hand side of the instrument.

warning buzzer if the probe tip comes into contact with the gemstone mount (gold, silver and platinum give a response similar to diamond). This 'metal alert' buzzer is operated by means of a small voltage which is connected between the probe's test tip and its metallized end section. Provided that the user is holding the gem mount in one hand, and the metallized section of the probe in the other hand (and does not have dry skin!) a very small current will pass through the user when the tip comes into contact with the mount, and this is used to trigger the buzzer circuit.

The reflectivity meter section of the Duotester has its test platform mounted in the horizontal section of the case, and its 3-digit display is located in the front edge of the unit. Both reflectivity and thermal tests can be compared with, and instrument calibration checks made against readings obtained on a set of seven diamond simulants which are supplied with the instrument. These stones are held in a tray which slides neatly away into the control box for transit purposes. An aperture in the opposite end of this tray forms a convenient holder for the probe. A pull-out panel is also provided on the control box, and when extended reveals a list which gives the range of reflectivity readings to be expected for diamond and the seven simulants provided.

As with the original Presidium 'Gem Tester', the thermal probe can be unplugged for transit and replacement purposes. The two built-in thermal test surfaces for checking simulant/diamond calibration are also retained in the new model. The 'Gem Tester' was unique in being the only commercial diamond tester to use a resistor-heated thermocouple as the transducer in its test probe, and this technique is repeated in the Duotester. As before, the thermocouple uses a copper-constantan combination, one end of the copper section being extended to form the spring-loaded test tip of the probe. The meter reading on the original thermal tester used to reach a maximum as heat was conducted away from its probe tip; after a few seconds, the reading then began to fall back as heat was also conducted away from the reference section of the thermocouple. During tests on the new version, this minor defect appeared to be far less noticeable. When used in its thermal mode, the Presidium Duotester is sensitive enough to distinguish a diamond from a simulant down to 0.02 carat in size. As is normal with reflectivity meters, the minimum size of stone that can be tested is limited by the diameter of the test aperture. In the Duotester, the minimum size is around 0.05 carat.

As the Duotester is designed for operation from an internal battery as well as from a mains supply, a warning indication is provided by two dots which are displayed between the digits on the reflectivity display panel when the battery needs replacing. A plug-in unit is supplied with the instrument for mains operation

To sum up, the Presidium Duotester has cleverly exploited the complementary characteristics of the reflectivity and thermal tester in one instrument, and has also made full provision for calibration checks on both ranges.

Reference

1. Read, P.G. 1983. Comment – Reflectivity versus Thermal Conductivity, *Gem Instrument Digest*, **1**, (1), 2–3.

[*Manuscript received 17 March 1988.*]

Gemmological Abstracts

BALFOUR, I., 1988. Famous diamonds of the world. XXXIII. The Tiffany. *Indiaqua*, **49**, 1988/1, 119-22.

The bulk of this section of Balfour's series is concerned with the financial struggle to amalgamate the many separate mining companies in Kimberley into De Beers Consolidated Mines Ltd. The stone that was to become the Tiffany diamond was found in one of the Kimberley mines in 1877 or 1878. The 287.42ct canary-yellow octahedron was cut in Paris in 1878 into a cushion-cut brilliant of 128.51ct. In 1879 the gem was purchased by Tiffanys for $18,000 and is still owned by the store.

P.G.R.

BALFOUR, I., 1988. Famous diamonds of the world. XXXIV. The De Beers diamond. *Indiaqua*, **49**, 1988/1, 123.

In 1888, a 439.86ct light yellow octahedron was found in the De Beers mine, not long after the incorporation of De Beers Consolidated Mines Ltd. It was cut, probably in Amsterdam, into a 234.50ct cushion-cut stone and was exhibited at the Paris exhibition of 1889. At a Sotheby's auction in Geneva in 1982 it failed to achieve its reserve price. More recently it has been acquired by a private buyer.

P.G.R.

BALFOUR, I., 1988. Famous diamond of the world. XXXV. Cleveland. *Indiaqua*, **50**, 1988/2, 139-40.

The rough stone, which was found in one of the Kimberley mines, weighed over 100 old carats. It was cushion-cut into a gem of 50ct and eventually named after Grover Cleveland who had just been elected the twenty-second President of the United States. Its present whereabouts are unknown.

P.G.R.

BALFOUR, I., 1988. Famous diamonds of the world. XXXVI. The 'Punch' Jones diamond. *Indiaqua*, **50**, 1988/2, 140-1.

This greenish-grey 34.46ct octahedron stone is the largest alluvial diamond to have been found in the United States. Discovered in the Appalachians in 1928 by William 'Punch' Jones, it was kept by him as a curio because he was not sure it was a diamond. In 1943 it was identified as a diamond by Professor Holden. The stone was never polished, and for a period was loaned to the Smithsonian Institution. It was auctioned by Sotheby's in 1984 for £67,500.

P.G.R.

BANERJEE, A., 1988. Gilson-Opale der neuen Generation. (New generation Gilson opals.) *Kurzmitteilungen aus dem Institut für Edelsteinforschung*, **4**, 2, 12, 2 figs.

Opal imitations created by Gilson are described. Instead of silica gel, zirconium dioxide is used as a matrix. In cases where it is difficult to identify the Gilson opal by optical means, IR-spectroscopy can be applied successfully, according to characteristic Si-O vibration in the region around 1250 cm^{-1}.

(Author's abstract) A.B.

BANK, F.H., BANK, H., GÜBELIN, E., HENN, U., 1988. Alexandrite von einem neuen Vorkommen bei Hematita in Minas Gerais, Brasilien. (Alexandrites from a new occurrence near Hematita in Minas Gerais, Brazil.) *Zeitschrift der Deutschen Gemmologischen Gesellschaft*, **36**, 3/4, 122-31, 15 figs, 1 table, bibl.

Alexandrites from the newly discovered alluvial occurrence near Hematita are discussed. Some of the stones show very good colour change and are remarkably clean. Some stones have a colour change plus chatoyancy, i.e., there are some alexandrite cat's-eyes. Physical data are within range of known natural and synthetic alexandrites. Microscopic feathers of liquid and two-phase inclusions or cavities filled with apatite, fluorite and cacite are visible. Stones show distinct growth structures. Typical alexandrite spectrum, red fluorescence.

E.S.

BERGMAN, S.C., DUNN, D.P., KROL, L.G., 1988. Rock and mineral chemistry of the Linhaisai

Minette, Central Kalimantan Province, Indonesia, and the origin of Borneo diamonds. *Canadian Mineralogist*, **26**, 23-43, 9 figs.

The alluvial diamonds found in central Kalimantan, Indonesia, may owe their origin to an unidentified lamproite or kimberlite in Borneo or adjacent south-east Asia. M.O'D.

BRACEWELL, H., 1988. The Argyle diamond mine. *Wahroongai News*, **22**, 4, 31-2.

A short account of today's largest diamond mine. A remote difficult region of north Western Australia has been opened up and Argyle Village built to accommodate 700 plus workers in virtual self-sufficiency. Some staff commute daily by air from Kunanurra, 220km away. Mine is open-cast, worked by modern earth-moving techniques. Treatment of spoil by crushing, scrubbing, screening and gravity separation, precedes diamond recovery by X-ray fluorescence. Product is 45% gem (5% of which are fine) and 55% industrial. R.K.M.

BROWN, G., 1988. Danburite. *Wahroongai News*, **22**, 4, 23-5, 3 figs.

A brief account of this calcium boro-silicate, which can be confused with topaz, particularly in its crystal form. R.K.M.

BROWN, G., 1988. Trapiche emeralds. *Wahroongai News*, **22**, 5, 20-2, 3 figs.

An interesting account of this strange crystallographic anomaly compiled from authoritative sources. The larger or better crystals are segmented to extract the emerald areas for faceting. The 'spokes' are better quality than the core. R.K.M.

BROWN, G., 1988. Chrysoberyl. *Wahroongai News*, **22**, 6, 21-5, 4 figs.

An exhaustive compilation of facts culled from half a dozen authoritative sources. Includes details of several known synthetic alexandrite products. R.K.M.

BUTINI, E., 1987. Impiego della 'Xeroradiografia' nell'indagine gemmologica qualitativa delle perle. (The use of 'xeroradiography' in the qualitative gemmological study of pearls. *La Gemmologia*, **12**,, 1/4, 6-22, 35 figs (31 in colour).

Xeroradiography is based on the interaction of X-rays with the atomic structure of some photoconductive substances such as selenium. A standard X-ray generator is used with a plate having an aluminium base with a thin deposited selenium layer on it. Selenium is capable of conducting electricity on exposure to X-rays and other radiations. This apparatus is capable of recording the structures of various types of pearl and examples are given with illustrations. When the photograph is taken the result is then recorded on special plastic paper which then provides a coloured image. M.O'D.

CASSEDANNE, J., 1988. L'Améthyste au Brésil (2). (Brazilian amethyst.) *Revue de Gemmologie*, 95, 3-9, 18 figs (3 in colour).

Second and final part of a paper on amethyst deposits of Brazil which are listed and geologically described. A bibliography is appended. M.O'D.

CAVENEY, R.J., 1987. De Beers Research Report No. 25. *Indiaqua*, **48**, 1987/3, 119-21.

The report deals with the surface properties of diamond and explains why diamond, normally hydrophobic (non-wettable) sometimes becomes hydrophilic (wettable) when its surface is contaminated. More rarely, some 'clean' diamonds refuse to adhere to the grease on diamond-recovery grease tables and belts. The mechanism here is still a mystery, but research is continuing into the surface chemistry of diamond, and this is becoming particularly relevant to the bonding of diamond particles to the surface of cutting and grinding tools. P.G.R.

CAVENEY, R.J., 1988. Comments upon De Beers large synthetic diamonds. *Indiaqua*, **50**, 125-8, 15 figs (14 in colour).

A single crystal synthetic diamond weighing 11.14ct has been grown by De Beers Diamond Research Laboratory. A selection of smaller crystals were sent to the GIA and reported on in the Winter 1987 issue of *Gems and Gemology*. M.O'D.

CURRIE, S.J.A., 1988. Some aspects of the heat treatment of ruby. *Wahroongai News*, **22**, 6, 2-3.

A 'guest editorial' describing a method seen in Thailand in 1987 in which ruby crystals were sealed in a clay crucible with an acidic solution, probably dilute nitric acid and salt, and baked in a charcoal kiln. Some speculation is made on the possible reaction, but the writer did not see the treated stones to assess the result. R.K.M.

DE BRUYN, WIM, 1987. World diamond record. *Industrial Diamond Review*, 6/87. 271, 1 fig.

The Amsterdam diamond dealers, D. Drukker & Zn NV, have succeeded in fashioning the world's smallest brilliant-cut diamond. It is 0.22mm in diameter, and weighs 0.0001022 ct. It has been accepted by the *Guinness Book of Records* as a new world record, easily beating the last holder of this title (a diamond 0.53mm in diameter). P.G.R.

DELBASTEH-MIANDOAB, R., 1988. Spodumene afghanischer und brasilianischer Herkunft. (Spo-

dumene from Afghanistan and Brazil.) *Kurzmitteilungen aus dem Institut für Edelsteinforschung*, **4**, 2,9-10, 2 figs.

Spodumene crystals of different colours (pink, green and colourless) from Afghanistan and Brazil have been investigated by means of X-ray diffraction technique, optical microscopy, SEM, NAA, OES, UV-VIS and IR-spectralphotometry. The following inclusions have been identified: idiomorphic beryl, quartz, Ca-amphiboles and Ca-pyroxenes, micas (muscovite and lepidolite), and zircon; two-and three-phase inclusions, negative crystals and some opaque ore minerals were also observed. Moreover, bent fissures and unusually shaped 'etched tubuli' were found. The Mn-contents of the pink kunzites were found to be approximately proportionate to the intensity of their colours. In hiddenites, the results of the chemical analyses indicate that only Fe, and not Cr, must be responsible for the green colour.

(Author's abstract) R.D-M.

FRITSCH, E., ROSSMAN, G.R., 1988. An update on color in gems. Part 3: Colors caused by band gaps and physical phenomena. *Gems & Gemology*, **24**, 2, 81-102, 16 figs in colour. 4 tables.

Concludes this important and informative series which now covers colour due to coarser physical features in gem minerals. Authors include an exhaustive table of gems, colours and causes, and three pages of references. Series as a whole is valuable. R.K.M.

FRYER, C.W. (ED.), CROWNINGSHIELD, R., HURWIT, K.N., KANE, R.E., 1988. Gem Trade Lab notes. *Gems & Gemology*, **24**, 2, 112-18, 18 figs in colour.

Almandite garnet star which is almost a cat's-eye; greyish-purple diamond; heart-shaped inclusion in diamond; pink diamonds offered as natural, showed zoning in yellow and pink, proved by absorption lines to be treated. All described and illustrated.

Biron synthetic emerald had high RI (1.570-1.578) and birefringence (0.008), otherwise similar to others seen. Unusual black opaque glass with red/green 'blink' is mentioned but neither the term nor its cause are explained. Variegated jadeite, fine green flecked with white, mounted in close-backed yellow setting described and illustrated. White jadeite teapot of exceptional translucency is described. Glass bead imitation pearls described as Edwardian are attributed to late 1800s or early 1900s. A cultured pearl in a necklace was found to have a wax bead centre. Plastic earring said to contain diamond, was shown to have none. A black pyrope with ilmenite inclusions was confirmed. A synthetic yellow sapphire showed Plato line effect without magnification. A blue synthetic sapphire had intersecting curved colour banding. Two specimens of brecciated tiger's-eye quartz are illustrated.

R.K.M.

GERRYTS, E., 1988. Memories of Mwadui in the 1950s. *Indiaqua*, **49**, 21-31, 16 figs (7 in colour).

The former chief diamond geologist at the Mwadui mine in Tanzania gives recollections of the mine and of Dr John T. Williamson. M.O'D.

GONZALEZ-CARRENO, T., FERNANDEZ, M., SANZ, J., 1988. Infrared and electron microprobe analysis of tourmalines. *Physics and Chemistry of Minerals*, **15**, 452-60, 6 figs.

Tourmalines from the dravite-schorl and elbaite-schorl series were examined with infra-red and electron microprobe equipment. The infra-red study differentiates between OH groups located at the centre of hexagonal rings and those which are placed between hexagonal pillars and which are coordinated to two Al ions. Electron microprobe tests on zoned coloured samples has shown that the Mn and Fe distribution is partially ordered in some samples of the elbaite-schorl series. M.O'D.

GÜBELIN, E.J., 1988. Feldspars as host and guest minerals. *Indian Gemmmologist*, **1**, 4, 5-11, 18 figs (16 in colour).

The feldspar minerals are reviewed in their roles as host and inclusion. A series of microphotographs illustrate various types of feldspar inclusion in a variety of gemstones. M.O'D.

HÄNNI, H.A., 1987. Corindoni trattati con microotturazioni in vetro. (Corundum treated with microscopic glass infillings.) *La Gemmologia*, **12**, 1/4, 30-8, 10 figs (5 in colour).

Examples of glass infillings in corundum are discussed and illustrated. M.O'D.

HARRIS, J.W., 1987. Recent physical, chemical and isotopic research of diamond. *Mantle Xenoliths*, 477-500.

Recent advances in the following fields of diamond research are reviewed: morphology, growth history, characterization and classification, surface features, substitutional and non-substitutional molecular impurities, colour, age and genesis. Diamond characteristics from southern Africa, Western Australia and North America are compared in detail; > 40 pristine surface features are recognized on common diamond morphologies and distinctions are made between diamonds from different kimberlite and alluvial sources, particularly in southern Africa. Only impurities of atomic size are considered. The substitutional impurities boron

and nitrogen are important because of their influence on colour and diamond type. $\delta^{13}C$ variations range between +5.0 and −34.4°/oo and the results discussed in terms of paragenetic associations and some preliminary nitrogen isotope studies; 55 non-substitutional impurities are known, but emphasis is placed on noble gas and alkali elements because of their potentially important role in determining the age of diamond. Radiogenic impurities from within diamond currently give ambiguous diamond ages. A new age-dating method, using the impurity of nitrogen, may help resolve some of these problems.
J.M.H.

HEFLIK, W., NATKANIEO-NOWAK, L., SOBCZAK, N., SOBCZAK, T., 1988. Nephrit aus Niederschlesien. (Nephrite from Lower Silesia.) *Zeitschrift der Deutschen Gemmologischen Gesellschaft,* **36,** 3/4, 153-60, 1 graph, 1 table, bibl.

Finds of nephrite in Lower Silesia were already mentioned in 1775 by the Swedish scientist Linne, but only recently workings were started. The occurrence is north-west of Jordanow and found together with serpentinite. Gabbro is found in the vicinity. The nephrite contains zoisite and diopside giving it a pink and white coloration. The white colour is also caused by veins of tremolite which are very poor in FeO. Blocks measuring 2.5m and up to 0.4m thickness have been found, but these sizes are unusual. Application is mainly the jewellery industry and to some extent it is used for production of mortars.
E.S.

HRABANEK, J., MALLEY, J., 1988. Moldavite aus Süd-Böhmen und Süd-Mähren. (Moldavite from south Bohemia and south Moravia. *Kurzmitteilungen aus dem Institut für Edelsteinforschung,* **4,** 2, 10-11, 1 fig.

Moldavites are one of the most famous occurrences of glass in nature; they are found in southern Czechoslovakia, and have been used as tools and gemstones since prehistoric times. Archeologists date specimens from cultural layers in sites in Austria and Czechoslovakia back to 30000 BC. The bulk chemistry of more than 30 recent findings are analysed and proved to be within the usual range. Typical inclusions such as lechatelierite 'Schlieren' help to distinguish moldavites from artificial glasses, as well as distinctive Al/Na_2O+K_2O ratios. Moldavites are assumed to be derived from the Nordlinger Ries meteoritic impact, south-west Germany. The impact of a meteorite of approx. 600m in diameter subjected the surrounding rocks to shock-wave metamorphism of more than 1000 kbar and 5000°C, causing a crater of 25km in diameter. Molten material burst out of the crater, and smaller particles (so-called tektites) were thus enabled to pass a distance of several hundred kilometers; after rapid cooling during their flight they were then deposited as glass pebbles with particular surface structures. (Author's abstract) J.H.

HUGHES, R.W., 1988. Brilliance, windows and extinction in gemstones. *Gemmological Digest,* **2,** 1/2, 10-15, 5 figs.

Brilliance, windows and extinction are discussed with reference to the grading of coloured gemstones. Diagrams illustrate the three concepts.
M.O'D.

KESSLER, P.F., 1988. Black slag, moon rock or natural glass? *Gemmological Digest,* **2,** 1/2, 15-19.

The author gives a brief survey of tektites with references to the literature. M.O'D.

KOIVULA, J.I., KAMMERLING, R.C., 1988. Gem news. *Gems and Gemology,* **24,** 2, 120-3, 8 figs in colour.

Very large floating diamond/gold dredge at Tejucana, Minas Gerais, is described and illustrated. Very efficient, but scars the land badly. A 52.59 ct emerald-cut diamond at Christie's, New York, has achieved a price of $7.48 million, $142,232 per carat, the highest so far!

Iridescent andradites are again reported from Sonora, Mexico. A 2.53 ct ruby crystal was found in North Carolina. Reports from Sri Lanka include considerable finds of ekanite [hope they are keeping this well screened]. Uranite, another radio-active mineral, also found. Orange sapphire and orange scapolite reported. Plastic imitations of malachite and lapis lazuli have been seen. Blister packs for synthetics, rather like pills, have reached the States.
R.K.M.

KOIVULA, J.I., 1988. Remarkable dissolution in diamond. Deutschen Gemmologischen Gesellschaft, **36,** 3/4, 149-52, 2 photographs, 1 photomicrograph, line drawings.

A natural diamond crystal section containing a negative crystal cavity open to the surface was studied. A small loose diamond crystal was found trapped within the cavity; both this crystal and the inner walls of the cavity were covered with brownish-green radiation stains. No such stains were observed on surface of the host diamond. Some theories as to how this could have happened are produced. E.S.

KOZLOWSKI, A., METZ, P., JARAMILLO, H.A.E., 1988. Emeralds from Somondoco, Colombia; chemical composition, fluid inclusions and origin. *Neuves Jahrbuch für Mineralogie, Abhandlungen,* **159,** 1, 23-49, 1 map.

Emeralds from the Somondoco district have been

analysed by electron microprobe colorimetry, emission spectrography, TGA and IR absorption. On the basis of 18 O, they typically show atomic substitutions: 0.13≃0.21 Al in the SiO_4 tetrahedra, 0.14≃0.40 for Σ(Cr+V+Fe+Mg) in the AlO_6 octahedra and 0.02≃0.06 Li +0.00≃0.17 □ in the BeO_4 tetrahedra; the 'channel' alkalis, mostly Na, total 0.13≃0.29. Fluid inclusions contain liquid H_2O and CO_2, together with daughter crystals of halite and calcite(?), and liquid and gaseous hydrocarbons; homogenization *T* are ≥470°C, but a rough *P* correction (≤1 kbar) would add 100°C to these values. The microprobe analyses for seven emeralds show Cr_2O_3 0.01≃0.34, V_2O_3 0.01≃0.12%. The ratio emerald : ore in the Chivor mines is 1 : 165 million, i.e. one tenth of the abundance of diamond in South African kimberlites. R.A.H.

LANDMESSER, M., 1988. Über den sogenannten 'Streifenchalcedon'. *Kurzmitteilungen aus dem Institut für Edelsteinforschung*, **4**, 2, 5-8, 7 figs (1 in colour).

Banded, bluish quartz aggregates have been studied by polarizing microscopy. There are distinct differences between these gemstones and agates: length-fast chalcedony is rare in these aggregates; they mainly consist of length-slow chalcedony and bigger quartz crystals. Their banding is different from the ordinary banding and Uruguay banding in agates. Some aspects of the genesis of these banded aggregates are discussed, and problems of their nomenclature are described.

(Author's abstract) M.L.

LANDMESSER, M., 1988. Transport und Akkumulationsmechanismen des SiO_2 in petrologischen Systemen: Achate. (Mechanisms of transport and accumulation of SiO_2 in petrological systems: agates.) *Zeitschrift der Deutschen Gemmologischen Gesellschaft*, **36**, 3/4, 101-19, 4 photographs, 3 tables, 5 graphs, bibl.

The problem of silica transport and accumulation during agate formation is discussed. A newly discovered mechanism by diffusion at low temperature is described. This is not confined to agate formation, but can be applied to other rock-forming processes such as silification of wood, formation of chert and flint and opaline materials. The conditions necessary for this process are outlined. E.S.

LINDBERG, J.D., 1988. Rabb Canyon sanidine. *Lapidary Journal*, **42**, 1, 39-44, 1 fig. in colour.

Gem quality sanidine is reported from Rabb Canyon, New Mexico, USA. The location is in the Black Range in the western part of the state.

M.O'D.

LIVSTRAND, U., 1988. Australisk Labradorit (Australit). (Australian labradorite (Australite). *Gem Bulletinen*, 1, 6-7.

Describes an Australian location for labradorite which has been undesirably named 'Australite'.

M.O'D.

MCGEE, E.S., 1988. Potential for diamond in kimberlites from Michigan and Montana as indicated by garnet xenocryst compositions. *Economic Geology*, **83**, 428-32, 2 figs.

Mg-and Cr-rich garnet is used in the location of kimberlites as an indicator mineral. A subset of pyrope-type composition from garnet peridotites may indicate the presence of diamond. Most peridotitic garnets are Mg-rich while those associated with diamond have sub-calcic Cr-rich compositions. In the study crystals of garnet with purple coloration were used to increase the chance of identifying subcalcic Cr-rich compositions.

M.O'D.

MANNUCCI, G., GAMBINI, E., 1987. Note sui caratteri cristallochimici di alcune imitazioni del diamante. (An investigation of some zirconia and hafnia imitations of diamond.) *La Gemmologia*, **12**, 1/4, 23-9.

Two varieties of cubic zirconia and one of cubic hafnia are identified on the grounds of their chemical composition and unit cell parameters. Hafnia constants are given as RI 2.23 and SG 9.07. M.O'D.

MEYER, H.O.A., 1987. Inclusions in diamond. *Mantle Xenoliths*, Wiley-Interscience, 501-22.

A large number of minerals occur as inclusions in diamonds, notably olivine, garnet, pyroxene, spinel and sulphides. They may be subdivided into two, major groups on the basis of chemical composition, i.e. an ultramafic suite and an eclogitic suite, and possibly a new minor calc-silicate suite. These suites reflect differences in the geochemical environment in which the host diamonds formed. The physical nature of the environment is uncertain since evidence can be cited in favour of crystallization from a partial melt (igneous) or from a solid state transformation (metamorphic). Data from various isotopic studies are at present insufficient to provide an answer to this problem, although recent isotopic investigation of inclusions has suggested that these, and by inference the host diamonds, are

Archaean in age, in spite of the kimberlite from which they were obtained being Mesozoic. The relationship of diamond to kimberlite, and probably lamproite, is one of passenger to transporting medium. In the absence of evidence to the contrary it is possible that some diamonds are the result of subduction whereas others represent primitive mantle carbon. J.M.H.

MÖLLER, R., 1987. Establecer, dentro de lo posible, las relaciones historico-linguisticas de las denominaciones 'verde' y 'esmeralda'. (To establish as far as possible the historical-linguistic relationship between the terms 'green' and 'emerald'.) *Gemologia*, **26/27**, 73/76, 5-40, 23 figs.

The author attempts to list and discuss the terms for green and emerald in a number of major languages including Russian and Chinese. Useful lists of terms are given. M.O'D.

MÖLLER, R., 1987. La gemologia en los sellos. (Gemmology in stamps.) *Gemologia*, **26/27**, 73/76, 41-5, 11 figs.

A brief review of gemstones appearing on stamps. M.O'D.

MÖLLER, R., 1987. Gemoterapia. (Gem therapy.) *Gemologia*, **26/27**, 73/76, 46-58.

A review of the curative powers attributed at various times to gemstones. M.O'D.

NASSAU, K., 1988. Mount Saint Helen's ashes. *Lapidary Journal*, **42**, 4, 41-2, 2 figs in colour.

Mount Saint Helen's ash from the eruption of 1980 has been found to consist of partly glassy and partly crystalline material. Particles range from over 1mm to less than 1 micrometre in size. A green glass purporting to consist of this ash and having an RI of 1.508 has been on sale in the United States; glassy material made from known specimens of the ash are black and have an RI ranging from 1.500-1.526. The green sample had an SG of 2.448 and the black 2.485. A flow test showed conclusively that the green glass could not have been made from the same material as the black glass. The green glass contained, it is thought, only 5-10% of the ash, if any. M.O'D.

PEARSON, D.G., 1988. Graphitized diamonds from North Morocco? *Indiaqua*, **50**, 35-9, 21 figs (20 in colour).

During the collision of Africa with Europe a portion of the mantle was tectonically emplaced into the crust. From investigations of the Beni Bousera peridotite in northern Morocco it appears that this portion of mantle was once very rich in diamond concentration. The diamonds were altered to graphite while being transported up from the mantle and can now be found as octahedral graphite aggregates. This is a new non- volcanic type of diamond occurrence. M.O'D.

POUGH, F.H., 1988. Beryl sources. *Lapidary Journal*, **41**, 10, 20-6, 4 figs in colour.

Review of the gem beryl minerals with emphasis on their mode of occurrence. M.O'D.

POUGH, F.H., 1988. Allanite. *Lapidary Journal*, **42**, 1, 16-18.

Allanite is a member of the epidote group of minerals and is usually black with brownish-greenish, greyish or yellow overtones. M.O'D.

POUGH, F.H., 1988. Augelite. *Lapidary Journal*, **42**, 4, 14-16.

A brief description of the aluminium phosphate augelite, which is very rarely cut as a gemstone. Details of its occurrence and formation are given. M.O'D.

POUGH, F.H., 1988. An introduction to mineralogy. *Lapidary Journal*, **42**, 4, 21-34, 7 figs (1 in colour).

The introduction attempts to cover basic mineralogy for the student of gemmology. M.O'D.

READ, P., 1987. Procesos de obtención de la esmeralda sintética Lennix, de Leonard Lens. (The testing of the Lennix synthetic emerald made by Leonard Lens.) *Gemologia*, **26/27**, 73/76, 59-62.

Spanish version of an article first published in the *Gem Instrument Digest*. M.O'D.

READ, P.G., 1987. Ultra-violet spectroscopy. *Canadian Jeweller*, August 1987, 28.

Includes a description of the Krüss second-generation UV spectroscope (the UVS-2000), in which the imaged spectra are stronger and sharper as a result of more intense illumination and improved optics. Dispersion has also been increased to give an effective scale length of 50mm. (Author's abstract) P.G.R.

READ, P.G., 1987. Synthetic gem-quality diamonds. *Canadian Jeweller*, September 1987, 14.

A review of the identification techniques so far available for the detection of gem-quality synthetic diamonds (GE and Sumitomo). Techniques covered are spectral, magnetic, fluorescent, and the absence of crystalline defects revealed by high-contrast surface inspection. (Author's abstract) P.G.R.

READ, P.G., 1987. An affordable sodium light source and microscope. *Canadian Jeweller*, October 1987, 14.

Describes the new Rayner sodium lamp unit which employs a low-cost GEC lamp having an operating life in excess of 6,000 hours (compared with 200 hours for the smaller Philips lamp used in the original Rayner unit). Also described is the Hodgkinson/Morgan Zenith immersion microscope. (Author's abstract) P.G.R.

READ, P.G., 1987. Measuring refractive index. *Canadian Jeweller*, November 1987, 27.

A review of the development of the critical angle refractometer. The article also describes other methods of determining a gem's refractive index including the 'direct' method, immersion in liquids of known RI and the use of the Brewster-angle of polarization. (Author's abstract) P.G.R.

READ, P.G., 1988. Gemstone optics. *Canadian Jeweller*, February, 1988, 14.

Describes the evolution of the modern 'ideal' cut for diamond, the 'Radiant' cut improvement on the emerald-cut for diamond and the optics of the preferred cuts for coloured stones.

(Author's abstract) P.G.R.

READ, P.G., 1988. Outback sapphire and opal. *British Jeweller*, April 1988, 40-1.

Describes lesser known sapphire and opal fields in New South Wales and Queensland respectively.

(Author's abstract) P.G.R.

READ, P.G., 1988. De Beers bring out the big gems. *British Jeweller*, July 1988, 11.

Covers the announcement of the De Beers Centenary diamond and a mention of the recovery of other large diamonds from the Premier mine. Also included are details of the large Sumitomo and De Beers gem-quality synthetic diamonds.

(Author's abstract) P.G.R.

RINGSRUD, R., 1988. Muzo emerald. *Lapidary Journal*, **41**, 10, 27-34, 7 figs (6 in colour).

A useful and topical account of present-day emerald mining at Muzo, Colombia. A map of the area is included. M.O'D.

ROBERT, D., 1988. Qu'est-ce que l'émeraldonite? (What is emeraldonite?) *Revue de Gemmologie*, 95, 19-20, 5 figs (1 in colour).

Emeraldonite is an undesirable name which has been given to a material consisting of an emerald deposit on a colourless natural beryl. A chemical analysis is given. M.O'D.

SCHMETZER, K., 1987. Lamellare Einschaltungen von Diaspor in Korund. *Aufschluss*, **38**, 335-7, 3 figs.

Natural corundums usually show conchoidal fracture without natural cleavage, but can sometimes be split parallel to the positive rhombohedron $r(10\bar{1}1)$, or even parallel to the base $c(0001)$. What is much rarer and seldom mentioned in text books, is the splitting along slightly curved, not crystallographically orientated faces when only slight mechanical pressure is applied. The blue-grey corundum crystals examined come from an occurrence in Mato Grosso, Brazil; they are barrel-shaped crystals of up to 5cm long. When slight mechanical pressure is applied these macroscopically well developed crystals split easily along slightly curved faces. Along these broken faces a thin lamellar mineral with a lower RI than corundum could be observed. This was found to be diaspore. The splitting is therefore assumed to be due to lamellar diaspore, the presence of which can be traced to a retrograde metamorphism. E.S.

SCHMETZER, K., MEDENBACH, O., 1988. Examination of three-phase inclusions in colorless, yellow and blue sapphires from Sri Lanka. *Gems & Gemology*, **24**, 2, 107-11, 3 figs (2 in colour).

Thin tabular negative cavities parallel to basal pinacoid found in 20% of 300 stones examined. Liquid and gas phases identified as CO_2, while solid phase is diaspore, a hydrated form of corundum.

R.K.M.

SCHWARZ, D., HÄNNI, H.A., MARTIN, F.L., FISCHER, M., 1988. Die Smaragde fer Fazenda Boa Esperanca bei Taua, Ceara, Brazilien: Vorkommen und Charakteristika. (The emeralds of Fazenda Boa Esperanca, Tauá, Ceará, Brazil: occurrence and characteristics.) *Zeitschrift der Deutschen Gemmologischen Gesellschaft*, **36**, 3/4, 134-47, 1 map, 3 diagrams, 4 tables, 10 photomicrographs, bibl.

A German version of the article published in the *Journal of Gemmology*, **21**, 3, 168-78. E.S.

SERSEN, W.J., 1988. Corundum type categories. *Gemmological Digest*, **2**, 1/2, 3-9.

An attempt is made to classify the colour of rubies and sapphires to take into account the individual colour of each specimen. The attempt is made for grading rather than gemmological purposes. M.O'D.

SPENCER, L.K., DIKINIS, S.D., KELLER, P.C., KANE, R.E., 1988. The diamond deposits of Kalimantan, Borneo. *Gems and Gemology*, **24**, 2, 67-80, 14 figs in colour.

One of the earliest known sources of diamond, Kalimantan has two main alluvial areas. Landak in the west is largely inactive, but the swamps of Banjarmasin in the south-east are now being in-

vestigated. The region is equatorial, wet and very hot, mining methods are mostly primitive, but a sampling project at Banjar Baru used sophisticated equipment. Sample pit yielded more than 1000 carats of small gem quality diamonds, 470 grams of gold and 178 grams of platinum. Diamonds are cut locally at Martapura. 15% of stones are one carat or more, mostly white or yellowish with some fancy colours. Almost no bort. Hoped that Indonesia can become a small but consistent producer of high quality diamonds. R.K.M.

STOCKTON, C.M., 1988. Pastel pyropes. *Gems & Gemology*, **24**, 2, 104-6, 2 figs in colour.

Pure pyrope is colourless and very rare, but has been found in Western Alps. Pastel shades of orange, or pink, are being found in parcels from East Africa. Low RI, between 1.734 (colourless grossularite) and 1.714 (colourless pyrope), identifies. [Confusion might occur with some spinels?] R.K.M.

THEMELIS, T., 1988. Intersecting folds in hydrothermal emerald. *Lapidary Journal*, **42**, 4, 19, 1 fig. in colour.

A fold-like effect can be seen in some hydrothermally produced emerald; these growth phenomena can best be seen by dark-field illumination. M.O'D.

ZEITNER, J.C., 1988. The Proctor beryls. *Lapidary Journal*, **41**, 10, 42-7, 4 figs in colour.

The Keith Proctor collection of fine minerals contains many items of gem quality. The article describes a selection of beryl crystals displayed at the 1988 Tucson Mineral and Gem Show. M.O'D.

ZEITNER, J.C., 1988. Louisiana's agatized palm. 42, 4, 43-6, 2 figs in colour.

Agatized palm wood, the state fossil of Louisiana, is fashioned into ornaments. It has a fine-grained texture and is hard enough to take an adequate polish. M.O'D.

ZWAAN, P.C., 1987. Orthopyroxene from the Embilipitya area in Sri Lanka. *Schweizerische Mineralogische und Petrographische Mitteilungen*, **67**, 119-25, 5 figs.

Colourless to deep brown orthypyroxenes with colourless specimens having RI 1.650, SG 3.194, are described from the Embilipitya area of Sri Lanka. All have a strong absorption band at 506nm. The intensity of the band deepens with the depth of the brownish colour though even colourless specimens show the band. M.O'D.

Book Reviews

BLAKEMORE, KENNETH, 1988. *The retail jeweller's guide*. 5th edn. Butterworths, London. pp 412. 166 black-and-white illus. £30.00.

This is the latest book in a long line that started with *The retail jeweller's handbook* by Selwyn in 1945. The seven editions of the *Handbook*, followed by five of the *Guide* have all attempted to cover the full range of goods dealt in by the retail jeweller.

Following this tradition, the current edition has been expanded to include chapters on glass and pottery; products increasingly handled by the modern jeweller. This material has been condensed from the same author's *A retailer's guide to glass and pottery*, which is unlikely to be reprinted.

Other chapters deal with precious metals, gemstones, silverware, boxes, jewellery and its manufacture, hallmarking, and clocks and watches. There are also five glossaries and five appendices. The book ends with a comprehensive index.

The gemstone section has additional material on modern synthetics and methods of enhancement. This chapter, although seeming somewhat compressed to a gemmologist, nevertheless contains an amazing amount of information. It is, however, unfortunate that of the two books recommended by further reading, one is *Gemstones for everyman* by B.W. Anderson. This has been out of print for many years, and is extremely scarce.

The hallmarking chapter has also been expanded to include details of the regulations concerning mixed metals (there is some confusion here between the 1975 and the 1986 amendments) and of international marks.

The author, who has been Editor of the *Watchmaker, Jeweller and Silversmith* since 1947, is to be congratulated on this excellent book that cannot be too highly recommended to anyone connected with the jewellery trade. Gemmologists not in the retail trade should consider it as essential reading. It will enable them to gain some knowledge of the many various sides to the modern jeweller's business, helping them to appreciate that gemstones are only a part (albeit a vital part) of that business. N.B.I.

CULME, J., RAYNER, N., 1987. *The jewels of the Duchess of Windsor.* Thames & Hudson in association with Sotheby's, London. pp.224. Illus. in black-and-white and in colour. £30.00.

The sale of the personal jewellery of the late Duchess of Windsor in April 1987 attracted a level of publicity rarely given to jewellery and gemstones. Though it has been said by many that some of the pieces were not particularly important from the standpoint of the jewellery historian, they are still of high quality and the stones they contain are often large and beautiful.

Readers who have the sale catalogue itself should get this book too as it contains additional biographical material and a list of the prices paid for each item as well as all the pictures and descriptions used for the sale. M.O'D.

HOSKIN, J., LAPIN, L., 1987. *The Siamese ruby.* World Jewels Trade Centre, Bangkok. pp.119. Illus. in colour. US$27.00.

This is a very attractively produced book designed to raise the image and status of the Siam ruby with the trade and the general public. The ruby is introduced as a gemstone with some gemmological detail and there are sensible notes on the vexed topic of colour and clarity alteration. A good deal of information is given in what is quite a small book – present- day marketing is described and illustrated with scenes of dealing. Other photographs show Bangkok and Chantaburi street scenes but those which really catch the eye are those depicting the stones themselves. Most appear to be of Burmese quality at least.

The book was published to commemorate the 60th birthday of His Majesty the King of Thailand and it deserves to be widely purchased. M.O'D.

KRASHES, L.S., 1986. *Harry Winston, the ultimate jeweller. 2nd revised edn.* Harry Winston, Inc., New York, and GIA, Santa Monica. pp. xiii, 218. Illus. in colour. £50.00.

Perhaps the most unusual picture in the book is that of Harry Winston himself who was said to be wary of publicity! The book contains an account of both the man and the firm with particular emphasis on his glittering clientèle and even more on the jewels and individual stones that he created and handled. The central section of the book describes and illustrates some of the most celebrated stones Winston created (mostly by re-cutting) with notes on their previous history. The standard of the illustrations is very high indeed and I was pleased to see the occasional painting as well as photographs. There is a short bibliography.

This is not a cheap book but of very high quality. M.O'D.

LIDDICOAT, R.T., 1987. *Handbook of gem identification.* 12th edn. GIA, Santa Monica. pp.362. Illus. in colour. £25.00.

This new edition of a famous old classic breaks new ground. The text, though arranged in the same sections as in previous editions, has been entirely re-set and the illustrations are all in colour. As before, after some introductory matter on gem testing in general, the bulk of the text deals with gemstones in chapters each covering a different colour. Many species are illustrated as are a number of the more important inclusions. The standard of the reproduction is high and the book concludes with a set of identification tables. Not many of the really rare species are omitted though I failed to find clinohumite. But such a search is expected of a reviewer and it is more interesting to look at the book as a whole and, of course, to compare it with *Gem testing.*

The *Handbook* is clearly aimed at the integrated residential gem testing classes so well run by the GIA; *Gem testing* constantly wanders from the point under discussion to refer to some aspect of mineralogy in general – this distinction seems to me to reflect in a rather pleasing way the most valuable and productive differences between the two approaches to gem testing. Readers of this review should already have *Gem testing* and should get the *Handbook* as soon as possible. Two small criticisms, one more important than the other. There is no bibliography (this is the more serious criticism); from a distance the dust jacket with the genial face of the author upon it rather resembles a Slavonic political or historical work. M.O'D.

MARCUM, D., 1986. *Dow Jones-Irwin guide to fine gems and jewellery.* Dow Jones-Irwin, Homewood, Illinois. pp. xxii, 213. Illus. in colour. US$25.00.

There are many books on gemstones aimed at the potential investor and as Western economies recov-

er and consumer confidence surges it is not surprising that the genre is gaining new members. This is quite a good example of its kind with most of the gemstone information quite accurate and including interesting data on price rises and maintenance (there are few recorded falls). At the price this is worth buying if you want a quick insight into the commerce of gemstones. M.O'D.

MORRILL, P., 1981. *Maine mines and minerals*. 2nd part. Winthrop Mineral Shop, Winthrop, MA 04343. US$18.00.

This is a useful guide for the field collector, giving alphabetical lists of locations followed by mineral lists. There are several maps and directions are given to most places, together with occasional references to the literature in outstanding examples. M.O'D.

MÜLLER, G., 1988. *Convection and inhomogeneities in crystal growth from the melt*. Springer Verlag, Berlin. pp.138. Illus. in black-and- white. DM128.00.

The text of this book is based on a German original published in 1986 but incorporates a number of emendations and additions. It forms volume 12 of the series *Crystals, growth, properties and applications* which has provided a very large amount of useful information over the years. It is also worth noting that this volume contains an author index for vols. 1-12. The crystals described are mainly those of semiconductor materials but the techniques of growth and characterization are well worth getting to know by anyone with an interest in the crystalline state.

The book begins with a discussion of fundamentals of process modelling for semiconductor crystal growth and then devotes a number of chapters to the topic of inhomogeneity and how it can be detected and avoided. There is a good bibliography and a list of symbols. M.O'D.

RAMSEY, J.L., RAMSEY, L.J., 1985. *The collector/investor handbook of gems*. Boa Vista Press, San Diego, California. pp.300. Illus. in colour. $16.95.

An interesting book giving a full if idiosyncratic account of world economic trends as they have affected and might affect the gemstone investment trade. There are also extensive notes, accurate for the most part, on individual gem species, courses of instruction and hints to buyers. It is reasonably priced and gives a good insight into contemporary thinking on this often vexed topic. M.O'D.

SEIM, R., 1981. *Minerale*. (Minerals.) GLB, Köln. pp. 408. Illus. in black-and-white and in colour. DM19.80.

This is a well-produced general guide to minerals, some of which are illustrated in colour in a central section. Each species has been chosen with European localities in mind and many have crystal diagrams. There is a short section on the gem minerals and on the history and properties of the chemical elements. The locality information is valuable and the book is completed by a short bibliography. M.O'D.

SHUVALOV, L.A., 1988. *Modern crystallography IV*. Springer, Berlin. pp. xviii, 583. Illus. in black-and-white. DM198.00.

With this volume, which carries the subtitle *Physical properties of crystals*, the set *Modern crystallography* comes to a distinguished conclusion. The translation from the Russian is very effective (the original work is entitled *Sovremennaja kristallografija*). The book opens with a discussion of the fundamentals of tensor and symmetry description of the physical properties of crystals and continues with the mechanical properties of crystals. Then come sections on the electrical and magnetic properties of crystals.

The next chapter, on semiconductors, gives a very useful introduction to metals, semiconductors and insulators, but many readers will turn first to the next chapter but one which deals with the optical properties of crystals. Many familiar concepts will be found concisely explained and I recommend readers who can get hold of the book to study this section. The final chapter covers liquid crystals and is followed by an extensive reference section. M.O'D.

SOPWITH, T., 1984. *An account of the mining district of Alston Moor, Weardale and Teesdale*. Davis Books, Newcastle-upon-Tyne. pp. viii, 183. Illus. in black-and-white. Price on application.

This is a reprint of the book first published in 1833. It describes in a fairly scientific and gossipy way the lead mining districts of the north-east of England which extend over approximately 400 square miles. Included in this area are a great number of mineral-producing sites, including some which gave the world's finest fluorite. I warmly recommend this book (which is in a larger format than the original) to all those with an interest in field work. M.O'D.

STOWE, C.W., 1987. *Evolution of chromium ore fields*. Van Nostrand Reinhold, New York. pp. xii, 340. Illus. in black-and-white. $40.80.

The book contains a series of papers on the development of chromium minerals and of other minerals in which chromium acts as a replacement element. This is a useful work for anyone interested

in the way in which chromium is formed and how it behaves. Each chapter has its own references.

M.O'D.

VERE, A.W., 1988. *Crystal growth*. Plenum, London and New York. pp. xiii, 258. Illus. in black-and-white. US$47.00.

This book will be found useful at several levels. It gives an always welcome state-of-the-art report and provides a large section of abstracts on seminal topics – a feature I have not previously encountered in the crystal growth field. The book forms part of the series *Updates in applied physics and electrical technology* and after a general introduction goes on to describe transport, nucleation and growth, growth from the liquid phase, vapour phase epitaxy, current trends in crystal growth, an extensive set of references and the abstract section which extends to over 100 pages.

Readers interested in the growth of ornamental materials will find a good deal to interest them.

M.O'D.

WHARTON-TIGAR, E., 1987. *Burning bright: the autobiography of Edward Wharton-Tigar.* Metal Bulletin Books, London. pp. vii, 280. Illus. in black-and-white. Price on application.

The subject of this adventure has been connected with mining for most of his life and the story reads like an Edwardian or Victorian boys' yarn. Mr Wharton-Tigar was for some time the thorn in the side of the Central Selling Organization (of diamonds) and began his mining career at the classic Yugoslavian lead-zinc mine of Trepca. After a colourful career in the war he became involved in the production of diamonds from West Africa and with their introduction to world markets. It was due to the prices paid for his goods by the CSO that he began to challenge their policies and price manipulation. At one time he challenged the Oppenheimers personally. This is a most interesting account of how part of the CSO worked at one period. The whole book is clearly written and the central character engagingly drawn. M.O'D.

Achat – Das tarbige Geheimnis. (Agate – the colourful secret.) Münchener Mineralientage Fachmesse GmbH, West Germany, 1987. pp. 96. Illus. in black- and-white and in colour. Price on application.

Published by Münchener Mineralientage Fachmesse GmbH on the occasion of their special exhibition 'Idar-Oberstein as guest'. Many beautiful colour photographs as well as numerous black-and-white ones, a number of reproductions of historical prints and photographs. The booklet deals with many aspects of the stone: its geology, with many occurrences detailed; how agates are worked, with special emphasis on and local history of the Idar mills; and various types of agate are discussed. E.S.

Crystals, growth, properties and applications. Vol. 11. Springer, Berlin, 1988. pp. 196. Illus. in black-and-white. DM168.

This volume is devoted to superhard materials, convection and optical devices. The three major papers are 'Shock- induced growth of superhard materials', 'Surface- tension-driven flow in crystal growth melts' and 'Electrooptical effects, crystals and devices'. The first paper, recognizing that the growth of diamond is expensive and that diamond tends to react with oxygen at much lower temperatures than boron nitride, discusses the growth of the latter material. Diamond's other tendency, to form carbides at elevated temperatures with transition metals, is also less of a problem when BN is substituted. The first synthesis of diamond by the shock wave method was carried out in 1961; Alder and Christian subjected compressed graphite powder to shock pressures of about 30GPa (300kbar) and a few per cent of the graphite were converted to very fine grained cubic diamond.

The paper on electrooptical crystals discusses lithium niobate, tetragonal bronzes, perovskites, KDP and semiconductors with sphalerite structure. Recent progress in device fabrication is reviewed, including bulk modulators, deflectors and lumped and travelling wave modulators made from wave guides. Electrooptic bistability and the photorefractive effect (the basis of holographic storage) are also discussed. Both papers have extensive lists of references and contain much useful data on transparent crystals of ornamental dimensions.

M.O'D.

Musée Cartier. London, 1988. pp.95. Illus. in black-and-white and in colour. Price on application.

Catalogue of an exhibition held in London during June 1988. The text and illustrations are taken largely from Nadelhoffer *Cartier – jewellers extraordinary**, Thames and Hudson, London 1984.

M.O'D.

*Reviewed in *Journal of Gemmology*, **XIX**, 8, 734. – Ed.

Proceedings of the Gemmological Association of Great Britain and Association Notices

OBITUARY

Mr Neville Deane, FGA (D.1954, Tully Medallist), Bewdley, died on 1 March 1987.

After a very unpromising childhood, being an orphan with severe deafness which was not diagnosed until his early teens, he rapidly gained qualifications in metallurgy and analytical chemistry.

He joined the Institution of Metallurgists as one of its earliest members in 1946 and was elected to the grade of Fellow in 1959. His earliest experience was as Junior Chemist to the Patent Shaft & Axletree Co., Wednesbury (1915-1917), and Works Chemist to J. & J. Siddons, Ironfounders, West Bromwich (1917-1919). In 1919 he was appointed Works Chemist to the Incandescent Heat Co., Smethwick, and remained there until 1923 when he set up his own business, principally concerned with aluminium and gun metal castings, and also as a consulting chemist and metallurgist.

After 1941 he was involved mainly with consulting work, and began to develop an increasing interest in gemmology and lapidary work, taking up serious study of this subject as a student under R. Keith Mitchell. He was one of the few students of gemmology who gained the Rayner Prize for first year work (1953) and the Tully Metal and the Rayner Diploma Prize (1954).

I first made contact with Neville through his metallurgical work, when we exchanged a few letters dealing with a problem just after the War, little knowing that we both were to meet several years later with an entirely different mutual interest.

After gaining my Diploma in the Association's examinations and being primarily interested in lapidary work, I was advised by the late Sid Tisdall to try to meet a fellow named Neville Deane, who at that time had a reputation for being very blunt and difficult to deal with. Having had earlier contact with Neville I had no such problems and found him a friendly and kind fellow, much in need of someone with whom to discuss his interests since he had only recently lost his wife.

He had a well equipped workshop for gem cutting and general lapidary work, and was a pioneer amateur and semi- professional cutter. Almost all of his information on this subject was American based, and he was an expert in the use of the Willems Dop for faceting. He willingly passed on information on his methods, and had much patience with struggling amateurs.

His great pride was in showing his 'bragging pieces' as he called them. These were large, faceted, colourless topaz stones of various design, including the famous Portuguese cut, and the notoriously difficult Varna star. The time spent with him went all too quickly – if he decided he had had enough he would switch off his hearing aid!

His other skill was in gardening, and he delighted in supplying flowers for his church. During the latter part of his life his Christadelphian fellow church members gave him much help and support, as he had no surviving relatives and he and his wife Nellie had had no family.

While he was still able, he attended most of the meetings of the Midlands Branch of the Gemmological Association and his blunt comments given in his strong 'Black Country' accent will be remembered by us for many years. A.D. Morgan

Mlle Dina Level, Hon. FGA, died at the age of 85 in a nursing home at Nimes in the south of France. She had been living there for the past few years; although no longer able to write, she continued to enjoy reading.

Dina Level is world renowned as a practical gemmologist, having spent a lifetime at the Paris Chamber of Commerce Laboratory. She started there under the direction fo Georges Göbel and upon his retirement there followed a period of co-operation and accord with the present director, J.P. Poirot. A dexterous exponent of the endoscope, she had, above all, a love of and an enthusiasm for the hidden subtler beauties of gemstones. Intrinsic beauty rather than monetary worth mattered most

to Dina Level. Although she had at times the privilege of entrée to the treasures of the Louvre Museum, she could nevertheless steep herself in the delicate fronds of moss agates, the convolutions of banded agates and the softer charms reflected by the flame structures of pink pearls.

She was an Honorary Fellow of the Gemmological Association of Great Britain. In her own country she was awarded the Gold Medal of Industry in recognition of her work at the Paris Laboratory. Those who were privileged to listen to her lectures at international conferences will remember the enthusiasm she projected for her subject. She contributed many articles for the *Revue de Gemmologie*, the French equivalent of our *Journal of Gemmology*. She wrote in a manner which combined a poetic touch with a gemmological approach almost of intimacy with the gems she was describing.

An anglophile with a considerable knowledge of our history, she was nevertheless a truly gallic personality, diminutive in stature but a giant in her world of gemmology. France has lost a truly great lady, we too share in that loss *Loin les yeux mais non loin du coeur.* A.E. Farn

GIFTS TO THE ASSOCIATION

The Council of the Association is indebted to the following for their gifts:

Mr A.G. Flewelling, FGA, Ontario, Canada, for a large quantity of rough sapphire from the USA and Australia. The samples will be used for study purposes.

Mr M.G. Pickford of the Laboratory of Molecular Biophysics for an SP500 Unicam Spectrophotometer which will remain at the Association until it may be put to good use either at a university or a laboratory.

Dr Yan Weixuan of the China University of Geosciences, Wuham, China, for two books entitled *Chinese arts and crafts* and *Xinjiang's gems and jades*.

NEWS OF FELLOWS

On 30 January 1988 Mr Peter Read was invited to give the Doug Page Memorial Lecture following the AGM of the Brisbane Branch of the Gemmological Association of Australia. The subject of the lecture was 'Cumputer-aided gem identification' and included a demonstration of Peter Read's GEMDATA computer program and the use of his GEMSTORE program contained in a miniature pocket-sized computer.

On 14, 22 and 23 June 1988 Mr Michael O'Donoghue, with Messrs Peter Read and Roy Huddlestone, gave two courses on behalf of Precious Stone Trading Services Ltd for preliminary and diploma students entering for the Association's examinations.

On 8 to 11 July 1988 Mr Michael O'Donoghue participated in a field study of some aspects of the mineralization of the northern Pennine orefield.

Following the series 'Gemmologia Europa I' in Milan in the autumn of 1986, when E. Alan Jobbins was invited to lecture, a second series 'Gemmologia Europa II' was arranged to present the theme of 'Treasures of the World'. This series commenced on 19 September 1988 when a lecture/video film on 'The British Crown Jewels' was presented by Dr Roger Harding, Alan Jobbins and Kenneth Scarratt. This lecture series was conceived by Dr Margherita Superchi of CISGEM (Centro Informazione e Servizi Gemmologici) under the aegis of the Chamber of Commerce, Industry, Handicraft and Agriculture of Milan (Camera di Commercio, Industria, Artigianato e Agricultura di Milano). The presentation in the series by Dr Superchi described the 'Treasures of Milan Cathedral' which includes the magnificent XVII century Airoldi chalice of Sicilian workmanship; it is illustrated on the front cover of this issue.

MEMBERS' MEETINGS

London

On 10 October 1988 at the Flett Theatre, Geological Museum, Exhibition Road, South Kensington, London SW7, Mr Clive R. Burch, Senior Lecturer in Gemmology and Geology at the Sunderland Polytechnic, gave an illustrated presentation entitled 'A review of inclusions in synthetic gemstones'.

Midlands Branch

On 16 September 1988 at Dr Johnson House, Bull Street, Birmingham, Mr David Wilkins gave an illustrated talk on the *Retail Jeweller's* study tour to the African sub-continent. He gave accounts of arduous trips to various mining operations.

North West Branch

On 21 September 1988 at Church House, Hanover Street, Liverpool, Mr Stanley Hill, FGA, gave a talk on jewellery design. Mrs Valerie Duke was also present and members were able to view various Brazilian gemstones that she had brought along.

EXECUTIVE MEETING

At a meeting of the Executive Committee held on 31 August 1988 at Saint Dunstan's House, Carey Lane, London EC2V 8AB, the business transacted included the election to membership of the following:

Fellowship
Baker, Sylvia V.J., Seoul, Korea. 1987
Marazzi, Roberto, Lugano, Switzerland. 1986
Ng, Li N., Penang, Malaysia. 1986

Ordinary Membership
Ashby, Steward M., Floyds Knobs, Ind., USA.
Bernadotte, Charlotte, Stockholm, Sweden.
Carrott, C.I.C., London.
Cho, Ki S., Seoul, Korea.
Cohen, Stanley P., Fort Worth, Tex., USA.
Combotis, Marianna, Athens, Greece.
Daly, John H., Glasgow.
D'Alessandro, Martha A., Houston, Tex., USA.
Dowdell, Jonathan, Hampton.
Flett, Robert S., London.
Fong, Chan K., East Molesey.
Galopim de Carvalho, Rui, Lisbon, Portugal.
Gunawardane, Leonard, Colombo, Sri Lanka.
Gupta, Ashwani, Slough.
Hagemann, Claus, Eunepetal, West Germany.
Harrison-Smith, Rosemary A., Benfleet.
Kaufman, Bradley S., Moweaqua, Ill., USA.
Khalil, Julie A., Bristol.
Mason, Susan E., Nottingham.
Matthews, Pauline, Cottesloe, Western Australia.
Pettit, Brian B., Cambridge.
Pring, Amanda L., Birmingham.
Rawat, Mohamed S., London.
Sirio, Alfonso, Madrid, Spain.
Siviter, David J., Worcester.
Stimler, Harvey J., London.
Sundin, Conny S.I., Solleftea, Sweden.
Tayara, Mona D., Athens, Greece.
Thomson, Sybelle M.F., Edinburgh.
Towns, Geraldine A., Naperville, Ill., USA.
Wainwright-Sundin, Manuela, Solleftea, Sweden.
Warrington, David, Queensland, Australia.
Weldon, Martin, Dublin, Eire.
Willis, Gaynor E., Austin, Tex., USA.
Wood-Cordilia, Ilse J., Farnborough.

COUNCIL MEETING

At a meeting of the Council held on 13 September 1988 at the Royal Automobile Club, Pall Mall, London SW1, the business transacted included the following: (1) the subscription rate for 1989 for Fellows and Ordinary members was increased to £30 for UK members and $80 for those overseas. (2) the following were elected to membership:

Fellowship
Bramham, Kathleen J., London. 1988

Ordinary Membership
Blacoe, James B., Athlone.
Kitchen, Peter J., Lusaka, Zambia.

CORRIGENDA

On p.43 above, second column, 2nd line, for 'cross- filter method of' read 'cross-filter method to'

On p.181 above, second column, Fig. 9, the photomicrograph has been printed upside down

Letter to the Editor

From R. Keith Mitchell, FGA

Dear Sir,

I wonder how many gemmologists have noticed the quite extraordinary optics attributed by TV and Press Advertising to the well-known prism shaped Toblerone chocolate made by the Swiss firm of Chocolat Tobler.

This remarkable sweet is apparently made in three differently coloured types [does that make it trichroic?] which are, of course, no less opaque than any of their competitors, and are depicted refracting light away from the normal and bending red wavelengths more than violet ones.

The three chocolate packs are shown reflecting in a polished surface, but the remarkable spectrum does not reflect! Can it therefore be assumed that this spectrum is not only entirely contrary to normal optics, but that it is also plane polarized?

Dare one ask what such an advertisement is supposed to convey to the sweet-eating public?

It is perhaps worth noting that the chocolate contains NUTS! Which could possibly explain everything!

Yours etc.,
R. Keith Mitchell

30 August 1988
21 Bark Hart Road, Orpington, Kent BR6 0QB.

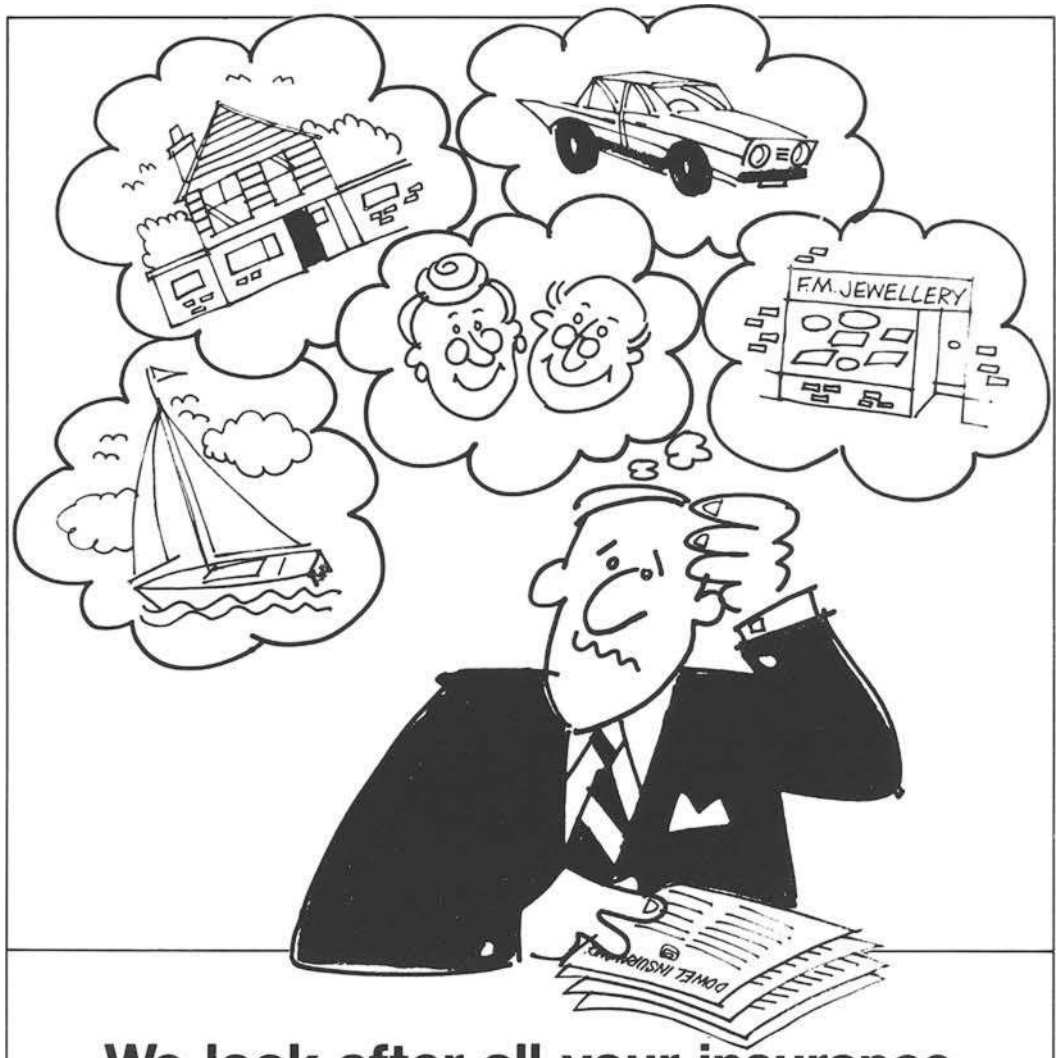

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The Arms and Crest of the Association, conferred by a grant of Arms made by the Kings of Arms under royal authority. The cross is a variation of that in the Arms of the National Association of Goldsmiths of Great Britain and Ireland. In the middle is a gold jewelled book representing the study of gemmology and the examination work of the Association. Above it is a top plan of a rose-cut diamond inside a ring, suggesting the scrutiny of gems by magnification under a lens. The lozenges represent uncut octahedra and the gem-set ring indicates the use of gems in ornamentation. The lynx of the crest at the top was credited, in ancient times, with being able to see through opaque substances. He represents the lapidary and the student scrutinizing every aspect of gemmology. In the paws is one of the oldest heraldic emblems, an escarbuncle, to represent a very brilliant jewel, usually a ruby. The radiating arms suggest light diffused by the escarbuncle and their tips are shown as jewels representing the colours of the spectrum.

Historical Note

The Gemmological Association of Great Britain was originally founded in 1908 as the Education Committee of the National Association of Goldsmiths and reconstituted in 1931 as the Gemmological Association. Its name was extended to Gemmological Association of Great Britain in 1938, and finally in 1944 it was incorporated in that name under the Companies Acts as a company limited by guarantee (registered in England, no. 433063).

Affiliated Associations are the Gemmological Association of Australia, the Canadian Gemmological Association, the Gem and Mineral Society of Zimbabwe, the Gemmological Association of Hong Kong, the Gemmological Association of South Africa and the Singapore Gemologist Society.

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Papers should be submitted in duplicate on A4 paper. They should be typed with double line spacing with ample margins of at least 25mm all round. The title should be as brief as is consistent with clear indication of the content of the paper. It should be followed by the names (with initials) of the authors and by their addresses. A short abstract of 50–100 words should be provided. Papers may be of any length, but long papers of more than 10 000 words (unless capable of division into parts or of exceptional importance) are unlikely to be acceptable, whereas a short paper of 400–500 words may achieve early publication.

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Cover Picture

Fabergé carving of John Bull, made from purpurine, lapis lazuli, white quartzite, jasper, aventurine quartz and sapphire (eyes).
Photograph by E. A. Jobbins

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The composition of an opaque red glass used by Fabergé

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Abstract

Opaque red glasses used by Fabergé in decorative carvings have been analysed by electron probe microanalysis and inductively coupled plasma spectrometry for major and minor elements. They are alkali-lead-silica glasses coloured by cuprous oxide (cuprite). The use of the terms purpurine and hematinon to describe the glass is discussed and purpurine provisionally preferred. The analyses are compared with those of red glass from the first and second millennia BC, and with those of aventurine glass or goldstone.

Introduction

An opaque red glass called hematinon or purpurine has been used by Fabergé as an ornamental material in the manufacture of boxes and carved figures. The present interest in the material arose as a result of discussions in 1984 between Mr A. K. Snowman and Mr G. C. Munn, of the firm of Wartski, and Mr E. A. Jobbins, then of the Institute of Geological Sciences, during which it became apparent that there was no general public knowledge of the composition of the glass, and in particular of the cause of its intense red colour. A programme was thus put in hand to remedy the first of these deficiencies firstly in the Geological Museum and subsequently in the British Museum (Natural History). At the same time one of us (SH) was carrying out similar investigations in Helsinki. The work in Helsinki and London was linked by a mutual friend, Mr Simo Laine, and this paper is a summary of our investigations so far.

Historical background

Opaque glass with a colour described by different authors as 'sealing-wax red' or 'sang de boeuf' has been made in the Mediterranean region from the 15th century BC. Pliny mentions an opaque red glass (Pliny, reprint 1971, p.157) and seems to imply that it was made locally in Roman times (Vose, 1980, p.31). Bimson (1981) has described glass of this type in the Mosan enamels which date from the 12th century AD. The Chinese made a true copper red glaze of similar hue in the early 15th century, but the technology was not thoroughly established (Rose Kerr, personal communication). At the beginning of the 18th century a method for making an opaque 'strong lively red' glass called porporino was discovered in the Studio del Mosaico in Rome (Röttgen, 1982, p.25). A similar method was known in Venice in the 18th century (Pylyaeva, 1888, p.339; Snowman, 1962, p.69), probably even earlier (Dillon, 1907, p.207). In that century the glass was used, for example, for snuff-boxes and buttons in Venice (Pylyaeva, op. cit.). There is a late 18th century golden pendant cross set with polished hard-stones and opaque red glass in the British Museum (Jeweller's Art, 1978, p.22, II), but in most cases glass of this type is found in 19th century Roman micromosaics; these were often set in frames of opaque red glass. At that time the glass was occasionally used in the manufacture of snuff-boxes and Florentine-type mosaics. By the 19th century, studies were being conducted in France to discover the 'recipe' for opaque red glass and Weyl (1951, p.422) states that M. von Pettenkoffer and E. Hautefeuille independently rediscovered the way to make hematinon in the mid-1800s.

In the late 1800s hematinon and aventurine glass were being produced in A Salviati's glass factory in Venice (Zulkowski, 1897, p.134). However, in the obituary of Leopold Bonafédé (Zapiski, 1878, p.88) it is stated that L. Bonafédé, who was chief chemist both in the Imperial Glass Factory and in the Factory's mosaic department in St Petersburg from 1858 to 1878, rediscovered a method for producing the long-forgotten purpurine, which became world-renowned; he was also the first to make aventurine glass in Russia.

*Sadly Alan Date died in January 1988

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Fig. 1. and Cover Picture. Fabergé carving of John Bull, made from purpurine, lapis lazuli, white quartzite, jasper, aventurine quartz and sapphire (eyes). *Photo by E.A. Jobbins.*

A tazza in the possession of the British Museum was described in the Slade catalogue (1871) as being of 'opaque red glass, of a very brilliant colour, and full of crystals. It is made with copper, an imitation of antique purpurine and is a product of the imperial manufactory of St Petersburg under the direction of the chemist Leopold Bonafédé. From the Universal Exhibition at Paris, 1867'. Gros-Galliner (1980, p.158) states that the tazza was certainly made in the Fabergé workshops but she does not supply independent supporting evidence, and the early date of the piece and its exhibition are inconsistent with the chronology given by Snowman (1979, p.152). This states that Peter Carl Fabergé took control of the firm in 1870, and that the first exhibits of the House were at the Pan-Russian Exhibition in Moscow in 1882. The earliest Fabergé pieces incorporating purpurine probably date from about 1880 and the source of the material is attributed to Petouchov in the Imperial Glass Factory in St Petersburg (Bainbridge, 1949). In all probability the person in question is Sergei Petrovich Petukhov* who was chief chemist in the Factory and made, among other things, smalti (opaque coloured glass) for mosaics (Sokolovskaja, 1982, p.294).

In *Steklodelie* (Glassmaking) Petukhov describes the appearance of purpurine and aventurine glass under the microscope, which were both made by him in the Imperial Glass Factory (Petukhov, 1898, p.30). Nowhere in the book does he take credit for the rediscovery of purpurine or refer to L. Bonafédé or M. von Pettenkoffer in connection with it. It seems likely that he had contacts or knowledge either of the work carried out in France, of the opaque red glass from Italy or of Bonafédé's purpurine. L. Bonafédé himself had worked in the Russian Mosaic Studio in Rome before he was invited to Russia in 1851 together with his brother Giustifiano, who was director of the Studio. In addition, in Bonafédé's and Petukhov's time many Russian artists, some of whom had either trained in the art of mosaic work in Rome (Butikov, 1974, p.18) or visited mosaic producing factories like A. Salviati's in Venice (Seleznev, 1896, p.76), were making mosaics in a number of churches including St Isaac's Cathedral in St Petersburg (Seleznev, 1896, p.74-5), and for these mosaics Petukhov's smalti was also used (Sokolovskaja, op. cit.).

Purpurine was used in the Fabergé workshops to the best effect in association with natural stones (Figure 1) such as lapis lazuli, sunstone, quartzite and obsidian, and Bainbridge comments 'personally I call this the rarest of all the substances, natural and artificial, used by Fabergé'. Purpurine has also been used by Fabergé's competitors. (Habsburg, 1986, p.290, 335, and this paper).

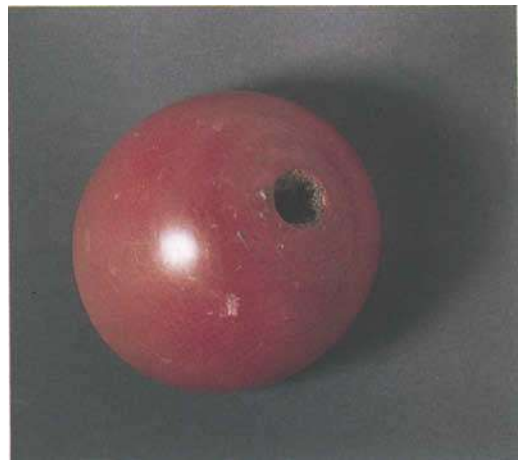

Fig. 2. Red glass from Fabergé hand seal. *Photo by F. Greenaway.*

*Transliteration based on ISO recommendation R9-1968.

Analysis of glass from Fabergé hand seal

The piece of glass supplied by Mr G. C. Munn for analysis comes from a hand seal signed by Fabergé's chief workmaster Michael Perchin (Figure 2). The seal was contained in a fitted hollywood box and was probably made about 1900 (G. C. Munn, personal communication), three years before Michael Perchin died. The glass is egg-shaped, drilled at one end and measures 32.9 mm (maximum length) by 27.0 mm (maximum diameter perpendicular to the length). The piece had been broken at one time and repaired with a water-soluble glue. In order to carry out the analyses it was soaked in water to separate the components, and a few fragments adjacent to the main break were taken for preparation of a polished section and for dissolution. The piece must originally have weighed just over 52 g.

When examined with a 10× lens the texture of the glass appears patterned with skeletal, dendritic or acicular structures. Under higher power magnification and in thin section these crystal structures are quite obvious (Figures 3-5), some measuring up to 2 mm in length.

The refractive index of the glass was measured in sodium light using a Rayner Dialdex refractometer on a polished fragment, and a mean value of 1.700 was obtained. Its specific gravity, determined in water, is 4.21. The glass is opaque but in light of sufficient intensity a spectrum of the reflected red colour may be seen in a hand-held spectroscope. This shows transmission in the red and absorption in the yellow, green and blue parts of the spectrum, a result that was confirmed and amplified by K. Scarratt using the Pye-Unicam PU8800/03 UV/visible spectrophotometer. He obtained a spectrum of transmitted radiation from a fragment of glass 0.85 mm thick, and the scan from 190-850 nm is shown in Figure 6.

The composition of the glass was determined by electron probe microanalysis (EPMA) of polished thin sections (for major elements) and by inductively coupled plasma spectrometry (ICPS) of solutions of the glass (for minor and trace elements). The results are given in Table 1, columns 1, 2 and 7.

The glass is essentially a soda-lead-silica glass with over 7% cuprous oxide. Crystals of the type illustrated in Figures 3-5 are narrower than the width of the electron beam (about 5 μm) and an analysis exclusive of glass could not be obtained. Nevertheless, although the figures given in column 2 include a small proportion of the elements from the surrounding glass, the value of 82.8% for Cu_2O and the relatively low values of all other elements suggest that the dendritic crystals are composed of cuprous oxide. An X-ray diffraction pattern of the red glass (5587F) obtained by S. Somogyi indicates the presence of an amorphous substance (the glass) and confirms the presence of cuprite (Cu_2O) as the only crystalline phase.

Webster was aware that there was more than one kind of purpurine for he states (1970, p.354) 'One of the purpurines... shows a structure resembling myriads of fern leaves... was found to have a

Fig. 4. Thin section (30μm) of glass shown in Figure 2; shows skeletal crystals of cuprous oxide in plane polarized light; field of view 4mm across.

Fig. 3. Crystals in red glass showing skeletal structure. *Photo by E.A. Jobbins.*

Fig. 5. Polished section of glass shown in Figure 2; shows skeletal crystals of cuprous oxide; field of view 0.6mm across.

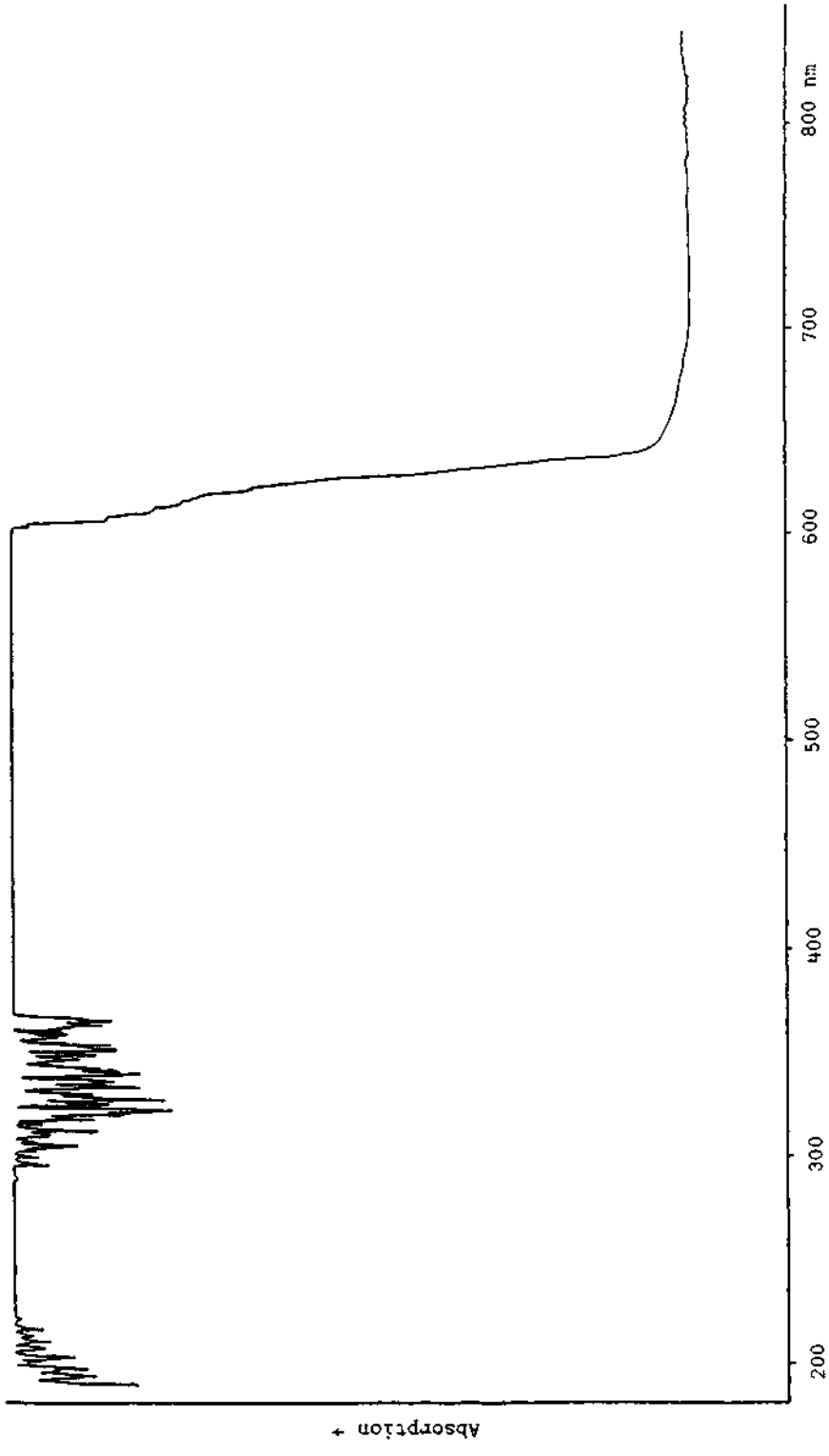

Fig. 6. Absorption spectrum of red glass from hand seal, using a Pye Unicam PU 8800/93 UV/visible spectrophotometer (Basil Anderson model) at room temperature. The span for the curve is four absorbance units, the band width was 2nm and the scan speed was 1nm/sec.

Table 1. Analyses of red glass and aventurine glass

Wt%	1	2	3	4	5	6	ppm	7	8
SiO_2	30.46	5.74	42.28	66.37	41.28	35.80	Ti	86	316
Al_2O_3	<0.2	<0.2	0.68	1.28	0.45	0.89	V	14	109
FeO	0.97	0.37	0.43	1.89	1.69	1.29	Cr	5	39
MgO	<0.2	<0.2	2.84	<0.2	0.10	tr.	Mn	110	6840
MnO	<0.2	<0.2	b.d.	0.93	0.19	1.50	Co	5	11
CaO	1.75	0.25	3.82	4.80	1.14	4.31	Ni	67	33
Na_2O	6.34	<0.2	9.46	12.26	4.20	6.31	Zn	15000	278
K_2O	<0.35	<0.2	1.43	2.17	2.36	2.60	Ge	0.9	0.9
Cl	0.35	<0.2	0.45	0.73	0.13	n.r.	Rb	3	12
Cu_2O	7.23	82.82	8.58	3.26	2.79	7.89	Sr	205	389
ZnO	2.80	<0.2	b.d.	<0.2	b.d.[1]	n.f	Y	0.5	3
As_2O_3	2.05	<0.2	b.d.	2.26	2.53	n.r.	Zr	3	2
Sb_2O_3	1.78	0.39	4.19	<0.2	2.87	n.r.	Mo	0.2	0.2
BaO	0.80	<0.2	b.d.	<0.2	0.09	n.r.	Ag	32	218
PbO	45.53	7.54	24.96	1.32	40.17	39.06	Cd	16	1
−O=Cl	−0.08	0.0	−0.10	−0.16	0.0	0.0	Sn	17	541
							Sb	2660	28
	99.98	97.11	99.02	97.11	99.99	99.55	Ba	5330	203

Notes: b.d. means below detection, tr. trace, n.f. not found, n.r. not reported and [1] presence confirmed by energy dispersive X-ray fluorescence; elements Fe, Mn, Cu, As, Sb, and Pb may be present in more than one oxidation state.

1. Mean of 6 analyses of red glass from hand seal; defocused beam covering glass and crystals.
2. Analysis of crystal in red glass from hand seal; the crystals are less than 5μm across and there is some contribution from surrounding glass.
3. Opaque red glass, 4th cent. BC, Nimrud; from Freestone, 1987, Table 1, Anal. 6.
4. Mean of 5 analyses of aventurine glass in regions with no visible crystals of copper; defocused beam.
5. Mean of 5 analyses of red glass from Fabergé egg 1; defocused beam covering glass and crystals.
6. Opaque red glass, late 19th cent. AD, Venice; from Zulkowski, 1897, p.135.
7. Mean of 2 analyses of minor elements in red glass from hand seal.
8. Analysis of minor elements in aventurine glass.

Analyses 1, 2 and 4 were carried out on a Cambridge Instruments Geoscan with Link Systems energy dispersive detector and computer. An accelerating voltage of 15kV, a specimen current of 5×10^{-9} amps and an electron beam focused to approximately 5μm were used. Limits of detection for each of the oxides are about 0.2 wt%.

Analysis 5 was carried out on a Jeol JCXA 733 electron microprobe system with three wavelength dispersive spectrometers. An accelerating voltage of 15kV, a specimen current of 20×10^{-9} amps and an electron beam focused to approximately 20μm were used. Standards used for the analyses comprised natural and synthetic minerals. Results were corrected using a ZAF-type correction program. Loss of alkalis during analyses were checked and was corrected for sodium using an empirical correction procedure suggested by Nielsen and Sigurdsson (1981).

Analyses 7 and 8 were carried out on the British Geological Survey (BGS) prototype Inductively Coupled Plasma Mass Spectrometer (ICP-MS). The instrument employs an inductively coupled argon plasma (ICAP) as the ion source operating at atmospheric pressure for production of ions for detection by a quadrupole mass spectrometer. The unknown samples are quantified using calibration against aqueous standards. The limits of detection are typically below 1 part per million in the solid for most elements on the periodic table (Gray and Date, 1983, and Date and Hutchison, 1987).

refractive index of 1.64 and a density of 3.77. Two types of opaque red glass, one with constants close to these (RI 1.65, SG 3.81 and RI 1.658, SG 3.79) and the other with higher constants (RI 1.70, SG about 4.26) have recently been analysed in Helsinki.

Description of red glass objects examined in Helsinki

Four objects of Russian origin, made of an opaque red glass, three of them from the Fabergé workshops, were available for study.

Object 1 is a gold-mounted miniature egg pendant with a gold suspension ring, drilled at one end and measuring approximately 15.5 × 11.4 mm without the mounting. The ring is stamped K.F. in Russian characters. The pendant had been brought to a goldsmith because the mounting, which had no peg but had been attached to the pendant with a glue, had come off the drilled end. In order to attach the mounting back securely, a new peg was soldered to it and the drill hole made slightly larger and deeper with a dentist's drill for the peg, which was to be cemented into the hole. This produced a small amount of fine-grained powder which was later used for microscopic observations, X-ray diffraction and electron probe microanalysis (EPMA). Without the mounting the weight of the pendant is 3.71 g.

Examination of the glass with a 10× lens and under higher power magnification showed the texture to be similar to that of the glass described above with the exception of some small almost crystal-free areas in its surface. Its refractive index, measured by the distant vision method using a Rayner Dialdex refractometer and sodium light, is 1.65. Using immersion oils of known refractive index and a Leitz SM-Pol polarising microscope, the refractive index of the glass powder was determined by the Becke line method. This gave a mean value of 1.658. The specific gravity of the glass, determined by hydrostatic weighing in distilled water at room temperature, is 3.79. The spectrum, observed by reflected light using a Beck prism spetroscope, is similar in pattern to that of the glass described above. An X-ray diffraction examination of the powder confirmed the presence of cuprite (Cu_2O); it also indicated the presence of an amorphous substance (the glass). The composition of the glass was determined by electron probe microanalysis of a polished surface obtained by embedding the powder in epoxy resin and prepar-

Fig. 7. Elephant carved in purpurine with rose diamond eyes.

ing a flat polished surface (maximum grain diameter after polishing 0.1 mm). The results are given in Table 1, column 5. The composition of the crystals in the glass was determined qualitatively with the electron probe microanalyser and the results (not given here) show major copper with some contribution from the surrounding glass.

Compared with the Cu_2O content of the red glass in column 1, the Cu_2O content of the glass is considerably lower. As mentioned above, the cuprite crystals are not homogeneously dispersed in the glass. This, coupled with the fact that the sampling area could not be chosen freely, may well account for its lower Cu_2O content.

Object 2 (Figure 7) is an elephant carving with rose diamond eyes and a downturned trunk. It is approximately 8.7 cm in height and weighs 396.50 g. On the front left foot the carving is engraved in Latin 'Fabergé' with inventory number 24340. Its refractive index, measured by the distant vision method, is 1.65. The specific gravity, determined by hydrostatic weighing, is 3.81. Examination with a 10× lens, microscope and spectroscope showed the glass to be similar to that of object 1.

Because preparation of the glass of the carving for quantitative analysis was out of the question, its composition as well as that of the glasses of the following two objects could only be deteremined qualitatively by the electron probe microanalyser or the scanning electron microscope, both fitted with an energy dispersive spectrometer. A carbon coating (soluble in acetone) was in part applied to the surface to prevent localized charging and any resulting distortion and deflection of the electron beam. These limitations on the technique of analysis mean that the levels of detection for different elements are higher than for properly prepared, polished and coated specimens. The energy dispersive X-ray spectrum of the glass of object 2 (Figure 8) shows major Si and Pb; minor K, Sb, Ca, Fe and Cu with traces of Na and As. It must be emphasized that the printed diagram has much poorer resolution than the original spectrum. For comparison, object 1 was also analysed under similar conditions. The resulting energy dispersive X-ray spectrum of the glass is similar to that of object 2.

Object 3 (Helsinki City Museum: 3145.139) (Figure 9) is a gold-mounted miniature egg pendant with a gold suspension ring, measuring approximately 15.0 × 11.0 mm without the mounting. The ring is stamped 56k and K.F. in Russian characters. Examination of the glass using a 10× lens, microscope and spectroscope showed no differences in the texture and spectrum from that of the hand seal in London. Its refractive index, measured by the distant vision method, is

Fig. 9. Gold-mounted miniature egg pendant.

1.70. The specific gravity of the glass was determined as follows. First the specific gravity of the pendant as such was determined by hydrostatic weighing. The weight of the gold mounting was then estimated by weighing a similar gold mounting of the same fineness; the length of the peg was estimated by X-ray radiography. Since the specific gravity of 56k or 14 carat gold is approximately known, the specific gravity of the pendant without the mounting can be calculated with some degree of accuracy. Thus the calculated specific gravity of the glass is 4.26. The energy dispersive X-ray spectrum of the glass (Figure 10) shows major Pb and Si; minor K, Sb, Ca, Fe, Cu and Zn with traces of Na and As.

Object 4 (Helsinki City Museum: 3145.146) (Figure 11) is also a gold-mounted miniature egg pendant with rose-cut diamond-set gold and silver ornament, in the form of a swallow, attached to the mounting. A gold suspension ring attached to the swallow is stamped E. S. in Russian characters. The egg is smaller than that in object 3, approximately 12.0 × 7.0 mm without the mounting.

The refractive index of the glass, measured by the distant vision method, is 1.70. Its specific gravity was not determined because of the swallow

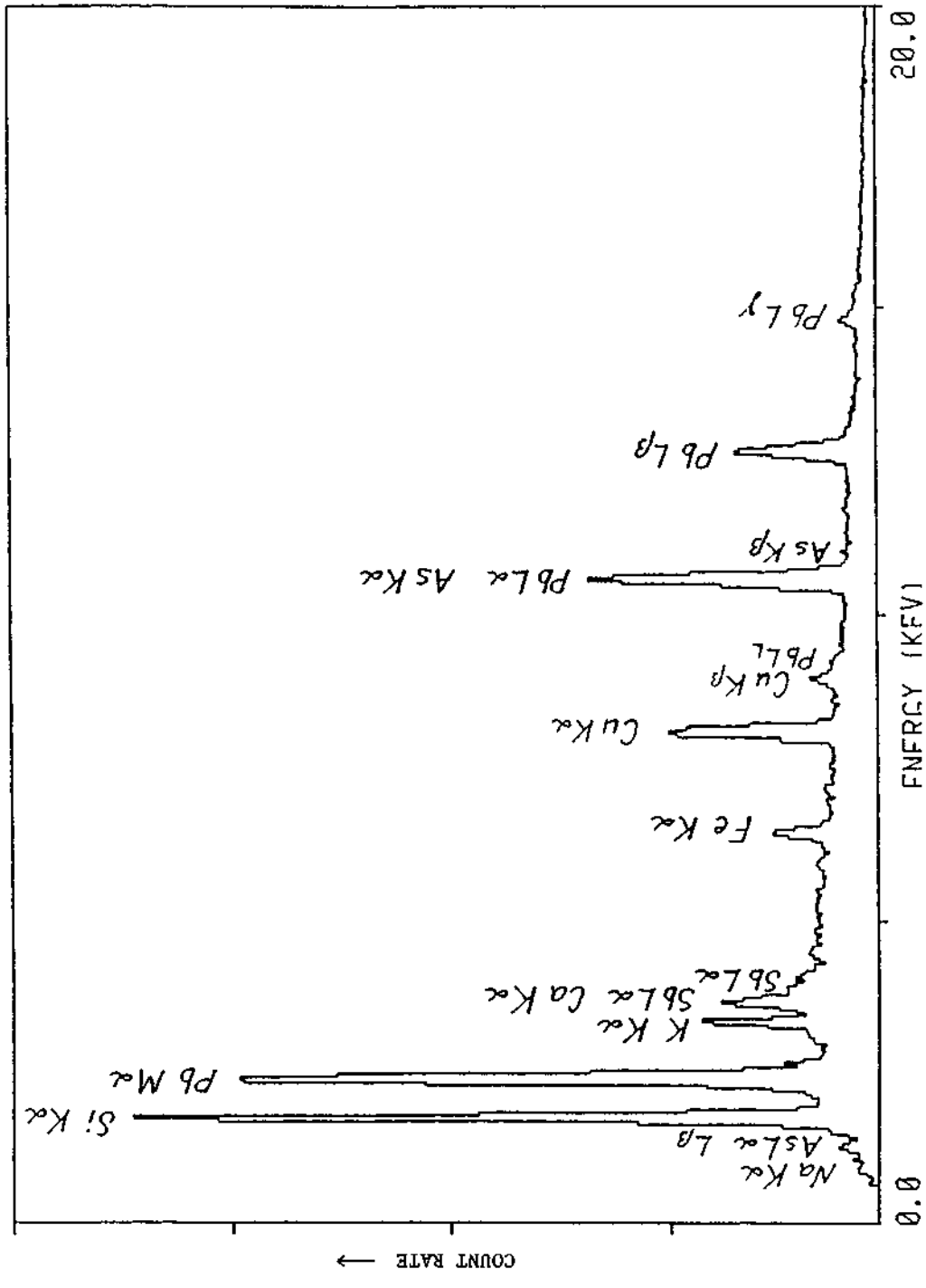

Fig. 8. Energy dispersive X-ray spectrum of purpurine elephant.

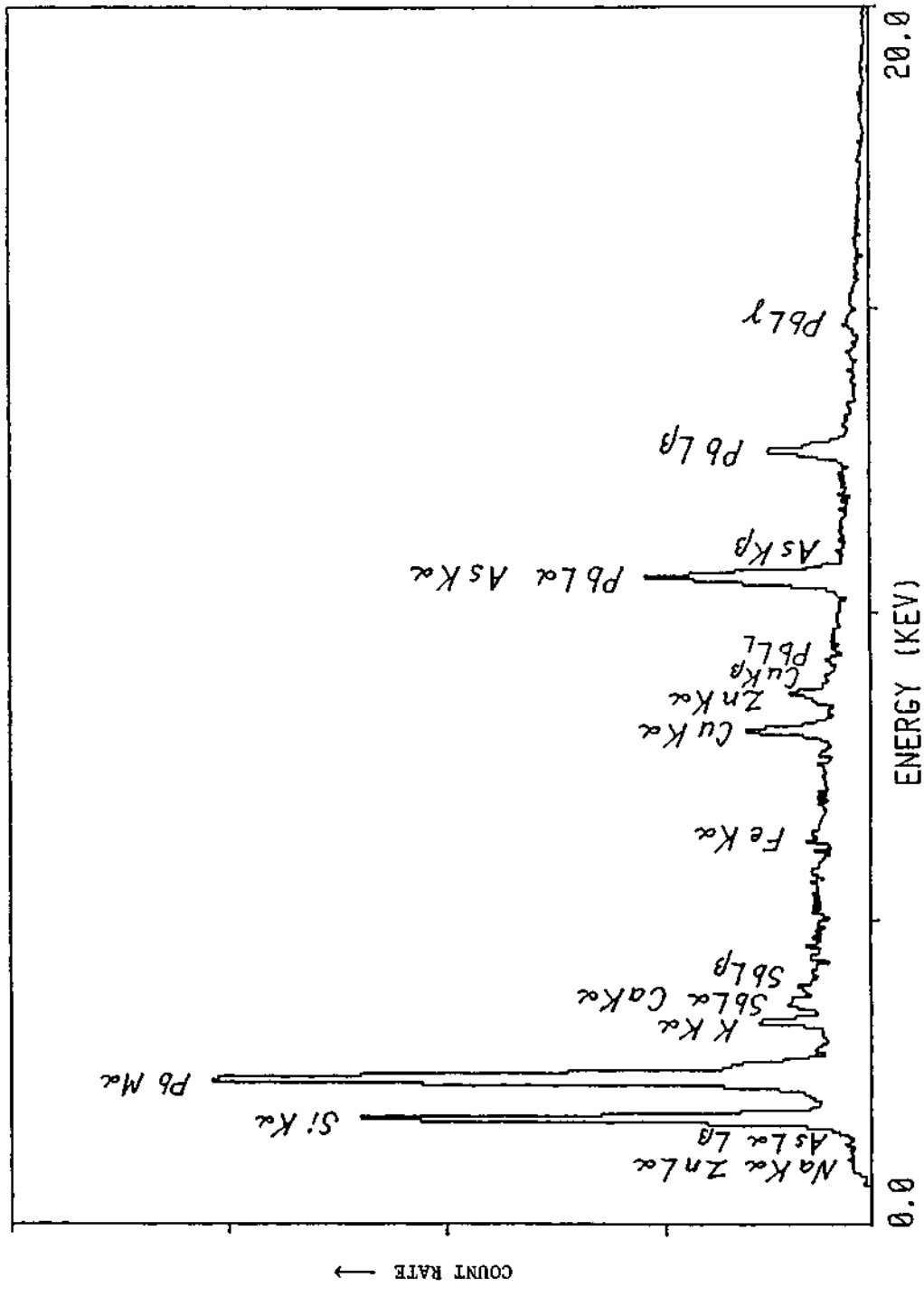

Fig. 10. Energy dispersive X-ray spectrum of glass of gold-mounted miniature egg pendant.

Fig. 11. Miniature egg pendant with swallow.

ornament. Examination with a 10× lens, microscope and spectroscope showed the glass to be similar to that of object 3, and the energy dispersive X-ray spectra of the two glasses are also similar.

The physical constants, texture and results from the analyses indicate that the glasses of objects 1 and 2 are of the same type, and differ from the glasses of objects 3 and 4. The presence of Zn in the glasses of objects 3 and 4 suggests that their chemical composition is close to that of the glass in the hand seal given in Table 1, column 1.

The four glasses described above are thus of two types. One has lower constants (RI 1.65, SG 3.81, and RI 1.658, SG 3.79) and is of a sodium-potassium-lead-silica type with negligible zinc content. The other has higher constants (RI 1.70, SG about 4.26) and is of a sodium-lead-silica type with a relatively high zinc content.

Objects 1, 2 and 3 can be attributed to Fabergé on grounds of the marks and engraving. Consequently at least two types of an opaque red glass have been used by that House and at least one of these has been used by Fabergé's competitors.

The purpurine tazza in the British Museum, alluded to in the Historical background section, has recently been examined in the Research Laboratory by Mavis Bimson and Drs I. Freestone and M. S. Tite and we are grateful for the following information: 'The glass consists of large dendritic red crystals in a clear glass matrix; X-ray diffraction examination confirms that the crystals are of cuprous oxide (cuprite). X-ray fluorescence analysis in air of the curved surface of the tazza gave the following semi-quantitative analysis: SiO_2 36%, CaO 0.7%, K_2O 7%, Cu_2O 8%, PbO 47%, Sb_2O_3 2%, SnO_2 0.2%, As_2O_3 0.5%'. This composition is similar in most respects to those listed in Table 1, columns 1, 3, 5 and 6; the major difference is the high content of K_2O. Thus the output from the St Petersburg factory included a potassium-lead-silica glass in addition to those described above.

Discussion

Glasses of very similar colour and opacity have been described by Zulkowski (1897), and recently by Bimson (1987) and Freestone (1987) in a study of red glasses from the 1st and 2nd millennia BC. The red glasses from the middle of the 2nd millennium BC are characterized by high copper and low or negligible lead while those from the first millennium BC may have low copper and lead (dull brownish red) or high copper and lead (bright red). An example of the latter group from Nimrud in northern Iraq was analysed (Freestone, 1987, Table 1) and is shown for comparison in Table 1, column 3. Compared with the Fabergé glasses, SiO_2, MgO, CaO and Na_2O are higher, and PbO is lower. The composition of the late 19th century red glass from Venice (Zulkowski, 1897, p.25) is also shown for comparison in Table 1, column 6. Compared with the two Fabergé glasses, its composition is quite similar. However, two elements that have not been found either in the ancient glasses or in that described by Zulkowski are zinc and arsenic and their presence in the Fabergé glasses may turn out to have a diagnostic significance (I. C. Freestone, personal communication).

The copper-bearing glass most familiar to gemmologists is the bronze-coloured aventurine glass or goldstone (Figures 12 and 13). For comparative purposes, a sample was analysed under the same conditions as the red glass in Table 1, column 1, and the results are shown in columns 4 and 8. The goldstone analysis shows major alkalis and silica and a low lead content, and the composition is quite different from that of the red glass. The minor element contents of the red glass and goldstone are also significantly different (compare columns 7 and 8 of Table 1).

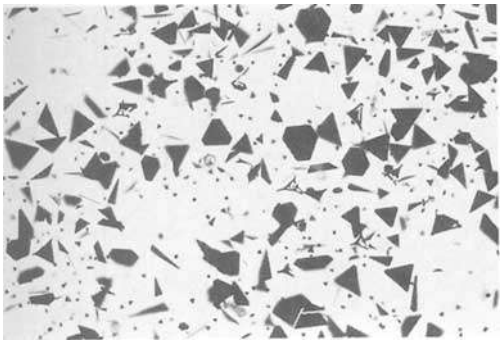

Fig. 13. Aventurine glass; thin section 30μm thick showing angular thin plates of copper metal in plane polarized light; field of view 1mm across.

Colour

The red glass used by Fabergé is so similar to some of the glasses studied by Bimson (1987) and Freestone (1987) that comments made in relation to these are probably also applicable here. In essence, they conclude that the major colourant of the opaque red glass is cuprite in the form of skeletal or dendritic crystals. Quoting extensively from the literature, they say that metallic copper can probably be discounted as a cause of the red colour, and that the grain-size of the cuprite crystals in glass shows a correlation both with colour and with the overall copper content of the glass. Thus glasses with less than 5% Cu_2O are a duller, browner red than those with 7-11% Cu_2O which give rise to the bright sealing-wax red. The low-copper glasses contain minute droplets of Cu_2O and as the copper content increases so does the proportion and size of dendritic or skeletal crystals. Despite this apparently neat correlation of colour with crystal size it may be seen in Figures 3-5 that there is not just one size of dendrite but a range from 2 mm down to submicroscopic, and how precisely this range is related to the quality of the colour is probably very complex.

The relation of grain-size to colour in gold-ruby and copper-ruby glasses is referred to by Bimson and Freestone (1985, pp.211-14) and by Nassau (1983, pp.310-11). These differ from the glasses described above in being transparent, and they owe their red colour to gold or cuprite particles only a few nanometres in size. Some glasses with a red colour in transmitted light are green in reflected light and are described as dichroic by people largely concerned with glass. In this context, gemmologists or mineralogists should be aware that the term does not refer to the kind of dichroism found in some birefringent crystals.

Fig. 12. Aventurine glass or goldstone.

When copper-ruby glass is quenched from the melt it is colourless, and the red colour is obtained by 'striking' or careful heat treatment for a certain length of time. If this heat treatment is lengthened, the cuprite particles grow and an opaque red glass develops, and with even longer treatment aventurine glass is eventually produced (Nassau, op. cit.). Webster (1962, p.335 and repeated in later editions) also refers to this connection thus 'One stage in the preparation of this aventurine glass is the formation of a dark red glass called hematinon or purpurine...'. The connection may also turn out to be significant in studies concerning the history of purpurine, for aventurine glass appears to have been known already in Venice in the 13th century (Duma, 1984, p.314). From the analyses presented in Table 1, it would appear that although purpurine, hematinon and aventurine glass may be made from a wide range of compositions, the content of copper and the nature of heat treatment are the main factors causing their distinctive appearance.

Nomenclature

Opaque glass with the colour described as sealing-wax red or sang-de-boeuf has been called purpurine by Bainbridge (1949) and Snowman (1962) and hematinon or purpurine by Webster (1962, p.335). According to Zulkowski (1897, p.134), at the end of the 19th century haematinon glass was often called il porporino (purple coloured in Italian); in Venice the glass was called la porpora (purple). As mentioned above (Röttgen, op. cit.), an opaque red glass called porporino was known in Rome at the beginning of the 18th century.

In Russia, Pylyaeva (1888, op. cit.) speaks of glass of similar type called purpur' (purple in Russian) and states that it was known in Venice in the 18th century. In the *Entsiklopedicheskij slovar'* (1892, p.296) gematinon (haematinon) or purpurino (porpurino in Italian) is defined as a type of glass of characteristic red colour found in ancient mosaics. According to the slovar' glass of this type has later been made by Pettenkoffer, Kejser* and the Imperial Glass Factory. Gematinon is similarly defined in the *Vsenauchnyj (entsiklopedicheskij) slovar'* (1878, p.420) whereas porpurino (p.506) is defined as a material of its own, viz. synthetic coloured mass made from minerals, earlier used in Italy and mainly in churches. In the *Russki entsiklopedicheskij slovar'* (1875, p.615) only gematinon is defined; the definition follows similar lines as before. Modern Russian encyclopaedias define neither purpurine nor hematinon.

In the *Oxford Dictionary*, haematinon or haematinum is defined as a red glass found in ancient mosaics and ornamental vases, and quotes the earliest reference as Phillips, 1706, with a further reference to C. W. King, 1861, who described the glass as 'entirely red, opaque sort'. The word purpurine or purpurin in the *Oxford* and *Chambers Dictionaries* is defined as 'of purple colour' (now obsolete), or as a 'red colouring matter, $C_{14}H_5O_2(OH)_3$, used in dyeing, orig. extracted from madder; also prepared artificially by the oxidation of alizarin'. There is no mention of glass. The entry in the Slade catalogue concerning the tazza in the British Museum referred to earlier contains an allusion to antique purpurine as though this were an established decorative substance. What exactly this was and whether or not it was natural or synthetic has not yet come to light and is a tantalizing indicator that more remains to be discovered.

If the opaque red glass is to have a name, then, at present, *purpurine* is provisionally recommended.

*Georg Cajetan Kaiser was professor of applied chemistry in München. Pettenkoffer worked for him some time in 1850s.

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[*Manuscript received 6 October 1988.*]

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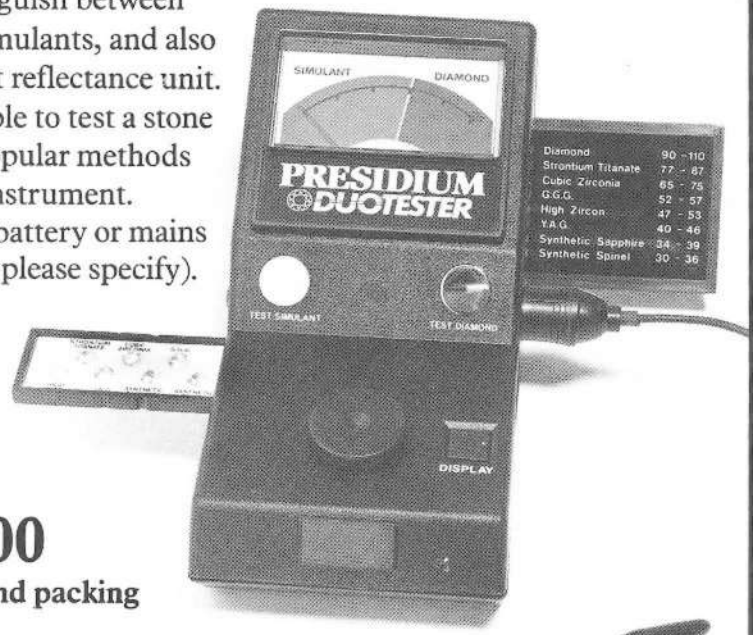

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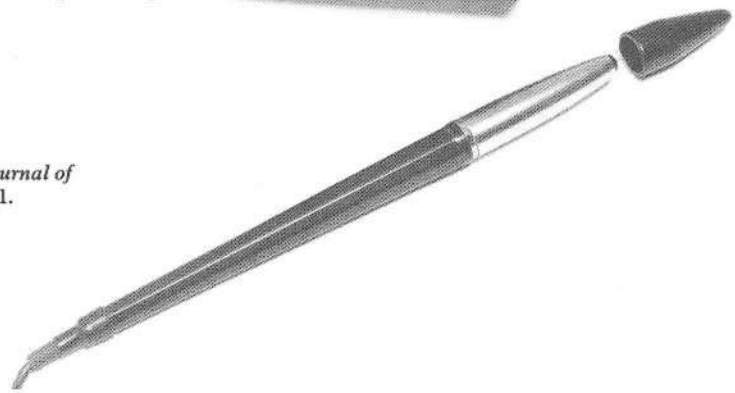

*For test report, see *Journal of Gemmology*, 21, 4, p251.

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Amber – fact and fantasy

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Foreword

Although gemmology is researched and practised as an exact science it does not come amiss – to my thinking – that its practitioners should know and understand the thoughts and beliefs of those philosophical 'gemmologists' of antiquity; 'gemmologists' such as Theophrastus (d.*c*.285 BC), Pliny (d.79 AD), and Dioscorides (d.90 AD).

For example: in the many treatises on gemstones written by Theophrastus he considered the stones to have certain attributes which dictated gender. Accordingly he classified gemstones as being either male or female. From this thinking arose the fanciful but widely accepted theory of stones breeding and begetting progeny.

Shortly after he relinquished command of the Roman Fleet which was stationed in the Bay of Naples and whose prime function was to suppress piracy, Pliny (the Elder) wrote his 37 books of *Historia Naturalis*. This massive work he dedicated to the Emperor Titus.

"No one", said Pliny, "has collected the scattered works that contribute to encyclic culture" (Enkyklios Paideia – the origins of the word encyclopedia).

Dioscorides (a founding father of pharmacy) wrote five books entitled *Materia Medica*. The fifth and last book describes the properties of over 200 stones recommended as possessing medicinal and healing properties.

For over 1600 years, *Materia Medica* was the recognized textbook of medicine; its formulae were frequently consulted by physicians and surgeons seeking an appropriate prescription for a particular malady.

Esoteric knowledge of and about gemstones has been conveyed to us over the centuries by many chroniclers and seekers of truth, such as the physician Galen – whose name is commemorated in the word 'Galenicals', a word used by the modern pharmacist in describing his bulk medicines.

Among the many philosophers whose thoughts and writings embraced gemstones are the Bishops Epiphanius, St Isadore and Marbode: bishops, respectively of Constantia, Seville and Rennes; Albertus Magnus who penned *Secrets de Vertus des Herbes, Pierres et Bestes*; Camillo Leonardo, one time physician to Caesare Borgia to whom his work *Speculum Lapidum* was dedicated.

All have their writings – either in prose or rhyme – gracing bookshelves in the world's premier universities.

True! They gather dust in their resting places, but who has not the imagination to recognize and regard them as rungs in the ladder of man's ascent to the stars?

Of those disseminating a knowledge of gemstones from the 16th century onward were, among many others: Reginald Scot, *Discoverie of witchcraft*; Jerome Cardan, *De Gemmis et Coloribus*; Thomas Nichols, *Faithful lapidary*; Dr John Schroder, *The complete chemical dispensatory*, and not the least or the last, Prof. Francis Barrett, *The celestial intelligencer*.

Researching the many facts, fantasies and superstitions of diamond and coloured gemstones has been, for me, quite rewarding and I trust that my essays on this subject make interesting and absorbing reading.

Amber – fact and fantasy

Pretty in amber to observe the forms
Of hairs, or straws, or dirt, or grubs, or worms!
The things, we know, are neither rich or rare,
But wonder how the devil they got there.

(Pope)

Philosophers of civilizations long since travelling the dusty paths of antiquity, have conjectured, imagined and woven delightful but fanciful theories in their attempts to explain the origins of amber. Religionists and philosophers of ancient Rome were not in the least embarrassed to borrow freely from the many gods and cults of the nations within their empire, and in doing so often modified the myths to suit their individual esoteric styles; in particular they borrowed many Grecian deities, changing their names as if to cover a lack of original thought. Roman gods became clothed with the mantles of

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their Greek counterparts and, for good measure, assumed many of their myths.

Insights into some thoughts and works of the ancients are presented to us in the many essays of Pliny, Metrodorus and Sudines; but by far the most enjoyable reading is to be discovered in some 250 Greek myths collected, translated, and bound together in an important and highly valued work entitled *Metamorphoses*; a work undertaken and put to 'paper' by the Roman, Ovid (43BC – AD17).

Listed by Dioscorides (AD40 – AD90) in his *Materia Medica* – together with some 200 other minerals and stones – amber is recommended as a useful and effective ingredient in medication. Its inherent healing properties are also gainfully employed by the physician and pharmacist in today's modern world; its effectiveness has not dissipated with time.

The name was derived from the Arabic 'Anabaron'; and for the electrostatic phenomenon displayed, the fossil resin was named 'Elektron' by the Greeks: from which is derived the modern word 'Electricity'.

Healing amber

For centuries amber has been used medicinally either as a cure or as a prophylactic: Pliny (*Historia Naturalis*) wrote: "Amber indeed is supposed to be a prophylactic against tonsilitis and other infections of the pharynx for the waters near the Alps have properties that harm the human throat in various ways".

Callistratus advised that "People of any age who are subject to attacks of wild distraction" were usually cured when powdered amber was taken in a little wine.

The Romans had a great faith and confidence in the curative properties of amber – especially for the treatment of such ailments as fever, croup, asthma, hay fever, and all infections of the throat – and to this effect was worn either as a necklace or as a pendant.

For those who suffered with ear problems, a medication of finely powdered amber mixed with honey and rose oil was introduced into the infected ear. This prescription was widely prescribed and is reported to have proved beneficial.

To improve poor sight, many Roman physicians recommended a mixture of amber powder and Attic honey to be taken internally. Only reddish ambers were considered suitably effective for medicinal purposes. (Callistratus: cited by Pliny).

To quote Camillus Leonardus MD (*Mirror of Stones* 1502*), physician to Cesare Borgia; "Succinum or Amber being taken inwardly, it provokes urine, brings down the menses and facilitates a birth. It fastens teeth that are loosen'd; and by the smoke of it poisonous insects are driven away".

Over the centuries, amber retained the faith of the medical profession in its ability to provide relief and comfort for the sick. This is well noted in the following paragraphs contained within the pages of a notable mid-17th century work (*Faithful lapidary*, Thomas Nichols, 1659).

"Amber is the best for physic use, and is thought to be of great power and force against many diseases, as against vertigo and asthmaticall paroxysmes, against catarrhes and arthreticall pains, against diseases of the stomach and to free it from putrefactions and against diseases of the heart, against plagues, venoms and contagions.

"It is used either in powder or in troches, either in men or of woman, married or unmarried or in the distempers of children."

Chapter XXIX, p.227 of Dr Rowland's translation of 'The complete chymical dispensatory' written by Dr Johann Schroeder mentions both bitumen and amber.

He says that bitumen is generally any fat mineral of which there are "divers sorts, as Ambe, Sperma-Ceti". "The special bitumens", he noted, "are Naphtha and petroleum, rock coal and jet."

"Amber", he writes, "generally signifies two sorts of bitumen; one called commonly Amber or Ambergreese to distinguish it from the other; the other is called Succinum."

He continues by giving two footnotes on the black and white ambers. Note 1 tells of the black ambers about which authors differ. "Some", he says, "make a true salt of amber weaker than the rest; others say it is made of musk, civet, wood aloes,

*First English translation 1750.

NOTE: The forerunners of the modern pharmacy were usually ordinary trading shops; shops which stocked such items as dried animals, parts of animals, and plants: human skulls and mummy were provided by grave robbers of the period.

A list advertising wares for sale at one particular 'medicine shop' is on display in the Wellcome Foundation premises on Euston Road, London NW1. It reads as follows:

HERE ARE PREPARED:

All sorts of remedies chemical and galenical.

We sell good cordials as well as Royal English Drops – Powders of Kent, Zell and Contrajerva Cordial.

Red Powder, Gaskain Powder with or without Bezoar, English Smelling Salts, true Glauber Salt and Epsom Salt and volatile essence of Ammonia, Human Skull, Mummy, and Hartshorn. Essence of Ambergris, Lavender, Musk and Citron.

Essences of oil of vijner, Vulnerary Balsam, Lochoch of Foxes Lungs, the Treacle of Andromachus, Dioscordium, Sparadrap, Alkermes Confection, Lavander Water, Queen of Hungary Water, Arquebusade and the Elixir of Proprietatis.

Note ii.

The Musaeum Britannicum of 1778 describes Gaskain powder as consisting of "Oriental Bezoar which is chief, White Amber, Red Coral, Crabs Eyes, Powdered Hartshorn, Pearl and Black Crabs Claws".

storax, laudanum; others call jet 'black amber' or succinum." The second note mentions a white amber called Sperma-Ceti. "The amber of the shops" (see footnote), he observes, "is a sort of bitumen that breaks into the 'shoar' from Fountains and Caverns of the Sea.

"The GRYSEAN (or grey) is the best, purged sweet and smooth, pricked with a needle, it sweats out fat succinum; the black and very white is not commended; for it is adulterated. The faltitious is easily known by its scent (which discovers the ingredients) and colour (by which it is black) also if you cast it on water, it is sooner lost than the natural."

Prepared salts of amber were made into many combinations of lotions, potions and electuaries; Dr Rowland quotes Renodus who says "the pleasanter the electuaries are, the sooner their strength is gone": a thought passing through the mind of many a modern day physician.

The virtues of this medication were (and possibly still are) that it "heals, dryes, dissolves; strengthens heart and brain and revives the Animal and Vital Spirits by its sweet sulphur; and is used in perfumes to burn against bad air, and keep the Spirits from infection: These are called Pome-Ambers".

Book II, Ch.LXXV, p.122 shows Dr Rowland giving instructions on how pomeambers (modern spelling POMANDERS) were to be made.

He writes: "Pomeambers are made of sweet powders with oyls, wax, storax liquid, Indian balsam, mucilage of 'tragaganth' and turpentine to make them fasten, adding rose water and the like, and so make into balls".

He makes special note that "They have their name from amber, not that it is a necessary ingredient always, but because they are sweet and imitate 'Ambergreese'".

Modern liniments

Time has not diminished man's faith in amber; it has retained its place as a source of medication in the armouries of the physician and pharmacist and is well documented between the covers of the modern Medical Codex consulted in most countries.

A pungent oil distilled from amber is known as 'Oil of Succinate' or 'Oil of Amber'.

This oily distillate has properties somewhat similar to turpentine and it is used extensively in the preparation of liniments. (British Pharmaceutical Codex).

Fumigation and joss-sticks

Germans called the material 'Bernstein' (burning stone) and burnt it for the pleasant pine aroma which pervaded the room in much the same way that smouldering Asian joss-sticks provide a pleasant atmosphere.

The Romans also burned amber but used an inexpensive white variety to produce vast quantities of aromatic smoke with which to fumigate dwellings: a most effective way to combat Mediterranean crawlies; the residual smell, too, was not unpleasant. Their name for amber was 'succinum'.

Urine of the lynx

Theophrastus mentioned, and Pliny described, certain authorities of Rome who believed that amber and gemstones were generated from the urine of the lynx.

"They claim", writes Pliny, "that this creature bears such a grudge towards mankind that it immediately conceals its urine, which is hardened by time when it transforms to a gem."

The 1st century Roman Senator and historian – Demonstratus – records in his manuscripts a popular belief that amber (which he noted as being called Lyncurium or Lynx-urine), was formed of the urine of the lynx; tawny dark sherry colours, he writes, being a product of the male while the female lynx produced the lighter coloured ambers.

Again, according to Demonstratus, others called the material 'Langurium' and he goes on to say that the habitat of the animals is in Italy where they are known as 'Languri'.

About 240 BC, Sudines, the astrologer who lived at the court of Attalus I of Pergamum, wrote a treatise of some importance on the mystical properties peculiar to gemstones. In this he writes that amber is the product of a tree that grows in Liguria; and that tree is known as the 'Lynx'.

A similar report on the origins of amber is given by Metrodorus – a scientist at the court of Mithridates VI.

Another ancient belief describes how the rays of a brilliantly setting sun become congealed in an evening sea and are eventually cast upon the shore in the form of amber.

Biers for gladiators

A centurian by the name of Julianus, in charge of a display of gladiators ordered by Emperor Nero, had occasion to send one of his knights to the Baltic coast of Germany to procure amber.

Some time later the knight returned to Rome with such an abundance of the fossil resin that nets used for preventing beasts escaping from the scene of contest and into the amphitheatre were made up and knotted with beads of amber.

"Moreover", writes Pliny, "all the equipment used on any one day had amber fittings; including the biers used to remove the bodies of dead

gladiators".

Pliny's awe at this display of affluence is understandable for he has noted that the price of a small figurine made from amber, however diminutive, exceeds that of a living, healthy slave.

"Pearls can be carried on the head and gems on the finger. In short, every other substance for which we have a weakness pleases us because it lends itself either to display or practical use, whereas amber gives us only the private satisfaction of knowing that it is a luxury."

In describing the colour of the hair of his wife Poppaea, Nero called it 'sucini' or 'amber coloured'. From that time respectable women (said Pliny) "began to aspire to this colour". (*Historia Naturalis*).

Diviner of poison

Over the centuries, both ancient and medieval, the fear of poison being administered in food or drink occupied the minds of those in envious position.

In Europe, any substance that could indicate the presence of poison by some physical change and thereby assist its owner to avoid an untimely end was very highly valued and avidly sought for.

An amber cup or chalice was believed to reveal the presence of poison by losing colour and opacity. (Chalices intricately carved from rhinoceros horn were used by the Chinese as a similar means of poison divination; in these the poisons effervesced: Wellcome display, Science Museum, Kensington).

The Sun Maidens

The Greek love of drama and tragedy is noticeable in an imaginative and original description of the origins of amber. The tragedy of Heliades (Phaethusa, Aegle and Lapetia) the Sun Maidens, is translated by Ovid in his *Metamorphoses*; a precis of which follows.

The sisters were happy for their brother and they joyfully harnessed the Steeds of the Sun to the Sun Chariot when Phaethon was allowed by Phoebus (against his better judgement) to drive the sun across the sky.

Things went well for a while when the steeds took the bit and bolted. Uncontrollable, the horses pulled the sun so close to Gaia (Heaven and Earth) that she was set on fire. Volcanoes were born, lands became parched, seas dried and forests turned to ashes.

Unable to withstand such painful devastation for much longer, she begged Zeus to save her. Taking pity on Gaia, the supreme god and ruler of Olympus threw a fatal and killing bolt of lightning at Phaethon.

The body fell into the river Eridanus (now known as the river Po) to be recovered by the Nymphs of the Stream. They carefully and reverently buried it on the river bank. His sisters eventually found the grave and knelt by it weeping copiously and perpetually. Unable to move through grief they became transfixed on the place where each knelt. There they stayed until their bodies gradually became covered with the bark which grew out from the surrounding trees; their limbs changed to branches; and they, finally, were transformed into Poplar Trees.

The sisters continued shedding a flood of tears which flowed into the river; and the tears were converted to amber.

Grease of amber

Amber was the name given to a wax-like substance found floating in tropical seas and in the intestines of the sperm-whale. Later, the name 'Ambre Jaune' or 'Succin' was given to fossil resin. 'Ambre-Gris' (grey amber) became the new name for the original 'Amber' of the whale to distinguish it from 'Ambre Jaune'; these are the names now in regular usage. Ambergris – a somewhat odoriferous substance – was at one time used extensively to provide a good base for quality perfumes until it was replaced by a secretion taken from the Civet cat.

In 1841 Pope wrote: "Praise is like ambergris; a little whiff of it, by snatches, is very agreeable; but when a man holds a whole lump of it to his nose, it is a stink and strikes you down".

Used in cookery

It seems impossible, knowing the origins of such a substance, that ambergris could ever have been used in the preparation and cooking of food.

To quote Macaulay (*History of England*, 1849.): "Something has been put into his [Chas.II] favourite dish of eggs and *ambergrease*". (*Oxford Dict.*).

This article is an excerpt taken from my larger work provisionally entitled: *Facts, Fantasies and Superstitions of Diamond and Coloured Gemstones*, which is yet to be published.

[*Manuscript received 6 October 1988.*]

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Notes from the Laboratory – 13

Kenneth Scarratt, FGA

The Gem Testing Laboratory of Great Britain, 27 Greville Street, London EC1N 8SU.

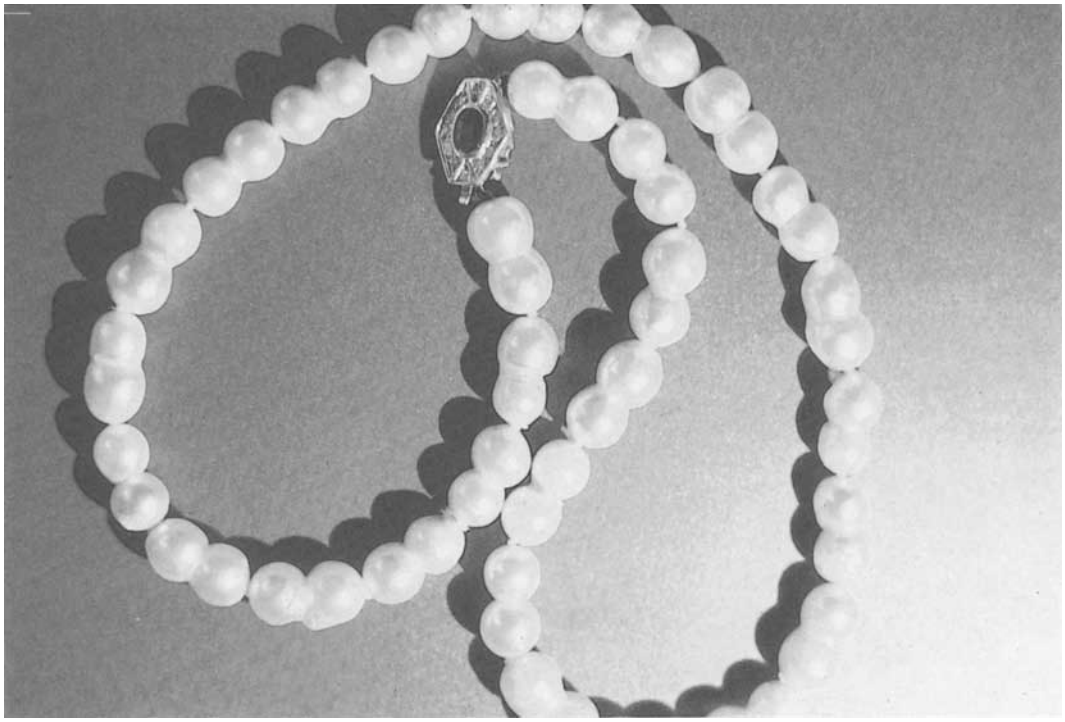

Fig. 1. A single row of double-nucleated cultured pearls.

Double-nucleated cultured pearls

We have seen many single cultured pearls which have had double nuclei in the past but we were astonished to see the necklace shown in Figure 1. There were 29 'double pearls' in the necklace, the largest being 8.35 × 13.2 mm and the smallest 6.59 × 12.8 mm. As the X-radiograph in Figure 2 shows, all of the pearls contained two mother-of-pearl beads. Under such circumstances the question that must be asked is are these merely pairs of pearls brought together by some form of adhesive or were they grown in this way. A close examination of the 'junction areas' revealed that the nacre, on which the 'overlapping platelets' could be seen quite clearly, passed smoothly from one side to the other and that there was no sign of any artificial junction. A close look at the radiograph also shows that the layers of nacre formed over both beads when they were in juxtaposition.

Repaired and filled pearl

Whilst still on the subject of pearl, yet another (Scarratt, 1986), hollow pearl that had been cunningly filled was submitted for examination. The pearl, which is shown in Figure 3, is drop-shaped and measures 26.4 – 24.9 × 29.3 mm. Its weight is

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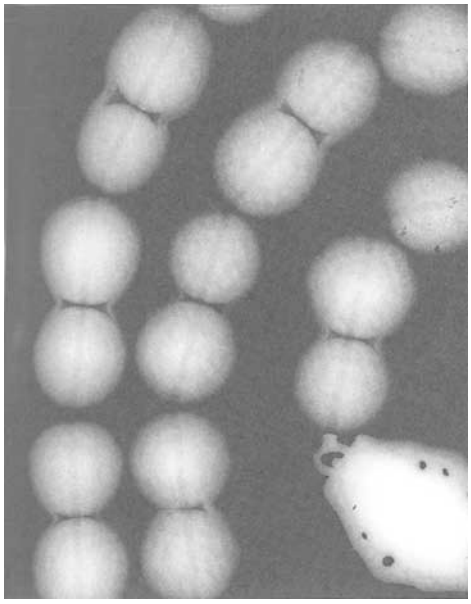

Fig. 2. Radiograph showing the two mother-of-pearl beads in each of the pearls in the necklace seen in Figure 1.

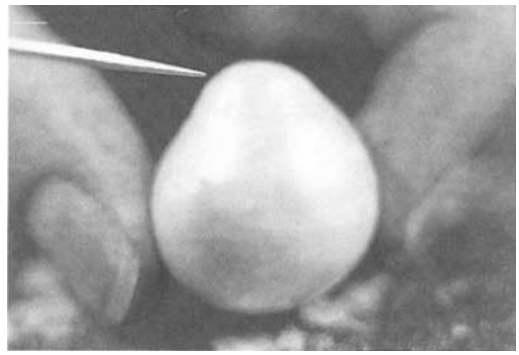

Fig. 3. 'Hollow' cultured pearl. The pointer indicates the area which has been coated with a substance similar to that which is used to coat imitation pearl.

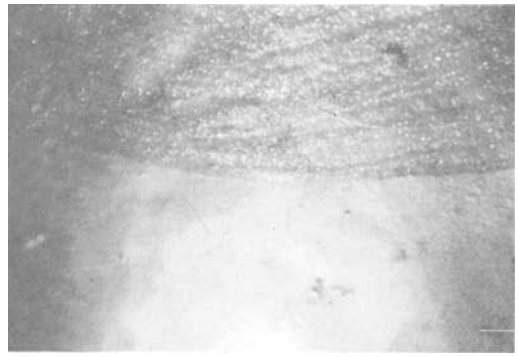

Fig. 5. A close view of the pearl in Figure 3 showing the demarcation between the artificial coating and the pearl.

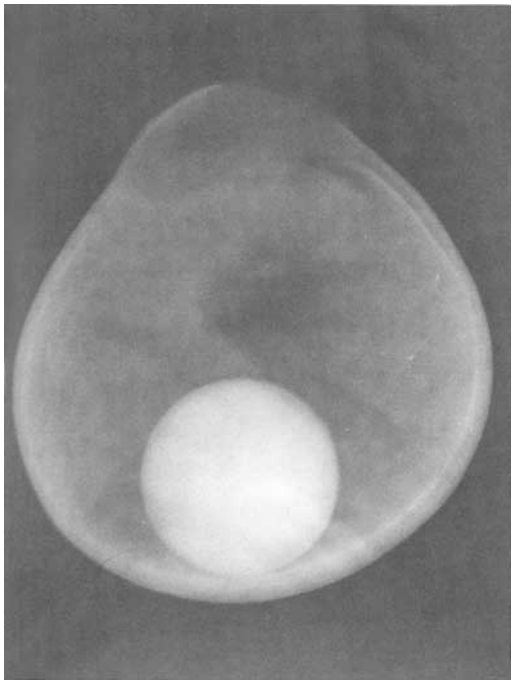

Fig. 4. Radiograph of the pearl seen in Figure 3. This shows the small mother-of-pearl bead and the fracture at the top of the pearl.

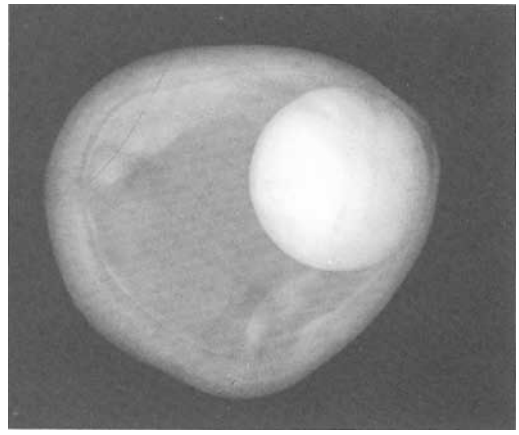

Fig. 6. Radiograph of a cultured pearl of a similar size and appearance to that in Figure 3, but in this case the surface has not been punctured.

67.49 ct. The radiograph (Figure 4) reveals it to be a cultured pearl in which the mother-of-pearl bead is both comparatively small and sits motionless at the base. From the radiograph it becomes immediately apparent that the pearl was largely hollow, but that it is now filled with an artificial substance thereby increasing the weight and adding strength to the thin shell. A closer look at the radiograph reveals a small hole in the area indicated in Figure 3 by the metal pointer, and this is obviously the place through which the pearl was filled. The hole is not visible from the exterior as the entire top of the 'pearl' has been coated with a substance usually used to coat imitation pearls (Figure 5). Another cultured pearl of similar dimensions was examined shortly after this and was found to have a similar interior (Figure 6) but in this case the entire surface was that which is usual for cultured pearls and there were no indications of it being punctured through to the 'hollow' centre.

Fig. 7. A 125.92 ct aquamarine said to be one of the stones cut from the 'Marta Rocha' crystal.

Large aquamarine of exceptional colour

An interesting and large aquamarine was submitted for examination. The stone weighed 125.92 ct, measured in the region of 38.0 – 26.2 × 17.0 mm and had a most extraordinary colour. Figure 7 displays the deep blue colour of the stone as seen from an angle with the table. The stone was submitted with supporting documents that described the stone as being one of the largest cut from the 'Marta Rocha' crystal. The Marta Rocha crystal was named after Miss Brazil of 1954. It was discovered in July of that year, just 6 km north-east of Topazio in the State of Minas Gerais, Brazil, and its weight was 34.7 kg and it yielded 57,200 ct of faceted gems (Proctor, 1984).

Amber 'imitation'

Amber is imitated by many substances and it can be treated in many different ways. It is imitated by a number of plastics including the most popular, bakelite, by glass, and by younger resins such a Kauri gum. The possible treatments include heat treatment, staining and 'pressing'.

Three barrel-shaped 'amber' beads, the largest weighing 26.05 ct, were submited for examination recently. Under magnification each was found to be manufactured, apparently, from several pieces of amber being held together by an unknown resin-like substance (Figure 8). Each of the individual pieces contained either insects or evidence of plant-life. These beads are similar to those described by Fryer *et al.* (1983).

Fig. 8. The interior of an 'amber' bead revealed that it is composed of several small pieces of amber enclosed in an unknown resin-like substance. Note also the included insect in one of the pieces.

The 'Pool emerald'

A hydrothermally grown synthetic emerald manufactured in Australia was brought on to the market around 1981 and marketed under the trade name of 'Biron'. In common with other synthetic emeralds grown in this way, the refractive indices of some of the Biron fell into the natural emerald range at 1.571–1.576. The early production of this material contained very little in terms of inclusions and indeed some could not be termed 'emerald' because they lacked a chromium content sufficient to be detected with the hand spectroscope. However, an arrow-head or sometimes treacle-like structure was seen in most stones and, if one searched, the stone might reveal very small 'nail head' inclusions consisting of spikey growth tubes and crystals of phenakite. Later productions revealed other indicators such as feathers with screw-like turns and they also contained sufficient chromium.

In early July 1988 we received a loose 0.41 ct 'emerald' from a jeweller in Scotland who was unsure of the correct nomenclature to use for the stone under retailing conditions. He was being offered the stone under the trade name 'Pool emerald' but the advertising literature being used as a selling aid avoided stating in a clear way the origin of the stone. The literature, which was in full colour, was headed '...The Pool Emerald. From the Emerald Pool Mine Western Australia (1929). Source of natural and refined emeralds...' After showing the literature to a few members of the trade, our opinion of the wording used was very much confirmed, i.e. that people were likely to think that the stones in question were 'treated natural emeralds' whereas, as our examination of the stone in question proved, they are synthetic.

It has been stated that the 'Pool emerald' is 'refined' by recrystallizing 100% low quality natural emerald from the Emerald Pool Mine and that the method of growth used is an adaptation of the Biron hydrothermal technique. In fact the synthetic Pool emerald appears very similar to, and has the same infrared spectrum as, the Biron synthetic emerald (Figure 9).

Putting the question of nomenclature to one side, it can be said that the synthetic Pool emerald, like the Biron, is in appearance very similar to the natural material. Both the refractive indices (varying, so far, from 1.568 – 1.572 to 1.570 – 1.575) and the SG, can fall into the same range as some natural emeralds, therefore if the stone were free of internal features this would make identification by normal gemmological techniques very difficult. Fortunately the first example of the synthetic Pool emerald to be examined in the laboratory contained feather formations and growth structures typical of those reported for the synthetic Biron emerald (Kane *et al.*, 1985). However, even

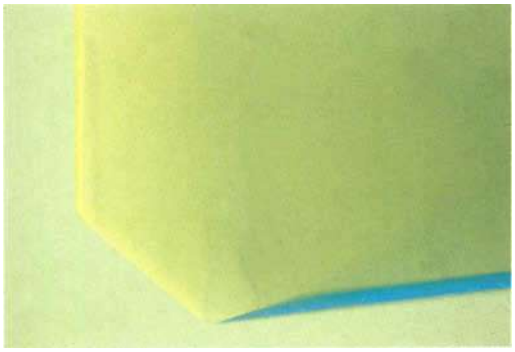

Fig. 10. A 'spiral feather' in a synthetic Pool emerald.

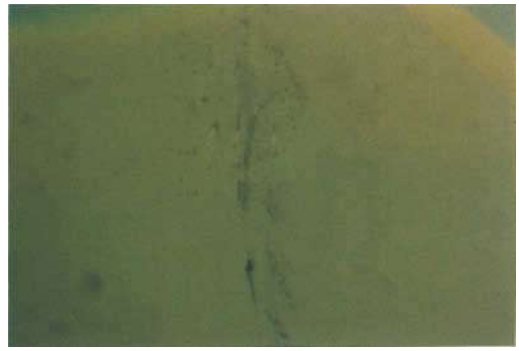

Fig. 11. A feather and three-phase inclusion in a synthetic Pool emerald.

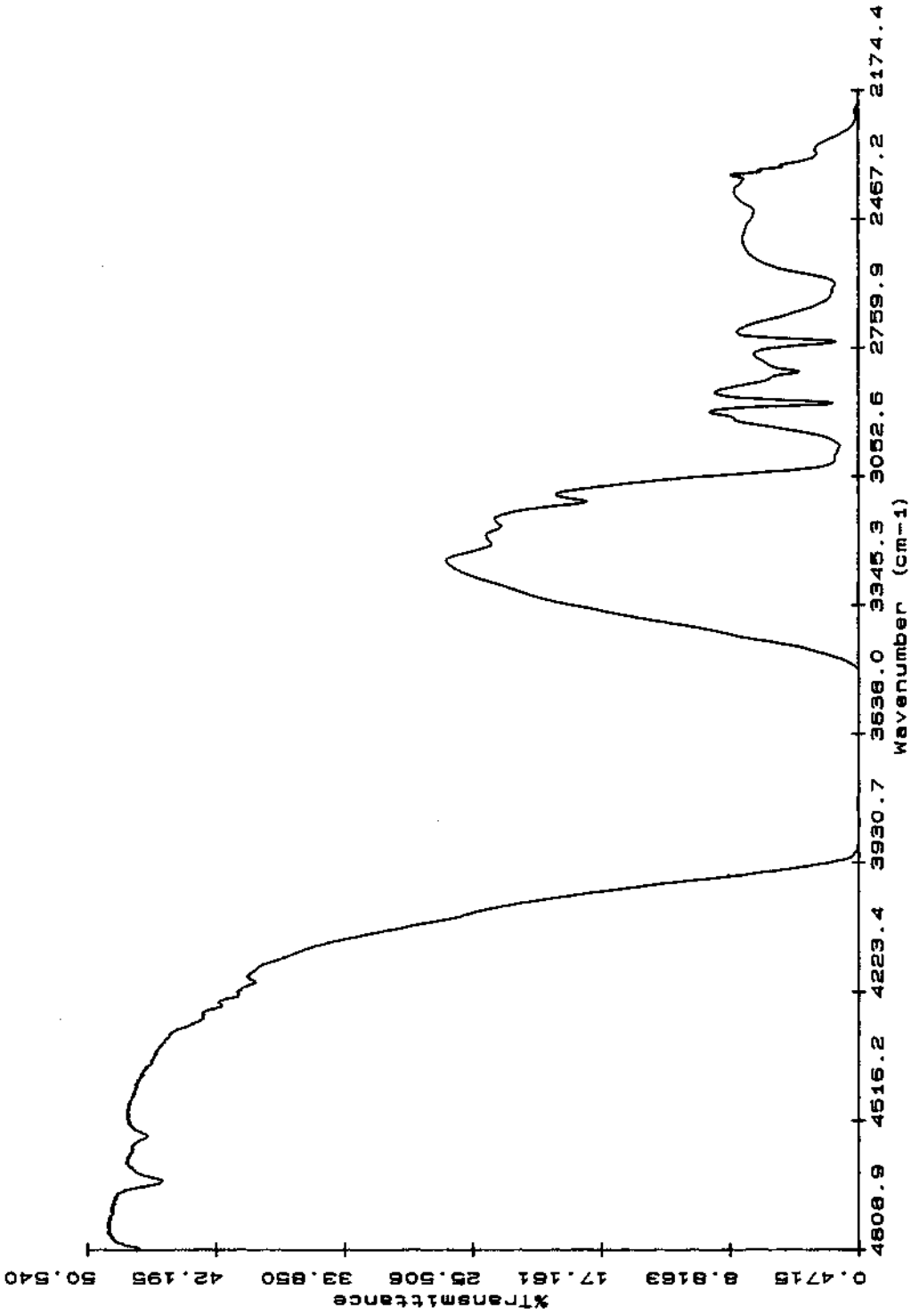

Fig. 9. Infra-red spectrum of the synthetic Pool emerald. Obtained using the Nicolet 510 FT-IR System.

with inclusions the situation could be confusing; a further example of the synthetic Pool emerald was examined in August 1988 and this stone, whilst containing the twisted feathers typical of synthetic emerald along with 'arrow-head' growth structures, also contained 'spiral feathers' (Figure 10) similar to those structures seen in some natural emerald (Fryer *et al.*, 1983) and three phase inclusions (Figure 11) similar to those typical of emeralds from Colombia.

When viewed through the Chelsea colour filter the synthetic Pool emerald appeared a dull red. Under short-wave ultraviolet light a slight reddish fluorescence was observed, but under long-wave ultraviolet light it was inert.

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Ruby/spinel teaser

Alan Hodgkinson, FGA

Clarkston, Glasgow G76 7JD

'Value my ruby necklace' was the request of a solicitor's wife, fresh from a holiday on the far side of the globe.

The two rows of faceted pink to red beads had a distinctive lack of corundum colour absorption pattern, with its modest fluorescent 686 nm line and characteristic dark door posts, along with the fainter repetition of the effect both up and over the 700 nm mark and down towards the orange. The pattern is instantly contrasted by pink sapphire/ruby with its strong chrome 693/694 doublet which pierces the red end and may show two slight support lines on the down side with the 660 more evident than the 668. Stronger coloured corundum gems would, of course, produce the diagnostic ruby trio in the blue, but these become increasingly reclusive in the paler pink sapphires, and do not appear in spinel.

Typical of a solicitor's thinking, the customer's husband had obtained a written guarantee that if the stones were not as described in identity or value, there would be a refund.

Our finding caused a strong Saxon/Gothic outburst by airmail which produced a prompt legal reply from solicitors acting for the jeweller in question. Obviously 'they' (the customers) had taken the necklet to a jeweller who knew nothing of gem identification(!), but if a bona fide gemmological laboratory report substantiated the claim all goods could be returned with costs and all moneys and expenses refunded.

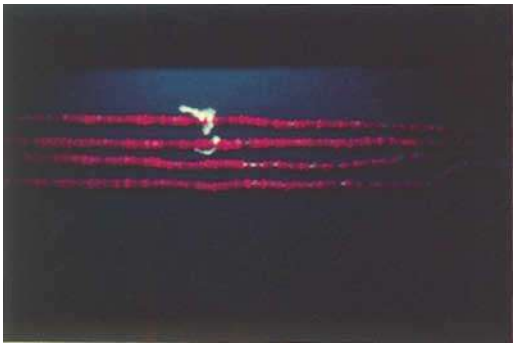

Fig 1. Chrome fluorescence in the necklace.

The trap was sprung. The photo of the necklace (Figure 1) indicates the nature of the problem – all 640 of them! – and being aware of legal niceties and not-so-niceties, I was well aware of the danger in letting our original pronouncement stand unsubstantiated. Suppose we sent the necklace all the way back, only for the other end to find two rubies in the necklace after all. Such a *faux pas* could be exploited by the articulations of the legal profession, e.g. 'Does your gemmological adviser not appreciate that the necklace does contain rubies?', which could put us in a very uncomfortable position with our own customer.

How do you test 640 red beads on two strands of red silk? I felt our case better served by leaving the stones threaded rather than loose. Where to begin? Ultraviolet light. The Long wave produced a positive response of red fluorescence without a single inert specimen (see Figure 1). The level of fluorescence varied dependent on the chrome/iron content, but typical for pink sapphire or spinel, so this did not resolve the issue.

The polariscope is a useful idea, but when you realize that the stones are as small as 1.13 mm, and there is a drill hole and thread through them, not to mention inclusions and strain birefringence in spinel, this was not going to give unequivocal proof. Also interpreting the Becke line technique was stymied by the same problems of small size, though there would have been no problem if the stones were loose. Looked at individually there were the inclusions characteristic and distinctive of spinel and corundum.

Lastly the spectroscope – but think of all those 640 stones. The conclusive answer took only seconds and has been demonstrated since on the *Retail Jeweller* Practical Gem Courses, and in darkness to boot. The students sit down one at a time confronted by the necklace lying across the

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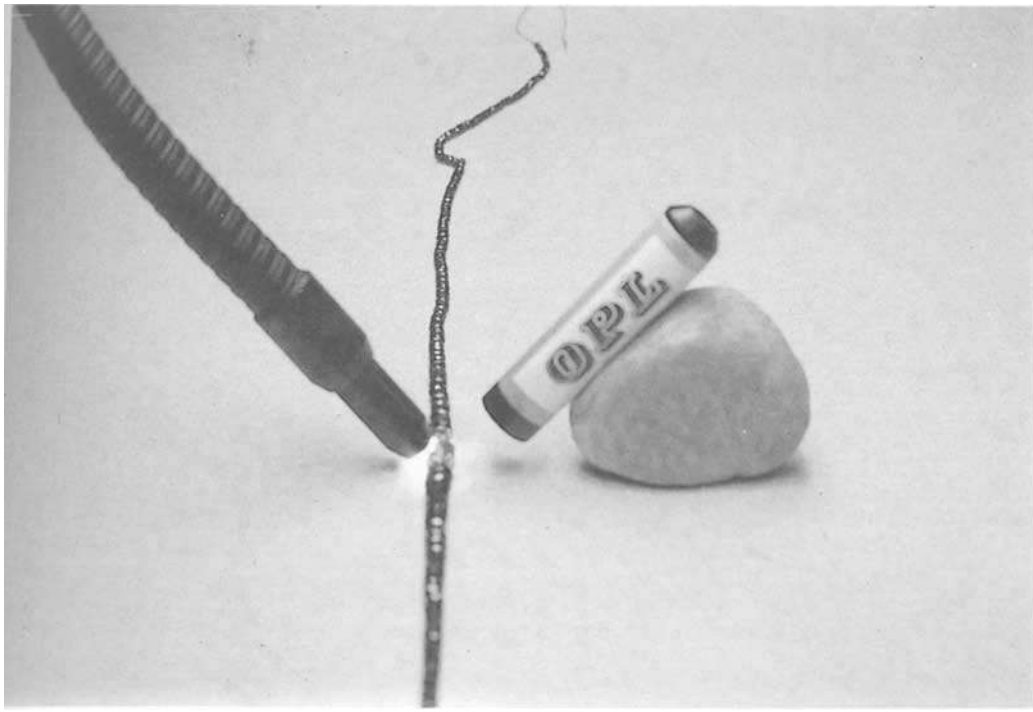

Fig 2. The spectroscope set up for the testing of the necklace.

partly 'earthed' fibre optic. (See Figure 2 for layout.) The lights are put out, and the observer sees the typical spinel pattern as described. The necklace is then drawn across the nose of the fibre optic with the spectroscope one inch distance. The necklace passes through in seconds, and amazingly the spectrum pattern stays coherently complete so long as the stones are the same. I can still hear the shouts of 'Now!', 'Now!', as on two occasions the semi-bright spinel line jumped its 686 nm to the 693/694 nm bright line position of the pink sapphire and immediately back again. The two shouts coincided with the two pink sapphire/pale rubies which lay concealed among the 640 stones – the two white cotton threads (Figure 1) indicate their position.

For all the small nanometre distance between these two key lines, 'the jump' was quite electric and an obvious gemmological treat for all who witnessed the phenomenon. The testing of the stones could be completed accurately in seconds, which goes to show the power of the spectroscope. The demonstration can easily be contrived by placing a ruby and a spinel side by side at the end of the fibre optic and panning the spectroscope from one stone to the other when the bright fluorescent line will be seen to jump back and forth as described.

[*Manuscript received 17 April 1988.*]

Growth patterns in Hong Kong

Rosamond Clayton, FGA, London, W11

Since the end of the Second World War, Hong Kong has had its growth miracles in many fields, not least in the science of gemmology.

Anne Paul, who played a leading role in the development of gemmology in Hong Kong and of the Gemmological Association of Hong Kong of which she was a founder member, left in June for a new life in Tokyo and it seemed an appropriate moment to give a background to the history of gemmology in this part of the world and to pay tribute to those who have worked there with such enthusiasm to spread the word.

First, of Anne herself, who became an FGA in 1975. This combined with her background of teaching, soon swept her into running classes to prepare students for the GAGB diploma examination. Additionally, from 1979 until her departure, she served on the executive committee of the GAHK holding the positions of Treasurer, Honorary Secretary, Vice President and President. Significantly, not in that order. Having been President, she subsequently of her own volition took upon herself the more arduous tasks on the executive committee. Anne taught students of all nationalities with great success and enthusiasm: Two Chinese students, one from Taiwan, who had unsuccessfully sat their diploma examination seven and eight times respectively, came to her for private tutorials in one determined last ditch attempt and with her help, mainly in overcoming the language problem, both passed.

Fig 1. Anne Paul

The first person to become an FGA in Hong Kong was Oleg Peresypkin (qualified 1948), a man of many parts and a true 'China hand' of the old school. He dealt in Chinese artworks, initially in Peking and later in Hong Kong and from his collection acquired in the former supplied the Mandarin Hotel, when it was first built, with beautiful gilded temple carvings and the pair of Chinese effigies, which to this day grace the entrance to the Chinese restaurant. He held the agencies for a number of well known British companies including George Lindley and later Thomson Gems.

Two years after Oleg Peresypkin, Mr Siu Man Cheuk qualified and for many years met with great resistance and struggle against the 'spurious' and uncomfortable knowledge he had assimilated from the UK. He recounts how his sanity was seriously questioned by the trade when he first pronounced a most desirable 'ruby' with curved growth bands, as a Verneuil synthetic corundum. Mr Siu is currently still well versed in the world of gemstones and has witnessed Hong Kong not only from the beginning of gemmology but from the days when many of his parents' contemporaries were victims of the opium divans.

By 1973 Hong Kong had still only claimed a total of nine successful candidates in the GAGB

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diploma examination, including one distinction: Noah Kan; the first person (there have only to date been two from Hong Kong) to continue his studies to the post diploma gem diamond examination: Mr Woo Shun-Wai; George Chan of opal and amethyst fame and Nissanka De Silva of the well established jewellers S.P.H. De Silva who in the years following his qualification gave many private words of advice and encouragement to aspiring FGAs.

At this point Hong Kong had reached a stage where it was burgeoning with businesses dealing in gemstones – far easier to acquire than an electric kettle or other domestic trifle – and although there was outstanding knowledge in some aspects of gemstones, formal gemmology was sadly lacking, misnomers abounded, and tuition in the subject difficult to obtain. In September 1972 Marcia Lanyon, an able gemmologist, had recently arrived in the Colony from London and set up classes both to prepare students for the diploma examination and general interest gemmology classes. There was no example to follow and Marcia Lanyon had the formidably task of preparing her own course notes and amassing a wide collection of stones.

This having been achieved and in a place where gemmology remained an alien subject, she turned a batch of listless European and Chinese housewives into career gemmologists and for those, mainly Chinese, already in the trade she provided the route to a new awareness and professionalism in their occupation. Amongst her successful students were Louis Lo the present GAHK president, and Anne Paul, Anne Strachan and Sandra Brauns who all went on to teach.

Apart from the gemmologists descending directly from this line; independently, a few years later, Dr T. C. Wong of the Hong Kong Chinese University qualified with distinction, Dr Healey, Dr Yu and Mrs C. M. Ou Yang from the University of Hong Kong qualified. Dr Healey became the first Chairman of the GAHK and apart from his teaching is always a willing lecturer capable of speaking on the most taxing topic, greatly respected by everyone and a guiding light in all matters gemmological. The indomitable Mrs C. M. Ou Yang has in recent years come very much to the fore with her mass production of FGAs, her thesis on Burmese jadeite jade and providing the liaison

Fig 2. Anne Paul teaching practical gemmology in Hong Kong University Laboratories.

between Wuhan University in China and gemmologists of international repute.

Mention should also be made of the Baptist College which has in recent years provided the centre for the GAGB examinations and for a number of years has offered tuition in gemmology. Initially Melinda Tilley, with her widely acknowledged flare for teaching, conducted the courses – she went on to run her own private classes – and for the past few years the centre has been co-ordinated by Kitty Wong.

Including the most recent diploma examination results, Hong Kong can now lay claim to almost two hundred FGAs, past and present, it has a thriving association of approximately 300 members comprising FGAs, GGs and DGemGs. There are many who have not been named who continue to contribute countless hours of time, much of it voluntary, and enthusiasm both in teaching and organizing. Last but not least it has been an enormous advantage to be placed on the cross roads of the Far East and in the midst of a gemstone and jewellery market for the world. As a result of these factors many gem experts and leading gemmologists find their way to this metropolis in the South China Sea and of their good nature and interest in the subject impart their knowledge by lecturing to the ever eager Hong Kong audiences.

The author would like to thank Mrs Memory Stather, FGA, who is carrying on much of Anne Paul's work, for providing information on Anne's career and for the initial thoughts on writing about gemmological education in Hong Kong.

[*Manuscript received 27 October 1988.*]

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Yellowish-green Gilson synthetic emerald

Dr Karl Schmetzer

Institute of Mineralogy and Petrography, University of Heidelberg, West Germany

Abstract

A yellowish-green faceted Gilson synthetic emerald with refractive indices of n_o 1.563, n_e 1.559 and a density of 2.65 g/cm^3 was examined. The flux-grown sample was found to contain chromium and nickel as dominant colour-causing trace elements and subordinate amounts of vanadium, iron and copper. Absorption bands and pleochroism of the sample are due to the presence of Cr^{3+}, Ni^{3+}, and Ni^{2+}, which is different from Russian chromium- and nickel-bearing hydrothermally-grown synthetic emerald.

According to gemmological literature at least three different types of Gilson synthetic emerald were commercially grown and marketed in the past. Most frequently, samples with bluish-green colour and distinct red fluorescence under long- and short-wave ultraviolet radiation were produced, the refractive indices of which were found to range from 1.562 to 1.568 for n_o and from 1.559 to 1.562 for n_e. Bluish-green Gilson synthetic emeralds with higher refractive indices between 1.577 and 1.580 for n_o and between 1.570 and 1.574 for n_e were found to contain distinct amounts of iron which is responsible for the quenching of fluorescence in long- and short-wave ultraviolet. Another type of Gilson synthetic emerald with yellowish-green colour and refractive indices ranging from 1.562 to 1.569 for n_o and from 1.558 to 1.564 for n_e is also reported in gemmological literature. Samples of this colour variety reveal a greenish-yellow, yellow or orangy-yellow fluorescence under ultraviolet radiation. The density of the bluish-green and yellowish-green fluorescent types of Gilson synthetic emerald is described as 2.65 g/cm^3, and the values measured for the bluish-green non-fluorescent iron-bearing variety were found in the range of 2.68 to 2.69 g/cm^3 (Gübelin, 1964; Liddicoat, 1964; Webster, 1964; Flanigen *et al.*, 1967; Fryer, 1970; Liddicoat, 1970).

During a systematic study of absorption spectra of natural and synthetic emeralds in the visible and ultraviolet range (cf. Schmetzer, 1988, 1989), all three types of Gilson synthetic emeralds were examined. The spectra of stones of the most commonly produced bluish-green fluorescent variety reveal ordinary chromium absorption bands without any special properties. In the spectra of samples of the bluish-green non-fluorescent type of Gilson synthetic emerald, the absorption bands of Cr^{3+} are superimposed by the spectrum of Fe^{3+} replacing Al^{3+} in octahedral sites, which consists of two strong absorption bands in the bluish-violet and ultraviolet range with maxima at 23,500 cm^{-1} (426 nm) and 27,000 cm^{-1} (370 nm). In both types of Gilson synthetic emerald a pleochroism of bluish-green $\parallel c$ and yellowish-green $\perp c$ is observed, which is due to absorption minima at 20,000 cm^{-1} (500 nm) $\parallel c$ and at 19,800 cm^{-1} (505 nm) $\perp c$. These results indicate that the high iron contents of the samples do not change colour and pleochroism of these synthetic emeralds.

Surprisingly, the absorption spectrum of one yellowish-green sample was found to reveal additional absorption bands, which could not be assigned to chromium and iron. Consequently, this Gilson synthetic emerald was examined more thoroughly in order to clarify its cause of colour as well as the spectroscopic properties of this particular type of Gilson synthetic emerald.

The sample of Gilson synthetic emerald to be described was provided by a private collector, who bought the stone in the late sixties or early seventies. The synthetic emerald, weighing 2.25 ct, was faceted with the table facet perpendicular to the *c*-axis of the beryl. The colour of the stone is described as yellowish-green, resembling high vanadium-bearing natural emeralds, e.g. from Muzo, Colombia. The pleochroism of the Gilson synthetic emerald is described as an intense green $\parallel c$ and a somewhat lighter yellow-green $\perp c$. In long- and short-wave ultraviolet radiation a weak yellowish fluorescence was observed. Refractive

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indices were measured as 1.563 for n_o and 1.559 for n_e with Δ 0.004, the density was determined as 2.65 g/cm^3. Microscopic examination revealed the stone to contain numerous wispy or veil-like patterns (Figures 1, 2), which are typical for early Gilson synthetic emeralds. The sample showed internal growth planes and colour-zoning parallel to the basal pinacoid *c* (0001). Infrared spectroscopy revealed the absence of water and proves the synthetic emerald to be flux-grown, most probably using a seed plate which was orientated perpendicular to the *c*-axis.

Chemical investigations by electron microprobe and X-ray fluorescence analysis yielded the following trace element contents measured on the table facet of the synthetic emerald [wt.%]: V 0.05, Cr 0.29, Fe 0.20, Ni 0.24, Cu 0.01.

According to these chemical data, this particular sample of Gilson flux-grown synthetic emerald contains distinct amounts of two dominant colour-causing trace elements, i.e. chromium and nickel. Vanadium in the concentration present is assumed to increase the intensity of chromium absorption bands, whereas the concentrations of iron and copper are too low for a distinct influence on the colour of the sample.

Fig. 1. Wispy or veil-like patterns of residual flux in yellowish-green Gilson synthetic emerald. 32×

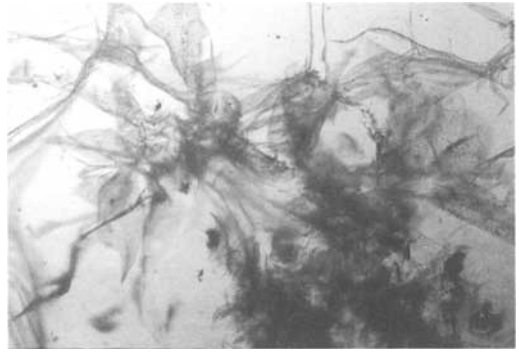

Fig. 2. Wispy or veil-like patterns of residual flux in yellowish-green Gilson synthetic emerald. 25×

Comparing chemical data and colour of the yellowish-green Gilson synthetic emerald with properties of other synthetic emeralds, which also contain chromium and nickel as dominant colour-causing trace elements, e.g. Russian hydrothermally-grown synthetic emeralds (cf. Schmetzer, 1988), the Gilson sample is expected to be bluish-green in colour, with a pleochroism of blue $\parallel c$ and yellow-green $\perp c$, and the absorption spectrum should consist of Ni^{3+} and Cr^{3+} absorption bands.

The absorption spectrum of the yellowish-green Gilson synthetic emerald described in this paper, however, consists not only of the absorption bands of Ni^{3+} and Cr^{3+} replacing Al^{3+} in octahedral sites as described recently for Russian hydrothermally-grown synthetic emeralds, but shows an additional absorption band at about 22,100 cm^{-1} (452 nm) with polarization $\parallel c$. This absorption band was assigned to divalent nickel replacing Al^{3+} in octahedral sites by Russian scientists (e.g. Solntsev, 1981a, b).

Due to the relative intensities of Cr^{3+}, Ni^{3+}, and Ni^{2+} absorption bands, the absorption minima in the Gilson spectrum are found at 19,850 cm^{-1} (504 nm) $\parallel c$ and at 19,500 cm^{-1} (513 nm) $\perp c$. In other words: due to the strong intensities of Ni^{3+} and Ni^{2+} absorption bands in the spectrum of this chromium- and nickel-bearing Gilson flux-grown synthetic emerald, the absorption minima $\parallel$ and $\perp$ *c*, which are found in chromium- and nickel-containing Russian hydrothermally-grown synthetic emeralds at about 20,300 cm^{-1} (493 nm) $\parallel c$ and at about 19,850 cm^{-1} (504 nm) $\perp c$, are shifted towards lower wavenumbers (higher wavelengths). According to these differences in the positions of absorption minima, the blue or greenish-blue colour of Russian synthetic emeralds $\parallel c$ is changed to an intense green in the Gilson sample, and the yellow component of the yellow-green in Russian stones $\perp c$ is strengthened in the Gilson sample.

Consequently, the colour of yellowish-green flux-grown Gilson synthetic emerald is caused by Ni^{2+}, Ni^{3+}, and Cr^{3+}, all of them replacing Al^{3+} in octahedral sites. The different valency states of nickel in various synthetic emeralds, e.g. in Russian hydrothermally-grown or in Gilson flux-grown synthetic emerald, are most probably due to different growth conditions.

Acknowledgement

The author is grateful to Dr H. Holländer of Eugen Blink KG, Pforzheim, FRG, who kindly supplied the specimen of yellowish-green Gilson synthetic emerald.

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Liddicoat, R.T., 1970. More on synthetic flux-melt emeralds. *Gems & Gemology*, **8**, 123-5.

Schmetzer, K., 1988. Characterization of Russian hydrothermally-grown synthetic emeralds. *Journal of Gemmology*, **21**, 3, 145-64.

Schmetzer, K., 1989. Two remarkable Lechleitner synthetic emeralds. *Journal of Gemmology* (submitted for publication).

Solntsev, V.P., 1981a. (Nature of color centers and EPR in beryl and chrysoberyl.) *Tr. Inst. Geol. Geofiz., Akad. Nauk SSSR, Sib. Otd.*, **499**, 92-140 (in Russian).

Solntsev, V.P., 1981b. (Absorption spectra and EPR spectra of trace impurities in beryllium-containing minerals and their relation to specimen color.) In: *Issled. Fiz. Svoistv i Sostava Sintet. Mineralov i Monokristallov, Novosibirsk* 1981, pp. 37-47 (in Russian).

Webster, R., 1964. The French synthetic emerald. *Journal of Gemmology*, **9**, 191-6.

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Gemmological Abstracts

APTER, M., 1988. L'agate et l'imaginaire. (Agate and the imagination.) *Revue de Gemmologie*, 96, 10-14, 13 figs in colour.

Agates illustrated depict shapes and forms suggesting other natural or anthropomorphic features. M.O'D.

AURISICCHIO, C., FIORAVANTI, G., GRUBESSI, O., ZANAZZI, P.F., 1988. Reappraisal of the crystal chemistry of beryl. *American Mineralogist*, **73**, 826-837, 8 figs.

The crystal chemistry of beryl is re-evaluated in accordance with modern principles and on the basis of fresh chemical analyses and X-ray structural refinements on samples from different sources and compositions. M.O'D.

BANCROFT, P., 1988. Rubies of Thailand. *Lapidary Journal*, **42**, 7, 45-57, 5 figs, 2 in colour.

Geological and marketing features of Thai ruby are described. M.O'D.

BANERJEE, A., 1988. Gilson-Opale der neuen Generation. (New Generation Gilson opal.) *Kurzmitteilungen aus dem Institut für Edelsteinforschung der Johannes Gutenberg-Universität Mainz*, **4**, 2, 12, 1 fig.

Zirconium dioxide has recently been used as matrix material by Gilson in place of silica gel. Gilson opal can be identified by IR spectroscopy, using characteristic Si-O vibrations in the region around 1250cm^{-1}. M.O'D.

BANK, H., 1988. Gemmologische Kurzinformationen. *Zeitschrift der Deutschen Gemmologischen Gesellschaft*, **36**, 3/4, 161-74. (a) Geschliffener, farbloser Mesolith von Poonah, Indien. Id., 163-4; (b) Durchsichtiger, brauner, bestrahlter Phenakit. Id.., 165-6.

(a) A cut, colourless mesolite from Poonah, India, is described. The crystals are needle-shaped, and the one discussed was found in a lot of zeolites from Poonah, RI 1.505-1.506, hardness 5, SG 2.27.

(b) A transparent, brown, irradiated phenakite measuring 9.9 x 7.9 x 5.8 mm and weighing 2.84 ct is discussed. E.S.

BANK, H., BANK, F.H., 1988. Gemmologische Kurzinformationen. Variationsbreite der Brechungsindizes von Aquamarinen. *Zeitschrift der Deutschen Gemmologischen Gesellschaft*, **36**, 3/4, 166-8. 2 tables, bibl.

An extensive note on the variation of refractive indices of aquamarines, finding the largest variation in those from Nigeria. E.S.

BANK, H., HENN, U., 1988. Gemmologische Kurzinformationen. Changierende, chromhaltige Turmaline von Ostafrika. *Zeitschrift der Deutschen Gemmologischen Gesellschaft*, **36**, 3/4, 161-3.

Colour-changing, chrome containing tourmalines from East Africa are described. They change from green in daylight to brownish-red to red in artificial light. Probably from Lelatema in Tanzania. The tourmalines are chrome containing crystals of the dravite-uvite series, the uvite content being about 55-65%. E.S.

BECKER, G., 1988. Gemmologische Kurzinformationen. Farbveränderungen von Apatit durch Erhitzen. *Zeitschrift der Deutschen Gemmologischen Gesellschaft*, **36**, 3/4, 172.

Colour changes in apatite by heat treatment are described. The apatite came from five different sources (Mexico, Madagascar, India and two Brazilian sources). The various apatites were heated to 300°C to 850°C and showed varying results, the most interesting being the Madagascan stones which changed from light green to tourmaline green, then blue and lastly to an aquamarine blue. E.S.

BROWN, G., 1988. Precious versus man-made opal. *Gemological Digest*, **2**, 3, 24-8, 6 figs.

The structure of natural and imitation opal is compared and nomenclature suggestions made. M.O'D.

BROWN, G., 1988. Paua Shell: New Zealand's distinctive organic gems. *Australian Gemmologist*, **16**, 10, 367-70, 13 figs most in colour.

'Paua' is Maori for the large abalone, the shell of which is discussed. Most shell is dye enhanced, some is cemented to black epoxy resin or other materials, including the cabochon glass front and possibly an opaque back to make the so-called 'sea opal', doublet or triplet forms. Buttons are made by encasing a circular paua fragment in clear plastic. R.K.M.

BROWN. G., 1988. Sapphirine. *Wahroongai News*, **22**, 7, 22-4, 2 figs.

A detailed account of an extremely rare gem which seems to exist as uncuttable grains or as a few small cut stones. It is apparently a layer structured monoclinic magnesium aluminium silicate which is usually blue, but can be purplish or even brown. RI 1.710-1.717, SG 3.5, H 7. A very obscure collector's gem [possibly made more so by naming it so similarly to sapphire, to which it is related only by colour. In 55 years I cannot recall seeing a cut specimen of sapphirine. The same name has been used for a blue chalcedony]. R.K.M.

BROWN, G., KELLY, S.M.B., SNOW, J., 1988. A coconut pearl? *Australian Gemmologist*, **16**, 10, 361-2, 3 figs.

An Indonesian spherical 'gem' claimed to be a specimen of the equivocal and possibly mythical 'coconut pearl' was shown to have been fashioned from thick sea-shell. R.K.M.

BROWN, G., KELLY, S.M.B., 1988. A Verneuil sapphire with induced fractures. *Australian Gemmologist*, **16**, 11, 419-21, 5 figs.

A sapphire with natural looking partially healed fractures was found to have curved colour bands, partly diffused by heat treatment, which confirmed it as synthetic. R.K.M.

BROWN, G., MCCABE, A.J., 1988. The New Zealand Aurora Shell, a unique organic gem material. *Australian Gemmologist*, **16**, 11, 401-7, 11 figs.

An account of the search by the McCabe family for green-lipped New Zealand mussel shell (Perna canaliculus) with iridescence suitable for jewellery use. Grahame Brown examined the finished products some of which were plastic coated, or backed with pink polyester resin to strengthen the shell and increase its colour effect. All shells processed are dyed. R.K.M.

BROWN, G., SNOW, J., 1988. The EW-120SG electron densimeter. *Australian Gemmologist*, **16**, 11, 422-3, 2 figs.

A report on a simple to use densimeter intended for assessment of gold qualities by specific gravity. Works well within limits of 2-120 grams, which restricts its use with gems to 10 ct or larger sizes. R.K.M.

BROWN, G., SNOW, J., 1988. An interesting hematite imitation. *Australian Gemmologist*, **16**, 10, 371-3, 5 figs.

A Study Club investigation which arose from a black cabochon set in a practical examination, correctly identified by an examinee but marked wrong by the examiner. [These things can happen] The error was discovered and the glass confirmed by its SG 2.57, RI 1.52, white streak and conchoidal fracture. Hematite (gem) SG about 5.00, RI as above refractometer range (3.22-2.95), red streak, splintery fracture. R.K.M.

BROWN, G., SNOW, J., 1988. Gemmology Study Club laboratory reports. *Australian Gemmologist*, **16**, 11, 424-9, 18 figs.

Deals with plastic imitations of lapis lazuli and malachite; with dumortierite in quartz and with a native necklace of elephant ivory. A diamond in a ring was badly damaged by a cleavage when dropped in a kitchen sink. Plastic imitation pearls tested by X-ray found to have radio-opaque outer coating. A greenish synthetic triplet spinel was thought to have a centre coloured section of water soluble silica 'glue', rather than glass, since it dissolved in dilute acetic acid. Sue Kelly identified a bronze coloured cabochon gem, with broad cats-eye, as the elaeolite variety of nepheline (SG 2.53, RI (spot) 1.55.) R.K.M.

BROWN, G., SNOW J., 1988. Is it amber? *Australian Gemmologist*, **16**, 11, 409-16, 21 figs.

An interesting attempt to provide procedures for identifying amber, modified amber, copal resin, various plastic simulants and glass which authors suggest should make amber identifiable from its imitations and treated forms. R.K.M.

CASSEDANNE, J., 1988. Les hélidores du Sapucaia. (Heliodor from Sapucaia.) *Revue de Gemmologie*, 96, 5-6, 6 figs, 1 in colour.

Heliodor is reported from the area of Sapucaia, Minas Gerais, Brazil. The crystals are quite large and a greenish-yellow. RI is given as 1.571-1.576 with a birefringence of 0.005 and SG of 2.69. M.O'D.

DE GOUTIÈRE, A., 1988. Photomicrography of gemstones. *Gemological Digest* 2, 3, 35-6, 3 figs in colour.

A brief description of the techniques used to photograph inclusions in gemstones. M.O'D.

DELBASTEH-MIANDOAB, R., 1988. Spodumene afghanischer und brasilianischer Herkunft. (The origin of Afghan and Brazilian spodumene.) *Kurzmitteilungen aus dem Institut für Edelsteinforschung der Johannes-Gutenberg Universität Mainz*, **4**, 2, 9-10, 2 figs.

Pink, green and colourless spodumene crystals from Afghanistan and Brazil show a variety of inclusions. Idiomorphic beryl, quartz, Ca-

amphiboles, Ca-pyroxenes, muscovite, lepidolite and zircon are among the minerals found. Also observed were two, and three-phase inclusions, negative crystals and fragments of opaque or minerals. Bent fissures and small etched tubes were noticed. Mn-content was found to be approximately proportional to the intensity of the colours. In the green crystals chemical analysis indicated that the colour was caused by Fe rather than Cr. M.O'D.

FRAZIER, S., FRAZIER, A., 1988. The Steinkaulenberg in Idar-Oberstein. *Lapidary Journal*, **42**, 7, 23-35, 4 figs (2 in colour.)

Agates have long been known from the prominent mountain overlooking Idar-Oberstein. Commercial mining there ceased in 1870/71 but the article reviews the mining history before that time. M.O'D.

HÄNNI, H.A., 1988. Les grenats. (Garnets.) *Revue de Gemmologie*, 96, 15-19, 11 figs (10 in colour).

The garnet group is reviewed with reference to the composition of the gem varieties which are described. M.O'D.

HÄNNI, H.A., WEIBEL, M., 1988. Origin of the cat's-eye effect in heat treated zircons from Sri Lanka. *Australian Gemmologist*, **16**, 10, 363-6, 5 figs.

Heat treatment is shown to produce minute disc-like fractures in some zircons, parallel to the *c* axis of the crystals, thought to be due to the decomposition of included apatite crystals which cause prismatic cleavages to develop. Another type exhibits needle-like inclusions. R.K.M.

HICKS, T., 1988. An American beauty. *Lapidary Journal* **42**, 6, 44-8, 4 figs (1 in colour).

A description of the rubies found in Cowee Valley, North Carolina, USA. M.O'D.

HRABANEK, J., 1988. Moldavite aus Süd-Böhmen und Süd-Mähren. (Moldavite from southern Bohemia and southern Moravia.) *Kurzmitteilungen aus dem Institut für Edelsteinforschung der Johannes Gutenberg-Universität Mainz*, **4**, 2, 10-11, 1 fig.

Characteristic inclusions of lechatelierite help to distinguish natural from artificial glass as well as distinctive $Al/Na0_2 + K$ ratios. M.O'D.

HUTTON, D.R., TROUP, G.J., 1988. The identification of a natural ruby by electron spin resonance (ESR). *Australian Gemmologist*, **16**, 11, 399-400, 2 figs.

A brief account of procedure and identifying ESR absorption features in a ruby variously identified previously as synthetic or natural. Writers speculate on whether other large rubies have been identified incorrectly as synthetic. R.K.M.

HUGHES, R.W., 1988. Pleochroism and colored stone grading. *Gemological Digest*, **2**, 3, 16-24, 9 figs.

Grading of coloured stones has to take pleochroism into account and various ways in which this can be done are discussed. M.O'D.

HUGHES, R.W., SERSEN, W.J., 1988. The Kanchanaburi sapphire secret. *Gemological Digest*, **2**, 3, 37-9, 3 figs in colour.

This piece gives a description, from the grading standpoint, of the Thai blue sapphires. M.O'D.

KOIVULA, J.I., 1988. Nasute: the soldier. *Australian Gemmologist*, **16**, 10, 388-9, 1 fig. in colour.

An amusing description, not of amber as such, but of a soldier termite entombed in amber some 35 million years ago. One strange fact emerges; many termites were trapped in this way, but an entrapped 'soldier' is quite rare. (Perhaps specialized 'military' were fed by the worker termites and did not often need to venture onto the resin bearing trees?)

The repellent fluid of the Nasute species is trinervitane, highly offensive, and lethal to ants etc, unknown elsewhere in nature. It would even divert anteaters from an attack. R.K.M.

KOIVULA, J.I., FRYER, C.W., 1988. Gemmologische Kurzinformationen. Native bismuth in quartz. *Zeitschrift der Deutschen Gemmologischen Gesellschaft*, **36**, 3/4, 168-70, 2 figs.

This note deals with native bismuth in quartz, from Teofilo Otoni, Minas Gerais, Brazil. The colourless host weighed 4.1 ct and measured 9.1 x 8.3 x 6.68 mm, and was purchased as a faceted emerald. The bismuth inclusions were accompanied by numerous, highly refractive tension fractures. E.S.

LANDAIS, E., 1988. Un réfractomètre universel automatique le 'Dialsan'. *Revue de Gemmologie*, 96, 7-8, 5 figs.

A refractometer developed by the Swiss firm of Djévahirdjan measures refractive indices in the range 1.44 to 3.00. It makes use of the Brewster angle and indicates readings digitally. An accuracy of $\pm$ 0.02 is claimed. M.O'D.

LANDMESSER, M., 1988. Uber den sogennanten 'Streifenchalcedon'. (About the so-called banded chalcedony.) *Kurzmitteilungen aus dem Institut für Edelsteinforschung der Johannes Gutenberg-Universität Mainz*, **4**, 2, 5-8, 7 figs (1 in colour).

Using polarized light banded bluish quartz aggregates have been distinguished from agates. Length-fast chalcedony is rare in the aggregates which consist mainly of length-slow chalcedony and larger quartz crystals. The detail of the banding differs from that seen in most agates and from the Uruguay-type banding. Aspects of formation are discussed. Specimens are from Namibia. M.O'D.

LANDMESSER, M., 1988. Bau und Bildung der Achate. (Structure and formation of agate.) *Lapis*, **13**, 9, 11-28, 47 figs (22 in colour).

The nature of the structure and formation of agate is reviewed with the aid of some high quality photographs, some taken with the electron microscope. M.O'D.

LARSEN, I., 1988. Das Sammeln von schleifbaren Mineralien und losen Einzelkristallen in Raum Mendig, Bell und Volkesfeld. (The occurrence of cuttable minerals and loose single crystals in the area of Mendig, Bell and Volkesfeld.) *Emser Hefte*, **9**, 4, 2-18, 14 figs (11 in colour).

Hauyne, olivine and sanidine, are found in the areas of Mendig, Bell and Volkesfeld, south of the Laacher See in the Eifel volcanic area of West Germany. These and other minerals are described. M.O'D.

LIU, G., KANG, X., ZHANG, L., 1988. On the genesis of demantoid from Xinjiang, China. *Chinese Journal of Geochemistry*, **5**, 4, 381-90.

Demantoid occurs in asbestos veins cutting ultramafic rocks in the W of the Zuenggel basin, Xinjiang. The garnets contain ±90% of the andradite molecule and range from emerald-green, to yellow-green, light green and apple green. The gem-quality, transparent, emerald-green variety forms 2 mm rhombic dodecahedra. Chemical analysis gave SiO_2 35.14, Al_2O_3 0.71, Cr_2O_3 0.531, Fe_2O_3 29.13, FeO 0.75, CaO 32.17, MgO 0.34, TiO_2 0.018, = 98.79; *n* 1.888, SG 3.835, *a* 12.06Å, VHN 1195=1200 kg/mm^2 (H.7.1=7.2). Mössbauer spectroscopy showed that Fe^{3+} occupies the octahedral site; IR absorption spectra are reported. The necessary trace Cr was derived from chromite and Cr-spinel in the ultramafic bodies. R.A.H.

MERTENS, R., 1988. Gemmologische Kurzinformationen. Schleifwürdiger Variscit aus dem Hunsrück. *Zeitschrift der Deutschen Gemmologischen Gesellschaft*, **36**, 3/4, 170-1.

Some cuttable variscite from the Hunsrueck, the mountain range between the Nahe and the Moselle, is described. The variscite is green. E.S.

MUNTYAN, B.L., 1988. Amazonite: The magic of microcline. *Coloured Stone*, *121*, 6, 15-29, 2 figs in colour.

The main American locations for amazonite as briefly described. M.O'D.

NASSAU, K., MILLER, A.E., 1988. Strontium titanate. An index to the literature on properties and the growth of single crystals. *Journal of Crystal Growth*, 91, 373-81, 1 fig.

Single crystals of $SrTiO_3$ have been found to be useful substrates for the epitaxial growth of high temperature superconducting films. Over 100 papers are listed in this index. Many have gemmological interest. M.O'D.

PIENAAR, H.S., 1988. A numerical approach to gemstone identification. *Australian Gemmologist*, **16**, 10, 374-8, 4 lists.

A rather way-out method of arriving at a reference number derived basically from the SG and RI of a species which, it is suggested, should make identification simpler. It is derived from on a formula devised by Gladstone and Gale in 1964, who were working on liquids, apparently to obtain constants which would be unaffected by temperature. [Constants of solids vary only very slightly in the normal ambient range so this advantage is lost.] RI 1.81 is used for all gems above the range of refractometer. Some ranges definitely overlap. [There are easier ways to identify gems today] R.K.M.

RAMSEY, J.L., 1988. Brazil, the ultimate field trip. *Lapidary Journal*, **42**, 5, 32-40, 7 figs (6 in colour).

The gemstones of Brazil are reviewed with details of their main occurrences. M.O'D.

REINITZ, I.M., ROSSMAN, G.R., 1988. Role of natural radiation in tourmaline coloration. *American Mineralogist*, 73, 822-5, 4 figs.

Optical spectra of elbaite subjected to large controlled doses of gamma radiation were found to show the same spectroscopic features as natural stones. Pink elbaite was examined for the purpose of this study. Absorption feature of Mn^{2+} in nearly colourless elbaites are lost during artificial irradiation, presumably due to $Mn^{2+} \rightarrow Mn^{3+}$ transformation. The radiation that some Californian pegmatite tourmalines have undergone has been computed with reference to artifically irradiated samples. The amounts usually correspond to the amounts needed

to restore the colour to elbaites that have lost colour during laboratory heat treatment and this shows that colour in natural pink elbaite is the result of natural radiation. The radiation process in nature could only have been effective if the pegmatite cooled below the decolourizing temperature of tourmaline. It is probable that most pink elbaite grew as near-colourless crystals in the pegmatites, only becoming pink from oxidation of Mn through ionizing radiation. M.O'D.

ROBERT, D., 1988. Padparadschas traités par irradiation. *Revue de Gemmologie*, 96, 4, 2 figs in colour.

Examples of corundum irradiated to give a padparadshah colour are given. A dosage of 309 Mrad is used. M.O'D.

SCHIER, J., 1988. Romancing the iris. *Lapidary Journal*, **42**, 7, 66-7, 4 figs in colour.

Iris agate is briefly described with particular reference to specimens found in Montana, USA. M.O'D.

SCHRADER, H.-W., 1988. Gemmologische Kurzinformationen. Synthetische Smaragde nach dem Hydrothermalverfahren aus der USSR – eine Ergänzung. *Zeitschrift der Deutschen Gemmologischen Gesellschaft*, **36**, 3/4, 173-4, 1 table.

Chemical data of nickel-bearing hydrothermally grown synthetic emeralds from the USSR are presented. E.S.

SERSEN, W.J., 1988. Colored stone grading and the question of nomenclature. *Gemological Digest*, 2, 3, 29-34.

Nomenclature use and misuse in the coloured stone grading context, is discussed and a set of standardized terms suggested. M.O'D.

STRIPP, D.M., 1988. The soft touch. *Lapidary Journal*, **42**, 6, 20-36, 7 figs (4 in colour).

An account of the faceting techniques practised by Art Grant who specilizes in difficult materials. Pleochroism is attributed to fluorite. M.O'D.

THOMAS, A.E., 1988. Emeralds of the N.E. Transvaal. *South African Gemmologist*, **3**, **1**, 5-13, 7 figs (6 in colour).

An account of the emerald deposits in the north-eastern Transvaal, South Africa with a partial bibliography of published papers. M.O'D.

TRET'YAKOVA, L.I., VOKHMENSTEV, A. YA., OSTROUMOV, M.N., 1987. (Diagonostic reflectance spectra for jewellery grade and industrial stones.) (Russian with English abstract.) *Zapiski Vses Min. Obshch*, **116**, 4, 486-97.

The IR reflectance spectra are presented over the range 400=1600 and 700=1600 cm^{-1} for gem and commercial grade stones. The location of the reflectance bands and of diffuse reflections in the visible range (400=800 nm) is tabulated for diamond, ruby, sapphire, chrysoberyl, alexandrite, spinel, citrine, amethyst, rose quartz, chrysoprase, chrysolite, zircon (hyacinth), pyrope, almandine, uvarovite, topaz, emerald, etc. Spectra of diffuse reflections are given for 51 gemstones. R.A.H.

WEERTH, A., 1988. Edelsteinvorkommen im Schatten der Achttausender. (Gem locations in the shadow of eight thousand [metres].) *Lapis*, **13**, 10, 11-28, 39 figs (22 in colour).

Gem minerals from the northern areas of Pakistan are described. They include topaz, tourmaline, spessartine, epidote, beryl, apatite and fluorite. M.O'D.

WILSON, M.M., 1988. Montana moss agate. *Lapidary Journal*, **42**, 7, 58-60, 4 figs (2 in colour).

Fine quality agates are found in a number of places in the state of Montana, USA. The mining and fashioning of the agates are described. M.O'D.

ZEITNER, J.C., 1988. American classics. *Lapidary Journal*, **42**, 7, 36-44, 3 figs in colour.

Agate deposits of North America are reviewed. M.O'D.

Book Reviews

BECKER, V., 1988. *Fabulous Fakes*. Grafton Books, London. pp. viii, 232. Illus. in colour. £19.95.

This is an exellent survey of imitation jewellery and the book is subtitled 'The history of fantasy and fashion jewellery'. It deals with glass, plastic, steel, Berlin iron and a wide variety of superficially unlikely materials used for ornament. The impetus toward the use of these materials began in the eighteenth century with a great increase in the use of paste accompanying the fashion for artifice and display which was so much a feature of that period. The next period to have a chapter to itself is described as Neo-classic to Romantic and covers the new regime in France, which, succeeding the Revolution, developed its own distinctive style characterized by a classical elegance and which later turned into a less severe and delicate fashion. Cameos were characteristic of this period and the use of Berlin iron and jet began at this time.

By the beginning of the twentieth century the somewhat heavy style of the late Victorian years had been succeeded by a more natural appearance in fashion generally. This period saw the rise of designers like Chanel; there was a great exuberance of design and many of the pieces illustrated show an amazing panache in the use of materials. The Art Deco years have a chapter of their own which is called 'Sophisticated barbarism' – the turning point in the use of decoration is said to be the 1910 performance in Paris of Diaghilev's Schéhérazade. The 'Cocktail style' covers the years 1930 – 1940 and with a break for the war, jewellery was overtaken by the rebellious styles of the 1960s, which to some extant still obtain today. This is a jolly good book; there is a useful list of references and plenty of first-class pictures, some reproducing sales catalogues which must be collectors' pieces by now.

M.O'D.

BURCHARD, U., 1986. *Mineral museums of Europe*. Walnut Hill Publishing Company with the Mineralogical Record, Carson City, Nevada, USA. pp. 269. Illus. in colour. £40.00.

Western European museums only are covered in this beautifully illustrated guide. Museums are arranged by country and in general only those with a full public access are included. Most entries give a historical account of the collections and all have listings of specimens of world or slightly lesser importance; this is in order to help the reader track down items that he particularly wants to see. This is not only a useful book but is pleasing to read through for interest.

M.O'D.

CHERMETTE, A., 1986. *La fluorite*. (Fluorite.) Gaston Lachurie, Paris. pp. 171. Illus. in black and white and in colour. FF180.

This is a useful introduction to fluorite and is, so far as I can see, one of the very few monographs to be devoted to this mineral. Though emphasis is placed on French deposits introductory chapters describe the main features, including crystallography, physical and optical properties and provide brief notes on the cause of colour and luminescence. Important world deposits are described and those in France marked on a map. The economic importance of fluorite is explained and production statistics given. There is a short though useful bibliography.

M.O'D.

GHASWALA, S., 1987. *Diamond, king of gems*. Bombay. pp. 302. Illus. in black and white. RS 175/-.

This is a useful survey of the diamond in all its aspects and although there is not much to say that is new, there are many interesting sidelights of Indian practice. Furthermore, the information is up-to-date so that the book will form a quick reference guide to the commercial handling of rough, the details of which vary from time to time. The illustrations, which are of fair quality, show a number of Indian scenes as well as portraits of celebrated diamantaires. The only serious lack is a bibliography but none the less the text is accurate and lucid; the book represents good value for students and will undoubtedly be used in this context.

M.O'D.

NRIAGU, J.O., MOORE, P.B., 1984. *Phosphate minerals*. Springer, Berlin. pp. vi, 442. Illus. in black and white. Price on application.

For years so much work has been carried out on the phosphates that all comprehensive texts are long out of date. This book attempts to improve on this position by listing all the known phosphates and at

the same time giving a set of accompanying chapters dealing with current work and problems. The preliminary descriptive section of 137 pages provides the best extent general survey in which details of each mineral are given, together with up-to-date references and constants. M.O'D.

O'DONOGHUE, M. 1988. *Gemstones*. Chapman and Hall, London and New York. pp XIV, 372. 18 colour plates. Line figures. £37.50

A few years ago the author mentioned his intent to rewrite and update *Gemstones*, the classic standard work by Dr G. F. Herbert Smith, which ran to some fourteen editions in half a century. The present book is shorter and is more a work of reference than a teaching text, but in other respects Mr O'Donoghue is to be congratulated on producing a modern book which, although written to a rather different format, takes over in place of the now regrettably unobtainable 'Herbert Smith'.

The short preface claims that this is the first attempt in English to bring together developments of the past thirty years. But the later editions of Webster's *Gems* were such attempts, as were works by other authors, and this new *Gemstones* scores in this respect mainly from having been written after the latest developments rather than before them.

Some of the colour plates supplied by the British Geological Survey are familiar friends from other works. Line drawings are also recognized. Much of the information has been abstracted from well-known authoritative works and may have suffered a little by drastic condensation from several large volumes into one comparatively slim one.

Misprints and errors are few and minor but some are mistakes in the source material which have been carried forward apparently without checking.

Dolomite, a lapidary challenge rather than a useful gem, has perfect rhombohedral cleavage, i.e. three directions, not one. Second order prisms are attributed to topaz, but the biaxial systems do not have first and second order forms. Amber is described as having a 'sticky feel'. In more than fifty years I have not noticed this. A test for Plato twinning is mentioned under synthetic corundum, but is not explained. The index refers to the brief glossary at the beginning of the book, but the Plato effect is not there. But these are small matters and should not detract from the general usefulness of the book.

The large descriptive section is split into Inorganic and Organic chapters, each dealing with most of its contents in alphabetical order, an arrangement which I found very convenient, even though it meant that the vastly more important commercial gems are also included strictly in their turn, but recognizable in most cases by the greater length of their entries. Rarer and collectors' gems are for the most part dealt with briefly, if sufficiently. The origins of gem names are given in all cases. Further chapters deal with Synthetics and Methods of Synthesis. Early sections cover the Formation of Gems with particular emphasis on their inclusions; the Nature of Gemstones; Gem Testing and Recent Developments in this; Colour with particular reference to the theory of its causes; Fashioning; Grading and Marketing.

Constants (SG, RI, DR, etc) are presented as ranges of possible values. Some of these differ from those published in most textbooks. Many minerals do vary quite widely and odd specimens are occasionally found which have testing constants outside the normally accepted range. Such occurrences should certainly be noted but to include them as end members of a range extends it possibly on the strength of a single non-typical specimen. Biaxial gems have values for the beta index quoted, but one spondumene which lacks this less useful constant gets accidentally relegated to uniaxial status.

Appendices include reference lists of SG and RI, mostly reduced to two places of decimals, but which do not always agree with those in the main text. Lists of Birefringence and Disperson would be more useful if they were complete. It is not really sufficient to say that those missing will be found in the text. They are all in the text so, on that basis, why print the lists at all? The highest disperson of glass is quoted as 'about 0.016'. This must mean natural glasses, for flint glass, much used in pastes, can go up to 0.040 or more.

The exhaustive bibliography runs to eleven pages but rather strangely does not include Herbert Smith's *Gemstones* which must have been the origin of Mr O'Donoghue's inspiration. Nor is that book mentioned elsewhere.

I am told that the author has said "It's all in there!". I am inclined to think that, at the very least, most of it certainly is.

R.K.M.

RAULET, S., 1986. *Van Cleef and Arpels*. Rizzoli, New York. pp. 328. Illus. in black and white and in colour. £58.00.

The celebrated jewellery firm of Van Cleef and Arpels was founded in Paris towards the end of the nineteenth century. Coinciding with the development of Art Nouveau the firm also attracted from the first the rich emigrés from Russia and American visitors to Paris. Later the business was expanded to towns outside Paris and up to the outbreak of war in 1939 it attracted an international and sometimes royal clientèle by virtue of its designs and the high quality materials used. After the war the firm continued to thrive and to attract wealthy customers and perhaps the high point reached in this context was the order for the jewellery used at the coronation of the late Shah of Iran in 1967.

The early chapters on the book tell the story of the birth and development of Van Cleef and Arpels. Succeeding chapters describe some of the famous diamonds which have passed through their hands and some of the most individual designs. Later in the book many pieces are illustrated in colour.

M.O'D.

SMITH, J.V., BROWN, W.L., 1988. *Feldspar minerals*. Second revised and extended edition. Vol. 1. Springer, Berlin. pp. xviii, 828. Illus. in black and white. DM360.

The history of this major work needs some explanation. The first edition was published in 1974 in two volumes with a third projected but never completed. By 1977 the incomplete draft for the projected third volume had become out-of-date, largely because of the advances made in the knowledge of feldspars – this in turn was fuelled by lunar mineral studies. The second edition is to be in two volumes; this first one is to be the new version of the original volumes 1 and 2 and the second volume will be an update of the unpublished volume 3.

The first volume deals with the origins, crystal structures, physical properties and experimental techniques employed in the study of feldspars, cell parameters and macroscopic thermal expansion and compression, light optics, nomenclature and determinative diagrams, electron-optical techniques, spectroscopy, miscellaneous physical properties, chemical properties, formation and intergrowths. References are extensive and divided into pre-and post-1973 and there are name, geographical and subject indexes. The second volume will cover phases relations and geological occurrence.

Feldspars are the most widespread of any mineral group and constitute about 60% of the earth's crust. Gemmologists will be familiar with the two main groupings of the feldspars but the relationship between individual minerals in the two groups and between the groups themselves are complex and not always easy to resolve. The various attempts and the techniques used in this task are well documented here and although the price is perhaps too high for the private library, serious students of feldspars should at least be aware of the book and know where it may be consulted. M.O'D.

TOMALIN, S., 1988. *Beads*. David & Charles, Newton Abbot. pp. 128. Illus. in colour. £10.95.

A book on beads is welcome since there are very few others in English. Not only does the author describe a great number of bead materials but she goes on to illustrate the stages of using beads for the manufacture of jewellery. As far as I can see the details she gives on the threading of beads have not been published (or not so conveniently) before and this is very interesting to read about. After the introductory chapters the book, very sensibly, deals with seven separate projects for making jewellery so that the reader can see exactly how it is done.

At the price I can recommend this book and the standard of illustration is high. Some of the details on gemstones, particularly the names, are incorrect and others are confusing, but this is not a gemmology text. M.O'D.

WAGNER, U., 1988. *Schatzkammer Hohe Tauern*. (Treasure house Hohe Tauern.) Doris Bode Verag, Haltern. Illus. in colour. DM39.

The Hohe Tauern area in the south of Austria includes the emerald locality of the Habachtal as well as the Ober-and Untersulzbachtal. Fine epidote crystals are found here, as well as phenakite and some tourmaline. The photographs seem to have reached a new level of excellence and there is a short bibliography. M.O'D.

Proceedings of the Gemmological Association of Great Britain and Association Notices

GIFTS TO THE ASSOCIATION

The Council of the Association are indebted to the following for their gifts:

Mr E. Fontana and Mr W.L. Kunsch of Sao Bernardo do Campo, Brazil, for a copy of the book *Gems of Brazil*.

Dr Dietmar Schwarz of Ouro Preto, Brazil, for a copy of his book *Esmeraldas – Inclusoes em Gemas*.

NEWS OF FELLOWS

The first International Amber Symposium took place in Poland from 20 to 23 October 1988. Helen Fraquet, FGA, attended as the only gemmologist at the event, which attracted 52 registrations from as far afield as Russia, Tanzania and the USA. The cross-interests of participants from differing backgrounds of geology, mineralogy, archaeology and paleoentomology, led to a vibrant series of discussions over two days of presentations in Warsaw. There was also a two-day field trip to Malbork and Golansk to view the rich archaeological and modern collections, as well as the current methods of amber extraction in the Baltic area and processing techniques. Full details will be published in a future issue of the *Journal*.

In October 1988 at Dulwich College, Michael O'Donoghue organized and assembled an exhibition of gemstones, crystals and rare books.

MEMBERS' MEETINGS

Midlands Branch

On 21 October 1988 at Dr Johnson House, Colmore Circus, Birmingham, the guest speaker was Mr Alan Hodgkinson, FGA, who brought along a selection of the gems in his collection. These included a 49 ct sapphire crystal, a black opal, a variety of colour-change gems, and a large red beryl.

On 18 November 1988 at Dr Johnson House, Mr R.V. Huddlestone gave an illustrated presentation on Siberian diamonds.

North West Branch

On 18 November 1988 at Church House, Hanover Street, Liverpool, the Annual General Meeting was held at which Mr R. Perrett, FGA, and Mrs I. Knight, FGA, were re-elected Chairman and Secretary respectively.

ANNUAL REUNION OF MEMBERS AND PRESENTATION OF AWARDS

The Annual Reunion of Members and Presentation of Awards was held on 25 November 1988 at the Guildhall, Gresham Street, London EC2. The Chairman of the Association, Mr David J. Callaghan, presided at the Presentation and welcomed those present to the new venue. He explained that the Goldsmiths' Hall, where the Presentation is usually held, was being refurbished, and he gave a brief history of the Guildhall, parts of which were almost a thousand years old.

This year award winners from many countries outside the UK including Brazil, Belgium, Canada, Italy, Japan, Kenya, The Netherlands, Spain, Sweden, USA and Venezuela, were present to receive their Diplomas.

Mr Callaghan then called upon Professor R.A. Howie, past-President of the Mineralogical Society and for many years Professor of Mineralogy at King's College, London, to present the awards.

After the presentation Professor Howie delivered his address. He began by quoting the words of his driving test examiner: 'OK, you have passed – now the real learning begins'. The same could surely apply to those who had just received their Diplomas. The best mineralogist is the one who has examined the most minerals and Professor Howie felt sure that the same principle applied to gemmologists; they should take every opportunity to examine as many gems as possible. Like mineralogists, gemmologists have to possess a unique blend of aesthetic and scientific judgement. At one checkout in a supermarket in Cambridge, Massachusetts, there was a sign which read 'One basket only'. A

Figs 1 and 2. The Anderson/Bank Prize winner, Birgitte Muste, and the Rayner Diploma Prize winner, David Webster, receiving their awards from Professor R.A. Howie.

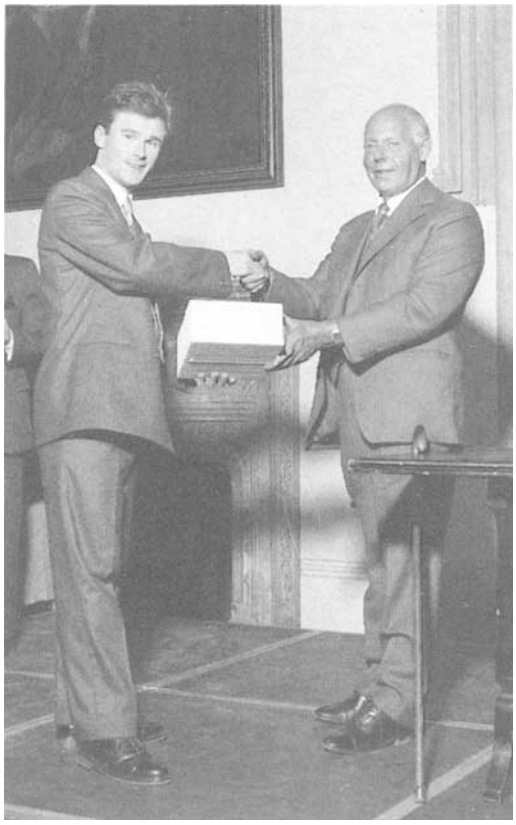

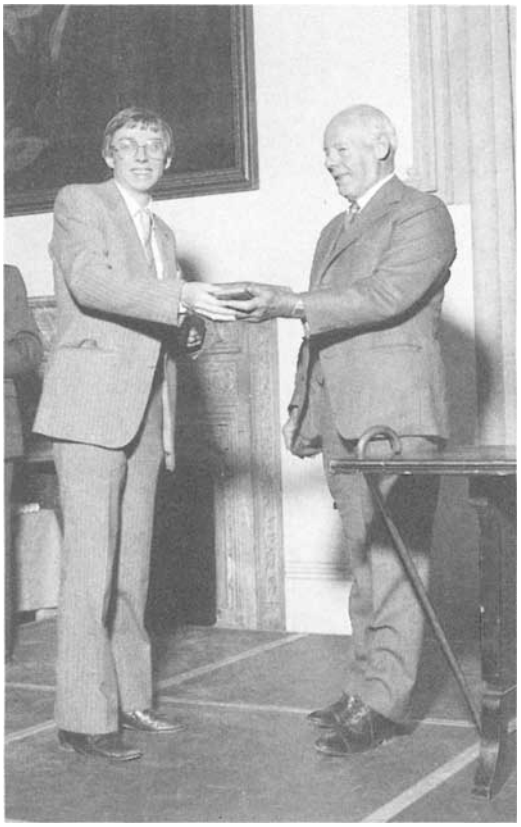

Figs 3 and 4. The Anderson Medal winner, Robert Maxwell Torrens, and the Rayner Preliminary Prize winner, Catherine Rieger, receiving their awards from Professor Howie.

young man approached with two baskets and proceeded to unload them. The lady at the checkout said to him: 'You are either from Harvard and can't count, or you are from MIT and can't read'!

He recommended that gems should be examined with one's eye or hand-lens rather than going straight to instrumental techniques. He stressed that mineralogy is the fundamental science which is the base of our own knowledge of gemmology.

Professor Howie went on to talk about his twenty-five years at King's College, London, although he had moved to Royal Holloway and Bedford New College, also part of the University of London, in 1985. Many eminent gemmologists had come from King's, including Basil Anderson, Alan Jobbins (the Editor of *the Journal*), and C.J.Payne. Professor Howie was at one time Admissions Tutor in Geology and a young student came to him and said that he had devised a new scheme for identifying minerals. Before he demonstrated this new method, Professor Howie said that he had a test for him and asked him to identify a colourless octahedral crystal of diamond. 'Fluorite', said the student. He was then given a hardness set to verify this, and when he passed the hardness of fluorite (4) and went steadily on to hardness 8, he was asked if he had any comment. 'Hard fluorite' said the student! By all means make a tentative identification from a stone's appearance, but always be prepared to alter your identification on the basis of further tests.

Professor Howie then spoke about the importance of the nomenclature of mineralogy. In 1950 the International Mineralogical Association set up a Commission for New Minerals and Mineral Names, and any new mineral should be approved by them before publication. There is a tendancy to give new names to known minerals and gems and one must be wary of this. Not all scientists, however, are happy to abide by the decision of the Commission. It comes down particularly heavily on editors using unapproved names. Professor Howie said that the only one he personally had a sympathy with was tanzanite, a lovely stone, though officially blue zoisite.

He then went on to stress the growing importance of computers in gemmology, and the necessity to learn how to use one. But, of course, the information you obtain from them is only as good as the data put in.

Professor Howie concluded with an exhortation modified from the inaugural address of President J.F. Kennedy: 'Think not of what the Gemmological Association can do for you, but what you can do for the Gemmological Association' In other words, attend the Association's meetings, and bombard the Editor with papers for the Journal!

The Vice-Chairman, Mr Noel Deeks, gave the vote of thanks. He said how fortunate we were that Professor Howie was able to present the awards, as he is a man of great standing in his field as well as being a humorist. He has dedicated most of his working life to mineralogy and is recognized throughout the world as a leading authority in his field. Mr Deeks went on: 'It may well be that you will not be able to aspire to these great heights, but possibly, as Professor Howie said, many of you will be able to make a contribution to the Gemmological Association by becoming members of the Council or by serving on a committee. If you are able to offer your services we will welcome you with open arms'. He went on to emphasize Professor Howie's point that you never stop learning, and hoped that many of those who had just qualified would go on to take the new Diamond Course which will be introduced very shortly.

Mr Callaghan then paid tribute to Mr Leslie Fitzgerald and his team for all their work in organizing the examinations and also thanked the Examiners and Instructors, congratulating them on the work done.

In conclusion Mr Callaghan then made a special presentation to Mr John Green who is retiring from the Rayner Optical Company, with the Association's grateful thanks for long service.

GEM DIAMOND EXAMINATION 1988

In the 1988 Gem Diamond Examination 48 candidates sat and 46 qualified, one with Distinction. Their names are as follows:

Qualified with Distinction
Burques Montserrat, Ma Jesús, Barcelona, Spain.

Qualified

Allen, Elizabeth A., London.
Aresti, Tony, Enfield.
Arthur, Lynne, Denny.
Asiainde Los Angeles, Jorge J., Barcelona, Spain.
Bernad Serra, Marcos, Barcelona, Spain.
Bernal Garcia, José, Barcelona, Spain.
Billingham, Carole J., Richmond.
Chan, Richard Ki-Mun, London.
Cros, Jean-Marc, London.
Dallas, James A., London.
Dalmau Bafulluy, Ma Nieves, Barcelona, Spain.
Dunn, Wendy S., London.
Dunstall, Robert, Northampton.
Glover, Graham D.B., London.
Guarino Alemany, Maite, Barcelona, Spain.
Hilton, Holly A., London.
Humpage, Susan A., Edgbaston.
Huppach, Friedrich H., Earby.
King, Barry J., Bury St Edmunds.
Latre Gonzalez, José, Barcelona, Spain.
Levy, Laurence, London.
Manders, Andrew P., Guildford.
Metaxas, George C., Nicosia, Cyprus.
Millar, Ewan, Paisley.
Molina Torreblanca, Amparo, Barcelona, Spain.
Morena Garcia, Rosa, Barcelona, Spain.
Navarro Garcia, Rodolfo, Barcelona, Spain.
Ortol-Lockwood, Dominique, London.
Padley, Stanley J., Bredenbury.
Pick, Velma M., London.
Pridham, Michelle A., Colchester.
Raymond, Robert S., London.
Riley, Mark J., Gloucester.
Romero Caminero, Luz, Barcelona, Spain.
Rosier, Jane L., Walton-on-Naze.
Sanhueza A., J. Antonio, London.
Sierra Martiñez, Dolores, Barcelona, Spain.
Straitouri, Sophia M., London.
Tait, Alistir W., Edinburgh.
Tapia Canadell, Laura, Barcelona, Spain.
Taylor, Alec E., Glasgow.
Turnbull, Daniel A., Glasgow.
Watson, Margery E., Edinburgh.
Watson, Thomas N., Edinburgh.
Wren, Rebecca J., Ware.

EXAMINATIONS IN GEMMOLOGY 1988

In the 1988 Examinations in Gemmology, 569 candidates sat the Preliminary Examination and 355 (62%) passed, and 398 candidates sat the Diploma Examination and 170 (43%) passed, 15 with Distinction.

In the opinion of the Examiners, no candidate achieved the high standard needed to warrant the award of the Tully Medal.

The Anderson/Bank Prize for the best non-trade candidate of the year in the Diploma Examination has been awarded to Birgitte Margarethe Muste of Dordrecht, The Netherlands.

The Rayner Diploma Prize for the best candidate of the year who derives his main income from activities essentially connected with the jewellery trade has been awarded to David Webster of Glasgow.

The Anderson Metal for the best candidate of the year in the Preliminary Examination has been awarded to Robert Maxwell Torrens of Crieff, Perthshire.

The Rayner Preliminary Prize for the best candidate under the age of 21 years on 1 June of the year of the examination, who derives her main income from activities essentially connected with the jewellery trade has been awarded to Catherine Jane Rieger of Maidstone.

The names of successful candidates are as follows:

DIPLOMA

Anderson/Bank Prize
Muste, Birgitte M., Dordrecht, The Netherlands.

Rayner Diploma Prize
Webster, David, Glasgow.

Qualified with Distinction
Baumann, Yvonne, Dungarvan, Co Waterford, Ireland.
Boozer, Joan B., Hong Kong.
Castro, Ana Isabel, London.
Feenie, Helen L., Hong Kong.
Grieder, Judith Y., Hong Kong.
Hergel, James E., Toronto, Ont., Canada.
Jassinger, Alexandre P.O.L., London.
Kim, Won-Sa, Daejon, Rep. of Korea.
Larsson, Thomas, Jarfalla, Stockholm, Sweden.
Muff, Walter C., Muri, Switzerland.
Muste, Birgitte M., Schoonhoven, The Netherlands.
Nangia, Rani, North Harrow.
Rosoff, Martin, Toronto, Ont., Canada.
Webster, David E., Glasgow.
Winterbottom, Martin, Watford.

Qualified
Alliance, Alma B., Cheadle.
Amiel Fresneda, Josefa, Figueres, Spain.
Atkins, Tristan A., Banstead.
Attar, Simon, London.
Axell, Anita C., Stockholm, Sweden.
Bagnall, Maria, London.
Barber, Susan A., Billingshurst.
Becker, Kim A., Francistown, Botswana.
Belenguer Blat, Ma del Carmen, Valencia, Spain.
Bignotti, Fabrizio, Novara, Italy.
Bode, William E.G., Harrogate.
Bramham, Kathleen, London.
Bramsden, Manny, Maidenhead.
Brandligt-van den Hoed, Maria A.G., Bussum, The Netherlands.
Bridgewood, Alan, Bramhope.
Bron, Harm, Heerenveen, The Netherlands.
Cadavid Tortosa, Manuel, Montgat, Spain.
Carracedo Oliva, Robert, Tarragona, Spain.
Carry, Peter D., Aberdeen.
Chan, Albert H.S., Hong Kong.
Chan, Yuk Ching, Hong Kong.
Cheng, Rosalia, Hong Kong.
Chiu, Sin Y., Hong Kong.
Cijvat, Els, Bussum, The Netherlands.
Climent Coscolluela, Nuria, Barcelona, Spain.
Collins, Steven J.C., Letchworth.
Corée, Henk, Borne, The Netherlands.
Cowdrey, John W.E., Harrow.
Dabell, Louise C., Nottingham.
Deacon, Richard H., Swindon.
De Bevere, Dirk, London.
Dechef, Eveline E.J., Ottawa, Canada.
De Waal, Irina, Delft, The Netherlands.
Easterbrook, Steven, Bridgend.
Escalona Larroy, Josep A., Barcelona, Spain.
Evans, Elma H., Spring Valley, Calif., USA.
Farinos Folgado, Ramon, Ribarroja Del Turia, Spain.
Findlay, Caroline E., London.
Fisher, Barbara E., Kahuku, Hawaii, USA.
Fowler, Jennifer A., Burnley.
Franco da Fonseca, Ana L., Sao Paulo.
Fung, Annie C.Y., Hong Kong.
Gay, Bernice M., Romsey.
Girod, Daniel F.G., Amsterdam, The Netherlands.
Glaysher, Andrew J., Horsham.
Glover, Andrew M., Horsham.
Gohel, Dilhar M., London.
Gomez da Silveira, Luiz A., Sao Paulo, Brazil.
Gordon, Scott M., Okhlahoma City, Okla., USA.
Gouverneur, Keith, Caracas, Venezuela.
Hammett, David W., Glasgow.
Harrison, Roger F.J., King's Langley.
Haufe, Wilfred, Toronto, Ont., Canada.
Hideyuki, Nakata, Tokyo, Japan.
Hiramatsu, Ikuo, Tokyo, Japan.
Hitcham, Peter J., Kingston-upon-Thames.
Hobbs, Fiona G., Winchester.
Holbech, William H., London.
Holloway, Sarah D., London.
Howat, Denise, Hong Kong.
Ivanoff Landovski, Tatiana, Barcelona, Spain.
Janssens, Nadia E., Brussels, Belgium.
Kaiyoorawongs, Julie B., Bangkok, Thailand.
Kathe, Madeline S., Hong Kong.
Kawamoto, Keiko, Hong Kong.
Kothari, Hema, Bombay, India.
Kuwahara, Chizu, Kanagawa Pref., Japan.
Kwan, Suet M., Hong Kong.
Kyriakidou, Katerina A., London.
Lam, Sau W., Hong Kong.
Laurie, John J.W., Monte Carlo, Monaco.
Lewis, Rachel, Stockport.
Lloyd, Florence M., Harpenden.
Lo Wong Chi Ping, Stella, Hong Kong.
Longden, Sharon D., Eckington.
Lopezzo, Lorraine V., Long Valley, NJ, USA.
Maharaj, Rajendra K., Toronto, Ont., Canada.
Mairal Nebot, Susana Ma, Zaragoza, Spain.
Mak Sin Leung, Gary, Kowloon, Hong Kong.
Malarek, Anna, Toronto, Ont., Canada.
Marriott, Janet, Amsterdam, The Netherlands.
Marti Gomez, Emilio A., Valencia, Spain.
Martinez Masip, Amelia Ma, Barcelona, Spain.
Matzener-Levy, Lydia, Zurich, Switzerland.
Mele Ardiaca, Ma Teresa, Barcelona, Spain.
Michalkow, Christina L., Manchester.
Mistry, Mukesh, London.
Moghadam, Paravanah, London.
Ng, Lai Yee, Hong Kong.
Nishizaki, Mikio, Tokyo, Japan.
Norton, Robert, Oak Wood.
Nunes, Michél, George, S. Africa.
Oshima, Takako, Osaka, Japan.
Parr, Rosalind, Wilmslow.
Planelles Fenollosa, Enrique V., Burriana, Spain.
Potts, James D., Telford.
Premnath, K.P., Salem, India.
Pye, James A., Leven.
Renieblas Salo, Sara, Barcelona, Spain.
Revol Macdonald, Brigitte M., Bangkok, Thailand.
Rice, Michael, Hull.
Richner, Sally J., Grosse Pointe, Mich., USA.
Roig Miguel, David, Barcelona, Spain.
Rufli, Jeanette, Stockholm, Sweden.
Rydeng, Rig, Finnsnes, Norway.
Rysenbry-Beens, Jantine C., Haarlem, The Netherlands.
Sayers, Angela C., London.
Schreier, Larry, Skokie, Ill., USA.

Schuch, Yvonne D.J., Capella, Aan den Yssel, The Netherlands.
Scott, Jean V., New York, NY, USA.
Sekiguchi, Kazuyoshi, Tokyo, Japan.
Serra Badia, Lluisa, Barcelona, Spain.
Serras, Helen, Athens, Greece.
Seung, Yuet Fan Pinky, Hong Kong.
Shimizu, Terukazu, Tokyo, Japan.
Sinclair, Anne L.K., London.
Sinclair, Lyall W., Cambridge.
Smith, Kevin M., Bangkok, Thailand.
Sneeringer, Margaret R., Worthington, Ohio, USA.
Socias Barenys, Ma Angels, Barcelona, Spain.
Stead, Heather E., York.
Stone, Emma E., Derby.
Sugihara, Kaori, Tokyo, Japan.
Sumar, Nizar P., Nairobi, Kenya.
Ten Berge, Robert B.H., Zuidlaren, The Netherlands.
Theriault, Peter J., Camden, Me., USA.
Tirat, Pierre, Poitiers, France.
Titina, Meher R., Bombay, India.
Triossi, Amanda C., London.
Tyler, Elizabeth V., London.
Underdown, Derek W., Horsham.
Urvik, Hilde, Oslo, Norway.
Ushio, Tsutae, Fukuoka City, Japan.
Van Camp, Coralie A., Auckland, New Zealand.
Van Deijl, Jacobus H., Parow, South Africa.
Vila Torrejon, Ma Enrique, Valencia, Spain.
Viladrich Ros, Ma Teresa, Barcelona, Spain.
Voordewind, Derk J., Delfzijl, The Netherlands.
Walker, Jeremy R.P., Workington.
Wallin, My, Stockholm, Sweden.
Warshow, Nancy, Nairobi, Kenya.
Weiss, Anthony S., Bushey.
Weston, Jonathan, Stourbridge.
White, Helen Leung Yuk-Ching, Hong Kong.
Wilson, Sandra McKinnon, Cumbernauld.
Wong, Che K., Hong Kong.
Wong, Helen, Toronto, Ont., Canada.
Wood, Teddy, Hong Kong.
Woolley, Shirl L., San Diego, Calif., USA.
Woszczyna, Paul D., Toronto, Ont., Canada.
Yi, Yu Hsiao-Wen, Taipei, Taiwan.
Yokoyama, Haruaki, Kurume City, Japan.
Yoshimoto, Misako, Munakata-gun, Japan.
Zabitsky, Shelley, Toronto, Ont., Canada.
Ziemelis, Ojars, Stockholm, Sweden.

PRELIMINARY

Anderson Medal

Torrens, Robert M., Crieff.

Rayner Preliminary Prize

Rieger, Catherine J., Maidstone.

Qualified

Abul Huda, Samar, Athens, Greece.
Achakane, Abdelaaziz, Birmingham.
Almenar Zamora, José A., Valencia, Spain.
Andrews, Suzanne M., Cheadle Hulme.
Arnau I,Graus, Concepció, Lleida, Spain.
Arranz Garcia, Félix, Cozuelos de Fuentidueña, Spain.
Arrufat I,Cervera, Silvia, Barcelona, Spain.
Asanis, Nikolaos, Athens, Greece.
Asfour, Hana, Athens, Greece.
Aston, Mandy, Birmingham.
Au, Kwok Ming, Hong Kong.
Aulosalo, Liisa H., Turku, Finland.
Azon Vilas, Félix, Almunia de San Juan, Spain.
Badenoch-Jones, Harwood G., Goring-by-Sea.
Barbara Solé, Ma Rosa, Reus, Spain.
Barrabes Lacarda, Silvia, Lleida, Spain.
Basham, Leslie J., Stowmarket.
Bengston, Anne-Marie, Täby, Sweden.
Bercik, R. Mary, Pickering, Ont., Canada.
Bieri, Josiane, Athens, Greece.
Blasco Jimenez, Josep Ma, Barcelona, Spain.
Bofill Montoro, Anna Ma, Barcelona, Spain.
Bohra, Sushil, Jaipur, India.
Boira Roges, Berta, Barcelona, Spain.
Bourdillon, Catriona C.C., London.
Brantly, Rhona M., Rio de Janeiro, Brazil.
Brinkhuis, Petrus J., Langewijk, The Netherlands.
Brotons Llopis, Rafael, Alicante, Spain.
Bubshait, Ahmed I., London.
Buxton, Diana M., Slough.
Canty, Gavin, Auckland, New Zealand.
Carroll, Patricia E., Hong Kong.
Cartwright, Freda H., King's Langley.
Castro, Ana I., London.
Chan, Angela Yin Nae, Hong Kong.
Chan, Chun Kit Michael, Hong Kong.
Chan, Kar Ming, Hong Kong.
Chan, Linda Ann Yong, Hong Kong.
Chan, Mazie Josephine Man-Wah, Hong Kong.
Chan, Mei Kuen, Hong Kong.
Chan, Suk Fun Betty, Hong Kong.
Chan, Wai Wah, Hong Kong.
Chan, Yoke Leng, Hong Kong.
Chen, Qian Yun, Hong Kong.
Cheney, Marguerite D., Rio de Janeiro, Brazil.
Cheung, Kam Ko, Hong Kong.
Chiu, Sau King, Hong Kong.
Chiu, Yuk Lan Rafia, Hong Kong.
Chow, Chi Leung Cristo, Hong Kong.
Chow, Kam King, Hong Kong.
Chow, Kar Wai Kevin, Hong Kong.
Chow, Yuen Ching Rita, Hong Kong.
Cloke, Deborah J., Sevenoaks.
Clover, Wai Ying, Hong Kong.
Cocke, David D., London.

Colley, Gordon, Denny.
Collingwood, Mark A., Pudsey.
Collins, Jessica M., London.
Cope, Andrew R.W., West Bridgford.
Corée, Henk, Borne, The Netherlands.
Corne-Halstenbach, Michele, Geneva, Switzerland.
Corta Alonso, Ma Lina, Barcelona, Spain.
Crosby, Neal J., Menston.
Cross, Margaret J., Leeds.
Davidson, June A., Toronto, Ont., Canada.
De Bevere, Dirk, Brussels, Belgium.
de Crecenzio Ferreira Ramos, Alejandro, Amsterdam, The Netherlands.
De Jonge, Martin L., Utrecht, The Netherlands.
de Kam, Anneke, Schoonhoven, The Netherlands.
Delaini, Giuglia, London.
Deller, Antony M., Mansfield.
Deraniyagala, Isanth R., Selsdon.
Dhir, Parikshat P., Nairobi, Kenya.
Dorab, Brian I., Hong Kong.
Douglas Marshall, Anna T., Cambridge.
Downes, Lisa E., Birmingham.
Dryden, Kenneth E., Spalding.
Eames, Simon F., Hemel Hempstead.
Eccles, Robert B., Bray, Co. Wicklow, Eire.
Edwards, Jennifer L., Hong Kong.
El-Saadi, Siham, Athens, Greece.
Elankainesan, Arulneshan, Colombo, Sri Lanka.
Emden, Lee, High Wycombe.
Ennis, Frances M., Dublin, Eire.
Espinosa Romera, Pedro, La Puerta de Segura, Spain.
Fabregat Miedes, Fernando, Teruel, Spain.
Fan, Siu Kam, Hong Kong.
Feld, Simon, Huddinge, Sweden.
Ferguson, Neil F., Balloch.
Fiducia, Suzanne J., Hong Kong.
Fisher, Barbara E., Hawaii, USA.
Foster, W. James, Pismo Beach, Calif., USA.
Fuertes Arruti, José A., Zaragoza, Spain.
Fuller, Mark R., London.
Fung, Eleanor So-Wan Au, Hong Kong.
Fung, Kam Man, Hong Kong.
Fung, Mun Yung Juliana, Hong Kong.
Galeote Torralbo, Albert X, Barcelona, Spain.
Gallagher, Marie, Middlesbrough.
Ganella Garcia, Ma del Pilar, Moncada i Reixac, Spain.
Garcia Ferrandiz, Javier, Alicante, Spain.
Gardner, Stewart J., Halifax.
George, Wanda M., Nairobi, Kenya.
Ghaffar, Gulnefer, Hong Kong.
Ghysels, Patrick G.B., Brussels, Belgium.
Gill, David C., Wellington, New Zealand.
Girardi, Josephine C., Hong Kong.
Glynn, Peter J., Bangkok, Thailand.
Gonzalez, Marie C.Y., Hong Kong.
Gonzalez Galvan, Francisco A., Jerez de los Caballeros, Spain.
Gower, Sarah-Jane, Yiewsley.
Guerra Vidiella, Laura, Barcelona, Spain.
Gunaratne, Madanasinghage D.R., Manori, Sri Lanka.
Gunther, Kenneth G., Nairobi, Kenya.
Hammett, David W., Glasgow.
Hara, Yoshiko, Osaka, Japan.
Harding, Ian, Nottingham.
Hasan, Zia-Ul, Toronto, Ont., Canada.
Hassink, Karin, Polsbroek, The Netherlands.
Hernandez Marin, Ma Teresa, Elx, Spain.
Higuchi, Miyuki, London.
Hirst, Jenny E., London.
Ho, Kar Fai Patrick, Hong Kong.
Ho, Kiam Fong, Singapore.
Ho, Siu Yeung, Hong Kong.
Hoffman, Cindy W., Herndon, Va., USA.
Holmberg, Petri I., Turku, Finland.
Hughes, David J., Cardiff.
Hui, Wah Kam, Hong Kong.
Hui, Wai Kwong, Hong Kong.
Huppach, Stefan A., Colne.
Hyde, Elizabeth E., Reading.
Imakubo, Kouhei, Nara, Japan.
Ingman, Ulf Nils Goran, Karis, Finland.
Irie, Michiko, Hyogo, Japan.
Isern Truy, Enric, Vic, Tarragona, Spain.
Jackson, Alexander V.M., Birmingham.
Jackson, Dan N., Watford.
Jacome Bolton, Maria José Peres, Luton.
Jain, Sanjay, London.
Jarvis, Hilary A., London.
Jassinger, Alexandre P.O.L., London.
Johnston, Paul W., Belfast.
Jones, Paul D., Isle of Man.
Kaiyoorawongs, Julie B., Bangkok, Thailand.
Kamman, Maria A., Schoonhoven, The Netherlands.
Kangasniemi, Arto J., Inari, Finland.
Kanodia, Jai P., London.
Kara, Shams A., Markham, Ont., Canada.
Karkkulainen, Kari J., Oulu, Finland.
Kehe, Alan, Nairobi, Kenya.
Keusch, Schohreh, Hong Kong.
Knott, Teresa, Leicester.
Ko, Olivia, Hong Kong.
Ko, Siu-Wah Johnny, Hong Kong.
Kochx, Johanna M.C., Amsterdam, The Netherlands.
Kothari, Hema, Bombay, India.
Ku, Herching, Hong Kong.
Laborda Ferrer, Ma Angeles, Zaragoza, Spain.
Lamb, Lois N., London.
Langridge, John P., Sompting.

Lau, Yuet Yung Ellen, Hong Kong.
Laurie, John J.W., Monte Carlo, Monaco.
Law, Patricia M., London.
Lawrence, Craig, Brampton, Ont., Canada.
Lazaro Anglada, Ma José, Zaragoza, Spain.
Leddicoat, Andrew, Guiseley.
Lederman, Victor, Koge, Denmark.
Lee, Ophelia, Hong Kong.
Lehtinen, Kirsi K., Helsinki, Finland.
Leon Martin, Josefa, El Tiemblo, Spain.
Leung, Chi Hon, Hong Kong.
Leung Lam, Anne, Kowloon, Hong Kong.
Lewis, Karen J., Hong Kong.
Li, Chi Man, Hong Kong.
Lilley, Elaine, Hull.
Lilly, Gregory R., Taranaki, New Zealand.
Ling, Lai Ching Apollonia, Hong Kong.
Link, Constance A., Nairobi, Kenya.
Liu, Charles Kwok-Hung, Hong Kong.
Liu, Mei Fong, Hong Kong.
Liyanage, Don C.S., Ashford Common.
Lockie, Debra L., Hong Kong.
Lodhia, Harish, Leicester.
Lopez Berbel, Ricardo, Guadix, Spain.
Lui, Man Lee, Hong Kong.
Luis|I. Pavia, Rosa Ma, Castello, Spain.
Luzondo Olea, Blancanieves, Tolosa, Spain.
McCosh, Samuel M., Birkenhead.
McKenna, Joseph T., London.
MacGregor, Rory, Rio de Janeiro, Brazil.
MacMillan, Fenella J., Borstal.
Magina Arachchige, Wimalaséna, Maharigama, Sri Lanka.
Mak, Kai Wing, Hong Kong.
Makinen, Heidi C., Hong Kong.
Manjavacas Cañego, Carina, Barcelona, Spain.
Mann, Alexandrina E., Nottingham.
Mannequin, Gilles E., Antananarivo, Madagascar.
Mariona De Urquijo, Victoria E., Zaragoza, Spain.
Martinez Del Campo, Leopoldo, Zaragoza, Spain.
Mas Lillo, Javier F., San Vicente de Raspeig, Spain.
Masters, Gary W., Alton.
Maung, Thet Oo, Bangkok, Thailand.
Maycock, Richard C., Wilton.
Merchant, Arti R., Bombay, India.
Minami, Kazumasa, Osaka, Japan.
Moghadam, Parvaneh, London.
More, Deepak K., Hong Kong.
Morris, David C., Dover.
Mossberg, Karsti M.C., Uddevalla, Sweden.
Mustchin, Vivienne, Auckland, New Zealand.
Nakajima, Miki, Osaka, Japan.
Nakamura, Chiyo, Hokkaido, Japan.
Nakano, Noriko, Tokyo, Japan.
Nakao, Kimitoshi, Tokyo, Japan.
Nandha, Manoj, Nottingham.
Negrin, Ilan, Amsterdam, The Netherlands.
Nenonen, Reijo O., Taivalkoski, Finland.
Nevalainen, Tuula M.-L., Helsinki, Finland.
Ng, Lai Yee, Hong Kong.
Nishida, Hiroko, Hyogo, Japan.
Nishizaki, Mikio, Bangkok, Thailand.
Nomura, Takayo, Tokyo, Japan.
Norberg, Carl S., Koping, Sweden.
Oakley, Maureen P., Hong Kong.
Ohmura, Keiko, Tokyo, Japan.
Okamoto, Koichi, Osaka, Japan.
Ooi, Kazunari, Osaka, Japan.
Osborne, Sean J., London.
Paakkari, Petri W., Lahti, Finland.
Paez Martinez, Ma Lluisa, Barcelona, Spain.
Page, Christopher D., Carlton.
Pak, Ching-Yuen Bernard, Hong Kong.
Pakarinen, Tea Maria, Espoo, Finland.
Papadopoulou, Stefania, Athens, Greece.
Parikka, Pekka J., Helsinki, Finland.
Parr, Rosalind, Styal.
Parsons, Ann S., Kemsing.
Parsons, Stephen, Middlewich.
Pedersen, Gunhild R., Nattland, Norway.
Peers, Sharon M., Chatham.
Peramaki, Kaarlo M., Koria, Finland.
Perquin, Manon C.A., Schoonhoven, The Netherlands.
Petersen, Rikke, Hong Kong.
Petersheim, Axel, Oslo, Norway.
Pfister, Hans, Zurich, Switzerland.
Pointon, Jean F., Tanggu, PR of China.
Preddy, Ma Del Pilar H., Hong Kong.
Pun, Yuk Ling, Hong Kong.
Quintana Martin, Margarita, Las Palmas, Gran Canaria.
Recaj Recaj, Eduardo, Ejea de los Caballeros, Spain.
Reitz, Catherine A., Pittsburgh, Pa., USA.
Revol MacDonald, Brigitte M., Bangkok, Thailand.
Rieger, Catherine J., Maidstone.
Riera Lopez-Feliu, Sara, Granollers, Spain.
Roberts, Anne M., Crawley.
Roberts, Katherine H., South Harrow.
Robres Garcia, Milagros, Zaragoza, Spain.
Rohloff, Michele A., Johannesburg, South Africa.
Roman Llopis, Juan F., Alicante, Spain.
Rosoff, Martin, Toronto, Ont., Canada.
Ruff, Agnes, Hong Kong.
Rufli, Michel, Stockholm, Sweden.
Ruiz Belver, Antonio J., Almería, Spain.
Ruusunen, Petri S., Kiukainen, Finland.
Sa'D, Ghia, Athens, Greece.
Saito, Reiko, Tokyo, Japan.
Sanchez Martinez, Antonio J., Valéncia, Spain.
Sancho Gracia, Ma Elena, Zaragoza, Spain.

Santacreu Rull, Montserrat, Lleida, Spain.
Sayed, Ahad, Brentford.
Schaetzle-Parisod, Arlette, Kaiseraugst, Switzerland.
Scott, Andrew M., Richmond, Yorks.
Scott, Kenneth MacDonald, Carluke.
Seaton, Johanna L., Hong Kong.
Sekiya, Mayumi, Hyogo-Ken, Japan.
Sempere Leal, Esther, Castalla, Spain.
Sergoulopoulos, Alexandros, Athens, Greece.
Seung, Yuet Fan Pinky, Hong Kong.
Shaw, Gillian A., Nairobi, Kenya.
Shinjo, Yasushi, Osaka, Japan.
Sinclair, Ann, L.K., Fernhurst.
Sjovold, Inger E., Oslo, Norway.
Smith, Kevin M., Bangkok, Thailand.
Smyth, Adrian J., Mold, Clwyd.
Soung, Min Hee, Bangkok, Thailand.
Sparks, Deborah A., Watford.
Spink, Michael C., London.
Stanley, Sylvia, Hong Kong.
Stanton, Jeremy, Edgware.
Sutton, Susan A., Elmswell.
Swarnasinghe, Wijendra G.A., Gunnepana, Sri Lanka.
Takahashi, Makoto, Hyogo, Japan.
Takashima, Kazuko, Tokyo, Japan.
Tam, Tat Kuen, Hong Kong.
Tam, Ying Che Lucilla, Hong Kong.
Tamblin, Carol S., Liskeard.
Tayara, Mona, Athens, Greece.
Taylor, David J., Isle of Wight.
Taylor, Sarah J.W., Solihull.
Teoh, Kiang-Hong, Singapore.
Thornton, Shirley E., Bangor.
Tipping, Maria De Carvalho, London.
Tirat, Pierre, Chorlton Cum Hardy.
Tock, Graham B., Hull.
Tompkins, Julian E., Tokai, South Africa.
Topley, Karen, Kirkby-in-Ashfield.
Torgerson, Norman, Bridgewater, New Jersey, USA.
Torrens, Robert M., Crieff.
Tse, Kwok-Fung, Hong Kong.
Tse, Mei Lai Daisy, Hong Kong.
Tsuda, Minako, Hyogo, Japan.
Turner, Susan E., Hong Kong.
Turunen, Kirsi A., Helsinki, Finland.
Udaya Saman, Halwatura G., Kandy, Sri Lanka.
Uriarte Terol, Ma Victoria, Alacante, Spain.
Usechi Espinosa De Los Monteros, Ma Amparo, Pamplona, Spain.
Van Den Haak, Hester, Krimpen ad Yssel, The Netherlands.
Van Den Top, Thea, Schoonhoven, The Netherlands.
Van Der Klauw, Angela V., Utrecht, The Netherlands.
Van Rijckevorsel-de Bruijn, Bernadette T.F.M., Amsterdam, The Netherlands.
Vataru, Monica, London.
Veecumsee, Dipal D., Bombay, India.
Velaz Azpilicueta, Mercedes, Pamplona, Spain.
Vermunt, Richard A.J., Tilburg, The Netherlands.
Vidal Ramia, Enriqueta, Tarragona, Spain.
Vildiridis, Athanassios, Thessaloniki, Greece.
Visker, Charlotte M.J.R., Beuningen, The Netherlands.
Volpe, Albert J., Toronto, Ont., Canada.
Waldron, Melanie J., Broadway.
Webster, Richard C., Chevy Chase, Md., USA.
Weiss, Daniel P., Vancouver, BC, Canada.
White, Nigel B., Cotgrove.
Whitney, Amanda, London.
Wielenga, Mark, Schoonhoven, The Netherlands.
Wijnands, Monique A.N., Heerlen, The Netherlands.
Wiles, Susan J., Hull.
Wissink, Marion E.J., Schoonhoven, The Netherlands.
Wong, Lai Ming, Hong Kong.
Wong, Lap Kwan, Hong Kong.
Wong, Wai-Yin, Hong Kong.
Wootton, Angela B., Sheffield.
Worthington, Sally L., Sowerby Bridge.
Woszczyna, Paul D., Downsview, Ont., Canada.
Xanthopoulos, Paraskevi, Athens, Greece.
Yamana, Katsunori, Wakayama-City, Japan.
Yamanaka, Kazuko, Osaka, Japan.
Yeung, Chan Siu Ling, Hong Kong.
Yeung, Siu-Kei, Hong Kong.
Yi, Yu Hsiao-Wen, Bangkok, Thailand.
Yount, Henrietta S., Hong Kong.
Yu, Kam-Hon Steven, Hong Kong.
Yuill, John M., Lanark.
Zanardi Landi, Sabina, London.
Zijlstra, Neeltje, Schoonhoven, The Netherlands.

MEETING OF OFFICERS

At a meeting of the Officers of the Association held on 30 November 1988 at Saint Dunstan's House, the business transacted included the election to membership of the following:

Fellowship

Alliance, Alma, Cheadle. 1988
Bagnall, Maria, London. 1988
Baumann, Yvonne, Dungarvan, Co. Waterford. 1988
Bloodworth, Roy N., Doncaster. 1985
Bode, William E.G., Harrogate. 1988
Boozer, Joan B., Sha Tin, Hong Kong. 1988
Brandligt-van den Hoed, Maria A.G., Bussum, The Netherlands. 1988

Bridgewood, Alan, Leeds. 1988
Castro, Ana I.J., London. 1988
Chan, Albert H.S., Hong Kong. 1988
Corée, Henk, Borne, The Netherlands. 1988
Cowdrey, John W.F., Harrow. 1988
Deacon, Richard H., Shrivenham. 1988
De Waal, Irina, Delft, The Netherlands. 1988
Easterbrook, Steven, Bridgend. 1988
Evans, Elma H., Spring Valley, Calif., USA. 1988
Fisher, Barbara E., Kahuku, Hawaii, USA. 1988
Fowler, Jennifer A., Perth. 1988
Fung, Annie C.Y., Yuen Long, Hong Kong. 1988
Glaysher, Andrew J., Horsham. 1988
Glover, Andrew M., Horsham. 1988
Gomez da Silva, Luiz A., Sao Paulo, Brazil. 1988
Grieder, Judith Y., Hong Kong. 1988
Hanslip, Malcolm J., Exeter. 1950
Hideyuki, Nakata, Tokyo, Japan. 1988
Hitcham, Peter J., Kingston-upon-Thames. 1988
Holloway, Sarah D., London. 1988
Janssens, Nadia E.L., Brussels, Belgium. 1988
Kaiyoorawongs, Julie B., Hollywood, Calif., USA. 1988
Kawamoto, Keiko, Kowloon, Hong Kong. 1988
Kothari, Hema P., Bombay, India. 1988
Kwan, Daisy S.M., North Point, Hong Kong. 1988
Laurie, John J.W., Monte Carlo, Monaco. 1988
Lo Wong Chi Ping, Stella, Kowloon, Hong Kong. 1988
Mak Sin Leung, Gary, Kowloon, Hong Kong. 1988
Malarek, Anna, Toronto, Ont., Canada. 1988
Marriott, Janet A., Amersham, The Netherlands. 1988
Mistry, Mukesh, London. 1988
Moghadam, Paravanah, London. 1988
Muste, Birgitte M., Schoonhaven, The Netherlands. 1988
Naylor, Tina, Ashton in Makerfield. 1987
Ng, Lai Y., Chai Wan, Hong Kong. 1988
Nishizaki, Mikio, Tokyo, Japan. 1988
Norton, Robert, Warrington. 1988
Parr, Rosalind, Styal, Wilmslow. 1988
Premnath, K.P., Salem, India. 1988
Revol Macdonald, Brigitte, Bangkok, Thailand. 1988
Rice, Michael, Humbleton. 1988
Rosoff, Martin, Toronto, Ont., Canada. 1988
Rydeng, Rig, Finnsnes, Norway. 1988
Rysenbry-Beens, Jantine C., Haarlem, The Netherlands. 1988
Schuch, Yvonne D.J., Ijssel, The Netherlands. 1988
Scott, Jean V., Bayside, NY, USA. 1988
Serras, Helen, Washington DC, USA. 1988
Seung, Yuet F.P., Wah Fu, Hong Kong. 1988
Smith, Kevin M., Calgary, Alta., Canada. 1988
Storm (née Rufli), Jeanette, Stockholm, Sweden. 1988
Ten Berge, Robert B.H., Zuidlaren, The Netherlands. 1988
Titina, Meher R., Bombay, India. 1988
Tyler, Elizabeth V., London. 1988
Voordewind, Derk J., Delfzijl, The Netherlands. 1988
Walker, Jeremy R.P., Allonby. 1988
Warshow, Nancy, Nairobi, Kenya. 1988
White, Helen Y.C., Shiu Fai, Hong Kong. 1988
Wong, Che K.J., Kowloon, Hong Kong. 1988
Wood, Teddy, Kowloon, Hong Kong. 1988
Woszczyna, Paul D., Toronto, Ont., Canada. 1988
Ziemelis, Ojars, Solna, Sweden. 1988

Transfers from Ordinary Membership to Fellowship

Atkins, Tristan A., Banstead. 1988
Axell, Anita C., Stockholm, Sweden. 1988
Barber, Susan A., Billingshurst. 1988
Bignotti, Fabrizio, London. 1988
Bramsden, Manny, Maidenhead. 1988
Carry, Peter D., Aberdeen. 1988
De Bevere, Dirk, Brussels, Belgium. 1988
Findlay, Caroline E., London. 1988
Gay, Bernice M., Romsey. 1988
Gordon, Scott M., Oklahoma City, Okla., USA. 1988
Gouverneur, Keith, Caracas, Venezuela. 1988
Harrison, Roger F.J., King's Langley. 1988
Hiramatsu, Ikuo, Tokyo, Japan. 1988
Hobbs, Fiona G., Winchester. 1988
Jassinger, Alexandre P.O.L., Epsom. 1988
Kim, Won-Sa, Daejon, Korea. 1988
Kyriakidou, Katerina A., London. 1988
Larsson, Thomas, Jarfalla, Sweden. 1988
Lloyd, Florence M., Harpenden. 1988
Longden, Sharon D., Eckington. 1988
Lopezzo, Lorraine V., Long Valley, NJ, USA. 1988
Nunes, Michél, George, South Africa. 1988
Richner, Sally J., Grosse Pointe, Mich., USA. 1988
Sayers, Angela C., London. 1988
Schreier, Larry, Skokie, Ill., USA. 1988
Sekiguchi, Kazuyoshi, Tokyo, Japan. 1988
Shimizu, Terukazu, Tokyo, Japan. 1988
Sinclair, Anne L.K., Fernhurst. 1988
Sinclair, Lyall W., Cambridge. 1988
Sneeringer, Margaret R., Worthington, Ohio, USA. 1988
Stead, Heather E., York. 1988
Stone, Emma E., Derby. 1988
Sugihara, Kaori, Tokyo, Japan. 1988
Theriault, Peter J., Camden, Me., USA. 1988
Tirat, Pierre, Poitiers, France. 1988
Underdown, Derek W., Partridge Green. 1988

Urvik, Hilde, Oslo, Norway. 1988
Ushio, Tsutae, Fukuoka City, Japan. 1988
Van Camp, Coralie A., Auckland, New Zealand. 1988
Van Deijl, Jacobus H., Parlow, South Africa. 1988
Weiss, Anthony S., Bushey. 1988
Winterbottom, Martin, Watford. 1988
Woolley, Shirl L., San Diego, Calif., USA. 1988
Yokoyama, Haruaki, Kurume City, Japan. 1988
Yoshimoto, Misako, Munakata-Gun, Japan. 1988

Ordinary Membership
Ahmed, Mohammed A., Jos, Nigeria.
Alabaster, Andrew G., Ashton Gate.
Arbisman, A.R., Selsdon.
Baldock, Janine, London.
Ballester, Emilio, Madrid, Spain.
Blanchard, Clive P., Leeds.
Bruyns, Jacques P., Rhode Saint Geneve, Belgium.
Cartwright, Freda H., King's Langley.
Chiu, Roy S.H., Central, Hong Kong.
Clarkson, Adam A., Baldock.
Conrad, Lucinda H., Tauranga, New Zealand.
Corne-Halstenbach, Michele, Geneva, Switzerland.
Cox, Edward M., Great Yarmouth.
Daines, Deirdre, Haywards Heath.
Dalfen, Daniel J., Harrow.
Davis, Danny A., London.
Deen, Mohamed A., Colombia, Sri Lanka.
Dobson, Michael, Sheffield.
Fong, Chan N., East Molesey.
George, Wanda M., Nairobi, Kenya.
Ghahramani, Nasser, Oxhey.
Gorden, Joachim M.B., London.
Hartnup, Stephen J., St Albans.
Heatherwick, Stefany R., London.
Jarmyn, Shirley J., Enfield.
Jones, Phyllis M., Sheffield.
Lancaster, Wendy, London.
Lewis, Karen J., Hong Kong.
Lewis, Richard D.F., Epsom.
Mairlot-Peterbroeck, Veronique, Brussels, Belgium.
Michallat, Mark L., Shipley.
Milne, Herta, London.
Moncrieffe, Christopher, Gillingham.
Muchmore, Leslie R., Liskeard.
Murray, Robert A., London.
Nattagh, Shahla A., Harrow.
Oldershaw, Caroline J.E., London.
Oura, Mamiko, London.
Parry, Michael F., Winchester.
Pickering, Joanne, Ossett.
Plumb, Helen L., London.
Pointon, Laurence, Edgware.
Scott, Ian, Wimborne.
Shaw, Gillian A., Nairobi, Kenya.
Skilton, Margaret, Auckland, New Zealand.
Spentza, Alexandra, Nutley.
Stalnaker, Karen J., London.
Stone, Peter M.B., Seeb, Sultanate of Oman.
Stulting, Wendy R., London.
Syn, Lucy, London.
Takahashi, Yasushi, Kofu, Japan.
Van Heesewijk, Jacqueline, London.
White, Felicity, London.
Whiting, Kevin, Buckingham.
Whittle, John E., Sutton Coldfield.

EXAMINATIONS 1989

The examination dates for 1989 are as follows:

Gem Diamond Examination:
Theory – Monday 5 June
Practical – Monday 5 June and Monday 12 June

Examinations in Gemmology:
Preliminary – Tuesday 27 June
Diploma Theory – Wednesday 28 June
Diploma Practical – Tuesday 27 June, Thursday 29 June and Friday 30 June.

The final date for receiving examination entry forms is 31 March.

The Buckingham Award

Mr W.C. Buckingham, FGA, has very generously donated his fine collection of zircon rough to the Gemmological Association of Great Britain to mark his retiral after fifty years from the firm of George Lindley & Co. Ltd. He is also offering an award to newly-qualified Fellows of the Association who carry out research on samples from the collection.

The criteria for the research are:

1. The rough specimens originate from various localities, mostly Indo-China, and the research might be directed towards determining any variation in properties from the different localities. However, other research topics would be considered.
2. Having carried out the research programme, the Fellow must present the results in the form of a paper which would, in the opinion of the Editor, be worthy of publication in *The Journal of Gemmology*.
3. A Fellow whose research and paper satisfy these criteria will be awarded the sum of £100 or books and/or instruments to that value.
4. The Fellow must first apply in writing to the Secretary of the Association, setting out his proposed research and methodology and the

instruments he proposes to use. The time to be taken must also be specified.

Research materials provided by the Association must be returned within the time stipulated.

The Association reserves the right to authorize or reject research projects at its sole discretion and will not enter into the reasons for any decision made.

Those interested in the Award are invited to write to the Secretary of the Gemmological Association, Saint Dunstan's House, Carey Lane, London EC2V 8AB, giving the information set out in item 4 above.

Letter to the Editor

From Dr Karl Schmetzer

Dear Sir,

In an article dealing with colour-changing chromiferous tourmalines from East Africa by H. Bank and U. Henn, 1988, (*Journal of Gemmology*, **21**, 102-3), two alexandrite-like tourmalines containing 0.36 and 0.64 wt.% Cr_2O_3 are described. According to the chemical data published, these two samples were magnesium tourmalines, i.e. intermediate members of the solid solution series dravite-uvite.

Colour-changing magnesium tourmaline from the Ural Mountains, USSR, containing exceptionally high amounts of chromium (10.86 wt.% Cr_2O_3) was analysed by Cossa and Arzruni (*Z. Kryst. Mineral.*, 1883, **7**, 1-16) which actually implies that alexandrite-like tourmaline is the second mineral, after chromium-bearing chrysoberyl (alexandrite *sensu stricto*), for which a distinct colour change between daylight and artificial light was observed long before alexandrite-like garnets, sapphires, spinels, etc., were described (cf. Schmetzer, Bank and Gübelin, 1980, *N. Jb. Miner. Abh.*, **138**, 147-64). However, it is worth while pointing out that not every chromium-bearing member of the dravite-uvite series reveals a distinct alexandrite effect. For example, one sample originating from Tsavo, Kenya, which contained 0.53 wt.% Cr_2O_3 (Schmetzer, Nuber and Abraham, 1979, *N. Jb. Miner. Abh.*, **136**, 93-112) did not show a remarkable colour change between daylight and artificial light.

In general, absorption spectra of chromium-bearing tourmalines from various localities are similar or almost identical, but small differences are found in the positions and intensities of absorption maxima and minima. This result of spectroscopic investigations is supposed to be due to a variable distribution of chromium between both octahedrally coordinated lattice positions of tourmaline, i.e. between magnesium and aluminium sites in tourmaline crystals which were grown in different environments (cf. Nuber and Schmetzer, 1979, *N. Jb. Miner. Abh.*, **137**, 184-97). A similar correlation of the intensity of colour change with variable site occupancies of chromium between two octahedrally coordinated polyhedra is already established for chrysoberyl, the structure of which contains two different aluminium positions (cf. Bukin *et al.*, 1980, *Inhomogenity of minerals and crystal growth*, Moskva, 317-28).

At present, no exact correlation between site occupancies of chromium in tourmaline and the presence or absence of a pronounced colour change is worked out and the influence of iron and titanium absorption bands is unknown. Consequently these problems need further experimental study and research.

Yours etc.,
K. Schmetzer

25 July 1988
Institute of Mineralogy and Petrography, University of Heidelberg, West Germany.

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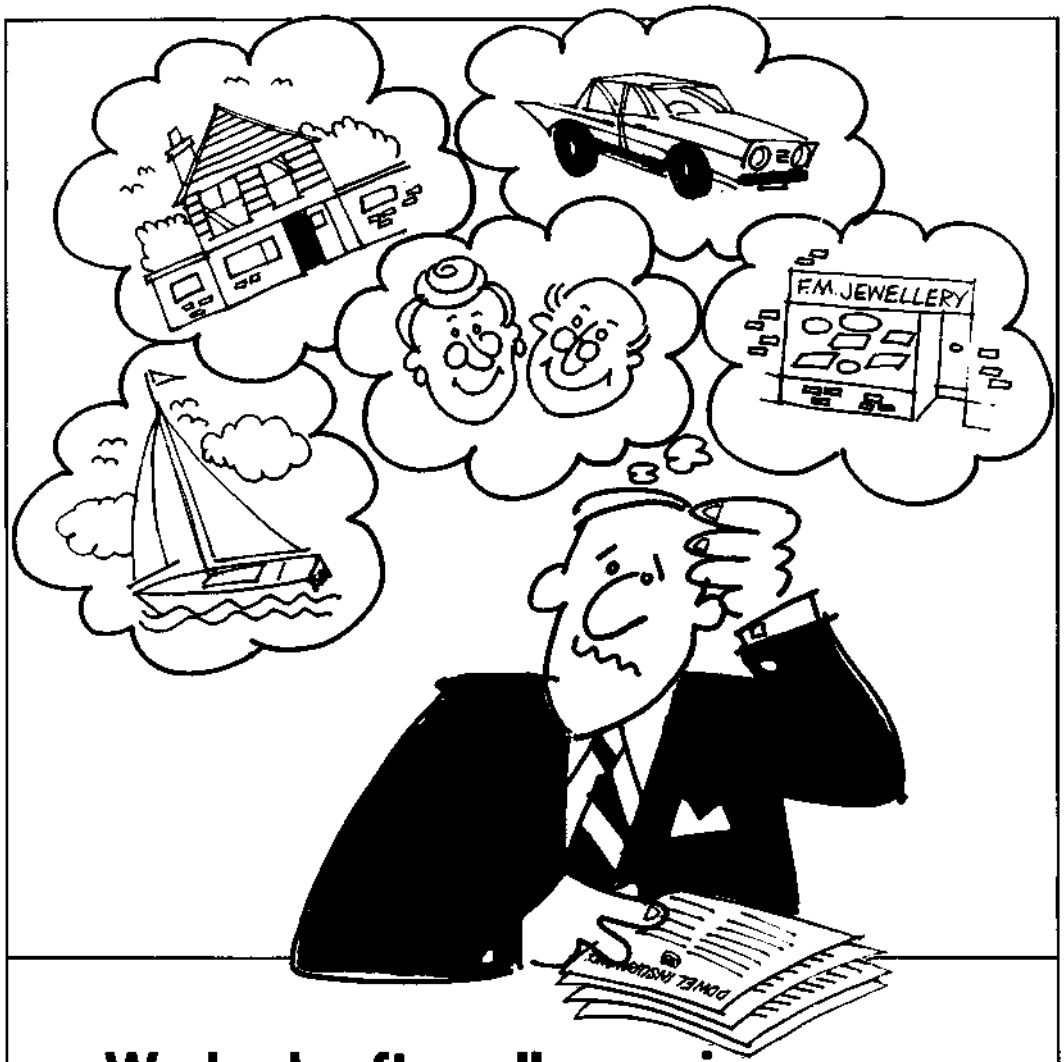

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The Arms and Crest of the Association, conferred by a grant of Arms made by the Kings of Arms under royal authority. The cross is a variation of that in the Arms of the National Association of Goldsmiths of Great Britain and Ireland. In the middle is a gold jewelled book representing the study of gemmology and the examination work of the Association. Above it is a top plan of a rose-cut diamond inside a ring, suggesting the scrutiny of gems by magnification under a lens. The lozenges represent uncut octahedra and the gem-set ring indicates the use of gems in ornamentation. The lynx of the crest at the top was credited, in ancient times, with being able to see through opaque substances. He represents the lapidary and the student scrutinizing every aspect of gemmology. In the paws is one of the oldest heraldic emblems, an escarbuncle, to represent a very brilliant jewel, usually a ruby. The radiating arms suggest light diffused by the escarbuncle and their tips are shown as jewels representing the colours of the spectrum.

Historical Note

The Gemmological Association of Great Britain was originally founded in 1908 as the Education Committee of the National Association of Goldsmiths and reconstituted in 1931 as the Gemmological Association. Its name was extended to Gemmological Association of Great Britain in 1938, and finally in 1944 it was incorporated in that name under the Companies Acts as a company limited by guarantee (registered in England, no. 433063).

Affiliated Associations are the Gemmological Association of Australia, the Canadian Gemmological Association, the Gem and Mineral Society of Zimbabwe, the Gemmological Association of Hong Kong, the Gemmological Association of South Africa and the Singapore Gemologist Society.

The *Journal of Gemmology* was first published by the Association in 1947. It is a quarterly, published in January, April, July, and October each year, and is issued free to Fellows and Members of the Association. Opinions expressed by authors are not necessarily endorsed by the Association.

Notes for Contributors

The Editors are glad to consider original articles shedding new light on subjects of gemmological interest for publication in the *Journal*. Articles are not normally accepted which have already been published elsewhere in English, and an article is accepted only on the understanding that (1) full information as to any previous publication (whether in English or another language) has been given, (2) it is not under consideration for publication elsewhere and (3) it will not be published elsewhere without the consent of the Editors.

Papers should be submitted in duplicate on A4 paper. They should be typed with double line spacing with ample margins of at least 25mm all round. The title should be as brief as is consistent with clear indication of the content of the paper. It should be followed by the names (with initials) of the authors and by their addresses. A short abstract of 50–100 words should be provided. Papers may be of any length, but long papers of more than 10|000 words (unless capable of division into parts or of exceptional importance) are unlikely to be acceptable, whereas a short paper of 400–500 words may achieve early publication.

Twenty five copies of individual papers are provided on request free of charge; additional copies may be supplied, but they must be ordered at first proof stage or earlier.

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The Journal of Gemmology

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Cover Picture

Hat ornament exhibiting the sumptuous principal stone, the Dresden Green, natural size. (See 'The Dresden Green', p.351.)
Photograph by Robert Bosshart

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GEMDATA – UPDATE 1

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Notes from the Laboratory – 14

Kenneth Scarratt, FGA

The Gem Testing Laboratory of Great Britain, 27 Greville Street, London, EC1N 8SU.

For many years the Laboratory knew that at some stage it would have to obtain an instrument which 'described' the absorbance and transmittance of 'light' in a graphic form. Whilst the hand-held spectroscope had, and still does serve us extremely well in the identification of many gem species, in a laboratory it does have its limitations.

Even B.W. Anderson, the father of gemmological spectroscopy and a lover of the hand-held spectroscope, in explaining his observations had at times to resort to somewhat imaginative descriptions for some characteristic spectra, e.g. the 'organ pipe' spectrum seen in spinels.

Observations with the hand spectroscope apart from fine lines, in general, have to be described in vague terms such as, 'an area of absorption centred at approximately...' and these are more than sufficient in the identification of most gem species such as sapphire, almandine garnet, peridot, diamond, etc. One must add at this point though, that when Anderson published the wavelength of a certain absorption feature having measured it with one and confirmed it with another of the laboratory's excellent hand-held wavelength measuring spectroscopes, in general the accuracy of that measurement has proved, following checks with modern spectrophotometers, to be remarkably good.

In terms of absorbance and transmittance, many gemmologists have also tried to describe the ultraviolet 'spectrum' of certain gemstones, such as ruby, emerald and diamond, by immersion contact photography and using a short-wave ultraviolet lamp. The objective being the separation of natural from synthetic and in the case of diamond to 'type' the stone as an aid to identifying artificial coloration.

In the modern gemmological laboratory though, the problems are such with modern synthetic gems, and treatments to otherwise natural stones, that every piece of information that one can coax out of a test is needed and if we can have such a thing as a 'degree' of accuracy, then that degree must be the highest. An example of this would be the description of those two absorption lines which may possibly be observed either side of the blue/green border (say 500nm) in some natural or treated brown green or yellow diamonds. These two lines are reported by Anderson to be situated at 504 and 497nm. The actual measurement for the '504', which is the zero-phonon* line of the H3 centre, is 503.2nm, and that of the '497', which is the zero-phonon line of the H4 centre, is at 496nm. At first glance these small errors in measurement may seem unimportant but as the 496nm line may only rarely be observed in a naturally coloured diamond and far more often observed in an artificially irradiated and subsequently annealed diamond, the advantages of having an ability to be absolutely sure about your observations is obvious. This becomes most apparent when one realises that just to the short wave side of the '496' is what can at times be a relatively strong absorption line which is the peak of the first phonon sideband of the H3 centre. Therefore, when using only a hand spectroscope at room temperature for a diamond that has a strong H3 line at 503.2nm, one could mistake the sideband of this centre for the 496nm line. There are examples concerning other gem materials, such as ruby and emerald, where one benefits from being able to 'read' an absorption curve rather than observing dark or bright lines crossing a narrow ribbon of colours down a tube.

The laboratory's first response to the problem in the late 1970s was to install a cooling unit for the examination of coloured diamonds. The unit reduced the temperature at which the diamond was observed to 120K, at which temperature the absorption bands became sharper to the eye and were therefore easier to observe. These observations were made with the hand-held spectroscope and therefore we still had no concept of the 'shape' of the spectrum. With the problems increasing all the time it was decided that to keep ahead in the field we had to obtain a recording spectrophotometer. Having decided this and knowing the limitations governing the financing of such a

*A phonon is defined as a quantum of sound or elastic vibrations.

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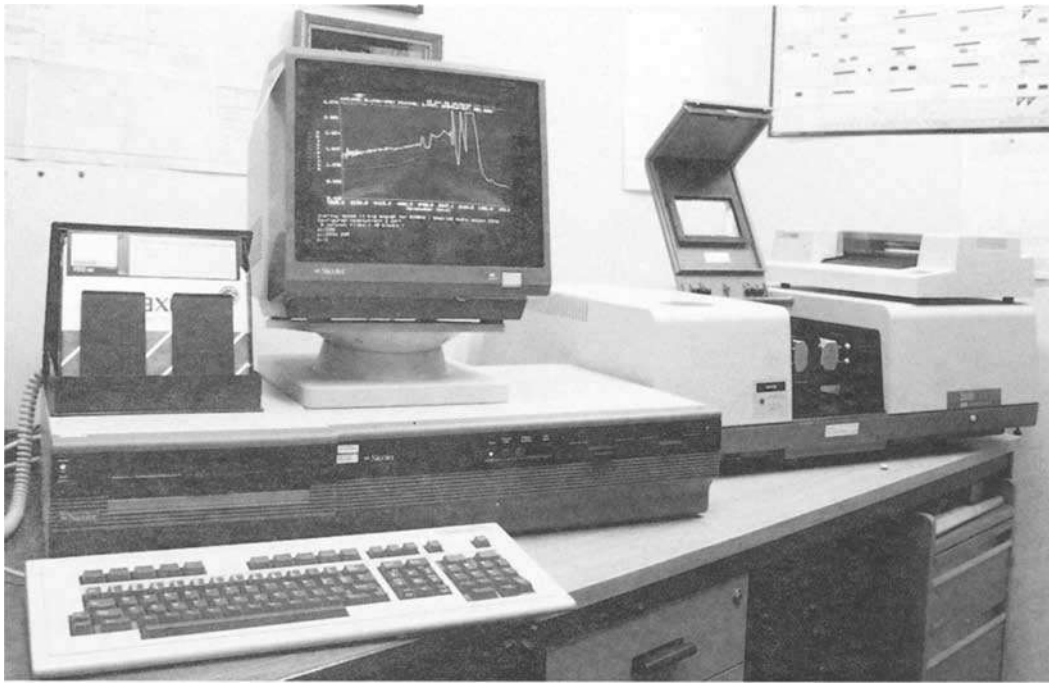

Fig. 1. Nicolet model 510 FT-IR spectrometer with 620 work station, plotter and added 8" floppy drive in use at the Gem Testing Laboratory of Great Britain.

purchase, we set about researching the market. Looking towards the future we hoped to be able to obtain an instrument at a reasonable cost that would record the spectra of faceted gemstones, without resorting to destructive testing, for the ultraviolet, the visible and the infrared regions. Spectrophotometers are not built taking into account a possible requirement of having to record the spectra of faceted gemstones and therefore the search for the correct instrument was not an easy one. In fact when the choice was made we had to accept that the infrared region was going to have to be a thing for the future, as not only could we not obtain an instrument that gave us all three regions, but even the recording of infrared spectra from whole faceted gemstones with a dedicated instrument was unsatisfactory. The instrument obtained, in the end through subscription and in the memory of B.W. Anderson,* was and still is one of the best of its type for obtaining spectra from gemstones, the Pye Unicam PU 8800 UV/visible spectrophotometer.

For some years we faced the fact that the infrared area was going to be out of our scope until a new form of instrument was developed that was more 'in tune' with the requirements of gemmology. Then problems in which the answers were held in the infrared became more frequent. New types of hydrothermal synthetic emerald, plastic impregnated opal, synthetic diamond and the answer to those treated yellow diamonds which had been annealed to higher temperatures to remove the characteristic 595nm line are a few examples.

The Research Department of the Gemological Institute of America obtained a Nicolet Fourier Transform Infrared spectrometer and published some excellent data, and with new hope we began the search for an FT-IR unit that would be most suitable for our needs. In the end, having chosen the instrument, we were fortunate enough that one of our members came forward and bought it for us – with no strings attached. We now have a Nicolet model 510 Fourier Transform Infrared Unit (Figure 1) which will give us all the information we need in the range previously not covered.

Increasingly the author is told by gemmologists throughout the world to 'keep it simple' so that 'ordinary gemmologists' can understand what is going on. Unfortunately sometimes the black or grey boxes are the only answer to some of the problems we all face. For the past few years when describing spectra in 'Notes from the Laboratory' and elsewhere, I have reproduced absorption curves rather than trying to attempt drawing what might be seen in the hand spectroscope. There has

*Opening of Appeal Fund, *Journal of Gemmology*, XIX, 5, 445. – Ed.

been some criticism over this change and people have told me that they cannot understand, but it really is not that difficult. If one looks down the left or right hand of the side of the curve it will be seen whether the curve was recorded in absorbance or transmittance; if it is in absorbance the sharp peaks are where dark lines will be seen and the wide bands are where areas of general absorption may be seen, in the hand-held spectroscope. Along the base of the curve are the units of measurement, which for the visible region are normally in nanometres. Apart from displaying a spectrum accurately one should not forget the obvious advantage in choosing to reproduce a curve, one can easily convert a curve to what might be seen in the hand spectroscope in the mind but it is not possible the other way around.

The move towards the black boxes in some cases may make a few gemmologists 'uncomfortable' but this latest update to the laboratory's equipment has already proved itself many times over with such problems as synthetic amethyst, synthetic alexandrite and amber. A few recent examples are detailed in the following paragraphs.

The De Beers and Sumitomo synthetic gem diamonds

Both the Sumitomo and the De Beers synthetic gem diamonds have been reported upon in the English speaking journals, although information on the latter has not as yet been published in these pages. An excellent descriptive paper was published in *Gems & Gemology* at the end of 1987 (Shigley *et al*, 1987).

During 1988 we were given the opportunity to examine ten of the De Beers synthetic diamonds and, whilst I refer the reader to the aforementioned paper for the expanded detail, with which our information and examination mostly concurs, we shall briefly note the characteristics one might observe with the aid of a microscope or an ultraviolet lamp, before seeing how the infrared spectra of these samples help in their identification.

The samples examined ranged in size from a 0.27 ct yellow emerald-cut to a crystal of 5.24 ct and the colours were either deep brownish-yellow, yellow or greenish-yellow (Figure 2). Under the long-wave ultraviolet lamp both the fluorescence

Fig. 5. A metallic needle-like inclusion in a De Beers synthetic diamond.

Fig. 6. A colourless cross formation in an uncut De Beers synthetic diamond.

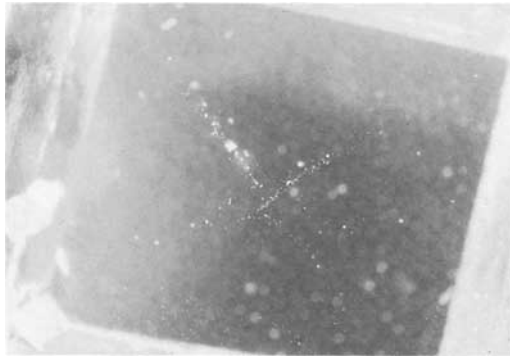

Fig. 7. Fine dust-like inclusions associated with the cross formation of the De Beers synthetic diamond of Figure 6. (Dark field).

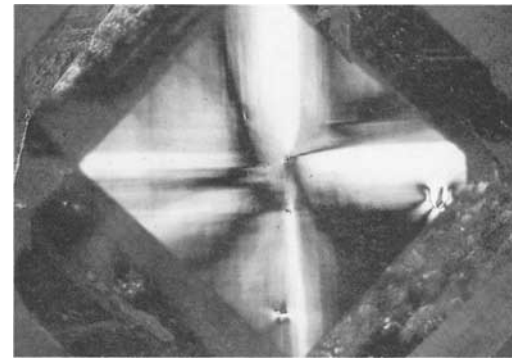

Fig. 8. The De Beers synthetic diamond of Figure 6 between crossed polarized light.

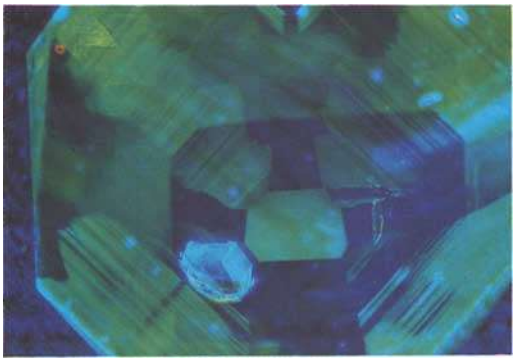

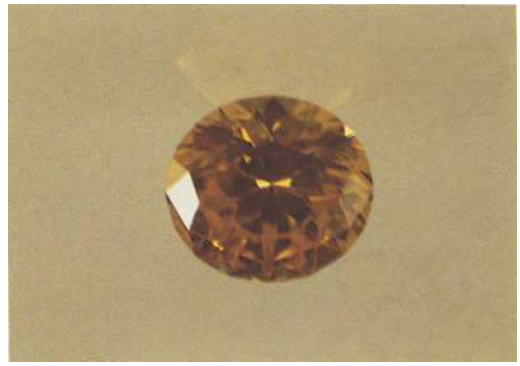

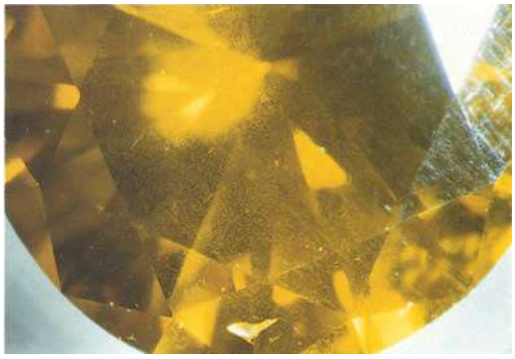

Fig. 2 (top). Faceted and uncut De Beers synthetic diamonds.

Fig. 3 (above, left). The fluorescence of a De Beers synthetic diamond when exposed to short-wave ultraviolet rays.

Fig. 4 (above, right). Fine dust-like inclusions clouding the interior of a De Beers synthetic diamond.

Fig. 9 (left). A natural type Ib diamond.

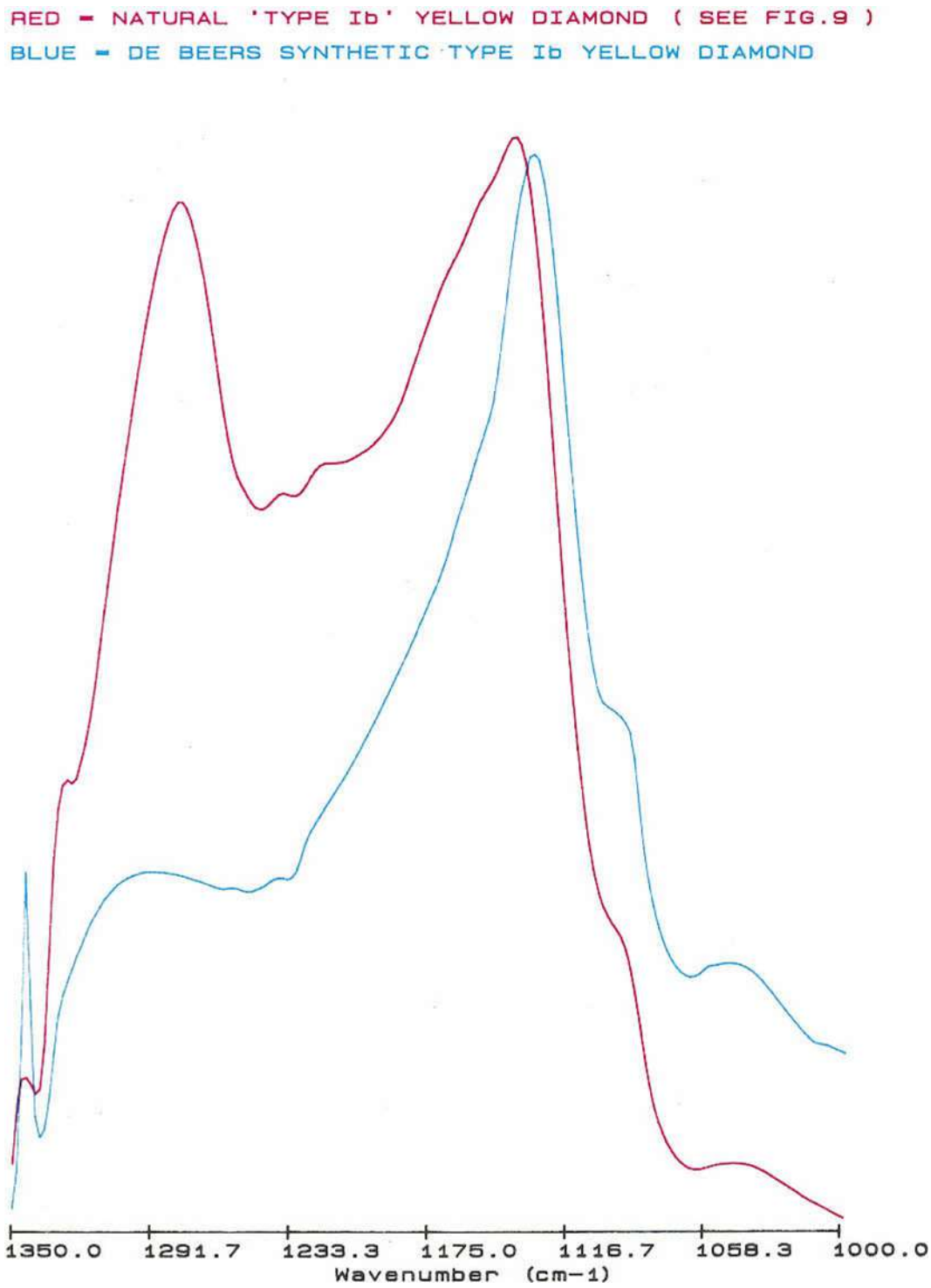

Fig. 10. A comparison between the infrared spectra of a natural 'type Ib' yellow diamond and a De Beers synthetic type Ib yellow diamond. Both curves are recorded in absorbance.

and phosphorescence varied from sample to sample. The more brownish stones were inert to this wavelength, the yellow stones tended to have a weak orange glow, with one stone being inert, and a clear phosphorescence (apart from one stone), and the greenish-yellow stones each displayed a moderate to clear phosphorescence whilst the fluorescence varied from almost inert to weak. Again under the short-wave ultraviolet lamp the response was varied. The brownish stones tended to have an orange background with distinct yellow zones which corresponded with the cubic growth sectors, (Figure 3), whilst the yellow stones were either a moderate orange with no phosphorescence or a distinctly zoned strong yellow with a strong phosphorescence. The greenish-yellow stones were either a zoned yellow or a moderate orange, but in both cases the phosphorescence was strong.

Material observed within the stones included dust-like particles (Figure 4) and metallic inclusions (Figure 5). Yellow/colourless zoning within these synthetics (Figure 6) relates to the nitrogen content in various growth sectors. When seen this zoning may serve as a first warning of a possible synthetic origin and when observed a little more closely as in Figures 6 and 7, it may be seen that tiny dust-like inclusions are orientated with this zonal structure. When observed between cross polarized light a distinctive cross-like pattern may be seen (Figure 8 [which relates to Figures 6 and 7]).

The infrared spectra observed for all of the De Beers synthetic stones were distinctive in that they revealed the characteristic peak for dispersed nitrogen (type Ib diamond) and there were no signs of the peaks associated with aggregated nitrogen (common to IaA and IaB diamonds). In natural Ib diamond it seems that almost invariably the peaks due to aggregated nitrogen are found to be present along with the dispersed nitrogen peak. This is clear when one looks at the example in Figure 9, which is a natural type Ib (canary) diamond with a visible spectrum similar to that of a synthetic yellow diamond, i.e. one of continuing and gradual absorbance towards the shorter wavelengths. The infrared curve of this stone shows a clear peak due to aggregated nitrogen (Figure 10) whilst a De Beers synthetic stone of a similar colour, as compared in Figure 10, shows only the dispersed nitrogen peak.

Coated amber

On two occasions recently we have been asked to identify material which has turned out to be coated amber, and infrared spectroscopy has helped in its identification. On the first occasion apart from a single row of coated amber beads, a pair of interesting amber earclips were also submitted.

As these were not coated with an 'artificial' substance, we shall deal with the amber in the earclips first. They were a rounded cabochon shape, the metal earclip was attached to the flat side, and the colour was approaching orange. The metal fitting, being attached with an adhesive, prevented an SG determination and as there were no inconspicuous areas where an olfactory test could be facilitated this too was initially ruled out. An estimation of the refractive index by the distant vision method put this constant in the region of 1.54. The material was 'cloudy' but contained no inclusions which would assist in identification.

On the back of one of the cabochons it was noticed that a small sliver of the material had parted from the main body but was being held, in place by, and under, the metal fitting. As the sliver was not 'attached' to the main body of the 'amber', with the careful use of a fine pair of tweezers we were able to remove it. In doing so we discovered that the colour was concentrated at the surface, whilst the centre was colourless (Figure 11). The colour was not a coating of an artificial substance but was actually a part of the surface. This is a feature which we have noted before in heat treated amber (Scarratt, 1986). In order to confirm its identity a small scraping was taken from the inside colourless part of the sliver and an infrared spectrum was taken from this. The resulting spectrum was characteristic of amber. The process from taking the scraping to obtaining the spectrum (see Figure 12 (1)) took no more than five minutes.

The artificial coating on the surface of the beads in the necklace was quite obvious when examined with either a 10x lines or a microscope (Figure 13), but identifying the material underneath would have been difficult if we were only to conduct the normal gemmological tests.

The beads appeared to be an orange colour but in a number of places, around the ends of the drill holes, the coating had come away to reveal that the material beneath was coloured yellow (Figure 13). A scraping was taken from the bead underneath the coating and as revealed in Figure 12 (2) the infrared spectrum produced from this was found to be that of amber. Interestingly, upon taking this scraping we discovered that the yellow colour of the bead was also a 'surface only' colour. The bead was colourless underneath, it had a yellow surface probably due to heat treatment, and on top of this was an artificial coating which was orange in colour.

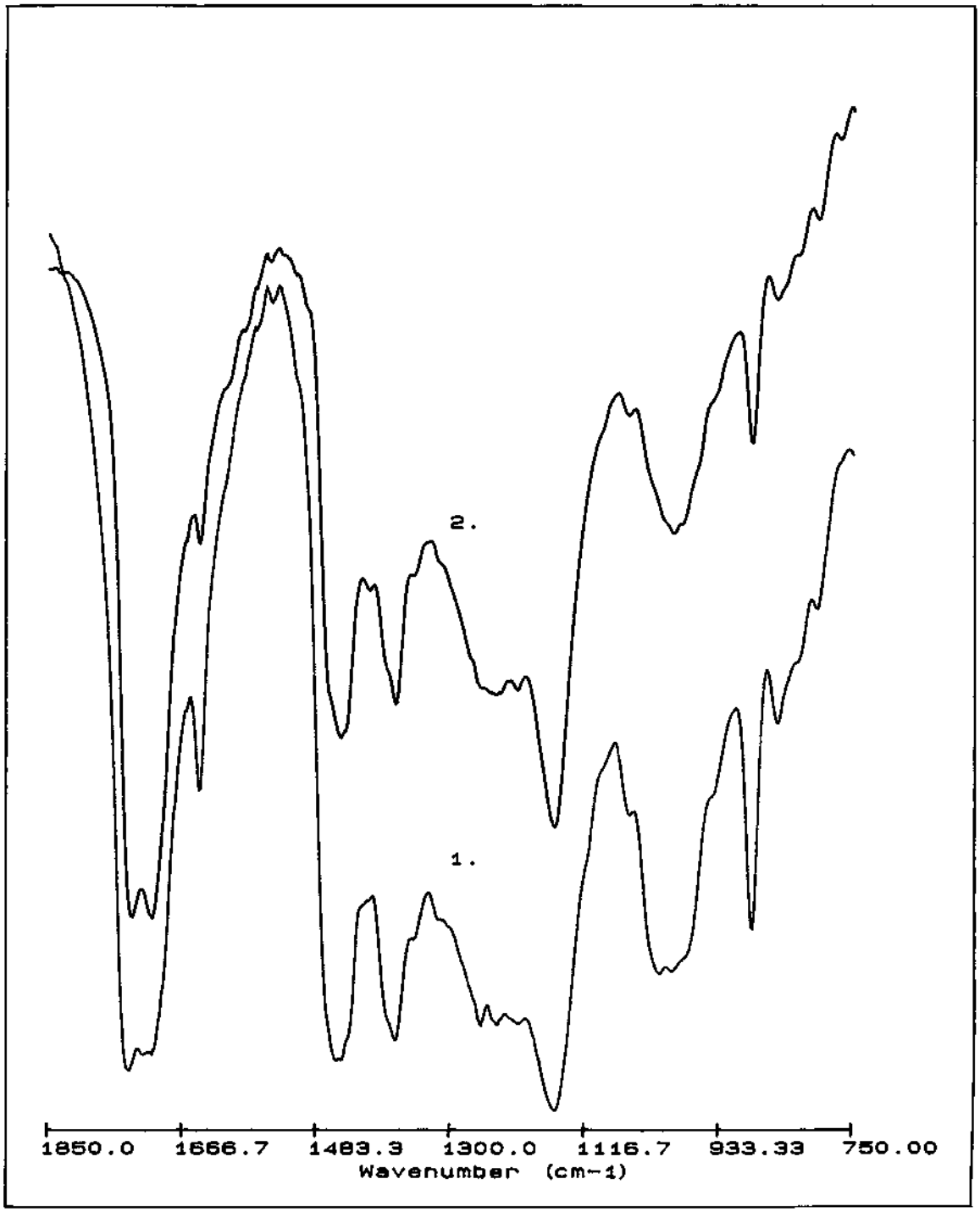

Fig. 12. The infrared spectra of two pieces of amber both recorded in transmittance. (1). An amber earclip, and (2) an amber bead which had an artifical coating (the scraping being taken from the bead below the coating).

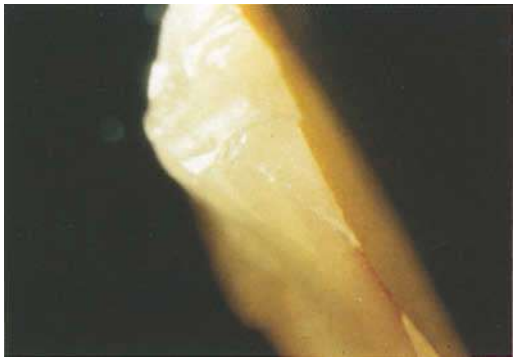

Fig. 11. A small sliver of amber removed from an earclip showing the colourless interior and coloured exterior.

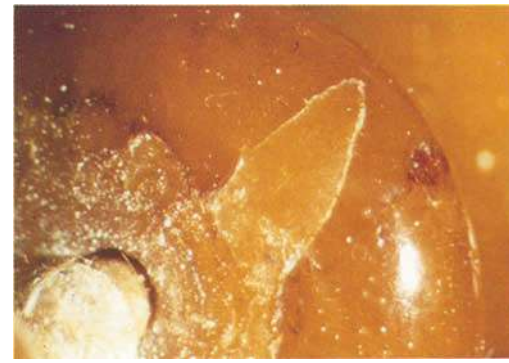

Fig. 13. A coated amber bead showing an area where the coating has come away.

Naturally coloured green Type IIb diamond

We mostly think of type IIb diamonds as being blue in colour although colourless and colourless/brown zoned stones have been reported. A short time ago an octagonally shaped faceted diamond weighing 5.80 ct was submitted for examination (Figure 14). The colour of the stone was a little difficult to describe, however: in a standard diamond grading light box grey, brown and green colours could be seen; under a bench lamp fitted with a tungsten bulb just green and brown could be seen; and in the normal laboratory lighting, i.e. daylight fluorescent tubes, both grey and green could be seen. The predominant colour appeared to be green in most instances but in some circumstances brown predominated.

Apart from making observations on the colour and examining the stone with the aid of a microscope, the first test carried out on the stone was the recording of its visible spectrum. The type of spectrum we were expecting, judging from the part brown colour, was either that typical of a brown type Ia stone or that of a Ib stone. The result was a little like a type Ib curve, with increasing absorption for the shorter wavelengths from about 520nm but with a wide absorption 'hump' stretching from 520 to 460nm and peaking at 490nm. The area of least absorption was in the green, as might be expected, but then unlike Ib stones the absorbance level begins to rise again for the longer wavelengths from 620nm. The level of absorbance at 750nm being slightly more than half that at 390nm.

Fig. 14. A green/brown (colour depending upon lighting) type IIb diamond. 5.80 ct.

The spectrum, in which there were no sharp peaks, did not fall into a convenient category, but the next test gave us a clue to the type of stone we were dealing with, and it was far from what we were expecting. Under both long-wave and short-wave ultraviolet light the stone appeared to be inert but when the short-wave lamp was switched off the stone displayed a strong blue-green phosphorescence. This being a typical characteristic of type IIb blue diamonds, we then tested the stone for electro-conductivity. Apart from confirming that the stone was a conductor of electricity, the test proved to be quite dramatic with blue flashes coming from within the stone almost from the instant that contact was made.

The infrared spectrum was then taken and compared with other type IIb spectra filed in the computer. The spectrum of this stone was the same as those recorded previously for type IIb blue stones.

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Proceedings of the First International Amber Symposium

Helen Fraquet, FGA

London

Fig. 1. Natural freeform amber necklace with pressed amber rods, pendant and bead.

Summary

Sixty participants from Europe, USSR, Africa and USA, were invited to the first International Amber Symposium, hosted by the Museum of the Earth, Warsaw, in October 1988.

Twenty-seven papers were offered, covering all aspects of the sciences and arts in relation to this fossil resin, in four working languages – German, Russian, English and Polish.

Introduction

This was in fact the sixth meeting on Amber and Amber-bearing sediments to be held in Poland, but the first of an international nature. Accordingly, much of the Symposium explored areas of future mutual exchange of samples and scientific papers. The first two papers – 'The present status of research of amber and other fossil resins' (Saw-

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kiewicz, S., Leningrad) and 'The significance of museum collections of amber and other fossil resins' (Kosmowska-Ceranowicz, B., Warsaw), explored the possibilities opened up by the global political thaw of the late 1980s, especially with regard to re-examining existing collections, many of which had been transferred across Europe during the progress of the two World Wars.

By cross-referencing experiences it became obvious that an extensive catalogue of the amber contained in various national collections would be a great step forward for both those working as art-historians and in the sciences. This is especially so, as many former great collections are now split between various museums. For example, that of the Albert University in Königsberg (Kaliningrad) which once comprised 70 thousand specimens, is thought to be split between the University Museum in Goettingen, the Natural History Museum of Humboldt University in Berlin, and the British Museum of Natural History in London. During the course of the conference it was learned from Dr Katinas, that his nation's Lithuanian Amber Museum at Palanga would be opened to the West for the first time.

New finds

Several new sources of amber were reported during the conference. Kosmowska-Ceranowicz and Krumbiegel, G. (Halle), presented a joint paper on Bitterfeld amber, a Miocene deposit (22 million years old) mined near Leipzig in East Germany, of which a proportion goes into the production of jewellery. The amber shows the usual colour range, clear and cloudy, etc. Sokolowa, T. (Leningrad), and Rasnitsyn, A. (Moscow), described four types of Cretaceous amber recovered from field trips to Northern Siberia and the Arctic Sea in the 1970s. Some of the pieces appear to be similar to gedanite, and all are too fragile for decorative purposes, although the inclusions are naturally of great interest to paleo-entomologists and botanists. A third find of Upper Cretaceous amber was also reported from Alberta in Canada.

Regional updates were offered from Romania, Sicily and the Dominican Republic, as well as from areas less familiar to the gemmologist such as Bulgaria and Nigeria. This last is an Eocene resin with a chemical structure shown by IR spectra to be a new species. It has been given the name Amekit. Perhaps the most obscure piece of amber to be discussed was a single nodule found at a depth of 2,302 m below sea level during the course of deep drilling in the Persian Gulf. Its infrared spectrum is identical to that of Rumanite from Romania. Several of the core samples contained this resin, but only one sample was analysed.

Schluter, T. (Dar es Salaam), gave a comprehensive paper about East African copal – and confirmed the author's view that very little copal has ever been used as jewellery.

Migaszewski, Z. (Kielce), showed current investigation into black resins, jet and the new appearance on the market of black amber jewellery. The latter is being produced by a Co-operative south of Warsaw with a source material of processed succinite. The streak mark left by this manufactured substance is black, the lustre is good, and under a microscope there are to be seen two distinct materials – dark grey particles cemented by a very fine grained light grey substance.

The Museum of the Earth in Warsaw has two samples of stantienite collected from the Palmnicken deposit in 1880. These have a velvet black colour, a brown to light brown streak, and under the microscope a structureless groundmass of dark grey containing 'yellow-orange and blood red inner reflections'.

Also in the collection are two samples of soft fossil resin from Lower Miocene deposits of the Ukraine and Bitterfeld. The microscope reveals a structureless, porous cracked lustreless resin of black colour yielding a dark greyish-brown streak. The samples have the same reflections as above with the addition of scattered fragments of crushed plant tissue.

A third type of black resin is represented by a sample from Bitterfeld and another from Bytow in Poland, whilst there are at least three petrographic varieties of jet assigned to the Lower Jurassic from Odrowaz in Poland.

Black resins were thought in the nineteenth century to originate from fire in the forest at the time of formation. However, the authors of this 1988 paper consider lightning to be a more likely theory.

Other scientific papers

The majority of those present at the Symposium represented the sciences of geology, mineralogy and paleontology. However, many of the papers proved interesting across traditional boundaries. To this end gemmologists should find useful 'Comparative studies on micro-elements in amber' from Koziorowska, L. (Warsaw), which included data such as the presence of silver amongst Baltic amber, but not that from Sicily or the Dominican Republic. Also 'Gas chromatography – an effective tool for chemical characterization of fossil resins', Vavra, N. (Vienna). This may prove to be a rapid method of investigation, which already differentiates samples from within the Dominican Republic. 'The presence of vertebrates and their remains in amber', Poinar, G. (Berkeley), should also be required reading for all those faced with abnormally large inclusions brought in by members of the public for verification.

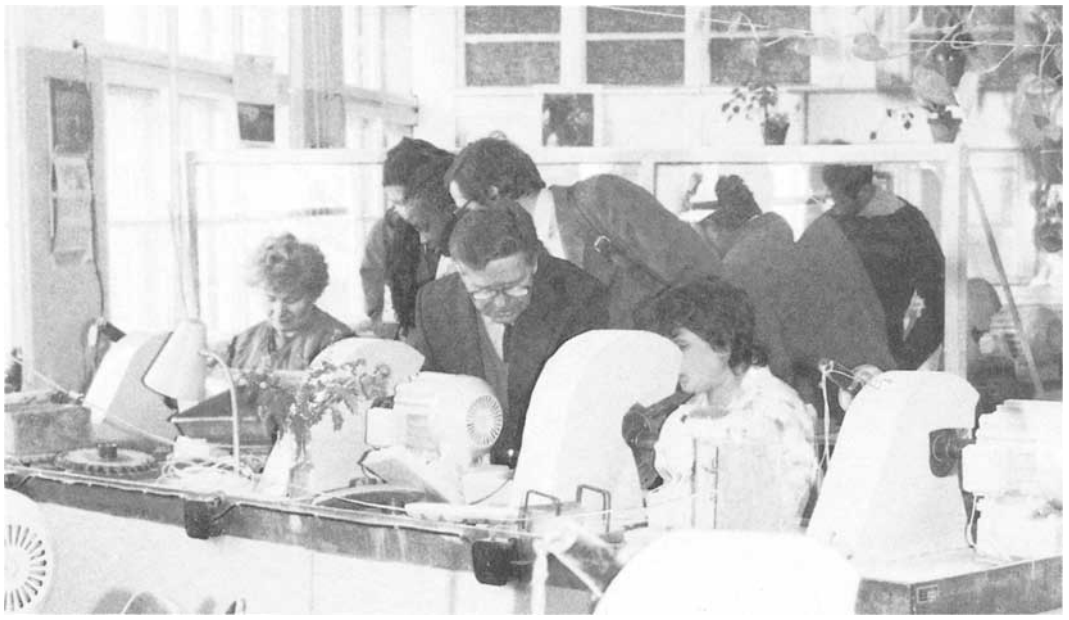

Fig. 2(a)

Fig. 2(b)

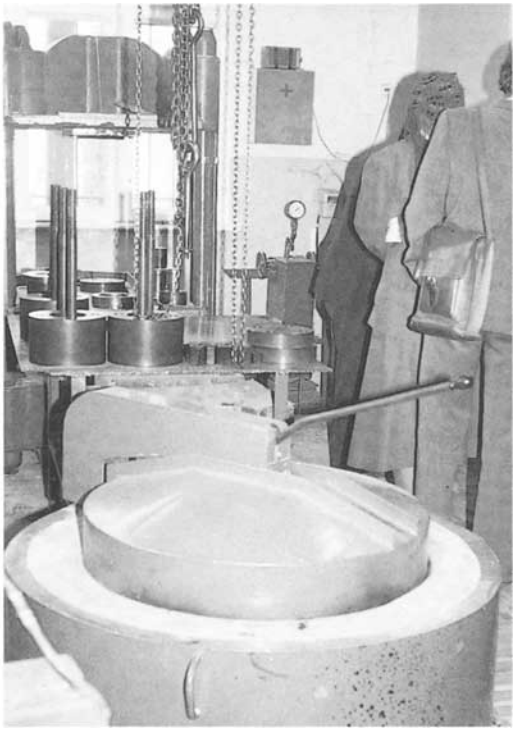

Fig. 2(c)

Fig. 2 (a, b and c) Interior of the Bursztyny amber co-operative, Gdansk, Poland: (a) visiting the grinding and polishing room; rods of pressed amber awaiting despatch; (c) the production area for heating and pressing amber into rods (the same equipment is used for producing amber with stress-induced inclusions).

Field Expedition to Gdansk and Malbork

The two days of presentations were followed by a weekend field trip to the coast. In Gdansk the party was able to join those working to extract amber from marshland with the aid of hydraulic hoses. The amount of amber washed out from the reed-bed deposit was surprisingly high, and paid the wages of ten people on that site alone. The land was owned by a nearby factory and had been leased by an amber processing co-operative in the town of Gdansk (Figure 2).

The co-operative was open to our detailed questioning – the operatives making round and faceted beads on simple rotating laps had been thus employed for up to 22 years, and coloured rods of pressed amber had been manufactured in black, green, red, sand, etc., as well as the usual two-tone swirled syrup since 1981. Although the author's overall feeling was one of depression, at least the larger, and purer specimens of amber were sorted out, after an initial clean, and reserved on one side not to be pressed but to be used without further processing. Although not seen, the factory apparently produced sun-spangled amber from time to time, using different time and pressure ratios.

There is much amber jewellery for sale in Gdansk and in the larger international hotels. It is expensive, and disappointingly unexciting. Very little is polished freeform (as is the necklace illustrated in Figure 1), most being non-graduated or graduated round or oval beads. The major colours represented are bright yellow (natural) or syrup/brown (pressed). There are some animal carvings of elephants, tortoises, etc. One exception to this general dull conformity was the use of thin-slab amber with silver in tie-clips, and brooches by a single shop in Gdansk. The lack of general flair is understandable given the isolated nature of the country. However, one is left with the impression that Poland is rebuilding, despite the system.

The hosts of this meeting in Warsaw only started collecting amber in 1951, yet today house one of the largest hoards of natural resin in Europe. The Archeological Museum in Gdansk overflows with amber finds made in the last few years, and the National Collection of Amber Artefacts at Malbork Castle already occupies a whole gallery. There is an infuriating lack of pin-point dating at the latter two institutions, and one or two gross errors – for example a whole display of phenol formaldehyde plastic beads, described as Sicilian Amber, but the academic enthusiasm is contagious.

Thanks must be given to all those who made this Symposium possible. Summary papers are available from the author, and it is hoped that before too many years elapse Britain will herself come forward to host such an event.

[*Manuscript received 26 January 1989.*]

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The Dresden Green

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Introduction

Once upon a time there lived a king. He was tall, strong, and immeasurably wealthy since his ancestors were already in possession of productive silver mines. He did not waste his treasures on foolish wars. On the contrary, he accumulated riches in the safe vaults of his castle of such vastness that his kingdom became renowned and was admired far and wide.

This is not the beginning of a legend but a sketch of what happened in the seventeenth and eighteenth centuries prior to and during the reign of the Saxon Elector August II, also named *August the Strong* (with the exception of the wars). His residential cities were Dresden and, after his coronation as King Frederick August I of Poland, also Warsaw. The accumulated riches of gold, silver, jewels, curiosities, and in particular gemstones, were arranged and stored below his residential palace in vaults painted green. These rooms soon came to be known as the *Green Vaults* (Grünes Gewölbe). They served as strong-rooms and, in anticipation of a coming era, also as a treasury museum, fitted as an elegant French-style mirror cabinet (1723-1724). In the following years, the copper-plate engraving cabinet, the gallery of paintings, the collection of porcelain and the collection of natural sciences were founded and exhibited in the pavilions of the Zwinger, stronghold of the former fortress. (Menzhausen, 1987a, 1988.) For good reasons, Dresden was known as the Florence of the Elbe River.

In 1741, the son of August the Strong, Elector August III of Saxony (since 1733 King Frederick August II of Poland), bought one of the rarest diamonds from a Jewish dealer. Together with the Diamond Suite (Copeland,1966, 29), the green gem was registered as No. 50 in the inventory of 1733 (cf transcription below Figure 1). From then on, the diamond was known by the name of 'Dresden Green Diamond' or shorter 'Dresden Green' and 'Green Brilliant' (Table 1). In 1742 this brilliant-cut stone was mounted into the Order of the Golden Fleece by the Dresden court jeweller J. F. Dinglinger. However, in 1746 it was reset 'à jour' by the Genevan jeweller A. J. Pallard at the court of Vienna (open-back bezel setting as in Figure 3) and in 1768 finally mounted by Diessbach into the hat brooch known to the present day (Figure 2).

The Dresden Green remained in the Green Vaults for over two centuries until, due to the Second World War, all Art Collections of Dresden were moved up to the Königstein (King's Rock), the imposing grey mountain fortress at the entrance to the Elbsandsteingebirge (Sandstone Sierra of the Elbe River region). From there the Soviet Trophy Organisation (Copeland, 1966, 25) transported the Collections into the subterranean safes of the USSR Ministry of Finance at Moscow (Menzhausen, 1987a) shortly after the war. They were handed out to the German Democratic Republic in 1958. Since then the Collections have been conserved and displayed mostly at the Albertinum and in the Zwinger. The State Art Collections of Dresden as much in their totality as also in their parts, e.g. the Saxon-Polish Crown Jewels of the Green Vaults or the Meissen Porcelain, are unique worldwide, but surprisingly little known, even in Europe.

It has come to be considered the destiny of many famous diamonds that their histories remain unknown or fragmentary at most. In the case of the Dresden Green this concerns its trade route before 1741 and the sojourn from 1945 till 1958. It is assumed that the stone originated in India rather than in Brazil.

The rarity of the Dresden Green is based not so much on its weight, which is over 40 ct, but rather on its green colour. In reality however, it is the coincidence of both properties that makes the diamond so exceptionally rare. Up to the present day, it has remained the largest cut diamond of natural green colour on record. Over the centuries it has not lost anything of its celebrity status. But on the contrary, it has become of increasing cultural interest and, recently, also of great scientific value.

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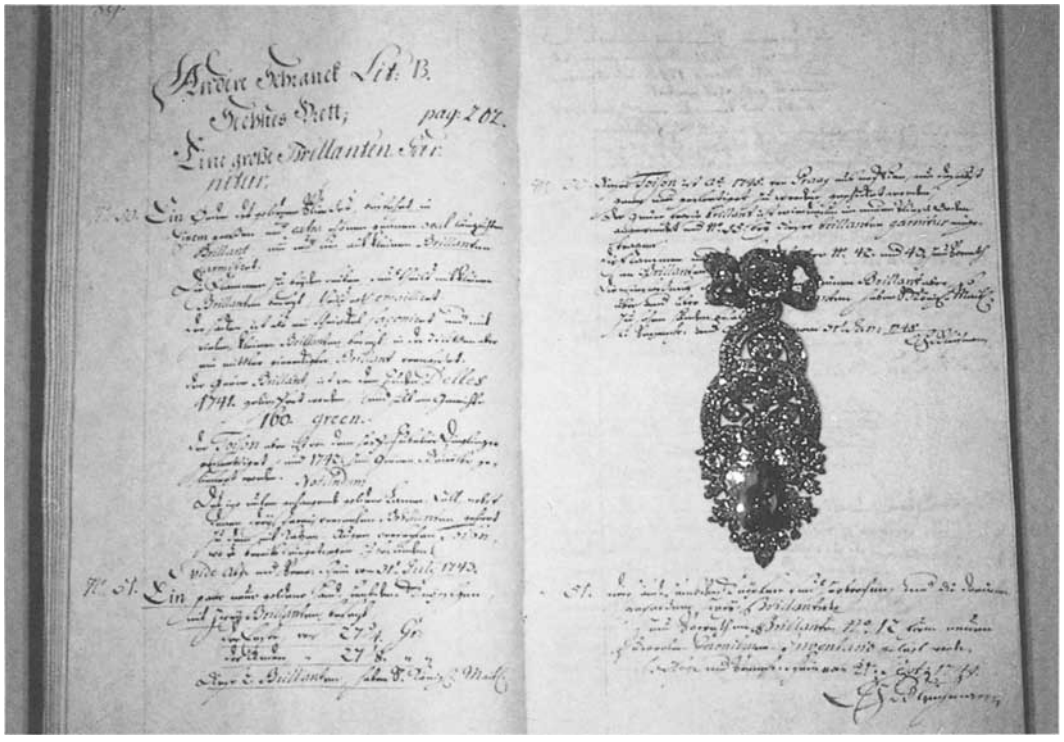

Fig. 1. Hat ornament (brooch) belonging to the Diamond Suite of the Elector August III of Saxony, displayed on the original volume of the 1733 Inventory of the Green Vaults.

Transcription of the Registration No. 50 in the Inventory (written in elderly chancery language, Pfister, 1988)

'[Seite] 89. Andere Schranck Lit: B.
Sechstes Brett: pag: 202.
Eine große Brillanten Gar.
nitur.

N°. 50 Ein Orden des goldenen Vließes bestehet in einem großen und extra schönen grünen oval länglichten Brillant um und um mit kleinen Brillanten carmisiret. [umrandet, eingefasst] Die Flammen zu beyden Seiten sind theils mit kleinen Brillanten besezt, theils roth emailliret.
Der Haken ist als ein Schnirkel façoniret und mit vielen kleinen Brillanten besezt. In der Mitten aber ein mittler viereckigter Brillant verfaßet.
Der grüne Brillant, ist von dem Juden Delles 1741. gelieffert worden, und hält am Gewichte 160. green. [von engl. grain?, ca 40 ct]
Der Toison aber ist von dem Hoff-Jubelier Dinglinger geferttiget und 1742. zum grünen Gewölbe geliefert worden [Watzdorf 1962]

Notandum
Das izo unten anhangende goldene Lamm-Fell, nebst denen drey darin versezten Brillanten gehöret zu dem mit Katzen-Augen versezten Toison, wo es bereits eingetragen zu befinden. vide abg. und Verw. Schein vom 31. July 1743. [Seite] 90.

N°. 50 Dieser Toison ist a°. 1745. von Praag aus nach Wien, um daselbst ganz neu gefertiget zu werden geschicket worden, Der grüne große brillant ist wiederum im neuen Vließ Orden angewendet und [als] N°. 55 bey dieser brillanten garnitur eingetragen. [Neufassung durch den Genfer J. Pallard, 1746] Die Flammen und der Schnirkel [Schnörkel] aber N°. 42 und 43. zum Vorrath an Brillanten geleget worden. Die Einfaßung um den großen grünen Brillant aber, so über und über mit kleinen brillanten, haben S. Königl. Mait. zu hohen Händen behalten.
C. Verwahr. und abg. Schein vom 31. Jan: 1748.

C. G. Cleichmann. [?]

N°. 51 Ein paar goldene Hand-Hembden-Knöpfgen mit zwey Brillanten besezt...'

Table 1. Physical Properties of the Dresden Green Diamond

CUT	Pear-shape with rounded tip (almond-shape), historic brilliant-cut style (pear-shaped old-cut brilliant)		
Measurements of diamond	Length × Width × Height approx. 30.30 × 20.35 × 10.288mm (TESA dial calipers and micrometer)		
	Table T	approx. 16.30 × 10.15 mm (SSEF	
	Culet C	approx. 3.25 × 1.65 mm table gauge)	
Proportions	Table width/Width	49.9%	
	Culet width/Width	8.1%	
	Height/Width	50.6%	
	Crown height/Width	approx. 17% (estimated)	
	Pavilion height/Width	approx. 33% (estimated)	
	Girdle width/Width	approx. 0.5% (where visible), i.e. very thin to sharp-edged	
	L / W	approx. 3 / 2	
	H / W	approx. 1 / 2	
	TW / W	approx. 1 / 2	
	TW / TL	approx. 1 / 1.6	
	CW / CL	approx. 1 / 2	
	Cr / Pv	approx. 1 / 2	
Symmetry	Good to very good: no large remnants of crystal faces ('naturals') or extra facets present, very sharp facet corners; bezel and pavilion (upper and lower main) facets in part slightly distorted, girdle slightly wavy		
Polish	Good to very good: table facet perfectly plane; some light wheelmarks		
Measurements of bezel	Gold bezel	L × W	approx. 30.90 × 20.60 mm
		Height	1.90 to 2.40 mm (without prongs)
	Silver bezel (pavilion)	Height	3.30 to 3.80 mm
		Thickness	0.48 to 0.51 mm
		Four drillholes for 'lacing' the silver bezel into the hat ornament (brooch) using silver wire (Arnold, 1988) drillhole diameters from 0.7 to 1.3 mm	
Condition	Girdle of diamond mediocre: numerous small breakages, girdle projecting over the gold bezel on almost half of the circumference (from right to top) and extremely thin. Bezel setting good: excepting a fine-grained layer on the gold bezel at top right, on right side and bottom left (Figure 3, remainders of tin solder rather than oxidized silver solder; no patina)		
WEIGHTS of the Dresden Green	A1	approximately 41.1 ct (author's calculation by means of similarly proportioned pear-shaped old-cut brilliants as length × width × height × 0.0065)	
	A2	approximately 43 ct (too high; calculation on the basis of the conversion factor 0.00678 for a loose pear-shaped old-cut of 13.24 ct of the Green Vaults)	

	B1	41 ct (Green Brilliant, Menzhausen 1987a)
	B2	Dresden Green, identical with Green Brilliant, i.e. 41 ct (Menzhausen, 1987b)
	C1	41.00 ct (Dresden Green, De Beers, 1983, 60)
	C2	40.00 ct (Green Brilliant, De Beers, 1983, 60), citation of erroneous indications in the Anglo-Saxon literature (Copeland, etc.)
	D1	48½ ct (Bauer, 1896, 157), contradiction to D2
	D2	40 ct (Bauer, 1896, 287: 'not 31¼ or 48 carat')
	E	160 green (Inventory volume 1733), [green = engl. grain (?), between 40 and 41 ct]
Weight including bezel setting	11.182 g (55.91 ct) (Owa laboratory balance 160 g max., e = 0.01 g)	
PURITY		
External characteristics	One small extra facet at the tip of the pavilion, one very small natural near the girdle on the right of the crown side	
Blemishes	Numerous small to tiny breakages along the girdle on the crown and pavilion side, one short curved scratch on the left in the table, some slightly abraded facet edges on the crown and pavilion side (Hänni and Bosshart, 1987)	
Internal characteristics	One small, concentrically ribbed tension fissure of a whitish appearance and similar to a healing crack and one shallow and short fissure with green specks (Figure 7), both on the left of crown near the girdle; very short tension fissures with green spots on the right of crown at the girdle, one group of tiny, brown reflecting opaque crystal inclusions (chromian spinels?) near a lower girdle facet on the right (approx. 0.15 mm deep)	
Growth characteristics	Weak to distinctive, lamellar zoning in triangular octahedral arrangement (three-point diamond)	
Strain birefringence	Fine, cross-hatched and pronounced, lamellar extinction pattern in cross-polarized light ('Tatami' type, Orlov, 1977, 116), no interference colours	
Damages	One small tension fissure emanating from a girdle chip on the right crown side, one tiny percussion mark in the bezel at the tip	
Purity grade	SI (small inclusions, CIBJO Rules 1986), theoretical possibility of improvement of the purity and girdle by a professional repolishing operation.	
COLOUR		
Description	Transparent, non-fluorescent slightly bluish-green of weak saturation	
Colour grade	Fancy colour	

Classification	After the Colour Atlas DIN 6164 (Biesalski, 1957) as colour index triplet		«hue : saturation : greyness»
	body colour K (in transmitted light)		≈ 21 : ½ : 1
	reflection colour R (in reflected light)		≈ 21½ : 3±2 : 3
	reflection colour R (Rösch, 1969)		≈ 22 : 2–3 : 3
Colour distribution	Apparently homogeneous body coloration (no colour zoning, mottled or surface colour)		
Colour type	Natural coloration (Menzhausen, 1987b)		
Cause of coloration	Light absorption (GR 1–8) at a limited number of crystal lattice defects, generated by a continued natural radioactive irradiation in the diamond deposit; annealing in the parent rock at a maximum of 350°C		
Colour stability	Possibility of fading of the green coloration by thermal healing of the GR 1–8 lattice defects starting at about 500°C (Woods and Collins, 1986)		
UV Fluorescence	Weak, impure yellowish-green, homogeneous (VEB Quarzlampen markkleeberg UA 150.1, 365nm/140W/10cm)		
ABSORPTION	UV/VIS Figure 6	GR 1	very weak absorbance band from 750 to 530 nm, with medium strong zero-phonon doublet (Collins, 1982) at 741.0 and 744.3 nm
		667	very weak line at 666.6 nm (after Davies, 1977 stable below 700K/430°C)
		594	extremely weak band at 594 nm (appears above 275°C only, Woods and Collins, 1986)
		495	very weak band at 495 nm
		473	very weak band at 473 nm
		TR 12	very weak line at 470.1 nm
		GR2–8	weak to extremely weak lines at 430.4, 429.5, 419.1, 413.2 nm, etc.
		R 10	very weak line at 393.5 nm
		R 11	weak line at 310.8 nm
		306	very weak line at 306 nm
		303	very weak line at 303 nm
		289	very weak line at 289 nm
		279	extremely weak band at 279 nm
		225	steep and high absorption edge at 225 nm
	MIR	No specific absorption bands in the middle infra-red region (4000 to 400 cm^{-1} / 2.5 to 25 μm) except the strong lattice absorption present in all diamonds between 2650 and 1400 cm^{-1} (Davies, 1977) → TYPE IIa	
RADIOACTIVITY	No residual β/γ-activity observed (background 0.2 counts/sec on Geiger counter EMA GZ25/VA–Z125)		
CONDUCTIVITY	Thermal conductor (EICKHORST Thermolyzer II), electrical insulator (voltmeter)		
DIAMOND TYPE	IIa		

Fig. 2. Hat ornament exhibiting the sumptuous principal stone, the Dresden Green. Magnification 0.8×

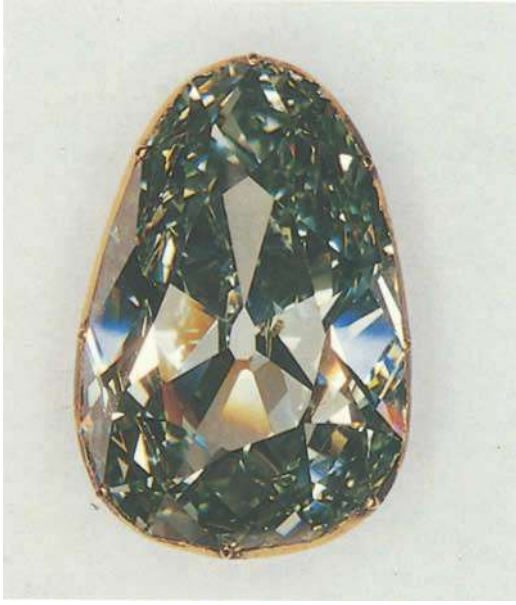

Fig. 3. The Dresden Green set in an eighteenth century gold (and silver) bezel and scintillating in all spectral colours. Magnification 3×.

Modern investigations of the Dresden Green diamond and interpretation of the results

Motivated by the contributions of Collins (1982) and Orlov (1977) on the one side and by Bauer (1896) and other writers of the past century on the other, the author applied for permission two years ago, to investigate the Dresden Green extensively by modern, non-destructive gemmological and analytical methods. A unique authorization was granted from 22 until 24 November 1988 to him as well as to R. E. Kane and S. F. McClure. These colleagues of the Gemological Institute of America jointly and shortly will report on the history and gemmological properties of the diamond and will publish professional colour reproductions.

Colour Testing

In addition to the urgently needed characterization of such a prominent diamond individual by weight, measurements, proportions, etc., the intention was to find out whether the Dresden Green belonged to the 'relatively rare, uniformly bottle-green' diamonds (according to Orlov) or whether it possessed, as Bauer put it, a 'very nice, light apple-green' colour (or even an 'oil-green, yellow-green, pale, leek, asparagus, pistachio, olive, siskin, emerald, bluish or greyish-green colour'?) The question is what sort of bottles and apples they meant. According to the Identity card of the Diamond (Table 1), the colour hue is definitely a bluish-green.

Collins (1982) confirmed that uniformly green (by this he did not mean surface-coloured but body-coloured green) diamonds are so rare that up to now no corresponding absorption spectra existed in literature. According to Collins, however, these spectra would be of scientific importance to solid state physicists for the clarification of the natural causes of green coloration (e.g. irradiation), as a possible precursor of yellow and brown colorations (annealing during or subsequent to irradiation).

In addition it would be a breakthrough of commercial significance if specialized gemmological laboratories henceforth would be in a position to differentiate between diamonds of natural and artificially caused green colour. At present few laboratories succeed in reliably identifying these colorations and then only in exceptional cases. For these reasons the author has pursued his goal for over three years now (outside the daily routine analysis of gemstones) to trace cut diamonds of guaranteed naturally green colour – this proved to be unusually difficult – and to measure them accurately. The research work will come to a close soon and will then be published (Bosshart, 1989).

Absorption Analysis

In some of the recognized gemmological laboratories it has been standard practice for more than

ten years now to record the absorption spectra of coloured diamonds applying refrigeration by liquid nitrogen (boiling temperature of LN_2 at atmospheric pressure: −196°C/77K, where Kelvin (K) = Celsius (°C) + 273.16). The advantages of this procedure are absorption diagrams which give much increased evidence compared to the spectra registered at ambient temperature (Collins, 1982), as is proved by Figure 4:

Survey spectra:
upper blue curve – medium refrigeration
lower blue curve – weak refrigeration
red curve – ambient temperature
(horizontal red line: baseline of spectrophotometer and cryogenic cell)

Figure 5 presents the well established cooling cell of the bath type developed by the author. In contrast to the cryogenic flow type devices of other laboratories cooling the diamond with nitrogen gas crossing the spectrometer sample beam at right angles (Scarratt, 1979, and Hofer and Manson, 1981), the Dresden Green was mounted in the N_2-vapour atmosphere of the illustrated highly-transparent cooling cell (i.e. above the liquid nitrogen bath) in such a manner that the diamond could be traversed by the light beam on a linear optical path.

It was and is a favourable and rather unusual circumstance that the Dresden Green, still mounted in its bezel setting, possesses a large culet facet parallel to the table facet. The optical path length between table and culet, however, was the absolutely shortest of the stone, corresponding to the weakest possible absorbance (cf Figures 3 and 6). On the other hand, the light traverse in the long or diagonal directions of the diamond was rendered practically impossible by the silver bezel hiding the pavilion of the diamond just below the girdle.

The 'Dresden Green Project' was consented to only after the author's party had furnished physical evidence that the necessary refrigeration (and subsequent warming up) could cause damage neither to the diamond nor its green coloration nor the bezel setting (Rosenfeld and Bosshart, 1987, etc.). Despite the author's many years of experience in refrigerating large and small, mounted and loose diamonds, there remained a residual risk which needed a little courage to overcome since doubts about the innocuousness of the project for the famous large diamond had been expressed in some gemmological circles. Although the present investigation has been completed successfully and without detriment to the diamond and its setting, this still must not be interpreted as an encouragement to deep-freeze gemstones unscrupulously as certain significant conditions have to be fulfilled.

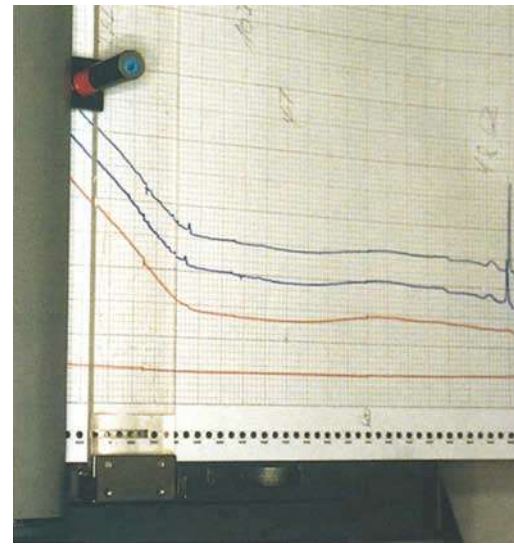

Fig. 4. The first three absorption spectra of the Dresden Green Diamond showing lesser spectral information in the red curve registered at ambient temperature than the spectra run at freezing temperatures (blue curves). Baseline of spectrophotometer and cryogenic cell (horizontal, red) and absorption curves vertically displaced for better understanding.

Fig. 5. The Dresden Green mounted in the N_2 vapour atmosphere of the highly transparent cooling cell and adjusted in the sample beam of the Pye Unicam SP8-100 UV/VIS spectrophotometer prior to the first absorption measurement in refrigeration.

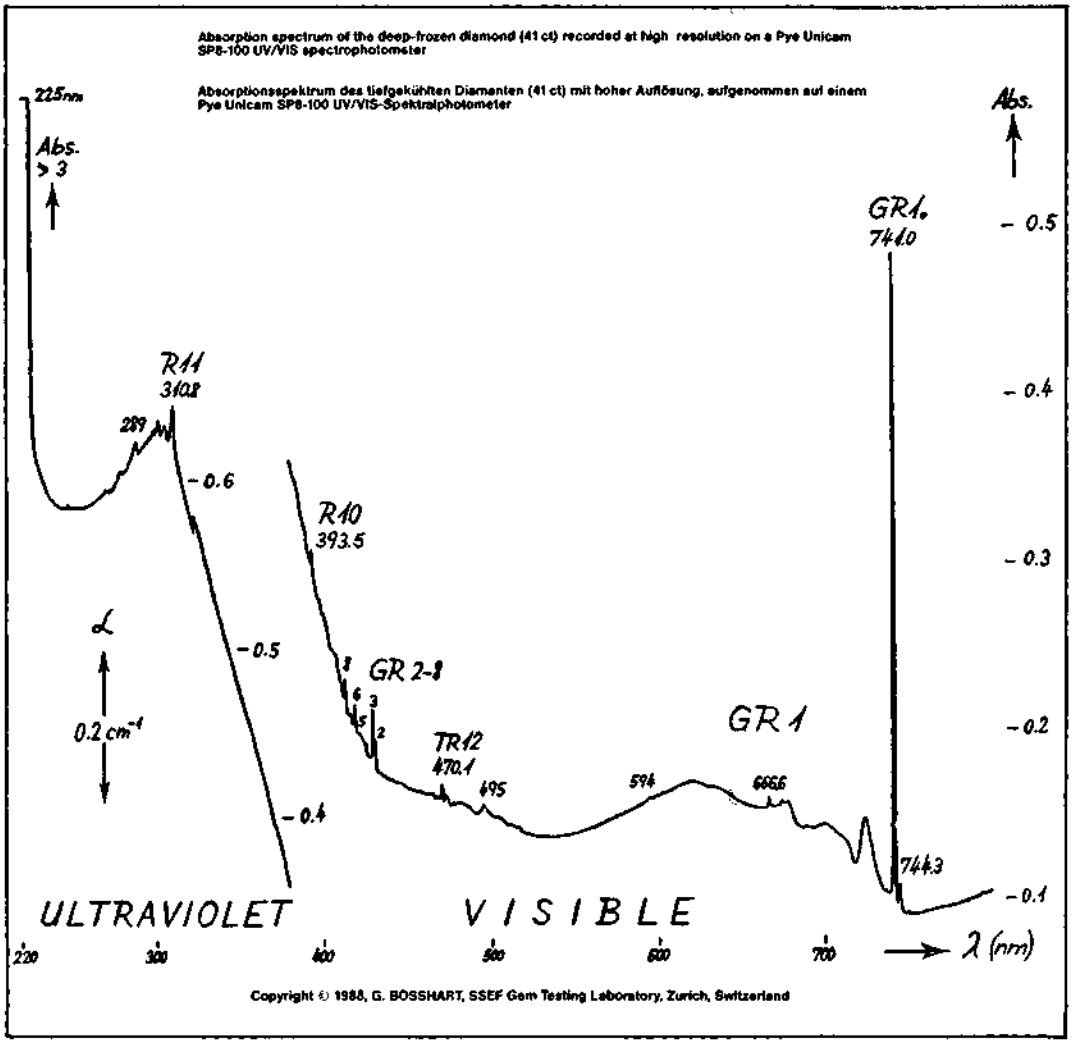

Fig. 6. High-resolution absorption spectrum of the refrigerated Dresden Green Diamond recorded on a Pye Unicam SP8-100 UV/VIS spectrometer at four-fold gain and slow wavelength scanning and chart advance speed. Optical path length from table to culet 10.288 (±0.005) mm. Classical absorption behaviour of an irradiated type IIa diamond.

Main spectral characteristics are the bands of the GR 1 absorption system (750 to 530 nm, present in all irradiated diamonds) and the GR 2-8 system. The wide absorption band between 440 and 250 nm is characteristic of irradiated type IIa diamonds, the chemically nearly pure form of natural and synthetic diamond. The absorption line R 11 occurs only in type IIa diamonds (Davies, 1977). The exceptionally steep and high absorption edge of the Dresden Green is situated immediately below 225 nm in the short-wave ultraviolet spectral region.

The absolutely lowest absorbance of the Dresden Green Diamond in the region of the spectral colours (visible electromagnetic waves between 700 to 400 nm) is found at 534 (±2) nm. A green hue corresponds to this wavelength (after DIN 6164 hue no. 22½). The human eye, however, senses the hue no. 21½, i.e. a *slightly bluish-green* because the absorption in the blue is even lower than in the orange portion. Due to the fairly weak GR 1 absorption in the red and orange regions (right half of Figure 4), the colour saturation of the Dresden Green is relatively moderate. As a result of this, virtually no body colour is visible through the culet (Figure 3). This observation was confirmed by comparison with the DIN Colour Atlas charts (Tab. 1: degree of saturation of the body colour K only about 0.5 units, i.e. very pale).

Fortunately numerous vividly green internal reflections are created by the interaction of the exceptional old-cut and the GR 1 absorption (Tab. 1: degree of saturation of the reflection colour R around 3 units, i.e. a green of medium saturation).

This reflection colour has made the Dresden Green into the famous diamond admired for centuries.

The absorption diagram of the Green Diamond of Dresden in the ultra-violet and visible portions (Figure 6) now represents one of the first if not the first published absorption spectrum for a naturally green, cut diamond (thus being body-coloured) which had been missed by Orlov (1977) and Collins (1982) so far. After the author had already measured other bluish-green old-cut brilliants of natural coloration identified as type IaA diamonds (containing considerable amounts of nitrogen, mainly as pairs named A), it came as a great surprise in the Green Vaults when it became evident that the Dresden Green unambiguously belonged to the rarer, almost nitrogen-free type IIa. This observation was clearly confirmed by the absence of absorption bands below 1600 cm^{-1} and above 2650 cm^{-1} in the recorded mid-infrared transmission diagram. Artificially coloured diamonds of type IIa hitherto encountered displayed indeed a blue colour but almost identical absorption spectra to that of the Green Diamond.

Virtually all diamonds showing a non-fluorescent green colour component owe this to the influence of natural or artificial high-energy radiation. In both cases it generates defects in the carbon lattice of diamond, the so-called vacancies, themselves causing the same kind of selective light absorption in all four known types of diamond (Ia, Ib, IIa, IIb), i.e. in the first place the *GR 1 (General Radiation) absorption system* presented in Figure 6.

At the beginning of this century, W. Crookes executed the first intentional irradiations of diamond by applying radium salts. The green coloration of diamonds can therefore only be accepted, for the intended research study, as guaranteed natural if they spent the last one hundred years under credible supervision (e.g. in a museum) as stones known to always have been green. Considering that industrial routine irradiation of diamond had already begun by approximately 1950, it must be attributed to fortunate circumstances that this can be proved for the Dresden Green even for its absence from Dresden.

- firstly, the colour of the diamond had been described as pale green (Bauer, 1896) long before the stone was stored away on the Königstein, a colour it still shows;
- secondly, the diamond retained several small and shallow fissures with diffuse green specks (Figure 7 and Table 1) encountered so far only as products of natural radiation emanating from radioactive groundwaters.

Undoubtedly, however, these few irradiation spots do not account for the homogeneous green coloration of the Dresden Green. A natural body colour must be present.

Weight Estimation

The author pointed out in the early stages of negotiation with the director of the Green Vaults, Dr J. Menzhausen, that the Dresden Green Diamond should be removed from its mounting and weighed precisely, for the literature (Bauer, 1896, De Beers, 1983, etc.) which until now contains the most incredible weight figures (cf. Table 1). Regrettably no permission could be procured for taking the diamond out of its setting. At that point, the author unfortunately did not know that the girdle projects over the top edge of the bezel on almost half of its circumference.

In order to be able to check the weight figure of 41 ct cited in most instances, two approaches of weight estimation were chosen:

- the weight determination of the diamond in the bezel setting did not permit a satisfactory approximation in spite of the precise measurement of the metal parts because their fineness was not known;
- calculation by means of the factor for the conversion of dimensions into weight of a loose pear-shaped old-cut brilliant of no less than 13 ct proved unsuccessful because the proportions deviated too strongly from those of the Dresden Green.

Based on data gathered in the laboratory, the author reached the conclusion that a conversion factor of 0.0065 would be the most supportable. Calculation with this factor resulted in a weight of 41.1 ct and thus confirmed Menzhausen's value (1987a). If the accurate weight differed, it would be slightly inferior (using the factor of 0.0064, near 40.5 ct).

Diamonds of type IIa reveal a clear tendency to be sizeable as well as nearly to completely colourless (Collins, 1982, translator's footnote p. 164) if not irradiated like the Dresden Green.

Examination of the Cut

The Green Diamond of Dresden was cut more than 240 years ago. Whoever examines this historic cut will be astonished by the quality of its symmetry, polish and proportions:

according to prevailing grading regulations (CIBJO Rules 1986), the quality would have to be classified as good or even very good. The table facet of a diamond of 41 ct although being expansive is optically plane. The common corners of joining neighbour facets are perfectly pointed. Facets of one kind have an identical size and are not distorted. Table and culet are exactly concentric. The outline is pleasingly rounded and symmetrical. The quality of this cut cannot easily be rivalled by more recent old-cuts. And to beat it all, this remarkably cut diamond exhibits a unique series of ratios of length to width, etc., in whole numbers (cf. Table 1).

Fig. 7. Shallow fissure in one of the upper girdle facets showing diffuse green spots on the fissure walls, very probably generated by radioactive waters having circulated on the diamond deposit. Gold bezel (top) and silver bezel (bottom) visible below the fissure. Dark-field illumination. Length of longer fissure approx. 0.4mm.

The question shall be admissible whether such a perfection of cut was conceivable already in the early eighteenth century. Tillander (1988) considers this possible if the diamond had been cut in London, and Guichon (1988) as well if a top cutter executed the opus. In those times already a lap (scaife) of porous cast iron was employed. Yet it did not turn at 3000 but at less than 1000 rpm. The diamond was almost completely coated with lead, and the lead dop was mounted on a thin and flexible copper stick for easy adjustment of the facet angles in relation to the grinding wheel. Because also less oil than boart was applied the cut remained 'cold' but took months for a large facet to be completed (Guichon, 1988).

Conclusions

The secret why a diamond of this size possesses such an outstanding cut and still displays its original coloration is that it was cut slowly and with little pressure only. In that manner neither the diamond nor the lead could heat up over a certain critical temperature.

Without cutters of the past centuries having realized it, green diamonds were protected by the 'thermostat effect' of the lead/tin alloy. Pb/Sn solders melt at low temperatures, varying with composition (CRC 1978):

Pb70/Sn30 at 255°C maximum
Pb60/Sn40 at 238°C standard
Pb40/Sn60 at 190°C minimum

The green radiation colours of diamonds are sensitive to heat, without exception. Hänni (1987 and 1988) checked this fact on an experimental basis on a naturally green-skinned diamond crystal and on an artificially greened brilliant. Many a diamond cutter of today involuntarily has had this experience with his own cutting goods (and many a diamond setter also during his jewellery work).

The discoloration of green diamonds resulting from overheating is a continuous process of healing up the GR 1-8 radiation damage in the crystal lattice. This fading process starts already at 500°C, e.g. when diamonds are brought to red-heat which is performed easily on a modern 3000 rpm lap. In type Ia diamonds the discoloration of green comes to an end at about 800°C (Woods and Collins, 1986), in type IIa at higher temperatures (Davies, 1977). The process takes place quicker the higher the effective heat is. In general, uncontrolled annealing leads to unpleasant brown colour changes of incorrectable stability.

Thanks to the thermostat reaction of the lead dop after the ancient cutting technique, the discoloration of the Dresden Green could therefore not start at all. Thus, if a larger number of historical green old-cut diamonds is unknown world-wide, this can only mean that these body-coloured diamonds are extremely rare, much rarer than the relatively abundant green-skinned rough diamond crystals. The latter lose their surface and sub-surface coloration entirely during cutting most of the time. Occasionally however, individual green specks survive the cutting process, more frequently on remnants of crystal faces ('naturals') than in natural fissures, e.g. like those in the Dresden Green (Figure 7). The causes of this rarity of green body coloration will be pursued in the planned study.

Two further consequences of the low melting point of the lead dop are noteworthy:

no burn marks can be observed on old-cuts after the lead dop technique was applied. As the author pointed out earlier, these surface corrosion marks develop only at 600°C (Hänni and Bosshart, 1987). This temperature can be exceeded easily with modern cutting techniques. According to what has been said so far, the production of burn marks under the prongs of the mechanical dop of

today forcibly involves the destruction of green body and skin-colours of diamond too;

the Green Diamond of Dresden cannot have exceeded the temperature of 260°C when it was cut more than 240 years ago. This means that the absorption band at 594 nm (in Figure 6 present in extremely weak intensity) cannot be an artefact caused by elevated cutting temperatures but represents a natural property of the Dresden Green. The absorption band at 594 nm only develops above 275°C (Woods and Collins, 1986) while the line at 667 nm is destroyed above 430°C (Davies, 1977). Hence it follows that the Dresden Green experienced a temperature of not more than 350 (±80)°C in the earth's crust.

Summary

It can be stated that the Dresden Green Diamond:

1. belongs to the rare and chemically pure type IIa and as such is typically big and free of macroscopic inclusions;
2. possesses internal strain of normal strength ('Tatami' type);
3. as an historical old-cut brilliant exhibits an extraordinarily good cutting quality and noteworthy proportions;
4. was cut at slow speed, with little pressure and, mounted in a lead dop, at less than 260°C and then was carefully set;
5. is damaged along the girdle (its purity and girdle theoretically being improvable by a professional repolish);
6. very nearly weighs 41ct;
7. should be weighed at least to the hundredth of the carat and be set anew;
8. experienced a moderate irradiation by radioactive ground-waters;
9. does not show residual radioactivity;
10. reveals a non-fluorescent bluish-green colour hue and a weak saturation (due to 8);
11. evinces a rare heat-sensitive body colour (due to 1 and 8);
12. displays a brilliant reflection colour (thanks to 3 and 8);
13. was heated in the earth's crust to about 350°C;
14. has retained its green coloration (owing to 4 and 13) but could lose it on the occasion of a repolishing operation on a rapid lap;
15. however, endured multiple deep freezing in a nitrogen gas atmosphere without any problems;
16. differs little in absorption behaviour from type IIa diamonds artificially coloured blue; and
17. will not reveal its place of origin in the near future, based on the inclusions present and on the criteria enumerated above.

Appreciation

The author wishes to express his satisfaction concerning the availability of such a unique gemstone as the Dresden Green for investigation, across all borders. The successful outcome of the 'Dresden Green Project' creates the hope that *in future an increasing number of projects of particular scientific or cultural significance could be realized between East and West.*

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First of all to Dr J. Menzhausen, Director of the Green Vaults, who deserves thanks for his readiness to have the famous gemstone analysed and for his endeavours in obtaining permission from the Ministry of Culture of the German Democratic Republic as well as Dr W. Quellmalz of the Research Department of the State Museum of Mineralogy and Geology at Dresden who supported and advised Dr Menzhausen on scientific and technical issues. Many thanks are owed to Mrs C. Wendt, restorer, and all her colleagues of the Green Vaults, the State Museum of Mineralogy and Geology and the customs and security services who assisted in the completion of the investigation.

Without the spirited response of Dr K. Herzog and Mrs R. Lunkwitz of the Physical Chemistry Department of the Technical University at Dresden in supplying an infrared spectrophotometer and technical know-how, evidence of the diamond type could not have been secured completely. Kind thanks are expressed to both as well as to their superior, Prof. Dr E. Steger.

The author is indebted to his brother, Robert Bosshart, for assistance with the transportation of the instruments and during the analysis, but foremost for his valuable photographic documentation of the Dresden Green Diamond and the working scenes (e.g. Figures 1 to 5) under pressure of time.

For microscopical examination and photomicrography (Figure 7), the author was provided with a Maxilab-Reichert Sierra StarZoom stereomicroscope by Messrs R. E. Kane and S. F. McClure of the Gemological Institute of America, Los Angeles. He is thankful to both colleagues for their collaboration prior to and during the period of research.

It is also recognized with thanks that the Board of Councillors of the SSEF Foundation participated in the necessary time exemption of the author and in the expenses for the project. In addition, the mastering of the workload at the SSEF Laboratory in Zurich by the author's colleagues, Mrs M. Fritsche and Dr H. A. Hänni, is gratefully acknowledged. The article benefited from the photography of the absorption spectrum (Figure 6) and from technical discussions with Dr Hänni.

Special thanks go to Mr A. Guichon, a diamond

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Furthermore the author appreciates the assistance of several friends in developing and outfitting the cooling cell and also the help by Dr M. Rosenfeld, a solid-state physicist in cryogenics, in establishing the evidence of innocuousness in the refrigeration for the Dresden Green.

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'Aqua Aura' enhanced quartz specimens

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Abstract

Singly and doubly terminated euhedral quartz crystals and crystal clusters with a coating producing an apparent blue colour and strong iridescence are being sold under the trade name 'Aqua Aura'. The authors report on their examination of a specimen which confirmed that the coating consists of gold.

Introduction

In the Fall of 1988 one of the authors (RCK) was shown an interesting quartz specimen by Mr. Peter Flusser of Overland Gems in Los Angeles, California. The crystal was singly-terminated, weighed 47.50 ct. and measured 52 millimetres in length. It had an unusual light blue to greenish blue body colour (Figure 1a) and strong iridescent colours on all surfaces (Figure 1b). This author was informed that the specimen had been obtained from the firm Bob Jackson Minerals in Renton, Washington, and was being marketed as 'Aqua Aura'. The authors subsequently saw additional specimens at the annual Pasadena Gem and Mineral Show in Pasadena, California, and Dr. Emmanuel Fritsch of GIA's Research Department later provided a crystal cluster of this coated quartz given to him directly by Bob Jackson for visual examination (Figure 2).

According to a small slip of promotional literature obtained at the Pasadena Show, 'Aqua Aura' specimens are 'Natural quartz crystals coated with pure gold'. Following is some additional text provided with the crystals that relate to the coating process used: 'Quartz crystals are naturally surrounded by an electrical charge. Aqua Aura is created by allowing pure gold molecules to adhere to that charge. The extremely thin gold coating breaks light into its spectral colours, causing the beautiful colours of Aqua Aura.' With respect to durability, the promotional piece states that 'Aqua Aura requires no special care to keep its beauty. The gold coating cannot be rubbed or scraped off'.

Gemmological examination

The examination began with the testing of the quartz crystal to determine its gemmological properties. The crystal had a colour that varied from greenish-blue to blue, with overlying iridescent colours of violet, blue, green and yellow. Of the iridescent colours, the violet was most prominent. Overall, the crystal had a high degree of transparency. As the crystal faces of the specimen were well-formed with reasonably good surface lustre, flat facet refractive indices readings were taken

Figs. 1a & b. 'Aqua Aura' coated quartz crystal (GIA Collection No.16667) showing (left) the blue colour (right) the iridescent colours provided by the coating. Oblique fibre optic illumination. *Photos by William Videto.*

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Fig. 2 (centre). 'Aqua Aura' quartz crystal cluster. Oblique fibre optic illumination. *Photo by William Videto.*

Fig. 3 (top, left). 'Aqua Aura' coated quartz crystal showing areas devoid of the coating and colour concentrated along the edge of the crystal face. 40x. *Photo by John I. Koivula.*

Fig. 4 (top, right). Surface pits on an 'Aqua Aura' quartz crystal in which little or no coating was observed. 30x. *Photo by John I. Koivula.*

Fig. 5 (right). Iridescent surface layer on an 'Aqua Aura' quartz crystal. 10x. *Photo by John I. Koivula.*

using a GIA GEM Instruments Duplex II refractometer and near-monochromatic light. Somewhat vague readings of 1.54-1.55 were obtained. In a field of polarized light a typical doubly refractive reaction was noted.

The specimen was also examined for its reaction to ultraviolet radiation and proved to be inert to both long- and short-wavelengths. No visible absorption features were noted when the crystal was examined with both diffraction-grating and prism type hand held spectroscopes, using both transmission and external reflection lighting methods.

Specific gravity was determined by immersing the crystal in a mixture of methylene iodide and benzyl benzoate calibrated to 2.67. When placed in this liquid the crystal floated very slowly – at essentially the same rate as an untreated rock crystal quartz. Specific gravity was thus estimated at 2.66.

Under magnification the coating revealed a number of interesting features. First, it appeared to vary in thickness on some crystal faces, with some small areas showing no coating at all (Figure 3). It also seemed not to have deposited as well in surface pits as it had on flat surfaces (Figure 4). The colour also looked to be concentrated near crystal edges (Figures 3 and 4) and appeared as if it may have been deposited directionally.

Durability testing

A number of additional tests were performed to determine the relative durability of the coating. A hardness pencil of Mohs hardness 6 failed to scratch the crystal or produce any visible mark on the coating, while one of Mohs hardness 7 produced a scratch. No visible reaction was noted when the surface was tested with a thermal reaction tester heated to a red heat (approximately 800 degrees Centigrade). The crystal was then placed on an electrically-activated 'Kanthal' bridge and heated to a temperature of approximately 1000-1100 degrees Centigrade (gold melts at 1064 degrees Centigrade). This also appeared to have no effect on the coating. Finally, one crystal face was rubbed vigorously with a cotton swab dipped in acetone. No discoloration appeared on the swab and no visible effect was noted on the crystal face.

Chemical analysis

The crystal was next examined by means of energy dispersive X-ray fluorescence (ED-XRF) to determine its elemental characteristics. The major elements detected were silicon, gold and titanium. The silicon was almost certainly from the quartz itself. It is believed that the titanium detected may have been from sub-microscopic rutile inclusions (TiO_2) in the quartz crystal or more probably from titanium in solid solution, because it is well known that titanium is one of the secondary elements commonly found as a solid solution constituent in natural quartz (Frondel, 1962). The other major element detected, gold, supports the information from the vendor that the coating used is pure gold. Dr. Fritsch also noted that, when tested for electrical conductivity on a conductometer, in some areas the gold coating showed excellent conductivity.

Table 1: Summary of gemmological properties

Colour:	Greenish-blue to blue
Iridescent colours:	Violet, blue, green and yellow; violet most prominent
Diaphaneity:	Transparent
Refractive indices:	o – 1.54; e – 1.55
Polariscope reaction:	Doubly refractive
UV fluorescence	
Long-wave:	inert
Short-wave:	inert
Absorption spectrum:	none
Specific gravity:	2.66 (heavy liquid method)
Hardness:	6½-7
Reaction to heat:	None observed to 1000-1100 degrees C.
Reaction to acetone:	None

Discussion

The blue colour shown by 'Aqua Aura' quartz is not an interference colour. Gold in thin film is bluish-green in transmitted light. Thus the green to blue colour exhibited by 'Aqua Aura' quartz is the true absorption-caused colour of gold (Nassau, 1983).

In addition to the thin film effects observed internally as inclusions in some gems (Koivula, 1980), thin film coatings, similar to the iridescent surfaces (Figure 5) shown by these artificially gold-coated 'Aqua Aura' quartz crystals, are known to occur in nature. The common oil slick on water

is probably the best single example (Ribbe, 1972) but some types of sun-oxidised glass, certain minerals such as cuprite, and the gems faceted from them, will also often show iridescent, metallic-appearing superficial thin films. The iridescence colours superimposed on the surface of 'Aqua Aura' quartz are related to the thickness of the gold film, probably of the same order of magnitude as the visible wavelength.

If we think of the already existing technology in relation to thin film applications of elemental gold, then the appearance of 'Aqua Aura' in the gem and mineral trade is not too surprising. Many of today's modern synthetics came to gemmology from other fields of science such as laser research and the computer industry. Now, as an apparent spin-off from the thin film gold-coating technology that gives us the sun visors on astronauts' helmets and the vacuum deposited conductive coatings for scanning electron microscopy, we have 'Aqua Aura'.

Conclusion

Based on the examination of this 'Aqua Aura' coated quartz crystal (GIA Collection No. 16667) as summarised in Table 1, it appears that the coating does not affect the normal quartz properties. The vendor's claim that the coating is 'pure gold' is substantiated through energy dispersive X-ray fluorescence testing. Furthermore, in view of the rigorous durability testing, statements relating to the relatively durable nature of the coating also appear to be accurate. At this point in time we have only seen single quartz crystals and crystal clusters given the 'Aqua Aura' treatment. But, knowing the history of other gemstone treatments, can faceted 'Aqua Aura' gems be far off?

Acknowledgements

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Methods for the distinction of natural and synthetic citrine and prasiolite

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Abstract

Different types of natural and synthetic citrine are characterized by a combination of absorption spectroscopy in the visible and ultraviolet range with microscopic investigations of structural properties such as twinning, growth structures, colour zoning as well as orientated channel-like inclusions or orientated striations.

Both methods reveal a number of typical features which indicate artificial irradiation and/or heat treatment. The colour of natural and synthetic citrine is caused by traces of iron and/or cobalt, as well as by radiation-induced colour centres. According to colour causes and treatment histories, natural and synthetic citrines are classified into different categories as indicated below:

(a) yellow to orange-brown heat-treated natural citrine, originally amethyst: Fe-containing particles;
(b) green heat-treated natural prasiolite, originally amethyst: Fe-containing particles and Fe^{2+} (I_6);
(c) light yellow, non-artificially-irradiated, non-heat-treated natural citrine; radiation-induced colour centres;
(d) light yellow, non-artificially-irradiated, heat-treated natural citrine: originally morion: radiation-induced colour centres;
(e) greenish-yellow artificially-irradiated, non-heat-treated natural citrine, originally colourless quartz: radiation-induced colour centres;
(f) greenish-yellow artificially-irradiated, heat-treated natural citrine, originally colourless quartz: radiation-induced colour centres;
(g) yellow to orange-brown synthetic citrine: Fe-containing particles;
(h) yellow to orange-brown synthetic citrine: Fe-containing particles and Fe^{3+} (I_4);
(i) green synthetic prasiolite: Fe-containing particles, Fe^{3+} (I_4) and Fe^{2+} (I_6);
(j) yellow to orange-brown synthetic citrine: Fe-containing particles and Co^{3+} (I_6);
(k) greenish-yellow artificially-irradiated, non-heat-treated synthetic citrine, originally colourless synthetic quartz: radiation-induced colour centres;
(l) greenish-yellow artificially-irradiated, heat-treated synthetic citrine, originally colourless synthetic quartz: radiation-induced colour centres.

A number of specific properties was found which are useful for the determination of growth and/or treatment histories of samples of unknown origin and for a distinction of natural versus synthetic citrine. Most natural citrines used in the trade are heat-treated natural amethysts. However, non-artificially-irradiated, non-heat-treated or heat-treated as well as irradiated and possibly heat-treated natural quartz is also found. Most synthetic citrines of the trade are different types of Fe-bearing as well as Fe- and Co-containing quartz crystals, which are grown hydrothermally from K_2CO_3-bearing solutions with or without additional oxidizers. Trace element analyses of synthetic citrine can indicate growth media and oxidizers used in the working solution.

I Introduction

In the past years great efforts were made and many investigations were undertaken for the characterization of the properties of natural and synthetic amethyst in order to develop practicable methods for the distinction of natural and synthetic samples. In the papers published so far emphasis is laid on infrared spectroscopy and microscopy as the two dominant methods to recognize features useful for diagnostic purposes (e.g. Schmetzer and Bank, 1980; Zecchini and Mérigoux, 1980; Lind and Schmetzer, 1982, 1983; Schneider and Dröschel, 1983; Lind *et al.*, 1983, 1985; Schmetzer, 1985, 1986; Lind and Schmetzer, 1985, 1987; Crowningshield *et al.*, 1986). Although in some of the papers mentioned above, some hints are given which are useful for the distinction of natural and synthetic citrine, no comprehensive publication exists which enables the practical gemmologist to decide whether a yellow or brown quartz of unknown origin is a natural or man-made, treated or untreated stone (cf. O'Donoghue, 1983).

In the present publication a combination of absorption spectroscopy in the visible and ultraviolet areas with microscopic investigations is suggested as a routine method for a distinction between natural and synthetic members of the quartz family with yellow, greenish-yellow, green, orange-brown or brown coloration. However, before describing the characteristic features of natural and synthetic quartz varieties, it is necessary to give a short review of the scientific literature dealing with colour and colour causes of natural citrine types as well as with

the production of synthetic yellow, yellowish-green, green, orange-brown and brown quartz. With the information given in the literature, most of the properties of all different types of natural and synthetic citrine, which are found in the gem trade, can be understood. In addition, a short overview of the literature should help to avoid further confusion between the different types of natural and synthetic citrines described so far, as well as between different applications of closely related terms such as citrine, honey quartz and greenish-yellow quartz for samples of identical origin or with similar growth and/or treatment histories (cf. Nassau, 1977).

According to the personal opinion of the present author, for practical reasons the terms natural citrine and synthetic citrine should be used for all yellow, greenish-yellow, orange-brown and brown members of the quartz group, as well as the terms natural prasiolite and synthetic prasiolite for green samples. The main argument for this suggestion is that the determination of the exact colour-causing trace element or colour-causing defect (colour centre) is not practicable in the gem trade for each sample. However, a general decision of international nomenclature commissions, e.g. a decision of the Commission on Gem Materials of the International Mineralogical Association or a decision of the CIBJO Commission, for the use of the term citrine are needed in order to clarify and avoid all possibilities of misunderstanding and misinterpretation.

II Review of the literature dealing with yellow, greenish-yellow, green, orange-brown or brown quartz varieties

A general survey of natural and synthetic quartz varieties, growth conditions and colour causes is given by various authors; these papers are suggested for additional reading (Gordienko *et al.*, 1969; Lehmann and Bambauer, 1973; Hutton, 1974; Lehmann, 1978a, b; Balakirev *et al.*, 1979; Elwell, 1979; Nassau, 1980; Balitsky, 1981; Sunagawa, 1982).

II.1 Heat-treated natural amethyst

Most yellow, yellowish-brown, orange-brown and brown natural citrines of the trade are natural amethysts which were converted to citrine by heat treatment at temperatures between approximately 400 and 600°C. The absorption spectrum of this type of citrine consists of an increasing absorption from the red area to the violet end of the visible region, which is due to an absorption band centred in the ultraviolet area and extending into the visible range with its low energy tail. According to EPR-investigations, this absorption is caused by small iron-containing particles, presumbly Fe_2O_3 precipitates, which are submicroscopically dispersed in the host crystal (Lehmann and Moore, 1966; Hutton and Troup, 1966; Lehmann, 1967, 1971a, b; Wild, 1968; Lehmann and Bambauer, 1973; Stock and Lehmann, 1977; Neumann and Schmetzer, 1984a, b). The colour of heat-treated natural amethyst crystals, which turn green during the annealing process (the so-called prasiolite of the trade) is due to interstitial Fe^{2+} on distorted octahedral sites, designated Fe^{2+} (I_6). The absorption band of Fe^{2+} (I_6) in quartz in the visible region is centred in the red area at about 13,500 cm^{-1} (approx. 741 nm), a second broad absorption band is observed at 10,500 cm^{-1} (approx. 950 nm) in the near infrared (Lehmann, 1967; Lehmann and Bambauer, 1973; Neumann and Schmetzer, 1984a,b).

II.2 Greenish-yellow, irradiation-treated natural quartz (originally colourless or light yellow)

Colourless natural quartz crystals of peculiar occurrences turn smoky or greenish-yellow by irradiation treatment with gamma rays. After subsequent heat treatment of irradiated samples at lower temperatures (e.g. about 150 – 250°C), smoky-quartz may turn greenish-yellow or colourless. Greenish-yellow quartz, which is produced by heat treatment of smoky quartz or directly without annealing by gamma irradiation, becomes colourless again by heat treatment at higher temperatures (e.g. about 250 – 350°C). Two different descriptions and interpretations of the absorption spectra of irradiated greenish-yellow quartz and irradiated smoky quartz, which turned greenish-yellow after subsequent heat-treatment, are found in the literature.

The first group of authors measured absorption spectra with two distinct maxima, one of them between 24,400 and 25,600 cm^{-1} (410 and 390 nm), the second one between about 15,600 and 16,100 cm^{-1} (640 and 620 nm). Both absorption bands are superimposed by an absorption in the ultraviolet area, the low energy tail of which extends to the visible region (Samoilovich *et al.*, 1969b; Bukanov and Markova, 1969; Lehmann, 1971a, b; Lehmann and Bambauer, 1973; Samoilovich *et al.*, 1976; cf. also the paper dealing with neutron irradiated quartz by Maschmeyer and Lehmann, 1984). Most characteristic for all these publications is the description of an absorption maximum in the 24,400 to 25,600 cm^{-1} area (410 to 390 nm), the position of which is distinctly shifted to the short wavelength region compared with the position of the ordinary maximum of the smoky colour centre in quartz. The maximum of this Al-related colour centre is found at approximately 23,400 to 22,200 cm^{-1} (427 to 450 nm).

The second group of papers dealing with irradiation-induced colour of greenish-yellow quartz describes the absorption spectra of all types of irradia-

ted smoky and greenish-yellow quartz crystals to be due to a superposition of an absorption maximum in the ultraviolet, the low energy tail of which extends to the visible area (so-called greenish-yellow absorption) with several distinct absorption maxima at 15,000 cm^{-1} (designated A_1), 20,650 cm^{-1} (designated A_2), 23,400 cm^{-1} (designated A_3, smoky colour centre) and 32,000 cm^{-1} (designated B) (Nassau and Prescott, 1975, 1977a).

In the first group of publications, besides an absorption maximum in the ultraviolet causing an increasing absorption from red to violet in the visible region, two different types of colour centres are assumed to be additionally present in the visible part of the absorption spectra of quartz crystals with smoky brown, yellowish-grey, and greenish-yellow colours. In these varieties of irradiated quartz crystals, the ordinary smoky centre is thought to be responsible for the absorption band at about 22,200 cm^{-1} (450 nm), and a similar, but not identical colour centre is thought to cause the absorption band at about 25,000 cm^{-1} (400 nm). The various colour shades of irradiation-treated samples with or without subsequent annealing are explained by combinations of the ultraviolet absorption maximum with the two absorption bands in the blue and violet, all three of them having different intensity ratios as well as different bleaching characteristics.

In the second group of publications all different smoky to greenish-yellow colour shades of irradiated quartz crystals are explained by combinations of two absorption bands only, i.e. by a superposition of the greenish-yellow absorption in the ultraviolet and the ordinary smoky absorption band. The presence of a different third absorption band, the maximum of which is shifted from 22,200 cm^{-1} to the short wavelength region is not assumed in those papers (cf. also the results of Sawyer, 1974, 1976).

In general, Al^{3+} on Si^{4+} sites with charge compensating alkali ions is thought to be responsible for the formation of smoky colour centres in quartz, and Al^{3+} on Si^{4+} sites with charge compensating hydrogen and lithium ions is assumed to cause greenish-yellow colours. However, not all details of irradiation-induced smoky and greenish-yellow colour centres are understood at present.

II.3 Natural yellow to brown quartz and heat-treated morion

Natural yellow and light brown quartz, which is not produced from amethyst by heat treatment, is long known in the gem trade. Part of the material used for cutting purposes is of natural colour, i.e. these stones are neither heat-treated nor artificially-irradiated. In some instances, natural smoky quartz or morion is able to be converted by heat treatment at about 300°C to yellow or light brown citrine (cf. Wild, 1968; Bank, 1976). The first papers, in which the independent nature of this third type of citrine coloration is recognized, were published by Samoilovich *et al.* (1976) and Lehmann (1977, 1978a). Further information about this type of citrine coloration is found in the publications of Nassau and Prescott (1977a), Steshchin (1979a,b), Maschmeyer *et al.* (1980), Lehmann (1981) and Maschmeyer and Lehmann (1983).

The absorption spectrum of this third type of citrine is similar to the spectrum of heat-treated amethyst, i.e. the spectrum consists of a strong absorption in the ultraviolet area, the low energy tail of which extends to the visible region. Instead of the coloration of heat-treated amethyst, natural untreated citrine of this third type is slightly pleochroic. The difference between artificially irradiated greenish-yellow quartz, i.e. the second type of citrine, and this third type of citrine coloration is the absence of a distinct absorption band at about 25,000 cm^{-1} (400 nm) as well as an improved thermal stability of the colour centres up to about 500°C. A model for two paramagnetic centres observed in two crystals of this third type of citrine from Madagascar was worked out by Maschmeyer *et al.* (1980) and Lehmann (1981), and new investigations by Maschmeyer and Lehmann (1983) using natural citrines from Madagascar revealed the presence of at least seven different hole centres. Most of them are related to substitutional Al on Si sites; however, the exact nature of additional defect structures which cause their difference to smoky quartz centres are still unknown.

The unique green quartz described by Nassau and Prescott (1977b) is possibly a citrine of this third type having an additional weak absorption band at about 16,100 cm^{-1} (620 nm), the origin of which is unknown at present.

II.4 Synthetic Fe-containing yellow, green, orange-brown and brown quartz

The first samples of synthetic brown and green quartz were described by Tsinober *et al.* (1959), Tsinober and Chentsova (1959) and Ballmann (1961). The crystals were grown on basal seeds in aqueous K_2CO_3-containing solutions by hydrothermal techniques. Brown crystals containing mainly Fe^{3+} were obtained from lower concentrations of K_2CO_3 and green crystals containing Fe^{3+} and Fe^{2+} were grown from solutions with very high K_2CO_3 concentrations. Heat treatment at 400 – 500°C turned brown crystals green by reducing part of Fe^{3+} to Fe^{2+}.

The growth of synthetic yellow quartz, so-called synthetic citrine, is described comprehensively by Chadschi and Reschetowa (1975) and Khadzhi and Reshetova (1977). The crystals were grown on quartz seeding plates orientated parallel to the basal pinacoid (0001) or with plates inclined at an angle

Table 1. Absorption bands assigned to trivalent iron in interstitial sites of distorted tetrahedral symmetry in the quartz lattice (in cm^{-1})

Lehmann, 1971a	Khaliov *et al.*, 1979	Transition
18,700	18,000	$^6A_1 \rightarrow {}^4T_1$
20,200	20,300	$\rightarrow {}^4T_2$
22,500	21,800 22,700	$\rightarrow {}^4A_1, {}^4E$
24,800	24,800	$\rightarrow {}^4T_2$
27,300	26,000	$\rightarrow {}^4E$
29,100	28,700	$\rightarrow {}^4T_1$

within the range of up to 20° to the basal plane in aqueous solutions of K_2CO_3. Furthermore, substances for the oxidation of iron such as nitrites and nitrates of alkali metals or potassium permanganate (e.g. $LiNO_2$, $NaNO_2$, KNO_2, $LiNO_3$, $NaNO_3$, KNO_3, $KMnO_4$) are added to the solution. The presence of Li^+ in the working solution of K_2CO_3 is responsible for purification from undesired aluminium impurities due to the formation of hardly soluble impurities such as eucryptite, $LiAlSiO_4$. Without the presence of lithium ions, capillary channels parallel to the optical axis of the quartz crystals are formed by Al impurities, disturbing the homogenity and colour quality of synthetic citrine.

A third method for the production of iron-bearing yellow to orange-brown quartz is recently described by Hosaka and Taki (1983). The hydrothermal growth was performed using NaCl- and KCl-containing solutions with X-cut (11$\bar{2}$0) and Y-bar seeds.

Various publications deal with colour and colour causes in synthetic Fe-containing yellow, brown and green quartz (Lehmann and Moore, 1966; Lehmann, 1967, 1971a,b; Samoilovich *et al.*, 1969a; Gordienko *et al.*, 1969; Lehmann and Bambauer, 1973; Samoilovich *et al.*, 1976; Zakharov *et al.*, 1978; Khaliov *et al.*, 1979; Balakirev *et al.*, 1979; Balitsky and Balitskaya, 1985, 1986). Some of the results can be summarized as follows: in synthetic yellow, orange-brown, brown and green quartz three different colour causes were found to exist. These are iron-containing colloidal particles, most probably Fe_2O_3, ferric iron on interstitial sites of distorted tetrahedral co-ordination, designated Fe^{3+} (I_4), and ferrous iron on interstitial sites of distorted octahedral co-ordination, designated Fe^{2+} (I_6). According to the details of crystal growth of an individual sample, the three colour-causing particles or ions are present in various amounts, and the colour is due to a superposition of three basic types of absorption spectra.

The spectrum of iron-containing colloidal particles consists of a strong absorption in the ultraviolet, the low energy tail of which extends to the visible area. A continuous absorption results increasing from red to violet. In the absorption spectrum of Fe^{3+} (I_4) numerous weak absorption bands are found in the visible and ultraviolet region (Table 1). The spectrum of Fe^{2+} (I_6) is dominated by two strong broad absorption bands with maxima at about 13,500 and 10,500 cm^{-1} (741 and 950 nm).

In yellow to orange-brown quartz grown in K_2CO_3 solutions with the presences of oxidizing phases, iron-containing particles are dominant. In brown quartz from K_2CO_3 solutions without the presence of oxidizers, iron-containing particles and Fe^{3+} (I_4) are observed. In green quartz, additional amounts of Fe^{2+} (I_6) are found. All colours of iron-containing synthetic quartz can be explained by a combination of all three colour-causing particles or ions in various concentrations. Upon heat treatment, brown samples of iron-containing synthetic quartz are converted to green prasiolite. This colour change is explained by a reduction of Fe^{3+} to Fe^{2+} accompanied by a migration from tetrahedral to octahedral interstitial sites, i.e. Fe^{3+} (I_4) $\rightarrow$ Fe^{2+} (I_6) (Tsinober *et al.*, 1959; Samoilovich *et al.*, 1969a; Lehmann and Bambauer, 1973).

II.5 Yellow, greenish-brown and yellow-brown, irradiation-treated synthetic quartz (originally colourless)

Irradiation-induced colour changes of synthetic quartz are slightly different from colour changes of irradiation-treated natural samples. In synthetic quartz, smoky and greenish-yellow colours are

obtainable after irradiation (Gordienko *et al.*, 1969; Sawyer, 1974, 1976; Samoilovich *et al.*, 1976; Nassau and Prescott, 1977a). Subsequent heat treatment turns smoky quartz blue, blue-green, green, greenish-yellow or colourless, whereas greenish-yellow quartz is only bleached by annealing processes (Nassau and Prescott, 1977a). In some papers, a correlation between trace element contents and irradiation-induced colour centres is discussed, e.g. for Al- and Ge-containing synthetic quartz with smoky coloration after gamma irradiation (Chentsova and Butuzov, 1962; Haven *et al.*, 1966; Tsinober *et al.*, 1967; Gordienko *et al.*, 1969) as well as for Ga-containing synthetic quartz with yellow-brown coloration after irradiation treatment (Balitskii *et al.*, 1970). The influence of charge compensating hydrogen and alkali ions (sodium and lithium) is also questionable (cf. Sawyer, 1974, 1976). However, not all details of irradiation-induced colour changes of synthetic quartz are understood at present.

For jewellery purposes, synthetic quartz crystals with irradiation-induced yellow, greenish-yellow or yellow-brown coloration are not suitable due to the low thermal stability of this type of citrine colour centres (Nassau and Prescott, 1977a), which are already bleaching in daylight (Balitsky, 1981).

II.6 Synthetic Co-containing yellow, brown and blue quartz

Co-bearing synthetic quartz is grown from Na_2CO_3- and K_2CO_3-containing solutions on basal seed plates. The colour of the samples obtained are blue from Na_2CO_3- and yellow to brown from K_2CO_3-containing environments, respectively. The absorption spectra of blue samples are assigned to bivalent cobalt in interstitial positions of distorted tetrahedral symmetry, designated Co^{2+} (I_4), whereas the spectra of brown cystals are explained by the presence of trivalent cobalt in interstitial positions of distorted octahedral symmetry, designated Co^{3+} (I_6). Brown samples turn blue after heat treatment at approximately 450°C. This colour change is due to a reduction of cobalt from trivalent to bivalent state accompanied by a displacement from distorted octahedral to tetrahedral interstitial positions, i.e. Co^{3+} (I_6) $\rightarrow$ Co^{2+} (I_4) (Wood and Ballman, 1966; Samoilovich *et al.*, 1969a; Gordienko *et al.*, 1969; Lehmann, 1969, 1971a; Lehmann and Bambauer, 1973). In addition to the presence of Co^{3+} (I_6), synthetic samples may also contain distinct amounts of Fe^{3+}, most presumably as colloidal particles (Gordienko *et al.*, 1969; Lehmann, 1969; Balakirev *et al.*, 1979). At present, no natural counterparts of synthetic Co-bearing blue, yellow or brown quartzes are known.

III Investigations of commercially available, and some non-commercially, natural and synthetic citrines including yellow, yellowish-green, green, orange-brown and brown quartz varieties

III.1 Materials and methods

Only few references are found in literature which contain specific indications on techniques applicable for the distinction of natural and synthetic citrine (cf. O'Donoghue, 1983). In the present research project, the two main methods which were suggested for the distinction of natural and synthetic amethyst, i.e. infrared spectroscopy and microscopic determination of twinning, growth structures and inclusions, were also tested for the determination of citrine. According to Zecchini and Mérigoux (1980), infrared spectroscopy in the 4000-3000 cm^{-1} range is useful for the distinction of natural and synthetic citrine. However, experiments performed by Th. Lind at Heidelberg University in 1982 and 1983 (unpublished) using heat-treated amethysts and Fe-containing synthetic citrines were not successful and failed to establish infrared spectroscopy as a routine method for the determination of cut citrines of unknown origin.

According to microscopic investigations, the recognition of the presence of polysynthetic twinning on the Brazil law is useful for the determination of natural citrine which is produced from natural amethyst by heat treatment (Schmetzer, 1985, 1986). This result was worked out using a horizontal microscope with immersion liquids and an especially developed sample holder. By the application of a simplified technique for the recognition of polysynthetic twinning in natural amethyst without microscopic investigations, an identical behaviour of natural amethyst and citrine produced by heat treatment of natural amethyst is described (Crowningshield *et al.*, 1986). This statement, however, was found to be partly incorrect and thus will be discussed below in detail.

In summary, it was assumed at the beginning of the present investigation, that the determination of twinning and other structural properties can be a useful method for the characterization of citrines of unknown origin whereas the application of infrared spectroscopy for the study of citrines, especially for faceted samples, was neglected in this project. However, it is evident from literature (cf. sections II.1-II.6), that different natural and synthetic varieties of citrine reveal various colour causes. Thus, the investigation of absorption spectra in the visible and ultraviolet region was assumed to be an adequate method to characterize the samples. In addition, it was suspected that possibly some spectroscopic properties of natural and synthetic citrines are not common for all types of samples. These considerations led to systematic investigations by a combination of microscopy and absorp-

tion spectroscopy in the visible and ultraviolet.

The samples investigated were selected in order to be typical and representative for the material used in the gem industry of Idar-Oberstein. For most natural samples, the exact localities were known. In contrast, no synthetic samples were found in the trade, for which an appropriate characterization of growth conditions was available and, therefore, the assignment of the samples investigated to certain categories of synthetic citrine as well as to specific growth conditions had to be worked out experimentally.

of this particular type of citrine. The absorption maximum in the ultraviolet extending to the visible is assigned to iron-containing colloidal particles in literature, which are formed during the annealing process. The weak absorption band at 21,000 cm^{-1} was not mentioned previously.

The absorption spectra of heat-treated natural amethysts which turned green during the annealing process, the so-called prasiolite of the trade (Figure 2), show an additional weak absorption band at about 13,500 cm^{-1} (741 nm), which was assigned to bivalent iron on interstitial sites of distorted

Fig. 1. Colour sequence of natural citrines; five samples represent heat-treated natural amethysts from Brazil, the right stone represents natural untreated citrine from Goyaz, Brazil. Diameter of the sample approx. 10 mm. *Photo by O. Medenbach, Bochum, FRG.*

III.2 Results

III.2.1 Heat-treated natural amethyst (citrine and prasiolite)

Yellow to orange-brown citrine and green prasiolite which was commercially produced by annealing of natural amethyst was available from different localities in Brazil, from Uruguay and Namibia. The designations Bahia, Palmeira and Madeira citrine are sometimes used in the trade in order to characterize the colour intensity of samples in the yellow to orange-brown sequence (Figure 1), greened amethyst is often called prasiolite.

Absorption spectra of this type of natural citrine (heat-treated amethyst) reveal a continuously increasing absorption from red to violet in all samples with different colour shades and intensities (Figure 2). The increasing absorption is caused by a strong band with maximum in the ultraviolet, the low energy tail of which extends to the whole visible area. In addition, a weak absorption band at about 21,000 cm^{-1} (476 nm) was measured in all samples

octahedral symmetry, Fe^{2+} (I_6). The colour of heat-treated amethyst is dependent only of the intensity ratios of the green and yellow to brown absorption, i.e. the colour after annealing is due to the relative amounts of iron-containing precipitates and Fe^{2+} (I_6) produced by heat treatment. However, the detailed mechanisms of the development of both types of iron in various ratios are not completely understood at present (cf. Neumann and Schmetzer, 1984a,b).

Polysynthetic twinning on the Brazil law is thought to be one of the most important properties of natural amethyst, the presence of which can be used for recognition of an unknown sample to be of natural origin. Unfortunately, the possibility for direct observation of polysynthetic twinning on the Brazil law in natural amethyst and heat-treated natural amethyst (citrine and prasiolite) is limited to a small number of specimens only (cf. Schmetzer, 1987). However, the presence of polysynthetic twinning is clearly indicated by the observation of

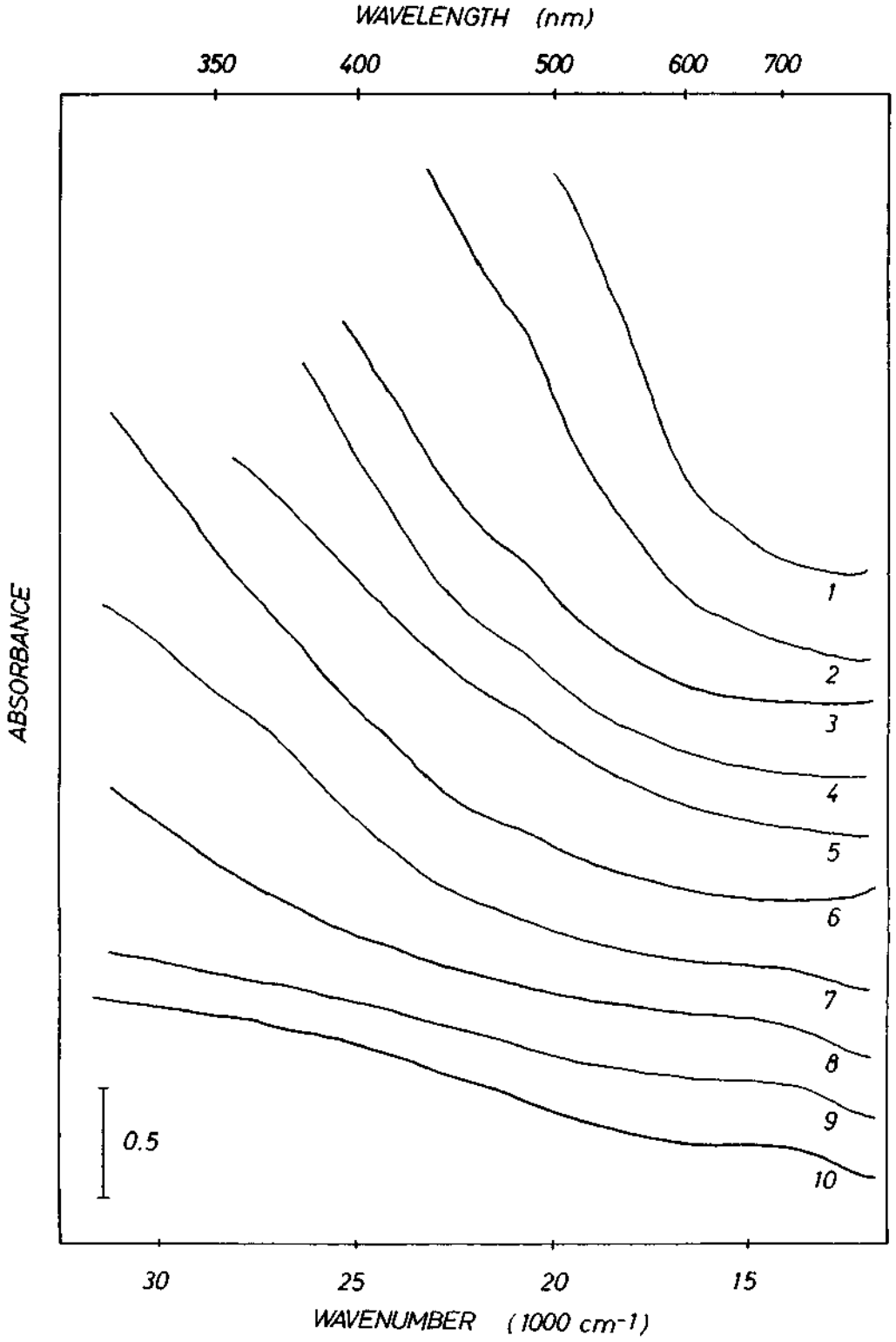

Fig. 2. Absorption spectra of natural citrines and natural prasiolites (heat-treated natural amethysts); citrines: 1 Brazil, 2 Brazil, 3 Brazil, 4 Uruguay, 5 Brazil, 6 Maramba, Brazil, 7 Bahia, Brazil; prasiolites: 8 Jakobina, Brazil, 9 Montezuma, Brazil, 10 Zambia.

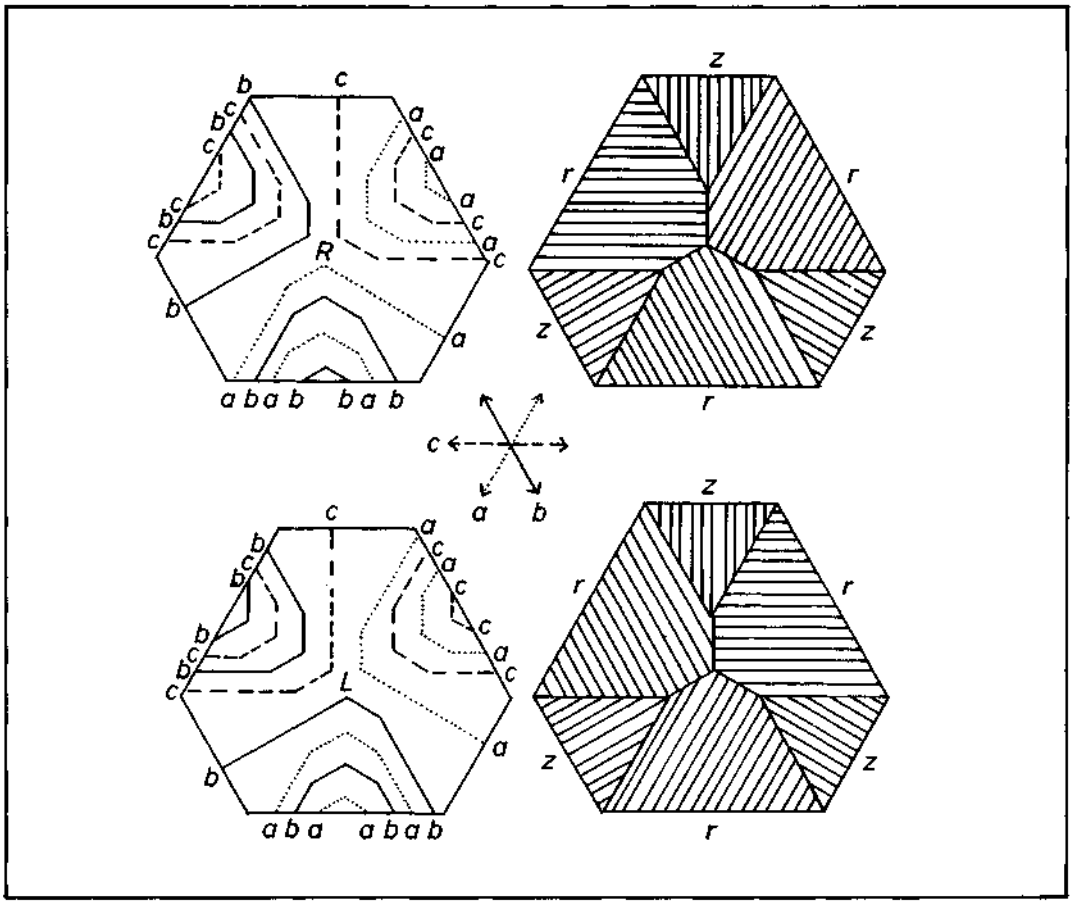

Fig. 3. Idealized drawings of natural citrine (heat-treated natural amethyst) in a view parallel to the *c*-axis showing the model of polysynthetic twinning on the Brazil law after McLaren and Pitkethly (1982) and the orientation of striations in growth sectors confined to the major and minor rhombohedron *r* and *z*.
Left: quartz crystals with right-handed (R) or left-handed (L) quartz in the centre. Brewster fringes (extinction bands) in growth sectors confined to the major rhombohedral faces *r* {10$\bar{1}$1} separate lamellae of right-handed and left-handed quartz, a single twin boundary enters each growth sector confined to the minor rhombohedron *z* {01$\bar{1}\bar{1}$}.
Centre: the directions of the double-headed arrows (which are represented by the symbols a, b and c) correspond to traces of the predominant twin boundaries; in subsequent Brewster fringes, alternating directions of predominant twin boundaries are observed.
Right: directions of orientated striations in growth sectors confined to the major and minor rhombohedron *r* and *z* in crystals with right-handed and left-handed quartz in the centre.

extinction bands (so-called Brewster fringes) in polarized light under crossed polarizers provided that the optic axis of the amethyst is arranged parallel to the line of sight. The investigation is possible in the horizontal microscope in combination with an immersion cell and immersion liquids. For convenient handling, the use of an improved sample holder with horizontal and vertical rotation axes is suggested (Schmetzer, 1985, 1986).

A somewhat simplified method was described by Crowningshield *et al.* (1986), using a standard gemmological polariscope with an immersion cell. According to the experience of the present author, both versions of the method yield similar or identical results for large cut stones. However, for smaller stones in the range of about 0.5 to 2.0 carats in weight, the application of the microscope may be necessary. In addition, samples from distinct localities, e.g. samples from Pará, Brazil, reveal an extremely complicated twinning structure. For the recognition of such samples as well as for a distinction from that particular type of twinning, which is found in synthetic amethyst (cf. Lind and Schmetzer, 1985, 1987), the author feels that the application

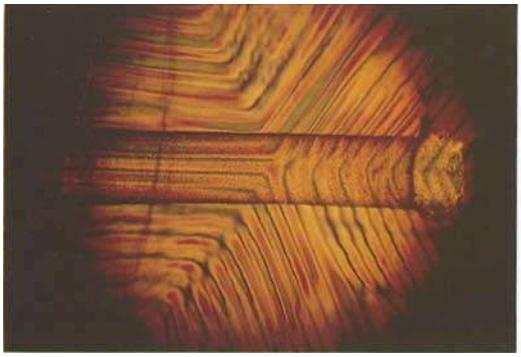

Fig. 4

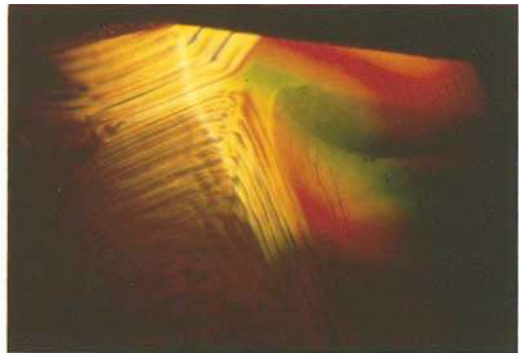

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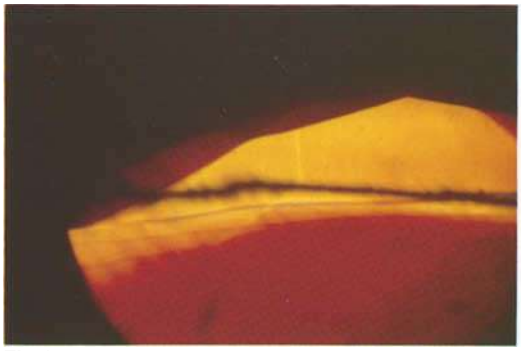

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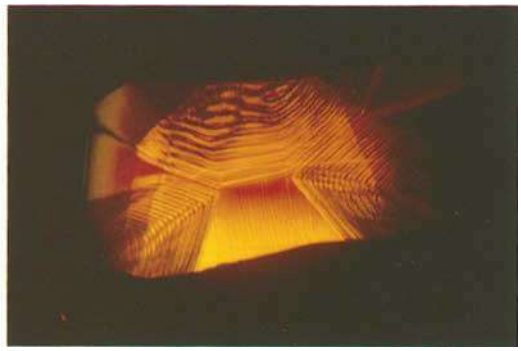

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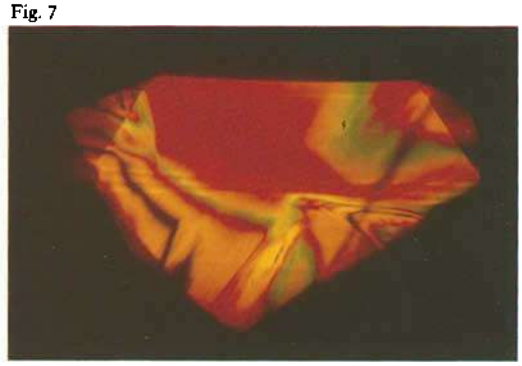

Fig. 9

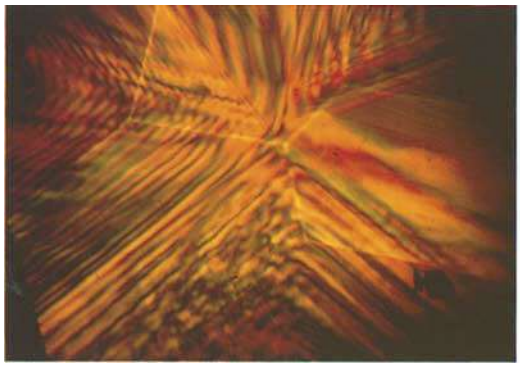

Fig. 10

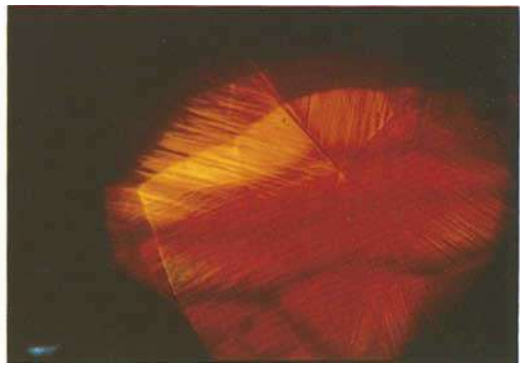

Fig. 11

of the gem microscope yields more reliable results. Furthermore, diagnostic structures in heat-treated amethyst may be extremely complicated thus favouring the investigation by use of the microscope.

In heat-treated natural amethyst two basic types of diagnostic structures and one group of samples with an intermediate type of characteristics are observable. In the first group of samples, the twinning structures of untreated amethyst are completely preserved during the annealing process. The growth sectors of the stones, which are confined to the major rhombohedron *r* $\{10\bar{1}1\}$, consist of polysynthetically twinned lamellae of alternating right-handed and left-handed quartz. The growth sectors confined to the minor rhombohedron *z* $\{01\bar{1}1\}$ do not show this type of twinning on the Brazil law; only one single twin boundary entering each *z* growth sector is observed (Figure 3, for a more detailed description the reader is referred to the papers of Schlössin and Lang, 1965; McLaren and Pitkethly, 1982; Schmetzer, 1985, 1986, 1987 as well as Crowningshield *et al.*, 1986). Typical microphotographs of interference figures of this group of samples are pictured in Figures 4-6.

The second important group of heat-treated amethyst does not show interference figures which are related to polysynthetic twinning on the Brazil law. In other words, investigations of this group of samples under crossed polarizers yield interference figures which are comparable to the interference patterns of quartz crystals, which do not consist of polysynthetic lamellae of right-handed and left-handed quartz. However, growth sectors confined to the major and minor rhombohedron *r* and *z* are still observable in the gem microscope. They are frequently recognizable due to different colour intensities with a more intense brown or yellow hue in growth sectors confined to the major rhombohedron *r* and a less intense brownish or yellow hue in sectors confined to the minor rhombohedron *z* (cf. colour zoning in heat-treated bicolour amethyst-citrine quartz; Nassau, 1981). In addition, boundaries between different growth sectors are distinctly outlined and orientated striations of dark brown colour are found in different directions confined to different growth sectors *r* and *z*, respectively (Figures 11, 12). In growth sectors confined to the minor rhombohedron *z* $\{01\bar{1}1\}$, these brown striations are orientated perpendicular to the three prism faces $\{01\bar{1}0\}$. In growth sectors confined to the major rhombohedron *r* $\{10\bar{1}1\}$, two different orientations of the brown striations exist, which are dependent on the nature of the centre of the untreated crystal, which may consist of right-handed or left-handed quartz. Schematic line drawings of the two possibilities mentioned are given in Figure 3. At present, no description or interpretation of this particular type of orientated striations are known to the present author from literature. Most probably, the disappearance of polysynthetic twinning on the Brazil law as well as the development of orientated brown striations is due to the annealing of natural samples. However, additional

Fig. 4. Natural citrine (heat-treated natural amethyst) from Brazil; interference figure showing polysynthetic twinning in three growth sectors confined to the major rhombohedron *r*; a drill-hole is running through the centre of the bead. Crossed polarizers. 20x.

Fig. 5. Natural citrine (heat-treated natural amethyst) from Maramba, Brazil; interference figure showing polysynthetic twinning in two growth sectors confined to the major rhombohedron *r* and not in growth sectors confined to the minor rhombohedron *z*. Crossed polarizers. 16x.

Fig. 6. Natural citrine (heat-treated natural amethyst) from Brazil; interference figure showing a single boundary entering one growth sector confined to the minor rhombohedron *z*. Crossed polarizers. 30x.

Fig. 7. Natural citrine (heat-treated natural amethyst) from Brazil; distorted interference figure showing polysynthetic twinning in three growth sectors confined to the major rhombohedron *r* and not in growth sectors confined to the minor rhombohedron *z*, a single twin boundary enters one growth sector confined to the minor rhombohedron *z*; striations orientated according to the growth sector they are confined to. Crossed polarizers. 14x.

Fig. 8. Natural citrine (heat-treated natural amethyst) from Brazil; distorted interference figure showing polysynthetic twinning in three growth sectors confined to the major rhombohedron *r* and not in growth sectors confined to the minor rhombohedron *z*, a single twin boundary enters one growth sector confined to the minor rhombohedron *z*; striations orientated according to the growth sector they are confined to. Crossed polarizers. 26x.

Fig. 9. Natural citrine (heat-treated natural amethyst) from Brazil; highly distorted interference figure showing polysynthetic twinning in three growth sectors confined to the major rhombohedron *r* and not in growth sectors confined to the minor rhombohedron *z*; striations orientated according to the growth sector they are confined to. Crossed polarizers. 20x.

Fig. 10. Natural citrine (heat-treated natural amethyst) from Uruguay; highly distorted interference figure showing polysynthetic twinning in three growth sectors confined to the major rhombohedron *r* and not in growth sectors confined to the minor rhombohedron *z*; striations orientated according to the growth sector they are confined to. Crossed polarizers. 20x.

Fig. 11. Natural citrine (heat-treated natural amethyst) from Brazil; interference figure showing no polysynthetic twinning on growth sectors confined to the major and minor rhombohedra *r* and *z*; striations orientated according to the growth sector they are confined to. Crossed polarizers. 40x.

investigations are necessary in order to clarify details of the process. Using a simplified technique without microscopic examination as described by Crowningshield *et al.* (1986), this second group of natural citrine originating from heat-treated amethyst yields the interference figure of untwinned quartz under the polariscope. Consequently, this type of heat-treated amethyst does not behave in the polariscope in the same manner as natural amethyst.

The third intermediate group of samples of heat-treated natural amethyst shows more or less distorted interference figures as well as more or less intense orientated brown striations (Figures 7-10). These observations are explainable by a decrease of polysynthetic twinning on the Brazil law parallel to a development of orientated striations, the directions of which are dependent on the respective growth sector which they are confined to.

Lamellar growth structures, parallel to the major and minor rhombohedron, which are frequently connected with colour zoning, are most common in natural amethyst. These zonal growth structures are still observable in all types of heat-treated natural amethyst. In most samples, sharp lamellar structures parallel to several rhombohedral faces are found, incidentally growth structures parallel to the hexagonal prism faces were also present. In a high percentage of samples, families of straight parallel growth planes parallel to the major and minor rhombohedron were observed, which form two characteristic angles of 94° (Figure 13, formed by the two faces *r* and *r'* or *z* and *z'*), 134° (Figure 14; formed by two adjacent rhombohedral faces *r* and *z*) as well as 76° (Figure 15; formed by two opposite rhombohedral faces *r* and *z*). Angular growth structures between prism and rhombohedral faces, forming an angle of 142° were found to be extremely rare.

According to information from the trade, only internally flawless material of natural amethyst without healing feathers consisting of liquid and two-phase inclusions are selected for heat treatment due to the formation of fissures and cracks in impure samples. Thus, the absence of healing feathers in commercially heat-treated amethyst is explained, which was confirmed by microscopic investigations of numerous samples. Only incidentally, the presence of black or reddish-brown solid state inclusions of iron oxides or hydroxides was observed (Figure 16).

III.2.2 Non-artificially-irradiated natural citrine

Natural citrines in the colour sequence light yellow, yellow, brownish-yellow and greyish-yellow were available from localities in Bahia and Goyaz, Brazil, from Salamanca, Spain and Madagascar (Figure 1). According to the informations given by the suppliers, these samples were not artificially heat-treated. However, samples of this type of citrine with more intense smoky coloration are known for a long time in the trade. In samples of this particular type (natural smoky quartz), smoky coloration is commercially removed by heat-treatment.

The samples available for the present investigation were not altered by heat treatment up to about 375°C. At 400°C the yellow coloration became lighter and was completely bleached at temperatures between 450 and 550°C. Exposition of heat-treated (colourless) and non-heat-treated (yellow) samples to gamma rays (dose rate about 30 Mrads) or neutrons (integrated fluence rate about 3×10^{15} n/cm^2) turned all samples an intense smoky coloration, which was bleached at temperatures between about 225 and 275°C. The resulting yellow or greenish-yellow coloration was stable up to 450-550°C in samples, which were not bleached artificially before and up to 325°C in artificially bleached samples. These results indicate, that an almost identical yellow or greenish-yellow coloration which is caused by colour centres with lower stability was induced in colourless samples or superimposed on the natural yellow coloration in unbleached samples by exposure to gamma rays and neutrons. This type of artificially-induced coloration will be described in the following chapter, more experimental details have been published elsewhere (Schmetzer, 1988).

The absorption spectra of all samples of non-artificially-irradiated citrine from different localities (Figure 17) consist of an absorption band in the ultraviolet, the low energy tail of which extends to the visible region causing a continuously increasing absorption from red to violet. In some samples an additional weak absorption band at about 15,500 cm^{-1} (645 nm) was measured (Figure 17).

Microscopic examinations of this type of natural citrine reveal the presence of diagnostic properties only in part of the samples. Some rough or cut stones were internally flawless and did not show growth structures or twinning on the microscope scale, i.e. no interference figures of polysynthetically twinned quartz were observed (Figure 18). Incidentally, in stones from Brazil and Madagascar thin plates or bodies were found to be inserted in the crystals (Figure 19). Most probably, the samples are macroscopically twinned on the Brazil law, as described comprehensively by various authors, e.g. Frondel (1962).

In samples from Brazil and Spain, growth structures were sometimes observed in the form of single growth planes which are orientated parallel to the prism faces *m* $\{11\bar{2}0\}$ as well as parallel to the rhombohedral faces *r* $\{10\bar{1}1\}$ and *z* $\{01\bar{1}1\}$

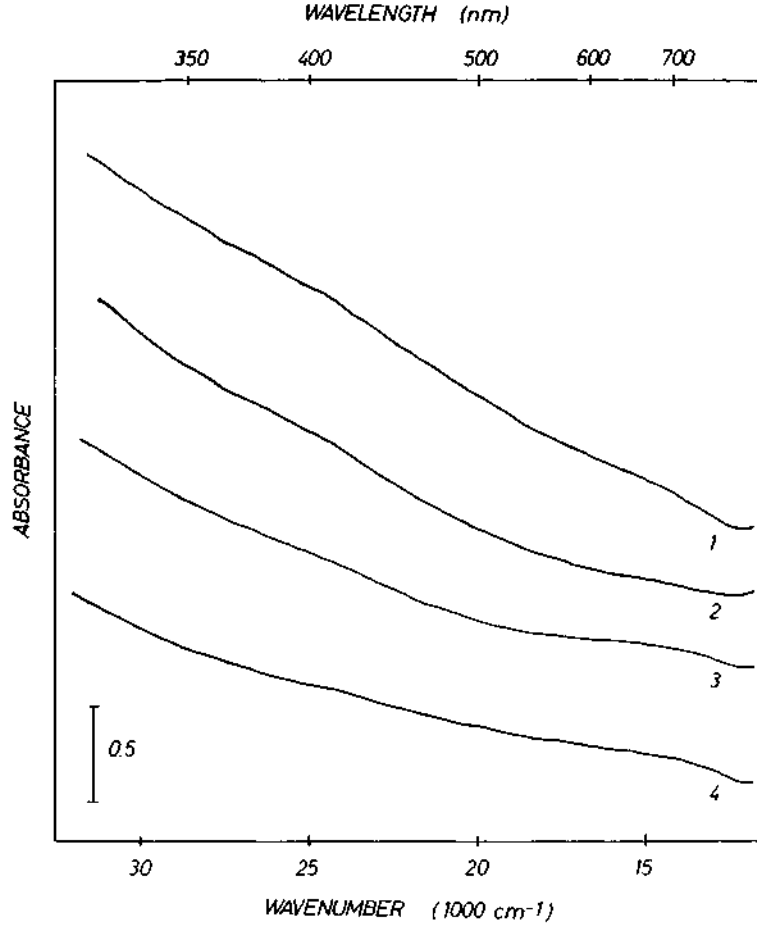

Fig. 17. Absorption spectra of natural citrines; 1 Salamanca, Spain, 2 Goyaz, Brazil, 3 Madagascar, 4 Bahia, Brazil.

of the crystals (Figures 20, 21). Occasionally, in citrines from Goyaz, Brazil, double refracting mineral inclusions were found to be confined to the growth boundaries parallel to prism and rhombohedral faces (Figure 21). These mineral inclusions were not yet determined exactly. In citrine crystals from all localities investigated, healing feathers consisting of liquid and two-phase inclusions were also present incidentally (Figure 22).

III.2.3 Artificially-irradiated natural citrine (originally colourless)

Some samples of artificially-irradiated greenish-yellow citrine from unknown localities were made available for investigation. The colour was completely bleached at 325 or 350°C. After irradiation with gamma rays (dose rate about 30 Mrads), the stones turned an intense greyish-black (smoky) or a lighter yellowish-grey colour. Subsequent heat treatment at 200°C bleached part of the irradiation induced smoky colour centres. After annealing of the samples at 225, 250 or 275°C, the smoky colour centres were completely bleached and the colour of the samples was identical to the as-received form. Subsequent heat treatment to 325 or 350°C again bleached the greenish-yellow colour.

Absorption spectra of one typical sample are presented in Figure 23. In the as-received greenish-yellow coloration, the absorption spectrum of the quartz crystal is composed of an absorption band in the ultraviolet, the low energy tail of which extends to the visible region. This increasing absorption from red to violet is superimposed by two absorption bands with maxima at about 15,500 and 26,000 cm^{-1} (645 and 385 nm). After irradiation, the

Fig. 12. Natural citrine (heat-treated natural amethyst) from Brazil; interference figure showing no polysynthetic twinning on growth sectors confined to the major and minor rhombohedra *r* and *z*; striations orientated according to the growth sector they are confined to. Crossed polarizers. 30x.

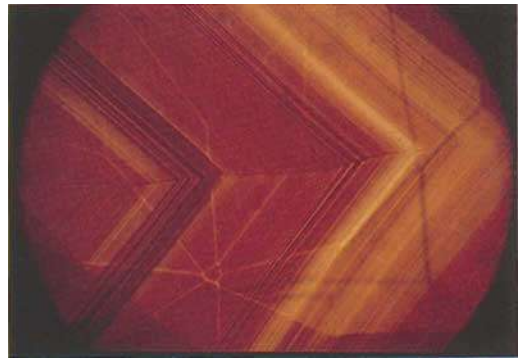

Fig. 13. Natural citrine (heat-treated natural amethyst) from Brazil; families of straight parallel growth planes parallel to the major rhombohedron *r* and *r'* $\{10\bar{1}1\}$ forming an angle of 94°. 30x.

Fig. 14. Natural citrine (heat-treated natural amethyst) from Brazil; families of straight parallel growth planes parallel to the major rhombohedron *r* $(10\bar{1}1)$ and parallel to the minor rhombohedron *z* $(01\bar{1}1)$ forming an angle of 134°, different colour intensities are observable in the growth sector confined to *r* (dark orange-brown) and the growth sector confined to *z* (light orange-brown). 30x.

Fig. 15. Natural citrine (heat-treated natural amethyst) from Brazil; families of straight parallel growth planes parallel to the major rhombohedron *r* $(10\bar{1}1)$ and parallel to the minor rhombohedron *z* $(01\bar{1}1)$ forming an angle of 76°, different colour intensities are observable in the growth sector confined to *r* (dark orange-brown) and the growth sector confined to *z* (light orange-brown). 26x.

additional absorption bands of smoky colour centres with absorption maxima at about 22,200 cm^{-1} (450 nm) are observable. Heat treatment between 200 and 325°C in intervals of 25°C each (annealing time 0.5 h at each step) caused first a bleaching of these additional smoky colour centres and subsequently a bleaching of the group of three absorption bands at 15,500 and 26,000 cm^{-1} and in the ultraviolet (Figure 23).

These results indicate that the greenish-yellow quartz crystals received from the trade are artificially irradiated samples, the smoky coloration of which were bleached by heat treatment at about 250°C. After complete bleaching, the smoky and greenish-yellow colour centres are restored by re-irradiation.

By microscopic investigations, the presence of small healing feathers in part of the citrines of this type was observed.

III.2.4 Heat-treated synthetic amethyst

Synthetic amethysts commercially grown in Japan and USSR were annealed at various temperatures. The amethyst colour centres bleached at about 460°C and the samples turned colourless. No yellow or brown coloration was developed at annealing temperatures and times up to 600°C and 24 h, respectively. However, the violet amethyst coloration was completely restored after subsequent gamma irradiation. This unexpected result indicates a stabilization of both precursor centres of the amethyst colour centre, i.e. trivalent iron on substitu-

Fig. 16. Natural citrine (heat-treated natural amethyst) from Namibia; black mineral inclusions (Fe-oxides or hydroxides). 65x.

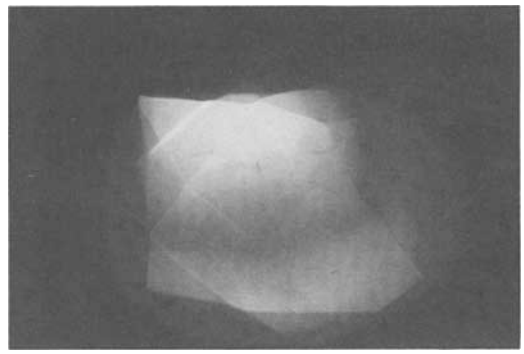

Fig. 18. Natural citrine from Goyaz, Brazil; interference figure of an optically untwinned crystal. 20x.

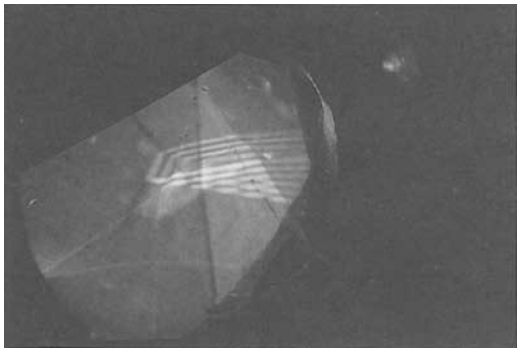

Fig. 19. Natural citrine from Brazil; isolated Brazil twin within an optically untwinned crystal showing interference colours and interference striations at the twin boundaries. Crossed polarizers. 16x.

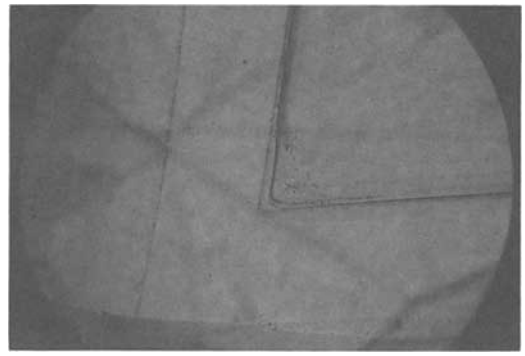

Fig. 20. Natural citrine from Brazil; growth planes parallel to the major rhombohedron r $(10\bar{1}1)$ and parallel to the minor rhombohedron z $(01\bar{1}1)$ forming an angle of 76°. 34x.

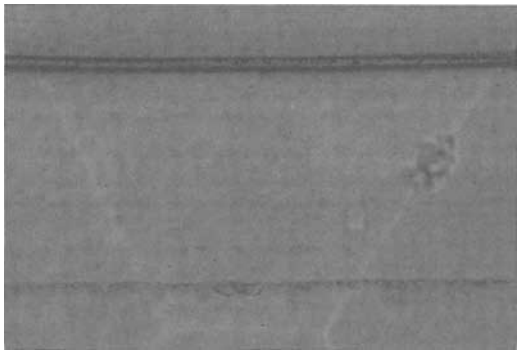

Fig. 21. Natural citrine from Brazil; growth planes parallel to the hexagonal prism $(10\bar{1}0)$, double refracting mineral inclusions are confined to one growth plane. 45x.

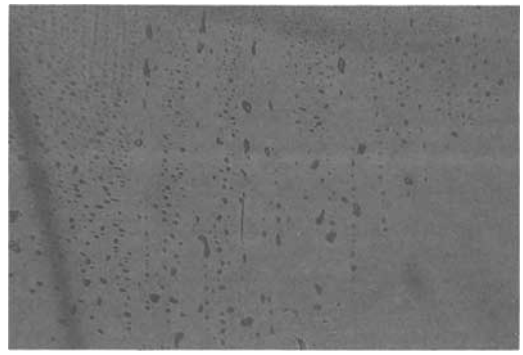

Fig. 22. Natural citrine from Goyaz, Brazil; healing feather consisting of liquid and two phase inclusions. 45x.

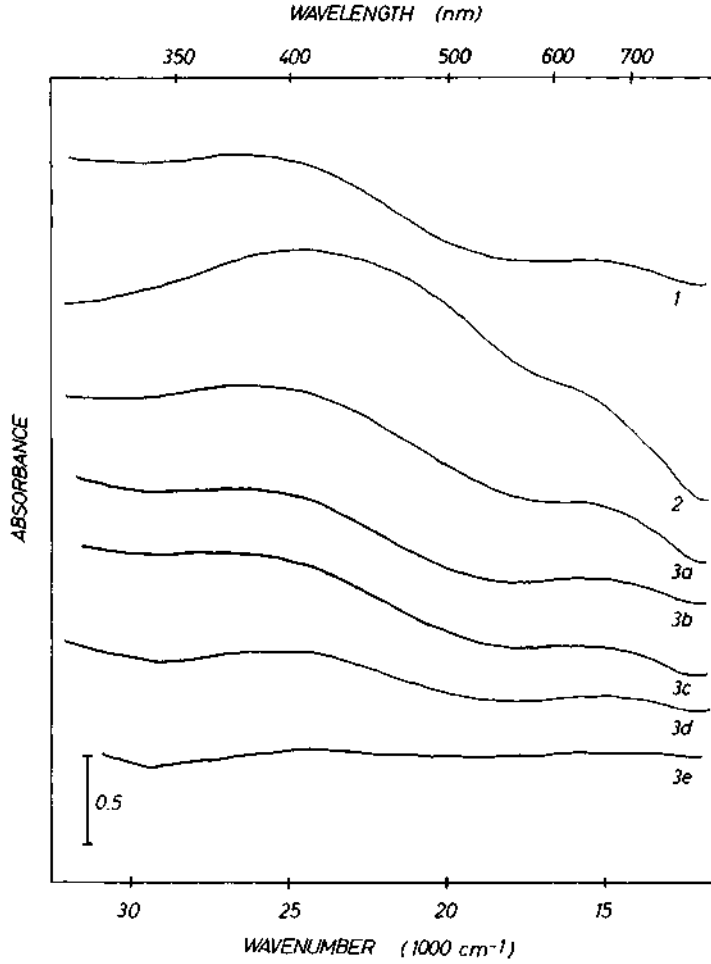

Fig. 23. Absorption spectra of artificially-irradiated natural citrine (originally colourless); 1 sample in the as-received form (greenish-yellow); 2 sample after heat treatment at 325°C (colourless) and subsequent gamma irradiation (yellowish-grey); 3a-e irradiation-treated sample after subsequent heat treatment at 200°C (3a, greyish-yellow), 225°C (3b, greenish-yellow), 250°C (3c, greenish-yellow), 275°C (3d, light greenish-yellow), 300°C (3e, very light yellowish), 325°C (not pictured, colourless).

tional silicon sites and on interstitial sites of distorted tetrahedral symmetry, which is different from the stabilization of the amethyst precursor centres in most natural samples.

III.2.5 Synthetic Fe-containing yellow, green and brown quartz (including Fe- and Co-bearing samples)

Most samples of synthetic Fe-bearing quartz with yellow, green and brown coloration, which were made available for the present study, were supplied from various cutting factories or gem collectors in Idar-Oberstein (Figure 24). In all cases, the country of production was the only information which was given by the trade. According to their diagnostic features, the samples were subdivided into several groups with identical or similar properties. In some cases, it was evident that a distinct type of synthetic Fe-containing citrine was grown by different producers using closely related or almost identical growth conditions. In other cases, it may be possible that samples from different producers or different producing countries were mixed with or without intention. Therefore, the present author feels that a subdivision and description of the samples according to their diagnostic properties is more suitable than a description according to the producer or producing country.

In addition, it has to be pointed out that, according to diagnostic properties, only part of the samples are easily assigned to a distinct type of synthesis as described in Sections II.4 and II.6. In other cases, some of the observed properties, e.g. absorption bands in the visible, are not known to the present author from literature. Thus, in order to work out at least some details of the production processes, trace element analyses were carried out using atomic absorption spectroscopy. A general survey of the samples investigated and some of their diagnostic properties is given in Table 2, analytical data are presented in Table 3, and absorption spectra are pictured in Figures 25-29.

The absorption spectra of all samples investigated consist of a strong absorption maximum in the ultraviolet, the low energy tail of which extends to the visible area. In all samples with the exception of KCl-NaCl-grown synthetic citrine (type 5, Figure 27), the continuously increasing absorption from red to violet is superimposed by several weak and strong absorption bands. These bands are assigned to Co^{3+} (I_6) in the case of intense yellow to intense yellow-orange citrines (type 6, Figure 28). This assignment is confirmed by analytical data (Table 3). In addition, it was observed that the colour of Co^{3+}- and Fe-containing synthetic citrines turned blue by heat treatment at 600°C, which is explained by a conversion of Co^{3+} (I_6) to Co^{2+} (I_4) (Figure 28). In green samples of type 7 a strong absorption band of Fe^{2+} (I_6) at 13,500 cm^{-1} is observed, which is consistent with literature data (Figure 29).

Several weak absorption bands measured in the spectra of brown, orange-brown, yellow-orange and green samples (Table 2, types 1, 2, 7, Figures 25, 29) are in good agreement with literature data (Lehmann, 1971a; Khaliov *et al.*, 1979; cf. Table 1).

Table 2. General survey of synthetic Fe-containing yellow, green and brown quartz investigated, including Fe- and Co-bearing samples

designation	type 1	type 2	type 3	type 4	type 5	type 6	type 7
country of production	USA, USSR	Japan, USSR	Japan, USSR	Japan, USSR	Japan	USA, USSR	USSR
colour	intense brown or intense orange-brown	intense yellow-orange	intense orange-brown	intense orange-brown	intense yellow-orange	intense yellow or intense yellow-orange	light green or intense green
working solution	K_2CO_3	K_2CO_3	K_2CO_3	K_2CO_3	KCl	K_2CO_3	K_2CO_3
absorption maxima (cm^{-1})							13,500 broad, strong
	18,700						
	20,200	20,200					20,200
	21,500	21,500					21,500
			22,000	22,000			
	22,500						
			23,500	23,500			
			24,500	24,500			
	24,800	24,800					24,800
	26,500						26,500
						26,800 broad, strong	
			29,000				29,000
optical twinning	not observed	not observed	not observed	not observed	not observed	not observed	not observed
growth inhomogenities and/or seed plane	(0001)	(0001)	(0001)	(0001) channels ‖ c distorted interference figure	not observed X-cut and Y-bar seeds were used*	(0001)	not observed

*Hosaka and Taki (1983)

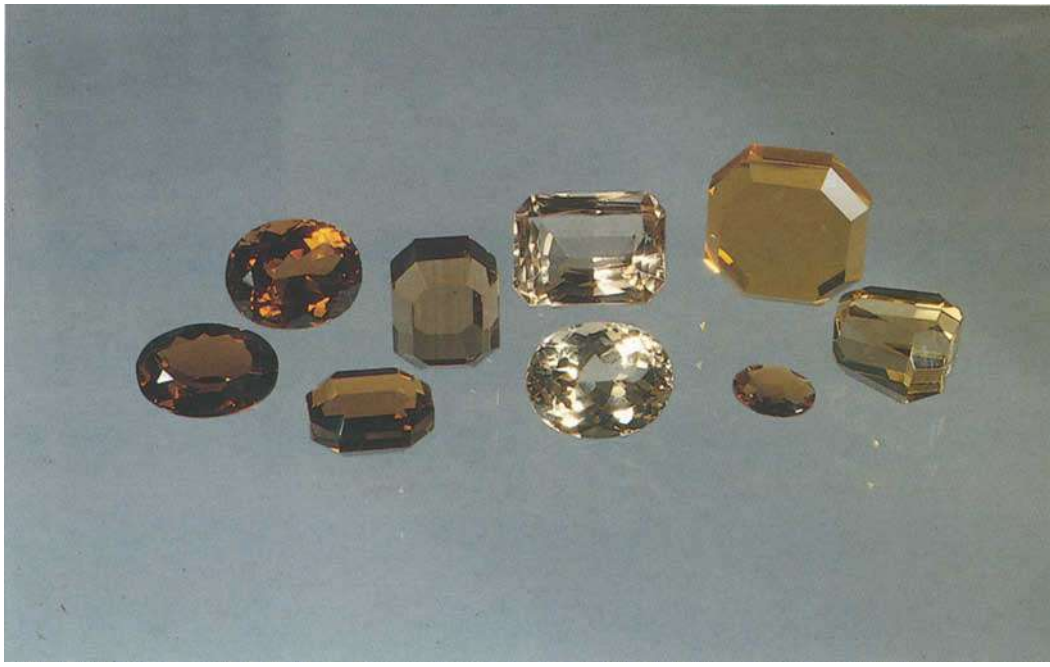

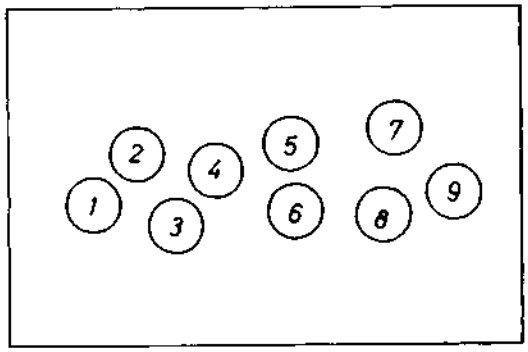

Fig. 24. Colour sequence of synthetic citrines: sample 1: type 1, produced in USSR; sample 2: type 4, produced in Japan; sample 3: type 4, produced in Japan; sample 4: type 3, produced in USSR; sample 5: type 3, produced in USSR; sample 6: type 4, produced in Japan (heat-treated); sample 7: type 6, produced in USA; sample 8: type 3, produced in Japan; sample 9: type 6, produced in USSR. Size of sample 2 approx. 11 × 14 mm. *Photo by O. Medenbach, Bochum, FRG.*

They are assigned to spin-forbidden transitions of trivalent iron in interstitial sites of distorted tetrahedral symmetry, Fe^{3+} (I_4). In contrast, the positions of several weak absorption maxima in the spectra of orange-brown synthetic citrines (Table 2, types 3 and 4, Figure 26) are distinctly shifted and thus, an assignment of these absorption maxima is rather uncertain. The different spectroscopic properties of various samples are certainly caused by differing growth conditions. However, without an exact knowledge of the compositions of the working solutions (e.g. concentrations of K_2CO_3 and Fe_2O_3), a more detailed interpretation of varying spectroscopic properties is impossible. An influence of different oxidizers such as $LiNO_2$, $LiNO_3$, $KMnO_4$ is also assumable (cf. manganese concentrations in samples of these particular types, Table 3).

All samples investigated were optically single crystals (Figure 30) and did not consist of macroscopically twinned or polysynthetically twinned individuals on the Brazil law (cf. Figures 4-12). Only in samples of type 4, an extremely distorted interference figure is observed when the stones are viewed parallel to the optical axis (Figures 31-32). An examination in a direction perpendicular to the optical axis reveals the presence of fibrous structures, the fibre axes of which are running parallel to the optical axis (Figure 33). Incidentally, liquid and two-phase inclusions are trapped within those channels. Similar fibrous or channel-like structures parallel to the *c*-axis [0001] were mentioned by Chadschi and Reschetowa (1975) and Khadzhi and Reshetova (1977). These capillary channels penetrating into the citrine crystals are due to the absence

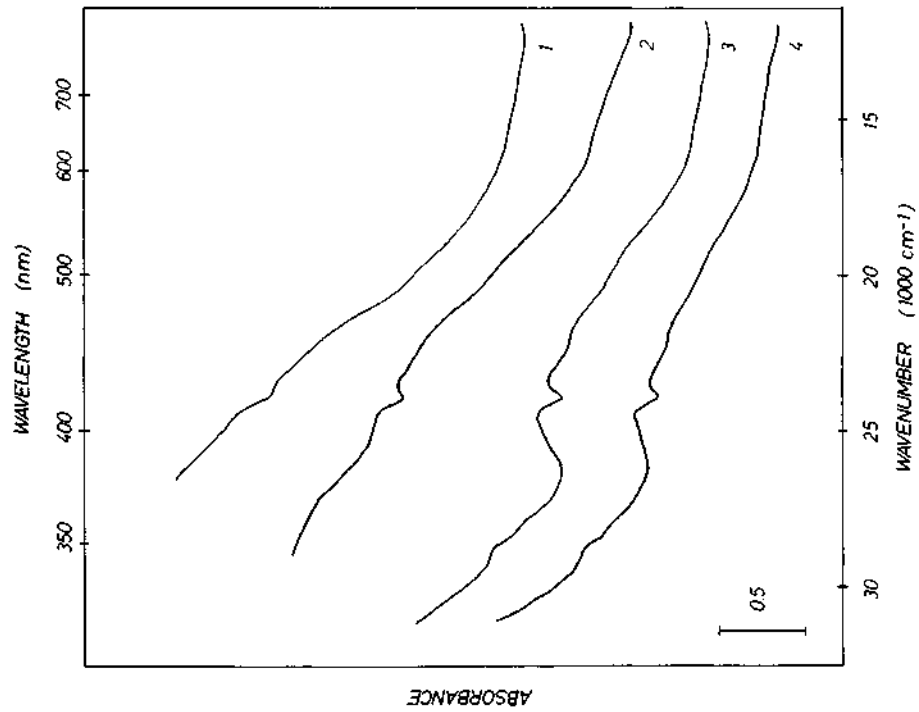

Fig. 26. Absorption spectra of synthetic citrines of types 3 and 4; type 4: 1 produced in USSR, 2 produced in Japan; type 3: 3 produced in Japan, 4 produced in USSR.

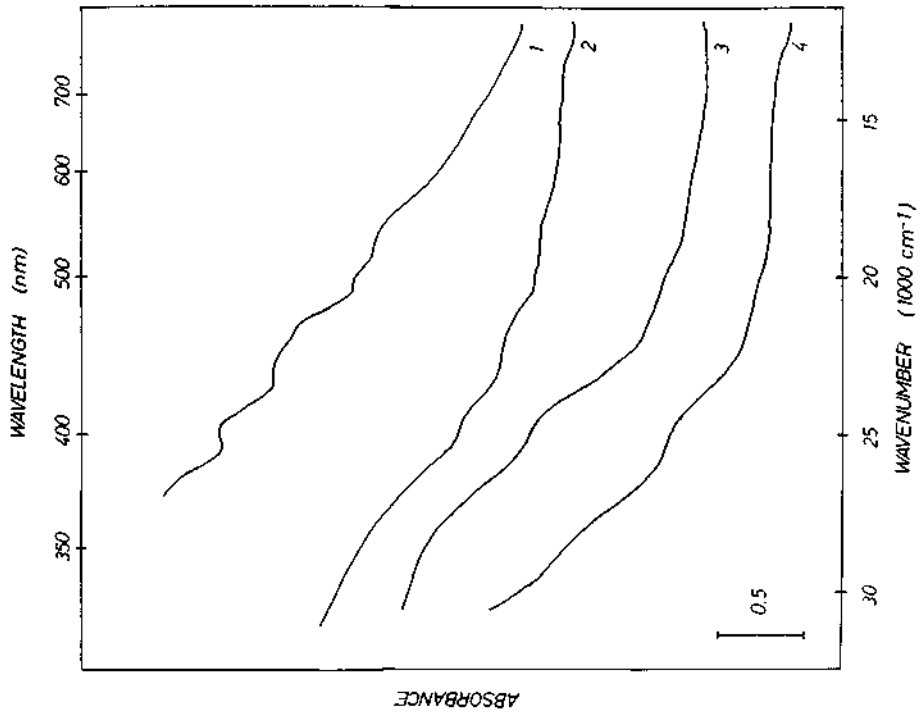

Fig. 25. Absorption spectra of synthetic citrines of types 1 and 2; type 1: 1, 2 produced in USSR; type 2: 3 produced in Japan, 4 produced in USSR.

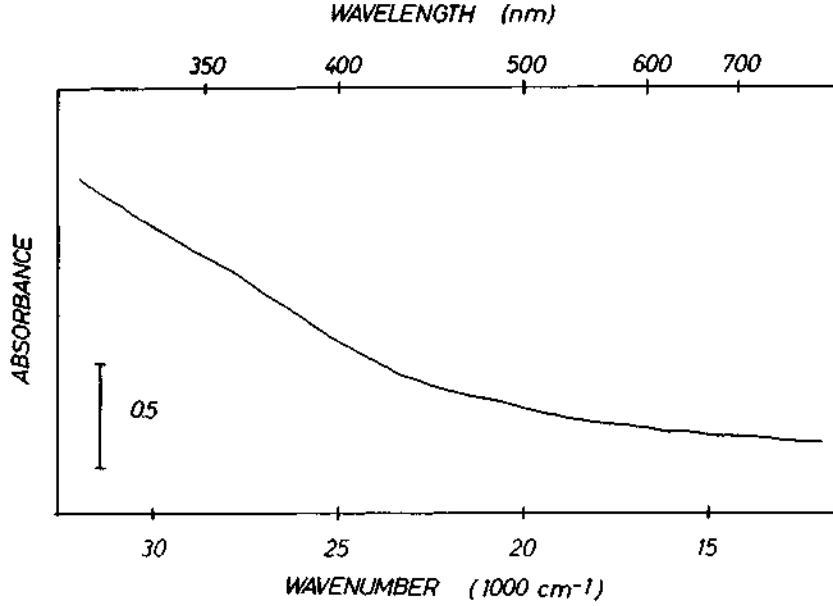

Fig. 27. Absorption spectra of synthetic citrine of type 5 produced in Japan.

of lithium nitrates or nitrites in growth media, which form hardly soluble silicates, e.g. eucryptite, and purify the solution from aluminium. Due to the paper of Sato (1986), the channel-like structures parallel to the optic axis are also observable using laser tomography.

According to microscopic examinations all samples of synthetic Fe-bearing citrine with the exception of type 5 and possibly some samples of type 7 are grown from basal seeds and thus reveal more or less pronounced growth structures and colour zoning parallel to the basal plane (0001) (Figure 34). Growth structures parallel to the basal pinacoid are not observed in natural citrine and natural heat-treated amethyst and, thus, basal growth structures and colour zoning unequivocally indicate synthetic citrines. However, it has to be mentioned, that some faceted synthetic citrines were cut from samples which were obviously grown under homogeneous conditions and, therefore, the samples do not display any growth inhomogenities in the gem microscope. These observations are consistent with the literature dealing with crystal growth of synthetic citrines (cf. Sections II.4 and II.6).

Only occasionally, solid state inclusions in the form of the so-called breadcrumb inclusions are observable in synthetic citrine (Figure 35). In stones of type 6, needle-like inclusions which are orientated parallel to the optical axis are rarely found. Feathers consisting of liquid and two-phase inclusions are also very rare.

Table 3. Chemical data of synthetic Fe-containing yellow and brown quartz investigated, including Fe- and Co-bearing samples (in ppm)

designation	type 1	type 2	type 3		type 4		type 5	type 6	
country of production	USA	Japan	USSR		Japan	USSR	Japan	USA	USSR
colour	intense brown	intense yellow-orange	intense orange-brown		intense orange-brown		intense yellow-orange	intense yellow-orange	intense yellow
Na	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10
K	354	777	376	460	1045	694	150	1120	935
Fe	1850	1350	455	580	870	1160	2830	960	880
Co	< 10	< 10	< 10	< 10	< 10	< 10	< 10	130	60
Mn	16	17	36	33	64	87	29	5	5

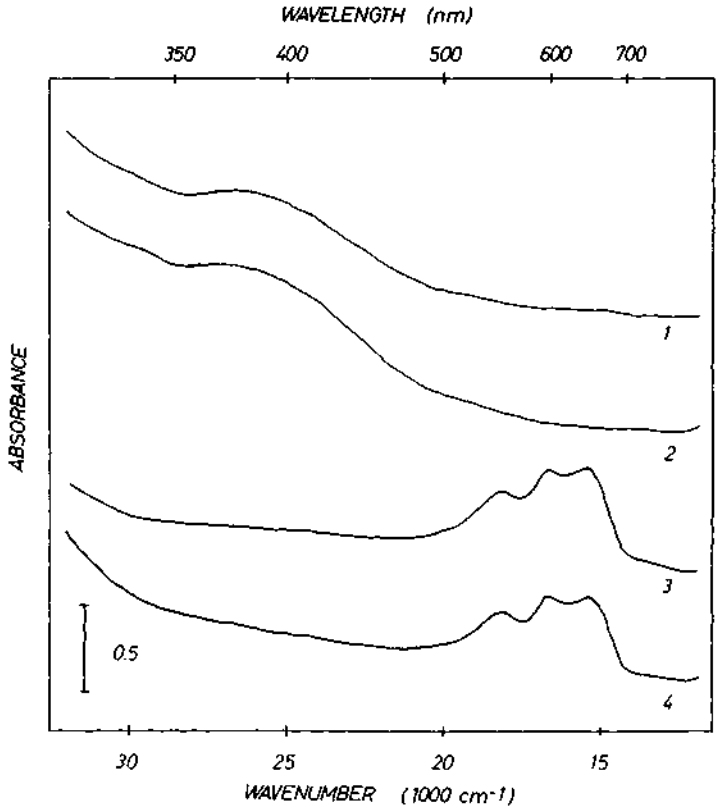

Fig. 28. Absorption spectra of synthetic citrines of type 6; samples in the as-received form: 1 produced in USSR, 2 produced in USA; samples converted to a blue colour by heat treatment: 3 originally sample 1, 4 originally sample 2.

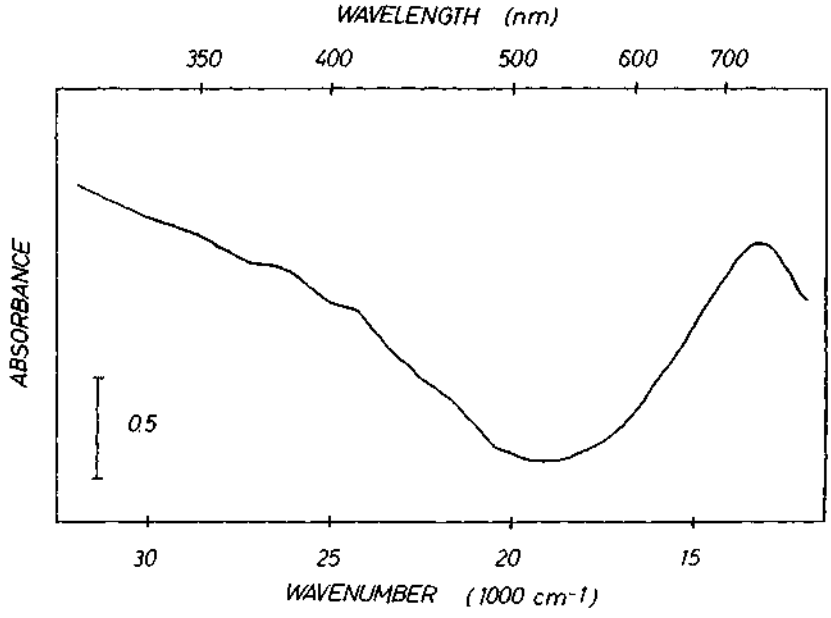

Fig. 29. Absorption spectrum of synthetic prasiolite of type 7 produced in USSR.

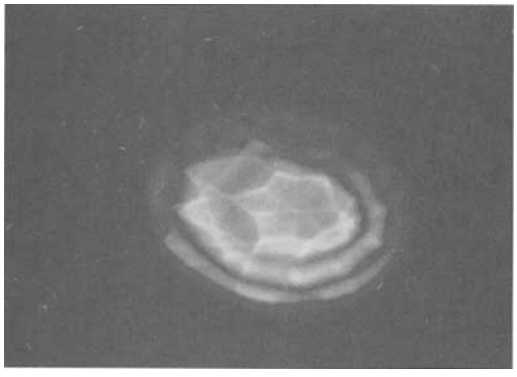

Fig. 30. Synthetic citrine of type 3 produced in Japan; interference figure of an optically untwinned crystal. Crossed polarizers. 14x.

Fig. 31. Synthetic citrine of type 4 produced in Japan; highly distorted interference figure. Crossed polarizers. 18x.

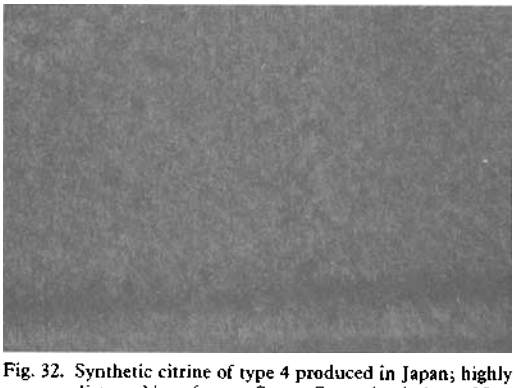

Fig. 32. Synthetic citrine of type 4 produced in Japan; highly distorted interference figure. Crossed polarizers. 35x.

Fig. 33. Synthetic citrine of type 4 produced in Japan; fibrous structures running parallel to the optic axis. 16x.

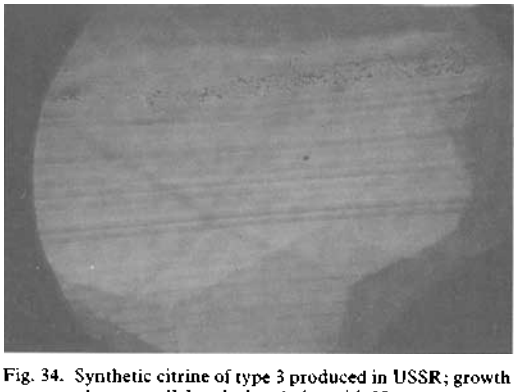

Fig. 34. Synthetic citrine of type 3 produced in USSR; growth planes parallel to the basal pinacoid. 22x.

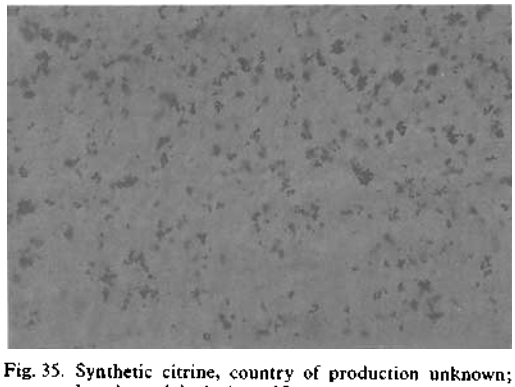

Fig. 35. Synthetic citrine, country of production unknown; breadcrumb inclusions. 35x.

III.2.6 ARTIFICIALLY-IRRADIATED SYNTHETIC CITRINE (ORIGINALLY COLOURLESS)

Though distinct types of colourless synthetic quartz turn yellow or greenish-yellow by irradiation treatment (cf. Section II.5), no irradiation-treated synthetic citrine of known origin was commercially available. However, two samples submitted for investigation were possibly of this type. The greenish-yellow faceted stones, 63.7 and 88.8 carats in weight, were internally flawless and without any optical twinning or growth structure of diagnostic value. The absorption spectra consisted of an absorption maximum in the ultraviolet, the low energy tail of which extended to the visible. This increasing absorption was superimposed by two absorption bands at about 15,000 and 26,000 cm^{-1} (667 and 385 nm). All these data are assumed to be found in both, natural and synthetic irradiation-treated yellowish-green citrines. By chemical investigations using energy-dispersive X-ray fluorescence analysis, the presence of distinct amounts of Ge was proved. Though not unequivocal, this result can be assumed as an important hint towards Ge-containing synthetic quartz, which was irradiation-treated (and possibly annealed subsequently) in order to produce a greenish-yellow coloration (cf. Section II.5).

IV Discussion

All types of natural and synthetic citrine, which are found on the gem market, reveal a number of characteristic features which are useful for diagnostic purposes. Combinations of spectroscopy in the visible and ultraviolet and microscopic investigations are suggested for the determination of citrines of unknown origin.

Natural iron-bearing citrines and prasiolites, which are produced from natural amethyst by heat treatment, are polysynthetically twinned on the Brazil law or display a distinct pattern of parallel striations, the orientation of which corresponds to the respective growth sector which they are confined to. Colour zoning and growth structures are dominant on faces parallel to the major and minor rhombohedron, *r* and *z*, forming characteristic angles of 94°, 134° and 76°. Absorption spectra consist of one strong maximum in the ultraviolet, the low energy tail of which extends to the visible, and one single weak absorption band at 21,000 cm^{-1} (476 nm). In prasiolites, an additional band at about 13,500 cm^{-1} (741 nm) is found.

All types of synthetic iron-containing citrine and green quartz are characterized by the absence of polysynthetic twinning on the Brazil law and the lack of orientated striations. Frequently, dominant growth structures parallel to the seed plane (0001) are observable. In one distinct type of synthetic iron-containing citrine, channel-like structures parallel to the optic axis are found. In addition, these samples reveal highly distorted interference figures.

The absorption spectra of all types of iron-bearing synthetic citrine consist of an absorption maximum in the ultraviolet, the low energy tail of which causes an increasing absorption from red to violet in the visible range. The spectra of all five types of synthetic iron-bearing citrine and synthetic green quartz, which are grown from K_2CO_3-containing solutions with or without additional oxidizers (e.g. $LiNO_2$, $LiNO_3$, $KMnO_4$) are superimposed by a number of weak absorption bands, which are not found in natural Fe-bearing citrines. Fe- and Co-containing synthetic citrines have a strong absorption band at about 26,800 cm^{-1} (373 nm). Only the absorption spectra of synthetic citrines, which are grown from KCl-NaCl-bearing solutions are identical with the spectra of heat-treated natural amethyst. Samples of this type of synthetic citrine, which are not yet grown commercially, however, do not display the microscopic characteristics of heat-treated natural amethyst.

Natural non-heat-treated, non-artificially-irradiated citrines, which are also used in the gem trade, are often macroscopically twinned and have growth structures parallel to the major and minor rhombohedron as well as parallel to the hexagonal prism. The absorption spectra consist only of an intense maximum in the ultraviolet, the low energy tail of which extends to the visible. The citrine colour centre is completely destroyed by heat treatment up to 450-550°C and cannot be restored by subsequent gamma or neutron irradiation. At present, this type of citrine has not yet been grown synthetically.

The thermal stability of artificially-irradiated (and in some cases subsequently heat-treated) natural quartz is lower than the thermal stability of artificially untreated citrine. A complete bleaching of this type of greenish-yellow citrine colour centres is observed up to 350°C or, in most samples, even at lower temperatures, and the colour centres are restored by subsequent irradiation. The absorption spectra of this third type of citrine are characterized by an absorption in the ultraviolet, the low energy tail of which extends to the visible. This absorption is superimposed by two bands at about 15,500 and 26,000 cm^{-1} (645 and 385 nm).

In the literature this type of citrine coloration is also described for synthetic quartz, which was artificially irradiated. However, it was not confirmed experimentally that samples of this type are found in the trade and no information about this is available to the present author. Due to the fact that a large amount of low costing natural quartz, e.g. from Brazil, is converted to a greenish-yellow

coloration by irradiation, no necessity exists to use more expensive synthetic colourless quartz samples for the production of greenish-yellow quartz by irradiation treatment.

In all types of natural or synthetic citrine, the presence of typical solid state inclusions, e.g. Fe-oxides or Fe-hydroxides in heat-treated natural amethyst, mineral inclusions in natural untreated citrine and breadcrumb inclusions in synthetic citrine may give additional information about the nature of the sample. The presence or absence of healing fissures or fingerprint patterns of liquid or two-phase inclusions, however, is of no diagnostic value.

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[*Manuscript received 20 April, 1987, revised 8 December 1988*]

Proceedings of the Gemmological Association of Great Britain and Association Notices

OBITUARY

Mr Syed Vaqar Ahmad, FGA (D.1970), London, died on 23 January 1989.

Mr Cecil A. Bond, FGA (D.1964), Ufford, Woodbridge, died on 4 January 1989 after a long illness. Cecil Bond was the third generation of retail jewellers known as A.A. Bond & Sons Ltd with shops at Hoddesdon and Waltham Abbey. He retired in 1983 because of ill health. As well as being a Fellow of the Gemmological Association, he was a craft member of the British Horological Institute and an active member of the National Association of Goldsmiths. He leaves a widow, Joan, two sons, a daughter and seven grandchildren.

Mr Ronald C. Stevens, FGA (D.1970), Howick, Auckland, New Zealand, died on 25 December 1988.

GIFTS TO THE ASSOCIATION

The Council of the Assocation is indebted to the following for their gifts:

Mr B.A. Handana of Indonesia for a copy of the book *Batu Permata* by Rahasia.

Mr E. Fontana and Mr W.L. Kunsch of Sao Bernardo do Campo, Brazil, for a copy of their book entitled *Gems of Brazil*.

Dr Dietmar Schwarz of Ouro Preto, Brazil, for a ›y of his book entitled *Esmeraldas – Inclusoes em ›nas*.

NEWS OF FELLOWS

)n 23 November 1988 Mr Peter Read gave two ıustrated talks at a Gala Buffet Supper arranged by the Gemmological Association of South Africa in the Sunnyside Park Hotel, Johannesburg. The subjects of the two talks were the laser Brewster-angle refractometer developed by Peter Read, and his GEMDATA computer program for gem identification. An experimental Brewster-angle refractometer was demonstrated after the first talk, and an IBM PC-compatible computer was made available to show the various features of the GEMDATA program. After his talks, Peter Read presented a copy of the 2nd edition of his *Dictionary of Gemmology* to the Association's Chairman, Mr Arthur E. Thomas, FGA.

MEMBERS' MEETINGS

London

On 29 March 1989 at the Flett Theatre, Geological Museum, Exhibition Road, South Kensington, London SW7, Mr E.A. Jobbins gave an illustrated lecture using the extensive collection of colour transparencies taken by him during his five months stay in Brazil in 1973 and his one month trip in 1987. As well as a description of the gemstones found in Brazil, Alan Jobbins explained some of the reasons for their distribution.

Midlands Branch

On 20 January 1989 at the Society of Friends, Dr Johnson House, Colmore Circus, Birmingham, Mr C.R. Burch, Senior Lecturer in Gemmology and Geology at the Sunderland Polytechnic, gave an illustrated talk on inclusions in natural and synthetic corundum.

On 17 February 1989 at the Society of Friends Mr John R. Bugg gave a talk entitled 'The law and the gemmologist'.

On 17 March 1989 at the Society of Friends, a talk was given by Mr Peter Read entitled 'The Brewster Angle refractometer'. Mr Read also demonstrated the new GEMDATA computer program.

North West Branch

On 18 January 1989 at Church House, Hanover Street, Liverpool 1, Mr John Pyke displayed and gave a talk on his collection of rare and interesting gemstones.

On 15 February 1989 Dr J.W. Harris, Senior Lecturer of Strathclyde University, gave a talk on diamonds and diamond mining around the world.

COUNCIL MEETING

At a meeting of the Council of the Association held on 28 February 1989 at the Royal Automobile Club, 89 Pall Mall, London SW1, the business

transacted included the following: (1) the appointment of Mrs Evelyne Stern, FGA, as an Examiner; (2) the election to membership of the following:

Fellowship

Bruggeman, Renate F., Almelo, The Netherlands. 1986
Chan, Yuk C., Hong Kong. 1988
Chan Cheng, Rosalia Y.K., Honolulu, HI, USA. 1988
Collins, Steven J.C., Letchworth. 1988
Dabell, Louise C., Nottingham. 1988
Dunn, Wendy S., London. 1987
Franco da Fonseca, Ana L., Sao Paulo, Brazil. 1988
Girod, Daniel F., Amsterdam, The Netherlands. 1988
Haufe, Wilfred, Toronto, Ont., Canada. 1988
Hergel, James E., Toronto, Ont., Canada. 1988
Kuwahara, Chizu, Yokosuka City, Japan. 1988
Lewis, David T.K., Nottingham. 1968
Lewis, Rachel, Stockport. 1988
McKearney, Michael C., London. 1984
Maharaj, Rajendra K., Toronto, Ont., Canada. 1988
Muff-Somma, Walter C., Muri, Switzerland. 1988
Nakamura, Midori, Ichikawa City, Japan. 1983
Ng, Siu K., Hong Kong. 1987
Potts, James D., Telford. 1988
Sumar, Nizarali P., Nairobi, Kenya. 1988

Ordinary Membership

Aoki, Kazuo, Fujisawa City, Japan.
Candela, Conchita, Bari, Italy.
Chang, Kuei Y., Taipei, Taiwan.
Chowdhary, Kawaljit, Wembley.
Christofi, Christiana, Limassol, Cyprus.
Costa, L.R., London.
Desor, Manmohan, Leicester.
Fernando, Joseph S., Colombo, Sri Lanka.
Fogarty, Jolyan L., Jackson, Wyo., USA.
Girardi, Josephine C., Hong Kong.
Grigoriadis, Giorgios D., Athens, Greece.
Hainovitz, Jonathan, Jerusalem, Israel.
Hare, Rebecca, London.
Hayakawa, Taketoshi, Chigasaki City, Japan.
Hill, Linda S., Jakarta, Indonesia.
Holt, Dorothy O., London.
Hughes, David J., Cardiff.
Itoyama, Mariko, Nagasaki City, Japan.
Jhaveri, Devang, London.
Johns, Alan T., Perranporth.
Kammerling, Robert C., Santa Monica, Calif., USA.
Kapur, Sharad, New Delhi, India.
Knudson, Eric, London.
Komai, Rie, Kawaguchi City, Japan.
Kuinose, Masafumi, Wakayama City, Japan.
Leadbetter, Bibette, Skelmersdale.
Lilly, Gregory R., Taranaki, New Zealand.
Lockie, Debra L., Auckland, New Zealand.
McDowell, Barry M., Wellington, New Zealand.
Matoba, Hiroshi, Nara City, Japan.
Murata, Michiko, Tokyo, Japan.
Naitoh, Yukihiro, Shimizu City, Japan.
Nakane, Tomoko, Tokyo, Japan.
Nercessian, Armine, New York, NY, USA.
Noyori, Kazuhiko, Fukuoko City, Japan.
O'Reilly, Stan J., Galway, Eire.
Ozaki, Keiko, Kawanishi City, Japan.
Palmer, Guen, Ditchling.
Pimantip, Nin, London.
Pine, Irving C., Delray Beach, Fla., USA.
Ravindran, Mahaluxmy, Bangkok, Thailand.
Richards, Keith, Epsom.
Safwat, Hanafi, London.
Sarin, R., Arlington, Va., USA.
Sarmiento, Luis, Madrid, Spain.
Satoh, Mariko, Yokohama City, Japan.
Seymour, Nicola, Hove.
Shimoda, Tetsuhiro, Fukuoka City, Japan.
Stanley, Sylvia, Clearwater Bay, Hong Kong.
Tachibana, Hirogi, Osaka, Japan.
Tanaka, Norihiro, Tokyo, Japan.
Tanzawa, Megumi, Nakacoma-Gun, Japan.
Tay, Thye S., Singapore.
Themelis, Ted., Clearwater, Fla., USA.
Wedekind, Kenneth J., Wakefield.
Wilson, Mathew D., Broadstairs.
Woods, Janina, Warwick.
Yasuda, Jun, Tokyo, Japan.
Yutani, Atsuko, Osaka, Japan.

GEMMOLOGICAL ASSOCIATION OF ISRAEL

The formation of this new organization has just been announced. The address is 1 Japotinsky Street, Ramat-Gan, 52520 Israel.

FORTHCOMING MEETINGS

The 1989 Annual General Meeting of the Association is to be held on 12 July 1989 at the Flett Theatre, Geological Museum, Exhibition Road, South Kensington, London SW7. This will be followed by a Gemmological Forum similar to those held in previous years that have proved so successful.

Letters to the Editor

From Rudolf Voll

Dear Sir,

As a gem tester, Mr Kenneth Scarratt fails to divulge the cause of double-nucleated cultured pearls from the *Pinctada martensii* oyster (Notes from the Laboratory – 13, *Journal of Gemmology*, 21, 5, 294); let me advise readers that there was no attempt whatsoever to create 'twins', but that, decades ago, the technique that prevented the undesired joining of large nuclei inside the gonad was insufficiently developed.

But today it is well-nigh impossible to find one twin among many 'kan' (kame) of cultured pearls. Kan is an ancient Chinese weight unit of 3.75kg or 1000 momme, which was outlawed for general use in Japan in 1960 and is, by special licence, only permitted to be used by the pearl industry.

'Twins' still occur today in the 2-3 mm nuclei but they are usually cut apart and used as pearls for 'trimming' or 'paving' purposes, having a practical near-half-pearl shape after separating.

The 'hollow' cultured pearls are a phenomenon which happened mainly in the freshwater mollusc *Hyriopsis schlegeli* in Lake Biwa. Because of the pearl-'unlike' weight and especially the usually 'dried prune' surface, cultivation has been discontinued.

My daughter Aloha, a 1981 winner of the Anderson Medal and student of Mrs Anne Paul's class, lives now in Bangkok, but I read the *Journal* which still arrives in Hong Kong, and I believe that you do not object to my co-operation on her behalf, believing to be competent enough as the only active non-Japanese member at the monthly Tokyo pearl auctions. I have specialized in cultured pearls since 1938 in Tokyo, but spend two weeks of every month in Hong Kong.

Yours etc.,
Rudolf Voll

14 February 1989
C-6, 15 Fl., Hankow Centre, 1 Middle Road, Kowloon, Hong Kong.

From Kenneth Scarratt, FGA

Dear Sir,

RE: LETTER FROM MR RUDOLF VOLL

I have often written items into 'Notes from the Laboratory' in the hope that someone with a close knowledge of that particular area of our subject will write to the Editor with additional information. This, however, and somewhat disappointingly, very seldom occurs. I was therefore very pleased to read Mr Voll's comments on the double-nucleated cultured pearls.

Mr Voll is correct in assuming that his contribution would be well received; one only wishes that there were more people in the gemstone industry who would put pen to paper and let us read of their experiences within these pages.

Yours etc.,
Kenneth Scarratt

24 February 1989
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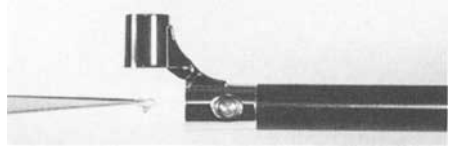

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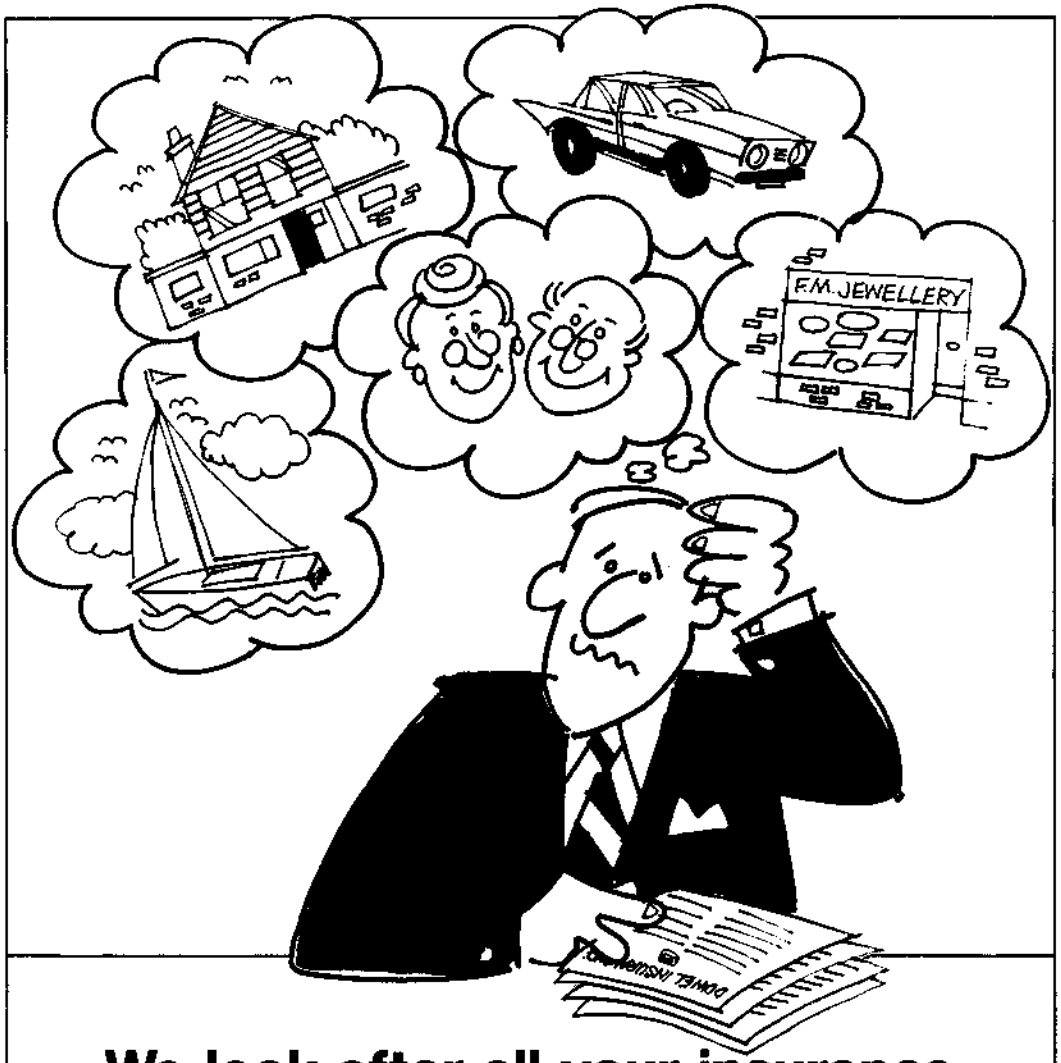

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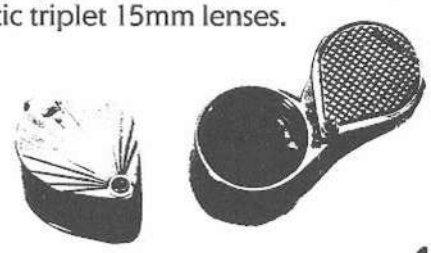

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The Arms and Crest of the Association, conferred by a grant of Arms made by the Kings of Arms under royal authority. The cross is a variation of that in the Arms of the National Association of Goldsmiths of Great Britain and Ireland. In the middle is a gold jewelled book representing the study of gemmology and the examination work of the Association. Above it is a top plan of a rose-cut diamond inside a ring, suggesting the scrutiny of gems by magnification under a lens. The lozenges represent uncut

octahedra and the gem-set ring indicates the use of gems in ornamentation. The lynx of the crest at the top was credited, in ancient times, with being able to see through opaque substances. He represents the lapidary and the student scrutinizing every aspect of gemmology. In the paws is one of the oldest heraldic emblems, an escarbuncle, to represent a very brilliant jewel, usually a ruby. The radiating arms suggest light diffused by the escarbuncle and their tips are shown as jewels representing the colours of the spectrum.

Historical Note

The Gemmological Association of Great Britain was originally founded in 1908 as the Education Committee of the National Association of Goldsmiths and reconstituted in 1931 as the Gemmological Association. Its name was extended to Gemmological Association of Great Britain in 1938, and finally in 1944 it was incorporated in that name under the Companies Acts as a company limited by guarantee (registered in England, no. 433063).

Affiliated Associations are the Gemmological Association of Australia, the Canadian Gemmological Association, the Gem and Mineral Society of Zimbabwe, the Gemmological Association of Hong Kong, the Gemmological Association of South Africa and the Singapore Gemologist Society.

The *Journal of Gemmology* was first published by the Association in 1947. It is a quarterly, published in January, April, July, and October each year, and is issued free to Fellows and Members of the Association. Opinions expressed by authors are not necessarily endorsed by the Association.

Notes for Contributors

The Editors are glad to consider original articles shedding new light on subjects of gemmological interest for publication in the *Journal*. Articles are not normally accepted which have already been published elsewhere in English, and an article is accepted only on the understanding that (1) full information as to any previous publication (whether in English or another language) has been given, (2) it is not under consideration for publication elsewhere and (3) it will not be published elsewhere without the consent of the Editors.

Papers should be submitted in duplicate on A4 paper. They should be typed with double line spacing with ample margins of at least 25mm all round. The title should be as brief as is consistent with clear indication of the content of the paper. It should be followed by the names (with initials) of the authors and by their addresses. A short abstract of 50–100 words should be provided. Papers may be of any length, but long papers of more than 10 000 words (unless capable of division into parts or of exceptional importance) are unlikely to be acceptable, whereas a short paper of 400–500 words may achieve early publication.

Twenty five copies of individual papers are provided on request free of charge; additional copies may be supplied, but they must be ordered at first proof stage or earlier.

Volume 21 No. 6. April 1989

The Journal of Gemmology

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Ornamental button in 22 ct gold set with Burmese red spinel crystals. The crystals are approximately 8-9mm from point to point; the base is 22mm in diameter. Button provided by Mr S. Moussaieff of the London Hilton Jewellers Ltd.
Photograph by E. Alan Jobbins.

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F.G.A

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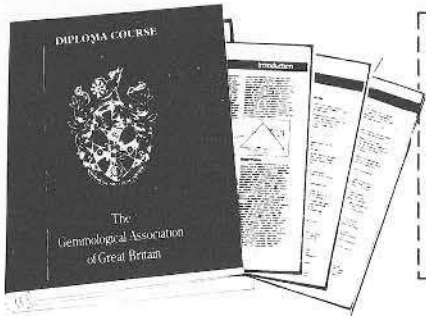

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Heat treatment of Geuda stones – spectral investigation

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Abstract

It is well known that Sri Lankan corundum with the milky white opaline character called 'geuda', when subjected to heat treatment can be converted to clear blue sapphires. In order to understand the processes taking place during heat treatment a large number of such stones were heated at different temperatures in the range 1200-1900°C for varying periods of time. The stones were spectroscopically examined after each heat treatment. The spectra so obtained confirms that the $(Fe\text{-}Ti)^{6+}$ bi-particle is responsible for the blue colour in the transformed stones. They also show that iron and titanium exist as Fe^{3+} and Ti^{3+} before heat treatment. The heat treatment process reduces the Ti^{3+} content significantly but not the Fe^{3+} content.

Introduction

'Geuda' is defined as the milky-white opaline character seen in some corundum based stones (Gunaratne, 1981). Sri Lanka has large reserves of corundum stones showing this feature. It is well known that certain varieties of these geuda stones when subjected to heat treatment can be converted to blue sapphires. In this investigation a large number of such stones were examined spectroscopically at different stages of heat treatment in order to gain an understanding into the transformations taking place.

Experimental Details

Around 50 stones showing 'geuda' characteristics were heated for varying periods of time at different temperatures in the range 1200-1900°C. The colour of these stones before heat treatment ranged from white to yellowish brown to light blue. None of them were of a transparent nature originally. The stones were cut and polished to present flat parallel surfaces and placed in alumina crucibles inside a furnace chamber fabricated from alumina refractories. The crucible was heated using an oxy-acetylene flame adjusted to give a neutral to slightly reducing flame. The stones were examined spectroscopically after heating for specified periods of time. The specimen was illuminated with white light and the transmitted light fed to a monochromator (EG & G 555). The output of the monochromator was analyzed using the EG & G 550 Radiometer/Photometer to obtain the intensity of each wavelength in the range 420-720 nm.

Results

On heating beyond 1500°C around 90% of the samples turned into blue sapphires having varying colour intensities. Heating at higher temperatures resulted in sapphires of a darker blue. The clarity also improved. The spectra of all these stones clearly showed the development of a broad absorption band beyond 560 nm as the blue colour developed. There were two other notable features which were shown by a majority of the stones. These are (a) a weak absorption at 540 nm which was present initially but gradually disappeared as the blue colour developed, and (b) a weak absorption at 450 nm which persisted throughout the heat treatment process.

The room temperature absorption spectrum of a representative sample which showed all the three features mentioned above are given in Figures 1 to 3.

This was a silky bluish-grey stone which showed a brownish colour under transmitted light (Figure 1). Heating at 1700°C turned it into a blue stone (Figure 2). Further heating in the temperature range 1800-1850°C turned it into a dark blue sapphire (Figure 3).

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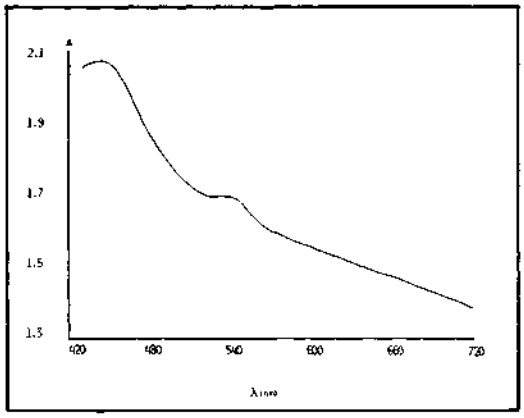

Fig. 1. Absorption spectrum before heat treatment.

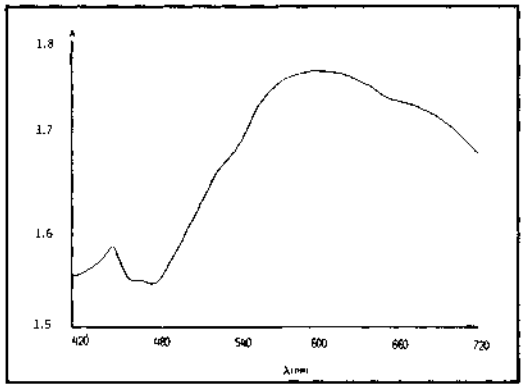

Fig. 2. Absorption spectrum after heat treatment at 1700°C.

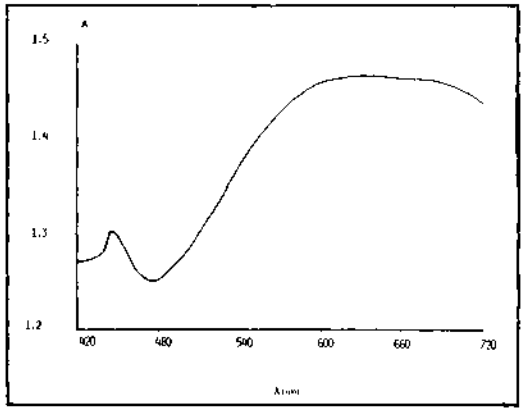

Fig. 3. Absorption spectrum after heat treatment at 1800-1850°C.

Discussion

The results presented above show three characteristic developments during heat treatment:

(1) development of a broad absorption band beyond 560 nm;

(2) reduction or disappearance of the weak absorption at 540 nm; and

(3) persistence of the weak absorption at 450 nm.

The broad absorption band beyond 560 nm in corundum have been associated with a $(Fe\text{-}Ti)^{6+}$ bi-particle (Eigenmann & Gunthard, 1972). The absorptions at 540 nm and 450 nm have been associated with Ti^{3+} and Fe^{3+} respectively (Schneider and Bank, 1980). Hence our results lead to the following conclusions:

(1) the blue colour in heat treated 'geuda' stones is due to the $(Fe\text{-}Ti)^{6+}$ bi-particle. This confirms the hypothesis of Harder and Schneider (1986) presented to explain their electron microprobe analysis;

(2) the Ti^{3+} concentration reduces appreciably during heat treatment;

(3) the Fe^{3+} concentration is not affected appreciably during heat treatment.

Based on these conclusions the following model is presented to explain the transformations taking place during the heat treatment of geuda stones:

(a) both Ti^{3+} and Fe^{3+} are present in 'geuda' stones with Fe^{3+} in excess;

(b) under heat treatment the $(Fe\text{-}Ti)^{6+}$ bi-particle forms using up the Ti^{3+} and Fe^{3+};

(c) Ti used up for the formation of this bi-particle reduces the Ti^{3+} content significantly;

(d) Fe^{3+} being in excess, the total Fe^{3+} content is not significantly affected by the bi-particle formation.

Acknowledgements

The contributions by Mr W. Weerasinghe and Miss G. Hewawasam in the heat treatment and spectral investigations respectively are gratefully acknowledged.

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The Muslim Lapidary

Some aspects of the gem folkways in Sri Lanka

M.M.M. Mahroof

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It is well known in gemmology that Sri Lanka* was and is famous for its wealth of gems. The ancient chronicle, the *Mahavamsa*[1], reputedly one thousand five hundred years old, speaking of the consecration of an early king *Devanampiya Tissa*, says:

> 'Pearls of the eight kinds, namely horse-pearl, elephant-pearl, waggon-pearl, myrobalan-pearl, bracelet-pearl, ring-pearl, kakuda fruit-pearl and common (pearls) came forth out of the ocean and lay upon the above in heaps. All this was the effect of Devanampiya Tissa's merit. Sapphire, beryl, ruby, these gems and many jewels and those pearls and those bamboo stems they brought, all in the same week, to the king.'

While Sri Lanka has had a good press for its gems throughout the centuries, concern for the human element and the mechanics of the gem trade has not been as pervasive[2]. Pliny; the fifth century Buddhist Chinese pilgrim Fa Hian; Cosmas Indicopleustis; Marco Polo; Odoric; Jordanus; Ibn Batuta; Ribeiro; and in more recent times, Max Bauer; Count de Bournon; C.G. Gmelin; M.H. Klaproth; were among those who had written, often admiringly, of Sri Lankan gems. Modern text writers, like Herbert Smith (and his subsequent editors) and Anderson deal with Sri Lankan gems more as a class and less as a country[3]. Webster gives more space but not so much as he devotes to Burma[4].

The present article attempts to deal with the activities of a community, members of which have been active in the sphere of gem trade throughout a millenium and more. While it would be hyperbolic to say that 'the trade is today almost entirely in the hands of Moslems as in the past'[5], it would be true to say that their task is that of the earthworm bringing the undersoil to the surface and thus helping to keep the soil and the economy sweet and fresh and alive.

*Until 1978 Sri Lanka was known as Ceylon. Both terms are used in the article, depending on context.

Gem cutting by the traditional method, Ratnapura. *Photo by E.A. Jobbins.*

The Muslims of Sri Lanka

Today the Muslims form seven per cent of the total population of Sri Lanka and number just over a million individuals. They are believed to be the descendants of the Arab sea-farers, who controlled the Indian Ocean trade up to the sixteenth century[6]. The standard history of Ceylon (Sri Lanka) noted that 'Arab historians have recorded that in the first decade of the eighth century the King of Ceylon sent to the Viceroy of the eastern Caliphate the orphan daughters of Muslim merchants who had died in his dominions' and that 'at the end of the Anuradhapura period [tenth century] there were communities of Muslims at seaports like Mahatitta and Colombo'[7].

The Muslim lapidaries of the period roughly up to the sixteenth century lived and worked in what came to be called 'fondachi'[8]. These were trading stations grouped as streets set aside for particular trades and managed by senior and influential traders. Lapidaries formed an important segment of this set up for, like some other trades where the possession of capital was sufficient to ensure domination in the trade, gem-buying and gem-selling, however low or however high, was dependent on physical handling and evaluation of the stones which was the work of the lapidary. A Chief Justice of Ceylon in early nineteenth century and a close observer of Muslim affairs wrote:

> 'During that period [twelfth and thirteenth centuries] the great Mohammedan merchants of Mannar and Mantota [in the north-west of Sri Lanka] received into the immense warehouses which they had established at this emporium, the most valuable produce of the island [Sri Lanka] from their subordinate agents, who resided at the different seaports which were situated in the neighbourhood of those provinces where the various articles of commerce were produced ...from those at Colombo cinnamon and precious stones.'[9]

These stones cut by the Muslim lapidaries were mainly for export, taken up by the Arab ships which regularly called at the seaports of Colombo and Galle (on the southern seaboard). Other stones took their place in the eight-item regalia of the indigenous princes, which included the crownlet, the girdle, the ceremonial thread, the necklace and armlets. Possibly some of them were taken to other countries for other purposes. It was reported that among the articles offered to the Chinese Emperors during fifth to eighth centuries, were pearls, filigreed gold, gems, ivory valances and some very fine shaggy stuff of white colour [10].

At any rate the Chinese of the mediaeval period were appreciative of the expertise of the Muslims for they called the gems of Sri Lanka, 'Mohammedan stones'[11]. Some of the Chinese mariners were Muslims. The Chinese Admiral Zheng He, who commanded the fleet under the Ming Emperor (Ming Yong Le) and who visited thirty countries of Asia between 1405 and 1431, was a Muslim [12].

The structure of the Muslim lapidary and gem-merchants (they were, really, the one shading into the other) was established by the European occupation of Sri Lanka. The Portuguese ruled the Maritime Provinces of Sri Lanka from 1505 to 1658, the Dutch from 1658 to 1796 and the British from 1796 (and the entire island from 1915) to 1948 when Sri Lanka became independent. The Portuguese imposed a series of naval sanctions, including a system of primitive navicerts, upon Muslim vessels. While the redoubtable family of Kunjaly Marikars, who traditionally commanded the fleet of the Zamorin (the Kerala Princes who were inveterate enemies of the Portuguese), were able to run the blockade, the Muslim gem trade, to a great extent, fell into a decline[13]. But the worst was to follow. Acting on the directions of the Viceroy at Goa, the Portuguese officials in Sri Lanka expelled the Muslims, with some exceptions, from Colombo in 1626. About four thousand of them were welcomed by the King of Kandy, the indigenous prince, who ruled the central massif of Sri Lanka and who settled them in the eastern portion of the country[14].

The impact of these diaspora was to fragment the gem trade and gem cutting. Towns on the west seaboard, which were also landing stages, attracted the lapidaries rather like Amsterdam attracting diamond-cutters. Beruwela (called Barberyn by the Dutch) some miles south of Colombo and Gintota, a hamlet of Galle (then a prestigious sea port), became noted for lapidary work. While they were far from official interference, they were not immune from the bourgeoisie who favoured gems. The Muslim lapidaries who had sought refuge in the Kandyan provinces had a different sort of experience. For one thing, they had a definite niche in society. The Kandyan caste structure placed the 'acaries', among whom the goldsmiths and associated craftsmen were reckoned, as fourth in ranking[15]. The Muslim lapidaries were exotic enough to be reckoned among the dominant castes but rigid sumptuary rules confined gem-wearing to a fixed clientele which included the king and the nobility.

When the Dutch took over Ceylon, it entered into the control of the Dutch East Indies Company – the VOC. The VOC was a massive and profitable trading and ruling corporation. In 1669 it paid forty per cent dividend on its capital of 6,500,000 florins. The VOC had 150 trading ships, 40 ships of war and 10,000 soldiers, and maintained the governments of Ternate, Java, Ambon, Macassar, Banda (all in present day Indonesia), Malacca, Ceylon and Good Hope[16]. More importantly, it had in its owners and staff a burgeoning bourgeoisie which gloried in the paintings of Rubens, Hals, Rembrandt, de Hooch and the brothers van der Velde. Gems formed an important part of its lifestyle. The life of the Muslims, lapidaries included, under the Dutch in Ceylon, was neither pleasant nor memorable. They were subject to capitation taxes, confinement to ghettoes, restrained from trade and to registration of residences[17].

Yet there was a constant demand for gem-cutting

and gems from the meijneheeren and meijnevrouwen of Dutch Ceylon, the gems forming portable wealth. The seventeenth and the middle eighteenth centuries (by which time the British were flourishing in the Carnatice), saw the rise of the larger zamindar, the 'poligars' in the south of India, who sometimes fought the British or the French or themselves, depending on their territorial needs. For the 'poligars', gems formed an easy way of drumming up support, retaining allies or, at the worst, portable wealth in flight. Lapidaries and gem-traders, nearly all of them Muslims, who had settled down in the coastal towns of south India, became important and their towns became important too. Two of these towns, Kilakarai and Kayalpattinam (in present day Tamil Nadu), were specially famous and were, and are, established centres of the gem trade, though they have failed to obtain high-profile among the itineraries and topographical guide books during the high-noon of British Imperialism[18] or among the popular yearbooks of today[19]. The Muslim lapidaries of Sri Lanka developed a close trading connection with these towns.

The British presence

The occupation of Ceylon by the British was to have important consequences on the gem trade and on the Muslim lapidary in particular. The British abolished trade monopolies as part of the implementation process of the Colbrooke Commission Report[20] and free and open trade sprang up between Ceylon and the British Empire, especially India[21]. Indisputably, these efforts depressed the gem trade. The normal paradigm in the gem trade is composed of the lapidary, the broker and the merchant, major and minor. The constraints of the Dutch had created a great number of brokers and middle-men, mainly Muslims, for the scarcity value of gems made possible the toleration of massive overheads. The open-door policy of the British made gem exports normal; it also enabled the British Establishment in Ceylon, which included the military officers, the officials and the higher mercantiles, to buy their precious stones from the major gem merchants themselves. Higher capitalization helped the major gem merchants to lay in larger stock. Hence, the displaced brokers came on the streets in a manner familiar to most tourists. William Maxwell Wood, the US naval surgeon, who visited Ceylon in 1856, described the scene vividly:

> 'Moormen [ie Muslims], in Arab particoloured caps, with shaven heads and voluminous shawls wrapped around their waists, are everywhere at our heels, on the shores, in the streets, in the hotels and the halls of private houses; even on the roadside to the distance of some miles in the country, they appear importuningly. These Moormen are the traders in jewelry and precious stones. Jewel boxes are taken from the folds of their shawls, and sapphires, rubies, amethysts, carbuncles, emeralds, cat's eyes and moonstones, displayed in gorgeous abundance or else good English and French imitation for these valuables.'[22]

An earlier US writer, William Samuel Wuthman Ruschenburger, also a naval surgeon, visiting Ceylon in 1835 had said the same things[23].

After the 1850s the situation improved somewhat. The opening of the interior of Ceylon for the cultivation of coffee – there were 40,000 acres under coffee in 1840 – and its subsequent decline, for by 1881 coffee had nearly gone out of production, had brought gem-mining into the scene again[24]. The roads that had come up as infrastructure for coffeee, the unemployed men now available, the jobless in the associated trades, were incentive enough.

The gem trade had and has a logic of its own. The gem-miners, who actually dig and prospect for gems, should have the attitude of a beachcomber, for his job is not a neat study of cost-benefit analysis. The lapidary is assured of a regular income but he is dependent on his supplier-employers. The gem merchant, both minor and major, have to be backed by sufficient financial reserves as antidotes to their sometimes inspired guesses at evaluation, the average Ceylonese gem merchant being without benefit of scientific analysis. This is particularly true of the Muslim lapidary and gem-dealer.

Another persistent problem which had affected the Muslim lapidary (by making his services unnecessary) and the Muslim gem-dealer (by evaporating his profits) is the presence of non-natural stones or at any rate, stones which the normal gem dealer is not willing to realize or concede as totally natural. The present day geuda controversy is thus a part of a continuous debate. The US visitors whose views were described earlier in this article, are only a few of the tourists who noted the presence in Ceylon of British and French versions of Ceylon gems. It was officially commented upon, as well. In 1907 Parsons, who headed the Mineralogical Survey of Ceylon, wrote:

> 'Reconstructed rubies are sold in Ceylon sometimes fraudulently as natural stones and sometimes in ignorance of their real character. I was recently offered some stones of this description at Matara [ie a town in southern Sri Lanka]. The only reliable test is to examine the suspected gem under a

microscope. Natural stones commonly show minute cavities which are hexagonal or at all events angular in outline, whereas the cavities in the reconstructed stones are spherical like bubbles in glass. In poor examples, these spherical cavities can be observed even with a good hand lens. The beauty and durability of a reconstructed ruby is equal to a good natural ruby. Reconstructed sapphires do not so closely resemble natural sapphires and the colour and lustre are not satisfactory.'[25]

The world was less sophisticated then but the average Muslim gem-dealer of those days disdained the use of even a hand lens.

The 1914-18 World War depressed the prices but the consequent inflation arising as an aftermath of the War made the acquisition of gems a more attractive proposition. Thanks to the risk-taking propensities of the average Muslim gem-dealer, the Muslims did not face a bleak future in the gem field. The *Handbook for Ceylon* for 1922, could state rather confidently: 'The stones are bought up by Moorish [ie Muslim] dealers to be cut and polished. Many of the best stones are exported to Europe and America but the inferior varieties are largely sold locally or in India.'[26] The work of avant-garde (then and now) jewellers like Fabergé and art movements like art deco had their spin-offs in Ceylon, when a demand was created for matching gems and fancy stones. By the 1930s the oldest Muslim gem firms had been sixty to seventy years on the scene. British, European and American collectors had come to include Ceylon gems in their portfolios. The debacle of World War Two was followed by the 'economic miracle' in Germany and later in Japan and yet again by the boom of the sixties when gem sales were keeping pace with works of fashionable animal painters in sales value. Constraints, and the geuda controversy were to replace them later[27].

The Muslim lapidary; the craft

The lapidary is the archetypal figure in the Muslim gem world in Sri Lanka. Characteristically, and with reason, successful gem dealers arise from lapidaries and sometimes, uncharacteristically, gem dealers lapse into lapidaries again. This is because a feel for the stones and a careful cultivation of the eye is essential to the gem dealer, for at every evaluation he pits his experience against the seller and buyer and has no benefit of science.

The typical Muslim lapidary is a man in his late twenties or thirties. Probably his father or near kinsman was a lapidary before him and so *ad infinitum*. It is not a job for the hobbyist or for the do-it-yourself enthusiast. It is essentially a painstaking and boring job. A hereditary concern for minute detail is needed. For it was mainly a Muslim occupation. For instance, a century ago of the 199 lapidaries working in Ceylon, 170 were Muslims.[28] Owing to the coming of machinery, the picture has changed somewhat.

The Muslim lapidary works on a changeless apparatus. One hundred and fifty years ago, Ruschenburger wrote as follows:

> 'They sit under a veranda or shed, in front of the house, squatted on their heels behind a rude lathe, raised a few inches from the ground. On the end of the axle there is a round plate of iron or steel, about eight inches in diameter, placed vertically, which is made to revolve backwards and forwards by a drill-bow about four feet long, made of bamboo and worked by the right hand, while the left applies the stone to be cut, held tightly between the finger and thumb against the wheel. A sort of emery or finely powdered sapphire of coarse quality, moistened with water, is the only intermediary substance used in cutting the stone.'[29]

That was in December 1835. Louis Siedle writing in 1933 stated that from 1912, carborundum manufactured in USA had replaced powdered corundum because carborundum is harder[30].

Polishing of stones has not undergone changes either. For corundum, the copper lap is normal; softer stones like moonstones need a wooden lap. The stones are cemented to wooden holders and held against the polishing surface. This is, of course, for cabochon cuts. Faceting requires an elaborate procedure, within this appropriate technology. The copper lap is horizontal and, by primitive driving gear, runs quite fast. By means of an elementary goniometer fixed on a sliding rod, facets of the stone are polished. The polishing material is paddy husks burnt to a soft consistency.

Of late, Linde A and other materials are coming into use and laps and arbours are of the modern do-it-yourself varieties. But the precision of modern laps and belt transport systems are not very familiar to the average lapidary who can stop and start with hand-power which he is used to.

The weaknesses of the cutting system of the Muslim lapidary are part of the mythology of the subject. It is remarked that the Muslim lapidary sacrifices shape at the altar of weight. But there are two reasons for this situation. The dealer who tells the lapidary to cut desires to have the maximum possible caratage, for stones are sold on the carat and not on the precision cutting. The second reason has been presaged even ninety years ago. The American visitor, Mary Thorn Carpenter, who

visited Ceylon in 1890 wrote that:

> 'Here [in Colombo] also are the jewellers' shops, where we were shown glittering heaps of precious stones but found scarcely a good ruby or sapphire among them. Streeter of London and the great New York firms purchase all the valuable gems, leaving flawed and imperfect stones for tourists'.[31]

Given that good stones would be re-cut abroad if exported, there is little incentive in bravura gem-cutting.

The traditional Muslim lapidary has one overriding advantage. Decades of experience gives him the perfect feel for the stone and its qualities. For instance, an experienced lapidary can say that a particular good blue sapphire is from the Rakwana (south central of Sri Lanka) area and that particular placing had been worked out by 1900. Being bereft of even elementary knowledge of crystal systems, axes, Miller's indices, the (now exploded) theory of the Beilby layer not to speak of sophisticated procedures like energy dispersive analysis or X-ray diffraction, the lapidary has a confidence sometimes rudely shaken, of his own experience. This is a case of ignorance being truly bliss.

In Sri Lanka, as is well known, the local jewellery trade does not contribute in large measure to the gem trade. Current wedding jewellery, with some outstanding exceptions, is gold-based and 22 carat at that. Less affluent women used to wear, on a gold base, a 'pavé' of 'Rangoon diamonds' (popularly called 'Rangoon kamalam') but that fashion is phasing out. Traditional Muslim jewellery of Sri Lanka is often chunky and a few are similar to those worn in Egypt during the first part of the nineteenth century[32]. Thirty years ago some Muslim women wore wedding necklaces with alternating chunks of gold and coral, rather like some Omani jewellery[33]. Muslim males wear, if at all, only silver rings with stones cut en cabochon.

Hence, most gems in Sri Lanka are exported; at any rate, all stocks of stones are exportable. The following propositions may be hazarded:

(a) sales may be divided into (i) one-off sales, e.g. lucky finds, which do not affect the market; (ii) sales by brokers, which increase the overheads; (iii) sales between minor and major merchants, which are always in favour of the major merchants; (iv) sales between minor merchants and those between major merchants, which is a reflection of replenishment of portfolios;

(b) the price paid is a guess of what the foreign buyer is willing to pay; hence, a buyer needing a special or fancy gem generally drives up the prices of all gems;

(c) in boom times, the heavy circulation of stones brought about by these passing through very many middle-men, raises prices unduly and a single refusal to buy, through negative multiplier effects, drives down prices unduly. Hence, booms have an inbuilt depressing factor;

(d) gem booms are related to booms in luxury articles, e.g. carpets.

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Black diamonds of Type IIb

S. Scandella, FGA

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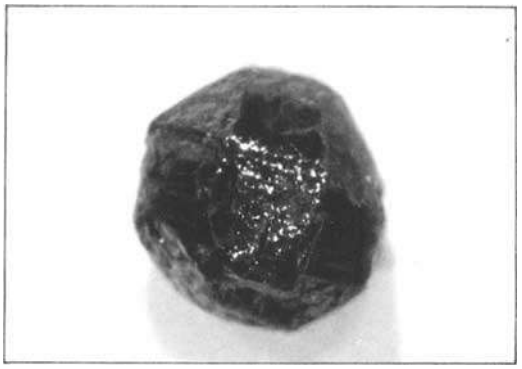

Fig. 1. Black diamonds, rough, 1.82 ct, electrical conductor. Maximal length 8 mm.

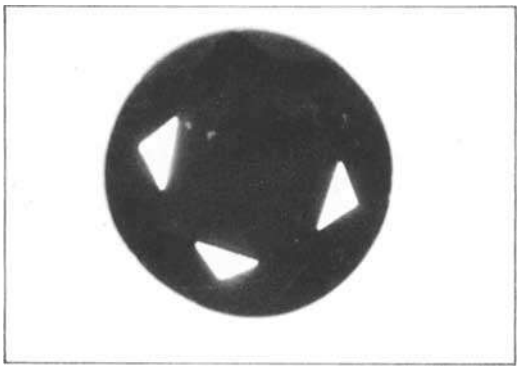

Fig. 2. Black diamond, brilliant cut, 0.44 ct, electrical conductor. Maximal diameter 5 mm.

Recently the Gübelin Gemmological Laboratory investigated five black diamonds for research purposes whose weight was between 0.37 ct. and 1.82 ct. There were two rough and three cut stones. It was stated that their origin was a source in Africa.

Several tests were carried out. The microscopic examination revealed masses of dark inclusions, which are responsible for the black colour and for the low transparency throughout the stones [1].

Colour was of natural origin. Heavily irradiated diamonds would show some spots of dark green colour in transmitted or reflected light[1 and 2]. However, the most astonishing thing that we discovered, for the first time in our records, was that two of the crystals showed electrical conductivity under 220 volts. This means that the two specimens belong to the Type IIb category (Figures 1 and 2).

With this note, our purpose is to prompt similar investigations. We would be interested in communicating with anybody having noticed similar properties in black diamonds.

Acknowledgements

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Further evidence for the controls on the growth of vanadium grossular garnets in Kenya

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Abstract

The physical and chemical controls on the growth of green vanadium grossular garnet in SE Kenya ascertained by Pohl and Neidermayr (1978) are confirmed on a regional basis. An intimate association of marbles with the host graphitic gneisses was mandatory for garnet growth during a regional metamorphism which reached granulite facies conditions. Kelyphitic rims around garnet pods in SE Kenya are not retrogressive products but also formed in the granulite facies due to an increase in the CO_2 content of the fluid phase. The graphitic gneisses represent altered bituminous black shales and testify to widespread late Proterozoic seafloor organic activity in the Mozambique Orogenic Belt throughout East Africa.

Introduction

From their work in SE Kenya, Pohl and Neidermayr (1978) concluded that there are four controls on the distribution of the green gemstone, vanadium grossular garnet ('tsavorite'), as follows:

1. *Regional Lithostratigraphy:* the garnets form within a single lithostratigraphic unit.
2. *Lithology:* the garnets are confined to graphitic gneisses which are either rich in calcium (due to the presence of thin marble seams or calcareous pods), or which are immediately adjacent to marble beds. This control was first noted by Bridges (1974).
3. *Availability of Chromophore:* a supply of V (cited as the main colouring agent by Gübelin and Weibel, 1975) Mn, Ti, Fe and Cr from the host gneisses.
4. *High Grade Metamorphism:* the vanadium grossulars formed during a regional progressive metamorphism under either upper amphibolite or granulite facies conditions.

These four controls reflect the standard conditions necessary for metamorphic mineral growth: favourable PT conditions and a suitable chemical environment. The purpose of the present study was to see if the same four controls have a regional application as valid exploration guides for new vanadium grossular garnet deposits. New data on the chemistry of the host graphitic gneisses and on metamorphic conditions in SE Kenya are presented.

The graphitic gneisses are part of a metasedimentary sequence in the Mozambique Orogenic Belt; a complex Upper Proterozoic to Lower Phanerozoic province which extends from Mozambique northwards through Eastern Africa as far as Ethiopia (*see* Holmes, 1951; Cahen *et al.*, 1984; Key *et al.*, in press). The vanadium grossulars were first discovered in Tanzania, with gem quality stones mined in the south-east of the country at Lelatema Hills. (Gübelin and Weibel, 1975). Subsequently, better quality garnets were also found on either side of the Tanzania/Kenya border. Mineral exploration in north-central Kenya, within the Mozambique Orogenic Belt, by a joint UK (British Geological Survey) – Kenya (Mines Department) team in the early 1980s located similar garnetiferous graphitic gneisses north-east of Baragoi (Figure 1, Key, 1987). However, in central Kenya at least, other major graphitic gneisses, e.g. at Ol Doinyo Ng'iro (Stewart, 1963), are devoid of vanadium garnets. Comparisons between the garnetiferous and garnet-free graphitic gneisses are used to test the four controls of Pohl and Neidermayr (1978) on vanadium grossular growth.

Regional Lithostratigraphy

In SE Kenya (Taita Taveta area of Figure 1) the vanadium garnets are confined to a single part (Lualenyi Member) of a thick sequence of marbles, graphitic gneisses and various biotite gneisses which Pohl and Neidermayr (1978) refer to as the Kurase Group (after Saggerson, 1962). In central-north Kenya a similar metasedimentary sequence is recognised as a distinctive mappable unit continuous over several hundred kilometres along

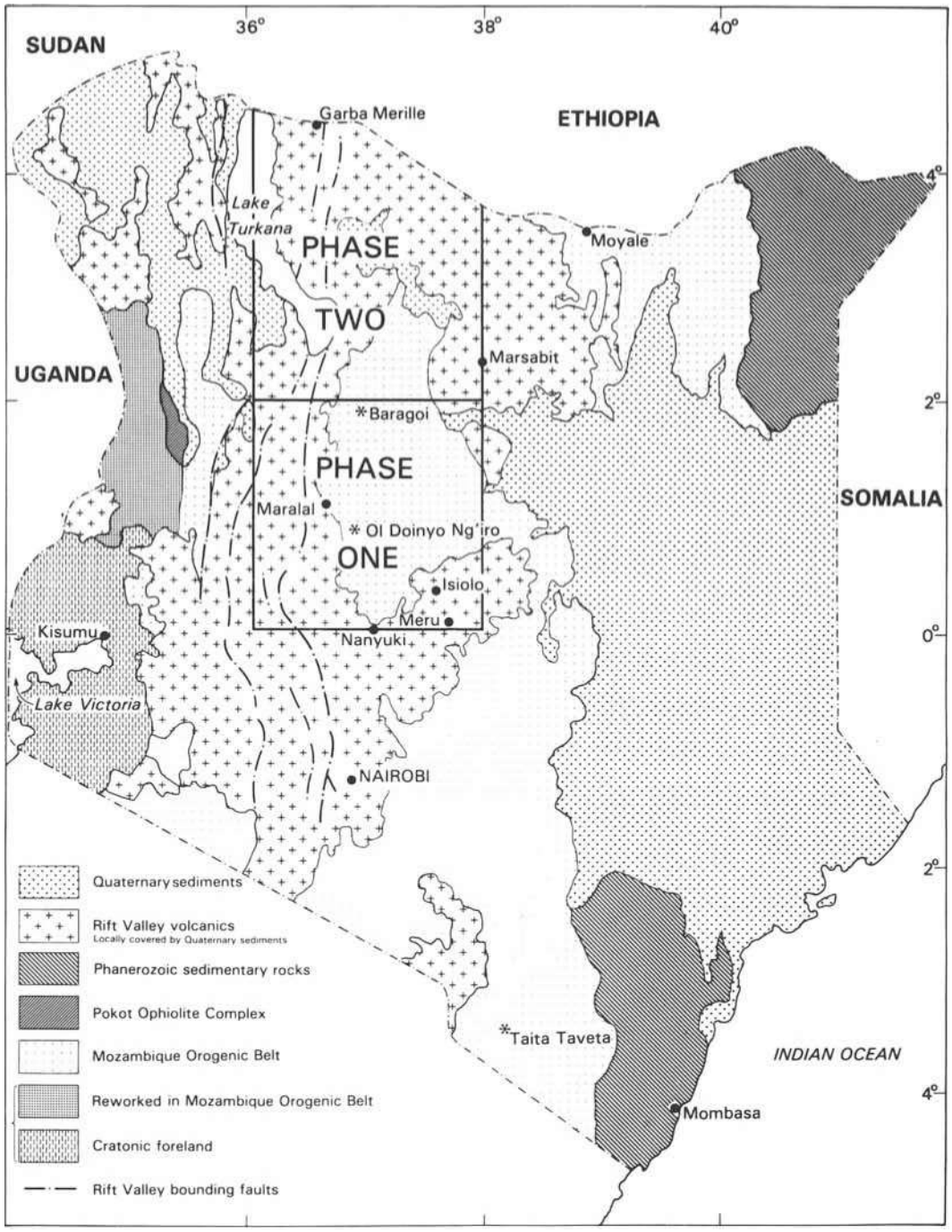

Fig. 1. Geological map of Kenya showing the main graphitic gneiss localities (*) and the area of northern Kenya explored jointly by the British Geological Survey and the Kenya Mines Department.

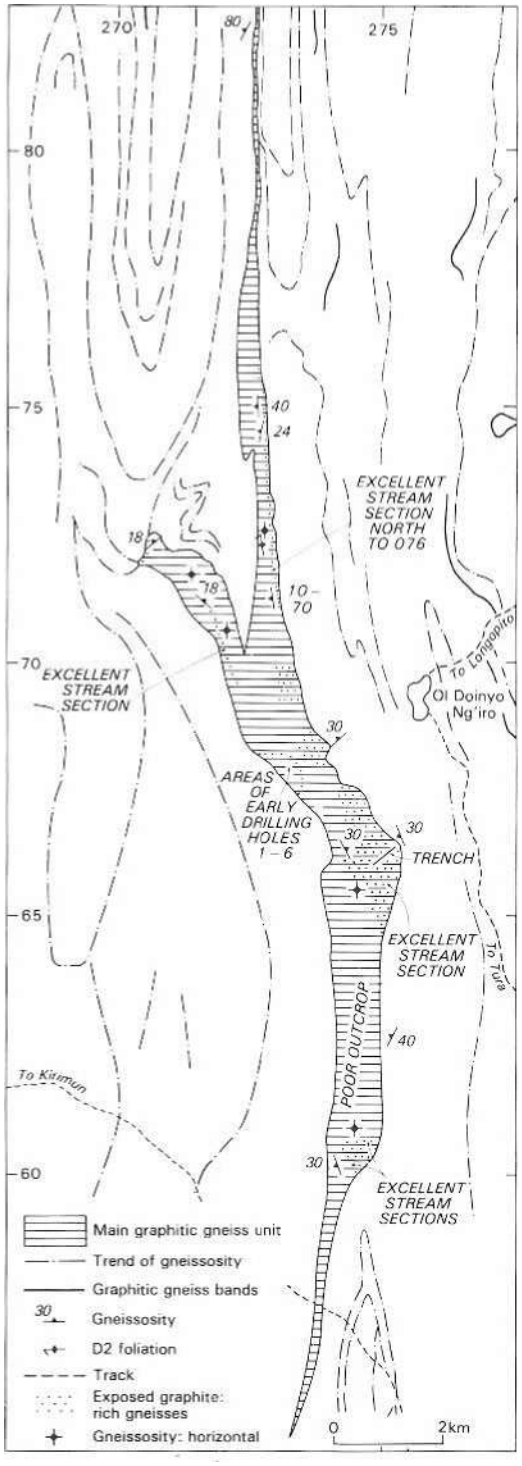

Fig. 2. The Ol Doinyo Ng'iro graphitic gneiss.

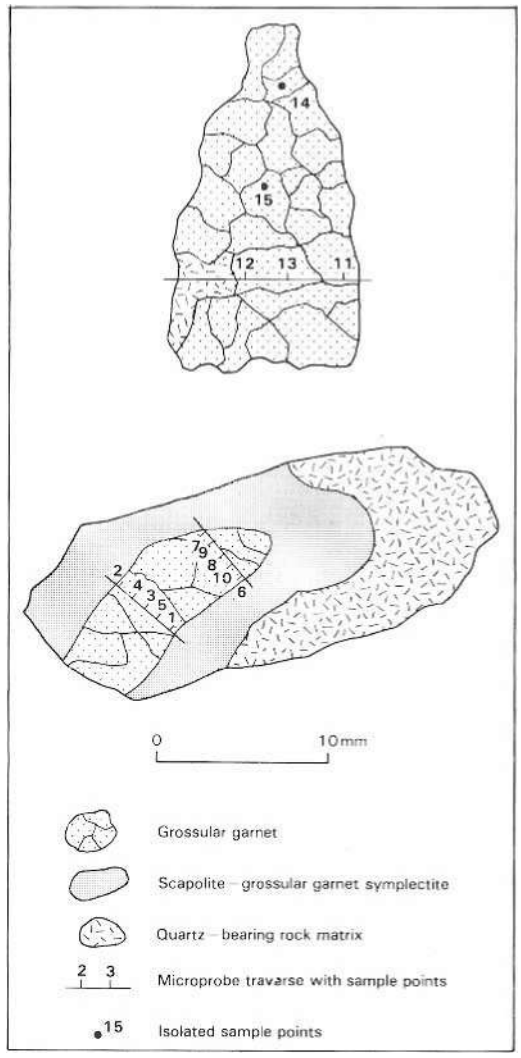

Fig. 3. Details of the analysed serial sections of vanadium grossular garnet from Lualenyi (Taita Taveta locality of Figure 1).

strike (Shackleton, 1946). It is referred to as the Ol Doinyo Ng'iro Gneisses (Hackman *et al.*, in press). The geological histories of the Kurase Group and Ol Doinyo Ng'iro gneisses are indistinguishable; both comprise altered marine continental shelf deposits laid down at about 840 million years ago (geochronological evidence reviewed in Cahen *et al.*, 1984; Key *et al.*, in press). They record the same late Precambrian history of early recumbent folding and thrusting accompanied by high grade metamorphism, subsequent upright folding, and finally retrogression with uplift and cooling at about 500 million years ago.

Table 1 – Mineral assemblage of three major graphitic gneisses within Kenya

Lualenyi

1. Graphite + quartz + plagioclase ± orthoclase, microcline, muscovite

2. Graphite + quartz + sillimanite + muscovite + accessory rutile, apatite, tourmaline, sulphides

3. Graphite + quartz + clinopyroxene + clinoamphibole + scapolite + epidote + grossular

4. Graphite + quartz + clinopyroxene + scapolite + sphene + secondary carbonate, iron oxide, serpentine

Baragoi

5. Graphite + quartz + plagioclase + boitite ± vanadium grossular garnet, muscovite, microcline, sillimanite or kyanite

6. Graphite + quartz + muscovite + opaline quartz

Ol Doinyo Ng'iro

7. Graphite + quartz + plagioclase ± biotite, sillimanite, iron oxides

1,2,3 Pohl & Neidermayr (1978)

4,5,7 This study

6 Baker (1963)

The south-east and central-north Kenya inliers of the Mozambique Orogenic Belt are separated by a volcanic carapace related to the Cenozoic East Africa Rift System (Figure 1). In a complex tectonothermal province such as the Mozambique Orogenic Belt, it is impossible to correlate disconnected lithological sequences in exact (member status) detail. However, the Kurase Group and Ol Doinyo Ng'iro gneisses are correlatable as a unique succession of thick marbles and major graphitic gneisses.

Lithology

Throughout Kenya the host graphitic gneisses form conformable beds up to 1000m thick, which, like all lithologies in the metamorphic belt, lens out along strike (Figure 2 is a typical example). Marble intercalations, calcareous pods and adjacent marble are ubiquitous in SE Kenya (Pohl and Neidermayr, 1978). At Ol Doinyo Ng'iro in central Kenya there are no intimate marble associations with the main garnet-free graphitic gneiss unit. In northern Kenya, around Baragoi, the graphitic gneisses lack internal calcareous pods but there are immediately adjacent marble seams (Baker, 1963).

The mineralogy of the graphitic gneisses is summarized in Table 1. At Lualenyi (near Taita Taveta) the green vanadium garnets either occur in randomly distributed (calcareous) pods or as disseminated idioblastic crystals. There are only disseminated garnets in the Baragoi graphitic gneisses. No vanadium garnets occur at Ol Doinyo Ng'iro where old graphite workings (Stewart, 1963) provide excellent exposures.

Gübelin and Weibel (1975) as well as Pohl and Neidermayr (1978) suggested that the graphitic gneisses represent altered bituminous black shales. A diagnostic characteristic of unmetamorphosed Phanerozoic sapropels is their relatively high vanadium contents. Wedepohl (1964) records values of up to 5000 ppm V in bituminous shales and limestones. This compares to a mean value of only 56 ppm V in surficial deposits of the USA (Shacklette *et al.*, 1971) and a mean value of 59 ppm for the Canadian Shield (Eade and Fahrig, 1973). As vanadium is also relatively immobile during high grade metamorphism (Eade and Fahrig, 1973) it remains in its original host rock to enter the new metamorphic mineral assemblages. Table 2 shows new analyses for V, Cr and TiO_2 of Kenyan graphitic gneisses as well as other contemporaneous East African graphitic gneisses. Their high vanadium contents and other data indicate that they are altered bituminous black shales. The wide

Table 2 – V, Cr and TiO_2 contents of graphitic gneisses from the Mozambique Orogenic Belt of East Africa

Locality	*V*	*Cr*	*TiO_2*
Kenya	(ppm)	(ppm)	(wt %)
Lualenyi	1259	732	0.78
Ol Doinyo Ng'iro – low grade	748	284	1.41
Ol Doinyo Ng'iro – high grade	1697	331	2.02
Taita Hills	1052	985	0.82
Tanzania			
Morogoro	249	91	2.19
Merelani	446	72	1.31
Madini Pit	934	79	1.31
Daluni	680	219	1.10
Malawi			
Katengeza	630	718	2.12
Lumbadzi River	588	1015	1.09
Lobi Pit	1902	701	3.37
Zimbabwe			
Lynx Mine	239	152	0.29

X R F analysis by David Bland as part of the BGS study of graphite resources of East Africa. Each analysis is of a single rock sample: 4 gms of powdered rock are mixed with 1 gm of elvacite binder and pressed into a disc. Note also that Sarbas *et al.*, (1984) record 1157 ppm V and 329 ppm Cr from graphitic schists from Lualenyi.

areal extent of contemporaneous graphitic gneisses within the Mozambique Orogenic Belt indicates a major phase of organic seabed activity during the Late Proterozoic.

Availability of Chromophores

As well as having anomalously high V contents (the green grossular garnet's main chromophore) all the graphitic gneisses, irrespective of whether they contain grossular garnet, contain significant amounts of Cr and TiO_2 (Table 2). Microprobe analysis across two serial sections of a typical vanadium garnet pod (Figure 3) from Lualenyi are very similar to the garnet composition (see Table 3) quoted by Gübelin and Wiebel (1975). Analyses presented in Table 3 were carried out on a Cameca Camebax electron probe microanalyser operating at an accelerating potential of 20KV with a probe current, as measured in a Faraday Cup, of 20 nanoamps. Standards used in calibration were as follows:– wollastonite for silicon and calcium, jadeite for sodium, corundum for aluminium, periclase for magnesium and rutile for titanium; other elements (vandium, chromium, manganese and iron) were calibrated against pure metals. Matrix corrections were carried out using a ZAF process similar to that described by Sweatman and Long (1969).

The high resolving capabilities of the fully focusing spectrometers fitted to the microprobe almost enables the overlap of Ti Kβ and the V Kα peak to be ignored. In the mineral under discussion, where vanadium far exceeds titanium, and in which the titanium content is low, the residual overlap effect is so small as to be negligible. Of

TABLE 3: Results (in wt.%) of microprobe analyses using a Cameca Camebax Microbeam. Sample from Taita Taveta (Lualenyi area) with analytical points shown in Fig.3. The scapolite and symplectite garnet analyses are from the kelyphitic rim shown in the same figure.

		MAIN GARNET										MAIN GARNET					Scapolite	Symplectite Scapolite	Symplectite Garnet		
	(a)	GT1	GT2	GT3	GT4	GT5	GT6	GT7	GT8	GT9	GT10	GT11	GT12	GT13	GT14	GT15					
SiO2	38.70	39.07	39.05	39.24	39.17	39.27	39.26	39.29	39.24	39.18	39.09	39.78	39.00	39.22	39.56	39.53	43.78	43.85	37.60	37.73	40.81
TiO2	0.25	0.46	0.42	0.44	0.40	0.45	0.45	0.47	0.43	0.45	0.40	0.47	0.45	0.43	0.29	0.43	0.02	0.01	1.05	1.14	0.95
Al2O3	20.90	20.99	20.80	20.68	20.68	20.84	20.88	20.78	20.80	20.87	20.85	22.20	22.01	21.91	22.44	22.44	29.79	29.20	12.23	12.34	13.90
V2O3	3.30	2.19	2.05	2.32	2.12	2.18	2.12	2.26	2.41	2.22	2.40	0.84	0.55	0.98	0.47	0.49	0.00	0.04	11.45	11.38	10.71
Fe2O3	0.05*	0.11	0.12	0.10	0.10	0.11	0.09	0.20	0.08	0.09	0.09	0.09	0.08	0.09	0.07	0.08	0.02	0.01	0.55	0.52	0.50
CaO	35.10	35.30	36.23	35.95	36.07	36.19	35.99	35.81	36.17	36.07	36.16	36.13	36.38	36.13	36.55	36.59	19.69	19.09	33.57	33.95	31.11
MgO	0.50	0.49	0.47	0.51	0.52	0.50	0.49	0.56	0.46	0.48	0.50	0.52	0.49	0.50	0.43	0.51	0.03	0.03	0.55	0.51	0.70
Na2O	0.10	0.00	0.00	0.00	0.00	0.02	0.00	0.03	0.03	0.01	0.01	0.02	0.03	0.01	0.02	0.01	2.27	2.29	0.02	0.01	0.17
MnO	0.75	0.69	0.75	0.77	0.76	0.71	0.73	0.83	0.68	0.71	0.70	0.82	0.79	0.79	0.64	0.74	0.03	0.04	1.41	1.17	1.24
Cr2O3+	0.19																				
Total	99.84	99.30	99.90	100.01	100.00	100.26	100.00	100.21	100.29	100.07	100.19	100.87	99.76	100.05	100.47	100.81	95.61	94.58	98.42	98.75	100.00
UV		0.01	0.01	0.01	0.01	0.00	0.01	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00			0.03	0.03	0.03
AD		0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01			0.04	0.04	0.03
GR		0.95	0.95	0.95	0.95	0.95	0.95	0.94	0.95	0.95	0.95	0.95	0.95	0.96	0.96	0.96			0.88	0.89	0.88
PY		0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02			0.02	0.02	0.01
SP		0.01	0.01	0.01	0.01	0.02	0.01	0.02	0.01	0.01	0.01	0.02	0.02	0.02	0.02	0.01			0.03	0.03	0.03
AL		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00			0.00	0.00	0.00

(a) - Analysis of Gubelin & Wiebel (1975)

* - As FeO

\+ - Cr2O3 in GT1-GT10 < 0.05 ; in GT11-GT15 < 0.03 ; in symplectite garnet < 0.10

greater importance is the effect of V Kβ on Cr Kα. In this situation a significant overlap occurs, to the extent where the Cr value determined is substantially overestimated. Chromium levels are therefore reported in terms only of a maximum concentration. Nevertheless the Cr_2O_3 values are significant in terms of its effect as a chromophore.

Neither section shows significant chemical zoning although there are differences in V_2O_3 and Al_2O_3 between the two sections. The V_2O_3 values increase in direct proportion to the decrease of Al_2O_3 confirming that the chromophore replace aluminium in the general grossular formula, $Ca_3Al_2(SiO_4)_3$.

High Grade Metamorphism

Upper amphibolite or granulite facies metamorphic conditions prevailed throughout Kenya during the period of vanadium grossular garnet formation (Cahen *et al.*, 1984). Around Baragoi in north Kenya granulite facies conditions were attained; two-pyroxene charnockites are sandwiched in the metasedimentary sequence which includes the graphitic gneisses (Dodson, 1963; Key, 1987). However, further south around Ol Doinyo Ng'iro the metamorphism remained in the upper amphibolite facies.

Pohl and Neidermayr (1978) suggested that in the Taita Taveta (Lualenyi) area, granulite facies assemblages are confined to a basal charnockitic igneous complex. This possibly represents an older basement to the metasediments affected by a subsequent lower grade (upper amphibolite facies) metamorphism when the vanadium grossular garnets were formed. Alternatively, Bagnall (1964) from his work in NE Tanzania, concluded that a single metamorphism affected the metasediments and associated igneous complexes and produced granulite facies assemblages in both. At Lualenyi the vanadium grossular garnet pods are enclosed by kelyphitic rims of epidote, scapolite, quartz, clinopyroxene and spinel. Pohl and Neidermayr (1978) concluded that the rims are late retrogressive products of the garnet cores. However, Sarbas *et al.*, (1984) showed that the scapolite-bearing rims formed during progressive metamorphism at higher grade (T>650°C, 3Kbars) than the enclosed garnet.

Fig. 4. Vanadium grossular garnet pod together with a cut stone in foregound. *(Photograph by E.A. Jobbins)*

Thin section examination of a typical garnet pod and its kelyphitic rim from Lualenyi identified a fine symplectite within the rimming scapolite (Figures 6 and 7). Subsequent microprobe analysis of the symplectite identified highly vanadiferous (10%-12% V_2O_3) grossular garnet in meionitic (only 2.29% Na_2O) scapolite (Table 3). The new microprobe data suggests that the reaction, V-grossular + quartz + CO_2 + Na^+ → Meionitic scapolite + V-enriched grossular, took place to produce the kelyphitic rim. The symplectite texture implies a stable co-existence (during synchronous growth) between the meionite and V-enriched grossular (Perchuk *et al.*, 1985).

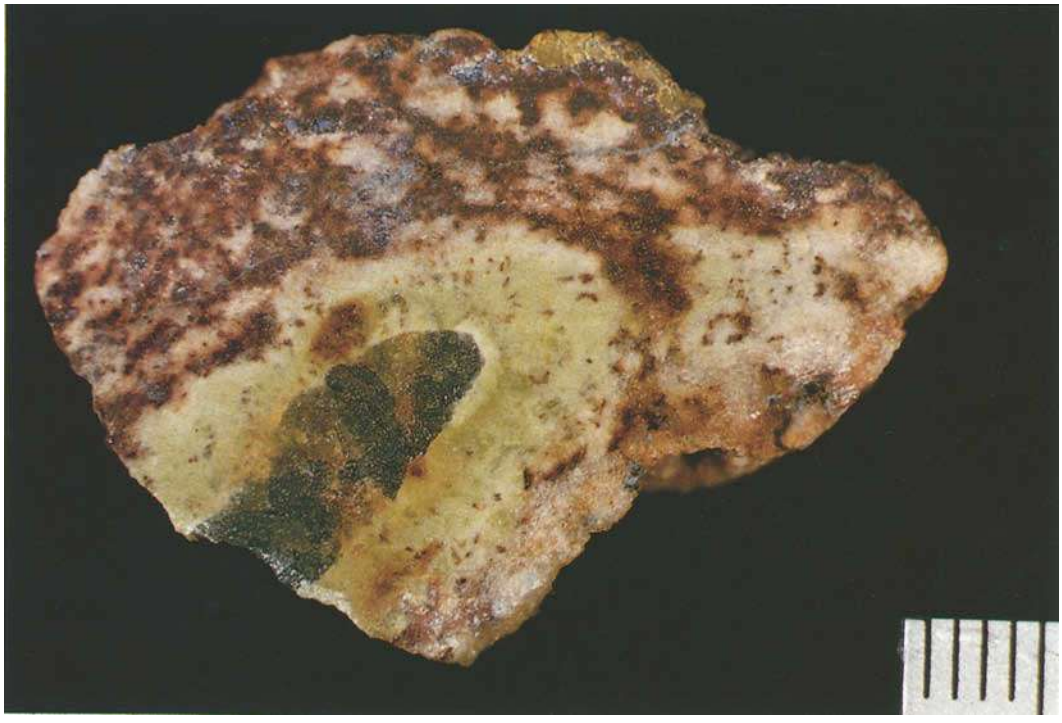

Fig. 5. The analysed garnet pod and its kelyphitic rim.

The assemblage grossular + quartz has been experimentally found to be stable under granulite facies conditions at over 750°C at 5 Kbars (Warren *et al.*, 1987) or 832°C at 7 Kbars (Perchuk *et al.*, 1985). Skmulovich (1979) as well as Gordon and Greenwood (1971) note that under these extreme conditions the assemblage is only stable at $XCO_2 < 0.20$ (XCO_2 is the mol. fraction of carbon dioxide in the fluid phase). Similarly, meionite is known (Oterdoom and Gunter, 1983; Goldsmith and Newton, 1977) to be the scapolite end member stable under granulite facies conditions; Baker *et al.*, (1987) suggest that its co-existence with grossular garnet indicates temperatures over 750°C at over 5 Kbars pressure. Therefore the kelyphitic rims appear to have formed under granulite facies conditions due to an increase in XCO_2 with sodium metasomatism. The ubiquitous marbles and calcareous lenses associated with the garnetiferous graphitic gneisses are an obvious source of both these components. Ferry (1983) showed that during high grade regional metamorphism of carbonates the progressive mineral reactions involved hydrolysis. This caused release of sodium (as NaCl) and CO_2 from the carbonates during reactions such as:

Calcic amphibole + calcite + quartz + H Cl → Diopside + sphene + NaCl + H_2O + CO_2 + $Ca\,Al_2\,Si_2O_8$.

Schreurs (1984) also concluded that CO_2 fluids become common under granulite facies conditions and Walsh (1960) suggested regional alkali metasomatism in SE Kenya at or after the thermal peak. An upper temperature limit to the granulite facies

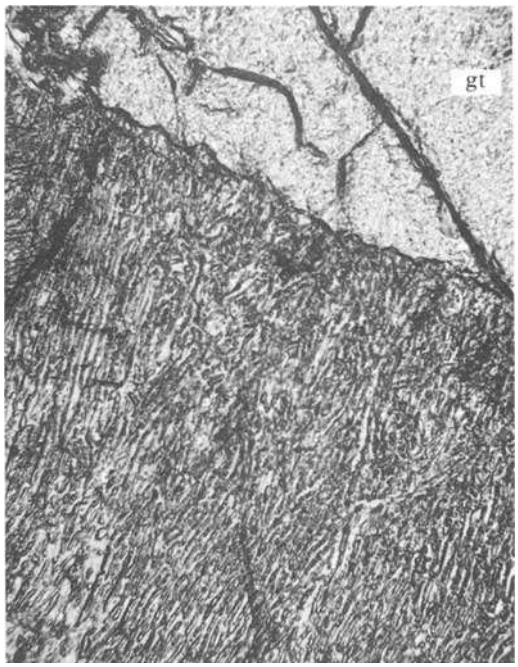

Fig. 6a 0 1 mm

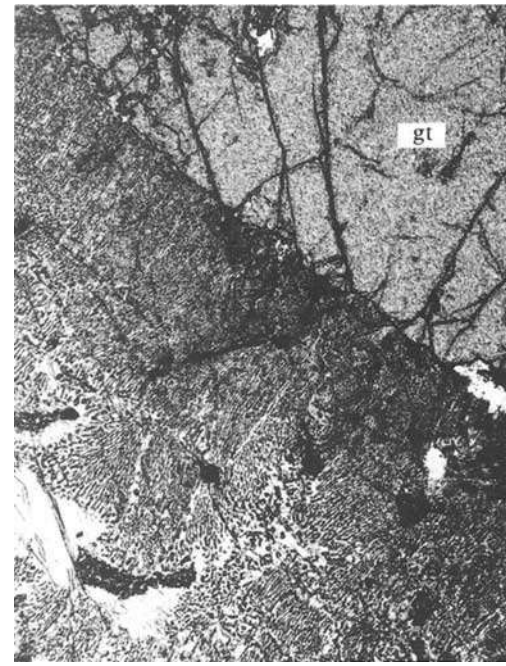

Fig. 6b 0 1 mm

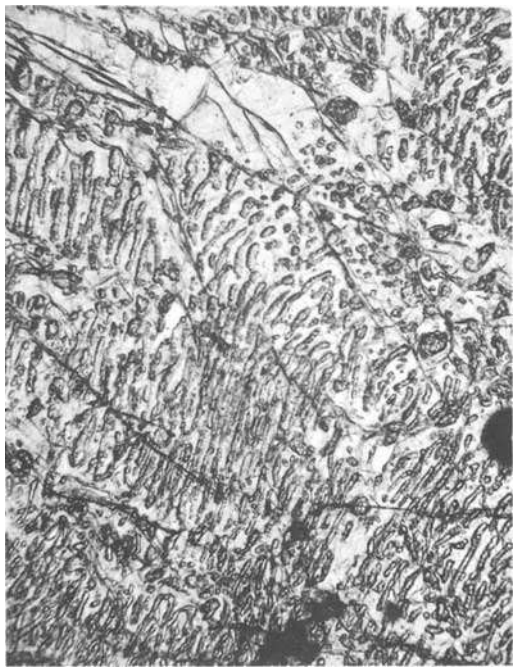

Fig. 7a 0.1 0.1 mm

Figs. 6 and 7. The symplectite texture in scapolite of the kelyphitic rim.

Fig. 6a. Grossular garnet (top right-hand corner) with kelyphitic rim. Plane Polarized Light (PPL) width of plate = 2mm.

Fig. 6b. Contact of garnet and its kelyphitic rim (PPL). Width of plate = 1mm.

Fig. 7a. Regular trails of V-enriched grossular garnet in rimming scapolite (PPL). Width of plate = 0.5mm.

Fig. 7b. Back-scatter electron microprobe image of scapolite (pale grey) with elongate V-enriched garnet trail (white) and isolated quartz (dark grey). Large scale bar = 10μm.

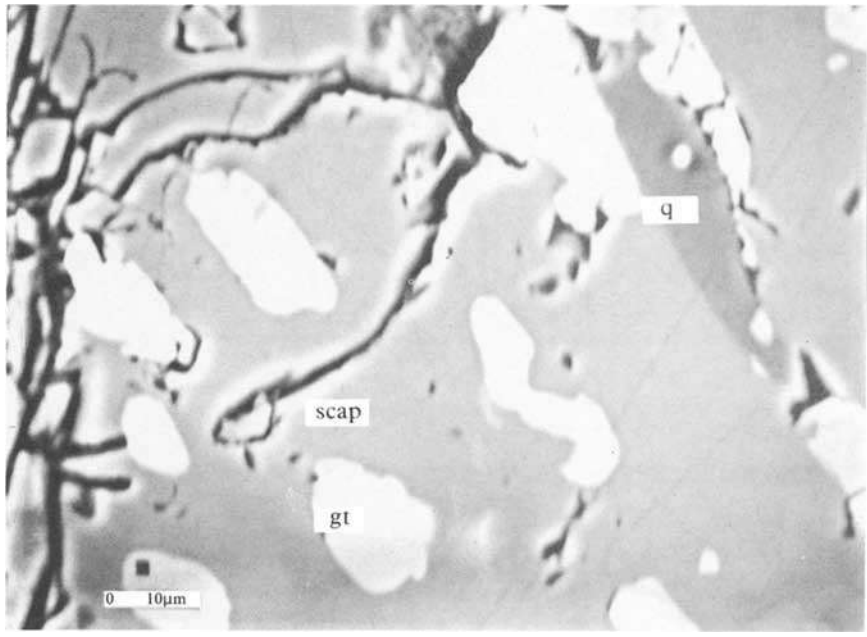

Fig. 7b

metamorphism in SE Kenya is provided by experimental data (Goldsmith and Newton, 1977) which shows meionite breaks down to anorthite and calcite at about 850-875°C over a wide range of pressures. Under similar conditions grossular and quartz break down to wollastonite and anorthite (Huckenholz *et al.*, 1981) although significantly Winkler (1967) notes that this reaction can be hindered by the formation of scapolite rims around grossular.

The new data indicates that the vanadium grossular garnets in SE Kenya formed under granulite facies conditions as did their kelyphitic rims. The marginal symplectites formed because of increased XCO_2 accompanied by a release of NaCl (from adjacent metacarbonates). This conclusion supports the view of Bagnall (1964) that in adjacent NE Tanzania the same period of metamorphism, which attained granulite facies conditions, affected both metasedimentary and igneous basement. The new data also agrees with the findings of Sarbas *et al.*, (1984) that the scapolite-bearing rims formed at higher metamorphic grade than the enclosed garnets.

Therefore, in Kenya at least, the vanadium grossular garnets appear to be restricted to graphitic gneisses affected by a granulite facies metamorphism.

Conclusions

An intimate association of graphitic gneisses and marbles, first recognized by Bridges (1974) is essential for the garnet's growth which may also be confined to granulite facies terranes. The physical and chemical conditions specified by Pohl and Neidermayr (1978) for vanadium grossular garnet growth in SE Kenya are indicated to occur throughout the Mozambique Orogenic Belt in Kenya. The host graphitic gneisses represent altered bituminous black shales and their extensive development indicates widespread Late Proterozoic organic seabed activity. Since granulite facies conditions are not confined to a basal igneous complex in SE Kenya, their occurrence has no significance in terms of basement-cover interpretations.

Acknowledgements

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Medium-dark blue aquamarines from Tongafeno, Madagascar, with high physical and optical properties, and showing three-phase inclusions

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Fig. 1. The seven faceted aquamarines from Tongafeno studied in this article.

Abstract

Aquamarines with high properties are known to occur (A.E. Farn[1], K. Nassau and D. L. Wood[2], J. Sinkankas[3]), and a detailed description of dark blue aquamarines from Zambia was recently published (H. Bank[4]). The aim of this article is to analyse the gemmological properties of aquamarines from Tongafeno, Madagascar, and to compare them with those with similar properties recorded from other localities.

Introduction

Recently, the author has had the opportunity to examine some rough crystals, and seven faceted aquamarines from Tongafeno, Madagascar (Figure 1), the measurements, weights and properties of which are described below.

Location and occurrence

Madagascar (1580 km long and 580 km wide) is one of the largest islands in the world (Figure 2).

Two major groups of rocks cover the island: ancient Precambrian basement rocks and younger sediments. The basement rocks which cover most of the area, consist mainly of gneisses and schists-quartzites. Numerous granite intrusions contributed pegmatite mineralization which is commonly complex and affords a large variety of minerals, including those suitable for gems and mineral specimens.

One of the most remarkable of all gem pegmatites in Madagascar was mined at Tsaramanga village, 3 km north of Mont Itongafeno, a peak 15 km south west of Antsirabe; this is the locality designated as 'Tongafeno' (Figure 3)[3].

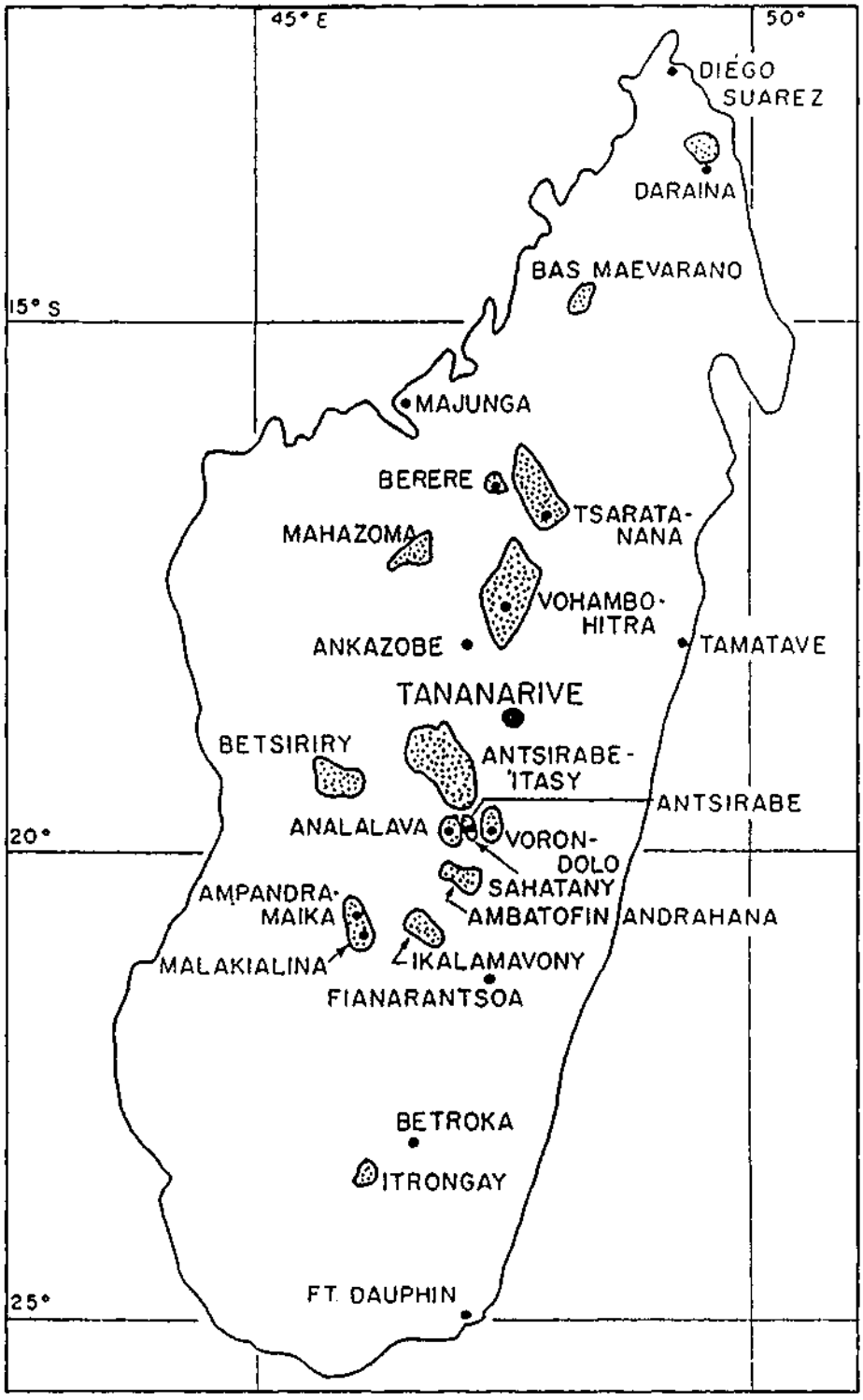

Fig. 2. Island of Madagascar, showing pegmatite deposits and the region of Antsirabe from where the aquamarines studied originate.

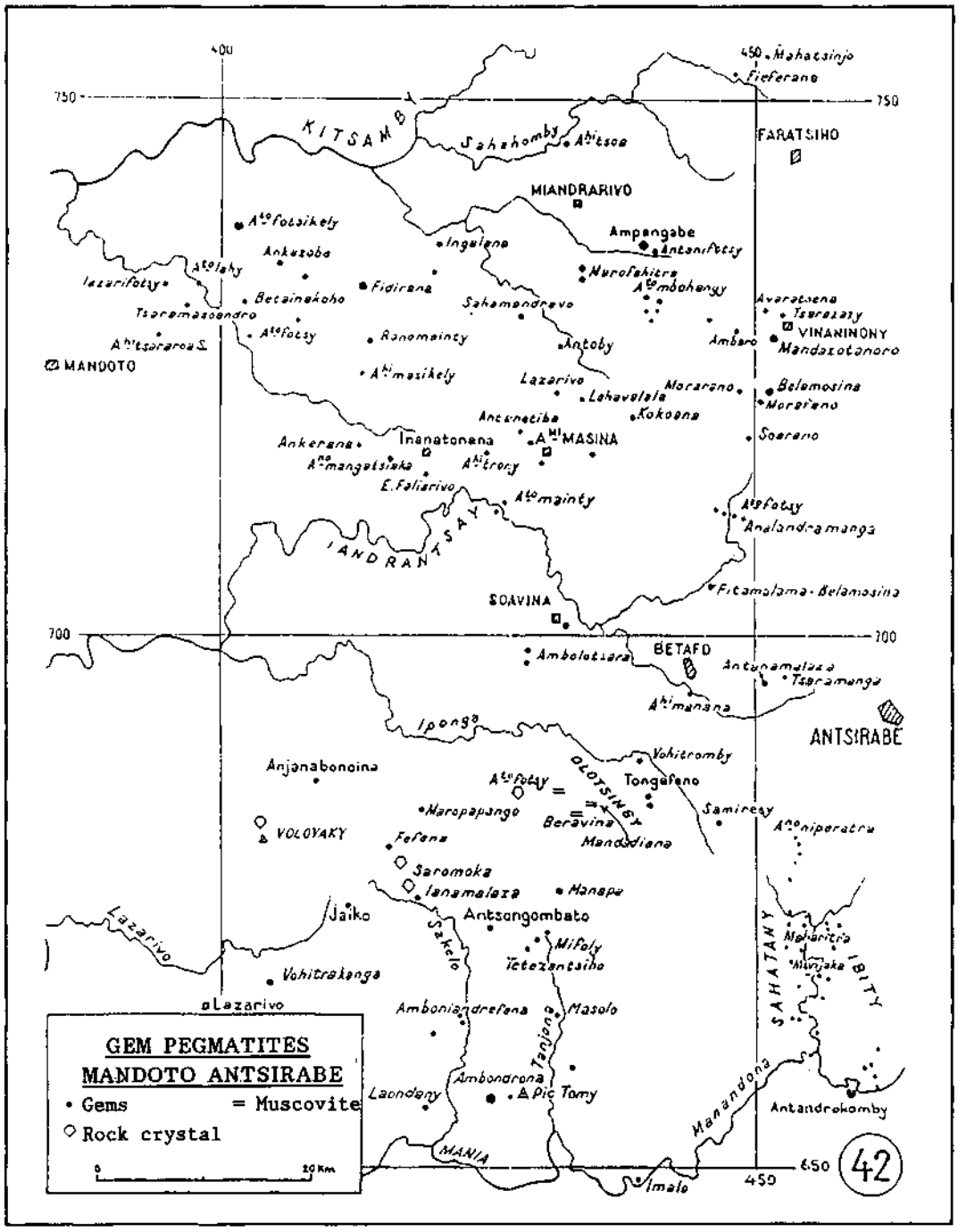

Fig. 3. Geographical location of the aquamarine deposit at Tongafeno.

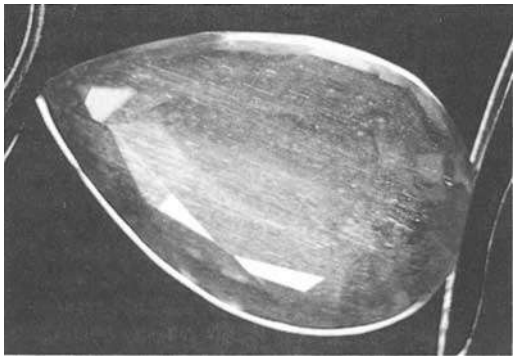

Fig. 4. Long, dense, canal-like needles running along the *c*-axis.

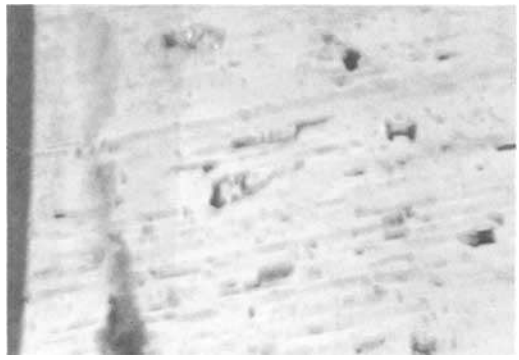

Fig. 5. A three-phase inclusion observed in an aquamarine from Tongafeno.

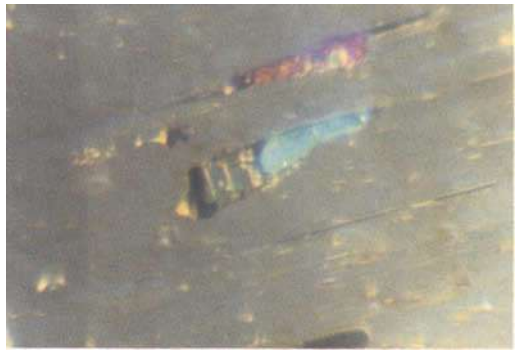

Fig. 6. The same inclusion as Figure 5 observed between crossed polaroids (half closed).

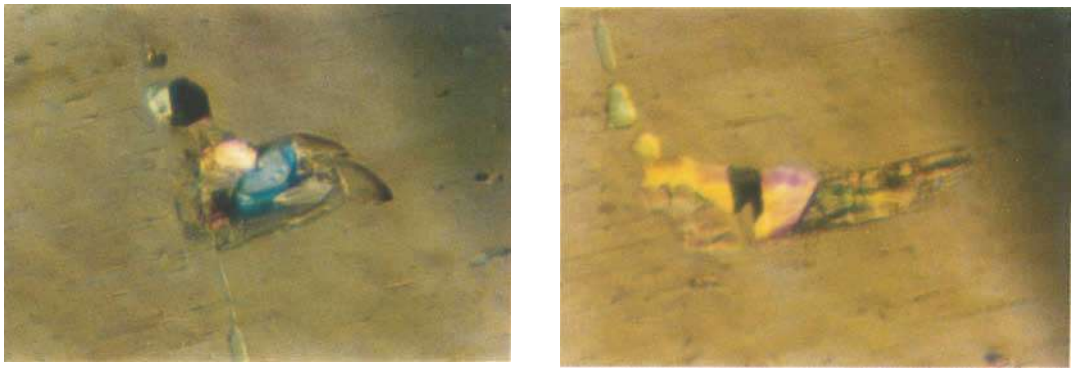

Fig. 7. Multi-phase inclusions observed in an aquamarine from Tongafeno between crossed polaroids (half closed).

TABLE 1. The physical properties of the seven faceted aquamarines and five rough crystals from Tongafeno, Madagascar

Cut or shape	Weight (carats)	Colour	Refractive index*	Double refraction	Specific gravity
Cabochon (flat base)	0.95	Medium blue	1.583-1.590	.007	2.730
Marquise	0.75	Medium-dark blue	1.582-1.590	.008	2.735
Cabochon (flat base)	0.42	Medium blue	1.582-1.590	.008	2.748
Brilliant	0.34	Medium-dark blue	1.583-1.590	.007	2.748
Pear-shaped	2.46	Medium-dark blue	1.583-1.590	.007	2.760
Baguette	1.50	Medium-dark blue	1.583-1.590	.007	2.766
Oval-shaped	0.77	Med.lt. bluish-green	1.582-1.590	.008	2.778
Rough crystals		Medium-dark blue	1.583-1.590	.007	No data
		Medium-dark blue	1.584-1.590[2]	.006	
		Medium-dark blue	1.586-1.592	.006	
		Medium-dark blue	1.590-1.596	.006	

*The superscript number at the end of the refractive index, indicates the number of times these indices were encountered.

Gemmological properties

Table 1 gives the gemmological properties of 7 medium-dark blue aquamarines and 5 rough crystals from Tongafeno which were examined for this study.

Visual appearance

The medium-dark blue aquamarines from Tongafeno show a very strong dichroism similar in strength to that of cordierite. The two colours observed under a calcite dichroscope were medium-dark blue for the ε ray, and colourless for the ω ray. All aquamarines that have their table facet cut parallel to the *c*-axis show a medium dark blue colour. One which is oval shaped, has its table facet cut perpendicular to the *c*-axis, shows medium light bluish-green.

Most of these aquamarines are traversed by long canal-like inclusions which are reminiscent of 'rain', and these found parallel to the *c*-axis give to those gems a sleepy aspect.

Except for these long canal-like inclusions, the aquamarines are clean to the eye, and transparent.

Refractive indices

The refractive index determinations were carried out using a Rayner Dialdex refractometer and monochromatic sodium light. Only the table facets were tested and the indices obtained from the seven stones are ω 1.590 ε 1.583 to 1.582, giving a birefringence of .007 to .008 with optic sign (–).

A minute fragment taken from five different rough aquamarine crystals revealed under the polarising microscope the following indices: ω 1.590 to 1.596 ε 1.583 to 1.590, giving a birefringence of .006 to .007, with optic sign (–).

These refractive indices are very high for aquamarine, but seem to correspond to the mean value of those recorded from Zambia, the Isle of Elba, and the Brazilian Maxixe-type beryl (Tables 1 and 2).

Specific gravity

The specific gravities were obtained by hydrostatic weighing of the stones in distilled water using a Mettler electronic PL 300c carat scale, and the seven Tongafeno aquamarines were found to have specific gravities between 2.730 and 2.778; much higher than those recorded for aquamarines from the major localities, but again similar to those from Zambia, and the Isle of Elba (Tables 1 and 2).

Reaction to ultraviolet light

The stones, examined with a Multispec combined LW/SW unit remained inert. In this respect

TABLE 2. Physical properties recorded from aquamarines from other localities

Gem locality	Weight (carats)	Colour	Refractive index*	Double refraction	Specific gravity
Zambia[4]		Dark blue	1.575-1.582	.007	No data
		Dark blue	1.575-1.584	.009	
		Dark blue	1.579-1.587	.008	
		Dark blue	1.581-1.590	.009	
		Dark blue	1.584-1.593	.009	
		Dark blue	1.586-1.596	.010	
Rough crystals†		Deep sky blue	1.574-1.582	.008	2.701
		Deep sky blue	1.580-1.586	.006	2.718
		Deep sky blue	1.581-1.587	.006	2.724
		Deep sky blue	1.582-1.587[2]	.005	2.730
Zimbabwe†	1.32	Light greenish-blue	1.573-1.580	.007	2.710
Nigeria†	0.82	Light blue	1.568-1.572	.004	2.698
Brazil†	17.35	Light blue	1.564-1.570[1]	.004	2.685
	5.39	Light blue	1.565-1.570[2]	.005	2.690
	8.15	Light blue	1.566-1.570[1]	.004	2.689
	6.49	Light blue	1.566-1.572[1]	.006	2.695
	6.49	Light blue	1.567-1.572[1]	.005	2.690
	9.34	Light blue	1.568-1572[10]	.004	2.688
	11.80	Light blue	1.568-1.573[3]	.005	2.690
	11.11	Light blue	1.569-1.574[5]	.005	2.691
	13.06	Light blue	1.570-1.574[4]	.004	2.692
	9.01	Light blue	1.570-1.576[3]	.006	2.692
	0.80	Light blue	1.571-1.578[1]	.007	2.703
Maxixe-type[3]		Dark blue	1.584-1.592	.008	2.805
Isle of Elba[3]		Sky blue	1.585-1.591	.006	2.763
Pakistan[3]		Ink blue	1.599-1.607	.008	No data

* The superscript numbers at the end of the refractive index, indicates the number of times these indices were encountered out of 5 rough crystals from Zambia, and 32 faceted aquamarines from Brazil.
† Physical properties recorded by the author.

the aquamarines from Tongafeno, like aquamarines from other localities show no reaction to ultraviolet light.

Spectroscopic analysis

The absorption spectra seen through a Gem Beck Spectroscope Unit, showed a strong absorption 400-410 nm, a set of three lines centred at 430, 620, 630 nm, and then another strong absorption 640-700 nm.

Microscopy

The inclusions were examined under a Bausch & Lomb Mark V Gemolite binocular microscope using dark field illumination or overhead lighting, depending on whether internal or external features were to be examined.

The most characteristic inclusion, and nearly always present, consisted in different lengths of dense canal-like needles oriented parallel to the *c*-axis (Figure 4), and giving a 'rain-like' effect. Sometimes, many isolated black pinpoints (crystallites) were observed. Two-phase inclusions in the form of a squarish shape were also present, and in one stone a three-phase inclusion has been noticed accompanied by other more complex three-phase and multiple-phase inclusions consisting of gas, liquid, and many solid inclusions (Figures 5 & 6).

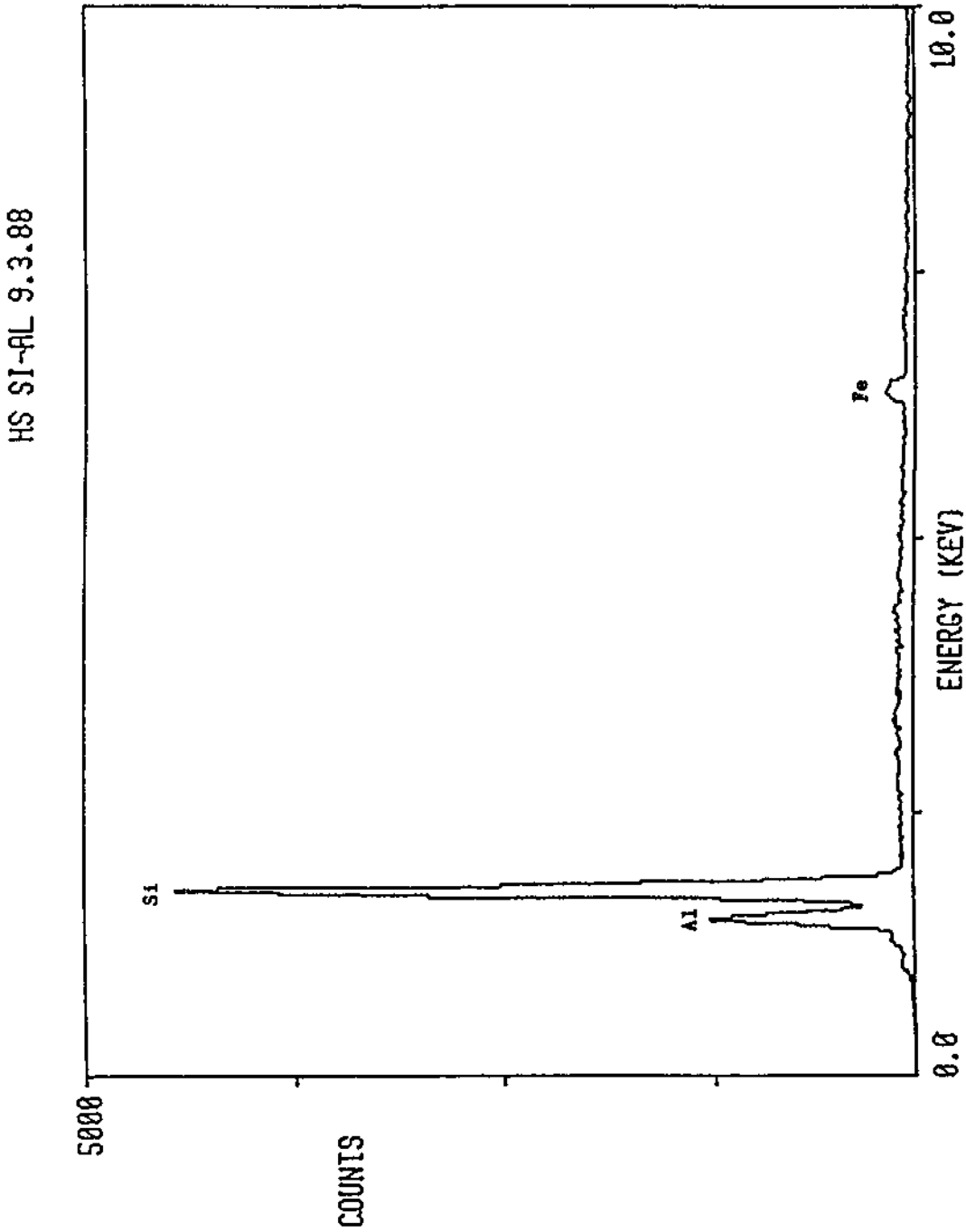

Fig. 8. Energy-dispersive qualitative spectra of the aquamarines from Tongafeno.

The complex three-phase inclusions have been observed on a horizontal Eickhorst Gemmoscope while the stone was immersed in benzyl benzoate.

Notice how the solid inclusions react while the stone is between crossed polaroids, by giving different polarising colours due to their crystallographic orientations. These inclusions were proved anisotropic, but unfortunately could not be determined (Figure 7).

Chemical analysis

Chemical analysis for the Tongafeno aquamarines were obtained through qualitative analysis by dispersion energy, which revealed the presence of aluminium, silica and iron (Figure 8).

It is interesting to note that the small amount of iron present in these aquamarines is probably responsible for the medium-dark blue colour, but of more gemmological value, of the distinct absorption line centred at 430 nm observed under the Gem Beck spectroscope unit.

Summary and conclusion

The aquamarines from Tongafeno due to their characteristic dichroism, inclusions, absorption spectrum, and high physical properties are remarkable and readily differentiated from those from other localities. However, as the colour of these stones is due to the presence of iron, as in all true aquamarines, it seems appropriate to give these the variety name 'aquamarine', despite the fact that they are not sky-blue, or sea-green, or pale green with decided tinges of blue.

In the case of the Maxixe-type beryls, such a name should not apply, since the colour is probably due to activation of a colour centre through irradiation, or a defect in the structure, but not to the iron present in a too small amount to be responsible for the colour[5].

There is also an inversion of the colour absorption. While in all 'true aquamarines' the colour is vehicled by the ε ray, in the Maxixe-type beryls the colour is vehicled by the ω ray.

Last but not least, the colour of the Maxixe-type beryls is not stable and fades in light. For all these reasons, such varieties should be called either Maxixe-type beryls, or blue beryls, rather than aquamarines.

A similar situation occurs when distinguishing between emeralds and green beryls. In this case the identification is based on the presence of chromium lines in the absorption spectrum. If these lines are present, then it is an emerald, and on the contrary, it must be a green beryl.

Acknowledgements

The author would like to thank Ms M. Ruegg, Mr A. Van der Schueren, Mr W. Meili and Professor H. Bank for producing the rough and faceted aquamarines described in this article; Dr H. Sarp for carrying out the chemical analysis. The author is also grateful to the Ministère de l'Industrie de l'Energie & des Mines de Madagascar for producing the map of the gem pegmatites of the Mandoto Antsirabe region.

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A fourteenth century crown

Amanda Gray, FGA

London

Fig. 1. The 'English Crown' displayed at the Schatzkammer of the Residence Museum, Munich. *Photo by permission of Bayerische Verwaltung der Staatlichen Schlösser, Gärten und Seen.*

One of the highlights of the spectacular Age of Chivalry Exhibition at the Royal Academy, London, was the beautiful fourteenth century 'English Crown'. This has not returned to England since it left in 1401, as part of the dowry that Blanche, the daughter of Henry IV, took with her on her marriage to Ludwig III of Bavaria. This is how it came into the possession of the Wittelsbach family, and it is now displayed in the newly refurbished Schatzkammer of the Residence Museum, in Munich, West Germany. Gemmologically the stones are of no great merit; however the combination of colours in their layout is aesthetically very pleasing. From a historical standpoint the crown is of great interest.

On examining crowns over the ages they appear to fall into three distinct categories. The single circlet, the two tier type and the ones which had closed-in tops. This crown falls into the second category, and, despite its fragile appearance it is in very good condition. The lower section of the crown consists of 12 rosettes which support 12 golden lilies of alternating heights. The lower rosettes are made up of a circular gold ring base within which is an enamelled hexagon which contains some fine gold tracery work. At the centre of each is a sapphire. These are of a pale blue colour and are mostly oval cabochon bead-shape. Some have been drilled through the centre, implying re-use of the stones.

They are held in position by gold claws. One of the stones is a flat hexagonal shape and appears to be a sliver from a trigonal corundum crystal. The colour of the enamel alternates between translucent red and blue and is overlaid with small white flowers made up of dots of opaque enamel. Each point of the hexagon is set with either a pale ruby cabochon stone, of almost pebble-like appearance, or a cluster of four drilled pearls with a tiny diamond octahedron in a rub-over mount in the centre. The red enamelled hexagons have rubies at the tops, and the blue ones have the pearl clusters. The interplay of the blue, red, pearls and gold is extremely effective and is repeated in the layout on the upper part of the crown. The taller lilies have three carved gold trefoil leaves with beaded edges at the top, with a cabochon ruby in their centre surrounded by four cabochon sapphires. At the very tip of the highest leaf there is a three-pearl cluster with a tiny diamond crystal in its centre, and another four-pearl and octahedron diamond cluster on the stem of the lily with a further sapphire and ruby below it. There are two pairs of small carved gold leaves, also in a trefoil design, sprouting from the sides of the stem. A single pearl protrudes from the lower points of the large leaves. The pearls are in good condition; apparently some restoration work was carried out in 1925, so it is possible some were replaced then. Their creamy colour stands out well against the gold. The smaller lilies have a sapphire in the centre of four rubies and either a ruby or an emerald with a single pearl on the stem. In contrast to the four pearl and diamond clusters which the larger lilies have at the tips of the upper leaves, these smaller lilies have a single pearl which is suspended on a gold wire from the upper leaf.

An interesting feature of the crown is the fact that it is possible to fold it for travelling purposes and it has its own fitted case. Between the rosettes are exquisitely decorated blue enamel plaques with delicate gold tracery overlay – these are the sections where the crown folds. They are even enamelled on the reverse with a small flower. Each rosette is also numbered 1 – 12 so that each lily can be fitted into the correct position.

There has been much speculation as to when the crown was made and for whom. In the late fourteenth century many of the portraits of the Virgin Mary depicted her wearing a crown of this style, e.g. Gerard David's 'Virgin' in the National Gallery. This style is also seen on other queens of the period as well as Blanche. As mentioned above, it came to Bavaria when Blanche married Ludwig III in 1401. Henry IV had spent six months arranging this marriage which he felt would be a politically beneficial alliance between England and Germany. However, as Blanche died in 1409 this was rather short lived.

Prior to the crown leaving England in 1401, it had been in the possession of Henry IV and is mentioned in 1399 in an inventory of jewels, gold and silver plate, which was to be transferred from the Treasury to the King's personal chamber. This collection had previously belonged to Edward III, Richard II and his Queen Anne, the Duchess of York, the Duke of Gloucester and Sir John Golafre (who was a Knight of the Chamber). This inventory does not give any precise indication of the crown's previous ownership and it is not possible to be certain that it belonged to any of these people. However, several of the 339 items listed belonged to Anne of Bohemia and it is possible that she brought it with her when she married Richard II in 1382.

It is very difficult to trace the work of goldsmiths of this period. Kings and nobles often employed their own craftsmen in their courts. Two of the techniques used on the crown suggest a French origin. Firstly, the enamelling is typical of the work carried out in France in the latter part of the fourteenth century, and secondly the gold beading on the leaves is similar to some examples found on rings in the hoard of jewellery which had been deposited in 1349, at Colmar in France. However, if the crown was made in Bohemia for Anne, it could have been made in Prague by French trained craftsmen; alternatively it may have been made for her in Paris. However, there are fourteenth century examples of similar enamelling and gold beading on English pieces (for example on the Oxwich brooch displayed at the same exhibition), and therefore this evidence is by no means diagnostic, and the origin of this interesting crown therefore remains obscure. Our interest is sufficiently held in appreciating the design and interplay of colours, and in speculating who has worn the crown through the ages!

[*Manuscript received 28 October 1988.*]

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The four optical attributes of a diamond

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Abstract

The four separable optical attributes of a diamond, lustre, brilliance, fire and sparkliness are treated in terms of physical optics. Other gemmological matters of interest which are derivative of these properties are discussed in some detail. These are (1) the possible improvements in 'liveliness' by adopting an odd-number symmetry cut, (2) the Brewster angle refractometer, (3) the effects of adventitious matter adhering to pavilion facets and (4) the possible benefits and disadvantages of depositing pure aluminium films on the pavilion facets. A brief description is given of two instrumental arrangements for demonstrating all the effects discussed. The article concludes with a plea for the standardization of descriptive English terms for brilliant cut diamonds.

If an inclusion-free diamond has been smoothly polished with its 58 facets placed at angles characteristic of the modern round brilliant-cut style, it can then exhibit its four most prized optical attributes. These are lustre, brilliance, fire and sparkliness. There is a fifth, which, apart from coloured diamond fancies, most prizes those stones which show the closest approach to a colourless body colour.

Lustre

This is the amount of white light specularly reflected from the individual surfaces of the table and crown facets alone, relative to the amount of white illuminating light falling directly on these surfaces. This measure is termed reflectance. It varies in a complex manner with the angle of incidence (i) of the illuminating ray. When i = o°, its value is given by the equation:–

$$R = \frac{I}{I_o} = \frac{(n-1)^2}{(n+1)^2}$$

where R is the ratio between the intensity of the light reflected (I) from a flat perfectly polished surface, to that of the incident light intensity (I_o). The refractive index is (n). The ratio R is usually expressed as a percentage, i.e. 100 R. The angle of reflection is always identical to the angle of incidence. If the n value for diamond is inserted in this equation, the value for R is found to be 0.172 (or 17.2%) when i = o°. For comparison, quartz has an R value of 0.046 (or 4.6%) when i = o°. When i = 90° the value of R for the polished surfaces of *all* substances becomes unity (or 100%).

Brilliance

This is a measure of the relative amount of light, which on entering the stone, can be twice totally reflected from the pavilion facets back to the observer only by way of the table or crown facets. Only white, or near-white (weakly-dispersed) light is being considered here.

If the number of the total reflections possible is reduced then there will of course be an increased loss of brilliance through forwards light leakage (as with a 'fisheye' cut) or from sideways leakage (as with a 'lumpy' cut). These rays cannot reach the eyes of the viewer.

Fire

This is a spectral effect produced by the complex prismatic nature of the diamond's flat facets. The size of the effect depends on the particular geometry of the table and crown facets and on their relative areas. A white light ray, on entering the stone by way of the table or crown facets, can, if its direction is appropriate, be totally reflected and this reflected white ray be split up into its constituent spectral colours. These rays emerge from the table and crown surfaces as flashes of fully-saturated (i.e. spectral) colours. The effect was first named 'fire' by Tolkowsky[2].

The effect, of course, depends mainly on the total number of those refracted rays capable of being totally reflected by the pavilion's facets and subsequently being spectrally dispersed by the table and crown facets.

The magnitude of the effect also depends on the high dispersion of the refractive indices of diamond, which for the region lying between the Solar spectrum lines B (wavelength = 687 nm) and G (wavelength = 431 nm) has the value 0.044.

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The most popular diamond substitutes or simulants have been those whose B-G dispersions are not too far removed from diamond's 0.044. The most acceptable of the natural stones, colourless zircon, has the value of 0.038. Among the colourless synthetic stones which have been sold as simulants are YAG (0.028), GGG (0.045) and CZ (0.061), the last-named of which is now by far the most used. Other colourless or near-colourless synthetic stones such as strontium titanate (0.200) and rutile (0.300) have also been marketed, but their very high dispersions produce such intense and spectacular 'fires' that they are held to be unappealing or even garish to the informed eyes.

Should it become possible to produce large colourless monocrystals of the beta-modification of silicon carbide (SiC) by a relatively inexpensive process, this material would probably displace CZ as the most favoured simulant. It possesses a cubic structure, a very high Mohs's hardness (9½), a large n (about 2.65; therefore the high lustre of R = 20.4% at i = 0°) and a not too excessive fire-producing dispersion (0.110).

Sparkliness

This twinkling effect requires movement and is mainly proportional to the number of crown facets present. These facets produce only *colourless* surface reflections. The crown facet movements, which can be quite small in angular terms, bombard the observer with myriads of tiny flashes or scintillations of intense white light. The greater the size of a facet, the greater will be the perceived intensity of a reflection. There can be also another contribution to sparkliness. This originates from the smaller number of colourless, or near colourless, rays which can emerge from the table and crown facets through the agency of internal total reflections from the pavilion facets.

Unlike the previous three effects, the observation of sparkliness requires movement. The three possible movements can be either those of the illumination, or of the diamond, or of the observer or wearer.

For the illumination to be really effective, it must be derived from one or more high intensity, condensed-filament lamps. The use of long tube-like fluorescent or opal incandescent lamps seriously dampens the effect.

The diamond alone or in its setting may be moved by being displayed on a revolving table, or by the wearer of the diamond jewellery or by the now unfashionable use of 'tremblers' in jewellery design.

In the absence of movement of the light source(s) or of the diamond, it is only by the movement of the observer or wearer that the effect can be seen. Again, unlike the three other optical attributes, sparkliness cannot be captured on a still photograph of a stone.

Stone design options

It is clear that as the ratio of table 'spread' to total 'spread' is changed, so also will the relative proportions of brilliance, fire, sparkliness, and even lustre. A larger table means a more brilliant appearance. A smaller table produces greater fire. A trade-off is usually necessary to satisfy the prevailing fashion. At present, the trend seems to be towards whiter sparkles.

There are no set rules for cutting diamond rough to obtain the highest commercial yields. Each stone presents a compromise between the conflicting aims of size and beauty, with beauty often trailing as second best. If beauty is the first choice, then certain design principles have been established by practical experience over many centuries to produce the most pleasing optical effects[1]. Pavilion angles should be very close to 41° with crown angles close to 34°, with impeccable polish, flatness and eight-fold symmetry. Very small ('ticked') culets help to avoid breakage and increase brilliance.

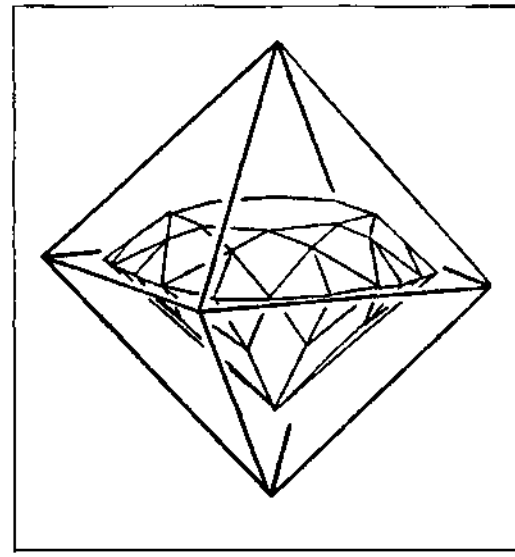

Fig. 1. Location of an 'ideal' round brilliant stone within an octahedral crystal, and cut to yield the largest possible girdle size.

Starting from an octahedral crystal such as shown in Figure 1, the cutting of an ideally-shaped diamond having a maximum girdle diameter would probably not give the best yield, particularly if an inclusion was badly located.

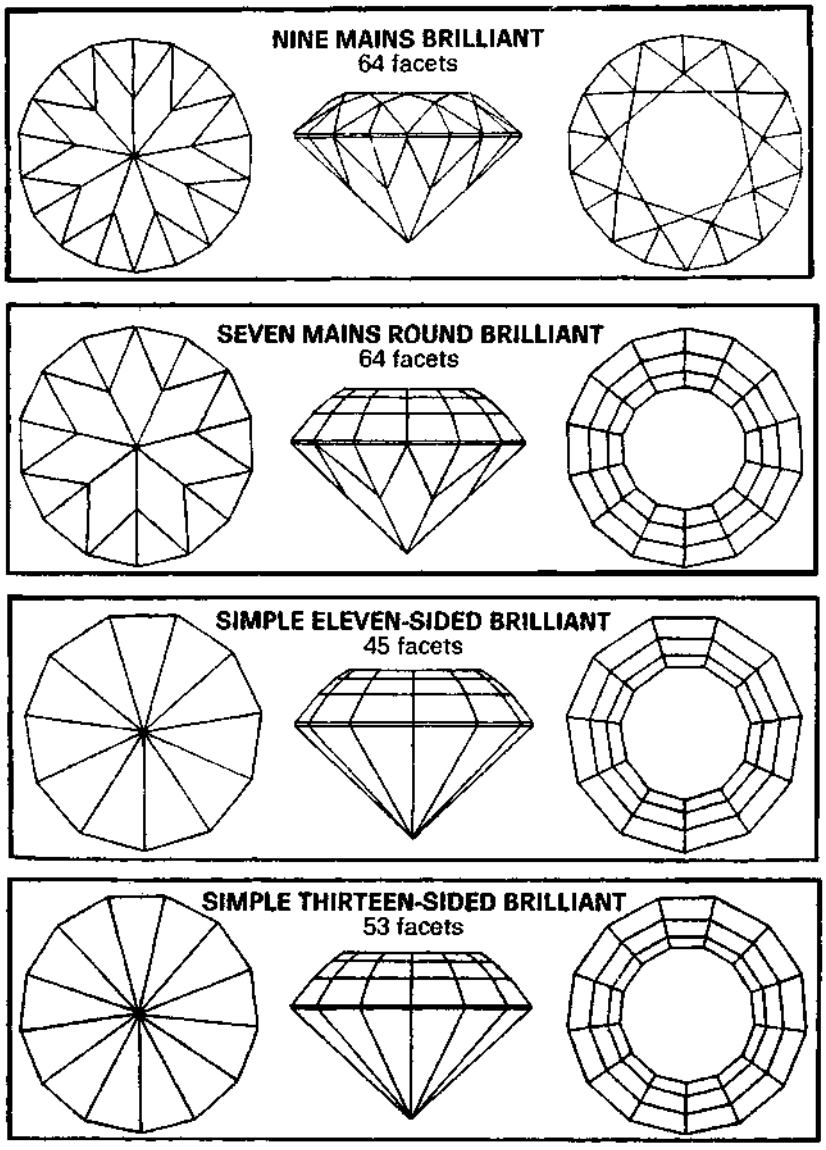

Fig. 2. Examples of round gemstones having mains facets with odd-numbered symmetries.

The physical optics of a round, brilliant-cut diamond

Much effort has been expended over recent years in trying to determine by calculation alone if it is possible to improve on the current generally favoured cutting angles and shapes of the round brilliant style[2-12]. The computer calculations have been concerned mainly with the two-dimensional angular relations of geometrical optics although there have been two attempts to introduce three-dimensional ray-paths and also involving light intensities[8-11]. One of these[11] however, only treats the situation where a wide, parallel light beam is directed to the diamond 'model' at i = o°.

The many simplifications needed to restrict the large numbers of parameters required for realistic computer predictions of 'optical goodness' have meant that the results have been of limited practical use to stone cutters.

It is clear that for some time yet, judgments of

the 'optical goodness' or perhaps 'beauty or attractiveness' criteria will have to rely on subjective assessments of new stone designs by panels of experts in the trade. Indeed, it is highly probable that it will be the coloured gemstone faceters and diamond cutters producing actual exploratory cuts, rather than the computer scientists, who will discover real improvements in stone design.

Claims were made recently by two gifted professional faceters that if the eight-fold symmetry of the brilliant cut were changed to certain odd-number symmetries such as 7-fold or 9-fold, then this would result in a 'better return of brilliance' than the standard cut[13]. Crown and pavilion facets would, as usual, lie in common meridians.

To test this view, a faceter, W. Carss, cut a suite of stones having 16 different axial symmetries, ranging from 5-fold to 20-fold in 1-fold steps. The stones were of clear, colourless, synthetic quartz, each cut to a girdle diameter of 12 mm in the round brilliant style, but with stepped crowns. See Figure 2. The suite of stones was displayed to an audience of experienced faceters who were participating in a faceting symposium. Each member was asked to look at the gemstones carefully and decide which one each liked best. The largest number of viewers chose the 11-fold stone; the next largest chose the 13-fold stone[14]. Somewhat unexpectedly, no one had chosen any of the even-numbered symmetry stones.

It is clear that a design demonstrated in quartz would not necessarily be a useful guide for diamond. Even if it were so, the diamond trade would raise the strongest objections to such a radical change. It would be argued that an odd-symmetry cut, whilst not a serious production problem, would have to compete with immense quantities of existing octagonal-cut jewellery; matching lost stones with those of different geometries would not be possible.

Nevertheless, the novelty or rarity of cut, purely by itself, might find a welcome niche within the traditional market.

The general interaction of light beams with transparent media

In spite of the poor performance of computer ray-path tracing leading to 'optical goodness' assessments, it is perhaps helpful to gemmology students, lapidaries and others to know a little of the basic physical optics of faceted gemstones, and of diamond in particular.

Figure 3a is a schematic illustration of the interaction of a single monochromatic light ray falling at a point 0 on a flat, polished block of any isotropic, colourless, transparent material. The symbols E, N, R, D, s and p represent directions only. They are the symbols used internationally* following the fundamental optical studies of the German physicist, Paul Drude[15].

The angle EON is the angle of incidence (i) and is equal to NOR, the angle of reflection. The important plane, known as *the plane of incidence*, is that containing the incident ray E, the surface normal, N and the reflected ray R. This plane also contains D, the direction of the refracted ray (r) which has entered the block of material.

The relationship between the value of i, the value of r and the value of the refractive index n, of the material of the block is given by:

$$\frac{\sin i}{\sin r} = n$$

It is known as Snell's law.

Figure 3b shows the angular relationships of the various rays in the plane of incidence when the refractive index of the material is taken as n = 1.5, the approximate value for ordinary glass. The value of r = 3°20′ is that found from Snell's law when i is taken as i = 5°00′, an angle near normal incidence. Similarly, the value of r = 41°37′ is found when i = 85°00′, an angle near grazing incidence.

The middle diagram shows a special situation when the sum of i and r attains 90°. The value of i for the n = 1.5 glass at this particular angle is known as the Brewster angle and is given the special symbol ($\bar{i}$). Here $\bar{i}$ = 56°19′ and $\bar{r}$ = 33°41′ where ($\bar{i} + \bar{r}$) = 90°00′.

So much for the angular relationships. It is now necessary to examine the intensity variations.

Returning to Figure 3a it is seen that there are two directional symbols, (p) and (s) which have not yet been discussed.

The incident ray EO is assumed to be unpolarised. That is to say the transverse vibrations (of the electromagnetic theory of light) in the incident light ray have completely random directions. On being reflected at 0, these transverse vibrations become no longer random, but are partially resolved into two components. One of these is the p-component whose vibrations lie in the plane of incidence. The other is the s-component whose vibrations marked s-s, lie perpendicularly to the plane of incidence.

*E = Einfallswinkel, meaning 'angle of incidence'.
N = Normal, meaning 'perpendicular to surface'.
R = Reflexionswinkel, meaning 'angle of reflection'.
D = Durchfallen, meaning 'transmitted'.
s = Senkrecht, meaning 'perpendicular to a plane'.
p = Parallel, meaning 'in the same plane'.

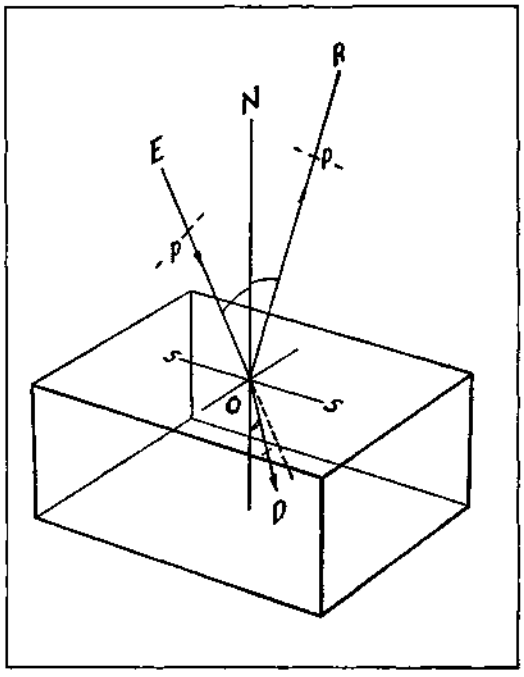

Fig. 3a. Illustration of the paths taken by a single monochromatic light ray after striking a flat polished block of a transparent, colourless, isotropic material such as glass. The meaning of the symbols are given in the text.

Thanks to the work of Drude[15], the physical reasons for this behaviour have been elegantly explained in terms of the Clerk-Maxwell electromagnetic wave theory of light. Unfortunately, a simple explanation in terms of a model or analogue is hard to find. It must be sufficient, therefore, to present Drude's calculations of the light reflectances and transmittances of the two vibrational components in graphical form.

External reflections. The case of the externally reflected light, associated with lustre, will be described first. In Figure 4, for a polished diamond surface the percent reflectance, R, is plotted on the vertical axis and the angle of incidence i plotted on the horizontal axis.

The reflectance of the s-component (R_s) is seen to increase slowly at small values of i, but increases rapidly until at i = 90° (with EO lying parallel to the block's surface) R becomes equal to unity (R = 100%). This means that the block reflects all the light falling upon it at this angle, but of course in actual viewing conditions, this situation will seldom be realized.

The maximum viewing angle could probably be reached when i = 60°. This corresponds with an R value of 40%, compared with 18% at i = 10°, which is probably the minimum viewing angle.

The reflectance of the p-component (R_p), behaves quite differently. It decreases slowly for small values of i until it becomes zero at a particular value called the principal angle of incidence, designated $\bar{i}$, or Brewster angle. It is related to the refractive index n by the designated expression tan $\bar{i}$ = n. This situation, when (i + r) = 90°, is illustrated for the case of a glass of n = 1.5 in the middle diagram of Figure 3b and in Figure 5 for the case of diamond.

Referring to Figure 4, it can be seen that when i is increased beyond the Brewster angle of $\bar{i}$ = 67.54°, R increases very rapidly, until at i = 90°, R again becomes 100%.

Drude showed that the s-component of the reflected ray is only partially polarized at all i values. Some polarization of the reflected p-component ray occurs at all values of i, except at the Brewster angle, when it becomes completely polarized. The vibration direction of this completely polarized p-component ray at $\bar{i}$ = 67.54° lies perpendicularly to the plane of the page of Figure 5 and is indicated by the four dots on the reflected ray.

It is now clear that the nature of the R_s curve alone is responsible for the dramatic increase in lustre when i is increased, because it is only weakly polarized. If R_s and R_p were completely polarized at all values of i, then the mean of the two curves would be that observed by the eye, which of course cannot see polarized light directly. The calculated mean curve is that shown by the dashed line in

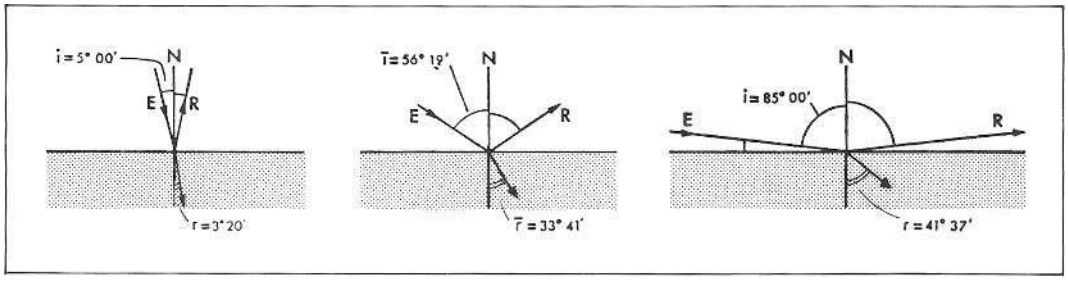

Fig. 3b. Illustrations of various ray paths in the plane of incidence, when the refractive index is taken as 1.5, the approximate value for ordinary glass. See text for explanations.

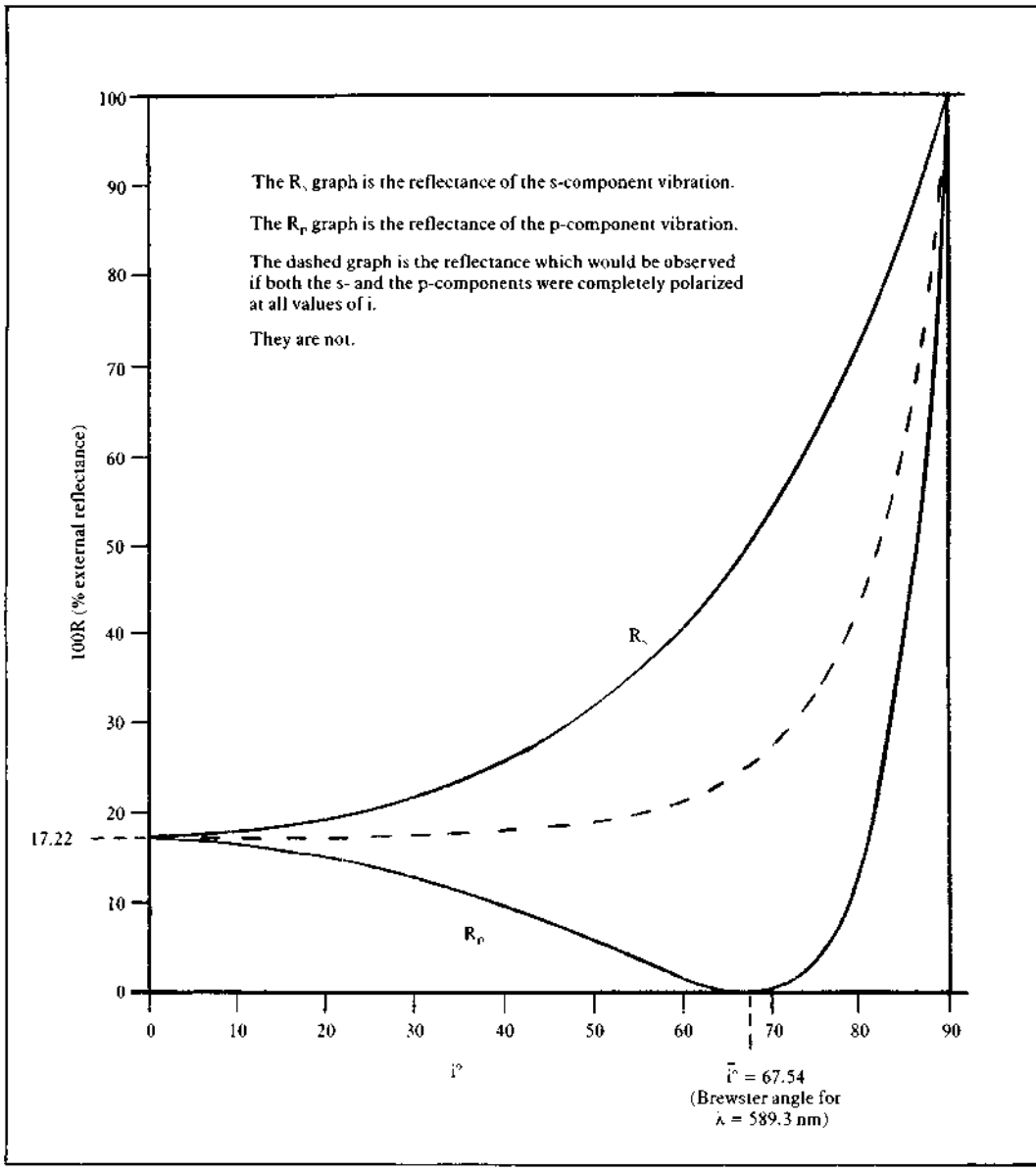

Fig. 4. Variation of the external reflectance, R, with the angle of incidence, i, from the surface of a polished diamond.

Figure 4. This indicates that there would be an almost imperceptible change in lustre for i values up to the practical limit of i = 60°. This does not happen.

Brewster angle refractometer

The relationship $n = \tan \bar{i}$, is the basis of a proposed Brewster angle refractometer[16,17,18]. The particular value of such a device is that it requires no optical coupling liquid, so that it can cope with stones whose n values are higher than the n = 1.81 limit of conventional refractometers. Another virtue is that it is relatively insensitive to scratches and imperfections on the table's surface, a problem which bedevils all infra-red reflectometer measurements. It would be especially useful in checking diamond and coloured stone simulants.

The main obstacle to its accurate performance is the intrinsic difficulty in determining when R_p reaches its critical zero value at i. This null point is

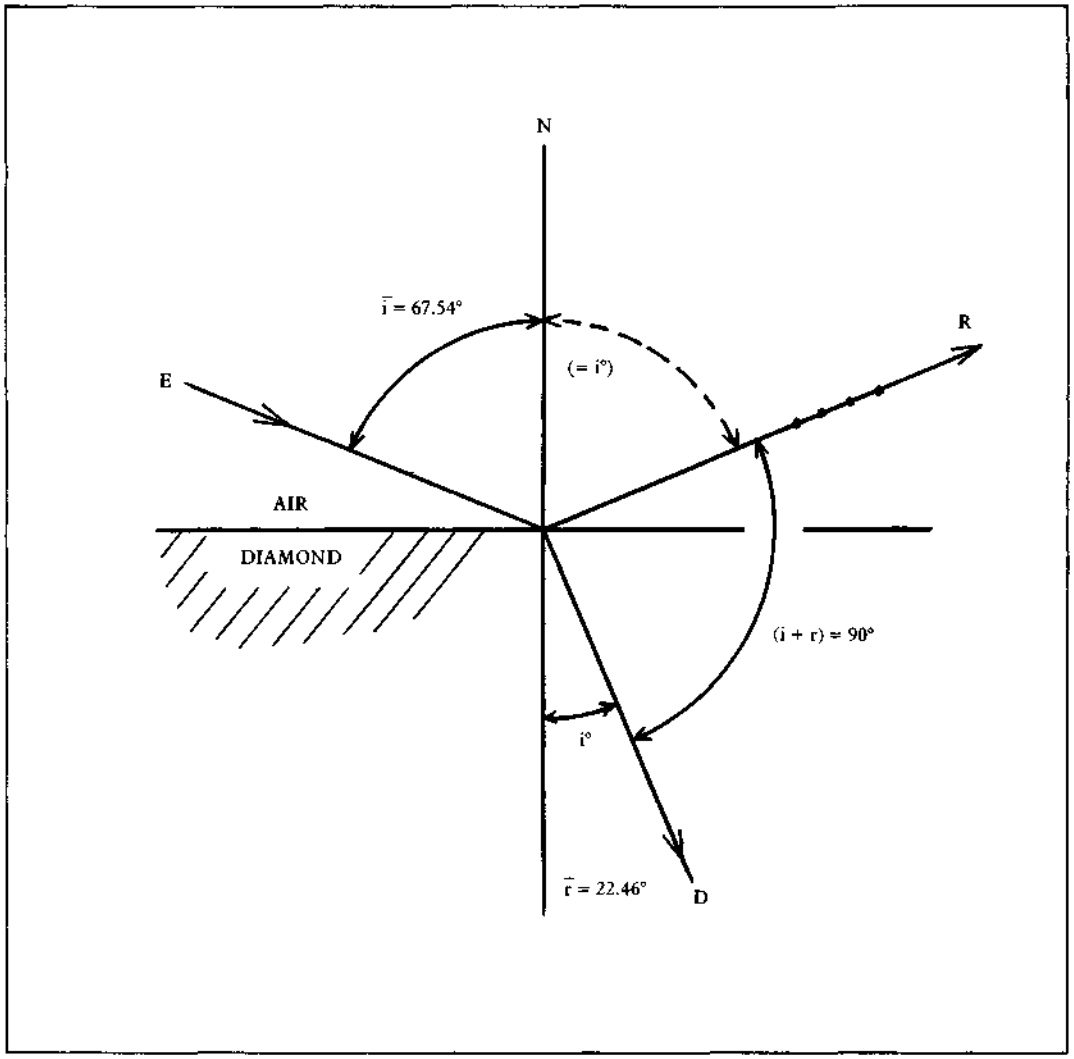

Fig. 5. The Brewster angle for diamond. For a λ of 589.3 nm. See text for explanation.

difficult to measure with the eye or even with a photocell, because of the shallow nature of the trough of the curve near the $\bar{i}$ position. However, by taking identical photocell readings on either side of the steeply-rising parts of the trough, this null point could be much more accurately determined. The mid-point of the i values would yield the correct $\bar{i}$ value, if an account was taken of the asymmetry of the trough. This is illustrated in Figure 6. The angular scale calibration would be simplified by the use of two calibrants. These could be a flat polished plate of CZ ($\bar{i}$ = 65.33°) and a basal plane growth face of alpha-silicon carbide ($\bar{i}$ = 69.31°). These would bracket the $\bar{i}$ value of diamond.

Internal reflections. Up to this point it has been the physics of the external reflections relating to lustre which have been discussed. It is now possible to examine those concerning the *internal* reflections of diamond. These are the rays which having penetrated the stone now proceed to leave it by way of the crown and table facets to produce the other two desirable attributes of brilliance and fire.

As the rays pass through (i.e. internally) the body of the diamond, they are reflected or refracted when they encounter the diamond-air interface.

To distinguish these internal reflections from the external reflections, a change in nomenclature must be made. The incident ray, now originating

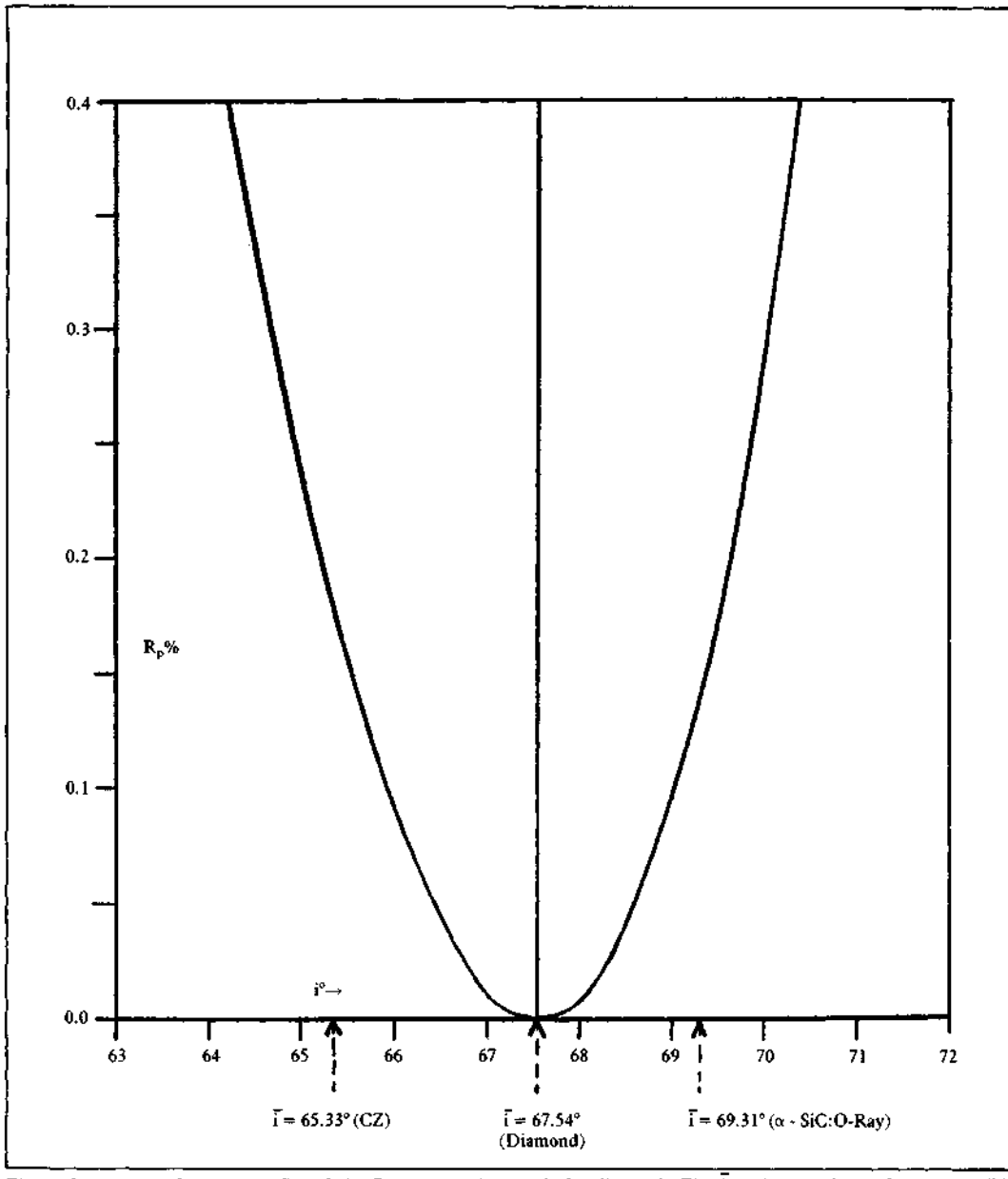

Fig. 6. Calculated reflectance profile of the Brewster angle trough for diamond. The $\bar{i}$ angles are shown for two possible refractometer scale calibrants. For a λ of 589.3 nm.

within the body of the diamond, must preserve its identity and be termed i. However, it is now an internal ray so that it has to be distinguished from the previously discussed external ray, i. This is done by the algebraic convention of 'priming' it, by giving it the symbol i'. The associated refracted ray is also symbolized by r'. They are spoken of as 'i prime' and 'r prime'.

The behaviour of the internally reflected rays is presented in Figure 7 in the same way as that shown in Figure 4 for the externally reflected rays.

It is seen that R'_s rises progressively to $R' = 100\%$, whilst R'_p descends and reaches $R' = 0\%$ at the internal Brewster angle ($\bar{i}'$) at 22.46°. It then rises very steeply until it reaches $R' = 100\%$ at an i' value of 24.42°. This is the

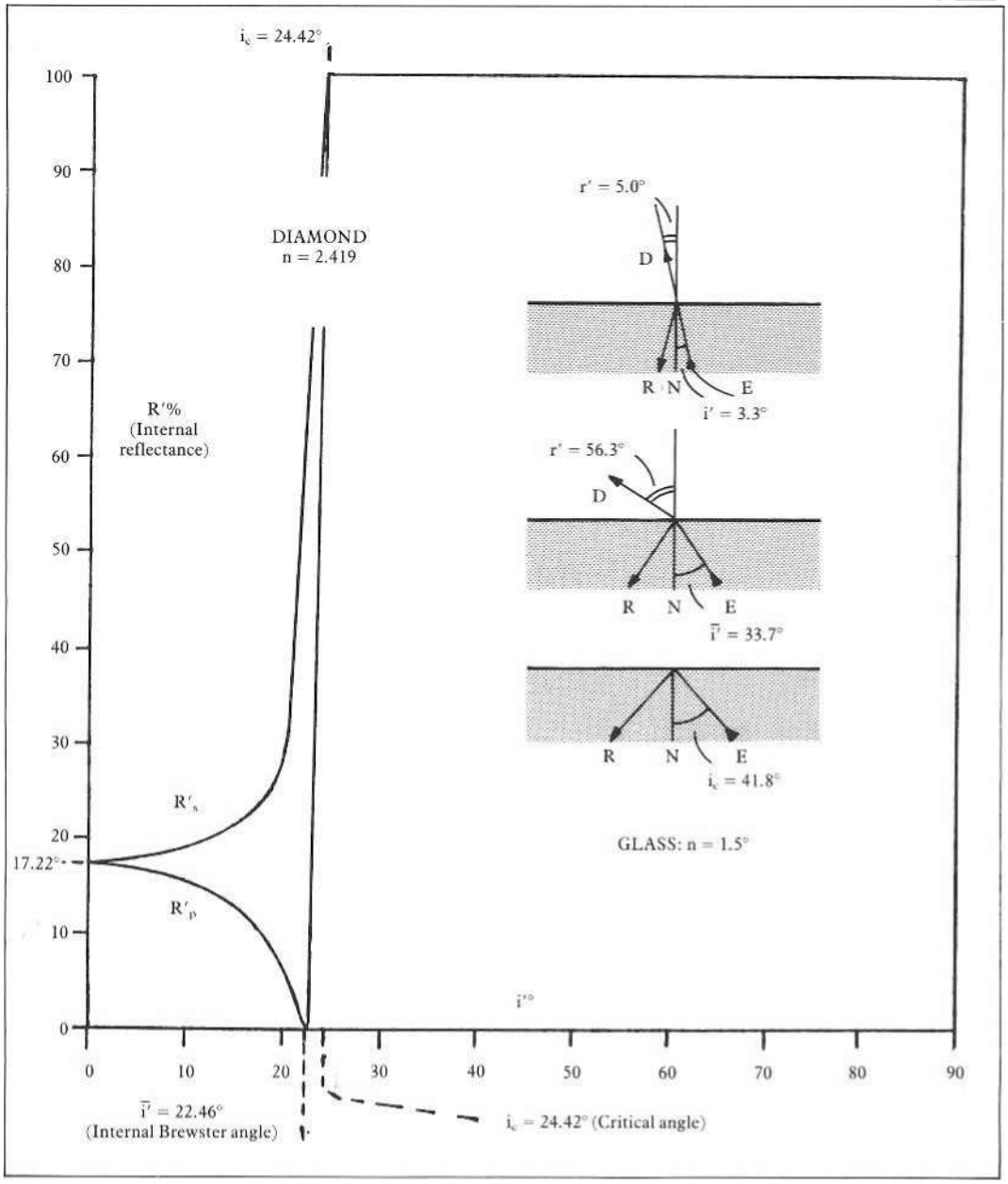

Fig. 7. Variation of the internal reflectance, R', with the angle of incidence, i', from a polished diamond surface. *Inset:* Illustrations of various ray paths in the plane of incidence, for rays originating within the denser medium (here, a glass with n = 1.5).

all-important *critical angle*, designateed i_c (no 'prime' is needed here). It is related to n by:

$$\sin i_c = \frac{1}{n}$$

When i' increases beyond this point right up to 90°, R' remains unchanged at 100%. In other words from i' = 24.42° to i' = 90°, the diamond-air interface behaves as a perfect reflector of light. The attributes of brilliance and fire hang entirely upon the phenomenon of the critical angle. Otherwise pavilion facets would have to be silvered or aluminised.

It is perhaps useful here to help clarify these somewhat involved descriptions. To this end, the

inset of Figure 7 returns to the case of the glass of n = 1.5.

The top diagram shows that Snell's law is not followed when the incident ray travels from the dense medium (glass) to air. (Compare with Figure 3b, first diagram.)

The middle diagram shows that when (i' + r') = 90°, the *internal* Brewster angle conditions prevail, giving an internal Brewster angle $\bar{i}'$ of 33.7°. It should be noted incidentally that this internal Brewster angle is not the same as the *external* Brewster angle of $\bar{i}$ = 56.3° (see Figure 3b, second diagram, and Figure 5).

The bottom diagram shows the situation at the critical angle i_c when the internal incident ray cannot pass across the glass-air boundary.

Reverting to diamond, one of the questions which frequently crops up during discussions of diamond grading is this. Why are the undispersed rays from the stone's interior so much more intense than the external ones?

The answer is now probably apparent. The diamond shape is such that the major proportion of the source light entering the crown and table facets is totally reflected (R' = 100%) as colourless or weakly-dispersed light. The remainder appears as refracted fire or is lost because a small proportion of the light fails to be totally reflected in spite of the low i_c, and leaks out through the sides and back of the stone.

There is however some loss of the totally reflected colourless light due to a different cause. Let it be supposed that light enters the table at i = 0°. It will suffer a loss of intensity of 17.22% (Figure 4), which is the amount of light specularly reflected, thus reducing the transmitted light to 82.78%. After twice being totally reflected, the light then passes across the diamond-air boundary, with a second loss of 17.22%. In this manner, the incident light of say 100% intensity, is returned to the viewer as light having an intensity of only 68.53% (0.8278 × 0.8278 × 100).

In relation to this emergent totally-reflected colourless light, the proportion of light contributed by the lustre is still modest. For example, Figure 4 shows that unless the angles between the light source, the stone's crown or table facets and the viewer can reach high values of i, (say i = 60°) the R_s values will not rise much higher than 40%.

Other effects which diminish brilliance and fire

There is a more practical matter which is seldom mentioned in discussions of the relative contributions of lustre and brilliance to a stone's 'life'. It is the dulling effect which occurs when adventitious substances adhere to the pavilions of diamonds in diamond-set jewellery.

Diamond jewellery owners are advised by the trade to clean their possessions as a matter of routine. However, jewellery repairers, dealers and valuers and gem-testing laboratories all testify to the fact that this advice is not taken seriously. The words 'disgusting state', 'shocking condition' and other more forceful expressions, are often heard from these quarters.

To be fair, the trouble arises from the inaccessibility of the pavilion facets. Soaps and detergents are totally ineffective unless accompanied by some scrubbing action. Ultrasonic baths are effective but are seldom possessed or used by jewellery owners. The crown and table facets usually do not escape the almost constant cleansing attentions which come from ordinary day-to-day wear and because they are not hidden from view.

Is this dulling effect not exaggerated? If not, what are the physical reasons for it?

The effect is indeed real, and can be linked to two specific mechanisms. So far as lustre and sparkliness are concerned, these attributes are scarcely affected because they originate mainly from the crown and table facets. On the other hand, brilliance and fire derive solely from the total reflections occurring at the pavilion's facets. Any interference with this phenomenon will be bound to change the magnitude of these attributes.

Let it be imagined that a diamond's pavilion facets are covered with a thin, clear, colourless, uniform film of natural skin oil (sebum) having an n value of 1.455. Its presence will result in a shift of the critical angle of a clean pavilion from i_c = 24.42° to an i_c = 43.42° for the sebum-coated pavilion. This means that there will be fewer totally reflecting rays available to participate in the production of brilliance. The resulting brilliance will resemble that of an equivalent cut fluorite (i_c = 44.14°), a water opal (i_c = 43.42°) or a silica-glass stone (i_c = 43.23°). The fire will be diminished proportionally.

A practical and simple experiment is worth trying. Choose two well-proportioned, colourless, CZ round brilliants which approximately match in size (girdle diameter of about 10mm or greater). Dip only the pavilion of one of them in either glycerine (n = 1.45) or medicinal paraffin (say Nujol with n = 1.46). A side-by-side comparison of the dipped with the undipped clean stone usually demonstrates quite effectively the reality of the dulling effect.

The dulling does not end with the adhesion of a film of clear liquid of low n value. The adhering undisturbed sebum oil is a very good collector of a large variety of microscopic particles. This results in the formation of a paste which is capable of strongly diffusing and scattering any light which

strikes it.

The author examined micro-samples of this material taken from the pavilions of gemstones set in many pieces of much-used jewellery. Using the analytical techniques of polarised light microscopy[19] alone and with dispersion-staining techniques[20], he was able to identify many of the constituent particles. These were found to be corn starch grains, very short fibres of human hair and cotton, talc particles, dried blood cells, epithelial cells (dandruff and dead skin cells), perfect microscopic cubes of common salt (presumably a product of perspiration), light-brown spheres of resin (from hair sprays), calcium palmitate aggregates (soap curd) and spindle-shaped particles of the brown iron mineral goethite (alpha-$Fe_2O_3.H_2O$). The presence of this last-named iron-bearing mineral was surprising, but not after reading an account of its presence on the *crown and table facets* of a constantly worn diamond finger ring[21].

In appearance, the soft, sticky pastes were never white, or even grey, but varied from light brown to deep brown and, in one instance, almost red. One can well imagine the powerful tinting effect which these impurities can confer on a stone's colour appearance. Even the colours of the metal alloys used as mountants can be picked up by the stone.

Is there a remedy? The question which inevitably must arise is this. Why are the pavilions of diamond brilliants not routinely covered with a shielding deposit of vacuum-evaporated pure aluminium? The body colour of the stones would of course, take on the colour of aluminium, but as its whiteness is virtually indistinguishable from pure white, this is hardly worth further consideration. What is worth pondering upon is the complete preservation of the stone's body colour which this process would ensure. As colour is an attribute which is especially dearly paid for, why should a 'D-colour' stone not remain forever a 'D-colour' without having to concern oneself about its pavilion's cleanliness? Another benefit would be that there would be less rigour needed in keeping to the classical pavilion cutting angles. With a coating, even a 'fish-eye' stone would not leak light.

It is not difficult to see why this coating strategem is presently regarded as distasteful. The eighteenth-century habit of gluing silver foil around the pavilion facets is now viewed as a rather nasty practice. For one thing, grease and dirt often became trapped between unstuck foil and the stone. For another, the silver became tarnished from sulphur dioxide in the environment, resulting in a film of black silver sulphide. Neither of these things enhanced the stone's beauty.

More recently, this unpopularity was reinforced because such treated stones, even though of good quality, were likened to those used in costume jewellery. These articles made much use of cheap pastes with moulded pavilion facets which were silvered and over-coated with protective lacquers.

Should this coating practice ever be seriously resurrected, it would have one commercially awkward consequence. It would make it impossible to assess *visually* small differences in the body colours of diamonds. The only way to view the stone would be the 'table up' direction, which is that showing the maximum fire. This strong fire would completely mask the feeble body colours of the Cape Series and make nonsense of accurate colour assessments. It would be possible to measure the body colour by non-visual means, but such electronic devices are expensive.

Again, there remains the all-important question of acceptability. Like the over-intense fire of strontium titanate, the effect would probably be regarded as 'unnatural'.

Demonstration units

The foregoing descriptions of the separate interactions which happen when a single theoretical pencil of light falls upon a diamond are far from easy for an individual to grasp and a computer to present. The use of this single ray and its progress to, through, and out of a two-dimensional diamond cross-section profile is an enormous simplification of the innumerable pathways actually taken by the infinite assembly of light beams impinging on a real three-dimensional stone. Then why bother, one is entitled to ask? The answer probably is that by breaking the problem down into little bits or steps, much better insights *might* follow.

The author felt that some additional insights might be gained if an analogue machine was designed and made to observe directly these separate ray pathways, in two dimensions at least. Such a device was built, and it was found to be most helpful in demonstrating the predictions of the paper arguments and indeed considerably more. For one thing, it did confirm the view that adhering paste does cause internal light scattering and diffusion and which also frustrates those rays capable of total reflection not only once but several times. Indeed, the author has put this phenomenon to serve a useful purpose in connection with the quantitative measurement of gemstone body colour. The method was termed by him, 'frustrated multiple internal reflection'.[22,23,24]

Description of the ray-path tracer

Three plates of optical quality glass were cut and polished to represent the central axio-symmetrical planes of round brilliants, simulating 'ideal', 'fisheye' and 'lumpy' cuts. Made of colourless glass

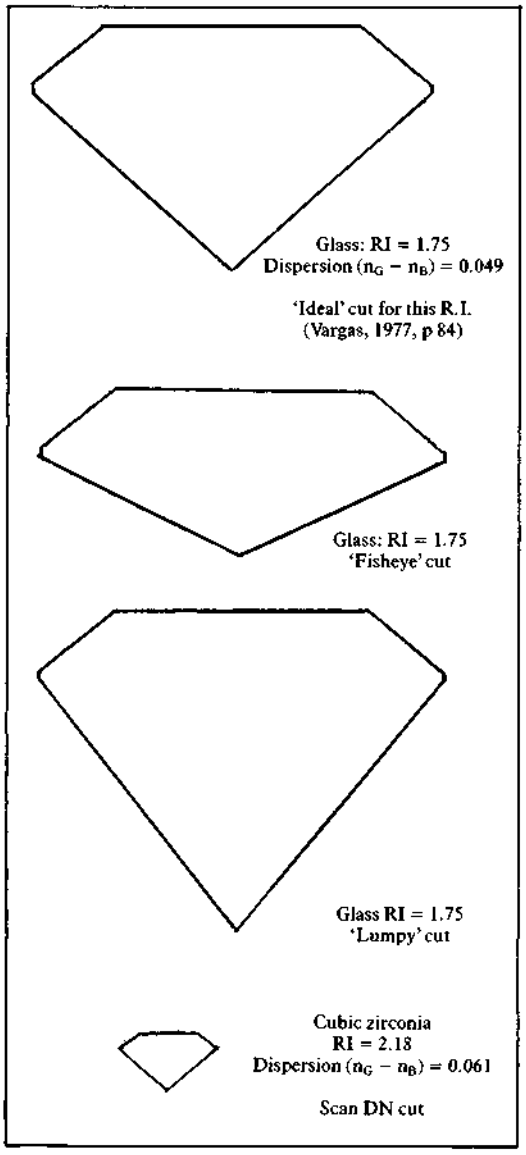

Fig. 8. Brilliant-type shaped plates cut in optical glass and cubic zirconia. Used in the ray-path tracing device shown in Figure 9 for visualizing ray paths in the meridional planes of 'ideal', 'fisheye' and 'lumpy' cuts.

having an n_D of 1.754 and an ($n_G - n_B$) disperson of 0.049, the profiles all had girdle 'diameters' of 100mm, with identical crown dimensions.

They were intended to demonstrate the behaviour of a single, thin parallel ray of white light as it enters and leaves the profile. Each stationary profile can be illuminated by the ray, either by varying the ray's angle of incidence continuously from +70° to −70° or by translating the whole profile bodily across the ray. Both angular and linear crown-scanning movements can be made simultaneously, providing any one of an infinite number of easily visible ray paths.

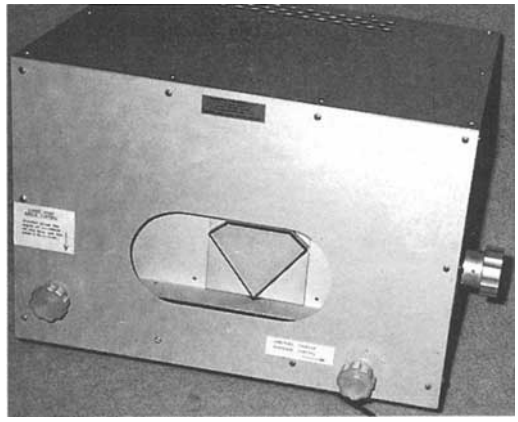

Fig. 9. Analogue optical device for visualizing ray paths in 'ideal', 'fisheye' and 'lumpy' profiles. The left-hand knob controls the angle of the incident ray and the right-hand knob controls the traverses of the profiles. The side knob brings each of the four profiles into view.

In this way it was found possible to trace visually the entire path of the ray, both externally and internally and to compare the ray paths of each profile.

A fourth profile made of colourless cubic zirconia, of a 'diameter' of 25mm and of Scan DN shape was also included in the assembly because its n value of 2.18 serves as a more realistic approach to diamond than that of glass. The four profiles are illustrated in Figure 8.

The optical effects which can be exhibited on each profile are those of Fresnel (i.e. surface) reflection, Brewster angle, internal (total) reflection, refraction, dispersion, internal (inclusion) scattering, external scattering (from adventitious matter optically adhering to the pavilion), light leakage and the unexpected observation of secondary and ternary internal ray paths.

If the ambient light level is unacceptably high, it is possible to use a colour television camera and monitor system. This has been found to be a particularly effective measure. All external light can be suppressed and the intrinsic contrast-control features of a television presentation can be exploited.

A photograph of the unit is shown in Figure 9.

Unit for separately demonstrating the four attributes

It was also felt that it might be helpful to be able to demonstrate visually the separate effects of lustre, brilliance, fire and sparkliness, using an actual polished diamond.

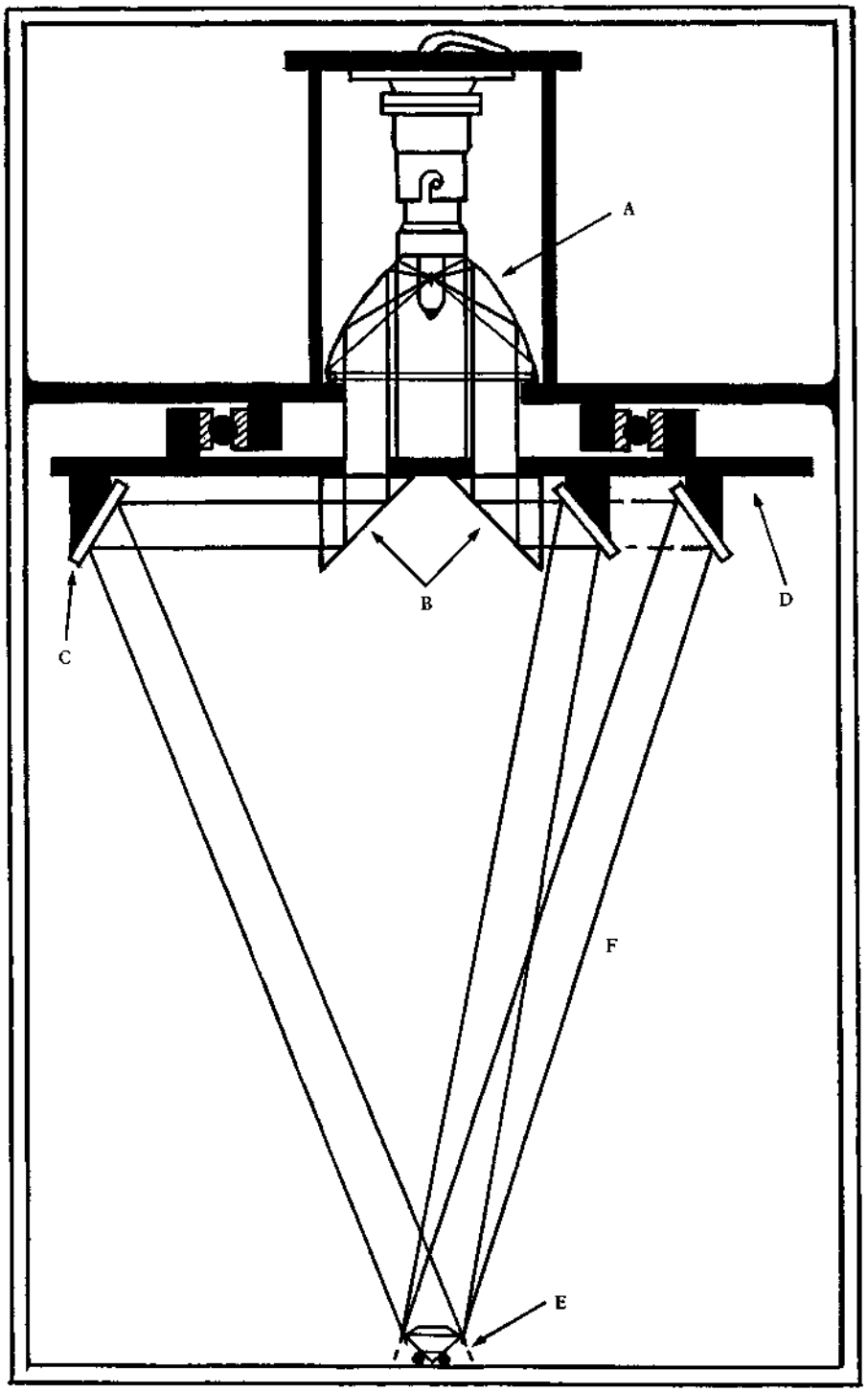

Fig. 10. Optical device for separately demonstrating the four optical attributes of a round, brilliant-type diamond.
Key to sketch
A. Quartz-halogen parabolic reflector lamp producing a single parallel beam of white light.
B. Three glass prisms, mounted 120° apart, for conducting three selected parallel beams on to three inclined mirrors.
C. Three mirrors angled so as to direct simultaneously each of the beams on to a faceted diamond at angles of incidence (i) of 10°, 20° and 30°
D. Rotating optics assembly mounted on a large ball-bearing. The assembly is rotated continuously at about 50 rpm by means of a small electric motor (not shown).
E. Diamond supported 'table-up' by means of a small black, rubber O-ring.
F. Vertical white screen for viewing the moving reflections.

As a first experiment, a diamond was placed on a rotating turntable and illuminated by three light beams from point sources. This was not found to be a suitable arrangement for separating the attributes.

A second experimental arrangement proved to be successful. Here, the diamond was kept stationary. It was again illuminated by three point sources of light, but this time the three focused beams were rotated together. They were directed on to the diamond but at different angles (10°, 20°, 30°). By placing a white reflecting screen behind the diamond, it was found to be possible to separate visually all four attributes. The device is shown in Figure 10.

On rotating the light beam assembly, the white scintillation spots on the screen were seen to originate from crown and table facets only. They were therefore the lustre's contribution to sparkliness.

These lustre scintillations were seen to be fairly well angularly separated from the spectral scintillations arising from dispersion. There were also white scintillations mingled with the dispersive fire. These white flashes were obviously linked with the brilliance contributions.

Taken together, the unit was able to demonstrate quite clearly the separation of the four prized optical attributes of diamond.

Problems in nomenclature

Almost every discussion of a diamond's appearance uses different descriptive terms. These cause much confusion which is further increased when English terms are translated into other languages or vice versa.

The four attributes discussed here are real properties each of which is capable of being quantitatively assessed by machines, if so required. Indeed Andrychuk[25,26] has described and used an electronic arrangement for such measurements on faceted gemstones. Again, he gives the attributes different names and compounds them to yield new terms relating to his 'quantitative performance parameters'.

Undoubtedly, the time has come for the international body of the diamond trade to encourage the standardisation of, at least, the English qualitative compound terms. The following are proposed.

Brilliancy = lustre + brilliance
Scintillation = fire + sparkliness
Liveliness = lustre + brilliance + fire + sparkliness

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The author wishes to thank both Mr Eric Bruton and Mr R. Keith Mitchell for their generous and helpful comments on various aspects of this article.

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[*Manuscript received 26 December 1987, revised 20 November 1988*]

Gemmological Abstracts

ASHBAUGH, C.E.III, 1988. Gemstone irradiation and radio-activity. *Gems & Gemology*, **24**, 4, 196-213. 14 figs in colour.

This excellent survey of the effects, intensities and sources/methods of irradiation, both natural and artificial, on the range of gem materials treated today, is by a senior lecturer on Nuclear Energy at UCLA.

We exist in a 'sea' of low level radiation of which some 82% is from natural sources. Certain gem materials contain radio-active elements, e.g. uranium and thorium in zircon and a few much rarer stones. Of the remaining 18% which can be said to be man-made, less than 1%, surprisingly, is due to fall-out.

Diamond, topaz, beryl, tourmaline and kunzite are among the stones artificially treated by various laboratory radiations. No methods for detecting resultant colour changes are given.

The author goes on to discuss the health and the legal aspects of marketing irradiated gems which may retain residual radio-activity for years after treatment and concludes that this raises very complex issues, and that current US regulations appear to be unrealistic. R.K.M.

BALFOUR, I., 1988. Famous diamonds of the world, XXXVI. The McLean diamond. *Indiaqua, 51*, (1988/3), 145-7.

An avid collector of jewellery, Mrs Evalyn Walsh McLean's named acquisitions included the Hope diamond, the 14.37 ct kite-shaped Star of the South, the Star of the East and a cushion-cut 31.26 ct diamond which became known as the 'McLean'. During the period of the Depression, many of her jewels saw the inside of New York pawn shops. However, after her death Harry Winston bought the entire collection, and in 1950 sold the McLean to the Duchess of Windsor. When the Duchess's jewels were auctioned by Sotheby's in 1987, the McLean diamond was bought for $3,153,333 by Mr Katsuji Takagi of Japan. P.G.R.

BALFOUR, I., 1989. Famous diamonds of the world, XXXVII. Little Sancy. *Indiaqua*, **52**, (1989/1), 147-8.

Nicholas de Sancy was a French financier who is remembered for giving his name to the famous 55.23 ct pear-shaped diamond which can be seen in the Louvre in Paris. However, he was also the owner of another sizeable diamond of around 30 ct which came to be known as the 'Little Sancy' or the 'Beau Sancy'. After his death, the Little Sancy was sold to Frederick Henry, Prince of Orange. Eventually the gem came into the possession of Frederick I of Prussia and became the premier stone in the Crown Jewels of Prussia. When last heard of the Little Sancy was displayed in a simple pendant in the Royal Prussian House in Bremen. P.G.R.

BALFOUR, I., 1989. Famous diamonds of the world, XXXVIII. Richelieu. *Indiaqua*, **52**, (1989/1), 148.

Owned by one of France's outstanding statesmen, Cardinal Richelieu, the Richelieu diamond was a rose-cut heart-shaped stone weighing around 19 ct, and took its name as soon as it became part of the French Crown Jewels. When Richelieu died he was succeeded by that other great collector of stones, Cardinal Marazin. The last mention of the Richelieu diamond was that it was set with the Marazins IV, V and VI in one of three pairs of earrings. The diamond was stolen in 1792, and no trace of it has been found since then. P.G.R.

BALFOUR, I., 1989. Famous diamonds of the world, IX. Harlequin. *Indiaqua*, **52**, (1989/1), 149.

No satisfactory reason has been found for the name 'Harlequin' that was applied to this 22 ct pear- shaped diamond. The stone was originally set in a bejewelled decoration created for Karl Alexander, Duke of Wurtemberg. Today it is owned by the Federal Republic of Germany. P.G.R.

BALFOUR, I., 1989. Famous diamonds of the world, XI. Dresden White. *Indiaqua*, **52**, (1989/1), 149.

Despite the fame of the unique 41 ct 'Dresden Green' diamond, the largest diamond mounted in the Saxon Crown Jewels is, however, the 49.71 ct cushion-cut 'Dresden White'. After being safely stored in the Fortress of Konigstein during World War II, the Crown Jewels, including the Dresden White, were removed by the Russians to Moscow, but in 1958 they were returned to Dresden where they are now on display. P.G.R.

BANK, H., 1988. Gemmologische Kurzinformationen. Durchsichtiger, geschliffener, gelber Milarit aus Rössing, Namibia. *Zeitschrift der Deutschen Gemmologischen Gesellschaft*, **37**, 3/4, 143, bibl.

This note deals with a transparent, cut, yellow milarite from Rössing in Namibia. This stone was first described by M. O'Donoghue. Values are slightly different. E.S.

BANK, H., 1988. Gemmologische Kurzinformationen. *Zeitschrift der Deutschen Gemmologischen Gesellschaft*, **37**, 1/2, 75-80. (a) Sternskapolith von Sri Lanka, Id., 76-8; (b) Hocklichtbrechender grüner Apatit von Rössing, Namibia, Id., 78-9; (c) Glas für Leucit ausgegeben, Id., 79-80.

Three short notes, all with bibliographies. Bank first deals with a star scapolite from Sri Lanka, then a high RI green apatite from Rössing in Namibia and lastly with a colourless glass which was offered as leucite. This stone came from Sri Lanka. E.S.

BANK, H., GÜBELIN, E., HENN, U., MALLEY, J., 1988. Alexandrit: natürlich oder synthetisch? (Alexandrite: natural or synthetic?) *Zeitschrift der Deutschen Gemmologischen Gesellschaft*, **37**, 1/2, 49-52, 4 figs, bibl.

An English version of this paper was published in the *Journal of Gemmology*, 1988, **21**, 4, 215-7. E.S.

BANK, H., GÜBELIN, E., HENN, U., SCARRATT, K., 1988. Rubin: natürlich oder synthetisch? (Ruby: natural or synthetic?) *Zeitschrift der Deutschen Gemmologischen Gesellschaft*, **37**, 1/2, 27-30, 8 figs (4 in colour), bibl.

The stone in question was a faceted ruby, 1.288 ct (6.0 x 6.0 x 4.15mm) from Nepal*. The authors identified the stone as natural, but there were some difficulties because of ambiguous features. E.S.

*The same ruby was described in *Journal of Gemmology*, 1988, **21**, 4, 222-6. – Ed.

BANK, H., HENN, U., 1988. Vergleichende physikalische, chemische und strukturelle Untersuchungen an vanadium-haltigen Grossularen aus Ostafrika. (Comparative physical, chemical and structural examinations of vanadium-containing grossularite from East Africa.) *Zeitschrift der Deutschen Gemmologischen Gesellschaft*, **37**, 1/2, 69-74, 1 graph, 2 tables, bibl.

The work is based on seven grossulars from East Africa, the colour of which varied from pale yellow green to dark green and with RI ranging from 1.735 to 1.759. The results show a linear correlation between the vanadium oxide content, the lattice constants and relative densities with increasing RI. E.S.

BANK, H., HENN, U., LIND, TH, 1988. Rubine aus Malawi. (Ruby from Malawi.) *Zeitschrift der Deutschen Gemmologischen Gesellschaft*, **37**, 3/4, 113-19, 8 figs (2 in colour), 3 tables, bibl.

The investigated rubies from Malawi showed a surprising variation in their RI, birefringence and density. These variations were correlated with their chromium and iron content. Mineral inclusions found were shown to be hornblende, plagioclase and zircon. Nothing is known as to quantity of rubies produced in Malawi, but colour intensity seems to vary widely. E.S.

BANK, H., PLATEN, H.v., 1988. Gemmologische Kurzinformationen. Blau gefärbter Magnesit als Lapis Lazuli-Ersatz angeboten. *Zeitschrift der Deutschen Gemmologischen Gesellschaft*, **37**, 1/2, 75-6, bibl.

A blue dyed magnesite which was offered as lapis lazuli is described in this short note. E.S.

BOURGEOIS, J., 1988. Caractéristiques des pierres rares. (Characteristics of rare stones.) *Revue de Gemmologie*, **97**, 14- 15.

Two tables give chemical composition, refractive index and birefringence, hardness and specific gravity, of a large number of less common gemstones. Stones in the second table are rarer than those in the first, and their birefringence is not given. M.O'D.

BOYAJIAN, W.E., 1988. An economic review of the past decade in diamonds. *Gems & Gemology*, **24**, 3, 134-54, 16 figs in colour.

In ten years diamond values have fluctuated dramatically and the GIA President has summarized events and causes with great authority and accuracy. This gemmology affects World economy and the GIA are doing a valuable service to the gem trade by publishing it.

De Beers organization is explained in detail and it is evident that they have manoeuvred skilfully to

combat adverse influences which were beyond direct control. During early years of the decade financial and other pressures reduced demand and prices reached low ebb by 1985/86. Since then there has been an upturn and prices are recovering despite the Stock Market crash of 1987.

A final section on World Diamond Production serves to put the whole vast subject into perspective.

An important paper which should be widely read and well digested. R.K.M.

BRACEWELL, H., 1988. Gems around Australia. *Australian Gemmologist*, **16**, 12, 459-63, 14 figs in colour.

Early in the 1980s Hilda and Harold Bracewell undertook an extensive and fascinating circumambient journey by car around Australia specifically to visit as many gem localities as they could. The paper reports gem finds at the start of this journey, and it is hoped that a series will eventually cover the whole of their epic trip. R.K.M.

BROWN, G., 1988. Bamboo coral. *Australian Gemmologist*, **16**, 12, 449-54, 6 figs.

Deep water bamboo coral has been found with pink and gold corals in the Molakai Channel off Dahu, Hawaii. Bamboo coral so named because it occurs in white longitudinally striated stem sections segmented by flexible nodes of black coral. R.K.M.

BROWN, G., 1988. Gold coral revisited. *Australian Gemmologist*, **16**, 12, 473-7, 10 figs in colour.

A general survey of this Hawaiian golden coral which can be bleached to improve its colour, impregnated or coated with plastic in further efforts to fake its appearance. R.K.M.

BROWN, G., 1988. Zircon. *Wahroongai News*, **22**, 9, 17-21, 3 line figs.

A thorough resumé of this well-known gem drawn from half a dozen authoritative sources. [Miller indices for first and second order prisms are reversed.] R.K.M.

BROWN, G., 1988. The Egyptian emerald mines. *Wahroongai News*, **22**, 12, 24-6, sketch map.

A paper based on W.F. Humes' *Geology of Egypt*, published in 1934. These were probably the first emerald mines, dating from Ptolomeic and early Roman times. Their emeralds would today be considered pale, heavily included and low grade, but, with no better stones to compare, they were valued highly at the time. Mines at Zabara, Sikait, Nugrus and Um Kabu, are briefly described. They are probably exhausted now. R.K.M.

BROWN, G., 1988. Merensky, diamond and fossilized oysters. *Wahroongai News*, **22**, 12, 22-3, sketch maps.

A short paper based entirely on one by Dr Hans Merensky in 1909, on the diamond deposits of Luderitzland, German SW Africa, published a year after the discovery of the coastal diamond fields. Merensky found the diamonds associated with fossil oysters of the Cretaceous period. Diamonds were of good colour and quality, well crystallized but small, and showed evidence of having been transported by river and sea over very considerable distances, and concentrated by wind action. R.K.M.

BROWN, G., 1988. Phenakite. *Wahroongai News*, **22**, 12, 19-21, 2 figs.

A comprehensive account of this rare beryllium silicate, based on three authoritative sources. Mr Brown comments that this may be a rare gem, but it does appear often in practical examinations. R.K.M.

BROWN, G., SNOW, J., 1988. The diamond selector II. *Australian Gemmologist*, **16**, 12, 440-2, 3 figs.

An evaluation of a 9v diamond tester which beeps and indicates diamond by flashing red lights, and was found to work efficiently at ambient temperatures when used in accordance with instructions. R.K.M.

BROWN, G., SNOW, J., 1988. The Pool Emerald. *Australian Gemmologist*, **16**, 12, 443-9, 14 figs in colour.

A report on a new emerald synthetic marketed as low grade crystals from the Emerald Pool mine, near Poona, WA, transformed into stunningly beautiful emeralds by a secret process, suggests that these are hydrothermally grown synthetics with inclusions and gemmological properties virtually identical to those of Biron synthetic emeralds, produced by the same Perth company. They appear to be grown on seed plates, possibly using natural beryl from the designated mine, doped with V^{3+}, as feed material. R.K.M.

BROWN, G., SNOW, J., 1988. Gemmological Study Club lab reports. *Australian Gemmologist*, **16**, 12, 464-70, 21 figs in colour.

The team found that polymer infilling in treated Brazilian opals could be detected by transillumination [shining light through them].

Lapis Nevada, a thulite-diopside skarn rock rather like unakite in appearance, was investigated. SG 2.83 and RI which varies with mineral grain tested.

A metallic looking cabochon from Mt Biggenden Mine was shown to be a rock composed of

bismuthinite, chalcopyrite, quartz and calcite.

Emmaville emeralds, the first found in Australia, had SG 2.68, RI 1.570-1.575 and seem to be coloured more by vanadium than by chromium.

Oval Mabe pearls are being imitated by coque-de-perle cut from nautilus shell, dyed, filled with coloured cement and backed by mother-of-pearl. Further imitations have been seen which are made from hemispherical pieces of the shell of a Philippine land-snail. This is thin and is strengthened with a black pitch-like substance which gives a silvery iridescence.

A ring of aventurine moss agate was examined; amethyst crystal earrings with mobile bubbles are described; calcite beads are thought to have been quench crackled in a brown dye; an attractive green glass with bubbles and spherical devitrification aggregates, morphologically like wollastonite, is described. R.K.M.

DIETRICH R.V., WHITE, J.S., NELEN, J.E., CHYI, K.-L., 1988. A gem-quality iridescent orthoamphibole from Wyoming. *Gems & Gemology*, **24**, 3, 161-4, 3 figs in colour.

Describes an attractive iridescent multi-colour rock, mostly brown and golden, identified as ferroanthophyllite with considerable goethite and garnet, cemented by opal. Similar material from Greenland compares. Density varies with mineral mixture and for similar reasons, and opacity, optical constants are not easy to obtain, but upper RI of 1.667 is suggested. R.K.M.

EPSTEIN, D.S., 1988. Amethyst mining in Brazil. *Gems & Gemology*, **24**, 4, 214- 28. 16 figs in colour.

A beautifully illustrated account of visits to Marabá and Pau d'Arco in Pará, and to Rio Grande do Sul. Each area is geologically different and mining methods vary accordingly. Much amethyst from the first and last of these localities is heated to make the rarer citrine, a change achieved at Marabá by the crude expedient of burying the amethyst in sand in a steel wheelbarrow over a wood fire. Other amethyst localities exist in Brazil, but these three are the most productive and are probably the major world sources of the gem today. R.K.M.

FRIEDMAN, D., 1988. Specular heat treated garnet. *Australian Gemmologist*, **16**, 12, 477.

An Indian very dark purple-red garnet, RI 1.803, was heated to 720°C to lighten the colour, but was found to have acquired a 'silvered' surface of what is thought to be specular hematite as a result of the heat. R.K.M.

FRITSCH, E., SHIGLEY, J.E., STOCKTON, C.M., KOIVULA, J.I., 1988. Detection of treatment in two unusual green diamonds. *Gems & Gemology*, **24**, 3, 165-8, 4 figs in colour.

Two irradiated greyish-green diamonds had H1b and, in one, H1c absorption bands in the near-infrared. First time these have been seen in green diamonds although they are common in irradiated, annealed yellow or brown ones. Believed these stones have been irradiated, annealed or irradiated again. Colour alone would not prove treatment. Fluorescence and spectroscopic data given. Another green diamond examined later yielded both infrared lines. R.K.M.

FRYER, C.W. (ED.), CROWNINGSHIELD, R., HURWIT, K.N., KANE, R.E., 1988. Gem Trade Lab notes. *Gems & Gemology*, **24**, 3, 169-74, 16 figs in colour.

A synthetic alexandrite had 'oily' appearance and many colourless transparent rounded inclusions of pin-point size, new to the investigator; stone proved synthetic by infrared spectrum. Dyed spangles in amber were unexpectedly both red and green. [Is this so unusual? I have a similar specimen and have seen others in the past.] A black opaque Chinese 'onyx', RI 1.702-1.728, SG approximately 3.35, identified as the monoclinic pyroxene augite by X-ray diffraction. A calcareous concretion with honeycomb structure and a conchyolin spot had sheen effect and was evidently of mollusc origin.

Three green diamonds were examined, each with different testing characteristics; one with bluish transmission colour showed Cape absorption spectrum with slight chalky fluorescence under LUV and faint yellow phosphorescence; SUV gave similar colours but weaker; a natural green. Second and largest stone had 498/504 and 594nm lines strongly developed proving irradiation, and gave strong greenish-yellow fluorescence under LUV and chalky green under SUV, with flight yellow phosphorescence in each. Smallest stone, dark bluish-green, had no detectable absorption lines but gave vague 'smudge' centred at 500nm when cooled; fluoresced weakly, chalky greenish-blue in LUV and similar weaker colour in SUV; non-conducting of electricity; another natural coloured stone.

An opal with ironstone base had a wavy junction typical of a genuine stone, but the backing had been cemented on with epoxy resin tinted to match. A cabochon 'golden jade' from Wyoming had a vague RI of 1.44 and a hint of a second much higher one; in 2.57 liquid it suspended lop- sidedly, suggesting rock with two or more components; X-ray diffraction revealed goethite and hematite at the 'heavy' end and a spessartine pattern for the light end, suggesting that this was another opal-bonded orthoamphibole of the type described by

Dietrich *et al.*, in this issue of *Gems & Gemology*.

A large South Seas type cultured pearl had very thick nacreous layer which drastically reduced the expected X-ray fluorescence. A synthetic ruby had surface inclusions of flux, but time prevented identifying the flux. Two stones with sagenitic inclusions of black tourmaline proved to be quartz and, far less usually, fluorite. A sapphire with symmetrical abrasions on the pavilion is thought to have been worn next to a three-stone diamond ring. A brown synthetic star sapphire was identified, a first for the West Coast Lab. An almost colourless taaffeite exceptionally fluoresced a chalky yellowish-green under LUV, rather like a colourless synthetic spinel, which could be confusing if no other test had been done. A greyish-brown transparent lithium-iron manganese phosphate was identified as triphylite, RI 1.689-1.695, SG about 3.40, no fluorescence, but absorption at 410, 425, 450- 460, 470, 485-498 and a weak band at 540-590; X-ray diffraction proved this new recruit to occasionally faceted minerals. R.K.M.

Fryer, C.W. (Ed.), Crowningshield, R., Hurwit, K.N., Kane, R.E., Hargett, D., 1988. Gem Trade Lab notes. *Gems & Gemology*, **24**, 4, 241-6. 18 figs in colour.

Dull beads in an otherwise polished black onyx necklace were opaque and found to be agate, painted to imitate the dyed beads.

'Diamond' crystals were identified as cubic zirconia, cut skilfully to convincing dodecahedral and octahedral shapes. Brown radiation stains seen in a pale yellow diamond were difficult to interpret, but may have related to inclusions at the surface which had pulled out in polishing, not known whether stains were artificially induced. A badly burned diamond had an unusual 'melted' scar indenting its table, again cause unknown. [Abstractor wonders whether burn was due to a high voltage spark discharge?]

Dyed green hydrogrossular was found by absorption and colour filter tests; a chess set purporting to be mammoth ivory was shown to be made from walrus tusk.

Grey irradiated cultured pearls showed the shell nuclei darkened but the nacre coating remained white; irradiation darkens freshwater shell but does not affect salt-water shell or nacre; also it can enhance freshwater Biwa type pearls to iridescent blacks which are more attractive than the dyed blacks. Very unusually a necklace of ten pear-shaped pearls proved to be thinly cultured over drop-shaped beads; it is understood that pear-shaped cultured pearls usually have round nuclei since pear-shaped beads tend to kill the oysters; the pear shape normally occurs accidentally or is induced by using round beads with a tissue culture method.

An exceptionally large faceted flux-grown ruby of 17 ct was seen at the East Coast Lab; synthetic 'topaz blue' spinels were identified. A warning is given that lost natural rubies, etc., may have been replaced by synthetics in otherwise genuine old pieces of jewellery. R.K.M.

Furui, W., 1988. The sapphires of Penglai, Hainan Island, China. *Gems & Gemology*, **24**, 3, 155-60, 7 figs in colour.

An important alluvial source of sapphires covers about 25km^2 in the NE of this tropical island; material similar to that found at Chantaburi, dark but good blue up to 30mm in size, RI 1.761-1.769, SG 3.99 to 4.02, strongly pleochroic, marked colour zoning and silk; heat-treatment lightened colour to good indigo blues with little zoning. [Faceted stone illustrated looks cloudy.] Prospects excellent. R.K.M.

Garcia Guinea, J., Rincón Lopez, J.M., 1988. Vidrios y materiales vitroceramicos artificiales de interes gemológico. (Glassy and artificial glass-type ceramics of gemmological interest.) *Boletin del Instituto Gemológico Espanõl*, 30, 22-36, 11 figs in colour.

22 glassy ceramics obtained from lithia glasses containing manganese, chromium, vanadium or cadmium oxides, are examined for their possible gemmological interest. Their properties are given. M.O'D.

Hänni, H.A., 1988. Certitude de la détermination de l'origine des gemmes. (The certainty of determining the origin of gemstones.) *Revue de Gemmologie*, 97, 4-5. 3 figs in colour.

The article reviews the various features which can indicate to the gemmologist the geographical origin of a particular specimen. Corundum and beryl are considered. M.O'D.

Heflik, W., Sobczak, T., 1988. Gemmologische Kurzinformationen. Rodingit – ein Schmuckstein von Jordanòw in Niederschlesien, Polen. *Zeitschrift der Deutschen Gemmologischen Gesellschaft*, **37**, 3/4, 144-5.

This note describes a rodingite from Jordanow in Lower Saxony, Poland. This white, ornamental stone with green inclusions is a rough grained grossular-vesuvianite rock, hardness 6-7, SG 3.40-3.47, RI 1.710-1.730. E.S.

Henn, U., 1988. Untersuchungen an Smaragden aus dem Swat-Tal, Pakistan. (Investigation of emeralds from the Swat Valley, Pakistan.) *Zeitschrift der Deutschen Gemmologischen Gesellschaft*,

37, 3/4, 121-7, 13 figs, 2 tables, bibl.

The most important emerald occurrences in Pakistan are in the upper Swat Valley. Chemical and physical data from five finds in the Swat Valley are compared (Makhad, Charbagh, Gujar Kili, Mingora I and II). Talc, calcite/dolomite, pyrite, chromite and molybdenite were found as mineral inclusions, besides liquid feathers, two-and three-phase inclusions and growth tubes. E.S.

HENN, U., MALLEY, J., BANK, H., 1988. Untersuchung eines synthetischen Alexandrits aus der UdSSR. (Investigating a synthetic alexandrite from the USSR.) *Zeitschrift der Deutschen Gemmologischen Gesellschaft*, **37**, 3/4, 85-8, 5 figs (2 in colour), bibl.

The synthetic alexandrite from Russia weighed 0.71 ct with a definite colour change from green to red with a slight violet tinge. It was shown to be flux-grown. Analyses showed it to have a considerable content of gallium as well as chromium and iron. Feathers of flux residue in which the elements bismuth and sulphur were detected, are typical features for the distinction from natural alexandrites. E.S.

HICKS, W. (ED.), 1988. The Pool emerald –Ⓓ,Ⓓ, or (R)? *Australian Gemmologist*, **16**, 12, 478-9.

A further note on this 'new' synthetic emerald which questions the validity of some aspects of the promotional literature. R.K.M.

KEELING, J.L., TOWNSEND, I.J., 1988. Gem tourmaline on Kangaroo Island. *Australian Gemmologist*, **16**, 12, 455-8 & 470, 5 figs and map.

Gem tourmaline was found in the early 1900s in the Dudley pegmatite on this island near Adelaide. Mostly shades of green and blue with some pink 'water-melon' crystals. R.K.M.

KOIVULA, J.I., KAMMERLING, R.C., 1988. Gem news. *Gems & Gemology*, **24**, 3, 176-81, 9 figs in colour.

Diamonds

Angola. Unita guerillas find huge deposits of diamond and plan to develop them.

China. A 32.79 ct diamond from Shandong Province will probably be cut in China.

Tanzania. Mwadui mine, formerly the Williamson, to take power from Kidatu hydro-electric plant and should double dwindling output.

Namibia. Rich deposit of diamonds discovered off coast near Luderitz may lead to cutting plant opening in that city.

USA. Murfreesboro, Arkansas, diamond deposit thought to contain $1000 million of diamonds.

Coloured stones

East Africa. Pyrope-spessartine garnets were bluish green by fluorescent and a good red by incandescent light. Colour change due to 1% of V_2O_3 rather than to chromium.

Washington State. Orange to dark yellowish-brown grossular garnets mined near summit of Vesper Peak.

New Mexico. Fine transparent moonstone from Black Range is suitable for faceting. A known locality for 50 years.

Alaska. Fine nephrite in large boulders found at Dahl Creek above Arctic Circle. Slabs sawn on site, worked at Anchorage or in Idar-Oberstein.

Oregon. Contra luz opal with considerable play of colour, and hydrophane found.

Sri Lanka. Clinozoisite, anhydrite and sapphirine reported.

Canada and Greenland. Sapphirine from Fiskenasset, Greenland, found with other gem species. Similar formations at Somerset Island, Canadian Arctic, also yielded sapphirine and other gems.

Australia's Northern Territory. Reports gem zircon in a range of colours from Harts Range near Alice Springs.

Pearls are being thinly cultured on coloured (blue or green) nuclei made from powdered and sintered shell with an inorganic dye. Colour shows through the nacre attractively.

Sydney University physicist, David McKenzie, has made an amorphous, glass-like, carbon which readily scratches diamond and could have important commercial applications.

Synthetic quartz complete with seed plate is being used to carve 'health' pyramids in Korea. Spheres also reported. R.K.M.

KOIVULA, J.I., KAMMERLING, R.C., 1988. Gem news. *Gems & Gemology*, **24**, 4, 248-53. 9 figs in colour.

Diamonds.

China. A Hong Kong firm is to open a diamond polishing factory at Shunda, Guangdong Province.

India. Renewed activity reported from diamond field at Panna, N. India, and in Andhra Pradesh.

Diamonds with artificially filled cracks which were radio opaque to X-rays [white patches on film], ruling out silicone previously suggested as the filling medium. Rectangularly stepped tubes seen in a small diamond were thought to be laser drillings [going round sharp corners?], but absence of relieved inclusions suggests that these very unusual tubes were natural.

Diamond thin-film deposited from vapour is being explored by several firms. Most processes need high temperatures, but Beamalloy Corp of

Ohio have found an ion-beam enhanced deposition technique which can coat super-hard carbon [diamond?] onto plastics. GIA are backing attempts to do this on gems such as emerald and opal to study their properties and gemmological implications.

Coloured stones

A pink stone with RI 1.718 sold as garnet was shown to be spinel, but had it been near colourless, inclusions would have been needed to separate them.

Tsavorite is again being mined in East Africa.

A new find of quartz in the Poona area of India shows the 'Lowell Effect', iridescence around the minor rhombohedral faces, first seen in amethysts from Uraguay.

Smoky quartz with radiating rutile inclusions is reported from Inyo Co., California.

Quartz crystals coated with an ultra-thin film of gold give an attractive blue which is being promoted as 'Aqua Aura'. The coating is too thin to affect RI or SG which are those normal for quartz. [Abstractor understands that this so far can be done only with piezo-electric minerals, e.g. quartz or tourmaline.]

Some Umba River sapphires have been found with heat induced haloes around solid mineral inclusions, suggesting that they have been colour treated.

The 'American Golden' citrine, 22 982 ct, cut by Leon M. Agee and currently the largest known faceted stone, has been donated to the Smithsonian Institution, Washington DC.

A 15.97 ct Burma ruby sold by Sotheby's, New York, fetched $3 630 000, the highest price ever for a coloured stone.

Synthetics

The Siberian Academy of Sciences at Novosibirsk has grown synthetic beryl |by| hydrothermal means in a number of colours. Red (Co), blue (Cu), pink (Mn) and purple (Cr/Mn) crystals were grown on colourless seeds of beryl and are illustrated. Not known whether these will come onto the commercial market, but their absorption spectra should identify them if they do.

The Pool synthetic emerald. Further comments on the promotional literature, and a report that this has now been modified to admit that they are hydrothermally grown, but maintaining that the basic material used for the synthesis is from the Emerald Pool mine. R.K.M.

Koivula, J.I., Kammerling, R.C., 1988. A gemological look at Kyocera's synthetic star ruby. *Gems & Gemology*, **24**, 4, 237-40. 6 figs in colour.

A discussion and examination of the Inamori star rubies which are semi-transparent, of good colour and have convincingly natural looking stars. The flat semi-polished bases give them a synthetic look, but roughed and rounded they would be even more deceptive. Strong red fluorescence to UV and a chalky overtone with SUV; microscope showing exceptional fineness of rutile needles compared with the coarser ones in the natural stars; white smoke-like patterns seen in all five stones, all underline synthesis, while the infrared spectrum shows no water, suggesting a high-temperature melt process. Chemical analysis by X-ray fluorescence showed no gallium, which should have been present in any natural corundum. R.K.M.

Koivula, J.I., Shigley, J.E., Fryer, C.W., 1988. A gemological look at clinohumite. *Zeitschrift der Deutschen Gemmologischen Gesellschaft*, **37**, 1/2, 53-5, 2 figs in colour, 2 tables, bibl.

The Gemological Institute of America was given a rough crystal and a small faceted stone of clinohumite from the Pamir Range in the Soviet Union. Properties were identical to those previously recorded. There were primary and secondary liquid and gas inclusions. Strong zoning, specially in the cut specimen. In polarized light the rough crystal showed twinning. E.S.

Müllenmeister, M.S., 1988. Neuentdecktes im Dominikanischen Bernstein. (New finds in Dominican amber.) *Zeitschrift der Deutschen Gemmologischen Gesellschaft*, **37**, 1/2, 1-25, 37 figs in colour, bibl.

While Baltic amber is often cloudy, Dominican amber is usually transparent and can show well preserved inclusions. Best viewed when immersed in benzyl benzoate as these substances have nearly the same RI (1.54). The beautiful photomicrographs show many curious palaeontological organisms, as well as multiple phase inclusions, some being inorganic, such as sand and even raindrops, as well as air bubbles. UV brings out a blue fluorescence in blue amber, probably caused by finely distributed burnt wood particles. The interior of one blue amber shows fissures which are filled with pyrites. E.S.

Ncube, A.N., 1988. Occurrences of gemstones and ornamental stones in Zimbabwe. *Zeitschrift der Deutschen Gemmologischen Gesellschaft*, **37**, 3/4, 139-42, 1 map.

Short survey of gemstones and ornamental stones in Zimbabwe and their geological setting. E.S.

Pearson, D.G., Davies, G.R., Nixon, P.H., Milledge, H.J., 1989. Graphitized diamonds from a peridotite massif in Morocco and implications for

anomalous diamond occurrences. *Nature*, 338, 60-2, 5 figs.

Octahedral and other cubic forms of graphite, interpreted as pseudomorphs after diamond, have been found in garnet pyroxenite layers in the Beni Nousera peridotite massif, northern Morocco. The occurrence demonstrates that fragments of highly diamondiferous mantle are tectonically emplaced into the continental crust and thus providing a source for diamond different from the usual kimberlite/lamproite vulcanism. M.O'D.

PLATEN, H.v., 1988. Zur Genese von Korund in metamorphen Bauxiten und Tonen. (On the genesis of corundum in metamorphic bauxites and clays.) *Zeitschrift der Deutschen Gemmologischen Gesellschaft*, **37**, 3/4, 129-37, 4 graphs, 2 tables, bibl.

During the formation of the bauxites, selective accumulation of Al_2O_3 takes place together with other oxides which contribute to the coloration of the corundum. During the metamorphic formation of the corundum from diaspore, isomorphic replacement by the colouring oxides becomes difficult as reaction temperature lies at approximately 400°C. In metamorphic clays which are undersaturated in SiO_2 corundum is formed from dioctahedrical mica minerals. At low pressures muscovite, paragonite and margarite react to form feldspar components, corundum and vapour. At high pressures, the alkali-micas produce SiO_2-rich melt and corundum. Corundum can also be formed at low temperatures when muscovite and chlorite produce biotite. E.S.

SCHWARZ, D., BANK, H., HENN, U., 1988. Gemmologische Kurzinformationen. Neues Smaragdvorkommen in Brasilien entdeckt: Capoeirana bei Nova Era, Minas Gerais. *Zeitschrift der Deutschen Gemmologischen Gesellschaft*, **37**, 3/4, 146-7.

This paper deals with a newly discovered emerald occurrence in Brazil: Capoeirana near Nova Era, Minas Gerais. The material is comparable to that obtained from the Belmont Mine, with similar inclusions. Alexandrites and high quality aquamarines are found in the district. E.S.

SCHWARZ, D., EIDT, TH., COUTO, P.A., 1988. Die Smaragde des Minengebietes Socotó, Bahia, Brasilien: Vorkommen und Charakteristika. (The emeralds of the mining district of Socoto, Bahia, Brazil: their occurrence and characteristics.) *Zeitschrift der Deutschen Gemmologischen Gesellschaft*, **37**, 3/4, 89-112, 26 figs (6 in colour), 8 tables, bibl.

The region is described in detail. There are granite batholiths whose pegmatites (source of Be) intruded the rock of the Serra de Jacobina and contacted an iron and chromium rich zone, forming the emeralds. RI varies from 1.597 to 1.582 and 1.567 to 1.590, birefringence from 0.007 to 0.009. SG 2.67 – 2.72. Inclusions show growth tubes and channels, regions with elevated concentration of inclusions, colour zones and growth striations, also fractures and fissures, fluid inclusions, two- phase but rarely three-phase inclusions. A number of mineral inclusions were identified. Mining is primitive, each owner marking his claim and supervising the work. Apart from these workings, groups of older men, women and children work and sieve the discarded material looking for emeralds. Altogether about 4000 people are assumed to be working in the district. E.S.

SMITH, K.L., 1988. Opals from Opal Butte, Oregon. *Gems & Gemology*, **24**, 4, 229- 36. 11 figs in colour.

Among the several varieties found, contra-luz, crystal and hydrophane opal are commercially the most important. Contra- luz displays its colour only when light shines through the opal. Much material crazes badly on exposure to dry air. Very slow drying may obviate this in about half the mined material. Oven-drying in wet sand yields about 25% uncrazed. The water content varies through the stone and causes uneven shrinkage and crazing. R.K.M.

THOMPSON, R.J., 1988. Jewels for a crown: the gemstones of Pakistan. *Australian Gemmologist*, **16**, 12, 471-2, 2 figs in colour.

A brief and imaginative eulogy of the gem minerals of the Hindu Kush, Karakoram and Himalayas. R.K.M.

WABER, N., FRIEDEN, T., HÄNNI, H.A., IFF, R., NIGGLI, E., 1988. Zur Farbveränderung von Korunden bei Hitzebehandlung. (Colour changes in corundum through heat treatment.) *Zeitschrift der Deutschen Gemmologischen Gesellschaft*, **37**, 1/2, 57-68, 6 graphs, 1 table, bibl.

The experiments were made with 17 colourless or only slightly coloured sapphires from Ratnapura, Sri Lanka. They were heat treated for six hours at 1720±10°C in an argon atmosphere. Six sapphires became blue, three an intense cornflower blue. Four stones turned out smoky coloured, while in seven sapphires zoning in blue and brown became apparent. The stones were carefully examined under a microscope before and after treatment, but no special features explaining results were found. Absorption spectra of the stones after treatment are reproduced. E.S.

Book Reviews

BAUMGÄRTEL, R., QUELLMELZ, W., SCHNAIDER, H., 1988. *Schmuck-und Edelsteine.* (Jewellery and gemstones.) VEB Deutscher Verlag für Grundstoffindustrie, Leipzig. pp. 300. Illus. in black-and-white. DM60.

Forming part of the series *Monographienreihe Nutzbare Gesteine und Industrieminerale*, this is a cheaply but well produced book describing a large number of gem minerals with details of their physical and chemical properties and their occurrence. Characteristic crystals are shown for most species and their optical directions are given in some cases. There is a table giving trade and varietal names and identification tables with a good bibliography. Details seem well up-to-date though some of the species included will scarcely ever be seen in cut form. Reproduced from typewriting, the book nevertheless makes a good impression as have others from this state publishing house and for those who can read German it can be highly recommended. M.O'D.

FEDERMAN, D., 1988. *Modern jeweler's gem profile: the first sixty.* Vance Publishing Corporation, Shawnee Mission, Kansas. pp. 131. Illus. in colour. £25.00.

The book describes sixty of the best-known gem species, each of which is illustrated in full page colour facing the description which gives up-to-date details of discovery and marketing. The information given appears to be accurate and is certainly presented in a clear and interesting way. The book will look good in the shop and it is clearly intended to be used in this way. The fine colour photographs are by Tino Hammid, who has made a special study of gemstone photography. M.O'D.

GERE, C., MUNN, G.C., 1989. *Artists' jewellery.* Antique Collectors' Club, Woodbridge. pp. 244. Illus. in colour. £29.95.

This welcome book describes jewellery made by the Pre-Raphaelites and their followers down to the workers in the Arts and Crafts movement, thus covering the late nineteenth and early twentieth centuries. The introductory chapter discusses the links between art and fashion and leads naturally into a further discussion of the role of art, this time in relation to commerce. The Romantic and Aesthetic fashions are then examined with particular reference to the work and influence of William Morris and A.W. Pugin.

D.G. Rossetti makes his appearance in chapter five which concentrates upon a period in which the taste for naturalism began to develop. Ruskin was lecturing on 'Natural ornament' in 1853 and the representation of plants in jewellery probably dates from that time though its incorporation into general fashion came in the 1880s. This chapter gives some interesting sidelights on parts of Ruskin's career. By the late 1880s the first signs of what came to be known as the craft revival could be seen and a good deal of work was carried out in Birmingham.

The final chapter gives details of methods and techniques and there is a useful bibliography. This is a most attractive book; it incorporates many hitherto unpublished drawings, many in colour, and the standard of the photography is high. M.O'D.

GRABOWSKA, J., 1983. *Polish amber.* Interpress Publishers, Warsaw. pp.39. Illus. in black-and-white and in colour. Price on application.

A larger book than the pagination suggests (there is a large colour section at the back), this is a translation of a Polish original drawing on high-quality photographs from the Castle Museum in Malbork, the National Museum in Krakow, the National Museum in Warsaw, the Archaeological Museum in Gdańsk, The Archaelogical and Ethnographic Museum in Lódź, the Earth Science Museum in Warsaw, the District Museum in Tarnów, the State Art Collection in Dresden, the Treasury in Jasna Góra, Cathedral Treasury in Wawel [Krakow], and a church in Wegrów. These collections are not all well known in the west. The short text describes the finding and fashioning of Baltic amber in Poland with a commentary on the work of artists practising today.

This is a most attractive book and as material from Eastern Europe goes very quickly out of print, readers should look out for it wherever possible. There are said to be French, German and Polish editions. M.O'D.

GRIBBLE, C.D., 1988. *Rutley's elements of mineralogy.* 27th edn. Revised by C.D. Gribble. Unwin Hyman, London. pp. xii, 482. £12.95.

Rutley was first published in 1882 and the time had come for another revision after twenty years. Although the Rutley form has remained, the text is largely updated; in particular the silicates have a chapter to themselves in which they are described under a crystal-chemical classification. Dana order is used for non-silicates. More stereographic projections are used in the crystallography section and optical mineralogy has been completely revised.

In paperback this is still a useful book and the author's predilection for Scottish locations can be traced. Several undesirable names for gem minerals make an unwelcome reappearance and the upper limit for the specific gravity of lapis lazuli is given as 2.45. Location citations could have been better chosen. M.O'D.

JAFFE, H.W., 1988. *Crystal chemistry and refractivity.* University Press, Cambridge. pp. x, 335. Illus. in black-and-white. £55.00.

The book describes the composition of natural and synthetic crystals on the atomic level with emphasis upon the nature of chemical bonding. The relationships of atomic arrays, electronic structure and optical properties are discussed with particular attention being paid to refractivity. In the first part of the book the general principles of crystal chemistry are reviewed and the concept of refractivity introduced: in the second part examples of the structures and bonding of a number of minerals and artificial substances are presented with high-quality illustrations. Some previously unpublished data on refractivity and polarizability and their applications to mineralogical needs are given. Each chapter has its own bibliography. M.O'D.

NÉRET, G., 1988. *Boucheron.* Rizzoli, New York. Illus. in black-and-white and in colour. £60.00.

The book is subtitled *Four generations of a world-renowned jeweller,* and jumping ahead through the text to modern times it is clear that this celebrated firm has for long been in the forefront, not only of jewellery design but of large-scale projects such as that commissioned for the housing of the Iranian Crown Jewels in 1958. With branches in London, New York and Moscow, as well as in Paris, there can be few discerning jewellery buyers who will not be grateful for Frédéric Boucheron's foundation of the firm in 1858. From the first the clients included not only the rich but the flamboyant and it is good to see the book reflect this in its style and production. Three hundred pieces have been chosen to illustrate the firm's continuous alliances with the contemporary — for it has always been ahead of many of its more traditional competitors — and these are well shown on the pages (which are of good quality paper).

The book follows the history and work of the firm chronologically and there is a short bibliography. With the price of second-hand jewellery books today and with the prospect (one day) of severe limitations on paper supply serious students of jewellery and gemstones should be sure to build up their collections of the relevant literature now. M.O'D.

O'DONOGHUE, M., 1988. *Crystal growth – a guide to the literature.* British Library: Science Reference and Information Service, London. pp. 67. £12.00.

This very useful guide is divided into the following sections: introduction, the Science Reference and Information Service, bibliographies, general topical works, journals, numerical data, conferences, crystal structures, phase relationships, solution growth, chemical vapour transport and solid phase growth), industrial crystallization, mixed crystals, ornamental and other uses of crystals, popular works, product availability, index (good). Some 23 pages are devoted to the literature of growth methods and this covers both Western and Russian technology – almost all are available in the British Library in London. The guide is an excellent start for anyone interested in crystal growth and is the third in a series by the same author. The earlier titles cover the literature of gemstones and mineralogy respectively. The high cost possibly reflects the somewhat limited appeal of the title and a consequently small print run. E.A.J.

SALOMON, P., ROUDNITSKA, M., 1986. *Tahiti – the magic of the black pearl.* Tahiti Perle, Tahiti, French Polynesia. pp.221. Illus. in colour. Price on application.

Some may see this volume as a superior 'coffee-table' book promoting the black pearl of Tahiti – maybe it is, but it also contains much technical and historical detail not available elsewhere. The history of the local mother-of-pearl industry is recounted as is the development of the culturing of the black pearl along Japanese lines; there are many useful production statistics. The latter part of the book describes modern marketing and promotion and may be said to be somewhat poetic. It makes interesting reading, contains an abundance of facts and the photographs delight the eyes. E.A.J.

SCHWARZ. D., 1987. *Esmeraldas: inclusões em Gemas*. (Emeralds: inclusions in gemstones.) Escola de Minas, Universidade Federal de Ouro Preto, Ouro Preto, Minas Gerais, Brazil. pp. xi, 439. Illus. in black-and-white and in colour. Price on application.

Despite the subtitle, this is a book about emerald in general since the chapter on inclusions takes up only the last section. Instead we have an exhaustive treatment of the mineralogy of the beryl group with particular reference to emerald; here the major occurrences are described with papers cited up to 1986 and a good deal of detail is given. After this section the different occurrences are classified on the basis of their genesis before notes are given on emerald synthesis.

Then comes the section on inclusions. These are described in what has come to be the traditional order of protogenetic, syngenetic and epigenetic. The various deposits are then discussed with reference to characteristic inclusions; synthetic emeralds are included at the end of this section. An appendix covers chemical analyses of Brazilian emeralds; new data on the Brazilian locality Santa Terezinha; emerald imitations; availability; gemmological microscopy and chemical composition of the minerals found as inclusions and an excellent bibliography.

Despite the somewhat low standard of production, this is a first-rate book and can be highly recommended. M.O'D.

Gemas do Brazil. (Gems of Brazil.) Mercedes-Benz do Brasil SA, Sao Bernardo do Campo, SP, Brazil, 1987. pp.130. Price on application.

This is a large-format limited-print prestige publication with coloured pictures of a number of species, some of which can scarcely be counted as ornamental but which nevertheless are attractively presented with captions and accompanying text in English and Portuguese. M.O'D.

A guide to fossicking in the Northern Territory. 2nd edn. Northern Territory Geological Survey, Darwin, 1986. pp.73. Illus. in colour. Australian $9.00.

A very-well produced and illustrated guide to the minerals to be found in the Northern Territory of Australia. The number of ornamental minerals is surprisingly large and includes quartz, garnet, epidote, tourmaline, zircon, prehnite, beryl, ruby and kyanite. M.O'D.

Opale Australijskie. (Australian opals.) Muzeum Ziemi, Warsaw, 1988. (Unpaged.) Illus. in colour. Price on application.

A short but attractive catalogue of the Australian opal collection of John and Zofia Benny-Wojciechowski, held at the Museum of the Earth, Warsaw, Poland, from May to August 1988. M.O'D.

ADVERTISING IN THE JOURNAL OF GEMMOLOGY

The Editors of the *Journal* invite advertisements from gemstone and mineral dealers, scientific instrument makers, publishers and others with interests in the gemmological, mineralogical, lapidary and jewellery fields.

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Proceedings of the Gemmological Association of Great Britain and Association Notices

MEMBERS' MEETINGS

Midlands Branch

On 21 April 1989 at Dr Johnson House, Colmore Circus, Birmingham, the Annual General Meeting was held at which Mrs Janet S. Leek, FGA, and Mr John R. Bugg, LL B., FGA, were re-elected Chairman and Secretary respectively.

The AGM was followed by an illustrated lecture by Mr G. Millington entitled 'Inclusions in gemstones'.

North West Branch

On 19 April 1989 at Church House, Hanover Street, Liverpool 1, Mr Walter Wild, FGA, gave a talk on his collection of rare gemstones and brought along a selection for members to view.

On 17 May 1989, at Church House, Mr Ron Walledge gave a talk on opal mining.

On 23 May 1989, members visited De Beers Consolidated Mines, Charterhouse Street, London EC1, where a lecture was given by Mr Roger van Eeghen.

On 14 June 1989 at Church House, Mr Alan Hodgkinson, FGA, gave a lecture entitled 'Colourization of diamond'. He also displayed some of the rare gemstones from his collection.

COUNCIL MEETING

At a meeting of the Council held on 21 April 1989 at the Royal Automobile Club, 89 Pall Mall, London SW1, the business transacted included the election to membership of the following:

Fellowship

Slack, Richard D., Cardiff. 1984

Ordinary Membership

Baird, Renee, London.
Bradford, Nikki A., Hassocks.
Davies, Maria C., Bridgend.
Day, Michael P., London.
Deacon, Daren J., Brighton.
de Haulleville, Jonja, Bousval, Belgium.
Dimitriadie, Milyo M., Rhodes, Greece.
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Lipton, Heinz, London.
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Pomeroy, Terence L., Exeter.
Sage, Barbara L., Spalding.
Sorensen, Carsten, Rungsted Kyst, Denmark.
Sprague, Frances A., Exeter, Devon.
Wates, Peter J., Coulsdon.

THE CARNEGIE MINERALOGICAL AWARD

Dr John Sinkankas has been awarded the Carnegie Mineralogical Award for 1988. The prestigious award recognizes contributions which promote and improve the preservation, conservation and educational use of minerals and mineral collecting, ideals exemplified in the Hillman Hall of Mineralogy at the Carnegie Museum of Natural History. Dr Sinkankas was presented with a certificate of recognition, a bronze medallion and a cheque for $1500.

Dr Sinkankas' contribution of the fields of mineralogical and gemmological literature is legendary. John was born in 1915 in Paterson, New Jersey, a fortunate birthplace as he was collecting zeolite minerals at the famous Newstreat Quarry by the age of seven. At 21 he entered the US Navy and graduated the Pensacola Naval Air Station as an aviator. Travel abroad gave John numerous opportunities to observe gem mining, cutting and marketing as well as spare time aboard ship to work on his lapidary skills. After retirement from the Navy in 1961, Captain Sinkankas spent five years as research assistant in mineralogy at the Scripps Institution of Oceanography, served for a time as editor of the *Lapidary Journal* and started,

with his wife Majorie, Peri Lithon Books, a business supplying antiquarian books in the earth sciences to collectors.

To date, Dr Sinkankas has published 11 books on mineralogy, gemmology, prospecting and lapidary art, among them the critically acclaimed *Gemstones of North America, Mineralogy for Amateurs* and, most recently, *Emerald and other Beryls*. He has also been a frequent contributor to popular and scientific journals, including the *Journal of Gemmology*.

In 1982 John was given the Gemological Institute of America's Distinguished Associate Award at the GIA's first International Gemological Symposium. In the same year he was awarded a Doctorate of Humane Letters from William Paterson College, Paterson, New Jersey.

Throughout the years John and Marjorie assembled an extensive library of gemmological books and related literature, which, in 1988, was purchased by the GIA. Over the last year the GIA's existing library was expanded to accommodate the 8000 to 10 000 volume collection, and the Richard T. Liddicoat Library and Information Center has now been opened so that the Sinkankas Library can be used by researchers and other interested individuals.

FORTHCOMING MEETINGS

On **Wednesday 11 October 1989** at the Flett Theatre, Geological Museum, Exhibition Road, London SW7, a lecture will be given by Mr John I. Koivula, GG, FGA, of the Gemological Institute of America, Santa Monica, California.

The Reunion of Members and Presentation of Awards is to be held on **Monday 6 November 1989** at the Guildhall, London EC2. Mr R. Crowning-shield, GG, FGA, of the New York laboratory of the Gemological Institute of America will be presenting the awards.

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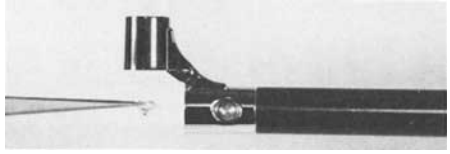

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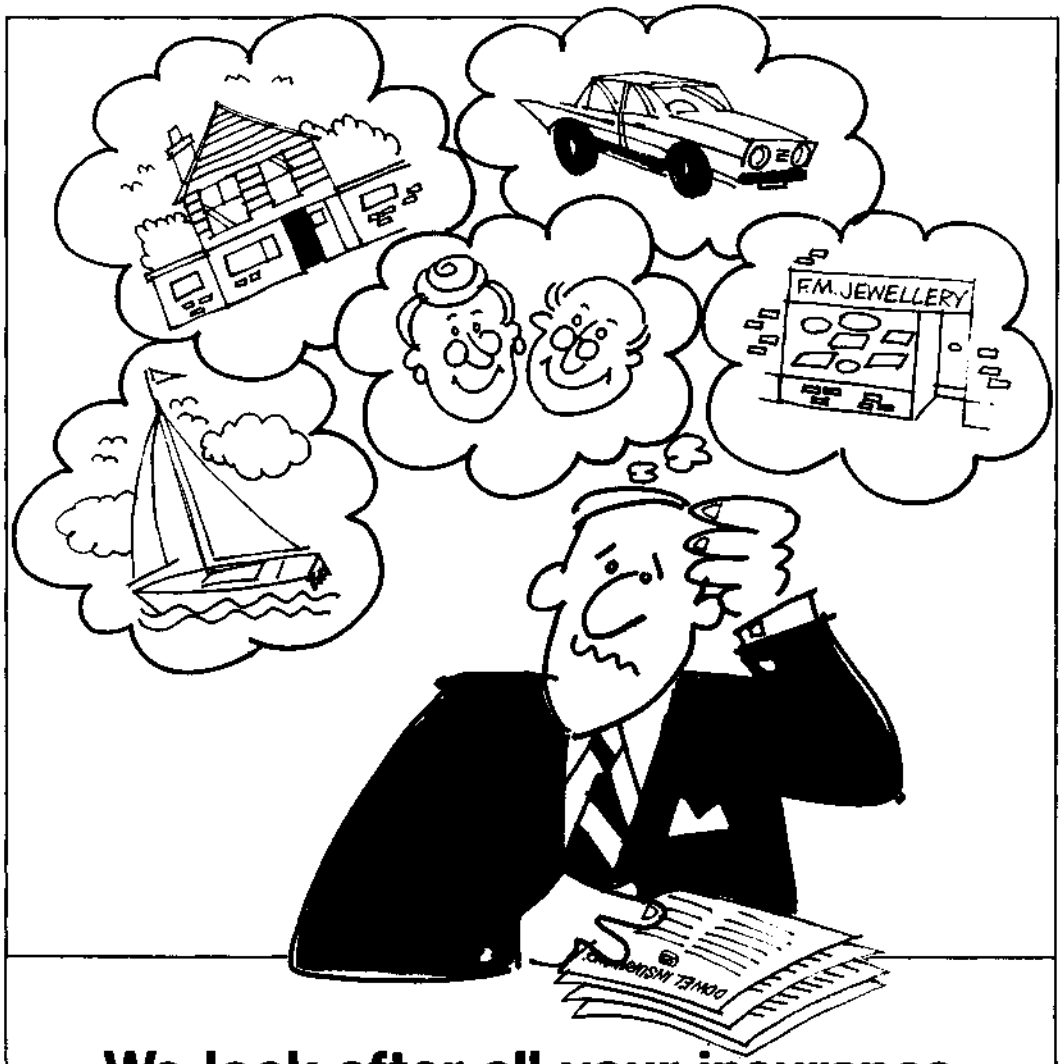

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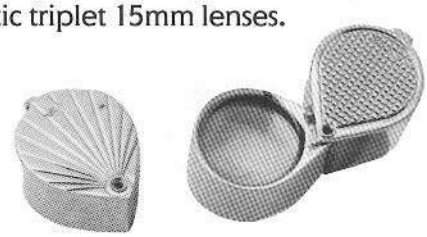

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The Arms and Crest of the Association, conferred by a grant of Arms made by the Kings of Arms under royal authority. The cross is a variation of that in the Arms of the National Association of Goldsmiths of Great Britain and Ireland. In the middle is a gold jewelled book representing the study of gemmology and the examination work of the Association. Above it is a top plan of a rose-cut diamond inside a ring, suggesting the scrutiny of gems by magnification under a lens. The lozenges represent uncut octahedra and the gem-set ring indicates the use of gems in ornamentation. The lynx of the crest at the top was credited, in ancient times, with being able to see through opaque substances. He represents the lapidary and the student scrutinizing every aspect of gemmology. In the paws is one of the oldest heraldic emblems, an escarbuncle, to represent a very brilliant jewel, usually a ruby. The radiating arms suggest light diffused by the escarbuncle and their tips are shown as jewels representing the colours of the spectrum.

Historical Note

The Gemmological Association of Great Britain was originally founded in 1908 as the Education Committee of the National Association of Goldsmiths and reconstituted in 1931 as the Gemmological Association. Its name was extended to Gemmological Association of Great Britain in 1938, and finally in 1944 it was incorporated in that name under the Companies Acts as a company limited by guarantee (registered in England, no. 433063).

Affiliated Associations are the Gemmological Association of Australia, the Canadian Gemmological Association, the Gem and Mineral Society of Zimbabwe, the Gemmological Association of Hong Kong, the Gemmological Association of South Africa and the Singapore Gemologist Society.

The *Journal of Gemmology* was first published by the Association in 1947. It is a quarterly, published in January, April, July, and October each year, and is issued free to Fellows and Members of the Association. Opinions expressed by authors are not necessarily endorsed by the Association.

Notes for Contributors

The Editors are glad to consider original articles shedding new light on subjects of gemmological interest for publication in the *Journal*. Articles are not normally accepted which have already been published elsewhere in English, and an article is accepted only on the understanding that (1) full information as to any previous publication (whether in English or another language) has been given, (2) it is not under consideration for publication elsewhere and (3) it will not be published elsewhere without the consent of the Editors.

Papers should be submitted in duplicate on A4 paper. They should be typed with double line spacing with ample margins of at least 25mm all round. The title should be as brief as is consistent with clear indication of the content of the paper. It should be followed by the names (with initials) of the authors and by their addresses. A short abstract of 50–100 words should be provided. Papers may be of any length, but long papers of more than 10/000 words (unless capable of division into parts or of exceptional importance) are unlikely to be acceptable, whereas a short paper of 400–500 words may achieve early publication.

Twenty five copies of individual papers are provided on request free of charge; additional copies may be supplied, but they must be ordered at first proof stage or earlier.

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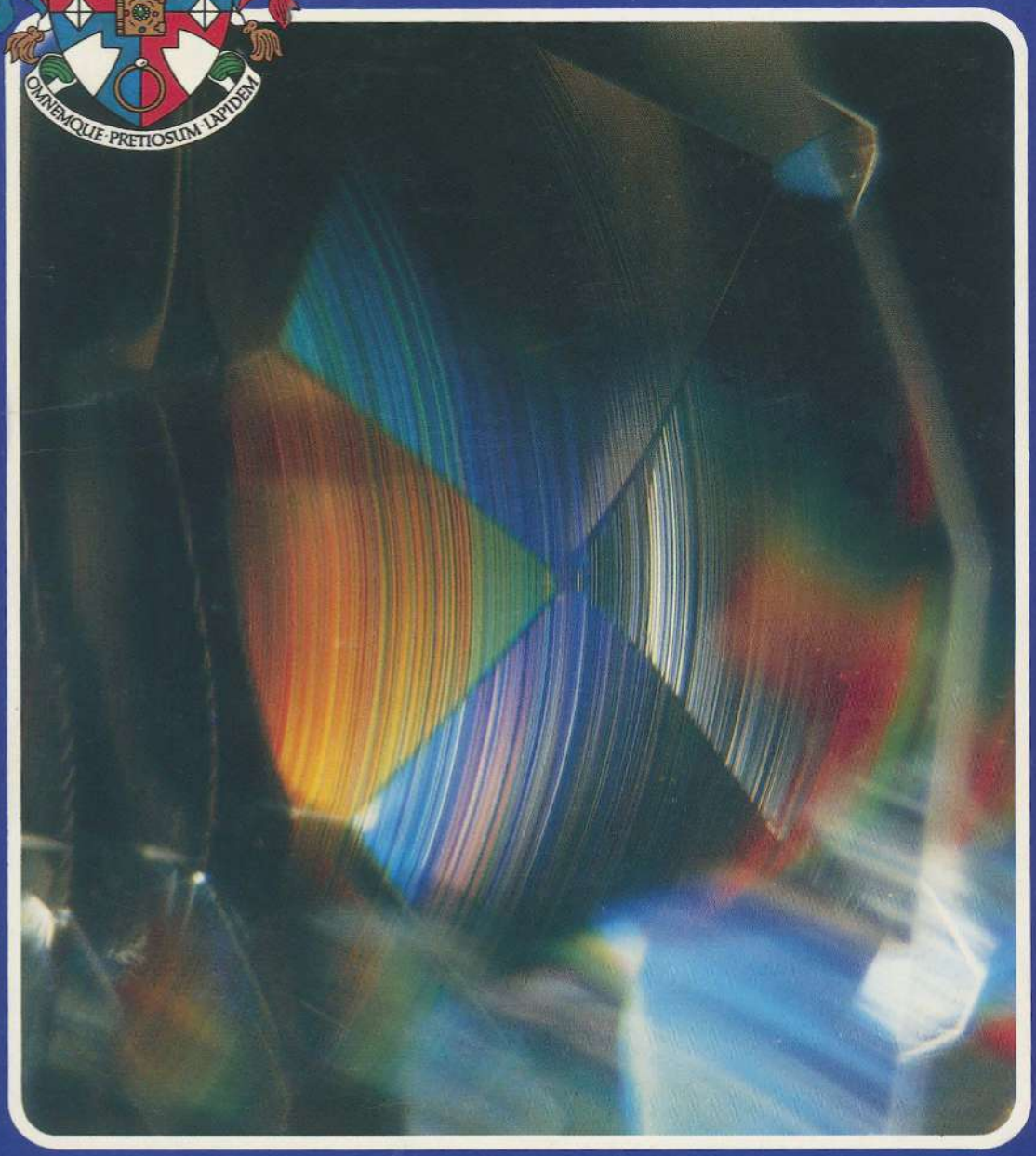

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Cover Picture

Irridescent glass with botryoidal form, exhibiting spectral colours due to interference on thin layers. (See 'Iridescent natural glass from Mexico', p.488.)

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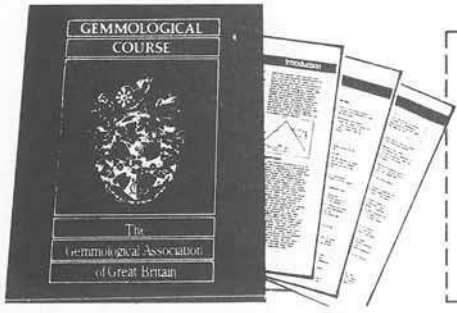

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Abstract

Various cabochon-cut star sapphire samples from the North-West of Kenya were examined to determine all the inclusions which may contribute to cause the asterism effect.

Optical observations, electron microprobe and X-ray diffraction analyses were carried out. The inclusions recognized were: cloudy areas, acicular inclusions, 'silk', tube-like inclusions, transparent crystals, 'feathers' and healed fractures. The acicular inclusions responsible for the asterism are separated into microstriae and needle-like inclusions.

Genetic growth considerations of these star sapphires are deduced.

Introduction

The world's main sources of star sapphire, up to this time, have been Burma and Sri Lanka. Kenya is now entering the list and becoming the third country and indeed the first country in Africa to produce and supply star sapphire.

Kenya and Tanzania, in addition to the many unusual gemstones, have been known to produce corundum in all possible colours and qualities from numerous occurrences. However, none of the sources ever supplied rough which can produce star stones in commercial quantity.

Several years ago, a small lot of blue sapphires appeared on the Kenyan gem market of which some samples produced a star. However, the source was never made known and similar or larger lots never appeared on the gem market.

Now the source has been relocated, and sapphire rough has started appearing on the local market since mid 1987. Hence the rough is available in commercially acceptable quality and quantity.

Some other rough with a fair amount of transparency can be faceted to produce nice blue to bluish-green gems. Lower grade rough can be used to produce cabochons (without a star) and even beads.

Most of the rough samples are slightly worn crystals with frosted surfaces and a very low percentage (1–5%) of either completely rounded or well-shaped crystals. In the sapphire lots there are some pieces of dark brown to black obsidian, brown zircon and translucent to opaque dark green epidote.

Location and geology

Corundum appears in Kenya as patches in metamorphic rocks (gneisses) which are believed to have been desilicated by a dunite (Parkinson, 1947). The same applies to the corundum of the nepheline-syenite dyke-like bodies in the valleys (Joubert, 1966).

Usually the crystals are of dirty-brown colour and sometimes fractured.

In the North-Western region, corundum is found in Tertiary volcanic olivine basalts or in secondary deposits (Bridges, 1982).

The actual, geologically important, deposit is not identified. Sapphires are being picked up from the large desert type sandy area in the North-Western region of Kenya. This is in the Turkana district of the Northern Rift Valley Province, and lies on the West side of Lake Turkana (formerly Lake Rudolph) (Figure 1).

This region is part of the Mozambique orogenic belt extending southwards to Malagasy and Mozambique and northwards through the Sudan and Ethiopia (Bridges, 1982).

The area is in the middle of the Y-shape of the fault systems, and stretches from the turn off the main Lodwar road to the Sudan. This is a secondary road (dirt road) leading to the Ethiopian border through Murangering and Lokitaung villages (see map).

Sapphires are mined from the top soil of desert type plains (Quaternary sediments) caused by the erosion and peneplanation of hills, namely Pelekesh (1794m) and Mornerith (1438m). The primary source of the star sapphires and their original occurrence is yet to be investigated. However, areas from which sapphires are probably collected are shown by the dashed area in the map (Figure 1).

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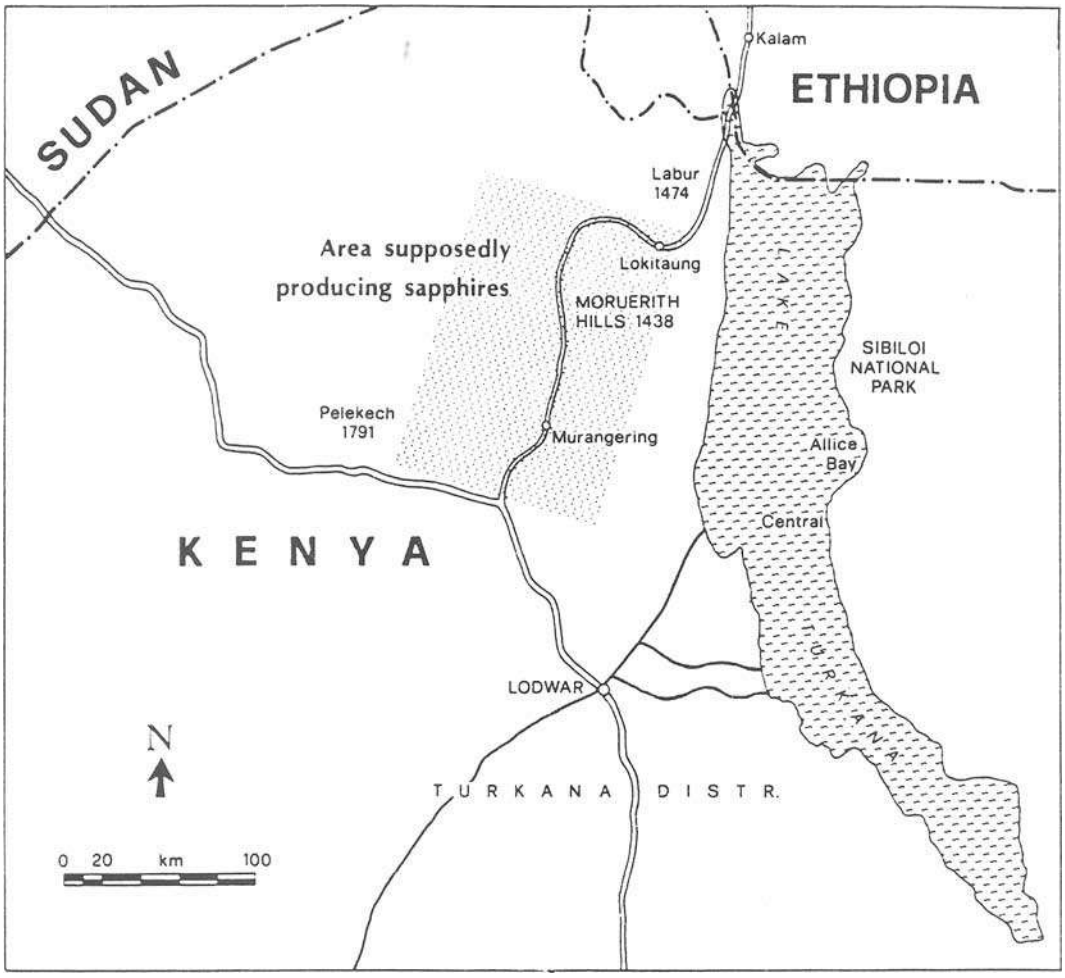

Fig. 1. This map shows the location of the star sapphires in the North-western region of Kenya. The mining area, dashed area in the map, is located in the Turkana district of the Northern Rift Valley Province on the west side of Lake Turkana.

Rough sapphire: its grading and cutting

The examined samples are in the form of ten cabochon-cut star sapphires (total weight: 1.253 gm). They cover various shades of body colour viz. blue, brownish-blue, greenish-blue, greenish-yellow, and blackish-brown.

They range in size from 3.6 × 3.8 × 1.7 mm to 5.9 × 5.3 × 3.0 mm; the weight of each specimen was measured to be a minimum 0.060 to maximum 0.782 gm.

'Silk' occurs in all the cabochons, but in eight of them it traverses the whole of the host sapphire and causes 6- and 12-rayed asterism. Nevertheless, in samples 9 and 10, the 'silk' appears densely woven, causing only 'silky-spots'.

The samples nos. 1, 2, 4, and 7 present a perfect star which displays six equally narrow rays, with characteristic angles intersecting at 60°; of equal length and brightness, extending fully in each specimen. A weak star not extending fully is displayed by the cabochons nos. 3, 5, 6, and 8.

This different behaviour is ascribable to deviations from the crystallographic arrangement of the elongated systems of inclusions in the body of the host sapphire, intergrown with the basal plane and aligned parallel to the prisms of first or second order.

Gemmological investigation

The cabochon sapphires were subjected to standard gemmological tests, and the results are discussed below.

Visual appearance and absorption spectra

The samples range in clarity and are classified as sapphires from medium transparent (diaphane) to opaque.

To the unaided eye, five cabochons, samples nos. 1, 2, 3, 4 and 6 appear a medium to excellent blue colour (Figure 2); nos. 5, 9 and 10 are dark-brownish to dark-blackish-blue (Figure 3), and Nos. 7 and 8 a pale greenish-blue to greenish-yellow.

Electron microprobe analyses carried out on the dark or brownish sapphires revealed the presence of iron: about 1-2%, and the absence of titanium. Therefore the colour hue is probably due to Fe_2O_3 dispersed in the bulk crystals (Weibel *et al.*, 1981).

The visible light absorption spectrum expressed by the lines at 450, 460 and 470 nm, is referable to iron, samples nos. 1 to 4 and 6 to 8. Instead the samples nos. 5, 9, and 10 are distinguished by a faint line at 470 nm and a single band from 450 to 460 nm.

Refractive indices, dichroism and fluorescence

Tested with gemmological refractometers, the refractive indices of the sapphire cabochons were evaluated by using the 'distant vision' method. It was possible to determine only an average value of $n_D = 1.765$ for all samples.

Using a dichroscope, various medium pleochroic colours were observed: namely shades of blue to green-blue and yellow to brownish.

Under both long- and short-wave UV radiation and through the Chelsea colour filter, the sapphires remained inert.

Specific gravity

Density was measured by means of the Berman balance. The data collected proved to be unreliable due to the peculiar characteristics of these sapphires rich with inclusions.

The results were estimated to be approximately 3.99 – 4.03 g/cm^3. Therefore the minimum value is 3.97, for sample 4, and the maximum is 4.08, for sample 10.

Micropscopic and SEM observations of the inclusions

The cabochons were examined with gemmological binocular microscopes and were tested both by by electron microprobe and X-ray diffraction procedures.

The specimen observed in immersion showed the presence of a frame of a blue colour inhomogeneously distributed in bands. Broader zones and the blue frame are made evident in the clustering of tiny needles.

A multitude of inclusions were observed and segregated into five categories:

1) Cloudy areas
2) Acicular inclusions
3) 'Silk'
4) Tube-like inclusions
5) Transparent crystals
6) 'Feathers' and healed fractures.

1) *Cloudy Areas*

Precise observations made it possible to select this type of inclusions into two groups:

- Striae
- Hazy and nebulous inclusions.

The cabochons were examined above dark field illumination and parallel striae were identified approximately orientated according to the length of the cabochon (Figure 3). However, it was difficult to discern the precise nature of this lamellar structure and the striae.

Microscopic, strongly magnified observations revealed that the unevenly spaced parallel striae are sometimes undulating and parallel to the rhombohedral faces of the crystal. These directions of weakness can probably be ascribed to lamellar twinning, also instigated by an incipient decomposition along these planes.

This hypothesis is supported by the sporadic presence of white, minute flakes, associated with the above mentioned striations.

Also present are straight-edged blue coloration and angular-growth zoning, which are referred to both multiple original growth episodes and to the hexagonal symmetry of the sapphire. (Figure 4.)

2) *Acicular Inclusions*

These inclusions form acicular systems crossing each other, and provoke the many-rayed stars (Figure 5), and may be roughly classified into two groups:

- Micro-striae
- Needle-like inclusions.

Optical observations and electron microprobe analyses were accomplished on each selected area of the samples, preferentially on the protruding terminations of the acicular inclusions. It was necessary to operate on the curved side of the cabochons, resulting in a larger degree of experimental uncertainty.

The micro-striae and the needles are apparently exactly alike, but are distinguished by means of electron microprobe analyses.

It was usually found that the former show a chemical composition as well as a pattern of minor elements similar to that of the embedding sapphire.

These micro-striae represent growth periods alternating with temperature variations during the

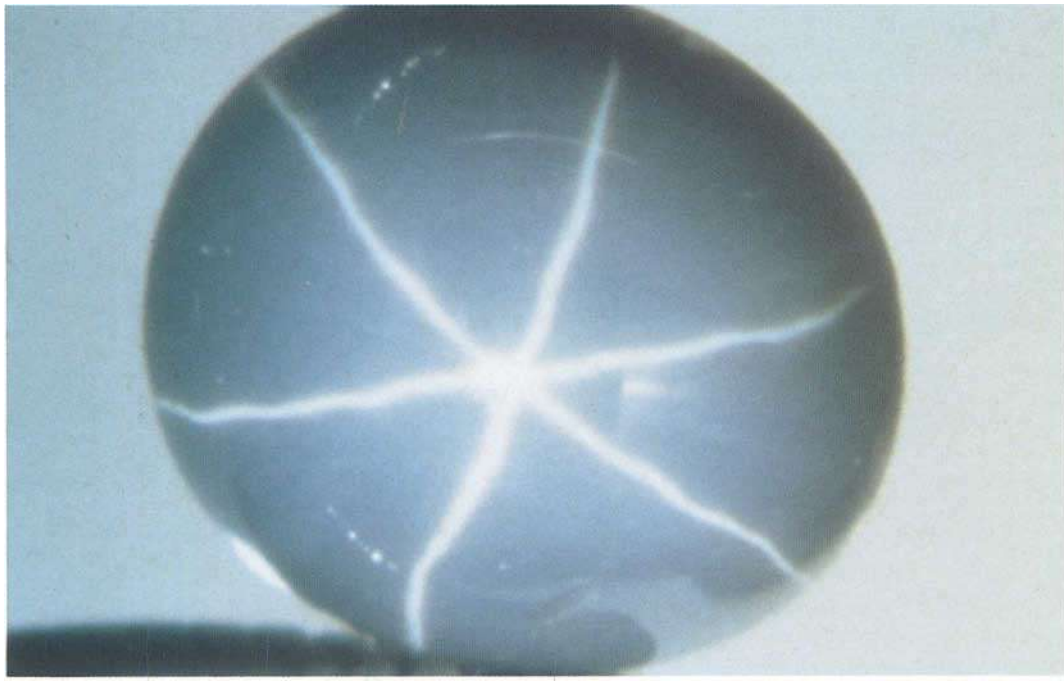

Fig. 2. A blue cabochon-cut star sapphire from Kenya displays a six equally rayed asterism. The hexagonally orientated acicular inclusions engender the six equally spaced narrow rays of same length and brightness, very sharp edged. The star effect in these gems is identical to that seen in the synthetic Linde sapphires. 10x.

Fig. 3. Dark brownish-blue cabochon-cut star sapphire from Kenya. The hue is related to the presence of hematite needles; the parallel striae are ascribed to a lamellar twinning structure. 8x.

Fig. 4. The straight-edged blue colour bands show the hexagonal sapphire symmetry and are referred to both multiple growth episodes and contemporary changes in the chemical environment. Fluid 'feather' and haloes of iron compounds create a characteristic microscopic appearance of these star-sapphires. 20x.

crystal growth.

Occasionally, an amount of titanium in the latter was ascertained, attesting the presence of rutile. The electron microprobe analyses also indicated a local enrichment of iron which would suggest the presence of needles of hematite.

The colour of the cabochons appears to be linked to these peculiar inclusions.

The excellent blue colour is preferentially ascribed to the needle-like inclusions of both micro-striae and of sporadic, acicular rutile crystals (samples nos. 1, 2, 3, 4, and 6). On the other hand, the hematite needles are responsible for the dark colour of sapphires wherever they are present (samples nos. 5, 7, 8, 9 and 10).

3) *'Silk'*

All samples show elongated thread-like needles

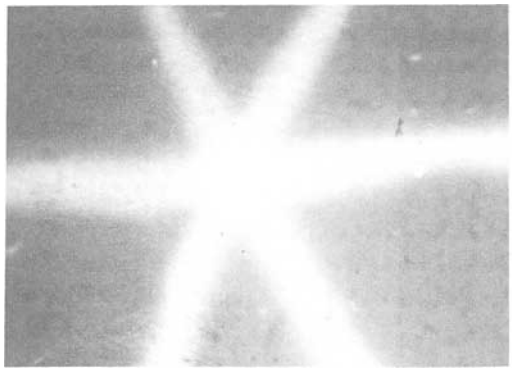

Fig. 5. Hexagonally orientated acicular systems provoke a six-rayed star in blue sapphire from Kenya. 30x.

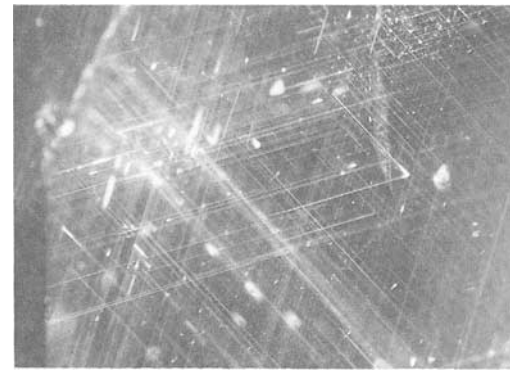

Fig. 6. The fine rutile needles constitute the 'silk', and form large or small nests. The regularly intergrown twin crystals are characterized by a re-entrant angle. 40x.

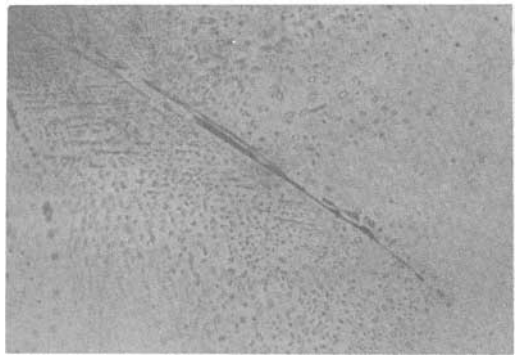

Fig. 7. A 'fingerprint' healing area is formed around a tubular cavity-filling of iron compounds. 45x.

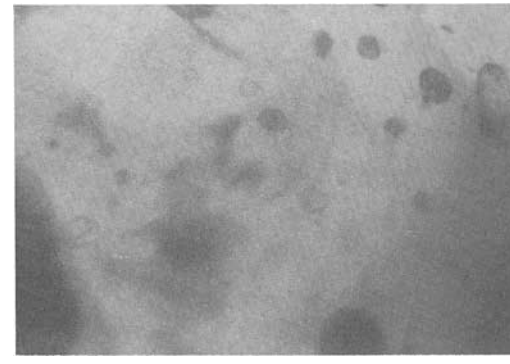

Fig. 8. Crystals of transparent and hexagonal corundum, brownish and prismatic rutile and haloes of iron compounds, are included in the host star sapphires from Kenya. 35x.

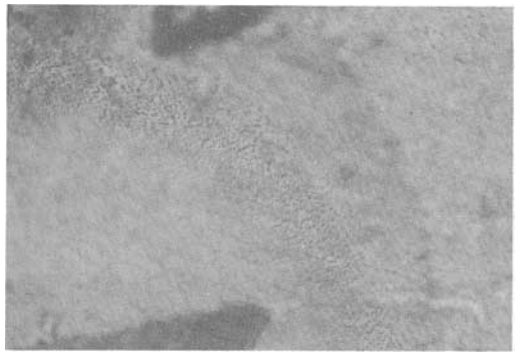

Fig. 9. Feathers of fluid inclusions, laminae of hematite and cavity fillings of iron compounds are related to the dark colour of the star sapphires from Kenya. 40x.

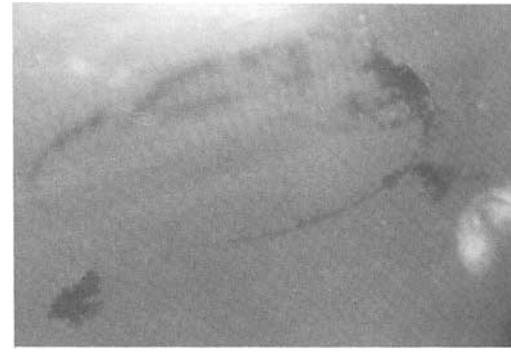

Fig. 10. The apparent ellipsoidal shape of this healed fracture is sealed off by brownish-red iron compounds. Thus they are epigenetic inclusions. 30x.

at random like particles of dust, which form the 'silk' (Figure 6).

X-ray diffraction patterns carried out on the bulk samples revealed some weak reflections referable to rutile.

A contribution to this peculiar aspect is due also to cloudy, hazy inhomogeneities, probably caused by light diffused by tiny fissures in the host.

4) *Tube-like Inclusions*

These inclusions are primary cavities which are normally caused by irregularities in growth structure of the host sapphire. Such channels, evidenced by fillings made up of scaly aggregates with a colour varying from brownish-red to yellowish and variously mixed (Figure 7).

The electron microprobe analyses showed the almost exclusive presence of iron in both the yellow and the red scales. Consequently they were ascribed to iron hydroxides or oxides.

This situation appears to be similar to the iron compounds filling the channels of scapolite (Graziani and Gübelin, 1981; Schmetzer *et al.*, 1977) and kyanite (Ghera *et al.*, 1988).

5) *Transparent crystals*

In the sapphires, sporadic, birefringent inclusions were present (Figure 8).

The transparent and colourless crystals (approx. 0.02 × 0.09 mm) are low in relief, have a 'ghost-like' nature and occur singly. They are hexagonal, tabular in shape with sharp angular corners. Analyzed with the electron microprobe they reveal a chemical composition of aluminium; therefore they are referable to sapphire.

The reddish-brown idiomorphous crystals (approx. 0.1 × 0.05 mm) of prismatic habit consist of titanium with a minor content of iron. These were identified as one of the three polymorphs of titanium oxide, and considering their morphology and high birefringence, as rutile or brookite.

Keeping in mind both the sapphire growth conditions and the unvarying appearance, these crystals are referable to rutile.

6) *'Feathers' and healed Fractures*

Analyses with the electron microprobe were carried out to attempt to clarify the nature of these inclusions. It was found that they are at least partially made up of tiny, elongated individuals (about 20 × 5 μm) whose chemical composition turned out to be aluminium and, sometimes, a little titanium. Consequently these inclusions are referable to both corundum and rutile or titanium plus aluminium compounds (Nassau, 1968). These elongated crystals constituted a kind of felt, representing the chemico-physical variations of the host crystal growth conditions and in some cases causing a hazy effect (Figure 4).

The healing areas are often sealed off and evidenced by feathers of fluid inclusions (Figure 9) and by yellow or brownish-red matter (Figure 10). The electron microprobe analyses showed the almost exclusive presence of iron, and consequently they were ascribed to iron hydroxides or oxides (Schmetzer *et al.*, 1977).

Conclusions

The cabochon-cut sapphire samples examined, which have identical genetic conditions, are remarkable for the presence of the same type of inclusions. These, however, are variously distributed in each specimen.

Indeed, the acicular inclusions, particularly the microstriae and also the needles both of rutile and hematite, decorate the sapphires with a crystallographically-dictated arrangement of minute lines, and represent the main cause of the asterism.

It is remarkable that the perfect star with sharp edges extending fully, samples nos. 1, 2, 4 and 7, is similar to the six-rayed asterism present in the Linde synthetic cabochon-cut star sapphires.

Nevertheless, the straight-edged angular-growth zoning caused by the hexagonal symmetry of the sapphire, and especially the absorption lines at 450, 460 and 470 nm, represent distinguishing features between these natural sapphires and synthetic sapphires.

Sporadic alterations of the physico-chemical conditions tended to produce straight-edged colour bands, growth-zoning and the formation of inclusions of corundum, rutile and hematite crystals. They document different episodes of the host crystal's growth.

Subsequently the mother-fluid penetrated into fractures of the embedding crystal, and iron compounds have been segregated.

The irregular contour of the channels and their fillings of yellowish and brownish-red matter can be generally correlated.

Furthermore, the presence of haloes, often surrounding the healing areas sealed by mother fluid, suggest a possible sequence of transformation of these iron compounds due possibly to the dehydration of iron hydroxides and the consequential formation of iron oxides, referable to an increase of the environmental temperature.

Considerations on the brookite-rutile equilibrium allow a hypothesis on high temperature and high-pressure sapphire crystal growth conditions (Dachille *et al.*, 1939). The presence of iron hydroxides and oxides, as well as hematite, suggests that the utmost temperature of crystallization was in any case higher than 500°C (Kulp *et al.*, 1951).

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The Brazilian emeralds and their occurrences: Carnaíba, Bahia

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1. Introduction

The emerald occurrences of Carnaíba and Socotó in the state of Bahia are located at a distance of about 40 kilometres from each other. The first one belongs to the county of Pindobaçu, the latter to the county of Campo Formoso (Figure 1). Campo Formoso is developing an infrastructure that is changing it into the regional trade centre for the gemstones mined in the state of Bahia (besides emerald, others include amethyst, citrine, aquamarine, diamond, sodalite and ruby). Actually it is the transfer point for the emeralds produced in the Carnaíba and Socotó mining fields. Starting from Salvador or Feira de Santana, Campo Formoso can be reached using first the BR 324 road going northwest up to Capim Grosso and after that using the BR 407 to Senhor do Bonfim. The distance between Salvador and Campo Formoso is about 400 kilometres.

The mining region of Carnaíba, located about 30 kilometres south of Campo Formoso, covers an area at the western border of the north-south extending mountains of the Serra de Jacobina (Figure 2). It has an extension of about 200 km^2 and lies between the villages of Pindobaçu, Saúde and Mirangaba, all located near the Serra de Jacobina. It was discovered in 1963 and has been the most important emerald mining region in Brazil until the discovery of the Santa Terezinha occurrence in the Gioás state. Mining activities began towards the end of 1963 in the sector known as Braúlia (Figure 3). In the following year, the mineralizations of Marota (Carnaíba de Baixo) have been found and only in 1972 were discovered those of the Trecho Novo in Carnaíba de Cima. After having reached its lowest production rate in 1981, when the discovery of the Santa Terezinha deposit resulted in the migration of many garimpeiros out of the region, the production has been increasing somewhat during the last few years.

Because of the necessity of moving the mining activities forwards with the aim of reaching the deeper layers and because of the growing production costs, a positive development of this mining region in the future can be expected only if the mining methods, which are quite primitive now, are replaced by a systematic exploitation with modern mining techniques.

2. Geology

The following remarks concerning the regional and local geological situation in the Carnaíba region are based on the works of Griffon *et al* (1967), Barbosa (1973), Santana *et al* (1980), Santana *et al* (1981), Couto and Almeida (1982), Moreira and Santana (1982), and Couto (1985). They were complemented by our observations made during our field works.

2.1 Regional Geology

The geological situation in the Carnaíba region is marked by the intrusion of granite batholiths (Figure 2) into lithologic units of the Serra de Jacobina. The rocks of the Serra de Jacobina were subdivided by Couto *et al* (1978) into the Jacobina Group and the Itapicuru Complex.

The Jacobina Group consists of an ultrabasic basement unit (with an age of 2.4 to 2.7 billion years) which, together with the granite, is of major importance for the formation of the emerald occurrence. To the east, stratigraphically above, follows the Itapicuru Complex, consisting mainly of phyllites, schists and itabirites. Between the formation of these two rock units and the granite intrusions occurred two metamorphic phases resulting mainly in the mineral parageneses of the greenschist facies.

The lithologies important for the emerald formation are:

a) Granites

They ascended probably along the tectonic western boundary of the Serra de Jacobina and partially intruded the rocks of the Jacobina Group. They

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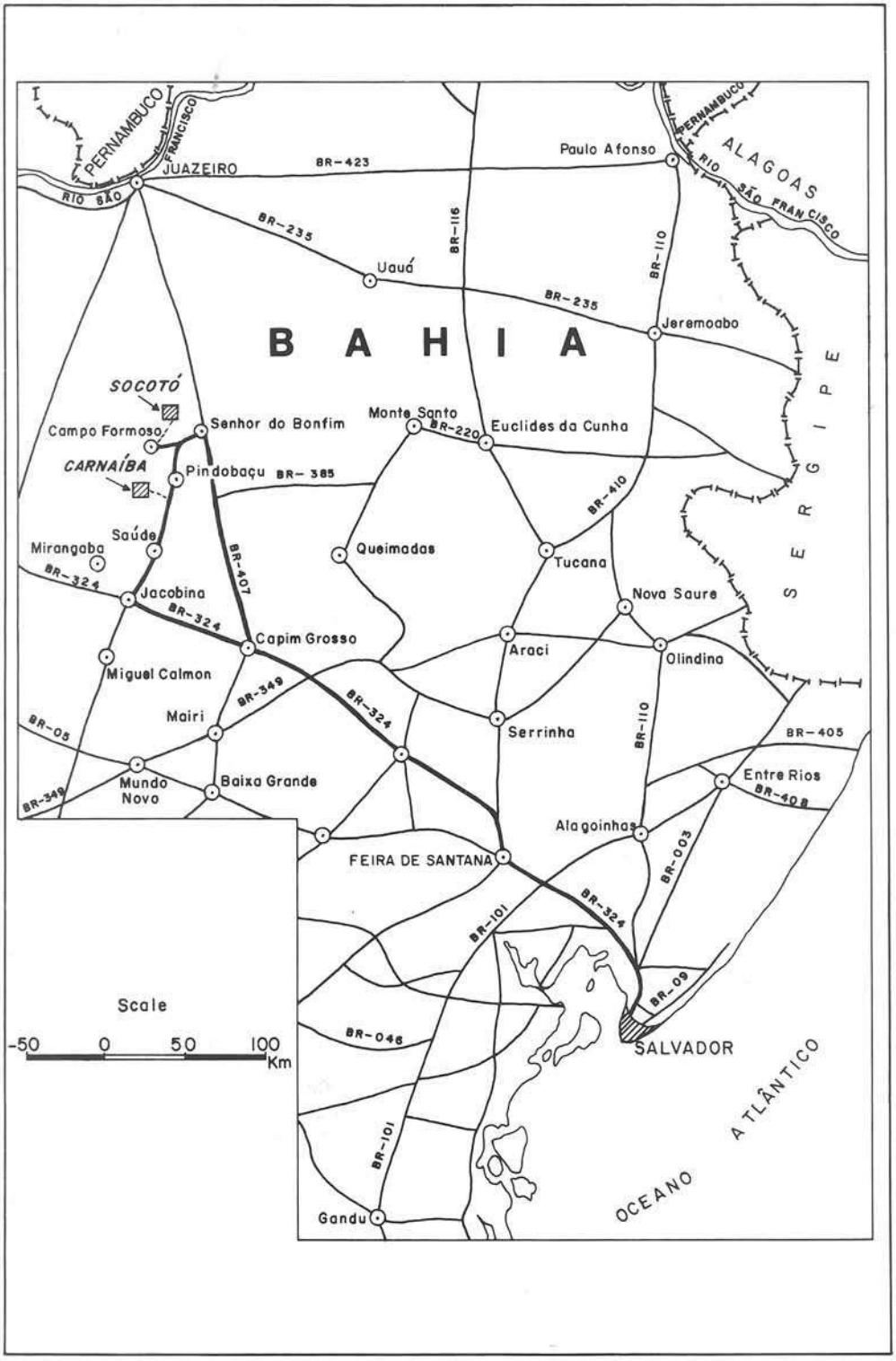

Fig. 1. Geographical map of the northeastern region of the Bahia state.

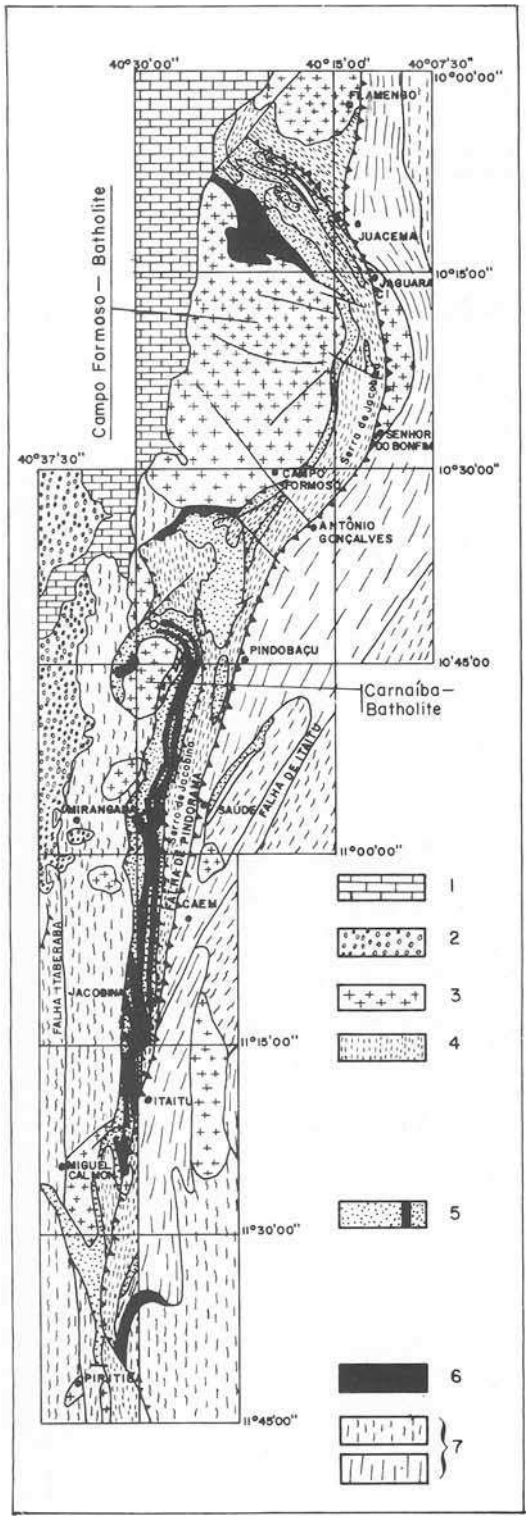

are associated with pegmatites and, with regard to their mineralogical composition, show similarities to lithologies of the metamorphic-migmatitic complex surrounding the Serra de Jacobina. Their average mineralogical composition is: oligoclase (20–70%), microcline (26–50%), quartz (22–30%), muscovite (up to 5%), and biotite (up to 5%). Rb/Sr age dating gave results ranging from 1.1 to 1.9 billion years (with emphasis on 1.9 billion years). This corresponds to one of the final tecto-no-magmatic phases of the Transamazonic Cycle during which the rocks of the Jacobina Group were deformed (Santana *et al*, 1980).

b) Ultramafites

Mainly Cr-rich serpentinites and peridotites which were intruded by pegmatites. In the immediate contact area, a metasomatic transformation into biotite/phlogopite schist took place.

The ultramafites can be observed: (1) as enclaves in the Carnaíba granite (the garimpos* called Bode, Gavião, Lagarta, and Formiga are located within such enclaves; compare Figure 3); (2) in strips up to an extension of 200 metres which are separated from the granite by migmatitic gneisses (garimpos of Braúlia and Marota); and (3) as stratiform lenses which were enclosed in quartzites during tectonic activities (garimpos of Trecho Velho and Trecho Novo in Carnaíba de Cima as well as Munde).

c) Quartzites

Intensively recrystallized, they are of light green colour passing into grey when in contact with pegmatites. In Carnaíba de Cima, ultramafites were enclosed within the quartzites during tectonic activities.

*Garimpo = mining area with shafts, pits and trenches, the exploitation is made using primitive methods only

Fig. 2. Geological map of the Serra de Jacobina showing the batholiths of Carnaíba and of Campo Formoso (the latter with the Socotó mining region) (in Inda & Barbosa, modified after Couto *et al.*, 1978).
1– Metasediments of the Una Group
2– Metasediments of the Espinhaço Super Group
3– Granitic rocks
4– Complexo Itapicuru (volcanoclastic sequence): feldspar-quartzites, phyllites and schists, amphibolites, metabasites, and serpentinites. Formations Água Branca (Tab), Serra da Algria (Tsl), Cruz das Almas (Tca), and mica schists with aluminium silicates (Tal)
5– Jacobina Group (clastic sequence): metaconglomerates, orthoquartzites, intercalated serpentinites. Formations Rio do Ouro (Tro) and Serra do Córrego (Tsc)
6– Basic and ultrabasic rocks
7– Basement (i.e. mainly archaic migmatites and gnaisses)

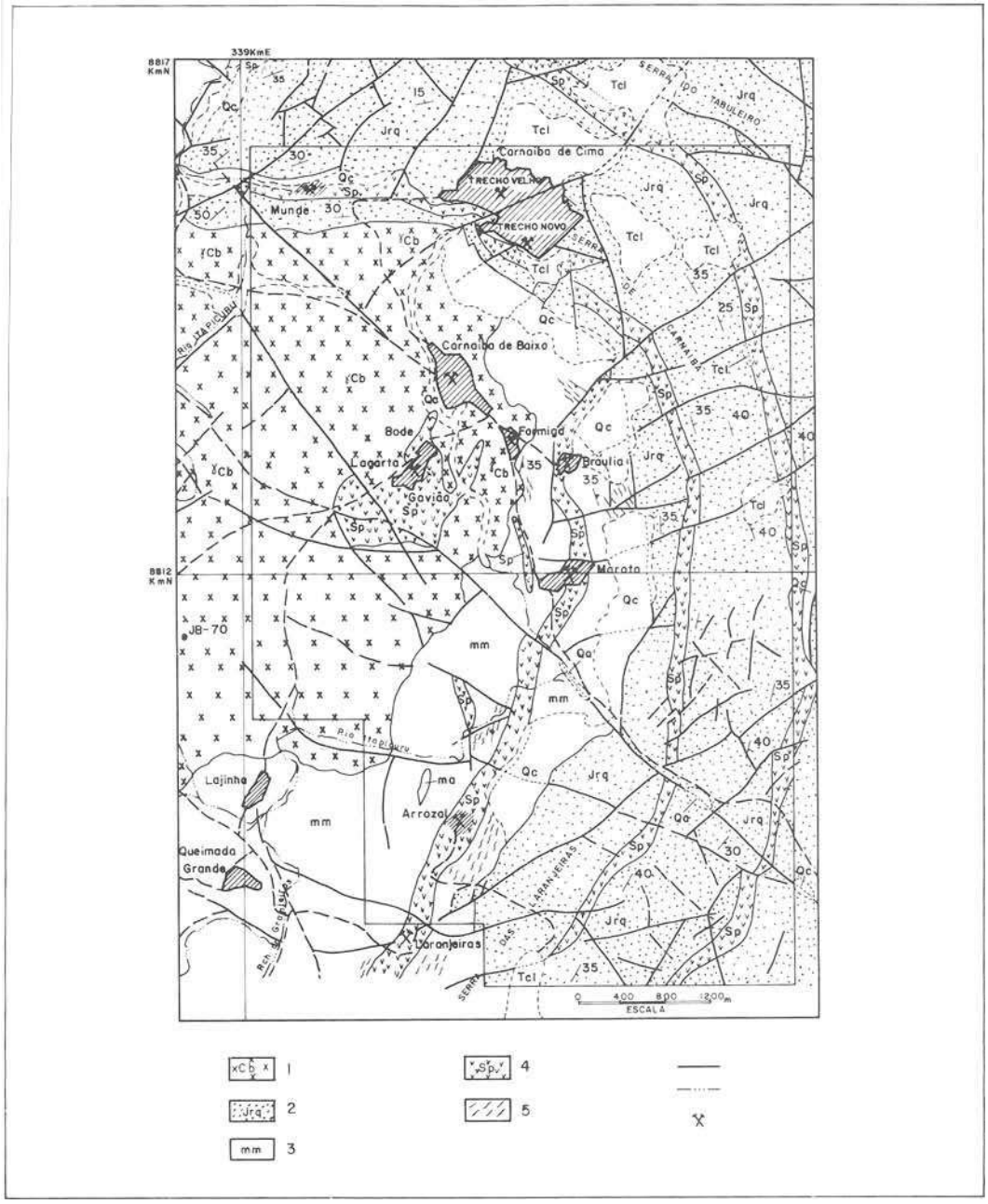

Fig. 3. Geological map of the Carnaíba region

1– Carnaíba granite	faults	
2– Jacobina Group	lithologic and/or	
3– Migmatites	stratgraphic contact	
4– Serpentinites		
5– Cataclastic rocks	emerald	mineralizations

(in: SME – CBPM, Salvador 1978)

d) Pegmatite veins

These have a thickness of not more than two metres and consist mainly of oligoclase and muscovite. Quartz can be found in varying amounts and sometimes forms veins of its own.

e) Metasomatic rocks

They consist almost exclusively of phlogopite or biotite/phlogopite and are in direct contact with the pegmatite- and quartz veins. The micas are oriented mainly parallel to the vein walls and show a lepidoblastic texture which gives the rock a schist-like appearance. The rock is called mica-schist or 'sludite' and is the emerald host rock. The emeralds occur either in form of aggregates or as single crystals. Associated minerals are molybdenite, quartz, apatite, schorl, alexandrite, pyrite, pyrrhotite, chalcopyrite, rutile and scheelite. In a transition zone between the mica-schist and the ultrabasic rocks, masses of talc with phlogopite and some still unweathered serpentinite can be observed.

Fig. 4. a) The 'Carnaíba de Cima' mining field (Upper side on the left).

2.2 Local geology and genetic aspects

In Carnaíba de Cima, the emerald host rock can be found in two horizontal levels as well as in several vertical layers. In Carnaíba de Baixo, occur vertical layers as well. The emeralds coming from different mining zones show different qualities (i.e. different colours and density of inclusions). Griffon *et al* (1967) give some processes explaining the formation of new minerals during the transformation of the ultra-basic rocks into mica-schists:

$KAlSi_3O_8$ (K-feldspar) + $Mg_6Si_4O_{10}(OH)_8$ (serpentine) = $KMg_3Si_3AlO_{10}(F, OH)_2$ (phlogopite) + $Mg_3Si_4O_{10}(OH)_2 + 2H_2O$ (talc)

Near the contact zone with the pegmatite, talc is also transformed into phlogopite:

$KAlSi_3O_8$ (K-feldspar) + $Mg_3Si_4O_{10}(OH)_2$ (talc) = $KMg_3Si_3AlO_{10}(F, OH)_2$ (phlogopite) + 3 SiO_2 (quartz)

Phlogopite (sometimes passing into biotite depending on the iron contents of the initial basic rock) forms a monomineralic zone. The great number of quartz veins associated with the mica-schist can be explained by the great amounts of liberated silica and water.

The following hypothesis concerning the genesis of the emerald mineralizations in the region of Carnaíba may be postulated. Metasomatic processes accompanying the intrusion of pegmatite bodies into the surrounding ultrabasic rocks are

responsible for the formation of emerald and alexandrite. The appearance of molybdenite and scheelite gives a rough idea concerning the PT-conditions during the metasomatic reactions. Molybdenite and scheelite are typical formations of the final phase of the pegmatitic stadium. Griffon *et al* (1967) settle the geochemical processes resulting in the Carnaíba mineral association in the temperature range of 600–800°C. Other authors suppose an emerald formation in the rothermal-pneumatolytic boundary region with temperatures of about 500°C.

1. Regional tectonics leading to the formation of faults during the metamorphic phases prior to the granite intrusion.
2. Fracture tectonics as a result of the intrusion of the granite body (the longitudinal narrowing of the Serra de Jacobina is probably related to the granite intrusion).

Thus, the Carnaíba deposit confirms the observations made in other emerald deposits showing that the emerald mineralizations are preferably related to the zones of strongest tectonic activities (often presenting mylonitization effects). This can

Fig. 4. b) The 'garimpo' Formiga in the 'Carnaíba de Baixo' mining field.

Griffon *et al* (1967) emphasize the complexity of the structural elements in the area of the emerald deposit. This is the result of several superimposed tectonic phases which are correlated either with the local tectonics (folding of quartzites, formation of faults, filling of fissures with quartz) or with the regional tectonic events of the Serra de Jacobina. Probably, the fault system was there prior to the granite intrusion. It was enlarged by the intrusion of the granite body, creating in such a manner good conditions for the migration of the pegmatitic solutions.

Schematically, the following events can be outlined:

be explained by the fact that within these zones of weakness the mobility of the solutions responsible for the material transport, is considerably increased. Genetically, Carnaíba belongs to the classic type of formation which is characterized by the association of mafic-ultramafic rocks or their metamorphic derivatives (Cr/Fe source rocks) with pegmatites (provide Be).

After Couto (1985) there exist three zones in the mining area which distinguish themselves by their productivity (Figure 3):

1. The 'schistified' ultramafic intercalations in the quartzites (Carnaíba de Cima with Trecho Velho and Trecho Novo).

Table 1. Refractive indices and birefringence of Carnaíba emeralds.

n_e	n_o	Δ_n	References
1.580–1.583	1.587–1.590	0.005–0.007	Bank (1969)
1.582	1.588	0.006	Eppler (1973)
1.566–1.575	1.572–1.582	0.006	Mumme (1982)
1.582	1.588	0.006–0.007	Gübelin (1974)
1.578±0.002	1.584±0.002	0.006–0.007	Sauer (1982)
1.577–1.582	1.582–1.589	0.005–0.008	Schwarz (1987)

Table 2. Microprobe analyses of Carnaíba emeralds. Total iron as FeO. CaO content < 0.01 Wt%.

Sample N°	CAR-P 1	CAR-T 2	CAR-8 3	CAR-12/1 4	CAR/FOR-5 5	CAR-12/2 6
SiO_2	66.92	63.92	66.49	66.34	66.16	63.99
Al_2O_3	15.43	15.63	16.12	14.92	15.80	15.19
Cr_2O_3	0.73	0.61	0.0	0.37	0.20	0.42
V_2O_3	0.0	0.0	0.08	0.03	0.07	0.0
FeO	0.69	0.78	0.52	0.67	0.65	0.74
MgO	1.87	1.92	1.63	2.34	1.82	2.45
Na_2O	1.29	1.57	1.47	1.85	1.53	1.89
K_2O	0.01	0.0	0.02	0.02	0.02	0.0
Total	86.94	84.43	86.33	86.54	86.25	84.68
Mineral formula (normalized: Si = 6)						
Si	6.000	6.000	6.000	6.000	6.000	6.000
Al	1.680	1.730	1.714	1.604	1.690	1.679
Cr	0.052	0.045	0.000	0.027	0.014	0.030
Mg	0.250	0.268	0.219	0.319	0.246	0.341
Na	0.225	0.285	0.257	0.330	0.269	0.343
Fe^{2+}	0.052	0.062	0.039	0.050	0.049	0.059

2. The less 'schistified' ultramafic belt in the contact region between the Carnaíba granite and the quartzites at the base.
3. The ultrabasic, somewhat granitized rock body intercalated into the Carnaíba granite.

The latter two zones are situated in Carnaíba de Baixo, number 3 also includes the sector of Formiga which had the highest production rates in 1984/85 and of which the emeralds are characterized by a quality above the average. Systematic investigations carried out on request of the Secretaria das Minas e Energia, performed by the Companhia Baiana de Pesquisa Mineral in 1978, led to estimates on reserves of about 2.000 tons of green beryl, including emerald. Of these, 990 tons came from Carnaíba de Cima and the rest from the different sectors of Carnaíba de Baixo.

3. Optical and chemical properties of the Carnaíba emeralds

Table 1 gives the optical data of Carnaíba emeralds determined by different authors. The measured density values range between 2.70 and 2.72 g/cm^3.

Structural and chemical considerations as well as the calculated mineral formula coefficients (Table 2) indicate that the following substitutions are present:

(a) Al^{3+} (octahedral) = $(Mg,Fe)^{2+}$ (octahedral) + Na^+ (channel site)
(b) Al^{3+} (octahedral) = $(Cr,Fe)^{3+}$ (octahedral)

In case of a coupled exchange of the substitution type (a), channel positions are occupied by Na^+, thus compensating the charge difference between Al^{3+} and $(Fe,Mg)^{2+}$.

The representing points shown in the formula coefficients diagram of (Mg + Fe) v. Na (Figure 5) lie below the line corresponding to a gradient of 1, demonstrating a slight excess of (Mg + Fe) over Na. This can be explained by a small amount of Fe^{3+} which needs no compensation by Na^+ in terms of electrical charge. Chromium, which is found in concentrations up to 0.73 Wt% Cr_2O_3, is incorporated in the crystal structure according to substitution type (b).

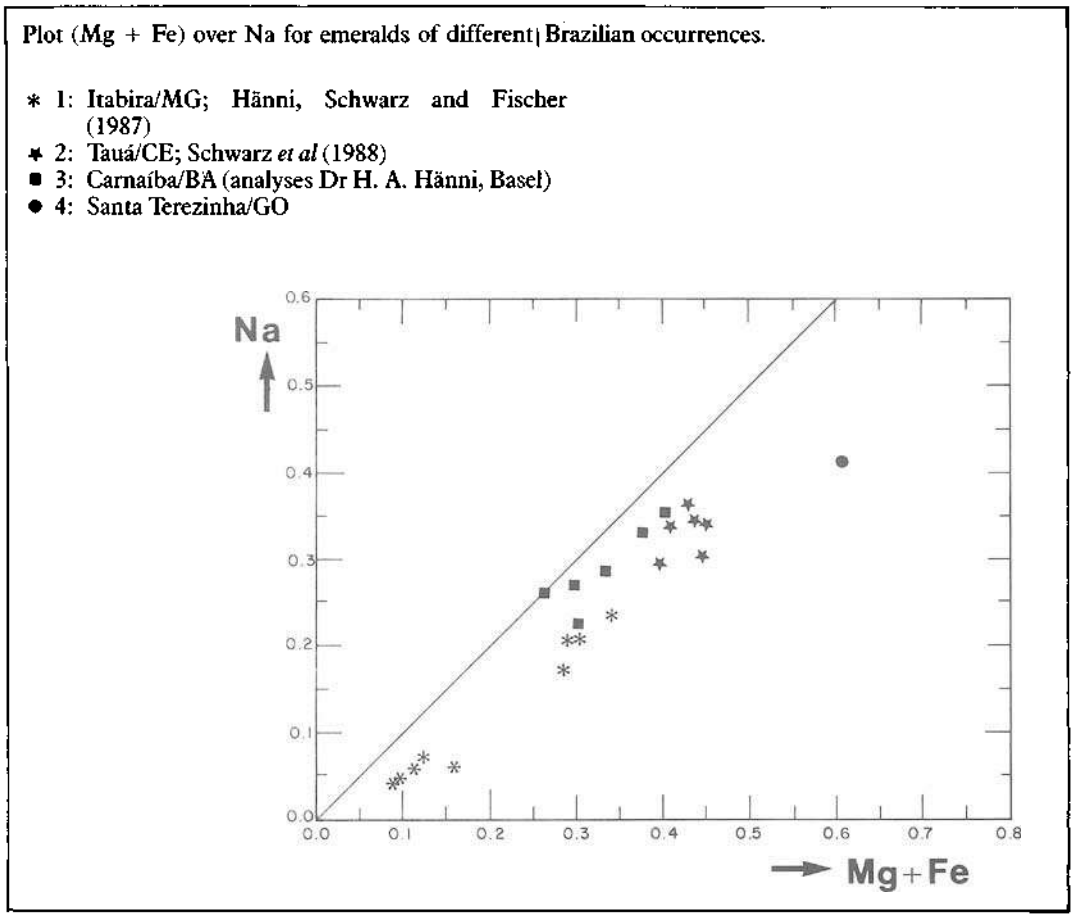

Fig. 5. Mineral formula coefficients Na v. (Mg + Fe) of Brazilian emeralds from different localities.

4. Inclusions

The most frequent inclusions in the Carnaíba emeralds are the so-called 'flocs' and 'stars' (Figures 6 and 7). When examined in the gem microscope – using an immersion liquid and transmitted light – they appear grey to black. Using high magnification (> 50x), it becomes obvious that these formations are composed of tiny particles (Figure 8) which are mostly cavities with a one-phase filling or with a 'l-g' two-phase filling. The flocs and stars are sometimes arranged like pearls on a string and they can also be seen within healed fractures. The particles themselves often form more or less compact agglomerations (clouds) or populate healed fractures where they represent the remnants of healing solutions. Sometimes these particles accompany larger inclusions with two-, three- or multi-phase fillings (Figure 9). The existence of great amounts of these inclusions is responsible for the lack of transparency of the majority of the emeralds from this occurrence (Figure 10).

Apart from mica, mineral inclusions are relatively rare in the Carnaíba emeralds. The most frequent inclusion mineral is a mica of biotite/phlogopite composition (see Table 3) which is represented mainly by two types of different appearance:

a) Plate-like crystals which possess no preferred orientation and present irregular/rounded outlines. These mica plates which obviously are protogenetic inclusions (Figure 11) generally show a more or less intensive brown colour.
b) Crystals showing an uncommon board- or lath-like form (Figures 12a and 12b). They also have no preferred orientation, show different shades of brown and are of protogenetic origin.

Other mineral inclusions, besides biotite/phlogopite, are muscovite and chlorite. The minerals described hereafter were observed only occa-

Table 3. Microprobe analyses of a feldspar inclusion (a), and of two mica crystals (b) in a Carnaíba emerald (Wt%).

	(a) Feldspar		(b) Phlogopite/biotite	Muscovite
SiO_2	69.85	SiO_2	40.22	50.07
TiO_2	0.0	Al_2O_3	13.63	29.14
Al_2O_3	19.83	Cr_2O_3	0.43	–
Cr_2O_3	0.0	FeO	5.42	4.02
V_2O_3	0.0	MgO	20.45	2.85
FeO	0.0	K_2O	9.96	8.22
MnO	0.0	Na_2O	0.37	0.41
MgO	0.18			
CaO	0.57			
Na_2O	11.54			
K_2O	0.01			
F	0.0			
Total	101.98		90.48	95.01

sionally during the examination of more than 600 rough and cut Carnaíba emeralds: tourmaline, albite (Figure 13), molybdenite, lepidocrocite (Figure 14), goethite, beryl (emerald), tremolite/actinolite (Figure 15), apatite (Figure 16), quartz (Figure 17), as well as pyrite and allanite (?) (Figure 15), (Schwarz, 1984).

Tourmaline appears in form of brown-black prismatic crystals which become somewhat transparent only when submitted to strong transmitted light. Tourmaline inclusions have been described several times in emeralds from other occurrences, e.g. from the Habachtal (Morteani & Grundmann, 1977), the Ural Mountains (Sinkankas, 1981), Zambia (Koivula, 1982), and Madagascar (Hänni & Klein, 1982).

Albite forms transparent tabular crystals (Figure 13) or irregular grains ranging from colourless to light brown. The microprobe analysis (Table 3) shows that it is an almost pure albite.

The small, opaque molybdenite plates have irregular rounded or hexagonal outlines and show typical lead-coloured or bluish-grey reflexes in incident light.

Lepidocrocite is characterized by the intense red-orange colour of its aggregates (Figure 14). Goethite occurs in the form of opaque aggregates which resemble splashes of ink, and settle mainly in fissures.

In a few samples we observed transparent tremolite/actinolite rods (Figure 15) as well as extremely fine, curved needles, probably of allanite (Figure 15). Partially, these needles have a hair-like appearance and generally they are not evenly distributed but form clusters and aggregates within the host crystal.

Apatite (Figure 16) forms prismatic, colourless-transparent crystals, partly exhibiting well developed outlines. The chemical analysis showed an F-content of 6.68 Wt%.

Quartz (Figure 17) occurs as prismatic crystals which are distributed all over their host crystal without showing a specific crystallographic orientation.

Pyrite grains, with their typical yellow metallic lustre, when seen in incident light, are also irregularly distributed within the host crystal.

Other crystalline inclusions are fragments or protogenetic chips of beryl (emerald) that have been described also by Gübelin (1974) in Colombian emeralds. In normal transmitted light, these inclusions are extremely difficult to detect because they generally are of the same colour and the same refractive index as their host crystal. They become clearly visible, however, when using crossed polarizers, because their dark position is usually different from the dark position of the host crystal.

Growth phenomena are a common inclusion type in the Carnaíba emeralds, they can be observed in a diversity of forms:

a) A concentric striation parallel to the prism faces (looking in the direction of the *c* axis).
b) Growth pyramids forming zig-zag lines (Figure 18) similar to those frequently seen in Colombian emeralds. They correspond to pyramid faces which are formed during certain growth

Note: The magnification of the inclusion photographs is given by the optical unit, composed of microscope objective, ocular, camera distance, etc. All photographs were taken using an immersion liquid.

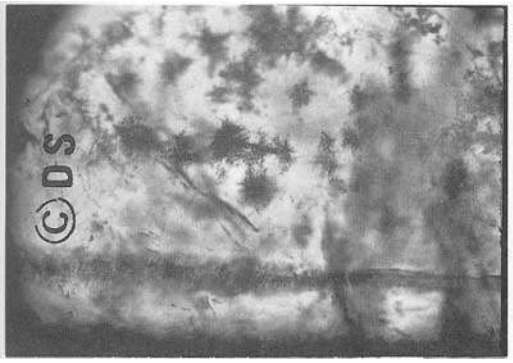

Figs. 6 and 7. The 'flocs' and 'stars' in the Carnaíba emeralds consist of tiny cavities with one- or two-phase fillings. 35x

Fig. 8. Under high magnification, single particles are visible which compose the floc- or star-like formations. 70x

Fig. 9. Larger cavities with two-, three-, or multi-phase fillings, accompanied by numerous tiny cavities with one- or two-phase fillings. 50x

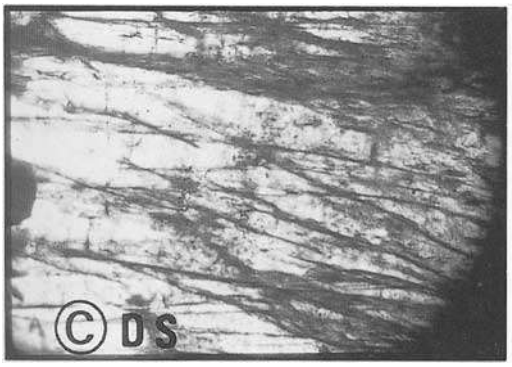

Fig. 10. Most Carnaíba emeralds are of low transparency. This is due to the great number of tiny particles (cavities with one- or two-phase fillings) forming dense clusters (clouds) or being concentrated within healed fractures. 35x

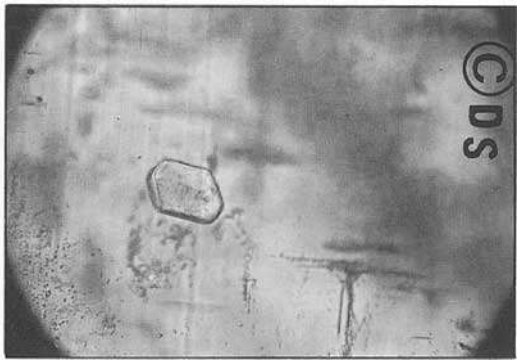

Fig. 13. Tabular, well-developed albite crystal. 50x

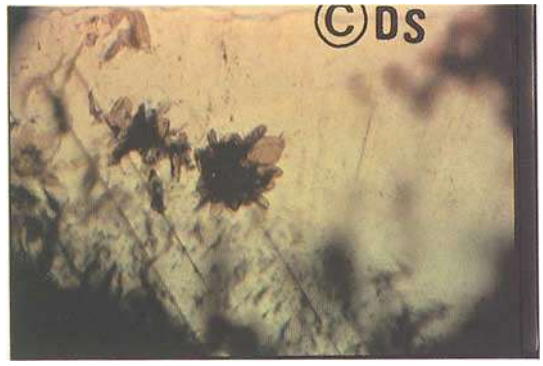

Fig. 11. Protogenetic mica crystals showing irregular outlines. 35x

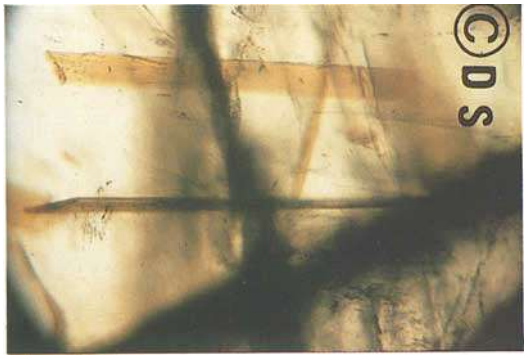

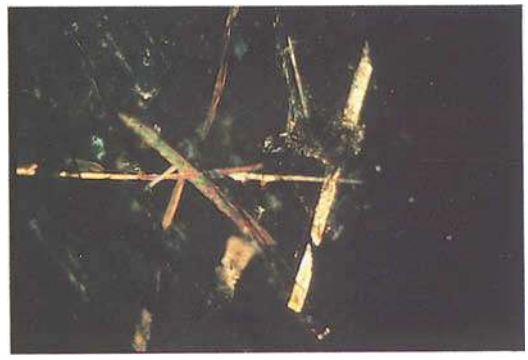

Fig. 12. Mica crystals showing an uncommon 'board'- or 'lath'-like form. a) transmitted light; b) using crossed polarizers, emerald host crystal in dark position. 50x

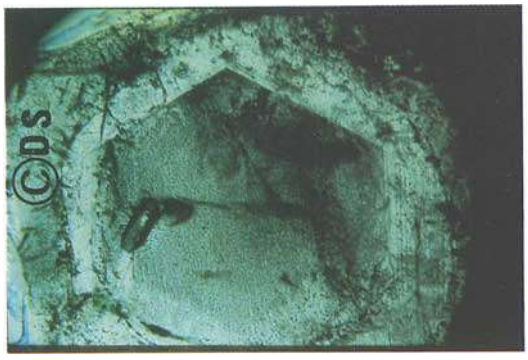

Fig. 17. Besides a sharply limited colour field indicating the hexagonal symmetry of the emerald a prismatic quartz crystal can be seen. 35x

Fig. 19. Typical growth striae (growth layers) with internal structure. 50x

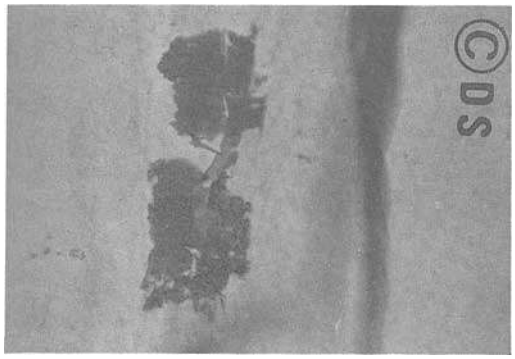

Fig. 14. Aggregates of lepidocrocite showing a strong red-orange colour. 70x

Fig. 15. Transparent-colourless tremolite/actinolite rods and hair-like crystals of a dark brown to black-brown colour (allanite?). 50x

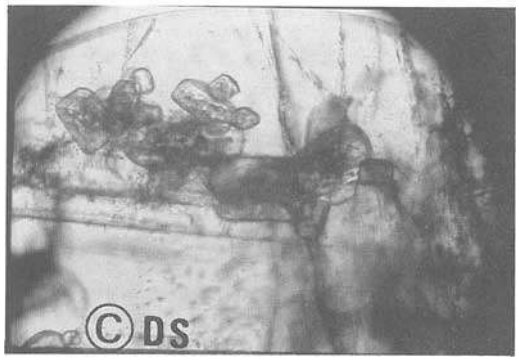

Fig. 16. Prismatic, partly well-formed, apatite crystals. They are distributed in the host crystal without a preferred crystallographic orientation. 35x

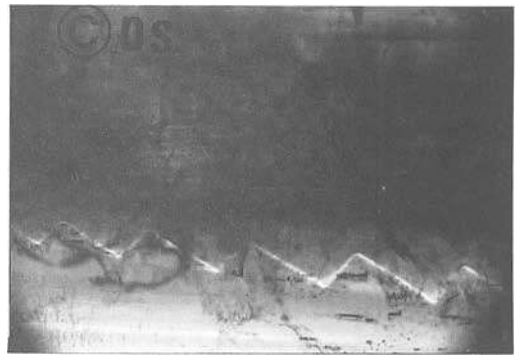

Fig. 18. Growth pyramids forming zig-zag lines. 35x

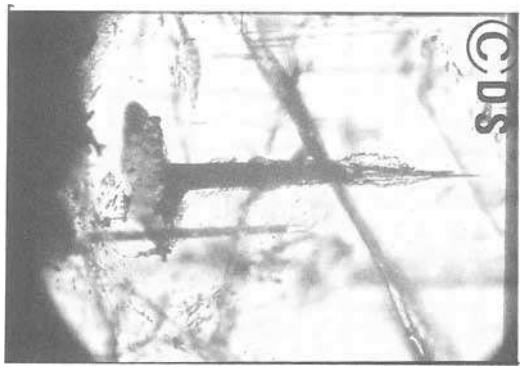

Fig. 20. Conically shaped growth tube, starting from a crystal inclusion. 70x

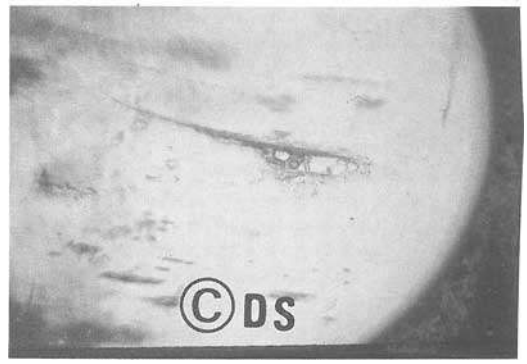

Fig. 21. Cavity with multi-phase filling. 70x

phases but are usually not observed macroscopically.

c) Growth striae or growth layers (Figure 19) which can occur in all directions parallel to both the basal face and the prism faces as well as in directions that are not observed macroscopically. Growth striae as such are common inclusion features both in natural emeralds of different localities and also in synthetic emeralds. Therefore, their appearance normally is only of restricted value as a distinctive mark. In the Carnaíba emeralds, however, features are often observed which can be considered as diagnostic of natural emeralds. The growth layers display an internal structure that remembers pyramids arranged side by side or one after another, or showing a fish scale effect. The formation of this internal structure is due to changing formation conditions during crystal growth. It gives the growth striation a somewhat diffuse (blurred) appearance which is distinctly different from the generally sharply developed growth striae in synthetic emeralds.

Besides the inclusions mentioned above, fine growth tubes are (relatively often) found in Carnaíba emeralds. These growth tubes sometimes start from crystal inclusions (Figure 20). Two-phase inclusions ('l-g' type), three-phase inclusions ('s-l-g' type) and, very rarely, multi-phase inclusions (Figure 21) occur further.

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Mineralogical Institute, University of Basel, and Swiss Foundation for the Research of Gemstones (SSEF), Zurich, Switzerland

Abstract

Transparent brownish 'iris opal' from San Luis Potosí (Mexico) was found to be a natural glass exhibiting layered and botryoidal textures. SEM studies on these layers indicate that they give rise to the iridescent effect, which occurs by interference on layers each of approx. 2μm thickness. An X-ray diffraction pattern shows the material to be amorphous. Infra-red spectroscopy revealed the presence of SiOH groups, but no evidence of water. Microprobe analyses indicated a composition which includes the elements Si, Al, Cs, K and Na as main constituents, and Rb and Fe occur in trace amounts. DTA analysis up to 1200°C resulted in an ignition loss of 0.9% above 900°C.

Introduction

As far back as 1964, transparent light brown stones were mentioned in a gemmological publication (Barbour, 1964), and these are the subject of the present study (Figure 1). In a later report (Sinkankas, 1966) they were called *iris opal*. Leiper (1965) had already noted the presence of spherulitic inclusions. Electron microscopy (TEM) revealed the thin-layered texture, which was thought to be responsible for the iris effect. Viewed under strong illumination (Figure 2 and cover picture) and at the correct orientation, the stones exhibit specific colour effects due to optical interference.

Nowadays, it is known that the play of colours in gem opal represents a colour effect due to the diffraction of white light on a regular pattern of minute spheres (Sanders, 1964). This phenomenon, caused by a 3-dimensional diffraction lattice, needed to be compared with the apparently different mechanism in 'iris opal'. The terms hyalite, hyaline, opal, etc., used in the trade were also thought questionable, and initiated interest in the undertaking of this present study.

The *Iris Effect* as an interference phenomenon at at thin layers has been known to gemmologists for a long time, but not however, in the case of opal! The iris agate mentioned by Webster (1983) exhibits iridescence colours because of interference at thin layers. We wish to differentiate between interference at thin layers (2-dimensional) and diffraction in spatial (3-dimensional) lattices as the cause of colour in gemstones. The first (Iris Effect) can be considered to be a special case of the second (play of colour).

Both the iris effect and play of colour can occur in silica minerals, especially in iris quartz, the various opals and the variety hyalite, as well as in chalcedony and agate. The question arises as to which of these classes the studied material belongs.

Depending on origin and structure of coloured opals, they can be classified into distinguishable mineralogical types (Flörke *et al.*, 1985[2]). In general, it can be said that opal can be formed at low temperatures from aqueous gels. This type exhibits an amorphous character to X-ray diffraction, as shown in opal from some sedimentary rocks from Australia. Opal can also form at higher temperatures and contain crystalline components in the form of cristobalite and/or tridymite within the amorphous mass. It can occur in cavities in volcanic rocks. This opal is not amorphous to X-ray diffraction, but exhibits diffraction patterns representing the crystalline SiO_2 minerals present.

A recent publication (Gübelin 1987, see Figures 21 and 22), which describes black opal from Lightning Ridge, shows scanning electron micrographs. Figure 21 shows the familiar spatially ordered spherical packing, which can cause opalescence. Figure 22, on the other hand, shows a distinct layered structure. The accompanying text describes the material as 'glassy hyaline opal'. The 'sporadic and few cristobalite and tridymite spheres' mentioned cannot be seen in the figure, and as they do not represent dense, ordered patterns, they cannot produce the play of colours. For this reason, the narrow layers would therefore seem to play a more important role in explaining the opal-like behaviour of the 'hyaline opal'. Discussions with the author (Gübelin, 1988) clearly indicate that the latter material is most probably identical to the glass from Mexico examined in this study.

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Fig. 1. A number of specimens of natural iridescent glass from Mexico. Rear left: natural untreated material; rear right: a frothy specimen of the glass after heating to 1200°C. The largest of the faceted stones weighs 3.2ct.

Origin and type of material

Our study material originates from the Tepetate and Lourdes area in the state of San Luis Potosí in Mexico (Koivula, 1988). Sinkankas (1966) also mentions a location near Durango. The host-rock is described as volcanic, probably a rhyolite, in whose cavities topaz and droplet-like to crusty forms of the studied glass occur. Reniform to grape-like masses are often called botryoidal forms. The iridescent glass occasionally forms caps on crystals of topaz, thus indicating a certain genetic relationship. Under the hand lens, the surfaces of the glass bodies (up to cm-large) and crusts can be seen to be composed of very fine step-like layers as sometimes seen on pearls, however in the case of the glass, some wedge-like features are often seen (Figure 3). Older natural surfaces are often pitted, and may be either the result of corrosion or are larger open pores.

Gemmological and optical characteristics

The following studies were carried out on eight stones, some of which are faceted or polished, the remaining uncut. Their colour varies between light yellowish- and greenish-brown, and the form of all stones is botryoidal, identical to that of hyalite.

Note should be made here of the similarity of the surface to that of artificial glass. The fine botryoidal layers can be easily mistaken for 'swirl marks' in artificial glasses, and the stress-induced birefringence exhibited between polarizing filters and the low values for density and refractive

Fig. 2. Iridescent glass with botryoidal form, exhibiting spectral colours due to interference on thin layers.

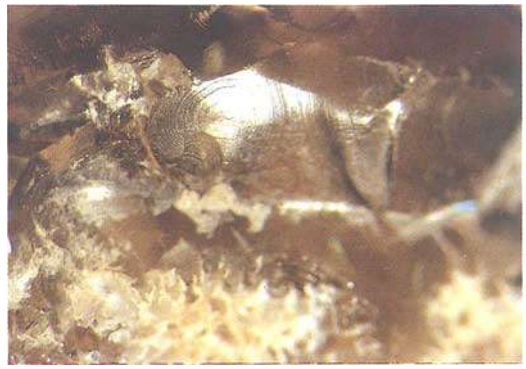

Fig. 3. Natural surface of iridescent glass, showing concentric layered structure. Magnification 10x.

indices are also similar to those expected in glasses. Spherical inclusions also resemble the gas bubbles or vesicles seen in many glasses. However, closer optical study reveals the presence of conical segments of fine and bent layered stacks, slightly tilted one to another, which make up the single crusts and clumps. This is an unknown phenomenon in artificial glasses. The description of the hyalite structure (Flörke *et al.*, 1985) as a consequence of a 'layer-by-layer deposition from droplets, which have built up cone-like common contact surfaces' also fits iridescent glass accurately.

Small, spherical forms (spherulites) are found as inclusions, from which short cracks radiate, or which are surrounded by foliated fissures. The spherulites are amorphous (Figure 4).

The stones are isotropic under polarized light, although in thicker layers, stress-induced birefringence becomes evident (Figure 5). Using fibre optics, spectral colours are produced which follow the thin-layered texture when the stone is tilted (Figure 2). Density and refractive index data are presented in Table 1.

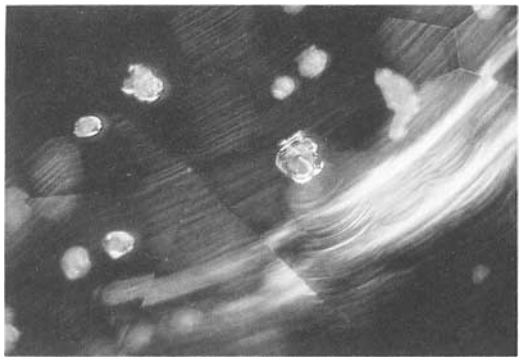

Fig. 4. Spherical inclusions (amorphous) with a 'wreath' of fine fissures, and finely layered botryoidal texture. Magnification ca. 20x.

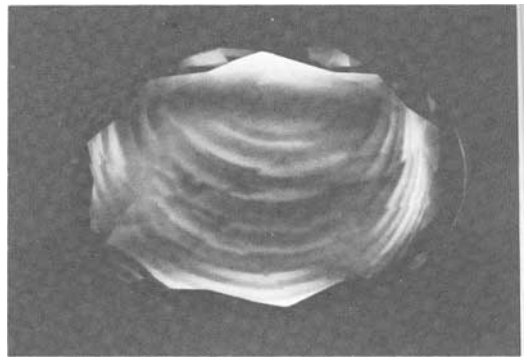

Fig. 5. Birefringence produced due to stress. Iridescent glass between crossed polarization filters.

Table 1: Physical data for iridescent glass from San Luis Potosí (Mexico)

Density	2.241–2.270 g/cm^3
(Sinkankas 1966: 2.257)	
Refractive index	1.462–1.467
(Sinkankas 1966: 1.4625)	

The absorption spectrum contains no identifiable lines. It is characterized by a slight increase of the absorption from 900 to 450nm. From there, the curve becomes steeper and attains a maximum at 430nm. This confirms the findings of Liddicoat (1985), who noted additional bands at 495 and 460nm, and compared the spectrum with that of a uranium glass described in Webster (1983).

The iridescent glasses exhibit a weak to medium strong greenish fluorescence under long-wave ultra-violet radiation.

Comparison of the data with that for density and refractive indices of artificial glasses in the Bannister diagram (Webster, 1983) shows that the values fall in the region of the so-called opal glasses, without the iris glass specimens exhibiting the milkiness of these artificial products.

Scanning electron miscroscopy (SEM) study

Fracture surfaces of the iridescent glass were studied with a Philips 515 SEM with an attached energy-dispersive analyser (Tracor). Using this equipment images were formed and energy-dispersive X-ray spectra produced. As the technique requires a conducting surface, the specimen surfaces were coated with a thin layer of gold.

The SEM micrographs plainly show the finely-layered texture of the material, and the bent form of the individual layers is also clearly visible (Figure 6). The wedge-like features can be seen in detail where the individual sectors and cones touch each other. At higher magnification, layered structures, each only 2.5μm thick, are recognisable on a fracture surface (Figure 7). This observation agrees remarkably well with the figures and data in Sinkankas (1966), who reports an average width of the bands of 2.24μm. At these dimensions, the stacked layers exhibit interference in ultraviolet radiation (Jones, 1952), and the phenomenon of iridescence is adequately explained.

The numerous minute cracks seen in Figure 7 could possibly represent a partial structure, or could be interpreted as shrinkage cracks.

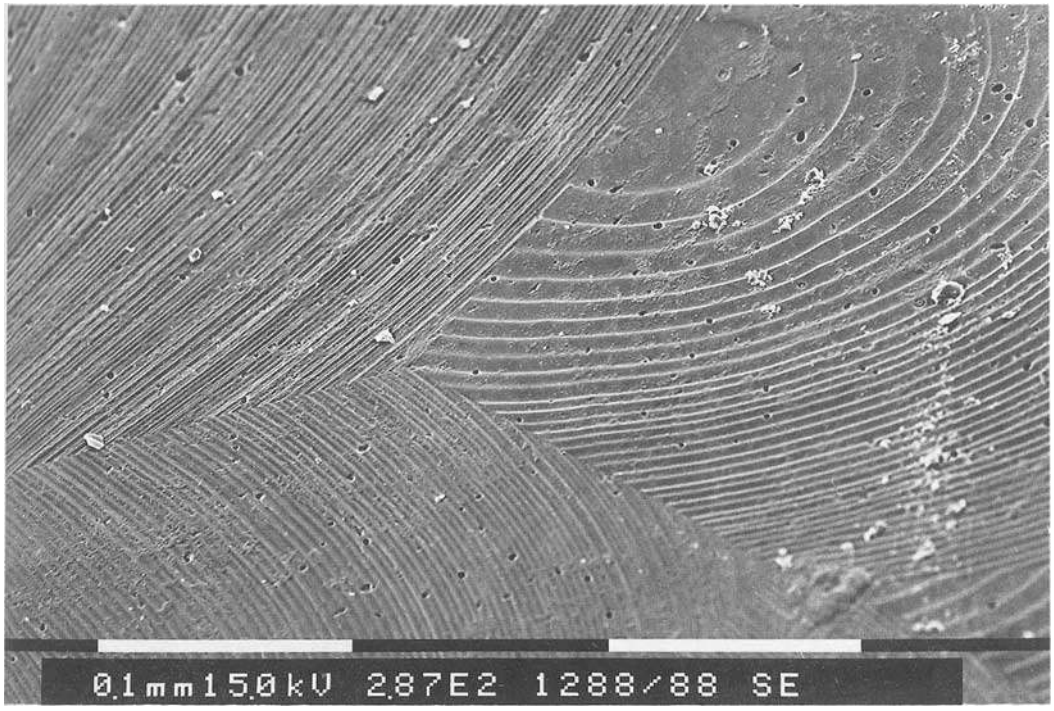

Fig. 6. SEM micrograph of the surface of a raw sample of iridescent glass revealing thin and bent layers as well as a few holes. White scale bar is 0.1mm long.

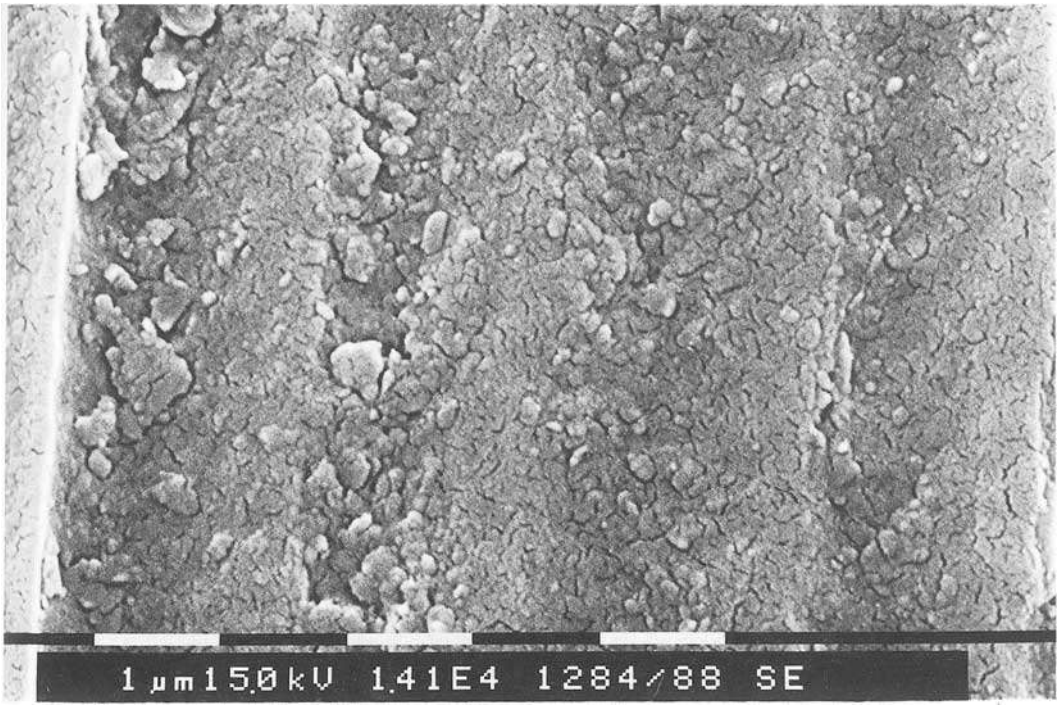

Fig. 7. SEM photograph of the surface showing the stepped nature caused by the emergence of the steeply inclined 2µm thick layers. The small crooked openings may be 'shrinkage cracks'. White scale bar is 1µm long.

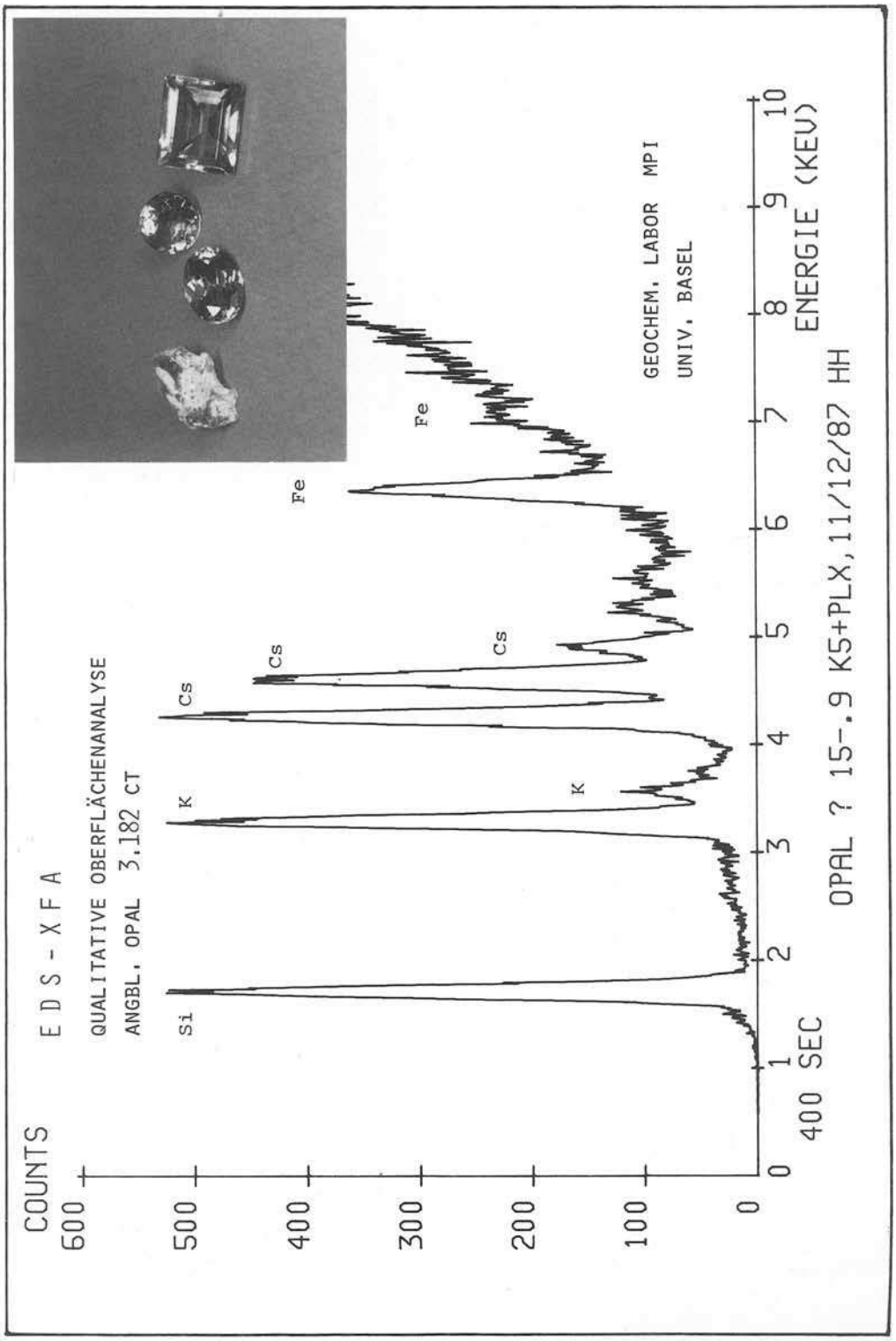

Fig. 8. General EDS-XRF spectrum of iridescent glass. The instrument conditions chosen only reveal the presence of the medium heavy elements.

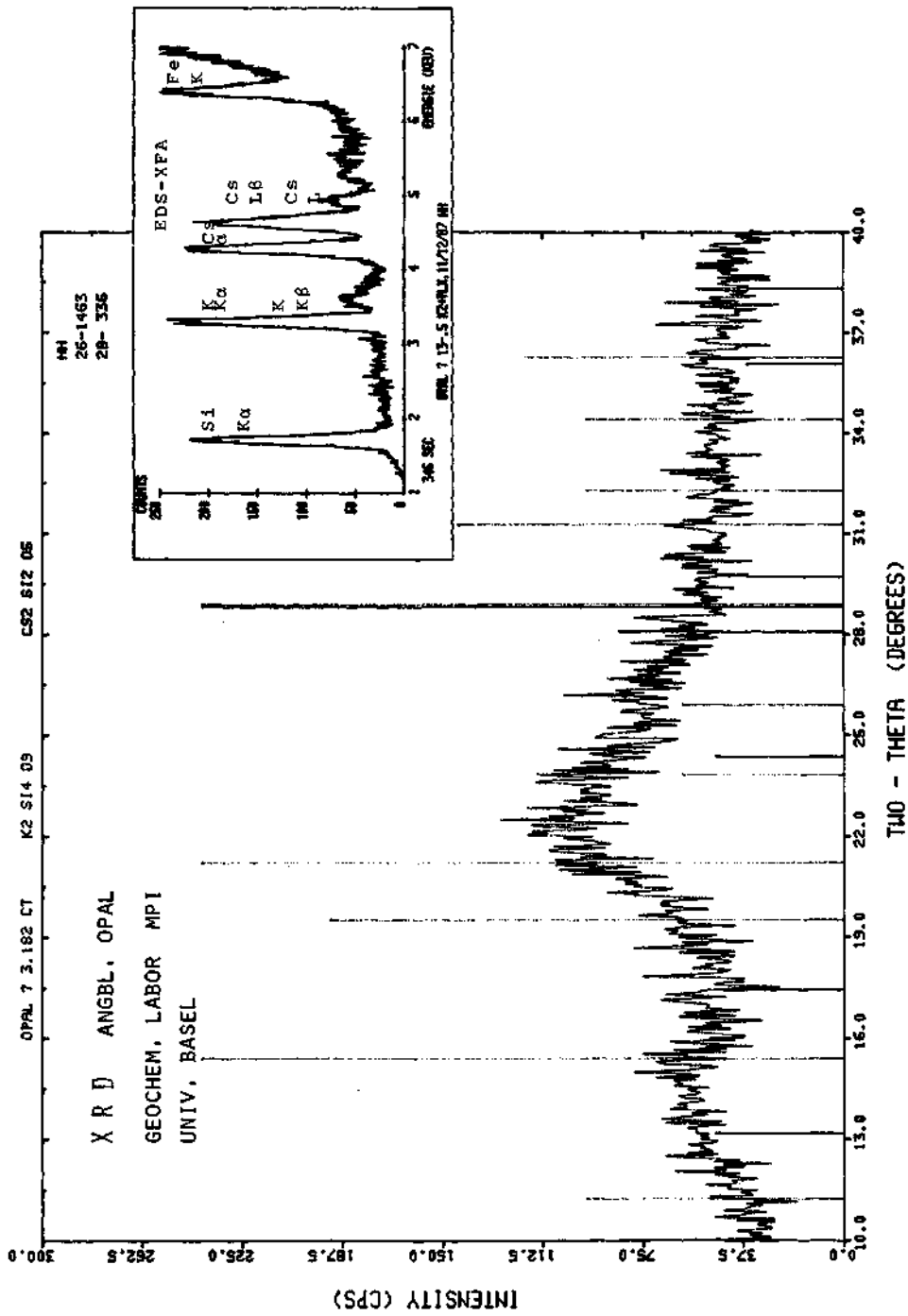

Fig. 9. X-ray diffractogram of iridescent glass from Mexico, showing the absence of crystallinity, thus indicating the amorphous character of the sample. The box (upper right) shows the EDXRF spectrum of Fig. 8.

Chemical study

No chemical data is presented in the publications cited. Our chemical study of iridescent glass was undertaken in a number of stages. Energy-dispersive X-ray fluorescence analysis (EDS-XFA) has been used in gemmology for some time now with success (Stern and Hänni, 1982). Qualitative analyses were undertaken using EDXRF (Figure 9). The spectra show the presence of elements which are for opal, to say the least, unusual. Apart from Si, K and Cs as major to minor elements, Fe, As and possibly U occur as trace elements.

The quantitative analysis of the major and minor components was undertaken with an electron probe microanalyser (Jeol JXA-8600), using a combination of EDS/WDS-analysis (Schwander and Gloor, 1980). The results of the quantitative analysis are presented in Table 2, supplemented by the semi-quantitative analysis for Cs, calculated from the SEM-EDS spectrum. Light elements and volatile components such as Li, B, Be, H_2O, CO_2, were omitted due to analysis problems encountered by such components. The fine-layered texture observed under the microscope appeared to be chemically homogeneous under the electron microprobe and no chemical zoning was indicated. However, chemical variations may exist, but lie below the resolution of the electron microprobe (EPMA).

Table 2: Chemical composition of iridescent glass from San Luis Potosí (Mexico)

SiO_2	87.90 Wt.%
Al_2O_3	3.64
Cs_2O	2.0
K_2O	1.93
Na_2O	0.55
Fe_2O_3	0.02
	96.02%

Light elements with Z<11 (e.g. Li, Be, B etc.) could not be analysed by EPMA.

A partial (EPMA) quantitative analysis in 1977 (pers. comm. Gübelin, 1988) was undertaken, most probably on the same material ('yellow hyaline', Mexico), and the contents of Si, Al, K, Na and Fe were similar to those given in Table 2. Values for Cs and Rb, however, are absent. From the analysis, the material thus cannot be regarded as opal nor as hyalite.

As opals (and hyalites) contain up to >99% SiO_2 (Flörke *et al.*, 1985[1]), the Mexican material (which contains 12 Wt.% other elements) cannot by definition be considered to be opal.

X-ray diffraction studies

A powder diffraction film contained no lines and the material is thus amorphous. An X-ray diffraction study using a Siemens Kristalloflex diffractometer revealed a weak and broad intensity maximum at 22° 2θ [CuKα] and a second even weaker one at about 15° 2θ (Figure 8). Such weak 'bulges' of the background can be explained by the presence of an unordered network of SiO_4 tetrahedrons. The proven amorphous character of the material indicates the absence of C/T opal (with cristobalite and tridymite), which often occurs in some volcanic areas of Mexico. An X-ray study of one of the spherulitic inclusions (powder technique, Bradley camera) again resulted in the absence of any diffraction lines, indicating the amorphous nature of the inclusions.

Infra-red spectroscopy (IRS)

IRS is used when the presence of certain molecules, organic groups or water has to be determined. As all opals contain 1–12% water occurring mainly as molecular water, this specific study was of particular significance. The IR spectra did not show the presence of any molecular water. Spectral bands seen at 3600 and 4450 cm^{-1} are assigned to Si-OH groups (Langer and Flörke, 1974). The content is <0.1 wt. %. A similar 'OH spectrum' is exhibited by certain silica glasses, which occur naturally as Libyan desert glass. A measurable hydrogen-content in the form of silanol groups (Si-OH) and the absence of molecular water (H_2O) are thus apparently characteristic of the Mexican iridescent glass and distinguish it from opal.

Thermal study

A thermo-gravimetric study using a Mettler thermobalance TA 3000 gave information on mass changes in the material when heated to 1200°C. Any water present will be expelled and the change in mass relative to temperature can be monitored. Heating the sample at 10°/minute initially revealed no change in mass until >900°C, at which stage a mass loss was registered attaining 0.92% at 1200°C. After heating, the appearance of the material had altered considerably and resembled a coarsely-blistered foam or froth. This behaviour is markedly different to that of opal, not only with the low ignition loss but also in this conversion to foam-like material. A subsequent study of the crystallinity showed that the material was still amorphous, and no cristobalite was formed as would have been the case with opal. Further studies are planned to determine the actual composition of the 0.92% material expelled during heating, using a heating arrangement in vacuum with a coupled mass spectrometer.

Discussion of results

The study has furnished much information which conflicts with the original idea that the Mexican material was hyalite or another variety of opal. A review by Flörke *et al.* (1985[2]) presents the non-crystalline and micro-crystalline SiO_2 minerals and their aggregates, known at that time, and hyalite is a specific sub-type and an amorphous variety of opal. The SiO_2 minerals and aggregates listed by Flörke *et al* are chemically very pure in comparison with the iridescent glass studied in this publication and which contains about 12 % wt. of other elements. The 3% alkali metals are of particular interest. Some Li could well be present since the analytical total of 96% (EPMA) leaves 4% unaccounted for. Although hyalite contains 3-5% molecular water and about 1% silanol (Flörke *et al.*, 1985[1]), less than 0.1% silanol was found in the Mexican glass. Thermal analysis of hyalite reveals a maximum weight loss around 275°C. This occurs only at >920°C with iridescent glass. On the basis of these substantial differences, iridescent glass cannot be considered to belong to the SiO_2 family, although some features similar to those of hyalite are observed: particularly the glassy appearance, the botryoidal form of the crusts, and possibly the large pore-like 'holes' (Figure 6), (Flörke *et al.*, 1985[2]). The occurrence and habit of the material is strongly reminiscent of hyalite.

The 'shrinkage cracks' seen in Figure 7 raise the question of whether these could have been formed by the migration or diffusion of molecular water originally present.

Finally, the question on the genesis of these unusual natural glasses is raised. We are used to linking the term 'glass' with a magmatic origin, but the extremely fine layers and the botryoidal texture would tend to discount this possibility. Thus we are left with the possible formation of this amorphous material from late-magmatic vapours, steams or aqueous solutions. The formation of iridescent glass is most plausibly explained by rhythmic deposition from steams, mainly indicated by the finely-layered texture. The latter may have been formed by successive deposits of chemically very different 2μm thick layers. In theory, therefore, a rhythmic deposition of (water-free?) opal with layers of alkali-rich substances is quite feasible. A steam phase could – in the rhyolitic area where the glass is found – quite easily have transported the alkalis. In future investigations, the precise composition of the steam must be determined and its function during formation of the glass and its subsequent disappearance explained.

Acknowledgements

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A jade moon?

R. Keith Mitchell, FGA

I wonder how many readers will agree with me in thinking that this picture looks remarkably like a full moon in a star-lit sky.

But it is in fact a disc of orange-veined yellow jadeite, just 2mm thick, photographed by transmitted light between two sheets of crossed polaroid simply because it shows to a very marked degree the fibrous structure of the material. The polaroids do increase the contrast, but only by a very little. I have used them mainly because they provide a nice background while allowing me to light the disc from the back. Such a multi-crystalline plate does not extinguish between polaroids.

One side was flat enough to give a reasonably good RI of 1.66, but I was not able to find any trace of the normally expected 437nm absorption when I used the spectroscope. The whole disc fluoresced slightly under LWUV, with the paler area at the bottom showing the most reaction. Close examination of surface reflection using a 10x lens revealed the expected 'orange peel' effect due to under-cutting when it was polished. Nephrite does not show this effect to the same degree.

Oh yes! The 'stars' in this 'night-sky' picture are minute dust particles between the two sheets of polaroid. Much household dust consists of cotton or other fibres which happen to be birefringent. Most, if not all, fabric fibres are!

It is perhaps worth mentioning that such fibres are often to be found abraded from the silk in the drill-holes of pearls or other beads. I recall an occasion at Chelsea Polytechnic more than forty years ago when a very knowledgeable gemmologist was temporarily foxed by such doubly refracting fibres found in a scraping taken from the drill hole of an emerald bead. They can be quite a surprise unless one is aware of the possibility of finding them.

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Cambay's indigenous silica powder for polishing ruby, sapphire and emerald

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Abstract

Through the ages the lapidary of Cambay has invented many indigenous materials for gem cutting. One such material is the polishing powder, a by-product derived while perforating the silica beads by using diamond tipped bow-drill. This silica powder is refined by wet sieving and heating to make it suitable for polishing hard stones like ruby, sapphire and emerald.

Key words

Lapidary, hard stone, chalcedony, bow-drill, perforation, polishing powder.

Introduction

Cambay (Khambhat: 22°19′N and 72°38′E) in Gujarat is an important centre for gem cutting in India. It has a long tradition of lapidary work that may be traced much before two millennia (Mehta, 1968, Shukla, 1972). Over the centuries, stones processed here were traded in many parts of the world (Arkell, 1936, Janaki, 1980). The methods followed for manufacturing ornamental stone beads have been explained by many authors (Possehl, 1981, Francis, 1982, Karanth, 1988). However, the technology of cutting and polishing coloured stones has not been explained adequately. Ingenuity of the lapidary of Cambay lies in becoming self sufficient in the process of gem cutting. The instruments used for gem cutting are fabricated locally. In fact, some of the lapidary techniques like tumbling were originated in Cambay. An important material produced indigenously is the fine powder used for polishing highly precious stones, viz. ruby, sapphire and emerald. Many authors have listed several kinds of powder for polishing gemstones all over the world (Baxter, 1950, Sparingen, 1950, Sinkankas, 1962). However, none of them has recorded the type of silica powder produced indigenously in Cambay.

Material

Silica powder under study is a by-product obtained while perforating the ornamental beads. By and large the decorative beads produced here belong to silica group, in particular the cryptocrystalline varieties (agate, etc.). The latter accounts for over 95% of the beads manufactured, as chalcedony varieties are mined extensively in nearby Ratanpura-Jhagadia in Bharuch district. The Cambay lapidary follows several steps to produce silica beads, one such step being driving a hole through the bead. Perforation of silica beads is carried out by a very primitive, nevertheless, very effective bow-drill method. The details of bead making and construction and mechanism of bow-drill has been explained in an earlier publication (Karanth, 1988).

The bow-drill unit essentially consists of a wooden shaft, fitted with a steel rib having diamond bits at the drilling end. The drill shaft is rotated with the help of bow-string (Figure 1). First, the place for perforation is marked with single diamond bit drill, and further, the full length perforation is carried out with the help of double diamond bit drill. The drilling is operated from both the ends which ultimately meet to produce a tubular hole. While drilling, the scooped out silica powder from the bead falls down with a thin stream of water (coolant) supplied through a long steel rib attached to a pot of water. Silica powder thus produced is collected in a bowl kept below the scaffold that holds the bead and taken for further processing to make it suitable for polishing.

Processing

Wet silica powder collected in the bowl is poured into a large container of water. After stirring and mixing the paste thoroughly in water, the coarser particles are allowed to settle at the bottom for some time. The upper part of water, ie, water with suspended fine particles is decanted and filtered through a fine cloth for removing the stray coarser particles and floating materials. Suspended fine particles are allowed to settle completely for a day or two. The paste of silica powder collected at the base is rolled into ovoidal balls of about 3–4 cm

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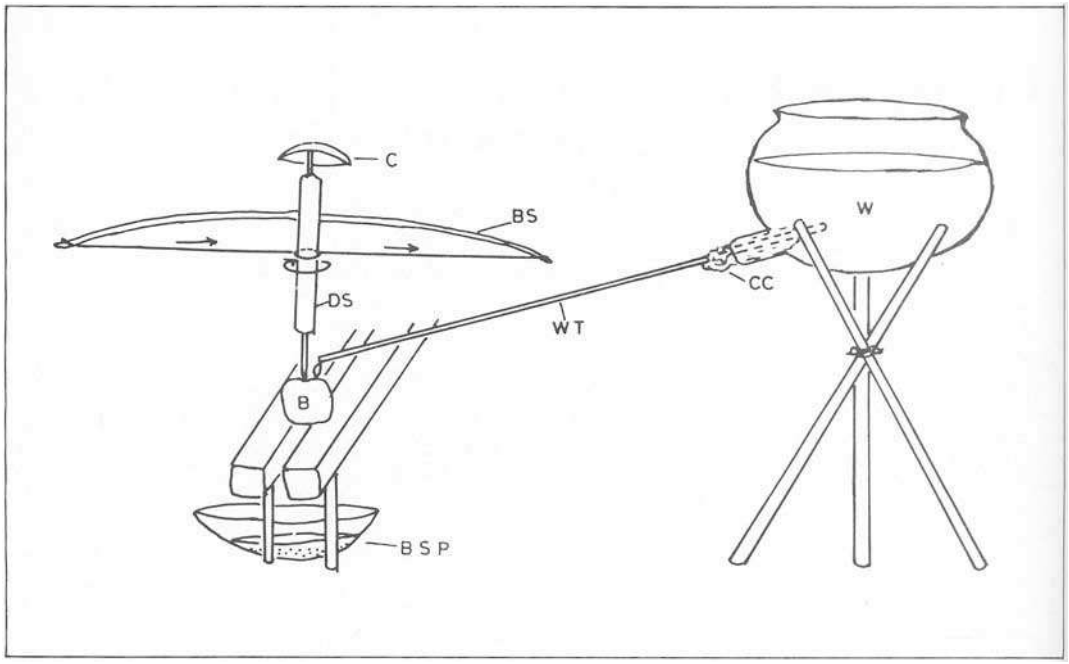

Fig. 1. Bow-drilling unit for perforation (B – silica bead, DS – drill shaft, C – Coconut shell for protection of hand while drilling, BS – bow-string, WT – Water transport, CC – cotton cloth for regulating water flow, W – water pot, BSP – bowl to collect silica powder).

diameter. After drying, these lumps are further placed in a heap of cowdung cake or saw dust and burnt overnight. This process appears to help in driving off intergranular/interfibre water molecules of chalcedony powder and makes the cryptocrystalline silica powder crumple further into much finer particles. The final product obtained is the lump of milky white silica powder, ready for polishing. Often the silica powder lump is used directly without burning.

Grain size

Grain size of silica was analysed for two samples in SACPZ Schimadzu Particle Size Analyser. The samples were run at 500 RPM for a period of 150 minutes. A majority of particles of both the samples measured about one micrometre (Table 1). Sample 1 supplied was more carefully filtered through a much finer cloth than Sample 2. This fact is adequately reflected in the data obtained. According to the lapidaries of Cambay this powder is highly effective for polishing hard stones.

Polishing

Varieties of corundum, chrysoberyl and beryl can be polished efficiently with the silica powder. However, Cambay lapidaries prefer different laps for different stones, as listed below: (i) natural corundum (ruby and sapphire HM* = HL** = 9): copper rich bronze lap; (ii) synthetic ruby – sapphire (HM = 9, HL = little less than 9) and chrysoberyl (alexandrite and cat's eye, HM = 8.5, HL = 8.5–8.8): copper lap; (iii) beryl (emerald and aquamarine, HM = 7.5–8, HL = 7): tin lap.

For polishing emerald, absolutely finer powder without any larger particle is preferred, while the lapidary would not mind a few larger particles (not more than 5–10 μm) for polishing corundum, as the latter is much harder than the former. In the case of emerald even a single large grain could spoil the smoothness of a facet by creating an ugly scratch. On the contrary, in the case of ruby-sapphire, Cambay lapidaries believe that the larger particle might help in removing prepolish irregularities of a facet (Mr. Mulchand Zaveri, personal comm.).

* HM = Mohs scale of hardness
** HL = Apparent lapidary hardness
Except the synthetic corundum, the values of hardness are after Sinkankas (1962).

Table 1. Particle size distribution of silica powder

Diameter in μm	Sample 1 cumul. %	Sample 2 cumul. %
10.0	0.0	0.0
8.0	0.0	0.3
6.0	0.0	0.3
5.0	0.0	0.3
4.0	0.0	0.3
3.0	0.0	0.3
2.0	0.0	23.9
1.0	62.4	79.8
0.8	75.5	88.9
0.6	87.1	NA
0.4	NA	NA

(NA – not analysed)

Discussion and conclusion

High efficiency of the silica powder obtained from bow-drilling has made the Cambay lapidary not to go for modern ultrasonic method of perforation. As mentioned earlier in the case of bow-drilling, the boring operation is executed from both the ends of a bead and is planned to meet at one place to produce a continuous hole. However, quite often the holes drilled from either sides meet irregularly making the operation of driving thread difficult. In the international market, this forms a main objection for the beads produced in Cambay. On the contrary, from the more efficient ultrasonic drill, a continuous, smooth hole can be obtained from one end itself. But from this method, the scooped out silica powder gets mixed with the abrasive powder (emery: coarse grit) used for boring and this mixture can not be used further for any purpose. Though a few ultrasonic perforators have been installed in Cambay, the majority of lapidaries are sticking to the ancient method because of the valuable by-product.

Acknowledgements

The author is grateful to Prof. N. M. Vashi, Head, Department of Geology, MS University of Baroda, for providing facilities for the study. His thanks are due to Dr L. S. Chamyal for analysing the particle size of the samples. He is highly indebted to Mr Mulchand Zaveri and Mr Vinod Patel of Cambay for providing samples and valuable information.

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Some inexpensive improvements to existing instruments

Charles Lewton-Brain, FGA

Alberta College of Art, 1407 14th Avenue NW, Calgary, Alberta T2N 4R3, Canada

In putting together my modest gemmology lab I did a lot of comparison shopping and adapting of various equipment to keep my costs down. The polariscope (Figure 1) for example, was a piece of PVC sewage pipe (new, of course) which had an access port cut in the side and two rings made by cutting a chunk from a slice of the same tube which then supported the filters. There were $7.00 polarizing camera filters used in it. The 49mm filters used happened to fit the GIA immersion cell perfectly and furnished me with a very useful polariscope at low cost. While all gemmologists could build such a tool fairly easily, there were several items that I thought worth sharing with your readers.

First is the method of spot readings from the Rayner refractometer suggested by Dr R. M. Yu in the *Journal of Gemmology*[1]. He suggested using a divergent lens[2] over the eyepiece of the refractometer which makes spot readings far easier. I found that stacking two lenses one on top of the other made the readings easier still on my Dialdex and even allowed spot estimates of birefringence in some cases (Figures 2 and 3). I cut the bottom of a plastic container of pills which fitted the eyepiece of the instrument perfectly and glued the lenses to it after cutting a hole in the bottom. This enabled me to install and remove the lens arrangement rapidly and has proved very useful in practice. The divergent lenses bring both refractive index shadow and Dialdex shadow bar into sharp focus at the same time. I believe that this combination gives greater accuracy for such tests than is possible on standard refractometers.

Second is an adaptation of the Hanneman specific gravity balance which increases its already very high accuracy to the point that it easily gives the correct SG reading for stones as small as 0.25ct, substantially better than with a glassed in chemical balance. It should be noted that I usually use an average of three readings. I also check the balance before and sometimes during use with a known sample to make sure all is well with it.

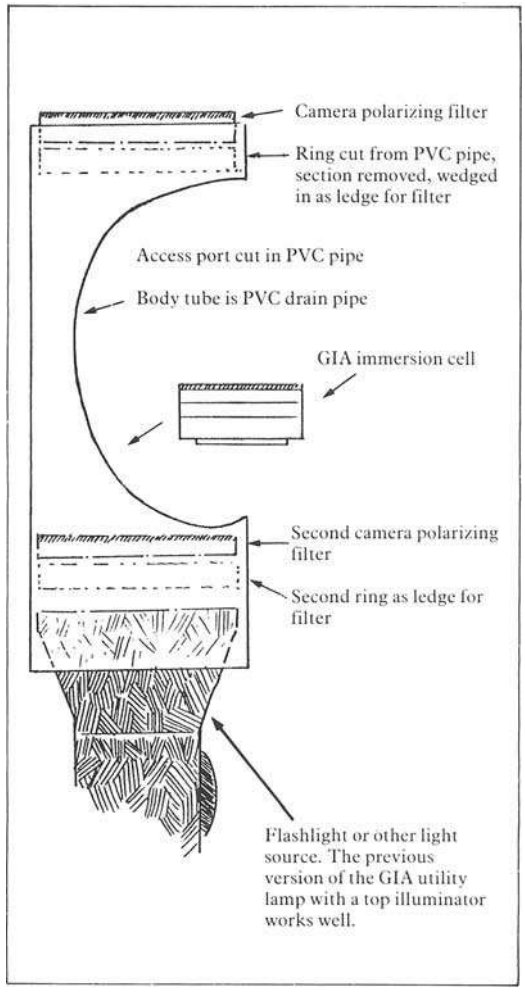

Fig. 1. A home-made polariscope.

[1]Yu, R. M. 1984, Improvements on the Rayner Refractometer, *The Journal of Gemmology*, **XIX**(1), 62–4.
[2]Divergent lens available from Edmund Scientific USA and Efston Scientific in Canada. The catalog number is #94,425.

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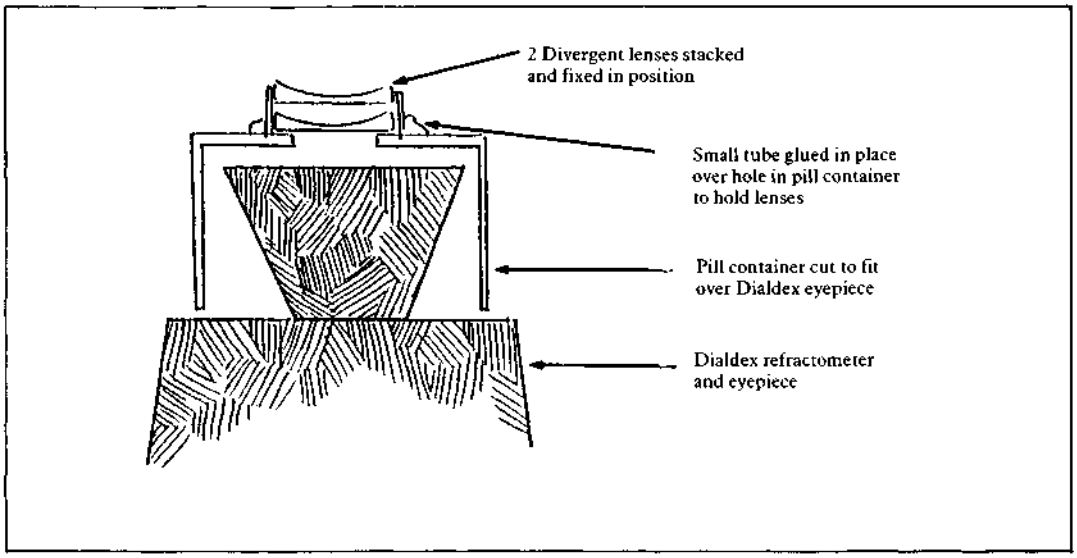

Fig. 2. Lens arrangement for improving spot readings on the Rayner refractometer.

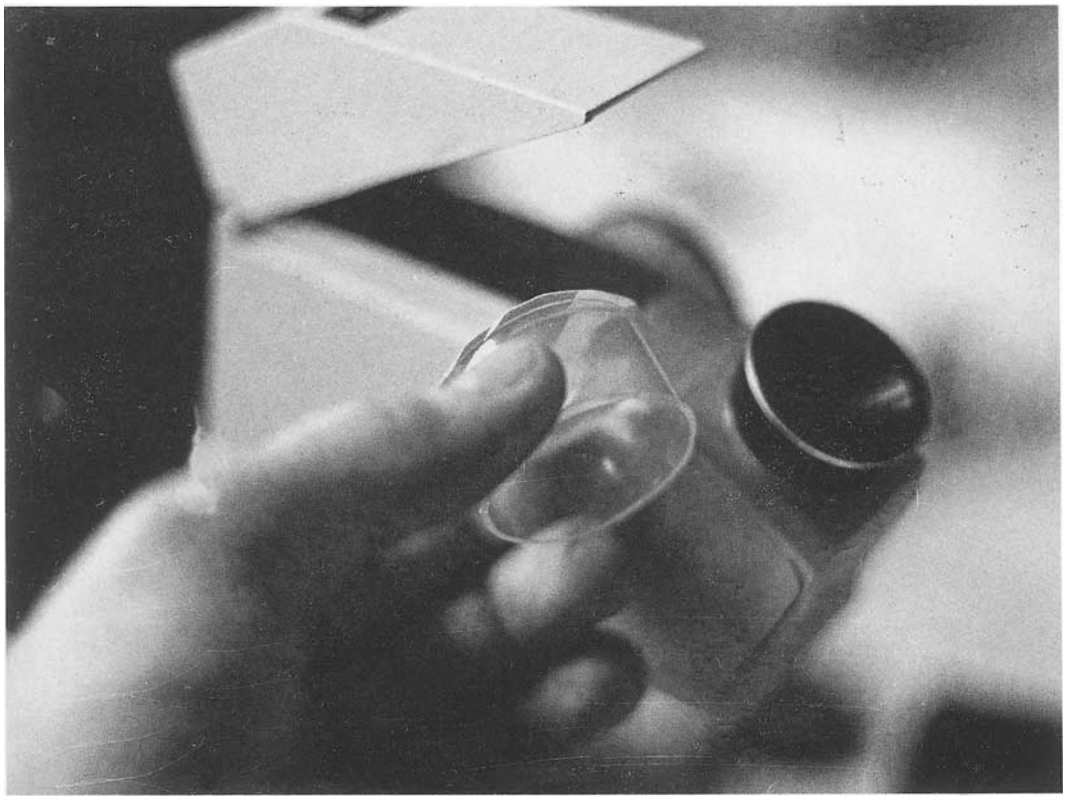

Fig. 3. Pill-box 'cover' for Dialdex eyepiece; open side in view, lenses on the other side away from view.

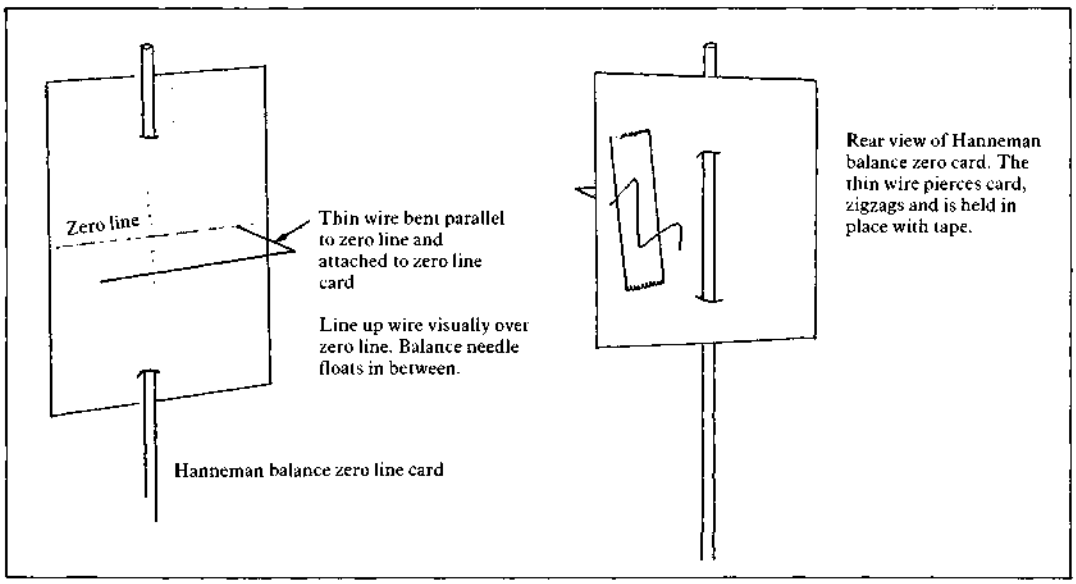

Fig. 4a, b. Improvements to the accuracy of the Hanneman specific gravity balance.

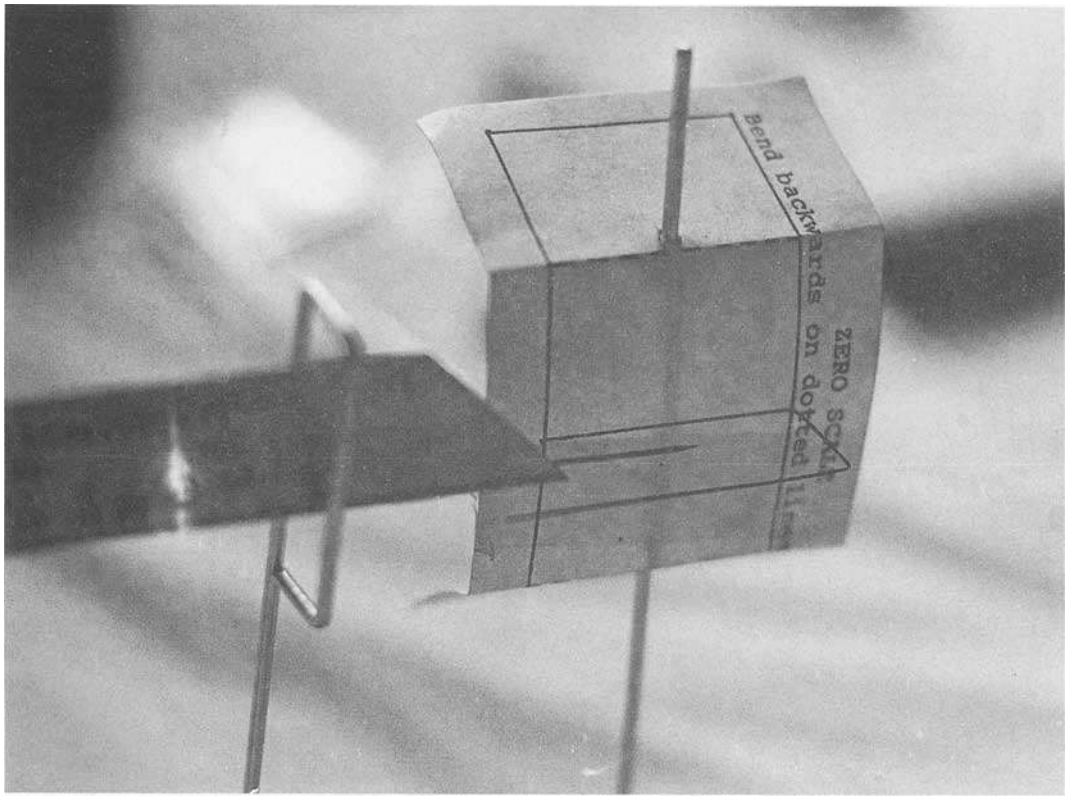

Fig. 5. View of Hanneman balance adaptation with balance arm needle floating between zero card and wire.

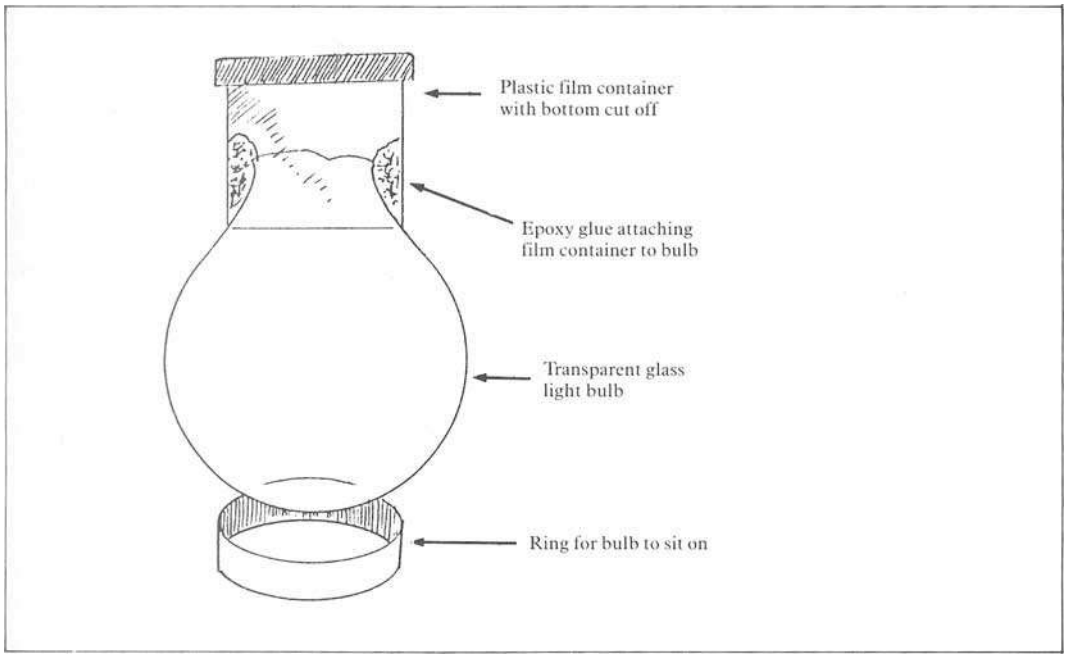

Fig. 6. A clear light bulb adapted for use as a round bottomed flask.

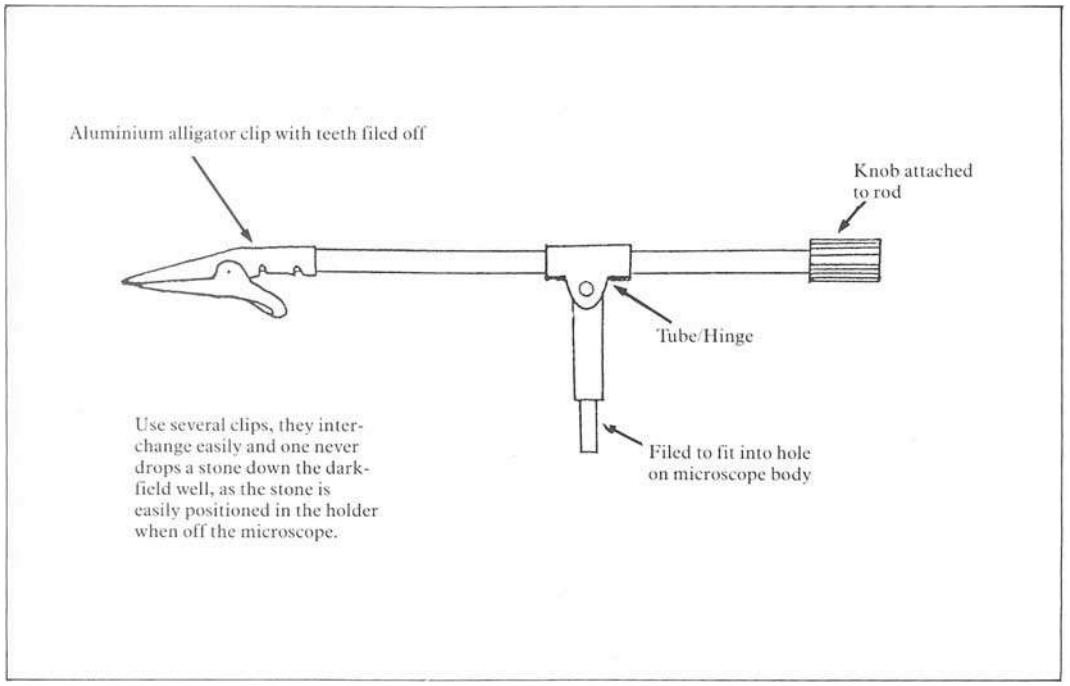

Fig. 7. Alligator clips adapted for use as stone holders.

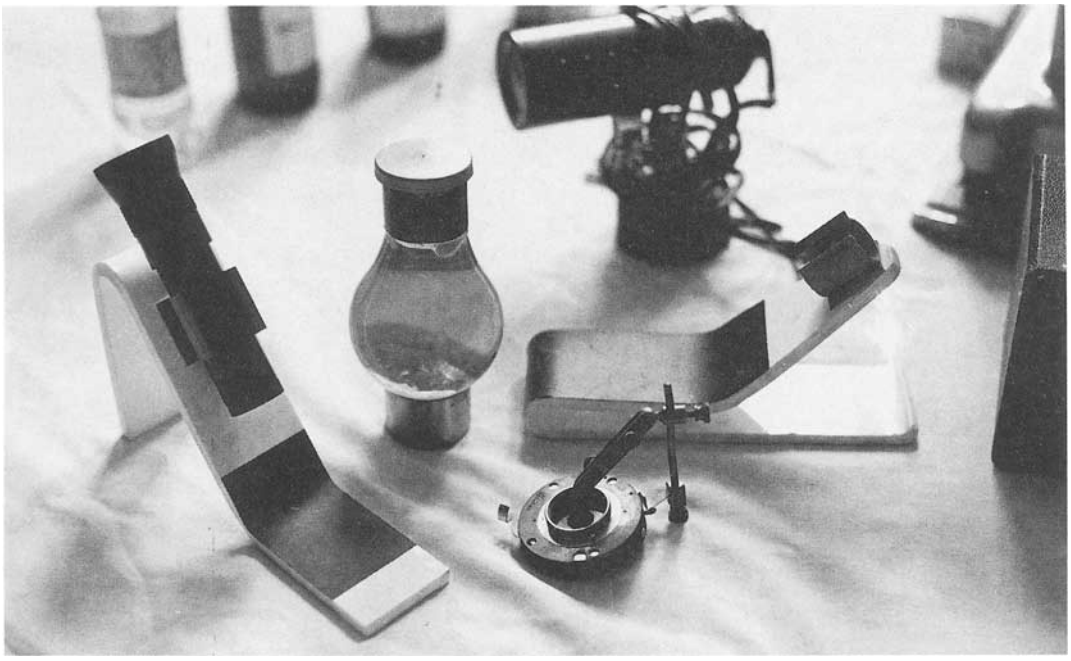

Fig. 8. Home-made spectroscope stands in plexiglass; camera lens iris diaphragm and stone holder for transmitted light spectroscopy and light bulb flask of copper sulphate solution.

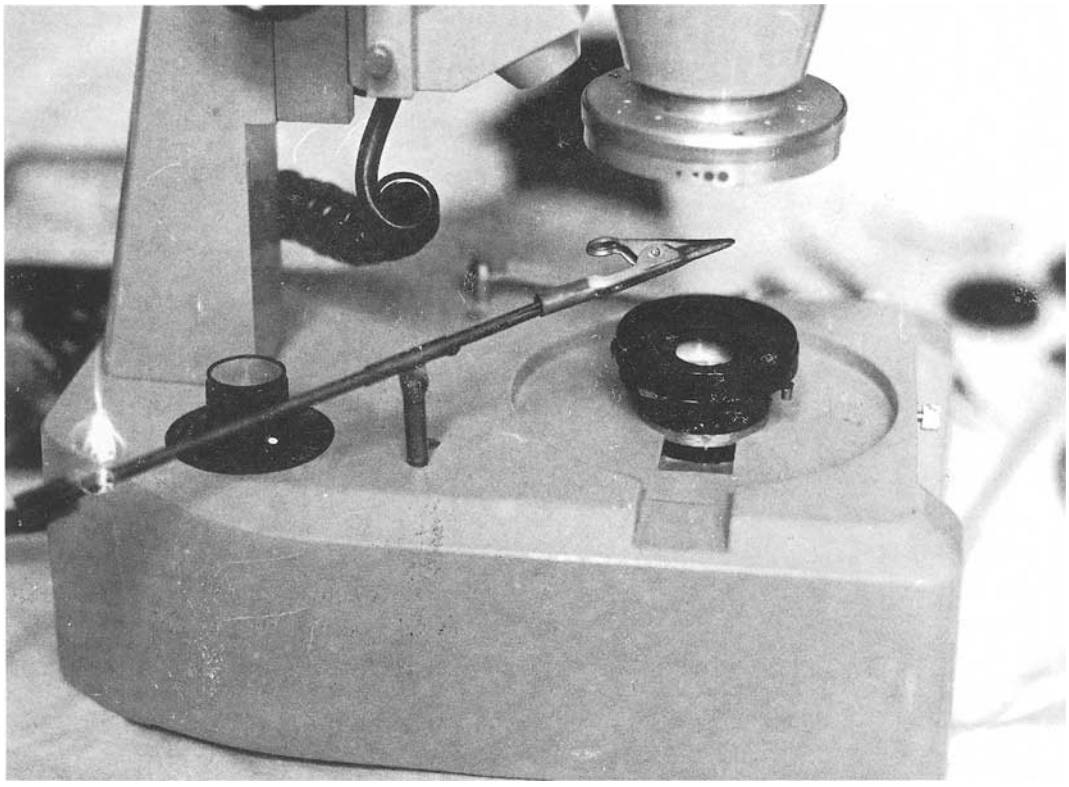

Fig. 9. Lewton-Brain, view of binocular microscope with used camera lens iris diaphragm as a dark-field well and interchangeable alligator clip stone holder.

One of the problems with the balance is that if one moves one's head during weighings one may be off on the reading. The improvement consists of a thin straight wire which is attached to the zero card of the balance so that it is parallel to the zero line on the card and about 1in (2.5cm) out from the card (Figures 4a, b and 5). The needle of the balance arm floats between the wire and the card. When you line up the wire and the zero line (the wire covers the zero line) then one's head is automatically in the same place relative to the balance. One can detect minute differences in needle placement using this method. Remember to use a very thin wire. I used thin iron binding wire which I straightened by placing one end in a vice, holding the other end with a pair of pliers and pulling. The wire stretches somewhat and is perfectly straight after this treatment.

Other adaptations included a clear light bulb (Figure 6) transformed into a round bottomed flask for copper sulphate solution and using alligator clips with all the teeth filed off as interchangeable stone holders (Figure 7) on my microscope. This latter arrangement is far more pleasant than commercial stone holders and one never drops a stone into a light well as the stone is put in the holder before the holder is in place on the microscope (Figure 8). Oh yes, old iris diaphrams may be had for free from camera repair shops and can be used for spectroscopy as well as, in my case, for constructing a dark field well for my binocular microscope (Figure 9).

Of the above perhaps the most useful is the Hanneman balance adaptation. I hope that this information may prove useful to gemmologists and students.

Clamps for spectroscope stands may be had from: Small Parts Inc, PO Box 381736, Miami, Florida, 33138. In USA called cable clamps.

[*Manuscript received 17 March 1989.*]

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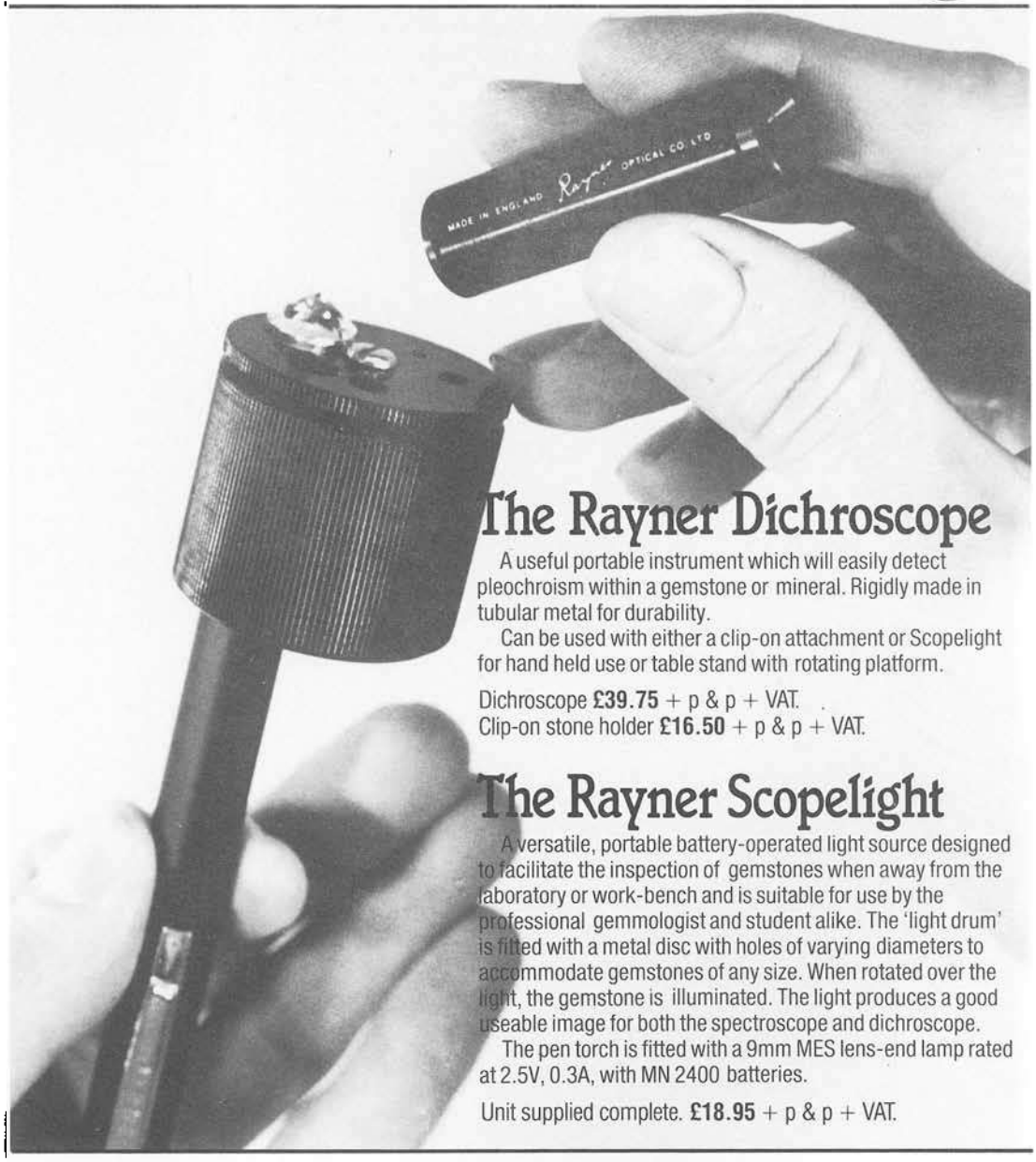

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Gemmological Abstracts

BALFOUR, I., 1989. Famous diamonds of the world, XLI. Penthièvre. *Indiaqua*, 53, (1989/2), 149-52.

The 10 carat yellow oval-cut Penthièvre takes its name from Louis-Jean Marie de Bourbon, Duke of Penthièvre, heir to the last of the legitimate sons of King Louis XIV of France. Although there is no record of the provenance of the rough stone, it is thought to have been mined in either India, Brazil or possibly Borneo. Much of the article is to do with the lineage of the Duke and the mystery surrounding one of his descendants, Louis Philippe, who became King of France. Although never worn by her, the Penthièvre can be identified as being part of the jewellery owned by Marie-Amélie, consort of Louis Philippe, and the stone subsequently survived at least two robberies. It is now on display as the principal gem in a large oval motif on a flat bandeau in the Condé museum at the Chateau de Chantilly. P.G.R.

BANCROFT, P., 1989. Record Russian spinels. *Lapidary Journal*, 43, 4, 41, 1 fig. in colour.

Large purplish spinels from the Pamirs, USSR, have been cut. Some reach sizes up to 28 ct as depicted. The location can be worked only in times of reasonable weather. M.O'D.

BOWERSOX, G.W., ANWAR, J., 1989. The Gujar Killi emerald deposit, Northwest Frontier Province, Pakistan. *Gems & Gemology*, 25, 1, 16-24, 14 figs in colour.

Describes deposits, mines, geology and gemmology of emeralds from the remote Swat river region of the Indus headwaters of Northern Pakistan. High iron and chromium content gives emeralds of dark colour and skilled cutting is required to produce acceptable stones. RI 1.589-1.599, DR 0.010, SG 2.72, strong absorption spectrum, with many inclusions and some healed cracks which are described as 'veil-like', hopefully not to be confused with the 'twisted veils' associated with synthetic emerald. R.K.M.

BRACEWELL, H., 1989. Gems around Australia, Part 2. *Australian Gemmologist*, 17, 2, 60-2, 64, 15 coloured figs.

The promised continuation of Mrs Bracewell's account of gems seen on their long autotrek around that vast continent. The area of Mt Isa, one of the largest mines for silver and lead, with zinc and copper as considerable by-products, is renowned for its variety of mineral specimens including actinolite, amethyst, beryl, calcite, dravite, epidote, feldspars, garnet, iolite, malachite-azurite, mica, quartz, rutile, scapolite, schorl, staurolite, etc. Ornamentals inculde jaspers, zig-zag amethyst, mudstone, gooseberry agate, spinifex stone, green fluorite, and torbernite (radio-active, not a gem mineral) and fossil trilobites. Other areas for petrified woods, pyrope, serpentine, transparent labradorite, etc., etc., are mentioned. The Bracewells must have had quite a time! R.K.M.

BROWN, G., 1989. Quality assessment of Thai gem corundum. *Wahroongai News*, 23, 5, 15-17.

An extract from a Siam Science Bulletin dated 1947, by U. Guhler, titled 'Studies of precious stones in Siam', is sufficiently rare to warrant abstraction. It covers some of the gemmology of the material, occurrence and recovery of stones and the factors influencing values of rubies, sapphires and zircons. Only 1% of fine sapphires are above 4 carats. Mr Brown suggests that these factors are as valid today as they were in '47. Abstractor doubts this! R.K.M.

BROWN, G., 1989. Siliciophite: Australian 'cat's-eye opal'. *Australian Gemmologist*, 17, 2, 48-51, 10 coloured figs.

Chrysotile asbestos fibres in a common opal matrix, when correctly oriented, cuts to give attractive cat's-eyes in yellowish-green or brown, with eyes of varying sharpness. RI and SG are right for opal but H is given as 6. Colour and appearance identifies. R.K.M.

Brown, G., Bracewell, H., Snow, J., 1989. Gems of the Mud Tank carbonatites. *Australian Gemmologist*, **17**, 2, 52-5, 17 coloured figs.

[Carbonatites are comparatively rare marble-like rocks which are of magmatic origin rather than sedimentary, and are sources of important included minerals.] In the Strangway Range, NE of Alice Springs, they were found to contain brown, reddish-brown, pink and purple high-type gem zircon, possibly with little uranium, so absorption lines are weak in pale specimens and absent in darker ones. Yellowish apatite of cabochon grade also found. R.K.M.

Brown, G., Callaway, P., 1989. Black-dyed synthetic opal. *Australian Gemmologist*, **17**, 1, 24-6, 5 figs in colour.

A Gilson white synthetic opal was found too porous to cut and polish well so the owner used sugar/acid dyeing to enhance the material, with very satisfactory results which showed up the highly characteristic distribution of colour. R.K.M.

Brown, G., Kelly, S.M.B., 1989. Australian colour-changing sapphire. *Australian Gemmologist*, **17**, 2, 47-8, 4 coloured figs.

A sapphire changed from bluish in daylight to purplish in incandescent light, due to patch of strong orange in base of the stone. R.K.M.

Brown, G., Snow, J., 1989. Gemmological study club lab reports. *Australian Gemmologist*, **17**, 1, 27-33, 18 figs in colour.

Reports are given on Finnish spectrolite; ox-eye labradorite from Malagasy; ornamental wurtzite material; cultured blister pearls from Broome, Western Australia; Ramaura synthetic ruby; Oregon labradorite sunstone; two different types of 'emerald' doublet; a modern whalebone scrimshaw; Mount Isa 'scapolites' which are now recognized as feldspar pseudomorphs of scapolite crystals. R.K.M.

Brown, G., Snow, J., Bracewell, H., 1989. Gemmology Study Club report. *Australian Gemmologist*, **17**, 2, 65-8, 13 figs, some in colour.

Describes two opals, one with a bubble-like formation and the other with a U-shaped colour distribution; a Sumitomo synthetic diamond octahedron with trigons and lamella [grooved edge] growth etc.; a yellow one with flux inclusions; dyed paua shell from New Zealand; and faceted cuprite from Namibia; red clarified amber with sun spangles; proliferated bubbles in synthetic spinel [these are usually called 'profiled' bubbles because their edge outline can look rather like the human face in profile]; howlite stained to imitate turquoise; other turquoise imitants; Pilbora 'jade', a decorative serpentine; and amethyst burned to prasiolite (green quartz) by the heat of the sun. All are illustrated. R.K.M.

Brown, G., Bracewell, H., 1989. Greenbushes spodumene-quartz (a new Australian lapidary material). *Australian Gemmologist*, **17**, 1, 14-17, 3 maps, 4 figs in colour.

This variegated pink-grey rock from Greenbushes in SW Western Australia, is mined as a source of lithium, but it is suggested that the deposit has gem potential for kunzite. The bi-mineral rock is also promising as an ornamental material. R.K.M.

Campbell, I.C.C., 1989. The physical appearance of rutile in a Sri Lankan grey asteriated corundum. *South African Gemmologist*, **3**, 2, 17, 3 figs.

Photographs of coarse rutile needles in a grey Sri Lankan star corundum show the difference between natural and synthetic star corundum in this context. M.O'D.

Cassedanne, J.P., 1989. The Ouro Preto topaz mines. *Mineralogical Record*, **20**, 3, 221-33, 21 figs (10 in colour).

Topaz and other minerals are described from the Quadrilátero Ferrífero in central Minas Gerais, Brazil. Geology and mining history are described and an alphabetical list of minerals given. The area is the type locality for euclase which occurs with topaz in loose single crystals, partly gem quality and pale blue, pale green or colourless. Topaz crystals show a wide range of colours and are usually singly terminated and some show a weak milky orange fluorescence. M.O'D.

Coldham, T.S., 1989. Hexagonal zoning and coarse needles in heat-treated sapphire. (Letter.) *Gems & Gemology*, **25**, 1, 42.

Disputes belief that sapphires with coarse rutile needles have necessarily not been heat-treated. Stones so treated to improve colour were found to retain some of their silk. R.K.M.

Coy-Yll, R., 1986. Luminescence in tourmaline. *Abstracts from the Proceedings of the 14th General Meeting of the International Mineralogical Association, 13-18 July 1986, Stanford, CA, USA.*

A pale pink tourmaline crystal, apparently closely related to the elbaite pole and a deep blue crystal close to the schorl pole showed interesting luminescent effects from sections cut perpendicularly to the *c*-axis. The specimens were heated to 500°C to observe possible thermoluminescent effects. Following each TL run the sample was

heated again to obtain the black-body background. The pink specimen showed a natural TL of three broad glow-peaks centred at 210, 310 and 360°C. The natural TL from the blue specimen includes six well-resolved glow-peaks at 160, 170, 185, 280, 300 and 380°C. M.O'D.

DIRLAM, D.A., MISIOROWSKI, E.B., COOK, J.L., WELDON, R., 1989. The Sinkankas Library. *Gems & Gemology*, 25, 1, 2-15, 16 figs in colour.

At the beginning of 1988 the Gemological Institute of America bought the vast and unique library of gemmological, gem and jewellery related works collected over some 40 years by John and Dorothy Sinkankas, the largest and most complete such collection in existence. Comprising something like 14,000 items, there are many extremely rare books dating from such works as Pliny's *Natural History* with translations into several languages, and complete runs such as all 14 editions of G.F. Herbert Smith's *Gemstones*, to innumerable other extremely rare and valuable books both ancient and recent, and a vast collection of pamphlets, periodicals in a variety of languages. The paper can scarcely begin to cover the full import of this vast accumulation of facts on every aspect of these subjects.

The incorporation of this collection as part of the Richard T. Liddicoat Information Centre is extremely reassuring, for such a remarkable library should be preserved intact once brought together, and never dispersed by piecemeal sale. The GIA is taking precautions against disasters such as fire and earthquake, ones which have to be reckoned with in California. Within limits imposed by security the library will be accessible to students, and to the public. The wisdom of this intelligent disposal by Captain and Mrs Sinkankas has to be applauded, but abstracter wonders whether they miss all those books, desperately? – or with relief?

R.K.M.

DOWNING, P.B., 1989. An Australian love affair. *Lapidary Journal*, 43, 3, 32-40, 8 figs (3 in colour).

An account of life and opal mining at Lightning Ridge, New South Wales, Australia. M.O'D.

FRIESE, B., 1989. Einschlüsse in Edelsteinen als diagnostisches Kennzeichen zur Bestimmung und Unterscheidung. (Inclusions in gemstones as diagnostic characteristics for determination and investigation.) *Aufschluss*, 40, 4, 221-9, 10 figs in colour.

Inclusions characteristic of a variety of gem minerals are illustrated by photomicrographs. A history of the study of inclusions is given. M.O'D.

FRYER, C.W., (ED.), CROWNINGSHIELD, R., HURWIT, K.N., KANE, R.E., HARGETT, D., 1989. Gem Trade Lab notes. *Gems & Gemology*, 25, 1, 35-41, 18 figs in colour.

A dark green 8 ct faceted brilliant was identified as a new variety of augite, RI 1.682-1.702, SG about 3.20 by heavy liquids, faint absorption at 500nm. X-ray diffraction confirmed augite rather than other monoclinic pyroxenes [not illustrated].

A dark opaque 'indigo' blue covellite was identified by sight, often veined with pyrite, sub-metallic lustre, SG about 4.6, vague spot RI 1.45, H 1.5 to 2.

East Coast Lab reports resurgence of coated diamond fakes, such deceptions generally die out once they are exposed in trade press. Roof-like arrangements of parallel needles intersecting at 90° were found in a diamond, while another had a dense bundle of laser drillings aimed at eliminating [?] one inclusion.

A natural freshwater pearl in a necklace dated 1858 is thought to be among the earliest of American Unio pearls 'because Scotland was largely worked out by this time.' [?] Two black three-quarter cultured pearl pendants were claimed by the jeweller to have been whole cultured at one time – another mystery?

A large crystal of rarely seen fine quality bluish-green phosphophyllite weighed 220 grams, size and colour gave a 448nm absorption not usually present in smaller and paler stones, RI 1.595-1.616, SG 3.10, H 3 to 3.5, SUV gave strong violet, an unusual specimen beautifully illustrated. Straight twin-planes gave the appearance of needles in a synthetic flame fusion ruby. A 204.39 ct star sapphire of 'pure' blue colour was examined and found to be entirely natural in colour. Another star sapphire was an unusual greyish-green colour, possibly from Thailand, although the absorption was reminiscent of Australian green stones. Attractive purplish-pink spinel from the Pamirs, USSR, showed close zoning and striation under magnification, a crystal of the same material had sugary grains, possibly calcite, and some mica-like flakes.

More examples seen of antique jewellery 'improved' by substituting cultured pearls, or synthetic sapphires in pieces dating from periods well before either were available; in the second case lack of re-setting damage suggests that the piece was in fact a reproduction, although the diamonds were old-cut. R.K.M.

GAUTHIER, J.P., AJACQUES, J.-M., 1989. La perle au microscope electronique. (Pearls under the electron microscope.) *Révue de Gemmologie*, 99, 12-17, 21 figs (5 in colour).

Pearl structures as seen with the electron microscope are described and illustrated. M.O'D.

GHERA, A., GRAZIANI, G., LUCCHESI, S., 1986. Genesis of vanadium-bearing beryls. *Abstracts from the Proceedings of the 14th General Meeting of the International Mineralogical Association, 13-18 July 1986, Stanford, CA, USA.* **p.110.**

An examination of vanadium-bearing beryl from Salininha, Brazil, suggests that the vanadium may have derived from bituminous sediments. The nature of the inclusions found seems to indicate that pressure-temperature conditions can be referred to metasomatism in dolomitic limestones.

M.O'D.

GHERA, A., LUCCHESI, S., 1987. An unusual vanadium-beryl from Kenya. *Neues Jahrbuch für Mineralogie, Monatshefte*, 6, 263-74, 6 figs.

A vanadium-bearing beryl crystal from Kenya had inclusions of talc, phlogopite, calcite, quartz and apatite, and was believed to have been formed as a result of metasomatic activity, referable to a pegmatitic intrusion in the pre- existing graphite-rich calc-silicate rocks and marbles of the Pre-Cambrian basement of southern Kenya. The mineral inclusions suggest the temperature and pressure of formation to be between 475-380°C at about 2-3kbar. M.O'D.

GIBBS, R.B., 1989. The Magdalena District, Kelly, New Mexico. *Mineralogical Record*, **20**, 1, 13-24, 16 figs (11 in colour).

The Kelly mine, no longer in operation, was celebrated for its fine specimens of botryoidal blue-green smithsonite, several of which are illustrated. The geology and mineralogy of the mine are discussed. M.O'D.

GRAESER, S., 1989. Phenakit im Binntal. (Phenakite in Binntal.) *Schweizer Strahler*, **8**, 5, 189-96, 5 figs.

Phenakite is reported from the Binntal in Central Switzerland. The mineral is rare for this location, celebrated for its sulfosalts. Crystal forms are described. M.O'D.

HÄNNI, H.A., BOSSHART, G., 1988. Danneggiamenti subiti dai diamanti tagliati. (Damage suffered by cut diamonds.) *La Gemmologia*, **13**, 1/2, 17-23, 10 figs in colour.

The various ways in which cut diamonds can be damaged are outlined. M.O'D.

HANSEN, N.R., 1989. Hong Kongs jademarked pa Canton Road. (The Hong Kong jade market on Canton Road.) *Gem Bulletinen*, 1, unpaged, 6 figs.

The famous open-air jade market is described.

M.O'D.

HARRIS, C., 1989. Oxygen-isotope zonation of agates from Karroo volcanics of the Skeleton Coast, Namibia. *American Mineralogist*, **74** (3-4), 476-81.

Oxygen-isotope profiles through six agates show $\delta^{18}O$ variation from 20.4 to 28.9‰, consistent with low temperatures of formation. Systematic differences in $\delta^{18}O$ exist beteween coarsely crystalline quartz bands and mycrocrystalline quartz within the same agate, with the coarse quartz being, on average, 3‰ lighter; this is consistent with crystallization of the coarse zones from H_2O vapour and the microcrystalline quartz from H_2O liquid at about 120°C. R.A.H.

HAWTHORNE, F.C., 1987. The crystal chemistry of the benitoite group minerals and structural relations in (Si_3O_9) ring structures. *Neues Jahrbuch für Mineralogie, Monatshefte*, 1, 16-30, 7 figs.

Structures discussed are pabstite and bazirite as well as benitoite with which they are both isostructural. M.O'D.

HEFLIK, W., KWIECINSKA, B., NATKANIEC-NOWAK, L., 1989. Colour of chrysoprase in light of mineralogical studies. *Australian Gemmologist*, **17**, 2, 43-6, 58-9, 11 figs, map.

Working on Polish deposits authors seem to have gone to a lot of trouble to show that the green colour of chrysoprase is due to nickel oxide in the form of bunsenite. [NiO has been recognized as the colouring agent in this stone for more than a century.] R.K.M.

HEPPE, S., 1989. Un grenat vertila tsavorite. (A green tsavorite). *Révue de Gemmologie*, 99, 5-7, 6 figs (4 in colour).

A review of the discovery, occurrence and properties of green transparent grossular. Raman spectra for the calcium garnets are illustrated and there is a graphic summary of chromium and vanadium content. M.O'D.

HICKS, W.H., 1989. Editorial *Australian Gemmologist*, **17**, 2, p48.

There are apparently 'no legally enforceable definitions of gems' in Australia, so that a synthetic emerald can be sold simply as 'refined' emerald without further qualification and without offending any laws. There is no Customs or Tax 'requirement to differentiate between natural stones and synthetics'. CZ simulants of diamond were offered with diamond emphasized and scarcely a mention of their true nature. The Victorian Department of Consumer Protection apparently showed little interest. The AG editor is concerned that tourists and others should be protected and should actually receive what they think they are buying. R.K.M.

HISS, D.A., 1989. Chrysoberyl: the phenomenal gem-spinel: so misunderstood. *Jewelers' Circular Keystone*, **159**, 4, 233-30, 20 figs in colour.

Brief descriptions of the chrysoberyl and spinel gemstones with notes on their current marketability. [Similar accounts by the same author on other species can be found in other issues of this Journal.] M.O'D.

HODSON, K., 1989. Mining rainbows. *Lapidary Journal*, **43**, 3, 41-3, 2 figs in colour.

A brief description of the Rainbow Ridge opal mine, Virgin Valley, Humboldt County, Nevada, USA. M.O'D.

HOLLIS, J.D., SUTHERLAND, F.L., 1986. Relationships between colour, crystallography and origins of gem zircons in E. Australia. *Abstracts from the Proceedings of the 14th General Meeting of the International Mineralogical Association, 13-18 July 1986, Stanford, CA, USA*. p.127.

Large gem quality zircon crystals from some Australian deposits derived from alkaline volcanic activity in the eastern part of the country. Zircons from three locations are examained and their colour correlated with the crystal forms displayed. M.O'D.

HUISHU, W.A., 1986. A mineralogical study of amber in the XIXIA region of Henan PRC. *Abstracts from the Proceedings of the 14th General Meeting of the International Mineralogical Association, 13-18 July 1986, Stanford, CA, USA*.

Amber is found in a red sand conglomerate formation of the Upper section of Mesozoic age in Henan province. Specimens are white, yellow, orange, red and reddish-brown and the RI is 1.5426-1.5549. Varying luminescence is shown; the SG is 1.113. M.O'D.

KAMPF, A.R., FRANCIS, C.A., 1989. Beryl gem nodules from the Bananal mine, Minas Gerais, Brazil. *Gems & Gemology*, **25**, 25-9, 5 figs in colour.

This mine, near Salinas, has yielded fine large aquamarine crystals with morganite cores. The morganite fades from orange to a more desirable pink on exposure to sunlight. Much material is good carving quality, with some of excellent facet grade. R.K.M.

KOIVULA, J.I., 1989. Ancient millipedes. *Australian Gemmologist*, **17**, 1, 14-17, 2 figs in colour.

Millipedes in amber are quite rare and those trapped are usually smaller species. [Monster tropical ones presumably had the strength to struggle free!] R.K.M.

KOIVULA, J.I., KAMMERLING, R.C., 1989. 'Opalite': plastic imitation opal with true play-of-color. *Gems & Gemology*, **25**, 1, 30-4, 5 figs in colour.

Polystyrene imitation opals of Japanese origin cannot be separated visually from natural or synthetic opals. Specimens purporting to be 'new', under the name 'Opalite' were examined and found to be assembled, i.e. with signs of a distinct basal layer of another plastic, probably acrylic resin. RI is 1.51, SG estimated at 1.20 ± 0.05, too high and too low respectively for true opal. A false claim that these imitations will not scratch or chip as easily as natural opal is belied by the hardness of about 2.5. Far warmer to touch than opal. If doubt still exists the infrared absorption is completely typical of Japanese plastic imitation opal. Alternative name is 'Opal Essence' and it is available world-wide. Virtually identical with other Japanese imitation opals. R.K.M.

KOIVULA, J.I., KAMMERLING, R.C., 1989. Gem News. *Gems & Gemology*, **25**, 1, 45-51, 14 figs in colour.

Angelite, a 'new' light bluish-grey opaque stone seen at the Tucson Show, is in fact anhydrite. Many fine African rhodolites, and dark red almandines from Orissa, India, were seen; also stones with man-made inclusions, either electrically deposited dendrites, or drilled and filled quartz. Mother of pearl gambling chips of Chinese 18th or 19th century origin were offered mounted or loose. Plastic one-piece imitations of cameos were offered. Hydro-thermal amethyst, citrine and rock-crystal were plentiful, while bi-colour purple-red/yellow-green tourmalines from Nigeria were available.

Coloured Stones.

A new and beautiful form of orthoclase from the Harts Range in Northern Territory, Australia, sold as 'Rainbow Lattice Sunstone', is illustrated. A new emerald deposit yielding yellowish-green stones found near Itabira, at Nova Era, Minas Gerais. A 708 ct polished spessartine garnet of fine quality, found 16 years ago, and thought to have come from Brazil, may be the largest polished transparent red gem in the world. A star almandine is reported from Idaho, and a star rhodolite from Tanzania is illustrated, the latter a new find. A light greenish-grey opaque wollastonite, suitable for carving, is mined at Viola, near Caliente in Nevada.

Instrumentation.

The Discan, a new spectroscope produced in conjunction with the GIA, is coupled to a liquid crystal display of the wavelength of each absorption as it is centred on a crosshair scanner. Another instrument couples a small fixed-slit diffraction

instrument with a video camera to give an on-screen display of the spectrum. [This would be useful in teaching!]

Synthetics.

Sumitomo are now producing yellow synthetic gem diamond crystals in the 5 ct range. Minute diamond crystals have been found in the residual soot from TNT explosions. A two kilogram 'synthetic diamond' reported in USSR in 1983 is now known to be an unusually large top-quality piece of cubic zirconia, Russian words for 'simulant' and for 'synthetic' do not distinguish clearly between them, error was in translation and not an attempt to deceive. Once more quartz crystals faked to look like emerald have been found; superficially convincing to the eye, the two crystals purchased in 'Southern Africa' involved the buyer in considerable financial loss. [Illustration shows a rhombohedral face and transverse striations on the prism, both typical of quartz and not of emerald.] Dark purple massive lepidolite artificially shaped to resemble crystals have apparently also been darkened by heating. 'Diamond' octahedra faked from cubic zirconia have been sold in Swakopmund, Namibia, while street pedlars have offered green bottle-glass fragments as tsavorite.

Porous azur-malachite from Arizona is being bonded with plastic, under pressure, to make workable blocks which cut and polish well as cabochons, with no intent to deceive. R.K.M.

Koivula, J.I., Kammerling, R.C., 1989. The gemmology of Kyocera's new synthetic star ruby. *South African Gemmologist*, **3**, 2, 5-14, 4 figs in colour.

A natural-looking star ruby has been manufactured by the Kyocera Corporation, Kyoto, Japan. A strong fluorescence under LWUV and characteristic inclusions of a high-temperature melt process show that this is an artificial product. The trade name is Inamori. M.O'D.

Kostov, R.I., 1986. A complex classification of gem minerals. *Abstracts from the Proceedings of the 14th General Meeting of the International Mineralogical Association, 13-18 July 1986, Stanford, CA, USA*. p.144.

The existing classifications of gemstones on physico-chemical grounds is criticized and an alternative scheme proposed. This would classify gem minerals on the basis of morphological status, art status (e.g. rough material or fashioned), genetic or locality status, optical, crystallographic or historical status or utilization status. M.O'D.

Kozlowski, A., Metz, P., Estrada Jaramillo, H.A., 1988. Emeralds from Somondoco, Colombia: chemical composition, fluid inclusions and origin. *Neues Jahrbuch für Mineralogie, Abhandlungen*, **159**, 23-49, 11 figs.

Emeralds from the Somondoco district of Colombia were analyzed by electron microprobe, colorimetry, emission spectrography, thermogravimetry and infrared absorption. Inclusions are illustrated. M.O'D.

Landmesser, M., 1988. Experimente zur Petrologie edelsteinbildender Prozesse: Chalcedon/Achat. (Studies on the petrology of gemstone-forming processes: chalcedony/agate.) *Kurzmitteilungen aus dem Institut für Edelsteinforschung*, **4**, 3/4, 13-24, 10 figs.

Work on the experimental synthesis of cryptocrystalline silica is described. M.O'D.

Leguey, S., Gimenez, G., Morante, M., Medina, J.A., 1986. Opals of gemological interest in the Neogene basin of Madrid. *Abstracts from the Proceedings of the 14th General Meeting of the International Mineralogical Association, 13-18 July 1986, Stanford, CA, USA*. p. 153.

Both black and white opal of gem quality occur in a siliceous rock in the Neogene basin of Madrid, Spain. Black opal shows RI 1.420-1.428 and SG 1.898-2.054, and white opal RI 1.436-1.449 with SG 1.886-1.891. The black material has a pleasing lustre while the white stones are translucent and highly fluorescent. M.O'D.

Li Ping, Peng Mingsheng, 1986. The study of the spectroscopy and the color nature of some gem minerals. *Abstracts from the Proceedings of the 14th General Meeting of the International Mineralogical Association, 13-18 July 1986, Stanford, CA, USA*. p.155.

Aquamarine, blue sapphire and lazurite are examined with a view to establishing the cause of their colour. Blue sapphire is reported from Hainan, Guangdong, People's Republic of China. The sapphire, which is found with spinel, zircon and olivine, all of gem quality, is pale blue with 0.73% Fe and 0.03% Ti. M.O'D.

Malley, J., 1988. Synthetischer Alexandrit aud der UdSSR. (Synthetic alexandrite from the USSR.) *Kurzmitteilungen aus dem Institut für Edelsteinforschung*, **4**, 3/4, 21.

Synthetic alexandrite grown in the USSR was found to contain gallium, with bismuth and sulphur in the flux feathers. These are clear evidence of artificial origin. M.O'D.

MINSTER, D., 1989. A practical diamond grading technique. *South African Gemmologist*, **3**, 2, 20-1, 4 figs in colour.

Polarized light is used to locate small imperfections in cut diamonds. M.O'D.

MONCORGE, P., 1989. 'Thaïlande-Kanchanaburi Bo Phloï': une page se tourne. (Thailand-Kanchanaburi Bo Phloi: a page turns.) *Révue de Gemmologie*, 99, 3-4, 7 figs (3 in colour).

Gem-quality blue sapphire is found near the town of Bo Phloi in Thailand and is recovered from alluvial deposits. Seven small basaltic hills are in the vicinity. M.O'D.

MOORE, P.B., SEN GUPTA, P.K., SCHLEMPER, E.O., 1989. Kornerupine: chemical crystallography, comparative crystallography, and its cation relation to olivine and to Ni_2In intermediate. *American Mineralogist*, **74**, 642-655, 2 figs.

Kornerupine from Mautia Hill, Tanzania, is discussed in relation to its chemical composition and crystallography. M.O'D.

NASSAU, K., 1989. DR JOHN SINKANKAS. *Lapidary Journal*, **43**, **4**, 42-9, 5 figs (3 in colour).

The gift by John and Marge Sinkankas of their large gemmological library to the Gemological Institute of America is marked by a short biography. M.O'D.

NASSAU, K., 1989. Opal treatment. *Lapidary Journal*, **43**, 3, 44-51, 2 figs in colour.

The various ways in which opal can be treated, stabilized or improved are described. Notes on identification are given. M.O'D.

NASSAU, K., 1986. The physics and chemistry of the thirteen causes of color in minerals. *Abstracts from the Proceedings of the 14th General Meeting of the International Mineralogical Association, 13-18 July 1986, Stanford, CA, USA*. p.184.

The author summarizes the 13 causes of colour in minerals from his monograph *Physics and chemistry of color*, 1983, Wiley. M.O'D.

NOGUES-CARULLA, J.M., VENDRELL-SAZ, M., ARBUNIES, M., LOPEZ-SOLER, A., 1986. Photometric study of UV- luminescence of cut diamonds and its relationship with their colour classification. *Abstracts from the Proceedings of the 14th General Meeting of the International Mineralogical Association, 13-18 July 1986, Stanford, CA, USA*. p.187.

UV-luminescence from cut diamonds has been measured in the visible range and the points display a linear distribution corresponding to a dominant wavelength of 484nm. The transmission curves of the diamonds were obtained between 400 and 700nm. The colour coordinates and colour saturation were calculated and the points of x and y adjusted to a straight line whose dominant wavelength corresponds to 578nm. The comparison of the two photometric results shows that the observed colour is the addition of both transmission and visible range emission luminescence. M.O'D.

NUNAN, T.J., 1989. The mining of sapphires. *Australian Gemmologist*, **17**, 1, 7-12, 18-9, 7 figs in colour.

A comprehensive paper on this general subject, but largely concerned with mining areas of Queensland and NSW. So far mining has been from alluvial areas and volcanic ash. Writer suggests that other sources should be sought. The economics of cutting in Australia are compared with the far lower costs in Sri Lanka and Bangkok. R.K.M.

OTTAWAY, T.L., WICKS, F.J., 1986. Characteristics and origin of the Muzo emerald deposit, Colombia. *Abstracts from the Proceedings of the 14th General Meeting of the International Mineralogical Association, 13-18 July 1986, Stanford, CA, USA*. p.193.

Emeralds occur in a stockwork of albite + calcite + dolomite ± barite veins cross cutting Cretaceous shales and limestones. There is no direct evidence of igneous activity either at Muzo or at other localities in the emerald belt of the Cordillera Oriental. Thermal metamorphism has not been seen in the vicinity of the vein systems. M.O'D.

POUGH, F.H., 1989. Carletonite. *Lapidary Journal*, **43**, 4, 16-18.

Details of carletonite are given along with other ornamental minerals from the nepheline syenites of Mt St Hilaire, Quebec, Canada. The other minerals described are serendibite and catapleite. M.O'D.

POZZI, A., 1988. Gemme della Tanzania. (Gemstones from Tanzania.) *La Gemmologia*, **13**, 1/2, 25-37, 8 figs in colour.

An up-to-date summary of gem minerals found in Tanzania, with a short bibliography and a map. M.O'D.

RODIONOV, A. YA, SOLNTSEV, V.P., 1986. Gem varieties of beryl, chrysoberyl and phenakite grown by chemical vapour transport. *Abstracts from the Proceedings of the 14th General Meeting of the International Mineralogical Association, 13-18 July 1986, Stanford, CA, USA*. p.213.

Coloured varieties of beryl, chrysoberyl and phenakite, were grown by chemical vapour transport in closed halogen- bearing systems. Several colour varieties were obtained for each species with appropriate dopants. M.O'D.

ROMBOUTS, L., 1987. Geology and evaluation of the Guinean diamond deposits. *Annales de la Société Géologique de Belgique*, **110**, 1, 241-59, 5 maps.

Nineteen Cretaceous kimberlite pipes, classified into three types, with area surfaces from 1100 up to 95,000 m^2, and alluvial diamond deposits are located in Upper Guinea, in the area bounded by Kissidougou, Kerollane and Macenta. The kimberlites, which seem all diamond-bearing, are intruded into the Archaean craton of the Guinea Rise and are closely related to the break-up of Gondwana. About 1700 diamonds, $\leq$ 10 ct, were examined for their crystallography and colour. Octahedra, dodecahedra and their twins are best represented, while cubes are very rare. White and yellow colours predominate over brown, grey and green. In the alluvial deposits of the Gbenko–Banankoro area 93% of the stones are of gem quality. R.V.T.

ROSSMAN, G.R., 1986. The hydrous component in garnets. *Abstracts from the Proceedings of the 14th General Meeting of the International Mineralogical Association, 13-18 July 1986, Stanford, CA, USA*. p.216.

Results suggest that a 'hydro' substitution in garnet is common but that the amount of H_2O is usually small. Most garnets have 1/100 the hydro content of classical hydrogarnets. M.O'D.

RYKART, R., 1989. Amethystfarbige Zepterquarze, grosse Barytkristalle und Fadenquarzaggregate aus dem Val Giuv, Tavetsch GR (Neufund). (Amethyst-coloured sceptre quartz, large baryte crystals and quartz aggregates with a central opaque portion from Val Giuv, Tavetsch, Grisons, [Switzerland].. New find.) *Schweizer Strahler*, **8**, 5, 196-201, 8 figs in colour.

Fine crystals of amethyst sceptre quartz with large baryte crystals and quartz aggregates with opaque centres have recently been found in the Val Giuv, Tavetsch, Grisons, Switzerland. Some of the quartz crystals have smoky portions. M.O'D.

SAADI, J.A., 1988. Rodocrosita argentina para la ciencia y el arte. (Argentinian rhodochrosite in science and art.) *Boletin del Instituto Gemológico Espanôl*, 30, 8-20, 36 figs in colour.

Rhodochrosite from the Capillitas location in Catamarca Province, Argentina, is described and illustrated. M.O'D.

SCHMETZER, K., 1988. Zur Charakterisierung von synthetischen, im Hydrothermalverfahren gezüchteten russischen Smaragden. (On the characterization of Russian synthetic emerald made by the hydrothermal method.) *Goldschmiede und Uhrmacher Zeitung*, **86**, 11, 97-192, 27 figs (in colour).

A large number of characteristic inclusions patterns are depicted for the Russian hydrothermally-produced synthetic emerald. SG is in the range 2.68-2.70 and RI 1.580-1.586 for the ordinary ray and 1.573-1.579 for the extraordinary ray. The DR is 0.006-0.007. Among the inclusions are very fine parallel needles and hexagonal flattened crystals which may be hematite. M.O'D.

SCHMETZER, K., 1988. Thermal stability of yellow colour and colour centres in natural citrine. *Neues Jahrbuch für MIneralogie, Monatshefte*, 2, 71-80, 2 figs.

Two types of colour centre are identified in natural citrine. The yellow colour centre of natural untreated citrine is bleached by heat treatment at temperatures between 450 and 550°C and this type of colour centre is not restored by gamma or neutron irradiation. The second type with lower thermal stability is produced in bleached and unbleached citrines by subsequent gamma irradiation and is stable up to about 300°C. Additional defect centres causing absorption maxima in the red or violet range as well as smoky colour centres are also discussed. M.O'D.

SNOW, J., BROWN, G., 1989. Optronix® gemmological instruments. *Australian Gemmologist*, **17**, 1, 3-4, 2 figs.

The Multi View II is a quartz-halogen fibre-optic light source for microsopy, spectroscopy and other optical purposes.

The Omni View is an up-dated version with many in-built facilities, including polariscope, UV luminescence, etc. Made in Bangkok, both are heavy instruments, 4.6kg and 7.7kg respectively, and quite costly. Electrical safety and some design factors are criticized. R.K.M.

STOCKTON, C.M., MANSON, D.V., 1986. The chemical and spectral characteristics of gem garnets from East Africa. *Abstracts from the Proceedings of the 14th General Meeting of the International Mineralogical Association, 13-18 July 1986, Stanford, CA, USA*. p.239.

Gem garnets from East Africa do not always fit existing classification schemes. The new colour types are discussed and referred to their composition. M.O'D.

SUTHERLAND, M.B., 1989. Sinhalite – golden gem of Sri Lanka. *South African Gemmologist*, **3**, 2, 15-16.

Brief account of the testing of a sinhalite. M.O'D.

SWARTZ, D., 1989. The discovery of a new emerald occurrence in Brazil: Capoeirana (Nova Era), Minas Gerais. *Australian Gemmologist*, **17**, 1, 4-5, 1 map.

Material similar in all respects to that from nearby Belmont mine has been found. R.K.M.

THOMAS, A., 1989. An update on the availability of hydro-grossular garnet. (Letter.) *Gems & Gemology*, **25**, 1, 43-4, 1 fig. in colour.

Disputes statement that this is now a scarce material, or that it is as common as an earlier letter from Dr Schreuders claimed. Recent finds have been sporadic, finer colours no longer available, but opaque greyish-green material is still found in quantity, most shipped to Far East. A superb multi-coloured hydro-grossular necklace, [from material found much earlier] is illustrated. R.K.M.

VIMOVA, E.S.E., ZAKHARCHENKO, O.D., SOBOLEV, N.V., MAKLIN, A.I., 1989. (Inclusions in diamonds from some kimberlite pipes.) *Zapiski Vses. Min. Obshch.*, **118**, 2, 74-6. (Russian wih English abstract.)

The problem of the abundance of kimberlitic diamonds which contain solid mineral inclusions is discussed. Microprobe analyses are reported for inclusions in pyrope-almandine, omphacite, magnesiochromite and chrome-diopside. R.A.H.

WILSON, W.E., 1989. The Anjanabonoina pegmatite, Madagascar. *Mineralogical Record*, **20**, 3, 191-200, 17 figs (8 in colour).

The Anjanabonoina pegmatite has produced exceptional crystals of liddicoatite, danburite, phenakite and pink beryl rich in caesium. The history and geology is described and an alphabetical list of minerals is given. Less prominent are spessartine and hambergite. Fine kunzite crystals are found in a reddish-coloured alluvium. M.O'D.

YAKHONTOVA, L.K., SOBOLEVA, T.V., NERADOVSKY, YU.N., BARZHITSKAYA, S.M., RUNDQUIST, T.V., 1989. (Turquoise from Tekhutskoe deposit: mineralogy and genesis.) *Zapiski Vses. Min. Obshch.*, **118**, 2, 83-93. (Russian with English abstract.)

Two morphological types of turquoise are distinguished from the Tekhutskoe deposit, Armenia. One has a streaky appearance and occurs in association with quartz and pyrite, while the other occurs as isolated nodules in quartz-mica-kaolinite weathering material from the quartz diorite host rock. Colloform turquoise gives a diffuse XRD pattern and IR spectrum; disseminated turquoise is better crystallized. The results of 31 chemical analyses for this turquoise are tabulated and the results plotted on a Cu–Al–Fe^{3+} diagram. IR spectra show the presence of $[HPO_4]^{2-}$ anions; the formula may be given as
$CuAl_6[PO_4]^3{}_2^-[HPO_4]^2{}_2^-(OH)_{10}.4H_2O$.

R.A.H.

ZECCHINI, P., MARTIN, F., 1988. Studio del corindone per mezzo della spettroscopia. (A study of corundum using the spectroscope.) *La Gemmologia*, **13**, 1/2, 7-15, 15 figs.

A spectroscopic study of the infrared regions of natural and synthetic corundum suggests that it might be possible to distinguish one type from another. M.O'D.

ZEITNER, J.C., 1989. Opals that made history. *Lapidary Journal*, **43**, 3, 23-30, 5 figs in colour.

An overview of the history of opal as a gemstone and of its occurrence in literature. M.O'D.

ZEITNER, J.C., 1989. Opal, anyone? *Lapidary Journal*, **43**, 3, 52-6, 1 fig. in colour.

Notes are given on the fashioning of opal.

R.K.M.

ZEITNER, J.C., 1989. Green as in emeralds. *Lapidary Journal*, **43**, 4, 22-40, 3 figs in colour.

A useful overview, aimed at the amateur, on the origin, history and properties of emerald. M.O'D.

ZEITNER, J.C., 1989. Crystal shapes. *Lapidary Journal*, **43**, 4, 53-6, 4 figs.

Crystal-like rose quartz formations are reported from the Black Hills of South Dakota. M.O'D.

Book Reviews

CHAUVET, M., 1989. *Frédéric Cailliaud*. Editions ACL-Crocus. pp.371. Illus. in black-and-white and in colour. F.295.

This book was written by a Nantais, to commemorate the bicentenary of one of Nantes' famous sons: the naturalist and egyptologist Frédéric Cailliaud (1787-1869). The author painstakingly retraces the expeditions of his compatriot in Egypt and the Sudan, covering the period 1815-1822.

Although primarily of interest to the student of egyptology, it will be remembered that M. Cailliaud also held the position of mineralogist to the Khedive, Mehemet Ali, and in this connection Chaps. 3 and 5 – dealing with Cailliaud's rediscovery of the ancient 'lost' emerald mines of Zabara and Gebel Sikait – are of particular, and historic, interest to the gemmologist.

Illustrations are from original prints of the period complemented by present-day photographs and there is a fold-out map of the country. N.C.

MANDARINO, J.A., ANDERSON, V., 1989. *Monteregian treasures*, Cambridge. pp.xiii, 281. Illus. in colour. £60.00.

This magnificent book describes the many mineral species found in the nepheline syenite of Mont St Hilaire, east of Montreal, Quebec, Canada. At the time of writing 221 species had been identified with a further 25 still to be identified. Most crystals are small and thus make excellent micromounts but one or two have been cut as gemstones; probably the best-known of these is serandite, a beautiful orange-red sodium magnesium calcium silicate. There are many beautiful photographs of minerals that in many cases have not been illustrated in colour before, tables and an excellent bibliography. M.O'D.

RYKART, R., 1989. *Quarz*. (Quartz.) Ott Verlag, Thun, Switzerland. pp.413. Illus. in black-and-white and in colour. DM69.00.

The book deals in the main with the various forms taken by quartz crystals from a wide variety of localites. Particular attention is paid to European occurrences, a valuable and surprisingly rare feature in mineral books. There is an extensive bibliography and apart from the excellent photographs, many illustrations in the text. Each of the colour illustrations has an extensive caption. This is a well-produced book and amazingly good value for the price. M.O'D.

STRONGE, S., SMITH, N., HARLE, J.C., 1989. *A golden treasury: jewellery from the Indian subcontinent*, Victoria and Albert Museum, London. pp.144. Illus. in colour. £20.00.

This is the catalogue of an exhibition which was staged in London during June 1989. It is also an authoritative treatise on the use of gold in the subcontinent where it has always been venerated and used in many decorative and social contexts. The first section deals with jewellery in Indian sculpture and is followed by a study of jewellery of the Mughal period. The third and final section, called 'The darker side of gold', gives an interesting and valuable account of the commercial handling of gold and the way in which it has been the object of smuggling and crime. Between the three sections is the catalogue proper with each object illustrated in colour with notes on its provenance, date, materials and size. M.O'D.

Proceedings of the Gemmological Association of Great Britain and Association Notices

OBITUARY

Dr Walter Campbell Smith (1887-1988) An Appreciation

Fellows and friends who attended the Association's lectures at Goldsmith's Hall from the late 1940s onwards may well recall the spare, upright, elderly figure of Dr Walter Campbell Smith, who took much pleasure in his appointment in 1947 as an Honorary Fellow of our Association, and gave support and encouragement by his presence at those meetings for so many years.

Now with great regret I have to report that this dear and kindly man died peacefully at his home in Goudhurst, Kent, on December 6th of last year, a few days after reaching the quite remarkable age of 101. A great petrologist, he was Keeper of the Department of Mineralogy at the British Museum (Natural History) from 1937 to 1952.

Graduating brilliantly at Cambridge in Crystallography, Mineralogy, Geology and Petrology, Campbell Smith joined the staff of the Department of Mineralogy in 1910. A petrologist was needed so he fitted ideally into that groove in time to deal with the enormous task of assimilating into the collections some 10,000 world-wide specimens which were handed over by the Geological Society's museum in 1911.

Already a member of the Territorial Army, Campbell Smith was mobilized in the Artists Rifles as a lance corporal at the outbreak of hostilities in 1914 and served with considerable distinction on the Somme and other battlefields throughout that war, eventually emerging with the Military Cross and the rank of Lieutenant-Colonel in 1919.

He had already worked on rock and mineral specimens collected by the ill-fated Terra Nova Antarctic Expedition, led by Captain Robert Falcon Scott in 1912, and now returned to continue this work and to a long association with Antarctic Research and the Scott Polar Research Institute at Cambridge.

Dr W. Campbell Smith

Further research into rare carbonatites from Nyasaland (Malawi) brought the realisation that these were magmatic rocks and not sediments as had been thought.

Valuable studies over the years on a great range of subjects were recorded in some 100 articles covering, among many other things, meteorites, oceanic island geology, feldspars and the origins of beautiful Neolithic green jadeite axe heads found in this country and in western Europe. His work over the years brought him a ScD degree from Cambridge.

The second war again deflected his energies, first to planning for the safety of the immensely

important and valuable collection which was now his responsibility, then when war was done, to organizing the long task of restoring the collection to its orderly places in a gallery which first needed repair after bomb-damage, and then the re-opening of the latter to public access. Although already in his fifties he served the Artists' Rifles again as second in command of the 163 OCTU until 1941.

He was appointed a CBE in 1949 and retired officially from the Museum in 1952, but was then re-employed to work part-time on a considerable number of projects and articles which culminated in a long paper based largely on his personal knowledge of 'Seventy Years of Research in mineralogy and crystallography in the Department of Mineralogy – under the Keeperships of Story-Maskelyne, Fletcher and Prior: 1857-1927' which was published in 1982 when he was 94.

Campbell Smith in his exceptionally long life was held in the greatest esteem for his total application, loyalty and integrity. My own experience of him was of a good and most kind friend who once, when living in a very pleasant first floor flat in Sevenoaks, was still able to get down stairs with remarkable speed to let me in, despite the fact that he was already well into his nineties. But with characteristic honesty he owned that going up again did take a little longer. A distinguished scientist, he had held many appointments of considerable importance and honour in various earth science societies over the years. A wise and intellectually brilliant man to the very end of his days, he had seen vast changes in the techniques of the sciences he served so well for most of his long lifetime, and had indeed contributed to those changes himself in no small measure.

In 1936 he married Dr Susan Finnegan, a senior member of the Department of Zoology at the Museum, a devoted, accomplished and delightful lady who, with a son and daughter and seven grandchildren, now survives him.

Regrettably my own contact with him was slight, and I am indebted to an obituary by Dr A.C. Bishop, the recent Keeper of Mineralogy, for most of the biographical detail in this appreciation. But that does not alter in any way my personal feeling of deep respect and admiration when writing about Dr Campbell Smith. He found time in a long and busy life to befriend and encourage our specialized science of gemmology and we were most grateful for his interest. R.K.M.

It is with great regret that we announce the death of **Mr F. E. Lawson Clarke, FGA** (D.1943), Treasurer of the Association from 1951 to 1983. A full obituary will appear in a future issue of the *Journal*.

Mr George A. Massey, FGA (D.1973), Sheffield, died in May 1989. Mr Massey was Chairman of the South Yorkshire Branch of the Association, and a full obituary will appear in a future issue of the *Journal*.

GIFTS TO THE ASSOCIATION

The Council of the Association is indebted to the following for their gifts:

Mr M. Kammerling, FGA, Idar Oberstein, West Germany, for three unique sapphire doublets.

Mr H. Tamiya, President of Cosmo Ltd, Japan, for a book on jadeite by Hisui.

MEMBERS' MEETINGS

London

On 12 July 1989 at the Flett Theatre, Geological Museum, Exhibition Road, South Kensington, London SW7, following the Annual General Meeting (see p.519), the film 'Considering crystals' was shown. Members were then able to view the new Exhibition 'The Natural History Museum Rock Festival' (see p.519). These events replaced the Gemmological Forum which had to be cancelled because of a train strike.

Midlands Branch

On 15 September 1989 at the Society of Friends, Dr Johnson House, Colmore Circus, Birmingham, Mr Richard Taylor of Professional Jewellery Services of Shrewsbury gave a talk on valuations.

EXECUTIVE MEETING

At a meeting of the Executive Committee held on 1 September 1989 at Saint Dunstan's House, Carey Lane, London EC2, the business transacted included the election to membership of the following:

Fellowship

Becker, Kim A., Francistown, Botswana. 1988
Jayawardena, Palihawadana A.J.L.P., Wattala, Sri Lanka. 1979
Thornton, Shirley E., Bangor, N. Ireland. 1989

Ordinary Membership

Barckley, Lucia, M., San Diego, Calif., USA.
Broadley, Michael, Walton On Thames.
Colomb, Nanette, D., Epsom.
Hoggett, Jane E., Gateshead.
Inkpen, Michael S., Kingsbridge.
Kim, Park J.S., Singapore.
Kneale, Janette, Maidenhead.
Lau, Clement H., London.
Leary, Ronald, Liverpool.
Mansell, Rosalind, London.
Mushtaq Ahmed, Muslim, Faisalabad, Pakistan.

Nangia, Rani, North Harrow.
Papaeliopoulos, George A., London.
Pattni, Dipesh S., Loughborough.
Pelham, David A., Colwyn Bay.
Ravona, Haim, Hadera, Israel.
Razvi, Abdul Q., Slough.
Reeve, Barbara H.C., Cambridge.
Rukbankerd, Poonsri, Bangkok, Thailand.
Simonis, Frank J., Long Beach, Calif., USA.
Swenson, Darrell R., Spring Valley, Calif., USA.
Taylor, Shelley C., Santa Monica, Calif., USA.

COUNCIL MEETING

At a meeting of the Council held on 11 September 1989 at the Royal Automobile Club, Pall Mall, London SW1, the business transacted included the following:

(1) the subscription rate for 1989 for Fellows and Ordinary members was increased to £33 for UK members and $90 for those overseas;
(2) The election to membership of the following:

Fellowship
Andrews, Suzanne, Cheadle Hulme. 1989
Douglas Marshall, Anna T., Cambridge. 1989
Fuller, Mark R., London. 1989

Ordinary Membership
Laidler, James, Cardiff.
Patel, Kokila R., Harrow.
Robertson, David, Edinburgh.

ANNUAL GENERAL MEETING 1989

The 58th Annual General Meeting of the Association was held on 12 July 1989 at the Flett Theatre, Geological Museum, Exhibition Road, London SW7.

The Chairman, Mr David Callaghan, FGA, presided and welcomed members to the meeting.

It was reported with regret that Mr Eric Bruton had decided to retire from the Council. Mr. Callaghan thanked him for the many years of service that he had given to the Association, particularly in connection with the Gem Diamond course.

Mr Callaghan thanked the Officers and Council for their help and support during the year, particularly Nigel Israel and Noel Deeks who had done a tremendous amount of work.

He thanked Secretary Jonathan Brown and his team for all they had done. He said that there had been many problems during the year to challenge Jonathan but he had never failed to respond.

Mr Nigel Israel, Treasurer of the Association, presented the audited accounts for the year ended 31 December 1988. The adoption of the Report and Accounts was duly proposed, seconded by Mr David Kent, and carried.

Sir Frank Claringbull, Mr David J. Callaghan, Mr Noel W. Deeks and Mr Nigel B. Israel were re-elected President, Chairman, Vice Chairman and Honorary Treasurer respectively. Dr A.J. Allnutt, Dr R.R. Harding, Mr D.M. Larcher, Dr J.B. Nelson, Mr W. Nowak and Mr C.H. Winter were re-elected and Mr R.J. Peace and Mr C. Burch elected to the Council.

Messrs Ernst and Whinney were reappointed Auditors, and the proceedings then terminated.

CRYSTAL HAUTE COUTURE AT 'THE NATURAL HISTORY MUSEUM ROCK FESTIVAL'

A new exhibition opened at the Natural History Museum on 6 July 1989 and looks at the many faceted world of the crystal. Alongside spectacular natural crystal formations and fantastic science-fiction comic art there is a collection of contemporary jewellery by leading French designers Jean Vendome, Kurt Neukomm, Laurent Stoll and Anne Silbermann (collectively known as Karenage). The exhibition runs at the Museum until 15 January 1990.

DR NASSAU RETIRES

Dr Kurt Nassau is retiring at the end of 1989 after 30 years with A T & T Bell Laboratories, Murray Hill, New Jersey.

In his technical research on crystal growth, lasers, semiconductors, glasses, and high temperature superconductors, among others, Dr Nassau has over two hundred technical publications and fifteen patents. He has published the textbook *The Physics and Chemistry of Color* (Wiley, 1983) and an Encyclopaedia Britannica article on 'Colour' for the 1988 and subsequent editions. He was awarded the Distinguished Technical Staff Award for Sustained Achievement by Bell Laboratories in 1988, consisting of an honorarium, a metal sculpture, and other benefits.

Dr Nassau is well-known in the field of gems and minerals for his gemmological research, reported in over one hundred and fifty articles and his two popular books, *Gems Made by Man* (GIA, Santa Monica, CA, 1987) and *Gemstone Enhancement* (Butterworths, Boston, 1984). He is on the board of governors of the Gemological Institute of America.

In his retirement in his recently-completed home in Tewksbury, NJ (mailing address 154A Guinea Hollow Road, Lebanon, NJ 08833; Tel: 200-832-2499), Dr Nassau intends to continue writing and expand his consulting and teaching activities.

THE GUILDFORD GEM, MINERAL AND LAPIDARY CLUB

The Guildford Gem, Mineral and Lapidary Club was inaugurated on 18 May 1989. The object of the Club is to interest, inform and entertain its members and to include within its scope such subjects as gemmology, mineralogy and mineral collecting, lapidary work (ornamental and gemstones), geology, precious metals and jewellery making, fossils, and similar related subjects. Monthly lectures or demonstrations are arranged, as well as field trips to collecting sites, visits to museums, shows and collections.

Full details of the Club may be obtained from the Secretary, Ms Pat Lapworth, 9 Trinity Churchyard, Guildford, GU1 3RR.

CORRIGENDA

On the front inside cover of *J.Gemm.*, 1989, **21**, 7, Mrs E. Stern, FGA, is omitted from the list of Members elected to Council

On p.450 above, first column, line 26, for 'Dahu', read 'Oahu'

On p.440 above, the refracted ray shown in Figure 5 should read r° and not i°. Also, the general incident ray i° should have appeared within the EON angle and in a similar position to the corresponding reflected ray (= i°)

THE JOURNAL OF GEMMOLOGY

Back issues

The Association has a limited quantity of back-dated issues of the *Journal* for sale. The copies, the majority of which are not in pristine condition, are available at the special price of £5.00 plus VAT, for a limited period until 31 December 1989.

As supplies of certain issues are limited, members are urged to place their orders without delay.

For a list of those available please contact Lorraine Durkin at the Gemmological Association, Saint Dunstan's House, Carey Lane, London EC2V 8AB. Payment may be made by cheque or the major credit/charge cards.

Letters to the Editor

From R. Keith Mitchell
Gemmological Association of Great Britain

Dear Sir,

WHAT IS HAPPENING TO OUR SOUTH KENSINGTON MUSEUMS?

Following considerable public concern at new management's drastic changes in the Victoria and Albert Museum, involving the removal of several heads of departments, we now hear, via the July-August issue of *Geology Today*, that 'The Geological Museum is being strangled. In fact, in one sense it is already dead', a statement based on the monthly *Events* leaflets issued by a controlling BMNH which since March of this year have shown a slow eclipse of the Geological Museum – in printed space allotted, in events and lectures forecast and even in the use of its name.

The magazine investigated further and found that that name has already been dropped unofficially, a move which only awaits Government ratification to make it official; that some GM staff are now redundant; that schoolchildren are now considered to be the primary audience of the NHM; that aid to teachers in the earth sciences is to stop; that adult education within the museums is to be abandoned and other retrograde steps taken.

Once again a new management must be regarded as responsible for changes which cause geology and allied subjects to be regarded 'merely as a branch of natural history'.

We now hear rumours that the NHM is sending staff to study the showmanship of Disneyland, possibly with the object of instilling such methods into the museum presentation.

But perhaps of greater concern to the gem trade and to gemmology is the suggestion that thought is being given to moving the world-renowned collection of superb cut gems and gem minerals from its dominant main hall position in the Geological Museum to a cramped and less frequented space

on the first floor gallery.

That collection has been assiduously built up in excellence of display and in content to become a major attraction for the general public and for overseas visitors for more than forty years. To move it now to a less accessible area, possibly at the same time dispensing with the very successful and much admired non-reflecting showcases, would seem to be the height of folly!

The Geological Museum name should be preserved. The famed and quite remarkable gem collection should remain in its present readily accessible position unless a convincing and rational case can be made for its re-siting. The keynote should not be 'Change for the sake of Change'.

Yours etc.,
R. Keith Mitchell,
Vice President.

11 August 1989
Orpington, Kent.

From Dr Karl Schmetzer

Dear Sir,

In an article dealing with irradiation effects and colour changes of hydrothermally- and flux-grown synthetic emeralds by H.-W. Schrader (*Journal of Gemmology*, **21**, 1988, 237-51), a conversion of flux-grown synthetic emeralds from green to violet colours as well as a conversion of hydrothermally-grown synthetic emeralds from green to smoky colours is described. The irradiation treatment of the synthetic emeralds was performed during six hours in a running nuclear reactor with a thermal fluence rate of 7×1011 neutrons/cm^2.sec (Schrader, Dissertation, Universität Mainz, 1987). After an exposure of violet samples to daylight for five months, the violet colour centres were bleached and the synthetic beryls turned smoky.

According to Schrader, the colour changes described are due to neutron radiation causing additional absorptions in the visible range of the spectrum which are superimposed to the normal chromium absorption bands of emerald. The smoky colour is due to an absorption band centred in the ultraviolet, the low energy tail of which extends to the visible area. The violet coloration is produced by an absorption maximum in the green range between 520 and 530 nm. In analogy to quartz colour centres, the absorption band in the ultraviolet was assigned by Schrader to a more stable smoky type $[AlO_4]^{4-}$ colour centre and the absorption band in the range of 520 to 530 nm was assigned to a less stable amethyst type $[FeO_4]^{4-}$ colour centre, with both, aluminium and iron, replacing silicon in tetrahedral lattice sites of beryl. However, these assignments as well as the assumption of neutrons as colour causing radiation are highly speculative.

First, it is common that in a running nuclear reactor in addition to neutrons extremely high dose rates of gamma radiation are also efficient during a radiation treatment of six hours. The smoky colour centres of hydrothermally- and flux-grown synthetic emeralds can also be produced by X-rays (Lind, Henn and Bank, 1986, *Z. Dt. Gemmol. Ges.*, **36**, 51-60; Schmetzer, unpublished data), and both violet and smoky colour centres were described for synthetic beryl irradiated with gamma rays from a Co-60 unit (Solntsev, 1981, *Tr. Inst. Geol. Geofiz., Akad. Nauk SSSR, Sib. Otd.*, **499**, 92-140). Consequently, gamma rays are also regarded as a colour causing radiation for smoky and violet colour centres of synthetic emerald.

Furthermore, the violet colour centre found in synthetic beryl after Co-60 radiation, which reveals an absorption maximum in the green area at about 520 to 530 nm, was characterized by Solntsev using electron paramagnetic resonance. The EPR signals were assigned to an O-electron hole centre confined to an Al^{3+} substituting for Si^{4+} in tetrahedral sites. This $(AlO_4)^{4-}$ colour centre, which is closely related to the smoky colour centre of quartz, is bleached after heating up to 80°C, i.e. both the absorption band in the green range as well as the EPR signals disappeared after heat treatment at 80°C. This assignment of the violet colour centre of irradiated flux-grown synthetic emerald to aluminium related colour centres, however, is consistent with the chemical data of Schrader, who found remarkable Si-deficiencies only in flux-grown synthetic emeralds.

The assignment of the ultraviolet absorption band, which causes a smoky coloration in irradiated hydrothermally- and flux-grown synthetic emerald, is more difficult. According to Solntsev, this type of absorption produces a yellow to brown colour in almost chromium-free synthetic beryl. Natural iron-bearing, almost colourless beryls are commercially irradiated with gamma rays, mostly from Co-60 units, in order to produce an intense yellow coloration. This type of irradiated beryl reveals a similar or identical absorption band centred in the ultraviolet, the low energy tail of which extends to the visible range. At present, it is unknown if those particular colour centres causing an intense yellow to brownish coloration in chromium-free natural beryls and those ones produc-

ing a smoky coloration in synthetic emeralds and a yellow to brown coloration in chromium-free synthetic beryls are identical. However, according to the fact that iron-bearing natural beryls turn a more intense yellow than almost iron-free natural beryls using identical gamma dose rates (Schmetzer, unpublished data), the yellow colour centres of natural beryls or at least part of them may be related to traces of iron.

Yours etc.,
K Schmetzer,

19 May 1989
Heidelberg, West Germany.

From A.E. Farn

Dear Sir,

I read with interest and admiration Kenneth Scarratt's lucid exposition of absorption curves as opposed to line drawings depicting what is seen in the hand held spectroscope (Notes from the Laboratory – 14, *Journal of Gemmology,* 1989, 21, 6, 339-46). As K. Scarratt states, the hand held spectroscope still serves us well in immediate identification for ordinary gemmologists (and most of us are).

A laboratory such as The Gem Testing Laboratory of Great Britain needs its sophisticated equipment to maintain its position in the forefront. However, my memories are of the tall figure of B.W. Anderson poised over the old brass microscope (used solely as a light gathering source), and the smell of scorched woodwork from the asbestos lined 500 watt lamp housing. His amazing accuracy with a hand held measuring spectroscope serve to reinforce and reiterate for me some of his basic observations.

For the ordinary gemmologist there are still the delights of discovery with the 10x lens and the hand spectroscope. Whilst not denying in any manner the importance for laboratories to possess every possible item of sophisticated equipment, we can be encouraged by the words of the man who made most things possible by his researches. B.W. Anderson was not just a pioneer gemmologist, among many other accomplishments he had the use of and command of words. The opening chapter of his book *Gemstones for Everyman* is entitled, 'What exactly is a gemstone?'. The book ends with the lines, '...and let it not be thought that efficient gem testing today must always depend upon sophisticated apparatus. A very important proportion of the work needs only two ingredients for its performance – a good gemmologist and a 10x lens'. Between these two excerpts Anderson encompasses a world of encouragement, explanation and enjoyable gemmology for us, 'the vast majority'.

Yours etc.,
A. E. Farn,

1 July 1989
Blatchington Green, Seaford, E. Sussex BN25 3HP.

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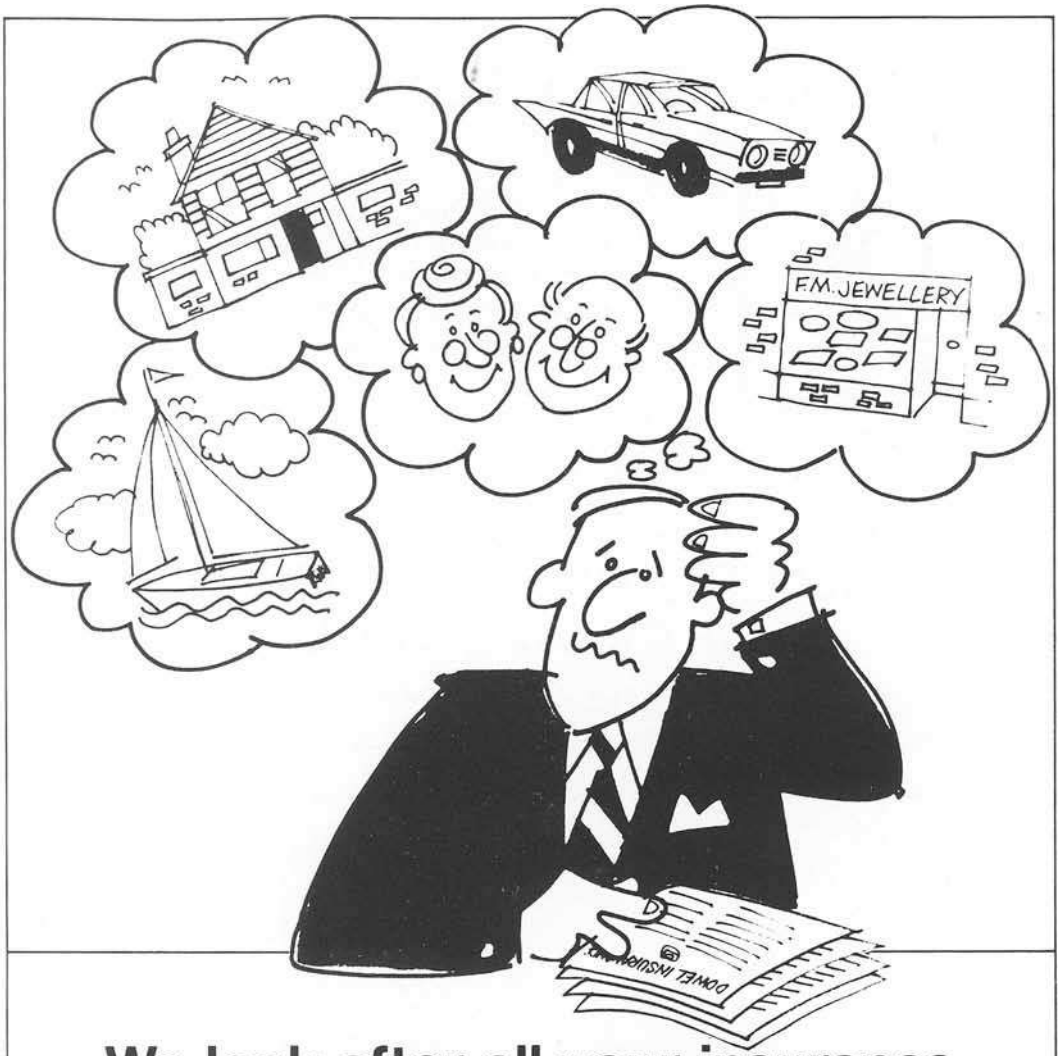

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GEMMOLOGICAL ASSOCIATION OF GREAT BRITAIN

The Arms and Crest of the Association, conferred by a grant of Arms made by the Kings of Arms under royal authority. The cross is a variation of that in the Arms of the National Association of Goldsmiths of Great Britain and Ireland. In the middle is a gold jewelled book representing the study of gemmology and the examination work of the Association. Above it is a top plan of a rose-cut diamond inside a ring, suggesting the scrutiny of gems by magnification under a lens. The lozenges represent uncut octahedra and the gem-set ring indicates the use of gems in ornamentation. The lynx of the crest at the top was credited, in ancient times, with being able to see through opaque substances. He represents the lapidary and the student scrutinizing every aspect of gemmology. In the paws is one of the oldest heraldic emblems, an escarbuncle, to represent a very brilliant jewel, usually a ruby. The radiating arms suggest light diffused by the escarbuncle and their tips are shown as jewels representing the colours of the spectrum.

Historical Note

The Gemmological Association of Great Britain was originally founded in 1908 as the Education Committee of the National Association of Goldsmiths and reconstituted in 1931 as the Gemmological Association. Its name was extended to Gemmological Association of Great Britain in 1938, and finally in 1944 it was incorporated in that name under the Companies Acts as a company limited by guarantee (registered in England, no. 433063).

Affiliated Associations are the Gemmological Association of Australia, the Canadian Gemmological Association, the Gem and Mineral Society of Zimbabwe, the Gemmological Association of Hong Kong, the Gemmological Association of South Africa and the Singapore Gemologist Society.

The *Journal of Gemmology* was first published by the Association in 1947. It is a quarterly, published in January, April, July, and October each year, and is issued free to Fellows and Members of the Association. Opinions expressed by authors are not necessarily endorsed by the Association.

Notes for Contributors

The Editors are glad to consider original articles shedding new light on subjects of gemmological interest for publication in the *Journal*. Articles are not normally accepted which have already been published elsewhere in English, and an article is accepted only on the understanding that (1) full information as to any previous publication (whether in English or another language) has been given, (2) it is not under consideration for publication elsewhere and (3) it will not be published elsewhere without the consent of the Editors.

Papers should be submitted in duplicate on A4 paper. They should be typed with double line spacing with ample margins of at least 25mm all round. The title should be as brief as is consistent with clear indication of the content of the paper. It should be followed by the names (with initials) of the authors and by their addresses. A short abstract of 50–100 words should be provided. Papers may be of any length, but long papers of more than 10,000 words (unless capable of division into parts or of exceptional importance) are unlikely to be acceptable, whereas a short paper of 400–500 words may achieve early publication.

Twenty five copies of individual papers are provided on request free of charge; additional copies may be supplied, but they must be ordered at first proof stage or earlier.

Volume 21 No. 8. October 1989

The Journal of Gemmology

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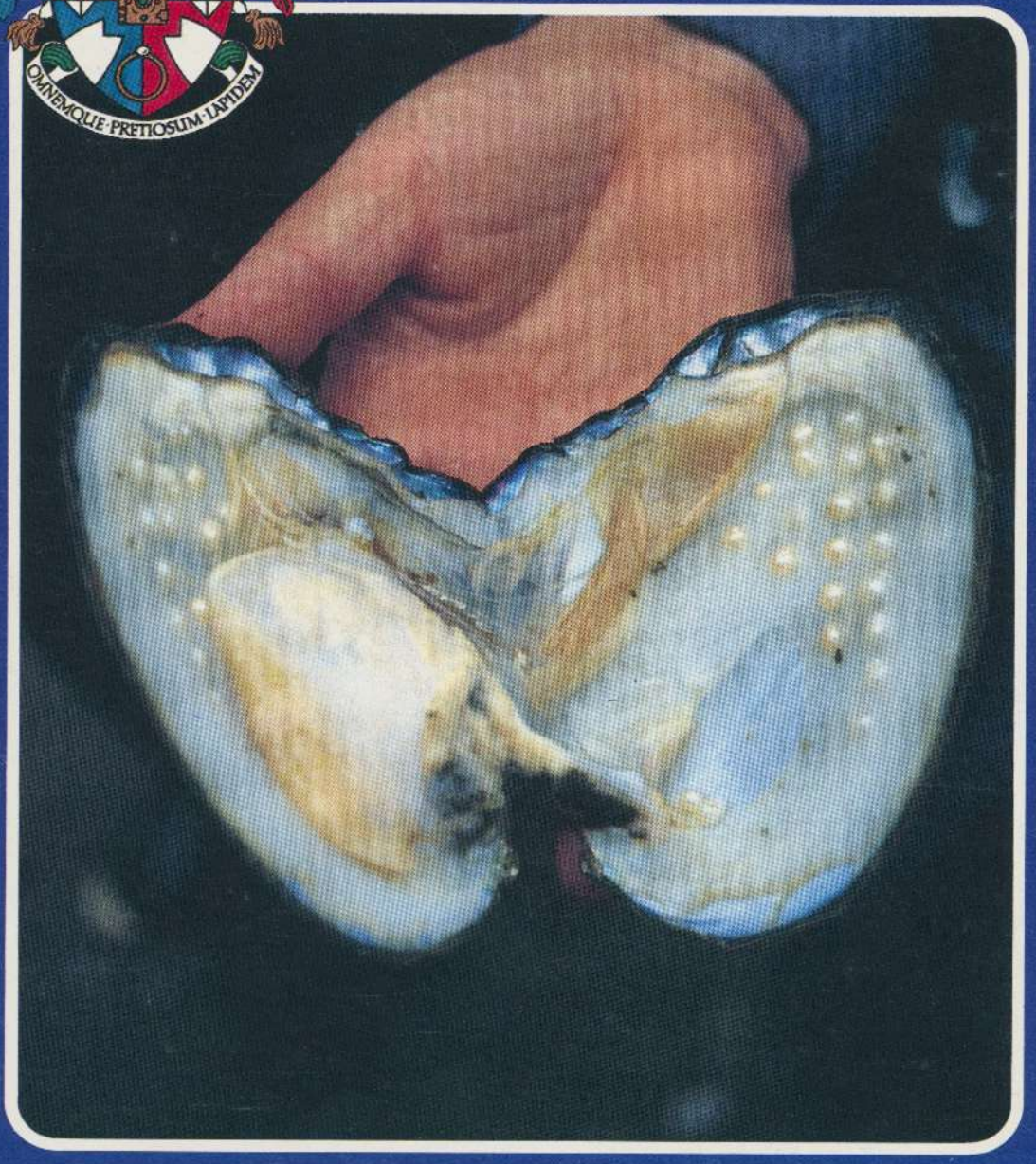

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Cover Picture

Opened valves of the pearl mussel *Cristaria plicata*, showing the translucent mantle covering the pearls, Yangxin, China (see Jobbins and Scarratt, p.3). *Photograph by K. Scarratt.*

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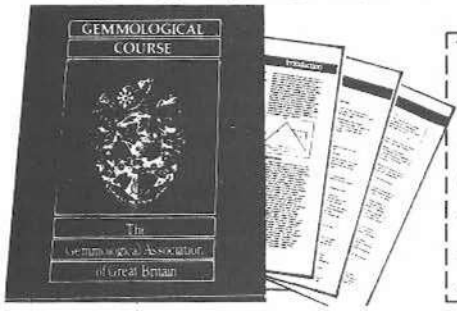

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Some aspects of pearl production with particular reference to cultivation at Yangxin, China

E. A. Jobbins and K. Scarratt***

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Fig. 1. The pearl mussel, *Cristaria plicata*, used in Yangxin, China, showing the growth stages of the mussel with a series of cultured pearls.

Abstract

The whole and beaded cultured pearl has been with us since the 1920s and has formed the major part of the pearl market for several decades. The non-nucleated cultured pearl, produced in Lake Biwa in Japan, came to the market in the late 1950s and at the time caused some difficulties in terms of identification. In recent years freshwater cultured pearls, such as those from Lake Biwa, have been referred to simply as 'freshwater pearls'. As natural freshwater pearls can be and are recovered from various rivers around the world, it is essential in the case of the freshwater cultured pearl to include such a qualifying term within any description.

During the last decade an enormous number of freshwater cultured pearls have been brought on to the market by the Chinese. Mostly these in the main have been the lower quality material which are said to resemble 'rice crispies'. So many of these were brought to the market that the price per row became extremely low. Freshwater cultured pearls of a higher quality are now produced in addition to the very popular 'rice crispy' type.

During May 1989 the authors were allowed to visit a pearl farm located in Yangxin, China. Here they discovered an arrangement of small man-made lakes, resembling a 'trout farm', that housed the various stages of

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mussel and pearl production. Their questions regarding the production techniques were answered readily and a number of specimens of the mussel (*Cristaria plicata*) and the good and poorer quality cultured pearls were purchased for future investigation. (See Figure 1.) Forty cultured pearls are produced from each mussel in a time span which may be as little as nine months.

Introduction

Pearl is unique amongst gem materials in that, apart from being drilled, it is mostly worn as it is found; whereas, with the exception of the rare well-formed crystal, diamonds, rubies, sapphires and emeralds all require cutting and polishing before they are seen at their best. Pearl is also unusual as a gem material in that it is growing 'at the present time' in many different parts of the world.

When one speaks or writes of a *pearl*, without qualification, then the material which is being described should be *natural* pearl. *Cultured* pearls should be so described, whether they are of salt-water or fresh-water origin. It has been argued by some, particularly in advertising standards disputes, that as the cultured pearl is growing in its *natural* environment, distinction between it and the natural pearl is less important. The argument against such a statement is quite compelling. Firstly, the natural pearl is one of the rarest of gems whereas the cultured pearl can hardly be considered in such a light, and secondly, whilst it may appear to be growing in its 'natural environment' in fact, the mollusc in which the cultured pearl grows is a product of man's nurturing.

The Gulf

It was not so long ago that *natural* pearl trading formed a significant, if not the major, part of the total trade for a number of States. In about 1915, just a short time before the whole cultured pearl first made its impact upon Europe, Qatar in the Gulf had 350 pearling boats (see Figure 2) based in its main town Doha. In order to understand the significance of this number one has to understand that the population of Doha at that time was just 12,000. There were only 50 shops in the suq, 60 sea going trading boats running to Oman and less than 100 fishing boats (Scarratt, 1987).

Fig. 2. Typical pearl fishing boat at Doha, Qatar.

Countries such as Qatar and Bahrain would sell their pearls (see Figure 3) to Indian merchants who in turn would drill them and make them up into 'Bombay Bunches' for sale to European merchants. Whilst these and other Gulf nations may still, in

some small way, fish for pearls in their waters, the vast majority of natural sea water pearls on the market today are 'old pearls'. That is pearls that have been strung and re-strung, sold and re-sold, over the last 50 years and more.

There are a number of reasons for the lack of present-day sea-water pearl fishing. There is the economic situation in the Gulf, the previous pearling nations no longer have to rely upon the pearl as a source of income since they now have oil and gas production. There is also plenty of safer and more profitable work that potential divers can do on dry land rather than risking their lives in the Gulf waters. There is the pollution factor, and finally the large production of cultured pearls in several areas of the world which give the natural product increased competition. It is obvious then that today new natural pearls, marine or freshwater, are difficult to obtain and the reasons for this are not simply, as is often recorded in the literature, that the beds are 'fished out' or have been killed off by pollution.

The introduction of the whole and beaded cultured pearl in the 1920s undoubtedly gave the natural pearl producing nations a few short-term problems, nevertheless without its introduction today's enormous 'pearl' market would not exist. The discovery of oil and gas in The Gulf made it inevitable that fewer natural pearls would have been available in any event. However, these same Gulf nations have far from lost their interest in the natural pearl and the population of states such as Bahrain still regard the pearl, if not quite with reverence, then as having a special place not only in history but also in modern life.

There is still a small production of natural freshwater pearls around the world, notably in Bangladesh, North and South America and Scotland. Some of the North American freshwater pearls are particularly beautiful and come in an attractive range of colours.

Fig. 3. Natural pearls at Doha, Qatar.

Scotland

The pearls fished from the rivers of Scotland can have a particularly attractive lustre which is quite characteristic (see Figure 4). There are very few pearl fishers in this part of the world and only one real specialist; his methods of operation have been handed down through his family. It is a lonely, back-breaking task, but occasionally there is an ample reward. Bill Abernethy wades into the fast-flowing rivers of Scotland with a split-ended pole, a home made glass bottomed jug and a large sack hanging from his shoulder (see Figures 5 and

Fig. 4. Scottish river pearls; the Abernethy pearl (11.5mm in diameter), the Cairncross necklace and valves of *Margaritifera margaritifera*, the parent mussel.

Fig. 5. Bill Abernethy and Ken Scarratt fishing for pearls in Scotland.

Fig. 6. The 'tools of the trade'; including home-made glass-bottomed jug, waders, cleft stick and bag for holding shells.

6). He knows exactly when and where to fish each river. Whilst bent over and looking through the glass bottom of his jug, which he holds in his teeth, he searches the rocky bottom until he locates a group of mussels, upright and mostly covered in gravel. The split end of the pole is then very skilfully pushed over each mussel and it is lifted from the water and placed into the sack. Once the sack is full he returns to the river bank and from the external appearance of each shell he predicts the possibility of a pearl being present. The mussels that he suspects might yield a prize he opens and searches through the fleshy interior for the pearl or pearls. Those mussels which he feels have no chance of containing a pearl are put back into the river unopened and still alive.

Japan

The whole and beaded cultured pearl which has held and expanded upon its place in the jewellery market since the 1920s, consists of a beaded core of mother-of-pearl, around which the pearl producing mollusc has deposited a nacreous layer. This layer may be relatively thick, as is often the case for those pearls cultured in the South Seas or Burma (see Figure 7), it may be reasonably thick, as is the case for the better quality Japanese pearls, or it may be so thin as to allow the observer to see the banded nature of the mother-of-pearl bead through the nacre. Indeed some layers are so thin that the phrase often used to describe them is that they have barely 'had a lick' from the mollusc (see Figure 8).

To produce this type of cultured pearl, a mother-of-pearl bead is inserted into the mollusc along with a small square of mantle tissue. The mollusc is then returned to the water. Providing that the bead is not rejected, a 'pearl sac' then forms around it and a gradual built-up of nacre is secreted over its surface.

The beautiful part of Japan south of Osaka known as Kashikojima, an area of tranquil inlets and islands, is home for many of the Japanese beaded cultured pearl producers. Here the pearl producing oysters hang quietly from hundreds of rafts (see Figure 9), but this quiet and apparently leisurely spot hides a hive of typically efficient Japanese industry.

The spat houses and 'operation rooms' have a clinical appearance (see Figure 10) for what is a production line activity. The young oysters are nursed through their early lives, with the water

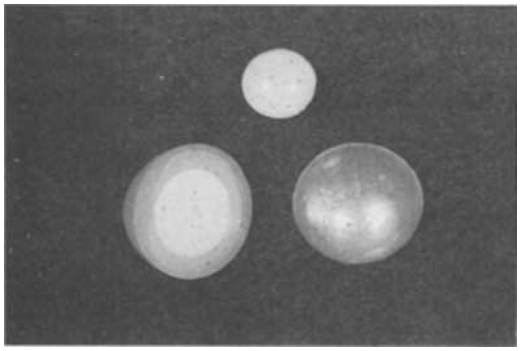

Fig. 7. Sectioned cultured pearl from Mergui, Burma; diameter of pearl 12mm, bead nucleus 7mm.

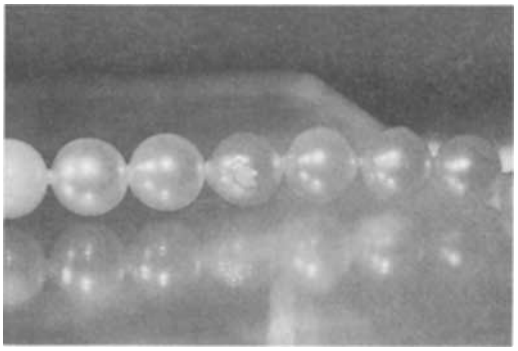

Fig. 8. Poor quality cultured pearl with thin outer nacreous layer.

temperature at given depths being checked at regular intervals. Once the operation to insert the bead has taken place the nursing continues, even to the extent of regular cleaning by a specially designed machine.

There is another type of cultured pearl which is known either as a 'non-nucleated' or 'tissue graft' cultured pearl. As the name implies, no bead nucleus is used to obtain these pearls – a small piece of 'tissue' is used instead. The other and main difference between these and the beaded variety is that the mollusc used is in the main a freshwater mussel rather than a marine oyster.

In the late 1950s this new form of freshwater cultured pearl began to appear on the London market. This was being produced in Lake Biwa, the largest lake in Japan.

By 1981, the spat were being reared in clean concrete tanks and supported in special nets. On maturity, mantle tissue was inserted and the mussel returned to the lake. The pearl cultivating areas were inlets from the main lake, often lined with

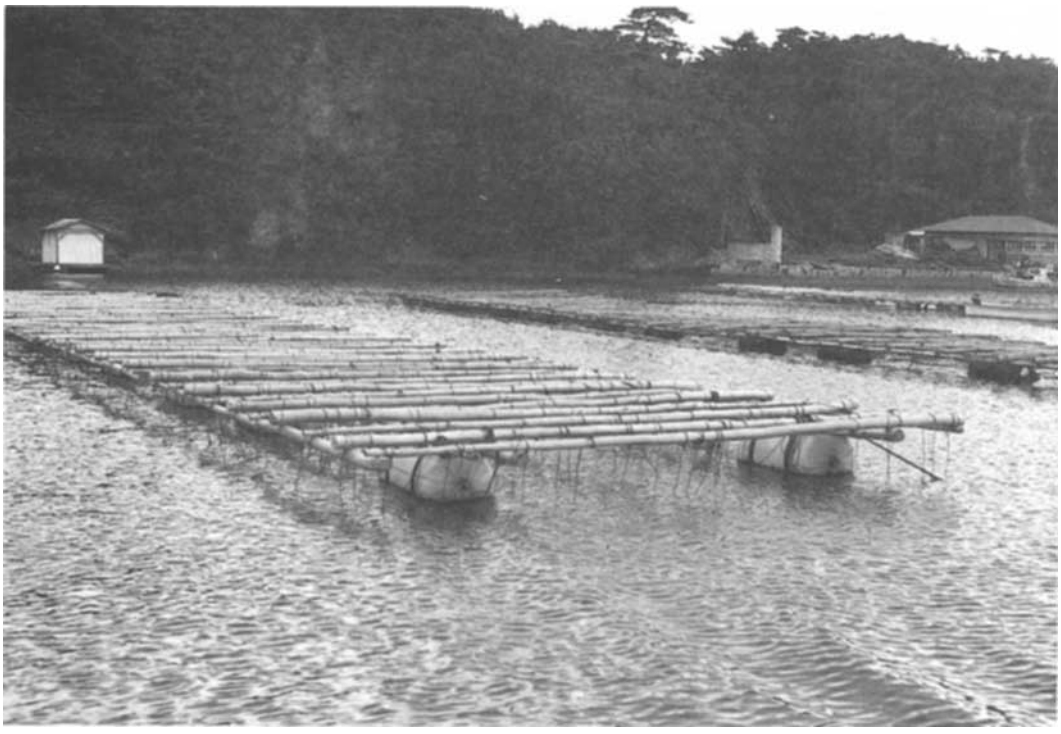

Fig. 9. Rafts supporting nets with marine oysters, Ago Bay, Japan.

Fig. 10. The 'clinical appearance' of the pearl 'operation room' at Ago Bay, Japan.

Fig. 11. Rafts surrounded by bamboo fences in the Lake Biwa area, Japan.

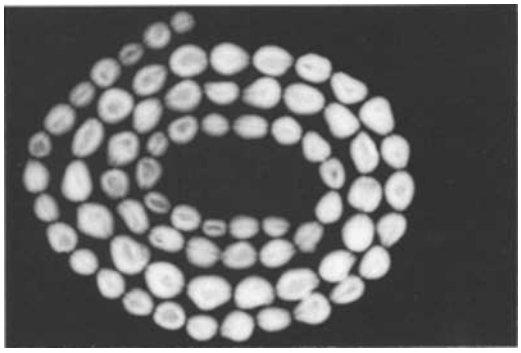

Fig. 12. X-radiograph of non-nucleated cultured pearls from Lake Biwa.

rushes at the sides. In the cleared areas were large pens bounded by closely spaced bamboo poles (see Figure 11). The pearl mussels were kept in nets suspended from long wires which in turn were supported by bamboo poles. The mussel used is *Hyriopsis schlegeli* and squares of mantle tissue cut from a sacrificial mussel are inserted into the mantle tissue of a living individual. Up to twenty inserts were placed into each valve of a mussel. Pearls of various colours and sizes were reported and quite bizarre shapes were routinely produced.

Having no 'normal' nucleus these pearls created new identification problems in terms of the results gained from X-radiography. They also virtually put the 'endoscope' into redundancy. The endoscope relied upon the behaviour of a beam of intense light within the 'pearl's' interior. A pinpoint beam of light directed into a natural pearl's concentric (onion like) structure from inside its drill hole merely followed the structure and emerged as a flash of light still within the drill hole. As the bead used in the 'normal' culturing process has a layered rather than concentric structure, the pinpoint beam did not emerge as with the natural pearl but most of it was directed along the 'layered structure' towards the outside of the 'pearl'. As the non-nucleated cultured pearl does not have a bead nucleus it is obvious that the endoscope would produce similar results for these as it would for the natural pearl. However it was not long before experienced testers learned to recognize the particular whitish appearance of the 'Biwa pearls', and their characteristic structure on an X-radiograph (see Figure 12).

In the early '80s the market began to see large numbers of 'freshwater cultured pearls'. These were produced by the old practitioners of the art, the Chinese. At one stage the market was so flooded with these low quality, 'rice crispy', cultured pearls that even in London one could obtain a row for a few pounds.

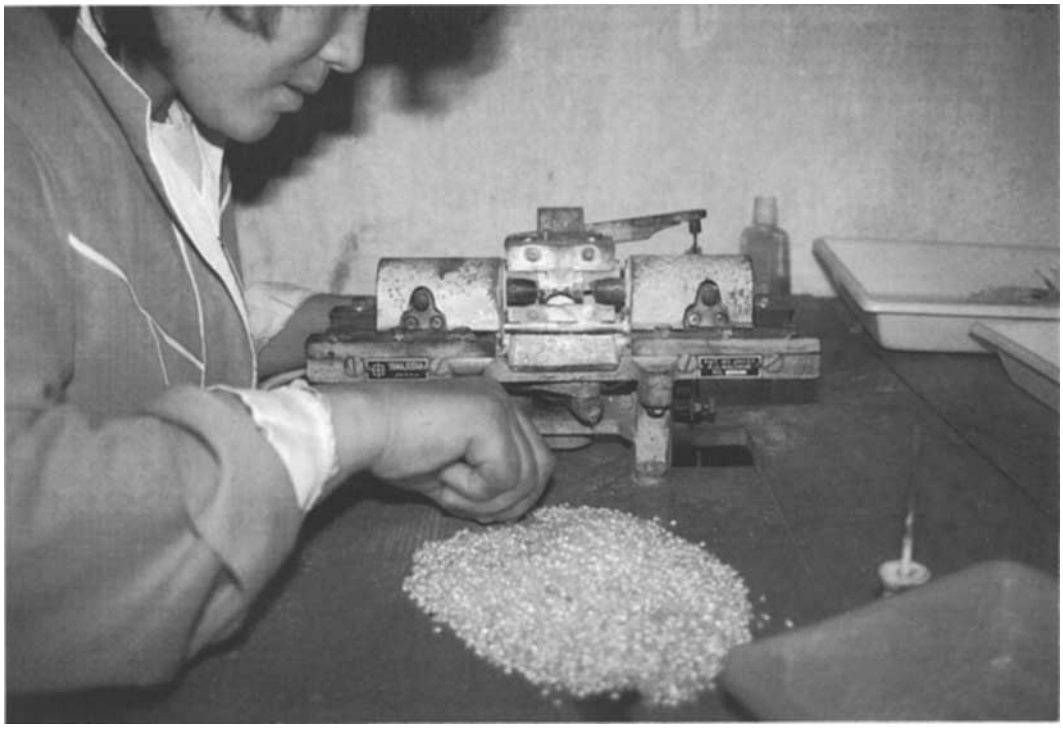

Fig. 13. Drilling small non-nucleated baroque cultured pearls with a double-ended drilling machine, Yangxin, China.

Despite some assertations to the contrary, in the authors' experience quite good quality Chinese freshwater cultured pearls have been available for a number of years, and this was confirmed during a recent visit by the authors to a pearl farm in China.

Pearl Farming in Yangxin, Hubei Province, China

During May 1989 the authors visited China following an invitation from the China University of Geosciences to instruct a group of lecturers in gemmology. During their stay in Wuhan (a large university town on the Yangtze river), they asked if it would be possible to visit a pearl farm.

The farm chosen was in Yangxin, which is situated south east of Wuhan, a distance of approximately 170km. The authors were accompanied by Professor Yan Weixuan and other members of the gemmology class, approximately twenty people in all. The countryside around Wuhan and all the way to Yangxin is extremely wet with hundreds of lakes and is ideally suited for rice growing. After having to change route and use some extremely rough roads the party arrived at about 1300 hrs. They were met by the mayor of the area and a number of other dignitaries including the foreign affairs representative. A large and special lunch was provided at the local hotel.

From the hotel they were taken to the offices and work rooms of the pearl farming company – The Yangxin Integrated Company of Pearl. The Company employs about 40 people with Mr Lu Chun Ming as engineer and Chairman of the Board. Here they observed the drilling at great speed of the small baroque non-nucleated cultured pearls (see Figure 13) and a display case showing the Company's products. The most striking exhibit was an open (preserved) mussel which, when closed, would be approximately 19-20cm in length and 12cm in width. This contained a large number of cultured pearls located in the upper portion of the mantle. Fifty loose, coloured pearls and two long strings of baroques (see Figure 14) were purchased for later investigation.

They then proceeded to the pearl farm itself (see Figure 15a), visiting the nursery ponds, the spat sheds, the pearl producing ponds and the culturing shed, in that order. The processes involved for the culturing of pearls at this farm are listed below.

1. The parent mussel, *Cristaria plicata* (specimen identified by Solene Morris of the British Museum (Natural History)) when about to spawn is placed into the nursery pond (see Figure 15b).

2. The parent spawns and is returned to the mature ponds.

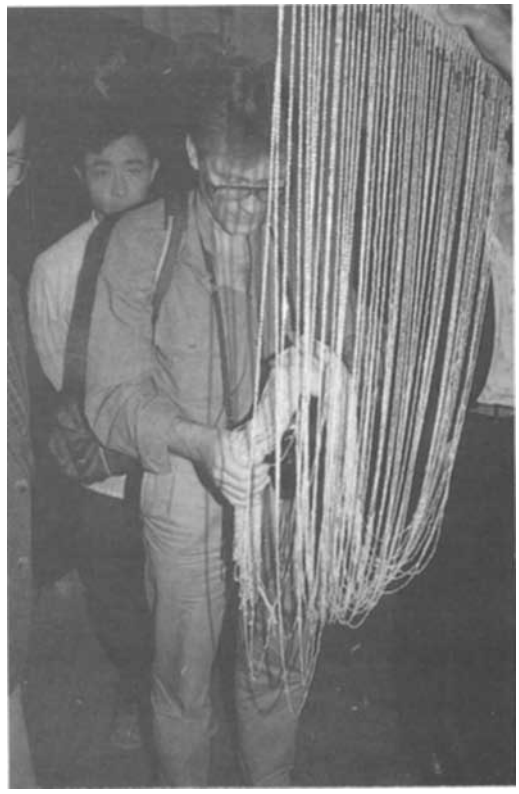

Fig. 14. Inspecting long rows of small baroque non-nucleated pearls at Yangxin, China.

3. The spat attaches itself to a specially introduced fish (described as having two barbs – no species given) and after a short time the fish is taken from the nursery pond and placed in the concrete 'spat trays' in the spat house (see Figure 16), where the water in the trays is always flowing.

4. When suitably grown, the spat fall off, and before the fish can eat them, the fish are removed.

5. At approximately 2cm the spat are placed in the nursery pond and left there until they reach 8cm in length.

6. At 8cm they are taken to a small shed where the culturing process takes place.

7. One mussel is sacrificed at this point for its almost transparent whitish mantle tissue – a strip approximately 1.5 to 2cm wide is taken from the outer edge of the mantle (see Figure 17), sliced once or twice lengthways and then crossways to make numerous squares of tissue.

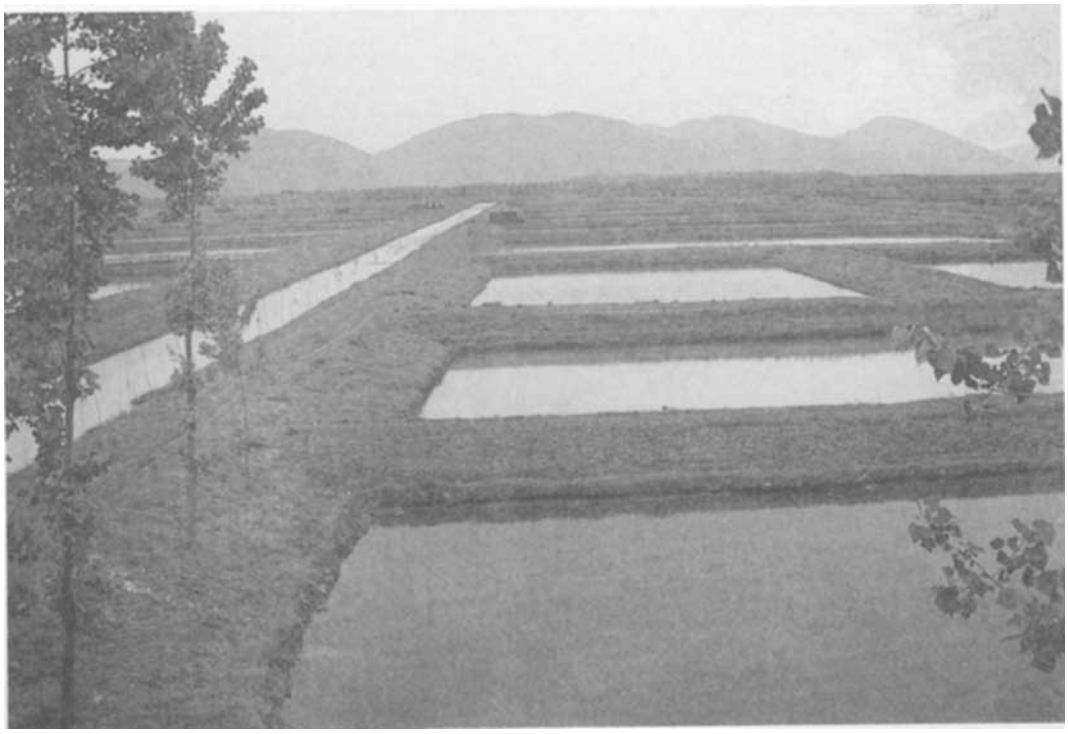

Fig. 15a. General view of the pearl farm at Yangxin, China.

Fig. 15b. The nursery pond at the pearl farm, Yangxin, China.

Fig. 16. Concrete 'spat trays' at the pearl farm, Yangxin, China.

Fig. 17. Removing the outer edge of the almost transparent mantle from the sacrificial mussel.

Fig. 18. Inserting the small squares of mantle tissue into the mussel.

Fig. 20. Mussel nets supported from wires – the non-floating type.

8. Forty squares of tissue are then inserted into another mussel (see Figure 18) and this is then placed into one of the two types of maturing pond with [a] floating and [b] non-floating support poles.

The floating type consists of a minimum of four intersecting bamboo poles, which, whilst being secured to the banks to keep them in position relative to the sides of the ponds, are not anchored to the bottom (see Figure 19). Therefore as the water rises or falls the mussels remain at the same depth – this method produces the better quality pearls. The non-floating type consists of a number of vertical bamboo poles placed in a line across the pond. A wire stretches from one side of the pond to the other and is supported at approximately equal distances by the upright bamboo poles (see Figure 20). From the wire the mussels are hung in nets in a similar manner to that used for the floating type. The nets contain from two to four mussels, and are of two basic types [a] resembling a net shopping bag without any support, in which the mussels are not separated and [b] a wide, supported, net in which the mussels are separated (see Figure 21).

Fig. 19. Recovering a net containing a pearl mussel from the floating type of raft.

Fig. 21. Opened pearl-bearing mussels and the different types of net in which they are grown.

With some forty pearls, 'rice crispy' quality or top quality, being produced from each mussel after a growth period of as little as nine months (see Cover Picture), one can imagine the enormous output possible from these farms. In fact one does not even have to 'imagine' this output, just look in any jeweller's window, anywhere in the world or go to any trade show and many examples of this product will be seen.

The pearls the authors brought back with them were examined by X-radiography. The structures seen on the resulting radiograph were found to be typical of non-nucleated cultured pearls.

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Star rhodolite garnet from Tanzania

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Abstract

This article describes the first reported asteriated rhodolite garnet from Tanzania and details the specimen's gemmological properties.

Acicular rutile crystals are a well-known inclusion in almandine garnets (Webster, 1983; Gübelin and Koivula, 1986; Liddicoat, 1987). When fashioned en cabochon, stones containing a relatively dense, even concentration of these fine needle-like inclusions may exhibit asterism in the form of a four-rayed or six-rayed star. Both India (Webster, 1983; Rohrbach, 1986) and the Emerald Creek area of Idaho, USA (Zeitner, 1986; Rohrbach, 1986) are reported as sources of star almandine garnet.

Rhodolite, a reddish-purple to purple mixture of almandine and pyrope garnets, was originally described from an occurrence in North Carolina, USA (Hidden and Pratt, 1898). Rhodolite garnet is also found in Sri Lanka (Webster, 1983), which has been a major commercial source (Federman, 1984). In the past few decades a number of rhodolite sources have also been described from (or off the coast of) Africa, including Zimbabwe (Campbell, 1972), Malagasy (Campbell, 1973) and Tanzania (Phillips, 1962; Sinkankas, 1968; Sarofim, 1970; Pough, 1973). The latter is now an important commercial source (Federman, 1984). Like almandine, rhodolite from a number of localities also contains acicular rutile crystals (Campbell, 1972; Webster, 1983). Little mention has been made, however, to these inclusions giving rise to asterism in rhodolite garnet (Rohrbach, 1986).

Recently the authors had the opportunity to examine a rhodolite garnet cabochon which exhibited a four- or six-rayed star, depending on the direction of observation. The stone, which had been purchased as rough and fashioned by Mr Barton Curren of Glyptic Illusions, Topanga, California, USA, came from a parcel of Tanzanian material reportedly from the Kangala mine. According to Mr Curren, the rough was relatively inexpensive as it was more highly included than most of the uncut Tanzanian rhodolite he had purchased in the past.

Gemmological properties

Visual appearance

The stone examined was a slightly off-round double cabochon weighing 15.60 carats and measuring 13.53mm × 13.13mm × 9.62mm (Figure 1). It exhibited a vitreous surface lustre and a very high degree of diaphaneity for an asteriated stone, being almost transparent. The asterism was in the form of a distinct four- or six-rayed star (Figure 2). Using the Gemological Institute of America's coloured stone grading nomenclature, the body colour would be described as a dark, slightly brownish purplish red.

Microscopic features

The most noticeable feature seen through the microscope were elongated, very fine acicular crystals of rutile showing typical 110/70 degree epitaxial orientation along the edges of rhombic dodecahedral faces (Figure 3). This rutile 'silk' in most cases runs the entire length or width of the stone.

Also noted under magnification were thin, flat, semi-transparent plates of ilmenite (Figure 4) and one small, dark subhedral crystal inclusion, surrounded by tension fractures, which appeared to be a zircon.

Refractive index and optic character

Using a GIA GEM Instruments Duplex II refractometer and employing the distant vision method, the spot refractive index was determined to be 1.75.

When examined in the polariscope the cabochon exhibited an anomalous doubly refractive reaction, as is typical of many red garnets (Webster, 1983). The true singly refractive nature of the gem was determined by the absence of any spot birefringence on the refractometer, the lack of doubling when viewed through the microscope, and the absence of pleochroism when examined through a calcite dichroscope. When viewed under crossed polars through the microscope, however, the doubly refractive nature of the rutile needles was confirmed.

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Fig. 1. When viewed from the side at a steep angle this star rhodolite garnet exhibits 6-rayed asterism, but when looking down on the dome of the cabochon a 4-rayed star is seen. *Photograph by Barton Curren.*

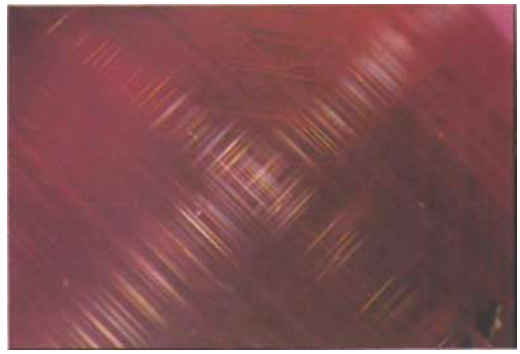

Fig. 2. The 'star effect' and its relation to the rutile inclusions can be seen here. 40x.

Fig. 3. Very fine acicular crystals of rutile pictured here are the cause of the asterism in this Tanzanian star rhodolite. 40x.

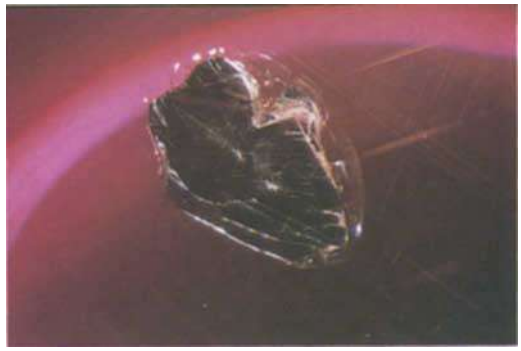

Fig. 4. Ilmenite plates, like the one pictured here, were also detected in the star rhodolite. 30x.

Spectrum, colour filter reaction and UV fluorescence

The visible-light absorption spectrum of the specimen was examined using a GIA GEM Instruments DISCAN digital scanning diffraction grating spectroscope. When viewed in direct transmitted light the stone exhibited the following absorption features: general absorption (i.e., a 'cutoff') from 400-440nm; a weak band at 465nm, a somewhat stronger band at 507-510nm, another weak band at 521-531nm, a strong band at 562-581nm; and general, very vague absorption in the blue-green to yellow regions, and in the far red. These features are generally consistent with those reported for rhodolite garnet (Webster, 1983; Stockton and Manson, 1985; Liddicoat, 1987).

When viewed through a Chelsea colour filter in direct transmitted light the star rhodolite garnet appeared brownish orange. It was inert to both long-wave and short-wave ultraviolet light, and exhibited no phosphorescence, as is to be expected from iron-containing garnets (Webster, 1983).

Specific gravity

The relative density of the rhodolite was determined using the hydrostatic weighing method on a Voland chain balance. Six separate weighings/calculations yielded a value of 3.80 plus or minus .01.

The gemmological properties of the East African star rhodolite garnet are summarised below in

Conclusion

The Tanzanian star rhodolite examined by the authors adds a new occurrence for such asteriated garnets. The gemmological properties determined for this specimen are in general consistent with those previously reported in the literature for the almandine-pyrope mixture known as rhodolite. In view of the relative common occurrence of acicular rutile as inclusions in the rhodolites from this region it is very likely that more of these asteriated garnets will be seen.

Table 1 – gemmological properties

Surface lustre:	Vitreous
Diaphaneity:	Nearly transparent
Star:	Distinct, 4- or 6-rayed star, depending on direction of observation
Colour:	Dark, slightly brownish purplish red
Magnification:	Fine, acicular rutile 'silk;' ilmenite plates; zircon (?) crystal
Spot RI.:	1.75
Polariscope reaction:	Anomalous doubly refractive
Spectrum:	440nm cutoff; 465, 507-510, 521-531, and 562-581nm bands; vague general absorption in blue-green to yellow regions and in far red
Chelsea filter reaction:	Brownish orange
UV Fluorescence:	LW – inert, no phosphorescence SW – inert, no phosphorescence
Specific gravity:	3.80 + .01

Acknowledgements

The authors would like to thank Mr Bartonon Curren of Glyptic Illusions, Topanga, California, for providing them with the specimen for this investigation.

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Rewarding 'howlers'

David Kent, FGA

London

Whilst the late Basil W. Anderson was marking the Gemmological Association's examination papers, he used to keep notes about mistakes or 'howlers' made by the candidates which amused him and which he called his examiner's 'rewards'. He published a selection of them in the *Journal* in 1970, 12, 3.

Three of his particular favourites at that time were:

'The removal of bubbles clinging to the surface of a stone during a hydrostatic density determination was by means of a camel's hair brush.'

'Imitation lapis is produced by dying agates and other poor cherts' (a pathetic thought!)

A test for radium treated diamond: 'it should be raped in black paper with photographic film'.

During the last nine years of marking papers, this examiner has followed B.W.A.'s example and collected similar slips, etc., made by students; very often they are caused by the appallingly poor standard of spelling which seems to exist these days.

It must be stressed that, of course, the students' names are unknown to the examiner – they are numbers only.

The behaviour of specimens in heavy liquids during a density test cause some of the lighter moments:

It sank like a stone!
It floated happily.
It sank sedately (a comforting thought).
It floated defiantly.
The stone remained suspended in all liquids!?
It sings in 3.06.
It plummets in 3.32.
It flouts in 3.06.
It bobbed back to the surface.

Amongst the description of crystals:

Topaz has a slippaly feel.
The crystal was doomed.
It had a chizzle end.
It was shaped like the Ace of Diamonds.
The stone suffers from basal cleavage (poor thing!).
It had every other corner knocked off.
'Chevrons' were seen on a diamond crystal.
The other end of the crystal is not present.
Crystal is a glass.

During the spectrum tests:

Zircon spectrum described by a candidate as 'like fence posts' and by another as 'a jailhouse'.
Almandine was like cricket stumps (a sports enthusiast?)
It has a pipe organ appearance.
Abortion lines in the blue.
Spectrum seen in the blue with the aid of 'a balloon of cobalt water'.

Optical effects, etc.:

It blinks in the polariscope.
Long distance RI.
Complete distinction.
Double refraction is single.
Stone is badly floored.
Amorous birefringence.
It had square bubbles.
Tiger stripped.
The zircon had been fried.
Boubles and stray.

In the unlikely event of our *Journal* being found in a dentist's waiting room, readers would not appreciate the 'rewards', but qualified gemmologists will, of course, know what the candidate intended to say.

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Two remarkable Lechleitner synthetic emeralds

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Abstract

Two samples of Lechleitner hydrothermally-grown fully synthetic emeralds were characterized microscopically as well as by modern analytical and spectroscopical methods. Two types of colour zoning corresponding to subsequent growth layers parallel to the table facets, as well as corresponding to neighbouring sub-individuals with sub-grain boundaries perpendicular to the table facets were observed. The distribution of colour-causing trace elements (chromium, iron, nickel and copper) in different layers and sub-layers of the synthetic emeralds clearly reflects the results of microscopic examinations and reveals details of growth histories as well as seeding and other growth techniques applied by J. Lechleitner for the production of the two samples. Colour and pleochroism of the stones as well as spectroscopic properties in the visible and infrared range are understandable as a function of chemical composition (traces of the transition metal elements chromium, iron, nickel and copper as well as minor amounts of alkali oxides, i.e. Li_2O and Na_2O). A general survey on various types of hydrothermally- and flux-grown Lechleitner synthetic emeralds is also given.

Introduction

Lechleitner synthetic emeralds have been commercially produced since the end of the fifties by Johann Lechleitner of Innsbruck, Austria. Different types of samples with distinctly varying properties were grown under variable growth conditions and seeding techniques. In gemmological literature, only part of these types of Lechleitner synthetic emeralds have been comprehensively described, and at present no adequate subdivision of growth types according to physical and chemical properties has been published.

The first type of Lechleitner's products, which was sold under the trade names 'Emerita' or 'Symerald', is composed of natural faceted or pre-shaped beryl cores which are overgrown hydrothermally by a thin layer of synthetic emerald (Holmes & Crowningshield, 1960; Schlossmacher, 1960; Gübelin, 1961a, b, c). Later on, continuing his experimental work, Lechleitner developed a product which was described as wafer- or sandwich-type hydrothermally-grown beryl-emerald-beryl composite and consists of a colourless natural beryl seed plate with dark green emerald layers on each side, which are fading into colourless beryl layers towards the table and base of the stones (Liddicoat, 1964; Flanigen *et al.*, 1965, 1967; Theisen, 1966; Lechleitner, 1988). In the next step of experimental work, using seed plates of synthetic emerald (Lechleitner, 1988), several fully synthetic emerald varieties were grown. One sample of this production which was examined by Eppler (1968), is described to consist of a hydrothermally-grown seed plate of synthetic emerald, which is almost symmetrically covered on both sides by four different layers of hydrothermally-grown synthetic emerald. Obviously, this specimen was placed several times in the autoclave in order to avoid growth of colourless chromium-free beryl layers.

The two samples to be described comprehensively in the present paper are hydrothermally-grown Lechleitner synthetic emeralds which are similar or almost identical with this multi-layered composite type examined by Eppler (1968). Due to the lack of adequate data of physical and chemical properties of Lechleitner fully synthetic emeralds, the present author took the opportunity to examine two samples of this type using modern gemmological and mineralogical methods. The results obtained are – according to his knowledge – unique for synthetic emeralds and, in addition, these data may be useful to demonstrate the relationship between different methods of investigation in order to determine adequate and representative properties of a sample.

Subsequently, in order to avoid further confusion in gemmological literature (c.f. Gunawardene, 1985), a general survey of Lechleitner synthetic emeralds is given, which is, however, partly incomplete due to the lack of adequate experimental data of all types of Lechleitner synthetic emeralds and, thus, needs further revision and supplementary work. This general survey was worked out by the present author and was submitted to J. Lechleitner in 1988 in order to eliminate mistakes and misunderstandings. Therefore, this general survey has to be regarded as an authorized summary of Johann

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Fig. 1. Faceted hydrothermally-grown Lechleitner fully synthetic emerald (sample 2). Size of the stone approx. 6.4 × 4.3mm. (*Photo by O. Medenbach, Bochum, West Germany*)

Lechleitner's work on growth of synthetic emeralds of various types.

Experimental details

The two samples to be described in the present paper were made available to the author by a private collector, who bought them in the late sixties or early seventies. Both samples were faceted gemstones, weighing and measuring 0.57 ct and 6.3 × 4.4 × 2.8mm (sample 1) as well as 0.55 ct and 6.4 × 4.3 × 2.7mm (sample 2, Figure 1), respectively.

The samples were investigated by ordinary gemmological techniques, and absorption spectroscopy of both stones in the visible and ultraviolet range was used to clarify the possible influence of different trace elements on the colour of these two Lechleitner synthetic emeralds. Colour-causing trace element contents were examined non-destructively by electron microprobe and X-ray fluorescence analysis. In addition, one faceted stone (sample 1) was sawn in a direction perpendicular to the table facet and part of the stone was examined by electron microprobe in order to determine the variation of chemical composition in different growth zones quantitatively. Another part of sample 1 was powdered and small amounts of emerald powder (2mg) were used to prove hydrothermal growth of the stone by infrared spectroscopy. The remaining powder was taken for wet chemical analysis in order to determine an average chemical composition of the sample.

Results

Microscopic examination in immersion liquid revealed both samples to consist of several layers the boundaries of which are orientated parallel to the tables of the faceted stones (Figures 2, 3). The angles between optical axes of the synthetic emeralds and the tables of the stones (i.e. the oblique angles between optical axes and boundaries of different growth zones) were determined as indicated in Table 1 using an especially developed sample holder (Schmetzer, 1985, 1986).

Two types of boundaries between different layers parallel to the table facet were observed in both samples: on one hand, these boundaries consisted of plane surfaces which separate differently coloured zones within the synthetic emeralds. On the other hand, part of the boundaries between layers parallel to the table facets of the stones revealed a distinct step-like microstructure. Pronounced colour zoning arranged perpendicular to the table facets is observed between different layers separated by both types of boundaries.

A somewhat more irregular and less distinct colour zoning is found within single layers, i.e. more or less intensely coloured areas are also found within single growth zones parallel to the table facets

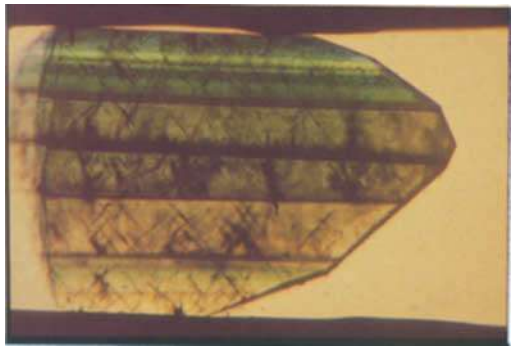

Fig. 2. Hydrothermally-grown Lechleitner fully synthetic emerald (sample 1); colour zoning and layered structure parallel to the table facet with a central seed (layer I) and two symmetrically arranged layers above and below (layers II and III), each of them consisting of several sub-layers. 25x.

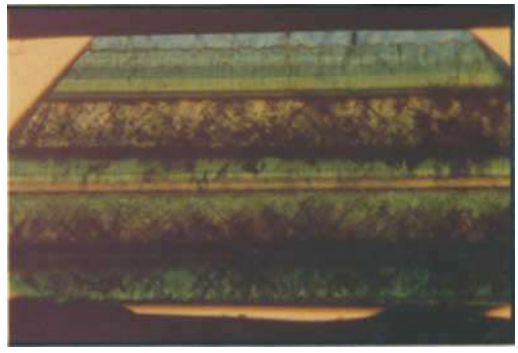

Fig. 3. Hydrothermally-grown Lechleitner fully synthetic emerald (sample 2); colour zoning and layered structure parallel to the table facet consisting of several layers and sub-layers, which are not symmetrically arranged above and below a central seed. 25x.

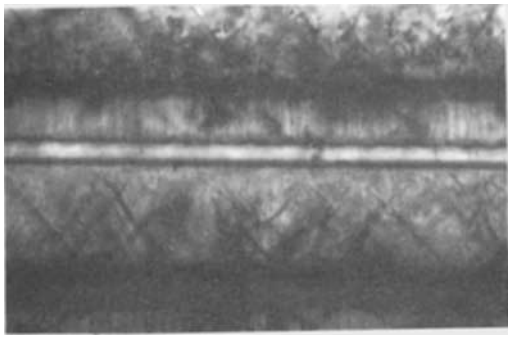

Fig. 4. Hydrothermally-grown Lechleitner fully synthetic emerald (sample 2); dominant layered structure parallel to the table facet consisting of step-like growth lines and colour zoning, subordinate irregularly changing sub-grain boundaries between sub-individuals connected with colour zoning almost perpendicular to the dominant layered structure, i.e. perpendicular to the table facet. 50x.

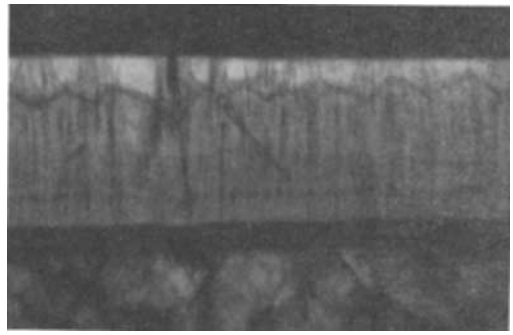

Fig. 5. Hydrothermally-grown Lechleitner fully synthetic emerald (sample 2); dominant layered structure parallel to the table facet consisting of step-like growth lines and colour zoning, subordinate irregularly changing sub-grain boundaries between sub-individuals connected with colour zoning almost perpendicular to the dominant layered structure, i.e. perpendicular to the table facet. 80x.

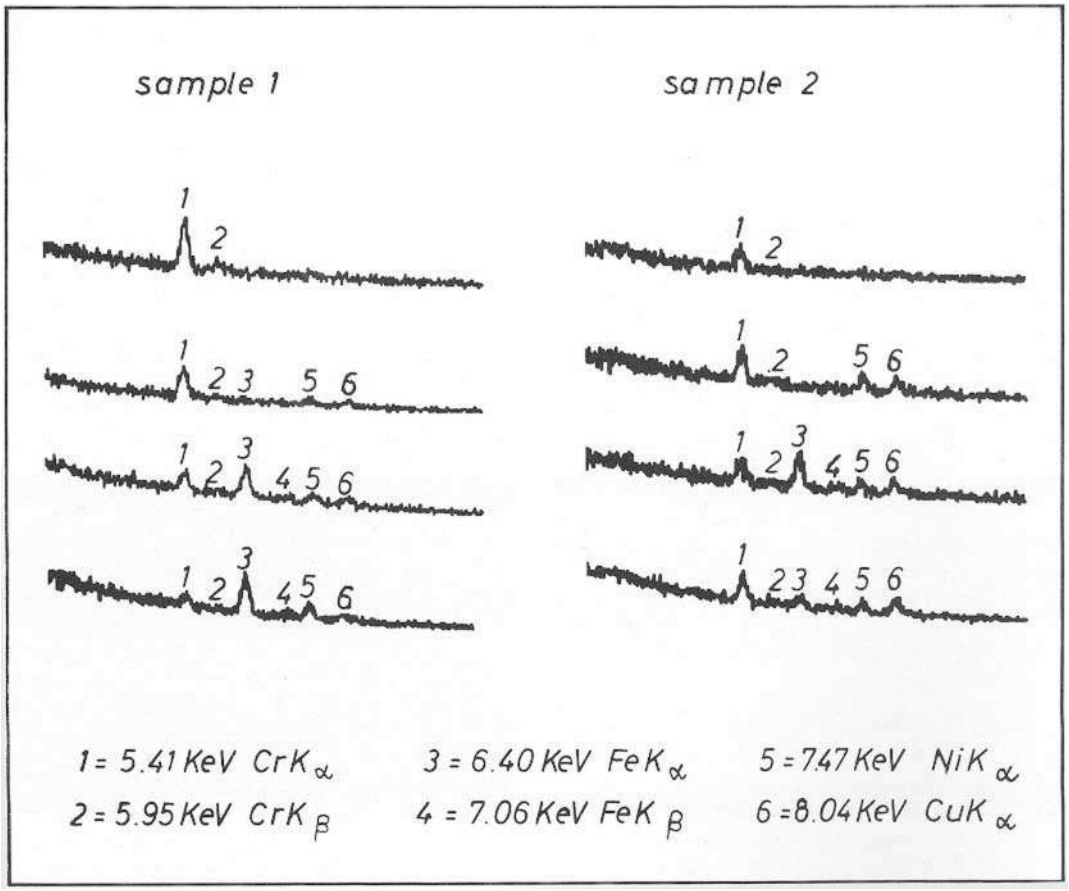

Fig. 6. Energy dispersive X-ray fluorescence spectra of colour causing trace elements (Cr, Fe, Ni, Cu) in different sub-layers of samples 1 and 2 of hydrothermally-grown Lechleitner fully synthetic emeralds indicating irregularly changing trace element contents in different growth zones.

Table 1 Physical and chemical properties of two samples of Lechleitner fully synthetic emeralds determined by non-destructive examinations

	Sample 1	Sample 2
Refractive indices n_o	1.568 broad shadow edges	1.568 broad shadow edges
n_e	1.573	1.573
Birefringence Δ n	0.005	0.005
Specific gravity [g/cm^3]	2.70	2.69
Inclination of layered growth zoning versus optical axis	32°	38°
Absorption spectrum in the visible and ultraviolet range	absorption bands of Cr^{3+} and Ni^{3+} in octahedral Al^{3+} sites as well as Cu^{2+} in tetrahedral Be^{2+} sites (Fig. 9)	absorption bands of Cr^{3+} and Ni^{3+} in octahedral Al^{3+} sites as well as Cu^{2+} in tetrahedral Be^{2+} sites
Chemical properties of the table facet determined by electron microprobe [in wt.%]	Range (6 analyses) Cr 0.15-0.20 Fe 0.47-0.53 Ni 0.15-0.20 Cu 0.19-0.24 average composition (calc.) Cr 0.18 Fe 0.49 Ni 0.17 Cu 0.20	Range (5 analyses) Cr 0.23-0.30 Fe 0.03-0.08 Ni 0.14-0.21 Cu 0.40-0.58 average composition (calc.) Cr 0.27 Fe 0.05 Ni 0.16 Cu 0.52
Chemical properties of the table facet determined by X-ray fluorescence [in wt.%]	average composition (meas.) V< 0.01 Cr 0.19 Fe 0.52 Ni 0.18 Cu 0.22	average composition (meas.) V< 0.01 Cr 0.29 Fe 0.10 Ni 0.16 Cu 0.54
Chemical properties of various colour zones (layers parallel to the table facet) as determined by electron microprobe [qualitative data only]	distinctly variable amounts of chromium, iron, nickel and copper in different layers (Fig. 6)	distinctly variable amounts of chromium, iron, nickel and copper in different layers (Fig. 6)

(Figures 4, 5). This colour zoning is caused by a distinct type of growth structure which is typical for hydrothermally-grown synthetic emeralds with seed planes inclined about 30-40° versus the *c*-axis of the beryl, e.g. for the commercial type of Russian hydrothermally-grown synthetic emeralds (cf. Schmetzer, 1988). In both samples of Lechleitner synthetic emerald described in this paper, growth lines parallel to the table facets of the stones reveal a distinct type of this step-like microstructure (Figures 4, 5). During crystal growth, sub-individuals of synthetic emerald are grown with a preferred sub-parallel orientation. The size of these sub-individuals and the form of the polycentrically growing step-like surface is continuously changed during the growth process. Thus, colour zoning in Lechleitner synthetic emerald is observed parallel to step-like growth lines as well as between neighbouring sub-individuals (Figures 4, 5).

This variability in colour within one single layer is reflected by chemical data of the table facets of both stones (Table 1), which were found by optical microscopy to lie within one single growth zone (cf. Figures 2, 3). Most surprisingly, the samples were found to contain not only the ordinary colour causing trace elements which are generally found in natural and synthetic emeralds, i.e. chromium and iron, but also distinct and slightly variable amounts of nickel and copper. The average compositions calculated from microprobe analyses of the table facets were found to be identical within the limits of error with analytical data obtained by X-ray

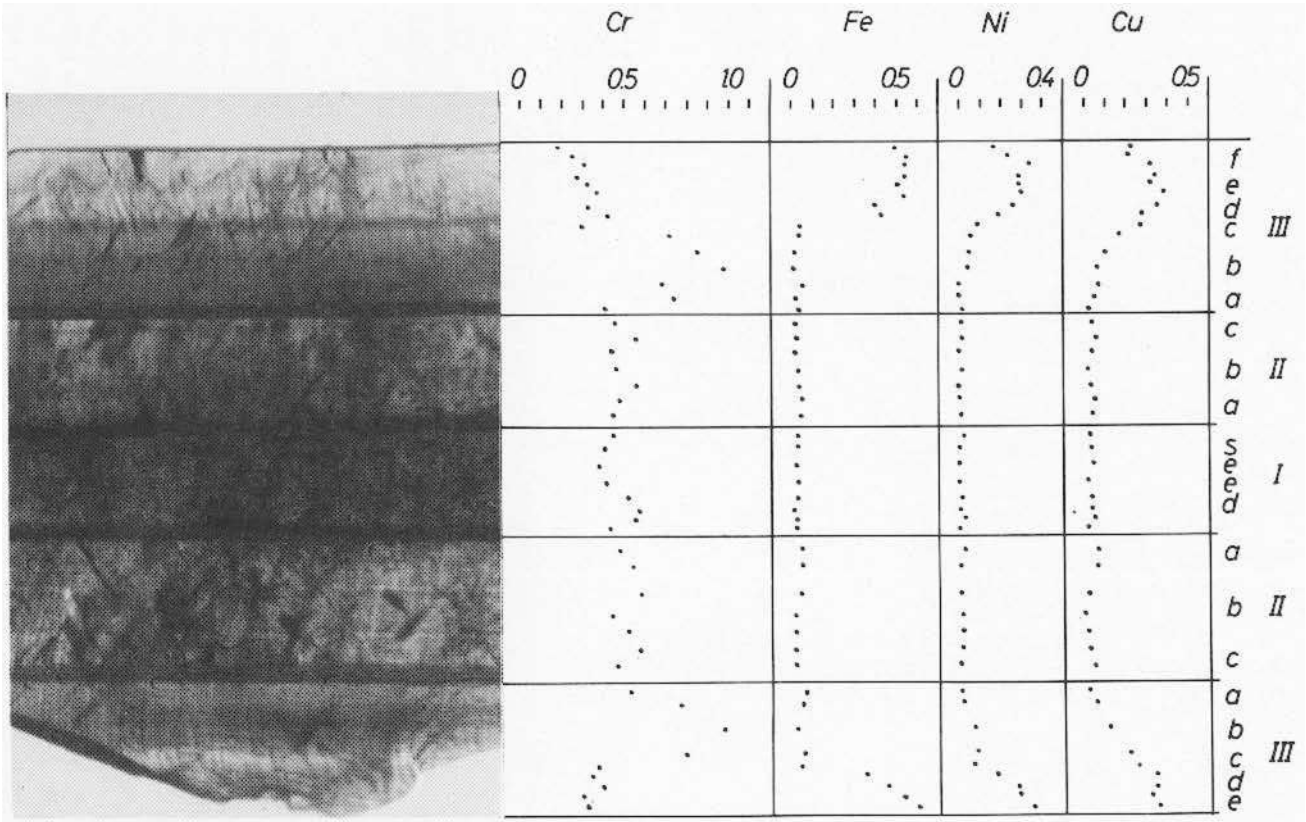

Fig. 8. Hydrothermally-grown Lechleitner fully synthetic emerald (sample 1) consisting of a central layer (seed) and two subsequent growth zones above and below, each of them sub-divided in several sub-zones; this microphotograph corresponds to the trace element distribution in different sub-layers as indicated in Figure 7. 40x.

Fig. 7. Quantitative distribution of colour causing trace elements (Cr, Fe, Ni, Cu) in different layers and sub-layers of hydrothermally-grown Lechleitner fully synthetic emerald (sample 1); subsequent to a central zone, two dominant growth zones, each of them consisting of several sub-zones are symmetrically arranged. According to almost identical trace element distributions in corresponding sub-layers, the microprobe analyses indicate that in two autoclave runs, above and below the central layer I (seed), layer II (with sub-layers IIa to IIc) and layer III (with sub-layers IIIa to IIIf) were grown.

Table 2 Physical and chemical properties of Lechleitner fully synthetic emerald (sample 1) determined by partly destructive examinations

Chemical properties of different colour zones (layers parallel to the table facet) determined by electron microprobe (cf. Figs. 7,8)

Designation of layer		Number of analyses	Average composition of colour zone [wt.%] Cr	Fe	Ni	Cu
	f	2	0.22	0.52	0.20	0.22
	e	4	0.32	0.53	0.30	0.34
	d	2	0.37	0.41	0.22	0.31
III	c	1	0.30	0.04	0.09	0.27
	b	3	0.85	0.02	0.05	0.11
	a	3	0.61	0.03	0.00	0.06
	c	2	0.51	0.01	0.01	0.04
II	b	3	0.48	0.02	0.00	0.03
	a	2	0.46	0.04	0.00	0.04
I (seed)		8	0.46	0.02	0.01	0.03
	a	2	0.50	0.04	0.00	0.06
II	b	3	0.51	0.02	0.01	0.01
	c	2	0.52	0.01	0.00	0.04
	a	2	0.64	0.04	0.00	0.03
	b	2	0.88	0.03	0.07	0.16
III	c	1	0.36	0.03	0.06	0.25
	d	2	0.36	0.41	0.23	0.34
	e	2	0.30	0.56	0.31	0.33
Average composition of the sample calculated from weighted analyses of different colour zones			0.52	0.11	0.06	0.11

Average composition of the sample determined by wet chemical analyses [wt.%]	Cr	Fe	Ni	Cu
	0.51	0.09	0.05	0.13
	Li	Na	K	V
	0.36	0.04	0.02	<0.02

Infrared spectrum in the range of H_2O stretching modes (KBr pressed disk technique, Fig. 10)	Absorption maxima [cm^{-1}] and intensity ratios		
	A	B	C
	3694	3592	3655

fluorescence analyses of the table facets of both samples (Table 1). In addition, a slight variation in chemical composition within one single growth zone is also indicated by somewhat broader shadow edges on the refractometer (Table 1) compared with other gemstones revealing well polished tables.

The chemical variation of trace element contents between different growth zones perpendicular to the table facets of both gemstones was first examined by non-destructive microprobe analyses of both faceted samples. Placing both stones with their table facets on an ordinary microprobe sample holder, it was possible to record energy-dispersive X-ray spectra of different growth zones of both synthetic emeralds (Figure 6). Due to the oblique and variable angle between the electron beam of the microprobe and the different backside facets of both emeralds no quantitative chemical data were obtainable. However, these investigations clearly indicated a strong chemical variability between all

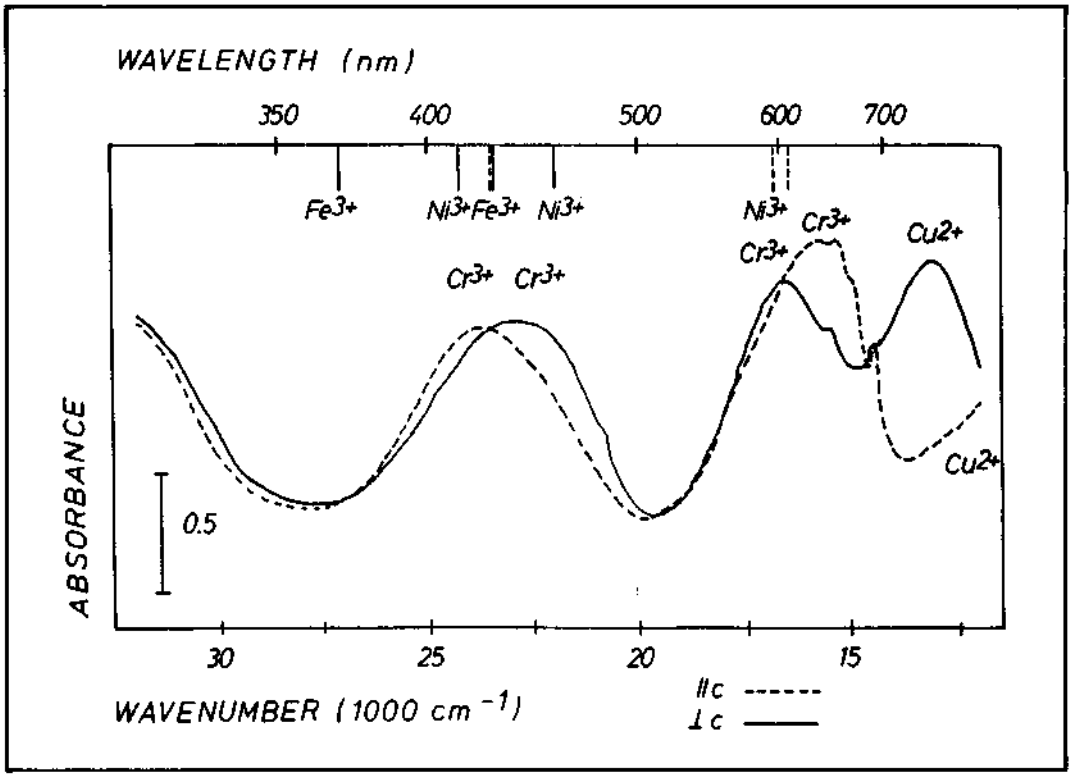

Fig. 9. Polarized absorption spectrum of Lechleitner fully synthetic emerald (sample 1); the spectrum reveals a superimposition of absorption bands of Cr^{3+} in octahedral Al^{3+} sites and Cu^{2+} in tetrahedral Be^{2+} sites; the position of Fe^{3+} and Ni^{3+} absorption maxima, which are not found in this particular spectrum, are also indicated.

four different trace elements, i.e. chromium, iron, nickel and copper, between different growth layers of the samples (Figure 6).

In order to obtain quantitative chemical data of different growth zones, sample 1 was sawn in a direction perpendicular to the table facet and quantitative chemical analyses of 46 points in different growth zones were then performable in a line from the table to the base of the synthetic emerald. Corresponding to microscopic observations, the analytical results (Table 2, Figures 7, 8) clearly indicate the presence of five dominant growth zones with several more or less distinct subzones.

Analyses of different points within the central growth zone (designated layer I) yield an almost uniform trace element distribution within that layer. According to chemical data, the two neighbouring growth zones of layer I are sub-divided into three sub-zones each (designated layers IIa to IIc), and the two growth zones subsequent to sub-layers IIc are sub-divided into six sub-zones (designated sub-layers IIIa to IIIf). The most remarkable feature of these 46 microprobe analyses is a symmetrical arrangement of growth zones from zone IIa to zone IIc and from zone IIIa to zone IIIe on both sides of the central layer I (Figures 7, 8).

These results indicate the use of a seed plate (layer I) which was cut at an angle of 32° versus the optical axis of the synthetic emerald. In two autoclave runs, zones IIa to IIc and zones IIIa to IIIf were grown on both sides of the seed plane with slightly variable thicknesses. In the first autoclave run, almost homogeneous growth conditions were present resulting in small chemical variations within sublayers IIa, IIb and IIc. In the second autoclave run, in which layers IIIa to IIIf were deposited, extremely inhomogeneous growth conditions were obviously present resulting in distinctly variable trace element contents in different sub-layers. Most probably, sub-layer IIIf was removed during the faceting process at the base of the synthetic emerald.

A careful microscopic examination of sample 2 did not reveal any symmetrical arrangement of colour zoning and growth structures parallel to a central layer (Figure 3). Most probably, this stone was grown hydrothermally in several autoclave runs

Table 3 Spectroscopic properties of Lechleitner synthetic emeralds in the visible and ultraviolet range

Position of observed absorption maxima [cm^{-1}]	[nm]	Polarization of absorption bands	Assignment
10,700	917	$\parallel c$	Cu^{2+} tetr.
13,300	752	$\perp c$	Cu^{2+} tetr.
15,900	629	$\parallel c$	Cr^{3+} oct.
16,600	602	$\perp c$	Cr^{3+} oct.
23,200	431	$\perp c$	Cr^{3+} oct.
23,800	420	$\parallel c$	Cr^{3+} oct.
Position of not observed iron and nickel absorption maxima [cm^{-1}]	**[nm]**	**Polarization of absorption bands**	**Assignment**
16,500	606	$\parallel c$	Ni^{3+} oct.
16,800	595	$\parallel c$	Ni^{3+} oct.
22,000	555	$\perp c$	Ni^{3+} oct.
23,500	426	$\parallel c > \perp c$	Fe^{3+} oct.
24,200	413	$\perp c$	Ni^{3+} oct.
27,000	370	$\perp c \gg \parallel c$	Fe^{3+} oct.
Position of absorption minima [cm^{-1}]	**[nm]**	**Polarization**	**Colour**
19,800	505	$\perp c$	yellowish-green
20,000	500	$\parallel c$	bluish-green

(in more than 2, possibly in 4 to 5 runs), and the seed plate or part of the seed plate was removed during the cutting process. Most probably, in this case two synthetic emeralds were cut from the synthetic emerald substance deposited on both sides of a seed plate. Cutting and polishing processes in between the different autoclave runs removing colourless or extremely impure parts of the emerald or beryl layers may furthermore have complicated the situation.

An average composition of sample 1 was calculated from 46 analyses of different colour zones which were weighted according to their variable thicknesses (Figures 7, 8). This calculated average composition was found to be almost identical with an average composition of the sample determined by wet chemical analyses of part of the sample (Table 2).

Polarized absorption spectra of both Lechleitner synthetic emeralds were almost identical (Figure 9). They were found to consist of dominant absorption bands of Cr^{3+} replacing Al^{3+} in octahedral sites as well as Cu^{2+} replacing Be^{2+} in tetrahedral sites (Table 3, cf. Schmetzer, 1988). This dominant absorption spectrum is superimposed by extremely weak absorption bands of Ni^{3+} in octahedral sites, and no distinct absorption bands of Fe^{3+} or Fe^{2+} were found to be present.

These spectroscopic data are consistent with the average chemical composition (Table 2) which indicates dominant absorption bands of chromium and copper and subordinate bands of nickel. The average amount of iron, however, which most probably enters the structure of this type of synthetic emerald as Fe^{3+} replacing Al^{3+} in octahedral sites (cf. Schmetzer, 1988), is too low for a distinct influence on the absorption spectrum.

Colour and pleochroism of the samples (bluish-green $\parallel c$ and yellowish-green $\perp c$) are caused by the positions of absorption minima in the green area (Table 3) which are the ordinary minima for chromium-containing, low iron-bearing natural or synthetic beryl. In the present case, the low nickel-content does not distinctly influence the absorption spectrum, the colour and the pleochroism of the samples. However, in samples with nickel-contents

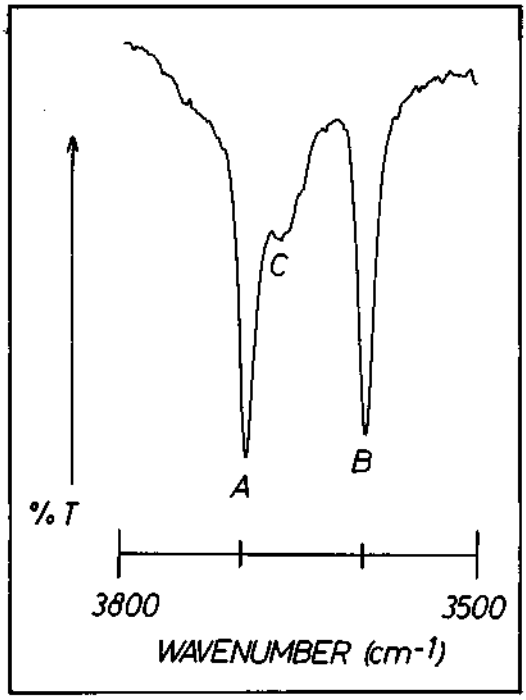

Fig. 10. Infrared spectrum of Lechleitner fully synthetic emerald in the range of water stretching modes consisting of three absorption bands A ≙ 3694 cm^{-1}, B ≙ 3592 cm^{-1}, and C ≙ 3655 cm^{-1} with intensity ratios A › B » C.

in the range of chromium values, e.g. in Russian hydrothermally-grown synthetic emeralds, the pleochroism is strengthened to blue or greenish-blue ∥ c and yellow-green ⊥ c (Schmetzer, 1988). Though copper-bearing chromium-free synthetic beryls are described as blue-green or turquoise coloured (Solntsev *et al.*,1976; Solntsev, 1981a,b; Lebedev *et al.*, 1986), the relatively low copper-contents in Lechleitner synthetic chromium-bearing emeralds do not influence colour and pleochroism of the samples. This is understandable by the fact that copper absorption bands with maxima in the red and near infrared (cf. Table 3) are not able to shift the absorption minima of the ordinary chromium absorption spectrum in the green area.

The infrared spectrum of sample 1 of Lechleitner synthetic emeralds (Figure 10) is typical for low alkali-bearing natural and synthetic emeralds. This type of spectrum (designated type 2 infrared spectrum of natural and synthetic beryls) is characterized by the presence of three absorption bands at 3694 cm^{-1}≙A, 3592 cm^{-1}≙B, and 3655 cm^{-1}≙C with intensity ratios A › B » C (Schmetzer, 1989; Schmetzer and Kiefert, 1989). This result is understandable by the distinct lithium- and low sodium-content of the stone (Table 2).

Discussion

Microscopic examination of both samples of Lechleitner synthetic emeralds clearly indicates the presence of different layers and sub-layers parallel to the table. Colour zoning is observed between subsequent layers and sub-layers (i.e. perpendicular to the table facet) as well as between neighbouring sub-individuals within one sub-layer (i.e. parallel to the table facet). According to these complicated microstructures, three corresponding groups of data are available (cf. Tables 1,2,3).

Microprobe analyses of the table facets represent chemical data of that particular sub-layer which is forming the table facet after cutting. The variation of chemical data within one sub-layer clearly indicates colour zoning between neighbouring sub-individuals, which is responsible for the broad shadow edges observed for n_o and n_e on the gemstone refractometer. An average composition of the table facet calculated from several point analyses by electron microprobe corresponds with the results of X-ray fluorescence analyses of the whole table facets.

The chemical variation of colour causing trace elements between different layers and sub-layers of both samples corresponds with colour zoning and growth structures observed in the immersion microscope. The symmetrical arrangement of equivalent types of layers and sub-layers on both sides of a central layer in sample 1 clearly indicates the use of layer I as seed plate and the subsequent growth of layers II and III (with sub-layers IIa to IIc and IIIa to IIIf) in two autoclave runs. According to growth inhomogeneities, a distinct variation of physical and/or chemical growth conditions (e.g. temperature, pressure, composition of nutrient) is evident during the second autoclave run.

An average chemical composition of sample 1 was calculated from 46 microprobe analyses, each of them weighted according to the thicknesses of the corresponding sub-layers. This calculated average composition is identical within the limits of error with wet chemical analyses of powdered material of sample 1 (Table 2). This average chemical composition with distinct amounts of chromium, iron, nickel and copper as well as lithium- and sodium-contents is responsible for the absorption spectrum in the visible area, as well as for the infrared spectrum and the specific gravity of both samples. Colour and pleochroism of the synthetic emeralds are caused by the high chromium contents of the samples, and the absorption bands of copper in the red and near infrared do not influence the colour and pleochroism of the stones. The infrared spectrum with three absorption bands in the range of H_2O stretching modes is understandable as a function of water and alkali- (lithium plus sodium) contents.

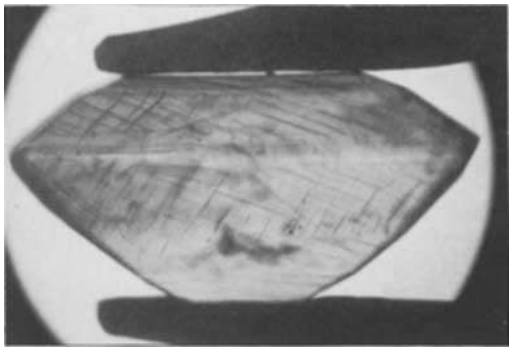

Fig. 11. Type B Lechleitner synthetic emerald; typical fissures and cracks in the hydrothermally-grown synthetic emerald skin on natural colourless beryl core. 22x.

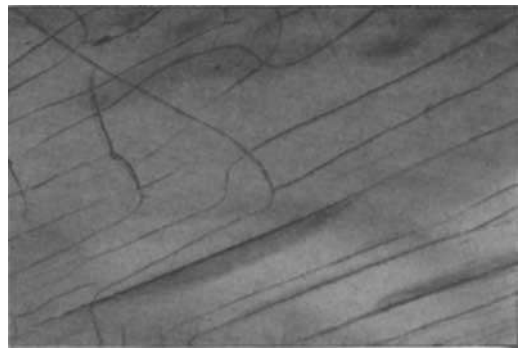

Fig. 12. Type B Lechleitner synthetic emerald; typical fissures and cracks in the hydrothermally-grown synthetic emerald skin on natural colourless beryl core. 35x.

Fig. 13. Type D Lechleitner hydrothermally-grown fully synthetic emerald; dark green central emerald layer (seed?) covered on both sides with light green synthetic emerald substance. 45x.

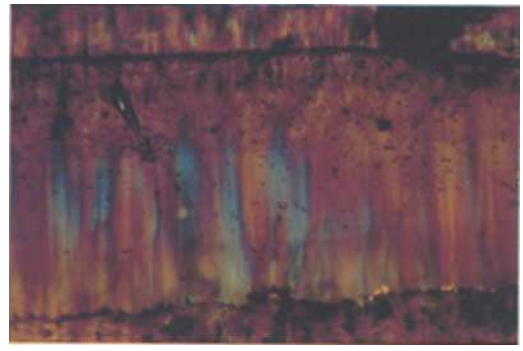

Fig. 14. Type D Lechleitner hydrothermally-grown fully synthetic emerald; irregularly changing sub-grain boundaries between sub-individuals. Crossed polarizers. 50x.

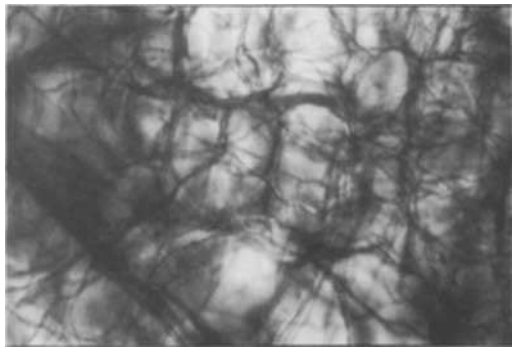

Fig. 15. Type F Lechleitner flux-grown synthetic emerald; view parallel to the *c*-axis, cellular pattern of wisp-like feathers consisting of residual flux material. 50x.

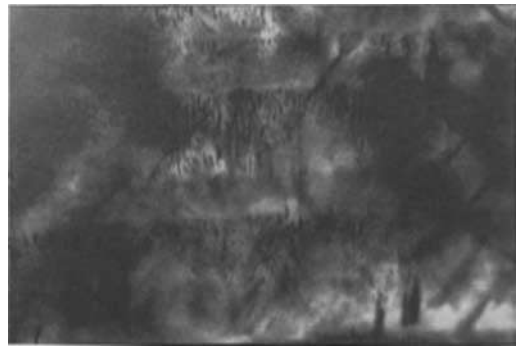

Fig. 16. Type F Lechleitner flux-grown synthetic emerald; view perpendicular to the *c*-axis, growth zoning of residual flux material parallel to the basal plane. 50x.

Comparing the physical and chemical properties of the two examined samples of Lechleitner fully synthetic emeralds with those of other types of hydrothermally-grown synthetic emeralds, some similarities are evident with the commercial type of Russian hydrothermally-grown synthetic emeralds (Schmetzer, 1988).

In addition to certain similarities in growth structures (step-like surfaces between subsequent sub-layers consisting of sub-parallel orientated sub-individuals, orientation of growth layers in the range of 30-40° versus the optic axis), both types of hydrothermally-grown synthetic emeralds reveal distinct amounts of iron, nickel and copper. In Russian synthetic emeralds, the relatively high amounts of iron, nickel and copper originate from the walls of the steel autoclaves used for industrial growth processes. These autoclaves are characterized by the lack of precious metal (platinum or gold) inserts and cause the incorporation of Fe^{3+} and Ni^{3+} in Al^{3+} sites as well as Cu^{2+} in Be^{2+} sites of the beryl lattice.

According to Lechleitner (1988), no compounds of iron, copper and nickel were added to the nutrient for hydrothermal growth of synthetic emeralds. Thus, for sample 1 of Lechleitner synthetic emerald examined in the present paper, the use of a steel autoclave without precious metal insert is evident for the second autoclave run causing the incorporation of material from the wall of the steel autoclave (Fe^{3+}, Ni^{3+} and Cu^{2+}) in the lattice of the synthetic emerald crystal. For material grown in the first run as well as for the growth of the seed plate, smaller amounts of iron, nickel and copper were analysed. This difference in chemical composition may be caused by the incorporation of smaller amounts of iron, nickel and copper due to the different physical and chemical growth conditions, which are comparable with growth conditions of sub-layer IIIa in the second autoclave run. On the other hand, the small amounts of iron, nickel and copper in the seed as well as in layer II can also be caused by impurities of the nutrient (unknown to the producer) and, thus, the use of an autoclave with precious metal insert is also possible for the first autoclave run.

In summary, the seeding technique as well as the use of autoclaves without precious metal inserts by J. Lechleitner in the late sixties is nowadays applied by Russian scientists for hydrothermal growth of high quality synthetic emeralds, and most structural and chemical properties of both types of synthetic emeralds are understandable with the basic information about growth conditions.

General survey of different types of Lechleitner synthetic emeralds

Type A Lechleitner synthetic emeralds

J. Lechleitner started his experiments in emerald synthesis in 1956 with flux growth of synthetic emeralds. Using seed plates of natural beryl, which were cut in a direction perpendicular to the *c*-axis, synthetic emerald plates up to 10mm in thickness were grown. This type of synthetic emerald was grown between 1956 and 1958, and only few samples were given to gemmological laboratories for investigation. Most probably, a plate of Lechleitner synthetic emerald with refractive indices of n_o 1.563, n_e 1.560, which was briefly mentioned by Liddicoat (1964) was a product of these early experiments in flux growth of synthetic emerald.

Type B Lechleitner synthetic emeralds

The first type of Johann Lechleitner's products, which was sold commercially, is composed of natural cores of colourless or slightly greenish beryl. These pre-shaped beryl seeds were overgrown hydrothermally in autoclaves with precious metal inserts with thin layers of synthetic emerald, and according to the producer, this type of synthesis was performed between 1959 and 1972. Variable refractive indices were described by different authors (e.g. Holmes and Crowningshield, 1960; Schlossmacher, 1960; Gübelin, 1961a,b,c; Flanigen *et al.*, 1965, 1967; Eppler, 1968, 1973), ranging from 1.571 to 1.597 for n_o and 1.566 to 1.587 for n_e, and even up to 1.610 for n_o and 1.601 for n_e (cf. also Bank, 1976, 1980; Bank and Zwetkoff, 1979; Bank and Bank, 1980). For samples, the refractive indices of the synthetic emerald skin varies in the range of 1.580 to 1.610 for n_o, and between 1.572 and 1.601 for n_e, variable chromium contents between 3.99 and 10.01 wt.% Cr_2O_3 were determined by electron microprobe (Schmetzer, 1981a,b).

According to unpublished data of the present author, type B Lechleitner synthetic emeralds are the only commercially available synthetic emeralds which reveal absorption spectra consisting of Fe^{2+} and Fe^{3+} absorption bands (due to the colourless core) which are superimposed by a typical Cr^{3+} spectrum of emerald (due to the skin). Nevertheless, this type of synthetic emerald is easily recognizable in the gem microscope (Figures 11, 12).

Type C Lechleitner synthetic emeralds

Continuing his experiments in emerald synthesis, J. Lechleitner used natural beryls which were cut at oblique and variable angles versus the *c*-axis as seed plates. The results of hydrothermal growth processes in autoclaves with noble metal inserts

were described as wafer- or sandwich-type Lechleitner synthetic emeralds in gemmological literature (Liddicoat, 1964; Flanigen *et al.*, 1965, 1967; Theisen, 1966; Eppler, 1968, 1973). In general, type C Lechleitner synthetic emeralds are grown in one single autoclave run and consist of a colourless central seed with dark green synthetic emerald layers on each side. These high chromium-bearing layers fade towards the table and base of the sample into lighter green synthetic emerald or even colourless synthetic beryl with refractive indices ranging from 1.567 to 1.570 for n_o and from 1.562 to 1.566 for n_e in colourless or almost colourless layers. In greenish layers, refractive indices of 1.573 for n_o and 1.567 for n_e are described.

According to the producer, type C Lechleitner synthetic emeralds were grown in 1962 and 1963, and samples were given only to gemmological laboratories for investigation. In addition the hydrothermally-grown layers of type C Lechleitner synthetic emeralds were used as seed plates for type D Lechleitner synthetic emeralds (which are the improved form of type C synthetic emeralds).

Type D Lechleitner synthetic emeralds

Two samples of type D Lechleitner synthetic emeralds are comprehensively described in this paper. Starting in 1964, this type of fully synthetic hydrothermally-grown synthetic emerald was produced in autoclaves with or without precious metal inserts. In general, several autoclave runs were used in order to produce synthetic emerald layers which were able to be faceted according to their thickness. Cut samples of type D Lechleitner synthetic emeralds consist of several layers and sub-layers which can be arranged symmetrical or asymmetrical with respect to a central light green seed plate. Another variety of type D Lechleitner synthetic emeralds are samples with dark green central layers and lighter green overgrowths (Figure 13), but still with distinct growth structures and sub-individuals in different layers (Figure 14). Analytical data of this variety of type D synthetic emeralds are also published by Hänni (1982).

Type E Lechleitner synthetic emeralds

Only very few samples of this type were grown for internal studies of the producer in 1961 or 1962 and only one sample was given to a collector. Type E synthetic emeralds consist of flux-grown seed plates which were hydrothermally grown to an appropriate thickness in several autoclave runs as described for type D samples. No gemmological data of type E Lechleitner synthetic emeralds are available at present.

Type F Lechleitner synthetic emeralds

Crystal growth of this last type of Lechleitner's products began about 1972 and was most probably performed during the seventies until the early eighties. Unfortunately, the producer did not want to disclose any details of the processes used for the growth of this type of fully synthetic emerald.

According to its low refractive indices of n_o 1.563 and n_e 1.560, a sample of Lechleitner fully synthetic emerald, which was mentioned briefly by Eppler (1973) is one of the first samples belonging to Lechleitner type F synthetic emeralds. Four samples of Lechleitner synthetic emeralds which were described as fully synthetic emeralds by Schmetzer and Bank (1982) were found to have similar low refractive indices between 1.562 and 1.566 for n_o and from 1.559 to 1.562 for n_e. However, no experimental examination of growth conditions for this type of Lechleitner synthetic emerald was worked out until now. Due to the relatively low refractive indices of these samples with chromium contents between 0.40 and 0.84 wt.% Cr_2O_3, compared with chromium-free or low chromium-bearing outer layers of type C Lechleitner synthetic emeralds as well as with optical data of Linde, Biron and Russian hydrothermally-grown synthetic emeralds, these data are more closely related to flux-grown synthetic emeralds of different producers. Consequently, type F Lechleitner synthetic emeralds are not necessarily grown by hydrothermal processes, but may be produced by flux techniques. Thus, this latest type of Lechleitner's products is possibly regarded as an improved form of type A Lechleitner synthetic emeralds.

In order to clarify production techniques of type F Lechleitner synthetic emeralds, one sample weighing 1.29 ct with refractive indices of n_o 1.563 and n_e 1.559 was made available for investigation. This stone was bought as Lechleitner fully synthetic emerald in 1981 from a dealer who was, at that time, working with the distribution of Lechleitner synthetic emeralds.

In the gem microscope, the sample was found to contain a cellular pattern of wisp-like feathers (Figure 15), which revealed some weak growth zoning parallel to the basal plane (Figure 16). The absence of water in this sample was proved by infrared spectroscopy and, in addition, the presence of traces of molybdenum was detected by X-ray fluorescence analysis. Consequently, type F fully synthetic emeralds of Lechleitner are flux-grown samples, most probably with lithium molybdate as dominant component of the flux and basal plates of natural or synthetic beryl used as seed material.

In summary, according to the information from

the producer as well as from the experimental results of the present author, three types of Lechleitner synthetic emeralds were grown and marketed commercially and three types of synthetic emeralds were grown for research and experimental studies only. The three commercially available products are:

- type B Lechleitner synthetic emeralds consisting of colourless natural preshaped beryl seeds which are hydrothermally overgrown with thin layers of synthetic high chromium-bearing emerald
- type D Lechleitner synthetic emeralds, which are characterized as hydrothermally-grown fully synthetic emeralds consisting of several layers and sub-layers arranged symmetrically or asymmetrically to a central seed of synthetic emerald
- type F Lechleitner synthetic emeralds, which were found to be flux-grown fully synthetic emeralds without significant growth structures.

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Coloration in electron-irradiated beryl

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Abstract

A bluish-green beryl has been produced through electron irradiation of colourless beryl. Absorption spectra for both the ordinary and extraordinary vibration directions show structure attributable to blue and yellow chromophores. The blue chromophore is a metastable 'Maxixe-type' colour centre. The yellow component appears to be due to ligand-metal charge transfer processes between trivalent iron and oxygen. The yellow colour is stable.

Introduction

The hexagonal and optically uniaxial cyclosilicate beryl ($Be_3Al_2Si_6O_{18}$) shows channel structure parallel to the crystallographic *c*-axis, (0001). The large channels result from the specific arrangement of the silica tetrahedra. The channel diameter varies between 0.28 and 0.57nm, which allows occupation by various metal ions and molecules. The electronic structure of the channel-occupied impurity species determines certain optical properties of the specimen, which may be altered by irradiation or thermal treatment.

Colour enhancement of beryl primarily uses the lesser valued colourless or very pale blue variety to produce a precious light to deep golden yellow hue in the specimen. Such colour changes and saturation intensification result from gamma or electron irradiation followed by thermal treatment. The latter treatment normally anneals out any undesirable irradiation effects and allows some adjustment of the level of saturation.

We are reporting here on an unusual occurrence in which an irradiated and heat treated colourless beryl, which had been coloured golden yellow, was changed to a light bluish-green hue on re-irradiation with electrons. The stone originally was part of a lot of colourless beryl which, on electron irradiation and heat treatment, resulted in three colour groups: golden yellow (40%), light bluish-green (35%) and bluish-green (25%). The referenced stone was one of the twenty-three golden yellow ones which were subsequently re-irradiated for purposes of increasing the saturation in the yellow part of the spectrum.

As to the various mechanisms and types of chromophores leading to coloration in beryl, channel Fe^{2+} was reported by Nassau and Wood (1968) to be involved in the blue coloration. Goldman *et al.* (1978) suggested that the yellow colour in beryl is most likely due to ligand-metal charge transfer (LMCT) between Fe^{3+} in the channels and ring-sited oxygens. Nassau and Wood (1973) studied Maxixe-type beryl. These beryls were originally discovered in the Maxixe mine in Brazil in 1917. Their superb blue colour faded on exposure to daylight. Blue coloured stones from other mines that fade are normally designated Maxixe type. The irradiation and heat effects were further characterized by Nassau, Prescott and Wood (1976). Edgar and Vance (1977) proposed CO_3^- as the blue chromophore in Maxixe-type beryl by correlating EPR, optical absorption and magnetic circular dichroism measurements. On the basis of further EPR work, Anderson (1979) proposed NO_3 and CO_3 as the chromophores in Maxixe and Maxixe-type beryl, respectively.

Experimental procedure and results

Twenty-three faceted beryl gemstones turned golden yellow upon electron irradiation and heat treatment with an electron beam from a 3 MeV Van de Graaff accelerator. The specimens were held in a steel mesh envelope on the periphery of a carousel which rotated at 8rpm in front of the beam window. The intermittent irradiation of the specimen allowed air-cooling, which proved sufficient at a beam window-to-specimen distance of approximately 4.5cm.

The 13 × 9mm golden yellow oval stone developed a light bluish-green coloration after a 55 minute exposure to a 100 microampere beam. At that point the total absorbed dose was approximately 330 megarad. During the next 3.0 hours of exposure the beam current was incrementally increased from 100 to 150 microamperes. After 3.25 hours of exposure, the stone was dark green with a blue overtone. The stone appeared to acquire no further saturation of bluish-green coloration up to

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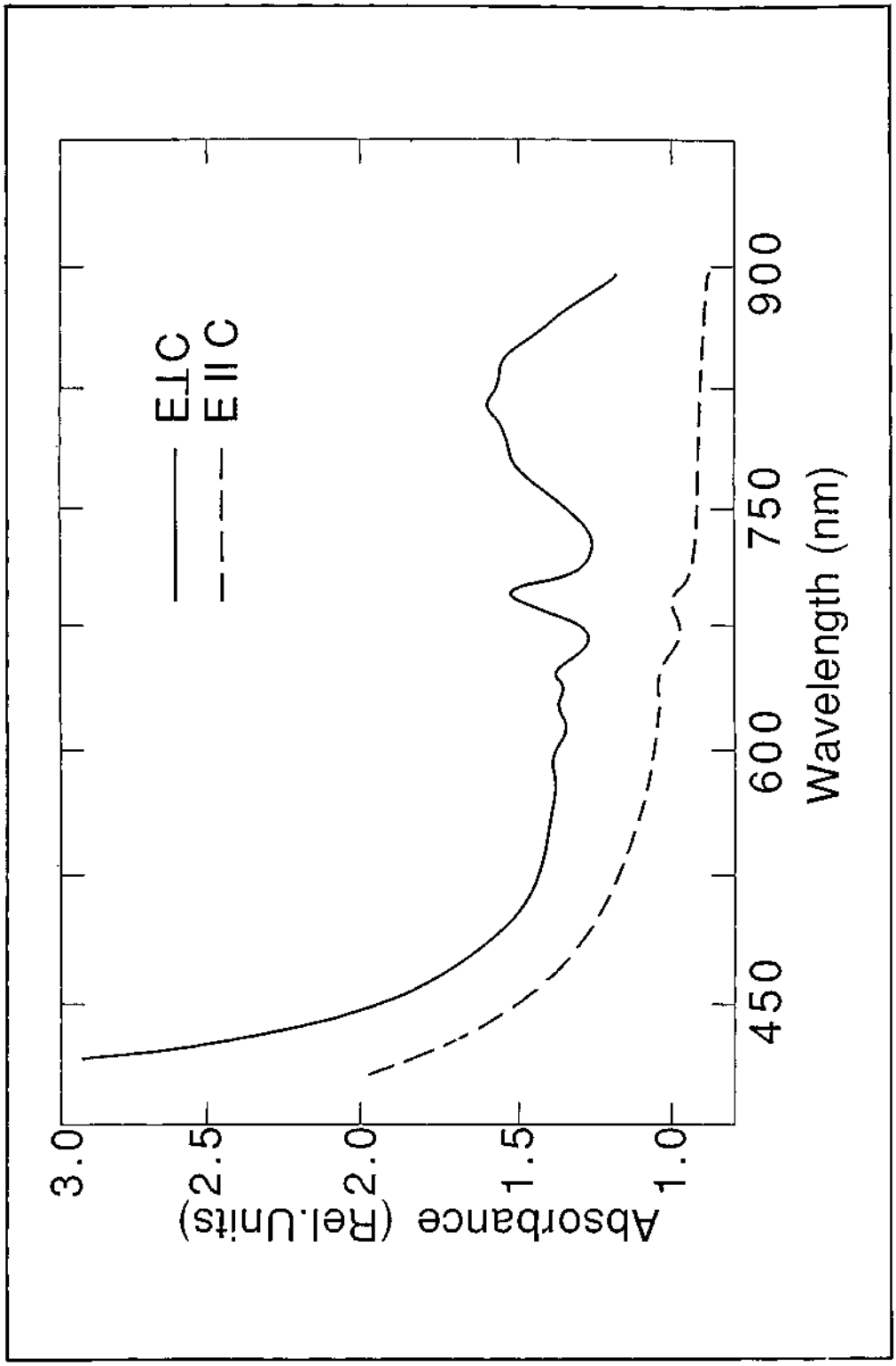

Fig. 1. Polarized absorption spectra of bluish-green beryl for the ordinary ray (E ⊥ C) and the extraordinary ray (E∥C) vibration directions.

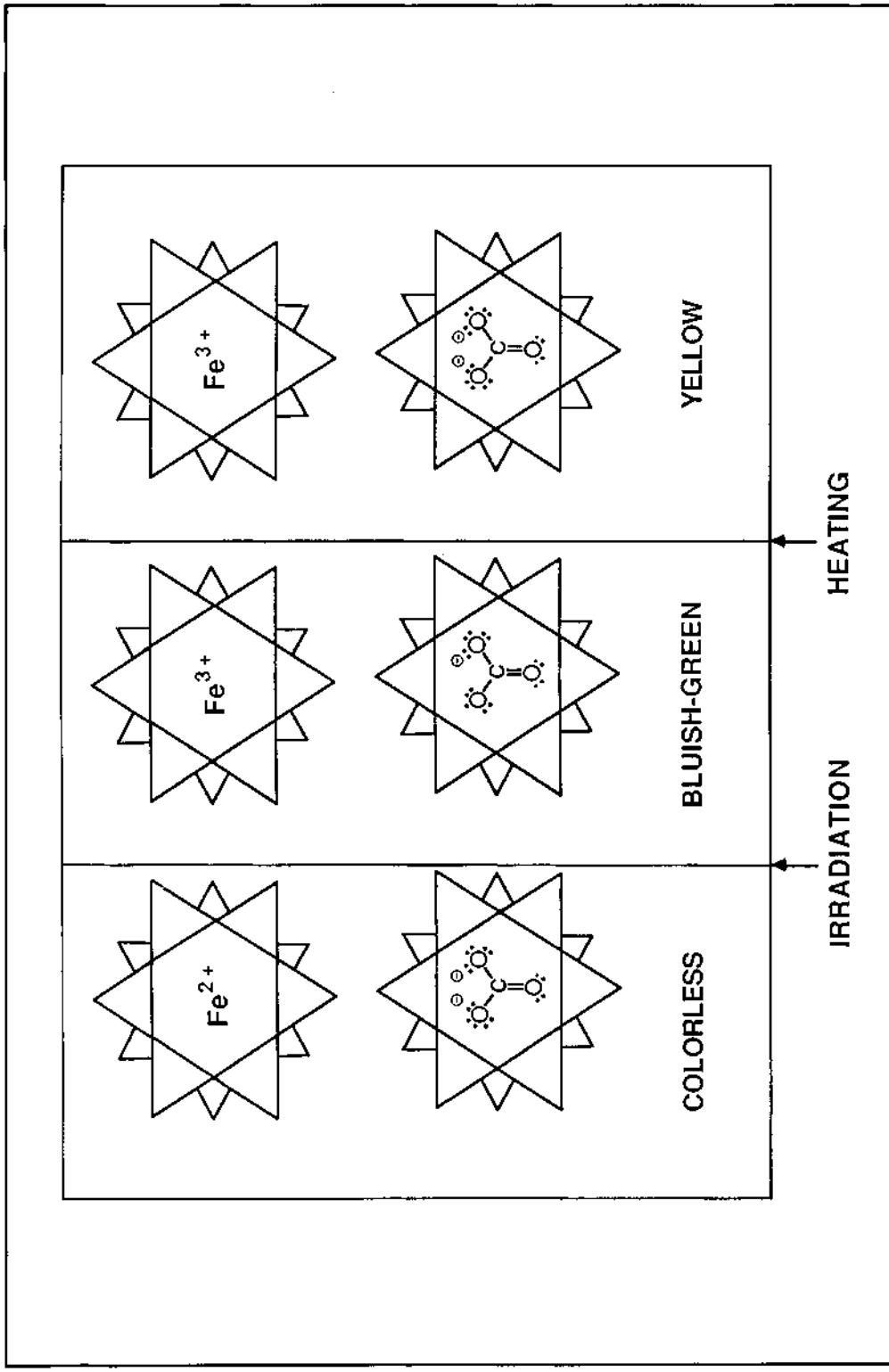

Fig. 2. Pictorial presentation of the mechanisms involved in creating colour centres in colourless beryl through electron irradiation and thermal treatment.

4.25 hours of exposure. The total dose at saturation must have been between 1450 and 2000 megarads.

The irradiated stone was optically oriented using a polarizing microscope. The crystallographic *c*-axis proved to be parallel to the 9mm width. X-ray diffraction was used to confirm this orientation after sawing. Two flat windows, parallel with each other and perpendicular to the (0001) axis, were ground on the stone to obtain the optical spectra in the ordinary and extraordinary ray directions. The polarized absorption spectra (see Figure 1) were obtained with an OLIS-converted Cary 14 double beam spectrophotometer.

After the crystallographic directions had been established but prior to the sawing operation, observations were made regarding the naked-eye-visible dichroism that had been produced by the irradiation. When viewed parallel to the *c*-axis (along the 9mm width) the stone appeared bluish-green but, when viewed perpendicular to the *c*-axis (along the 13mm length) it appeared brownish-yellow. Examination in the direction perpendicular to the *c*-axis, using a simple hand-held dichroscope, allowed further characterization of the dichroism. It was composed of two distinct colours; olive green and brownish-yellow and judged to be of moderate degree.

For the ten-month period between irradiation and optical absorption measurements, the stone retained its blue component. It also retained its naked-eye pleochroism. It had been in storage under dark laboratory conditions.

Interpretation of results

Figure 1 shows the room temperature absorption spectrum for the ordinary ray ($E \perp C$) direction, in the range 375 to 900nm. The best resolved peak occurs at 689.9nm with a series of poorly resolved ones towards lower wavelengths, between 690 and 575nm. This structure is characteristic of the ordinary ray spectrum of Maxixe-type beryl. The broad band high wavelength absorption, centred around 810nm, has been associated with divalent iron in channel positions by Goldman *et al.* (1978). The sharp absorption increase in the violet and ultraviolet at wavelengths shorter than 450nm, could be interpreted as due to ligand-metal charge transfer between Fe^{3+} and O^{2-} in the ring structure, as postulated by Goldman *et al.* (1978). It presumably produces the yellow coloration in beryl.

Figure 1 also shows the complementary $E \parallel C$ spectrum. There are no well resolved structures. At best there are hints of some detail, characteristic of that found for Maxixe-type beryl in the $E \perp C$ spectrum. The yellow producing (LMCT) intense absorption on the short wavelength side of 450nm appears to be the only feature of significance.

Figure 2 conceptually depicts the changes induced by electron irradiation and thermal treatment in the investigated stone. The initial oxidation state of the channel iron is 2+, the CO_3 molecules are trapped in the channels, and the beryl is colourless. Upon electron irradiation, the iron is oxidized to the 3+ state producing the yellow colour and the CO_3 molecule becomes a radical through hole trapping thus producing the Maxixe-type (unstable) blue chromophore. The composite colour is bluish-green. Further heating causes the CO_3 radical to capture an electron which destroys the blue chromophore but does not affect the oxidation state of the channel iron. The beryl turns a golden yellow. This colour is stable and can only be destroyed at temperatures well above 200°C.

The oxidation of the divalent iron is surprising in the heavily reducing environment of electron irradiation. The oxidation process may involve the trapping of a hole on a ring oxygen in the immediate vicinity of a channel iron which turns into Fe^{3+} through hole capture.

In summary, we have observed and interpreted the simultaneous occurrence of LMCT-caused yellow and Maxixe-type blue chromophores in a single beryl specimen. In commercial irradiation of colourless beryl, especially electron irradiation, one frequently observes a greenish-yellow colour, probably due to the combinations of both yellow and blue absorption. These green overtones can often be removed by thermal annealing at temperatures below 190°C. The resultant purer yellow or golden colour is likely to be due to the removal of the Maxixe-type blue chromophores.

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XXII International Gemmological Conference, Italy 1989

E. A. Jobbins

The scientific sessions of the conference were held at Tremezzo on Lake Como from 25-29 September, followed by an excursion from 30 September to 8 October. This included visits to Portofino; the marble quarries, workshops and museum in Cararra; the alabaster workshops and museum in Volterra; the Pietre Dure Museum and workshops in Florence; the alabaster mine and quarry at Castellina Marittima; the goldsmithing factory of Uno-a-Erre at Arezzo; coral and cameo factories and museum at Torre del Greco; an ascent of Vesuvius and the Vatican Museum.

The papers presented at the scientific sessions are listed below in the order in which they were presented. The proceedings at the Open Day sessions with Italian gemmologists (in Milan) are then listed.

Fig. 1. Carving translucent alabaster (gypsum) in a small workshop in Volterra, Italy.

Authors	*Title*
Jobbins, E.A., Scarratt, K.	The cultivation of freshwater pearls in Yangxin, China.
Norström, S.E.	On Swedish deposits of freshwater pearl mussel.
Sobolev, N.	A relative abundance of crystalline inclusions in small and large diamonds from Mir and Udachinaya pipes, Yakutia.
Meyer, H.O.A., Zhang, A.	Diamonds and kimberlites of North East China.
Peterson, D.L.	The American 'Yogo' sapphire.
Tombs, G.A.	Comparisons and similarities between Kenyan, Australian and Ceylon sapphires.
Saul, J.	The Taita-Tsavo-Umba gem area of East Africa.
Becker, G.	Observations of fluorescence on different rubies from African occurrences.
Becker, G.	Comparison of behaviour of two new occurrences of apatite from Madagascar after (or during) heat treatment.

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Arps, C.E.S.	Hessonites from Sri Lanka.
Schwarz, D.	The chemical properties of the Brazilian emeralds.
Zwaan, P.C.	More data on the orthopyroxenes from Embilipitiya, Sri Lanka.
Norström, S.E.	On Swedish deposits of rhodonite.
Harding, R.R.	Rhodonite and argillite from British Columbia, Canada.
Segnit, E.R.	Prehnite from Wave Hill, Northern Territory, Australia.
Pienaar, H.S.	On the gem-quality sodalite occurrences near Swart-booisdrif, Namibia.
Henn, U., Bank, H.	A study on gemstones of the plagioclase group.
Bank, H., Henn, U.	Correlation between physical features and chemical composition of some gemstones.
Kanis, J.	Fascinating gemstone occurrences in Central Nigeria.
Chikayama, A.	Gemstones from Madagascar.
Zoysa, E.G.	Current research and statistics data on Sri Lankan gem deposits.
Arps, C.E.S.	So-called natural glasses from Sri Lanka.
MacGregor, E.	An end use of a gemstone.
Sersen, W.	Buying and selling gems: which light is best?
Eliezri, I.	On the question of the boundary between ruby and pink sapphire, and between emerald and green beryl.
Shin, K.S.	Any better way to decide clarity grade of diamonds?
Van Bockstael, M.	Layered growth in diamonds as demonstrated by optical and physical characteristics. Regional differences.
Scarratt, K.	Naturally coloured blue non-conducting diamond crystals and faceted stones.
Schiffmann, C.A.	A note on the NIR spectrum of diamonds.
Scarratt, K.	Green diamond identification: the problems concerning the reliability of 'scientific evidence'.
Sunagawa, I.	Growth twinning in quartz – how and under what conditions they are generated.

Balitsky, V.S., Sunagawa, I., Lu, T.	Twins in synthetic amethyst, their origin and diagnostic meaning.
Koivula, J.I., Fritsch, E.	Brazil law twinned synthetic quartz.
Sunagawa, I., Taijing, L.	Origin of Brewster fringes in amethyst.
Graziani, G., Lucchesi, S., Scandale, E.	Growth marks and growth history of gem materials by X-ray topography.
Sunagawa, I., Yokogi, A.	Growth histories of pegmatitic beryls as revealed by the internal textures.
Shida, J.	Observation of heat-treated stones using laser tomography.
Miyata, T., Kitamura, M.	Scanning cathode luminescence (SCL) method and its application to gemmology.
Ponahlo, J.	Cathodoluminescence of synthetic diamonds and some (loupe-clean) coloured gemstones.
Delé-Dubois, M.L., Poirot, J.-P.	On emerald's inclusions studied by laser Raman microspectrometry.
Norström, S.E.	A new synthetic opal.
Schubnel, H.J.	Pierres de la nuit des temps (video).
Cusi, R.	Some peculiar gems.
Superchi, M.	Italian treasures.
Gübelin, E.	Mogok, valley of rubies (film).
Open day session with Italian gemmologists	
Jobbins, E.A.	Gemstones of Europe.
Liddicoat, R.T.	Observations about the gems of North America.
MacGregor, E.	An outline of recent gem province discoveries in South America.
Pienaar, H.	Gemstones and Africa.
Segnit, E.R.	Gemstones of the Island continent.
Sersen, W.J.	The gemstones of Asia.
Gemmological news:	
Koivula, J.I.	Diamond clarity enhancement by infusion.
Balitsky, V.	Jewellery-quality synthetic malachite: history of creation and the main gemmological characteristics.
Poirot, J.-P.	Raman microspectrometry: application to gemmology.

Gemmological Abstracts

ATTANASIO, D., FLAMINI, A., GRAZIANI, G., MARTINI, M., SCANDALE, E., 1989. Further observations on the Lennix synthetic emerald. *Zeitschrift der Deutschen Gemmologischen Gesellschaft*, **38**, 1, 1-10, 8 figs (1 in colour), 1 table, bibl.

Some Lennix synthetic emeralds from recent batches have been investigated by the authors. The emeralds are moderately transparent and relatively homogeneous in colour. The presence of vanadium and absence of iron was noted. Inclusions were somewhat different from those present in earlier productions. A shimmer effect similar to Zambian emeralds was caused by clusters of flux remnants and there were some three-phase inclusions as in some Colombian stones. E.S.

BANK, H., 1989. Gemmologische Kurzinformationen. Hochlichtbrechender Smaragd aus Sta. Terezinha de Goiás, Brasilien. (Short gemmological notes. Emerald with high refractive index from St Terezinha de Goiás, Brazil.) *Zeitschrift der Deutschen Gemmologischen Gesellschaft*, **38**, 1, 41-3, bibl.

The stones have an RI of 1.593-1.604, SG 2.78. E.S.

BANK, H., HENN, U., 1989. Gemmologische Kurzinformationen. *Zeitschrift der Deutschen Gemmologischen Gesellschaft*, **38**, 1, 43-6. (a) Andesin-Mondstein aus Indien, Id., 43-44; (b) Schleifwürdige Korunde von Ngoronghoro, Tansania, Id., 44-6.

(a) 'Moonstone' from India was identified as andesine (plagioclase). (b) Cuttable corundums from Ngoronghoro, Tanzania, with colours pink, brownish-red to red. E.S.

BANK, H., HENN, U., LIND, TH., 1989. Synthetische Smaragde aus Australien (synthetische 'Pool emeralds'). (Synthetic emerald from Australia (synthetic 'Pool emeralds'.) *Zeitschrift der Deutschen Gemmologischen Gesellschaft*, **38**, 1, 11-16, 12 figs (4 in colour), 2 graphs, bibl.

The Pool Mine in Western Australia was first worked in 1929/30, and reopened in 1979. The stones are of poor quality and are crystallized by hydrothermal synthesis (method according to Brion) into synthetic emeralds. The firm now also uses poor quality stones from Zambia, Brazil and Colombia. According to CIBJO regulations, these synthetic stones should not be called 'Pool emeralds' or treated, improved or recrystallized emeralds. The stones show curved veils consisting of two-phase inclusions, sometimes zoned, black, opaque metallic triangles or hexagonal inclusions, which can also have the shape of small rods or even dendrites, and irregular growth lines. E.S.

CROWNINGSHIELD, R., 1989. Grading the Hope diamond. *Gems & Gemology*, **25**, 2, 91-4, 5 figs in colour.

A modern assessment of the world's most famous blue diamond by a team from the New York Lab found it to be a 'fancy dark greyish-blue', weighing 45.52 ct, of VVS clarity. No fluorescence in LUV and possibly faint fluorescence in SUV, followed by strong red phosphorescence after SUV. R.K.M.

FRITSCH, E., CONNER, L., KOIVULA, J.I., 1989. A preliminary gemological study of synthetic diamond thin films. *Gems & Gemology*, **25**, 2, 84-90, 7 figs in colour.

The past two decades have seen diamond or diamond-like carbon (DLC) films grown onto surfaces by a chemical vapour deposition technique from carbo-hydrate gases. DCLs seem easier and it is thought such films might be used on gems to increase resistance to wear. They are mostly polycrystalline but Sumitomo have experimented with producing single crystal diamond on synthetic diamond [to increase size?.

Other possible gemmological uses to improve diamond simulants, or add a diamond surface to softer gems are discussed. The films seem to be detectable with little trouble, and so far there do not

appear to be any commercially diamond-coated gems on the market. R.K.M.

FRITSCH, E., SHIGLEY, J., 1989. Contribution to the identification of treated colored diamonds: diamonds with peculiar color-zoned pavilions. *Gems & Gemology*, 25, 2, 95-101.

GIA Research Department has documented more than 1000 coloured diamonds to aid detection of artificially irradiated and annealed ones. Some yellow, dark green or blues are zoned, with strong colour concentration in the culet or keel area. No proven natural diamond with such zoning has been seen or reported, so it is assumed that the zoning results from laboratory treatment. In some stones this takes the well-known 'umbrella' pattern. Marked differences are seen in colour between table up and culet up positions. It is not certain whether such colour is surface only or extends into the body of the stone. A marked colour zone only in the culet of a diamond probably indicates that it has been irradiated and heated. R.K.M.

FRYER, C.W., ED., CROWNINGSHIELD, R., HURWITT, K.N., KANE, R.E., HARGETT, D., 1989. Gem Trade Lab notes. *Gems & Gemology*, 25, 2, 102-6, 15 figs in colour.

A large chrysoberyl cat's-eye had a fainter line at right angles (star effect) when seen obliquely. A pink diamond had turned brown by a coating caused by hard water (sulphuric acid removed this). A diamond cube with a cube-shaped cloud inclusion reported in 1976 was re-photographed to record an elusive cross-formation and a vague frame of cloud not recorded in the earlier shot. An intense yellow diamond with strong Cape absorption had a green radiation stain which proved colour was natural. A natural green irradiated diamond was found to have an almost colourless area when sawn.

An emerald with a plastic-like 'infill' repair had also been oiled; infill fluoresced bluish-white, oil a strong yellow. Lapis lazuli necklace was shown to be dyed marble. Another one was X-rayed to show the beads were of two different substances, dyed calcite and Swiss lapis. A 15mm diameter 'pearl' was identified as from a 'Cherry-stone clam' by its minute honeycomb structure and colour.

A 3.02 ct ruby purporting to come from Burma proved to be a completely natural stone, untouched by heat treatment, with calcite and short rutile needle inclusions enmeshed in colour swirls of the type known as 'treacle';; 'a rare treat to see such a magnificent unaltered stone in this day and age!'. A zircon from Orissa State, India, had rutile and hematite inclusions [part of the text is missing so this entry is difficult to understand]. R.K.M.

KOIVULA, J.I., KAMMERLING, R.C., 1989. Gem news. *Gems & Gemology*, 25, 2, 110-18, 12 figs in colour.

Gives diamond news from Angola, Australia and China, and says that sub-micro crystals of diamond have been found in enormous quantities when 'primitive meteorites' were dissolved with acid.

Coloured stones:

One of two identical amethysts cut by Bart Curran was heated to 525°C for six hours in air to produce a fine citrine colour, both stones illustrated.

Aquamarine found in Big Horn Mountains. Doug Parsons on a China visit reported aquamarine, citrine, amethyst, blue and green tourmaline and pyrope from Altay region. In Yunnan province white topaz, and some blue; good tourmaline crystals, topaz and aquamarine in Inner Mongolia; fine diopside crystals reported from Kunlun Mountains near Kashmir and Pakistan borders. Muzo emerald mine in Colombia encountering problems with debris from strip mining and are opening up shafts to locate emerald veins which may have been covered; rock is soft and wet so these need heavy reinforcement.

The interesting mineral hackmannite seen at the Tucson Gem and Mineral Show is pale yellow, but flushed immediately to bright orange under LUV, leaving a saturated pink which fades rapidly in ordinary light. The two colours are illustrated, with difficulty for photo lights caused rapid fade!

March rains in the opal fields at Coober Pedy, Mintabie and Andamooka have flooded mines and destroyed heavy machinery, seriously disrupting production, and will force prices up. May take up to a year to return to normal.

Fine Herkima type quartz crystals have been found near Oaxaca, Mexico, some with 'fenester' or window-like growth; fine rose quartz is being mined in Fairfield County, Connecticut. Fine sapphire and star sapphire reported from two new discoveries in Kenya. A yellow sapphire crystal from Anakie, Australia, was multi-zoned unusually in blue, orange and yellow. A pleasing 10 ct padparadschah was seen at the Tucson Show. Himalaya Mine, San Diego County, California, reports finding of a large pocket of specimen grade pink and bi-coloured tourmaline crystals. *Pearls:*

Two remarkable freshwater pink pearls from the Concho River were examined; colour due to manganese, but expected fluorescence in X-rays was not seen, possibly due to the dark colour.

Synthetics and simulants:

Synthetic berlinite, structurally isomorphous with quartz, showed similar bull's-eye interference (circular polarization) figure between crossed polar-

izers. A blue and white cameo of exceptional hardness proved to be ceramic corundum with vague RI of 1.75-1.76. An imitation emerald crystal shown to have been broken across the prism, the two pieces hollowed out and filled with dyed epoxy or other green plastic, then cemented together again; low SG 2.36, and lack of residual red through emerald filter, plus gas bubbles, gave away a rather convincing fake. Chatham are now cutting their synthetics both in Hong Kong and in Thailand and are producing the crystals outside the US; over 10 000 ct a month were sold in 1988. Union Carbide are growing colourless and pink sapphire to 20 cm diameter by a Czochralski pulling technique, principally for laser and other commercial uses, but lesser quality trimmings are being sold by bid to the gem trade. R.K.M.

KOIVULA, J.I., KAMMERLING, R.C., FRITSCH, E., FRYER, C.W., HARGETT, D., KANE, R.E., 1989. The characteristics and identification of filled diamonds. *Gems & Gemology*, **25**, 2, 68-83, 21 figs, mostly in colour.

Many diamonds with surfacing flaws filled to improve their apparent clarity have been seen by the GIA Labs in the past two years, and some at least have been treated by a method developed by Zvi Yehudi of Ramat Gan, Israel. This important paper describes investigations into several stones, finding clarity in most greatly improved by filling, but with lower colour grade due to the yellowish-brown glass compound of lead, bismuth, oxygen and chlorine used as a filler. This has an RI almost equal to that of diamond so that reflecting surfaces of cleavage cracks and other fissures practically disappear.

The filling is attacked by sulphuric acid, e.g. processing pickle, and is also damaged by heat, as in a claw re-tipping situation where the diamond is not removed. The first will leach the filling out near the surface, while the heat will cause it to exude.

Under microscopic examination filled flaws were yellow against a dark background, but flashed a reciprocal bright blue when lighting was shifted to give a light background.

Since filling can make formerly obvious cleavages and other cracks much more difficult to see, this careful investigation has to be seen as a great service to the Diamond Trade in alerting it to the practice. Other vendors may be using this service and there are rumours of lead glass fillings in India, while some stones show evidence of less expert and imperfect filling.

Such fillings should always be disclosed at every level of sale and should not be used to enhance prices unreasonably. R.K.M.

LEPOLD, M., SCHRAMM, M., 1989. Gemmologische Kurzinformationen. Schleifwürdige, grüne Peridote aus Lanzarote. (Short gemmological notes. Cuttable, green peridots from Lanzarote.) *Zeitschrift der Deutschen Gemmologischen Gesellschaft*, **38**, 1, 40-1.

These stones have a low RI (1.649-1.688) and low SG 3.29. E.S.

MRÁZEK, I., 1989. Gemstones of Nicaragua. *Zeitschrift der Deutschen Gemmologischen Gesellschaft*, **38**, 1, 17-30, 9 figs, bibl.

The most attractive gemstone found in Nicaragua is a malachite from the Rosita Mine in the northeast of the country. All other stones seem to come from the west part. The malachites have a banded structure with different shades of green and a silky lustre caused by the divergent fibrous structure. More important are the jaspers, as well as chalcedonies and agates. Other less important finds of stones used for decorative purposes and cabochons are silicified palms, fibrous gypsum, rose quartz, tourmalines, some common opal. Various types of volcanic, sedimentary and metamorphic rocks are also worked by lapidaries. E.S.

NATKANIEC-NOWAK, L., HEFLIK, W., SOBCZAK, N., SOBCZAK, T., 1989. Ein Beitrag zur Farbe niederschlesischer Chrysoprase. (A contribution to the discussion regarding the colour of chrysoprase.) *Zeitschrift der Deutschen Gemmologischen Gesellschaft*, **38**, 1, 31-6, 2 figs, bibl.

The chrysoprase being discussed comes from the Szklary massive in lower Silesia and has been known since 1425. It is only since the Australian Marlborough Creek was discovered in 1960, that chrysoprase of similar quality and quantity has become commercially available. Much work has been done to find the real cause of the colour, but no definite answer has yet been found. The authors suggest that the colour is caused by nickel in the SiO_2 position. E.S.

PONAHLO, J., 1989. Gemmologische Kurzinformationen. Quantitative Kathodolumineszenz von Rubinen aus Malawi. (Short gemmological notes. Quantitative cathodoluminescence in rubies from Malawi.) *Zeitschrift der Deutschen Gemmologischen Gesellschaft*, **38**, 1, 340, 2 figs.

The cathodoluminescence seems to be due to high chromium content. With the help of the described method the author states that these natural rubies can easily be distinguished from synthetics. E.S.

Proceedings of the Gemmological Association of Great Britain and Association Notices

OBITUARY
A tribute to the late Mr F.E. Lawson Clarke

Mr F.E. Lawson Clarke.

I first met Lawson in the summer of 1955 when I was given the day off from school to travel to London for an interview with him, the hope being that I would be offered an apprenticeship with Wilson & Gill. He was very kind to me, took me out to lunch I remember, and then told me that I was not the person he was looking for. I am sure he was right! As it happened I began work that same autumn just round the corner from Wilson & Gill, at Hancocks & Co., as an apprentice. It wasn't until I became Chairman of the National Association of Goldsmiths that I really came to know Lawson well for he was to be NAG President during my term of office.

Lawson Clarke was very closely connected with the trade from his youth because his father, Victor Clarke, was already in the trade at Wilson & Gill in Regent Street. Lawson qualified in opthalmic optics, not an unusual entry into the trade at that time, and in 1924 he joined his father at Wilson & Gill. His father was very active in trade affairs being Chairman and President of the NAG, and then from 1931-1943 Treasurer of the Gemmological Association and then Chairman from 1943-1946. Lawson was to follow closely in his footsteps because he was also NAG Chairman (1949/1950) and the Treasurer of the GA from 1950-1983.

This catalogue of service to the trade is a very statistical story, and in no way conveys the charming character of Lawson. He always had a warmth to his welcome, a great interest in young people, a lively open mind to new ideas and yet always seemed so able to play the part of 'the elder statesman'. He had a great sense of honour and fun and his interest in the world of gemstones was one of a person always ready to enquire. He was a practical man and had a great interest in horology, a practical interest rather than just theoretical. He used to maintain his own car, for instance, and was also a keen gardener. He even built the most elaborate brick and tile circular arch in his garden and this stood the test of many years only to be finally beaten in the great storm two years ago. All in all he was a man of many parts, but for me I shall always remember him for his manner. He was a true gentleman, polite, charming, elegantly dressed with a distinctive walk that was part of his instantly recognized character. He even managed to wear his bowler hat in a jaunty manner, and yet remained the proper businessman. So, by virtue of the fact that he and I were closely involved with the NAG we did come to work together, and then when I became Chairman of the GA we worked together for a while longer as he was still Treasurer. When in 1968 Wilson & Gill was sold he joined his son Christopher in a new venture when the firm of Hesters was bought, and they began the very successful company re-named Hester Clarke.

Christopher and his wife Ann were to be joined by their daughters in the business and the very rare three generation team came together. It can only have been Lawson's own love of the trade that brought his own son into the business and in turn his granddaughters. He did love the trade and the people in it and those of us who knew him could only but love and admire him too. He and his wife Frances – they were married in 1974 widower and widow alike – travelled all over the UK as President and his lady, and Frances quickly established herself in people's affection.

Early in 1989 I heard that Lawson had not been at all well the previous year and had spent some time in hospital following an unexplained collapse. He had written to me earlier on a typewriter and it was clear that he had not quite mastered that 'machine', saying that he should resign from the GA because of his age. I replied, refusing him such 'nonsense' and he suggested that my wife Mary and I might like to go to see him and Frances to renew our friendship. So we did, and the four of us had a marvellous time talking about the friends and the characters we had met over the years. He told me of the changes he had seen in Regent Street and we had a thoroughly enjoyable afternoon together. We had planned to go again during the August Bank holiday but sadly this was not to be. However, I am lucky because I shall always be able to remember that convivial afternoon that was to be the last time that I was to see him. All of us who knew him, had the pleasure of working with him, and the admiration for his style have had a real privilege. I do not think it is likely that we shall meet another Lawson Clarke for times have changed, but he was able to bridge the gap between the old ways and the new. He and his family have given an enormous amount to the trade, and Christopher himself is doing so too, having served the NAG for nearly 30 years, and now on the Court of the Worshipful Company of Clockmakers.

So we have lost a special man, gemmologist, clockmaker, good team man, all rolled into one, but for those of you in the future who just come across the name do ask any of us who know him to tell just our own special memory and then you will meet for just a while a unique man who had the love and interest of the trade for over 65 years and has passed that on to others who in turn enjoy it all the more for having known him. D.J.Callaghan

★ ★ ★

Miss Elsie A. Short, FGA (D.1952), Twickenham, died on 1 October 1989 after a long and painful illness. Following four years of war service with the Royal Air Force, Miss Short joined George Lindley & Co., London, in 1947. Some thirty years to her retirement in 1976 were spent in developing the export business of the company in precious stones, with meticulous attention to the high quality and grading standards required in a wide international market. W.C.B.

Mr K.C. Cole, FGA (D.1965), Swanage, died during August 1989.

GIFT TO THE ASSOCIATION

The Council of the Association is indebted to Mr R. Holt of R. Holt & Co. Ltd, London, for his gift of various stones including a synthetic uncut emerald, a chrysoberyl cat's-eye and an opalized shell.

NEWS OF FELLOWS

On 12 September 1989 Mr Michael O'Donoghue spoke to members of the Guildford Gem, Mineral and Lapidary Club. His subject was 'Gemstones of northern Pakistan', and representative samples, some self-collected, were displayed. On 20 September 1989 Mr O'Donoghue gave a talk entitled 'Gemstones' to the Ightman and District Historical Society. On 4 November 1989 at the Flett Theatre, Geological Museum, Exhibition Road, South Kensington, London SW7, Roger Harding, Alan Jobbins and Ken Scarratt gave illustrated lectures on the Crown Jewels. On 5 November 1989 at the Flett Theatre Alan Jobbins gave an illustrated lecture entitled 'European gemstones'. On 11 November 1989 at the Society of Antiquaries of London, Burlington House, Piccadilly, a symposium was held, organized by the Society of Jewellery Historians, entitled 'Gemstones in Jewellery'. Lecturers included David Callaghan, Robert Crowningshield, Alan Jobbins, Jack Ogden and Ken Scarratt.

MEMBERS' MEETINGS

London

On 11 October 1989 at the Flett Theatre, Geological Museum, Exhibition Road, South Kensington, London SW7, Mr John I. Koivula, FGA, of the Gemological Institute of America, gave an illustrated lecture entitled 'An evening of microgemmology'.

Midlands Branch

On 20 October 1989 at the Society of Friends, Dr Johnson House, Colmore Circus, Birmingham, Mr S. Mather gave a talk on 'The gems and minerals of Norway'.

On 22 October 1989 the Branch organized a gem testing equipment seminar at the Cobden Hotel which was well supported by students and the trade. On 17 November 1989 at the Society of Friends Mr Gwillam Jones, FGA, gave an illustrated lecture entitled 'Gemmological Mish-Mash'.

ANNUAL REUNION OF MEMBERS AND PRESENTATION OF AWARDS

Fig. 1. Mr Robert Crowningshield giving his address.

The Annual Reunion of Members and Presentation of Awards was held on 6 November 1989 at the Guildhall, Gresham Street, London EC2. Mr David J. Callaghan, Chairman of the Association, presided at the Presentation and welcomed those present. He explained that, for the second time, the awards ceremony was being held at the Guildhall as Goldsmiths' Hall, where the event usually takes place, was being refurbished. The Chairman called upon Mr Robert Crowningshield, Vice-President of the Gemological Institute of America, to present the awards. During his address Mr Crowningshield explained the advances made in gemmology since he qualified in the Association's examinations in 1947. He discussed many of the new synthetic and simulated gemstones that had not been invented in 1947, as well as the various forms of gemstone treatment now used. Although there is the necessity for advanced instrumentation in the specialist laboratories to distinguish these stones, he stressed the importance of the microscope and advised students to work at improving their microscopic skills.

Mr Crowningshield congratulated the successful candidates and said that they now had to keep up-to-date with their gemmological knowledge, and suggested that they study the enormous amount of literature published on the subject.

The Vice-Chairman of the Association, Mr Noel Deeks, gave the vote of thanks.

GEM DIAMOND EXAMINATION 1989

In the 1989 Gem Diamond Examination 55 candidates sat and 53 qualified, two with Distinction. Their names are as follows:

Qualified with Distinction

Cadavid Tortosa, Manuel, Barcelona, Spain.
Vila Torrejon, Ma Enriqueta, Barcelona, Spain.

Qualified

Amiel Fresneda, Josefa, Barcelona, Spain.
Birchall, Steven, Hyde.
Booker, Martin, London.
Bramham, Kathleen, London.
Carracedo Oliva, Robert, Barcelona, Spain.
Castro, Ana, London.
Climent Coscolluela, Nuria, Barcelona, Spain.
Cowdrey, John, Harrow.
Easterbrook, Steven, Bridgend.
Escalona I Larroy, Josep A., Barcelona, Spain.
Farinos Folgado, Ramon, Barcelona, Spain.
Farrow, Karen, Great Yarmouth.
Fox, Julie, Maidstone.
Gomes Da Silveira, Luiz A., Barcelona, Spain.
Harrison, Roger, Kings Langley.
Hayes, Alan, Stockport.
Hitcham, Peter, Kingston-upon-Thames.
Heatlie, James, Edinburgh.
Holloway, Sarah, London.
Ivanoff Landovski, Tatiana, Barcelona, Spain.
Iquaz Esteban, Yolanda, Barcelona, Spain.
Kramer, Stephen, Bradford.
Kyriakidou, Katherine, London.
Larcher, David, Sutton Coldfield.
Lekamge, Neil, London.
Lewis, Rachel, Stockport.
Longden, Sharon, Sheffield.
McCleland, Susan, Bognor Regis.
Mairal Nebot, Susana Ma, Barcelona, Spain.
Marti Gomez, Emilio A., Barcelona, Spain.
Martinez Masip, Amelia, Barcelona, Spain.
Meler Ardiaca, Ma Teresa, Barcelona, Spain.
Mills, Edwin, Ely.
Mistry, Mukesh, London.
Naylor, Tina, Wigan.
Parker, Vaughan, King's Lynn.
Potts, James, Telford.
Renieblas I Salo, Sara, Barcelona, Spain.
Roig Miguel, David, Barcelona, Spain.
Serra I Badia, Lluis, Barcelona, Spain.
Slack, Richard, Cardiff.

PRESENTATION OF AWARDS CEREMONY

Fig. 2. Tully Medallist, Helen Plumb, receiving her award from Mr. Robert Crowningshield.

Fig. 3. Rayner Diploma Prize winner Andrew Cope.

Fig. 4. Rayner Preliminary Prize winner Robert Murray.

Socias Barenya, Ma Angela, Barcelona, Spain.
Torrance, Claire, Surrey.
Tyler, Elizabeth, London.
Vcte P. Fenollosa, Enrique, Barcelona, Spain.
Walker, James, Edinburgh.
Walker, Jeremy, Cumbria.
Webster, David, Glasgow.
Weiss, Anthony, Bushy.
Weston, Jonathan, Birmingham.
Wilson, Sandra, Edinburgh.

EXAMINATION IN GEMMOLOGY 1989

In the 1989 Examinations in Gemmology, 511 candidates sat the Preliminary Examination and 329 succeeded in qualifying, 372 candidates sat the Diploma Examination and of these 185 succeeded in qualifying, 20 with Distinction.

The **Tully Medal** for the candidate (trade or non trade) who submits the best set of answers in the Diploma Examination has been awarded to Helen Louise Plumb of London. The **Anderson/Bank Prize** for the best non-trade candidate of the year in the Diploma Examination has been awarded to Karen Jill Lewis of Hong Kong.

The **Rayner Diploma Prize** for the best candidate of the year who derives his main income from activities essentially connected with the jewellery trade has been awarded to Andrew Richard Cope of Nottingham.

The **Anderson Medal** for the best candidate of the year in the Preliminary Examination has been awarded to Anja Kaarina Pehkonen of Helsinki.

The **Rayner Preliminary Prize** for the best candidate who is under the age of 21 years on 1 June 1989, who derives his main income from activities essentially connected with the jewellery trade has been awarded to Robert Andrew Murray of London. The names of the successful candidates are as follows:

DIPLOMA

Tully Medal
Plumb, Helen L., London.

Anderson/Bank Prize
Lewis, Karen J., Hong Kong.

Rayner Diploma Prize
Cope, Andrew R., Nottingham.

Qualified with Distinction
Andrews, Suzanne, Cheadle Hulme.
Chan, Mazie Man-Wah, Hong Kong.
Chawla, Ishita, Bhudaneswar, Fung, Eleanor So-Wan Au, Hong Kong.
Galibert, Olivier, Bangkok, Thailand.
Hughes, David J., Cardiff.
Langdon, Ingrid B., Corpus Christi, Texas, USA.
Lilly, Gregory R., Hawera, New Zealand.
Pfister, Hans, Zurich, Switzerland.
Roberts, Kate, Harrow.
Ruff, Agnes, Hong Kong.
Seaton, Johanna L., Hong Kong.
Taylor, Sarah J.W., Birmingham.
Tse, Matthew Kwok Fung, Hong Kong.
Veecumsee, Dipal D., Madras, India.
Whitney, Mary A., London.
Zanardi-Landi, Sabina, London.

Qualified
Achakane, Abelaaziz, Birmingham.
Adams, Jacqueline E., London.
Andrews, Fern, London.
Arranz Garcia, Felix, Barcelona, Spain.
Athanassopoulos, Joanna D.E., Athens, Greece.
Barbara Solé, Ma Rosa, Barcelona, Spain.
Barrabes Lacarda, Silvia, Barcelona, Spain.
Bauco, Robert, London. Bieri, Joisane, Athens, Greece.
Bofil Montoro, Ana Ma, Barcelona, Spain.
Boira Roges, Berta, Barcelona, Spain.
Bourdillon, Catriona C.C., London.
Bowis, Mark L., London.
Boyadjian, Liza, London.
Brantly, Rhona, Rio de Janeiro, Brazil.
Brown, Naomi A., Willowdale, Canada.
Carroll, Patricia E., Hong Kong.
Chan, Linda A.Y., Hong Kong.
Chan, Yoke L., Hong Kong.
Chiu, Fung Mei Janis, Hong Kong.
Chiu, Sau King Doris, Hong Kong.
Chiu, Yuk Lan Rafia, Hong Kong.
Chow, Kevin Kar Wai, Hong Kong.
Chow, Rita Yuen-Ching, Hong Kong.
Civitello, Odile, Montreal, Quebec, Canada.
Clover, Wai Ying, Hong Kong.
Cocke, David D., London.
Collins, Jessica, London.
Corta Alonso, Ma Lina, Barcelona, Spain.
Cox, Vann S., Bedford.
Danis Terra, Rut, Barcelona, Spain.
de Crecenzio, Alejandre, Schoonhoven, The Netherlands.
Dwyer, Katherine, Oregon House, Calif., USA.
Edie, Tong Wai Man Annie, Brighton.
Edwards, Jennifer L., Hong Kong.
Ellis, Phillipa, London.
Fan, Siu Kam, Hong Kong.
Farzan, Ali Reza, London.
Frampton, James, London.
Frederick, Helen Marie, Wellington.
Fuller, Mark R., London.
Fung, Kam Man, Hong Kong.

Furne, Neus Gambin, Barcelona, Spain.
Garbouchian, Lilian J., Bangkok, Thailand.
Garcia Ferrandiz, Javier, Barcelona, Spain.
Garty, Annemarie, Dundee.
Gellini, Delio, Harrogate.
George, Wanda M., Nairobi, Kenya.
Ghaffar, Gulnefer, Hong Kong.
Girardi, Josephine C., Hong Kong.
Gould, Jean, H.I., London.
Hapugaskumbura, Asanga, Sri Lanka.
Hasan, Zia-Ul, Toronto, Ont., Canada. Hausler, Rebecca, Bangkok, Thailand.
Hawkins, Richard A., Sutton.
Hirst, Jenny, London.
Hitchin, Peter, Bangkok, Thailand.
Ho, Kar Fai Patrick, Hong Kong.
Ho, Kiam Fong Steve, Singapore.
Hossen, Iqbal Hamid, Port Louis, Mauritius.
Howard, David, Preston.
Isern Truy, Enric, Barcelona, Spain.
Jackson, Mark, Worcester.
Jarvis, Hilary A., London.
Kangasniemi, Arto J., Helsinki, Finland.
Karkkulainen, Kari, Oulu, Finland.
Keerthi, Koku Hannadige, Idar-Oberstein, W. Germany.
Keusch, Shohred, Hong Kong.
Keys, Malcolm, Manchester.
Komai, Rie, Saitama Pref., Japan.
Koslowski, Peter C., Bangkok, Thailand.
Laborda Ferrer, Ma Angeles, Barcelona, Spain.
Lau, Yuet Yung Ellen, Hong Kong.
Law, Patricia M., London.
Lazaro Anglada, Ma Jose, Barcelona, Spain.
Leddicoat, Andrew, Guiseley.
Lee, Sheung Wah, Hong Kong.
Lehtinen, Kirsi, Helsinki, Finland.
Leon Martin, Josefa, Barcelona, Spain.
Levin, Igor, Toronto, Ont., Canada.
Lewis, Richard D.F., London.
Lieftinck, Felicia A., Rotterham, The Netherlands.
Lindqvist, Thérese, Stockholm, Sweden.
Ling, Lai C. A., Hong Kong.
Lintunen, Eva, Helsinki, Finland.
Lockie, Debra A., Auckland, New Zealand.
McIlwraith, Philomena M., Hong Kong.
MacGregor, Rory, Rio de Janeiro, Brazil.
McKenna, Joseph T., London.
Mariona De Urquijo, Victoria E., Barcelona, Spain.
Marshall, A.T. Douglas, Cambridge.
Mas Lillo, Javier F., Barcelona, Spain.
Maung, Thet Oo, Bangkok, Thailand. Meeles, Frederik Q.A., Rotterdam, The Netherlands.
Merchant, Arti R., Bombay, India.
Mohideen, Mohamed F., Colombo, Sri Lanka.
More, Deepak K., Hong Kong.
Morris, David C., Dover.
Murray, Robert, Kensington.
Nakamura, Chiyo, Hokkaido, Japan.
Nakao, Kimitoshi, Osaka, Japan.
Ng, Ai Moi, Hong Kong.
Nevalainen, Tuula, Helsinki, Finland.
Nottingham, Peter R., Leeds.
Osborne, Sean J., Pimlico, London.
Osmond, Catherine, Bangkok, Thailand.
Ozaki, Keiko, Hyogo Pref., Japan.
Page, Christopher D., Newmarket.
Pak Ching-Yuen, Bernard, Hong Kong.
Panayiotis, Panayi, Manchester.
Parikka, Pekka J., Helsinki, Finland.
Pattni, Minakshi, Harrow.
Pedersen, Gunhild R., Oslo, Norway.
Peter, Christina, Bangkok, Thailand.
Petrides, Eugene P., London.
Pette, Jan W., Arnhem, The Netherlands.
Pfeiffer, Brigitte C.E., London.
Pring, Amanda L., Birmingham.
Pun, Yuk Ling, Hong Kong.
Puviharan, Mylvaganam, Idar-Oberstein, W. Germany.
Ravindran, Mahaluxmy, Bangkok, Thailand.
Reuser, Laetitia, Schoonhoven, The Netherlands.
Rieger, Catherine J., Maidstone.
Richardson, Cathryn, Silsden.
Ruiz Belver, Antonio J., Barcelona, Spain.
Ruusunen, Petri S., Helsinki, Finland.
Santacreu Rull, Montserrat, Barcelona, Spain.
Schaetzle-Parisod, Arlette, Kaiseraugst, Switzerland.
Schat, Ellen M., Schoonhoven, The Netherlands.
Scott, Kenneth MacDonald, Carluke.
Seifert, Jannice, Hong Kong.
Sempere Leal, Esther, Barcelona, Spain.
Sergoulopoulos, Alexandros, Athens, Greece.
Shigeoka, Mayumi, Tokyo, Japan.
Shimoda, Tetsuhiro, Fukuoka Pref., Japan.
Shimoe, Yasuhiro, Osaka, Japan.
Singh, Runbir, Hong Kong.
Stanley, Sylvia, Hong Kong.
Stanton, Zoe, Andreas, Isle of Man.
Sullivan, Patricia, Toronto, Ont., Canada.
Sutton, Susan A., Stowmarket.
Tachibana, Hirogi, Osaka, Japan.
Tayara, Mona D., Athens, Greece.
Thornton, Shirley, Bangor.
Tielinen, Tarja H., Ylamaa, Finland.
Tielinen, Teuvo K., Ylamaa, Finland.
Turner, Susan E., Hong Kong.
Turunen, Kirsi, Helsinki, Finland.
Usechi Espinosa De Los Monteros, Amp, Barcelona, Spain.
Van Der Klauw, Angela, Utrecht, The Netherlands.
Van Sterkenburg, Sandra, Schoonhoven, The Netherlands.

Vataru, Monica, London.
Velaz Azpilicueta, Mercedes, Barcelona, Spain.
Vidal Ramia, Enriqueta, Barcelona, Spain.
Vildiridis, Athanassios N., London.
Wat, Wanda Hoi-Chi, Hong Kong.
Wiborg-Jenssen, Nellie, Tunbridge Wells.
Worthington, Louise, Sowerby Bridge.
Xanthopoulou, Paraskevi, Athens, Greece.
Yeung, Chan Siu Ling, Hong Kong.
Yim, Tae Young, Republic of Korea.
Yoheswaran-Poulin, Bangkok, Thailand.
Yoo, Ok Hee Han, Korea.
Yount, Henrietta S., Hong Kong.
Yuill, J. Martin, Lanark.

PRELIMINARY

Anderson Medal
Pehkonen, Anja K., Helsinki, Finland.

Rayner Preliminary Prize
Murray, Robert A., London.

Qualified
Adachi, Kouichi, Osaka, Japan.
Alabaster, Andrew G., London.
Alcover Falco, Anna, Barcelona, Spain.
Alejo, Deirdre K., Hong Kong.
Altena, Frances R., Amsterdam, The Netherlands.
Alvarez Suarez, Fernando, Oviedo, Spain.
Anderson, Aud Naes, Grimstad, Norway.
Andres Gomez, Andres, Sant Adria Del Besos, Spain.
Anjali, Javeri, Bombay, India.
Arbisman, Alexander R., Surrey.
Argirakou, Ioulia, Volos, Greece.
Aryatilake, Bamunuarachchige L., Sri Lanka.
Askew, Cheryl G., Wigan.
Aspasis, Gini, Athens, Greece.
Auberni Serra, Gemma, Barcelona, Spain.
Baldock, Janine R., Crawley.
Barker, Damon A.N., Winchester.
Barrie, Lindsay M.O., London.
Bashour, Hiyam, London.
Beentjes, Theodorus P.C., Uitgeest, The Netherlands.
Bendel, Helle, Sao Paulo, Brazil.
Berk, Merle, Pennsylvania, USA.
Berlioz, Roger F.B., Kandy, Sri Lanka.
Bernad Soria, Jose M., Barcelona, Spain.
Bertolin Marti, Carlos, Barcelona, Spain.
Beveliotis, Christos, Athens, Greece.
Bing, Sara V., Exeter.
Birrell, Andrew T., London.
Boaden, Richard J., Hexham.
Bolano Cid, Jordi, Barcelona, Spain.
Bowler, Simon R., Birmingham.
Boyd, Stephen D., Bournemouth.
Brooks, Anna T., Watford.
Brown, Naomi A., Ontario, Canada.
Buckland, Christine J., Wilmslów.
Bullen, Anne, Ontario, Canada.
Canero Sesar, Inmaculada, Barcelona, Spain.
Cardo Sabater, Elisabeth, Barcelona, Spain.
Carr, Owen, Coventry.
Carter, Maurice W., Ontario, Canada.
Cases Canes, Josep R., Barcelona, Spain.
Casas Royo, Jose A., Alfaro, Spain.
Chalmers, Rachael A., Knutsford.
Chauhan, Mahaveer S., Bombay, India.
Chawla, Ishita, Orissa, India.
Chen, Xiugin, Wuhan, China.
Cheng, Kit Ling Connie, Kowloon, Hong Kong.
Chiu, Fung Mei Janis, Hong Kong.
Chiu, Lai Sim Sarah, Hong Kong.
Chiu, Roy Shuk-Hung, Hong Kong.
Chiu, Shuk Han, Hong Kong.
Choy, Yuen Yee Margaret, Hong Kong.
Christaki, Ourania, Volos, Greece.
Chu, Sin Yi Christine, Hong Kong.
Chung, Josephine Mei-chee Mak, Hong Kong.
Cipriani, Tony, Quebec, Canada.
Clifton, Sarah E., Birmingham.
Colomina Hernandez, Roberto, Alicante, Spain.
Copestick, Bruce J., Harpenden.
Craghill, William, Northampton.
D'Alessandro, Martha A., Rio de Janeiro, Brazil.
Davidson, Anthony, Newcastle-upon-Tyne.
Desir Valen, Aline, Zaragoza.
de Vilhena, Manuel J. Sousa, London.
Doran, Sean F., Liverpool.
Downer, Martyn D., London.
Edwards, Susan M., London.
Egner, Valerie S., London.
Einstoss, Philip Michael, Toronto, Canada.
Eldridge, Lawrence, Maryland, USA.
Ellis, Phillipa R., London.
Elola Lekuona, Juan J., Barcelona, Spain.
Everest, Deborah, Aldershot.
Ewart, Jane W., Broadway.
Farrett, Kirsten J., Dover.
Farzan, Ali-Reza, London.
Fernandes, Bevelyn E., Bombay, India.
Filazzola, Anthony, Ontario, Canada.
Fitzmaurice, Karl, Castlerea.
Flack, Inger, Hosle, Norway.
Folgado Reig, Vicente, Valencia, Spain.
Fortea Bellido, Javier, Valencia, Spain.
Frampton, James J.M., Bakewell.
Fraser, James W., Glasgow.
Fu, Lintang, Wuhan, China.
Fung, Chung Min Newson, Kowloon, Hong Kong.
Fung, Wai Yin, Hong Kong.

Galibert, Olivier, Calas, France.
Ganzabal Hernandez, Amparo, Barcelona, Spain.
Garbouchian, Lilian J., Bangkok, Thailand.
Garrido Cardenal, Juan J., Alicante, Spain.
Garty, Annemarie, Dundee.
Gasco Galindo, Teresa, Valencia, Spain.
Gau, Robert Ben-Rong, Taiwan, China.
Gaynor, Geoffrey, Peterborough.
Georgiadou, Elizabeth, Volos, Greece.
Ghisi, Maria, Athens, Greece.
Gibson, Bracken G., London.
Gledhill, Paul, York.
Gorro Felip, Eva Maria, Tarrega, Spain.
Gowan, Joanne C., Sawbridgeworth.
Green, Sheila M., Glasgow.
Grootjans, Sandra, Schoonhoven, The Netherlands.
Gunasekara, Rajasinghe S., Sri Lanka.
Hakansson, Ulf J.M., Noorkopine, Sweden.
Haribachi, Naoki, Japan.
Hasasnoot, Annette, Utrecht, The Netherlands.
Hasegawa, Tamio, Osaka, Japan.
Hassan, Ali R., Manchester.
Hastings, Duncan J., Oxford.
Hausler, Rebecca, Bangkok, Thailand.
Hester, Colette L., Schoonhoven, The Netherlands.
Hitchin, Peter F., Bangkok, Thailand.
Holen, Yvonne, Schoonhoven, The Netherlands.
Hollanders, David J., Maidenhead.
Holst, Frank L., Kolding, Denmark.
Hoogeboom, Paulus N., Hoogland, The Netherlands.
Hoogendoorn-Van der Wijaard, Elisabeth G., The Netherlands.
Howard, J., London.
Huang, Qian, Wuhan, China.
Huebra Chico, Antonio, Alicante, Spain.
Huerta Sanchez, Ana Ma., Barcelona, Spain.
Hughes, Josephine M.H., Dublin, Eire.
Hugi, Michael F., Switzerland.
Hung, Chi Ling Vivian, Hong Kong.
Ibanez Pueyo, Jordi, Barcelona, Spain.
Inagaki, Saeko, Osaka, Japan.
Inkpen, Michael S., Kingsbridge.
Jakobsson, Thomas A., Huddinge, Sweden.
Janse, Theodora J., Rotterham, The Netherlands.
Javeri, Anjali, Bombay, India.
Jhaveri, Devang, London.
Joensuu, Anne H., Ilamaa, Finland.
Jones-Brunet, Catherine E., Ontario, Canada.
Jongerius, Joost J.W., Schoonhoven, The Netherlands.
Jurado Garcia, Ma del Carmen, Valencia, Spain.
Kadowaki, Kayoko, Osaka, Japan.
Kangas, Anne K., Helsinki, Finland.
Kermorgant, Claire, Stain Renan, France.
Keys, Malcolm H., Manchester.
Killias, Andree, Hong Kong.
King, Andrew W., Glenfield.
Ko, So Ling Amy, Hong Kong.
Kohara, Sanae, Osaka, Japan.
Komiya, Keiko, Tokyo, Japan.
Komppa-Vigar, Leena M., Bedford.
Korsten, Paul H.J., Ontario, Canada.
Koslowski, Peter C., Bangkok, Thailand.
Kozlowsky, Lida A., Ontario, Canada.
Kung, Kwai, Hong Kong.
Kwok, Yee Man Emily, Hong Kong.
Lai, Tik Shan Sana, Hong Kong.
Lancaster, Wendy, London.
Lankadeva, Gardiye H.G.A., Sri Lanka.
Lati, Seppo I., Espoo, Finland.
Lati, Melody Sau-Ha, Hong Kong.
Lavin, Padraic, Ballaghaderreen.
Le Cornu, Elizabeth B., Jersey, CI.
Lee, Kevin Yat-Kin, Hong Kong.
Lee, King To., Hong Kong.
Lee, Mei Ling, Hong Kong.
Lee, Rowena Yuen Fee, Hong Kong.
Lees, John A., Virginia, USA.
Lehnert, Annette I., Schoonhoven, The Netherlands.
Lentz, Janine, Schoonhoven, The Netherlands.
Leung, Chee Wing, Hong Kong.
Levin,Igor, Ontario, Canada.
Levy, Aaron N., London.
Lewis, Richard D.F., Epsom.
Li, Fung Mei Sarah, Hong Kong.
Li, Kam Yiu Dick, Hong Kong.
Li, Yali, Wuhan, China.
Liao, Xiangjun, Wuhan, China.
Lindberg, Marja Leena, Espoo, Finland.
Linden, Vanessa, London.
Lindqvist, Kristian V., Siuntio, Finland.
Li-Ran, Dorit, Nairobi, Kenya.
Liv, Shang I., Hong Kong.
Lo, Mun Shan Ivy, Hong Kong.
Lonka, Valtteri A., Kuopio, Finland.
Lopez Gracia, Anna Ma, Barcelona, Spain.
Lu, Lianzhong, Wuhan, China.
Ludlow, Andrew P., Buckhurst Hill.
Lui, Kin Wah Kelvin, Hong Kong.
Lynch, Kieran J., Coventry.
McConnachie, David C., Glasgow.
McQueen, Amanda J., Hong Kong.
Malani, Sajina, London.
Mallett, Gillian E., Cambridge.
Marcos Pascual, Celia, Oviedo, Spain.
Martin, Julie, Glasgow.
Martinez Bautista, Santiago, Barcelona, Spain.
Matthews, Lisa J., Winchester.
May, Catherine J., Torquay.
Meeles, Frederik Q.A., Rotterdam, The Netherlands.

Michallat, Mark, Shipley.
Milstein, Alan G., Solihull.
Mira Sanchis, Margarita, Alicante, Spain.
Miralles Duch, Jordi, Barcelona, Spain.
Moreiras Blanco, Damaso-Baldomero, Oviedo, Spain.
Moreno Rastrero, Eduardo, Logrono, Spain.
Mori, Junko, Hyogo, Japan.
Mori, Keiko, Nara, Japan.
Moriyama, Yoshiko, Nara, Japan.
Mourogiannis, Stephanos, Volos, Greece.
Nathorst, Marie O.A., Stockholm, Sweden.
Ng, Ai Moi, Hong Kong.
Ng, Hung Lai, Hong Kong.
Ni, Ruilan, Wuhan, China.
Nicholson, Annie Yim Wan, Hong Kong.
Niiniharju, Juhani, Siikaranta, Finland.
Nishiura, Hisako, Osaka, Japan.
Noyori, Kazuhiko, Fukuoka City, Japan.
Nuotio, Rauno Martti, Helsinki, Finland.
Obiols Navarry, Enrique, Barcelona, Spain.
O'Brien, Gillian M., North Berwick.
Oldershaw, Caroline J., Penn.
Osmond, Catherine, Bangkok, Thailand.
O'Sullivan, Beatrice, Rugeley.
Oura, Mamiko, London.
Owen, Margaret E., Pietermaritzburg, South Africa.
Palmer, Guendolen C., Hassocks.
Panayi, Panayiotis, Manchester.
Park, Myoung-Ok, Daejon, Korea.
Patel, Kokila R., Nairobi, Kenya.
Patel, Pankajkumar, Manchester.
Patterson, Debra A., Ontario Canada.
Pawlik, Tammy J., Ontario, Canada.
Peter, Christina, Bangkok, Thailand.
Petrides, Eugene P., London.
Pettigrew, Louise, Glasgow.
Pool, Richard J., York.
Pourgouris, Evangelos, London.
Qi, Lijian, Wuhan, China.
Quek, Cho Siang Jessie, Hong Kong.
Rackley, Trevor, Wantage.
Ratnakumara, Dodangodage, Sri Lanka.
Ravindran, Mahaluxmy, Bangkok, Thailand.
Reveliotis, Christos, Athens, Greece.
Ripley, Thomas, Stockton-on-Tees.
Rodriguez Fernandez, Margarita, Asturias, Spain.
Ronkainen, Maija R., Lohja, Finland.
Rowlands, Alan F., London.
Rudolphy, Willemine P.C., Schoonhoven, The Netherlands.
Ruiz Domenech, Anaa Ma, Tarrega, Spain.
Ruuthunen, Tuula K., Helsinki, Finland.
Saito, Takako, Osaka, Japan.
Sanchez Comerma, Juana Ma, Alicante, Spain.
Sancroft-Baker, Raymond S., London.
Sanson, Steven N.J., London.
Santacreu Rull, Elisenda N., Barcelona, Spain.
Saywell, Neil, West Bridgford.
Schaapherder, Robertus C., Blarcum, The Netherlands.
Senarath, Pragnarathna K.A., Sri Lanka.
Shammas, Siham, London.
Sim, Evelyn, Harlow.
Simmons, Charlotte R., Maryland, USA.
Singh, Runbir, Hong Kong.
Skilton, Margaret, Auckland, New Zealand.
Skinner, Lesley, Stenhousemuir.
Skrablin, Lada L., London.
Smith, Karen, Dewsbury.
Smith, Michael, Seaton Sluice.
Smookler, Sheryl, Pinner.
Spencer, Stephen R., Nottingham.
Spentzas, Alexandra, Athens, Greece.
Steele, Janice P., Alberta, Canada.
Stewart, Carolyn L., Hong Kong.
Sullivan-Humphrey, Patricia E., Toronto, Ont., Canada.
Taavila, Aino-Inkeri, Iisalmi, Finland.
Takahashi, Yasushi, Kofu, Japan.
Takano, Hirofumi, Tokyo, Japan.
Tan, Ming, Wuhan, China.
Tang, Suk Chun Jenny, Hong Kong.
Tannahill, James, Croydon.
Tanzawa, Megumi, Yamanashi, Japan.
Thoma, Carol A., Ontario, Canada.
Thornley, Charisse M., Ontario, Canada.
Trathen, John E., Ontario, Canada.
Tsang, Wai Ming, Hong Kong.
Tsujimoto, Toshiaki, Osaka, Japan.
Tuovinen, Risto P.J., Kouvola, Finland.
Uribe Molto, Ma Victoria, Barcelona, Spain.
Valero de la Nuela, Ignacio, Barcelona, Spain.
Valero Sebastian, Alicia, Barcelona, Spain.
Valethuizen, Irmine H.S., Arnhem, The Netherlands.
Valora Miqueo, Tatiana Ma, Barcelona, Spain.
Van Acker, Adriaan A.M.A., Tilburg, The Netherlands.
Van Heesewijk, Jacqueline W., London.
Van Putten, Rozanne C., The Netherlands.
Vartiainen, Risto K., Rovaniemi, Finland.
Vela Clemente, Fernando, Barcelona, Spain.
Vernon, Susan A., Kirk Langley.
Vilabella Fernandez, Ramon, Barcelona, Spain.
Wang, Manjun, Wuhan, China.
Watambe, Tatsuo, Tokyo, Japan.
Wates, Peter J., Coulsdon.
Watson, Muriel, Durham.
Weston, A.L., Maryland, USA.
Wightman, Ian E., Kenton.
Williams, Jason F., Cobham.
Wilson, Nean E., Longniddry.

Wong, Hon Chung, Hong Kong.
Wong, King Suen, Hong Kong.
Wong, Ming Chu Constance, Hong Kong.
Wong, Waikiu, Hong Kong.
Wong, Yin Wah Ziggy, Hong Kong.
Woodham, Sharon, Birmingham.
Wright, Michael J., Watford.
Wright, Wendy E., Ontario, Canada.
Wu, Haiou, Wuhan, China.
Wu, Mei Wan, Harlow.
Yamamoto, Keiko, Otsu City, Japan.
Yau, Wai Ling Janet, Hong Kong.
Yen, Weixuan, Wuhan, China.
Yoheswaran-Poulin, Vinodhini S., Bangkok, Thailand.
Yoo, Ok Hee Han, Bangkok, Thailand.
Young, Roy T., Dunedin, New Zealand.
Yu, Sum Pui, Hong Kong.
Zander, Marie-Claire M., Sao Paulo, Brazil.
Zeeman, Walentin, Bunnik, The Netherlands.
Zhang, Fan, Wuhan, China.
Zhang, Liang Ju, Wuhan, China.
Zhang, Youxu, Wuhan, China.
Zoeter, Johannes S., Rotterdam, The Netherlands.

EXECUTIVE COMMITTEE MEETING

At a meeting of the Executive Committee held on 15 November 1989 at Saint Dunstan's House, the business transacted included the election to membership of the following:

Fellowship

Adams, Jacqueline E., London. 1989
Athanassopoulos, Joanna D.E., Athens, Greece. 1989
Bieri, Joisane, Athens, Greece. 1989
Bowis, Mark L., London. 1989
Boyadjian, Liza A., London. 1989
Brantly, Rhona, Rio de Janeiro, Brazil. 1989
Brown, Naomi A., Willowdale, Canada. 1989
Carroll, Patricia E., Kowloon Hong Kong. 1989
Chan, Linda A.Y., Hong Kong. 1989
Chan, Mazie M.W., Stanley, Hong Kong. 1989
Chan, Yoke L., North Point, Hong Kong. 1989
Chiu, Fung Mei Janis, Hong Kong. 1989
Chiu, Yuk Lan Rafia, Hong Kong. 1989
Chow, Kevin Kar Wai, Hong Kong. 1989
Chow, Rita Yuen-Ching, Hong Kong. 1989
Clover, Wai Ying, Hong Kong. 1989
Collins, Jessica M., London. 1989
Dwyer, Katherine, Oregon House, Calif., USA. 1989
Edwards, Jennifer L., Hong Kong. 1989
Farzan, Ali Reza, London. 1989
Frampton, James J.M., London. 1989
Fung, Eleanor S.W.A., N. Vancouver, Canada. 1989
Fung, Kam Man, Hong Kong. 1989
Gellini, Delio, Harrogate. 1989
Gould, Jean, H.I., London. 1989
Ho, Kar Fai Patrick, North Point, Hong Kong. 1989
Jackson, A.V. Mark, Birmingham. 1989 Keerthi, Koku H.U.J., Kelaniya, Sri Lanka. 1989
Keusch, Shohred, Hong Kong. 1989
Keys, Malcolm, Manchester. 1989
Lee, Sheung Wah, Kowloon, Hong Kong. 1989
Lehtinen, Kirsi, Helsinki, Finland. 1989
Levin, Igor, Thornhill, Canada. 1989
Lindqvist, Thérese, Stockholm, Sweden. 1989
Ling, Lai C. A., Kowloon, Hong Kong. 1989
Mak, Yim M., Windsor, Canada. 1989
Medlicott (née Taylor), Sarah J.W., Birmingham. 1989
More, Deepak K., Hong Kong. 1989
Morris, David C., Dover. 1989
Nakao, Kimitoshi, Osaka, Japan. 1989
Ng, Ai Moi, Hong Kong. 1989
Osborne, Sean J., Pimlico, London. 1989
Osmond, Catherine, Bangkok, Thailand. 1989
Page, Christopher D., Newmarket. 1989
Pak Ching-Yuen, Bernard, Pokfulam, Hong Kong. 1989
Park, Stephen W., Romford. 1983
Pattni, Minakshi, Stanmore. 1989
Pfeiffer, Brigitte C.E., London. 1989
Pfister, Hans, Zurich, Switzerland. 1989
Puviharan, Mylvaganam, Colombo, Sri Lanka. 1989
Richardson, Cathryn, Silsden. 1989
Roberts, Kate, South Harrow. 1989
Ruff, Agnes, Realty Gardens, Hong Kong. 1989
Ruusunen, Petri S., Kiukainen, Finland. 1989
Scott, Kenneth MacDonald, Carluke. 1989
Seaton, Johanna L., Kowloon, Hong Kong. 1989
Seifert, Jannice L., Hong Kong. 1989
Singh, Runbir, North Point,ong Kong. 1989
Stanton, Zoe, Andreas, Isle of Man. 1989
Styles, Suzanne S., Romford. 1983
Sutton, Susan A., Cotton, Nr Stowmarket. 1989
Tielinen, Tarja H., Ylijarvi, Finland. 1989
Tielinen, Teuvo K., Ylijarvi, Finland. 1989
Tse. Kwok F.M., Kowloon, Hong Kong. 1989
Van Der Klauw, Angela V., Utrecht, The Netherlands. 1989
Vataru, Monica, London. 1989
Wat, Wanda Hoi-Chi, Wanchai, Hong Kong. 1989
Worthington, Sally L., Sowerby Bridge. 1989
Yeung, Chan Siu Ling, Kowloon, Hong Kong. 1989
Yoo, Ok Hee Han, Bangkok, Thailand. 1989
Yount, Henrietta S., Atlanta, GA, USA. 1989
Zanardi-Landi, Sabina, Rome, Italy. 1989

Transfers from Ordinary Membership to Fellowship
Andrews, Fern, London. 1989
Bourdillon, Catriona C.C., London. 1989
Cox, Vann S., Bedford. 1989
D'Alessandro, Martha A., Houston, Tex., USA. 1989
Edie, Tong Wai Man Annie, Brighton. 1989
George, Wanda M., Nairobi, Kenya. 1989
Girardi, Josephine C., Hong Kong. 1989
Hamid Hossen, Iqbal, London. 1989
Hirst, Jenny E., London. 1989
Howard, David, Preston. 1989
Hughes, David J., Cardiff. 1989
Jarvis, Hilary A., London. 1989
Komai, Rie, Saitama Pref., Japan. 1989
Law, Patricia M., Cambridge. 1989
Leddicoat, Andrew, Guiseley. 1989
Lewis, Karen J., Shatin, Hong Kong. 1989
Lewis, Richard D.F., Epsom. 1989
Lilly, Gregory R., Taranaki, New Zealand. 1989
Lockie, Debra L., Auckland, New Zealand. 1989
McIlwraith, Philomena M., Chorley. 1989
McKenna, Joseph T., London. 1989
Mackinnon (née Pring), Amanda L., Birmingham. 1989
Murray, Robert A., London. 1989
Nakamura, Chiyo, Hokkaido, Japan. 1989
Ozaki, Keiko, Hyogo Pref., Japan. 1989
Pedersen, Gunhild R., Nattland, Norway. 1989
Petrides, Eugene P., London. 1989
Plumb, Helen L., London. 1989
Ravindran, Muhaluxmy, Victoria, Australia. 1989
Schaetzle-Parisod, Arlette, Kaiseraugst, Switzerland. 1989
Shimoda, Tetsuhiro, Fukuoka Pref., Japan. 1989
Stanley, Sylvia, Clearwater Bay, Hong Kong. 1989
Tachibana, Hirogi, Osaka, Japan. 1989
Tayara, Mona D., Outremont, Canada. 1989
Vildiridis, Athanassios N., Thessaloniki, Greece. 1989
Wiborg-Jenssen, Nellie, Tunbridge Wells. 1989
Yim, Tae Young, Tokyo, Japan. 1989
Yuill, Martin J., Lanark. 1989

Ordinary Membership
Bellamy, Michelle L., Swansea.
Bendel, Helle, Sao Paulo, Brazil.
Bubshait, Ahmed I., Bahrain.
Cangardel, Linda, London.
Carbray, Marianne E., Maidenhead.
Connor, Arthur, London.
Degaiffier, Edmond, Washington DC, USA.
Dugmore, Andrea M., Northland, New Zealand.
George, Kenneth P., Boothstown.
Grant, Miranda J., Edinburgh.
Jurukov, Vasil, London.
Laklia, Andrew T., Greenhithe.
Lang, Bernhard, Basle, Switzerland.
Ling, Chock S., Singapore.
Lycouris, Anna M., Esher.
Mitchell, John O., London.
Nicolaidis, Nicholas, Harare, Zimbabwe.
Nillegoda, Lakshman N., Colombo, Sri Lanka.
Patel, Jagdish I., London.
Scott, Sarah L., Norwich.
Shepherd, Genevieve R., York.
Stock, Robert G., Kidderminster.
Wakefield, Melanie K., Horsham.
Wear, William F., Northallerton.

EXAMINATIONS 1990

The examination dates for 1990 are as follows:

Gem Diamond Examination:
Theory – Monday 4 June
Practical – Monday 4 June and Monday 11 June.

Examinations in Gemmology:
Preliminary – Tuesday 26 June
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The final date for receiving examination entry forms is **31 March.**

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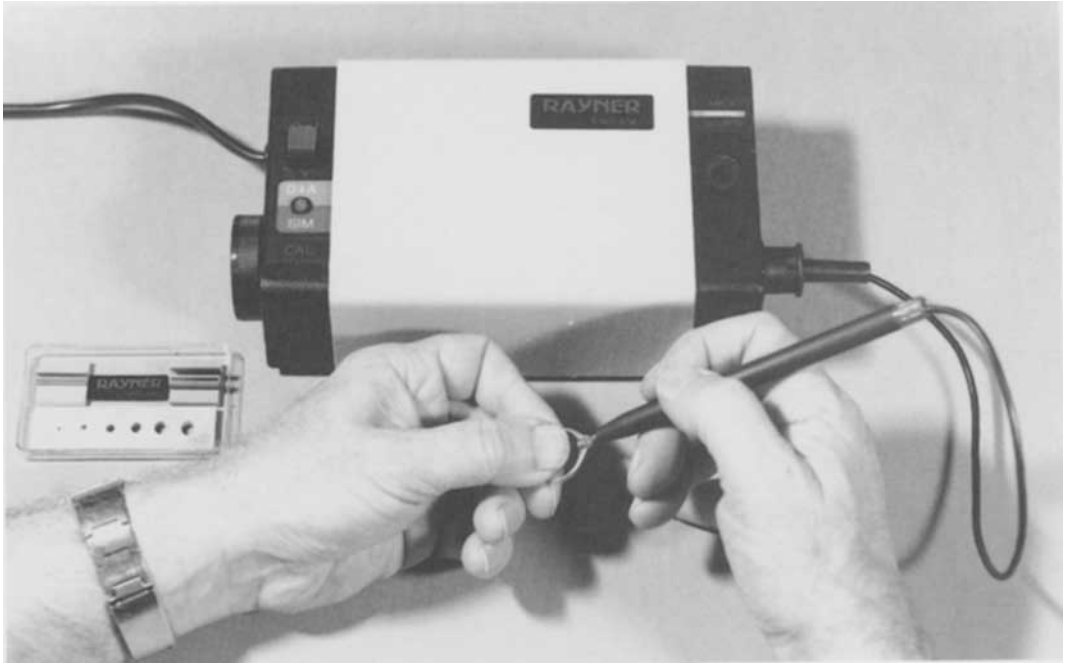

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The mini gem testing kit.

CORRIGENDUM

In *Journal of Gemmology*, **21**, 7, p. 404, right-hand column, line 14, for 'Schneider and Bank, 1980' read 'Schmetzer and Bank, 1980'

Letter to the Editor

From Philip A. Sadler

Dear Sir,

May I be permitted to use the columns of the *Journal* to express my thanks to Dr Hänni and his colleagues in Switzerland. I am sure the *Journal's* readers noticed not only the article by Dr Hänni on iridescent glasses but also the spectacular cover of the October '89 issue showing this resplendent gem.

Acting through Ken Scarratt, I made contact with Dr Hänni over a minor query concerning his paper. Immediately a specimen was dispatched and I found my doubts laid to rest and agreeing with Dr Hänni's observations. But perhaps most importantly, it allowed about 30 British gemmologists to see the iridescent effect for themselves and to appreciate the quality of the work needed to produce the article.

For the fortunate few who were able to see the effect it makes Henry Hänni's contribution more memorable and of greater interest than for those who were not so lucky.

Yours etc.,
P.A. Sadler

14 December 1989
MPFS Laboratory, London SE1 7LP.

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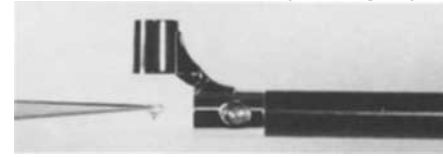

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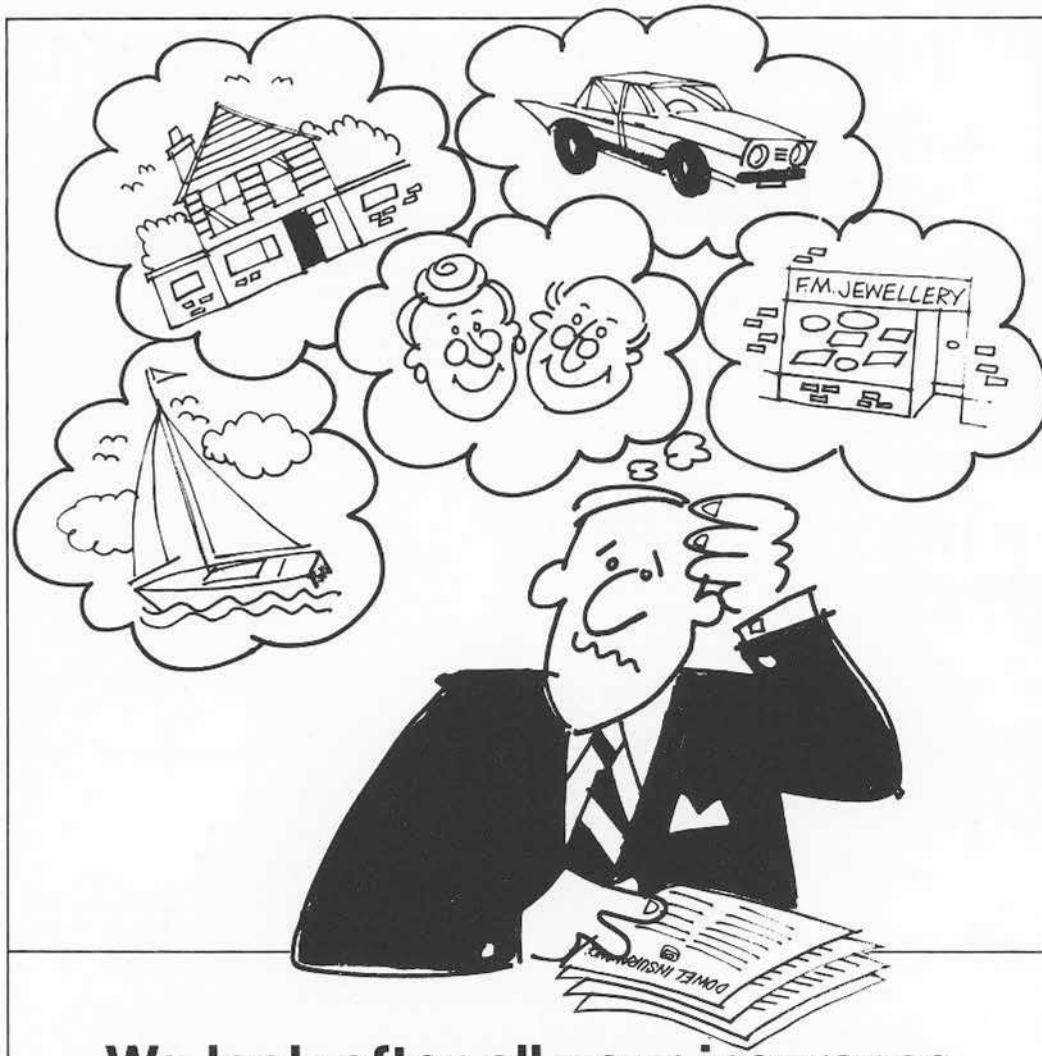

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Historical Note

The Gemmological Association of Great Britain was originally founded in 1908 as the Education Committee of the National Association of Goldsmiths and reconstituted in 1931 as the Gemmological Association. Its name was extended to Gemmological Association of Great Britain in 1938, and finally in 1944 it was incorporated in that name under the Companies Acts as a company limited by guarantee (registered in England, no. 433063).

Affiliated Associations are the Gemmological Association of Australia, the Canadian Gemmological Association, the Gem and Mineral Society of Zimbabwe, the Gemmological Association of Hong Kong, the Gemmological Association of South Africa and the Singapore Gemologist Society.

The *Journal of Gemmology* was first published by the Association in 1947. It is a quarterly, published in January, April, July, and October each year, and is issued free to Fellows and Members of the Association. Opinions expressed by authors are not necessarily endorsed by the Association.

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The Editors are glad to consider original articles shedding new light on subjects of gemmological interest for publication in the *Journal*. Articles are not normally accepted which have already been published elsewhere in English, and an article is accepted only on the understanding that (1) full information as to any previous publication (whether in English or another language) has been given, (2) it is not under consideration for publication elsewhere and (3) it will not be published elsewhere without the consent of the Editors.

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Twenty five copies of individual papers are provided on request free of charge; additional copies may be supplied, but they must be ordered at first proof stage or earlier.

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The Journal of Gemmology

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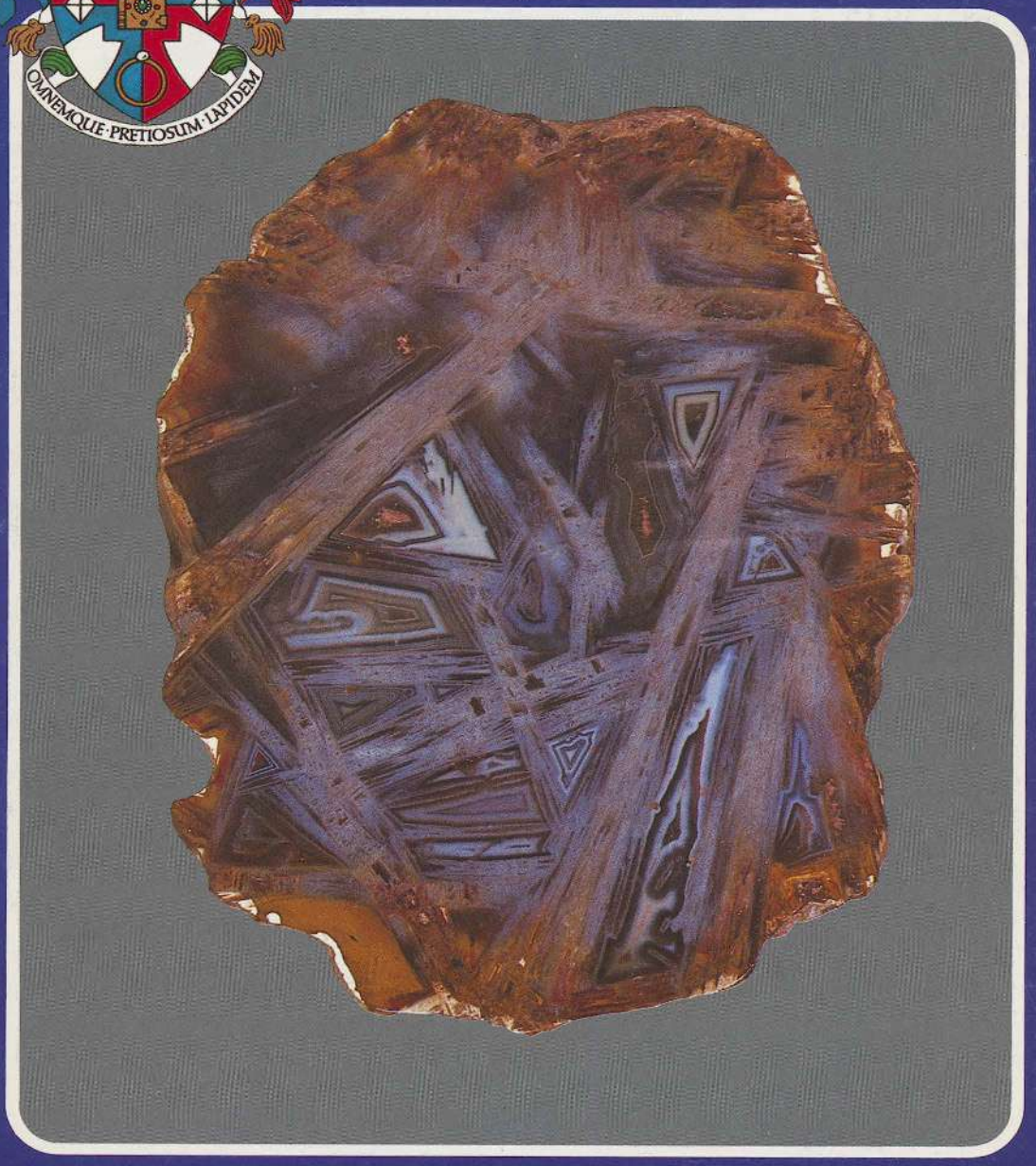

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VOLUME 22

NUMBER TWO APRIL 1990

Cover Picture

An unusual Guyanese agate showing long, interlocking 'quartz' crystals with banded agate filling the interstices. (See 'An unusual agate from Guyana', p.76)

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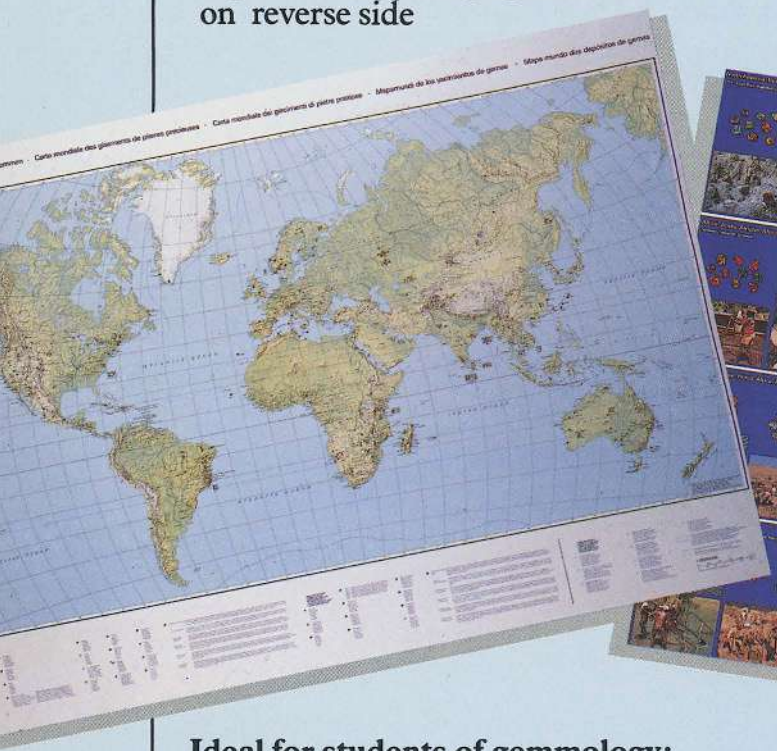

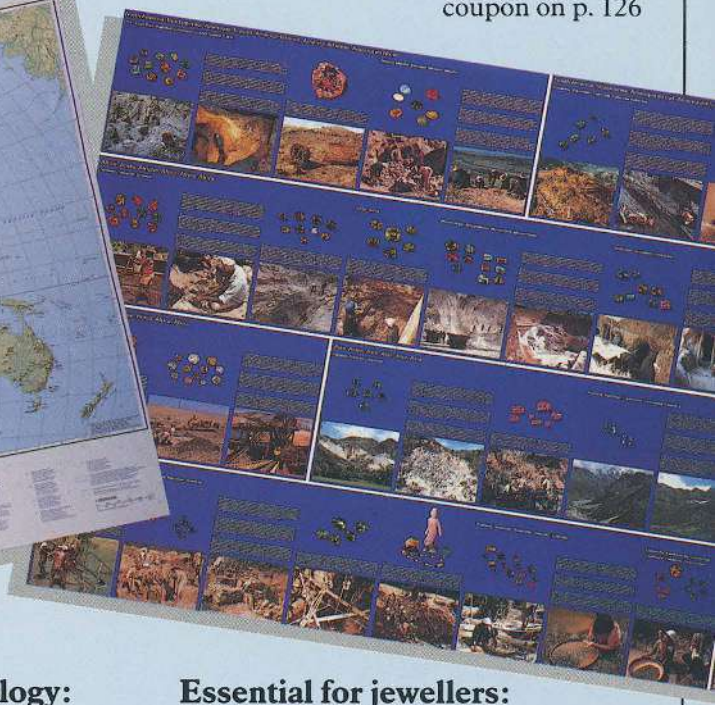

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A contribution to the distinguishing characteristics of sapphire from Kashmir

Dr H. A. Hänni, FGA

Mineralogical Institute, University of Basel, Switzerland

Abstract

This investigation was undertaken to contribute to the knowledge of sapphire from Kashmir, and over 50 cut stones were studied. Comparison of the observed inclusions with those described in other publications, identified in part using the scanning electron microscope SEM/EDS, confirmed the results of earlier findings (tourmaline, pargasite and zircon inclusions). In addition, some internal characteristics are newly described: plagioclase, uraninite, allanite and rutile (?) occurring in various forms, healed fissures and zoned growth. Spectral properties are presented. The significance of origin reports is discussed.

Introduction

Sapphire, the blue variety of corundum, is produced from numerous deposits distributed worldwide. The term **Kashmir Sapphire** is used to denote the origin of a stone from a specific location, and should not be regarded as a term describing either quality or colour. Some of the earlier worked deposits are no longer in production, their supply being either exhausted or no longer economically viable. This would also seem to be the case of the sapphire deposits of Kashmir.

Sapphire deposits can be classified into a number of types, on the basis of their genesis or geological setting (Deer *et al.*, 1980; Kiefert, 1987). Basaltic occurrences of the mineral (e.g. in Australia, Malawi, Thailand, Cambodia, etc.), often producing too dark, greenish-blue stones, do not host the most coveted blue corundum. Sapphires from pegmatitic dykes and metamorphic deposits are often too light or exhibit mixed colours, and are not generally considered to be of particular value (Montana, Tanzania, Sri Lanka). Nevertheless, the production of rough material with excellent colour from the latter type of deposits is considerable. These sapphires may attain top class quality after cutting (such as some from Burma, Sri Lanka, Kashmir).

Historical review

According to a number of authors (Mallet, 1882; La Touche, 1890), sapphire was discovered in 1881 at Soomjam in the district of Padar (Jammu and Kashmir Province) in India. The deposits, which occur at an altitude of about 4400m, were intermittently mined at several localities (Old Mine, New Mine, Valley). The production included some large crystals and a large quantity of medium-sized and smaller crystals. The colour and transparency of the stones varied considerably (Middlemiss, 1931; Roy, 1949), and mining figures for some years clearly show that the operation was often unprofitable. Due to the low yield and often inferior quality of the sapphire, mining was frequently interrupted and management changed on many occasions. A recent article describing all aspects of the deposit can be found in Atkinson and Kothavala, 1985. In his book on corundum, Hughes (in press) also presents a comprehensive list of literature on sapphire from Kashmir.

Origin of study material

The following study was carried out on cut sapphires submitted to the Swiss Foundation for the Research of Gemstones (SSEF) Laboratory in Zürich (Figure 1). Rough corundum of gem quality from Soomjam was not available to the author, and such material is at present not being mined. Study of inferior grade material (of which much is available), is of limited significance when information on transparent gem quality is required. The author received cloudy material together with host rock from Soomjam from two independent and reliable sources. The samples from both sources appeared identical and corresponded with information given in the original literature (Mallet, 1882; La Touche, 1890; Bauer, 1896). Corundum, which occurs in lenses and pockets, is hosted by a rock often described as kaolin. A sample of this fine-grained 'plumasitic' rock was examined and contains feldspar, sheet silicates and also black tourmaline, as described by La Touche (1890). The sample material studied was supplemented by a transparent sapphire crystal provided by a museum.

Earlier descriptions and photomicrographs of diagnostic inclusions (Phukan, 1966; Schubnel, 1972; Gübelin and Koivula, 1986) are scarce, but

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individual characteristics have been identically described. In the sapphires studied here, new inclusions were identified in addition to the classical diagnostic Kashmir inclusions (pargasite, tourmaline, milky lines with short traverse streaks, see Gübelin and Koivula, 1986). As far as possible, these new inclusions were mineralogically identified by Scanning Electron Microscope with Energy Dispersive System (SEM/EDS).

Absorption spectra exhibit a characteristic course, different from other sapphire curves. Thus, a second diagnostic criterion in addition to the inclusions is available for origin determination. Spectral behaviour, inclusion paragenesis and trace element content has been discussed with colleagues experienced in sapphire identification.

The new internal characteristics revealed in this paper have been used for the determination of origin, as they have consistently been shown to be typical of sapphire from Kashmir. The presence of all mineral inclusions identified so far in Kashmir sapphire can be satisfactorily explained by the geological setting at Soomjam. This paper reveals and discusses the additional characteristics.

The determination of origin by characteristics typical of the locality must be carried out in comparison with the properties of all other occurrences of sapphire. Some properties may be characteristic but not diagnostic for a definite population, since they are also found in stones from other localities. Thus, a fundamentally safe assignment of each stone to a specific locality does not always exist. Further discussion of the certainty of determining origin is presented in Hänni, 1988[a].

Habit and colour of Kashmir sapphire

The crystals normally display a simple pyramidal form with small basal planes (Goldschmidt, 1918). They are either totally or partially transparent, and the frosted to coarse surfaces are covered with a white crust (Bauer, 1896; Middlemiss, 1931), see Figure 2. The small, semi-translucent crystals of a grey colour and with a coarse surface are often still encountered as rough stone material today. They appear to have been found in large amounts and are suitable to a degree for heat treatment ('Kashmir-Geuda', Figure 2). Grey crystals of this kind have been described by Middlemiss (1931).

A particularly marked characteristic of much Kashmir sapphire is the velvety blue colour, due to slightly reduced transparency of the stones. It is the result of a cumulation of effets:

- turbidity due to microscopic and submicroscopic features of an unknown nature (Tyndall Effect on segregations of rutile (?) dust particles). Figure 3.
- scattering of light on microscopically small flat inclusions of an unknown nature (films of rutile or fluid inclusions?), which are distributed both homogeneously and oriented in rows throughout the stone. (Figure 4).
- zonal growth as sequences of transparent (blue or colourless) and turbid white lamellae with sharp borders (Figure 5).
- lamellar or block-like textures of different crystallographic planes with slightly varying refractive indices which tend to disturb the light path.

Absorption spectra

The blue colour of Kashmir sapphire can be explained by iron and titanium contents (Schmetzer and Bank, 1981). The absorption spectra exhibit the characteristic maxima caused by Fe^{2+}/Ti^{4+} pairs, and Fe^{3+}. Occasionally, light red portions occur in larger, bi-coloured crystals or as light pink crystals. Likewise, the occurrence of light rubies has been noted (Middlemiss, 1931). In fact, small quantities of chromium have been occasionally observed in Kashmir sapphire, identifiable by the emission line at 693nm in the absorption spectrum or by energy-dispersive X-ray fluorescence spectroscopy (Stern and Hänni, 1982). The blue colour of sapphire is the result of the relative absorption of all colours but blue (transmission from ca. 420-470nm). The spectral part from red, yellow and green is absorbed by a broad band centred at 580nm for the ordinary ray (*o*) and at 690nm for this extraordinary (*e*) ray. Fe^{2+}/Ti^{4+} pairs are responsible for this absorption behaviour. Absorption in the UV and VIS is also caused by Fe^{3+} eventually present, with absorption maxima at 374, 388 and 450nm. The presence of Fe^{2+}/Fe^{3+} pairs, mainly in green and greenish sapphire, results in an absorption maximum at 700 (*e* vibration) and 600nm (*o* vibration) affecting the colour. Even small amounts of Cr^{3+} in sapphire lead to an absorption at 600nm and the fluorescence line at 693nm. More information can be found in Bosshart (1981) and Schmetzer and Bank (1981).

The intensities of the absorption lines of Kashmir sapphire at 374, 388 and 450nm are similar to those for sapphire from Sri Lanka (weak) and weaker than those for sapphire from Burma (fairly strong). The maximum transmissions for the *e* vibration lie characteristically at 350, 420 and 470nm. The absorption curve edge starts to rise at below 370nm, usually passing into the general absorption at 320-330nm. A low Cr^{3+}-content results in a small band at 410nm (*e* vibration). Thus, the most important portion of the absorption curves of sapphire for determination of origin lies between 500 and 280nm.

Fig. 1. Three cut Kashmir sapphires (6-14ct) showing different degrees of transparency and colour saturation.

Fig. 2. Corundum crystal of low quality from Soomjam, and a slice of parent rock containing black tourmaline. The milky crystals are used for heat-treatment (so-called 'Kashmir Geuda'), blue pieces at right after treatment. Width of photo ca. 10cm.

Inclusions described in literature

Descriptions and illustrations of internal characteristics in sapphire from Kashmir are relatively rare compared to those from other deposits. On the basis of optical study, Phukan (1966) described the following characteristic features:–

P1 – oriented rutile needles, partly decomposed
P2 – fine dust, scattered between rutile needles or concentrated in cloudy patches of extremely fine particles
P3 – zircon, with or without 'winged' fracture haloes
P4 – opaque black prismatic crystals, surrounded by liquid feathers
P5 – liquid feathers, partly with tiny drops arranged in rows
P6 – healing feathers with grid-like patterns
P7 – flat liquid films or fluid-filled cavities

Schubnel (1972) considered the characteristic inclusions (the first two of which were identified using the electron microprobe) to consist of:–

S1 – tourmaline, greenish and possessing irregular forms
S2 – pargasite, fine light green needles up to 6mm in length
S3 – partly corroded colourless crystals (his Figure 26b, p.166)
S4 – flat fluid films.

According to Gübelin and Koivula (1986), the following inclusions are typical of Kashmir sapphire:–

G1 – zoned texture and cloudy haziness
G2 – randomly-scattered brush-stroke-like inclusions and nebulous clouds
G3 – wispy pennant-like inclusions attached to strings
G4 – corroded (profiled) zircon crystals
G5 – pargasitic hornblende
G6 – tourmaline
G7 – 'flags' of sealed fluid remnants.

Confirmation of known and new inclusion types

Modern gem microscopy profits over the old monocular microscopy through the availability of improved illumination and binocular observation. Only the use of powerful oblique illumination (e.g. by fibre optics) against a dark background will reveal certain types of inclusions, for example cloudiness, fine dust tracks and very fine rutile needles. In the past, such features could not be recognized, and thus cannot be expected to be reported in earlier literature.

After observation of an inclusion, the next step is its identification. A definite identification requires knowledge of its chemical composition and its crystal structure. One is usually restricted in the possibilities of analysing inclusions in gemstones (as either they do not reach the surface, or they are fluids, or because the crystals are corroded, not idiomorphic, etc.). In addition, there is also the pressure of time when analysing very precious gems. In this paper, the following abbreviations are used to indicate the method of identification:

LM Optical light microscopy
SEM Scanning electron microscopy with energy-dispersive system
EMP Electron microprobe analysis
XRD X-ray diffraction analysis

Structural features

The methods recommended by Schmetzer (1986) for the optical measurement of crystallographic growth and colour zoning were used by Kiefert (1987) for the study of zoning in sapphire. Due to the lack of suitable material, they could not be applied in the case of the Kashmir sapphire. The evaluation of crystallographic features on a large number of Kashmir sapphires supplied valuable evidence for the determination of origin (Peretti, Schmetzer, 1989). Narrow twin lamellae parallel to the rhombohedron face rarely occur in Kashmir sapphire (Figure 7).

Healed fissures

They presumably originated during various phases of crystallization of the corundum. The patterns of these original fissure planes can be very diverse and in varying stages of healing (see Roedder in Gübelin and Koivula, 1986, p.84). Feathers and veils consisting of minute cavities and negative crystals can exhibit various forms, although they are formed of a mainly simple, lobular fissure plane. Occasionally, this can be bent or folded, but seldom overlapping. Depending on the stage of healing of the original fissure, the veils can exhibit various patterns (Figures 8-12):–

- covered with isometric voids to short tubes, graded in size from outside to inside, occasionally in a sort of fishbone pattern (Figure 8): of type P5.
- covered with connecting canals, but also with extensively dissolved networks (Figure 9).
- containing flat cavities or negative crystals, which often possess trigonal step patterns and sometimes black, opaque platelets (graphite ?) as partial fillings. (Figure 10).
- flat negative crystals with minute satellites, presumably formed by bursting of the main cavity and healing of the fissure plane (Figure 11).
- very incompletely healed fissures with a frost pattern (Figure 12).

The small cavities, flat negative crystals or interlinked canals are suspected of containing fluid inclusions.

Fig. 3. Turbidity induced by dust particles (rutile?) occurring in zonal lamellae and as fine dust tracks or traces. 30X.

Fig. 4. Flaky inclusions of an unknown nature lying in one or several parallel planes. 50X.

Fig. 5. Sequence of transparent and milky bands originating from zoned growth. 10X.

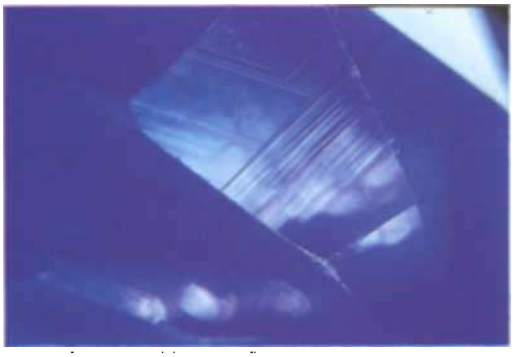

Fig. 6. Reflecting zoned growth in the form of various crystallographic planes and blocks. 20X.

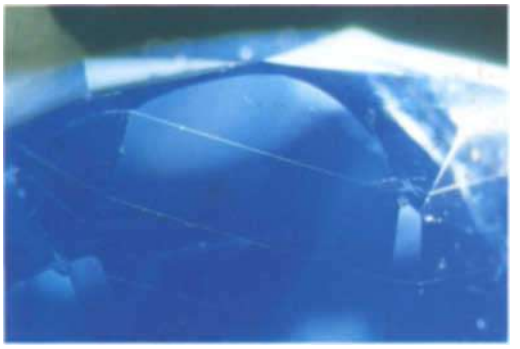

Fig. 7. Very small intercalated twin lamellae. 15X.

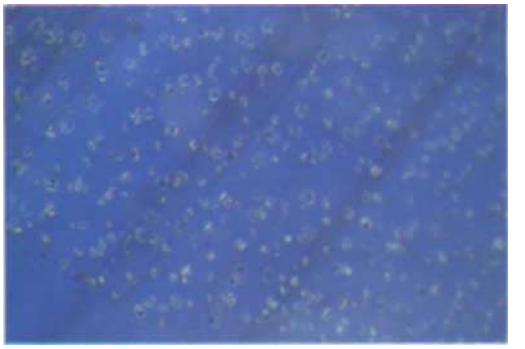

Fig. 10. Healed fissure with flat, strongly recrystallised cavities (negative crystals), a few containing opaque crystallites. 50X.

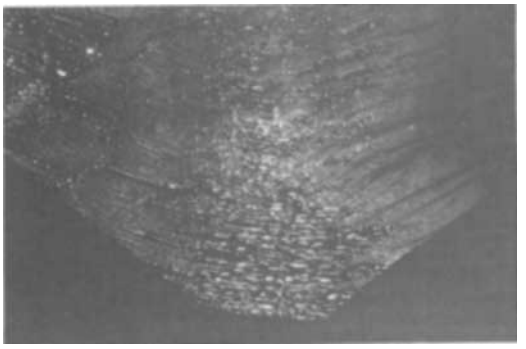

Fig. 8. Graded healed fissure with short tubes and residual droplets. 30X.

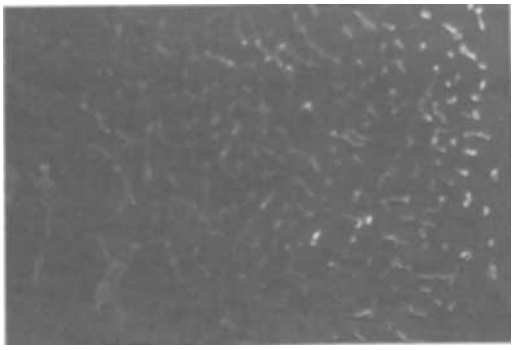

Fig. 9. Healing fissure with a more or less disintegrated network of canal structures. 30X.

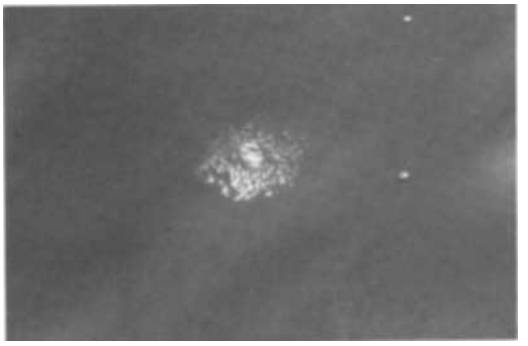

Fig. 11. Apparently burst negative crystal with healed fissure plane containing minute cavities. 50X.

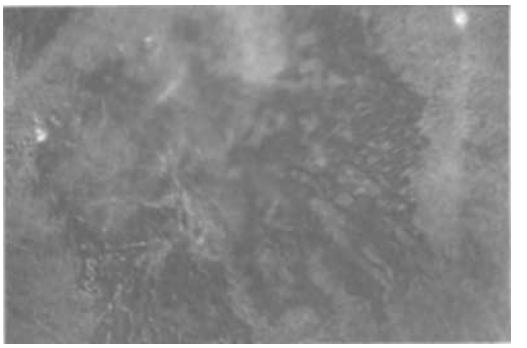

Fig. 12. Incompletely healed fissure with a frost pattern. 30X.

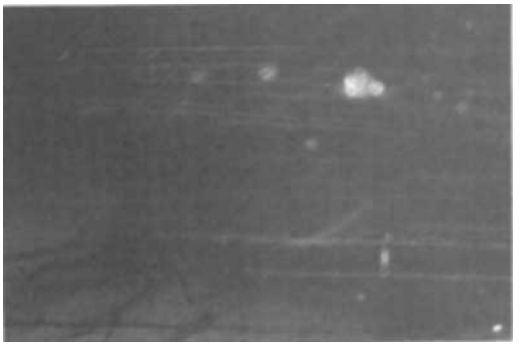

Fig. 13. Lines of dust-like tracks or trails, which cross at acute angles and exhibit fine diagonal striations. 25X.

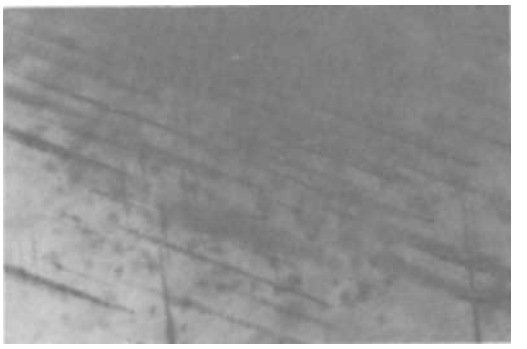

Fig. 14. Intersecting long and shorter dust lines (running in three directions). 25X.

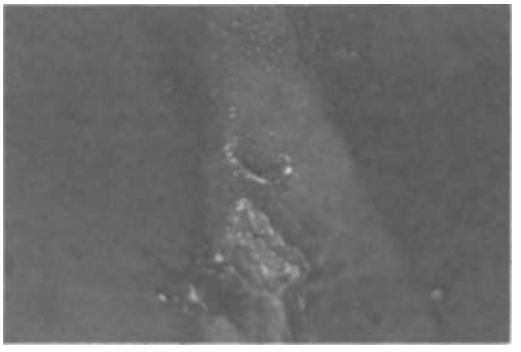

Fig. 15. Green inclusions of tourmaline crystals in Kashmir sapphire, mainly corroded and broken, seldom idiomorphic. 30X.

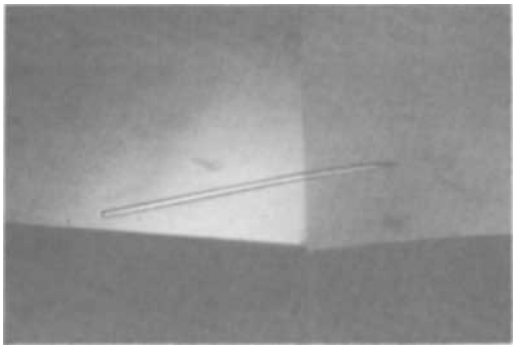

Fig. 16. Long pargasite needle exposed on surface and analysed by SEM/EDS. 45X.

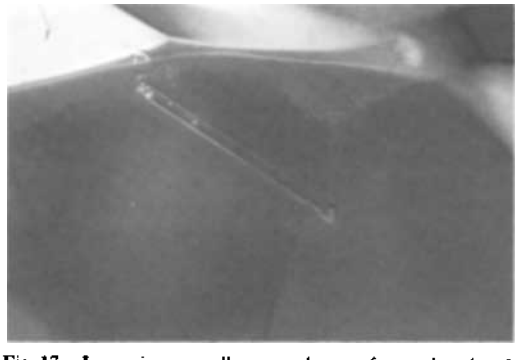

Fig. 17. Long zircon needle exposed on surface and analysed by SEM/EDS. 40X.

Fig. 18. Corroded zircon crystal inclusion. 60X.

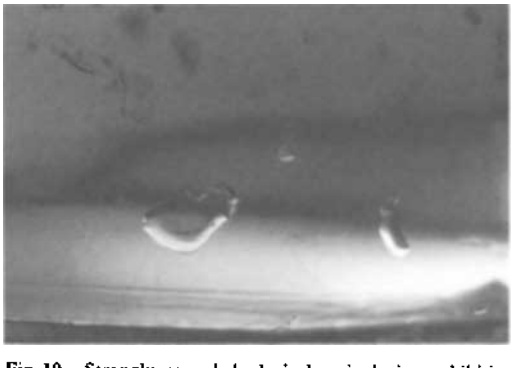

Fig. 19. Strongly corroded plagioclase inclusion exhibiting rounding and indentation. 50X.

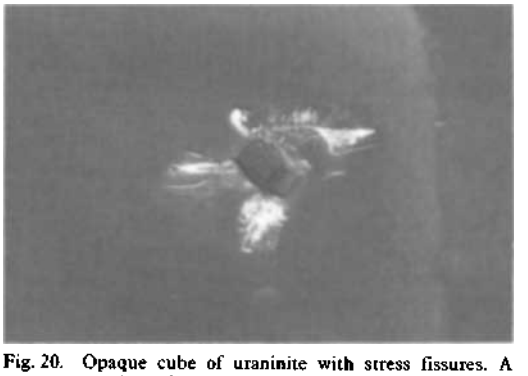

Fig. 20. Opaque cube of uraninite with stress fissures. A number of such crystallites reach the surface and could, therefore, be analysed (SEM/EDS). 40X.

Fig. 21. Allanite (orthite) inclusions occur rarely in Kashmir sapphire. 30X.

Solid inclusions

Rutile (LM) could not be analytically confirmed. Kashmir sapphire can contain few short rutile needles, and it is assumed that the very fine dust particles occurring in zones may be developing rutile crystallites. The formation of rutile needles normally has not taken place. It is assumed that the frequent lamellar turbidity is also due to the presence of extremely fine rutile dust in layers (Figures 3-5). Compare: P1. The segregation of rutile needles from the corundum may have been prevented during fairly rapid cooling, and only dust-like particles were formed and are observed as turbid zones in most of the Kashmir sapphire. The nature of the very fine particles which usually form indistinct, more or less linear white trails is still unclear. Such lines traverse the sapphire roughly perpendicular to possible crystal faces, forming acute angles with each other (Gübelin and Koivula, 1986, p.342). They are constructed of short traverse lines (Figure 13) and could also represent minute rutile features. Compare: P2, G2, G3.

A further form of such minute white structure are the small, cruciform bodies, also shown by Gübelin and Koivula (1986). They seem to be composed of three intersecting planes of dust concentrations, also crystallographically oriented (Figure 14). Compare: G1.

Mineral inclusions in Kashmir sapphire were already observed in the last century (Mallet, 1882). Tourmaline and pargasite are considered to be the classical mineral inclusions specific to the deposit. Zircon has also been mentioned in earlier publications (Phukan, 1966; Schubnel, 1972; Gübelin and Koivula, 1986).

Tourmaline (dravite, SEM) occurs as short greenish crystals occasionally forming groups of inclusions. The stout crystals seldom possess any clear crystallographic forms and could represent partly dissolved crystals (Figure 15). Compare: S1, G6.

Pargasite (EMP, alumino-pargasite to aluminotschermakitic hornblende) forms fine long needles. These needles are so thin, that they are either colourless or pale green (Figure 16). Pargasite occurring as inclusion in corundum has been described in ruby from Burma (Schubnel, 1972) and in ruby from Tanzania (Schubnel, 1972; Eppler, 1973). Compare: S2, G5.

Zircon (SEM) has been found with varying length:width ratios. A ratio of 3:1 is common. A particularly long zircon needle (SEM) displayed a ratio of 18:1 (Fig 17). Stress fissures are nearly always found around the shorter zircons. They contain traces of uranium which explains the occurrence of the fissures, caused by an increase in volume. Some of the zircons are indented perpendicular to the long axis and occasionally contain small opaque inclusions (Figure 18). Compare: P3, G4.

Plagioclase (SEM, Ca-rich) was often observed, but could seldom be analysed. Plagioclase occurs in small, strongly resorbed crystals, sometimes in groups. Twinning is sometimes present. The colourless plagioclase is most easily identified by its habit – rounded form and often containing indentations (Figure 19). Compare: S3.

Uraninite (SEM) occurs as cubic black crystals, from which stress fissures usually radiate (Figure 20). The crystals often possess the same width as growth lamellae into which they are arranged. Rarely, uraninite can form inclusion groups with zircon.

Allanite (SEM, with traces of U and Th) was identified in one case. Again, stress fissures radiate from the colourless to pale reddish brown crystals into the hosting sapphire, presumably due to its content of radioactive elements (Figure 21).

Significance of determination of origin of Kashmir sapphire

Kashmir sapphire is considered by laymen to be unrivalled, but such a judgement cannot be justified as each deposit can produce high and low grade material. The question arises why sapphire from this region is so highly regarded. The fantasy is, of course, affected by the idea of gemstones originating in the past from legendary regions of the inaccessible East! The mines in question, however, are considered to have been exhausted for the last fifty years, and most of the valuable stones of the productive period may lie in the depths of the treasuries of the Maharajahs. Thus, the few Kashmir sapphires on the free market are avidly sought.

The determination of origin of Kashmir sapphire is of particular importance. Often, large price differences are noted on the market between sapphire from Kashmir, accompanied by a credible original report, and from other sources, despite being otherwise visually similar. The non-

desirability of 'documents of origin' for gems is discussed by Hughes (1990). Obviously, a definite geographical origin is not a guarantee of high quality, and value should be determined by the beauty of a stone, governed by its colour, size, transparency and cut.

The origin of many stones cannot be stated with certainty, and even localities well-known for their production of quality material also produce inferior stones (Hänni, 1988[b]). In no respect should a 'superior' origin be used as an excuse to increase the value of a poor stone.

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An unusual agate from Guyana

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Fig. 1. Amerindians collecting agates in a gully leading to the Ireng river.

In a far off part of the world there is a country that has the Kanuku or Blue Mountains, the Kaieteur Falls with a sheer drop of nearly 800 ft, large areas of unexplored jungle, arid savannahs and breathtaking scenery. The Republic of Guyana is located on the northern Atlantic coast of South America and is bordered by Surinam, Brazil and Venezuela. About the size of Great Britain, Guyana has a population of some 850,000, most of whom live on the narrow coastal plain. The mineral-rich interior comprises 70 per cent of the land area and is relatively uninhabited. As a result of geological expeditions in Guyana a new industry was set up in 1973. This was achieved by the setting up of a small industrial lapidary workshop in the capital, Georgetown, and also arranging for the collection of raw materials in the interior. Then after a period of training for a group of young Guyanese the artistic products were arranged for the sale and export.

To the 'Black pearl of Guyana' (Gosling, 1976), an international interest in gold and diamond deposits, and the many varieties of jasper (Gosling, 1986) that occur, may now be added a very unusual form of agate that may prove to be unique to Guyana.

In the early 1970s an investigation of the agate deposits in the north Rupununi savannahs was carried out by a survey team from the Geological Survey and Mines Department in Georgetown.

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The quantity and quality found encouraged the Ministry of Energy and National Resources to set up a new industry based on the utilization of these materials. This project was assisted by British Technical Aid arranged by the Ministry of Overseas Development and the author was privileged to carry out the scheme for the people and Government of Guyana.

Initial prospecting was carried out along the banks of the Ireng, Takutu and Manari rivers. In order to obtain information about conditions under the ground, trial pits and trenches were dug wherever there were good indications of agates. These trial pits and trenches, in addition to providing samples of the deposits excavated allowed inspection of the rocks in the walls of the pit or trench. While working on the commercial collection of the agates some were found to have percussion cracks and it is interesting to speculate on the original geological movements in the area. The best deposits were found near Sunnyside on the Ireng river some 34 miles north of Lethem. The Ireng river is the natural boundary with Brazil. The area is bounded by the Good Hope Mountains in the north and the Kanuku or Blue Mountains in the south. These mountains are largely unexplored and are the site of ancient burial grounds, while further south near Aishalton are some wonderful deep caves undoubtedly used by ancient mankind and containing fine examples of cave paintings deep underground. The savannahs are gently rolling plains covered with sandpaper trees and Itè palms by the water courses. The roads are rough tracks of red ferruginous lateritic soils which are very dusty and full of potholes in the dry season and almost impassable in the wet season.

During the initial surface collection considerable quantities of agates were found in the dry gullies which carry the surplus water off the savannahs in the rainy season into the river. A small number of agate boulders were collected in the low cliffs at the edge of the river. These were mostly cut into magnificent matching book-ends and a set was presented to the Prime Minister at the official opening of the lapidary workshop in Georgetown. These agates were carefully checked and packed into the Landrover and the boxes were transported to Lethem and then to Georgetown on a DC3 plane that was part of a regular transport flight to Georgetown.

Fig. 2. Amerindian digging out agates.

At our various camp sites we found that as southern Guyana is almost on the Equator and there was very little twilight and that the night settles in very quickly – which is instantly the signal for every frog to give voice and for the fireflies or 'candleflies' to light up the darkness with their brilliant displays

Fig. 3. Pit in river terrace deposits showing agates in situ.

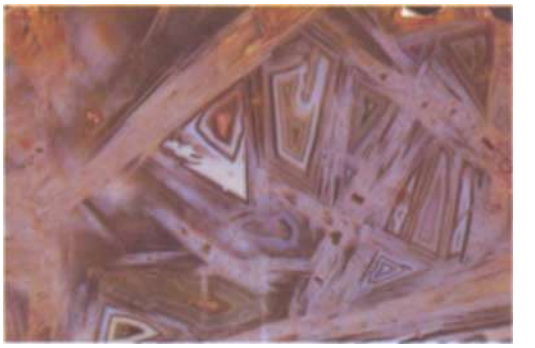

Fig. 4. Guyanese agate showing complex interlocking quartz crystal structure and infilling with banded agate.

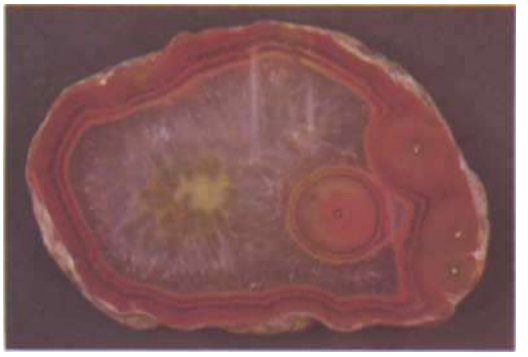

Fig. 5. Example of banded agate found near Sunnyside on the banks of the Ireng river.

Fig. 6. Sliced Guyanese agate used as a clock face.

Fig. 7. Teaching seminar at the lapidary workshop in Georgetown showing the cutting of banded agate with a diamond saw.

of luminescence.

The agates are found on the Rupununi savannah and occur in gravel beds that overlie the Takatu Formation. Most of the agates found in these gravels are very beautiful examples of the banded varieties and are of many different colours and patterns. At the same location are found some agates of a very different type. These were known to the local geologists as 'fire agates' and were formed of a criss-crossing open lattice of quartz crystals (like frost on a window pane) with banded agate filling the interstitial cavities. The outer surfaces of these agates showed a rough fibrous structure quite unlike that found on the more usual type of agate boulder. These were quite unlike any type of agate that the author had experienced and may well be unique to Guyana.

After transporting the materials to the workshop in Georgetown it was found that the cutting and polishing of this 'fire agate' was similar to normal lapidary practice, but that care had to be taken in sawing and grinding to avoid damaging the long crystals of quartz. The lapidary workshop was equipped with two 24" diamond saws and there was always intense interest in cutting agate as each one displayed new shapes, patterns or colours. During the use of 80, 220 and 400 grit sizes of silicon carbide great care had to be taken to wash off all traces of the grit being used before proceeding to the next finer grade as we found it was very easy to miss a few particles trapped in the cavities of the coarse quartz matrix which resulted in disastrous scratches. In the final polishing of the agate using cerium oxide on a felt mop, considerable problems were experienced in removing the polishing compound that had dried in the small holes in the open quartz crystal lattice.

This special Guyanese agate is very unusual and specimen blocks and clock faces aroused intense interest; its formation will surely intrigue geologists. The project continues to flourish and it is hoped in time to expand to other areas of the country.

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Spectroscopic evidence for heat treatment of blue sapphires from Sri Lanka – additional data

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Abstract

Differences in the absorption spectra of particular types of natural blue untreated and heat treated sapphires are due to the presence or absence of Fe^{3+} absorption bands of distinct intensities. These features are useful for the recognition of artificial heat treatment in samples of the trade.

Heat treatment of milky white, bluish or yellowish sapphires from Sri Lanka has been performed for the last ten years (or even longer) in order to develop an intense blue coloration of the samples. Though technical details of the processes used by commercial treaters, e.g. in Bangkok, are kept secret, some information about colour improvement of these so-called 'geuda-sapphires' has been published in recent years (e.g. Harder, 1980, 1982; Crowningshield and Nassau, 1981; Gunaratne, 1981; Nassau, 1981; Keller, 1982; Abraham, 1982).

In general, the development of colour is based on heat treatment of natural samples under reducing conditions at temperatures above 1550°C for several hours. This process causes a dissolution of rutile needles or particles in the corundum host, i.e. the formation of a solid solution between the host crystal and guest minerals (see Nassau, 1982; Harder and Schneider, 1986). The reverse of this process is commercially used for the formation of rutile precipitates in synthetic and natural sapphires. In order to develop or improve asterism, these samples are annealed at temperatures between 1100 and 1500°C for several hours.

In practical gemmology, the detection of heat treatment in natural sapphires as well as the recognition of natural blue samples as untreated sapphires is performed in general by microscopic investigations, which are based on the presence or absence of distinct features, e.g. on the presence of rutile needles or two-phase inclusions in untreated samples as well as on the presence of internal stress fractures around single crystal inclusions in heat treated samples (Nassau, 1981; Crowningshield and Nassau, 1981; Koivula, 1986; Gübelin and Koivula, 1986). However, some hints towards a possible identification of heat treatment of natural sapphires by spectroscopic investigations are found in the papers of Nassau (1981) and Crowningshield and Nassau (1981), who mentioned the absence of the 22,200cm^{-1} (450nm) absorption band in treated sapphires, which is assigned to Fe^{3+} replacing Al^{3+} in the corundum structure. The aim of the present paper is to elucidate this difference in spectroscopic properties of treated and untreated samples, which is useful for diagnostic purposes.

Natural blue sapphires can be subdivided into two basic types, depending on the presence or absence of the Fe^{2+}/Fe^{3+} charge-transfer absorption band in the near infrared at 11,500cm^{-1} (870nm) with polarization $\perp c > \parallel c$. Blue sapphires without a prominent Fe^{2+}/Fe^{3+} band (natural sapphires of type I) are known from e.g. Mogok, Burma; different localities in Sri Lanka; Umba Valley, Tanzania; Montana, USA; Kashmir, India; blue sapphires with a dominant Fe^{2+}/Fe^{3+} band (natural sapphires of type II) are known from alkali basalts as mother rocks, e.g. from different localities in Australia and Thailand; Jos, Nigeria; Pailin, Cambodia. Absorption spectra of type I natural blue sapphires are pictured in Figure 1, typical absorption spectra of type II natural blue sapphires were recently published in this journal by Kiefert and Schmetzer (1987).

The colour of both, heat treated and non-heat treated natural blue sapphires of type I is caused exclusively by the Fe^{2+}/Ti^{4+} intervalence transfer absorption, the absorption maxima of which are found at 17,880cm^{-1} (559nm) [polarization $\perp c > \parallel c$] and at 14,300cm^{-1} (699nm) [polarization $\parallel c \approx \perp c$] (Schmetzer and Bank, 1980; Burns and Burns, 1984; Schmetzer, 1987). All samples of this particular type reveal an identical pleochroism of light blue $\parallel c$ and intense blue to bluish violet $\perp c$. In this type of blue sapphire, the presence or absence of a weak Fe^{3+} absorption at 22,200cm^{-1} (450nm) does not influence colour or pleochroism of the samples.

Heat treatment of milky white so-called 'geuda' sapphires from Sri Lanka (and only this type of heat treated sapphires will be discussed in this paper)

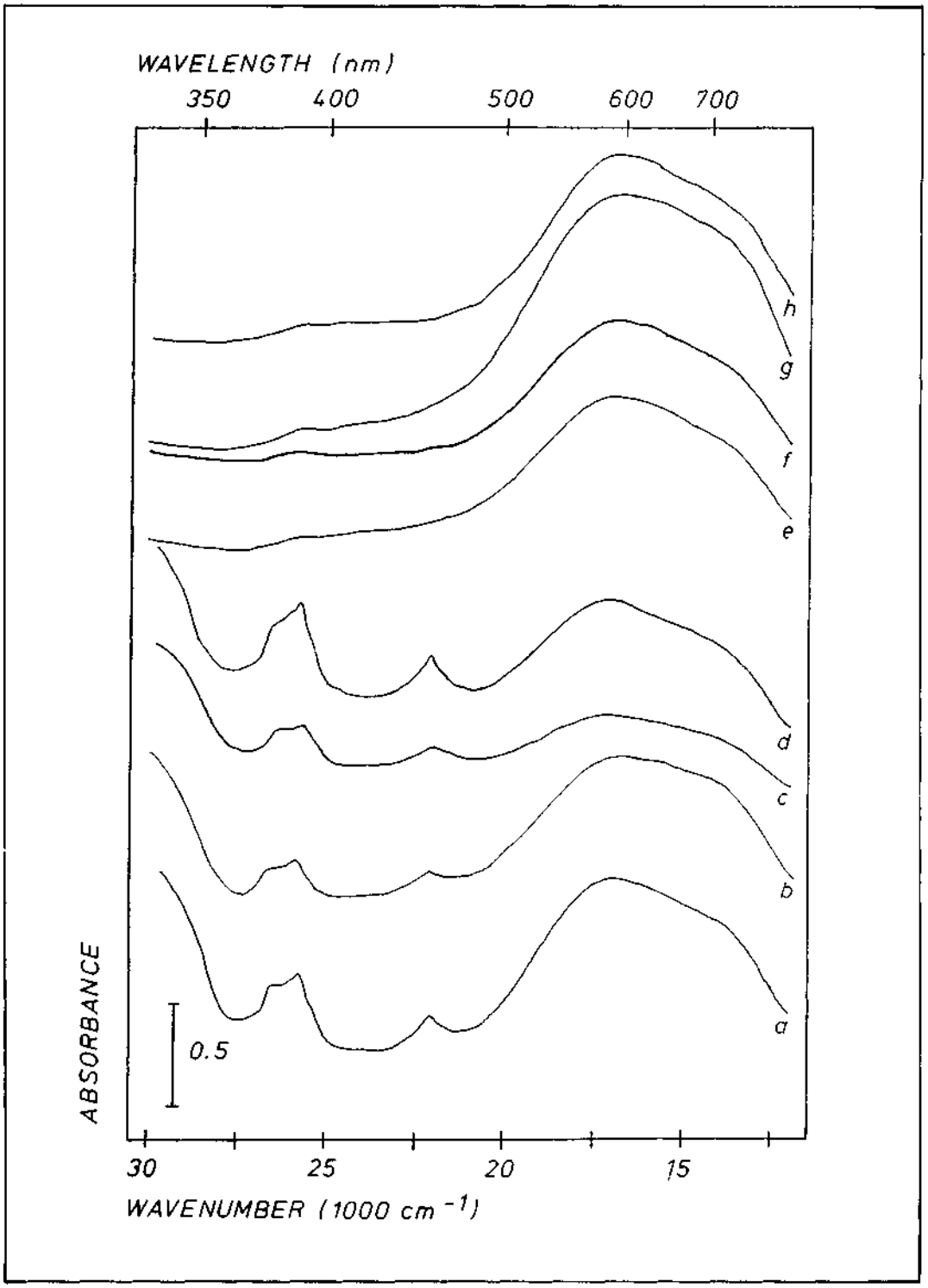

Fig. 1. Absorption spectra of natural untreated and heat treated blue sapphires. [Untreated samples: (a) Mogok, Burma, (b) Sri Lanka,] (c) Montana, USA, (d) Umba, Tanzania. Heat treated samples: (e) and (f) Sri Lanka, samples of the trade, (g) and (h) Sri Lanka, samples treated by the authors.

produces absorption spectra with dominant Fe^{2+}/Ti^{4+} absorption bands but without any Fe^{2+}/Fe^{3+} intervalence transfer absorption (Figure 1). In addition, samples of the trade and also those samples treated by the authors in general did not reveal any absorption bands of Fe^{3+} in the blue and ultraviolet range at 22,200, 25,800 and 26,600cm^{-1} (at 450, 388 and 376nm). An absorption spectrum of this type was never observed by the authors in untreated natural blue sapphires from different localities.

The absence of Fe^{3+} absorption bands in heat treated samples, which were spectroscopically found to be present in untreated samples before treatment was applied by the authors, is explainable by the conversion of trivalent iron to bivalent iron in connection with the dissolution of rutile particles after the scheme:

$$\underset{\text{rutile}}{TiO_2} + \underset{\text{corundum (colourless)}}{(Al^{3+},Fe^{3+})_2O_3} \rightarrow \underset{\text{corundum (blue)}}{(Al^{3+},Ti^{4+},Fe^{2+})_2O_3}$$

According to this scheme, in samples in which titanium contents exceed iron contents, no residual Fe^{3+} absorption bands are expected to be present after extended heat treatment. Similar facts are responsible for the absence of Fe^{3+} absorption bands in the spectra of synthetic Verneuil-grown blue sapphires with a chemical composition revealing higher amounts of titanium than iron.

However, in some heat treated natural samples, residues of small amounts of Fe^{3+} were observed by spectroscopic investigations. Two possible explanations can be quoted for this observation; on the one hand, the time of heat treatment can be too short to finalize the reaction according to the scheme given above or, on the other hand, the amounts of iron in the samples may exceed the amounts of titanium. In addition, the influences of different reducing or oxidizing atmospheres on the reaction described has not yet been studied in detail by the authors. According to these facts, the presence of Fe^{3+} absorption bands of distinct intensities is not thought to be useful as an unequivocal criterion for untreated blue sapphire, but the absence of Fe^{3+} absorption bands of distinct intensities is useful to classify a sample of undoubtedly natural origin (proved by microscopic examination) as artificially heat treated natural blue sapphire.

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Red and orange corundum (ruby and padparadscha) from Malawi

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Abstract

Physical, chemical, spectroscopical and microscopical features of red and orange corundum from Malawi are described. The stones investigated show good gem quality. The rubies vary in colour from pale red to dark red. The variation of colour intensity is accompanied by a remarkable variation of the physical data (refractive indices, birefringence, specific gravity) as well as chemical characteristics (chromium and iron contents).

Introduction

An occurrence of gem quality corundum in Southern Malawi was reported by Bloomfield (1958). The locality described is situated on the Chimwadzulu Hill, approximately 50 miles south of Lake Nyasa, close to the frontier of Mozambique. (Figure 1). The corundums occur in situ in an epidotized amphibolite. The crystals are embedded in a coarse aggregate of hornblende crystals, enclosed in a matrix of epidote and plagioclase.

First gemmological investigations were carried out by Rutland (1969). He examined rough crystals of blue, pink, yellow, pale green and dark greyish-green colours, showing well developed basal pinacoids and less rhombohedral faces. The crystals were 5 to 40mm in length and had a distinct basal parting. Later he investigated, together with E.A. Jobbins, some lots of several hundred cut stones, weighing up to 12ct each. The colours of these corundums varied from yellow to blue, pale blue, greyish-blue and greenish-blue. The red stones were smaller in size and pale in colour. Only some stones showed fine colours, comparable with good rubies from Thailand. The quantity of the mined mineral is unknown and for a long time nothing was heard about that occurrence.

In April 1988 the authors obtained some specimens of corundum, showing partly fine ruby quality with varying colour intensity from pale red to intense and dark red (Bank and Henn, 1988; Bank *et al.*, 1988). The crystals showed well developed basal pinacoids and were up to 15mm in length. Distinct basal parting was also visible. Later, in March 1989, one of the authors has visited the mine at the Chimwadzulu Hill (Figure 2) and brought with some more material and larger crystals for examination, also orange coloured corundums.

Physical features

The determination of the physical characteristics, refractive indices, birefringence and specific gravity demonstrated a remarkable rise in constants of the rubies investigated (Table 1). The refractive indices increase from 1.760 to 1.770 for n_e and 1.768 to 1.780 for n_o with $\Delta n = 0.008$ to 0.010. Also the specific gravity increases from 3.96 to 4.04g/cm^3. Rutland (1969) described refractive indices of n_e = 1.762-1.763 and n_o = 1.771-1.772 for red corundums from Malawi. The intense red and dark red specimens investigated by the authors have refractive indices, which were never described and/or

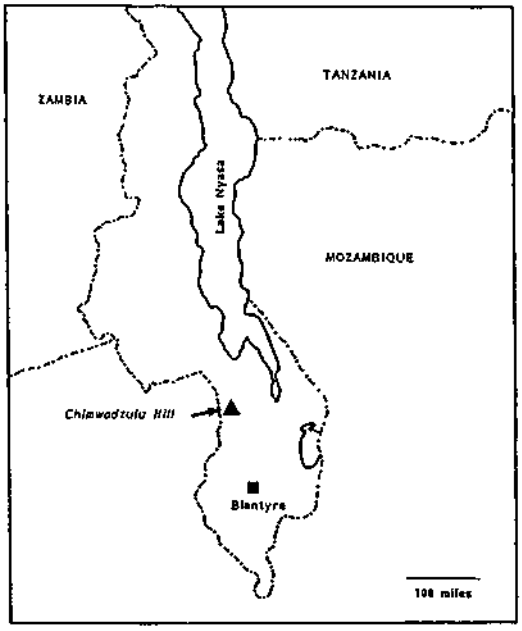

Fig. 1. The Chimwadzulu Hill corundum occurrence in Malawi.

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Fig. 2. One of the authors near the Chimwadzulu Hill (visible in the background) corundum occurrence in Malawi.

published before for rubies. Hitherto, such high values of refractive indices were measured and published only for orange corundums from the Umba Valley in Tanzania (Bank, 1970) and green stones (Webster, 1983). The refractive indices, birefringence and specific gravity of the orange coloured corundums from Malawi are in the known ranges hitherto measured for stones from Sri Lanka and Tanzania.

Chemical features

Chemical analyses of the trace elements chromium and iron were carried out with the microprobe. The results are shown in Table 1 together

Table 1. Physical and chemical features (in wt.%) of rubies and orange coloured corundums from Malawi.

colour	n_e	n_o	Δn	SG (g/cm^3)	Cr	Fe
reddish	1.760	1.768	0.008	3.96	0.08	0.38
pale red	1.761	1.769	0.008	3.97	0.20	0.32
red	1.765	1.773	0.008	3.99	0.29	0.53
red	1.766	1.775	0.009	4.02	0.48	0.51
intense red	1.768	1.778	0.010	4.04	0.79	0.50
dark red	1.770	1.780	0.010	4.05	1.55	0.64
orange	1.763	1.771	0.008	3.97	0.04	0.38
orange	1.765	1.773	0.008	3.98	0.11	0.74

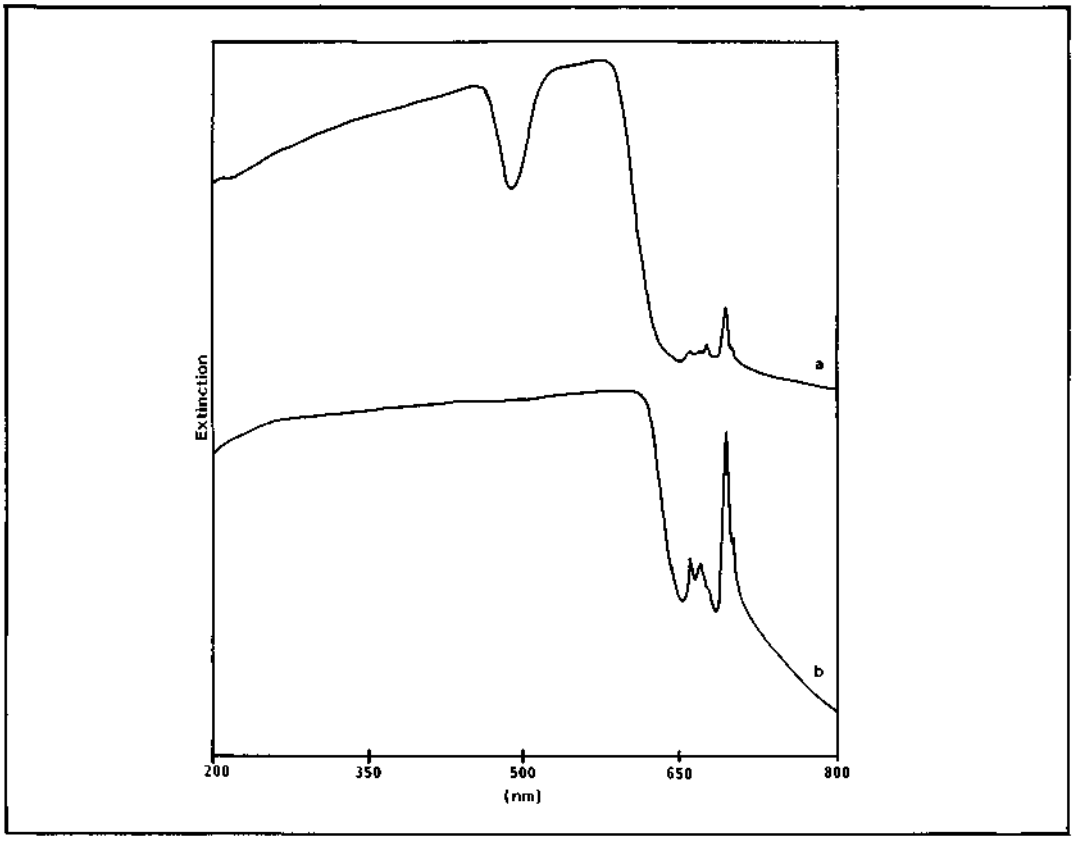

Fig. 3. Absorption spectra of a red (a) and a dark red (b) corundum from Malawi.

with the values of refractive indices, birefringence and specific gravity. From the reddish to the dark red ruby a distinct increase of the chromium contents from 0.08 to 1.55wt.%Cr is visible. Such high values of 1.55wt%Cr were hitherto only measured in rubies from Mogok/Burma, Longido/Tanzania and Manyari/Kenya (Kuhlmann, 1982). The iron contents of the rubies from Malawi vary between 0.32 and 0.64wt%Fe and are relatively high compared with iron concentrations of rubies from other occurrences. Only for some stones from Sri Lanka, Umba/Tanzania and Greenland were comparable values determined hitherto (Zwaan, 1974; Kuhlmann, 1982). The orange coloured corundums from Malawi show chromium and iron contents, which are comparable with yellow-orange to orange-brown specimens from the Umba Valley in Tanzania (Schmetzer *et al.*, 1982).

Spectroscopical features

Spectroscopical investigations were carried out with a Perkin Elmer Lambda 9 Spectrophotometer in the 800-200nm range. Only the ruby with the lowest physical and chemical values (n_e = 1.760, n_o = 1.768, Cr = 0.08wt%, Fe = 0.38wt%) shows a typical chromium spectrum with two broad absorption bands in the green and violet range and a minimum in the blue region of the spectrum. A second absorption minimum is situated in the UV range at 363nm. The rubies with medium physical and chemical data (n_e = 1.761-1.768, n_o = 1.769-1.778, Cr = 0.20-0.79wt%, Fe = 0.32-0.50wt%) show an increase of the Cr^{3+}-lines in the red range at 695, 669 and 659nm and only one Cr^{3+}-absorption-band in the green region at 555nm (Figure 3a). Additionally a decrease of the absorption minimum in the blue range is visible. This decrease and the increase of the Cr-lines in the red region are due to the rise in the chromium content. The ruby from Malawi with the highest physical and chemical values (n_e = 1.770, n_o = 1.780, Cr = 1.55wt%, Fe = 0.64wt%) shows only the sharp Cr^{3+}-lines in the red range of the spectrum with maxima at 700, 694, 675, 669 and 659nm (Figure 3b). From orange to violet a complete absorption can be recognized in this sample.

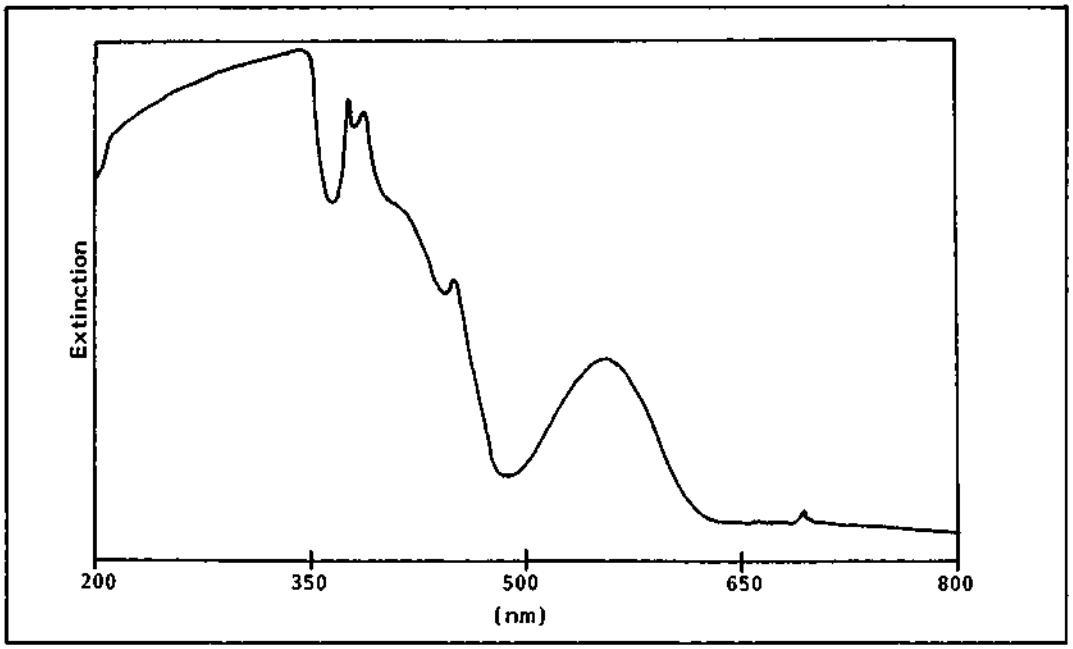

Fig. 4. Absorption spectrum of an orange corundum from Malawi.

The orange coloured corundums from Malawi show absorption spectra with bands of Cr^{3+} and Fe^{3+} (Figure 4). Such a type of absorption spectra was described by Schmetzer *et al.* (1982) with yellow-orange to orange-brown corundums from the Umba Valley in Tanzania. Cr^{3+} causes a broad absorption band in the green range with a maximum at 555nm. Bands caused by Fe^{3+} are situated at 450, 388 and 377nm in the blue and violet part of the absorption spectrum.

Microscopical features

Fine channels, small black crystals, short rods (presumably of hornblende), twinning planes, healing fissures (containing both liquid and gas) and colour zoning were described as inclusions in corundums from Malawi by Rutland (1969). A remarkable three-phase-inclusion in a yellow corundum from this locality was mentioned by Grubessi and Marcon (1986), a cavity, surrounded by fingerprint-like healing fissures, is filled with a liquid, gas and rutile-needles.

Microscopical studies of the rubies and orange coloured corundums from Malawi yielded three general groups of inclusions.

1. *Mineral inclusions*

Nearly all corundums from Malawi investigated show enclosed crystal inclusions. The most frequent type of enclosed minerals are rounded, prismatic, double refractive crystals (Figure 5), which sometimes form clusters (Figure 6). These inclusions were identified by microprobe analyses as zircons. Other doubly refractive mineral inclusions were determined by chemical analyses with the microprobe as anorthite and hornblende. Orientated interbedded rutile-needles were observed in some stones (Figure 7). More frequent is fine distributed rutile dust, interbedded along growth planes of the corundum host (Figure 8). Black, opaque inclusions were also observed (Figure 9), but not identified in detail, also some flat, rounded, double refractive crystals (Figure 10).

2. *Liquid inclusions*

Healing fissures and liquid feathers are the most frequent inclusions in the corundums investigated. Two different types of feathers were observed. One consists of elongated, more or less parallel orientated cavities (Figure 11), containing two inmiscible liquids or both liquid and gas. The second type is built up by irregularly shaped cavities (Figure 12), generally filled with liquid and gas.

3. *Twinning lamellae and growth structures*

Lamellar twinning (Figure 13) was observed in nearly all rubies and orange corundums from Malawi. The twinning lamellae are often orientated parallel to the three rhombohedron planes (Figure 14) and are invested with thin hollow tubes, filled with doubly refractive mineral substance, presum-

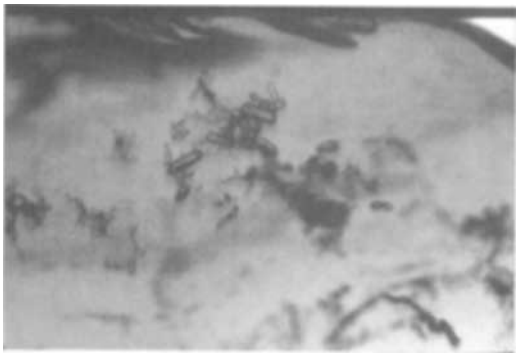

Fig. 5. Ruby from Malawi enclosing rounded zircons. 40X.

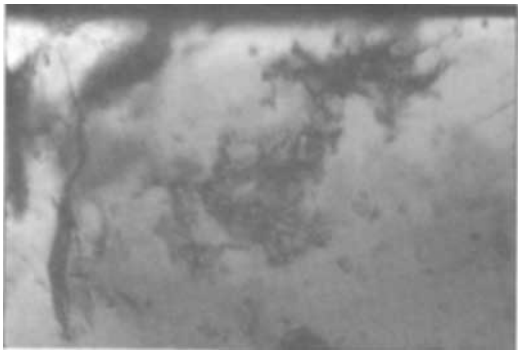

Fig. 6. Ruby from Malawi with clusters of rounded zircon inclusions. 50X.

Fig. 7. Orange corundum from Malawi showing a net of orientated rutile-needles. 15X.

Fig. 8. Ruby from Malawi showing rutile dust, interbedded along growth planes of the corundum host. Darkfield. 10X.

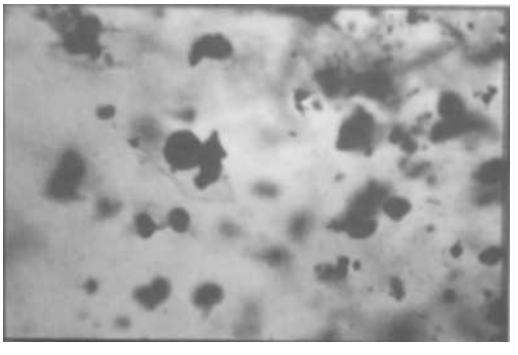

Fig. 9. Orange corundum from Malawi with black, opaque mineral inclusions. 40X.

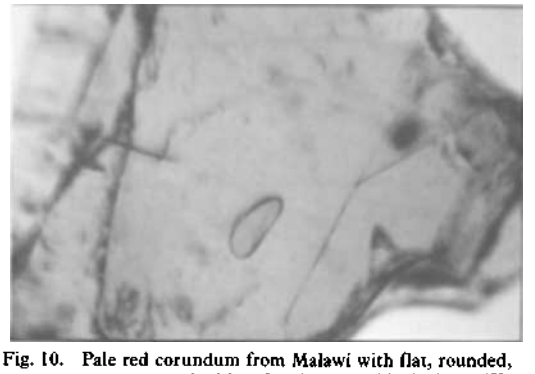

Fig. 10. Pale red corundum from Malawi with flat, rounded, transparent, doubly refractive crystal inclusion. 35X.

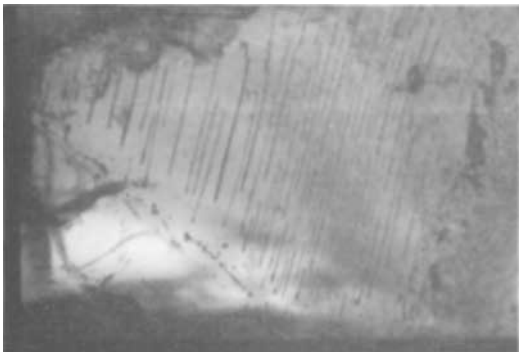

Fig. 11. Ruby from Malawi showing liquid feather, consisting of elongated, more or less parallel orientated cavities, containing two immiscible liquids or both liquid and gas. 30X.

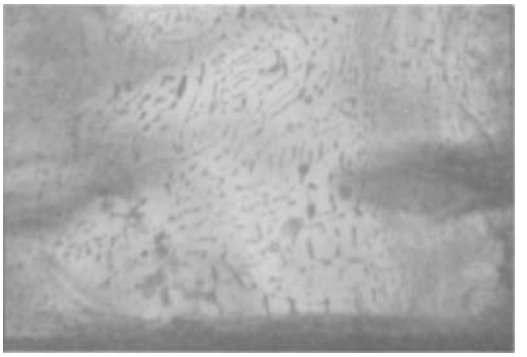

Fig. 12. Ruby from Malawi with liquid feather, consisting of irregularly shaped cavities, generally filled with liquid and gas. 35X.

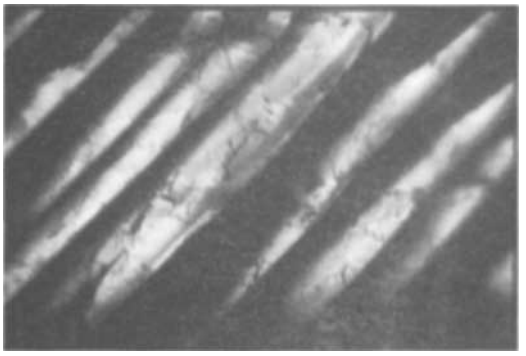

Fig. 13. Ruby from Malawi showing lamellar twinning. Crossed polars. 10X.

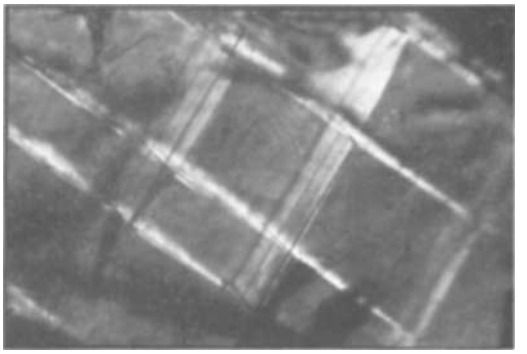

Fig. 14. Ruby from Malawi with twinning lamellae orientated parallel to the rhombohedral planes of the corundum host. Crossed polars. 15X.

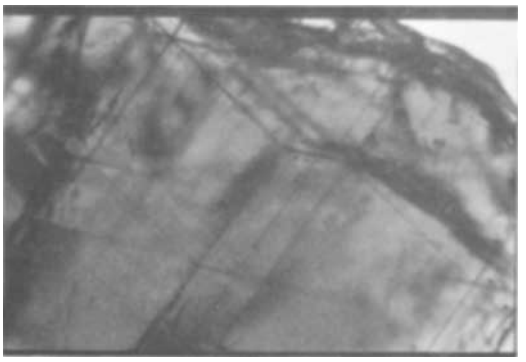

Fig. 15. Ruby from Malawi with thin hollow tubes, filled with doubly refractive mineral substance (boehmite?). 15X.

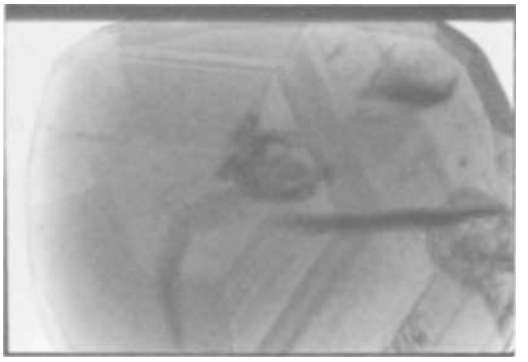

Fig. 16. Ruby from Malawi showing distinct colour zoning. 10X.

ably boehmite (Figure 15). Typical growth structures showing hexagonal symmetry perpendicular to the *c*-axis of the corundum host crystal have been observed (Figure 16). In some stones the colour is distributed along these growth planes. Such colour zoning is sometimes visible by the naked eye.

Conclusions

Production of corundum in the East African state Malawi started at the end of the fifties of this century, but for a long time nothing was reported about the occurrence and the mining. In 1988 red and orange corundums were obtained from that locality, sometimes showing fine gem quality. The rubies enclose a remarkable variation of colour intensity from pale red to dark red. In relation to that variation of colour intensity an alteration of the physical characteristics such as refractive indices, birefringence and specific gravity was demonstrated. The variation of the physical values is due to the concentrations of the trace elements chromium and iron.

Acknowledgements

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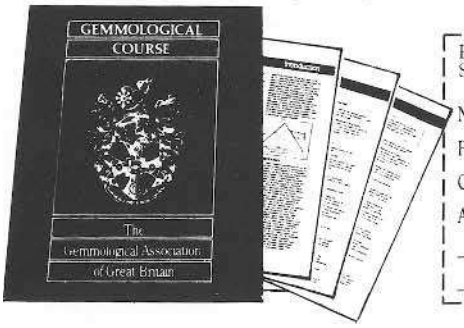

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The diamond drill used in the Cambay bead industry

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Abstract

A simple but very effective diamond-tipped bow drill constructed by indigenous technology is being used by the Cambay lapidary to perforate tough and hard silica beads. To start with a single diamond drill is used for marking and then further full length drilling is carried out by a double diamond bit driller. Each bead is perforated from both the ends so as to meet at the centre. Construction of the primitive, yet efficient, bow drill unit; intricacies of the mechanism of single as well as double diamond bit drill and the resultant features will be discussed in the paper.

Introduction

Perforation of hard and tough stones like chalcedony is a highly difficult job. However, it is being executed at ease by the lapidary of Cambay with the help of primitive diamond-tipped bow drill at an astonishing speed. It takes less than a minute for drilling a bead of one centimetre diameter.

Cambay (Khambhat:22°19′N and 72°38′E) is a large town in western India, situated at the estuary of Mahi River which flows into the Gulf of Cambay. The town is known for gem cutting for more than two thousand years. Archaeological excavations have unearthed a large number of ornamental beads processed in the Early Historic times (Mehta, 1968). Even today a majority of its population is involved in gem cutting.

According to Janaki (1972), Cambay was an important international trade centre since the 10th Century AD from where gemstones were among the important items exported. Arkell (1937), Possehl (1981), Francis (1982) and Karanth (1988) have given the details of bead making in Cambay. Recently Gorelick and Gwinnett (1988) have attempted to interpret the mechanism of drilling of beads with the help of the scanning electron microscope (SEM) pictures of drill hole impressions. Their explanations are, however, inadequate. The present author, having studied the Cambay bead industry for nearly a decade, is attempting to give a detailed account of diamond-tipped drilling carried out by the artisans of Cambay.

Construction of bow drill

To construct a bow drill, it requires neither great expertise nor expensive gadgets. But for the diamond bits, the drill unit can be constructed from the materials thrown out at a junk yard. Even the diamond bits used are not specially splintered or cut, but they are the discarded rough pieces that are unfit for jewellery purposes. A look at the materials used for its construction can explain to a greater extent how a bead can be sold at a fraction of a penny.

The bow drill consists of two main units (Figure 1), viz. (1) the *bow* made from a long bamboo stick measuring about three-fourths of a metre and a loosely-tied thick strong string and (2) the *arrow* consisting of a wooden rod about 12-14cm long, 1cm thick fixed with metal sticks at either end. Generally the metal stick used is the steel rib meant for holding umbrella cloth. The upper metal stick is about 1cm long and the length of the lower one depends on the length of the bead to be drilled (usually 2-3cm long). The top of the drilling end is provided with a diamond bit.

For perforating, the string of the bow is tied around the drill-shaft with one loop and driven to and fro by one hand while the other hand is busy in pressing the drill-shaft against the bead. In order to protect the palm from the upper steel rib, a piece of coconut shell is kept in between. To have a better grip over the bow, the artisan prefers to tie the bow-string around his forefinger with one loop. Tying the string around his skilful index finger also helps in producing subtle changes in the movements of the drill-shaft.

The bead to be perforated is placed on a wooden platform (Figure 1). A slit is provided in the platform for holding longer beads in proper position at the time of boring. The slit is held tight with the help of a metal ring. At the time of drilling water is made to fall drop by drop on the bead which acts as a coolant as well as lubricant. It is quite appropriate to mention the way water is transported.

The earthenware pot used for holding water is bored with a hole and a tubular earthenware piece is cemented to it. A metal stick is inserted deep into

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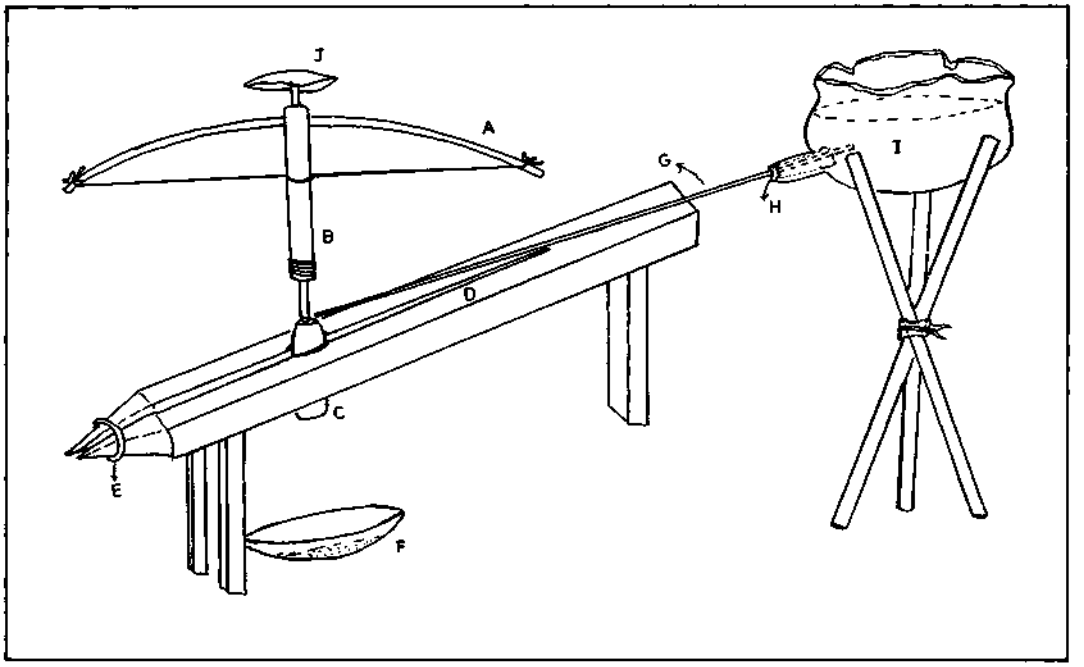

Fig. 1. Complete drilling unit: A – bow with string; B – drill shaft; C – bead; D – wooden platform; E – metal ring for tightening; F – earthen bowl for collecting mixture of silica powder and water; G – water transporting stick; H – cotton cloth; I – water pot; J – coconut shell.

the tube with a piece of cotton cloth around it. Water creeps through the damp cloth and is eventually transported along the stick and finally falls on the bead. The cloth piece is also used in regulating the flow of water by loosening or tightening it. Once again the metal stick used here is the umbrella rib.

It is interesting to note that almost invariably the pots used here are broken at the rim. Either the driller has picked up a broken pot discarded at the junk yard or he has not bothered to replace it when the rim is broken. The explanation given by a lapidary is 'whether broken or whole, it serves the purpose'.

Drilling is executed in two steps, viz., (1) marking and (2) full length drilling. Different drill points are used for these two purposes, namely single diamond bit driller and double diamond bit driller respectively (Figure 2). The bead whether small or long, is bored from both ends so as to meet at the centre thus producing a continuous hole.

To start with, the place for drilling is marked with a shallow depression (Gwinnett and Gorelick, (1988) prefer to call it a guide hole or starter hole) by using a single diamond bit drill. Generally the bead is taken for drilling before the final step of polishing, so that marking the place for boring becomes easier on a rough ground surface. If the bead is already polished, it is again ground at opposite ends for marking. The single bit drill is placed on the bead and rotated with the help of the bow string. Initial play of the rotating drill shaft on the bead results in a rather broader rim (Figure 3: compare A-B with C-D and E-F). The depth of the depression seldom exceeds a millimetre or two. The main boring is performed by using the double bit drill. Whilst drilling the scooped out powder from the bead falls out along with the thin flow of water that drops on the bead and this powder is then collected carefully in a bowl placed below the platform. Not that the artisan is interested to maintain cleanliness of his surroundings from the messy fluid that stains, but it has a special significance which will be described briefly in a later section.

The most important part of the drilling operation is, however, the position of the diamond bit placed at the drilling end.

Diamond bits

Diamond bits used for drilling are of very small dimensions, weighing about 5 cents/point/grains (1 carat = 100 cents), i.e. 10mg. Bits with rugged surface are prepared for boring. If the bit has a smooth surface, such as crystal face, it is made uneven with the help of another diamond fragment.

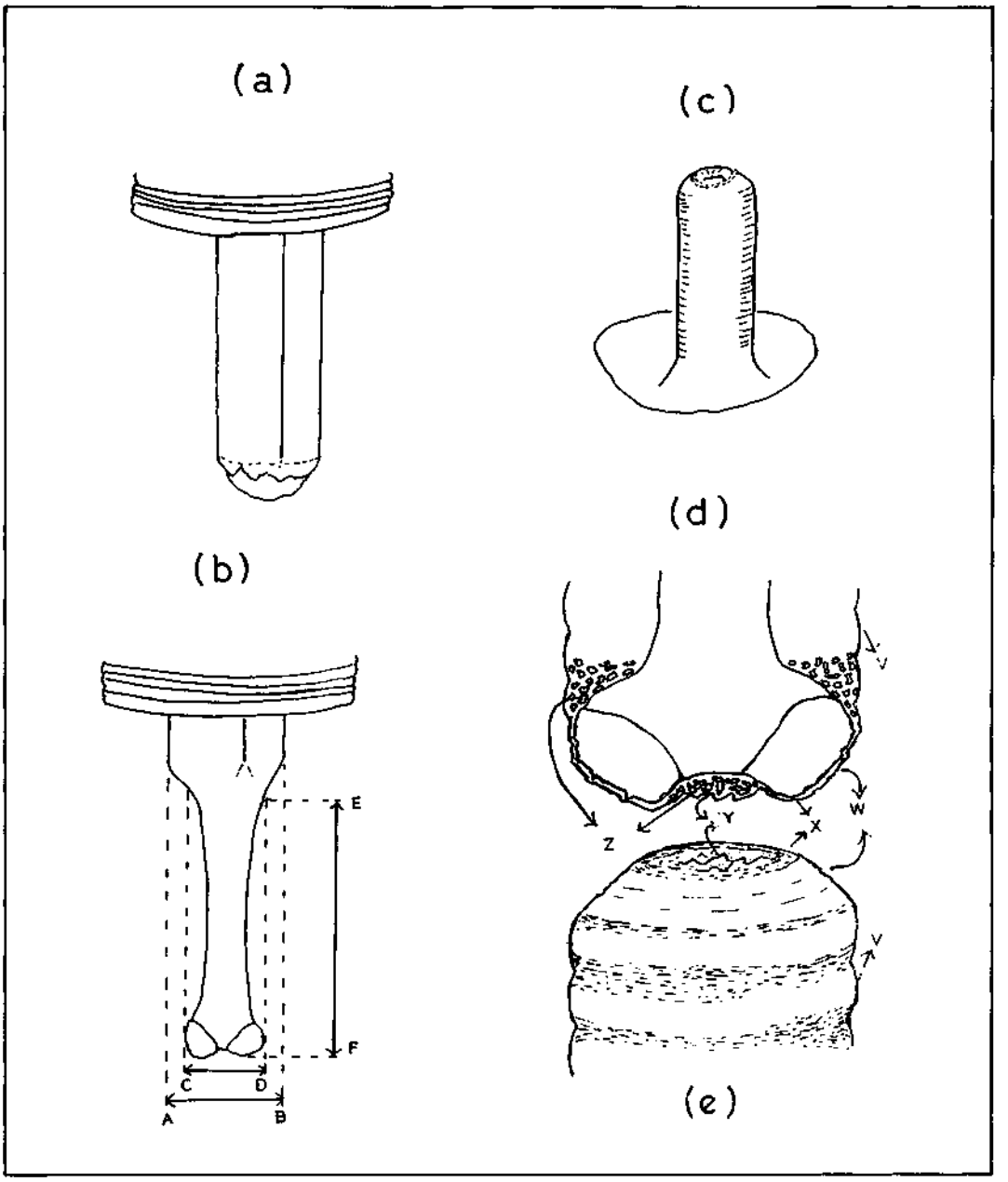

Fig. 2a. Single diamond bit drill with diamond bit fixed in the tip of the metal stick.

Fig. 2b. Double diamond bit drill: A-B – original width of metal stick; C-D – width of leading end; E-F – effective length that can get into drilled hole.

Fig. 2c. Sketch drawn from silicone impression of drill hole: Figure 1a of Gorelick and Gwinnett, 1988.

Figs. 2d. and 2e Cross-section of hole under drilling and sketch of drill hole impression respectively: V – grooved side wall; W – slope of the leading edge; X – deepest part drilled; Y – central elevation at the leading edge showing conchoidal fracture pattern; Z – scraped out and chipped off fragments from side wall and the gap between drill bits.

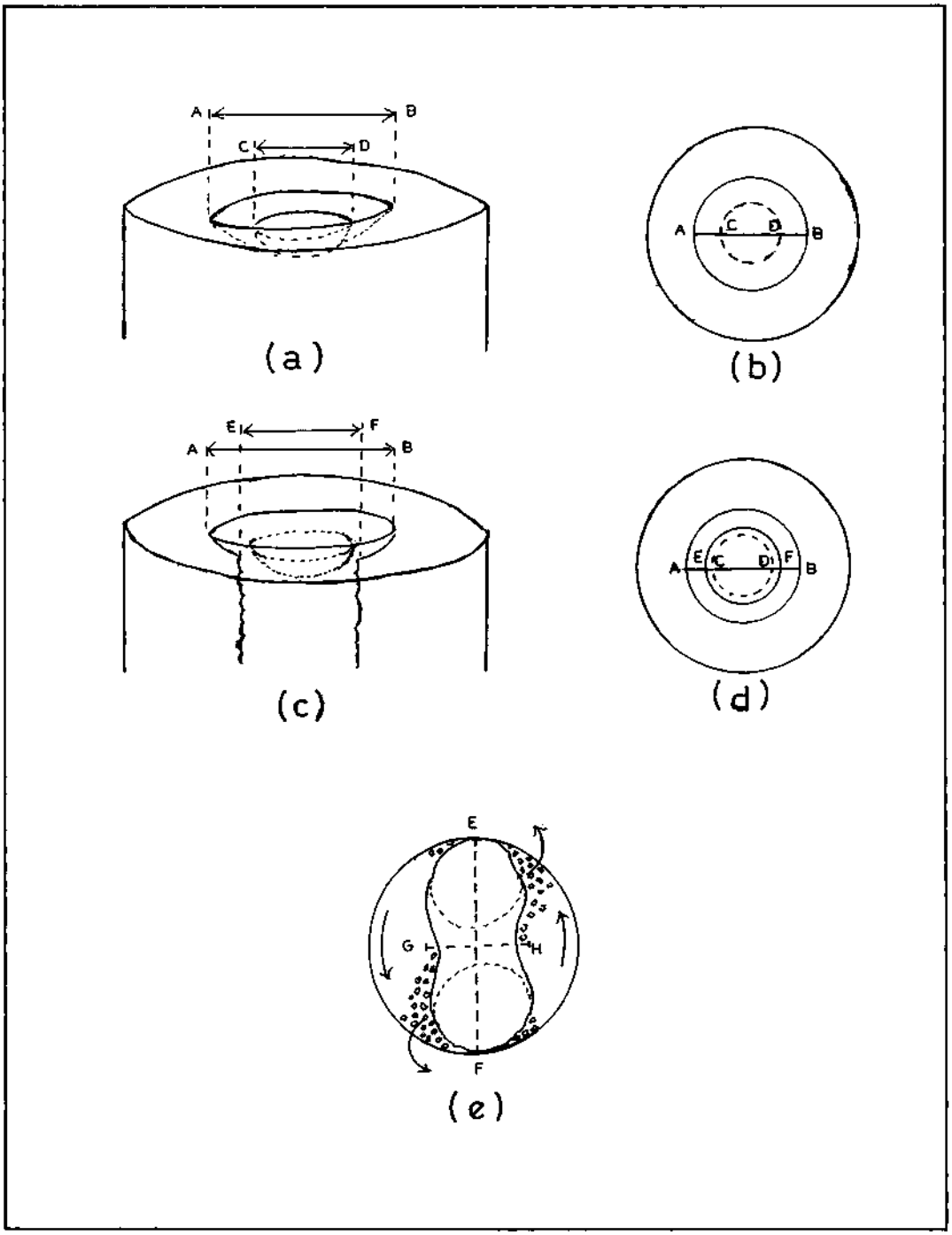

Fig. 3. Patterns produced by single bit (a,b) and double bit (c,d) drills respectively: A-B – width of broader depression created by initial play of marker drill; C-D – diameter of marker diamond bit; E-F – diameter of hole created by double bit driller. Sketch (e) illustrating the width of the broader axis of the double bit drill (E-F) and width of the trimmed metal holder (G-H). Note the space in which cut bead fragments collect.

Interestingly no adhesive or soldering material is used to fasten the diamond bit to the metal stick, but the artisan follows certain indigenously developed methods. For the single bit marker, a depression is carved at the tip of the holder by using a pointed steel rod driven by the bow-string and the diamond bit is then place in it. Further, rim of the carved depression is pressed against diamond bit so that it gets fixed properly in the tip and will not fall off in action (Figure 2a). In the case of the double bit point used for full length performation, initially the metal stick is trimmed with a steel file up to a length that may enter the bead and the tip of it is flattened. Two diamond fragments are placed in the depressions carved on either side of the flattened metal tip (Figure 2b). After placing, the drill bit is hit gently but firmly by a thick metal or wooden piece so that it gets fixed in the metal holder. This action can better be called pressing than hitting. During the act of pressing, the thick metal piece glides over diamond bit and rim of the metal depression clasps diamond tightly.

The single bit marker tip is more or less a permanent arrangement, but in the case of the double bit perforator, the diamond fragment gets loosened and falls off after boring a few beads. The artisan can feel its detachment during rotation. However, the detached diamond bit seldom escapes the alert eyes of the artisan who puts it back in the same way as explained earlier. The broader axis of the drilling tip is always maintained wider than the metal stick that enters the bead, lest the metal stick gets worn out or would not enter the drill hole, (compare E-F with G-H in Figure 3e). Furthermore, the gap produced at right angles to the longer axis of the leading end (Figure 3e) offers space for collecting scooped out bead fragments which pass through the space between the drilled wall and trimmed metal holder. Thus, trimming of the metal stick, flattening of the tip and arrangement of diamond bits are of the utmost importance. Single bit drill is incapable of doing this job as no space is offered by it to displace the scooped material and proceed farther.

Slope of the leading edge (Figures 2d and 2e) depends on the shape and position of the diamond bits used. The conchoidal pattern in the central elevation of leading edge (Figure 2e, sketch drawn after Gorelick and Gwinnett's silicone impressions) can be explained by the following mechanism: while diamond bits scrape out the sides, the central portion situated in the gap between two drill bits remains unscratched. At the same time, the impact of drill bits rotating around the gap forces the bead portion to be chipped off (Figure 2d). Obviously, when silica mineral is chipped off, conchoidal pattern is obtained. Curiously enough, this kind of fractured central elevated portion is not seen in the beads drilled by copper rod and loose grit of emery (Figures 4a and 4b of Gwinnett and Gorelick, 1986). On the contrary, such leading edge is characterized by relatively smooth central elevation. Here the smoothness is entirely due to abrasive action of the loose grit of emery, but not due to the forced chipping that the rotating diamond bits induce.

Each groove in the side wall (Figures 2d and 2e) represents one way movement of the bow, i.e. when the bow is moved to one side, say left, the drill bits carve up to a particular depth, resulting in the development of a groove and again when it is further pressed and moved to the right, the bead is further cut for some more depth resulting in another groove. The shaft rotates for at least 10-12 revolutions in one run of the bow for drilling one groove length. If the movement is continuous in only one direction, the grooves would be having helical pattern (either dextro or laevo) but not in a concentric pattern.

Diamond bits get eroded during the action of cutting and usually last for drilling about 100 bead holes of 5cm length each. Enormous heat is produced during this process, both in the upper metal portion and the drilling end. When both the ends are touched, immediately after drilling, the heat can be felt at the upper metal stick that touches the coconut shell, whereas heat felt in the drilling end is considerably less because of the continuous supply of coolant. A charring effect can be seen at the place where the metal rod pierces the shell.

In this connection it is also worthwhile discussing the fading of grooves in the leading edge that Gwinnett and Gorelick (1988) have observed. Unlike the prominent and deeper grooves of the side wall, the faint grooves are formed by the uneven surface of the cutting slopes of diamond bits. Since two such sloping rugged diamond bits are in action, the grooves carved out by one may be eroded or modified by the other simultaneously rotating bit and thus the leading edge becomes more or less smooth. Even if the grooves are present, they are very faint and shallow.

Scooped out silica powder

The drilled out silica powder is carefully collected in a bowl kept below the platform. The slit provided in the platform ensures that powder suspended in water would not flow elsewhere and be lost, but it would fall directly into a bowl. The powder thus collected is processed further for use as an efficient agent for polishing highly precious stones like ruby, sapphire and emerald. The details of processing, grain size analysis and polishing laps used have been discussed elsewhere (Karanth, 1989). However, the major objection against the Cambay bead is that in

some examples the holes drilled from either side are offset and barely touch each other's side walls resulting in a crooked passage. Driving a string through such perforation becomes exceedingly difficult. The reward of the precious silica powder by-product is the main reason for the Cambay lapidary not going for modern ultrasonic perforator, though the latter does the job of drilling more efficiently producing a continuous and elegant hole. A couple of ultrasonic perforators installed a few years back have been more or less ignored by the lapidaries of Cambay.

Time taken for marking and perforating

Marking with a single drill bit takes only about a couple of seconds, whereas the time taken for full length drilling varies with the length of the bead. As Possehl (1981) has stated, drilling a 5mm bead takes 20 seconds and a 4.5cm bead takes about 7 minutes. On an average about 50 beads of 5cm length can be bored in one day by a single artisan. Longer beads take more time per millimetre as care has to be taken to keep the drill rod in proper alignment with the axis of the bead or else the metal rod bends and consequently might even break or the hole gets misaligned.

Conclusion

Perforating tough, hard silica beads is a specialised art and involves many intricate mechanisms which the Cambay lapidary has mastered. Indeed, often threading the bead with a crooked hole is difficult, nevertheless one would not mind when one sees the effort involved in producing it. Probably crookedness of the perforation adds value to such bead as it is something odd and hence special. After all, not all beads are blessed with crooked holes!

Acknowledgements

Help of the expert lapidary, Mr Vinod Patel of Cambay in providing valuable information is gratefully acknowledged.

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Reflections on reflectivity

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Acting as tutor in the Association's correspondence courses, and helping to run various preparation courses for the Association's Preliminary and Diploma examinations has made me realize that the connecting links between some of the interesting phenomena in gemmology are often overlooked.

While most of us are well aware of the use of immersion techniques in microscopy, have occasionally been inconvenienced by the disappearance of a gemstone in a heavy liquid, and are quite familiar with the reflectivity meter, the connection, particularly at the student level, may not have been made between these practicalities and the vital relationship which links them together.

This relationship is the one which exists between reflectivity and refractive index which (for an isotropic mineral with the incident light at normal to its reflecting surface*) is quantified in the simplified version of Fresnel's equation[1]:–

Reflectivity (ratio of reflected to incident light intensity) = $(n-A)^2/(n+A)^2$

Where n = refractive index of gemstone.

A = refractive index of surrounding medium (for air = 1)

For example, expressed as a percentage:–

reflectivity of diamond = 17%

reflectivity of quartz = 4.5%

When a gem is immersed in a liquid whose RI is close to that of the gem, the value of A in the numerator section of the Fresnel equation approaches that of n, and the resultant reflectivity from the surface of the gem falls towards zero. In the case of the immersion microscope this reduces the amount of unwanted surface reflections from the facets of a polished gem and allows more light to enter the stone. The same circumstance explains why a gemstone sometimes 'disappears' in a heavy liquid whose RI is close to that of the gem, and this can also be used as a means of estimating the RI of a gem by the immersion and the Becke Line methods.

The third link is with the reflectivity meter which depends on the Fresnel relationship between reflectivity (lustre) and refractive index for its operation. Although not capable of giving readings with the same degree of precision as a refractometer and being much more dependent on the cleanliness and condition of a gem's surface, the reflectivity meter has the big advantage of being able to identify diamond and its high RI simulants.

As a gem instrument it has a long history. The first device of this kind for gemstone identification was developed in 1959 by L.C. Trumper[2], who was awarded a Research Diploma by the Gemmological Association for his thesis on the measurement of RI by reflection. His instrument took the form of an optical comparator in which the intensity of reflection from a gem's surface was visually matched against a calibrated and manually adjustable source of illumination. However, because it was too complex for economic manufacture it was not exploited commercially.

The advent of the low-cost reflectivity meter had to await the introduction of the miniature light-emitting diode and its associated photo-detector. As the most efficient LED available emitted its peak energy in the near infra-red at around 830nm, this also favoured the instrument's ability to separate diamond from strontium titanate. Despite the fact that at the sodium wavelength of 589.3nm the refractive indices of these two materials are very close, at 830nm the large difference in their dispersions makes their effective RIs easily separated by the reflectivity meter.

Since the introduction in 1975 of the first commercial reflectivity meter[3,4] (the 'Gemeter' – Figure 1), there have been many versions of varying sophistication. Perhaps the simplest of these was the Hanneman 'Jeweler's Eye'[5]. Of the more complex models, there have been three which illustrate the extent to which a simple concept can be developed.

* For absolute measurement. (When making comparative measurements using a gemmological reflectivity meter, the relationship is sufficiently close to identify anisotropic and isotropic gems. For practical reasons of construction, the incident angle to the normal in most gem reflectivity meters is around 20 degrees.)

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Fig. 1. Gemeter, the first commercial reflectivity meter. The top section of its meter scale is calibrated in RI values 1.4 to 2.7. Printed letters on the lower portion of the scale indicate the meter readings for some of the principal gems (Q for quartz, Z for zircon, D for diamond, etc.).

Fig. 2. The Martin Gem Analyser was the first reflectivity meter to use pulsed infra-red illumination which minimized the effect of ambient light entering through the rear of the stone under test.

The first of these was the 'Martin Gem Analyser'[6] (Figure 2) which introduced pulsed infra-red illumination/detection (Figure 3) as a means of combating the effect of spurious light entering the back of the stone under test.

The next major innovation was the 'Gemexpert'[7] (Figure 4) which used a microcomputer to store the reflectivities of gems and identify them by name on an alpha-numeric LCD display panel.

My own contribution to the development of the reflectivity meter was the Rayner 'DiamondScan'[8] (Figure 4). This is a reflectivity probe using an LED display for the identification of diamond and its simulants, and, as far as I am aware, the only version to use fibre optics to achieve incident illumination at normal to the gem's surface.

The refractometer, which exploits the critical angle resulting from the optical contact between the surface of its prism and that of the gem under test, also relies partly on reflection for its operation, as it is the light striking this surface at angles greater than the critical angle that is reflected back into the prism to illuminate the bright section of the scale. However, there are two other practical aspects of the

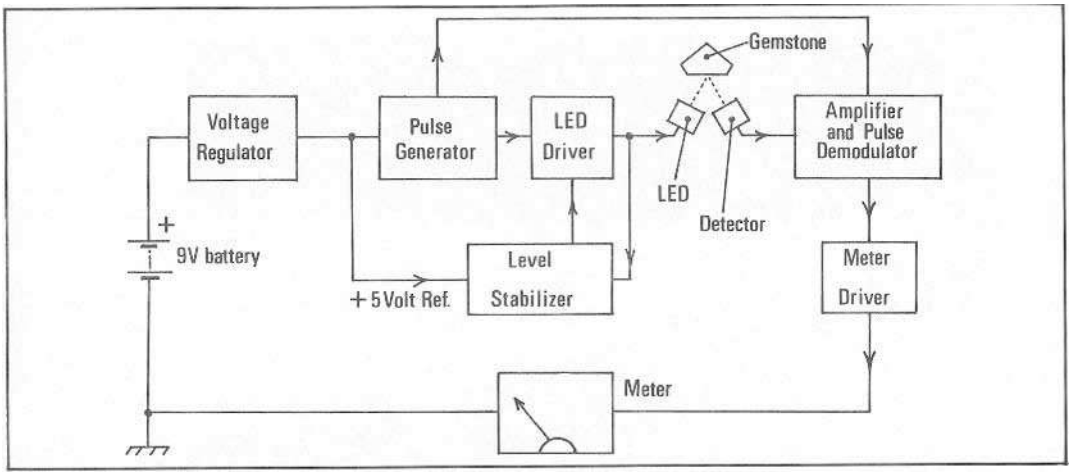

Fig. 3. Block diagram of Martin Gem Analyser circuit, showing a method of pulsing the infra-red LED and decoding the resultant reflectivity signal from the photo-detector.

critical angle of a gemstone, both of which are connected with reflection.

The most important of these concerns the lapidary and diamond polisher, who determines the angles and proportions of a gemstone to achieve an optimum total internal reflection of light rays entering its crown facets. The critical angle of a gem is related to its refractive index as follows:–

$$\text{Critical angle} = \text{the angle whose sine} = \frac{\text{RI of rarer medium}}{\text{RI of denser medium}}$$

With air as the rare medium, critical angle = arc.sine

$$\frac{1}{\text{RI of gemstone}}$$

For diamond the critical angle is 24.43 degrees (compared with 40.33 degrees for quartz). Rays of light entering the crown facets to meet the pavilion facets at angles greater than this will be totally internally reflected (rays 1 in Figure 6), but those rays meeting the pavilion facets at less than this angle will be refracted out of the pavilion (ray 2 in Figure 6).

However, if the pavilion facets of a gemstone become coated with grease (or, as frequently happens, with soap!) the RI of the medium surrounding the pavilion increases, typically to 1.6. Diamond, with its affinity for grease, is particularly vulnerable in this respect and such a coating would result in an increase in the critical angle to around 41 degrees, with the consequent loss of rays through the pavilion facets and a reduction in the stone's overall brilliance.

To complete this brief survey of inter-related reflectivity phenomena, I will mention one that is of

Fig. 4. The GfD Gemexpert contained a microprocessor which enabled it to display the name of the gem under test on its LCD panel.

Fig. 5. The Rayner DiamondScan used fibre optics to produce an 0.75mm diameter infra-red beam at normal to the test surface. For large stones it could be fitted with an end cap which provided a flat reference face.

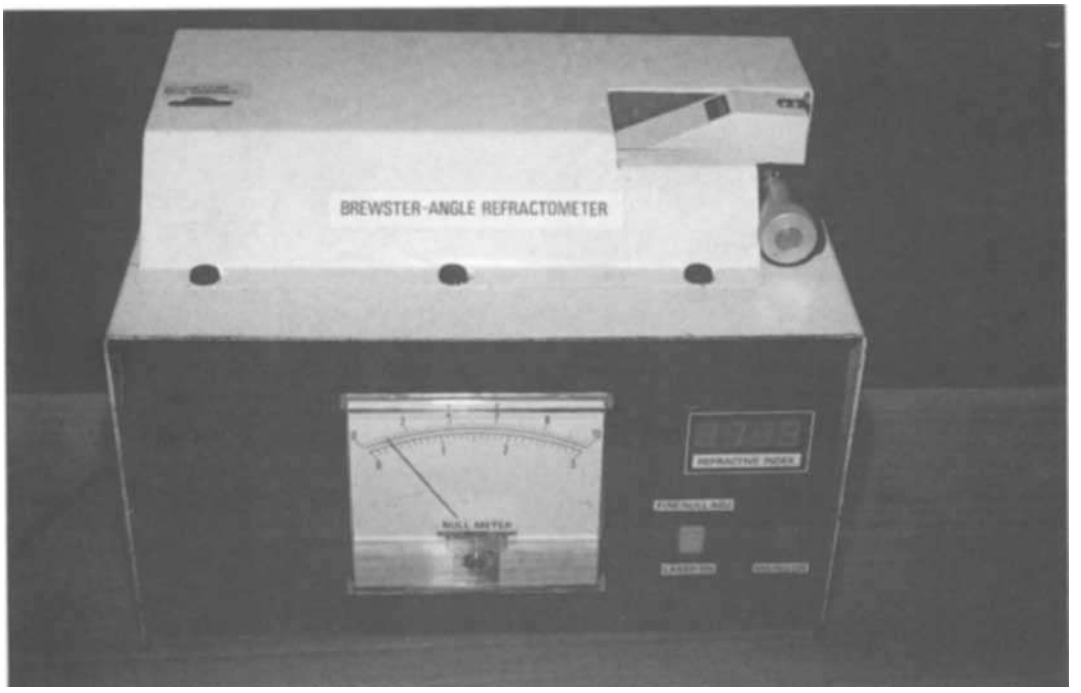

Fig. 7. The latest version of a Brewster-angle refractometer developed by the author. The instrument uses a small polarized laser. The reflected ray from the gem under test is displayed on the null meter in the centre; the laser beam angle is adjusted (by means of the knurled edge control at the top left) for a minimum reading, and the resultant RI reading is displayed on the LED panel meter on the right.

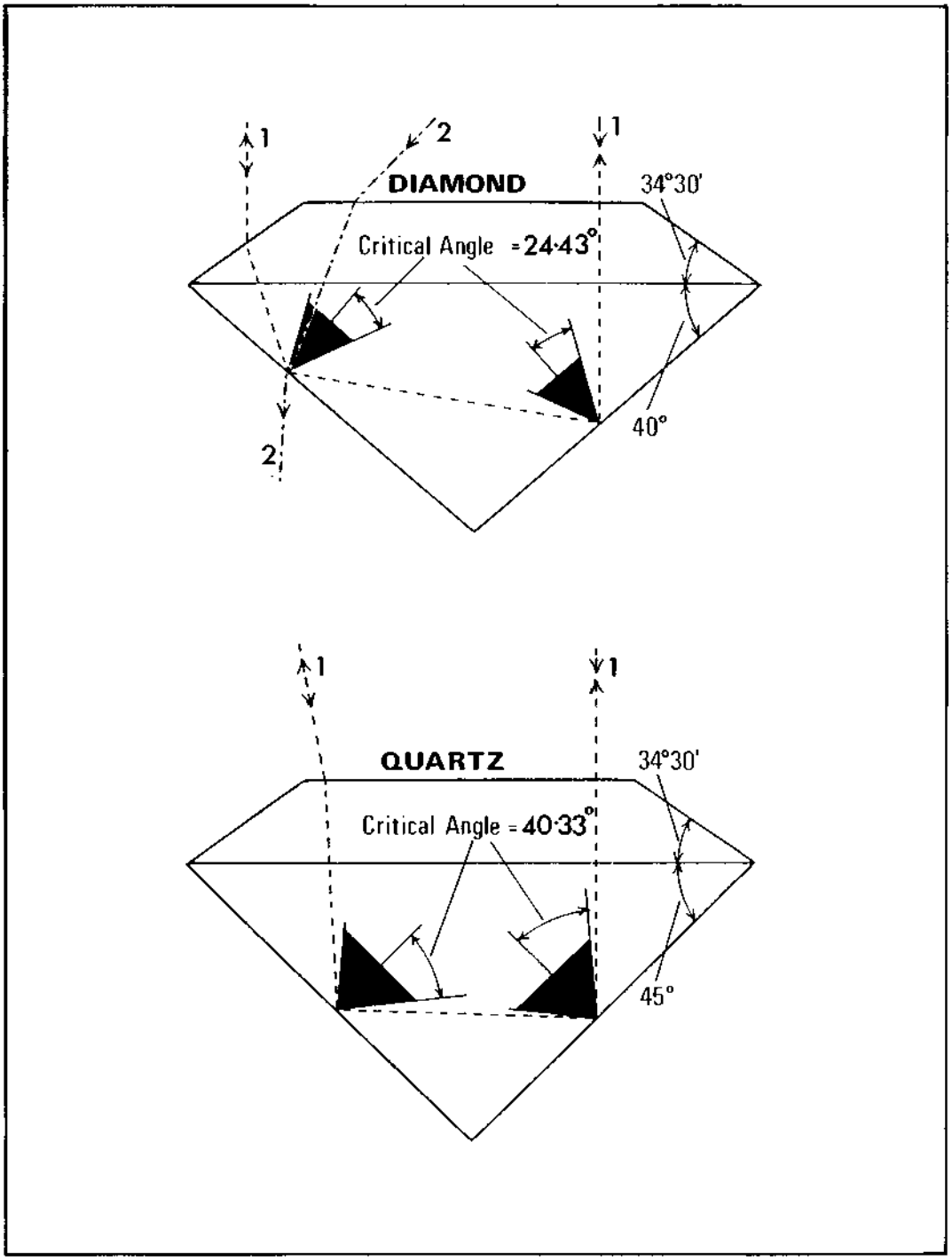

Fig. 6. Showing how the brilliance of a polished gem (in terms of total internal reflection) depends on its cut which in turn is dictated by the critical angle of the gem. Ray 2 in the top illustration indicates how light rays entering the cone of the critical angle are refracted out of the pavilion. The lower illustration shows how the pavilion of a quartz gem has to be cut deeper to achieve a similar total internal reflection (for ray 1) as shown in the diamond above it.

particular interest to me – the Brewster-angle of polarisation. This is the angle at which only those rays whose plane of polarization coincides with the plane of the reflecting surface obey the laws of reflection.

An historic application of this phenomenon occurred in an early polariscope, which used a plate of glass tilted at the Brewster-angle to produce polarized light.

Naturally-occurring polarized light is also produced as the result of the Brewster-angle of polarization. It is generated from horizontal surfaces such as water, and its glare can be reduced by means of vertically-polarized sun glasses.

Of more relevance to gemmology is the law relating the Brewster-angle of polarization of a material to its refractive index. Brewster's law states that complete polarization of light reflected from the surface of a denser medium occurs when it is normal (i.e., at right angles) to its associated refracted ray in that medium. From this, the relationship between a material's Brewster-angle and its RI can be formulated:–

RI of reflecting material = tan of its Brewster-angle

The first person to make use of this relationship to measure the refractive index of a gemstone was B.W. Anderson[9], who in 1941 used the newly introduced Polaroid filter sheet to confirm the practicality of this method. Thirty-eight years later I too built an experimental refractometer[10] using the Brewster-angle phenomenon (an even simpler instrument was proposed in the same year by R.M. Yu of Hong Kong University[11]). When a relatively low-cost polarized laser became available I was finally able to translate my simple optical model into an elecronic version[12].

With the assistance f the Rayner Optical Company, this latest example of the exploitation of reflection in the aid of gemmology has been developed into an instrument with an RI measuring range of 1.4 to 3.3 and with the ability to measure double refraction from 0.01 upwards (Figure 7).

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Gemmological Abstracts

AKIZUKI, A., 1989. Growth structure and crystal symmetry of grossular garnets from the Jeffrey mine, Asbestos, Quebec, Canada. *American Mineralogist*, 74, 859-64, 4 figs.

Orange garnets from the Jeffrey mine, Asbestos, Quebec, Canada, may show non-cubic symmetry and birefringence. Study of the ordered atomic arrangements show that the symmetry is monoclinic. Some colourless and green grossular crystals show orthorhombic symmetry though some parts are strained. These findings do not apply to all grossular garnets from this locality. M.O'D.

ARANYAKANENI, P., 1989. Amphoe Bo Phloi. A New Thai sapphire deposit. *Wahroongai News*, 23, 7, 7-12.

Reprinted from *The Great Mine of Thailand*, published by SAP Mining Co. Ltd, this is a long account of a new deposit on a hillside about 40km from Kanchanaburi which is itself about 130km west of Bangkok. Sapphires are found in basalt, some of which is columnar. Alluvial deposits concentrate the sapphire but are often found as hard conglomerates. The paper is concerned almost entirely with geological provenance and the occurrence of the sapphire-bearing load and gives little indication of quality, sizes and quantities found. But deposits are apparently mined with some enthusiasm so the find is probably an important one in an area already known for its sapphires. [On a personal note, abstractor is fairly certain that Kanchanaburi relates closely to 'Kanburi', one of the many terrible prisoner-of-war camps on the route of the Burma/Siam railway along the River Kwai. He missed those camps by the skin of his teeth in 1943 and was shipped up to northern Japan instead. But a great many good friends died on that appalling railway.] R.K.M.

BALFOUR, I., 1989. Famous diamonds of the world, XLII. The Agra. *Indiaqua*, 54, (1989/3), 171-5.

The Agra diamond, a light pink cushion-cut stone weighing 41.25ct, was said to have been worn in the turban of the first Mogul ruler, Babur. The city of Agra, from which the gem takes its name, was founded by the Mogul emperors as their capital and is the site of the Taj Mahal.

In 1844 a diamond thought to be the Agra was acquired by the Duke of Brunswick. Later, this stone was recut to 31.4 ct (32.24 metric carats) to eliminate some internal black spots. After a complicated history, described in detail by the author (and updated in this article subsequent to the publication of his book *Famous diamonds* in 1987), a 31.5 ct pink diamond believed to be the Agra was purchased for 82,000 francs at a Paris auction in 1909. It is now in private ownership. P.G.R.

BANK, H., HENN, U., 1989. Changierender Taaffeit aus Sri Lanka. (Colour-changing taaffeite from Sri Lanka.) *Zeitschrift der Deutschen Gemmologischen Gesellschaft*, 38, 2/3, 89-94, 5 figs (1 in colour), graph, bibl.

The taaffeite from Sri Lanka weighed 12.23 ct and showed a colour change from reddish to blue. RI 1.724-1.720, DR 0.004, SG 3.61. The absorption spectrum showed typical bands caused by Fe^{2+} and is characterized by absorption minima in the red and blue range and an intense maximum in the green. E.S.

BANK, H., HENN, U., 1989. Farbloser, klar durchsichtiger, geschliffener Sellait aus Brasilien. (Colourless, clear transparent, cut sellaite from Brazil.) *Zeitschrift der Deutschen Gemmologischen Gesellschaft*, 38, 4, 143-5, 2 figs, bibl.

The faceted, cut, colourless, transparent specimens were said to come from the Brumado mine in Bahia, Brazil. RI 1.378-1.390, DR 0.12, SG 3.15. Microscopic examination showed multiple growth tubes, flat, irregularly shaped cavities with liquid gaseous filling, as well as three-phase inclusions. Sellaite is a magnesium fluoride. E.S.

BANK, H., HENN, U., 1989. Gemmologische Kurzinformationen. Schleifwürdiger, transparenter blauer Saphir aus Kenia. *Zeitschrift der Deutschen Gemmologischen Gesellschaft*, 38, 2/3, 105-6, bibl.

Describes a cuttable, transparent, blue sapphire from Lodwar on Lake Turkana in Kenya. There was lamellar twinning and distinct growth structures. E.S.

BANK, H., HENN U., 1989. Gemmologische Kurzinformationen. Ein ungewöhnlicher Granat aus Ostafrika. *Zeitschrift der Deutschen Gemmologischen Gesellschaft*, 38, 4, 161-4, 2 figs, bibl.

Describes an unusual orange-brown garnet from

East Africa weighing 64.47 ct. RI 1.739, SG 3.74, found to be a pyrope-spessartine mixed crystal containing grossular as well as almandine. E.S.

BANK, H., HENN, U., PETSCH, E., 1989. Gemmologische Kurzinformationen. Spinelle aus dem Umba-Tal, Tansania. *Zeitschrift der Deutschen Gemmologischen Gesellschaft*, **38**, 4, 166-8, 1 fig., bibl.

Deals with spinels from the Umba Valley in Tanzania. The spinels were of pink, red, orangish-red and bluish-violet colour, RI 1.713-1.718, SG between 3.54-3.69. Colouring matter determined by spectroscopy. E.S.

BANK, H., HENN, U., SCHMIDT, S.TH., 1989. Gemmologische Kurzinformationen. Hochlichtbrechender Rubin aus Malawi. *Zeitschrift der Deutschen Gemmologischen Gesellschaft*, **38**, 2/3, 106-8, 1 table, bibl.

Describes a ruby from Malawi, RI 1.770-1.780, DR 0.01, SG 4.05. The stone was found about 50 miles south of Lake Nyasa. E.S.

BANK, H., PLATEN, H.V., AMARASINGHE, A.G.B., 1989. Gemmologische Kurzinformationen. Saphirblauer, durchsichtiger Sapphirin aus Sri Lanka. *Zeitschrift der Deutschen Gemmologischen Gesellschaft*, **38**, 2/3, 103-5, 4 tables, bibl.

Describes a sapphire-blue, transparent stone from Sri Lanka which was identified as sapphirine. RI 1.704-1.711. E.S.

BEATTIE, R., 1989. Personalities behind the gem world: Kokichi Mikimoto 1858-1956 [1954?]. *Wahroongai News*, **23**, 6, 27-30.

A concise biography based on Eunson's book *The Pearl King*, about the first successful producer of spherical cultured pearls. Born in humble circumstances only five years after Commodore Peary landed in Japan, forcing that country out of the feudal system and into the modern world, Mikimoto by sheer hard work and dedicated purpose throughout his long life eventually achieved what has to be seen as a major advance in the world of gems. R.K.M.

BERK, M., 1989. New from New England. *Lapidary Journal*, **43**, 8, 44-8, 2 figs in colour.

Amethyst has recently been found at locations in Maine and New Hampshire, USA. M.O'D.

BILLE, C., CHAPOULE, R., DORBES, J., SCHVOERER, M., 1989. Reconnaissance d'un diamant de synthèse De Beers parmi d'autres gemmes grâce a la cathodoluminescence. (Recognition of a De Beers synthetic diamond from others thanks to cathodoluminescence.) *Revue de Gemmologie*, 100, 19-21, 4 figs (2 in colour).

Cathodoluminescence was able to distinguish a De Beers synthetic diamond from natural diamond, YAG and zircon, giving a strong characteristic emission line at 520nm. M.O'D.

BIRMINGHAM, J.C., 1989. Mourning jewellery. *Australian Gemmologist*, **17**, 3, 82-4, 4 figs.

A brief history of memorial jewellery through the ages. R.K.M.

BORELLI, A., 1988. A brief note on problematical yellow-brown diamond. *La Gemmologia*, **13**, 3/4, 27-32, 6 figs in colour.

A brilliant-cut stone of yellow to yellowish-brown colour with zoning along possible crystal faces was identified as natural diamond. No trace was seen of absorption in the 594nm region though lines were observed at 478 and 415.5nm, though the latter was difficult to detect. Under LWUV the stone showed a strong bluish-white to nearly white fluorescence and a persistent yellow phosphorescence. Under SWUV the stone gave a medium intensity bluish-white to pale yellow. M.O'D.

BRACEWELL, H., 1989. Wave Hill prehnite. *Australian Gemmologist*, **17**, 4, 127-8, 7 figs in colour.

Gives details of prehnite bearing areas near Kalkaring, south of Darwin. Colours white, through green, yellowish-green and yellow; SG about 2.87; RI 1.614-1.637, quite variable; H 6-7; fluorescence under LUV dull brown; absorption band vague at 440nm; some material is facetable. R.K.M.

BROWN, G., 1989. Dayboro variscite. *Australian Gemmologist*, **17**, 3, 98-100, 4 figs in colour.

Once thought to be bluish-green turquoise, this hydrated aluminium phosphate is now identified as variscite, found at nicely named Mt Scrubbytop, Queensland, it occurs in thin veins and, more rarely, in nodules in a blackish chert. H 4, SG 2.4, RI 1.56, all appreciably lower than turquoise constants. Chalky green fluorescence in LUV. No absorption bands. R.K.M.

BROWN, G., 1989. Kauri gum revisited. *Wahroongai News*, **23**, 10, 21-8, 4 figs and sketches.

An excellent account of a comparatively unconsidered New Zealand gem material, based at least in part on the work of the GANZ study group. Found only in the north of North Island, the gum can be either fossil, possibly of great age, or recent. Kauri trees are still thriving so can be bled for the gum even today. This paper covers history, mode of occurrence, prospecting and 'mining', plus gemmological and other testing. SG 1.03 to 1.09, increasing

with age; RI 1.54; young gum is more soluble in ether than amber, but this decreases with age of the gem; alcohol is perhaps a better solvent but again it will not distinguish ancient fossil kauri gum (perhaps 30m years old) from amber (similar age?); UV fluorescence is variable and very similar to that of amber. Crazed surface is much more common in young kauri gum, but can occur in amber. General conclusion is that it would be hard to distinguish between the better fossil qualities of kauri gum and amber. R.K.M.

BROWN, G., BRACEWELL, H., 1989. Yundamindera 'fire' opal. *Australian Gemmologist*, 17, 3, 101-3, 8 figs in colour.

Yellowish-brown to amber common opal is found at this attractively named semi-desert locality in Western Australia. SG about 2, RI 1.42, inclusions: flow structures and dendrites, no play of colour, but an attractive gem which 'deserves greater promotion'. R.K.M.

BROWN, G., KELLY, S.M.B., SNOW, J., 1989. Russian hydrothermally-grown emerald. *Australian Gemmologist*, 17, 3, 103-5, 6 figs in colour.

These synthetic emeralds are generally eye-clean but microscope reveals characteristic phenakite based 'dagger' inclusions, partly healed cracks, wavey growth patterning, occasional brassy metallic needles. Colour dark bluish-green; Chelsea filter gives green; inert to UV; dichroism blue and green. RI 1.571-1.579, DR 0.009, SG 2.76. Investigators report that 680nm fluorescent doublet was no seen [but it is listed in their table of properties]. Physical properties overlap those of natural emerald, so inclusions are vital for identification. R.K.M.

BROWN, G., SNOW, J., 1989. Some observations on helenite. *Australian Gemmologist*, 17, 3, 88-90, 5 figs in colour.

An American olive-green glass said to be made from 'pure' volcanic ash from the Mt St Helen's eruption in Washington State in 1980, some specimens from pure ash and some from ash 'diluted' with glass. Discs of the latter are cut from rods spun from highly viscous glass and retain marked concentric lamellae. SG 2.448, RI 1.508, grains of possible ash, bubbles and swirls were seen. R.K.M.

BURT, D.M., 1989. Vector representation of tourmaline compositions. *American Mineralogist*, 74, 826-39, 21 figs.

Instead of the traditional triangular method of representing tourmaline group composition, a vector method is proposed. This method has been used successfully for the mica and amphibole mineral groups. M.O'D.

BUZAS, Z., 1989. Interessante Einschlüsse in mexicanischem Opal. (Interesting inclusions in Mexican opal.) *Lapis*, 14, 10, 27-8, 2 figs in colour.

Quartz crystals are reported as inclusions in opal from Queretaro, Mexico. M.O'D.

CAMPBELL, I.C.C., 1989. Visual structural differences between elephant ivory, bone and vegetable ivory. *South African Gemmologist*, 3, 3, 20-7, 17 figs (11 in colour).

Scrapings of elephant ivory, bovine bone, vegetable ivory and walrus tusk are examined and photomicrographs illustrated. M.O'D.

CAMPBELL, I.C.C., KLEYENSTÜBER, A.S.E., 1989. An alexandrite of apparent Hematita origin. *South African Gemmologist*, 3, 4, 8-11, 7 figs in colour.

An alexandrite reported to have come from the Hematita deposits in Brazil showed quartz and kaolin traces on electron microprobe analysis, suggested a pegmatitic origin. The traces appear to have come from inclusions breaking the surface. M.O'D.

CASSEDANNE, J.P., 1989. Diamonds in Brazil. *Mineralogical Record*, 20, 5, 325-36, 16 figs.

The paper gives a history of the working and discovery of diamond in Brazil. By the end of the 1700s Brazil was the world's leading diamond producer, only yielding this place to South Africa in the nineteenth century. Typical crystal forms are illustrated and there is a map of the diamond-bearing areas. A table lists some of the major diamonds found in Brazil. M.O'D.

CASSEDANNE, J.-P., 1989. Découverte d'un nouveau gîte d'émeraude. *Revue de Gemmologie*, 98, 3-4, 7 figs (1 in colour).

Emerald is reported from a ravine called Riacho do Mamao, Fazenda Paioli (Capoeirana), in the municipality of Nova Era. The area is about 90km ENE from Belo Horizonte, Minas Gerais, Brazil. The established Belmont emerald mine is only about 10km distant from the new site. Stones examined have SG 2.660, RI 1.577-1.584, with DR 0.007. There is no luminescence nor radioactivity. Pleochroism is greenish-blue/pale yellowish-green and crystals consisting of broken prisms with signs of corrosion and frequently colour-zoned are found in schists close to pegmatite bodies. Two-phase inclusions are reported but no mineral inclusions. M.O'D.

CASSEDANNE, J., 1989. Maricota, un nouveau gisement d'andalousite (Minas Gerais, Brésil). (Maricota, a new location for andalusite, Minas Gerais,

Brazil.) *Revue de Gemmologie*, 100, 7-9, 6 figs in colour.

Green and rose-coloured andalusite is reported from a new location named Maricota in the Fazenda Lageadão, 40km north-east of Araçuai and 10km west of Itinga, in the north-east of the Brazilian state of Minas Gerais. The colour of faceted stones is olive-green to yellowish-green and rose colour. Pleochroism gives a pale olive green to a violet-red. The material is found in quartz. M.O'D.

COZAR, J.S., 1989. Determinación de rasgos de tratamiento, en topacios azules irradiados, por espectroscopia gamma de alta resolución. (Determination of signs of treatment in irradiated blue topaz, using high-resolution gamma-ray spectroscopy.) *Boletin del Instituto Gemmologógico Español*, **31**, 8-18, 7 figs in colour.

Gamma-ray spectroscopy is at present the only way to detect treatment of gemstones by ionizing radiations, if these have stimulated activation. Details of the methodology are given. M.O'D.

CROWNINGSHIELD, R., 1989. Grading the Hope diamond. *Gems & Gemology*, 25, 2, 91-4, 5 figs in colour.

A modern assessment of the world's most famous blue diamond by a team from the New York Lab found it to be a 'fancy dark greyish-blue', weighing 45.52 ct, of VVS clarity. No fluorescence in LUV and possibly faint fluorescence in SUV, followed by strong red phosphorescence after SUV. R.K.M.

DAWIDOWICZ, T., 1989. L'influence des inclusions sur la structure cristalline. (The influence of inclusions on crystal structure.) *Revue de Gemmologie*, 100, 23-4.

The paper gives a brief account of crystalline defects and their influence on spectrographic testing methods. M.O'D.

DUBOIS-FOURNIER, J., LENAIN, B., LE MAGUER, D., 1989. La microspectrofluorescence et ses applications en gemmologie. (Microspectrofluorescence and its gemmological applications.) *Revue de Gemmologie*, 100, 15-18, 10 figs (1 in colour).

Microspectrofluorescence is used to detect elements in gemstones – in this case, in corundum. Fluorescence spectra are measured and illustrated and compared with those given by the Verneuil product. M.O'D.

EPSTEIN, D.S., 1989. The Capoeirana emerald deposit near Nova Era, Minas Gerais, Brazil. *Gems & Gemology*, 25, 3, 150-8, 12 figs in colour.

Discovered in 1988 this mine is yielding quantities of gem emerald very similar in quality and properties to stones from the Belmont mine 10 kilometres away. Most are light bluish-green in colour and some best described as green beryl. RI of ten stones tested varied slightly around 1.577-1.583. SG about 2.71. Some had been oiled. No red or pink through emerald filter; two-and three-phase inclusions seen, but unlike the jagged-edged cavities in Colombian stones; biotite and calcite or dolomite were identified; inclusions plentiful but fewer than in the Belmont stones and identical in type. Chemical composition was also consistent with those stones. R.K.M.

EPSTEIN, D.S., 1989. Brazilian trio. *Lapidary Journal*, **43**, 8, 22-8, 4 figs in colour.

Three amethyst-producing areas in Brazil are described, Maraba, Pau D'Arco and Rio Grande do Sul. Differences in the product are discussed. M.O'D.

FRAZIER, S., FRAZIER, A., 1989. Phantoms. *Lapidary Journal*, **43**, 9, 66-80, 3 figs in colour.

The development of phantom crystals, mostly in quartz, is discussed. M.O'D.

FRAZIER, S., FRAZIER, A., 1989. Inter-Agate. *Lapidary Journal*, **43**, 5, 28-42, 5 figs (3 in colour).

The agate deposits in the Idar-Oberstein area of West Germany are described with a note on their

FRITSCH, E., CONNER, L., KOIVULA, J.I., 1989. A preliminary gemological study of synthetic diamond thin films. *Gems & Gemology*, 25, 2, 84-90, 7 figs in colour.

The past two decades have seen diamond or diamond-like carbon (DLC) films grown onto surfaces by a chemical vapour deposition technique from carbo-hydrate gases. DCLs seem easier and it is thought such films might be used on gems to increase resistance to wear. They are mostly polycrystalline but Sumitomo have experimented with producing single crystal diamond on synthetic diamond [to increase size?.

Other possible gemmological uses to improve diamond simulants, or add a diamond surface to softer gems are discussed. The films seem to be detectable with little trouble, and so far there do not appear to be any commercially diamond-coated gems on the market. R.K.M.

FRYER, C.W., (ED.), CROWNINGSHIELD, R., HURWIT, K.N., KANE, R.E., HARGETT, D., 1989. Gem Trade Lab notes. *Gems & Gemology*, 25, 3, 171-6, 15 figs in colour.

'Black onyx' seal stones from Hong Kong were

identified as glass; SG 2.51 and RI 1.53 suggest an effort to get near to chalcedony constants; H 5.5 to 6 was low.

A 2.68 ct 'Old Mine' diamond with a concave table facet probably dated from 1910 when J.L.Gonard patented the cut, to 'increase brilliancy'; it does reduce table reflection. A flat six-sided lozenge of diamond had a central Latin cross machine-engraved and painted black; today the engraving would be simpler by laser. Facet edges of diamonds in a bracelet were abraded, evidentally what used to be known as 'paper-worn'. [This happened when a stone-paper of diamonds was carried around in the pocket of a dealer for a long time; the diamonds did did the damage, not the paper.] A diamond brooch had five dead iridescent green beetles set in it for added colour [a minor Victorian fashion].

Necklace pearls chipped at one end of the drill-hole had been drilled through from the opposite end, instead of half way from each side. A yellowish 'demi-pearl' is illustrated, one end nacreous, the other dull and pitted; why is not known. Pinkish cultured pearls often show traces of dye around the string hole; one is illustrated with a red clot alongside the hole.

A star ruby illustrated is thought to be an early synthetic one and resembles a purplish-red natural star stone; strings of minute gas bubbles looking like silk, and curved striae were seen. A tanzanite had an unexplained iridescent coating which did not affect tanzanite RIs. It was easily removed by an ink eraser. [Hair lacquer deposited accidentally while holding hair in place with the ring hand? Such coatings usually come off with paint stripper!]

R.K.M.

GENDRON, F., 1989. Le jade en Meso-Amérique, symbole de pureté et de vie. (Jade in Central America, symbol of purity and of life.) *Revue de Gemmologie*, 98, 5-10, 6 figs (3 in colour).

The article gives an historical review of the uses of jade in the civilizations of Central America. Useful names and categories are distinguished.

M.O'D.

GODOVIKOV, A.A., BULGAK, L.V., 1989. (Fersman.) *Lapis*, **14**, 10, 11-17, 11 figs (8 in colour). [In Russian.]

The collections of the A.E. Fersman Mineralogical Museum in Moscow are described. Among the specimens illustrated are outstanding examples of emerald and alexandrite. M.O'D.

GOEBEL, M., DIRLAM, D.M., 1989. Polynesian black pearls. *Gems & Gemology*, **25**, 3, 130-48, 23 figs in colour.

Superbly illustrated account of naturally coloured black and grey cultured pearls grown in the large black-lipped oyster *P. Margaritifera*, in the lagoons of the Tuomotu Archipelago and the Gambier Islands in French Polynesia. These large pearls have better lustre and iridescence than most natural black pearls, and supercede black-stained cultured pearls which dominated this market until the 1960s. *P. Margaritifera* was overfished for shell last century and natural black pearls became rare. Today the oyster is farmed and cosseted, and the shell a bi-product of a multi-million dollar production of fine pearls. Largest recorded specimen, 20.8mm diameter, is illustrated.

Bead nucleus and mantle tissue are inserted in the gonad (reproductive gland) of the oyster rather than in the mantle. Bead sometimes ejected and a 'keshi' (tissue-nucleated) black pearl may result. R.K.M.

GOUPIL, V., 1989. Les évangéliaires précieux. (The precious gospels.) *Revue de Gemmologie*, 98, 11-19, 8 figs (6 in colour).

Discusses the jewelled bindings of 9th-10th century versions of the Gospels. M.O'D.

GRIFFIN, W.L., COUSENS, D.R., RYAN, C.G., SIE, S.H. SUTER, G.F., 1989. Ni in chrome pyrope garnets: a new geothermometer. *Contributions to Mineralogy and Petrology*, 103, 199-202, 2 figs.

The positioning of nickel between chrome pyrope and olivine found in garnet-peridotite xenoliths from kimberlites is found to be strongly temperature-dependent and allows an estimation of the temperature of formation for single pyrope grains such as those found as diamond inclusions.

M.O'D.

HÄNNI, H.A., 1989. Les feldspaths. (The feldspars.) *Revue de Gemmologie*, 101, 19-20, 3 figs in colour.

A brief introduction to the ornamental varieties of the feldspar mineral group. M.O'D.

HÄNNI, H.A., 1989. Irisierendes natürliches Glas aus Mexiko. (Iridescent natural glass from Mexico.) *Zeitschrift der Deutschen Gemmologischen Gesellschaft*, **38**, 2/3, 51-62, 9 figs (2 in colour), 2 tables, bibl.

An English version of this paper appeared in *Journal of Gemmology*, **21**, 8, 488-95. E.S.

HÄNNI, H.A., WEIBEL, M., 1989. Ursache des Katzenaugen-Effekts bei erhitzten Zirkonen aus Sri Lanka. (Cause of cat's-eye effect in heated zircons from Sri Lanka.) *Zeitschrift der Deutschen Gemmologischen Gesellschaft*, **38**, 2/3, 95-101, 5 figs (2 in colour), bibl.

After heat treatment, certain zircons from Sri

Lanka showed a cat's-eye effect. The oriented inclusions which caused the chatoyancy are very fine fissures crystallographically orientated parallel to the *c*-axis, apparently in the (100) and (010) planes. Prismatic crystals were found in the centre of the disc-shaped fissures (diameter approximately 5 microns), probably thermally decomposed apatite. E.S.

HARDER, H., 1990. Spinell-attraktive, aber wenig bekannte Edelstine. (Spinel, attractive but little-known gemstone.) *Aufschluss*, **41**, 13-25, 7 figs in colour.

The gem variety of spinel is less well-known than its beauty warrants. The paper gives physical, chemical and geological details of the spinel minerals, grouping the red stones according to their resemblance to ruby, pyrope and almandine. Blue spinel is compared to sapphire and some stones are compared to padparadscha. M.O'D.

HENN, U., BANK, H., BANK, F.H., 1989. Gemmologische Kurzinformationen. Orangefarbene Korunde aus Malawi. *Zeitschrift der Deutschen Gemmologischen Gesellschaft*, **38**, 4, 164-6, 1 fig., bibl.

A note on orange coloured corundums from Malawi. RI 1.763-1.773, DR 0.008, SG 3.97-3.98. Lamellar twinning, healing cracks, and double refractive, rounded inclusions were observed. E.S.

HICKS, W.H., 1989. Editorial appreciation. *Australian Gemmologist*, **17**, 4, 139, 1 fig.

Bill Hicks illustrates a photo-copying attachment supplied by Jack Snow in answer to a dire editorial need. R.K.M.

HISS, D.A., 1989. Geuda transforms Sri Lanka's 'City of gems'. *Jewelers' Circular Keystone*, October 1989, 244-7, 5 figs in colour.

The geuda sapphire industry in which colourless corundum is heated to give a fine blue has revived some of the fortunes of Sri Lanka's gem merchants. M.O'D.

HLAING, T., 1989. The characteristics of Burmese spinel. *Australian Gemmologist*, **17**, 3, 84-7, 3 figs.

Part of a thesis which made a detailed study of spinel from the Mogok area. Notes that Burma is now called Myanmar [which will take some getting used to!]. R.K.M.

HOCHLEITNER, R., 1989. Blauer Euklas aus Zimbabwe. (Blue euclase from Zimbabwe.) *Lapis*, **14**, 10, 24-7, 7 figs (5 in colour).

A sapphire-blue variety of euclase is reported from south west of Miami in Zimbabwe, Central Africa. The mineral occurs in a pegmatite. M.O'D.

HOCHLEITNER, R., 1989. Die Sonderausstellung des Fersman-Museums in München. (Special exhibition of the Fersman Museum in Munich.) *Lapis*, **14**, 12, 25-7, 6 figs (4 in colour).

Fine specimens from the Fersman Mineralogical Museum in Moscow on exhibition in Munich included a red crystal of topaz from the Sanarka River, Ural Mountains and two specimens from Mursinka, a blue topaz and a greenish-yellow beryl. M.O'D.

HODGKINSON, A., 1989. Visual optics. *Australian Gemmologist*, **17**, 4, 137-8, 4 figs in colour.

A brief résumé of Hodgkinson's direct vision testing as applied to diamond and some of its imitations, a skill calling for careful assessment of tiny spectra which needs to be used with caution. R.K.M.

HOLZHEY, G., 1989. Untersuchung einer Opal-Imitation. (Investigation of an opal imitation.) *Zeitschrift der Deutschen Gemmologischen Gesellschaft*, **38**, 4, 139-42, 4 figs (3 in colour), 1 table, bibl.

The stone investigated was of unknown origin, a cabochon weighing 0.48 ct, 10 x 7 mm. It did not look polished, but probably pressed or cast. The colourful stone was found to be glass, but could not be identified with any previously known imitation. E.S.

HUGHES, R.W., 1989. Talkin' 'bout gem-testing instruments. *Australian Gemmologist*, **17**, 4, 159-64.

A long and rather flippant diatribe which attacks in humorous terms several instrument manufacturers, either disguised by a pseudonym or named, for bad design, unreliable construction and other offences. I find myself puzzled that having found one table spectrometer quite unsatisfactory Mr Hughes apparently went on and requested three more of them.

In the matter of spares, he says 'The frequency of bulb failure will be in direct proportion to the importance of that bulb, and in inverse proportion to the ease of getting spares. Those bulbs which fail most often will be located in totally inaccessible locations within the instrument, and will be exotic items containing radon gas encased in a hollowed out taaffeite chamber, utilizing the pubic hair of a now-extinct homosexual Amazonian flea as the filament. The bulb is available only from an obscure black magic shop in Burundi, and no, they don't accept American Express.' – and more in that vein. This is patently fiction and serves no real purpose if this gentleman has genuine complaints about instrument design or supply.

[I am left wondering whether this long and amusing paper is intended to be taken seriously, or whether it has been written simply as a humorous exercise. If the former, then it does itself a disservice in including the fictitious invention extracted.] More is promised. R.K.M.

HUNSTIGER, C., 1989. Darstellung und Vergleich primärer Rubinvorkommen in metamorphen Muttergesteinen. Petrographie und Phasenpetrologie. Teil I. (Description and comparison of primary ruby occurrences in metamorphic rock. Petrography and phase petrology. Part I.) *Zeitschrift der Deutschen Gemmologischen Gesellschaft*, **38**, 4, 113-38, 8 figs (3 in colour) 8 tables, bibl.

The formation of ruby requires relative accumulation of Al_2O_2 compared to SiO_2 plus some chromium to produce the red colour. During metamorphism corundum is formed from diaspore, or can be changed from muscovite or margarite into feldspar + vapour + corundum. This article deals with rubies in amphibolites: Fiskenaesset in Greenland, Kittilae in Finnish Lapland, Valle d'Arbedo in Switzerland and also north of Locarno in Switzerland, Chantel in France, Longido in Tanzania and the Harts Range in Australia. The mineral analysis of corundum carrying amphibolites are compared. E.S.

KAMMERLING, R.C., KOIVULA, J.I., 1989. Thermal alteration of inclusions in 'rutilated' topaz. *Gems & Gemology*, **25**, 3, 165-7, 3 figs in colour.

Colourless faceted topaz with acicular inclusions has been offered as 'rutilated'. Needles identified as dislocation channels stained with limonite. Heat altered the yellowish-brown limonite to dark red hematite and inclusions became more prominent. The dark red colour is regarded as proof of heat treatment. R.K.M.

KARWOWSKI, L., DORDA, J., 1986. The mineral-forming environment of 'Marmaros diamonds'. *Mineralogia Polonica*, **17**, 1, 3-16, 21 figs.

'Marmaros diamonds' are euhedral, transparent and generally colourless quartz crystals found at a number of locations in the Flysch Carpathians, Poland. Thermo-and barometric study of the fluid inclusions contained in the crystals revealed a chloroform content which appears to indicate that the principal components of the mineral-forming fluids were aliphatic hydrocarbons. Other hydrocarbons are found in minor amounts. M.O'D.

KELLY, S.M.B., 1989. Using the spectroscope. A personal assessment of the contribution to gemmology of J.J. Snow, FGAA, FGA. *Australian Gemmologist*, **17**, 4, 118-19.

This edition of the magazine is a memorial to Jack Snow, one of the most active exponents of gemmology in Australia for many years, who died last June. Ms Kelly describes Jack's dedicated tuition when she had problems with this rather difficult instrument. R.K.M.

KOIVULA, J.I., 1989. Geofingerprints. *Lapidary Journal*, **43**, 6, 20-35, 6 figs in colour.

An introduction to the study and classification of inclusions in gemstones, with a list of references. M.O'D.

KELLY, S.M.B., BROWN, G., 1989. Synthetic periclase. *Australian Gemmologist*, **17**, 3, 90-2, 5 figs, some in colour.

Offered as 'natural sapphire', this material had H 5.5 and cubic cleavage, SG 3.57, RI 1.73, single and an included bubble. Identified as the magnesium oxide, periclase, and had been manufactured in Austria. After some months polished surfaces became dulled by hydration which gave a whitish efflorescence, probably brucite. R.K.M.

KOIVULA, J.I., 1989. The hidden beauties of gemstones:-Artistry through the microscope. *Australian Gemmologist*, **17**, 4, 139-42, 10 figs in colour.

Some quite remarkable pictures of gem surfaces and inclusions contributed by one of the greatest specialist photographers of such things as a photo-essay in memory of Jack Snow. R.K.M.

KOIVULA, J.I., FRITSCH, E., 1989. The growth of Brazil-twinned synthetic quartz and the potential for synthetic amethyst twinned on the Brazil law. *Gems & Gemology*, **25**, 3, 159-64, 8 figs in colour.

Natural amethyst is interpenetrantly twinned on what is known as the Brazil law, which is evinced by interrupted spectral rings seen between crossed polarizers, a feature which has been regarded as proof of natural origin. But quartz is being synthesized with this twinned habit and test can no longer be considered reliable. There is no proof that commercial amethyst growers are yet exploiting this, but the quartz is easy to grow and Brazil twinned synthetic amethysts may be expected. R.K.M.

KOIVULA, J.I., KAMMERLING, R.C., 1989. Gemmological properties of emerald from Nova Era, Minas Gerais, Brazil. *South African Gemmologist*, **3**, 4, 20-5, 4 figs in colour.

Emeralds are found in a biotite-phlogopite-mica schist at the Nova Era mine, Minas Gerais, Brazil. Ten faceted stones were tested and showed properties in the established range for emerald. Two-and three-phase inclusions and fine acicular growth tubes parallel to the *c*-axis were observed. M.O'D.

KOIVULA, J.I., KAMMERLING, R.C., 1989. A gemmological study of 'Opalite' and 'Opal Essence'. *Australian Gemmologist*, **17**, 3, 93-8, 5 figs, some in colour.

Two names for the same 'new' plastic opal which seemed to be identical to earlier plastic imitation opals. A needle pressed lightly onto these 'stones' dented them readily; very warm to touch; hot needle gave acrid smell; the plastic was hydrophobic and a drop of water placed on it formed a hemispheric bead; natural or synthetic opal are hydrophilic and water spreads rapidly across the surface. Low SG 1.15 to 1.25, RI 1.51, H 2.5 and the usual microscopic features should identify. But in a setting these can deceive. R.K.M.

KOIVULA, J.I., KAMMERLING, R.C., 1989. An investigation of three imitation opalized shells. *Australian Gemmologist*, **17**, 4, 148-52, 10 figs in colour.

It is fitting that these shells should be discussed in the *Australian Gemmologist* for they originated in that country and were undoubtedly made to deceive.

The shells looked entirely wrong with large angular chunks of boulder opal conforming in some strange way to the required outlines of the fossil shapes, not at all like the normal homogeneous opalized shell. Examination showed a mixture of opal, opal breccia, and iron-stone held in a plastic matrix and either moulded or ground to shape. They were too well polished, and had spherical bubbles trapped in the binding material. Hardness, hot needle and water spot tests all confirmed plastic. Spot RIs of about 1.55 were obtained from each of them. Opal portions fluoresced bluish-white under LUV, other parts were inert, some gas bubbles also fluoresced. It seems another chapter has been added to the opal story. [A deception to look out for!]

R.K.M.

KOIVULA, J.I., KAMMERLING, R.C., 1989. Gem news. *Gems & Gemology*, **25**, 3, 177-84, 12 figs in colour.

Diamond

CSO report diamond sales of $2 317 billion, highest ever for a six month period. Diamond cutting seen at Foshan, Guangzhau Province, China, used jam peg dops more normal for coloured stones; no mechanical dops seen and each stone was worked short time only, to avoid cement softening. Argyle officials, Australia, deny recruiting Indian diamond cutters to train cutters in China. Economic viability of a kimberlite intersection is being tested near Prince Albert, Saskatchewan. Australians are exploring possibilities of kimberlite pipes in Wisconsin and Michigan. A De Beers subsidiary is joining Max Resources of New Zealand to explore for diamonds near Darwin, Australia.

Coloured stones

Plumbago Mining have opened an amethyst mine at Sweden, Maine, New England. Same company are reopening the Mt Mica tourmaline mine, also in Maine. Sceptre amethyst is reported from Malawi. The Bolivian amethyst-citrine mine is reported closed but 'poached?' material is still readily available. Fine quality large aquamarines are coming from Madras State, India; blasting and heat damage spoils much of the material; 41 ct specimen examined had graining due to strain but colour was exceptional and not due to heating. A cave in the Namib desert is yielding 'chandeliers' of quartz crystals, one formation was estimated to weigh 13 tons. Rough Santa Terezinha de Goias emeralds, Brazil, are being heated moderately with Opticon, a synthetic sealant; a further report is in preparation.

A large bi-colour yellow and green water-worn sapphire from Anakie, Queensland, is illustrated.

Kanchanaburi, Thailand, sapphires are often heat treated, resultant colour sleepy or a greyish blue rather like similarly treated stones from Sri Lanka; pin points of dark blue 'ink-drops' occur as inclusions; untreated stones have fine dust-like silk (as in Burmese sapphires) or long needles (as in Sri Lankan); boehmite and apatite crystals also included. Undersea searches inspired by Thai Government and UN Development Department are seeking corundum, titanium, zirconium and gold in the Gulf of Thailand; they have already found tin under the Andaman Sea. Paraiba, Brazil, is producing some exceptional colour blue and green tourmalines, mostly under one carat but largest seen was 15.18 ct.

Pearls

A large cultured blister pearl was seen in a fresh-water mussel shell represented the goddess Kwan Yin; insert was probably carved shell or plastic and X-ray did not detect it.

Synthetics and Simulants

'Jadeite' concentric mobile sphere balls seen in a Guangzhou (Canton) factory were mostly bowenite, with a few of low-grade jadeite; workers insisted that all were 'jade', confirming that this word has broader application in Chinese. 'Opalized fossil' shells from Australia were found to be composite made from opal, boulder opal and iron-stone matrix cemented with a plastic, moulded or ground to shape. R.K.M.

KOIVULA, J.I., KAMMERLING, R.C., 1989. Examination of a gem spinel crystal from the Pamir

Mountains. *Zeitschrift der Deutschen Gemmologischen Gesellschaft*, **38**, 2/3, 85-8, 3 figs in colour, bibl.

The gem quality pink spinel crystal examined came from the Pamir mountain range in the south of the USSR, almost parallel to the northern border of Pakistan and the Wakhan Corridor belonging to Afghanistan. RI 1.711, SG 3.55. Inclusions are described. E.S.

KORITNING, S., 1989. Achate aus dem Harz. (Agate from the Harz.) *Aufschluss*, **40**, 349-59, 12 figs (10 in colour).

Fine agates are described from the Harz region of West and East Germany. M.O'D.

LARSSON, T., 1989. Adelstenar bland Fältspaterna. (Feldspar gemstones.) *Gem Bulletinen*, 2, [unpaged] 1 fig.

Varieties of the feldspar mineral group with gem or ornamental application are described. M.O'D.

LIEBER, W., 1989. Smithsonit von der Kelly Mine, New Mexico, USA. (Smithsonite from the Kelly Mine, New Mexico, USA.) *Lapis*, **14**, 10, 29-31, 6 figs (4 in colour).

Fine bluish-green smithsonite from the classic source of the Kelly Mine, Socorro County, New Mexico, USA, is described. The mineral is found in the Magdalena Range. M.O'D.

LIEBER, W., 1989. Broken Hill. *Lapis*, **14**, 5, 11-29, 38 figs (26 in colour).

The survey of the mineralization of Broken Hill, New South Wales, Australia, contains details of the occurrence and photographs of transparent crystals of rhodonite which is usually found on galena. M.O'D.

LINTON, T., BROWN, G., 1989. Economic microscopes for gemmologists. *Australian Gemmologist*, **17**, 4, 120-1 and 156-8, 5 figs.

Describes the SZM-1 Stereozoom microscope, A$665; the SZM-2 Stereozoom microscope with phototube; the SM-4G Stereoscopic microscope (Chinese) at A$355; the SMS-10 Stereoscopic microscope at A$150 and the EK-1 Fibre optic cold light illuminator, A$563. Other microscopes are briefly mentioned. Prices are tax-exclusive and in any case would not apply in Britain. R.K.M.

MCCAUGHTRY, G., 1989. An evaluation of the 'Gemdata' gem identification program. READ, P. Comments on the evaluation of 'Gemdata'. Editorial comment. *Australian Gemmologist*, **17**, 3, 107-9.

Assessment based on test reports by one student were used,and 'Gemdata' gave approximately two-thirds correct results, including a number in which a multiple choice of answers was offered. The narrow tolerances of the program plus the use of broad SG ranges provided by flotation methods of testing probably increased the failure rate. Microscopic and spectroscopic tests were not included. Spot RIs were too approximate. Criticism suggests that the program could not be used for examination purposes. [Examinations are to test gemmological interpretation by the student. A computer could hardly do that.]

Peter Read, the originator of 'Gemdata', replies and intends further modifications which may increase its efficiency. Editorial comment makes further suggestions. [One can see weaknesses in the method of assessment as well as in the program itself, and is left wondering whether the computor offers any real improvement over old fashioned brain-power and gemmological 'nous'?] R.K.M.

MCKAY, D.J., O'DONOGHUE, M., 1989. Computerized information services. In: WOOD, D.N., HARDY, J.E., HARVEY, A.P., (EDS), *Information Sources in the Earth Sciences*, 78-133.

Available earth science databases are listed and critically discussed. (Author's abstract) M.O'D.

MITCHELL, R.K., 1989. Some thoughts on snuff-bottles. *Australian Gemmologist*, **17**, 4, 129-31, 1 fig. in colour.

An attempt to list the many materials used to make these collectable Chinese items, and to describe the methods of fashioning. Inspired by a stray question in a 1982 examination paper. (Author's abstract) R.K.M.

MIYAMOTO, M., AKAISHI, M., OHSAWA, T., YAMAOKA, S., FUKUNAGA, O., 1989. Morphology and formation process of diamond from glassy carbon. *Journal of Crystal Growth*, 97, 731-8, 9 figs.

Glassy carbon was used as a starting material for diamond formation with a catalyst metal. The hydrogen present in the starting carbon greatly affects the diamond formation and for this to take place the hydrogen content has to be between 1200 and 2200ppm. Using an iron-rich catalyst a characteristic needle-like diamond was formed. M.O'D.

MÖLLER, R., 1989. Filatelia y gemas. (Philately and gems.) *Gemologia*, **30**, 81/82, 17-20, 10 figs.

Some examples of the use of gemstones on stamps are given. M.O'D.

NASSAU, K., 1989. Amethyst and citrine. *Lapidary Journal*, **43**, 8, 30-4, 5 figs (4 in colour).

The transformation of amethyst into citrine by heat treatment and the conversion of citrine into

amethyst by irradiation are discussed. M.O'D.

O'Donoghue, M., 1989. Secondary literature: bibliographies, abstracts and indexes. In: Wood, D.N., Hardy, J.E., Harvey, A.P., (Eds), *Information Sources in the Earth Sciences*, 64-77.

Bibliographies, indexes and abstracts in the earth science field are listed and critically discussed.

(Author's abstract) M.O'D.

Pilati, T., Gramaccioli, C.M., Sosso, F., 1988. Identification of gemstones by single-crystal X-ray diffractometer. *La Gemmologia*, **13**, 3/4, 19-25.

Distinction between quartz and scapolite, topaz and danburite and sinhalite and olivine are made by the single-crystal X-ray diffractometer. The technique is applicable both to crystals and to faceted stones. M.O'D.

Platonov, A.N., Taran, M.N., Klyakhin, K., Klyakhin, V.A., 1989. On two colour types of Mn^{3+}-bearing beryls. *Zeitschrift der Deutschen Gemmologischen Gesellschaft*, **38**, 4, 147-54, 5 figs, 1 table, bibl.

Two types of Mn^{3+} coloured natural beryls are investigated. Differences in absorption spectra, thermal stability of colour and behaviour under irradiation are caused by differing crystal field symmetry of the Mn^{3+} ions in the beryl structure. The difference between morganite and pink beryl as caused by Mn^{3+} distortion is discussed. E.S.

Ponahlo, J., 1989. Mikrospektralphotometrie der Edelstein-Kathodolumineszenz. (Microspectrophotometry of gemstone cathodoluminescence.) *Zeitschrift der Deutschen Gemmologischen Gesellschaft*, **38**, 2/3, 63-84, 27 figs (17 in colour), 2 tables, bibl.

The author explains the use of microspectrophotometry of cathodoluminescence of gemstones as a method of distinguishing between natural and synthetic stones. The method can be used on luminescing gemstones and ornamental stones. The necessary apparatus is described in detail, as are the CL-spectra of rubies, emeralds, padparadschahs, alexandrites, diamonds and lapis lazuli. The method has a number of advantages: results are easily compared, parcels can be examined as well as single stones, it can be applied to all stones with usable CL bands, although also weakly luminescent material can be tested and differences between natural and synthetic stones can be explored. E.S.

Pough, F.H., 1989. Chrysoprase. *Lapidary Journal*, **43**, 9, 20-4, 1 fig. in colour.

A short account of the mineralogy and properties of the chrysoprase variety of quartz. M.O'D.

Read, P., 1989. A synthetic by any other name. *Australian Gemmologist*, **17**, 4, 153-6, 4 figs, some in colour.

'Synthetic' is a word which carries a stigma when connected with gems and Mr Read discusses the urge among some manufacturers to find ways around its use when describing their products.

In Britain a synthetic is a synthetic and must be so described, but in some other countries the rules are less exacting and there appear to be ways round the problem. Thus Chatham in the US is, after considerable litigation, legally allowed to call his stones 'created emeralds', while the Australian 'Pool emerald', although very similar to the Biron synthetic emerald, is to be described as 'refined natural emerald recrystallized under hydrothermal conditions'.

The Knischka synthetic rubies are advertised as 'Knischka-created-rubies' and are produced by what is called a 'luxury synthetic process', because it takes about a year to produce the stones.

In many cases such semantics are backed by claims that the product in question is practically indistinguishable from the natural stone except by sophisticated methods of analysis; indeed the best examples are often so good that their very purity and superb colour can themselves arouse suspicions of synthesis. In most cases they can in fact be identified as synthetic fairly simply and must, in the UK at least, be sold as such. The other common factor seems to be that once the repugnant term 'synthetic' has been eliminated, the prices tend to rise dramatically.

The writer finally makes the point that these evasions may not be so serious at the point of first sale but that they could become much more problematical when a stone is inherited or sold on through several owners long after the initial transaction was completed. R.K.M.

Robert, D., 1989. Synthèses de l'émeraude. (Syntheses of emerald.) *Revue de Gemmologie*, 100, 4-6, 4 figs in colour.

The paper forms the first part of a series in which emerald syntheses are described. This part deals with some hydrothermal and the Chatam product. Characteristic inclusions are illustrated. M.O'D.

Robert, D., 1989. Synthèses de l'émeraude. 2nd part. *Revue de Gemmologie*, 101, 5-7, 2 figs in colour.

The productions of Lens, Gilson and Lechleitner are reviewed with notes on Soviet and Japanese material. M.O'D.

ROMBOUTS, L., 1987. Geology and evaluation of the Guinean diamond deposits. *Annales de la Société Géologique de Belgique,* **110**, 1, 214-59, 5 maps.

Nineteen Cretaceous kimberlite pipes, classified into three types, with area surfaces from 1100 up to 95 000 m^2, and alluvial diamond deposits are located in Upper Guinea, in the area bounded by Kissidougou, Kerouane and Macenata. The kimberlites, which seem all diamond-bearing, are intruded into the Archaean craton of the Guinea Rise and are closely related to the break-up of Gondwana. About 1700 diamonds, $\leq$ 10 ct, were examined for their crystallography and colour. Octahedra, dodecahedra and their twins are best represented, while cubes are very rare. White and yellow colours predominate over brown, grey and green. In the alluvial deposits of the Gbenko-Banankoro area, 93 per cent of the stones are of gem quality. R.V.T.

RUSTIONI, M., BERTONI, S., 1988. BGO, a new material of gemmological interest? *La Gemmologia,* **13**, 3/4, 7-17, 4 figs (2 in colour).

Bismuth germanium oxide is described and its ornamental potential discussed. Grown by heat exchange, Bridgman or pulling techniques it has a hardness of 5, SG 7.12 and RI 2.10. It crystallizes in the cubic system. With a dispersion of 0.050 it might be considered as a possible diamond substitute, were it not for the low hardness. [The abstractor commented on BGO several years ago in *Synthetic Crystals Newsletter* and also observed its high degree of brittleness. M.O'D.

SCHMETZER, K., 1989. Im hydrothermalverfahren hergestellter synthetischer Aquamarin aus der UdSSR. (Hydrothermally-grown synthetic aquamarine from the USSR.) *Goldschmiede und Uhrmacher Zeitung,* 9-89, 139-41, 12 figs in colour.

Aquamarine is now manufactured by the hydrothermal growth process in the USSR. Constants given are SG 2.69, RI 1.583 and 1.575 with DR 0.008. A variety of different types of inclusion is found and some are illustrated. M.O'D.

SCHÜPBACH, T., 1989. Ein interessanter Quarz-Epidotfund aus dem Val Punteglias. (An interesting quartz-epidote find from the Val Punteglias.) *Schweizer Strahler,* **8**, 8, 353-65, 9 figs (7 in colour).

Gem quality crystals of quartz and green epidote have been found in the Val Punteglias, Switzerland. M.O'D.

SCHWARZ, D., 1989. Smaragdabbau in Kolumbien: Neue Aspekte. (Emerald mining in Colombia: new aspects.) *Zeitschrift der Deutschen Gemmologischen Gesellschaft,* **38**, 4, 155-60, 1 map, 3 tables, bibl.

Survey of emerald production in Colombia in early 1989. Coscuez could not be visited for security reasons. Yacopi was producing, but mainly light green crystals, well formed and transparent. Penas Blancas is situated in a district controlled by guerillas. Gachala is being cleaned and prepared for working. Production from Chivor varies a lot, both in quality and quantity. Buenavista is at the moment not being worked. Difficulties in export of emeralds and other gem materials is also discussed. E.S.

SERGUNENKOV, B.B., 1989. (Gem scapolite from the Tarakuloma Ridge (the Pamirs).) *Zapiski Vses, Min, Obshch.,* **118**, 4, 84-90. (Russian with English abstract.)

Gem scapolites of lilac and other colours occur in secondary cavities in granite pegmatites cutting marbles in this area. They are dipyres of composition Me_{18}=Me_{37}. Their lilac colour is related to $Mn^{3+}{}_6$ and electron centres $SO^-{}_3$. IR spectra are presented. The blocky crystals have faces {010}, {110}, {120}, {111}. {011} and {001}, with surface sculpture including hillocks and pits at the outlets of acicular channels oriented along *c*. These channels are hollow or contain dispersed material. Refractive indices and cell dimensions are reported; a scapolite with composition Me_{18} has ε 1.536, ω 1.541, *a* 12.070, *c* 7.583 Å. R.A.H.

SNOW, J.J., 1989. The use of the Figure-O-Scope in gemmology. *Australian Gemmologist,* **17**, 4, 122-6, 9 figs, some in colour.

A reprint from a 1979 issue in which Jack Snow described the simplified conoscope that he designed to facilitate observation of interference figures in birefringent stones. R.K.M.

SNOW, J., BROWN, G., 1989. Inamori stones' rough (some observations and speculations). *Australian Gemmologist,* **17**, 4, 132-5, 9 figs in colour.

A résumé of observations on the synthetic gem products of the Kyocera Corporation, discussing aspects of bubble inclusions and other identifying features. Synthetic corundum, alexandrite and opal are dealt with. Some illustrations seem not to convey what the captions suggest they should. Have a couple of them got mixed? A useful paper! R.K.M.

THEMELIS, T., 1989. Clues to identity. *Lapidary Journal,* **43**, 6, 36-40, 2 figs in colour.

A short note on the use of inclusions as gem testing tools. M.O'D.

THEMELIS, T., 1989. Some inclusions in Umba corundums. *Lapidary Journal*, **43**, 8, 19, 2 figs in colour.

Among inclusions noted in corundum from the Umba region of East Africa are apatite, rutile, boehmite and graphite. M.O'D.

THEMELIS, T., 1989. Longido. *Lapidary Journal*, **43**, 9, 49-50, 3 figs (2 in colour).

The Longido mine is located near the settlement of Mdara in northern Tanzania and is celebrated for ruby crystals in green zoisite. After a lengthy cessation of mining limited operations have recommenced. M.O'D.

WANG, F., GUO, J., 1989. Chicken-blood stone from China. *Gems & Gemology*, **25**, 3, 168-70, 3 figs in colour.

This Chinese Cretaceous or Jurassic rock of volcanic origin is found at Changhua, Zhejiang Province, and at Balinyouqi in Inner Mongolia. The fine-grained dickite-kaolinite and quartz mixture is known as chicken-blood stone, a material prized for carving for many centuries. Once incorrectly called pyrophyllite, it may be white, yellow, green or grey, with patches, clouds or spots of bright to dark red of cinnabar, the redder the higher the value. SG varies 2.6 to 3.0; H 3; RI for background material ('dong') about 1.55-1.56; microgranular; very easy to carve.

R.K.M.

WIERSEMA, B., 1989. Spotlight on Scripps. *Lapidary Journal*, **43**, 5, 20-6, 4 figs (3 in colour).

The newly-opened Scripps Hall of Mineralogy at the San Diego Museum of Natural History is described. M.O'D.

WILSON, A.F., 1989. The use of isotopes in exploration for gemstones. *Australian Gemmologist*, **17**, 4, 142-6.

A detailed account of the use of isotopes of radio-active elements such as uranium, thorium, rubidium and potassium to determine 'age signatures' of host rocks in order to assess gem bearing potentials and save expensive exploration of barren pegmatites.

A totally different approach uses stable, non-radio-active isotopes of oxygen, carbon, hydrogen or sulphur to assess physical conditions of mineral formations, while potassium/argon ageing can also be assessed.

Methods and applications are explained together with some examples. An important and highly technical paper which puts modern prospecting and mining into a new and very intriguing light. R.K.M.

XU, M.Y., JAIN, H., NOTIS, M.R., 1989. Electrical properties of opal. *American Mineralogist*, 74, 821-5, 4 figs.

One natural and two synthetic opals were tested for electrical conductivity with a complex impedance analysis. The conductivity of the synthetic material is lower and its activation enthalpy higher. This may be due to the lower concentration of Na^+ charge carriers. The dielectric constant of the synthetic opal is anisotropic and is dominated by the presence of water. M.O'D.

ZEITNER, J.C., 1989. Thunder Bay. *Lapidary Journal*, **43**, 8, 36-42, 3 figs (2 in colour).

A large deposit of amethyst is found at Thunder Bay, Ontario, Canada, on the northern shore of Lake Superior. The deposit has been worked for amethyst since the early seventeenth century.

M.O'D.

ANON. 1989. Diamond sorting made easy. *Industrial Diamond Review*, **49**, 6, 265-6, 5 figs.

Examination of large quantities of diamonds or jewellery under a loupe or miscroscope is extremely time consuming. A new microscope system (the Sortoscope) is described which is suitable for the examination of polished gem diamonds, precious stones, pearls and finished jewellery, but can also be used for examining uncut gem and industrial diamonds. The acrylic glass slides suitable for examining diamonds have an 84.5° notch on the top side and are slightly recessed on the underside; the diamaonds are scattered on the notch and examined with the aid of stereozoom optics using dark-field optic fibre lighting. To inspect an individual diamond more closely, it can be rolled about its own axis while simultaneously pulling the slide. The position of the diamond is not changed with tweezers but with a fine retouching brush, which is also used to remove dust particles. R.A.H.

ANON. 1989. Debex's diamond recovery plants double for andalusite. *Indiaqua*, **54**, 3, 59-60, 5 figs in colour.

This article, in the form of a press release, describes the use of a dense medium separation plant (DBS) designed by Van Eck and Lurie and manufactured in South Africa by Debex (Pty) for the recovery of industrial andalusite in the Northern Transvaal area of South Africa. Unlike the rare gem quality andalusite, this aluminium silicate is used in high-grade refractories and ceramics. When heated to a sufficiently high temperature it changes to mullite which is in demand for its high melting point, good electrical and thermal insulating properties, low coefficient of expansion and high resistance to mechanical and thermal shock. The mineral is used in refractories for furnaces, oil and gas fire boxes, combustion funnels, spark plugs, enamel and chinaware. P.G.R.

Book reviews

CHAUVET, M., 1989. *Frédéric Cailliaud*. Editions ACL-Crocus. pp.371. Illus. in black-and-white and in colour. F295.

This book was written by a Nantais, to commemorate the bicentenary of one of Nantes' famous sons: the naturalist and egyptologist Frédéric Cailliaud (1787-1869). The author painstakingly retraces the expeditions of his compatriot in Egypt and the Sudan, covering the period 1815-1822.

Although primarily of interest to the student of egyptology, it will be remembered that M. Cailliaud also held the position of mineralogist to the Khedive, Mehemet Ali, and in this connection chapters 3 and 5 – dealing with Cailliaud's rediscovery of the ancient 'lost' emerald mines of Zabara and Gebel Sikait – are of particular, and historic, interest to the gemmologist. Illustrations are from original prints of the period complemented by present-day photographs and there is a fold-out map of the country.

N.C.

LEVINE, G., VOOKLES, L.L., 1986. *The jeweler's eye*. Hudson River Museum, Yonkers, New York. pp.111. Illus. in black-and-white and in colour. Price on application.

The catalogue illustrates and describes a collection of nineteenth century jewellery in the collection of Nancy and Gilbert Levine. A preliminary essay discusses the social setting of nineteenth century jewellery and is followed by the catalogue itself in which the majority of the pieces are illustrated in colour. The catalogue is followed by an essay on the culture of beauty. This is a well-produced catalogue with good quality photographs and interesting essays.

M.O'D.

MACPHERSON, H.G., 1989. *Agates*. Natural History Museum, London, and National Museums of Scotland, Edinburgh. pp.72. Illus. in colour. £5.95.

This is a most welcome short guide to agates with particular reference to specimens found in the British Isles. As might be expected, most of the sites are in Scotland. There is a discussion of the types of rock in which agates are found and of why they are there; this is followed by a description of agate structure and coloration. Most of the book is devoted to descriptions of fine British specimens and there are also notes on cutting and on the use of agate in ornament. It is good to have established sites mentioned – many of the locations quoted by Matthew Heddle in the *Mineralogy of Scotland* have never been identified.

M.O'D.

MOREL, B., 1988. *The French crown jewels*. Fonds Mercator, Antwerp. pp.417. Illus. in colour. £60.00.

This sumptuous book gives the history of the French crown jewels from the earliest times to their final incorporation into the collections of the Louvre. It should be noted that the articles used as coronation regalia did not form part of the crown jewels in the same way as in England, and for this reason this particular group of artefacts is treated separately in the first section of the book. The crown jewels proper were the result of the establishment by Francois I of a national collection of jewels and although they have been dispersed more than once many have been recovered. The book in fact covers ten centuries of French history as well as describing the manufacture and history of the pieces themselves. After the opening section describing the artefacts of the coronation ceremonies the book goes on to discuss the collection founded by Francois I on 15 June 1530 and its development. This takes up sixteen chapters and is a chronological account ending with the acquisition by the Louvre of some pieces long dispersed from the collection. Despite the price of the book (by no means excessive for what you get) it is very well worth buying if you have the smallest interest in fine historical jewellery. The illustrations are of high quality and there are useful bibliographies of a topic which has not been covered in detail since the nineteenth century and a lot has happened since then.

M.O'D.

STRASSER, A., 1989. *Die Minerale Salzburgs*. (The minerals of Salzburg.) Published by the author: Salzburg. pp.348. Illus. in black-and-white and in colour. Price on application.

Notes on beryl and phenakite deposits can be found in this excellent guide to the minerals of the Salzburg area of Austria which includes a first-class bibliography.

M.O'D.

Proceedings of the Gemmological Association of Great Britain and Association Notices

OBITUARIES

John Joseph (Jack) Snow 1923-1989.

We are deeply sorry to report the death of one of Queensland's leading gemmologists on 2 July 1989, after a long and courageous battle with emphysema.

John Joseph (Jack) Snow, FGAA, FGA, was born in Brisbane in 1923, the youngest son of James and Maud Snow. He had little formal education but was apprenticed as an optical mechanic after leaving primary school. For the remainder of his working life he was closely associated with various aspects of the optical industry. He even came into gemmology as a result of his then employment as Queensland Manager for British Optical, who were the distributors for Rayner gemmological instruments.

Jack joined the Queensland Branch of the Australian Gemmological Association in May 1959, according to his application, solely in order to learn something of the gemmological instruments he was selling. By the end of 1960 he had obtained his Fellowship Diploma for the GAA and was starting almost thirty years of devotion to gemmology. Characteristically, he confirmed his knowledge and ability by sitting and passing the Gemmological Association of Great Britain's examination in 1976. His significant and valuable contribution to Australian gemmology was formally acknowledged when he was awarded Honorary Life Membership of the GAA in 1980.

Jack Snow's contribution to gemmology was considerable. At various times over the three decades he occupied most of the elected positions on the Queensland Branch Council; lectured and demonstrated optics, gemmological instruments and practical gem testing to several generations of students and to members of the general public; was on the GAA's Instrument Evaluation Committee; a member of several Federal Executives and was a gemmological researcher of international standing. As a consequence of these many interests he contributed some 45 papers to gemmological publications world-wide as well as writing regularly for the Queensland Branch publication – *Wahroongai News* and for the *Australian Gemmologist.*

The November 1989 issue of the latter journal was published most fittingly as a memorial issue to Jack Snow, and in it Geoff Tombs, GAA Patron, described him as 'One of the quiet achievers' who was known to so many as 'Practical Jack'. There is little doubt that this kindly and clever man will be greatly missed, but the hope is expressed that his example will be echoed in the achievements of future Australian gemmologists.

Grahame Brown, Federal President, GAA
R. Keith Mitchell, Vice President, GAGB

* * *

Mrs Anne Eaton, FGA (D.1984), Lymm, Cheshire, died in June 1989.

Mrs Linda Hennessy, FGA (D.1984), Wahroonga, NSW, Australia, during 1989.

Mr John G. Luder, FGA (D.1969) of Den Haag, The Netherlands, died in November 1989, aged 77. After a long and brave fight with kidney failure, the end came peacefully, and at his request he was buried by the sea near his home. A good man and an excellent gemmologist. He leaves a widow, Elizabeth, and one son.

NEWS OF FELLOWS

On 26 January 1990 Mr Michael O'Donoghue gave a lecture entitled 'Gemstones of Pakistan' to the Russell Society at the University of Loughborough.

MEMBERS' MEETINGS

London

On 19 March 1990 at the Flett Theatre, Geological Museum, Exhibition Road, South Kensington, London SW7, Mr George Bosshart, M.Sc., GG, gave an illustrated lecture entitled 'The coloration of green diamonds'.

Midlands Branch

On 19 January 1990 at the Society of Friends, Dr Johnson House, Colmore Circus, Birmingham, Mr David Callaghan, FGA, gave an illustrated lecture entitled 'The Duchess of Windsor's jewellery'.

On 16 February at the Society of Friends Gwen Kingsley gave a lecture entitled 'History of the Stonbridge Glass Industry'.

North West Branch

On 20 September 1989 at Church House, Hanover Street, Liverpool 1, Val Duke gave a lecture on the gemstone trade in Brazil.

On 18 October 1989 at Church House, David Callaghan, FGA, gave an illustrated lecture entitled 'The Duchess of Windsor's jewels'.

On 15 November at Church House, the Annual General Meeting was held, at which Mr William Franks, FGA, was elected Chairman and Mrs Irene Knight, FGA, re-elected Secretary.

On 17 January 1990 at Church House, a social evening was held, when members brought along interesting gemmological specimens. On 21 February 1990 at Church House, Dr Jeff Harris gave a lecture on colour in diamonds.

On 21 March 1990 at Church House, Mr David Callaghan, FGA, gave an illustrated lecture entitled 'From gem to jewel'.

COUNCIL MEETING

At a meeting of the Council of the Association held on 22 February 1990 at the Royal Automobile Club, Pall Mall, London SW1, the business transacted included the election to membership of the following:

Fellowship

Chiu, Sau K.D., New Territory, Hong Kong. 1989
Civitello, Odile, Outremont, Canada. 1989
Cope, Andrew R.W., Nottingham. 1989
Ellis, Phillipa, Sydney, Australia. 1989
Hawkins, Richard A., Sutton. 1989.
Hitchin, Peter F., Bangkok, Thailand. 1989
Ho Kiam Fong, Steve, Singapore. 1989
Lambley, Jenifer G., Brightwell cum Sotwell. 1981
Lau, Ellen Y.Y., Hong Kong. 1989
MacGregor, Rory, Teresopolis, Brazil. 1989
Nevalainen, Tuula M.L., Helsinki, Finland. 1989
Pette, Jan W., Arnhem, The Netherlands. 1989
Pun, Yuk L.M., New Territory, Hong Kong. 1989
Rieger, Catherine J., Maidstone. 1989

Ordinary Membership

Adams, Suzanne, Sutton.
Ashitaka, Nobuyoshi, Osaka, Japan.
Azizollahoff, Geoffrey, London.
Bauer, La Shawn, Kingman, Kan., USA.
Birrell, Andrew T., London.
Clark, Susan W., London.
Davis, David R., London.
De Silva, Nihal G.J., Mitcham.
Echeverry, Jose F.O., Bedford.
Forge, Claude, Paris, France.
Fujimori, Syohei, Fukuoka-Pref, Japan.
Fujisawa, Takako, Chiba-Pref, Japan.
Galligan, Fiona L., Greenford.
Gilson, Pascale N., Brussels, Belgium.
Hausler, Rebecca, Bangkok, Thailand.
Hills, Margaret A., Tonbridge.
Horiguchi, Yasuhiko, Tokyo, Japan.
Irikura, Hisanobu, Tokyo, Japan.
Ishikawa, Noriko, Tokyo, Japan.
Jain, Neerja, Birmingham.
Jinbo, Kazuko, Tokyo, Japan.
Jupp, Thomas H., London.
Kewell, Geoffrey, Cranbrook.
Kimura, Hiroyuki, Tokyo, Japan.
Lake, Richard J., Grouville, Jersey, CI.
Lim, Heng M., Burong, Singapore.
Madhvani, Marie-Laure, Nairobi, Kenya.
Mason, Alec J., Retford.
Matsumoto, Masako, Osaka, Japan.
Matsumoto, Tamio, Takyo, Japan.
Millot, Valerie, Paris, France.
Moreiras-Blanco, Damaso, Oviedo, Spain.
Munakata, Yoshio, Wakayama-Pref, Japan.
McCarthy, Edward J., Cambridge.
Nilsson, Assar, Varmdo, Sweden.
Oda, Mineko, Tokyo, Japan.
Pattni, Mamta C.P., Nairobi, Kenya.
Peh, Angeline, Glasgow.
Rigby, L. Clare, Doncaster.
Sasako, Miyuki, Kanagawa-Pref, Japan.
Schmidt, Simon P., London.
Shibata, Hirofumi, Osaka, Japan.
Smith, Alan J., Alton.
Soma, Hiroshi, Kanagawa-Pref, Japan.
Suzuki, Hiroshi, Tokyo, Japan.
Takeda, Mari, Tokyo, Japan.
Takeuchi, Kumi, Chiba-Pref, Japan.
Tanigawa, Sonoh, Tokyo, Japan.
Tazima, Kazumi, Tokyo, Japan.
Tsuda, Miwako, Hyogo-Pref, Japan.
Van Opstal, W.B.M., Tilburg, The Netherlands.
Von Redlich, Anna B.A., Monza, Italy.
Watanabe, Naoki, Tokyo, Japan.
Wells, Andrew, Caterham.
Wilson, Nean E., Longniddry.
Wooldridge, James M., Worcester.
Yasuda, Atsuko, Tokyo, Japan.

INTERGEMLAB GROUP

The INTERGEMLAB Group comprises a number of gemmologists representing internationally recognized laboratories. The Group meets twice a year to discuss gemmological problems which directly effect their laboratories. The members of the group as at January 1990 are listed below:

France
J.-P. Poirot, Public Service for the Control of Diamonds, Natural Pearls and Precious Stones, Chamber of Commerce of Paris, Paris.

Great Britain
K. Scarratt, The Gem Testing Laboratory of Great Britain, London.

Italy
M. Superchi, CISGEM, Chamber of Commerce of Milan, Milan.

The Netherlands
P.C. Zwaan, Netherlands Gem Laboratory, Leiden.

Switzerland
C.A. Schiffmann, Gemmological Laboratory Gübelin, Lucerne.

Following the Intergemlab Group meetings in 1986, the Group announces that an Agreement has been reached between its members with regard to the issuing of reports on pearls.

The Agreement is specific both with regard to the wording used in reports and the methods of examination. In all cases, regardless of the type or number of pearls involved, the reports issued by the member laboratories will describe the pearls both in terms of weight and size, and sometimes state the method(s) used for examination, e.g. X-ray, radiography, Laue diffraction and/or optical methods. The units to be used in specific instances both for weight and size descriptions and the form of wording to be used in cases relating to various possible results have been agreed.

The Agreement has been in operation for two years and has been found to work well for each member. The results given in one laboratory are similar in wording to those given in another.

One of the reasons why members felt it was necessary to draw up an agreement of this kind was the increase in inexperienced persons setting up 'X-ray' equipment and declaring themselves 'pearl experts'. A number of inaccurate and/or misleading reports have been issued by such inexperienced persons over the last few years. The Group also felt that the trade and the public should have consistent reporting from each member and most importantly they should be informed of the limitations of each method used for examination.

An area for concern is the reporting on natural pearl necklaces by X-radiography. On rare occasions, using X-radiography alone, it is possible to give a result for every pearl in a natural pearl necklace but in the majority of cases this is not possible. The Group strongly recommend that in the case of natural pearl necklaces, the pearls should be cut from the silk to allow for each pearl to be examined and reported upon. In the vast majority of cases, reports on natural pearl necklaces based upon X-radiography alone may only be considered as 'sample reports'. Amongst those pearls which remain unidentified by this method could be a number of cultured pearls, particularly of the non-nucleated variety (i.e. with organic implant). When the client insists upon a 'sample report' he will find the following statement on reports issued by the Group:

'NB This single examination by X-radiography did not prove the identity of every pearl in the necklace; therefore the 'pearls' must be removed from the silk for every pearl to be determined.'

In the issuing of 'sample reports' each member is operating to specific but unpublished guidelines.

The Group also warns those inexperienced in the examination of pearls that the identification of a large number of natural and non-nucleated cultured pearls cannot be relied upon from radiographs taken only in one direction. The Group also works to specific guidelines for reports on both cultured pearl necklaces and those with a mixture of natural and cultured pearls.

TRADE FAIRS

The **Gem and Mineral Fairs 1990**, organized by the British Lapidary and Mineral Dealers Association, are listed below. Full details may be obtained fromJohn F. Turner, Glenjoy, 19/21 Sun Lane, Wakefield, Yorkshire, telephone 0924 373786.

Bristol and West
Watershed Media Centre, Canons Road, Bristol. 26 and 27 May

Harrogate International
Crown Hotel, Harrogate. 25, 26 and 27 August

London International
Holiday Inn, Swiss Cottage, London. 20 and 21 October

The **3rd World Gems Expo** is to be held from 2 to 5 June 1990 at the Hong Kong Convention and Exhibition Centre, 1 Harbour Road, Wanchai, Hong Kong. Details from co-organizers: Hong Kong Diamond Bourse and Headway Trade Fairs Ltd, 9/F Sing-Ho Finance Building, 168 Gloucester Road, Hong Kong.

The **Bangkok Gems and Jewellery Fair 1990** is to be held from 12 to 16 September in the Exhibitions Halls, Department of Export Promotion, Bangkok. For further information contact the Secretariat Office of the Fair, Exporter Service Division, Department of Export Promotion, 22/77 Rachadapisek Road, Bangkok 10900, Thailand. Telephone 5131909 Ext. 272, 273.

NEW AND UPDATED PRODUCTS FROM THE ASSOCIATION

The Association is proud to announce that it has been appointed sole UK distributor for the **World Map of Gem Deposits** published by the Swiss Gemmological Society and based upon the work of Dr Edward Gübelin and his colleagues.

The Map is said by many to be a gemmological masterpiece and is the culmination of much investigative research. It measures 92 x 128cm and has an information key printed in English, Spanish, German, French, Italian and Portuguese. All maps are discretely overprinted with the Association's Coat of Arms (unless otherwise requested).

Such a publishing achievement is remarkable and will be a constant visual source of vital information, not only for students and persons interested in gemmology and jewellery, but as a 'backdrop' for window displays wherever quality gems and jewellery are exhibited.

The face side identifies deposits world-wide and a colour code is used to highlight the sites of eleven major gems and various ornamental gem materials. The reverse side features 65 full colour illustrations of gems as well as photographs of gem deposits and mining operations.

The whole concept of such a work has been enthusiastically received by the world's leading jewellers and gemmologists, and the following are just two reviews:

'A most useful display document for both customers and staff. The Map can be used as a sales aid for normal business and special promotions, and I have no hesitation in recommending this wonderful pictorial chart to both retail jewellers and gemmologists.' – *Richard Peplow of W.H. Peplow, Worcester, and Chairman of the National Association of Goldsmiths*

'This modern production updates and extends the pioneer work produced by H.J.Schubnel some decades ago. The map is much larger enabling more deposits to be shown in greater detail. The series of fine photographs of gem deposits on the reverse of the Map provides a convenient cross section of the methods of mining, both primative and sophisticated, used around the world. A most useful publication for teaching and for display in jewellers' shops and elsewhere.' – *Alan Jobbins, Editor, the Journal of Gemmology.*

The map can be supplied either folded or flat. Your company's logo, name and address can be overprinted on the Map (minimum order 100 copies) making it an ideal gift for valued clients. The price for the folded map is £13.50 (£14.50 flat) plus postage and packing.

The second annual update of the computer program **GEMDATA**, developed to assist in gemstone appraisal identifications and gemmological studies, has just been released. The new version has been designed mainly in response to user requests and as a result of independent evaluation tests. In addition to small modifications to gem constants, a new section enables crystal specimens to be identified from inputs for crystal system/optical character, colour, transparency and SG, and is supported by a graphics page of typical crystal habits.

In the polished stone section there are now optional inputs for uniaxial/biaxial stones, for 'negative' readings above the range of the standard refractometer, and for extended SG tolerance limits for the hydrostatic weighing of small stones. Crystal system/optical character is now included with the information displayed for each gemstone. When a list of gemstones is requested there is also a scroll stop-continue feature which provides a page-by-page view of the data, and it is now possible to re-run a gem identification using alternative search limits without having to input the test data again.

GEMDATA is compiled in QuickBASIC and can be loaded direct from DOS on any IBM PC-compatible computer having a minimum memory of 128K. GEMDATA is supplied on either a single 5.25 inch double-sided double-density disk or a 3.5 inch disk, and comes complete with operating instructions and gem index. Separate versions of the program are available for use with colour or monochrome monitors. GEMDATA (Update 2) is available from the Gemmological Association, price £90.00 (plus VAT, postage and packing).

To order either of these products please use the coupons on p.126. Payment can be made by the major credit/charge cards. To obtain a catalogue and price list of instruments contact the Gemmological Association of Great Britain, Saint Dunstan's House, Carey Lane, London EC2V 8AB.

THE JOURNAL OF GEMMOLOGY BACK NUMBERS

A member of the Association has for sale a complete set of *The Journal* from 1972 to 1989, as well as back issues of overseas journals. Enquiries to the Association, Box No. 1713.

CORRIGENDA

On the front inside cover, Vol. 22, No. 1, under 'Members elected to Council', C.R. Burch, B.Sc., FGS, R.J.Peace, B.Sc., C.Chem, FRSC, FGA, and E.Stern, FGA, should have been included, and E.M.Bruton, FGA, omitted. The South Yorkshire and District Branch Chairman, G.A.Massie, FGA, should have been omitted also

On p.52 above, second column, Stig E. Sundin, Hylkje, Norway, was omitted from the list of those that qualified in the 1989 Preliminary Examination.

Letters to the Editor

From K. Scarratt
The Gem Testing Laboratory of Great Britain

Dear Sir,

A short paper written by S. Scandella was published in the July 1989 issue of *The Journal* (**21**, 7, p.411) regarding observations made during the examination of a number of black diamonds. The paper, in its title and content, assumed that the stones in question were of the Type IIb. This assumption had been made, in the main, from two clear facts, (a) that the stones were diamond, and (b) that they conducted electricity.

Whilst realizing the difficulties involved in arriving at a 'Type' for what must have been almost, if not entirely, opaque diamonds, one has to question the wisdom of publishing statements that are based upon insufficient evidence. The paper made no mention of the UV/visible or IR absorption characteristics of the stones, even though it is these very factors which assign a 'Type' to a given diamond.

Shortly before the publication of this paper the Gem Testing Laboratory in London had been examining a similar group of black diamonds which also conducted electricity. However, it was concluded that as graphite (the black appearance of the stones resulted from the inclusion in the diamond of a black material that was possibly graphite) conducted electricity no safe conclusion with regard to the diamonds' Type could be made without more detailed work. Indeed, tests indicated that the stones did not conduct in those areas where the included material did not reach the surface.

In order that we might clearly 'Type' these stones, the Laboratory purchased one example in which there appeared to be a narrow tunnel of inclusion-free diamond running through the stone. So that visible and infrared spectra could be obtained, the stone was laser-cut and polished to take best advantage of the inclusion-free area. The resulting visible and infrared spectra (Figures 1 and 2) determined the stone to be Type IaA.

In concluding we would like to thank Mr C. Welbourne of the Diamond Trading Company

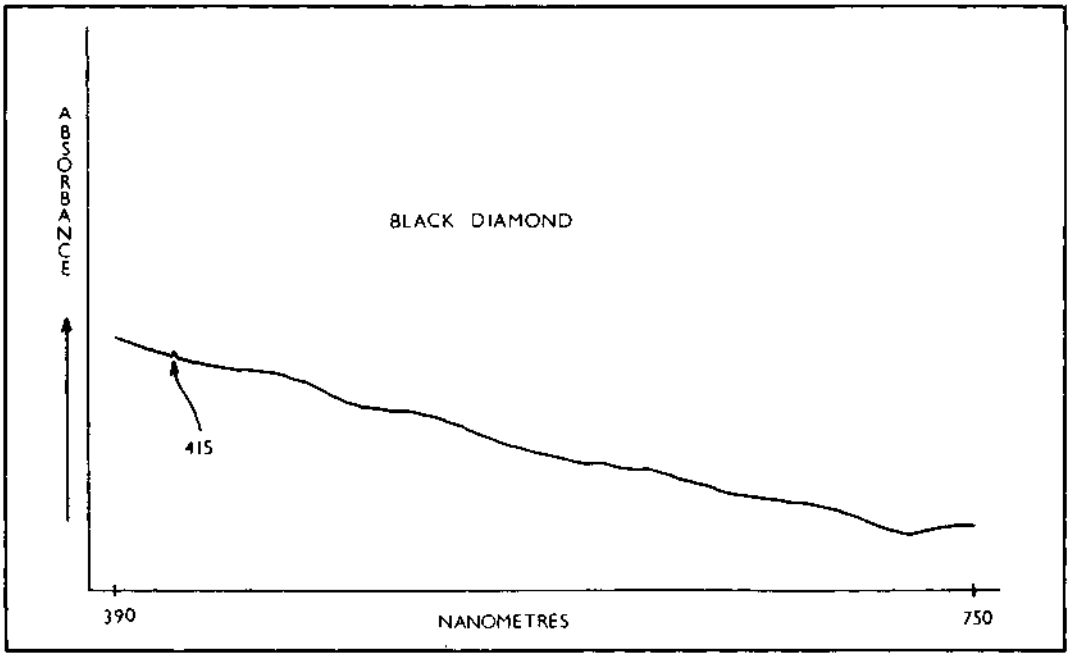

Fig. 1

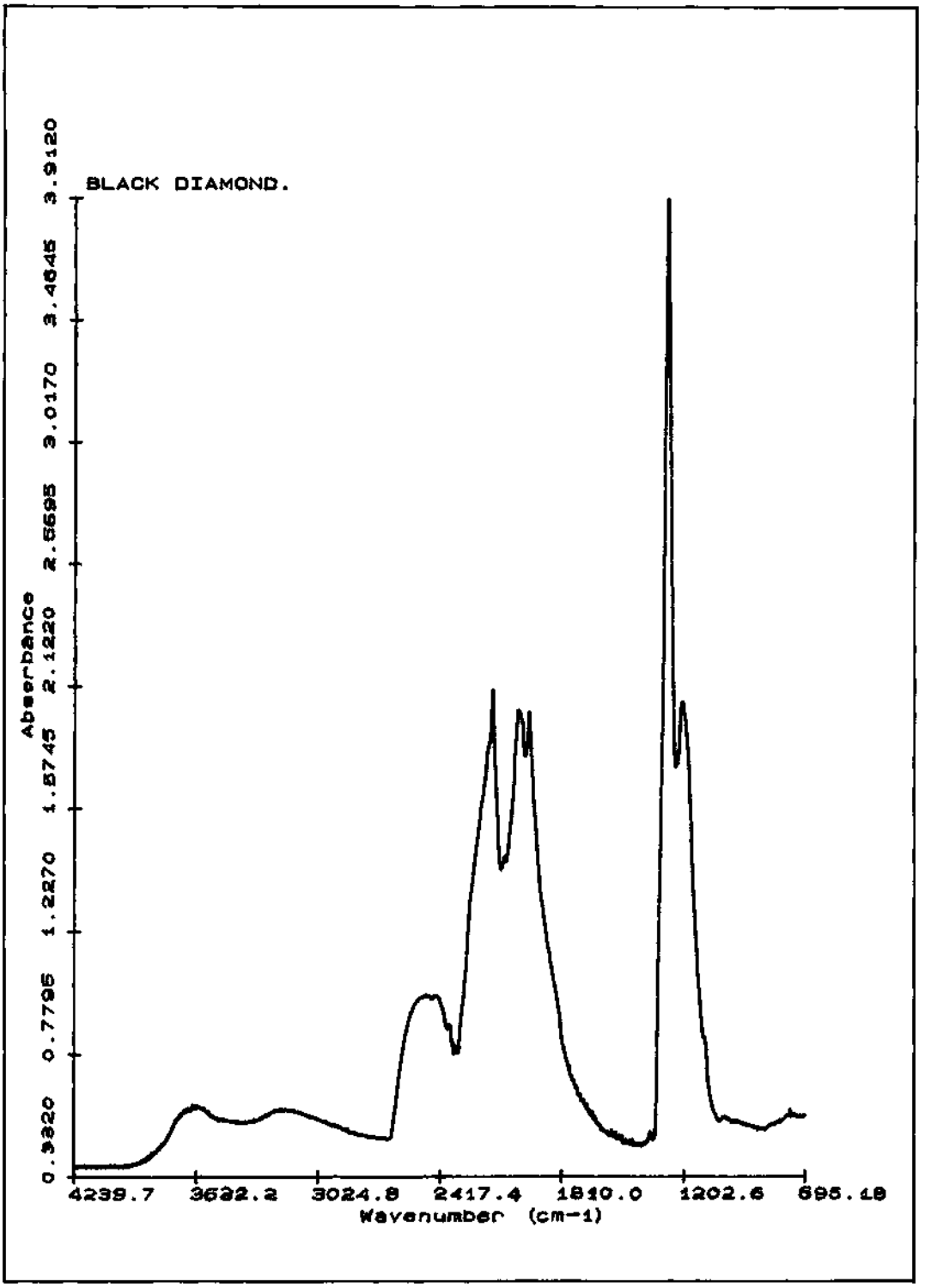
BLACK DIAMOND.
Absorbance
0.3820
0.7795
1.2270
1.6745
2.1220
2.5695
3.0170
3.4645
3.9120
4239.7
3632.2
3024.8
2417.4
1810.0
1202.6
595.18
Wavenumber (cm-1)

Fig. 2

Research Department both for his assistance in arranging for the stone to be laser-cut and polished and for his comments upon the spectra.

Yours etc.,
K. Scarratt

26 February 1990
The Gem Testing Laboratory of Great Britain, 27 Greville Street, London EC1N 8SU.

From S.Scandella and C.A.Schiffmann
Gübelin Gemmological Laboratory

Dear Sir,

Thank you for informing us of the letter of Mr Ken Scarratt referring to the testing of two black diamonds. The remarks of Mr Scarratt are correct in showing the steps to be taken in such an analysis.

On the other hand, we know that gemmology must often be practised under quite limiting circumstances. In this case the diamonds were opaque, there was no permission to slice them and they had to be given back within a short time.

Going back to the semi-conducting behaviour of these diamonds, we don't quite see how a Type I diamond full of graphite (?) would still retain the usual tenacity and hardness of diamond.

We would welcome any further suggestion!

Yours etc.,
S.Scandella and C.A.Schiffmann

6 March 1990
Gübelin Gemmological Laboratory, Denmalstrasse 2, CH-6000 Lucerne 6, Switzerland.

From R. Keith Mitchell FGA

Dear Sir,

In an abstract of mine on p.42 of the January 1990 issue of the *Journal*, the comment '[part of the text is missing so this entry is difficult to understand]' has been printed. That comment was incorrect and my misreading was due to slightly awkward phrasing at the beginning of the next column. I tried to cancel this at the time, but my 'phone call was evidently too late. My apologies to the author for carelessness on my part.

Yours etc.,
R. Keith Mitchell

5 March 1990
Orpington, Kent.

ADVERTISING IN THE JOURNAL OF GEMMOLOGY

The Editors of the *Journal* invite advertisements from gemstone and mineral dealers, scientific instrument makers, publishers and others with interests in the gemmological, mineralogical, lapidary and jewellery fields.

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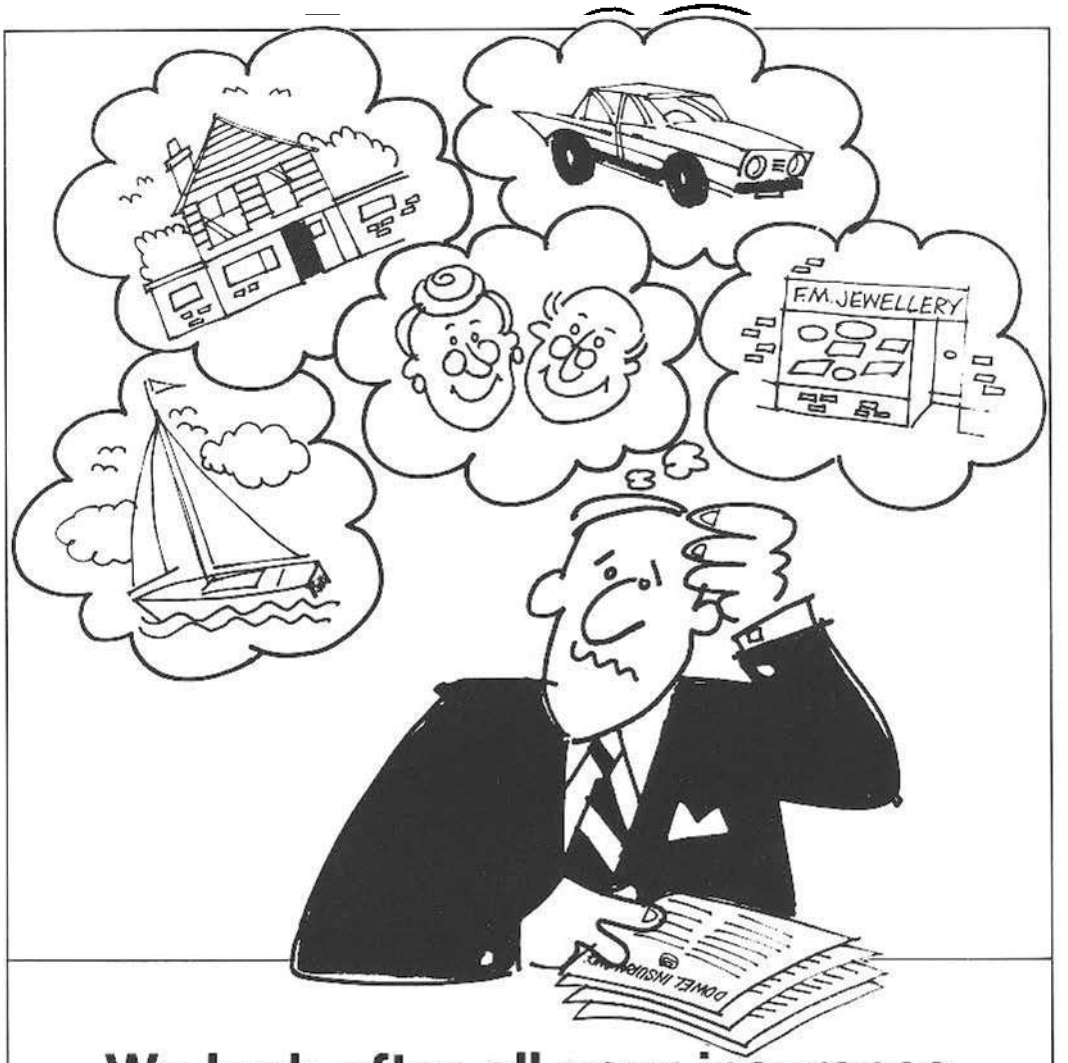

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The Arms and Crest of the Association, conferred by a grant of Arms made by the Kings of Arms under royal authority. The cross is a variation of that in the Arms of the National Association of Goldsmiths of Great Britain and Ireland. In the middle is a gold jewelled book representing the study of gemmology and the examination work of the Association. Above it is a top plan of a rose-cut diamond inside a ring, suggesting the scrutiny of gems by magnification under a lens. The lozenges represent uncut octahedra and the gem-set ring indicates the use of gems in ornamentation. The lynx of the crest at the top was credited, in ancient times, with being able to see through opaque substances. He represents the lapidary and the student scrutinizing every aspect of gemmology. In the paws is one of the oldest heraldic emblems, an escarbuncle, to represent a very brilliant jewel, usually a ruby. The radiating arms suggest light diffused by the escarbuncle and their tips are shown as jewels representing the colours of the spectrum.

Historical Note

The Gemmological Association of Great Britain was originally founded in 1908 as the Education Committee of the National Association of Goldsmiths and reconstituted in 1931 as the Gemmological Association. Its name was extended to Gemmological Association of Great Britain in 1938, and finally in 1944 it was incorporated in that name under the Companies Acts as a company limited by guarantee (registered in England, no. 433063).

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The Editors are glad to consider original articles shedding new light on subjects of gemmological interest for publication in the *Journal*. Articles are not normally accepted which have already been published elsewhere in English, and an article is accepted only on the understanding that (1) full information as to any previous publication (whether in English or another language) has been given, (2) it is not under consideration for publication elsewhere and (3) it will not be published elsewhere without the consent of the Editors.

Papers should be submitted in duplicate on A4 paper. They should be typed with double line spacing with ample margins of at least 25mm all round. The title should be as brief as is consistent with clear indication of the content of the paper. It should be followed by the names (with initials) of the authors and by their addresses. A short abstract of 50–100 words should be provided. Papers may be of any length, but long papers of more than 10 000 words (unless capable of division into parts or of exceptional importance) are unlikely to be acceptable, whereas a short paper of 400–500 words may achieve early publication.

Twenty five copies of individual papers are provided on request free of charge; additional copies may be supplied, but they must be ordered at first proof stage or earlier.

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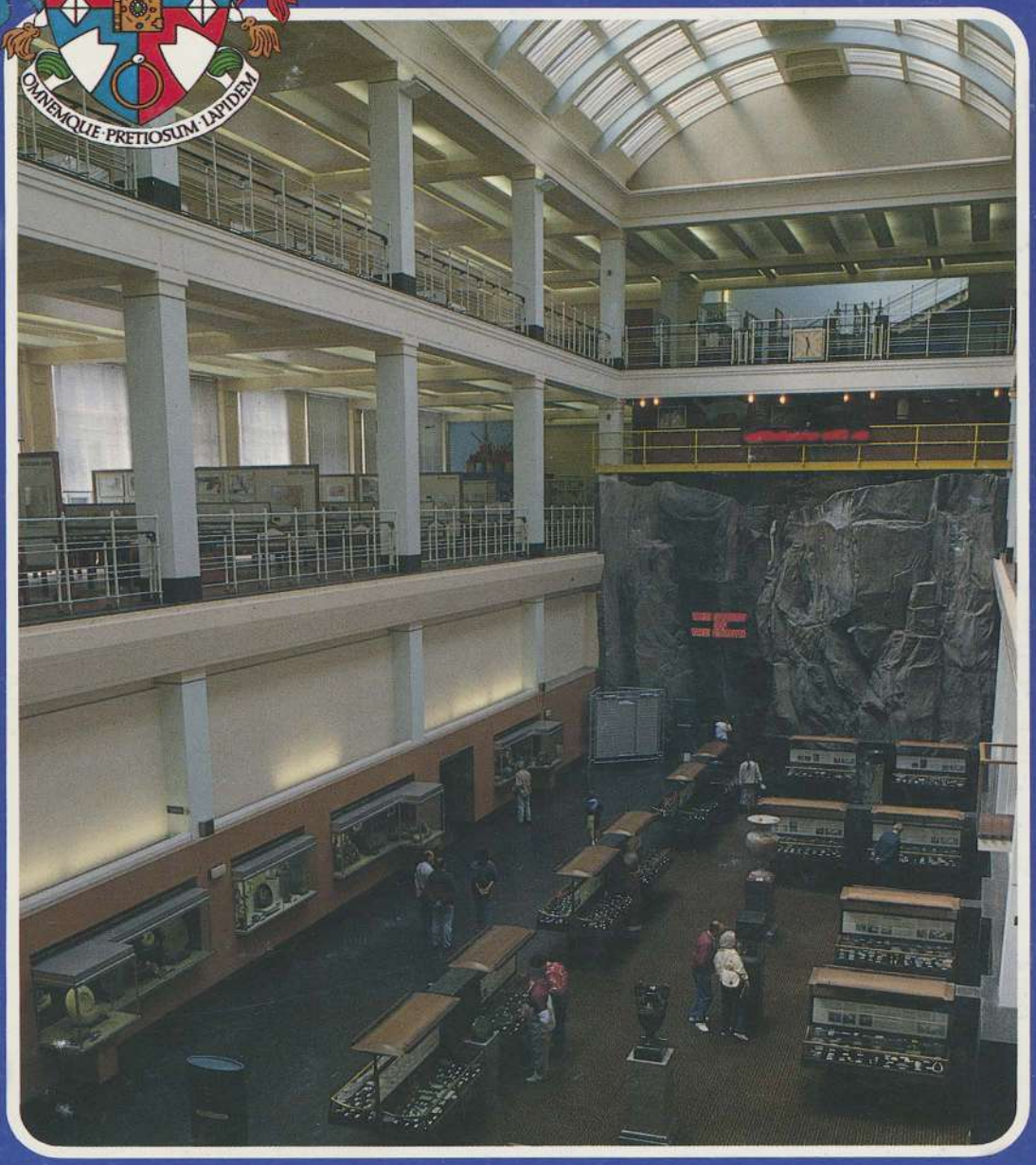

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Cover Picture

The gemstone exhibition in the Geological Museum, London (now designated part of the Earth Sciences Galleries of the Natural History Museum). This comprehensive display is threatened with closure, and all readers are urged to take the opportunity to view it again before it is dismantled.

The celebrated Mineral Gallery in the Natural History Museum is also scheduled to share the same fate. It is planned to combine the two exhibitions in a very considerably contracted area on one side of an upper gallery of the Geological Museum.

See 'The case of the disappearing gemstones' on page 130.

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The case of the disappearing gemstones

Many of our readers will be familiar with both the magnificent mineral and gemstone display in the Mineral Gallery of the Natural History Museum, and the remarkable gemstone exhibition on the ground floor of the Geological Museum (see front cover illustration).

These two displays together probably constitute the world's finest reference display of gemstones and minerals, and attract visitors to London from all over the world.

We understand that the 'management' of the Museums (the Geological Museum was 'given' by the British Geological Survey to the Natural History Museum in April 1985) intend shortly to combine these two displays onto part of one side of one of the upper galleries of the Geological Museum. The drastically reduced area will inevitably mean that the vast majority of the collections will go into storage, never to be seen again. This will be made worse by the intention that the new exhibition will be a 'theme' rather than a 'reference' display. This apparently means that only a very few items will be displayed, so that the least intelligent visitor to the Museum will not get confused.

We urge our readers to visit the current displays before the Museums' management perpetrate what is likely to be the greatest jewel robbery ever inflicted on the unsuspecting public who are, after all, the actual owners of the National Museums and their collections.

STOP PRESS.....MURDER MOST FOUL.....STOP PRESS

Since writing the above, we have learnt that the Museum management, as part of its plan to perpetrate the jewel robbery, has literally *killed gemmology* within the *Museums*.

The Director, Dr Neil Chalmers, has announced a new corporate plan. This involves a major reduction in the scientific staff, and the complete withdrawal from several scientific areas, including all gemstone related services and research. The post of Curator of Gemstones is to be abolished. The posts of the only other qualified gemmologists (two in 'exhibition design') are also to be axed.

This means that there will soon be nobody employed by the Museums who will be qualified to identify gemstones, including those in the Museums' own magnificent collections.

Whilst by no means ameliorating the current situation, it is worth mentioning here that the Gem Testing Laboratory of Great Britain (the oldest such laboratory in the world) is ready and able to provide any gemmological testing services previously supplied by the Museums.

It is hoped that the Laboratory will, later this year, merge with the Gemmological Association of Great Britain (the world's oldest gemmological association), ensuring that the United Kingdom retains at least one strong gemmological organization.

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A black jade dilemma

John I. Koivula, C. W. Fryer, Robert E. Kane and Robert C. Kammerling

Gemological Institute of America, California, USA

Abstract

Three of four opaque black gems being represented in the trade as the pyroxene jadeite were identified by X-ray diffraction as rocks containing a major component of amphibole, probably kaersutite. The fourth stone showed the diffraction pattern for jadeite. Since the basic gemmological properties of some amphiboles like kaersutite overlap those of jadeite, routine gemmological testing cannot separate the two. More advanced testing techniques, such as X-ray diffraction and chemical analysis, are needed to make this separation.

Introduction

Four opaque, black stones (Figure 1) were submitted for identification to the GIA Gem Trade Laboratory, Inc. It was reported that these and similar stones were being sold in the trade as black jadeite jade. The source of these stones was reported to be Guatemala; black jadeite is known to come from Guatemala in significant amounts (David Hargett, Personal Communication).

The values obtained for refractive index, specific gravity and hardness, and the lack of either ultraviolet luminescence or an absorption spectrum, indicated that the stones could be jadeite jade. However, the very nature of opaque black jade-like materials is such that they are not conducive to identification by routine gemmological testing because there are other minerals and rock types with the appearance and properties overlapping those of jadeite. Therefore, the two polished oval cabochons weighing 23.66 and 44.66 carats and the two polished table cuts at 8.05 and 26.52 carats respectively, were subjected to further testing by X-ray powder diffraction and chemical analysis in an effort to determine the true nature of this material.

Gemmological Testing

Visual Appearance

All four stones at first appeared to be quite similar when examined in oblique incident light with the unaided eye. When each stone was studied more carefully, however, some slight differences were noted. The smaller oval cabochon and the two rectangular table cuts (Figure 1) possessed a good polish with a vitreous lustre. They also appeared to be mottled with tiny whitish spots that stood out against the black background. Although the larger oval cabochon (Figure 1) also had a good to very good polish with a vitreous lustre, it lacked the tiny whitish spots and had a very dark grey, rather than black, body colour when viewed with strong fibre-optic incident light.

Refractive Index

The cabochons had polished bases which made them much easier to test for refractive index. Using a GIA GEM Instruments Duplex II refractometer and, in turn, both sodium vapour and white light sources, a refractive index of 1.67 was obtained from a flat, well-polished surface on each of the four stones. No birefringence was noted on any of the specimens.

Specific Gravity

Specific gravity was first estimated using the sink-float method. Both of the table cut stones as well as the larger oval cabochon sank very slowly in pure methylene iodide (specific gravity 3.32), at the same rate as a known jadeite indicator. The smaller of the two oval cabochons, however, barely floated in the liquid with a vertical, base-up tilt, with just a minute portion of the girdle edge breaking the liquid's surface.

The specific gravity was also determined by the hydrostatic weighing method, using a Voland diamond balance, with three readings being taken on each of the four stones. The specific gravity values obtained for the four stones varied slightly from a low reading of 3.29 to a high value of 3.34.

Luminescence Reactions

In total darkness, no reaction to either long-wave (366.0 nm) or short-wave (253.7 nm) ultraviolet radiation was observed, even when ultraviolet contrast control glasses were used. The four stones also proved to be inert to X-radiation.

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Fig. 1. The four opaque black stones studied for this report. The large oval cabochon shown here, weighing 44.66 ct, was identified as primarily jadeite, while the other stones were identified as rocks composed primarily of amphibole(s). *Photography © Tino Hammid.*

Spectroscopy

The visible-light spectra were next examined using a GIA GEM Instruments spectroscope unit with a Beck prism spectroscope. In surface reflected light no absorption characteristics were observed in any of the four stones. This is to be expected for dark-coloured jadeite. During this phase of the examination, however, we did observe that very thin edges of the stones transmitted a dark green colour when illuminated with a very strong fibre-optic light source, but this weak transmission was insufficient for transmitted-light spectroscopic testing.

Hardness

Hardness was tested under magnification, using hardness points on an inconspicuous area of each stone. Based on the results of this testing the hardness of all of the samples was estimated to be approximately 6½ on the Mohs' scale.

Microscopy

A binocular gemmological microscope was used to examine the surfaces of the stones in reflected oblique illumination. All four stones showed what seemed to be an intermixing of various grains that appeared whitish to near-colourless and very dark green to black. Shadowed oblique illumination was then employed on a flat surface of the largest table cut stone to see if any individual grains had undercut during the polishing process as would be expected from a rock. Figure 2 shows that undercutting, and therefore slight variations in hardness of the individual grains, exists. The other three stones also showed this same visual evidence of granular undercutting.

The results of these standard gemmological tests suggested that the four stones might be an impure jadeite jade, or more specifically, a rock composed primarily of jadeite with other minerals. X-ray diffraction and chemical analysis were now deemed necessary to identify the material(s) more precisely.

X-Ray Diffraction

Using a sharp-edged diamond scribe, a minute amount of powder was carefully scraped from the girdle of the smallest table cut and a spindle for X-ray powder diffraction was prepared. This spindle was then mounted in a Debye-Scherrer powder camera and exposed for eight hours to X-rays generated at 49 kV and 18 mA from a copper target tube. The resulting pattern, when compared with our standard diffraction pattern for jadeite jade, did not match. By using the Joint Committee for Powder Diffraction Standards Mineral Powder Diffraction File Search Manual and Data Book (1986), however, a close match was obtained with the amphibole kaersutite (ASTM file 17-478).

The remaining three stones were then similarly

tested using X-ray diffraction. Only the largest oval cabochon showed a jadeite pattern, the other two samples also revealing amphibole group X-ray diffraction patterns close to that of kaersutite.

Based on the results of X-ray diffraction, the larger oval cabochon was identified, in its greatest portion, as jadeite jade. At this point the other three stones could now be called amphiboles or amphibole rocks, but could not be classified specifically as kaersutite because of the complex nature of the amphibole group of minerals. Chemical analysis was next employed to try to determine if they could be identified as a specific mineral.

Chemistry

The four stones were turned over to Carol Stockton, Senior Gemologist in GIA's research department, for chemical analysis. Using the electron microprobe at the California Institute of Technology in Pasadena, California, Ms Stockton analyzed the largest table cut and found that titanium was present in amounts up to 0.43 weight per cent TiO_2. Although this is not a high enough weight per cent of titanium to call the sample kaersutite (Deer, Howie and Zussman, 1974) it suggests, together with the diffraction pattern, that some kaersutite may at least be present.

Thin Section Examination

After obtaining permission from the owner, two thin sections were prepared, one each from the apparently different materials, jadeite and amphibole (kaersutite?). The granularity of the two thin sections was then studied in polarized light. The section taken from the cabochon that produced an X-ray diffraction pattern of jadeite was composed of a mass of grains so small (less than 0.001 mm) that none of the typical pyroxene characteristics were observed. This entire section was also veined with an opaque material that appeared as black clouds throughout the thin section (Figure 3). This fine-grained nature results in a lack of microscopically resolvable pyroxene characteristics. However, the combination of the gemmological properties and the X-ray diffraction pattern obtained from this sample served adequately to identify it as jadeite jade.

Although badly fractured, the section taken from the amphibole sample still contained easily visible individual grains up to 0.01 mm in size. Some of these showed the typical prismatic cleavage associated with amphiboles (Figure 4). The impurity of this sample was also apparent, with an abundance of grains not showing any of the characteristics of amphiboles.

In view of these findings, and taking into consideration the inconclusive X-ray diffraction pattern and chemical analysis, the stone from which this

Fig. 2. Undercutting on the largest table cut stone. All four gems showed similar polished-surface undercutting, indicating slight variation in granular hardness and therefore suggesting an impure aggregate nature. Shadowed oblique illumination. 50X.

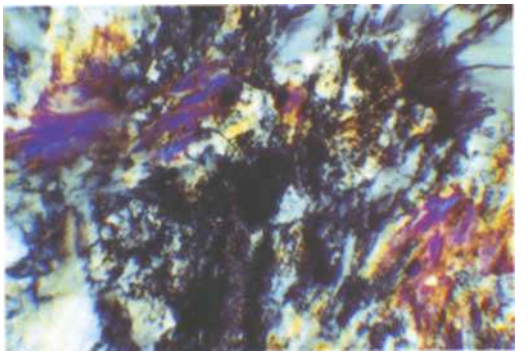

Fig. 3. Polarized light view of the thin section taken from the larger oval cabochon that gave an X-ray diffraction pattern of jadeite. Note the lack of granularity, unusual for a pyroxene like jadeite, and also the opaque black fine-grained contaminant. 100X.

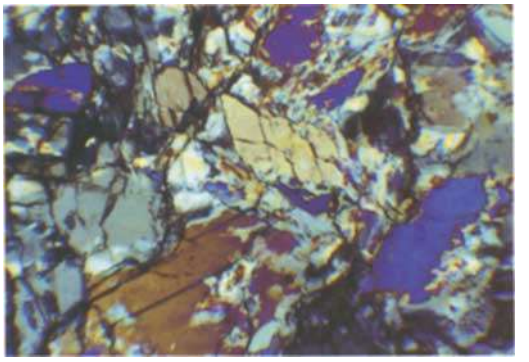

Fig. 4. In polarized light, accented by interference colours, the heavily fractured appearance of the impure amphibole rock is apparent in this thin section. Note also the prismatic 'diamond-shaped' amphibole cleavage shown by the light brown grain near the centre. 100X.

thin section was cut would be best classified gemmologically as a rock containing amphibole(s) as a major component(s), one of which may be kaersutite.

Conclusion

Although it has been seen in the gem trade, truly black jadeite is not common. Most of the black jade on the market, rather, is nephrite, a massive compact variety of actinolite, an amphibole. And even though nephrite is an amphibole, its properties are sufficiently different from jadeite to make their gemmological separation rather straightforward. This is not the case, however, with some other amphiboles, such as those studied for this report.

Pyroxenes such as jadeite, and amphiboles like kaersutite, are known to occur in very close geological association (Mason, 1968; Deer, *et al.*, 1974). In impure, compact, massive form, some amphiboles such as kaersutite have a very dark green to black colour, with their gemmological properties overlapping those of jadeite jade. Therefore, in the course of standard gemmological testing, these amphiboles cannot be separated from black jadeite jade. Rather, additional tests such as X-ray diffraction or chemical analysis are required to make an identification. In view of the above discussion, it is very possible that at least some material being represented as black 'jadeite jade' may be a rock containing amphibole(s) (possibly kaersutite) and not the pyroxene jadeite. It is therefore suggested that, when gemmologists are confronted with opaque black materials showing the outward gemmological properties of jadeite jade, they proceed with caution in their identifications.

Acknowledgement

The authors would like to thank Mr David Hargett, Manager of Gem Identification in the GIA Gem Trade Laboratory, New York, for his valuable comments during the preparation of this report.

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[*Manuscript received 1 July 1989.*]

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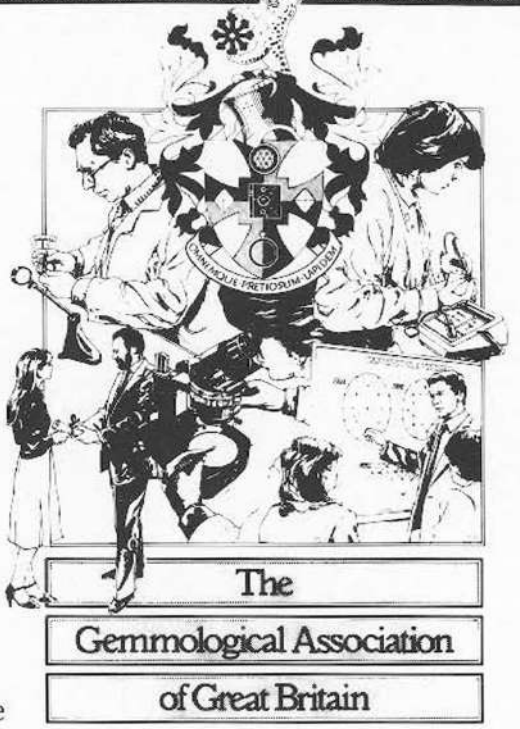

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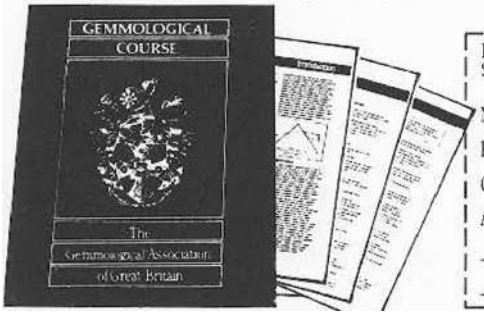

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Sapphirine from the Kolonne area, Sri Lanka

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Abstract

Gem sapphirine is being recovered from a mine about 9 miles north-west of Embilipitya, Sri Lanka. The geological setting of the deposit is briefly described and electron microprobe and ICPS analyses of the sapphirine are reported. The similarities between sapphirine and serendibite are discussed.

Introduction

Sapphirine is a gem mineral recently discovered and now becoming more generally known in Sri Lanka. It has been reported by Fryer 1985, Scarratt 1987 (from Sri Lanka), Kane 1987 (from Thailand), and Koivula and Kammerling 1988 (from Sri Lanka and Canada), and has also been identified as an inclusion in ruby by Koivula and Fryer 1987.

In Sri Lanka the gem sapphirine comes from a mine located near the 9th milepost along the Rakwana-Embilipitya Road (Figure 1). It is 4 miles east of the village of Kolonne which is already well known for its sapphire, ruby, spinel, zircon, sillimanite (fibrolite), scapolite and fluorite.

This note briefly describes the geological setting of the sapphirine and reports its chemical composition.

Geological setting

Sapphirine is derived and obtained from rocks of the Highland Series, a sequence of high-grade metamorphic rocks consisting of gneisses, charnockites, quartzites and other metasediments (see Figure 1). Typical terrain and outcrop are shown in Figures 2 and 3. Miners have recovered sapphirine by digging and sorting overburden to depths of 6 feet and sapphirines found locally in biotite gneiss fragments indicate that the source rock is nearby.

More than 75% of the sapphirine fragments are small in size and poor in quality; the remainder are of variable transparency, are dark greenish blue or pinkish brown and exhibit strong pleochroism. The largest gem-quality rough specimen seen by one of us (GZ) is clear pinkish brown and weighs 13.61 carats.

Analyses of sapphirine

Two fragments of blue sapphirine, maximum length 8 mm, were examined. Both were confirmed as sapphirine by X-ray diffraction (films 7393F and 7394F). One fragment was set in resin and a polished face prepared. Refractive index readings

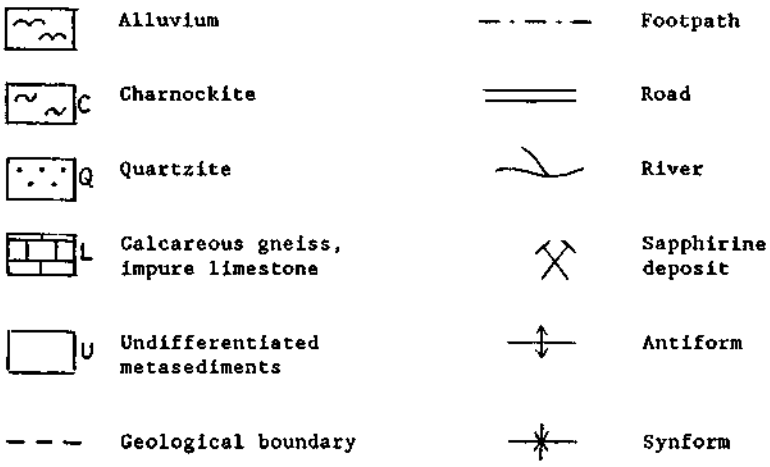

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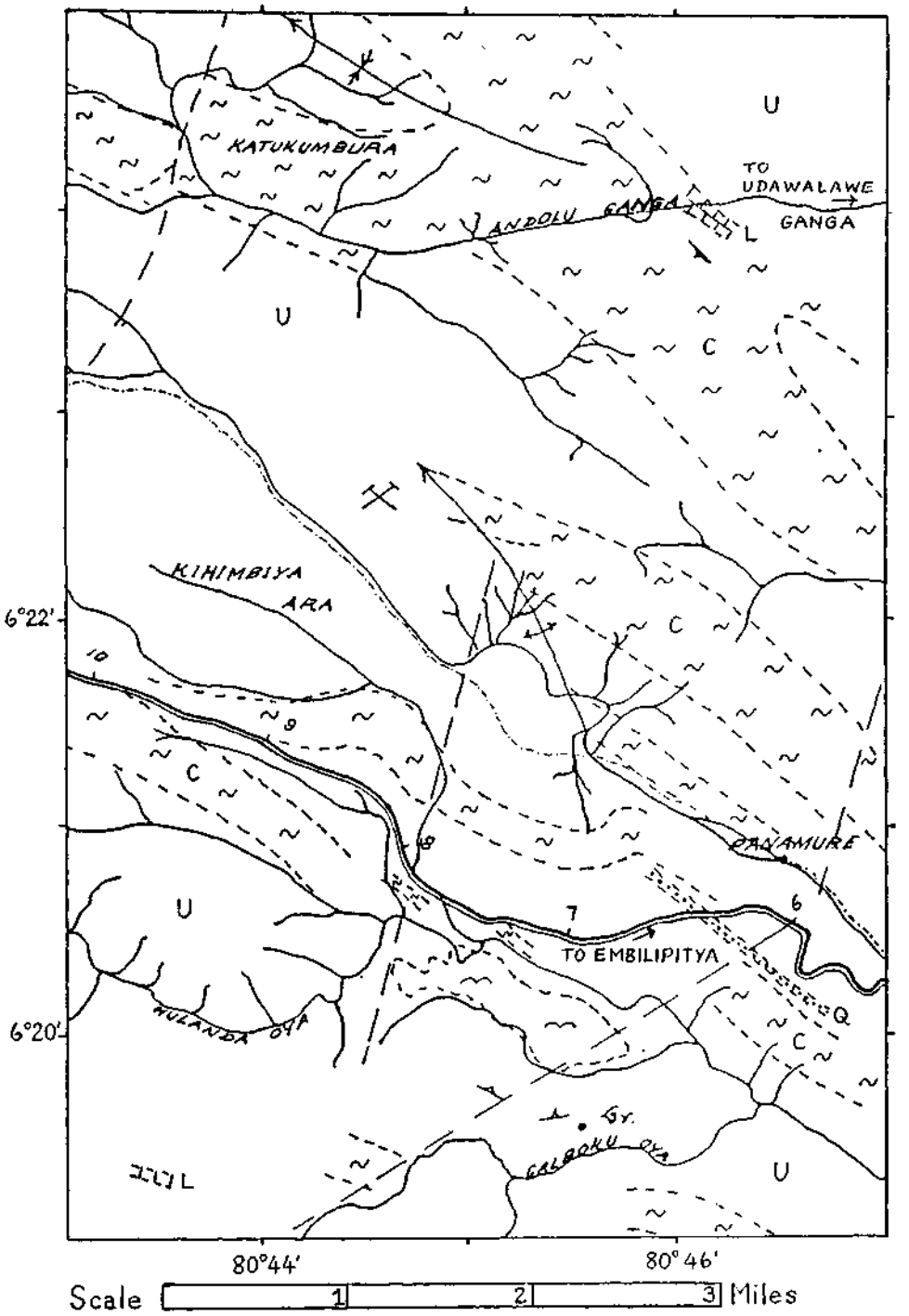

Fig. 1. Geological sketch map of area east of Kolonne.

Table 1. Analyses of sapphirine from Sri Lanka

Wt%	1A	2	3	ppm	1B
SiO_2	14.4	14.9	<0.2	Li	52
Al_2O_3	63.8	61.9	<0.2	Be	23
FeO	1.83	1.7	<0.2	Ti	<50
MgO	19.2	19.9	0.45	V	24
CaO	0.08	< 0.1	54.16	Cr	<50
Na_2O	< 0.1	< 0.1	0.41	Mn	85
P_2O_5	0.04	< 0.1	42.74	Ni	40
B_2O_3	0.28	n.d.	n.d.	Cu	<20
Others	0.4	n.d.	n.d.	Zn	45
Total	99.7	98.4	97.76		

Notes: Columns 1A and 1B are results of ICPS analysis using (i) Na_2CO_3 fusion in dil. HNO_3/HCl for Al, Li, B; and (ii) $LiBO_2$ fusion in dil. HNO_3 for remaining elements (analyst V. K. Din). Total Fe is given as FeO. The Hitachi SEM-Link Systems EDS was used to obtain analyses of a polished surface of sapphirine (Column 2, mean of 3 spots analysed) and an apatite inclusion in the sapphirine (Column 3, mean of 3 spots analysed). Boron cannot be determined using this method and n.d. means not determined; total Fe is given as FeO. The low total for the apatite analysis may mean that OH or F is present; Cl was sought but is below detection limits of 0.1%.

obtained on a Rayner Dialdex refractometer were 1.705 and 1.711, giving a birefringence of 0.006.

The polished fragment was then analysed with a Hitachi SEM-Link Systems EDS and the results are given in Table 1, column 2. Energy-dispersive analysis does not provide values for elements with atomic number less than 11 (sodium) and to obtain more comprehensive data the second fragment was analysed by inductively-coupled plasma spectrometry (ICPS). The results are given in Table 1, columns 1A and 1B.

A clear crystal inclusion present at the surface of the polished fragment of sapphirine was identified as apatite (Table 1, column 3), and it is possible that the small amounts of phosphorus and calcium in the ICP analysis are attributable to apatite inclusions.

The ICPS analysis indicates the presence of 0.28% B_2O_3. Boron has not as yet been reported as a constituent of sapphirine (see Deer, Howie & Zussman, 1978, pp 618-621), and it is not known if the boron in this analysis represents a structural component or if it derives from an inclusion containing boron such as sinhalite ($Mg(Al,Fe)BO_4$).

Comment

Sapphirine is very similar in colour to serendibite, a mineral that was first found in Sri Lanka and described in 1903 by Prior and Coomaraswamy; the locality is Gangapitya, about 12 miles east of Kandy. In addition to colour there are other striking similarities between the two minerals and the relevant data below have been taken from Deer, Howie and Zussman, 1978, pp 615, 659.

To the best of the authors' knowledge there are no cut gems of serendibite in existence, but if there were, the above properties suggest that there is no simple gemmological test one can use to separate the two species. Refractive index, birefringence, specific gravity and colour ranges all overlap. Two further properties, absorption spectrum and fluorescence characteristics, may in future provide a means of distinguishing the minerals but preliminary results are not promising. Sapphirine does not have a distinctive spectrum and is inert in long and short wave ultraviolet radiation, while the corresponding data for gem serendibite have not yet been established. Observations on serendibite in rocks from Gangapitya and from Johnsberg, New York, indicate that there is no fluorescence in ultraviolet radiation and that there does not appear to be a distinctive spectrum. Currently either chemical or X-ray determination must be undertaken to confirm an identification.

On the basis of X-ray diffraction measurements the two fragments analysed in this investigation are undoubtedly sapphirine. Nevertheless, in view of the presence of Ca and B in the chemical formula of serendibite, it is interesting to note that small amounts of Ca and B are present in the ICPS analysis of sapphirine (Table 1, column 1A). As

	Sapphirine	Serendibite
Refractive index	1.701 - 1.734	1.700 - 1.743
Birefringence	0.005 - 0.007	0.005 - 0.006
Specific gravity	3.40 - 3.58	3.42 - 3.52
Colour	Blue - pale pink	Blue - pale yellow
Crystal system	Monoclinic (−) or (+)	Triclinic (+)
Chemical formula	$(Mg,Fe^{2+},Fe^{3+},Al)_8O_2[(Al,Si)_6O_{18}]$	$Ca_2(Mg,Al)_6O_2[(Si,Al,B)_6O_{18}]$

Fig. 2. Typical terrain near Kolonne.

Fig. 3. Typical outcrop near Kolonne.

Fig. 4. Sapphirine crystals in gneiss.

Fig. 5. Gem-quality sapphirine.

Fig. 6. Cut and polished sapphirine 1.06 ct.

mentioned above, further work is needed to decide whether these elements are present in the structure of the sapphirine or as inclusions.

Acknowledgements

We would like to thank J. G. Francis and S. Somogyi for carrying out X-ray diffraction determinations on the sapphirine, V. K. Din for providing the ICPS analysis, and F. Wall for expert help with the Hitachi SEM-Link Systems EDS.

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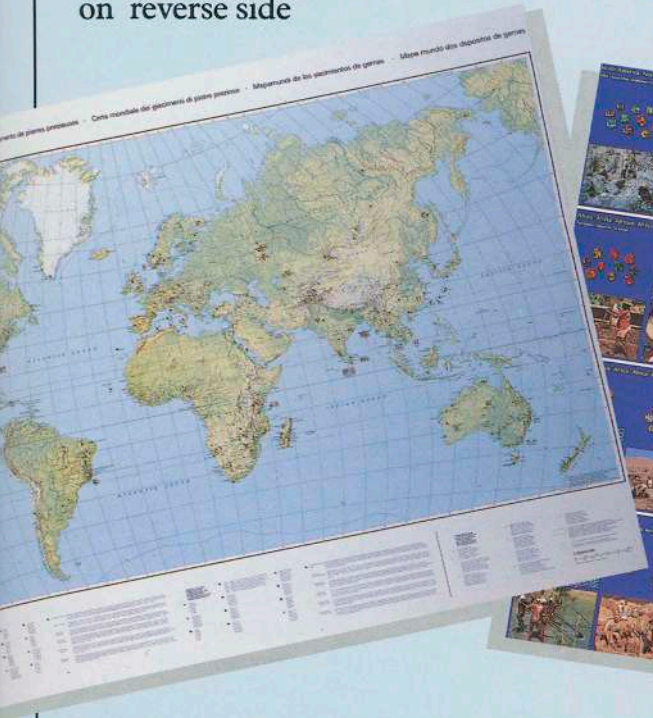

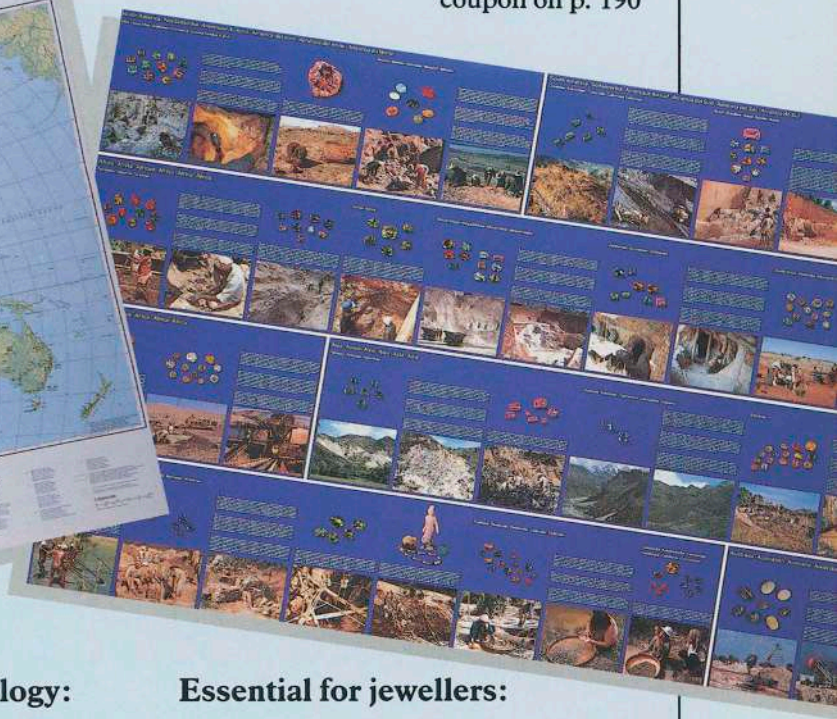

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Testing of colourless natural diamonds by room temperature optical absorption

G. Lifante, F. Jaque, M. A. Hoyos and S. Leguey

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Abstract

Highly sensitive optical absorption measurements at room temperature including derivative techniques have been used for colourless natural diamonds. It has been established that the presence of absorption bands due to N3 centres in natural gems can be used to distinguish natural from synthetic colourless gems.

Introduction

Spectroscopic techniques in optical absorption, luminescence, Raman scattering, electron paramagnetic resonance and nuclear magnetic resonance have been successfully applied in previous years to study structure of small cluster and kinetics of impurity precipitations in ionic crystals (Agulló-López, 1986). Recently, these spectroscopic methods, in particular optical absorption, have been used to distinguish natural from synthetic gems. The key for distinguishing them is the presence or not of vibronic absorption bands associated with nitrogen aggregates (N3 centres) (Shigley, 1986). It is well known that the N3 structure is only normally present in natural diamonds (the centre is constructed from three substitutional nitrogen atoms bonded to a common carbon atom) (Davies, 1974), whereas synthetic diamonds exhibit only a gradual absorption increase in the visible region (Shigley, 1986).

The N3 absorption characteristics, which clearly appear at liquid nitrogen temperature (LNT) can still be observed at room temperature (RT), although with lower intensity (Davies, 1974).

This fact is very important because it allows working at RT and thus reduces the risk in the sample manipulation, especially in the cooling stage down to LNT (77 K): the standard cooling rates, about 10 K/min, can produce strains in the sample and consequently cracks in the gem. Most published optical tests have been reported for coloured diamonds, and the potential of this method for colourless diamonds is yet to be published.

It is clear that working at RT with very weak optical absorption requires very sensitive techniques, but if its feasibility is established it could be very interesting taking into account that production and marketing of synthetic colourless diamonds may be a factor in future years.

The purpose of this note is to show that highly sensitive optical absorption measurements at RT together with derivative spectroscopy can be applied to distinguish between colourless synthetic and natural diamonds through the detection and identification of the optical absorption associated with N3 centres.

Experimental

Optical absorption spectra at RT were taken with a Hitachi 150-20 spectrophotometer that was capable of derivative spectra (the optical density OD is defined as $OD = Log_{10}(I_0/I)$, where I_0 and I represent the incident and transmitted light intensity respectively). LNT spectra were taken with a Cary 17 spectrophotometer by means of a cryostat which fits into the spectrophotometer chamber.

Four samples of (H) and of (J) diamond crystals, in the GIA grading scale, have been investigated. Diamonds of approximately 0.20 ct weight, 3.5 mm diameter and 2.3 mm height were supplied by the School of Gemmology of the Universidad Autónoma de Madrid.

Experimental results

Figure 1a shows the absorption spectrum corresponding to a (J) grade diamond sample recorded at RT. It can be seen that three absorption bands in the 390-420 nm region with an optical density of $\approx 10^{-2}$ are present (length of path light through the crystal $\simeq$ 2 mm): the position of these bands can clearly be determined by using derivative methods. The first derivative spectrum is given in Figure 1b. The wavelengths corresponding to the maximum of the absorption bands are 415, 403 and 394 nm respectively, values that are in agreement with the position found in colourless natural diamond absorptions due to N3 centres (Davies, 1974). The presence of the N3 absorption bands implies that the diamond studied is a natural gem.

Figure 1c shows the second derivative spectrum corresponding to the same gem. It is important to

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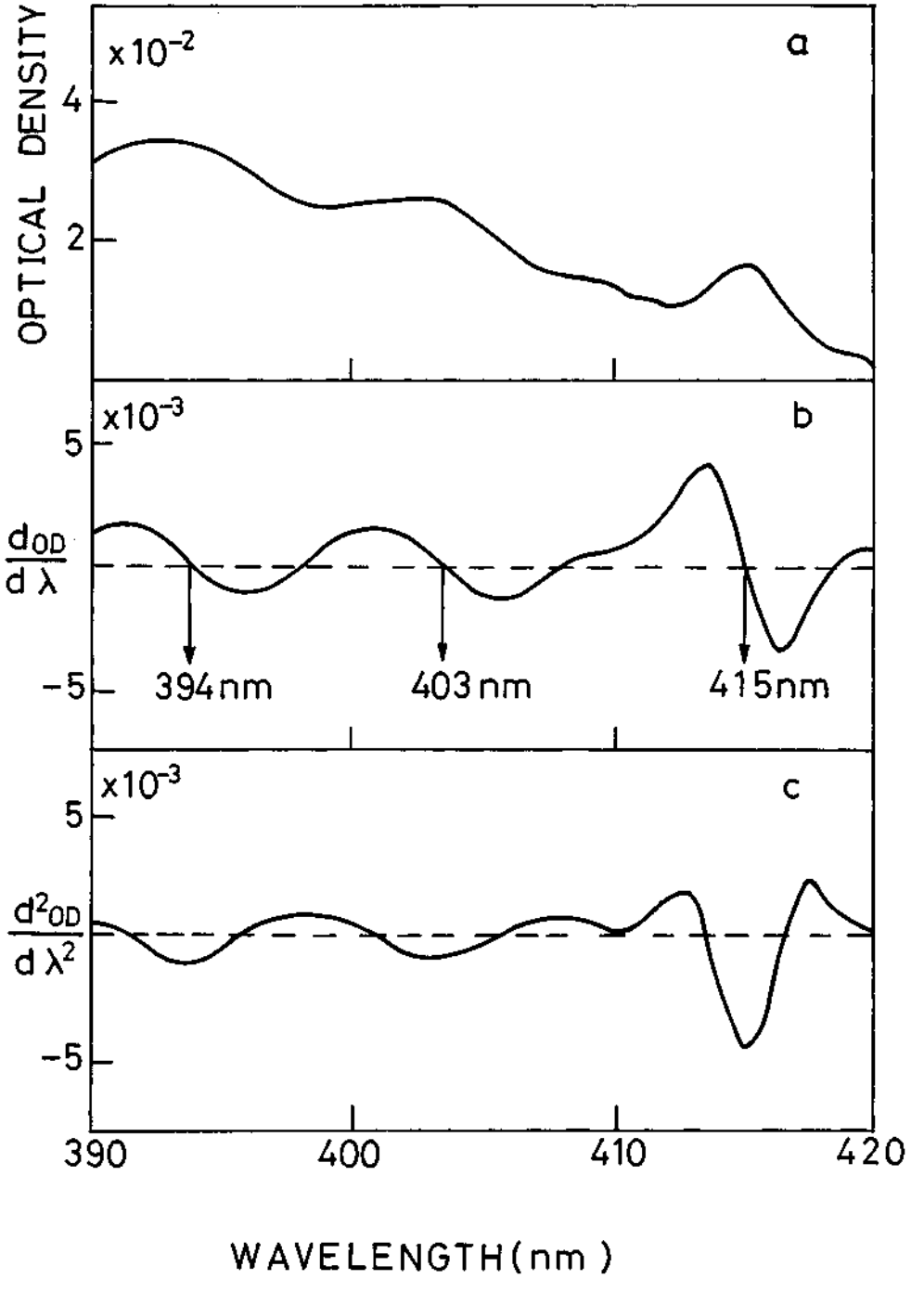

Fig. 1. a) Absorption of a (J) grade diamond at RT.
b) First derivative of the absorption spectrum (a).
c) Second derivative of the absorption spectrum (a).

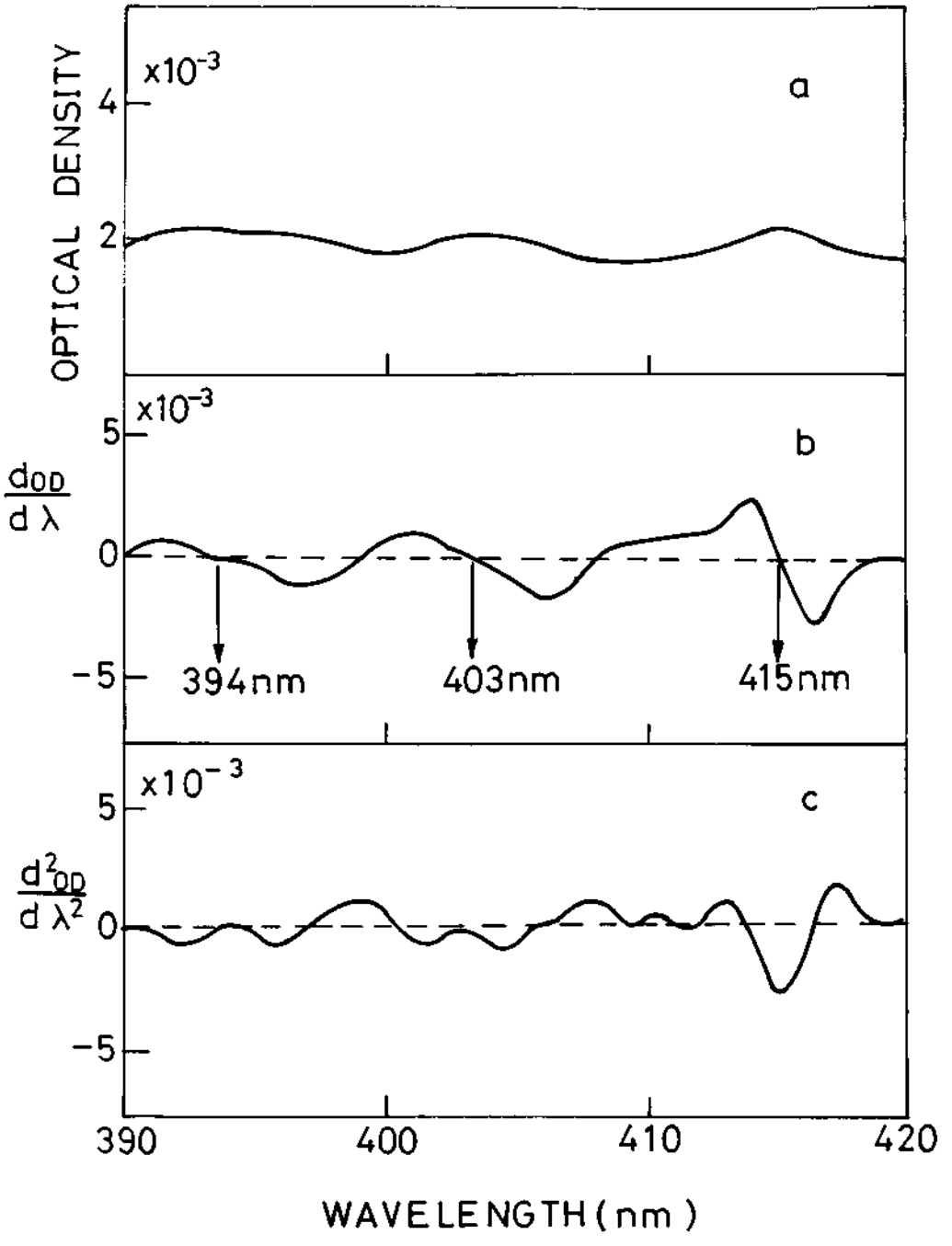

Fig. 2. a) Absorption spectrum of an (H) grade diamond at RT.
b) First derivative of the absorption spectrum (a).
c) Second derivative of the absorption spectrum (a).

point out the very good signal-noise ratio and the appearance of a richer structure in accordance with the very complex spectrum characteristic of the N3 centres and clearly observed in coloured diamond at LNT.

The good signal-noise ratio obtained allows one to apply optical absorption measurements to more transparent gems. In this line (H) grade diamonds have also been studied. Figure 2a shows the optical absorption spectrum in the 390-420 nm range obtained at RT. The same absorption bands seen in the (J) grade crystal stones are recorded again but with smaller optical density (OD about 10^{-3}). The positions of these bands are marked in the first derivative spectrum (Figure 2b), and are also coincident with those found in coloured diamonds.

The second derivative spectrum is given in Figure 2c; although the optical density is very weak, the 415 nm band is clearly observable and the second derivative spectrum can be used for detecting N3 centres in (H) grade diamonds. Looking at this last result, the lower limit in the N3 centre absorption detection could be determined, and a value of OD$\approx 10^{-3}$ appears as the lowest discernible with a spectrophotometer similar to the one used in this work. Recently, however, spectrophotometers with higher sensitivity in the optical detection (OD$\approx 10^{-5}$) have become available and so the power in the diamond optical testing can be improved by an order of two magnitudes.

In conclusion, the optical spectroscopy including derivative techniques can be useful to distinguish natural from synthetic diamonds, even in colourless samples without the inconvenience of lower temperature manipulation.

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The Brazilian emeralds and their occurrences: Socotó, Bahia

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1. Introduction

The mining area of Socotó is located in north-western Bahia about 25 km NE of Campo Formoso and 40 km NE of the emerald deposit of Carnaíba (Figures 1 and 2). The entrance to the Socotó mining area is reached by a dirt road from Campo Formoso. Following the dirt road north-eastwards you will pass the small villages of Vanvana (after 8 km) and Ituiutiba/Socotó (after 15 km). The area which is currently being mined belongs to the farm 'Fazenda Piabas' and was occupied by garimpeiros (freelance miners) in January 1983. A few weeks later more than 500 garimpeiros had reached the area and by the beginning of February of the same

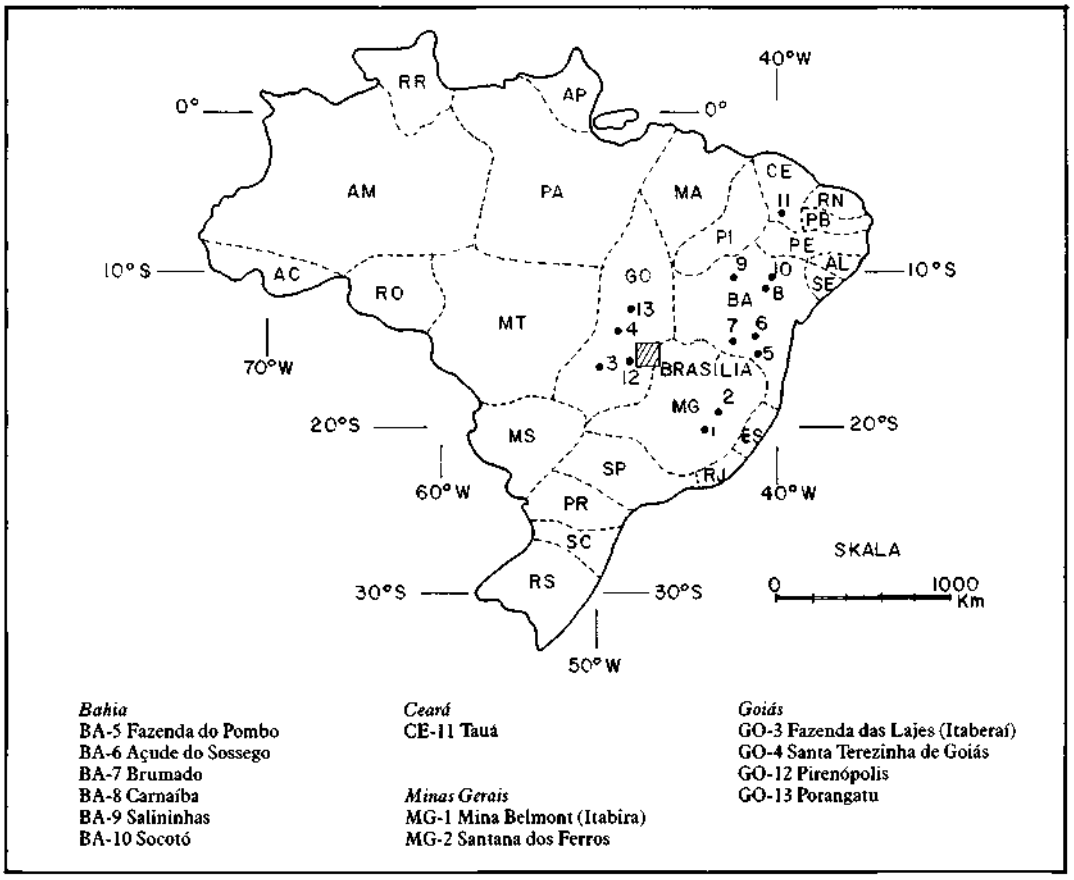

Fig. 1. The emerald occurrences in Brazil.

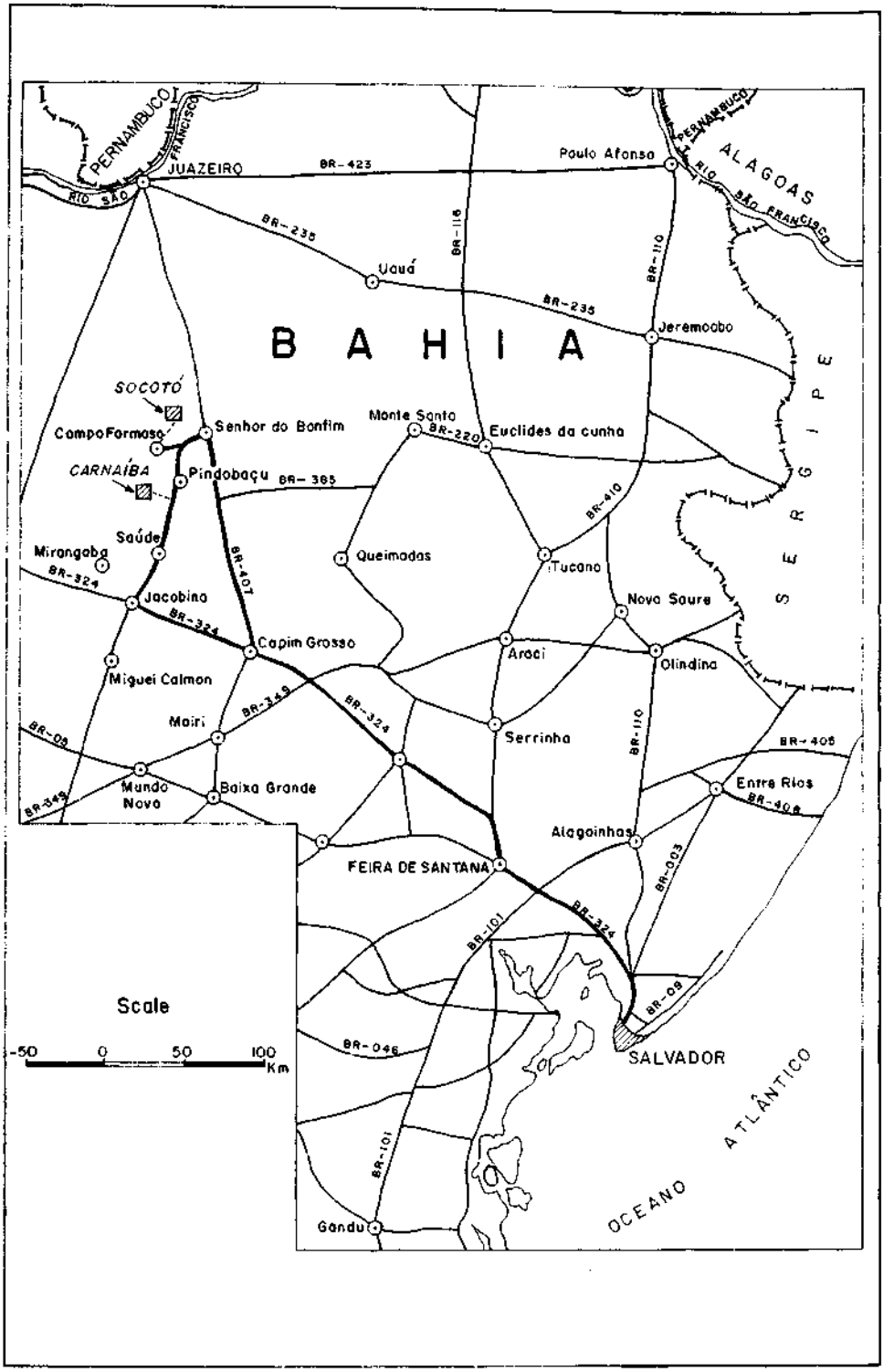

Fig. 2. Bahia state with the emerald occurrences of Socotó and Carnaíba.

Fig. 3. 'Quijillas' searching the waste material for emeralds.

year 132 grams of emeralds from 'medium to good' quality had been mined. The officially registered amounts of emeralds being mined in 1984 were 2 181.726 kilograms in Socotó and 3 459.630 kilograms in Carnaíba. The value of the mined emeralds in 1984 was estimated to be US$ 1 000 000 for Socotó and US$ 430 000 for Carnaíba (Couto, 1984).

Table 1 (Couto, 1986) shows the official annual output (in kg) of emerald/green beryl of the Carnaíba area (1977-1982) and for both areas (Carnaíba and Socotó) for the years 1983 to 1986. Despite a decrease in the total amount being mined, the total value of the emeralds increased because of the steadily increasing portion of faceting grade material. The best stones are found in the Trecho Velho (Socotó) and in Formiga/Trecho Velho (Carnaíba).

Based on the similar geological setting in the mining areas of Carnaíba and Socotó extensive emerald reserves are expected at Socotó. For the first 11 months of 1985 an official output valued at 4.4 million US$ was registered in the region. According to the official statement of the Receita Federal (Government Office) about ⅔ of this had been mined in Socotó and ⅓ in Carnaíba.

With the exception of the Belmont Mine in Itabira/MG, the mining methods in the Socotó area are typical for Brazilian deposits. The emeralds are mined underground. Shafts follow the mineralization zones in 'galerias', horizontal or slightly inclined tunnels. Sometimes the tunnels are straight but mostly they are curved or they change their direction abruptly. In part, the entrance to the tunnel is made directly from the surface; normally, however, pits about 100 metres deep are used. The length of the tunnels can reach more than 300 metres.

Table 1. Annual output of emerald/green beryl in the mining area of Carnaíba (1977-1982) and Carnaíba/Socotó (1983-1986).

Year	Output (kg)
1977	18 642.3
1978	8 652.3
1979	15 302.4
1980	14 503.4
1981	8 842.1
1982	7 467.4
1983	13 371.3
1984	5 641.3
1985	4 129.3
1986	3 794.7

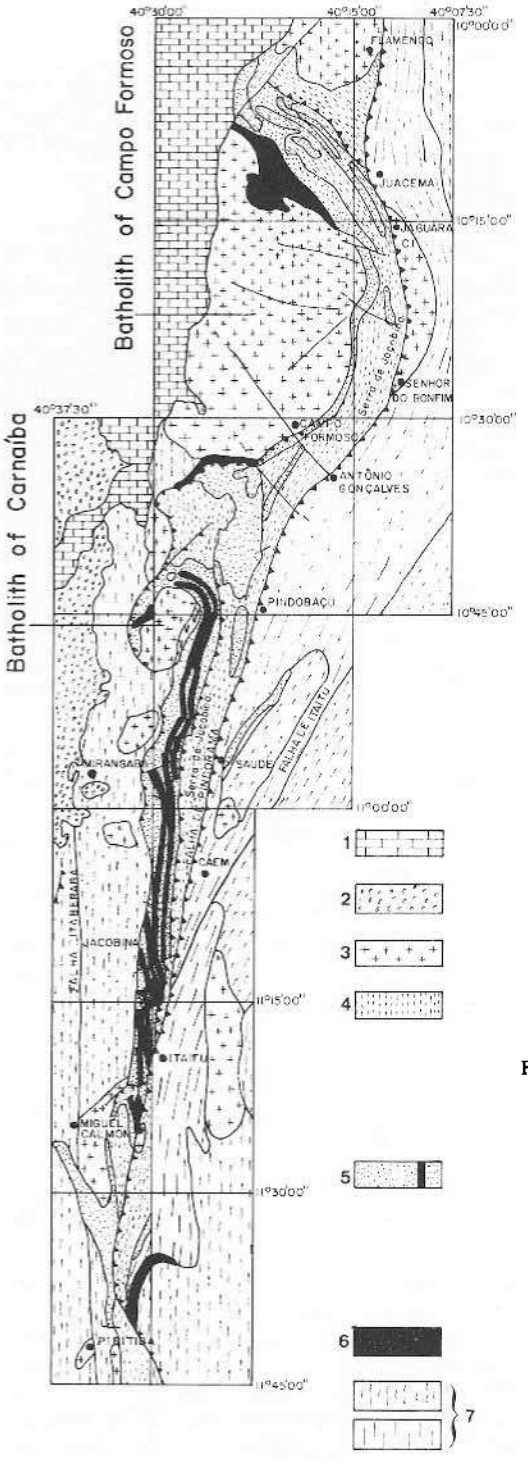

The mining of the vein material is by hand, mainly with primitive tools like pickers, hammers, chisels and jimmies. Use of pneumatic hammers is rare. To remove the vein rock, pushcarts are operated in the tunnels. In the pits, transportation is with the help of buckets or containers made of old car tyres operated either by hand or by electrical winches. Tunnels and pits are lined or supported by wooden beams. Entering water has to be constantly removed by pumps.

The limits of each claim ('serviço') are marked on the surface upon agreement with the landowner, who receives a percentage of the profit. Besides the actual owner of the claim, those people who raise money for starting the mining (the so-called 'capitalistas') also participate in the profit. Among the people who are directly involved in the mining, the 'cortador' (the man in charge of opening up new shafts and drifts) is the most important and best paid. He is responsible for carrying out the excavation operations.

The separation of the emeralds from the rocks is done personally by the owner of the claim in the presence of the 'cortador', the most important crew members and the financiers. Also involved in the mining operation are the 'quijillas', a group composed of elderly men, women and children who search the waste material with sieves and small hammers to find the last pieces of emeralds (Figure 3).

The Government tries to give some technical assistance to the miners and to control mining activities through the DNPM (Departamento Nacional de Produção Mineral). All garimpeiros have to be registered at the office of the 'Receita Federal'. At the end of 1986 in the Socotó area there

Fig. 4. Geological map of the Serra de Jacobina showing the batholiths of Carnaíba and of Campo Formoso (the latter with the Socotó mining region). (in Inda & Barbosa, modified after Couto *et al*, 1978).
1 – Metasediments of the Una Group
2 – Metasediments of the Espinhaço Super Group
3 – Granitic rocks
4 – Complexo Itapicuru (volcanoclastic sequence): feldsparquartzites, phyllites and schists, amphibolites, metabasites, and serpentinites. Formations Agua Branca (Tab), Serra da Alegria (Tsl), Cruz das Almas (Tca), and mica schists with aluminium silicates (Tal).
5 – Jacobina Group (clastic sequence): metaconglomerates, orthoquartzites, intercalated serpentinites. Formations Rio de Ouro (Tro) and Serra do Córrego (Tsc).
6 – Basic and ultrabasic rocks.
7 – Basement (i.e. mainly Archean migmatites and gneisses)

were 144 operating claims with about 600 garimpeiros. In the Carnaíba area there were 90 claims with about 400 garimpeiros. The total 'population' of both areas was about 4 000 persons.

2. Geology

2.1 Regional Geology

The regional geological conditions are practically identical for the emerald deposits of Carnaíba and Socotó. They are characterized by the occurrence of granite batholiths whose pegmatites penetrated rock units of the Serra de Jacobina (Figure 4) and, in contact with its chromium bearing rocks (ultrabasites) caused the formation of emerald mineralizations. The age of the granites has been dated as about 2 billion years.

Figure 5 (modified after Rudowski *et al.*, 1987) shows the outcrop pattern in the Serra de Jacobina and Figure 6 (Couto, 1984) shows a sketch of the Campo Formoso batholith in the region of Socotó. The Campo Formoso batholith, a complex of K/Na-rich rocks, covers a semicircular area of about 700 km^2. Most abundant in it are granites and variations which have been petrographically determined to be adamellites and granodiorites. In the northern part of the batholith these rocks contain, in addition to pegmatites, numerous large xenoliths. The xenoliths vary from quartzites to amphibolites and from metabasites to normally serpentinised ultrabasites. Most xenoliths have the lithologies of the Serra de Jacobina.

The emplacement of the Campo Formoso batholith as well as other plutons was in part responsible for the east-west narrowing of the Serra de Jacobina (see Figure 4). It was accompanied by folding and imbricate faulting. The formation of the intrusive granites such as the Campo Formoso batholith occurred during the Transamazonian Cycle which shows granitisation effects of regional extent. However, the intrusive character of the Campo Formoso batholith is proved by the presence of granite-apophyses which penetrate the rocks on the western edge of the Serra de Jacobina. Also, xenoliths of green quartzites belonging to the Jacobina Group occur within the granite. The intrusion of the batholith caused much faulting, in particular, in the area of the emerald deposit.

The metasediments of the Una group lie discordantly above the Campo Formoso granites in the western area. In the north and southeast, the Campo Formoso granite is in contact with rocks of the basic-ultrabasic complex. In the east it borders on the quartzites of the Serra de Jacobina.

2.2 Local geology and genetic aspects

Based on the results of detailed mapping, geologists of the DNPM/CPRM (CPRM = Companhia de Pesquisa de Recursos Minerais) have concluded that besides the area currently being worked (3.0 × 0.3 km) there are more emerald-bearing bodies which show identical structural and petrographical characteristics. Indeed, several serpentinised bodies have already been found on the northern rim of the batholith, one of them extending over more than 40 km^2. It is quite possible that mineralizations of the same types observed in Carnaíba will be found. There, the first discovered mineralized zone was situated in an ultramafic block within the granite. Only later the metamorphosed ultrabasites were discovered that are inserted in the Jacobina quartzites. The garimpo Socotó is located (as can be seen in Figure 6) in the tectonically most affected area of the whole region. Observations made in other emerald deposits have shown that – independent from the type of genesis – the mineralizations of emerald appear preferentially in areas with intensive tectonism. This is due to the easier migration in these zones of the solutions that are responsible for the transportation of the emerald components. So we can assume that the local geological conditions in the area of the Socotó garimpo were especially advantageous for the emerald mineralizations.

The ultramafite body which hosts the emerald mineralizations of Socotó has a length of 3 650 metres with an average width of 200 metres. It represents an enclave within the granitic rocks of the Campo Formoso batholith. In the centre of the main body, known as Trecho Velho and Trecho Novo, occur serpentinites, talcites, amphibolitic rocks, biotite schists, gabbros, metadiabasites and cataclastic rocks. The following petrographic types predominate: actinolite-talcite, biotite-chlorite schist, amphibolite (metadiabase) and – in the contact zones with the granite-cataclasites, muscovite-quartz schist and rocks with granodioritic composition. Besides emerald and green beryl, the occurrence of molybdenite, scheelite, powellite, phenakite, chromite, asbestos and sulphides (chalcopyrite ?) was confirmed. Locally, a lot of black tourmaline can be observed in a tourmaline-biotite schist.

Comparing the garimpo of Socotó with the mining area of Carnaíba (Eidt & Schwarz, 1988), the currently mined area is equivalent in its geological and petrographical nature to the area called Carnaíba de Baixo. It is an ultramafite body located in the middle of the granite and which is penetrated by pegmatite veins. The pegmatite veins are accompanied by metasomatically altered zones in which the emerald mineralizations occur. The area which would correspond to Socotó de Cima (the area which is characterized by the occurrence of schistified ultramafite lenses in quartzites) has not yet

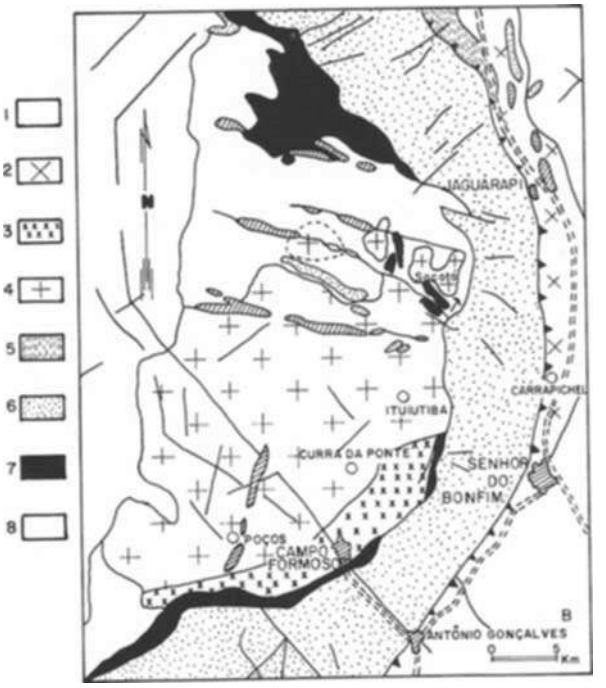

1 Proterozoic superior cover

2 Jaguarari granite

3 Two-mica granite

4 Porphyroid two-mica granite

5 Chloritoschist phyllites

6 Quartzites and volcano-sedimentary formations

7 Serpentinites

8 Archean gneisses, metatexites and diatexites

Fig. 5. Outcrop pattern in the Serra de Jacobina with the Campo Formoso batholith (modified after Rudowski *et al.*, 1987).

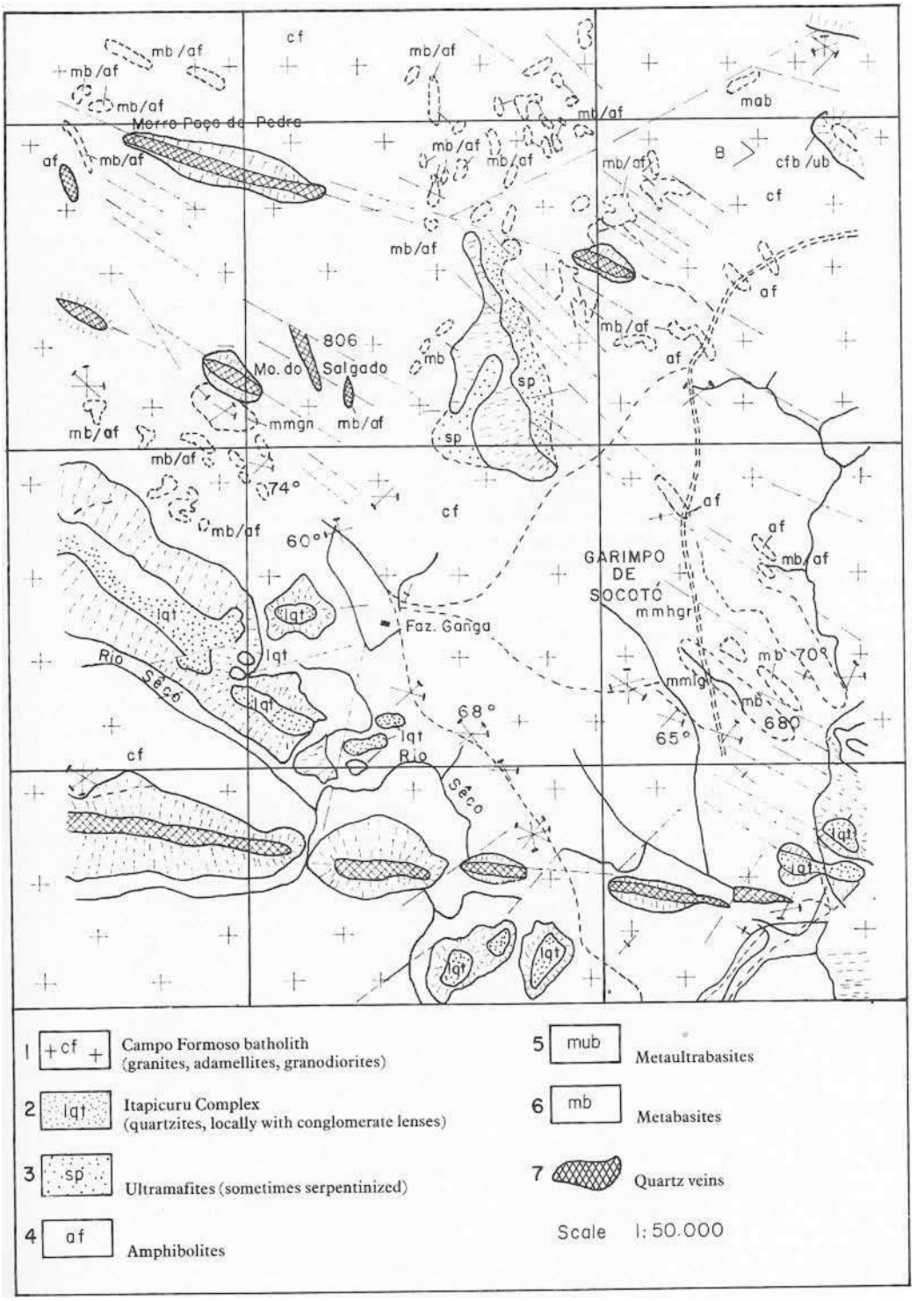

Fig. 6. Sketch of the Campo Formoso batholith in the Socotó area.

been mined.

Despite the fact that the regional geological features are practically identical in Carnaíba and Socotó, some peculiarities of the latter deposit should be emphasized. First is the considerably larger extension of the Campo Formoso batholith, which increases significantly the mineralization potential. Second, the area of Socotó shows a larger variety of tectonic structures and rock types. On the whole, these factors result in a larger range of variation in the mechanism of formation of the Socotó emeralds. It is interesting to notice that the greater variety of environments is not only observed when studying the geological and petrological conditions, but also when examining the Socotó emeralds under the gem microscope.

Like the occurrences of Carnaíba and Tauá/CE, Socotó belongs to the classic type of emerald deposit. The elements Cr and Fe derive from mafic and ultramafic rocks (or their metamorphosed derivates). The (main) suppliers for beryllium are pegmatites. The Belmont Mine at Itabira/MG is considered to represent a special type of the classic genesis and in the Santa Terezinha/GO deposit the main suppliers for beryllium are non-pegmatitic rocks (Schwarz, 1987).

3. Optical and chemical properties of the Socotó emeralds

Table 2 gives the optical data of Socotó emeralds, the measured density values range between 2.67 – 2.72 g/cm^3.

Table 2. Refractive indices and birefringence of Socotó emeralds.

n_e	n_o	Δn
1.579–1.582	1.587–1.590	−0.007–0.009

The results of the microprobe analyses performed on twenty emeralds from the Socotó mining region are compiled in Table 3.

Structural and (crystal-)chemical considerations as well as the calculated mineral formula coefficients (Table 3) indicate that – as we can see also in emeralds from other occurrences – the following substitutions dominate:

(a) Al^{3+}(octahedral) = $(Mg,Fe)^{2+}$ + Na^{+} (channel site)

(b) Al^{3+}(octahedral) = $(Cr,Fe)^{3+}$(octahedral)

It is interesting, however, that in the Na-(Mg+Fe)-diagram for the mineral formula coefficients the points for most of the Socotó emeralds are distinctly shifted to the right, indicating that the $(Mg,Fe)^{+}$ excess is higher than that normally observed in emeralds from other locations (Figure 7).

4. Inclusions

The first results of examinations of inclusions in emeralds from the Socotó occurrence were presented at the 33rd Brazilian Geological Congress in Rio de Janeiro (Schwarz, 1984a). Since then, further detailed studies have been made using a large

Table 3. Microprobe analyses of Socotó emeralds. Total iron as FeO. CaO-content <0.01 Wt%.

Sample	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
SiO_2	65.51	65.13	64.76	64.81	64.73	66.01	65.89	65.19	64.55	65.66	65.31	64.88	65.53	64.42	64.44	63.48	63.76	66.68	64.53	64.38
Al_2O_3	15.38	15.72	15.48	14.81	15.51	16.24	16.35	16.16	16.02	16.59	16.72	15.94	16.50	15.54	15.31	16.02	16.25	16.96	16.20	15.80
Cr_2O_3	0.36	0.16	0.30	0.30	0.22	–	0.11	–	0.11	0.11	–	0.13	–	0.25	0.41	0.18	0.25	0.75	0.34	0.35
FeO	0.96	0.88	0.95	0.91	0.89	0.53	0.66	0.79	0.76	0.75	0.58	0.76	0.67	0.87	0.91	0.77	0.49	0.51	0.67	0.77
MgO	2.55	2.28	2.39	2.63	2.24	2.27	1.91	2.05	2.06	1.81	1.88	2.42	2.05	2.58	2.50	1.89	2.12	1.56	1.98	2.15
K_2O	–	–	0.10	–	0.06	–	–	–	0.08	–	–	–	0.07	–	0.10	0.07	0.06	–	0.07	–
Na_2O	1.15	1.00	1.11	0.98	1.08	0.87	0.92	0.68	1.00	0.84	0.99	1.05	1.09	0.89	1.05	1.62	1.59	0.96	1.20	1.16
MnO	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
CaO	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Total	85.91	85.15	85.11	84.44	84.73	85.92	85.86	84.87	84.58	85.76	85.47	85.18	85.91	84.55	84.72	84.02	84.52	87.41	85.00	84.60

Mineral formula coefficients (normalized: Si = 6)

Sample	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Si	6.000	6.000	6.000	6.000	6.000	6.000	6.000	6.000	6.000	6.000	6.000	6.000	6.000	6.000	6.000	6.000	6.000	6.000	6.000	6.000
Al	1.660	1.707	1.691	1.616	1.694	1.740	1.755	1.753	1.755	1.786	1.810	1.737	1.780	1.705	1.680	1.785	1.802	1.798	1.776	1.735
Cr	0.028	0.012	0.022	0.022	0.016	0.000	0.008	0.000	0.008	0.008	0.000	0.010	0.000	0.018	0.030	0.013	0.018	0.054	0.025	0.026
Fe	0.073	0.068	0.074	0.071	0.069	0.040	0.051	0.061	0.059	0.058	0.044	0.059	0.051	0.068	0.071	0.061	0.039	0.038	0.052	0.060
Mg	0.349	0.313	0.331	0.369	0.309	0.308	0.260	0.282	0.285	0.246	0.257	0.333	0.280	0.359	0.348	0.266	0.297	0.209	0.275	0.298
K	0.000	0.000	0.012	0.000	0.008	0.000	0.000	0.000	0.010	0.000	0.000	0.000	0.008	0.000	0.012	0.008	0.008	0.000	0.009	0.000
Na	0.204	0.179	0.199	0.176	0.195	0.153	0.163	0.121	0.179	0.149	0.177	0.188	0.194	0.161	0.190	0.297	0.291	0.167	0.215	0.210
Total	8.314	8.279	8.329	8.254	8.291	8.241	8.237	8.217	8.296	8.247	8.288	8.327	8.313	8.311	8.331	8.430	8.455	8.266	8.352	8.329

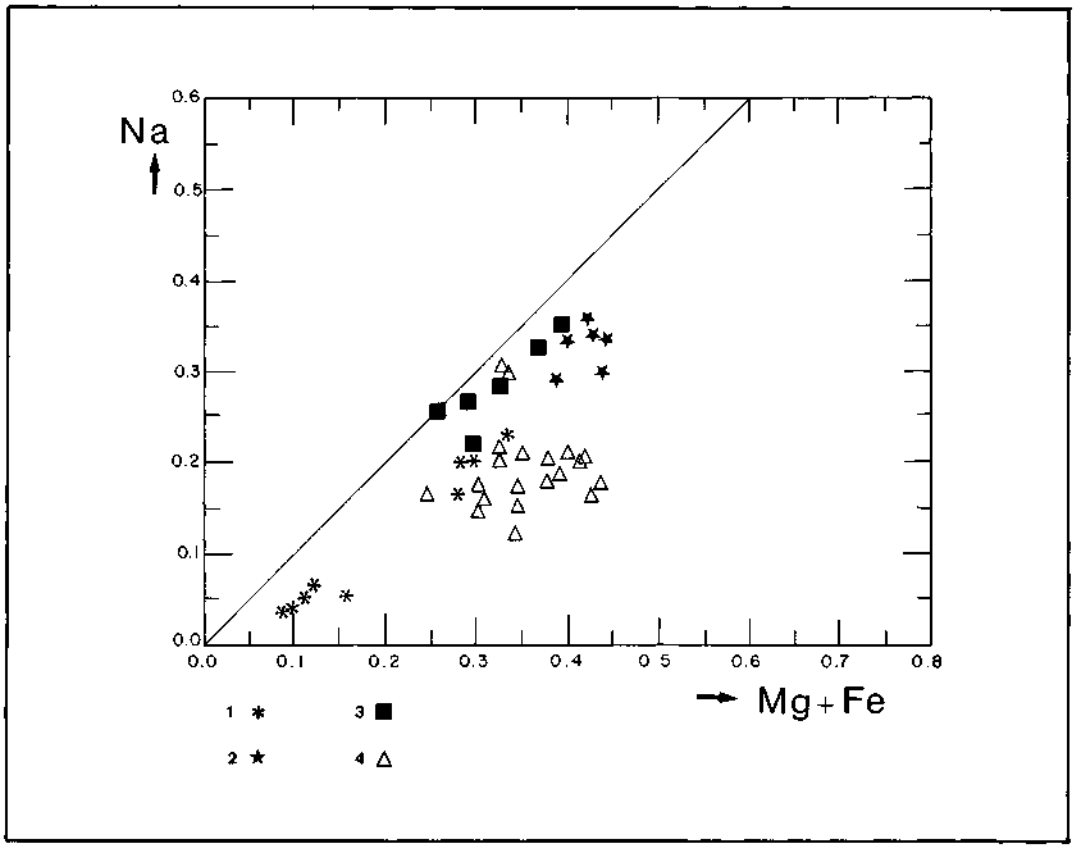

Fig. 7. Plot (Mg+Fe) over Na for emeralds from different Brazilian occurrences.
1. Itabira/MG (Hänni, Schwarz and Fisher, 1987).
2. Tauá/CE (Schwarz *et al.*, 1988).
3. Carnaíba/BA (Schwarz & Eidt, 1988).
4. Socotó/BA.

number of emeralds from the Socotó mining area (on the whole about 1000 samples were examined under the gem microscope). Following the microscope examinations, a number of selected samples were analyzed using X-ray diffraction and micro-X-ray spectroscopy techniques (microprobe).

Considering the geographic proximity and the fact that the regional geology is almost identical for the two occurrences of Socotó and Carnaíba, we expected to find that inclusion features would also be more or less identical. However, a comparative study shows that the inclusions in the Socotó emeralds are abundant and that numerous inclusions are not (or only very rarely) observed in the Carnaíba emeralds (compare Schwarz & Eidt, 1988). The emeralds from Carnaíba are characterized by the appearance of the so-called 'flocs' and 'stars' (mostly composed of minute liquid droplets or 'l-g'-two-phase inclusions), mineral inclusions are relatively rare. The most frequent inclusion mineral in the Carnaíba emeralds is a mica (member of the biotite/phlogopite series), that sometimes shows a very uncommon 'board' or 'lath'-like form that can be considered as diagnostic of emeralds from this occurrence (Schwarz, 1984b). In the emeralds from Socotó, on the contrary, a great variety of different mineral inclusions can be observed. However most of these are not very frequent.

Mica

The most common inclusion mineral in the Socotó emeralds is – as should be expected – a mica of biotite/phlogopite composition (Table 4). This is due to the fact that the largest portion of the Socotó emeralds has a biotite/phlogopite schist as its host rock. Margarite and muscovite are much rarer as inclusions.

Normally, the mica crystals occur in the form of rounded or irregular-shaped platelets. Their colour

Table 4. Microprobe analyses of mica inclusions in Socotó emeralds.

	Biotite/Phlogopite			Margarite
SiO_2	41.48	39.50	42.12	29.42
Al_2O_3	13.11	12.84	13.08	44.61
TiO_2	0.09	–	0.13	–
V_2O_3	–	–	–	–
Cr_2O_3	0.55	1.18	–	–
FeO	8.71	11.12	8.53	0.29
MnO	–	0.22	–	–
MgO	20.36	17.54	21.01	0.68
CaO	0.19	0.17	0.12	12.86
Na_2O	0.08	–	0.17	0.60
K_2O	10.32	12.43	10.41	–
Total	94.99	95.00	95.57	88.46

Table 5. Microprobe analyses of actinolite/tremolite inclusions in Socotó emeralds.

SiO_2	55.70	57.34	54.27	58.11	59.22
Al_2O_3	0.73	1.96	1.38	2.08	3.83
TiO_2	–	–	–	–	–
V_2O_3	–	–	–	–	–
Cr_2O_3	0.22	0.05	0.29	0.21	–
FeO	6.95	6.88	7.39	7.25	6.08
MnO	0.18	0.21	0.14	0.21	0.19
MgO	18.18	19.07	18.69	20.17	16.55
CaO	14.06	12.82	12.57	12.96	11.25
Na_2O	–	0.54	1.19	0.64	0.67
K_2O	–	–	0.09	0.15	0.09
Total	96.02	98.87	99.02	101.78	97.88

Table 6. Microprobe analyses of different mineral inclusions in Socotó emeralds.

	Allanite	Apatite	Chromite	
SiO_2	28.71	–	0.55	2.41
Al_2O_3	14.19	0.13	7.72	5.88
TiO_2	0.31	–	0.38	0.41
V_2O_3	1.89	–	0.43	0.73
Cr_2O_3	1.86	–	52.56	53.02
FeO	10.20	–	34.17	32.75
MnO	0.62	–	1.62	2.11
MgO	0.45	–	0.73	0.38
CaO	12.31	54.01	–	–
Na_2O	0.45	–	1.58	0.70
K_2O	–	–	–	0.08
P_2O_5	–	41.50	–	–
NiO	–	–	–	–
	~30% Ce			
Total	70.99	95.74*	99.74	98.71

is generally light to dark brown; greenish brown shades are rarer. Margarite and muscovite are practically colourless. Only rarely do the mica crystals occur isolated; mostly they form agglomerations ('clouds') that can be so dense that the emerald host crystal shows a dark brown colour and appears almost opaque in these regions. Many times the mica crystals, present in a great number, reflect the formation history of the Socotó emeralds: sometimes they are oriented practically parallel to the emeralds growth striae or they contribute, through an elevated concentration in concentric 'growth rings', to the formation of a zonal structure in the emerald (see below). Sometimes, tubes (channels) of variable thickness are observed, oriented in the direction of the emeralds *c*-axis and filled with mica (Figure 8).

Talc

Talc occurs in the form of transparent, almost colourless platelets.

Chlorite

Because of their very similar appearance the separation of mica and chlorite in the gem microscope is sometimes very difficult. Chlorite, which is observed frequently together with mica, normally has a more greenish colour.

*Actinolite/Tremolite**

In the first Socotó emeralds available for inclusion studies, actinolite/tremolite was observed relatively often (Schwarz, 1984b). In the stones examined at that time it occurred with almost the same frequency as mica and often was found together with the latter. Additional examinations made on a great number of Socotó emeralds, however, showed that the importance of actinolite/tremolite as an inclusion mineral falls clearly behind that of the micas. This fact is in accordance with the observations made in the emerald mining area showing that an actinolite schist is much rarer as an emerald host rock than is the mica schist.

Actinolite/tremolite sometimes forms thick needles or rods that are practically colourless and transparent. These occur isolated or form nest-like agglomerations of numerous unoriented crystals (Figure 9). These can be restricted to certain regions of the host crystal or can be randomly distributed.

The quantity of actinolite/tremolite crystals in some of the Socotó emeralds can be so large that these can be confused, at first sight, with emeralds

* It is true that the crystals examined by micro-X-ray spectroscopy (see Table 5) are all actinolites, but we can suppose that some of the amphibolite inclusions in the Socotó emeralds are members of the actinolite/tremolite series.

Table 7. Microprobe analyses of feldspar inclusions in Socotó emeralds.

	Albite	K-feldspar	Plagioclase
SiO_2	68.39	64.23	61.60
Al_2O_3	20.21	19.47	26.02
TiO_2	–	–	–
V_2O_3	–	–	–
Cr_2O_3	–	–	–
FeO	–	–	–
MnO	–	–	–
MgO	0.35	–	0.28
CaO	0.13	–	6.59
Na_2O	10.25	–	6.92
K_2O	0.44	15.79	0.16
Total	99.77	99.49	101.57

from Sandawana (Figure 10). Normally, however, they don't have the 'hair-like' appearance of the curved tremolite crystals typical for the Sandawana emeralds. Besides the colourless-transparent crystals occur others of a greenish to light-brown colour, that sometimes show the characteristic 'bamboo'-like appearance (Figure 11.)

Allanite (Orthite)

The Ce-epidote allanite (orthite) forms prismatic crystals of a dark brown colour (Figure 12).

Apatite

Occurs as prismatic crystals that are sometimes slightly corroded and rounded. They are colourless and almost always show cleavage planes parallel to the basal face. Based on their outer appearance and on the manner of distribution within the emerald host crystal we can infer that these crystals are protogenetic inclusions (Figure 13).

Quartz

The prismatic quartz crystals show more or less distinctly developed corrosion phenomena (Figure 14).

Feldspar

The Socotó emeralds are partly found in feldspar masses and this explains the appearance of isolated feldspar crystals and of fractures filled with feldspar in the emeralds. The chemical analyses (Table 7) show that different types of feldspar are present: an almost pure Na-feldspar (albite), a K-feldspar and a plagioclase of andesine composition.

Carbonates

The presence of carbonate inclusions in the emeralds of Socotó is also not surprising because the emeralds are occasionally found in carbonate rocks.

Table 8. Microprobe analyses of carbonate inclusions in Socotó emeralds.

	Calcite	Dolomite	Breunnerite
SiO_2	1.21	–	–
Al_2O_3	0.25	–	–
TiO_2	0.28	–	–
V_2O_3	–	–	–
Cr_2O_3	–	–	–
FeO	–	2.09	15.78
MnO	–	–	0.34
MgO	0.17	19.44	35.63
CaO	56.04	29.53	0.14
Na_2O	–	–	–
K_2O	–	–	–
Total	57.95	51.06	51.89

Table 9. Microprobe analyses of tourmaline inclusions in Socotó emeralds.

SiO_2	33.79	33.63	33.45	36.72	36.13	35.44
Al_2O_3	29.41	29.76	31.31	33.88	33.73	31.98
TiO_2	0.14	0.23	–	–	–	0.16
Cr_2O_3	0.67	–	–	–	0.30	–
FeO	4.00	3.41	3.84	4.16	3.93	4.14
MgO	9.84	9.92	8.59	9.30	8.98	9.62
K_2O	–	0.08	–	–	0.09	–
Na_2O	1.95	2.24	2.36	2.62	2.31	2.37
CaO	1.98	1.64	0.78	0.91	0.80	1.54
Total	81.78	80.90	80.33	87.59	86.25	85.25

Unlike the Santa Terezinha emeralds from Goiás that often show well-developed rhombohedra, the carbonates in the Socotó emeralds are normally small, irregular shaped grains. These are, in general, concentrated in certain regions of the host crystal or fill fracture planes; rhombohedral crystals are rare. Although single crystals are practically transparent and merely show a more or less broad and dark border line when observed in transmitted light, carbonate masses in the fissures can be so thick that they appear practically opaque.

Besides an almost pure Ca-carbonate (calcite) the microprobe analyses (Table 8) revealed the presence to two other carbonate minerals: one of Ca/Mg (dolomite) and the other of Mg/Fe (= ferromagnesite or breunnerite).

Tourmaline

Tourmaline is – as is true also for the emeralds from the Carnaíba mining region – a rare inclusion mineral in the Socotó emeralds. It forms long prismatic or rod-like crystals of a dark brown colour that don't show a preferred orientation in the

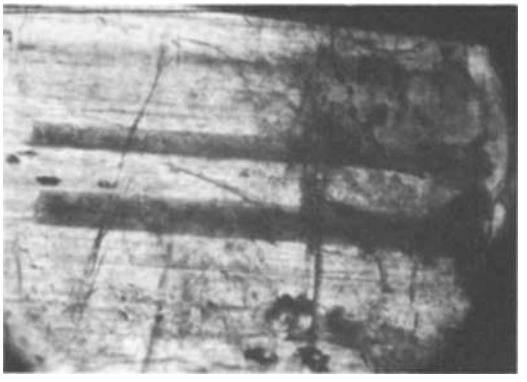

Fig. 8. Channels, oriented parallel to the *c*-axis and filled with mica. 35x

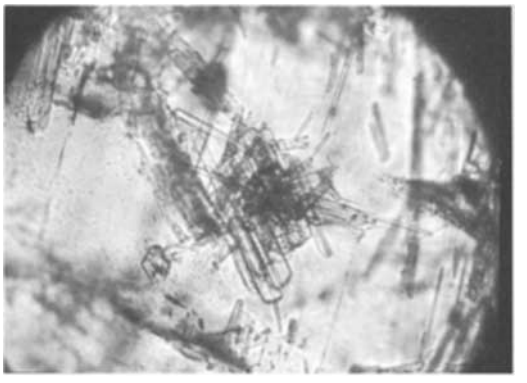

Fig. 9. Agglomeration of prismatic, colourless-transparent actinolite/tremolite crystals. 35x

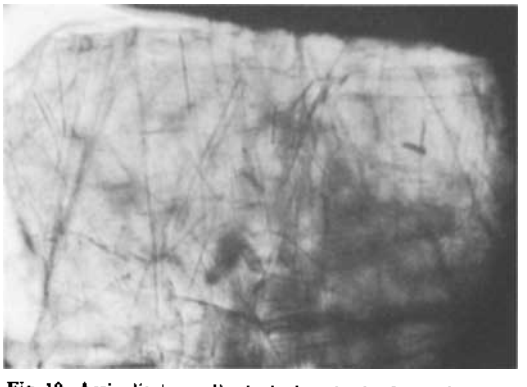

Fig. 10. Actinolite/tremolite inclusions in the form of needle-like prismatic crystals. 20x

Fig. 11. Actinolite/tremolite crystals of green-brownish colour and 'bamboo'-like appearance. 20x

Fig. 12. Dark-brown, prismatic crystals of allanite (orthite). 50x

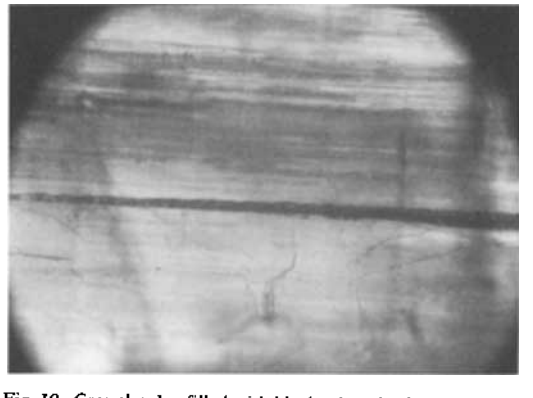

Fig. 19. Growth tube, filled with black mineral substance. 70x

emerald host crystal. According to their chemical composition they are members of the dravite-schlorite series (Table 9).

Hematite/Goethite – Limonite/Lepidocrocite

Hematite occurs as (pseudo-) hexagonal platelets (Figure 15) or as small, irregular crystals that can be found mostly within fissures or dispersed over the surface of the emerald crystals. Hematite that occurs on the emerald's surface or within fissures is almost always partially or completely altered to geothite/limonite (Figure 16). In these cases it has the appearance of black, opaque flakes or simulates ink-blots. Sometimes skeleton crystals or irregular-shaped platelets can be seen. Lepidocrocite, which is distinguished by a strong orange-red colour, is a rare inclusion mineral and forms, generally, irregular platelets or skeleton-like crystals.

Molybdenite

Molybdenite, which belongs to the group of the rarer mineral inclusions in the Socotó emeralds, forms hexagonal platelets that are distinguished by a strong silvery-grey metallic lustre in incident light (Figure 17).

Pyrite and chromite

Other opaque mineral inclusions are pyrite (generally as cube-like crystals) as well as a black mineral that strongly resembles the picotite inclusions so frequently seen in the Santa Terezinha emeralds. It almost always forms small grains that occur isolated or in cloud-like, more or less compact agglomerations. The microprobe analyses (Table 6) show that these are crystals of chromite, a member of the spinel group.

Emerald/Beryl

Among the most interesting mineral inclusions in the Socotó emeralds are crystals of emeralds/beryls. Generally, these are not fragments or chips, as were described, for example, in emeralds from Colombia (Gübelin, 1974) or from Carnaíba (Schwarz, 1984b), but well developed, prismatic crystals. These can be oriented parallel to the *c*-axis of the host emerald or be present without showing a preferred orientation.

During a superficial examination in the gem microscope, emerald/beryl inclusions can be easily overlooked, because their colour is practically identical to that of the host crystal. But when using crossed polarizing filters, they become distinctly visible because their extinction position is generally different from the extinction position of the host crystal. Sometimes they can be easily recognized because they are covered on their surface by another material or because they contain so many inclusions that they clearly contrast with their surroundings.

Among the most striking inclusion features in the Socotó emeralds are some phenomena whose formation is directly related to the growth process of the emerald host crystal. These phenomena show a variety that has never been observed by the authors in emeralds from other occurrences:

Growth tubes and channel-like cavities

The growth tubes observed in Socotó emeralds show a surprising variety with regard to form, size, colour and tube fillings. Some of them are elongated cavities that are sometimes empty but, in general, present a one or two phase filling. The cavities can be arranged in parallel strings (in direction of the *c*-axis) causing a 'silky' or 'milky' turbidity-effect that can also be observed in many Brazilian aquamarines and in the emeralds from the Belmont mine near Itabira/MG. Emeralds with numerous inclusions of this type sometimes show – when cut as cabochon – a chatoyancy effect.

Another type of tube forms larger, frequently slightly flattened, channels that generally traverse the emerald host crystal in its total length. These channels are mostly concentrated in irregularly delineated zones that clearly reflect the hexagonal symmetry of the host crystal ('central core', see Figure 18). As a rule, the channels have a two phase filling ('l-g'-type); others are filled with mineral material (Figure 19).

The larger growth tubes normally traverse the full length of the emeralds (Figure 18), but sometimes they end abruptly in the interior of the host crystal and then they look as if they had been cut by a pair of scissors. This fact suggests that the growth environment suffered abrupt changes. Sometimes groups of growth tubes can be seen that start from fracture planes. Other tubes (channels) present a hexagonal cross-section and are of an intensive brown colour. At higher magnifications in the gem microscope these tubes are not homogeneous but show a somewhat granular aspect, i.e. their walls are coated with grains and platelets of a brown mineral. The microprobe analyses show that this material is mica.

Zones with an elevated density of inclusions

We previously described an inclusion type showing the concentration of growth tubes or channels that results in a more or less sharply delineated 'central-' or 'core-zone'. The zoning based on an elevated inclusion density can be caused also by different mineral inclusions (Figures 20 and 21). Generally, these are mica, carbonate(s), or feldspar; sometimes other minerals also occur. The concentration of the inclusion minerals can be so high that their volume is larger than that of the surrounding

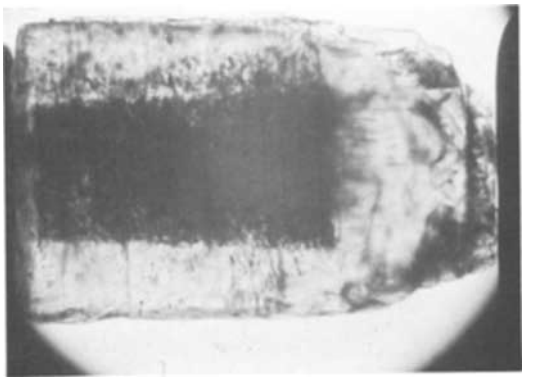

Fig. 20. Sharply delineated 'core-zones', formed by the concentration of numerous mineral inclusions (principally mica, feldspars and carbonate(s). 20x

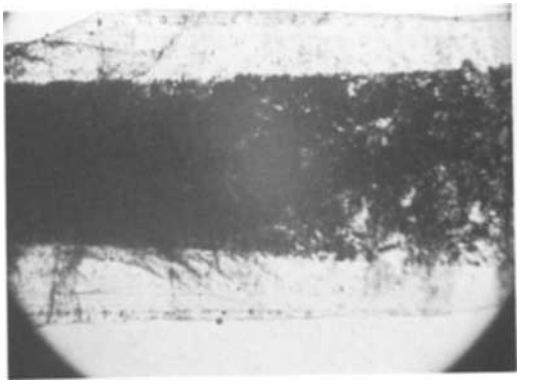

Fig. 21. Sharply delineated 'core-zones', formed by the concentration of numerous mineral inclusions (principally mica, feldspars and carbonate(s). 20x

Fig. 22. Growth layers parallel to the basal face, formed by a high concentration of mineral substance or of growth tubes. 35x

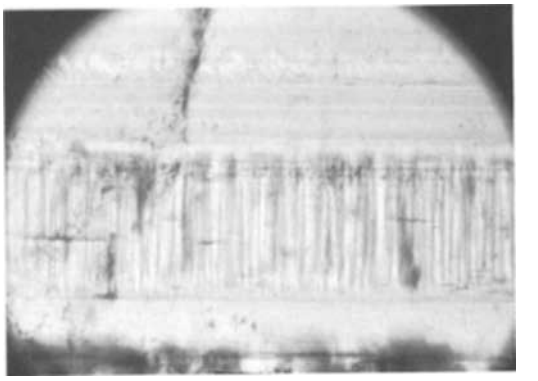

Fig. 23. Internal structure of a growth layer resulting in a somewhat diffuse aspect. 50x

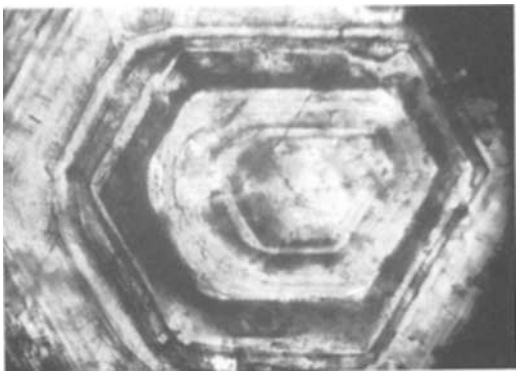

Fig. 24. Concentric colour zoning (looking parallel to the *c*-axis). 50x

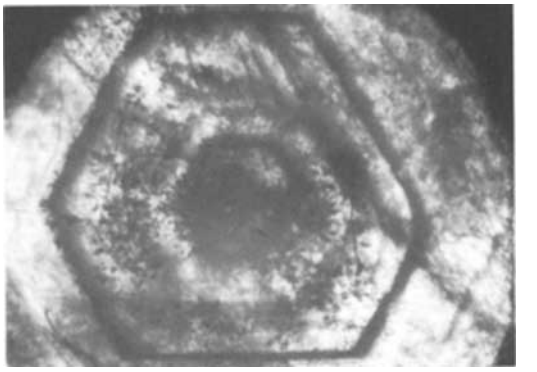

Fig. 25. Enrichment of mineral substance in concentric 'growth-rings'. 35x

Fig. 13. Apatite in the form of prismatic crystals showing corrosion phenomena and cleavage planes parallel to the basal face. 70x

Fig. 14. Partially corroded quartz crystals. 50x

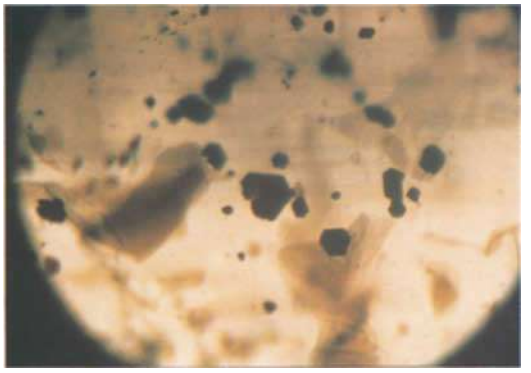

Fig. 15. (Pseudo-)hexagonal hematite platelets and brown mica crystals. 20x

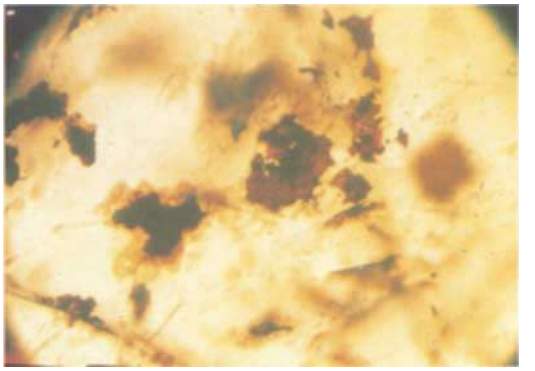

Fig. 16. Hematite is often partially or completely altered to goethite or limonite/lepidocrocite. 20x

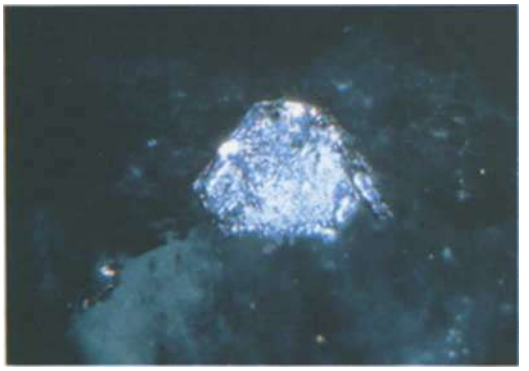

Fig. 17. Hexagonal platelet of molybdenite showing a strong silvery-grey metallic lustre. 50x

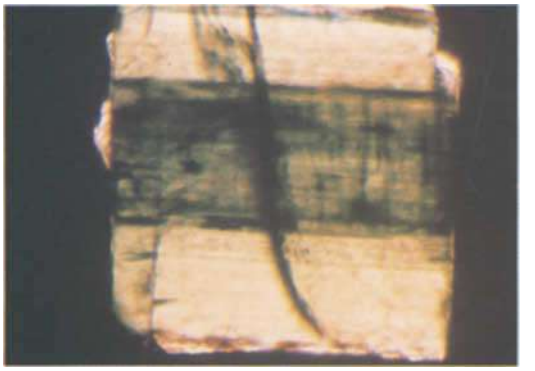

Fig. 18. 'Core-zone', formed by a high concentration of growth tubes that are present through the full length of the emerald. 20x

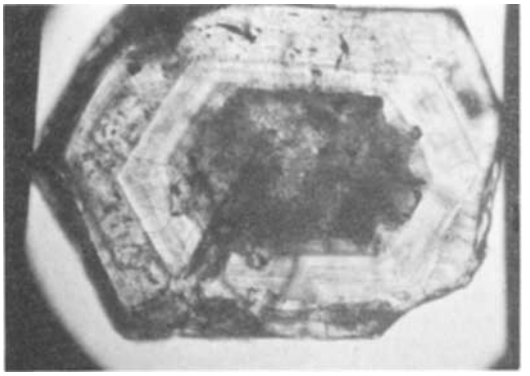

Fig. 26. Concentric colour zoning and 'central core' (caused by the enrichment of growth tubes), reflecting the hexagonal symmetry of the host crystal. 20x

Fig. 27. Three phase inclusion ('s-l-g'-type) with birefringent crystal. 50x

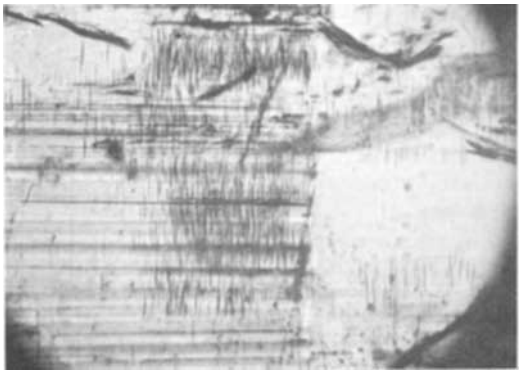

Fig. 28. Swarm of fine, disc-like fissures, oriented parallel to the emerald basal face. 35x

emerald. As a rule, the 'core-zone' traverses the host crystal in its full length. Sometimes, however, it is fairly sharply delimited, ending in its interior. The presence of the core-zones as well as the growth layers described below, show that the growth history of the Socotó emeralds is characterized by repeated abrupt alterations of the environment.

Besides the concentration of growth tubes and mineral inclusions in the core-zone, frequently, enrichment of these inclusions can be observed in layers parallel to the basal plane (Figure 22). Like the core-zones these layers are composed mostly of mica, carbonate(s), feldspar and of growth tubes showing different sizes. As a consequence of the presence of these layers many Socotó emeralds break easily along these layers, i.e. parallel to the basal face. The fracture planes show a strong glass- or nacreous lustre and simulate a good cleavage of the emerald.

As in the Carnaíba emeralds an internal structure of the growth layers can frequently be seen also in the stones from Socotó. This gives rise to a somewhat diffuse aspect of the growth layers (Figure 23), difference from the regular and sharply delimited growth layers generally seen in synthetic emeralds.

Colour striae/colour zoning

A large portion of the Socotó emeralds shows a distinctly developed colour zoning that can express itself both in a strongly coloured central zone with paler border zones, and in a paler central area with darker (i.e. greener) border zones. Other crystals show a sequence of darker and paler 'growth rings' (Figure 24).

The concentric colour zoning is frequently accompanied by the concentration of inclusions (growth tubes, mineral inclusions) in concentric rings (Figure 25) or in certain, generally well delineated, domains of the host crystal (Figure 26). Rarer than the concentric colour zoning are colour striae running parallel to the emerald's *c*-axis.

Fluid inclusions and fractures

Besides the above described mineral inclusions and growth phenomena can be found two phase inclusions of the 'l-g'-type (within the growth tubes or in rectangular cavities). Three phase inclusions (the solid phase is birefringent!; Figure 27) and multiphase inclusions are rarely seen.

More frequent are fractures that generally have no orientation and that are mostly unhealed. Other fractures have a disc-like shape and form swarms oriented parallel to the emerald's basal plane (Figure 28).

Acknowledgements

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Note

All photographs were taken using an immersion liquid. All photographs by D. Schwarz.

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The Pharaohs' forgotten emerald mines

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Introduction

The aim of latest expedition to Djebel Sikeit and Djebel Zabarah by the brothers Angelo and Alfredo Castiglioni was the re-discovery of the Pharaoh's emerald mines.

The Castiglioni expedition was successful in the re-discovery of these forgotten ancient mines and has collected samples and documents on these famous deposits of precious stones, providing emerald specimens of great interest to gemmologists and archaeologists, as will be revealed in this paper.

Historical notes

While there are scientists who believe that emeralds were already in use in Egypt during the 12th dynasty, 2000-1788 BC (Ball, 1931), they were certainly widely diffused during the Ptolemaic (304-30 BC) Roman (30 BC-395AD) and Byzantine period (395-640AD) and the mines were fairly intensely exploited until 1237 during the reign of Sultan Al-Kamel.

The problem of dating the first appearance of the emerald is complicated by some confusion caused by the word that the ancients used for emerald. Apparently, the Egyptian word 'mafek' or 'wed' and the Greek word 'smaragdus' were freely used for all the green stones which were or appeared to be emeralds.

On this matter, Lucas (1934) who is undoubtedly an authority on the nature and use of ancient Egyptian materials, points out that the Egyptian mines were '...probably of the Greek-Roman period. There is, in fact, no evidence that they were exploited during the reign of Amenopsis III, as Wilkinson (1890) affirms; on the contrary it is certain that beryl has not been used in Egypt before the Ptolemaic period: all the stones examined by author from before that time, were not beryls but amazonite or other greenish materials.'

According to Lucas this was due to several archaeologists who, examining various collections, had classified a lot of green stones as emeralds or under the vague term of 'mother-of-emerald', even if they were not.

Previous explorations

In the following centuries, it seems that the mines may have been exploited by the Turks. However, around 1750 all activity stopped and the decline began, eventually reaching the point at which all records of the location of the mines was lost and it became as if they had never existed.

The first man to revive interest in these mines was a French explorer and archaeologist F. Cailliaud, who, commissioned by the Viceroy of Egypt, Ali Mohammed Pascha, in 1816, went back along the caravans path which led from the Nile to the mining areas of Djebel Zabarah and Djebel Sikeit. For several years his initiative aroused treasure hunting by travellers and scientists such as Belzoni in 1820 and Brocchi in 1823.

The latter (1841) described the fundamental geology of the area and provided some mineralogical information on the various minerals associated with the emerald. From 1841 until the end of the last century, these areas were again forgotten.

In 1899 McAlister made an extensive geographical and geological description of the mining area.

In 1911 a Frenchman, J. Couyat, visited the region and provided a brief mineralogical description of the emeralds. He described, in fact, only the colour, the morphology of the crystals and their occurrences. He affirmed, particularly, that the colour varies with the locality: 'deep green at Djebel Sikeit and bluish green at Djebel Zabarah and Abou Reched.' He also suggested, with great insight, that the different colours might be the reason that the ancients used different names for the same mineral.

In 1934 another Italian geologist, A. Stella, visited the area and stayed for a while by the Djebel Umm Kabu mine, which is the third and smallest mine in the area. Stella was the first to suggest that the berylliferous mineralization might be due to pneumatolytic or hydrothermal impregnation in the crystalline schists of the Etbai. He therefore suggested, using geological data, that there was a genetic analogy with the beryls from the Urals (USSR), Habachtal (Austria) and Leysdorp (South Africa).

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In 1957 Basta and Zaki re-explored the region and produced the first mineralogical information on the beryls from Wadi Sikeit and Djebel Sikeit. They reported occurrences, paragenesis, refractive indices, inclusions and X-ray powder patterns. On the basis of refractive indices they indicate the 'presence of about 15% alkalies.'

The expedition

To approach Mount Zabarah, the emerald mountain, the Castiglioni brothers used IVECO 75 PC 4×4 lorries equipped with advanced technological instrumentation called 'Satellitale' which could give at any time the exact latitude and longitude of their position. However, in spite of the sophistication of the computer, their personal experience and the old camel tracks proved to be their main aids in facing a journey bristling with difficulties.

The expedition set off from Alexandria, heading south and near the city of Edfu they left the fertile Nile valley and headed on into the desert and the barren mountains by the Red Sea. The valleys are often dominated by high peaks, some of which have old dry-stone pyramids on them, which are thought to have been ancient sign posts.

Thousands of years of caravan traffic have scattered the desert with caravanserais, of which today only the great dry stone walls remain. They were used to enclose the wells and thus protect them from the sand. The remnants of these wells reveal the perfection of their construction. The Bir Hammet well, found approximately 90 km from the Nile, on the Quseir road, octagonal in shape, more than 25 m deep, with a diameter of almost 4 m, was accurately surveyed by the Castiglioni brothers. The walls are compact, built with large blocks, perfectly fitted together without a single crack.

Slightly beyond this well one finds the Uadi Hammamat gorge and then the 'Green breccia' quarries, where huge abandoned blocks given evidence of a very ancient exploitation. Among the masses of broken blocks and piles of stones, it is possible to distinguish the form of a sarcophagus, which has lain there, forgotten for 25 centuries (Figure 1).

All around are remnants of simple dwellings, several heiroglyphic inscriptions and the remains of signal towers from the Roman period. In addition, practically everywhere are the constantly recurring symbols of the god Min, 'the divinity of the Eastern desert', who is represented with his head surmounted with huge feathers, his left arm raised, and his virile organ always erect (Figure 2).

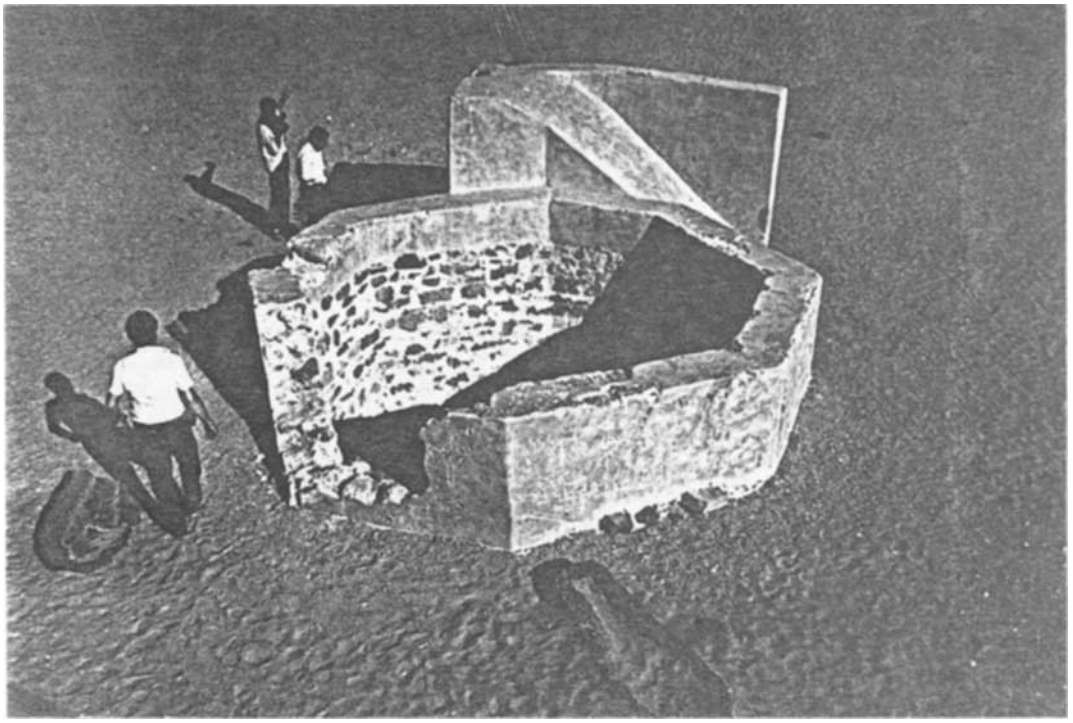

Fig. 1. The Great Bir Hammat well. Located 90 km from the Nile, on the Quetseir road, this well was for centuries an important stop for the caravans, which were going towards or were coming from the Red Sea. A few sarcophagi, broken during the transport and left on the sand, confirm the ancient time of construction of this spot of water.

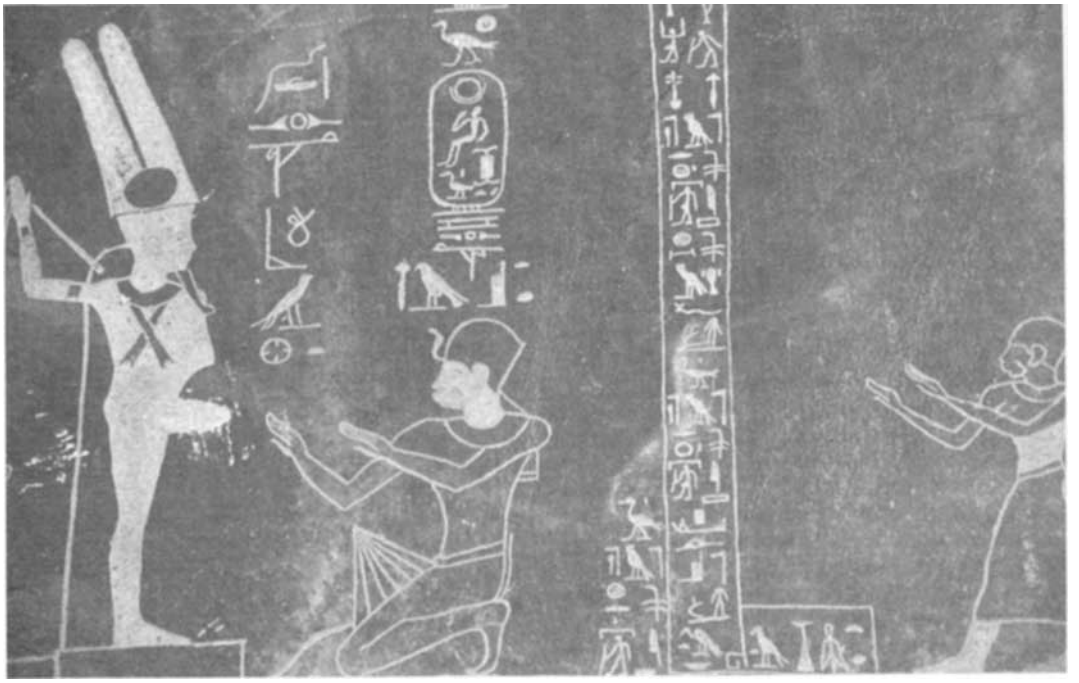

Fig. 2. The God Min. 'The lord of the region', his image used to be frequently crafted on the rocky walls of the Uadi Hammamat. His head surmounted by large feathers, his left arm stretched up and his virile organ always erect.

Fig. 3. The ancient residences of Sikeit miners. The ruins of the houses are scattered on two sides of the mountains which flank the valley. The constructions show a great accuracy of execution: the stones, without mortar, are accurately selected in order to fit in one another to form a compact, smooth and exactly vertical wall.

Fig. 4. The temple at Sikeit. Opened in the middle of the mountain, this ancient place of worship, which thousands of years have eroded, still shows its attractive architectural beauty.

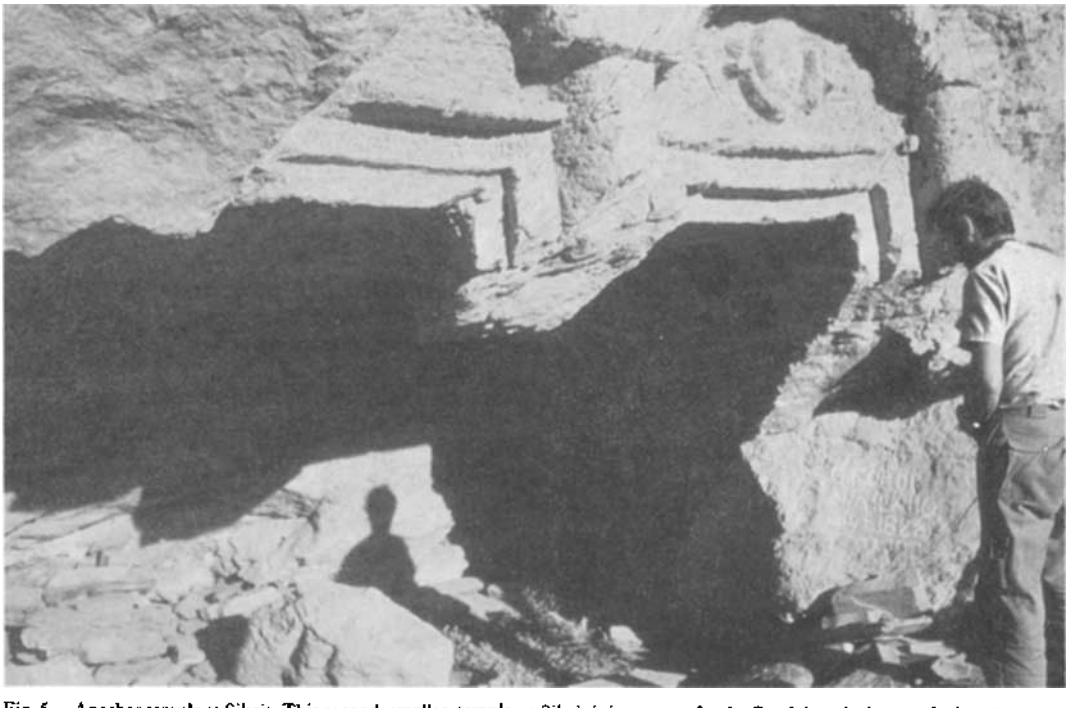

Fig. 5. Another temple at Sikeit. This second, smaller, temple at Sikeit is important for the Greek inscriptions crafted on the arches and for the solar symbols, surrounded by two snakes, which surmount the architrave. This high-relief allows dating of the temple as Ptolemaic in age.

Fig. 6. The entrance of the Pharaohs' emerald mine.

Fig. 7. Some of the members of the Castiglioni expedition in the emerald mine at Djebel Zabarah. On the walls the marks made centuries ago by thousands of blows, using diorite wedges, bronze chisels, iron tools for crushing quartz, are still visible.

The ancient city of the miners

The first sign of the forgotten mines is a low, dry stone building, the home of the Blemmis, the Sikeit miners, who supplied emeralds to the Ptolomans and to the Romans. The remnants of the house show that they were constructed with considerable accuracy; they are scattered along the sides of the mountains which flank the valley, and are furnished with stone benches and niches in the walls (Figure 3).

Zabarah, the emerald mountain

After leaving the Sikeit valley, other buildings were observed by the travellers arranged in lines, built in a very simple and modern way, that made up the miners' village of the past. Piles of quartz splinters lay inside and outside the houses together with small bright green fragments of emerald. A little farther on, the valley narrows and there are the ruins of ancient cemeteries, piles of debris and at last the mountains pock-marked with holes which indicate the entrance of the ancient mines.

Fig. 8. Emerald from Djebel Zabarah mine.

The temples of Sikeit

Sikeit also includes traces of two ancient temples. One is a tiny construction almost entirely in ruins, while the other larger one is in the middle of the mountain, its elegant slender columns carved out of the living rock. One of the internal columns is broken; without its central part it seems to challenge the laws of gravity, because the upper capital and part of the column shaft are still hanging from the ceiling, while one would expect to find them shattered on the floor of the temple. Only on closer inspection is it revealed that all columns are part of the same single piece, painstakingly carved out of the rock (Figures 4 and 5).

The mines

The entrance is normally a narrow corridor, carved out in the mica-schist, which suddenly opens into a chasm from which at various heights very narrow cavities start (Figure 6).

To explore these cavities, made by generations of miners, following the irregular path of emerald-rich quartz and feldspar veins, proved to be extremely difficult.

The space is restricted and breathing was made difficult due to a kind of very fine talc, thrown up by mere footsteps. The humidity increases as one

descends to the lower levels. The result is an irritating yellowish-white crust that gradually covers the body, damp with sweat, that vividly reminds one of the sufferings of the men who were forced to work for hours in the pale light of torches or terracotta lanterns. These would have burnt up the oxygen making the situation even worse, and all this for the glory of the Pharaohs. The rocks, blackened by the smoke of thousands of torches, still clearly show the efforts of those men.

The columns and stone arches found at various points were used to tie ropes on to, that allowed men to go down the shaft or to pull up baskets of material (a few pieces of hemp are still hanging in these shafts (Figures 7 and 8).

Among the other dangers there were the scorpions (*Androctonus australis*), who tend to build their nests in the entrance of the caves.

But were the emeralds of Zabarah really worth all dangers, efforts and sufferings?

For the ancient Egyptians the answer was yes, because they considered the emerald to be the symbol and purest essence of eternal life, and thus every sacrifice to obtain it was justified; this stone symbolized rebirth in the after life and had the colour of the life that flourishes on the banks of the Nile, after the fertilizing flood.

The emeralds from Djebel Zabarah

The characterization of the emeralds from Djebel Zabarah, the larger and historically most important of the three Egyptian mines, is strictly speaking, more a geo-archeological contribution than a gemmological one.

The emeralds are often '....pale green in colour, cloudy and exhibit considerable inclusions' as Cailliaud described them, or '...fairly clear, irregularly coloured and affected by several hairline fractures' as Stella said, although one can find clear crystals varying in colour from yellowish-green to bluish- and dark green.

The rough material examined occurs as large beryl crystals enclosed in a quartz mica-schist matrix consisting of plagioclase (oligoclase $Ab_{84.7}An_{15.3}$), mica (phlogopite), chlorite, (analyses reported in Table 1), quartz and calcite.

Carefully selected emerald fragments exhibiting few or no incusions have been analysed using the traditional first level gemmological analysis (Table 2), followed by second level analysis (chemical

Table 1: Analysis of associated minerals (electron microprobe)

	Plagioclase	Phlogopite	Chlorite
SiO_2	64.79	41.66	30.77
Al_2O_3	22.15	15.61	18.37
FeO	–	11.14	14.38
MnO	–	–	0.20
MgO	–	18.39	23.76
Cr_2O_3	–	0.24	0.32
TiO_2	–	1.14	–
CaO	3.25	–	0.23
Na_2O	9.93	0.50	–
K_2O	–	9.71	–
Total	100.12	98.39	88.03

Table 2: Properties of Djebel Zabarah mine emerald

Lustre	: Vitreous
Density	: 2.75 g/cm^3
Colour	: Medium green
Hardness	: 7.5
Refractive index	: $N_o = 1.596 - N_e = 1.590$
Birefringence	: – 0.006
Pleochroism	: N_o = light/dark green N_e = yellow
Ultra-violet fluorescence	: none
Inclusions	: Colour zoning, veils, fractures, two-phase inclusions, hair fine primary growth tubes in parallel alignment, growth hillocks. Negative crystals. Solid inclusions of mica and beryl.

analysis, X-ray diffraction and infrared spectroscopy).

Gemmological properties

Chemical analyses

The chemical analyses of the emerald and the associated minerals of the matrix were performed by the electron microprobe analyzer JEOL JXA-50A, equipped with the LINK SYSTEM 860 energy dispersive spectrometer (EDS). Be and Li were analyzed by a PERKIN ELMER 5000 spectrometer equipped with a graphite crucible. The weight-loss determination was carried out by thermo-gravimetric analyses on a PERKIN ELMER TGS-2 (Table 3).

In Table 3 are reported the analyses of the emeralds from some known mines like St Teresiña (Brazil), Habachtal (Austria), Muzo (Colombia) and Urals (USSR) for comparison (Aurisicchio *et al.* 1988) together with the sample from the Zabarah mine.

The Djebel Zabarah beryl reveals a large substitution of the Al in the octahedral site and therefore it is classified in the octahedral series (Aurisicchio *et al.*, 1988, see Figure 9 this paper).

It is worth stressing that the prevailing substitution for Al is by Mg ions as it is for the emeralds

Table 3: Chemical analyses of emeralds

		St Teresiña 31*	Zabarah E	Habachtal 23*	Muzo 10*	Urals 26*
SiO_2		64.36	64.78	63.60	65.34	65.14
Al_2O_3		13.99	14.84	14.54	16.51	17.72
FeO		1.11	0.72	0.38	0.31	0.24
MgO		2.68	2.36	2.27	0.87	0.44
Cr_2O_3		0.32	0.11	0.35	0.37	–
V_2O_5		–	–	–	0.64	–
TiO_2		0.22	–	–	–	–
BeO		13.03	13.11	13.01	13.37	13.46
Li_2O		0.05	0.04	0.04	–	0.05
Na_2O		2.03	1.64	1.72	0.49	0.51
K_2O		–	0.07	–	–	–
Cs_2O		0.33	–	–	–	–
L.O.I.		2.00	2.01	2.60	2.40	2.30
Total		100.13	99.89	98.51	100.30	99.86
		Number of ions on the basis of 18 oxygens				
Si	T′site	6.016	6.033	6.025	6.025	6.001
Al	O site	1.541	1.628	1.623	1.794	1.924
Fe^{3+}		0.009	0.008	–	–	–
Fe^{2+}		0.077	0.048	0.030	0.024	0.018
Mg		0.373	0.328	0.320	0.119	0.060
Cr		0.024	0.008	0.026	0.027	–
V		–	–	–	0.047	–
Ti		0.015	–	–	–	–
Be	T″site	2.925	2.932	2.960	2.960	2.978
Li		0.019	0.015	0.015	–	0.018
Na	Rf	0.368	0.296	0.316	0.088	0.091
K		–	0.008	–	–	–
Cs		0.013	–	–	–	–
Total		11.367	11.304	11.315	11.084	11.090

L.O.I. = loss on ignition; dash = below detection; Fe^{3+} by charge balance; * = these numbers refer to the samples reported in the reference, Aurisicchio *et al.*, 1988. T′site = tetrahedral site; T″site = different tetrahedral site; O site = octahedral site; Rf = alkali ions; Me = divalent metals.

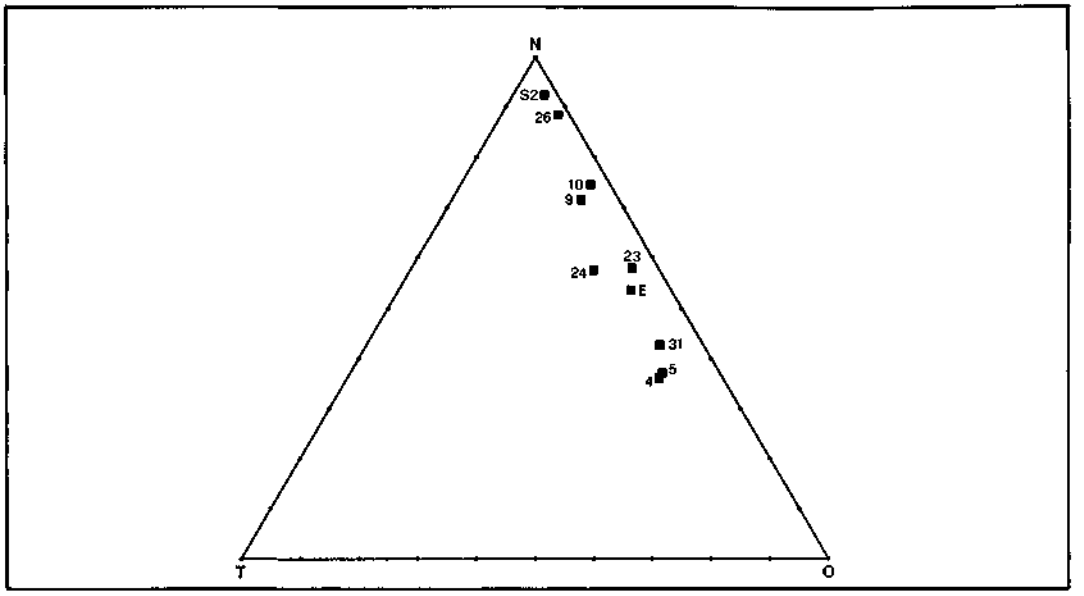

Fig. 9. Ternary diagram based on end members: 'Normal' beryl = N. $Al_2Be_3Si_6O_{18}.zH_2O$; 'Tetrahedral' beryl = T. $Rf+Al_2Be_2LiSi_6O_{18}.zH_2O$; 'Octahedral' beryl = O. $Rf+AlMe^{2+}Be_3Si_6O_{18}.zH_2O$. Drawn from figure 6 of the work Aurisicchio *et al.*, 1988.

from St Teresiña and Habachtal, the only other beryls showing Mg enrichment. From this point of view then, the beryls shown in Table 3 all have their genesis in an Mg-rich environment so it would be very useful to know the kind of conditions controlling the substitution in the pattern shown.

On the basis of the reported analyses therefore, and as hypothesized by Stella (1934) from geological evidence, the Zabarah emerald shows a close chemical analogy with the Habachtal emerald. This similarity is supported in the ternary diagram of Figure 9 in which the Ural emerald (26) lies close to the 'Normal' apex and the St Teresiña emerald (31) with 2.68% MgO substituting for Al_2O_3 lies closer to the 'Octahedral' apex. For further details the reader is referred to the work of Aurisicchio *et al.*, 1988.

X-ray diffraction

The unit cell parameters of the emeralds studied were obtained by the powder method with an automatic SEIFERT MZIV diffractometer. Si powder was used as internal standard (Table 4).

The synthetic emerald S2, obtained by flux fusion, was produced in our laboratory (Flamini *et al.*, 1983).

The *c/a* values in the range 0.991 – 0.996 put in evidence the trend corresponding to the 'octahedral' beryls; 'normal' and 'tetrahedral' beryls show *c/a* values in the range 0.997 – 0.999 and 1.000 – 1.003.

Table 4: Lattice parameters *a* (Å), *c/a* ratio, cell volume of some natural and synthetic emeralds.

	a	*c*	*c/a*	V
31 St Teresiña, Brazil	9.263	9.196	0.9927	683.7
4 Mingora, Pakistan	9.263	9.199	0.9931	683.6
E Djebel Zabarah	9.253	9.166	0.9938	679.6
5 Val Vigezzo, Italy	9.257	9.201	0.9940	682.8
23 Habachtal, Austria	9.249	9.200	0.9947	681.6
4 Morrua, Zambia	9.237	9.190	0.9950	679.0
9 Carnaíba, Brazil	9.226	9.192	0.9963	677.0
10 Muzo, Colombia	9.218	9.189	0.9969	676.2
26 Ural Mts., USSR	9.217	9.197	0.9977	676.7
S3 Gilson	9.217	9.197	0.9978	676.8
S2 Flux-fusion sint.	9.205	9.195	0.9989	674.8

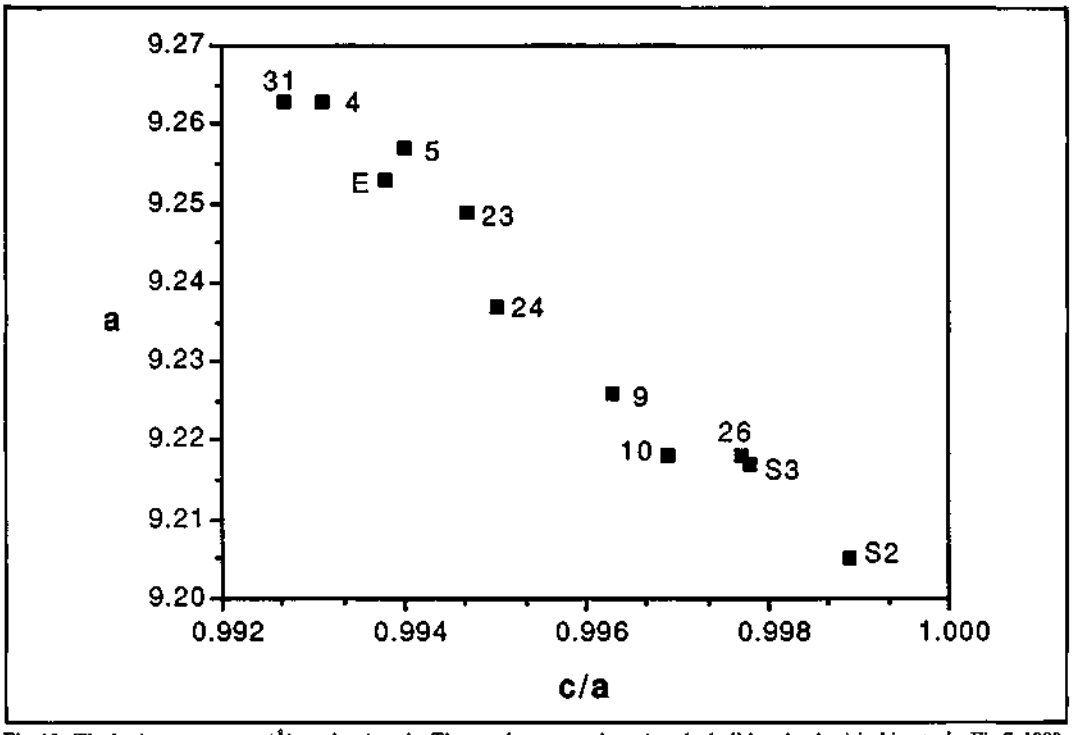

Fig. 10. The lattice parameter *a* (Å) vs. the *c/a* ratio. The trend corresonds to 'octahedral' beryls. Aurisicchio *et al.*, Fig.7, 1988.

In Figure 10 the unit cell-edge of the studied emeralds is plotted against the *c/a* ratio. The Djebel Zabarah beryl falls just on the line of the 'octahedral' beryls, confirming its behaviour.

Infrared spectroscopy

IR spectra were performed with a double beam PERKIN ELMER spectrometer with diffuse reflectance attachment, in the range 4000 – 250 cm^{-1}.

The IR spectrum is a powerful tool for studying cut and rough gem-materials. It can give us basic information about the structure, chemical composition, isomorphic substitutions, water and CO_2 content and space organization of the molecules in the channels. The Djebel Zabarah emerald shows the spectrum of Figure 11 which also shows the IR patterns of the St Teresiña and Muzo emeralds which show a different degree of octahedral behaviour. From a detailed examination of the spectra and a comparison with our data bank of emeralds and beryls from various world wide localities, it appears that the spectrum of the Egyptian emerald is made up of three main parts: the first in the range around 4000 – 2500 cm^{-1} where the characteristic water absorption is located; a second zone in the middle with CO_2 stretching and water bending vibrations; the third part down to 1300 cm^{-1} shows the structural bands of the beryls due to the vibrational frequencies of each bond.

Aurisicchio *et al.* (1988) describe the good correlation between structural data (the parameter of the cell) and band shifting (520 cm^{-1} vibration) with increasing Al substitution. Here, in Figure 12, we report the trend of the a parameter versus the position of the band located at about 520 cm^{-1} for the mentioned emeralds. This peak is due to the vibrations of the octahedral bonds and shifts its position notably as Mg, Fe, and other ions enter in to this site. The Zabarah emerald lies on the trend given for the emeralds or generally for 'octahedral' beryls.

Conclusions

With the aid of the non-destructive analyses used in this work it has been possible to characterize entirely the Zabarah emerald confirming its structural, chemical and genetic affinity with the Habachtal emerald whose use as gemstone in ancient times was not known (Sinkankas, 1981).

It should be desirable, therefore, to carry out comparisons with ancient gemstones assumed to be of Egyptian origin to verify if the used methodologies could give some help to the historians and archaeologists.

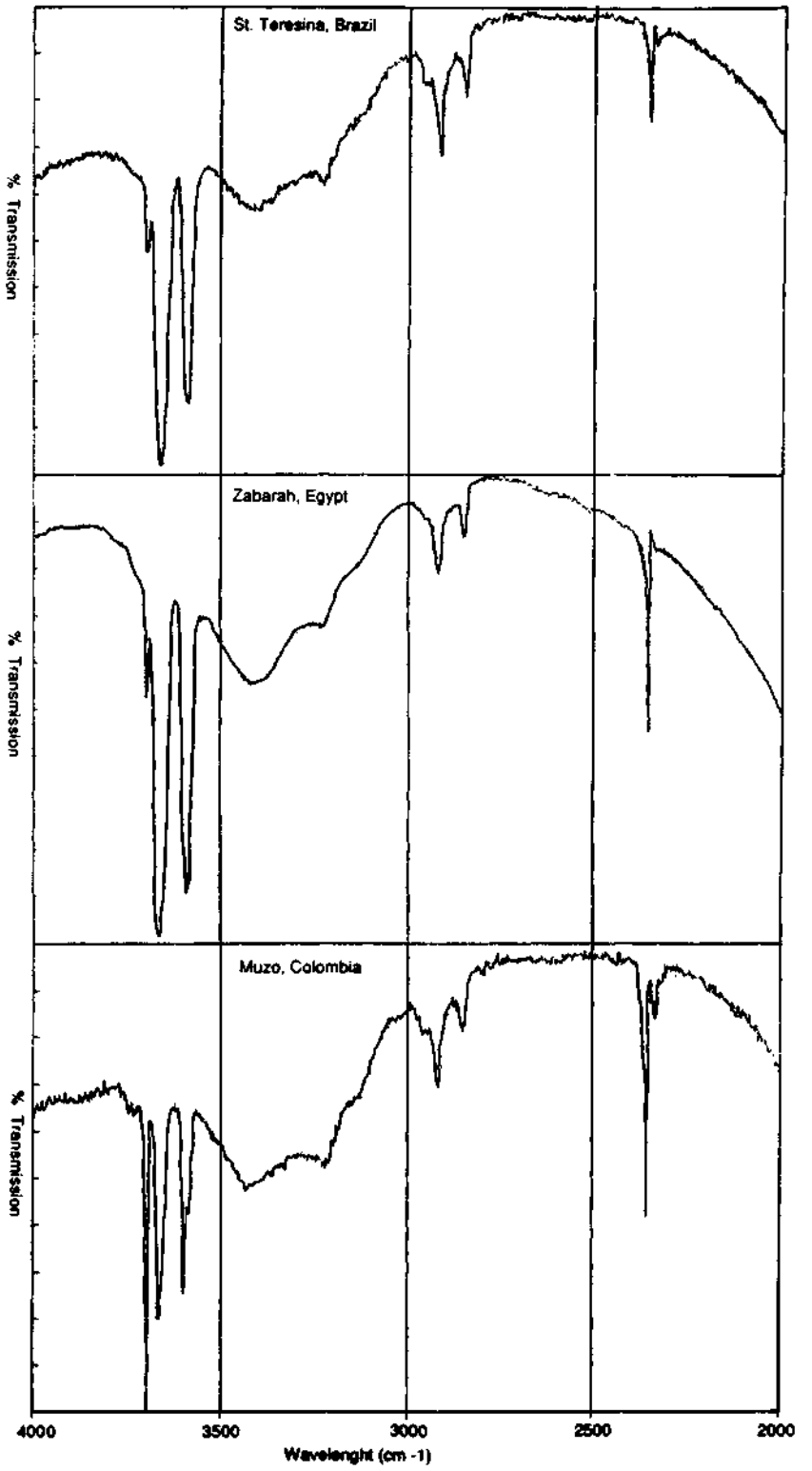

Fig. 11a Infrared spectra of emeralds from St Teresiña, Muzo and Zabarah at the temperature of liquid nitrogen.

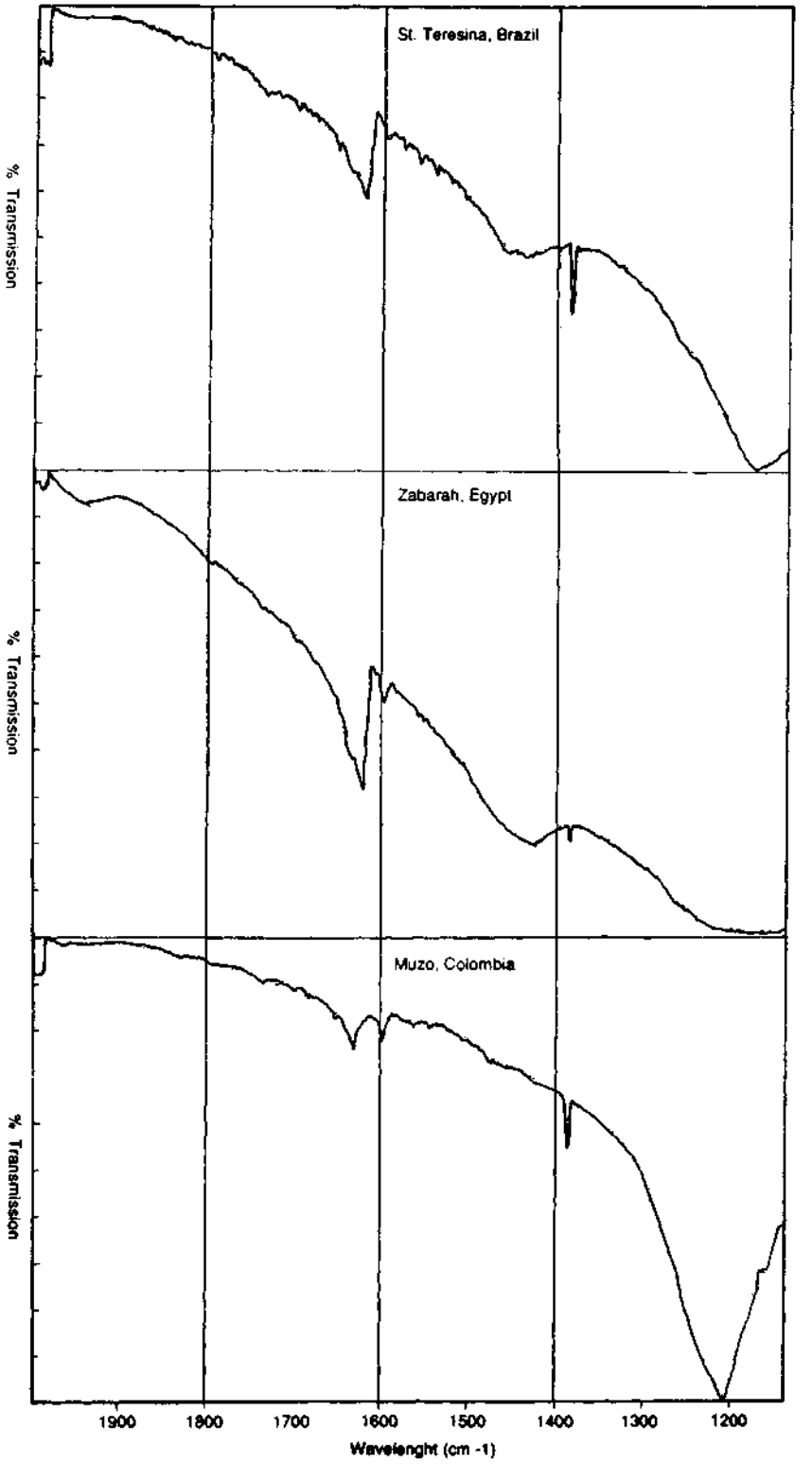

Fig. 11b Infrared spectra of emeralds from St Teresina, Muzo and Zabarah at the temperature of liquid nitrogen.

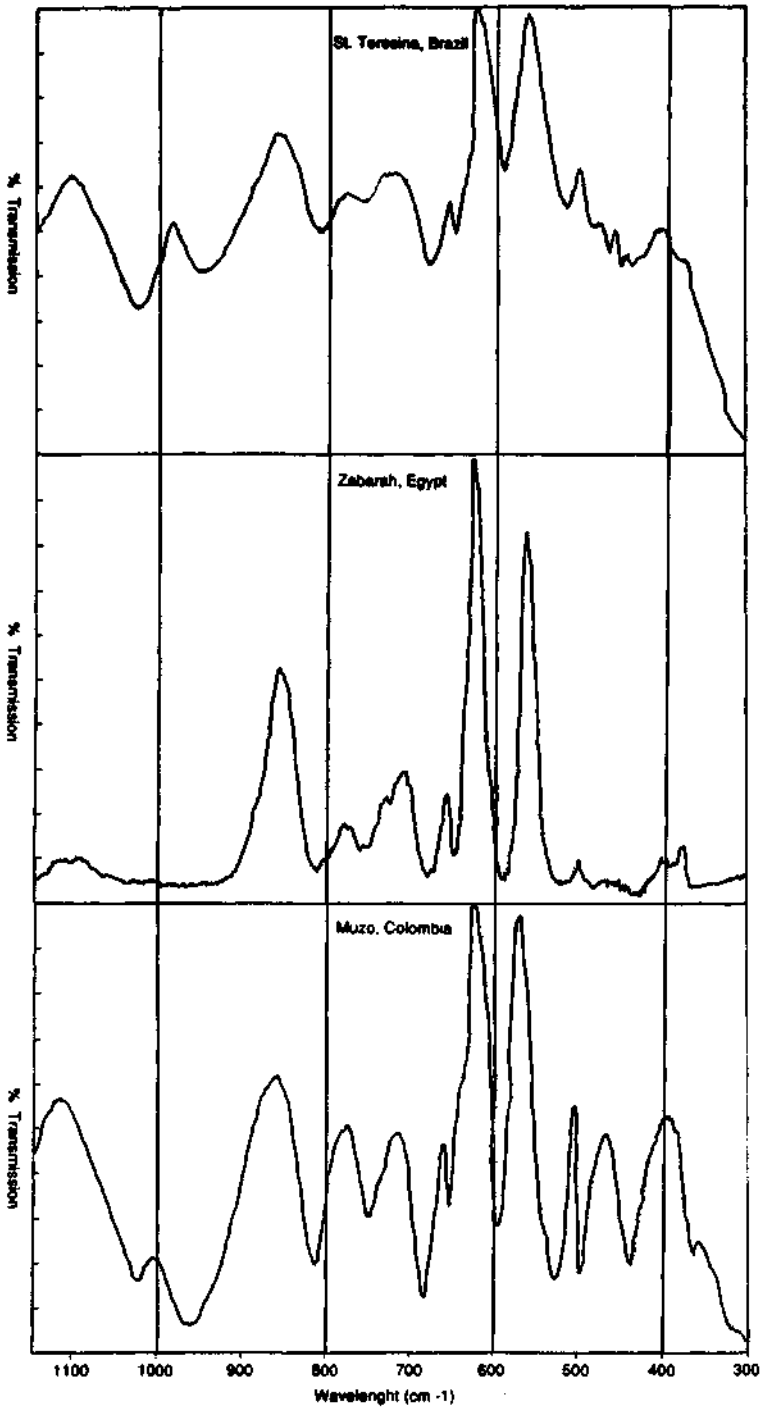

Fig. 11c Infrared spectra of emeralds from St Teresina, Muzo and Zabarah at the temperature of liquid nitrogen.

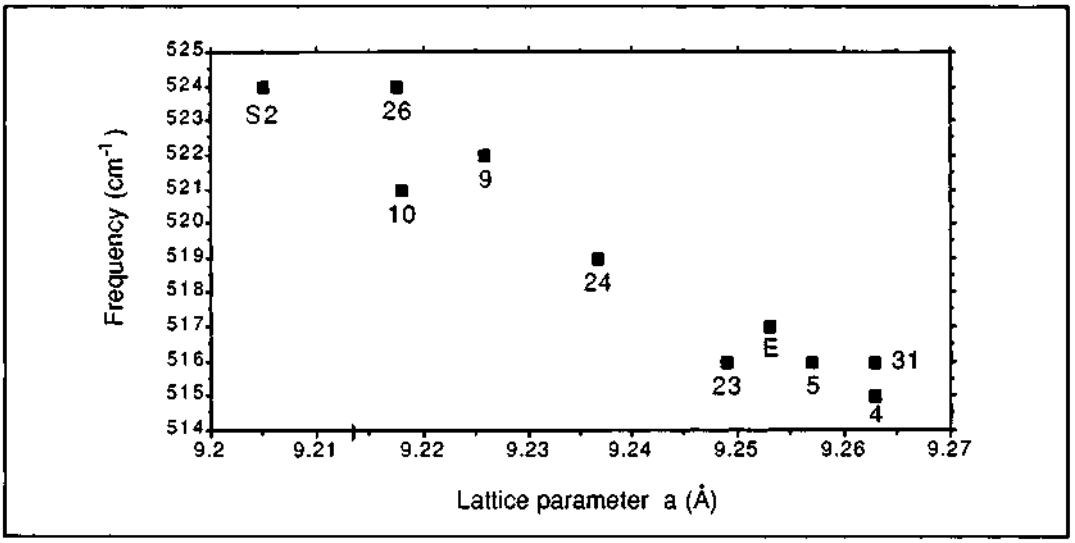

Fig. 12. The lattice parameter a (Å) vs. the 525 cm^{-1} mode shift for Zabarah and other known emeralds. The trend corresponds to 'octahedral' beryls.

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[*Manuscript received 7 July 1989.*]

Gemmological Abstracts

BANK, H., HENN, U., 1990. Untersuchung eines im Flussmittelverfahren hergestellten synthetischen roten Spinells aus der UdSSR. (Examination of a flux-grown red spinel from the USSR.) *Zeitschrift der Deutschen Gemmologischen Gesellschaft,* **39**, 1, 45-8, 6 figs.

The red synthetic spinel from the USSR was a 1..5cm long crystal weighing 13.14 ct. It is an octahedron with level faces allowing reading the RI which was 1.716. SG 3/62/ Absorption spectra analysis showed the stone to be coloured by Cr^3. The microscope showed tension cracks causing undulous extinction and some black particles, probably residues of the flux. E.S.

BANK, H., HENN, U., BANK, F.H., PLATEN H.v., HOFMEISTER, W., 1990. Leuchtendblaue Cu-führende Turmaline aus Paraiba, Brasilien. (Brilliant blue Cu-containing tourmalines from Paraiba, Brazil.) *Zeitschrift der Deutschen Gemmologischen Gesellschaft,* **39**, 1, 3-11, 5 figs, 2 tables, bibl.

The brilliant blue tourmalines come from a new occurrence near Salgadinho in the State of Paraiba, Brazil. RI 1.615-1.632 to 1.620-1.640. DR 0.0117-0.020. SG 3.04-3.07. A microprobe showed the stones to be elbaites, relatively rich in Mn, containing CuO and Bi_2O_3. The bright blue colour is due to absorption bands of Cu and Mn. At temperatures of about 600°C the colour changes to greenish-blue. E.S.

BANK, H., HENN, U., 1990. Ein Beitrag zur Unterscheidung natürlich blauer und durch künstliche Bestrahlung blaugefärbter Topase anhand von Thermolumineszenzuntersuchungen. (A contribution to the differentiation between natural blue topaz and those coloured blue through artificial irradiation with the help of examination by thermoluminescence.) *Zeitschrift der Deutschen Gemmologischen Gesellschaft,* **39**, 1, 65-72, 5 figs, 1 table, bibl.

The authors describe method of differentiating between natural and artificially coloured (by gamma-, electron-and neutron-irradiation) blue topaz by using thermoluminescence. The apparatus is described in detail. Natural blue topaz shows intensive thermoluminescence between 250-350°C, while the irradiated stones thermoluminesce between 400-550°C, those that have been treated with gamma rays requiring the higher range of temperatures, and those treated with electrons the lower ones. E.S.

BRIDGES, C.R., GRAZIANI, G., GÜBELIN, E., 1990. A Kenyan gemstone of the feldspar family; further observations. *Australian Gemmologist,* **17**, 5, 177-83, 11 figs in colour.

Describes in detail delicate blue and green albite cabochons from Kioo Hill, Kenya, which are identified as peristeritic. RI α1.531 and γ1.539, with slight variation; weakly pleochroic; spectrum confused; whitish weak fluorescence under LUV. R.K.M.

BROWN, G., KELLY, S.M.B., 1990. Knischka-created rubies. *Australian Gemmologist,* **17**, 5, 199-204, 14 figs in colour.

Study Club report on recently produced ebauchated crystal, a well-formed crystal and cut stone, which gives the history of Professor Knischka's clever synthetic and its gemmological properties in some detail. A useful paper. 'Ebauche' is French for 'rough-hewn', which describes the serrated, file-like appearance of this multiple crystal rather well. R.K.M.

FAULKNER, M.J., SHIGLEY, J.E., 1989. Zircon from the Harts Range, Northern Territory, Australia. *Gems and Gemology,* **25**, 4, 207-15, 8 figs in colour.

Zircon from this remote central region is largely pale, brownish-purple, pink, yellow and some which can be made almost colourless by heating but no blue or golden shades, and is remarkable for its low content of radio-active uranium or thorium. Location, access, geology and gemmological properties are described. RI well above 1.81, SG between 4.62 and 4.72, H 7 to 7.5. Absorption showed 653nm most prominently but other lines at 535, 590, 657 and 689 were weak; confirmed by spectrometer. Spectra varied slightly with crystallographic direction. Mr Faulkner provides notes on cutting and polishing this material. R.K.M.

FRYER, C.W., ED., CROWNINGSHIELD, R., HURWIT, K.N., KANE, R.E., HARGETT, D., 1989. Gem Trade Lab notes. *Gems and Gemology*, **25**, 4, 236-42, 17 figs in colour.

A large mass of orange, white, yellow and brown rough, sold as amber in Tahiti, proved to be plastic, probably polyvinyl chloride. An almandine-pyrope inclusion in diamond is described and illustrated. A bi-colour yellow and white marquise diamond fluoresced blue in its white centre and chalky yellow at its yellowish tips, followed by a weak chalky yellow phosphorescence over entire stone. Another diamond contained a colour-change garnet, red-purple in incandescent, and saturated green in fluorescent light. A large pear-shaped green diamond was radio-active, probably from radium salts treatment early this century; report advises against its use in jewellery. An irradiated octahedron, one of several treated crystals seen, was a superficial blue concentrated mainly in the crystal edges; lines at 415.5, 498/504 and a weak 594nm were seen, rather as expected. [One wonders why crystals are treated in this way? Cutting would surely eliminate most of the surface colour?]

Sample beads of jadeite purported to be 'before' and 'after' versions of a new treatment, but both types were found to have been impregnated with plastic, probably polyacrylate.

A seemingly solid natural pearl in a bezel-set ring was found to consist of two parts when unset, probably worked from two blister pearls, the join was obscured in an X-radiograph by the bezel of the ring. A black cultured pearl from a three strand necklace, represented as natural coloured, was sectioned and showed the presence of black dye, probably silver, in the nacreous outer layer; the two pearls examined were inert under LUV, where a naturally coloured black cultured pearl [or a natural black pearl for that matter] would have fluoresced brownish-red.

An attractive untreated Burma ruby in a ring came back some weeks later for a damage report. The stone had been ruined by sudden temperature change, the result of re-tipping a prong [claw] without unsetting the ruby! A 26.11 ct faceted purple scapolite is said to be unusual in such a size; illustration suggests that it was slightly cloudy; much such Burmese material is cut as cat's-eyes. A fine 15.18 ct violet-blue tourmaline from a new mine at San Jose Baltalha, Paraiba, Brazil, resembled tanzanite, a new colour for tourmaline and unusually large for this mine; the absorption was strong and unusual. A pair of earrings offered as zirconia, in a real estate presentation, proved to be paste (RI 1.57) and foiled. R.K.M.

HARDER, H., 1990. Klare und trübe Korunde als Rohsteine für wärmebehandelte Saphire aus Sri Lanka. (Clear and opaque corundums as raw material for heat treated sapphires in Sri Lanka.) *Zeitschrift der Deutschen Gemmologischen Gesellschaft*, **39**, 1, 73-87, 6 photographs in colour, 2 tables, bibl.

Common corundum which lend themselves to heat treatment into sapphires occur in Sri Lanka. This raw material can be clear or opaque. Locally the clear varieties are known as Ural and Ottu, the opaque as Geuda and Dot. Ural refers to clear colourless corundum with a small intensely blue concentration. Ottu are those clear corundums with bluish-green parts, blue lines in the crystal or on the surface. Geuda are the opaque stones or those somewhat translucent, milky with a lot of silk. Dot are opaque with a white shimmer, milky with a lot of silk. The potential value of these rough stones can be estimated according to hints on the content of iron and titanium. The content of iron can be guessed from some blue lines or dots or from some greenish to brownish weathering coloration. Reducing conditions in flames lead to the best quality colours in sapphires depending on quality of rough stones. X-ray fluorescence tests of the highly evaluated Ottu qualities show similar content of iron and titanium as cornflower blue, untreated sapphire of good quality. The relationship between iron and titanium in corundum is not only the key for untreated sapphires, but also for various qualities of corundum which can be heat treated into blue sapphires. E.S.

HENN, U., BANK, H., 1990. Blaue Saphire aus Malawi. (Blue sapphire from Malawi.) *Zeitschrift der Deutschen Gemmologischen Gesellschaft*, **39**, 1, 89-92, 7 figs (1 in colour), 1 table, bibl.

Previously cuttable rubies and padparadshas from Malawi have been described. Now some gem quality sapphires have come onto the market. RI 1.762-1.770, DR 0.008,. SG 3.97-3.99. The blue colour is caused by absorption bands of Fe^2/Ti^4 charge transfer and Fe^3, FeO, TiO and Cr_2O_3 have been found by analyses. Lamellar twinning, boehmite, rutile and zircon have been found under the microscope. E.S.

HUNSTIGER, C., 1990. Darstellung und Vergleich primärer Rubinvorkommen in metamorphen Muttergesteinen. Petrographie und Phasenpetrologie. Teil II. (Representation and comparison of primary ruby occurrences in metamorphic rocks. Petrography and petrology. Part 2.) *Zeitschrift der Deutschen Gemmologischen Gesellschaft*, **39**, 1, 49-63, 8 figs (3 in colour) 4 tables, bibl.

The second part of the thesis deals with rubies in gneises. The characteristic of these rocks seems to

be a complete absence of quartz whenever rubies are present. The excess of SiO_2 first combines to Al-Silicates before corundum is formed. The occurrences which are described in detail are the rubies of Azov in the USSR in the east of the Crimean peninsular, those in Froland, Norway, near Arendal, south Norway, rubies found in Alipur, Mysore, India, and those in the Hida metamorphic belt in Japan. There is a comparison of mineral analyses of ruby carrying gneises and a short note on the petrology of gneises. E.S.

KAMMERLING, R.C., KOIVULA, J.I., KANE, R.E., 1990. Examination of an interesting cultured blister pearl. *Australian Gemmologist*, **17**, 5, 174-5, 5 figs in colour.

Report on a blister pearl in a fresh-water shell depicting the goddess Kwan Yin. Most such inserted images are metal but this one was transparent to X-rays and was probably of moulded plastic with similar X-ray characeristics to those of the shell. R.K.M.

KANE, R.E., KAMMERLING, R.C., MOLDES, R., KOIVULA, J.I., MCCLURE, S.F., SMITH, C.P., 1989. Emerald and gold treasure of the Spanish galleon Nuestra Senora de Atocha. *Gems and Gemology*, **25**, 4, 196-206, 12 figs in colour.

Bullion, coins, gold and emerald treasure has been found near the wrecks of galleons sunk between Cuba and Florida almost 350 years ago. Some of the gold and emerald jewellery from the Atocha was examined by the GIA Gem Trade Laboratory. Most emeralds had lightly frosted surfaces, presumably etched by long exposure to sea-water. Gold work had been cast in almost pure gold; chains made from drawn wire; missing beads in a rosary chain thought to have been wood which disintegrated in water. Some items had probably been decorated with enamel or with niello. Emeralds probably Colombian. Craftsmanship described as superb, mainly produced by a lost wax process; in the soft gold, setting and engraving were exceptionally skilled. R.K.M.

KOIVULA, J.I., KAMMERLING, R.C., 1989. Gem news. *Gems and Gemology*, **25**, 4, 244-51, 13 figs in colour.

Diamonds

An earlier statement that glass filler could not be completely removed from diamond was shown to be wrong. Australian and Canadian companies are jointly exploring for diamonds at Pilbara, W Australia, about 650 miles from the Argyle project. Diamond output in Botswana is to be increased. Ghana may privatize mines. Diamond cutting in Mauritius is to expand. Diamonds are being mined from the sea on two concessions on west coast of South Africa.

Coloured stones

Myanmar (Burma) gold mines have contracted for Yugo Slav technology. Adularescent violet-blue chalcedony found in Mojave desert. A rare star chrysoberyl from Sri Lanka is illustrated. Psilomelane and basalt were among black gem materials seen. Quench crackled green-dyed quartz sold as 'green amethyst' without mention of dyeing. A 40kg double terminated sapphire crystal found at Rakwana, Sri Lanka, had gemmy bluuuuuue arreas and others which might heat to blue. Sapphires have been found in Burundi. Gold, sapphire and ruby mines are re-opening in Vietnam, following the withdrawal of troops from Cambodia. Laos and Cambodia are calling for similar investment arrangements with the Thais. Drought followed by severe flooding has hit gem production in Sri Lanka, terrorism adds to the problems. Small poor quality emeralds have been found in SE Sri Lanka, colour of one crystal seen was very dark. A new find of attractive green zircons, and an exceptionally fine hessonite are also reported from the island. Paraiba, Brazil, green to blue tourmalines show strong absorption centres at 700nm possibly due to copper. A high cabochon green tourmaline had a thin blue base which changed the colour of the stone to blue when lit vertically from below.

Synthetics and simulants

George Bosshart of Switzerland alerts trade to 'water-worn crystals' of ruby and sapphire bought in Sri Lanka, which proved to be flame fusion synthetics shaped to long barrel habit with lateral stepped striations and other convincing features cut onto the 'prism' faces; striations were not parallel, and optic axes were 30° out of line; curved colour banding and fluorescence confirmed synthesis. A 'hydrothermal' red synthetic spinel from Russia was found to be flux-grown; irregular flux inclusions were seen but a stone cut to exclude these would be virtually identical to a natural stone. A new man-made 'garnet' from Switzerland, called oolongite, is made in colourless, blue, bluish-green and lilac shades: RI 1.93 to 2.00, SG 6.7 to 7.0, H 7.5 to 8. Chemical composition is not quoted. R.K.M.

LINTON, T., BROWN, G., 1990. A dark-field illuminator for gemmological microscopes. *Australian Gemmologist*, **17**, 5, 171, 3 figs.

A Japanese accessory which is given full marks for ease of installation and use, but some parts reflect confusingly. R.K.M.

MCAUGHTRIE, G., 1990. A preliminary assessment of the gem identification system (GIS) software. *Australian Gemmologist*, **17**, 5, 172-3.

System was found to have low success rate due to lack of flexibility in constants and other testing factors. So far these computorised systems do not seem to compete very well with normal gemmological methods. R.K.M.

MALONE, F.J., HANCOCK, D.A., JEFFRIES, B., 1988. The Western Australian pearling industry. *Australian Gemmologist*, **17**, 5, 184-92, 1 map.

Abstracts from the report of the Pearling Industry Review Committee, Fisheries Management paper No. 17. Fisheries Department of Western Australia. Reviews and reports on pearl-shell industry and more particularly on recent growth of the cultured pearl industry around Broome and the neighbouring coast of W. Australia. Future would seem to be tied in with production in Indonesia and the Philippines. The industry seems to be largely Japanese dominated. R.K.M.

MARTIN, F., MERIGOUX, H., ZECCHINI, P., 1989. Reflectance infrared spectroscopy in gemology. *Gems and Gemology*, **25**, 4, 226-31, 6 figs in colour.

A non-destructive laboratory test which identifies gem minerals with comforting certainty; even distinguishing between some natural stones and their synthetic counterparts. Only Type II diamond will not respond because it is transparent to the infrared wavelengths used. Use of reflectance rather than transmission makes the test far simpler. Some 64 infrared spectra are illustrated in bar-graph form, an unfamiliar representation of a spectrum region which is unknown to most gemmologists. The reflecting unit is illustrated but a more detailed explanation would help the ordinary gemmologist to understand the test better. [The full apparatus is costly.] R.K.M.

MITCHELL, R.K., 1990. A letter. *Australian Gemmologist*, **17**, 5, 208.

An attempt to put right confusion between 'profilated' (Webster) and 'proliferated' (Brown). when describing extended bubbles in some synthetic spinels. The attempt is foiled by a characteristic printer's error which turns my quote of Grahame Brown's 'proliferated' into 'profilerated', an even greater abomination. The correct expression for such bubbles is surely 'profiled', although the new word 'profilated was coined by Anderson long before Webster copied it in his book *Gems*.

(Author's abstract) R.K.M.

NASSAU, K., LEWAND, E.A., 1989. Mildly radioactive rhinestones and synthetic spinel and glass triplets. *Gems and Gemology*, **25**, 4, 232-5, 2 figs in colour.

Certain greenish-yellow peridot-like pastes and synthetic spinel and glass triplets were found to be slightly radio-active due to the use of uranium glass, but are thought to present no health hazard. Authors express wonder that this glass is still used since the colour can be obtained by other means.

R.K.M.

PHILLIPS, G., BROWN, G., 1990. Mtorolite. *Australian Gemmologist*, **17**, 5, 205-7, 3 figs in colour.

This is the natural chrome-coloured chalcedony which so closely resembles the chrome-*stained* product which imitates natural chrysoprase so badly that one wonders whether there can be a market for the natural product. The sharper one band spectrum at 680nm differs from the vague three band effect seen in some of the stained material. R.K.M.

ROBERT, D., 1990. Emeraldolite. *Australian Gemmologist*, **17**, 5, 196.

A short report on a new coated beryl made by depositing a thin layor of flux-grown emerald crystals onto a colourless natural beryl 'seed'. SG is that of natural beryl and RI low, as for flux emerald. Used as scintillating green rough or as cut, carved or polished specimens in a variety of forms. R.K.M.

SCHWARZ, D., 1990. New aspects of the emerald workings in Colombia. *Australian Gemmologist*, **17**, 5, 168-70, 1 map.

Deposits were exploited by Muzo and Chibcha Indians long before arrival of the Spanish Conquistadores, and highly regarded by Incas, Mayas and Aztec cultures. Mining was always open-cast, more recently with modern machines moving enormous masses of overburden are creating serious environmental problems. Now Coxeminas and Tecminas are tunnelling to emerald bearing calcite which is then extracted with greater care by hand methods. Other mines are expected to follow. Guerilla activity interferes with production and several mines are inactive. New mine at Yacopi, south of Muzo, is producing quantities of pale, clear emerald. Drift (tunnel) mines are displacing thousands of 'guaqueros' who formerly fossicked among tailings and rubble for missed emeralds. Vast social problems are expected, especially with the association with drug traffic. Most emerald is smuggled out of the country despite government control of mines.

R.K.M.

SEGNIT, E.R., 1990. The XXII International Gemmological Conference. *Australian Gemmologist*, **17**, 5, 193-5.

A report on the conference held at Lake Como and visiting various other Italian centres, as seen by Australian representatives. R.K.M.

Book reviews

BENNETT, D., MASCETTI, D., 1989. *Understanding jewellery*. Antique Collectors' Club. pp.386. Illus. in black-and-white and in colour. £29.95.

Unlike other jewellery books this one starts with a substantial section of some 40 pages on gem identification. This includes descriptions of all the gemstones likely to be encountered in commercial jewellery, followed by very helpful sub-sections on the various materials used to simulate each gemstone. There are 36 colour plates in the section, largely of inclusions in gems from the excellent Gübelin/Koivula *Photoatlas of Inclusions in Gemstones*, but also including good pictures of gems in jewellery and typical cuts for diamonds. This preliminary section should serve as a precautionary warning to those in the antique trade who imagine that the identification of gemstones is straightforward and without pitfalls.

The principal chapters of the book begin with the jewellery of the period 'From the late 18th century to the 1820s' with following chapters describing the jewellery of the succeeding 20 year periods up to '1920-1940'. The last chapter is entitled 'The 1920s and the Post-war years'. The outstanding feature of these chapters is the provision of over f1565 excellent colour photographs of a very considerable range of jewellery (including tiaras, parures, earrings, necklaces, brooches, pendants, bracelets and rings) selected from the vast library of Sotheby's auction operations. The designers have been very successful in marrying text with illustration – usually on the same page spread.

The reasons for the development of the various styles of jewellery are examined in some detail and include the influence of wars, revolutions, patronage, politics, economics and the development of new technologies – all of which influence fashion and, of course, jewellery. The book concludes with a reasonable bibliography and a very useful guide to approximate values of all the items illustrated at the start of 1990. This is a fascinating book, beautifully illustrated and marketed at a very economical price when one considers the cost of colour printing. Thumbing through the pages is, at once, informative, aesthetically pleasing and, for some of us, nostalgic. E.A.J.

KELLER, PETER C., 1990. *Gemstones and their origins*. Van Nostrand Reinhold, New York, USA. pp. 144. Illus. in black-and-white and in colour. US$49.95.

This is a volume that many geologists/gemmologists might wish they had written; it has been needed for years. It is a superbly illustrated book and at first sight it might appear to be yet another gemmological 'coffee table' production; it is far more than that. The principal photographers are the well-known Van Pelts of Los Angeles and two eminent gemmologists, Dr E. Gübelin and Peter Keller himself; both are doubly qualified to combine artistic excellence with geological competence. The photographs and the text are well married by the easily understandable narrative style. The gemstone occurrences are described under four principal modes of origin with typical examples of each category being dealt with in some detail. The groups are:

(1) gemstones deposited by water on the Earth's surface – the gem gravels of Sri Lanka and the opals of Australia;

(2) gemstones of igneous or hydrothermal origin – the emeralds of Colombia, the gem pegmatites of Minas Gerais, Brazil, and the ruby deposits of Chantaburi/Trat, Thailand;

(3) gems formed by very high temperatures and pressures – the ruby deposits of Mogok, Burma, and the jadeites of Tawmaw, Burma; (4) gemstones formed at great depths – the Zabgargad peridot deposits in the Red Sea and the Argyle diamonds of Australia.

The text is not just pure geology (which is, however, treated in very understandable terms with excellent diagrams) but also includes history, mining techniques, concession rights and, most spectacularly, a series of Van Pelt photographs illustrating famous gems both set in jewellery and as stunning crystals with their associated matrix minerals. Field and mining processing photographs are contributed by Edward Gübelin (many of localities no longer accessible), by Keither Proctor who knows the Brazilian deposits so well and, of course, the author himself who has visited so many 'difficult of access' gem occurrences around the world. This is not a dry academic textbook; its easy style will help the reader to understand the processes of natural gem formation and should assist in distinguishing natural stones from their synthetic counterparts. The clear accounts of the selected deposits are followed

by excellent bibliographies for the interested reader, whether amateur or professional, to follow up the whetted appetite. This book is beautifully produced and this reflects the painstaking care with which it has been researched, written and illustrated. For a quality product the price is reasonable and it is recommended reading for all gemmological aficionados, since it is probably the first of its kind in the English language. E.A.J.

MERCER, I.F., 1990. *Crystals*. British Museum (Natural History), London. pp. 59. Illus. in colour. £4.95.

Forming one of a series of popular earth science guides (the other titles are *Gemstones*, *Agates* and *Britain's offshore oil and gas*), this is a beautifully-produced and very well written introduction to the world of crystals. Frequent references are made to the occurrence of crystals in everyday life (in the freezer and fur in kettles) as well as to the basic rules of crystal symmetry and a lucid introduction to the way in which crystals grow. M.O'D.

O'DONOGHUE, M., 1990. *The pocket guide to rocks and minerals*. Dragon's World. pp.224. Illus. in colour. £6.95.

This is a small (19 x 13cm) spirally-bound book, printed in Singapore, with very good (if small) colour illustrations of rocks and minerals. It is presumably aimed at the amateur collector, but could interest a wider readership. The book starts with a brief explanation of the nature of rocks with some good photographs which actually look like rocks in the hand in contrast with many other texts. The general introduction on minerals, including classification, crystal morphology and properties, growth of crystals, crystals and light, collecting, conservation and cleaning, takes up some 50 pages. These sections are generally well presented and understandable to the beginner, but the reviewer takes issue with the author when he gives details (albeit with warnings!) on the use of hydrofluoric acid and sodium cyanide for cleaning specimens. These are highly dangerous chemicals in inexperienced hands.

The mineral descriptions, comprising some 150 pages, are generally good and the illustrations excellent – some could well be photographs of micromounts. Some of the species included in the descriptions are very rare and it seems doubtful if most amateurs will ever encounter them. There are, of course, a number of minor errors, including the allocation of dolomite to the pyroxene group on page 107, but these should not be allowed to detract from the overall pleasant presentation.

This book has a cheaply produced, but probably robust, binding and the photographs and general appearance are good. It will be a very good introduction for the beginner and a first reference book for the more advanced amateur. It is cheap enough to be purchased by interested but impecunious young people. E.A.J.

ROBERTS, W.L., CAMPBELL, T.J., RAPP, G.R., 1990. *Encyclopedia of minerals*. 2nd edition. Van Nostrand Reinhold, New York. pp. xxiii, 979. Illus. in black-and-white and in colour. £75.00.

The previous edition of the *Encyclopedia* in the mid-1970s was a brave and successful attempt to provide mineralogists with a comprehensive mineral encyclopedia whose entries gave brief but vital details of all minerals known at the time. It also gave a most valuable 'best reference in English' and contained a section of beautiful colour pictures of micromounts (diamond in particular). The new edition has been fortunate to have Wnedell Wilson as its Photo Editor and 400 new species have been added with 1000 entirely new entries. The total number of species described is 3200 and though the book is expensive serious mineralogists will need to have it on their desks along with Fleischer's *Glossary of mineral species*, Deer, Howie and Zussman's *Rock-forming minerals* and the Natural History Museum's *Chemical index of minerals* – the present book, by its topicallity, helps to remedy the long wait for a new edition of the latter. To replace the pictures of micromounts this edition has a centre section of megnificent colour photographs, many the work of Wendell Wilson. Mineral pictures seem to get better year by year and it is hard to imagine there being much room for improvement!

One of the values of this book to the mineralogist, apart from its comprehensiveness, is the noting of species belonging to groups, whose significance is increasingly appreciated with the developing links between mineralogy and chemistry. M.O'D.

WILSON, W.E. (ED.), 1990. *Goldschmidt's world mineral locality index*. Mineralogical Record, Tucson. pp. 44. US$12.00.

Victor Goldschmidt's *Atlas der Krystallformen* (1913-1923) will probably be familiar only to academic gemmologists. The nine volumes of text are accompanied by nine volumes of crystal drawings which Goldschmidt took from every possible printed source. Until now it has not been possible to access the 23,606 drawings by locality but this simply-produced book enables this to be done. This is a very high achievement indeed and most welcome to anyone working on old localities. M.O'D.

Proceedings of the Gemmological Association of Great Britain and Association Notices

OBITUARIES

Robert Arend

This account of Robert Arend, a Dutchman who emigrated to Toronto, Canada in 1956, was delayed first by an advising letter from Mr Paul Leonard of Coburg, Ontario, which was sent to an office I had left more than ten years before and had to be returned to be readdressed care of the Association, and then by a lack of biographical information which has taken several months to fill.

Bob Arend was a correspondence course student of mine in 1959, taking his Diploma with Distinction in the following year. I obtained an impression that he was an intelligent and ambitious young man with great determination to succeed, one who believed implicitly in his own abilities. This was confirmed when he came to see me some years later in my Holborn office.

Back in Toronto Arend continued his gemmological interests, eventually taking over D.S.M. Field's classes at George Brown College, and going on to serve as President of the Canadian Gemmological Association. Details are not available, but he evidently ran a successful business of his own in down-town Toronto.

But despite preoccupation with the gem trade, there is no doubt at all that Arend's real enthusiasm was for flying, and he was known to side-track from gemmology to talk about this greater interest. A fully qualified commercial pilot, he excelled in aerobatics and in 1975 became Canadian Advanced Champion in that type of flying. Among other exploits he had raced from London, England, to Victoria, British Colombia, in a light plane, and had toured America and Canada in aerobatic displays. An island hopping trip to Venezuela and back gave him the idea for what was to prove to be his last flight.

His childhood hero was Colonel Charles Lindberg, and Arend planned to emulate the latter's solo flight in 1927 from New York to Paris. With that object in mind he spent several years planning and adapting a 17 year old fabric covered single engined plane for the attempt. Navigation aids, radios and extra fuel tanks were fitted and the engine largely rebuilt. Meanwhile he was talking of extending the trip to a circumnavigation of the world in 36 days. For some reason he elected to start the venture from Victoria B.C., with the idea that the 30 hour flight to St John's, Newfoundland, would serve as a test run for the Atlantic crossing. Unfortunately the heavily laiden plane failed to make it across the Rockies and crashed in flames on 24 June 1989 near the town of Hope, less than one hundred miles from its starting point.

Robert Arend was 56 and leaves a widow and two sons. His epic flight was to have been made in aid of the Canadian Cancer Society and other charities.

The writer very deeply regrets that this story has to be an obituary and not an account of great triumph. A brave and remarkable man, an excellent gemmologist, who perhaps had too much faith in his ability to achieve. Not many of us go out quite so spectacularly. R. Keith Mitchell

Speranza Cavenago Bignami Moneta

It is with regret that we record the death of the celebrated Italian gemmologist Senora Cavenago Bignami. Born in Milan in 1902, she moved with her family in 1927 to Brazil where she spent four years involved in singing and piano playing and began her gemmological studies at the University of Sao Paolo. In 1931, on her return to Italy, she opened the first Italian gemmological laboratory at a Milan pawnbrokers and continued to manage it until 1948. During this period she initiated studies into the testing of pearls using X-rays and investigated many other problems. In 1948 the publishers Hoepli commissioned her to write a 'gemmology manual' which was published in 1959 as *Gemmologia*. It became a classic and encyclopedic work developing into three massive volumes and is now in its fourth edition.

In 1952 she began lecturing and demonstrating in Valenza and these activities developed into the establishment of the Public Precious Stone and Pearl Control Department. The Milan Chamber of Commerce opened its testing laboratory in 1966

and Cavenago Bignami directed both laboratories until 1973. She has a strong combative spirit and was always enthusiastic and endowed with exceptional communication skills and power of oratory.

* * *

Mr Roy Lucas, FGA (D.1930), Hadley Wood, Barnet, died on 19 May 1990.

Mr Donald F. Rossiter, FGA (D.1948), Jersey, Channel Islands, died on 9 April 1989.

Mr E. Trillwood, OBE, FGA (D.1929 with Distinction), Rickmansworth, died on 15 April 1990.

MEMBERS' MEETINGS

London

On 2 May 1990 at the Flett Theatre, Geological Museum, Exhibition Road, London SW7, Mr Peter Read FGA gave an illustrated lecture entitled 'An update on gem instruments'. Following the lecture, Peter Read, assisted by Dr Jamie Nelson and Mr Roy Huddlestone, displayed and demonstrated a number of the instruments.

Midlands Branch

On 16 March 1990 at the Society of Friends, Dr Johnson House, Colmore Circus, Birmingham, Mr Jim Porter gave an illustrated talk on his trip earlier in the year, to Thailand and the Chanthaburi mines. On 20 April 1990 at the Society of Friends, the Annual General Meeting was held at which Mr David Larcher, FBHI, FGA, was elected Chairman and Mr John R. Bugg, FGA, re-elected Secretary. The AGM was followed by a talk by Carol Gibbs who recounted her years as a trader in the Gilbert Islands, with a particular interest in tortoiseshell.

North West Branch

On 16 May 1990 at Church House, Hanover Street, Liverpool, Mr Peter Read gave a lecture on the Presidium Duotester.

EXECUTIVE MEETING

At a meeting of the Executive Committee held on 10 May 1990 at Saint Dunstan's House, Carey Lane, London EC2V 8AB, the business transacted included the election to membership of the following:

Fellowship

De Crecenzio, Alejandro, Amsterdam, The Netherlands. D.1989
Hapugaskumbura, Asanga W.W., Kandy, Sri Lanka. D.1989
Karkkulainen, Kari J., Oulu, Finland. D.1989
Onozawa, Katsumi, Tokyo, Japan. D.1979
Phillips, Jean M., The Peak, Hong Kong. D.1982
Schat, Ellen M., Schoonhoven, The Netherlands. D.1989
Shigeoka, Mayumi, Tokyo, Japan. D.1989
Turner, Susan E., Hong Kong. D.1989

Ordinary Membership

Bedwell, Victoria L., London.
Bensimon, Colette, London.
Bhonsle, Uday S., Gloucester.
Brown-Greaves, Rosemary L., Horsham.
Chin Chao, Dick, Taipei, Taiwan.
Collins, Stephanie, New Malden.
Costa, Georgia M., London.
De Goutiere, Anthony, Victoria BC, Canada.
Desai, Suryakant C., Nairobi, Kenya.
Eggleston, Avrina, London.
Gademsetty, Subba Rao, Chigwell.
Georgiou, Stavros, London.
Gordon, Mark I., London.
Harmsen, Harmanus P.D., Brenhelen, The Netherlands.
Henry, John M., Bolton.
Katz, Edwin S., Houston, Tex., USA.
Kyriakidis, Dimitrios K., Hamburg, W. Germany.
Lee, Tom L., Grand Rapids, Mich., USA.
Lees, John A., Waterford, Va, USA.
Liden, Ulf, Lycksele, Sweden.
Liontos, Theodoros, Chania, Crete.
Li-Ran, Dorit, Nairobi, Kenya.
Michel, Isabelle, Los Angeles, Calif., USA.
Mildenhall, Caroline, Brighton.
Mistry, Dharmesh, London.
Mitchell, Beverly J., London.
Montonati, Cristina, Portalbera, Italy.
O'Shea, Anthony L., Ruislip.
Park, Myoung O., Seoul, Korea.
Paskou, Thomas, Waukesha, Wis., USA.
Rothewicz, Jack, Bogota, Colombia.
Semenov, Steven, London, Ont., Canada.
Share, Stella, Harrow Weald.
Shearman, Jean D., Happy Valley, Hong Kong.
Smith, Michael H., Edinburgh.
Spencer, Riitta M., Horsham.
Stanuell III, Stewart, Houston, Tex., USA.
Stassinopoylos, Elias, London.
Sundin, Stig E., Hylkje, Norway.
Walker, Averil L., London.
Webster, Robin G.S., Macclesfield.
Wilkinson, Cleotilde S., Farnham Common.
Zaidi, Masud, London.

AUSTRIAN GEMMOLOGICAL RESEARCH INSTITUTE

On 17 April 1990 the Austrian Institute (EÖGG) moved to new premises. The address is now Schwedenplatz 2/33c, A-1010, Vienna, Austria. Telephone (222) 535 6246 or (222) 533 5823. Fax (222) 535 6245.

THE JOURNAL OF GEMMOLOGY BACK ISSUES

A member of the Association has various back issues of the *Journal* for sale, dating from 1948. Enquiries to Mary Burland at the Gemmological Association of Great Britain, 27 Greville Street, London EC1N 8SU.

Letter to the Editor

From Dr W.D. Ian Rolfe
Keeper of Geology, National Museums of Scotland

Dear Sir,

EXPORT OF NATURAL HERITAGE SPECIMENS

The recent near-loss from this country of an outstandingly important fossil, the earliest known reptile, has clarified the position regarding the export of such material. Natural science material, and in particular geological specimens, are not covered by the Export of Goods (Control) Order 1989, and therefore all such material, no matter how significant, is free for sale abroad. This is markedly at variance with the position regarding the man-made heritage, where export controls have long been in force for outstanding artefacts.

Prompted by this current issue, the Reviewing Committee on the Export of Works of Art has been asked by the Minister for the Arts to consider this problem and to make recommendations. It is anticipated that such outstanding natural heritage items would only rarely come before any such body for consideration, say perhaps once every ten years. It would help us considerably in presenting our case to the Committee to have case histories of previous losses of such specimens, or brief accounts of material saved from such loss, to inform the Committee's deliberations. Would anyone knowing of any such cases therefore please send brief details to any of the following: Dr W.D. Ian Rolfe, Keeper of Geology, National Museums of Scotland, Chambers Street, Edinburgh EH1 1JF; Dr L.R.M. Cocks, Keeper of Palaeontology, Natural History Museum, Cromwell Road, London SW7 5BD; Dr Paul Henderson, Keeper of Mineralogy, Natural History Museum, Cromwell Road, London SW7 5BD.

Yours etc.,
W.D. Ian Rolfe

4 June 1990
National Museums of Scotland, Chambers Street, Edinburgh EH1 1JF.

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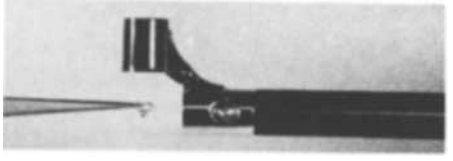

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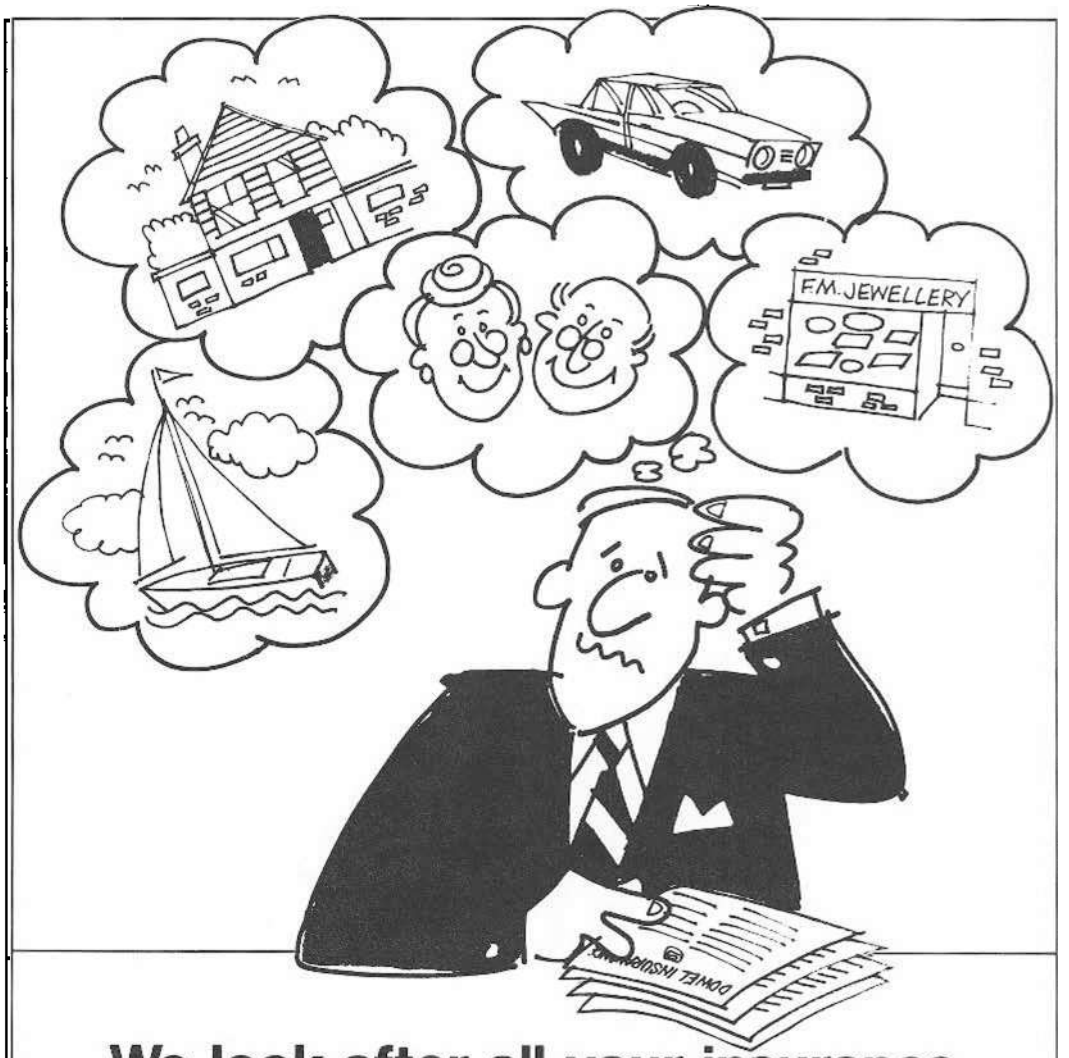

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Historical Note

The Gemmological Association of Great Britain was originally founded in 1908 as the Education Committee of the National Association of Goldsmiths and reconstituted in 1931 as the Gemmological Association. Its name was extended to Gemmological Association of Great Britain in 1938, and finally in 1944 it was incorporated in that name under the Companies Acts as a company limited by guarantee (registered in England, no. 433063).

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The Editors are glad to consider original articles shedding new light on subjects of gemmological interest for publication in the *Journal*. Articles are not normally accepted which have already been published elsewhere in English, and an article is accepted only on the understanding that (1) full information as to any previous publication (whether in English or another language) has been given, (2) it is not under consideration for publication elsewhere and (3) it will not be published elsewhere without the consent of the Editors.

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Twenty five copies of individual papers are provided on request free of charge; additional copies may be supplied, but they must be ordered at first proof stage or earlier.

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Cover Picture

A series of necklaces fashioned from a variety of gem materials.
Identification will be provided in the January issue.
(See 'Bead buyers and parcel pickers filter set', page 212)

The merger

Many members will be aware that the Gemmological Association has merged with the Gem Testing Laboratory of Great Britain. This merger was recommended by the Council of the GA at a meeting on 25 June 1990 and was agreed by attending members and proxy voters at an Extraordinary General Meeting held on 4 September 1990. Other members may wonder about the reasons for this merger and therefore we set out below the background events leading up to this decision.

The Gemmological Association can trace its history back to 6 July 1908 when it was proposed at the Annual Conference of the National Association of Goldsmiths that teaching courses and examinations in gemmology be launched. The first Gemmology Diplomas were awarded by the NAG in 1913. In October 1931 the GA was formally inaugurated as a NAG branch. In 1938 the Association's title was changed to the Gemmological Association of Great Britain, and in April 1947 it was incorporated as an independent Company.

Throughout its history the GA has operated from the NAG premises with its administration being carried out by NAG staff. This arrangement has become increasingly difficult as both Associations have developed along different lines and last year the NAG intimated to our Association that the joint administration would come to an end on 31 December 1990. It was decided therefore that it would be most convenient for our Association, as well as its subsidiary Gemmological Instruments Ltd., to move to new premises at 27 Greville Street, London, on 30 June 1990.

When, last year, the separation from the NAG became a probability the Officers of the Association had to consider its future – the primary concern being the continuity of its operations. However, it was also necessary to explore ways by which the Association could expand and prosper in the future. It was considered that a close association with the Gem Testing Laboratory of Great Britain could be beneficial. The Gem Testing Laboratory is the world's oldest such laboratory, founded in 1925 with Basil Anderson as Director. It has become a world leader in commercial gem testing and diamond grading, as well as in gemmological research.

When considering the history of our Association and the difficulties encountered over several years with its relationship with the NAG we became extremely anxious that our Association should not re-create these problems by entering into some sort of partnership with another independent organization. It was felt, therefore, that we should investigate the possibility of a complete merger with the Laboratory. A series of meetings followed where the proposal was discussed at length. These culminated in the signing of an agreement between the Laboratory and the GA on 6 August 1990. This agreement was ratified at the Extraordinary General Meeting on 4 September 1990.

Professional advice was given to the effect that the most efficient way to effect the merger would be for the GA to transfer its assets to the Laboratory. At the same time the Laboratory would change its name to 'The Gemmological Association and Gem Testing Laboratory of Great Britain' and admit the Association members to the relevant class of membership. GA and Laboratory members would all have one vote at all General Meetings of the merged company. The Laboratory has also altered its Memoranda of Association to include the Educational Aims of the Association and its Articles of Association to include provision for a Members' Council.

The actual day-to-day management of the new company is under the control of a Council of Management which consists initially of the Chief Executive (Ken Scarratt), the Director of Gemmology (Roger Harding), supported by six non-executive directors. These would all have to be elected (if they wished to stand) at the first Annual General Meeting of the merged company. At each Annual General Meeting thereafter a third would retire by rotation, but could stand for re-election.

The Members' Council is envisaged rather along the lines of a Board of Trustees. It cannot interfere in the day-to-day management of the Company, but will be empowered to enquire into all operations, and, if it considers it necessary, to take its recommendations directly to the Members by calling an Extraordinary General Meeting of the Company. The Members' Council has been appointed initially from the current Council of the Association and the Committee of the Laboratory. All will retire at the second Annual General Meeting of the merged company, but may stand for re-election. At each Annual General Meeting thereafter a third will retire by rotation, but may stand for re-election. The members of the Council of Management are not, of course, eligible to serve on the Members' Council.

We have also been advised that it would be prudent to keep the Gemmological Association of Great Britain in existence and the mechanisms to achieve this were included in the resolutions passed at the recent Extraordinary General Meeting.

To summarize, the Gemmological Association and the Gem Testing Laboratory have amalgamated to form a single organization with a common administration. The educational aims of the GA will be expanded and the Laboratory services will be widened.

Gemstone prospects in Central Nigeria

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Abstract

The localities and geological setting of recent gemstone mining activities in central Nigeria are briefly described. Aquamarine and topaz occur in areas generally related to the edges of Younger Granite bodies. Tourmalines are associated with pegmatites of the Older Granite bodies. Sapphires and zircons have been extracted from eluvial deposits on weathered alkali basalts. The gem-quality zircons range from red to colourless and chemical analyses are reported of stones covering this range.

Introduction

Around 1980 the first information about new gemstone discoveries in Central Nigeria reached the outside world and by the middle of the eighties Nigeria had become an important producer of aquamarine, topaz, tourmaline and sapphire. A few articles about Nigerian gemstones were published between 1982 and 1987 (see references), but these deal mainly with their microscopic and physical properties.

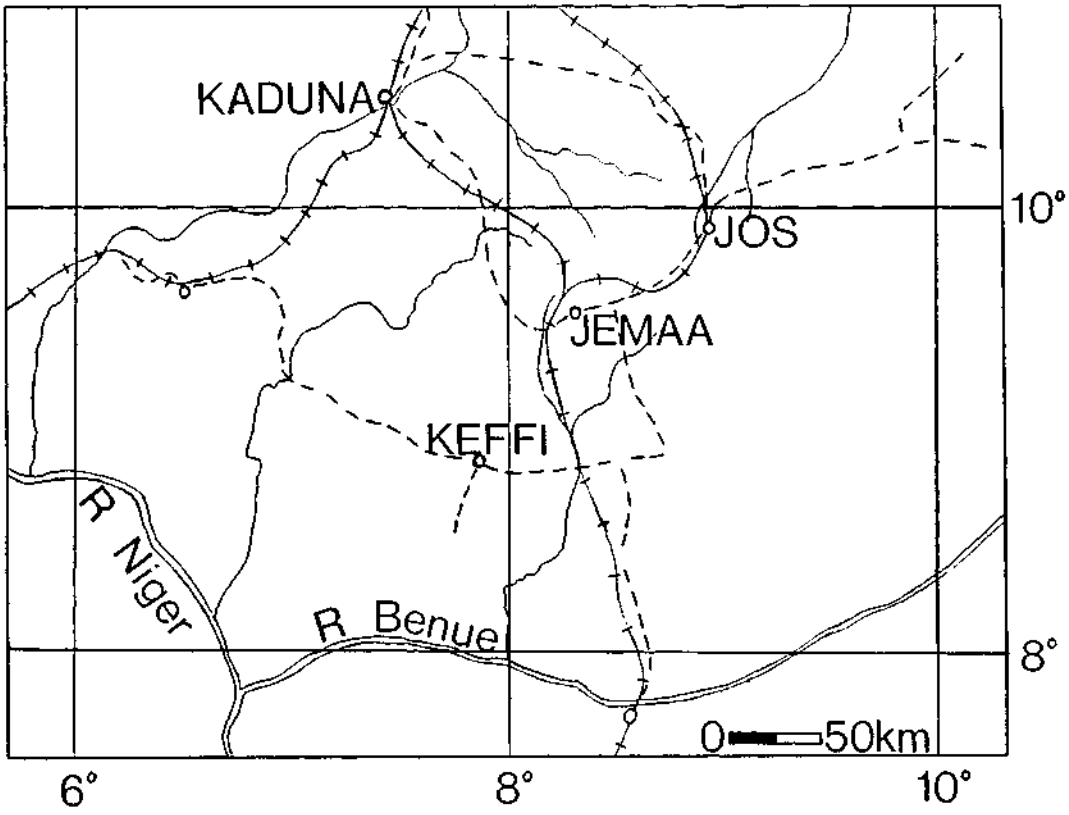

Fig. 1. Sketch map of part of Plateau and Kaduna States, Nigeria; location of places mentioned in the text.

† *Present address:* Gemmological Association and Gem Testing Laboratory of Great Britain, 27 Greville Street, London EC1N 8SU.

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Most of these gemstones have been taken out of the country illegally and very little is known to date about production figures, or about the location and paragenesis of these gem deposits.

Recently one of us (J.K.) made a few short journeys to the central Nigerian Plateau- and Kaduna States (Figure 1), where all the newly discovered gemstone deposits occur.

Previous cassiterite mining

Since the turn of the century the central Nigerian district of Jos, in Plateau State, has been well known for the production of cassiterite (see Jacobson and Webb, 1946, and Geological Survey of Nigeria, 1988). It is interesting to note that the tin production from pegmatites, associated with some of the Older Granites, never amounted to more than 2% of total production. On the other hand, according to MacLeod, Turner and Wright (1971), cassiterite of economic interest can invariably be correlated here with Younger biotite-Granites and the richest tin mineralization is in those granites which have undergone a higher degree of late albitization. The cassiterite has occurred in a multitude of narrow greisen veins and quartz stringers in the roof zones of the biotite-granite intrusions, and has been retained within the parent rock beneath an impermeable cover of roof rocks.

This kind of cover favoured a lateral dispersion of the mineralization of cassiterite in these plutons. The cooling and consolidation must have been rather rapid and the opportunity for the separation and concentration of the ore fluids greatly reduced. Hence, the almost total absence of payable lodes and pegmatitic formations.

Therefore, the richest concentration of cassiterite, both alluvial and primary, can always be correlated with recently 'unroofed' and superficially eroded intrusions of biotite-granite.

Although cassiterite is not a gemstone, the tin paragenesis is mentioned here because the aquamarine and topaz occurrences, described below, probably have a similar origin.

Fig. 2. Pits dug in eluvial deposits of aquamarine, in 'unroofed' zone of Younger Granite pluton; Rafin Gabas Hills.

Aquamarine of the 'Rafin Gabas Hills' District

Approximately 34 air km SSE of the town of Keffi, in the most western part of Plateau State, are the 'Rafin Gabas Hills', which form part of a mountainous Younger Granite complex of Upper-Cretaceous age (Figure 2). Gem-quality beryl in greenish and yellowish colours and aquamarines in blue to very deep blue shades have come from this district during the last eight years (Bank 1984a, 1986, Lind, Schmetzer & Bank 1986).

The occurrence of industrial beryl, together with tin and columbite, in the Younger Granites of North

Nigeria has been described by Taylor (1959) who reports that these primary deposits are located in quartz veins, stockworks and greisens, within or near the granite contacts.

In the 'Rafin Gabas Hills' district, the aquamarine crystals, white to pale blue topaz and smoky quartz crystals occur in narrow stringers and thin layers, which form a stockwork over an extensive area, mainly in the 'roof' zones of the granite hills. The granites consist mainly of quartz, albite and orthoclase with less than 5% mica (siderophyllite) and accessory minerals. The latter include serpentine, hematite, zircon, cassiterite, columbite, thorite and oxides containing thorium, uranium, lead and rare-earth elements.

In other parts of Plateau State the aquamarine, topaz and smoky quartz crystals occur in fissures, joints and shear zones at the edges of granite bodies (Figure 3). Such channels enabled solutions to be transported through the granite to the outer zones of the plutons, where they cooled rapidly forming disseminated deposits of beryl/topaz and other rare minerals. We also observe syngenetic miariolitic and schlieren beryl occurrences here, which, according to Sinkankas, 1981, pp339,342, typically contain beautiful euhedral crystals, and this explains why so many well-formed aquamarines and topaz crystals have been found in the eluvial deposits.

During the middle of the eighties it was relatively easy to collect the eluvial, colluvial and alluvial aquamarine and topaz crystals on or near the surface, but the production has recently dropped dramatically, since this material is found only sporadically now.

Unless new areas of eluvial and alluvial deposits of aquamarine and topaz are discovered in this inhospitable mountainous region of Plateau State, Nigerian aquamarines might soon be a thing of the past. However, similar occurrences might well be discovered in other districts as the Younger Granite plutons are widespread throughout central Nigeria. Failing this, new gemstones will have to come from hard rock mining, but the irregular pattern and distribution of aquamarine- and topaz-bearing veinlets in a hard granite, in many situations makes mining of these gemstones by blasting uneconomic.

Fig. 3. Prospectors follow narrow stockwork veins in Younger Granite with pegmatites in search of aquamarine and topaz.

Rarely, aquamarines of an outstanding deep blue colour are found (Bank, 1986), and recently an aquamarine nodule, in which a clear gemmy core is surrounded by a flawed margin, has been reported by Kampf and Francis (1989).

Tourmaline pegmatites SE of Keffi

The first article on the Nigerian tourmaline pegmatites appeared in 1984 (Bank, 1984c), but their location was at that time unknown to us. Now

Fig. 4. Tourmaline-bearing pegmatite SE of Keffi.

we know that these fine tourmalines have come from a granitic pegmatite belt, approximately 12 air km SE of Keffi and NW of Takwa Hill. The geological setting of these pegmatites is as follows: the major plate tectonic event of Pan African age took place 600 ± 150 million years ago and led to widespread re-activation of the internal region of Nigeria with the emplacement of large volumes of granites, called Older Granites. The Pan African belt evolved as a consquence of collision between the passive margin of the W. African Craton or stable shield area, and the active margin of a continent to the East. The Older Granites intruded both the Precambrian migmatite-gneiss complex and the schist belts and are themselves traversed by numerous pegmatites, many of which are albitized. These pegmatites are concentrated around the Older Granites and related to them.

The tourmaline bearing pegmatites SE of Keffi (Figure 4) consist mainly of orthoclase feldspar, partly albitized, relatively little quartz, biotite and muscovite. Lepidolite and albite, in the form of cleavelandite are commonly associated. The border zones, in contact with adjacent gneiss, are well defined with an abundance of small muscovite 'books'. A few beryl crystals occur in the border zones and although blue in colour, these crystals are always opaque and of no gem value.

One of us (J.K.) visited seven tourmaline-bearing pegmatites and according to the local miners, another thirteen pegmatites in this belt are known to contain tourmalines. The visited pegmatites vary in width from 3 to 5 m, dip very steeply and appear to have a length of 400 m or more. Workings have been erratic and shallow, never more than to a depth of 6 m, probably due to lack of capital and proper mining equipment. Lately, tourmaline production has virtually halted in this district. However, the little mining done so far, has certainly established the potential of gem quality tourmalines in many colours throughout this pegmatite belt. Over the years these pegmatites have yielded tourmalines of gem quality from finest green to bottle green, red tourmaline in many shades and various fancy colours in yellow, rose and even violet. In addition water-melon tourmalines and gem-quality tourmaline nodules have been found here.

Sapphires and zircons of the Jemaa District

In the southwestern corner of Kaduna State and approximately 50 air km SW of Jos is the village of Jemaa.

The first sapphires were discovered here in 1968 by a tin mining company, but the company ceased operations after a few months. Most of the sapphires found were too dark to market at that time and the commercial heat-treatment of sapphires was still unknown. Sapphires reported to be from this area appeared in 1974. Production seems to have increased considerably from 1984 onwards (Figure 5), although no statistics are available as practically all sapphires have been smuggled out of Nigeria by Senegalese and Mali traders (Figure 6).

Geologically the Jemaa sapphires are related to basalts and the occurrence appears to be identical to the sapphire deposits of New South Wales in Australia and those in Thailand and Kampuchea. The Newer Basalts in central Nigeria were erupted after the Plateau had achieved its present-day topography and certain lava flows in the Jemaa and Gimi river area can be followed over a distance of some 20 km. Some of the basalts are now largely decomposed.

The Jemaa alkali basalt is dark grey porphyritic and amygdaloidal. The amygdales are commonly filled with carbonate, largely siderite in composition with bands of manganoan siderite which has grown inward from the walls. The phenocrysts of olivine and feldspar are euhedral, subhedral, rounded or embayed. Irregularly-shaped pyroxene grains occur in the groundmass of the basalt and analyses indicate that it is a clinopyroxene of salite composi-

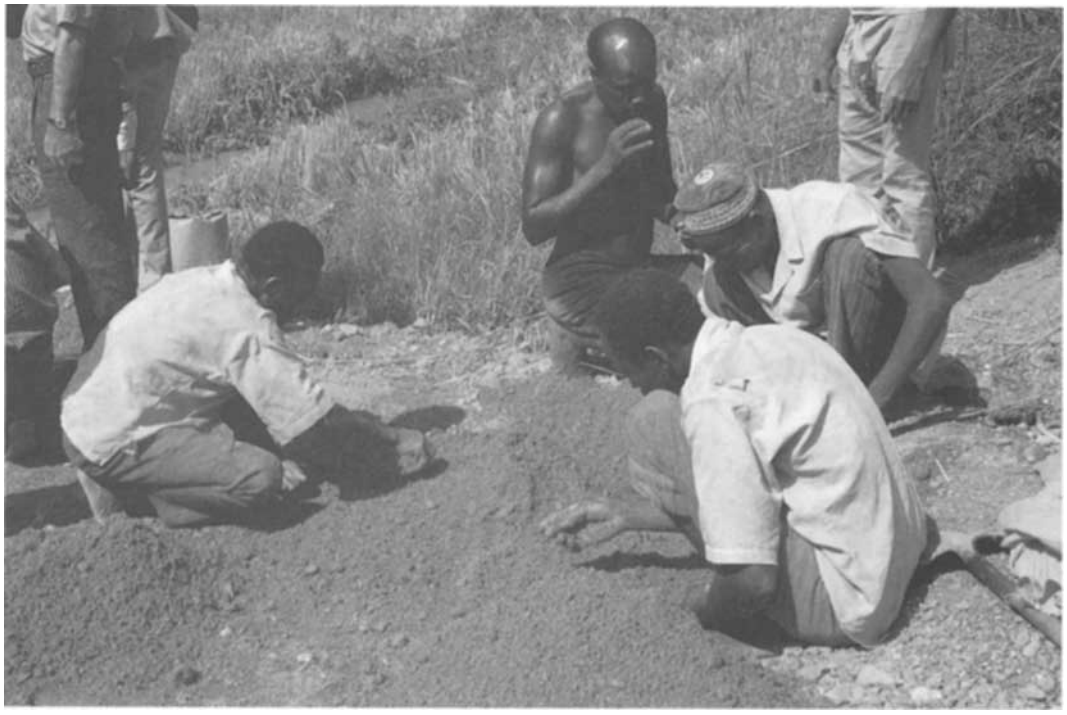

Fig. 5. Washed concentrate being sorted for sapphire and zircon, near Jemaa.

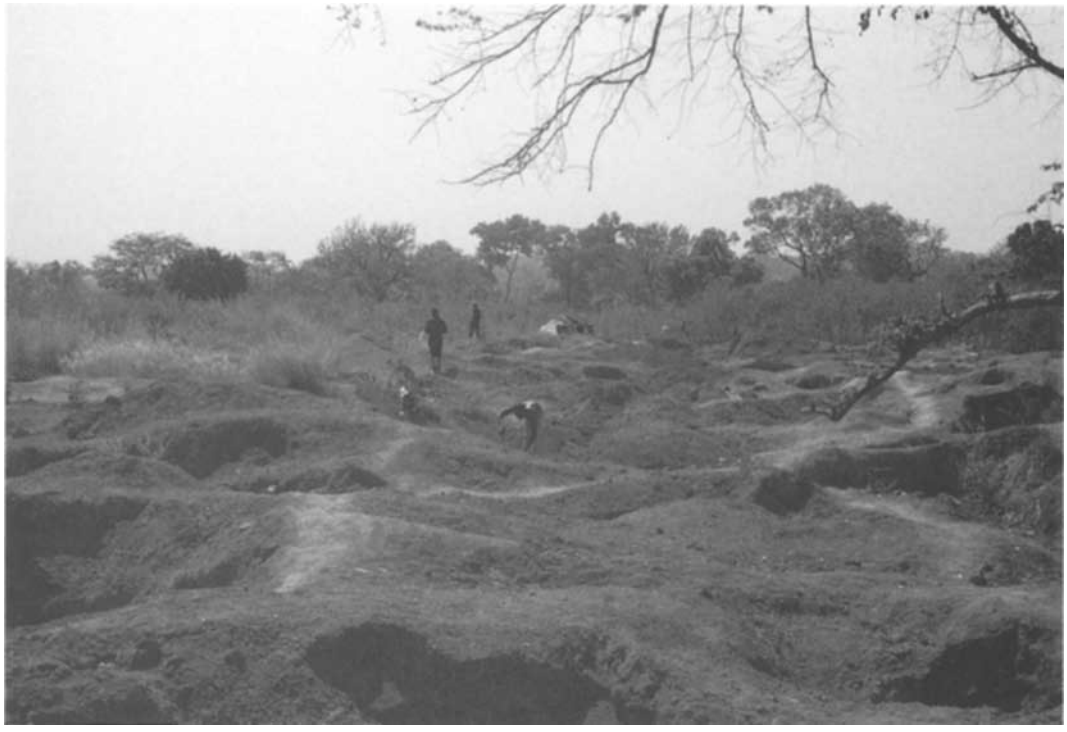

Fig. 6. Illegal sapphire diggings in decomposed alkali basalt flows near Jemaa.

Fig. 7. Zircon crystals from decomposed alkali basalts near Jemaa, showing range of colour and degree of rounding. The largest crystal in the picture is 19 mm long.

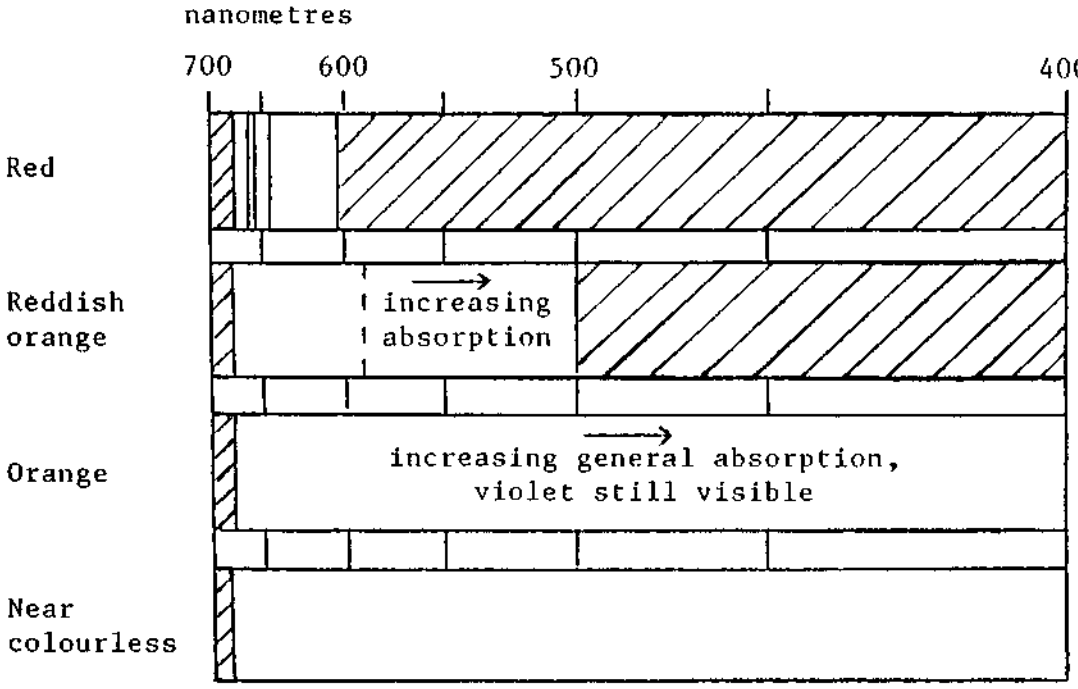

Fig. 8. Sketches of absorption spectra in four zircons showing a colour range from red to colourless.

tion. The chemical data determined for the olivines, pyroxenes and ilmenite are all consistent with those described in the literature for alkali basalts or their ultramafic nodules.

The sapphire and zircon zenocrysts embedded in the basalt flows have dull, slightly corroded surfaces and rounded edges. They were probably derived from a deep crustal rock that was invaded and shattered by upward-moving basaltic magma (Scarratt, Harding and Din, 1986).

The physical, spectroscopic and microscopic properties of the Nigerian sapphires are described by Kiefert and Schmetzer (1987), and Henn (1986) describes idiomorphic apatite crystals, rounded zircon crystals, 2-phase and other inclusions.

Most Nigerian sapphires have a distinct colour zoning and show a flat prismatic habit. Although most sapphires range in colours from dark blue to fine blue, green, yellow and bi-colour sapphires also occur here.

The average crystal diameter of these gemstones, recovered by very simple washing methods, is probably near 0.75 cm, but greater quantities of smaller crystals could be recovered with more sophisticated mining methods.

The same basalt lava flows also contain zircon crystals as slightly rounded euhedral prisms, some up to 2 cm in diameter. They range from transparent to opaque, in different colours from deep red to orange and almost colourless. A large percentage of the zircons is of gem quality (Figure 7).

Four samples showing the range in colour were selected for chemical analysis and to determine whether colour is related simply to composition. Sketches of their absorption spectra are given in Figure 8, and the analyses are given in Table 1.

The results indicate that red zircon (Table 1, col. 1) has a minor element content significantly different from those of the orange and near-colourless zircons. It contains more Ca, Nb, Sc, Th, U, Y and REE than the other stones, but less Mn and Ti. The analysis of the reddish orange zircon in column 2 is not significantly different from that of the orange stone in column 3 and the visible gradation in colour intensity is not paralleled by the values of the minor elements determined. The cause of the red or orange colours therefore remains unresolved.

The analyses indicate that the zircons contain a variety of minor and trace elements, and there may be a correlation between depth of colour and one or more of these elements. But assigning the colour variation to one particular element or group of elements would require analysis by electron spin resonance or nuclear magnetic resonance techniques.

Table 1. Analyses of zircons from Nigeria

Wt%	1	2	3	4
SiO_2	33.2	32.4	31.8	32.1
ZrO_2	65.3	65.6	65.3	66.5
HfO_2	1.23	0.91	0.85	0.64
Al_2O_3	0.02	0.08	0.09	0.01
Fe_2O_3	0.12	0.83	0.37	0.08
CaO	0.30	0.01	0.01	0.01
Total	100.17	99.83	98.42	99.34
ppm				
As	<5	<5	<5	<5
Co	<35	<35	<35	<35
Cr	<35	<35	<35	<35
Cs	<1.5	<1	<1	<1
Cu	<25	<25	<25	<25
Mn	11	38	27	16
Nb	469	22	19	18
Ni	<10	<10	<10	<10
Rb	<40	<20	<20	<20
Sb	<1	0.4	0.4	<0.3
Sc	83	19.9	14.7	7.1
Ta	7.1	1.6	1.6	0.9
Th	448	71	55	40
Ti	148	240	374	134
U	436	62	56	38
V	<10	<10	<10	<10
Y	1035	404	270	219
REE				
La	<5	<5	<5	<5
Ce	<20	<15	<15	<15
Nd	<25	<20	<20	<20
Sm	1.84	0.64	0.83	0.98
Eu	1.34	0.52	0.70	0.75
Gd	<25	<25	<25	<25
Tb	5.7	1.31	2.58	2.14
Tm	39.6	15.5	17.3	12.5
Yb	360	119	130	95
Lu	63.8	16.0	19.1	13.5

Notes: determination of Si, Zr, Al, Fe, Ca, Co, Cr, Cu, Mn, Nb, Ni, Ti, V, Y, and Yb were made by ICP (inductively coupled plasma) emission spectrometry. Sample solutions were prepared by:

(a) fusion of ca 40mg with Na_2CO_3/Na_2O_2, in nickel crucibles, dissolution in HCl (200 ml) for SiO_2 and ZrO_2;

(b) fusion of ca 100mg with KHF_2, in platinum crucibles, dissolution in H_2SO_4 (50 ml) for all but SiO_2 and ZrO_2.

Determinations of Hf, As, Cs, Rb, Sb, Sc, Ta, Th, U and REE except Yb were made by INAA (induced neutron activation analysis)

1. Red zircon, lab. no. 8698
2. Orange zircon, lab. no. 8699
3. Orange zircon, lab. no. 8700
4. Near-colourless zircon, lab. no. 8701

Conclusion

Central Nigeria might well have more gemmological surprises in store for us. Indications of an emerald deposit have already been mentioned by Bank (1984b), and pegmatites with rare blue gem-quality gahnite in the Jemaa area have been reported by Jackson (1982). Furthermore, Nigeria has supplied large quantities of white topaz used for irradiation purposes during the last decade (see Schmetzer, 1987).

Acknowledgements

We would like to thank V.K. Din who carried out ICP analyses of the zircons, and Dr C.T. Williams who performed the INAA analysis for certain trace elements in these crystals.

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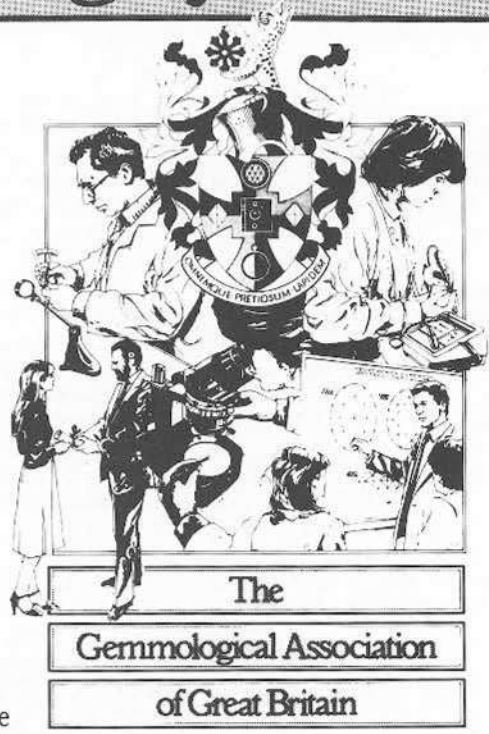

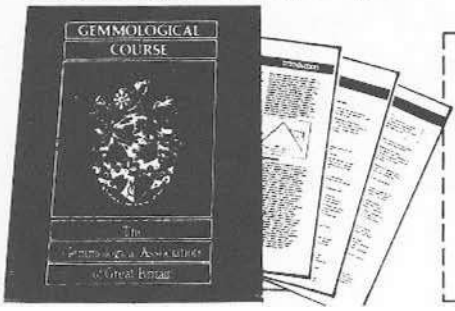

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Hematite inclusions in Eonyang amethyst from Korea

Prof. Dr Won-Sa Kim, FGA

Department of Geology, Chungnam National University, Daejon 305-764, Rep. of Korea

Abstract

Eonyang amethyst is the highest gem grade material produced by Korea thus far. It often contains solid inclusions which occur as aciculae which may be terminated at one end by a small thin and elongate patch, dendrites, and angular plates. These inclusions, up to 3 mm in length and oriented nearly parallel to the developed growth lines, have been identified as hematite by reflected light microscopy, scanning electron microscopy and X-ray diffraction analysis.

Introduction

Korea's best gem-quality amethyst has been produced from geodes which have developed within the fine-grained mass of Eonyang granitic body. The granite is found near the town of Eonyang, located in the southern part of Korea peninsula. Annual production of approximately 10 kg of gem-quality material, produced from the Jeil Amethyst Mine, has been far below domestic demand necessitating the importation of large amounts of rough material, principally from Brazil. After the imported Brazilian amethyst is faceted, some is sold on the domestic market as 'Eonyang (or Korean) amethyst'. A resemblance between the Eonyang and Brazilian amethysts sometimes makes distinguishing between the two difficult. In general, Eonyang amethyst displays a deep purple colour with a red tint, the red tint being absent in the Brazilian material. However, a more reliable indicator is the presence of solid and, occasionally, fluid inclusions, which are characteristics of the Eonyang amethyst. As such, these solid inclusions were analysed using transmitted and reflected light microscopy and scanning electron microscopy, which were supplemented by X-ray diffraction.

Investigation

The solid inclusions, which are frequently observed in Eonyang amethyst, may be acicular (Figure 1), dendritic (Figure 2) or angular (Figure 3). The aciculae are often terminated at one end with a small elongate patch (Figure 4). The inclusions attain a maximum size of 3 mm, and may be visible to the naked eye. In most cases they occur parallel to growth lines in the amethyst, which is often marked by distinct colour zonation.

For further examination, approximately 200 amethyst crystals were cut into thin slices and

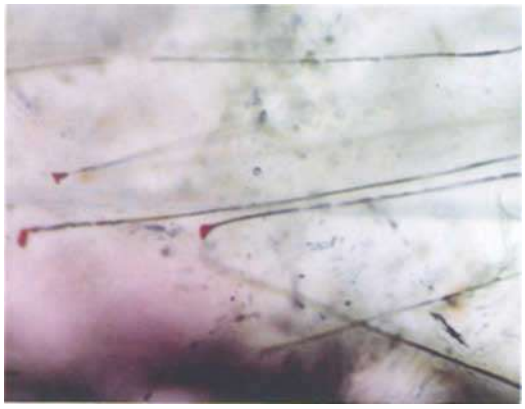

Fig. 1. Hematite aciculae oriented nearly parallel to the growth lines developed in Eonyang amethyst from Korea. Transmitted light. 100X.

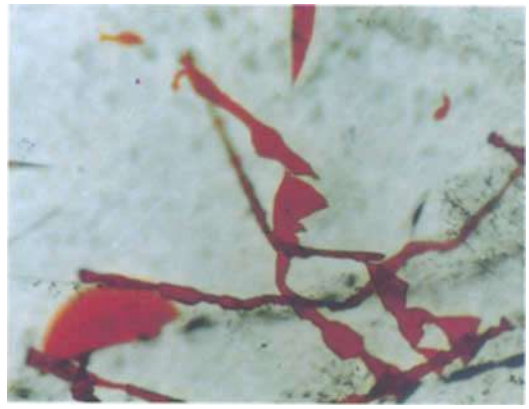

Fig. 2. Dendritic hematite crystals in Eonyang amethyst from Korea. Transmitted light. 100X.

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Fig. 3. Anhedral fragment of hematite in Eonyang amethyst from Korea. Growth planes intersecting at 120° are seen. Transmitted light. 200X.

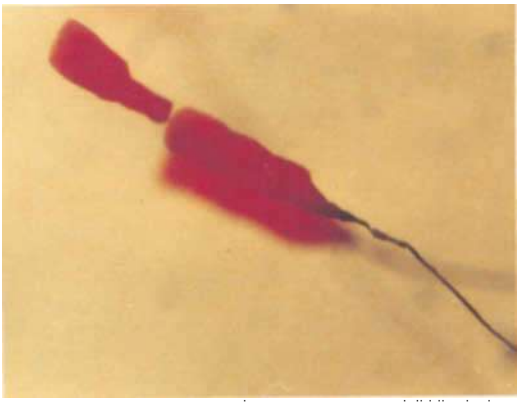

Fig. 4. Opaque hematite acicula attached to translucent (red) hematite patch in Eonyang amethyst from Korea. Transmitted light. 400X.

doubly polished. Under a polarizing microscope, the acicular crystals were observed to be opaque for the most part, while crystals of differing habits were translucent, showing various shades of red. In reflected light, the inclusions exposed at the polished surface are greyish-white with a bluish tint, and show a distinct pleochroism and a strong anisotropism. Vickers micro-indentation hardness tests give VHN_{100} = 974-1039, in good agreement with the value of 1038 reported by Craig and Vaughan (1981) for hematite.

Qualitative energy-dispersive X-ray analysis (Figure 5) carried out with the aid of a scanning

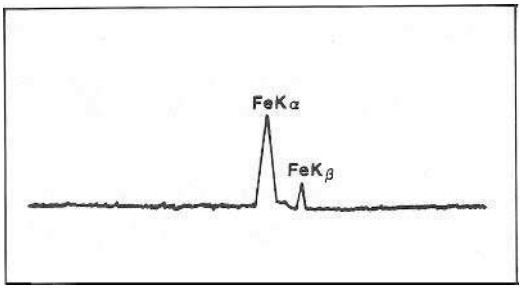

Fig. 5. Energy-dispersive spectrum of hematite inclusion in Eonyang amethyst from Korea.

Table 1. X-ray powder diffraction data of Eonyang amethyst containing hematite inclusion.

			1		2	
h	k	l	d_o(Å)	I/I_o	d_o(Å)	I/I_o
1	0	0	4.26	35	4.26	33
0	1	2	3.66*	2(30)		
1	0	1	3.342	100	3.341	100
1	0	4	2.690*	10(100)	2.686*	8(100)
1	1	0	2.519*	7(70)	2.511*	5(70)
1	1	0	2.459	17	2.460	15
1	0	2	2.282	17	2.280	15
1	1	1	2.238	5	2.237	5
2	0	0	2.125	10	2.128	10
2	0	1	1.980	6	1.976	6
0	2	4	1.838*	4(40)	1.839*	1(40)
1	1	2	1.816	15	1.816	15
1	1	6	1.689*	11(45)	1.690*	1(45)
2	0	2	1.672	10	1.672	10
2	1	1	1.541	15	1.543	13
1	1	3	1.453	4	1.455	4
2	1	2	1.384	8	1.381	8
2	0	3	1.375	5	1.376	15
1	0	4	1.282	10	1.288	3
3	0	2	1.253	2	1.256	2
2	2	0	1.226	4	1.228	4
2	1	4	1.198	4	1.199	3
1	1	4	1.183	4	1.183	3

1, Amethyst with red hematite patches. 2, Amethyst with opaque hematite aciculae. * represents X-ray line belonging to hematite and numbers in parentheses indicate intensities of hematite (JCPDS Card No. 33-664). CuKα radiation, 114.6 mm Gandolfi camera used.

electron microscope, reveals that Fe is the major element of the inclusions. X-ray diffraction analyses were also attempted on the opaque and translucent reddish crystals. Amethyst fragments, relatively rich in inclusions, were selected, and immersed in an HF solution for many hours to dissolve the enveloping amethyst. The undissolved material was then ground in an agate mortar. X-ray powder diffraction patterns of the undissolved amethyst and solid inclusion mixtures were obtained using a 114.6 mm Gandolfi camera with Ni-filtered CuKα radiation and 2 hour exposures. The X-ray powder data for the opaque and translucent inclusions (Table 1), after removal of reflections belonging to amethyst, agree well with X-ray data reported for hematite (JCPDS card No. 33-664). All the analytical data obtained in this study confirm the identity of the solid inclusions as hematite.

Acknowledgements

I thank Prof. G. Y. Chao of Carleton University, Ottawa, for the X-ray diffraction analyses, and Mr Y. K. Koh, president of Jeil Amethyst Mine of Korea for access to the mine and the donation of amethyst samples. Thanks are also extended to Ms H. S. Shin for her assistance in the laboratory. Financial support was given by the Korea Science and Engineering Foundation.

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Gemmological visual aids

John Eadie, BSc, ARCST, FGA

Barmulloch College, Glasgow

Abstract

Three visual aids are described suitable for use in the classroom situation.

Introduction

While the main armoury of a teacher is blackboard and chalk, three-dimensional models can often enlighten a physical concept, or help in interpreting special configurations particularly as in the science of crystallography.

Description

Visual Aid (1) [Axes of Symmetry, Figures 1 and 2]

Pop rivets were inserted into a 10cm edge white pine softwood cube at the face centre, the centre edge and the corners of the cube. The cube was supported on a mild steel stand having a lower fixed jaw and an adjustable upper jaw. The jaws consisted of ⅛ inch diameter mild steel round stock and pointed at the ends to allow the cube free rotation within the pop rivets. Three colours were used to paint the cube so that each pair of parallel faces were

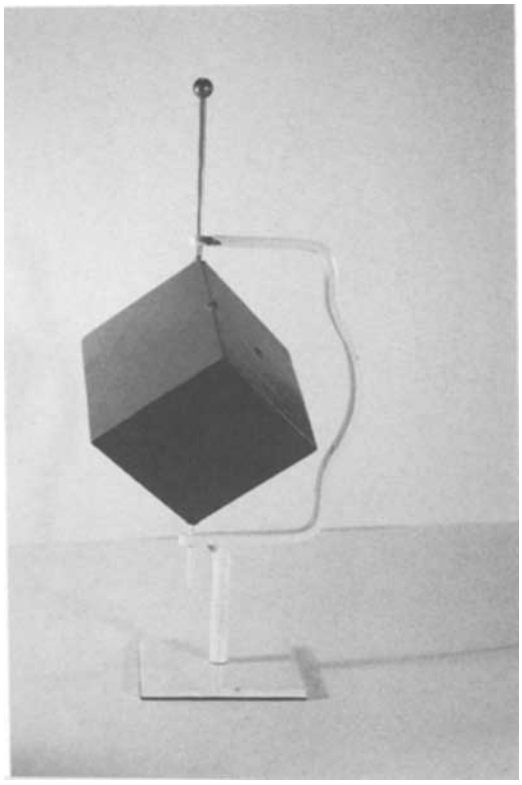

Fig. 1. Model of cube – triad axis.

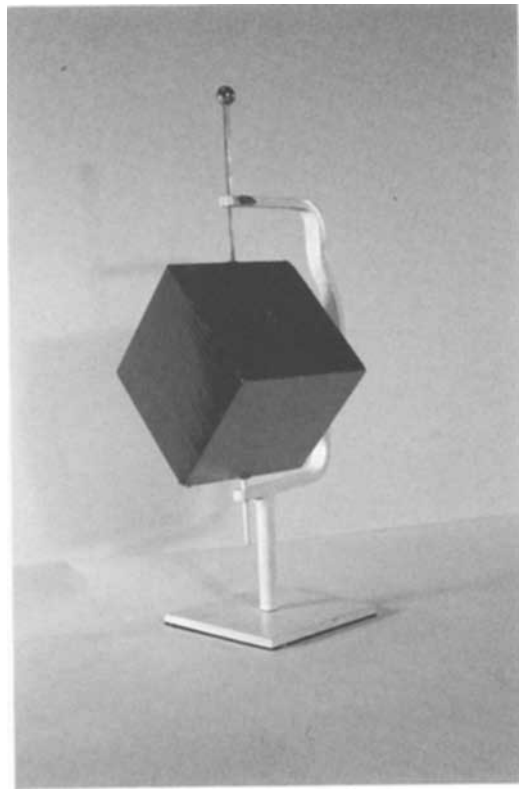

Fig. 2. Model of cube – diad axis.

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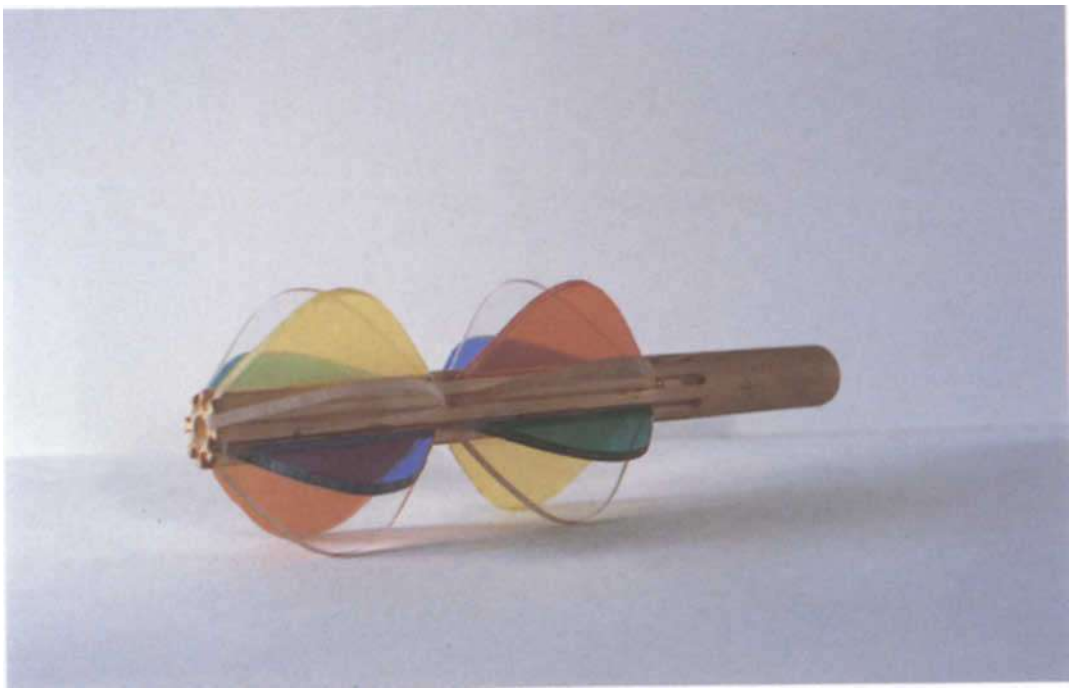

Fig. 5. Model showing the nature of ordinary light – fixed wavelength.

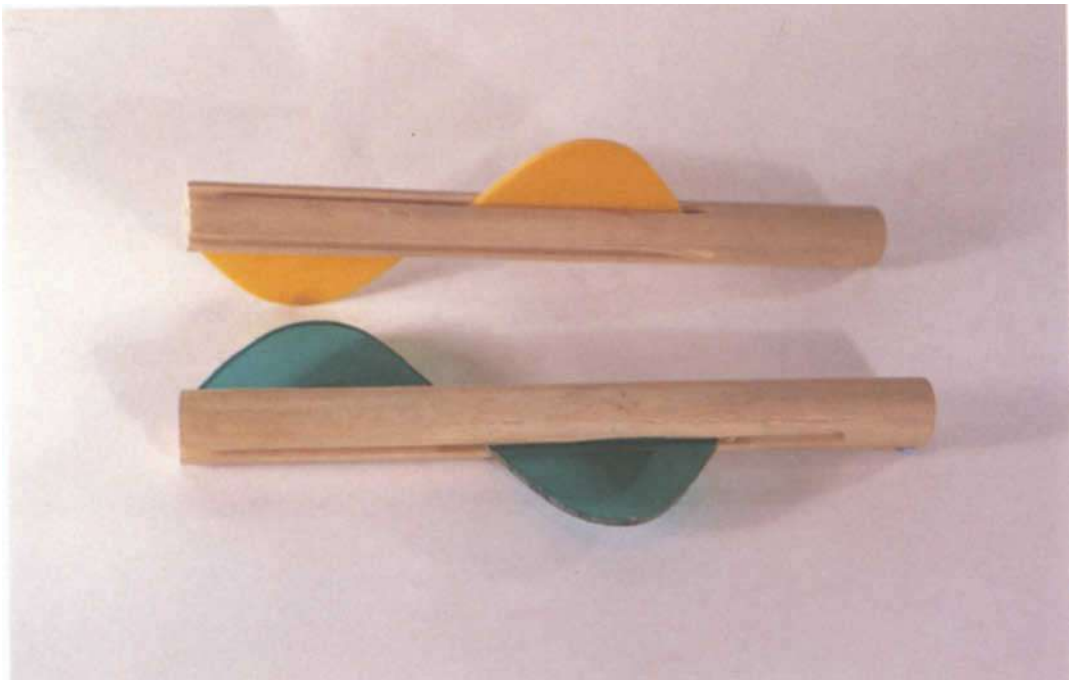

Fig. 6. Model showing the nature of plane polarized light rays.

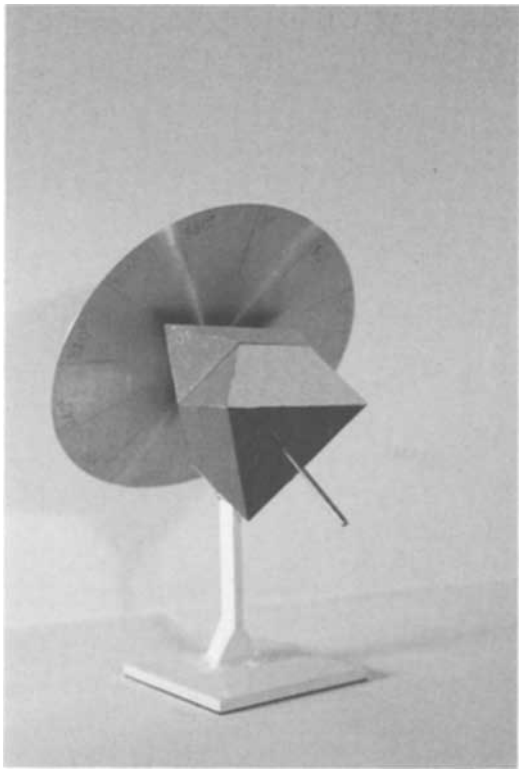

Fig. 3. Model of macle 180° rotation – symmetrical twin.

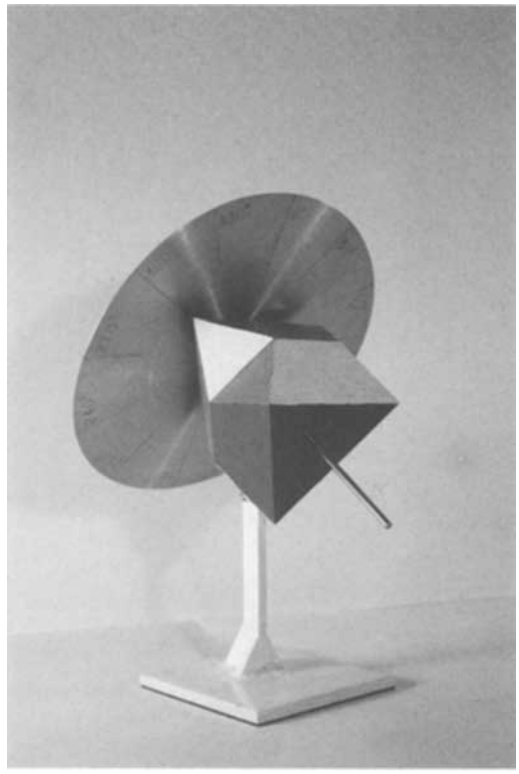

Fig. 4. Model of macle showing 300° rotation.

of the same colour. The model may serve either for demonstrations or by allowing students to explore, they can readily discover that the cube has 13 axes of symmetry – 3 tetrad, 4 triad and 6 diad. The stand can be employed for other crystal systems.

Visual Aid (2) [Spinel Twin or Macle, Figures 3 and 4]

If a regular octahedron was made and then cut along the twin plane, the two resultant parts would not be identical due to the kerf of material removed by cutting along a sloping face.

Hence two identical halves were made separately by milling the required shape from a block of nylon and fitting the two halves together to produce an octahedron of 10cm edge. The twin axis consisted of ⅛ inch diameter mild steel round stock inserted through the centroid of two opposite parallel faces with the twin axis at right angles to each of the faces. The lower half of the octahedron was fixed by machine screws to the stand's pillar while the upper half was free to rotate. To measure the angle of clockwise rotation of the upper half, an 8 inch diameter brass protractor plate provided with a collar and thumb screw locked the collar on to the twin axis. The octahedron was finally painted with 4 colours, each single colour corresponding to a pair of parallel faces. Congruency of the two halves is found by rotating the upper half of the octahedron about the twin triad axis through an angle of 60°, 180° or 300°. However it is only for a 180° rotation that each half is a mirror image about the twin plane ie a 180° rotation is equivalent to reflection across the twin plane resulting in a symmetrical twin.

Visual Aid (3) [Light, Plane Polarized Light, Figures 5 and 6]

Light wave vibrations at right angles to the direction of propagation of a single light ray of constant wavelength has been represented by a 1 inch diameter wooden dowel rod, slotted along its length so as to accommodate several ⅛ inch-thick perspex sheets. The perspex is shaped as a sinusoidal wave and arranged radially around the rod. Polarized light is represented in a similar manner by a single sinusoidal wave.

Unlike the previous two visual aids which may be regarded as 'real models', the latter represents a simplified conceptual model.

[*Manuscript received 7 June 1990.*]

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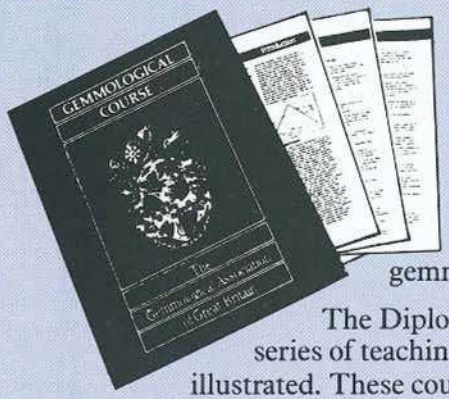

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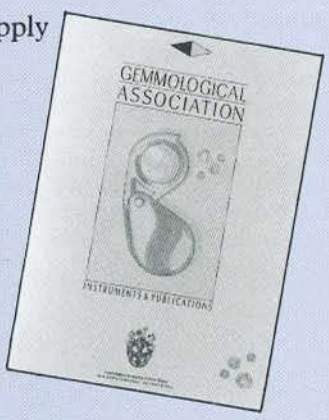

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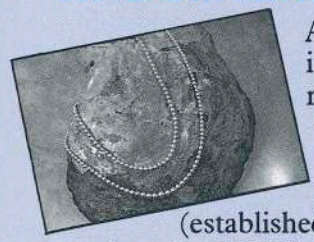

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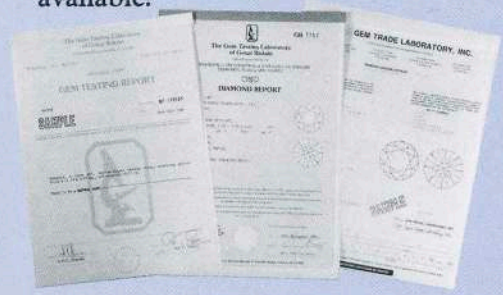

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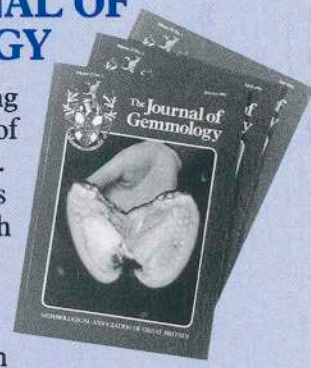

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Bead buyers and parcel pickers filter set

R. Keith Mitchell, FGA

Orpington, England

Hanneman Gemological Instruments of California have compiled a set of four colour filters under this rather quaint name. The stated principle behind these as a set is that a necklace or parcel of stones of one kind will all appear to be identical when viewed through one of these four filters. It is not made clear whether this applies to all the filters, or that this effect is to be expected with at least one out of the four. It is said to hold true regardless of the type of light used and of the sight of the observer, etc. Any stone which appears different should be examined more carefully to ascertain the reason for that difference. It is suggested that the use of the filters serves to eliminate variations in perceived colour between individual observers. Dr Jamie Nelson has passed one of these sets to me for an independent assessment.

By and large this use can be substantiated to some extent with two of the filters, but I feel that the proviso should be made that the necklace or parcel in question should be all one colour in the first place. For example my wife has a tourmaline necklace which has yellow, pink, green, blue and purple-red beads, and this appears similarly mixed through each of the four Hanneman filters despite being quite definitely all tourmaline. A box of mixed colours of zircon failed in the same way. One expected this, but the instructions accompanying the set should be specific on this point. There is always the occasional person who is dim-witted enough to accept the printed word without question, and I have seen more than one gemmological error arise from crass stupidity. Testing matched parcels I found that the effect seen could vary rather drastically with depth of actual stone colour.

Two of the filters have registered names, the *Aqua-Filter* and the *Ruby Filter*, although such a straight descriptive term as the latter can hardly claim legal protection with much hope of preventing others from using it. This is rather like trying to register the name 'Shoe-Polish' or 'Strawberry Jam'. These two filters are said to be particularly useful under strong incandescent light to 'characterise' [identify?] blue and red stones respectively.

The Aqua-Filter

This is very similar to our *Chelsea Filter* and appears to be identical with an American one offered in Australia as the Discrimagem Filter. Both pass rather wider bands of green and deep red wavelengths than the Chelsea, plus a narrow region in the orange. The Hanneman filter is a pinkish-grey colour as against the more sombre greenish-grey of the Chelsea. Hanneman describes the filtered colour of aquamarine through this one as 'green', but in my eyes it is rather more blue, but the point is that the filter strengthens the natural blue-green of aquamarine just as the Chelsea filter does. A number of aquamarine coloured pastes and doublets gave a filtered colour almost identical with several of the aquamarines tested. Light blue spinel is claimed to be 'pinkish', but this refers to the synthetic material coloured by cobalt, and the instructions should make this clear. Again the Chelsea Filter gives the same result. It may be noted here that the extremely fine and rare 'cobalt' blue natural spinel gives a superb wine-red through either filter. Normal natural dark blue spinels gave a nondescript dark grey through the filters.

The effect with light blue topaz is described as 'blue-grey' but I think this could possibly be confused with the filtered colour of paler aquamarines. Pale blue and medium blue sapphires give a rather nondescript grey through either filter. Tanzanite loses its violet-blue and acquires a pinkish cast. Blue zircon gives a filtered blue-green which differs from that of aquamarine. I was unable to see the flashes of red which are mentioned in the instructions.

All of these effects are seen almost identically through the Chelsea Filter. In view of this similarity I tried the Hanneman version to authenticate emerald, although this use is not claimed in the instructions. It works for emeralds of good colour but gives a distinct green when poorish stones of

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South African origin are examined. Poor coloured stones from the ancient Austrian mines at Habachtal gave a similar filtered green. This is because of the wider band transmision of green wavelengths. The Chelsea filter does not do this and is therefore the safer one for emeralds although, as pointed out below, it still needs to be used with care.

The Ruby Filter

This appears to be a standard tri-colour green, and has the rather startling effect of making rubies appear 'bright blue'. I would quarrel with the description 'bright' and would describe the effect seen when Burma rubies are viewed, as a sapphire-like blue with a hint of violet, while Thai rubies give a deeper violet blue. Light red spinels appear grey, but good ruby-red ones give a violet-blue which could just possibly be mistaken for the Thai ruby reaction. Almandite (almandine) is also said to appear grey through the filter; some do, but violet-red ones give a decided violet-grey, while brownish-reds appear brown.

A pyrope (RI 1.76), which is ash-grey in daylight and a fine raspberry-red in incandescent light, gave a decided blue. A fine large violet-red pyrope (RI 1.742) was blue enough through this filter to match the filtered blue of some Burma rubies. Three other violet-red garnets gave similar blue filtered colours and two of these were proved to be almandine-pyropes by their absorption spectra. The one exception, to my delight, was found to be a Thai ruby of 0.74 carats. [Careless re-parcelling of a stone at some earlier date?] That exception does prove the value of this particular filter, although I did take the precaution of checking it by spectroscope and refractometer, tests which are far more reliable than any filter.

No claim is made for this filter in respect of alexandrites, but I feel that it should be mentioned that a good quality natural stone was found to give practically the same filtered blue as the synthetic corundum 'alexandrine' imitation.

My best Siberian alexandrite gave a better blue than that of a Burma ruby seen through this filter. In premises lit entirely by incandescent bulbs it is just possible that such a stone could be assessed as ruby if nothing but the filter is used to test it.

The remaining two filters are not claimed specifically for any task beyond the general one mentioned earlier.

The Deep Green Filter

This one has been achieved by combining a blue filter, with absorption resembling that of cobalt in glass, with a yellow one which passes all wavelengths from green to deep red. The result is interesting since it will sort out Burma rubies (a brilliant glowing red through the filter, which unfortunately is shared identically by synthetic rubies, by the best of the red spinels and by some red pastes and doublets), from Thai rubies which are a darker and much less emphatic red through the filter. It is fair to note that Hanneman says that these filters will not separate synthetic stones from their natural counterparts. But it is evident that a mixture of the stones I have listed could be passed as being of one species.

Tentative tests with this filter on light blue aquamarines, blue topaz and blue and green tourmalines revealed that they gave almost identical versions of the filtered colour seen in aquamarines under the Aqua-Filter, although this varied a little with the depth of colour of each stone. The conclusion has to be that this particular filter is too 'open', ie. passes too much of the visual spectrum to be really safe, so that once again a parcel containing an assortment of these three species could appear to be of a single species when viewed through it. It does seem that the stated purpose of the set is not achieved in this one.

The Blue Filter

The fourth filter has a three band absorption resembling a slightly closed-up version of that of cobalt in glass, although its colour is rather violet. Again it is very 'open', with a range covering almost all the visible spectrum apart from those absorption bands. I have tried this one on a considerable number of different coloured stones but have not found a convincing use for it beyond the very general fact that a necklace or parcel matched in colour [not necessarily of one species] may still look matched through the filter. The instructions claim that this one will distinguish between different yellow or orange stones. There is a great variety of yellow and orange stones among the gem species and I was able to try it on similarly coloured yellow and golden zircons, beryls, tourmalines, sphenes, sphalerites, hessonites, spessartines, yellow sapphires, both synthetic and natural, scheelite, fluorite, apatite, citrines and topaz, and for the most part was not able to distinguish one from the other with any certainty. Indeed in many cases stones of similar colour gave practically the same filtered colour regardless of the species. Many of them could be identified on sight more easily in ordinary light without the filter.

The general conclusion is that these filters, as most of their kind, provide some empirical tests which need to be used with considerable care. In my opinion they do not give identification which can be implicitly relied upon in every instance and in some cases do not separate stones which are different species but the same or nearly the same colour. After

all, even our own much loved Chelsea Filter needs to be used intelligently, and I can cite one case where the gemmologist owner of a provincial jeweller's shop valued a bracelet of small semi-opaque blue-green beads as emerald, simply because they looked pink through the Chelsea Filter. The bracelet was in fact stained green chalcedony, which should have been instantly obvious once it was looked at without using the filter.

[*Manuscript received 30 July 1990.*]

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Water in beryl – a contribution to the separability of natural and synthetic emeralds by infrared spectroscopy

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Abstract

Infrared absorption spectra of natural and synthetic emeralds in the range of water and hydroxyl stretching modes (3500 to 3800 cm^{-1}) are subdivided into five basic groups. Groups 0 and I represent flux-grown synthetic emeralds and synthetic emeralds which were hydrothermally grown from alkali-free media, respectively. Group II represents low alkali-bearing natural emeralds, e.g. from Colombia or Nigeria, as well as low alkali-bearing hydrothermally-grown synthetic emeralds, e.g. samples grown commercially in Russia. Groups III and IV represent medium to high alkali-containing natural emeralds. With the exception of group II, in which an overlap of spectroscopic properties between natural and synthetic samples is observed, all natural and synthetic emeralds belonging to groups 0, I, III, and IV are unequivocally recognizable as natural or synthetic by infrared spectroscopy in the 3500 to 3800 cm^{-1} range. Advantages and disadvantages of different techniques of infrared spectroscopy for the examination of emeralds are briefly discussed.

Introduction

Infrared spectroscopy has been applied to problems concerning the distinction of natural and synthetic emeralds since about 1967 (Wood & Nassau, 1967; Flanigen *et al.*, 1967). In general, this method is based on the presence or absence of one or two types of water molecules in the specimen in question. In flux-grown synthetic emeralds, no water absorption bands are observable by infrared spectroscopy, and in hydrothermally-grown synthetic emeralds water molecules which are not bound to alkali ions (type-I water molecules) are present. In natural emeralds, type-I water molecules as well as water molecules which are bound to alkalies (type-II water molecules) are found (Wood & Nassau, 1967, 1968; Flanigen *et al.*, 1967; Flanigen, 1971; Flanigen & Mumbach, 1971; Nassau, 1976). According to most recent structural refinements of natural and synthetic beryls and emeralds (Gibbs *et al.*, 1968; Morosin, 1972; Hawthorne & Černý, 1977; Brown & Mills, 1986) alkali ions and water molecules of both types are located in channel sites of the beryl structure (Figure 1).

The assignments of water absorption bands in the infrared were originally based on spectroscopic investigations of natural beryls and emeralds from different sources as well as on the spectra of synthetic flux-grown and hydrothermally-grown alkali-free synthetic beryls and emeralds, which were recorded by various authors using thin polished plates or finely powdered material (KBr pressed disk technique). Fundamental vibrations of water molecules were observed between 3500 and 3800 cm^{-1} (assigned to stretching modes of water molecules) and between 1500 and 1700 cm^{-1} (assigned to deformation modes of water molecules). A large number of absorption bands were found in the near infrared (from 4000 to 10000 cm^{-1}) which were assumed to be due to combination and overtone frequencies of the fundamental vibrations of both types of water molecules (cf. Nassau, 1980; Nassau & Nassau, 1980).

However, the criteria mentioned above became partly invalid since descriptions of spectroscopic properties of alkali-bearing, i.e. lithium- and/or sodium-containing synthetic beryls and emeralds were published, which were found to reveal absorption bands of both types of water molecules (Klyakhin *et al.*, 1981; Shatsky *et al.*, 1981; Kodaira *et al.*, 1982; Lebedev *et al.*, 1986). Additional problems arise from the possibility of incorporation of type-I and type-II water molecules in flux-grown synthetic beryl by hydrothermal treatment as described by Kodaira *et al.* (1984) and from absorption bands which are assigned to hydroxyl groups in beryl (e.g. Nikol'skaya & Samoilovich, 1979).

With the exception of flux-grown synthetic emeralds, practical problems for the examination of faceted emerald specimens of unknown origin arise from low transparencies in the range of fundamental water absorption bands (cf. Leung *et al.*, 1986; Stockton, 1987) and from high polarization dependencies of H_2O bands in the infrared (cf. Wickersheim & Buchanan, 1959; Wood & Nassau, 1967, 1968). For these reasons, in the papers of Leung *et al.* (1986) and Stockton (1987) additional

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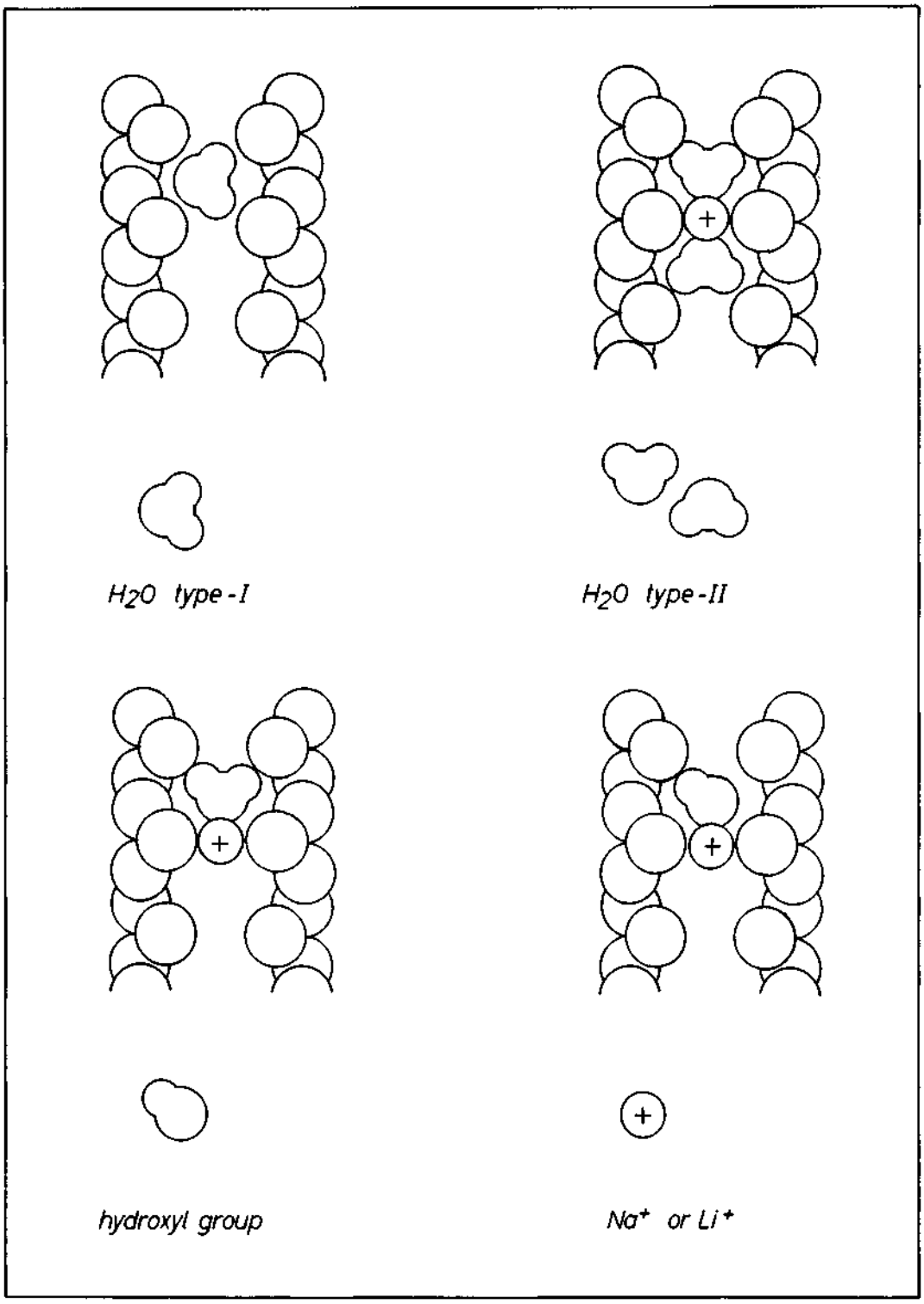

Fig. 1. Schematic drawing showing water molecules, hydroxyl groups and alkali ions as possible constituents in beryl. The *c*-axis is vertical in the diagram.

criteria for the distinction of natural and synthetic emeralds were worked out for different spectral areas, e.g. for the 2600 to 3000 cm^{-1} range measuring transmission specra of faceted samples by use of a conventional double-beam infrared spectrophotometer (Leung *et al.*, 1986) as well as by the application of a Fourier transform infrared unit (Stockton, 1987). However, these criteria were found to be invalid for part of the specimens investigated, e.g. for Russian hydrothermally-grown synthetic emeralds, the spectra of which were identical to those of natural emeralds (Stockton, 1987).

The aim of the present paper is to elucidate spectroscopic properties of natural and synthetic emeralds in the range of fundamental stretching modes of water molecules and hydroxyl groups (from 3500 to 3800 cm^{-1}) in order to clarify the applicability of infrared spectroscopy for the distinction of natural and synthetic samples. In addition, the results presented can be applied to the assignment of overtone and combination frequencies in the near infrared in further studies.

Experimental details

Infrared spectra were recorded for 75 samples of natural emeralds, for 13 samples of synthetic hydrothermally-grown emeralds as well as for 15 samples of flux-grown synthetic emeralds in the range of H_2O stretching modes (from 3500 to 3800 cm^{-1}) using a Perkin-Elmer model 180 infrared double-beam grating spectrophotometer. Comparing literature data dealing with chemical properties of natural and synthetic emeralds as well as microprobe analyses performed by one of the present authors (cf. Schmetzer, 1989), the research material was selected in order to cover a wide range of chemical variability from synthetic flux-grown and hydrothermally-grown alkali-free emeralds to synthetic low alkali-bearing hydrothermally-grown emeralds from different producers, as well as low, medium and high alkali-bearing natural emeralds from different sources. All samples investigated were crystals or faceted stones of gemstone quality, and, in general, zones without major mineral inclusions were microscopically selected for spectroscopic examination. From all samples available for the present study, 2 mg of powder were scraped from faceted or rough emerald crystals using a diamond point, and KBr disks were pressed from 2 mg of emerald powder and 200 mg KBr.

Results

According to spectral features in the range of H_2O and OH stretching modes (from 3500 to 3800 cm^{-1}), infrared spectra of natural and synthetic emeralds are subdivided into five basic groups (Table 1, Figure 2):

Group 0: In the spectra of flux-grown synthetic emeralds no absorption bands of water were observed.

Group I: The spectra of synthetic alkali-free emeralds yield only one strong absorption band with maximum at about 3694 cm^{-1} (designated band A).

Group II: In the spectra of low alkali-bearing natural and synthetic emeralds in addition to band A, a second absorption band at 3592 cm^{-1} (designated band B) was present. In different samples, variable intensity ratios of band A versus band B were observed, and beginning at a ratio of about 2:1 between bands A and B, a third absorption with maximum at 3655 cm^{-1} (designated band C) occurs as a weak shoulder of band A. However, in all spectra of group II, band A exceeds band B in intensity.

Group III: In this group, the intensity of band B exceeds that of band A. In different samples of this particular group, all of them natural emeralds with distinct sodium-contents, an increase of band C at about 3655 cm^{-1} is found to be parallel to a decrease of band A in intensity. In other words, the spectra of all samples of this group yield three absorption maxima (bands A, B and C) with significantly variable intensity ratios.

Group IV: In some natural samples with high sodium content, only absorption bands B and C were present, but no distinct absorption at 3694 cm^{-1} (band A) was observed.

In all four types of spectra of water-bearing natural and synthetic emeralds, no intensity correlation was found to be present between bands B and C. However, with increasing type C absorption bands, decreasing intensities of band A were found to be correlated (Figures 2, 3). In general, in all samples investigated by infrared spectroscopy and electron microprobe, a distinct trend of increasing sodium contents from about 0.03 to 2.5 wt.% Na_2O parallel to increasing intensities of B and C absorption bands and decreasing intensities of the A absorption maximum were measured (cf. Table 1, Schmetzer, 1989). The chemical variability within emeralds from one distinct source are reflected by infrared spectroscopy, i.e., samples originating from one mine or locality were found to reveal distinctly varying intensity ratios of infrared absorption bands A, B, and C (Figure 4).

Discussion

Though the method applied is partly destructive for an emerald sample of unknown origin, the KBr technique was preferred to the measurement of thin polished plates, which have to be cut from faceted or rough emerald crystals. On the one hand, the

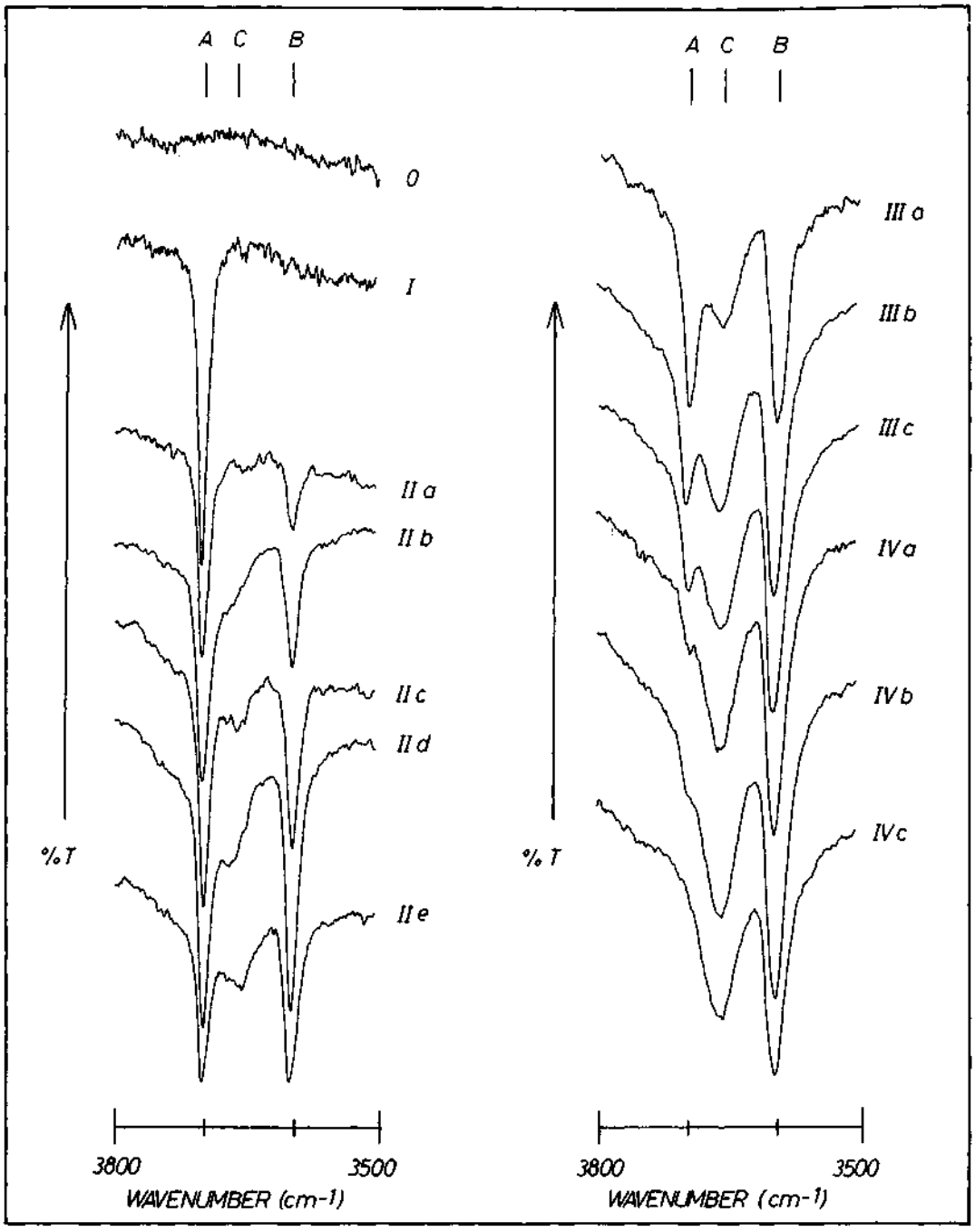

Fig. 2. Infrared spectra of natural and synthetic emeralds in the range of water and hydroxyl stretching modes: 0 water-free flux-grown Chatham synthetic emerald; I hydrothermally-grown Biron synthetic emerald; IIa natural emerald, Jos, Nigeria; IIb hydrothermally-grown Russian synthetic emerald; IIc natural emerald, Colombia; IId hydrothermally-grown Lechleitner synthetic emerald; IIe natural emerald, Chivor, Colombia; IIIa natural emerald, Itabira, Brazil; IIIb natural emerald, Socotó, Brazil; IIIc natural emerald, Zambia; IVa natural emerald, Sta. Terezinha, Brazil; IVb natural vanadium-bearing beryl, Salininha, Brazil; IVc natural emerald, Machingwe, Zimbabwe. Absorption bands are represented by the symbols A ≙ 3694 cm^{-1}, B ≙ 3592 cm^{-1}, and C ≙ 3655 cm^{-1}.

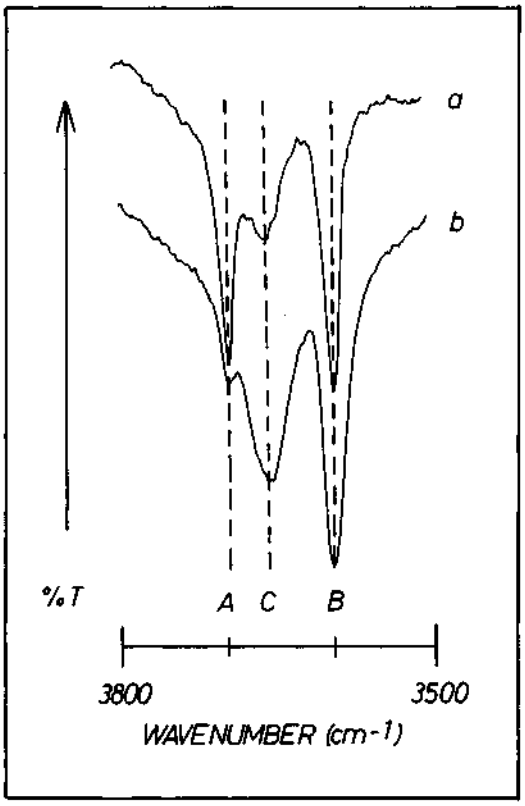

Fig. 3. Infrared spectra of natural emerald, Colombia (sample a) and natural emerald, Tauá, Brazil (sample b), indicating the high variability of absorption bands, which are represented by the symbols A ≙ 3694 cm^{-1}, B ≙ 3592 cm^{-1}, and C ≙ 3655 cm^{-1}.

method applied avoids polarization dependencies of infrared absorption bands and, on the other hand, using modern microbeam techniques, the method is performable with less than 0.5 mg of emerald powder. Thus, the KBr technique can be applied not only to fundamental research problems, i.e. to a classification of infrared spectra of natural and synthetic emeralds, but is also useful for practical identification of faceted emerald samples of unknown origin. In other words, this method can be applied to the identification of emerald specimens (with permission of the owner), if other non-destructive methods, e.g. microscopy or absorption spectroscopy in the visible and ultraviolet range (cf. Schmetzer, 1988, 1990) do not yield criteria for an unequivocal determination of the sample.

According to the great variability of intensity ratios of absorption bands A, B, and C, which are correlated with chemical data, especially with sodium contents of the samples, the three absorption bands in the range of water and/or hydroxyl stretching modes (from 3500 to 3800 cm^{-1}) are assigned to three different types of water molecules and/or hydroxyl groups. A detailed discussion of this assignment and a model of water and/or hydroxyl types in natural and synthetic beryl and emerald is given by Schmetzer (1989). In summary, band A at 3694 cm^{-1} is assigned to type-I water molecules which are not bound to adjacent alkali ions. Bands B and C at 3592 and 3655 cm^{-1}, respectively, are caused by type-II water molecules and/or hydroxyl groups, which are bound to alkali ions. Most probably, band B is due to water molecules which are bound to alkalies (lithium and/or sodium) in the sequence H_2O-Na-OH_2 (type-IIa water molecules), and band C is assigned to water molecules or hydroxyl groups which are bound to alkalies in the sequence H_2O-Na-□ (type-IIb water molecules) or HO-Na-□ (hydroxyl groups) [Figure 1], with □ representing vacancies in channel sites of the beryl structure. However, bond strength calculations favour the presence of water molecules and the absence of hydroxyl groups adjacent to alkali ions in channel sites of the beryl structure.

For practical application of infrared spectroscopy to the determination of emerald samples of unknown origin, according to the present state of the authors' experience including also literature data, all emeralds with spectra belonging to groups 0, I, III and IV are identifiable unequivocally as spectra of synthetic or natural emeralds (cf. Table 1). Spectra belonging to groups 0 and I are assigned to non-water-bearing flux-grown synthetic emeralds and to type-I water-containing synthetic emeralds which were grown hydrothermally from alkali-free media, respectively. Spectra of groups III and IV are caused by medium to high alkali-bearing natural emeralds with distinct amounts of alkali-bonded type-IIa and type-IIb water molecules and lower amounts of non-alkali-bonded type-I water molecules. At present, spectra of samples belonging to groups III and IV were not measured for synthetic emeralds of commercially available types nor for synthetic beryls or emeralds grown for research purposes.

Spectra belonging to group II are possibly due to low alkali-bearing natural emeralds, e.g. samples from Nigeria or Colombia, or can be caused by synthetic emeralds which are grown hydrothermally from alkali-bearing media, e.g. Lechleitner fully synthetic emeralds or samples of the commercial type of Russian hydrothermally-grown synthetic emeralds (cf. Schmetzer, 1988). Both groups of samples contain distinct amounts of non-alkali-bonded type-I water molecules as well as alkali-bonded type-IIa water and lower amounts of alkali-bonded type-IIb water molecules.

Table 1. Classification of natural and synthetic emeralds according to spectroscopic features in the infrared from 3500 to 3800 cm^{-1}.

Group	Absorption bands and intensity ratios: A ≙ 3694 cm^{-1}; B ≙ 3592 cm^{-1}; and C ≙ 3655 cm^{-1}	Chemical properties	Examples
0	no distinct absorption bands	flux-grown synthetic emeralds	Chatham, Gilson, Lennix, Russian flux-grown synthetic emeralds
I	A	synthetic emeralds grown hydrothermally from alkali-free media	Linde, Biron, Pool, Swarovski hydrothermally-grown synthetic emeralds
II	A > B ≫ C	low alkali-bearing natural and synthetic hydro-thermally-grown emeralds, sodium contents ranging from approx. 0.03-0.5 wt.% Na_2O	Emmaville, New South Wales, Australia. Jos, Nigeria. Eidsvold, Norway. Sandawana, Zimbabwe. Colombia, different localities. Russian hydro-thermally-grown synthetic emerald. Orissa, India. Lechleitner hydrothermally-grown synthetic emerald*.
III	B > A > C	medium alkali-bearing natural emeralds, sodium contents ranging from approx. 0.5-1.0 wt.% Na_2O	Ural Mountains, USSR Colombia, different localities. Itabira, Minas Gerais, Brazil. Lake Manyara, Tanzania. Carnaiba, Bahia, Brazil.
	B > A ≈ C		Socotó, Bahia, Brazil. Filabusi, Zimbabwe.
	B > C > A	high alkali-bearing natural emeralds, sodium contents ranging from approx. 1.0-2.0 wt.% Na_2O	Lake Manyara, Tanzania. Maria Mine, Morrua, Mozambique. Zambia, different localities. Cobra Mine, Gravelotte, South Africa. Tauá, Ceará, Brazil.
IV	B > C ≫ A	high alkali-bearing natural emeralds, sodium contents ranging from approx. 1.5-2.5 wt.% Na_2O	Habachtal, Austria. Sta. Terezinha, Goiás, Brazil. Ankadilalana, Madagascar. Sandawana, Zimbabwe. Salininha, Bahia, Brazil. Ajmer, India. Machingwe, Zimbabwe.

*fully synthetic emerald without natural seed (cf. Eppler, 1968).

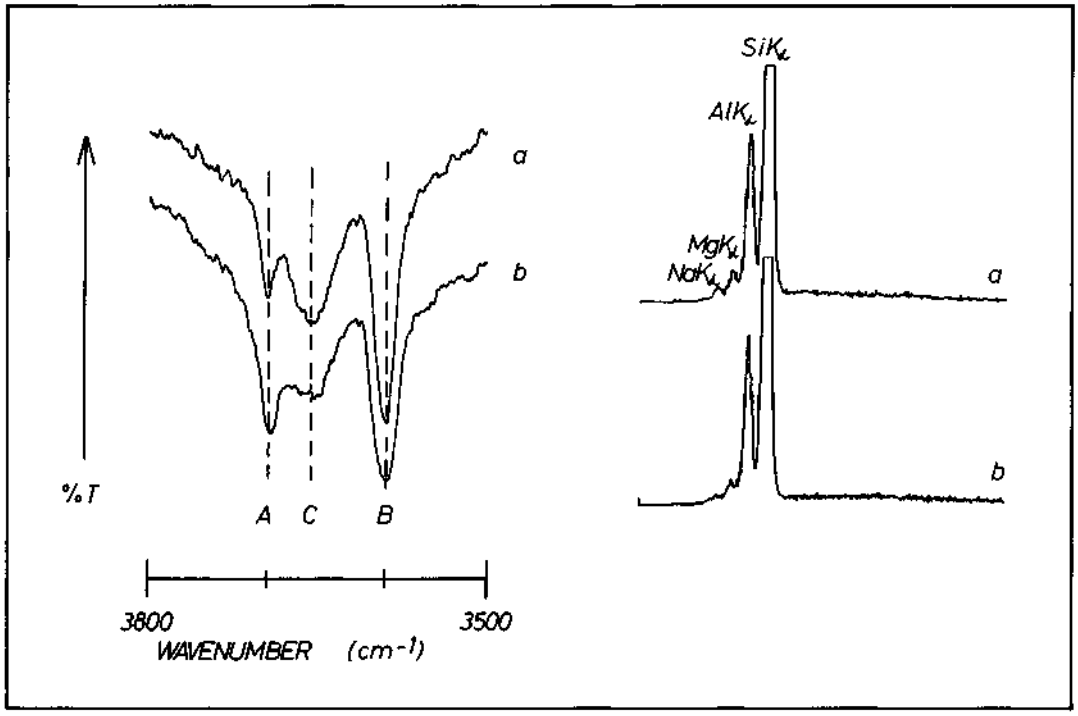

Fig. 4. Infrared spectra (left) and energy dispersive X-ray spectra (right) of two natural emeralds (samples a and b), both from Lake Manyara, Tanzania, indicating the variability of absorption bands, which are represented by the symbols A ≙ 3694 cm^{-1}, B ≙ 3592 cm^{-1}, and C ≙ 3655 cm^{-1}; with decreasing amounts of Na_2O from sample a to sample b decreasing intensities of band C and increasing intensities of band A are correlated.

According to these results, most natural and synthetic emerald samples can be distinguished by infrared spectroscopy in the range of H_2O or OH stretching modes (3500 to 3800 cm^{-1}) using the KBr pressed pellet technique. Due to the fact, that an overlap of spectroscopic properties is observed for low alkali-bearing natural and synthetic samples in the range of fundamental vibrations, similar overlaps are expected for the range of overtone and combination frequencies in the near infrared (from 4000 to 10000 cm^{-1}). In addition, each examiner has to be aware of the high polarization dependencies of emerald water absorption bands in all spectral areas.

For these reasons, in order to work out unequivocally criteria for a determination of faceted emerald samples of unknown origin, non-destructive examinations of single-crystals in the infrared have to be carried out with polarized light on optically orientated stones. These preconditions, however, may cause extreme difficulties and, in some cases, may favour the KBr technique, using less than 0.5 mg of emerald powder which may be scraped carefully by a diamond point from the girdle of a faceted stone. In addition, using the KBr pressed pellet technique, a careful examiner is able to record spectra for powdered material scraped from distinct parts of a faceted gemstone, which are selected before by microscopic examination. Thus, this method is useful to distinguish between flux- or hydrothermally-grown synthetic emerald and natural seed material.

An example is given here for Swarovski synthetic emerald. According to Stockton (1987), infrared spectroscopy of this non-commercial synthetic emerald using the Fourier transform technique yields spectroscopic features which are typical for natural emerald or, at least, not conclusive. The investigation of some powder of Swarovski synthetic emerald consisting partly of hydrothermally-grown synthetic material and partly of natural seed material using the KBr disk technique yields an infrared spectrum which is typical for group II spectra and does not allow to determine the sample as synthetic emerald (Figure 5). However, after careful preparation of powder consisting of hydrothermally-grown material only (without residues of the natural seed), an infrared spectrum of group I typical for synthetic emerald was obtained (Figure 5).

Thus, for both techniques advantages and disadvantages are known to exist, and each examiner

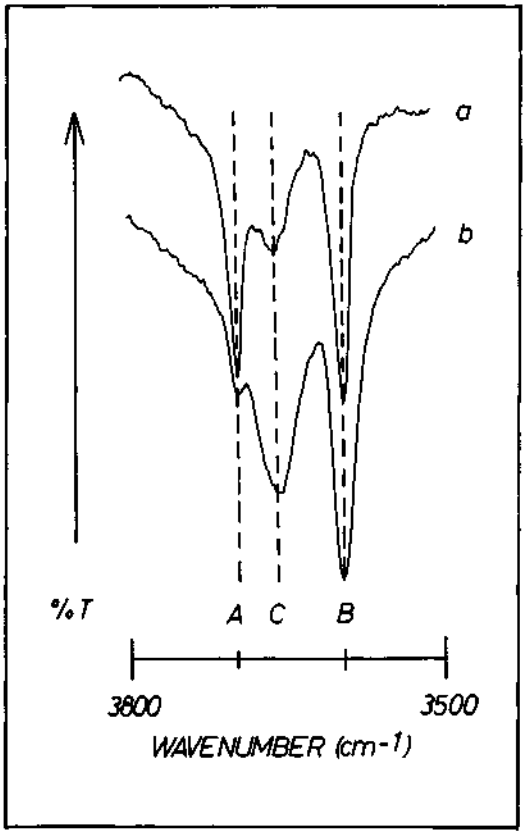

Fig. 5. Infrared spectra of Swarovski synthetic emerald excluding seed material (sample a) and including seed material (sample b) indicating the variability of absorption bands, which are represented by the symbols A ≙ 3694 cm^{-1}, B ≙ 3592 cm^{-1}, and C ≙ 3655 cm^{-1} in samples with or without admixtures of natural seed materials.

has to be aware of the overlaps in each method. Using some emerald powder in connection with KBr pressed pellet techniques, the observed overlap in group II spectra is due to identical or almost identical amounts of alkalies as well as to identical ratios of type-I, type-IIa and type-IIb water molecules, respectively. At present, this overlap is only important for Lechleitner synthetic emeralds as well as for Russian hydrothermally-grown synthetic emeralds, which can be identified by absorption spectroscopy in the visible as well as by microscopic and chemical investigations (cf. Schmetzer, 1988, 1990). In other words, emerald samples of unknown origin, the infrared spectra of which were found to belong to group II, have to be examined by other methods in order to work out unequivocal criteria for the presence or absence of Russian hydrothermally-grown synthetic emeralds or Lechleitner hydrothermally-grown fully synthetic stones.

The reasons for overlaps in the infrared spectra of faceted single-crystals as described by Leung *et al.* (1986) and Stockton (1987) are unkown at present, and further research has to be carried out in order to clarify these specific properties of infrared spectra of natural and synthetic emeralds.

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[*Manuscript received 4 December 1988.*]

CONGRATULATIONS TO THE FINNISH GEMMOLOGICAL SOCIETY ON THE OCCASION OF THEIR 25TH ANNIVERSARY

It is a pleasure to salute the achievement of our gemmological friends in Finland in promoting the scientific study and dissemination of information concerning gemstones.

Challenges to our skills in identifying gem and decorative materials are constantly arising in a fast-changing world and it is reassuring to know that there are in existence stable organizations of integrity to whom professionals and ordinary members of the public can turn for help and guidance.

To reinforce this aspect of professional service the Gemmological Association and Gem Testing Laboratory of Great Britain have, this year, merged to form one organization. This new grouping will continue to offer education courses, examinations, gem testing and grading, and to sell books and instruments world-wide, and will expand in those areas of gemmological challenge.

With our best wishes
from

The Gemmological Association and Gem Testing Laboratory of Great Britain

27 Greville Street London EC1N 8SU
Telephone: 071-404 3334 Fax: 071-404 8843

J. Gemm., 1990, 22, 4

Gemmological teaching in Hong Kong and China

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Since 1982, the writer has designed and manufactured a variety of instruments and apparatus related to the teaching and practice of gemmology. Most of these items have been sold outside the UK through sales agencies in Adelaide, Chicago, Colombo, Dusseldorf and Hong Kong.

His Hong Kong agent, Mrs Ou Yang was a member of the Executive Committee of the Gemmological Association of Hong Kong (GAHK) and a teacher at the Department of Geography and Geology, Hong Kong University. She had recommended to both bodies that the writer be invited to give three evening lectures and to organize two daytime weekend practical courses on appropriate gemmological subjects. The most suitable time was mid-May 1988. A formal invitation was received which could not possibly be refused.

Fig. 1. The cool courtyards of Robert Black College, University of Hong Kong.

It was then suggested that Mr Alan Jobbins be asked to deliver two additional evening lectures. The first would be on 'Corundum deposits around the World' on which subject he has an unrivalled on-the-spot experience. The second would consist of a talk with questions describing the FGA teaching syllabus, the form of the examinations and the offering of guidance on the best ways for preparing and sitting the examinations. Happily for the times proposed, Mr Jobbins's other gemmological commitments allowed him to join us later in Hong Kong.

The writer and his wife Doris were met at the airport by Mrs Ou Yang and her gemmologist colleague Mrs Christine Wong. We were taken, together with our numerous boxes of teaching equipment, to the University's Robert Black College. This is a special guest house financed by the University to provide accommodation for foreign lecturers and their wives. It stands behind the University campus on a steep tropical wooded hillside. It consists of a group of separate suites of rooms grouped around cool ornamental courtyards designed in the Chinese fashion. (See Figure 1.)

The lodgings provided were luxurious by any standard and the central restaurant catered to any national taste. The balconies of the suites gave a panoramic view of the spectacular city and its enormous harbour. Figure 2 shows the blue roofs of the guest house, the University buildings on the left and part of the harbour as a backdrop.

Our friends lost no time in putting the writer to work. His first lecture was given on the day following our arrival. The evening lectures were held in the rooms of the Hong Kong Diamond Bourse. The courses, limited to 14 students, took place from 2.00pm to 6.30pm in the laboratory of

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Fig. 2. The roofs of Robert Black College with Hong Kong University buildings (left) and Hong Kong harbour as a backdrop.

the University's Department of Geography and Geology.

Much use was made in the courses of the instruments and visual aids developed by the writer to demonstrate the actual physical principles involved in gemstone testing instruments. Some of this apparatus will be described later.[1]

The 8-day schedule (which started on Friday 13 May) was hectic as can be seen from the table below.

Schedule of lectures and courses

13 May	Lecture. 'The four optical attributes of a diamond' JBN
14 May	Course. 'Gemstone characterisation and grading' JBN
15 May	Course. 'Diagnostic gemstone inclusions' JBN
17 May	Lecture. 'The characterisation of pearls using X-rays' JBN
19 May	Lecture. 'Practical methods for determining gemstone body colour using the CIE Tristimulus Colour System'. JBN
20 May	Lecture. 'Corundum deposits around the world' EAJ
21 May	Course. Repeat of course of 14 May. JBN
22 May	Course. Repeat of course of 15 May. JBN
22 May	Lecture. 'The FGA Examination' EAJ

Needless to say, there was some time for sightseeing. The city itself, the harbour and best of all, the restaurants were superb. Mrs Christine Wong took us on a conducted tour in her Range Rover to the New Territories beyond Kowloon on the Chinese mainland.

The GAHK was founded in 1979 when it had a start-up membership of over 300. Its Annual General Meeting was held on 21 May at the Royal Garden Hotel. Here the President, Mr Louis Lo, presented Mr Jobbins and the writer with engraved commemorative plaques. The occasion was also marked by the presentation of many leave-taking gifts to Mrs Anne Paul. Mrs Paul is one of the Founder Members of the Association and has served on its Executive Committee since its inception. She has devoted much time and effort to furthering the cause of gemmology in Hong Kong. Following the AGM, a farewell banquet in her honour was enjoyed by over eighty members. She has now returned to New York.

The routine teaching of gemmology is carried out mainly by individual qualified gemmologists who conduct classes and tutorials in their own homes or business premises. The basic pieces of testing equipment, i.e. refractometers, loupes and OPL spectroscopes, are usually the personal property of each student. Almost all instructors possess the more costly items such as GIA microscopes, wavelength-scale spectroscopes, specific gravity

Fig. 3. Students engaged on course work in a laboratory at Hong Kong University. Mrs Ou Yang and the writer are seen centre rear.

sets, UV fluorescence units, colour camera accessories for photographing inclusions and other visual aids. The Association has also managed to acquire, both by purchase and donation, a considerable amount of similar apparatus. It is thus able to loan out this material whenever required for all the larger teaching sessions or lectures, as it did for the present series.

Curiously enough, the Association has no permanent premises of its own. However, its good relations with the Department of Geography and Geology of the University allow it to make use of its splendid laboratory and lecture room at weekends and evenings. Mrs Ou Yang, who serves part-time on the Department's teaching staff, acts as the coordinator for such arrangements. In Figure 3 Mrs Ou Yang and the writer are seen (centre rear) in the University laboratory where students are engaged on course work. It was she who had suggested earlier to her geological friends in the University of Wuhan, China, that our lectures might also be of interest to them. As one who had earned her second degree from the terrestrial discovery of the green mineral ureyite (cosmochlore), the chromium analogue of jadeite, in certain Burmese jade-like gemstones,[2] she was well-known in these circles. She had often visited Wuhan to deliver talks on her various gemmological researches.

To our great surprise they were most enthusiastic about this offer and seemed anxious to embrace anything gemmological. It appears that while China had trained over 100,000 geologists since 1976, the end of the horrendous ten-year long Cultural Revolution of Mao Zedong, there were now only 3 qualified gemmologists in the entire People's Republic of over 1.2 billion people! The virtual destruction of the Geology Faculty of Beijing (Peking) University by the young anti-intellectual Red Guards had resulted in the 1976 decision to transfer the main teaching centre for geology to a new home in Wuhan. This is a large sprawling city on the Yangste River, some 1000 kilometres upstream from Shanghai on the East China Sea. It is actually a twin city connected by a huge road-rail bridge; this is doubly remarkable for its clever and elegant construction and for its being the first bridge upstream from the coast (see Figure 4).

However, they explained that our offer posed a problem. China's recent explosive economic expansion had swallowed up most of the government's available hard currency, leaving no funds for any leap into gemmological teaching by paid foreign instructors. They proposed to Mrs Ou Yang a solution to this obstacle which delighted us the moment we heard of it. It was this. All that was required of us was to bear the cost of transporting ourselves and our personal and teaching baggage the short, 'hard-currency' distance to Guanzhou

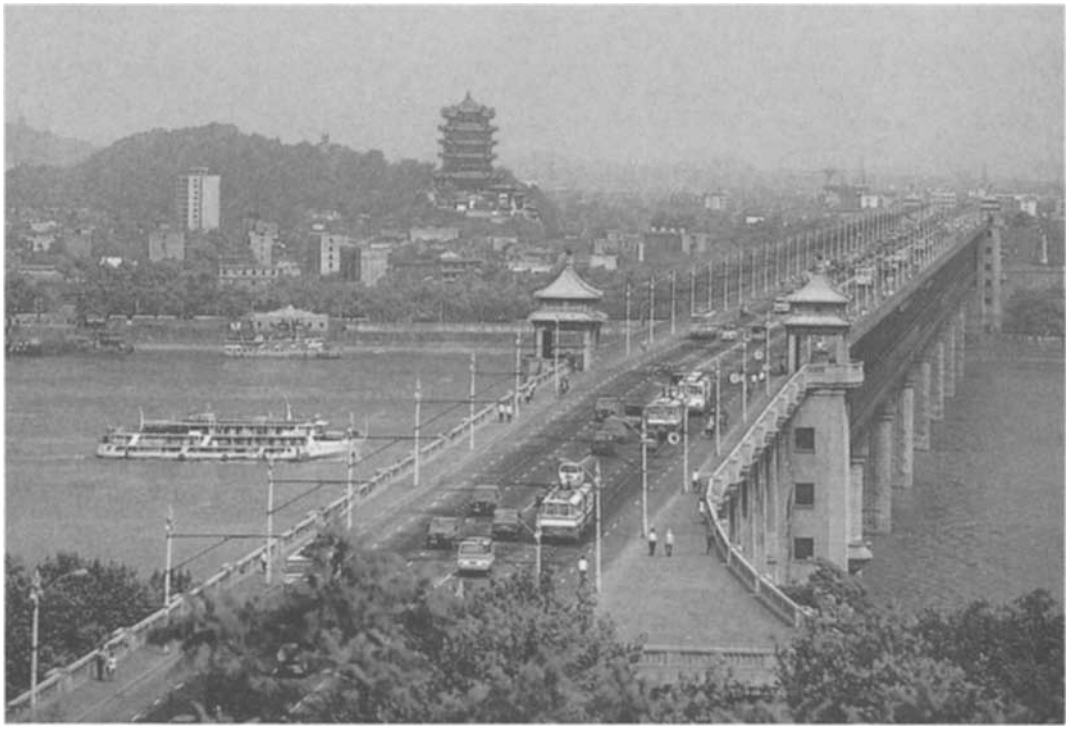

Fig. 4. The Changjiang Bridge across the Yangste at Wuhan.

Fig. 5. Alexand Zhang, our guide, in the gardens of the Shaanxi Museum at Xi'an.

Fig. 6. General view of the University of Geosciences campus, Wuhan.

Fig. 7. The Library, University of Geosciences, Wuhan.

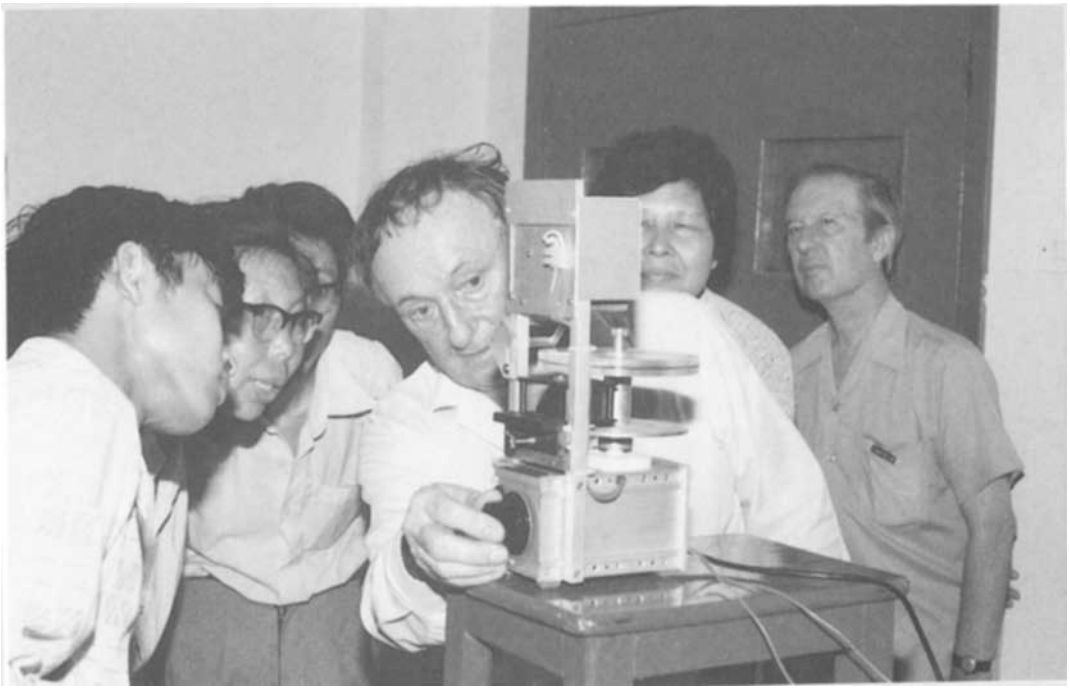

Fig. 8. Dr Nelson demonstrating to students at the University of Geosciences, Wuhan.

(Canton) from Hong Kong and back. Once inside China, the Faculty of Geology could easily meet our entire travelling and accommodation expenses in their own currency. As recompense for our teaching labours, it would also provide us with a week-long sight-seeing tour of China, together with an English-speaking guide to smooth our travels. We doubted whether we ever had a better offer in our lives!

Just as we have our own endearing names for foreigners, so have the Chinese. We soon discovered that Anglo-Saxons are known as the 'long-nosed pink faces'. The three of us were thus easily identified by our guide at Guanzhou railway station. He was a personable and handsome young man, Alexand Zhang of the Foreign Affairs Office. He at once ran into the first of many travellers' trip-wires. He discovered that our reserved airline seats to Wuhan had been re-allocated to some ex-Chinese nationals from Taiwan, now a much-beloved tourist dollar source. Failing to obtain places of any kind on the alternative long railway journey, he flew into a well-staged fury and eventually won us train tickets and sleeper reservations. Our subsequent adventures proved he had the right stuff for coping with the wilder aspects of free-lance travel in China. Maximizing one's comfort there is a full-time occupation and he was good at it. We quickly named him 'Alexander the Great' (see Figure 5).

Arriving at Wuhan, we were quickly installed in the University's residential block for visiting scientists. While spartan in comparison with our HK quarters, it was spacious and spotless. The food was plentiful, but of the 'fuel' rather than of the gourmet kind of the Robert Black College.

We were welcomed by Professor Chen Zhonghui,* Vice-President of the China University of Geosciences (Wuhan) who showed us around the campus buildings. Occupying an area of about 0.6 by 1.0 kilometres beside a picturesque lake and at the foot of a wooded hill, it is located on the outskirts of the city. It is primarily a geological university of science and engineering with supporting liberal arts and business administration departments and is one of the nation's key universities. It has nearly 5000 full-time undergraduate students and about 1000 professional teachers. About 400 students are now specializing for their masters and doctorate geological degrees at the Graduate School. A view of the campus is shown in Figure 6. The magnificent library of which they are particularly proud is shown in Figure 7; it houses 620,000 books and periodicals in Chinese and foreign languages.

The lecture hall held about 150 students and was

*In China, as in Spain, the first written name of a person of either sex is that of the father. The last is the given or mother's name.

Fig. 9. Professor Yen Weixuan, helped by students, translating English specimen labels into Chinese.

full even at repeat sessions of the same lecture. These were the same five as delivered in Hong Kong. Mr Jobbins added a sixth, describing the discovery of the sources of New Zealand jade. Very few spoke English, so that all lectures were translated into Mandarin by another Foreign Affairs Office interpreter, Mrs Hua Xin. She had spent two years in Heidelberg, Germany, on a study of meteorites. Her grasp of technical detail and speed of translation was superb.

The person who master-minded the timetable of lectures and courses was Professor Yen Weixuan, the wife of Professor Chen. When we innocently stated our willingness to work all the hours necessary, she took us precisely at our word and was in continuous hot pursuit to fill all her time slots – up to midnight on several occasions!

When first shown the small bare room which was to be our courses classroom, we despaired of making any use of it. However, in a twinkling, power supplies, projectors, blackboards and benches for 15 students were installed. A new, large, tailor-made blackout curtain was made and fitted without fuss.

The courses given in Hong Kong were unsuitable for beginners in gemmology so that generalized introductory talks and equipment demonstrations were given instead (see Figure 8). The writer had brought with him his collection of some 500 cut stones and euhedral crystals and these were supplemented by Alan Jobbins's collection. With these and the use of the conventional instruments brought from the UK, the students were able to examine and sometimes measure their properties. The only equipment which the Mineralogy and Petrology Department were able to provide were lots of classical petrological microscopes; these were only of limited use.

The English names on the stones' polythene bags had, of course, no meaning in the practical sessions. Undaunted, during a session lasting well beyond midnight, Professor Yen, accompanied by some eight students and armed with a large, battered English/Chinese geological dictionary and with a little guidance from the writer, translated the whole 500-odd names and other details (see Figure 9). The writer, conscious of this impressive collective labour, has preserved these little slips of Chinese writing in his collection, all of which returned home safely. The instruments still remain in Wuhan however!

To cope with the large number of students, many of whom were professional geologists from other parts of China, several repeat sessions were held both during the day and in the evenings. It was a truly exhausting time for Mr Jobbins and myself, but the sheer enthusiasm of the students to learn something about this new, almost naughty, subject was enough to recharge our flagging batteries.

Why 'naughty', one might ask? It must be remembered that China is a poor, industrially under-developed nation. While her cities are large (Chungking, 'the furnace of China', about another 1000 kilometres upstream from Wuhan, has a population of 14 million), 95% of her people are peasant-farmers living far from cities. There never has been, unlike India, a long tradition favouring personal adornment with jewellery or decorative clothing, except among the Mandarin ruling classes. The Marxist-Leninist dynasty, still very much in power since 1949, does not favour such western 'bourgeois liberal' habits. Indeed, the Revolutionary Red Guards forcibly removed and destroyed any such articles from those bold enough to wear them. The 1979 reformist economic policy of Deng Xiaoping did relax these strictures somewhat, but the recent crackdown in Tiananmen Square has moved this small reform into a swift reverse. There is now, unfortunately, a new kind of Great Wall of China which has been erected to seal off the pro-democracy movements in the European Marxist countries.

The reason for the sudden Chinese interest in gemmology arises purely for its potential for obtaining the hard currencies of Japan and the western countries to pay for its economic plans. China possesses great mineral wealth and doubtless untapped and as yet undiscovered gemstone mineral deposits which a gem-hungry world now needs.[3]

Unfortunately, in the past, many valuable gemstone crystals were inadvertently destroyed by miners ignorant of their worth. The Geological Museum in Beijing now houses some of the finest surviving specimens in the country, including the largest diamond found recently in the Changma district – a clear 119-carat octahedron.

Between lectures and classes, we found time to discuss with Professor Chen and his wife the possibility of future links with the GA of GB. They were clearly eager to start such liaisons. As a friendly gift from the GA, Mr Jobbins presented them with the manuals for the Preliminary and Diploma Correspondence Courses. This gesture delighted them and after studying the manuals carefully over the next few days, they made several interesting proposals.

The first was that they be allowed to translate them into Chinese, with the intention of using them as the basis for starting up their own gemmology teaching in Wuhan. The translations would be used only in the People's Republic of China itself. As recompense, the GA would have the sole rights to offer them to other Chinese-speaking teaching centres throughout the rest of the world, including Taiwan.

Secondly, they would like to invite Mr Jobbins and the writer to teach a more intensive 10-day course in Wuhan in May 1989. They proposed that a group of 15 students would be selected to begin preparations for taking the GA Preliminary Examination. The May 1989 visit would be in the nature of a coaching exercise with a mock examination test for sitting the July 1989 examination (see later Postscript).

Finally, they requested that we advise them as to the most suitable instruments with which to equip their proposed new gemmology teaching laboratory and to tender officially for this apparatus. There followed much detailed discussion, with Doris Nelson using all her acquired business skills as a negotiator on behalf of the GA. Shortly afterwards, the President of the China University of Geosciences (Wuhan), Professor Zhao Peng-da, arrived from Beijing. His visit was presumably, among other matters, to consult with Professor Chen about these negotiations. Following this, a kind of celebra-

Fig. 10. Academic group prior to departure from Xi'an: left to right, Dr J. Nelson, Prof Yen Weixuan, Dr Hua Xin, Mrs Nelson, Mrs Jobbins, Prof. Chen Zhonghui and E.A. Jobbins.

tory banquet was held, at which he attended.

On the evening prior to our departure for our first sightseeing excursion, a final agreement was reached on all the points discussed, subject to ratification by our own Executive Committee and Council.

By this time, Mr Jobbins' wife, Mary, had flown from Hong Kong to Wuhan to join us on our trip to far-distant Xi'an (see Figure 10). This is the celebrated city on the Silk Road, of the clay warrior army found in the mausoleum of China's first Emperor, Qin Shi Huang more than 2000 years ago.

Postscipt

The invitation for May 1989 was taken up by Alan Jobbins and Ken Scarratt, who were worked equally hard. By this time both the GA Preliminary and Diploma courses were translated into Chinese and were available to students in duplicated form. In June 1990 twelve students from China sat the Diploma examination; ten passed, one with distinction – a highly creditable performance.

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Detection of synthetic emeralds by thermal conductance

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In reporting on three thermal conductance meters (the Gemtek Gemmologist,[1] the Alpha-test[2] and the Gem-trak[3]), all of which were designed to identify coloured gemstones as well as diamond simulants, I now find that I had failed to emphasize one interesting additional capability of this type of instrument.

Recently, while using an Alpha-test unit (see Figure 1) to check a Gilson synthetic emerald, I confirmed that the thermal conductance of the synthetic stone was at least twice that of a natural emerald.

To explore this phenomenon more thoroughly I then made a series of tests using the Alpha-test instrument to check the thermal conductance of a range of natural and synthetic emeralds. Five separate measurements were made on each sample, and these were then averaged for each stone (see Table 1). From the results it became clear that the flux-melt synthetic emeralds showed a consistently greater thermal conductance than did the natural emeralds (with the Alpha-test, the lower the reading, the greater is the measured thermal conductance). With the hydrothermally produced samples, the resulting Alpha-test readings tended to be closer to the lower limit of the natural stones, but could still provide a reasonable discrimination (no similar thermal discrimination could be discovered during earlier tests on natural and synthetic corundums).

Of the two coated-type Lechleitner emeralds that were tested, the one with a good surface lustre gave a reading close to that of natural emerald, while the

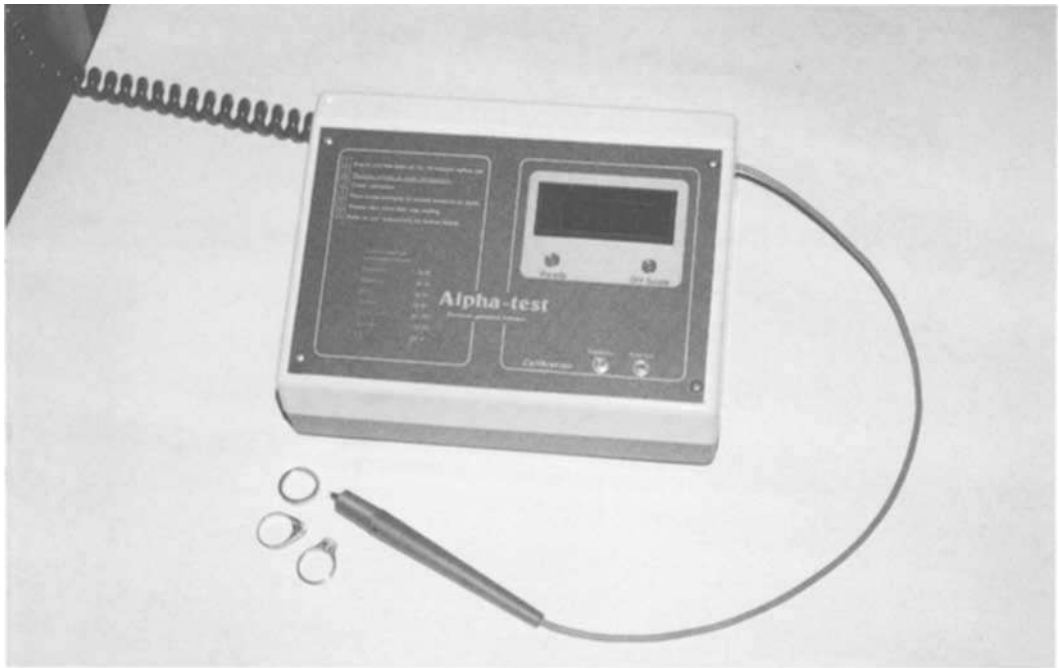

Fig. 1. The Alpha-test thermal conductance tester uses two pre-set probe tip temperature sensing levels to operate a counter/timer which indicates on a digital display the rate of heat absorption by the specimen.

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Table 1. Alpha-test readings (low readings indicate high thermal conductance)

Synthetic emeralds	Average reading	Natural emeralds	Average reading
Gilson crystal (flux-melt)	71	Indian (Ajmer)	216
Gilson – block (flux-melt)	77	Indian (unknown)	221
Crescent Vert (flux-melt)	92	South African (Cobra mine)	233
Lennix 2,000 (flux-melt)	83	South African (Cobra mine)	177
Lennix 2,000 (flux-melt)	89	Colombian (Muzo)	230
Lechleitner coated (hydrothermal)	*	Colombian (unknown)	157
Lechleitner coated (hydrothermal)	153	Brazilian (unknown)	211
Lechleitner solid (hydrothermal)	80	Pakistan (dark green – Swat)	221
Biron (hydrothermal)	132	Pakistan (light green – Swat)	185
		USSR (Ural mountains)**	150

Note: All stones within size range 0.25 to 3 carats, except where shown.

*Off-scale reading (very low thermal conductance)
**159.8 carats

one with the poorer lustre consistently produced an off-scale reading (indicating a very low thermal conductance).

Finally, I would like to acknowledge the help of Mr Roy Huddlestone who provided all the test samples, recorded the results and subsequently demonstrated the Alpha-test's ability to detect synthetic emeralds at my talk to the Association in the Flett theatre, London on 2 May 1990.

Note: The Alpha-test is the only thermal conductance model of this type still commercially available. Stockists are H.S. Walsh, 232 Beckenham Road, Kent BR3 4TS.

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[*Manuscript received 5 July 1990.*]

Gemmological Abstracts

ARJALAGUER, I., VILARDELL, D., 1989. Abacos del peso aproximado y de proporciones correctas de los diamantes con talla brillante tipo Tolkowsky. (Calculations of approximate weight and correct proportions of Tolkowsky-type brilliant-cut diamonds.) *Gemologia*, **31**, 83/84, 7-21, 27 figs, pull-out tables.

Charts and diagrams are used to illustrate methods of weight calculation for Tolkowsky-type brilliants. Estimation of ideal proportions can also be carried out with the same methods. M.O'D.

BALFOUR, I., 1990. Famous diamonds. The Taylor-Burton diamond. *Industrial Diamond Review*, 1/90, **50**, 536, 32/3, 2 figs in colour.

In the first of a series of articles written for IDR, the author recounts the purchase of some of the gems that Richard Burton gave to Elizabeth Taylor. The best known among these was the 69.42 ct pear-shaped diamond, later to be called the 'Taylor-Burton' diamond.

The diamond had been cut from a 240.80 ct stone recovered from the Premier mine in 1966 and purchased by Harry Winston. After a six month study of the stone, Harry Winston's cleaver parted the diamond (under the glare of television lights) into two pieces weighing 78 and 162 carats. The 69.42 D-flawless gem cut from the larger of these pieces was first sold in 1967 to Mrs Harriet Annenberg-Ames of the USA. Then in 1969 it was auctioned and purchased by Robert Kenmore, Chairman of the Kenmore Corporation (owners of Cartier Inc.), who paid the record price of $1.05m and named it the 'Cartier'. Subsequently Richard Burton, who was outbid at the auction, purchased the stone for an undisclosed sum from Cartier and the stone was renamed the 'Taylor-Burton'.

After Miss Taylor's divorce from Richard Burton the diamond was sold in 1979 for nearly five million dollars to a New York jeweller (part of the proceedings being intended for the building of a hospital in Botswana). By the end of that year the stone had been sold once again and was last reported to be in Saudi Arabia. P.G.R.

BANERJEE, A., 1990. Erkennungsmöglichkeiten von künstlich gefärbtem Lapislazuli. (Practical recognition of artificially coloured lapis lazuli.) *Kurzmitteilungen aus dem Institut für Edelsteinforschung der Johannes Gutenberg-Universität Mainz*, **5**, (1/2), 4-5, 1 fig.

Imitation and dyed lapis lazuli can be distinguished from the natural untreated product by UV-VIS spectra. M.O'D.

BROWN, G., 1989. Synthetic quartz update. *Wahroongai News*, **23**, 11, 20-3.

Facts on man-made quartz. R.K.M.

BROWN, G., 1989. Kuri Bay cultured pearls. *Wahroongai News*, **23**, 11, 27-8.

A brief account of cultivation of large pearls on NW Australian coast. About 35% of them are marketable. *P. maxima*, silver-lipped oysters, are fished on Eighty Mile Beach and transported to culturing farms at Kuri, about 300 miles to the north east. R.K.M.

BROWN, G., 1989. Cowell jade update. *Wahroongai News*, **23**, 11, 31-2.

A new assessment of this important deposit in green and black varieties, said to be the largest known source of high quality nephrite. Dendritic weathered grey-blue variety is rare and valuable. R.K.M.

BUSHNELL, N., 1989. Diamonds – Australia's great treasure hunt. *Mazal U'Bracha*, 30, 62-73, 5 figs.

In an article first published in *Australian Business* the present production of the Australian diamond fields is reviewed. A list of the companies involved with details of their prospecting and mining areas is appended. M.O'D.

CAMPBELL, I.C.C., 1990. Doublets which simulate emerald. *South African Gemmologist*, **4**, 1, 21-3, 3 figs in colour.

A parcel of faceted emerald simulants was shown to consist of true emerald doublets in that both crown and pavilion were natural emerald glued together in the plane of the girdle. The stones ranged in size from less than 1 carat to over 8 carat and showed RI in a range feasible for emerald, 1.570-1.574 to 1.589-1.596. DR varied from 0.004-

0.007. The presence of natural inclusions could cause problems in stones in which the join is not visible. Some gas bubbles could be seen in the junction plane but this was not observed in all specimens examined. M.O'D.

CARLSSON, G., 1990. Radiamanter fran Australien. (Diamond from Australia.) *Gem Bulletinen*, 1/1990, 3pp.

The history and occurrence of diamond in Australia are described. M.O'D.

CASSEDANNE, J.P., LEDOUX, L.A., 1990. Une curieuse opale chatoyante. (A curious chatoyant opal.) *Revue de Gemmologie*, 102, 3-5, 5 figs in colour.

A piece of rough opal from an unspecified location in the Brazilian state of Bahia provided chatoyant stones with a fairly sharp whitish eye with a brownish-green background. The SG was measured at 2.15 and the RI at 1.46. No luminescence nor radioactivity was detected. Ferric iron was indicated by the presence of a strong absorption band at 490-400nm. M.O'D.

CLIFFORD, P., 1990. Gem fire. *Lapidary Journal*, **43**, 12, 20-6, 3 figs in colour.

A gemstone collection has been inaugurated in the Cleveland Museum of History, Ohio, USA. Highlights are described. M.O'D.

COENRAADS, R.R., SUTHERLAND, F.L., KINNY, P.D., 1990. The origin of sapphires: U-Pb dating of zircon inclusions sheds new light. *Mineralogical Magazine*, **54**, 113-22, 7 figs.

Uranium-lead isotope dating of two zircon inclusions in sapphires from the Central Province of New South Wales, Australia, show the ages to be 35.9±1.9 and 33.7±2.1 Ma. These and other data show that there is a genetic link between the growth of large corundum crystals and the processes involved in alkali basaltic magma generation. It has been found impossible to grow corundum from a corundum-bearing basaltic composition and the presence of U, Th, Zr, Nb and Ta in inclusion minerals show that corundum could not have crystallized from most basaltic compositions since these elements are incompatible with them. It is possible that crystallization took place with a high proportion of incompatible elements and volatiles in the melt. The crystallization products are carried to the surface by upward movement of later magmas. The economic concentration of sapphire is probably dependent upon the corundum carried by a particular basaltic province. M.O'D.

DERJAGUIN, B.V., FEDOSEEV, D.V., 1990. Low pressure diamond growth. *Industrial Diamond Review*, 3/90, **50**, 538, 155-9, 2 figs.

A review of diamond film science and technology by two leading Soviet specialists specially commissioned by IDR. Today it is almost universally accepted that low pressure diamond film growth was first achieved in the USSR, and the basic concepts further developed and 'commercialized' in Japan, followed by the USA and the rest of Europe.

As more than 1000 papers and patents have been published on the synthesis of diamond from a gas phase, the authors have restricted their review to the main fundamental results obtained in this field and have supplemented this with references to original works where necessary (although these text references, numbering fifty, appear to have been omitted from the published review).

The review deals first with the growth of synthetic diamond on diamond seed powders from the gas phase (methane, acetylene, and other hydrocarbons) in which the gas is heated up to the substrate temperature. The growth of diamond from methane is generally proportional to its pressure. When carbon is deposited from the gas phase, different carbon phases (mainly diamond, carbon and graphite) grow on the seed powder substrate. Graphite blocks the surface of seed crystals and diamond does not grow on the graphite surface at moderate supersaturations. The resulting synthetic diamond crystals, grown from methane up to a temperature of 1600°C possess a higher thermal stability (i.e. the ability to retain a high crushing strength after being heated to elevated temperatures) than the seed powder.

The second part of the review describes the various methods used to grow diamond crystals and thin films by chemical reactions. Thermal pulsing via a focused high-intensity light source (laser beam) is used to raise the temperature of the substrate from a mean of 1000 to around 2000°C. It was found that thin polycrystalline diamond films could be grown on a single seed crystal within the temperature range 1300 to 1600°C. Subsequently, prevention of the formation of graphite and the improvement of the diamond film was obtained by the use of a methane/hydrogen DC plasma, and this made it possible to grow thin polycrystalline diamond films on non-diamond substrates. Diamond films, grown at the rate of 0.1 to 10 μm per hour, had an electrical resistivity higher than 10^9ohm.cm, and a thermal conductivity of about 1,800 W/m/°C (natural diamond ranges from around 1000 for Type I to 2600 for Type II). P.G.R.

DOMENECH, M.V., SOLANS, J., 1989. Estructura cristalina, composicion quimica y propriedades fisicas de las gemas. 1. Densidad. (Crystal struc-

ture, chemical composition and physical properties of gemstones. 1. Density.) *Gemologia*, **31**, 83/84, 22-5.

The relationship between chemical composition and density is explained using gem materials as examples. M.O'D.

EVEN-ZOHAR, C., 1990. Namibia: walking on diamonds. *Mazal U'Bracha*, 33, 59-66, 11 figs.

Recent developments in diamond mining in Namibia are described with remarks on the new Elizabeth Bay mine. M.O'D.

FIELD, R., 1989. Colour in Scottish agates. *Journal of Mines and Minerals*, 7, 13-17, 15 figs (6 in colour).

The formation and colouring of agate is discussed with particular reference to Scottish material. Several important localities are described. M.O'D.

FRANK, F.C., LANG, A.R., EVANS, D.J.F., ROONEY, M-L.T., SPEAR, P.M., WELBOURN, C.M., 1990. Orientation-dependent nitrogen incorporation on vicinals on synthetic diamond cube growth surfaces. *Journal of Crystal Growth*, 100, 354-76, 12 figs.

Several significant phenomena concerning the optical properties of diamond and the inhomogeneity of impurity distribution in synthetic diamond are described. Evidence is based on optical transmission at 430nm, Schlieren photography, birefringence, IR absorption microscopy, differential abrasion resistance patterns, cathodoluminescence topography and X-ray topography with synchrotron and conventional sources. Phenomena are detailed and correlated for one specimen with data from a second similar specimen. Material belonged to one cube growth sector designated (001) with the seed absent. The chief feature of interest was a Maltese Cross type of cathodoluminescence which showed on both surfaces parallel to (001). M.O'D.

FRITSCH, E., ROSSMAN, G.R., 1990. New technologies of the 1980s: their impact in gemology. *Gems and Gemology*, **26**, 1, 64-75, 11 figs in colour.

These include computers and micro-processors; image furnaces concentrating light to make synthetics, still largely experimental; low pressure and low temperature diamond films; improved radiation to alter colour; new fillers for cracks in diamond and other gems; the electron probe for analysis; infrared, X-ray and Raman spectroscopy; cathodoluminescence; neutron magnetic resonance; electron-spin resonance and proton induced X-rays. [Most of these require apparatus outside the reach of the average gemmologist.] R.K.M.

FRYER, C.W., (ED.), CROWNINGSHIELD, R., HURWIT, K., KANE, R.E., HARGETT, D., 1990. Gem Trade Lab notes. *Gems and Gemology*, **26**, 1, 94-8, 12 figs in colour.

Synthetic amethysts salted into a natural parcel are bad enough, but synthetic sapphire of the required purple was also found, fortunately detectable by routine tests.

A rare andalusite cat's-eye is described and illustrated. A flawless fancy yellow diamond shattered under stress of minor repair-cutting. Another diamond had an internal cleavage covered with trigons.

An apparently fine emerald had filled fractures showing 'flash effects' similar to those seen in diamonds, and it was confirmed that Zvi Yehuda is now treating emeralds. A pair of natural opals were seen with black tops and white opal bases, first thought to be doublets, but no join could be seen at the sharp demarcation.

A string of naturally grey cultured pearls were found to have an exceptionally thick layer of black conchiolin.

Rough from Africa was identified as quartz with a beautiful blue colour due to inclusions of fine lazulite. All items are nicely illustrated. R.K.M.

GARCÍA GIMÉNEZ, R., LEGUEY, S., 1990. Saphirs et rubis de Tanzanie. (Sapphires and rubies of Tanzania.) *Revue de Gemmologie*, 102, 6-8, 8 figs (5 in colour).

Ruby, blue sapphire and other colours of corundum from Tanzania, are described. Colours are referred to a chromaticity coordination chart and details of inclusions and absorption spectra are given. M.O'D.

GAUTHIER, J.-P., LASNIER, B., 1990. La perle noire obtenue par traitement à l'argent. (Black pearl obtained by silver treatment.) *Revue de Gemmologie*, 103, 3-6, 8 figs (2 in colour).

Treatment with silver can turn a pearl to a near-black. Details of the treatment and characterization are given. M.O'D.

GAUTRON, L., 1989. Alpine quartz. *Journal of Mines and Minerals*, 7, 29-39, 20 figs (2 in colour).

The crystal habit of Alpine quartz is discussed with notes on various geological environments. Some collecting anecdotes are included. M.O'D.

GILLBERG, L., 1990. Opaler i Australia. (Opal in Australia.) *Gem Bulletinen*, 1/1990, 2pp, 1 fig.

A short description of the occurrence of gem-quality opal in Australia. M.O'D.

GIULIANI, G., RODRIGUEZ, C.T., RUDEA, F., 1990.

Les gisements d'emeraude de la Cordillere Orientale de la Colombie: nouvelles données metallogèniques. (Deposits of emerald in the eastern Cordillera of Colombia: a new metallogenic data.) *Mineralium Deposita*, 25, 105-11, 4 figs.

In Colombia emeralds are found in Lower Cretaceous shales of the eastern Cordillera. The tectonic pattern of the deposits is related to deep reverse and large regional fault systems and emerald mineralization is controlled by hydrothermal solutions which permeate through fractures and along stratification planes. Emerald is found in calcite veins, pockets and brecciated zones associated with pyrite, quartz, parisite, codazzite and fluorite. The emerald-forming process is epigenetic hydrothermal in type. Alteration of arenite shale formations in the Cretaceous may have contributed to the formation of solutions and establishment of hydrothermal channels. Black shales could yield Cr, V, Fe, Al and Si for the emerald but the source of the beryllium is unclear and is further discussed. M.O'D.

GROMOV, A.V., GRANADCKIKOV, B.G., ANDREYENKO, E.D., 1990. (Typomorphic features of emeralds from various deposits.) *Zapiski Vsesoyuznogo Mineralogicheskogo Obshchestva*, **119**, 2, 102-12, maps. (Russian with English abstract.)

Comparative studies of emeralds from various deposits of the USSR, Pakistan, Afghanistan and Colombia are reported, concentrating on diagnostic features of this gemstone in raw material, facet insets and cabochons, and jewellery. Solid and fluid inclusions have been studied in parallel-sided polished plates from low-quality crystals and 'emerald aerugo' and in faceted stones; homogenization temperatures are reported. Spectroscopic studies in the range 400≃750mm reveal the colour variations in emeralds from the different deposits. Density and refractive indices are tabulated; emeralds from Swat, Pakistan, have the highest values, with D 2.78 g/cm^3, ε 1.588≃1.591, ω1.596≃1.600. R.A.H.

GRUNDMANN, G., MORTEANI, G., 1990. Emerald mineralization during regional metamorphism: the Habachtal (Austria) and Leysdorp (Transvaal, South Africa) deposits. *Economic Geology*, 84, 1835-49, 16 figs.

The classic theory of emerald formation in schists attributes the formation to interaction between invading pegmatitic magma or vapour phases and pre-existing metasediments, metavolcanics and/or ultrabasic rocks. Detailed studies of the emerald deposits in the Habachtal and at Leysdorp show that the emerald formation was not due to a single-stage contact metamorphism at the border zone of magmatic intrusive bodies. In these two deposits the emeralds are found in metasomatic (blackwall) zones associated with ultramafic bodies formed by syn-to post-tectonic reactions during low-grade regional metamorphism. These reactions occur at the contact of pre-existing beryl-and phenakite-bearing pegmatites and albitite pegmatoids with biotite-talc and actinolite schists at Leysdorp or at the contact of beryllium-rich garnet-mica schists and biotite-plagioclase-gneisses with serpentinites and talc-schists in the Habachtal. M.O'D.

HENN, U., BANK, H., 1990. On the colour and pleochroism of Cu-bearing green and blue tourmalines from Paraiba, Brazil. *Neues Jahrbuch für Mineralogie, Monatshefte*, 6, 280-8, 6 figs.

A recent find of tourmaline in the state of Paraiba, Brazil, has produced material coloured bright blue and green. The colour is ascribed to trivalent Mn and/or divalent Cu. In the blue specimens two strong absorption bands show maxima at 700 and 520nm, the first band caused by divalent copper and the second by trivalent Mn. Both are in distorted octahedral coordination and cause different absorptions in ordinary and extraordinary ray directions. In the green stones only the divalent copper absorption band is recorded at 700nm. M.O'D.

HÖBELT, K.H., 1990. Opale von Yowah, Queensland, Australien. (Opal from Yowah, Queensland, Australia.) *Lapis*, **15**, 5, 37-9, 8 figs (7 in colour).

Precious opal in the form of nuts or nobbies is found at Yowah, Queensland, Australia. Examples of gem quality are illustrated and briefly described. M.O'D.

JARRY, A., 1990. Excursion à Madagascar. (Excursion to Madagascar.) *Revue de Gemmologie*, 103, 11-12, 8 figs (5 in colour).

Ruby, spessartine, danburite, tsavorite, kornerupine, apatite and spodumene are among the gem-quality minerals described. M.O'D.

KAMMERLING, R.C., KOIVULA, J.I., 1990. An interesting imitation of jadeite. *South African Gemmologist*, **4**, 2, 20-3, 2 figs in colour.

Dyed green quartzite as an oval cabochon weighing 11.54 ct was offered as jadeite. RI was 1.540-1.549, DR 0.009, uniaxial positive and aggregate reaction between crossed polars. The stone was unevenly coloured medium dark to yellowish green. SG was estimated as 2.66 and the stone showed a diffuse absorption band from 688-662nm. M.O'D.

KAMMERLING, R.C., KOIVULA, J.I., KANE, R.E., 1990. Gemstone enhancement and its detection in the 1980s. *Gems and Gemology*, **26**, 1, 32-49, 18 figs in colour.

This beautifully illustrated paper summarizes developments in the decade, covering the many effects of heat treatment; irradiation; dyeing; oiling; fracture-filling, with special reference to glass-filled holes in rubies and sapphires, and to the latest 'Yehuda-filled' cracks in diamonds and emeralds.

Where possible, ways of detection are given, but it is recognized that some treatments leave no trace other than the colour itself which may be unexpected in a natural stone. Altogether an important and extremely valuable paper. R.K.M.

KLEYENSTÜBER, A., 1990. Observations on a pyrope-almandine garnet. *South African Gemmologist*, **4**, 2, 14-19, 4 figs (2 in colour).

A transparent orange-brown cabochon weighing 7.55 ct was found to be pyrope-almandine garnet on the basis of gemmological testing and energy-dispersive X-ray analysis. The stone had n=1.749, SG 3.756 and absorption between 600 and 400nm. Wavy round channels becoming flat before breaking through the polished surface were observed with the microscope. These are hollow structures perhaps containing crystal inclusions. M.O'D.

KOIVULA, J.I., KAMMERLING, R.C., 1990. A gemmological review of Colombian emeralds. *South African Gemmologist*, **4**, 1, 5-15, 6 figs in colour.

Properties of ten Colombian emeralds are given with coloured photomicrographs depicting characteristic inclusions. M.O'D.

KOIVULA, J.I., KAMMERLING, R.C., 1990. Gem news. *Gems and Gemology*, **26**, 1, 100-9, 19 figs in colour.

First a report of things seen at the Tucson '90 Mineral Fair; new and convincing cabochon 'emerald' triplets were from Kammerling of Idar-Oberstein; deeper diffusion in treated blue sapphires was claimed by Gem Source representative, immersion microscopy detected the treatment; a six-armed star ekanite was seen [the first ekanite found was also asteriated, but with four arms only]; cat's-eye iolite was also seen (last two not illustrated); three different mother-of-pearl cameos are shown; quartzite dyed green to simulate jade was also seen.

Montana sapphires were available in a range of colours, and light blues from Colombian and Brazilian sources. An unusual greyish-violet spinel cat's-eye, and a rare red taaffeite with a uraninite inclusion, are illustrated; the new 'fluorescent' bluish-green and emerald green tourmalines from Paraiba were confirmed by Gerhard Becker of Idar-Oberstein as heat-treated, with a table showing changes obtained at 50° intervals from 350°C to 550°C; heat removes red of trivalent manganese and leaves other colourants, such as divalent copper; Tanzanian zircon was seen for the first time.

Diamonds

New 'flash' colours have been seen in glass-filled diamonds, pinkish-purple changing to yellowish-green against a bright background. Cloudy circular white patterns were on surfaces of some treated stones. 34 stones were graded before and after filling, 21 were down in colour and 18 improved in apparent clarity, only nine of which showed both changes, four showed no changes and 12 lost on colour without increasing clarity. In Australia Argyle diamonds are installing a computerized clarity analysis machine which assesses from three directions fifty times faster than human sorters. Kimberlite pipes have been found in Saskatchewan, Canada, one with micro-diamond, other pipes were sought; a computerized Israeli/Japanese diamond-cutting plant is opening in Israel. Ghana government is inviting private mining to increase dwindling production; Australians have developed new air-survey for diamond, using light beams, resultant spectra giving immediate image quality.

Coloured Stones

Amethyst sceptre crystals found at Salem, Connecticut; a 2250 ct 'emerald' beryl found in Finland; a major discovery of orthoclase from Itrongahy, Madagascar, is reported by E. Julius Petsch jun., who also supplied sample colours of spinel from the Umba region of Tanzania. Star quartz (not illustrated) reported from Plumas County, California; sunstone from Idaho is illustrated; a 20.37 ct liddicoatite tourmaline from Minas Gerais is thought to be the largest; unusual spectral iridescence in a metamict green zircon from Sri Lanka was due to laminated structure.

Synthetics and Imitations

Another large 'crystal', purporting to be emerald, was a five-sided glass prism with shrunken surfaces, unconvincing colour, moulded or partially melted edges, internal bubbles and adhered clay and mica. Other examples are known to originate in Africa. A new type of synthetic ruby, believed to be from USSR, had an aggregate grained texture with some homogeneous areas. R.K.M.

KOIVULA, J.I., KAMMERLING, R.C., FRITSCH, E., 1990. Gemmological description of a glass imitation emerald from Zambia. *South African Gemmologist*, **4**, 2, 7-13, 8 figs in colour.

A yellowish green supposed emerald crystal with RI 1.53 (mean) and estimated SG 2.50 and inert to UV turned out to be glass. Numerous gas bubbles could be seen. A 'matrix' proved to be partly a clay-like substance and partly mica, coating the five-sided habit which must have been the result of fashioning. The specimen weighed 82.85 ct.

M.O'D.

LAHL, B., 1990. Achat und Jaspis zwischen St Egidien und Hohenstein-Ernstthal in Sachsen. (Agate and jasper between St Egidien and Hohenstein-Ernstthal in Saxony.) *Lapis*, **15**, 7/8, 61-6, 15 figs in colour.

Fine specimens of agate and jasper are found between St Egidien and Hohenstein-Ernstthal, Saxony [East] Germany. Many have been cut and polished for ornamental use. M.O'D.

LARSSON, T., 1990. Den Förbisedda Adelstenen. *Gem Bulletinen*, 1/1990, 3pp.

A description of the growth, characterization and history of natural and synthetic spinel. M.O'D.

MISIOROWSKI, E.B., 1990. Jewelry of the 1980s: a retrospective. *Gems and Gemology*, **26**, 1, 76-93, 22 figs in colour.

A nicely illustrated resumé which endeavours to cover the vast spread of design tendencies in the decade, some of which were highly innovative. It is pleasing to find some British examples here, but one or two examples, e.g. the Windsor flamingo brooch, were not of that decade, although they were auctioned then. R.K.M.

NASSAU, K., 1990. Gemology – the current decade. *Lapidary Journal*, **43**, 11, 74-9, 4 figs in colour.

The various types of treatment undergone by some gem species are reviewed. M.O'D.

NASSAU, K., 1990. Synthetic gem materials in the 1980s. *Gems and Gemology*, **26**, 1, 50-63, 13 figs in colour.

Dr Nassau is a leading expert in his subject and has summarized the synthetic situation in the 1980s most efficiently.

He points out that a slowing of research in other fields, usually a source of 'spin-off' synthetic gems, led to a dearth of new man-made gems, a tendency which he thinks will continue, giving gemmology breathing space in which to perfect detection methods.

He suggests that major manufacturers of synthetic diamond may aim at the gem market, but considers the threat not to be imminent. The possible uses of single layer diamond films up to 2 μm thick is discussed [a μm is 1000th of a millimetre, not 100th]. Thicker films are technically difficult and need not yet be feared. R.K.M.

O'DONOGHUE, M., 1986. Kamienie szlachetne i ozdobne wysp brytyjskich. (Gem and ornamental minerals of Britain.) *Mineralogia Polonica*, **17**, 1, 111-14.

Occurrences and quality of gem minerals found in the British Isles are reviewed. Particular reference is made to fluorite and to agate.

(Author's abstract) M.O'D.

PETROV, I., 1990. Role of natural radiation in tourmaline coloration: discussion. *American Mineralogist*, 75, 237-9.

The paper reviews the various theories of tourmaline coloration so far proposed. The optical absorption band at 515nm and the colour-producing processes in elbaite are composed of several different phenomena. These are metastable O^{1-} centres, $Mn^{4+} \rightarrow Mn^{3+}$ electron centres and electronic transitions of transition metal ions, Mn^{3+} for example. M.O'D.

PLASZYŃSKA, M., 1988. Measurement of transmission of Chelsea filter. *Mineralogia Polonica*, **19**, 1, 113-15, maps.

The transmission spectrum of the Chelsea filter (produced by Gemmological Instruments Ltd, London) has been measured in the visible range (333≈800nm). It is zero at 333≈361.4 and 607.7≈684.5nm and increases strongly for λ684.5nm; there is a minor maximum at 578.7nm.

R.A.H.

READ, P.G., 1989. Identification methods, old and new. *Canadian Jeweller*, November 1989, 49, 1 fig.

The article contrasts the use of the Chelsea emerald filter (in the identification of emerald simulants and synthetic spinel simulants of aquamarine, sapphire and tourmaline) with the possible use of scattered Raman radiation in the identification of diamond.

(Author's abstract) P.G.R.

READ, P.G., 1990. Identifying synthetic amethysts and filled diamonds. *Canadian Jeweller*, March 1990, 27.

Test methods for distinguishing between twinned natural quartz and untwinned synthetic quartz (including the use of the conoscope) are reviewed, with the warning that they may no longer be valid as the synthetic untwinned material was developed specifically for the electronics industry and is not necessarily a feature of synthetic quartz. Identifica-

tion methods for detecting glass-filled rubies and diamonds are also described.

(Author's abstract) P.G.R.

ROBERT, D., 1990. Ces nouvelles tailles, vous connaissez? (Do you know these new cuts?) *Revue de Gemmologie,* 103, 7-9, 8 figs (2 in colour).

Several new cuts, suggested mainly for diamond, are described and illustrated. M.O'D.

RODRIGUES, P., BANERJEE, A., 1990. Anwendung der Infrarotspektroscopie in der Edelsteinkunde: Untersuchungen des Infrarot-Pleochroismus von Dipyr (Na-reichem Skapolith). (The application of infrared spectroscopy in gem testing: investigation of the infrared pleochroism in dipyre (Na-rich scapolite).) *Kurzmitteilungen aus dem Institut für Edelsteinforschung der Johannes Gutenberg-Universität Mainz,* **5,** (1/2), 1-4, 4 figs.

Polarized IR spectra were obtained from thin crystal plates of dipyre in different radiation directions at room temperature. Distances between O and H atoms could be calculated by measuring the IR pleochroism of the OH-stretching frequencies from 3700 to 3200cm^{-1}. KBr spectra showed that the OH vibrations arise exclusively from hydroxyl rather than molecular water. Specimens were of gem quality. M.O'D.

SCHWARZ, D., 1990. Die brasilianischen Smaragde und ihre Vorkommen: Santa Terezinha de Goiás/Go. (The Brazilian emeralds and their occurrence: Santa Terezinha de Goias/Go.) *Zeitschrift der Deutschen Gemmologischen Gesellschaft,* **39,** 1, 13-44, 23 figs (4 in colour), 6 tables, bibl.

New investigations of the emerald occurrences in Santa Terezinha de Goias/Go show deposits are stratiform. The optical data (RI and birefringence) measured are the highest ever observed in emeralds (up to 1.593-1.602; 0.008-0.010). They have the highest mean concentration of all Brazilian emeralds for chromium and iron. Fluid inclusions in general are very small. Mineral inclusions can be spinel, carbonates, mica, talc, amphibole, pyrite, and to some extent rutile, hematite, chalcopyrite, pentlandite and ilmenite. E.S.

SERSEN, W.J., HOPKINS, C., 1989. Al comprar y al vender gemas-que luz es la mejor? (Which light is the better for testing and selling gemstones?) *Gemologia,* **31,** 83/84, 26-50, 9 figs.

The effect of incident light on gem testing and display is examined. M.O'D.

SHIGLEY, J.A., DIRLAM, D.M., SCHMETZER, K., JOBBINS, E.A., 1990. Gem localities of the 1980s. *Gems and Gemology,* **26,** 1, 4-31, 28 figs, and world map.

A superbly illustrated summary of some old, and many new sources which came to light in the 1980s, most of which, if not all, were reported at the time in *Gems and Gemology.*

Perhaps the most important of these was the discovery and exploitation of diamonds in the north of Western Australia, which put that country to the forefront of diamond production by 1988.

This long and important paper ends with a detailed table of gem localities and nearly 200 references which emphasize the work that has gone into it. [Illustration of a Sri Lankan pink star sapphire on page 26 shows curved striae which look uncommonly like evidence of synthesis.] R.K.M.

SOBCZAK, N., SOBCZAK, T., 1985. Korale ozdobne. (Gem coral.) *Mineralogia Polonica,* **16,** 2, 85-93.

A useful account of coral and its main imitations. M.O'D.

SOBCZAK, T.S., SOBCZAK, N.R., 1987. Royal Lavulite – nowy kamien ozdobny. (Royal lavulite – a new gem material.) *Mineralogia Polonica,* **18,** 1, 73-5.

A short account of the manganoan sugilite with the trade name Royal Lavulite. M.O'D.

SONNELLRATH, J., 1990. Brasilianische Andalusite und Zink-Staurolithe von Edelsteinqualitä: Chemismus, Bildungsbedingungen, optische und kristallographische Eigenschaften. (Gem quality andalusite and zincian staurolite from Brazil: chemistry, formation conditions, optical and crystallographic characteristics.) *Kurzmitteilungen aus dem Institut für Edelsteinforschung der Johannes Gutenberg-Universität Mainz,* **5,** (1/2), 5-6.

Gem quality andalusite and zincian staurolite have been found in several placer deposits in Brazil, notably from Paramirim das Crioulas, Bahia. Crystallographic and structural details are discussed together with notes on occurrence, chemistry and colour. M.O'D.

SZENICS, T., 1990. The rediscovery of axinite at Thornberry Mountain near Coarsegold, Madera County, California. *Mineralogical Record,* 21, 127-32, 5 figs in colour).

Some medium- to low-quality axinite crystals were recovered from an albite-actinolite matrix in a dike approximately 4⅛ miles north-east by east of Coarsegold, California. Previous finds from this site, at first incorrectly described as a pegmatite, have included gem-quality material but there seems to be no more available. M.O'D.

THEMELIS, T., 1990. Oiling emerald. *Lapidary Journal*, **43**, 12, 19, 2 figs in colour.

The practice of oiling emerald is described with notes on how to recognize it. M.O'D.

WALTER, D.R., 1989. Australian gems: malachite. *Wahroongai News*, **23**, 11, 29-30.

Found mainly at Burra, north of Adelaide. Another source of green and black malachite is at Harches Creek, Northern Territory. Neither cuts to very large sizes. R.K.M.

WARD, F., 1990. Emeralds. *National Geographic Magazine*, July 1990, 38-69, 34 figs in colour.

An up-to-date and accurate overview of the mining and marketing of emerald throughout the world with notes on identification techniques. M.O'D.

WATT, J.C.Y., 1990. Neolithic jade carving in China. *Transactions of the Oriental Ceramic Society*, 53, 11-26, 22 figs.

During the past few years important Neolithic sites in the areas beyond the Yellow River basin have been investigated. In some of these sites bowenite is found as well as nephrite and it has been used for similar artefacts. The latest thoughts on the purpose of some of the obscurer objects are given. M.O'D.

WHITE, J.S., COOK, R.B., 1990. Amethyst occurrences of the eastern United States. *Mineralogical Record*, 21, 203-13, 19 figs (18 in colour).

Amethyst occurs in four distinct types of geological environment in the eastern United States. Most occurrences are restricted to crystalline units of the Piedmont and Blue Ridge physiographic provinces. Other amethyst deposits occur in Triassic traprock dikes and sills extending from northern Virginia to Nova Scotia. Especially fine gem quality material has been recovered from Upper Providence Township, Delaware County, Pennsylvania. M.O'D.

WILSON, W.E., 1990. What's new in minerals? *Mineralogical Record*, 21, 253-60, 17 figs in colour.

A report of notable exhibits at the 1990 Tucson Gem and Mineral Show includes well-formed chrysoberyl crystals from Pancas, Espirito Santo, Brazil; dark green apatite from the Jose Pinto mine, Governador Valadares, Minas Gerais, Brazil; gem quality realgar from Shimen, Hunan Province, China; rose quartz from the Pitorra mine, Minas Gerais, Brazil; sceptre elbaite from Barra de Salinas, also in Minas Gerais; clear yellow orthoclase crystals from Itrongay, Malagasy Republic and fine azurite groups from the Bou Beker mine near Touissit, Morocco. M.O'D.

WOODRUFF, R.E., FRITSCH, E., 1989. Blue pectolite from the Dominican Republic. *Gems and Gemology*, **25**, 4, 216-25, 13 figs in colour.

Best known for amber and conch 'pearls', this Caribbean country is now producing an attractive massive blue pectolite, a sodium calcium silicate coloured here by copper. Finest material is a good turquoise blue, grading to bluish-green and green; fibrous, polycrystalline with RI 1.59 tgo 1.63, SG 2.62 to 2.83 for best blues, H 5 to 6 for the fibrous material. Fluoresces green, through yellow to blue, more intensely in SUV. Dendritic acicular red hematite and other attractive graining due to the fibrous structure increases the appeal of the stones. Authors consider output could increase if geology of deposit were studied. R.K.M.

ZEITNER, J.C., 1990. Obsidian. *Lapidary Journal*, **43**, 12, 43-50, 2 figs in colour.

The mode of occurrence of obsidian is described and some of the types are listed, with notes on fashioning. Locations in the United States are mentioned. M.O'D.

ZEITNER, J.C., 1990. Eternal sky. *Lapidary Journal*, **43**, 11, 49-57, 3 figs (2 in colour).

The various turquoise deposits of North America are reviewed with notes on Indian artefacts and on contemporary production. M.O'D.

ANON. 1989. Geological Museum Newsletter 1989/2. Hot rocks from Hawaii. *Wahroongai News*, **23**, 11, 7-8.

A brief account of lava flows in Hawaii, one type smooth and billowy called Pahoehoe; the other block and tumbled, called Aa. Lavas largely labradorite feldspar, but large grains of peridot can be found. R.K.M.

1990. World's largest opal to be sold at Christie's Geneva, 15 November. Press release, Christie's.

The world's largest opal, Jupiter-Five, and a smaller stone, Persephone, are due to be sold at Christie's Geneva on 15 November 1990. Jupiter-Five weighs 5.27 kilos [26,350 ct] and was found in 1989 at Coober Pedy, South Australia. Persephone weighs 765 ct and shows strong red and orange as well as other colours; this stone is polished and the colours appear strong in dim light. M.O'D.

Book reviews

ADAMSON, G.F.S., 1988. *At the end of the rainbow: gold in Scotland*. Albyn Press, Haddington. pp.94. Illus. in black-and-white. £6.95.

This interesting book lists many occurrences of gold in Scotland with chapters on gemstones and freshwater pearls in which these topics are briefly covered. Much of the information would be hard to find elsewhere; grid references would have been useful but perhaps security considerations prevented this. M.O'D.

ANDERSON, B.W., 1990. *Gem Testing*. 10th edn. revised and updated by E.A. Jobbins. Butterworths, London. pp. x, 390. Illus. in black-and-white, with 70 coloured plates. £30.00.

It is ten years since the late and greatly missed Basil Anderson revised his *Gem Testing* for its 9th edition. Originally published as *Gemtesting for Jewellers* nearly 50 years ago, the book has developed and matured over the years to become one of the most readable and certainly the most authoritative of gemmological texts. Four reprints of that edition, the last in 1988, added no new information, although a glaring printers' error among the spectrum illustrations was corrected.

Such a valuable text should not be allowed to die, and a 10th edition was badly needed. Very sadly, Basil Anderson passed away in 1984 at the age of 81, and Mr E.A. Jobbins, formerly Curator of Minerals and Gemstones at what was then the Geological Museum, and a gemmologist of very considerable note, has now taken on the exacting task of updating and revision.

The major part of this new edition remains largely as written by Anderson, and new facts, of which there are many, have been inserted discretely without disrupting his eminently readable style. Official pronouncements from various international bodies in the last decade or so have decreed certain changes and we find the wavelength of light, which was formerly measured in Angstrom Units (Å), now quoted in nanometres (nm). Heavy liquids and those used for optical purposes have been given new names: the familiar, and one might almost say much loved, 'methylene iodide' now becomes 'diiodomethane' which may make organic chemists happy, but tends to leave established gemmologists puzzled; while 'mono-bromo-naphthalene' becomes '1-bromonaphthalene'. [The latter is no great change, but one is left wondering why the first liquid retains its Greek suffix instead of becoming '2-iodomethane'.] However these are changes imposed from outside and were necessary parts of the updating. Basil Anderson, too, would almost certainly have conformed, but I do not think he would have been happy at abandoning the Angstrom.

The greatest change in this new edition is the inclusion of two valuable new chapters: '7 The manufacture of synthetic and imitation stones' and '8 Gemstone enhancement'. Many of the excellent illustrations and facts for these are taken from the books *Man-made Gems* and *Gemstone enhancement* by Dr Kurt Nassau, a world authority on these matters, with his permission and that of his publishers. Figure 7.1, a diagram of the Verneuil furnace, has been taken from the 9th edition of the Anderson book and still has the oxygen and hydrogen input tubes labelled in reverse. (B.W.A. was aware of this, and that the same drawing was also incorrect in his book *Gemstones for Everyman*, but he apparently did not leave a note of the error with a possible tenth edition in mind.)

Chapter 9 'Detection of synthetic, imitation and composite stones', has been re-shuffled to accommodate new developments in a logical order.

The further sixteen chapters dealing with specific gems are again left largely as Anderson wrote them, but with many important new facts and developments incorporated skilfully to maintain the continuity. Only in one or two instances do facts seem slightly out of sequence and a check shows that they were so in the 9th edition.

The new book has 390 pages as against 434 in the 9th, but the page size of the 10th is 23 x 16cm (9th, 21 x 13cm), with 50 lines (9th, 42 lines) to the page, so the new edition is substantially the longer book. Many of the mono-chrome illustrations [I am tempted to call them 1-chrome] are from previous editions, occasionally turned around to present a fresh and perhaps better aspect, but there are many new ones, some of which are quite outstandingly good. But the truly great feature in this respect is the 70 superb colour plates covering 16 pages which, being unnumbered, are additional to the 390

pages of the text. Many of these are the exceptional work of the revising author, Alan Jobbins, who is also responsible for the Topaz crystal group used for the dust cover. Much care was taken to ensure that the reproduction of the colour plates is as it should be, and the general result is outstanding.

The book is clearly printed, in a good modern type-face which I found easy on rather ancient eyes. The few printers' errors are almost all a matter of a single missing or misplaced letter and do not alter meanings in the ones I found. But it is normal practice for printers to correct spelling errors when they spot them and this can occasionally lead to 'corrections' where the original typescript was right and the correction wrong. One such occurs on page 328 where a source of glass imitation cat's-eye is given as 'India (Cathay)'; this I am told should have been '(Cambay)'. Cathay is the old name for northern China.

Webster's unscientific recipe 'ten level teaspoonsful salt to a normal tumblerful of water' for brine to float amber, is quoted twice, and I was relieved to see that the second time was followed by a more exact version (50g salt in 250ml of water). Teaspoons vary with the maker. They are not standard size, a fact which I brought to Robert's notice many years ago, without effect.

Alan Jobbins has done an excellent job in bringing this valuable work up to date, despite illness which necessarily delayed its production. It should now serve as a reliable and indispensable textbook for students world-wide, as indeed earlier editions have done in the past. It is an essential and very valuable addition to any gemmologist's library.

R.K.M.

CALVERT, J., 1990. *The gold rocks of Great Britain and Ireland*. Goldpanners Association, Beaconsfield. £12.50.

Facsimile reprint of a book first published in 1853. M.O'D.

DOWNING, P.B., 1990. *Opal adventures*. Majestic Gems and Carvings, Tallahassee. pp.234. Illus. in black-and-white and in colour. £11.50.

This is an excellent account of opal and opal mining, set chiefly in Australia, with special emphasis on South Australia, but with notes on other world locations. The author has visited many mines and gives step-by-step notes on how opal is identified in the mine and recovered. Different fields are compared and there are notes on the way opal is valued in the rough and on cutting. The author's notes on Japanese involvement in opal buying are interesting and the book can be strongly recommended. The colour photographs are good and there is a useful glossary of opal mining terms. A short bibliography concludes the book. M.O'D.

FEDERMAN, D., 1990. *Modern jeweler's consumer guide to gemstones*. Van Nostrand Reinhold, New York. pp.253. Illus. in colour. £14.00.

This is an update of a book first published in 1988 under the title of *The First 60*. Sixty species are described in this update too, each one having updated mining and marketing information as well as brief gemmological notes where they are generally and commercially informative. The coloured photographs by Tino Hammid are excellent for a relatively cheap book which can be recommended for the jeweller's counter as well as for the gemmologist and student. M.O'D.

Edited by KAZMI, A.H., SNEE, L.W., 1989. *Emeralds of Pakistan: geology, gemology and genesis*. Geological Survey of Pakistan and Van Nostrand Reinhold Co., New York. pp. xxi, 269. Illus. in black-and-white and in colour. £28.00.

This is a major multi-author work on a single gem mineral from a particular area and as such is a rarity in gemmological literature. However, this type of work is likely to become more common in future as academic departments with experienced staff become more involved with the study of gemstones. This development is long overdue and most welcome. The book is well-produced on the whole (though my copy has some pages repeated, none appear to be missing) and the standard of the colour pictures is high. This is especially true of the set of inclusion photographs by Dr E.J. Gübelin. For such a book the price is very reasonable.

The book opens with an overview of the geology and metallogenic provinces of Pakistan, describing in particular the collision between the Indo-Pakistan and Eurasian plates. This collision resulted in the upthrust of the world's highest mountains and the mineral deposits formed in geological environments unique to the various tectonic zones resulting from the original collision and subsequent movements. The book then turns to the geological setting of the emerald deposits and then to the deposits themselves. The major mines in the Mingora area are fully described, the chapter treating each individual quarry in detail with maps and plans. The other deposits are then described; these include Gujar Killi, Khaltaro, Charbagh, Makhad, Barang and Nawe Dand. The deposit of emerald-like vanadium beryl at Gandao is also described.

The next chapter covers the gemmological characteristics of the emeralds and here the set of 36 coloured pictures of inclusions by Dr Gübelin show how the Pakistan emerald can in general be recognized by the presence of combined curved secondary fluid inclusions, jagged three-phase primary

inclusions and either euhedral dolomite crystals with chromite and/or fuchsite: this pattern is especially characteristic of the Mingora emerald. Stones from Charbagh show curved fluid inclusions with gersdorffite and/or magnesite and/or pentlandite. Khaltaro stones show primary and secondary fluid inclusions forming an endogenesis with albite, calcite and actinolite. These are general pictures only and it should be stressed that there is no overall diagnostic inclusion pattern for the emeralds.

The next chapter outlines regional chemical differences among emeralds and host rocks of Pakistan and Afghanistan with implications for the origin of emerald. This chapter gives considerable analytical detail of specimens and results from individual mines and sections of mines are compared. This section is followed by a survey of the mineral chemistry of emeralds and some associated minerals from Pakistan and Afghanistan. The survey used an electron microprobe. Next comes a reconnaissance study of the fluid inclusion geochemistry of the same deposits.

The rest of the book is devoted to the geology of worked emerald deposits in which many classic areas are given a similar treatment to that given to the Pakistan deposits earlier in the book. Each chapter in the book has its own bibliography and general references, selected by the US Geological Survey, come at the end. There are author and subject indexes to complete a major and superb work. The reviewer was delighted to renew acquaintance with areas where he spent many happy hours. M.O'D.

LINTILHAC, J.-P., 1987. *Black pearls of Tahiti*. Royal Tahitian Pearl Book, Papeete, Tahiti. pp. 109. Illus. in black-and-white and in colour. Price on application.

The text is a translation from the French and describes the pearls of Polynesia. The oyster concerned is said to be *Pinctada margaritifera* and its variant *cumingi* also produces pearls. Despite the title most of the Polynesian pearls do not originate from Tahiti and few are truly black; the main pearl-producing areas are some of the outer islands of French Polynesia, especially those in the Tuamotu Archipelago and the Gambier Islands. Pearl colour varies from white to steel grey, bronze, blue, green, purple and pink; some examples are copper and gold or black. Shapes may be round, button-shaped, blister or keshi.

The book, whose style and presentation clearly aims at a wide readership, opens with a brief description of French Polynesia and continues with a history of pearl oyster fishing in Polynesia. The pearls from this area were unknown to Europeans until the visits of explorers in the seventeenth and eighteenth centuries. Details of the original methods of diving show how dangerous a practice this was and many lives must have been lost. This account is followed by a description of modern methods of pearl recovery. The next section of the book describes the oyster itself, *Pinctada margaritifera Cumingi*, which is the most characteristic pearl-producing mollusc in the region. The old theory of pearl growth initiated by a solid intruder is discounted but no new theory is advanced. Methods of pearl farming are described and pearl classification outlined. The photographs which decorate almost every page add to the attraction of this useful guide. The pictures of molluscs are especially clear. M.O'D.

PIENAAR, H.S., GLENISTER, D.A., 1987. *The Stellenbosch gem index: a numerical approach to gemstone identification*. De Beers Laboratory, University of Stellenbosch, South Africa. pp. ii, 39. US $4.00 plus postage.

A value to be called the SGI value is calculated from the specific gravity and refractive index of a wide variety of gem minerals and is proposed as a useful single figure for identification in the range 1-6000, not all SGI values applying to known individual species. The book provides a list of gem minerals in numerical order of the values followed by an alphabetical listing. Separate tables for materials with a refractive index higher than 1.81 and for glass and plastics are also given. The idea is interesting and the tables useful though many minerals occur over a wide range of SGI figures; elbaite for example turns up in sixteen groups covering the numerical range 115-136. The concept would need wide acceptance to be really useful but the relative positions of species in the tables are interesting in themselves. Silicon carbide would fill one of the gaps, according to my calculations.

M.O'D.

Proceedings of the Gemmological Association and Gem Testing Laboratory of Great Britain and Notices

OBITUARIES

Mr W.A. Burslem, FGA (D.1964), West Derby, Liverpool, died on 16 July 1990.

Mr A.M.N. Thurlow, FGA (D.1934), Sevenoaks, died in May 1990.

Mrs Christine Wong, FGA (D.1984), Hong Kong, died on 30 April 1990.

MEMBERS' MEETINGS

London

On 25 September 1990 at the Flett Theatre, Geological Museum, Exhibition Road, London SW7, **Dr George Harlow** gave a lecture entitled '100 years of gems at the American Museum of Natural History'.

Midlands Branch

On 21 September 1990 at the Society of Friends, Dr Johnson House, Colmore Circus, Birmingham, **Mr Spencer Mather** gave a talk on the cutting of gemstones and lapidary work using machinery, much of which was home-made.

North West Branch

On 19 September 1990 at Church House, Hanover Street, Liverpool, **Mr John Bugg, FGA,** gave a talk entitled 'The law and gemmology'.

NEWS OF FELLOWS

Mr Alan Hodgkinson and **Dr Jamie Nelson** were invited to attend the Annual Spring Meeting of the German Gemmological Society (Deutschen Gemmologischen Gesellschaft) held in May 1990 at Idar-Oberstein, West Germany, and to speak on topics of their choice.

On 26 May a gathering of members of the Society was held in the Ausbildungszentrum (teaching centre and laboratories of the DGG). Six working groups gave lecture/demonstrations. Mr Hodgkinson demonstrated his 'Visual optics' technique of gemstone identification without instruments and Dr Nelson gave a talk/demonstration on 'The four optical attributes of a diamond'.

On 27 May a meeting was held in the Diamond and Gemstone Bourse (Börsensaal) at which Dr Nelson gave a lecture 'On the colour assessment of gemstones', illustrated with slides and demonstrations.

On 28 May in the Ausbildungszentrum events included a series of interlocking 'hands-on' demonstrations by Mr Hodgkinson and Dr Nelson of a variety of apparatus relating to research, teaching and student applications.

On 4 June 1990 **Mr Michael O'Donoghue** spoke on 'Gemstones' to Sotheby's 'Looking at Jewellery' course.

On 12-14 June 1990 **Mr Michael O'Donoghue,** with **Mr Peter Read** and**Mr Roy Huddlestone,** conducted a three-day course in preparation for the Association's examination.

On 10 July 1990 **Mr Michael O'Donoghue** gave a talk entitled 'Synthetics' to the Essex Rock and Mineral Society.

On 24 July 1990 **Mr Michael O'Donoghue** gave a talk on his latest book, *Field guide to rocks and minerals*, on Radio Kent.

On 3 October 1990 **Alan Jobbins** gave the opening lecture on 'Jades' in the 'Gemmologia Europa III' series of lectures which are held biennially in Milan, Italy, under the auspices of CISGEM, the Milan Gem Testing Laboratory and the Milan Chamber of Commerce and Industry. Prominent gemmologists from France, Germany, The Netherlands and Portugal will present other lectures in the series.

ANNUAL GENERAL MEETING 1990

The 59th Annual General Meeting of the Association was held on 4 September 1990 at the Thames Restaurant, Earls Court Exhibition Centre, London SW5.

The Chairman, Mr David Callaghan, FGA, opened the meeting and welcomed members. Mr Callaghan reported that, as a result of the severance with the National Association of Goldsmiths (see

p.194), Mr Jonathan Brown and Mr Bill Pluckrose were no longer serving the Association. Mr Callaghan thanked them for the tremendous amount of work they have done which was very much appreciated. He also thanked Noel Deeks and Nigel Israel for their help and support during the year.

Mr Nigel Israel, Honorary Treasurer of the Association, presented the audited accounts for the year ended 31 December 1989. The adoption of the Report and Accounts was duly proposed, seconded by Mr David Larcher, and carried.

Sir Frank Claringbull, Mr David J. Callaghan, Mr Noel W. Deeks and Mr Nigel B. Israel were re-elected President, Chairman, Vice-Chairman and Honorary Treasurer, respectively. Messrs A.E. Farn, A.J. French, Dr. G. Harrison-Jones, E.A. Jobbins, D.G. Kent, A.D. Morgan, P.G. Read, K. Scarratt and Mrs E. Stern, were re-elected to the Council.

Messrs Hazlems Fenton were appointed Auditors, and the proceedings then terminated.

EXTRAORDINARY GENERAL MEETING

At an Extraordinary General Meeting of the Association held on 4 September 1990 in the Thames Restaurant, Earls Court Exhibition Centre, London SW5, immediately following the Annual General Meeting, the following resolutions were proposed and passed:

1. THAT the Memorandum of Association be amended by the inclusion of the following at the end thereof:- 'THAT the Association shall transfer its assets and liabilities to The Gem Testing Laboratory of Great Britain substantially in accordance with an agreement in the form of that presented to the meeting with such amendments as may be agreed by the Officers.'

2. THAT the Articles of Association be amended by the inclusion of the following at the end thereof:- 'Notwithstanding any other provisions of these Articles the following shall, pursuant to the transfer of the assets of the Association to The Gem Testing Laboratory of Great Britain, have effect pending dissolution of the Association:-

1. There shall be only three members of the Association who shall each have one vote and shall by their presence in person constitute a quorum at any meeting of the members. They shall not be required to pay any subscription. The first such three members shall be the individuals who are respectively, as at the date of this Resolution, the Chairman, the Vice Chairman and the Honorary Treasurer. All the present members other than the said three shall *ipso facto* on the passing of this Resolution cease to be members.

2. There shall be no officers of the Association but there shall be three members of the Council of Management who shall be the same persons as the three members and who shall by their presence in person constitute a quorum at any meeting of the Council of Management. All the present members of the Council of Management other than the said three shall *ipso facto* on the passing of this resolution cease to be members thereof.

3. Such members of the Council of Management shall continue to be such unless and until their resignation or death.

4. In the event of the:-

(a) resignation of one of the members the others shall have the right to and shall immediately appoint a replacement and no such resignation shall be effective unless his co-members shall have appointed a replacement.

(b) death of one of the members the others shall have the right to and shall immediately appoint a replacement. In the case of the remaining members not having made such an appointment within 28 days after the vacancy arising, the appointment may be made by the Gem Testing Laboratory of Great Britain.

5. No resignation of any sole remaining member shall be effective unless he shall have appointed replacements for his co-members and for himself.

6. In the case of the death of any sole remaining member without having made such appointment as is referred to above the appointments of the three new members shall be made by The Gem Testing Laboratory of Great Britain.

7. No appointment shall be effective unless the appointee shall have signified in writing his acceptance of the appointment.

8. No member of the Council of Management shall be a Chairman or have any second or casting vote.'

COUNCIL OF MANAGEMENT MEETING

At a meeting of the Council of Management held on 19 September 1990 at 27 Greville Street, London EC1N 8SU, the business transacted included the election to membership of the following:

Fellowship

Alejo, Deidre K., Kowloon, Hong Kong. D.1990
Anver, Mohamed F., Harpenden. D.1990
Barker, Damon A.N., Winchester. D.1990

Bing, Sara V., Exeter. D.1990
Bowler, Simon R., Birmingham. D.1990
Boyer, Alice M., Silver Spring, Md., USA. D.1990
Charatan, Ivan L., London. D.1990
Copestick, Bruce J., Harpenden. D.1990
Davidson, Anthony, Newcastle upon Tyne. D.1990
Downer, Martyn D., London. D.1990
Garty, Annemarie, Dundee. D.1990
Gibson, Bracken G., London. D.1990
Hinds, Andrew F., Rickmansworth. D.1990
Hollanders, David J., Maidenhead. D.1990
Lynch, Kieran J., Coventry. D.1990
Mallett, Gillian E., Cambridge. D.1990
Mann, Alexandrina E., Nottingham. D.1990
Parkhill, Melanie J., Wickhamford. D.1990
Rackley, Trevor, Wantage. D.1990
Ripley, Thomas, Stockton. D.1990
Sanson, Steven N.J., London. D.1990
Saywell, Neil, West Bridgford. D.1990
Sergoulopoulos, Alexandros, Athens, Greece. D.1989
Shafar/Pettigrew, Louise, Eaglesham. D.1990
Smith, Karen, Dewsbury. D.1990
Smookler, Sheryl, London. D.1990
Spink, Michael C., London. D.1990
Veecumsee, Dipal, Madras, India. D.1989
Well (née Green), Sheila M., Glasgow. D.1990
West, Kenneth J., Hove. D.1990

Transfers from Ordinary Membership to Fellowship

Baldock, Janine, London. D.1990
Bubshait, Ahmed I., Manama, Bahrain. D.1990
Clark, Susan W., London. D.1990
Colomb, Nannette D., Epsom. D.1990
Corne-Halstenbach, Michele, Geneva, Switzerland. D.1990
Davies-Lloyd, Susan M., Tarporley. D.1990
Edwards, Susan M., London. D.1990
Fitzmaurice, Karl M., Dublin. D.1990
Gademsetty, Subba R., Chigwell. D.1990
Gunaratne, Ananda L., Kundasale, Sri Lanka. D.1990
Hayakawa, Taketoshi, Kanagawa Pref., Japan. D.1990
Henry, John M., Bolton. D.1990
Inkpen, Michael S., Kingsbridge. D.1990
Ishikawa, Noriko, Tokyo, Japan. D.1990
Jhaveri, Devang, London. D.1990
Jinbo, Kazuko, Tokyo, Japan. D.1990
Komppa-Vigar, Leena M., Westoning. D.1990
Lancaster, Wendy, New Malden. D.1990
Lees, John A., Waterford, Va., U.S.A. D.1990
Liyanage, Don C.S., Ashford Common. D.1990
Matsumoto, Tamio, Tokyo, Japan. D.1990
Nakane, Tomoko, Tokyo, Japan. D.1990
Oldershaw, Caroline J.E., Penn. D.1990
Pyzowski, Carl C., Frackville, Pa, USA. D.1990
Roberts, Anne M., Crawley. D.1990
Shah, Anurag D., Nairobi, Kenya. D.1990
Shibata, Hirofumi, Osaka, Japan. D.1990
Sim, Evelyn, London. D.1990
Skilton, Margaret, Auckland, New Zealand. D.1990
Spencer, Stephen R., Drewsteignton. D.1990
Terpilak, Thomas J., Bethesda, Md, USA
Van Heesewijk, Jacqueline W., London. D.1990
Wilson, Nean E., Longniddry. D.1990
Wright, John C., Solihull. D.1990

Ordinary Membership

Balas, Sharon L., London.
Bett, Dana I., London.
Brown, Irwin H., Northwood.
Burgess, Ian D., London.
Chetwin-West, Sheridan L., Morecambe.
Dale, Sharon J., Sutton.
De Agustin, Luis, New York, NY, USA.
Doyle, Robert, London.
Duff, Alexandra S.F., Limerick.
Duff, Wayne A., Harrow.
Durkin, Larraine J., London.
Embleton, M.L., Basildon.
Gemmell, James, Havant.
Gonzalez Notario, Alfredo, Madrid, Spain.
Graham, Josephine M., London.
Gutmannsbauer, Winfried, Allschwil, Switzerland.
Hering, Peter J., Cambridge.
Jhaveri, Shree, Bombay, India.
Jordan, Steven L., Boston.
Kejriwal, Bindu, London.
Lloyd, Brian R.D., Nairobi, Kenya.
Martin, Melanie J., London.
Miller, Carol B., Hong Kong.
Neilson, Robert W.E., Strumpshaw.
Nickless, Christine M., Birmingham.
Olver, Paul A., Farnham.
Packard, Gilian E., London.
Patel, Chetan, Harrow.
Pollard, Adrian N.F., Stockport.
Sayed, Ahad, Brentford.
Seaman, Teresa L., Hornchurch.
Smith, Sarah J., London.
Sollitt, Heidi, Thaxted.
Stapley, Kerrie, Lancing.
Steffensen, Torben A., Copenhagen, Denmark.
Tubel, Wayne P., London.
Tucker, Keith A., Ilkley.
Vaughan, John W., London.
Wasserman, Caron J., London.
Webb, Lionel, Reading.
Wilkins, Antony C.F., Folkestone.
Zander, Marie C.M., Sao Paulo, Brazil.
Zwaan, Johannes C., London.

EXHIBITIONS

History of the Cheapside Hoard

The famous Cheapside Hoard of Jewellery, discovered by a City workman in 1912, is being redisplayed in a new case in The Museum of London, London Wall, London EC2, from 18 September 1990. Fibre optic lighting adds an extra sparkle to the gemstones and delicate settings of these 16th and 17th century specimens.

The range of gems, settings and vessels in the hoard indicate that it was probably the stock in trade of a working goldsmith but contemporary portraits show that the jewels appear to date from the mid-16th to the mid-17th century. The enamelled chains and delicate hair pendants are typical of the 1560s although they were still worn in the early 17th century, whereas the enamelled fan holders or dress ornaments which can be seen in the late 16th century portraits, judging from prints by Wenceslaus Hollar, were fashionable in the 1640s. The wide variation in date and the presence of rock crystal tankards, salt, chalice and case suggest that this unknown goldsmith was also operating as a pawnbroker. The reliquary pendants and cameos with Christian subjects indicate that some of these pledged goods may have come from an ecclesiastical source.

The gems included garnets from India and Sri Lanka and turquoises from Nishapur, Persia and Sinai peninsula which were obtained through the Turkish market (hence the name). The emeralds were imported from Colombia after Christopher Columbus's voyage of discovery in 1492. Amethysts found in the Alpine regions, were believed to protect the wearer against harm in battle, and acted as an antidote against poison and drunkenness. Cameos and intaglios dating from Roman and Byzantine times were set in rings and pendants and indicate the contemporary interest in earlier gems.

Treasures and Trinkets

From January 1991 The Museum of London, London Wall, London EC2, will present an exhibition drawn from its collection of jewellery found in London from pre-Roman times to the 1930s. *Treasures and Trinkets* will include jewellery worn as symbolic of love, death, belief and social status.

The exhibition will have a strong educative purpose. The pieces will not simply be displayed for their glitter but to demonstrate the development of the jewellery trade in London, to explore the significance of symbols and association in jewellery and to cover changing fashions in jewellery and its relationship to dress from Roman to Victorian times. All these aspects will also be examined in the fully illustrated catalogue. There will be a full programme of lectures, demonstrations and workshops and a day conference organized in association with the Society of Jewellery Historians.

1990 INTERGEM FAIR

The sixth INTERGEM Fair was held in Idar-Oberstein from 7-10 September 1990. It was opened by the German Minister for Economics. The central theme this year was 'Africa'; there was a special exhibition showing some beautiful specimens from that continent and there was also a series of lectures dealing with stones from Africa. Johnny Roux talked about 'Rough diamonds', and there were also talks entitled 'Tsavorite', 'Tourmalines in Namibia', 'Tanzanite' and 'East African corundums'.

Large quantities of mainly cut gemstones were on show, many cut in the modern idiom, some quite attractive. A number of beautifully carved animals and birds were exhibited.

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A member of the Association has for sale a complete set of *The Journal* from 1972 to 1989, as well as back issues of overseas journals. Enquiries to the Association, Box No. 1713.

CORRIGENDA

On the front inside cover of Vol. 22, No. 3, last line, for '071-404 3344' read '071-404 3334'

On p.163 above, first column, line 4, for 'authords' read 'authors'

On pp.174, 175 and 176 above, below graphs, for 'Wavelenght' read 'Wave number'

On p.182 above, first column, line 25, for 'f1565' read 'f750'

On p.183 above, second column, line 18, for 'Wnedell Wilson' read 'Wendell Wilson'

On p.183 above, second column, line 30, for 'megnificent' read 'magnificent'

On p.185 above, first column, line 35, for 'Presidium Duotester' read 'Gem test instruments'

On p.146 and p.190 above, the price shown for the Gemdata – Update 2 should read £90.00 (plus postage and VAT).

Letter to the Editor

From Dr H.A. Hanni, FGA

Dear Sir,

Some readers of my recent 'Contribution to the distinguishing characteristics of sapphire from Kashmir' (*Journal of Gemmology* 1990, 22, 67-75) would have welcomed an absorption spectrum in the publication of the described sapphires. I agree with this proposal and should like to give the following graphs of typical spectra of four different sapphire types. The comparison of them is meaningful concerning origin determination, since each of the four sources expresses its characteristic formation by a more or less typical absorption spectrum.

The graph shows spectra of sapphires from Kashmir, Sri Lanka, Burma and Pailin. The spectra are recorded with a spectrophotometer plus polaroid filters on oriented cut gemstones, thus an ordinary (o') and extraordinary (e') curve was produced, showing more or less pure o and e vibration spectra.

From left to right they show increasing strength of Fe^{3+} presence, expressed by the peaks at 374, 388 and 450 nm. As well as the Fe^{3+} signal, the position of the cut-off (from 295 to 340 nm) is also of diagnostic value. In addition sapphires from Burma and Ceylon most frequently show a 'lump' at 328 nm, where the absorption is already approaching the cut-off edge.

Not every sapphire from a particular origin shows exactly the same characteristic path of the curve. There is some variation among them, e.g. the cut off may shift up or down some 10 nm. The depicted curves represent thus only mean values. An absorption spectrum from the characteristic part (between 500 and 290 nm) gives us further indications along with others (inclusions, chemistry etc) but cannot

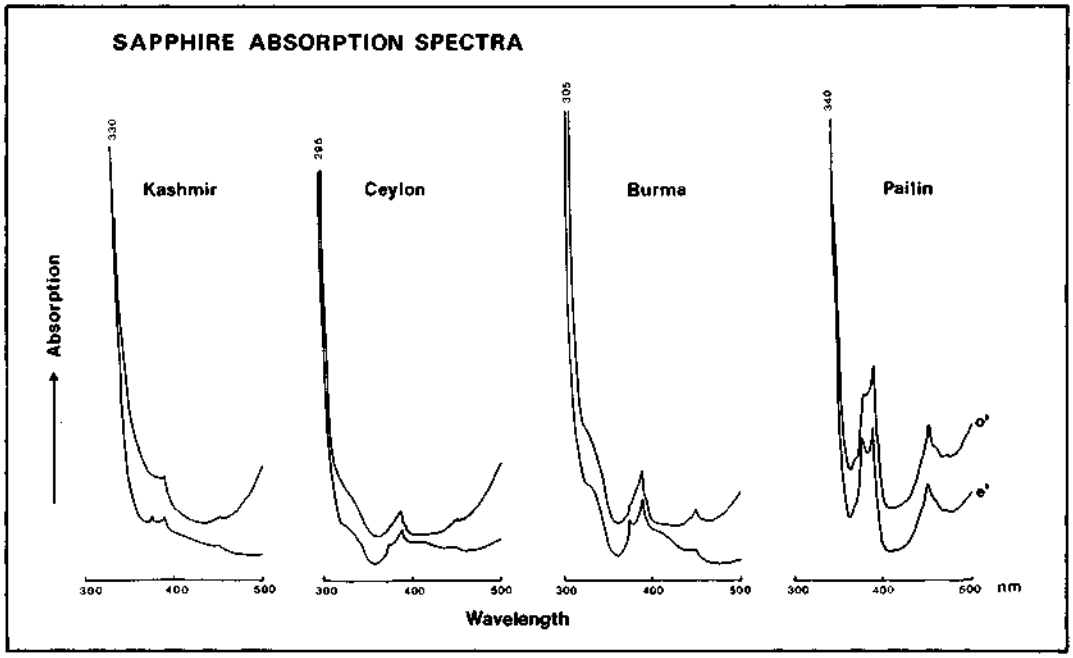

be regarded as an isolated foolproof method.

The spectrum of 'Pailin sapphire' stands for a very large group of sapphire origins, those coming from alkali basalt deposits. It is therefore not typical for a geographic place, but for geological conditions under which basaltic sapphires were formed.

I hope to have satisfied those readers who were interested in additional and somewhat more technical information on sapphire spectra. Understanding this addition helps in that one is now able to differentiate between Kashmir and Pailin sapphires (two types which are often confused with each other). Even with a spectroscope the strength of the 450 nm line allows a safe differentiation.

Yours etc.,
H.A. Hanni

8 July 1990
SSEF Laboratory, Löwenstrasse 17, Zurich, Switzerland.

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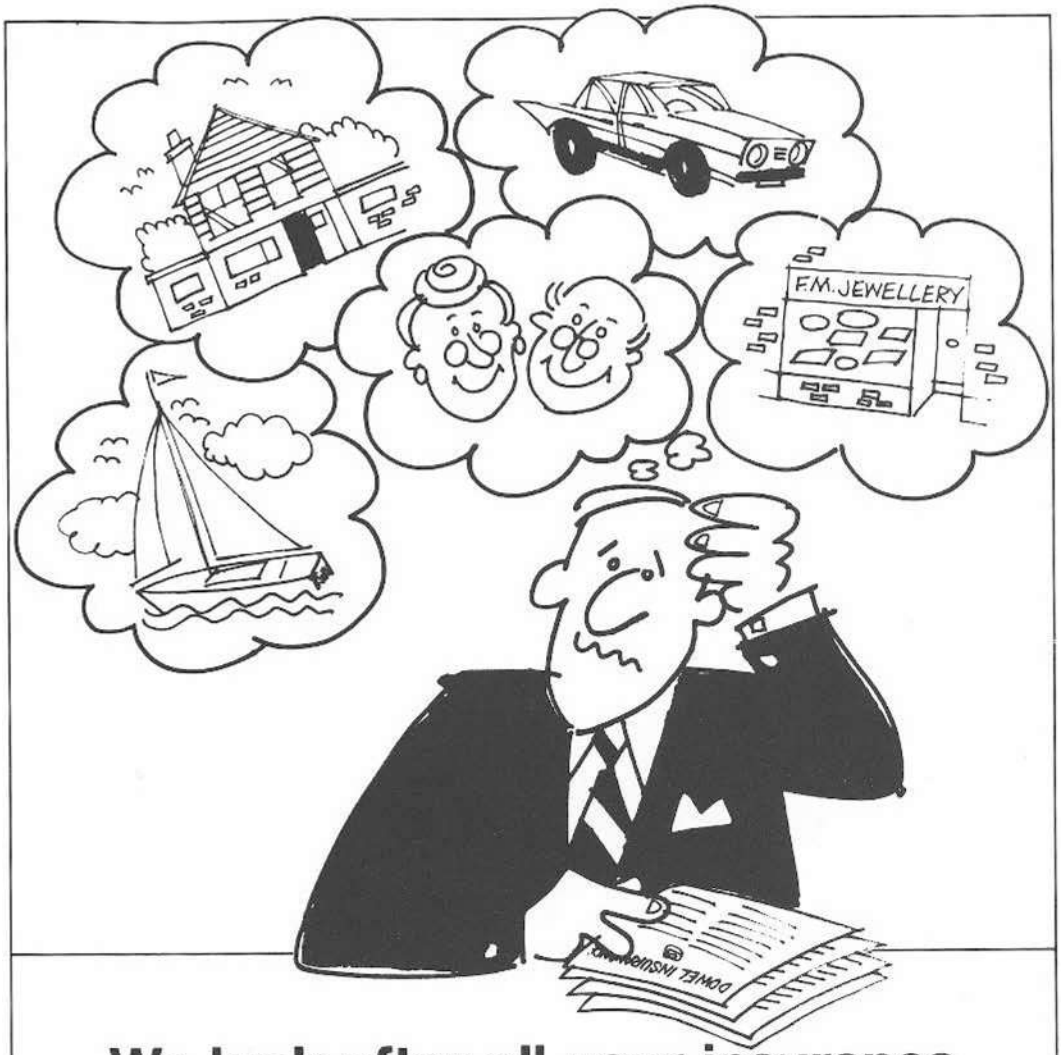

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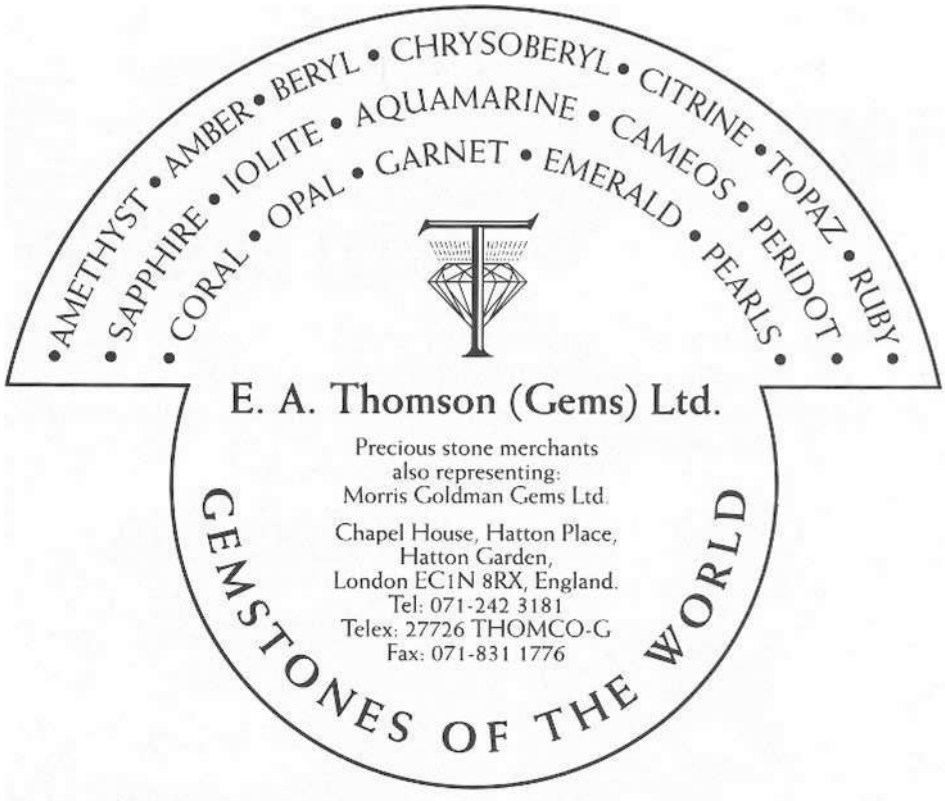

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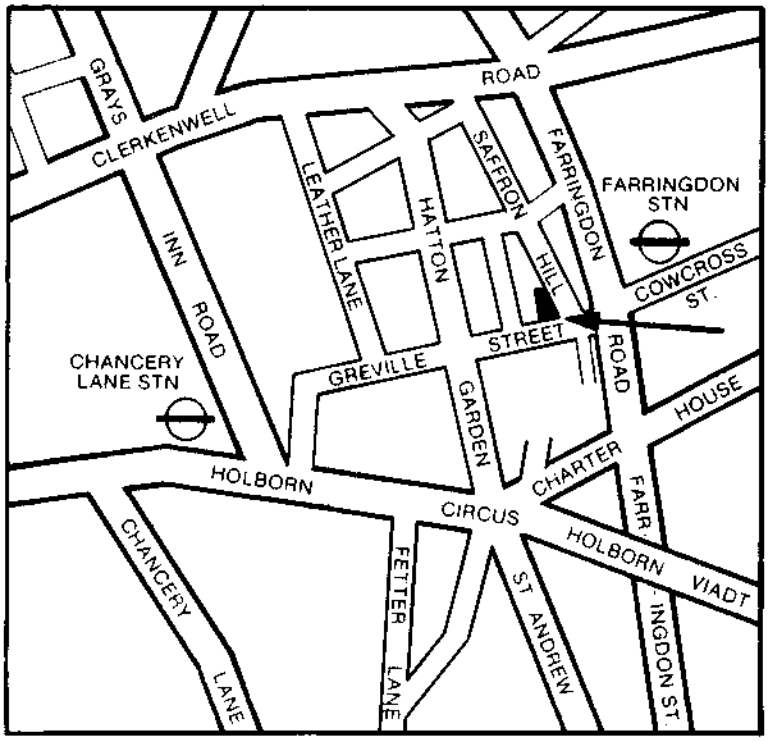

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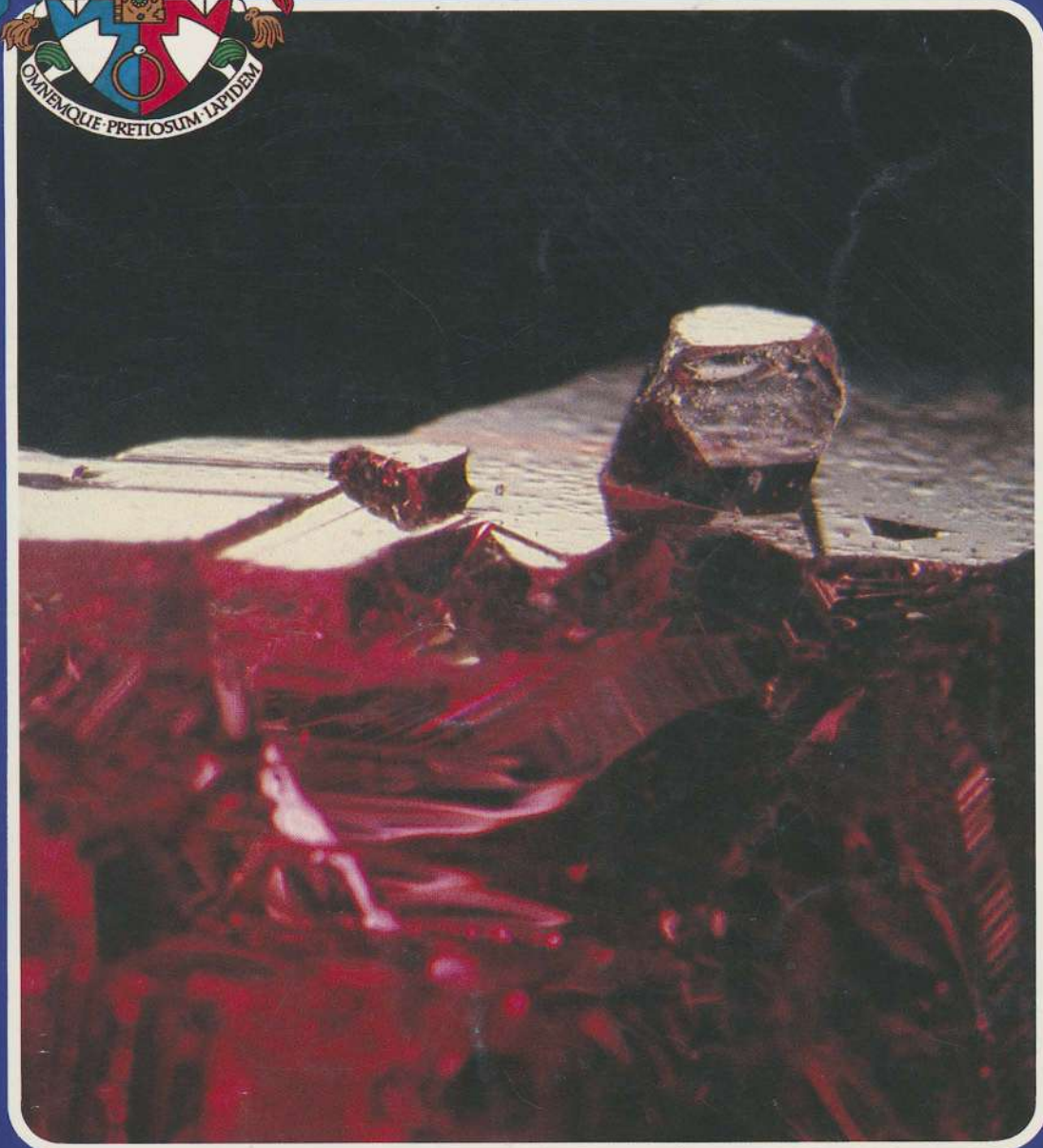

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The Journal of Gemmology

VOLUME 22

NUMBER FIVE JANUARY 1991

Cover Picture

Two small secondary synthetic spinel 'satellites' grow from an octahedral face on the main crystal. Magnified 5x. (See 'Gemmological investigation of a synthetic spinel crystal from the Soviet Union' by J.I. Koivula, R.C. Kammerling and E. Fritsch, p.300).
Photomicrograph by John I. Koivula.

ISSN: 0022-1252

EXAMINATIONS IN GEMMOLOGY 1991

Refresher Courses

The courses outlined below aim particularly to help gemmology students who will be sitting their Diploma Examinations, but one course also caters for the Preliminary Examinations. The tutorials, which may extend over one, two or three days (as set out below), usually include mock practical examinations. Some courses provide tuition only, whereas others include meals and accommodation.

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Examination Dates

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GEM DIAMOND EXAMINATION:

Monday 3 June

EXAMINATIONS IN GEMMOLOGY:

Preliminary – Tuesday 25 June

Diploma Theory – Wednesday 26 June

Diploma Practical – Thursday 27 June

The final date for receiving examination entry forms is 31 March.

Colour as a guide to the composition of scapolite from Burma

A.G. Couper

Department of Mineralogy, British Museum (Natural History), London*

The Pain collection of gemstones (BM 1973, 246-375) from Mogok, Burma, bequeathed to the British Museum (Natural History) in 1973, is remarkable not only for the number of gem-quality mineral species found in such a relatively small area of Burma, but also for the extraordinary range of colour within some of the species or groups. Foremost amongst the latter is the scapolite group which has marialite ($Na_4Al_3Si_9O_{24}Cl$) and meionite ($Ca_4Al_6Si_6O_{24}CO_3$) as its sodium-rich and calcium-rich end-members respectively.

There has always been much confusion surrounding the nomenclature of the scapolite group and in an attempt to simplify the problem the Commission on New Minerals and New Mineral Names of the International Mineralogical Association has approved the following proposals (P. Bayliss, 1987):-

1. The name scapolite should be retained as a group name to encompass minerals in the marialite-meionite series;
2. The names of marialite ($Na_4Al_3Si_9O_{24}Cl$) and meionite ($Ca_4Al_6Si_6O_{24}CO_3$) should be given species status;
3. Dipyre and mizzonite should be regarded as varietal names;
4. Wernerite is synonymous with scapolite and should be discarded.

Intermediate members of the series are given by Strunz (1970) as dipyre (Ma_8Me_2 – Ma_5Me_5) and mizzonite (Ma_5Me_5 – Ma_2Me_8). Gemmologists, however, tend to use only the end-member names, marialite for scapolites with Na>Ca (in atom per cent) and meionite for those with Ca>Na (in atom per cent) (Dunn *et al.*, 1978).

While accumulating data to be used when cataloguing the twelve Pain collection scapolite gemstones (BM 1973, 364-375), it became apparent that when they were listed in order of either increasing refractive index, n_o, (1.544-1.588) or specific gravity (2.60-2.72), they were arranged also in colour groups with dark-blue specimens having the lowest values and grey and colourless specimens the highest. In between were groups of mauve, pink, yellow, greenish-yellow and beige stones in order of increasing refractive index and specific gravity. Scapolite with such a range of colour has not been found at any other locality.

As a general rule the density of scapolite increases with the meionite content, but it can be used only as a rough guide to composition. Prediction of the meionite percentage from optical parameters is still the best and quickest procedure, according to Ulbrich (1973), and the claim is made that estimation from the refractive index n_o regression line (Ulbrich 1973, Figure 2 and equations 5-6, Table 4) is accurate within ± 5 per cent meionite at the 95 per cent confidence interval.

The 0.044 difference between the highest and lowest values of n_o (the refractive index n_o should be used preferentially over the average refractive index n_m (Ulbrich 1973)) indicates a considerable variance in composition between the colourless and the dark blue scapolite from Burma. The fact that the composition of scapolite varies widely was noted by Dunn *et al.*, (1978) when describing gem scapolites from world-wide localities. Among the specimens used for that study were three from Burma and one of them, G 3674, is described as pink with 30 per cent meionite content and having a refractive index n_o = 1.558; a second specimen, R 11157, is light yellow and has 57 per cent meionite content; the third specimen, G 3783, is colourless with 72 per cent meionite content and a refractive index, n_o = 1.587, but elsewhere in that paper the same specimen is described as light yellow. This may be a printing error or, as has been found in this present study, some otherwise colourless or grey material appears to have a very faint yellow tinge.

In order to obtain refractive indices of as many Burmese scapolites as possible, five more stones in the BM(NH) collection were examined and three from a private (A.J.) collection. The records of fourteen stones in the former Institute of Geological Sciences gem collection provided additional data, although in the case of the cabochon-cut stones

*Present address: Henfield, West Sussex

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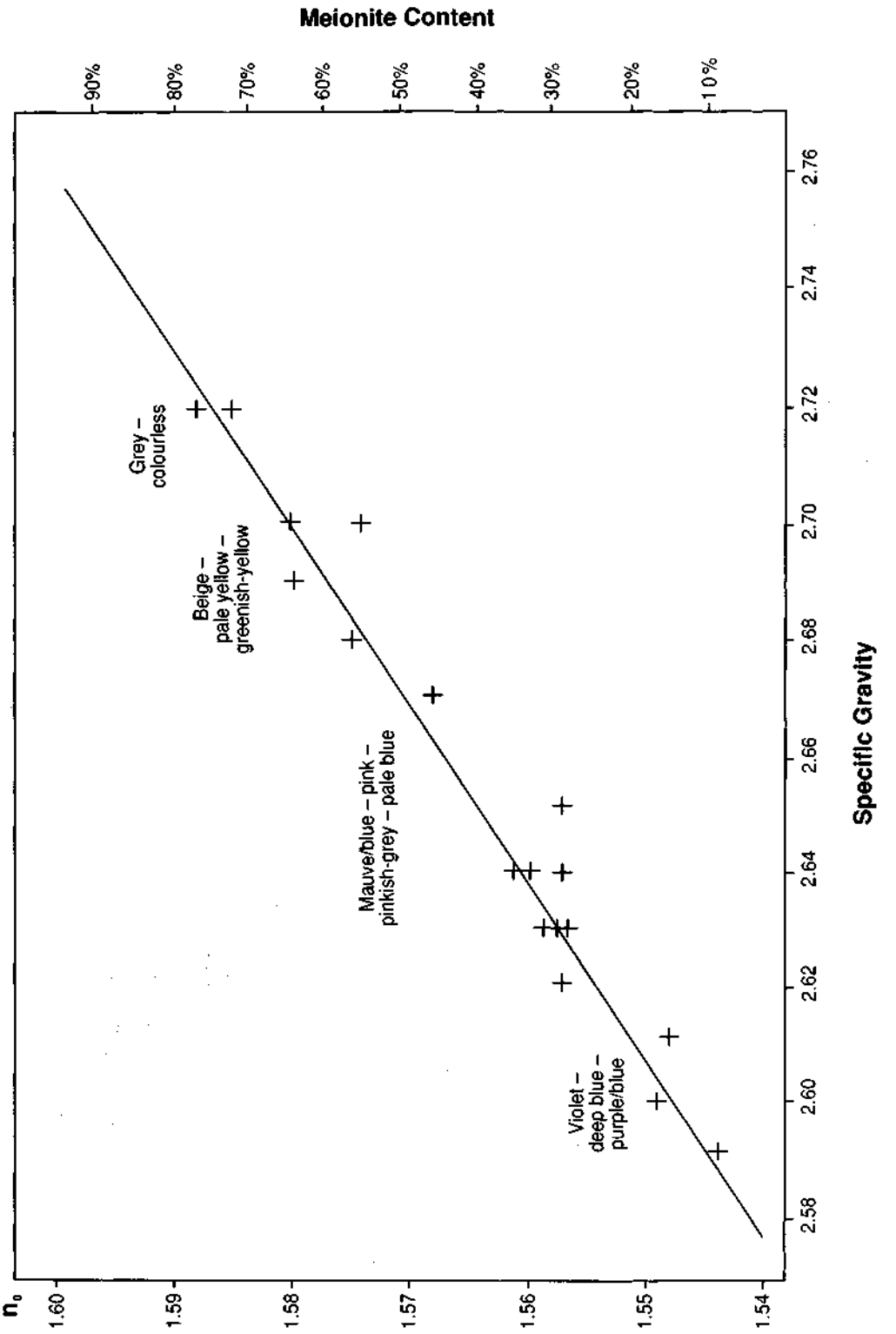

Fig. 1. Gem scapolite from Burma. Refractive index, n_o, and meionite content plotted against specific gravity. Colour of stones has been added.

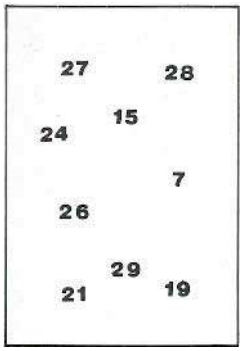

Fig. 2. A series of chatoyant scapolites from Burma. The key numbers relate to Table 1. *Photo Alan Jobbins.*

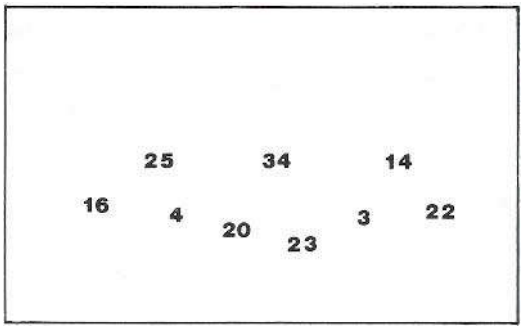

Fig. 3. A series of faceted scapolites from Burma. The key numbers relate to Table 1. *Photo Alan Jobbins.*

both refractive indices could not readily be determined. The refractive indices of the large cabochon-cut stones in the BM(NH) collection were obtained by scraping a very small amount of powder from around the girdle and measuring in sodium light using mixtures of paraffin oil and α-monobromonaphthalene as immersion media, the values of which were checked on a Bellingham and Stanley refractometer. Faceted stones were measured on a Rayner refractometer in sodium light and, in the case of the small cabochon-cut stones, a 'rough' measurement was obtained on a Rayner refractometer using the 'distant vision' or 'spot' method described by Lester Benson (1948). The specific gravities of the seventeen BM(NH) stones and the three from the private (A.J.) collection were obtained by weighing them in ethylene dibromide and correcting for temperature.

The thirty-four scapolite stones from Burma used in this study are listed (Table I) in order of increasing specific gravity, together with their colour and refractive indices if known. As it has been shown by Ulbrich (1973) that a close estimation of meionite percentage in scapolite can be made from the refractive index n_o, these two values (per cent meionite and n_o) have been related using the regression line calculated by Ulbrich (1973) Figure 2, and plotted against specific gravity (Figure 1). A scale showing the colours of the stones has been introduced to show the apparent relationship with

TABLE 1: Colours and optical data of some gem scapolites from Burma listed in order of specific gravity.

					S.G.	n_o	n_e
1.	MI 35774	Faceted	Violet	Burma (?)	2.59	1.544	1.538
2.	BM.1973,374	Cabochon	Deep-blue	Mogok	2.60	1.55*	
3.	MI 35519	Faceted	Purple-blue	Burma	2.60	1.549	1.539
4.	BM.1973,370	Faceted	Deep-blue	Mogok	2.61	1.548	1.538
5.	BM.1973,375	Cabochon	Deep-blue	Mogok	2.61	1.55*	
6.	BM.1966,296	Cabochon	Pink	Mogok	2.62	1.557	1.543
7.	MI 28939	Cabochon	Pink	Mogok	2.63	—	—
8.	BM.1973,367	Cabochon	Pink	Mogok	2.63	1.55*	
9.	BM.1933,97	Cabochon	Pinkish-grey	Mogok	2.63	1.558	1.543
10.	BM.1912,684	Cabochon	Pink	Mogok	2.63	1.557	1.546
11.	AJ.O.1792	Cabochon	Pale-pink	Mogok	2.63	1.56*	
12.	AJ.O.2952	Cabochon	Mauvish-blue	Mogok	2.63	1.56*	
13.	BM.1966,295	Cabochon	Pink	Mogok	2.63	1.557	1.545
14.	BM.1973,368	Faceted	Pink	Mogok	2.63	1.559	1.543
15.	MI 35518	Cabochon	Pink	Burma	2.63	—	—
16.	MI 35522	Faceted	Pale-pink	Burma	2.63	1.557	1.542
17.	BM.1973,366	Cabochon	Pinkish-grey	Mogok	2.64	1.56*	
18.	BM.1912,683	Cabochon	Pink	Mogok	2.64	1.560	1.546
19.	MI 28940	Cabochon	Pink	Mogok	2.64	—	—
20.	MI 30205	Faceted	Pink	Mogok	2.64	1.557	1.540
21.	MI 30211	Cabochon	Blue	Mogok	2.64	—	—
22.	MI 35521	Faceted	Pink	Burma	2.64	1.561	1.544
23.	MI 35520	Faceted	Pale-blue	Burma	2.65	1.557	1.541
24.	MI 35524	Cabochon	Pale greyish-green	Burma	2.67	—	—
25.	BM.1973,369	Faceted	Pink	Mogok	2.67	1.568	1.545
26.	MI 28938	Cabochon	White	Mogok	2.68	—	—
27.	MI 30206	Cabochon	Pale-buff	Mogok	2.68	—	—
28.	BM.1973,372	Cabochon	Pale-yellow	Mogok	2.68	1.575	—
29.	BM.1973,373	Cabochon	Greenish-yellow	Mogok	2.69	1.580	—
30.	BM.1973,365	Cabochon	Beige	Mogok	2.70	1.574	1.552
31.	BM.1973,364	Faceted	Colourless	Mogok	2.70	1.580	1.550
32.	BM.1973,371	Cabochon	Grey	Mogok	2.72	1.588	—
33.	AJ.1.6908	Rough	Colourless	Mogok	2.72	1.588	1.557
34.	MI 31629	Faceted	Colourless	Burma	2.72	1.585	1.554

*Obtained by 'distant vision' method.

'MI' numbers refer to specimens in the collection of the Institute of Geological Sciences (IGS).

composition. Optical values obtained by the 'distant vision' method have not been used in the preparation of this graph.

It is interesting to note that the colours, refractive indices and composition of the three Burma scapolites used by Dunn *et al.* (1978) and referred to above, fit comfortably on to the graph (Figure 1). The wide range of composition of Burmese material shown by Dunn *et al.* (1978) to be from 30 per cent meionite for the pink stone, to 72 per cent meionite for the colourless stone, now appears from this study to be even greater, with the meionite content estimated to be 10-17 per cent for the group of violet, deep-blue and purplish-blue stones and 72-76 per cent for the group of grey and colourless stones. It must be noted, however, that there is some doubt about the locality of IGS 35774, the violet stone with the lowest estimated meionite content at 10 per cent, but it is thought most likely to come from Burma. The largest group consists mainly of pink stones with a few pale-blue or mauve amongst them and their estimated meionite content ranges from 30 to 35 per cent. Apart from a lone pink stone at about 45 per cent meionite there is a large gap from about 35 to 55 per cent meionite when blue disappears as a background colour and yellow appears to be the main influence in the body colour of the stones. From about 55 to 65 per cent meionite the stones are beige, pale-yellow, greenish-yellow and an almost colourless stone with a very faint yellow tinge. The next group on Figure 1 is at 72 to 76 per cent meionite and consists of a grey stone, with a very faint hint of yellow, and a colourless stone.

This study has shown that by using the refractive index, n_o, to estimate the meionite content of eight of the Pain scapolites, and then using colour and specific gravity as guides in the case of the remaining four, it is possible to classify the dark-blue scapolite as marialite, the pink as marialite (variety dipyre) and the pale-yellow, greenish-yellow, beige, grey and colourless stones as meionite (variety mizzonite).

Acknowledgements:

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'Machingwe': A new emerald deposit in Zimbabwe

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Abstract

Geological and gemmological details of a promising new emerald deposit in the Mweza Range Greenstone Belt of southern Zimbabwe are discussed and compared with data from Sandawana and other nearby emerald deposits.

Introduction

In May 1987 the first author was fortunate enough to have the opportunity to pay a short visit to a newly discovered emerald occurrence in Zimbabwe, named 'Machingwe deposit', thanks to the kind permission granted by the owner, Mr C.C. Chigumba, and with the assistance of the Mineral Marketing Corporation of Zimbabwe. This Corporation is a state controlled department based in Harare. It channels, on a non-profit basis, all gemstone and mineral sales from producers to world markets. The Corporation also acts as an advisory body to the small operator.

Geotectonic setting

With the exception of Palaeozoic mountain belts along the northwestern and southern margins, the African continental crust developed during the Precambrian. The major structural units of central and southern Africa can be subdivided into two cratonic blocks that were stabilized since middle Proterozoic times (about 1100 Ma) and are separated from each other by the so-called Pan-African Mobile Belts (Damara, Zambezi and Mozambique Mobile Belts – about 550 Ma in age). Within the cratons several older Archaean cratons occur, with ages of 2500 Ma and older, of which the Rhodesian Craton (Figure 1) is of special importance in the present study.

The Rhodesian Craton stabilized at about 2550 Ma; it is surrounded by the Zambezi and Mozambique Mobile Belts in the north and east respectively, and the Early Proterozoic Limpopo Mobile Belt (about 1850 Ma) in the south. The cratonic basement consists of older gneisses, a variety of schist belts, better known as Greenstone Belts, and younger (gneissic) granites and pegmatites.

The Greenstone Belts are elongated or irregular shaped bodies of steeply dipping, (partly) tightly folded, generally schistose rocks. Their length may reach a few hundred kilometres.

Geology of the Zimbabwean Greenstone Belts

Stratigraphically the Zimbabwean greenstone formations can be subdivided into three divisions, respectively the Sebakwian, Bulawayan (2700-2600 Ma) and Shamvaian Supergroups. They are composed of ultramafic, mafic to felsic intrusive and volcanic rocks, such as peridotites, basalts (pillow lavas), andesites and rhyolites, with intercalations of sedimentary rocks (conglomerates, pelite, banded iron formation, limestones, etc.).

The older Sebakwian and to a lesser extent the Bulawayan are mainly volcanic deposits with intercalations of meta-sedimentary rocks, while the younger Shamvaian Supergroup is largely represented by metamorphic clastic deposits. These volcano-sedimentary deposits seem to have covered large areas of the Archaean crust.

The Zimbabwean and other greenstone formations in the world have been intensively investigated (see Windley, 1977). With respect to the stratigraphy, volcanic geochemistry and structural appearance they are remarkably similar. Furthermore they are always surrounded by older gneisses and younger, partly intrusive, granitoid plutons, and nearby high-grade metamorphic terrains.

The Zimbabwean Archaean basement rocks underwent a low-grade regional metamorphism. The (ultra)mafic rocks recrystallized into upper-greenschist facies to lower amphibolite facies 'greenstones'. Current rock-types of the Greenstone Belts are serpentinites, talc schists, chlorite schists, tremolite-chlorite schists, hornblende schists, phyllites and quartz-mica schists.

Specific higher-temperature exceptions occur near the contacts with the younger granites and the large number of pegmatitic off-shoots. In these environments, especially at the contacts with the ultramafic schists, pegmatoid impregnations under

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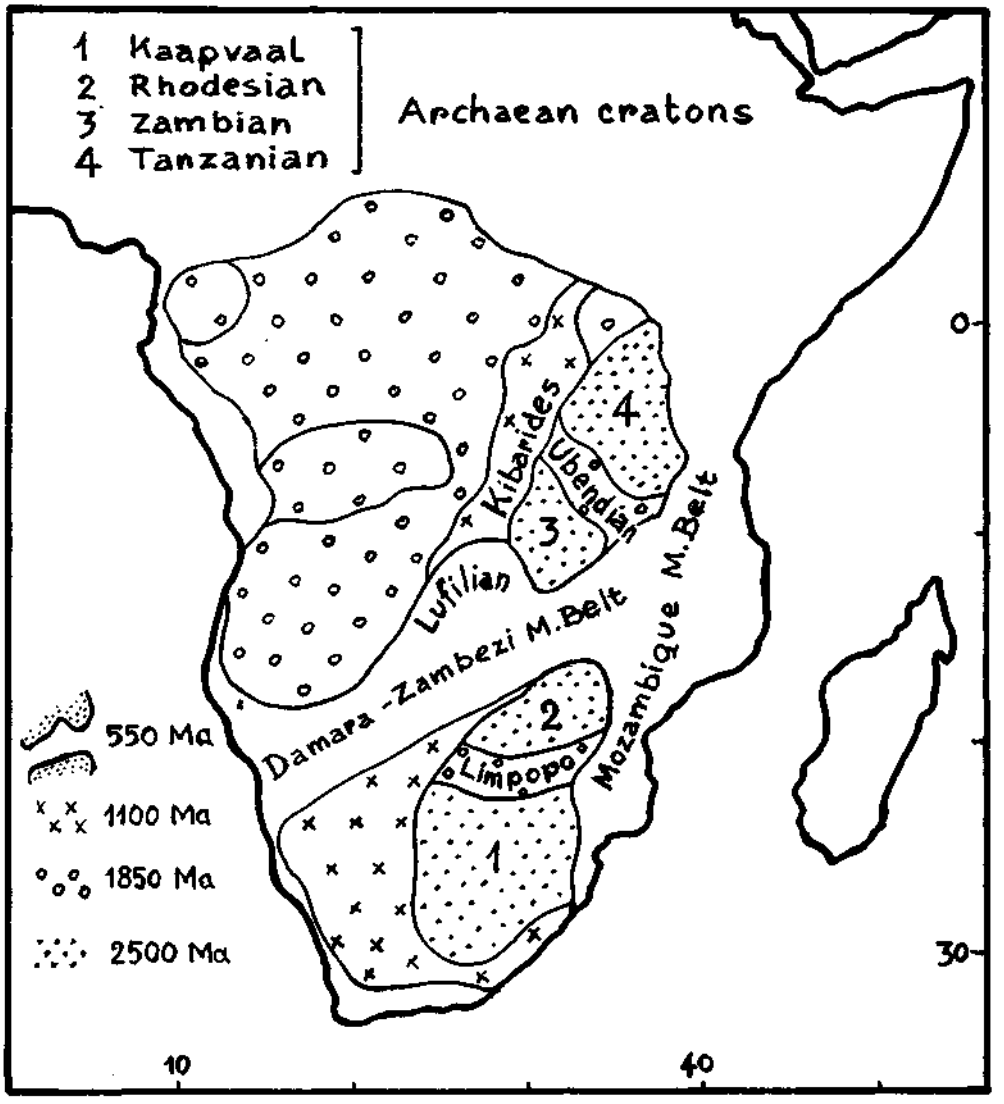

Fig. 1. Distribution of the Precambrian geotectonic units in central and southern Africa.

high pressure (pneumatolitic) were responsible for restricted but intense contact-metasomatic reactions altering the ultramafic rocks into biotite and biotite-phlogopite schists. A similar lithology has been reported from other emerald-producing areas (Martin, 1962; Sliwa & Nguluwe, 1984; Schwarz & Eidt, 1989).

The formation of phlogopite took place according to the mineral reactions (1) alkali feldspar + serpentine = phlogopite + talc + water, and (2) alkali feldspar + talc = phlogopite + quartz, while the appearance of biotite instead of, or, in addition to phlogopite depended on the original iron content of the ultrabasic rock (Schwarz & Eidt, 1989).

The mafic and ultramafic rocks of greenstone belts are well known suppliers of mineral ores containing the economically important elements like chromium, cobalt, nickel, copper, zinc, silver, gold, manganese and iron. In earlier days greenstone belts were called 'gold belts'.

Chromium and nickel are mainly restricted to the ultramafic rocks, i.e. serpentinites and talc schists (Martin, 1962; Windley, 1977; Metson & Taylor, 1977). This fact, in combination with extensive intrusions of beryllium-bearing pegmatites, has in several places lead to the fortuitous crystallization of emeralds at, or adjacent to, the contacts of the pegmatitic impregnations with the greenstones.

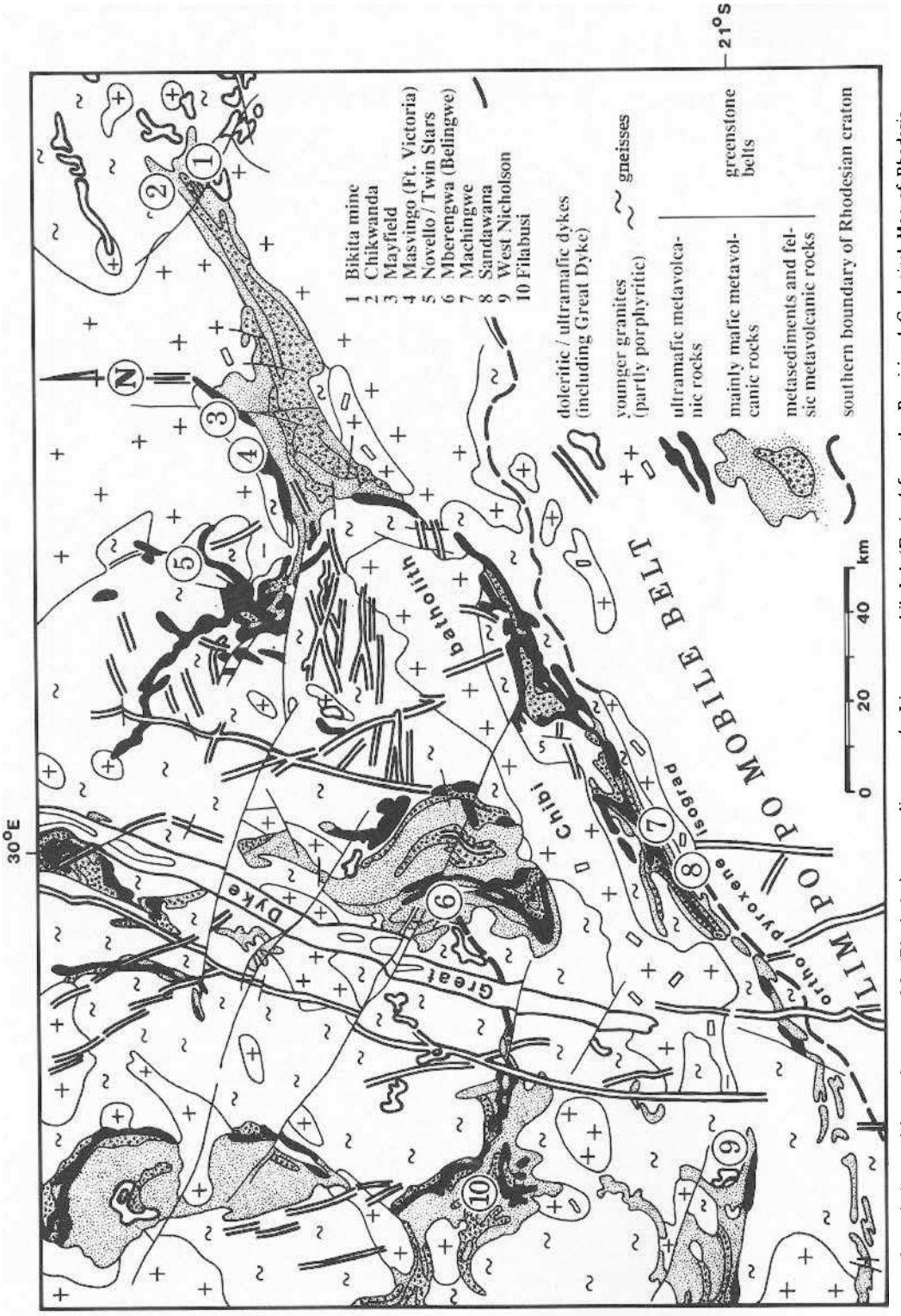

Fig. 2. Geological map of the southern part of the 'Rhodesian' craton adjacent to the Limpopo mobile belt (Derived from the Provisional Geological Map of Rhodesia, 1971, and the Provisional Map of the Granitic Rocks of the Rhodesian Craton, A.E. Phaup, 1971).

Fig. 3. The hills of the Mweza Range Greenstone Belt covered by dense bush; a bulldozer has been operating near the No.3 shaft (1987).

The geological sketchmap of Figure 2 shows the southern part of the Rhodesian Craton in juxtaposition with the high-grade Limpopo Mobile Belt. Both units are separated by the 'pyroxene isograd', which is arbitrarily the northern boundary of the Limpopo Mobile Belt.

A striking feature on the map, southwest of Masvingo (previously Fort Victoria) and very close to the southern contact, is a narrow NE-SW trending 140 km long belt. This is the Mweza (Range) Greenstone Belt, consisting of volcano-sedimentary deposits belonging to the Bulawayan Supergroup, more or less adjacent to the elongated Chibi granite batholith.

The emerald occurrences

In May 1957 (Böhmke, 1982) the renowned Sandawana emerald deposit was discovered. Since then a number of other minor emerald occurrences have been discovered within the southern part of the Rhodesian Craton, such as the localities Novello, Twin Star, Chikwanda, Mayfield, Popoteke and Renders in the Masvingo Greenstone Belt and Mustard and others in the Filabusi Greenstone Belt (Anderson, 1976, 1978; Martin, 1963).

The most important emerald discovery to date, however, since the Sandawana emeralds on the Zeus claims, is a new occurrence approximately 12 km NE of the Sandawana mine, along the Mweza Range, which is named 'Machingwe' mine, after a nearby stream.

The presence of emerald in the Mweza Range Greenstone Belt is connected with the pegmatitic intrusions derived from the younger Chibi granite batholith. The metasomatic rocks at the contact of the pegmatoids and the (ultra)mafic rocks, i.e. the biotite and biotite-phlogopite schists, are the main host-rocks of the emeralds. But, as a result of contamination of the pegmatoid material, this gemstone is also present in the adjacent pegmatite.

The Machingwe Emerald mine

The car journey from Masvingo to the Mashingwe mine takes about 3½ hours. The first 135 km is a well-kept tarred road, passing various important asbestos mines exploited in the serpentinites of the Zvishavana (Shabani) district. Thereafter, the journey has to be continued over a 55 km very rough gravel road and only 4-wheel drive vehicles will be able to pass.

The vegetation of the Mweza Range greenstone hills is quite dense (Figure 3) and in sharp contrast

to the surrounding almost barren granitic rocks with thorny bushes and little grass.

Amphibolite schists are the predominant rock-type on the Machingwe claims and various pegmatites, aplites, quartz-feldspar and feldspar veins and quartz stringers have intruded these amphibolites. Emerald is present in the schists as well as in the felsic rocks (Figure 4).

The first emeralds of the Machingwe stream area were found in December 1984 and the official name for the mine became 'Machingwe Syndicate No.2 Mine', but is better known under the name Machingwe mine.

At the time of the first author's visit to the mine the No.1 shaft was sunk on a 3m wide N-S striking, steeply dipping pegmatite (Figure 5) to a depth of 21m where the water table was struck. Just above this level is a 15m long adit.

Approximately 150m NW of the No.1 shaft is the No.2 or 'Mahonde' shaft with a depth of 15m. The near vertical pegmatite mined here is about 2m wide and is striking E-W. This well-developed pegmatite has a number of interesting apophyses which are emerald-bearing (Figure 6). A further 60m E of the No.2 shaft is the vertical No.3 shaft, where the same pegmatite is mined, which has widened here to 3½m and is dipping slightly south. The emerald production came mainly from the No.3 shaft. Also the first emeralds found in the area were discovered in the same place where later on the No.3 shaft was sunk.

Apart from producing ore from the three prospecting shafts, all mining has been carried out by open cast method. Two bulldozers were clearing the overburden and waste rock. Not only was the mining based on very simple methods at the time the mine was visited, but also the plant and the treatment of the emerald-bearing rock was very basic. A small screening trommel was the only mechanized equipment while all other work was done by hand.

The emerald potential of this occurrence, however, appears to be large and the fact that the nearby Sandawana mine, after more than thirty years, still produces emeralds of good quality, even at their deepest level of 150m, makes the Machingwe mine even more interesting as the geological conditions are likely to be similar.

In the past beryl was a very important strategic mineral, and Zimbabwe was the world's second

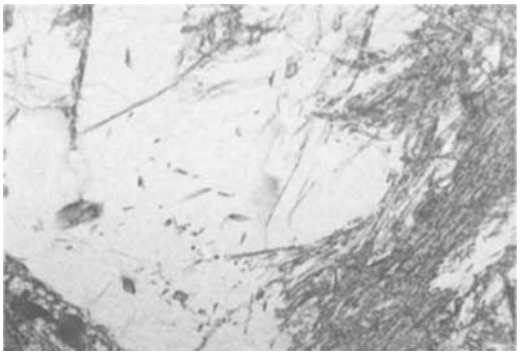

Fig. 4(a)

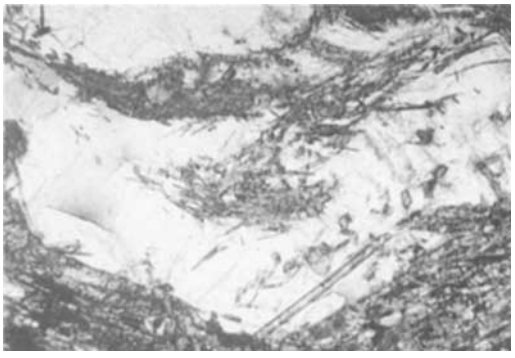

Fig. 4(b)

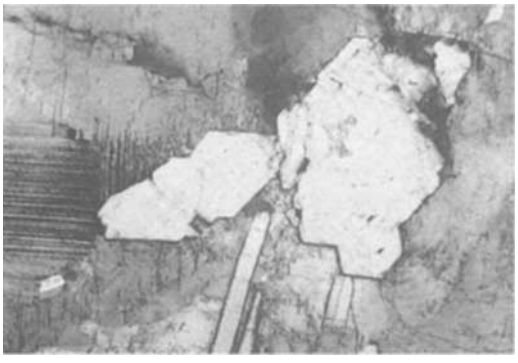

Fig. 4(c)

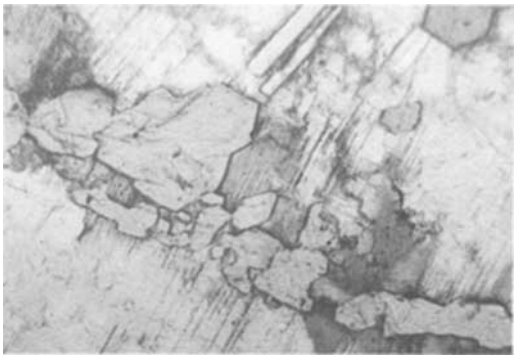

Fig. 4(d)

Fig. 4. Thin-section photomicrographs of emerald-bearing amphibolitic schist (a) and (b) and pegmatite (c) and (d). Note the presence of actinolitic inclusions in the metablastic emeralds of the amphibolite in contrast to the inclusion-free euhedral emerald crystals of the pegmatite.

Fig. 5. A 15m long adit in emerald-bearing pegmatite near the No.1 shaft (1987).

Fig. 6. Large emerald crystals, above coin, in pegmatite apophysis near the No.3 shaft. The adjacent altered zone consists of serpentinite, biotite-, tremolite-, and talc schists.

Fig. 7. Parcel containing small emerald crystal fragments. Mag. 2x.

largest producer with beryl occurring in many localities. This circumstance, combined with the fact that specific rock-types of the many Greenstone Belts are chromium-bearing, makes it very possible that further emerald discoveries of note may yet be made in Zimbabwe.

Properties of the Machingwe emeralds

The colour hue of the Machingwe emerald is a superb emerald green, including the smallest 'pin-head' sizes, and their brilliance is magnificent, very similar to the Sandawana emeralds. Most emeralds are rather small, broken pieces (Figure 7). Well-developed crystals were only seen in the fine grain-sizes.

The largest faceted and very clean Machingwe emerald was just under 5 carats in weight. The bulk of the faceted stones is, however, under one carat. Good quality cabochon cut emeralds occur in much larger sizes.

The chemical composition of a pale green and a deep green emerald sample of Machingwe mine was analysed by atomic absorption spectrometry (AAS) and inductively coupled plasma spectrometry (ICPS) methods. The results are listed in Table 1. The chemical data from two Sandawana emerald samples have been added. The latter results, however, were obtained by different methods in different periods and should therefore be evaluated with care.

The most noticeable differences with the Sandawana material are the contents of chromium, beryllium and iron. Part of magnesium, sodium and lithium should be attributed to the influence of inclusions (Böhmke, 1982).

The refractive indices and densities of a number of Machingwe emeralds were determined, giving the following (average) results:

N_e 1.584-1.586 and N_o 1.589-1.593 (eleven samples)
birefringence 0.006-0.008
density 2.761 g/cm^3 (eight samples)

A number of refractive index measuremens of the Machingwe emeralds have been put together with the data from other Zimbabwean emeralds in a diagram (Figure 8) as was previously published by Anderson (1978).

Although a deep red colour under the Chelsea colour filter was to be expected, it turned out to be a dull red, and not really very bright. This may be due to a lower chromium content and a higher iron content than emeralds from Sandawana (see Table 1).

Under ultra-violet light the emeralds are bright green; the short wave conditions of a lesser intensity, better described as greenish only.

The absorption spectrum is very distinct. Chromium lines in the red and a strong band in the yellow-green part of the spectrum, particularly in the samples with the finest colours, are easily seen, even with the simplest hand spectroscope.

The properties of the emeralds present in the felsic rocks or the schists are slightly different with respect to colour, i.e. chromium content, and inclusions.

As a general rule the Machingwe emeralds within the pegmatites are of a lighter green hue than the

Table 1: Quantitative geochemical analyses of African emeralds.

	'Machingwe' 1	2	Sandawana 3	4	Miku 5
SiO_2	67.42	67.11	65.00	63.84	62.23
Al_2O_3	13.60	12.81	15.50	18.06	15.41
Fe total	0.76	0.86	0.50	0.30	0.11
MgO	2.65	3.00	3.00	0.75	0.76
MnO			—	—	0.02
CaO	0.05	0.05	—	—	0.31
Na_2O	2.21	2.28	2.00	2.03	2.63
K_2O	0.04	0.03	—	0.05	2.89
Li_2O			0.15	0.10	—
BeO	11.24	11.88	13.60	13.28	11.90
Cr_2O_3			0.50	0.60	0.33
Cs_2O	0.04	0.04	—	—	—
H_2O+	—	—	—	1.07	2.59
H_2O-	—	—	—	—	0.06
Total	98.01	98.06	100.25	100.08	99.24
Sr	6.0	4.0			
Ti	39.0	32.0			
Co	113.0	111.0			
Mn	173.0	286.0			
P	61.0	48.0			
V	192.0	213.0			
Zn	66.0	49.0			
Li	730.0	637.0			
Ni	30.0	38.0			
Cr	1800.0	3970.0			

Main elements are in Wt.%, trace elements in ppm.
Nos. 1 and 2: resp. green and deep green emeralds from 'Machingwe', analysis by ICP (Induced Coupled Plasma) and AAS (Atomic Absorption Spectrometry) methods, Analytical Geochemical Lab. (analyst: Mrs. Ir. T.G. Djie-Kwee), Inst. Earth Sci., State University at Utrecht, The Netherlands;
No. 3: emerald from Sandawana, data from Böhmke, 1982, modified after Gübelin, 1958;
No. 4: emerald from Chingachura, near Sandawana, wet-chemical, spectrographic and flame photometric methods, data from Martin, 1962;
No. 5: emerald from Miku (Kafubu area, Zambia), data from Sliwa & Nguluwe, 1984.

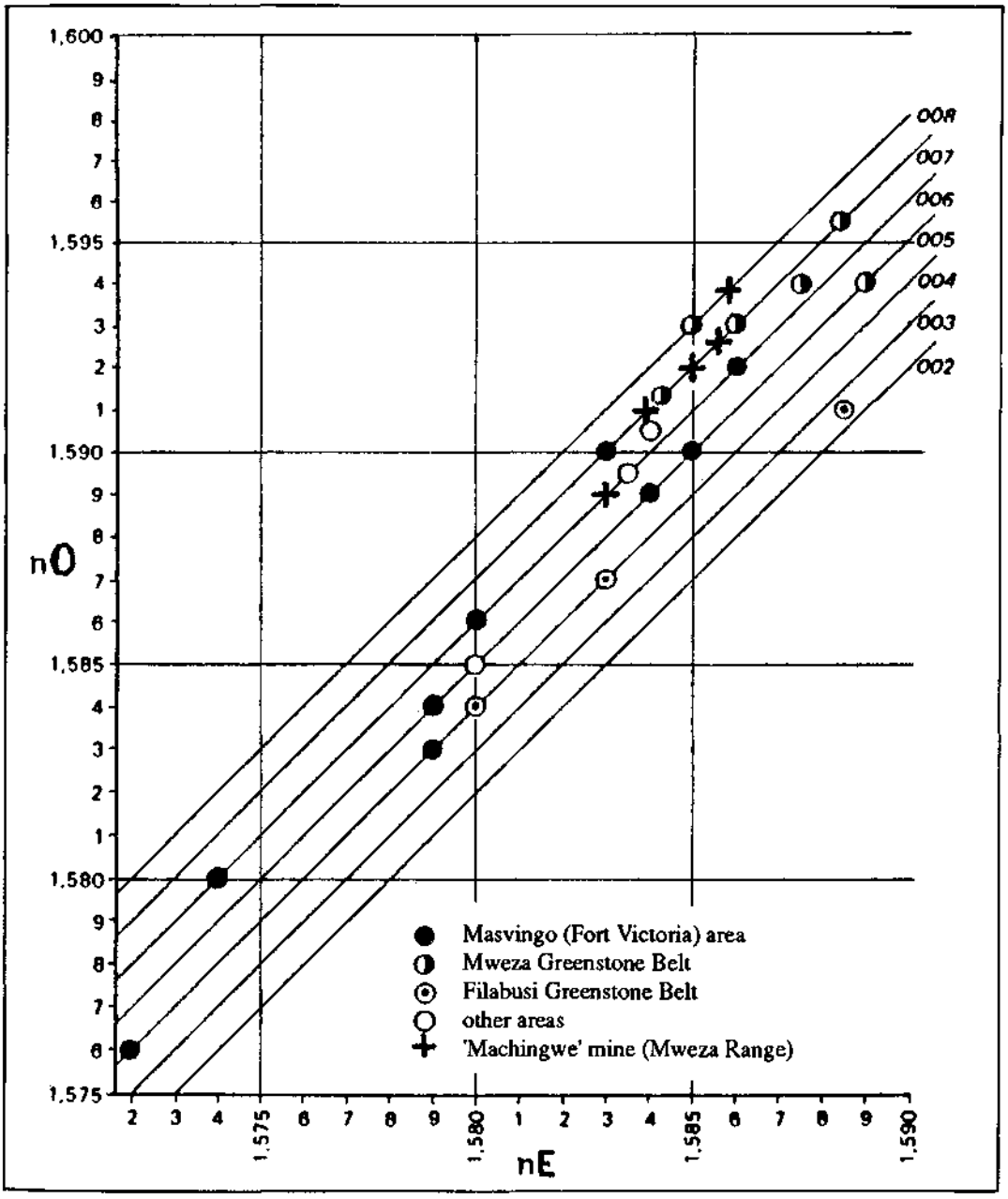

Fig. 8. Refractive indices and birefringence of Zimbabwean emeralds. Data from Anderson, 1978, and the present study.

poikiloblast-type in the adjacent (ultra)mafic rock of the altered zone.

On the other hand the pegmatite emeralds are relatively free of inclusions, in contrast to the emeralds from the altered zone. Microscopic investigation of the inclusions reveals (Figure 9), as expected, a great similarity to the Sandawana emeralds, which is demonstrated by an abundance of actinolite/tremolite needles, or at least long prismatic pale yellowish to brownish crystals of some member of the amphibole group, either clustered together as well as individual crystals pointed in different directions.

In some of the specimens flake-like inclusions can be seen, very likely consisting of colourless to light brown, distinctly pleochroic mica.

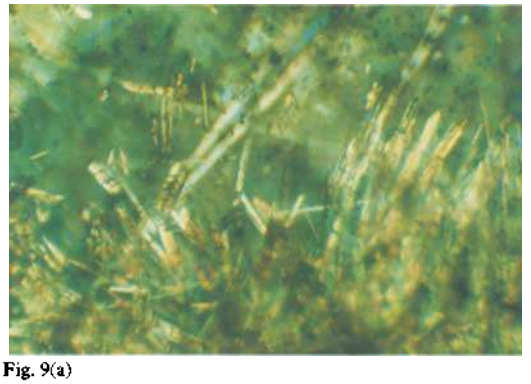

Fig. 9(a)

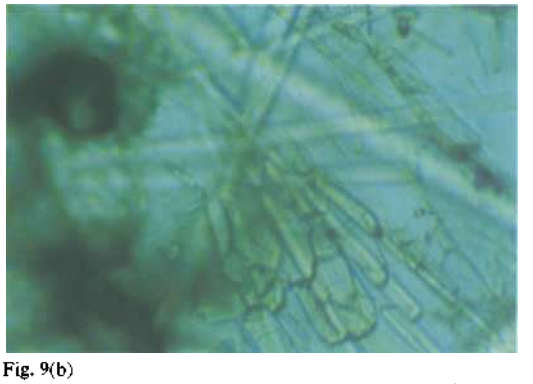

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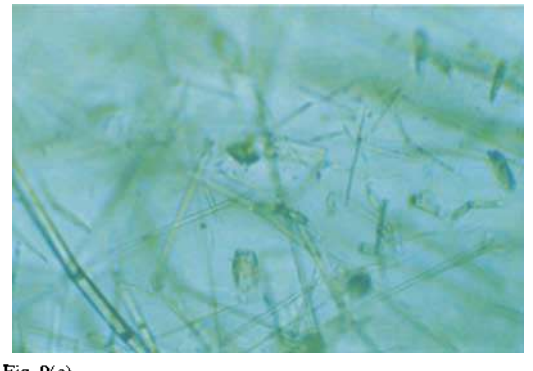

Fig. 9(c)

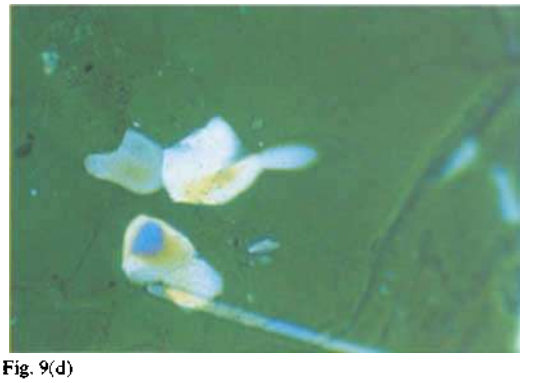

Fig. 9(d)

Fig. 9. Typical inclusions in emeralds from the 'Machingwe' mine: actinolite/tremolite needles either (a) densely accumulated (crossed nicols), (b) radially oriented or (c) at random; (d) fine needle with some mica flakes (crossed nicols).

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Crystallized and massive rose quartz deposits in Brazil

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Abstract

Brazilian rose quartz originates from granitic pegmatites which produce the bulk of massive rose quartz and the whole of the crystallized rose quartz. Other occurrences (eluvial, coluvial and alluvial) are almost insignificant.

The massive rose quartz pegmatites belong to a zoned type characterized by a blocky zone with giant crystals of quartz and K-feldspar, but without sodic substitution. Associated minerals are: schorl, cassiterite, niobotantalite, beryl (with scarce pale aquamarine), some phosphate minerals and, locally, weathered spodumene. The massive rose quartz makes up the whole or part of the core and/or joins together the K-feldspars of the blocky zone. The deposits are: Pé da Chapada, Córrego Piabanha, Olho d'Água, Boqueirão and Fazenda São Jorge (State of Minas Gerais), Córrego do Lodo, Ribeirão do Largo and Fazenda Conceição (State of Bahia), Borracha (State of Pernambuco) and Alto Feio (State of Paraíba). Geology, mining, mineralogy and production of each deposit is briefly quoted. Many occurrences of massive rose quartz in pegmatites are scattered in eastern Brazil.

The crystallized rose quartz pegmatites belong to a very differentiated type, frequently gem tourmaline-bearing with important Na substitution bodies. Associated minerals are: albite, muscovite, niobotantalite, beryl and locally typical phosphate minerals: eosphorite, wardite, roscherite, etc.

The deposits of crystallized rose quartz are concentrated in Minas Gerais State: Jequitinhonha valley near the towns of Araçuaí and Itinga (Lavra da Ilha, Laranjeira) and Rio Doce basin (Alto da Pitora). Seven small occurrences are also reported. The crystallized rose quartz belongs to a late stage of the pegmatite evolution. It is frequently found in vugs, perched upon quartz, feldspar or mica, and occurs single or in clusters, rosettes, crowns or irregular groups, rarely as sceptre. Prominent characteristics which allow us to recognize the origin of many specimens are emphasized.

Gemmological properties of rose quartz are reported.

Introduction

Less common than the other varieties of crystal quartz is the pink coloured crystallized and massive rose quartz, of which Brazil is probably, to date, the greatest producer. Our intention is to describe briefly the larger Brazilian deposits and occurrences of this gemstone.

Massive or crystallized Brazilian rose quartz originates from granitic pegmatites. Its occurrences may be classified as follows: pegmatites where the aforementioned mineral is extracted from the rocks; coluvium and eluvium above and in the neighbourhood of the pegmatites, and nearby alluvium. The first type produces the bulk of massive rose quartz, and the whole of the crystallized rose quartz. However it must be pointed out that rose quartz-bearing pegmatites belong to two types which are clearly distinct one from the other: massive rose quartz-bearing pegmatites without other associated gems (or some clear aquamarine) and crystallized rose quartz-bearing pegmatites, common producers of gem tourmalines. Using the textural-paragenetic evolution scheme of Vlasov (1952), supplemented by the knowledge of the Brazilian gem deposits (Cassedanne, in press), it is easy to mark the two models referred to above. The massive rose quartz-bearing pegmatites belong to a common and unique type, almost without substitution and with giant crystals, whereas the crystallized rose quartz-bearing pegmatites occur near the end of the pegmatitic evolution trend. The latter is Na-rich whereas the K-feldspar prevails in the first one.

In order to exemplify the above basic principles, the most important rose quartz deposit will be described. Other occurrences and deposits will then be listed. The last section will deal with crystallized rose quartz occurrences.

Massive rose quartz: The Alto Feio deposit

It is located in the State of Paraíba, 230 kilometres to the nortwest of the city of Recife, near a small town called Pedra Lavrada, and near the boundary between the States of Paraíba and Rio Grande do Norte. The region is located in a bush covered high plain and belongs to the Seridó Group (Seridó Formation, 1,570-1,100 million years (Ma)), made of biotite garnet schists which were intruded by several granites, mainly of the Brazilian tectonic cycle (about 500 Ma).

The deposit trends ENE-WSW, is a lenticular pegmatite, outcropping in a low EW hill, with an

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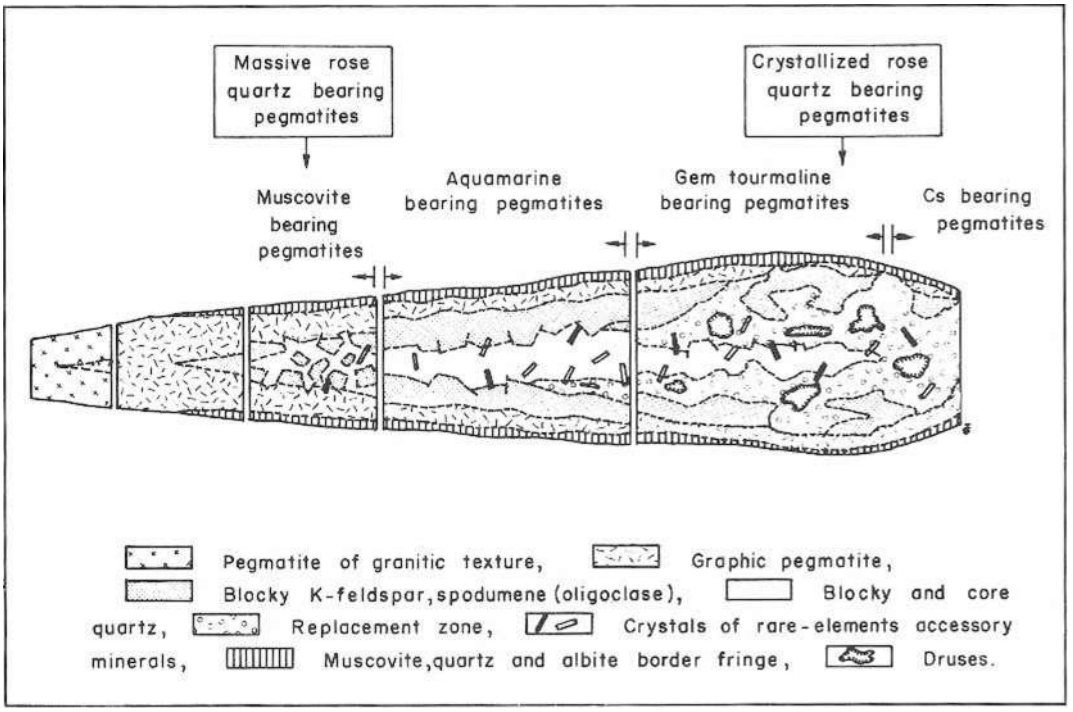

Fig. 1. Location of rose quartz-bearing pegmatites in a schematic section of different textural-paragenetic pegmatite types (Vlasov, 1952 – modified).

area of 500 × 80 metres (20,600 square metres after Almeida, 1946). The pegmatite lies between a fine grained rose coloured granite in the south and biotite garnet schists in the north. The deposit, discovered in 1928 was intensively worked on for beryl and tantalite during World War II and thereafter sporadically quarried, for the recovery of K-feldspar and rose quartz. The following zones succeed one another from the wall rock to the core:

– A few centimetres to a few decimetres thick band of fine grained mica,

– A centimetre grained pegmatite zone, with granitic texture and large prisms of schorl,

– A blocky zone with albite and quartz and giant crystals of K-feldspar, some of which reach up to 100 tons in weight. The area covers 6,800 square metres and massive rose quartz commonly surrounds the giant crystals,

– A lenticular core.

Minerals associated with the rose quartz: several decimetres long, milky to translucent quartz crystals, morion, citrine, muscovite, lepidolite, beryl (with some clear aquamarine), schorl (with very cracked blue and green uncommon tourmaline), garnet, zircon, manganese and iron phospates (predominantly heterosite), niobotantalite, uraninite, bismuth and bismutite and uncommon pyrite, chalcopyrite, chalcocite and covellite. Mining is by way of irregular quarries, the older ones having caved in. The larger excavations in development are in the west and the east of the pegmatite. Reserves are not available but very likely amount to several thousands of tons (Cassedanne & Cassedanne, 1978).

Rose quartz, always xenomorphic, occurs as irregular masses reaching up to tens of tons in weight, with a variable network of fissures, either surrounding giant K-feldspar crystals or in several metres long lenses in the core of the pegmatite. The colour varies from vivid pink to milky or a very light pinkish, in several hues, but never reaches intense colours. The rose quartz is transparent, translucent, misty or opalescent. An almost regular banding is common, due to very milky strips, a few millimetres thick, rich in minute two-phase inclusions. On exposure to sun light the colour of the rose quartz fades comparatively quickly: specimens of the dumps mined some years ago turned milky as happened to the front of many houses within the neighbourhood of the mine, houses previously adorned during their erection with small pieces of rose quartz. The masses of the latter are fractured and locally, iron and manganese oxides invade the fissures, resulting sometimes in fine dendritic specimens. Microscopic veils and two-phase inclusions are common in the rose quartz which exhales a

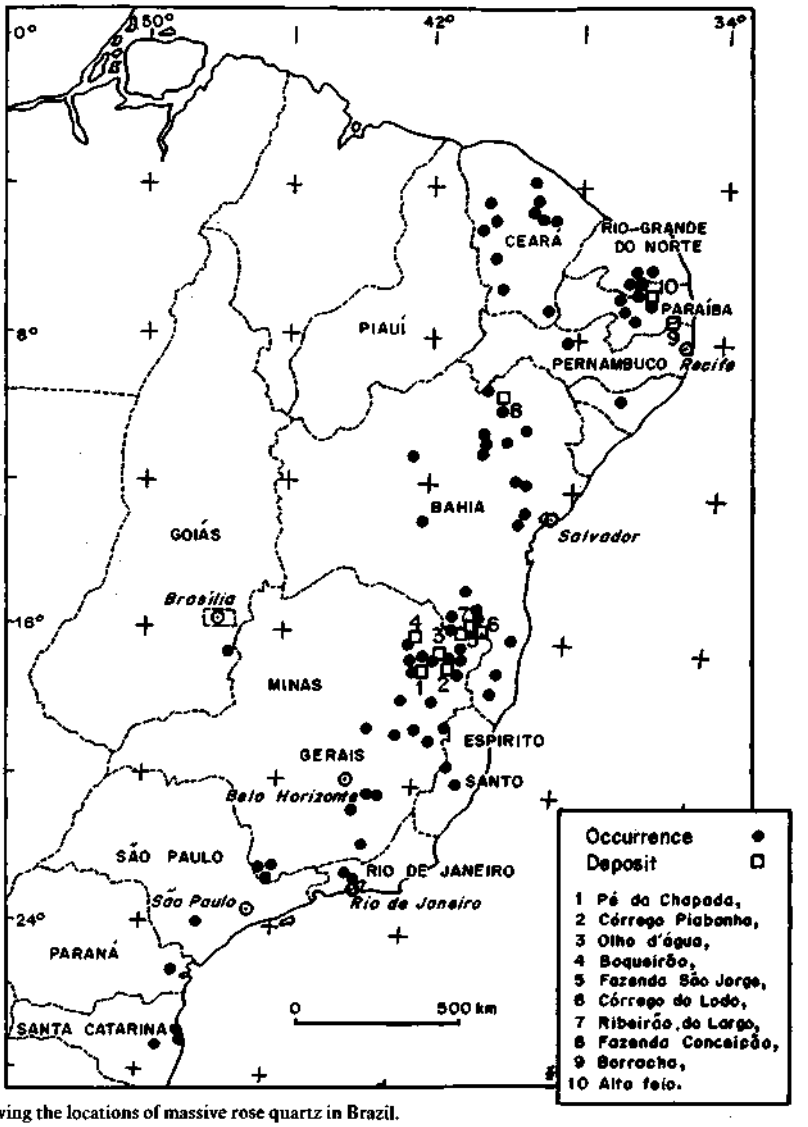

Fig. 2. Map showing the locations of massive rose quartz in Brazil.

fetid H_2S odour when broken. Its physical properties are classical. Some examples exhibit asterism after proper cutting.

Rose quartz from the Alto Feio is used for ornamental purposes (mainly ground and wall covering) and carving, sorted blocks of tens of kilograms being commonly extracted. Translucent homogeneous 'eyes' are always small.

Other massive rose quartz deposits

Besides the deposits, hereunder described, where the size of its concentration allows economic working, the massive rose quartz is a minor constituent of many Brazilian granitic pegmatites. It is found from Santa Catarina in the south to the Ceará in the north, mainly in the "Eastern pegmatitic Province" that obliquely crosses the east of Minas Gerais and enters into Espirito Santo and southern Bahia States, as well in the "Borborema pegmatitic Province" which overlaps the States of Paraíba and Rio Grande do Norte. The rose quartz is disseminated or in masses variable in size but is almost always small, with light colour. This scattering explains the many quotations found in the literature. The localities frequently reported without more information, particularly by Ferraz (1929), Leonardos (1936), Calmbach (1938) and Mendes (1973 & 1975) are plotted on the map.

In the mineralized pegmatites the rose quartz makes up the whole or part of the core and/or joins

together with K-feldspar crystals of the blocky zone. The thickness of the core, lens or string-shaped, varies from a few metres to more than 15; its length locally reaches up to 300 metres. In the core of the pegmatites occurs an heterogeneous mixture of massive rose and milky quartz chunks haphazardly located and sized and sometimes heavily fractured. Associated minerals inside the rose quartz are rare: mainly schorl in needles or in scattered large prisms near the contact between the core and the blocky zone of the pegmatite. Unweathered, faded quartz cores remain as long walls above the plains of the Borborema region.

In the blocky zone, the rose quartz is also mixed with the milky one and welds the giant K-feldspar crystals. It occurs generally unmixed, rarely associated with some druses of quartz, a little schorl and/or beryl. The mineralogy of rose quartz-bearing pegmatites is always simple: quartz, K-feldspar, sometimes albite, biotite, schorl, muscovite and some beryl, niobotantalite and apatite or spodumene, practically without collectors' specimens.

Mining in all deposits is by way of rudimentary quarrying. Blast holes are almost always manually bored, very rarely using a pneumatic drill. After blasting, sorting takes place with the use of a sledge-hammer for the large blocks and a light-hammer for the small good coloured pieces and for translucent eyes. Output is stock-piled until it is transported, frequently with a short intermediate horse stage as far as the nearby road suitable for trucking. Translucent eyes are withdrawn daily from the deposit. Morion and window quartz crystals are by-products in some places.

At present the Brazilian massive rose quartz production occurs in four States: Minas Gerais, Bahia, Pernambuco and Paraíba. The deposits (plotted with a number on the map) are described hereunder from South to North.

Pé da Chapada

(= Santana, Lagoão). The Pé da Chapada deposit began production in 1987 and is located 20 kilometres north-west of Caraí, on the right bank of the São Joãozinho creek. It is a N70°E running and 70°NW or vertical dipping pegmatite of which the wall rock is a fine grained grey granite. Various

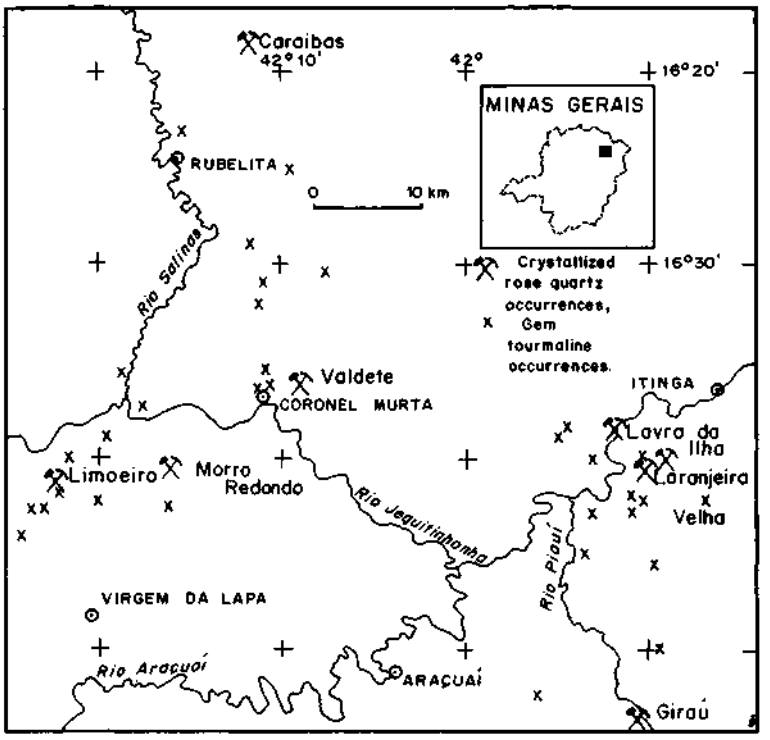

Fig. 3. Map showing the occurrences of crystallized rose quartz in Minas Gerais, Brazil.

Fig. 4. Lavra do Bianor (Minas Gerais). View of the quarry with the massive rose quartz core in the foreground.

small quarries are located all along the pegmatite, about 50 metres in length. The core is string-shaped, 0 to 2.5 metres wide. The rose quartz is of good medium colour with some chunks almost pinkish-red and sub-translucent. The relative lack of fissures allows the recovery of blocks several tens of kilograms in weight. Associated minerals are: schorl, morion, window quartz crystals (= quartz à fenêtre or jacaré) with some biotite, hematite, muscovite and scarce aquamarine. In the south a thick eluvium was worked out: production exceeded 400 tons.

Córrego Piabanha

(= Lavra Schupp). This deposit, known more than 100 years ago, 14 kilometres South of Joaima, produces, as regards colour, the best rose quartz in Brazil. The mine operates a NS running, sub-vertical, zoned pegmatite containing a large core in the south and many giant crystals in the north. The mining takes place within three large quarries, one of which is more than 30 metres in height. The width of the pegmatite reaches 16 metres and its length 300 metres. K-feldspar crystals of more than a metre long are surrounded by rose quartz that also occurs in irregular masses of several tons in weight. Hues, banding and fissures vary in the deposit. The most common colour is bright pink, almost reddish-pink. The quartz is translucent to almost transparent or milky sometimes with an incipient banding. Also NS fissures parcel out the core, many of them are sealed and allow the recovery of large blocks. Sorting is manual, the darker specimens commonly being small in size. Dumped fragments, more than 50 years old, do not show any fading. Schorl, bottle-green apatite and large weathered lathes of spodumene are associated. Production figures are unknown but exceed two thousand tons (Cassedanne, 1981).

Olho d'Água

(= Ilha Alegre, Lavra do Bianor). Located 25 kilometres east north-east of Itaobim, on the left bank of the Jequitinhonha river, this N50°E running, vertical pegmatite with giant crystals, is 15 to 20 metres wide and known along 60 metres in length. The wall rock is a fine grey granite. The rose quartz occurs in the core and between the feldspar crystals; it is massive, homogeneous or with little banding and large translucent eyes. Recovery should be 60% run of mine quartz. Actual production exceeds 300 tons. More than 0.8 metre long schorl prisms are found in the rose quartz with which are associated: bluish-white beryl, biotite and some columbite. Some vugs are coated with long grey to milky quartz crystals. This deposit as well as that of Pé da Chapada are currently the main producers in Minas Gerais State.

Fig. 5. Alto Feio (Paraíba). Giant K-feldspar crystal, 3 m in height, surrounded by massive rose quartz of the blocky zone.

Boqueirão

(= Zé de Tônia, Cóbico and Cubículo). In the neighbourhood of Salinas, it is a N50-60°E running, highly SE dipping pegmatite which reaches 25 metres in thickness and 100 metres in length. Wall rock is a grey granite. Mining is by way of a 25 metres high quarry and several adits. In the string-shaped core, the rose quartz is highly fissured and banded and only blasted for the recovery of translucent eyes. The sorted monthly production amounts to some tens of kilograms. The sorted pieces are commonly walnut to fist size. Associated minerals are: a little beryl, columbite, biotite, amethyst, hematite, schorl and quartz crystals with clay inclusions.

Fazenda São Jorge

(= Veredinha, Boqueirão). In the south southwest of Vitória da Conquista, near the boundary between the Minas Gerais and Bahia States, this deposit is an EW running, 30-40°S dipping well zoned pegmatite with a width of 8 to 10 metres, mined along a length of 120 metres. The wall rock is a highly dipping micaschist. Many irregular lenses and chunks of fetid rose quartz are scattered in the core of the pegmatite, with a parallel banding either to the dip or to the fissures that transect the core. 30% of the blasted quartz would be suitable for sale, with non-fading medium colour. Production probably exceeds 1000 tons. Irregular schorl crystals concentrations occur in the deposit.

Fig. 6. Lavra do Bianor (Minas Gerais). Large schorl crystal in quartz. Length of the ball-pen: 14 cm.

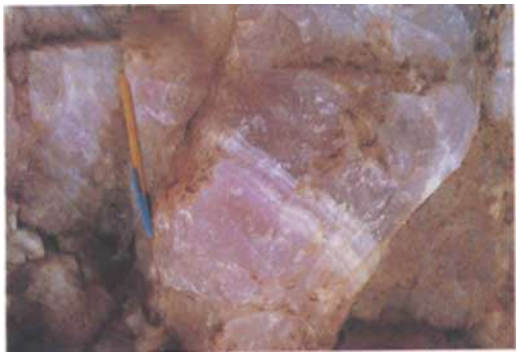

Fig. 7. Alto Feio (Paraíba). Massive rose quartz, with light banding in the central quarry. Length of the ball-pen: 15 cm.

Fig. 9. Córrego Piabanha (Minas Gerais). Sorted translucent dark pink quartz.

Fig. 10. Alto Feio (Paraíba). Massive medium rose quartz ready for shipping.

Córrego do Lodo

(= Fazenda Mangerona). 23 kilometres to the south south-west of Macarani, near the boundary between Bahia and Minas Gerais States, this deposit, found in 1957, is a NS20°E running, 60°W dipping, 8 metres wide pegmatite, known along a length of 40 metres. Working was by way of a quarry 25 metres high. Rose quartz occurs in the core and surrounding giant K-feldspar crystals. Colour is medium good with a recovery of 60% from the blasted ore. Several hundreds of tons were produced before temporary abandonment. Several decimetres long lathes of biotite, large twinned muscovite flakes, schorl, window quartz crystals and some beryl are associated with the rose quartz.

Ribeirão do Largo

(= Quartzo róseo). 30 kilometres south south-west of Itambé, this deposit is an N50°E running, vertical, a few metres wide pegmatite known along a length 50 metres. Rose quartz is scattered into the string-shaped core of milky quartz, and fades after some years of exposure to sunlight. A little schorl is associated. Production should exceed 200 tons.

Fazenda Conceição

(= Flamengo). North north-east of Jaguarari and 13 kilometres from the Flamengo railway halt, this deposit is an N20°W running, 25°SW dipping, 6 to 8 metres wide pegmatite. Working is by way of a 30 × 15 metres quarry, 10 metres in height. Rose quartz occurs between giant K-feldspars of the blocky zone which is surrounded by a thick granitic zone with large graphic texture. The fetid rose quartz, with low fracturing is of good medium colour with white strips and grey patches. Large schorl crystals and a small amount of beryl and muscovite are associated. Several hundreds of tons were produced before the present flooding of the quarry.

Borracha

(= Sitio Novo). North-west of Nazaré da Mata, near the boundary of the Paraíba State, this recently discovered deposit, located in a small creek, is made of blocks and large boulders. These outcrop in an ellipsoidal EW area 50 × 30 metres in size, probably resulting from a pegmatite not yet unearthed by erosion. The fetid rose quartz, with a medium good colour shows white and grey chunks, some banded and some almost reddish-pink translucent zones. Production exceeds 150 tons.

Before concluding it must be pointed out that production from the deposits formed by the decomposition of pegmatites is low to very low. The eluvium that covers some pegmatites allows the local mining of from some tens and up to one hundred tons of massive rose quartz, as in the Pé da Chapada deposit. Here the rose quartz occurs as blocks and little rounded boulders reaching up to 1 cubic metre in volume. They generally are partly sunk into the soil and the regolith. Working is always easy. With the creeping action, the blocks run downwards, sometimes accumulating upon a flat of the hill slopes, downstream of the pegmatite (Córrego do Lodo colluvial occurrence, for instance), before reaching the bottom of the nearby creeks. A little rose quartz was produced from isolated or scattered blocks sunk in gem-bearing alluvium, worked either for chrysoberyl (Córrego do Fogo, north of Minas Gerais State) or for aquamarine (Malacosta, Espirito Santo State). However, these occurrences compared with pegmatite deposits are almost insignificant.

Crystallized rose quartz deposits

In contrast to the massive quartz deposits, the deposits of crystallized rose quartz are generally concentrated in the Minas Gerais State; the bulk lying in the Jequitinhonha valley near the towns of Araçuaí and Itinga. A few others belong to the Rio Doce basin and are located south-east of Governador Valadares.

Previously some good specimens of crystallized rose quartz were recovered during mining of the Sapucaia pegmatite, near Galiléia. In 1969, the discovery of the deposit known as "Lavra da Ilha" made the region of Itinga and Araçuaí a very famous place worldwide due to the abundance of crystallized rose quartz. Besides this there is always easy access for collectors and museums in arranging samples of rose quartz material. Here, the specimens are preserved for mineralogical purposes or used 'in natura' – in their natural state for mounting in modern jewellery.

The main producers, which are the deposits of Lavra da Ilha, Laranjeira and Alto da Pitora, will be described briefly hereunder and the other occurrences listed (see detailed map). Prominent characteristics which allow us to recognize the origin of many specimens presently found in the mineral market will be emphasized.

Lavra da Ilha

The deposit is located 40 kilometres west south-west of Itaobim on an island of the Jequitinhonha River, dry only during low-water stage, that is to say from June to October. The island, located on the right side of the river is approximately 500 metres in length at an elevation of 250 metres.

There is a heterogeneous pegmatite partially covered by unsorted alluvium, striking 40°E, dipping vertically, with a wall rock of quartz micaschist. Workings have uncovered the pegmatite in an

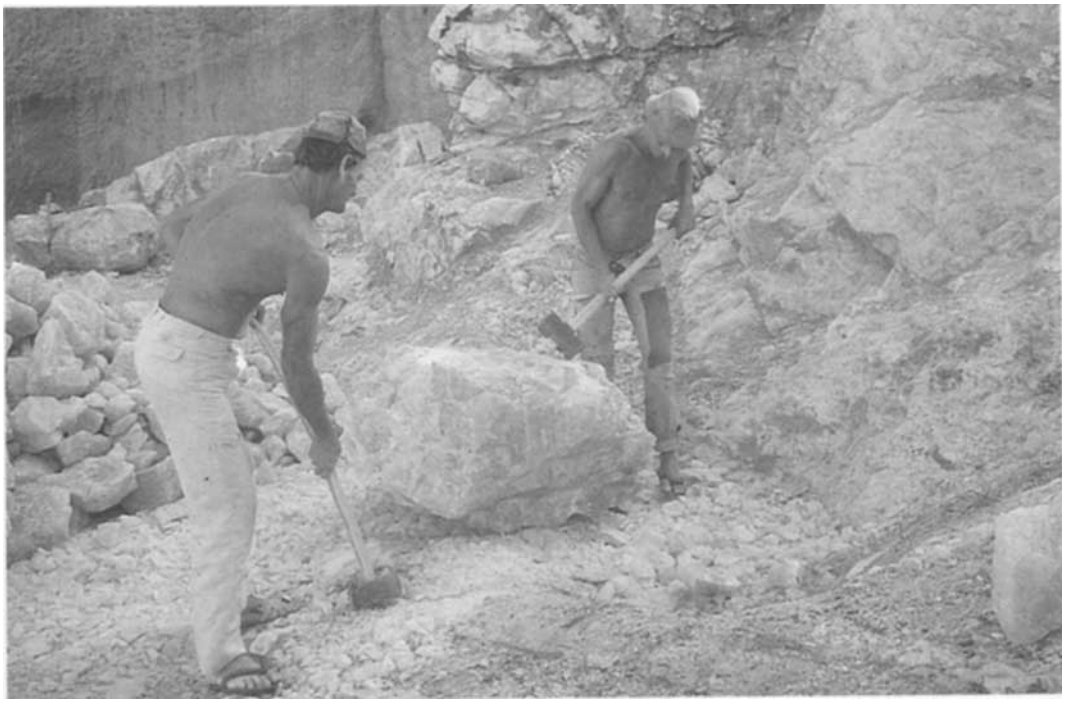

Fig. 8. Lavra do Bianor (Minas Gerais). Sorting massive rose quartz using a sledge-hammer.

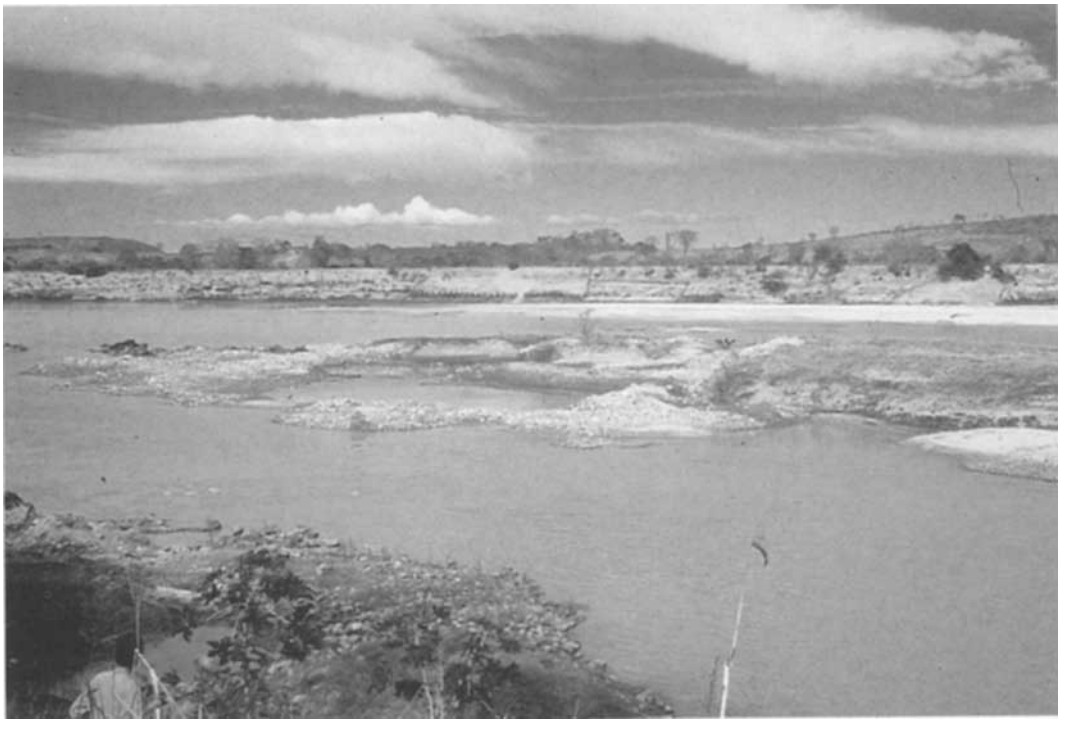

Fig. 11. Lavra do Ilha (Minas Gerais). The quarry, located near the end of the island flooded by the Jequitinhonha river (July 1989).

irregular quarry 50 × 10 metres in extent, 15 metres deep, which is flooded and sand-covered during every annual inundation. The pegmatite, of medium grain size is composed essentially of muscovite with feldspar on both sides of the quartz core, with sodic replacement bodies and small vugs in the vicinity of the core, where crystallized rose quartz is found. Associated minerals within the deposit are: pale green diamond-shaped muscovite, fine groups of sphalerite crystals, niobotantalite, cassiterite and milky beryl. The phosphate minerals are abundant: gem amblygonite, eosphorite, roscherite, rockbridgeite, montgomeryite, wardite, whiterite, collinsite, apatite and vivianite, resulting in part from the weathering of the triphyllite, many of them being excellent collectable specimens (Cassedanne & Cassedanne, 1973).

The crystallized rose quartz belongs to a late state in the pegmatite evolution. Colour ranges from light purplish-pink to light pinkish-white. The crystals vary from translucent to quite transparent or opalescent and their faces are occasionally striated or show growth figures. Variation of shades in one crystal is very rare. The matrix of the rose quartz crystals is generally milky or translucent automorphic or sheared quartz of the first stage. A thin film of chalcedony is common between the two types of quartz. Less frequently the matrix is composed of other minerals. The rose quartz stands as a quite regular coating upon the matrix, but more often it is in radial clusters and parallel or interpenetrated aggregate crystals passing through transparent to rose colour. The most spectacular specimens are those which are occurring as a crown of doubly terminated individuals around a white or translucent quartz crystal of decimetre size. The sizes of the individual crystals vary from a few millimetres to two centimetres with one or two terminations. The association with clusters of eosphorite (predominant), roscherite, wardite and/or apatite allows the quick recognition of the source of specimens coming from this deposit.

Fig. 12. Alto da Pitora (Minas Gerais). Small clusters of crystallized rose quartz. The sceptre is 1.5 cm long.

Laranjeira Velha

(= Ademar). This deposit is located in the neighbourhood of the Lavra da Ilha. It lies in the Laranjeira creek, a right hand tributary of the Jequitinhonha river. Workings started in early 1979 at the top of a small hill, where many excavations irregularly scattered in a subcircular-shaped area (approximately 600 metres in diameter) were dug in search for gem tourmaline. In May of 1979, a deeper pit reached the unexpected pegmatite, covered by the eluvium. The pegmatite runs NW-SE with a northeastern dip of 20°, a width of some metres and an approximate extension of 100 metres. It is zoned with large grain size. Near the core there are

irregular vugs that contain crystallized rose quartz, with cleavelandite, gem tourmaline and translucent quartz crystals with stepped faces. Size and shape of these vugs are variable but may reach up to one metre in length. Associated minerals are: amblygonite, lepidolite, beryl, spodumene, cassiterite, niobotantalite, arsenopyrite and, as phosphate minerals: frondelite, heterosite, moraesite, phosphosiderite, cyrilovite and wardite (Cassedanne & Cassedanne, 1980).

The rose quartz occurs either as a partial or whole crown around the quartz crystals that may be transparent or milky, sometimes fetid when broken, and additionally, it may fill up the interstices between the translucent quartz crystals. Crowns are the most spectacular specimens. Their axis of symmetry may be the same as that of the supporting quartz or they may be undulating. Some specimens display a cluster of crystals lying upon a face of a milky quartz crystal; this may resemble the 'quartz flowers' which occur in the amethyst region of southern Brazil. Small crowns of crystallized rose quartz around tourmaline prisms are also known to occur, being outstandingly beautiful specimens. The crowns are made of interpenetrating small prisms and rhombohedrons with their axes subparallel or divergent to the surface: the result is dazzling. Growth figures on the crystal faces are common as repeated 'sceptre' forms. A thin coating of powdery white quartz sporadically covers the rose quartz groups. Colours range from light pink to purplish-pink, reminding one of the famous samples from the Sapucaia mine in the same State. The crystals are transparent to translucent with, on the whole, a relatively homogeneous coloration. However, light variation of shade may be observed with a lens.

Black or greenish-blue to water-green elbaite, sometimes with chatoyancy, is commonly associated with the rose quartz; but crystallized phosphate minerals never occur. This observation permits easy distinction from the samples produced at the Lavra da Ilha pegmatite.

Fig. 14. Laranjeira (Minas Gerais). Crown of crystallized rose quartz around a grey transparent quartz crystal upon a matrix of K-feldspar and tourmaline.

The other occurrences in the tourmaline-bearng area are of little or no importance. They include:

Caraibàs

(= Mariano Dias). Near the Rubilita town, this pegmatite has produced some light coloured crystallized rose quartz samples, associated with green gem tourmaline.

Valdete

A few crystallized rose quartz specimens were produced in this pegmatite located near Coronel Murta. The main specimen features remind one of

those of the Laranjeira samples. Millimetric sized pyrite crystals and purplish apatite are scattered upon the rose quartz.

Limoeiro

Famous for its gems, years ago (Cassedanne & Lowell, 1982), this deposit produced in July 1989 groups of crystallized rose quartz perched upon grey quartz crystals with a milky shell, associated with diamond shaped light yellow muscovite plates. Some crowns around milky quartz crystals, several centimetres in diameter, were also recovered.

Morro Redondo

In the south of Barra da Salina, very good examples of crystallized rose quartz were recovered in an old gem tourmaline occurrence called Morro Redondo. The recent reopening unearthed fine large crystallized rose quartz crowns around doubly terminated translucent quartz crystals which reach up to 25 centimetres in length.

Laranjeira

A rich green and blue gem tourmaline eluvium with clusters and rosettes of good crystallized rose quartz was discovered in December 1989, 2 kilometres north north-east of the Laranjeira Velha deposit. Below the eluvium more than 20 prospect adits cross the sub-horizontal, N70°E running pegmatite.

Giraú

In the upper Piauí creek, this thin pegmatite produced in 1988 a few tens of kilograms of good well coloured, crystallized rose quartz specimens. The crystals, frequently doubly terminated occur as crowns and rosettes perched upon or around gem tourmaline prisms of an outstanding green or blue colour. Phosphate minerals are unknown here.

In the Rio Doce valley, the *Sapucaia* pegmatite mine is of historic interest. East south-east of Governador Valadares, this lens-shaped deposit 100 × 40 metres in size, vertical, well zoned, was a great producer of beryl and mica during World War II. Its mineralogy is very complex having many phosphate minerals. A small quantity of rosettes, crowns and chalice-shaped deep pink crystallized rose quartz specimens were recovered during mining activities in the 1940 and 1950 decades.

Alto da Pitora

The crystallized rose quartz production begun in the first days of 1989 in this deposit, an old gem tourmaline producer, from an extensive eluvium. The deposit, located 50 kilometres east south-east of Governador Valadares, north-east of Galiléia, on the northern slope of the Serra da Pitora range, is an almost vertical dipping, NE-SW running pegmatite, with a wall rock of coarse granite with lens-shaped micaschist xenoliths. The pegmatite is 1.5 to 5 metres wide, zoned, medium grained with a straight central blocky zone made of large K-feldspars, several decimetres long, spodumene lathes and grey and milky quartz. Parallel fissures with either gently NE or 20°SE dips cut the pegmatite and are frequently associated with small elongated vugs that contain milky quartz crystals, hydrothermalized K-feldspar and late albite, with some muscovite, upon which rose quartz crystals are perched. Other less common associated minerals are; schorl, late sericite and chlorite, cassiterite, niobotantalite, pyrite, amblygonite, beryl and rare lepidolite. Iron and manganese oxides are widespread and stain many specimens. Working is by way of twenty or so adits along the pegmatite, some of them reaching up to 80 metres in length, with irregular rooms and pits. Adits explore the pegmatite about 300 metres in extension and 60 metres in height. C. Vasconcelos, from Governador Valadares, assures us that approximately 1,000 kilograms of crystallized rose quartz were produced until October 1989 with 100 kilograms of superior quality and 100 of very good colour.

The rose quartz crystals occur in clusters, in groups of sub-parallel prisms, isolated (single) or sometimes in crowns around quartz crystals; it is commonly similar to that previously reported in the other deposits. Irregular and repeated variations of sections along the *c* axis are common as are growth figures on the faces; small perfect sceptre specimens also occur. Many samples starting as hexagonal prisms end with several terminations due to the change into parallel smaller crystals during a late development stage. Variations of shade from transparent to pink are common in the samples. Sometimes clusters of small sericite plates are scattered upon the rose quartz.

The lack of phosphate minerals and tourmaline is typical of the Pitora specimens, which are frequently free of matrix.

Gemmological properties

In the deposits the rose quartz varies from strong rose-pink to almost white, it is always cloudy or fissured and never entirely clean, although some material may be found which is sufficiently clear and translucent or almost transparent to cut into faceted stones. However, the material is mainly used for ornamental purposes as production of figurines, house or ground facing, ash trays, book ends, eggs, spheres, cabochons, beads and small carved objects. Material from some deposits fades after long exposure to light or sun.

Despite the fact that much of the material may be marred by cracks, the density of the rose quartz

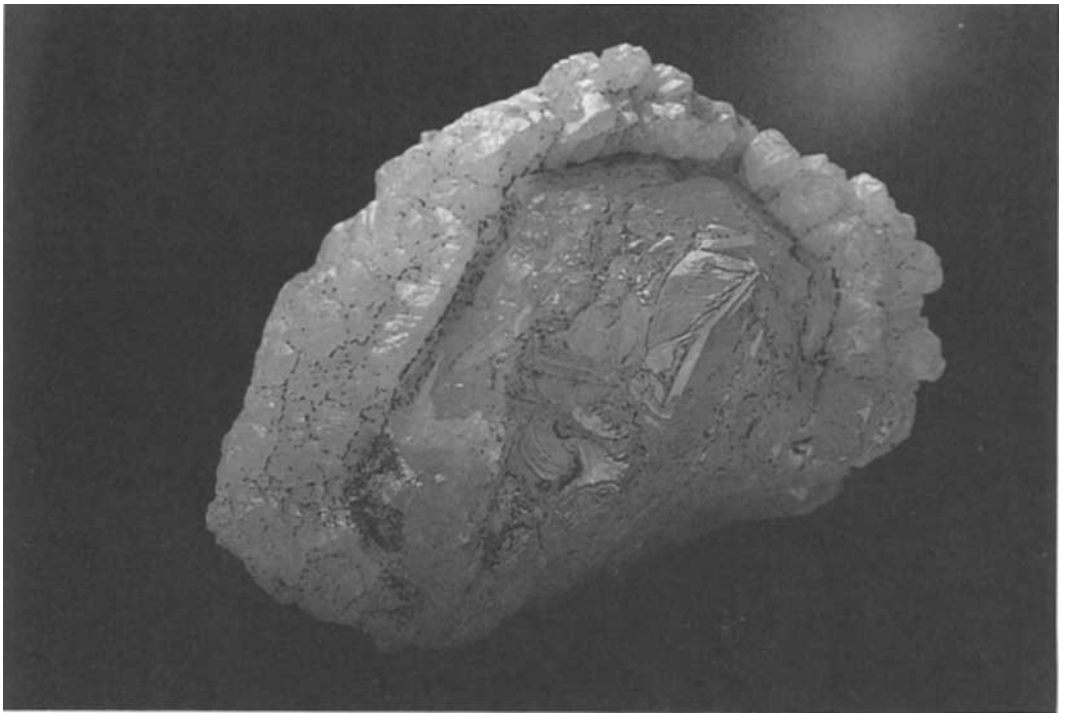

Fig. 13. Lavra da Ilha (Minas Gerais). Crown of crystallized rose quartz around a grey translucent quartz crystal, without matrix (sample collected in 1969). Length of the specimen: 17 cm.

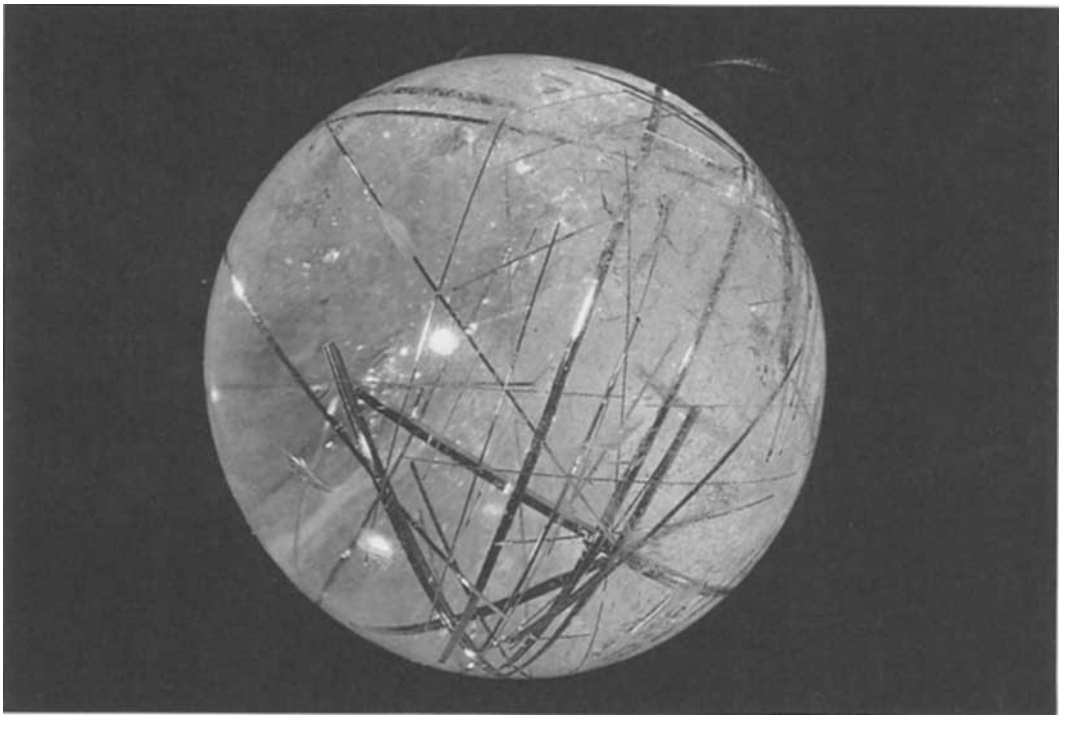

Fig. 15. Rose quartz cabochon with tourmaline needles.

does not vary very much from rock crystal (2.65). Acid, heat and shock resistant (when not heavily fissured), the rose quartz crystal has a conchoidal fracture.

The refractive indices are very constant too and have the values of 1.544 for the ordinary ray and 1.553 for the extraordinary ray. The sign of refraction is, therefore positive and the birefringence is 0.009. Rose quartz shows a fairly strong pleochroism in the deep coloured material (dark pink/light pink), but the effect disappears greatly from the paler material and in the very pale material little or no dichroism can be observed. Rose quartz may be almost translucent, cloudy, nearly opaque or almost transparent, rarely opalescent with a vitreous lustre and shows little fire. The value of dispersion between the B and G interval is only 0.013 (Webster, 1970). There is no distinctive absorption spectrum and rose quartz shows a very little luminescence under ultraviolet light. There is no radioactivity. On heating the pink colour vanishes at about 575°C.

Much rose quartz contains microscopic needles of rutile oriented in definite crystal directions in the host crystal. These needles produce, by a diasterism phenomenon a star effect when the stone is viewed in the correct direction at a source of light. Star rose quartz is sometimes cut as round beads and spheres that reveal a six or twelve-sided star.

Centimetre long rutile or tourmaline needles are not rare in massive rose quartz; this material is used for cutting cabochons, beads, spheres and small figurines. In the fractures, iron and manganese oxides occur frequently as dendrites and allow the cut of unusual cabochons.

Internally, microscopic two-phase inclusions, milky veils, small secondary healing fractures and fissures with or without iridescence are the most common imperfections.

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Suggestions for photographing jewellery

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Abstract

Jewellery photography presents special problems with lighting, depth of field, and background. We conclude that difficulties in these areas are best dealt with by (1) choosing size, colour, and magnification of backgrounds that are appropriate for the purpose to which the photograph is to be used, (2) selecting a technique that maximizes depth of field, if depth of field is needed, (3) using as many lights as possible to emphasize reflectable colour, transmittable colour, and background colour, (4) having on hand mirrors, magic markers, tape, plasticine, and pieces of pseudo-suede, and (5) designing formats that are artistically pleasing and as original as possible.

Introduction

The purpose of this paper is to help you to take better pictures and, by increasing your knowledge, improve the standard of jewellery photography in general. Light, depth of field, background, and special effects are discussed.

Light

There are four principal sources of light for photography of jewellery: sun, light boxes, electronic flash, and incandescent light (Blaker, 1965a; Mineo, 1966; Feininger, 1976; Grossman, 1981). Sunlight is excellent, but if too bright, will cast harsh shadows. These can be softened or removed by using small mirrors cut from sheets of reflective plastic vinyl. When held in place by tape to objects, such as film spools, they can direct additional light where it is needed. By painting the surfaces of the mirrors with a black magic marker to leave only small unexposed areas, small spots of light can be delivered precisely as desired. In the field a small piece of plasticine behind a piece of jewellery can elevate it above the background so that the background will be out of focus. A word of caution: since colour values are at their best at mid-day and shift to red and blue values in the early morning and late evening respectively, pictures should be taken at mid-day if possible.

The second choice of light is a light box. Light boxes use a circular or rectangular fluorescent tube around the upper inner surface of a metal frame. They can be bought in a variety of sizes and come with instructions on how to correct colour for use with daylight film. Usually a magenta colour correction filter is needed to prevent an unpleasant greenish tint. Light boxes are portable, cast virtually no shadows, and can be used with different backgrounds. Their major disadvantage is that they can occasionally produce unwanted highlights on polished surfaces especially beads and rounded objects. However, carved pieces of stone, even though highly polished, can usually be satisfactorily photographed. The method, furthermore, avoids hot spots produced by other techniques. With light boxes, backgrounds can be placed under them and kept out of focus by photographing jewellery on supported non-reflecting glass. In this way coloured backgrounds do not reflect upon the jewellery itself and shadows are not cast.

A third light source is electronic flash. Electronic flash can produce harsh shadows like bright sunlight. These can be made less harsh by using a soft box. A soft box is a collapsible structure which diffuses light and is designed to fit over a flash gun head. It is made of fabric, weighs little, and comes in a variety of sizes. Small ones are useful when working in the field. In the studio they are unnecessary since inexpensive sheets of mylar can be used in front of the lights or flash guns. If backlighting is employed, the shadows produced in front of photographed objects can be reduced with light reflected from reflectors made of metallic cloth, foil, or white card (Figure 1).

The fourth choice is incandescent lighting, usually tungsten and or halogen. In most instances, powerful incandescent lamps are unsatisfactory for photographing jewellery especially jewellery that has specular reflections, be they from metal or gemstones. They should not be used close to the subject, since they tend to produce a flat appearance. Lighting is better controlled with multiple small sources such as fibre-optic wands. The latter can be positioned to direct light in almost any

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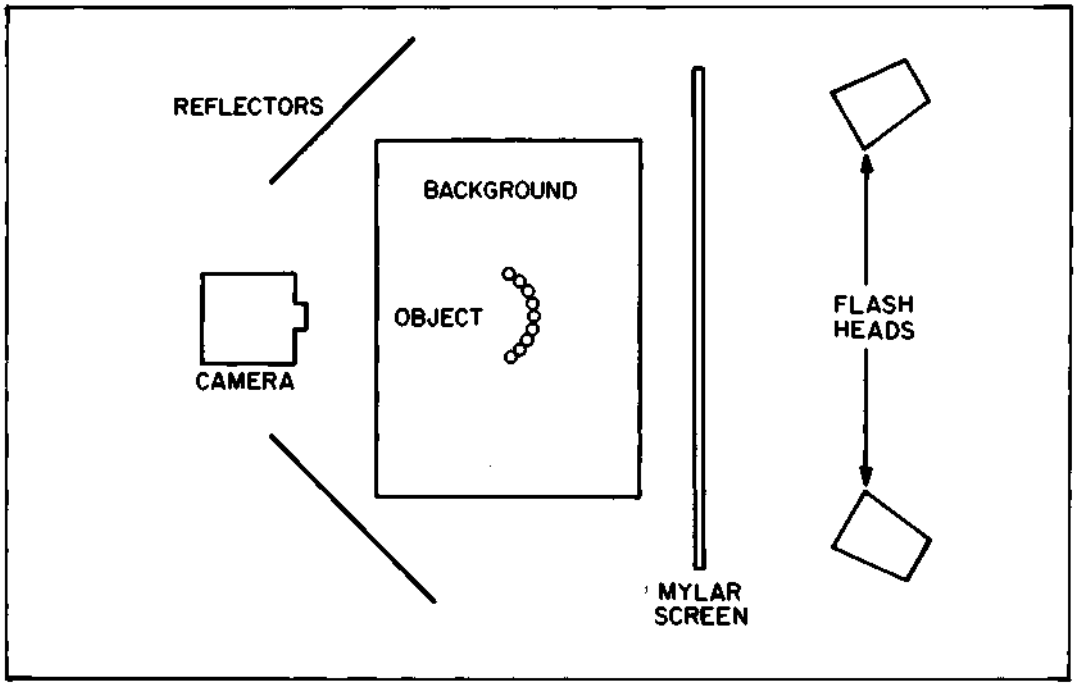

Fig. 1. Backlighting provides a background of varied intensity and highlights that are on the upper rim of the subject and not on the surfaces of interest. To soften frontal shadows, light should be diffused at the source and then reflected onto the subject being photographed.

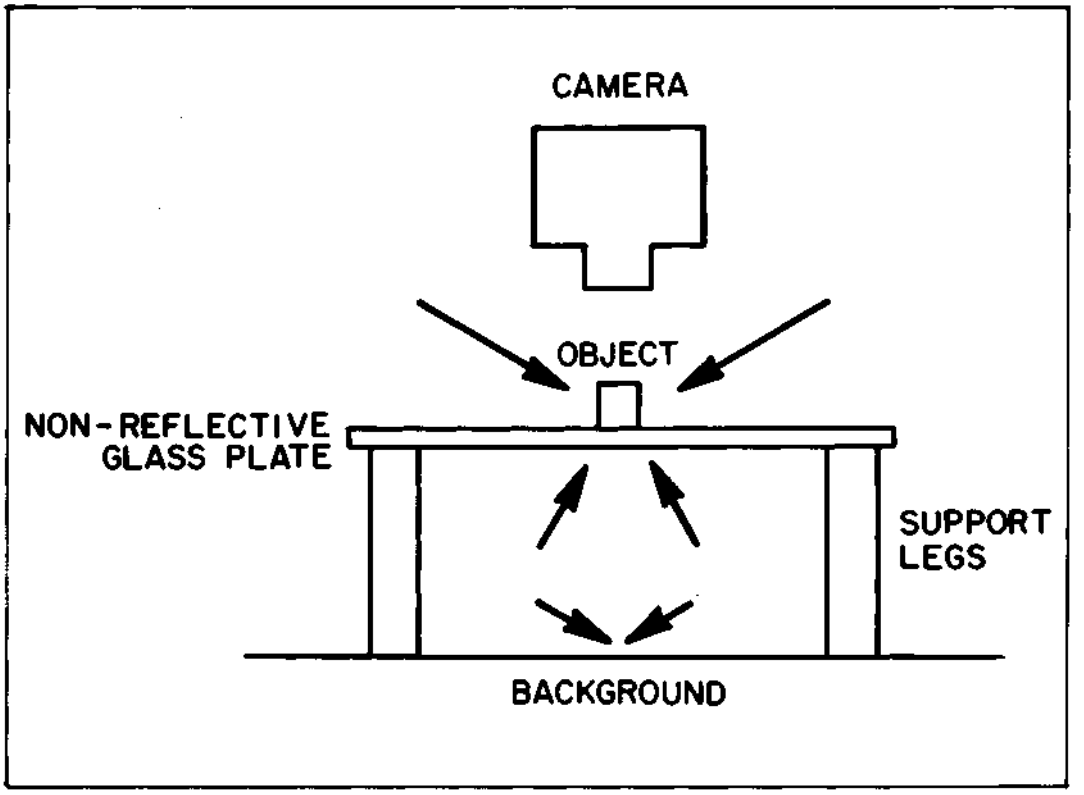

Fig. 2. The flat appearance produced by direct lighting from a single source can be improved by using fibre-optic wands. By mounting jewellery on non-reflecting glass above the background, multiple wands (indicated by arrows) can be directed to produce spotlight backgrounds, high lights and full lights on the subject itself, and transmitted light through gemstones if they are not backed.

direction. Furthermore, the light can be diffused and intensity varied as needed. Figure 2 illustrates how a piece of jewellery might be photographed. The object is placed on a supported plate of non-reflecting glass. The arrows indicate how two fibre-optic wands can be directed to produce a light on the background, two to illuminate the subject from above, and two to illuminate the subject from below if the jewellery has unbacked transparent stones. One need not stop at six lights. In some instances more may be better. The lights on the background produce either a spotlight or a vignetted effect depending on their intensity. If there are transparent coloured stones in open backed settings, small snoots or fibre-optic needles, which can direct light in a fine beam, can be used to illuminate them from behind to bring out colour. The major advantage of incandescent artificial lighting is that one can see the results of one's lighting and make whatever adjustments are necessary.

Depth of field

When photographing flat jewellery such as necklaces, depth of field is rarely a problem. However, it is often necessary to maximize depth of field, when taking pictures of jewellery that is bulky for its size, like bracelets or small objects under high magnification. This can be done in three ways. First, one can use a small aperture (Lefkowitz, 1979; Blaker, 1989b). The two factors that determine depth of field are magnification and aperture opening. The smaller the aperture the greater the depth of field and the improvement in focus. Second, one can use either a view or field camera both of which allow tilting of the lens board and film plane, thereby extending depth of focus (Shaman, 1977; Stroebel, 1986). These large format cameras are relatively heavy, usually take considerable time to set up and, as a consequence, restrict the number of photographs that can be taken in a day. They do, however, produce negatives that are large enough to be retouched. The third choice is scanning light photomacrography (McLachlan, 1964; Schram, 1981; Root, 1985; Gerakaris, 1986). See Figure 3. This technique uses multiple light sources to produce a plane of light that is less than the depth of field of the camera's lens. The lens of the camera is opened in a dark room while the object is mechanically raised through the plane of light. The camera is focused in this plane of light so that, as the object passes through it, it is painted by the light and the entire image is recorded in focus. Unfortunately scanning light photomacrography systems are expensive and are not without their detractions. They

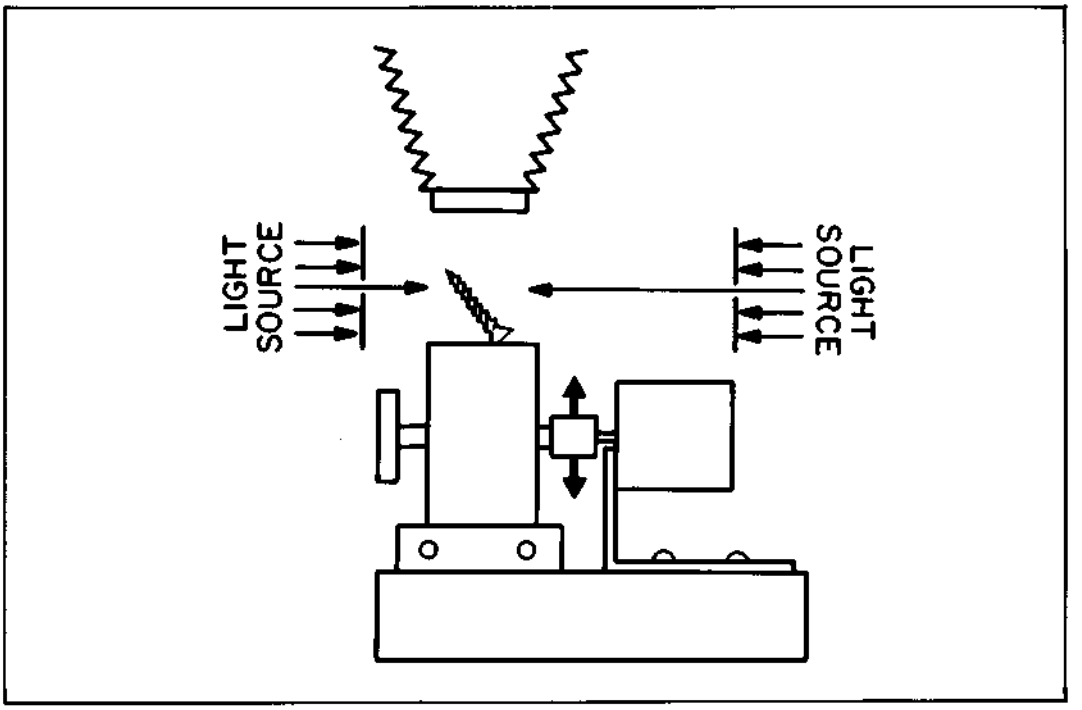

Fig. 3. Scanning light photomacrographs are produced by photographing the object in a dark environment as it is mechanically moved through a plane of light less than the depth of field of the lens. By focusing on the object in the plane of light, the entire image recorded appears in focus. Magnification is limited only by the width of the plane of light and vibration.

are cumbersome to carry. When photographing faceted stones, specular reflections can be very troublesome. Finally, exposures must be approximated so that the method is wasteful of film.

Background

We tender five suggestions to optimize background (Blaker, 1965b; Blaker, 1989a). First, select a background that is appropriate for the use to which the picture is going to be put. Second, if coarse textures are to be used, photograph them at least partially out of focus. Third, be inventive with colour and light. Fourth, be sure, if jewellery is being photographed under magnification, that no dust is present. Fifth, do not be afraid to try unusual backgrounds. Each of these points deserves brief discussion.

The background should be aesthetically chosen and relate well in size to the object being photographed. Colour is important as well. There are no rules about colour. Most people find, however, that greys, blacks, and neutral blues are more satisfactory than bright yellows, greens, and purples. If you have a need for bright colours, consider using silks and rayons that have colours with more colour saturation than dyed materials like paper and cotton.

Cloth fabrics used for background have texture. These are often disconcerting if in focus. A small piece of black plasticine can be shaped to raise a piece of jewellery sufficiently that texture is poorly perceived by the camera. If there is concern that the plasticine is going to leave an oily mark on the background, it can be placed on a coin. For work in the field, a piece of black or maroon pseudo-suede, as well as mirrors, magic markers, tape, and plasticine, are useful to have available. Pseudo-suede can be brushed free of dust and washed when dirty. Another reason for not placing jewellery with metal surfaces directly on coloured fabrics is that the metal will often take on the colour of the background. A small piece of non-reflecting glass that can be supported by film spools is a useful addition to the camera bag.

Taking pictures of jewellery at high magnification introduces the problem of dust. Canned air with a fine tubular nozzle is a convenient way to blow away dust, but should not be carried on airplanes, since pressure changes can cause explosions. Small brushes work well on glass and if one uses velvet, pseudo-suede, or other fabric backgrounds, sticky tape of any sort can be very helpful.

Be creative about backgrounds. Most hobby shops sell plastic acrylics that look like marble, granite, slate, sandstone, etc. that make excellent as well as inexpensive backgrounds. Also available are wood veneers, coloured woods, slates, sands, and sand papers, feathers, flower petals, silks, velvets – even human and non-human models – the list is endless. Backgrounds can also be made by projection to introduce colours, abstract patterns, textures, and scenery.

Special effects

Spectacular pictures are great challenges to take and reputations of photographers are made on these. The following are a few suggestions on how to achieve special effects but, with a little imagination, others can be developed.

If one wishes to photograph a group of stones at right angles to their tables, this can be done with a black background by mounting the stones upright on a black matte acrylic surface with black plasticine or, if another background colour is required, by gluing them to a piece of non-reflecting transparent glass raised above a background colour as needed and photographing straight on. If one uses large format film, one can then retouch the negatives with emulsion paint. One can also mount the stones with their tables on the glass and photograph them with the camera beneath them facing upwards.

To photograph a piece of jewellery on an exotic setting like clouds, ocean waves, or desert, put the object on a mirror and mount the background picture on a card parallel to and above the mirror. Then photograph the jewellery with the background reflected on the mirror.

One of the biggest problems in taking pictures of gemstones is photographing emeralds. Irrespective of their original colour, the colour reproduced is frequently murky. Films do not exist that consistently record a good emerald green. Sometimes it is necessary to retouch a poor green with Kodak emulsion paint to get a satisfactory colour.

Finally, how can one photograph a long thin bracelet? True, one can photograph it diagonally or perhaps partially curled upon itself, but a more attractive alternative method exists. Using a black reflecting acrylic surface and standing the bracelet on its side, one can often obtain a striking image of the bracelet and its reflection. Polished metals or mirrors can also be used as reflecting surfaces.

Summary

In conclusion we would like to emphasize five points. First, select backgrounds of size, colour, and magnification appropriate to the purpose for which the photograph is to be used. Second, choose a technique that maximizes depth of focus, if depth of field is needed. Third, use as many lights as necessary to optimize reflective colour, transmitted colour, and background colour. Fourth, to be always prepared to take pictures of jewellery, have available pieces of pseudo-suede, mirrors, magic markers,

tape, and plasticine. Fifth, and by no means least important, design formats that are artistically pleasing and as original as you can make them.

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Vulcanite or gutta-percha? That is the question

Grahame Brown
Brisbane, Australia

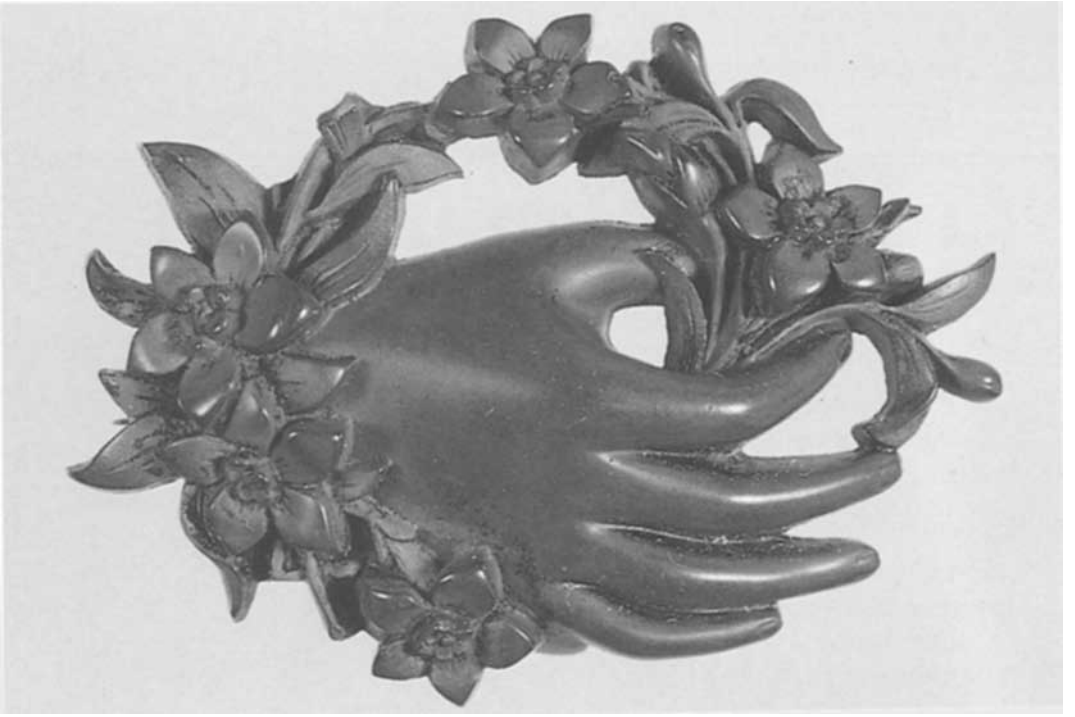

Fig. 1. Moulded gutta-percha 'hand' brooch of similar design to that of the vulcanite brooch illustrated as Figure 7.10 in Helen Muller's book *Jet*.

Abstract

Both moulded gutta-percha, and vulcanite, have been used to imitate jet jewellery of Victorian age. Due to gutta-percha's softness, and its low moulding temperature, this natural rubber is less likely to be found today than jet imitations that have been moulded under heat and pressure from man-made thermosetting vulcanite. The results of this investigation suggest that gutta-percha jewellery can be effectively distinguished from vulcanite jewellery by a combination of careful hand lens examination, judiciously applied hot point tests, and differential solubility tests.

Introduction

Moulded vulcanite (Figure 1) and gutta-percha (Figure 2) are two look-alike imitations that may confuse gemmologists when they attempt to identify articles of Victorian jewellery purported to be manufactured from jet. Indeed the jet expert, Helen Muller[1], has stated that gutta-percha [*sic*] is 'a natural plastic obtained from the milky secretion of a tree *Dichopsis gutta*' that was '... not durable and it is most likely that those pieces of jewellery described as gutta-percha are in fact made of vulcanite'.

As my experience with alleged gutta-percha or vulcanite jewellery does not support Helen Muller's unequivocal statement; and, as the gemmological literature is remarkably vague about the identifying

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features of both jewellery grade gutta-percha and vulcanite; perhaps the time is appropriate when the sources, methods of manufacture, chemistry and gemmological properties of both these materials should be described.

What is gutta-percha?

Gutta-percha[2,3] is a soft, heat sensitive, inelastic greyish to brownish solid substance obtained by evaporating the milky latex of two species of Malaysian tree – the no longer cultivated *Palaquium gutta**, and the commercially cultivated *P. oblongifolia*.

Source

Before Western explorers discovered the Malaysian Peninsular, its Malay and Chinese inhabitants used gutta-percha to manufacture large, light, fibrous textured drinking bowls that they called *mazers*. Early European explorers mis-identified the wood-like texture of these bowls, so their journals recorded that the mazers they acquired had been manufactured from 'mazer wood'. This misunderstanding was the historical source of the oft-quoted 'mazer wood tree' origin for gutta-percha.

For over 200 years, from the early 17th century, 'mazer wood' was brought into Europe as a curiosity. However, by the early 1840s 'maser wood' had been correctly identified as being an evaporated plant sap product. It was subsequently named gutta-percha. In 1848, gutta-percha was first used commercially to sheathe the newly introduced underwater telegraph cables of Ernst Werner von Siemens. Interestingly, late in the 19th century, gutta-percha was replaced for this purpose by the much more durable and recently discovered insulating material – vulcanite. By the 1850s Europe was infatuated by gutta-percha, and all manner of utilitarian and decorative objects were moulded from it – including the gutta-percha golf balls, or 'gutties', used by golfers from the late 19th century until the 1920s.

The source for gutta-percha, latex, is usually collected from deliberately felled trees, since gutta-percha latex only flows very slowly from tapping incisions cut through the bark of standing trees. At harvest, mature trees yield sufficient *Palaquium* latex to furnish 1-2 kg of gutta-percha. When this milky suspension is boiled over open wood fires it yields a solidified mass of gutta-percha.

Chemistry

Gutta-percha is a naturally occurring polymer of isoprene, formed from covalently linked linear chains of isoprene mer (polymer) units. Gutta-percha has a molecular weight of about 30,000.

**Palaquium gutta* is the current name for the tree *Dichopsis gutta*, quoted by H. Muller.

Fig. 2. Simple moulded vulcanite pendant.

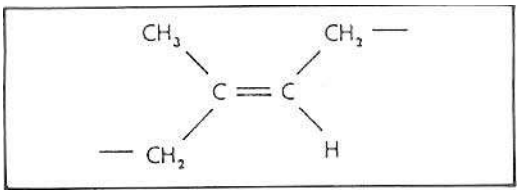

Isoprene polymer

Individual polyisoprene chains, forming gutta-percha, are held together by weak fields of attraction known as Van der Waals forces. In nature, gutta-percha predominantly occurs as crystalline alpha gutta-percha – a linear trans-polyisoprene form, having its chain forming CH_2 units located on opposite sides of the double bond. This linear structure gives gutta-percha some mechanical strength and reduced plasticity.

When naturally occurring crystalline alpha gutta-percha is heated above 65°C it melts. Extremely slow cooling of this melt will allow alpha gutta-percha to recrystallize. But, more rapid cooling,

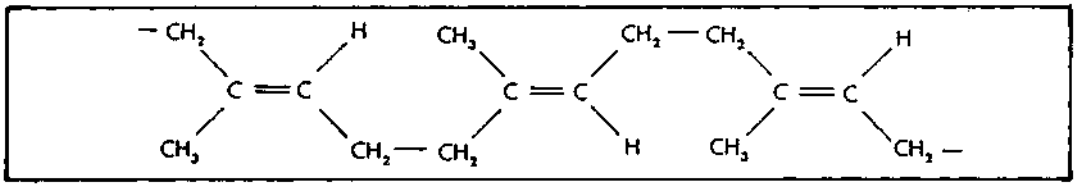

Trans-polyisoprene (Alpha gutta-percha)

such as the rate of cooling that occurs when gutta-percha latex is evaporated to yield solid gutta-percha, will yield crystalline beta gutta-percha having a distinctive diagonal linear structure.

Jewellery grade gutta-percha

When gutta-percha is formulated, for thermoplastic moulding purpose (e.g. to create imitations of jet), gutta-percha must be remelted and filled with inert materials such as zinc oxide and/or chalk, and various waxes and resins. Subsequent heat softening, and moulding, of this filled gutta-percha will, on cooling, yield a mixture of about 60% beta gutta-percha and 40% amorphous gutta-percha. This jewellery grade gutta-percha has the following gemmological characteristics:

Colour: Reddish to brownish grey
Surface texture: Fibrous to coarsely granular
Hardness: 1 (easily scratched by the finger nail)
Tenacity: Brittle
Sectility: Readily pared with a sharp blade
Specific gravity: 0.96-1.0 (pure gutta-percha)
1.2-1.9 (filled gutta-percha)
'Spot' refractive index: SR 1.58 (difficult to determine due to the solubility of gutta-percha in refractometer fluid)
Lustre: waxy
Diaphaneity: Opaque
Solubility: Insoluble in water. Readily soluble in common organic solvents e.g. toluene* (toluol), chloroform, ether
Thermal stability: Softens and becomes pliable between 40-50°C. Melts between 65° and 70°C. An applied hot point will yield a distinctive odour that does not resemble that of burning rubber.

The greyish or brownish fibrous to granular surface of moulded gutta-percha jewellery is invariably painted black or dark brown, to simulate the smooth, highly lustrous, black polished surface attained by jet.

With increasing age, oxidation causes jewellery grade gutta-percha to become brittle, while its surface tends to become crazed by a reticulated pattern of superficial cracks. Additionally, with age painted gutta-percha surfaces tend to lose much of their coating.

What is vulcanite?

Vulcanite[4,5] is a man-made thermoset solid manufactured by compounding natural rubber or *caoutchouc* with up to 32% sulphur at 168°C and 90 psi (0.62×10^6 N/m^2) of steam pressure. The process of vulcanization was discovered in the late 1830s, with the vulcanization process being patented by the American Charles Goodyear in 1842.

Source

Caoutchouc, the natural rubber of Central and South American Indians, is produced from the

*CAUTION: Hepatotoxic, carcinogenic.

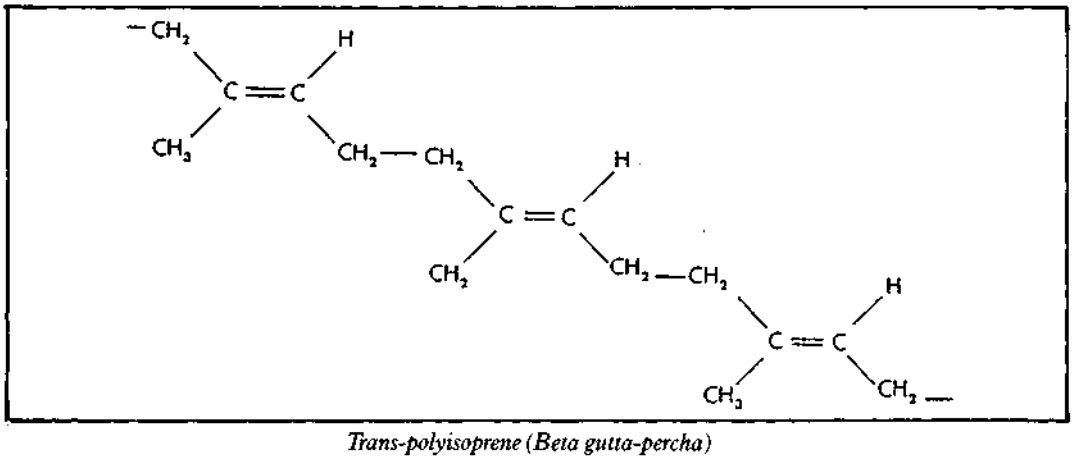

Trans-polyisoprene (Beta gutta-percha)

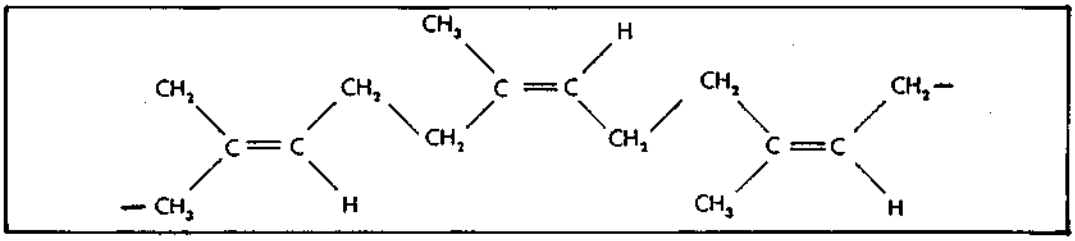

Cis-polyisoprene (Natural rubber)

dried milky latex of several tropical trees including: the *Sephonia elastica* of Brazil, the *Castilloa elastica* of Cental America, the *Ficus elastica* of south-east Asia, and the *Urceola elastica* of the island of Borneo. The latex, from which natural rubber is derived, is primarily an aqueous suspension of microscopic particles of *caoutchouc*. Natural rubber latex has a specific gravity which may vary from 1.02 to 1.41, depending on its *caoutchouc* content.

Recovery of natural rubber from latex involves the following steps:

1. Solidification of rubber from the latex: by evaporation in sunlight or artificial heat; or by acetic or citric acid precipitation. Evaporated 'biscuit' is creamy white, odourless, and has a specific gravity of 0.915.
2. Solid impurities are removed from the 'biscuit' by shredding and protracted washing with water.
3. Cleaned 'biscuit' is consolidated and compressed in steam heated trays into thick sheets of natural rubber.

Simple global economics soon dictated that naturally gathered Brazilian Para rubber was soon replaced by cultivated plantation rubber from south-east Asia. In Europe and America, *caoutchouc* became known as *India rubber*; as a consequence of its initial major use as an efficient eraser of black pencil marks from paper.

Chemistry

Structurally, natural rubber is also an isoprene polymer (polyisoprene) – having its isoprene polymer units covalently linked in a kinked 'cis' form (linking CH_2 groups on the same side of the double bond).

It is this kinked chain-like structure that gives natural rubber its elasticity. Structurally, natural rubber and gutta-percha are both isoprene isomers.

However, it was soon discovered that natural rubber became hard and brittle in cold weather, yet was sticky in hot weather. Experiments to increase the usefulness of natural rubber, led to the discovery that by chemically reacting natural rubber with sulphur, until all the double bonds of natural rubber were saturated, stable man-made hard rubber or vulcanite was formed.

Jewellery grade vulcanite

Thermosetting black jewellery grade vulcanite, or 'ebonite', was soon formulated for use in the creation of relatively inexpensive moulded imitations of the then popular jet. 'Ebonite' was formulated to contain 50% natural rubber, 30% sulphur, 3% black pigment, and 17% fillers. Jewellery grade 'ebonite' vulcanite has the following gemmological characteristics:

Colour: Black, but with time oxidation modifies the vulcanite hue to brown, khaki, then yellowish brown
Surface texture: Compact
Hardness: 1-2 (Not scratched by finger nail, but just scratched by gypsum)
Tenacity: Tough

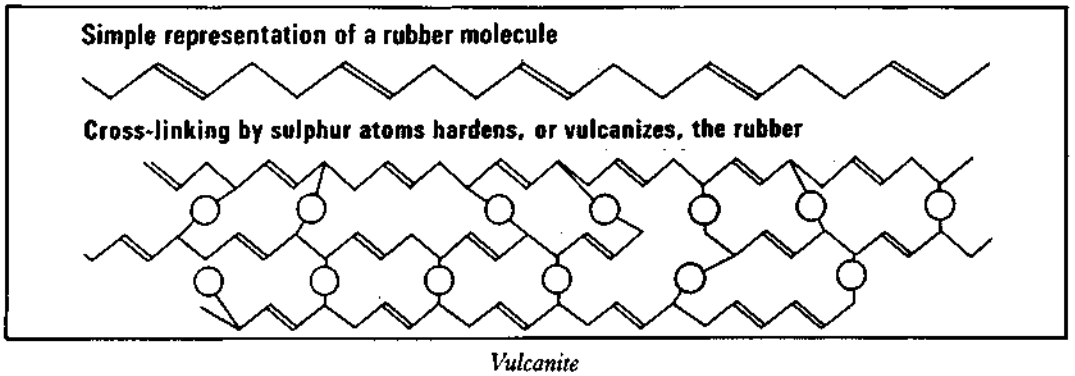

Vulcanite

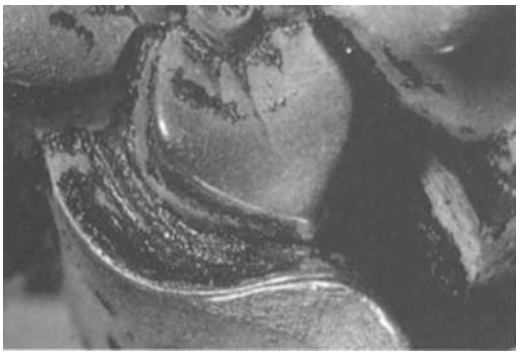

Fig. 3. Granular brownish surface of the gutta-percha brooch (Figure 1) illustrating the significant loss of its black coating.

Fig. 4. Smooth brown surface of the vulcanite pendant shown in Figure 2.

Sectility: Readily pared with a sharp blade
Specific gravity: 1.20+ (depending on filler content)
'Spot' refractive index: SR 1.60/1.61
Lustre: Waxy-resinous (velvety) when freshly polished. Tends to become finely pitted with age.
Diaphaneity: Opaque
Solubility: Insoluble in water, alcohol, glycerol, acetone, and aliphatic hydrocarbons; but somewhat soluble in aromatic hydrocarbon solvents, such as toluene
Thermal stability: Will not soften without decomposition in a flame. A judiciously applied hot point will yield the acrid odour of burning rubber.

Distinguishing gutta-percha from vulcanite

As both thermoplastic moulded gutta-percha, and thermoset moulded vulcanite, have been used to imitate Victorian jet jewellery, the challenge of positively identifying these relatively uncommon jet imitations should be of some interest and importance to practising gemmologists.

Unfortunately, as most vulcanite or gutta-percha jewellery contains other jewellery components, such as metallic pins and clips, determination of their specific gravity is usually impossible. Additionally, attempts to determine 'spot' refractive indices for vulcanite or gutta-percha jewellery can be somewhat difficult due to the complex shapes in which these materials are commonly moulded; the solubility of gutta-percha in refractometer contact liquid; and the presence of a pigmented coating on gutta-percha jewellery that will not yield the true refractive index of this material.

Therefore, the distinction between vulcanite and gutta-percha must be made on the basis of the following tests:

1. Hand lens and/or low-power microscopic examination
   ... looking for evidence of the black or brown coated surface that is often partly missing from the greyish or brownish fibrous or granular surface of gutta-percha (Figure 3). In contrast, vulcanite is evenly coloured, and of uniformly smooth texture throughout its mass (Figure 4).

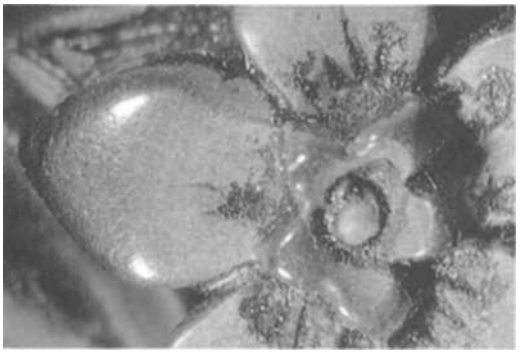

Fig. 5. Uncoated, crazed surface of the gutta-percha brooch shown in Figure 1.

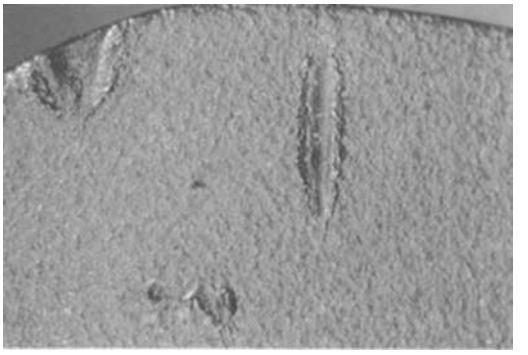

Fig. 6. Response of the surface of gutta-percha to an applied hot point of 150°C.

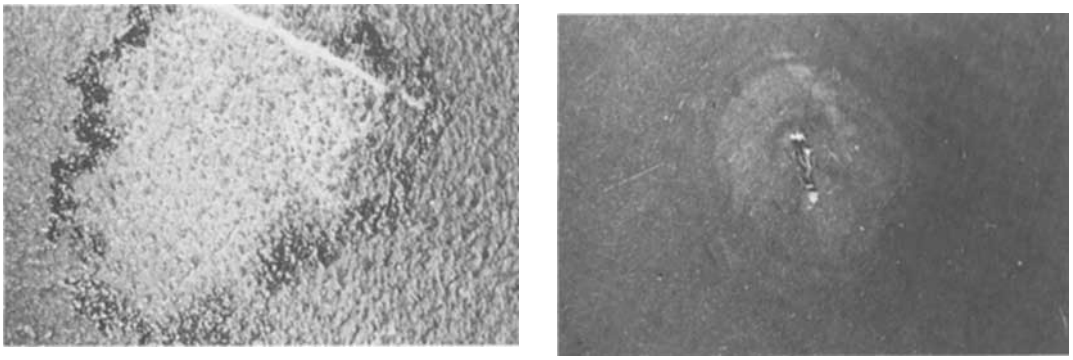

Fig. 7. Response of polished surfaces of gutta-percha and vulcanite to an applied drop of toluene. Note the extensive softening of the gutta-percha surface (A) compared with the minor softening of the vulcanite surface (B) – as indicated by the scratch.

Note: The uncoated surface of moulded gutta-percha frequently crazes with increasing age (Figure 5).

2. A judiciously applied hot point test
   ... low heat (appx. 60°C) will readily soften gutta-percha (Figure 6);
   while,
   ... vulcanite will only char at much higher temperatures, yielding the odour of burning rubber.
3. A judiciously applied solubility test
   ... a minute drop of toluene will rapidly soften gutta-percha (Figure 7A); but only slightly soften the surface of vulcanite (Figure 7B).

Muller claims[1] that ... 'Because vulcanite is thermoplastic, only one cut is necessary in the chain link which can then be opened when heated and slipped onto the next link and closed again. Thus distinguishing jet from vulcanite chains is merely a question of ascertaining whether the links have one or two joins'... should be treated with caution; for it is most unlikely that thermosetting vulcanite also displays thermoplastic properties. One simply cannot join two pieces of thermosetting vulcanite together by heat softening and fusing them with hand pressure. Gutta-percha chains, on the other hand, can be quite easily heat sealed at a working temperature much below 100°C.

Conclusion

As both moulded vulcanite and gutta-percha may be found imitating jet, gemmologist must be able to effectively distinguish these materials. Careful observation for the presence of a coating; and a judiciously applied hot point and/or suitable solubility test should provide the effective distinction between gutta-percha and black vulcanite or 'ebonite'.

A plea

As this research has been based on specimens of vulcanite and gutta-percha jewellery loaned from Australian collections, they may represent a biased sample of jet imitations. The author would be delighted to correspond with other gemmologists who share an interest in these two uncommon organic gem materials.

Acknowledgement

The author is greatly indebted to N. Mackay, Curator of Specimens for the Western Australian Branch of the Gemmological Association of Australia, for the loan of study specimens of vulcanite and gutta-percha; and to Helen Muller and her husband for their helpful review of this paper.

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[*Manuscript received 29 June 1990, revised 8 September 1990.*]

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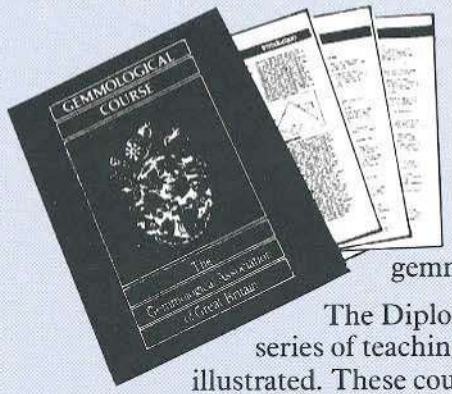

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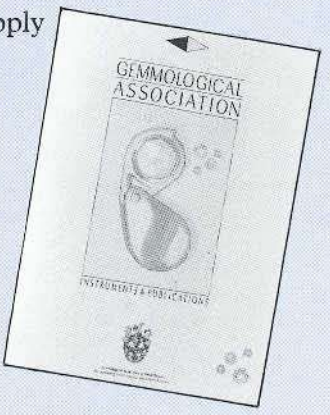

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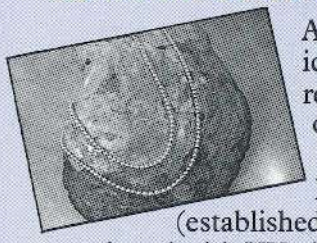

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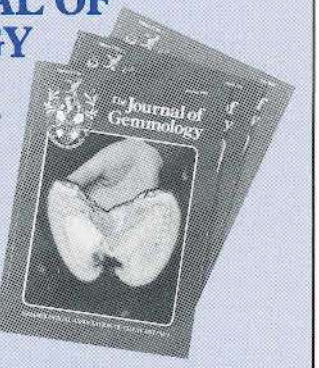

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Gemmological investigation of a synthetic spinel crystal from the Soviet Union

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Gemological Institute of America, 1660 Stewart Street, Santa Monica, California, USA

Abstract

A transparent purplish-red octahedral synthetic spinel crystal grown in the Soviet Union was studied. The properties were investigated to determine if the material could be identified using standard gemmological tests. It was also examined by means of energy dispersive X-ray fluorescence, UV-visible spectrophotometry and infrared spectrometry to document these properties.

Introduction

For gemmologists, so-called synthetic spinel – in colours other than red – has never been considered a problem synthetic. The mass-production of this material has always been by the flame-fusion 'Verneuil' process, which requires that excess alumina be present in the structure (Nassau, 1980). This sets up a distinctive pattern of internal strain in the boules that, in cut stones, is quite easily recognizable in a field of polarized light. This distinctive anomalous double refraction has been variously called a 'cross-hatch effect' or 'tabby extinction' by gemmologists.

This excess alumina enrichment also results in an abnormally elevated refractive index and a slightly higher specific gravity than would normally be encountered in most colours of natural spinel. Because of this, until now, the separation of natural from most synthetic spinel has been one of the easiest and most straightforward of the synthetic-versus-natural separations that a gemmologist is likely to face.

In the case of red synthetic spinel, however, the ratio of Al_2O_3 to MgO must be virtually identical to that found in nature (1 to 1) if the chromium dopant is to give the desired red colour (Nassau, 1980). Because of the variable burn-off rates of Al_2O_3 and MgO, it is very difficult to grow red synthetic spinel by the flame-fusion method.

With flux growth, however, the chemical components do not suffer from high-temperature burn-off symptomatic of flame-fusion growth above 2200°C. So the commercial growth of synthetic red spinel by the flux-melt method is feasible from a technical, if not economic, standpoint.

At a fall 1989 gem and mineral show held in Denver, Colorado, U.S.A., Mr. Bill Vance, a local gemmologist, noticed two large transparent intense red octahedral crystals that looked like fine gem-quality spinels. They were in the possession of a gentleman from the Soviet Union. Mr. Vance was told that the crystals were 'synthetic spinel grown hydrothermally in the Soviet Union'. He was able to purchase the smaller of the two crystals but was told that the larger one was not for sale. He was not able to determine if these crystals are being produced in quantity for commercial sale.

Because of his crystal's unusual size and quality Mr. Vance contacted the authors to find out if this apparently new type of synthetic might be of interest for detailed gemmological investigation and description.

It has been long known that gem-quality spinel crystals have been grown experimentally by methods other than flame fusion. In 1848 J.J. Ebelmen was probably the first to successfully grow synthetic spinel in a borate flux (Nassau, 1980). The book "Color Encyclopaedia of Gemstones" (Arem, 1987) mentions flux-grown red and blue synthetic spinel. One of the authors has personally examined a collection of small pink and light blue octahedrons grown by a flux-melt process. But such methods of crystal growth were considered experimental and were always deemed too costly for the production of synthetic spinel in general – particularly when flame-fusion material in colours other than red could be produced quite easily and at very little cost.

A recent ICA Lab Alert (Bank and Henn, 1989) described a flux-grown synthetic red spinel octahedron weighing 13.14 carats. At 17.19 carats the crystal purchased by Mr. Vance is the largest synthetically grown octahedron yet studied. And its colour is equal to a fine colour in natural red spinel. Therefore, considering the new (Soviet) source, and in view of the transparency and pleasing red colour, a thorough gemmological investigation was carried out.

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Gemmological characteristics

Crystal description

Other than size, the first thing that strikes the observer about this crystal is its obvious quality. It is a transparent, near-perfect octahedron with one truncated (cube face) tip so that the crystal can be balanced on point rather than resting on an octahedral face (Figure 1).

On a Mettler PC400C electronic diamond balance, the spinel crystal was determined to weigh 17.193 carats with corresponding measurements of 14.79 × 13.40 × 11.76 mm.

Colour

The daylight colour could be described as an intense slightly purplish-red. In artificial incandescent light, a very slight orange component was present. Under fluorescent illumination the orange component was eliminated and the purplish overtone was somewhat stronger, resulting in a purplish-red body colour. Direction of observation had no effect on the colour appearance as expected for an isotropic gem species. GIA GEM Instruments ColorMaster notation was C-20-11-18.

Refractive index

The synthetic spinel crystal had sufficiently flat octahedral faces to allow flat facet refractive index readings to be taken. Using a Duplex II refractometer and a near-monochromatic, sodium-equivalent light source, the refractive index was determined to be 1.719. This value is within the range previously determined for natural spinel and as such does not offer any means of separation.

Specific gravity

Methylene iodide, with a 3.32 specific gravity, was used for standard sink-float testing to estimate specific gravity. The spinel crystal readily sank in this liquid when submerged just below the surface and released. When compared to the sink rate of an 8.25 carat round brilliant flame-fusion synthetic sapphire, the spinel sank visibly slower. But its sink rate was virtually identical to that of a 1.71 carat natural purplish-pink spinel crystal and to that of a 3.21 carat emerald-cut light blue flame-fusion synthetic spinel as well.

Because of its weight and apparent quality, the synthetic spinel crystal's specific gravity was determined by hydrostatic testing. Three separate runs were carried out at room temperature. The average specific gravity for those three runs was 3.58 ± 0.01. This value for specific gravity falls within the range established for natural gem-quality spinel.

Ultraviolet fluorescence

Under darkroom conditions the spinel crystal was examined against a non-fluorescent black background using both long-wave and short-wave ultraviolet radiation. Contrast control goggles were worn to help eliminate secondary reflections. Samples of both natural red and pink spinel from Burma and Sri Lanka were used as comparison stones.

The fluorescent reaction to long-wave radiation was a strong purplish to orangy-red that seemed to vary slightly with direction, while the short-wave fluorescence was only slightly weaker, a moderately strong slightly orangy-red. Additionally, under short-wave, some of the edges between crystal faces appeared superficially chalky and, in certain directions, yellowish-orange. There was no purplish overtone under short-wave radiation. No phosphorescence was detected from either wavelength when the ultraviolet lamp was switched off.

With the exception of the slight chalkiness to short-wave, the fluorescence characteristics of this synthetic spinel crystal were almost identical to those shown by the natural red and pink spinel comparison stones.

Visible light spectroscopy

A Beck prism spectroscope with an illuminated wavelength scale was used to determine the visible light absorption characteristics for the synthetic spinel crystal. Because of its euhedral octahedral form and high transparency the crystal behaved as a 'window' being ideal for transmitted light spectroscopy. The crystal showed general absorption in the violet and blue from 400 to 450 nanometres, a diffused weak absorption band between 580 and 630 nm, a strong, fine line at 680 nm, and a strong fluorescent line in the deep red at 690 nm.

Once again, because natural red spinels show similar absorption characteristics, visible light absorption as observed through a hand spectroscope is of no value in separating this synthetic spinel from natural gems of similar colour.

UV-visible absorption spectroscopy was performed using a Pye Unicam 8800 spectrophotometer. The spectrum of this synthetic as viewed with the spectrophotometer is similar to that of natural red spinel. However, the 'chromium lines', which appear as two weak, sharp bands around 650 nm in the spectrum of natural red spinel, were just one, much broader band in the spectrum of the synthetic sample.

Chelsea colour filter reaction

When the synthetic spinel crystal was placed on the tip of a fibre optic illuminator and examined in several directions with a Chelsea colour filter, the colour through the filter was a strong orangy-red.

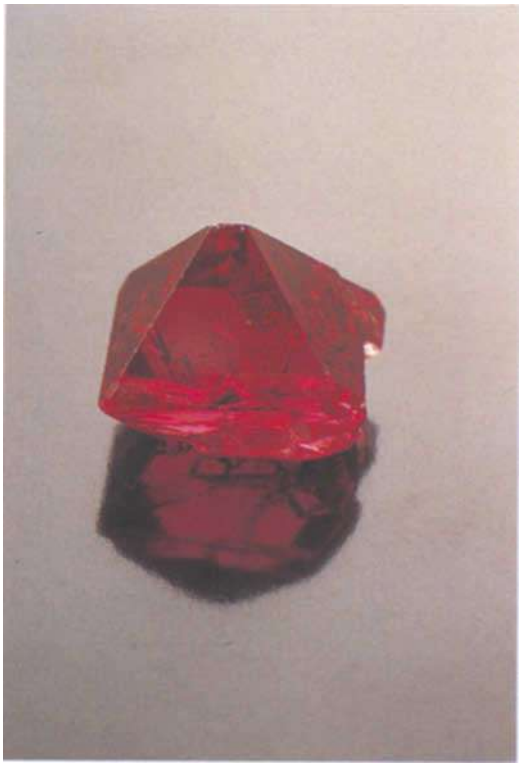

Fig. 1. Transparent synthetic spinel crystal weighing 17.193 carats reportedly grown in the Soviet Union. *Photograph by Robert Weldon.*

Fig. 2. Primary flux inclusions in the synthetic spinel crystal. Magnified 20×. *Photomicrograph by John I. Koivula.*

Fig. 3. The truncated surface that appears to be the point of attachment or growth-nucleation of the synthetic spinel. Magnified 5×. *Photomicrograph by John I. Koivula.*

Fig. 4. Brightly reflective and iridescent air-filled fractures resulting from strain as observed in the synthetic spinel. Magnified 10×. *Photomicrograph by John I. Koivula.*

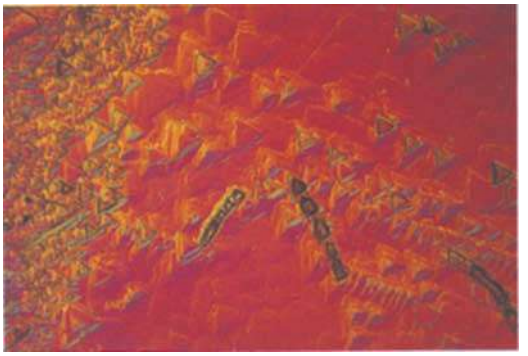

Fig. 5. Triangular etch features observed on the octahedral face of a *natural* spinel crystal. Magnified 80×. *Photomicrograph by John I. Koivula.*

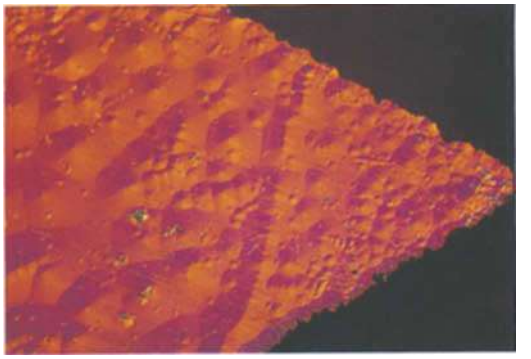

Fig. 6. Growth hillocks on an octahedral face of the flux-grown *synthetic* spinel crystal. Magnified 80×. *Photomicrograph by John I. Koivula.*

Natural spinels of similar body colour show virtually the same orangy-red colour when viewed through the filter. This test therefore does not provide a means of natural-versus-synthetic separation.

Magnification

A standard gemmological microscope equipped for a variety of illumination techniques, including polarized light, shadowing and oblique illumination, was used to study the synthetic spinel crystal both internally and externally.

Surprisingly, because it was represented as hydrothermal, the crystal contained what appeared to be primary flux inclusions of a deep orangy-brown colour with an angular to jagged profile (Figure 2). These inclusions formed a pyramid-shaped phantom in near-perfect alignment with the external faces of the octahedron that was centred just under the surface of the truncated octahedral tip. The truncated surface was pitted and ridged in a manner indicating that it was the surface of crucible attachment during growth (Figure 3).

The crystal also showed some brightly reflective and iridescent air-filled fractures (Figure 4) that seemed to have their point of origin at or near the phantom of dark inclusions. In polarized light, strain was observed in association with the fractures and flux-like inclusions suggesting that perhaps the pyramid-shaped phantom delineated the original borders of a growth discontinuity and that the fractures are the result of strain.

Externally, closer inspection of the major crystal revealed three small secondary satellite modified octahedral crystals protruding in parallel growth from one octahedral face (cover picture). Most natural spinel crystals which have not been subjected to mechanical water erosion show either virtually smooth surfaces or, on close inspection, slight signs of chemical dissolution in the form of minute triangular etch pits (Figure 5) on their octahedral faces. The smooth-appearing octahedral surfaces of the synthetic crystal, however, were covered with semi-circular growth hillocks (Figure 6) of a type not yet reported on natural spinel crystals.

Infrared spectrometry

The mid-infrared absorption characteristics of the synthetic spinel crystal were studied using GIA's Nicolet 60SX Fourier-transform infrared spectrometer. The results of this testing showed that while two very weak broad features were observed in the mid-infrared at about 3620 and 3375 cm^{-1}, they do not compare in intensity with the features observed in hydrothermal materials. Additionally, no intense broad absorption centred at 3600 cm^{-1} (indicating the presence of hydroxyl groups) was detected. Hydroxyl groups indicate the presence of water and have been observed in all natural and synthetic hydrothermally-grown materials, including natural and synthetic emeralds and amethysts. The absence of this feature rules out hydrothermal growth as the means of synthesis and indicates that the crystals were grown from a melt. The additional observation of inclusions typical of flux-grown synthetic materials proved that this octahedral crystal was grown by a flux-melt technique.

Chemistry

Using GIA's Tracor Northern Spectrace 5000 energy dispersive X-ray fluorescence system, a bulk qualitative chemical analysis was done on the synthetic spinel crystal. In addition to the expected magnesium, aluminium and chromium, trace amounts of iron, nickel, vanadium and molybdenum were detected. Molybdenum is a common component of fluxes used to grow gem materials. Titanium, a common component of natural spinels, was not detected.

Conclusion

Red is generally considered the most valuable colour of natural gem spinel. Because of the precise ratio of magnesium to aluminium required it has always been very difficult to grow using the flame-fusion technique. The appearance of large flux-grown synthetic crystals, however, may mean that faceted synthetic red spinels will become available commercially. The extent to which these flux-grown synthetic red spinels are being manufactured in the Soviet Union (and marketed) is not yet known. However, because large crystals have now been reported in both West Germany (Bank and Henn, 1989) and the United States, it is possible that there may be a serious marketing effort on a worldwide scale.

So far, to our knowledge, only large transparent rough crystals have been seen. But faceted stones of high clarity weighing several carats could be easily cut from such crystals. If they are, without flux inclusions to identify them as synthetic, they will be very difficult for the jeweller-gemmologist to identify because all of the standard gemmological properties such as refractive index, specific gravity, UV fluorescence, spectrum, etc., shown by these synthetics are virtually identical to those properties in natural red spinels.

Acknowledgements

Mike Moon in GIA's research department provided the infrared spectral data and part of the qualitative chemical analysis, while Meredith Mercer, also of the GIA research department, performed the UV-visible spectrophotometry. The authors are thankful to Mr Bill Vance for the loan of the specimen for this study.

References

Arem, J.E., 1987. *Color Encyclopaedia of Gemstones*, Van Nostrand Reinhold Company, New York, New York.

Bank, H., Henn, U., 1989. *Flux Grown Synthetic Red Spinel From U.S.S.R.*, ICA Laboratory Alert Number 26.

Nassau, K., 1980. *Gems Made by Man*, Chilton Book Company, Radnor, Pennsylvania.

[*Manuscript received 26 January 1990.*]

Gemmological Abstracts

BENJAMIN, M., 1990. Letter. Imitation opalized shells. *Australian Gemmologist*, 17, 7, 277-8.

The dealer who supplied the opalized shell dealt with in the November issue of *Australian Gemmologist* by John Koivula, states that their artificial structure was fully obvious both to him and to Susan Johnson who passed them on to the GIA.

R.K.M.

BRACEWELL, H., 1990. Gems around Australia. Part 3. *Australian Gemmologist*, 17, 7, 265-9, 15 figs, mostly coloured.

Continuing the Round Australia search, the Hart's Range is dealt with, offering zircon, garnet, feldspar, beryl, tourmaline, kyanite, epidote, ruby, iolite and chrysocolla. Paper comments on dirty condition and appalling language of young aborigines (self-imposed problems), but aborigine elders were gentlemanly and Mrs Bracewell found them a delight to deal with. R.K.M.

BROWN, G., 1990. Some rare ivories. *Australian Gemmologist*, 17, 7, 256-62, 23 figs.

A dental expert deals with the rare ivories from walrus, including fossil tusks preserved in Arctic cold for perhaps 2000 years, crocodile teeth, tiger teeth, boar teeth and dugong tusks. R.K.M.

BROWN, G., 1990. The appropriateness of GAA's gemmological nomenclature, 1990 Presidential address. *Australian Gemmologist*, 17, 6, 216-18 and 248-50.

Grahame Brown argues cogently for a commonsense approach to naming gem substances and decries the misuse of names which is apparently common in Australia. He summarizes rules laid down by the Commission set up by the International Mineralogical Association and by CIBJO. He goes on to analyse the degree of acceptance and to discuss the use of the word 'synthetic' and the often confused multiplicity of names applied to synthetics. Much of what he said applies world-wide.

R.K.M.

BROWN, G., 1990. Biron synthetic pink beryl. *Australian Gemmologist*, 17, 6, 219-20, 2 figs.

A new synthetic morganite for which the author quotes constants, SG 2.68 and RI 1.571-1.578, DR 0.007, saying that these are 'considerably' lower than for natural morganite. The Biron synthetic has moderate orange fluorescence in LWUV. R.K.M.

BROWN, G., 1990. Gemmological study club lab report. *Australian Gemmologist*, 17, 6, 221-30, 22 figs in colour (not sequentially numbered).

Describes or investigates, oiled ruby; rainbow lattice sunstone; silicon imitating hematite; Keppel Bay variscite; quartz soudé 'amethyst'; Dungowan (Tamworth) nephrite; Aqua Aura; Australian prasiolite; ß quartz, and Argentinian rhodochrosite. (Suggests that natural radiation has converted some prasiolite to amethyst. Prasiolite is normally obtained by heating amethyst, and the heat of the tropical sun has been known to do this, so the report seems to indicate a reversal of that process.) R.K.M.

BROWN, G., BRACEWELL, H., 1990. Mt Philp aventurescent iolite. *Australian Gemmologist*, 17, 6, 231-4, 15 figs in colour.

Located 55 km SE of Mt Isa, this deposit yields a deep blue iolite with inclusions of hematite platelets, pinite, apatite (?), and a possible amphibole. Constants are in line with Mt Isa iolites, the hematite giving the Mt Philp material an aventurescent sheen. R.K.M.

BROWN, G., KELLY, S.M.B., BEATTIE, R., BRACEWELL, H., 1990. Gemmology study club reports. *Australian Gemmologist*, 17, 7, 279-86, 24 figs, some in colour.

The Club reports on a chalcedony with dendrites of copper minerals from Mt Isa which provides a new ornamental material; a pair of mottled black-dyed cultured pearls had been waxed; faceted colourless calcite; natural pale yellow sapphire which had been heated to give the rarer colourless variety; a purple triplet of colourless synthetic spinel; a diamond etched by heat; a colour-change (purple to blue) didymium doped cubic zirconia; various new Russian quartz synthetics; turquoises with brecciated texture; reconstructed kauri gum carvings; scenic Peruvian common opal and a natural pearl necklace with a single imitation pearl at its centre, a fair match which was easily detected by lens. [Abstracter finds the unconventional numbering of illustrations for this paper confusing and rather irritating.] R.K.M.

BROWN, G., LINTON, T., 1990. Treasure Chest gem tester. *Australian Gemmologist*, **17**, 7, 274-5, 1 fig.

'Yet another' thermal conductivity probe which gives results which are 'probable' rather than 'positive', suitable for single diamonds but not for continuous use, nor for other species. R.K.M.

BROWN, G., SNOW, J., BRIGHTMAN, R., 1990. YAGG: a gemmology study club report (not indexed). *Australian Gemmologist*, **17**. 6, 239-42. 10 figs in colour.

A report on yttrium aluminium gallium garnet, $Y_3(Al,Ga)_5O_{12}$ (doped with chromium), made by Dr J. Osman of JO Crystal Co, Calif. True silicates are viscous when melted and tend to finish as a glass. So these silica free 'garnets' are simpler to synthesise. YAGG was made in a flux of lead and other oxides and imitated tsavorite, the green vanadium grossular garnet. 2000 carats were produced before rising costs brought the enterprise to a halt. H 8+, SG 5.05, RI 1.88, Chelsea filter, bright red, LWUV strong red, chromium spectrum, inclusions of yellow/brown flux, platinum(?) and veil-like healed cracks. R.K.M.

FRITSCH, E., SHIGLEY, J.E., ROSSMAN, G.R., MERCER, M.E., MUHLMEISTER, S.M., MOON, M., 1990. Gem quality cuprian-elbaite tourmalines from São José da Batalha, Paraíba, Brazil. *Gems & Gemology*, **26**, 3, 189-205, 18 figs in colour.

A detailed account of the exceptionally fine blue and green copper-rich elbaite from Paraíba, Minas Geraes. RIs vary around 1.619-1.639, SG 3.04. Some stones heated to convert bluish-purple to fine green or blue, which colours are also found naturally. R.K.M.

FRYER, C.W., ED., CROWNINGSHIELD, R., HURWIT, K.N., KANE, R.E., HARGETT, D., 1990. Gem trade lab notes. *Gems & Gemology*, **26**, 2, 153-8. 18 figs in colour.

'Pearls' cultivated using mantle tissue without nacre-producing cells, were coated with black/brown calcareous concretion. A coral imitation was identified as barium sulphate, with plastic and colouring agent, 'spider-web' structure detected, RI 1.58, SG abt 2.33, H 2 to 3.

A diamond octahedron with etched channels is illustrated; a rare purple diamond was type IaA and had no 550nm line. A yellow glass egg fluoresced strongly, very radio-active, probably uranium glass. An unusual banded lapis lazuli is illustrated.

A grey baroque salt-water cultured pearl had its bead markedly off-centre. A large old natural baroque pearl had been trimmed up, half-drilled in four places and a hole plugged with another pearl.

Semi-transparent sodalite cut into some 2000 small beads looked very like synthetic sapphire; a faceted pink spinel lacked octahedral inclusions but had polysynthetic twin planes, oriented needles and a bluish tone in transmitted light; an antique looking Russian blue stone earring was paste, with old-cut diamonds and a post-revolution hallmark which dated it after 1917 (?); a blue three stone ring had deep Sri Lankan-cut synthetic sapphires set with diamond chips (cleavage flakes?), the intact silver and gold setting looked antique, but synthetic sapphires were first made in 1910. R.K.M.

FRYER, C.W., ED., CROWNINGSHIELD, R., HORWIT, K.N., KANE, R.E., HARGETT, D., 1990. Gem trade lab notes. *Gems & Gemology*, **26**, 3, 220-7, 20 figs in colour.

An 8.38 ct emerald dyed with green oil and with green dop wax on its girdle was detected, both enhancing the colour, poor chromium absorption and light pink through colour filter suggest a pale stone artificially improved by the dye; a superb chatoyant 31.04 ct carved horse head was identified by spot RI 1.75 and by 445nm absorption band as chrysoberyl, carved in Idar-Oberstein.

A light bluish-green diamond was identified as electron irradiated by colour zoning around the culet which was visible when the stone was immersed; a mottled 4.26 ct black diamond was natural with electro-conductive areas which suggested type IIb, but clear areas fluoresced blue to LUV and yellowish-green to SUV, confirming type I diamond, probably the many graphite inclusions accounted for colour and conductivity; a number of laser-drilled diamonds have resulted in cleavage cracks and branched drill-holes, in one case the laser hole reached an included diamond octahedron which would not be improved by such treatment (and inclusion could have been made more obvious if an air gap was created).

A Mexican opal had a large egg-like whitish inclusion, most obvious in transmitted light; a new type of cultured pearl nucleus from Japan is illustrated, made from powdered oyster shell, plastic-bonded and coloured, it is used to nucleate black or grey pearls, the nacreous layer is unusually translucent and drilling causes the binding plastic to melt.

A necklace of natural fresh-water pearls of a dark brownish purplish-pink, from San Angelo lakes and rivers in West Texas, selected over 15 years from many thousands found, is probably rare (but not very attractive). Naturally black or grey Polynesian cultured baroque pearls were compared with similar baroque blacks from Japan and were found to have larger nucleii.

Montana sapphire rough is being investigated to

determine whether it has been heat-treated or surface diffused. A 63.65 ct colourless sapphire from Sri Lanka is described and illustrated, as is a natural cobalt spinel with colour change from blue to purple. R.K.M.

GUO, J.F., WANG, F.Q., 1990. Chicken-blood stone. *Australian Gemmologist*, **17**, 7, 262-5, 2 figs in colour.

Changhua, or chicken-blood stone is an altered silicic tuff rock, with cinnabar inclusions which make it a fine red, a symbolic colour for the Chinese. Historically a seal stone, it is today used more for other carvings. H 2 to 3, SG 2.6 to 2.9, RI 1.53 to 1.60, waxey lustre, fine specimens rare and can command high prices. R.K.M.

HANANO, J., WILDMAN, M., YURKIEWICZ, P.G., 1990. Majorica imitation pearls. *Gems & Gemology*, **26**, 3, 178-88, 17 figs in colour.

Describes the history and products of Majorica SA, a Spanish factory for imitation pearls of high quality. Although these are said to be closely similar to salt-water cultured pearls in appearance, detection is a simple application of the same tests as for other imitation pearls. R.K.M.

HARGETT, D., 1990. Jadeite of Guatemala: a contemporary view. *Gems & Gemology*, **26**, 2, 134-41, 10 figs in colour.

A fascinating account of the rediscovery of jadeite by the Ridingers in the Zacapa region of Guatemala in 1974. Further discoveries were made and green, 'blue', white, 'black' (dark green) and variegated green, some with pyrite, are now known. Jadeite was mined and greatly valued in several pre-Colombian civilizations and their artifacts have been found from Peru to Mexico. The new material is used to make copies of these, and as beads and cabochons. 'Black' material is most sought, but bluish jadeite is rarest. R.K.M.

HLAING, U.T., 1990. Burmese zircon. *Australian Gemmologist*, **17**, 6, 237-9, 3 figs.

A short paper covering crystal proportions, heat treatment and analysis, not all of which is easy to follow. H.K.M.

HLAING, U.T., 1990. Myanmar diamonds from north to south. *Australian Gemmologist*, **17**, 7, 278.

Octahedral, trisoctahedral and hexoctahedral diamond crystals, often distorted and colourless, found in alluvial areas near Mong-mit, Toungoo and Mergui in Burma (Myanmar). (Those diamonds I have seen from these regions have been small, white, with exceptionally lustrous curved faces.) R.K.M.

HUGHES, R., 1990. Talkin' 'bout gem testing instruments. *Australian Gemmologist*, **17**, 6, 242-6.

A second instalment of rather flippant criticism of design, efficiency and high cost of Western gemmological instruments, this time on dichroscopes, refractometers, immersion cells and stone holders. [It now seems possible that these papers may be a preliminary hype for the author's declared intent to manufacture such items. Hopefully we may yet see well-designed, super-efficient instruments produced by cheap skilled labour in Bangkok, at prices suited to the pockets of hard-up gemmologists the world over. Go to it Mr Hughes!] R.K.M.

KANE, R.E., KAMMERLING, R.C., KOIVULA, J.I., SHIGLEY, J.E., FRITSCH, E., 1990. The identification of blue diffusion-treated sapphires. *Gems & Gemology*, **26**, 2, 115-33, 23 figs in colour.

Surface-blued sapphires are increasingly prevalent. Near colourless faceted and polished stones are packed in a powder of alumina and titanium and iron oxides, and heated for several hours at above 1700°C. This causes blue to diffuse into the suface to about 0.15mm, which in many stones has been increased to about 0.42mm by further heatings. The colour tends to penetrate more at facet junctions and around the girdle. High temperatures destroy lustre and stones need repolishing, which tends to remove blue unevenly.

To the eye the stones look like normal well-coloured sapphires, but breaks or depressions in the surface are not repolished and remain dark blue. High temperatures affect inclusions in the usual ways.

The general blotchiness of colour is the main clue to this treatment, and is best seen by the naked eye, with the stones immersed in a glass dish of liquid over a strong but diffuse light source. Methylene iodide (di-iodomethane) is the best liquid, but water or glycerine are also suggested.

Geuda rough, which fails heat treatment to improve colour, is being fashioned and then given this blue-diffusion treatment. The stones are natural but the thin layer of colour has been diffused synthetically and should be declared as such. Any subsequent repolishing or re-cutting would largely remove it. R.K.M.

KANE, R.E., KAMPF, A.R., KRUPP, H., 1990. Well-formed tsavorite gem crystals from Tanzania. *Gems & Gemology*, **26**, 2, 142-8, 7 figs in colour.

Euhedral crystals of tsavorite are extremely rare, but H. Krupp obtained several while on a visit to Tanzania. The gem is found in association with tanzanite on both sides of the border with Kenya.

Gemmological properties are described, with emphasis on the perfection of these crystals from the Karo-pit in the Merelani Hills. Stones up to 14 carats have been cut. R.K.M.

KOIVULA, J.I., KAMMERLING, R.C., 1990. An unusual Indian aquamarine. *Australian Gemmologist*, **17**, 7, 270-2, 5 figs.

Found near Kangyam in Madras, this 41 ct aquamarine had constants within the normal range for the material, with faint but anomalous absorption and strong pleochroism. Parts of the stone are so strained that they show biaxial figures with the conoscope. R.K.M.

KOIVULA, J.I., BOEHM, E., KAMMERLING, R.C., 1990. Diamond grit-impregnated tweezers: a potentially destructive gemological tool. *Gems & Gemology*, **26**, 2, 149-51, 6 figs in colour.

Demonstrates the considerable damage done to a ruby rotated just once with its table in contact with these tweezers, which are unsuitable for any stone other than diamond, and even that can be scratched! R.K.M.

KOIVULA, J.I., KAMMERLING, R.C., 1990. Gem news. *Gems & Gemology*, **26**, 2 159-68, 16 figs in colour.

Research for new synthetic materials of equivalent hardness to diamond calculates that a carbon nitride would have almost the same bulk modulus. A plant set up at Ipoh in Malaysia by Belgian companies is processing 900,000 diamonds a year; Botswana produced 13 million carats in 9 months of 1989, a new crushing plant at Jwaneng comes into use soon. Intraco of Singapore join Russian Almaz to deal in diamonds, coloured stones, etc; a new Angolan field at Lucapa is being prospected; Argyle are training cutters near Beijing, China, to process Australian diamonds; kimberlite pipes are being drilled for diamond potential in Michigan; a joint Swiss/Sri Lankan project will cut diamonds and coloured stones at Katunayake free trade zone; Mwadui mine, Tanzania, is expected to run out in nine years and they are searching for more diamond pipes; Australian Molopo are prospecting for diamonds and gold in Botswana by aeromagnetic methods.

Coloured stones

A glass-capped plume agate doublet is described in detail; light emerald-green tourmaline from Paraíba, Brazil, and greenish-blue apatite, claimed to come from the same area, seen at the Tucson Show, but apatite most likely Madagascan; some bluish-green apatite was sold as emerald in Kenya; zoned white and green chrysoprase from Goias, Brazil, investigated and found to fluoresce greenish-blue in UV light, chrysoprase is normally inert; good quality jadeite exists in Niigata, Japan, in green, blue, purple, black and white but little is mined owing to inaccessible terrain and bad climate, other deposits in Hokkaido and Hyogo prefecture also not exploited.

Idaho opal is assembled as cat's-eye triplets, with quartz or glass tops and chalcedony backs; San Carlos Indian Reserve, Arizona, produces about 600 kg cabochon grade peridot a month, October to March, too hot other months, 15 kg small sizes are facet grade; a Patagonian Jurassic chalcedony fossil pine cone is illustrated; while at Chantaburi, Thailand, Dr H.A. Hänni of Switzerland, saw ruby rough reportedly from Vietnam, similar to Burmese, Pakistani and Afghan material – he feels that heat treated this might rival Burma or East African ruby.

A quartz, opal and pyrite rock found near Lafayette, Louisiana, gives cabochons speckled with play of colour; a yellowish-brown chatoyant topaz was the first seen by News editors; Hector Barbosa tells of his discovery of the Paraíba tourmaline mine. Some tourmaline cat's-eyes examined in Idar proved to be doublets, clear tourmaline cemented to fibrous tourmaline base; they also report assembled bi-colour tourmalines.

Synthetics and simulants

Plastic cameos with backs misshapen like shell cameos are illustrated; 'emerald' crystals from S. Africa were quartz with green cementing agent, coated with limonite and mica flakes, RI as for quartz, spectrum indicated a dye similar to that used for stained jadeite, bubbles in soft cement and a piece of emerald included in one 'crystal', these were similar to fakes described earlier by Dr Hänni; 'rhodochrosite' beads, bought in Mexico, were massive calcite, dyed pink, which left traces on an acetone swab. R.K.M.

KOIVULA, J.I., KAMMERLING, R.C., 1990. Gem news. *Gems & Gemology*, **26**, 3, 228-38, 15 figs in colour.

Diamonds

News from Brazil; Botswana; Sierra Leone; Australian prospecting in Hunan, China; Goa; India; Borneo; of Sri Lankan investment; Thai auction of smuggled diamonds; new find of diamonds near Archangel'sk; Soviet visit to Israel cutting plant; Israeli cutting in Warsaw and Bucharest, and widespread diamond exploration in Australia.

Coloured stones

A fossil mushroom found in amber from The Dominican Republic is an estimated 40m years old and the best one known; a greenish-blue cat's-eye apatite is said to be a new variety; Zimbabwe

emerald mines are described; unusual greyish-brownish-green chatoyant cabochon was identified as diopside, and a fine iolite cat's-eye is described and illustrated.

A team of geologists have investigated Inner Mongolia, China, and report many gem sites of commercial significance.

A chatoyant opal was unusual in being a true cat's-eye, with weak pleochroism; a chatoyant scapolite had two weaker light bands which make it effectively a star stone; an unusually carved tanzanite is illustrated before and after heating to a blue colour; a rare tanzanite cat's-eye is also depicted; the sugilite mine near Kuruman, S. Africa, is increasing production.

Aqua aura gold-film bluing of faceted gems is now a commercial process; Mexican opal coated with dark plastic on one side to enhance the play of colour on the other, is described and the coating illustrated; and another opal had been sugar-treated and the entire stone coated with plastic, thicker on the base where an RI of 1.56 was obtained.

Synthetics and simulants

Prof. P.O. Knischka of Steyr, Austria, reports producing synthetic ruby crystals over 5cm long, capable of yielding cut stones of 67 carats, a half crystal of accordion-like stepped growth is illustrated and said to have glassy two-phased inclusions and platinum platelets, colours available – light, medium or dark Burmese or Thai purple.

A fake emerald originating in Madagascar was submitted to Jean-Paul Poirot of the Paris laboratory, who identified it as green fluorite roughly shaped to a hexagonal prism and cemented to tourmalinized rock by plastic mixed with mica, M. Poirot points out that green fluorite has a similar absorption to emerald and is pink through the Chelsea filter, but it fluoresces violet with LWUV and the cement fluoresced yellow/white.

A carved 'jade' sphere from Hong Kong proved to be a calcite/serpentine rock which had been selectively dyed in various shades of green and brown, and then waxed. R.K.M.

Kopf, R.W., Hurlbut, C.S., Koivula, J.I., 1990. Recent discoveries of large diamonds in Trinity County California. *Gems & Gemology*, **26**, 3, 212-19, 7 figs in colour.

Former geologist and miner, Edgar J. Clark, found four large diamonds of record sizes for California in alluvial sand and gravel of the Hayfork Creek tributary of Trinity River, Northern California, in the late 1980s. Weights 3.90, 14.33, 32.99 and 17.83, they were named Jeopardy, Serendipity, Doubledipity and Enigma, and were complex twinned crystals with encrusted faces, none of cuttable quality, but smaller gem quality stones have been found when placer mining for gold and platinum group minerals in that area. R.K.M.

Kovacs, E., 1990. Letter. Preliminary assessment of gem identification system (GIS) software. *Australian Gemmologist*, **17**, 7, 276-7.

Argues case for computerized system. Editorial comment points out that expert computer programming cannot substitute for training and experience. R.K.M.

Linton, T., 1990. Radiation alert. *Australian Gemmologist*, **17**, 7, 278.

Some Meltler balances B5, B6, and M5 imported into Australia before 1960 have been found to contain radium 226, but are unmarked as radiation hazards. They should be withdrawn for expert decontamination. R.K.M.

Linton, T., Brown, G., 1990. Medo Hand vacuum tweezers, model MH-100 and Linicon LV-125 vacuum pump. *Australian Gemmologist*, **17**, 7, 272-3, 2 figs.

A new approach to the problem of stones which fly from conventional tweezers. Works well sucking stones into a close hold, and blowing loose dust from instruments. Weight 1.2 kilos, price $A295, efficient but at DbA 60 at 1 metre, noisy! R.K.M.

Mitchell, R.K., 1990. Letter to the editor. *Australian Gemmologist*, **17**, 7, 275.

A further note on the word 'profilated' in reference to 'profiled' bubbles in some synthetics, pointing out that it was coined by our late and very good friend Basil Anderson, and not by Robert Webster, another excellent but regrettably deceased friend. (Author's abstract) R.K.M.

Schmetzer, K., 1990. Hydrothermally grown synthetic aquamarine manufactured in Novosibirsk, USSR. *Gems & Gemology*, **26**, 3, 206-11, 9 figs in colour.

A single specimen of Russian synthetic aquamarine described in careful detail, had constants within the normal range for natural material, but nickel from the stainless steel crucible was detected by spectrophotometer, while infrared spectroscopy proved hydrothermal origin. Tested stone contained many tell-tale inclusions which reduce its acceptability as a gem. Absence of significant amounts of sodium and magnesium also indicated synthesis. R.K.M.

Trioani, T., 1990. Rare-earths. *Australian Gemmologist* **17**, 6, 235-6.

A brief account of the so-called 'rare earth' elements. R.K.M.

Book reviews

HUGHES, R.W., 1990. *Corundum*. (Butterworth Gem Books.) Butterworth-Heinemann, London. pp. xviii, 314. Illus. in black-and-white and in colour. £35.00.

Presumably out of deference to the importance of the material described, this is a larger work than the others from the same Butterworth stable. This is one of the few monographs dedicated to a particular species to be published in English during this century and is welcome on that score alone. The first chapter deals with the history of corundum, with reference to early literature and, like succeeding chapters, includes its own bibliography. The second chapter describes chemistry and crystallography and here it is pleasing to see text diagrams taken from Goldschmidt's *Atlas der Krystallformen*; in this book the Goldschmidt diagrams have been relabelled and improved for the modern reader. Most gem monographs, for space reasons, have to be sparing with this kind of illustration and they are both useful and relevant here.

The book continues with physical and optical properties with useful notes on thermal expansion and thermal conductivity, optical properties, colour, luminescence, absorption spectra (with notes on the use of the hand spectroscope) and pleochroism. The effect of pleochroism on cutting is well illustrated by text diagrams.

The chapter on inclusions follows and again black-and-white photographs and text figures help the reader even when he has the Gübelin inclusion books. Thai corundum is described particularly closely and since some of this material is the subject for enhancement this is a valuable feature here. Diagrams also show how primary fluid inclusions may be trapped in gemstones and illustrate zonal primary liquid inclusions; the healing of a crack is also usefully depicted.

Nearly thirty pages are devoted to corundum enhancement and the reader will turn eagerly to this section in a book emanating from Thailand where so much treatment is carried out. Five major processes are listed for the heat treatment of corundum: they are removal of silk, development of silk, development of a blue colour from colourless material, removal of blue colour (the lightening of over-dark sapphires and the removal of the blue component from yellow-green sapphires to give a fine yellow) and development of yellow colour from white or pale yellow, mainly Sri Lanka material. The author makes the point that his information is second-hand and speculatory – this is, of course, for reasons of commercial secrecy on the part of those carrying out the treatments. One anecdote illustrates the dangers of treatment – read the book to find out the details! After describing irradiation and other forms of treatment the author outlines current thinking on disclosure.

Synthetic and composite corundum are described in chapter seven which is particularly exhaustive and contains a good bibliography. Fashioning is described in the next chapter and after sections on quality, famous stones and classification, we come to the geology of corundum and notes on world deposits. It should be said that the section on classification contains a great deal of information, particularly on Thai classification, not previously published and most interesting. Preference of different societies for particular colours is most valuable for dealers in corundum.

In the section on world deposits the history of the deposits is given as well as the current situation so far as this is known at the time of writing. Even better, different localities are given their own bibliography. The book ends with an index.

This is a first-class book, well-printed and quite well bound. All gemmologists should buy a copy.

M.O'D.

Proceedings of The Gemmological Association and Gem Testing Laboratory of Great Britain and Notices

OBITUARIES

It is with great regret that we announce the death of **Sir Frank Claringbull, Ph.D., F.Inst.P., FGS**, on 23 November 1990, President of the Association and an Examiner for many years. A full obituary will be published in the April 1991 issue of *The Journal*.

Mr Albert ('Bert') C. Colclough, FGA (D.1964), Rainham, died in October 1990.

Miss Jean G. Lumsden, FGA (D.1951), Edinburgh, died on 12 October 1990.

NEWS OF FELLOWS

Mr Michael O'Donoghue spoke on gemstones to the South East Branch of the National Association of Goldsmiths on 18 October 1990 and to the Sevenoaks Hard of Hearing Club on 27 November 1990.

Dr R.M. Key and Mr J.O. Ochieng gave a lecture on 'Green garnets and blood-red rubies: a girl's best friend in East Africa' at the British Geological Survey, Edinburgh, on 17 December 1990.

MEMBERS' MEETINGS

London

On 14 November 1990 at the City Conference Centre, Mark Lane, London, Mr John I. Koivula, FGA, Chief Gemologist of the Gemological Institute of America, gave an illustrated lecture entitled 'Recent developments and observations in gemmology'.

Midlands Branch

On 26 October 1990 at the Society of Friends, Dr Johnson House, Colmore Circus, Birmingham, Mr Alan Hodgkinson, FGA, gave a lecture entitled 'Leave the moth in the diamond'.

On 16 November 1990 at the Society of Friends Mr Roy Huddlestone gave a lecture entitled 'The Cobra emerald mine in the Transvaal'.

North West Branch

On 17 October 1990 at Church House, Hanover Street, Liverpool, Mr Kenneth Scarratt, FGA, gave a talk on the work of the Gem Testing Laboratory.

On 21 November 1990 at Church House the Annual General Meeting of the Branch was held, at which Mr W. Franks, FGA, and Mrs Irene Knight, FGA, were re-elected Chairman and Secretary respectively.

ANNUAL GENERAL MEETING

On 29 October 1990 at Goldsmiths' Hall, Foster Lane, London EC2, the Annual General Meeting of The Gemmological Association and Gem Testing Laboratory of Great Britain was held.

Mr V.P. Watson, FGA, chaired the meeting, and welcomed members to the first Annual General Meeting of the joint company. Mr Watson reported that the Laboratory had given a first class service during the year, including gem testing, diamond grading and consultancy work. Negotiations had taken place during 1989 for the Laboratory to be able to provide GIA Diamond Certificates, and this service came into operation in October of that year. The Chairman thanked David Callaghan and Ken Scarratt for the tremendous amount of work they had undertaken during the year, particularly in connection with the proposed merger between the Gem Testing Laboratory and the Gemmological Association.

The Annual Report and Accounts were approved and signed.

Sir Frank Claringbull and Mr R. Keith Mitchell were re-elected President and Vice-President respectively.

Messrs D.J. Callaghan, N.W. Deeks, N.B. Israel, E.A. Jobbins, I. Thomson, V.P. Watson, K. Scarratt and Dr R.R. Harding, were re-elected to the Council of Management.

Messrs Hazlems Fenton were appointed Auditors, and the proceedings then terminated.

REUNION OF MEMBERS AND PRESENTATION OF AWARDS

Fig. 1. Tully Medallist Kathryn Anne Jarvis, receiving her award from Mr Eric Bruton.

The Annual Reunion of Members and Presentation of Awards was held on 29 October 1990 at Goldsmiths' Hall, Foster Lane, London EC2. Mr David Callaghan presided and welcomed those present, which this year included award winners from Canada, Finland, France, Greece, India, Kenya, The Netherlands, Spain, Switzerland and the USA. Mr Callaghan thanked the Worshipful Company of Goldsmiths for allowing the Presentation to be held once again in Goldsmiths' Hall, which had been closed for the past two years for refurbishment.

Mr Callaghan reported that the 1990 Examinations had been held at 61 centres in 24 countries.

Mr Callaghan then introduced Mr Eric M. Bruton, FGA. He said that as well as being Editor of the *Retail Jeweller*, the author of *Diamonds* and other books related to the jewellery trade, Mr Bruton has also written many books on crime. He has been an Examiner for the Association for a number of years, and has done a tremendous amount of work on the new Diamond Course. After making the presentations, Mr Bruton delivered the address which is printed below.

The vote of thanks was given by Mr Noel Deeks.

ADDRESS BY MR ERIC M. BRUTON, FGA

'It is a pleasant experience to be faced by so many successful people. You're lucky too. Not, of course, to have passed your examinations. I know you had to work hard to do that. As if we didn't know it, it was confirmed to me in an unlikely way last week.

'I was on a course. Nothing to do with gemmology. No one there knew I had any connection with it, or even what I did for a living. At lunch one day, I was talking to the man next to me. From Northumberland he was. He said: "I don't suppose you've ever heard about it, but there's a thing called gemmology" (he called it gem-nology, like most people who never heard of it). He went on to say that he'd been sailing and one of the crew was taking an examination. It was terribly hard, there were so many different subjects and he'd failed the first time. I think he must have succeeded this time and is possibly here tonight.

'I mention this for two reasons. The first is that knowledge of gemmology is spreading, albeit very slowly. It is shown by the people who now come on gemmology courses. You would of course expect those connected with the jewellery trade. And all those directly related, like jewellery designers,

craftsmen, manufacturers and lapidaries. And those to whom a knowledge is valuable, dealers and brokers. Also related are geologists and mineralogists, even archaeologists. We've had a scientific worker in a government archaeological laboratory. We've had antique dealers, auctioneers, diamond sorters, insurance assessors, as well as the true amateurs who have discovered the spell of gems but otherwise have no connection with them or with jewellery.

'Oh, I forgot Customs officers! Way back in the 1960s, my wife and I were invited to stay with some tea broker friends in Ceylon. Naturally I took the chance to visit as many mines and gemmologists as possible. One day I was introduced to a prominent jeweller and gem dealer in Colombo. I asked him if he had a padparadschah sapphire as I'd never seen one. "Yes", he said, "yes I have". But I'd have to come back another day to see it. I supposed it was in a safe deposit elsewhere. But he continued, "If you are coming back tomorrow, you can see it then. Today it is under the floorboards... This afternoon we are having a *secret* raid by the Customs Department."

'A day or two later we were having breakfast when the 'phone rang. My friend said, "It's for you. The Chief Customs officer, Mr Da Silva. Can you go and see him this afternoon?" A nasty shock for breakfast time. Naturally I thought there had been some mistake, but couldn't imagine what I'd said or done to interest the Customs. Except that I'd been asking a lot of questions about 'FEECS', a government scheme to encourage exports by letting the exporter retain some hard currency. I'd found out how some unscrupulous gem dealers were recycling the same parcels of gems to change large sums of rupees into dollars or pounds. Anyway I went. Mr Da Silva was friendly, which was a relief. He' heard I was on the Council of the Gemmological Association. I have absolutely no idea how. He led me into another room where there were, I think, eight of his officers lined up. He introduced them one by one. Every one of them was an FGA! He said there were more FGAs in Customs than in the whole of the gem trade in Ceylon!

Fig. 2. Anderson/Bank Prize winner Susan Clark.

Fig. 3. The Rayner Diploma Prize winner Michele Corne Halstenbach.

Fig. 4. The Rayner Preliminary Prize winner Spencer Benham.

'A sequel was that the padparadschah jeweller asked me to swap a refractometer for an ancient bronze statue of Queen Kuveni. His youngest son was taking the Association's correspondence course and couldn't get a refractometer because of the exchange restrictions! I did of course. His son got his FGA and I've still got Queen Kuveni.

'Probably the most dedicated gem student ever was a Japanese. What we call a "mature student". To study for his gemmology exams in London, Mr Nemoto left his wife in charge of his jewellery shops in Japan for around four years, only returning occasionally. Apparently in Japan, the basic English course teaches the letters of the alphabet and how to write and understand words and sentences. If you want to speak English, you have to take another course. Mr Nemoto had only done the first course. So he couldn't really talk to anyone and certainly couldn't understand the lecturers. He made friends with some of the other students and used to copy out their notes in the evenings. A big problem was understanding diagrams. But he graduated, became an FGA, and went on to get his Diamond Diploma. Later he wrote out his impressions of Britain and the courses in longhand and had photocopies bound, which he brought to some of us who had instructed him. He still couldn't speak a sentence. One inexplicable diagram in the book was a cross-section of the Scottish Highlands. Perhaps he got it mixed up with his inclusions!

'Many outsiders are surprised at the varied subjects, a basic knowledge of which is needed for exams in gemmology. They may well be qualified in one or another of them.

'I said at the beginning that I was on a course last week and had another point to make. Having got through the basics, it's much easier to keep on learning. Don't let it drop. Read the journals, take other courses if you can. Above all keep asking questions of people who're supposed to know. Very often you'll find they don't. So try to find out for yourself. It's surprising how a simple question about something we take for granted can open up a surprising number of doors. I had that experience a couple of years ago. When you're examining a diamond, at certain angles you get an intense flash of light. Anyone who grades diamonds has seen it. I tried to work out how this happened in some detail but got into trouble, so I asked a specialist on the behaviour of light. A few days later he rang back to say it wasn't as simple as it had first appeared. The cause of the flash was very complex and involved with the two planes of polarization. So he was writing a scientific paper about it. You can ask questions like that. Commercial as well as scientific ones.

'You never can stop learning. Don't think for a moment you're 'there' when you get your diploma. Above all you will begin to find that learning is very enjoyable and you never, never, get bored. You young people have a bigger incentive to learn than any past generation. If you've read your newspapers you'll know that there is a rapidly increasing demand for skilled younger people in business. This will continue into the foreseeable future. More than ever before, those who succeed are those who have *learned how to learn.*

'Well, I hope you hear and note what I say. There is only one absolute certainty in this world. Everything CHANGES. It is the only fact you can rely on absolutely. That means you have to change too. On that note, it only remains to wish you well and every success from all of us.'

GEM DIAMOND EXAMINATION 1990

In the 1990 Gem Diamond Examination 41 candidates qualified, 4 with Distinction. The names of the successful candidates are as follows:

Qualified with Distinction

Bourdillon, Catriona, London.
Plumb, Helen L., London.
Ruiz Belver, Antonio J., Barcelona, Spain.
Vidal Ramia, Enriqueta, Barcelona, Spain.

Qualified

Andrews, Suzanne, London.
Arnau Graus, Concepio, Barcelona, Spain.
Arranz Garcia, Felix, Barcelona, Spain.
Barbara Sole, Rosa, Barcelona, Spain.
Barrabes Lacarda, Silvia, Barcelona, Spain.
Bassioudis, Vassilis, Thessaloniki, Greece.
Bauco, Robert, London.
Blasco Jimenez, Josep, Barcelona, Spain.
Bofill Montoro, Ana, Barcelona, Spain.
Boira Roges, Berta, Barcelona, Spain.
Caycedo, Miguel J., Ilford.
Duckett, Karen L., Long Preston.
Ferguson, Neil F., Balloch.
Fuller, Mark R., London.
Garcia Ferrandiz, Javier, Barcelona, Spain.
Garty, Anne M., Dundee.
Hossen, Iqbal H., Mauritius.
Hughes, David J., Cardiff.
Isern Truy, Enric, Barcelona, Spain.
Jain, Sanjay, Southall.
Keys, Malcolm H., Manchester.
Laborda Ferrer, Ma Angeles, Barcelona, Spain.
Law, Patricia M., London.
Lazaro Anglada, Ma Jose, Barcelona, Spain.
MacKinnon, Amanda L., Birmingham.
Mariona de Urquijo, Victoria E., Barcelona, Spain.
Meigh, Melanie J., London.
Morris, David C., Whitfield.

Osborne, Sean J., London.
Patel, Pankajkumar, Manchester.
Santacreu Rull, Montserrat, Barcelona, Spain.
Taylor, Richard P., Shrewsbury.
Usechi Espinosa de los Monteros, Amp, Barcelona, Spain.
Vataru, Monica, London.
Velaz Azpilicueta, Mercedes, Barcelona, Spain.
Vildiridis, Athanassios, London.
Worthington, Sally L., Bradford.

EXAMINATIONS IN GEMMOLOGY 1990

In 1990 Examinations in Gemmology, 551 candidates sat the Preliminary examination, 335 (61%) of whom qualified, 398 candidates sat the Diploma examination and 197 (49%) qualified, 10 with distinction.

The **Tully Medal** for the candidate who submits the best set of answers in the Diploma examination which, in the opinion of the Examiners are of sufficiently high standard, was awarded to Kathryn Anne Jarvis of Vancouver BC, Canada.

The **Anderson/Bank Prize** for the best non-trade candidate of the year in the Diploma examination was awarded to Susan Clark of London.

The **Rayner Diploma Prize** for the best candidate of the year who derives her main income from activities essentially connected with the Jewellery trade, was awarded to Michele Corne-Halstenbach of Geneva, Switzerland.

The **Anderson Medal** for the best candidate of the year in the Preliminary examination was awarded to Nicholas Nicolaidis of Harare, Zimbabwe.

The **Rayner Preliminary Prize** for the best candidate under the age of 21 years on 1st June 1990 who derives his main income from activities essentially connected with the Jewellery trade was awarded to Spencer Benham of Isle of Man.

DIPLOMA

Qualified with Distinction

Aryatilake, Bamunuarachchige, Maharagama, Sri Lanka.
Clark, Susan W., London.
Corne-Halstenbach, Michele, Geneva, Switzerland.
Huegi, Michael F., Gumligen, Switzerland.
Jarvis, Kathryn A., Vancouver, Canada.
Marcos-Pascual, Celia, Oviedo, Spain.
Pyzowski, Carl C., Frackville, Pa., USA.
Rodriguez-Fernandez, Margarita, Ujo-Asturias, Spain.
Vorasaph, Tracy, Bangkok, Thailand.
Willmott, Keith R., Colombo, Sri Lanka.
Weixuan, Yen, Wuhan, China.

Qualified – UK

Anver, Mohamed F., London.
Baldock, Janine R., London.
Barker, Damon A.N., Winchester.
Bing, Sara V., Exeter.
Bowler, Simon R., Birmingham.
Burt, Peter O.K., Deal.
Byrne, David M., Birmingham.
Charatan, Ivan L., London.
Cloke, Deborah J., Sevenoaks.
Colomb, Nanette D., London.
Copestick, Bruce J., Harpenden.
Davidson, Anthony, Newcastle on Tyne.
Dietz, Susanne C., Birmingham.
Downer, Martyn D., London.
Edwards, Susan M., London.
Farrett, Kirsten J., Dover.
Farthing, Russell, Colchester.
Fitzmaurice, Karl M., Glenamaddy.
Gademsetty, Subba R., London.
Gibson, Bracken G., London.
Green, Sheila M., Glasgow.
Henry, John M., Bolton.
Hinds, Andrew F., Rickmansworth.
Hollanders, David J., Maidenhead.
Inkpen, Michael S., Kingsbridge.
Jhaveri, Devang, London.
Jones, Colin P., Birmingham.
Johnston, Paul W., Belfast.
Jordan, Lynn P., Manchester.
Komppa-Vigar, Leena, Ampthill.
Lamb, Lois N., London.
Lancaster, Wendy, London.
Levy, Aaron N., London.
Lithiby, Jonathan P., Kingston-upon-Thames.
Liyanage, Don C.S., Ashford Common.
Lloyd, Susannah M.D., Chester.
Lynch, Kieran J., Coventry.
Mallett, Gillian E., Cambridge.
Mann, Alexandrina E., Nottingham.
Matthews, Lisa J., Winchester.
Meigh, Melanie J., Painswick.
McCosh, Samuel M., Birkenhead.
Offord, Philip A., Chandlers Ford.
Oldershaw, Caroline J.E., Penn.
Parkhill, Melanie J., Broadway.
Pettigrew, Louise, Eaglesham.
Platt, Karen K., London.
Rackley, Trevor, Wantage.
Ripley, Thomas, Stockton-on-Tees.
Sanson, Steven N.J., London.
Saywell, Neil, Nottingham.
Shammas, Siham, London.
Sim, Evelyn, Singapore.
Sinclair, Lesley, Stenhousemuir.
Smith, Karen, Dewsbury.
Smookler, Sheryl, London.

Spencer, Stephen R., Nottingham.
Spink, Michael C., London.
Tock, Graham B., Hull.
Van Heesewijk, Jacqueline, London.
West, Kenneth J., Hove.
Wilson, Nean E., Longniddry.
Woodham, Sharon, Lichfield.
Wright, John C., Solihull.
Wright, Michael J., Watford.

Qualified – Overseas
Alejo, Diedre K., Kowloon, Hong Kong.
Argirakou, Ioulja, Volos, Greece.
Aulosalo, Liisa, Eura, Finland.
Beentjes, Theodorus P.C., Uitgeest, The Netherlands.
Berlioz, Roger F., Kandy, Sri Lanka.
Bernad Soria, José M., Zaragoza, Spain.
Carlos Bertolin, Marti, Barcelona, Spain.
Bolaño Cid, Jordi, Barcelona, Spain.
Boyer, Alice M., Silver Spring, Md., USA.
Bubshait, Ahmed I., Manama, Bahrain.
Canty, Gavin, Papatoetoe, Auckland, New Zealand.
Cardó Sabater, Elisabeth, Barcelona, Spain.
Carter, Maurice W., Toronto, Canada.
Casas Royo, Jose A., Alfaro (La Rioja), Spain.
Cases Canes, Josep R., Barcelona, Spain.
Chan, Lais Sim Luisa, Hong Kong.
Chen Xiugin, Wuhan, China.
Chow, Marianne, Toronto, Canada.
Chu, Sin Yi Christine, Kowloon, Hong Kong.
Cogan, Joanne M., Omaha, Nebraska, USA.
De Jonge, Martin L., Nieuwegein, The Netherlands.
De Kam, Anneke, Rotterdam, The Netherlands.
Désir Valén, Aline, Zaragoza, Spain.
Dorab, Brian I., Hong Kong.
Druguet Torner, Maria E., Barcelona, Spain.
Einstoss, Philip M., Toronto, Canada.
Farkas, Susan, Vancouver BC, Canada.
Fernandes, Bevelyn E., Bandra, Bombay, India.
Fu, Lintang, Wuhan, Hubei Province, China.
Fung, Wai-Yin, Hong Kong.
Gini, Aspasia, Byron, Athens, Greece.
Gonzalez, Marie C.Y., Hong Kong.
Goyal, Sanjay S., Bombay, India.
Gunaratne, Ananda Lakshman, Kundasale, Sri Lanka.
Hayakawa, Taketoshi, Kanagawa Pref, Japan.
Holen, Yvonne, Utrecht, The Netherlands.
Hoogeboom, Paulus Nicolaas, Hoogland, The Netherlands.
Huerta, Sanchez Ana Ma, Barcelona, Spain.
Hui, Wah Kam, Kowloon, Hong Kong.
Hui, Wai Kwong, Hong Kong.
Hung, Chi Ling Vivian, Hong Kong.
Ip, Ting Cheong, Kowloon, Hong Kong.
Ishikawa, Noriko, Koto-ku, Tokyo, Japan.
Janse, Theodora J., Schiedam, The Netherlands.
Javeri, Anjali J., Bombay, India.
Jhaveri, Hina Sushil, Bombay, India.
Jinbo, Kazuko, Kita-ku, Tokyo, Japan.
Jones-Brunet, Catherine, Mississauga, Ont., Canada.
Jones-Napier, Pennye K., Washington DC, USA.
Jordi, Ibañez, Pueyo, Barcelona, Spain.
Kangas, Anne K., Helsinki, Finland.
Kermorgant-Abily, Claire, Hong Kong.
Kinev, Kathryn A., Atlanta, Ga., USA.
Kung, Kwai, Kowloon, Hong Kong.
Lai, Sau Ha Melody, Kowloon, Hong Kong.
Lai, Tik Shan Sana, Hong Kong.
Lam, Yick Man Raymond, Kowloon, Hong Kong.
Lamahewa, Ranjith, Idar-Oberstein, Germany.
Lees, John A., Waterford, VA, USA.
Leong, Kei Tong, Hong Kong.
Liao, Xiangjun, Wuhan, Hubei Province, China.
Li, Yali, Wuhan, Hubei Province, China.
Lo, Mun Shan Ivy, Hong Kong.
Lonka, Valtteri, Kuopio, Finland.
Lopezi Gracia, Anna Ma, Barcelona, Spain.
Lui, Kin Wah Kelvin, Hong Kong.
Luzondo Olea, Blancanieves, Barcelona, Spain.
Ma, Kiu Chu Kitty, Kowloon, Hong Kong.
Martinez Bautista, Santiago, Barcelona, Spain.
Matsumoto, Tamio, Minato-Ku, Tokyo, Japan.
Montgomery, Richard S., South Sathorn, Bangkok, Thailand.
Moreno Rastrero, Eduardo, Logroñ, Spain.
Mustchin, Vivienne, Birkdale, Auckland, New Zealand.
Naken, Tomoko, Kita-Ku, Tokyo, Japan.
Nazareth, Christopher T., Bombay, India.
Oza, Bhagvat M., Bombay, India.
Paez Martinez, Ma Lluisa, Barcelona, Spain.
Pandya, Neesha N., Bombay, India.
Parker, Duncan, Toronto, Canada.
Patterson, Debra A., Toronto, Canada.
Pehkonen, Kaarina A., Helsinki, Finland.
Perez Barrera, Jose Luis., Barcelona, Spain.
Porebska-Brozyna, Dorota., East Rutherford, NJ, USA.
Premarathna, Hennayake M.S., Maharagama, Sri Lanka.
Qi, Lijian, Wuhan, Hubei Province, China.
Ranatunga, Wasla M.T.K.B.R., Idar-Oberstein, Germany.
Ratnakumara, Dodangodage, Nugegoda, Sri Lanka.
Reveliotis, Christos, Athens, Greece.
Roberts, Anne M., Kowloon, Hong Kong.
Rudolphij, Willemiene P.C., Schoonhoven, The Netherlands.

Ruiz Domenech, Anna M., Torredembarra, Spain.
Schell, Martin A., Nonthaburi, Thailand.
Seufert, Karin G., Amsterdam, The Netherlands.
Shah, Anurag D., Nairobi, Kenya.
Shibata, Hirofumi, Osaka, Japan.
Skilton, Margaret, Pakuranga, Auckland, New Zealand.
Soung, Min Hee, Busan, Korea.
Suno, Michiko, Kobe-City, Hyogo Pref, Japan.
Tan, Min, Wuhan, Hubei Province, China.
Temelcoff, Catherine F., Toronto, Canada.
Terpilak, Thomas J., Bethesda, Md., USA.
Tuovinen, Petri, Kouvola, Finland.
Tsui Hiu Ying, Jeanie, Kowloon, Hong Kong.
Ueta, Kohei, Kochi-Ken, Japan.
van Acker, Alain A.A.M., Tilburg, The Netherlands.
Vakil, Hetal H., Bombay, India.
Vartiainen, Risto K., Rovaniemi, Finland.
Vela Clemente, Fernando, Binefar, Spain.
Velthuizen, Irmine H.S., Arnhem, The Netherlands.
Vilabella Fernandez, Ramon, Barcelona, Spain.
Wang, Manjun, Wuhan, Hubei Province, China.
Weston, Amy L., Baltimore, Md., USA.
Wong, King Suen, Kowloon, Hong Kong.
Wright, Wendy E., Toronto, Canada.
Wu, Haiou, Wuhan, China.
Yau Wai Ling, Janet, Hong Kong.
Zeeman, Walentin, Bunnik, The Netherlands.
Zhang, Liangju, Wuhan, Hubei Province, China.
Zoeter-Johannes, Simon, Rotterdam, The Netherlands.
Zugazagoitia Urresti, Aitor, Durango, Spain.

PRELIMINARY

Qualified – UK

Adams, Suzanne, Sutton.
Adams, Philip J., Staffordshire.
Allani, Magda, London.
Anderson, Nicola M., Falkirk.
Antoniou, Lucas G., Barnet.
Anver, Mohamed F., Harpenden.
Arnull, Edward E., Romford.
Bailey, David E., London.
Bailey, Lisa J., Birmingham.
Balducci, Annette L., Neston.
Ball, Chantal, Cheltenham.
Ball, David J., Cheltenham.
Barrett, Nicola J., Sutton-in-Craven.
Benham, Spencer H., Onchan, Isle of Man.
Blackwell, Barry Q., Bexhill-on-Sea.
Boyd, Heather K., Manchester.
Bradley, Michelle A., Norwich.
Briggs, Harry J., London.
Burgess, Ian D., London.
Corrall, Corrall E., London.
Clark, Susan W., London.
Clayton, Paul N., Wetherby.
Cochran, Marian E., Blackpool.
Collins, Heather, Coatbridge.
Collins, Stephanie, New Malden.
Colomb, Nanette, London.
Combe, Ian, Haddington.
De Silva, Nihal G., Mitcham.
Dietz, Susanne C., Kidderminster.
Duff, Wayne A., Harrow.
Durlacher, Noel H., London.
Euangelou, George C., Enfield.
Flint, Sara E., Leeds.
Fromming, David E., Aylesbury.
Gademsetty, Subba R., Chigwell.
Gallagher, Aileen, Wolverhampton.
Gemmell, James, Havant.
Gordon, Mark I., London.
Graham, Barry D., Glasgow.
Grant, John, Colchester.
Grant, Miranda J., Edinburgh.
Green, Allan A., Oxford.
Green, Christopher M., Slough.
Hamilton, Sandra L., Southampton.
Hamp-Gopsill, David, Burton-on-Trent.
Hanafi, Safluat M., London.
Hare, Rebecca M.A., Fleet.
Hendry, Adrian L., Stansted.
Henn, Christopher J., Tong, Nr. Shifnal.
Henry, John M., Bolton.
Hering, Peter J., Cambridge.
Hills, Margaret A., Tonbridge.
Hobbs, Peter G.A., Lavenham.
Hopper, Geoffrey C., North Harrow.
Hunter, Charlotte T., Northampton.
Jain, Neerja, Birmingham.
Jones, Stephen W., Carnetown, Mid Glam.
Judd, Guy A., Peterborough.
Jupp, Thomas H., London.
Jurukov, Vasil, London.
Kejriwal, Bindu, London.
Khimji, Priti, London.
King, Margaret A., Glasgow.
Laklia, Andrew T., Greenhithe.
Laurie-Lynch, Carl A., Birmingham.
Leathley, Adam B.D., York.
Lee, Mary F.A., Addlestone.
Leonard, Anri B., London.
Lithiby, Jonathon P., Kingston Hill.
Long, Ann D., Colchester.
Lowe, David J., Colchester.
MacIntyre, Jacqueline N., Edinburgh.
Madden, Adrien M., Harrogate.
Mason, Alec J., Retford.
Matthews, Lisa K., London.
Michelson, Max J., Lincoln.
Mildenhall, Caroline, Kemp Town, Brighton.

Mistry, Dharmesh, London.
Mitchell, Beverly J., London.
Model, John E., Hatfield.
Moydakis, Vaji L., Burnage, Manchester.
Nash, Helen E., Slough.
Nishino, Kiyoshi, Canterbury.
Offord, Philip A., Chandlers Ford.
Ogden, Anne-Marie, Ealing.
Papaceit, Gloria B., London.
Patel, Pankaj, Wembley.
Pattni, Dipesh S., Loughborough.
Peh, Angeline, Birmingham.
Penton, Keith, London.
Plaxton, George A., Helensburgh.
Pointon, Laurence B., Edgware.
Pollard, Adrain N., Cheshire.
Redgrove, Claire A., Selsey.
Richards, Keith, Stoneleigh.
Richards, Stephen, Eastbourne.
Rigby, Lesley C., Bawtry.
Roberts, Amanda, Wirral.
Robinson, Nathan J., Birmingham.
Rogers, John W.S., Stroud.
Sabbagh, Samuel J., London.
Sabbagh, Steven E., Manchester.
Schmidt, Simon P., London.
Scott, Sarah L., Norwich.
Shah, Fatehchand J., London.
Share, Stella A., Harrow Weald.
Smith, Gerard J., Wargrave.
Syn, Lucy, London.
Taylor, Victoria A., London.
Tees, Audrey, Glasgow.
Thomas-Everard, Lucilla, London.
Vannet, Mary A., Dundee.
Vaughan, Michael, Budleigh Salterton.
Vause, Corinne J., Collingham.
Walker, James D., Edinburgh.
Waller, Mark S., Bradford.
Webster, Kathleen A., London.
Welch, Lizanne, Somerset.
Wells, Andrew, Caterham.
White, Alison P., York.
Williams, Alison D., Dorking.
Williams, Ruby, London.

Qualified – Overseas

Abel, Arlan R., Minneapolis, Minn., USA.
Alvarez-Palacios, Ester, Asturias, Spain.
Anastassiou, Evagelia, Maroussi, Athens, Greece.
Anderson, Ekaterini, Piraeus, Greece.
Au, Chung King, Hong Kong.
Au, Sze Yin, Hong Kong.
Bakayianni-Sa Bou, Aristea, Nikea Piraeus, Greece.
Bernaus Vidorreta, Isabel, Barcelona, Spain.
Bevoort-Alwicher, Terrence J., Nymegen, The Netherlands.
Blancardi-De Jong, Iris S., Sospel, France.
Bosque Moral, Luis, Barcelona, Spain.
Campos Novergues, Begona, Barcelona, Spain.
Casacuberta i Ramirez, Josefina, Barcelona, Spain.
Chan, Bonnie Suk Kwan, Hong Kong.
Chan, Catherine Siu Man, Kowloon, Hong Kong.
Chan, Chi Keung, Kowloon, Hong Kong.
Chan, Francis Chi Man, Kowloon, Hong Kong.
Chan, Keziah, Hong Kong.
Chan, Lai Sim, Hong Kong.
Chan, Rosana, Hong Kong.
Chan, Sok-Han, Hong Kong.
Chau, Kwong Lim, Shatin, NT, Hong Kong.
Cheang, Chong Nun, Hong Kong.
Chen Munoz, Cristina, Barcelona, Spain.
Cheng, Siu Hing, Kowloon, Hong Kong.
Ching, Wai Yai, Shatin, NT, Hong Kong.
Cho, Eun-Gyeong, Seoul, Korea.
Chow, Marianne, Toronto, Ont., Canada.
Chow, Tze Joak, Kowloon, Hong Kong.
Chui, Yiu Wing, Hong Kong.
Chiu, Fan Chuck, Hong Kong.
Chudawala, Sucheta, Bombay, India.
Chung, Tsz Kin, Kowloon, Hong Kong.
Clavero Monzon, Alfredo, Barcelona, Spain.
Compte Jornet, Javier, Barcelona, Spain.
Crespo Leal, Juan Gines, Barcelona, Spain.
Cusco Tortajada, Montserrat, Barcelona, Spain.
Daalmeyeer-Verheyden, Gertruda, Leiden, The Netherlands.
de Kok, H., Zandvoort, The Netherlands.
Desai, Suryakant C., Nairobi, Kenya.
de Winter, Rene G., Amsterdam, The Netherlands.
Dikken, Paulien G., Hilversum, The Netherlands.
Dimitriadis, Milko M., Rhodes, Greece.
Dong, Jianhua, Wuchang, China.
Dukel, Dorinda M., Giessenburg, The Netherlands.
English, Dora Pang, Kowloon, Hong Kong.
Escola Folguera, Montserrat, Barcelona, Spain.
Escola Folguera, Teresa, Barcelona, Spain.
Falk, Carita L., Helsinki, Finland.
Farkas, Susan, Vancouver, Canada.
Felipe De Los, Martin, Barcelona, Spain.
Fernando, Francis, X., Mt. Lavinia, Sri Lanka.
Ferrer Mas, Lucia, Barcelona, Spain.
Fontcouberte, Andre L., Paris, France.
Foo, Pui Man, Hong Kong.
Galloway, Linda L., Kowloon, Hong Kong.
Galopim de Carvalho, Rui M., Lisbon, Portugal.
Garcia Roe, Emilia, Barcelona, Spain.
Garcia Escrivo, Rosa, Barcelona, Spain.
Garcia Lopez, Carmen, Barcelona, Spain.
Garofalaki, Katerina, Greece.
Ginger Sanchez, Ana, Barcelona, Spain.
Gofa, Sophia, Athens, Greece.
Goyal, Sanjay S., Bombay, India.

Granero Saumell, Angel, Barcelona, Spain.
Hanley, Shaun, Kowloon, Hong Kong.
Harmsen, Harmanus P., Bruekelen, The Netherlands.
Helppi, Veikko J., Rouaniemi, Finland.
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On 26 November 1990 at 27 Greville Street, London EC1N 8SU, a meeting of the Council of Management was held at which the business transacted included the election to membership of the following:

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Aryatilake, Bamunuarachchige L., Maharagama, Sri Lanka. 1990
Beentjes, Theodorus P.C., Uitgeest, The Netherlands. 1990
Byrne, David M., Birmingham. 1990
Canty, Gavin, Auckland, New Zealand. 1990
Carter, Maurice W., Scarborough, Ont., Canada. 1990
Chow, Marianne, Toronto, Ont., Canada. 1990
Chu, Sin-Yi C., Kowloon, Hong Kong. 1990
Cloke, Deborah J., Sevenoaks. 1990
Cogan, Joanne M., Omaha, NE, USA. 1990
De Kam, Antje J., Hazerswoude, The Netherlands. 1990
Farrett, Kirsten J., Dover. 1990
Farthing, Russell, Colchester. 1990
Fung, Wai Y., N.T., Hong Kong. 1990
Gonzalez, Marie C.Y., Hong Kong. 1990
Goyal, Sanjay S., Bombay, India. 1990
Hasan, Zia-ul, Toronto, Ont., Canada. 1989
Holen, Yvonne, Utrecht, The Netherlands. 1990
Hoogeboom, Paulus N., Hoogland, The Netherlands. 1990
Huegi, Michael F., Guemligen, Switzerland. 1990
Hui, Fredy W.K., Victoria, Australia. 1990
Hui, Wah K., Kowloon, Hong Kong. 1990
Hung, Chi L.V., N.T., Hong Kong. 1990
Ip, Ting C., Shatin, Hong Kong. 1990
Johnston, Paul W., Belfast. 1990
Jones, Colin P., Birmingham. 1990
Jones-Napier, Pennye K., Washington DC, USA. 1990
Jordan, Lynn P., Manchester. 1990
Kermorgant-Abily, Claire, Bangkok, Thailand. 1990
Kinev, Kathryn A., Atlanta, Ga, USA. 1990
Kung, Kwai, Kowloon, Hong Kong. 1990
Lai, Sau H.M., Kowloon, Hong Kong. 1990
Lam, Yick-Man R., Kowloon, Hong Kong. 1990
Lamb, Lois N., London. 1990
Leong, Kei T.D., Ribeiro, Macau. 1990
Levy, Aaron N., London. 1990
Lieftinck, Felice A., Rotterdam, The Netherlands. 1989
Lopez Gracia, Anna M.S.I., Barcelona, Spain. 1990
Lui, Kin W.K., Causeway Bay, Hong Kong. 1990
Ma, Kiu C.K., Kowloon, Hong Kong. 1990
Matthews, Lisa J., Winchester. 1990
Meigh, Melanie J., London. 1990
Montgomery, R. Scott, Bangkok, Thailand. 1990
Mustchin, Vivienne, Auckland, New Zealand. 1990
McCosh, Samuel M., Birkenhead. 1990
Offord, Philip A., Chandlers Ford. 1990
Pandya, Neesha, Bombay, India. 1990
Parker, Duncan, Toronto, Ont., Canada. 1990
Patterson, Debra A., Toronto, Ont., Canada. 1990
Platt, Karen K., London. 1990
Schell, Martin A., Nonthaburi, Thailand. 1990
Shammas, Siham, Paris, France. 1990
Soung, Min-Hee, Busan, Korea. 1990
Tan, Min, Shenzhen, China. 1990
Tock, Graham B., Hull. 1990
Tuovinen, Petri R.J., Kouvola, Finland. 1990
Ueta, Kohei, Kouchi-Ken, Japan. 1990
Van Acker, Alain A.A.M., Tilburg, The Netherlands. 1990
Vartiainen, Risto K., Rovaniemi, Finland. 1990
Velthuizen, Irmine H.S., Arnhem, The Netherlands. 1990
Weston, Amy L., Baltimore, Md, USA. 1990
Wong, King S., Kowloon, Hong Kong. 1990
Woodham, Sharon, Birmingham. 1990
Wright, Michael J., Watford. 1990
Wright, Wendy E., Toronto, Ont., Canada. 1990
Zoeter, Johannes S., Rotterdam, The Netherlands. 1990

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Zafer, Raymond D., Twickenham.

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Fellowship
Aulosalo, Liisa H., Turku, Finland. 1990
Einstoss, Philip M., Toronto, Canada. 1990
Elias, Abdul H., London. 1983
Jarvis, Kathryn A., Vancouver, Canada. 1990
Jones-Brunet, Catherine, Mississauga, Canada. 1990
Vorasaph, Tracy, Bangkok, Thailand. 1990
Willmott, Keith R., Colombo, Sri Lanka. 1990

Ordinary Membership
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Burrow, Denis W., Gravesend.
Day, James P.M., Tunbridge Wells.
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Faithfull, John W., Leicester.
Friedland, Melissa, London.
Ibbott, Jane, London.
Kwok, Chi K., Kowloon, Hong Kong.
Meza, Samwel P., Glasgow.
McFarlane, Neil R., Alloa.
Ng, Soon H., London.
O'Brien, Gillian M., North Berwick.
Ogezi, Agbaji E., Jos, Nigeria.
Paterson, Lea M.F., Brighton.
Pout, Margaret E., Guildford.
Thurlwell, Christopher, Tunbridge Wells.
Van Papen, Lorraine, Guildford.
Walter, Keith, Peebles.
Whelan, Stella A., Morecambe.

COVER PICTURE – OCTOBER 1990 ISSUE

The necklaces (left to right) were fashioned from the following materials: microcline (amazonstone); lavender jadeite; lapis lazuli; labradorite; nephrite jade; tiger's-eye; malachite; common opal ('chlor-opal'); tourmaline; moss agate/cornelian; golden coral (shell rondels); matt quartzes.

Letters to the Editor

From James B. Nelson
Nelson Gemmological Instruments

Dear Sir,

In Peter Read's article on 'Reflections on reflectivity' (*Journal of Gemmology* 1990, **22**, 97-102), a drawing was given of a profile of a hypothetical quartz gemstone.

The first thing which caught my eye was the pavilion angle of 45°. Gem faceting practice forbids the use of such a pavilion angle, even for quartz stones[1]. With this angle, I would see internal reflections of myself in the table, as with a right-angle prism.

A 45° pavilion also implies that any rays entering the stone's table at a zero degree angle of incidence would leave the table exactly parallel to the incident beam. The drawing showed an emergent angle far from zero.

Having been stimulated to learn more about this new strange optical behaviour, the accompanying diamond profile was examined. This time I was armed with a schoolboys' protractor and a familiarity with Snell's law. The celebrated Dutchman would have been intrigued to see how his physics have changed since his time. Most things, particularly prices, have changed, but even $E = mc^2$ has not risen to $E = mc^3$.

May I make a plea for authors to have more compassion for beginners in gemmology who would have to struggle in vain to make sense out of such diagrams which are only qualitatively but not quantitatively correct?

It is always a serious matter if a student's confidence has been shaken, but particularly so when moving into a new territory.

Yours etc.,
J.B. Nelson

15 November 1990
2 McCrone Mews, Belsize Lane, London NW3 5BG.

[1] Harding, B.L., 1975. Faceting limits. *Gems & Gemology*, XV, 3, 78-88.

From Peter G. Read

Dear Sir,

I am grateful to Jamie Nelson for drawing attention to the apparent error in my sketch of the profile of a hypothetical quartz gemstone. However, the error in the sketch was confined to an incorrect labelling of the pavilion angle, and not to the ray path as he assumed.

To make the point that the pavilion angle of a quartz gem must be increased over that of a brilliant cut diamond (in order to achieve total internal reflection) I had increased this angle so that this condition was *just* achieved for quartz's critical angle of 40.33 degrees. Unfortunately I then labelled this angle as 45 instead of 43 degrees, at which latter angle the path for ray 1 in my sketch is substantially correct. I trust that this error has not offended any lapidary reader of *The Journal* (who in any case would rarely use the diamond profile for quartz).

Regarding Nelson's amusing comment on $E = mc^2$, I must also confess to have taken some license with the velocity of light in the diamond sketch in that the angles of refraction should have been drawn more realistically to acknowledge diamond's refractive index of 2.417 (increasing the in-air angles with respect to the normal for rays 1 and 2 would put this right). In mitigation I would point out that engineering sketches (as opposed to fully dimensioned drawings) usually bear the legend 'do not scale', so perhaps I should have taken this precaution and thus avoided the application of Nelson's protractor!

I am indebted to my learned colleague's critical eye, and hope that the offending sketch still conveyed the importance of a gem material's critical angle when determining its pavilion angle, which was after all my prime objective. I also hope that no student of gemmology has had his 'confidence shaken' by the 'qualitative' nature of this sketch, or has felt obliged to reach for his protractor!

Yours etc.,
Peter G. Read

30 November 1990
68 Forest House, Russell-Cotes Road, Bournemouth, Dorset BH1 3UB.

From Peter G. Read

Dear Sir,

With reference to my note on the 'Detection of synthetic emeralds by thermal conductance', which appeared in the October 1990 issue of *The Journal*, I have since been loaned four more synthetic emeralds by Alan Hodgkinson. I tested these stones under the same constraints as those tested previously, with the following results:-

	Average of 5 readings
Biron (hydrothermal), 1.04ct	98
Lechleitner coated (hydrothermal), 2.26ct	129
Lechleitner 'sandwich' (hydrothermal), 0.68ct	106
Linde crystal (hydrothermal), 3.72ct	84

This appears to confirm that the 'solid' hydrothermal stones, in common with the previously tested flux-melt synthetic emeralds, also have a much greater thermal conductance than the natural stone.

During a subsequent telephone call from Nigel Israel, who like myself evaluated the original Gemtek 'Gemmologist' (a forerunner of the Alpha-test instrument), I learned that he had found it possible to discriminate between peridot and sinhalite using this instrument. In confirming this, I obtained the following figures:-

Peridot	102
Sinhalite	64

As the RI and SG of the two stones are similar, and it is not always easy to determine their differing optic signs or discover the additional band in sinhalite's spectrum, this adds yet another useful test feature to the Alpha-test instrument.

Yours etc.,
Peter G. Read

7 December 1990
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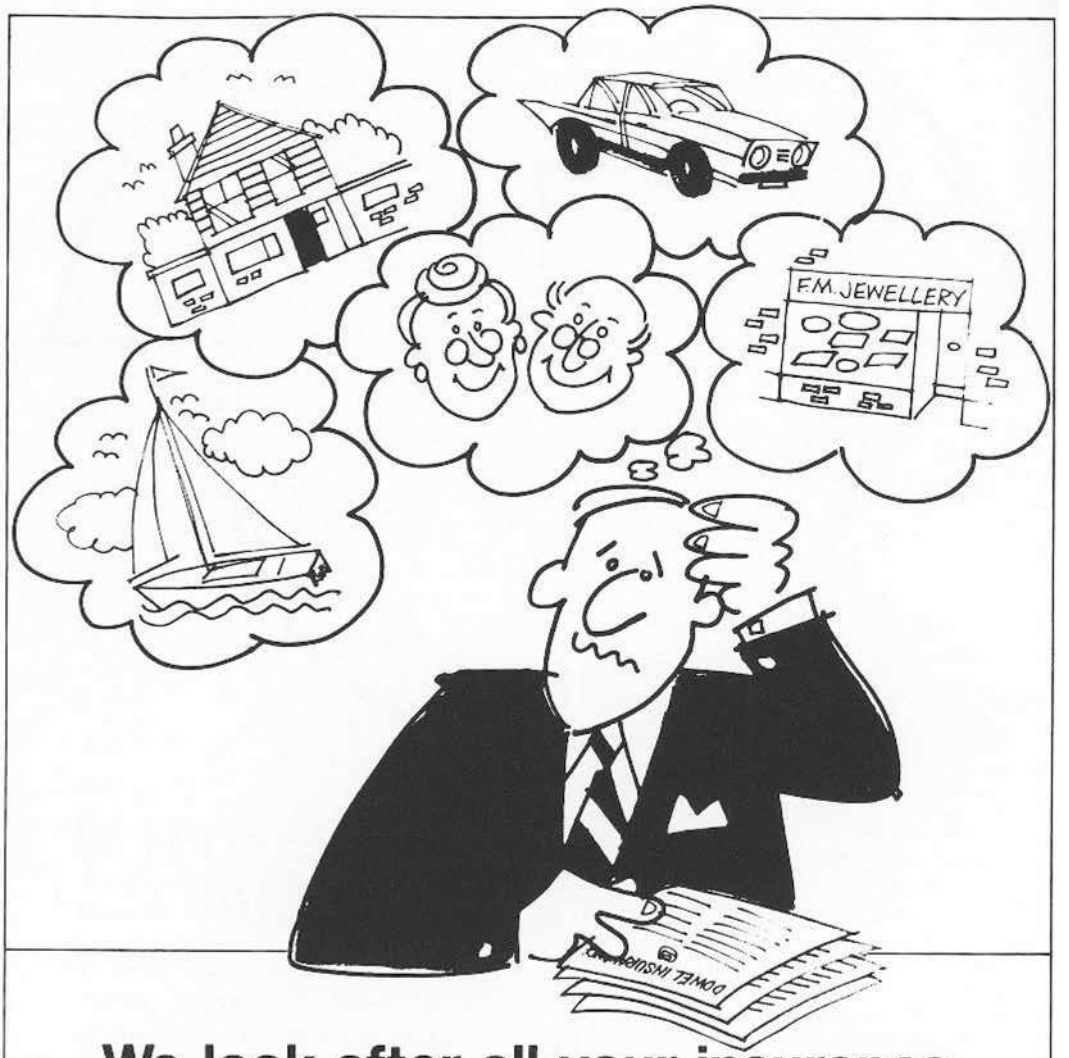

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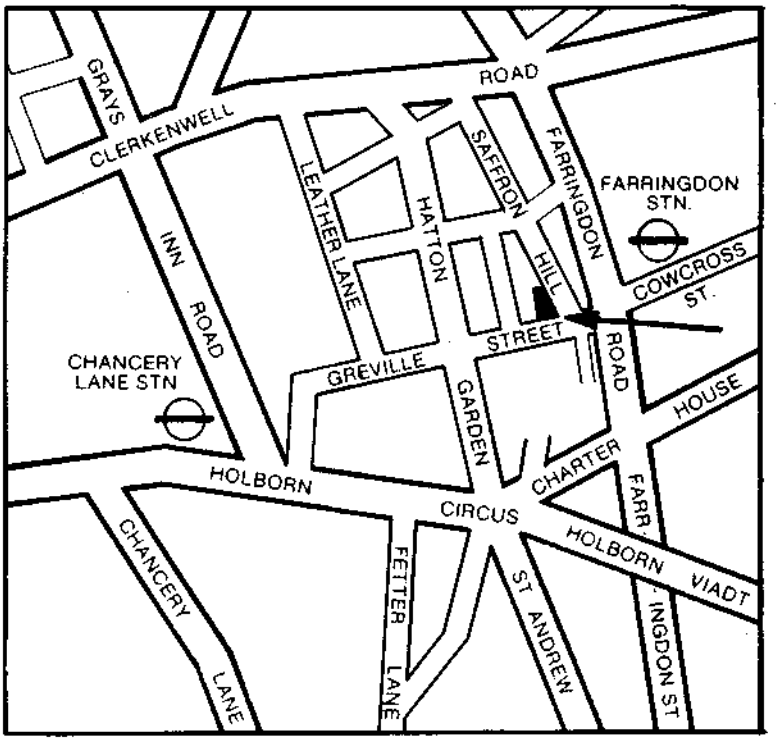

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Volume 22 No. 5. January 1991

The Journal of Gemmology

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Cover Picture

A crystal of emerald on calcite from Muzo, Colombia, from The Mineral Collection, Federal Institute of Technology, Zurich, presented and photographed by Dr E. Gübelin of Meggan, Switzerland.

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Sir Frank Claringbull 1911-1990

It is with great regret that we report the death, on 23 November 1990, of Sir Frank Claringbull, an Examiner from 1938 to 1970 and President of this Association from 1972. He had been in ill-health for some years.

Gordon Frank Claringbull, B.Sc., Ph.D., F.Inst.P., FGS, Born 21 August 1911, was educated at Finchley Grammar School and then at Queen Mary College, University of London, where he gained first class honours in geology. This was followed by the award of Ph.D. for his study of igneous rocks in the Balmoral area, Aberdeenshire. He joined the staff of the British Museum (Natural History) in 1935 and worked there, apart from the war years, until his retiral in 1976. Initially he worked under Dr Campbell Smith on curatorial duties with the rock collections and continued his studies of Scottish rocks.

During the war he moved to Birmingham where he worked on the crystallography and the development of explosives for the Special Operations Executive.

Following his return to the Museum in 1945 he worked with Dr F.A. Bannister on the development of X-ray diffraction methods for the identification of minerals. After his appointment as Keeper of Minerals in 1953 he ensured that his department was well equipped for the rapid analysis of minerals and rocks. X-ray diffraction was followed by X-ray fluorescence and with great prescience he sent one of his staff to Cambridge to collaborate in the development of the electron-microprobe for use on minute mineral grains.

In many of his scientific papers Claringbull worked with Dr M.H. Hey, the Museum expert on microchemical analyses; he also collaborated with B.W. Anderson and C.J. Payne of the Gem Testing Laboratory. In 1951 this quartet elucidated the nature of the spinel-like mineral, taaffeite, which had been found as a gemstone by Count Taaffe in a jeweller's junk box in Dublin. In 1952 Claringbull and Hey announced the discovery of the new mineral, sinhalite, which had previously lurked as a 'brown olivine' gemstone and had been viewed with suspicion by Anderson and Payne and by G. Switzer of the US National Museum in Washington. In 1956 Claringbull, Hey and Payne announced the discovery of another new mineral, painite, found as a crystal by A.C.D. Pain at Mogok in Burma and named in his honour. Claringbull worked on many other minerals and this is reflected in a series of papers in the mineralogical journals. Claringbullite, a new hydrated copper chloride mineral, was named in his honour in 1977.

In 1968 Claringbull was appointed Director of the Museum, and his experience in the reopening of the famous Mineral Gallery (now threatened with closure) stood him in good stead. The attention to detail, so necessary in that exhibition, was to be of immense value in the wider tasks ahead. The 'Hall of Human Biology', opened in 1977, was the first of the 'new' exhibitions developed under his direction; it was widely popular, especially with the young who did not mind the somewhat cramped viewing space and the paucity of natural specimens.

Claringbull was a man of bustling activity with a constant desire to finish the work in hand as soon as possible. As Secretary of The Mineralogical Society for many years he was immensely efficient and a great stickler for punctuality at meetings. He was eminently fair and one former member of the old Geological Museum staff can recall being in a somewhat tense dispute in the Keeper's room with four members of the BM staff when Claringbull observed that 'four of us to one of him' was not fair odds.

His wife, Enid, son and daughter survive him.

E.A.J.

Pocahontas

A.E. Farn

Seaford, East Sussex

I voted for the merger of The Gemmological Association with The Laboratory because it seemed inevitable and, frankly, sensible. I did so, though, not without regret at the passing of two distinct yet analogous bodies. Both were very important in my working life as a trade gemmologist. When I retired, a previous chairman of The Precious Stone Trade Section said that it was the end of an era, i.e. Anderson, Payne, Webster and Farn. I felt the same way about the merger. Now we have a new beginning and fresh fields to conquer.

Setting about a clearance of many old papers of the now defunct GA, I came across the minutes of a GA council meeting on 28 February 1989. One of the matters discussed was *The Journal;* the third and last paragraph contained the following:–

"Mr Jobbins also requested more contributions from the membership for *the Journal*, promising that all would be looked at sympathetically and they need not be too 'learned' or contentious to be included."

I took considerable heart from this refreshing aspect of the *Journal's* reading matter and felt 'not too learned' and hopefully not very contentious.

The longer one is separated from the gemmological scene and the less one practises gem testing, the sooner accumulated knowledge disappears. Be that as it may, I have been thinking, not of gemstones, but of pearls and some interesting parallels or connections with them. It seems I made a literary contact with an aspect of their history when I received a book from a favourite aunt on my ninth birthday. The book was entitled *'Captain John Smith'*. My aunt was a maiden lady named Emily Chatterton (the name E. Chatterton is of interest). The book was written by E. Chatterton but at the moment of writing there is no immediate importance to be attached to the coincidence. The book's content at the time was above my head even though I was an omnivorous reader for my age. I let it be for a couple of years and then enjoyed it.

About sixty years later, in retirement, I was approached to write a monograph on pearls. It was something that I had never seriously contemplated. I felt, somewhat righteously, that I was really a coloured stone man and had only undertaken pearl testing because of the retirement of Anderson, Payne and Webster. The new staff had no experience with pearls and so it was inevitable that I did the pearl testing – which became my metier – and, of course, the book. I sought as many references as possible, not just on pearls, but on equipment, X-ray production and the biology of oysters (scallops really). Being a pearl tester, however efficient, doesn't make one into a marine biologist. A good editor is most useful since grammar, punctuation and nomenclature, all make their demands. I was working at home and out of touch with laboratory facilities.

Delving into the literature of Dakin, Jameson, and Kunz and Stevenson, I was impressed by their erudition. I began to realise how poor was my geography, how lacking my knowledge of history and how weak was my schoolboy French. I was amazed at the ingenuity of French workers, in particular in tackling the problem of detecting cultured pearls. I learned afresh of Chilowski and Perrin, Simon and Renee Bloch, and read very slowly the recorded observations of J. Galibourg and F. Ryziger (1927). Their work embraced density, structure, transparency to light rays, penetration by X-rays and how light travelled concentrically in pearls and along layers in mother-of-pearl. Knowledge of the subject matter and gemmology helped in the translation. Old hat it may be but the endoscope as used by the French and English laboratories was 100% accurate in testing drilled (necklace) pearls. Undrilled pearls succumbed to the penetration of X-rays thanks to the work of Röntgen, Von Laue, Dauvillier, Shaxby and Doelter.

When I needed to find out about historical/famous pearls and, in particular, the sources of pearls, I turned to *The Book of the Pearl* by Kunz and Stevenson. This was a veritable mine of information – if one can have a mine for pearls. When I came to the pearls of the Americas, viz. Panama, Venezuela, Mexico, Virginia and the Mississippi

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Valley, I was stopped in my tracks. Here was reported the account of Captain John Smith who set out in 1605/6 to colonize Virginia, the same man as in my boyhood book. I felt 'This is where I came in'.

Captain John Smith was a remarkable man. Born in Willoughby, Lincolnshire, in 1579, he was an apprentice in King's Lynn (Norfolk). He then went abroad as a mercenary and served four years with the French army. Later he fought with the Austrians against the Turks in Transylvania. Taken prisoner, he was sent to Constantinople as a present to the wife of a local Turkish pasha. She feared for his safety and sent him to Varna on the Black Sea, where he was a slave. He killed his master and escaped to Western Europe and returned to England in 1604. Here he joined a London company expedition to colonize Virginia. Three ships plus a hundred or so migrants set sail from Blackwall late in December 1606 under licence from James I. They landed in Virginia in May 1607. Here they founded the settlement of Jamestown on the James river; both were so named in honour of King James I of England. In his notes Captain Smith mentions the importance that the tribes of the tidal water region placed upon pearls for adornment. Some thirty tribes of Algonquin Indians were ruled by a powerful chief named Powhatan. He was not happy with the presence of the white settlers and at one time took Smith prisoner with intent to kill him. Smith's life was saved by the intervention of Pocahontas, the daughter of Powhatan. She was about twelve years of age. A few years later among the additions to the settlement was John Rolfe, a graduate seeking his fortune in Virginia; his ship had been wrecked on the Bermudas. Rolfe came from Heacham, a village on the north Norfolk coast; he experimented with tobacco planting.

Following various affrays with the Indians, Pocahontas was held hostage, but was well treated. She received religious instruction and was eventually baptised Rebecka. She married John Rolfe in 1614 and their son was born the following year. A year later in 1616 they sailed for England, first visiting Heacham to see his mother before being presented at the court of King James and his consort Queen Anne. Pocahontas found England's climate chilly, with London wet and smoky, and was in poor health. John Rolfe was appointed Secretary and Recorder General of the Virginia colony. In March 1617 they set out for the return to Virginia but were held up at Gravesend. Here Pocahontas died; she was twenty-two years of age. She was buried in St. George's church, Gravesend. Rolfe eventually returned to Virginia where he died in a massacre in 1622; his son who had remained in England went to Virginia when he was twenty-five. He had one daughter, Jane.

My wife comes from a north Norfolk village not far from Heacham. Typing the details of Virginia (sources of pearls) for the book she remembered a school friend from Heacham who had pointed out a house at Heacham where it was said an Indian princess had lived long ago. She had married into the Rolfe family who were an old and important family in Heacham.

Last month we had a holiday in north Norfolk, re-visiting old haunts. We decided to visit Heacham because of my interest in Pocahontas, pearls and Captain John Smith. In Heacham parish church were many engraved tablets and memorial stones to members of the Rolfe family who had nobly served their king and country over hundreds of years. In the poor light of the interior I could see a bas-relief sculpted bust of Pocahontas which had been presented to the church by American visitors who claimed to be descendants of Rolfe's granddaughter Jane. We also obtained a short account of Pocahontas written by Jane Neville Rolfe. She was the last member of the family in Heacham and died in 1989 aged seventy-nine. A private burial plot enclosing many tombs and memorials of the Rolfe family is surrounded by a close clipped yew hedge, bringing strongly to mind that excerpt from Thomas Gray:–

"Beneath that elm, that yew tree's shade
Where heaves the turf in many a mouldering heap
Each in his narrow cell forever laid
The rude forefathers of the hamlet sleep."

Returning albeit briefly to my working life, it seems strange now to think of the hundreds of times en route for the Laboratory from Cannon Street Station I passed by the Wren church (1680) of St Mary-le-Bow, Cheapside. Usually it served to remind me that my mother's family were true Cockneys, having been born not a stone's throw from Hatton Garden, within the sound of Bow Bells. My grand-father worked in Mitre Court at the end of Hatton Garden. In Wren's churchyard stands a statue to Captain John Smith. It bears the following inscription: "Citizen and Cordwainer (1580-1631). First among the leaders of the settlement at Jamestown, Virginia, from which began the expansion of the English speaking peoples".

A few hundred yards westward towards the Laboratory stands St Sepulchre's Church at the junction of Holborn Viaduct (London's first flyover, 1866) and Newgate Street; here Smith was buried.

It seems a little ironic when I recall that my main memory of St Sepulchre's stems from a drinking fountain set in the corner of a wall. It was carved, I believe, from reddish serpentine from the Lizard, Cornwall.

Development has removed or obscured many facets of Old London. Development is one of those

words bracketed to or which has a connotation with mergers and 'the end of an era'.

On Wednesday, 3 May 1989, at 11.00 hours, Long Wave, the BBC broadcast an excellent programme on Radio 4. It was entitled 'The Peace of Pocahontas'.

[*Manuscript received 15 October 1990.*]

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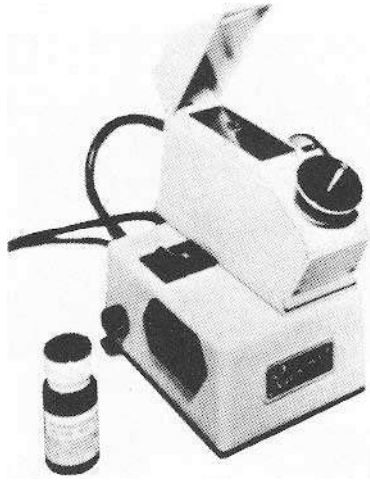

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Gem thaumasite from the Black Rock Mine, South Africa

Ulrich Henn, Markus Redmann and Hermann Bank

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Introduction

Thaumasite is a complex mineral with the chemical formula $Ca_3Si(CO_3)(SO_4)(OH)_6 12H_2O$. The hexagonal mineral shows distinct cleavage parallel to the vertical prism and conchoidal fracture; the hardness is 3½.

Thaumasite is a typical neogenic mineral and soluble in acids. White compact aggregates of tiny acicular or needle-like crystals are usual. The known occurrences can be divided into three types:
1. associated with sulfidic ores (e.g. Sweden, Tennessee/USA),
2. in cavities of basic effusive rocks as well as in basic metamorphic rocks (e.g. Hungary, Austria, New Jersey/USA),
3. in limestone contact zones associated with amphibole, pyroxene, chlorite, garnet, idocrase and sporadic babingtonite (e.g. Czechoslovakia, USSR, Utah/USA, California/USA).

Some occurrences represent transition types, e.g. Myto near Tachov in SW Bohemia. That locality is grouped with the genetic type 3, but numerous indications (e.g. the presence of zeolite) show close relations to type 2 (Kourimsky, 1977).

Euhedral thaumasite crystals of remarkable size have been discovered in South Africa. The locality is the Black Rock Mine in the Kalahari Manganese Field (Figure 1). That region is well known for occurrences of gem sugilite (Dunn *et al.*, 1980; Henn, 1986; Shigley *et al.*, 1987) and transparent rhodochrosite (Bank and Becker, 1977).

The thaumasite-bearing manganese ore-body contains dark brown to black manganese ores, especially hausmannite, psilomelane, pyrolusite, bixbyite and braunite. Additionally, manganese-bearing garnets have been discovered.

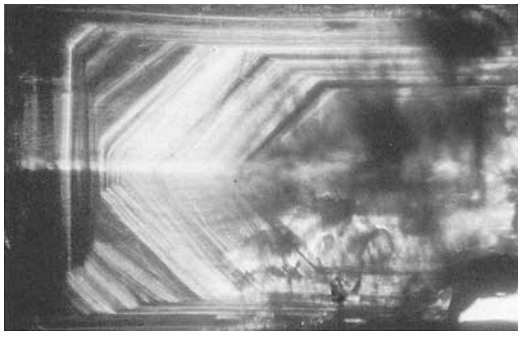

Fig. 2. Distinct growth-zoning in a Black Rock thaumasite. x10.

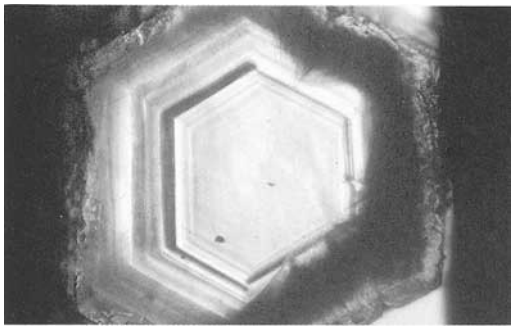

Fig. 3. Distinct growth-zoning perpendicular to the *c*-axis of the thaumasite. x10.

Results of examinations

The Black Rock thaumasite crystals investigated are up to 1.5 cm in size and show distinct hexagonal prismatic habit with well developed prism $(10\bar{1}0)$ and basal (0001) faces.

Fig. 4. Liquid films. Dark field illumination. x30.

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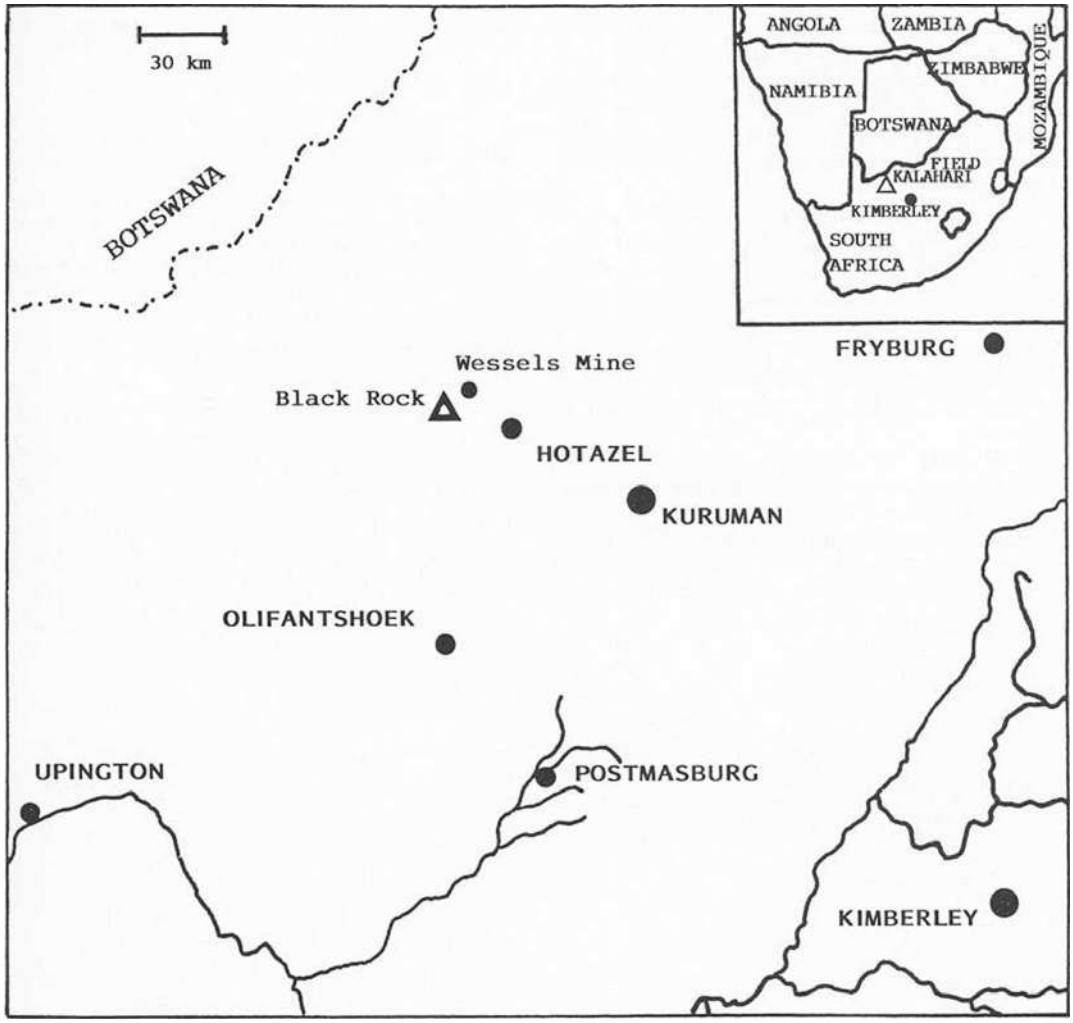

Fig. 1. Geographical map of the Kuruman region in the Kalahari Manganese Field with the Black Rock Mine and the Wessels Mine near Hotazel (after Shigley *et al.*, 1987).

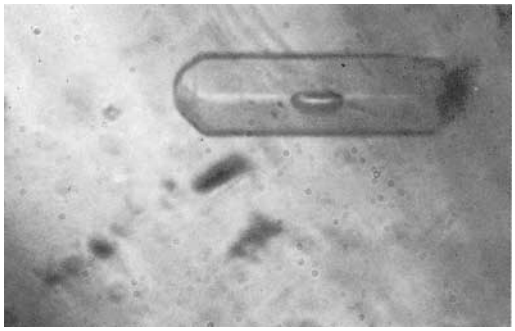

Fig. 5. Prismatic negative crystal filled with a liquid and a gas bubble. x50.

Fig. 6. Bunch-like crystal inclusions. x25.

Refractive indices, birefringence and density have been determined as n_o=1.505-1.510, n_e=1.467-1.480, Δn=−0.030 to 0.038 and D=1.88-1.90 g/cm^3. These data correspond to those of thaumasites from various localities, published by Kourimsky (1977): n_o=1.500-1519, n_e=1.464-1.476, Δn=−0.031 to 0.043, D=1.87-1.90 g/cm^3.

Thaumasite crystallizes in the hexagonal-pyramidal crystal class; the lattice constants have been determined as a_o=11.077(6) Å and c_o=11.412(6) Å by Guinier techniques.

The microscopical features of the Black Rock thaumasite are:

1. distinct growth-zoning parallel (Figure 2) and perpendicular (Figure 3) to the *c*-axis of the thaumasite host,
2. fine liquid films (Figure 4),
3. negative crystals, partially filled with liquid and a gas bubble (Figure 5),
4. bunch-like inclusions (Figure 6).

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Gemmological teaching in Catalonia

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The writer was asked by the Director of the Escola de Gemmologia, University of Barcelona, Spain, if he would like to deliver several lectures on current gemmological topics. The invitation was of course eagerly accepted.

The first of four lectures was in the nature of a demonstration of apparatus designed and made by the writer. These instruments had sprung from a desire to demonstrate the actual physical principles involved in gemstone testing. He has long felt that there has been an inadequate practical treatment of these basic principles in most international gemmology teaching centres. He believes that before an instructor places any conventional gemstone testing instrument in the hands of a student for the first time, there should be offered a clear explanation of the fundamental mechanics and optics upon which the instrument operates. This is most easily done by using simplified, large-scale bench-type apparatus. The students, rather than the instructor, must be encouraged to manipulate the devices themselves. This generates an understanding and confidence, particularly in students whose exposure to even elementary scientific matters has been lacking. These exercises also convey something of the beautiful complexity of design and the remarkable performances and accuracy of the tools which they routinely use. Beginners usually perceive them

Fig. 1. The 'goniometer unit' being demonstrated.

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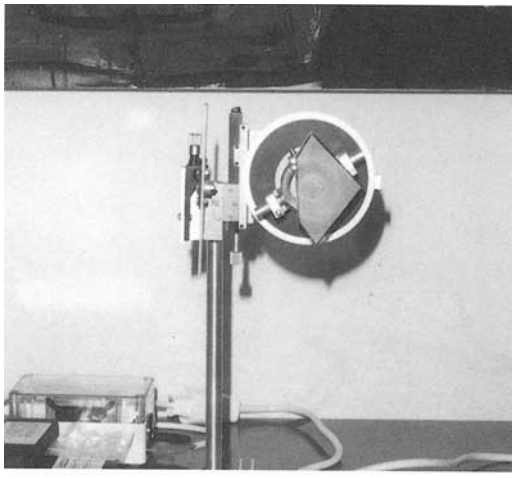

Fig. 2. A perspex profile of a 'brilliant' mounted on gimbals on the 'goniometer' circle.

simply as short lengths of capped tubing or oddly-shaped boxes with bits of glass embedded in them.

Without doubt, the most informative unit demonstrated was a device which the writer calls a 'single-circle goniometer.'

It consists of an arrangement of which one part produces a thin, parallel ribbon of intense white light. This narrow beam, or ray, can be directed in turn on to a glass prism or diffraction grating or on to various other refracting objects. One of these is a large polished Perspex plate shaped in the form of a brilliant-cut gemstone profile. The unit is thus able to display the simulated optical ray paths of the single ray of white light as it impinges on and enters and leaves the profile when it is turned through 360°.

It can also measure the angles between the facets of a variety of polished profiles or the reflecting faces of euhedral crystals, with an accurancy of ± 0.5°.

With the help of ancillary attachments, it allows the angular changes of refracted or reflected rays from various pre-aligned crystals and polished prisms of plastic, glass and cubic zirconia to be observed and measured. Such measurements can then yield values of refractive index, birefringence and dispersion using the minimum-deviation method. At the same time, it can demonstrate Snell's Law, the external and internal Brewster angles and Fresnel reflection intensities at angles of incidence from 1° to 89°. The production of colours, by the use of a set of gelatine filters and by selected spectral absorption, using neodymium-doped YAG and glass filters, helps to de-mystify both phenomena. Here, both diffraction gratings and prisms are used independently. Finally, long-wave ultraviolet fluorescence and phosphorescence can be observed by excitation in the invisible ultraviolet end of the spectrum. Figure 1 shows the goniometer unit being demonstrated, while Figure 2 shows a Perspex profile mounted on gimbals on the goniometer circle.

In addition to this unit, several other visual teaching aids were exhibited. One illustrated the formation of on-axis and off-axis conoscopic figures. Another employed a horizontal axis immersion microscope to project images of the internal microstructures of gemstones directly on to a large screen. It enabled any particular image to be isolated from the general optical 'noise', by making controlled movements of the gemstone while immersed in the optical matching liquid.

A particular effort was made to illustrate the increasing interest in the quantitative measurement of the body colour of gemstones. A simple apparatus allowed the student to produce any surface colour at will through the use of both additive and subtractive colour filters. The quantitative aspect was represented by a spinning disc tristimulus colorimeter. This permitted the student to measure the colour of transparent coloured faceted stones and cabochon-cut jade, lapis lazuli, fire opal and turquoise in terms of the three CIE Tristimulus coordinates for both 'A' and 'C' CIE Illuminants. A partial view of the colorimeter is shown in Figure 3.

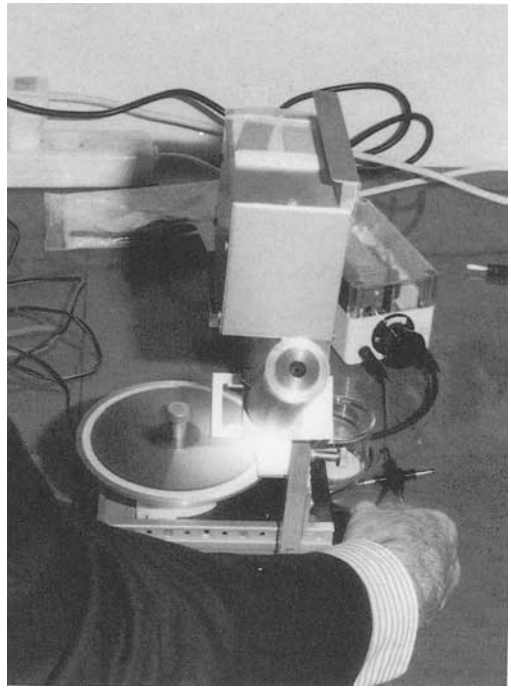

Fig. 3. A simple spinning disc tristimulus colorimeter.

The second session was an illustrated lecture on *Synthetic diamonds and gemmological methods to detect them.* A polished laser-cut section of a Sumitomo canary-yellow synthetic diamond was exhibited for microscopic examination, together with a 0.19 carat brilliant-cut stone of the same material.

The third lecture dealt with *The four optical attributes of a diamond.* Each of these (lustre, brilliance, fire and sparkliness) was treated in terms of their physical optics. Other matters which are derivative of these attributes were discussed. These are odd-number symmetry cuts, the Brewster angle refractometer, effects of adhering scattering matter, and the possible benefits and disadvantages of depositing thin films of aluminium on the pavilion facets. Various pieces of apparatus made to illustrate the optical pathways were shown.

The final lecture concerned *The measurement of the body colour of gemstones, including diamond.* An account was given of the CIE Tristimulus System, which is the internationally adopted standard procedure for colour measurement. This system is able to express any colour quantitatively in terms of only three properties. 'hue', 'saturation' and 'luminance'. A brief description was given of the apparatus and techniques developed by the writer for obtaining these CIE colour coordinate numbers for any faceted gemstone or piece of gemstone 'rough'.

In Barcelona the Catalan language is widely spoken. That Catalan is indeed a curious and different tongue can be seen from the table below. The terms were solicited from an audience at question time following the lecture on diamonds. After much good-natured argument, the translations from English of the four optical attributes of a diamond were finally approved. The lack of initial agreement certainly showed up the real difficulties in defining and translating even these few gemmological terms.

ENGLISH	CASTILLIAN	CATALAN
Attribute	Propiedad	Propietat
Lustre	Brillo	Lluisor
Brilliance	Resplendor	Resplandor
Fire	Fuego	Foc
Sparkliness	Centelleo	Llambreig

These lectures and demonstrations were held in the lecture hall of the School of Gemmology during the 7th to the 9th March, 1989. The School occupies a large separate enclave within the Geology Faculty of the University.

Other gemmology teaching centres had already been established in some of the other autonomies, but it was not until 1971 that Barcelona's own centre was established. This is surprising because Catalonia has by far the highest gross domestic product of all Spain's seventeen autonomies. Its creation was largely due to the professional and political skills of its two founding fathers, Professor Manuel Font-Altaba and Dr José Bosch Figueroa. The syllabus of the courses offered was based upon that of the Gemmological Association of Great Britain. Indeed both gemmologists acted as external examiners for the GA Diploma until their retirement in 1987. Their successors are Professor Joaquim Nogués Carulla and Dr Marius Vendrell Saz, Director and Secretary respectively, with Professor Angel López Soler serving as part-time professor. The School has an annual enrolment of about 120 Preliminary, 70 Diploma and 25 Diamond Course students. The examinations for the School's own 'Titulo de Gemologo' as well as that of the Diploma of the GA of G.B. are conducted both in the Catalan and Castillian Spanish languages. A view of the well-equipped class-room is shown in Figure 4. The courses are held in the daytime only.

One of the most remarkable features of the student enrolment is that by far most of the students are gemstone afficionados, collectors, hobby-lapidarists and amateur jewellery makers. Few are actually involved in the jewellery retailing or manufacturing trade. In one sense, this was not too surprising.

Barcelona's long prosperity shows in its wide, impressive, super-clean streets and squares which seethe with people until all hours of the night. It shows in its elegant shops, its new cars and its stylish fashions. However, astonishingly few women of any age were seen to wear jewellery, whether gem-set or not. Jewellers shops are scarcely to be found, apart from shops selling watches and silverware. No one who was questioned about this curious state of affairs had a ready, single explanation. All agreed that it did not exist in Madrid. A few thought that Barcelona's drug-related street crime, which peaked two years ago, was responsible, but most were dismissive of this view.

Seemingly in conflict with this observation is the high popular regard for gemmology itself. This was evident by the fact that the writer's lectures were announced daily in the 'Conferencias' columns of Barcelona's principal morning newspaper 'La Vanguardia'. Whatever its effect, each session was well attended in spite of the talks being given in English and delivered with a heavy Scottish brogue.

By virtue of its being an integral part of the University, the School enjoys very considerable benefits. Its students have instant access to all the scientific and technical libraries on the campus. All lectures are free. If post-graduate students are

Fig. 4. A general view of the well-equipped classroom in the School of Gemmology, Barcelona.

Fig. 5. Part of the laboratory at Dr Celades Colom's home used by the Club de Talle de Gemas de Barcelona.

Fig. 6. Professor López, Dr J.B. Nelson and Dr Celades in the laboratory.

research-minded they have the opportunity to make use of expert advice and all the conventional and advanced laboratory intrumentation scattered throughout the complex.

With regard to the research aspects, the staff of the School, since its inception, have produced many original research papers on gemmology, particularly in their speciality of diamonds. These have been published only in the national journal 'Gemologia' so that they have not become universally known. This has brought home to them that a European journal of gemmology is now a much-needed vehicle for disseminating general information, research work and news. From their enquiries, many other European Societies, whose journals, magazines, news-letters and bulletins enjoy only small circulations, would also welcome such a move. They hope that the spur of the 1992 events in the EEC will catalyse the creation of a single uniquely European journal of gemmology which will bring the various national publications under one banner.

As well as the School of Gemmology, there exists another important gemmological activity. This is a non-profit lapidary club. It was started in 1982 by a small group of self-taught amateurs under the stimulus of an industrial chemist, Dr Roberto Celades Colom. Named the 'Club de Talle de Gemas de Barcelona' it is the first enterprise of its kind in Spain. Its purpose is to popularise the lapidarist's art and to encourage hobbyists and amateurs to design and make their own jewellery and to display the faceted and 'cabbed' stones cut by them. The Club members supply their own starting materials and pay a small annual subscription; otherwise there are no fees. The sessions are held throughout the year outside the normal working hours, sometimes in week-day evenings. There is a regular Saturday and Sunday daytime session covering a total period of about twelve hours. This is especially useful for those members not living in Barcelona. It has been found that most members are able to facet two gemstones and four cabochons during a week-end's session.

The Club forms a balanced complement to the formal day-time studies at the School of Gemmology. The faceting instruction is provided by three volunteer teachers, two of whom have had commercial experience of diamond polishing. Another instructor is responsible for the design, construction and maintenance of the Club's apparatus. All four possess the FGA and the School's 'Titulo do Gemologo'. There is a wide spectrum of members, from retired people to quite young persons. Most are collectors, gemmology students from the School, jewellery professionals and those generally interested in the lapidary art as a captivating hobby. Since it inception, some 550 members have come to the Club. Many who now have their own machines, still come to enlarge their skills and exhibit their stones.

Fig. 7. Dr Celades at one of the busy lapidary classes in his laboratory.

Fig. 8. Mrs Doris Nelson congratulating an 11 year old student who has just given the final polish to a well-made emerald-cut quartz.

The plans for the future are to maintain these activities, and extend them to deal with more sophisticated cutting techniques and to promote the formation of similar lapidary teaching centres in Spain.

Dr Celades invited the writer and Professor López Soler together with their wives to attend a week-day evening session in action. The Club premises cover the entire first and second floors of Dr Celades spacious residence in central Barcelona. He and his wife occupy the third top floor, where he has his private laboratory (see Figures 5 and 6). In Figure 7 he is seen in one of the several laboratories talking to Professor López Soler and his wife. A view of one of the faceting benches is shown in Figure 8. The writer's wife is just congratulating an eleven year old member who at that moment had given the final polish to a well-made emerald-cut quartz.

This Barcelona visit was a most enjoyable experience for the writer and his wife. The hospitality of our gemmological hosts was massive and the enthusiasm of the students was unmistakable. The City itself is a delight. There are more museums and galleries than in many European Capitals. It has a magnificent Cathedral in the old town. The uncompleted Church of the Sacred Heart, started by Gaudi in the nineteen-twenties in the new city, is truly breath-taking. The food is superb and the municipal retail food markets are something we can only dream about in London. Barcelona's geographical position in the Mediterranean is an enviable one. It is situated in a region of great natural beauty. Its success as host to the 1992 Olympic Games is virtually guaranteed. One can only hope to return soon.

Acknowledgements

The writer is indebted to Señor Carlos Baguena-Canals for the photographs shown in Figures 1, 2 and 3 and to Professor Nogués Carulla for that of Figure 4.

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The microscopic determination of structural properties for the characterization of optical uniaxial natural and synthetic gemstones

Part 1: General considerations and description of the methods

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Abstract

The most significant crystal faces of the three optical uniaxial gem minerals corundum, beryl and quartz, as well as the angles formed by these crystal faces with the *c*-axis or the angles formed by two crystal faces are given. Methods for the determination of these structural features for faceted gemstones in the immersion microscope are described. Means used for the determinative procedure are 1) a two-axial sample holder with a 360° dial attached to the vertical axis of the sample holder and 2) a rotary measuring ocular with cross hairs attached to the eyepiece and a 360° dial attached to the ocular tube. An easy and generally performable way for a determination of all structural properties of a faceted gemstone by an efficient combination of both methods is described.

I. Introduction

Because of the value and demand of the gem varieties of corundum (ruby, sapphire) as well as beryl (emerald, aquamarine) and quartz (amethyst, citrine), an increasing number and quantity of synthetic stones of these gem varieties is produced. With improving techniques it is easy to grow synthetic gems with properties similar to those of their natural counterparts or even stones without any significant inclusions of diagnostic value.

For this reason, the determination of structural properties of gems, such as straight growth planes parallel to external crystal faces or twin planes, is becoming increasingly important as an additional and easily performable method for the distinction of natural and synthetic gemstones. In addition to the increasing applicaion of spectroscopic data, these new supplementary and non-destructive techniques of microscopic examination enable the determination of structural properties of faceted gemstones and, thus, reveal data of diagnostic value, which are similar to those characteristics obtainable by X-ray topography. However, the application of an immersion microscope is easily performable in every gem testing laboratory and avoids the high cost of an X-ray topography facility.

The aim of the present publication is to introduce a new method for the determination of structural properties like straight parallel growth planes or twin boundaries in natural and synthetic gems. In addition, a second method which was already described by one of the authors (Schmetzer, 1985, 1986) is completed with supplementary details for practical use.

For both methods it is necessary to use the horizontal microscope in order to facilitate the application of an immersion cell and immersion liquids. For the older already described method a sample holder with one vertical and one or two horizontal rotation axes is applied to determine crystal faces by measuring the angle between the optic axis, i.e. the *c*-axis of optically uniaxial crystals, and families of straight parallel growth planes, or to determine twin planes by measuring the angle between the optic axis and the twin plane. Part of this first method as well as a detailed description of one distinct type of the applied sample holders were published by Schmetzer (1985, 1986).

The new method to determine structural properties of faceted natural and synthetic gemstones is based on the use of an eyepiece with cross hairs and a 360° dial attached to the eyepiece tube. With this equipment it is possible to measure angles between two different families of straight parallel growth planes independently from the orientation of the optic axis of the crystal.

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Table 1: Selected crystal faces and angles of corundum, $\alpha-Al_2O_3$, trigonal, crystal class $D_{3d} \triangleq \bar{3}\frac{2}{m}$

Name	Designation	hkl*	angle between *c*-axis and crystal face (rotation angle δ)
basal pinacoid	*c*	(0001)	90°
second-order hexagonal prism	*a*	$(11\bar{2}0)$	0°
positive rhombohedron	*r*	$(10\bar{1}1)$	32.4°
negative rhombohedron	*d*	$(01\bar{1}2)$	51.8°
negative rhombohedron	γ	$(01\bar{1}5)$	72.5°
second-order hexagonal dipyramids	*n*	$(22\bar{4}3)$	28.8°
	w	$(11\bar{2}1)$	20.1°
	v	$(44\bar{8}3)$	15.4°
	z	$(22\bar{4}1)$	10.4°
	v	$(44\bar{8}1)$	5.2°
	ω	$(1414\bar{2}\bar{8}3)$	4.5°

* based on the morphological cell with *a*:*c* = 1:1.365 (cf. Klein & Hurlbut, 1985)

Angles made by two crystal faces

$a \wedge a'$	120°	$c \wedge a$	90°		
$z \wedge z'$	121.1°	$c \wedge r$	122.4°		
$w \wedge w'$	124.0°	$c \wedge d$	141.8°		
$n \wedge n'$	128.0°	$c \wedge \gamma$	162.5°		
$r \wedge r'$	86.1°	$c \wedge n$	118.8°	$a \wedge n$	151.2°
$r \wedge n$	154.0°	$c \wedge w$	110.1°	$a \wedge w$	159.9°
$d \wedge n$	148.0°	$c \wedge z$	100.4°	$a \wedge z$	169.6°
$r \wedge d$	133.0°				

Table 2: Selected crystal faces and angles of beryl, $Be_3Al_2Si_6O_{18}$, hexagonal, crystal class $D_{6h} \triangleq \frac{2}{m}\frac{2}{m}\frac{2}{m}$

Name	Designation	hkl*	angle between *c*-axis and crystal face (rotation angle δ)
basal pinacoid	*c*	(0001)	90°
first-order hexagonal prism	*m*	$(10\bar{1}0)$	90°
second-order hexagonal prism	*a*	$(11\bar{2}0)$	0°
first-order hexagonal dipyramid	*u*	$(10\bar{1}1)$	41.0°
first-order hexagonal dipyramid	*p*	$(10\bar{1}2)$	60.1°
second-order hexagonal dipyramid	*s*	$(11\bar{2}2)$	45.1°

* based on the structural cell with *a*:*c* = 1:0.996 (cf. Klein & Hurlbut, 1985)

Angles made by two crystal faces

$m \wedge m'$	120°	$c \wedge m$	90°		
$a \wedge a'$	120°	$c \wedge a$	90°		
$m \wedge a$	150°	$c \wedge u$	131.0°	$m \wedge u$	139.0°
		$c \wedge p$	150.1°	$m \wedge p$	119.1°
		$c \wedge s$	135.1°	$a \wedge s$	134.9°

Table 3: Selected crystal faces and angles of quartz, SiO_2, trigonal, crystal class $D_3 \triangleq 32$

Name	Designation	hkl*	angle between *c*-axis and crystal face (rotation angle δ)
basal pinacoid	*c*	(0001)	90°
first-order hexagonal prism	*m*	$(10\bar{1}0)$	0°
positive rhombohedron (major rhombohedron)	*r*	$(10\bar{1}1)$	38.2°
negative rhombohedron (minor rhombohedron)	*z*	$(01\bar{1}1)$	38.2°

* based on the structural cell with $a{:}c = 1{:}1.102$ (cf. Klein & Hurlbut, 1985)

Angles made by two crystal faces

$m \wedge m'$	120°	$c \wedge m$	90°		
$r \wedge r'$	94.2°	$c \wedge r$	128.2°	$m \wedge r$	141.8°
$r \wedge z$	133.7° (adjacent)	$c \wedge z$	128.2°	$m \wedge z$	141.8°
$r \wedge z'$	76.4° (opposite)				

In a second and third part of this publication, the authors discuss some fields of application in detail, e.g. the determination of crystal faces and twinning in natural and synthetic emerald (part 2) as well as in sapphire, ruby, amethyst and citrine (part 3). These structural properties are strongly dependent on growth conditions applied for the production of synthetic gem materials as well as dependent on the condition of formation of natural gem minerals. The examples are designed to prove the applicability of the two methods described by the authors for a characterization of natural and synthetic gemstones, and the application of some of these data to problems of the determination of samples of unknown nature.

II. Significant angles of optical uniaxial minerals

In order to understand the introduced methods for the measurement of significant angles useful for the determination of growth structures and twinning in the three important gem minerals corundum, beryl and quartz, which are used as examples for optically uniaxial crystals, it is necessary to give some basic explanations about crystal faces and significant angles used in this publication.

All crystals of the above mentioned three mineral species show hexagonal or trigonal symmetry, their morphology mainly consists of prism, rhombohedral and pyramidal faces. In addition to these crystal faces, the minerals corundum and beryl normally reveal the basal pinacoid as a characteristic morphological feature. The basic habit of these three minerals consists of a low number of significant, recurring crystal forms. The angles formed by one crystal face and the *c*-axis as well as the angles formed by two distinct crystal faces are fixed and well known for the three minerals [Tables 1, 2 and 3].

Under microscopic observation, the angles formed by two crystal faces are directly visible and, thus, are used in this publication. In general, these angles are designated ϕ', whereas the usual crystallographic literature works with interfacial angles ϕ' with $\phi' = 180° - \phi$ [Figure 1]. However, in microscopic investigation a direct observation of the traces of crystal faces is possible and therefore the angle ϕ', which is formed directly by two crystal faces is used within this series of publications.

In Figure 2 a cross-section through a hexagonal or trigonal crystal is shown. The morphology of the crystal is formed by the basal pinacoid (*c*), a first- or second-order hexagonal prism (*m* or *a*) and any given hexagonal dipyramid or rhombohedron (*f* or

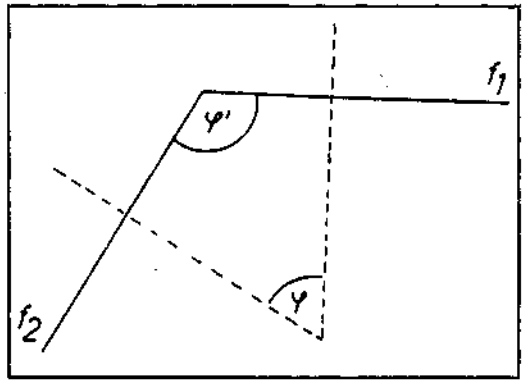

Fig. 1. Straight growth planes that form an angle; f_1, and f_2 traces of growth planes, ϕ interfacial angle, ϕ' angle made by the two faces.

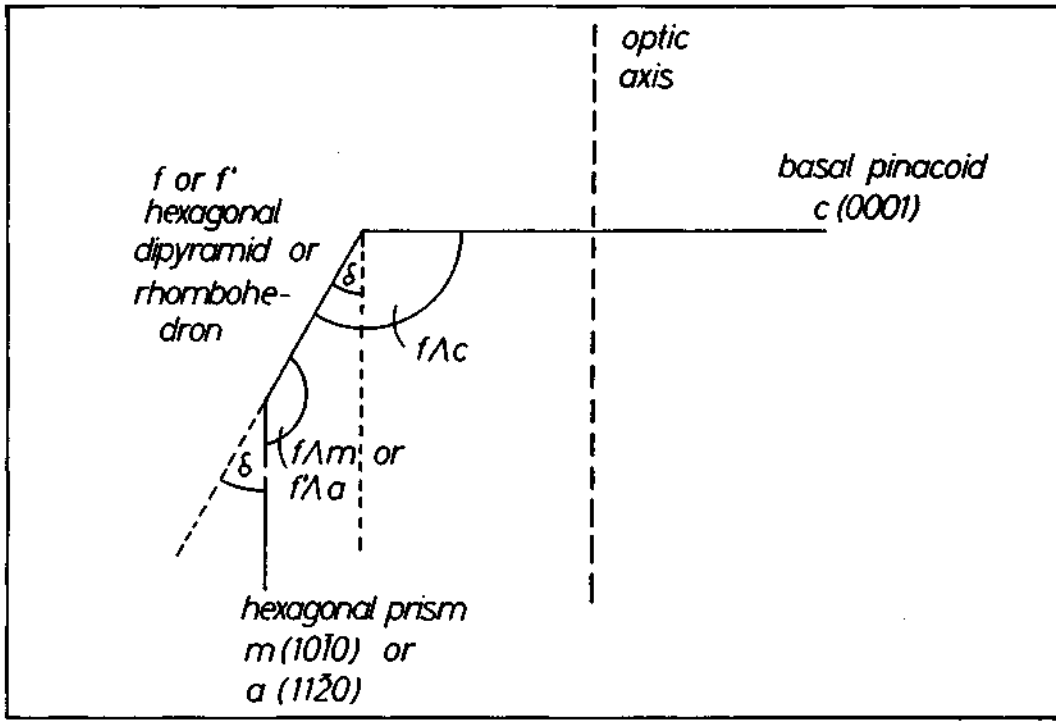

Fig. 2. Cross-section through a hexagonal or trigonal crystal showing the determination of internal structural features by use of the rotation angle δ, which is formed by the optic axis of the uniaxial crystal and any rhombohedral or dipyramidal growth plane (*f* or *f'*); further characteristic angles are formed by the basal pinacoid (*c*) or a hexagonal prism face (*m* or *a*) with any rhombohedral or dipyramidal growth plane (*f* or *f'*). View perpendicular to the *c*-axis.

f'). The angle formed by one of the crystal faces with the optic axis is designated δ. This angle indicates how much the crystal has to be tilted away from the optic axis in order to be able to observe the trace of the crystal face clearly in the microscope. By measuring this rotation angle δ, it is easy to determine the corresponding crystal face by using Tables 1, 2 or 3, respectively.

The different rhombohedral or dipyramidal crystal faces (*f* or *f'*) form characteristic angles with the basal plane (*c*) or with prism faces (*m* or *a*), which also can be easily observed in the microscope. In dependence of δ [cf. Figure 2] there are four important formulae indicating the relation between the angle formed by any given crystal face (*f* or *f'*) and prism faces (*m* or *a*) or between the angle formed by any given crystal face (*f* or *f'*) and the basal pinacoid (*c*):

$$f \wedge m = 180° - \delta$$
$$f' \wedge a = 180° - \delta$$
$$f \wedge c = 90° + \delta$$
$$f' \wedge c = 90° + \delta$$

Besides the above mentioned angles there exist some other important angles formed by rhombohedral or dipyramidal faces, e.g. the angles between two rhombohedral faces *r* and *r'* {10$\bar{1}$1} in corundum.

In Tables 1, 2 and 3 the most significant crystal faces are listed which occur in natural and synthetic corundum, beryl and quartz. In addition, the angles formed by the corresponding crystal faces with the *c*-axis (δ-angles) and the most important angles formed by two crystal faces are given. In Figures 3, 4 and 5 some idealized line drawings of the relevant minerals with all important crystal faces of diagnostic value are pictured revealing the relative orientation of these faces in the crystals.

III. Means for the determination of crystal faces and characteristic angles

III.1 Sample holder with two rotation axes and its use

In order to investigate and determine diagnostic structural properties in a faceted gemstone in different directions of view, it is often necessary to examine a given faceted sample in different orientations, i.e. to remove the sample from the holder and to place the object under investigation after its rotation back into the holder again. According to the geometrical properties of the cut gemstone, distinct directions of view in connection with the

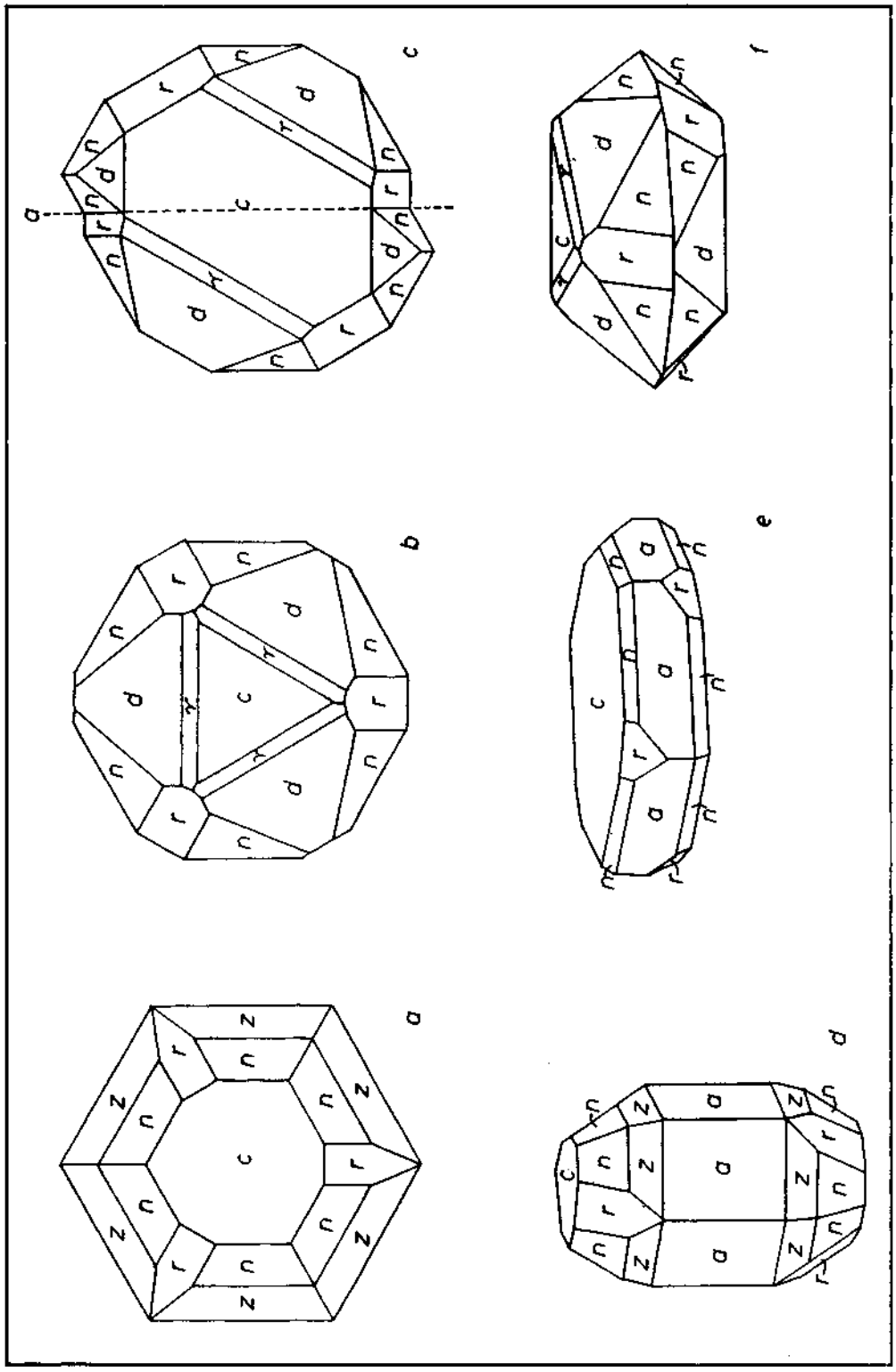

Fig. 3. The characteristic habit of natural and flux-grown synthetic corundum; a) *c*-axis projection of a natural crystal, b) *c*-axis projection of a flux-grown synthetic crystal, c) *c*-axis projection of a flux-grown synthetic crystal, contact twin across $\{10\bar{1}0\}$ with a $(11\bar{2}0)$ as composition plane, d) clinographic projection of a natural crystal, e) clinographic projection of a natural crystal, f) clinographic projection of a flux-grown crystal.

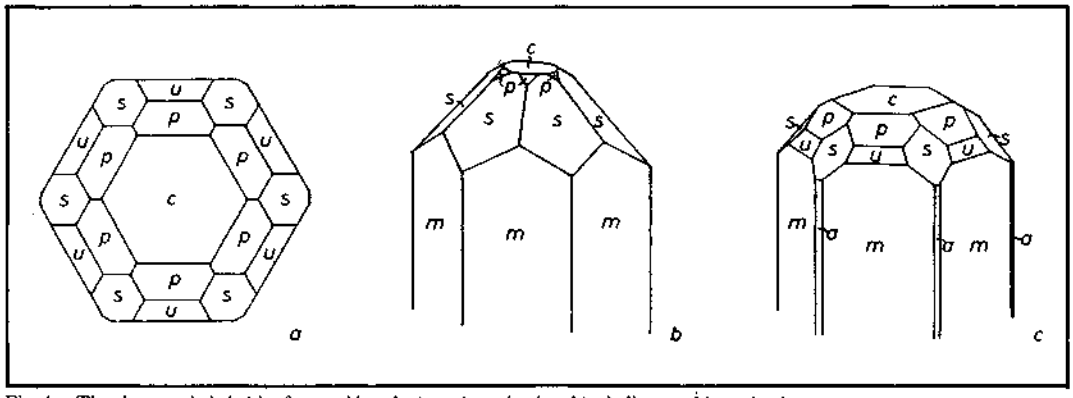

Fig. 4. The characteristic habit of natural beryl; a) c-axis projection, b), c) clinographic projections.

ordinary 360° rotation about the vertical axis of the conventional sample holder are easily accomplished. In other words, a cut gemstone is easily placed in distinct orientations into the conventional sample holder with one single vertical rotation axis, e.g. the gem is held by the crocodile clips between the table and culet or at the girdle. However, additional and different orientations of a cut gemstone are more difficult to obtain.

Because of this fact, it is very time consuming or sometimes even impossible to adjust the optic axis of a normally faceted gemstone parallel to the microscope axis. The recognition of structural properties, e.g. the exact determination of growth planes using the rotation angle δ, and the verification of the applicability of growth features for the distinction between natural and synthetic gemstones is practically impossible or at least very time consuming with the conventionally used gem holders.

For this reason, one of the authors (Schmetzer, 1985, 1986) improved the conventional sample holder with the generally available 360° vertical rotation axis by adding a second horizontal rotation axis. By use of this new axis a rotation of the sample about the horizontal axis through an angle up to about ± 40° is practicable. By attaching a dial with a 360° subdivision to the conventional vertical axis and adding a small indicator with set screw to the 360° dial, the angle between two structural properties of a gemstone, e.g. the angle between the optic axis of an optically uniaxial mineral and a distinct growth or twin plane can be measured easily [cf. Figure 2].

The measurement of structural elements is carried out as follows: by using crossed polarizers in the gem microscope, interference figures consisting of coloured interference rings are observed in distinct orientations of the crystal. Tilting the crystal towards a position in which the angle between the optic axis of the sample and the

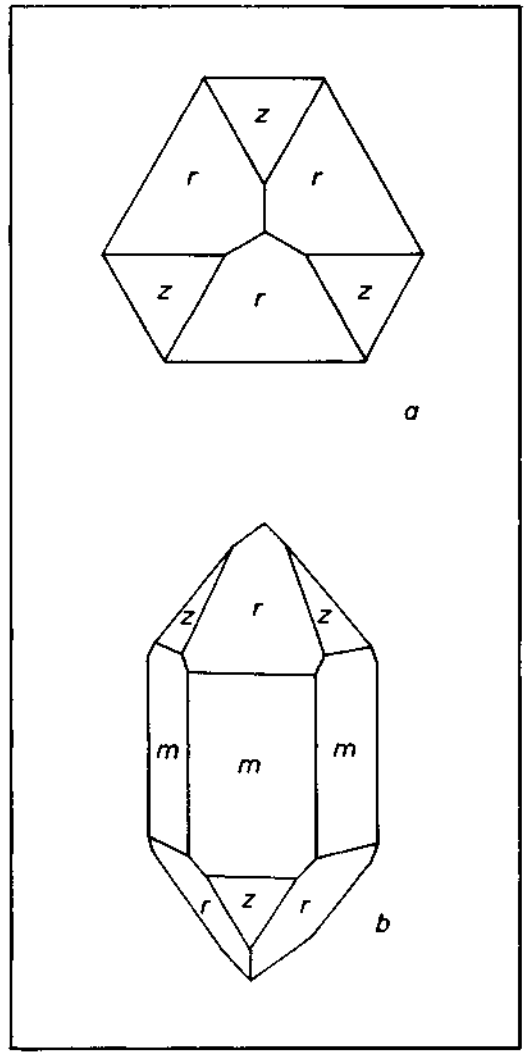

Fig. 5. The characteristic habit of natural quartz; a) c-axis projection, b) clinographic projection.

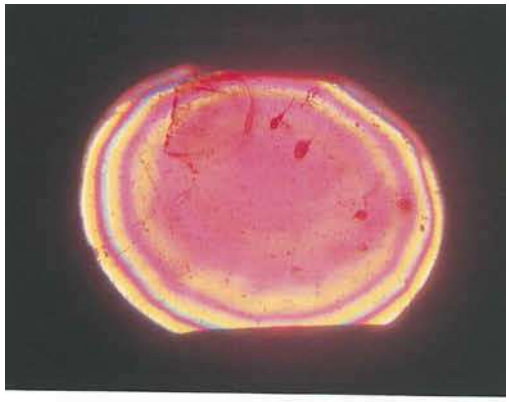

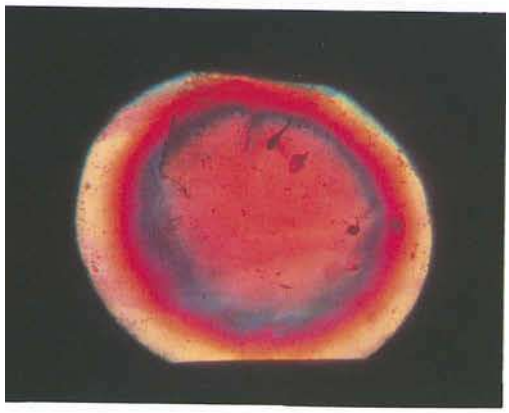

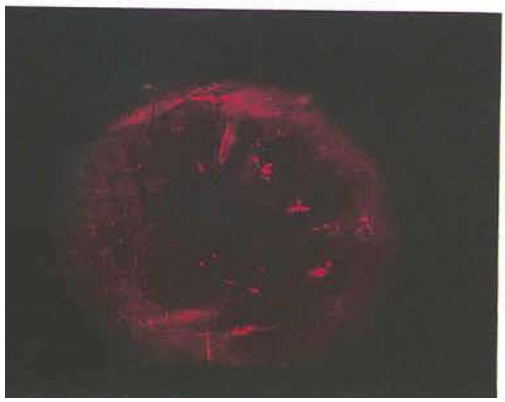

Figs. 6, 7, 8. This series describes the variation of interference figures of a natural ruby from Burma during a slight rotation of the stone; Fig. 6: the angle between the optic axis and the microscope axis is about 35°; Fig 7: tilting the corundum crystal slowly towards a position, in which the angle between the optic axis and the microscope axis is diminished moves the interference rings towards the centre; Fig. 8: the optic axis is exactly parallel to the microscope axis. Crossed polarizers, 60×.

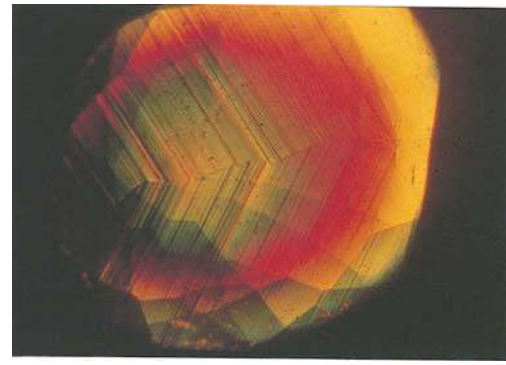

Fig. 9. Angled growth structure in natural sapphire from Pailin, Cambodia; planes parallel to the hexagonal dipyramids z and z' $(22\bar{4}1)$ form an angle of 121.1°. View 10.4° inclined to the c-axis, crossed polarizers, 20×.

microscope axis is diminished, the interference rings move towards the centre of the stone [Figures 6, 7]. After having placed the optic axis in the best available position [Figure 8], the indicator attached to the dial of the vertical axis is fixed to 0°. Afterwards, the sample is rotated about the vertical axis towards a position, in which sharp parallel growth planes or a single twin plane become visible in the gem microscope [Figure 9]. By use of a rotation angle δ, which is now directly readable on the dial, the growth or twin plane under investigation is exactly determined [cf. Tables 1, 2 and 3]. The experimental limit of error in the measurement of δ with the method described equals ± 1°. Consequently, all crystal faces quoted in Tables 1, 2 and 3 are unequivocally determined with the exception of ν $(44\bar{8}1)$ and ω $(14\ 14\ \overline{28}\ 3)$ in corundum with δ-values of 5.2 and 4.5°, respectively.

For a more detailed description of this sample holder with two rotation axes and its use for the distinction of natural and synthetic ruby as well as natural and synthetic amethyst consult the paper of Schmetzer (1986) in this journal.

A further improvement of the sample holder described above is the use of three independent rotation axes and three attached dials. This type of sample holder [Figure 12] allows the conventional 360° rotation about the vertical axis, and additional rotations about two horizontal axes, which are orientated parallel and perpendicular to the microscope axis, through angles up to about ± 40° in both directions. This three-axial sample holder can be used like that one with two rotation axes, but it is also possible to use all three axes with attached dials for the determination of crystal faces by means of the stereographic projection. However, this procedure needs more experience and is quite complicated. Therefore, this method will not be discussed in further detail within this publication. The three-

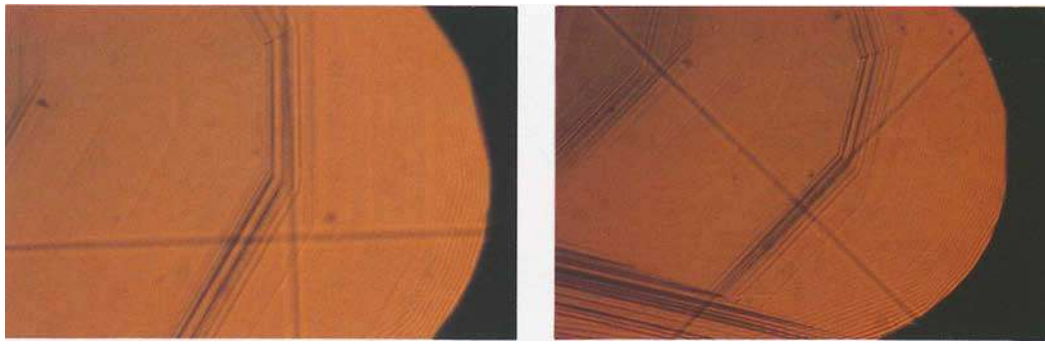

Figs. 10, 11. This series describes the determination of an angle ϕ' formed by two families of straight parallel growth planes in a natural emerald from Nigeria; Fig. 10: one wire of the cross hairs attached to the objective lens is tilted towards a position exactly parallel to the first group of parallel growth planes [in this case growth planes parallel to the basal pinacoid c (0001)], the dial attached to the objective tube is adjusted with its 0°-position coincident with the indicator fixed to the ocular; Fig. 11: the objective with fixed indicator is tilted into a position, in which the wire of the cross hairs is exactly parallel to the second group of parallel growth planes [in this case growth planes parallel to the hexagonal dipyramid p $(10\bar{1}2)$], the angle formed by the two sets of growth planes [in this case 150.1°] is now directly readable on the 360° dial. – View perpendicular to the c-axis, the c-axis runs almost horizontally, crossed polarizers, 20×.

axial type of sample holder is especially applicable for optical biaxial gem minerals, e.g. for the distinction of natural and synthetic alexandrite.

III.2 Measuring ocular and its use

In situations when the optic axis is not easily orientated parallel to the microscope axis or for a direct determination of two families of straight parallel growth planes, it is often useful to work with a measuring ocular in addition to one of the above described sample holders.

The measuring ocular consists of the normal rotary eyepiece of the gem microscope with cross hairs attached to the ocular lens. Attached to the eyepiece tube there is a fixable 360° dial, and connected to the ocular there is a fixed indicator. With these supplementary facilities attached to the conventionally available eyepiece, it is possible to measure easily the angle ϕ formed by two structural features, e.g. between two families of straight parallel growth planes, which reflect the morphology of a rough crystal [Figures 9, 10 and 11].

Using the above mentioned facilities, first the trace of two families of straight parallel growth planes have to be observable in the microscope. By rotating the eyepiece with the cross hairs, the ocular is placed in a position with one wire of the cross hairs parallel to the first family of growth planes [Figure 10]. Subsequently, the dial attached to the objective tube is rotated and adjusted with its 0°-position coincident with the indicator, which is fixed to the ocular. The ocular is now turned into a position, in which the direction of the second family of parallel growth planes coincides with the wire of the eyepiece [Figure 11]. The angle between the two sets of growth planes is now directly readable at the position of the indicator fixed to the objective at the 360° dial attached to the ocular tube. In general, both crystal faces under investigation are determinable by the use of Tables 1, 2 or 3, respectively.

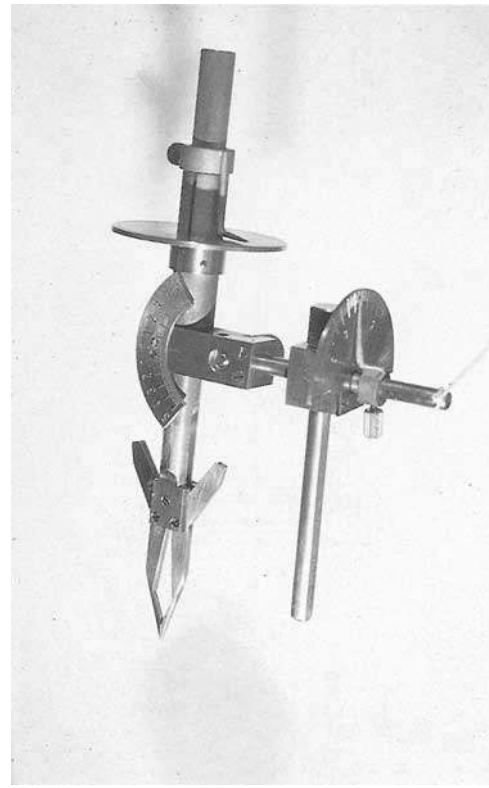

Fig. 12. Improved three-axial sample holder with one 360° vertical and two ±40° horizontal rotation axes, each of them having an attached dial.

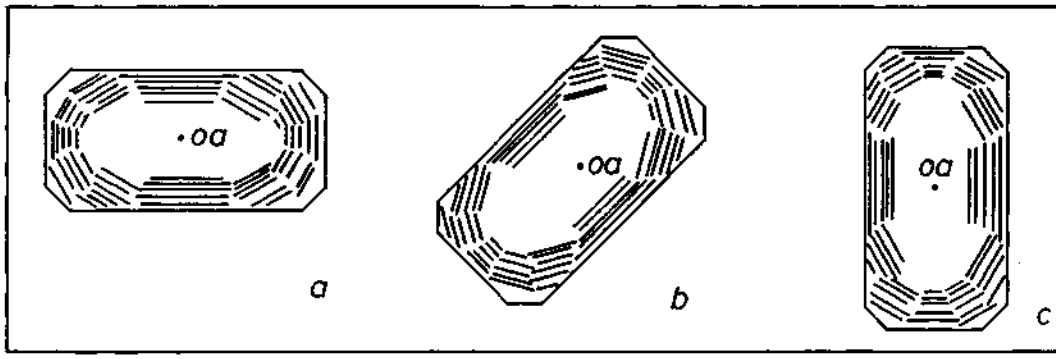

Fig. 13. Cross-sections of a faceted optically uniaxial gemstone (natural emerald) in different orientations with the optic axis parallel to the microscope axis (cross-sections (a), (b) and (c) are related by a rotation of 45° about the optic axis); rotating the crystal about the 360° vertical rotation axis, in each of the different orientations (a), (b) and (c) the traces of various sets of parallel growth planes become visible in the microscope and are determined by use of the rotation angle δ.

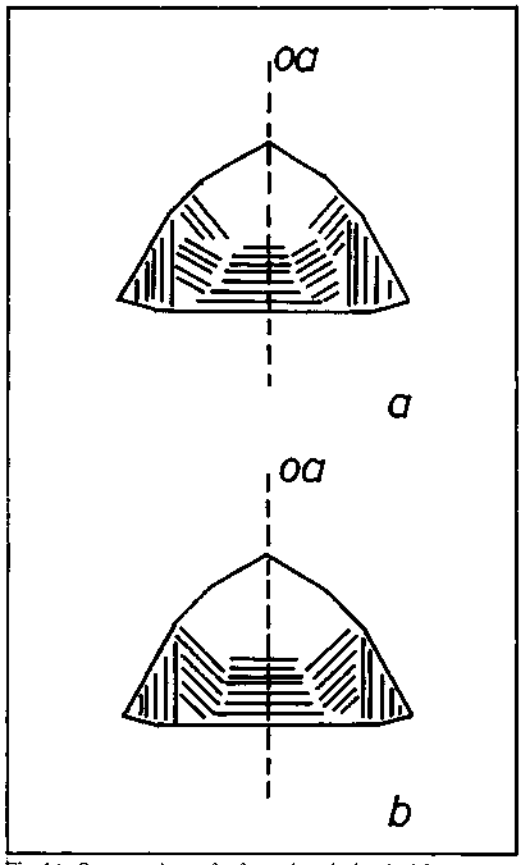

Fig. 14. Cross-sections of a faceted optical uniaxial gemstone (natural emerald) in different orientations with the optic axis parallel to the 360° vertical rotation axis (cross-sections (a) and (b) are related by a rotation of 30° about the optic axis); by a rotation through 30° about the 360° vertical rotation axis (i.e. in this particular orientation about the optic axis), various sets of growth planes become visible; by a rotation through 60°, identical sets of growth planes are repeated.

III.3 Suggested combination of both methods

For a combination of both methods described in sections III.1 and III.2, a first general step would be the determination of the position of the optic axis of the faceted gemstone under investigation as explained in section III.1. For subsequent procedures, it is helpful to retain the orientation of the optic axis relative to the girdle or relative to dominant facets, e.g. the table facet of the cut gemstone, and also relative to distinct types of inclusions if present. Now part of the internal crystal faces can be determined according to section III.1 by rotation of the gemstone about the vertical axis and measuring the rotation angle δ between appearing straight parallel growth planes and the optic axis.

To obtain a maximum number of crystal faces by this method, the stone itself should be placed in different orientations into the sample holder, which are related by a rotation of 45° about the optic axis as shown in Figure 13, keeping the optic axis parallel to the microscope axis in all different orientations. This procedure is necessary because in one simple orientation, only part of all growth planes of the gemstone become visible through a 360° rotation of the sample about the vertical axis of the sample holder.

In a second step, the gemstone should be rotated through 90° towards an orientation, in which the optic axis of the gemstone is placed in a direction parallel to the 360° vertical axis of the sample holder [Figure 14]. In that particular orientation, the growth structures parallel to the basal pinacoid (*c*) or parallel to the first- or second-order hexagonal prism faces (*m* or *a*) can be recognized easily. During a rotation of the gemstone about the 360° vertical axis of the sample holder, the basal pinacoid (*c*) or growth structures parallel to this face are permanently visible in the gem microscope [Figures 14, 15]. After each 30° or 60° rotation,

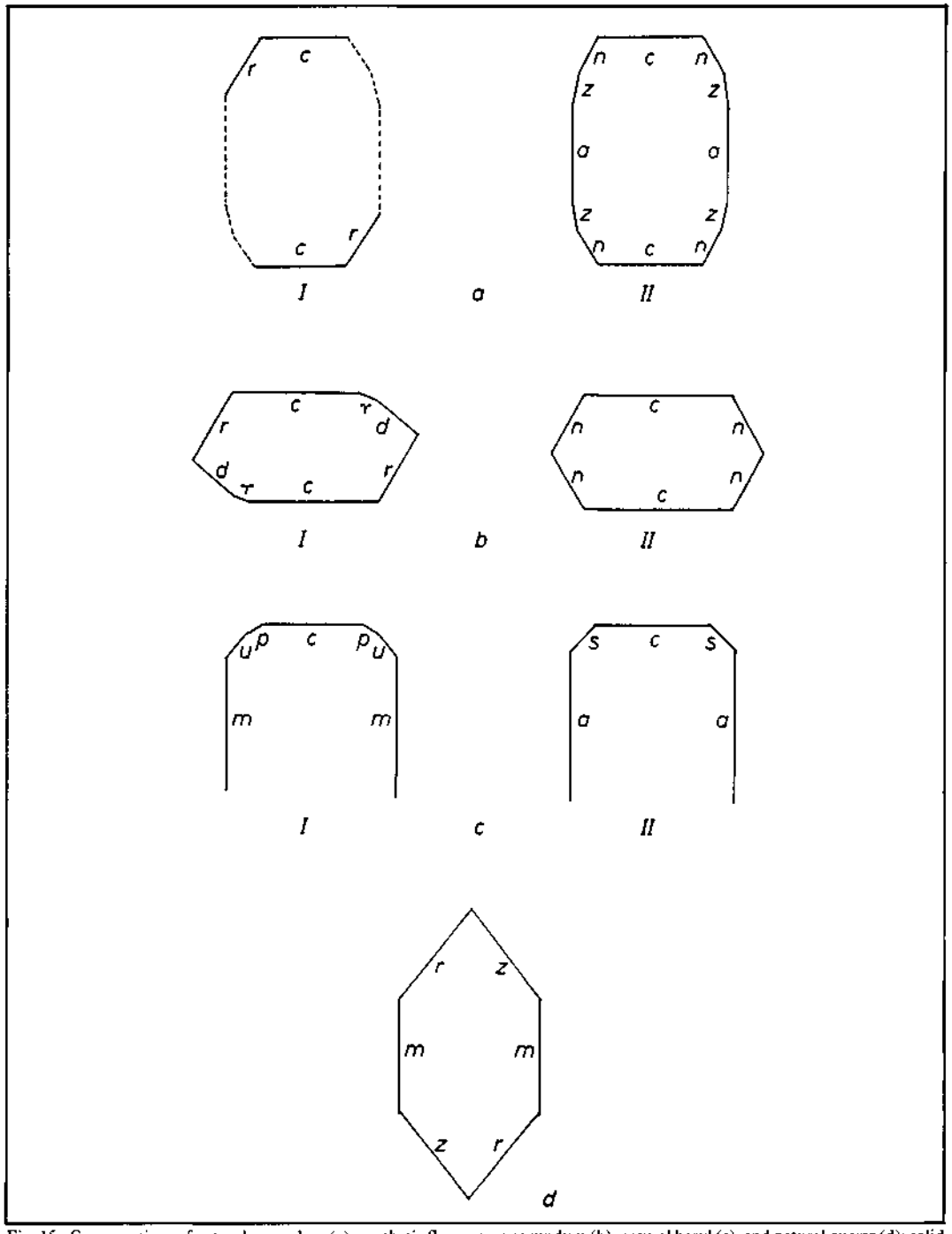

Fig. 15. Cross-sections of natural corundum (a), synthetic flux-grown corundum (b), natural beryl (c), and natural quartz (d); solid lines represent traces of crystal faces, dashed lines represent edges of the crystals; (a), (b), and (c): by a rotation through 30° about their optic axis, cross-sections (I) of the optical uniaxial crystals are converted to cross sections (II); by a rotation through 60° about the optic axis cross-sections (I) of the optically uniaxial crystals are converted to cross-sections (I′) with identical faces or cross-sections (II) are converted to cross-sections (II′) with identical faces, respectively; (d): by a rotation through 60° about the optic axis identical cross-sections are repeated. – View perpendicular to the *c*-axes, the *c*-axes run vertically.

subsequent first- and/or second-order prism faces become visible (if present in the sample under investigation). After measuring the angles ϕ' formed by an unknown crystal face (f or f') with the basal pinacoid (c) or with prism faces (m or a; cf. Figure 2) using the method described in section III.2, both angles can be used for the determination of the unknown growth planes (cf. Tables 1, 2 and 3).

After the exact determination of one group of growth planes is performed in one distinct orientation of the sample, subsequently rotating the hexagonal or trigonal gemstone about its vertically placed optic axis, after each rotation through 30°, successively the next set of growth planes with different ϕ' angles should appear for corundum and beryl [Figures 14, 15]. However, the angles between the growth planes (f or f') and the basal pinacoid (c) or one of the prism faces (m or a) are repeated after each rotation through 60° for all three minerals, corundum, beryl and quartz [Figure 15]. In general, with several subsequent rotations of the crystal about the optic axis through 30° each, a complete set of growth structures becomes visible in the gem microscope and the determination of all structural properties of the mineral is performable.

IV. Conclusions

In this first part of the article a general survey of different possibilities for the determination of structural features of faceted uniaxial gemstones by use of a sample holder with two independent rotation axes is given. The basic purpose for the addition of a second horizontal rotation axis is an easy orientation of the optic axis of the gem parallel to the microscope axis. With an additional improvement of the two-axial sample holder towards a three-axial one, it is also possible to determine characteristic crystal faces and angles of optically biaxial minerals, e.g. alexandrite. For this somewhat more complicated method the use of the stereographic projection is necessary.

In a first step, it is important to locate the optic axis of the stone under investigation relative to the dominant facets of the stone. With the optic axis orientated parallel to the microscope axis, it is possible to determine the rotation angles δ of growth planes by tilting the gemstone in a direction, in which the optic axis is horizontally twisted towards an orientation perpendicular to the microscope axis. The angle δ between the optic axis and a family of straight parallel growth planes is readable at the dial fixed to the 360° vertical axis of the sample holder. Having performed the alignment of the optic axis and the determination of growth structures by rotation of the sample about the vertical axis of the sample holder and measurement of the rotation angle δ, this procedure is at least twice repeated in different orientations of the gemstone, which are related by a rotation of 45° about the optic axis.

A second new method for the determination of crystal faces of optical uniaxial minerals used by the authors is the measurement of characteristic angles between two crystal faces by using cross hairs in a measuring ocular and a 360° dial attached to the tube of the eyepiece. In order to perform these subsequent series of measurements, the stone is removed from the sample holder and reorientated in a position, in which the optic axis is perpendicular to the microscope axis. This means the optic axis is now parallel to the vertical 360° rotation axis of the sample holder, which allows a rotation of the faceted gemstone under maintenance of the position of the optic axis. The structural features are then determinable by measuring the angles between known crystal faces that appear frequently, like the basal pinacoid (c) or one of the hexagonal prism faces (m or a), and an unknown crystal face (f or f'). With the same method a determination of twin or glide planes is possible. Furthermore, the angles between adjacent rhombohedral or pyramidal faces are able to be determined.

With some experience, the combination of both methods allows the complete determination of all existing growth structures as well as twin or glide planes of every optically uniaxial mineral.

In the second and third part of this publication, which will appear in subsequent issues of this journal, some examples for the application of the methods described for the characterization of important gem minerals of distinct occurrences as well as some common synthetic gemstones available in the trade are described in detail.

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Emeralds from Colombia (Part 1)*

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Switzerland

Abstract
Introduction (Part 1)
A1. The history of the Colombian emerald mines
A2. The geographical location of the emerald occurrences

B1. The emerald deposits and their geological environment
B2. Hypotheses of emerald genesis
B3. The mine workings

Gemmological properties (Part 2)
C1. Morphology, quality and size of the emerald crystals
C2. Chemical composition, chromophore and trace element contents
C3. Light absorption, colour and fluorescence
C4. Optical values and density
C5. Inclusions and growth characteristics

Treatments (Part 3)
D. Oil, ultrasonic and heat treatments

Discussion
E. Differentiation of the Colombian emeralds from natural emeralds of other origins, synthetic emeralds and emerald imitations

Acknowledgements
Bibliography

Abstract

A condensed historical and mining survey is followed by a compilation of the most notable crystals of Colombian emeralds ever found and of the details of their chemical composition. A summary of the elemental substitutions and their effects on the outlined range of gemmological data is given.

Special emphasis is placed on the cause of the famous, vividly green coloration, i.e. on the selective absorption of orange-red and violet light, dictated by minor contents of the chromophoric elements Cr and V substituting for Al^{3+} in octahedrally coordinated sites of the beryl lattice (Cr ≈ V, with the Cr/V ratio found to be ranging from 4.5 to 0.5, in extreme cases from about 10 to 0.1). Iron, however, has barely been detected in the UV/VIS absorption spectra of Colombian emeralds. Though generally present in slightly larger amounts than Cr^{3+}, iron does not recognizably influence the colour (little Fe^{2+} and possibly some Fe^{3+} positioned in the axial channels of the ring-silicate structure).

A detailed presentation of the currently known internal characteristics (inclusions and growth structures) is supplemented by a discussion of identification problems with treated emeralds and the disclosure of the treatment during transactions in the wholesale and retail trade.

Allocation of the emeralds to individual Colombian mines on the basis of inclusion patterns does not appear possible in most instances. However, the differentiation of Colombian emeralds from other natural emeralds (such as those from the Panjsher Valley exhibiting very similar (s,l,g) three-phase inclusions) or from difficult, modern hydrothermal and flux synthetics is shown to be feasible by a combination of microscopy, refractometry, and absorption spectrometry (UV/VIS and NIR/MIR), assisted by chemical analysis only in the most difficult cases. Safe identification of authenticity, treatment, and origin of emeralds, however, is increasingly becoming the task of the experts in the specialized laboratory.

The mineralogical definition of emerald as a yellowish to bluish-green variety of natural beryl is shown to be valid for any Cr and V-containing variety except possibly the rare, absolutely chromium-free (V,Fe)-beryls (modification of the former definition of type II emerald): in many of the preferred Colombian emeralds, chromium is clearly dominated by vanadium (Cr/V ratio < 1). However, chromium has a higher efficiency of coloration than vanadium and a much higher one than iron ions in the various substitutional and interstitial lattice sites of beryl. Cr influences colour even at very low trace levels.

An extensive and up-dated selection of literature, covering all aspects cited, completes the synopsis.

*This is a paper which will be published in *The Journal* in three parts. The complete bibliography is presented with Part 1.

The introduction to this review is based on the study of a fraction of the extraordinarily extensive literature on Colombian emeralds.
The main part of the paper (Part 2) contains data collected and findings achieved over many years in the SSEF Laboratory in Zurich.
Part 3 will deal with the difficulties encountered in identifying treated emeralds and with the disclosure necessary when selling them and will discuss the possibilities of differentiation between Colombian and other natural emeralds and the synthetic emeralds.

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Introduction

A1. *The history of the Colombian emerald mines*

The ancient South American Indian tribes were rich in natural resources, yet their need of these goods was modest and sensible. Gold and emeralds were used commercially as well as for royal insignia. Both had a symbolic and ceremonial character. The original inhabitants of Peru, Mexico and the Caribbean were treated less kindly by fate than the Chinese, Japanese or other ancient cultures. From about 1500 onwards, the Incas, Aztecs and Mayans were overrun, enslaved and exploited by the so-called discoverers from the Old World.

The emerald pits of the Chibcha Indios near Somondoco, later called Chivor, were discovered by the Spaniards in the early sixteenth century and from then on intensely mined. The finds of the Muzo Indians took the same course once the tribes had been subjected by the Spaniards. In the seventeenth century, the decimation of the Colombian Indians through imported illnesses and drudgery was such that it led to a shortage of cheap slave labour. Chivor was forced into oblivion for the next 200 years and the deposits were overgrown by jungle vegetation. Mining in Muzo became sporadic.

However, between 1537 and 1650 the Spanish royalty had accumulated such immense riches that all purchasing wishes of the Indian Moguls, the Ottoman aristocracy and the European courts could be satisfied. Because of the scarcity of green woods and fields in their own countries, the Muslims have treasured for ages the colour green. In fact it is the holy colour of Islam. This explains the abundance of Colombian emeralds in the treasuries of Arabian sheiks. The Persian crown jewels in particular are said to abound with these gems. Hundreds of cabochons and faceted emeralds over 100 carats, some even over 300 carats, were to be found in the safes of the Banque Markazi in Teheran.

Beautiful and large, rough and cut, engraved and inscribed Colombian emeralds from that period can also be admired in the Topkapi Palace Museum in Istanbul.

Notable historic crystal groups, single crystals and Colombian emerald gems from colonial times are also exhibited in the Natural History Museum in Vienna (among others the group of crystals named 'Moctezuma', measuring 17x16 cm and consisting of single Muzo and Chivor crystals glued together). An original Chivor crystal group approximately 30 cm across, carried by the figure of a Moor, and an emerald suite are displayed in the Green Vaults of Dresden. Fine specimens are to be seen in many other museums (except in Spain where royalty was said to have preferred gold to emeralds).

Not all Colombian emeralds reached the Spanish coast 400 years ago. A ship of the Tierra Firme fleet, the galleon Nuestra Señora de Atocha for instance, sank in 1622 near the Florida Keys, carrying valuable gold and emerald freight. In 1985, over 2300 loose and set emeralds were successfully lifted off the wreck. The largest stones recovered weighed 64 and 30 carats.

A2. *The geographical location of the emerald occurrences*

The Andes are mountain chains rich in raw materials. Together with the Himalayas, the Alps and the North American cordilleras, they belong to the youngest and highest mountain systems in the world. All these Alpine type mountain ranges were and still are being thrust upward at the front of slowly drifting Continental plates (in the case discussed, at the front of the very old Brazilian and the Guyana plates)[1].

The results of plate movements and orogenies are frequent earthquakes and volcanic eruptions, such as the big quakes in North Yemen (1982), Mexico City (1985), the San Francisco Bay (1989) or the Philippines (1990) and the eruptions of Mount St. Helens (1980) or of the Nevado del Ruiz (1985), less than 100 km north-west of Muzo.

From the south-west to the north-east, the Colombian Andes divide into three mountain ranges, the Cordillera Occidental, Central and Oriental. The connection with the North American cordilleras is established via both Central American branches, the western chain running directly through the west of Mexico, the eastern chain bending via Venezuela and the long Caribbean archipelago back to Yucatan and then northward towards the Rocky mountains.

Extending for some 150 km, the *Colombian emerald belt* stretches from the north to the east of the capital, Bogotá, across the eastern branch of the Andes. This Cordillera Oriental divides the belt into two mining districts[2] with Muzo and Coscuez in the north-west (Boyacá Province), and Chivor (Boyacá and Cundinamarca P.) and the mines of Gachalá in the south-east (Cundinamarca Province). Even between neighbouring mines of the Muzo district there is no very obvious geological relationship. The rugged terrain and the thick

[1]The formation of the Colombian Andes is not due to simple or nappe folding. They are marine and continental block formations generated by the horizontal north-west drift of the Guyana plate (presently at a rate of about 50 mm per year) onto the subducted Pacific Nazca plate. Geological terms: orogeny = formation of mountains, subduction = down-movement (of marine plates), circum-Pacific mountain systems = Andes/Rocky Mountains/Aleutian island arch/Japan/Philippines/New Guinea/New Zealand Alps.

[2]The mines of the Muzo district from south to north are: El Peñon, Aposentos (near Yacopi), Coper, Maripi, Muzo (Tequendama, Santa Barbara, El Chulo), Coscuez and Peñas Blancas. Those of the Chivor district from S to N are: Vega de San Juan, Las Cruces, El Toro, El Diamante (all near Gachalá), Mundo Nuevo, Buenavista, Chivor, Achiote and Sagrada Familia (near Somondoco).

subtropical mountain vegetation have made access for geological mapping and systematic prospecting very difficult.

Apart from the mines of Muzo and Chivor – renowned worldwide for the quality and quantity of their emeralds – there is supposedly a large number of smaller, less important diggings and mines (about 200), the names and locations of which are obscure or conflicting. Localities such as Borur, Borbur and Burbar are quoted, but it is conceivable that all these names refer to one and the same occurrence. The spelling of several mines also varies in literature (Coscuez/Cosquez, Peñas Blancas/Peña Blanca, etc.). Apart from further mines in the Colombian emerald belt, Kazmi & Snee (1989) mention an isolated occurrence in the Valle Andalucía (240 km WSW of Bogotá). Reports that emeralds have been found as far south as Ecuador, however, have not been confirmed (Schwarz, 1989a).

B1. *Emerald deposits and their geological environment*

The Colombian emeralds occur in dark, carbonaceous shales and thin, inter-layered limestones of early Cretaceous age, that is, about 120 to 130 million years old. This rock series was formed of chalky and argillaceous, marine and continental sediments of high organic content and is therefore grey to black in colour. Since the early Tertiary period, they have been lifted, folded, faulted and mineralized (Figure 1).

Emeralds appear enriched in places where large-scale tectonic faults once cut through the sediments. The Muzo district lies directly at the Rio Itoco fault (striking NW-SE) and the Chivor district at the San Fernando fault system (striking NE-SW). The emeraldiferous lodes and veins follow the minor lateral clefts as well.

In the so-called Villeta series of Muzo and in the somewhat older Caqueza series of Chivor the veins form sills and often fill out cavities and steep fissures. The emeralds preferably concentrate in the lower fold axes of the carbonaceous shales but especially at intersections of veins and clefts. The crossings seem to have offered quieter crystallization conditions creating an easier migration of mineral forming solutions than in the actual veins.

In the *district of Muzo* the emerald-bearing lodes and veins consist mainly of calcite and show thicknesses of a few up to 300 millimetres. In contrast, veins with dolomite, albite and baryte are frequently barren of emeralds (sterile). The calcite veins of Muzo are characterized by the following succession of parageneses (chronological sequence of mineral associations):

1. Calcite and pyrite,
2. *Main crystallization:* calcite, pyrite, dolomite, quartz and emerald with the accessory minerals parisite, albite, pink apatite and colourless fluorite,
3. Calcite, pyrite, dolomite and baryte.

Parisite is a very rare, brownish Ca(Ce,La,Di)-carbonate named after the Colombian José Ignacio Paris (last century).

The northern part of the *district of Chivor* is less well explored than the Gachalá and Muzo areas. In Chivor the veins are known to be poor in calcite, but rich in albite and pyrite, and found between or underneath nearly horizontal limonite beds. The crystallization sequence is:

1. Pyrite and quartz,
2. Pyrite, emerald and albite with subordinate apatite and dolomite.

Limonite (mainly goethite) on the one side and micas (muscovite, sericite, fuchsite) plus clay minerals (kaolinite) on the other side are encountered as dissociation products of pyrite and albite (the white feldspar). A second beryllium mineral, a bluish euclase ($BeAl[SiO_4]OH$, monoclinic), has been detected in company with the emeralds of Gachalá as well, although not often.

Omnipresent minerals in Muzo are calcite and pyrite and in Chivor pyrite and albite.

B2. *Hypotheses of emerald genesis*

The genesis of the emerald deposits is controversial. The postulation put forward most frequently in literature is the *formation from hydrothermal solutions*. This conclusion has been reached by studies of the paragenesis of the gangue (vein matrix) and of the homogenization temperatures of multi-phase inclusions in the emeralds (Kozlowski, *et al.* (1988) suggesting a minimum temperature of the fluids of 470°C, prior to taking into account a correction of at least +100°C for an overburden pressure of $\leq$ 1 kbar).

Fluid phases under pressure are exceptionally mobile and can easily travel long vertical distances. As hydrothermal differentiation products of magmatic crystallization cycles, they are thought to represent residual solutions which delivered the light elements Si, Al, Na, (Mg) and in particular the volatile beryllium. However, other origins of the solutions such as fossil and possibly marine waters from rock pores containing sodium and chlorine may be argued as well.

Rising through the fracture systems and clefts in the argillaceous, calcareous and evaporitic sediments characteristic of these parts of the Cretaceous succession, these brines in addition could have dissolved:

1. carbonates, sulphides, sulphates, fluorides, phosphates and quartz, all observed as gangue minerals,
2. the emerald colour-causing transition elements

Cr and V plus Fe,
3. the element Be (Escovar, 1979) and
4. some rare earths (Ottaway, *et al.*, 1986).

Generally it seems less likely that chromium and beryllium have been extracted or leached out from the limestone and clay rocks (except in the Gachalá area), in contrast to vanadium which is well known to be present geochemically in sediments with organic constituents such as those in the dark shales. Correspondingly, vanadium is observed in elevated concentration in the Trapiche emeralds of the Muzo district (Hänni, 1982). In addition, hardly any metamorphic rocks, ultrabasic or acid bedrocks have been found in the wider vicinity of either mining district which could be considered as possible sources of Cr and Be (major ophiolitic and granitic rocks are present in the western Colombian cordilleras only, associated with important platinum and gold deposits).

A variant of the hydrothermal hypothesis is the concept of metasomatism, in which process individual minerals of the wall rocks are not only leached out by the hot brines, but are replaced materially (i.e. they are carbonatized and albitized). This appears to have happened in the area of the mines El Diamante and Las Cruces near Gachalá. In contrast, the wall rocks in the Muzo district are said to be unaltered.

The third variant of the hydrothermal hypothesis of emerald formation involves *circulating ground waters*. Such carbon dioxide-containing waters seep into inclined rock layers and fault systems, reach a certain depth and mineralize under the influence of heat and pressure. During their re-ascent, the waters become oversaturated due to decreasing temperature and pressure so that their mineral contents are precipitated on the side walls of the clefts.

Fig. 1. Two specimens of carbonaceous shale with calcite veins (one with abundant pyrite) and a pale emerald crystal group, about 4cm in length. All specimens from the Colombian mining district.

However, the postulation of hydrothermal formation must be re-examined in view of the facts that the hypersaline brines have been at temperatures of up to 600°C and that in many places they have apparently not affected the wall rocks of the emerald veins at all. For the time being, the origins of beryllium, chromium and water (fossil rock porosity waters originally of marine provenance, from depths of ≥ 5000m?) also remain unexplained.

According to Kazmi & Snee (1989), the suture

zones of the earth's crust contain the highest potential for emerald deposits in the world. Examples are the broad collision belt between the Indian sub-continent and the Eurasian plate in North Pakistan and Afghanistan and to a lesser extent the Ural mountains and the vicinity of the African Rift Valley (Egypt, Tanzania, Moçambique). The collision of submarine ultrabasic rocks and acid plutons, with their geochemically increased contents of chromium and beryllium respectively, would alone offer the rare and favourable conditions for the formation of emeralds in these suture zones. The Cordillera Oriental in Colombia also represents a collision zone (in front of the north-west drifting Guyana plate). In the author's judgement (cf. C5. Inclusions and growth characteristics, footnote 7), the Colombian emerald belt has yet to give up the secret of its possibly remote chromium and beryllium sources.

B3. *The Mine Workings*

Since the end of the last century the Colombian mines have had an eventful history. At times the mines were in private hands, sometimes they were supervised by the Government or the Banco de la República. Alongside these more or less strictly controlled forms of management, a tolerated black market fed by the unorganized guaqueros (treasure hunters) has for a long time been an important economic factor. These guaqueros search the waste washed down to the river beds below the mines. Nationalized mining also suffered heavy losses after the closure of the Muzo mines from 1973 to 1977 due to a series of murders. Today the whole district is a prohibited area, closely guarded by the army.

Since 1978 private companies were given mining leases by the State for five year periods. It is said that such short contracts (today the leases are for ten years) force the managements to use dynamite as well as bulldozers and pressurized water to move large rock masses. This is a very questionable development in operating the mines, with immense effects on the ecology of the environment.

Over the centuries, the *Muzo* mines have yielded by far the largest and most constant production of emerald in the world (1986 estimated to be an enormous 300,000 ct). Until approximately 20 years ago, these mines were worked almost exclusively by open-cast methods in small terraces, but from then on by massive removal of complete rock layers. Presently it is planned to convert to modern underground mining.

The neighbouring *Coscuez* mine has also been worked for 400 years, but this deposit has been marked by long periods of inactivity. In the past few years, however, Coscuez has overtaken Chivor as the second largest producer with an estimated yearly output of 150,000 ct (1986). Because of the clear concentration of emeralds in large clefts, tunnelling is the preferred method of mining.

Chivor, historically the oldest mine, has had production peaks and total break-downs since the times of the Conquista. At present the output appears to be fairly low. Chivor was and still is essentially an open-pit benching operation, but there is some underground mining too.

The mines near *Gachalá* were discovered in 1953 and flourished during the fifties and sixties. Since then the emeralds from these mines are hardly ever encountered on the gem market.

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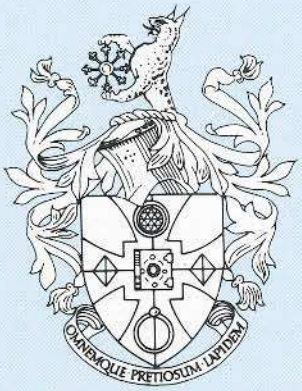

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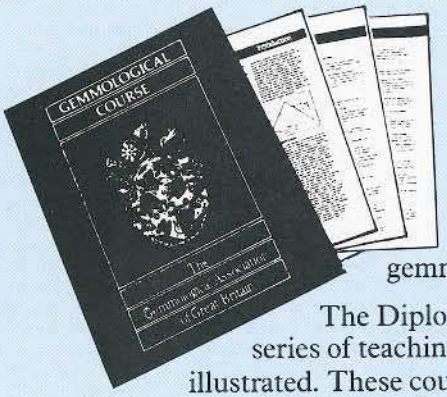

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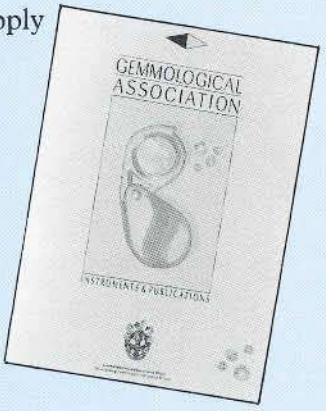

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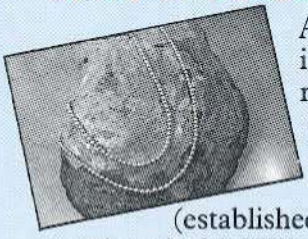

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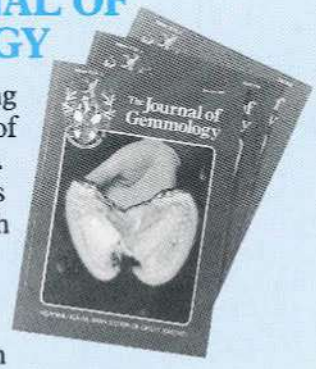

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Sodium polytungstate as a gemmological tool

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Currently, the use of heavy liquids is probably the most noxious activity of gemmologists. Aside from health factors, these liquids are foul smelling and are light sensitive. They decompose into acidic and/or corrosive products and they are not reclaimable. There ought to be a better approach – and there is. It utilizes a substance known as sodium polytungstate (Ref. 1,2,3,4).

Pure sodium polytungstate ($3Na_2WO_4.9WO_4.H_2O$) is a white crystalline powder. It is not volatile and has no odour. Sodium polytungstate is both heat and light stable. It is easily dissolved in water, easily rinsed from a gem, and can be easily reclaimed. It is non-reactive, and its solutions are neutral.

Sodium polytungstate is available in small quantities as a solution of 2.8 g/cm^3 density for $12 per ounce from Hanneman Gemological Instruments, P.O. Box 2453, Castro Valley, CA 94546. Densities as high as 3.1 g/cm^3 are easily prepared. A dropper is supplied to facilitate dilutions.

Safety

As is true with all substances, the dose makes the poison. Consequently, not even water or oxygen can be guaranteed to be completely safe. Currently there is no evidence at all that sodium polytungstate causes health problems for its users (Ref. 2,4). It produces no fumes and is not absorbed by the skin. Nevertheless, one obviously should not eat it, and one should keep it away from children. In any case, in all aspects it is a vast improvement over the organic bromine compounds currently being used.

Use of sodium polytungstate solutions

Gemmologists accustomed to using the traditional heavy liquids should have few problems adjusting to the use of sodium polytungstate solutions. They are simply a high concentration of an inorganic salt dissolved in water. Consequently, if left open to the atmosphere, the water will evaporate, leaving the white salt. However, the solution can be easily reconstituted by replacing the water.

Whenever a gem is removed from this heavy liquid solution, both the stone and the stone tongs should be dipped into a container of rinse water. Any 'lost' sodium polytungstate can be reclaimed later by simply allowing the rinse water to evaporate.

Retrofitting heavly liquid sets

The simplest type of retrofit for practising gemmologists (especially those with several sets of bottles containing dried up and/or decomposed heavy liquid solutions) is to clean out the old bottles and, using the same reference stones, replace the liquids with appropriate solutions of sodium polytungstate. This service is also provided by Hanneman Gemological Instruments.

Determination of density using sodium polytungstate solutions

The determination of any density below the value of 3.10 g/cm^3 on any gemmological specimen can be easily accomplished using sodium polytungstate solutions. The procedure starts with a saturated solution of sodium polytungstate or one in which the test specimen floats. Then, by the careful addition of water by means of a dropper, the density of the solution is reduced to the point at which the specimen just remains suspended. The density of the solution now matches that of the gem. A drop of the liquid is then removed, and its refractive index (n_D) is determined on any gemmological refractometer. This value is compared with the graph shown in Figure 1 from which the density can be determined.

Alternatively the density can be calculated by using the following equation:

$$\text{Density (g/cm}^3) = 2.80 + 8.43\,(n_D - 1.555)$$

Notes on the use and preparation of solutions

When making solutions of sodium polytungstate, only distilled, deionized, or softened water should be used. The presence of calcium ions will cause the formation of a fine white precipitate. If this should happen, either ignore it or allow it to settle to the

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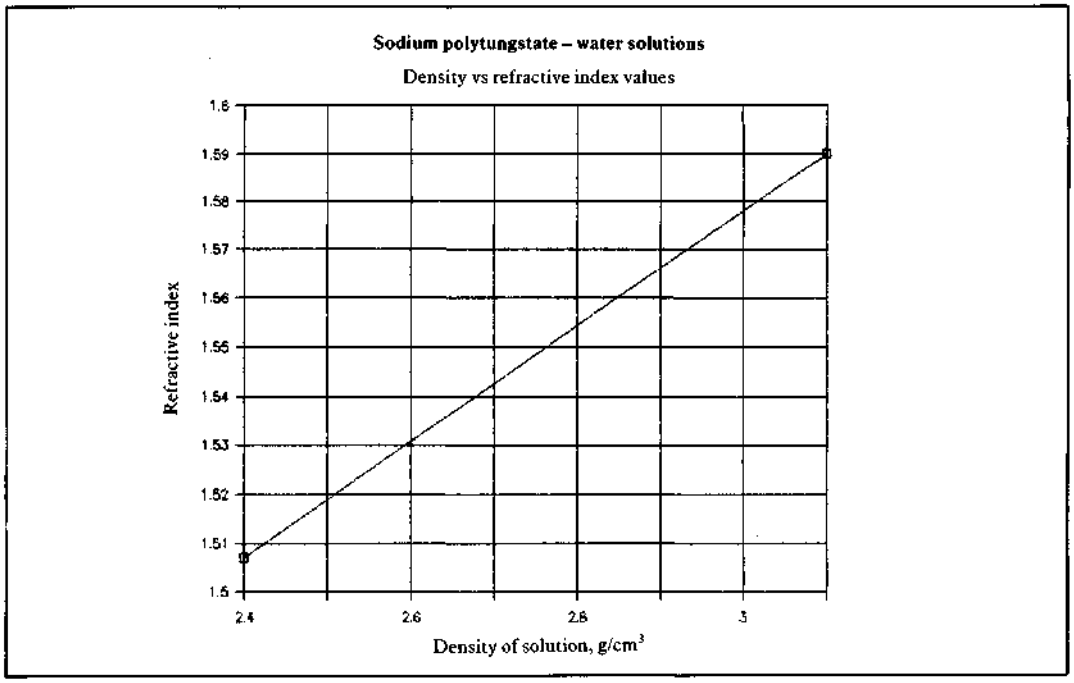

Fig. 1. Graph showing the relationship between refractive index and density of sodium polytungstate solutions.

bottom and remove it.

The solubility of the sodium polytungstate in water is enhanced by heat. Supersaturated solutions are easily prepared by the addition of solid salt to a warmed solution. On standing overnight, crystals will form as the supersaturated solution becomes merely saturated. The density of this solution is about 3.10 g/cm^3. Probably the best way to maintain your sodium polytungstate stock solution is as a saturated solution with a few crystals in the bottom.

Unlike organic heavy liquids, there is only a minor change in density when a warm solution cools. Since the refractive index also changes, there is a built-in temperature compensation. As a practical matter, as long as density values are expressed to only two decimal places, the effects of temperature can be neglected.

Sodium polytungstate can be reclaimed from solutions at any time by allowing the water to evaporate. Overnight, in an open vessel, will usually be sufficient. Heat will accomplish it in a very short time. It is not necessary to go to complete dryness. Nevertheless, it is usually helpful to have a small quantity of dry salt available for adjusting densities upward. This is simpler than evaporation.

Any powdery film of salt remaining on a gem, tool, or refractometer surface can be removed by wiping with a soft damp cloth.

Densities above 3.1 g/cm^3

From the preceding, it is apparent sodium polytungstate solutions cannot replace pure methylene iodide (density 3.32 g/cm^3). Because of its high refractive index (1.73), methylene iodide is extremely useful as an immersion liquid for the microscopic examination of the corundum gems. Consequently, methylene iodide probably always will remain a vital component of the gemmologist's arsenal. As such, it will still be available for density determinations. Fortunately, of all the heavy organic liquids, methylene iodide is probably the least noxious.

On the other hand, for those workers who wish to obviate all heavy organic liquids as well as the highly toxic Clerici Solution, the Hanneman Direct Reading Specific Gravity Balance (Ref. 5) is the most cost-effective approach.

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Spessartine garnet in Brazilian topaz

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Fig. 1. Two of the six topaz crystals examined for this report. The larger of the two measures approximately 24 millimetres in length. Note the orange-coloured inclusion clearly visible in the smaller crystal. *Photograph by Robert Weldon.*

Abstract

Spessartine garnet inclusions were identified in topaz crystals from an area north of Teofilo Otoni in Minas Gerais, Brazil. The inclusions were studied using a combination of optical microscopy and X-ray powder diffraction analysis.

Introduction

The topaz crystals examined for this report were obtained in February 1990 in Tucson, Arizona at the annual gem and mineral show. Natalino Eugenio de Oliveira, a Brazilian mineral dealer from Belo Horizonte had a collection of approximately 40 of these crystals ranging in size from about 1 to 6 centimetres in length. He stated that they had been mined from a small granitic pegmatite near the town of Padre Paraiso in Minas Gerais, Brazil, approximately 100 kilometres north of Teófilo Otoni on highway 116.

One of the authors purchased six of these crystals for examination, two of which are shown in Figure 1. The crystals were sold only as topaz, and while some of them had prominent eye-visible mineral inclusions of a slightly pinkish-brownish orange colour, no mention was made of them by Mr. Oliveira. It was, however, these inclusions that where of interest to the authors.

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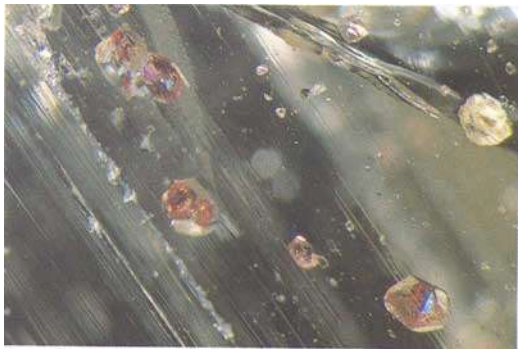

Fig. 2. Several well-defined spessartine garnets lie just beneath a prism face of their host topaz. *Photomicrograph by John I. Koivula*. Magnified 5×.

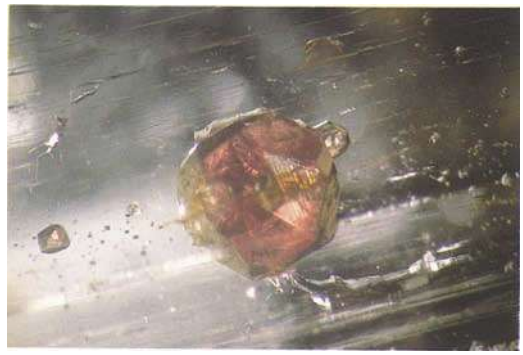

Fig. 3. The largest of the inclusions, a 1.7 millimetre spessartine garnet exhibiting distinct isometric symmetry. *Photomicrograph by John I. Koivula*.

Description

The colour of the topaz crystals was a very pale brownish-yellow, possibly resulting, at least in part, from the presence of brownish-yellow limonitic stains in surface-reaching pits and fractures. A well-developed prismatic form, typical for topaz, was common to all these crystals (Figure 1). The terminations were a combination of pyramid faces and pinacoids, while the bases looked to be cleavage planes modified by very light etching.

The inclusions in all of the topaz crystals were confined to the near-surface area (Figure 2). They showed a slightly pinkish brownish orange colour as previously mentioned, with a transparent to translucent diaphaneity. Initial examination with a gemmological microscopic revealed an outward shape of the inclusions that suggested an isometric structure. While some of the inclusions exhibited distorted forms, others showed obvious dodecahedral symmetry (Figure 3). The reported pegmatitic origin of the topaz hosts together with the generally isometric appearance and colour of the inclusions, suggested that the inclusions might be spessartine garnet.

As all of the inclusions were completely enclosed by the host topaz it was decided that one of the crystals would be broken in order to expose some of the inclusions for analysis by optical microscopy and X-ray diffraction.

A rock and mineral splitter was therefore used to accomplish the task of exposing the inclusions for further study. Once the topaz was broken one of the largest inclusion fragments was removed from its host and placed on a 3×1 inch glass slide for microscopic examination. The inclusions, still attached to the freshly broken topaz surface, were set aside for X-ray powder diffraction analysis.

Optical microscopy

The inclusion fragment on the glass slide was centred on the stage of a Zeiss research microscope and a tiny drop of refractometer contact liquid (RI 1.81) was placed on the fragment. When so immersed the fragment virtually disappeared, showing that the inclusion and the liquid were almost identical in refractive index. Examination of the inclusion with polarized light while immersed in the liquid proved it to be isotropic.

Next, brightfield illumination was employed. The microscope was critically focused on the fragment and the stage lowered, increasing its distance from the objective lens. This caused the bright Becke line to move slightly outward into the liquid, proving that the liquid (1.81) had an index of refraction higher than the inclusion. The results showed that the inclusion's refractive index was within the range previously established for spessartine garnet (Liddicoat, 1989; Anderson, 1990).

X-ray diffraction

Using a glass fibre, a spindle was prepared for X-ray powder diffraction from a minute amount of powder obtained by scraping one of the inclusions exposed at the topaz crystal's surface. The spindle was mounted in a Debye-Scherrer powder camera and exposed for 13 hours to X-rays generated from a copper target tube by a voltage of 46 kilovolts and a current of 26 milliamperes. Once exposed, the film was developed and allowed to air-dry.

Because spessartine was initially suspect, the resulting pattern was first compared to our standard file pattern for this garnet. The result was a perfect match, indicating structure very close to the (pure) spessartine end member.

Conclusion

Optical microscopy and X-ray diffraction were used to identify the euhedral to slightly distorted high-relief inclusions in these topaz crystals as spessartine garnets. The distinct shape and near-surface entrapment of the inclusions are typical of late-stage syngenetic growth.

This is not the first time that spessartine garnet has been identified as an inclusion in topaz (Gübelin and Koivula, 1986). However, this is the first time that the authors have had the opportunity to examine specimens that are so locality-specific.

Topaz and spessartine garnet are both known to occur in complex granitic pegmatites (Roberts, Campbell and Rapp, 1990). They are sometimes found as well-formed, gem-quality crystals in the core-zone of these pegmatites, in 'gem pockets' (Shigley and Kampf, 1984). Within these 'pockets' topaz is the more common of the two minerals. Because of its chemistry, topaz can crystallize late in the development of a 'pocket', as can spessartine for the same reason. The near-surface location of the spessartine inclusions in these topaz crystals indicates that a single cycle of garnet growth occurred near the end of the growth cycle of the topaz (James E. Shigley, *personal communication*).

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Gemmological Abstracts

ARJALAGUER I VILARDELL, D., 1990. Abaco para determinación de los precios aproximados de los diamantes con talla brilliante de River à Top Cape y para las purezas de Internally flawless a Pique en el intervalo de pesos de 0.25 a 3.00 quilates. (Abacus for determining the approximate prices for brilliant-cut diamonds from River to Top Cape and from clarity grades Internally Flawless to Pique with weight intervals from 0.25 to 3.00 ct.) *Gemologia*, **32**, 85/86. 5-11, 1 loose chart.

An abacus [chart] is proposed for the determination of brilliant-cut diamond prices within certain qualities and clarity grades. M.O'D.

BANK, H., HENN, U., 1990. Künstlich gefärbte Quarze als Imitationen für Smaragd, Rubin und Saphir. (Artificially dyed quartzes as imitations for emeralds, rubies and sapphires.) *Zeitschrift der Deutschen Gemmologischen Gesellschaft*, **39**, 2/3, 147-51, 7 figs (6 in colour), bibl.

The raw materials for these imitations are transparent to translucent quartzes, i.e. rock crystal to milky quartz. Both rough crystals and cut stones have been examined by the authors. Cracks are artificially induced, then the dye concentrates in these cracks, colouring them green, red or blue. According to CIBJO regulations these stones must be offered as artificially irreversible (or permanently) dyed agates. E.S.

BANK, H., HENN, U., 1990. Geschliffener, rosafarbener Hodgkinsonit aus Franklin Furnace, New Jersey, USA. (Cut, pink hodgkinsonite from Franklin Furnace, New Jersey, USA.) *Zeitschrift der Deutschen Gemmologischen Gesellschaft*, **39**, 4, 273-4, bibl.

The authors describe the physical data of cut, pink hodgkinsonite from Franklin Furnace in New Jersey. Hodgkinsonite is a silicate of the euclase-hodgkinsonite group $MnZn_2[(OH)_2SiO_4]$ and is monoclinic-prismatic. SG 3.98, RI values n_x = 1.720, n_y = 1.739, n_z = 1.743. DR 0.023. E.S.

BANK, H., HENN, U., PLATEN, H.v., 1990. Geschliffener, durchsichtiger, gelbbrauner Parisit aus Muzo, Kolumbien. (Polished, transparent, yellowish-brown parisite from Muzo, Colombia.) *Zeitschrift der Deutschen Gemmologischen Gesellschaft*, **39**, 4, 229-32, 1 graph, 1 table, bibl.

Parisite is a well-known inclusion material of emerald. It is also found in Muzo in combination with emerald, pyrites, marcasite, dolomite, albite, calcite, quartz and gypsum. The authors examined a faceted specimen which was transparent and yellowish-brown. SG 4.33-4.34, RI 1.671-1.772, DR 0.101, hardness 4-4½. The stone showed a distinct rare earth spectrum Nd^{3+} and Pr^{3+} E.S.

BARTOLI, F., BITTENCOURT ROSA, D., DOIRISSE, M., MEYER, R., PHILIPPY, R., SAMAMA, J.-C., 1990. Role of aluminium in the structure of Brazilian opals. *European Journal of Mineralogy*, 2, 5, 611-19, 6 figs.

Major and trace element analyses by ICP of precious opals from the State of Piaui, NE Brazil, show that the Al_2O_3 content appears to be the major control on the close-packed structure of silica spheres, surface properties and colour. The Al-poor opals (Al_2O_3 0.·6≈1.·3 wt.%) are white-yellow to dark yellow, relatively well ordered and associated with sandstones; their physically adsorbed water is lower (2.·6≈3.·4 wt.%) than in Al-rich opals. In contrast, the Al-rich opals (Al_2O_3 1.·4≈1.·8 wt.%) and hydrated opals (physically adsorbed water 3.·8≈4.·9 wt.%) present blue iridescence due to a less dense packing of silica spheres; they occur in claystones. The IR, XRD and DTA patterns all show that the substitution of Al for Si in the tetrahedral network is a function of the Al_2O_3 content. R.A.H.

BECK, R.J., 1983. A new development in understanding: the prehistoric usage of nephrite in New Zealand. *Bulletin of the Friends of Jade*, 3, 48-53, 5 figs.

After a general note on New Zealand nephrite, an account is given of experiments to duplicate the appearance of prehistoric artefacts by heating. Hardness tests are also described. M.O'D.

BENTE, K., THUM, R., WANNEMACHER, J., 1991. Colored pectolites, so-called 'Larimar' from Sierra de Baoruco, Barahona Province, southern Dominican Republic. *Neues Jahrbuch für Mineralogie, Monatshefte*, 1, 14-22, 2 figs.

Pectolites from the Siera de Baoruco, Dominican Republic, are found in white to greenish and light

bluish to blue colours. They form part of hydrothermal alteration products within a picritic basalt of Cretaceous age. Formation temperature is thought to have been below 240°C. M.O'D.

BIANCHI POTENZA, B., DE MICHELE, V., LIBORIO, G., NANA, G.P., 1989. L'olivina della Val Malenco (Sondrio) come materiale di interesse gemmologico. (Olivine from the Val Malenco (Sondrio) as a material of gemmological interest.) *La Gemmologia*, **14**, 3/4, 23-33, 15 figs (12 in colour).

Green transparent olivine from the Giuel quarry in the Val Malenco, Sondrio, Italy, has SG 3.39, RI 1.661, 1.679, 1.699. Composition is close to 85.7 mol% forsterite, 14.0 mol% fayalite and 0.3 mol% tephroite. Serpentine fibres and colourless diopside crystals are found as inclusions. M.O'D.

BITTENCOURT, ROSA D., 1990. Les opales nobles du District de Pedro II dans l'Etat de Piaui-Région Nord-Est du Brésil. (Precious opal from the Pedro II district in the state of Piaui, north-east Brazil.) *Revue de Gemmologie*, 104, 3-7, 14 figs (3 in colour).

Precious opal is reported from the Pedro II district of Piaui state, north-east Brazil. The opals have a comparatively low water content and should be stable. Quality is said to be good. M.O'D.

BLANKENSHIP, D.T., 1985. The toughness of nephrite. *Bulletin of the Friends of Jade*, 4, 56-60.

The toughness of nephrite is discussed with particular reference to modern lapidary methods. M.O'D.

BLEIKER, R., 1991. Die berühmte chilenische Lapis-Lazuli-Lagerstätte bei Ovalle, Region Coquimbo. (The famous Chilean lapis-lazuli location near Ovalle, Coquimbo region.) *Lapis*, **16**, 1, 18-23, 10 figs (8 in colour).

Lapis-lazuli is found in Chile near Ovalle in the Coquimbo region on the border with Argentina. Geological details of the occurrence are given. M.O'D.

BOSSHART, G., 1990. Les émeraudes de Colombie. (Colombian emeralds.) *Revue de Gemmologie*, 105, 13-16, 1 fig. in colour.

The paper introduces the history of Colombian emerald mining and goes on to describe the geography of the mine sites. Emerald formation and properties are discussed and there are notes on exploitation. M.O'D.

BROWN, G., 1985. Detecting dyed jadeite. *Bulletin of the Friends of Jade*, 4, 28-32, 1 fig.

Standard gemmological tests for jadeite are outlined. M.O'D.

CASSEDANNE, J., 1990. Un nouvel indice de microcline gemme à Minas Gerais. (A new variety of gem microcline from Minas Gerais.) *Revue de Gemmologie*, 104, 13-14, 6 figs (2 in colour).

A hyaline variety of microcline is reported from Fazenda Bel Vista, or Corrego do Luis, Minas Gerais, Brazil. The microcline occurs in a pegmatite and has SG 2.57, H 6.5, and RI 1.518, 1.522 and 1.525 with a DR of 0.007. No absorption spectrum nor luminescence could be detected. Various inclusions are described. M.O'D.

CASSEDANNE, J., 1990. Un nouveau matériau gemme: le quartzite à lazulite (Bahia-Brésil). (A new gem material: lazulite in quartzite from Bahia, Brazil.) *Revue de Gemmologie*, 105, 117-18, 3 figs in colour.

Gem quality translucent to opaque blue lazulite is reported from a quartzite in the north-west of the state of Bahia, Brazil. The locality is between the valleys of the Rio Paramirim in the east and the São Francisco in the west. Cabochons cut from the lazulite have SG 2.76, RI 1.603-1.635 and 1.639-1.674. Stones appear a greyish-maroon through the colour filter. Neither luminescence nor a useful absorption spectrum were observed. M.O'D.

CASSEDANNE, J.P., ALVES, J., 1990. Crystallized rose quartz from Alto da Pitora, Minas Gerais, Brazil. *Mineralogical Record*, **21**, 5, 409-12, 7 figs (6 in colour).

Fine crystallized rose quartz is reported from Lavra [mine] da Pitora, on the northern slope of the Serra da Piorra range, 8km east north east of Galilea, Minas Gerais, Brazil. The quartz occurs in radiating clusters, in groups of parallel to subparallel prisms and as isolated crystals. M.O'D.

CHENG, TE-K'UN, 1985. Chinese jade exhibition, Chengtu 1945. *Bulletin of the Friends of Jade*, 4, 61-6.

An introduction to Chinese jade in general precedes details of a jade exhibition held in Chengtu in 1945. Chinese characters for the basic jade artefact shapes are given. M.O'D.

CHIHARA, K., 1989. (JADEITE IN GUATEMALA.) *Journal of the Gemmological Society of Japan*, **14**, 1/4, 26-35, 10 figs. (In Japanese.)

Geology, petrology, mineralogy and usage of Guatemalan jadeite are discussed. M.O'D.

COENRAADS, R.R., 1990. Key areas for alluvial diamond and sapphire exploration in the New England gem fields, New South Wales, Australia. *Economic Geology*, 85, 1186-207, 19 figs.

At least two distinct periods of volcanic activity

are recorded for the Tertiary Central volcanic province which includes the New England gem fields of New South Wales, Australia. These define key areas for diamond and sapphire exploration. Other gem minerals found with sapphire include zircon, rare chrysoberyl and chrome spinel in the placer deposits and in nearby basaltic soils olivine and enstatite have been found. M.O'D.

CONKLIN, L.H., 1990. The Harvard diamond crystal. *Matrix*, **1**, 6, 90-2, 3 figs (1 in colour).

A yellow diamond crystal weighing 84 ct and of octahedral form was stolen from the Harvard mineral museum in 1962. The history of the crystal is given. M.O'D.

CORONA-ESQUIVEL, R., BENAVIDES-MUÑOZ, M.E., 1989. Excursión de la Sociedad Mexicana de Mineralogía a las minas de ópalo del Estado de Querétaro. (Excursion to the Querétaro opal mines by the Sociedad Mexicana de Mineralogía.) *Boletin de Mineralogia*, **4**, 1, 80-5, 3 figs.

Details of the opal mines in the Mexican state of Querétaro are given with notes on the geology and mineralogy. The most important of the mines are La Carbonera and Santa María Iris, both north of the town of San Juan del Río. M.O'D.

COZAR, J.S., 1989. Determinación de rasgos de tratamiento, en topacios azules irradiados, por espectroscopia gamma de alta resolución. (Determination of signs of treatment in irradiated blue topaz by gamma-ray spectroscopy.)*Boletin del Instituto Gemológico Español*, **31**, 8-18, 14 figs (8 in colour).

Gamma-ray spectroscopy is ruled to be the only method of distinguishing natural from irradiated blue topaz. M.O'D.

COZAR, J.S., SARMIENTO, L., BARBOSA, J.E., 1990. Trifilita gema. (Triphylite as a gemstone.) *Boletin del Instituto Gemológico Español*, 32, 31-6, 14 figs (7 in colour).

Orange-brown triphylite from Minas Gerais, Brazil, has SG 3.51, RI 1.689, 1.693, 1.698 with DR 0.007. M.O'D.

CURRAN, R.T., 1988. A Hamlin Mount Mica tourmaline. *Matrix*, **1**, 5, 77-8, 2 figs.

A crystal from the collection of the Hamlin family has come to light in the author's collection. A cavity at Mount Mica was opened by Augustus C. Hamlin in 1868 although the first tourmaline discoveries in the area date back to the 1820s. The crystal measures 1⅞ inches in length and weighs approximately 60 ct. The colour is fine blue-green. M.O'D.

DE MICHELE, V., 1988. Kamienie szachetne i ozdobne wloch. (Gem materials of Italy.) *Mineralogia Polonica*, **19**, 2, 127-36, 1 fig.

Translation of a paper first appearing in *La Gemmologia*, **7**, 3/4, 17-25, 1981. M.O'D.

DIEHL, R., MENG, K.H., 1990. Ein gravierter Kashmir-saphir. (An engraved Kashmir sapphire.) *Zeitschrift der Deutschen Gemmologischen Gesellschaft*, **39**, 4, 193-200, 7 figs (1 in colour), bibl.

The sapphire weighed 6.175 ct and measured 12.19 x 10.04 x 5.32 mm, antique cut. 32 crown facets and 4 x 16 facets on pavilion. Thin girdle. Silk and microscopic inclusions showed it to be of Kashmir origin. The engraving represents a lion sitting on a crown. The sapphire was found to have been engraved with fine diamond points using non-rotating tools. Due to the complexity of the motif, the documents thus sealed could not be forged. It is assumed that the seal was used by an Indian ruling family, probably Sikh, but origin and age are not known, although this sapphire has been used frequently as an official seal. E.S.

FERREIRA, J.A.M., KARFUNKEL, J., SILVA, L.T., 1990. Turmaline mit ungewöhnlich intensiven Farben von Salgadinho, Paraiba, Brasilien. (Tourmalines with exceptionally intensive colours from Salgadinho, Paraiba, Brazil.) *Zeitschrift der Deutschen Gemmologischen Gesellschaft*, **39**, 2/3, 165-7, bibl.

This new find in Paraiba in the north east of Brazil consists of four small occurrences in Salgadinho. The tourmaline crystals are up to one metre in length, but internally flawed due to tectonic movements. The cuttable stones are therefore relatively small. Colours are particularly intense and occur as emerald green to red, aquamarine-blue to violet. Multi-coloured stones are no exception. Some physical and chemical data are added. E.S.

FLINT, D.J., DUBOWSKI, E.A., OLLIVER, J.G., 1985. Latest report on Cowell jade. *Bulletin of the Friends of Jade*, 4, 82-5.

More than one hundred outcrops of nephrite have been found since 1966 in the Cowell area of the Eyre Peninsula, South Australia. Country rocks are quartzo-feldspathic gneiss and dolomitic marble. M.O'D.

FREY, R., 1983. Jade in Korea. *Bulletin of the Friends of Jade*, 3, 66-69, 4 figs.

Several colours of nephrite are found in Korea, a large deposit of white-to-cream material being particularly valuable. This occurs at the Chuncheon mine situated near the city of the same name, about

70 km north-east of Seoul. M.O'D.

FRIESE, B., 1991. Morphologie und Entstehung der Sternsaphire aus Zaire. (Morphology and origin of star sapphires from Zaire.) *Aufschluss*, 42, 47-52, 11 figs (10 in colour).

Star sapphire with a yellowish-brown background and a dark star is reported from Zaire. M.O'D.

FUERTES MARCUELLO, J., GARCIA GUINEA, J., 1990. Caracterización mineralógica e historica del larimar de Barahona (Republica Dominicana). (Mineral characteristics and history of larimar from Barahona, Dominican Republic.) *Boletin del Instituto Gemológico Español*, 32, 6-12, 11 figs in colour.

The ornamental blue variety of pectolite, larimar, is found at Barahona in the Dominican Republic. Characteristics and mining history are given. M.O'D.

GRICE, J.D., BOXER, G.L., 1990. Diamonds from Kimberley, Western Australia. *Mineralogical Record*, 21, 6, 550-64, 9 figs (3 in colour).

The Argyle AK1 mine is producing the largest number of diamonds in the world at the time of writing. Pink stones are conspicuous in the production and 'cognac', yellow 'champagne', apricot, green and blue stones are also found. M.O'D.

GROAT, L.A., RAUDSEPP, M., HAWTHORNE, F.C., ERCIT, T.S., SHERRIFF, B.L., HARTMAN, J.S., 1990. The amblygonite-montebrasite series: characterization by single-crystal structure refinement, infrared spectroscopy and multinuclear MAS-NMR spectroscopy. *American Mineralogist*, 75, 992-1008, 9 figs.

The F = OH substitution in the amblygonite-montebrasite series is referred to a battery of tests. M.O'D.

GRUBESSI, O., AURISICCHIO, C., CASTIGLIONI, A., 1989. Lo smeraldo delle miniere dei faroni. (Emerald mines of the Pharaohs.) *La Gemmologia*, **14**, 1/22, 7-21, 9 figs (5 in colour).

Emeralds found in a quartz and mica schist with phlogopite, plagioclase and calcite at Djebel Zabarah, Egypt, are thought to be similar to stones used in early Egyption jewellery. They are akin to Habachtal stones in properties and appearance. M.O'D.

GRUNDMANN, G., SCHÄFER, W., HOFER, H., 1991. Smaragde aus der Kesselklamm, eine interessante Neuentdeckung im Untersulzbachtal. (Emerald from the Kesselklamm, an interesting new discovery in the Untersulzbachtal.) *Lapis*, **16**, 2, 37-46, 20 figs (14 in colour).

Emerald has been found on the Kesselklamm in the Austrian Untersulzbachtal. The area is south-east of Neukirchen and the emeralds, some crystals of which reach 7 mm in length, occur in a biotite schist. M.O'D.

HÄNNI, H.A., 1990. Les gemmes du groupe des beryls. (Gemstones of the beryl group.) *Revue de Gemmologie*, 104, 8-12, 8 figs in colour.

Gemstones of the beryl group are described and some notable specimens illustrated. M.O'D.

HÄNNI, H.A., 1990. Ein Beitrag zu den Erkennungsmerkmalen der Kaschmir-Saphire. (A contribution to the determination of Kashmir sapphires.) *Zeitschrift der Deutschen Gemmologischen Gesellschaft*, **39**, 2/3, 107-20, 21 figs (9 in colour), bibl.

More than fifty cut Kashmir sapphires were investigated. The detected inclusions confirmed those previously described in literature. Those specifically examined were tourmaline, pargasite, zircon, plagioclase, uraninite, allanite and probably rutile. Specific healing fissures and growth characteristics and spectral peculiarities are discussed. E.S.

HEMRICH, G.L., 1983. The jade work of India. *Bulletin of the Friends of Jade*, 3, 54-7.

The article discusses the origin of the jade pieces in the collection of the Moguls. Afghanistan is suggested as a place of origin for some of the pieces. M.O'D.

HENN, U., 1990. Cordierit aus Süd-Norwegen. (Cordierite from south Norway.) *Zeitschrift der Deutschen Gemmologischen Gesellschaft*, **39**, 2/3, 99-106, 5 figs (4 in colour), 1 table, bibl.

The cordierite occurrence in south Norway lies a few kilometres away from Kragero, in an aventurine-feldspar-rich pegmatite layer surrounded by Precambrian para-gneiss and amphibolitic zones. RI 1.532-1.534 to 1.537-1.540, DR 0.010-0.012. SG 2.55-2.57. The pleochroic colours are blue, bluish-violet and yellow, caused by iron. The spectrum shows two bands at 936 and 573 nm, caused by iron. There are hematite platelet inclusions causing the aventurism and/or a cat's-eye effect. E.S.

HENN, U., BANK, H., 1990. Über die Farbe der Sodalith-Minerale: Sodalith, Lasurit (Lapis lazuli) und Hauyn. (About the colour of the sodalite minerals: sodalite, lazurite (lapis-lazuli) and hauyne.) *Zeitschrift der Deutschen Gemmologischen Gesellschaft*, **39**, 2/3, 159-63, 1 table, 1 graph, bibl.

The article summarizes the causes of colour in minerals of the sodalite group. Colour centres are

responsible for the colour. The blue colour is caused by SO_3^- or O^- centres, while sulphur complexes like SO_4^- or SO_3^- and S_3^- or S_2^- are responsible for the blue colour in lazurite and hauyne. S_2^- centres are the reason for the orange-red luminescence. E.S.

HENN, U., BANK, H., BANK-SCHERNER, M., 1990. Rubine aus dem Pamir-Gebirge, UdSSR. (Rubies from the Pamir mountains, USSR.) *Zeitschrift der Deutschen Gemmologischen Gesellschaft*, **39**, 4, 201-5, 6 figs (1 in colour), bibl.

The cuttable rubies originate in a marble zone of the Pamir mountains in the USSR near to the Chinese border. The red, reddish, and violet-red stones have an SG 3.98, RI N_e = 1.761-1.762, n_o = 1.769-1.770, DR 0.008. Under the microscope one can see twinning lamellae, healing cracks, fluid inclusions, rutile dust and distinct growth striae. Trace elements were found to be chromium, iron and titanium. The absorption spectra showed typical Cr bands and the fluorescence is strong red. E.S.

HUNSTIGER, C., 1990. Darstellung und Vergleich primärer Rubinvorkommen in metamorphen Muttergesteinen. Petrographie und Phasenpetrologie. Teil III. (Presentation and comparison of primary ruby occurrences in metamorphic rock. Petrography and phase petrography. Part III.) *Zeitschrift der Deutschen Gemmologischen Gesellschaft*, **39**, 2/3, 121-45, 7 figs (4 in colour), 3 tables, extensive bibl.

Part III of this article deals with the formation of rubies in marble, in more detail with the occurrences in Prilep in Macedonia, where the rubies of irregular shape occur in white marble. The corundum found in Passo Campolungo/Passo Cadonighino in Switzerland is found as ruby as well as sapphire. Other ruby-carrying marbles mentioned are those in Stirigma in Greece and those in Hunza, Kashmir. The petrology of rubies in marbles and dolomites is discussed. Further occurrences described are those in Mangari in Kenya, in kyanite, tourmaline and feldspar rock, those found in Ngorongoro in Tanzania, found in anatextite, as well as finds in O'Briens Claim, Zimbabwe, Mashishimala in South Africa, three mines in Madagascar (Vatomandry, Ankaratra and Gogogogo) and finally those in Malawi. In the majority of cases the rubies seem to be a decomposition product. E.S.

KAMMERLING, R.C., KOIVULA, J.I., 1990. An update on assembled emerald specimens from Africa. *South African Gemmologist*, **4**, 3, 9-15, 4 figs in colour.

Supposed emerald crystals from Zambia turned out to be colourless quartz fragments cemented with a green epoxy-like material. M.O'D.

KAMMERLING, R.C., KOIVULA, J.I., 1990. An investigation of a dyed quartzite resembling sugilite. *South African Gemmologist*, **4**, 3, 20-7, 3 figs in colour.

A dyed quartzite was confused with manganoan sugilite from the Wessels Mine near Kuruman, South Africa. The colouring is seen to be concentrated in fractures. M.O'D.

KATO, M., 1989. (Nomograph for calculating facet cutting angles.) *Journal of the Gemmological Society of Japan*, **14**, 1/4, 12-15, 4 figs. (In Japanese.)

Nomographs are presented for the purpose of evaluation of facet cutting angles. M.O'D.

KATO, M., 1989. (Nomographs for diamond incidence-radiation.) *Journal of the Gemmological Society of Japan*, **14**, 1/4, 16-20, 4 figs. (In Japanese.)

Four nomographs are presented to illustrate the elucidation of scintillation in diamond. M.O'D.

KATO, M., 1989. (Nomographs of diamond incidence-radiation on a pavilion.) *Journal of the Gemmological Society of Japan*, **14**, 1/4, 21-5, 4 figs. (In Japanese.)

Nomographs are used to illustrate the passage of light through the pavilion of diamond. M.O'D.

KATO, M., 1988. (The scintillation by the incident rays through the pavilion.) *Journal of the Gemmological Society of Japan*, **13**, 1/4, 13-19, 15 figs. (In Japanese.)

The paper discusses how to counteract loss of some of the incident rays through the pavilion of gemstones. M.O'D.

KATO, M., 1988. (Incidence-radiation relations between the incident rays through the pavilion.) *Journal of the Gemmological Society of Japan*, **13**, 1/4, 22-4, 5 figs. (In Japanese.)

Five examples of gemstone cutting are discussed with particular reference to the behaviour of rays passing to and through the pavilion. M.O'D.

KEVERNE, R., 1983. A worldwide view of the jade market. *Bulletin of the Friends of Jade*, 3, 14-21.

Sale-room prices for notable jade artefacts are given: the year represented an improvement on previous market performance. M.O'D.

KINNUNEN, K.A., MALISA, E.J., 1990. Gem-quality chrysoprase from Haneti-Itiso area, central Tanzania. *Bulletin of the Geological Survey of Finland*, **62**, 2, 157-66.

Gem-quality, apple-green, Ni-bearing chalcedonic silica occurs as veins in silicified serpentine in

the Haneti-Itiso area. AAS gave high Ni 0.55 wt.% and low Co and Cr (120 and 1ppm, respectively); NAA revealed near chondritic REE contents. XRD showed that the chrysoprase consists mainly of α-quartz and some opal-CT. The chrysoprase has RI 1.548-1.553, mean SG 2.56. Microscopically the Tanzanian chrysoprase consists of spherules which are highly disordered, concentric, and composed of bipyramidal quartz, chalcedony, quartzine and opal-A. They can be classified into four main types according to the arrangement of concentric shells. The diameter of the spherules ranged from 40 to 77 μm. Fluid inclusion types in the bipyramidal quartz are single phase, low-T type. The spherules, silica types and REE contents suggest that this chrysoprase was deposited by evaporation of surface waters connected with the silicification of the serpentinites. R.A.H.

KIDWELL, A.L., 1990. Famous mineral localities: Murfreesboro, Arkansas. *Mineralogical Record*, **21**, 6, 545-55, 14 figs (3 in colour).

The area is the largest and best-known diamond producer in the United States and forms part of the Prairie Creek intrusive, about 3.5 km south-east of Murfreesboro, Pike County, south-west Arkansas. Diamond crystals are recovered from several different places in the area where they occur randomly. Their origin is at present unknown. M.O'D.

KOIVULA, J.I., FRYER, C.W., 1990. Forsterite in Arizona pyrope. *Zeitschrift der Deutschen Gemmologischen Gesellschaft*, **39**, 4, 207-9, 5 figs in colour, bibl.

Some Arizona pyropes were examined by X-rays and under the microscope. Forsterite was identified as the inclusion. Pyrope is also a common inclusions in peridot (which is olivine of forsteritic composition). E.S.

KOIVULA, J.I., KAMMERLING, R.C., FRYER, C.W., 1990. Gormanite in quartz. *Zeitschrift der Deutschen Gemmologischen Gesellschaft*, **39**, 2/3, 153-7, 3 figs in colour, bibl.

Crystal inclusions of a dark bluish-green stalk-like birefringent mineral in a rough grouping of quartz crystals are described and identified, at least in part, as gormanite (an iron aluminium phosphate) by means of X-ray diffraction and optical microscopy. The host quartz was collected from the Yukon territory in north-west Canada. E.S.

KOMATSU, H., 1989. (Origin and a counterplan of 'Uroko' (scaly spot) on the surface of pearls.) *Journal of the Gemmological Society of Japan*, **14**, 1/4, 3-11, 19 figs. (In Japanese.)

Scaly spot is a local deterioration of the nacreous layer on the surface of pearls. Incidence can be lowered by keeping specimens in low or constant humidity conditions. M.O'D.

LARSSON, T., 1990. Värmebehandlade bla safirer. (Heated blue sapphire.) *Gem Bulletin*, 2, 4-7.

Details of the heat treatment of blue sapphire are given with a short list of references. M.O'D.

LEAMING, S., 1983. On the origin of jade. *Bulletin of the Friends of Jade*, 3, 30-4.

The crystal structure and chemical composition of the jade minerals are discussed. M.O'D.

LEUNG, I.S., 1990. Silicon carbide cluster entrapped in a diamond from Fuian, China. *American Mineralogist*, 75, 1110-19, 7 figs.

A diamond crystal from Fuian, China, was found to contain four bluish-green *6H* silicon carbide crystals overgrown by grains of the *3C* polytype. The multicrystalline cluster is surrounded by a thin layer of K-Al-Si-rich glass in which an iron-rich spherule is embedded. It appears that cubic SiC is a distinct though unnamed mineral species. M.O'D.

LHOEST, J.J., GAUTHIER, G.J., KING, V.T., 1991. The Mashamba West mine, Shaba, Zaire. *Mineralogical Record*, **22**, 1, 13-20, 19 figs (13 in colour).

Among the minerals found at this copper mine are cobaltian calcite and transparent cuprite. Both are of gem quality. M.O'D.

LINTON, T., 1990. Lighting techniques for microscopic observation. *Wahroongai News*, **24**, 6, 24-7, 6 line drawings.

A useful paper on illumination and use of a polarizing microscope. R.K.M.

LOWE, E.J., 1983. The jade dilemma of the 1980s. *Bulletin of the Friends of Jade*, 3, 22-9.

The general charactistics of jadeite and nephrite are discussed with notes on the main sources and a short bibliography. M.O'D.

MCCOLL, D., PETERSON, O.V., 1990. Titanite crystals from the Harts Range, Central Australia. *Mineralogical Record*, **21**, 6, 571-4, 7 figs (5 in colour).

Gem quality crystals of sphene [titanite] are reported from a feldspathic vein in the Harts Range of Central Australia, 200km north-east of Alice Springs. M.O'D.

MACKENZIE, R.W.K., 1990. An additional use for the Eikhorst [sic] Thermolyzer. *South African Gemmologist*, **4**, 3, 28-31.

The Eickhorst Thermolyzer is used to distinguish diamond from its simulants. It can also be used to say what these simulants are. A thermal conductivity table of gem materials is appended. M.O'D.

MEYER, A.B., 1985. The nephrite question 1888. *Bulletin of the Friends of Jade*, **4**, 20-7.

Theories on the origin of jade artefacts found in America are advanced. It is believed that the pieces originated in Asia but the article challenges this theory on the grounds of as yet unlocated deposits in Mexico and near the Amazon River. M.O'D.

M.G.C., 1985. Jade auction in Burma, 1979. *Bulletin of the Friends of Jade*, 4, 67-80.

The paper consists largely of a reproduction of a catalogue of gems, jade and pearl issued by the Myanmar [Burma] Gems Corporation in 1979. M.O'D.

MIYATA, T., 1988. (An introduction to gem mines of Pakistan.) *Journal of the Gemmological Society of Japan*, **13**, 1/4, 31-42, 20 figs. (In Japanese.)

The gem production of Pakistan is discussed with a map of general deposits and a smaller scale map of the Hunza ruby mines. M.O'D.

NAITO, Y., 1988. (Gem-grade chromian diopside found in the upper stream of Sano River, Yamanashi Prefecture.) *Journal of the Gemmological Society of Japan*, **13**, 1/4, 25-30, 9 figs. (In Japanese.)

Large single crystals of emerald-green chrome diopside are reported from the upper stream of the Sano River in the Kamisano area of Yamanashi Prefecture, central Japan. Crystals up to 2 cm in length have been found. M.O'D.

NICHOL, B., 1983. Nephrite jade deposits near Cowell. *Bulletin of the Friends of Jade*, 3, 77-88, 5 figs.

Nephrite is found associated with an isoclinally folded dolomitic marble and calc-silicate rock horizon in the upper 'Gneiss' complex of the Cleve Metamorphics (Lower Proterozoic) near Cowell, Eyre Peninsula, South Australia. Colours are greenish-yellow and green and vary from pale tones to black with increasing iron content. Fine-grained black nephrite is the most valuable. M.O'D.

PLASZYNSKA, M., 1988. Measurement of transmission of Chelsea filter. *Mineralogia Polonica*, **19**, 1, 113-15, 1 fig.

The transmission curve for the Chelsea filter is examined using a spectrophotometer. The distinctive transmission characteristic equals zero at 333-361.4nm and 607.7-684.5nm and increases distinctly for $\lambda > 684.5$nm reaching the value $\gamma \cong 70\%$ in the region of λ which responds in the deep red. There is a minor maximum at $\lambda_0 \cong 578.7$nm. M.O'D.

PLASZYNSKA, M., 1988. Niektore wspolczesne metody badan kamieni szlachetnych. (New methods in gem testing.) *Mineralogia Polonica*, **19**, 1, 131-6, 2 figs.

The paper describes the Ceres Diamond Probe and the Gem Diamond Pen. A useful short biblography is appended. M.O'D.

PONAHLO, J., 1990. Kathodolumineszenz-und Absorptionsspektren gelber Saphire. (Cathodoluminescence and absorption spectra of yellow sapphires.) *Zeitschrift der Deutschen Gemmologischen Gesellschaft*, **39**, 4, 225-8, 2 figs, bibl.

A microspectrophotometric method is proposed based on cathodoluminescence spectra to differentiate between yellow, yellow-brownish and orange sapphires coloured by Cr and Fe from similar sapphires with different colouring agents. E.S.

QUELLMALZ, W., 1991. Die edlen Steine Sachsens. (Gemstones of Saxony.) *Lapis*, **16**, 1, 24-35, 8 figs in colour.

Gem and ornamental minerals from Saxony, Germany, are briefly described with notes on the whereabouts of notable specimens. M.O'D.

QUELLMALZ, W., 1990. A brief look at the Saxon Erzgebirge. *Mineralogical Record*, **21**, 6, 565-70, 10 figs (6 in colour).

Among the minerals found in the Erzgebirge (ore mountains) area of Saxony, Germany, are yellow topaz from Schneckenstein, violet crystals from Greifenstein, honey-yellow baryte crystals from Poehla near Schwarzenberg and several occurrences of native silver. Gem quality quartz crystals are found at Ehrenfriesdorf (rock crystal); amethyst is found at Wiesenbad near Annaberg and smoky quartz at Zinnwald. M.O'D.

RAMSEYER, K., MULLIS, J., 1990. Factors influencing short-lived blue cathodoluminescence of alpha-quartz. *American Mineralogist*, 75, 791-800, 19 figs (16 in colour).

Crystals of alpha quartz from the Swiss Alps and from Grand Canary showed a short-lived blue, bluish-green or yellow luminescence with some areas remaining inert. A longer-lived violet and a brown luminescence of increasing intensity are less often seen in alpha quartz. The phenomenon is ascribed to the uptake of charge balancing single charged cations associated with the substitution of

Al for silica. H can also cause short-lived cathodoluminescence. M.O'D.

REDMANN, M., 1990. Changierender Fluorit aus dem Schwarzwald. (Colour-changing fluorite from the Black Forest.) *Zeitschrift der Deutschen Gemmologischen Gesellschaft*, **39**, 2/3, 169-72, 1 graph, bibl.

The colour-changing fluorite was found in the Clara Mine near Wolfach in the Black Forest. The Clara Mine yields mainly barytes and fluorites but also many rare minerals. The fluorites are usually colourless or blue, violet, green, yellow or pink. The colour-changing stone was deep blue in daylight and violet in artificial light. RI 1.434, SG 3.18. The absorption spectrum contains bands with maxima at 580, 400, 335 and 225nm, caused by a F_m^{3+} colour centre. Absorption minimum in the visible range is located at 480nm. E.S.

ROBERT, D., 1990. Mesure de couleur au microscope. (Colour measurement with the microscope.) *Revue de Gemmologie*, 105, 19-20, 4 figs in colour.

A means of assessing colour values using the microscope is outlined. M.O'D.

ROBINSON, G.W., 1990. Famous mineral localities: De Kalb, New York. *Mineralogical Record*, **21**, 6, 535-41, 13 figs (6 in colour).

Some of the green transparent diopside crystals from De Kalb, New York, are of gem quality. They are found in Precambrian metasedimentary rocks of the Grenville series and are retrieved from a north-trending ridge of interbedded quartzite and calcite rock. Their matrix ranges from a quartz-tremolite schist to a nearly pure white massive diopside. Crystal habits vary from simple to fairly complex, the green colour being pale on the whole. M.O'D.

ROBINSON, G.W., KING, V.T., 1990. What's new in minerals? *Mineralogical Record*, **21**, 5, 481-92, 10 figs (9 in colour).

Among the minerals described are pale morganite from Pala, California; very fine bi-coloured elbaite from the Himalaya Mine at Mesa Grande, California, and morganite crystals on albite from the White Queen Mine in the same state. Gem quality fire opal is reported from Sabine Parish, near Toledo Bend Reservoir, Louisiana. Fine morganite is reported from the Bennett Mine, Buckfield, Maine. Lettuce-green gem quality spodumene is reported from Resplendor, Minas Gerais, Brazil. In the same state are very high quality rose quartz crystals at the Pitora Mine near Galilea and fine colour zoned elbaite crystals from Barra de Salinas. Fine quality zoned elbaite is also reported from the Jos region of Nigeria. From the area of Pereval, Lake Baikal, USSR, come pale pink octahedra of spinel in white marble. M.O'D.

ROSENZWEIG, A., 1983. On the 'rind' of nephrite jade. *Bulletin of the Friends of Jade*, 3, 70-1.

The brownish coating of many nephrite pebbles has been attributed to weathering but the author suggests that in some cases at least the effect may be a consequence of inherent colour zoning. M.O'D.

ROSENZWEIG, D., 1983. Flowers in Chinese jade carving. Part 1. *Bulletin of the Friends of Jade*, 3, 37-44, 4 figs.

Flowers are a common Chinese jade decoration and are found particularly on Qing (1644-1911) pieces. Flowers are commonly grouped into sets (e.g. the four noble plants, plum, chrysanthemum, bamboo and orchid). M.O'D.

SCHÄFER, W., 1990. Belmont und Sta. Terezinha. Reise zu den brasilianischen Smaragdminen. (Belmont and Sta Terezinha. Journey to the Brazilian emerald mines.) *Lapis*, **15**, 11, 13-26, 29 figs (23 in colour).

The paper describes a visit to the Belmont and Santa Terezinha emerald mines in the state of Goias, Brazil. Crystals are found in various matrices, including quartz and biotite on the one hand and yellowish feldspar or dolomite on the other. Details of marketing are given. A table lists the constants for the Itabira [Belmont] and Santa Terezinha emeralds. M.O'D.

SCHLUESSEL, R., 1990. Les saphirs de Bo Ploi (Kanchanaburi-Thailande). (The sapphires of Bo Ploi, Kanchanaburi, Thailand.) *Revue de Gemmologie*, 105, 6-10, 20 figs (6 in colour).

Geology and gemmology of blue sapphires found at Bo Ploi, Thailand, are described together with notes on handling, cutting and marketing. The sapphires are a dark to medium blue, have refractive indices 1.761-1.769, DR 0.008 and SG 4.0. Plagioclase crystals, acicular rutile and some multi-phase inclusions showing interference colours are among the inclusions reported. M.O'D.

SCHWARZ, D., 1990. Die chemischen Eigenschaften der Smaragde. I. Brasilien. (The chemical properties of emeralds. Part I. Brazil.) *Zeitschrift der Deutschen Gemmologischen Gesellschaft*, **39**, 4, 233-72, 1 map, 14 graphs, 15 tables, extensive bibl.

The author comprehensively researched the chemical properties of emeralds from different localities world-wide. This first part deals with Brazilian emeralds. About 200 samples were examined by

microprobe. The amount of variation and mean concentration of the elements chromium, iron, magnesium and sodium are tabulated. The results are also correlated in graph form. E.S.

SCHWARZ, D., 1990. Turmalin als Einschluss in Beryll. (Tourmaline as an inclusion in beryl.) *Zeitschrift der Deutschen Gemmologischen Gesellschaft*, **39**, 4, 191-2, 1 fig. in colour (on front cover of issue).

The author describes the crystals of brown tourmaline found as inclusions in a colourless beryl from the Governador Valadares district, Minas Gerais, in Brazil. Tourmaline is a common inclusion material in beryl from many localities (Zambia, Urals, Habachtal, Madagascar, Socoto and Carnaiba). Beryl as an inclusion in tourmaline is rare. The author explains this be a definite crystallization sequence, the boron-rich phase coming before the beryllium enrichment. E.S.

SCOVILL, J.A., WAGNER, L., 1991. The Fat Jack mine, Yavapai County, Arizona. *Mineralogical Record*, **22**, 1, 21-8, 19 figs (9 in colour).

Fine crystals of amethyst and smoky quartz are found at the Fat Jack mine, Yavapai County, Arizona. The mine is located in a large schist inclusion in the Crazy Basin quartz monzonite. Some of the quartz takes the sceptre form. M.O'D.

SENA SOBRINHO, M. DE, 1985. Notas sobre aluvioës diamantiferas do Estado de Minas Gerais, Brazil. (Notes on diamond-bearing placers in the state of Minas Gerais, Brazil.) *Iheringia. Série Geologia*, 10, 3-18, 14 figs.

A study of the diamond-bearing placers of the main producing areas of Minas Gerais, Brazil, showed that at least three geological ages for alluvial fertile deposits have been defined. M.O'D.

SOBCZAK, T., SOBCZAK, N., 1990. Die klassischen polnischen Chrysopras-Vorkommen von Szklary in Niederschlesien. (The classic Polish chrysoprase location of Szklary in Lower Silesia.) *Lapis*, **15**, 10, 29-31, 3 figs (2 in colour).

The Polish chrysoprase deposit at Szklary in Lower Silesia is described. The chemical and physical details of chrysoprase are given. M.O'D.

SOBOLEV, N.V., SHATSKY, V.S., 1990. Diamond inclusions in garnets from metamorphic rocks: a new environment for diamond formation. *Nature*, 343, 742-6, 2 figs.

Cubo-octahedral diamonds averaging 12 μm in size are found in zircon and garnet from high-pressure metamorphic garnet-pyroxene and pyroxene-carbonate-garnet rocks, biotite gneisses and schists from the Kokchetav massif, northern Kazakhstan, USSR. Kyanite, mica, rutile, sphene, clinopyroxene and zircon occur as inclusions in garnet; the inclusions are often intergrown with diamond. It is thought that the material of the host protected the diamonds from retrogressive transformation to graphite. M.O'D.

SOLANS, J., DOMENECH, M.V., 1990. Estructura cristalina, composición quimica y propriedades fisicas de las gemas II. La dureza. (Crystal structure, chemical composition and physical properties of gemstones. II. Hardness.) *Gemologia*, **32**, 85/86. 13-20, 1 fig.

The use of hardness in gem testing is discussed. M.O'D.

SOSSO, F., SOI, V., PILATI, T., DIELLA, V., LOBORIO, G., GRAMACCIOLI, C.M., 1989. Alessandrite sintetica: nuovi dati cristallografici ed analitici. (Synthetic alexandrite: new crystallographic and analytical data.) *La Gemmologia*, **14**, 3/4, 7-21, 9 figs (5 in colour).

Synthetic alexandrite from the USSR is examined and found to be Cr-rich and Fe-poor. Negative crystals in parallel arrangement and with crystalline phases within are characteristic of the product. M.O'D.

SOUZA, R.A., WILSON, W.E., GANGEWERE, R.J., WHITE, J.S., KING, J.E., 1990. The Hillman Hall of Minerals and Gems, the Carnegie Museum of Natural History, Pittsburgh. *Mineralogical Record*, **21**, 5, 32pp [outwith the main pagination of the issue], 54 figs in colour.

Fine crystals of peridot, grossular garnet, topaz, tourmaline and quartz, are among the exhibits featured in the recently re-opened display. M.O'D.

WADE, K., FUJINUKI, T., 1988. (Factors controlling amounts of minor elements in pearls.) *Journal of the Gemmological Society of Japan*, **13**, 1/4, 3-12, 5 figs. (In Japanese.)

A chemical analysis compared the amounts of minor elements in pearls with those in molluscan shells. In general seawater pearls have larger amounts of alkaline earth elements, alkali metal elements and anion elements, while freshwater pearls are rich in manganese. M.O'D.

WEERTH, A., 1991. Neue Mineralfunde aus den berühmten pakistanischen Edelsteinpegmatiten. (New mineral discoveries from the famous Pakistan gem pegmatites.) *Lapis*, **16**, 1, 36-7, 3 figs in colour.

Tabular crystals of a pinkish apatite, prismatic morganite and schorl crystals with colourless topaz

on albite are reported from the gem pegmatites of Stak-Nala, Shigar-Dassu and Shingus respectively. All these locations are in the northern areas of Pakistan. M.O'D.

WIGHT, W., 1988. Kamieni szlachetne i ozdobne Kanady. (Gems and ornamental stones of Canada.) *Mineralogia Polonica*, **19**, 1, 119-29, 1 fig.

Translation of a paper first appearing in *Journal of the Gemmological Society of Japan*, 8, 27-39, 1983, and the *Journal of Gemmology*, **18**, 6, 544-62, 1983. M.O'D.

WILKE, H.-J., 1990. Die mineralogische Sammlung des Natural History Museum in London. (The mineral collection of the Natural History Museum in London.) *Lapis*, **15**, 10, 13-24, 16 figs (12 in colour).

The history and present arrangement of the mineral collections of the Natural History Museum in London are described. Some outstanding mineral specimens are illustrated. M.O'D.

WILSON, W.E., 1991. What's new in minerals? *Mineralogical Record*, **22**, 1, 53-5, 8 figs in colour.

Fine crystals of red beryl from the Violet claims in the Wah Wah mountains of Utah feature in this short article together with stalactitic groups of rhodochrosite from the La Capillita mine, Catamarca, Argentina, and beryl from Dusso, Pakistan. M.O'D.

WOLLAERT, E., VOCHTEN, R., VAN LANDUYT, J., 1990. Characterisation of gem opal and inferior opal qualities by means of electronmicroscopy. *Zeitschrift der Deutschen Gemmologischen Gesellschaft*, **39**, 4, 211-23,, 11 figs, 1 graph, bibl.

The structural differences between gem opal and potch are investigated by means of the electron microscope. Potch does not show any play of colour because it lacks the necessary complete uniformity of a perfect stacking of perfect spheres of identical size and absence of void filling with silica. In gem opal the colour grains of the surface are the result of different orientation of the microscopic planes that constitute the surface. E.S.

ZHILIANG, N., 1983. Preface to collected illustrated works on ancient jade. *Bulletin of the Friends of Jade*, 3, 58-62.

Seventeen Chinese language books on jade are briefly summarized with brief notes on bibliography and text. M.O'D.

1990. Fluorit. (Fluorite.) [Single topic issue of] *Emser Hefte*, **11**, 3, illus. in black-and-white and in colour.

World fluorite occurrences are described, the main emphasis being placed on German-speaking countries. Extensive lists of references are provided. M.O'D.

Gemmologie Aktuell, 2/90. [No individual authors.]

The issue includes descriptions of: violet scapolite from Afghanistan; tourmaline and kunzite cat's-eyes from Brazil and a zoned tourmaline coloured purple and rose-colour from Paraiba, Brazil; colourless, light yellow and light green montebrasite from Brazil; alexandrite from Orissa, India, and an Indian ruby cat's-eye; yellow, yellowish-brown and brown parisite from Colombia; adularescent orthoclase from Austria; star chrysoberyl from Sri Lanka; rose-coloured spinel from the USSR and ruby from the Pamirs where the USSR borders China; facetable hodgkinsonite from Franklin, NJ, USA; ruby and sapphire from North Vietnam. A synthetic ruby made from polycrystalline material is also reported. M.O'D.

1991. FM-IGMS-MSA symposium on azurite and other copper carbonates. *Mineralogical Record*, **22**, 1, 64-9, 9 figs (8 in colour).

The papers abstracted are: Ribbe and Eriksson on azurite and malachite, chemically and structurally related minerals: North on azurite and malachite from the Morenci and Metcalf mines, Greenlee County, Arizona: Wenrich on azurite and other copper carbonates in northern Arizona solution-collapse breccia pipes. M.O'D.

1990. Guinean diamond production: a model to be emulated? *Mazal U'Bracha*, 34, 43-50, 10 figs (8 in colour).

The article describes the progress made recently in exploiting the diamond mines of Guinea. M.O'D.

1985. 'Khotan' jade, past and present. *Bulletin of the Friends of Jade*, 4, 40-50, 1 fig.

Some accounts of Khotan and its jade deposits are extracted from the literature. M.O'D.

Book reviews

ANNELS, A.E., BURNHAM, B.C. (EDS), 1986. *The Dolaucothi gold mines*. 2nd edition. Division of Mining and Minerals Engineering, School of Engineering, University of Wales College of Cardiff, Cardiff. pp.62. Illus. in black-and-white. Price on application.

Gold has been mined in this area of South Wales at least as far back as Roman times and this study outlines the work done on reconstructing the mining history of the area. Mineralogy and geology are discussed and the archaeology of the site is related to other sites in the vicinity. It is hoped that some of the mine may be established as a working mine museum. M.O'D.

ANTHONY, J.W., BIDEAUX, R.A., BLADH, K.W., NICHOLS, M.C., 1990. *Handbook of mineralogy*, Vol. 1. Mineral Data Publishing, Tucson, USA. pp. vii, 588. US$82.50 plus $5.00 shipping.

It is now 40 years since the last volume of *Dana's system of mineralogy* was published and, apart from Michael Fleischer's *Glossary of mineral species* there has been no up-to-date monographic treatment of minerals since then. The present book devotes one page to all the known and accredited elements, sulphides and sulphosalts up to 1988 in most cases. Further volumes will follow in due course; the second will cover silica and the silicates, the third halides, hydroxides and oxides, the fourth arsenates, phosphates, uranates and vanadates and the fifth borates, carbonates and sulphates. Smaller groupings will accompany larger related ones in the appropriate volume and organics will be covered by volume 5.

Each entry gives crystal data, physical properties, optical properties, cell data, chemistry, occurrence, association, name, location of type material, where known and the best references. Where known and appropriate X-ray powder patterns, polymorphism and series are also given: major locations are given in all cases though of necessity these have to be selective.

The book is very well produced and when we realize that there were over 3,000 distinct species known at the time of writing we can see that the book is long overdue. M.O'D.

BEVINS, R.E., SHARPE, T., 1982. *Welsh minerals*. National Museum of Wales, Geological Series no. 4, Cardiff. pp.9 [19]. Illus. in colour. £1.80.

This small book in landscape format illustrates thirty Welsh minerals, some with possible ornamental application. Part of the economic and informative publishing programme of the NMW, this is a well-produced book, giving chemical composition, mode of occurrence, hardness, specific gravity, size of speciment depicted and location for the thirty selected minerals. M.O'D.

CRAM, L., 1988. *Journey with colour*. Lightning Ridge, NSW. Reproduced from typewriting. Unpaged.

This unusual production consists of typewritten sheets containing papers, or the whole text, from the Lightning Ridge Flash newspaper of the famous Australian opal field. A great deal of interesting information is included. M.O'D.

DABDOUB, T., 1985. *Opal report from Honduras 'The fire still burns'*. Tropical Gem Explorations, Metairie, LA. pp. iii, 61. Illus. in black-and-white and in colour. Price on application.

A useful guide to the opal fields and mining industry of Honduras. At Erandique, the chief opal locality, the stones are found in seams or veins penetrating basalt/trachyte rock. Various backgrounds are found with play of colour and stones from this area are not subject to crazing. Other

mining areas are also described and the author includes some entertaining and informative anecdotes. M.O'D.

DIETRICH, R.V., SKINNER, B.J., 1990. *Gems, granites and gravels: knowing and using rocks and minerals*. Cambridge University Press, Cambridge. pp. viii, 173. Illus. in black-and-white and in colour. £15.00.

The book attempts to answer the question 'Why study minerals?' and concentrates upon explanations of the nature and use of mineralogy, petrology and soil science. The book begins with an overview of the mineral world and then describes the crystalline state and mineral chemistry. Later chapters cover rocks, soils, dusts and muds, ores and ore minerals, building materials and concludes with a discussion of rocks and minerals in diverse environments. Three appendices give a description of chemical symbols and the periodic table, identification of the common-rock forming minerals and the identification of rocks. Coloured pictures of good quality form a centre section. The book is presumably aimed at a wide readership and is a good attempt to bring a complicated science to the attention of those who may one day take it up.

M.O'D.

DUNHAM, K.C., 1990. *Geology of the northern Pennine orefield. Vol. 1. Tyne to Stainmore*. 2nd edition. HMSO, London. pp. x, 299. Illus. in black-and-white and in colour. £32.00.

The northern Pennine orefield is one of the world's major producers of fluorite in both commercial and specimen qualities. This new edition replaces one which had become a quarry for collectors and covers that part of the orefield which contains the most productive fluorite deposits. All mines, both working and abandoned, are described in considerable detail with plans of the most important veins. Each chapter has its own list of references and a final chapter comments on future prospects for the area. Baryte and witherite, both long sought by collectors, are also prominent in this area. The books forms an economic memoir covering the areas of 1:50,000 and one inch geological sheets 19 and 25, with parts of sheets 13, 24, 26, 31 and 32 (England and Wales). Having spent many hours at many of the working and abandoned sites above and below ground, I can strongly recommend this book which I saw in proof some years ago and greatly welcome now.

The book begins with a history of mining in the area followed by a survey of the country rock of the Lower Paleozoic foundation and sedimentary stratigraphy. Next comes a survey of the igneous intrusions followed by an overview of the general structure. The remainder of the main text, over 200 pages, is devoted to the general and detailed description of the mineral deposits which are divided into the nine areas of the Escarpment, Alston Moor, West Allendale, East Allendale, Weardale, Teesdale, Haydon Bridge and the Durham Coalfield. The book is well printed and the mass of detail is easy to work through; maps are clearly lettered. M.O'D.

GILLARD, G., 1983. *Gemfields*. Boolarong Publications, Ascot, Queensland. pp. 60. Illus. in black-and-white. Price on application.

This attractive book contains sketches of mining life at the gem centres of Anakie, Rubyvale, Sapphire and other centres in central Queensland.

M.O'D.

GRICE, J.D., 1989. *Famous mineral localities of Canada*. National Museum of Natural Sciences, Ottawa. pp. 190. Illus. in colour. £16.95.

The author presents some of Canada's most interesting mineral localities chosen because he particularly likes them. This idiosyncratic approach makes for a readable book with quite good coloured pictures (though not quite up to the best standards of today). Among the localities producing minerals of ornamental interest are the Jeffrey mine, Asbestos, Quebec, celebrated for grossular garnet; Thunder Bay, Ontario, an amethyst location; Nain, Labrador (labradorite); Baffin Island (lapis-lazuli); the Cassiar Mountains, British Columbia (nephrite). Other sections describe the naming of minerals, mineral identification and mineral formation, but this varied information is made part of the general treatment of particular localities. There are useful lists of minerals by locality (those described in the text) and a good bibliography. This is a good book to give to someone beginning to study minerals, whether they plan to visit Canada or not. The style is personal and friendly and the price gives very good value for today. M.O'D.

HAILL, R.G., 1982. *Opals of the Never Never*. Castle Books, Cammeray. pp. viii, 152. Illus. in black-and-white and in colour. Price on application.

Paperback reissue of the book first published in 1981*. M.O'D.

HAMMOND, C., 1990. *Introduction to crystallography*. Oxford University Press and the Royal Microscopical Society, Oxford. pp. viii, 101. Illus. in black-and-white. £19.95.

This short book forms Vol. 19 of the Royal Microscopical Society's *Microscopy Handbooks* and provides a question-and-answer format with useful

*Reviewed *Journal of Gemmology*, **XVIII**, 5, 444. – Ed.

notes on computer programs to assist learning what is described as a very simple subject. Black-and-white photographs illustrate various types of packing but as always the paucity of well-formed natural crystals prevents photographic illustration in depth (cost may also play some part in this). A useful appendix gives biographical details of celebrated crystallographers and the names and addresses of crystal-making kits are given. Otherwise the treatment of the subject follows established lines.

M.O'D.

HOLBECHE, S., 1989. *The power of gems and crystals: how they can transform your life*. Piatkus, London. (Reprinted 1990.) pp. 185. Illus. in black-and-white and in colour. Price on application.

Whatever your opinion on the power of inanimate objects to alter human health and behaviour, this is an attractively produced book whose contents will help many to get through life if no other source of inspiration or comfort is available. Some at least of the gemmological material is accurate, but this is not the first purpose of the book. M.O'D.

MASCETTI, D., TRIOSSI, A., 1990. *Earrings from antiquity to the present*. Thames and Hudson, London pp. 224. Illus. in black-and-white and in colour. £30.00.

Two members of the staff of Sotheby's have collaborated in the production of a recognizable Thames & Hudson book; large, well printed and with carefully chosen illustrations of high standard of reproduction and captioning.

Worn throughout recorded history by men and women, earrings are perhaps the most popular item of jewellery and are found in all civilizations with access to any form of ornamental material. This makes the field of study so wide that a single book could not cover it adequately and for this reason male and ethnic earrings have been omitted. The authors also make the point that at the time of writing earrings have seen the greatest developments in materials and design, especially in the past few years when the number of materials used has never been greater. The book begins by surveying the historical background from antiquity to the seventeenth century. At the end of this period earrings had become complicated and the eighteenth century saw a more subdued elegance with the use of the girandole consisting of a surmount with detachable drops, the style first coming into use in the middle of the preceding century. This design followed changes in fashion and hair styles and gave jewellery makers the chance to use a variety of stones in fairly large sizes. The nineteenth century saw a renewal of experiment, with complicated designs, classical imitations and considerable use of enamel. One or two pages from the catalogues of designers are reproduced and it is plain that earrings were now intended to be used by a much wider social group.

By the present century experiment with earrings could be seen in many countries and above all this has been the century in which earrings gave designers the opportunity to display their products. Many designers have been one-person workshops and innumerable attractive pieces are seen in daily use. This chapter outlines developments before the First World War and then decade by decade.

With the close of the historical survey the book goes on to give biographical notes on the major designers and a glossary and index. There is a short but useful bibliography; here space prevents citation of periodical articles. This is a most enjoyable book and successfully bridges the sometimes imaginery gap between a work relying only on its illustrations and a purely scholarly undertaking.

M.O'D.

MUMME, I.A., 1988. *The world of sapphires*. Mumme Publications, Port Hacking, NSW, Australia. pp. xvii, 189. Illus. in black-and-white and in colour. Price on application.

Early October 1990 was a time of corundum for this reviewer since both this book and the Richard Hughes book, *Corundum*, arrived in the same week. There is no need to compare the two – both are first-class, but the work under discussion deals only with the various types of sapphire and omits ruby. By far the largest section is devoted to the sapphire regions of the world though the book opens with a discussion of the types of sapphire and ends with the more usual details of properties and testing, synthetics and fashioning. The chapter on the world deposits gives a particularly rich amount of detail on Australian occurrences and this alone makes the book well worth buying. Many of the deposits are depicted on maps and there are some, though not many, bibliographical references.

This is an attractive book, written in a style which demands many very short paragraphs, and it is clearly aimed at students. There are a number of misprints which should have been caught but they in no way detract from the quality of the book. I should have liked to see a much larger bibliography and better quality colour pictures – some of those in the book are amateurish and do not show the detail of their subject. For several reasons the picture showing mounted sapphires would have been better omitted. M.O'D.

NEWBURY, C., 1989. *The diamond ring: business, politics and precious stones in South Africa*.

Clarendon Press, Oxford. pp. xvi, 431. Illus. in black-and-white. £42.50.

The book studies the history and production of diamonds with their marketing from the time of the Kimberley diamond rushes and the rise of De Beers to the formation of the Central Selling Organization. In the preparation of the book many sources hitherto unpublished have been drawn upon; these include mining company archives as well as public ones. The sources, as well as a most useful bibliography, can be found at the end of the book. A considerable amount of labour history and of the effects of diamond sales on the overall economy of South Africa forms the main theme which opens with a study of ownership and governance, 1867-1889. The development from loose miners' oligarchies led to company consolidation and thence from monopoly to cartel over the years 1890-1919 with the beginning of the De Beers operations. This second part of the book takes up the years to the end of the First World War and the formation of Consolidated Diamond Mines. The third and last part of the book deals with the cartel contracts, alluvial mining, the Diamond Corporation, cutting and industrial outlets and a survey of the strategy of diamond marketing and the formation and control of the diamond stockpile. This is a most interesting survey of a complicated topic and should be required reading for anyone working on the politics and economics of mining; it also helps to straighten out some of the intricate details of the development of the De Beers organization and of the near-monopoly that it holds. M.O'D.

O'Donoghue, M., 1990. *Kvartz*. (Quartz.) Mir, Moscow. pp. 135. Illus. in black-and-white and in colour. 85 kopecks. (In Russian.)

Russian edition of the author's *Quartz*, first published in 1987. (Author's note) M.O'D.

Palmer, A., 1990. *Poona WA and the seekers of its emeralds*. Lap Industries, North Lake, WA. pp x, 97. Illus. in black-and-white. Price on application.

This is an excellent account of the finding and exploitation of the emerald deposits in the Poona area of Western Australia. The book begins with the mining and social history of the area and goes on to describe the finding of emerald. The deposits began to be worked commercially in the 1920s but work declined in the late 1930s, to be revived later. For some years exploitation and recovery appeared to have failed to reach the levels expected but in the 1970s a number of efforts to revive production were made. At the time of writing a further period of inactivity seems to have succeeded one of small production.

The area also produces gold and there are many references to gold recovery as well as to that of emerald. Useful details of the geology are given and there are text maps which help to place the area. Even more useful are the citations to newspaper articles and to obscure journals which would otherwise be impossible to trace. M.O'D.

Robertson, R.S., Scott, D.C., 1990. *Geology of Coober Pedy precious stones field*. Geological Survey of South Australia, Adelaide. (Geological Survey of South Australia. Report of investigations.) pp.55. Illus. in black-and-white and in colour. Price on application.

The report summarizes work on the Coober Pedy opal fields during 1981-1986 giving details of each worked claim. Excellent colour photographs show the various kinds of rock in which opal has been found to occur and there is a general summary of the area geology to open the book. A geological map of the area comes in a pocket at the end of the report. M.O'D.

Schubnel, H.-J., 1990. *Cristeaux precieux*. (Precious crystals.) Muséum National d'Histoire Naturelle, Galerie de Minéralogie, Paris. pp. 40. Illus. in black-and-white and in colour. Price on application.

This is a beautiful catalogue, with short accounts of various aspects of the mineral collections of the Natural History Museum in Paris. Among the gem quality specimens illustrated are Brazilian beryl crystals and emerald crystals from Colombia. M.O'D.

Schubnel, H.-J., 1987. *Larousse des minéraux*. (Minerals of Larousse.) 2nd edition. Librairie Larousse, Paris. pp. 365. Illus. in colour. Price on application.

This well-produced book describes a very large number of minerals in alphabetical order. Each description includes chemical composition and crystal system, note on nomenclature and the main constants. Very brief locality notes are given and preliminary material covers the usual introduction to chemistry, crystallography and the history of mineralogy. The standard of illustrations is quite high but does not reach present-day levels of achievement. The lack of a bibliography is a serious fault and the small print may make reading difficult for some. Notes on French nomenclature variation provide a certain charm as does the use of rhombohedral as a name for the trigonal crystal system. M.O'D.

SNOWMAN, A.K. (ED.), 1990. *The master jewelers.* Thames and Hudson, London. pp. 262. Illus. in colour. £28.00.

Fifteen major jewellers of the period from 1850 to the present are discussed with illustrations of some of their finest pieces. The jewellers are Castellani and Giuliano (taken as one), Fontenay, Hancock, Falize, Boucheron, Fabergé, Tillander, Lalique, Vever, Fouquet, Tiffany, Cartier, Van Cleef and Arpels, Verdura and Bulgari. There is a section of useful notes and a bibliography at the end of the main text. The standard of colour reproduction is very high and the book provides an attractive introduction to the period for the jewellery historian and student of the decorative arts. M.O'D.

WEIBEL, M., GRAESER, S., OBERHOLZER, W.F., STALDER, H.-A., GABRIEL, W., 1990. *Die Mineralien der Schweiz. Fünfte Auflage.* (Minerals of Switzerland. Fifth edition.) Birkhauser Verlag, Basel. pp. 222. Illus. in black-and-white and in colour. DM48.00.

The first edition, by Weibel alone, was published by John Wiley in 1966 and was planned to form the first of a series covering all the European countries. Standards of production have improved since then and the projected series never materialized but this book is a pleasure to read and use, with high-quality illustrations, diagrams and maps. Some Swiss minerals are gemmologically interesting if not significant and in any case greater awareness of Alpine-type mineral associations is always valuable. Among minerals with ornamental or specimen importance are fluorite, quartz and sphene. M.O'D.

WYKOFF, G.L., 1982. *Beyond the glitter.* Adamas Publishers, Washington DC. pp. iv, 206. Illus. in black-and-white. $17.95.

The book attempts to give jewellers and their customers some idea of the principles behind gemstone and jewellery purchasing, valuation and care. While very many small details are inaccurate and much of the writing rather breathless, the book succeeds fairly well in its task and does include much material which would be hard to find without a good deal of searching. M.O'D.

Proceedings of The Gemmological Association and Gem Testing Laboratory of Great Britain and Notices

OBITUARIES

Mr Edward H. Tindall, FGA (D.1950), Poole in Wharfedale, died in January 1991.

NEWS OF FELLOWS

Michael O'Donoghue gave lectures on gemstones to Ightham Historical Society on 16 January 1991 and to the West Kent Radio Society on 18 January 1991.

Alan Hodgkinson, Alan Jobbins and **Kenneth Scarratt** gave lectures at the Tucson (Arizona) Gem and Mineral Fair in February 1991. Their subjects were respectively 'A taste of Scottish gemmology', 'The Cheapside Hoard' and 'The diamond connection'.

MEMBERS' MEETINGS

London

On 26 March 1991 at the Flett Theatre, Geological Museum, Exhibition Road, London SW7, films were made available by De Beers, covering many aspects of the diamond industry.

Midlands Branch

On 18 January 1991 at the Society of Friends, Dr Johnson House, Colmore Circus, Birmingham, **Dr J.C. Wright** gave a talk entitled 'Macro to micro'.

On 15 February 1991 at the Society of Friends, **Mr Nick Sturman** gave a talk entitled 'Pearls and pearl identification'.

On 15 March 1991 at the Society of Friends, **Dr Roger Harding** spoke about the work of the Geological Museum and also that of The Gemmological Association and Gem Testing Laboratory of Great Britain.

North West Branch

On 16 January 1991 at Church House, Hanover Street, Liverpool 1, **Mr Kenneth Snowman** gave a talk entitled 'Little boxes'.

On 20 February 1991 at Church House, **Mr John Pyke** gave a talk entitled 'A gem collection'.

MEETING OF THE COUNCIL OF MANAGEMENT

At a meeting of the Council of Management held on 13 March 1991 at 1 Burlington Gardens, London W1X 2HP, the business transacted included the election to membership of the following:

Fellowship

Chen, Xiugin, Hubei Province, China. 1990
Cook, Peter B., Bewdley. 1958
Fu, Lintang, Hubei Province, China. 1990
Li, Yali, Hubei Province, China. 1990
Liao, Xiangjun, Hubei Province, China. 1990
Nazareth, Christopher T., Bombay, India. 1990
Porebska-Brozyna, Dorota, E. Rutherford, NJ, USA. 1990
Puerto Albero, Magdalena, Baneres, Spain. 1990
Qi, Lijian, Hubei Province, China. 1990
Temelcoff, Catherine F., Toronto, Ont., Canada. 1990
Wang, Manjun, Hubei Province, China. 1990
Wezel, Annemarie, Den Haag, The Netherlands. 1986
Wu, Haiou, Hubei Province, China. 1990
Yan, Weixuan, Hubei Province, China. 1990
Zeeman, Walentin, Bunnik, The Netherlands. 1990
Zhang, Liangju, Hubei Province, China. 1990

Ordinary Membership

Araki, Kazuo, Hyogo Pref, Japan.
Asano, Isamu, Osaka, Japan.
Banks, Mary, Exeter.
Blackett, Barbara, Windsor.
Bowles, Michael, Pretoria, S. Africa.
Bradford, Christine L., Hassocks.
Brooks, Anna T., Watford.
Brown, Parvis S., London.
Callaghan, Stephen, Horsham.
Carmona, Charles, Los Angeles, Calif., USA.
Cassidy, Lucinda, Bristol.
Charlot, Donald R., Ruislip.
Day, Brynley J., Oldham.
De Kock, Jhr H.M., Gouda, The Netherlands.

F.G.A.

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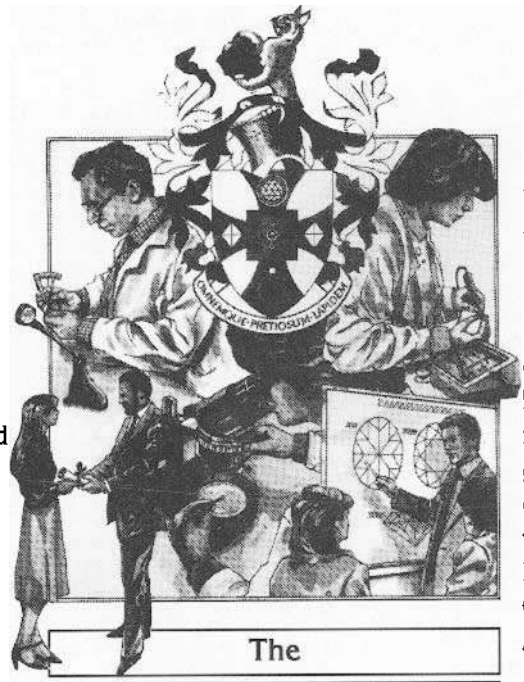

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Fleitman, Beth, Milton, Mass., USA.
Fruttauro, Patrícia A., Kew.
Fukushima, Hideaki, Tokyo, Japan.
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Kawabe, Makoto, Kyoto, Japan.
Kawaguchi, Michie, Osaka, Japan.
Kohara, Sanae, Osaka, Japan.
Kvasnik, Brian, Minnesota, USA.
Larkins, Barry, London.
Mansfield, Julia R., London.
Maung, Thein L.O., Singapore.
Minami, Kazumasa, Osaka, Japan.
Moon, You S., Osaka, Japan.
Mori, Junko, Hyogo Pref., Japan.
Morikawa, Shuji, Osaka, Japan.
Nishi, Tetsuomi, Hyogo Pref., Japan.
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Oyama, Keiko, Fukuoka-ken, Japan.
Papi, Stefano, Rome, Italy.
Preece, Susanne L., Trowbridge.
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Romano, Rossella, Ilford.
Sandum, Mark A., Margate.
Sato, Hiroshi, Tokyo, Japan.
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Sugihara, Hideko, Osaka, Japan.
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Tanami, Kazuhiro, Kanagawa Pref., Japan.
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Taniuchi, Toshiko, Osaka, Japan.
Toft, Peter C., Copenhagen, Denmark.
Trathen, John E., Stoney Creek, Ont., Canada.
Tsai, Shwu-jen, Hsinchu, Taiwan, ROC.
Tsai, Yeou Y., Hsinchu, Taiwan, ROC.
Tsurita, Kazuo, Osaka, Japan.
Vaughan, Michael, Ellesmere Port.
Wikstrom, Michael D., Iowa, USA.
Yamamoto, Atsuko, Hyogo Pref., Japan.
Yamamoto, Keiko, Shiga Pref., Japan.
Yamamoto, Midori, Fukuoka-shi, Japan.
Yamanaka, Kazuko, Osaka-fu, Japan.
Yonehara, Machiko, Hyogo Pref., Japan.
Yoshikawa, Youichi, Hyogo Pref., Japan.
Yumoto, Atuko, Osaka-fu, Japan.
Zhang, Youxu, Hubei Province, China.

CULTURED BLACK PEARL AUCTION

The Cook Islands, a close neighbour of Tahiti and one of the smallest island nations in the world, will be holding its second Cultured Black Pearl Auction from 8 to 12 June 1991.

The Cook Islands have a large natural resource of *Pinctada margaritifera* from which the black pearl is produced. The black pearl industry was introduced in 1986 by a Tahitian company and has expanded rapidly. The pearls are grown in the atoll of Manihiki, a small atoll with a population of 600 people, located 400 miles away from its closest neighbour.

Approximately 30 farmers will be selling their pearls with a minimum of 30,000 pearls being offered. The size range is expected to be mostly above 10mm, and of a high quality. The growth of each pearl takes, on average, a period of two years, and requires individual attention by each farmer.

For more information contact Cook Islands Pearl Farmers Association, PO Box 160, Rarotonga, Cook Islands, South Pacific. Telephone: 682 21743, Fax 682 21543.

Verbal testing at Laboratory

Would Fellows and Associate Members please note that as from 1 April 1991 the charge for a verbal test on articles sent to the Laboratory by post will be £11.00 per stone (including VAT) plus £4.00 postage and packing. The articles should be accompanied by a cheque for the total amount made payable to the GA & GTL of GB. The goods will be returned by Registered Post with a receipt for the amount paid.

Letter to the Editor

From R. Keith Mitchell, FGA

Dear Sir,

DI-IODOMETHANE AND ALL THAT

In my review of E.A. Jobbins' excellently revised 10th edition of B.W. Anderson's valuable text book *Gem Testing* (*The Journal of Gemmology*, 22, 4) I commented that certain name changes, particularly those of our old friends methylene iodide and mono-bromo-naphthalene 'might make organic chemists happy, but tend to leave established gemmologists puzzled', and I went on to wonder why the second of these names should exchange the 'mono-' prefix for the figure 1, while methylene iodide becomes di-iodomethane and not 2-iodomethane.

These comments were made in a somewhat 'tongue-in-cheek' frame of mind and might be attributed to a dour outlook engendered by a surfeit of years. We 'Golden Oldies' tend to dislike change for the sake of change!

However, I am not an organic chemist and I did speak out of turn on something of which I knew very little, a fact which my good friend and former student, A.D. Morgan, FIBF, FGA, of Northfield, Birmingham, who understands the subject far better, made plain in a kindly personal letter at the end of last year.

Another letter on the same lines was received by our Editor in February, from Dr Martin F. Ansell, of Blackheath, London.

Doug Morgan points out that the old name 'methylene iodide' was a poor one since 'iodide' implies that it is a salt of iodic acid, which it is not! The heavy and highly refractive liquid (the heaviest known at normal temperatures apart from the metal mercury) is based on methane, CH_4 (marsh gas!), in which two of the hydrogen atoms are replaced by two iodine atoms to give CH_2I_2 which is now more logically and correctly named di-iodomethane. The two molecules can be formulated diagramatically as in Figure 1.

The name 1-bromonaphthalene is again more accurate and logical than monobromonaphthalene. I have always thought that the prefix 'mono-' and the figure 1 were synonymous, e.g. mono-rail, mono-syllable, meaning one rail or one syllable. But in the far greater complexities of organic chemistry they are used to convey different meanings.

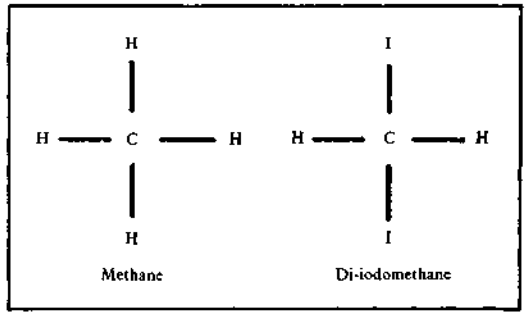

Fig. 1.

So 'di-' in di-iodomethane indicates that there are two atoms of iodine, but the 1 in 1-bromonaphthalene indicates that a bromine atom replaces a hydrogen in the two linked six-sided rings that comprise the naphthalene ($C_{10}H_8$) molecule at position 1. The hydrogen positions are numbered 1 to 8 in a clockwise direction, as shown in Figure 2. Mr Morgan mentions that a compound with two bromine atoms would have them at positions 1 and 3 in the double ring and would be called 1-3-dibromonaphthalene.

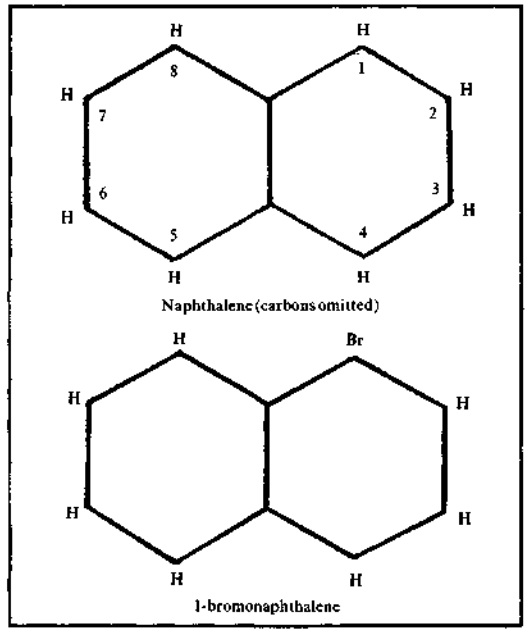

Fig. 2.

Dr Ansell points out that my contention that the name could be written '2-iodomethane' is nonsense, since it implies the presence of two carbon atoms in the methane molecule when there is only one. The di-iodomethane name makes clear that there are indeed two univalent iodine atoms which together with the two hydrogen atoms satisfy the tetravalence of the one atom of carbon.

I am indebted to both these gentlemen and I promise not to use 1-chrome when I mean monochrome.

It will be noted that organic formulae need to be diagramatic in order to be explicit, and the actual naming describes the positions and the numbers of replacing atoms, at least in the simpler compounds. All this reflects the immense complexity of organic chemistry in comparison with inorganic chemistry, which is largely our concern in gemmology. The former is the chemistry not only of simple hydrocarbons, but of life itself. While agreeing with Dr Ansell that a knowledge of this greater science is helpful, I thank Heaven that I am merely a Gemmologist, and perhaps too old to learn new tricks!

Yours etc.,
R. Keith Mitchell

20 March 1991
Orpington, Kent.

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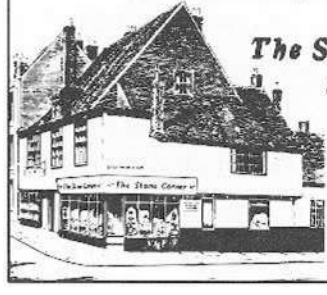

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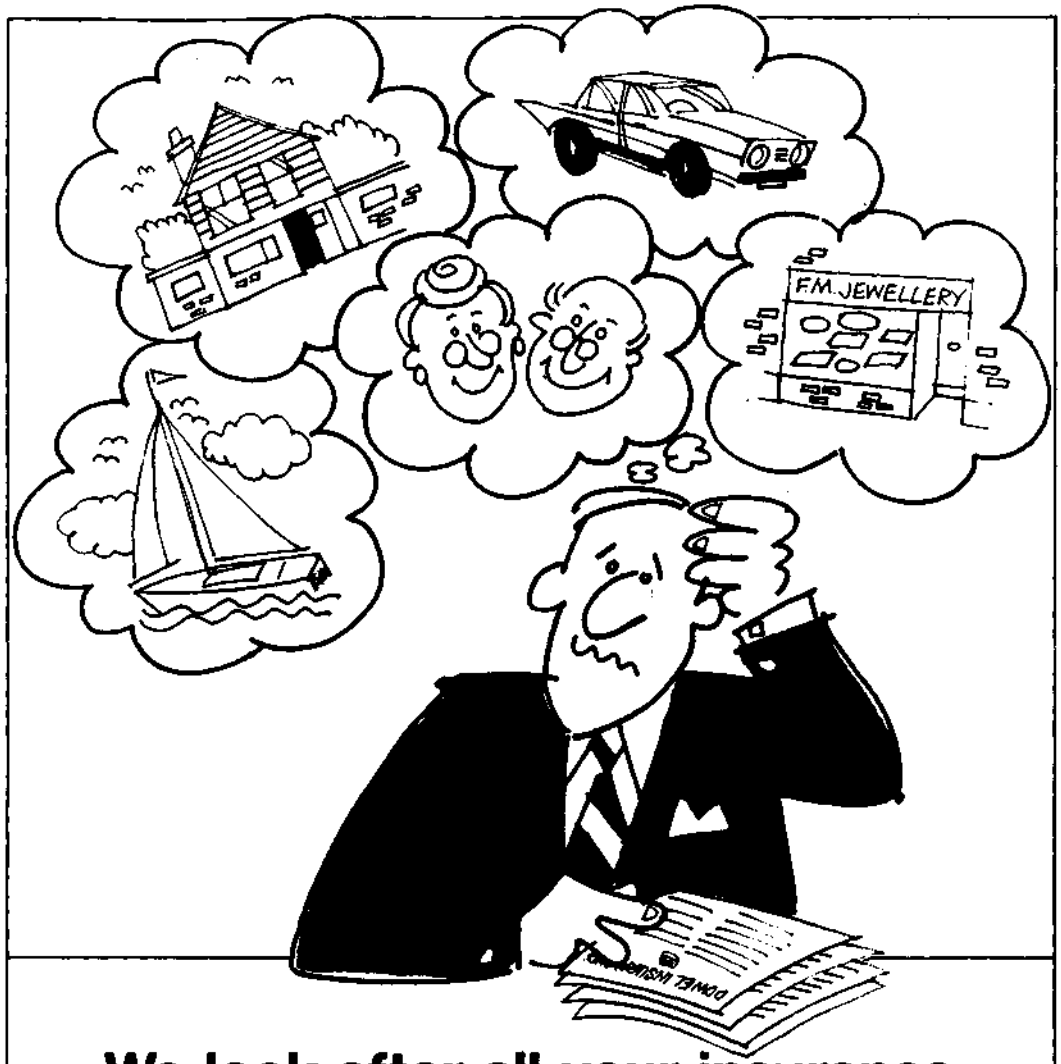

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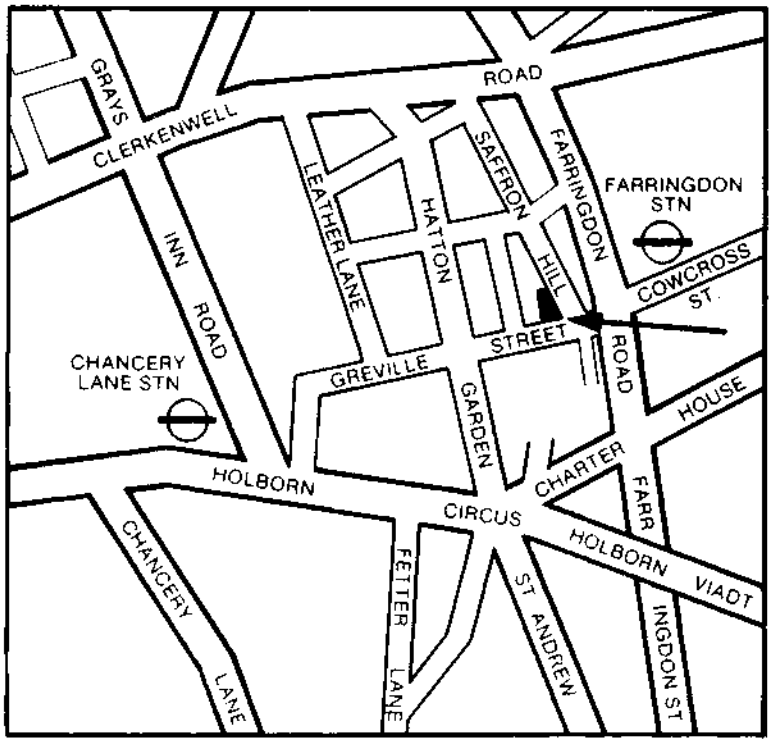

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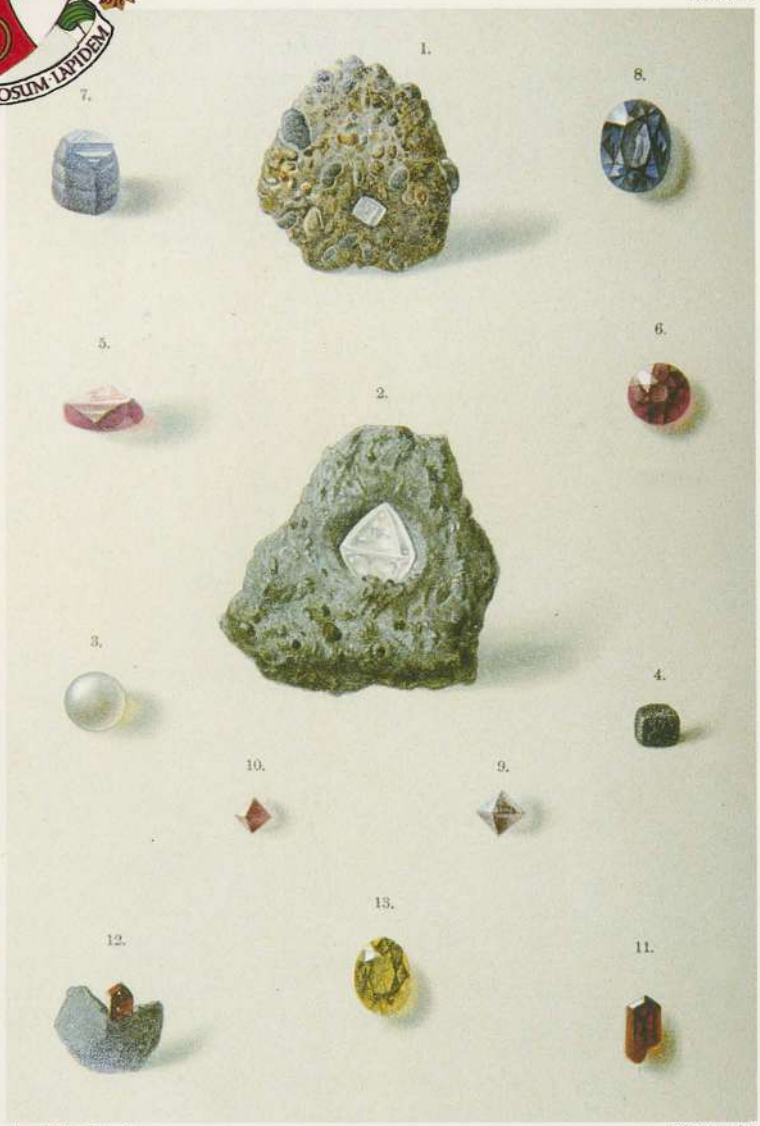

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Cover Picture

Plate I from Bauer's *Edelsteinkunde* published in German in1896 (translated into English by L.J. Spencer in 1904 as *Precious Stones*). The specimens are diamond (1-4), ruby (5-6).sapphire (7-8). spinel (9-10) and zircon (11-13). (See Two types of historical traps: on 'Diamond Softening' and the'Antiquity of Emerald Oiling' by Kurt Nassau p.399-403.)

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Two strongly pleochroic chatoyant gems

Robert C. Kammerling and John I. Koivula

Gemological Institute of America, Santa Monica, California 90404, USA

Abstract

This article describes the gemmological features of two rare, strongly pleochroic cat's-eye gems: iolite and tanzanite.

Introduction

Gemstones exhibit a number of visual characteristics which are used by the trained gemmologist to identify them. These include such features as the gem's colour, colour distribution, diaphaneity, brilliance and lustre; virtually every gem can be described in terms of these factors which, in turn, relate to their optical properties.

In addition, a limited number of gems display additional unusual optical effects, which gemmologists refer to as optical 'phenomena'. One broad category of these includes a number of effects caused by the interference of light, such as opal's play-of-colour, fire agate's iridescence, pearl's orient, and labradorite feldspar's 'labradorescence' (or 'schiller') (Webster, 1983).

Another general class of optical phenomena results from reflections of light from internal structures or inclusions within the host gem. These include the glittery aventurescence or spangled effect seen in such natural gems as aventurine quartz, sunstone feldspar and 'bloodshot' iolite, as well as in the man-made 'goldstone' glass; the asterism or 'star effect' exhibited by some rubies, sapphires, garnets, rose quartzes and other gems; and the chatoyancy or 'cat's-eye effect' exhibited by several gems (Webster, 1983; Gübelin and Koivula, 1986).

This last phenomenon, chatoyancy, is most often caused by reflections of light from fine, parallel, elongated inclusions contained within the gem. These may be either solid, acicular crystals of such minerals as rutile or goethite, as for example in some cat's-eye chrysoberyl or diopside, or they may be hollow growth tubes as is the case of some cat's-eye tourmaline and beryl. Less commonly, chatoyancy results from a fine, parallel acicular structure of the gem itself, cat's-eye actinolite being a prime example. In such gems, the effect will only be seen when the stone is cut en cabochon and oriented so that the planes of the acicular inclusions/structure are parallel to the base of the stone (Liddicoat, 1989).

Chatoyancy is seen with varying frequency in a number of gem species. In addition to those mentioned above are apatite, enstatite, kornerupine, scapolite, sillimanite and zircon (Liddicoat, 1989). Recently the authors have had the opportunity to examine a number of unusual chatoyant gems. Two of these in particular, cat's-eye iolites and a cat's-eye tanzanite, are exceptional for both their great rarity and the fact that they are highly pleochroic gems.

Cat's-eye iolites

The gem material iolite, known to mineralogists as cordierite, is usually fashioned into gems which exhibit a blue to violet face-up body colour and no optical phenomena. Some material from Sri Lanka and India, however, contains small metallic magnetite, hematite and/or lepidocrocite platelets which produce a silvery (magnetite) or reddish (hematite/lepidocrocite), glittery effect; as mentioned above, material with reddish aventurescence has been called 'blood-shot' iolite.

On two separate occasions recently the authors had the opportunity to examine iolite cabochons which exhibited distinct chatoyancy. The first stone, a 23.65 carat gem, was shown to us at the 1990 Tucson Gem and Mineral Show. The gem had a fairly light blue body colour, an overall 'cloudy' appearance, and exhibited a sharp chatoyant band (Koivula and Kammerling, 1990). This was the first such phenomenal iolite that either author had seen, although apparently similar gems have been reported infrequently in the gemmological literature (see, for example, Brown *et al.*, 1982; Fryer *et al.*, 1982).

The second stone, an attractive oval double cabochon weighing 8.25 carats and measuring 14.84

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Fig. 1. When examined face-up, this 8.25 ct cat's-eye iolite shows a light bluish-grey body colour on either side of the sharp chatoyant band. *Photo by Robert Weldon, Gemological Institute of America.*

Fig. 2. When examined from the side, the cat's-eye iolite shown in Figure 1 appears a dark violet colour due to strong pleochroism. *Photo by Robert Weldon, Gemological Institute of America.*

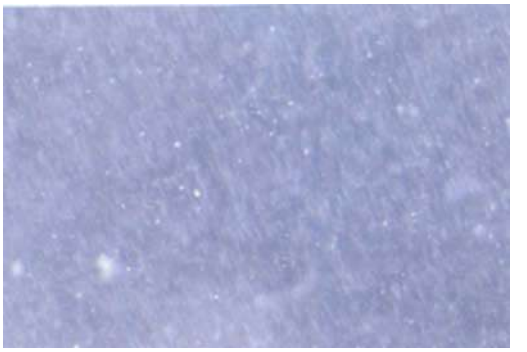

Fig. 3. Magnification reveals the cause of the chatoyancy in the cat's-eye iolite to be minute, whitish-appearing parallel fibres. *Photomicrograph by John I. Koivula, Gemological Institute of America.* Magnified 30x.

× 11.78 × 7.58 mm, reportedly originated in South India. The stone appears semi-transparent when viewed from above but would be almost transparent were it not for the fact that the base had been roughly ground. In surface-reflected incident light it exhibits an exceptionally strong chatoyant band; this is even quite evident under diffused overhead fluorescent lighting. When examined face-up it shows a light bluish-grey body colour on either side of the chatoyant band (Figure 1) while the periphery of the base shows a medium dark violet colour due to the stone's strong pleochroism (Figure 2).

Gemmological properties determined for the second stone were as follows:

Refractive Index: 1.53, determined by the distant vision ('spot') method on the apex of the cabochon with a Duplex II refractometer and white light source.

Optic Character: Biaxial, determined by resolution of an optical interference figure between crossed polaroids. During the polariscope examination the investigators noted that the chatoyant band appeared to bisect the 2V angle.

Pleochroism: Very strong, in dark violet, light bluish-grey, and light brownish-yellow, as observed with a calcite dichroscope.

Chelsea Filter reaction: Inert (appeared green).

LWUV fluorescence: Inert; no phosphorescence.

SWUV fluorescence: Inert; no phosphorescence.

Absorption spectrum: No distinct features observed.

Specific gravity: 2.60, estimated using the sink-float method with heavy liquids.

Magnification: Microscopic investigation revealed the cause of the chatoyancy to be minute, whitish-appearing parallel fibres (Figure 3). Also noted were small, low-relief, colourless crystals of undetermined identity.

Cat's-eye tanzanite

Another chatoyant gem mentioned in the literature but very rarely seen is cat's-eye tanzanite. It thus came as a pleasant surprise when we were shown the stone pictured in Figure 4. This semi-transparent, high-domed oval cabochon with a slightly convex base weighs 2.69 carats and measures 8.21 × 6.81 × 5.51 mm. When examined from above it exhibits an attractive medium dark greyish violet-blue body colour and a sharp chatoyant band.

Gemmological properties determined for the chatoyant tanzanite were as follows:

Refractive Index: 1.69, determined by the distant vision ('spot') method on the apex of the cabochon with white light source.

Optic Character: Biaxial, determined by resolution of an optical interference figure between crossed polaroids.

Pleochroism: Very strong, in blue, purple and greyish green, as observed with a calcite dichroscope. It was interesting to note that, as with the cat's-eye iolite described above, a deeper colour was noted when the stone was viewed down the sides in both the long (Figure 5) and narrow directions.

Chelsea Filter reaction: Inert (appeared green) in most directions with a slight orangy overtone when viewed down the length of the cabochon.

LWUV fluorescence: Inert; no phosphorescence.

SWUV fluorescence: Inert; no phosphorescence.

Absorption spectrum: No distinct features observed.

Specific gravity: 3.38, estimated using the sink-float method with heavy liquids.

Magnification: Microscopic investigation revealed the cause of the chatoyancy to be numerous parallel whitish channels running perpendicular to the 'eye' (Figure 6). Spike-shaped 2-phase inclusions were also noted. When looking down the length of the channels a light transmission effect similar to that shown by the mineral ulexite (so-called 'television stone') was also noted.

Discussion and conclusion

As is the case with cat's-eye alexandrite and some other strongly pleochroic chatoyant gems, orienting the iolite and tanzanite described herein so as to centre the chatoyant band across the dome of the cabochon resulted in less than the best face-up colour.

It is also possible that light reflections off the chatoyancy-producing inclusions in these two gems 'whitened out' the true body colour and contributed to less than ideal colour appearance when viewed from above. This would be similar to the case of some silky Australian sapphires, in which masses of fine acicular inclusions reflect and scatter the two polarized rays as they pass through the stone, resulting in the blue and blue-green dichroic col-

Fig. 4. This 2.69 ct tanzanite also exhibits distinct chatoyancy. *Photo by Robert Weldon, Gemological Institute of America.*

Fig. 5. As with the cat's-eye iolite, due to its strong pleochroism the chatoyant tanzanite pictured here displayed a deeper colour when viewed down the sides. Note also the ends of the chatoyancy-causing parallel channels. *Photomicrograph by John I. Koivula, Gemological Institute of America.* Magnified 25x.

Fig. 6. Magnification shows the cause of the chatoyancy in the tanzanite to be numerous light reflecting parallel whitish channels running perpendicular to the 'eye'. *Photomicrograph by John I., Koivula, Gemological Institute of America.* Magnified 30x.

ours merging into one undesirable greenish blue hue. The effect in such sapphires may be so complete that the stone appears the same in any direction of observation (Coldham, 1985).

Acknowledgements

The authors would like to thank Mr Kim D. Barr of Inter-Gems in Sherman, Texas, for bringing the 23.65 ct cat's-eye iolite to our attention; Mr Yianni Melas, an instructor at the Gemological Institute of America in Santa Monica, California, who first brought to our attention the 8.25 ct chatoyant iolite and Mr Manu Nichani of Temple Trading Company in Encinitas, California, who subsequently loaned the stone for gemmological examination; and Peter and Bobbi Flusser of Overland Gems in Los Angeles, California, for the loan of the cat's-eye tanzanite.

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Two types of historical traps: on 'Diamond Softening' and the 'Antiquity of Emerald Oiling'

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Introduction

The interpretation of ancient texts is always a hazardous undertaking. It is easy to fall into two types of traps: scoffing at apparently ridiculous statements at one extreme; accepting apparently reasonable statements at face value without careful analysis at the other extreme.

An example of the first type of trap, on which I was able to shed some light, is the 'softening of diamond' with warm goat's blood as mentioned in the 'Natural History' of Pliny (Gaius Plinius Secundus, Roman historian, 23 AD to 79 AD). A trap of the second type into which I myself fell previously, is involved with Pliny's description of emerald oiling, the apparent antiquity of which is sometimes cited as justification for current practice.

Pliny's 'Diamond Softening'

An example of the first type of trap is Pliny's statement on diamond: "Adamas ... can be broken up by goat's blood. But it must be steeped in blood that is fresh and still warm ..." (Eichholz, 1962, p. 209). In his commentary on this passage Ball (1950, p. 252) calls this a myth and cites derivative statements by later writers. These frequently describe this process as a technique for 'softening' diamond for easier cutting, some stating that it did not work, with others claiming that they had used it successfully!

When I originally came across this passage, I was greatly amused, just as everyone else. It was only while studying the even older 'Papyrus Graecus Holmiensis', an Egyptian manuscript titled Baphika (on dyeing) written by Bolos of Mendes about 200 BC (e.g. see Nassau and Hansen, 1985) that I realised this 'mythical' recipe actually works! For the papyrus describes in several recipes in varying details, a process which is still in use today, although it is given by Pliny in a rather garbled form.

This process applies not to diamond but to quartz, for the term 'adamas' then included both materials. It uses goat's blood – today we use water which works just as well! And the papyrus includes a step which Pliny and later recipes omit, the step of heating the quartz before dropping it into the liquid; for the whole process was intended to crackle the quartz for subsequent dyeing.

Exerpts from a new translation (Nassau and Hansen, unpublished) of just three of the many recipes in the 'Papyrus Graecus Holmiensis' will illustrate the process as it was used over two thousand years ago:

> No. 29. Mordanting [or Softening] of Stones.
> ... hide them [the stones] in a dried fig or [in] plump dates. These should be worked over charcoal and blown with bellows until they [the fig or dates] burn and become charred. And take out [the stones] with tongs not with your hand [implying that they are too hot to touch], and thereupon plunge while warm into the dye solution and let cool there ...
>
> No. 36. Softening of Crystal.
> To soften crystal take goat's blood, heat the crystal over a gentle fire and dip it in until it pleases you.
>
> No. 46. Dipping for Lychnis [a red stone, possibly tourmaline or ruby].
> Begin by mordanting [or softening] as above. Take orchil and alkanet [both red substances] and vinegar. Drop the stone into this until it pleases you.

In 200 BC and later the first part of this two-step process was called 'mordanting' or 'softening' by analogy with the 'softening' of wool by a mordanting process which was in use from ancient times until quite recently to make the wool more receptive to dyes (Nassau, 1984, pp. 9 and 158). However, classicists preparing the previous translations of this papyrus had missed the essential point from not knowing enough gemmology. It required a new translation involving my interaction with Professor A.E. Hansen of the Classics Department of Prince-

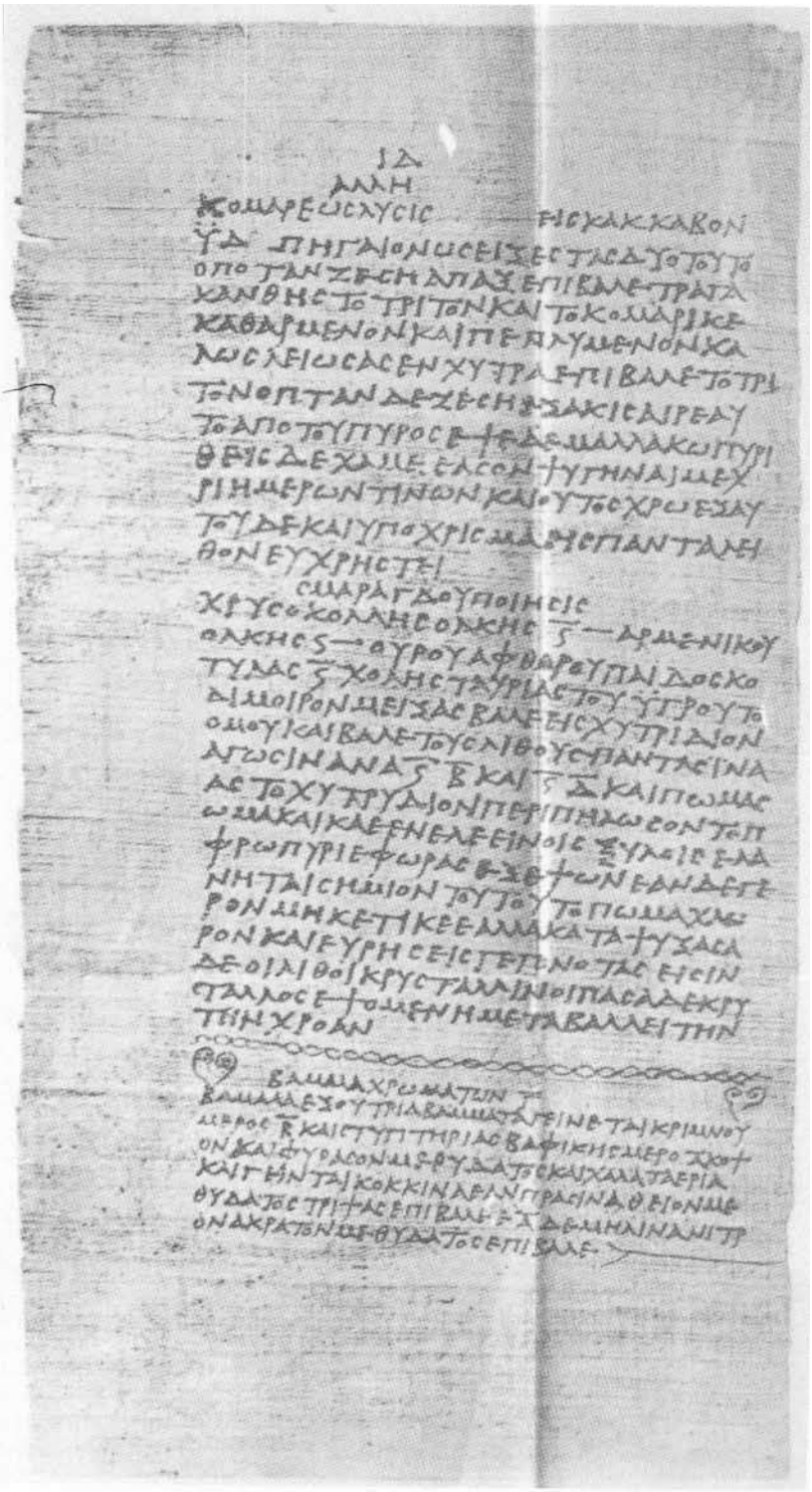

Fig. 1. A page from *Papyrus Graecus Holmiensis*, the first gemstone treatment text, about 2000 years old, copied about 300 AD.

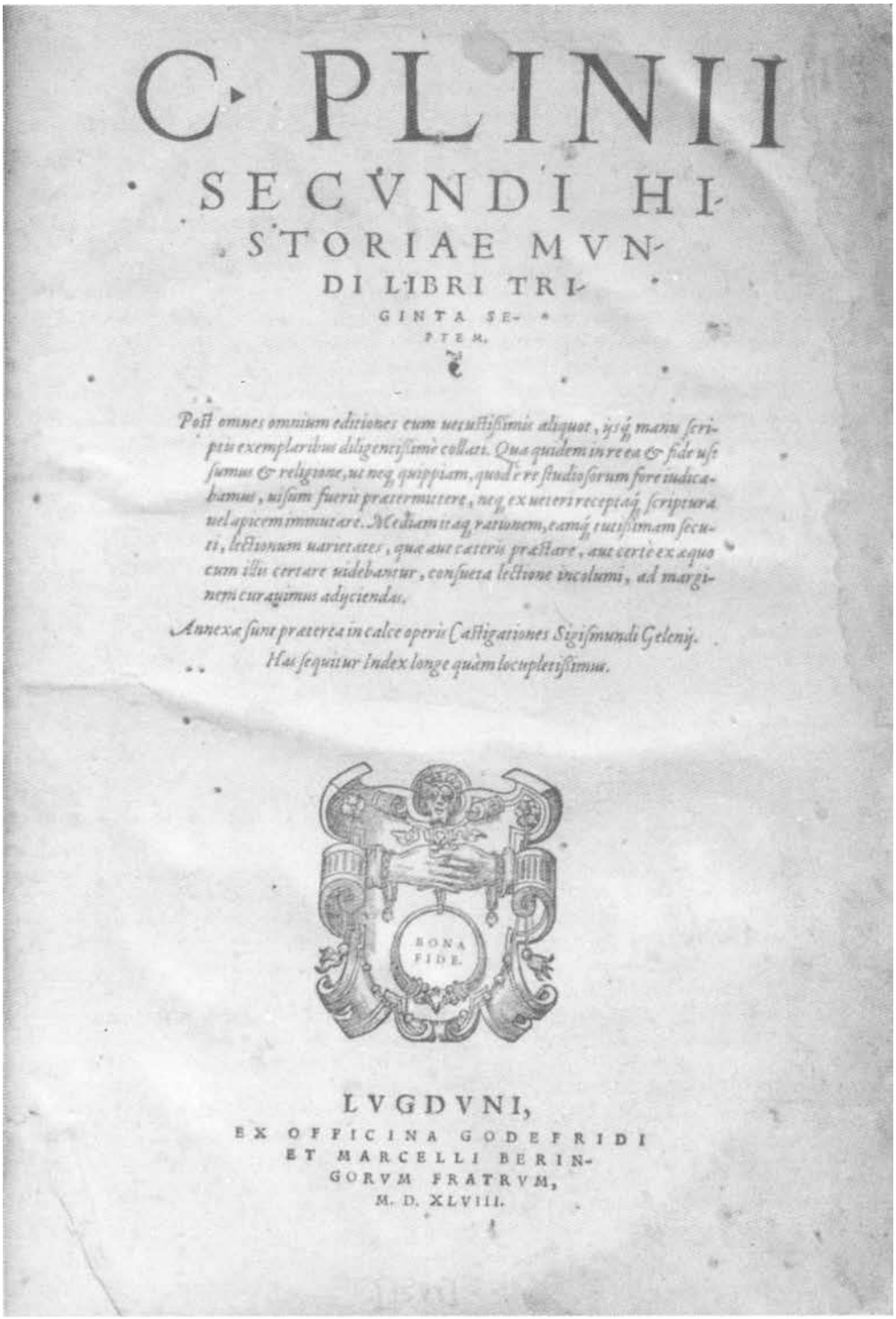

C. PLINII
SECVNDI HI-
STORIAE MVN-
DI LIBRI TRI-
GINTA SE-
PTEM.

Post omnes omnium editiones cum uetustissimis aliquot, iisq; manu scriptis exemplaribus diligentissimè collati. Qua quidem in re ea & fide usi sumus & religione, ut neq; quippiam, quod è re studiosorum fore iudicabamus, iussum fuerit prætermittere, neq; ex uetere receptaq; scriptura uel apicem immutare. Mediam itaq; rationem, eamq; tutissimam secuti, lectionum uarietates, quæ aut cæteris præstare, aut certè ex æquo cum illis certare uidebantur, consueta lectione uiculum, ad marginem curauimus adiciendas.

Annexæ sunt præterea in calce operis Castigationes Sigismundi Geleni.
Has sequitur Index longe quàm locupletissimus.

LVGDVNI,
EX OFFICINA GODEFRIDI
ET MARCELLI BERIN-
GORVM FRATRVM,
M. D. XLVIII.

Fig. 2. Title page of 1548 edition of *Natural History* by Pliny, written in the first century AD, the first book containing extensive gemmological information.

ton University to achieve understanding of the subtleties involved and this also resulted in an understanding of Pliny's 'myth', which almost certainly was based on the papyrus recipe No. 36 cited above.

Pliny's 'Emerald Oiling'

The routine oiling of emerald without disclosure is sometimes considered to be justified on the claim that it has been in use for at least two thousand years. We are here speaking of the use of a colourless oil to fill open cracks and fissures in emerald to make these defects invisible or at least less obvious to the naked eye. The claimed antiquity of this process is based on a passage in Pliny. I myself accepted the conventional interpretation of this source in one of my books (Nassau, 1984, pp. 7, 100) and elsewhere, but have now investigated this matter in detail, reaching a very different conclusion.

Here again, it is absolutely vital to establish exactly what the words used meant. First of all, the word 'smaragdus' is stated by Pliny to include twelve varieties. These are now recognised to encompass not only emerald but also other green to bluish-green materials such as green sapphire, turquoise, malachite, amazonite, lapis lazuli, green alabaster, green jasper, and so on (Eichholz, 1962, p.213; Ball, 1950, pp. 140 ff, 256 ff). Pliny himself states that all smaragdi except the Scythian, Egyptian, and Attic ones are found in copper mines. Eichholz (1962, p. 214) concludes that only the Scythian and Egyptian smaragdi of Pliny were true emeralds.

Another critically relevant fact is that green gemstones were preferred to blue ones at that time. As one example, Pliny says: "... of all colours, green is the most pleasing to the eye" (Ball, 1950, p. 140). Again, Pliny states (Ball, 1950, p. 143) with respect to Persian smaragdus (probably turquoise): "... they have this fault that they have the colour either of gall or the sky ... but are still not green".

With these two considerations in mind, let us examine what Pliny actually does say about the oiling of smaragdus in Chapter 18 of Book 37. Here are the three authoritative translations of the passage:

> I: "Such smaragdi [of Media] as are not naturally green may be improved and reach their full beauty by being washed in wine and oil" (Ball, 1950, p. 144, based on Philemon Holland's translation of 1601).

> II: "... [Median smaragdi] appear naturally of a green colour, but become improved by the addition of oil" (Bostock and Riley, 1898, p. 412).

> III: "Such stones [Median smaragdi], in spite of their varied colours, seem to be green by nature, since they may be improved by being steeped in oil" and footnote: "Pliny probably means that green seems to be the natural colour, because this colour is the one 'restored' by steeping the stones in oil" (Eichholz, 1962, p. 221).

There is general agreement that Median smaragdus is not emerald: it is either malachite (Eichholz, 1962, p. 220), turquoise or intergrown malachite and azurite (Ball, 1950, p.144). If it is malachite, then a poor chalky grade could have its colour improved by oiling. A much more likely candidate is turquoise, a material that does occur in 'varied colours' – both blue and green – and can be readily changed from blue to the then-preferred green colour by acid, acidic perspiration, and undoubtedly by oil, especially if it is mixed with acid wine or is acidic from rancidity.

If it means anything at all, Pliny's 'oiling of smaragdus' can thus be interpreted as the turning green by oiling of blue turquoise or of poor quality malachite!

Essentially all the occasional references to emerald oiling in the centuries that followed are clearly based on the usual misinterpretation of Pliny's smaragdus oiling. As one example (King, 1860), the Abbot Marbod, writing in France about 1070 AD, also cites twelve varieties of smaragdus, as did Pliny, and again paraphrases Pliny:

> "If steeped in verdant oil or bathed in wine
> It's deepened hues with perfect lustre shine."

There is also mention of the use of oil on gemstones in the much earlier papyrus discussed above, but there the oil is the medium that carries dyes and pigments into crackled stones to produce imitations. There seems to be no hint of the use of a colourless oil merely to hide defects.

In summary, there are no convincing ancient reports of emerald oiling. This is not to say that some may not have tried these instructions in the conventionally misinterpreted form throughout the centuries and obtained an improvement in appearance from the filling with oil of the cracks in the emerald. But we do not have any persuasive documentary evidence of it. Therefore we cannot attribute the emerald oiling process to antiquity.

Modern emerald oiling

When we examine more recent sources, such as the writings of the great gemmologists of the nineteenth and twentieth centuries, we find an even more surprising situation. None of these refers to emerald oiling before the 1960s! This is most

astonishing in the case of Max Bauer, whose *Precious Stones* of 1904 is one of the most detailed gemmological treatises ever written. In his text he mentions many treatments, but for emerald only green foil backings for pale stones and closed black settings for fissured stones. Equally astonishing is the absence of emerald oiling in early editions of Webster's authoritative *Gems*, where only in the fourth edition of 1983 (Webster and Anderson, 1983) does an account finally appear. (The 'oiling' with kerosene by Brazilians mentioned on p.91 of Webster's third edition of 1975 is clearly *not* the modern oiling process). There is also no mention of emerald oiling in early editions of Liddicoat's *Handbook of Gem Identification* or Anderson's *Gem Testing*.

The first reference to modern emerald oiling that I have been able to locate is in Liddicoat's 6th edition (1962, p.280), where it is referred to as a 'longstanding' process. The process itself is outlined for the first time in an unsigned article in 1981 in the *Retail Jeweller* (Anon., 1981), soon followed by a detailed description by Ringsrud in 1983. I should like to hear if any reader knows of earlier references to the modern oiling process which I have overlooked.

Unable to locate older convincing documentary mention of the modern oiling process, I finally turned to the memory of the master gemmologists Richard T. Liddicoat and Robert Crowningshield of the Gemological Institute of America, to both of whom and their associates I am grateful for help. They also checked with several octogenarian sources accessible to them. The earliest any of these sources could definitely locate trade emerald oiling was about 1910. There was also some feeling, but certainly no proof, that trade emerald oiling may *not* have existed before 1910.

If we then assume that trade emerald oiling began soon after the turn of the century, how to explain the 'conspiracy of silence' that existed among gemmologists for some half a century, with but a minimal mention over the next 30 years? An examination of the aquamarine heating process may be relevant: this enhancement has been used to convert essentially all green aquamarine to the currently more desired blue colour (blue is rare for aquamarine as mined). Here again there is no mention of this process in Bauer; Liddicoat first refers to it in 1981 in the eleventh edition of his *Handbook of Gem Identification*; Anderson mentions it only in the ninth edition of his *Gem Testing* in 1980; but a description does occur as early as 1962 in Webster's first edition of *Gems*. There is thus an earlier complete absence of mention of this process and subsequently only rarely a reference to it. It is usually accepted that the reason for this derives from the widespread use of aquamarine heating being known by all, with everyone recognizing it as obvious and indeed to be expected. Perhaps this type of explanation applies equally well to trade emerald oiling in the twentieth century. There is, of course, one significant difference between these two products: the colour of heat-treated aquamarine is stable in normal use, but the oil in oiled emerald may dry out or be washed out by detergent.

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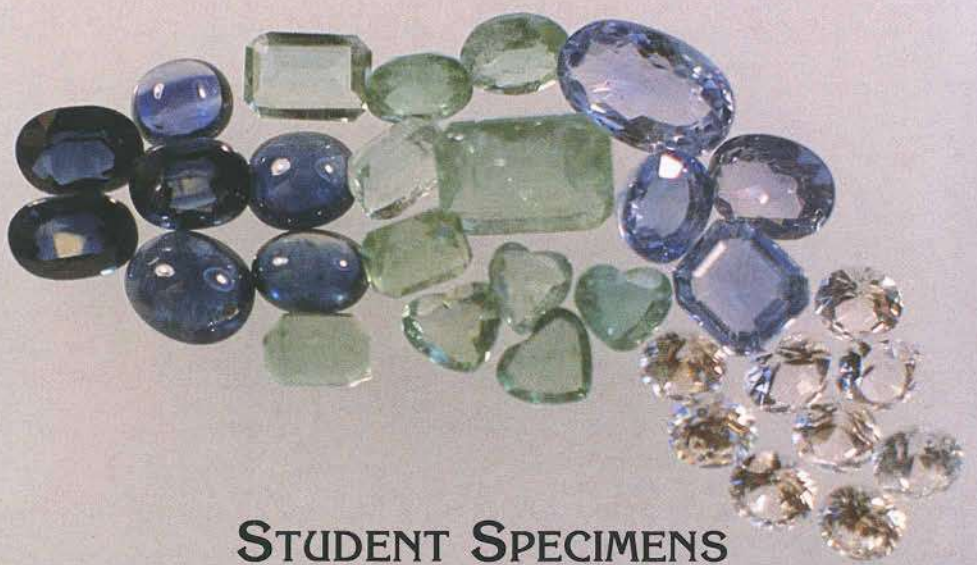

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Anomalous behaviour of certain geuda corundums during heat treatment

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Abstract

A geuda variety known as 'ottu' with dark blue patches on the outer surface when heat treated at (1800-1850)°C under reducing conditions produced three types of samples. They showed (a) good blue colour and clarity (b) insufficient blue colour but good clarity (c) formation of a thick white precipitate ('dead milk') on the outer surface. In order to understand the cause of these changes EPMA results were studied.

The results, while confirming that Fe and Ti are necessary for producing a good blue colour, indicate that the presence of other minor impurities hinders this process. The results also indicate that a high concentration of Fe and Ti, together with V and some other impurities gives rise to the formation of the thick white precipitate on the outer surface during heat treatment.

Introduction

Sri Lanka has a large reserve of the low quality gem variety called 'geuda'. Geuda is the term used to describe the whitish or pale blue corundum of poor colour and clarity. Heating at temperatures in the range (1600-1900)°C could transform these into good quality blue sapphires. Depending on the visual character, terms such as blue geuda, diesel geuda, silky geuda, ottu etc. are used in the trade to describe different varieties.

Light blue or colourless stones with dark blue patches on outer surfaces – varieties of 'ottu' – when heat treated under reducing conditions in the temperature range 1800-1850°C produced three types of results. They were:

(a) Clear blue stones

(b) Clear stones that did not attain a satisfactory colour

(c) Stones with a non-transparent white coating ('dead milk').

Over 50% of the results belong to the (c) group.

When the initially heated stones were re-heated under oxidising conditions in the temperature range 1600-1800°C, types (a) and (b) showed a reduction of blue colour. No change was observed in type (c) stones. This white coating could not be removed even after heating at higher temperatures. Hence an investigation was initiated using the Electron probe micro-analyser (EPMA) to study the cause of these changes.

Experimental details

Around 50 stones of the 'ottu' variety all with dark blue patches on the outer surfaces were heat treated in the temperature range 1800-1850°C for 1 hour under reducing conditions. The types (a), (b) and (c) obtained after heat treatment were selected and analysed using the EPMA (Schimadzu – Model 8705). This is a unit with multiple wavelength dispersive X-ray spectrometers (WDX) to enable elements from $_4$Be to $_{92}$U to be detected. The 3 channel spectrometer was used with the spectral crystals RAP, PET and LIF. Accelerating voltage and specimen current were set at 15kV and 0.05 μA respectively throughout the analysis. Constant beam width of 100μm was always employed to analyse the samples.

The samples were scanned at a very low scanning speed of 0.1Å/min to carry out qualitative identification of the trace elements. Exact peak positions were searched for elements of interest and cumulative counts were recorded at the peak positions and background for 10 second intervals.

Since this analysis was concentrated mainly on colour-causing impurities such as Fe and Ti similar procedure was repeated to analyse standard solid samples with varying concentration of Fe and Ti in Al_2O_3 (Fe,Ti range: 0.01%-0.5%). Calibration curves were used to estimate trace elements semi-quantitatively.

The selected areas on the samples were flattened and mirror polished. Cross sections of the stones of type (c) were taken to analyse the blue (centre) and dead milk areas (edge).

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Results and discussion

The samples were scanned at very low scanning speeds under the same experimental conditions using the EPMA, and the results were analysed and averaged. The lowest detecting limit of Fe and Ti was 0.03%. The concentration levels were classified as: low – 0.03% to 0.15%; medium – 0.15% to 0.3%; high – above 0.3% (see Table 1).

Table 1: EPMA results of heat treated 'geuda' corundums

Samples	Fe	Ti	V	Minor Trace Level Impurities
(a) Good blue stones	*	X	ND	Na, K, Mn
(b) Very pale blue/ colourless stones	*	*	ND	Na, K, Ca, Si, Zn
(c) Stones with 'dead milk'				
(i) 'dead milk' area	**	***	Y	Na, K, Ca, Mg, Ga, Mn, Si, Cr
(ii) blue area	*	*	Y	Na, K, Mg, Si

* – low (0.03-0.15%)
** – medium (0.15-0.3%)
*** – high (above 0.3%)
X – average value below lowest detecting limit
Y – significant minor impurities
ND – Not detected

It is generally accepted that the blue colour of sapphires was caused by the formation of the $(Fe.Ti)^{6+}$ bi-particle (Nassau, 1984; Eigenmann and Gunthard, 1972; Harder & Schneider, 1986; Ediriweera & Perera, 1989).

The average results (Table 1) show that the concentration level of Fe in types (a) and (b) were similar, whilst the concentration level of Ti seemed to be lower in type (a) than in (b). The majority of the type (a) samples showed Ti up to about trace impurity level and a few samples showed a slightly higher level similar to Fe. The only detected additional impurities in (a) were Na, K and Mn. Some type (a) specimens did not even show traces of any of the minor impurities. However in type (b) stones, the presence of a number of minor impurities were clearly noticeable (Na, K, Ca, Zn, Si).

When the 'dead milk' areas in type (c) stones were analysed, relatively higher concentration levels of Fe and Ti were detected than in clear areas. In all these type (c) samples the Ti level was noticeably higher than Fe (Table 1). Among other minor impurities V was always present in all the type (c) samples analysed. In 'dead milk'-free areas the Fe and Ti levels were much lower than in the 'dead milk' areas and the number of minor impurities were also low.

However the reported minor trace impurities were identified during the qualitative analysis. Since presence of V was possibly more significant than the other minor impurities, those results were tabulated separately, but no quantitative estimates are available for V.

The possibility of contamination due to sample preparation was ruled out by analysing similar types of samples without employing the special preparation method. Further detection of similar impurities in natural corundums have been reported by Schmetzer and Bank (1980, 1981), Bosshart (1982), Schmetzer and Bosshart (1983) and Schrader (1986).

Conclusion

This study suggests that whilst the presence of Fe and Ti is necessary to give a blue colour to corundum, the presence of other minor impurities could prevent the formation of the required bi-particle and hence not produce an acceptable blue colour. This confirms the hypothesis of Schmetzer and Bank (1980) in the explanation of different behaviour of heat treated corundums due to other additional impurities.

The formation of the thick white precipitate ('dead milk') on the outer surface was apparent in stones with high impurity concentration levels especially Fe and Ti. It is possible that V and some of the other impurities present in the sample may have helped this process.

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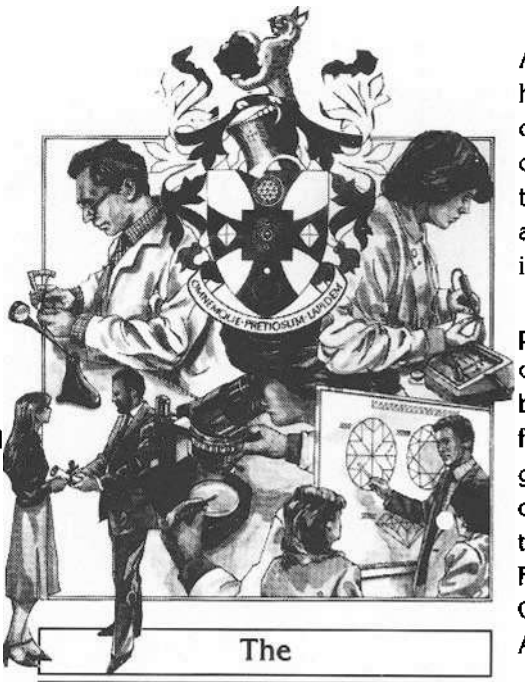

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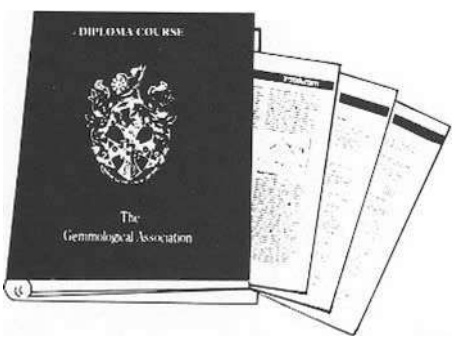

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Emeralds from Colombia (Part 2)*

George Bosshart

Switzerland

Abstract
Introduction (Part 1)
A1. The history of the Colombian emerald mines
A2. The geographical location of the emerald occurrences

B1. The emerald deposits and their geological environment
B2. Hypotheses of emerald genesis
B3. The mine workings

Gemmological properties (Part 2)
C1. Morphology, quality and size of the emerald crystals
C2. Chemical composition, chromophore and trace element contents
C3. Light absorption, colour and fluorescence
C4. Optical values and density
C5. Inclusions and growth characteristics

Treatments (Part 3)
D. Oil, ultrasonic and heat treatments

Discussion
E. Differentiation of the Colombian emeralds from natural emeralds of other origins, synthetic emeralds and emerald imitations

Acknowledgements
Bibliography

Abstract

A condensed historical and mining survey is followed by a compilation of the most notable crystals of Colombian emeralds ever found and of the details of their chemical composition. A summary of the elemental substitutions and their effects on the outlined range of gemmological data is given.

Special emphasis is placed on the cause of the famous, vividly green coloration, i.e. on the selective absorption of orange-red and violet light, dictated by minor contents of the chromophoric elements Cr and V substituting for Al^{3+} in octahedrally coordinated sites of the beryl lattice (Cr ≈ V, with the Cr/V ratio found to be ranging from 4.5 to 0.5, in extreme cases from about 10 to 0.1). Iron, however, has barely been detected in the UV/VIS absorption spectra of Colombian emeralds. Though generally present in slightly larger amounts than Cr^{3+} iron does not recognizably influence the colour (little Fe^{2+} and possibly some Fe^{3+} positioned in the axial channels of the ring-silicate structure).

A detailed presentation of the currently known internal characteristics (inclusions and growth structures) is supplemented by a discussion of identification problems with treated emeralds and the disclosure of the treatment during transactions in the wholesale and retail trade.

Allocation of the emeralds to individual Colombian mines on the basis of inclusion patterns does not appear possible in most instances. However, the differentiation of Colombian emeralds from other natural emeralds (such as those from the Panjsher Valley exhibiting very similar (s,l,g) three-phase inclusions) or from difficult, modern hydrothermal and flux synthetics is shown to be feasible by a combination of microscopy, refractometry, and absorption spectrometry (UV/VIS and NIR/MIR), assisted by chemical analysis only in the most difficult cases. Safe identification of authenticity, treatment, and origin of emeralds, however, is increasingly becoming the task of the experts in the specialized laboratory.

The mineralogical definition of emerald as a yellowish to bluish-green variety of natural beryl is shown to be valid for any Cr and V-containing variety except possibly the rare, absolutely chromium-free (V,Fe)-beryls (modification of the former definition of type II emerald): in many of the preferred Colombian emeralds, chromium is clearly dominated by vanadium (Cr/V ratio < 1). However, chromium has a higher efficiency of coloration than vanadium and a much higher one than iron ions in the various substitutional and interstitial lattice sites of beryl. Cr influences colour even at very low trace levels.

An extensive and up-dated selection of literature, covering all aspects cited, completes the synopsis.

*This is a paper which will be published in *The Journal* in three parts. The complete bibliography is presented with Part 1.

The introduction to this review is based on the study of a fraction of the extraordinarily extensive literature on Colombian emeralds.
The main part of the paper (Part 2) contains data collected and findings achieved over many years in the SSEF Laboratory in Zurich.
Part 3 will deal with the difficulties encountered in identifying treated emeralds and with the disclosure necessary when selling them and will discuss the possibilities of differentiation between Colombian and other natural emeralds and the synthetic emeralds.

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Table 1. Some of the largest known Colombian emerald crystals of special quality, in the chronological order of their discovery

(1831)	Muzo (Devonshire Emerald)	1384 ct	unknown (once Brit. Mus., London)
1920	Chivor (Patricia Emerald)	632 ct	Amer. Mus. Nat. Hist., New York
(1950)	Muzo (five crystals, 220-1796 ct)	1759 ct	Banco de la República, Bogotá
1967	Vega de San Juan (Gachalá)	858 ct	Smithson. Inst., Washington DC
1969	Las Cruces, Gachalá (Emilia)	7025 ct	private Colombian collection

Gemmological properties

C1. *Morphology, quality and size of the emerald crystals*

The crystal forms most commonly observed in Colombian emeralds are the first and second-order hexagonal prisms with flat end faces (basal pinacoid) and their modification with small pyramidal faces. It is definitely rarer to find the dihexagonal prism, the dihexagonal bipyramid and combinations of crystal forms with still more faces. Elongated crystals often grow parallel to each other or form fan-shaped or radiating aggregates. Such growth types may contain cavities.

Most Colombian occurrences produce a wide range of emerald qualities with respect to colour and transparency. The opaque material called '*moralla*' presents the poorest quality grade. Good qualities, however, are very saleable in Europe and, according to statistics, even more so in Japan, for instance as centre stones in finer jewellery.

The showy *Trapiche emeralds* from Muzo, Coscuez and Peñas Blancas on the other hand appear to be collectors' items more than jewellery components. The name 'Trapiche' is derived from the hexagonal cog-wheel barrel used in Colombian sugar mills. The growth forms of Trapiche emeralds are fairly variable looking. They consist of six sectors respectively six radial emerald crystals, regularly arranged around a steeply tapering hexagonal pyramid and separated from each other by white albite or dark carbonaceous shale particles (cf. special literature). Very rarely *cat's-eye emeralds* have been reported also (a specimen of 4.6 ct is housed in the Smithsonian Institution, Washington DC).

Outstanding emerald crystals have grown to prism lengths of 10 cm (and more) and to diameters of 6 cm, corresponding to weights of the order of 4000 carats. This is phenomenal for emeralds, yet not unusual for other beryl varieties, with beryls of industrial quality reaching weights of several tons.

Probably the largest emerald crystal of good quality ever found weighed 3204 g (16,020 ct) and was baptised 'Muzo' after its place of origin. The largest polished emerald also came from Muzo and is a perfume bottle, 10.9 cm in height, which was engraved in the year of 1641 by Dyonisio Miseroni in Prague. It weighs 2680 ct and can be admired in the Treasury of the Hofburg in Vienna. 'Patricia', the unofficially most beautiful emerald was reported to have been dethroned by two single crystals dug out in Muzo in 1988, measuring 5.8 and 5 cm in prism length.

C2. *Chemical composition, chromophore and trace element contents*

In natural emerald the major constituents of beryl – BeO, Al_2O_3, and SiO_2 – are commonly accompanied by minor constituents and trace elements, the individual amounts of which vary considerably. Three kinds of minor constituents can be differentiated:

- water molecules (in the open Si_6O_{18}-ring channels),
- alkalis (mainly Na_2O and MgO) and
- chromophores (mostly Cr_2O_3 and Fe_2O_3, but also FeO and V_2O_3).

In his review *Esmeraldas*, Schwarz (1987) compiled a significant number of published chemical compositions of emeralds.[3a] The data vary in part widely from author to author.

From the compiled compositions it can be deduced that the *water content* of the Colombian

[3a] The formula of the cyclosilicate structure of emerald is $Be_3(Al,Fe,Cr,V)_2[SiO_3]_6.xH_2O$, with $x < 1$. According to literature, synthetic emeralds produced by flux or hydrothermal procedures show minimal contents of the major constituents BeO, Al_2O_3 and SiO_2 of 13, 17 and 64.5 weight % respectively. The corresponding values of most natural emeralds are below these limits, while those of Colombian, Afghani and Nigerian ones are slightly above. Numerous natural, many Colombian and some Afghani emeralds show a higher content of MgO and Na_2O than the synthetics (maximum values of the synthetics so far are 0.6 and 0.3 wt.% respectively). Apart from that, the Colombian, like all other natural emeralds, contain zeolitic water of type I and II (while the flux synthetics do not). Conversely, the Colombian emeralds are free from chlorine (Cl can be found in the hydrothermal synthetics of Linde and Biron/Pool, as well as in the fluid inclusions of Colombian emeralds, of course). They do not contain nickel (Ni^{3+}) and only traces of lithium and moderate iron (unlike the recent hydrothermal synthetics of Russian manufacture, Schmetzer 1988).

[3b] Schwarz (1990a) found the following subdivision useful for the characterization of minor constituent contents in emeralds:

low	*medium*	*high*	
< 1.5	1.5 – 2.5	> 2.5	wt% MgO
< 1.0	1.0 – 2.0	> 2.0	wt% Na_2O
< 0.2	0.2 – 0.4	> 0.4	wt% Cr_2O_3
< 0.5	0.5 – 1.0	> 1.0	wt% FeO

emeralds (0.5 to 1.9 weight% H_2O) is below or equal to the average of natural emeralds of other origins.

The infrared spectra of Colombian emeralds usually indicate a slight predominance of type II water over the free type I water. This is mainly due to the presence of Na^+: As electric dipoles, water molecules are orientated and bonded in the ring channels by neighbouring alkali and other cations and thus called type II water. Type I water is not alkali-bonded (Wood & Nassau 1968).

A *coupled atomic substitution by alkalis* regularly takes place in natural emerald: Mg^{2+} mainly replaces Al^{3+} on the lattice sites of beryl while the larger-sized Na^+ ion is built into the ring channels of the crystal structure for electric charge compensation.

The *magnesium and sodium oxide contents*[3a,3b] of Colombian emeralds (averaging 0.7 and 0.6 wt% respectively) are definitely lower than the corresponding values of natural emeralds of metamorphic and other provenance, excepting the very low Mg and Na contents of the recent emerald finds from Jos, Nigeria.

Colombian emeralds take up a central position with regard to the substitution of aluminium in the beryl structure by the colouring transition elements, *the chromophores Cr^{3+} and V^{3+}* (in company with some Fe^{3+} and Fe^{2+}). Often they contain a little more Cr than V and relatively little total Fe (averaging about 0.3, 0.1 and 0.3 oxide%[3b] respectively and a Cr/V ratio of approximately 3). In the next chapter, the effects on absorption and colour will be compared to those of natural emeralds with higher iron or vanadium contents.

In addition to these minor constituents, the following *trace elements* (and molecules) foreign to the beryl formula have been reported in Colombian emeralds:

Ca,Sr,Ba,Mg^{2+} / K,Rb,Cs^+ / CO_2(?), F_2 and radiogenic He in the structural ring channels

Li^+ (and vacancies) on the tetrahedrally coordinated Be^{2+} lattice sites (i.e. each beryllium ion is surrounded by four oxygen ions located in the corners of a slightly distorted tetrahedron)

Ti^{4+},Sc^{3+} / Mn,Ni,Fe^{2+} / Li^+ (and vacancies) on the octahedrally coordinated Al^{3+} lattice sites (AlO_6 octahedra) and

Al^{3+} on the tetrahedrally coordinated Si^{4+} lattice sites (SiO_4 tetrahedra).

All the properties discussed below are the results of the fluctuating supply of chemical elements during emerald growth and of the imperfect structure of these crystals. This so-called real structure has been considerably disturbed by the incorporation of foreign chemical elements and by inhomogeneous growth conditions (rapid pressure/temperature changes, geotectonic stress, etc.).

C3. *Light absorption, colour and fluorescence*

Chromophores causing green colour in beryls (and other silicates) by means of selective absorption of light are the transition metals *Cr,V,Fe,(Mn),Ni,Co and (Cu).*[4]

Cobalt and copper appear to be absent in Colombian emeralds. Their iron contents and traces of manganese and nickel have no colouring effect in the presence of chromium and vanadium as will be shown in the evaluation of the spectra.

If (Cr,Fe)-emeralds are designated 'normal' or type I emeralds and the yellowish-green (V, Fe,Ni,Mn,Cr)-beryls as type II (Taylor 1977), the Colombian emeralds with their Cr/V ratio averaging about 3 may be classified as the last representatives of the more frequent type I. This type shows Cr/V ratios from 1.0 to 40 (in extreme cases to over 100). Thus the Colombian emerald population is bordering the rarer type II which has Cr/V ratios below 1 (normally far below parity). Therefore they could also be considered as an intermediate emerald type.

Most other natural type I emeralds are lower in vanadium (V-free to V-poor) but higher in Fe^{3+} and Fe^{2+} (ferriferous to Fe-rich). They display a bluish-green to blue-green colour, most obvious in the border-cases between emeralds and aquamarines like in certain stones from Miku, Zambia.

The other extreme is represented by the (V,Fe)-beryls, e.g. by those from Salininha (Bahía). They are nearly free from chromium (Cr/V < 0.1) and are still green, yet more yellow-green than the Colombian emeralds. On average, their absorption minima are shifted only 10-15 nm towards the yellow (in Figures 2a and 3 from approximately 502 to 513 nm for the mean value of the *o* and *e* spectra). Usually Biron synthetics also show a higher content of V than of Cr (Cr/V ratios from about 0.2 to 0.7).

Evaluation of the absorption spectra

The absorption diagrams of emeralds do not allow a quantitative analysis of the colouring agents Cr, V, Fe, etc.:

In the visible (VIS) region of the electromagnetic spectrum, chromium efficiently masks medium iron and vanadium contents (Figures 2a,b,c) due to its very high absorption coefficient (a beryl plate of 10 mm thickness is discernibly coloured by as little

[4] According to the mineralogical definition, emerald is the yellow-green to blue-green variety of beryl. Every gemmological attempt to sharply separate Cr-emeralds from other green beryls must fail regardless of whether the criterion is the absolute chromophore content (i.e. colour saturation) or the ratio of the individual chromophore contents (i.e. colour hue). Delimitations of the emerald term for the needs of the gem trade as proposed by Superchi & Rolandi (1980) suggesting the use of the DIN 6164 Colour charts are remarkable but lack the international approval and a generally accepted, simple usage.

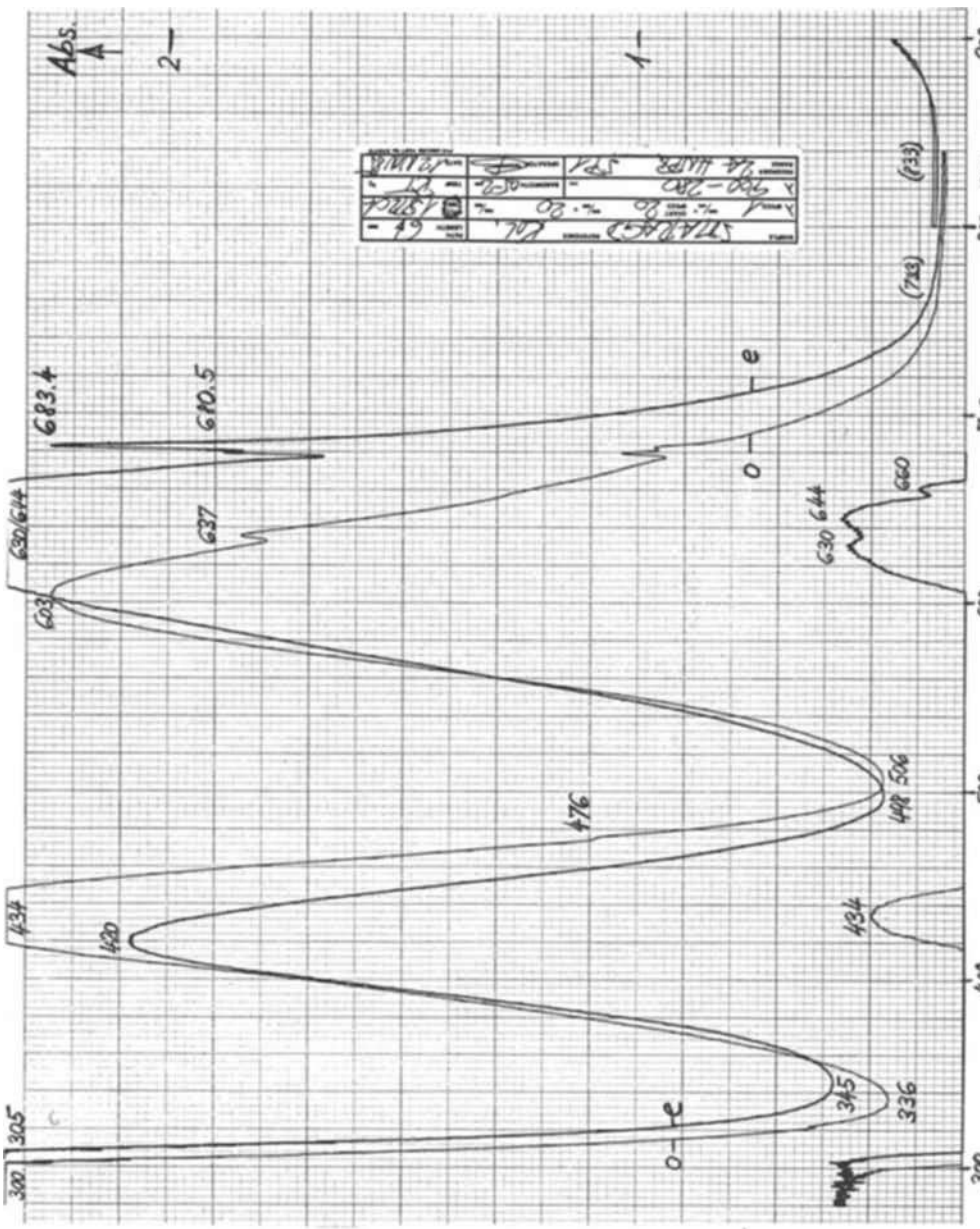

Fig. 2a. Polarized absorption spectra of a saturated green Colombian emerald. Emerald type I due to a Cr/V ratio ≥ 1 (here Cr/V ≈ 1.5). Weight 1.872 ct, density 2.713 g/cm³, $n_{D,o}$ 1.578, $n_{D,e}$ 1.585, optical path length nearly 6 mm. Medium chromium content (high for a Colombian emerald). Ordinary (o) and extraordinary (e) ray spectra with polarization perpendicular and parallel respectively to the optical axis, recorded at ambient temperature in the first focal focus of a Pye Unicam SP8-100 UV/VIS spectrophotometer (Bosshart 1982), with a Polaroid HNP'B polarizer filter mounted in front of the detector.

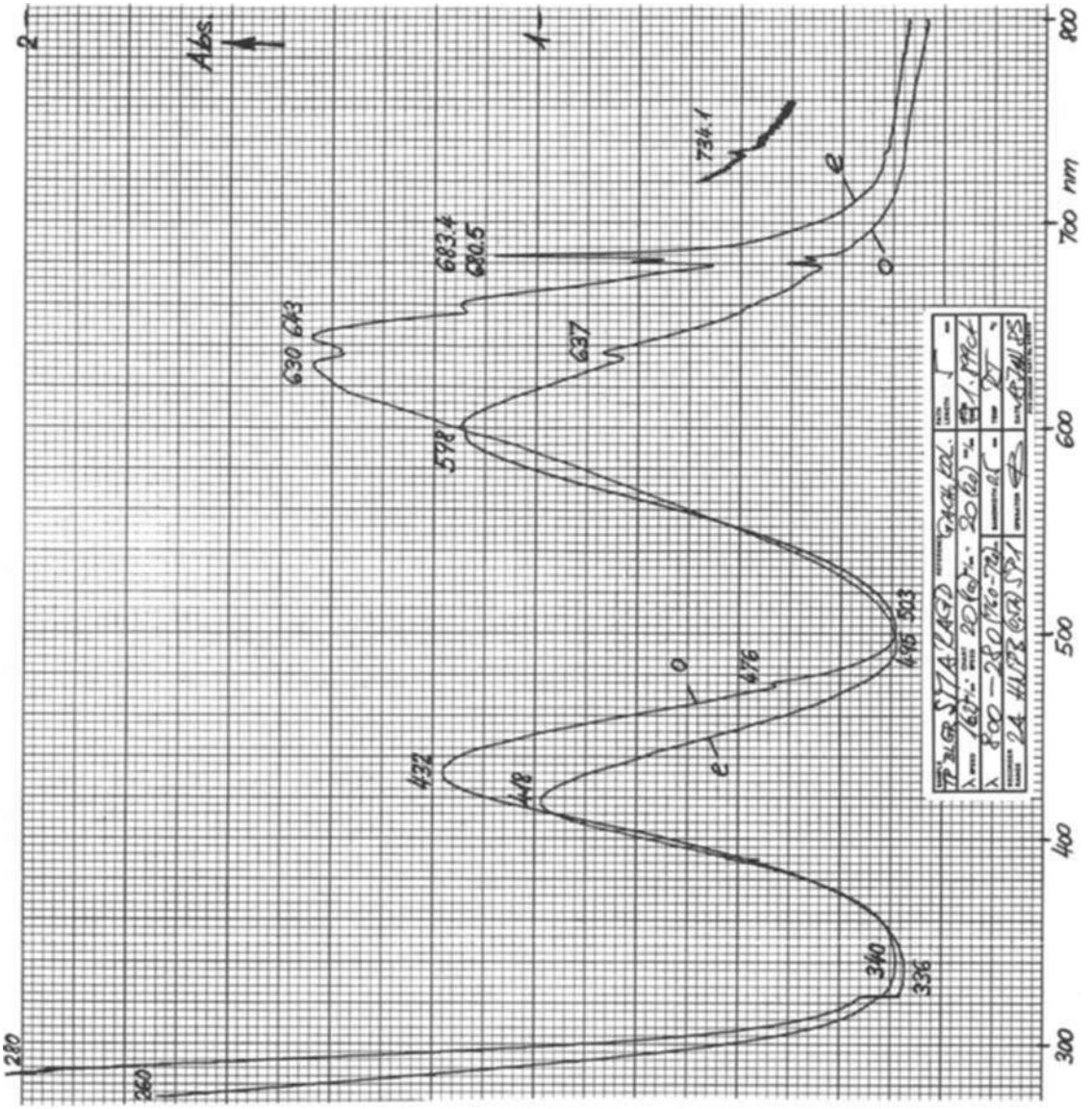

Fig. 2b. Polarized absorption spectra of a pale bluish-green emerald from Gachalá(2), Colombia. Emerald type I, Cr/V ≈ 4. Weight 1.899 ct, density 2.687 g/cm³, $n_{D,o}$ 1.574, $n_{D,e}$ 1.580, optical path length about 5 mm.

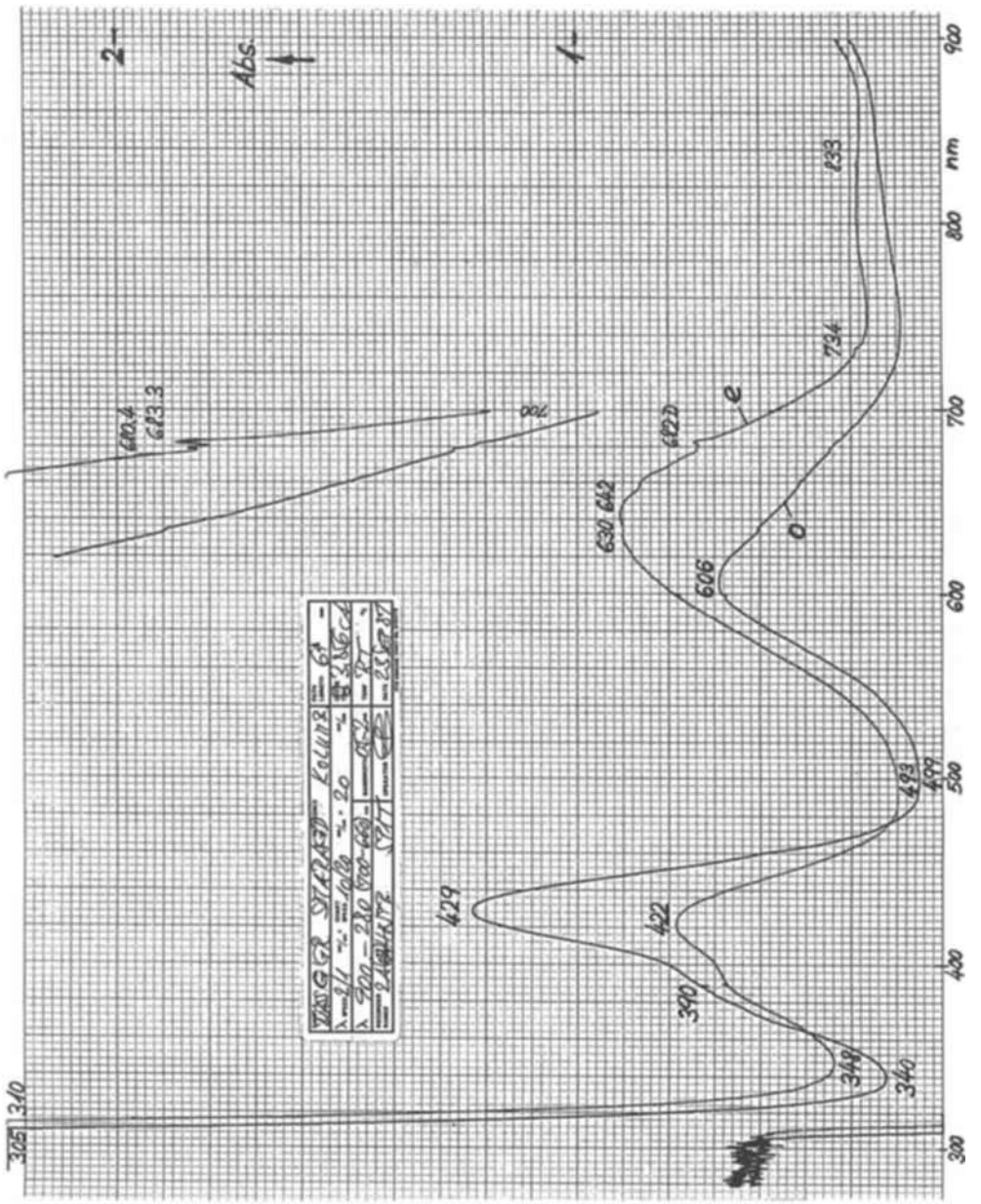

Fig. 2c. Polarized absorption spectra of a pale yellowish-green Colombian emerald. Emerald type II, Cr/V ≈ 0.8 (possibly less). Weight 3.856 ct, density 2.690 g/cm^3, $n_{D,e}$ 1.572, $n_{D,o}$ 1.579, optical path length about 6 mm.

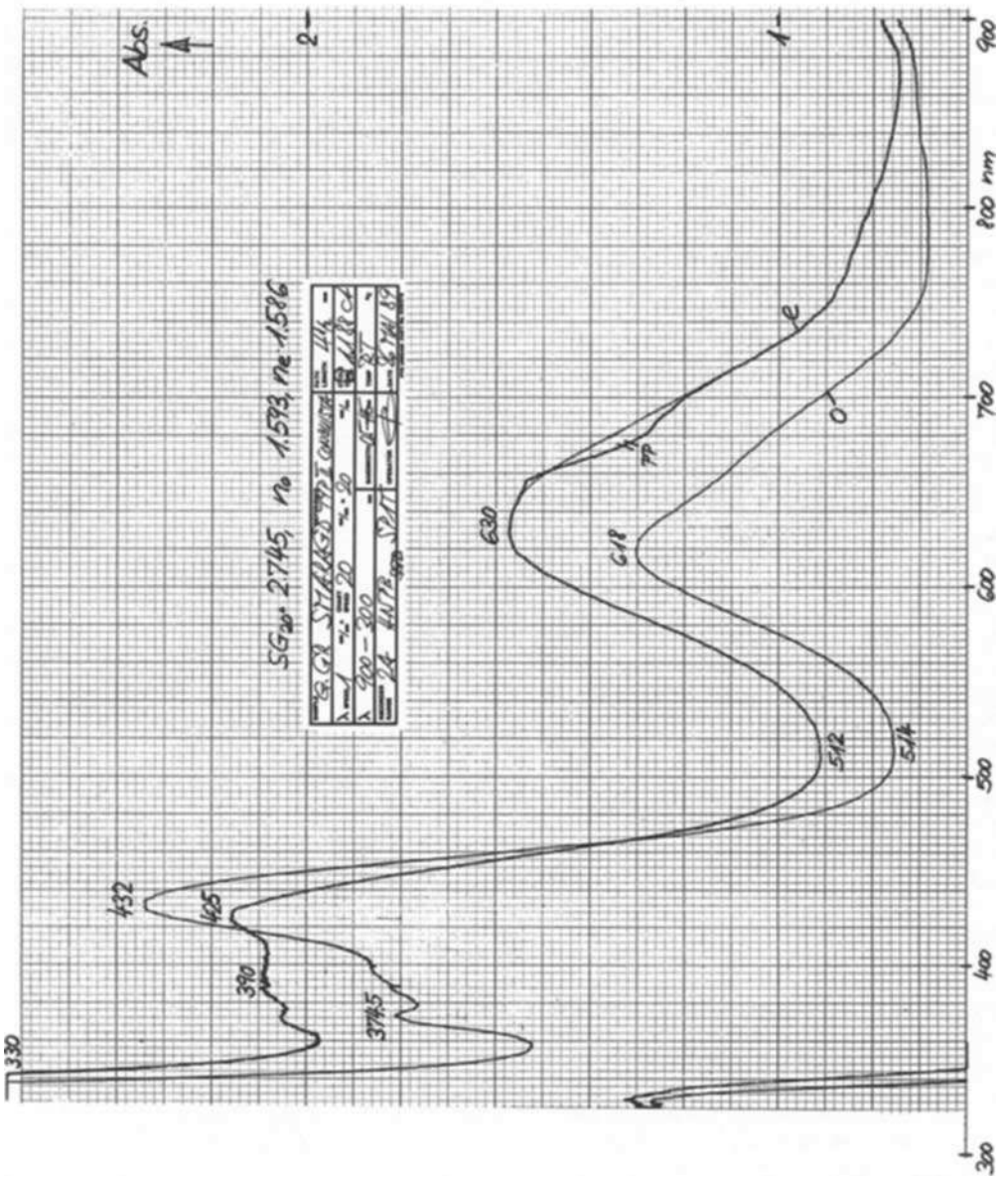

Fig. 3. Polarized absorption spectra of a yellowish-green Brazilian emerald from Conquista(?). Emerald type II, Cr/V < 0.1. Weight 1.188 ct, density 2.745 g/cm³, $n_{D,o}$ 1.586, $n_{D,e}$ 1.593, optical path length about 4.5 mm.

as 0.0025 % = 25 ppm Cr_2O_3, Wood & Nassau 1968).

In addition, the vanadium spectrum in the VIS (Figure 3) is very similar to that of chromium Fe^{3+} and Fe^{2+} may be positioned in various lattice and channel sites and then absorb in variable hues and mostly in low intensities.

a. The *positions of both colour-decisive*[4] *absorption bands in the violet and orange-red spectral region* are nearly identical for Cr and V:

polarization perpendicular to the *c*-axis (ordinary-ray vibration, *o*)
Cr bands near 430 and 593 nm,
V bands near 434 and 618 nm

polarization parallel to the *c*-axis (extraordinary-ray vibration, *e*)
Cr bands near 416 and 628/644 nm,
V bands near 426 and 630 nm.

While Al-substitution by chromium causes the well known *absorption lines* at
476, 637 nm (*o*), 660 nm (*e*) and
680.5/683.4 nm (doublet, $e \gg o$).
in addition to the bands cited above, absorption lines in the V spectrum are looked for in vain (they are situated in the near infrared region, according to personal communication with K. Schmetzer, 1989). Thus vanadium is optically masked in the VIS by the presence of chromium.
Nevertheless, well polarized, low-iron spectra enable a *rough estimate of the Cr/V ratio* by evaluating the position of the absorption bands. Overlapping of the Cr and V spectra produces intermediate positions of the absorption maxima, with laboratory recordings for Colombian emeralds averaging approximately
431 and 600 nm for the *o*-ray and
419 and 628 nm for the *e*-ray.
On this basis the average Cr/V ratio amounts to about
2.5 (variation from 0.5 to 4.5).
However, the most recent microprobe analyses (Schwarz 1990b, 1991), prove that V may be distinctly superior to Cr and in individual cases even much superior (or inferior). The variation of the Cr/V ratio of Colombian emeralds thus is wider, ranging from approximately 0.1 to 10.
The unexpected but incontestable fact is that the most cherished Colombian emeralds frequently are type II (vanadium) and not type I (chromium) emeralds.

b. Superposition of the Cr and V spectra intensifies the VIS absorption bands and increases the steepness of their slopes, thus creating the *brilliant and pleasingly pure colour* of the Colombian emeralds. Their slightly yellowish or bluish-green hue is highly valued. Hue and saturation are not caused by a particularly high Cr content as in the emeralds from Sandawana (Zimbabwe), Santa Terezinha (Goiás) or the Swat Valley (Pakistan) (in the latter two combined with high iron). Hue and saturation of the Colombian emeralds rather are generated by a subtle combination of low to medium amounts of the colour inducing elements Cr and V with comparatively little Fe.

The *dichroism* (*o*-ray yellowish-green, *e*-ray bluish-green) is weak in the majority of these stones, thus generally less distinct than in the ferriferous emeralds from metamorphic occurrences with their definitely aquamarine-blue *e*-ray component.

The *colour saturation* can vary considerably from one Colombian emerald to another. Apart from that, the colour distribution within a single crystal can be extreme to such an extent that a colourless zone is adjacent to a saturated green one. As a rule, the colourless zone is the older prismatic nucleus enveloped by a younger green skin, or there are paler zonal lamellae intercalated between saturated green basal growth layers. Conversely, even large emeralds can show an homogeneous and strong green saturation.

Colourwise, emeralds from the various Colombian mines cannot be distinguished, perhaps with the exception of those from Gachalá. They tend to be paler and a little more bluish-green than other Colombian emeralds (Figure 2b). Chemical data of Gachalá emeralds are scarce. The most recent analysis[5] demonstrates that this colour is not caused by a higher iron content but by lower Cr and V concentrations. Fe is also much lower than the Colombian average (0.3 wt%), and an aquamarine component in the *e*-ray absorption (due to Fe^{2+}/Fe^{3+} charge transfer) is not present.

c. UV/VIS absorption spectra of emeralds permit statements to be made with respect to chromophore ratios and colour, as well as *differentiations between*

[5] *Partial chemical analysis of eight Gachalá emerald crystals*
Microprobe data, in weight % (Schwarz 1991)

	Variation	Mean
SiO_2	66.77 – 67.55	67.22
Al_2O_3	16.69 – 17.48	17.15
Cr_2O_3	0.02 – 0.43	0.10
V_2O_3	0.02 – 0.15	0.09
FeO (Fe_{tot})	0.03 – 0.12	0.07
TiO_2	n.d. – 0.02	0.01
MnO	n.d. – 0.03	0.02
MgO	0.15 – 0.48	0.34
Na_2O	0.14 – 0.29	0.25
CaO	n.d. – 0.02	0.01
K_2O	n.d. – 0.01	0.01
Sum		85.27

BeO and H_2O not analysed Cr/V = 1.1

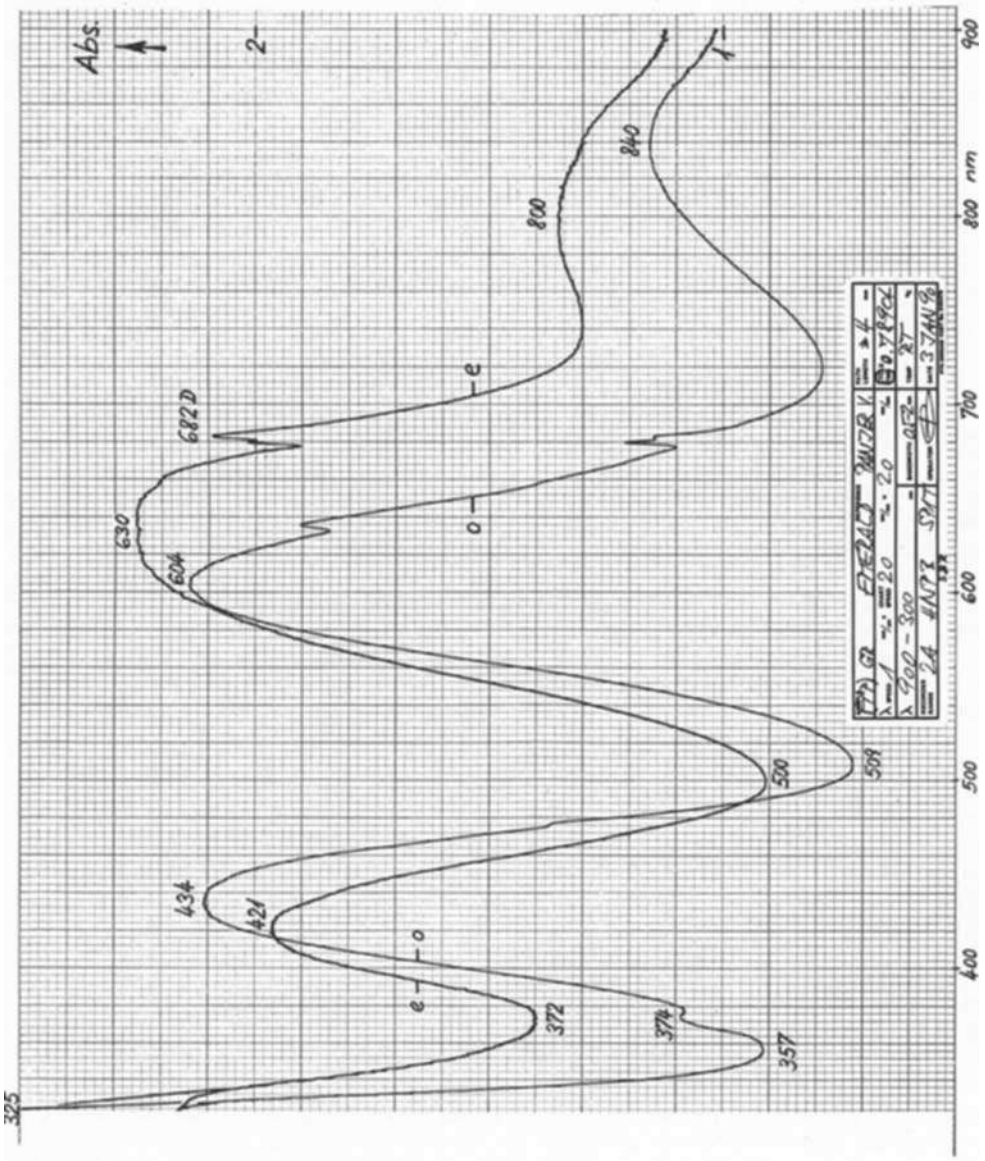

Fig. 4. Polarized absorption spectra of a bluish-green emerald from the Panjsher valley, Afghanistan. Emerald type I, Cr/V ≈ 1.5. Weight 0.789 ct, density 2.721 g/cm^3, $n_{D,e}$ 1.580, $n_{D,o}$ 1.588, optical path length about 4 mm. Maxima of the absorption bands near 430 and 630 nm and of the line doublet near 682 nm quenched by stray light losses on the dense inclusion pattern.

certain origins and synthetic productions. For the latter, evaluation of the absorption features is carried out in the UV, similarly to that pertaining to the natural and synthetic rubies (Bosshart 1982), as well as in the very near infrared (see special literature for near and mid-IR analysis).

The average *position of the absorption minima in the ultraviolet region* for Colombian emeralds is at

340 (±5) nm for the *o*-ray and at

346 (±5) nm for the *e*-ray.

Transition from the *absorption edge* to the general absorption, on average, is at

298 (±15) nm for the *o*-ray and at

304 (±10) nm for the *e*-ray.

These UV minima and absorption edge positions have been found to be at lower wavelengths than those of natural emeralds from other deposits, including Jos, Nigeria, and Panjsher, Afghanistan (Figure 4), as well as those of synthetics containing iron or iron, nickel and copper (certain Gilsons, Inamori; Vasar USSR, etc.). Moreover, the UV minima of the Colombian emeralds are more deeply developed.

On the other hand, the low-iron synthetic emeralds (Chatham, Biron etc.) can be differentiated by their absorption edges at lower wavelengths and by their broader UV minima.

Absorption bands in the very near infra-red caused by Fe^{2+} (near 820 nm) have hardly been detected in Colombian emeralds nor in low-iron synthetics. In most natural emeralds (Figure 4) and in Fe-containing synthetics (Vasar), however, they can be observed. The structural position of Fe^{2+} is disputed (Al^{3+} octahedral, Be^{2+} tetrahedral or structural channels?).

The moderate Fe^{3+} content of Colombian emeralds usually does not make its appearance in their absorption spectra: the substitution of Al^{3+}oct. and Si^{4+}tetr. is very subordinate and the aquamarine component from Fe^{2+}/Fe^{3+} charge transfers on Al lattice sites is absent. Therefore the colour-inefficient positioning of Fe^{3+} might be suspected to take place in the structural channels.

Two minor absorption lines at 733.8 and 833.4 nm ($e \gg o$) are virtually always observed in Colombian stones, but have also been noticed in a Panjsher emerald and a synthetic Biron individual. The cause of these absorption lines is not evident.

d. Marginal notes for the practising gemmologist:

Cr absorption (and emission) lines can be seen through the spectroscope in type I but not necessarily in type II emerald (see Figures 2 and 3). However, because of the V masking discussed above, the observation of Cr lines in the hand spectroscope does not infallibly mean that the examined stone is a type I emerald containing more Cr than V, or even no V (examples Figure 2c and Biron synthetics).

The *UV-fluorescence* under long-wave radiation varies in Colombian emeralds from inert to medium weak red. The reaction to short-wave UV rays is nearly always inert. This, as also the behaviour observed with a Chelsea filter, is undiagnostic and not suited for the discrimination of emeralds from many synthetic emeralds.

A typically turbid, red *VIS-fluorescence* may be excited in many Colombian emeralds with strong, UV-poor lateral illumination from a fibre-optic beam (Figure 10).

C4. *Optical values and density*

The values given in Table 2 are low to average, compared to those of other natural emeralds. They relate to the numerous and largely independent substitutions by water, alkalis and chromophores which can be small to medium in amount. Accordingly there is *no strictly linear correlation of n and D.* This irregularity can be explained by the variable addition of zeolitic water (H_2O type I and II in the channels) which appears to influence density more than the optical values.

The sets of data taken from the literature and the values collected at the Laboratory largely agree. Table 2 does not include data for Trapiche emeralds nor moralla, but only for mediocre to excellent quality grade. The n (RI) and D values of Colombian gem-quality material are unlikely to lie outside the given ranges, yet slightly higher figures are to be expected for the rare specimens with abnormally high chromophore (or alkali) contents. Abnormally low density values such as 2.64_6 g/cm^3 (laboratory minimum 2.676) relate to enclosed cavities or artificial resin-like organic fillers (applied in new, permanent treatments).

While refractive indices may very occasionally be found to vary on strongly (colour-)zoned emerald individuals, the hydrostatic determination of the density in all cases results in one value only, the bulk density.

C5. *Inclusions and growth characteristics*

Solid and (primary and secondary) fluid inclusions, as well as growth inhomogeneities, are known as the main internal characteristics of Colombian emeralds. They permit conclusions to be drawn as to crystal growth and growth conditions. Characteristic features of Colombian emeralds are three- and multi-phase inclusions (Eppler 1973, Gübelin 1973, Roedder 1982, Gübelin & Koivula 1986, Kozlowski *et al.* 1988).

a. Primary *fluid inclusions* appear in crystallographically orientated, shallow cavities. Pseudo-

Table 2. Optical values and density of Colombian emeralds

Extraordinary refractive index	$n_{D,e}$	1.565 to 1.578	Literature
		1.566 to 1.581	Laboratory
Ordinary refractive index	$n_{D,o}$	1.571 to 1.584	Literature
		1.572 to 1.588	Laboratory
Maximum birefringence	n_e-n_o	−0.005 to −0.007	Literature
		−0.005 to −0.008	Laboratory
Anomalous double refraction		frequently present, strong 'moiré' extinction pattern (due to strain in the optic axis direction)	
Optic axis figure		axial cross, mostly open (abnormal, slight biaxiality)	
Dichroism		often weak (*o*-ray ≥ *e*-ray) *o* yellowish-green, *e* bluish-green	
Density (in g/cm³)	D	2.64_6 to 2.73_0	Literature
	$D_{20°/4°C}$	2.682 to 2.727	Laboratory

Accuracy of Lab. data (estim.) $n_D \pm 0.002$, $D_{20°/4°C} \pm 0.005$ g/cm³.

secondary fluid inclusions are usually smaller and not orientated as the primary ones are. In larger numbers, the secondary inclusions are connected to each other. They indicate slightly to strongly vaulted, ancient tension cracks (now healed fissures). In their entirety these *healing fissures* mostly produce but a slight turbidity. The gem trade sometimes calls the eye-visible veil in its green surroundings a 'jardin' (Figure 5).

The individual, more or less shallow primary *cavities* parallel to the main growth axis *c* are typically pointed or tapering into thin tubes. They form jagged peaks like regular fine palisades or coarse stockades (Figures 6,7,8). In basal directions they present more roundish, shape-less or angular contours. A peculiarity which the author until now has only observed in Colombian emeralds, is fluid inclusions bending off from the prismatic to the basal direction (or vice versa). The widespread interpretation as to the formation of the spiky-prismatic voids prior to the basal ones is very doubtful in this light. Their dissimilar shape does not point to a chronological succession but to growth conditions depending from directional differences within the crystals.

The cavities were originally filled with a homogeneous, single-phase brine at a temperature of over 470°C. This was an aqueous solution with a salt content of approximately 40 wt% Cl and Na ±(Ca,Si,Al,(C),K etc.). *At room temperature* and with magnification, this fluid filling is seen to be *mostly exsolved into three phases*: an immobile gas bubble (phase *g*) and one or several similar crystals (*s*, for solid phases, also called daughter minerals), embedded in the saturated residual liquid (phase *l*).

The *gas bubbles* take up 10 to 11%, the crystals 12 to 15% and the brine about 75% of the cavity volumes. The gas bubbles contain carbon dioxide under variable pressure and can be surrounded by a thin crescent of liquid carbon dioxide (≤ 3% CO_2).[6] This can be detected only in shallow cavities (Figure 8). In the thicker ones the bubbles appear too dark because of the strong optical relief. Methane (CH_4) and nitrogen gas (N_2) have also been reported.

The square to rectangular *daughter crystals* have been identified as halite (NaCl, cubic). It is assumed that there is also some subordinate sylvine (KCl, cubic). These 'flattened' cubic crystals are more often found than crystal forms resembling rhombohedra. Considering their anisotropic nature, the latter are assigned to a carbonate. It seems most probable that they are calcite or dolomite crystals (Figure 8).

Hexagonal, small-grained anisotropic crystals exsolved from the fluid fillings have been pictured as well. A single emerald crystal and even a single cavity can house cubic, lozenge and other daughter crystals. Combinations of several types of daughter crystals and a gas bubble in the saturated residual

[6] The longitudinal extension of fluid inclusions may have been epigenetically constricted or even cut off. This event, called 'necking down' or 'necking', modified the cavity fillings with respect to the relative volumes of the individual, segregated phases as opposed to the normal undisturbed (s,l,g) state. For instance, one very large gas bubble may have built up in one and a daughter crystal may have been cut off in the neighbouring, separated cavity.

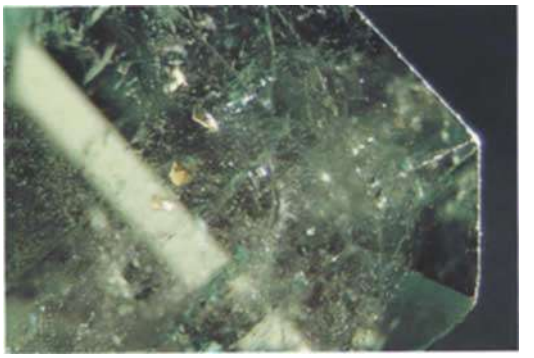

Fig. 5. Dense inclusion array in an octagonal emerald from Colombia. Width of photograph represents approximately 6 mm.

Fig. 6. Predatory octopus and his protégée with full stomachs in a green sea. Three-phase inclusions of variable appearance, the largest one being a 0.4 mm long and unusually thick cavity, spiky on one side and filled with a gas bubble and a salt crystal (also containing an inclusion).

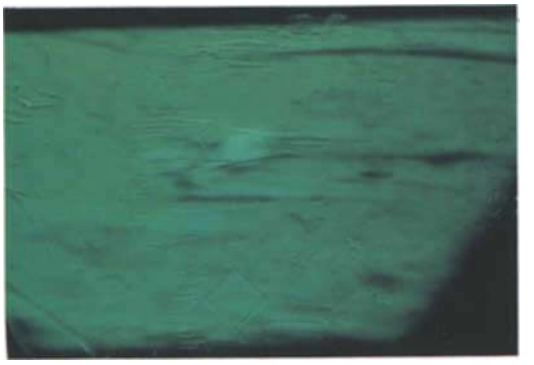

Fig. 7. Exceptionally thin cavities filled with residual brine, slightly brighter gas bubbles (almost without any relief) and two exsolved, zoned halite daughter crystals. Jagging of these primary growth voids running parallel to *c*, the main axis [0001] of the emerald crystal. Width of photomicrograph represents approximately 1.2mm.

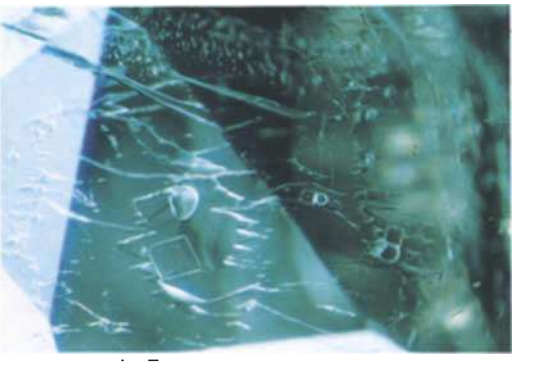

Fig. 8. Primary axial healing fissure with flat cavities containing different exsolution components of constant volume proportions of s/l/g. Largest gas bubble with a delicate crescent seam of liquid carbon dioxide (CO_2), largest daughter crystal with a rhombohedral habit and zonal structure (a carbonate), smaller daughter crystals with a cubic habit (halite). Long diagonal of the rhombohedron circa 0.25 mm.

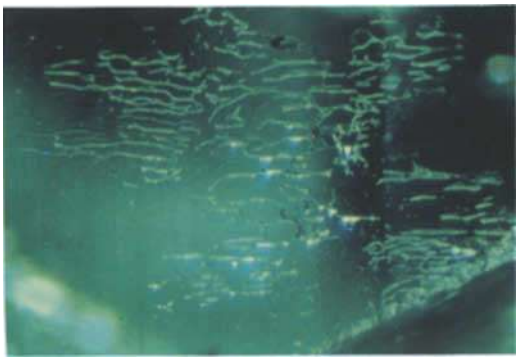

Fig. 9. Plane (pseudo?)secondary gas and fluid network in a Colombian emerald. Width of photomicrograph represents approximately 2.4 mm.

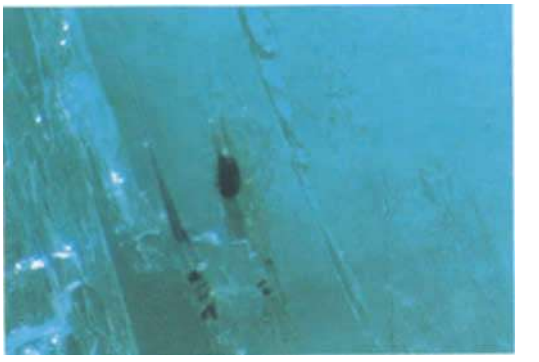

Fig. 10. Yellow and dark brown primary cavity fillings of segregated organic liquids (presumably light carbohydrates). Length of drop about 70 μm (0.07 mm).

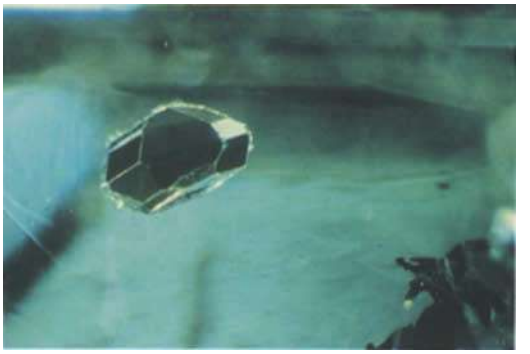

Fig. 11. Distorted polyhedral pyrite crystal with fine tension fissures along its edges, enclosed in a structurally disturbed emerald. Length of pyrite crystal approximately 0.85 mm.

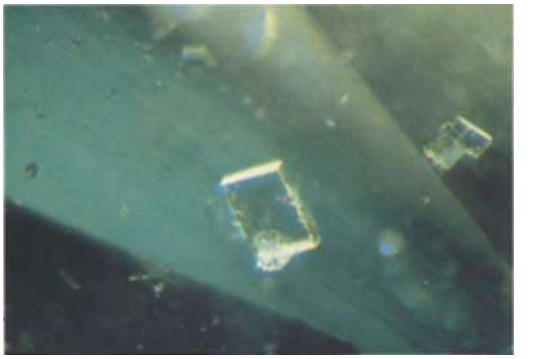

Fig. 12. Rhombohedral, colourless syngenetic mineral inclusion (calcite?) in a very transparent emerald. Smaller grains with less euhedral shapes (albite, quartz, parisite?). Long diagonal of largest rhombohedron about 0.4 mm.

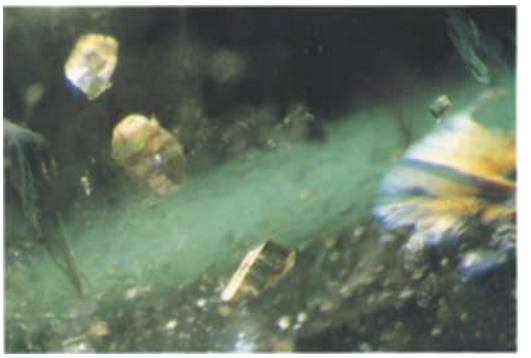

Fig. 13. Loose group of larger, brownish and smaller, yellowish parisite crystals included in the emerald displayed in Figure 5. Barrel-shaped, short-columnar and pyramidal habits. Iridescent tension crack (not 'Opticon'-treated). Width of largest crystal approximately 0.35 mm.

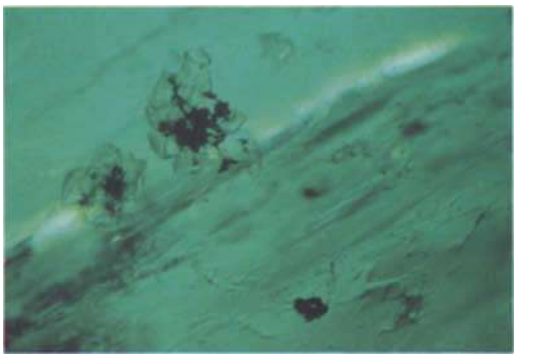

Fig. 14. Aggregate of transparent crystals and small opaque grains (albite or carbonate and carbonaceous shale). Width of largest cluster about 0.3 mm.

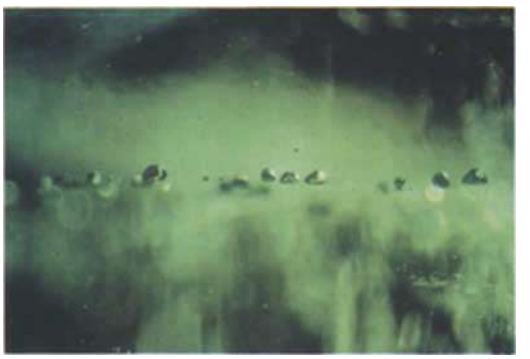

Fig. 15. Small syngenetic pyrite crystals of different shape and size, distributed on a basal plane. Width of photomicrograph represents circa 8 mm.

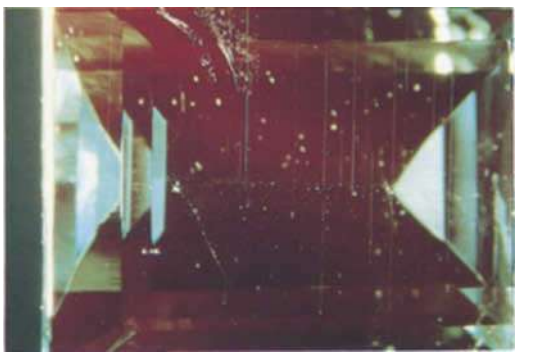

Fig. 16. Red fluorescence (682 nm chromium emission) strongly excited by a 100 watt fibre-optic side illumination in a particularly transparent emerald octagon displaying long axial growth tubes and slightly vaulted pseudo-secondary healing fissures. Tiny mineral inclusions having acted as starting points for the slender acicular crystallization disturbances. Width of emerald approximately 9.2 mm.

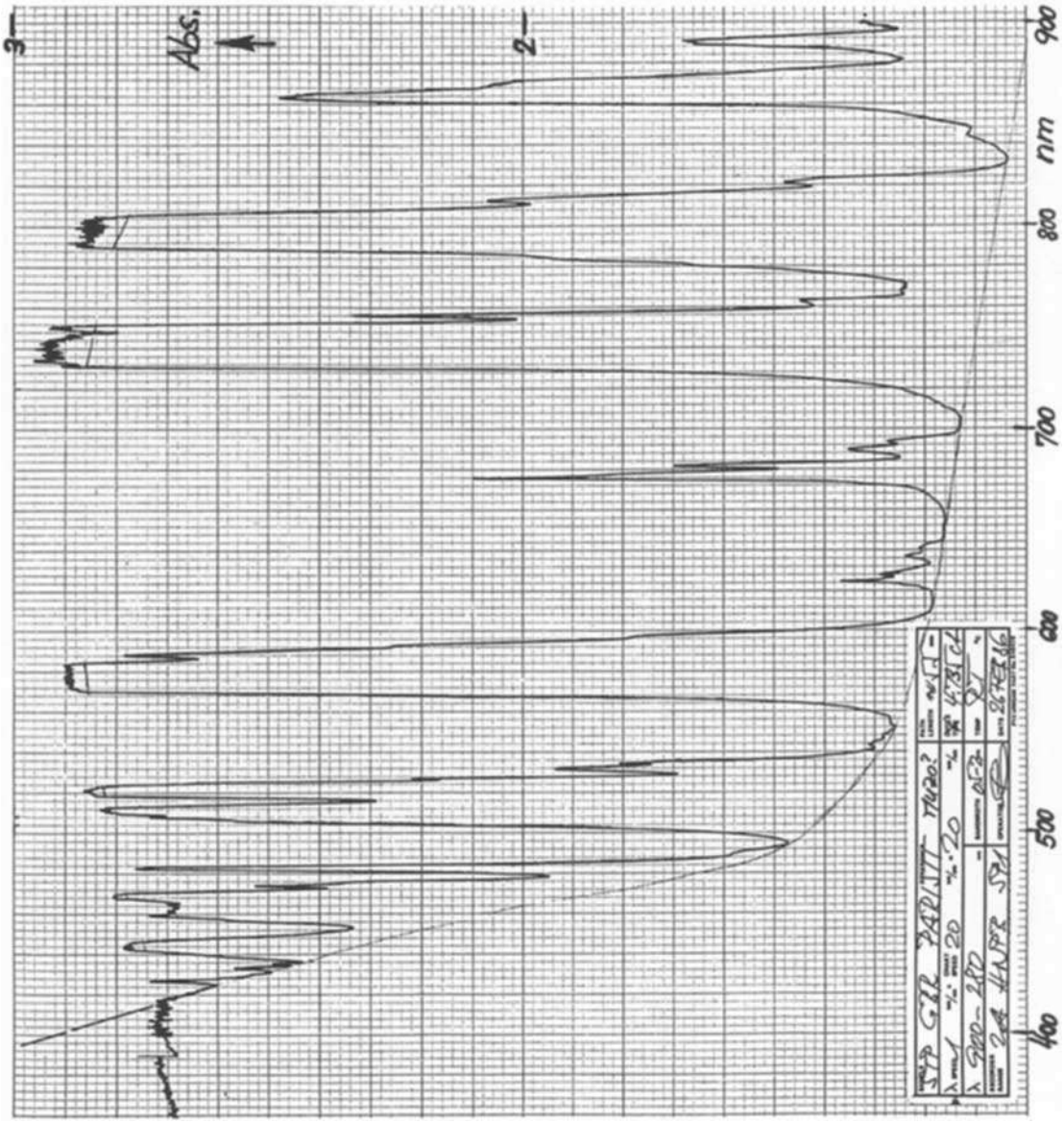

Fig. 13a. Polarized absorption spectrum of a semi-transparent, brownish orange-yellow parisite crystal from Muzo(?), Colombia. Weight 4.735 ct, density 4.34 g/cm^3, optical path length about 5.5 mm. Classical rare earth absorption behaviour: the numerous and very strong but more or less equally spaced absorption bands (fine multiplets) in the visible region have a lesser effect on the parisite body colour than the continuous increase of underlying absorption towards the violet-blue region. The multiple absorption centred at 580 nm, however, is the cause of a slight colour-change effect (Bosshart *et al* 1982) seen in some parisites. For the sake of clarity, only the e-ray spectrum is displayed.

solution are known as *multi-phase fillings*. Another kind of multi-phase inclusion can be made up of a fluid, some liquid carbon dioxide, a gas bubble and solid rock salt.

Two-phase fillings in the cavities are noticed less frequently than three- or multi-phase inclusions. In healed fissures these (l,g) inclusions are small and delicate. As autonomous basal networks of liquid and gas, they can show spectacular relief (Figure 9). This is yet another proof that the original chemical composition of the fillings had not to be identical in every single cavity or healing fissure of an emerald.

The observed phenomena point to a complex geological history of the emeralds, marked by syngenetic infiltration of fluid phases into the primary growth voids and by secondary formation and filling of tension cracks.

Occasionally the brine was heterogeneously enclosed together with an immiscible constituent of some dark brown liquid which could well be a cracked mineral oil. Brownish-yellow to dark brown liquids sometimes are also found as *single-phase fillings* of cavities (to present without a surface contact, i.e. sealed in). They are rare and presumably also primary formations. In Figure 10 two types of organic liquids can be distinguished, the darker hydrocarbon having segregated in several instances as droplets from the lighter variety.

b. *Proto- and syngenetic mineral inclusions* are not particularly frequent in Colombian emeralds. They consist of pyrite crystals displaying a bright yellow metallic lustre (Figure 11) and the following colourless minerals: tabular albite, rhombohedral calcite or dolomite (Figure 12, sometimes whitish) and rarely also prismatic quartz.

Small reddish to yellowish-brown spear-shaped crystals of the decidedly rare, trigonal *parisite* $Ca(Ce,La,Nd,Pr)[(CO_3)_3/F_2]$ may be noted in Colombian emeralds.

The most prominent parisite inclusions encountered were fairly large, brownish-yellow barrel-shaped to pyramidal crystals (maximum length 0.7 mm, maximum diameter 0.35 mm, Figure 13). Parisite (Ca(Ce,REE)-carbonate) was successfully identified by the main lines and bands of the rare earth absorption spectrum at 442, 460, 512, *520*, 534, 574/*579*/584 and *678* nm. The spectrum was observed through a hand spectroscope held into the ocular tube of a stereo-microscope and compared to the absorption spectrum of a crystal specimen from Colombia recorded on a spectrophotometer (Figure 13a). Recent chemical investigations by ED-XFA and electron microscope analyses of these inclusions and other Colombian parisite samples confirmed the elements Ca,Ce,La,Nd+Pr and a very good cleavage. In addition, traces of Y and Th were found to be present.

Another, more frequent feature of Colombian emeralds are *aggregates* of tiny, dark grey grains. They are thought to be particles of the wall rocks, that is traces of carbonaceous shale such as those found in Trapiche emeralds (Figure 14). Pyrite, as well as albite, quartz, calcite and parisite, can occur in free crystal groups or grainy aggregates. Accumulation of a single mineral species on a growth plane has also been seen (Figure 15). Bands of fine dust ‖ c are occasionally observed also.

From time to time rusty to yellow-brown goethite turns up as a crust on fissures or as grainy aggregates in cavities. This list of crystal inclusions may not be absolutely complete.[7]

Microscopically and spectroscopically the listed mineral inclusions are not readily identifiable, with the exception of parisite and the ore mineral pyrite.

Statistically speaking, pyrite crystals appear most commonly in Chivor emeralds and calcite and parisite in Muzo emeralds. However, pyrite and calcite are found in emeralds of both districts and parisite also in those from Coscuez. Thus in the individual testing case, determination of origin by mineral inclusions is not feasible.

So far Gachalá emeralds alone seemed to be recognizable to some extent. They exhibit a better transparency (fewer healing fissures), a paler and more greenish-blue colour, more mineral inclusions (albite), more and longer growth tubes and a stronger VIS-fluorescence (Figure 16) than other Colombian emeralds. These properties, however, are said to be virtually identical to those of emeralds from the 'new' Yacopí mine in the Muzo district (personal communication by D. Schwarz, 1989).

c. *Internal growth characteristics* of five different kinds have been noted in cut Colombian emeralds: as colour zoning, colour spindles, growth zoning, growth spirals, and growth tubes. On the other hand, twinning has not been observed in a single instance (twinning in beryl is extremely rare).

As a rule, colour zoning as well as straightforward growth zoning (i.e. zoning without colour contrast, Figure 17) occur as series of prismatic and/or basal planes. Pyramidal zoning is less widespread.

Prismatic colour zoning classically consists of a sharply defined, colourless, yellowish or pale green prismatic core, surrounded by a saturated green shell. Colour distribution can also be inverse. Hosts of colourless 'holes' are met with much less frequently. These are essentially colourless prism-like

[7] Fujisaki (1976) identified several ore minerals in a Colombian emerald individual: pyrite, pyrrhotine, pentlandite and rutile. The formation of the last three minerals is difficult to explain in the postulated hydrothermal growth environment (especially pentlandite $(Fe,Ni)_9S_8$, cubic) except, if some connection from a remote (ultra)basic source to the deposit had been in existence.

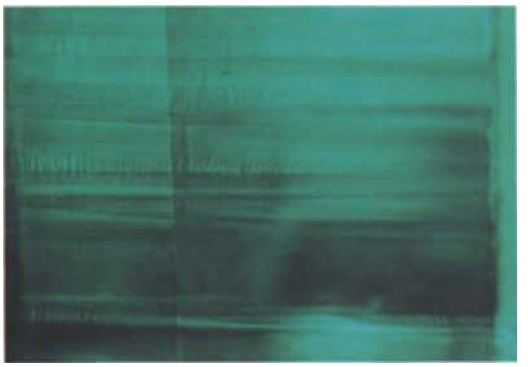

Fig. 17. Lamellar to slightly wedge-shaped basal growth structures with palisades of short spindles on individual growth planes. Photomicrograph height represents 1.50 mm.

Fig. 18. Host of nearly colourless, axial columns in an emerald cabochon. Largest diameter of the columns approximately 1.5 mm.

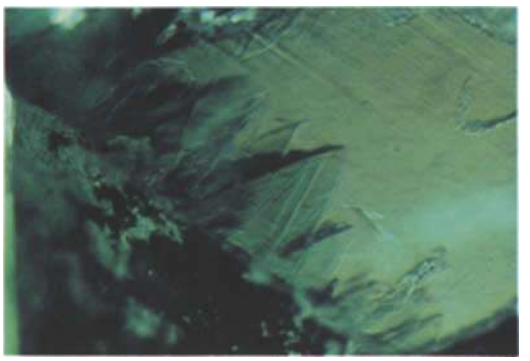

Fig. 19. Steep, saturated green pyramids with axes parallel to the main growth direction *c* of the emerald. Height of pyramids up to about 0.5 mm.

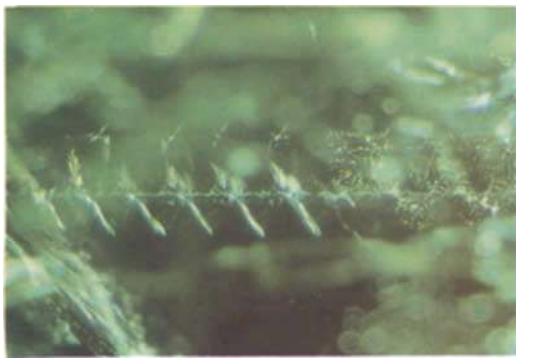

Fig. 20. Axial growth tube with a spiral passing from a fissure into a healing fissure. Next to it a more delicate helix in reverse sense of rotation. Width of photomicrograph represents approximately 2 mm.

Fig. 21. Axial view onto a basal plane covered with corrosion cells. Shallow etch pits structured with modified or hinted hexagonal contours. Width of photomicrograph about 9 mm.

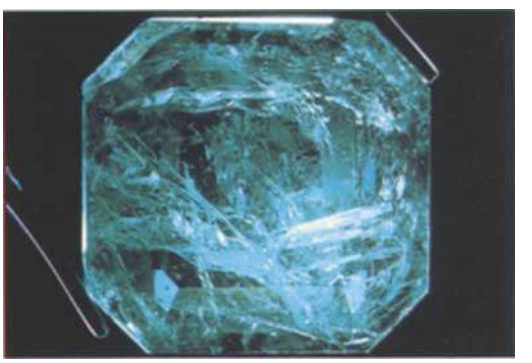

Fig. 22. Faceted Colombian emerald with characteristic, strongly reflective tension cracks, in the de-oiled state. Length of brightest crack approximately 1.25 mm.

columns of small diameter parallel to the *c*-axis in otherwise green crystals (Figure 18).

Basal colour zoning can be a sequence of colourless and green, flat and well defined lamellae. As cutters usually orient the emerald with the *c*-axis almost parallel to the table, the basal zoning can be quite obvious as a colour striation traversing the crown of the stone. Similarly, in the case of the fluid inclusions, transitions can be seen between the prismatic and the basal zoning which, in reality, are combinations of both directions with small pyramidal growth zones in between.

The *pyramidal colour zoning* normally starts on basal planes. These pyramids may show very strong green colour saturation and steeply sloped arches tapering in the growth direction (Figure 19). Pyramids may also be pale in colour and have formed prior to the growth of green zones. Well-defined zigzag formations towards the outside of the crystals do not necessarily stem from irregular pyramidal growth of variable inclination but rather from growth planes separating the older core and the younger shell.

Closely related with the growth pyramids, on the other side, are palisades of flame-like spindles which also originate on basal planes (Figure 17). Neither colourless nor coloured spindles are very common but they can reach lengths of up to 2 mm.

Small hillocks on basal planes reminiscent of the shallow growth pyramids of Linde synthetics have also been detected.

Under the microscope, *basal, prismatic and pyramidal growth zoning* can easily be recognized and differentiated. According to Kiefert & Schmetzer (1990), combinations of zonal structures enable identification of authenticity of Colombian emeralds but not of their exact provenance.

Growth spirals are attractive but sporadic phenomena in Colombian emeralds. They prove two facts: that an emerald crystal does not have to be built up by planar growth fronts and that healing of the spirals by fluid brines can set in and be terminated at any stage of growth (Figure 20). The same phenomena can be observed in the hydrothermal synthetics after Biron (today Pool, Australia), however, without a central growth tube.

Other subtle and quite common characteristics are the *growth tubes*. They run parallel to the main growth direction (Figure 16), occasionally also vertical to the *c*-axis. These tubes are very fine and long and can show two-phase (l,g), three-phase (s,l,g) or multi-phase fillings (s_1,s_2,l_1,l_2,g).

Starting point for the growth tubes are sometimes the mineral inclusions described above because these solids have formed intrinsic obstacles facing the growth front. Tubes are growth gaps comparable to very long negative crystals (often measuring several millimetres).

Actual *negative crystals* have not frequently been encountered among gem quality material, the largest one according to laboratory notes having been a lathe-like cavity measuring about 1.6 × 0.8 × 0.45 mm.

d. Flat primary cavities, colour zoning, growth spirals and tubes are all indicators of emerald crystal build-up. The contrary, decomposition, is much rarer, making its appearance in the form of flat, cellular *etch pits* on basal planes (Figure 21, as occasionally also seen on the base of emerald crystals). These etch marks have been overgrown again, subsequent to the corrosion phase. Under crossed polars they show strain birefringence instead of straight extinction and low optical relief.

Although Figure 21 can also be interpreted as flat hillocks (truncated pyramids) as a consequence of spiral or polygonal beryl growth (cf. Sinkankas 1981, Figures 9-26), this interpretation is less probable than corrosion in view of the irregularity of their contours.

Similar or identical cellular phenomena have also been described as thin, basal layers of calcite crystals.

e. The least desirable properties of many Colombian emeralds are undoubtedly their numerous *tension cracks*. They have formed either during or after growth (and could have been healed out) and some could have formed during mining. Since white light is reflected back from these fractures to the outside after a short light path through the emerald, the cracks are very obvious and look white rather than green (Figure 22).

[*Manuscript received 19 March 1990.*]

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The microscopic determination of structural properties for the characterization of optical uniaxial natural and synthetic gemstones

Part 2: Examples for the applicability of structural features for the distinction of natural emerald from flux-grown and hydrothermally-grown synthetic emerald

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Abstract

The application of diagnostic growth structures for the distinction of natural and synthetic emeralds is discussed. Typical examples for the characterization of natural emeralds from distinct sources as well as of their synthetic counterparts of some producers are given. Criteria which are useful for the recognition of faceted gemstones as natural or synthetic are underlined. Gem materials described in detail are natural emeralds from Colombia and Nigeria, flux-grown synthetic emeralds from Chatham, Russia and Gilson as well as different hydrothermally-grown synthetic emeralds (Linde, Regency, Lechleitner, Biron, Pool, and Russian synthetic emeralds).

Zusammenfassung

Die Anwendung von Wachstumsstrukturen zur Unterscheidung natürlicher und synthetischer Smaragdse wird beschrieben.

Nicht nur typische Beispiele zur Charakterisierung von natürlichen Smaragden verschiedener Herkunft werden erwähnt, sondern auch von synthetischen Gegenstücke.

Nützliche Kriterien zur Erkennung geschliffener Edelsteine als natürlich oder synthetisch werden betont.

Die ausführlichst beschriebene Edelsteine sind natürliche Smaragde aus Kolumbien und Nigeria sowohl nach dem Flußmittelverfahren gezüchtete Smaragde (Chatham, Gilson, Rußland) als auch verschiedene nach dem Hydrothermalverfahren gezüchtete synthetische Smaragde (Linde, Regency, Lechleitner, Biron, Pool und russische synthetische Smaragde).

Resumen

Se, discute la aplicación de marcas de crecimiento diagnósticas para identificar las esmeraldas naturales y sintéticas. Se facilitan ejemplos típicos para la caracterizacion de esmeraldas naturales de yacimientos determinados. Se subrayan criterios que son útiles para reconocer gemas talladas como naturales o sintéticas. Las gemas descritas con detalle son esmeraldas naturales de Colombia y Nigeria, esmeraldas sinteticas Chatham, rusas y Gilson obtenidas por el procedimiento "melt" al igual que otras esmeraldas obtenidas por el procedimiento hidrotermal (Linde, Regency, Lechleitner, Biron, Pool y esmeraldas sintéticas de origen ruso).

I. Introduction

In the first part of this publication (Kiefert & Schmetzer, 1991) a detailed description of methods for the determination of characteristic crystal faces in faceted optical uniaxial gemstones by use of two simple auxiliary means is presented. These means are a two-axial sample holder (cf. Schmetzer, 1986) and a rotatable measuring ocular with cross hairs attached to the lens, both with attached 360° dials and fixable indicators. The best obtainable results, i.e. a complete determination of the structural characteristics present in one sample, are available by a combination of both methods.

This second part of the publication will reveal some examples for the practical applicability of the methods described in the first part in detail. The characterization of natural emeralds from two important sources (Colombia and Nigeria) as well as of some of their commercially available flux-grown

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Fig. 16. Growth structures in natural emerald from Colombia; planes parallel to the hexagonal prism *m* and *m'* $\{10\bar{1}0\}$ form an angle of 120°, smaller planes parallel to the prism *a* $(11\bar{2}0)$ are also present. View parallel to the *c*-axis. Crossed polarizers. 18x.

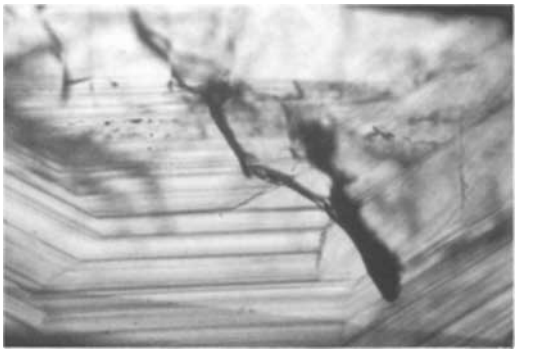

Fig. 17. Growth structures in natural emerald from Colombia; planes parallel to the hexagonal prism faces *m* $\{10\bar{1}0\}$ and *a* $\{11\bar{2}0\}$ form angles of 150°. View parallel to the *c*-axis. Crossed polarizers. 25x.

and hydrothermally-grown synthetic counterparts by means of growth structures is selected as one of the typical and important problems of determinative gemmology.

Figures 1-15 as well as Tables 1-3, which are occasionally referred to in this second part of the publication, are presented in the first part (Kiefert & Schmetzer, 1991).

II. Natural emeralds from Colombia and Nigeria

Natural emerald is mainly found in metamorphic deposits. Emeralds from these sources are recognizable by the presence of many different mineral inclusions such as mica and actinolite. Further diagnostic properties of emeralds from metamorphic deposits are characteristic sodium- and magnesium-contents, which are generally higher than those of synthetic stones. Absorption spectroscopy, which can, besides microscopic investigations, also be used as a non-destructive method, frequently reveals distinct iron absorption bands as well as a characteristic aquamarine component (Schmetzer, 1988). The emeralds from metamorphic source rocks, however, in many cases do not disclose characteristic growth structures of diagnostic value.

On the contrary, emeralds from deposits with a temperature of formation lower than that of samples from metamorphic deposits, reveal characteristic growth features useful for diagnostic purposes. Typical examples for these types of emeralds occur in different deposits in Colombia, in Nigeria, and, occasionally, are also found in material from Afghanistan. Larger quantities of emeralds from Afghanistan are very difficult to obtain and, therefore, samples from this particular source will not be considered in this publication.

Colombian and Nigerian emeralds, in contrast to emeralds from metamorphic source rocks, in most cases do not reveal any diagnostic contents of sodium and magnesium and, using only this feature, are hardly distinguishable from synthetic emeralds. Absorption spectra of Colombian emeralds also disclose no characteristic iron absorption bands, which are very often useful as diagnostic features for natural emeralds from metamorphic source rocks. Consequently, high quality emerald samples from Colombia or Nigeria sometimes create problems in determinative gemmology. In order to determine additional characteristic properties for these two types of emeralds, more than 200 rough and cut Colombian emeralds from different mines, and more than 100 rough and cut Nigerian emeralds were made available for a detailed investigation.

In general, the internal growth structures of Colombian cut emeralds correspond to the morphology of rough samples. The most significant growth planes in all Colombian emeralds are the first-order hexagonal prism *m* $(10\bar{1}0)$ [Figure 16] and the basal pinacoid *c* (0001). Part of Colombian samples additionally reveal the second-order hexagonal prism *a* $(11\bar{2}0)$, most frequently in a size

Fig. 18. Growth structures in natural emerald from Colombia; planes parallel to *c* (0001), *p* $(10\bar{1}2)$, *u* $(10\bar{1}1)$ and *m* $(10\bar{1}0)$. View perpendicular to the *c*-axis, the *c*-axis runs vertically. 80x.

Fig. 19. Growth structures in natural emerald from Colombia; planes parallel to *c* (0001), *s* $(11\bar{2}2)$ and *a* $(11\bar{2}0)$. View perpendicular to the *c*-axis, the *c*-axis runs vertically. 85x. Figs. 18 and 19 are related by a rotation of 30° about the *c*-axis.

Fig. 20. Growth structures in natural emerald from Colombia; planes parallel to *c* (0001), *p* $(10\bar{1}2)$ and *m* $(10\bar{1}0)$. View perpendicular to the *c*-axis, the *c*-axis runs vertically. 80x.

Fig. 21. Growth structures in natural emerald from Colombia; planes parallel to *c* (0001), *s* $(11\bar{2}2)$ and *a* $(11\bar{2}0)$. View perpendicular to the *c*-axis, the *c*-axis runs vertically. 70x. Figs. 20 and 21 are related by a rotation of 30° about the *c*-axis.

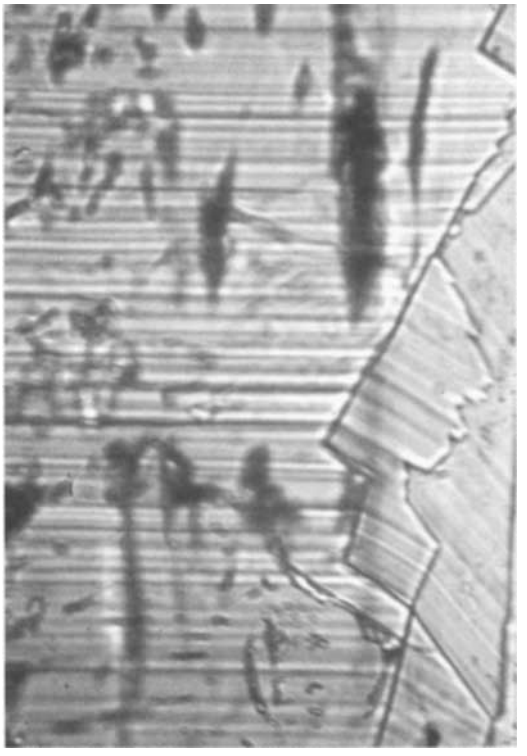

Fig. 18

Fig. 19

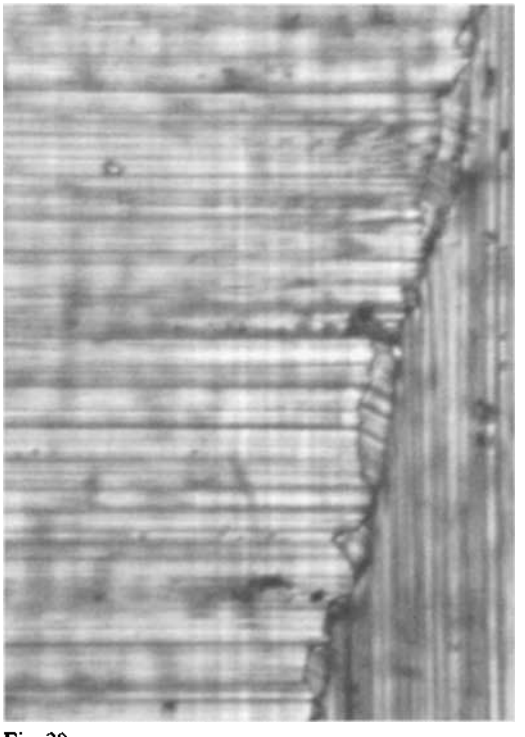

Fig. 20

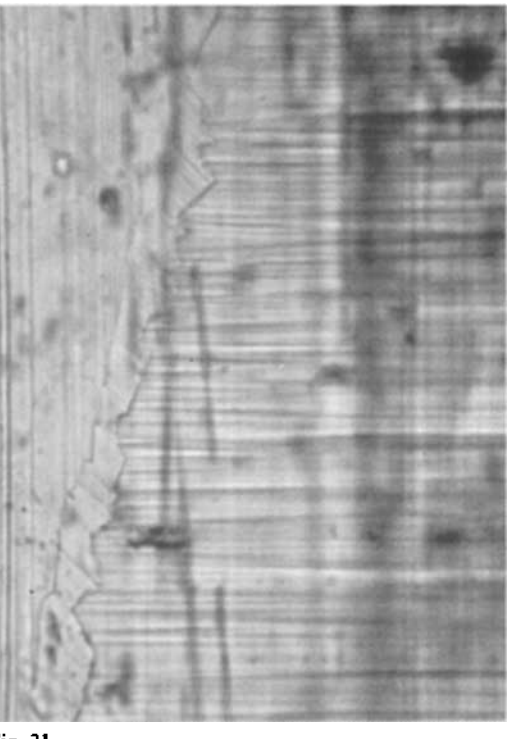

Fig. 21

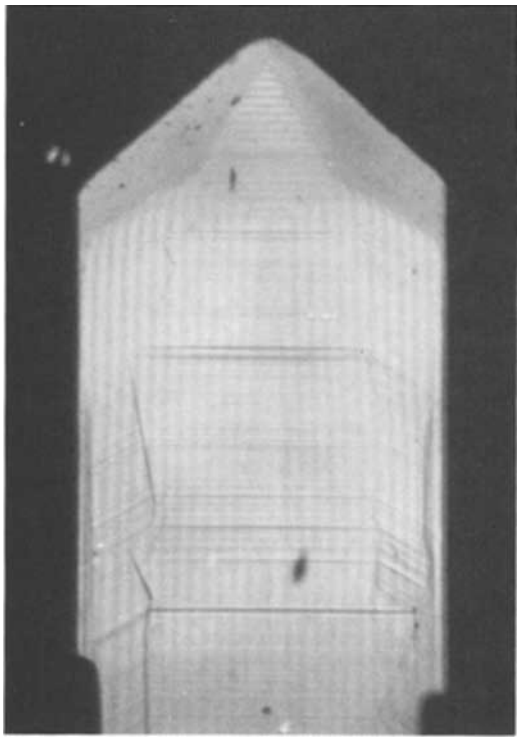

Fig. 22

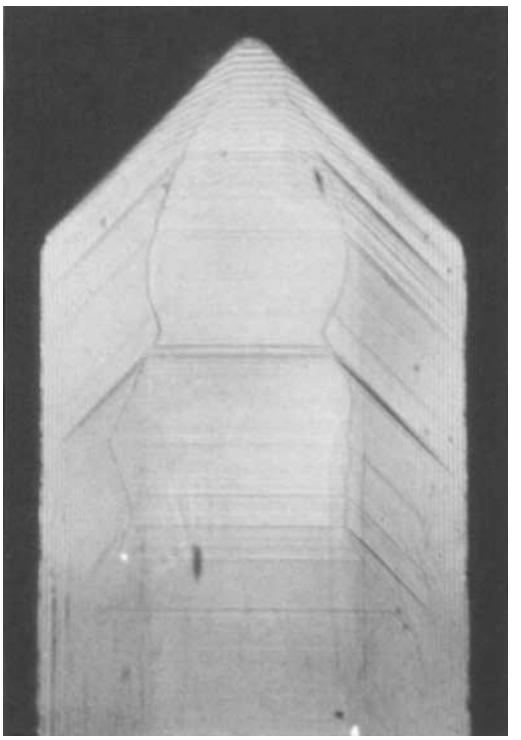

Fig. 23

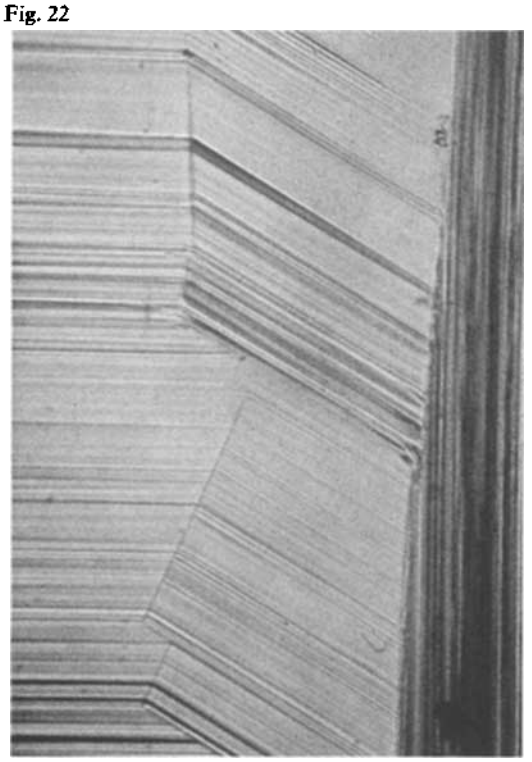

Fig. 24

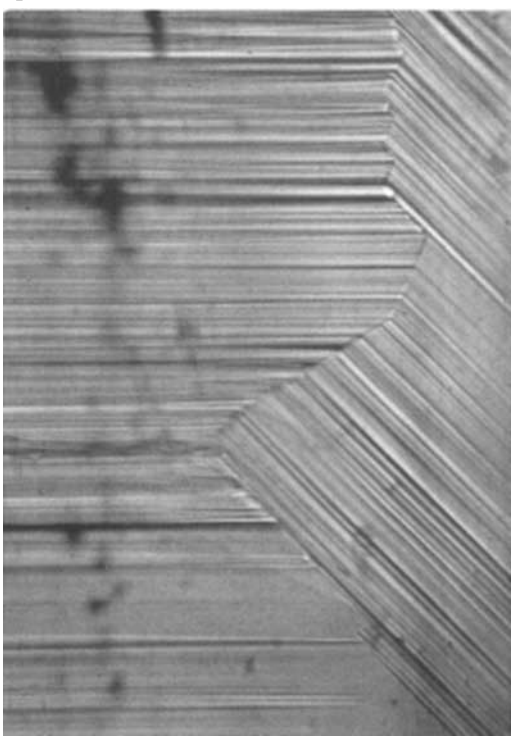

Fig. 25

smaller than the prism *m* as shown in Figures 4c and 16. Occasionally, this face also can reach the same size as the first-order hexagonal prism *m* $(10\bar{1}0)$ [Figure 17]. Additional growth planes are the first-order hexagonal dipyramids *u* $(10\bar{1}1)$ and *p* $(10\bar{1}2)$ and the second-order hexagonal dipyramid *s* $(11\bar{2}2)$ [Figures 4a, 4c, 18, 19]. These dipyramids were found to occur all together in some samples, other samples revealed only the first-order hexagonal dipyramid *p* $(10\bar{1}2)$ and the second-order hexagonal dipyramid *s* $(11\bar{2}2)$ [Figures 4b, 20, 21], and others disclosed, additionally to the above mentioned basal and prism faces, only the second-order hexagonal dipyramid *s* $(11\bar{2}2)$. So far, it has not yet been possible to distinguish between emeralds of the two major mining districts Chivor and Muzo, because part of the material available to the authors, most presumably, was already mixed up in Colombia.

The morphology as well as the internal growth structures of the investigated emeralds from Nigeria are identical with growth structures of aquamarines from the same mining districts (cf. Lind *et al.*, 1986). Beryls from this source always disclose the first-order hexagonal prism *m* $(10\bar{1}0)$ [Figure 27] and the second-order hexagonal dipyramid *s* $(11\bar{2}2)$, as well as the basal pinacoid *c* (0001) in different sizes [Figures 4b, 23, 25]. Besides these crystal faces, Nigerian emeralds very rarely show a small second-order hexagonal prism *a* $(11\bar{2}0)$ or a small first-order hexagonal dipyramid *p* $(10\bar{1}2)$ [Figures 4b, 22, 24, 26]. The first-order hexagonal dipyramid *u* $(10\bar{1}1)$, which is quite common in Colombian emeralds, has not yet been observed in Nigerian samples.

In comparison to synthetic emeralds produced by the flux method, a characteristic feature of emeralds from the two groups of deposits discussed above is the presence of the first-order hexagonal dipyramids *u* $(10\bar{1}1)$ and *p* $(10\bar{1}2)$ as well as the second-order hexagonal dipyramid *s* $(11\bar{2}2)$, which, in general, do not occur in synthetic emeralds produced by the flux method (see section III). However, the crystal faces *c* (0001), *m* $(10\bar{1}0)$ and *a* $(11\bar{2}0)$ can also be present in synthetic emeralds and, therefore, in samples in which only these crystal faces are determined, no definite characterization of the emerald by means of growth structures is possible.

Fig. 22. Growth structures in natural emerald from Nigeria; planes parallel to *c* (0001), *p* $(10\bar{1}2)$ and *m* $(10\bar{1}0)$. View perpendicular to the *c*-axis, the *c*-axis runs vertically. Crossed polarizers. 20x.

Fig. 23. Growth structures in natural emerald from Nigeria; planes parallel to *c* (0001) and *s* $(11\bar{2}2)$. View perpendicular to the *c*-axis, the *c*-axis runs vertically. 20x. Figs. 22 and 23 are related by a rotation of 30° about the *c*-axis.

Fig. 24. Growth structures in natural beryl from Nigeria; planes parallel to *c* (0001), *p* $(10\bar{1}2)$ and *m* $(10\bar{1}0)$. View perpendicular to the *c*-axis, the *c*-axis runs vertically. 30x.

Fig. 25. Growth structures in natural beryl from Nigeria; planes parallel to *c* (0001) and *s* $(11\bar{2}2)$. View perpendicular to the *c*-axis, the *c*-axis runs vertically. 30x. Figs. 24 and 25 are related by a rotation of 30° about the *c*-axis.

III. Some important types of flux-grown synthetic emeralds

The results of some experiments, in which spherical seeds of natural beryl crystals were prepared and subsequently used for growing synthetic emeralds in a flux of V_2O_5 were published by Ushio (1977). During these experiments Ushio observed in the first state of crystal growth the crystal forms *c* {0001}, *m* $\{10\bar{1}0\}$ and *a* $\{11\bar{2}0\}$ as well as different first- and second-order hexagonal dipyramids. After some days, however, all hexagonal dipyramids disappeared, and the final morphology of the synthetic emeralds produced by this flux method resulted in dominant basal pinacoids *c* {0001} and first-order hexagonal prism faces *m* $\{10\bar{1}0\}$, occasionally with a subordinate small second-order hexagonal prism *a* $\{11\bar{2}0\}$.

This morphology corresponds to the morphology of flux-grown synthetic emeralds produced by Chatham as well as to Russian flux-grown synthetic emeralds as described in the literature. According to Schrader (1987), crystal growth of Chatham flux-grown synthetic emeralds is performed by the use of small seed crystals. Russian flux-grown synthetic emeralds are produced by means of seeded growth as well as by spontaneous crystallization (Bukin *et al.*, 1980, 1986), which is also mentioned for Chatham flux-grown synthetic emeralds (e.g. Nassau 1976, 1980).

Consistent with literature data dealing with the morphology of both types of flux-grown synthetic emeralds, faceted samples of Chatham and Russian flux-grown synthetic emeralds examined by the authors disclose, as internal growth structures, only a combination of *c* (0001), *m* $(10\bar{1}0)$ and *a* $(11\bar{2}0)$ [Figures 28, 29, 31, 32, 33]. Other growth planes, for example in natural emeralds frequently observed hexagonal dipyramids *u* $(10\bar{1}0)$, *p* $(10\bar{1}2)$ and *s* $(11\bar{2}2)$ were not found in these flux-grown synthetic emeralds, and residual seeds were not observed. In addition to growth structures, another common feature of flux-grown synthetic emeralds is the zoning of residual flux parallel to dominant growth planes [Figures 30, 32], which does not arise in natural stones in this particular form.

As an example for flux-grown synthetic emeralds often containing residual seed plates, properties of

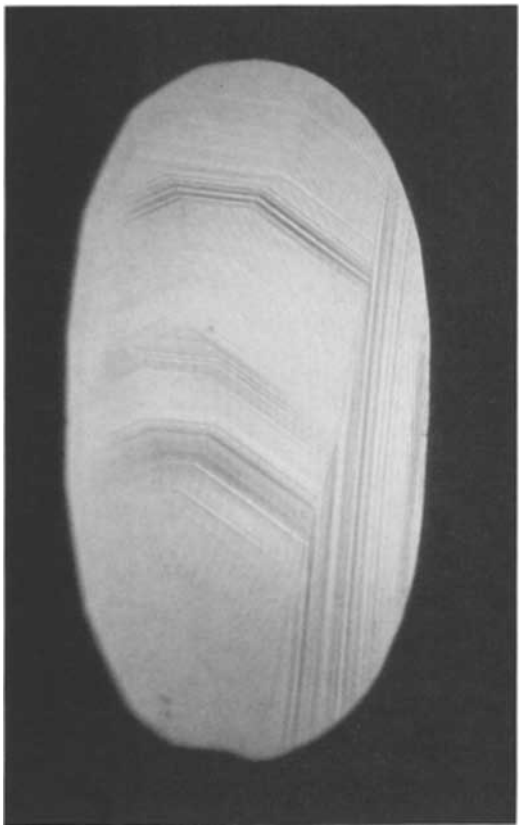

Fig. 26. Growth structures in natural emerald from Nigeria; planes parallel to c (0001), p ($10\bar{1}2$) and m ($10\bar{1}0$). View perpendicular to the c-axis, the c-axis runs almost vertically. Crossed polarizers. 12x.

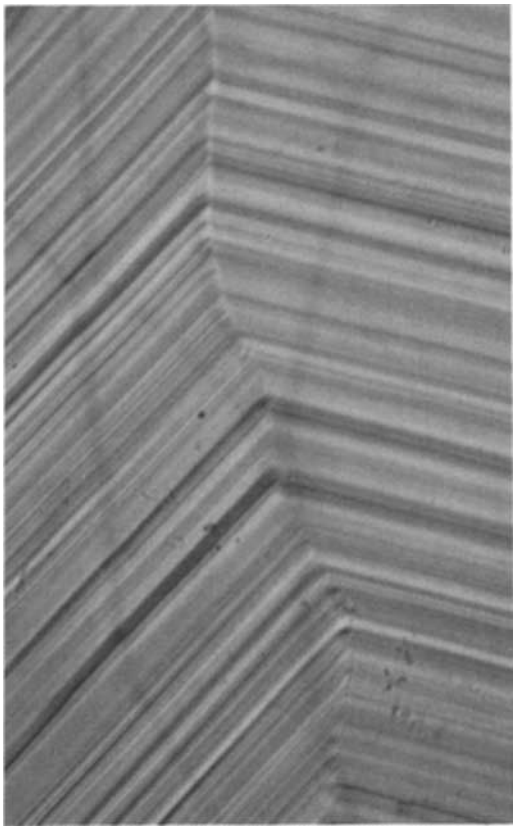

Fig. 27. Growth structures in natural beryl from Nigeria; planes parallel to the hexagonal prism m and m' $\{10\bar{1}0\}$ form an angle of 120°. View parallel to the c-axis. 30x.

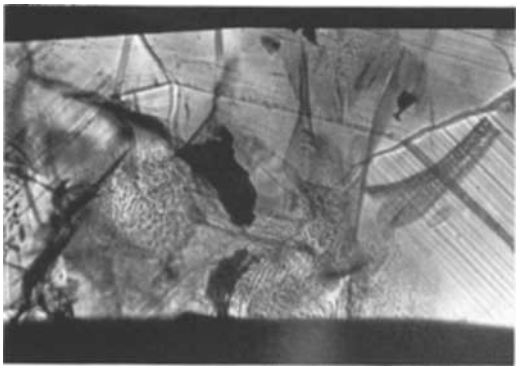

Fig. 28. Growth structures in Chatham flux-grown synthetic emerald; planes parallel to the hexagonal prism faces m $\{10\bar{1}0\}$ and a $\{11\bar{2}0\}$ form angles of 150°. View parallel to the c-axis. Crossed polarizers. 35x.

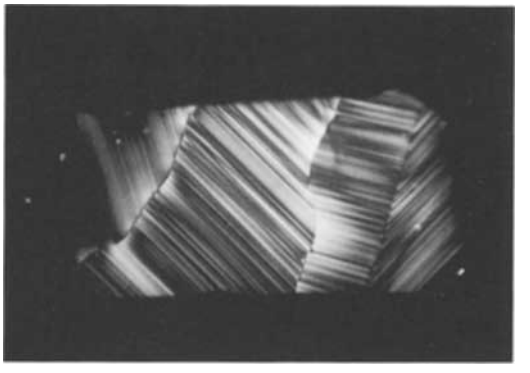

Fig. 29. Growth structures in Russian flux-grown synthetic emerald; planes parallel to the hexagonal prism faces m $\{10\bar{1}0\}$ and a $\{11\bar{2}0\}$ form angles of 150°. View parallel to the c-axis. Crossed polarizers. 20x.

Fig. 32. Growth structures in Chatham flux-grown synthetic emerald; planes and zoning of residual flux parallel to the basal pinacoid *c* (0001). View perpendicular to the *c*-axis, the *c*-axis runs vertically. 40x.

Fig. 33. Growth structures in Russian flux-grown synthetic emerald; planes parallel to the basal pinacoid *c* (0001) and parallel to one of the prism faces (*m* or *a*) form an angle of 90°; an intense colour zoning is also visible, growth zones confined to the prism are intense green, growth zones confined to the basal pinacoid are light green. View perpendicular to the *c*-axis, the *c*-axis runs vertically. 25x.

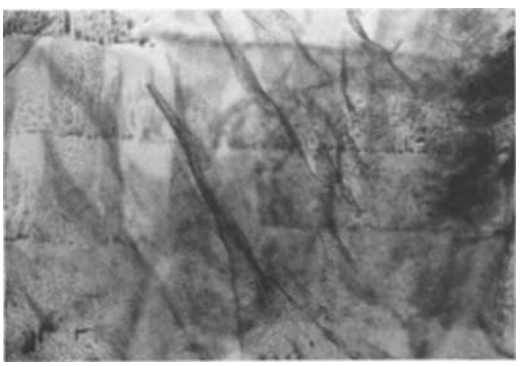

Fig. 30. Growth structures in Chatham flux-grown synthetic emerald; zoning of residual flux parallel to the basal pinacoid *c* (0001). View perpendicular to the *c*-axis, the *c*-axis runs vertically. 20x.

Fig. 31. Growth structures in Russian flux-grown synthetic emerald; planes parallel to the hexagonal prism *m* and *m'* $\{10\bar{1}0\}$ form an angle of 120°, smaller planes parallel to the prism *a* $(11\bar{2}0)$ are also present. View parallel to the *c*-axis. Crossed polarizers. 20x.

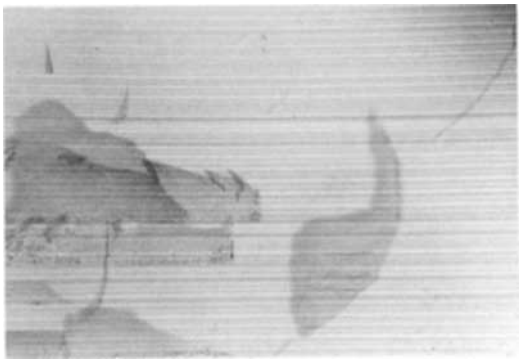

Fig. 34. Growth structures in Gilson flux-grown synthetic emerald; planes parallel to the basal pinacoid *c* (0001). View perpendicular to the *c*-axis, the *c*-axis runs vertically. 40x.

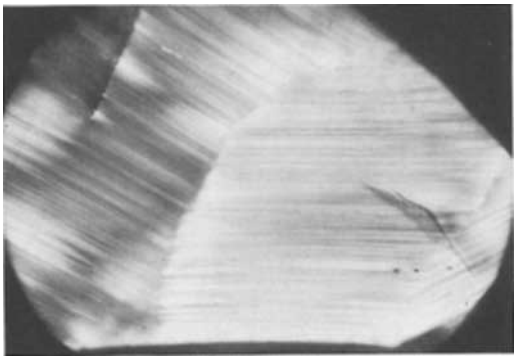

Fig. 35. Growth structures in Gilson flux-grown synthetic emerald; planes parallel to the hexagonal prism faces *m* $\{10\bar{1}0\}$ and *a* $\{11\bar{2}0\}$ form angles of 150°. View parallel to the *c*-axis. Crossed polarizers. 34x.

Gilson synthetic emeralds will be discussed in some details. In an earlier state of the production of Gilson synthetic emeralds, most presumably seed plates cut parallel to the basal pinacoid *c* (0001) were used (Sinkankas, 1981; Schrader, 1987), which is recognizable in cut samples by growth structures parallel to this dominant growth plane (cf. Schmetzer, 1989).

Obviously, the orientation of seed plates in Gilson synthetic emeralds was changed for the more recent commercial production. According to Diehl (1977), a tabular seed plate of natural colourless beryl cut parallel to the second-order hexagonal prism *a* $(11\bar{2}0)$ was observed in a rough crystal of Gilson synthetic emerald. Later on, seed plates of synthetic emerald were cut in the same orientation from the synthetic overgrowth of the colourless beryl seed and used instead of that (Nassau, 1976, 1980). During crystal growth, a morphology is developed, which, in addition to the basal pinacoid *c* $\{0001\}$, consists of two larger second-order hexagonal prism faces *a* and *a'* $\{11\bar{2}0\}$ on opposite sides of an octagonally shaped crystal, as well as of six crystal faces built by the first-order hexagonal prism *m* $\{10\bar{1}0\}$. This information is based on the investigations of rough crystals of Gilson synthetic emeralds by Diehl (1977, 1982) and Schrader (1987), and part of it is also found in the publication of Schwarz (1987).

The information given in the above mentioned publications corresponds to the observations made by the present authors. However, it has to be underlined that the material available for this investigation only consisted of faceted Gilson flux-grown synthetic emeralds weighing up to about 5 cts. This means that only structures were observable, which are characteristic for parts of the whole rough crystal plates of Gilson synthetic emerald. During the investigation of faceted samples, which were cut out of the crystal plates described above, emeralds with part of the seed plate and stones without residuals of the seed could be distinguished. Consistent with the more recent literature cited above, the samples examined by the authors contained only seed plates of flux-grown synthetic emerald. Depending on the position from which the stone was cut out of the synthetic emerald crystal, different possibilities of growth structures are observable in cut samples.

In those without part of the seed plate a number of stones revealed only a distinct zoning parallel to the basal pinacoid *c* (0001) as growth structure [Figure 34], others showed only structures parallel to one of the prism faces *m* $(10\bar{1}0)$ or *a* $(11\bar{2}0)$. In another part of this type of cut stones growth structures were observed, which revealed two sets of prism faces *m* and *m'* or *m* and *a* [Figure 35]. In other examples, the basal pinacoid *c* (0001) in combination with one of the two prism faces *m* $(10\bar{1}0)$ or *a* $(11\bar{2}0)$ was found [Figure 36].

In natural emeralds, no growth structures resembling those mentioned above were observed because of the size of natural emeralds. In other words, no natural samples with growth structures parallel to only one single basal or prism face in the whole cut sample or parallel to one prism face and the basal pinacoid were observed by the authors. For natural stones, it is not customary to cut only a small section out of a crystal with more or less prismatic natural habit. Faceted natural emeralds, in general, reveal growth structures of the whole rough crystals, e.g. the basal pinacoid *c* (0001) in combination with six larger prism faces *m* $\{10\bar{1}0\}$ and six smaller prism faces *a* $\{11\bar{2}0\}$ as well as different hexagonal dipyramids.

In Gilson flux-grown synthetic emeralds, in which part of the seed plate was still observable in the cut samples, the following different kinds of growth structures were examined: some of the stones could be determined, which showed growth

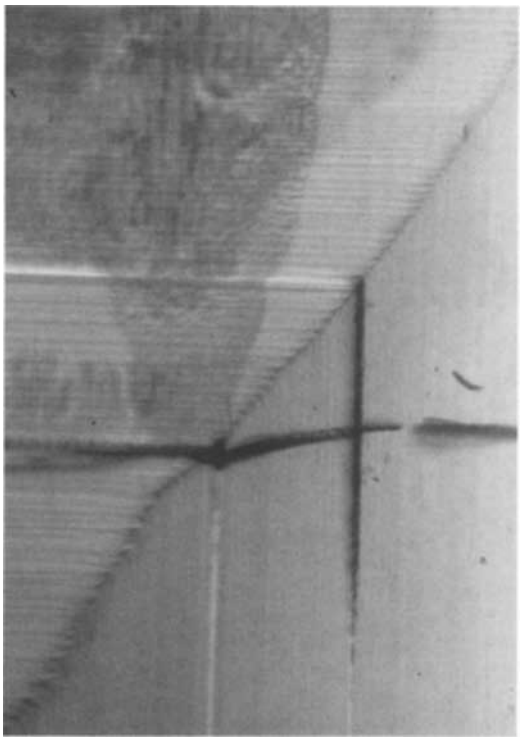

Fig. 36

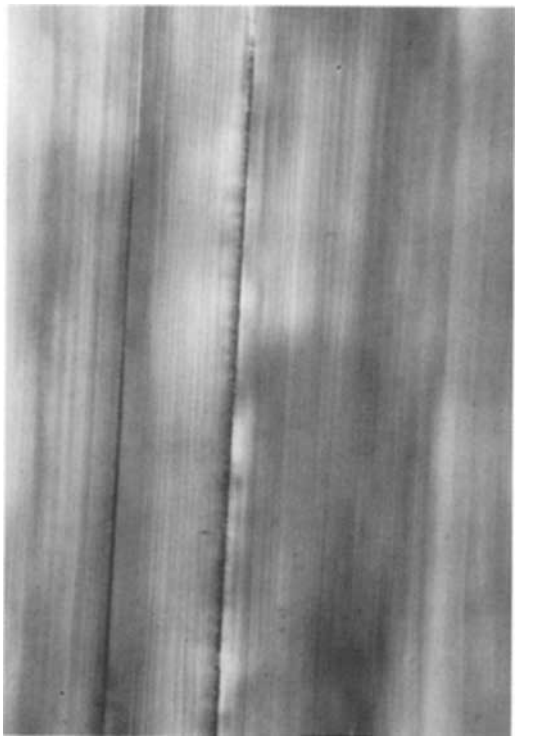

Fig. 37

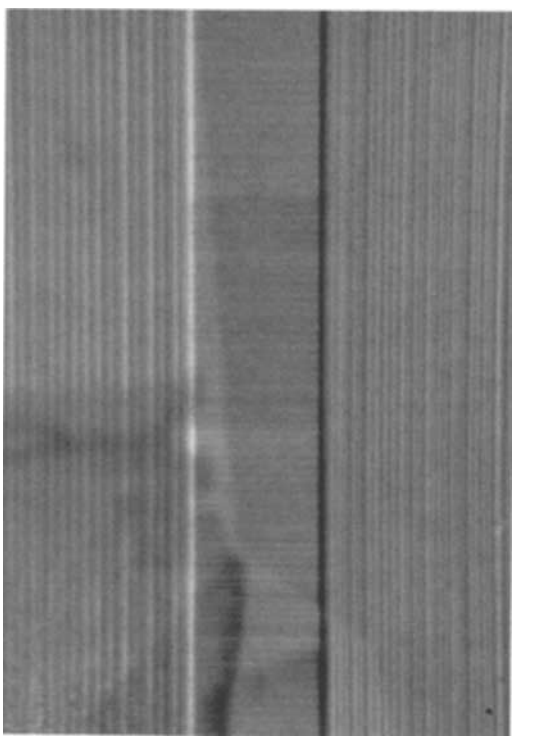

Fig. 38

Fig. 36. Growth structures in Gilson flux-grown synthetic emerald; planes parallel to the basal pinacoid *c* (0001) and parallel to one of the prism faces (*m* or *a*) form an angle of 90°. View perpendicular to the *c*-axis, the *c*-axis runs vertically. 30x.

Fig. 37. Growth structures in Gilson flux-grown synthetic emerald; planes parallel to one of the hexagonal prism faces (*m* or *a*) are found in the seed and the overgrowth. View perpendicular to the *c*-axis, the *c*-axis runs vertically. 30x.

Fig. 38. Growth structures in Gilson flux-grown synthetic emerald; planes parallel to the basal pinacoid *c* (0001) are found in the seed, planes parallel to one of the prism faces (*m* or *a*) are found in the overgrowth. View perpendicular to the *c*-axis, the *c*-axis runs vertically. 40x.

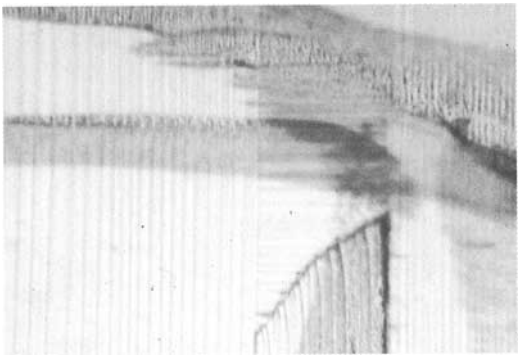

Fig. 39. Growth structures in Gilson flux-grown synthetic emerald; planes parallel to the basal pinacoid *c* (0001) and parallel to one of the prism faces (*m* or *a*) are found in the seed, planes parallel to one of the prism faces (*m* or *a*) are found in the overgrowth. View perpendicular to the *c*-axis, the *c*-axis runs vertically. 65x.

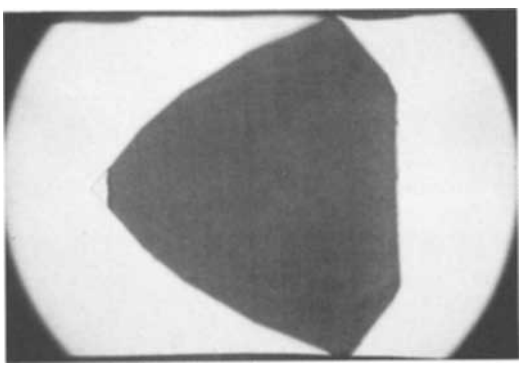

Fig. 40. Growth structures in Russian hydrothermally-grown synthetic emerald; residue of the seed at the culet, step-like growth lines and colour zoning parallel to the boundary colourless seed/synthetic emerald, irregularly changing sub-grain boundaries. View 31° inclined to the *c*-axis. 34x.

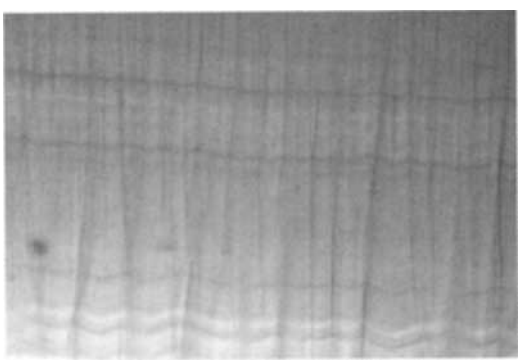

Fig. 41. Growth structures in Russian hydrothermally-grown synthetic emerald; step-like growth lines and colour zoning, irregularly changing sub-grain boundaries almost perpendicular to the colour zoning. View 31° inclined to the *c*-axis. 25x.

planes parallel to one of the prism faces, both in the synthetic emerald seed and in the emerald overgrowth [Figure 37]. In other samples the growth structures of the seed were orientated parallel to the basal pinacoid *c* (0001), whereas the overgrown areas showed growth planes parallel to one of the prism faces [Figure 38]. In others, growth planes parallel to the basal pinacoid *c* (0001) and parallel to one of the prism faces were observed in the seed, and the additionally grown synthetic emerald showed structures parallel to one prism face [Figure 39]. In the remaining stones examined, the seed revealed one of the growth structures mentioned above, whereas in the overgrown areas both the basal pinacoid (*c*) and one of the prism faces (*m* or *a*) were found as growth structures.

All these types of growth structures were never observed in any natural emerald. Furthermore, the pyramidal faces *u*, *p*, and *s*, which are characteristic for part of natural emeralds, e.g. from Colombia or Nigeria (cf. section II), do not occur in synthetic flux-grown emeralds. An additional feature of Gilson flux-grown synthetic emeralds are residues of flux materials which occur in zones confined to growth structures. This phenomenon is caused by growth intervals, which lead to a varying incorporation of flux in different areas of the crystal. This kind of structure is also a feature of synthetic emeralds and does not occur in natural stones.

IV. Hydrothermally-grown synthetic emeralds

The most characteristic feature of hydrothermally-grown synthetic emerald is the orientation of the seed plate. According to the patents of Flanigen (1971) and Flanigen & Mumbach (1971), crystal growth is most efficient if seed plates are cut in an angle of 45° to the *c*-axis of the beryl. Satisfactory results were also obtained by using seed plates with angles between 30 and 60° (Flanigen, 1971) or between 10 and 60° to the *c*-axis (Flanigen & Mumbach, 1971). Poor crystal growth was observed when the seed plate was cut parallel to the basal pinacoid *c* (0001) or parallel to one of the prism faces.

The orientation of the seed plate parallel to one of the prism faces was used in the experiments by Swarovski, Austria. These synthetic emeralds, however, were never produced commercially. All other commercially produced hydrothermally-grown synthetic emeralds available to the authors are made by using seed plates cut oblique to the *c*-axis.

In faceted stones, due to this kind of orientation of the seed plate, either residues of the seed plate with a distinct boundary of a seed plate versus the overgrowth, or, in the hydrothermally-grown part itself, dominant growth structures parallel to the

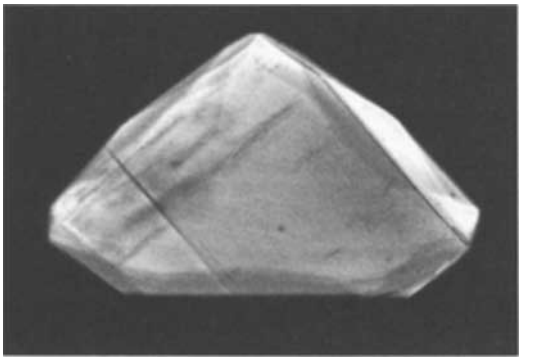

Fig. 42. Growth structures in Biron hydrothermally-grown synthetic emerald; residue of the seed [right], dominant growth line parallel to the boundary colourless seed/synthetic emerald [left]. View 23° inclined to the *c*-axis. Crossed polarizers. 20x.

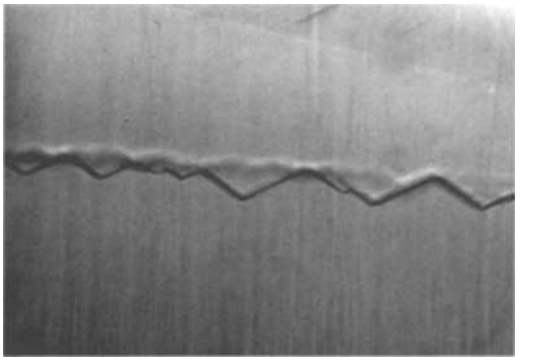

Fig. 43. Growth structures in Biron hydrothermally-grown synthetic emerald; step-like growth line and colour zoning, irregularly changing sub-grain boundaries almost perpendicular to the growth line. View 23° inclined to the *c*-axis. 50x.

orientation of the seed plate were detected.

In Linde hydrothermally-grown synthetic emeralds, which were produced according to the patents mentioned above, the angles between the *c*-axis and dominant growth structures were measured by the present authors between 36 and 38°, which is quite a constant factor (cf. Galia, 1972). Regency hydrothermally-grown synthetic emeralds, which are manufactured by use of the same patents as applied for the growth of Linde synthetic emeralds (O'Donoghue, 1983), revealed angles of 38° between dominant growth structures and the *c*-axis [Figure 45]. A number of samples of Lechleitner hydrothermally-grown synthetic emeralds showed a variation of angles between 32 and 40° (cf. Schmetzer, 1990). Biron synthetic emeralds, on the other hand, with angles of 22 to 23° [Figures 42, 43] as well as Pool synthetic emeralds, which are supposedly grown by the same hydrothermal process (Brown & Snow, 1988; Scarratt, 1989), with angles of 22 to 24° [Figure 44], reveal a certain constancy, too. So do Russian hydrothermally-grown synthetic emeralds with quite constant angles between 30 and 32° [Figures 40, 41] (cf. Schmetzer, 1988).

As a general rule, in faceted synthetic samples of all these producers or types, one dominant set of growth structures parallel to the orientation of the seed plate can be determined, which are most frequently connected with a distinct colour zoning. In addition, the oblique orientation of the seed plate is responsible for the formation of sub-grain boundaries (cellular structures), which have already been discussed in detail for Russian hydrothermally-grown synthetic emeralds (Schmetzer, 1988). In general, similar or almost identical growth structures were found in each commercial type of hydrothermally-grown synthetic emerald.

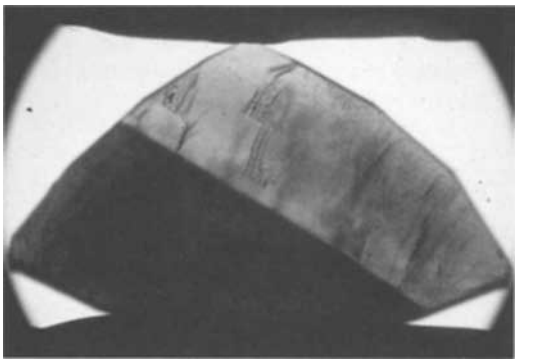

Fig. 44. Growth structures in Pool hydrothermally-grown synthetic emerald; dominant growth line and colour zoning. View 24° inclined to the *c*-axis. 22x.

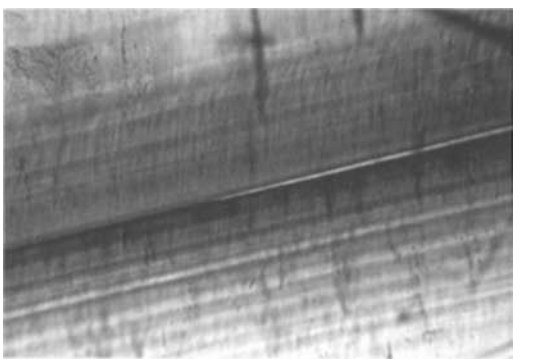

Fig. 45. Growth structures in Regency hydrothermally-grown synthetic emerald; growth lines and colour zoning, irregularly changing sub-grain boundaries almost perpendicular to the colour zoning. View 38° inclined to the *c*-axis. 35x.

Dominant growth structures in orientations comparable to those present in hydrothermally-grown synthetic emeralds, i.e. growth structures forming angles between 22 and 40° with the optic axis, do not occur in natural emeralds (cf. section II). In addition, the growth features caused by the orientation of the seed plate are typical for these varieties of synthetic emeralds and can, therefore, be considered as a characteristic feature of diagnostic value.

V. Conclusions

Frequently, the recognition of emeralds of unknown origin as natural or synthetic is possible by use of characteristic growth structures. In some cases, even the source of a natural emerald or the producer of a flux-grown or hydrothermally-grown synthetic emerald is unequivocally determined according to the presence of characteristic growth structures. However, there are also distinct types of growth faces, which are found in both, natural and synthetic emeralds. In those cases, no unequivocal determination of an unknown sample by means of growth structures is possible. But even in those particular cases, growth structures can be useful to exclude some possibilities for natural or synthetic emerald, i.e. to reduce the possibilities to a limited number of natural sources or producers of synthetic emeralds.

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Kiefert, L., Schmetzer, K., 1991. The microscopic determination of structural properties for the characterization of optical uniaxial natural and synthetic gemstones Part 1: General considerations and description of the methods. *Journal of Gemmology*, **22**, 344-54.

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[*Manuscript received 3 May 1989.*]

Gemmological Abstracts

ALLEN, R.M., 1991. The Yogo sapphire deposit. *Gemmological Digest*, **3**, 2, 9-16. 13 photographs in colour, 2 maps, 1 fig.

Recent work on the Yogo sapphire deposit in Montana, USA, may make the various colours of corundum more available on the market. Short notes on the geology and mining history are given. Rutile is one of the reported inclusions and the best stones rank with some of the finest from other sources. M.O'D.

ATHINEOS, D., 1991. The orchid of the mineral kingdom. *Christie's International Magazine*, **8**, 3, 20-2, 5 figs in colour.

A short but well-illustrated and accurate account of coloured diamonds, many of which have passed through the saleroom. Up-to-date information on colour alteration is given. M.O'D.

BARNES, L.C., BECK, R.J., LEAMING, S.F., TAN, L.-P., 1988. World review of nephrite jade - geology, production and reserves. *Bulletin of the Friends of Jade*, **5**, 14-69, 6 maps.

Nephrite is produced in at least 46 countries but commercial output is restricted to Canada, Taiwan, New Zealand, Australia, China, USA and Korea. World production of nephrite, exclusive of China, amounts to an average of 780 tonnes a year since 1962. China may produce as much as 500 tonnes a year; Taiwan production has ceased. A shortage of nephrite is expected to be relieved by production from the Cowell field in Australia or by increased use of simulants. Commercial deposits are surveyed with a view to estimating future production. Considerable geological detail is given. There is a most useful bibliography. M.O'D.

BECK, R.J., 1988. Jade of the Pacific. *Bulletin of the Friends of Jade*, **5**, 75-8.

The article describes a visit to China and to the Uygur Autonomous Region, Taiwan and South Korea. M.O'D.

BLANKENSHIP, D.T., 1988. The sawing of jade. *Bulletin of the Friends of Jade*, **5**, 70-4.

The various methods used for jade sawing are described with notes on the Chinese terms used. There is a short bibliography. M.O'D.

BLANKENSHIP, D.T., 1989. Orange peel. *Bulletin of the Friends of Jade*, **6**, 81-3.

The surface of nephrite is discussed from the Point of view of the lapidary. The 'orange peel' effect was not apparently a feature of the nephrite from eastern Turkestan. M.O'D.

BOGDANOVIC, K.I., 1989. Nephrite deposits in the Kuen-Lun mountains. *Bulletin of the Friends of Jade*, **6**, 74-80.

Nephrite deposits in eastern Turkestan are described. All in situ deposits are situated in high mountain areas which are difficult to reach. M.O'D.

BOSSHART, G., 1990. Il verde di Dresda*. *La Gemmologia*, **15**,1/2, 7-21, 6 photographs in colour, 1 fig.

The Dresden Green diamond is investigated and found to weigh approximately 41 ct and to belong to Type IIa. Some areas display anomalous birefringence and the stone is well cut to ideal proportions. M.O'D.

BOSSHART, G., 1991. Les emeraudes de Colombie. *Revue de Gemmologie*, **106**, 19-24, 12 photographs in colour, 4 figs.

This part of the paper describes absorption. colour and fluorescence, optical constants, density, inclusions and growth features. Some characteristic inclusions are illustrated. M.O'D.

BRACEWELL, H., 1991. Gems around Australia. *Australian Gemmologist*, **17**, 9, 377-8, 6 figs.

Mrs Bracewell continues her account describing further scenes, finds and adventures in the Bracewell circumtouring of that Continent early in the 1980s. She describes Northern Australia, finding ribbonstone, prehnite and amethyst. R.K.M.

BROWN, G., 1990. A rare baler shell pearl. *Australian Gemmologist*, **17**, 8, 307-8, 5 figs.

*Translation of a paper first published in *Schweizer Uhren-und Schmuck*, 1989, 2, 513-19.

Found in the large melo amphora shell, which can reach 50cm in length, this rare 68.97 ct non-nacreous pearl is pinkish-orange in colour with a flame pattern reminiscent of that seen in pink conch pearls, SG 2.83, DV/RI value 1.67, inert to UV and no visible absorption. R.K.M.

BROWN, G., 1991. Some Australian turquoise deposits. *Australian Gemmologist*, 17, 9, 369-73, 4 figs.

Turquoise occurs in almost every state, but little of it is of fine quality. R.K.M.

BROWN, G., BEATTIE, R., SNOW, J., 1991. Verneuil synthetic red spinel. *Australian Gemmologist*, 17, 9, 344-7, 6 figs.

Hitherto a difficult synthetic to find, this is now apparently in circulation in fragmented form in Australia and USA. RI 1.720, SG 3.59 and strain free between crossed polars, fluorescing like natural stone and with identical absorption/emission spectra, these stones need close examination under magnification to reveal characteristic inclusions of curved growth banding, tadpole and profilated bubbles [these writers persist in calling these 'proliferated', a term which has quite a different meaning from that intended by Anderson when he coined the new word]. It is not known whether these are old stock or a new production. R.K.M.

BROWN, G., CHAPMAN, J., 1991. Argyle champagne and cognac diamonds. *Australian Gemmologist*, 17, 9, 350-1, 1 fig.

A brief résumé of occurrence, colours and qualities. R.K.M.

BROWN, G., KELLY, S.M.B., BEATTIE, R., BRACEWELL, H., 1990. Gemmology Study Club report. *Australian Gemmologist*, 17, 8, 325-32, 20 figs badly numbered.

A ruby/sapphire combined in one crystal; massive stichtite, a rare ornamental material from Tasmania, are described. A mounted suite of 10 large orange sapphires was found to be yellow synthetic corundum diffusion treated with synthetic ruby; bought for US$35 in Srinagar, Kashmir, one wonders at the economics of the deal [and even more that the purchaser should need them valued]; diffusion-treated synthetic blue sapphire with curved colour zones has been seen. A glass imitation of aquamarine spalled after cutting, while another was made from photo-sensitive glass of the type used for sun-glasses. Emerald from 'Harry's Mine' near Torrington, NSW, is shown to be green beryl rather than emerald, it has no chrome spectrum and is green through the Chelsea filter; sunstone quartz from Tingha near Inverell, NSW, thought to be due to included hematite plates, is described. [The figures in this paper are again numbered in separate groups and there is misuse of the word 'including'. An inclusion should not be said to be 'including' the host mineral.] R.K.M.

BROWN, G., KELLY, S.M.B., BEATTIE, R., 1991. Gemmological Study Club Lab reports. *Australian Gemmologist*, 17, 9, 363-7, 13 figs.

Deals with Hong Kong dyed and waxed jadeite; a coated (heated) sapphire; cerussite; prawn-claws as earrings; pipi blister pearls from Cook Island; carved bone from India and red Kauri gum. [The idiosyncratic numbering of figures in these reports is confusing. In this one there are seven with the number 1. Can editor not do something to rationalize this.] R.K.M.

BROWN, G., KELLY, S.M.B., SNEYD, R., 1990. Russian flux-grown synthetic spinel. *Australian Gemmologist*, 17, 8, 315-17, 10 figs.

A specimen of this fairly new synthetic red spinel was purchased in Hong Kong and conformed very closely in constants with similar octahedral crystals described elsewhere. Etch (growth?) marks and triangular dissolution edges and marks on the octahedral faces, adherant octahedra, dark flux, platinum flakes, air-filled curved fractures and dendrites were seen. Authors conclude that if a visually clean stone could be cut from such material, it would be identical with natural red spinel, undetectable by normal tests. R.K.M.

BROWN, G., KELLY, S.M.B., SUTHERLAND, C., CALLAWAY, P., 1990. Imitation chicken-blood stone. *Australian Gemmologist*, 17, 8, 311-13, 5 figs.

A visually effective imitation of this Chinese valued material was detected by warmth to touch, bubbles in cinnabar imitation and coating, and strong fluorescence to LUV. The grey base material is described as soapy to the touch, while the coloured coating had a waxy feel; both peeled readily. R.K.M.

BROWN, G., LINTON, T., 1991. An inexpensive conversion unit. *Australian Gemmologist* 17, 9, 355, 1 fig.

A metal base which allows a Kiowa microscope to be turned through 90° for horizontal examination of immersed stones. R.K.M.

BROWN, G., TOMBS, G., 1991. An introductory note on the manmade products of Dominique Robert. *Australian Gemmologist*, **17**, 9, 381-2, 5 figs in colour.

Emeraldolite is a synthetic druse of emerald coated onto a large crystal or other base of natural beryl. Heat whitens and opacifies the seed material. Oulongite is another synthetic 'garnet', formula unspecified; colours so far white, blue, green, pink. H about 7.5, SG 6.9, RI 1.93-1.99, Disp. 0.030. R.K.M.

CAIRNCROSS, B., 1991. The Messina mining district, South Africa. *Mineralogical Record*, **22**, 3, 187-99, 12 photographs (8 in colour), 11 maps and plans.

Quartz crystals coloured sky blue by inclusions of ajoite and measuring up to 5cm in length are reported from the Messina mining area, northern Transvaal, South Africa. M.O'D.

CAMPBELL, I.C.C., 1991. A report on one of a number of emeralds from Madagascar. *South African Gemmologist*, **5**, 1, 8-15, 7 figs in colour.

Large emeralds from Madagascar have been seen in the South African gem market. SG is reported as 2.73-2.74, RI 1.585, 1.591, 1.593 [sic] (a previous study gives 1.589-1.591 for the ordinary ray and 1.581-1.585 for the extraordinary ray). Birefringence is reported by the earlier study as 0.006-0.008. Stones are inert to UV and show strong yellowish-green and strong greenish-blue dichroism. The cabochon examined contained goethite, limonite, hematite and colour zoning, as the previous report stated. In addition phlogopite was identified and the stone may have been oiled. Biotite, muscovite, apatite, quartz, tourmaline and two-phase inclusions could not be identified with the limited equipment available, though they featured in the previous report. The strongest absorption was in the region of 680nm and diffuse bands were noted in the region from 650-640nm. There was moderately strong absorption of the orange-yellow from approximately 630-570nm. No absorption was noted in the blue region. Under the colour filter the stone gave a slightly reddish colour with a dull and dark appearance. M.O'D.

CAMPBELL, I.C.C., 1991. Fine quality large cut opal. *South African Gemmologist*, **5**, 1, 22, 1 fig. in colour.

A fine quality white opal measuring 28.62 x 21.92 x 9.74mm and weighing 35.16 ct is described and illustrated. M.O'D.

CHANCEREL, C., 1991. Bloody opals ...! *Revue de Gemmologie*, **106**, 3-7, 20 figs (6 in colour).

A brief account of mining and cutting operations at the Australian field of Lightning Ridge, New South Wales. Some personal cutting experiences are described. M.O'D.

CLUNAS, C., 1989. Jade carvers and their customers in Ming China. *Bulletin of the Friends of Jade*, **6**, 33-52, 7 figs.

Jade carving in China between Han dynasty and the eighteenth century is examined. There is a useful bibliography. It is interesting that the connoisseurs of the Ming period did not appear to regard jade as highly for its tactile qualities as has been thought. M.O'D.

DYAR, M.D., PERRY, C.L., REBBERT, C.R., DUTROW, B.L., HOLDAWAY, M.J., LANG, H.M., 1991. Mossbauer spectroscopy of synthetic and naturally occurring staurolite. *American Mineralogist*, **76**, 27-41, 7 figs.

Room temperature Mossbauer spectroscopy of 23 natural and 12 synthetic staurolites showed that the majority of the Fe in all samples is Fe^{2+}. This occupies the Fe1, Fe2 and Fe3 subsites of the tetrahedral Fe site in an average ratio of 43/12/27. M.O'D.

FREY, R., 1989. Satellite scans: technical notes and gazetteer. *Bulletin of the Friends of Jade*, **6**, 60-1, 1 fig.

A satellite photograph shows the nephrite source of the Karakash River. A short gazetteer gives some of the places shown. M.O'D.

FRYER, C.W., Ed., CROWNINGSHIELD, R., HURWIT, K.N., KANE, R.E., HARGETT, D., 1990. Gem Trade Lab notes. *Gems & Gemology*, **26**, 4, 294-9, 17 figs..

Collection quality mineral specimens of azurite were examined including exceptional ones from Chessy, France and Bisbee, Arizona; the latter with rosettes of azurite on a back-ground of malachite [most beautiful!]. A yellow zirconia was found matched with a yellow diamond in a ring, and had absorption lines at about 453 and 478nm, normally belonging to Cape diamonds. Intense yellow marquise diamonds in a brooch were probably proved by fluorescence and absorption to be natural, but were very like Sumitomo synthetics in appearance. Another diamond shown to be irradiated green by the 'umbrella' around the culet, but had additional dark zoning.

Dyed black cultured pearls fluoresced a distinct yellow under LUV and a tellurium dye was sus-

pected. Bouton cultured pearls had lentil shaped nuclei, not used much because tend to kill the oyster.

A ruby with a glass infill had not been fired to a high temperature. The glass fluoresced chalky yellow in LUV and contained bubbles. A synthetic ruby cabochon had also been glass-filled where damaged and we are warned to look out for bubbles in the glass and curved striae in the ruby. A synthetic sapphire contained prominent lines of tiny bubbles which looked like needles [illustration shows that these were not at the required inclination of 120°]; striae and curved colour zones were less obvious. Robert Kane says a dark blue filter over a transmitted light source makes curved striae and bubbles easier to see in yellow and orange synthetic sapphires, normally quite difficult stones to identify. A large piece of blue material had RI 1.56, H about 2½, SG below 2.57, eliminating turquoise which it was apparently intended to resemble. Acid revealed carbonate plus a plastic binder. R.K.M.

HÖCHLEITNER, R., WEISS, S., 1991. Neue mineralfunde aus Pakistan und Afghanistan. *Lapis*, **16**, 3, 15-16, 3 figs (2 in colour).

Stibiotantalite and tremolite are described from Ştak-Nala in Pakistan and from Nuristan, Afghanistan, respectively. From the illustrations the quality approaches the ornamental. The stibiotantalite is yellow and occurs with tourmaline and albite. The tremolite is white and resembles Alpine adularia. M.O'D.

HODGKINSON, A., 1991. Padparadscha - what is meant by this term? *Australian Gemmologist*, **17**, 9, 378-80, 3 figs.

Discusses various versions of orange/pink corundum sold under this and similar names, and the ruby/pink sapphire question, going on to include synthetic padparadschas, which are by far the commonest of this name. R.K.M.

HUANG, U.T., AUNG, Z., HTEIN, W., 1991. Radioactivity in some minerals in the Mogok area. *Australian Gemmologist*, **17**, 9, 356-9, 2 figs.

Researchers found more uranium in zircon, and more thorium in sphene, than in apatite. An erudite scientific paper having little to do with the gem potential of these stones. R.K.M.

HUGHES, R.W., 1991. There's a rumble in the jungle - the sapphire face-lift face-off saga. *Gemmological Digest*, **3**, 2, 17-28, 11 figs in colour.

Diffusion-treated corundum is discussed with illustrations of treated stones and notes on identification. The history and some of the politics of the method are also discussed. M.O'D.

HUGHES, R.W., SERSEN, W.J., 1991. Vietnamese ruby. *Gemmological Digest*, **3**, 2, 68-70, 7 photographs in colour, 1 map.

Fine quality ruby is reported from Luc Yen, Vietnam, a site about 150km north-west of Hanoi. Stones resemble Burmese material in colour and strong fluorescence. M.O'D.

HUTTON, D.R., TROUP, G.J., 1990. ESR spectrum of Australian synthetic Biron emerald. *Australian Gemmologist*, **17**, 8, 299-301, 5 diagrams.

Electron-spin resonance of this new synthetic is demonstrated in diagrams of spectra [Figure 3 has the wrong caption] and suggests that the material is of laser quality. [Interpretation is not easy for the uninitiated.] R.K.M.

KAMMERLING, R.C., KANE, R.E., KOIVULA, J.I., MCCLURE, S.F., 1990. An investigation of a suite of black diamonds. *Gems & Gemology*, **26**, 4, 7 figs.

Six quite large mounted black diamonds were examined for transparent dark green areas which would indicate artificial irradiation. Minute transparent areas in these stones were white or blue. Facets were pitted and polishing drag lines were prominent, as with most black diamonds. Colour was due to graphite. No distinct absorption lines or bands were seen. Two stones showing blue transparent areas fluoresced strong blue under LUV and green in SUV another stone gave a chalky mottled yellowish-green. All the black stones had been cemented into their settings. probably in deference to the many cleavages which made the stones vulnerable to setting pressures. Thermal conductivity was normal for diamond. A detailed list of possible simulants is given. R.K.M.

KAMMERLING, R.C., KOIVULA, J.I., 1991. Examination of a plastic coated 'sugar treated' opal. *Australian Gemmologist*, **17**, 9, 352-5, 4 figs.

Submitted for investigation by John Fuhrbach of Amarillo, this stone had been bought as black opal at high cost. It is a dyed (sugar/acid treated) stone which had also been coated with plastic, causing anomalous fluorescence and many included bubbles. R.K.M.

KAMMERLING, R.C., KOIVULA, J.I., 1991. Opals displaying cat's-eye effects. *South African Gemmologist*, 5, 1, 23-7, 3 figs in colour.

A number of natural opals show chatoyancy. Idaho opal mounted as composites show chatoyancy and in this case the phenomenon is attributed to planar faults in the stacking of the silica spheres. An opal whose chatoyancy is attributed to light reflection from parallel acicular inclusions is described. Since the stone showed a weak pleochroism its origin may have been as a pseudomorph after a birefringent fibrous mineral such as goethite. M.O'D.

KAMMERLING, R.C., KOIVULA, J.I., FRITSCH, E., 1990. An examination of chrysoprase from Goias, Brazil. *Australian Gemmologist*, 17, 8, 313-15, 2 figs.

The pale yellowish green to dark vivid green is probably due to nickel in the form of bunsenite. RI 1.539, SG 2.64. Rather strangely a quite marked greenish-blue fluorescence in LUV, and fainter in SUV, have apparently not been previously noted. R.K.M.

KANE, R.E., MCCLURE, S.F., MENZHAUSEN, J., 1990. The legendary Dresden Green diamond. *Gems & Gemology*, 26, 4, 248-66, 16 figs.

A very full investigation of this historic 41 ct diamond by a team which visited Dresden especially for the purpose. Photographs reproduced show the stone in a recently drawn reconstruction as part of the order of the Golden Fleece, which is also used as the front cover of this issue of the journal. Others show a glass copy and the stone itself, which registers as paler than either the copy or the drawing.

The history of the stone is researched with care and it seems certain that the rough came from India, since Brazilian diamonds were discovered only a year or so earlier. It was cut, probably in London, shortly afterwards and in 1742 was incorporated in the Fleece badge only to be broken up four years later, when it was used in a second version which also included the 49.71 metric carat Saxon White diamond. [Two weights are given for this stone, the first being in pre-metric carats.] The badge was again dismantled in 1768 and Dissbach commissioned to fashion the centre part into a shoulder knot and a hat ornament, both of which exist today, the Dresden Green being transferable.

The present team investigated the stone very thoroughly, and report on shape, cut, proportions, finish, clarity and colour. Finish and symmetry are very good and transparency is exceptional. Colour is usually described as apple green; the team call it 'fancy green', photographs of the actual stone published here suggest lightish yellow-green. Graining was seen in three directions and polariscope revealed considerable cross-hatched strain; a powerful source of UV revealed weak green fluorescence. Natural radiation damage was evidenced by small green or brown stains at three places near the girdle, but do not cause the body colour. No distinct spectrum at normal temperatures but low temperature spectroscopy revealed a general radiation pattern, with absorption lines at 594, 495, 470, 310, 393, and a cut-off at 225nm. There are similarities with a known radiation-treated stone. Further details are given, but 594nm is considered to indicate a treated stone, yet the Dresden was known long before such treatment was available. Infrared absorption spectra suggest the stone is a Type IIa diamond, and this leaves the question of separating natural from artificially treated green Type IIa diamonds wide open. R.K.M.

KEVERNE, R., 1988. Worldwide view of the jade market, 1986. *Bulletin of the Friends of Jade*, 5, 7-13.

Details of jade pieces sold at auction are given (hammer prices excluding the 10% commission levied on the buyer). Sales conducted by Christie's and Sotheby's are covered worldwide. Jadeite vessels were strong performers over the year and good qualities did well while sub-standard pieces failed to attract buyers. Jewellery of the best colours did well. M.O'D.

KEVERNE, R., 1989. Worldwide view of the jade market 1987 (1988). *Bulletin of the Friends of Jade*, 6, 8-19 (20-32).

Considerable enthusiasm exists, on the basis of the Christie's and Sotheby's sales in the two years reviewed, for high quality jade artefacts. The 1988 season in particular was the most successful since the early 1970's. Fine jewellery and good white carvings were in strong demand. M.O'D

KOIVULA, J.I., 1990. Snail shells in amber. *Australian Gemmologist*, 17, 8, 309-10, 2 figs.

In common with other animals and plants in amber from the Dominican Republic, these lcm spiral (pulmonata) snail shells are remarkably well preserved for forty million years old. Author says that one area of Panama has an estimated snail population today of over seven million snails per acre, mostly of sizes suitable for such entrapment. [He also says that most snails serve as scavengers of dead plant and animal matter. The million or

so in my garden are much braver and tackle living plants with considerable appetite!] These two are small, the larger about 1cm in length. R.K.M.

KOIVULA, J.I., KAMMERLING, R.C., 1990. Gem news. *Gems & Gemology*, 26, 4, 300-9, 16 figs.

Diamonds

De Beers have grown a 14.2 ct good quality industrial yellow stone thought to be the largest yet, but not commercially viable; only industrials are aimed at in such experiments. Nearly half the China-cut diamonds offered in Singapore were sold; development and exploration of diamond mining in Guyana has been agreed.

Coloured stones

Vast gold reserves found in Afghanistan, with gem mining, this is expected to attract foreign investment; cat's-eye opal triplets, synthetic corundum stars and quartz cabochons backed with computer chips are among new assembled stones; black coral is being exploited in the Mexican Caribbean; heavy excavating equipment is being used in Kanchanaburi sapphire mines; a peace pact has been signed between warring factions in the Colombia emerald area, and production is expected to increase; an unusual African grossular garnet was parti-coloured yellowish brown and orange with different RI (1.38, light, and 1.4 darker area).

Australian research is investigating use of safe heavy organic water-soluble compounds for mineral separation; a black cat's-eye opal from Mexico is described and illustrated; a 14 x 10 cm gem quality opal found at Boi Morto Mine, Brazil, was brownish white in colour with pinfire on all surfaces; a 16.39 ct cobalt spinel of violet-blue colour in fluorescent light, turned purple under incandescent light, RI 1.714, red through Chelsea filter, chalky-red in LUV, strong fluorescent line at 686nm weaker one at 552 and broad diffuse absorption at 454-461nm; a large light bluish-green topaz sculpture weighing about 35000 ct has been cut from part of a 79 lb crystal bought by Edward Swoboda in the 1950s, polishing large facets gave a lot of trouble in the final stages; cat's-eye red/blue tourmaline had tubular inclusions in the blue section only, skilled cutting retained the 'eye' at the junction of the two colours; a Welsh firm has exclusive agreement with USSR geology ministries to attract foreign interest in gem mining; waxing of jades was described and illustrated in a Hong Kong magazine.

Enhancements

Robert Crowningshield showed that techniques to detect colour diffusion treatment in loose sapphires can work equally with mounted stones; Aqua Aura treatment of quartz can also use silver or platinum which do not colour the crystal but leave the surface iridescent; synthetic sapphire cabochons are being 'improved' by matt surfacing the backs to reduce transparency; Thailand is now cutting CZ for the US; glass imitations of Imperial jadeite are described and illustrated; pectolite is imitated by blue Imori stone (glass); dyed quartz sold as purple onyx in Indian jewellery in the States seems to be a micro-version of crackled quartz with a strong resemblance to sugilite. R.K.M.

KROSCH, N.J., 1990. Queensland chrysoprase. *Australian Gemmologist*, 17, 8, 303-6, 2 figs, 2 maps.

The exceptionally fine Marlborough chrysoprase, sometimes incorrectly called Queensland jade, has been known for more than thirty years. Mined by open-cast method from nickel-ferrous serpentines. Gemmological details are not quoted. R.K.M.

LEAMING, S., 1989. From the mines in the mountains to the rocks in the river. The development of alluvial jade deposits from jade lodes. *Bulletin of the Friends of Jade*, 6, 63-8, 1 fig.

The movement of nephrite from in situ deposits to alluvial finds is discussed. The equation

$$T=C\ \frac{D \times W}{E_d \times R} \times U_r$$

where T is the time in years taken for a block to travel, D the distance between two locations, W the weight of the block, E_d the difference in elevation between the two locations, C a constant specific to nephrite, R the roundness of the block and U_r the rate of uplift is postulated. The case in question covers the distance between the mines at Shahidulla to the oasis of Khotan. M.O'D.

LINTNER, B., 1988. Along Burma's jade trail. *Bulletin of the Friends of Jade*, 5, 81.

A reprint of an article in *The Far Easatern Review* in 1987 describing the difficulties of working the Jade Tracts in Myitkina, Burma. M.O'D.

LINTON, T., BROWN, G., 1990. Presidium MiniMate. *Australian Gemmologist*, 17, 8, 318-20, 3 figs.

Another well-designed and reliable heat-probe for testing mounted diamonds. Usual precautions must be taken in use. R.K.M.

LINTON, T., BROWN, G., 1990. Presidium

DiaMeter - System Berger. *Australian Gemmologist*, **17**, 8, 301-6, 3 figs.

A slide rule for diameter/weight calculations for well-made round diamonds, combined with an electronic version of the Leveridge gauge. Combination works well for stones of good make. R.K.M.

LINTON, T., BROWN, G., 1991. The gold-meter. *Australian Gemmologist*, **17**, 9, 360-2, 2 figs.

An assessment of a new electro-chemical meter for testing gold which proved accurate for qualities up to 18ct, but did not specify quality above that. Needs to be used with care. [An obsolete address of Gemmological Instruments Ltd is quoted.] R.K.M.

MAAS, H.H., 1991. Museen in Westdeutschland. (Museums in West Germany.) *Aufschluss*, **42**, 2, 29-40.

A useful list of museums in West Germany with geological, mineralogical or fossil collections arranged in alphabetical order of place. The name of the director is given together with hours of opening, telephone number, postal address and main theme of the collections. M.O'D.

MONTGOMERY, R.S., 1991. In the dark: separating synthetic and natural gems by ultraviolet spectroscopy. *Gemmological Digest*, **3**, 2, 45-53, 18 figs (17 in colour).

The Krüss UVS 2000 is evaluated. Significant differences were noted between the spectra of the following pairs: natural and synthetic ruby, heated and unheated rubies, natural and synthetic blue sapphires, heated and unheated blue sapphires and natural and synthetic red spinels. M.O'D.

PEARSON, G., 1990. Multiple chatoyancy in Australian sapphire. *Australian Gemmologist*, **17**, 8, 296-8, 8 figs.

An interesting account of 12-ray asterism in a cabochon sapphire from Rubyvale in Queensland, thought to be due to rutile (diffuse white star) and ilmenite (intersecting bronze coloured star showing additional reflective centres). [This is asterism not chatoyancy.] R.K.M.

PEILE, J., 1988. Trouble at the mines. *Bulletin of the Friends of Jade*, **5**, 81.

A reprint of an article in *The Times* of London in 1893 describing the difficulties of working the Jade Tracts in Myitkina, Burma. M.O'D.

PEMADASA, T.G., 1991. Gem deposits of South West Sri Lanka. *Australian Gemmologist*, **17**, 9, 347-9 and 351, 4 figs.

A gneissic region with rich sources of alluvial gems including chrysoberyl cat's-eyes, alexandrite, rose quartz, hessonite and other gem species. Yield increases as the Singharaja Hills are approached suggesting that these are the primary source. R.K.M.

ROBERT, D., 1991. Emeraldolite (letter). *Australian Gemmologist*, **17**, 9, 381-2.

An answer to A. Taylor's letter, claiming that colourless beryl is an excellent foil for the artificial druse of synthetic emerald. R.K.M.

ROBERT, D., FRITSCH, E., KOIVULA, J.I., 1990. Emeraldolite: a new synthetic overgrowth on natural beryl. *Gems & Gemology*, **26**, 4, 288-93, 7 figs.

A product rather similar to Lechleitner coated emeralds, but opaque in this case, and different in technique from the Lennix process, since fluorine is used as the transport agent. Emerald layer grows in conformity with the substrate crystal, giving even coloration. Spot RI 1.56, SG 2.66. No UV fluorescence or phosphorescence. There were numerous surface specks of white which were thought to be lithium feldspar. Intense red through Chelsea filter, no surface cracking. Unique appearance makes identifying easy. Generally used unpolished, but can be polished or carved. R.K.M.

SCHLUESSEL, R., 1991. Des saphirs étoilés synthétiques ... pas comme les autres. *Revue de Gemmologie*, **106**, 10-12, 12 figs in colour.

Several methods of distinguishing natural from synthetic star sapphires are outlined. Inclusions characteristic of the synthetic material are illustrated. M.O'D.

SCHUHBAUER, E., 1991. Bemerkenswerte Neufunde von Roten Beryllen in den Wah-Wah Mountains, Utah. *Lapis*, **16**, 6, 38, 4 photographs in colour.

Fine red beryl crystals are reported from the southern Wah-Wah Mountains in Beaver County, Utah, USA. The find of particularly good crystals was made in August 1990 at the Violet Claims. M.O'D.

SCHWIEGER, R., 1990. Diagnostic features and heat treatment of Kashmir sapphires. *Gems & Gemology*, **26**, 4, 267-80, 24 figs.

A well-researched paper which serves to distinguish the rare and very lovely Kashmir sapphire

from those fine stones from Burma or Sri Lanka, which are often called 'Kashmir' in ignorance. Typical silk and other inclusions are illustrated, and the unique absorption recorded by spectrophotometer is compared with those of stones from other sources. Kashmir sapphires are markedly different in the blue-violet region, while comparison with heated Sri Lankan stones was even more marked. But a Kashmir sapphire, similarly heated, became lighter in colour, some 'snowflake' inclusions dissolved and some areas became colourless. The spectrum also changed and became much more like that of a Sri Lankan sapphire. Unheated Kashmir stones can probably be identified with some certainty, but once heated they may lose colour and identifying characteristics. R.K.M.

SERSEN, W.J., 1991. Gemstones and early Arabic writers. *Gemmological Digest*, 3, 2, 34-9, 4 photographs (3 in colour), 1 fig.

Several Arabic writers of the thirteenth century onwards have commented on aspects of gemstones. Some of these are illustrated with comments on old mines and nomenclature. M.O'D.

SHAW, R., 1989. Visits to High Tartary, Tarkand and Kashgsar 1868/69. *Bulletin of the Friends of Jade*, 6, 69-70.

A nineteenth century account of jade mining in Khotan. M.O'D.

SHEAF, C., 1989. Jade around the clock. Reflections on jade sales at Christie's, Hong Kong. *Bulletin of the Friends of Jade*, 6, 53-9.

An account of the organization of jade auctions in Hong Kong in which both jadeite and nephrite are discussed. M.O'D.

STEIN, M.A., 1939. Sand-buried ruins of Khotan. *Bulletin of the Friends of Jade*, 6, 71-3.

An account of a visit to the jade diggings of Khotan in 1900. M.O'D.

SUNG, W.-H., LIEN, C.-M., 1989. A study of zoo-anthropomorphic jade earrings of prehistoric Taiwan. *Bulletin of the Friends of Jade*, 6, 87-91, 1 map.

A type of earring, hitherto unrecorded, has been found in Taiwan in sites dating from the Neolithic period. The material is either tremolitic nephrite or compact serpentine. [Paper reproduced from Bulletin No. 44 of the Department of Anthropology. National Taiwan University, 1984.] M.O'D.

TANG, S.M., TANG, S.H., MOK, K.F., RETTY, A.T., TAY, T.S., 1991. A study of natural and synthetic rubies by PIXE. *Gemmological Digest*, 3, 2, 63-7, 2 photographs in colour, 2 figs.

Proton-induced X-ray emission is used to examine 160 natural and synthetic rubies. Vanadium and iron are found in the natural stones rather than in the synthetic ones. M.O'D.

TANG, S.M., TANG, S.H., TAY, T.S., RETTY, A.T., 1991. Analysis of Burmese and Thai rubies by PIXE. *Gemmological Digest*, 3, 2, 57-62, 2 photographs (in colour), 2 figs.

Proton-induced X-ray emission techniques are used to identify trace elements in 60 Burmese and Thai rubies. Burmese stones were found to contain higher concentrations of all impurities except iron. They also show a higher concentration of vanadium than Thai stones, which contain on average four times the amount of iron. M.O'D.

TAYLOR, A., 1991. Emeraldolite (letter). *Australian Gemmologist*, 17, 9, 381-2.

Queries loss of water and colour when seed beryl is heated. R.K.M.

TAYLOR, W.R., JACQUES, A.L., RIDD, M., 1990. Nitrogen-defect aggregation characteristics of some Australasian diamonds: time-temperature constraints on the source regions of pipe and alluvial diamonds. *American Mineralogist*, 75, 1290-1310, 11 figs.

Fourier transform infrared microscopy is used to make a quantitative determination of the proportions of aggregated N substitutional defects platelet intensities and bulk N contents in Type Ia diamonds from the Argyle and Ellendale olivine lamproite pipes in the Kimberley block of north-west Australia and from alluvial deposits in western and central Kalimantan (Indonesia) and Copeton in eastern Australia. M.O'D.

TOMBS, G.A., 1990. Argyle diamonds. *Australian Gemmologist*, 17, 8, 321-4, 6 figs.

An account of the typical rough surfaced diamonds found in the Argyle area of W. Australia. Mines operate continuously year round, alternating staff commute from Perth fortnightly. The mines are open-pit and lamproite matrix is crushed and separated by gravity processes on site, computer controlled. Extreme roughness of surfaces is explained; crystals usually badly strained making polishing difficult; about 5% are gem quality. Strong pinks and purples are known but are extremely rare and fetch exceptionally high

prices; it is not known whether more of these may be found. [Two captions to figures have been transposed.] R.K.M.

WARD, F., 1988. The search for jade. *Bulletin of the Friends of Jade*, 5, 86-92.

The author describes his work in preparing an article on jade for the National Geographic Magazine. He was able to visit some of the jade-producing areas of the world. M.O'D.

WEISS, S., 1991. Eisenhaltiger gelber Orthoklas - ein wiederentdeckter Edelstein aus Madagaskar. (Iron-bearing yellow orthoclase - a rediscovered gemstone from Madagascar.) *Lapis*, **16**, 3, 13-14, 3 figs (1 in colour).

Fe-bearing yellow orthoclase from Madagascar is described with notes on the location and on the crystal forms encountered. The mineral is of gem quality and is found in pegmatites in the general region of Itrongay. M.O'D.

WILKE, H.-J., POPOVA, E.E., 1991. Das Mineralogische Museum des Leningrader Bergbau-Institute. *Lapis*, **16**, 6, 24-37, 13 photographs in colour.

The museum of the Leningrad Mining Institute contains a fine collection of mineral specimens from the USSR and elsewhere. Exceptional crystals of brazilianite and uvarovite are among those of gemmological interest. M.O'D.

WOODHEAD, J.A., ROSSMAN, G.R., SILVER, L.T., 1991. The metamictization of zircon: radiation dose dependent structural characteristics. *American Mineralogist*, **76**, 74-82, 9 figs.

IR spectroscopy was used to examine a suite of gem zircon samples from Sri Lanka. XRD and chemical analysis were also used. The degree of metamictization increases systematically with U-Th content up to the point of total metamictization. The amount of metamictization is determined by examination of unit cell parameters. In the IR spectrum band widths increase and intensities decrease with increasing U-Th content. Bands related to Si-O bonds persist and bands related to Zr-O bonds disappear thus indicating that the structure of metamict zircon consists of distorted and disoriented isolated silica tetrahedra with few if any displaced Zr cations. M.O'D.

YEUNG, I., 1989. Treasures of Peinan culture found in Taiwan dig. *Bulletin of the Friends of Jade*, **6**, 8-6.

Archaeological examination of sites in the central mountain range of Taiwan has revealed nephrite artefacts in burial sites dating from 2025-1025 BC. Many of the objects are a fine green. M.O'D.

What's new in minerals? 1991. *Mineralogical Record*, **22**, 3, 213-20, 22 photographs (20 in colour).

Gem quality minerals seen at the 1991 Tucson Gem and Mineral show included copper-coloured blue tourmaline from the Batalha mine, Paraiba, Brazil; green diopside crystals from Kaflu (?), Pakistan; aquamarine crystals from the Jaqueto mine, Bahia, Brazil; vesuvianite crystals from the Jeffrey mine, Asbestos, Quebec; pink apatite crystals from Nagar, Pakistan, and fine multi-coloured tourmaline crystals from the Cruzeiro district, Minas Gerais, Brazil. M.O'D.

Book reviews

FLEISCHER, M., MANDARINO, J.A., 1991. *Glossary of mineral species 1991*. The Mineralogical Record Inc., Tucson. pp.256. Price on application.

This is the sixth edition of the invaluable *Glossary*. Since the printing of the previous edition in 1987 about 200 new mineral names have been added and about 900 previous entries have had to be revised. Six new mineral groups have been added. As before the listing is alphabetical with chemical composition, crystal system, colour where necessary, allocation to groups which are themselves listed at the back of the book, dimorphs and polymorphs and particulars of references, mostly in *The American Mineralogist* but also in other journals where appropriate. Where there appears to be a close relationship between minerals without the entire series of compositions between them being known the words 'compare with' are used. 'Isostructural with' is used to denote two crystal structures of the same type with different chemical compositions, as with grossular and berzeliite. There are also boxes which can be completed by the reader to denote what species are found in his collection. M.O'D.

HURLBUT, C.S., KAMMERLING, R.C., 1991. *Gemology*. 2nd edition. John Wiley, New York. pp. xiv, 336. Illus. in black-and-white and in colour. £43.70.

Since the first edition appeared several years ago there have been a number of developments in gemstone synthesis and enhancement. A new chapter has been added for this reason and the coloured illustrations are more numerous and of good quality. Additional species have been added to the descriptive section and in this edition the more important species are listed first. Both sections are in alphabetical order. Details of important synthetic materials are also given in the sections on their natural counterparts.

The details of instruments and of gem testing are clearly given and the simple diagrams will be useful for students. Refractive index is well explained and the description and details of the use of interference figures are particularly successful. In contrast to many other simple gemmological texts this book includes basic details of fashioning.

The book is well-produced and very suitable for students and the academic background of the authors ensures a balanced presentation of material. M.O'D.

KERRICK, D.M., 1990. *The Al_2SiO_5 polymorphs*. The Mineralogical Society of America. Washington DC. pp. xii, 406. Illus. in black-and-white. US $20.00. [Reviews in mineralogy Vol. 22.]

Gemmologists will be interested in Al_2SiO_5 since andalusite, kyanite and sillimanite are members of the group. The book opens with an introductory section in which facies series and baric regimes are discussed together with tectonic metamorphic analysis of metamorphic belts and geothermometry as applied to the aluminium silicates. The next section covers crystal structures, optical and physical properties and is followed by a lengthy section on phase equilibria, an important feature in minerals displaying polymorphism. Later sections cover non-stoichiometry lattice defects, Al/Si disorder, problems with fibrolite (here the name is distinguished from sillimanite), metamorphic reactions, reaction kinetics and crystal growth mechanisms, aluminium metasomatism and a final section dealing with aluminium silicates in anatectic migmatites and peraluminous granitoids. There is a general list of references at the end of the book. Gemmologists will find the greatest interest in the section discussing colour and chemical composition. M.O'D.

NIEDERMAYR, G., 1990. *Fluorit Mineral des Regenbogens*. Bode, Haltern. pp. 80. Illus. in colour. DM 14.80.

The book covers nine major European fluorite locations, each section being contributed by a different author. British and other world locations are briefly described in a final chapter. Each section has its own valuable list of references and the first chapter deals with the mineral itself with notes on its common modes of occurrence. Maps are provided for major sites and the colour pictures are superb. M.O'D.

Proceedings of The Gemmological Association and Gem Testing Laboratory of Great Britain and Notices

OBITUARY

Mr Rodney F. Parcel, Jr, FGA (D.1981), Perris, California, USA, died recently.

NEWS OF FELLOWS

On 8 May 1991 **Michael O'Donoghue** gave a talk entitled 'Improved gemstones' to the Snodland Parish Circle.

On 20 May 1991 **Michael O'Donoghue** lectured on gemstones at Sotheby's 'Looking at jewellery' course.

MEMBERS' MEETINGS

London

On 21 May 1991 at the City Conference Centre, 76 Mark Lane, London EC3R 7JN, an Emerald Evening was held. The ICA video entitled 'Colombia emeralds' was shown. Following the video, Ken Scarratt, Harry Levy and John Kessler discussed various aspects concerning emeralds, including localities, synthetics and treatments.

Midlands Branch

On 19 April at Dr Johnson House, Bull Street, Birmingham, the Annual General Meeting was held at which Mr David Larcher, FBHI, FGA, and Mr John Bugg, FGA, were re-elected Chairman and Secretary respectively The AGM was followed by a showing of the Snowman video 'The wonders of Fabergé'.

North West Branch

On 17 April 1991 at Church House, Hanover Street, Liverpool 1, Carol Gibbs gave a talk entitled 'Tortoiseshell of the Gilbert Islands'. On 15 May 1991 at Church House Gordon Brohier gave a talk entitled 'The gems of Sri Lanka'.

MEETING OF THE TRADE LIAISON COMMITTEE

At a meeting of the Trade Liaison Committee held on 21 March 1991 at 100 Hatton Garden, London EC1, the business transacted included the election to membership of the following:

Gold Laboratory Membership

Raymond Bloch, 74 Rue la Fayette,75009, Paris, France.

Carlo Jewellers Ltd, 25a Hatton Garden, London EC1N 8BN.

Ordinary Laboratory Membership

Chatila Jewellers, 22 Old Bond Street, London W1X 3DA.

Floralake Ltd t/a Bao Bijoux, 59 Beauchamp Place, London SW3 1NZ.

Mozaffarian Jewellers Ltd, 66 Knightsbridge, London SW1Y 7LA.

Palladian Diamond Co. Ltd, 100 Hatton Garden, London ECIN 8NX.

Michael Rose Jewellers, 3 Burlington Arcade, London W1.

Lionel J. Wiffen Ltd, 88-90 Hatton Garden, London EC1N 8PN.

MEETINGS OF THE COUNCIL OF MANAGEMENT

At a meeting of the Council of Management held on 17 April 1991 at 27 Greville Street, London EC1N 85U, the business transacted included the election to membership of the following:

Fellowship

Argirakou, Ioulia, Volos, Greece. D.1990.

Farkas, Susan, Vancouver, Canada. D.1990.

Ordinary Membership

Blanch, Gloria, London.

Hull, Munira F., Harrow.

Mansfield, James G. London.

Mizuno, Kayoko, London.

Pirkl, Stephen V., Glendale, Calif., USA.

Schupp, Frank J., Pforzheim, Germany.
Shah, Fatehchand J., London.
Windwick, William, Moray.

At a meeting of the Council of Management held on 22 May 1991 at E.A. Thomson (Gems) Ltd, Chapel House, Hatton Place, London EC1N 8RX, the business transacted included the election to membership of the following:

Fellowship
Berlioz, Roger F.B., Kandy, Sri Lanka. D.1990.
Sinclair, Lesley, Stenhousemuir. D.1990.

Ordinary
Ashton, Donald, Beckenham.
Michels, Hans-Joachim, Dinslaken, Germany.
Newton, Beverly A., Alhambra, Calif., USA
Niblock, Simon G., Ebop, New Zealand.
Nodznaia, Dikran, Southall.
Smith, Penelope A., Cirencester.
Tamada, Tomohide, Kobe, Japan.
Yoshimoto, Yoshihiro, London.

CORRIGENDA

On p.382 above, 2nd column, line 18 from foot, for 'Minerals of Larousse' read 'Larousse of minerals'

FORTHCOMING MEETINGS

London

3-4 November 1991	Conference and Presentation of Awards (see p. 394)

Midlands Branch

Meetings held at Dr Johnson House, Bull Street Birmingham. Further details from David Larcher on 021 554 3871.

13 - 15 September 1991	The Branch will participate, with an exhibition of gem testing, in the National Exhibition of Time to be held at The British Horological Institute, Upton Hall, Nr Newark, Notts.
20 September 1991	Mr F. Deitsch of Mikimoto Pearls. 'Pearls'
18 October 1991	Mr Alan Hodgkinson. 'A taste of Scottish gemmology'
15 November 1991	Mr J. Gosling. 'The Guyana lapidary project'

North West Branch

Meetings held at Church House, Hanover Street, Liverpool 1. Full details from William Franks on 061-928 1520.

18 September 1991	Mr Matthew Girling of Bonhams. 'The selling of jewellery at auction'
16 October 1991	Mr Alan Hodgkinson. 'A gemmological bonanza'
20 November 1991	Annual General Meeting.

Letter to the Editor

From A.E. Farn, FGA

Dear Sir,

It is always a pleasure to read a 'Letter to the Editor', particularly when penned by our Vice President, R.K. Mitchell. I refer to his letter upon the name changes of methylene iodide and mono-bromo-naphthalene (The Journal of Gemmology, 1991, 22, 6, 387-8). In B.W. Anderson's day at 55 Hatton Garden I feel sure we termed it alpha-mono-bromo-naphthalene. 'Alpha' was also used by Basil Anderson when referring to the 4155Å line in diamond. That of course was in the days before the dwarfing effect of nanometres.

Keith Mitchell admits to a somewhat tongue-in-cheek frame of mind in his comments. He attributes this to a surfeit of years and a dislike of change. I am completely in accord with his sentiments. This of course, is hardly surprising as we are both elderly trade products and share a great regard for the memory and name of Basil Anderson. Anderson, despite his erudition, had a very human touch and a great sense of humour. He gave names to his favourite gemmological tools, such as Henry and Henrietta respectively for two much used pearl scoops. He also had names for his spectroscopes which may well be mentioned in the forthcoming treatise of Eric Bruton and Keith Mitchell on Anderson's research and work with the spectroscope.

May I take this opportunity to draw attention to a short notice on page 386 of volume 22, no.6, adjoining Keith Mitchell's letter. It is headed 'Verbal Testing at the Laboratory' and then proceeds to describe the method of sending articles for verbal testing by post - this puzzles me. I can understand 'mono' in monocular and 'di' in dichroscope, but fail to relate 'verbal', by post.

Yours in retrospect.
A.E. Farn

6 June 1991
Seaford, Sussex.

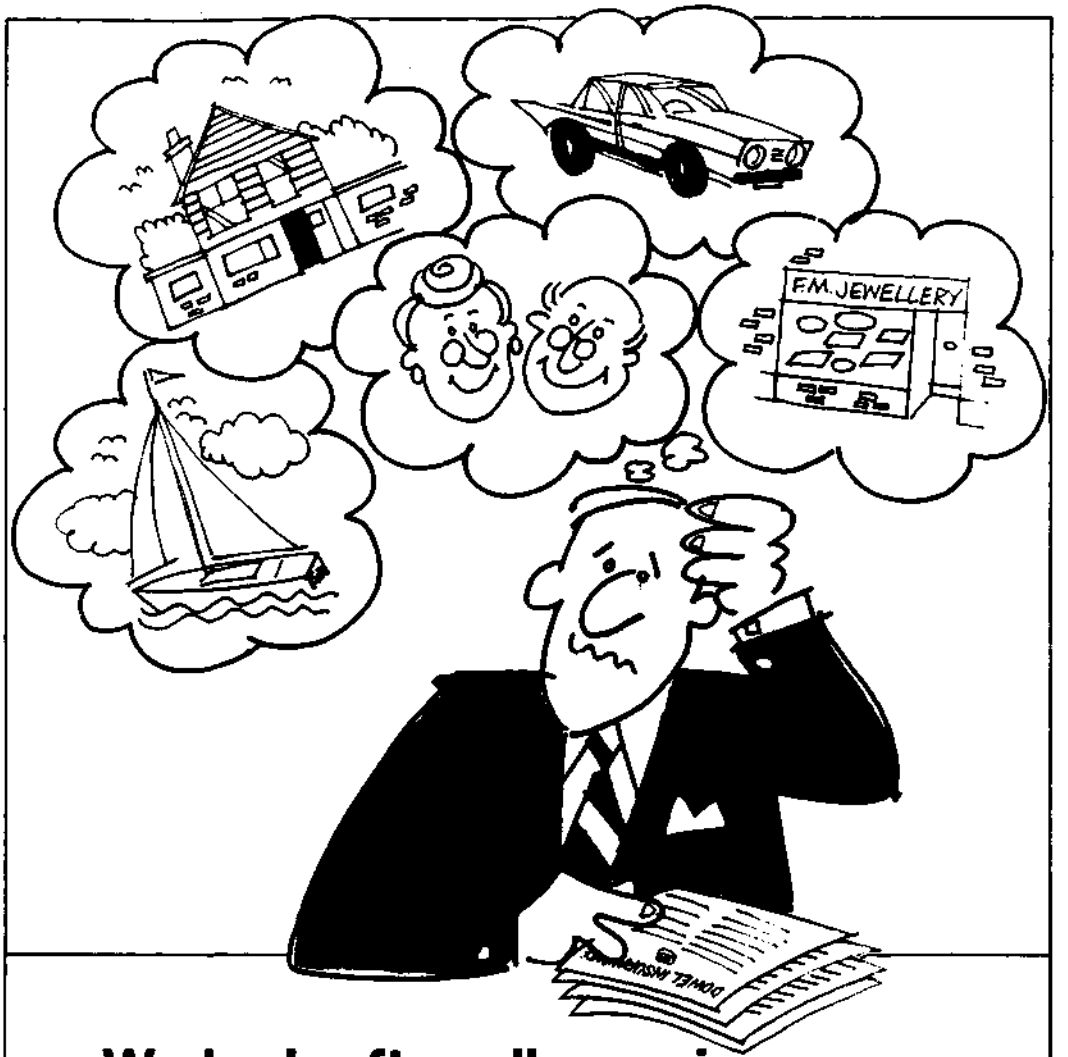

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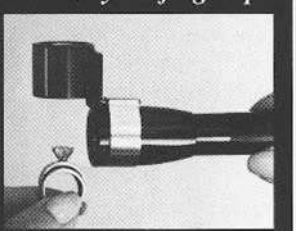

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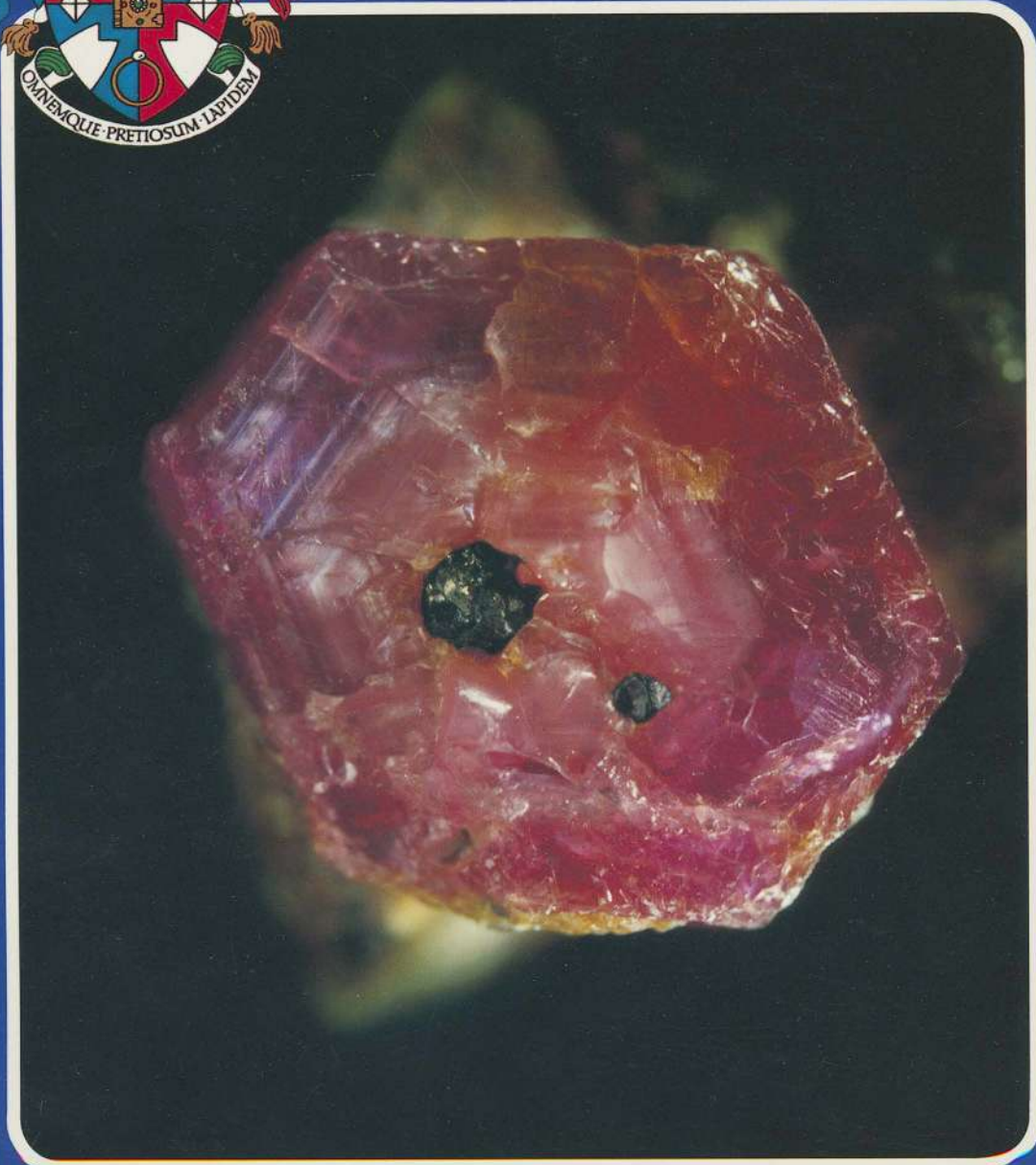

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Cover Picture

Cross section of ruby crystal with massive rutile inclusion. (Plate 5, 'The growth of rubies in south-east Kenya' by R.M. Key and J.O. Ochieng, p.484).

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An unusual assembled inclusion specimen

Robert C. Kammerling and John I. Koivula

Gemological Institute of America, Santa Monica, California 90404, USA

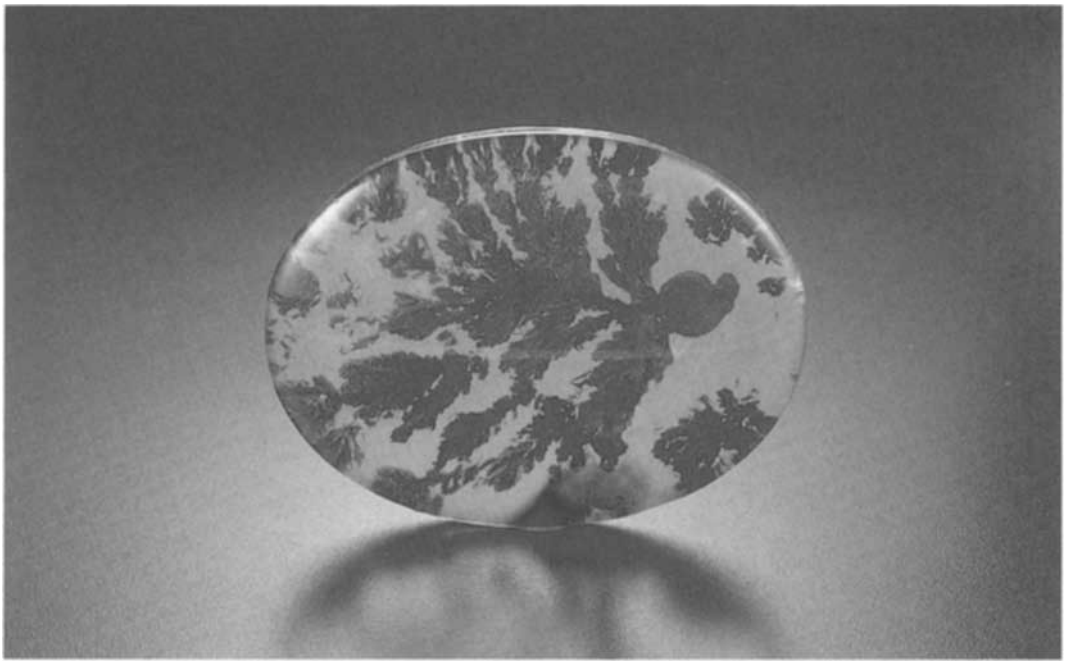

Fig. 1. This assembled agate specimen weighs 61.39 carats and measures 39.00 × 30.45 × 6.42mm. Photograph by Robert Weldon, Gemological Institute of America.

Abstract

This article reports on an assembled stone consisting of glass and dendritic agate components.

Introduction

Inclusions are an important feature in gemstones for a number of reasons. For the diamond grader, the presence of a minute inclusion, just visible with 10x magnification, can set the clarity grade and greatly affect the stone's value. Although often less closely scrutinized from an evaluation standpoint, 'eye-visible' inclusions can also have a significant effect on the value of a coloured stone (in this regard, 'blemishes' on pearls are also an important consideration).

Additionally, features detected under magnification are of concern in gem identification. With the proliferation of new synthetics and the growing availability of so-called 'sophisticated' man-made gems, inclusions are usually the most reliable – sometimes the only – means of determining the nature of a gem. No longer is it just a question of natural vs. Verneuil synthetic ruby. Today we face the possibility of having to identify flux synthetic rubies; flux blue, pink and orange sapphires; synthetic opal in a variety of body colours and patterns to their play-of-colour; synthetic alexandrite and even cat's-eye alexandrite; and the list goes on. Furthermore, even when we do determine, for

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example, that a ruby is natural, we may then have to determine whether or not it has been heat-treated to modify colour and/or clarity, or had surface cavities filled with a glass to improve appearance and add weight.

Inclusions (and related structural features) are also important in that they are responsible for some of the most intriguing gems, those which display optical phenomena. Were it not for fine, parallel acicular crystal inclusions in chrysoberyl, there would be no cat's-eye stones; but for intersecting, oriented rutile 'needles' there would be no star rubies and star sapphires. There would be no sunstone or aventurine feldspars had not minute hematite or copper crystals precipitated out in these gem materials.

Altered inclusion specimens

Occasionally we also come across gem materials that have been treated with the apparent purpose of fabricating or altering inclusions. Two such fabricated specimens the authors have examined were colourless quartz crystals with man-made 'three-phase' inclusions. Thin, tubular columns had been drilled in from their bases and had been partially filled with a liquid. The final touch – 'phase three' – was a minute faceted gem; in one specimen this 'solid phase' was a blue gem, in the other, a bright red stone. Each stone had its base sealed with what appeared to be a mixture of epoxy resin and quartz fragments (Koivula and Kammerling, 1989).

In 1986 the authors first saw faceted colourless as well as blue topaz containing brownish yellow acicular inclusions. First described as 'rutilated' topaz, it was later shown that the inclusions were limonite-stained etched dislocation channels (Koivula, 1987). Late in 1988 one of the authors was shown similar material in which the inclusions were a dark red-brown and which reportedly had been altered by heat treatment. Subsequent investigation showed that the heating had altered the limonite staining to hematite, changing the colour of the inclusions and making them more prominent (Kammerling and Koivula, 1989).

Also seen occasionally are translucent to semi-translucent chalcedonies containing large, apparently artificially induced dendritic inclusions. It is believed that the gems are first soaked in a copper solution, after which an electric current is applied in order to precipitate out a dendrite of elemental copper (Dunn *et al.*, 1981; Koivula and Misiorowski, 1986; Koivula and Kammerling, 1989). The copper solution is also probably responsible for the blue-green body colour of such treated gems. There is also a brief mention in the literature of an agate cabochon on the back of which dendrites were engraved and then filled with a black substance (Nassau, 1983). Equally germane to this discussion are 'most agate doublets'. These are produced by precipitating out manganese oxide dendrites within gelatine on a glass plate and then gently heating to remove excess water; another glass plate is then cemented on top and assembled stones fashioned from the composite piece (Webster, 1983).

Description of specimen under investigation

In the spring of 1990, a resident gemmology student at the Gemological Institute of America in Santa Monica donated a most interesting assembled stone for examination. The specimen, a very shallow-domed oval single cabochon (Figure 1), had been purchased at the Tucson Gem and Mineral Show in February, where it was represented as a dendritic agate; there was no indication from the vendor that the piece was assembled or in any other way altered. The stone, which weighs 61.39 carats and measures 39.00 × 30.45 × 6.42mm, is essentially colourless and almost transparent where inclusions are not present. It exhibits an attractive pattern of dark reddish to greenish brown dendrites in the type of general pattern which in the US trade is referred to as 'plume' structure (Figure 2). One small, irregular area has a dark yellowish brown colour with wavy, agate-like banding.

When examined from the side, the assembled nature of the piece becomes obvious (Figure 3). The top consists of a very transparent, colourless convex cap joined to a flat, light grey, semi-transparent to translucent base.

Magnification

When examined under magnification the cap appears virtually inclusion-free. Between the cap and base there is a fairly thick (approximately 0.5mm) transparent, colourless layer containing many minute, spherical gas bubbles (Figure 4). Using a straight metal pin and very little pressure it was easy to both scratch and indent this layer, which we believe to consist of an epoxy or similar synthetic resin (or perhaps a 'gel-type' cement). Some of this epoxy-like material runs out over part of the cap and some irregular drops of what appears to be this material are found on the cap near the separation plane. The entire base of the stone is also coated with this material; several scratches (Figure 5) and other irregularities (Figure 6), some resembling human fingerprints, are noted on the coating. The base section, which is approximately 1.2mm thick, contains (in addition to the dendritic inclusions already described) some irregular, wispy, milky-white areas, some of which show typical 'botryoidal' or 'fortification agate' structure (Figure 7).

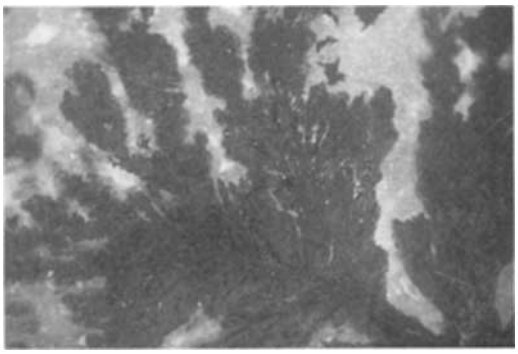

Fig. 2. The dendrites in the assembled stone exhibit an attractive 'plume' structure. Photomicrograph by John I. Koivula. Magnified 3x.

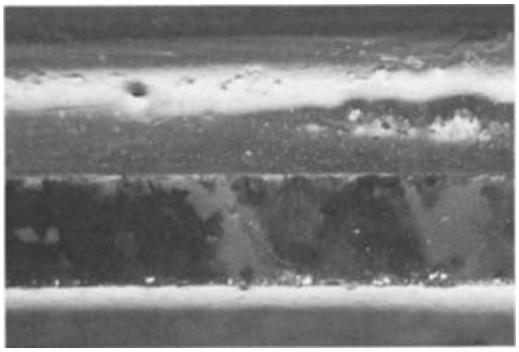

Fig. 3. When examined from the side, the assembled nature of the stone becomes obvious. Photomicrograph by John I. Koivula.

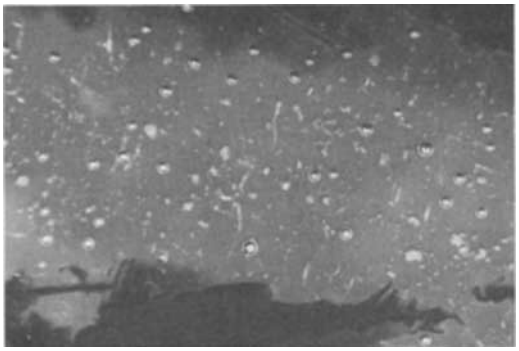

Fig. 4. Numerous minute, spherical gas bubbles can be seen in the colourless cement layer between the cap and the base. Photomicrograph by John I. Koivula. Magnified 40x.

Fig. 5. A scratch can be seen in the colourless coating on the base of the assembled agate. Photomicrograph by John I. Koivula. Magnified 10x.

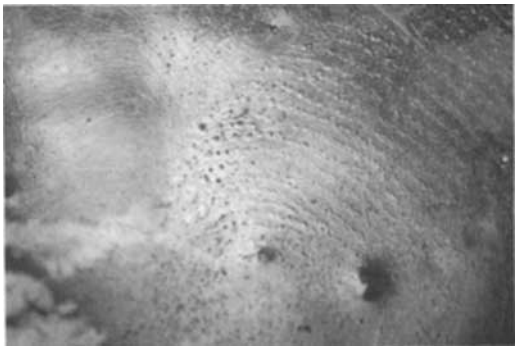

Fig. 6. Irregular surface features, probably human fingerprints, were also noted on the coated base. Photomicrograph by John I. Koivula. Magnified 5x.

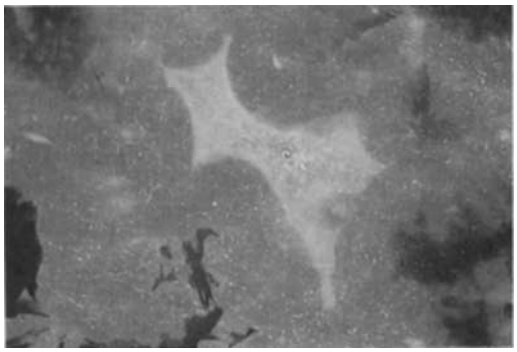

Fig. 7. The typical agate structure was detected in some areas of the agate base. Photomicrograph by John I. Koivula. Magnified 30x.

Gemmological properties

A spot refractive index reading taken on the apex of the cap with a Duplex II refractometer revealed a value of 1.51, while a flat-facet type reading on the base gave a value of 1.56. No birefringence or pleochroism was noted, and no absorption features were detected using a Beck prism spectroscope mounted on a dual direct-transmission/fibre-optic illuminator base. When examined face-up in the polariscope between crossed polaroids the stone exhibited an aggregate reaction; when examined through the side, parallel to the separation plane, the cap gave a singly refractive reaction while the base gave an aggregate reaction. Through the careful use of hardness pencils it was determined that the cap had a Mohs hardness of approximately 5½.

Viewed face-up under long-wave ultraviolet radiation, no fluorescence was detected; when examined parallel to the girdle plane, however, the epoxy-like layer was seen to fluoresce a bright bluish white. Viewed face-up under short-wave ultraviolet light, the stone fluoresced a moderate chalky yellow; examined from the side, however, it was seen that the cap was fluorescing a strong chalky yellow, the epoxy-like layer fluoresced a moderate chalky bluish-white and the base was inert. Interestingly, when viewed through the base of the cabochon the yellow fluorescence of the cap was masked.

Conclusion and discussion

Based on the above test results, it was determined that the specimen was a glass and dendritic ('plume') agate doublet, the two components being joined with a colourless cement layer. Although it would appear inconsistent with the identification of the base section, the 1.56 RI obtained for this component was probably due to the thickness of the coating on the base, that is, the reading was that of the epoxy and not of the underlying chalcedony. In the authors' experience, this reading is in the range of some synthetic casting resins with which they have experimented.

One might ask why anyone would go to the bother of producing such an assembled stone. Dr Emmanuel Fritsch of the GIA Research Department offered one possible explanation, stating that only in a relatively thin section might the agate base have exhibited the desired 'plume' effect; the assemblage allowed this effect to be seen in a larger (and perhaps more durable) stone. Another possible explanation is that, as with some turquoise and opal, the finished piece may merely have been too thin to have offered adequate durability, hence the assemblage.

Acknowledgement

The authors would like to thank Mr Pieter Bennett for bringing the assembled 'plume' agate specimen to their attention and for donating it to the GIA Permanent Collection.

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Contributions to a history of gemmology Carl Peter Thunberg and Ceylon gemstones

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The literature of antiquity frequently mentions the gem riches of Ceylon, today known as Sri Lanka, but only in the 18th century, did a modern, trained scientist, Peter Carl Thunberg (1743-1828), Swedish medical doctor and naturalist, systematically collect and describe its gemstones. The account first appeared in a narrative of his voyage to the Far East and elsewhere, *Resa uti Europa, Africa, Asia... 1770-1779*, published in Uppsala, Sweden, 1788-93. He briefly describes four non-gem minerals and twenty gemstones which herein are affirmed as to identity or suggested as being different from the species to which assigned by Thunberg.

Biographical note

Carl Peter Thunberg was born at Jönköping on 11 November 1743 where in his youth he attended local schools then entered the University at Uppsala for his higher education. Here he obtained his doctorate in medicine in 1770. While at Uppsala he studied under the celebrated naturalist Carolus Linnaeus (1707-1778) who made him his protege and declared him to be his most promising student. From this master of natural history he received the inspiration to devote almost his entire life to studies in the natural sciences with greatest emphasis on botany. However, immediately after leaving the university he travelled to Paris to further study medicine for one year. Here he received an invitation from the Dutch East Indies Company to act as surgeon and naturalist in their colony at Cape Town, South Africa. Setting sail from Europe he arrived at the Cape in April 1777, and for a period of almost three years assiduously collected over 3,000 species of plants, of which over 1,000 were new to science.

An opportunity now came his way to travel farther to Japan, again acting in similar official capacities. He boarded ship in 1775 and after stops in the Dutch East Indies eventually arrived at the island of Deshima in Nagasaki Harbour to which place the Dutch were confined by order of the Japanese government. Despite restrictions placed on travel and social exchanges Thunberg managed to assemble a large collection of native flora, especially plants that were used for food or in the native economy, which proved to be the next largest collection after that formed earlier by Engelbert Kaempfer (1651-1715) also a visitor to Japan in 1690. Thunberg's collection was dispatched to Sweden and formed the basis for his monumental *Flora Japonica*, 1784, in which treatise he described over 300 previously unknown plants. He left Japan in December 1776, stopping during his voyage home in Batavia, Colombo, Cape Colony, and London, in the last city making the acquaintance of a number of scientists, including Sir Joseph Banks (1743-1820). He arrived in Sweden in 1779 and in 1781 was appointed demonstrator in botany at Uppsala, and then succeeded his mentor, Linnaeus, as Professor of Botany in 1784. Thunberg founded a botanical garden at Uppsala and gave to his university his large collection of natural history objects. In addition to the Japanese botany mentioned, he also wrote *Icones plantarum Japonicum*, 1794-1805, *Prodromus plantarum*, 1800, and *Flora Capensis*, 1807-1812. He first described the remarkable South African plants known as the proteas while the genus, *Thunbergia*, containing 65 species and much cultivated in warmer climes, was named in his honour. His travels proved popular reading and were published in German, 1792-4, in English, 1794-5, and in French, 1794. After a useful and productive life, Thunberg died at Tunaberg, near Uppsala, on 8 August, 1828.

Historical accounts of Ceylon gemstones

This pleasant, tropical island, lying immediately south of the Deccan Peninsula of India, has been identified by various names as Serendib, Taprobane, and others (Yule, 1871; Gübelin, 1968; Casson, 1989). Its gem treasures were known for some centuries prior to the Christian era as is made clear in the *Periplus of the Red Sea*, or sea-trader's guide to the Red Sea and other Near East waters, a new translation of which has been made by Casson (1989, esp. pp. 230 ff). By the beginning of the first century traders knew of numerous animal, vegetable, and mineral products of the region, all of

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which were exchanged among Greek, Roman, Egyptian, and Moslem merchants. Well into the Christian era the fame of Ceylon's riches spread throughout the civilized world but the first reliable eyewitness account appears to be that of Marco Polo (1254-1324), famed Venetian adventurer, who visited the island on his return trip from China sometime between 1292, when he left China, and 1295 when he arrived in Venice.

Polo writes (Yule, 1871): "Now I will... tell you of the most precious article that exists in the world. You must know that rubies are found in this Island and in no other country in the world [*sic*] but this. They find there also sapphires and topazes and amethysts, and many other stones of price. And the King of this Island possesses a ruby which is the finest and biggest in the world; I will tell you what it is like. It is about a palm in length, and as thick as a man's arm; to look at, it is the most resplendent object upon earth; it is quite free from flaw and red as fire. Its value is so great that a price for it in money could hardly be named at all. You must know that the Great Khan [Kublai Khan, 1216-1294] sent an embassy and begged the King as a favour greatly desired by him to sell him this ruby, offering to give for it the ransom of the city, or in fact what the King would. But the King replied that on no account whatever would he sell it, for it had come to him from his ancestors".

Yule (p.256) comments on the story of this enormous 'ruby' as told by others who in the past claimed to have some knowledge of it but offers himself no explanation as to the stone's identity even though it was probably obvious to Yule that it could not have been a true ruby. Alternatively, the stone could have been a large tourmaline crystal, possibly red in colour and from Burma where in modern times at least, very large rubellite crystals were found in the pegmatite mine at Sakangyi. Furthermore, Bauer (Spencer transl. 1904, p.371) notes that "two very fine specimens of crystallized rubellite from Burma are exhibited in the Mineralogical Gallery of the British Museum, one of these, remarkable for its size and shape, being seven inches high and six inches across, was given by the King of Ava to Colonel Symes when on an embassy to that country in 1795; the other, not so large, but of a fine deep colour, was presented to the Museum in 1869 by Mr C.S.J.L. Guthrie".

After Marco Polo the next eyewitness from Europe appears to be Jean Baptiste Tavernier (1605-1689), the daring French traveller-gem merchant, who made no less than six voyages to the Near East and into India, seeking and buying gems of great value for resale in Europe. His account makes fascinating reading and is still highly esteemed for its historical detail, gemmological information, and general accuracy. Its first edition, *Les six Voyages*, etc., appeared in Paris in 1676. Tavernier visited Ceylon from May 12 to July 25, 1648, noting that "there are only two places in the East where coloured stones are obtained, namely in the Kingdom of Pegu [Burma] and in the island of Ceylon" (Tavernier, Ball-Crooke transl., 1925, 2, 77). Further, "the other place in the East whence rubies and other coloured stones are obtained is a river in the island of Ceylon. It flows from high mountains which are in the middle of the island, and as the rains greatly increase its size – three or four months after they have fallen, and when the water is lowered, the poor people go to search the sand, where they find rubies, sapphires, and topazes. The stones from this river are generally more beautiful and cleaner than those of Pegu" (*ibid*, p.79). While Tavernier's first edition appeared in 1676 the information on India's and Ceylon's gemstones actually appeared beforehand in the 1665 edition of *Chappuzeau's Histoire des Joyeaux*, which, however, is said to be a pirating of information derived from Tavernier's 'original memoirs', according to Valentine Ball (Tavernier, Ball-Crooke edit, 2, 471-6). An English version of Chappuzeau is also known, published in 1671. Neither of the works contain any information which is not already in Tavernier.

Thunberg's visit

Apparently Thunberg's knowledge of Ceylon's gemstones was gained largely as a result of a several weeks stay at Matara, which gem district he visited in response to an urgent request for his medical attention to the wife of Count Rantzow, Dutch Comptroller of the 'factory' at Mature (as it was called). Thunberg states that "I daily made excursions in the vicinity of this place, and as the precious stones of the island are found and dug up more especially in these parts, I procured the proper intelligence, as well concerning the different kinds of them, as the manner in which they are sought for and made use of" (Engl. transl. p.215, ff.). He notes that the major part of gemstones are locally cut and sold afterwards in India, it being the occupation of the "poorer sorts of Moors to cut and polish them", referring here to the Moslems of Sri Lanka who until recently monopolized the lapidary treatment of native gemstones. Thunberg took care to buy both rough and cut stones, the rough to be preserved with other 'fossils', i.e., mineral specimens, which he collected during his travels. The non-gem species from Ceylon are few: an 'iron ore' found in the earth and clay and suggesting limonitic or goethitic concretions, mica in "large laminated masses... the slivers of this are used for ornamenting... umbrellas, made of large Talpat

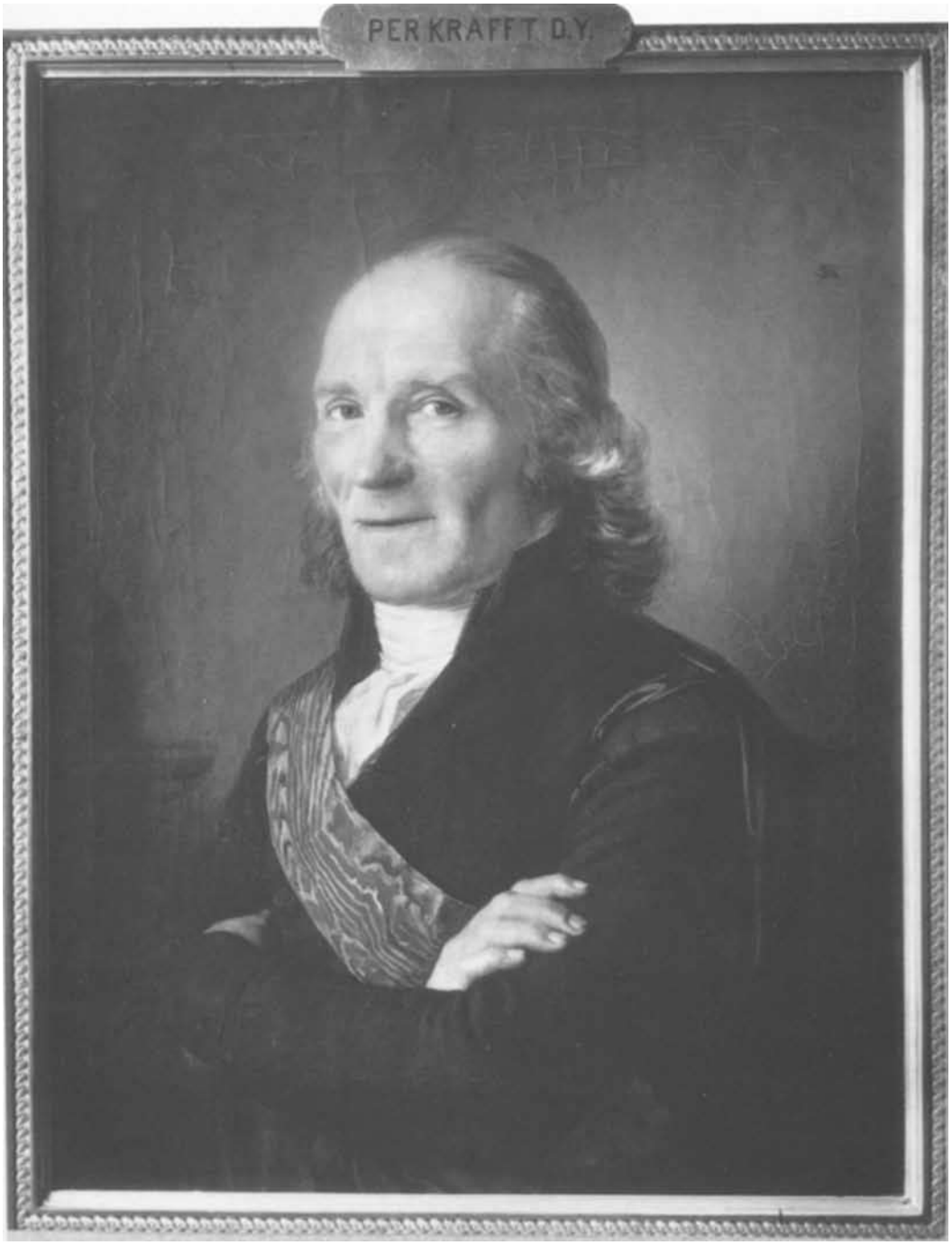

Fig. 1. Portrait (original in oils) of Carl Peter Thunberg by Per Krafft, The Younger, painted in 1808, now in the University of Uppsala, Sweden. Courtesy Dr. Kurt Boström.

(*Licuala*) leaves", 'plumbago' or graphite, and 'stahlstein, or crystallized pyrites (or siderite), "used for making buttons of".

The gemstones are as follows, with synonyms in English, Malabarese, Singhalese, and Swedish, the last added from Thunberg's article on same in the transactions of the Swedish Academy of Sciences (Thunberg, 1784). The first name is from the English translation (Thunberg, 1795).

Ruby: robyn, elinges chogeppu, lankaratte, rubin. "Genuine ruby".

Amethyst: scuandi (in Malabar. & Singhal.); Swedish like English. "Purple-coloured Mountain Crystal."

Robals: rauwa, rawa; granater. "Small transparent Garnets of dark-red colour".

Hyacinths: No synonyms given; "made to pass for rubies". The name is classically assigned to red zircon, which gemstone is abundant in Sri Lankan gravels in short prismatic tetragonal crystals and rounded pebbles.

Red Tourmaline: pania turemali, penni tourmalin; röd turmalin. "A quartz inclining to a red colour". As with other colours of zircon, called indiscriminately 'tourmaline', even today.

Blue Saphire: nilem, nile; blå saphir. "A genuine blueish coloured Saphire, frequently with blue spots", here probably referring to the many sapphire crystals in Ceylon gravels that display pigmentation only in patches, zones, or thin skin areas.

Blue Tourmalin: nile turemali (both Malab. & Singhal.); blå turmalin. "A Quartz, in colour inclining a little to blue".

Green Saphire: patje padian (both Malab. & Singhal.); grön saphir. "Genuine saphire".

Green Tourmalin: patje turemali (both Malab. & Singhal.), also called the "Maturese diamond", and noting that this name "is given to both Chrysolites with tetrahedral prisms, and even sometimes to the Chrysopras". In the Swedish version, Thunberg defines 'Grön Turmaline' as occurring in 'fyrsidig prisma', again almost certainly describing tetragonal crystals of green zircon. The 'chrysopras' used here is not further identified by Thunberg.

Topaz: puresjeragen, purperagen, but the latter is given in Thunberg's article as 'pusperagan'. "Genuine topaz".

Cinnamon-stone: komedegam (both Malab. & Singhal.); canelsten. "A fine flame-coloured or yellowish-brown garnet". Grossular.

Yellow Tourmaline or *Maturese Diamond:* kaneke turemali (both Malab. & Singhal.). "A Topez [*sic*] of a greenish-yellow colour", but most likely another colour phase of zircon; the second term for many years has been applied to zircons, especially from the Matara area, which have been heat-treated to drive off colour.

White Tourmalin or *Maturese Diamond:* sudu turemali (both Malab. & Singhal.). "Topaz of pale yellow colour", but Thunberg's Swedish gives it as 'gröngul', i.e., 'greenish-yellow'.

White Crystal: wille palingu, sudu palingu; hvit crystall. "Transparent and colourless mountain Crystal".

White Saphires or *Water Saphires:* willie padjan, sudu padjan; hvit saphir or vatn-saphir. "Small fragments and slivers of the most transparent white mountain Crystals".

Taripo: "a milk-coloured quartz".

Yellow Crystal: manjel palingu, kaha palingu. "A lighter coloured smoky Topaz". Citrine.

Brown Crystal: tillia palingu (both Malab. & Singhal.). "Smoky mountain Crystal, or a dark coloured smoky Topaz". Smoky quartz.

Black Crystal: karte palingu, kallu palingu. "Partly in Crystals, partly in fragments, is the Electrical Tourmalin of Ceylon". Apparently referring here to schorl.

Cat's Eye: wairodi (both Malabar. & Singhal.); kattöga. "Pseudo-Opal".

Commentary

The meagre descriptions above are augmented for some stones in the text that follows the listing, giving colour qualities of ruby and amethyst, and properties such as transparency and presence or absence of inclusions. Accurate identifications of gemstones, especially when in the form of rolled pebbles and lacking morphological clues, were not easy in the last part of the 18th century, and even when Thunberg enlisted the aid of Torbern Bergman it is obvious that mistakes still occurred. For example, in Thunberg's discussion of ruby (p.220), he states that "most of them are round and flat, from having been agitated and rolled about in the water", which is actually more likely to be the case with every other Sri Lankan alluvial gemstone than the ruby or sapphire. The corundum crystals of these gravels commonly display small to large remnants of crystal faces, and even when severely worn, they present general shapes that are readily identified as belonging to crystals of this species. The confusion in identity, or, rather, the application of the name 'ruby' freely to any reddish stone, causing such confusion, is typified in Thunberg's following remark in which he claims that "some [rubies] I have found crystallized with eight sides, of which four were broad, and four very small, and terminated by two points, consisting of four sides each", an excellent description of a typical doubly-terminated zircon crystal displaying first and second order prisms and the bipyramid but not of a corundum

crystal. Next he notes that "the Moors say that these approach nearest to the Diamond in hardness, and polish them, in order to render them fit for being set in rings", but now it seems obvious that the Moors [Moslems] are speaking of true corundums and not zircons, the difference in hardness between the two readily apparent to anyone who has applied them to the lapidary's grinding wheel.

The difficulties in identification that beset Thunberg and others in his day were to a large extent mitigated by the success of chemical analytical methods utilizing alkali fusions of hitherto intractable minerals, and from the fusions, now water-soluble, further isolating distinctive compounds – usually oxides such as 'silica', 'alumina', etc. Among the most successful analysts at the close of the 18th century and into the first years of the 19th century was Martin Heinrich Klaproth (1743-1817), characterized by Mary Elvira Weeks, *Discovery of the Elements* (Weeks, 1956, p.263) as "the most distinguished German mineralogical and analytical chemist of his time". Klaproth published his numerous analytical results in various journals but these are found conveniently collected in his *Beiträge zur chemischen Kenntnis der Mineralkörpers*, 6 volumes, 1795-1815, of which the first two volumes in the English edition are utilized here (Klaproth, 1801). Thus, on corundum, or "oriental sapphire", Klaproth disputes Bergman's analysis, in which the latter includes 35% silica, and after a lengthy description of his analytical procedure, arrives at his own analysis, essentially all alumina and only a little iron oxide and calcium oxide, which is nearly identical to currently accepted analyses for corundum. From this and other comparisons with the analyses of gemstone provided earlier by Bergman it becomes clear why even consultation with this contemporary of Thunberg did not always result in accurate identifications of the gemstones that Thunberg brought back from Ceylon. Before advanced methods of chemical breakdown became available there was little that mineralogists could do to identify many species which nether reacted before the blowpipe flame nor allowed attack by then available acids and reagents.

In his further discussion of Ceylon gemstones, Thunberg has little difficulty identifying amethyst in which the crystals are characteristically terminated, "some have six sides, and one hexagonal point" (p.222). However, the "robal", said to be dark-red, darker than ruby, is not further described and its identity must remain speculative. Thunberg's "hyacinths" that occur in "small yellowish-brown or reddish prisms" appear to be zircons, and the added remarks on "red tourmalin" that speak of crystals that "seem to have four similar sides on their oblong column, and a quadrangular pyramid", again apply best to zircon. Speaking of this species, it was Klaproth (p.175 ff.) who "discovered zirconia in 1789 while analyzing a zircon from Ceylon" (Weeks, p.543), further noting colours, crystal forms, and specific gravities, but giving credit to

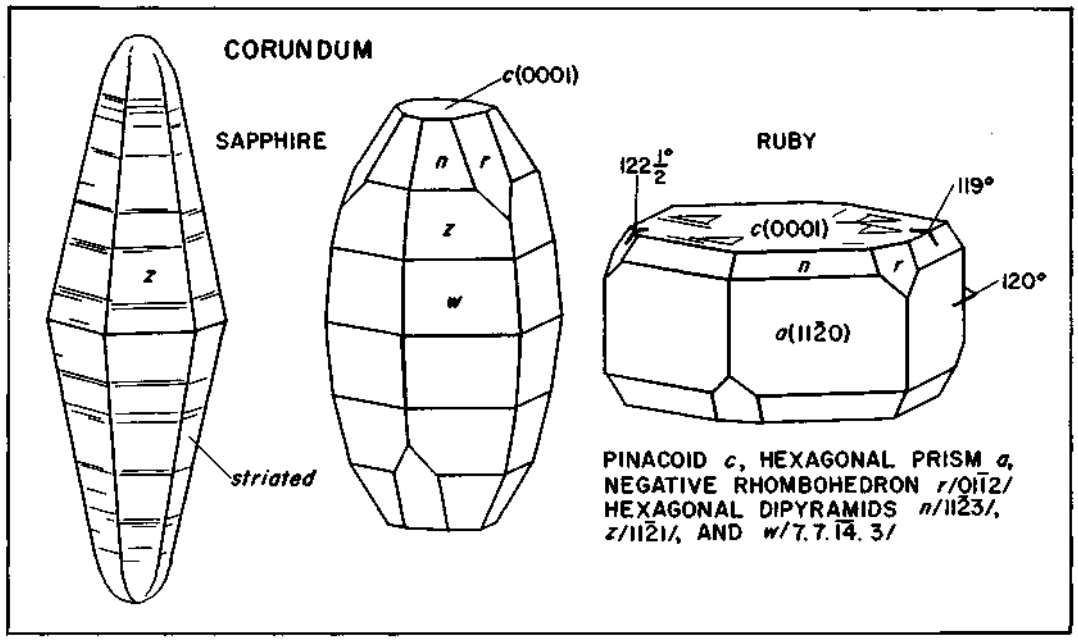

Fig. 2. Sapphire and ruby crystals, the sapphire at extreme left being particularly typical of those found in the gem grvels of Sri Lanka. From a drawing by John Sinkankas in his *Mineralogy*.

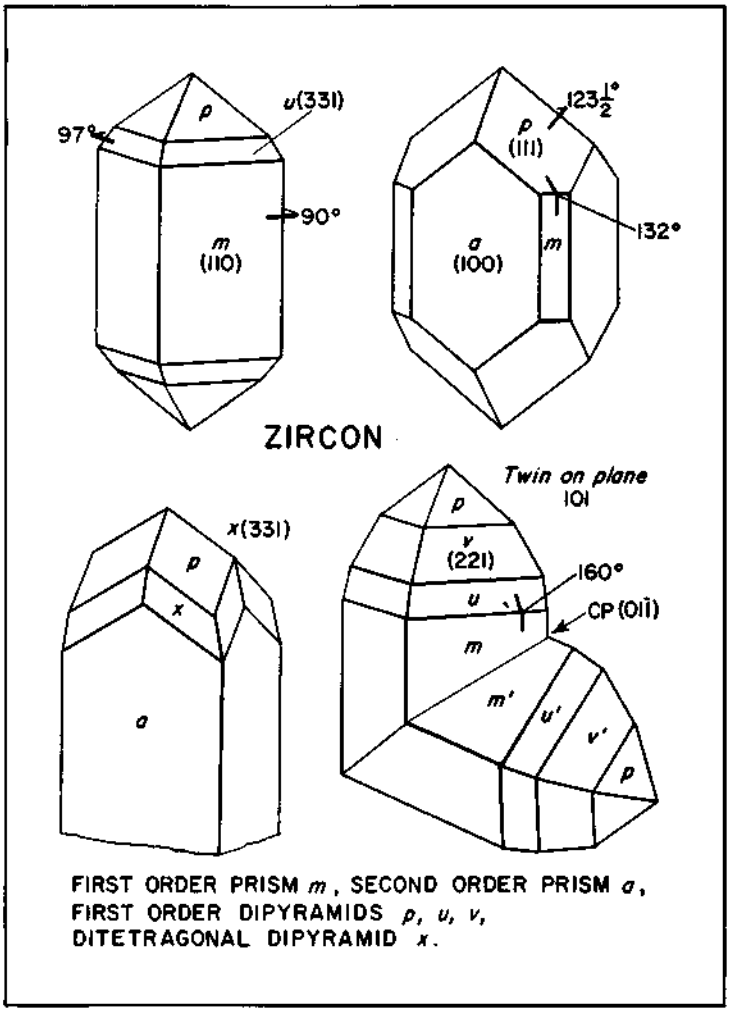

Fig. 3. Zircon crystals showing common forms, the upper two examples being noted very frequently among the crystals found in the gem gravels of Sri Lanka. From a drawing by John Sinkankas in his *Mineralogy*.

J.B.L. Romé Delisle (1736-1790) for being the first mineralogist to suggest that zircon was a distinct species. Klaproth also analyzed hyacinth from Ceylon (p. 195), noting again that erroneous analysis by Bergman (who failed to recognize the presence of zirconia) and determining that chemically it was the same as zircon.

Thunberg's "blue saphire" may also be misidentified because all specimens that he saw are claimed to be more uniformly coloured than amethysts, "all those which I saw had been worn smooth by their agitation in the water", and "all made use of, when cut, for buttons and rings". This description seems unlikely for true sapphire but could be applicable to iolite, aquamarine, or topaz. He repeats his previous statement that "blue tourmalin" is nothing but quartz with a tinge of blue. On the other hand, a green sapphire is reaffirmed as "geniune", while the "green tourmalin", again from his description of its crystals, is most likely to be zircon. Topaz is reaffirmed as genuine, and is said to occur "mostly in yellowish splinters", while the "cinnamon-stone", a term long applied to grossular from Ceylon "derives its name from its colour, which in some measure resembles the oil drawn from the best and finest cinnamon" (p.225).

The "yellow tourmalin" was never seen in crystals by Thunberg but only in alluvial stones "always worn smooth... from the size of a grain of rice to that of a pea". Nothing further is given as an aid to the identification of this gemstone. The so-called "white tourmalin", also called "Maturese diamond" from the town of Matara is certainly zircon and Thunberg provides some of our earliest knowledge of heat treatment of gemstones to improve their colour when he stated that this stone is "almost always the colour of milk, so that its transparency is not perfectly clear. For this reason it is frequently

calcined in the fire, in consequence of which the colour vanishes, and the stone becomes much clearer, although not perfectly white. It is then enveloped in fine lime, and burned with rice-chaff (oryza)." This is "Matara diamond" or colourless zircon known for hundreds of years by that name in the gem trade.

As to other stones in Thunberg's list, the "white crystal", is ordinary rock crystal, but "water-saphire" is certainly neither corundum nor iolite; under the above misnomer it has for many years masqueraded as corundum but here appears to be nothing more than a colourless zircon. Thunberg says it very much resembles the white crystal but is clearer and "is especially distinguishable by its hardness, in which it surpasses the Crystals." While this suggests corundum, Thunberg admits that he never could obtain any of these stones as crystals but only as "shapeless pieces, or else flat and rounded off, with rugged surface, full of small impressions like dots." Passing on to other "crystals" the kind called "taripo" is defined as milky quartz, while the yellow and brown crystals correspond to our citrine and smoky quartzes. But in the same breath Thunberg mentions "black crystal" which now appears to be schorl because he notes that some crystals display "six dissimilar sides and an obtuse triangular point," a fair description for many of the black to brown or reddish-brown strongly dichroic tourmaline crystals commonly found in Sri Lankan gem gravels, and in shape ranging from smooth ovate pebbles to some which are stubby prisms, doubly-terminated, to some which are practically compressed to wafer-like shapes with scarcely more than traces of prism faces. Thunberg notes that he "could not observe, that the Indians were acquainted with its electrical properties, which they never denote by the name of Tourmalin, but bestow that denomination upon several other species".

One of the stones on the list is the cat's-eye called a "pseudo-opal", which is neither chrysoberyl nor opal, but chatoyant quartz. He describes the stone as "a very hard stone, which approaches more or less white or green, and is semi-diaphanous, with a streak the breadth of a line in the middle, which streak is much whiter than the stone itself, and throws its light to whatsoever side this is turned. In this respect therefore it resembles a cat's-eye, whence it derives its name". The largest piece he saw was the size of a hazel nut. From further remarks it is plain that it is not chrysoberyl, the term "pseudo-opal", apparently being used in his time to describe certain varieties of quartz which bore some fancied resemblance to opal. In fact, Klaproth, who analyzed a specimen from "the coasts of Malabar", noted that its specific gravity was 2.625 as compared to 2.660 for a cut cat's-eye from Ceylon, and from the analyses established the material as almost pure silica (Klaproth, p.78 ff). Despite the evidence of hardness and irregular, splintery fracture, Klaproth suggested that "it would be more proper, in my opinion, to class it with the opals; among which also it was formerly reckoned under the names of Pseudopal, Cat's-eye-opal" (p.84).

Thunberg ends his amplifying remarks by noting that "the stone known in Europe under the name of Tourmalin, and celebrated for its electrical virtues, is not known by the same name by the Indians; but that they denote by the word Tourmalin, several stones, which possess not electrical properties, and which are even of different species, of different colours, and of different degrees of transparency". Regarding the genuine tourmaline of Ceylon, its pyroelectrical properties had been known long before Thunberg's collection of same as pointed out by R.W. Home (Aepinus, 1979) who notes that "samples of this stone had begun to be imported into Europe from Ceylon in the early years of the eighteenth century for use in jewelry. The Dutch and German jewelers who for many years enjoyed a virtual monopoly over the tourmaline trade soon discovered in working them that their stones possessed the remarkable property of attracting a coating of ash to themselves as they were heated in the fire". Thunberg's tourmaline specimens, in part, were turned over to his celebrated compatriot, Torbern Olof Bergman (1735-1784), chemist, mineralogist, pharmacist and professor in the university at Uppsala, who investigated them to the best of his ability and resources and then published the first adequate analysis of same and at the same time remarking on the strong dichroism, variations in properties, and crystal habits (Bergman, 1784). It was to Bergman that Thunberg turned for aid in identifying his Ceylon treasures, acknowledging that he "very kindly furnished me with their mineralogical names" (Thunberg, 1795, p.229).

In conclusion it is noted that another early report on Ceylon's minerals appeared in an article by John W. Webster who summarized a report by Dr John Davy, of England, that originally appeared in the fifth volume of the *Transactions of the Geological Society of London* (Webster, 1824). Davy noted that topaz is called "white sapphire" in Ceylon, that tourmaline is rare and met with by him only in honey-yellow specimens, and that cinnamon-stone garnet, although abundant, is found only in two places, namely Cotta and Belligam. He also noted that zircons of the Matara district receive the name "Matara diamonds" for their finest varieties. Davy claimed that "the natives of Ceylon are perfectly ignorant of the true nature of zircon, and sell the

yellow varieties as topazes of a peculiar kind, the green as tourmalines, the red as rubies, and the light grey as diamonds" (Webster, 56). In 1823, J.L. Bournon (1751-1825), the French mineralogist (hence *bournonite*), examined and described spinels from Ceylon, and suggested possible origins of the alluvial gemstones of that island, basing his remarks on the reports of J.B.L.C.T. Leschenault De Latour (1773-1820) who visited the island and the coast of Coromandel (Bournon, 1823).

Acknowledgement

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The microscopic determination of structural properties for the characterization of optical uniaxial natural and synthetic gemstones

Part 3: Examples for the applicability of structural features for the distinction of natural and synthetic sapphire, ruby, amethyst and citrine

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Abstract

The application of diagnostic growth structures for the distinction of natural and synthetic optically uniaxial gem minerals such as corundum and quartz is discussed. Typical examples for the characterization of natural gem varieties of corundum and quartz are quoted, e.g. sapphires and rubies, amethysts and citrines from distinct sources are described by means of growth structures. In addition, their synthetic counterparts of some producers are compared using structural features of diagnostic value. Criteria, which are useful for the recognition of faceted gemstones as natural or synthetic are underlined. Gem materials described in detail are natural sapphires from alkaline host rocks (Australian, Nigerian, Cambodian and Thai sapphires), Chatham synthetic sapphires, natural rubies from Malawi, Knischka synthetic rubies, natural amethysts and citrines from different sources as well as synthetic amethysts and citrines from different producers.

Zusammenfassung

Die Anwendung von Wachstumsstrukturen zur Unterscheidung natürlicher und synthetischer Edelsteinminerale mit einer optischen Achse, wie Korund und Quarz wird beschrieben.

Typische Beispiele zur Charakterisierung natürlicher Edelsteinarten von Korund und Quarz werden erwäht, u.a. Sapphire und Rubine, Amethyste und Citrine verschiedener Herkunft werden beschrieben an Hand der Wachstumsstrukturen.

AuBerdem werden die synthetische Gegenstücke einiger Hersteller mit einander verglichen mittels struktureller Merkmale diagnostischer Art.

Nützliche Kriterien zur Erkennung geschliffener Edelsteine als natürlich oder synthetisch werden betont.

Ausführlichst beschriebene Edelsteine sind natürliche Sapphire ads alkalinen Muttergesteinen (australische, nigerianische, kamobschanische und thailändische Sapphire), Chatham synthetische Sapphire, natürliche Rubine aus Malawi, Knischka synthetische Rubine, sowohl natürliche Amethyste und Citrine verschiedener Herkunft, wie auch von verschiedenen Herstellern gezüchtete Amethyste und Citrine.

Resumen

Se discute la aplicación de marcas de crecimiento diagnosticas para la distinción entre minerales de calidad gema naturales o sintéticos que son opticamente uniaxicos, tales como el corindón y el cuarzo. Se facilitan ejemplos típicos para la caracterización de variedades naturales de calidad gema de corindón y cuarzo; por ejemplo, se describen mediante el uso de marcas de crecimiento zafiros y rubíes, amatistas y cuarzos citrinos de determinados yacimientos. Ademas, se comparan entre si muestras sintéticas de algunos fabricantes de estas gemas haciendo uso de caracteristicas estructurales de valor diagnóstico. Se subrayan criterios, que son útiles para distinguir entre gemas talladas naturales o sintéticas. Se describe con detalle los siguientes materiales de calidad gema; los zafiros naturales con origen en rocas alcalinas (Australia, Nigeria, Cambodia y Thailandia), zafiros sintéticos de Chatham, rubies naturales de Malawi, rubies sintéticos de Knischka, amatistas y cuarzos citrinos naturales de distintos yacimientos al igual que amatistas y cuarzos citrinos sintéticos de distintos fabricantes.

I. Introduction

In the first part of this publication (Kiefert & Schmetzer, 1991a) a detailed description of methods for the determination of characteristic crystal faces and growth structures in faceted

optical uniaxial gemstones by use of two simple auxiliary means is given. In the second part of this paper (Kiefert & Schmetzer, 1991b), the characterization of natural and synthetic emeralds by the use of growth structures and their application to practical problems of determinative gemmology is discussed in detail.

This third part of the publication will reveal some new examples for the application of the methods described in the first part, e.g. for the characterization of natural sapphires originating from alkali basalts or for the characterization of the most recent type of Knischka synthetic rubies. Additionally, a summary of results obtained by these methods, part of them already published in earlier issues of this journal, is presented, e.g. the recognition of Chatham synthetic sapphires or the distinction of natural and synthetic amethysts and citrines.

Figures 1-15 as well as Tables 1-3, which are occasionally referred to in this third part of the publication, are presented in the first part (Kiefert & Schmetzer, 1991a).

II. Natural sapphires from alkaline rocks

In connection with systematic investigations of sapphires from different localities, a great number of faceted sapphires and rough crystals from alkaline rocks as sources have been at the authors' disposal. The sapphires originating from alkaline source rocks were of Australian, Nigerian, Cambodian and Thai origin (cf. Vichit *et al.*, 1978; Jobbins & Berrangé, 1981; Keller, 1982; Coldham, 1985; Kiefert & Schmetzer, 1987). During these investigations the authors discovered a significant similarity in structural properties of sapphires originating from alkaline rocks, i.e. in most cases from alkali basalts. By measuring the crystal faces of the rough samples and comparing these common morphological properties with internal growth structures determined by the methods described, a correspondence between the external crystal faces and the internal growth structures was proven for all sources. Another common feature of all sapphires originating from alkaline rocks are their spectroscopic properties, which were found to be similar or almost identical for all samples from different localities examined (cf. Kiefert & Schmetzer, 1987; Schmetzer, 1987a).

All rough crystals from alkaline rocks reveal the basal pinacoid c {0001} and the hexagonal dipyramid z $\{22\bar{4}1\}$ as dominant forms, and the positive rhombohedron r $\{10\bar{1}1\}$ appears frequently. Subordinate forms, e.g. some other pyramidal faces or the hexagonal prism, differ only slightly from locality to locality [cf. Figures 3a, d]. The above mentioned three crystal faces dominate in cut samples as growth planes. In connection with growth planes of sapphires from alkaline rocks there is nearly always a strong blue, greenish-blue, bluish-green or yellowish-green colour zoning observable. However, the crystal faces, especially those of the dominant forms mentioned above, vary markedly according to their sizes for samples of different occurrences. Compared with sapphires from other types of host rocks, e.g. sapphires from Sri Lanka, the appearance of the hexagonal dipyramid z $\{22\bar{4}1\}$ is only observable in sapphires from alkaline rocks in this significance [Figures 46-57].

Australian rough crystals, for example, show pyramidal habit with the hexagonal dipyramid z $\{22\bar{4}1\}$ as dominant form. The basal pinacoid c {0001} is very small in these samples. The positive rhombohedron r $\{10\bar{1}1\}$ as well as the hexagonal dipyramid n $\{22\bar{4}3\}$ appear less frequently. Corresponding to this morphology, the dominant growth planes determined in the microscope with the above mentioned methods occur parallel to z $(22\bar{4}1)$. In addition, growth planes parallel to the positive rhombohedron r $(10\bar{1}1)$ as well as parallel to the basal pinacoid c (0001) are observed. Other growth planes such as faces parallel to the hexagonal dipyramids w $(11\bar{2}1)$ and n $(22\bar{4}3)$ appear occasionally, faces parallel to the second-order hexagonal prism a $(11\bar{2}0)$ as well as parallel to the hexagonal dipyramids v $(44\bar{8}1)$ and v $(44\bar{8}3)$ are extremely rare [Figures 46-49, 51, 53, 55, 57].

For rough crystals of Nigerian sapphires, which showed well developed crystal faces, a typical morphology was determined as follows: the majority of the crystals reveal tabular habit with the basal pinacoid c {0001} and the hexagonal dipyramid z $\{22\bar{4}1\}$ or with the crystal faces c, z and the positive rhombohredon r $\{10\bar{1}1\}$. In addition to the crystal faces mentioned above, sapphires with barrel-shaped habit reveal the hexagonal dipyramid n

Fig. 46. Growth structures in natural sapphire from Australia; planes parallel to c (0001) and r $(10\bar{1}1)$. View perpendicular to the c-axis, the c-axis runs vertically. Crossed polarizers. 16x.

Fig. 47. Growth structures in natural sapphire from Australia; planes parallel to c (0001), n $(22\bar{4}3)$ and z $(22\bar{4}1)$. View perpendicular to the c-axis, the c-axis runs vertically. Crossed polarizers. 16x.

Fig. 48. Growth structures in natural sapphire from Australia; planes parallel to c (0001) and r $(10\bar{1}1)$. View perpendicular to the c-axis, the c-axis runs almost vertically. Crossed polarizers. 16x. Figs. 46 and 47 as well as Figs. 47 and 48 are related by a rotation of 30° about the c-axis, Figs. 46 and 48 are related by a rotation of 60° about the c-axis.

Fig. 49. Growth structures in natural sapphire from Australia; planes parallel to c (0001), n $(22\bar{4}3)$ and z $(22\bar{4}1)$. View perpendicular to the c-axis, the c-axis runs diagonally from lower left to upper right. Crossed polarizers. 20x.

Fig. 46.

Fig. 47.

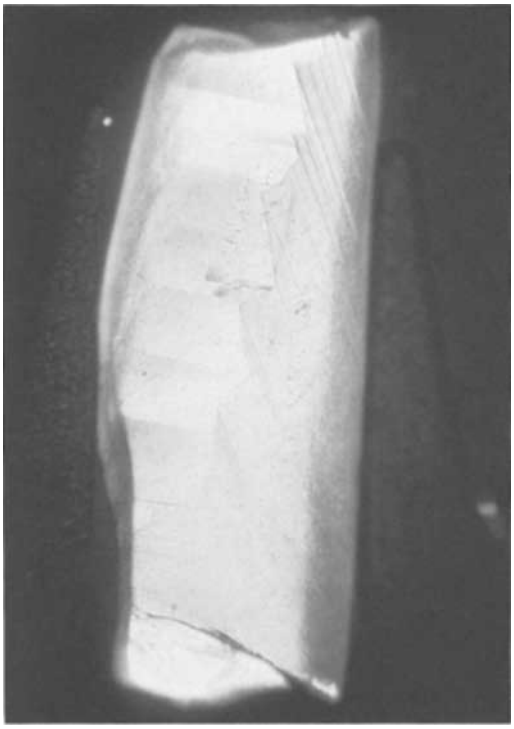

Fig. 48.

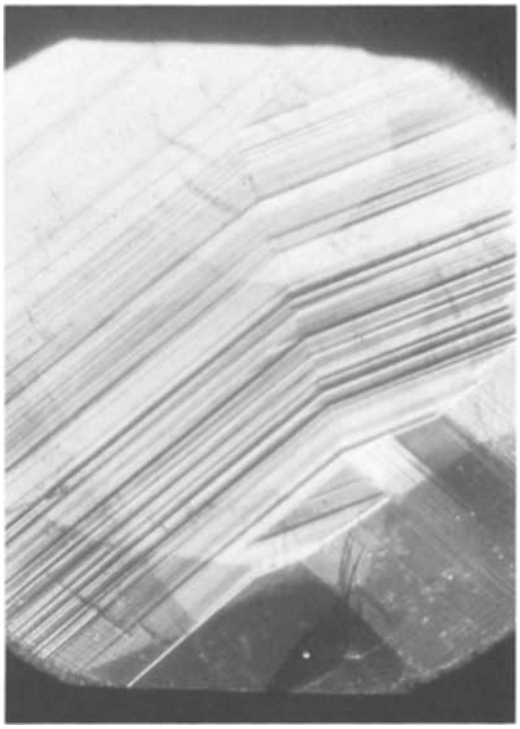

Fig. 49.

$\{22\bar{4}3\}$ [Figure 3a]. Crystals with prismatic habit display the hexagonal prism a $\{11\bar{2}0\}$ in addition to the forms mentioned above [Figure 3d]. The determination of growth structures in the microscope by use of the methods described, reveals that the growth planes are, according to the morphology of the rough crystals, mainly parallel to dominant crystal faces like the hexagonal dipyramid z $(22\bar{4}1)$, parallel to the positive rhombohedron r $(10\bar{1}1)$ and parallel to the hexagonal dipyramid n $(22\bar{4}3)$ and parallel to the hexagonal prism a $(11\bar{2}0)$ may occur [Figure 54, see also Kiefert & Schmetzer, 1987].

Cambodian sapphires available to the authors disclosed very rarely well developed crystal faces. The few crystals with preserved external morphology are described as follows: the majority of these samples reveal tabular habit with the basal pinacoid c $\{0001\}$ and the hexagonal dipyramid z $\{22\bar{4}1\}$, occasionally the positive rhombohedron r $\{10\bar{1}1\}$ is observed. This morphology corresponds to the morphology of part of the Nigerian sapphires [cf. Figures 3a, d]. Besides these forms part of the Cambodian sapphires reveal pyramidal habit with only the hexagonal dipyramid z $\{22\bar{4}1\}$ as the crystal form. Occasionally tabular crystals with the second-order hexagonal prism a $\{11\bar{2}0\}$ and the basal pinacoid c $\{0001\}$ appear. In accordance with the examination of sapphires from Australia and Nigeria, the determination of internal growth structures of Cambodian sapphires in the microscope reveals that the most frequently appearing growth planes correspond to the external morphology of the crystals. These are the hexagonal dipyramid z $(22\bar{4}1)$ as well as the basal pinacoid c (0001). As subordinate growth planes the positive rhombohedron r $(10\bar{1}1)$, the second-order hexagonal prism a $(11\bar{2}0)$ as well as the hexagonal dipyramids n $(22\bar{4}3)$, w $(11\bar{2}1)$, v $(44\bar{8}3)$ and ν $(44\bar{8}1)$ could be determined [Figure 50].

Among the investigated sapphires from Thailand, no rough crystals with well developed crystal faces were available. However, similar to the sapphires from the occurrences mentioned above, the dominant growth planes in the microscope are the hexagonal dipyramid z $(22\bar{4}1)$ and the basal pinacoid c (0001). The frequency of other appearing growth planes is similar to that of Cambodian sapphires. The crystal faces observed are occasionally the positive rhombohedron r $(10\bar{1}1)$ and the hexagonal dipyramid w $(11\bar{2}1)$, and, less frequently, the hexagonal dipyramids n $(22\bar{4}3)$ and v $(44\bar{8}3)$ as well as the hexagonal prism a $(11\bar{2}0)$ [Figures 52, 56].

In summary, the morphology of all natural sapphires originating from alkaline rocks is dominated by the basal pinacoid c $\{0001\}$ and the hexagonal dipyramid z $\{22\bar{4}1\}$. In addition, the positive rhombohedron r $\{10\bar{1}1\}$, the second-order hexagonal prism a $\{11\bar{2}0\}$ as well as different hexagonal dipyramids n $\{22\bar{4}3\}$, w $\{11\bar{2}1\}$, v $\{44\bar{8}3\}$ and ν $\{44\bar{8}1\}$ may occur as more or less subordinate forms. Sapphires from alkaline rocks often occur with a thick tabular habit, but barrel-shaped, pyramidal or prismatic crystals were also found, and sapphires with a habit intermediate between these three basal morphologies were also examined.

At present, no hexagonal dipyramids with the exception of n $(22\bar{4}3)$ and no second-order hexagonal prisms a $(11\bar{2}0)$ were observed as crystal faces of flux-grown synthetic sapphire (cf. section III). Thus, the presence of at least one of these growth structures indicates a sapphire of natural origin. Among several hundreds of faceted samples examined, part of them without characteristic mineral inclusions, each of those natural sapphires originating from alkaline rocks disclosed characteristic growth structures and, consequently, were determinable as natural using the above mentioned criteria.

III. Growth structures and twinning in flux-grown Chatham synthetic blue sapphires

All different syntheses of corundum produced by the flux method show a distinct, limited number of crystal faces, which are easily determinable with the methods described by the authors. Due to the composition of the flux as well as other variable growth conditions, which are applied for the production of the individual synthesis, the number of crystal faces vary for the different commercial productions of corundum. For example, the common crystal faces of Chatham synthetic rubies are c, r, d, and n [cf. Table 1]. In rubies made by Kashan c, r, and n appear as crystal faces, and Knischka synthetic rubies reveal the crystal faces c, r, d, n, and γ. The morphology of synthetic rubies produced by Ramaura consists of c, r, and d (cf. Schmetzer, 1986).

An important feature for the distinction of natural and synthetic rubies is the absence of prism and some pyramidal faces in synthetic stones, whereas the negative rhombohedra d and γ never appear in natural samples (cf. Schmetzer, 1986).

Flux-grown Chatham synthetic sapphires are described here in some detail and will be compared with natural sapphires from alkaline rocks (cf. section II). For the investigation of structural properties of Chatham synthetic blue sapphires, both rough crystals and faceted stones were available (cf. Kiefert & Schmetzer, 1988). The rough samples were found to consist of single crystals and twinned individuals. Twinning is easily recognizable due to the re-entrant angles of the samples. The crystal faces which were identified in both untwin-

Fig. 50. Growth structures in natural sapphire from Pailin, Cambodia; planes parallel to c (0001) and r ($10\bar{1}1$). View perpendicular to the c-axis, the c-axis runs vertically. 25x.

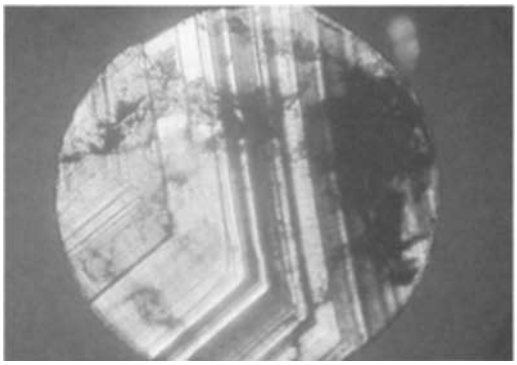

Fig. 52. Angled growth structure in natural star-sapphire from Thailand; planes parallel to the hexagonal prism faces a and a' ($11\bar{2}0$) form an angle of 120°. View parallel to the c-axis. Crossed polarizers. 26x.

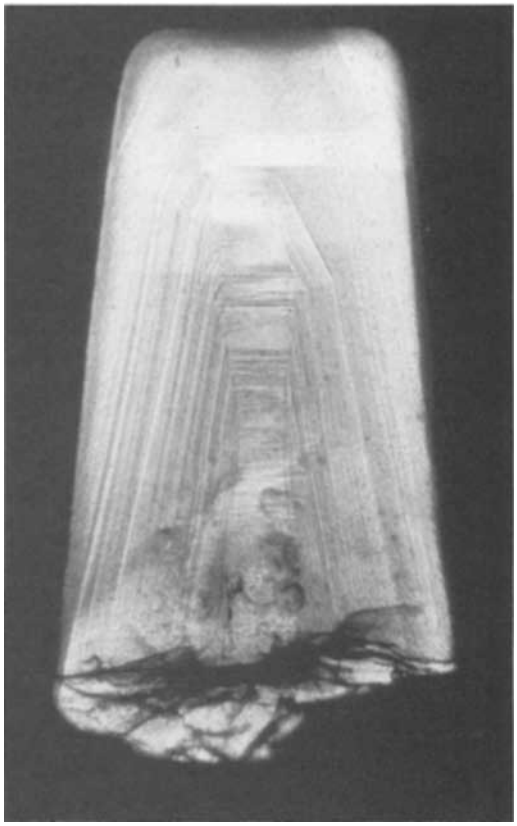

Fig. 51. Growth structures in natural sapphire from Australia; planes parallel to c (0001), n ($22\bar{4}3$) and z ($22\bar{4}1$). View perpendicular to the c-axis, the c-axis runs vertically. Crossed polarizers. 20x.

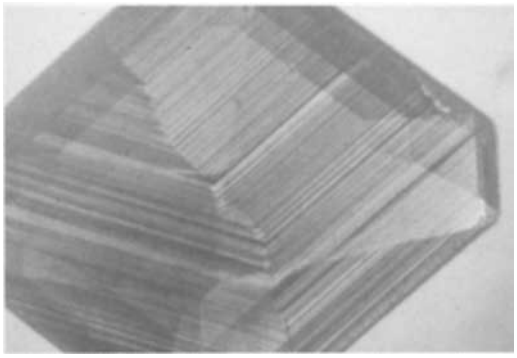

Fig. 53. Angled growth structure in natural sapphire from Australia; planes parallel to the hexagonal dipyramids z and z' ($22\bar{4}1$) form an angle of 121.1°. View 10.4° inclined to the c-axis. 20 x.

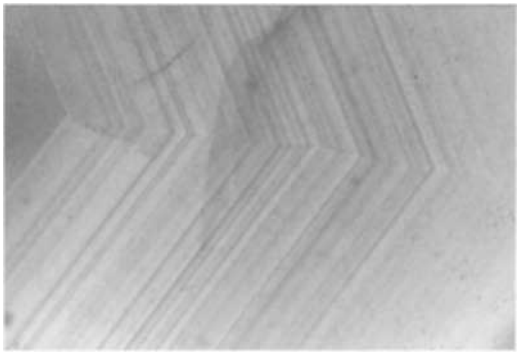

Fig. 54. Angled growth structure in natural sapphire from Nigeria; planes parallel to the hexagonal dipyramids z and z' ($22\bar{4}1$) form an angle of 121.1°. View 10.4° inclined to the c-axis. 25x.

ned and twinned crystals are identical, the samples displayed tabular to rhombohedral habit with the basal pinacoid c {0001}, the positive rhombohedron r {10$\bar{1}$1}, the negative rhombohedron d {01$\bar{1}$2} and the hexagonal dipyramid n {22$\bar{4}$3} as predominant forms, as well as the negative rhombohedron γ {0115} as subordinate form [Figures 3b, c, f]. Occasionally, an oscillatory development of both negative rhombohedra d and γ was observed causing parallel striations on these crystal faces. No prism faces were detected. All single and repeatedly twinned individuals (cyclic twinning) were contact twins with the second-order hexagonal prism a {11$\bar{2}$0} as composition plane and the first-order hexagonal prism m {10$\bar{1}$0} as twin plane [Figure 3c].

In the immersion microscope, families of straight parallel growth planes were determined which reflect the external morphology of the crystals. These growth faces are parallel to the predominant external forms, i.e. parallel to c (0001), r (10$\bar{1}$1), d (01$\bar{1}$2), and n (22$\bar{4}$3) [Figure 58]. The composition planes a {11$\bar{2}$0} of the individuals, which are related by reflection twinning on {10$\bar{1}$0} are also observable in the gem microscope without having problems [Figures 58, 59].

The most significant difference between Chatham synthetic sapphires and natural sapphires from alkaline rocks is the absence of the hexagonal dipyramids, e.g. z {22$\bar{4}$1}, in Chatham synthetic sapphire, which is one of the most characteristic crystal forms in natural sapphires from alkaline rocks. On the other hand, the negative rhombohedra d {01$\bar{1}$2} and γ {01$\bar{1}$5} of Chatham synthetic sapphires were never observed in natural sapphires.

Another important difference, which can easily be identified by the method used by the authors, is one distinct type of twinning, which is found only in flux-grown synthetic sapphires. The only kind of twinning in natural sapphires from alkaline rocks is lamellar twinning on the positive rhombohedron r (10$\bar{1}$1). This kind of twinning is very common in all natural sapphires, but was recently also observed in some Chatham synthetic flux-grown sapphires [Figure 60]. However, in Chatham synthetic sapphires, an additional type of twinning occurs. The twinned individuals are related by reflection twinning across (10$\bar{1}$0) with the second-order hexagonal prism a (11$\bar{2}$0) as composition plane. These composition planes occur as single growth lines, which are diagonally passing through the rough or faceted crystals, and consequently are determinable by the methods used by the authors without any difficulties [Figures 58, 59; see also Kiefert & Schmetzer, 1988].

The production of Chatham synthetic sapphire is supposed to be similar to the production of flux-grown Chatham synthetic rubies. According to their morphology, both syntheses are most probably produced by using the same or almost identical compositions of fluxes, which was confirmed by chemical investigations of residual flux material in rough and faceted samples. Both syntheses, ruby and sapphire, reveal twinning across (10$\bar{1}$0), which is not known for natural corundum. The only difference between Chatham synthetic ruby and Chatham synthetic sapphire is the occurrence of small faces of the negative rhombohedron γ (01$\bar{1}$5) in synthetic sapphire, which so far was not found in synthetic ruby.

IV. Natural ruby from Malawi

Corundum from Malawi was already mentioned in earlier publications (Rutland, 1969; Grubessi & Marcon, 1986), but in recent months larger quantities of high quality rubies from this source have been found on the market. Rough crystals show tabular habit, the basal pinacoid c {0001} is observable on both sides of the crystals. There were, however, no pyramidal, rhombohedral or prismatic faces exposed because all rough crystals were irregularly broken on all sides perpendicular to the basal pinacoid. According to the most recent microscopic investigations of the present authors, several types of this kind of ruby exist. Part of these rubies frequently reveal no characteristic mineral inclusions, but have definite diagnostic growth structures.

An example, which was investigated by the authors using the methods described in part 1 of this paper, was a cut ruby from Malawi of excellent quality weighing 2.60 ct. This particular stone was free of any characteristic mineral inclusions. The determined growth structures were the basal pinacoid c (0001), the hexagonal prism a (11$\bar{2}$0), the hexagonal dipyramid n (22$\bar{4}$3) as well as the positive rhombohedron r (10$\bar{1}$1) [Figures 61-63]. In other words: the determination of internal growth structures revealed an external morphology similar to the crystal drawn in Figure 3e. According to the complete determination of all growth structures with the methods introduced here, this stone can definitely be classified as natural ruby because of the absence of growth structures parallel to a (11$\bar{2}$0) in all types of commercially available synthetic rubies.

V. Most recent commercial production of Knischka synthetic rubies

Several generations of synthetic rubies with different habits were produced by Prof. P.O. Knischka of Steyr, Austria. For example, Knischka synthetic rubies of the last experimental generation

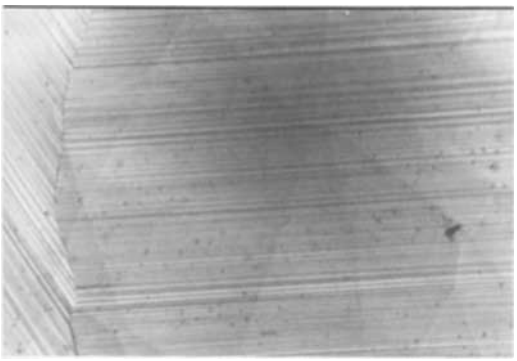

Fig. 55. Angled growth structure in natural sapphire from Australia; planes parallel to the hexagonal dipyramids *w* and *w'* $\{11\bar{2}1\}$ form an angle of 124.0°. View 20.1° inclined to the *c*-axis.

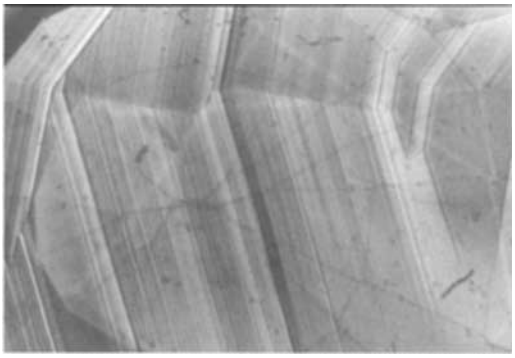

Fig. 56. Angled growth structure in natural sapphire from Thailand; planes parallel to *r* $(10\bar{1}1)$, *n* and *n'* $\{22\bar{4}3\}$ form angles of 154.0°. View about 30° inclined to the *c*-axis. 30x.

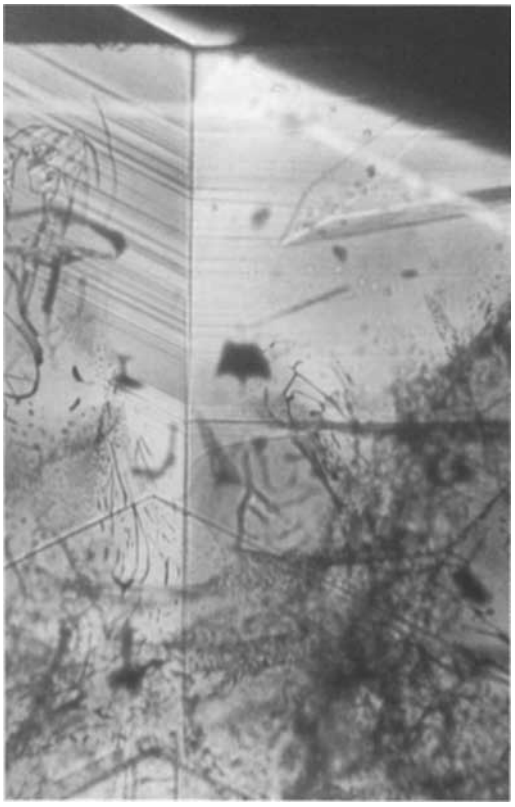

Fig. 58. Growth structures and twinning in flux-grown Chatham synthetic sapphire; growth sectors confined to the rhombohedron *r* $(10\bar{1}1)$ [right part] and the hexagonal dipyramid *n* $(22\bar{4}3)$ [left part] are divided by a twin boundary parallel to *a* $(11\bar{2}0)$. View about 30° inclined to the *c*-axis. 40x.

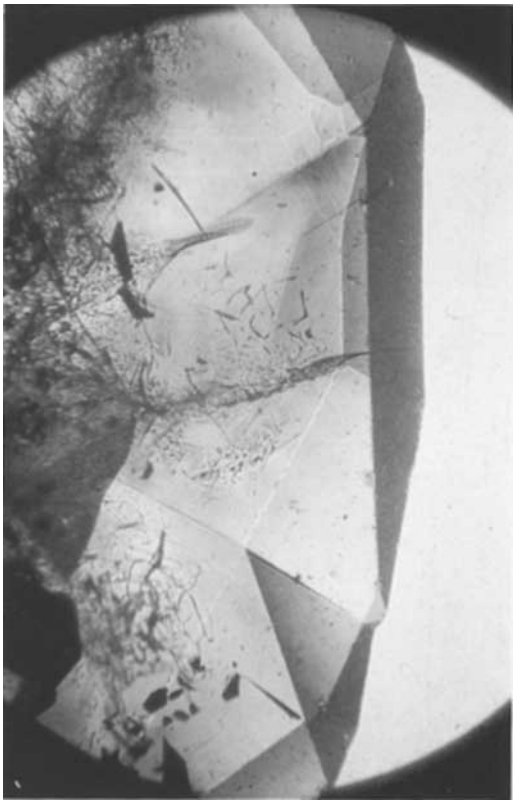

Fig. 59. Growth structures and twinning in flux-grown Chatham synthetic sapphire; repeated twinning across $\{10\bar{1}0\}$ with two composition planes *a* and *a'* $\{11\bar{2}0\}$ observable. View parallel to the *c*-axis. 24x.

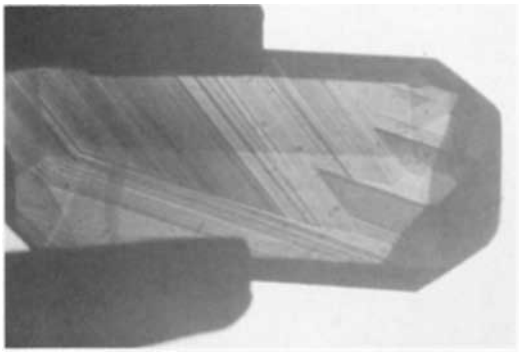

Fig. 57. Angled growth structure in natural sapphire from Australia; planes parallel to r $(10\bar{1}1)$ and n $(22\bar{4}3)$ form an angle of 154.0°. View about 30° inclined to the c-axis. 30x.

Fig. 60. Twinning in flux-grown Chatham synthetic sapphire; intercalated lamellae of corundum in twin position on r $(10\bar{1}1)$. View 32.4° inclined to the c-axis. 40x.

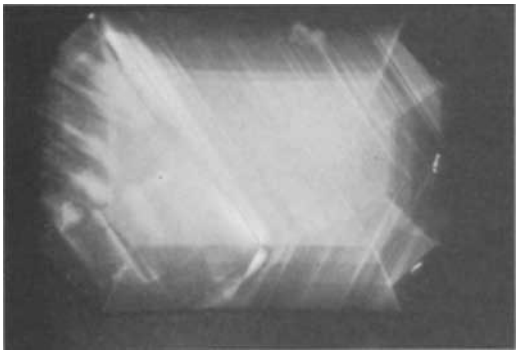

Fig. 61. Angled growth structure in natural ruby from Malawi; planes parallel to the hexagonal prism faces a and a' $\{11\bar{2}0\}$ form an angle of 120°. View parallel to the c-axis. Crossed polarizers. 16x.

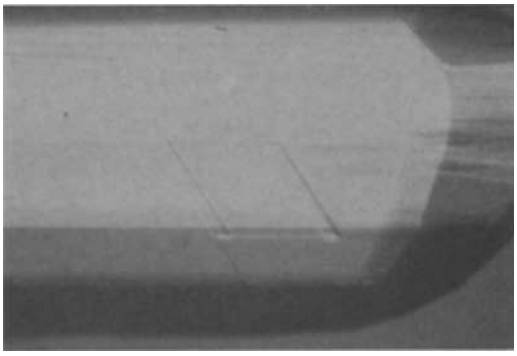

Fig. 62. Growth structure in natural ruby from Malawi; planes parallel to c (0001) and r $(10\bar{1}1)$. View perpendicular to the c-axis, the c-axis runs vertically. 20x.

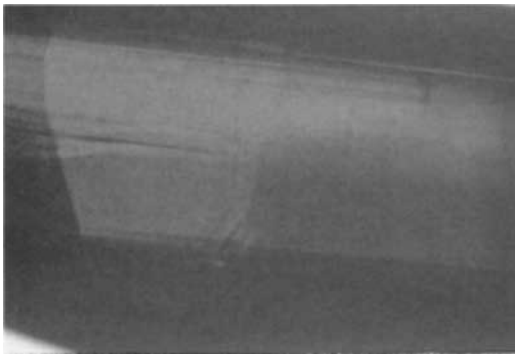

Fig. 63. Growth structure in natural ruby from Malawi; planes parallel to c (0001), n $(22\bar{4}3)$ and a $(11\bar{2}0)$. View perpendicular to the c-axis, the c-axis runs almost vertically. 26x. Figs. 62 and 63 are related by a rotation of 30° about the c-axis.

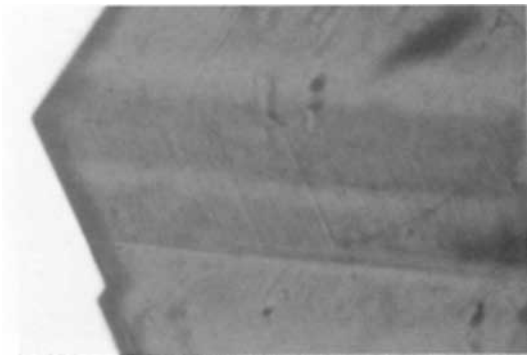

Fig. 65. Growth structures in Knischka synthetic ruby; oscillating planes parallel to n $(22\bar{4}3)$ and $\bar{n}$ $(2\bar{2}\bar{4}3)$ form angles of 122.4°. View perpendicular to the c-axis, the c-axis runs vertically. 35x.

reveal the crystal faces c {0001}, r {10$\bar{1}$1}, d {01$\bar{1}$2}, n {22$\bar{4}$3} and γ {01$\bar{1}$5} and, consequently, show a certain similarity to Chatham synthetic sapphires and rubies [cf. Figures 3b, f; see also Galia, 1987]. There is, however, a diagnostic feature commonly observed in all generations of Knischka synthetic rubies, which is due to the composition of the flux, part of which always contains a certain percentage of a tungsten-bearing compound (cf. Schmetzer, 1987b). This diagnostic feature of the synthetic rubies made by Knischka is the oscillatory growth of the second-order hexagonal dipyramids n {22$\bar{4}$3} and $\bar{n}$ {2$\bar{2}\bar{4}\bar{3}$}, causing parallel striations on the external crystal faces (cf. Knischka & Zirkl, 1986). If these oscillatory striations of n and $\bar{n}$ become very dense, the external habit of the crystals is similar to prismatic, i.e. a dense repitition of n and $\bar{n}$ can simulate the presence of the second-order hexagonal prism a (11$\bar{2}$0).

A new type of commercial production of Knischka synthetic rubies has been grown since autumn 1986 and marketed since about 1987 (Knischka, 1989). An important component of the flux in this production is still a tungsten-bearing compound. In this new generation of Knischka synthetic rubies, crystals with columnar habit and a length of up to 6 cm are grown [Figure 64]. These crystals reach a weight above 100 ct. The surface of these columnar appearing crystals is formed by the oscillatory grown faces n (22$\bar{4}$3) and $\bar{n}$ (2$\bar{2}\bar{4}\bar{3}$). In faceted samples, besides feathers of residual flux material, the oscillatory occurrence of n (22$\bar{4}$3) and $\bar{n}$ (2$\bar{2}\bar{4}\bar{3}$) is distinctly recognizable in the immersion microscope [Figures 65-67]. This oscillation of the two pyramidal faces n and $\bar{n}$, forming angles of 122.4°, is easily observable in the view perpendicular to the optic axis, with a rotation of the crystal about the 360° vertical axis of the sample holder as described in the first part of this publication. Consequently, a significant and diagnostic feature is now available for synthetic rubies of that particular generation of Knischka synthetic rubies. Similar or identical growth structures were never observed in natural stones up to now.

VI. Natural amethyst and citrine

Structural properties like growth planes and twinning of both natural as well as synthetic amethyst and citrine have already been discussed in detail in earlier issues of this journal (Schmetzer, 1986, 1989; Lind & Schmetzer, 1987). In these earlier articles, however, only part of the now available methods used for these investigations were applied. Therefore, a summary of the most significant results, obtained by the methods discussed in the first part of this paper, is presented.

In all rough samples of natural amethyst and heat-treated natural amethyst (citrine) examined, only the positive rhombohedron r (10$\bar{1}$1) or the major rhombohedron r (10$\bar{1}$1) in combination with the minor rhombohedron z (01$\bar{1}$1) were observed [Figure 5]. The first-order hexagonal prism m (10$\bar{1}$0) is subordinate if present at all, and of small size only.

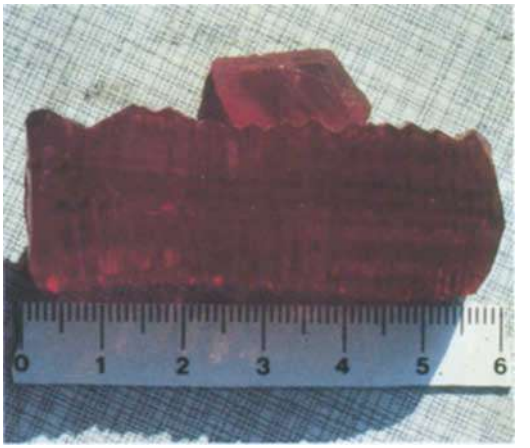

Fig. 64. Rough crystal of Knischka synthetic ruby of the most recent commercial production revealing columnar habit. Photo by courtesy of the producer.

Natural amethysts as well as heat-treated amethysts frequently disclose growth planes in the form of sharp lamellar structures, often connected with a distinct colour zoning. The colour zoning parallel to the positive and negative rhombohedra r and z is violet in natural amethyst and yellowish-brown in heat-treated natural amethyst (citrine). Growth planes, which are commonly parallel to the rhombohedral faces, form three characteristic angles of diagnostic value. Structures parallel to two positive rhombohedral faces r and r' {10$\bar{1}$1} form an angle of 94.2° [Figure 68], growth planes parallel to the positive rhombohedron r (10$\bar{1}$1) and the negative rhombohedron z (01$\bar{1}$1) form an angle of 133.7° if both faces are adjacent [Figures 69,70], and an angle of 76.4° if they are opposite to each other [Figure 71].

Besides lamellar colour zoning parallel to the rhombohedral growth planes, natural amethyst and heat-treated natural amethyst (citrine) often reveal another kind of colour zoning in the areas confined to the positive and negative rhombohedra. The areas confined to the positive rhombohedron r {10$\bar{1}$1} in natural amethyst have a dark violet colour, i heat-treated natural amethyst (citrine) they show an intense yellow to brownish colour, whereas in the areas confined to the negative rhombohedron z {01$\bar{1}$1} the colour is a lighter violet or a lighter yellowish-brown, respectively [cf. Figure 69].

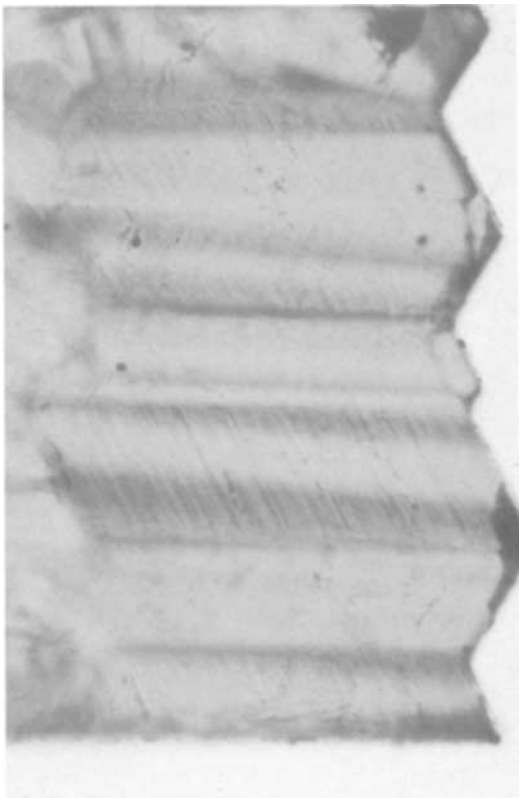

Fig. 66. Growth structures in Knischka synthetic ruby; oscillating planes parallel to n $(22\bar{4}3)$ and $\bar{n}$ $(2\bar{2}\bar{4}3)$ form angles of 122.4°. View perpendicular to the c-axis, the c-axis runs vertically. 25x.

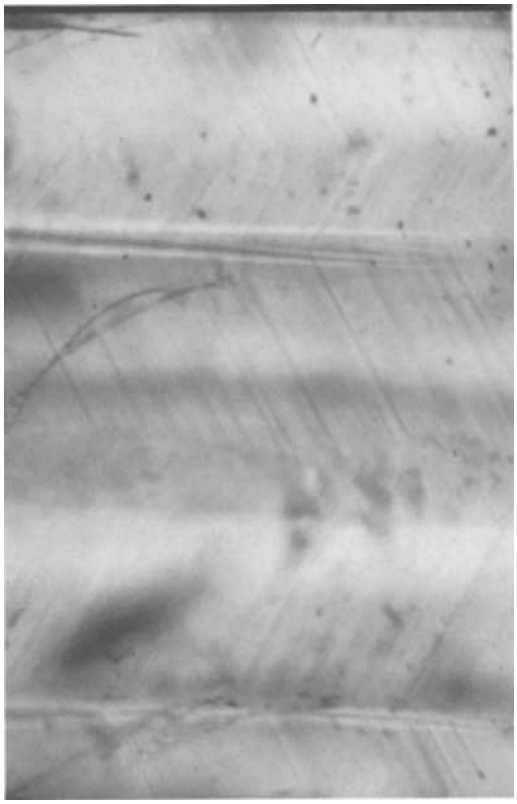

Fig. 67. Growth structures in Knischka synthetic ruby; oscillating planes parallel to n $(22\bar{4}3)$ and $\bar{n}$ $(2\bar{2}\bar{4}3)$ form angles of 122.4°. View perpendicular to the c-axis, the c-axis runs vertically. 40x.

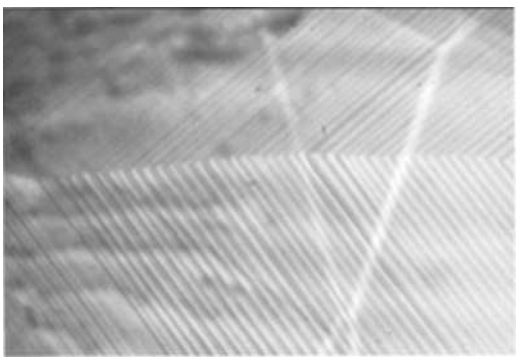

Fig. 68. Angled growth structure in natural amethyst from Brazil; planes parallel to the positive rhombohedra r and r' $\{10\bar{1}1\}$ form an angle of 94.2°. View 38.2° inclined to the c-axis. 60x.

Fig. 69. Angled growth structure in natural amethyst from Uruguay; adjacent planes parallel to the positive rhombohedron r $(10\bar{1}1)$ and parallel to the negative rhombohedron z $(01\bar{1}1)$ form an angle of 133.7°; growth sectors confined to the positive rhombohedron r [below] are dark violet, growth sectors confined to the negative rhombohedron z [above] are light violet in colour. View 38.2° inclined to the c-axis. 35x.

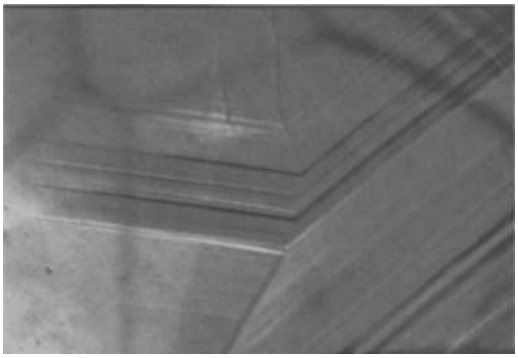

Fig. 70. Angled growth structure in natural citrine (heat-treated amethyst) from Brazil; adjacent planes parallel to the positive rhombohedron r ($10\bar{1}1$) and parallel to the negative rhombohedron z ($01\bar{1}1$) form an angle of 133.7°. View 38.2° inclined to the c-axis. 40x.

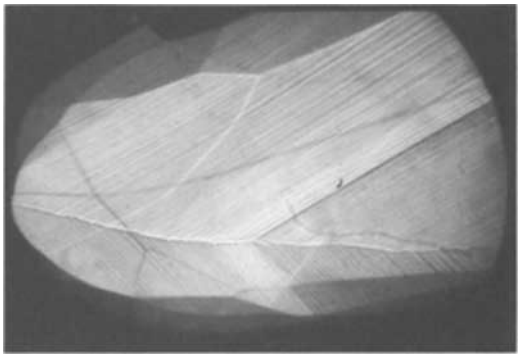

Fig. 71. Angled growth structure in natural citrine (heat-treated amethyst) from Brazil; opposite planes parallel to the positive rhombohedron r ($10\bar{1}1$) and parallel to the negative rhombohedron z' ($01\bar{1}1$) form an angle of 76.4°. View perpendicular to the c-axis, the c-axis runs horizontally. Crossed polarizers. 26x.

Polysynthetic twinning of the Brazil law, which is also a characteristic feature of natural amethyst and heat-treated natural amethyst (citrine) will not be discussed in this paper (cf. Schmetzer, 1986, 1989). However, it has to be mentioned, that in heat-treated natural amethyst an alteration of twinning may occur, which is connected with the development of orientated brown striations, which are also useful as diagnostic criteria.

In contrast to natural citrine obtained by heat treatment of natural amethyst, in natural untreated citrine the first-order hexagonal prism m ($10\bar{1}0$) is clearly developed (cf. Schmetzer, 1989). The crystal forms determined are the first-order hexagonal prism m $\{10\bar{1}0\}$ and the positive rhombohedron r $\{10\bar{1}1\}$ or, in other crystals, the forms m $\{10\bar{1}0\}$, r $\{10\bar{1}1\}$, and the negative rhombohedron z $\{01\bar{1}1\}$. The angles formed by different crystal faces are identical with those of natural amethyst. In addition, an angle of 141.8°, formed by the two crystal faces m and r or by m and z may also occur.

In natural untreated citrine, growth structures occur occasionally in broader distances than in natural amethyst. In cut samples, few single growth planes can be observed, which may form characteristic angles as listed in Table 3. Twinning in natural citrine is occasionally present in form of inserted bodies or plates of quartz in an orientation different from the host crystal.

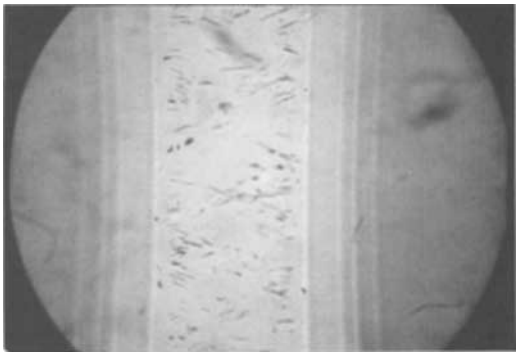

Fig. 72. Growth structures in hydrothermally-grown synthetic citrine from USSR; residue of the seed orientated parallel to the basal pinacoid c (0001) in the centre, growth planes and colour zoning parallel to the boundary seed/synthetic citrine. View perpendicular to the c-axis, the c-axis runs horizontally. Crossed polarizers. 30x.

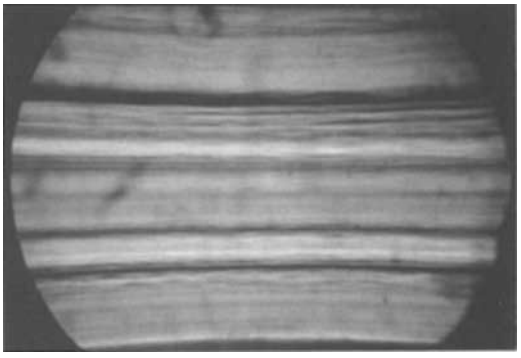

Fig. 73. Growth structures in hydrothermally-grown synthetic citrine from USA; growth lines parallel to the basal pinacoid c (0001). View perpendicular to the c-axis, the c-axis runs vertically. Crossed polarizers. 32x.

VII. Synthetic amethyst and citrine

Synthetic amethyst is commercially grown by using seed plates cut parallel to the positive rhombohedron r ($10\bar{1}1$) or parallel to the negative rhombohedron z ($01\bar{1}1$). The main crystal growth habitually is parallel to the seed plate, which means, parallel to one rhombohedral face. Parallel to this single dominant rhombohedral face, i.e. parallel to the seed plate, in different samples examined all

stages of growth structures between no zoning and an intense lamellar zoning as observed in natural amethyst are observable. However, it has to be underlined that only in the single dominant growth direction parallel to the seed plate distinct growth structures as well as colour zoning are observable. No characteristic angles between this dominant rhombohedral face and other growth structures, i.e. other rhombohedra, were observed so far in faceted samples.

In synthetic amethyst, a distinct type of twinning may occur occasionally (Lind & Schmetzer, 1987). In samples of this particular type, triangular shaped twinned areas are incorporated into the normally untwinned host crystal. These acute-angled zones are easily recognizable under crossed polarizers.

Different types of commercially produced synthetic yellow quartz are grown with seed plates orientated parallel to the basal pinacoid *c* (0001). In some of the samples growth structures parallel to the seed plate, parallel to the basal pinacoid *c* (0001), in connection with colour zoning were observable [Figures 72, 73] (Schmetzer, 1989). This type of growth structure is neither existent in natural amethyst or heat-treated natural amethyst (citrine) nor in natural untreated citrine, because the basal pinacoid *c* (0001) does not appear as a growth plane in natural quartz. An additional characteristic feature of synthetic citrine is the lack of polysynthetic twinning as it is commonly observed in natural amethyst and heat-treated natural amethyst (cf. section VI).

VIII. Conclusions

As described in detail in this third part of the paper, the consequent determination of growth structures using the easily available microscopic methods introduced in part 1 of the publication reveals a great number of characteristics which can be used as diagnostic criteria for the distinction of natural and synthetic gem minerals. These additional diagnostic features can be extremely helpful in cases, in which no unequivocally diagnostic inclusions are available in the faceted gemstone under investigation. The methods described can easily be made available for every gem testing laboratory and the techniques of examination can be learned by use of some characteristic samples within a few days. Hopefully, the application of the techniques described will lead to an improvement of the methods by other colleagues as well as to some further developments in the recognition of characteristic criteria which can be applied to problems of practical gem testing and gem identification. In general, the microscopic determination of growth structures and twinning can reveal criteria, which are of comparable value for the gemmologist as the investigation of chemical or spectroscopic properties.

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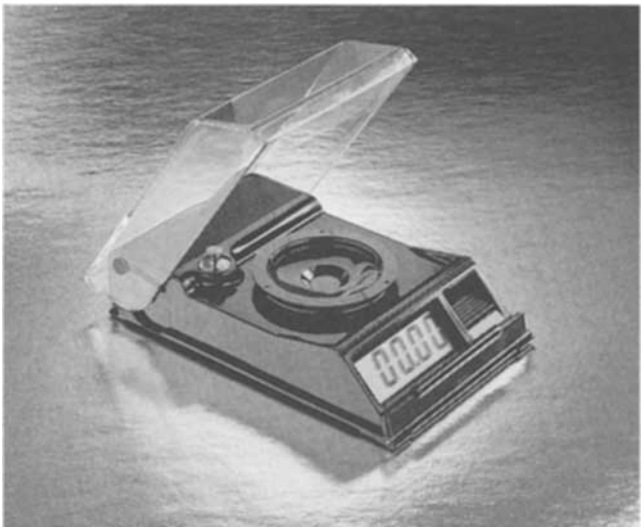

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The growth of rubies in south-east Kenya

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Abstract

Gem quality rubies from south-east Kenya, associated with small ultramafic intrusions, formed during a late Precambrian allochemical metamorphism under upper amphibolite or granulite facies conditions. PT estimates for the metamorphism from two-feldspar thermometry indicate temperatures of between 630 and 670°C at pressures in excess of 7 kbars. The red colour of the rubies, as well as the green and blue body colour of co-existing tourmalines and kyanites respectively, are all due to very high amounts of Cr_2O_3 in these minerals. Growth colour bands in the rubies reflect variations in their crystal matrix Cr_2O_3 and TiO_2 contents. Exsolved rutile needles formed during cooling to cut across the colour bands and may be related to decompression.

Introduction

The first discovery of corundum in south-east Kenya, at Kinyiki, was announced in the Annual Report for 1936 of the Geological Survey of Kenya. Small quantities of gem-quality sapphires were recovered from soils and gravels derived from corundum-bearing wall-rock to an ultramafic (dunite) intrusive (Parkinson, 1947). It was in 1973 that the first rubies were found in south-east Kenya, in the Mangari area, by two American geologists, John Saul and Elliott Miller (Figure 1). The Mangari ruby deposits are now known to be amongst the world's richest and Hughes (1990) notes that East Africa in general has the potential to become the future centre of world ruby mining. In order to facilitate future exploration for new ruby deposits the present study is an attempt to elucidate the physical conditions under which the rubies in the Mangari area were formed. John Saul provided samples of ruby and its rock matrix for optical and chemical investigations. The mineral phases of the ruby deposits were examined in thin sections and electron microprobe analyses of polished thin sections provided the chemical compositions of the main minerals.

Geology

The Mangari ruby deposits occur at the contacts of small ultramafic intrusions with metasediments of the Kurase Group (Pohl *et al.*, 1977, after Saggerson, 1962). Psammitic gneiss is the dominant metasediment with marble and graphitic schist intercalations. Gem quality vanadiferous grossular garnets ('tsavorite') occur in the graphitic schists; these deposits have been described in a previous paper (Key and Hill, 1989). The area around Mangari comprises flat, poorly exposed, scrub-covered country. Bedrock is concealed beneath layered superficial deposits of sand and black cotton soil above kunkar (secondary limestone). Prior to the ruby mining operations, the Mangari ultramafics were not exposed and are consequently not shown on the original regional geological map of Walsh (1960). Similar ultramafics are best seen in northern Kenya in the Baragoi area (Figure 2). The local geology of the Mangari area is described by Walsh (1960) with Pohl *et al.*, (1977). Bridges (1982) and Hughes (1990) providing descriptions explicit to the ruby mines.

On a regional scale the ruby deposits occur within the late Precambrian Mozambique Orogenic Belt which underlies much of East Africa between Ethiopia and Mozambique. The Mozambique Orogenic Belt developed as a result of Neoproterozoic collision between a western continental plate (Tanzanian Craton) and an eastern 'Kibaran' plate. Shelf sediments and oceanic volcanics were laid down during an initial extensional phase and subsequently disrupted by major folding and associated ductile shearing and thrusting. This collision-related deformation resulted in tectonic interfingering of different lithologies and lithostratigraphic units. Regional metamorphism at amphibolite to granulite facies, as well as crustal melt igneous intrusion, accompanied deformation. The rubies formed during this event.

At the end of the Precambrian, meridional transpressive shearing and folding was again accompanied by regional metamorphism (greenschist to amphibolite facies) with crustal melt igneous intrusion.

Regional uplift throughout Cambrian times

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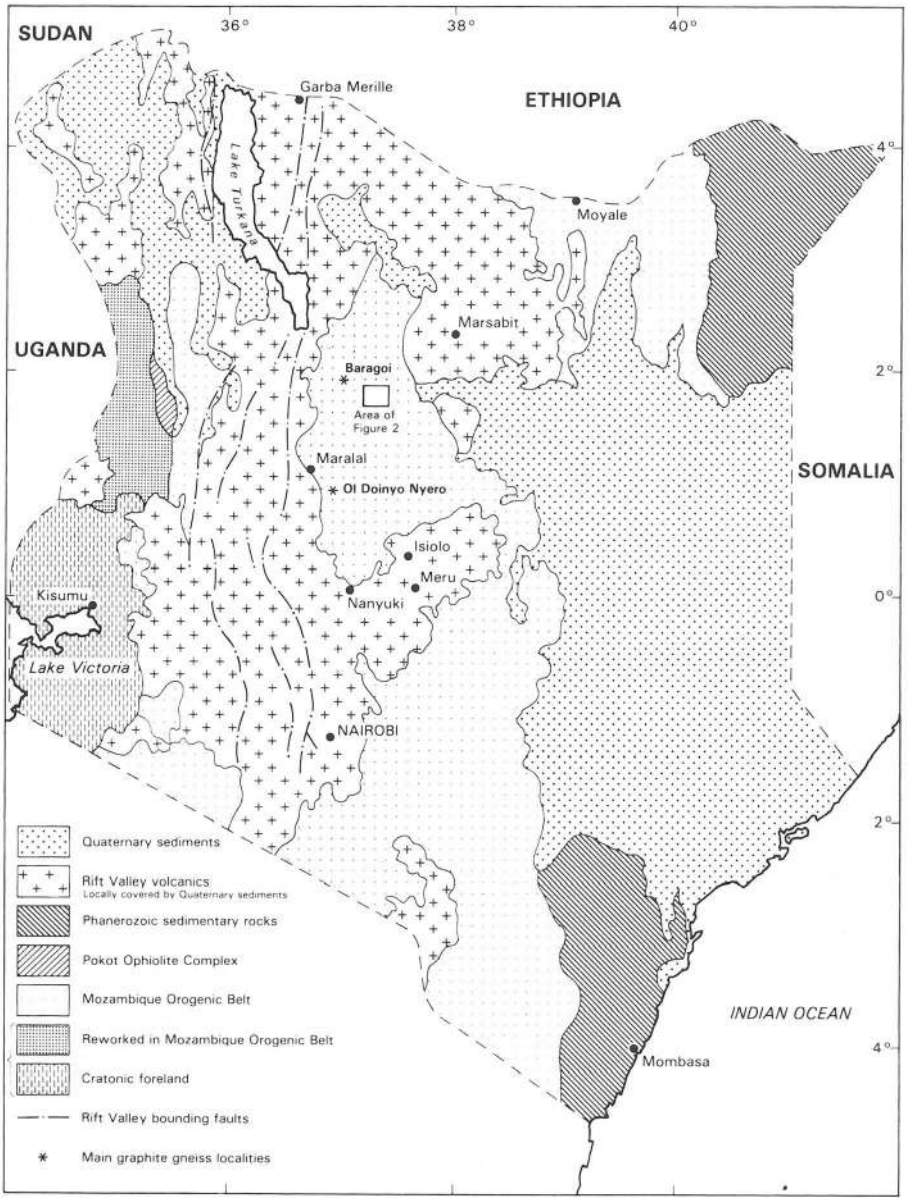

Fig. 1. The geological framework of Kenya showing the location of the study area.

accompanied orogenic cooling. Recent reviews of the Mozambique Orogenic Belt are given by Cahen *et al.*, (1984), El Gaby and Greiling (1988), Shackleton (1986), and Key *et al.*, (1989).

According to Pohl and Horkel (1980) the corundum deposits (in bedrock) of south-east Kenya are of the following four types.

1. Desilicated plumasitic pegmatites in ultramafic bodies.
2. Desilication zones at the contacts of the ultramafics and metasedimentary country rocks.
3. In aluminous metasediments (not economically important).
4. In marbles, associated with red spinel (not economically important).

These authors note that the Mangari rubies result from complex desilication processes between small ultramafics (altered talc – enstatite – tremolite/anthopyllite – chlorite rocks) and intrusive pegmatites or paragneisses (see also Hughes, 1990). The rubies are associated with plagioclase, mica, tourmaline and kyanite in the pegmatites and with

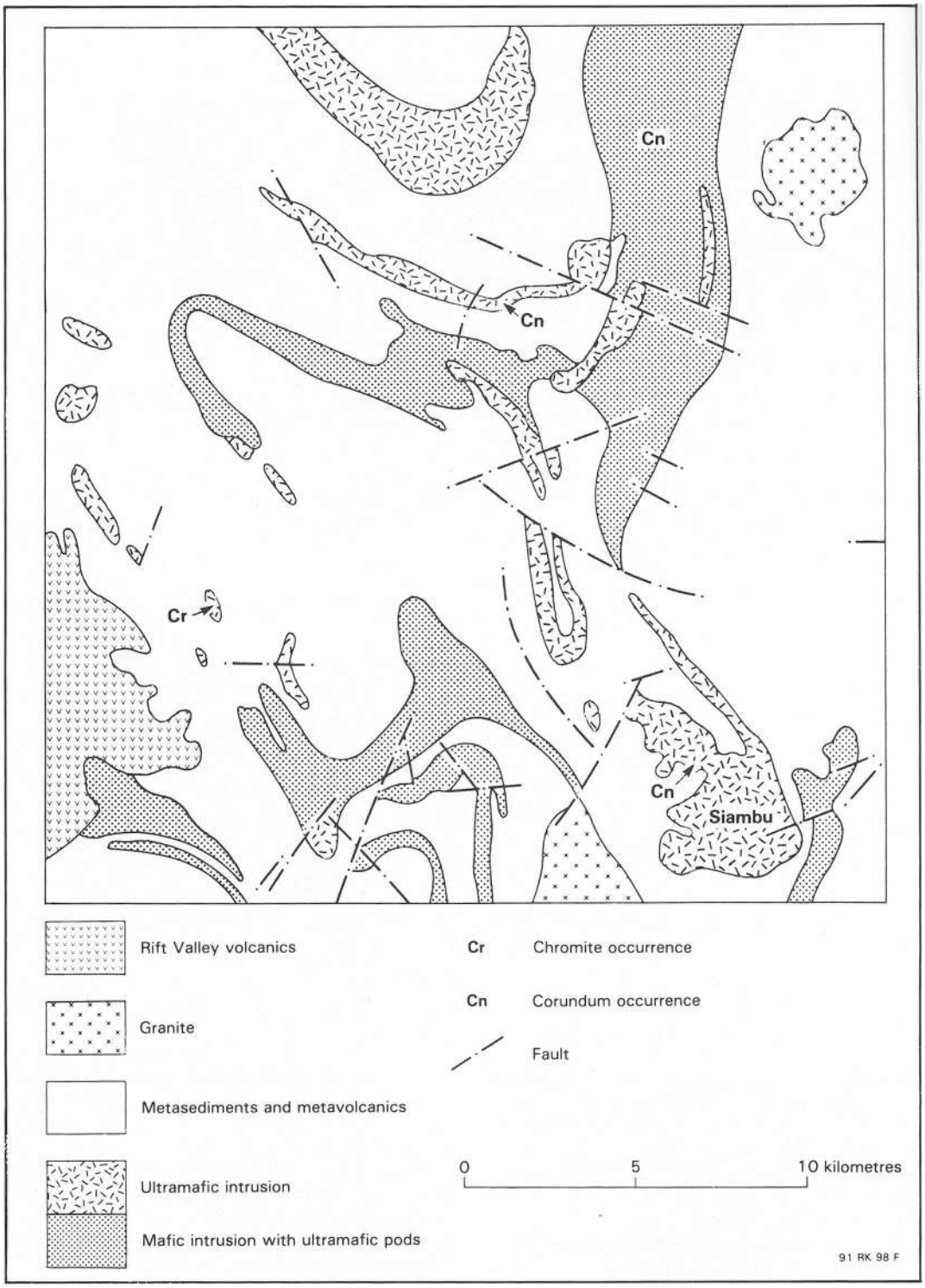

Fig. 2. Details of the geology of a well exposed area of north-central Kenya, near Baragoi, which illustrates the typical outcrop shape of ultramafic bodies in the Mozambique Orogenic Belt.

Plate 1. Colour zoned ruby with marginal white corundum rim. The diameter of the sample is about 2cm.

kyanite/sillimanite, tourmaline and mica aggregates in the desilicated gneisses. All the mineral phases formed during the regional metamorphism which controlled the desilication processes.

Mineralogy

The following ruby-bearing assemblages occur in the examined samples,

Ruby + muscovite + plagioclase (oligoclase – andesine) + xenotime* (sample 4)
Ruby + phlogopite (sample 5)
Ruby + muscovite + kyanite + plagioclase (sample 5b)
Ruby + phlogopite + plagioclase (andesine) (sample 7)
Ruby + margarite – paragonite + plagioclase (bytownite-labradorite) + tourmaline + graphite (sample 8)

*Identified on the electon microprobe

Ruby + muscovite + phlogopite + plagioclase (andesine) + K-feldspar + tourmaline + kyanite + zircon (sample 8)
Ruby + muscovite + plagioclase (oligoclase) + K-feldspar + zircon + xenotime (sample 9)
Ruby + margarite + tourmaline (sample 11)
Ruby + muscovite + pyrite + spinel (sample 12)

Ruby forms idioblastic hexagonal prisms and elongate hexagonal spindles up to several centimetres in diameter and mostly with a strong colour zoning mimicking the prism faces. This zoning is best seen in sections cut parallel to the basal pinacoid and comprises white, pink and red sharp and diffuse bands (see Plate 1). Polysynthetic twins enhanced by long, white boehmite, AlO(OH), needles (Hughes, 1990) cut across the colour zoning (see Plate 2). Rutile needles orientated parallel to the faces of the hexagonal prism to intersect at 120° are ubiquitous. The needles also cut the colour

Plate 2. Twin planes in ruby cutting across the colour zoning. White boehmite needles may be aligned in the twins (Sample 6). Field of view about 0.8mm by 1mm.

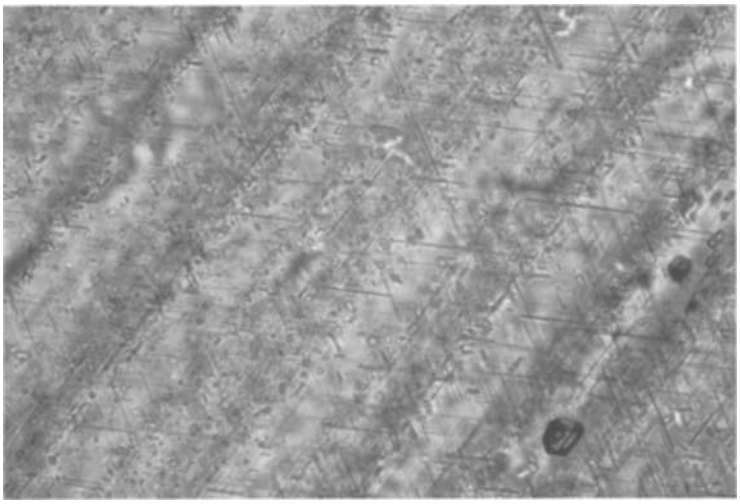

Plate 3. Oriented rutile needles and equant mica inclusions in ruby. Note that the rutile needles cut across the colour banding (Sample 3). Field of view about 3mm by 4mm.

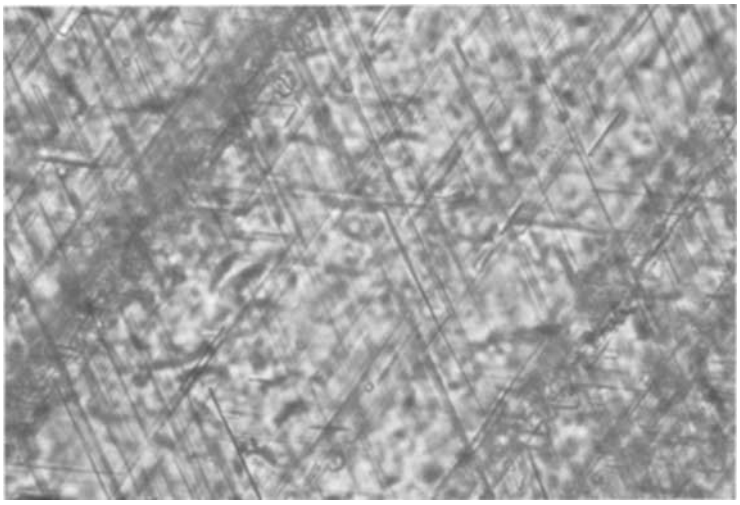

Plate 4. Close up of Plate 3. Field of view about 0.8mm by 1mm.

Plate 8. Mesoperthite with white albite spindles in K-feldspar. Sample 9. Field of view about 0.8mm by 1mm.

banding (see Plates 3 and 4). Less common inclusions are small, colourless to pale green chrome-muscovite plates (see Plates 3 and 4). One sample comprised a red, translucent ruby with massive rutile grains embedded in its centre (Plate 5 – see cover picture). The rutile needles formed after the colour banding and are regarded as exsolution features produced during cooling of the rubies (see also Hughes, 1990). Their distribution is influenced by the distribution of TiO_2 in individual grains and a close examination of Plates 3 and 4 shows that there is a strong concentration in the darker bands of rutile needles aligned parallel to the banding. The microprobe data confirm that the dark bands are enriched in crystal matrix TiO_2 relative to the lighter bands (see below).

Ruby appears to be in equilibrium with the other phases although marginal margarite plates may be replacive (see also Harding and Scarratt, 1986). Plagioclase is more abundant than K-feldspar; both minerals form an equigranular groundmass with accessory zircon and xenotime (Plate 8). The plagioclase grains are commonly polysynthetically twinned but the K-feldspar is untwinned with rare mesoperthitic textures (Plate 8). Tourmaline and kyanite form poikilitic grains in the presence of feldspar. They have strong green (tourmaline) and blue (kyanite) body colours (Plates 6 and 7). Graphite forms isolated typically ragged blades (Plate 9).

The mineral phases are generally unaltered as can be seen in the various plates. There is local marginal alteration of ruby to margarite and minor sericite replacement of the feldspar. The absence of fluids in the rocks following high grade metamorphism may have prevented major retrogression during cooling. Sillimanite has been recorded after kyanite in south-east Kenya (Pohl and Niedermayr, 1978) which indicates that the cooling history was not isobaric. Pressure release on cooling may explain the pronounced orientation of exsolved rutile in the rubies, caused by slight expansions of the ruby lattice.

Chemistry

The various mineral phases were chemically analysed on the Edinburgh University Cameca Camebax electron probe micro-analyser operating at an accelerating potential of 20 kv, with a probe current, as measured in a Faraday Cup, of 20 nanoamps (see Key and Hill, 1989). Standards used in the calibration were as follows: wollastonite for silicon and calcium, jadeite for sodium, corundum for aluminium, periclase for magnesium, rutile for titanium, orthoclase for potassium, and the artificial compound MgF_2 for fluorine. Other elements (vanadium, chromium, manganese and iron) were calibrated against pure metals. Matrix corrections were carried out using a ZAF process similar to that described by Sweatman and Long (1969). The analyses occur at single points within individual grains and the point fluorescence during analysis provides instant confirmation of the nature of certain analysed minerals. Rubies have a red fluorescence under the probe beam; chrome-rich (mean value of 0.424% Cr_2O_3) kyanite also has a red fluorescence which changes to pale blue in the presence of significant titanium (0.127-0.152 % TiO_2).

Ruby analyses

Tables 1 and 2 summarize the results of the ruby analyses. It is apparent from these tables that the main chromophore is Cr_2O_3. In the unzoned rubies the mean Cr_2O_3 content varies from 0.391 to 0.963% with the highest values in the best quality

Plate 6. Green tourmaline and ruby cluster. Size of specimen about 3cm.

Plate 7.
Blue kyanite and ruby. Size of specimen about 3cm.

Table 1: Mean ruby analyses for unzoned rubies

	Sample 7	Sample 8b	Sample 11	Sample 8	Mangari*	Umba*	Morogoro*
Al_2O_3	99.546	99.336	99.803	99.647			
Cr_2O_3	0.963	0.920	0.447	0.391	1.10-1.80	0.01-0.10	0.060-0.090
TiO_2	0.029	0.030	0.016	0.024		0.006-0.020	
V_2O_5	0.039	0.027	0.009	0.027	0.000-0.003	0.002-0.01	0.004
FeO	0.017	0.008	0.013	0.010	0.060-0.50	0.10-0.25	0.010-0.020
Total	100.594	100.321	100.288	100.099			
n	5	2	5	4			

Values in weight %
n – No. of analyses
* From Hughes (1990), Umba and Morogoro are in Tanzania

(reddest) stones. The chrome values are slightly lower than those reported by Hughes (1990) for Mangari rubies but are still higher than rubies from adjacent parts of Tanzania. The ultramafic intrusions are thought to be the original source of the chromium as these rocks have high Cr_2O_3 and locally, in Kenya, host podiform chromite (Key, 1987). Iron contents are very low which is reflected by the lack of brown tints to the Mangari rubies – one of the reasons that they are so prized as gemstones. Vanadium contents are also very low in the rubies and all the other mineral phases.

The internal colour banding of dense or partly translucent ruby grains is reflected by variable Cr_2O_3 and TiO_2 contents (Figure 3 and Table 2). The darker (redder) bands have higher Cr_2O_3 values relative to adjacent paler bands and the overall mean Cr_2O_3 value for the dark bands is significantly higher than the corresponding figure for the light bands (0.571% compared with 0.400%). The same is true for the distribution of TiO_2 (0.286% mean value for dark bands and 0.168% mean value for light bands). The colour banding is regarded as a primary growth feature; diffusion of Cr_2O_3 and TiO_2 in the ruby crystal matrix. As shown earlier, the TiO_2 at least in part, was exsolved during cooling as orientated needles.

Other minerals

Table 3 presents the mean chemical analyses of the main mineral phases associated with ruby. All the micas have significant Cr_2O_3 values. In particular the muscovites have mean Cr_2O_3 values of 0.447% with the bright green fuchsitic micas having mean Cr_2O_3 values of 3.130%, and the highest individual analysis of 5.925% Cr_2O_3. For reference, Deer and others (1970) record maximum values of about 6% Cr_2O_3 for fuchsite. The fuchsite inclusions in the Mangari rubies have the highest Cr_2O_3 values.

The green body colour of the tourmaline (Plate 6) is due to Cr_2O_3 (mean value 0.478%) and not V_2O_5 (mean value 0.061%). Therefore the vanadiferous tourmalines reported to occur in south-east Kenya are unlikely to come from Mangari. This is supported by field evidence (J. Saul, pers. comm.). Similarly the blue body colour of the kyanite blades (Plate 7) is due to Cr_2O_3 (mean value 0.424%). The chrome content of the kyanites is amongst the highest ever reported. Altherr and others (1982) record values of 0.139% Cr_2O_3 for Tanzanian kyanite which they regard as exceptionally high. Table 4 shows two ICP (inductively coupled plasma) spectrometry analyses of tourmalines from Mangari. These analyses are similar to the microprobe analyses and they also provide data on the boron contents of the tourmaline.

The most common plagioclase phases have compositions in the oligoclase-andesine range. Albite occurs as late overgrowths or as lamellae within mesoperthites (Plate 8). The most calcic plagioclases are associated with margarite and tourmaline and the host rock must consequently have been relatively calcic. Barium was detected in the K-feldspar grains but was not quantitatively analysed.

Metamorphism

Previous work in south-east Kenya has shown that the grade of the regional metamorphism within the Mozambique Orogenic Belt attained upper amphibolite or granulite facies conditions (see Pohl and Niedermayr, 1978; Key and Hill, 1989). The peak temperature of the progressive metamorphism in this area has been established as greater than 550°C and possible over 750°C. Thus, Arneth and others (1985) deduced that the metamorphism took place at temperatures of between 550°C and 650°C based on carbon isotope studies of the graphitic metasediments. Key and Hill (1989) concluded that the peak temperature of metamorphism was at least 750°C based on mineral assemblages in the grossular deposits of Mgama Ridge. Similar temperatures were established by Sarbas and others (1984) who, from their studies of the grossular garnet-bearing assemblages, concluded that peak temperatures exceeded 650°C. Pressures during metamorphism

Table 2: Mean analyses (in weight %) of a single zoned ruby from Mangari (see Figure 3)
2A Light toned bands

	1	2	3	4	5	6	7	8	9
Al_2O_3	99.540	99.634	99.735	99.453	99.718	99.985	99.870	99.849	99.741
Cr_2O_3	0.427	0.414	0.372	0.385	0.362	0.343	0.336	0.302	0.400
TiO_2	0.041	0.065	0.064	0.146	0.057	0.047	0.046	0.054	0.168
V_2O_5	0.003	0.020	0.012	0.000	0.022	0.009	0.022	0.009	0.017
FeO	0.000	0.011	0.011	0.010	0.005	0.019	0.020	0.012	0.011
Total	100.011	100.144	100.194	99.994	100.164	100.403	100.294	100.226	100.337
n	3	3	13	2	4	7	3	2	7

n – No. of analyses
9: mean analyses for 7 bands in sample 9

(Table 2 cont'd: Mean ruby analyses for dark toned bands (see Figure 3)
2B Dark toned bands

	10	11	12	13	14	15	16	17	18	19	20
Al_2O_3	99.311	99.181	99.625	99.727	99.336	99.683	99.409	99.646	99.777	99.502	99.351
Cr_2O_3	0.619	0.523	0.505	0.489	0.475	0.415	0.377	0.367	0.330	0.294	0.571
TiO_2	0.126	0.528	0.064	0.122	0.140	0.374	0.318	0.205	0.285	0.478	0.286
V_2O_5	0.017	0.034	0.043	0.010	0.010	0.044	0.016	0.030	0.011	0.012	0.024
FeO	0.006	0.008	0.011	0.002	0.006	0.012	0.006	0.015	0.020	0.012	0.018
Total	100.079	100.274	100.248	100.350	99.967	100.528	100.126	100.263	100.423	100.298	100.250
n	3	5	3	3	2	3	4	9	2	4	5

10: mean analyses for 7 bands in sample 9

Table 3: Mean mineral analyses (excluding ruby)

	1	2	3	4	5	6	7	8	9	10	11	12	13
Na_2O	0.487	2.404	0.234	4.318	0.563	9.951	9.412	7.628	4.435	2.639	1.059	1.655	0.014
SiO_2	45.617	35.067	40.921	41.070	44.863	67.429	63.069	59.424	52.333	48.226	63.475	37.462	36.917
K_2O	10.518	0.209	8.692	0.460	9.940	0.684	0.181	0.159	0.051	0.033	14.173	0.042	0.009
Cr_2O_3	0.447	0.133	0.371	0.00	3.130	0.016	0.016	0.020	0.018	0.015	0.001	0.478	0.424
F	0.046	0.016	0.556	0.039	0.219	0.040	0.00	0.093	0.055	0.00	0.037	0.166	0.038
Al_2O_3	36.271	45.754	22.609	43.971	32.239	21.437	22.836	25.371	29.816	32.216	18.256	33.688	62.672
CaO	0.008	9.251	0.036	2.331	0.007	0.395	4.168	7.071	11.219	14.279	0.008	1.771	0.006
V_2O_5	0.262	0.020	0.060	0.00	0.487	0.00	0.029	0.015	0.00	0.014	0.001	0.061	0.017
MgO	0.560	0.075	17.821	0.171	1.662	0.225	0.010	0.018	0.002	0.014	0.009	10.339	0.044
TiO_2	0.156	0.023	0.590	0.018	0.331	0.008	0.016	0.012	0.018	0.008	0.005	0.313	0.078
MnO	0.015	0.006	0.037	0.00	0.031	0.009	0.010	0.018	0.004	0.013	0.009	0.016	0.003
FeO	0.162	0.024	0.040	0.019	0.034	0.014	0.003	0.014	0.019	0.009	0.007	0.042	0.037
Total	94.549	92.982	91.969	92.397	94.506	100.206	99.793	99.732	97.969	97.466	97.574	86.032	100.253
n	9	6	9	2	7	2	3	6	1	3	3	11	7

Values in weight %
n = No. of analyses
1. Muscovite
2. Margarite
3. Phlogopite
4. Paragonite
5. Fuchsite
6. Albite
7. Oligoclase
8. Andesine
9. Labradorite
10. Bytownite
11. K-feldspar
12. Tourmaline
13. Kyanite
(A complete list of analyses is available from the authors)

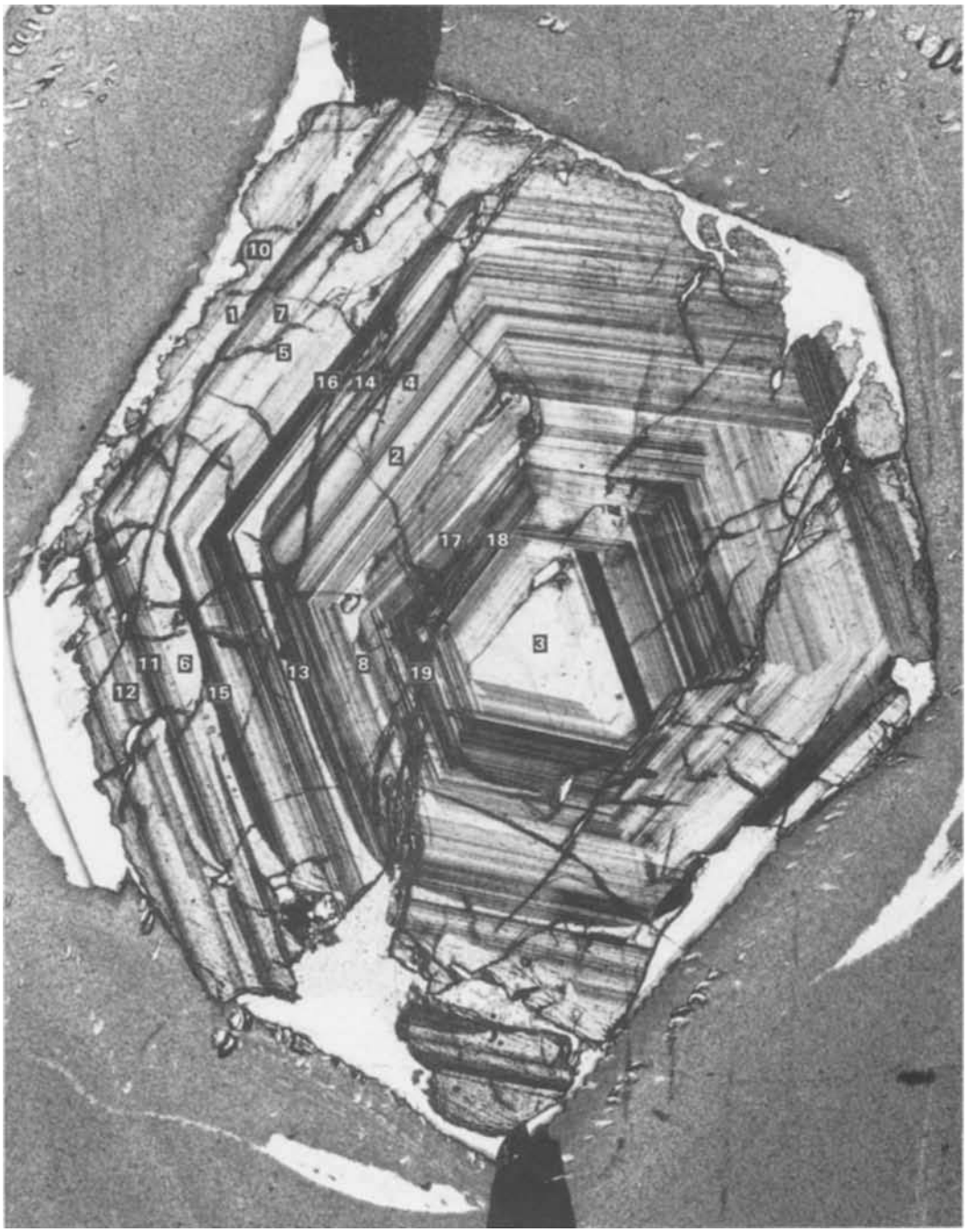

Fig. 3. The analysed ruby with the locations of the analysed pale and dark bands shown in Table 2.

Table 4: Two ICP analyses of tourmaline grains from Mangari

	Tourmaline 3	*Tourmaline 10*
SiO_2	39.30	38.13
Al_2O_3	29.86	30.04
TiO_2	0.35	0.30
Fe_2O_3	0.31	0.42
MgO	9.95	10.82
CaO	2.40	1.57
K_2O	0.35	0.13
Na_2O	1.82	1.66
MnO	0.02	0.02
P_2O_5	0.04	0.04
B_2O_3	9.17	9.73
Cr	840 *ppm*	1030 *ppm*
Zn	280 *ppm*	75 *ppm*

are not so well constrained and have been estimated at greater than 5 kbars with no upper limit yet established. Gneisses bearing two pyroxenes are recorded by Walsh (1960) from the area south of the Taita Hills, to support the conclusion that the metamorphism attained granulite facies conditions.

In the present study it is possible to estimate the PT conditions of the metamorphism during which ruby formed, by two methods. A direct method uses the compositions of co-existing plagioclase and K-feldspar. Thus Haselton and others (1983) provide the following formula:

$$T_K = \frac{(X_{Or}^{AF})^2(18810 + 17030\,X_{Ab}^{AF} + 0.364P) - (X_{An}^{Pl})^2(28230 - 39520\,X_{Ab}^{Pl})}{10.3\,(X_{Or}^{AF})^2 + 8.3143\ln\left\{\dfrac{(X_{Ab}^{Pl})^2(2 - X_{Ab}^{Pl})}{X_{Ab}^{AF}}\right\}}$$

Where T_k = Temperature (°C)
P = Pressure (bars)
X = Various mole fractions in the ternary system, orthoclase (Or)-albite (Ab)-Anorthite (An). AF and Pl refer to alkali feldspar and plagioclase respectively.

This equation is preferred to other two-feldspar thermometers because it takes in to account the anorthite content of both plagioclase and K-feldspar which is significant in the Mangari feldspars. Using the feldspar analyses summarised in Table 3 in the above formula provides temperatures of between 630°C and 670°C irrespective of pressure. The presence of kyanite as the Al_2SiO_5 polymorph indicates that pressures must have exceeded 7 kbars in this temperature range (Holdaway, 1971). These PT conditions agree with previous work as listed earlier.

An indirect approach to ascertaining the PT conditions of the metamorphism is provided by experimental data on the stability of the mineral assemblages. Altherr and others (1982) concluded that corundum in the Morogoro area of Tanzania formed in a metamorphism with temperatures of about 695°C at 7.7 kbars pressure (assuming an activity of H_2O of 1). This was based on the assemblages, albitic plagioclase + muscovite + phlogopite + corundum and albitic plagioclase + kyanite or sillimanite + phlogopite. These assemblages occur at Mangari. However, no account of the effect of the presence of CaO in the mineral phases was taken by Altherr and his co-workers. The very detailed study by Cartwright and Barnicoat (1986) on corundum-bearing restites from Scotland does discuss the effect of CaO. They note that the assemblage, corundum + K-feldspar + white mica + plagioclase + kyanite + liquid, indicates temperature of around 800°C with pressures of about 12 kbars. The PT conditions at Mangari cannot be exactly specified beause of the non-stoichiometric compositions of the mineral phases at Mangari and because of the unknown composition of the fluid phases. However, it can be concluded that the present study has confirmed that the Mangari rubies formed during a metamorphism which reached granulite facies conditions, defined as temperatures in excess of about 650°C irrespective of pressure, see Miyashiro (1961) and Zwart (1967).

It is relevant to note that Maesschalck and Oen (1989) show that Sri Lankan rubies, found in similar rocks to the Kenyan rubies, formed under very similar conditions to those specified in the last two paragraphs. They record that the rubies formed during a metamorphism with a temperature of about 630°C and pressures of about 5.5 kbars. Rubies in Tanzania are also found in areas of the Mozambique Orogenic Belt which preserve granulite facies mineral assemblages (Malisa and Muhongo, 1990).

Plate 9. Equigranular plagioclase grains with ragged graphite flakes (centre of plate) and tourmaline intergrowths (yellow). Sample 8. Field of view about 3mm by 4mm.

Plate 10. Two ruby grains (one strongly twinned) with idioblastic tourmaline and interstitial margarite. Sample 11. Field of view about 3mm by 4mm.

Plate 11. Several ruby grains with interstitial tourmaline. Sample 11. Field of view about 3mm by 4mm.

Plate 12. Intergrowth of muscovite with ruby; plagioclase grains clustered in lower left hand corner of the plate. Sample 9. Field of view about 3mm by 4mm.

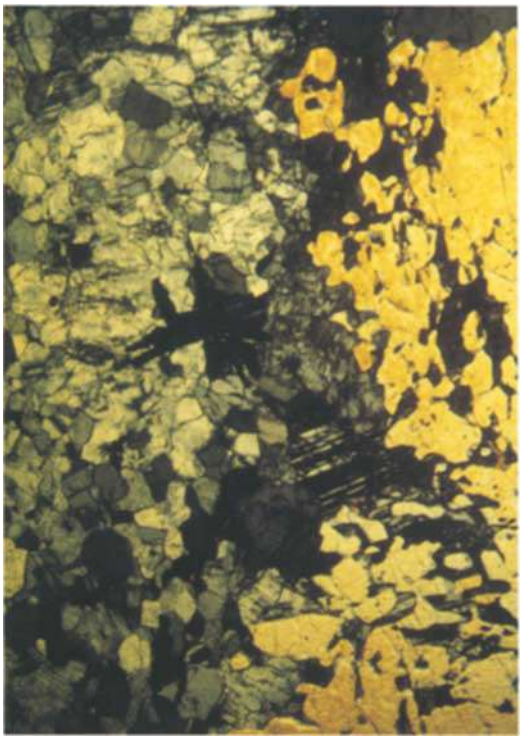

Plate 9

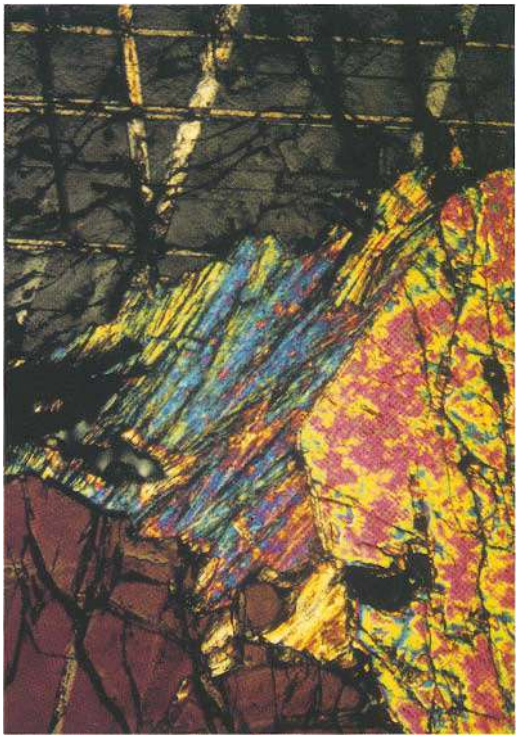

Plate 10

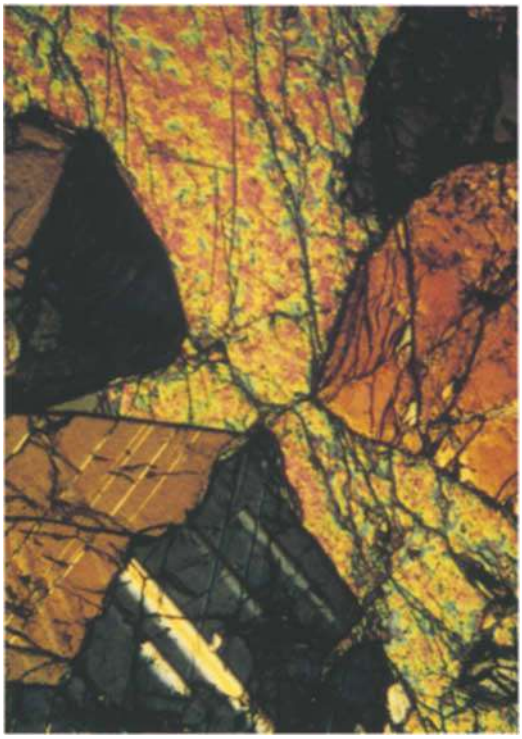

Plate 11

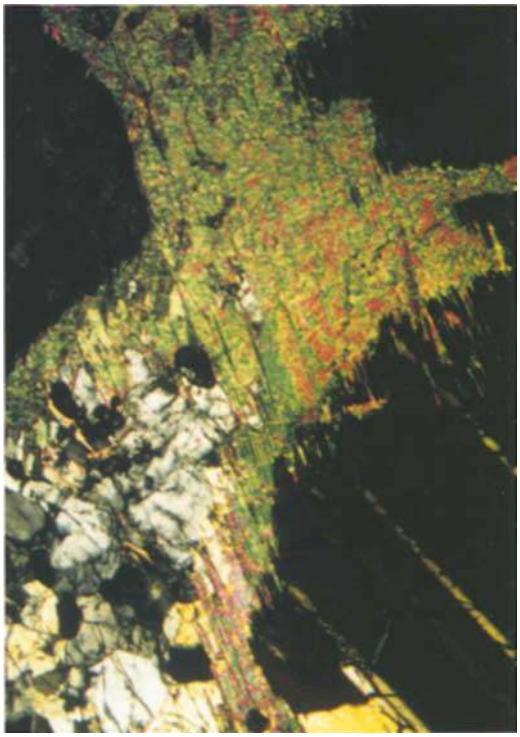

Plate 12

Conclusions

1. The Mangari rubies formed during regional metamorphism under upper amphibolite to granulite facies conditions: minimum temperatures of between about 630 and 670°C and pressures in excess of 7 kbars.
2. The pink and red body colours of the rubies are due to high values of Cr_2O_3 in the ruby matrix and low values of FeO. Titanium is present in significant amounts which is partly reflected by the ubiquitous presence of exsolved rutile needles. Vanadium is only present in trace amounts.
3. The strong colour banding is due to variations in the chromium and titanium contents of the rubies.
4. Chromium is also the chromophore in green tourmaline and in blue kyanite associated with the rubies. The ultramafic rocks associated with the rubies provided the chromium.

Future work

Many ultramafic intrusions in south-east Kenya do not appear to have marginal ruby deposits. There is an obvious need to compare the composition of the barren ultramafics with ruby-related ultramafics in order to see if there are chemical differences between the two sites. The chemistry of the ultramafics must significantly affect the desilication process which formed ruby.

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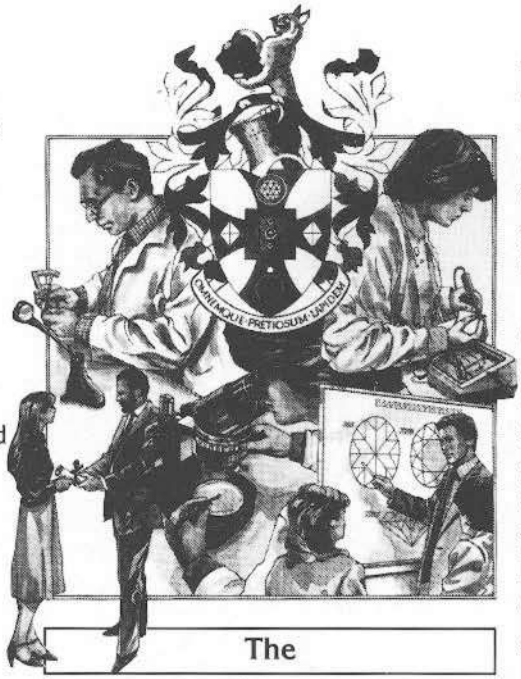

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Figs. 1-3 A selection of postage stamps depicting gem crystals and cut stones, mining activities and corals.

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RSA 15c
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8
BRITISH VIRGIN ISLANDS
Coral Reefs USA 15c
Coral Reefs USA 15c
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Coral Reefs USA 15c
10
BRITISH VIRGIN ISLANDS
15
BRITISH VIRGIN ISLANDS
75
BRITISH VIRGIN ISLANDS

Emeralds from Colombia (Part 3)*

George Bosshart

Gübelin Gemmological Laboratory, Maihofstrasse 102, CH-6000 Lucerne 9, Switzerland

Abstract
Introduction (Part 1)
A1. The history of the Colombian emerald mines
A2. The geographical location of the emerald occurrences

B1. The emerald deposits and their geological environment
B2. Hypotheses of emerald genesis
B3. The mine workings

Gemmological properties (Part 2)
C1. Morphology, quality and size of the emerald crystals
C2. Chemical composition, chromophore and trace element contents
C3. Light absorption, colour and fluorescence
C4. Optical values and density
C5. Inclusions and growth characteristics

Treatments (Part 3)
D. Oil, ultrasonic and heat treatments

Discussion
E. Differentiation of the Colombian emeralds from natural emeralds of other origins, synthetic emeralds and emerald imitations

Acknowledgements
Bibliography

Abstract

A condensed historical and mining survey is followed by a compilation of the most notable crystals of Colombian emeralds ever found and of the details of their chemical composition. A summary of the elemental substitutions and their effects on the outlined range of gemmological data is given.

Special emphasis is placed on the cause of the famous, vividly green coloration, i.e. on the selective absorption of orange-red and violet light, dictated by minor contents of the chromophoric elements Cr and V substituting for Al^{3+} in octahedrally coordinated sites of the beryl lattice (Cr ≈ V, with the Cr/V ratio found to be ranging from 4.5 to 0.5, in extreme cases from about 10 to 0.1). Iron, however, has barely been detected in the UV/VIS absorption spectra of Colombian emeralds. Though generally present in slightly larger amounts than Cr^{3+} iron does not recognizably influence the colour (little Fe^{2+} and possibly some Fe^{3+} positioned in the axial channels of the ring-silicate structure).

A detailed presentation of the currently known internal characteristics (inclusions and growth structures) is supplemented by a discussion of identification problems with treated emeralds and the disclosure of the treatment during transactions in the wholesale and retail trade.

Allocation of the emeralds to individual Colombian mines on the basis of inclusion patterns does not appear possible in most instances. However, the differentiation of Colombian emeralds from other natural emeralds (such as those from the Panjsher Valley exhibiting very similar (s,l,g) three-phase inclusions) or from difficult, modern hydrothermal and flux synthetics is shown to be feasible by a combination of microscopy, refractometry, and absorption spectrometry (UV/VIS and NIR/MIR), assisted by chemical analysis only in the most difficult cases. Safe identification of authenticity, treatment, and origin of emeralds, however, is increasingly becoming the task of the experts in the specialized laboratory.

The mineralogical definition of emerald as a yellowish to bluish-green variety of natural beryl is shown to be valid for any Cr and V-containing variety except possibly the rare, absolutely chromium-free (V,Fe)-beryls (modification of the former definition of type II emerald): in many of the preferred Colombian emeralds, chromium is clearly dominated by vanadium (Cr/V ratio < 1). However, chromium has a higher efficiency of coloration than vanadium and a much higher one than iron ions in the various substitutional and interstitial lattice sites of beryl. Cr influences colour even at very low trace levels.

An extensive and up-dated selection of literature, covering all aspects cited, completes the synopsis.

*This is a paper has been published in *The Journal* in three parts. The complete bibliography was presented with Part 1.

The introduction to this review is based on the study of a fraction of the extraordinarily extensive literature on Colombian emeralds.
The main part of the paper (Part 2) contains data collected and findings achieved over many years in the SSEF Laboratory in Zurich.
Part 3 deals with the difficulties encountered in identifying treated emeralds and with the disclosure necessary when selling them and will discuss the possibilities of differentiation between Colombian and other natural emeralds and the synthetic emeralds.

Treatments

D. *Oil, ultrasonic and heat treatment*

A few inevitable words to the subject of *'oil treatment'*. Regrettably it is not true that only a small number of Colombian emeralds are improved in appearance. In principle all fractures and fissures are subjected to filling with colourless oils, Canada balsam etc. Success is largely dependent on the quality of the emeralds. Qualitatively good emeralds cannot show an improved appearance simply because they do not possess oilable (surface-reaching) tension cracks. For objective quality assessment, emeralds should be de-oiled before any transaction is finalized (Figure 22). Oil removal is easily achieved with warm acetone. These fracture fillings are not permanent. They readily evaporate or alter in other ways, either chemically or optically (oxidation in air, reaction with alcohol, soapy water, cosmetics etc., Figures 23 and 24). Ultimately there is a general need for subsequent retreatment.

According to laboratory experience, the private owner may be puzzled by the deteriorated appearance of the oiled emerald sold to him as untreated. He may even become annoyed by the slow or sudden 'generation' of shockingly flashing cracks, as he can prove that he did not damage the emerald. The experience with his 'sensitive' emerald can make him so sceptical that he is deterred from buying other gemstones. Any explanation by the jewellery staff after the sale to the effect that oil treatments have long become customary will definitely provide little solace. North-American sales personnel seem to be better trained with respect to disclosure of gemstone treatments than the European trade.

New treatment methods have recently made progress. Open cracks are permanently filled and do not turn turbid (but may appear blue in transmitted light and show orange flashes in reflected light). These techniques make use of artificial resins and hardeners and similar stabilizing substances.

It must be stated that emeralds are not necessarily endangered by the use of *ultrasonics*. Beryls are not more brittle or friable than many other gemstones. They even lack a proper cleavage. The reaction of emeralds to any mechanical stress is dependent – as in the case of oil treatment – primarily on their quality. Every kind of gemstone with definite tension and cleavage cracks presents a higher risk than a fine stone without flaws. But even these can be damaged under extreme circumstances, for instance when a sharp girdle of a diamond baguette exerts pressure on a set emerald (Figure 25).

Emeralds are also no exception when required to tolerate high temperatures (≥700°C), irregular *influence of heat* and thermal shock during jewellery work. The weak basal cleavage in beryl then causes the stone to disintegrate into turbid slices. In these extreme conditions the internal pressure of the fluid inclusions or the intrinsic strain caused by inhomogeneous chemical composition or geotectonic stress can lead to a rupture of the stone. The coloration of emerald by chromium and vanadium, on the other hand, is largely resistant to heat and is not affected by irradiation.

Discussion

E. *Differentiation of Colombian emeralds from other emeralds and emerald substitutes* is easily managed as nearly every Colombian stone shows the characteristic jagged three- and multi-phase inclusions and definite growth structures, has low to (at most) medium refractive index and density values and exhibits no iron spectrum, with the exception of an occasional weak Fe^{3+} line at 374 nm or a trace of the Fe^{2+} band centred at about 800 nm. In addition, the absorption edge at the transition to the general absorption and the absorption minimum in the UV are at extraordinarily low wavelength positions.

However, three- and multi-phase inclusions are by no means found exclusively in Colombian emeralds. Resembling them the most are the healing fissures observed in Afghani and Pakistani emeralds. The expert can usually distinguish the patterns by various details. More effective identification properties of *Pakistani emeralds* are the high refractive index and density values (due to their elevated contents of Fe, Cr and alkalis) as well as the dissimilar mineral and wallrock inclusions (albite and carbonaceous shale in Colombian emeralds and talc, molybdenite, hematite, chromite, magnetite and recently also gersdorffite (NiAsS, cubic) in the Pakistani stones). Pyrite and carbonates are common to emeralds of both mining districts.

A greater problem of identification appear to be the *Afghani emeralds* from the Panjsher Valley, little known up to now. Their inclusions are similar to and their refractive index and density values hardly higher than the Colombian ones. However, the absorption spectrum is clearly different (Figure 4: UV absorption edge and minimum at higher wavelengths, distinct Fe^{3+} band at 374.5 nm plus Fe^{2+} bands at about 840 nm (*o*) and 800 nm (*e*); iron content of the Panjsher emerald of 0.789 ct confirmed by microprobe partial analysis).

The gemmological data of certain *Brazilian and Australian emeralds* are often congruent with those of the Colombian stones. But, because of their different types of inclusions, identification presents no more difficulty than that of emerald imitations (made of Cr-doped YAG, zirconia, glass) or of composite stones (e.g. soudé 'emeralds' made of quartz/green glass/quartz; emerald-green rough made of assembled and dye-filled crystals). On the other hand, modern flux and especially hydrother-

Fig. 23 Covering of oil, fat or Canada balsam on an extended tension crack in a Colombian emerald, transformed into a semi-solid, ugly-looking white crust. Width of photomicrograph about 0.40 mm.

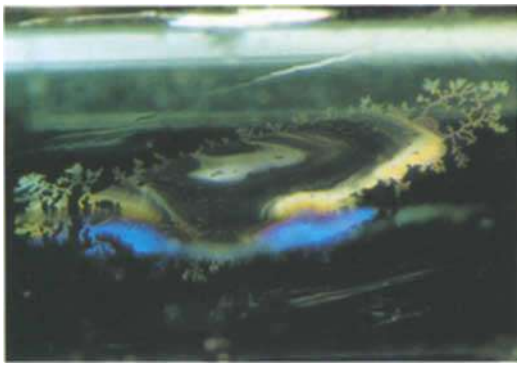

Fig. 24 Iridescent and greenish reflective oil film on a tension crack, in an advanced state of dendritic dessication. The owner of the emerald noticed the puzzling rainbow phenomenon one day with the bare eye. Length of oil film 2.2 mm.

Fig. 25 Extensive irregular breakage caused by the strong unilateral pressure of a diamond baguette on this emerald, formerly a centre stone in a ring. Development of breakage from the point of contact (the asymmetric indentation below the girdle) over the entire left crown side of this Colombian emerald, free from cracks and poor in inclusions. Length of the notch approximately 2.65 mm.

mal synthetics may pose problems which can no longer be solved except with the help of UV/VIS and near- and mid-infrared absorption spectra, chemical analyses and possibly ESR spectra.

While the *determination of origin,* based on the colour and microscopic, chemical and physical properties mentioned above, is comparatively simple for emeralds from Colombia, substantiation of the specific mine is nearly impossible.

Article 5 of the CIBJO Rules (1988) demands an unequivocal declaration as to emerald treatment with coloured oils or the permanent filling of cracks with artificial substances of the new generation.

Evidence of each and every kind of treatment with the microscope and UV lamp is often ambiguous. Iridescent reflection colours, for instance, are not specific: the orange flash on the fissure shown in Figure 13 looks very similar to those from 'Opticon' sealed cracks yet it is not due to this treatment. Systematic application of the CIBJO nomenclature regulations therefore is virtually impossible. Microspectrophotometric cathode-luminescence tests (Ponahlo 1989) could help here if they would facilitate differentiation of the various chemical compounds used.

Metal foils formerly applied to the pavilion of mounted emeralds are rarely encountered nowadays. They have not been durable, just like the modern green lacquers or iridescent coatings on emeralds, and are also recognizable at moderate magnification.

Many gemmologists and gemstone dealers do not appear in a 'moral' position to accept without contradiction the unintentionally broad mineralogical *definition of emerald* plainly as green beryl variety (i.e. without any restriction as to the hues and saturations of green). The author, nevertheless, insists on the fact that small quantities of Cr^{3+} (Al^{3+}oct.), being the cause of the green colour of all type I emeralds, appreciably participate in the coloration of type II emeralds also, due to the greater colouring effect of Cr than V or Fe. If there was a type of green beryl which might not be designated as an emerald, it should only be the V, Fe-beryls, absolutely free of Cr. Because of their chromium traces, most natural vanadium beryls, such as the ones from Eidsvoll (Mjösa Lake, Norway), Emmaville (New South Wales), Salininha (Bahía) or Gandao (Mohmand Agency, Pakistan), must be allocated to the emerald type II and should thus be called emeralds as well.

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Ottobrunn, Dr K. Schmetzer, Munich, Dr W. Quellmalz, Dresden (Germany), Prof. Dr G. Niedermayr, Vienna (Austria), Prof. Dr E. Gübelin, Meggen, Prof. Dr H.A. Stalder, Berne, and Dr H.A. Hänni, Basle (Switzerland). Thanks are returned to the latter for figures 1, 7, 9-12, 14, 15, 19-23 and for the partial EMX analysis of the Panjsher emerald of Figure 4, and to D. Schwarz for the EMX data on the Gachalá emeralds. The author also appreciates the new chemical data on parisite specimens (e.g. on the inclusions pictured in Figure 13) worked out by Prof. Dr W.B. Stern, Prof. Dr R. Guggenheim (Basle) and Dr A. Peretti (Lucerne).

The original article 'Smaragde aus Kolumbien', published in the *Goldschmiede-Zeitung* (Rühle Diebener Verlag, Stuttgart, 1990, nos. 4,6,8), benefitted from the primary English translation by Mrs E. Stern, London, and reviewing of the final updated version by Mr E. Boehm, Los Angeles (presently Lucerne, Switzerland).

Corrigenda

On p.416 above, first column, 4th line, for 'that of chromium Fe^{3+}' read 'that of chromium and Fe^{3+}'.

On p.418 above, second column, line 13, for '(Figure 10)' read '(Figure 16)'.

[*Manuscript received 19 March 1990.*]

Proceedings of The Gemmological Association and Gem Testing Laboratory of Great Britain and Notices

OBITUARY

Mr Johannes S. Hermans, FGA (D.1981), Delft, The Netherlands, died recently.

Mr Bjarne Jensen, FGA (D.1963), Bergen, Norway, died in October 1990.

Mr Gerald Leybourn-Needham, FGA (D.1980 with Dist.), Aston by Budworth, died in May 1991.

Mr Henry McNeilly, FGA (D.1929), Belfast, N. Ireland, died in February 1990.

Mr Akseli Valta, FGA (D.1973), Helsinki, Finland, died recently.

NEWS OF FELLOWS

On 12 June 1991 **Mr Michael O'Donoghue** gave a talk entitled 'Gemstones' to the Meopham Historical Society.

On 11 to 13 June 1991 **Mr Michael O'Donoghue** and **Mr Peter Reed** lectured at two courses held by the Precious Stone Training Services.

On 13 to 15 September 1991 **Alan Hodgkinson, David Larcher, Sharon Longden** and **Ken Stirton** participated in the National Exhibition of Time held at the British Horological Institute, Upton Hall, Nr Newark, Notts, with an exhibition of gem testing. The event proved to be very successful with a record attendance.

THE GIA INTERNATIONAL GEMOLOGICAL SYMPOSIUM

This very successful event was held in Los Angeles from 20-24 June 1991 in conjunction with the Conclave of the American Gem Society. There were over 1800 representatives (from 45 countries) from the international gemmological fraternity and the jewellery industry. The programme comprised four concurrent feature presentations all day Friday and Saturday with four concurrent panel discussions on the Sunday morning. As with most all-embracing conferences, the problem was to choose which *one* of the simultaneous lectures to attend – all four were always of considerable interest. British input was by K. Scarratt and E.A. Jobbins in the Gem Identification sessions, D.J. Callaghan and R.R. Harding in the Period Jewellery sessions, with K. Scarratt and P.G. Read participating in various Panel Discussions. E. Emms was involved in discussions on Diamond Grading.

For the enthusiastic gemmologist the Poster session provided excellent opportunities to view and to discuss with exhibitors the results of recent research and new discoveries. There were some 90 displays from a wide spread of countries.

To mark the Diamond Jubilee of the GIA, David Callaghan (our Chairman) presented to Bill Boyajian (GIA President) a Herbert Smith refractometer for their collection of historical instruments.

The evening functions were produced in the grand manner and included a fashion show hosted by cultured pearl interests from Japan and America and also a gala 'Maestro and Masterpieces: Italian Jewels of the Opera', a dinner party and display hosted by Italian jewellery organizations and the Platinum Guild International. Beautiful jewels, dresses and models! The overall theme was 'Facing the Future' and every aspect of gemstones and jewellery from the mine to the retail mall was featured. There was something for everyone in this superbly organized extravaganza – congratulations and thanks to the GIA.

MEMBERS' MEETINGS

London

On 2 July 1991 at the City Conference Centre, 76 Mark Lane, London EC3R 7JN, a Pearl Evening was held. Mr Alan Jobbins gave an illustrated lecture on pearls, followed by reports from Nicholas Sturman on pearl testing by X-rays and Alan Clark on the newly devised Pearl Quality Report.

Midlands Branch

On 20 September 1991 at Dr Johnson House, Bull Street, Birmingham, a talk was given by Mr F. Deitch of Mikimoto entitled 'Pearls'.

North West Branch

On 18 September 1991 at Church House, Hanover Street, Liverpool 1, Dr J. Franks gave an illustrated lecture on the Smithsonian Museum.

FORTHCOMING MEETINGS

London

3-4 November 1991 Conference and Presentation of Awards

Meetings will be held at the City Conference Centre, 76 Mark Lane, London EC3R 7JN, on the dates set out below. Full details and topics of lectures will be circulated prior to each meeting.

Tuesday 28 January 1992
Tuesday 10 March 1992
Wednesday 13 May 1992
Tuesday 9 June 1992
Tuesday 24 November 1992

Midlands Branch

Meetings to be held at Dr Johnson House, Bull Street, Birmingham. Further details from David Larcher on 021 554 3871.

15 November 1991	Mr J. Gosling. 'The Guyana Lapidary Project'
17 January 1992	Members' practical evening
21 February 1992	Mr Clive Burch. (Subject to be announced)
20 March 1992	Mr David Callaghan. (Subject to be announced)
10 April* 1992	Annual General Meeting followed by lecture

*NB. This meeting has been arranged for the second Friday of the month because of the Easter holiday.

North West Branch

Meetings to be held at Church House, Hanover Street, Liverpool 1. Full details from William Franks on 061-928 1520.

20 November 1991	Annual General Meeting
15 January 1992	David Pelham. 'On small gold mines'
19 February 1992	Helen Fraquet. 'Amber'
18 March 1992	Dr Jeff Harris. 'An aspect on diamonds'
17 June 1992	'Exchange and Mart'. Buying and selling of books, crystals and instruments, plus social evening
16 September 1992	Adrian Klein. 'Emerald'
21 October 1992	Dr Jamie Nelson. 'Optical attributes of a diamond'
18 November 1992	Annual General Meeting

GEM DIAMOND EXAMINATION 1991

In the 1991 Gem Diamond Examination 28 candidates qualified. The names of the successful candidates are as follows:
Ann M. Allnutt, Chislehurst.
Jose Miguel Bernad Soria, Zaragoza, Spain.
Gloria Blanch Papaceit, Barcelona, Spain.
Liza Boyadjian, London.
Anna Brooks, Watford.
Jose Antonio Casa Royo, Alfaro (La Rioja), Spain.
Ivan L. Charatan, Hackney.
Bruce J. Copestick, Harpenden.
Caroline E. Findlay, Edinburgh.
John Mainwaring Henry, Bolton.
David J. Hollanders, Maidenhead.
Yvonne Holton, Edinburgh.
Ana Ma Lopez Gracia, Barcelona, Spain.
Blancanieves Luzondo Olea, Tolosa (Guipozcoa), Spain.
Eduardo Moreno Rastrero, Logrono, Spain.
Brigitte C.E. Pfeiffer, London.
Trevor Rackley, Northampton.
Anna Ma Ruiz Domenech, Torredembarra, Spain.
Ahad Sayed, Brentford.
Louise Shafar, Glasgow.
Fatehchand Jivanlal Shah, London.
Evelyn Sim, Singapore.
Lesley Skinner, Stenhousemuir.
Stephen Spencer, Nottingham.
Kevin. G. Williams, Edinburgh.
Nean E. Wilson, Longniddry.
Michael Wright, Watford.
Mei Wan Wu, Harlow.

EXAMINATIONS IN GEMMOLOGY 1991

The 1991 Gemmology examinations were held at 62 centres in 26 countries throughout the world. 552 candidates sat the Preliminary Examination of whom 341 (61%) qualified and 429 candidates sat the Diploma Examination and 211 (48%) qualified, 17 with Distinction.

In the opinion of the Examiners, no candidate achieved the high standard required to warrant the award of the Tully Medal.

The **Anderson/Bank Prize** for the best non-trade candidate of the year in the Diploma Examination has been awarded to Peter J. Wates of Coulsdon, Surrey.

The **Diploma Trade Prize** for the best Diploma candidate of the year who derives his main income from activities essentially connected with the Jewellery trade has been awarded to Anura S. Edirisuriya of Dickwella, Sri Lanka.

The **Anderson Medal** for the best candidate of the year in the Preliminary Examination has been awarded to Wun Mo Seong of Daejon, Korea.

The **Preliminary Trade Prize** for the best Preliminary candidate of the year under the age of 21 at 1st June 1991, who derives her main income from activities essentially connected with the trade has been awarded to Anne Margaret Bailey of Rugby.

DIPLOMA

Qualified with Distinction
Ma Ester Alvarez-Palacios, Salinas (Asturias), Spain.
Rene Gerard de Winter, Amsterdam, The Netherlands.
Anura S. Edirisuriya, Dickwella, Sri Lanka.
Linda Lee Galloway, Hong Kong.
Rafel Ginebra i Molins, Vic, Spain.
Virginia Hogguer, Alphen aan den Rijn, The Netherlands.
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Alec J. Mason, Retford, Nottingham.
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Simon Schmidt, London.
Carolyn L. Stewart, Hong Kong.
Stig E. Sundin, Bergen, Norway.
Peter J. Wates, Coulsdon.
Alison D. Williams, Abinger Common.
Hong Chung Wong, Hong Kong.
Qinfang Xue, Wuhan, China.
Mingxing Yang, Wuhan, China.

Qualified
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Suzanne Adams, Sutton.
Christopher Amo, Williamsville, N.Y., USA.
Evangelia Anastassiou, Maroussi, Greece.
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Alexander Arbisman, Selsdon.
Henry N. Atkinson, London.
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Aristea Bakayianni-Sabou, Athens, Greece.
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Members having gained their Diploma in Gemmology or the Gem Diamond Diploma (FGA or DGA) may now apply for use of the Coat of Arms on their stationery or within advertisments.

Laboratory members are also invited to apply for use of the Laboratory Logo.

It is still a requirement of GAGTL, in accordance with the Bye Laws, that written permission be granted by the Council of Management before use.

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MEETING OF THE COUNCIL OF MANAGEMENT

At a meeting of the Council of Management held on 12 June 1991 at E.A. Thomson (Gems) Ltd, Chapel House, Hatton Place, London EC1N 8RX, the business transacted included the election to membership of the following:

Fellowship

Fan, Siu-Kam, Kowloon, Hong Kong. D.1989
Kangas, Anne K., Helsinki, Finland. D.1990.

Ordinary Membership

Cattell, Nicla M.L.V., Kettering.
Corbett, John A., Edgbaston.
Daryanani, Nita, Hong Kong.
Emmett, John L., Pleasanton, Calif., USA.
Pakzad, Mohammad A., London.
Parkinson, Frederick, Leighton Buzzard.

At a meeting of the Council of Management held on 17 July 1991 at 1 Burlington Gardens, London W1X 2HP, the business transacted included the election to membership of the following:

Fellowship
Reveliotis, Christos, Athens, Greece. D.1990.

Ordinary Membership
Ben-Zur, Eitan, London.
Carter, Stuart M., Bristol.
Cerins, Andris, Cambridge.
Comersford, Jessie, Alexandria, Egypt.
Grossman, Julie F., Hounslow.
Gunasekara, S., Boulder, Colo., USA.
Halai, Amy, Solihull.
Kassam, Sultan M., London.
Koundourou, Ratka, Athens, Greece.
Prajapati, Jagdish, London.

At a meeting of the Council of Management held on 21 August 1991 at 27 Greville Street, London EC1N 8SU, the business transacted included the election to membership of the following:

Ordinary Membership
Berreux, Cedric, La Chaux-de-Fonds, Switzerland.
De Granville, Francesca, Oklahoma City, Okla., USA.
Denson, Keith, Oldham.
Fox, Rosemary T., Brighton.
Gautama, Surinder, Ilford.
Milne-Buckley, Deborah J., Chertsey.
Salama, Susan F., Beckenham.
Schlussel, Joseph L., New York, NY, USA.
Thorbjornsen, Bjorn T., Bergen, Norway.
Tillakaratne, Adikari M.N.K., Kano, Nigeria.

Transfers – FGA to FGA, DGA
Allnutt, Ann M., Chislehurst. D.1962.
Boyadjian, Liza A., Heston, D.1989.
Charatan, Ivan L., London. D.1990.
Copestick, Bruce J., Harpenden. D.1990.
Findlay, Caroline E., Edinburgh. D.1988.
Henry, John M., Bolton D.1990.
Hollanders, David J., Nelson. D.1990.
Holton, Yvonne, Edinburgh. D.1986.
Pfeiffer, Brigitte C.E., Isleworth. D.1989.
Rackley, Trevor, Brackley. D.1990.
Shafar, Louise, Eaglesham. D.1990.
Sim, Evelyn, London. D.1990.
Skinner, Lesley, Stenhousemuir. D.1990.
Spencer, Stephen R., Woodborough. D.1990.
Williams, Kevin G., Edinburgh. D.1983.
Wilson, Nean E., Longniddry. D.1990.
Wright, Michael J., Watford. D.1990.

Transfers – Ordinary Membership to Diamond Membership
Blanch, Gloria, London.
Brooks, Anna T., Watford.
Sayed, Ahad, Brentford.
Shah, Fatechand J., London.
Wu, Mei W., Harlow.

MEETING OF THE TRADE LIAISON COMMITTEE

At a meeting of the Trade Liaison Committee held on 4 July 1991 at 87 Hatton Garden, London EC1, the business transacted included the election to membership of the following:

Gold Laboratory Membership
Roselaar & Co., c/o LDB, 100 Hatton Garden, London EC1N 8NX.
Bernard Schipper BV, Kalverstraat 36-38, 1012 PD Amsterdam, The Netherlands.
Richard Shepherd & Co., Suite 123, 100 Hatton Garden, London EC1N 8NX.

Ordinary Laboratory Membership
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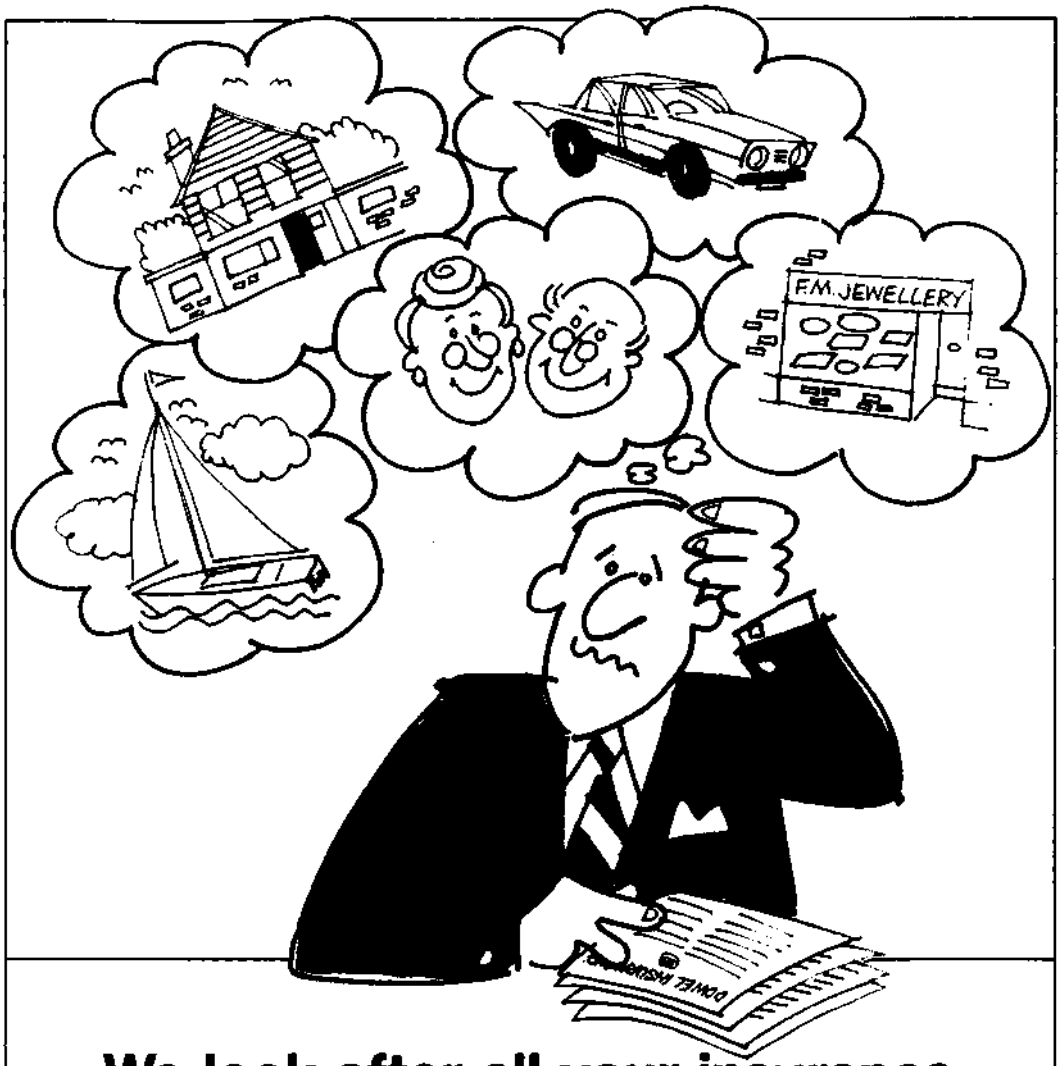

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Cover Picture

A synthetic diamond during electron bombardment. Symmetric arrangement of various growth sectors of greenish-yellow and blue clearly revealed. (*See* Cathodoluminescence (CL) and CL spectra of De Beers' experimental synthetic diamonds by Johann Ponahlo, p.3-17.)

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R. Keith Mitchell, FGA

It is fitting that as we introduce this new volume of the *Journal* we honour one of our eminent Fellows who celebrates his eightieth birthday on January 28 1992.

Mr Mitchell joined the silver and leather-goods buying department of Mappin and Webb Ltd in 1928. Geology and minerals had always fascinated him and he eventually obtained a move to their gem department in 1933.

The previous year had been significant since he then joined the gemmology course under J.G. Jardine at Chelsea Polytechnic. In 1934 he won the Tully Memorial Medal despite strong rivalry from Robert Webster and other students in what had been a remarkable year - the first in the charge of B.W. Anderson - when nearly half the students who sat the examination achieved Distinction passes and no one failed.

He wrote occasionally for the *Gemmologist* and other journals until marriage in 1937, and the War two years later, diverted his interests.

1936 had seen him working first for B. Barnett Ltd and then for A.E. Davis Ltd in London's Piccadilly, where he remained through the desperate period of the London Blitz until call-up in 1941 sent him north to Catterick to train as an operator in the Royal Corps of Signals.

Training completed he was shipped to Singapore, arriving ten days before Japan entered the war. Ten weeks later Singapore fell and he was incarcerated with some fifty thousand other prisoners in the Changi area. After 15 months and much ill-health he was shipped to Hokkaido, the northern island of Japan, to slave long and hard under extremely arduous conditions on an insufficient diet of rice, levelling airfields, feeding steel furnaces and mining coal.

At the end of the War he came home to rejoin A.E. Davis in Piccadilly and remained with that firm until 1957. A misguided appointment with a provincial jeweller swiftly foundered and Mr Mitchell started dealing from home on his own account in July of that year.

By this time his interest was largely in antique jewellery and in rare and unusual gems and over the years the writer, who had first met Keith Mitchell in 1950, had, in his capacity as Curator of Gem and Mineral Collections at the Geological Museum, acquired from him many outstanding and mouth-wateringly beautiful gems for those National collections. Some of these had come from contacts with over-seas students in the course of Keith's teaching activities.

He had assisted the late Thorold Jones with practical classes at Chelsea Polytechnic in 1947 and, when Anderson gave up teaching and Webster took over the practical instruction in 1949, moved on to tutor first year students in the Gemmological Association Correspondence Courses. Within a year C.J. Payne opted out of the Diploma course instruction and the late Gordon Andrews, the shrewd secretary of the Gemmological Association, asked Mr Mitchell to take both Courses over. He then ran these single-handed until 1959 when Vera Hinton took on 100 of the first year students and then, a year or so later, the Rev. Nikon-Cooper also took over some of the first year people. Mr Mitchell still coped with a substantial surplus of first year students and with the entire Diploma quota for twenty years (during which eight of his students gained Tully Medals), plus frequent revision of course notes to keep them in line with a rapidly advancing subject, until 1969 when sudden illness forced him to give up this work. One year he had found himself with a work-load of some 240 students, some of whom elected to write in their own languages rather than in English. In 1979 he was once more asked to revise the Course notes which had been allowed to become rather static in the ten years since he had retired as an instructor. By the mid-eighties a veritable team of instructors had taken his place.

In business he continued to work from home until insurance problems forced him to take an office in Holborn in 1967, a happy move which was to prove very rewarding until he retired from active business in 1979. But the habits of a lifetime die hard, and even today he still dabbles a little with gems and jewellery and undertakes some coaching when students ask.

Always interested in writing, he has contributed some fifty papers of greater or lesser scientific importance to this and to other Journals both here and overseas since the mid-thirties and compiled a set of Gem Crystal Transparencies which assist the teaching of crystal recognition. Today he is perhaps best known for the numerous abstracts from foreign magazines which have appeared over the initials R.K.M. for many years in our *Journal*, and for lamentably frequent obituaries of old friends.

In April 1984, 50 years after acquiring his Tully Medal, R. Keith Mitchell was elected Vice-President of our Association - a well-deserved tribute and a fitting reward for the very considerable service he has afforded to the Association for more than half a century. We wish him well for many years to come.

Cathodoluminescence (CL) and CL spectra of De Beers' experimental synthetic diamonds

Johann Ponahlo, FGA

formerly Austrian Gemmological Research Institute (E.Ö.G.G.), Vienna, Austria

1. Introduction

Large man-made experimental diamonds have been described by various authors in the past (Crowningshield (1971), Koivula *et al.* (1984), Shigley *et al.* (1986, 1987)). There is no doubt, anymore, about the technical potentialities to grow single crystals of diamonds up to 20ct. Two years ago, by courtesy of the Diamond Research Laboratory, Johannesburg, and the DTC Laboratories, Great Britain, the author had the opportunity to investigate ten yellow to brown experimental synthetic diamonds made by De Beers (Table I). The gemmological properties of similar stones have already been described (Shigley (1987)). Since little information on cathodoluminescence (CL) of these yellow synthetic diamonds was given their CL properties were studied more thoroughly. Twelve natural diamonds of similar colours were included in the investigation.

Nowadays, not much is known to the average gemmologist on the cathodoluminescence (CL) of diamonds – their interests being focused on transmission spectrography. This paper should give an indication of the wealth of information that can be obtained on natural and synthetic diamonds by means of CL if the CL methods described are properly applied. References are also given to some relevant recent CL literature.

2. Procedures

The CL features and spectra were studied at room temperatures using a modified LUMINOSCOPE® (Ponahlo (1989)). Instead of fibre-optics, direct focusing of the enlarged image of the luminescing sample surface onto the entrance slit of the monochromator proved to be a more efficient arrangement which increased the transmissivity of the whole system.

In the past CL methods have been criticized since they may have induced colour changes during bombardments with electrons. With the present arrangement (Ponahlo (1989)) no such detrimental effects were observed. Due to the high surface energy of a diamond traces of oil from the pumping system may diffuse into the vacuum compartment and become absorbed on the surface of a sample where they are cracked by the electron beam. By placing a molecular sieve between the pumping system and the vacuum compartment contamination can be avoided. If, in rare instances, a slight yellow to brown discoloration of a bombarded diamond facet is observed the thin film may easily be removed using a polishing agent.

Photomicrographs of the CL features and CL spectra were taken with the diamond sample resting on a movable platform inside the vacuum compartment, the table or a (001) face parallel to the stage of the microscope. Visual observations and CL spectra were taken at lower energies of excitation than the photomicrographs, but the data of the latter are given within the captions of the photomicrographs.

3. CL features of synthetic and natural diamonds

The following Figures (1 to 29) represent a selection of photomicrographs and CL spectra of most of the diamonds investigated. In contrast to the very weak luminescence intensities obtained when using UV light, CL is known for bright luminescence effects which are concentrated in a thin surface layer (1 to 2 μm). This offers a striking advantage for both visual observations and microscopic studies as well as for quantitative measurements of the CL spectra. Any sort of morphological luminescing detail (defects, banding, inclusions, etc.) will show brightly, sometimes in different colours or shades.

CL features of synthetic diamonds with cubooctahedral habit were first studied by Woods and Lang (1975) and by Vishnevsky (1975). Lang also refers extensively to CL studies of natural diamonds in Field (1979). More detailed information on large experimental synthetic diamonds carried out by solid state physicists became available, especially with the papers by Burns *et al.* (1990) and by Frank *et al.* (1990) which contain – besides further references – information on CL spectra taken at low temperatures, on IR-spectra and electron microscopy. From these papers and the information

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Fig. 1. Set of 7 experimental synthetic diamonds made by De Beers. Top row, left to right: DMY-4 (0.97 ct), DMY-6 (0.40 ct), DMY-10 (0.44 ct) and DMY-5 (1.03 ct). Bottom row, left to right: DMY-1 (5.24 ct), DMY-2 (4.57 ct) and DMY-3 (4.10 ct). Note cubo-octahedral habit and natural colours. 2.6x, incandescent light.

contained in this work it is hoped that it will become evident to the gemmologist that CL constitutes a most useful technique for the identification of synthetic diamonds.

Fig. 2. CL colours of five experimental synthetic diamonds made by De Beers. Top row, left to right: DMY-10, DMY-6 and DMY-5. Bottom row, left to right: DMY-3 and DMY-4. 1.05x, cond. excit.: 7.5 kV, 0.9 mA.

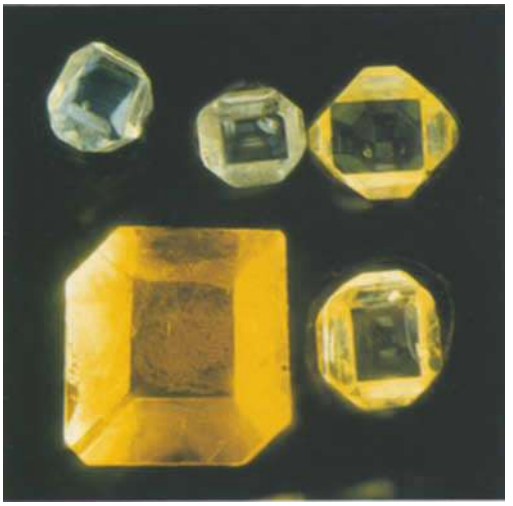

3.1. CL features of the experimental synthetic diamonds

Figure 1 gives an impression of the colour and habit of seven experimental synthetic diamonds in incandescent light. The high CL intensities of some of these synthetic diamonds is evident in Figure 2. During an electron bombardment using a beam-energy of 7,5 kV at 0,9 mA for visual observation, even the inclusions in the synthetic specimens (DMY-10, DMY-6 and DMY-5) become easily visible.

The following two Figures 3 and 4 are close-ups of the synthetic diamond DMY-1. Figure 3 is taken under incandescent light between crossed polars with stress-induced polarization phenomena. Figure 4 shows the same large crystal inclusion at higher magnification during the electron bombardment. The greenish-yellow CL colour as well as a stress-induced cloud around this crystal not visible in Figure 3 should be specially noted. Fine parallel orange-red needles are also noticeable. The blue CL colour may indicate different N-concentrations in otherwise not visible 110 and 113 minor growth sectors.

Figure 5 is a typical example showing the topography of the experimental synthetic diamonds brilliantly made visible by means of CL. The regular pattern of the various growth sectors is

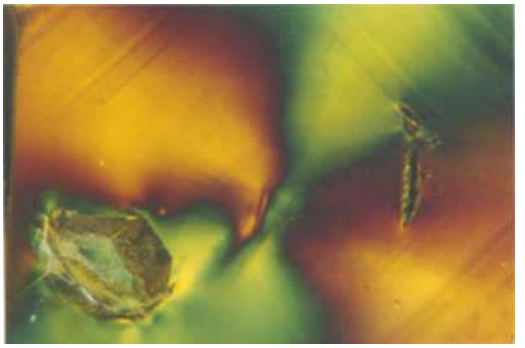

Fig. 3. Inclusions in DMY-1 with stress-induced polarization figures (catalyst and large euhedral crystal of unknown composition). Transmission photograph, crossed polars. 22x.

Fig. 4. The same large crystal inclusion as Fig. 3 during electron bombardment. Note greenish-yellow CL colour, stress-induced cloud around the crystal and fine orange-red needles barely visible in transmitted light. Blue CL colour indicates lower N-concentration, irregularly distributed. 43x (24 x 36mm).

Fig. 5. Typical growth sectors in the experimental synthetic diamonds with characteristic double bell-form of 111 sectors intensely banded, and bright greenish-yellow 001 sector. Intercalated blue and dark green sectors resembling higher indexed faces. Cond. excit.: 12 kV, 0.9 mA. 28x (24 x 36mm).

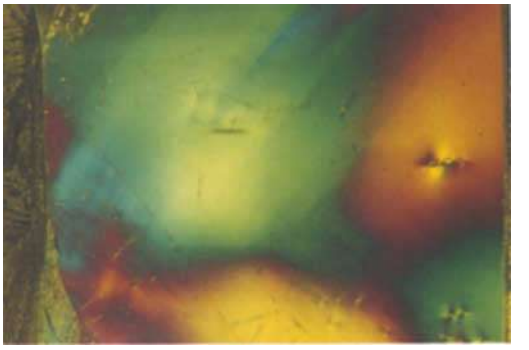

Fig. 6. Transmission photograph of DMY-3 with stress-induced zones of various colours, small transparent inclusions fine needle-like exsolved (?) material. Crossed polars, 22x.

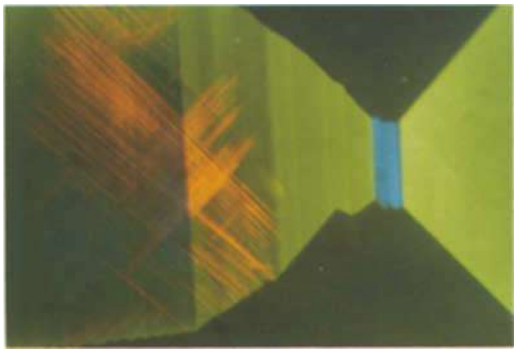

Fig. 7. Part of several growth sectors of DMY-3. Two greenish-yellow growth sectors with strong banding with intercalated blue rectangular area ((110) and (113)) faces. On the left two bundles of orange-red needles intersecting each other at about 90°. Cond. excit.: 15 kV, 0.95 mA. 28x (24 x 36mm).

Fig. 8. CL of the natural yellow cut diamond DM-M3. Bundles of parallel (multiple) twinning lines become easily visible by CL, the colour being a golden yellow with a distinct tinge of orange. Such effects in natural diamonds can be clearly differentiated from those visible in Fig. 7. Cond. excit.: 8.5 kV, 0.9 mA. 10x (24 x 36mm).

Table I: CL Spectra of ten experimental synthetic diamonds made by De Beers

Sample	weight (ct)	CL spectra (nm)		CL colour + features	remarks
DMY 1	5.240	526	strong	gr. yell. (100)+(111)	banding
DMY 2	4.570	535 + 570	medium	gr. yell. (100)+(111)	violet incl. in (100)
DMY 3	4.104	526, 544, 575	medium	gr. yell. (100)+(111)	+add. blue in (110) orange-red needles
DMY 4	0.972	548	v. strong	yell. with gr. tint	banding
DMY 5	1.037	484 + 520		blue + gr. + yell.	st. banding
DMY 6	0.40	480, 520, 538	medium	yell. CL colour change	white + blue
DMY 7	0.901	537	v.v. strong	gr. yell.	st. banding orange-red needles
DMY 8	0.386	480, 514, 524	medium	blue + weak yell.	banding
DMY 9	0.270	480, 554, 820!	weak	blue + golden yell.	st. banding
DMY 10	0.44	532 + 539	med. strong	white + blue + yell.	banding

Abbreviations: gr. yell. = greenish-yellow CL colour; (111) = luminescing growth sectors; incl. = inclusions visible in CL; v. = very; add. = additional CL colours; st. = straight; wavelength in (nm).

striking. Small dark laths and blue geometrical patterns represent higher indexed faces ((110) and (113)). The greenish-yellow 111 sector extending to the upper left in Figure 5 shows regular parallel banding like other octahedral faces of the sample. A 001 growth sector – parallel to the stage of the microscope – does not exhibit such banding although it is brightly luminescing in the same greenish-yellow colour. These features are documents to the differential uptake of impurities (N) by the different types of growth sectors which are unique to these true large cubo-octahedral synthetic diamonds.

Figures 6 to 8 should be studied together so as to compare some rare but characteristic internal structural features of both a synthetic and a natural yellow diamond. DMY-3 was chosen for its orange-red needles running crosswise (Figure 7), and DM-M3 (Figure 8) because of its similar inclusions of a golden-yellow colour. DMY designates a synthetic diamond, DM a natural one.

The orange-red needles – made visible by means of CL only (!) and noticeable in DMY-1 (Figure 4) (and DMY-9 too) exhibit a distinct spectrum (Figure 28 shows the visible and near infrared (VIS-NIR) spectrum of DMY-9). Its origin remained obscure until now, but recently similar orange-red needles with the distinct NIR-spectrum have been discovered in one small yellow synthetic diamond made in the USSR.

Some of the irregularly distributed dark inclusions of Figure 6 – they look like pencil marks – may be inclusions of catalyst or rather large dislocations. In Figure 7 the small blue rectangular growth sector between the greenish-yellow luminescing ones shows a weak banding. Note that the shape and the banding of the 111 growth sectors in DMY-3 are similar to those in DMY-1 and DMY-2 (the latter not shown in a photomicrograph).

These features, made visible by means of CL, should be clearly differentiated from occasionally observed multiple twinning in natural diamonds, an example of which is shown in Figure 8, the weakly luminescing DM-M3. A further differentiation is possible by means of their respective CL spectra (see section 4.2.).

The synthetic diamond DMY-4 shows a more yellow CL colour with a lesser greenish tint but somewhat similar to DMY-3.

The Figures 9 and 10 are other examples of the discriminatory power of the CL microscopy over studies with crossed polars alone. The blue and green CL colours of DMY-5 in Figure 10 disclose a variety of symmetrically arranged growth sectors with strong banding in some of these. Stress phenomena around larger inclusions become easily visible, also a weak orange luminescence of intersecting needles that characterize a (001) face. The blue seams around the green banded sectors are higher indexed (110) and/or (113) faces. Even these small faces show some banding.

Other inherent structural details become strikingly obvious when comparing Figure 11 of DMY-7 with Figure 12 of the natural yellow

diamond DM-M2. In the latter the blotchy irregular blue, brownish-yellow and dark brown patterns, with the faint indication of a drawing superimposed, are unmistakable indicators of CL features of a natural diamond. Contrasting evidence of the synthetic origin of DMY-7 is furnished by the symmetrical arrangement of banded growth sectors. They show vivid greenish-yellow CL colours of octahedral faces and an octagonal shaped (001) face with a Maltese cross. A close-up of the latter feature is presented in Figure 14. Such Maltese crosses have frequently been found on cube growth faces when bombarding yellow or greenish-yellow synthetic Sumitomo diamonds (Ponahlo, 1989). Recently, Frank *et al.* (1990) have dealt extensively with that feature caused by inhomogeneities of impurity distributions in cube growth sectors. Figure 13 illustrates other surprisingly beautiful internal features made visible by means of CL: around a large inclusion orange-red needles become visible (compare also Figures 7 and 11).

Figures 15 and 16 refer to the synthetic diamond DMY-8. The photomicrograph of Figure 15 was taken in incandescent light. Only elongated and round inclusions become noticeable. The four isosceles triangles in cross-like arrangement are images of polished facets of this octagonal step-cut experimental synthetic diamond DMY-8. Figure 16 reveals a blue CL colour, its intensity being strong enough to make visible not only the inclusions of Figure 15 but also other features like the symmetrical arrangement of the growth sectors and some banding.

The most colourful synthetic diamond investigated was DMY-9. It displayed a blue CL colour and showed distinct 001 and 111 growth sectors with banding as distinct signs of its man-made origin.

The following Figures 17 and 18 make obvious how much has still to be learned about CL of diamonds. When first looking at the synthetic diamond DMY-10 under crossed polars in incandescent light (Figure 17) a strong greenish-yellow CL was expected with strong banding concentrated within specific growth sectors. Figure 18 shows this man-made product luminescing in a brilliant blue with blue-white banding of growth sectors. CL also reveals more details of and around inclusions. Some parts of this luminescing cuboctrahedron exhibit a greenish or yellowish CL colour.

3.2. CL features of some natural diamonds

Some advantages of CL as a non-destructive testing method for diamonds are emphasized by the following photomicrographs of yellow and yellowish-brown *natural* diamonds specially selected for similar colour and appearance.

DM-M5, of cognac colour, is emitting blue, green and strong straw-yellow CL with unique geometric patterns that give evidence for its natural origin (Figure 19). The CL colour of the yellow natural diamond DM-K1 is predominantly blue. A small straw-yellow pentagon in its CL topographical pattern makes it easy to distinguish it from any synthetic counterpart (Figure 20). The pentagonal pattern results from octahedral growth horizons intersecting differently inclined polished facets. Welbourn (1989), and Hanley *et al.* (1977) have examined CL effects in natural diamonds and given evidence of type-II natural diamond intermixed within type-I diamonds as a possible cause for the straw-yellow *stratigraphical* patterns that can be seen in the Figures 19 and 20.

The natural colour of diamond DM-M1 is cognac as is DM-M5. However, it luminesces in a saturated greenish-yellow, but the CL topography is completely different from that of other natural diamonds (Figure 21). The rectangular geometrical pattern closely resembles a site of ruins fittingly described as 'Pueblo structure'. It should be stressed that in no case were such yellow and/or blue growth patterns detected in any of the ten experimental synthetic diamonds made by De Beers or in other small synthetic diamonds investigated so far.

4. CL spectra

4.1. Some general remarks

CL spectra of diamonds originates from defect centres which have been the subject of extensive studies in the past. Some have special symbols (Collins, 1982). Marfunin (1979) presents a short survey. In diamond research solid state physicists refer to so-called zero-phonon lines as distinct very small bands visible in absorption and luminescence spectroscopy but below −100°C only. A zero-phonon line is accompanied by a range of additional bands of weaker intensity at the longer wavelength-side of a CL spectrum. As these bands disappear when spectra are taken at room temperature, such CL spectra would show the enveloping curve of such low-temperature signals. Therefore, no final assignments are given here and reference is made to Burns *et al.* (1990).

4.2. CL spectra of the experimental synthetic diamonds

DMY-1 to DMY-3

The peak-maxima of the CL spectra of these diamonds (Figure 22) show a tendency to shift from 526nm (DMY-1) to 535nm (DMY-2) and further to 541nm (DMY-3). The corresponding energies are

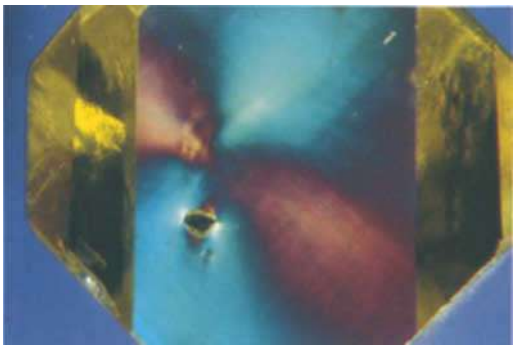

Fig. 9. Undulous extinction figure in DMY-5 and large transparent inclusion of unknown composition. Transmission photomicrograph. Crossed polars. 10x (24 x 36mm).

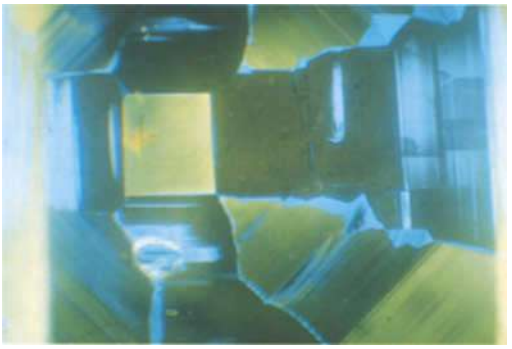

Fig. 10. The same synthetic diamond (DMY-5) as in Fig. 9 during electron bombardment. Symmetric arrangement of various growth sectors of greenish-yellow and blue CL colours clearly revealed. Note strong banding in 111 quasi bell-shaped sectors and different shades of blue in higher indexed ones. Cond. excit.: 11 kV, 0.9 mA. 28 x (24 x 36mm).

2,359 eV (DMY-1), 2,323 eV (DMY-2) and 2,281 eV (DMY-3).

Of these diamonds DMY-3 with its orange-red needles (Figure 7) gave rise to a CL band in the NIR with a peak at 820nm (1,513 eV). Such a signal was also found in the CL spectra of the synthetic diamonds DMY-6 and DMY-9 (compare the spectra in the Figures 24 and 28). The spectra of DMY-3 and DMY-6 are not reproduced because of the similarity of the 820nm band in the NIR.

DMY-4

The CL spectrum of this yellow synthetic diamond resembles that of DMY-3 up to 750nm, but the peak-maximum is shifted to a higher wavelength at 548nm (2,264 eV).

DMY-5

The CL colour of DMY-5 is a mixture of blue and yellow apparently resulting from different growth sectors. The CL spectrum contains, therefore, two distinct peak-maxima; the first at 481nm, the second at 526nm. Other parts luminescing yellowish show weak satellite bands at 612 and 750nm (2,027 eV and 1,654 eV).

DMY-6

DMY-6 is another example of a greenish-yellow luminescing synthetic diamond with distinct banding in the growth sectors. The CL spectrum taken of one of the banded pyramidal growth sectors contains a band with a peak at 481nm similar to DMY-5, DMY-8 and DMY-9. After a few minutes

Fig. 11. CL of DMY-7 with its characteristic growth sectors in perfect symmetric arrangement. Small blue rectangular sectors barely visible between large cubic and octahedral ones. Vivid greenish-yellow CL colour. Maltese cross in cubic sector indicated. Cond. excit.: 11 kV, 0.9 mA. 11.5x (24 x 36mm).

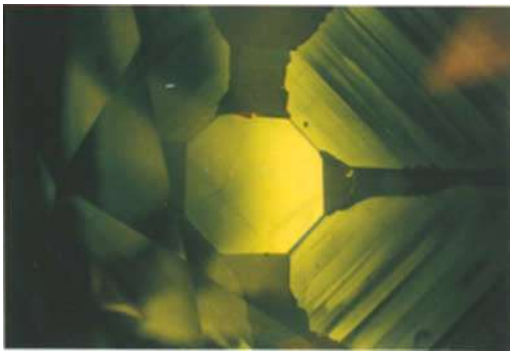

Fig. 12. Natural yellow diamond DM-M2 which luminesces with nearly the same greenish-yellow CL colour as the synthetic diamond DMY-7 but showing totally different growth features. Note the delicate geometric pattern within the yellow central blotch. It should be compared with Fig. 21. Cond. excit.: 9.5 kV, 0.9 mA. 10x (24 x 36mm).

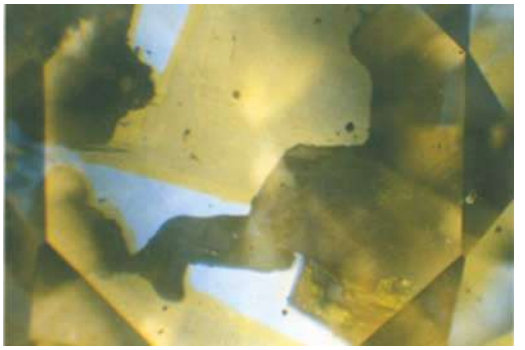

Fig. 13. Same stone (DMY-7) as in Fig. 11 with one 111 growth sector containing large inclusion surrounded by orange-red needles of unknown composition. Higher indexed faces luminescing steel blue. Cond. excit.: 11 kV, 0.9 mA. 10x (24 x 36mm).

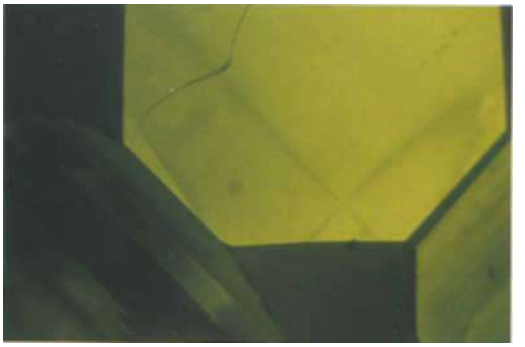

Fig. 14. Same stone (DMY-7) as in Fig. 11 showing dark Maltese cross on greenish-yellow luminescing octagonal growth sector at higher magnification of 28x (24 x 36mm). Same cond. excit.

of bombardment its CL colour starts to change into a steel-blue. Some parts of the growth sectors lose colour turning into a weak whitish-yellow. The new CL spectrum is characterized by two distinct bands with maxima at 481 and 520nm (2,386 eV). The Figure 23 gives an impression of the CL spectra of DMY-4, DMY-5 and DMY-6, the last one with a CL spectrum right before the colour change still showing a band with a maximum at 537nm (2,308 eV) similar to that of DMY-2.

DMY-7

DMY-7 is a brownish-yellow brilliant-cut synthetic diamond. Its CL spectrum is presented in Figure 24. The maximum of the intense band lies at 532nm (2,332 eV). The CL colour resembles that of many Sumitomo-synthetic diamonds, but unlike the Sumitomo-products this large synthetic diamond made by De Beers is characterized by symmetrically arranged growth sectors with pronounced banding.

DMY-8

DMY-8, a greenish-yellow cut synthetic diamond displays a blue CL spectrum which contains a marked shoulder at 480nm followed by a band peaking at 520nm (2,384 eV). A subdued yellow CL is also noticeable. Figure 24 shows a smoothed CL spectrum of this sample.

DMY-9

Of the ten synthetic diamonds tested DMY-9 seems to belong to a rare type. It is the most colourful synthetic diamond tested so far. Its CL colour is a golden-yellow within various growth sectors and some blue. The CL spectrum is of weak intensity and characterized by a shoulder at about 483nm and a peak at 527nm. In the NIR a medium

Fig. 15. Transmission photomicrograph of synthetic octagonal step-cut synthetic diamond DMY-8. Elongated and irregularly shaped opaque metallic inclusions. Four isosceles cross-like triangles are polished facets. 12x (24 x 36mm).

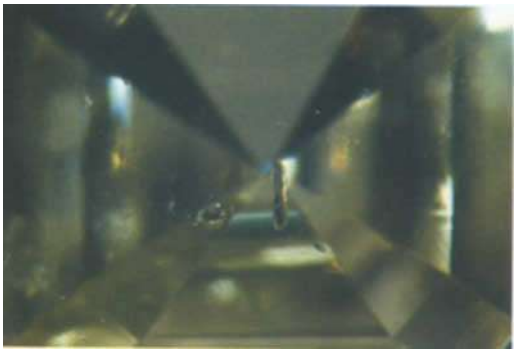

Fig. 16. Same stone (DMY-8) as in Fig. 15 showing blue and subdued yellow CL colours with illuminated but non-luminescing inclusions. Note already familiar geometric arrangement of banded growth sectors. Cond. excit.: 10 kV, 0.95 mA. 10x (24 x 36mm).

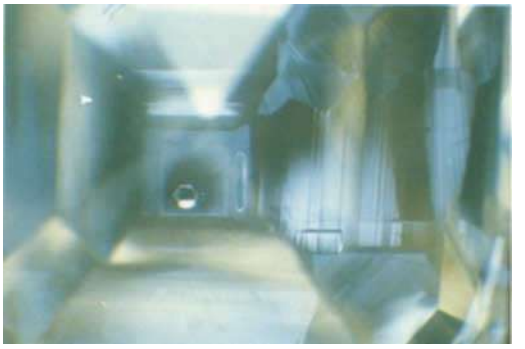

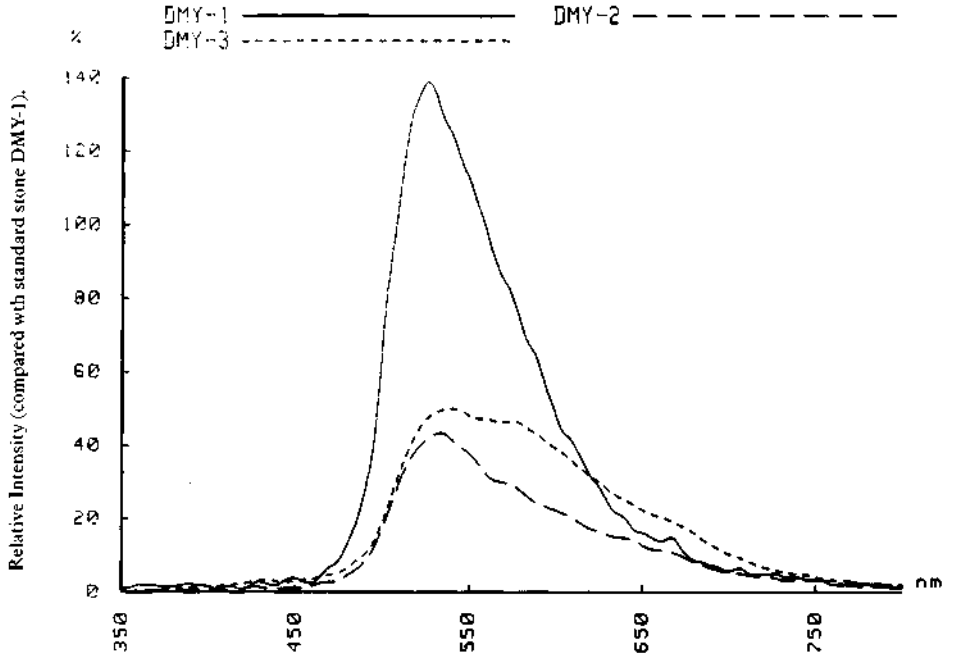

Fig. 22. CL spectra of 3 experimental synthetic diamonds made by De Beers. Polished (001) faces of cubo-octahedral specimens with greenish-yellow CL colour.

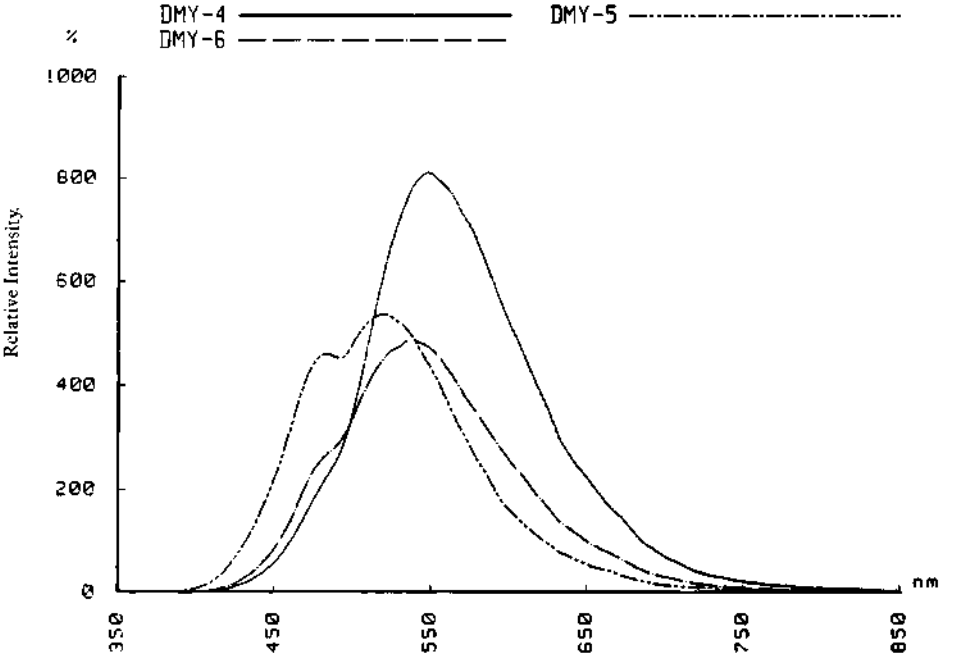

Fig. 23. CL spectra of 3 experimental synthetic diamonds made by De Beers. Polished (001) faces of cubo-octahedral specimens with greenish-yellow CL colour (4 and 6) and blue-yellow section (5).

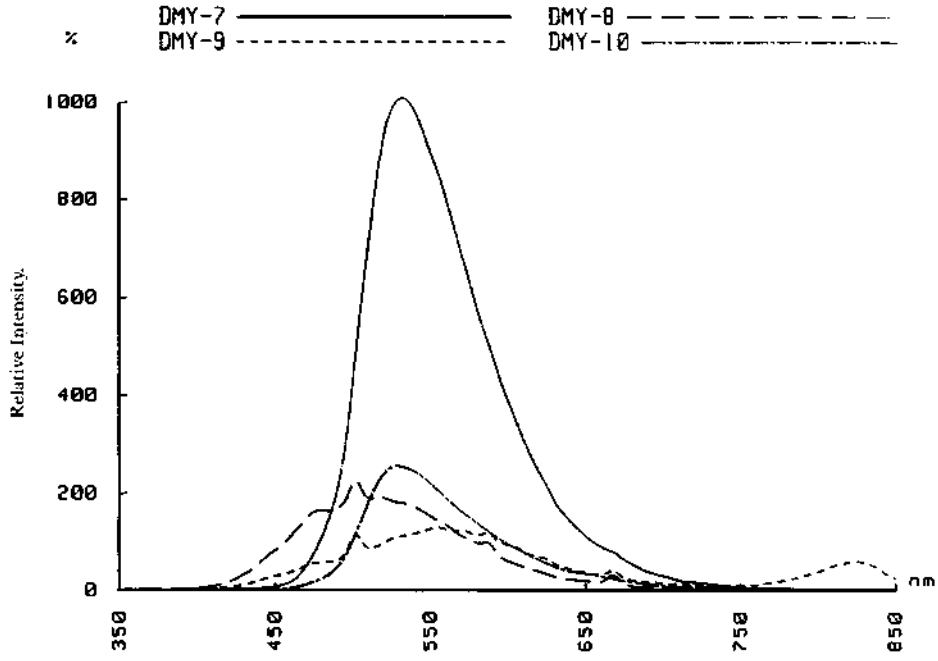

Fig. 24. CL spectra of 4 experimental synthetic diamonds made by De Beers. Polished (001) faces of cubo-octahedral specimens with greenish-yellow to yellowish-green CL colour (7 and 10), blue (8) and blue plus golden-yellow (9).

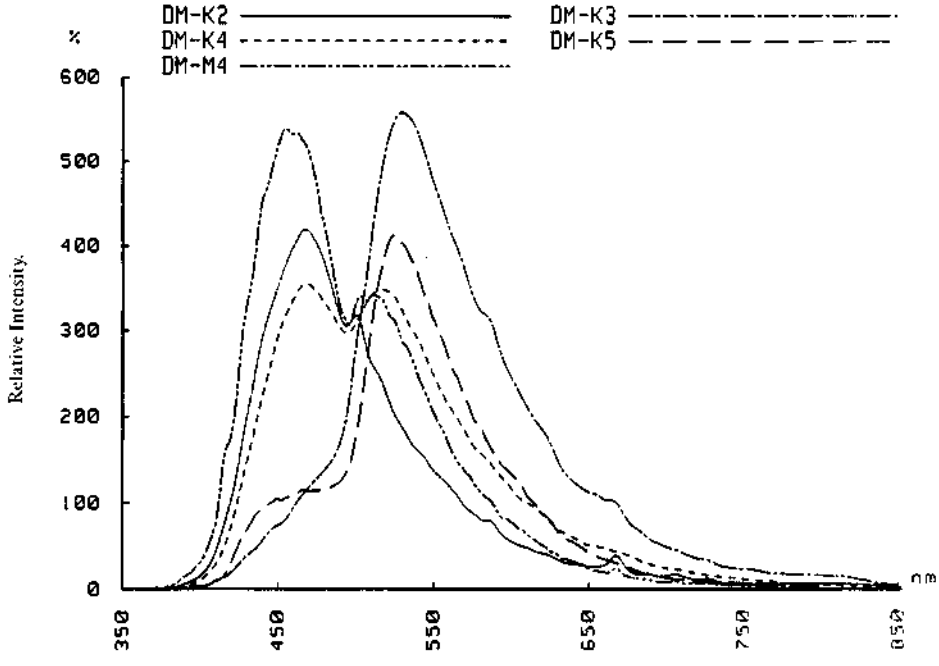

Fig. 25. CL spectra of 5 natural yellow and brownish cut diamonds, table up showing blue CL colour (K2, K4 and K5, M4) and yellowish-green CL colour (K3).

Fig. 17. Transmission photomicrograph of DMY-10 showing vivid interference colours under crossed polars and large inclusions. 6x (24 x 36mm).

Fig. 18. Same stone (DMY-10) as in Fig. 17 showing bright blue and blue-white CL colours with some sections exhibiting greenish yellow CL colours (not shown). Note banded double bell-shaped growth sector. Cond. excit.: 12 kV, 0.9 mA. 28x (24 x 36mm).

to strong band centred at 820nm (1,511 eV) was found. At closer inspection golden-yellow twinning lines and orange-red needles were located. They are thought to be the main cause for the 820nm-band. Figure 24 gives an indication of its intensity.

DMY-10

This small yellowish-green synthetic rough DMY-10 luminesces strongly when bombarded by electrons. Its CL colours are blue, greenish-yellow and yellow. The greenish-yellow growth sectors are heavily banded. CL peaks were measured at 532nm and 539nm. Other growth sectors show a shift to lower peak-wavelengths between 527 and 529nm.

4.3. CL spectra of yellow and brown natural diamonds

Table II shows CL and other data on 12 carefully selected yellow and brown natural diamonds (DM-K1 to 6 and DM-M1 to 6) providing a good colour match to the experimental synthetic diamonds described in the previous sections. Much information can already be obtained from visual studies of the CL features of natural diamonds. The Figures 8, 12, 19-21 should serve as relevant examples. According to the data three groups of natural diamonds may be differentiated:

a) medium to weakly blue-luminescing diamonds;
b) diamonds with a very weak blue CL, visible only as a luminescing cap on the table; and
c) diamonds showing mainly a greenish or brownish-yellow or straw-yellow medium to strong CL intensity.

Fig. 19. CL colours and growth stratigraphy of the natural diamond DM-M5. Its daylight colour is cognac. Rectangular dark blue, greenish and straw-yellow zones give evidence of a different growth history of such natural diamonds from their synthetic counterparts (see also text and literature). Cond. excit.: 7 kV, 0.9 mA. 10x (24 x 36mm).

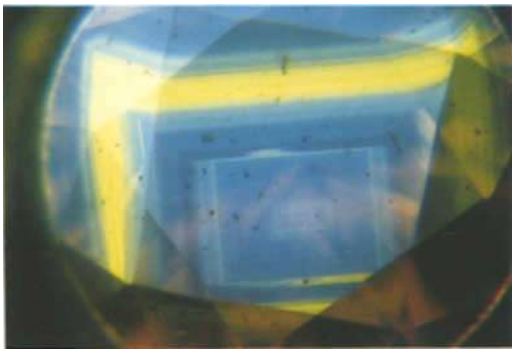

4.3.1. (a and b) Blue CL

At room temperature the blue luminescing yellow or brown natural diamonds have distinct CL peaks at 468nm (2,651 eV) or a little lower. If these diamonds show a straw-yellow geometrical pattern as an indicator of their growth history – such as can be seen from the Figures 19 and 20 – a CL band with a maximum at 636nm (1.949 3V) may be detected. But in most cases the CL spectrum of such natural diamonds will cover the entire visible spectrum range, the tail reaching to 750nm. Some CL spectra show two (or more) bands, one between 440-481 and another between 511-530nm. DM-K4 is a typical example with two CL bands of equally high intensity (Figure 25), one has a maximum at 469nm (2,643 eV), the other at 517nm (2,397 eV).

4.3.2. (c) Yellow CL

DM-M6 luminesces bright yellow (Figures 28 and 29). The CL spectrum shows a distinct band with a peak at 532nm (2.330 eV), the intensity being forty times stronger than any of the other CL

Table II: CL data of natural cut diamonds

Sample	weight (ct)	CL spectra (nm)				CL colour	remarks
DM-K1	0.462	(402)	(481)	–	–	blue	yell. p.p.
DM-K2	0.664		**468** s	–	–	blue	yell. p.
DM-K3	0.559	–	–	**530** s	–	gr. yell	
DM-K4	2.18	–	**469**	**517** s	–	blue	
DM-K5	0.70	(450)*	(470)*	**525** s	–	blue	
DM-K6	1.59	(440)	464 w	–	–	blue cap	
DM-M1 c.	1.661	**452**	–	(519)	–	blue	yell. p.
DM-M2 yell.br.	0.466	–	–	**548**	–	yell. +	w. blue
DM-M3 yell.	0.374	–	–	530	–	br. yell.	
" o.r.p-	"	–	–	–	**612/618**	orange	or. needles
DM-M4 br.yell.	0.21	**456**	**463**	(512)	–	s.blue	milky
DM-M5 br.yell.	0.170	(457)	**464**	(512) w	–	blue	milky
DM-M6 yell.	0.506	–	–	**526** ss	–	yell.	
DM-MX yell.	0.266	–	**476**	**514** s	–	blue	

Remarks: s. = strong CL signals; ss = very strong CL signal; w = weak CL signals; yell. = yellow CL colour; yell.p. = straw-yellow rectangular pattern; MX = masterstone; yell.p.p. = straw-yellow pentagonal pattern; o.r.p. = orange-red inclusions; br.yell. = brownish-yellow daylight colour; c = cognac daylight colour; Shoulders = *; weak bands = brackets; main peaks = bold.

spectra of natural yellow and brown diamonds tested so far. Such a CL spectrum comes close to the CL spectra of some of the synthetic diamonds investigated with a peak wavelength of 526nm (2.356 eV). The completely different growth stratigraphies of both types of diamond made visible by means of CL should provide a reliable method to distinguish synthetic from natural diamonds of the types described.

DM-M3 seems to be a rarer exception of a yellow natural diamond with a golden to brownish-yellow CL colour plus distinct orange-red patches (Figure 8). The CL intensity is rather low with a band centred at 530nm resembling that of DM-M6 (526nm). The dashed double-dotted line of Figure 28 is the CL spectrum of the golden-yellow luminescing area of DM-M3. The orange-red patches of DM-M3 furnish a clearly different broad band CL spectrum peaking at 614nm (see the long dashed line in Figure 28). The small dashed line in

Fig. 20. Predominantly blue CL colour of another natural diamond. A small straw-yellow pentagonal growth pattern acts as a distinguishing feature from any synthetic diamond tested so far. Cond. excit.: 7.7 kV, 0.9 mA. 10x (24 x 36mm).

Fig. 21. Growth stratigraphy of the natural diamond DM-M1 revealed by means of CL. Daylight colour is cognac. CL colour greenish-yellow. Geometric growth pattern resembles a site of ruins fittingly defined as 'Pueblo structure' indicating a rarer example of growth history of a natural diamond. Cond. excit.: 8.5 kV, 0.9 mA. 28x (24 x 36mm).

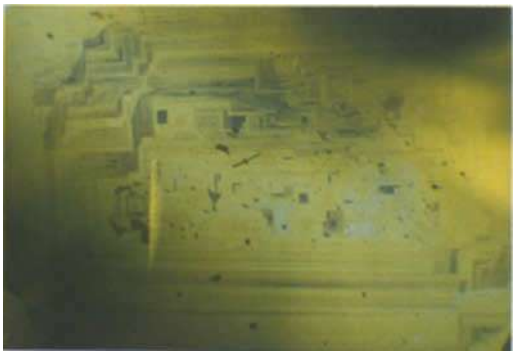

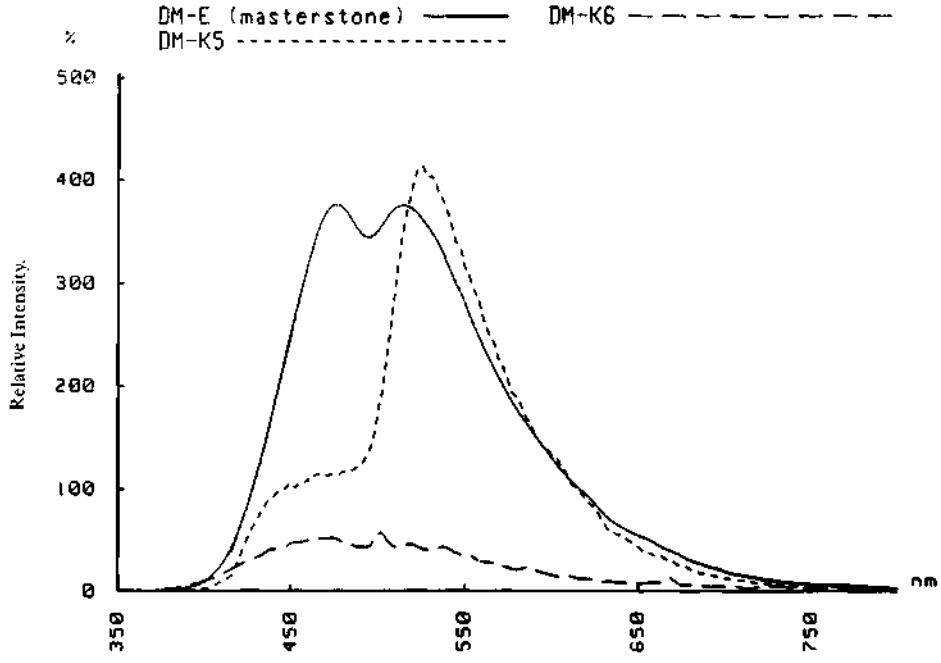

Fig. 26. CL spectra of 3 natural yellow cut diamonds with blue and straw-yellow CL (K5), much more blue (E) and one with a blue cap (K6).

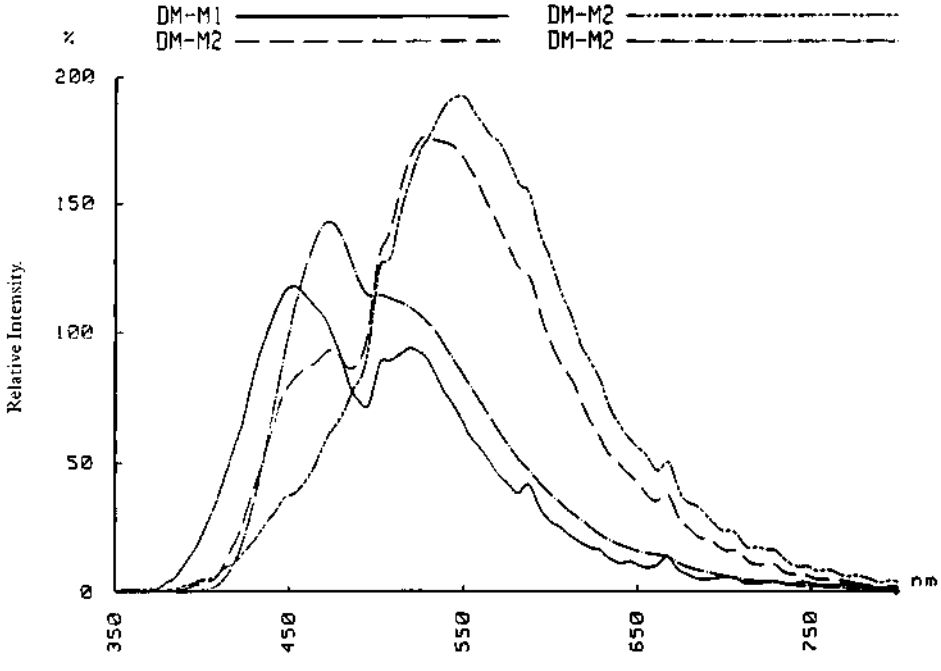

Fig. 27. CL spectra of 2 natural cut diamonds; M1 = yellow, M2 = brown colour. CL colour of M1 = blue, dash twice-dotted line M2 with yellow CL and a little blue. Dashed line M2 with less yellow and more blue. Dash dotted line M2 with much blue and little yellow CL.

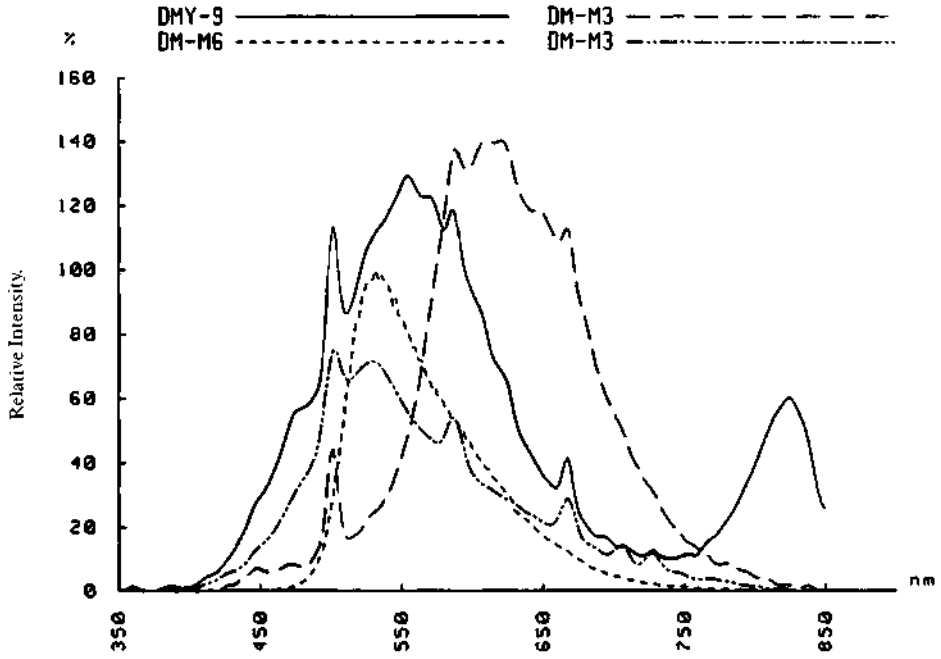

Fig. 28. CL spectra of one experimental synthetic diamond (9) made by De Beers and two natural ones (3 and 6). M6 CL spectrum normalized. Note CL band of DMY-9 at 820nm (red to orange-red needles).

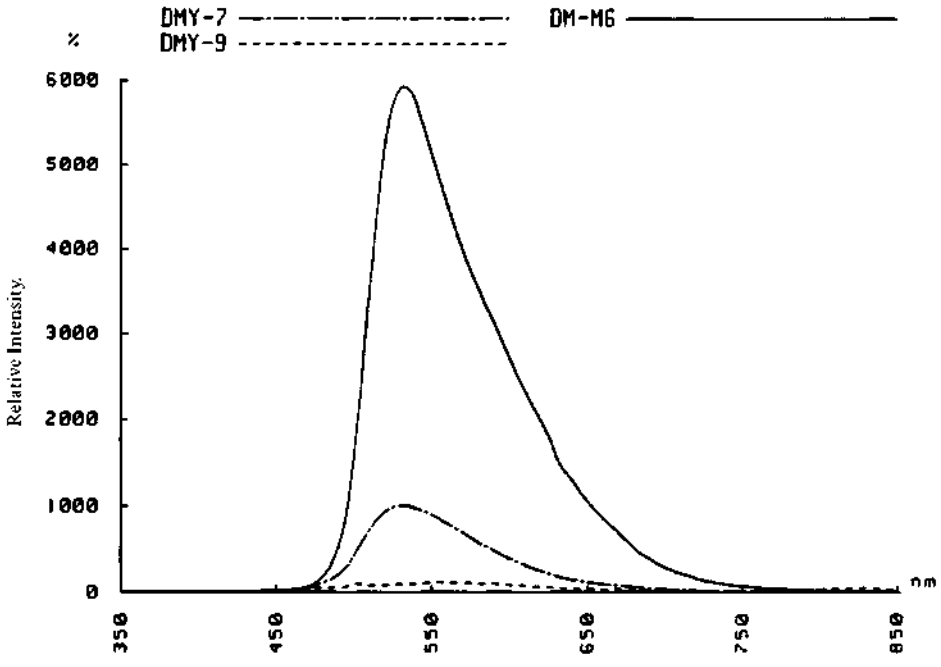

Fig. 29. CL spectra of one natural yellow diamond with high CL intensity (M6) and two experimental synthetic diamonds made by De Beers (7 and 9).

the same figure is the normalized CL spectrum of DM-M6. To compare these spectra with that of the synthetic diamond DMY-3 or DMY-9 the CL spectrum of the latter is included in Figure 28. Remembering the orange-red needles discovered in these man-made diamonds the CL spectrum (full line) is characterized by two distinct bands with maxima at 554 and 820nm (2.237 and 1.512 eV). To the knowledge of the author there exists no similar CL band shown by any yellow or yellowish-brown or brown natural diamond tested so far.

Taken at the same conditions of excitation, Figure 29 shows the CL spectra of three cut stones: the yellow natural DM-M6 and the two yellow synthetic diamonds DMY-7 and DMY-9. These spectra should be compared not only with each other because of the marked difference in CL intensities, but also with reference to their respective growth stratigraphy as disclosed during an electron bombardment.

5. Conclusions

Considering the consistency of results obtained from a rather small number of natural and synthetic diamonds tested so far, the following conclusions can be drawn.

5.1 Microscopic studies of CL phenomena and investigations of CL spectra have proved to be a powerful means of revealing internal features of natural diamonds which differ from those in large experimental synthetic diamonds.

5.2 The luminescing synthetic diamonds show growth-sectors of a distinct geometrical pattern. This results from the cubo-octahedral habit which is unique to such synthetic diamonds grown with low homogeneous supersaturation.

5.3 A greenish-yellow CL colour of high intensity is emitted from cubic and octahedral growth sectors. The CL spectra have peak-wavelengths between 526 and 534nm.

5.4 Pronounced sector banding was primarily found to occur in octahedral faces. On higher indexed faces ((110) and (113)) a moderate to weak blue CL colour was observed. The faces were small, of irregular shape with occasional banding. The CL spectra of the blue sectors showed a band centred at about 480nm. Mixed CL with blue and yellow sector growth was also observed.

5.5 The growth stratigraphy of all natural diamonds tested exhibited distinct differences from the sector growth observed in synthetic diamonds.

5.6 Predominantly, the CL colour of these natural yellow diamonds was blue. But diamonds with yellow and brown CL colours were also found. Two of them revealed so-called 'Pueblo-structures'.

5.7 The CL spectra of the blue luminescing natural diamonds differ from those of the blue luminescing synthetic diamonds.

5.8 Three of the ten experimental synthetic diamonds contained orange-red inclusions not visible under normal conditions of lighting but visible during electron bombardment. These inclusions showed a distinct band in the near infrared (NIR) (820nm).

6. Acknowledgements

This study has been carried out by the author at the former Austrian Gemmological Research Institute in 1988-89. It would not have been possible without the most generous loan of the ten large experimental synthetic diamonds from De Beers. The author is much indebted to Dr R.J. Caveney, Director of Research, Diamond Research Laboratory, Johannesburg, Republic of South Africa. Valuable comments and helpful criticism made by Dr C.M. Welbourn were most welcome and are gratefully acknowledged; he also supplied additional and most recent literature, including his own, as principal scientist at the DTC Research Centre, Maidenhead, Great Britain. The natural diamond samples on loan were a selection from many supplied by wholesalers and retailers in Austria (members of the E.Ö.G.G). My thanks go to Miss Tirala for her assistance in taking the CL spectra, and to my son, Johannes-Matthias, for writing reliable additional software and for delicate service work. Part of this study was sponsored by a grant from the FFF (Research Fund For the promotion of craft-industries in Austria) and by Austrian jewellers, whose help is gratefully acknowledged.

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Cut gemstones showing a 'Maltese Cross' and the 'Star of David'

J. B. Pullishy

Alberta, Canada

These ingenious cuts were developed by Paul H. Paulsen, one of Canada's foremost gem cutters, whose family originated from Denmark. The surfaces of these cut gems exhibit a series of polished and cross-grained (frosted) faces.

The 'Maltese Cross cut' is octagonal in outline, with eight simple triangular faces on the pavilion; polished and frosted faces alternate. The crown exhibits an octagonal table with an inner and outer row of triangular facets adjoining the table and girdle respectively; all eight girdle facets are frosted, as is the girdle itself. On looking through the table a 'Maltese Cross' is very clearly displayed (Figure 1).

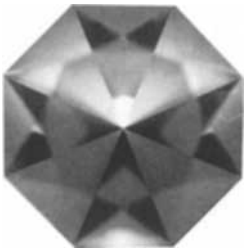

Fig. 1. A 'Maltese Cross' showing in a 'Frosette cut' gemstone by Paul H. Paulsen.

Fig. 2. A 'Star of David' showing in a 'Frosette cut' gemstone by Paul H. Paulsen.

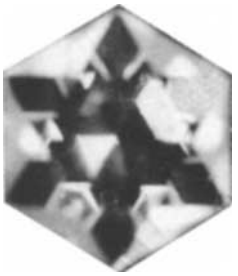

An analogous style of cutting and polishing on a hexagonal stone produces the 'Star of David' (Figure 2) and the 'Lone Star' is developed from a five sided stone.

The Maltese Cross, of course, has associations with the Knights of St John and the island of Malta, and the Star of David with Judaism and the state of Israel. These 'Frosette cuts' are produced by Paul Paulsen in Canada. Frosette Gems Ltd have generously presented two examples of these Maltese Cross cuts (in amethyst and citrine) to The Gemmological Association and Gem Testing Laboratory of Great Britain.

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The Sri Lankan ruby: fact or fable?

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Colombo, Sri Lanka

Sri Lanka, or Ceylon as it was called until 1972, was quite conscious of its gem wealth. The early chronicle, *The Mahavamsa,* is replete with references to gems [1]. For instance, this one thousand five hundred years old historical work, in recounting the coronation of an early king, *Devanampiya Tissa,* a contemporary of Emperor Asoka of India, said:

> 'Pearls of the eight kinds, namely horse-pearl, elephant pearl, waggon-pearl, myrobalan-pearl, bracelet-pearl, ring-pearl, kakuda-fruit pearl, and common [pearls] came out of the ocean and lay upon the shore in heaps. All this was the effect of Devanmpiya Tissa's merit. Sapphire, beryl, ruby, these gems and many jewels and those pearls and those bamboo stems they brought all in the same week to the king.' [2]

It should be noted that the chronicle does not refer to the non-native gems, emerald and diamond.

The indigenous appreciation of gems was reciprocated by foreign elites. Nonetheless, there was a hiatus in the Sri Lankan gem story. As I have written elsewhere:

> 'While Sri Lanka has had a good press for its gems throughout the centuries, concern for the human element and the mechanics of the gem trade has not been so pervasive [3]. Pliny, the Roman naval officer turned historian, the fifth century Buddhist Chinese pilgrim Fa Hian, Cosmas Indicopleustis, Marco Polo, Odoric, Jordanus, Ibn Batuta, Ribeiro, and in more recent times, Max Bauer, Count de Bournon, C.G. Gmelin, M.H.K. Klaproth, were among those who had written, often admiringly, of Sri Lankan gems. Modern text writers like Herbert Smith (and his subsequent editors), and Anderson deal with Sri Lankan gems more as a class and less as a country. Webster gives more space, but not so much as he devotes to Burma.' [4] [5].

Another hiatus is the nature and scope of the use of the term 'ruby'.

The Sri Lanka Ruby; its natural history

The Concise Oxford Dictionary definition of ruby is a catch-all. It says that 'ruby' is a 'rare precious stone consisting of corundum with colour varying from deep crimson or purple to pale rose' [6]. However, the ideal use of the term is to confine it to the blood-red (or at least crimson) species of corundum. A recent authority on Sri Lanka gems wrote: 'A fine Ceylon pigeon blood ruby takes the first place but is rarely found in nature' [7]. Yet, when one looks through the literature on the gemstones of Sri Lanka of the past and the present (not to speak of the lay press where there is a fair chance of every off-pink stone being conferred the name of 'ruby'), 'ruby' is given the pride of place even over the blue sapphire which is, of course, the staple stone of the gem industry of Sri Lanka. The purpose of this article is to note anomalies in historical gem literature as well as in more recent works and to suggest some possible reasons for the literary proliferation of this rarely-occurring gem.

The reference from the ancient chronicle, the *Mahavamsa* has already been cited. One more reference would be in place. The Mahavamsa, in discussing the auspicious signs occurring in the course of the building of a religious construction, records the following:

> 'In a south-easterly direction from the city of Anuradhapura, near the village of Sumanava, many precious stones appeared. The dwellers in the village put them, mingled with sapphires and rubies, into a vessel and went and showed them to the king.' [8]

Other classical Sinhala (and Tamil) literary works are full of references to the ruby. The *Amara Kosa,* a medieval Sanskrit thesaurus which was translated into the Sinhala language and was essential reading to the would-be educated Sinhala gentleman, gives considerable space to the ruby [9]. It gives four synonyms for the ruby: (a) rathu keta, (b) gona ratne, (c) lohitaka and (d) padmaraga [10].

A well-informed English traveller and writer of recent times, could state:

> 'It was always rubies, "The finest yet discovered" says Ribeiro in the 1660s; The finest rubies", echoes du Jarrie, "Rubies esteemed the best in

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the Indies" writes the 'Beschrijving', "Generally more beautiful than those of Pegu" particularizes Tavernier – and he was a jewel-expert.'[11]

The most famous travellers to Ceylon in the Middle Ages were not without their foibles – and one such foible was their exultation over Ceylon rubies, if indeed it was a foible. The Venetian traveller and Kublai Khan's commissary was a case of this sort.

Marco Polo (1254-1324) was in Ceylon – he called it accurately 'Zeilan' in the course of his lengthy travels. Being a trader of luxuries, he should have been knowledgeable of gems, for when he eventually returned to Venice, he had to demonstrate his identity to the cynical Venetians, by ripping off his shabby clothes to reveal cascades of gemstones. Yet, apparently, he was naïve about rubies in Ceylon.

Marco Polo, after enumerating the kinds of gemstones found in Ceylon, wrote, 'The island produces more beautiful and valuable rubies than are found in any other part of the world'[12]. Marco Polo went on to the special ruby possessed by the King of Zeilan, which was a span in length and the thickness of a man's arm, brilliant in its glory and totally flawless [13]. It was obviously beyond any price. Marco Polo also recounted that his patron, Kublai Khan who ruled most of China at that time, had sent emissaries to the King of Zeilan to ask for it, promising to recompense the King of Zeilan with a value of a city. The King, however, declined the offer stating that the ruby was not available at any price and such heirlooms would not leave the country. Kublai Khan had to be content with this refusal [14].

A modern editor of Marco Polo had misgivings about this story. He noted, that:

> 'This description [of the ruby] seems to be intended for what is vaguely termed the carbuncle which Woodward defines to be "a stone of the ruby kind of a rich blood-red colour" and is believed to have the quality of shining in the dark... If this extraordinary stone had any real existence it may have been a lump of coloured crystal, but it is not uncommon with eastern princes in the preambles of their letters and warrants, to boast the possession of imaginary and impossible curiosities; and, in this instance, the fallacy of the pretension, will account for the king's rejecting the magnificent terms held out for the purchase of it by the emperor of China.' [15]

A safer guess would be, of course, that the stone in question was a Balas ruby spinel [16].

The next great traveller to Ceylon was the Moroccan of the fourteenth century, Ibn Battuta, who was jurist, scholar but no Tavernier nor even Marco Polo concerning gems. He spoke of the Lake of Rubies in Ceylon, where rubies were found easily [17]; yet, he had some reservations about several of these stones. In discussing the stones put on the forehead of the 'white elephant' owned by the King, he calls these 'marvellous rubies' but also calls them 'bahrimen', which his editor interprets as carbuncles [18].

It is possible to find some reasons for these wholesale confusions of the classical ruby with indifferently pinkish corundums or those of different gem varieties. The reasons might be schematically grouped as follows:

(1) During the classical times and in the early medieval period, ideal (blood-red) rubies actually existed in Ceylon in large quantities, particularly in river beds. These 'veins' were worked out in course of time. Wilhelm Geiger, the Indo-Aryan scholar, who studied the life and culture of Ceylon in medieval times, speculated on the possibility of even gold being found in Ceylon in those early periods [19];

(2) The ideal ruby never existed in Ceylon; the reference to rubies in ancient Sanskrit, Pali and Sinhala works are a purely literary device, which the rules of Sanskrit poetry ('the alankara', the metaphoric use) decreed [19a]. It might be hazardous to accept this thesis, for the total non-existence of a particular jewel or gemstone would opt it out of further literary works;

(3) That the extant techniques of Ceylonese jewellery craft sparingly used the 'reddish' corundum on aesthetic grounds. Since Ceylonese jewellery (gold pieces) are always made of 22 carat gold, any 'insetting' of a red stone (other than a blood red variety) makes the stone look shabby unlike the blues (sapphires) which dazzle pleasingly. This is purely a matter of contiguous-opposed-colour-reflection. Hence, medieval goldsmiths used blues plentifully and when they had to use red stones, avoided 'pink sapphires'. They used lower kinds of stone, perhaps Balas ruby, while keeping up the illusion that they were true rubies. Since jewellery in medieval and modern times is frequently melted and re-made (that is why goldsmithing is a full-time profession), the softness of lesser quality gems does not matter so much. (Even today, a lot of jewellery, particularly of low-income groups carry, 'Rangoon diamonds' or paste) [20];

(4) Then there is the question of the re-constructed stone. It was possible that the technique of reconstructed stones had been mastered by the end of the Middle Ages. That was due partly to the development of ayirveda, the traditional medical science of India and Ceylon in which sublimations of some gems were used [21]. Though perhaps, it could not have reached the sophistication of later years, when an official report could say:

'The beauty and durability of a reconstructed ruby is equal to a good natural ruby. Reconstructed sapphires do not so closely resemble natural sapphires and the colour and lustre are not satisfactory.'[22]

At any rate, since stones were 'sunk' in ancient and medieval jewellery, opportunities for the use of reconstructed stones are substantial;

(5) The trade in gems between Ceylon and the international market of ancient and medieval times was mediated by several ports and landing-stages of south India. Two of them, important even today, are Kayal Pattanam (in the Tinnely district) and Kilakarais (in the Ramnad district). Curiously, they are low-profiled and most topographical and published itineraries [23]. Ibn Batuta confuses them, placing them in the China Seas [24].

However, Marco Polo mentions Kayal Pattanam calling it 'Kael'. He says that it is 'a considerable city' and was ruled by a prince who maintains peace and order. As a result, Kael attracted ships coming from the west such as Ormuz, Shisti, Aden and various parts of Arabia with merchandise and horses, making it well-situated for commerce [25]. The comments of the editor of Marco Polo on this issue are interesting. He writes:

'In the Tamil language, the word 'Kael' or 'Koil' signifies a temple and forms the terminating syllable in the names of several places in the southern part of the peninsula. It was also pre-eminently the name of a considerable town and port in what we now term the Tinneve country, not many miles from Tuticorin. Its situation may be seen on the map prefixed to Valentyn's Beschrvying van Coromadel (vol.v) where its ancient consequence is denoted by the addition of the word 'patnam'; but having disappeared in modern maps, we may conclude that Kael-patnam no longer exists even as a town; yet in Dalrymple's collection of Plans of Ports we find one (from van Keulen) which lays down the situation, not only of Cayl-patnam, but also of Porto Cayl and of a place termed old Cayl.'[26]

It seems reasonable to infer that along with the non-native stones such as emerald and diamond, rubies (perhaps from Burma) were brought into Ceylon for essential purposes such as adorning the regalia;

(6) There is also the question of royal presence. When a courtier or high official or foreign traveller is in the presence, he is not much inclined to critically examine the stones worn on the king's person or in his immediate environment; he is even less inclined to write down his assessment. As the sumptuary laws forbade the use of gems by the normal population, the average layman would not have been able to identify a ruby even if he saw one.

There is the off-chance that 'burnt' pink-sapphires might be converted to good-looking rubies. With the technology of the Middle Ages the possibilities of the stones splintering or 'spotting' were far greater at any event and they would have had a smokey look.

The Ruby: subsequent developments

In the post-Middle Ages ruby continued to play a dominant role in the literature of those times. For instance, Robert Knox, the English mariner of the seventeenth century, who fell into the hands of the King of Kandy, the indigenous prince who ruled the non-maritime parts of Ceylon, and lived many years in those parts almost as a prisoner, recounted in his work, 'Also there are certain rivers out of which it is generally reported they do take rubies and sapphires, for the king's use, and cat's-eyes'[27].

That received doctrine was carried over in British times. Rev. Cordiner, the clergyman who went on to become the first chairman of the School Board (the chief executive as it were of state educational system) in the early part of the last century, and who wrote an authoritative work on Ceylon, enumerated as the precious stones of this country, the ruby, emerald, topaz, amethyst, sapphire, cat's-eye or opal, cinnamon stone or garnet, agate, sardonyx, and some others [28].

The tourists, many of whom were Americans, did not fail to show their appreciation or at least awareness of rubies. For instance, Mary Thorn Carpenter, wrote in 1892, 'You are soon seated at a table before heaps of sparkling rubies, cat's-eyes, pale sapphires and moonstones'[29].

Again in 1903, another American, Clara Kathleen Rogers, who took a critical view of Ceylon stones, said, '... we poked around among the jewellers, examining and buying some of the Ceylon precious stones. Moonstones, rubies, emeralds, pearls and tourmalines of all kinds are found here.'[30]

The official publications were not far behind. For instance, one such work records that, discussing precious stones of Ceylon, 'The important are sapphire and ruby (varieties of corundum), (including cat's-eye and the rare alexandrite), beryl or aquamarine'[31].

The question of ruby was of academic interest to the gem trade of Sri Lanka until recent years. That was because the marketing of gems was in clearly hierarchical lines. There were the handful of top gem dealers, all of them based in Colombo (the metropolis of Sri Lanka for four hundred years or more), who dealt with the top-drawer tourists and exported gems to the world markets; the rural-based 'mine head' gem traders who supplied the top dealers; and the local gem-shops which serviced the normal tourist traffic and the foreign bargain-

hunter seeking gemstones. The pink sapphires (which is the general term for the Sri Lankan ruby) arranged themselves neatly in this scheme. The most pinkish and standard stones were offered to the top dealers, who sold these to their clientele, the more choosy ones would not settle for anything other than those from Burma, which were imported for this purpose. The low-grade pinks were taken up by the local gem shops. Specially backed in jewellery, these were not bad bargains.

World War II changed all that. Burma and other traditional sources for ruby were no longer available. Prices began to rise as the situation of supply did not change for quite some time after the War. The attitude of the international market for ruby is, of course, different say from that of emerald. While the supply of emerald is partly a 're-cycled' one, the market's appreciation for ruby is one of inexhaustible demand. Two factors added to this demand and expectation. One was the easy-money conditions of the Sixties, which created greater demand for luxury articles and antiques. The other factor was the paradoxical one – developments in the technology of synthetics. Anderson noted, in passing, 'As in the case of ruby, the most effective substitute for natural sapphire is its synthetic counterpart' [32]. The better the synthetic, the greater is the demand for the natural stone that is even better (among the elite, that is).

Sri Lanka was immune from all this push-pull till the late-Seventies. Sri Lanka had always been noted for its blue sapphires; it would hardly be an exaggeration to say that it was the leading exporter of standard blue sapphires.

The Thai gem dealers who entered Sri Lanka began to purchase 'geuda', which till that time was a discounted product. A recent report states:

> 'It is well known that Sri Lankan corundum with the milky white opaline character called 'geuda' when subjected to heat treatment can be converted to clear blue sapphires.' [33]

The success (some might even say the enormous success) of the Thai 'geuda-conversion' had several depressing effects on the Sri Lankan gem industry and market. In the first place, it had a disestablishing effect on the Colombo market, while strengthening the Bangkok market, already based on the supply of the Chantaburi fields. Secondly, prices for blues were depressed, knocking the livelihoods out of many middle-middlemen and sub-brokers. The acquisition of the geuda-conversion technique by the Sri Lankan gem industry (at present, perhaps, not fully mastered in its total sophistication) is possibly not a full solution for this is an ideal 'Catch 22' situation. If the Sri Lankan mastery of the technique is less than adequate, the 'burnt' stones will depress the market prices, for the bulk of the natural stones are themselves imperfect. If, on the other hand, the technique is sophisticated enough to create clear blues, every natural good blue will become suspect (since most gem-dealers go by the rule-of-thumb methods) and prices will hug the minima.

The short-fall in the demand for Sri Lanka sapphires has caused a revival of interest in the corundums of the red variety. This re-appraisal was given point at the Third Conference of the International Coloured Gemstone Association (ICA), the sessions of which concluded on 26 May 1989 in Colombo [34]. It was reported that resolutions were passed 'recommending that the pink sapphire be brought into the classification of "ruby"' [35]. It was expected that this recommendation would be submitted to the CIBJO for approval. These moves, of course, will have important consequences, in practical terms as well as academically. It is widely estimated that the price per carat is at least $5000 higher than for pink sapphire. This is obviously a time-bound frame. Academically (or rather, scientifically) speaking, a precise colour-codification will have to be devised and implemented, ranging perhaps from 'very pale pink rubies' to 'blood-red rubies'. In that case, the term 'pink-sapphire' will drop out of the gem-dealer's vocabulary [36].

In summary, the Sri Lankan ruby, though prolific in literature is rare in nature, its literary predominance, perhaps, being attributable to a small cache of naturally-occurring stones, reinforced by some imports and royal 'one-up-manship' [37].

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14. Ibid.
15. Ibid., p.350.
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20. Mahroof, M.M.M., op. cit. The present writer hopes to treat these issues at length in the comprehensive work on the history of gems and gem craft in Sri Lanka, which he is preparing at present.
21. Geiger & Bode, op. cit. It was believed, for instance, that powdered corundum when taken internally would destroy the intestinal tract.
22. Parsons (Director), *Mineralogical Survey of Ceylon for 1907*. Government Printer, Colombo, p.E13.
23. For instance: *Itineraries in the South Indian Railway Company*, South Indian Railways, Madras, 1900; *Manorama Year Book 1981*, Manorama Newspaper Publishing Company, Kottayam, Kerala, India.
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26. Marco Polo, op. cit., p.375. The editor's (Wright's) assertion that the Tamil prefix 'kayal' is derived from a word denoting 'temple' is not correct. Actually, the temple prefix is 'ko' (as in Koil patti'). The Tamil word 'kayal' or 'kael' stands for 'lagoon' and is perfectly descriptive of the town of Kayalpattinan.
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Jemeter Digital 90 – A test report

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Although experimental reflectance instruments for gemstone identification had been developed in 1959[1] and 1972[2], it was not until 1975[3] that the first commercial model was marketed by Sarasota Instruments of the USA. This instrument, called the 'Gemeter '75' was fitted with an analogue meter calibrated directly in RI values from 1.4 to 2.7 (Figure 1).

Fig. 1. The Sarasota Instruments 'Gemeter '75' – one of the first reflectance meters.

The fact that the Gemeter '75 was calibrated in RI values was probably the main reason why users of the instrument, unfamiliar at first with the operating constraints of a reflectance meter, expected accuracies similar to those achieved with the critical angle refractometer (and were quickly disillusioned!).

Subsequently, reflectance meters produced by other companies were calibrated in gemstone names rather than RI values, and this enabled the expected ranges for these gemstones and the possible overlaps between them to be indicated on the meter scale. Other reflectance meters used a digital display whose readings had to be referred to a table containing the range of readings expected for each gemstone.

In 1990 the development of the reflectance meter came full circle when Sarasota Instruments introduced their Jemeter Digital 90 (Figure 2). Like their first model in 1975, this latest version displays the RI value of the stone being tested. However, this time the display is a 4-digit LCD unit with a high-contrast 12mm-high readout covering the RI range 1.450 to 2.999, and the associated electronics have been much improved.

The direct digital readout of RI is not too remarkable a technical feat. However, it does necessitate matching the reflectance characteristic of a flat polished surface (as indicated both by Fresnel's reflectivity equation and the intervals in the Gemeter '75 scale) to that of the linear digital readout.

The excellence of the electronics design is evidenced by the high stability of the instrument's digital readout (with the light-excluder dust cap placed over the stone, the least significant figure changes only occasionally by one digit). The unique feature of this instrument, however, lies in its use of a polarizing filter between the test aperture and the photodetector. This latter feature allows the double refraction of a gemstone, previously only vaguely detected with a conventional reflectance meter, to be measured in a manner similar to that employed on a critical angle refractometer (i.e. by rotating the stone in small increments to find the minimum/maximum values).

With care, and taking all the precautions necessary with a reflectance meter (i.e. ensuring that the stone is clean and in good condition, keeping it centered over the test aperture, and keeping the test aperture clean and free from dust), repeatable readings to an accuracy of 0.005 can be obtained.

Double refraction up to 0.04 can also be measured to the same accuracy, although with larger DRs this accuracy becomes more difficult to achieve due to the need for precise angular increments. Centering the gemstone over the test aperture is made easier by the provision of a series of concentric rings around the high-impact plastic rim

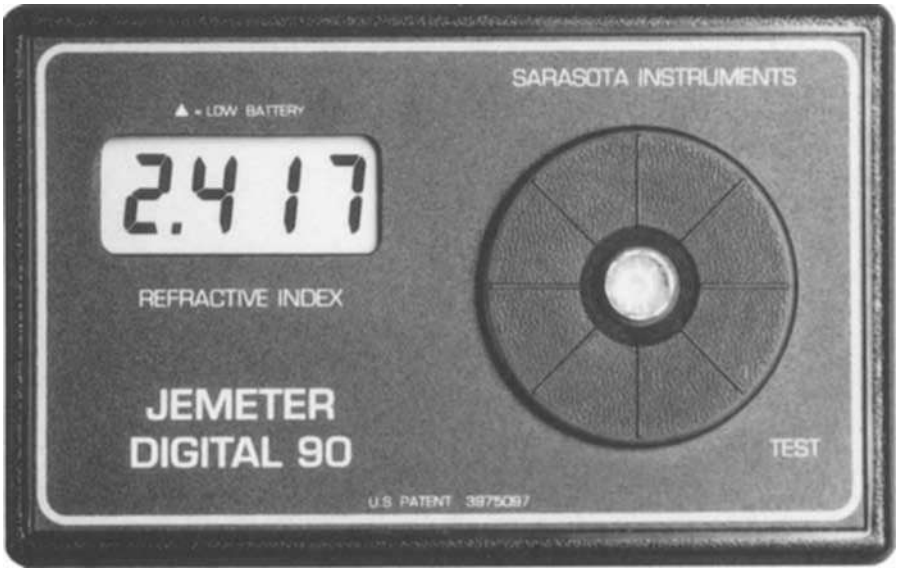

Fig. 2. The Sarasota Instruments 'Jemeter Digital 90' reflectance instrument measures gemstone RIs to three decimal places over the range 1.450 to 2.999. Fitted with a polarizing filter, it can also measure double refraction down to around 0.01.

of the aperture. The area around the test aperture is divided into 45 degree segments and forms a useful guide when rotating a gemstone to check its DR.

The test aperture itself has an internal diameter of 1mm, but this is no problem providing the main facet of the gem under test covers the aperture completely. As continuous rather than pulsed I-R emission is used in the optics, it is necessary to use the supplied light-excluder/dust cap to prevent spurious light rays entering the rear of the stone under test.

The instrument dispenses with the conventional 'on/off' switch, and instead is activated by pressing the section of its front panel labelled 'TEST'. The unit switches itself off automatically after 3 minutes, and also indicates (by means of a triangle symbol on its digital display) when the battery needs replacing and when the unit is about to switch off.

The Jemeter Digital 90 represents an important advance in the design of reflectance meters, and used with the degree of care necessary with this class of instrument fully deserves the description of 'reflectance refractometer'. The reduction in sensitivity as compared to the standard critical angle refractometer is more than compensated for by the fact that the instrument does not require the use of a contact fluid.

The unit is calibrated by means of its two preset adjustments (as instructed in the accompanying manual) using beryl at 1.575 and diamond at 2.417. Because the instrument is measuring RI at a wavelength of around 930nm rather than at the sodium wavelength of 589.3nm, highly dispersive gems such as zircon, strontium titanate and rutile will produce lower readings in rough proportion to the size of their dispersions (e.g. strontium titanate reads typically 2.220 instead of 2.420). For this reason, the operating manual includes a list of gems, grouped under colour varieties, which indicates the low, mean and high values to be expected. Stones having a dispersion from 0.04 downwards are only minimally affected because the scale is calibrated against diamond towards the top end of the range.

The instrument's manual is well written and contains gemmologically correct definitions of refractive index and double refraction, and of the terms mineral, synthetic and imitation (a welcome change!).

The Jemeter Digital 90 measures 5.7 × 3.6 × 1.2 in. (14.5 × 9 × 3.25cm), and uses a long-life alkaline 9-volt PP3 type battery. The manufacturers are Sarasota Instruments, 1960 Main Street, Sarasota, Florida 34236, USA and the instrument is also available from GAGTL.

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Moonstone mining in Sri Lanka: new aspects

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Abstract

Moonstones with a deep blue mobile shine are sodium-rich potassium feldspars. Exsolution of sodium and the concentration of the very fine sub-microscopic albite lamellae more or less orientated in the schiller-plane are the reason for the beauty of this gem.

The most important moonstone deposit during this century for top qualities is economically Metiyagoda, which is situated in the south of Sri Lanka. Here moonstones are mined from a strongly kaolinised feldspar pegmatite. The weathering has enlarged the schiller-plane, which might suggest that albite weathered more easily than orthoclase.

The hard unweathered pegmatite, locally called 'moonstone-rock', has been reached at some places by the intense mining activity. The hard feldspars show a close-meshed net of cleavages and cracks. The plate tectonic position of this pegmatite is the reason for these numerous cracks. This geological reason explains the fact that the cut moonstones from Metiyagoda are mostly very small and too flat. The costs of mining and cutting are much higher in the unweathered moonstone than the production from the weathered material, where the moonstone is recovered ready for cutting.

Moonstones from newly opened mines near Balangoda in the central mountains area have not the same top qualities as those from Metiyagoda.

The blue, semi-blue and the white moonstones have different alkali-contents. The white quality is richer in potassium, the highly appreciated blue moonstones are richer in sodium. In top blue moonstone qualities more than half of the alkali position in the lattice of the feldspar is occupied by sodium, so top blue moonstones are more an albite than an orthoclase.

Introduction

Moonstones with a characteristic deep blue sheen, which suddenly appears to float within the stone, are feldspars, whose beauty can easily compare with many other gems. The formation place of these gems are the pegmatites. Chemically moonstones are mainly potassium feldspars with a content of sodium (Bauer, 1932). This sodium content, which is installed in the lattice as solid solution by higher formation temperatures, exsolved through the formation of sodium feldspar lamellae during the time of cooling down. According to W.C. Bröger (1890) the perthitic exsolution of lamellar albite-feldspars are responsible for the beauty of the moonstones. They occur in extremely fine microscopic size. The study of microstructures has been expanded to transmission electron microscope observation (a summary has been given by R.A. Yund, 1983). The perthitic exsolution lamellae are mostly regularly ordered in a feldspar lattice and thus are visible in the so-called 'schiller'-plane when observed from a special direction. This effect is also called adularescence, a term which stems from the feldspar locality of Switzerland in Graubünden 'Mons Adular', which is the Rätoromanian name for the Rheinwaldhorn. This 'schiller'-plane is more or less nearly vertically orientated to two cleavages of the feldspars. In cut stones this 'schiller'-plane should lie parallel to the top of the cabochon. Only in this way may the effect of beauty of the moonstone be realised in its best quality. The high domed top of the cabochon makes the light reflection even more brilliant. The more convex the cabochon the more intense is the optical effect. The top of the rounded cabochon acts as a magnifying glass.

Besides the moonstones with a clearly blue sheen, qualities occur in semi-blue and mainly white schiller, showing a silvery to pearl-white lustre (Table 1). The blue, the semi-blue and the white moonstone qualities of Metiyagoda can be seen in Figure 12. Besides the schiller effect a specific body colour may be seen in some moonstones. This body colour can be seen from all directions and not only from a special direction as the schiller colour.

The moonstones of Sri Lanka partly show their body colour in a very faint grey, greenish or brown colour shades, which in local trade are called 'muddy' moonstones. The clarity or transparency is decisive and another factor for the quality of moonstones. Some of the moonstones of Sri Lanka are not transparent but are translucent. The various qualities are linked throughout the whole colour scale. The most attractive qualities are the transparent moonstones (crystal quality), particularly with

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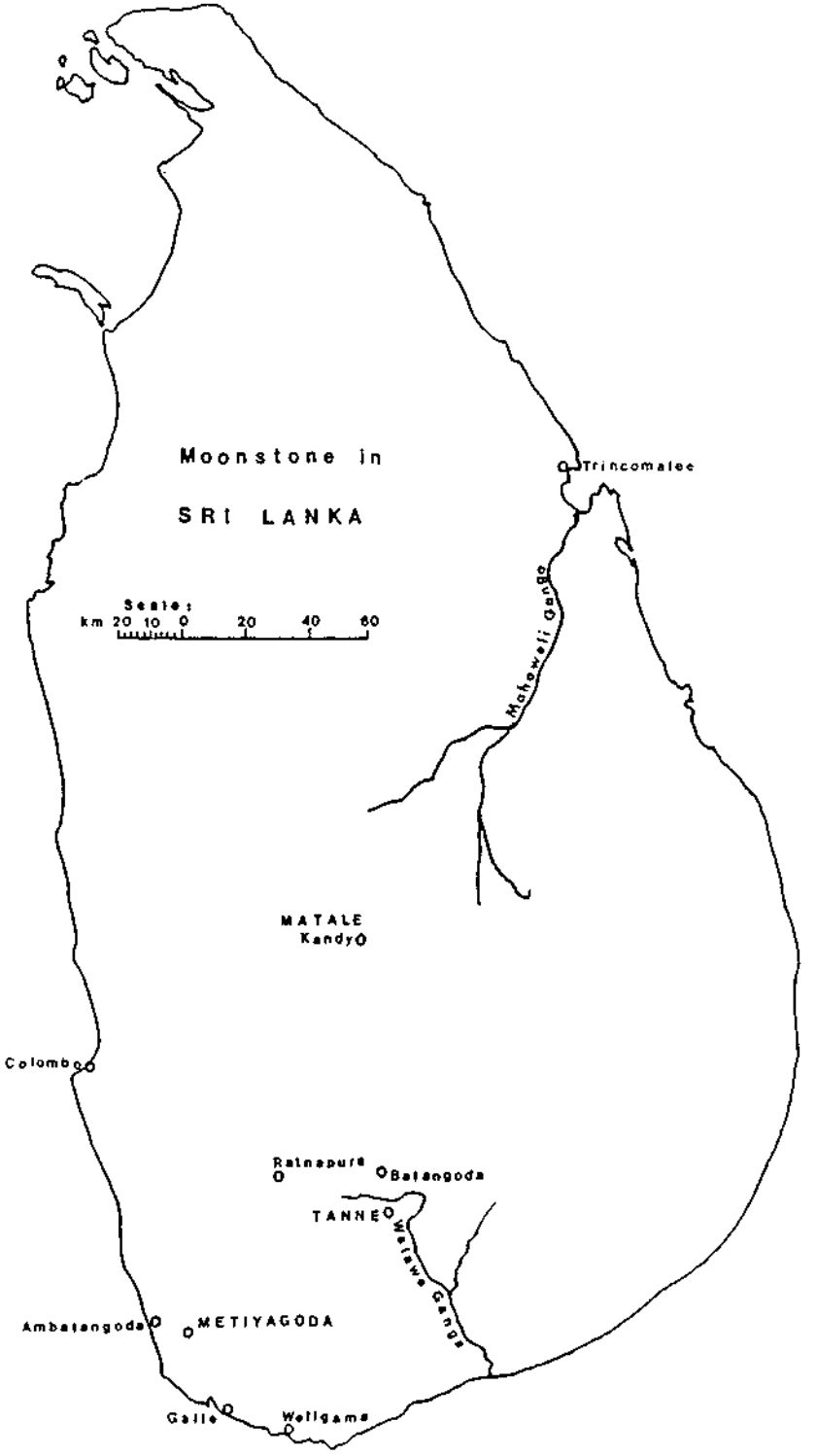

Fig. 1. Map of Sri Lanka showing principal localities.

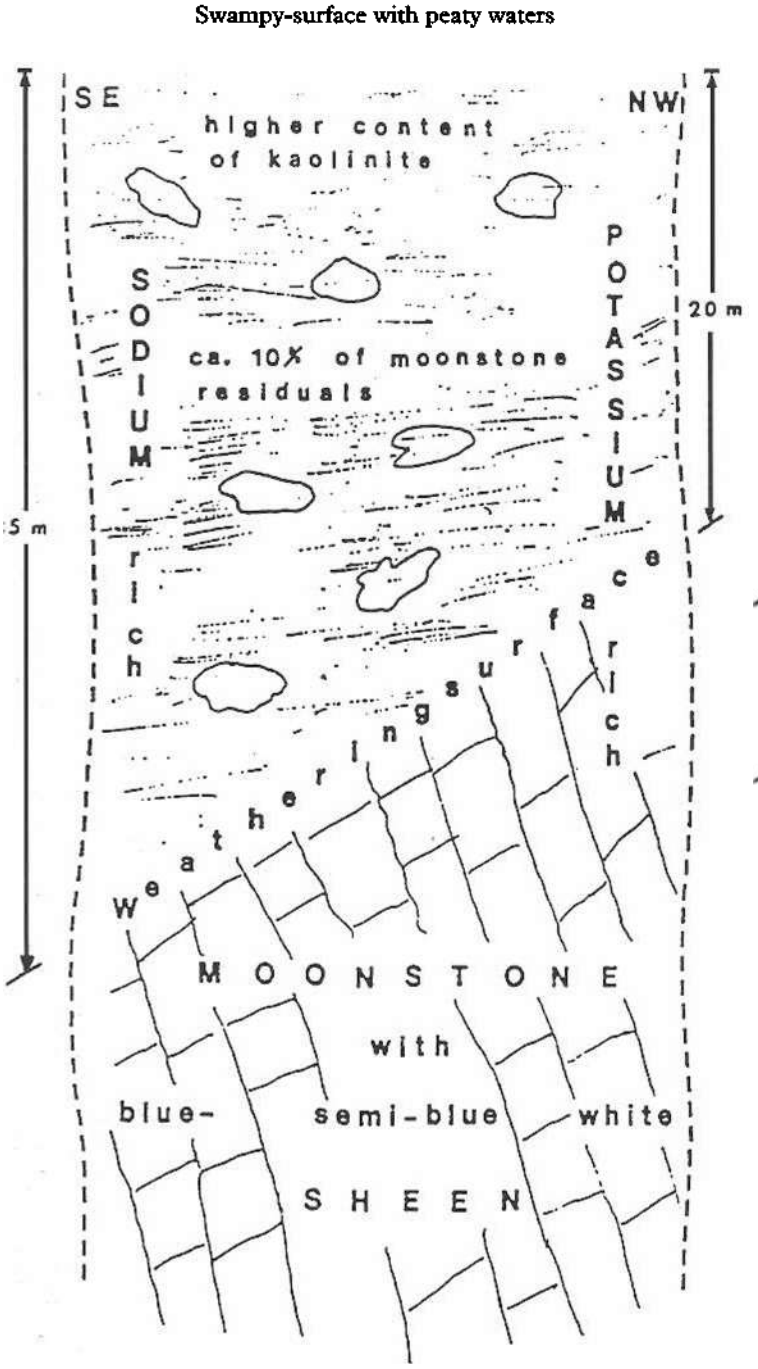

Feldspar weathered to kaolinite with moonstone residuals. The weathering has enlarged naturally the schiller-plane of the Na-rich $KAlSi_3O_8$

Feldspar residual

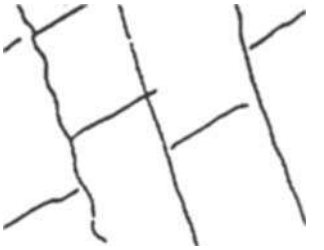

Feldspar with 'plate tectonic' cleavage

'Moonstone-rock' - unweathered normal pegmatite; hard feldspar with some intergrowth of quartz, biotite, etc. Plate tectonics have produced close-meshed net of cleavage + cracks in big feldspar crystals. The small and too-flat sizes of many cut moonstones from Metiyagoda are thus understandable.

Fig 2. Schematic profile of moonstone mines of METIYAGODA with a soft rotted china clay surface and in depth primary unweathered feldspar pegmatite. The blue moonstones are in the SE, the semi-blue in the middle part, and the white in the NW of this pegmatite.

Table 1. Moonstone qualities of Sri Lanka

Blue Moonstone	
Crystal blue*	
normal blue	
muddy blue**	
Semi-blue Moonstone	
Top semi-blue*	
normal semi-blue	
muddy semi-blue	
White Moonstone	
Crystal white*	
silvery	white*
pearly	white*
normal white	
muddy white	

*only in Metiyagoda
**only in Balangoda

the strong sky-blue to dark blue schiller colours, which unfortunately occur very rarely.

Moonstones with a blue schiller do not only appear on the market from Sri Lanka but also originate from Burma (Mogok) and south India (where they are called Ceylon-qualities). The better qualities – particularly from the mining of Metiyagoda, near Ambalangoda in the south of Sri Lanka (Figure 1) – dominate the market. In the last decade the growing demand from Switzerland, Germany and recently Japan, for blue moonstones has reduced the quantities of blue moonstone in bigger sizes. In this paper some new information about the mine of Metiyagoda and some other mines of Sri Lanka is given. Furthermore, it is intended to analyse the chemical or mineralogical difference between the blue and the white moonstone qualities, which is not well known in modern scientific literature.

Moonstone from the rotted pegmatite of Metiyagoda

This famous moonstone deposit was discovered during agricultural work in the year 1906 and is described in detail in the work of Spencer, 1930. The situation mentioned in the paper above is still in existence. The moonstone deposit underlies a swampy area. The ore material which is mined is a strongly kaolinised feldspar pegmatite, the feldspars occurring as weathering residuals in minor quantities (Figures 2 and 4).

Kaolinite is often formed by decomposition of feldspar. The lattice of kaolinite can either be formed from weathering solution or from hydrothermal waters. Postmagmatic, hydrothermal solutions may have circulated after the formation of pegmatite and may have decomposed the feldspar. In contrast to weathering processes, hydrothermal processes may occur even in the lower part of the pegmatite. Tropical weathering conditions, mainly under the influence of peat solutions are favourable for kaolinisation. These conditions are nowadays found in Sri Lanka. Spencer discussed both kaolinite formation possibilities of the moonstone deposit of Metiyagoda. Recent exploration shows that strong weathering took place even in the surrounding rocks which leads to some china clay mining.

The mined kaolinite-rich material is washed out in order to enrich the residual feldspar. The remaining material consists of feldspar with a pitted or frosted external brittle surface and a compact unweathered moonstone core. The inner feldspar material is exposed by breaking it out from the

Fig. 3. Schematic diagram showing the different moonstone qualities in the mines of Metiyagoda.

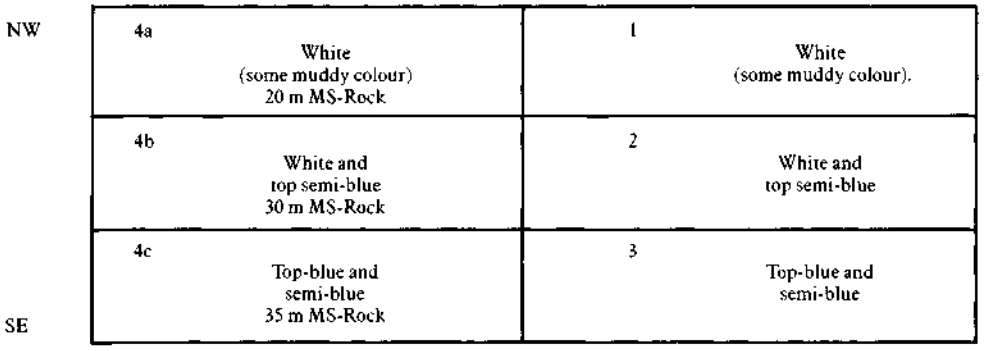

Mines numbered 4a-c belong to 'The World Crafts', Galle. In these mines the unweathered pegmatite is reached at depths of 20-35m. Locally this hard material is called 'moonstone rock' (MS-Rock). Beyond these depths all other mines work in the soft kaolinite-rich material. Mine No. 1 has stopped mining in recent years due to water problems.

Fig. 4. Moonstone pegmatite mine Metiyagoda. The material, which is mined here is a strongly kaolinised feldspar pegmatite containing moonstone as weathering residuals.

weathered rim. The weathering has enlarged the tablets of the schillerized feldspar plane. This observation is mineralogically reasonable because sodium feldspar weathers more easily than potassium feldspar (Correns, 1961). The remains of weathering often show naturally formed planes which are parallel with the schiller-plane and which are thus suitable for the cabochon cut. The first rough and form-giving cutting work, the so-called 'ebauchieren' is not necessary for moonstones from the weathering zone, as the schiller-plane has been exposed through weathering.

Occurrence of moonstones with different colour sheens in the pegmatite of Metiyagoda

Moonstones with a blue, semi-blue or white schiller are not regularly distributed over the whole pegmatite. The area where the moonstone is mined is about one acre (4068 m^2, ie a square of 64m) according to the information of S.H.M. Mohideen. Today the mining is done by digging pits to a depth of 35m, which corresponds to the statement of Spencer, who mentions 100 feet. The mining is controlled today by 4 companies, see Figure 3. Blue moonstones are to be found in areas 3 and 4c, semi-blue in the areas 2 and 4b, whereas only white moonstones in the areas 1 and 4a.

Unweathered core of the moonstone-pegmatite of Metiyagoda

The kaolinised surface of the pegmatite has been mined for nearly one century and the unweathered pegmatite has been reached at some places. This pegmatite material is locally called moonstone rock (in Figures 2 and 3 it is called 'MS-Rock'). It is interesting to mention that the weathering surface reaches much deeper in this pegmatite area, which contains blue moonstones. It may be caused by unknown geological factors but the higher sodium content of this part of the pegmatite seems to be the reason for it, since albite weathers more easily than the orthoclase. In the unweathered feldspars of this area no kaolinite is detected, neither optically nor by X-ray investigation, nor by differential thermal analysis. All moonstone qualities which are known from the kaolinised part of the deposits, also occur in the unweathered part of the pegmatites. In some of the hard unweathered pegmatite an intergrowth of feldspar and quartz may be found, less frequently with biotite and phlogopite. The various stones which the author examined, showed a relatively tight net of cleavage and cracks. The reason why these moonstones from Metiyagoda occur in relatively small and mostly flat pieces is found in the tectonic-geological position of this deposit. This

pegmatite occurs near the shore and even more important near a tectonic border of the island. Moonstones which occur farther from the tectonic border show far less cleavage and these mines produce much bigger stones. The carat-price of these moonstones does not much depend on the size of the stone, whereas the moonstone prices of Metiyagoda stones strongly increase with the size.

Economic differences in the mining of moonstones of kaolinised or unweathered pegmatites

The mining of moonstone from the unweathered feldspar material is far more expensive. The breaking of hard feldspar rocks is much more difficult than mining of the soft kaolinite material. The remains of the residual feldspar material appear in a form, which is very favourable for moonstone cutting, whereas the big unweathered feldspar crystals must be split first and knocked to pieces in order to get clear moonstones. During this process the feldspars crack in the direction of both cleavages but seldom in the schiller-plane. This schiller-plane must be cut artificially in order to produce the beauty of the moonstone. The ebauching, the first rough cutting, of the moonstones from the unweathered core of the pegmatite is necessary and

Fig. 5. The mined kaolinite-rich material is washed out in order to enrich the moonstone.

Fig. 6. Collected washed out rough moonstone. Below the brittle surface of the rough moonstone is a hard, cuttable core of feldspar, with an enlarged 'schiller'-plane weathering.

causes additional cost. Only 1-5% of the feldspar material could be cut as gems from the unweathered pegmatite, whereas 25% of the residual moonstone from the rotted pegmatite could be commercially used according to the information given by S.H.M. Mohideen (Jeiser), the owner of the biggest part of the mine (in Figure 3, the areas 4a, 4b and 4c).

The weathering of moonstone has not only enriched the crack- and inclusion-free material, as it is the case with some other gems, but in addition to that it has exposed the schiller-plane, which shows the real beauty of the moonstone.

Other moonstone occurrences in the mountains of Sri Lanka

In former times moonstones of various qualities have been found in the central mountains at different localities. These moonstones could be cut to bigger stones than those from Metiyagoda. The pegmatite hosts of these feldspars were found in various places, for example in Matele north of Kandy (Figure 1). The geological surroundings of these pegmatites are the gneisses, which are the most important rock formation of the island. In the

Metiyagoda moonstone area these gneisses are to some extent different from those in the central mountains. In the past numerous moonstones were found in the gravels of recent rivers and also from worked gem gravel, for instance the illam from Elipitiya, Pitigala, Horton Plains and Weligama in the south of Sri Lanka; also from the recent rivers, the Mahawelli Ganga in the north-east and the Walawá Ganga in the south, where probably material from the pegmatite of Balangoda has been deposited.

A newly opened moonstone mine at Tanne near Balangoda is situated in the central mountains, 45 km east of Ratnapura and has similar geological surrounding as in the Kandy moonstone area. The exact location lies south-east of Balangoda at the side road to Uggalkaltota, near the village Tanne at milestone 12 (about 19 km). At about 5 km from this village traces of mining activities are to be seen. From the dump material it can be deduced that normal unweathered pegmatite material is mined. Many feldspars, quartz and large biotites are found. Nowadays topaz is mined to the west of this road. There must be a large number of pegmatites.

At the end of 1990 two new moonstone pegmatite localities were found in the mountains of Sri Lanka. One is near Yatiyantota, about 40km east of Colombo; the other is near Haputala, about 35km east of Balangoda in Uva province. The latter locality produces moonstone with an unusually strong blue sheen and is known as 'Royal blue'.

The moonstone schiller of the material of Balangoda does not have the intensity of the moonstones from Metiyagoda. The clear top blue qualities and the top semi- and top white qualities were not found in this deposit. The moonstones show a lower semi-blue and mostly a pearly white quality. The body of the moonstones are not so clear and the medium light muddy colour could easily be detected. These qualities, which in trade are called Balangoda, are similar to some moonstones of south India, which are called 'Ceylon'-quality. In 1987 a large quantity of Balangoda material was mined and cut in the environs of Galle, the former capital in Dutch times and in those days and even today an important gem trade centre. Meanwhile the trade has learned that there are different qualities of Sri Lanka moonstones. As the sale of cheap moonstone qualities was reduced due to declining tourism, the mining of the moonstone deposit of Balangoda stopped working at the end of 1988.

Chemical investigation of Sri Lanka moonstones

Two full analyses of material from these two most important moonstone localities were carried out (Table 2). The SiO_2 and Al_2O_3 contents were determined by means of gravimetric analyses. The K_2O, Na_2O, CaO, and MgO contents were analysed by atomic absorption, Fe by spectrophotometric investigation and the trace elements Mn, Ba, Sr, Rb and Cs by X-ray fluorescence. Apart from the significant difference in the alkali-content of the two different moonstone localities, the values of the other main and trace element contents are very similar, as shown in Table 2. The Fe content of the sample from Ambolangoda is a little higher, which may be explained by the stronger greenish body colour of the stone. The brighter blue moonstones of Metiyagoda have essentially higher sodium contents, whereas the sample of Balangoda shows higher potassium content. In general Ba (up to 0.05%) and Rb (up to 0.07%) tend to favour the white potassium-rich rather than the blue sodium-rich feldspar (Ba only 0.004% and lower, Rb only 0.00X – 0.024%). Calcium replaces more easily in the sodium position and is found in slightly increased amounts in the blue moonstone of Metiyagoda. The result of the different sodium content in the blue and white moonstone quality could be verified by numerous X-ray fluorescence determinations of potassium in the various qualities, but X-ray fluorescence analysis of potassium with an inner standard of Si is not as precise as the wet chemical analysis. Since the X-ray fluorescence

Table 2. Chemical composition of two moonstones from Sri Lanka

	Ambalangoda Metiyagoda	Balangoda Tanne
SiO_2	66.2	65.1
TiO_2	0.004	0.02
Al_2O_3	18.8	18.6
Ga_2O_3	≈ 0.002	≈ 0.002
FeO	0.02	0.03
Cr_2O_3	0.003	0.02
MnO	0.01	0.03
MgO	< 0.00	< 0.00
PbO	≈ 0.02	≈ 0.00X
BaO	0.004	0.03
CaO	0.3	0.2
SrO	0.02	0.08
Na_2O	3.7	1.8
Rb_2O	≈ 0.3	≈ 0.04
K_2O	10.1	13.8
Ign. loss 950°C	0.16	0.07
	99.64%	99.82%
Potash -feldspar	59.7%	81.5%
Soda -feldspar	31.3%	15.2%
Lime -feldspar	3.1%	1.8%

Fig. 7. Unweathered moonstone pegmatite material of Metiyagoda locally called 'moonstone rock'. Crystal-clear feldspar with a strong deep blue sheen (size of the sample 100 × 60mm). The picture shows a single feldspar crystal. The two cleavages and the 'schiller'-plane are clearly visible. These three directions cross each other more or less at right angles. In the middle part of the sample an intergrowth of quartz and small micas with the moonstone is visible.

Fig. 8. Blue moonstone in a crystal blue quality (size of the sample: 58 × 45mm). The clear transparent and colourless area of the moonstone is limited by a tight net of cleavage and cracks. The size of cut moonstone from this sample could only be up to 7mm. This pegmatite occurs near the plate tectonic border of the island. This geological fact is the reason why cut moonstones from Metiyagoda mostly occur in small flat pieces.

does not destroy the gems, more expensive moonstones could be analysed. The irregular shape of the moonstone samples could be one reason for the analytical error of the X-ray fluorescence methods. The rounded cabochons of the moonstones are not very suitable for these X-ray methods. A further reason for differences between the wet and the X-ray fluorescence analyses is the possible loss of sodium from the moonstone surface which was in contact with water. The natural weathering or the activity of water during the cutting, takes more sodium away from the surface layer and slightly enriches the potassium on the surface. The X-ray fluorescence only analysed the surface layer and not the whole moonstone body, which is analysed during the wet analysis. One other chemical difference could be produced by the exsolution of the sodium during the forming of the schiller-plane in the moonstone. The side of the moonstone, which shows a strong sheen, is richer in sodium than the other side, which shows higher potassium values in X-ray fluorescence analyses.

Chemical difference between Sri Lanka moonstones with a blue or with a white sheen

The bluish schiller is attributed to the layered micro-structure in the cryptoperthite of orthoclase-albite. The interference phenomenon, which is possible in this structure and/or the scattering from very fine particles cause the bluish moonstone effect. But apart from all these differences in microstructure it could be shown by numerous analyses that the colour of the schiller of the different moonstones reflects the different alkali content of the moonstone. Blue colour moonstones show a very high content of sodium, up to 6.3%

Fig. 9. Intergrowth of feldspar with quartz from the 'moon stone rock' of Metiyagoda. The moonstones show a non-transparent quality with a normal white sheen.

Fig. 10. Baveno twin feldspar in a crystal blue moonstone quality. One side of the twin shown in this position exhibits the strong blue moonstone sheen. The other side (the small part) shows the blue sheen when turned.

Fig. 11. Semi-blue moonstones.

Fig. 12. Different qualities of moonstones from Metiyagoda. The deep blue quality (the small stone on the left) normal blue, semi-blue and the silvery white qualities with a strong white sheen on the right side, are seen in this picture.

Na_2O in some analysed samples. The sodium content in the semi-blue samples is to some extent lower than in the blue samples. Samples of white moonstones are much richer in potassium than in sodium, some of these samples contain only 2% Na_2O (Table 3).

Table 3. Table showing how the different sodium/potassium content controls the blue, semi-blue or white sheen of the moonstone from Sri Lanka

Blue moonstones
- 7.9-9.5% K_2O (16 analysed samples)
- soda – feldspar content up to 51%

Semi-blue moonstone
- 9.5-10.9% K_2O (12 analysed samples)
- soda – feldspar content between 45-37%

White moonstones
- 10.1-14% K_2O (12 analysed samples)
- soda – feldspar content lower than 38%

Top blue moonstone qualities of Sri Lanka are more an albite than an orthoclase; an albite, which contains up to 46% potassium feldspar.

Acknowledgement

It is a pleasure for me to express my thanks to several friends in Sri Lanka. Talks with well-informed moonstone merchants were very helpful for this paper. The information from S.H.M. Mohideen (Jeiser) was especially valuable.

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XXIII International Gemmological Conference, South Africa 1991

Alan Jobbins

At this conference, which was superbly organized by Herbert Pienaar and his helpers, the excursions (5-12 October) preceded the scientific sessions. Delegates visited The Diamond Research Laboratory (DRL) near Johannesburg; the Daggafontein operations of the East Rand Gold and Uranium Division (ERGO); the Vaal Reefs Gold Mine near Klerksdorp; the Premier Diamond Mine at Cullinan near Pretoria; Western Deep Levels Gold Mine near Carletonville; the alluvial diggings on the Vaal River; De Beers Consolidated Mines, the Big Hole and Kimberley Mine Museum and various safari game parks. The scientific sessions (14-18 October) were held in Stellenbosch at the Public Library Hall, by courtesy of the Town Council; and at the University of Stellenbosch. The papers presented are listed below in alphabetical author order.

Arps, C.E.S. (The Netherlands). Agates: composition, petrogenesis and structures.

Bank, H. (Germany). Gemstone news from Idar-Oberstein.

Barot, N.R. (Kenya), and Gübelin, E.J. (Switzerland). Chatoyant East African gemstones.

Becker, G.F.A. (Germany). Emeralds from Nigeria and olivines from outer space.

Chikayama, A. (Japan). Modern large-scale mining of ruby and sapphire in Thailand.

Gurney, J. (South Africa). Different crystallographic forms of diamond; origin and post-crystallization history.

Gurney, J., *et al.* (South Africa). Television film on recovery of diamonds from coastal deposits of Namaqualand, South Africa.

Harding, R.R. (UK). Notes on two unusual archaeological materials.

Jobbins, E.A. (UK). The gemmology of the Cheapside Hoard of jewellery.

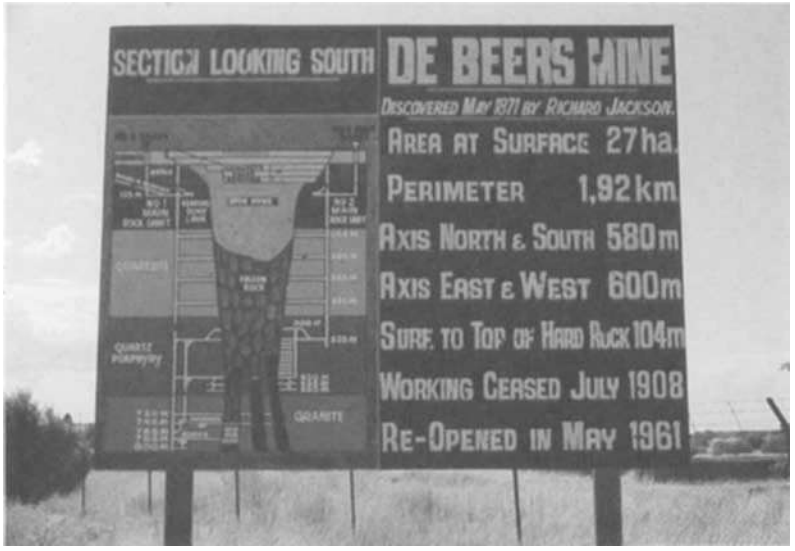

The vital statistics of the De Beers Mine, Kimberley. To complete the story, the mine was closed in October 1990.

Kane, R.E. (USA). The current status of ruby and sapphire mining in the Mogok Stone Tract, Burma (Myanmar).

Kanis, J. (Germany). Gemstone chips from Orissa, India.

Kirkley, M., and Gurney, J. (South Africa). Diamonds from algae: organic sources for carbon in diamond.

Koivula, J.I. (USA). Recent observations of inclusions.

Levinson, A.A. (Canada). (1) Diamond exploration in Western Canada. (2) The mineralogy and geochemistry of human urinary stones.

Meyer, H.O.A. (USA). Marine diamonds from Namibia.

Meyer, H.O.A., and Winston, R. (USA). Famous diamonds at the House of Winston.

Miyata, T. (Japan). A new ceramic cameo made by Kyocera, Japan.

Pie Roger, R.M., Balagua, E., and Madred, I. (Spain). Coral from the Catalan Costa Brava, Spain.

Pienaar, H.S., Glenister, D. (South Africa). On a gift of diamonds from Cecil John Rhodes - for services rendered.

Poirot, J.-P. (France). Spectrometry and X-ray fluorescence on some sapphires.

Ramos, Z., Skinner, E.M.W., Bristow, J.W., and Robinson, D.N. (South Africa).

Read by C. Hatton. Kimberlites and the mantle in Southern Africa.

Saul, J.M. (France), Sturman, N.P.G., Castro, A.I., and Harding, R.R. (UK). Characteristics of some gem materials from East Africa, Madagascar and Afghanistan.

Scarratt, K. (UK). Read by R.R. Harding. A cultured pearl grading system.

Schwarz, D. (Germany). The chemical properties of Colombian emeralds.

Segnit, R.E., and Jones, J.B. (Australia). On the cracking of opal.

Shida, J. (Japan). Treated jadeite.

Sunagawa, I. (Japan). (1) Basic concepts in the identification of natural and synthetic diamonds. (2) Crystal growth and gemstones.

Superchi, M., and Cusi, R. (Italy). The pink topazes of an historical jewellery set.

Tombs, G. (Australia). Inclusions and internal features of Kenyan golden sapphires.

Zoysa, G.E. (Sri Lanka). Some recent discoveries from Sri Lankan gem-rich soil.

Zwaan, P.C. (The Netherlands). More data on the kornerupines from Embilipitiya, Sri Lanka.

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1991 Conference and Presentation of Awards

Mary A. Burland

The first Conference of the recently amalgamated Gemmological Association and Gem Testing Laboratory of Great Britain was held in London on Sunday 3 and Monday 4 November 1991, sponsored by T.H. March & Co. Ltd, Insurance Brokers. The venue for the events on the first day was the Tower Thistle Hotel, with a magnificent view of Tower Bridge and the River Thames, and also overlooking St Katharine's Dock. Proceedings continued on the Monday afternoon at Goldsmiths' Hall, where delegates had the opportunity of viewing the exhibition of the work of the designer De Vroomen. The Conference was well attended with delegates from Australia, Canada, Japan and the USA, as well as many European countries. A range of instruments and books were on display, and the Directors and staff were present to discuss the services offered by the GAGTL. David Larcher of the Midlands Branch and Irene Knight of the North West Branch were available to explain the advantages of taking part in Branch activities. As well as a programme of excellent lectures, full reports of which are given below, Gem Identification and Diamond Grading workshops were held throughout the first day. Two video shows were also arranged, 'Gemstones of America' and 'Mogok Valley of Rubies', a film made by Dr E. Gubelin providing an insight into the mining and trading of rubies in the country famed for the finest stones. Social events included a Dinner Dance on the Sunday evening at the Tower Thistle Hotel and a dinner following the Presentation of Awards ceremony.

Workshops

The workshops, which offered 90 minutes of intensive instruction and hands-on experience, proved very popular, the only problem being which of the excellent lectures or video shows should one miss in order to take part in one of the sessions.

Diamond Grading

After a short introductory talk on the various aspects of diamond grading, each student had a work station with a grading lamp, 10 x lens, dia-

Fig. 1. Students participating in the Diamond Grading workshop.

mond cloth and course notes. An integral part of the workshop was the demonstration of the use of diamond colour comparison stones to colour grade polished diamonds. Under the instruction of Eric Emms and Alan Clarke students examined many diamonds through the microscope. Stones studied included stones with glass-infilled fractures, and also laser-drilled diamonds (a method whereby dark inclusions can be modified by laser drilling) in which the fine drill holes targeted on inclusions could be seen. The way in which variations of symmetry and proportions are graded in brilliant cut diamonds was demonstrated with the use of the proportionscope.

Gem Identification

Each session commenced with an illustrated talk on the problems of identification posed by various synthetic and treated gemstones on the market today. At four work stations, equipped with microscopes and a light box to view the radiographs of pearls, students were able to examine the stones that had been discussed during the talk. These included corundum with cavity filling, deceptive synthetic stones with straight growth lines, and deep-diffusion-treated sapphires; Yehuda-treated diamonds, laser drilled diamonds, a Sumitomo synthetic diamond and a diamond-topped doublet; natural emeralds from Colombia and Sandawana, Opticon filled fractures in emerald and Lennix synthetic emerald; natural, cultured, non-nucleated and dyed pearls.

Fig. 2. Ian Mercer assisting students at the diamond work station.

Fig. 3. Colette Bensimon giving instruction on the identification of pearls.

Practical Gemmology

An illustrated lecture entitled 'Practical Gemmology' in two parts and covering a range of subjects was given by Alan Hodgkinson.

Refractometer

Mr Hodgkinson commenced by stressing the importance of accuracy when using the refractometer. It is essential that the stone being tested is placed centrally on the prism, and that as well as your eye being very close to the eye-piece it should be in the same position for every reading,and this calls for a comfortable posture. It is also vital to check the accuracy of your refractometer, and a stone with a known RI, e.g. rock crystal, should be kept for this purpose. If readings are slightly incorrect they can be adjusted with the use of colour filters; 'Quality Street'

chocolate wrappers was one inexpensive suggestion.

It is becoming increasingly necessary to confirm that your refractometer readings indicate whether uniaxial gems are positive or negative. Also to pinpoint *beta* so that biaxial gems can be designated as positive or negative. Mr Hodgkinson demonstrated a simple inexpensive method of optical sign interpretation for all birefringent gems.

For those who had difficulty in obtaining a reading by the *distant vision* method it was suggested that, as well as using the normal light source, a fibre optic should be additionally directed through the top of the specimen. The *distant vision* method was demonstrated using such items as carvings, bangles, etc., as well as cabochon-cut stones.

Visual Optics

Mr Hodgkinson then went on to discuss the use of visual optics, a method whereby various optical phenomena can be detected at the retina.

It is possible, using only a light source, to calculate the RI and DR of a stone, measured against a 48 inch adding machine paper roll, which made for a delightful refractometer substitute. The prototype of a Hanneman/Hodgkinson student refractometer encapsulated the technique into a pocket instrument.

Opals

Natural, synthetic, plastic and stained opals were illustrated. Transmitted and crossed polarized light was shown to be a useful means of identification and a fibre optic light was used on a difficult mounted doublet.

'Always expect the unexpected'

The second part of the lecture warned of the dangers of making assumptions about gemstones. Even when the identity of a stone appears obvious, confirmation should be obtained by testing the specimen thoroughly. Examples illustrated included cobalt-coloured synthetic spinel, a green sapphire boule coated with synthetic blue spinel, a doublet composed of a diamond crown on the cubic zirconia pavilion, flux-grown rubies, and some surprising alexandrites which had crystallized out in a 'Chatham synthetic ruby' accident some years ago.

Polarization

Mr Hodgkinson explained how cross polarization could be used by various techniques to determine whether a cut stone was uniaxial or biaxial. Many excellent illustrations of the phenomena were shown.

Earlier this year gemmologist Pat Daly introduced Mr Hodgkinson to the theory that there was a polarized band in the sky. The following morning their student group discovered this for themselves by experimenting with gemstones, and found that part of the sky could be used as a dichroscope. The highlight was a slide transparency showing the interference figure of quartz using the sky crossed with a single polaroid as a polariscope.

Corundum

The second part of the lecture concluded by looking at corundum. Those illustrated included Scottish sapphires of 58 and 100 carats; a cabochon displaying an adjacent double star; natural and synthetic star stones; 'gas bubbles' impersonated in corundum caused by heat treatment and identified as a balled-up form of alumina; synthetic sapphires ingeniously damaged to imitate natural inclusions; and finally, the increasing quantity of sapphirine which resembles sapphire in more than name.

The History of Gemmology and its Literature

A review of gemmological literature from the Bible to the present day was given by Nigel Israel. Slides shown included a number of beautifully illustrated books that had been published on the subject. The lecture proved that much of the knowledge that is generally thought of as 20th century can be traced back hundreds of years.

In the final part, Nigel Israel dealt with the development of gemmology from the first synthetics in 1885, through the first gemmology classes in 1893 and early refractometers, up to UV and IF meters.

A full report of 'The history of gemmology and its literature' will be published in a future issue of The Journal.

The Crown Jewels

Dr Roger Harding continued the historical theme with an illustrated lecture on the British Crown Jewels, from their origins in the unification of the Crowns of England and Scotland under the reign of James I to the present day. In 1605 a decree was issued which declared that certain jewels be 'indivisible and inseparate, forever and hereafter annexed to the Kingdom of this realm'.

During the time of Charles I and Cromwell, however, many items disappeared from the collection, notably 'The Sancy' and 'The Mirror of Portugal', two famous diamonds which were pledged, together with many other pieces, to the Duc d'Epernon by Henrietta Maria, the wife of

King Charles I, to raise money for the Royalist cause. Unfortunately she could not afford to redeem the diamonds and in 1657 the Duc released her from the debt and sold them to Cardinal Mazarin. Subsequently the Sancy was also known as Mazarin I and the Mirror of Portugal as Mazarin III. On his death, Mazarin left both diamonds to the French crown.

Many of the remaining Crown Jewels were sold during the Commonwealth Period, but those that survived form the nucleus of the collection which is in existence today.

Although records of the Crown Jewels were kept by the Crown Jewellers and various books have been published on the subject, in 1986 it was decided to compile a detailed account of the collection, including a gemmological description of the more important stones. This was done by Alan Jobbins, assisted by Roger Harding and Ken Scarratt, which involved transporting all the necessary equipment into the Jewel House at the Tower of London during a period when it was closed to the public. Roger Harding then described some of the pieces examined, as well as giving details of their history.

Two of the items mentioned were the Sovereign's Orb and the Sceptre with Dove made for the Coronation of Charles II. The Orb contains a total of 772 gemstones including diamonds, emeralds, sapphires, rubies, amethyst and pearls. The emeralds are believed to be of Colombian origin, and the rubies contain silk and crystal inclusions typical of Burmese stones. Although the Sceptre with Dove has fewer stones (285) than the Orb, it contains one more gem species - three spinels (polished rough) very similar in colour to the rubies.

George IV introduced the concept of the rose, thistle and shamrock to the Crown Jewels in two items on display in the Jewel House, the Jewelled Sword of State and the Diamond Diadem. The latter was a favourite of Queen Victoria, and our present Queen is depicted wearing the Diadem on stamps and banknotes. The Diadem is set with 1333 diamonds weighing 320 ct, the largest being a pale yellow round brilliant-cut of 4 ct, as well as 169 pearls (those examined were found to be natural).

The most famous of Queen Victoria's acquisitions was the Koh-i-Noor diamond. It weighed 186.10 ct, and a model is on display in the Tower of London. In 1852 it was recut to a cushion-shaped brilliant weighing 105.60 ct. In 1905 the Cullinan Diamond was found and was offered to Edward VII. Cutting began in 1908 and Cullinan I, a pear-shape stone weighing 530.20 ct and of exceptional colour and clarity, was set in the Sceptre with Cross in 1910.

Cullinan II was set in the front of the Imperial State Crown, directly below the Black Prince's Ruby. This is a polished red spinel crystal of good colour, although it is in a foil-backed setting. At the rear of the crown is the Stuart Sapphire, supposedly part of the Crown Jewels when the Stuarts reigned, but with a documented history only from the time of George IV. At the summit of the crown is a cross containing the St Edward's Sapphire, reputed to have been set in a ring which belonged to Edward the Confessor. With this range of stones in the Imperial State Crown about nine hundred years of history are symbolically represented, from the sapphire of Edward the Confessor, to the rough polished spinel of the 14th century, the early cuts of diamonds, the high quality of the emeralds, sapphires and rubies, the pearls and cultured pearls, and finally the Cullinan II diamond.

Items of regalia in the Tower of London are regularly used and are not merely museum pieces, and it is to be hoped that in the future they will be joined by new pieces symbolic of important events in the country's history.

The Conference continued on the afternoon of Monday 4 November at Goldsmiths' Hall, Foster Lane, London EC2, with the Annual General Meeting, a full report of which appears on p.50.

Review of treated gemstones

Following the AGM, Mr Ken Scarratt gave an illustrated lecture on treated gemstones. A tremendous number of gemstones are now treated, and Mr Scarratt began by giving the official definition of a treated stone as being one in which the 'appearance or durability has been artificially enhanced'. He then gave details of those currently on the market, and methods by which the various treatments could be identified.

Amber:

The appearance of amber can be improved by gradual heat treatment If it is heated too quickly a spangling effect occurs. The colour does not penetrate but is concentrated on the surface of the stone, so amber treated in this way should not be repolished as the colourless material below could be revealed. Specimens of amber with a surface lacquer coating and reconstituted amber were also illustrated.

Coral:

Much of the coral on the market today has been

Fig. 4. Rough amber and three cabochons cut from the same material. Bottom, from left to right: before heat treatment, after heat treatment, and after heat treatment and repolishing.

stained to a red colour. This may be detected by the concentration of colour around the drill hole. Coral can also be coated with plastic to improve the finish.

Diamond:

There are many types of diamond treatment used today and the identification of artificial colouring is a complex subject. Recent advances in identification techniques include the observation of slight colour concentrations in the area of the culet and the discovery of two extra peaks in the infrared spectrum when stones have been heated above the 1000°C point.

Natural blue diamonds, one reputedly from India and others from Australia, have been found to be non-conducting. Australian stones have been identified as Type Ia, hydrogen rich.

Diamonds have been laser drilled to reduce the visibility of black inclusions. Open fractures had been infilled for some time; under the microscope fractures show a blue flash which changes to orange when the stone is turned. Some of the more modern infills show a blue flash changing to pink. Faceted cubic zirconia coated with a diamond film were first seen in South Africa three years ago. The coating can sometimes be seen to be uneven, and these stones do not react in the same way as diamond on the reflectance meter.

Fig. 5(a) and (b). Colour flashes in feathers seen in a resin treated emerald *(Photographs R. Kammerling).*

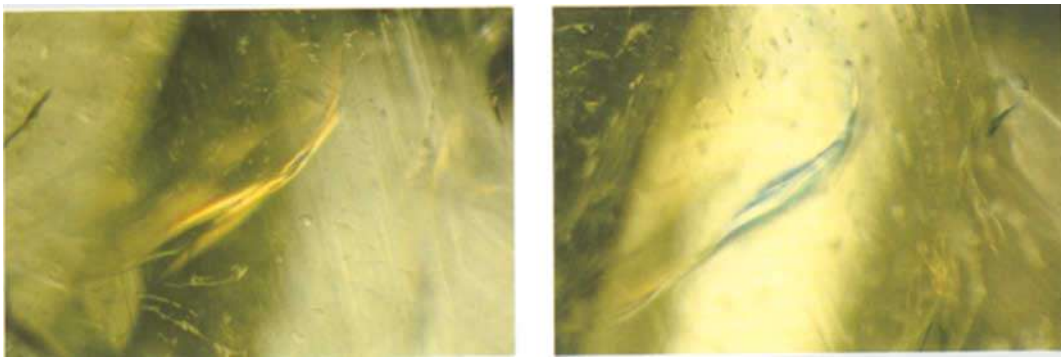

Emerald:

The speaker first discussed the oiling of emeralds, which is not a declarable treatment. A tremendous number of emeralds nowadays are being filled with one of the resins, one of which has the trade name Opticon, which greatly reduces the visibility of fractures. This treatment is declarable, according to CIBJO rules. Opticon-treated stones can be difficult to identify, but under the microscope the fracture has a yellowish colour which changes to a blue flash when the stone is turned. A similar infill treatment may be applied to other stones with a similar refractive index, such as amethyst and tourmaline.

Jade:

Although jade has been stained since time immemorial, specimens are now coated with a type of epoxy resin. Approximately 80% of jade in Hong Kong is now treated in this way. The coating is raised from the surface in some cases, which aids identification.

Opal:

Plastic impregnated opal can be detected by the specific gravity of the stone, or by the infrared spectrum.

Pearl:

Stained pearls can be identified by the deepening of the colour around the drill hole, and this may be seen with a 10X lens. Some treated black pearls owe their colour to irradiation treatment; the mother-of pearl bead discolours when irradiated which shows through the outer layers. Large hollow pearls have been drilled and filled with various substances, including wire, to strengthen them and increase their weight.

Corundum:

Examples of glass infilling in both ruby and sapphire were shown. The majority of sapphires coming on to the market today have been heat treated. Although this improves the colour of the stone, the wonderful silk seen in reflected light is lost after heat treatment, and the whole of the internal world of the sapphire is changing. Diffusion treated sapphires, i.e. the introduction of colour into the surface area of the stone, can be identified by the concentration of colour on facet edges. Colourless sapphire can be changed to yellow by exposure to X-rays, but the colour lasts only a few days.

Quartz:

Quartz can be coated with a thin layer of gold to produce Aqua Aura. Again, a concentration of colour can be seen on the facet edges.

Fig. 6. Heat altered inclusion in sapphire.

Turquoise:

To identify turquoise stabilised with plastic, cavities on the back of the stone, which often contain pyrite, should be examined for residue of impregnation. Turquoise can also be reconstructed.

Zircon:

Blue zircon will change to brown under ultraviolet light (if worn whilst on a sun bed for example), and will change back to blue if heated in an

Irradiated stones:

There have been scares in America about the dangers of radioactivity in treated stones. US Customs officials are particularly concerned about large parcels of such stones that they are handling.

In conclusion, Ken Scarratt suggested that, when handling treated gemstones, three aspects should be taken into account:

'Is anything artificial added'

'Is it permanent'

'Is it safe'

Fig. 7. A specimen of Aqua Aura.

Presentation of Awards

The Conference culminated in the 1991 Presentation of Awards ceremony, also held at Goldsmiths' Hall. Mr David J. Callaghan presided and welcomed those present, particularly Jeanne Miller from the USA who qualified in the Association's examinations 25 years ago and had made the trip to celebrate the anniversary of her achievement. This year award winners from Finland, Germany, Greece, Japan, The Netherlands and Spain were present to receive their Diplomas.

Mr Callaghan went on to say that for the 1991 Examinations it had been necessary to arrange 62 centres in 26 countries which takes a lot of organisation, particularly getting the specimens for the practical section through Customs to arrive at the centres on time. He thanked the examination team, headed by Ian Mercer, for their hard work, and also paid tribute to the Examiners.

He then called upon Mr George F.H. Burne, Director of the Central Selling Organisation, to present the awards.

In his address, Mr Burne reminded those present that 1991 was the 60th anniversary of the Association - the Diamond Jubilee, a celebration honoured by the King of Gems. He went on: 'I have worked for 34 fascinating years in the diamond business and can therefore only commend you on your choice of subject.

Fig. 8. Mr George F.H. Burne, Director of the CSO.

Address by Mr George Burne

'One thing I can assure you is that each day brings something new, some extra experience and knowledge. I am of course biased towards diamonds and you must forgive me for that. However, whatever gem we specialise in we know that all are beautiful, all have their own special magic, all can create masterpieces of jewellery to delight the eye and raise the spirit. The modern world is often beset by problems of tedious practicality; an obsession with the ordinary, and the mundane. In jewellery we can seek a more spontaneous celebration of life, a return to a time when adornment was seen as a basic need. Our forefathers had no doubts. They attributed strange and wonderful properties to gems, particularly diamonds. Resistance to disease, fortitude in battle, good fortune. Your task, our task, is to defend the integrity of our business. To ensure that what is false, what is synthetic, what is treated is exposed and shown to the world for what it is. Your knowledge and your skills should protect and advise our industry, encouraging excellence, meticulous appreciation and the setting of the highest standards. You are now qualified, or are in the course of qualifying, to join a large and growing industry. Worldwide sales of jewellery last year are estimated to have totalled $70bn and with growing prosperity in the Far East who can doubt the future?

'My congratulations go to all 580 candidates who were successful in the examinations set in various locations in 26 different countries. The percentage of the pass rate, 61% for the preliminary and 48% for the diploma, indicates the high standard set.

'We, at De Beers Centenary and the CSO, are fully aware that to be elected to the Fellowship of your Association represents a considerable personal achievement. To have the initials FGA appearing after one's name commands respect and credibility throughout the entire jewellery

Fig. 9. David Callaghan with the Anderson/Bank Prize winner, Peter J. Wates of Coulsdon, and Preliminary Trade Prize winner Anne Margaret Bailey of Rugby.

world. That the Diploma Trade Prize should have been awarded to a Sri Lankan, the Anderson medal to a Korean, and that thirteen of the 17 distinctions were earned by candidates from Canada to China and from Norway to Nairobi, certainly makes this point. This large overseas interest in attaining the FGA qualification continues to demonstrate the international appreciation of your Association in this, your 'Diamond Anniversary' year.

'The first Chairman of the Gemmological Committee was Samuel Barnett who held the office in 1908 and the first Diploma Holders are recorded in 1913. Of Samuel Barnett it was said, "he had sown the seed which marked the beginning of organised gemmology not only in this country, but in the whole world". 'A sentiment which reflects the fact that the first American correspondence course candidate, Robert M. Shipley, who gained his diploma in 1929, went on to found the Gemmological Institute of America two years later.

'As so often with inventions and ideas started in this country we may reflect, somewhat wryly, on the extent of the knowledge, we have so generously helped to export abroad!

'In the souvenir catalogue prepared for your Golden Anniversary and '50 Years of Gemmology' exhibition held there at the Goldsmiths' Hall ten years ago, I note that it was

my former colleague, Lionel Burke, who presented these awards in 1963. We are fortunate to join an illustrious line of distinguished presenters who have distributed awards almost without interruption since 1931.

'You now have a new diamond course starting this year and we are impressed with its professional presentation and scope. We have given and will continue to give it our support. A number of CSO executives have enrolled and I am sure they will be followed by many more in the years to come. Howard Vaughan tells me that you are already being bombarded with questions on crystallography from Charterhouse Street. This course is a descendent of those held by Norman Harper in Birmingham and Eric Bruton at the Sir John Cass College in London. As Mr. Bruton would be the first to admit, a lot of water has passed under the bridge since then, and certainly the world, its peoples, and the jewellery business have changed out of all recognition. With diamonds, for example, who could have expected that the production of natural diamonds would double to over 100 million carats over the last 10 years. Or, that competitive labour rates and a vastly expanded market (may I say as a result of De Beers advertising) would have resulted in the emergence of a diamond cutting centre employing 700,000 workers in India. It is surprising that automation has progressed so little in our industry, perhaps because it continues to pride itself in craftsmanship and personal skills. However De Beers has just held the first international technical symposium for the diamond industry in Israel, an event which may herald change in the future. For 1990 our researchers estimate that some 14 million carats of polished diamonds were set into some 52 million pieces of jewellery, which would have sold for a mere 39 billion dollars.

'The diamond industry has indeed been democratised giving wealth to the miners, often in developing countries, employment for many hundreds of thousands in cutting and polishing, jewellery manufacturing and in retail shops and joy to millions of customers. Long may this happy industry prosper, ensuring that every woman, and man if he wishes, may wear the radiance of the stars trapped for ever in ice'.

Mr Burne concluded his address by again congratulating the award winners. He also complimented those concerned in the production of the new Gem Diamond Course stating 'How just and appropriate that it should have started in this year Diamond Anniversary year'. Mr Ken Scarratt thanked Mr Burne for presenting the awards. He also thanked the CSO for their help and support with the new Gem Diamond Course, which now provides the diamond trade with its own professional qualification.

In conclusion Mr Callaghan thanked the Worshipful Company of Goldsmiths for allowing the Association to hold the ceremony in the Hall.

He also thanked T.H. March and Co. Ltd. for sponsoring the Conference which had proved very successful.

F.G.A.

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Book Reviews

HUGHES, F.E., 1990. *Geology of the mineral deposits of Australia and Papua New Guinea.* Australasian Institute of Mining and Metallurgy, Parkville, Victoria. 2 vols., pp. xxiii, 1828, 45, 3. Illus. in black-and-white and in colour. Both volumes include maps in pockets. Price approximately £150.00.

This very large work contains papers on the geological details of important minerals deposits (exclusive of coal and oil). Many papers describe gold deposits but a number deal with gem materials. Atkinson, Smith, Danchin and Janse provide an overview of Australian diamond deposits (pp. 69-76): opal deposits are described by Barnes and Townsend (77-84): Boxer and Jaques outline the Argyle (AKI) diamond deposit (697-706): the Arunta block, in which some gem quality pink corundum is located, is described by Shaw (869-874). In the second volume Flint and Dubowski deal with the Cowell nephrite jade deposits (1059-1062): the Ellendale diamond deposits feature in a paper by Hughes and Smith (1115-22) and the Argyle alluvial diamond deposits are in a paper by Boxer and Deakin (1655-8). Fazakerley (1659-64) describes the Bow River alluvial diamond deposit. A detailed reading of the whole book would no doubt throw up more hidden information. Each paper has its own list of references and there are very extensive author and subject indexes, repeated in each volume. Finally large geological maps are provided, one to each volume, covering Australia and Papua New Guinea respectively. M.O'D.

MITRA, S., 1989. *Fundamentals of optical, spectroscopic and X-ray mineralogy.* Wiley, New York. pp. xv, 236. Illus. in black-and-white and in colour. £16.30.

The book gives a useful overview on a variety of topics of interest to the gemmologist although the information is no longer new. Readers may find the sections on spectroscopic studies and on reflection optics the most interesting. A number of inaccuracies can be found. M.O'D.

MURANO, A.P., SAGGESSE, A.P., 1989. *L'Arte del corallo.* Gaetano Macchiaroli, Naples. pp.145. Illus. in colour. £54.00.

This well-illustrated book tells the story of coral manufacture at Naples and Torre del Greco during the eighteenth and nineteenth centuries. Each chapter [there is neither a list of contents nor index] has its own extensive list of references and there is a section of colour plates at the end of the book. In addition there is a general bibliography arranged chronologically. The book gives accounts of the major manufacturers and methods of coral working; particular attention is paid to the major manufacturer, Ascione of Torre del Greco. M.O'D.

NEWMAN, R., 1991. *The ruby and sapphire buying guide.* International Jewelry Publications, Los Angeles. pp. 204. Illus. in black-and-white and in colour. US$19.95.

The book is subtitled How to spot value and avoid ripoffs, but this to a European reader suggests a more commercial type of book than in fact is the case. The text covers colour, fashioning, synthetics and imitations, colour alteration, sources, appraisals, certification, care of corundum-set jewellery, travel abroad and buying stones and jewellery there and how to find a bargain in so far as that is possible. The text is clear and includes a great deal of gemmological as well as commercial information; text photographs are clear and cover many situations for appraisal which have rarely been put forward in gemmology texts before. Some of these points include colour assessment in different types of light and the provision of a section of questions at the ends of the chapters will be useful to the gemmology student as well as to the dealer or purchaser of jewellery. At the price this book can be highly recommended. M.O'D.

QUELLMALZ, W., 1990. *Die Edlen Steine Sachsens.* Deutscher Verlag fUr Grundstoffindustrie, Leipzig. pp.200. Illus. in black-and-white and in colour. DM 49.80.

Among the gem minerals found in Saxony are varieties of quartz, tourmaline, topaz, beryl and turquoise. Details of mining in the past three

centuries are outlined; there is an excellent bibliography and good quality coloured pictures.
M.O'D.

READ, P.G., 1991. *Gemmology*. Butterworth-Heinemann, London. pp.358. Illus. in black-and-white and in colour. £30.00

Peter Read is the author of several gemmological books, and series editor for a number of others by various writers. His particular interest has been in gemmological instruments, a fact which adds strength to his latest volume.

Clearly and explicitly written and profusely illustrated, it perhaps runs to rather more detail than is needed for a teaching text, but is none the worse for that. Most students are sufficiently selective to avoid swotting up on many microscopes and several refractometers when one of each is enough. The fourteen colour plates are realistic and convincing, while most black-and-white illustrations have printed well.

The sequence of chapters is perhaps unconventional and among other changes 'The fashioning of gemstones' and 'Diamond grading' are left until the end of the main book. I found this re-arrangement of subject matter refreshing and in no way detrimental to understanding. The main text is followed by eleven appendices covering: A Bibliography; B Organic gems; C Inorganic gems; D Synthetic gems not occurring in nature; E A summary of colour theory; F Examination notes, including sample theory papers for Preliminary and Diploma years; G Two lists of constants, one alphabetic and a more useful second one in order of RI values; H Units of measurement; I Table of the elements; J Principal Fraunhofer lines; and K Gemstone weighing.

Appendix C deals with gem species in a note form suitable for memorizing for examination purposes; stones needed for the Preliminary syllabus are marked with an asterisk.

It should be noted that since the book was written the Gemmological Association has issued a new Prospectus of Examinations which will apply from 1992 onwards. According to this the appearance and names of stones may be required in the Diploma Theory paper, for any of about forty of the more rarely cut collectors' gems, most of which do not feature in this book. Mr Read has added a short paragraph on this requirement, but has listed only twelve of the extra stones, saying that occurrence and distinguishing features may be required.

A very few minor misprints were noted but on p.161 the words 'achromatic and aplanatic' have been transposed in the description of pocket lenses; p.189 '59 band' should be '594 band'; p.273 Webster's inexact 'ten teaspoons of salt' recipe for brine to float amber is repeated. Teaspoons vary considerably in size and it is safer to say 50 grams of table salt. Mr Read has also used the term 'metamerism', I think incorrectly, to describe the colour change in alexandrite. Far better to call it 'the alexandrite effect' since there seems to be no specific term for it.

This attractive and well-produced book is a valuable and up-to-date addition to any gemmological library, written in explicit terms which are easy to understand, and priced reasonably when the very considerable content is taken into consideration. R.K.M.

SOFIANIDES, A.S., HARLOW, G.E., 1990. *Gems and crystals from the American Museum of Natural History*. Simon and Schuster, New York. pp.208. Illus. in colour. US$40.00. ISBN O 671 68704 2.

With photographs by Harold and Erica Van Pelt, this is a large-format guide to the collections of the American Museum of Natural History in New York City. The book is arranged in order of the most important gemstones followed by pearls, rare and unusual species, glossary, short reading list and index. An introduction describes the formation and development of the Museum's gemstone collection, with notes on prominent personalities such as G.F. Kunz and J.P. Morgan. This section is followed by general remarks on gemstones and how they were successively valued as talismans, palliatives and ornament.

Each major gem species is introduced by general remarks with constants shown separately and usefully in a box. In general the notes are clear and accurate and major stones have historical notes appended. As expected the Van Pelts have excelled themselves once more and the pictures are beautiful. Apart from slight inaccuracies and the misspelling of gahnite throughout the text appears to be reliable and in any case the book succeeds admirably in displaying the beauty of gemstones to museum visitors. M.O'D.

Proceedings of The Gemmological Association and Gem Testing Laboratory of Great Britain and Notices

GEM AND JEWELLERY NEWS

In December 1991 the first issue of *Gem and Jewellery News* was published. This newsletter is a joint venture between the Gemmological Association and Gem Testing Laboratory of Great Britain and the Society of Jewellery Historians, and will be published alternately with the *Journal of Gemmology*.

Comments and contributions should be sent to the Editor, *Gem and Jewellery News*, GAGTL, 1st Floor, 27 Greville Street, London ECIN 8SU.

OBITUARY

Mr Darel W.J. Dambrink, FGA (D.1963 with Dist.), Beekbergen, The Netherlands, died in 1991.

Mr Douglas N. King, FGA (D.1949), Birmingham, Chairman of the Association from 1978 to 1980, died on 26 December 1991. A full obituary will be published in the April issue of *The Journal*.

Mr Eric Robert Levett, FGA (D.1946 with Distinction and the Tully Medal) died 22 September 1991, aged 84.

Eric Levett had been one of the last two surviving subscribers to the Memorandum and Articles of Association which in 1947 gave the Gemmological Association its status as a Company Limited by Guarantee.

He was the proprietor of 'Frances Harling', a delightful period shop in Heath Street, Hampstead, retaining the name of its previous owner, for a number of years. Here he dealt largely in antique jewellery and developed a collector's interest in Japanese *netsuke* and other specialized items.

He moved to Rhodesia for several years before coming back to take over the Harling shop again until retirement, when he went to live in North Devon and ultimately in the Lot et Garonne area of SW France for some twenty years.

After his second wife, Christine, died in 1987 he came home to live at Martlesham in Suffolk, near his only remaining relative, Mrs D.E.C. (Mac) Levett, widow of his elder brother Frank, who took such great care of him in his last illness.

A highly intelligent man, remembered as 'a bright, penetratingly eager and lively mind', interested in natural history and science, a life-long vegetarian, devoted to fine classical music and to art, closely associated with Ernest Rutland, Basil Anderson, Robert Webster and others well-known in our specialized world, an excellent gemmologist and a wonderful friend of more than forty years, he will be greatly missed.

R.K.M.

MEMBERS' MEETINGS

London

On 3 and 4 November 1991 at the Tower Thistle Hotel and Goldsmiths' Hall the Annual Conference and Presentation of Awards were held. A full report is given on p.38.

Midlands Branch

On 17 October 1991 at Dr Johnson House, Bull Street, Birmingham, an informal evening was held.

On 15 November 1991 at Dr Johnson House, Mr J. Gosling gave a talk entitled 'The Guyana Lapidary Project'.

North West Branch

On 20 November 1991 at Church House, Hanover Street, Liverpool 1, the Annual General Meeting was held at which Mrs Irene Knight and Mr Joe Azzopardi were elected Chairman and Secretary respectively.

ANNUAL GENERAL MEETING

On 4 November 1991 at Goldsmiths' Hall, Foster Lane, London EC2, the Annual General

Members having gained their Diploma in Gemmology or the Gem Diamond Diploma (FGA or DGA) may now apply for use of the Coat of Arms on their stationery or within advertisments.

Laboratory members are also invited to apply for use of the Laboratory Logo.

It is still a requirement of GAGTL, in accordance with the Bye Laws, that written permission be granted by the Council of Management before use.

Members interested in further information please contact:

Linda Shreeves

Gemmological Association and Gem Testing Laboratory of Great Britain

♦ 27 Greville street, (Saffron Hill Entrance), London EC1N 8SU ♦

Tel: (071) 404 3334 Fax: (071) 404 8843

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Please send me details and an application form for the Gem Diamond Course.

Name: _____

Address: _____

_____

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_____

_____ Telephone: _____ JG10/91

Meeting of the Gemmological Association and Gem Testing Laboratory of Great Britain was held.

Mr David Callaghan, FGA, chaired the meeting, and began by paying tribute to Noel Deeks and Nigel Israel for the tremendous amount of work they had undertaken during the year for the Association. He then thanked the Council of Management for their help and support, and the staff of GAGTL for their hard work.

The Annual Report and Accounts were approved and signed.

Mr Callaghan reported with regret that Sir Frank Claringbull, President of the GAGTL, had died during the year. Mr R. Keith Mitchell was re-elected Vice-President.

Mr V.P. Watson was re-elected and Mr C.R. Cavey elected to the Council of Management. Mr N. Deeks and Mr N.B. Israel retired from the Council of Management and did not seek re-election.

All members of the Members' Council were re-elected, with the exception of Mr C.R. Cavey and Mr A. Hodgkinson who did not seek re-election.

Messrs Hazlems Fenton were re-appointed Auditors.

Mr Callaghan thanked the retiring members of the Council of Management, Noel Deeks and Nigel Israel, for all they had done for the Association. He then made a presentation to them, saying: 'It is customary when someone leaves you to give them a small token to commemorate the event. On this occasion it is very difficult because of extent of the work they have undertaken, but we wish to offer them a small token of our thanks'.

This concluded the business of the meeting.

MEMBERSHIP AND QUALIFICATIONS

With the introduction of the Gem Diamond Correspondence Course and the Gem Diamond Diploma, we should like to remind members of the qualifications governed by the GAGTL and outline the circumstances of their use.

Anyone may apply to join the GAGTL and, upon approval by the Council of Management will be accepted for membership.

A member who passes the Diploma Examination in Gemmology may apply for Fellowship of the GAGTL and, upon approval by the Council of Management, may use the initials FGA after his or her name. Likewise, members who pass the examination for the Gem Diamond Diploma may use the initials DGA after their name.

Non-members may NOT use any of the above initials after their name, even if they hold our qualifications (Diploma in Gemmology, Gem Diamond Diploma, or the Diamond Certificate). Those wishing to use the initials must have current membership of the GAGTL.

Holders of the Diamond Certificate, awarded up to 1991, may use the initials DGA after their name if they are current members of the GAGTL.

Members holding both the FGA and DGA are required to pay only one membership fee.

MEETING OF THE COUNCIL OF MANAGEMENT

At a meeting of the Council of Management held on 16 October 1991 at Chapel House, Hatton Place, London ECIN 8RX, the business transacted included the election to membership of the following:

Fellowship

Abel, Arlan R., Minneapolis, Minn., USA. D.1991
Achakane, Abdelaaziz, Marrakech, Morocco. D.1989
Amo, Christopher P., Amherst, Buffalo, NY, USA. D.1991
Atkinson, Henry N., Cape Town, S. Africa. D.1991
Bailey, Lisa J., Birmingham. D.1991
Ball-Edwards, Chantal, Cheltenham. D.1991
Barratt, Claire A., Gillingham. D.1991
Benham, Spencer H., Braddan, Isle of Man. D.1991
Bouvier, Benoit, Cornwall, Ont., Canada. D.1991
Boyd, Heather K., Chorlton-cum-Hardy. D.1991
Cage, Corrall E., Ipswich. D.1991
Campbell, Daniel W., Bedminster, NJ, USA. D.1991
Chan, Chi K.R., Kowloon, Hong Kong. D.1991
Chan, Suk K.B., Pokfulam, Hong Kong. D.1991
Cheng, Kit L.C., Kowloon, Hong Kong. D.1991
Cheng, Siu H.M., Kowloon, Hong Kong. D.1991
Chow, Kam K., Central, Hong Kong. D.1991
Christaki, Ourania, London. D.l99Cipriani, Tony, St Laurent, Quebec, Canada. D.1991
Clifton, Sarah E., Edgbaston. D.1991
Collingwood, Mark A., Bradford. D.1991
Combe, Ian, Haddington. D.1991

Dayasagara, Kalupahana L.D., Nugegoda, Sri Lanka. D.1981
Dennis, Stuart G., London. D.1991
Dhir, Pablo, Nairobi, Kenya. D.1991
Evangelou, George G., Enfield Wash. D.1991
Falk, Carita L., Helsinki, Finland. D.1991
Fixter, Robert H., Lincoln, Nebr., USA. D.1991
Fromming, David E., Aylesbury. D.1991
Fung, Chung M.N., Tuen Mun, Hong Kong. D.1991
Georgiadou, Elizabeth, London. D.1991
Green, Alan A., Kidlington. D.1991
Green, Christopher M., Slough. D.1991
Hendry, Adrian L., Stansted. D.1991
Hobbs, Peter G.A., Lavenham. D.1991
Hogguer, Virginia N., AD Rijn, The Netherlands. D.1991
Hoogendoorn, Elizabeth G., Houten, The Netherlands. D.1991
Ichniowski, Jacqueline A., Ellicott City, Md, USA. D.1991
Jain, Neerja, Birmingham. 1991
Jakobsson, Thomas A., Huddinge, Sweden. D.1991
Jameson, Cynthia C.V., Bethesda, Md, USA. D.1991
King, Margaret A., Glasgow. D.1991
Kwan, Pik S., Kowloon, Hong Kong. D.1991
Lam, Kwong K., Pokfulam, Hong Kong. D.1991
Lam-Paktsun, Christiana K., Brisbane, Queensland, Australia. D.1991
Lau, Yan W.G., NT, Hong Kong. D.1991
Laurie-Lynch, Carl, Birmingham. D.1991
Lavin, Padraic, Co. Roscommon, Eire. D.1991
Lee, Mary F.A., Addlestone. D.1991
Lentz, Janine, CD Haarlem, The Netherlands. D.1991
Leung, Wing S., Kowloon, Hong Kong. D.1991
Li, Kam Y.D., Shatin, NT, Hong Kong. D.1991
Liu, Shang I., NT, Hong Kong. D.1991
Long, Ann D., Colchester. D.1991
Loong, Kok 0., Butterworth, Malaysia. D.1991
McConnachie, David C., Bearsden. D.1991
Mak, Wing H.W., North Point, Hong Kong. D.1991
Mathieson, Jacqueline N., Edinburgh. D.1991
Matthews, Lisa K., London. D.1991
Mehta, Reshma, Hong Kong. D.1991
Mueller, Hilda M.M., Karlsruhe, Germany. D.1991
Nikookar, Tahmineh, Vancouver, BC, Canada. D.1991
Pasini, Roy J., N. Olmsted, Ohio, USA. D.1991
Pattni, Rajendra A., Nairobi, Kenya. D.1991
Peers, Sharon M., Bromley. D.1991
Pehkonen, Kaarina A., Helsinki, Finland. D.1990
Penton, Keith, London. D.1991
Pool, Richard J., York. D.1991
Redgrove, Claire A., Selsey. D.1991
Rogers, John W.S., Stroud. D.1991
Rohmer, Neva D., Hong Kong. D.1991
Sabbagh, Samuel J., Minas Gerais, Brazil. D.1991
Sabbagh, Steven E., London. D.1991
Salmi, Tarja A., Helsinki, Finland. D.1991
Stewart, Carolyn L., Hong Kong. D.1991
Tamblin, Carol S., Liskeard. D.1991
Tees Audrey, Glasgow. D.1991
Tsang, Sui C., Central, Hong Kong. D.1991
Vaughan, Michael J., Budleigh Salterton. D.1991
Veenemans, Vivianne M.M., Antwerp, Belgium. D.1991
Waller, Mark S., Bradford. D.1991
Washbrook, Simon J., Stockport. D.1991
Webster, Kathleen A., London. D.1991
Welch, Lizanne, Taunton. D.1991
Wenting, Eduard J., EH Wehl, The Netherlands. D.1991
Wilson, Jane, Marford, Nr Wrexham. D.1981
Zebrowski, Rafal, Mississauga, Ont., Canada. D.1991

Ordinary Membership

Baker, Maj-Britt A.K., London.
Barnes, Stephen P., London.
Baruah, Tipsuda, London.
Batis, David, Athens, Greece.
Brahmbhatt, Baldevbhai B., Nairobi, Kenya.
Coughlin, Donald G., Colombo, Sri Lanka.
Eames, Lucy, Belgrade, Yugoslavia.
Edgerton, Edward G., Taunton. Goddard, Valerie J., Cranleigh.
Goldingay, Raymond F., St John, Jersey, CI.
Hofer, Peter, Northwood.
Hue Williams, Sarah G., London.
Jeha, Zead, Beirut, Lebanon.
Kim, Hei J., Seoul, Korea.
Kim, Sang-ki, Seoul, Korea.
Kyoung, Byun J., Seoul, Korea.
Lee, Tonny S., Taiwan, China.
Luke, Ting C.L.A., Kowloon, Hong Kong.
Lysons, Jon D.E., Macclesfield.
Magnusson, Peter A., Goteborg, Sweden.
May, Frank, Edinburgh.
Moth, Anthony D., High Wycombe.
Ozaki, Ken, Sapporo, Japan.
Piper, Rachel, London.
Prior, Louise, London.
Rajani, Kishorkumar M., Daressalaam, Tanzania.
Rawat, M.S., London.

Requena, Juan A.S., Barcelona, Spain.
Robins, Eric M., Hauraki Plains, New Zealand.
Rossell, Ramon, Andorra la Vella, Andorra.
Sakon, Yuichi, Bougival, France.
Saunders, Frank, Spennymoor, Co. Durham.
Sharma, Kul B., Lusaka, Zambia.
Shindler, Bernard D., Stanmore.
Tasaki, Kazuyo, Kobe, Japan
Tasaki, Toshiaki, Kobe, Japan.
Topham, Darren M., Brighton.
Travis, Peter J.B.C., London.
Tsipoura-Vlachou, Maria, Athens, Greece.
Turner, Ian B., Bury St Edmunds.
Van der Wal, Peter, Antwerp, Belgium.
Walker, Errol J., Oldham.
Ward-Jones, Ann, London. Williams, Alison D., Cobham.

Transfers - Ordinary Membership to Fellowship

Adams, Suzanne, Sutton. D.1991
Arbisman, Alexander, Selsdon. D.1991
Bascombe, Frieda M., Hong Kong. D.1991
Bassioudis, Vassilis, Thessaloniki, Greece. D.1991
Bensimon, Colette Z., London. D.1991
Brooks, Anna, Watford. D.1991
Chiu, Roy S.H., Hong Kong. D.1991
Collins, Stephanie, New Malden. D.1991
D'Alessandro, Martha, Rio de Janeiro, Brazil. D.1991
De Silva, Gamini, London. D.1991
De Winter, Rene G., Amsterdam, The Netherlands. D.1991
Egner, Valerie S., London. D.1991
English, Dora P., Hong Kong. D.1991
Foster, Brenda C., St Albans. D.1991 Franklin, Neil, Newcastle upon Tyne. D.1991
Fukushima, Hideali, Tokyo, Japan. D.1991
Galloway, Linda L., Hong Kong. D.1991
Gau, Robert B.R., Taipei, Taiwan, China. D.1991
Gofa, Sophia, Athens, Greece. D.1991
Grant, Miranda J., Edinburgh. D.1991
Hare, Rebecca M.A., Fleet. D.1991
Hunter, Charlotte T., Northampton. D.1991
Ito, Yuko, Kanangawa-ken, Japan. D.1991
Kejriwal, Bindu, London. D.1991
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Spencer , Riita M., Helsinki , Finland . D . 1991
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Takeda, Mari, Tokyo, Japan. D.1991
Tanigaki, Takako, Osaka City, Japan. D . 1991
Thomas-Everard, Lucilla, London. D.1991
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Wasserman, Caron J., London. D. 1991
Wates , Peter J ., Coulsdon . D . 1991
Wells, Andrew, Banstead. D. 1991
Yonehara, Machiko, Hyogo Pref, Japan. D . 1991
Zander, Marie-Claire M., Sao Paulo, Brazil. D.1991
Zwaan , Johannes C ., London . D . 1991

EXAMINATIONS IN GEMMOLOGY 1991

The following qualified in the 1991 Diploma Examinations in Gemmology, but were omitted from the list published in *The Journal of Gemmology*, 22, 8, 506-9.
Gemma Auberni i Serra, Barcelona, Spain.
Ravinda Samaranayake, Colombo, Sri Lanka.

GEM & MINERAL FAIRS 1992

Gem and Mineral Fairs will be organized by the British Lapidary & Mineral Dealers' Association during 1992 as follows:

London 11-12 April 1992. Holiday Inn, Swiss Cottage.
Leicester 16-17 May 1992. Holiday Inn.
Harrogate 29-31 August 1992. Crown Hotel.
London 17-18 October 1992. Holiday Inn, Swiss Cottage.

Further details from Fair Organizer: John F. Turner, Glenjoy, 19/21 Sun Lane, Wakefield, W. Yorkshire. Telephone 0924 373786.

FORTHCOMING EVENTS

London

Meetings will be held at the City Conference Centre, 76 Mark Lane, London EC3R 7JN, at a cost per lecture of £5.00 for GAGTL members, £10.00 a member and a guest, and £8.00 for non-members. Further details and tickets from the GAGTL.

Gemstone deposits and the trade associated with them

Tuesday 10 March 1992	Sri Lanka
Wednesday 13 May 1992	Australia
Tuesday 9 June 1992	South East Asia
Tuesday 24 November 1992	Africa

Midlands Branch

Meetings will be held at Dr Johnson House, Bull Street, Birmingham.
Further details from David Larcher on 021 554 3871.

21 February 1992	Mr Clive Burch (subject to be announced)
20 March 1992	Mr David Callaghan (subject to be announced)
10 April 1992	Annual General Meeting followed by lecture

North West Branch

Meetings to be held at Church House, Hanover Street, Liverpool 1.
Further details from Irene Knight on 051-924 3103.

19 February 1992	Helen Fraquet. 'Amber'
18 March 1992	Dr Jeff Harris. 'An aspect on diamonds'
20 May 1992	Nigel Israel. 'Historical aspects and valuations'
17 June 1992	'Exchange and Mart'. Buying and selling of books, crystals and instruments, plus social evening.
16 September 1992	Adrian Klein. 'Emerald'
21 October 1992	Dr Jamie Nelson. 'Optical attributes of a diamond'
18 November 1992	Annual General Meeting

EXAMINATIONS 1992

The examination dates for 1992 are as follows:

Gem Diamond Examination:
Theory - Wednesday 17 June
Practical - College students Wednesday 17 June
Correspondence Course students to be advised

Examinations in Gemmology:
Preliminary - Monday 29 June
Diploma Theory - Tuesday 30 June
Diploma Practical - Wednesday 1 July, or as advised
The final date for receiving examination entry forms is **31 March.**

GAGTL GEM WORKSHOPS 1992

Diamond Grading Workshop

Three-day Diamond Grading Workshops are being arranged in March and May 1992, at a cost of £300.00 plus VAT.

Diploma Course Students

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Wednesday 1 and Thursday 2 April
Tuesday 7 and Wednesday 8 April
Saturday 11 and Sunday 12 April
Saturday 25 and Sunday 26 April

The price of the Diploma Workshop is £120.00 plus VAT.

For further information and a booking form please contact Ian Mercer or Louise Macdougall at the GAGTL Education Office on 071-404 3334.

Letter to the Editor

From R. Keith Mitchell, FGA

Dear Sir,

I am a little surprised that Mr Farn's letter in your July issue should have been published without some attempt to check its facts.

I refer primarily to 'a forthcoming treatise by Eric Bruton and Keith Mitchell on Anderson's research and work with the spectroscope'. I have corrected Alec Farn on this more than once yet he persists in the error.

Eric Bruton is concerned only in so far as he has agreed to publish the book, which is not in any sense a treatise either by him or by me, jointly or otherwise. Ninety per cent of the written text is pure Anderson and if it is to be regarded as a treatise at all then it is by his hand and not mine or Eric Bruton's. My task, self-appointed, has been to edit and up-date Anderson's vastly important series of 40 articles published in the 1950s in the now defunct Gemmologist. Added to which I found it necessary to re-draw almost all of the spectra, since about half of the original T.H. Smith drawings were missing and the rest were too spoiled and dilapidated for satisfactory plates to be made. Some additional chapters were needed and many minor alterations of text were found necessary. The whole task has taken me several years, roughly three times as long as I anticipated when I originally volunteered to do the work with Barbara Anderson's approval.

It may seem strange to 'book' these articles now after more than thirty years. But the facts written so explicitly by Anderson, who, with C.J. Payne, pioneered the methods of spectroscopic gem testing, are still completely valid and applicable to normal gemmology today. This book has been needed for far too long and should now be regarded as a vital text for students and for practising gemmologists; and as a memorial to this country's greatest, and the World's first, full-time Gemmologist.

Regarding α-monobromonaphthalene, I well remember having a bottle of that liquid which was so labelled. This to my mind meant that somewhere there had to be a β-version of the stuff. But now the only text I can find which uses this antideluvian prefix to the name is Sir Henry Miers' *Mineralogy* published in 1902. Bauer, Dana Ford, Herbert Smith, Anderson, Webster and many other books I have referred to, have either dropped the practice or fail to mention the liquid at all. In a book review and letter dealing with its recent renaming there was no point at all in resuscitating ancient terminology.

My old English master more than 60 years ago made the comment that 'verbal' meant 'in words' and that those words could equally well be by 'word of mouth' or in print. However the stones sent by post for 'verbal testing' would surely be identified in a telephoned reply, so Mr Farn's interpretation of 'verbal' would apply. Strictly the word 'oral' should be used rather than 'verbal' (see *The Complete Plain Words* by Sir Ernest Gowers). For me 'verbal testing' conjures up a vision of someone talking to gems rather as Prince Charles is said to talk to flowers.

Yours sincerely,
R. Keith Mitchell
12 August 1991
Orpington, Kent.

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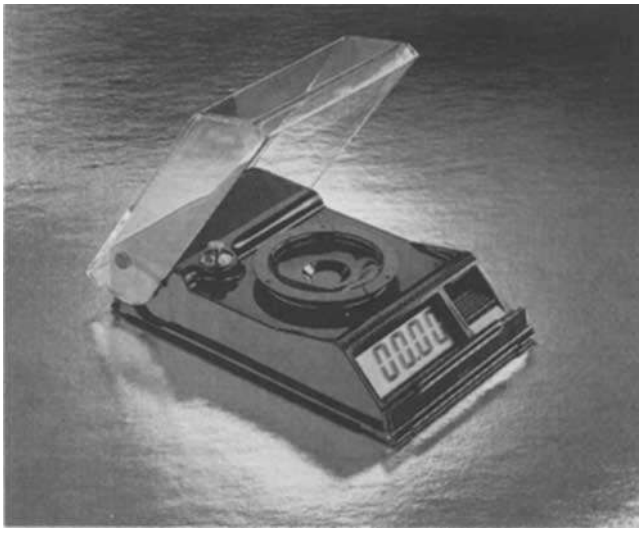

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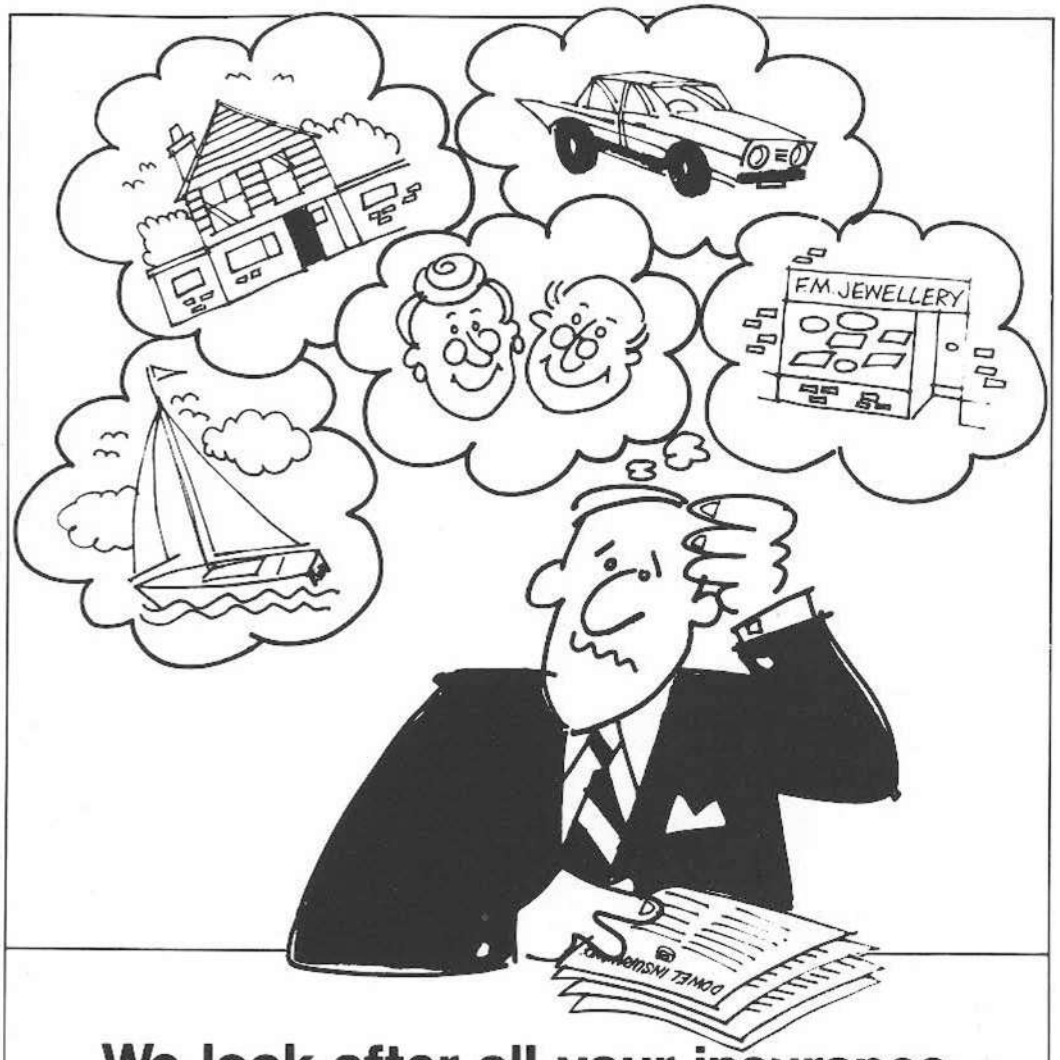

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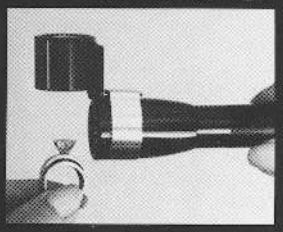

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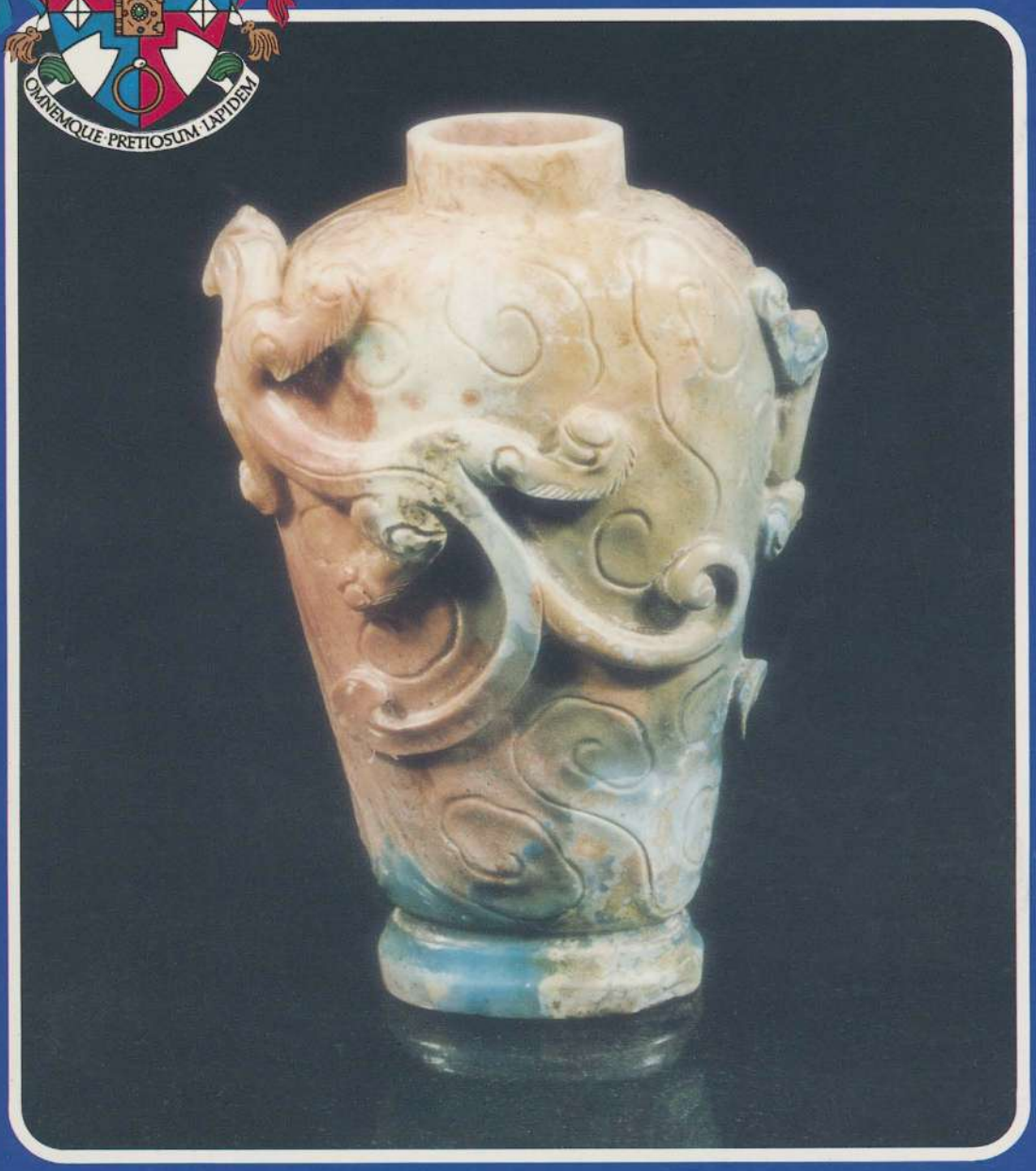

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Cover Picture

The photograph represents a vase carved from nephrite jade during the late Ming period (circa 1580). The original colour of the stone was probably a cream/white with a few veins and mineral inclusions. Unlike jadeite, nephrite will usually sustain heating to considerable temperatures, and many carvings were burnt by accident in fires, and survived the ordeal. The item illustrated is quite striking as it must have been heated in close association with other domestic objects, as metallic oxides from these have coloured some areas of its surface (if the stone is re-polished the surface colour is usually only skin deep). During the 19th century these jades were very popular in China and were manufactured and burnt intentionally in furnaces, to supply the demand for this extraordinary material. The vase stands 8.5cm tall, and varies in thickness from 1.5mm to 2.5mm.

Photograph C.R. Cavey

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Vanadian grossular garnet (tsavorite) from Pakistan

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Abstract

Faceted vanadian grossular garnets from Swat, Pakistan make exquisite gems. Though small they have a strong 'emerald green' colour attributed to vanadium. The physical properties and chemistry are similar to vanadian grossular garnets from East Africa: n 1.743, D 3.640; SiO_2 38.17, TiO_2 0.44, Al_2O_3 18.33, Fe_2O_3 0.04, V_2O_3 4.60, MnO 0.29, Cr_2O_3 0.00, MgO 0.10, CaO 36.52, Na_2O 0.00, Total 98.05 (goldmanite 12.83%, grossular 86.08%, others minor). Inclusions include graphite, wollastonite, mica, zircon negative inclusions.

Preamble

Tsavorite is the name given to the green to slightly yellowish-green variety of grossular garnet (Stockton *et al.*, 1985). 'Emerald green' tsavorite, from African sources, have been known since the late 1960's. The cause of colour in these garnets has been variously assigned to chromium and/or vanadium: the colouring agents being locality specific. Green vanadium-rich grossular garnets from Kenya engendered a great deal of interest and much has been written about them. In contrast the vanadian 'emerald' green tsavorites from Pakistan, even though equally attractive, have receive little gemmological attention presumably because they are less abundant and generally smaller.

Anderson (1966) described transparent green grossular sent from Pakistan in the hope that they might be emerald. These, he states, were similar to a specimen he had examined a year before and all specimens showed a chromium absorption spectrum. Tsavorite, from the Swat area of northern Pakistan, has been recorded, though not in detail* (O'Donoghue *pers comm.*).

This study is based on a parcel of 25 cut stones, weighing 2.5ct, from the Swat area.

*Green grossular has been found in graphitic schists in Jambil area of Swat, near Koy in Malakand Agency and near Targhao in Bajaur Agency. The Jambil garnets are of excellent green colour though very small.

Colour and chemistry

The overall colour to the eye is one of rich vivid greens with no apparent yellow component. Even the smallest stones, 0.02ct, display a strong depth of colour.

The analyses presented in Table 1 were carried out on a Microscan V electron probe microanalyser operating at an accelerating potential of 20kV with a probe current of 30 nanoamps. Standards used in calibration were as follows:- wollastonite for silicon and calcium, jadeite for sodium, corundum for aluminium, periclase for magnesium, and rutile for titanium; other elements (vanadium, chromium, manganese and iron) were calibrated against pure metals.

Surprisingly, even given the difficulty in estimating chromium because of VKβ and CrKα overlap, chromium is believed to be absent or in quantities below the resolution of peak overlap. Cr_2O_3 concentration based on the calculated limits of detection has a maximum value of 0.05% though any Cr_2O_3 presence is likely to be even less than this. Studies of the effect of weight %Cr_2O_3 on the % of green coloration trends (Manson *et al.* 1982) indicated that Cr_2O_3, despite two exceptions, in amounts of less than 0.05% contributed to no more than 35% of the green coloration. On the other hand V_2O_3 concentrations above 2% contribute over 80% to the green coloration trend. With V_2O_3 concentrations averaging 4.52% the major, if not sole, influence on colour is therefore clearly vanadium. The fact that no colour change was observed through the Chelsea Colour Filter reinforces this view.

No significant chemical zonation was detected in either sample though the relationship between the proportions of V_2O_3 and Al_2O_3 indicated that vanadium was replacing aluminium in the ideal grossular formula $Ca_3Al_2(SiO_4)_3$ giving the general formula $Ca_3(Al,V,Fe)_2(SiO_4)_3$: Table 1.

Physical properties

The optical and specific gravity properties of

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Table 1: Analyses of green vanadian grossular garnets from Swat, Pakistan.

	Sample 1 (1-8)						Sample 2 (9-15)								
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
SiO_2	37.73	38.17	37.96	38.19	38.42	38.00	38.36	38.12	38.22	38.41	37.81	38.42	38.36	38.07	38.21
TiO_2	0.44	0.43	0.44	0.43	0.45	0.47	0.44	0.44	0.43	0.43	0.46	0.46	0.43	0.46	0.44
Al_2O_3	18.33	18.54	18.63	18.44	18.29	18.17	18.81	18.58	18.47	18.71	18.67	18.81	18.19	18.33	18.66
Fe_2O_3	0.04	0.05	0.05	0.05	0.04	0.07	0.03	0.03	0.05	0.04	0.05	0.06	0.05	0.06	0.05
V_2O_3	4.60	4.56	4.53	4.56	4.69	4.93	4.27	4.43	4.60	4.38	4.41	3.87	5.14	4.62	4.27
MnO	0.29	0.29	0.31	0.28	0.29	0.27	0.31	0.32	0.31	0.30	0.29	0.30	0.26	0.30	0.32
Cr_2O_3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MgO	0.10	0.09	0.10	0.09	0.09	0.11	0.10	0.11	0.09	0.10	0.11	0.10	0.10	0.09	0.09
CaO	36.52	36.61	36.56	36.65	36.72	36.66	36.69	36.67	36.28	36.44	36.61	36.83	36.54	36.75	36.71
Na_2O	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	98.05	98.74	98.58	98.69	98.99	98.68	99.01	98.70	98.45	98.81	98.41	98.85	99.07	98.68	98.75

	(a)	(b)	(c)
SiO_2	38.17	38.70	39.26
TiO_2	0.44	0.25	0.43
Al_2O_3	18.51	20.90	21.28
Fe_2O_3	0.05	*0.05	0.10
V_2O_3	4.52	3.30	1.70
Cr_2O_3	0.00	0.19	0.00
MnO	0.30	0.75	0.74
MgO	0.10	0.50	0.50
CaO	36.62	35.10	36.12
Na_2O	0.00	0.10	0.02
Total	98.71	99.84	100.15
Uvarovite	00.00	00.55	00.00
Andradite	00.13	00.00	00.27
Grossular	86.08	86.31	91.41
Pyrope	00.35	1.82	1.81
Spessartine	00.60	1.55	1.53
Almandine	00.00	00.10	00.00
Goldmanite	12.83	9.68	4.98

(a) Average analysis of tsavorite from Swat Valley, Pakistan

(b) Tsavorite from Lualenyi, Kenya (Gubelin & Wiebel, 1975)
(* as FeO)

(c) Average analysis of tsavorite from Lualenyi (Taita Taveta locality)
(Key & Hill, 1989)

% molecular end members

Table 2

	n	D	n (calc)	D (calc)
Grossular	-----	-----	1.734	3.594
Goldmanite	-----	-----	1.832	3.765
Tsavorite (Swat Valley)	1.743	3.640	1.735	3.62
Tsavorite (Lualenyi)	1.743	3.610		

grossular vary considerably as the non grossular components, particularly andradite, increase. The above analyses (Table 1) indicate that the tsavorite from Swat Valley has a high goldmanite ($Ca_3V_2(SiO_4)_3$) component. Table 2 presents the calculated values of refractive index and specific gravity for end member grossular (Deer *et al.*,1982) and goldmanite (Strens,R.G.J., 1965) together with the observed and calculated mean values for Swat Valley and observed values for Lualenyi, Kenya (O'Donoghue, M.,1988) tsavorite.

Absorption spectrum

The absorption spectra of tsavorites vary with the colouring agent. Those tsavorites coloured by chromium can show a doublet at 697mn with weaker lines at 660nm and 630nm and diffuse bands near 605nm and 505nm: these are often difficult to observe.

Vanadian tsavorites on the other hand rarely show anything other than general absorption of the far blue and violet beginning at about 460nm. In addition to this some very faint diffuse absorption of the red/orange and yellow was observed in the Swat Valley material.

Inclusions

Most stones show fracturing to varying degrees some of which has been partially healed or filled with secondary iron staining. There are occasionally very small platy, irregular to crudely hexagonal, negative gas filled inclusions. These, along with tiny droplets which often show necking down features, are characteristically arranged in wispy veils. There are also a considerable number of very small mineral particles included in most stones; those anisotropic crystallites with high relief and surrounded by tension haloes are thought to be zircons, the remainder, as yet unidentified, often forming dark spotted wispy trails. The latter may be due to small negative inclusions, the walls of which have been coated with secondary material. Slightly rounded hexagonal platy inclusions of, presumably, graphite are common. These occur as black opaque crystals and aggregated crystal masses and tend to occur in swathes with a high degree of preferential alignment though isolated crystals are not uncommon (Figure 1). Minor leaching of the graphite and subsequent replacement with secondary iron oxides gives rise to brown and reddish-brown rounded hexagonal patches.

Hexagonal and rectangular columnar inclusions with low relief and no evidence of extinction are thought to be negative crystals formed by the leaching of the original material and subsequent coating of the cavity walls with secondary staining (Figure 2). These are similar to the so called corrosion tubes found in East African green vanadian

Fig.1 Aligned rounded plates of graphite with iron staining and minor mica.

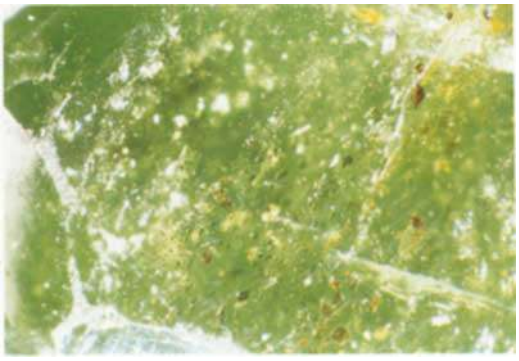

Fig.2 Elongated negative inclusions (gemstone is immersed in diiodomethane)

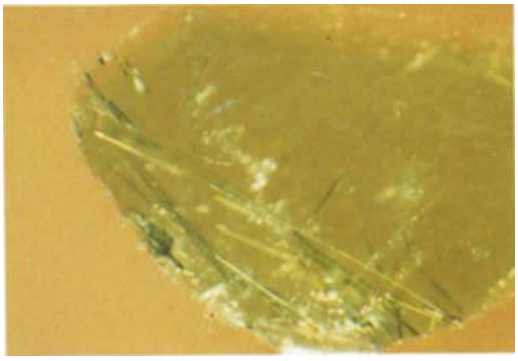

grossular garnets. Occasionally small thin plates of mica are seen. During microprobe analysis an inclusion was encountered that gave the following analysis (Table 3).

Table 3: Microprobe analysis of an inclusion in vanadian grossular garnet from Swat, Pakistan, compared with wollastonite polymorphs.

	mineral inclusion	wollastonite -1T	wollastonite -7T	wollastonite -2M
SiO_2	51.46	50.57	51.73	50.42
TiO_2	00.00	00.16	00.00	00.01
Al_2O_3	00.08	00.33	00.00	00.00
Fe_2O_3	00.00	03.09	00.00	00.00
V_2O_3	00.00	00.00	00.00	00.00
Cr_2O_3	00.00	00.00	00.00	00.00
MnO	00.10	01.94	00.00	00.16
MgO	00.06	00.42	00.00	00.02
CaO	48.27	43.65	48.30	48.65
Na_2O	00.00	00.14	00.00	00.01
Total	99.97	100.25	100.03	99.29

On the basis of the analysis and a subsequent match using Minident-PC (A computer program for mineral identification) the inclusion is thought to be one of the wollastonite polymorphs.

The inclusions in tsavorite from Swat Valley are very similar to the inclusions seen in tsavorite from East Africa. This reflects the comparable geological environment in which they occur: graphitic gneiss in East Africa and graphitic schist in Pakistan.

Summary

Faceted vanadian grossular garnets from Pakistan make exquisite gems. Though small they have a strong 'emerald green' colour attributed to the high vanadium content (4.60%). The properties and inclusions are similar to vanadian grossular garnets from East Africa.

Acknowledgements

I am most grateful to P.G. Hill, Geology Dept., Edinburgh University, for undertaking the microprobe analyses.

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An examination of 'Aqua Aura' enhanced fashioned gems

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Fig. 1. Two faceted rock crystal quartz gems prior to treatment by the 'Aqua Aura' process. *Photo by Robert Weldon, Gemological Institute of America.*

Fig. 2. These four faceted gems have all been treated by the 'Aqua Aura' process. The two in the centre are quartz, shown in their pre-treatment state in Figure 1; the two outer specimens are topaz. *Photo by Robert Weldon, Gemological Institute of America.*

Abstract

This article reports on the background and gemmological properties of faceted quartz and topaz gems enhanced by the 'Aqua Aura' process. This treatment involves the deposition of a fine surface layer of gold on the fashioned stones.

Introduction

The authors have reported previously in the gemmological literature on 'Aqua Aura' quartz, single crystals and crystal clusters of colourless quartz which had a thin film of gold applied to their external, natural surfaces. These treated specimens displayed both the blue to greenish-blue transmission colour of the gold as well as a thin-film, superficial iridescence (Koivula and Kammerling, 1988; Kammerling and Koivula, 1989).

Subsequent to the publication of those reports, the authors contacted the vendor, Mr Bob Jackson

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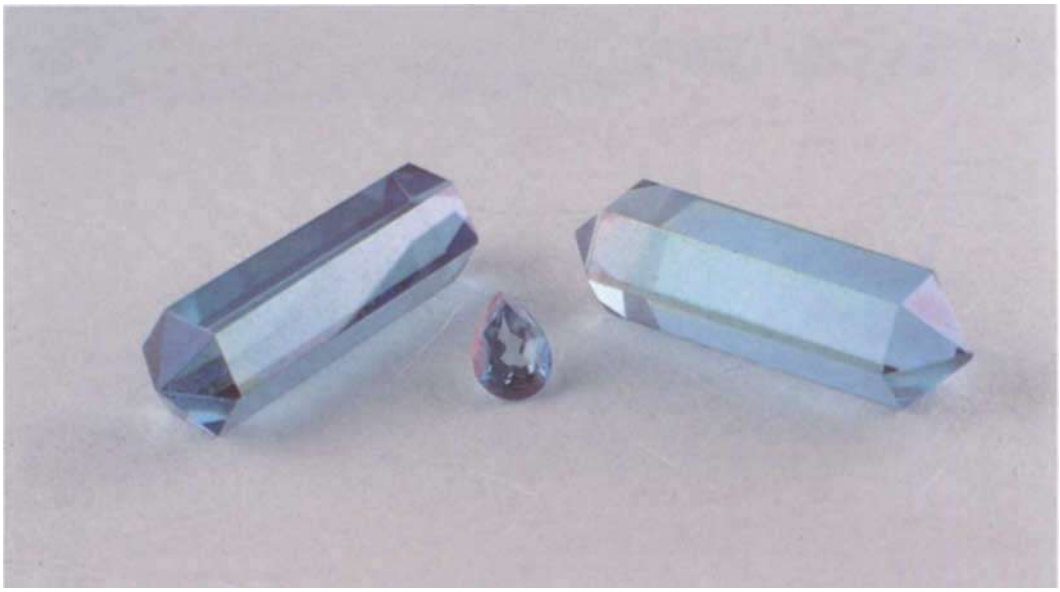

Fig. 3. The two faceted 'prisms' and pear-shape brilliant are all quartz gems treated by the 'Aqua Aura' process. *Photo by Maha Smith, Gemological Institute of America.*

of Renton, Washington, who agreed to attempt treatment of some faceted stones for us on an experimental basis. Submitted for this purpose were two each colourless quartz (Figure 1), beryl, synthetic cubic zirconia and topaz. Mr Jackson later returned the successfully treated faceted quartz gems which had taken the treatment (Figure 2); also returned were the unsuccessfully treated cubic zirconia and topaz, plus fragments of the beryls. According to Mr Jackson, at that time only the quartz gems had taken the treatment and the beryls had 'exploded' (the latter, we surmise, may have been due to fluid inclusions which ruptured during treatment). Mr Jackson indicated, however, that these were some of the first faceted stones they had attempted to have treated with this process (B. Jackson, pers. comm.). Thus, successful treatment of gems other than quartz was not ruled out.

In the spring of 1989 a report in a US lapidary hobbyist magazine shed further light on this enhancement method (Hadley, 1989a). According to the report, the process was developed by Messrs. Bill McKnight and Tom Stecher of Vision Industries, Lynnwood, Washington. A second report appearing four months later in the same publication indicated that faceted gems were also being treated (Hadley, 1989b).

This treating of faceted stones is now taking place on a commercial basis. In the autumn of 1989 we obtained two fashioned pieces at a gem show in Santa Monica from International Crystal

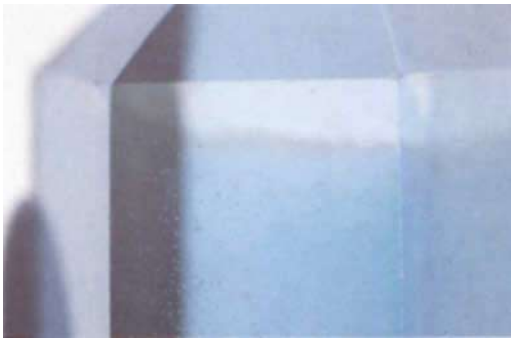

Fig. 4. Note the large colourless area on this treated quartz gem where there is no surface treatment Magnified 4x. Diffused transmitted light. *Photomicrograph by John I. Koivula, Gemological Institute of America.*

Fig. 5. The apparent body colour and superficial iridescence are both noticeable in these three faceted 'Aqua Aura'-treated topazes. *Photo by Maha Smith, Gemological Institute of America.*

Company, Inc., of Seattle, Washington. These were quartz that had been fashioned into hexagonal 'prisms' with pyramidal terminations (Figure 3). Then, at a Los Angeles gem show in November 1989 we first saw 'Aqua Aura' treated faceted topaz set in silver pendants. The vendor, TransGem Corporation of West Bend, Wisconsin, was contacted for further information. In response, Mr Johnathan J. Parentice of TransGem informed us that they were soon to begin marketing this material nationwide and that some 10,000 carats were being submitted for enhancement in December. Mr Parentice also kindly provided us with several samples for our examination.

Gemmological Properties

Quartz: The quartz gems examined gemmologically consisted of a 0.70 ct pear-shape brilliant cut supplied by TransGem and the two faceted 'prisms' (16.63 and 18.18 ct) obtained from International Crystal Company (again, see Figure 3).

Topaz: The treated topaz gems examined gemmologically consisted of eleven faceted stones supplied by TransGem. These included two oval brilliants of 2.12 and 2.21 ct and nine pear-shape brilliants ranging from 0.71 to 2.19 ct (again, see Figure 2; also, Figure 5).

Table 1: Gemmological properties of 'Aqua Aura' treated gemstones.

	Quartz	Topaz
Colour	Ranging from medium light to medium dark slightly greenish-blue with weak to strong superficial iridescence. The pear-shape brilliant and smaller of the two 'prisms' appeared quite uniform in colour; the larger 'prism' displayed one large colourless area (Figure 4).	Ranging from medium light to medium dark blue to greenish-blue; in all cases the stones faced up a very uniform colour. They exhibited an overlying weak to moderately strong iridescence that was most noticeable on the larger stones.
Diaphaneity	Transparent	Transparent
Refractive Indices	Readings obtained on the two 'prisms' were somewhat vague at 1.542-1.550 while the pear-shape stone gave similarly somewhat ill-defined readings at 1.543-1.551. Birefringence on all three specimens was 0.008. All readings taken with a Duplex II refractometer and near-sodium equivalent light source.	Alpha = 1.610, +/- 0.001; beta =1.614, - 0.001; gamma= 1.620, - 0.001; birefringence 0.009-0.010 .
Optic Character	All three specimens displayed 'bull's-eye' uniaxial optical interference figures between crossed polaroids and plotted uniaxial positive on the refractometer.	Biaxial optical interference figures were resolved on nine of the eleven stones; all eleven plotted biaxial positive on the refractometer.
Pleochroism	None noted when examined with a calcite dichroscope.	None noted when examined with a calcite dichroscope.

	Quartz	Topaz
Ultraviolet Fluorescence	All three specimens were inert to both long- and short- wave radiation; there was no phosphorescence.	All eleven stones were inert to both long- and short- wave radiation; there was no phosphorescence.
Chelsea Filter Reaction	Inert (appeared brownish-green).	Inert (appeared brownish-green to green).
Absorption Spectra	No distinct features noted when examined with either a Beck prism spectroscope or a DISCAN digital-readout diffraction grating unit.	No distinct features noted when examined with either a prism or diffraction grating unit.
Specific Gravity	All three stones sank very slowly when immersed in a solution of methylene iodide and benzyl benzoate calibrated to S G 2.67. The S G was thus estimated to be approximately 2.70.	The specific gravity was determined on two of the larger stones using the hydrostatic weighing method. This produced values of 3.58 for both stones.

Magnification

Examination using a stereoscopic binocular microscope revealed diagnostic features of the 'Aqua Aura' enhancement of faceted gems. When examined with diffused, direct transmitted light, all of the faceted specimens— both topaz and quartz exhibited one or more of the following features: (1) diffused, dark outlining of some facet junctions (Figure 6); (2) white-appearing facet junctions where either the treatment did not 'take' or where it had been abraded away (Figure 7); (3) a combination of fine white-appearing facet junctions immediately bordered on either side by slightly dark blue outlining; (4) irregular, minute, random white-appearing abrasions on facet junctions and/or surface pits, scratches and areas where the treatment did not take on facet surfaces (Figure 8); (5) irregular blue coloration on some facets and slight iridescence visible even in diffused transmitted light (Figure 9); areas of no colour on some facets (again, see Figure 8). One of the pearshape topazes exhibited an area of exceptionally heavy deposition near its point. When examined in surface-reflected light under magnification, the iridescence became very noticeable on all specimens and the surface irregularities were easy to detect (Figure 10).

Durability

Additional testing was carried out to determine some of the durability characteristics of this surface enhancement. Both quartz and topaz specimens were first exposed to the electrically heated tip of a thermal reaction tester, this produced no noticeable effect on the treatment later even when the tip was a bright reddish orange. Furthermore a number 6 Mohs hardness point failed to scratch an 'Aqua Aura' faceted quartz gem and a number 7 Mohs hardness point similarly had no apparent effect on one of the enhanced topazes. However, subsequent testing with a buffing wheel and jeweller's rouge--the kind of abrasive action a stone might face when prongs are buffed--resulted in the removal of some of the gold coating from stones where they came in contact with the polishing wheel. The fact that normal polishing in the course of jewellery manufacture or repair will remove some of the coating should be taken into consideration by anyone working with 'Aqua Aura'-treated gems. Stone repolishing or recutting also would be expected to remove the treatment layer (Koivula and Kammerling, 1991).

Discussion and Conclusions

The more greenish-blue specimens of 'Aqua Aura' treated quartz or topaz could be visually mistaken for heat-treated zircon, especially those displaying fairly prominent iridescence, as this might at first glance be mistaken for dispersion. Refractive index, birefringence and specific gravity readings, however, would quickly help to identify the gem materials as topaz or quartz respectively.

While there is no natural blue single-crystal quartz with which the 'Aqua Aura' quartz could be confused, it does bear a resemblance to some

Fig. 6. Dark, diffused outlining of facet junctions, as exemplified by this topaz, is a key feature of 'Aqua Aura' treatment of faceted gems. Magnified 6x. Diffused transmitted light. *Photomicrograph by John I. Koivula, Gemological Institute of America.*

Fig. 7. The diagnostic white-appearing facet junctions on this treated topaz represent areas where either the treatment did not 'take' or where it has been abraded away. Magnified 10x. Diffused transmitted light. *Photomicrograph by John I. Koivula, Gemological Institute of America.*

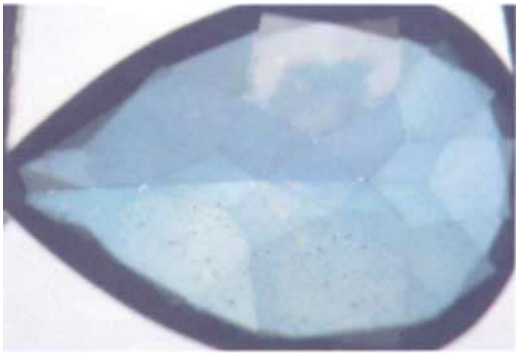

Fig. 8. This 'Aqua Aura' treated topaz exhibits characteristic irregular, minute, random white-appearing abrasions on facet junctions and surface pits and scratches on facet surfaces. Note also the colourless area at the top of the photo. Magnified 4x. Diffused transmitted light. *Photomicrograph by John I. Koivula, Gemological Institute of America.*

Fig. 9. Several of the facets on this treated topaz display irregular blue coloration. Magnified 6x. Diffused transmitted light. *Photomicrograph by John I. Koivula, Gemological Institute of America.*

Fig. 10. When examined in surface-reflected light under magnification, the iridescence on this 'Aqua Aura' treated topaz becomes very noticeable and the surface irregularities are easy to detect. Magnified 12x. *Photomicrograph by John I. Koivula, Gemological Institute of America.*

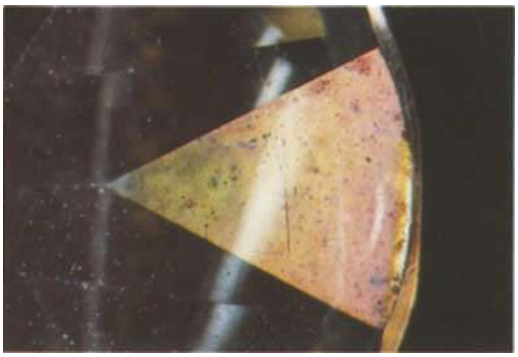

cobalt-doped blue synthetic quartz. In this instance Chelsea filter reaction and absorption spectrum would make the separation, as the synthetic quartz appears pinkish through the filter and exhibits cobalt absorption (Liddicoat, 1989). The 'Aqua Aura' topaz might easily be mistaken initially for the irradiated blue topaz which is so prevalent in today's gem market; Mr Parentice did in fact acknowledge that TransGem's product could be used as an alternative (J. Parentice, pers. comm.). In all cases, however, with both the topaz and quartz gems the superficial iridescence is a strong indicator and magnification would quickly reveal the 'Aqua Aura' treatment. The total absence of pleochroism might also draw suspicion.

One final point worth noting relates to two of the features seen under magnification. It struck the authors that both the dark concentrations of colour along facet junctions and the uneven coloration were similar to features we have noted on blue diffusion-treated sapphires which are being seen with more regularity in the gem trade (Kane *et al.*, 1990).

Acknowledgements

The authors would like to thank Mr Bob Jackson of Renton, Washington, for treating and providing materials; and Mr Johnathan J. Parentice of TransGem Corporation, West Bend, Wisconsin, for providing treated gems and information.

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[Manuscript received 8 October 1990]

A Book Anniversary

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For gemmologists this is the fiftieth year of one of our best and most enduring textbooks. I refer of course to the late B.W. Anderson's *Gem Testing*, first published by Heywood & Company under the slightly more limiting title *Gem Testing for Jewellers* in 1942.

Anderson had at that time headed the London Chamber of Commerce Pearl and Precious Stone Laboratory for some seventeen years and was the foremost gemmologist in this country and already renowned world-wide. It would have been difficult to find a more suitable author for such a book, or one more capable of conveying his very considerable knowledge in an eminently readable form to the comparatively unscientific reader.

That first modest hard-cover edition ran to 194 pages with 43 illustrations, and retailed for the now astonishingly low price of 7/6 in old coinage, 37.5p today. 2nd and 3rd editions appeared in 1943 and '44 which were in truth simply reprints of the first owing to war-time restrictions on paper and other materials.

1947 saw the re-written 4th edition which ran to 224 pages and 53 illustrations, plus a coloured frontispiece of absorption spectra drawings as seen through a diffraction grating instrument, which had been recommended in the earlier editions, although the text now came down firmly in favour of the Beck 2458 prism instrument.

A 5th edition in 1951 (German version in 1955) was augmented to 246 pages and 62 illustrations, and included synthetic rutile, synthetic star rubies and sapphires and added some 20 of the rarer gems to the appendix list of stones.

The 6th edition (1958) brought in synthetic strontium titanate, new emerald synthetics and a sintered spinel imitation of lapis lazuli. New identification techniques included immersion contrast photography and the crossed filter fluorescence test, both introduced to gemmology by Anderson some years earlier.

Further types of synthetic emerald were included in the 7th edition (1964), and new sources of fine ruby and emerald from African locations were dealt with. The newly discovered radio-active mineral ekanite from Ceylon (Sri Lanka) was included for the first time, while flesh-nucleated fresh-water cultured pearls from Japan, and other non-nucleated ones from the coastal waters of Australia and Burma, were also discussed.

The 8th edition (1971) (French and Italian 1973; Spanish 1977) introduced the 'rare-earth garnets', man-made products of laser research many of which were cuttable as gems; more new synthetic emeralds and new jade-like massive natural garnets and chalcedonies. The most important new gem included in this edition was the violet-blue form of the mineral zoisite which was named tanzanite after its country of origin.

The 9th edition (1980) (Japanese and Russian 1983, Italian 1984) described more innovative gems than any previous edition. These included synthetic turquoise, alexandrites and opals; cubic zirconia, by far the most successful simulant of diamond; Slocum imitation opals; new opal doublets; various synthetics by processes more akin to those of nature; colour improvement by oiling, impregnating, staining and irradiation; fine green grossular garnets; garnets with a colour change; new sources of fine rubies, emeralds and other gems in Africa.

The Dialdex refractometer by Rayner, and the RIPlus which reads to 2.26, and other instruments involving the reflection of infrared light were described. And in this edition prism type spectra were illustrated in black and white both in the European 'red on the left' version, and the American 'red on the right' version.

That, very regrettably, was to be the last edition prepared by Basil Anderson himself, for he died suddenly and peacefully aged 82 in January 1984. But such a valuable and popular textbook could not be allowed to die with its author, and several years later Mr E.A. Jobbins, formerly Curator of Gems and Minerals at the Geological Museum, was asked to produce another edition.

The 10th and current edition (1990) ran to 389

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larger pages, with 160 illustrations in black and white (a few of which span the half century), plus seventy excellent colour plates which were largely the very skilled work of Mr Jobbins himself.

It still contains a great deal of Anderson's original and explicit text from the earlier editions, but has been skilfully and compatibly updated and expanded to give new chapters on the manufacture of synthetics and imitations, and on gemstone enhancement, while the existing chapter on the detection of synthetics, imitations and composite stones has been rearranged, and in part re-written.

Faceted yellow synthetic diamonds are dealt with and new reflectivity and conductivity meters to combat diamond simulants are described. The artificial production of fancy colours in diamond by various types of irradiation is discussed and ways to identify such treatment are given.

Many new sources of gems from such widely differing places as Brazil (fine alexandrites); Nigeria (sapphire and aquamarine); Kenya/Tanzania (new colours in garnets); Pakistan (fine emeralds and natural pink topaz); Afghanistan (kunzite) and a very promising range of gems from China, are described.

Over the years various of the earlier editions have been translated into many languages. In view of the vastly enhanced compilation of valuable gemmological facts now within the covers of this tenth edition, I feel there is a good case for further translations into those and other languages to bring students in foreign countries up to date in the gemmological scene.

Basil Anderson, the enthusiast and pioneer of so much of our trade science, has passed on in the fullness of time, but this splendid textbook remains as a best-selling tribute to his remarkable genius and life-long love of gems, and may well do so for many more editions and years to come.

[*Manuscript received January 1992.*]

Radioactive glass imitation emeralds and an unusual Verneuil synthetic ruby

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Abstract

Radioactivity in glass substitutes has been reported recently ([1, 2]). Induced fingerprints in Verneuil synthetics are not unknown, but in a lamellar-twinned synthetic they can be even more deceiving. This article reports on the use of treatments to alter the appearance and consequently to make a straightforward identification more difficult.

Radioactive glass imitation emeralds

A pair of emerald-cut green stones that approached the finest emerald colour were received recently by the author for identification.

Approx. measurements and weight
14.69 × 11.97 × 7.60mm, 12.46 carats
14.99 × 11.94 × 6.81mm, 11.07 carats

Under a Bausch & Lomb Mark V Gemolite binocular microscope using dark field illumination, the stones were found to contain skeins of large and small gas bubbles, which with a 10× lens could easily have been mistaken for natural fluid inclusions (Figures 1 and 2).

The refractive index determination carried out using a Rayner Dialdex refractometer and monochromatic sodium light gave 1.635. Under the polariscope, the stones confirmed their optic character to be isotropic.

Their specific gravity was obtained by hydrostatic weighing of the stones in distilled water using a Mettler electronic PL 300C carat scale, and the stones were found to have a specific gravity of 3.754 and 3.767.

The fluorescence was examined with a Multispec combined LW/SW unit, and both stones showed under long-waves chalky orange; and under short-waves chalky green.

The absorption spectrum seen through a Gem Beck Spectroscope Unit showed a strong absorption 400-440 nm, a set of two lines centred at 460, 470 nm, and a strong absorption 600-700 nm.

The two stones were identified as glass, and according to Bannister's graph could be either lead glasses or barium glasses ([3]).

A routine test performed by the author is to submit all stones he receives to a Geiger counter. To his great surprise, when the glass imitation emeralds were submitted to a Solar Electronics Radiation Alert Monitor 4, they were found to be radioactive (Figure 3).

Although the radioactivity recorded showed 0.08 mR/h if only one glass rested on the counter window of the Monitor 4, it records 0.12 mR/h when the two glasses were tested together under the same condi-

Fig. 1. Skeins of large and small gas bubbles found as inclusions in the radioactive glass imitation emerald.

Fig. 2. A similar type of inclusion showing a large and well formed gas bubble.

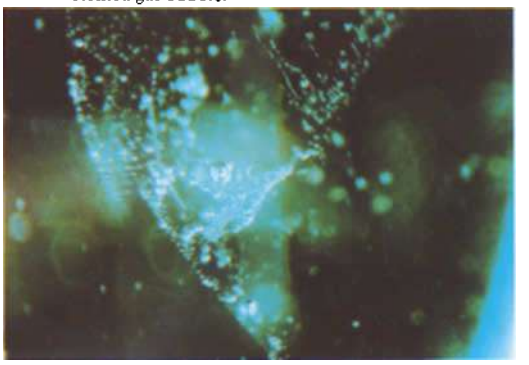

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tions (Figure 4). It should be noted here that background levels indicate 0.00 mR/h to 0.02 mR/h. This means that these two glasses when tested together were registering up to twelve times background levels.

Discussion

Unfortunately, the author was unable to perform a qualitative chemical analysis to determine the heavy elements contained in these glasses (lead, iron, uranium, etc.), so the question remains open as to their composition.

According to the gemmological data, the author believes that these glasses could be lead glasses containing uranium and iron. This would be an answer both for the radioactivity observed and for the iron absorption spectrum recorded. Anyway, this is purely of an academic interest only. The important point is to be aware that since many gemstones are irradiated, it is wise to check these routinely with a Geiger counter for radioactivity. It is also important to realize that as shown in Figure 3, the radioactivity increases with quantity. In other words, if a sole 'weakly' radioactive stone presents 'little' danger, a set composed of these would certainly be of 'some' risk.

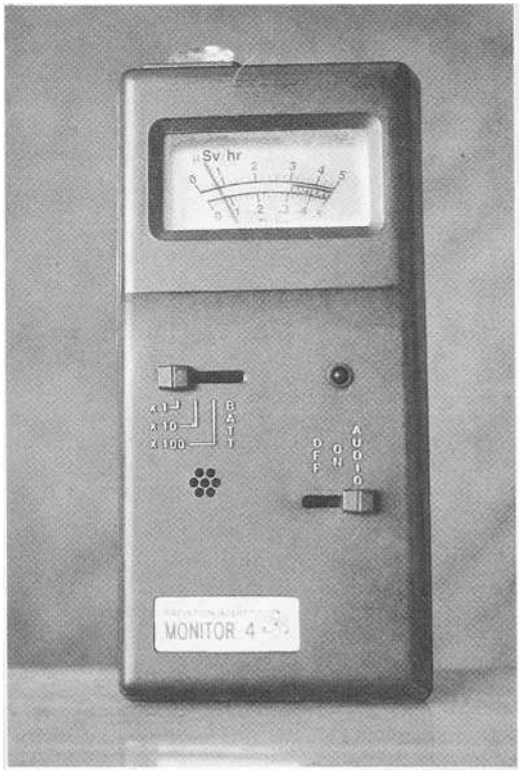

Fig. 3. The radioactivity of 0.08 mR/h recorded by Solar Electronics Radiation Alert Monitor 4, for a single glass imitation emerald.

Fig. 4. The radioactivity of 0.12 mR/h recorded under the same conditions, but for the pair of glass imitation emeralds.

Lastly, considering these glasses formed a pair, what would be the consequences if these were set as ear-clips, worn daily near the lymphatic glands.

The question as to why simulate emeralds with radioactive glass finds no positive answer, for there exist very good imitations with colouring agents other than uranium.

A Verneuil synthetic ruby showing polysynthetic twin lamellae and induced fingerprints

Among the interesting stones held by a private collector was a 6.84 ct cushion-shaped red stone that was bought some 15-20 years ago as a ruby.

Although the owner had some doubts concerning the authenticity of the stone, it is only recently that he decided to have it tested.

Routine gemmological tests: refractive indices, absorption spectrum and specific gravity, confirmed the stone to be corundum, variety ruby. The next step was to tell whether the ruby was natural or synthetic.

The stone measured approx. 11.15 × 9.76 × 6.20mm, was surprisingly well proportioned with a symmetrical pavilion.

Fig. 5. Fractures and fingerprints as they appeared under the microscope, in the Verneuil synthetic ruby.

Fig. 6. Induced fingerprints showing a dendritic-like pattern, observed under the microscope in the Verneuil ruby.

The visual appearance revealed many internal fractures, with some breaking the surface. Under a 10× lens, numerous 'feathers', some with healed 'fingerprint' patterns could be seen. Since 'fingerprints' are also encountered in many modern sophisticated synthetics (Chatham, Kashan, Knischka, Ramaura, etc.), and can be induced in Verneuil synthetics ([4]), these had to be closely examined to see if they contained liquid and gas-filled voids, like the genuine corundums, or were filled with solid flux, like the synthetics.

Observed under the microscope, the fractures and the 'fingerprints' were immediately seen (Figure 5). With higher magnification, the filled healed fractures showed a dendritic-like pattern, probably due to the crystallization of the low temperature melt (?) induced in them (Figure 6).

Another deceiving inclusion observed under high magnification consisted of a small dense 'nest' of very fine gas bubbles (Figure 7). These found lying between internal strain fractures could incorrectly have been taken for exsolved rutile needles.

Straight and parallel twinning lines were also present in this stone (Figures 8 and 9).

It should be noted here that with crystal inclusions, healing planes filled with liquid drops and zonal effects in straight lines, polysynthetic twin lamellae are regarded as one of the characteristics of genuine corundum. If this twinning occurs frequently in rubies (Thai, East Africa), it is less so in sapphires (Pailin, East Africa). In synthetic Verneuil corundum, and due to the fact that a 'boule' consists in general of a monocrystal, this type of twinning is encountered rather exceptionally. To this day, out of hundreds of synthetic Verneuil corundums observed by the author, only two showed this type of twinning ([5]).

Prominent tightly curved structure lines, similar to the grooves seen on a gramophone record, were present as could be expected in a flame-fusion synthetic ruby (Figure 10).

Although it was evident that this was a synthetic flame-fusion Verneuil ruby, it was decided for effectiveness to perform an ultimate test.

Fig. 7. Small dense 'nest' of very fine gas bubbles lying between internal strain fractures. Observed under the microscope in dark-field illumination, in the synthetic Verneuil ruby.

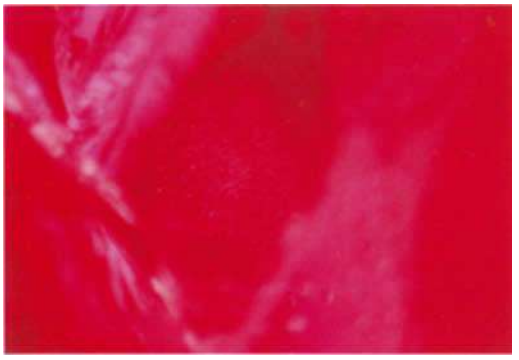

Fig. 8. Straight and parallel twinning striations as they appeared under the microscope, in the synthetic Verneuil ruby.

Fig. 9. Detailed view of a polysynthetic twin lamellae, observed under the microscope. Notice the fracture breaking the surface of the synthetic Verneuil ruby.

Fig. 10. Curved growth lines and the fractures, observed under the microscope in the synthetic Verneuil ruby.

The stone was immersed in methylene iodide, between crossed polars set to their dark position; once the optic axis was located, a 'Plato striation' effect, which betrays Verneuil synthetics was obtained (Figure 11).

Discussion

The unnatural appearance of synthetic Verneuil stones that are devoid of inclusions can be considerably improved by the act of 'quench-crackling', and letting a chemical substance such as borax crystallize into the cracks to form 'fingerprint-like' patterns.

If the former is an early synthetic Verneuil, like the one described here, then the existing small groups of gas bubbles it contains, in conjunction with the newly created environment, can be misinterpreted, and add to the confusion.

Had this stone been cut by an innocent lapidary, with a 'native' cut instead of the mechanical symmetrical cut this stone showed, this surely would have increased the possible confusion. Especially if a jeweller came across this stone on a buying trip in gem localities, where he would normally expect to see genuine stones, with a 10× lens as his sole equipment.

Concluding thoughts

For the author, radioactive glass imitations, and induced fingerprints in synthetics, cannot be regarded as innocent imitations, or ordinary synthetics. They are intentionally made to deceive, can be a threat to the health, should be considered forgeries, and for these reasons, these treatments must be disclosed.

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[*Manuscript received 4 January 1991.*]

Fig. 11. 'Plato striation' obtained parallel to the *c*-axis while the stone was immersed in methylene iodide between crossed polaroids in their dark position. Observed in the synthetic Verneuil ruby.

The French Connection

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The cordial understanding engendered by Edward VII's visit to Paris in 1903 was a valuable precursor towards the Anglo-French Entente of 1904. The term 'Entente Cordiale' may equally well be used to describe the gemmological ties between the laboratories of London and Paris. Long long before CIBJO there was a strong bond of mutual assistance between these two pearl trade centres.

However it is not my intention to write of the early days of pearl testing. Rather it is to write of one particular member of the Paris laboratory. I have been brought to this historic pitch through leafing among some of the writings of Mlle Dina Level. Each time I read Dina's writings I marvel afresh at her effervescent enthusiasm.

She served under both Georges Gôbel the first director and Jean-Paul Poirot the second (present) director of the Paris laboratory. Details of her years of service, awards and presentations appear in the July 1988 *Journal of Gemmology* (21, 3, 140-1).

If I could liken her to any other gemmologist it would be Robert Webster. Both were of small stature, both were giants in their sphere. Dina Level was an important petite person who could wax enthusiastic with the merest frond of moss agate, a fugitive fluorescence, a nuage of gas bubbles or the watered silk reflection from a pale pink pearl.

Vivid, vivacious, volatile, Dina was truly Gallic yet was nevertheless an anglophile. It is impossible in English to convey the personal approach she took when describing colour, size, weight or any characteristic of a gem. She had a sympathy and concern for the mis-shapen, the lop-sided, the baroque and the broken. She *talked* to her gems (pierre tu vas me dire quelque chose).

Being Dina Level, 'Grande amoureuse des gemmes' she employed the intimate 'tu' rather than the usual 'vous'. In the '*Revue du Gemmologie*,' afg, 24, Sept 1970, pp4-6, Dina Level wrote of her 'Aventures dans les Musées d'Angleterre'.

She often conducted parties of students on tours of selected museums in the south east of England using Newhaven as the arrival port. In a brief description she describes a visit to 'the charming museum of Hove' close to Brighton and relates, 'L'Aventure d'une aventurine'.

A rough, bronze-coloured block entered triumphantly through the main entrance. It was large and heavy, 70cms in length, 50cms wide and of a similar height. Placed in the centre of a gallery it was mounted on a low pedestal supported on four feet and enclosed by wooden rails. Thus visitors could see without touching and at the same time admire the bright spangled reflections from its uneven surface.

Alas one day some gemmologists recognized what it was. A block of sub-translucent glass with inclusions of triangular copper spangles. Unceremoniously it was relegated to a position at street level at the entrance and labelled, 'Aventurine Glass'. In this account written in 1970, Dina says that it was some 15 years ago, which places it at about 1955. 'In my early days at the laboratory I remember Basil Anderson speaking of his encounter with a local museum where a large block of aventurine glass was imposingly displayed. Basil Anderson was living at that time in the nearby Sussex village of Ditchling.

Dina's final comment on this little episode was to write philosophically; 'If it is still in the same place the inclement weather will tarnish it. Unfortunately after its brilliant but ephemeral success it has to be like any other stone.' (Regrettably, from recent enquiries, there no longer seems to be a display of gemmological interest.) I was informed that changes had taken place in the museum. This observation must have a familiar sound to some of us?

In an earlier article by Dina Level in the June 1970 *Revue de Gemmologie* she writes in retrospective mood of 'Quarante ans dêrriere la Binoculaire', 'Quarante ans d'enthousiasme', literally 40 years behind the binocular microscope and in italics 40 years of enthusiasm.

She remembers her first sight of No 18 Rue de Provence in April 1930. In the office of La Chambre Syndicale des Négociants en Diamants, Perles Fines, Pierres Précieuses et des Lapidaires there was a wall chart. One half was printed in red

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showing the rutile needles in natural rubies and curved structures of synthetic rubies. The other half, printed in blue, depicted the straight line hexagons and chevrons of natural sapphires with the soft curves and bubble clouds of synthetic sapphires.

Memories and images follow in succession sometimes overlapping. She recalls the great fly-wheel structure looking like a ship's steering wheel of the X-ray generating set. This like London's early X-ray set only produced lauegrams. The memory of black cloth-covered trays full of pearls, the subtle nuances and éclat completely escaping her novice's eye.

The tiny hollow needle of the endoscope (shades of Arsène Lupin), whose minute point sheltered two mirrors thanks to which one could see a fleeting ray of 'sunshine' lifting in succession the theatre curtains of the golden layers (conchiolin?) of natural pearls or the uniform snowy centres of cultured pearls.

There was another image which, whilst agreeable to the eye, tortured her for a week; she vowed she'd never stay a week in this laboratory. It was the density balance of gilded copper gleaming in its cage of glass, its pans suspended by chains and the diabolical beam of such sensitivity that to take a density for her was as difficult as it was for a camel to pass through the eye of a needle. Dina repeats 'When I say take a density, I wish to say attempt once, twice, ten times to measure the density of the same stone and to get the same result. At last I succeeded and the cyclopic eye of the balance out of its glass cage ceased to wither me every morning'. She was able at last to verify the true identity of a variety of gemstones used in tests for 'eye spotting'. (In the old lab we used well established specimens such as slices of innocuous indeterminate coloured gem material for early practice in establishing densities by hydrostatic method.)

She pays tribute to the untiring patience of Georges Gôbel who showed her how to take photographs of inclusions and how to develop and fix her negatives. Whether it is the development of a negative for a print, or an enlargement, she confesses that she never fails to see the image appear in the developing dish without emotion. The action in the developing dish she describes 'As if it is coming back from a vanished world and is reborn dancing in the liquid depths'.

This magic fluid has a name which is fully justified (sensible); it is the revélateur (revealer) and can be allied to the unrolling of the wrappings of mummies. Finally the fixer which will, as the hardening element, preserve the portrait of the inclusion long after the host gem has rejoined its owner.

She describes the examination of hundreds and hundreds of calibré sapphires using the binocular microscope as: 'A diver amazed and wonderstruck in these hermetically sealed waters. Fish following each other, liquid drops in flight, waving fronds of seaweed, phantom vessels stranded amongst the mountains of the sea bed'.

Dina describes how she spent one night alone in the laboratory taking photo-micrographs of inclusions and external features of some rough industrial diamonds. Many were clean and had good crystal shapes; she was entranced by the Egyptian beauty of these 'double' pyramids, looking like the reflections of the pyramids in the Nile at Giza. One in particular captivated her; she describes one of its faces as a hollow triangular engraving like a staircase becoming narrower and narrower as it penetrated towards the centre of the octahedron.

Plunged into a new ecstasy she wanted to make them re-live in her photo-micrographs – 'To which sleeping Pharaoh did the steps of the hollow pyramid lead?' All equal intersections, luminous, transparent, perfect. What divine chisel cut them in this adamantine block? How should they be illuminated in order to transfer to a flat film the dimensional relief seen in the lens of the microscope?

After a long session of photography, placing film, siting the diamonds for maximum result and aware of the war-time shortage of good quality film she was ready. The portable lamps had been placed in a circle surrounding the camera and microscope, the diamond being literally the cynosure of all. Dina switched off the lights, but in the centre a blue-mauve glow was being emitted – the diamond was phosphorescent. It seemed about 15 seconds before the glow finally died.

She says, 'That moment was the most intense of my life. Imagine the silence of the night, undetected behind the black-out curtains, impossible to go out, the seclusion imposed by the curfew, and the solitude of the deserted laboratory. To wonder in that desperate war-time atmosphere, what made this message of hope come not from outside but from inside this solid substance, this materialization of the eternity of this immaculate carbon. This gem made from a unique element, omnipresent in every thing which lives and breathes. I can at will re-live this dazzling tête à tête but I do not dwell on this memory, I lift up my eyes towards that staircase divine to the steps to the Light'.

Dina Level ends her long reminiscence saying, 'Ah, if it was to be done again I would re-do it'.

She died on 17 July 1988 at Nimes in the south of France – she was 85. With Basil Anderson and Robert Webster she leaves her mark in the annals of Gemmology. *We shall never see her like again.*

[*Manuscript received 12 December 1991.*]

On the properties of meteoritic gem olivine from a pallasite from Esquel, Patagonia, Argentina

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[2] Friedrich August Becker, Idar-Oberstein, Germany

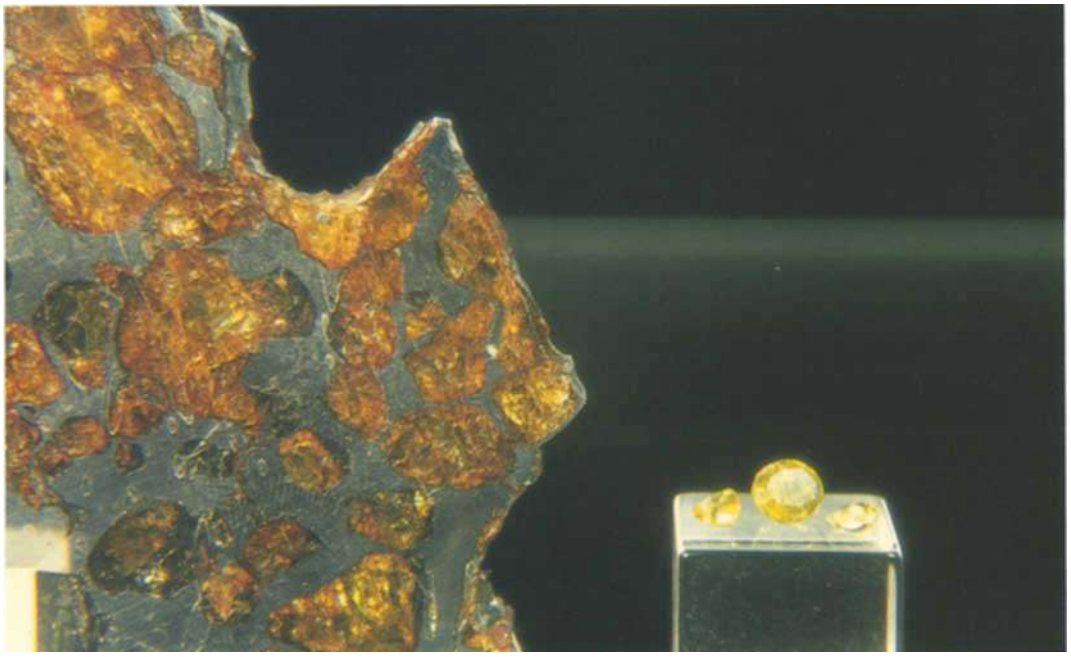

Fig.1. Pallasite plate from Esquel, Patagonia, Argentina, and three faceted meteoritic gem olivines (largest 1.6 ct).

1. Abstract

The properties of faceted gem olivines (peridot) from a stony-iron meteorite (pallasite) found at Esquel, Patagonia, Argentina, are described.

2. Introduction

Olivine is one of the common rock-forming minerals in the earth's crust with an average content of about 3.5%. Transparent green crystals of gem quality olivine are generally called peridot. The most important occurrence was on the island of Zeberget (Egypt) in the Red Sea; today's commercial production is from the Mogok District of Upper Burma and Arizona, USA.

The minerals of the olivine group form a complete series of mixed crystals with the end-members forsterite Mg_2SiO_4 and fayalite Fe_2SiO_4; another diadochy is present between fayalite and tephroite Mn_2SiO_4. In magnesium-rich olivines nickel is commonly present. The green colour is due to Fe^{2+} of the fayalite component.

Olivine as a constituent of meteorites is well known, and Webster (1983) mentioned specimens said to be of a sufficient size and quality to be suitable for cutting into gemstones. One of the authors has now separated transparent green fragments from a meteorite plate from Esquel in Patagonia, Argentia, and cut these into faceted stones up to 1.60 cts (Figure 1).

Meteorites are fragments of celestial bodies of the asteroid belt between Mars and Jupiter and are divided into three types: (1) iron meteorites, (2)

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iron-stone meteorites and (3) stony meteorites. The gem quality olivines described here originate from a type of stony-iron call pallasite, which consists of a network of nickeliferous iron (iron meteorite) with crystals of olivine about 1 square centimetre in size. The meteoritic olivines are distinctly fractured, but clean cuttable parts are present up to 5 square millimetres in size.

Gemmological investigations of the physical, chemical and microscopical properties have been carried out to compare the meteoritic olivines with sublunary gem olivines.

3. Physical properties

3.1. Refractive indices, birefringence and density

Within the olivine group the values of refractive indices, birefringence and density increase linearly with the chemical composition from forsterite to fayalite, between which there is continuous variation: n_x=1.635-1.827, n_y =1.651-1.869, n_z=1.670-1.879, Δn=0.035-0.052, D=3.22-4.39 g/cm^3 (Deer, Howie & Zussman, 1983). The values of gem quality olivines hitherto published in literature vary between n_x=1.640, n_y =1.657, n_z=1.675, Δn=0.035, D=3.20 g/cm^3 for a nearly colourless stone from Sri Lanka with a forsterite content of 95% (Bank, 1984) and n_x=1.670, n_y=1.688, n_z=1.706, Δn=0.036, D=3.43 g/cm^3 for a green specimen from the Eifel, Germany, with a FeO content of 16.79 wt.% (= 81% forsterite) (Bank, 1986).

The meteoritic olivine of the pallasite from Esquel in Argentina has refractive indices, birefringence and density of n_x=1.658-1.660, n_y=1.671-1.673, n_z=1.693-1.696, Δn=0.034-0.037, D=3.34-3.37 g/cm^3, which are in the known range of gem olivines.

3.2 Absorption spectrum

The unpolarized absorption spectrum in the 300-2000 nm (33,333-5,000 cm^{-1}) range (Figure 2) shows absorption bands of Fe^{2+}, which are typical for olivine (Runciman et al., 1973; Smith & Langer, 1982). The maxima are at 9,350, 11,490, 15,770, 19,120, 20,280, 22,120 and 24,810 cm^{-1} (1070, 870, 634, 523, 493, 452 and 403 nm).

4. Chemical properties

The results of semi-quantitative EDS-analyses of three samples of the meteoritic olivines are listed in Table 1. The calculated composition characterizes the material as mixed crystals with dominant contents of forsterite and distinct fayalite distributions. The tephroite contents are relatively low. These olivine compositions correspond to the values of refractive indices, birefringence and density given in the known correlation diagrams for the minerals of the olivine group (e.g. Deer, Howie & Zussman, 1983).

Fig. 2. Unpolarized absorption spectrum of a meteoritic gem olivine in the 300-2000 nm range.

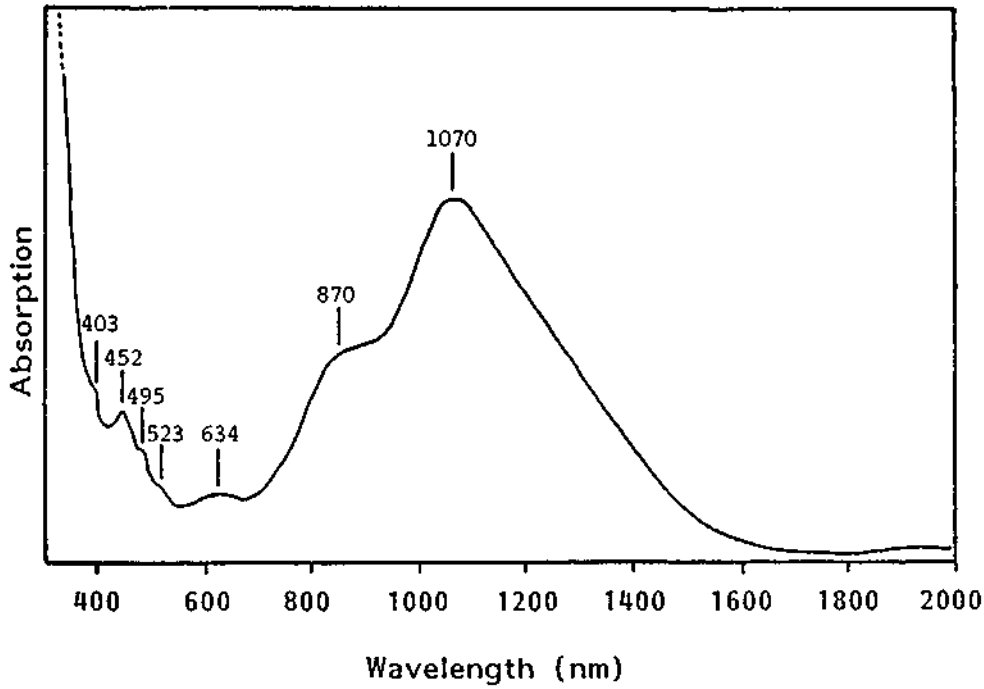

Table 1. Chemical composition of meteoritic olivines from Esquel, Argentina

	1	2	3
wt.%			
SiO_2	40.69	40.75	41.09
MgO	43.13	43.28	43.49
FeO	14.21	14.02	13.57
MnO	0.34	0.38	0.32
number of cations on the base 0=4			
Si	1.03	1.03	1.04
Mg	1.63	1.63	1.63
Fe	0.30	0.30	0.29
Mn	0.01	0.01	0.01
percentage distribution			
forsterite	84.02	84.02	84.46
fayalite	15.46	15.46	15.03
tephroite	0.52	0.52	0.51

5. Microscopical features

Studies with an immersion microscope yielded very interesting internal features. All samples investigated show needle-like inclusions (probably hollow tubes) running through the whole stone and crossing at angles of 90° due to the orthorhombic crystal system of olivine (Figure 3).

Fig. 3. Needle-like inclusions (probably hollow tubes) crossing at angles of 90°. At the crossing points opaque shapeless inclusions (probably residues of the nickliferous iron of the meteoritic matrix) are embedded. Immersion. x25.

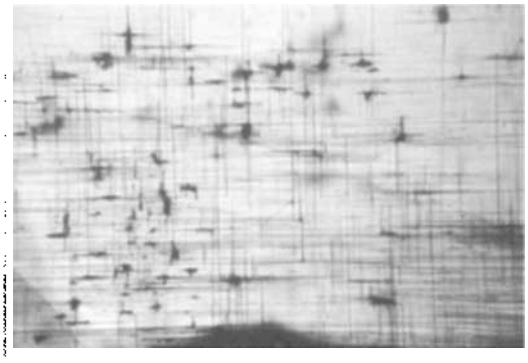

At the crossing points black opaque shapeless inclusions (probably residues of the nickeliferous iron of the meteoritic matrix) are embedded.

6. Conclusions

The cut meteoritic olivines of the pallasite stony-iron from Esquel in Patagonia, Argentina, possess physical and chemical properties typical of sublunary olivines. The microscopical features, however, are unusual and not typical for sublunary gem olivines.

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The Museum of Ouro Preto, Minas Gerais, Brazil

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In early times, the establishment of many small villages in the State of Minas Gerais and also in other parts of Brazil, was a consequence of the search for gold, diamonds and precious stones. The city of Ouro Preto followed this rule. By the year 1696, a man known as Duarte Nunes, also known as 'The Mulato', first discovered gold in Ouro Preto – small nuggets with a steel colour. Thus, the first name given to this place was Vila Rica do Ouro Preto (Rich Village of Black Gold). Later this name was changed to Vila Rica, and finally to Ouro Preto. Until 1729, only gold was found by the 'mineiros' in the soil of Minas Gerais, but later diamonds of the Tejuco, in the village of Serro do Frio (later known as Diamantina) were also discovered.

Historic episodes of the 'Inconfidencia Mineira', a movement which resulted in national independence, occurred during the gold cycle. From the years 1721 to 1897, Ouro Preto was the capital of Minas Gerais State. On 12 December 1897, the new city of Belo Horizonte was inaugurated and the capital of the State of Minas Gerais was transferred from Ouro Preto to this new location.

Ouro Preto, one of the oldest cities in Brazil, located at an altitude of 1150 metres, can be reached by two fairly good paved roads 97 kilometres distant from Belo Horizonte; approximately 33 kilometres by the BR-040 and 64 kilometres along another state road. Companies which work iron ore are located along the road. The famous Pico de Itabira (69% pure hematite) which as a landmark for the 'bandeirantes', scouts in search of gold, who departed from the coast in Rio de Janeiro and headed into the interior, can be seen on the right. Ten kilometres from Ouro Preto, a large aluminium factory in the Saramenha district, exploits the large resources of bauxite which exist in the region. Finally, we arrive in Ouro Preto, where the Itacolomi Peak (the stone and the daughter in Indian language), 1752 metres high, can be seen as a

Fig. 1.
The exterior of the Museum at Ouro Preto.

(Photo: the author)

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background to the city.

Ouro Preto was nominated by the United Nations as a World Historical Monument. The city and the small villages which surround it are also known as the best topaz producers in the world, including yellow, red, orange and pink colours.

Claude Henry Gorceix, born in France in Saint Denis des Murs (Haute Vienne) on 19 October 1842, arrived in Brazil on 17 October 1876 and at the age of 34 years founded the Ouro Preto School of Mines in a building which was formerly the Palace of the Government of the State of Minas Gerais. Gorceix brought with him several samples of minerals, and continued to collect samples in the Ouro Preto region, creating a collection which is presently one of the most important in the world. From 1881 to 1885, Gorceix also wrote many articles about Brazilian minerals. These articles and archives are preserved in the Ouro Preto School of Mines Museum.

The museum is an old, two storey building located on Praça Tiradentes N° 20 (Tiradentes Square) in the centre of town (Figure 1). The museum was restored in 1974 and exhibits are open to the public from 12 noon to 5.00pm. A 50 cents (American) admission fee is charged and the money is used to buy new specimens and for the conservation of the museum. In the entrance hall we see a huge quartz crystal weighing 6000 kilograms, which measures one metre high by one metre wide (Figure 2). It should be noted that the floors of the great hall on the ground level are made of a perfectly

Fig. 2. A very large quartz crystal weighing some 6000kg and measuring 1m x 1m, in the entrance hall of the Museum. *(Photo: R. Mendes)*

Fig. 3. A view of the exhibition in the great hall of the Museum; note the floor of beautifully polished quartzite. *(Photo: R. Mendes)*

Fig. 4. A fine terminated crystal of orange topaz 13cm in height in the Museum. *(Photo: R. Mendes)*

polished, beautiful white and grey quartzite (Figure 3).

About 98% of the specimens displayed in the museum are from Brazil. However, a lovely vivianite from France is shown in one of the glass cases on the first floor.

There are two distinct mineral collections. The first, more technical and started by Gorceix, which presently comprises over 24,000 items, occupies a large room on the first floor of the museum. The best minerals belong to this first collection, which is displayed in ten glass island cases and in seven wall cases around the room. Four spots of special lighting are placed over each glass case, giving perfect illumination.

The second collection, not as rich as the first, has approximately 2000 minerals occupying five rooms on the second floor of the museum. These minerals are distributed in some forty glass cases in various rooms. All minerals are classified according to name, place of origin and chemical formulae. Some outstanding specimens of the collection include a perfectly terminated yellowish-red topaz measuring 13cm in height (Figure 4), considered one of the best specimens of the museum; a spectacular specularite 21 x 17cm (Figure 5) considered one of the world's best; a dark green flawless crystal of the rare mineral euclase, shown together with other euclase crystals – blue, light blue and pale yellow in colour; a beautiful round morganite 10cm in diameter; a transparent yellowish-green baryte; a group of magnesite crystals, each crystal measuring approximately 7cm and a tabular pyrrhotite crystal about 12cm long.

Many varieties of beryl can be seen, including goshenite, morganite, heliodor, aquamarine and emerald. The tourmaline group is represented by the species elbaite, dravite, uvite, liddicoatite, schorl, buergerite and ferridravite.

Special exhibitions include a collection of iron minerals, which are abundant in this region including hematite, martite, magnetite, limonite, pyrolusite and also a glass case with calcium carbonate minerals enrich the museum, as well as tektites, platinum, gold, silver and the reproduction of the largest diamonds in the world which ensures that all the minerals found in Brazil are displayed in the museum collections.

On the second floor of the museum, besides the five rooms with the minerals, there is a chapel with old images of saints and another room with paleontological specimens, fossils, shells and skeletons of birds and wild animals.

Finally, a room is dedicated to Gorceix, the founder, showing some old instruments used to test stones and also some early mineralogical literature

Fig. 5. A spectacular specimen of hematite measuring 21 x 17cm in the Museum. *(Photo: R. Mendes)*

Fig. 6. The author (right) and Mr Cesar Mendonça in front of a bust of Claude Henry Gorceix, the founder of the Museum.

(Photo: the author)

and historical documents. Eugene Hussack, the famous German mineralogist, discovered a mineral which he named gorceixite in his honour. Hussack also wrote many papers which are housed in the museum archives.

In addition to the Mineralogy Museum, Ouro Preto has the most important School of Engineering in Brazil. A committee composed of Mr Geraldo Cardoso, Mr Osmar Alves de Oliveira Jr, and Mr Cesar Mendonça, is responsible for the acquisition and display of the minerals in the museum.

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The author expresses his thanks to Mr Jorge Geraldo Brito dos Santos who made the arrangements to visit the museum, and to Mr Cesar Mendonça for all his advice and co-operation during this visit.

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Lamellar inclusions in spinels from Morogoro area, Tanzania

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Abstract

Lamellar double refractive inclusions in spinels from Morogoro area, Tanzania, were identified by transmission electron microscopic techniques as iron-free, high titanium-bearing högbomite. The inclusions occur as four sets of thin lamellae parallel to the octahedral faces of the spinel host crystals.

In June 1987, one of the present authors received the first samples of an apparently new source of natural gem quality spinels. The red, pink, orange, reddish-purple, purplish-blue and blue crystals forming octahedra up to about 1cm in size supposedly originated from the Morogoro area, which is situated about intermediate between Dodoma and Dar es Salaam in central Tanzania (see also Hänni and Schmetzer, 1991). Meanwhile, the authors obtained several parcels of faceted and rough gem quality spinels from the new Tanzanian source, which were submitted by different persons in the trade to the authors or to colleagues. All those dealers, with one single exception, independently named the Morogoro area in Tanzania as the origin of the gemstones. According to the fact that most of the samples from all different parcels, which were examined by the present authors contained doubly refractive, lamellar inclusions to be described later, it is almost certain that all these parcels of gem spinels came from one single locality only. Consequently, the Umba valley, in northern Tanzania, close to the Kenyan border, which is quoted by Bank *et al.* (1989) as source of the new East African gem spinels, most probably is invalid as a locality for these new gem materials.

Physical and chemical properties of the spinels were found to be in the range of natural gem quality spinels, e.g. from Sri Lanka and Burma. Trace element analyses as well as spectroscopic investigations (cf. Schmetzer *et al.*, 1989) revealed results, which indicated no differences worth mentioning between samples of this new source and gem spinels from the long known localities in Sri Lanka and Burma. Dependent on the colour of the individual samples, trace element contents in the range of 0.05 wt.% to 0.55 wt.% Cr, 0.25 wt.% to 1.25 wt.% Fe, up to 0.15 wt.% V and up to 0.2 wt.% Ti were determined by electron microprobe (cobalt contents were below the detection limit of the microprobe but were proven by X-ray fluorescence analyses), and the absorption bands in the spectra of spinel crystals with different coloration were consequently assigned to chromium, vanadium, iron (in different valence states) and cobalt (Schmetzer *et al.*, 1989). In contrast to these non-spectacular results, microscopic investigations indicated that about 70% of the spinel samples from the new source in Tanzania showed lamellar inclusions as a characteristic feature, which was neither observed by the authors in gem quality spinels before nor was described and identified in specific mineralogical or gemmological papers. The first hint towards these characteristic lamellae is found in the publication of Bank *et al.* (1989), who mentioned 'irregular growth structures' in their Tanzanian spinels. In addition, Kane (1990) mentioned 'numerous sheets of polysynthetic twinning planes' in spinel from Tanzania.

The lamellar structures to be described were observed in four different orientations parallel to the octahedral {111} faces of the spinel host crystals. In each view parallel to one of the <110> axes of the spinel hosts (Figure 1), two sets of thin lamellae were observed parallel to the octahedral spinel faces, forming characteristic angles of 109.47° and 70.53°, respectively. Under crossed polarizers in the gemmological microscope using methylene iodide as immersion liquid (Figure 2), the inclusions were found to consist of doubly refractive lamellae. Because of the small thickness of the lamellae, characterization and identification of the mineral inclusions by electron microprobe was not successful.

However, by the application of transmission electron microscopic techniques using ion-beam thinned petrographic thin sections, the present authors were able to characterize and identify the inclusions (Schmetzer and Berger 1990). The exact thickness of different lamellae was determined to be

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Fig. 1. Plane polarized light, 40x.

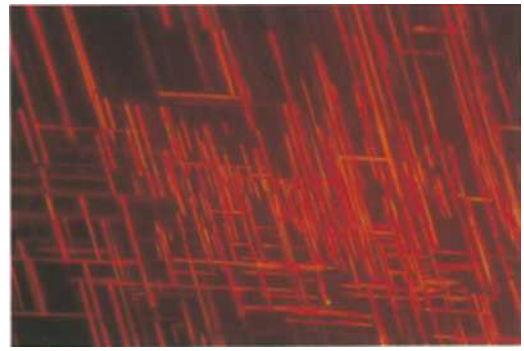

Fig. 2. Crossed polarizers, 40x.

Figs. 1, 2. Double refractive lamellae of högbomite in pink spinel (Fig. 1) from Tanzania. The lamellae are orientated parallel to two octahedral {111} faces of the host. View parallel to an <110> axis of the spinel crystal, using an immersion microscope with methylene iodide as immersion liquid.

variable between 0.01 μm and 0.1 μm. Using electron diffraction, the lamellae were found to have trigonal (rhombohedral) symmetry with unit cell dimensions of a_0 = 5.7 Å and $c_0 \approx$ 12 x 4. 65 Å = 55.8 Å. Quantitative EDX-analyses with a 15nm diameter electron spot characterized the lamellae as Mg-Al-Ti oxides. In summary, the lamellae were identified as an iron-free, high titanium-bearing member of the chemically varying högbomite series.

Högbomites are hexagonal or trigonal (rhombohedral) Fe-Mg-Al-Ti oxides with complex chemical composition (Petersen *et al.* 1989). Structurally, högbomite is closely related to spinel in that the högbomite structure is derived from a spinel structure through partial replacement of magnesium atoms by titanium (Gatehouse & Grey, 1982) according to the formula $2\ Mg^{2+} \rightarrow Ti^{4+}$ (Coolen, 1981). Similar structures are also known for the Be-Mg-Al oxides taaffeite and musgravite (Nuber & Schmetzer, 1983).

In practical gemmology, the observation of different sets of doubly refractive lamellar inclusions in a spinel of unknown origin is able to characterize the sample as natural spinel originating from Tanzania. According to the fact that flux-grown synthetic spinels are now appearing in increasing quantities in the trade, the diagnostic feature described in this paper may be helpful occasionally.

Acknowledgements

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Determination of dispersion using a refractometer

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When using white light with a refractometer, the rainbow effect on the shadow edge resulting from dispersion is readily apparent. Since the refractometer is already used to determine refractive index, birefringence and optic character, it seems reasonable to expect that it also could be used to determine dispersion. Indeed, it can.

Dispersion, by definition, is the numerical value equal to n_G minus n_B. It would appear that one could use red and blue filters to define the light sources, determine the indices of refraction on the refractometer scale, and calculate the value for dispersion.

Over the years, a number of investigators have tried this approach. However, only Americans seem to get reasonable results. There is an explanation for this. Besides demonstrating why such results were simply fortuitous, this paper will present a method which can be used by anyone to actually determine dispersion using a refractometer.

For all gemstones, the index of refraction for blue light (n_G) is greater than that for red light (n_B). However, when these 'apparent values' are determined on the refractometer scale, 'n_B' has a greater value than does 'n_G'. This is why, when using a red filter to produce monochromatic light, one must subtract the value of 0.003-0.005 from the refractometer scale reading in order to obtain the correct RI value.

The reason for this is that dispersion and RI are measures of what happens to light at the interface of a gem and air. The refractometer reading, on the other hand, is a function of what happens to light at the interface between the gem and the refractometer prism.

Since air has an index of refraction lower than that of the gem and the prism has one higher than the gem, the rainbow in the refractometer appears to spread in the 'wrong' direction.

Consequently, in order to be useful, refractometer scales are all calibrated in terms of a single wavelength – 589nm., i.e. n_D or yellow light. This value has been designated as the RI (refractive index). Any 'index of refraction' values obtained from the refractometer scale when using other wavelengths of light have no real meaning.

Nevertheless, the numerical scale on a refractometer can be used for indicating the effects of dispersion occurring at the gem-refractometer prism interface. The dispersion value is an intrinsic physical property of a gem, however, the optical properties of refractometer prisms are defined by their manufacturers. Consequently, a separate calibration scale is required for each make of refractometer. The actual calibration scale is also a function of the red and blue light sources used.

A useful calibration scale can be constructed from the results obtained from two reference gems – benitoite, having a dispersion value of 0.047, and fluorite, having a dispersion value of 0.007. Red and blue light is produced by the use of filters and the numerical difference of the refractometer scale readings ($\triangle$ scale) is plotted against the known dispersion values. A line is constructed connecting these two points to serve as the calibration. Figure 1 shows the calibration scales for two widely used commercial refractometers – the British Dialdex and the American Duplex II.

The points for garnet, ruby and tourmaline, were positioned on the basis of published dispersion values and experimentally measured $\triangle$ scale values. They confirm the general validity of this calibration scheme.

Fortuitous Results

The reason for Americans getting 'reasonable' results even though using the invalid assumption that the $\triangle$ scale reading = dispersion, is also illustrated in Figure 1. This erroneous relationship is represented by the dotted line extending upwards to the right. Note the slope is opposite to those of the calibration lines.

The dotted line intersects the American Duplex II calibration line at a dispersion value of 0.020. Since a great number of the lower RI coloured gemstones have dispersion values of that magnitude

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(e.g. ruby, garnet and tourmaline), 'reasonable values' can be obtained by using either line as the calibration line.

On the other hand, English investigators using the Dialdex refractometer would find that the true calibration curve is crossed by the dotted line at a value of only 0.010. For most gemstones, this is not a 'reasonable value' of dispersion and the investigator is immediately alerted to the error.

Determination of dispersion using a gemmological refractometer

Equipment:
Gemmological refractometer of any manufacture. Red and blue filters to define light sources. Dispersion reference standards: fluorite (0.007) and benitoite (0.047).
Graph paper.

Procedure:

1. Determination of upper standard point.
A. Using the blue filter, determine the refractometer scale reading corresponding to the shadow edge for benitoite.
B. Repeat step A using the red filter.
C. Determine the absolute difference of the two readings. This is designated the △ Scale Reading.

2. Determination of lower standard point.
A. Repeat steps 1A, B, and C using the fluorite standard.

3. Construction of Calibration Chart.
A. Construct a graph relating △ Scale Reading vs. Dispersion and plot the points for the standards as shown in Figure 1.
B. Construct a straight line connecting the reference points.

4. Determination of Dispersion of Unknowns.
A. Repeat the steps outlined in 1A, B, and C using the unknown specimen.
B. Using the value of △ Scale Reading and the calibration chart, determine the dispersion of the unknown.

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Determination of dispersion using a refractometer

W. Wm. Hanneman, Ph. D.

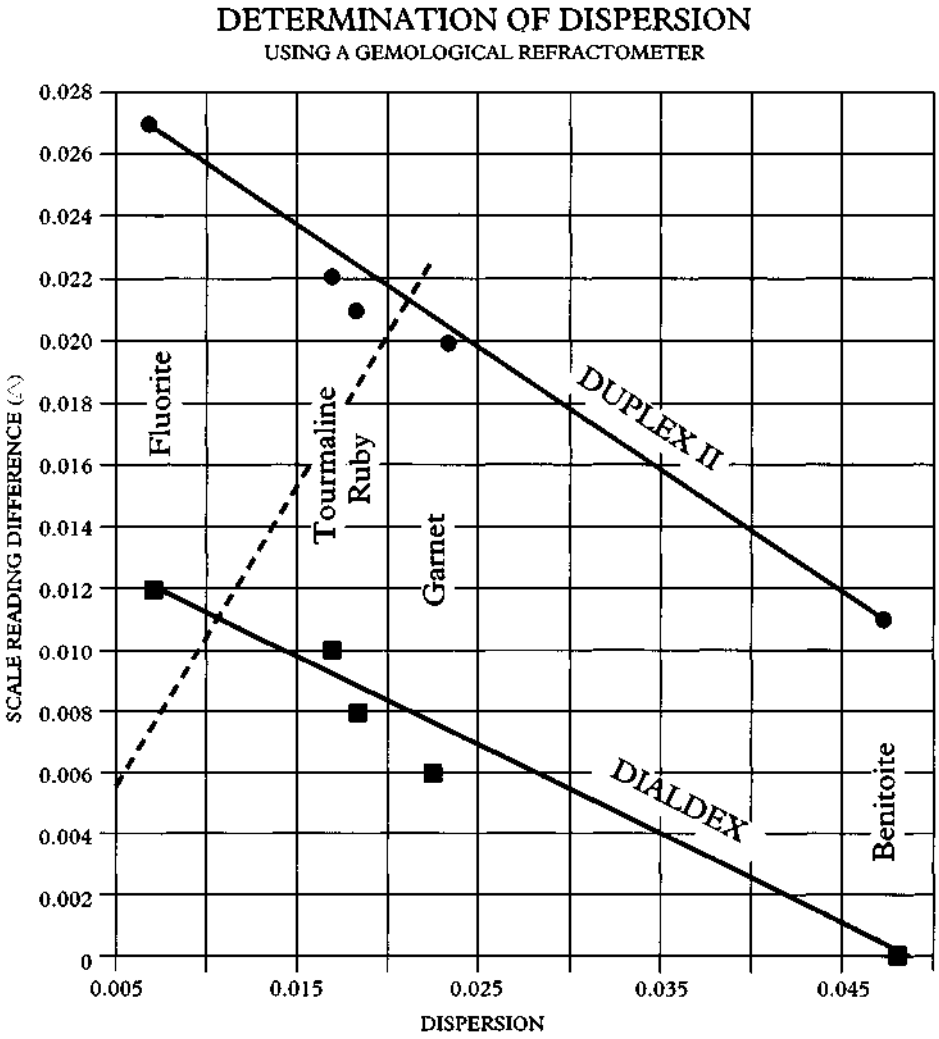

Fig. 1. The calibration scales for two widely used commercial refractometers – the British Dialdex and the American Duplex II.

Magnetic resonance distinction between synthetic and natural 'padparadscha' sapphires

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Abstract

The examination of natural and synthetic sapphires, in the 'padparadscha' ('lotus flower') colour range, by magnetic resonance spectroscopy, gave the following results. Ferric iron is readily detectable in Sri Lankan and Tanzanian natural material, but is absent, or very difficult to detect, in synthetic boule (flame fusion) material. The lines are much broader in the Tanzanian stones than the Sri Lankan. Ferric iron is also easily detectable in flux-grown (Chatham) material, but the lines are so narrow that 'forbidden' transitions in the ferric spectrum, and hyperfine structure in the chromic spectrum, are seen.

We conclude that magnetic resonance spectroscopy can distinguish synthetic from natural sapphires in the 'padparadscha' colour range; may give a lead to the point of origin of naturals; and can distinguish the mode of manufacture of synthetics.

Introduction

It is usually possible, by thorough microscopic examination, to determine whether a correctly identified 'padparadscha' variety of sapphire is natural or synthetic. In the comparatively few cases where this is inconclusive, is there another possible test?

In 1975, Scala and Hutton[1] showed that magnetic resonance spectroscopy could be used to distinguish between natural (Australian) and synthetic golden sapphire. In 1981, the technique was extended by Anderson, Hutton and Troup[2], to enable the distinction between synthetic and natural blue sapphire to be made. At the Gemological Institute of America International Symposium in Los Angeles, June 1991, one of us (GJT) was asked whether magnetic resonance would distinguish between natural and synthetic 'padparadscha' sapphire. This paper gives the reply to that question.

'Padparadscha' sapphire lies somewhere between 'apricot' and 'pink' in colour, and usually has a slight brownish tinge also[3]. The main source is Sri Lanka, but similarly coloured stones have recently been found in Tanzania. Verneuil flame-fusion (boule) synthetics exist, as do flux-melt ones (Chatham). Strangely enough, we found it more difficult to obtain the synthetic material than the natural! In the Chatham case, this is presumably because Chatham ceased production of their 'padparadscha' sapphire in 1990, after commencing about 10 years before, with no plans to continue.

Materials and Methods

A variety of natural 'padparadscha' and similarly hued sapphires from Sri Lanka and Tanzania were obtained, as were a cut boule 'padparadscha' and a cut Chatham 'padparadscha'. Similarly coloured boule samples were also prepared to be examined. The stones were examined in a previously described magnetic resonance spectrometer[4]. The perpendicular spectrum, when the DC magnetic field is perpendicular to the trigonal axis of the sample, is readily found, and was recorded for each sample: for some samples, the parallel spectrum (DC magnetic field parallel to the trigonal axis) was also recorded. The microwave frequency used was in the vicinity of 9.2 GHz, and all measurements were carried out at room temperature.

Results

(a) Natural material

Figure 1 shows the perpendicular spectra for four natural stones from Sri Lanka: 'apricot', 'padparadscha', and close to 'pink'. All specimens showed Fe^{3+} signals, and contained various amounts of Cr^{3+}; the concentration of Cr^{3+} increased from 'apricot' to 'pink'. The variation in the relative intensities of the Fe^{3+} lines is due to the change in transition probabilities of the various lines as the direction of the DC magnetic field with respect to the microwave magnetic field differs.

Figure 2 shows the spectra of four natural sapphires, in the appropriate colour range, from Tanzania. It is seen that the Fe^{3+} lines are very much broader than in the Sri Lankan cases, and that there appears to be relatively less Cr^{3+}. This gives grounds for using magnetic resonance in helping to establish the point of origin of 'padparadscha'-like sapphires. In a previous study[2], it was already noted

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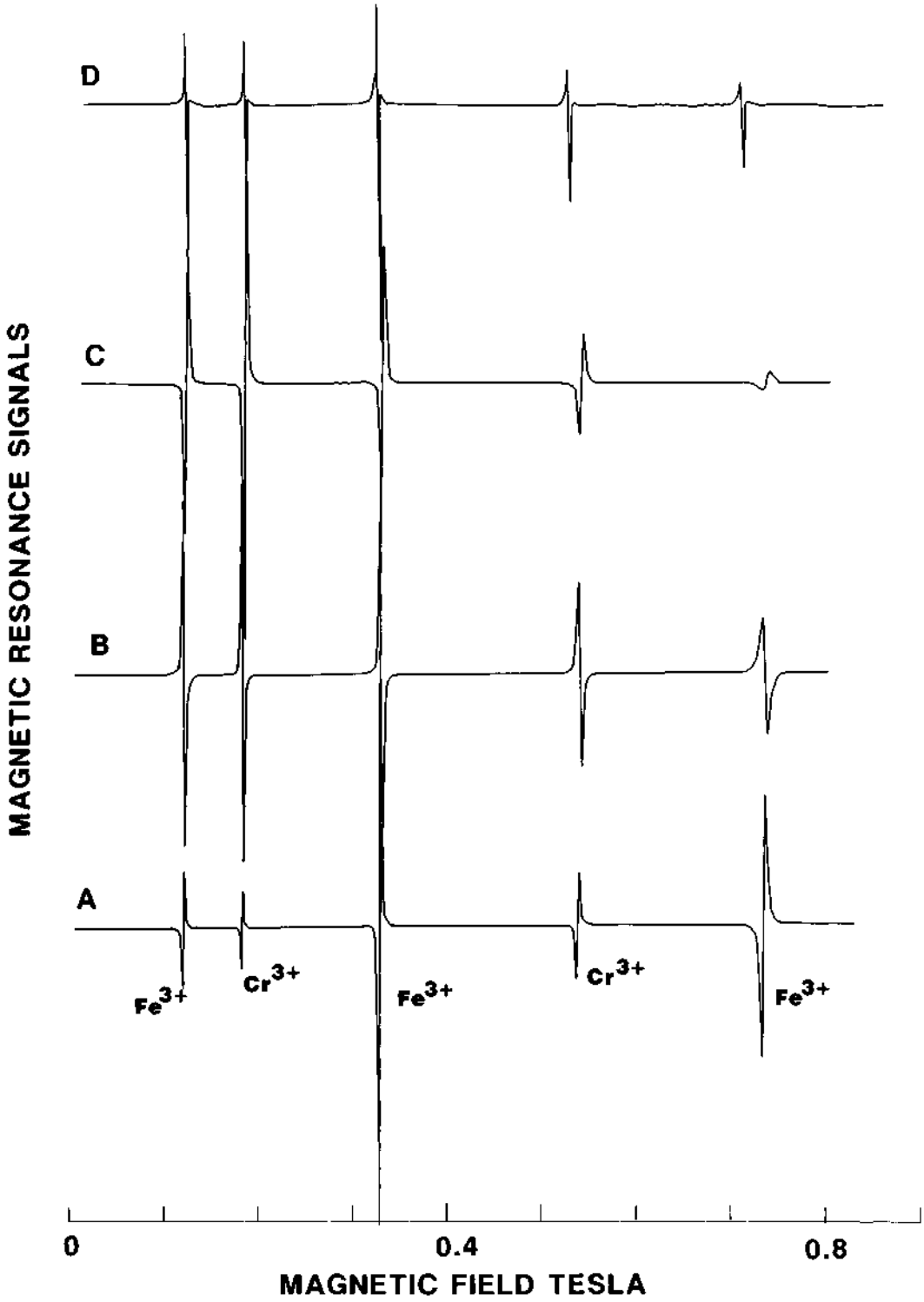

Fig. 1. Perpendicular spectra of 4 sapphires from Sri Lanka. A: 'apricot' sapphire; B: 'pink' sapphire; C: 'Padparadscha' (0.37 ct); D: 'Padparadscha' (0.74 ct).

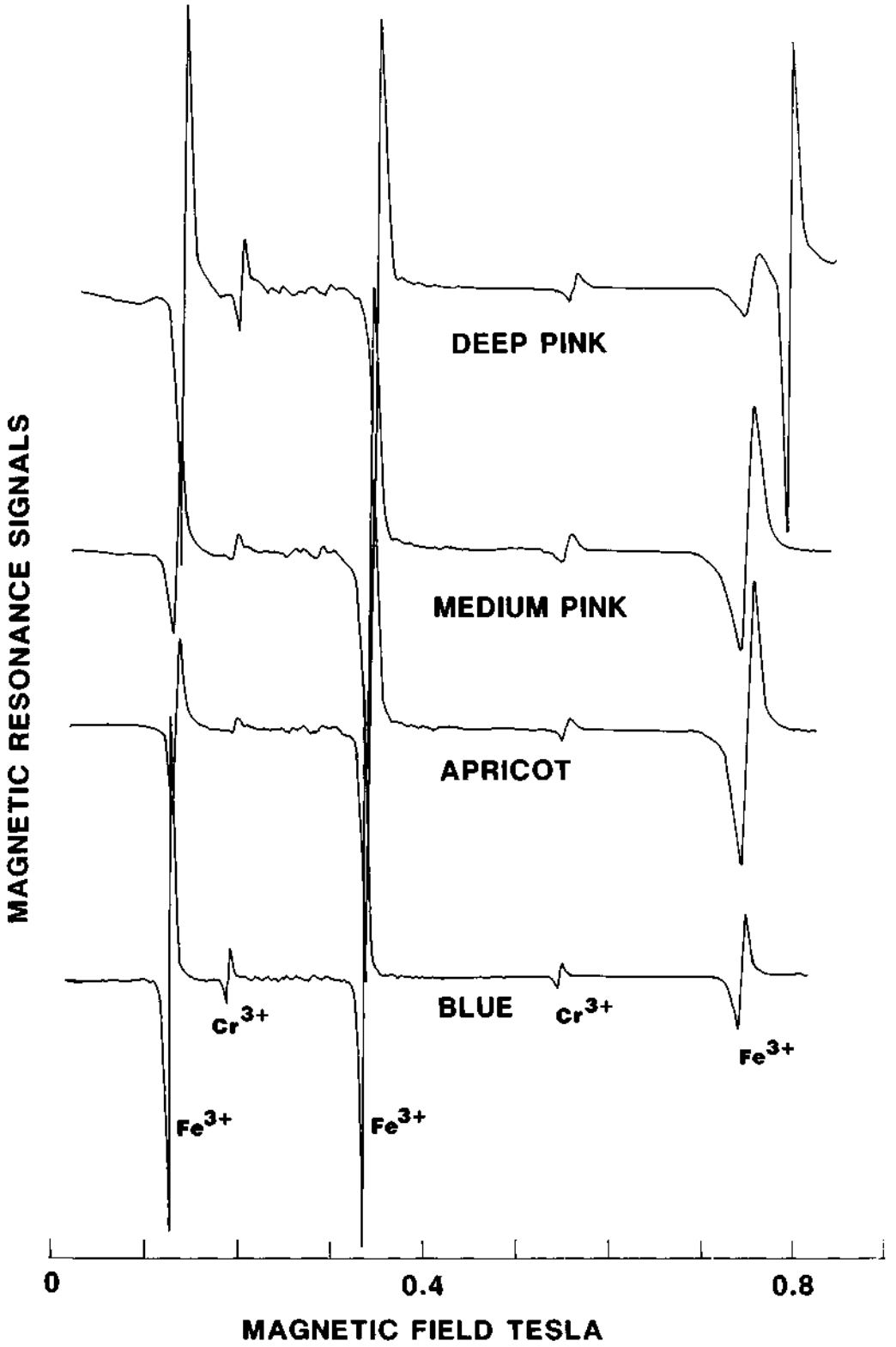

Fig. 2. Perpendicular spectra of 4 sapphires in the 'Padparadscha' colour range from Tanzania.

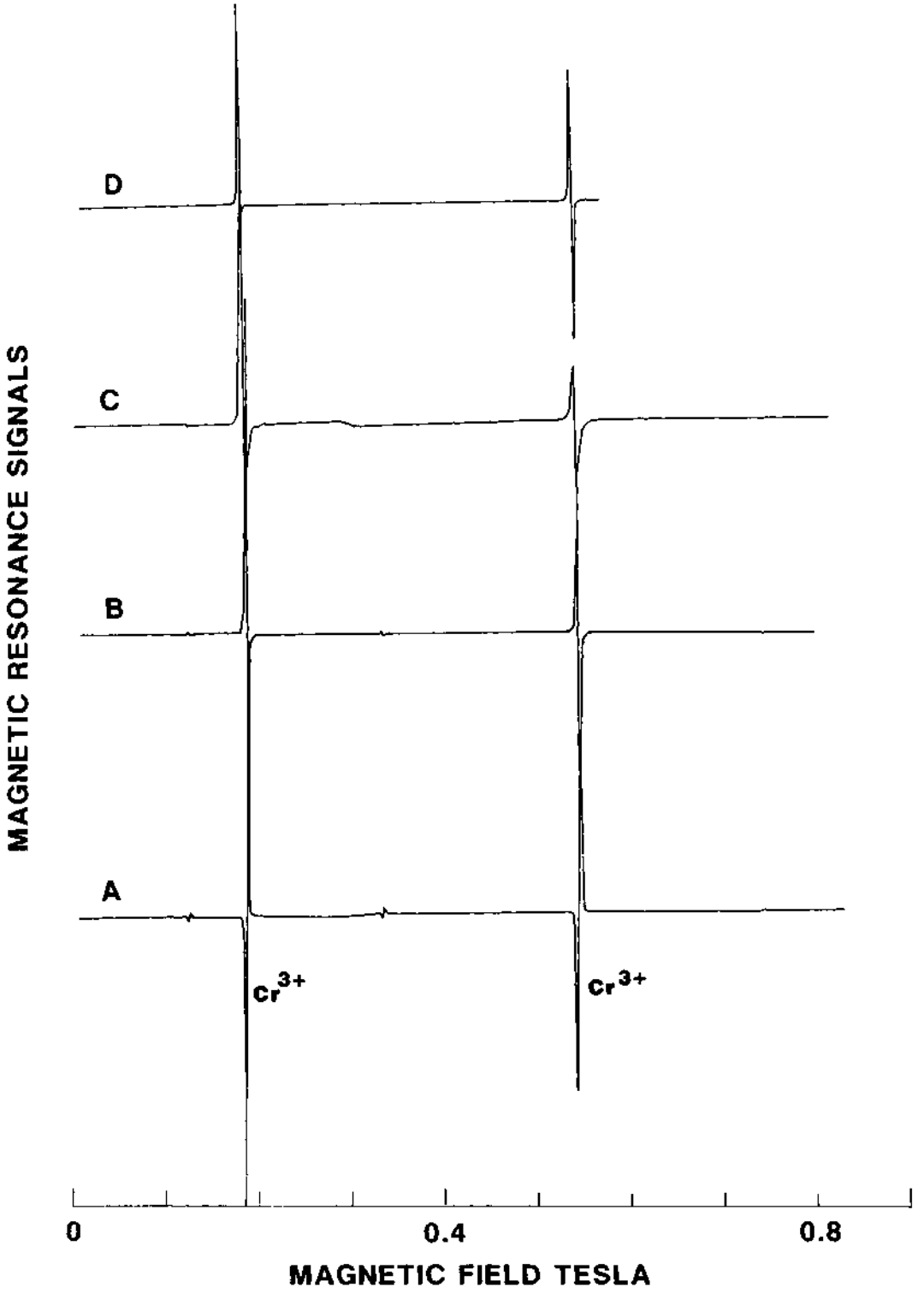

Fig. 3. Perpendicular spectra of flame-fusion (boule) synthetics, in the appropriate colour A: Orange; B: brown-red; C: purple; D: cut synthetic 'Padparadscha'.

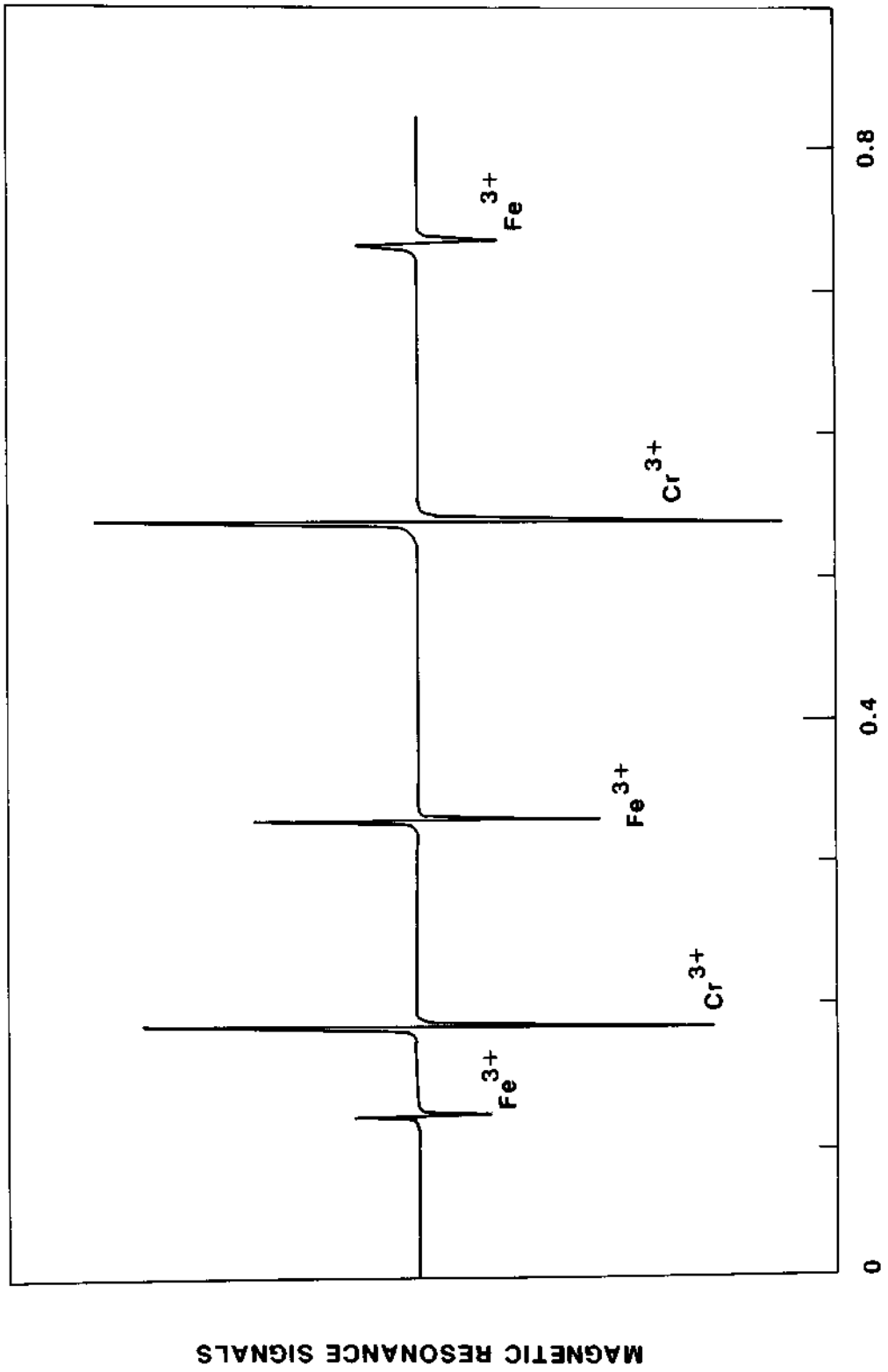

Fig. 4. Perpendicular spectrum of Chatham synthetic (flux-melt).

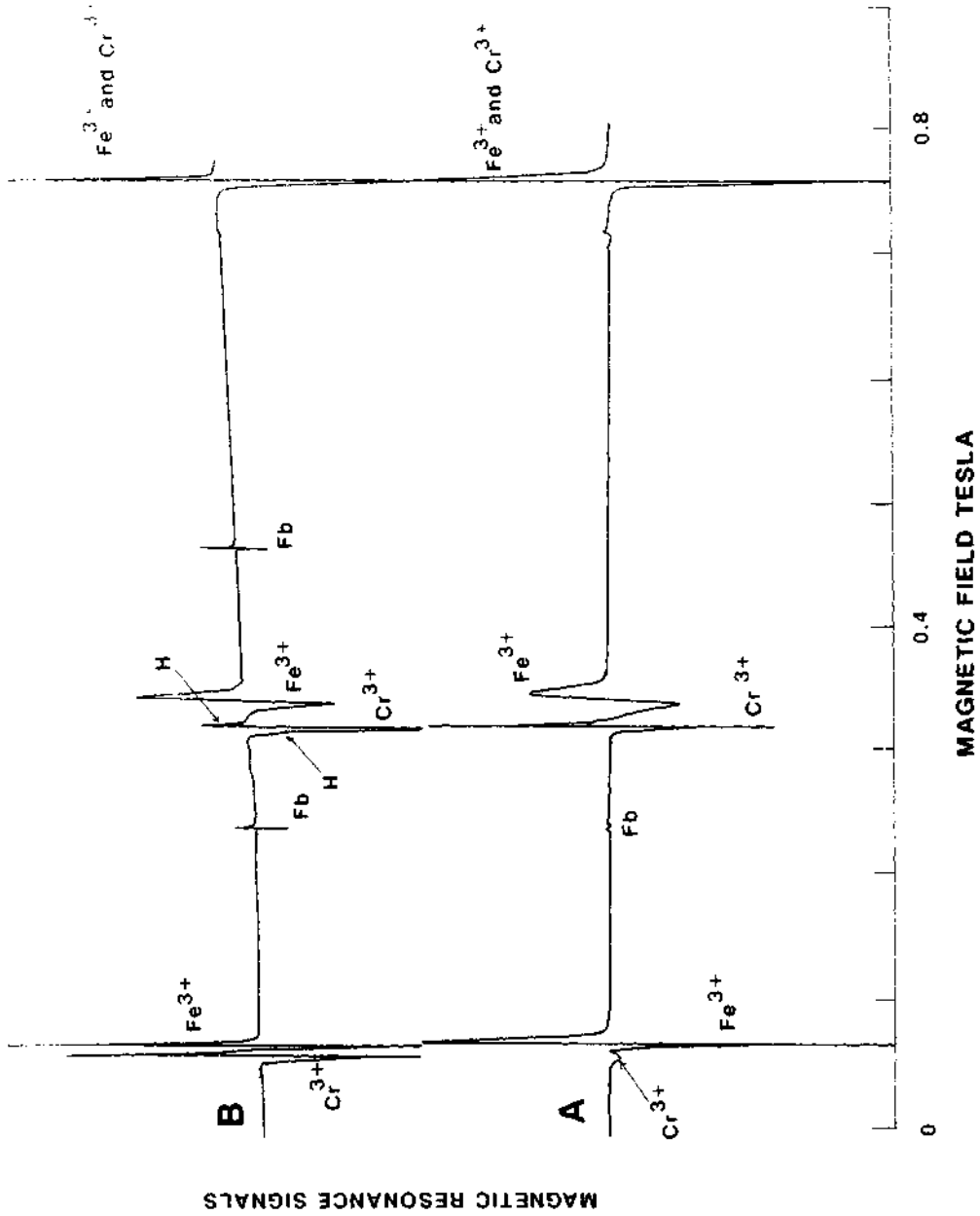

Fig. 5. Parallel spectra of A: Sri Lanka 'Padparadscha' (0.37 ct); B: Chatham synthetic. H means Cr^{3+} hyperfine structure; Fb means 'forbidden' transition.

that Sri Lankan sapphires had the narrower magnetic resonance lines.

(b) Synthetic materials

Figure 3 shows the perpendicular magnetic resonance spectra of four boule (synthetic) samples in the appropriate colour range, including a 'certified cut padparadscha'. It will be seen that the amount of Fe^{3+}, as judged from the signals, is very significantly (1:100) less than that in the natural stones of the two known provenances.

Figure 4 shows the perpendicular spectrum of the Chatham synthetic. While Fe^{3+} and Cr^{3+} are present, the lines are significantly narrower than those in even the best quality natural Sri Lankan stone. Figure 5 shows the parallel spectra of the best Sri Lankan 'padparadscha', and the Chatham synthetic. Significant differences are apparent.

Discussion

That synthetic 'ruby', 'brown sapphire' and 'yellow sapphire' made by the Verneuil process contain little Fe^{3+} in comparison to Cr^{3+} was already known[1]. The synthetics of intermediate hues, close to the 'padparadscha' range, could therefore be expected to behave similarly, and this has been verified. Therefore, a stone of 'padparadscha' hue, with little or no Fe^{3+}, is very likely to be from a boule.

Both Sri Lankan and Tanzanian naturals show comparatively large Fe^{3+} signals: the Fe^{3+} concentration is obviously larger in the Tanzanian stones, both because of signal height and of the much greater line width. As pointed out earlier, these properties can help in the determination of place of origin.

The Chatham synthetic is an extremely good synthetic 'simulant' of the natural spectrum. As pointed out in an earlier work[2], it is *too* good, because of the sharpness of the lines, which give an indication of crystal lattice perfection. A careful comparison with the best Sri Lankan 'padparadscha' spectrum will show that the lines of the Chatham stone are much narrower. As in previous work[2], for confirmation, it may be necessary to go to the parallel spectrum; the comparison is given in Figure 5, between the Chatham, and the best Sri Lankan 'padparadscha'.

Admittedly, the number of stones studied has been small, but the results are remarkably consistent. However, we would like to requote Barrington's[5] comments on the original work of Scala and Hutton[1]: 'Whilst the number of tests performed may fall short of ideal requirements for statistical proof, the uniformity of the results achieved point to the fact that this method is a worthwhile technique *where there is doubt**, and other more readily available tests are inconclusive'. Gemmological identification is based on a *battery* of tests, not one single test, and with this we agree. [*Our emphasis.]

Finally, Nassau and Valente[6] speculate, in accordance with their 'seven types of yellow sapphire' classification, that there may be seven types of 'padparadscha'. These types include synthetics and heat-treated material (synthetic and natural). The 'no iron' and therefore 'no Fe^{3+}' natural classification is very difficult for us to agree with. Work on Sri Lankan (and other) yellow sapphires will be the subject of a future publication.

Acknowledgements

We would like to thank Gillian Finch Inskeep, of Lanka Gems, Sonoma, California 95476, USA, for posing the original question. For obtaining natural and synthetic material of known provenance, we would like to thank Grant and Debbie Hamid, of Hamid Bros, Melbourne, Victoria, Australia; Julia Myers, of Affiliated Importers, Sydney, New South Wales, Australia; and the US suppliers, Chatham, New York 10036 for their 'padparadscha', and New Era, Grass Valley, California 95945 for the Tanzanian material; and E. Gamini Zoysa, Mt. Lavinia, Sri Lanka, for 'padparadscha' (natural).

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[*Manuscript received 30 October 1991.*]

Gemmological Abstracts

ASTRIC, R., MERIGOUX, H., ZECCHINI, P., 1991. Etude theorique de l'aspect d'un diamant taille brillant en fonction de ses parametres de taille. *Revue de Gemmologie*, 107,

The brilliant cut for diamonds is described with notes on cutting parameters. Various versions of the brilliant cut are compared.

M.O'D.

BOSSHART, G., 1991. Les emeraudes de Colombie [continuation]. Revue de Gemmologie, 107, 7-12, 9 figs in colour.

French version of a paper first published in German. M.O'D.

BOWERSOX, G., SNEE, L.W., FOORD, E.E., SEAL II, R.R., 1991. Emeralds in the Panjshir Valley, Afghanistan. *Gems & Gemology*, 27, 1, 26-39, 19 figs.

A nicely illustrated paper on the emeralds and mines of a valley high in the Hindu Kush mountains north of Kabul. Access is very difficult, and the unsafe adit mines are high in the rugged limestone mountains several thousand feet above the villages. The emerald crystals are often colour-zoned with pale centres, most about 5 carats, but larger stones are found, including one of 190 carats. Crystal habit normal for emerald, but often eroded or etched. RIs (e) 1.574 and (o) 1.580 variable but generally high; SG 2.68 to 2.74; no reaction to UV; pink or orange under Chelsea filter; inclusions numerous, often multi-phased (brine, gas, and several different mineral crystals in cavities reminiscent of the jagged ones of Muzo), solid crystals include limonite, pyrite, a carbonate and feldspar. Most output is exported by mule-train to Pakistan where it is almost certainly oiled. The multi-crystal content of three-phase inclusions identifies provenance of these emeralds.

Area is thought to be producing about $10 million rough a year, cut stones available world-wide. With end of the Russian war production is expected to increase. R.K.M.

BRACEWELL, H., 1991. Gems around Australia, Part 5. *Australian Gemmologist*, 17, 11, 454-6, 5 figs.

The Bracewells, continuing their long tour, reached Kununurra some 200km north of the Argyle diamond mine and home of the red-striped siliceous argillite known as zebra stone. To Mrs Bracewell's surprise the difficult problem of polishing this strange form of sandstone is overcome by using a spray can of Dulux lacquer. Prehnite and quartz were found in this area but were scarcely worth extracting. The gold area of Hall's Creek, 370km south, billed a natural 'China Wall' of quartz as a tourist attraction, while Geiki Gorge to the west yielded some rather disappointing calcite.

R.K.M.

BRACEWELL, H., 1991. Gems around Australia, Part 6. *Australian Gemmologist*, 17, 12, 502-3, 2 figs and map.

Describes pearling and shell industry at Broome and its environs, including culture of large pearls since 1956 in Kuri Bay. Names on map are illegible.

R.K.M.

BRACEWELL, H., 1991. Faded amethyst. (Letter). *Australian Gemmologist*, 17, 12, 525.

Mrs Bracewell reports on a pair of amethysts which were mislaid in a dark cupboard for three years and faded to almost colourless. R.K.M.

BRAUNS, S., 1991. Nya Fyndorter under 1980-Talet. *Gem Bulletinen*, 1/91,7-9.

Brief details of gemstone finds during the 1980s are given. Adapted from a paper in Gems & Gemology 1990. M.O'D.

BRIGHTMAN, R., 1991. Gem quality almandine garnets from Antarctica. *Australian Gemmologist*, 17, 11, 470-3, 2 maps, 6 figs.

Crystal fragments collected in the Rauer Islands, Prydz Bay, Antarctica, were found to be dark red almndine garnet, RI 1.770 to 1.782, SG 3.955 to 4.040. Thin pieces had normal absorption spectra. Inclusions of rutile (?) silk, other crystals and large healed finger-print cracks were seen. Occurrence is unlikely to be exploited since there is an embargo on commercial mining. R.K.M.

BROWN, G., 1991. Quality assessment - to be or not to be? GAA Presidential Address. *Australian Gemmologist*, 17, 10, 393-6.

The President suggests that quality assessment and valuation should be taught in gemmology. [The idea is not new but its achievement is set with considerable difficulties: e.g. who is to decide what constitutes fine colour; who to fix prices and at what levels? How do impoverished schools acquire the fine stones to teach quality? Valuation is dependent on many years of buying and selling by people prepared to back their judgement with hard cash. Colour and quality are very much a matter of individual opinion and taste.] R.K.M.

BROWN, G., 1991. Corallium precious corals. *Wahroongai News*, 25, 11, 28-32, 2 figs.

A short paper based on researches of Professor Rick Gregg of University of Hawaii, dealing with *C. rubrum*, *C. secundum*, *C. konojoi*, *C. japonicum*, *C. nobile*, *C. elatius*, *C. regale* and a *C. sp. nov.* and principally concerned with the possible exhaustion of supplies of these precious corals in the next decade or so, due to over-fishing. R.K.M.

BROWN, G., 1991. Treated Andamooka matrix opal. *Gems & Gemology*, 27, 2, 100-6, 11 figs.

This carbon impregnated opal appeared in the 1950s [offered in London as 'completely natural black opal']. The matrix opal is shaped and polished, then heated to 105°C in a slightly acid 20% solution of glucose and lactose (1:4) until sugars solidify and darken. Stones are broken out and then boiled in concentrated sulphuric acid for five hours, and washed for several hours to eliminate residual acid. A final polish has to be light to avoid removing the shallow layer of carbon. [In London the first parcels were bought at high prices with a view to repolishing, a move which failed miserably].

R.K.M.

BROWN, G., 1991. Jewfish pearl. (Letter). *Australian Gemmologist*, 17, 12, 525, 1 fig.

A 'pearl' the size of a small human skull is illustrated, but comes from a sperm-whale, and is identified as an otolith (inner-ear bone). That of the jew-fish (jewel-fish) grows to about 4cm. R.K.M.

BROWN, G., BEATTIE, R., 1991. A new surface diffusion-treated sapphire. *Australian Gemmologist*, 17, 11, 457-9, 10 figs.

One parcel of Kanchanaburi sapphires purchased in Thailand for recutting in Australia, consisted entirely of rather crudely surface-diffusion treated stones which lost colour when repolished. Easily recognized after discovery by low-power magnification while immersed. Many imperfections, pock-marks, colour concentration at facet and girdle edges belied the good face-up colour. Authors say *'Caveat emptor!'* R.K.M.

BROWN, G., HAMID, D., 1991. A faded amethyst necklace. *Australian Gemmologist*, 17, 10, 426-8, 4 figs.

A necklace of tumbled light amethyst beads faded badly after prolonged exposure to window lighting and sunlight. A few beads shielded by the display case did not change but the rest had changed to pale citrine or colourless. [This fade factor in these stones appears to vary considerably with the origin of the amethyst, rather as does its reaction to heat. Some heat must have been involved here but this would probably have affected the covered section too if it was responsible for the change.] R.K.M.

BROWN, G., KELLY, S.M.B., 1991. Lechleitner coated corundums. *Australian Gemmologist*, 17, 10, 408-11, 14 figs.

Flux-coated seeds of synthetic or natural corundum have been produced by Lechleitner since 1983. 12 specimens of rough and finished gems were examined, gemmological properties corresponded with those of natural corundums, but wispy veils, reticulated fractures in the synthetic coating and curved colour striae in the synthetic seeds were easily seen. [The excellent colour illustrations here make it obvious that the seeds are crudely pre-formed and one would expect some patchy removal of the colour layer when finishing.] R.K.M.

BROWN, G., KELLY, S.M.B., BRACEWELL, H., 1991. Gemmology study reports. *Australian Gemmologist*, 17, 10, 417-25, 31 figs.

Reports on plastic imitation of walrus tusk scrimshaw with blebs of plastic in the 'engraved' lines; metz heshi devitrified glass by Iimori of Tokyo possibly imitating malachite; star ruby and sapphire imitations achieved by ruling flat base of synthetic corundums with lines intersecting at 120°; Czochralski pulled lithium niobate in various colours made to imitate fancy diamonds, RI 2.20 to 2.30, high DR and high dispersion 0.120 make distinction simple, SG also high (4.64), included bubbles. Basal and rhombohedral parting were seen in yellow sapphire crystal from Queensland; massive rutile from Mt Perry, Queensland, resembles hematite when polished; a carved opal doublet was from Lightning Ridge; profiled bubbles as in synthetic spinel [and synthetic rubies] found in Verneuil synthetic rutile; a jelly opal had been 'improved'

by backing with black paint; zebra stripes in amethyst are discussed and illustrated; a bakelite imitation of amber had been carved with a drill, SG and RI too high for amber; influx of South Africans to Australia is bringing Zambian, Sandawana and other African emeralds in increasing numbers, excellent photomicrographs of Zambian inclusions are printed. R.K.M.

BROWN, G., KELLY, S.M.B., BRACEWELL, H., 1991. Gemmological study club lab reports. *Australian Gemmologist*, **17**, 11, 475-8, 15 figs.

Green smithsonite; Gilson triplet opals; inclusions in synthetic spinel; imitation pearl made from fish jaw-bone; faceted sodalite; South African 'jade' (hydrogrossular garnet); Mississippi mussel nacre cabochons and agatized dinosaur bone are examined and reported upon. R.K.M.

BROWN, G., KELLY, S.M.B., BRACEWELL, H., 1991. Gemmology study club reports. *Australian Gemmologist*, **17**, 12, 526-31, 16 figs.

Deals with heated cornelian known as 'Fires of Mt Warning'; cat's-eye emerald; a green doublet which seemed to have quartz crown and natural beryl base [cutters have been known to dop doublets upside down by accident]; an imitation star sapphire doublet [?] which had both dome and base of cobalt blue spinel, and three intersecting sets of scored lines at its back; a dubious Chinese turquoise that was proved to be natural; a new focusing pen torch useful for microscopy; a new imitation jade from Kowloon identified as dyed calcite coated with wax; a natural sapphire/synthetic ruby doublet, set to conceal the girdle, which was identified by careful scrutiny by binocular microscope; and a large crystal of ekanite from Ratnapura which weighed 210 grams. R.K.M.

CASSEDANNE, J.-P., ALVES, J.-N., 1991. L'aigue-marine au Bresil-1. *Revue de Gemmologie*, **107**, 13-16, 7 photos (2 in colour), 2 maps.

First part of a paper on Brazilian aquamarine describing pegmatitic and alluvial occurrences with notes on the general geomorphology of the areas described. M.O'D.

CAVENEY, R.J., 1991. De Beers Research Laboratory Report 1991. *Indiaqua*, 1991, 241-6, 22 figs (21 in colour).

The Laboratory has synthesized a 14.2 ct industrial diamond crystal of good quality which is thought to be the largest yet to be manufactured. Over 500 hours of high temperature/high pressure running was needed to complete the synthesis. The crystal is yellow, the colour being attributed to nitrogen. In general synthetic single crystals of this type are sliced for industrial products rather than used in jewellery. M.O'D.

[Abstractor's note: *Indiaqua* now appears annually rather than quarterly.]

CHIPENKO, G.V., et al., 1990. A new habitus type of diamond crystal. *Doklady Akademii Nauk SSSR*, **312**, 1990, 876-9 (in Russian). Abstr. *Industrial Diamond Review*, **51**, 1991, 148.

Describes the production of a new synthetic diamond crystal habit by the recrystallization method. The major factors influencing the growth of this form of diamond crystal are found to be temperature, rate of transfer of carbon and amount of nitrogen present. The crystals are characterized by the predominance of an unusual combination of forms, mainly of the (111), (110) and (311) forms. E.S.

COENRAADS, R.R., VAN DER GRAAF, R., 1991. An occurrence of gem garnets from Horse Gully in New England gemfields, New South Wales. *Australian Gemmologist*, **17**, 10, 412-15, map and 4 figs.

Pyrope-almandines of red to purplish colours have been found in association with sapphires and other gems, some with slight tendency to colour change to orange red in incandescent light. RIs vary from 1.759 to 1.772 in the seven stones examined, euhedral crystals probably of apatite were included. [A small inset map has towns of Inverell and Glen Innes transposed.] R.K.M.

EDIRIWEERA, R.N., PERERA, S.I., WEERASINGHE, W., 1991. Method of creating required atmospheric conditions within crucibles placed inside a furnace. *Australian Gemmologist*, **17**, 11, 443-5, 3 figs.

A simple and inexpensive way to pipe oxygen or reducing gases through a furnace base to surround geuda sapphire or other stones during heat treatment. R.K.M.

FRYER, C.W., Ed., CROWNINGSHIELD, R., HARGETT, D., HURWIT, K.N., 1991. Gem Trade Lab notes. *Gems & Gemology*, **27**, 1, 40-5, 18 figs.

An alexandrite had figures and initials scratched just below the girdle, natural turquoise-coloured chalcedony from Mexico is to be marketed; a 1.07 ct grey-blue diamond was exceptionally electro-conductive; a sharply zoned emerald was suspected as doublet but a fracture crossing the 'join' proved otherwise; a

rare banded Afghan lapis lazuli was seen.

Iolite and coloured moonstone necklaces were seen and considered unusual; natural bronze pearl reported fished from La Paz area of Baja, California, suggest that a naturally destroyed former source has regenerated; 17mm cultured pearls seen by East Coast Lab, one thinly coated, the other exceptionally thick nacre.

A large antique cabochon emerald and diamond pendant had been enlarged by adding diamond set cultured pearls of much later date; Verneuil ruby had cut 'natural' crystal prism, pinacoid and rhombohedral faces; an orange-red flux-grown synthetic corundum had straight banding [gemmologists need to be wary of all kinds of deception].

A weak star sapphire revealed surface diffusion treatment for both star and colour enhancement, the dual surface diffusion process has not been a commercial success, it is questioned whether heat-treatment of star material to produce clean and facetable crystals is depleting supply of star stones; six calibrated blue synthetic sapphires had unusual triangular two-phased inclusions. R.K.M.

FRYER, C.W., CROWNINGSHIELD, R., HARGETT, D., MOSES, T., HURWIT, K., KANE, R.E., 1991. Gem Trade lab notes. *Gems & Gemology*, 27, 2, 108-14, 19 figs.

An amber necklace 'washed' in alcohol had developed a white 'bloom' and lost its polish; electron-treated coloured diamonds are recently more numerous and a 37ct yellow was identified as irradiated by colour zoning near the culet; another old-cut yellow diamond was found mounted in an art nouveau brooch, but was again a treated stone although the brooch apparently dated from before the treatment was available; a 'filled' crack in a diamond had anomalous orange and green flashes against dark ground illumination [these colours would surely vary with the width of the crack?]; a light green octahedron was a predicted pale yellow when cut, the GR1 absorption band was present in the green coating, but was lost when that was cut away; two instances of irradiation staining in etch cavities in cut diamonds are illustrated and theorized upon.

A cultured pearl with nacre covering only half the bead was examined, the other half was pinkish brown and non-nacreous for reasons unknown; 'rose-bud' pearls forming a necklace were typical products of the American fresh-water *Unio* mussel; a pair of cultured blister pearls were found to be plugged, and therefore assembled, when X-rayed.

An early flux-grown synthetic ruby had a natural seed with a blue outline; a violet spinel became pinkish purple in incandescent light and fluoresced chalky green in LUV; a cobalt blue synthetic spinel had veil inclusions possibly due to strain; a blue topaz had 'lightning' streaks of damage due to radiation treatment; a radio-active low zircon [green?] emitted 0.4 milliroentgens per hour and would probably be unsafe to wear, no uniaxial interference figure could be obtained. R.K.M.

FRYER, W., CROWNINGSHIELD, R., HARGETT, D., MOSES, T., HURWIT, K., KANE, R.E., 1991. Gem Trade Lab notes. *Gems & Gemology*, 27, 3, 174-9.

A rare hexagonal pit (combined positive and negative trigon) and a quite extraordinary hexagonal acicular tube in diamond are illustrated and explained; a type IIb blue diamond exhibited natural radiation stains on its girdle – first time this has been noted.

A 15.17ct 'accidental' sea-water tissue-nucleated cultured pearl, is probably the largest so far seen – it is thought that none are in deliberate production; an unusual greenish-black necklace of natural pearls had been dyed; another black necklace had been dyed except for two pearls which were naturally black and appeared brownish on immersion and gave a chalky-green colour under LUV; a bullet-shaped cultured pearl of natural colour had a deep hole in its back which was partly filled by another natural black cultured pearl, author speculates on how this could occur.

A pendant earclip had a half-drilled pearl which was 'smooth to the teeth' and identified initially as imitation, but X-rays showed it to be cultured which had been worked (polished). The Tucson Show offered white mabe pearls with strong pink over-tones due to a plastic core with a reflecting lacquer coating; a pair of matching mabe also had lacquer on their inner surfaces but one lacked a solid insert.

A pendant drop of diamonds and 94 calibre rubies contained only 8 natural rubies, the rest being early synthetics, possibly Geneva rubies cut from pea-sized boules, pre-Verneuil synthesis. A final note is made of the resurgence of diffusion treated sapphires since early 1990; the trend continued in 1991 and some large ones have been found in important jewellery. Writer advises all sapphire be checked by immersion as the safest way to detect this colour faking. R.K.M.

GEHRMANN, A.L., 1991. Der Granatenkogel (3.304mm). *Mineralien Welt*, 2, 4, 53-6, 9 photos (6 in colour), 1 map.

Crystals of almandine are found on the Granatenkogel in the Otztaler Alps of the Austrian Tirol. Well-formed crystals up to 5cm

are reported though most are not of gem quality. M.O'D.

GIL IBARGUCHI, J.I., MENDIA, M., GIRARDEAU, J., 1991. Mg- and Cr-rich staurolite and Cr-rich kyanite in high-pressure ultrabasic rocks (Cabo Ortegal, north western Spain). *American Mineralogist*, **76**, 501-11, 9 figs.

Green pleochroism of staurolite and blue pleochroism of kyanite (in non-gem crystals from the Cabo Ortegal complex in north-western Spain) are attributed to substitution of Al by Cr in octahedral sites. It is suggested that Mg- and Cr-rich staurolite and Cr-rich kyanite were stable through ecologitic composition. Although the Cr contents of kyanite and staurolite could indicate Cr-rich bulk composition the occurrence of small colourless Cr-poor kyanite included in matrix minerals and blue Cr-rich matrix kyanites suggests increasing Cr substitution in kyanite with increasing pressure and temperature. M.O'D.

GRIGG, R.W., BROWN, G., 1991. Tasmanian gem corals. *Australian Gemmologist*, **17**, 10, 399-404, 42 figs.

Several species of bamboo, gold and black varieties of coral have been accidentally trawled off South Tasmania while catching deep water fish known as 'orange roughy'. Morphology, hand-lens characteristics and gemmological properties are given. Trawl-net damage is costly and these finds are not welcomed by fishing fraternity. R.K.M.

HÄNNI, H.A., SCHMETZER, K., 1991. New rubies from the Morogoro area, Tanzania. *Gems & Gemology*, **27**, 3, 156-67, 16 figs.

A new find of red to blue spinels contained about 10% of cabochon quality ruby, a few of which would facet. Treacly swirls and angular zoning were seen and a few stars were cut. Some crystals pseudo-octahedral with angles more acute than in spinel. Twin lamellae and colour planes parallel with the rhombohedral faces, negative crystals, fissures, rutile silk, apatite and spinel inclusions were also found. These stones resemble Burma material in type while earlier Morogoro rubies do not. R.K.M.

HASSAN, I., GRUNDY, H.D., 1991. The crystal structure and thermal expansion of tugtupite $Na[Al_2Be_2Si_8O_{24}]Cl_2$. *Canadian Mineralogist*, **29**, 385-90, 2 figs.

Tugtupite, a sodalite group mineral, has fully ordered framework *T* cations [where *T* represents Al^{3+}, Be^{2+} and Si^{4+}], the order lowering the symmetry from cubic (as in a number of sodalite group minerals) to tetragonal. Large Si-O-Be angles are typical of the structure and these angles are larger than those in helvite group mlnerals. Thermal expansion is controlled largely by rotations of the TO_4 tetrahedra. The thermal expansion was modelled using the *DLS* program, the crystal structure was obtained by using an automated single crystal four-clrcle X-ray diffractometer using MoKα radiation. M.O'D.

HENN, U., 1991. Geschliffener Aegirin und Aegirin-augit aus Norwegen. (Cuttable aegirine and aegirineaugite from Norway.) *Zeitschrift der Deutschen Gemmologischen Gesellschaft*, **40**, 1, 69-71, 1 graph, 1 table, bibl.

The material comes from the Langesund fjord in southern Norway and is a mixed mineral between diopside and acmite. Physical properties are given. E.S.

HENN, U., 1991. Burma-type rubies from Vietnam. *Australian Gemmologist*, **17**, 12, 505-9, 10 figs and map.

Another report on the heavily included Burma type rubies found in marble, northwest of Hanoi near the China border. Constants are normal, twinning more common and solid inclusions less so than in Burmese stones. R.K.M.

HENN, U., BANK, H., 1991. Epidot von der Knappenwand im Untersulzbachtal, Österreich. (Epidote from the Knappenwand in the Untersulzbach valley in Austria.) *Zeitschrift der Deutschen Gemmologischen Gesellschaft*, **40**, 1, 1-9, 13 figs, 2 tables, bibl.

The best known source of epidote in Europe is the Knappenwand in the valley of the lower Sulz in Austria. This has been worked for 125 years and from time to time crystals of cuttable quality are found. Some of this material has been examined: n_x = 1.731-1.738, n_y = 1.748-1.753, n_z = 1.761-1.773. DR 0.031-0.036, SG 3.37-3.44. Typical inclusions are byssolite, calcite, apatite as well as liquid inclusions and growth zoning. E.S.

HENN, U., BANK, H., SCHUPP, F.J., 1991. Rubine aus Vietnam. (Rubies from Vietnam.) *Zeitschrift der Deutschen Gemmologischen Gesellschaft*, **40**, 1, 25-8, 8 figs, bibl.

The rubies seem to come from the Huang Lien Son Province, about 250km north-west of Hanoi. The colour of the rough crystals varies from pale red to red, sometimes with a distinct violet hue. Weak pleochroism, red to yellowish-

red. Physical data lie within known range of corundum. The colour is caused by Cr^3. Inclusions are healing cracks, fluid inclusions, lamellar twinning, hollow tubes, rutile dust, rounded crystal inclusions, cracks and growth lines. E.S.

HLAING, U.T., 1991. A new Myanmar ruby deposit. *Australian Gemmologist*, **17**, 12, 509-10, 1 fig.

The first published report of rubies from Mong Hsu area of Shan State, S.E. Myanmar [Burma]; four stones examined were rather poor. R.K.M.

HODGKINSON, A., 1991. Synthetic red spinel. *Australian Gemmologist*, **17**, 11, 466-8, 1 fig.

Inspired by queries about identifying flawless red spinels, the paper offers answers based on the blue/red crossed filter technique advocated by Anderson to detect chrome fluorescence and now offered in solid filter form by McCrone Instruments. [Many red spinels do not fluoresce and I doubt if this paper necessarily solves the problem of distinguishing them.] R.K.M.

HOLZHEY, G., 1991. Feueropal aus Aleksejewskoje, Kasachische SSR, UdSSR - ein Beitrag zu vergleichenden gemmologisch-mineralogischen Untersuchungen mikrokristalliner SiO_2 Minerale. (Fire opal from Aleksejewskoje, Kazakstan in the USSR - a contribution to comparative gemmological-mineralogical examinations of microcrystalline SiO_2 minerals.) *Zeitschrift der Deutschen Gemmologischen Gesellschaft*, **40**, 1, 11-23, 2 colour photographs 5 photomicrographs, 3 graphs, 1 table bibl.

The Russian fire opals from Aleksejewskoje are compared with those from Zimapan, Mexico. RI (1.448) and SG (2.06) are average. The submicroscopic structure with a system of cracks can be compared with other microcrystalline SiO_2 minerals such as agates and point to a primary gel-like state of silicic acid. The trace elements show a higher content of non-volatile constituents suggesting a granitic host for the fire opals. E.S.

HOOVER, D.B., 1991. Peridot or sinhalite? (Letter). *Australian Gemmologist*, **17**, 12, 524.

On detection of sinhalite by its greater thermal conductivity; further applications of the method are discussed. R.K.M.

HOSAKA, H., 1991. Observations on hydrothermally synthesized massive agate-like crystals. *Australian Gemmologist*, **17**, 12, 503-5, 6 figs.

A diagram suggests that quartz is deposited, rather in the order found in a natural geode, at the hotter end of an autoclave instead of the cooler end; cristobalite was the source powder. R.K.M.

KAMMERLING, R.C., KOIVULA, J.I., 1991. Identifying features of filled diamonds in review. *South African Gemmologist*, **5**, 2, 10-16, 7 figs (2 in colour).

Signs of filled diamonds are described and illustrated. M.O'D.

KAMMERLING, R.C., KOIVULA, J.I., 1991. Rough grinding pavilions for intentional light scattering. *South African Gemmologist*, **5**, 2, 17-21, 3 figs in colour.

Rough grinding of the base in some synthetic stones causes light scattering and a more natural appearance when stones are examined face up. Ruby and blue synthetic spinel are illustrated. M.O'D.

KAMMERLING, R.C., KOIVULA, J.I., FRITSCH, E., 1991. Characterization of a so-called 'Reconstructed lapis lazuli'. *Australian Gemmologist*, **17**, 11, 450-3, 3 figs.

A convincing new imitation consisting of barium sulphate with pyrite inclusions, bonded in a polymer, was translucent to a powerful light placed behind it. Natural lapis would have been opaque. SG 2.31 is low, while RI 1.55 is too high for true lapis. 'Reconstructed lapis lazuli' is a misnomer. [Darker blue around pyrite inclusions normal to most natural lapis seems to be absent.] R.K.M.

KAMMERLING, R.C., KOIVULA, J.I., FRITSCH, E., 1991. Plastic imitation opals purchased in Thailand. *Australian Gemmologist*, **17**, 12, 498-501.

Bracelets of plastic imitation opals were liberally infested with gas bubbles and owed their colour-play to fragments of film or laminate, they gave broad bands at 560, 608 and 650nm plus a background of fine lines through the whole spectrum. Superficially similar to Slocum Stone. R.K.M.

KAMMERLING, R.C., KOIVULA, J.I., FRYER, C.W., 1991. An unusual imitation jade carving. *Zeitschrift der Deutschen Gemmologischen Gesellschaft*, **40**, 1, 29-32, 3 photographs, 3 photomicrographs, bibl.

The jade carving - a sphere - was bought in the jade market in Kowloon, Hong Kong. It is pierced and carved, weighs 933.50 ct and ranges from 52.0-53.3mm in diameter. It is opaque except in thin edges, where it is semitransparent. Colour varies from dark reddish-brown to medium yellowish-brown to vivid dark

yellowish-green. It was found to be a rock consisting of calcite and lesser amounts of serpentine, possibly a serpentine marble called ophicalcite. The sphere had been selectively dyed brown in the calcite areas and green in the serpentine areas, the whole piece being wax or paraffin coated. E.S.

KAMMERLING, R.C., KOIVULA, J.I., KANE, R.E., MADDISON, P., SHIGLEY, J.E., FRITSCH, E., 1991. Fracture filling of emeralds. Opticon and traditional 'oils'. *Gems & Gemology*, **27**, 2, 70-85, 17 figs.

Compares the epoxy resin 'Opticon' with Canada balsam and with cedarwood oil when used as fillers for surfacing cracks in emerald. All may be damaged in cleaning by ultra-sound or steam, or by heating in repair of a mount, but Opticon is less prone to damage in cleaning. The epoxy resin is applied by soaking the emerald in hot filler followed by a surface coating of hardener which is removed after ten minutes. The filling is hardened at the surface but remains liquid within the filled crack.

GIA advocate the use of the wording 'Foreign matter is present in some fractures reaching the surface', rather than 'oiling' which does not apply to all treated stones. Filled surface flaws can be expected in stones other than emeralds and colour is sometimes added with the filler. Other substances are also being used as fillers. R.K.M.

KANE, R.E., MCCLURE, S.F., KAMMERLING, R.C., KHOA, N.D., MARA, C., REPETTO, S., KHAI, N.D., KOIVULA, J.I., 1991. Rubies and fancy sapphires from Vietnam. *Gems & Gemology*, **27**, 3, 136-55, 32 figs.

An important paper on new sources of ruby and pink sapphire from the Luc Yen and Quy Chau area in Northern Vietnam. Other localities in the south are not yet worked commercially. Aquamarine and colourless topaz have been found near Quy Chau.

Mining is principally by open-pit, with much contrabanding by 'independent' miners, most crystals small. Gemmological constants as expected for corundum; twin laminations; inclusions largely reminiscent of Burmese or Thai rubies plus some unique to this locality. Stones not heated at mine but may be treated later.

Dark blue colour zones common in the rubies and colour is generally patchy, swirled and treacly, bluish clouds, and whitish ones of larger particles also common, and iron stained fractures exceptionally so. Acicular needles thought to be boehmite; crystals of included apatite and calcite were identified while opaque rods proved to be pyrrhotite and not rutile. Less often stones contained orange crystal patches of the rare mineral nordstrandite, new in corundum; phlogopite mica was also seen. Rubies of similar type are found across the border in China and possibly in Laos. Further gem areas are expected and the whole region could become a significant source of ruby. Illustrations on neutral backgrounds seem to depict the colour and quality nicely. R.K.M.

KEELING, J.L., 1991. Review of a new theory on emerald formation in schist deposits. *Australian Gemmologist*, **17**, 11, 440-2.

Recent studies of Habachtal (Austria) and Leydsdorp (Transvaal) emeralds by Grundmann and Morteani of Munich University suggest that emerald in biotite mica schists has formed in the course of low-grade regional metamorphosis. [A paper more interesting to petrologists than to the average gemmologist.] R.K.M.

KIRKLEY, M.B., GURNEY, J.J., LEVINSON, A.A., 1991. Age, origin, and emplacement of diamonds: scientific advances in the last decade. *Gems & Gemology*, **27**, 1, 2-25, 20 figs.

A detailed account of basic knowledge of diamond formation arrived at in the 1980s which estimates the probable age range as between 990 and 3200 million years (My) based on age-dating of inclusions of garnet, pyroxenes, etc., by assessment of radio-active residues. These findings have added a great deal to the understanding of diamond origin deep in the earth's mantle and it is now considered likely that they are xenolithic, having formed in eclogite under enormous pressure before being carried some 150km to the surface, in upsurges of kimberlite or lamproite, from a molten zone in the mantle. It is also thought that the carbon source of diamond is either CO_2 or methane, rather than coal [or oil?]. Processes involved are extremely complex and still appear to be far from completely understood despite these advances. An interesting though complex subject well treated here. R.K.M.

KLEYENSTUBER, A., 1991. Observation of inclusions in a Madagascar emerald and their possible implications. *South African Gemmologist*, **5**, 2, 4-9, 6 figs (4 in colour).

An emerald from Madagascar weighing 32.50 ct and cut as an oval cabochon contained black mica flakes and fracture fillings of yellow goethite as well as elongated hollow growth channels, apparently devoid of mineral or liquid filling and a large individual hexagonal crystal with distinct yellow to green pleochroism. This is tentatively identified as apatite or tourmaline. M.O'D.

KOIVULA, J.I., KAMMERLING, R.C., 1991. Gemological examination of a red taaffeite. *Zeitschrift der Deutschen Gemmologischen Gesellschaft*, **40**, 1, 33-7, 1 fig., bibl.

The stone is a well-proportioned oval modified brilliant-cut of intense, medium-dark, slightly brownish-red colour. The weight was confirmed as 0.58 ct. Measurements 5.21 x 4.43 x 3.51 mm. Said to be the largest and only second reported red taaffeite. Properties were identical to those reported in literature for the only other known taaffeite of this colour. E.S.

KOIVULA, J.I., KAMMERLING, R.C., 1991. Gem news. *Gem & Gemology*, 27, 1, 46-55, 19 figs.

A general report on this year's Tucson Show:

Diamonds

Coloured diamonds increase in number each year, mostly treated, commonly to blue, yellow and to browns with grey or green overtones; natural colours are declared as such; irradiated stones are not - [a reversal of the required practice!] three Russian synthetic yellow diamonds had no colour zoning.

Coloured stones

Blue-green apatites from Madagascar were there again but heat sensitivity makes faceting difficult; bead materials included a banded dolomite, fluorite and brecciated pyrite; a cat's-eye beryllonite, looking like ulexite, was rare enough to purchase for the GIA permanent collection; a 2.89 ct clinohumite was the largest so far seen; sapphires were available in profusion, mostly heat-treated Montana; also some Brazilian sapphires, again some with colour change; and some so-called padparadschas from Umba region of Tanzania.

Thais are fashioning cubic zirconia and other stones in square and rectangular brilliant styles very effectively; drusy agate, black and pale purple quartz, pyrite-rich lapis lazuli and other gems were shown in carved forms; some small Uralian beryl and light emeralds were examined; Alta Ligonha, Mozambique, is producing pale morganite; white opal from Piaui State and blacks from Boi Morto, Brazil, were also seen, some too porous to take a good polish and some layered in a spectral sequence of colours.

Cultured pearls from Tahiti were the best yet, with many fine strands of large blacks; small peridot from Arizona were plentiful and a 131.89 ct one from Burma was also seen, as were bi-colour amethyst/rock-crystal; cat'seye rose quartz; faceted rhodolite garnet from Orissa, India, and a violet scapolite cat's-eye from Burma with low birefringence.

Tanzanite mines are being worked under Tanzanian Army supervision to stop illegal diggers, plenty of these stones seen at Tucson; Paraiba blue tourmaline again much in evidence; further Vietnam finds of ruby are reported from Luc Yen near Hanoi, and sapphires from the south.

Enhancements

Plasticised Alberta ammonite shell, and dyed and plastic coated Paua shell are reported; coloured Opticon is being used to fill emerald cracks; Sri Lankan rubies heated by blow-pipe; diffusion treated sapphires from Bangkok were plentiful but similarly treated rubies are not successful due to blue chromophores in the material.

Synthetics and Simulants

A light coloured synthetic alexandrite from J.O. Crystals exploits the pleochroism as well as the colour change, bubbles and zoning were seen; Chatham had some 'cleaner' synthetic emeralds, and some extremely large crystals of flux-grown ruby with clean areas, they have no plans to market padparadschah synthetic corundum; Pool emeralds are now offered as Kimberley Created Emeralds; less dense silicon (2.33) is being used to replace heavy hematite (5.20) for bead material although less black in colour; a natural looking imitation lapis lazuli was translucent to intense light and weakly fluorescent to SUV, inert to L W , plastic binder suspected; gold-quartz/white ceramic doublets were seen; Soviet synthetics included the flux-grown purple/ red spinels, flux-grown alexandrite; hydrothermal beryl in a range of colours; synthetic emerald on tumbled aquamarine seeds; much synthetic quartz, advertised as Siberian Blue Quartz; synthetic tanzanite and tourmaline are hinted at but the Russian word for synthetic is the same as for imitation, so these are probably imitations, a similar mistake occurred when they claim large faceted CZ gems to be 'synthetic' diamonds.

R.K.M.

KOIVULA, J.I., KAMMERLING, R.C., 1991. Gem News. *Gems & Gemology*, 27, 2, 116-25, 19 figs.

Diamonds

Reports on the 273ct heart-shaped Centenary Diamond, reportedly flawless and the largest outside the British Crown Jewels, but with a confusing illustration; on a 'chameleon' greenish-grey diamond which turned brownish yellow when hot; on

Soviet diamond production; on Australian permit to explore Timor Sea for diamonds; a world record price at Sotheby's, Geneva, for a 101.84ct diamond (US$12,760,000); on a pair of 'Star of David' shaped double twinned macles; a bluish-grey boron-rich micro-coating of low-temperature synthetic diamond on colourless diamonds had high electrical conductivity, and could also be detected by an edge fugitive tendency giving a white abraded look under magnification.

Coloured stones

Reports on tourmalines from Namibia, Zambia and Madagascar; on increased ruby output from Tanzania, with better padparadscha from the Umba River region, and on aquamarine from Zimbabwe, amethyst from Afghanistan; ruby in green mica from Northwest Frontier Province, Pakistan; a joint venture to cut and market Uralian emeralds; labradorite from Madagascar carved as cubes, spheres and other shapes; opal with fine greenish body colour from Peru; iridescent green exoskeletons of beetles mounted as jewellery. The first auction of Cook Island black cultured pearls had many silver grey pearls and sold just over half the items offered, mostly to Japan; rich green transparent zoisite is available from the Merelani district of Tanzania, and resembles the fine tourmalines of Paraíba, Brazil.

Enhancements

Buffing settings of aqua aura blued stones can remove the gold coating and spoil the colour; jadeite with cracks filled with epoxy resin is reported; quartzite beads dyed to lavender blue were offered as dyed jadeite, penetration of colour was complete; gems made from fibre optic glass are described and illustrated; backed Mexican opal slices embedded in plastic to simulate black opal are offered as 'opal encapsulado'; plastic imitations of opal containing iridescent films or foil were purchased in Bangkok, multitudinous gas bubbles made the deception obvious; Russian flux-synthetic red spinels seen in recent years have been made from 'defective' natural crystals from the Pamir Mountains so constants approach those of natural spinel.

Instrumentation

A dark-field loupe has been developed by GIA GEM; two new automated and versatile cutting machines have been developed to facet girdle edges of diamonds, one in Belgium, the other in Israel; an Israeli firm offers ROBOGEM, a computerized stone cutting machine which has image-processing technology to provide 'optimum yield' from rough and can be programmed to produce all common shapes, graduated sets, pairs or maximum weight, and can preform girdling in less than a minute.

R.K.M.

Koivula, J.I., Kammerling, R.C., 1991. Gem News. *Gems & Gemology*, 27, 3, 180-90, 16 figs.

Diamonds

Argyle are expanding ore processing at AKI pipe, WA, to keep up with lesser productivity at depth, and are now cutting diamonds in China; Namibia's Elizabeth Bay deposit has been reopened as an open-cast mine by Consolidated Diamond Mines and expects to produce about 2.5 million carats of mainly gem quality stones in the next ten years; there is much organized theft there particularly from the Orangemund mine; a major new Russian diamond field is reported at Baryatskaya near the Mongolian border.

The second European Conference on diamond, diamond-like and allied coatings held in Nice was notable for the number of presentations on diamond-like coatings (extremely hard amorphous carbon of great potential in industry, an inherent colour seems to be a problem with DLC, but the brown of CDV (carbon vapour deposition) films is due to interstitial graphitic deposits and may be improveable.

Maico Diamonds recently introduced their 'Dream-cut' diamonds which have the normal rounded girdle left straight-sided, making the table look larger and utilizing relatively flatter rough. Small modifications of facets help to minimize light leakage normal to shallow stones, with resultant greater weight yield and larger looking stones. [Brilliant, marquise and drop are illustrated but images are too confused to allow one to assess details]. GIA report finding stereoscopic photographs taken at the turn of the Century relating to early diamond mining in S. Africa.

Coloured stones

Colombian emerald exports reached an all time high in 1990, mostly to Japan. A large grey South Sea pearl is reported in Thailand, 42mm long with high lustre, when shaken internal liquid could be heard; Myanmar is to permit export of rough and cut stones to a Thai company in Rangoon; a Myanmar postage stamp illustrates the 496.5ct Nawata ruby rough found at Mogok in 1990 and confiscated the same year as illegally mined; much Thai sapphire is still produced by traditional hand mining and sorting. Attractive pink spinels from Umba River region of Tanzania were seen at the Tucson show, some were velvety with submicroscopic inclusions; the Longido ruby mine, Tanzania, is being worked again producing cabochon grade stones; the Tanzanian government

invites tenders for mineral rights in the Merelani tanzanite area.

Large Paraíba blue/green tourmalines are now reported; two African tourmalines were colour-change when seen in combined incandescent and fluorescent light, and fluoresced chalky yellow under SUV; dissimilarity of pleochroism between brown tourmaline and andalusite is noted and a warning given on over-reliance on visual clues to identify; idocrase in purple, green and bi-colour have been found at Jeffery mine in Quebec; an unusual black tanzanite was pleochroic in red, greenish and purple along its principal axes under powerful light [would heat have made this a usable stone?].

Enhancements

There are reports of diamond-film coated stones but GIA are aware of only three diamonds which were experimentally coated with Type IIb blue diamond film; DLC films adhere to a variety of soft stones and sapphire point will not scratch them, they impart anomalous adamantine lustre and a brownish tint to the stone [Do such ultra-thin coatings affect the RI?]. Dry Cottonwood Creek mine, Montana, is producing blue and yellow sapphires which can be heated to deepen the colour, some develop unwanted zoning; experimental diffusion of red colour into corundum has so far been unsuccessful and some stones lose colour from over-polishing.

Synthetics and simulants

A white Gilson type synthetic opal adhered to the tongue and absorbed water readily.

Instrumentation and new techniques

It is pointed out that heat-coating and heat-diffusion are different processes, the former does not affect pleochroism, while this is enhanced by heat diffusion of colour. A new method of setting diamonds in a carbon-based polymer plastic defeats thermal conductivity tests but inclusions are still typical of diamond and the X-ray transparency test still applies; a new and greatly improved colour imaging process is described and so is surgical tape to increase the adhesion of gem tweezers. R.K.M.

Krosch, N.J., Cooper, W., 1991. Queensland Sapphire. *Australian Gemmologist*, **17**, 11, 460-4, 2 maps.

The first instalment of a paper based on a Queensland Govt. Mining Journal report of 1990 dealing with the many sapphire areas of eastern Queensland, only two of which are mined on a commercial scale. These are the Rubyvale, Sapphire and Anakie region in central Queensland and Lava Fields in the north. Sapphire tends to occur in basaltic rocks which are widespread in these areas. R.K.M.

Krosch, N.J., Cooper, W., 1991. Queensland Sapphire: part II. *Australian Gemmologist*, **17**, 12, 511-15.

Deals with surface, shaft and large scale mechanical mining, producers, production, marketing and future potential. Most stones are cut in Thailand. Competition from Nigeria and China anticipated. R.K.M.

Linton, T., Brown, G., 1991. Polaroid 'spectra' system with close-up stand Model 7500. *Australian Gemmologist*, **17**, 10, 429-31, 4 figs.

Report on a Polaroid camera adapted for close-up photography of gems and small jewellery says shallow depth of field (<12mm) plus high cost of camera and film makes it less attractive than claimed, while centre definition leaves something to be desired. R.K.M.

Linton, T., Brown, G., 1991. Coral identification kit. *Australian Gemmologist*, **17**, 11, 465.

A collection of 15 different corals, both rough and polished, from deep waters south of Tasmania, including various bamboo corals, black and gold corals, with notes on the main features which identify corals from these seas. Reasonably priced at $A25. R.K.M.

Linton, T., Brown, G., 1991. The Shibuya 150 gemmological refractometer. *Australian Gemmologist*, **17**, 11, 468-9, 2 figs.

A Japanese refractometer with scale range from 1.30 to 1.83, but supplied in this case with 1-bromonaphthalene (RI 1.66) as contact fluid. An in-built yellow interference filter is not quite as accurate as a sodium light source, but the instrument is assessed as high quality. Some difficulties were experienced with spot testing high RI cabochons.

Linton, T., Polita, M., Brown, G., 1991. A new dark-field loupe. *Australian Gemmologist*, **17**, 10, 396-7, 2 figs.

A report on an American 10x dark-field lens combined with a focusing Mini-Mag pocket torch. Efficient when batteries are new but restricted for large sizes of stone, and expensive. R.K.M.

McCabe, A.J., 1991. Paua shell and how to work it. *Wahroongai News*, **25**, 7, 4-7.

Advice on working rough paua shell to a satisfac-

tory finish. The rather strange Maori name is pronounced 'pa-wa'. R.K.M.

NIEDERMAYR, G., 1991. Eine Dose aus Bleiberger Muschelmarmor. *Mineralien Welt*, **2**, 4, 49-52, 6 figs (5 in colour).

Examples of fire marble from the Natural History Museum in Vienna are illustrated with notes on their composition and on the places where the material was found. Chief among these is Bleiberg, Carinthia, Austria. M.O'D.

PAULITSCH, P., 1991. Kupfer und Jade aus China. *Aufschluss*, **42**, 207-12, 2 photos in colour, 1 fig.

The history and use of jade in China is briefly described with notes and tables of jade-like minerals. Copper also features in the paper. M.O'D.

REDMANN, M., HENN, U., BANK, H., 1991. SchleifwUrdiger, klar durchsichtiger, farbloser bis blassgelblicher Thaumasit aus, Südafrika. (Cuttable, transparent, colourless to pale yellow thaumasite from South Africa.) *Zeitschrift der Deutschen Gemmologischen Gesellschaft*, **40**, 1, 67-8, bibl.

The colourless to pale yellow gem quality thaumasite from the Black Rock mine in the Kalahari manganese field is described. N_o = 1.505-1.510, n_e = 1.467-1.480, DR 0.030-0.038, SG 1.88-1.91. E.S.

ROBERT, D., 1991. Un simulant de roches mauves. *Revue de Gemmologie*, **107**, 3-6, 3 figs in colour.

Charoite, sugilite and common beryl are reviewed as mauve gem or ornamental materials. M.O'D.

RUFLI, J.-C., 1991. Ny intensiv blå och grön Ädelsten från Brasilien! *Gem Bulletinen*, 1/91, 2-3. A brief note on the deep blue tourmalines recently found in Paraiba, Brazil. Adapted from a paper in Gem News. M.O'D.

SCHLÜTER, J., WEITSCHAT, W., 1991. Bohemian garnet – today. *Gems & Gemology*, **27**, 3, 168-73, 16 figs.

Pyrope has been mined commercially in what is now Czechoslovakia since the 16th century and although now considered exhausted a small mine still operates at Podsedice in the Bohemian Hills. Stones are cut and set in Turnov. The alluvial deposit is from peridotite pipes and the garnet is mostly in small crystals. Other localities are being explored. Mining is open-cast and 320 tonnes of gravel are washed and sieved daily to yield about 45kg of concentrates, which are then hand-sorted to give about 5kg of cuttable crystals yielding rose-cuts from 3 to 5mm in diameter. Weight loss in cutting is said to be only 10%. R.K.M.

SCHMETZER, K., 1991. Lechleitner synthetic emeralds, rubies and sapphires. *Australian Gemmologist*, **17**, 12, 516-23, 18 figs.

Deals in some detail with each type of synthetic produced by Johann Lechleitner, who is now 70, from A to F; type B, natural seed beryl, over-grown with thin plates of chrome-rich synthetic emerald; type D, fully synthetic emerald grown on a central synthetic seed, and type F, flux-grown full synthetic emerald are available commercially. Lechleitner started experimenting with synthetic corundum in 1983 again by over-growth of synthetic ruby on colourless Verneiul cores, and other colours followed, using molybdenum and lead fluxes; following year he produced ruby by coating synthetic ruby onto natural corundum cores. All these are composite or synthetic stones and must be so marketed. R.K.M.

SCHMETZER, K., BERHARDT, H-J. BIEHLER, R., 1991. Emeralds from the Ural Mountains, USSR. *Gems & Gemology*, **27**, 2, 86-99, 14 figs.

Emeralds from the Takovaya River area, north of Sverdlovsk, in eastern Urals, are being found in quantity, as a by-product of beryllium mining, after a lapse of several decades. Qualities vary from pale to dark green and from heavily included to flawless. RIs vary from 1.581p1.575 to 1.590-1.582, SG from 2.72 to 2.75. Three-phase inclusions are less frequent than in Colombian stones and lack the jagged outline of the latter; healed fractures, flat liquid-filled feathers parallel to the basal pinacoid, and phlogopite and other inclusions are common but most are similar to inclusions from other localities. R.K.M.

SCHWARZ, D., 1991. Die chemischen Eidenschaften der Smaragde. II Australien und Norwegen. (The chemical properties of emeralds. II Australian and Norwegian.) *Zeitschrift der Deutschen Gemmologischen Gesellschaft*, **40**, 1, 39-66, 1 photomicrograph, 2 maps, 6 graphs, 5 tables, bibl.

The emeralds from Norway came from Eidsvoll near the Mjosa Lake, the Australian specimens from Pilgangoora, Wodgina, Calvert White Quartz Hill, Warda Warra, Melville and Torrington in Western Australia, Emmaville in New South Wales and from Menzies in West Australia. On average, compared with the Brazilian material, there is less magnesium,

sodium and iron content in both the Norwegian and Australian stones, especially the Norwegian and the Emmaville samples have extremely low Na_2O and MgO contents. The Mjosa emeralds have a high vanadium content. E.S.

SCHWARZ, D., 1991. Australian emeralds. *Australian Gemmologist*, **17**, 12, 488-97, 3 figs and a map.

Part of a research on emeralds from main sources world-wide by microprobe, more of interest to the petrologist or mineralogist than to the gemmologist. R.K.M.

SHERRIFF, B.L., GRUNDY, H.D., HARTMAN, J.S., HAWTHORNE, F.C., CERNY, P., 1991. The incorporation of alkalis in beryl: multi-nuclear MAS NMR and crystal-structure study. *Canadian Mineralogist*, **29**, 271-85, 10 figs.

Stereochemical details of the incorporation of alkali ions into the beryl structure are examined using multi-nuclear MAS NMR spectroscopy and single-crystal structure refinement. M.O'D.

STÖTZEL, N., SCHWEISFURTH, G., HOCHLEITNER, R., 1991. Siegerland-Mineralienland. Die klassischen Mineralstufen aus den Siegerländer Erzgangen. *Lapis*, **16**, 7/8, 27-67, 115 photos (95 in colour), 6 figs.

Fine quality rhodochrosite, malachite and sphalerite are among the minerals found in the German Siegerland mining area. Other minerals are described and illustrated and a complete list for the area is given. M.O'D.

TILLANDER, H., 1991. En kritisk Analys av De Beers Diamantbroschyr. *Gem Bulletinen*, 1/91, 10-16.

Review of a pamphlet on diamond grading issued by De Beers for consideration within the Scandinavian countries in 1989. M.O'D.

TOMBS, G., 1991. Some comparisons between Kenyan, Australian and Sri Lankan sapphires. *Australian Gemmologist*, **17**, 11, 446-9, 6 figs.

Corroded, fragmentary crystals of sapphire from Kenyan sources at Garba Tula, Lodwar and Samburu are compared with Australian (New England) and with Sri Lankan sapphires, and the differences in colour enhancement by heating attributed to the considerable variations in iron content. Repairers are warned to unset sapphires before applying heat to a mount. R.K.M.

URMOS, J., SHARMA, S.K., MACKENZIE, F.T., 1991. Characterization of some biogenic carbonates with Raman spectroscopy. *American Mineralogist*, **76**, 641-6, 3 figs.

Biogenic carbonates from a scleratinian coral (Porites sp.), Corallium reale and C. secundum corals, pink and uncoloured respectively and from natural and cultured pearls are examined by Raman spectroscopy. Aragonitic Porites coral and pearls show Raman bands characteristic of aragonite but bands from the natural pearl are slightly sharper than the corresponding bands from Porites and cultured pearls. Deep-sea precious corals show Raman spectra closely resembling those of magnesian calcite but pink corals show seven additional bands in the region 1020-3759cm^{-1}. The extra bands are attributed to a carotenoid pigment which gives rise to the pink colour of the coral skeleton. M.O'D.

VON BEZING, K.L., DIXON, R.D., POHL, D., CAVALLO, G., 1991. The Kalahari manganese field: an update. *Mineralogical Record*, **22**, 279-97, 38 photos (18 in colour), 1 map.

Gem quality crystals of rhodochrosite and sugilite are among the minerals listed and described in this update. The crystals are small in general. A complete list of minerals discovered so far and a list of references are given. M.O'D.

WELZEL, J., 1991. Glass Art - now and then. *Industrial Diamond Review*, **51**, 141-3, 5 figs (2 in colour), bibl.

In reproducing famous glassware from the classical period and finishing it by fine grinding and engraving, master craftsman J. Welzel is convinced that diamond abrasives were in use from the first to the fourth century AD.

Mr Welzel has reproduced the Lykurgos goblet and the Portland vase. E.S.

ZEIHEN L.G., 1987. The sapphire deposits of Montana. *Bulletin, Montana Bureau of Mines and Geology*, No. 126, 28-39, 5 photos, 2 maps.

The three main sapphire-bearing areas described are the Yogo Creek deposits and those on the Missouri River bars and on Rock Creek. A brief mention is made of other deposits. In general sapphire crystals are small with a wide range of colours. Few finished stones would reach two or more carats but the colours can be very fine in many specimens. M.O'D.

Proceedings of The Gemmological Association and Gem Testing Laboratory of Great Britain and Notices

OBITUARY

Mr R.L. Austen, FGA (D.1937 with Dist.), Chichester, died on 9 December 1991.

Mr Edwin T. Mills, FGA (D.1986), Ely, died on 10 February 1992.

Professor Dr D.H.G. Keuskamp, FGA (D.1981), Streefkerk, Netherlands, died on 12 February 1992.

Mr R.W. Yeo, FGA (D.1929 with Dist.), Instow, died in February 1992. A full obituary will be published in a future issue of *The Journal*.

NEWS OF FELLOWS

Mr Alan Hodgkinson, FGA, represented the Gemmological Association and Gem Testing Laboratory of Great Britain by giving two lectures at the Tucson Gem & Mineral Fair in February 1992.

Following on from last year's theme, this year's heading was 'A further taste of Scottish gemmology', but behind the lighthearted title was a wealth of factual information on gem testing techniques and the latest finds and developments of natural and artificial gemstones.

The diamond/graphite coating on a brilliant-cut cubic zirconia caused such interest that it was displayed on the stand of the Canadian Gemological Association and American Gemological Association via close circuit television from a microscope video. The two 'one-and-a-half hour' lectures lasted five hours in all, and with a standing room only situation the door had to be shut to prevent further entry.

On 3 April 1992 **Dr J.B. Nelson** gave an illustrated talk on 'Gemmological teaching in Hong Kong and China' to the Sussex Mineral and Lapidary Society at Haywards Heath.

MEMBERS' MEETING

London

On 10 March 1992 at the City Conference Centre, Mark Lane, London EC3, Alan Jobbins and Amanda Goode gave illustrated lectures to an audience of more than 150 on the gemstone deposits and trade in Sri Lanka.

Midlands Branch

On 17 January 1992 at Dr Johnson House, Bull Street, Birmingham, a members' practical evening was held.

On 21 February 1992 at Dr Johnson House, Mr Clive Burch gave an illustrated lecture on inclusions in gemstones.

On 20 March 1992 at Dr Johnson House, Mr David Callaghan gave an illustrated lecture on cameos and intaglios entitled 'On the face of it'.

North West Branch

On 15 January 1992 at Church House, Hanover Street, Liverpool 1, Mr David Pelham gave an illustrated lecture entitled 'Small scale gold mining and gem mining'.

On 19 February 1992 at Church House, Helen Fraquet gave a lecture on 'Amber'.

On 18 March 1992 at Church House, Dr Jeff Harris gave an illustrated lecture entitled 'An aspect on diamonds - alluvial diamond deposits'.

MEETINGS OF THE COUNCIL OF MANAGEMENT

At a meeting of the Council of Management held on 18 December 1991 at Chapel House, Hatton Place, London EC1N 8RX, the business transacted included the election to membership of the following:

Fellowship

Anastassiou, Evagelia, Athens, Greece. D. 1991.

Chan, Nga Y., Causeway Bay, Hong Kong. D. 1991.

Chu, Yiu W.T., Kowloon, Hong Kong. D. 1991.

Chudawala, Sucheta, Bombay, India. D. 1991.

FORTHCOMING EVENTS

London

Meetings will be held at the City Conference Centre, 76 Mark Lane, London EC3R 7JN, at a cost per lecture of £5.00 for GAGTL members, £10.00 a member and a guest, and £8.00 for non-members. Further details and tickets from the GAGTL.

Gemstone deposits and the trade associated with them

Tuesday 9 June 1992	South East Asia
Tuesday 24 November 1992	Africa

North West Branch

Meetings to be held at Church House, Hanover Street, Liverpool 1.
Further details from Irene Knight on 051-924 3103.

20 May 1992	Nigel Israel. 'Historical aspects and valuations'
17 June 1992	'Exchange and Mart'. Buying and selling of books, crystals and instruments, plus social evening
16 September 1992	Adrian Klein. 'Emerald'
21 October 1992	Dr Jamie Nelson. 'Optical attributes of a diamond'
18 November 1992	Annual General Meeting

TRADE WORKSHOPS IN JULY

GAGTL staff will be running their popular Trade Workshop again in July. More than a dozen people are already on the waiting list for this Workshop, and if you wish to take part in observing gem materials from the trade point of view, please contact GAGTL Education Office on 071-404 3334 for further details. The Workshop will be held close to Hatton Garden and will cost £60.00 plus VAT.

Chung, Tsz K., Kowloon, Hong Kong. D. 1991.
Doshi, Setu H., Bombay, India. D. 1991.
Ghisi, Maria, London. D. 1991.
Ha, Wai M.C., Kowloon, Hong Kong. D. 1991.
Harrison, Victoria A., Taunton. D. 1991.
Khimji, Priti, London. D. 1991.
Lai, Mui G.M., Hong Kong. D. 1991.
Lau, Mee S.L.M., Kowloon, Hong Kong. D. 1991.
Lee, King T., Kennedy Town, Hong Kong. D. 1991.
Lilley, Elaine, London. D. 1991.
Merchant, Azmet, Bombay, India. D. 1991.
Mourogiannis, Stephanos, Volos, Greece. D. 1991.
Ng, Chee K., Quarry Bay, Hong Kong. D. 1991.
Oo, Thein L., Singapore. D. 1989.
Pang, Shing C., Kowloon, Hong Kong. D. 1991.
Simmons, Charlotte R., Huntingdon, Md., USA. D. 1991.
Vesters, Marco., Hertogenbosch, The Netherlands. D. 1991.
Wong, Hon C., Kowloon, Hong Kong. D. 1991.
Wong, Siu P., Kowloon, Hong Kong. D. 1991.
Yeung, Kit Y.K., Hong Kong. D. 1991.
Zhang, Linxia, Shen Zhen, China. D. 1991.

Ordinary Membership
Allaman, John, Sarasota, Fla., USA.
Beckett, Shona-Maria F., London.
Beltran, Luruenta F.J., Madrid, Spain.
Bevoort-Alwicher, Terrence, GE Nijmegen, The Netherlands.
Bolton, Jane A., London.
Butler, Ian P., High Barnet.
Campbell-Pedersen, Maggie, London.
Chan, Lo M.Y.F.C., Kowloon, Hong Kong.
De Jongh, Laurentia M., The Hague, The Netherlands.
Deshapriya, Sarath B.A.M., Perivale.
Drowley, Brigitte, Haslemere.
Frutos, Carmen, London.
Hertani, Abdul, Lancing.
Huang, Chin T., Taipei, Taiwan.
Humphrey, Mary S., London.
Kinnunen, Kari A., Espoo, Finland.
Makoundoul, Chris M., Solva, Sweden.
Matsumoto, Naoko, Chicago, Ill., USA.
Messer, J. Wayne, Candler, NC., USA.
Packard, Alice V., London.
Rochat-Huguenin, Chantal, Lausanne, Switzerland.
Sarmento, Rodrigo W., Lisboa, Portugal.
Wilkins, Anthony E., Bridgwater.

At a meeting of the Council of Management held on 22 January 1992 at Chapel House, Hatton Place, London EC1N 8RX, the business transacted included the election to membership of the following:

Fellowship
Bakagianni-Sabou, Aristea, London. D. 1991.
Baxendale, Paul D., London. D. 1965.
Dietz, Susanne C., Koenigstein/TS, Germany. D. 1990.
Mehra, Shilpa, Hong Kong. D. 1991.
Nolet, Theresa A., Castlegar, BC, Canada. D. 1991.
Ranabahu, Mallikage K.T.S.N., Ratnapura, Sri Lanka. D. 1982.
Samaranayake, Ravinda, Colombo, Sri Lanka. D. 1991.

Ordinary Membership
Boulton, Brian C., London.
Harper, Jonathan, London.
Hart, Juliana L., Colonel Light Gardens, S. Australia.
Leong, Weng, Maidstone.
Schmetzer, Karl, Peterhausen, Germany.
Speet, Scilla M.A., London.

At a meeting of the Council of Management held on 19 February 1992 at Chapel House, Hatton Place, London EC1N 8RX, the business transacted included the election to membership of the following:

Fellowship
Campomanes Eguiguren, Amalia, Alicante, Spain. D. 1991.
Xue, Qinfang, Hubei, China. D. 1991.
Yang, Mingxing, Hubei, China. D. 1991.
Zhang, Fan, Huei, China. D. 1991.

Ordinary Membership
Arai, Takahiro, Chiba Pref, Japan.
Hasegawa, Tomoko, Tokyo, Japan.
Higo, Kenji, Qsaka, Japan.
Higo, Yoshiko, Osaka, Japan.
Horsfall-Ertz, Priscilla J., London.
Hotta, Shigemitsu, Nara Pref, Japan.
Ikeda, Noriko, Hyogo Pref, Japan.
Kariya, Tomoko, Tokyo, Japan.
Katsuta, Morifumi, Osaka, Japan.
Kiji, Michio, Osaka, Japan.
Kinda, Yumiko, Osaka, Japan.
Klein, Jeffrey L., Southend on Sea.
Liu, Zhao, Hubei, China.
Magara, Yoshiaki, Fukui Pref, Japan.
Mina, Jacqueline, Twickenham.
Mitsuno, Atsushi, Kyoto, Japan.
Miyamoto, Kiyomi, Osaka, Japan.
Morino, Yoshio, Tokyo, Japan.
Mumetani, Miho, Hyogo Pref, Japan.
Murakami, Chie, Osaka, Japan.
Nakamura, Haruji, Kyoto, Japan.
Nakane, Chie, Hyogo Pref, Japan.
Nishimura, Tadahiro, Osaka, Japan.
Noritomi, Hidekazu, Osaka, Japan.
Odawara, Hiroko, Osaka, Japan.
Park, Jung S., Seoul, Korea.
St Clare, Edward, Southport.
Sakaki, Kouki, Ibaraki Pref, Japan.
Sano, Hajime, Tokyo, Japan.
Semi, Saoko, Kanagawa Pref, Japan.
Takai, Reiko, Niigata Pref, Japan.
Tanaka, Kazuhide, Osaka, Japan.
Tanaka, Mariko, Hyogo Pref, Japan.
Taniguchi, Toshiko, Osaka, Japan.
Tateno, Haruyuki, Ibaragi Pref, Japan.
Uchi, Naoko, Hyogo Pref, Japan.
Udagawa, Koichi, Tokyo, Japan.
Warne, William R., Birchington.
Yamagami, Mayumi, Tokyo, Japan.
Yamasuga, Ryoji, Hyogo Pref, Japan.
Yashima, Aiko, Hyogo Pref, Japan.
Zhang, Yabin, Hubei, China.
Zubaida, Albert, London.

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At a meeting of the Council of Management held on 18 March 1992 at Chapel House, Hatton Place, London EC1N 8RX, the business transacted included the election to membership of the following:

Fellowship

Colborne, Janette., Brisbane, Australia. D. 1991.

Van Den Haak, Hester, Krimpen, The Netherlands. D. 1991.

Ordinary Membership

Alteen, Michael L., Nova Scotia, Canada.
Boote, Caroline M.E., London.
Deolia, Damji, Hounslow.
Dillistone, Jason S., Hove.
Dinnis, Simon J., Swadlincote.
Duigan, Ingeborg, Kowloon, Hong Kong.
Hug, Markus E., Schaffhausen, Switzerland.
Page, Tayma F.L., Hong Kong.
Roper, Bebs, Tasmania, Australia.
Yenson, Patrick, London.

MEETING OF THE TRADE LIAISON COMMITTEE

At a meeting of the Trade Liaison Committee held on 13 February 1992 at 100 Hatton Garden, London EC1, the business transacted included the election to membership of the following:

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Teh Jun Co. Ltd., Room 1206, Lane Crawford House, 70 Queens Road Central, Hong Kong.

S. Muller & Sons NV., Schupstraat 1-7, Bus 6, 2018 Antwerp, Belgium.

C.N. Ross-Field Ltd., 12 Hatton Garden, London EC1N 8AN.

Ordinary Laboratory Membership

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Hugh Rice Ltd., 10-14 George Street, Hull, N. Humberside HU1 3AJ.

The Jewellers & Silversmiths, 15 Thames Street, Kingston Upon Thames, Surrey.

REPLICA DIAMONDS

One of the attractions at the Birmingham NEC Jewellery and Giftware Fair in February was the public launch on the GAGTL stand of a new series of cubic zirconia stones cut to imitate famous diamonds. The series also includes sets which show the most popular cuts used for diamonds, the development of the brilliant cut, and a range of round brilliants of different weights. Each of 13 famous diamonds can be bought separately and are available through Gemmological Instruments Ltd., Fax 071-404 8843.

GEM & MINERAL FAIRS 1992

Gem and Mineral Fairs will be organized by the British Lapidary & Mineral Dealers' Association during 1992 as follows:

Leicester 16-17 May 1992. Holiday Inn.
Harrogate 29-31 August 1992. Crown Hotel.
London 17-18 October 1992. Holiday Inn, Swiss Cottage.

Further details from Fair Organizer: John F. Turner, Glenjoy, 19/21 Sun Lane, Wakefield, W. Yorkshire. Telephone 0924 373786.

Letter to the Editor

From A. E. Farn

Dear Sir,

It is unfortunate that letters to the Editor have three months to wait before a reply dealing with the matter can be published. Worse still if a reply is published six months later, by which time the patient reader may well say, 'what are they on about'. Phrases such as 'Storm in a teacup' or 'Much ado about nothing' spring readily to mind. Keith Mitchell and myself are friends of long standing, we both hold the works, researches and memory of Basil Anderson in great admiration. Thus when I used the word, 'treatise' incorrectly in describing Keith Mitchell's work in a book to be published by Eric Bruton it was an enthusiastic attempt on my part to draw attention to and hopefully to spur gemmologists to buy the book when it appears. Thirty five years at the laboratory, most of them in close working contact with Basil Anderson, all of them in friendship

with Keith Mitchell, probably promoted 'an enthusiasm too far'— mea culpa.

To revert to other contents of the January Journal, on pp 40,41, under the sub-title 'The Crown Jewels', I was particularly interested to read of the Koh-i-Noor. Purely by coincidence I was reading up the details of the Koh-i-Noor for material for a short story, fiction based on facts, the day before the Journal arrived. Since we are informed on page 41 that in 1986 it was decided to compile a detailed account of the collection by staff of the GAGTL I feel hesitant to query the figures quoted for the Koh-i-Noor.

The Journal article on the Koh-i-Noor states: 'The Koh-i-Noor was recut in 1852 from 186.10ct to 105.60ct'. Eric Bruton's '*Diamonds*', p4, states, 'The Koh-i-Noor was recut in *Amsterdam* to 108.93ct'. On page 452 it states that the Koh-i-Noor was recut and polished by two workers from Costers of Amsterdam who came to London to carry out the work at the premises of Messrs. Garrard in Panton Street, London, in 1862.

De Beers, *'Notable diamonds of the world'*, states that two workers from Costers of Amsterdam came to London to carry out the work. The result was a weight of 108.93ct. Thus is my confusion confounded by a convergence of data.

Yours sincerely
A.E. Farn
18 February 1992
Seaford, E. Sussex.

The Koh-i-Noor was removed from its setting in 1988 to ascertain exact weight; 105.60ct is the correct figure. Ed.

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The Editors of the *Journal* invite advertisements from gemstone and mineral dealers, scientific instrument makers, publishers and others with interests in the gemmological, mineralogical, lapidary and jewellery fields.

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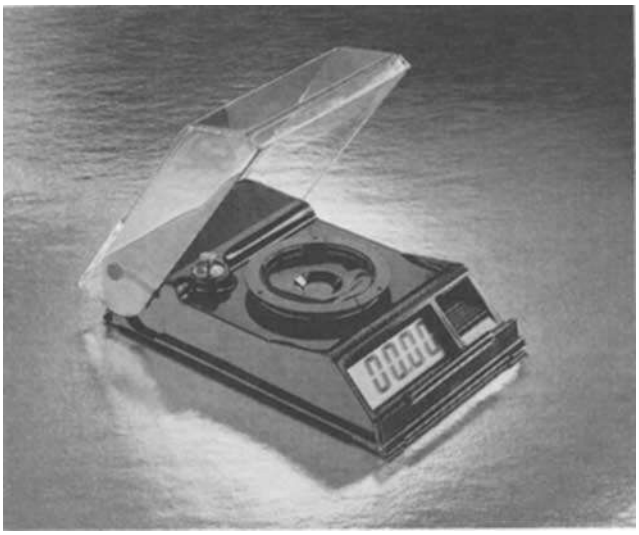

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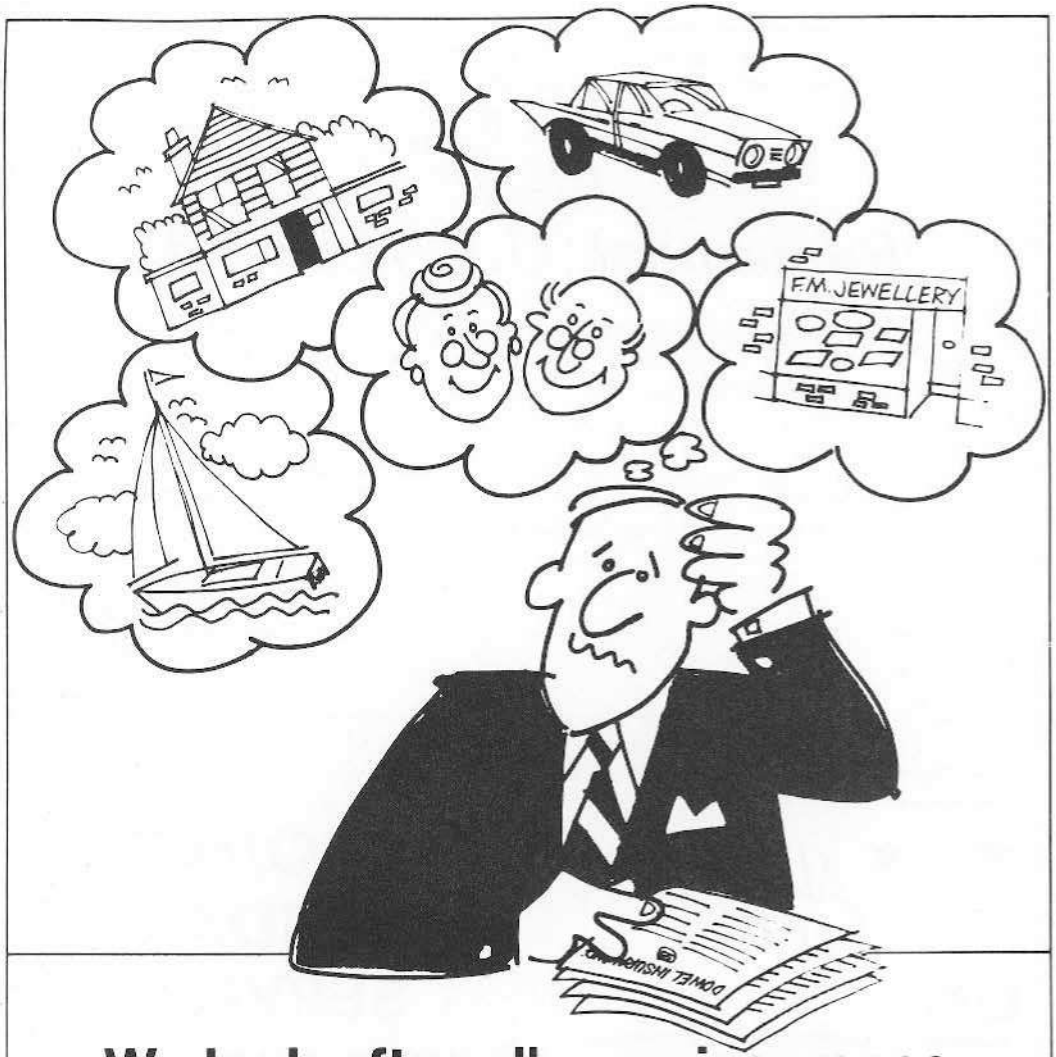

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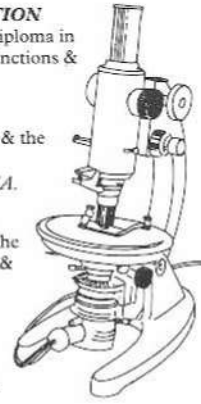

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Cover Picture

An orange coloured pearl showing a 'flame structure' comparable with that displayed by pink pearls from the Giant Conch, *Strombus gigas*. This pearl was fished off the Mergui archipelago, Myanmar (Burma) around 1960 and is 20mm in diameter; others have been found in the Baler shell, *Melo amphora* in Australian and Malaysian waters.

Photograph taken in sunlight by E. A. Jobbins

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Kenneth Scarratt

Gemmological Association and Gem Testing Laboratory of Great Britain, London EC1N 8SU

Damaged fire opal

Gems with a water content, such as opal and pearl, need special care when being displayed for sale. These gems when kept for extended periods in an enclosed atmosphere and under strong heat-generating lighting are prone to dehydration which may result in cracking or other forms of damage. To reduce the risk of damage many traders keep a small container of water in a show case where pearls or opals are on display, and also regularly wipe them with a damp cloth.

A client sold a 2.31ct pear-shaped fire opal set in a cluster ring, seen in Figure 1, to a retailer approximately three years ago. Recently the retailer returned the ring stating that a large opaque cone had appeared stretching from the rear facets into the centre of the stone. The new 'inclusion' was easily visible to the unaided eye and therefore the stone was no longer saleable.

Our client unset the stone and sent it to the Laboratory for examination and any recommendations that could be made to bring the stone back to its former beauty. The opaque cone (see Figure 2) was indeed quite large and had a dramatic effect on the appearance of the stone.

The solution was both simple and effective. The stone was placed in a container of water for a period of three weeks, after which the opacity had virtually disappeared. After a further week in the water the opacity had disappeared altogether leaving only a small turbid area (Figure 3).

Fig. 1. Pear-shaped fire opal set in a cluster ring. Note the opaque cone at the top right and under the table facet.

Fig. 2. The pear-shaped fire opal in Fig. 1, unset and displaying a side view of the opaque cone.

Fig. 3. The pear-shaped fire opal in Figs. 1 and 2 after soaking in water for four weeks. The opaque cone has disappeared leaving only a small turbid area.

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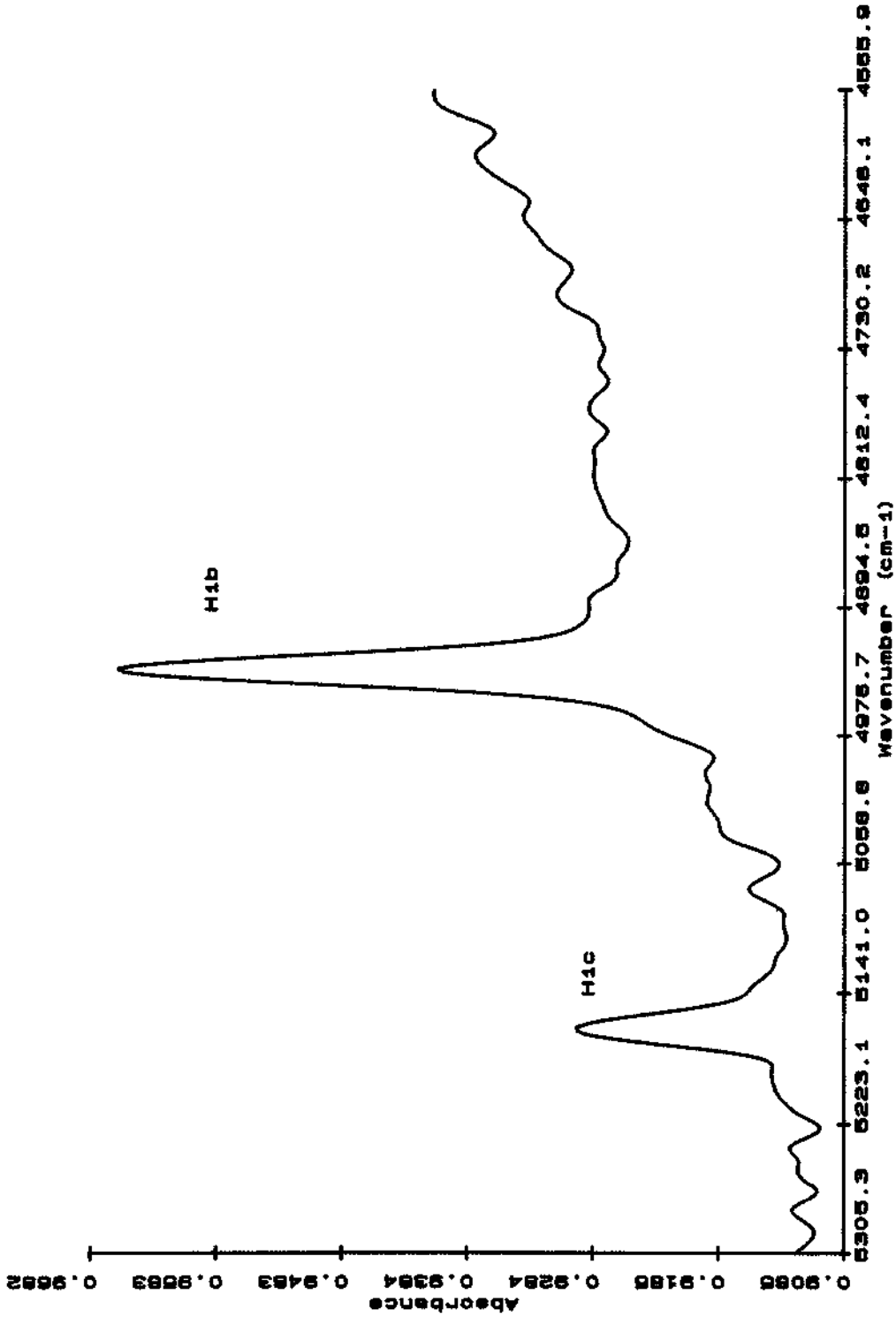

Fig. 5. Partial infrared spectrum of the 33ct treated yellow diamond in Fig. 4, displaying the H1b and H1c peaks at 4935 and 5165cm^{-1}.

Large treated yellow diamond

It is sometimes difficult to understand why certain stones are artificially treated. Obviously, colour or clarity enhancement can make a stone more saleable. However, when one has a 33ct diamond irradiated and annealed to produce a 'treated yellow' one has to question whether it is more saleable before or after treatment.

Figure 4 shows a 33ct round brilliant-cut 'intense yellow' diamond recently submitted to the Laboratory for a report on the origin of its colour. Examination of the stone's visible spectrum using a hand-held spectroscope revealed an intense line at 503nm but there were no indications of the 595nm line usually seen in treated yellow diamonds. Low temperature spectroscopy, down to 120K, using a Pye Unicam Pu 8800 UV/vis spectrophotometer confirmed that the stone had a strong Cape spectrum along with peaks at 503 and 496nm, and also the absence of the 595nm peak.

Fig. 4. A 33ct treated yellow diamond.

The peak at 595nm normally seen in treated yellow diamonds is destroyed if the annealing temperature, during treatment, rises to the 1000°C region. Fortunately, whilst this treatment indicator is destroyed, two further peaks in the infrared are formed i.e., the H1b and H1c (at 4935 and 5165cm^{-1}). An examination of the infrared spectrum of this 33ct stone revealed the presence of both the H1b and H1c peaks (Figure 5) proving the stone to be treated.

An unusual imitation pearl

An unusual green imitation pearl was submitted recently for X-ray examination. The 'pearl' (Figure 6) weighed 9.27ct and measured 13.13 x 9.80 x 9.30mm. A visual examination determined that it

Fig. 6. An unusual composite imitation 'pearl'.

was a composite with a junction between the two parts occurring approximately two-thirds of the distance down from the 'top', (see Figure 6). Overall the imitation fluoresced a dull blue/white under short-wave ultraviolet radiation and a stronger version of a similar colour under long-wave ultraviolet, whilst the area of the junction fluoresced a stronger blue. As the imitation had an unusual translucent appearance, and peculiar colour, it was also examined with the hand-held spectroscope. The spectrum revealed a strong band in the region of 650nm and a further but much weaker absorbence in the area of the orange/yellow border.

Two radiographs were taken in directions at 90° to each other and the results may be seen in Figure 7. The 'pearl' exterior was found to be quite transparent to X-rays and therefore could only be seen in low relief. However, the interior was found to be quite opaque to X-rays, and stood out in very high relief.

Fig. 7. Two radiographs of the composite imitation 'pearl' in Fig. 6. Left: side view. Right: plan view. Note the high transparency of the exterior and the opacity of the interior to X-rays.

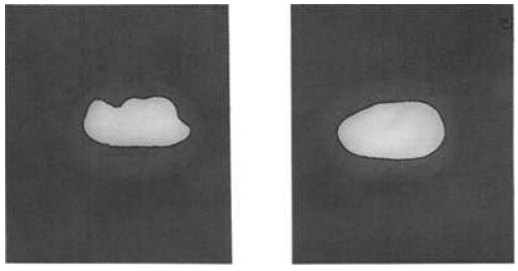

Fig. 8 Highly porous Brazilian opal before (rough) and after being dyed and plastic impregnated.

Dyed and plastic-impregnated opal

During my recent visit to the USA, John Koivula gave me a piece each of a new 'blue enhanced opal' and the material before treatment (see Figure 8).

Highly porous Brazilian opal of a chalky-white colour is soaked in solutions of potassium ferrocyanide and ferric sulfate and this produces a material of a distinct blue colour. The treaters, Gerard and Joyce Raney, of Redwood City, California, then allow the material to dry. The material is then placed in a slightly warmed plasticizing liquid of methyl methacrylate with a small amount of benzoyl peroxide. This last stage has two effects upon the finished product, firstly it seals the pores reducing the porosity, and secondly it clarifies the stones to the point where they are almost transparent. Once fashioned into cabochons this material provides an excellent 'imitation' of the much valued black opal, although its distinctive blue colour in transmitted light should provide the gemmologist with the first indication of its unnatural nature. The stones also feel quite light in the hand and have a 'plastic' feel to them.

Proof of the treatment may be obtained by infrared spectroscopy. Figure 9 compares the infrared spectrum of the treated with that of the untreated material. A number of extra features are seen in the treated material, principally at 5953, 4735 and 4680cm $^{-1}$.

Fig. 10. Kyocera synthetic alexandrite in the light produced by a 'fibre optic' source.

Synthetic alexandrite

Despite the very apparent dangers presented by the modern synthetic gemstone, i.e. those produced by processes other than the Verneuil method, the Laboratory is asked only rarely to identify stones which are eventually discovered to have been produced in this way. Recently the twelve-sided faceted stone featured in Figure 10 was submitted for examination. The stone weighed 1.75ct and measured 7.18 x 7.61 x 4.69mm, and had a distinct colour-change from green in daylight to that seen in Figure 10 when illuminated by the light produced from a fibre optic source. The least and greatest biaxial refractive indices recorded for the stone are 1.740 and 1.748, and the spectrum was also typical of alexandrite. The stone was seen to be a bright red when viewed through the Chelsea Colour Filter and fluoresced a bright red under both long-wave and short-wave ultraviolet light.

When viewed microscopically the stone was found to be relatively free from inclusions but fine structural growth lines which appeared to be slightly curved were observed. These growth features were similar to those previously observed in specimens of Kyocera synthetic alexandrite. However, as can be seen from Figure 11 one should remember that in other examples of this type of synthetic the growth features may appear to be angular rather than curved. Infrared spectroscopy (Figure 12) confirmed the stone to be a Kyocera type synthetic alexandrite.

Fig. 11. Kyocera synthetic alexandrite showing angular appearing growth features.

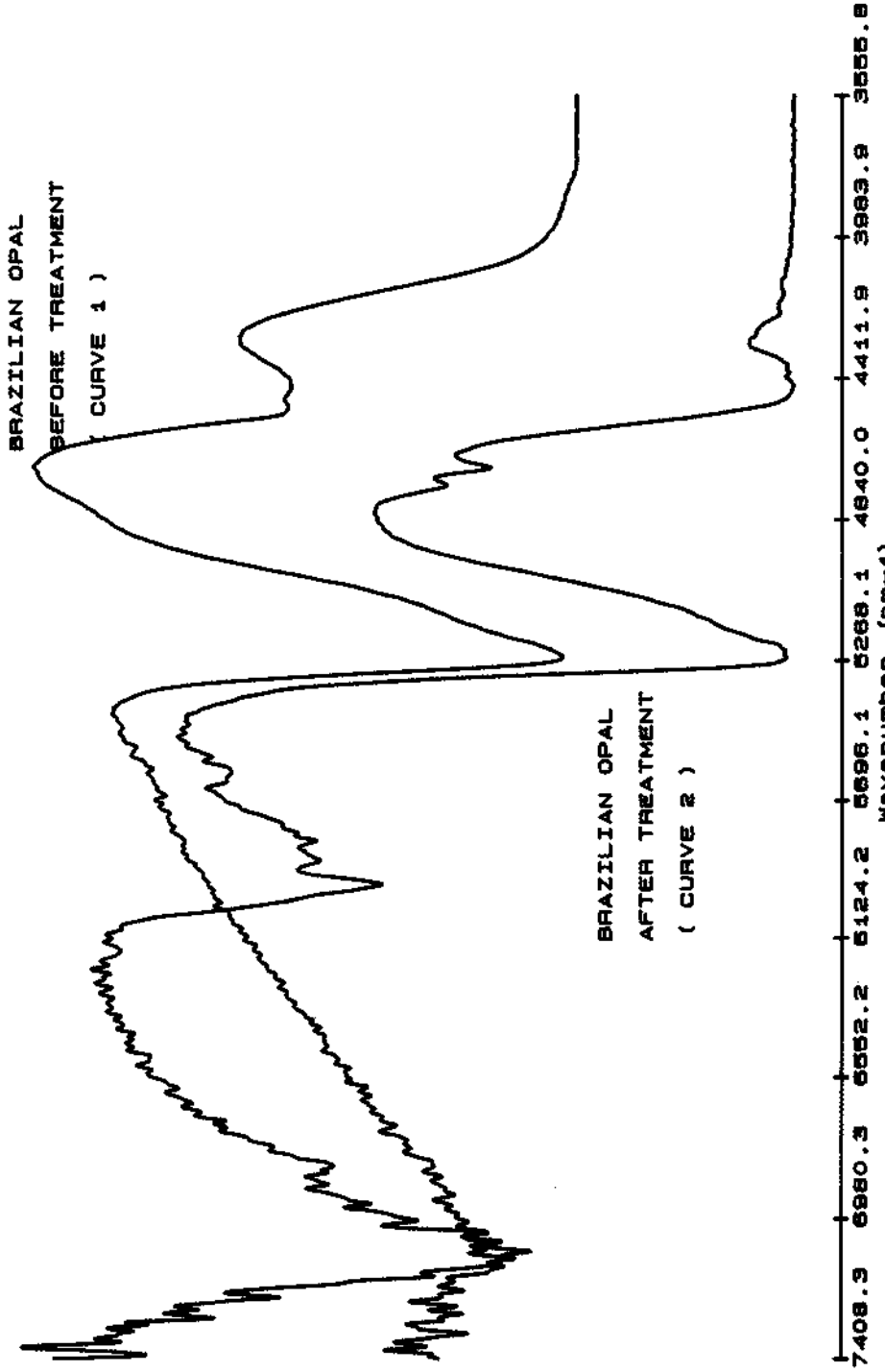

Fig. 9. The infrared transmittance spectra of the Brazilian opal in Fig. 8 – curve 1, before treatment and curve 2, after treatment.

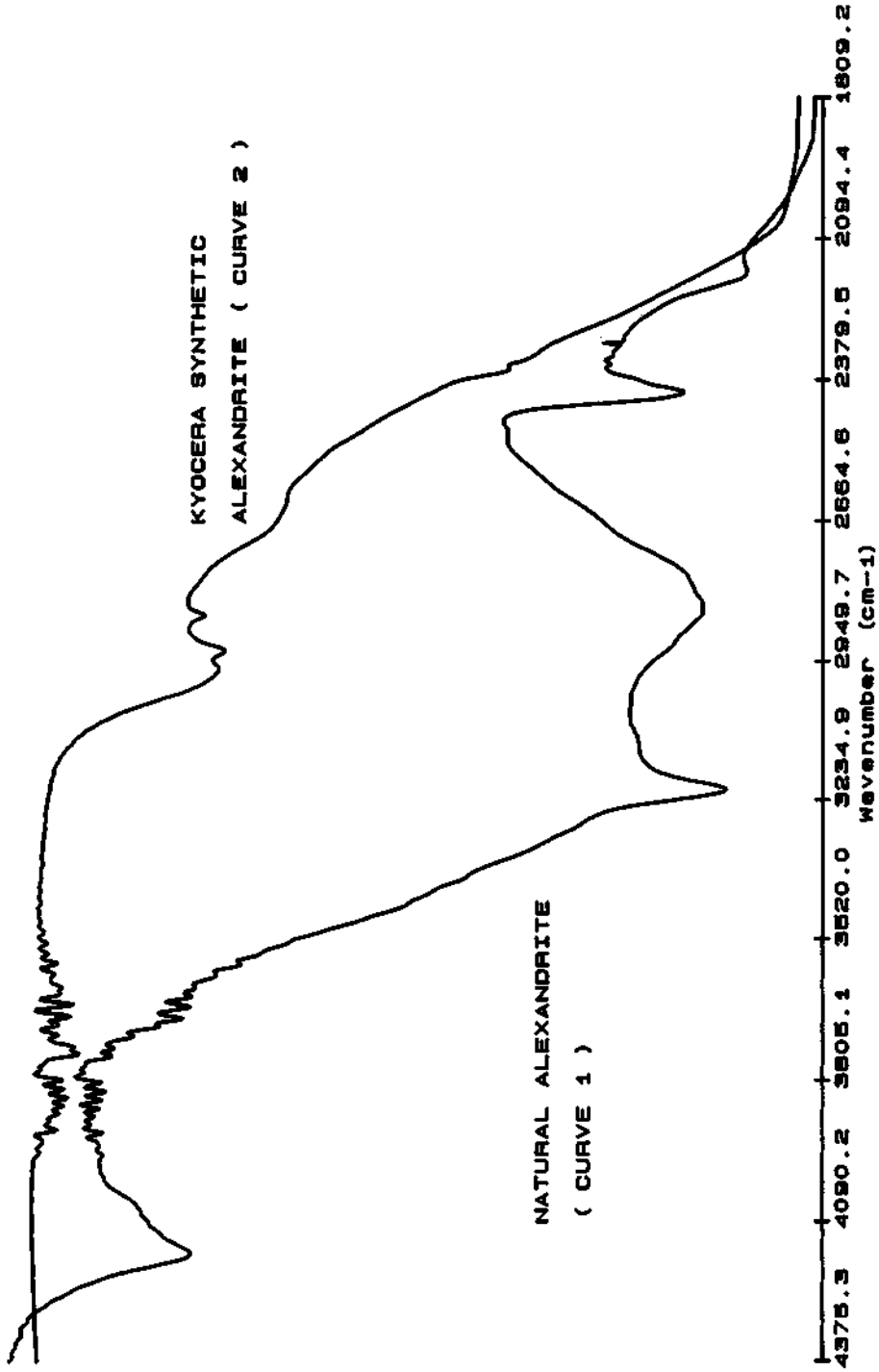

Fig. 12. Infrared transmittance spectra of a natural alexandrite (curve 1) and the Kyocera synthetic alexandrite in Fig. 10 (curve 2).

Fig. 13. A Mabe type composite cultured pearl.

Mabe pearl – coloured with nail varnish

The Mabe type composite cultured pearl is a very popular product often used in earrings and brooches (Figure 13). Following the inauguration of our 'Nacre Thickness Reports' for whole cultured pearls (see Gem and Jewellery News, January 1992), we were approached by one merchant who wondered why his Mabe products could not be assessed in a similar manner and given a Nacre Thickness Grade. He stated that the same problems were occurring with his product as had instigated the introduction of nacre thickness reporting with whole cultured pearls, i.e. the introduction on to the UK market of 'cultured pearls' with extremely thin coatings of nacre.

In further conversations, the merchant stated that not only was the nacre thickness extremely thin in some cases, but in addition these same Mabe type composites tended to have been painted on the inside with 'nail varnish' in order to give them a pinkish 'bloom'.

Fig. 14. A radiograph of two Mabe type composite cultured pearls, showing clearly the mother-of-pearl base, the bead in the centre and the nacreous exterior. Note also the bright line on the inside edge of the nacreous exterior which is indicative of that surface being coated with 'nail varnish' to give the 'pearl' a slight pinkish colour.

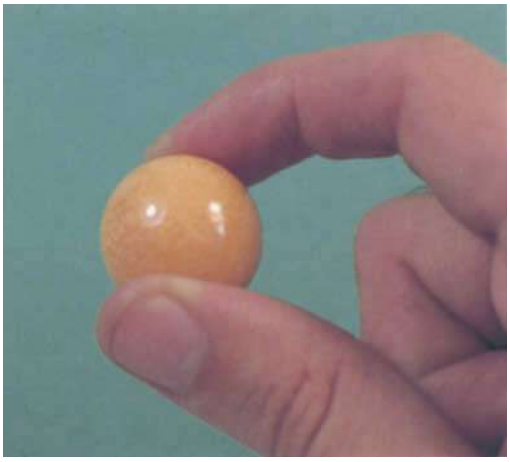

Fig. 15. A 110.48ct orange pearl, possibly from the Baler shell, examined in 1983.

In attempting to assess the nacre thickness problem a number of radiographs were taken and in doing this it was discovered that the 'nail varnish' used to give the product its colour, was clearly revealed on the radiograph as a bright white line running along the inside edge of the nacre (Figure 14).

Three interesting orange pearls

In 1983 we examined a perfectly round orange pearl (Figure 15) with a surface structure similar in appearance to that normally seen on pink pearls from the conch (*Strombus gigas*), i.e. the characteristic 'flame structure'. At the time it was assumed that the pearl was of the 'conch variety' and indeed at 110.48ct was the largest we had recorded.

Recently three orange pearls similar in appearance to the 1983 example were submitted for examination (Figure 16). The first was of a normal size and shape for a 'conch pearl' (ovoid measuring 13.7 x 12.6 x 11.00mm and weighing 14.04ct), and displayed the characteristic 'flame structure'. The

Fig. 16. Three orange pearls, possibly from the Baler shell, submitted for examination recently – the largest weighing 139.71ct.

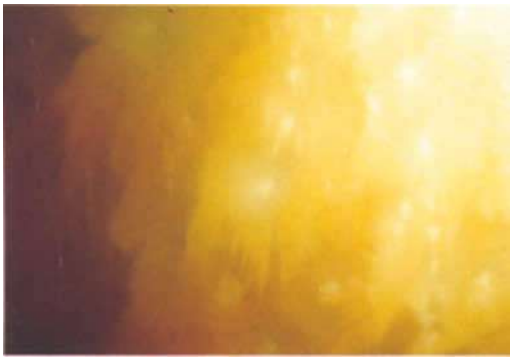

Fig. 17. The unusual not entirely 'flame-like' structure seen on the round pearl in Fig. 15.

second pearl was almost perfectly round, measured 19.0mm in diameter, and weighed 54.93ct. The interesting feature of this pearl was the unusual surface structure which was not entirely 'flame-like' (Figure 17). The structure, which was over the entire surface, was in fact closer to the structure one normally observes in one direction only for other such pearls. The third and largest pearl displayed a good 'flame structure', measured 31.0 x 26.4 x 22.7mm, weighed 139.71ct, but had a shape more akin to a peach stone rather than a pearl. However, this is undoubtedly the largest of this 'type' of pearl that we have recorded.

A pearl with a similar colour and appearance that was recovered from a species of the Baler shell, the *Melo amphora*, was described in a report in the *Australian Gemmologist* (Brown and Kelly, November 1990). It is possible that the 1983 pearl and the others described here have a similar origin.

Clarity enhancement – 'The Oscillating Technique'

Alan Hodgkinson recently sent two diamonds to a London company in order that their clarity might be enhanced by the 'laser drilling' technique. When

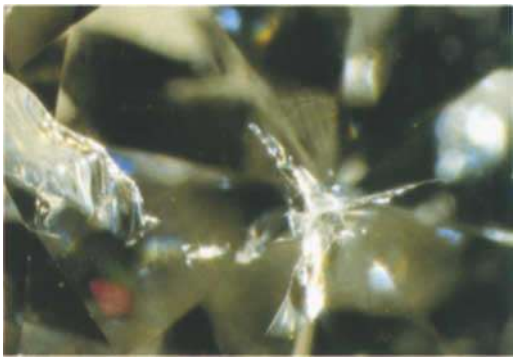

Fig. 19. The same surface reaching fractures in Fig. 18 after being treated by the 'oscillating technique'.

the stones were returned, one had indeed been enhanced by the requested method, but the other had been treated by a process which the company termed 'oscillating'.

The stone treated by this technique originally contained a number of black lined surface-reaching fractures and a central inclusion (Figure 18). Following the treatment the 'blackness' in fractures disappeared (Figure 19). When questioned about the treatment, beyond stating that they now treated all surface reaching fractures by this method, the company refused to discuss the process beyond giving its title.

Upon examination the treated fractures have a peculiar appearance. They appear to be 'clinically clean', very bright, and the internal surfaces are similar in appearance to that seen on a freshly broken surface of colourless glass (Figure 20). Where the fracture meets the surface a yellowish material could be seen within the fracture boundaries.

An examination by X-ray fluorescence (XRF) determined that no heavy metals were present and that therefore the treatment was not a glass filling process such as that of Yehuda or Koss. The filler

Fig. 18. Black-lined surface reaching fractures in a diamond (as seen from the pavilion) before being treated by the 'oscillating technique'.

Fig. 20. A closer view of the treated fractures seen in Fig. 19 showing their almost glassy appearance.

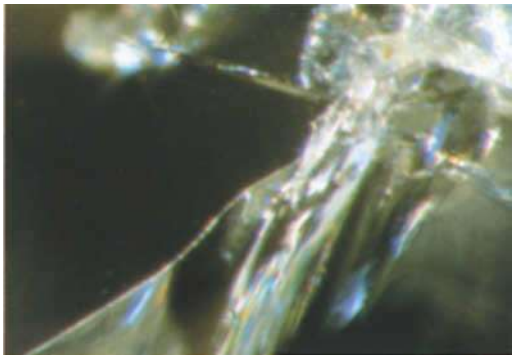

sealing the fractures at the surface was determined to be organic in nature with a possible chlorine content. At this stage it is not possible to determine the details of the treatment process, without further information from the company. However, bearing the descriptive title in mind, it is possible that the fractures are 'cleaned' with a non-viscous acid that is assisted on its journey into the fracture by a technique that involves the stone and/or the acid vibrating. Once treated the fracture is sealed at the surface with an organic substance presumably to prevent foreign material from entering. The sealant by its very nature will not be permanent.

An interesting ewer

The ewer in Figure 21 was submitted recently in order that the material of its body could be determined. The ewer, which measured 30cm in height, had four engraved colourless sections that were joined by white metal collars. The beautifully balanced handle was mounted with three enamelled representations of an eagle eating a serpent, a bust of a turbaned gentleman, and what is possibly a figure of Pan. Of the four engraved colourless sections, the base, lower main body, and spout were found to be quartz, whilst the upper main body was found to be glass. The quartz sections had refractive indices in the region of 1.55 (distant vision technique) and observable double refraction. Included crystals and feathers were also present in these sections. The glass section had a moulded appearance, internal 'swirl' structures, bubbles, and a refractive index in the region of 1.57.

Fig. 21. A 30cm high quartz ewer in which the upper part of the main body was found to be glass.

Acknowledgements

It is with great pleasure that the author acknowledges the input of his two colleagues Nick Sturman and Ana Castro, on a number of the topics discussed. He is also grateful to Alan Jobbins for producing Figures 20 and 21, to Nick Sturman for producing Figure 16, and to Alan Hodgkinson for producing Figure 17.

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Emeralds from Madagascar

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Introduction

The island of Madagascar is known for its wealth of precious stones. In his survey on the occurrences of precious stones in Madagascar, Chikayama (1989) has mentioned 50 different precious stones found and mined on this island situated off the east coast of Africa. Among these precious stones, the mineral beryl plays an important part. When the island was occupied by the French in 1883, news about important occurrences of aquamarines and other beryls of various colours became known in Europe.

In his 'Mineralogie de Madagascar', Lacroix (1922) gave a detailed survey on the Madagascar occurrences of beryls of cuttable quality. He mentioned a large number of primary and secondary (i.e. alluvial) occurrences, where colourless, yellow, pink (morganite) and blue (aquamarine) beryls were found. Especially the blue beryls possess an extraordinary wide colour variation – from light blue to deep blue, and from greenish-blue to bluish-green.

Until that time, emerald occurrences had not been known in Madagascar. Although Levat (1912) had mentioned an occurrence of emerald of medium quality in Madagascar, but no detailed information had been published.

According to Lacroix (1922), certain beryl crystals were found together with large amounts of rose quartz in a kaolinized pegmatite at Tongafeno, near Tsaramanga, about 3 kilometres north of Mont Itongafeno, and south west of Antsirabe. The beryl crystals possessed a blue external zone and an 'emerald green' nucleus, which did not consist of emerald, however, but rather of iron-coloured green beryl.

Sinkankas (1981) has mentioned an emerald occurrence located in the Mananjary-Ifanadiana region at the east coast of the island. This alluvial occurrence consists of small, rounded emerald fragments together with kyanite. The occurrence is situated about 50 kilometres west-south-west of Mananjary, and about 250 kilometres south-east of Tananarive.

In 1982, Hänni & Klein described a primary emerald occurrence at the south-east coast of Madagascar. Near Kianjavato, in the so-called Ankadilalana mine, blue-green emeralds of faceting quality are found in mica-schists. The characteristics of this material are comparable with those of emeralds from Zambia.

Chikayama (1989) has also mentioned emerald occurrences near Mananjary, near the east coast of Madagascar.

The occurrences of emeralds in the Mananjary region have been known for 20 years and now and again various interested parties have successfully prospected emeralds in this region. For about 5 years occurrences situated about 30 kilometres south of Mananjary have been exploited commercially. The occurrences are very extensive, and hopes for an important emerald production seem to be justified. The source rocks of these emeralds are mica-schists. For this paper, thorough investigations have been carried out with material originating from the Morafeno region, near Mananjary. The mine extends over an area of about one square kilometre. It yields partly transparent emerald crystals of some centimetres in size, embedded in dark mica.

Physical properties

The values of refractive indices, birefringence and densities are shown in Table 1 together with other data for emeralds from Madagascar and Zambia, hitherto published in gemmological literature.

The refractive indices, birefringence and densities measured by the authors of this work are in the same range as the data determined by Hänni & Klein (1982) on Madagascar emeralds. The values are compared with those of Zambian emeralds, because of the similar colour. The emeralds from Madagascar possess data, which are comparable with features of Zambian material located in the lower variation range. The higher values of Zambian emeralds have been determined on material

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with relatively high iron contents (Bank, 1981; Schmetzer & Bank, 1981).

Chemical properties

Table 2 gives the chemical data of six emeralds from the Morafeno mining region in Madagascar. Columns 1-6 show the single analyses, column 7 gives the amounts of variation of the analysed oxides and column 8 the mean concentrations observed in the six analysed samples. Table 3 shows the chemical data of some emeralds from other African mining regions for comparison.

The element correlation diagrams of Figures 2-4 show the representative points for the Morafeno emeralds, together with those for emeralds coming from occurrences in Brazil, Australia, Norway and some African mining areas (for details see legends of Figures 2-4).

The element correlation Al_2O_3/MgO shows a clearly developed diagonal trend (with negative ascent): the increase of the MgO concentration is accompanied by decreasing Al_2O_3 contents. This behaviour is controlled by the substitution reaction: $Al^{3+,VI} = Mg^{2+,VI}$.

The representative points for the Morafeno emeralds are situated in the lower third of the population area and also show a distinct diagonal distribution pattern. The mean concentrations of MgO in the examined samples (1.71-3.00%) are medium to high.*

The population area for the representative points of emeralds from different localities in the Na_2O/MgO correlation diagram shows also a well pronounced diagonal trend (with positive ascent): the increase of the magnesium concentration parallels the rising sodium contents. The crystallochemical model which defines this behaviour is given by the reaction:

$Al^{3+,VI} = Mg^{2+,VI} + Na^{1+}$ (channel)

ie, the sodium necessary for electric charge compensation (substitution of trivalent Al ions by bivalent metal ions, principally Mg^{2+}) occupies positions in the channels of the beryl structure. The

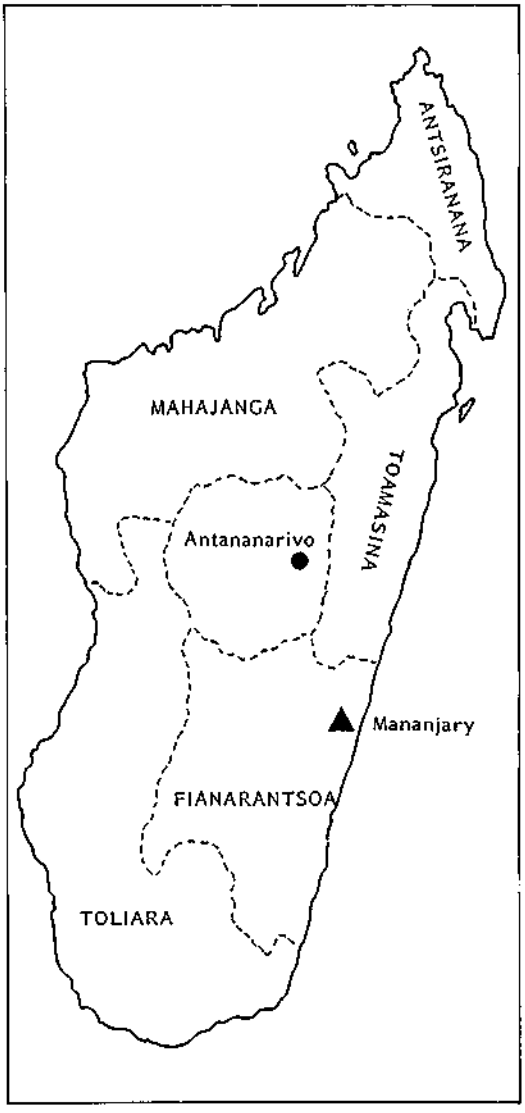

Fig. 1. Geographical location of the Mananjary emerald occurrences.

Table 1: Physical properties of emeralds from Madagascar and Zambia

	Madagascar*	Madagascar**	Zambia***
n_e	1.580-1.582	1.581-1.585	1.580-1.592
n_o	1.588-1.591	1.589-1.591	1.583-1.602
Δn	−0.008 to −0.009	−0.006 to −0.008	−0.007 to −0.010
D [g/cm^3]	2.68-2.71	2.727	2.74-2.77

* present work
** Hänni & Klein, 1982
***Campbell, 1973; Bank, 1974, 1980

Table 2: Chemical data of emeralds from the Morafeno mining region, Madagascar

	1	2	3	4a	4b	5	6
SiO_2	65.04	64.01	64.67	64.41	64.23	63.48	63.78
Al_2O_3	14.54	13.40	13.96	14.60	13.93	12.91	12.78
Cr_2O_3	0.19	0.12	0.08	0.24	0.12	0.21	0.34
V_2O_3	<	0.03	0.01	0.02	<	0.02	0.02
FeO	1.00	1.30	1.10	0.91	1.06	1.11	1.05
MnO	–	–	–	–	–	–	–
MgO	2.20	3.00	2.64	1.71	2.40	2.83	2.81
Na_2O	1.49	2.16	1.81	1.28	1.54	2.09	1.93
CaO	0.05	0.05	0.05	0.03	0.10	0.04	0.06
K_2O	0.12	0.09	0.14	0.05	0.21	0.12	0.15
TiO_2	<	<	<	<	<	0.01	0.01

	7	8		7	8
SiO_2	63.48-65.04	64.23	MgO	1.71-3.00	2.51
Al_2O_3	12.78-14.60	13.73	Na_2O	1.28-2.16	1.76
Cr_2O_3	0.08- 0.34	0.19	CaO	0.03-0.10	0.05
V_2O_3	< - 0.03	0.01	K_2O	0.05-0.21	0.13
FeO	0.91- 1.30	1.08	TiO_2	< - 0.01	–
MnO	-	–			

Observations:
- 1-6 = single analyses
- 4a, 4b = crystal showing color zoning:
  - a – border zone
  - b – core zone
- 7 = amounts of variation
- 8 = mean concentrations of 6 analysed samples
- < = element concentration below detection limit of applied analytical method (Electron microprobe)
- – = no data for this element

Morafeno emeralds are situated in the upper part of the population area and also show a strong diagonal distribution pattern. The mean sodium contents (1.28-2.16% Na_2O) are medium to high.*

The element correlation diagram FeO_{tot}/MgO does not show a broadly simple diagonal distribution trend: besides the diagonal 'distribution corridor' in which most of the representative points (also those for the Morafeno emeralds) are situated, we can observe a separate population area somewhat below the diagonal distribution corridor which contains the representative points for the Brazilian emeralds from Pirenópolis/GO, Salininha/BA, and Itaberaí/GO and also those for the African emeralds

Table 3: Chemical data for emeralds from different African mining regions

	a	b	c	d	e
SiO_2	63.81	64.91	63.8	67.27	63.5
Al_2O_3	15.07	16.98	14.6	13.21	14.2
Cr_2O_3	0.31	0.23	0.4	0.42	0.6
V_2O_3	0.02	–	0.0	0.02	0.0
FeO	1.03	0.40	0.9	0.81	0.5
MnO	<	–	0.0	–	0.0
MgO	2.04	1.49	2.3	2.83	2.9
Na_2O	1.86	1.12	1.9	2.25	2.2
CaO	0.03	–	–	0.05	–
K_2O	0.04	0.06	–	0.04	–
TiO_2	<	–	0.0	<0.01	0.0

Observations:
- a = mean concentrations of 11 analysed samples from Kamakanga/Zambia (Schwarz, 1991b)
- b = mean concentrations of 5 analysed samples from Cobra Mine/Transvaal (Fillmann, 1987)
- c = mean concentrations of 2 analysed samples from Zambia (Hänni, 1982)
- d = mean concentrations of 2 analysed samples from Machingwe/Zambia (Kanis *et al.*, 1991)
- e = mean concentrations of 2 analysed samples from Zimbabwe (Hänni, 1982)
- < = element concentration below detection limit of the applied analytical method
- – = no data for this element

*The concentration bands for the elements chromium, vanadium, iron, and magnesium were delimited empirically by the following values (in wt% Cr_2O_3, V_2O_3, FeO, Na_2O and MgO; data for chromium, iron, magnesium and sodium from Schwarz, 1988:

	low	medium	high
chromium	<0.2	0.2-0.4	>0.4
vanadium	<0.2	0.2-0.4	>0.4
iron	<0.5	0.5-1.0	>1.0
sodium	<1.0	1.0-2.0	>2.0
magnesium	<1.5	1.5-2.5	>2.5

from Machingwe/Zimbabwe (Kanis *et al.*, 1991) and 'Zimbabwe' (Hänni, 1982). The pegmatite beryls from the regions of Aracuai-Salinas and Governador Valadares, Minas Gerais, Brazil, examined by Correia Neves (1984) are located outside the emerald population areas. Their representative points are displaced distinctly upwards.

Absorption spectra

Absorption spectra have been carried out with a Perkin Elmer Lamda 9 Spectrophotometer in the UV/VIS/NIR-spectral region.

Figure 5 shows the absorption spectrum of an emerald from the Morafeno occurrence in the 1000-300 nm range (10,000-33,333cm^{-1}). The

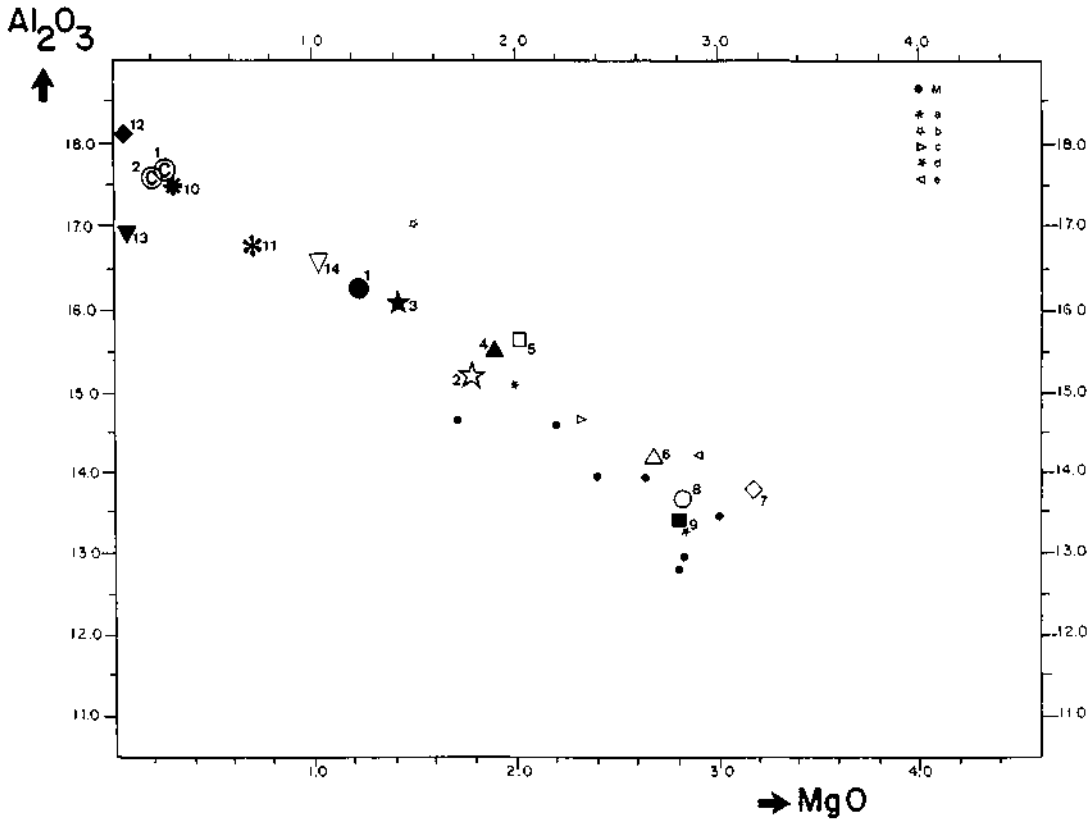

Fig. 2. Correlation diagram Al_2O_3/MgO for emeralds from Brazil, Australia, Norway and Africa

M =	Morafeno/Madagascar	(06)*
a =	Kamakanga/Zambia (Schwarz, 1991)	(11)*
b =	Cobra Mine/Transvaal (Fillmann, 1987)	(05)*
c =	Zambia (Hänni, 1982)	(02)*
d =	Machingwe/Zimbabwe	(02)*
e =	Zimbabwe (Hänni, 1982)	(02)*
1 =	Carnaíba/BA	(38)*
2 =	Capoeirana/MG	(16)*
3 =	Belmont Mine/MG	(48)*
4 =	Socotó/BA	(63)*
5 =	Tauá/CE	(11)*
6 =	Pirenópolis/GO	(07)*
7 =	Salininha/BA	(05)*
8 =	Itaberaí/GO	(13)*
9 =	Santa Terezinha/GO	(29)*
10 =	Poona/Western Australia	(12)*
11 =	Menzies/Western Australia	(08)*
12 =	Emmaville/New South Wales	(05)*
13 =	Eidsvoll/Norway	(04)*
C1 =	Pegmatite beryls from the Aracuai-Salinas region (Correia Neves *et al.*, 1984)	(09)*
C2 =	Pegmatite beryls from the Governador Valadares region (Correia Neves *et al.*, 1984)	(05)*
* =	number of analysed samples	

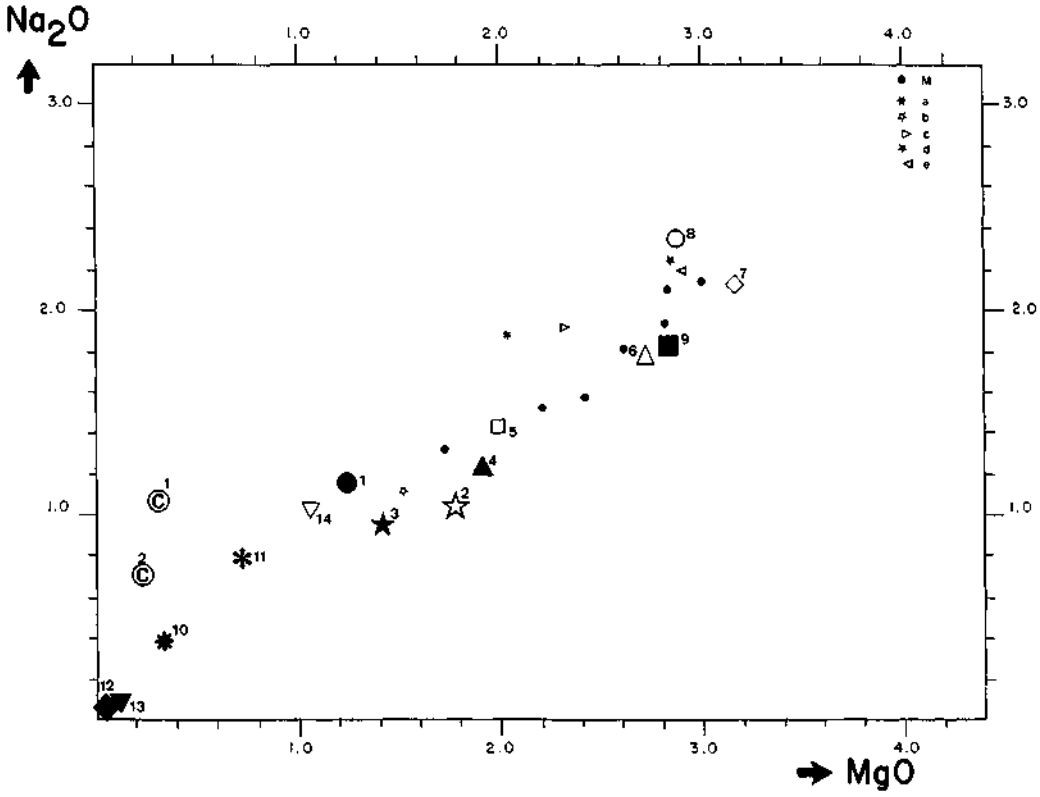

Fig. 3. Correlation diagram Na_2O/MgO for emeralds from Brazil, Australia, Norway and Africa

M =	Morafeno/Madagascar	(06)*
a =	Kamakanga/Zambia (Schwarz, 1991)	(11)*
b =	Cobra Mine/Transvaal (Fillmann, 1987)	(05)*
c =	Zambia (Hänni, 1982)	(02)*
d =	Machingwe/Zimbabwe	(02)*
e =	Zimbabwe (Hänni, 1982)	(02)*
1 =	Carnaíba/BA	(38)*
2 =	Capoeirana/MG	(16)*
3 =	Belmont Mine/MG	(48)*
4 =	Socotó/BA	(63)*
5 =	Tauá/CE	(11)*
6 =	Pirenópolis/GO	(07)*
7 =	Salininha/BA	(05)*
8 =	Itaberaí/GO	(13)*
9 =	Santa Terezinha/GO	(29)*
10 =	Poona/Western Australia	(12)*
11 =	Menzies/Western Australia	(08)*
12 =	Emmaville/New South Wales	(05)*
13 =	Eidsvoll/Norway	(04)*
C1 =	Pegmatite beryls from the Aracuaí-Salinas region (Correia Neves *et al.*, 1984)	(09)*
C2 =	Pegmatite beryls from the Governador Valadares region (Correia Neves *et al.*, 1984)	(05)*
* =	number of analysed samples	

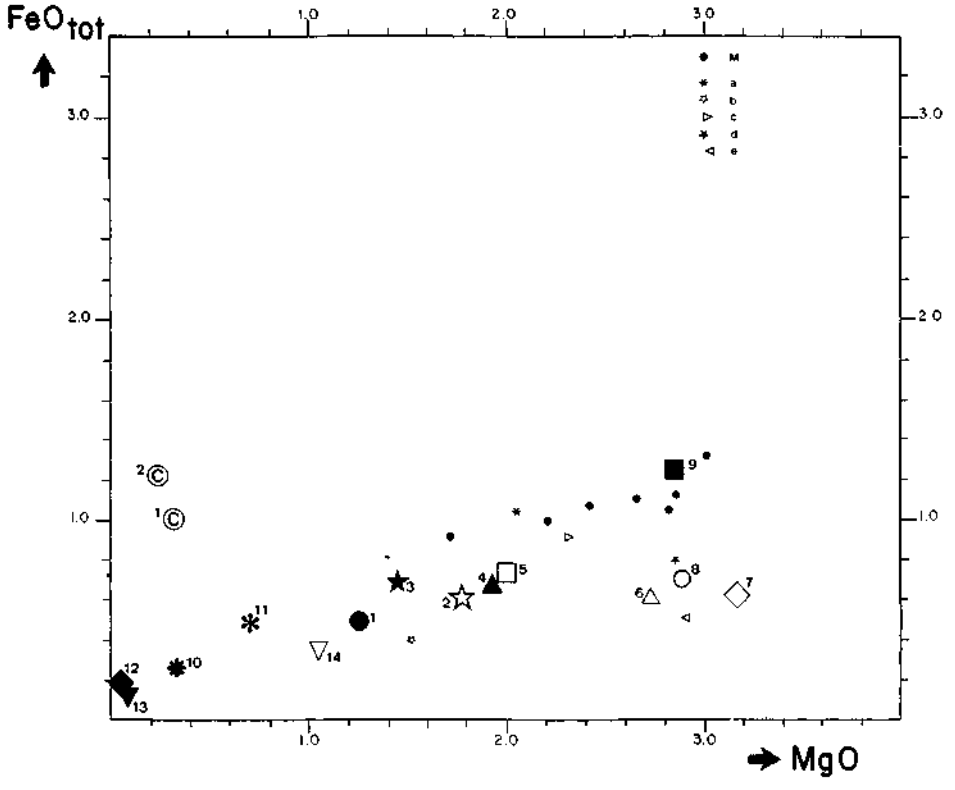

Fig. 4. Correlation diagram FeO_{total}/MgO for emeralds from Brazil, Australia, Norway and Africa

M =	Morafeno/Madagascar	(06)*
a =	Kamakanga/Zambia (Schwarz, 1991)	(11)*
b =	Cobra Mine/Transvaal (Fillmann, 1987)	(05)*
c =	Zambia (Hänni, 1982)	(02)*
d =	Machingwe/Zimbabwe	(02)*
e =	Zimbabwe (Hänni, 1982)	(02)*
1 =	Carnaíba/BA	(38)*
2 =	Capoeirana/MG	(16)*
3 =	Belmont Mine/MG	(48)*
4 =	Socotó/BA	(63)*
5 =	Tauá/CE	(11)*
6 =	Pirenópolis/GO	(07)*
7 =	Salininha/BA	(05)*
8 =	Itaberaí/GO	(13)*
9 =	Santa Terezinha/GO	(29)*
10 =	Poona/Western Australia	(12)*
11 =	Menzies/Western Australia	(08)*
12 =	Emmaville/New South Wales	(05)*
13 =	Eidsvoll/Norway	(04)*
C1 =	Pegmatite beryls from the Aracuai-Salinas region (Correia Neves *et al.*, 1984)	(09)*
C2 =	Pegmatite beryls from the Governador Valadares region (Correia Neves *et al.*, 1984)	(05)*
* =	number of analysed samples	

Table 4: Absorption maxima in the 1000-300 nm range of emerald from Morafeno area, Mananjary, Madagascar

wavelength [nm]	wavenumber [cm^{-1}]	assignment
835	11,980	Fe^{2+}oct
685	14,600	Cr^{3+}oct
662	15,100	Cr^{3+}oct
648	15,430	Cr^{3+}oct
638	15,670	Cr^{3+}oct
611	16,370	Cr^{3+}oct
427	23,420	Cr^{3+}oct
371	26,950	Fe^{3+}oct

absorption maxima and their assignments are given in Table 4. The *o*-spectrum is characterized by a broad absorption band in the near infrared, which is split by Jahn-Teller effect. This absorption is caused by spin-allowed d-d-transitions of Fe^{2+} in octahedral coordination (Platonov *et al.*, 1978). The maximum of the band is situated at 835 nm (11,980cm^{-1}) but is less well developed in the *e*-spectrum. Absorption bands of Cr^{3+} in octahedral coordination are located in the orange-red and in the violet spectral region. The Cr^{3+} absorption line in the red is at 685 nm (14,600cm^{-1}) with $e > o$. Weak absorption bands of Cr^{3+} are located at 662 nm (15,100cm^{-1}) for *e* and at 638 nm (15,670cm^{-1}) for *o*. The main pleochroic Cr^{3+}-absorption band has its maximum at 648 nm (15,430cm^{-1}) for *e* and 611 nm (16,370cm^{-1}) for *o*. The second Cr^{3+}-absorption has its maximum at 427 nm (23,420cm^{-1}).

These absorption bands correspond with those described in the literature for natural and synthetic emeralds (Wood & Nassau, 1968; Schmetzer *et al.*, 1974). In the UV range a sharp absorption band is detectable at 371 nm (26,950cm^{-1}) in both *o* and *e* direction. This absorption is caused by octahedral coordinated Fe^{3+}

The absorption minimum is located at 507 nm for *o* and 498 nm for *e*. The pleochroism is yellowish-green for *o* and greenish-blue to blue for *e*.

The absorption spectrum of the Morafeno emerald represents a typical mixed spectrum, containing both an emerald component with Cr^{3+}-absorption bands and an aquamarine component with Fe^{2+} and Fe^{3+} bands. The main Cr^{3+} absorption bands in the orange-red and violet spectral region are both overlapped by iron absorption resulting in more or less asymetrical shapes to the bands. Similar absorption spectra have been described by Schmetzer & Bank (1981) for Zambian emeralds and by Hänni & Klein (1982) for Madagascar emeralds.

Figure 6 shows the absorption spectrum of a Morafeno emerald in the near infrared region in the range of 2500-1000 nm (4,000-10,000cm^{-1}). The observed absorption bands completely refer to vibrations of H_2O molecules in the channel sites of the beryl structure. The maxima of these vibration bands and their assignments are given in Table 5.

Table 5: H_2O-vibration bands in the 2500-1000 nm range of emerald from Morafeno area, Mananjary, Madagascar

wavelength [nm]	wavenumber [cm^{-1}]	type H_2O
1897	5271	II
1789	5590	I
1465	6826	I
1413	7077	II
1401	7138	I
1376	7267	I
1151	8688	II
1132	8834	I

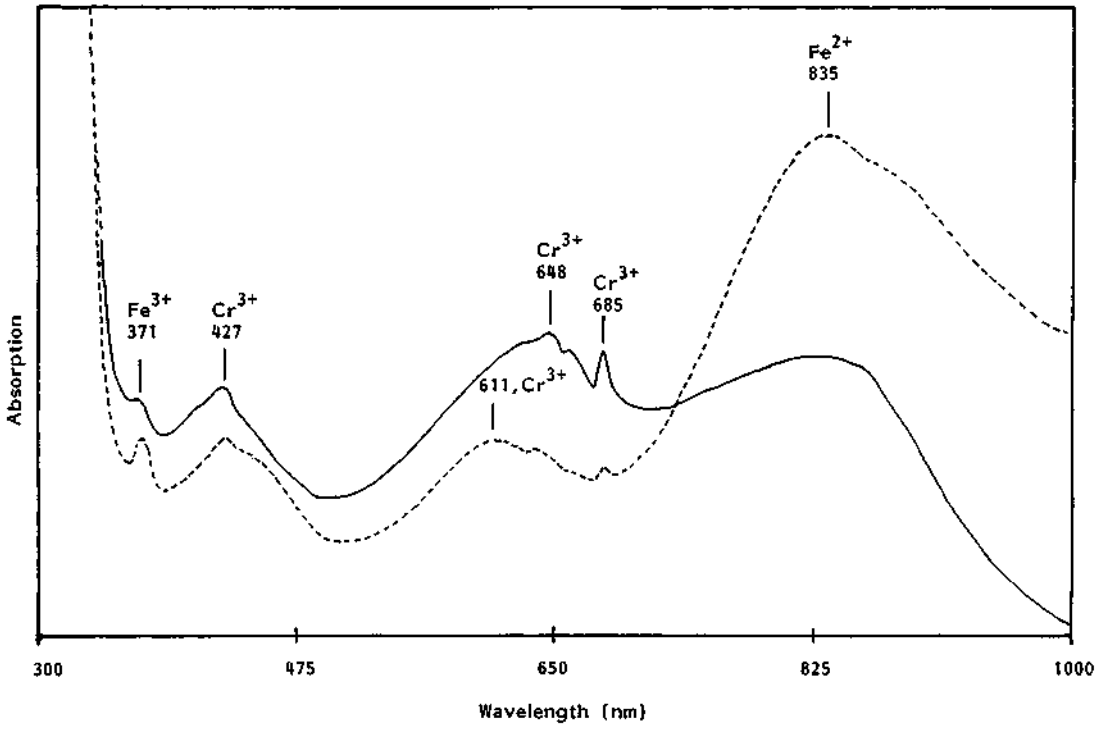

Fig. 5. Polarized absorption spectrum in the 1000-300 nm range of a Morafeno emerald (———o, ———e).

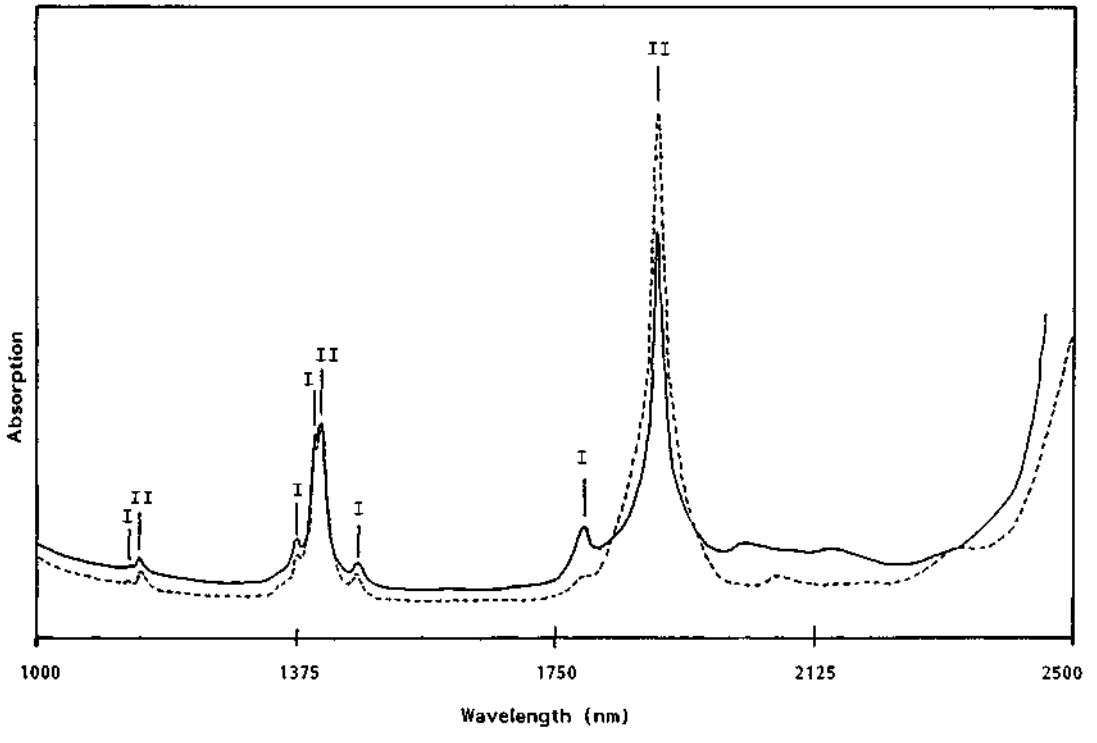

Fig. 6. Absorption spectrum of a Morafeno emerald in the near infrared region (--------E‖c; ———E⊥c).

Internal features of Madagascar emeralds

The mineral inclusions in Madagascar emeralds from the Morafeno region are very interesting. Apart from brown mica crystals, many of the examined stones exhibit a large number of greenish-brown tremolite/actinolite rods and needles which are not oriented and show an uneven distribution in the host emerald. Frequently the tremolite/actinolite rods present the well-known 'bamboo' appearance. Other mineral inclusions are colourless and transparent prismatic crystals that are oriented in the direction of the emerald's *c*-axis. These are generally associated with fluid inclusions (enclosed in negative crystals or growth tubes). This inclusion type is practically identical to the internal features observed in many Brazilian emeralds from the Belmont mine and the Capoeirana/Nova Era mining field (Hänni *et al.*, 1987; Schwarz *et al.*, 1988). The Madagascar emeralds do not display, however, the enormous variation of different types of fluid inclusions that can be observed in their Brazilian counterparts. A second type of colourless and transparent crystal inclusion is well-rounded and sometimes shows almost ideal spherical or egg-like forms. Other mineral inclusions are opaque grains or opaque pseudo-hexagonal plates and colourless to brownish crystals with a strong relief.

Besides the mineral inclusions, the Madagascar emeralds present the well-known healed fractures (feathers, veils) with small fluid inclusions and also larger fluid inclusions (partly developed as negative crystals) with different types of filling. Most common are two-phase inclusions of the 'lg'-type (liquid and gas), but three-phase inclusions ('slg'-type) and multi-phase inclusions occur also.

Other internal features observed in Madagascar emeralds are colour zoning (almost colourless central area with a green rim); systems of almost parallel-running fractures that are only partly healed; concentrations (agglomerations) of different inclusions (minerals, fluid inclusions) in certain domains of the emerald host crystal.

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Surface features on natural rubies and sapphires derived from volcanic provinces

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Abstract

The majority of surface features observed on natural rubies and sapphires associated with volcanic provinces reflect their trigonal crystal structure and are the result of layer dissolution or etching that occurred while the crystals were exposed to a hostile melt environment en route to the surface. Such features generated by magmatic resorption include trigonal prismatic hillocks, trigonal pyramids, inverted trigonal pyramids, flat floored trigonal and hexagonal depressions (often with a central rhombohedral or pyramidal termination), and 'brick-like' stacks of trigonal prisms. The style of features observed on a given surface is dependent both on the angle of the surface to the *c*-axis of the corundum crystal and the degree of subsequent etching. More irregular sculpture-like features appear to arise from continued dissolution, and the growth and merging of the above-mentioned features. Many of the crystal surfaces also show a superimposed surface texture consisting of fine corrosion pits.

Fluvial transport and residence in the alluvial environment are responsible for the remainder of the surface features observed. These include conchoidal fracture surfaces radiating from points of impact (particularly along exposed edges on some stones), clean fracture surfaces where pyramidal and prismatic protrusions have been broken, and exposed healed-fracture surfaces.

The grain surface features indicate minimal amount of damage due to fluvial transport. This, together with the spatial variability in the physical characteristics of corundum in a given placer deposit, indicates a minimal degree of downstream reworking and mixing. Such observations suggest that the corundum sources are local to the placer deposits.

Introduction

Ruby and sapphire are members of the corundum family. They are aluminium oxide (Al_2O_3), which is colourless when pure, and owe their striking colours to the presence of minor amounts of other elements. In ruby, chromium is responsible for the red colour whereas in sapphire, titanium and divalent iron are responsible for the blues and greens.

Corundum crystallizes in the trigonal system with ruby and sapphire often displaying quite distinct forms. Crystals of ruby typically display short six-sided prisms and large basal pinacoids, with only minor rhombohedral and bipyramidal development between the pinacoid and prism faces.

Fig. 1. Ruby and sapphire crystal forms belonging to the rhombohedral division of the trigonal system. Ruby crystals typically display short six-sided prisms and large basal pinacoids, with only minor rhombohedral and bipyramidal development between the pinacoid and prism faces (part a) whereas sapphire crystals show a more pronounced development of the bipyramidal faces with only minor prismatic and pinacoid development (c and d).

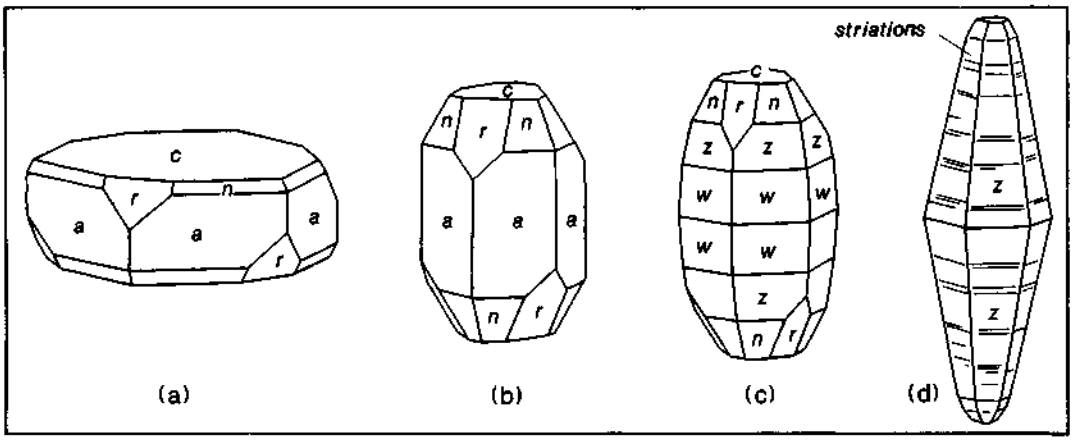

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The result is a flat to tabular prismatic habit shown in Figure 1a. Crystals of sapphire show a more pronounced development of the bipyramidal faces with only minor prismatic and pinacoid development, such as shown in Figure 1b. Oscillation between the different bipyramid forms gives the crystals a stepped tapering appearance with fine striations on the bipyramid faces at right angles to the *c*-axis. These features are masked in sapphires of volcanic origin due to dissolution of the crystal surfaces.

Origin of volcanic ruby and sapphire

Rubies and sapphires are mined from heavy mineral concentrates in alluvial gravels which have been derived from either volcanic or metamorphic terrains. Gem fields associated with basaltic volcanism include New England and Anakie in Australia (MacNevin, 1972; Broughton, 1979; Coenraads, 1990); Pailin in Cambodia (Jobbins and Berrange, 1981); Chanthaburi-Trat, Denchai, Bo Ploi and Khorat Plateau in Thailand (Vichit *et al*, 1979; Barr and MacDonald, 1981; Keller, 1982; Gunawardene and Chawla, 1984; Vichit, 1987); Bokeo Plateau, Xuan Loc Plateau, Cardamones Massif, Solovens Plateau and Kassens Plateau in Kampuchea (Lacombe, 1969-70); Haut Chalong Plateau, Pleiku Plateau, Darlac Plateau and Djiring Plateau in South Vietnam; Kouang Tcheoci Wan, Fujian Province and Hainan Island in Southern China (Keller and Wang, 1986; Keller and Keller, 1986); Mercaderes Rio Mayo area in Colombia (Keller *et al*, 1985); Gimi Valley near Jemaa and Kaduna Province in Nigeria (Kiefert and Schmetzer, 1987). These gem fields are associated with predominantly alkaline basaltic lava fields, cones or eroded remnants.

The corundum appears to be of the same age as the associated alkaline volcanic rocks, as shown by (Coenraads *et al*, 1990) for the New England gem fields. Mineral inclusion compositions and the present study suggest that the corundum formed as part of a coarse-grained, pegmatite-like assemblage that crystallized from strongly evolved, silica-poor magmas rich in volatiles and incompatible elements. Alkali basaltic magmas served as carriers, firstly disaggregating and partially resorbing the corundum assemblage, and then bringing the material rapidly to the surface.

Surface features of Ruby and Sapphire

The surface features of a large number of stones from placer deposits associated with volcanic provinces in both eastern Australia and Thailand were examined.

Australian sapphires were collected from Reddestone Creek No 1 plant (29°41′30″S, 151°38′50″E), No 2 plant (29°43′00″S, 151°38′20″E), and Kings Plain Creek (29°41′00″S, 151°27′50″E) near Glen Innes, New South Wales; and Braemar (29°47′20″S, 151°17′30″E), near Inverell, New South Wales. Thai sapphires were collected from the SAP Mining Co, near Bo Ploi, Kanchanaburi region (14°20′30″N, 99°29′30″E); and the Elem Mine near Ban Khlang, Chanthaburi-Trat region (12°36′10″N, 102°18′10″E). Thai rubies were collected from the Elem Mine and the Ruby Well Mine, near Noen Chali, Chanthaburi-Trat region, (12°32′0″N, 102°30′10″E).

Samples were examined with a binocular microscope, then selected specimens were cleaned for 5 to 10 minutes in an ultrasonic bath of water or hydrogen peroxide, mounted on scanning electron microscope stubs and gold coated. Photographs

Fig. 2. 1. Negative crystal socket in blue sapphire, X18. 2. Negative crystal in blue-purple sapphire, X14. 3. Negative crystal socket in purple ruby, X14, all from the Ruby Well mine, Chanthaburi-Trat. 4. Sapphire from Reddestone Creek, No.2 plant, New England, X25; a) detail showing flat topped triangular hillocks, X66; b) detail showing relief of hillocks and their irregular, eroded appearance, X330; c) detail of one hillock showing gradual rise from the floor into the hillock wall, X935; d) detail of one hillock showing pock marked, etched surface, note damage to top edge of the hillock due to fluvial transport, X1210.

Fig. 3. (p.154) 1. Blue sapphire from Reddestone Creek, No.1 plant, New England, surface perpendicular to the *c*-axis; a) oriented flat, shallow hexagonal etch depressions with central hillocks, X358; b) detail of several hexagonal depressions, X2200; c) stages of formation of etch features, right-early stage of originally flat surface breaking down into etch depressions with central hillock, bottom centre-edges of depressions removed leaving only sub-triangular to rounded hillocks, left-more extensive etching gives surface a spongy appearance, X237. 2. Blue sapphire from SAP mine, Bo Ploi, hexagonal etch depressions with a central hillock, X1100. 3. Pink-purple ruby, Ruby Well mine, Chanthaburi-Trat, showing early stages of formation of triangular and hexagonal hillocks: a) X330; b) X660. 4. Deep prominent etch sculpturing on a pink-purple ruby, Ruby Well mine, Chanthaburi-Trat; a) complete specimen, X28; b) detail of etch channels, X138.

Fig. 4. (p.155) Blue sapphires from New England; a) complete specimen, X7; b) detail of 'shark skin like' etch channels, X66. 2. SAP mine, Bo Ploi; a) 'intaglio-like surface due to extensive etching, X61; b) detail of a) showing structural control of 'intaglio' pattern and microlamination due to successive layer dissolution, X440. 3. Braemar, New England; a) etch pattern resembling trigonal prismatic 'stacked bricks' on a surface oriented at a low angle to the *c*-axis, X825; b) detail of surface, X2200. 4. Braemar, New England; a) triangular pyramidal depressions resulting from etching of a surface at an intermediate angle to the *c*-axis, X825; b) detail of pyramidal depressions, X2200.

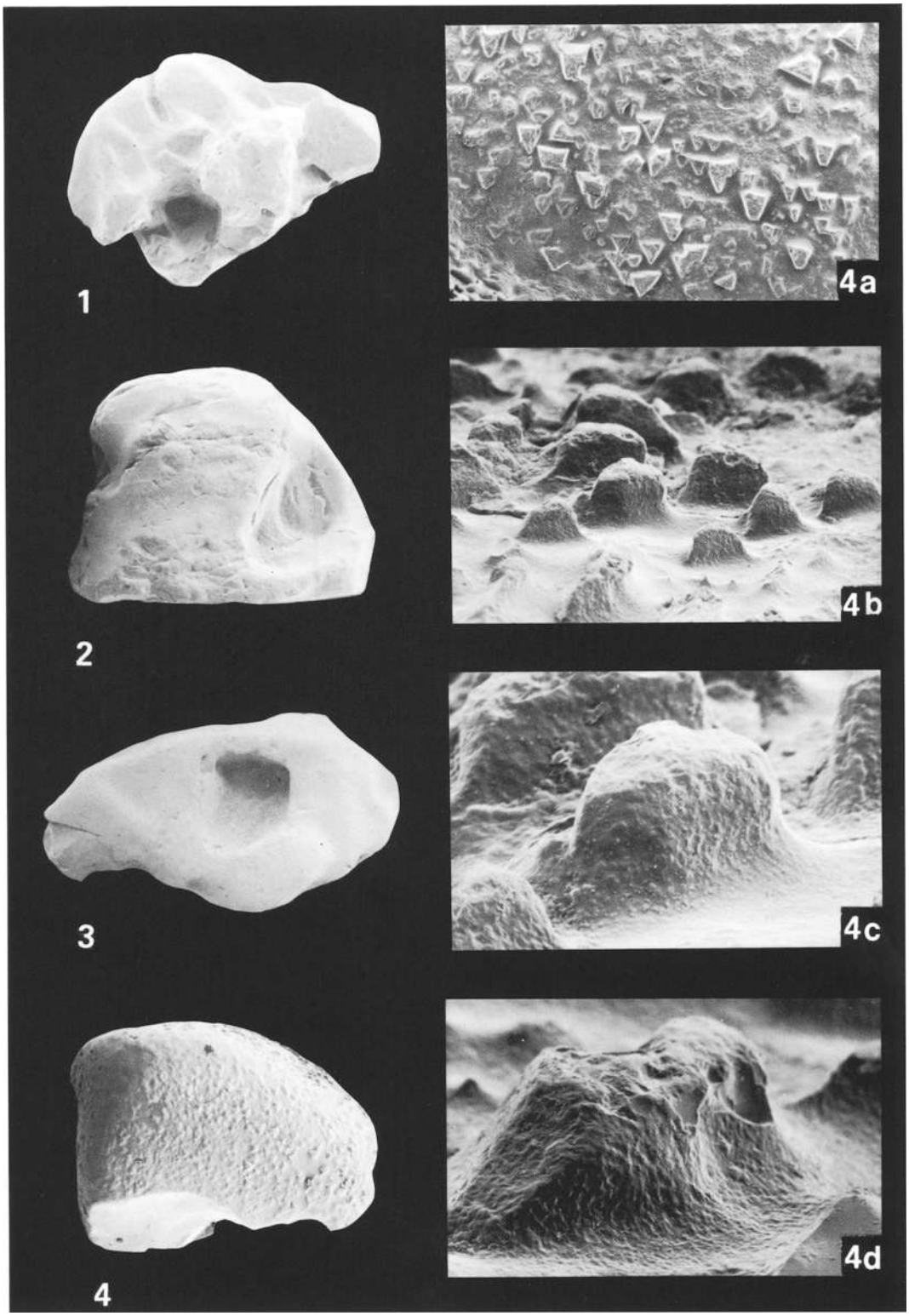

Fig. 2.

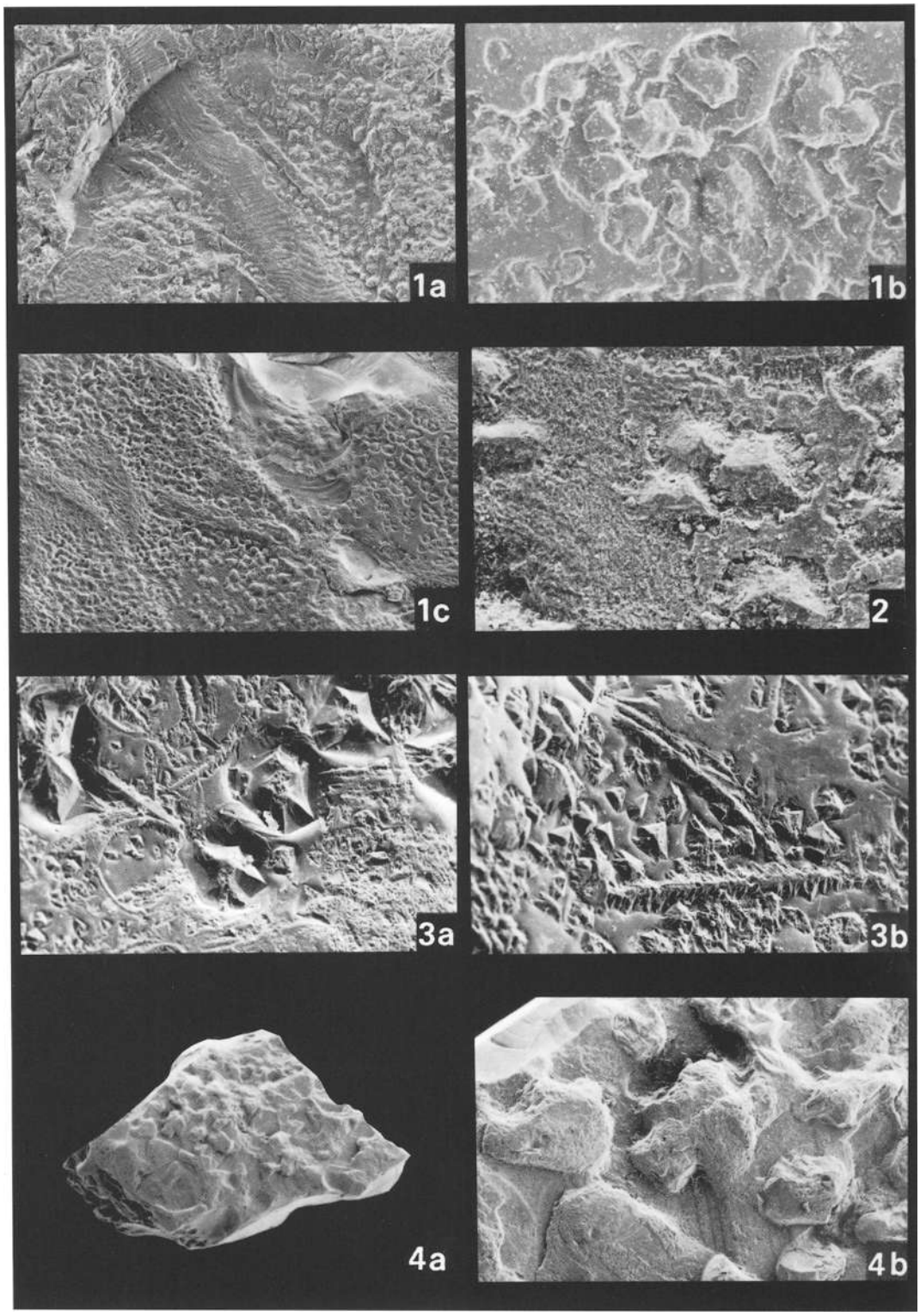

Fig. 3.

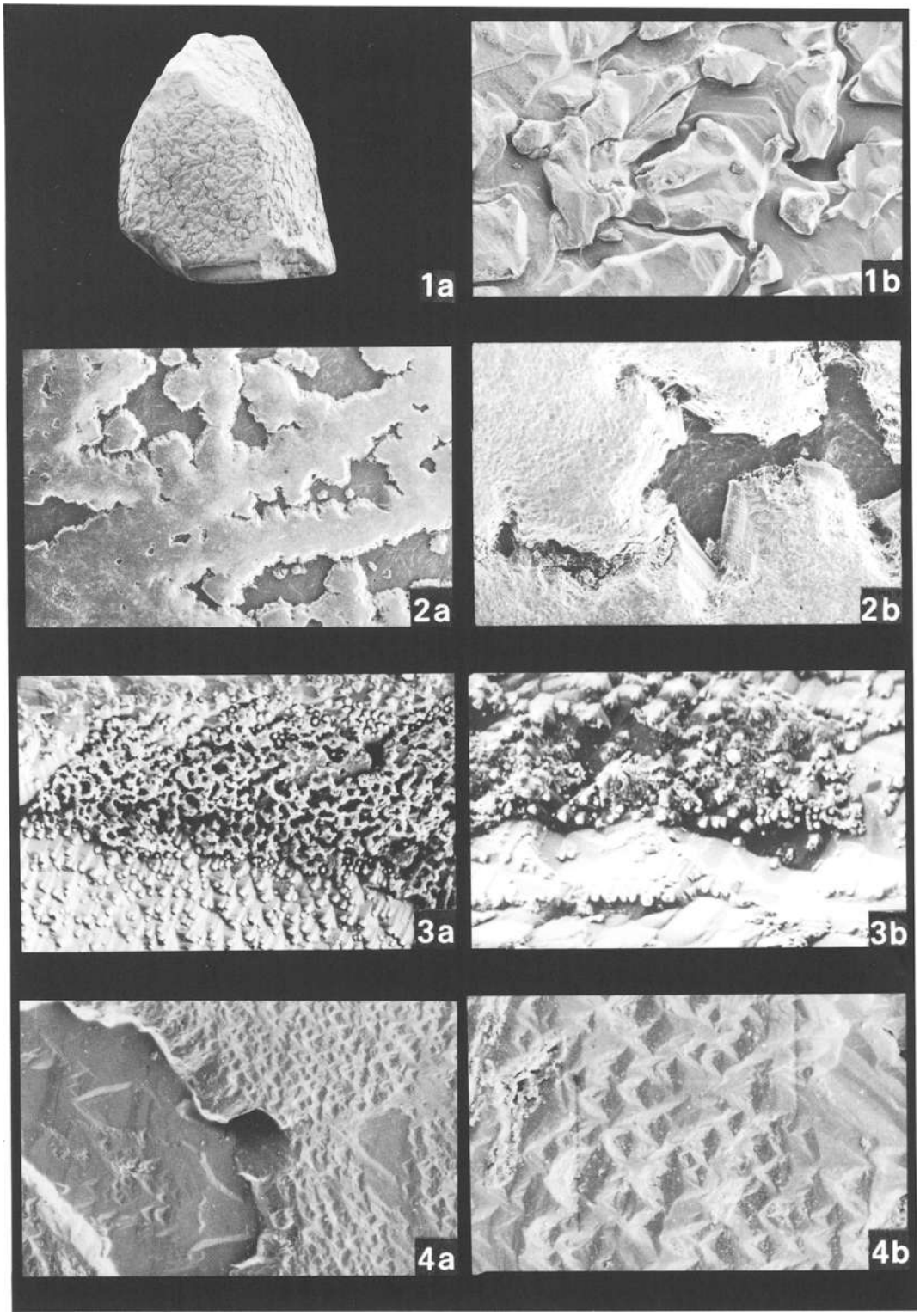

Fig. 4.

were taken with a JEOL JSM 840 scanning electron microscope.

The observed features may be broadly grouped as negative crystal impressions, surface resorption or etch features, including chatter marks, and surface damage consistent with transport in the alluvial environment.

1. Negative Crystal Impressions

Figures 2-1, 2-2 and 2-3 show sharp edged, deep, geometric shaped holes, or crystal impressions of the order of 0.5-1.0mm across on sapphire and ruby crystal faces. The angles between the impression faces in Figures 2-1 and 2-2 are 120°. The negative crystal shape in Figure 2-3 is particularly interesting in that it appears to show tetragonal symmetry, thus precluding the possibility of it having been a fluid filled negative crystal cavity. These impressions developed as the corundum grew as part of a coarsely crystallized aggregate with minerals such as anorthoclase and zircon (Coenraads *et al*, 1990) and spinel (Vichit, 1987).

2. Surface Etch Features

The above figures, as well as Figures 2-4, 3-4a, 4-1a, 5-3a, 6-1a and 6-2a show the corundum to be sub-rounded to rounded in appearance. This rounding, although once attributed to alluvial wear, is clearly the result of resorption by magmas responsible for carrying the corundum to the surface. The grains in Figures 2-4 and 6-1a show the surface to be covered with flat topped triangular hillocks of the order of 15-20 μm which reflect the internal trigonal crystal symmetry. The only exception is where the bottom of the grain in Figure 2-4 has broken away along a conchoidal fracture surface. A further enlarged view of the sapphires' surface in Figure 2-4b shows the relief of the triangular hillocks and their irregularity in detail. They stand like sculptured 'monoliths' on the surface of the sapphire, roughly equidimensional and have a relief of about 20 μm. Figures 2-4c and 2-4d show the gradual rise of the surface from the floor in between the hillocks into their walls, and the surface in detail, which is covered with sub-geometrically regular to rounded pock marks or shallow dishes about 1 μm in diameter. These features give the hillocks a distinctly eroded appearance.

The hillocks are most likely of similar origin to the pyramidal or drop shaped hillocks on rounded surfaces of diamonds (Orlov, 1977, p.93) and also reproduced in etching experiments (Patel and Agarwal, 1966).

Figures 3-1a and 3-1b show relief on a face perpendicular to the *c*-axis {0001} of a sapphire crystal. The etching is variable in distinct bands. Figure 3-1b shows detail of the etching as oriented flat shallow hexagonal depressions of the order of 5-10 μm in diameter with a hexagonal shaped remnant hillock centrally positioned in each. The probable sequence of formation of the etch features is illustrated in Figure 3-1c where all stages are present on the one crystal, and where each form merges into another across the surface. In the bottom centre of the photograph, below the large chip displaying conchoidal fracture, the surface is covered by sub-triangular to rounded hillocks described earlier. In the right of the photograph can be seen what may be the early stages of formation of such a surface. Here an originally flat surface has been etched to produce a number of hexagonal depressions, each with a centrally placed hillock. In the left of the photograph the surface has a spongy or porous appearance, probably as a result of extensive etching.

Figures 3-3a and 3-3b show detail of the early stages of formation of hexagonal and triangular hillocks on a Thai ruby. Peaked hillocks bounded by crystal faces, ranging up to 50 μm, are surrounded by a moat into which the outer wall gradually slopes. In some cases preferential alignment of etching has led to the formation of ridges as seen in Figure 3-3b. The hillocks are similar in appearance to the hexagonal etch marks (of the order of 10-20 μm) seen on a Thai sapphire (Figure 3-2 and also Figure 3-1b, described above), only in this case, the outer walls of the moats are roughly sculptured as opposed to being smoothly sloping. The reason for the development of a peaked hillock remnant bounded by crystal faces situated centrally within an etch pit is not clear, although it could be a response by the crystal to minimize its surface free energy when it was in contact with the hostile carrier magma.

As the dissolution process proceeds, etch features appear to grow and interfere with one another producing deep and prominent sculpturing ('shark skin' appearance) such as seen on the surface of the Thai ruby (Figures 3-4a and 3-4b) and Australian

Fig. 5. Blue sapphires from Braemar, New England. 1. Detail of etch surface at a low angle to the *c*-axis resembling trigonal prismatic 'bricks', X3300. 2. Chatter marks or sub-parallel curved grooves attributed to mechanical stress; a) X358; b) detail of chatter marks X1375; c) further detail, finely striated faces within chatter marks indicate that they have been enhanced by dissolution, X2365. 3. Sapphire traversed by numerous fractures; a) complete specimen, X18; b) detail of fractures, X193; c) detail of b), X495. 4. Fracture radiating from an inclusion in sapphire, X110.

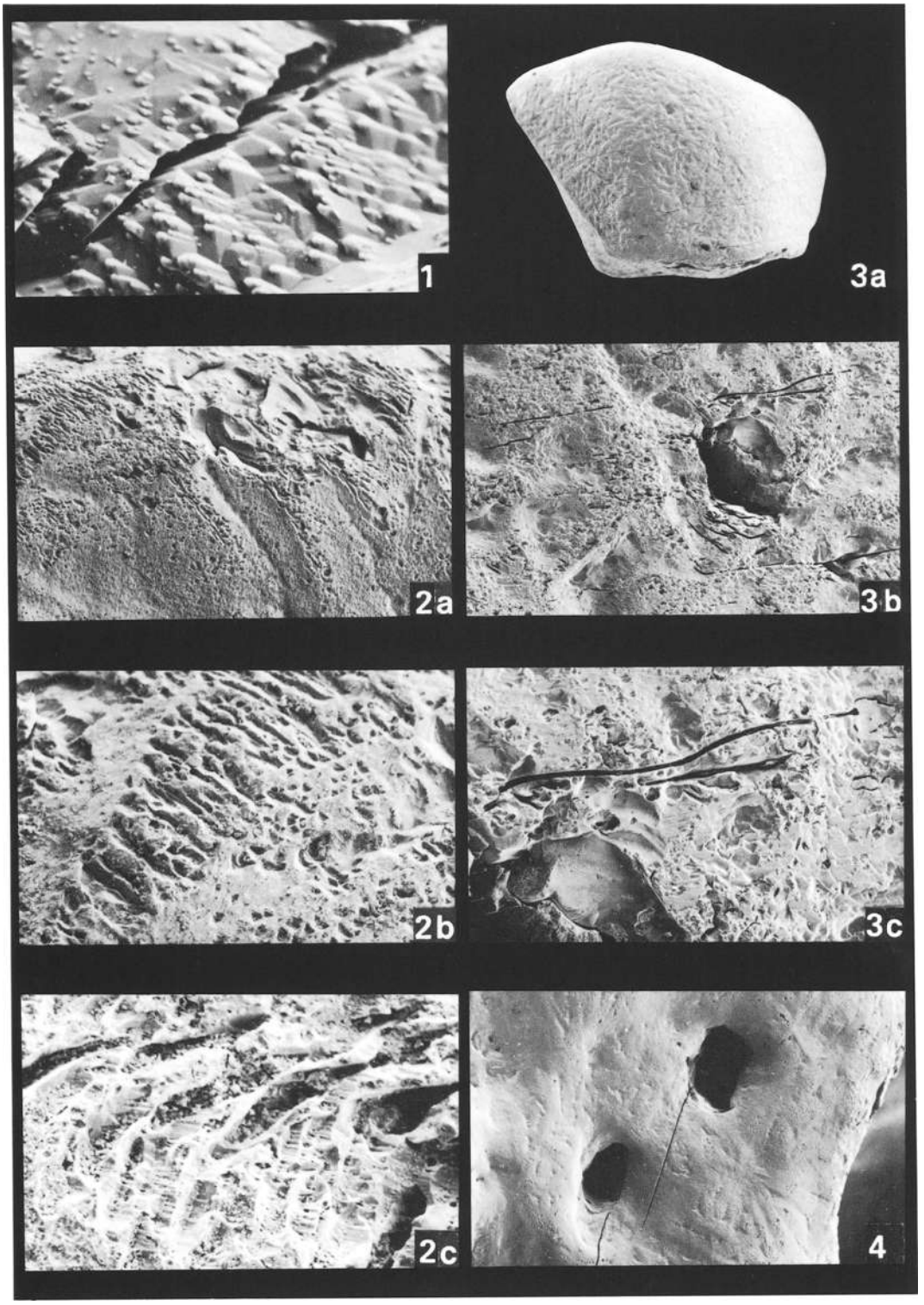

Fig. 5.

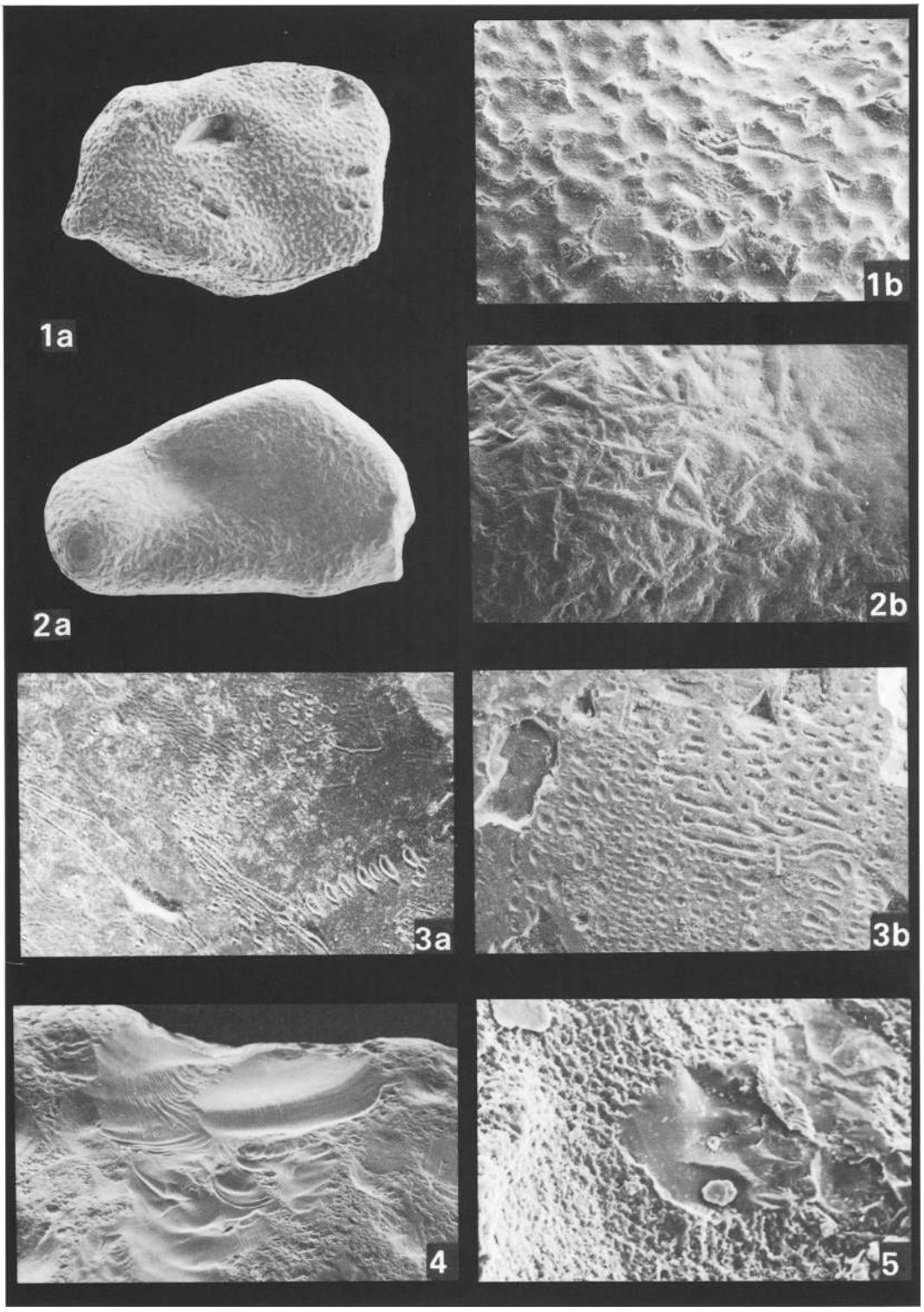

Fig. 6.

sapphire (Figures 4-1a and 4-1b). Orlov (1977, p.98) found similar features on the octahedral faces of diamond resulting from continued dissolution which caused the etch trigons to grow larger and crowd in on one another. Such extensive dissolution also seems to have been responsible for the 'intaglio-like' surface produced on the sapphire in Figure 4-2a. The outer surface has been removed in places to a depth of about 15 μm, to a lower level which appears to be more resistant and only lightly etched. Detail in Figure 4-2b reveals a fine micro-lamination which has been emphasized by the dissolution as a series of steps of the order of 1 μm in size. Such micro-lamination is also observed in diamond (Orlov, 1977, p.87) and has been attributed to successive layer dissolution.

On surfaces which appear to be at a lower angle to the *c*-axis of the corundum crystal (see Figures 4-3a, 4-3b and 5-1), the etch patterns are quite different, and resemble inclined stacks of elongated, triangular shaped bricks. These structures clearly reflect the internal crystal structure of the corundum. Figure 4-3a shows two surfaces; in the lower part of the photograph, a surface roughly parallel to the *c*-axis displays triangular prisms whilst in the upper part of the photograph a surface perpendicular to the *c*-axis, partially covered by lichen, shows typical triangular hillocks described earlier.

Figure 4-4a and the detail in Figure 4-4b, show triangular depressions of the order of 1-2 μm across, with the depression walls forming a negative triangular pyramid. Such features appear to be the result of etching on a surface at an intermediate angle to the *c*-axis.

The surface features of most grains studied, even those with an apparently random 'blade-like' texture such as seen in Figure 6-2a, could be ultimately explained in terms of surface etching. Under magnification (Figure 6-2b), a crystallographic control of the features is revealed. In Figure 6-2b the raised 'blades' are seen to form the sides of triangular shaped pits.

Chatter marks are occasionally present and are shown in Figures 5-2a, 5-2b and 5-2c. These features are attributed to some form of mechanical stress leading to the formation of a series of parallel or curved marks on the surface of the grain. Detail in Figure 5-2c shows that the marks may be of 1-2 μm in width and as deep or deeper. The finely striated faces within the curved chatter mark grooves show a pattern, not unlike that described in Figures 4-3a, 4-3b and 5-1. This suggests that the grooves have been enhanced by dissolution and implies that the corundum displaying chatter marks has been subject to stresses prior to, or possibly during transport to the surface.

3. Healed fracture surfaces and damage resulting from transport in an alluvial environment

Figures 5-3a, 5-3b and 5-3c show narrow (1-2 μm) but deep fractures which traverse the stone irregularly or in a semi-oriented manner. These start and end abruptly and probably represent healed or partially healed stress fractures. They are described by Orlov (1977, p.53) as planar dislocation growth defects originating from a defect centre such as an impurity or inclusion in the interior of the crystal and radiating to the faces. Such may be the case in Figure 5-4. It is logical that such planes of weakness would be likely sites for breakage in the alluvial environment. Figures 6-3a and 6-3b show such rebroken healed fracture surfaces revealing a 'fingerprint-like' pattern of tubes of about 1-2 μm in size. Such fingerprints are commonly photographed within gem rubies and sapphires using light microscopes (Gübelin and Koivula, 1986, p.340).

Damage in the alluvial environment results from impacts during transport. This is seen as conchoidal fracturing particularly around the more exposed edges of crystals as shown in Figure 6-4, or as chipping on protruding hillocks (Figures 2-4d and 6-1b). In Figure 6-5, an impact has completely broken off a protruding hillock leaving a smooth fracture surface.

Conclusion

Surface features on rubies and sapphires from volcanic provinces may give an insight into the history of such crystals from the time of their growth to their eventual recovery by mining.

1. Negative crystal impressions suggest that the corundum grew as part of coarsely crystallized aggregates together with minerals such as anorthoclase, zircon and spinel.
2. Surface resorption or etching and layer dissolu-

Fig. 6. Blue sapphires 1. Ruby Well mine, Chanthaburi-Trat showing surface covered with triangular hillocks; a) complete specimen, X30; b) detail of triangular hillocks, some chipped due to fluvial damage, X165. 2. Reddestone Creek No. 1 plant; a) complete specimen showing a 'bladed' surface texture, X24; b) detail shows crystallographic control as the raised 'blades' form two sides of triangular pyramidal shaped pits, X110. 3. SAP mine, Bo Ploi. Rebroken healed fracture surfaces reveal a 'fingerprint-like' pattern of exposed fluid remnants; a) X440; b) X550. 4. Reddestone Creek, No.1 plant, New England. Conchoidal fracturing on the edge of this sapphire is evidence of damage in the fluvial environment, X138. 5. Ruby Well mine, Chanthaburi-Trat. Protruding hillock broken off at its base leaving a clean fracture surface is evidence of damage in the fluvial environment, X2200.

tion features clearly result from reaction with the magmas responsible for carrying the corundum to the surface. These features include, triangular and hexagonal hillocks and depressions on faces perpendicular to the *c*-axis, and stacks of triangular prisms on surfaces parallel to the *c*-axis of the corundum crystal. Chatter marks imply that the corundum has been subject to stresses prior to, or possibly during transport to the surface.

3. Surface damage including impact marks displaying conchoidal fracture, broken off protrusions and exposed healed fracture surfaces indicate the degree of reworking in the alluvial environment. The grain surface features generally indicate minimal damage due to fluvial transport. This observation, when considered in conjunction with the spatial variability in the physical characteristics of corundum in a given placer deposits (Coenraads, 1990), indicates minimal degree of downstream reworking and mixing, and suggests that the corundum sources are local to the placer deposits.

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H_2O and all that!

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It is generally accepted that quartz in its many varieties is the most abundant and ubiquitous mineral, although if all the different feldspars were to be considered as one mineral there could be some argument as to which of these two predominates in the terrestrial crust. The feldspars are the more important in the classification of rocks.

But there is a very familiar third contender for predominance which is scarcely thought of as a mineral by the layman. I refer to H_2O, – water – which at the sub-zero temperatures of the Poles obviously forms a massive mono-mineralic rock which we know as *ice*. Once that fact is accepted, then the liquid hydrosphere has to be included correctly under the heading of mineral.

The oceans cover about 71% of the Earth's surface, and their mean depth is estimated at about 12,000 feet (3650 metres) which gives us 317,000,000 cubic miles (1,320,000,000km^3) of water, give or take a river-full. Fresh water in ice caps (2½%), lakes and rivers, plus ground-water amounts to no more than 3½%. Atmospheric water forming rain evaporates from just the surface of oceans or land and deep water in both zones can wait for thousands of years before taking its turn to form rain clouds. Once in the upper regions of the atmosphere water vapour can remain air-borne for more than a year before coming down again as rain.

In its crystalline form as ice, water is trigonal in symmetry, although this is generally observable only in the ephemeral microscopic beauty of a single crystal of snow (Figure 1). Its SG as a solid is 0.917, the mean RI is 1.31 and the birefringence is 0.004. (Liquid water is both denser and has a slightly higher RI of 1.33; while ice under great pressure assumes other crystalline forms some of which are denser than liquid water.) Hardness evaluation is complicated by the fact that pressure causes ice to melt, but it can be considered to be a soft mineral since ice skates obviously scratch it, and it is also cleavable and very easily frangible in most circumstances. (I have had personal experiences, however, of the remarkable tenacity of thin films of ice when backed by iron plates, while the iced superstructure of a steel ship can be almost impossible to clear of the dangerously top-heavy mass that can accumulate.)

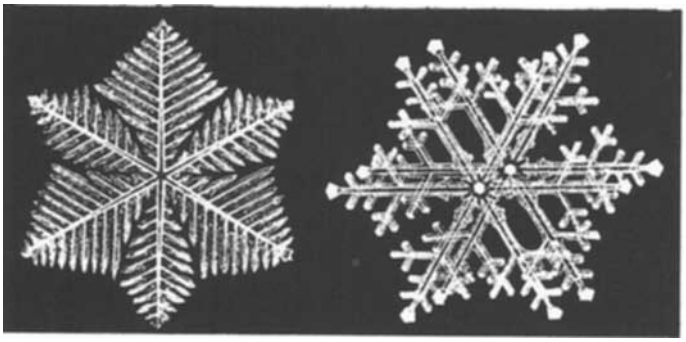

Fig. 1. Diagrams of two snow crystals showing the characteristic trigonal form. After A.E.H. Tutton, 1911.

The estimated relative amounts of quartz, feldspar and water are, of course, largely hypothetical, for no one knows with certainty what quantities of each might exist deeper in the crustal layers, and liquid water certainly penetrates strata many kilometres deep, a great deal of it at pressures and temperatures which enable it to behave as a gas,

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with additional properties which will be described below. As vapour it forms part of the atmosphere to very considerable heights, and can constitute up to 7% of the total air in exceptional circumstances. There is a great deal of water about! [None of which information appears to concern us much in gemmology, apart from the occasional trade references to 'ice' when describing a particularly fine diamond, or an item of diamond jewellery of outstanding merit.]

However, gemmologists normally use water for hydrostatic weighing and this practice brings us to one of the most peculiar properties of this ubiquitous liquid mineral.

We are taught that the specific gravity of a gem is its weight compared with that of an equal volume of pure water at 4°C. (A more exact figure is 3.8°C.) At that temperature water is at its densest. At higher

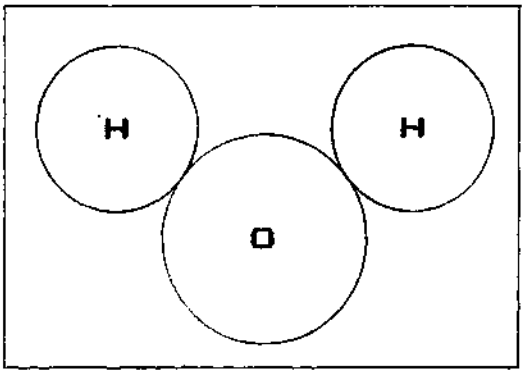

Fig. 2. The strange configuration of the water molecule, causing polarity which results in the idiosyncratic behaviour at low temperatures and as ice.

temperatures it is less dense, e.g. at a room temperature of (20°C) its density is 0.99823. As the temperature gets lower the density increases, as it would in any liquid, until at 3.8°C it reaches a value which is regarded as unity (1.00). However, as further heat is lost, water behaves quite abnormally and starts to expand and become less dense until at 0°C it reaches 0.99987. At this temperature it freezes, turning to ice, and a truly dramatic increase in volume occurs, the density going down suddenly to 0.917.

The reason for this anomaly has been understood only comparatively recently. For many years it was thought that the water molecule had a linear configuration, like the word OXO, i.e. H-O-H. then it was shown that the two hydrogen atoms attach themselves to the negative oxygen at an angle of 105° (Figure 2). Ideally they would be at right angles, but the hydrogens are positively charged and repel each other, so that the angle between them widens. This fact also gives the molecules polarity, so that even in the liquid state they tend to join up to form larger but constantly changing complex structures of molecules, a tendency which increases as the temperature gets lower.

The thermal vibration of molecules in liquids and in solids keeps them apart, but this movement decreases as temperature falls, so that almost all substances become progressively denser as they cool, and vice versa; and the solid, or close-packed version of a liquid, is usually denser still and therefore sinks in the liquid. This applies to almost all other liquids, including molten metals when cooling and solidifying.

But in the case of water the unusual bent configuration of the single molecule prevents such close-packing, or any further reduction in volume beyond that achieved at 3.8°C and as more and more molecules join up to form large multiples the density reduces from 1.00 to 0.99987. Then ice forms and the molecular configuration takes over completely, forcing an irresistible expansion which lowers the density suddenly to 0.917. So ice is about one-tenth less dense than liquid water. In other words it occupies one-tenth more space than it did before freezing and does so inexorably regardless of pressure. This, I think, makes it clear why water at 3.8°C is used as a standard when determining the specific gravity of solids.

It will be seen that ice floats, a fact with which we are so familiar as to accept it without further thought. Also cold water can continue to sink only until it cools to a density of 1.00, after which it starts to ascend again as it gets colder still. If it then goes on to freeze, the much less dense ice can only form at the surface, where it provides a thermal barrier which effectively prevents freezing from going far below the surface layers. The lower regions of deep water are almost always in a state which makes freezing unlikely and really thick ice can achieve permanence only on land. In water the frozen under-surface is continually thawing and reforming, or being replaced from the top by compacted snow. Icebergs slowly melt both above and below the surface of the water in which they float. If that water is appreciably warmer they are reputed to turn turtle as they melt more rapidly there than in the air and become top-heavy, but a little thought will show that as the base reduces in size so the whole mass will settle in the water and such acrobatic somersaults seem rather unlikely to occur other than in shallow water.

Back to gemmology. Water of crystallization becomes part of the mineral structure and temperatures below zero probably do not affect it. But where, as in the case of opal, the water is held entrapped by the silica structure I feel that there is some possibility that freezing may contribute to the tendency for that gem to crack.

Another gemmological point can be made here in the fact that we are told to use water at room temperature for hydrostatic weighing and to multiply the result by the density of water at that temperature, a calculation which is scarcely necessary since a specific gravity of 2.65 becomes 2.645 when multiplied by 0.99823 (the density at 20°C), which is well within the margin of experimental error in normal hydrostatic weighing of small stones. For most practical gemmology the temperature gradient can be ignored.

Another important property of water lies in its behaviour when it is heated to the critical temperature of (374°C), which can be done by heating in a sealed autoclave, or 'bomb', so that it is under pressure of its own super-heated vapour. (This is not a unique condition since all liquids have their critical temperature at which they can no longer remain as liquids even under pressure.) In these conditions water becomes highly compressed very hot steam, and will take minerals such as quartz, beryl, corundum and others into solution quite readily. This gives us yet another connection with gemmology, since it is the basis for hydrothermal manufacture of synthetics, where mineral substances are taken into solution at or above the critical temperature in an autoclave, the lower end of which is allowed to cool, so that the gas condenses to its liquid form again and deposits the dissolved mineral as crystals, either spontaneously or onto a seed crystal. By careful regulation of temperatures and of colouring impurities superb synthetic crystals are obtained for cutting as gems (or for laser use).

Another gemmological tip arising from our earlier discussion of hydrostatic weighing is the fact that it is by no means a waste of time to do a hydrostatic on a stone in a mount. How often are we called upon to estimate the weight of a set stone for insurance purposes or with a view to buying it in over the counter? Various methods have been advocated from plain guesswork, to gauges of greater or lesser efficiency, to comparison with stones of a known weight, to weighing another mount to get somewhere near the weight of the one in question, or even to measuring the stone in all its dimensions and working out a weight using complicated mathematical formulae to obtain an approximation. Some of these might work, but there is a risk of getting hopelessly wrong answers to what should be a simple enough question even when we cannot get permission to unset and weigh the stone separately.

In the past I have been offered a peridot ring with the remark that it 'Must weigh over 12 carats' and have found myself in possession of a nice stone of over 26 carats. A star sapphire offered at 'about 15 carats' estimated weight, turned out to be around 35 carats when I took it out of its setting. Such inexact guesses are quite unnecessary and are very dangerous to the jeweller if he is valuing the stone. The answer lies in doing an ordinary hydrostatic weighing, a matter of a few minutes only.

Simply weigh the whole item in air and then weigh it again in water. Subtract the second weight from the first to find the total loss of weight.

Then, if we already know what the stone is (from its RI) and the nature and quality of the metal (hallmark), it is very easy to arrive at a weight for either the stone or for the mount by simple calculation. First assume that the whole ring is composed of stone and multiply the stone's SG by the loss of weight. Deduct this figure from the total weight of the piece and that will give us the extra weight due to the greater density of the metal used. Divide this figure by the known SG of the metal *less* the SG of the stone.

SGs of PRECIOUS METALS:–

YELLOW GOLD		WHITE GOLD	
9ct	11.2	9ct	12.0
14ct	14.1	14ct	12.9
18ct	15.5	18ct	16.1

PLATINUM 21.4

SILVER 10.3

VICTORIAN GOLD MOUNTS with silver settings are usually 15ct gold, so an SG figure of 12 would be a fair approximation, but the method is a little less accurate with such mounts.

This gives us the loss of weight due to the mount alone. Subtract this from the total loss of weight to find the loss due to the stone only, and multiply the result by the SG of the stone. This sounds complicated, but it is nothing of the kind. Try it and see. The longest part is the weighing and even that should not take more than a few minutes.

To give an actual example:

An aquamarine (SG 2.70) and 18ct gold (SG 15.5) ring weighs 35.32cts.

In water it weighs 28.75 carats.

Loss of weight = 6.57 carats.

If all aquamarine then weight would be 6.57 x 2.70 = 17.74.

Extra weight due to gold = 35.52 − 17.74 = 17.58.

So loss of weight of mount is 17.58 divided by 15.5 − 2.7 = 1.37.

So loss of weight due to the stone is 6.57 − 1.37 = 5.20.

Weight of stone is then 5.20 x 2.70 = 14.04 carats.

There are very minor differences in the SG of a

gem species from stone to stone, and rather greater differences in the SG of gold of a given caratage [bullion dealers for this reason usually quote only to one place of decimals]. But this method can usually be relied upon to give an answer well within 10% of the true weight of a stone. Where there are a few small diamonds included in the design one obviously needs to take these into account at the end of the main calculation by deducting say half a carat from the estimated weight of the main stone. Most jewellers are expert at estimating the weight of small diamonds by sight and should have little difficulty in making a reasonable correction for this situation. The method only really comes to grief when a mass of large stones of mixed species are found in one mount, and even then some guidance can be obtained from the exercise if it is used intelligently.

Reverting to the extraordinarily anomalous behaviour of water at low temperatures it may be seen with a little thought that if this did not happen life could never have developed on this planet, for an ocean in which ice sank to the bottom could not remain liquid very far below the surface layers. Even in equatorial latitudes currents could not descend to carry oxygen down to maintain life; and life is known to have started in the oceans many millions of years before it moved out onto the land.

Again the sudden and irresistible expansion when ice forms is probably one of the most important natural forces of all, in that it is this which cracks hard rocks and gradually reduces them to smaller and smaller sizes until a fine soil is produced in which plant life can flourish.

Without these extraordinary responses to temperature, life as we know it could not exist.

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Application of geochemistry to exploration for gem deposits, Sri Lanka

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Abstract

Geochemical analysis of stream sediments, when integrated with heavy mineral surveys, can be used as an effective tool in the exploration for sedimentary gem deposits. Recent research studies carried out by the authors have shown that certain rarer minerals associated with the gem minerals leave a special geochemical signature which could be identified and used in the delineation of areas suitable for further detailed exploration for gem minerals. In the placer gem-bearing terrains located within a high-grade metamorphic terrain in Sri Lanka, it has been found that Sr/Rb ratios, thorium and uranium, fluorine, tantalum, niobium, yttrium and the rare-earth elements can be used as pathfinders in the search for new gem deposits.

Introduction

Exploration for gem deposits in an alluvial environment very often consists of panning stream sediments for heavy minerals. Geochemical drainage surveys had been developed from this practice of tracing heavy minerals in stream gravels. Most of the world's major gold and tin camps had been discovered by the identification of gold and cassiterite in panned concentrates (Hawkes and Webb, 1965). Chemical analysis of the stream sediments integrated with mineralogical investigation of the heavy concentrates forms a powerful tool in the exploration for economically important heavy mineral deposits.

Anomalous concentrations of metals in stream sediments occur in primary ore minerals, resistant secondary minerals and in precipitates of various kinds. The heavy mineral fraction of the stream sediments contains the resistant primary ore minerals commonly having a high specific gravity. Beryl however, on account of its lower specific gravity, is generally found in the lighter fraction associated with quartz.

Chemical analysis of the heavy mineral fraction often highlights the anomalous concentrations of geochemically immobile elements such as Au, Sn, W, Hg, Ta and Nb. Under exceptional circumstances however, some of the more mobile elements are known to occur in the heavy fraction (Hawkes and Webb, 1965).

As a special group of minerals, gems occur in the heavy fraction of the stream sediments. Figure 1 illustrates the mean density values of the more important sediment forming minerals inclusive of gem minerals. The chemistry of this heavy mineral fraction of the stream sediments is not often fully utilized in the geochemical exploration for gem deposits. This paper describes the successful application of geochemistry in the search for new gem deposits in Sri Lanka.

Chemistry of rare minerals

Even though many of the more common gem minerals are found in nature as oxides (or silicates) they tend to be associated with rarer minerals which have a unique geochemical signature. Many of these rarer minerals have anomalous concentrations of rare-earth elements (REE) Ta, Nb, Zr, Th, U, Ti, Be, and F. Table 1 shows the chemistry of the rarer minerals associated with the gem minerals in the stream sediments. Some elements such as Zr, Be, and F will naturally be found in gem minerals such as zircon, beryl and topaz respectively and their abundances will lead to the discovery of these minerals and hence other associated gem minerals such as corundum, spinel, garnet and tourmaline.

Rare earths and rare elements, when found in anomalous concentrations lead to the discovery of occurrences of minerals such as zirkelite, monazite, gadolinite, chevkinite, samarskite, aeschynite, anatase etc. These rare-earth bearing minerals are commonly associated with the gem minerals, as in the case of the sedimentary gem deposits of Sri Lanka, and can therefore be used as excellent indicator minerals in the search for gem-bearing terrains. It must be emphasized however, that the use of rare-earth elements and rarer minerals in the search for gem occurrences depends largely on the geology of the terrain and possibly on a genetic link between the mineral suites concerned. In their study on the corundum, Cr-muscovite rocks at O'Briens, Zimbabwe, Kerrich *et al.* (1987) com-

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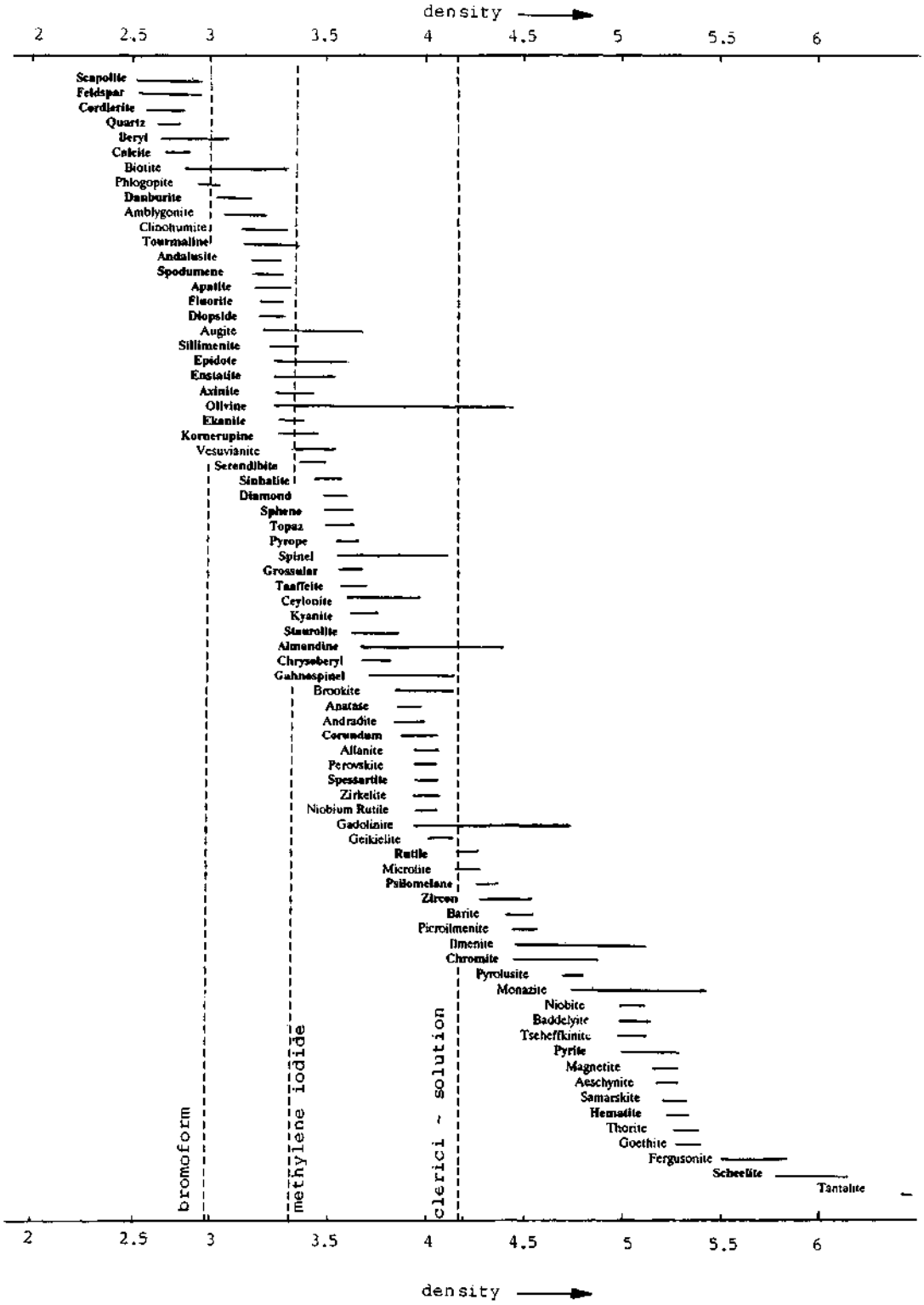

Fig. 1. Mean density values of the more important sediment-forming minerals inclusive of gem minerals.

Table 1: Some rare minerals associated with gems in Sri Lanka

Mineral	SG	Chemical formula	Other elements found
Ekanite	3.28	$K(Ca,Na)_2Th(Si_8O_{20})$ $CaTi(O/SiO_4)$	
Serendibite	3.4	$(Ca,Mg)_5(AlO)_5[BO_3/(SiO_4)_3]$	
Anatase	3.9	TiO_2	Nb,Ta,REE
Allanite	4	$(Ca,Ce)(Fe^{3+},Fe^{2+})$ $Al_2O(SiO_4)(Si_2O_7)(OH)$	
Perovskite	4	$CaTiO_3$	Nb,Ta,REE
Zirkelite	4	(Ca,Ce,Y,Fe) $(Ti,Zr,Th)_3O_7$	1-14%U_2O_8,REE
Rutile	4	TiO_2	Nb,Ta,Fe
Gadolinite	4-4.7	$Y_2Fe^{2+}Be_2[O/SiO_4]_2$	
Geikielite	4.05	$MgTiO_3$	
Microlite	4.2	$(Ca,Na)_2(Ta,Nb,Ti)_2O_6$ (OH,O,F)	
Zircon	4.3-4.5	$ZrSiO_4$	U,Th,Hf,REE
Chromite	4.5-4.8	$(Fe,Mg)Cr_2O_4$	
Monazite	4.8-5	$CePO_4$	U,Th,REE
Columbite	5	$(Fe,Mn)(Ta,Nb)_2O_6$	
Baddeleyite	5	ZrO_2	
Tantalite	5-8	$(Fe,Mg)(Ta,Nb)_2O_6$	
Samarskite	5.24	$(Y,U,Ca)_2(Nb,Fe^{++})_2(O,OH)_6$	Ta,REE
Thorite	5.3	$ThSiO_4$	U
Fergusonite	5.6-5.8	$Y(Nb,Ta)O_4$	4%U_3O_8,REE
Scheelite	5.9-6.1	$CaWO_4$	
Cassiterite	6.8-7.1	SnO_2	Nb,Ta,Ti, Mn,Zr,W,Fe
Thorianite	9.7	$(Th,U)O_2$	

mented, for instance, on the inter-element relationships for certain major and trace elements. The variations of V, Sc and Y relative to Zr and Hf during genesis of the rocks were attributed to hydrothermal alteration rather than to intrinsic variations diagnostic of different precursors. These authors used the rare-earth elements patterns effectively to make significant observations on the origin of the corundum rocks.

Tantalum and niobium are two elements of great importance in geochemical investigations for granite-associated heavy minerals. The features of the magmatic and postmagmatic evolution for granite related tantalum and niobium mineralization is reflected in the geochemistry. These mineralizations are often associated with geochemically specialized granites and are characterized by their enrichment in fluorine. Alkali granites containing alkali pyroxenes and/or amphiboles are noted for their high Fe, F, Nb, Rb, Zr, Sn and REE and for their low Ca, Ba, Sr and Ta/Nb. Sediments derived from such granite precursors therefore yield valuable geochemical clues as to the possible source rocks of gem mineralizations and their locations. Pollard (1989a, 1989b) and Cerny (1989) have discussed in detail the geochemistry of Ta and Nb mineralizations and their geochemical exploration strategies.

Use of fluorine geochemistry in gem exploration

Pathfinder elements and mineralizers are factors that are of great importance in the formation of mineral deposits. Among these are B, CO_2, F, Cl, Br, I, S and Sc. It has been known that the two elements B and F are universal indicators of nearly all types of epigenetic deposits; where one is not present, the other is, and in many deposits both occur (Boyle, 1984).

Table 2: Fluorine-bearing minerals around Rattota and Matale area

MINERAL	CHEMICAL FORMULA	F^-%
Fluorite	CaF_2	48%
Topaz	$Al_2SiO_4(OH,F)_2$	13-20%
Amblygonite	$Li,Al[(F,OH)PO_4]$	0.57-11.71%
Apatite	$Ca_5(PO_4)_3(F,Cl,OH)$	1.35-3.77%
Biotite	$K(Mg,Fe)_3[(OH,F)_2AlSi_3O_{10}]$	
Hambergite	$Be_2[(OH,F)BO_3]$	
Sphene	$CaTiSiO_5$	.07-1.27%

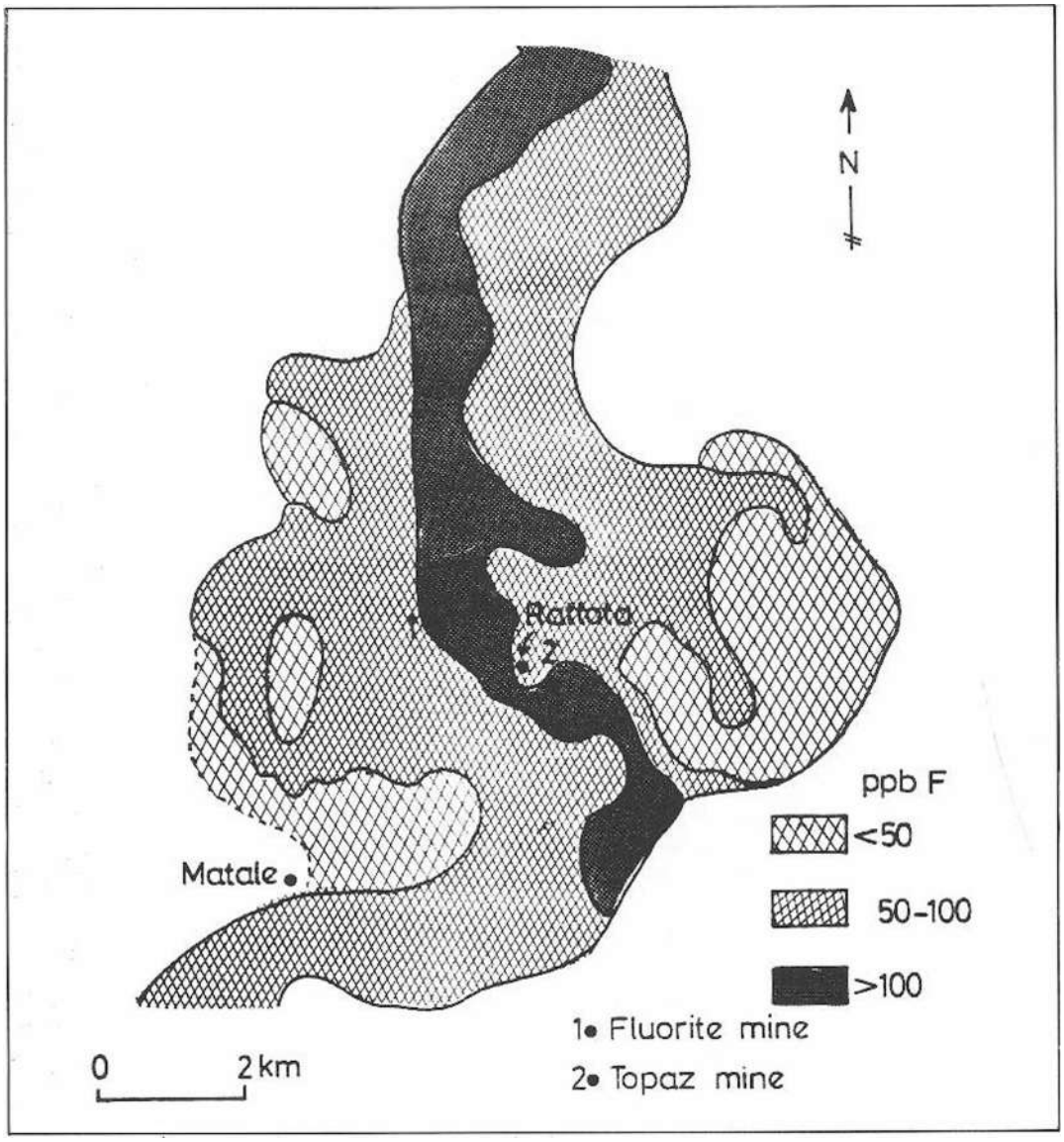

Fig. 2. Hydrogeochemical map of fluorine in ground water in the study area (values in ppb).

Table 3: Rare-earth element abundances in Ratnapura* and Elahera gem-bearing sediments. (ppm)

Sample no.	7*	15*	16*	19*	21*	29*	30*	31	35	37	38
La	79.00	136.82	105.69	145.70	99.85	79.24	53.01	55.10	66.86	52.02	49.53
Ce	215.00	246.18	198.74	392.00	178.11	158.00	251.95	127.00	164.60	124.00	113.00
Pr	19.40	28.05	21.95	39.00	18.42	–	14.33	14.00	–	13.06	13.25
Nd	67.80	107.68	93.05	119.00	61.20	66.45	42.91	48.40	59.21	44.71	41.00
Sm	13.00	17.29	16.71	21.76	9.57	11.80	7.83	9.00	9.43	8.59	6.55
Eu	2.21	2.55	3.23	2.76	0.96	2.29	1.34	1.70	1.39	1.24	1.47
Gd	13.00	18.45	21.40	21.00	7.52	–	–	9.00	7.40	–	–
Tb	1.60	2.00	2.54	2.61	1.07	1.33	1.00	1.30	1.11	1.18	1.04
Dy	8.94	11.55	13.80	15.50	5.66	7.94	–	7.50	5.13	5.43	6.60
Ho	2.11	2.40	3.55	3.00	1.09	–	1.00	1.50	1.08	1.24	1.34
Er	–	–	8.66	10.40	2.71	–	–	4.20	–	3.35	3.97
Tm	–	–	–	–	–	–	–	–	–	–	–
Yb	5.80	6.70	7.75	8.22	2.55	4.33	2.30	4.40	2.70	3.48	3.78
Lu	0.87	1.03	1.15	1.25	0.40	0.66	0.38	0.64	0.42	0.58	0.48

Fluorine is an element widely distributed in ore deposits and in the accessory minerals in igneous rocks. It is also known as an excellent mineralizer that accompanies a large number of metals, and it is this property of fluorine that makes it useful as an indicator in mineral exploration. As pointed out by Lalonde (1976), the mobilization of metal ions as metal-halide complexes in mineralizing solutions is an important aspect of most metallogenic theories and is supported by numerous analyses of fluid inclusions, connate brines and thermal waters. It is therefore logical for one to expect dispersion haloes of halogens around ore deposits, bearing in mind that fluorine is the most promising geochemical indicator of mineralization.

Recent geochemical surveys by the authors in the areas around Rattota and Matale in Sri Lanka known to be a mineralized zone indicated a clear potential for the use of fluorine geochemistry in gem exploration. Table 2 shows the fluoride-bearing minerals that were found in the area.

Nearly 200 groundwater samples were collected from the area concerned and analyzed for their fluoride concentrations. The data obtained were plotted on maps and the regions of anomalous fluoride concentrations highlighted (Figure 2). The dispersion haloes were clearly associated with the topaz and fluorite-bearing regions of the mineralized zone. It should however be emphasized that to obtain the best results one needs to integrate the geochemical survey with a heavy mineral survey of the stream sediments.

Rare-earth elements in gem-bearing sediments

The sedimentary gem deposits of Sri Lanka are well known for their wide variety of gemstones dominated by varieties of corundum, chrysoberyl, spinel, garnet, tourmaline, topaz, zircon etc. These gem-bearing sediments have been the subject of several studies (Katz, 1972; Silva, 1976; Dahanayake *et al*, 1980; Munasinghe and Dissanayake, 1981; Dissanayake and Nawaratne, 1981; Rupasinghe *et al* 1984). Overstreet (1967) had earlier commented on the abundance of monazite in placer deposits of Sri Lanka and emphasized their high Th and REE concentrations.

Rupasinghe and Dissanayake (1984a) made a detailed study of the rare-earth element abundance in the sedimentary gem deposits of Sri Lanka and observed their relatively high concentrations (Table 3). In general the Ratnapura type gem deposits are enriched in REE when compared to the REE of average shale (ZGI-TB – Flanagen, 1973). Table 4 shows the degree to which the gem sediments of Sri Lanka are enriched in REE as compared to shales. The averages for these sediments far exceed those determined for the post – Archean upper crust and the Archean exposed crust, the greatest enrichments being for La-Sm. Figure 3 illustrates the differences in the REE distributions in the two main gem fields of Sri Lanka.

In general, it could be concluded that the gem-bearing sediments of Sri Lanka are highly enriched in REE, particularly LREE, a negative Eu- anomaly being prominent. Rupasinghe and Dissanayake (1984b) assumed that the REE concentrations of the gem-bearing sediments are intimately associated with a charnockite-granite progenitor.

Geochemical mapping of rare-earth element anomalies in stream sediments could yield useful

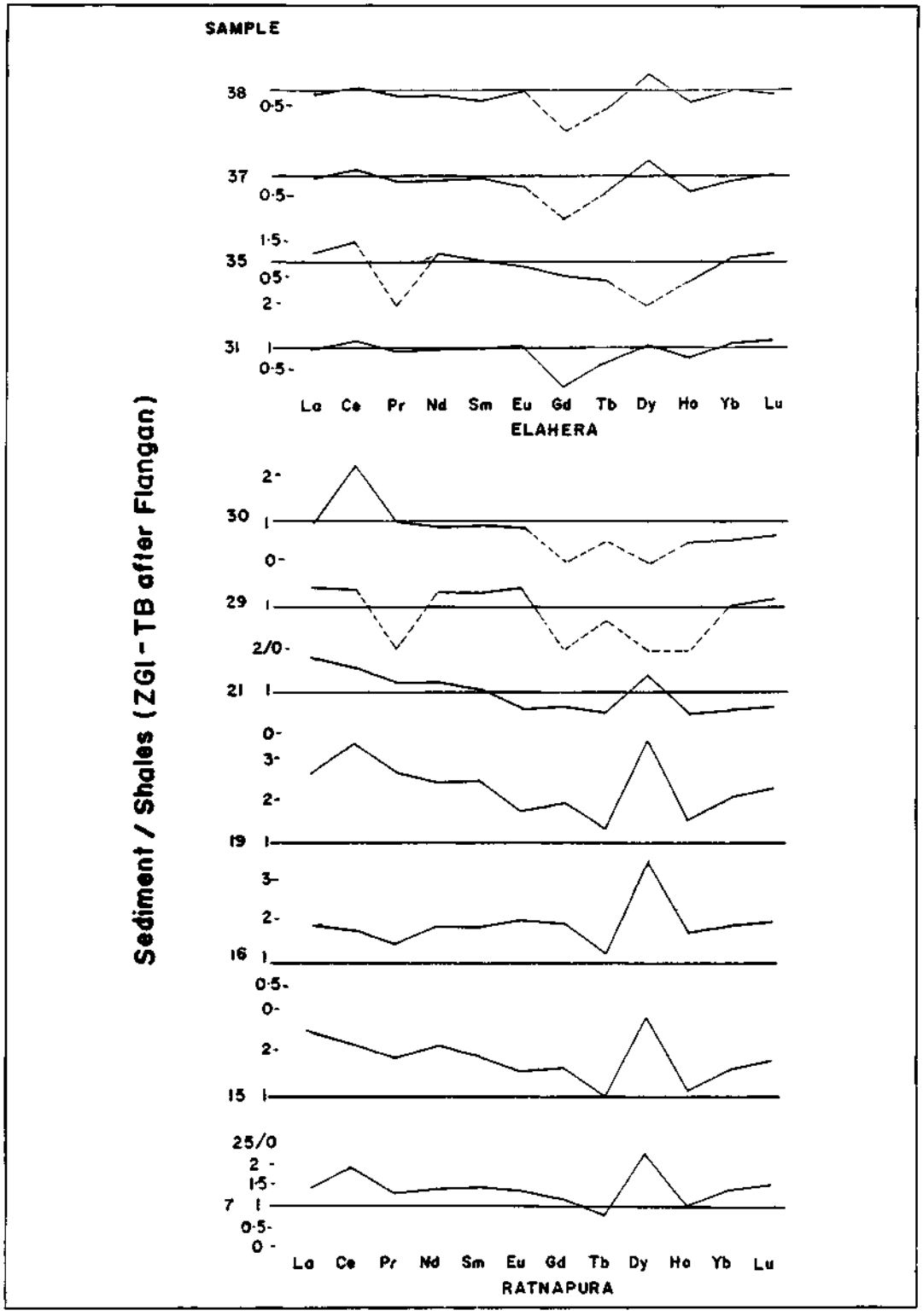

Fig. 3. The rare-earth element distributions in the two main gem fields of Sri Lanka.

Table 4: The REE contents of the gem-bearing sediments of Sri Lanka and of shales, chondrites and crustal averages ppm

	PAAS	ES	NASC	AAS	Chondrites	Post-Archean upper crust	Archean exposed crust	Gem sediments of Sri Lanka	
								Ratnapura	Elahera
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
La	38.0	41.1	32.0	12.6	0.367	30.0	12.6	99.90	55.87
Ce	80.0	81.3	73.0	26.8	0.957	64.0	26.8	234.28	132.15
Pr	8.9	10.4	7.9	3.1	0.137	7.1	3.1	20.16	9.85
Nd	32.0	40.1	33.0	13.0	0.711	26.0	13.0	79.73	48.33
Sm	5.6	7.3	5.7	2.8	0.231	4.5	2.8	13.99	8.39
Eu	1.1	1.5	1.2	0.9	0.087	0.9	0.9	2.19	1.45
Gd	4.7	6.0	5.2	2.9	0.306	3.8	2.8	11.24	4.10
Tb	0.8	1.0	0.9	0.5	0.058	0.6	0.5	1.74	1.16
Dy	4.4	–	5.8	2.9	0.381	3.5	2.9	9.06	6.17
Ho	1.0	1.2	1.0	0.6	0.085	0.8	0.6	1.89	1.29
Er	2.9	3.6	3.4	1.8	0.249	2.3	1.8	3.11	2.88
Tm	0.4	0.6	0.5	0.3	0.036	0.3	0.3	–	–
Yb	2.8	3.3	3.1	1.8	0.248	2.2	1.8	5.39	3.59
Lu	0.4	0.6	0.5	0.3	0.038	0.3	0.3	0.86	0.53
ΣREE	183.0	198.0	173.2	70.3	3.89	143.3	70.3	483.54	275.76
LaN/YbN	9.2	8.4	7.0	4.8	–	9.2	4.8	18.53	15.56

(1) = Post-Archean average Australian Shale (Nance and Taylor, 1976); (2) = European Paleozoic Shale composition (Haskin and Haskin, 1966); (3) = North American Shale Composite (post-Archean) (Haskin and Paster, 1979); (4) = Archean average Sedimentary rocks (Australia) (Taylor and McLennan, 1981a); (5) = chondrite-normalizing factors derived from abundances in Type 1 carbonaceous chondrite (Evensen et al., 1978; Mason, 1979); multiplied by 1.5 to allow for removal of volatiles; (6) = taken to be 20% lower than PAAS to account for low REE-bearing rocks such as carbonates and evaporites (after Taylor and McLennan, 1981b, 1982); (7) = Same as AAS; (8) = Ratnapura gem sediments; (9) = Elahera gem sediments.

indications leading to the discovery of associated gem mineralization.

Abundances of Y and Nb

The presence of minerals such as niobian rutile, perovskite, fergusonite etc in the gem-bearing sediments has resulted in the choice of the elements Y and Nb as pathfinders, particularly in view of the availability of more sensitive and accurate methods of chemical analysis. Dissanayake and Rupasinghe (1986) in their study of the abundances of Nb and Y in some gem-bearing sediments of Sri Lanka showed that Nb and Y are found at maximum concentrations of 229 ppm and 318 ppm respectively. The source rocks of Nb and Y were presumably rocks of the charnockite – granite association and related pegmatites found in the Highland Group of Sri Lanka. During weathering and sedimentation, Nb and Y enter the hydrolysates and get concentrated in the sediments. Apart from the gem minerals themselves, the sediments found in the gem fields of Ratnapura and Elahera contain abundant Nb and Y.

Goldschmidt (1958) noted that during the processes of weathering and sediment evolution, a small fraction of Nb remains in resistant minerals like cassiterite, columbite and rutile, and as such is arrested in residual sediments such as sands and sandstones. Most of the Nb, however, is fixed in hydrolysate sediments such as clays and bauxites along with Ti and Sr. The REE, Nb and Ta and economically useful elements such as Th and U are found in the hydrolysate group (Figure 4) and it is of interest to note that these elements are abundant in the gem-bearing sediments of the Highland and Southwest Groups of Sri Lanka. The fact that the

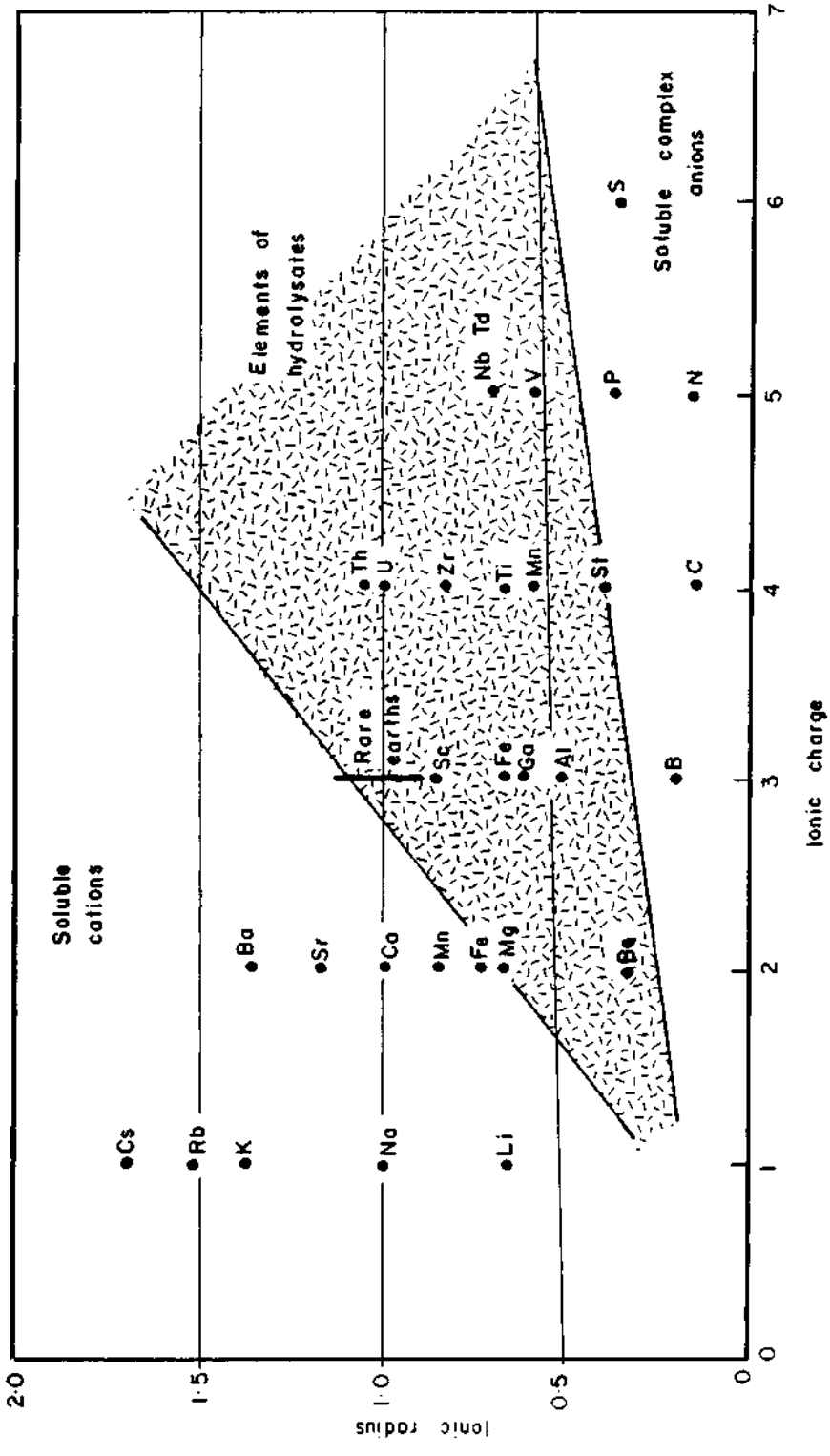

Fig. 4. Geochemical separation of some elements on the basis of their ionic potential (after Mason 1966).

Table 5: Strontium–rubidium ratios of the stream sediments in areas of varying gem potential

Areas	Number of samples analyzed	Nature of sediments	Ratio of Sr/Rb
Prominent gem bearing areas			
Opanayake (west)	05	gem pit sediments	
Opanayake (west)	10	stream sediments	0.2-1.0
Hattota Amuna	30	gem pit sediments &	0.4-1.75
Hattota Amuna	30	stream sediments	0.75-1.5
Areas of moderate potential for gemstones			
Bogawantalawa	60	–do–	0.75-2.5
Pubbiliya	04	gem pit sediments	2.0-3.0
Pubbiliya	42	stream sediments	3.0-5.0
Areas of low potential for gemstones			
Nilambe	55	–do–	0.75-2.0
Opanayake (north and east part)	80	–do–	3.0-7.0
Areas of very low potential for gemstones			
Ridigama (north to south east)	50	–do–	3.0-7.0
Ridigama (south west)	40	–do–	4.0-8.0
Area of no potential for gemstones			
Wariyapola	55	–do–	6.0-12.0

elements concerned are found in the hydrolysates makes them highly amenable to geochemical exploration of gem-bearing sediments. The element Y which has geochemical properties similar to those of rare-earth elements follows them in its geochemical transport mechanisms and hence is another useful pathfinder element. Niobium in particular is indicative of minerals such as titanomagnetite, ilmenite, sphene, zircon etc.

Thorium and uranium

In Kaikawala, a locality in the Southern Province of Sri Lanka, there is a moderately significant deposit of monazite. A clear density separation has resulted in the association of monazite with ilmenite and garnet. Sri Lanka's monazite is known to contain anomalously high concentrations of ThO_2 (approximately 10%) and this is one of the highest percentages found in monazite anywhere in the world. Associated with thorium is the element U which is also found in high concentrations (viz ~ 4000 ppm). La, Ce, Sm are also found in very high amounts (12.4%, 26%, 1.4% respectively). Geochemical analysis of these pathfinder elements will lead to such mineralogical associations indicating the existence of gem minerals such as garnets. The tracing of these heavy mineral concentrates leads to the source regions of the gem-bearing formations.

Use of the Sr/Rb ratio

Ratios of chemical elements are often useful in the delineation of geochemically distinct regions. In a recent study by the authors, it was observed that the Sr/Rb ratio in the stream sediments is a very useful guide in the demarcation of gem-bearing regions from those of non gem-bearing ones.

Stream sediment samples were collected at 200-400m intervals from the following regions:
(a) prominent gem-bearing areas
(b) areas of moderate gem potential
(c) areas of low gem potential
(d) areas of low to no gem potential and
(e) areas totally devoid of gems.

Vertical profile samples and 'illam' (gem-gravel) soil samples from several gem pits were also collected.

A total of 430 stream sediment samples from the above mentioned areas and 35 profile samples from 4 gem pits were collected and analyzed by X-ray fluorescence spectrometry.

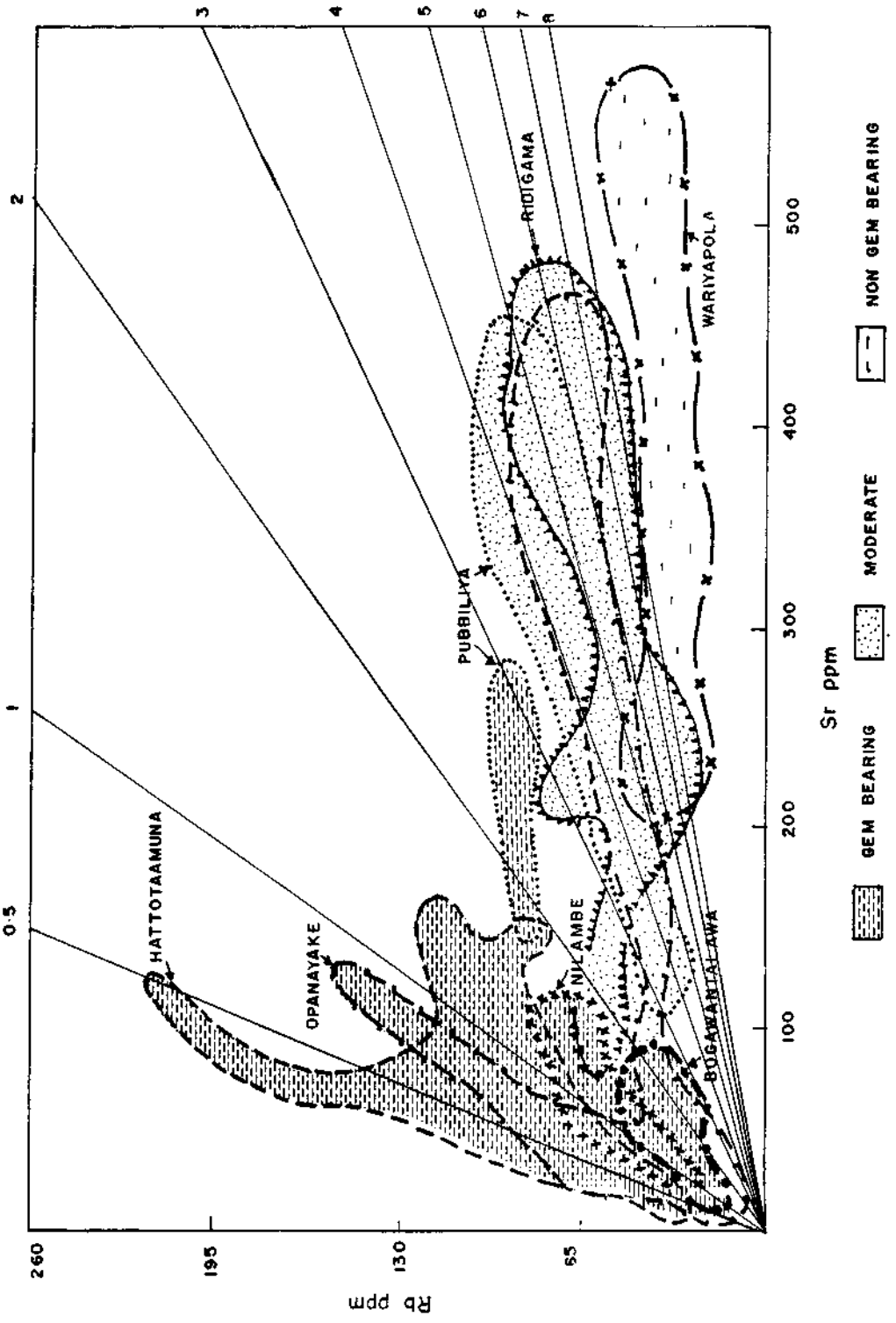

Fig. 5. Delineation of gem-bearing areas on the basis of the Sr/Rb ratios of stream sediments.

The analytical results showed that the concentrations of Sr and Rb in the stream sediments varied significantly between areas while within each subarea the variance was small. The more important observation made however was that the Sr/Rb ratio appeared to be characteristic for a particular area, bearing in mind that the gem deposits of Sri Lanka are located in a metamorphic terrain of granulite facies grade. In general, higher values for this ratio were found in non-gem bearing areas while the areas known for their high gem potential had lower ratios. Table 5 shows the results obtained from the geochemical survey. It is worthy of note that even within a particular gem-bearing region, certain locations, where for certain geological and structural reasons, no gems could be found, differed in their Sr/Rb ratios. In the Opanayake area, well known as a gem field in Sri Lanka, very low Sr/Rb ratios were observed for the gem-bearing part in the Southern and Western regions while higher Sr/Rb ratios were observed for the North-eastern part where no gem pits had been located (Figure 5). Most of the prominent gem-bearing locations had a Sr/Rb ratio of around 1 or less in the stream sediments and this particular value could be used as a rough guide in the delineation of target areas for detailed gem exploration.

Conclusions

Gem minerals concentrated as placer deposits are very often associated with other rarer minerals and which have a special geochemistry. The identification of these unique geochemical anomalies can lead to the delineation of target areas most suitable for gem exploration. Elements such as thorium, uranium, beryllium, fluorine, tantalum, niobium, yttrium and the rare-earth elements are examples of pathfinder elements amenable to geochemical exploration for gem deposits.

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'The most unkindest cut of all'* - recutting the Koh-i-Nûr

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London

It is the author's hope that this short paper may resolve at least some of Alec Farn's confusion over the recutting of the Koh-i-Nûr diamond (Letter to the Editor, *Journal of Gemmology*, 23, 2, 120).

The recutting of the stone, by order of Queen Victoria, was instigated by Prince Albert after consultations with, amongst others, Sir David Brewster, Professor Tennant and the Rev. W. Mitchell (the latter two of King's College, London). The intention was to produce a more brilliant stone, with what seems now to be an appalling disregard for the history of this famous diamond.

It was carried out in 1852 on Garrard's Panton Street premises. The work was entrusted to Coster of Amsterdam. Guillaume Coster came to London with his chief cutter Voorzanger and an assistant, Fedder.

The *Illustrated London News* depicted the Duke of Wellington placing the stone on the scaife for the cutting of the first new facet on Friday 16 July. Several authorities, however, credit the Prince Consort with performing this ceremony. It is likely that both gentlemen were present. The recutting was completed on 7 September after 38 twelve hour days of cutting. The reported cost was £8,000.

Emanuel in 1865 (*Diamonds and Precious Stones*) gives the recut weight as 106$^{1}/_{16}$ carats. Streeter in 1882 (*Great Diamonds of the World*) repeats this, adding that the stone had been reduced by exactly 80 carats from an original weight of 186$^{1}/_{16}$. These figures are repeated by Davenport in 1897 (*The English Regalia*), and by many later authorities.

The pre-metric carat in use in England at the time appears to have equalled 0.205409 grams. 106$^{1}/_{16}$ old carats converts to 108.93 metric carats. This, as Alec Farn points out, is stated as the recut weight in numerous books.

However, W. Pole (an associate of Professor Tennant) in 1858 (*Transactions of the London and Middlesex Archaeological Society*, Vol. 1) gives weights of 186 and 102$^{1}/_{4}$ carats. Dieulafait in 1871 (*Diamants et Pierres Précieuses*) gives a recut weight of 102$^{3}/_{4}$ with which Professor Church in 1882 (*Precious Stones*) agrees. This latter figure converts to 105.53 metric carats. This is only seven points less than the known current weight of 105.60 metric carats.

I would, therefore, suggest that the recut weight may, with reasonable confidence, be stated in old English carats by converting the modern figure. This gives a weight of 102$^{13}/_{16}$ old English carats.

The much quoted weight of 108.93 metric carats seems to represent a classic example of spurious information in one book being assiduously repeated by later authors, with no referral to original sources. I have also found numerous other spurious weights mentioned in supposedly authoritative books, ranging from 82$^{3}/_{4}$ carats in *A Popular Treatise on Gems by Feuchtwanger* in 1859 (who says that the original weight of 186$^{1}/_{2}$ carats was 'rough') to 122$^{3}/_{4}$ carats in the 1874 English edition of *Diamonds & Precious Stones* by Dieulafait.

The author would be most grateful if any readers could throw further light onto this subject.

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* Julius Caesar, Act III, Scene II. - Ed.

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Book Reviews

BARIAND, P., POIROT, J.-P., 1992. *The Larousse Encyclopedia of Precious Gems.* Van Nostrand Reinhold, New York. pp. vii, 248, illus. in colour. £37.95.

A translation of Larousse des pierres précieuses, published in 1985, the book is translated by Emmanuel Fritsch and contains work by Michel Duchamp on seals, cylinders, intaglios and cameos. The book is pleasantly and sometimes very well illustrated, almost entirely in colour, and the text on the whole is accurate and balanced. There are many instances, however, of uneven treatment of subject, with some references unexplained. Colour centres are mentioned several times but I could find no section expanding the phrase although there is a short and generally unhelpful glossary which includes amphibole but not pyroxene and notes 'secondary' in a surprisingly recondite sense as an attribute of electrical transformers in a text in which the reader might expect to find an explanation of secondary mineralization!

The glossary is so amateurishly compiled that early reference to it prepares the user for equal disasters in the main text. Here are some of them: the use (in an English translation) of almandite; rubicelle as a main entry not referred to spinel (and it should not be there anyway); subscripts denoting the different rays refracted by a crystal have missed the eye of the translator and are presented with the French initials; chrysolite as a main entry, the text of which wanders over several species - this is confusing and would better have been omitted; choice of species is capricious with perovskite (has no gemmological interest) included. Lame excuses are provided in a brief review of nomenclature for the use of outdated names. It is a great pity that such an undeniably attractive book should introduce problems into a subject at this elementary level; readers will begin their study of gemstones with much information they will later have to abandon. Referral to professional staff at a national or major university museum would have helped raise the standard of the text.

M.O'D.

BENESCH, F., 1991. *Der Turmalin: eine Monographie. 2 durchgesehene und verbesserte Auflage.* Urachhaus, Stuttgart. pp. 380, illus. in black-and-white and in colour. DM296.00.

With a size of 50 x 31cm and a weight (with its slip case) of 4lb this book impresses before the pages are turned. The contents open with a section dealing with references to tourmaline in early books (some of which are reproduced) and continues with a discussion of species nomenclature. The remainder of this preliminary section deals with the different types of crystals and crystal coloration. Then comes a section of 151 pages in all of which (save one) tourmaline crystals are shown in colour photographs. I have seen no mineral and certainly no gemstone book which comes anywhere near the magnificence shown here, an effect enhanced by the superb quality of the colour and by the size of the pages. Though captions on the plates themselves are limited to country names, the following section of text expands on this - wisely, in my opinion, since the effect of the plates would have been diminished by several lines of text.

The second part of the book begins on page 213 with details of geochemistry and paragenesis; this is followed by a section of tourmaline crystallography in which pages from Goldschmidt's *Atlas der Krystallformen* are reproduced and then by a more general discussion of the resemblances between the crystal symmetry of tourmaline compared to that shown by other natural forms, particularly those of plants.

This speculative part of the text is followed by 15 coloured plates of parti-coloured tourmaline crystals from Madagascar; these have been painted by Christiane Lesch with explanations by Bernhard Wihrmann. These are beautifully portrayed.

The text then continues with the place of tourmaline in religious and apocalyptic literature. I am unable to comment on this. There are further reproductions of title pages and sections of text from older scientific books to supplement the points made in this part of the text. There is a

useful alphabetical table of names used for tourmaline varieties here and the whole section has its own short bibliography.

Gemmologists will find the section on tourmaline occurrence very useful; it occupies 35 pages and is accompanied by a double-spread map. The book ends with a large general bibliography.

For the size of the book the text, though useful and interesting, is not outstanding, reflecting perhaps the author's preoccupation with non-scientific or anthropological topics. Nonetheless the plates are so magnificent that the book would grace many a museum display or teaching exhibit. Opportunities for this may be limited for non-German gemmologists who may have failed to see the publishers' pre-publication advertisements - almost as spectacular as the book. The first edition was sold out in so short a time that I was offered the second edition as long ago as two months after the exhaustion of the first, in 1990. I am now told that the second edition also has a short print- run and that there is unlikely to be a third. By the time you read this review copies may be unobtainable. M.O'D.

BLAUER, E., 1991. *Contemporary American jewelry design.* Van Nostrand Reinhold, New York. pp. x, 198, illus. in colour. £29.00.

The book introduces American studio goldsmithing with very useful details of the show system and descriptions of the work of a number of major craftsmen and women. Most of the pieces illustrated are made of various precious and other metals, relatively few being gem-set but nonetheless readers will find the book a painless introduction to an aspect of jewellery that may be a little unfamiliar. Appendices list major galleries, craft schools, teachers, organizations and publications. M.O'D.

BULLIS, D., 1990. *Crystals, the science, mysteries and lore.* Crescent Books, New York. pp. 128, illus. in colour. £6.99.

This is an attractively produced book whose text needs to be read with caution! Leaving the mysteries and lore aside (with an open mind) the photographs of crystals are good. M.O'D.

CARSWELL, D.A. (Ed.), 1990. *Eclogite facies rocks.* Glasgow, Blackie. pp. xv, 396, illus. in black-and-white. Approximately £60.00.

As far back as Haüy in 1822 eclogite was assumed to be a rock composed mainly of garnet and clinopyroxene though since that time there has been a wide diversity of interpretations with some emphasis placed upon the characterization of eclogite by the presence more specifically of omphacite or chloromelanite clinopyroxenes with high Al^{VI} and Na contents and by pyrope rich garnets. From the standpoint of the diamond prospector eclogites are well worthy of study since diamond occurs as a primary phase. Eclogitic diamonds are usually sharp-edged octahedra compared with the rounder diamonds found in kimberlite. Other primary phase minerals include graphite, amphibole, rutile and sphene; these, while not of a significant gem importance in this context, are useful indicators of the chemical composition of particular rocks.

Important observations of this kind, of interest to the geologist/gemmologist, occur throughout the book, which is a multi-author compilation of papers, beginning with definitions and continuing with studies of eclogite facies mineral parageneses with experimental studies, surveys of mineral barometry and thermometry, the role of kinetics, isotopic systems and geochronology, occurrence and stability conditions of low- and medium-temperature eclogites from different locations. The points mentioned at the beginning of the review are expanded in the final section of the book, a study of high-temperature and ultra high-pressure eclogites. M.O'D.

CAVEY, C., 1992. *Gems & jewels fact and fable.* Studio Editions Ltd, London. pp. 144, illus. in colour and black-and-white. £14.95.

Christopher Cavey was commissioned to write this work by a firm specializing in art publications rather than scientific ones. His own great interests are in fine mineral specimens, hardstone carvings and antique intaglio seals, as well as the main interest of gemmology. He owns a specialized library of antique and modern books dealing with such things.

The publishers required a book emphasizing the art side of gems and jewels without the scientific bias towards gemmology. Mr Cavey has succeeded admirably in complying with their request in an inexpensive large-format book, and has given us a volume containing 'Over 100 colour illustrations' (I counted 147) and many more in monochrome, the vast majority of which will be new to the reader.

Many gem groups and other pictures are the work of Alan Jobbins, our Editor, and lately Curator of Minerals and Gemstones at the former Geological Survey Museum in London. Some excellent pictures of minerals are from Brian Lloyd of Gregory Bottley & Lloyd. Others are of quite wonderful hardstone carvings by

Gerhard Dreher of Idar Oberstein, Germany, and historic carvings by the late Alfred Pocock of London, who was associated with Faberge's London Manager, H.C. Bainbridge (these printed by courtesy of Mrs W. Bottley); modern jewellery by courtesy of Patrick Aldridge of Gemcut SA, Geneva, and a very considerable number of pictures of intaglios, cameos and other unique items taken by the author himself, together with many black-and-white reproductions from works in his library of associated books.

In a few cases the insistence by the publishers on black backgrounds to some of the colour plates has resulted in needless darkening of detail. But by far the greater part of the illustrations are exceptionally well reproduced and beyond criticism. The text frequently refers the reader to specialist books on various subjects and a reasonably comprehensive bibliography facilitates such reference. The text is also concerned with some of the early history and myth of gem lore, and from time to time refers to gem and crystal healing, apparently one of the many 'alternative medical' procedures of today, but does not attempt to describe this.

This is an exceptionally well illustrated book on the gem aspects which it covers and has been produced at a very reasonable price when compared with other similar volumes recently published. It can be recommended accordingly.

R.K.M.

CODY, A., 1991. *Australian precious opal: a guide book for professionals*. Andrew Cody Pty Ltd, Melbourne. pp. 65, illus. in colour. Price on application.

This is one of the best-produced and attractive opal books I have seen, with a very high standard of colour reproduction. Brief but clear notes on the history, geology and mineralogy of opal precede sections which depict different qualities of cut black and white stones. The plates show enough stones for some idea of grading to be obtained and there are several illustrations of major named stones. There are notes on patterning and on composites and it is good to see a diminution of trade names, the over-use of which has spoilt some earlier opal books. There is a useful glossary and some notes on cutting. A double-page colour spread indicates the main Australian opal fields. This is a good book for the gemmologist and excellent for the customer. M.O'D.

CRAM, L., 1991. *Beautiful Queensland opal*. Robert Brown & Associates, Buranda, Queensland. pp. 28, illus. in colour. Price on application.

This beautiful book gives a stunning introduction to the types of opal characteristic of the Queensland fields. History and anecdotes of the fields take second place to the colour photographs but the text is well worth reading and takes the reader over the whole history of Queensland opal production. As might be expected, considerable attention is paid to boulder opal and to the famous Yowah field. All opal lovers should have this book. M.O'D.

EGGER, G., 1988. *Generations of jewelry from the 15th through the 20th century*. Schiffer Publishing, West Chester, Pennsylvania. pp. 219, illus. in black-and-white and in colour. £49.95.

The book is a translation of *Bürgerlicher Schmuck*, first published in 1984. The English title does not accurately reflect the main argument of the text, which deals in fact with the development of the middle classes in Europe and the parallel development of their jewellery. Thus, major 'royal' pieces are excluded from the survey which extends from the fifteenth century to the Art Deco period. The standard of reproduction is fair; there is a useful bibliography. As with some other books of this type, the text consists, in the main, of captions to photographs. M.O'D.

FARNETI CERA, D. (Ed.), 1992. *Jewels of fantasy: costume jewelry of the 20th century*. Abrams, New York. pp. 408, illus. in colour. Approximately £38.00.

This is a translation of *I gioielli della fantasia* first published in 1991. It is a catalogue of a travelling exhibition of 20th century costume jewellery with accompanying essays by various hands. Sections cover the new century and Art Nouveau (1900-1915): the opulence of the poor look (France and Germany 1900-1950): flights of fancy (France 1920-1939): the luxury of freedom (USA 1935-1968): bijoux de culture (France 1927-1968): from the artisan's workshop to the international style (Italy 1945-1970): the return of the ornament, 1965 to the present. Technical essays deal with the history of the manufacture of glass stones and costume jewellery in Bohemia: the history of the production of ornamental jewels in Tyrol; and the dominance of Providence, Rhode Island and the contribution of electroplating. There is a glossary and a brief technical guide.

This is a splendid book with a very lucid text and excellent quality of illustration. The weight may have daunted those who obtained their copies before visiting the exhibition and who took them round it; I found it better to concentrate on the exhibits and recollect their undoubted beauty in the tranquillity of my office! Do not be put off, however; this is a serious and major study of an aspect of jewellery which has had insufficient treatment hitherto.

M.O'D.

JARGSTORF, S., 1991. *Glass in jewelry.* Schiffer Publishing, West Chester, Pennsylvania. pp. 174, illus. in colour. £29.95.

This is a very useful and attractively produced monograph of the ornamental use of glass, with particular reference to European glass work. Chapters cover bead and gem manufacture in Murano, Bavaria, Thuringia, Bohemia and Silesia; techniques of bead manufacture; faceted glass; glass cameos and incrustations, millefiori and mosaic jewellery and aventurine jewellery. There is a chapter on changing fashions in glass jewellery, a value guide and an index.

The standard of production is quite good and the book is one of the best I have seen in recent years in this field. The subject is a large one and no doubt the book could be doubled in size without covering a great deal more in the area. Interest in glass is increasing as prices rise for natural gemstones and what is cheap today may well be sought after fifty years on. M.O'D.

LIMA-DE-FARIA, J. (Ed.), 1990. *Historical atlas of crystallography.* Kluwer for the International Union of Crystallography, Dordrecht. pp. ix, 158, illus. in black-and-white and in colour. £20.00.

A scheme of time-maps is used to give a continuous comparative chronology of geometrical, physical, chemical and structure determination crystallography. Chapters accompanying the maps fill out the picture and contain very useful bibliographies. An interesting section of the book illustrates the title pages of many seminal works and there is a general bibliography and author and subject indexes. The book will be useful for many and vital for some, since the information will be hard to gather from the multiple sources covered by the production team. M.O'D.

LINTON, T., 1992. *The effective use of gemmological instruments.* 2nd edn. Wellington Point, Queensland. pp. 60, illus. in black-and-white. Price on application.

An excellent survey of currently available and simple gem testing instruments with worked-out examples of how they can best be used. Short lists of references accompany each chapter and there are notes on the commercial exploitation of gem testing practices. M.O'D.

NEWMAN, R., 1991. *The diamond ring buying guide.* 2nd edn. International Jewelry Publications, Los Angeles. pp. 151, illus. in black-and-white. US 12.95.

This is an excellent and sensible guide which disclaims any element of gemmological teaching, concentrating instead on providing hints for the jeweller and customer on the various signs to look for in a diamond if it is to be a reasonable purchase. Nonetheless, a good deal of gemmologically useful information has crept in, particularly cutting and on diamond simulants and composites. As the book covers the whole ring, not just the stone, it includes a discussion on the kind of precious metals used and how to test them.

M.O'D.

POUGH, F.H., 1991. *Peterson first guides-rocks and minerals.* Houghton Mifflin, Boston. pp. 128, illus. in colour. £3.99.

This is an attractive pocket guide which really fits the pocket. After a very brief account of geological processes over 120 examples of the commoner minerals are illustrated with brief though useful descriptions. M.O'D.

READ, PETER, 1992. *Diamond mine* [a novel]. The Book Guild, Lewes. pp. 188. £11.95.

Reviews of works of imagination are rare in these columns but the present book is worth noticing on account of the various aspects of diamond mining and selling which form part of the simple and dramatic plot. The book moves quickly and smoothly and while the principal characters might not be on many dinner party lists they are all very well in a book. I liked the idea of ..., no, I must not give away details of the plot!. M.O'D.

SCHIFFER, N.N., 1988. *Costume jewelry: the fun of collecting.* Schiffer Publishing, West Chester, Pennsylvania. pp. 176, illus. in colour. £26.95.

Interest in costume jewellery has always been considerable but there seems to have been a heightening of the interest in the past few years. No doubt this is due to world-wide recessions and the generally high prices asked for natural

stones and precious metals. The present book which consists in the main of captioned photographs gives a useful overview of the type of cheaper jewellery that may attract the collector. For this reason the text is arranged by usage: thus we have bracelets, belts, buckles and buttons, earrings, head ornaments, necklaces, pins, rings, matching sets; the book concludes with a list of marks, a price guide and an index. This is a useful and reasonably-priced book with a good deal of interesting detail. M.O'D.

SMITH, J.R., 1991. *A guide to understanding crystallography*. Crystallography, Box 12, Fairfax, Virginia 22030, USA. pp. 176, text figures. Price on application.

This handy-sized ring-bound book introduces basic crystallography, or rather crystal description in easily understood terms, and forms a useful guide for students and others faced with the need to describe crystals. Many concepts hitherto found essential for inclusion in any book about crystals are omitted and the text seems none the worse; there are a few misprints (the worst I have seen is Bravis for Bravais) but the sense is not affected and the book can be recommended. Publication was under the auspices of the Rochester Mineralogical Symposium. Text figures illustrate all systems and most if not all of the occupied classes; there are introductions to Miller indices and to Herman-Mauguin symbols. At the end is a short glossary and several cut-out crystals whose outlines would need to be transferred to a stouter medium if adequate models are to be made. M.O'D.

WILKS, JOHN, WILKS, EILEEN, 1991. *Properties and Application of Diamond*. Butterworth/Heinemann, Oxford. pp. 525, bibl., index, 417 illustrations comprising tables, diagrams, graphs, photographs, photomicrographs. £90.00.

This is a most useful and comprehensive reference book about today's diamond technology.

After an introduction, the book is divided into three parts, dealing with structure, mechanical properties and application and wear respectively. The introduction deals with the genesis of diamond; some mining methods are briefly mentioned; there is an easily understandable description of various methods of synthesis, the growing of diamond films and the production of PCD (sintered polycrystalline diamonds).

The five chapters on the structure of diamond (impurities, optical absorption and colour, luminescence, morphology and geometric defects in the lattice) and the six chapters on mechanical properties (strength and fracture, plastic deformation, polishing and shaping, mechanical differences between diamonds, friction and PCD) are the most detailed and the most valuable part of the book for the gemmologist. The morphology is particularly well explained; lonsdaleite, however, is not mentioned. All aspects of the manufacturing process are described in detail, perhaps the use of lasers might have been enlarged on. The third part of the book provides information on the various applications of industrial diamond in turning, boring, milling, grinding, sawing and drilling. The authors incorporate recent data on wear and surface characteristics of the diamond and the effect on the workpiece.

The subject is well and clearly presented. Scientific data (such as the growth mode of synthetic diamonds or dislocations in the lattice) are easily understandable and should be of great help to the student. It seems a pity that in so comprehensive a work only just over two pages are devoted to diamond as a gem material. A diagram shows the Tolkowsky cut, no other cut is described, but the existence of other cuts is mentioned.

Each chapter closes with its own full bibliography, a recommendable time-saving device for the researcher. The text itself includes many references to literature.

Drs John and Eileen Wilks have produced an invaluable handbook for anyone interested in any aspect of the diamond industry. E.S.

Chinese jade. Spink & Son Ltd, London, 1991. pp. 84, illus. in colour. £10.00.

164 jade artefacts forming an important private collection are briefly described and well illustrated in a sale catalogue in which prices range up to £10,000. There is a short glossary, introductory matter and a bibliography. Entries include references. M.O'D.

Chinese jewellery, accessories and glass. Spink & Son Ltd, London, 1991. pp. 83, illus. in colour. £10.00.

This well-illustrated sale catalogue includes jade, gold and turquoise jewellery as well as snuff bottles and various artefacts in glass. The descriptions include references where appropriate. M.O'D.

Proceedings of The Gemmological Association and Gem Testing Laboratory of Great Britain and Notices

NEWS OF FELLOWS

On 27 May 1992 at the Crown Hotel, Blandford Forum, Dorset, **Peter Read** gave a talk on researching his novel *Diamond Mine* to the Wessex Branch of the National Association of Goldsmiths. The talk included a series of slides showing mining operations in the Premier, Finsch and CDM mines, as featured in the novel.

Launch of the book included an interview on 28 May with BBC presenter Sally Taylor on Solent Radio, Southampton, in which Peter publicised the courses of the GAGTL, and on 30 May an 'author signing' event at the Athena bookshop, Old Christchurch Road, Bournemouth.

During the period 9 to 11 June 1992 **Michael O'Donoghue** and **Peter Read**, with Roy Huddlestone, conducted a course for students intending to sit the GAGTL examinations in 1992.

MEMBERS' MEETINGS

London

On 13 May 1992 at the City Conference Centre, Mark Lane, London EC3, Dr Roger Harding, Dr J.W. Harris and M. Issacharoff gave illustrated lectures on the gemstone deposits and trade in Australia.

On 9 June 1992 at the City Conference Centre, Alan Hodgkinson and Harry Levy gave an illustrated lecture on the gemstone deposits and trade in South East Asia.

Midlands Branch

On 24 April 1992 at Dr Johnson House, Bull Street, Birmingham, the Annual General Meeting of the Branch was held at which David Larcher, FGA, was re-elected Chairman and Gwyneth Green elected Secretary.

North West Branch

On 20 May 1992 at Church House, Hanover Street, Liverpool 1, Nigel Israel, FGA, gave a talk entitled 'Historical Aspects and valuations'.

On 17 June at Church House an 'Exchange and Mart' evening was held, when members had the chance to buy and sell books, crystals and instruments.

GIFTS TO THE GAGTL

The GAGTL is grateful to the following for their gifts:

Ameena Kaleel, FGA, D Gem G, of Mount Lavinia, Sri Lanka, for 93 crystal specimens, selected for their crystal shapes, spectra or inclusions, donated for teaching purposes;

Dominic Mok, FGA, of the Asian Gemmological Laboratory, Hong Kong, for specimens of bleached and resin-impregnated jadeites;

Hong Kong gemmology lecturer Memory Stather, FGA, for several fancy cut diamond simulants for use in the DGA Practical Workshops.

MEETINGS OF THE COUNCIL OF MANAGEMENT

At a meeting of the Council of Management held on 15 April 1992 at 27 Greville Street, London EC1N 8SU, the business transacted included the election to membership of the following:

Fellowship

Senaratne, Amal C., Dehiwela, Sri Lanka. D.1986

Ordinary Membership

Grafin Von Zech-Burkersroda, Euphemie, Reutlingen, Germany.

Ku, Sarah J., Tuen Mun (NT), Hong Kong.

Lambert, Jonathan, Margate.

At a meeting of the Council of Management held on 20 May 1992 at Chapel House, Hatton Place, London EC1N 8RX, the business transacted included the election to membership of the following:

FORTHCOMING MEETINGS

TRADE LUNCHEON

This year's Trade Luncheon, to which all members of GAGTL are invited, will be held on Tuesday 22 September 1992 at the Ironmongers' Hall, London EC2. Tickets for this prestigious event will be £35.00 plus VAT (inclusive of wine). For reservations please contact: Miss L. Shreeves, GAGTL, 27 Greville Street, London EC1N 8SU. Telephone: 071-404 3334.

1992 ANNUAL CONFERENCE AND PRESENTATION OF AWARDS

The second GAGTL Annual Conference is to be held on Sunday 8 and Monday 9 November, at the Great Western Royal Hotel, Paddington, London, with a full programme of lectures and displays.

The Conference will be followed on the evening of Monday 9 November by the Presentation of Awards which will take place at Goldsmiths' Hall, Foster Lane, London EC2. This year the awards will be presented by Dr Kurt Nassau.

Full details of the Conference and Presentation of Awards will be circulated to members nearer the time.

MEMBERS' MEETINGS

London

On 24 November 1992 at the City Conference Centre, Mark Lane, London EC3R 7JN, lectures will be given on the gemstone deposits of Africa and the trade associated with them. Admission by ticket only, at a cost of £5.00 for GAGTL members, £10.00 a member and a guest, and £8.00 for non-members. For further details and tickets contact the GAGTL.

Midlands Branch

Meetings will be held at Dr Johnson House, Bull Street, Birmingham. Further details from Gwyn Green on 021-440 1428 or 021-445 5359.

25 September 1992	Bring and Buy evening. Sale of books, specimens and gem testing instruments.
1 November 1992	Annual Practical Gemmology Seminar, to be held at the Cobden Hotel, Birmingham. Tickets £18.00 from David Larcher, Midlands Branch Chairman, c/o GAGTL.
27 November 1992	Nigel Dunn. 'Jewellery through the ages'
27 January 1993	Edgar Taylor. 'Fossicking in Wales'
26 February 1993	Robert Campbell-Legg. 'The art of the engraver'
26 March 1993	Peggy Stock. 'Crystal healing'
30 April 1993	AGM and filmshow

North West Branch

Meetings to be held at Church House, Hanover Street, Liverpool 1. Further details from Irene Knight on 051- 924 3103.

16 September 1992	Adrian Klein. 'Emerald'
21 October 1992	Dr Jamie Nelson. 'Optical attributes of a diamond'
18 November 1992	Annual General Meeting

Members having gained their Diploma in Gemmology or the Gem Diamond Diploma (FGA or DGA) may now apply for use of the Coat of Arms on their stationery or within advertisments.

Laboratory members are also invited to apply for use of the Laboratory Logo.

It is still a requirement of GAGTL, in accordance with the Bye Laws, that written permission be granted by the Council of Management before use.

Members interested in further information please contact:

Linda Shreeves

Gemmological Association and Gem Testing Laboratory of Great Britain

♦ 27 Greville street, (Saffron Hill Entrance), London EC1N 8SU ♦

Tel: (071) 404 3334 Fax: (071) 404 8843

Fellowship
Flint, Sara E., Leeds. D.1991

Ordinary Membership
Almudallal, Mohammad, Abu Dhabi, UAE.
Boxsey, Pauline M., Eton.
Dansereau, Eva M., Anola Manitoba, Canada.
Fricker, Rowena, Dulwich, SA, Australia.
Jones, Michael, Bournemouth.
Mifsud, Ivan, Sliema, Malta.
Nilaratanakul, Chiraphong, Bangkok, Thailand.
Pash, A., London.

MEETING OF THE TRADE LIAISON COMMITTEE

At a meeting of the Trade Liaison Committee held on 30 April 1992 at 100 Hatton Garden, London EC1 the business transacted included election to membership of the following:

Ordinary Laboratory Member
Laurick Jewellery Ltd, 17 Station Bridge, Harrogate, Yorks HG1 1SP.

THE CANADIAN GEMMOLOGICAL ASSOCIATION

On 24 and 25 October 1992 the Gem Conference '92 will be presented by the Canadian Gemmological Association at the Park Plaza Hotel in Toronto, Canada. Presentations and workshops covering a wide range of topics relevant to the jewellery and gem trade will be included.

For further information contact the CGA office on (416) 603-0451.

CORRIGENDA

On p.90 *above*, Fig. 2, for '6000 kg' read '600 kg'

On p.91 *above*, second column, line 12, insert 'and other' after 'iron'

On p.96 *above*, Fig. 1 was omitted; it is included with this issue as a separate sheet so that it may be inserted in the correct place

PEARL CONFERENCE

The Society of Jewellery Historians will be holding a one-day Conference on Saturday 7 November 1992 at the Society of Antiquaries, Burlington House, London W1, on the subject of 'The history and use of pearls'. A variety of aspects will be covered ranging from sources and use in the ancient and medieval world to modern cultured pearls and pearl treatments and testing.

The cost of the day will be £25.00 for SJH members and their guests (limit one guest per member), and £40.00 for non-members. If you would like to attend, please send your name and address (plus stamped, self-addressed envelope if in the UK) to Nigel Israel, 14 Ryfold Road, Wimbledon Park, London SW19 8BZ. Please state whether you are a member of the Society of Jewellery Historians.

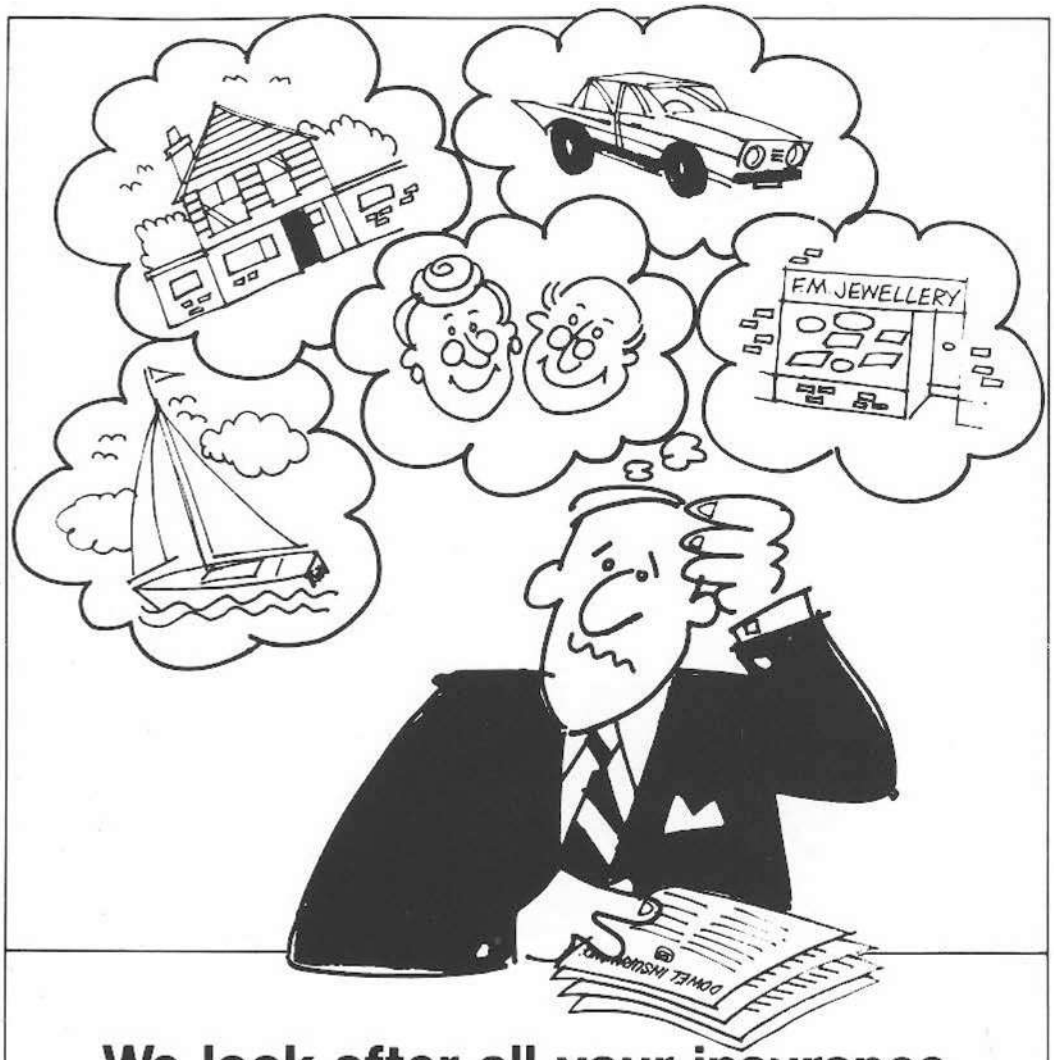

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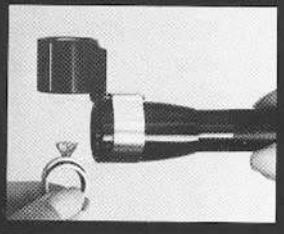

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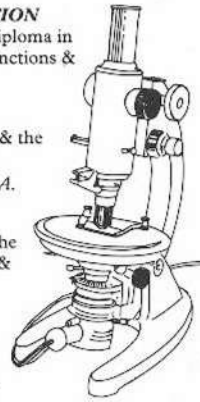

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Papers should be submitted in duplicate on A4 paper. They should be typed with double line spacing with ample margins of at least 25mm all round. The title should be as brief as is consistent with clear indication of the content of the paper. It should be followed by the names (with initials) of the authors and by their addresses. A short abstract of 50–100 words should be provided. Papers may be of any length, but long papers of more than 10 000 words (unless capable of division into parts or of exceptional importance) are unlikely to be acceptable, whereas a short paper of 400–500 words may achieve early publication.

Twenty five copies of individual papers are provided on request free of charge; additional copies may be supplied, but they must be ordered at first proof stage or earlier.

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The Journal of Gemmology

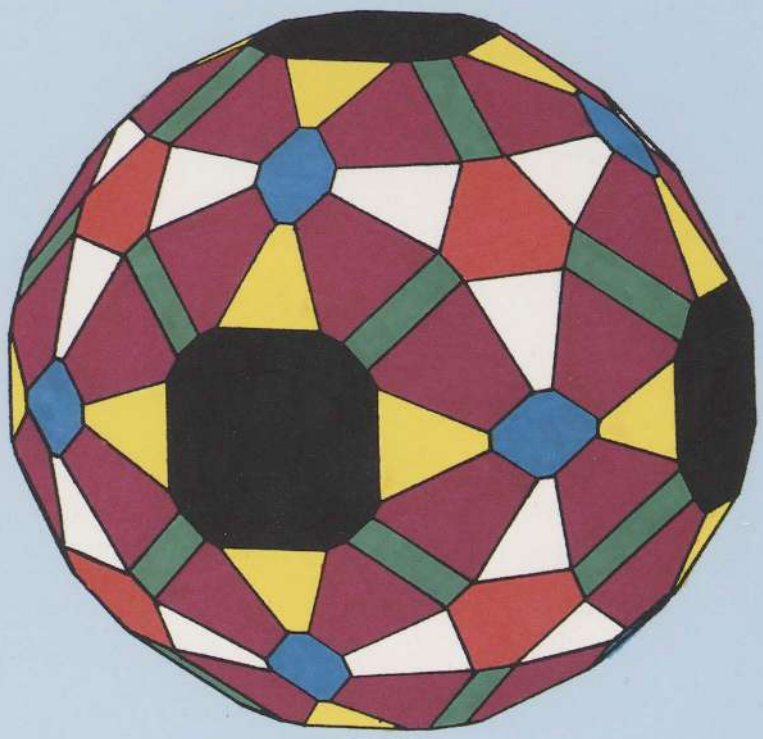

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Cover Picture

A 146-faced 'sphere' formed by the combination of the cube, octahedron, rhombdodecahedron, trisoctahedron, hexoctahedron, icositetrahedron and tetrahexahedron. (See 'Symmetrical polyhedra for gemstones' on p. 207).

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FORTHCOMING MEETINGS

1992 ANNUAL CONFERENCE AND PRESENTATION OF AWARDS

The second GAGTL Annual Conference is to be held on Sunday 8 and Monday 9 November at the Great Western Royal Hotel, Paddington, London.

Dr K. Nassau will deliver the keynote lecture on treatments in a full programme dealing with coloured stones, diamonds, valuation procedures and the Duchess of Windsor's jewellery.

The Conference will be followed on the evening of Monday 9 November by the Presentation of Awards which will take place at Goldsmiths' Hall, Foster Lane, London EC2. This year the awards will be presented by Dr K. Nassau.

MEMBERS' MEETINGS

London

On 24 November 1992 at the City Conference Centre, Mark Lane, London EC3R 7JN, lectures will be given on the gemstone deposits of Africa and the trade associated with them. Admission by ticket only, at a cost of £5.00 for GAGTL members, £10.00 a member and a guest, and £8.00 for non-members. For further details and tickets contact the GAGTL.

Midlands Branch

Meetings will be held at Dr Johnson House, Bull Street, Birmingham. Further details from Gwyn Green on 021-440 1428 or 021-445 5359.

25 September 1992	Open Forum. Any questions to our panel.
30 October 1992	Bring and Buy. Specimens, books, equipment - 10% to Branch funds.
1 November 1992	Annual Practical Gemmology Seminar, to be held at the Cobden Hotel, Birmingham. Tickets £18.00 from David Larcher, Midlands Branch Chairman, c/o GAGTL.
27 November 1992	Nigel Dunn. 'Jewellery through the ages'.
5 December 1992	Fortieth Anniversary Dinner.
27 January 1993	Edgar Taylor. 'Fossicking in Wales'.
26 February 1993	Robert Campbell-Legg. 'The art of the engraver'.
26 March 1993	Peggy Stock. 'Crystal healing'.
30 April 1993	AGM and filmshow.

North West Branch

Meeting to be held at Church House, Hanover Street, Liverpool 1. Further details from Irene Knight on 051-924 3103.

21 October 1992	Dr Jamie Nelson. 'Optical attributes of a diamond'.
18 November 1992	Annual General Meeting.

Oxidation treatment of the sapphires from Shandong Province, China

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Abstract

It is now well known that a large number of dark blue sapphires are found in Shandong Province, China. In order to improve the grade of these sapphires, the traditional heating treatment was used at the temperature of 1700°C. However the blue hue of sapphire was almost lost and became a grey colour. Instead, a new method was applied to enhance the clarity of the sapphire so as to improve its quality. In this method the electrolysis technique using molten salts was used to produce a very vigorous oxidation of the corundum. The Fe^{2+} contained in the sapphire was partly oxidized; as a result the samples treated by electrolysis show a very beautiful colour with a light blue hue. The absorption spectra of the specimens also confirm that the sapphire colour was improved.

Introduction

Recently, large natural corundum resources have been found in Shandong Province, China. However there are only a few gem-grade sapphires among these corundums and many of them show an especially distinct pleochroism. These sapphires show bluish-violet colours perpendicular to the *c*-axis of the crystal, and green or greenish-yellow colours parallel to the *c*-axis. These stones cannot be used as gemstones but they might possibly convert to gem-grade sapphires after treatment. Usually these sapphires are heated at different temperatures in the range of 1400-1850°C for varying periods of time. This may enhance the clarity of these sapphires, but treated samples showed bluish-grey or grey colours. The sapphires which show grey colours would not sell. In this investigation such stones were treated by a new method using an oxidation technique with molten salts at the temperature of 940°C only. These treated sapphires can show good blue hues and better clarity compared with the sapphires treated by the heating method.

Experimental

The molten salts used are AlF_3, Na_3AlF_6, CaF_2, TiO_2 and Al_2O_3. The composition is approximately 75.5% Na_3AlF_6, 5% AlF_3, 5% CaF_2, 4.5% TiO_2 by weight and the Al_2O_3 content should be held at near the saturation solubility (10-11wt%). The salts were mixed and placed into the carbon crucible inside a temperature-controlled furnace. As shown in Figure 1, Pt (platinum) wire was used as the anode and the sapphire sample was also coiled by the platinum wire. The carbon crucible was used as the cathode. At the cathode, aluminium metal containing a little titanium was produced and deposited on the bottom of the crucible. Once the electrolyte was molten, the anode and sample were immersed together into the bath and electrolysis was conducted at a cell voltage of 3.0 volts for 30-45 minutes, then the anode and sample were taken out of the bath and cooled at the rate of 9°C/min.

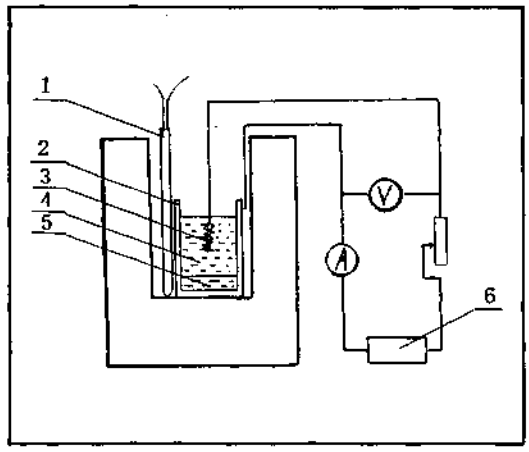

Fig. 1. Electrolysis test assembly
1 thermocouple; 2 carbon crucible; 3 Pt anode with sample; 4 electrolyte; 5 aluminium; 6 direct supply.

For the heating treatments the sapphires were placed in the carbon crucibles and heated in a high frequency furnace in air, and held for 10 hours at the temperature of 1700°C and then cooled at the rate of approximately 9°C/min. The treated samples were cut and polished to present flat parallel surfaces which were examined spectroscopically perpendicular to the *c*-axis of the sapphires.

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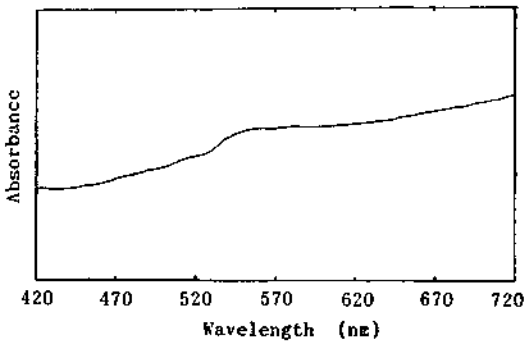

Fig. 2. Absorption spectrum before treatment.

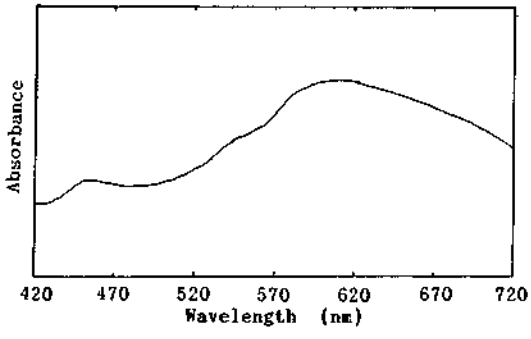

Fig. 3. Absorption spectrum after electrolysis treatment

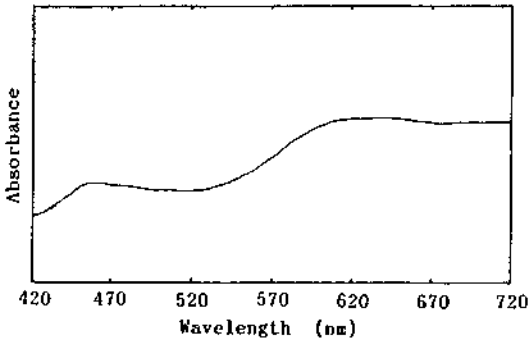

Fig. 4. Absorption spectrum after heat treatment.

Results

Most samples can be changed to a light blue colour from dark blue after electrolysis. The clarities of the samples were obviously improved. The samples showed a pure blue colour perpendicular to *c*-axis of the crystal and the grey hue was not observed. However, samples were dissolved slightly by the melts and lost approximately 8% in weight.

During the heating at 1700°C most of the samples turned into bluish-grey or grey and their clarities were improved slightly also. In the crucible itself traces of Ti were checked by electron microprobe analysis, but the sapphires lost very little Ti during high-temperature heat treatments. The absorption spectra of these sapphires taken perpendicular to the *c*-axis, clearly show the difference before and after treatment by different methods. These results are shown separately in Figures 2, 3 and 4.

Discussion

The blue sapphire is a single crystal of Al_2O_3 containing minor Fe and Ti oxides. The pure Al_2O_3 single-crystal is colourless and absolutely transparent. Small amounts of Fe and Ti contained in the crystal can absorb certain wavelengths of light and this results in the sapphire having colour. The colour and clarity of the sapphire entirely depend on the contents and states of Ti and Fe contained in the sapphire crystal. There is a high content of Fe in the dark sapphire, especially Fe^{2+}, which leads to the sapphire looking dark blue. By decreasing the Fe content or oxidising Fe^{2+} to Fe^{3+}, the dark sapphire would turn to lighter blue and the clarity would be improved.

The traditional heat treatment method is used for the purpose of the oxidation of Fe^{2+} ions, but this oxidation process requires a high temperature, approximately 1700°C. However the Ti ions in the crystal may diffuse outwards and be lost under such a high temperature (over 1300°C). The sapphire that loses only a little Ti exhibits a grey colour. So the sapphire sample heated at 1700°C shows bluish-grey, but its clarity is improved. Figures 2 and 4 show that absorption peaks occur at 450nm after heat treatment, and these have been assigned to Fe^{3+} [1]. The heat treatment has led to the oxidation of Fe^{2+} to Fe^{3+} inside the crystal. Comparing Figure 2 with Figure 4, the absorption band at around 550nm, associated with Ti^{3+} [1], is reduced or disappears after heating. Meanwhile, Ti traces were found in the crucible after the heat treatment. This suggests that some Ti contained in the sapphire was surely lost because of heat treatment.

In order to oxidize the sapphire, but prevent it losing Ti, the electrolysis technique was used. The fluoride melts can corrode the crystal lattice of the sapphire (Al_2O_3) at the temperature of only 940°C.

Alumina (Al_2O_3) can be readily dissolved by the fluoride melts. The saturation solubility is above 11 wt% at the temperature of 940°C. Thus the mass transfers are very easy to execute at the interface between the sapphire and the molten salts. During the electrolytic process, much oxygen and a little fluorine gas were produced on the Pt anode. Fluorine and oxygen have a very strong ability to oxidize at high temperatures. The fluorine atom is very small, so fluorine and oxygen may enter the crystal lattice and oxidize Fe^{2+} to Fe^{3+} and the content of Fe^{3+} increases significantly inside the sapphire. The absorption bands at 450nm have been assigned to Fe^{3+} [1] and the broad absorption bands beyond 570nm have been associated with Fe^{3+} [2]. The spectra so obtained confirm oxidation of Fe^{2+} to Fe^{3+} (see Figures 2 and 3).

The samples that were treated by electrolysis develop a light blue colour from dark blue and the grey hue was not observed. During electrolysis at 940°C, Ti ions diffuse with difficulty because of the relatively low temperature. Meanwhile the Ti ion concentration (as TiO_2) of the electrolyte is about 4%wt, more than the concentration of Ti in the sapphires. Thus, even though there is the diffusion of Ti ions, they diffuse into the sample from the melt, which probably leads to the Ti content of the sapphires increasing slightly; this is consistent with the spectra. The absorption near 550nm has been associated with Ti^{3+} [1]. Before treatment, samples exhibited a weak absorption band at 550nm and after electrolysis it still persisted, or has an enhanced intensity of absorption maybe owing to diffusion from melt to crystal (compare Figure 2 with Figure 3).

Based on above conclusions the following model is presented to explain the transformations taking place during the electrolysis and heating treatment of the sapphires:

(1) heat treatment can promote the oxidation of Fe^{2+} to Fe^{3+} in the sapphire crystal, which improved the clarity of sapphire;
(2) in the 1700°C heating process, some Ti ions of the sapphire were lost which made sapphire show a grey colour;
(3) during electrolysis at 940°C, the Fe^{2+} of the sapphire was oxidized to Fe^{3+}, which improved the sapphire colour significantly;
(4) at 940°C with the electrolysis process, the Ti ions of the sapphire cannot be lost, and the sapphire could even absorb some Ti ions from the molten salts, so retaining or even increasing the Ti content and colour of the sapphire.

Acknowledgements

The authors are grateful to Beijing Syntone Gem Plant, which supplied the samples for investigation.

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CONGRATULATIONS TO THE DEUTSCHE GEMMOLOGISCHE GESELLSCHAFT E.V. ON THE OCCASION OF THEIR 60TH ANNIVERSARY

It is a pleasure to salute the achievements of the German Gemmological Association in promoting the scientific study of gems and dissemination of information from one of the most famous centres for coloured gemstones in the world.

May the DDG prosper in the future and maintain the high standards of enquiry, reporting and communication established worldwide through its meetings and journal.

With very best wishes
from

The Gemmological Association and Gem Testing Laboratory of Great Britain

27 Greville Street, London, EC1N 8SU

Determination of the age and origin of emeralds using rubidium-strontium analysis

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Abstract

The rubidium-strontium method has been used to determine the age of natural and synthetic emeralds. Precise ages of emeralds from Precambrian Shields (Brazil, Zambia, Madagascar) have been calculated. Although the age of emeralds of geologically younger formations is more difficult to establish, Colombian emeralds are probably 61 ± 5 million years old.

Introduction

"Where does this emerald come from?" is a common question asked by collectors. Not satisfied by the beauty alone of a gem, they also want to know where it has been formed by Mother Nature. To penetrate the secret of an emerald, the gemmologist studies its inclusions, reflecting its paragenesis, and may thus determine occasionally a likely geographical origin when only a few deposits of the same type are known.

It is also the inclusions that enable a gemmologist to distinguish with certainty, man-made emeralds and chrome-bearing beryls (named synthetic emeralds). Nevertheless there are some synthetic emeralds that have no typical inclusions. Then it becomes difficult to objectively affirm their artificial origin, even if subjectively it is suspected: the investigation of trace elements, by destructive procedures through neutron activation analysis (NAA), for example, may then become necessary (Schrader, 1983).

Another approach in solving these problems is to determine exactly the age of an emerald. Generally, an emerald's age will be closely related to that of the environment of its growth, which can be dated by isotopic geochronology. Among the methods commonly used in geochronology (Faure, 1986), the rubidium-strontium (Rb-Sr) method is the one to offer most prospects in the study of emeralds and their host rocks. Indeed, it is known that some natural emeralds can contain measurable quantities of rubidium, a geochemical companion of potassium.

Normal Rb-Sr analysis methods cannot be routinely applied to cut gemstones as small amounts of powder from the specimen must be dissolved for determination. However only a few milligrams (a few percent of a carat) are needed for the analysis, and the taking of small samples from a batch of stones may be considered acceptable.

The rubidium-strontium geochronology method (Faure, 1986), uses the transformation, through the emission of β-rays, of the rubidium 87 isotope into the strontium 87 isotope. The ^{87}Rb is said to decay to ^{87}Sr and it does so at a constant rate which is most easily expressed as a 'half life'. The time taken for 1 gram of Rb to decay to 0.5 grams (the half life) is about 50 thousand million years, and the product, 0.5 grams of Sr, is known as radiogenic strontium.

Analytical Technique used on Emeralds

Details of the Rb-Sr techniques as carried out in the Clermont-Ferrand (France) Laboratory with regard to sampling, control of purity, cleaning, equipment, processing, and calculations of ages, by means of 'model-age' or 'isochron method', can be obtained from one of the authors (P.V.).

Results:

The results are summarized in Table I and may be considered in three groups:

EMERALDS FROM PRECAMBRIAN ROCKS (Brazil, Madagascar, Zambia) have significantly high enrichment in radiogenic strontium; the major reasons are their age, and their rather high rubidium content. Where high radiogenic strontium is present in a mineral with low initial (non-radiogenic) strontium the conditions are favourable for calculating a 'model age'. This can be done for the emeralds in this group and the determined 'model' ages are obtained with nearly 2% precision. They match with the known evolution of these Precambrian shields.

EMERALDS FROM YOUNG ROCKS (Colombia, Pakistan, Afghanistan), have low radiogenic strontium enrichments, because of their younger ages and their low rubidium contents; they also have relatively high primary strontium contents. These

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Table I – Rb/Sr analyses of emeralds from various localities.

Origin		weight mg	Rb (μg/g)	primary Sr (1) – (μg/g)	$^{87}Rb/^{86}Sr$ (2)	$^{87}Sr/^{86}Sr$	Model Age with initial $^{87}Sr/^{86}Sr$ = 0.705. Million years (Ma)
Brazil	em.1*	16.4	76.9	0.085	1148.	42.59	2517
	em.2*	66.0	77.4	0.098	1779.	59.07	2273
Santa Terezinha	em.1	169.7	11.8	162.8	0.210	0.72036	
	em.2	92.8	21.9	3.48	18.49	0.8357	496
	sch	74.0	14.3	308.3	0.0134	0.72061	
Socoto	em.	234.4	51.3	1.24	119.4	2.717	1180
	mi.	24.0	1062.	11.1	956.0	25.65	1814
Itaberai	em.1	76.4	14.3	1.02	38.64	0.98805	514
	em.2	46.9	17.0	1.77	26.33	0.88830	489
	mi.	81.4	209.	2.32	334.1	3.55	597
Madagascar	em.1	179.7	76.0	2.26	96.9	1.5578	618
	em.2	142.9	93.7	2.85	94.9	1.3744	497
Zambia	em.1	91.4	28.1	0.029	1627.	12.309	500
	em.2	94.1	94.4	0.005	10934.	65.65	598
Colombia	em.1	195.3	1.0	0.45	6.29	0.7197	
(Penas	em.2	161.6	2.26	0.28	22.6	0.7324	
Blanca)	em.3	108.1	1.42	0.20	18.61	0.7316	
	em.4	114.1	1.80	0.17	27.43	0.7380	
	ca.	56.0	1.47	42.8	0.0995	0.71281	
Pakistan	cm.	130.7	5.0	0.85	16.83	0.71599	
Afghanistan	cm.	151.1	16.5	7.15	6.69	0.71388	
Lennix		31.9	0.45	0.038	13.9	0.7122	
Gilson	1	42.7	1.59	n.d.		n.d.	
	2	30.1	1.55	n.d.		n.d.	

(1) Primary strontium content has been determined by subtracting the laboratory strontium blank (1.8ng) from the analyzed strontium in the sample.
(2) ^{86}Sr = primary ^{86}Sr + blank ^{86}Sr.
* Precise locality unknown.
em: emerald; mi: mica; ca: calcite; sch: schist.

three factors combine to give low measured $^{87}Sr/^{86}Sr$ ratios and 'model ages' are not precise enough to give satisfactory results.

However, the use of several samples from the same deposit enables the use of another technique to obtain the age, called the isochron method. This is illustrated in Figure 1, where four samples of Colombian emeralds (Penas Blanca deposit) plotted on a graph of $^{87}Sr/^{86}Sr$ vs $^{87}Rb/^{86}Sr$ indicate an age of 61 ± 5 million years (Ma).

SYNTHETIC EMERALDS: Lennix emeralds contain low Rb and low Sr with no detectable additional Sr due to the radioactive decay of Rb. The Sr content is lower than in most natural emeralds. Similar results were obtained from Gilson synthetic emeralds. We conclude that for these samples the synthetic emeralds have Rb-Sr chemical and isotopic characteristics very different from those of natural emeralds.

Prospects

The rubidium-strontium method has the potential to authenticate and even date emeralds. In comparison with natural emeralds, synthetic emeralds may have noticeably different characteristics.

Other studies should be undertaken, and it would be interesting, from the genetic point of view, to determine isotopic compositions of associated minerals and host-rocks. In the context of this investigation, the Penas Blanca (Colombia) emeralds are in isotopic equilibrium with their associated calcite, and those from Santa Terezinha (Goias State, Brazil) are in equilibrium with their host-rock. Rubidium and therefore radiogenic strontium

Fig. 1. Four Penas Blanca (Colombia) emeralds isochron providing a 61 ± 5 Ma age.

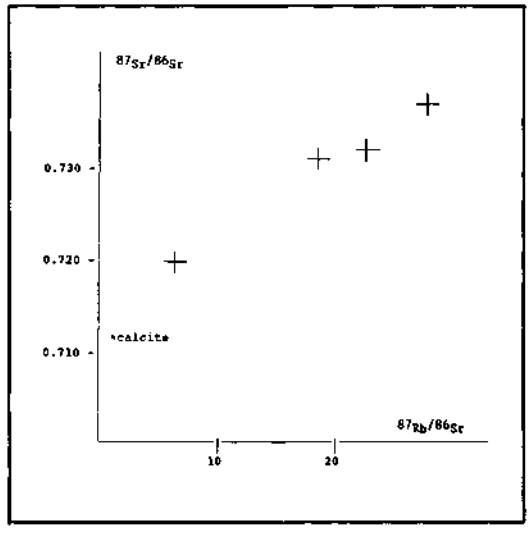

Table II – Acid leaching experiments on Zambian emerald sample.

	weight mg	Rb (μg/g)	primary Sr (I) – (μg/g)	$^{87}Rb/^{86}Sr$ (2)	$^{87}Sr/^{86}Sr$	Model Age with initial $^{87}Sr/^{86}Sr$ = 0.705. Million years (Ma)
Unground sample	77.2	130.0	0.38	2188.	13.270	403
ground sample residue	102.5	10.8	0.44	71.56	1.226	510
solution	1.6	0.20	0.53	1.135	0.7115	

could be contained within emeralds, possibly in the structural canals (as in morganites), or possibly also in fluid and solid inclusions. With this in mind, Giuliani and Weisbrod (1988) have studied phlogopite inclusions in Brazilian emeralds. Even primary strontium should be interesting to localize. Table II shows the results of a pilot test in which a few opaque sulphide granules and thin tubes parallel to the *c*-axis were studied. Their fluid content could not be determined by Raman probe for their section (less than 0.1mm) is too small to measure by this method. A second approach was by conventional isotopic analysis of a sample. Thirdly, part of the sample was finely ground, the powder was leached with acid, and residues as well as leachates were separately analyzed. It is clear from these analyses that all the rubidium and radiogenic strontium is contained in the emerald structure, and not inside fluid inclusions which would have been released during leaching.

Finally, it is advisable to comment on the reason for the spread of model ages of Precambrian emeralds (see Tables I and II) beyond analytical error. This spread is probably attributable to variable loss, along dislocations, of radiogenic strontium which is loosely held in the crystal structure. This phenomenon is widely-known in minerals rich in rubidium and poor in primary strontium, such as micas, which undergo a thermal event after crystallization. Besides, it seems that emeralds should be more sensitive to the radiogenic strontium loss than associated micas, according to Table I results (Socoto, Bahia State; Itaberai, Goias State – Brazil).

Acknowledgements

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Identification of fissure-treated gemstones

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Introduction

The subject of enhancing the appearance of various gemstones in which fractures have a detrimental effect on their beauty or saleability has been addressed previously by a number of authors (e.g. Ringsrud, R., 1983; Kane, R., 1984; Scarratt, K., and Harding, R.R., 1984; Martin, D.D., 1987; Hänni, H.A., 1988; Koivula, J.I., *et al.*, 1989; Themelis, T., 1990; Shida, J., 1991; Kammerling, *et al.*, 1991; Hänni, H.A., 1992).

Fissures in gemstones, originate from mechanical tension, pressure or temperature stress. They originally contain vacuum, gas or a fluid. If such fractures reach the surface of the stone, the narrow voids of the fractures are filled with air. All of the above media possess refractive indices considerably lower than that of the gemstone itself. The fractures are therefore capable of reflecting light. This is an undesirable capability that would be considerably reduced if they were to be filled with a substance of a similar refractive index to that of the gemstone.

The objective of this short review is to bring the topic of artificially introduced filling substances, which may be used in gemstone enhancement procedures to the attention of the reader. It seems to the author that developments in this field have either not been given sufficient exposure, or have gone unnoticed by certain elements of the trade during the last few years. It is also important to be able to differentiate clearly between natural deposits on fracture planes (e.g. iron hydroxide) and organic artificial matter, commonly but very often incorrectly called 'oil'.

Why a treatment can be effective

Light entering a faceted gemstone only re-emerges after multiple internal reflections between several facets. Along its path the light is absorbed selectively and in a manner that the transmitted spectral colours result as the perceived colour of the gemstone. The shorter the distance the light travels, the weaker the absorption and the lighter the colour. Should the light path be interrupted by a fracture, because it is reflected at this point, the length of light path is shorter than it might be if the crack were not present and the colour thus weaker. Also the reflecting fractures are conspicuously lighter to the observer (or darker if the fracture plane is observed from behind the 'mirror' of the reflecting plane).

If a filler replaces the air previously in the fracture, and the filler substance has a refractive index higher than air and near to that of the treated stone, it inhibits a reflection of light rays from most incoming directions. The light may then travel across the fracture plane and is not deviated or reflected. The fracture no longer acts as an obstacle in the light path.

On many occasions fractures, pores or grain boundaries of polycrystalline stones are used to introduce colour into the material. Recently jadeite has been treated with acid, then heated to widen the grain boundaries and increase the porosity. The stones are now easier to treat with an artificial resin. The result is called B-Jade and in the Far East leads to a superabundance of supposed Imperial jade.

Another example is represented by an originally colourless, heavily fractured corundum which is cut into beads for necklaces (Figure 1). The beads are treated with a ruby-red stain, which may be seen on fractures and twin planes. The material makes a very convincing imitation of ruby (Schmetzer *et al.*, 1992).

How treatments are performed

For decades, if not centuries, fillings of oils and resins with a viscosity low enough to penetrate into fractures have been used to seemingly improve the quality of the stones. The lower the viscosity of the filling medium, the more complete is the penetration into the fissure. Sometimes vacuum techniques are used to improve the result. The range of fillers encompasses numerous substances: apart from those such as vegetable and mineral oils with volatile components (Figure 2), there are the more durable fillers like fats and resins. Compounds such as synthetic epoxy resins are frequently used today (Themelis, 1990); these possess the advantage of a

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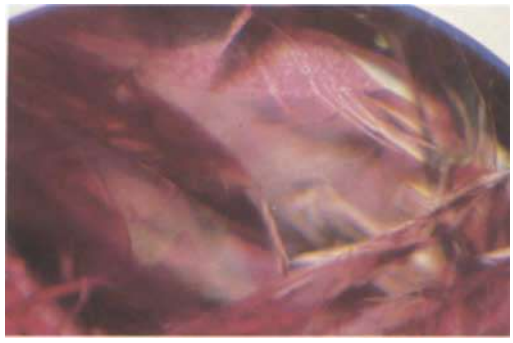

Fig. 1. Fractures stained red do not make a ruby! this picture shows part of one button shaped bead in a necklace. The material was originally near-colourless corundum. Magnification 25x.

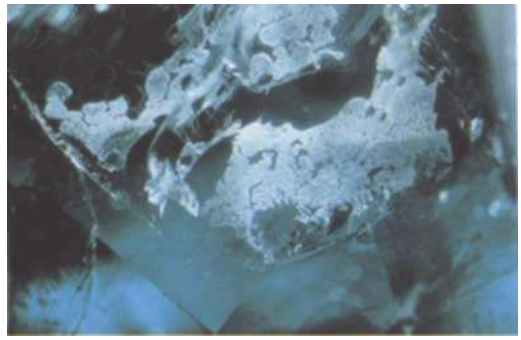

Fig. 2. Emerald with oil-treated fracture. Extensive 'lakes of air' form their lobular patterns near the fracture opening when the oil dries out. Magnification 20x.

more stable adhesion to the stone. This leads to a longer lasting improvement in appearance which is not possible with volatile compounds like oil and paraffin used traditionally. The latter are released quite easily due to their solubility in soaps, detergent and solvents.

The most stable fracture filler material is glass, which is introduced into fractures in its molten state. For the moment, diamond and corundum are the only gemstone species treated by this method. Only these species resist the required high temperature without being seriously damaged (Kane, 1984; Hänni, 1986). All other stones like quartz, tourmaline, beryls, jade, lapis lazuli etc are normally treated with natural or artificial organic compounds.

Emeralds

Before a filler is applied to an emerald, a cleaning process should be used to remove all dirt and residual filler material from any former treatments. This may be done by prolonged immersion in solvents and/or acids, possibly with the assistance of ultrasonics or steam. The use of a vacuum may extract previously inserted 'oil'. The procedure of cleaning may, depending on the intended filler to be used, take many hours or even days (Themelis, 1991).

For a good penetration into the fractures, a low viscosity filler is essential. This objective is reached with oil, paraffin (Figure 3) or resin by slightly heating these and using a vacuum to assist in the treatment. Special additives are sometimes used to lower the viscosity as far as to 260 centistokes.

A well known product name is sometimes used for a group of epoxy resins with similar characteristics: Opticon. Most emeralds in the trade today are treated in the rough or cut state with 'Opticon' or a similar product. Other epoxy resins such as Araldite NU 471, Dobeckot 505, Novogen P40 etc have similar effects as fillers. Their refractive indices are in the range 1.5 to 1.6.

Fig. 3. Resin treated fracture in an emerald, with spectral colour flashes and dendrite-shaped gas bodies. Opticon treated fractures may look like this. Magnification 20x.

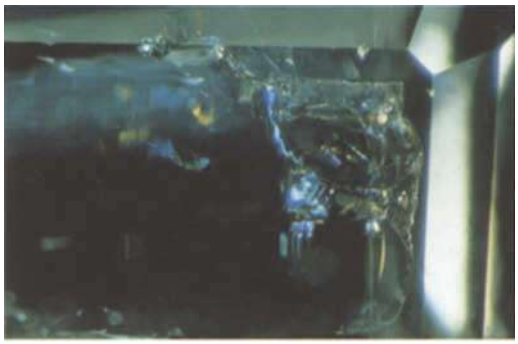

Fig. 4. Ruby with a fracture, probably treated with wax or paraffin. A typical dendrite-like pattern is visible.

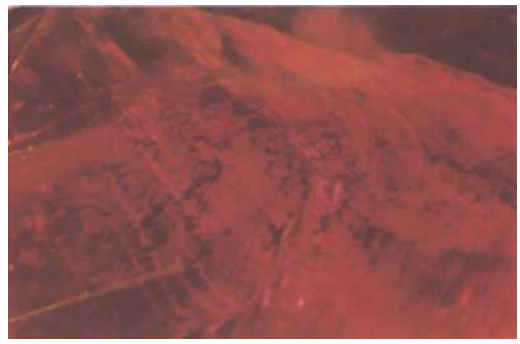

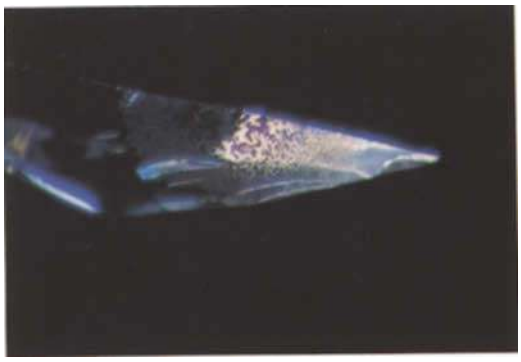

Fig. 5. Sapphire with a filling of artificial resin, showing dendrite-like patterns of gas bodies. In UV light the filling has a whitish fluorescence. Magnification 40x.

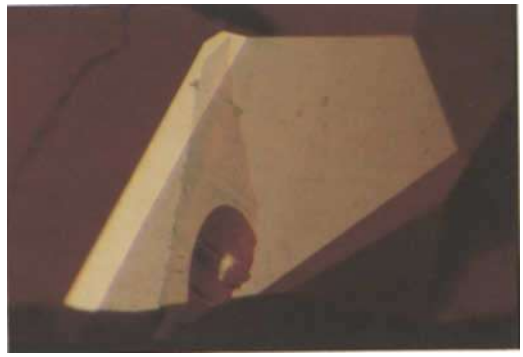

Fig. 6. A facet of a heat and glass treated ruby. A cavity (and all open fractures) have been filled with glass, identifiable by its lower lustre compared with corundum. Within the glass part an air bubble is cut by the surface. Magnification 20x.

Epoxy resins can be used with or without a hardener. If the resin is used without a hardener, it remains soft and usually entirely fills the fracture. Gas bubbles and other structures like viscous fingering are rare in the fissure planes. When the artificial resin is mixed with a hardener, polymerisation takes place. A shrinking effect causes fine fissures and pseudo-dendritic patterns to occur in the filler plane, making it easier to detect.

Corundum

Although some historical filling substances are encountered today (most probably wax or paraffin) the majority of fractures in ruby and sapphire are treated with a boro-silicate melt. Before treatment, a process of cleaning is performed to remove all dirt and residual filler material from any former treatments. Also natural deposits like iron hydroxide or clay minerals must be dissolved. A cleaning treatment is normally carried out by using hydrofluoric acid, which attacks all silicate minerals that may still adhere on rough stones. Sulphuric or hydrochloric acid may also be used to remove foreign material on and in the open fractures of corundum.

The treatment requires the presence of boron or lithium to lower the melting point of the silica-compound forming the melt. The melt, besides filling the fractures, also acts as a solvent or flux respectively and enables some recrystallization of the fracture planes.

Treatments with glassy substances today appear to be performed faster and/or at lower temperatures than some time ago, since the included rutile 'silk' may not be affected during the glass infilling treatment.

How treatments are identified

Some of the filler materials contain air or gas bodies, forming individual bubbles or dendrite-like patterns. Such patterns, when present, prove the existence of two different phases on a fissure plane. Many of the organic fillings show a bright fluoresc-

Fig. 7. Artificially healed fracture in a ruby. Under the flux effect of the glass the fracture plane has recrystallized. In newly formed crystalline cells, the glass has been trapped, devitrified and formed bunches of white radiating crystals. Magnification 40x.

Fig. 8. Treated cleavage fractures in a brilliant-cut diamond. Yellow and violet interference colours together with gas bodies are characteristic for the Yehuda treatment.

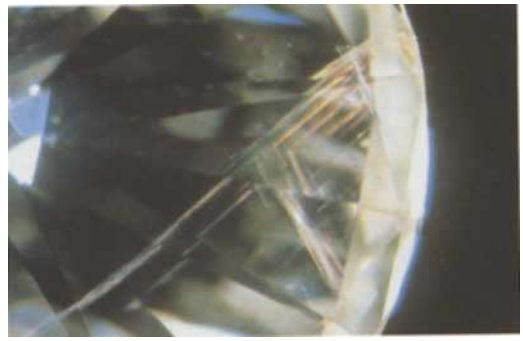

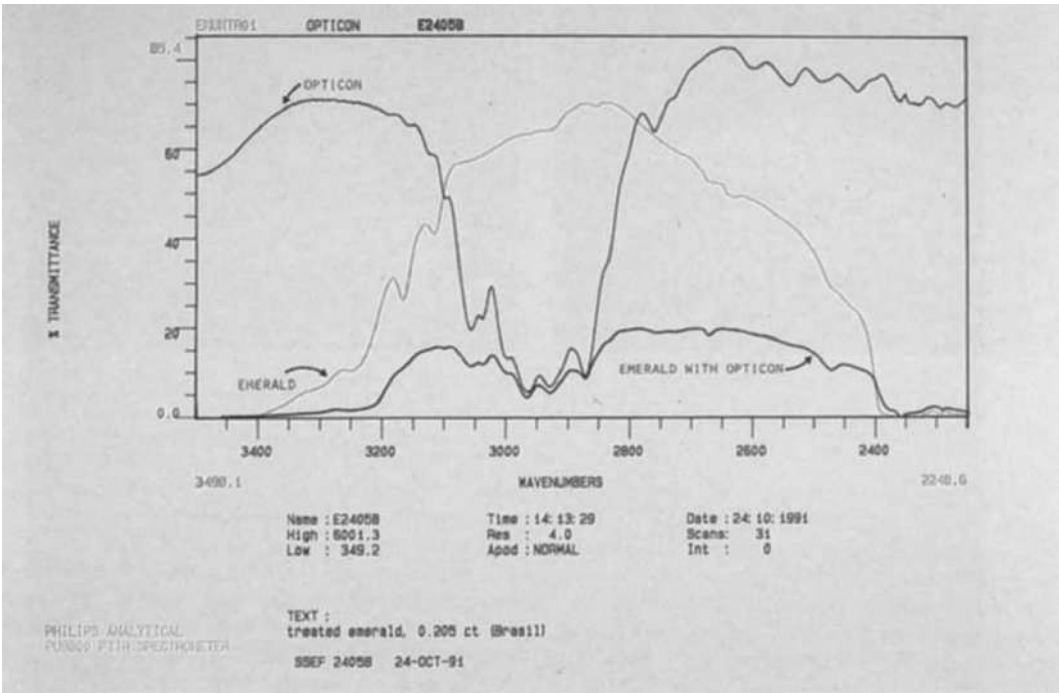

Diagram 1. Infrared spectra of untreated emerald, Opticon (artificial epoxy resin), and emerald treated with artificial epoxy resin. FTIR-Spectrum recorded by E. Jegge, SSEF laboratory, Zurich.

ence under ultraviolet light which is visible either with the unaided eye or a loupe.

The presence of oil can be indicated by bathing the stone in a solvent such as acetone or hexane for a short period. The soluble oil is diluted by the solvent. Under a microscope the drying out of the solvent which has replaced some of the oil is easily visible. Lobular air dendrites develop at the fracture openings. Such a reaction does not appear with resin treated fractures, since resins are less soluble.

Artificial resin fillings are often apparent by their orangy or violet colour flashes (Figures 4 & 5). A further proof for a foreign organic filling is possible by means of the hot needle. If the needle is put next to the fracture opening, the filling turns to a liquid state and moves slightly. The examination should be observed through the microscope and performed very carefully. The 'observation' of a foreign filling in a fracture by microscopic inspection may be quite easy, but the 'identification' of a particular filler may be difficult. Organic fillers, can be detected by infrared spectroscopy (see Diagram 1). The infrared spectrometer appears to be the most reliable tool for an identification, but owing to the numerous varieties of organic compounds, and the difficulties due to the superimposition of the stone's spectra over the filler spectra, this may prove to be a handicap for an exact identification of a particular filler. Also, if stones were subjected subsequently to different treatments without proper cleaning, the IR spectrum may be difficult to interpret.

Glassy substances, at the surface of a stone may be recognized by their different lustre compared with that of corundum (Figure 6, Hänni, 1986). If glassy fillings are to be identified within the stone, Raman spectroscopy may be the most useful method. In many cases, voids filled with artificial glass are whitish. The glass has served as a flux, recrystallized the fracture plane and sealed itself into a newly formed geometric void. In some instances devitrification starts, resulting in the appearance of radiating fibrous crystals that emerge from trapped gas bubbles (Figure 7).

Heavy liquids possess a high refractive index. This property is utilized for the Yehuda fracture treatment of diamond (Figure 8). Also with this fracture treatment, the filler shows vivid colour flashes, and the fracture planes contain gas bubbles and 'lakes' (see Koivula *et al.*, 1989). The heavy elements are identifiable by X-ray spectroscopy (Scanning Electron Microscope SEM or Energy Dispersive X-ray Fluorescence Analysis EDS-XFA). Glassy fillings in corundum show the presence of silica and Yehuda treated diamonds indicate the presence of lead and occasionally bismuth.

Outlook

Although the above mentioned treatments are not new, it appears that many trade members have little knowledge of some of them or do not wish to complicate their business by acknowledging their presence on the market. The use of colourless oiling is accepted as a common enhancement practice. This rather historic treatment method is being increasingly replaced by more stable treatments that utilize modern filler substances. Whilst the newer treatment methods in no way represent single cases, it is unfortunate that only a small number of stone dealers, jewellers or goldsmiths have the time, the knowledge, the motivation or the equipment to check or confirm these treatments. So it will probably take a long time for trade opinions about this kind of treated stone to change and make an impact on the market place.

At present time the CIBJO rules require only a disclosure of fracture treatments performed with substances other than colourless oil. This means that almost all emeralds, an important number of rubies and many sapphires should be labelled or sold respectively as treated gemstones. The exact identification of the numerous more or less viscous oils (vegetal, animal or synthetic), fats, paraffins, natural and artificial resins is rarely simple and often impossible. The analyses might be expensive and finally come only to the result that the stone is treated and has a foreign organic substance in its fissures. Because of the multitude of organic compounds which could serve as fillers it may be more appropriate not to draw an arbitrary line between 'permitted' treatments and those which are not tolerated without declaration.

This would mean a change in the CIBJO rules that govern this problem. To the author it seems advisable to handle all fracture treatments in the same way, either to disclose all fracture filled stones or to consider fracture filling as a common practice (whatever substance is used) and omit any comment to individual stones. However, the author considers that disclosure of the glass filling of any gemstone should be mandatory.

In any case the final consumer should be informed of the commonly used practices by his gemstone specialist to prevent damaging action by people with unfair goods.

Acknowledgement

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Symmetrical polyhedra for gemstones

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Abstract

Faceted 'spheres' cut recently are described. Regular convex polyhedra including platonic solids, rhombic forms and other equidimensional forms are discussed with respect to face shape and number, and their inter-relationships. They are placed into symmetry classes. The well-known crystallographic hexoctahedral class with its two platonic solids, one rhombic form and four variable forms is discussed. Combinations of the first three forms and also of the seven forms with faceting angles are given. The platonic dodecahedron and icosahedron are variously combined. The little known rhombic triacontahedron with faceting angles is given. Combinations of these three closely related forms are given. The virtually unknown four variable forms with the same symmetry were derived theoretically and a combination of the seven forms with its 362 faces is illustrated.

Introduction

The gemstone collection of a talented amateur faceter, Dick Rothkugel, was recently examined. Possibly the most intriguing of the items of an interesting collection is a 'sphere' of smoky quartz with 32 symmetrically arranged facets weighing 20 carats and 15mm in diameter. This, together with an article by Paul C. Smith on making a sphere of this sort, provided inspiration to investigate the fascinating realm of symmetrical polyhedra in order to produce alternate designs that would challenge the enthusiastic faceter. Findings included several forms related to the pentagonal dodecahedron and the icosahedron. Having cut another sphere on the previous design but of amber cubic zirconia of 45 carats, Dick Rothkugel subsequently produced a 47-carat triacontahedron on my calculated data. These two gem polyhedra are illustrated in Figure 1. The beauty of these cuts is in the symmetry of the facets and the light pattern reflected from them.

Fig. 1. Faceted spheres: A – a combination cubic zirconia sphere; B – a smoky quartz triacontahedron.

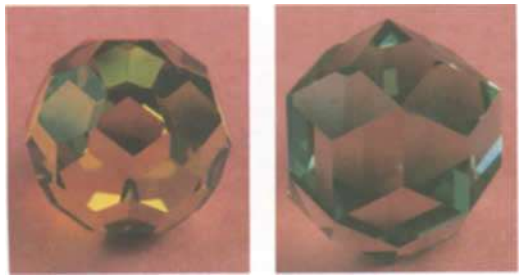

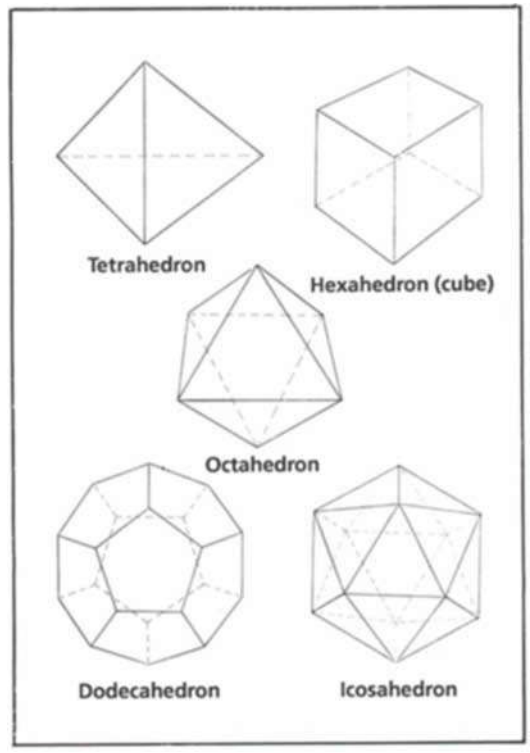

Fig. 2. The platonic polyhedra.

Regular polyhedra

There are only five convex polyhedra each of identical faces that are regular polygons with equal internal angles. This fact was known by the Greek philosophers and the polyhedra are therefore referred to as the platonic solids. These are: the tet-

Table 1: Some equidimensional polyhedra

	Non-crystallographic	Crystallographic		Face form
Class	Hexicosahedral	Hexoctahedral	Hextetrahedral	
Symmetry*	$6A_5$ $10A_3$ $15A_2$ 15P C	$3A_4$ $4A_3$ $6A_2$ 9P C	$4A_3$ $3A_2$ 6P	
Platonic forms	Trigonal icosahedron 20	Trigonal octahedron 8	Tetrahedron 4	▲
	–	Square hexahedron (cube) 6	Square hexahedron (cube) 6	■
	Pentagonal dodecahedron 12	–	–	⬟
Non-platonic forms	Rhombic triacontahedron 30	Rhombic dodecahedron 12	Rhombic dodecahedron 12	♦
	Trigonal pentadodecahedron 60	Trigonal tetrahexahedron 24	Trigonal tetrahexahedron 24	▲
	Trigonal trisicosahedron 60	Trigonal trisoctahedron 24	Trigonal tristetrahedron 12	▲
	Trapezoidal hexcontahedron 60	Trapezoidal icosatetrahedron 24	Deltoid dodecahedron 12	♦
	Hexicosahedron 120	Hexoctahedron 48	Hextetrahedron 24	◢

* A denotes a rotation axis of symmetry, subscripts indicate repetitions/360°; P denotes a plane of symmetry; C denotes a centre of symmetry.

rahedron (four faces), the hexahedron (or cube with six faces), the octahedron (eight faces), the pentagonal dodecahedron (12 faces) and the icosahedron (20 faces). These are illustrated in Figure 2. Note that the only polygonal faces involved are the equilateral triangle, the square and the regular pentagon. These polyhedra all fulfil the Euler (18th Century Swiss mathematician) characteristic namely: Vertices + Faces − Edges = 2.

Because of the regular arrangement of their constituent faces and consequent symmetry such polyhedra are visually pleasing. Obviously the more component faces involved the more closely the polyhedron approaches a spherical form. Thus the dodecahedron and the icosahedron are the more interesting forms to investigate.

Fig. 3. Rhombic forms.

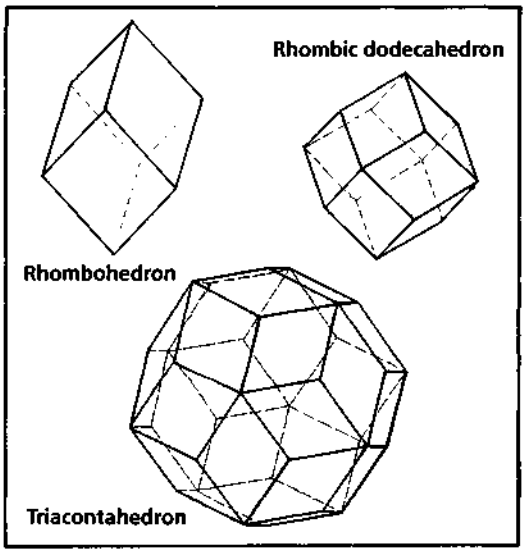

There are three additional symmetrical polyhedra with the rhombus as face form (Figure 3). They are: the variable rhombohedron (6 faces), the fixed rhombic dodecahedron (12 faces) and the variable triacontahedron (30 faces).

The closed forms of higher symmetry are classified in Table 1. The crystallography classes are well known; the proposed new symmetry class, the hexicosahedral, is now added. The author has constructed models of each of the seven forms of this new class.

Crystallographic polyhedra

Of the above platonic solids only the tetrahedron, the cube and the octahedron are encountered in crystallography (where faces are parallel to planes of atoms in their structure). There are actually several dodecahedra possible crystallographically but these do not have equilateral pentagonal polygon faces. For instance, the pyritohedron, a form in which the mineral pyrite sometimes crystallizes is, in fact, a pentagonal dodecahedron but the pentagon faces have a side of odd length and consequently the form has much lower symmetry. Interestingly, the so-called 'iron cross' interpenetrant twin form has higher symmetry. The tetrahedral pentagonal dodecahedron has irregular pentagonal faces and even lower symmetry. Garnets often crystallize as dodecahedra in which the faces are rhombs (Figure 4).

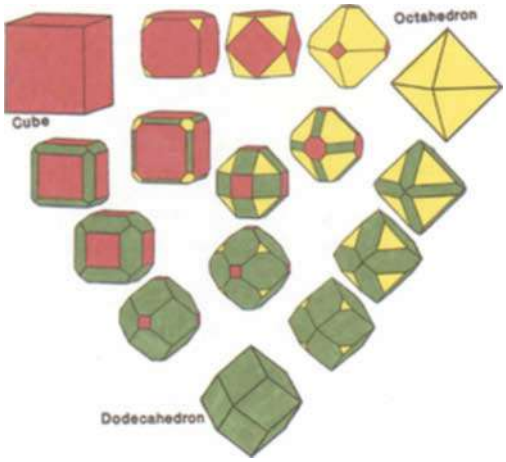

Fig. 4. Combinations of cube, octahedron and dodecahedron.

There are a large number of other polyhedra encountered in crystals but the faces of these are not regular polygons. Those of the most symmetrical crystal class (of 32) namely, the so-called Hexoctahedral Class, Isometric System, generally have the most faces and are equidimensional. They provide the best basis for the development of faceted spheres. They comprise the following forms: two platonic solids, namely, the cube (hexahedron) and octahedron; the rhombic dodecahedron (12 faces, the tetrahexahedron (24), the trisoctahedron (24), the icositetrahedron (24) and the hexoctahedron (48).

The cube and the octahedron have an interesting relationship in that the cube has 6 faces and 8 quoins, the octahedron 6 quoins and 8 faces. Furthermore, each of the cube and octahedron have 12 edges while the rhombic dodecahedron has 12 faces. Bevelled edges of both the cube and the octahedron would, in fact, produce the dodecahedron if these bevels were extended or symmetrically ground down. The three forms have the same symmetry and can be combined as illustrated (Figure 4). Note the relative development of the simple forms in each model.

Fig. 6. Model of a 146-faced 'sphere'.

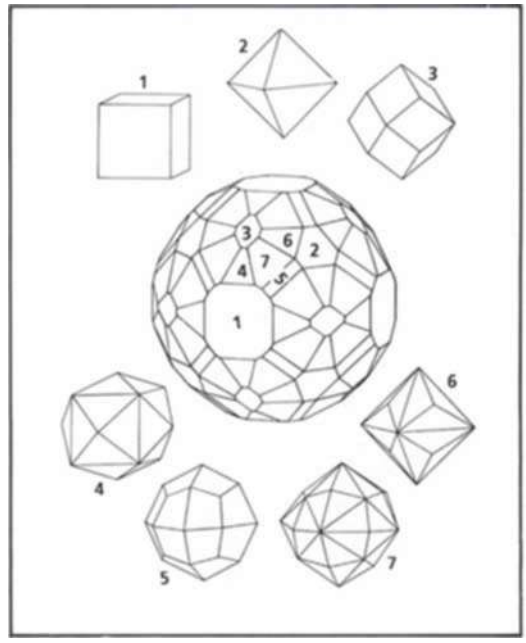

Fig. 5. Hexoctahedral combinations.

The remaining four forms of the class are not fixed in respect of inter-facial angles and intercepts with the crystallographic axes. There are, in fact, several variants of each form possible.

What may be regarded as the ultimate faceted sphere with pleasing symmetry in this class is produced by combining the seven forms of the hexoctahedral class to produce a 146-faced sphere. A result is shown in Figure 5. Those representatives of each of the variable forms have been chosen that have the simplest relationship with the crystallographic axes of the Isometric System, i.e. they have

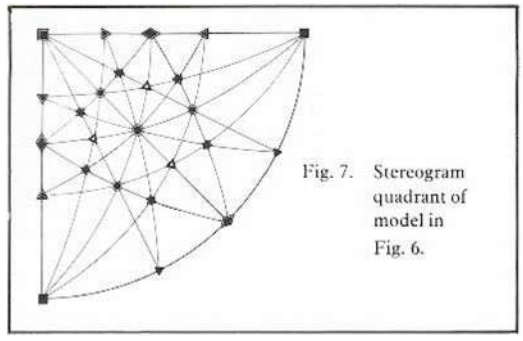

Fig. 7. Stereogram quadrant of model in Fig. 6.

the lowest Miller face symbols. These have the simplest relationship with one another and the fixed forms and the greatest degree of co-zonality. The parallel-perspective view of the combination was produced by means of a drawing technique using the stereographic projection of the poles of the faces.

The cube faces have been made dominant to serve as 'table' facets. A model in seven colours to represent the seven forms has been constructed out of sheet perspex. This is shown in Figure 6. One quadrant of the stereogram is shown in Figure 12. Construction of the model required the interfacial angles, the bevel angles for fitting adjacent faces together and also the plane face angles. Involved was considerable spherical trigonometry but the most formidable task was assembling the model.

This was accomplished after several unsuccessful attempts and by evolving a procedure for controlling angular distortion. The model obeys the Euler equation having 146 faces, 240 vertices and 384 edges. Parallelism of interfacial edges in the perspective view indicates the various zones in which faces lie and presents the faceter with a modus in respect of cutting order of facets. The angles for faceting are given in Table 2 below.

PLAN A

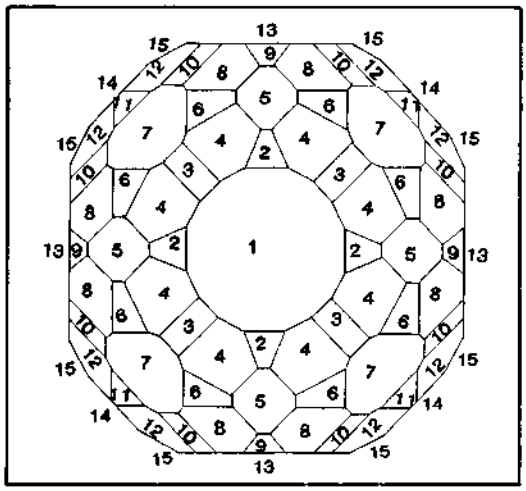

Hexicosahedral polyhedra

The first three polyhedra of this class have an analogous inter-relationship to that between the cube, the octahedron and the rhombic dodecahedron: the pentagonal dodecahedron has 12 faces and 20 coigns while the icosahedron has 20 faces and 12 coigns. In a sense, the one is the reverse of the other. Thus, in a particular orientation the spatial position of each face of the one would be in the position of a coign of the other. Thus each of a series of combinations of the two polyhedra consists of a total of 32 faces. Both have 30 edges. The triacontahedron has 30 faces and 32 (12+20) coigns. Interestingly, a crystalline form of boron has 20 atoms arranged at the coigns of an icosahedron. The symmetry of the three simple forms and the combinations are all the same, namely, six five-fold, ten three-fold, 15 two-fold rotation axes and 15 planes of symmetry and a centre of symmetry.

Table 2: Faceting angles for the construction of the 146-faced 'sphere'

Upper hemisphere					
Angle	Facet	Indices			
0	1. Cube	Any			
26.6	2. Tetrahexahedron	80	20	40	60
32.2	3. Trapezohedron	10	30	50	70
36.7	4. Hexoctahedron	6	14	26	34
		46	54	66	74
45.0	5. Dodecahedron	80	20	40	60
48.2	6. Trisoctahedron	6	14	26	34
		46	54	66	74
54.4	7. Octohedron	10	30	50	70
57.7	8. Hexoctahedron	4	16	24	36
		44	56	64	76
63.4	9. Tetrahexahedron	80	20	40	60
68.2	10. Trapezohedron	6	14	26	34
		46	54	66	74
70.2	11. Trisoctahedron	10	30	50	70
74.5	12. Hexoctahedron	7	13	27	33
		47	53	67	73
90	13. Cube	80	20	40	60
90	14. Dodecahedron	10	30	50	70
90	15. Tetrahexahedron	6	14	26	34
		46	54	66	74
Lower hemisphere					
Repeat of upper hemisphere in reverse order. Orientation controlled by facets 13, 14 & 15.					

Three of the two-fold axes which are normal to each other may be chosen as reference axes thus enabling the models to be viewed in analogous orientation (cf crystallographic axes).

A number of dodecahedral/icosahedron combinations are shown in Figure 8. The simple polyhedra, the dodecahedron and the icosahedron, are placed at the ends and the series of combined polyhedra illustrate a continuously increasing development of the one simple form and a simultaneous diminishing development of the other, depending on the order in which they are looked at.

The combination in which the two forms are in equilibrium or more or less equally developed, i.e. where they are reduced to regular pentagons and hexagons of equal side length (a design of the soccer football) is particularly pleasing. This is, in fact the sphere described by Paul Smith and made by Dick Rothkugel (see Figure 1). The 60 coigns of this combination also represent the relative positions of the atoms of the 3rd trimorph of carbon (the others: graphite and diamond) recently discovered and referred to as 'buckyballs' (see Figure 9). Thus, while none of the forms of this symmetry class are encountered in external morphology in crystallography some are nevertheless represented in molecular structure. For faceters who may be interested the interfacial angles which are applicable to each of the combinations illustrated and any others of different development are:
Dodecahedron/dodecahedron: 63.44°
Dodecahedron/icosahedron: 37.38°
Icosahedron/icosahedron: 41.81°

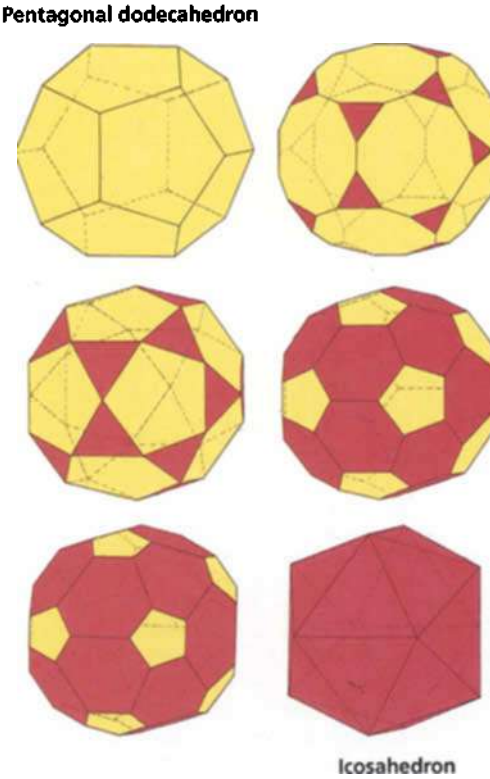

Fig. 8. Dodecahedron/icosahedron combinations.

Fig. 9. Arrangement of carbon atoms in a 'buckyball'.

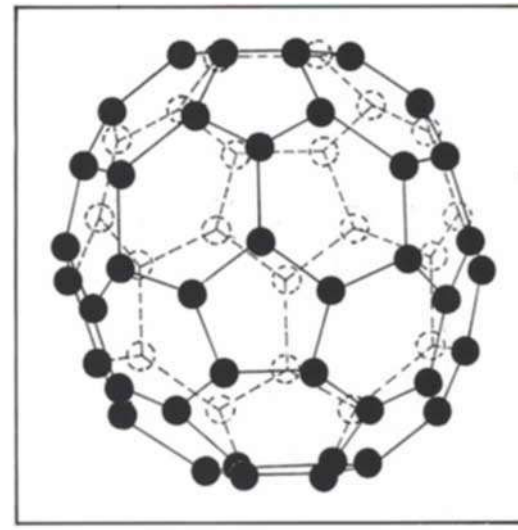

Combinations with the triacontahedron

Further designs involve bevelling the interfacial edges of the two forms (30 in each case). A dodecahedron modified in this manner has 42 faces (Figure 10, models 12, 11, 10) while the modified icosahedron has 50 faces (Figure 10, models 6, 7 and 8). The equilibrium combination of the former constitutes an alternative design for the soccer football (Model 11).

These bevels, in fact, constitute the positions of a triacontahedron, i.e. symmetrical grinding down of the bevels eliminating the other faces will produce a 30-faced triancontahedron in both cases. In fact this author was unaware of its existence and 'discovered' it by modifying the dodecahedron. The faces are all identical rhombs with plane face angles of 63.44° and 116.56° and interfacial angle of 36°. This form is illustrated in Figures 1 and 3. It is in fact one of a number of possible triacontahedra and is thus, in contrast to the pentagonal dodecahedron, the icosahedron and the other platonic solids, a variable form.

The various triacontahedra have sets of plane face

Table 3: Faceting angles for the construction of the triacontahedral 'sphere'

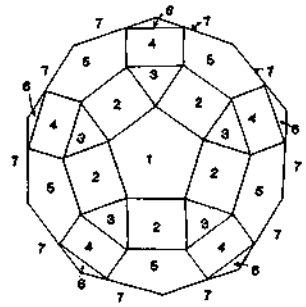

No.	Degree	Indices (80)				
1	0.0	Any				
2	31.7	8	24	40	56	72
3	37.4	80	16	32	48	64
4	58.2	80	16	32	48	64
5	63.4	8	24	40	56	72
6	79.2	80	16	32	48	64
7	90.0	4	12	20	28	36
		44	52	60	68	76

Lower hemisphere repetition in reverse order with 7 facets common. Ratio of diameter/side length = 4.

angles ranging between 108° and 120° (a) and between 72° and 60° (b). In each triacontahedron a + b = 180°. Although not a platonic solid since internal face angles are not the same the triacontahedron represents the ultimate of the forms possible consisting of identical rhombs. Another two are the crystallographic forms: the rhombohedron (a variable form typified by calcite) and the rhombic dodecahedron (a fixed form) both shown in Figure 3.

Table 4: Faceting angles for one of the variable forms of the triacontahedron

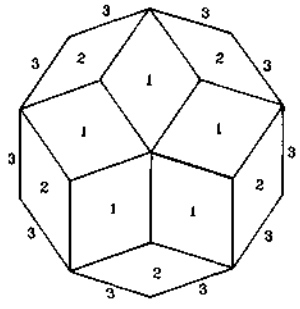

No.	Degrees	Indices (80)				
1	31.75	0	16	32	48	64
2	58.25	8	24	40	56	72
3	90.00	4	12	20	28	36
		44	52	60	68	76

Lower hemisphere: repetition in reverse order;
No. 3 facets common.
Ratio: Sphere diameter/rhomb side = 3.2

Examples of combinations of the three forms together of this symmetry class are also given in Figure 10 (models 13, 14, 15 and 16). 13 placed nearest the dodec has the dodec as the dominant form and the other two forms subordinate. Similarly, 14 represents the icosahedron dominant and 15 the triacontahedron dominant. Notice that throughout the two fixed forms have regular polygonal faces: equilateral triangles (icosahedron), regular pentagons (dodecahedron). The ultimate design in terms of symmetry, number of faces and aesthetics is, I believe, the equillibrium form where the triacontahedral faces become perfect squares and the polygons all have identical side lengths (model 16).

Faceting settings for this combination are given in Table 3.

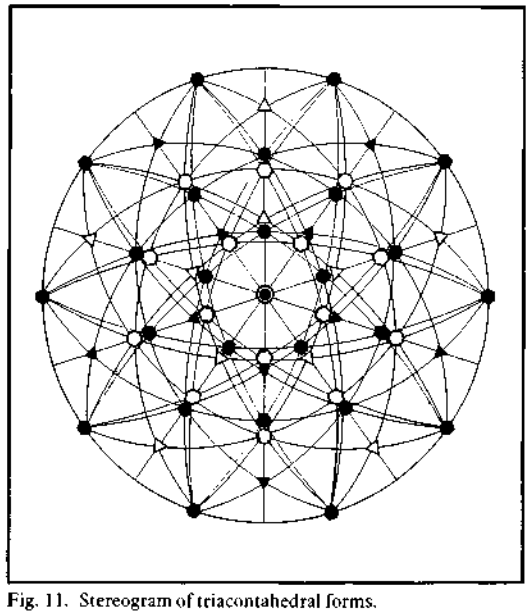

Fig. 11. Stereogram of triacontahedral forms.

Figure 11 is the stereogram of the combination projected with a dodec face horizontal. The combination fulfils the Euler equation (62 + 60 − 120 = 2).

The triacontahedron itself makes an attractive faceted sphere (Figure 1). Angular values of one of the variable forms are given in Table 4.

From purely theoretical considerations it was realised that a further four variable forms must exist to complete the seven entities of the symmetry group. These were first conceptualised from a stereographic projection, angles calculated and drawings produced by modifying those of the first three forms. Nomenclature was slightly problematical (see Table 1).

These four additional forms together with the three already discussed are shown in Figure 12. A

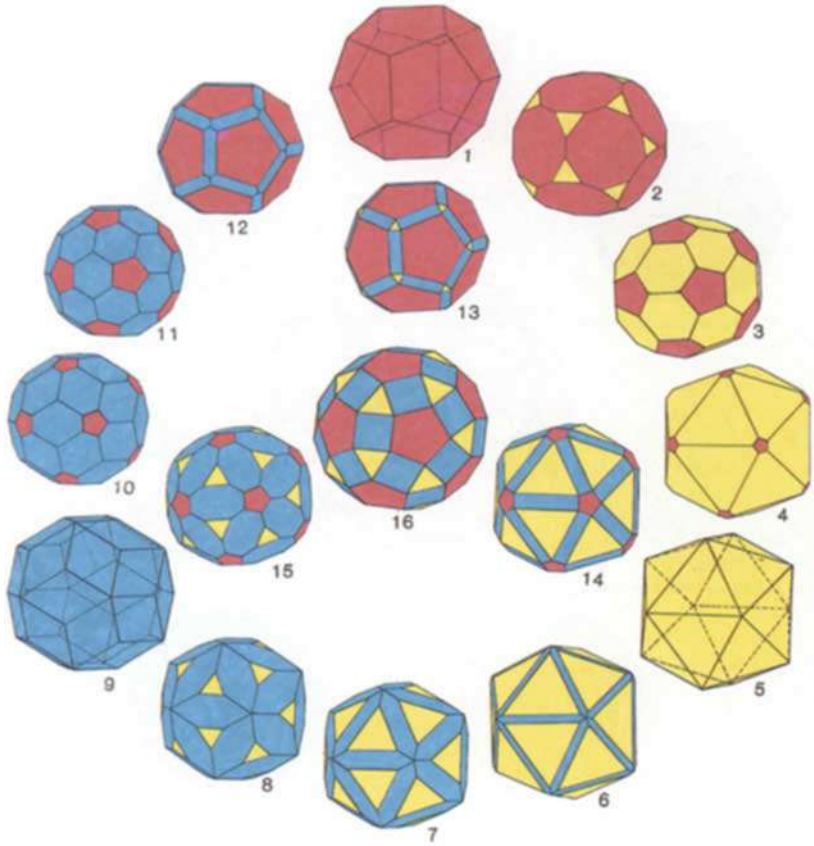

Fig. 10. Combinations of triacontahedral class.

combination of the seven forms with 362 faces is also shown. As before, examples of the variable forms with the simplest relationship to the fixed forms are shown. The entire group have been drawn in the same orientation – three orthogonal two-fold symmetry axes have been chosen as convenient reference axes (cf crystallographic axes) for this purpose. For the combination: vertices (360) + faces (362) − edges (720) = 2. Some mathematicians regard this as proof of the existence of the polyhedron!

Conclusion

Although there are an infinite number of polyhedra possible in consequence of the possibility of varying the relative development of the components of combined forms I believe that in respect of simple convex closed forms (those made of identical plane faces capable of independent existence) with maximum symmetry all the possibilities from a purely geometric point of view have been considered. Analysis reveals that:

1. All those symmetrical forms consisting of equilateral triangular faces have been considered: the tetrahedron, the octahedron, the icosahedron (all platonic solids). They involve respectively 3, 4 and 5 60° vertices meeting at a coign. One more (6) would total 360° and constitute a plane. Other forms consisting of equilateral triangles (there are five) have variable face numbers meeting at vertices and therefore lack or have low symmetry.

2. The only form possible consisting of square faces is the platonic cube. 3 90° vertices are a maximum.

3. The only form possible consisting of regular pentagonal faces is the platonic pentagonal dodecahedron. Only 3 vertices of 108° can form a coign.

4. The three non-platonic forms consisting of rhomb faces include the crystallographic rhombohedron (variable) and rhombic dodecahedron and also the triacontahedron (variable) now described in detail. Although the faces of these do not

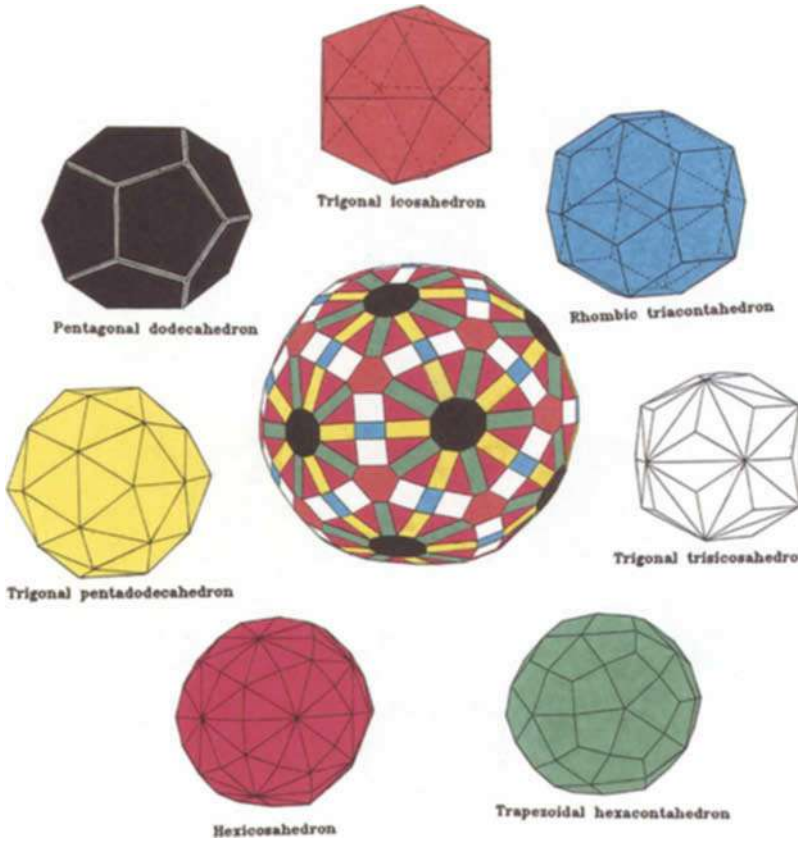

Fig. 12. Combination of the hexicosahedral polyhedra.

conform to platonic definition they do have two-fold symmetry and the triacontahedron additionally has the full symmetry of the platonic pentagonal dodecahedron and the icosahedron. These rhombic forms involve 3, 4 and 5 acute vertices forming coigns and 3 obtuse vertices forming the other coigns.

Fig. 13. The pentagonal hexcontahedron.

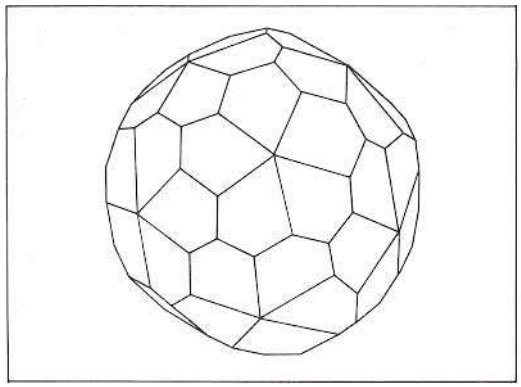

5. The additional forms with the same symmetry as the foregoing have all been considered. Other multiple identical faced (60, etc.) forms exist but they have lower symmetry. An example is the pentagonal hexcontahedron which lacks planes of symmetry (Figure 13).

6. The four additional forms of the isometric hexoctahedral class (all variable) have been considered since they do represent the highest crystallographic symmetry.

7. Numerous other simple forms, some crystallographically possible, have not been considered because of relatively low symmetry.

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Notes from the Laboratory – 16

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An interesting large spinel

A client recently submitted 'for interest only' a cushion-shaped red spinel (Figure 1). The stone weighed 149.92ct, measured approximately 32.5 x 31.5 x 15.7mm, and was in a specially made case.

The gemmological properties were consistent with natural spinel. The refractive index was 1.716, and when the stone was bathed in light filtered through a solution of copper sulphate the typical organ pipe spectrum (Anderson, 1990) was observed with the hand spectroscope. The fluorescence under long-wave ultraviolet was an intense red and under short-wave the appearance was somewhat 'chalky'. The stone contained numerous, and well formed, crystal inclusions (Figure 2). Some needle-like inclusions were also present. When viewed between crossed polars the stone displayed strain birefringence.

At two points on the stone's girdle the remains of drill holes (Figure 3) were observed, indicating that the stone was ancient and had been recut from the old traditional style of fashioning for spinel – essentially a polished crystal in which the basic crystal form is retained; such stones are usually drilled in various directions to facilitate different settings, including the possibility for it to be worn in a turban.

Fig. 1. The 149.92ct red spinel displaying the typical red colour. *(Photo K. Scarratt)*

Fig. 2. A closer view of the red spinel in Figure 1 and its well formed crystal inclusions. *(Photo K. Scarratt)*

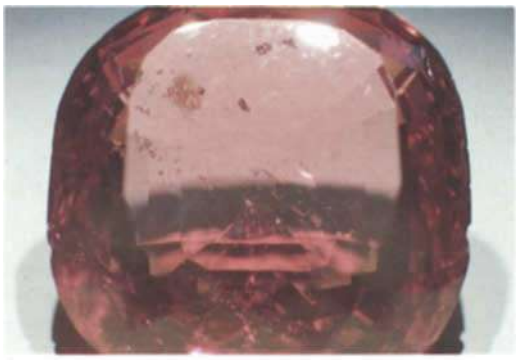

Fig. 3. A side view of the spinel shown in Figures 1 and 2 showing the semi-circular remains of a drill hole at the girdle. *(Photo K. Scarratt)*

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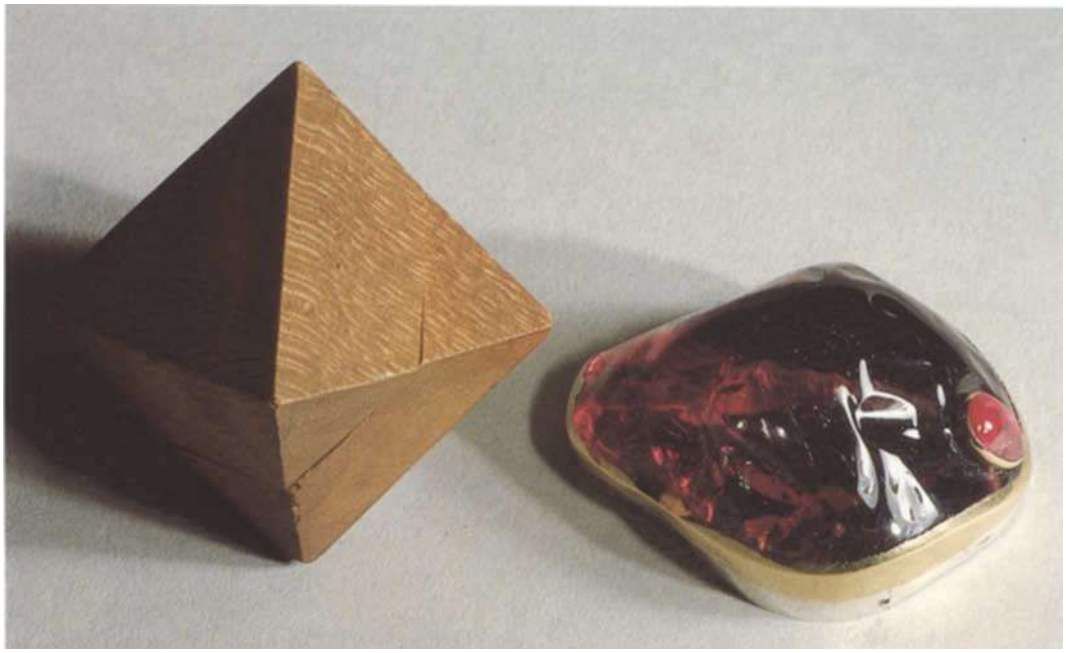

Fig. 4. The 'Black Prince's Ruby', a large spinel which is displayed in the front of the Imperial State Crown of the British Crown Jewels. The octahedron model has been positioned in a similar orientation with the faces of the 'Black Prince's Ruby'. *(Photo E.A. Jobbins)*

Originally the stone might well have been in a similar form to that of the 'Black Prince's Ruby' (an historical name for the large spinel displayed in the front of the Imperial State Crown of the British Crown Jewels). The 'Black Prince's Ruby' (with an octahedron model in similar orientation) is shown in Figure 4; it measures 43.3 x 33.8 x 20.1mm and weighs 220.50ct inclusive of its setting and inset cabochon-cut Burma ruby. There are four drill holes in the 'Black Prince's Ruby'. Given the present weight and dimensions of the two stones, it is possible that prior to recutting the 149.22ct cushion-shaped stone was originally larger than the 'Black Prince's Ruby'.

Fig. 5. 0.40ct treated blue diamond seen in reflected lighting conditions. *(Photo Jobbins/Scarratt)*

A Treated Diamond with an unusual blue colour

Whilst searching through the private coloured diamond collection of a New York dealer friend, I came across the treated diamond seen in Figure 5. The colour was unusual enough for me to want to examine the stone in more detail and the dealer was only too pleased for me to do so. He stated that he had had the stone treated in New York some years previously.

Infrared spectroscopy determined the diamond to be of the type Ia category and an examination of the stone's visible spectrum determined the presence of a strong 'General Radiation Band' and GR1. The normal face-up colour of the stone was an unusual shade of bright blue that tended towards turquoise (Figure 6). When viewed from a slight, and increasing angles, from the normal to the table, and also from the pavilion, much of the colour is lost (Figure 7). Peculiar yellow patches are also visible from certain angles (Figure 8).

The most interesting feature was the concentration of blue colour in the culet area (Figure 9) which is indicative of electron irradiation (Fritsch and Shigley, 1989). Whilst we have observed such colour concentrations in treated diamonds on many occasions, this must be one of the strongest examples recorded.

Fig. 6. The 0.40ct treated blue diamond in Figure 5 displaying the 'normal colour' seen by this stone. *(Photo Jobbins/Scarratt)*

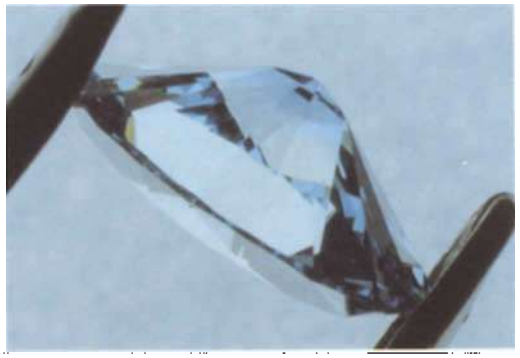

Fig. 7. Side view of the treated blue diamond showing the lack of colour in the body of the stone. *(Photo Jobbins/Scarratt)*

Fig. 8. The treated blue diamond viewed from the pavilion, and showing the lack of colour in the body of the stone. Peculiar yellow patches are also present. *(Photo Jobbins/Scarratt)*

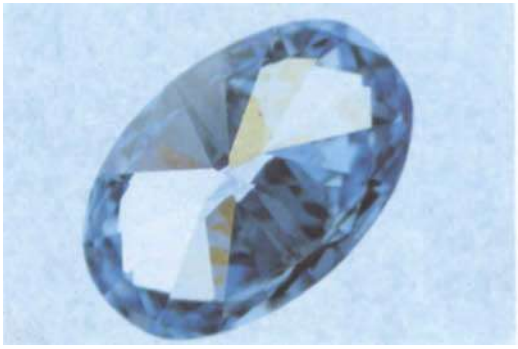

Fig. 9. Enlarged view of the pavilion area of the treated blue diamond seen in Figures 7 and 8. The colour concentration in the culet area indicates electron treatment. *(Photo Jobbins/Scarratt)*

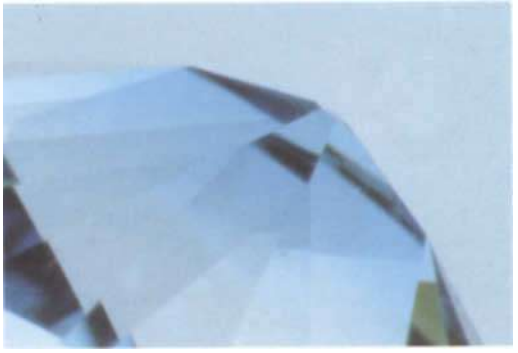

'Impregnated', 'Bleached' or 'B-Jade'

We have now had the opportunity to examine what is being termed 'bleached' or 'B-Jade' from two sources in Hong Kong. The first treated samples (a piece of rough and a fashioned disc or 'pi') were donated to the Laboratory by Dominic Mok of Hong Kong and the second set (treated rough and a treated cabochon) were provided by Mrs Anne Paul of Hong Kong, via Alan Hodgkinson in the UK (Figure 10).

The treatment process involves the removal of the brown 'iron stained' areas in lower quality jadeite samples, by soaking in hydrochloric acid and then impregnating the resultant material with a resin. The resin may be of the Araldite type or Opticon – the resin often used for the fracture filling of emeralds. The treated material appears to have a mugh higher lustre than one would expect for jadeite (Figure 11) and this may be the first indication that a piece of jadeite may have been treated in this manner.

Both the treated oval cabochon weighing 5.65ct

Fig. 10. Resin impregnated jadeite or 'B-Jade'. The disc on the right weighing 1.56ct and the cabochon on the left weighing 5.65ct. *(Photo K. Scarratt)*

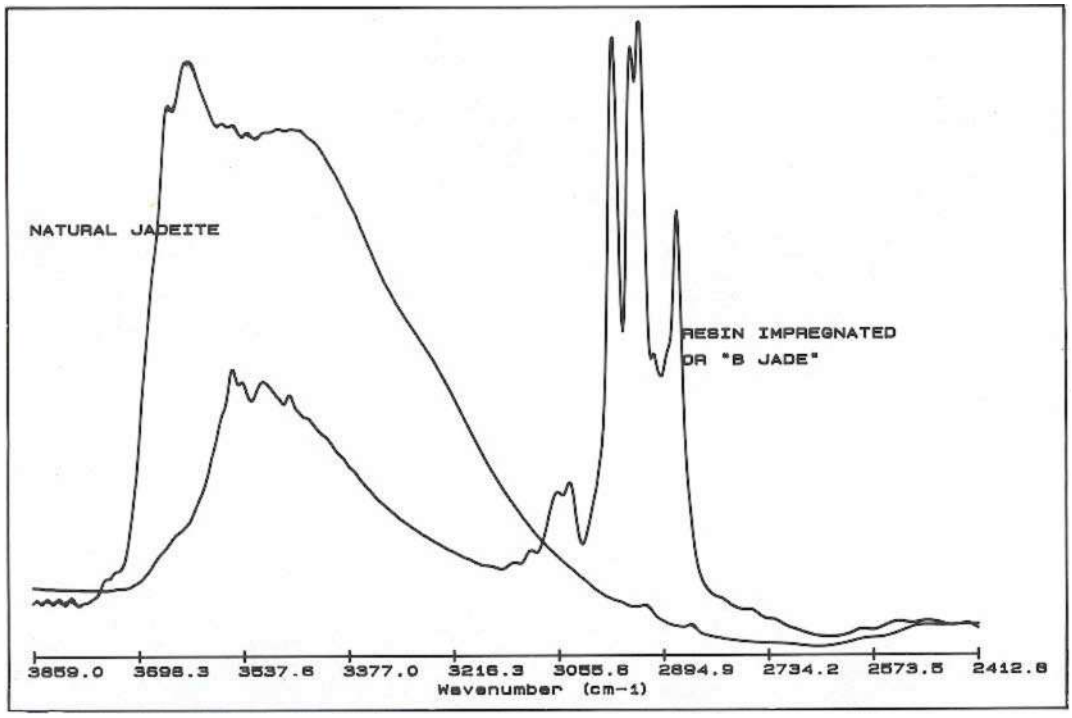

Fig. 12. Comparative infrared curves, in absorbence, of natural untreated jadeite and resin impregnated or 'B-Jade'.

and the disc weighing 1.56ct fluoresced a dull blue under short-wave ultraviolet light. The cabochon fluoresced an overall even blue under long-wave ultraviolet light whereas the disc was a more patchy blue. Of the two treated rough specimens, the larger weighing 40.71ct fluoresced a bright greenish-blue, whilst the smaller weighing 21.73ct fluoresced a bright blue under long-wave ultraviolet light. Under short-wave ultraviolet the two rough specimens fluoresced a more chalky version of their long-wave colour.

The refractive index taken from the flat back of the treated cabochon was 1.655, which is 'normal' for jadeite. The SG, obtained by hydrostatic weighing, was 3.31, which is also within the normal range for jadeite. Using the hand-held spectroscope, the normal jadeite absorption line at 437nm could be seen strongly in all the treated specimens. The normal jadeite 'chromium lines' were also readily apparent.

Fig. 11. A close view of the 1.56ct resin impregnated jadeite disc in Figure 14, showing the unusually high lustre. *(Photo Jobbins/Scarratt)*

A hot point was applied to the surfaces of the two fashioned specimens and the test areas examined through the microscope for signs of 'sweating' from the resin, but no signs of 'sweating' or any surface movement were observed. The two rough specimens both had a thick coating of the resin, and when the same test was applied to them the resin 'powdered'.

An infrared spectrum was taken of the treated cabochon (Figure 12) and compared with a piece of jadeite from the Laboratory collection. Additional features at 2969, 2942, 2928 and 2827cm^{-1} were noted in the cabochon's spectrum and these correspond with those reported for Opticon.

Cast polyester resin as an imitation of tortoiseshell, horn, ivory, bone and jet

Cast polyester resins in various colours and of differing internal structural patterns are being distributed by a company in West Sussex, (UK). The material is said to be of a quality suitable for

machining, drilling, threading, boring, and specialized turning, and takes an exceptionally high polish. Rods are being supplied from 20mm to 128mm in diameter and 1.5 metres in length. Rectangular sections, also in 1.5 metre lengths, are available in sizes from 25 x 35mm to 45 x 75mm. The material is also available in sheet form.

Amongst others, the colours and textures manufactured are those of ivory, bone, tortoise-shell, horn and jet (Figure 13). Given that the sale, or production, of items of adornment from ivory, tortoise-shell and horn is unacceptable to many people and governments, it is likely that polyester resin as a substitute may make an increasing appearance on the market in the future.

All colour types have a similar refractive index, hardness, SG, and IR spectrum. Separation from the natural materials may be achieved by either refractive index or SG determination (see Table 1), or more simply by microscopic observations.

The structures seen in the ivory imitation bore a little resemblance to ivory itself. Slightly wavy structural lines may be observed along the length, and in cross-section a slightly swirled structure may be seen (Figures 14 and 15). However, these should not be mistaken for the more distinctive elephant ivory structures (Figures 16 and 17).

Very little is visible in the bone imitation in the way of structure (Figure 13, right) whereas the structure of bone itself is very distinctive, (see Figures 18 and 19). The tortoise-shell imitation has an interesting colour distribution which gives an overall impression of the imitated material (Figure 14) but the structure is sufficiently different from tortoise-shell (Figure 20) for it to cause no problems with identification.

Fig. 14. The structures seen in the cast polyester resin imitations of: top row, left to right – horn and tortoise-shell (2), bottom row – 'onyx marble' and ivory. *(Photo E.A. Jobbins)*

The horn imitation has a structure quite different from the rhinoceros horn (Figure 21) it is supposed to imitate, with swathes of colour in cross-section (Figure 14) and a 'woodgrain' appearance along its length.

Fig. 13. The 'varieties' produced in cast polyester resin to imitate (rods, from left to right) tortoise-shell, 'onyx marble', jet, ivory, tortoise-shell, horn and bone. *(Photo E.A. Jobbins)*

Fig. 15. The slightly swirly structure seen in the cross-section of the cast polyester resin imitation of ivory. *(Photo K. Scarratt)*

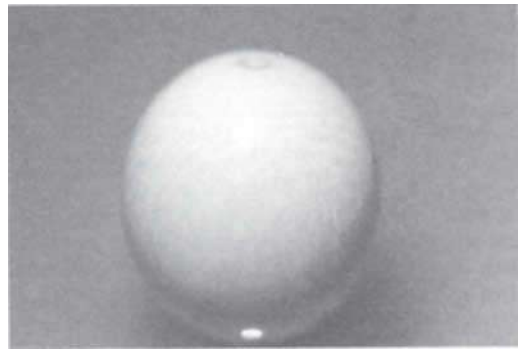

Fig. 16. An ivory bead showing the distinctive 'engine turning' structure common to elephant ivory. *(Photo K. Scarratt)*

Fig. 17. A thin section of elephant ivory showing the typical fine undulating structure seen on magnification – x10. *(Photo E.A. Jobbins)*

Fig. 18. The structure seen along the length of bone – x10. *(Photo E.A. Jobbins)*

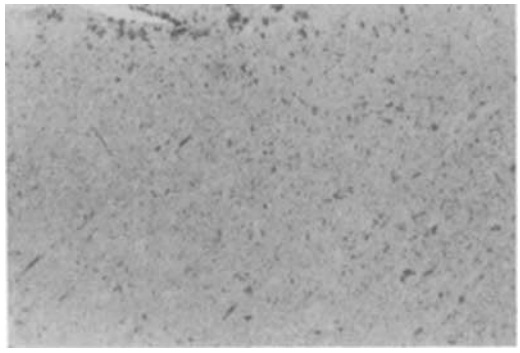

Fig. 19. The cross-section structure of bone – x10. *(Photo E.A. Jobbins)*

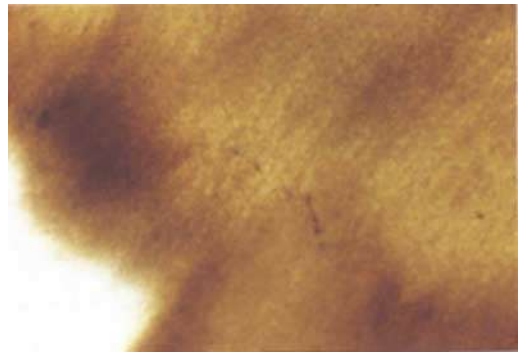

Fig. 20. Magnified view of the structure seen in natural tortoise-shell – x10. *(Photo E.A. Jobbins)*

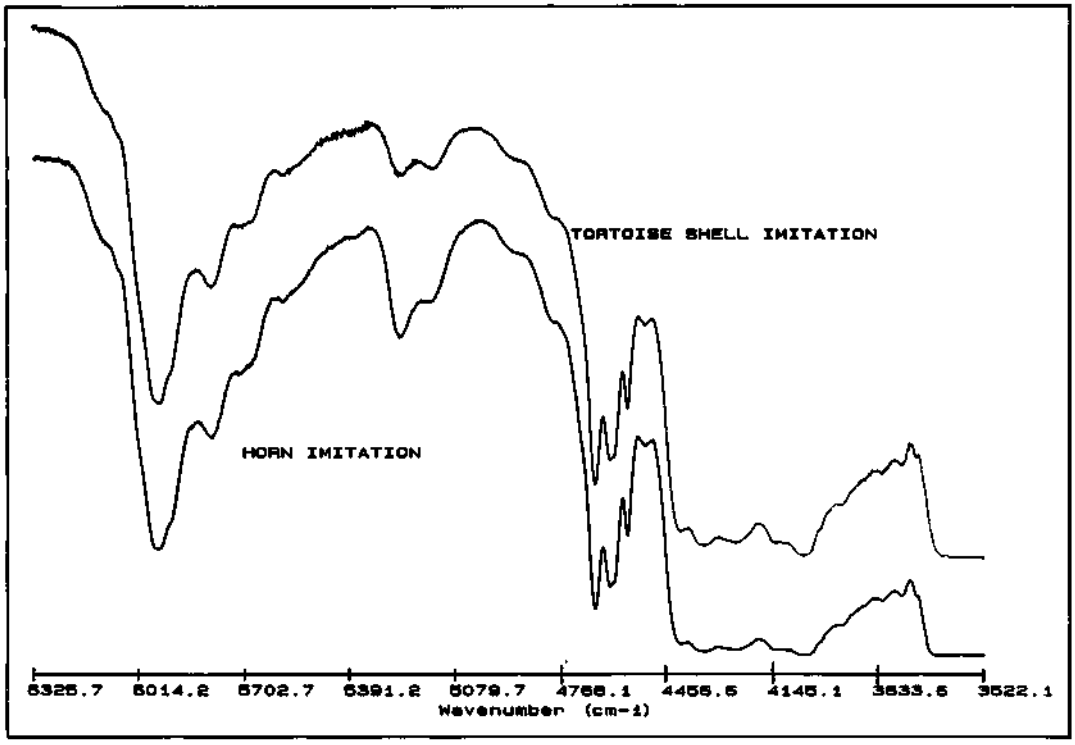

Fig. 24 Comparative infrared spectra, in transmission, of the cast polyester resin imitations of tortoise-shell and horn.

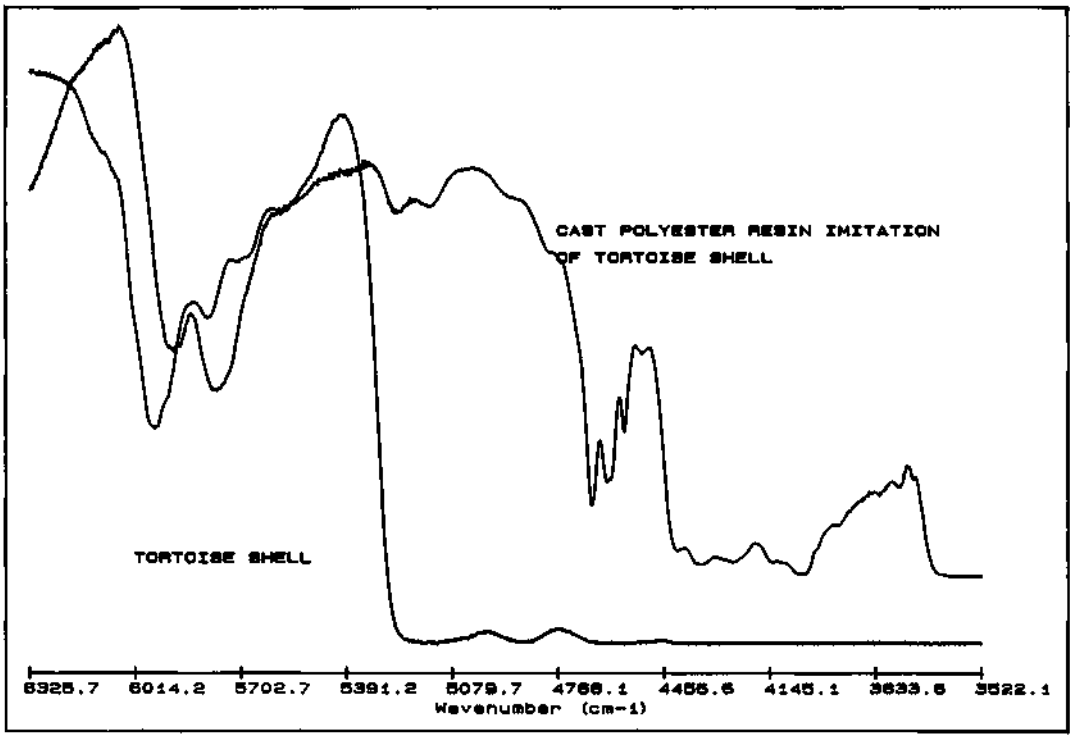

Fig. 25 Comparative infrared spectra, in transmission, of the cast polyester resin imitation of tortoise-shell and natural tortoise-shell.

Fig. 21. Section of rhinoceros horn showing the 'congealed hair-like' structure. *(Photo E.A. Jobbins)*

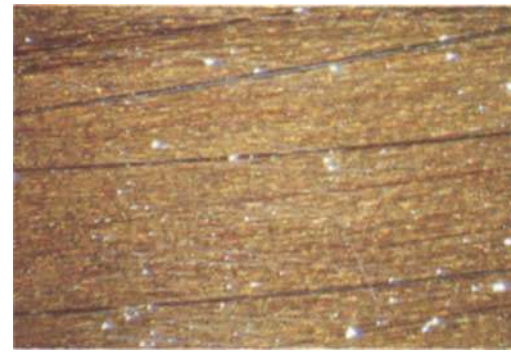

Fig. 22. Polished section of natural jet, showing 'wood grain' structure (moistened with light oil) – x25. *(Photo E.A. Jobbins)*

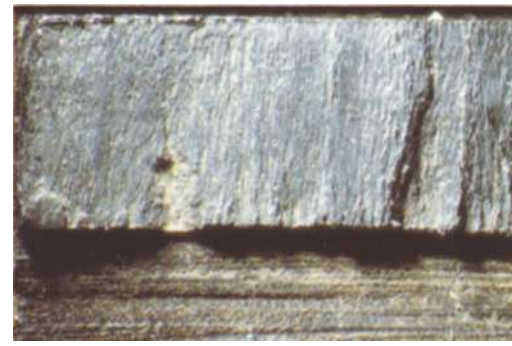

Fig. 23. Dry fracture surface of natural jet (above) with sawn section below – x25. *(Photo E.A. Jobbins)*

Table I

Material	RI	SG	H
Ivory (elephant)	1.54	1.7 – 1.9	2¼ – 2¾
Bone	1.54	2.00	2½
Horn (rhinoceros)	–	1.29	–
Tortoise-shell	1.55	1.29	2½
Jet	1.66	1.33	2½
Cast Polyester Resin	1.548	1.20 – 1.22	1½

A high magnification examination of the surface structure of jet will sometimes reveal a wood-like structure with brownish reflections (Figures 22, 23) whereas the polyester resin imitation shows no structure at all. A hot point placed on the surface of jet will give off the characteristic smell of burning coal, whereas the polyester resin gives off a 'sweet' and somewhat 'sickly' odour.

Positive identification of cast polyester resin may be achieved by infrared spectroscopy. Figure 24 compares the tortoise-shell and horn imtations whilst Figure 25 compares natural tortoise-shell with the resin imitation. The principal infrared features for cast polyester resin are situated at 5957, 5799, 5245, 5153, 4668, 4621, and 4574cm^{-1}.

A Note from the Bahrain Laboratory*

Although the Laboratory receives a much greater proportion of pearls for testing than gems, it does see more amber and its simulants than the London Laboratory. One of the reasons for the popularity of amber in Bahrain is that, owing to its light weight and 'pleasant feel', it is a material ideally suited for fashioning into 'worry beads'.

Seeing this quantity and variety of amber, inevitably means that the Bahrain Laboratory encounters various forms of enhancement in the course of testing. Some of these enhancements reveal clear identification features that allow for a straightforward description, whilst others are not so co-operative.

Recently an example of the type of problem encountered when testing amber arrived in the Laboratory. A necklace consisting of 47 yellow/orange faceted beads (see Figure 26) was submitted for examination.

The usual tests associated with the identification of amber were carried out. The necklace floated in saturated brine, hot needle tests applied to a number of beads produced the characteristic aromatic odour of amber, and sectility tests revealed that the material splintered in the manner normal for amber (these last two tests may only be applied with extreme care and only to an 'inconspicuous area' of the sample, e.g. inside the drill hole of a bead).

The problems began to arise when the necklace was examined with the aid of a microscope. The colour appeared to be confined to the surface and formed a symmetrical pattern on the facets of each bead. Detailed examination revealed that the surface colour was concentrated in the centre of each facet with the edges only showing the much paler underlying colour. However, the lustre of the surface was even and no form of 'coating' could be seen.

When the necklace was immersed, the colour pattern bore a similarity to that normally seen on the facets of an immersed diffusion-treated corundum (Nassau, 1981), but in reverse. In this instance the beads were pale or colourless at the facet edges with the concentration of colour being in the central area of each facet.

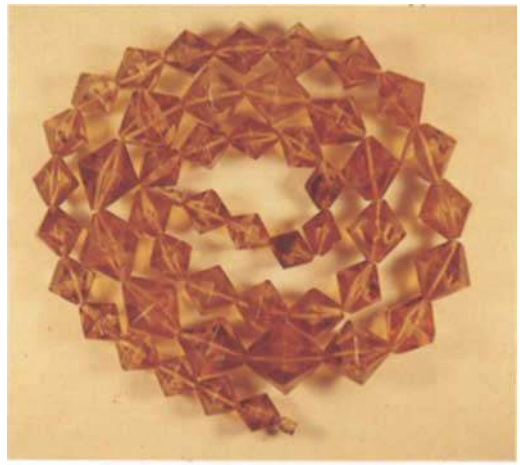

Fig. 26 A necklace of 47 surface colour enhanced amber beads. *(Photo N. Sturman)*

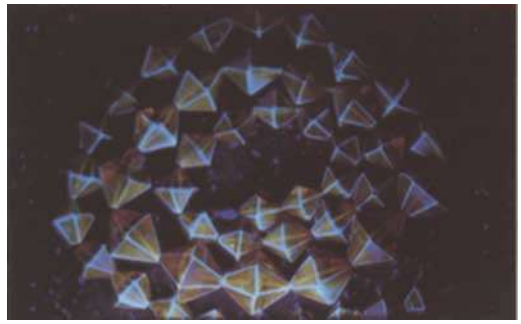

Fig. 27 The effect seen when the amber necklace seen in Figure 26 is bathed in ultraviolet light. *(Photo N. Sturman)*

In addition to the unusual colour distribution, the beads revealed a peculiar and striking fluorescence (Figure 27) when exposed to both long-wave and short-wave ultraviolet light. Where the colour was concentrated the fluorescence was one of a dull chalky greenish-brown, whilst in the areas of no colour it was a very bright chalky bluish-white.

Inclusions such as plant-life, bubbles, swirls and thread-like tubules indicated that the material was

*The Gem and Pearl Testing Laboratory of Bahrain is a government laboratory set up and operated with the assistance of GAGTL. Ahmed Bubshait is the head of the Laboratory and currently Nick Sturman is the GAGTL officer on secondment. This is the first note from Ahmed and Nick to be included in 'Notes from the Laboratory', and we look forward to more in the future.

Fig. 28 Examples of surface enhanced amber showing the deep yellow exterior contrasting with the colourless to near-colourless interior. Each specimen has been specially sectioned and polished to display the effect of the treatment. *(Photo K. Scarratt)*

not pressed amber. This was confirmed by the absence of the characteristic strain patterns normally associated with some forms of pressed amber.

The nature of this enhancement is not certain but it may be similar to the heat-treated amber discussed by Scarratt (1986) and in Burland (1992). In such cases the surface colour concentration is a by-product of the 'clarification process'. Cloudy amber which has already been fashioned into the desired form, is gradually heated by 50° steps up to approximately 200°C in an ordinary domestic type oven. This process clarifies the amber but sometimes lessens the interior colour to a point where it is almost colourless, whilst at the same time producing a much darker exterior (Figure 28). The Laboratory's conclusion was 'surface colour enhanced amber'.

Acknowledgements

It is with thanks that the author acknowledges the assistance of his colleagues in the Laboratory, in particular Steve Kennedy who produced the visible spectrum of the treated blue diamond, and confirmed the SG's of the impregnated jadeite and cast polyester resin. He also wishes to record his appreciation of the tremendous assistance given by Alan Jobbins in the production of the photomicrographs.

Also acknowledged is the generosity of Mr Peter Kaplan for allowing the author to examine his coloured diamond collection. The author also wishes to thank Mrs M.E. Hutchinson of the Ancient Monuments Laboratory (English Heritage) for bringing the cast polyester resin imitations to his notice. Both Ahmed Bubshait and Nick Sturman acknowledge, with grateful thanks, the assistance of their colleagues in Bahrain and London.

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The Chemical Properties of Colombian emeralds

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Abstract

Ninety emeralds from different mining regions (Muzo, Coscuez, Yacopí, Chivor/Somondoco, and Gachalá) in the Cordillera Oriental/Colombia were examined by micro-X-ray-spectroscopy (microprobe). The results of the chemical analyses are discussed using the correlation diagrams Al_2O_3/MgO, Al_2O_3/Na_2O, Al_2O_3/FeO_{tot}, Na_2O/MgO, Na_2O/FeO_{tot}, and FeO_{tot}/MgO.

1. Introduction

The Colombian emerald occurrences are situated in the so-called 'emerald-belt' of the Cordillera Oriental. Within this belt two mineralized zones can be distinguished: the Western zone containing the mining regions of Muzo, Coscuez, and Yacopí (Figure 1) and the Eastern zone with the mining regions Chivor/Somondoco and Gachalá (Figures 1 and 2).

2. Chemical data

In the course of our examinations a total of 90 emeralds originating from different mining regions of the Cordillera Oriental/Colombia were chemically analyzed by micro-X-ray-spectroscopy (microprobe). In detail, emeralds from the following localities were examined (number of samples in parentheses):

Muzo	(20)
Coscuez	(07)
Yacopí	(11)
Chivor	(14)
('Polpito' and 'El Oriente' areas)	
Gachalá	(08)
('Vega de San Juan', 'El Diamante' and 'Las Cruces' areas)	

For another 30 samples the mines of origin could not be exactly determined, these are designated in a general manner as 'Colombian emeralds'.

Table 1 gives the chemical data (width of variations and mean concentrations) for emeralds from the Western mineralization zone (covering the regions of Muzo, Coscuez and Yacopí). The chemical data for emeralds from the Eastern mineralization zone with the regions of Chivor/Somondoco and Gachalá are compiled in Table 2 (including the data from Kozlowski *et al.*, 1988, for emeralds from Achiote-Somondoco). The chemical data of 4 samples showing colour zoning are given in Table 3. Table 4 contains a compilation of literature data

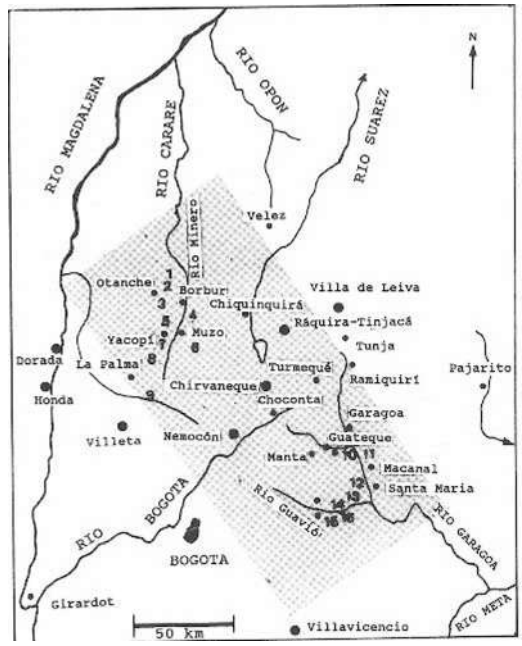

Fig. 1. The 'emerald belt' of the Cordillera Oriental/Colombia with the Western (Muzo-Coscuez-Yacopí) and the Eastern (Chivor/Somondoco-Gachalá) mineralization zones.

1 = Penas Blancas
2 = La Chapa
3 = Coscuez
4 = Santa Rosa
5 = Muzo
6 = Maripí/Coper
7 = Yacopí
8 = La Mina (Glorieta) /Aposentos
9 = El Penon
10 = Achiote/Somondoco
11 = Sagrada Familia/ Pavaranado
12 = Chivor
13 = Buenavista
14 = Mundo Nuevo
15 = Las Cruces/El Toro/ El Diamante
16 = Vega de San Juan

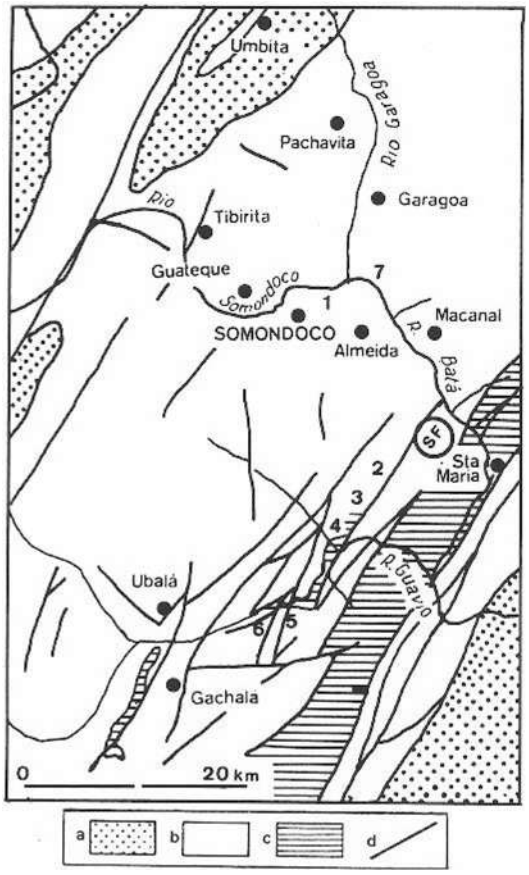

Fig. 2. The Colombian emerald occurrences (geographic situation) in the region Chivor/Somondoco-Gachalá. (Modified after Kozłowski *et al*, 1988).
1 = Achiote/Somondoco
2 = Chivor
3 = Buenavista
4 = Mundo Nuevo
5 = Las Cruces/El Toro/El Diamante
6 = Vega de San Juan
7 = Sagrada Familia/Pavaranado
a = Tertiary
b = Cretaceous
c = pre-Cretaceous
d = faults
SF = San Fernando fault

from earlier studies (Zambonini, 1928; Tsherepivskaya, 1971; Hänni, 1980; Hänni, 1982; Schrader, 1987, and Aurisicchio, 1988) and also the values for width of variations and mean concentrations of 26 emeralds from different (but not exactly known) mining areas in the Cordillera Oriental that were examined by the author.

Partial analyses of Colombian emeralds can be found in Staatz *et al.* (1965), Barriga & Villalba (1973), Schrader (1981) and Landais (in Gübelin, 1982).

Emerald as a member of the beryl group has the chemical formula $Be_3Al_2Si_6O_{18}$. The oxide concentrations that correspond to this ideal composition are SiO_2 = 67.07%, Al_2O_3 = 18.97% and BeO = 13.96%. But it has been known for a long time that natural beryls only in rare cases come to this standard composition, mostly they show distinct deviations from it (this is a well-known behaviour that can be observed also in many other minerals). These discrepancies go back to the fact that certain lattice components can substitute for each other and some additional ('extraneous') elements (that do not appear in the chemical formula) may enter the crystal structure.

As we can see from the chemical data of Tables 1-4, in the case of emerald these 'extraneous' elements are mainly magnesium, sodium, iron, and, naturally, the colouring agents chromium and vanadium. Therefore, the discussion of the chemical characteristics of the beryl variety emerald may be restricted initially to these 5 elements. But in view of geochemical-genetic considerations it is certainly of interest to include in future certain trace elements.

Our investigations, realized on emeralds from different localities (Brazil, Schwarz, 1990; Norway and Australia, Schwarz, 1991a; Habachtal and Ural Mountains/USSR, Schwarz, 1991b) have clearly shown that the contents of the 'extraneous' elements present, in part, considerable widths of variations. This is valid not only for samples coming from the same mining region, but also for the (mean) concentrations in emeralds from different localities (see also Section 3). It is a factor that in many former studies was not taken into account sufficiently. Sometimes, inadmissible or generalized conclusions based only on a few chemical data have been drawn to characterize the chemical properties of emeralds originating from a certain mining field or a certain geographic region.

With regard to magnesium and sodium our studies show that the contents of these elements in Colombian emeralds are low.*

The lowest mean concentrations (0.25% Na_2O and 0.34% MgO) were observed in the emeralds from the mining region of Gachalá. The highest contents of these oxides (about 1% MgO and 0.7-0.8% Na_2O) are shown by crystals from Yacopí

*The concentration bands for the elements chromium, vanadium, iron, sodium and magnesium were delimited empirically by the following values (in wt% Cr_2O_3, V_2O_3, FeO, Na_2O and MgO; Schwarz, 1988 and 1990):

	low	medium	high
chromium	‹0.2	0.2-0.4	›0.4
vanadium	‹0.2	0.2-0.4	›0.4
iron	‹0.5	0.5-1.0	›1.0
sodium	‹1.0	1.0-2.0	›2.0
magnesium	‹1.5	1.5-2.5	›2.5

Table 1: Chemical data (width of variations and mean concentrations for the number of samples given in parentheses) of Colombian emeralds from the mining regions of Muzo, Coscuez and Yacopí.

	Muzo	(20)	Coscuez	(07)	Yacopí	(11)
SiO_2	65.47-67.63	67.07	66.81-67.81	67.31	66.10-67.08	66.65
Al_2O_3	16.24-18.11	17.23	15.40-17.02	16.19	16.54-17.67	16.98
Cr_2O_3	0.06- 0.69	0.27	0.02- 0.08	0.05	0.02- 0.09	0.06
V_2O_3	0.05- 0.81	0.29	0.03- 0.08	0.05	0.02- 0.10	0.08
FeO	0.03- 0.16	0.07	0.05- 0.40	0.19	0.04- 0.25	0.17
MnO	< - 0.05	0.02	< - 0.03	0.02	< - 0.06	0.02
MgO	0.44- 1.10	0.65	0.59- 1.48	1.00	0.67- 1.27	0.98
Na_2O	0.24- 1.02	0.53	0.53- 1.03	0.72	0.56- 1.04	0.80
CaO	< - 0.02	–	< - 0.01	–	< - 0.01	–
K_2O	< - 0.02	0.01	< - 0.02	0.01	< - 0.02	–
TiO_2	< - 0.02	0.01	< - 0.02	0.01	< - 0.03	–

Obs.: < = element concentration below detection limit of the analytical method

Table 2: Chemical data (width of variations and mean concentrations for the number of samples given in parentheses) of Colombian emeralds from Chivor and Gachalá (including the data of Kozlowski *et al.*, 1988, for emeralds from Achiote/Somondoco).

	Chivor	(14)	Gachalá	(08)	Somondoco	(07)
SiO_2	66.22-68.20	67.59	66.77-67.55	67.22	64.18-65.55	64.96
Al_2O_3	16.64-17.71	17.11	16.69-17.48	17.15	17.04-18.84	18.25
Cr_2O_3	0.01- 0.50	0.18	0.02- 0.43	0.10	0.01- 0.34	0.17
V_2O_3	0.03- 0.23	0.08	0.02- 0.15	0.09	0.01- 0.13	0.08
FeO	< - 0.50	0.10	0.03- 0.12	0.07	0.14- 0.60	0.30
MnO	< - 0.03	0.02	< - 0.03	0.02	0.0 - 0.05	0.02
MgO	0.32- 0.85	0.63	0.15- 0.48	0.34	0.74- 1.65	1.11
Na_2O	0.20- 0.54	0.39	0.14- 0.29	0.25	0.70- 1.50	1.01
CaO	< - 0.02	–	< - 0.02	0.01	0.0 - 0.02	0.01
K_2O	0.01- 0.08	0.02	< - 0.01	0.01	0.03- 0.09	0.05
TiO_2	< - 0.04	0.02	< - 0.02	0.01	0.0 - 0.03	0.01

Obs.: < = element concentration below detection limit of the analytical method

Table 3: Chemical data of Colombian emeralds showing colour zoning.

	(A)		(B)		(C)		(D)	
	R	K	R	K	R	K	R	K
SiO_2	66.50	66.19	66.31	66.67	65.84	65.40	64.63	64.19
Al_2O_3	17.27	17.52	17.44	16.99	17.04	16.93	16.44	17.51
Cr_2O_3	0.28	0.05	0.16	0.03	0.17	0.01	0.64	0.01
V_2O_3	0.11	0.04	0.21	0.06	0.20	0.05	0.56	0.03
FeO	0.06	0.06	0.05	0.10	0.05	0.13	0.06	0.03
MnO	<	<	–	–	–	–	–	–
MgO	0.71	0.69	0.41	0.87	0.46	0.89	0.67	0.84
Na_2O	0.58	0.55	0.32	0.91	0.45	0.88	0.54	0.70
CaO	<	<	<	0.01	0.02	<	0.01	<
K_2O	0.01	0.01	<	<	0.03	0.02	0.03	0.03
TiO_2	<	<	0.01	0.02	<	<	<	0.02

Obs.: R = green border zone
K = colourless central zone
< = element concentration below detection limit of the analytical method
– = no data for this element

Table 4: Chemical data of Colombian emeralds: compilation of literature data from Zambonini (1928), Tsherepivskaya (1971), Hänni (1980), Hänni (1982), Schrader (1987), and Aurisicchio (1988). The width of variation and mean concentrations of 26 emeralds analyzed by the author coming from different (but not exactly known) localities in the Cordillera Oriental are also given.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)
SiO_2	65.26	65.07	65.8	66.0	66.4	66.6	65.2	64.6	67.15	64.98	64.39	65.95	65.34	65.23-68.48	66.58
Al_2O_3	17.60	18.51	16.7	16.9	16.9	17.7	16.3	16.3	17.94	17.43	17.55	17.19	16.51	15.54-18.33	17.17
Cr_2O_3	–	0.13	0.8	0.6	0.2	0.3	0.2	0.2	0.58	0.32	0.22	0.03	0.37	0.01- 0.93	0.15
V_2O_3	–	–	–	–	0.3	0.4	0.8	0.6	0.10	0.11	0.06	0.05	0.64	< - 1.27	0.24
FeO	0.08	0.65	0.1	0.0	0.0	0.0	0.0	0.0	0.05	0.07	0.04	0.10	0.31	< - 0.23	0.08
MnO	0.06	0.02	0.0	0.1	0.0	0.0	0.0	0.0	–	–	–	–	<	< - 0.07	–
MgO	0.77	0.24	0.5	0.4	1.4	1.0	1.0	1.2	0.31	0.34	0.17	0.97	0.67	0.13- 1.52	0.66
Na_2O	0.50	0.43	0.4	0.4	1.0	0.6	0.8	0.8	0.27	0.18	0.07	0.74	0.49	0.11- 1.16	0.46
CaO	0.09	0.65	0.0	0.0	–	–	–	–	0.01	0.01	0.01	0.01	–	< - 0.02	–
K_2O	0.22	0.16	0.0	0.0	–	–	–	–	–	–	–	–	<	< - 0.05	–
TiO_2	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.1	–	–	–	–	<	< - 0.04	–

Obs.: (1) = Zambonini (1928) (Muzo)
(2) = Tsherepivskaya (1971) (Muzo)
(3), (4) = Hänni (1980)
(5)-(8) = Hänni (1982)
(7), (8) = 'Trapiche' emeralds
(9)-(12) = Schrader (1987) (9, 10; 11 Chivor)
(13) = Aurisicchio (1988) (Muzo)
(14) = width of variations of 26 Colombian emeralds (this paper)
(15) = mean concentrations of 26 Colombian emeralds (this paper)
< = element concentration below detection limit of the analytical method
– = no data for this element

and Coscuez. Comparing the Na and Mg concentrations of emeralds coming from the two mineralized emerald zones of the Cordillera Oriental, it is obvious that there are no distinct differences. This fact indicates that the geological-geochemical processes that are responsible for the introduction of the elements sodium and magnesium in the two mineralization zones are basically of the same nature. Besides this it shows that regional mineralization processes (e.g. with the participation of the evaporites present in the whole region) are more than probable locally restricted events (as is, for example, the case when contact metamorphism is related to the emplacement of pegmatites).*

The iron contents in Colombian emeralds are low to very low throughout. The highest iron concentration of the samples examined by the author was observed in a Chivor emerald (0.50% FeO). The Somondoco emeralds examined by Kozlowski *et al.* (1988) exhibited FeO concentrations from 0.14-0.60% with a mean concentration of 0.30% FeO. Barriga and Villalba (1973) and Landais (in Gübelin, 1982) report FeO contents of 0.9% and up to 0.72% respectively for emeralds from Muzo.

The elements responsible for the brilliant green colour of the Colombian emeralds are chromium and vanadium. Contents of these vary widely. This behaviour is also known of emeralds coming from other (genetically different) localities. Frequently in the literature it has been pointed out that emerald crystals found immediately side by side in the same vein may show quite different shades of green. Besides this, many emeralds (from the most different occurrences) distinguish themselves by a distinct colour zoning (compare also Table 3). This clearly shows that the supply of chromium in the emerald 'mother liquor' suffered strong variations through time and space.

As can be seen from the analytical data, all these considerations are valid in an analogous manner also for the element vanadium. It must be emphasized that the samples from Colombia are amongst those with the highest vanadium concentrations of all emeralds analyzed by the author up to the present. They are surpassed only by the Norwegian emeralds from the Eidsvoll/Lake Mjosa deposit (mean concentration of four samples = 1.29% V_2O_3; Schwarz, 1991) and the so-called 'V-beryls' from Salininha/Bahia, Brazil. At this point we should like to emphasize again the fact that the mean concentrations of vanadium and chromium in Colombian emeralds are of the same order of magnitude (the mean concentrations of the 90 emeralds examined by the author during the present investigation are 0.16% Cr_2O_3 and 0.18% V_2O_3 respectively). In many samples the vanadium content is even distinctly higher than the chromium concentration. On the other hand there are many emeralds that show a more or less pronounced dominance of chromium. A third 'type' of Colombian emeralds contains comparable amounts of these colouring

*A detailed compilation and a discussion of the different hypotheses used to explain the genesis of the Colombian emerald occurrences is given by Schwarz, 1991(c).

Table 5: Chemical data of some Colombian emeralds showing different ratios of the colour-influencing elements chromium, vanadium, and iron.

	Cr_2O_3	V_2O_3	FeO_{tot}
Yacopí	0.02	0.10	0.25
Chivor	0.11 0.34	0.04 0.08	0.50 -
Gachalá	0.43 0.02	0.15 0.10	0.09 0.03
Muzo	0.69 0.34 0.51	0:59 0.81 0.52	0.05 0.08 0.09
Coscuez	0.02	0.03	0.40
Mining region not known	0.31 0.06 0.93	1.27 0.69 0.54	0.13 0.43 0.10

elements (see also Table 5). Surely, the significance of the element vanadium as agent for the green colour of emerald has not been taken into consideration adequately in the past. It would be desirable with regard to a future discussion on the definition of the term 'emerald' to give more importance to the element vanadium. From the mineralogical point of view it is surely not justified to consider the chromium content as only criterion for the delimitation emerald-green beryl.

Table 3 shows the chemical data of four Colombian emeralds presenting a distinct colour zoning with an almost colourless central part and a green border zone ('rim'). As can be expected, the colour zoning is clearly related to the concentrations of the colouring elements chromium and vanadium. The contents of these elements are distinctly higher in the border zone. On the other hand the iron concentrations are in the same order of magnitude in the different parts of the crystals. It seems that there is no correlation between the content of this element and the intensity of the green colour. The concentrations of the elements sodium and magnesium are much higher in the central zones of three samples, however, in the fourth one these concentrations show almost no variation. By this, we can conclude that for the crystals examined the incorporation tendency of the elements sodium and magnesium is contrary to that observed for the colouring agents chromium and vanadium!

Emeralds from Colombia showing a colour zoning are relatively common. Crystals with a colourless or a weakly coloured greenish central core and a deep green border zone ('rim') have been described, among others, by Scheibe (1926) and Ringsrud (1986) from Muzo. MacFadden (1934) describes an emerald from Somondoco with several concentric 'colour-rings' around a colourless central core that becomes increasingly darker from the inner to the outer regions.

Sinkankas (1981) and Kozlowski *et al.* (1988; a crystal from the Juntas mine in Achiote/Somondoco) mention stones with a distinct colour zoning consisting of a green emerald core surrounded by a colourless border zone.

Among the data of former investigations (compiled in Table 4) the high CaO content of a Muzo emerald (analyzed by Tsherepivskaya, 1971) is just as striking as the high concentrations (compared to the data published by other authors) of K_2O in emeralds from Muzo reported by Zambonini, 1928 (0.22%) and Tsherepivskaya, 1971 (0.16%).

3. Discussion of element correlation diagrams

3.1 *Correlation diagram Al_2O_3/MgO*

In the diagram of Figure 3, the representative points of the chemical analyses (mean concentrations) of emeralds from Colombia, Brazil, Australia, Norway, Austria, and the USSR are marked. For comparison purposes the data for pegmatite beryls from the mining regions of Governador Valadares and Araçuai-Salinas, Minas Gerais, Brazil, are also shown.

It is interesting to note in this diagram, the large variation of the contents of Al_2O_3 and MgO in emeralds from different occurrences. The lowest mean concentrations of MgO (0.05%) of all samples examined by the author up to the present are shown by the emeralds from the Emmaville mining region in New South Wales, Australia. The highest mean concentrations of this oxide (about 3%) were observed in Brazilian emeralds from the occurrences Salininha/BA, Santa Terezinha/GO, and Itaberaí/GO. The representative points for emeralds from the different Colombian deposits are placed, throughout, in the upper left part of the population area. This means that their magnesium contents are low and their aluminium concentrations are high. The distinctly developed diagonal distribution trend (with negative slope) of the population field verifies that the introduction of magnesium into the emerald-/beryl structure follows the substitution reaction (1).

$$(1)\ Al^{3+,VI} = Mg^{2+,VI}$$

3.2 *Correlation diagram Al_2O_3/Na_2O*

The representative points in the correlation diagram Al_2O_3/Na_2O (Figure 4) show a behaviour that is analogous to the one observed in the diagram Al_2O_3/MgO: the clearly developed diagonal trend with negative ascent shows that the rising Na content of the emeralds is accompanied by a decrease of the Al_2O_3 concentration. This behaviour is based on the following substitution reaction (2).

$$(2)\ Al^{3+,VI} = Me^{2+,VI} + Na^{1+\ (channel)}$$

Correlation diagrams for Al_2O_3/MgO (Fig. 3), Al_2O_3/Na_2O (Fig. 4), Al_2O_3/Fe_{tot} (Fig. 5), Na_2O/Fe_{tot} (Fig. 7), Fe_{tot}/MgO (Fig. 8), with the representative points (mean concentrations for emeralds from Colombia, Brazil, Australia, Norway, Austria and the USSR (data from this paper and from Schwarz, 1990; Schwarz, 1991a and Schwarz, 1991b).

(1)	Carnaíba/BA	(38)*	(13)	Eidsvoll, Norway	(04)*
(2)	Capoeirana/MG	(16)*	(14)	Ural Mountains, USSR	(11)*
(3)	Belmont Mine/MG	(48)*	(15)	Habachtal, Austria	(10)*
(4)	Socotó/BA	(63)*	(16)	Untersulzbachtal, Austria	(06)*
(5)	Tauá/CE	(11)*	(17)	'Colombia' (exact mines of origin not known)	(30)*
(6)	Pirenópolis/GO	(07)*	(18)	Yacopí, Colombia	(11)*
(7)	Salininha/BA	(05)*	(19)	Coscuez, Colombia	(10)*
(8)	Itaberaí/GO	(13)*	(20)	Muzo, Colombia	(20)*
(9)	Santa Terezinha/GO	(29)*	(21)	Somondoco, Colombia (Kozlowski *et al.*, 1988)	(07)*
(10)	Poona/Western Australia	(12)*	(22)	Gachalá, Colombia	(08)*
(11)	Menzies/Western Australia	(04)*	(23)	Chivor, Colombia	(14)*
(12)	Emmaville/NSW, Australia	(05)*			
(C1)	Pegmatite beryls from the Araçuai-Salinas region/MG (Correia Neves *et al.*, 1984)				(09)*
(C2)	Pegmatite beryls from the Governador Valadares region/MG (Correia Neves *et al.*, 1984)				(05)*
* =	number of analyzed samples				

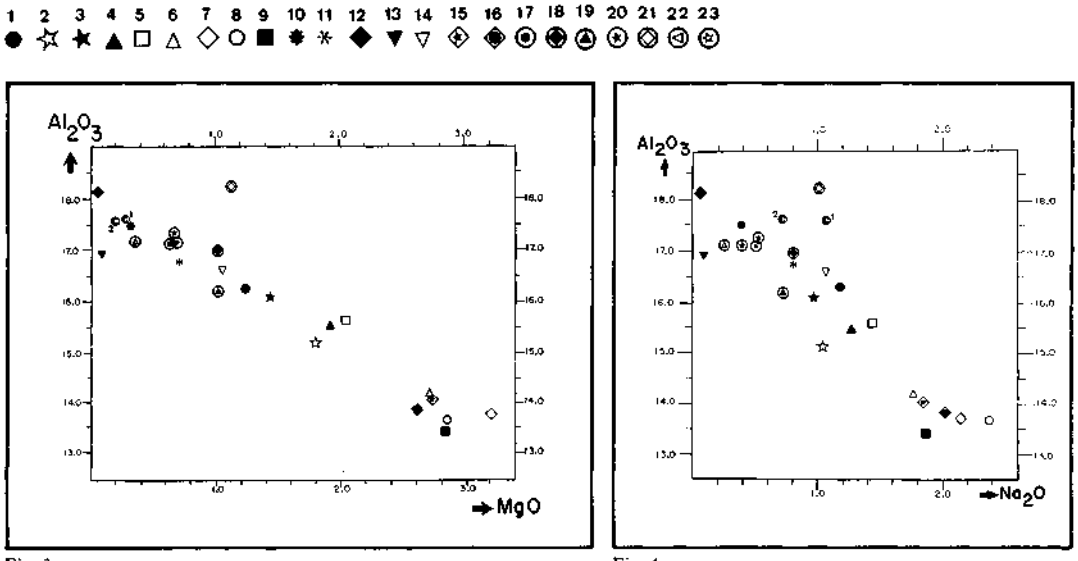

Fig. 3.

Fig. 4.

Fig. 5.

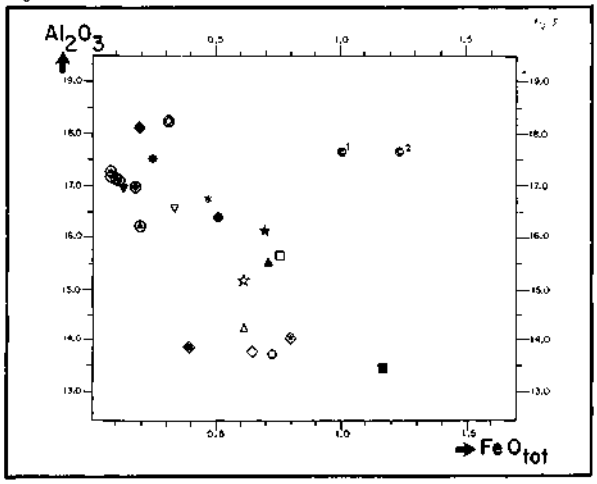

Fig. 7.

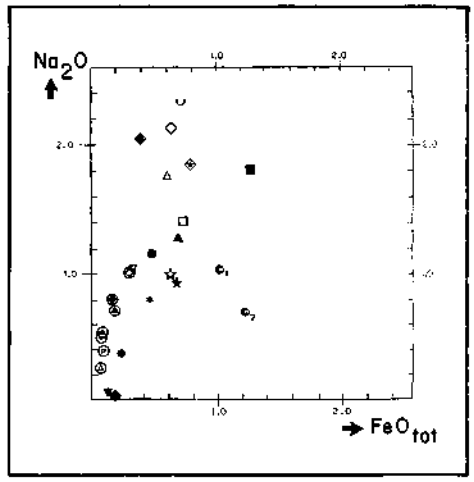

Fig. 8.

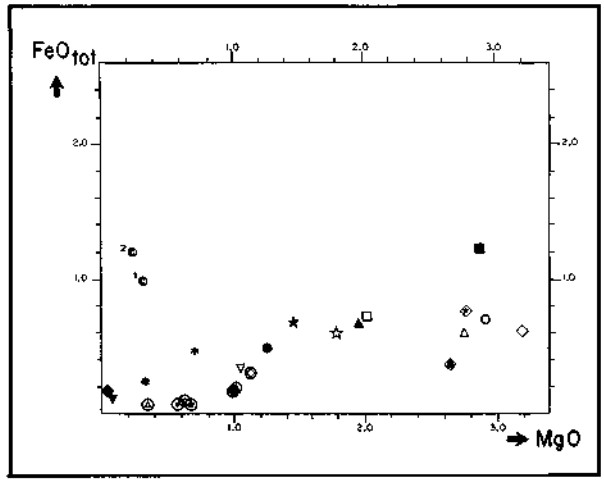

Fig. 6. Correlation diagram for Na_2O/MgO with the representative points (single analyses) for emeralds from Colombia, Brazil, Australia, Norway, Austria, and the USSR (data from this paper and from SCHWARZ, 1990; SCHWARZ, 1991a and SCHWARZ, 1991b).

1 = Colombia	2 = Brazil	3 = Norway
4 = Australia	5 = Ural Mountains	6 = Habachtal

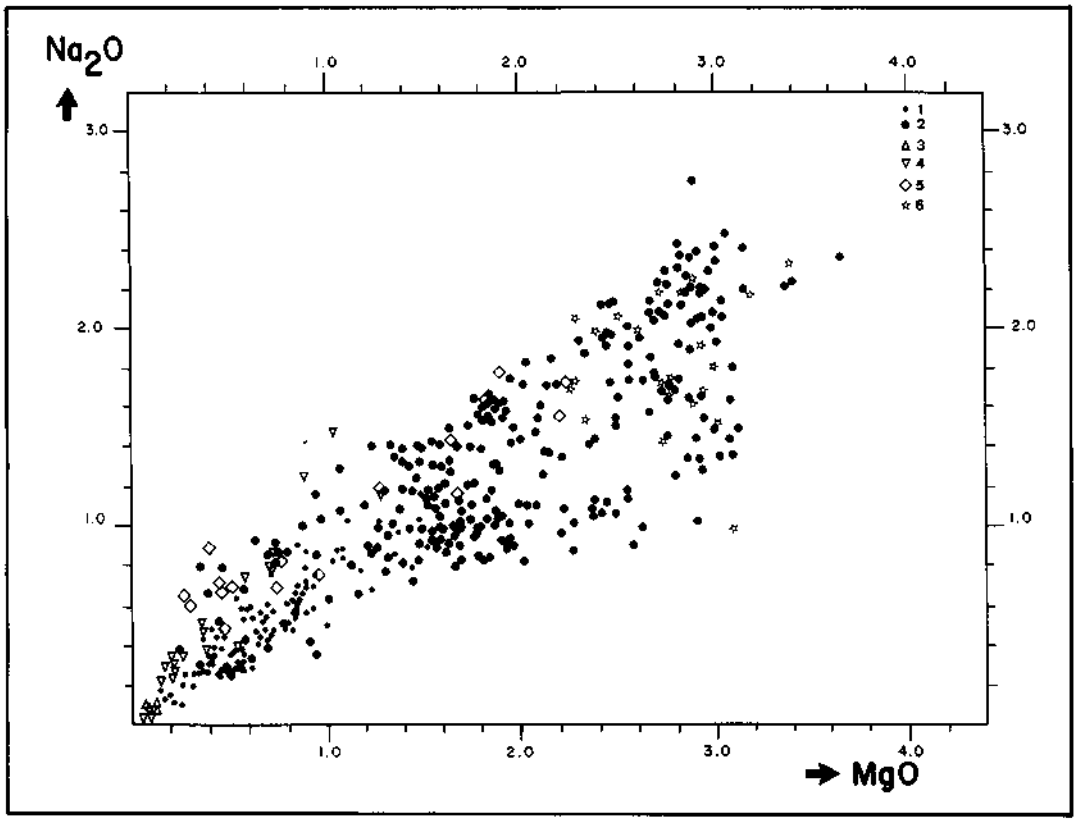

The substitution of the trivalent aluminium by bivalent metal (Me) ions (in emerald predominantly Mg^{2+}) requires a charge compensation. This is achieved practically exclusively by the additional incorporation of monovalent sodium in channel positions.

The representative points for all Colombian emeralds in the Al_2O_3/Na_2O correlation diagram are situated in the upper left region of the population area: their mean Na concentrations are low, the mean concentrations of aluminium, however, are high.

3.3 *Correlation diagram Al_2O_3/FeO_{tot}*

The general trend of the representative points in the correlation diagram Al_2O_3/FeO_{total} (Figure 5) shows indeed a diagonal distribution pattern (with negative ascent). This is however far less well developed than in the correlation diagrams of Al_2O_3 with MgO and Na_2O. The absence of a clearly defined diagonal distribution trend indicates that the incorporation of iron into the emerald/beryl structure does not always follow the 'ideal' substitution reactions (3a) and (3b).

$$(3a)\ Al^{3+,VI} = Fe^{3+,VI}$$

$$(3b)\ Al^{3+,VI} = Fe^{2+,VI} + Me^{1+\ (channel)}$$

The Colombian emeralds with their low iron content (mean concentrations of emeralds from different occurrences <0.3% FeO_{tot}) are placed in the upper left part of the population field.

It is of particular interest that the pegmatite beryls examined by Correia Neves *et al.* (1984) are placed distinctly outside the 'emerald' population field.

3.4 *Correlation diagram Na_2O/MgO*

As can be seen from the data of the chemical analyses of Tables 1-4, magnesium and sodium are the only uni- and bivalent 'extraneous' elements present in higher concentrations in the Colombian emeralds (surely, emeralds from some other localities also contain, in part, higher contents of Fe^{2+}). Structural chemical considerations and the distribution patterns of the representative points in the different correlation diagrams confirm for these two elements the crystallochemical reaction (4).

$$(4)\ Al^{3+,VI} = Mg^{2+,VI} + Na^{1+\ (channel)}$$

The magnesium/sodium incorporation into the emerald/beryl structure follows practically completely this 'ideal' substitution reaction. This is shown by the very clearly developed diagonal distribution pattern (with positive ascent) of the representative points in the correlation diagram Na_2O/MgO (Figure 6).

3.5 *Correlation diagram Na_2O/FeO_{tot}*

The Na_2O/FeO_{tot} correlation diagram (Figure 7) shows a general diagonal distribution trend (with positive ascent) of the representative points, but this is developed less distinctly than we have seen in the correlation diagrams discussed before. This means that the processes controlling the incorporation of the elements iron and sodium into the emerald structure cannot always be directly correlated. Partly, this behaviour goes back to the fact that iron, at least in part, is present in the form of the trivalent ion which needs no charge compensation by sodium when introduced into the emerald structure. On the other hand, it must also be taken into consideration that the incorporation of sodium into emerald is largely controlled by the substitution of aluminium through magnesium.

Because of their low iron and sodium concentrations the representative points for the Colombian emeralds in the Na_2O/FeO_{tot} diagram are restricted to the lower left area of the population field.

3.6 *Correlation diagram FeO_{tot}/MgO*

At first sight the correlation diagram FeO_{tot}/MgO (Figure 8) doesn't show a definite distribution pattern. The variation of the mean magnesium concentrations in emeralds from different occurrences is very strong. On the other hand the mean FeO_{tot} contents are normally less than 1%. The only exception from this behaviour is shown by the samples from the Santa Terezinha de Goiás mining region. A special chemical feature of these emeralds is the poor variation of the (always high) magnesium content in combination with strongly varying iron concentrations (compare Schwarz, 1990).

Of special interest with regard to the chemical differentiation of emeralds on the one hand and pegmatite beryls on the other hand may be the fact that the representative points of the pegmatite beryls from the mining regions of Araçuai-Salinas and Governador Valadares (both in Minas Gerais state, Brazil) are situated completely outside the 'emerald' population field.

The Colombian emeralds are amongst the samples with the lowest iron and magnesium contents so far analysed by the author. Their representative points are placed within the lower left area of the population field in the FeO_{tot}/MgO diagram.

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[*Manuscript received 14 August 1991*]

Gemmological Abstracts

ANDERGASSEN, W., 1990. Inclusione a pió fasi in un corindone giallo. *La Gemmologia*, 15, 3/4, 33-5, 4 photos in colour.

A yellow sapphire weighing 2.27ct contained a negative crystal in which liquid CO_2 was identified. The stone was Sri Lankan in origin. M.O'D.

ANDERSON, A.L., 1991. Curves and optics in non-traditional gemstone cutting. *Gems & Gemology*, 27, 4, 234-9, 8 figs.

This author is getting some attractive effects by combining curved facets with crownless open-table cuts. The pavilion has a combination of large plane facets and curved ones which give a mobile pattern of reflections as the stone is moved. Generally more effective in closed settings and better for large stones of pale to medium colour than for those of deep colour. R.K.M.

BALFOUR, I., 1991. Famous diamonds of the world XLVII - The Centenary Diamond. *Indiaqua Annual 1991*, 255, 4 figs (2 in colour).

The 599 carat rough diamond from the Premier Mine was cut and polished under the supervision of Gabi Tolkowsky to produce a part heart-shaped, part shield-shaped gem of 273 carats which was unveiled at the Tower of London to commemorate the 100th anniversary of De Beers. P.G.R.

BALFOUR, I., 1991. Famous diamonds of the world XLVI - Some notable diamonds in 1990. *Indiaqua Annual 1991*, 251-4, 9 figs (7 in colour).

Contains details of recent diamonds plus new information on older diamonds which has come to light since the author's book *Famous Diamonds* was published three years ago. Recent diamonds include the shield-shaped 89.01 carat 'Guinea Star', a 101 carat pear-shaped stone and an emerald-cut light pink 28.67 carat gem. P.G.R.

BROWN, G., 1992. Trade embargo on coral. *Australian Gemmologist*, 18, 1, 5-6.

Export and import of native corals is now prohibited in Australia, including black coral harvested since 1981 and some other types since 1990. Precious white, pink and red corallium corals are exempt at the moment and gold and bamboo corals are also excluded from the order. Leaves many non-gem species protected and problems are anticipated when it comes to separating banned species from those which may still be traded. Do not rely on assurances from vendors. R.K.M.

BROWN, G., LINTON, T., 1992. Halogen lamps - a warning. *Australian Gemmologist*, 18, 1, 2-4, 2 figs.

Tungsten-halogen lamps emit UV light strongly from about 300nm which is passed freely by the quartz glass envelope and can cause serious damage to skin, eyes and other tissues. All such lamps should include lead glass or other filters to eliminate these harmful rays. Photographic filters are less useful since they are damaged by heat. R.K.M.

CASSEDANNE, J.-P., 1991. L'aigue-marine au Brésil. *Revue de Gemmologie*, 108, 3-7, [second part], 8 photos (3 in colour), 1 fig.

Geological and mineralogical details are given for the more important Brazilian aquamarine gem deposits. Techniques of recovery are described. M.O'D.

CAVENEY, R.J., 1991. De Beers Diamond Research Laboratory Report, Part V: Now for the backroom ... *Indiaqua Annual 1991*, 246, 3 figs.

A 14.2 carat good-quality industrial monocrystal diamond was synthesized at the De Beers Diamond Research Laboratory in Johannesburg. The synthesis took over five hundred hours of high temperature/high pressure running, and required prolonged maintenance of the delicately balanced conditions necessary for successful synthesis. The production of a synthetic diamond of this size is extremely expensive, and would not normally be commercially viable. However, this stone was produced for experimental purposes to test the technology and equipment. The 14.2 carat stone is yellow in colour, a characteristic of synthetics containing nitrogen. Synthetic mono crystals are generally sliced into industrial products and are not suitable for use in jewellery. P.G.R.

COLLYER, T., RODRIGUES, E.G., MACHADO, J.I.L., 1991. Das Malachitvorkommen der Serra Verde, Curionopolis, Pará, Brasilien. *Zeitschrift der Deutschen Gemmologischen Gesellschaft*, **40**, 2/3, 99-102, 2 illustrations (one in colour), bibl.

The malachite is mined in the municipality of Curionopolis in the south-east of Para. It is the first mineable deposit of gem quality malachite in Brazil. Mining is connected with the neighbouring gold deposits and found in hydrothermally formed veins. The material is suitable for cabochons, beads and objets d'art. At times it is found together with chrysocolla and other Cu materials, similar to the 'Eilat' stones. E.S.

DUDA, R., MOLNAR, J., 1992. DieMineralien aus den slowakischen Edelopal-Lagerstätten. *Lapis*, **17**, 4, 23-8, 9 photos in colour, 2 maps.

Details of some of the types of precious and common opal, with brief descriptions of accompanying minerals and general geology are given for the classic Czechoslovakian location of Cervenica-Dubnik. M.O'D.

EDIRIWEERA, R.N., 1991. Scientific Aspects of Geuda Beneficiations. *Zeitschrift der Deutschen Gemmologischen Gesellschaft*, **40**, 2/3, 149-54, 1 graph, 1 table, 1 diagram, bibl.

Milky-white corundums with a slight yellow or blue hue are named 'geuda' in Singhalese. By heat treatment some of these corundums can be altered to blue or yellow sapphires. The heat treatment dissolves the rutile inclusions and alters the colour-influencing ions. The blue colour is caused by iron-titanium particles with a positive charge of 6, the yellow colour by iron ions with a positive charge of 3, at temperatures between 1600-1850°C. For blue sapphires one requires a reducing, for yellow sapphires an oxidizing atmosphere. The treatment is conditional on the presence of sufficient iron and titanium particles. E.S.

FRYER, C.W., CROWNINGSHIELD, R., HARGETT, D., MOSES, T., HURWIT, K., KANE, R.E., 1991. Gem trade lab notes. *Gems & Gemology*, **27** 4, 248-53, 14 figs.

A large (13cm) yellow-brown clinochlore IIb carving was thought to be a Tang Dynasty, Chinese sceptre, about 1200 years old; a green diamond confirmed by uniform colour and spectrum as neutron-treated also had natural radiation burns on the girdle suggesting that it was a pale natural green enhanced by artificial irradiation; a large Oriental brownish-yellow carved hardstone vase with spot RI of 1.74 was grossular, confirmed by X-ray diffraction analysis; a fine green jadeite had heat damage around the girdle after a repair to the ring mount, suggesting that it was waxed - stone should have been removed before using heat; a lapis lazuli with narrow curved banding is described; an X-ray of a 96 carat baroque pearl revealed a large interior cavity partly filled by a small shell bead and cement; fashionable black jewellery is exceeding available black onyx supplies and various substitutes are being offered including a black dolomite/quartz which is illustrated.

An orange-yellow sapphire had no relevant absorption, no reaction to LUV, no pleochroism and a purplish iridescence unknown in sapphire and was identified as a coated stone, soaking in warm HCl removed the colour - other coatings, similar to 'Aqua-Aura', are anticipated; two sapphires with repeated twin layers were thought natural until curved banding and gas bubbles were detected, such twinning, probably due to heating to reduce the banded structure, can be confusing and careful immersed examination of stones is called for. R.K.M.

GARZON JIMÉNEZ, J., 1991. Esmeraldas sintéticas e imitaciones. *Boletin del Instituto Gemológico Español*, **33**, 9-29, 76 photos in colour, 8 figs.

The whole field of emerald synthesis and imitation is covered, with many photographs of characteristic inclusions. Those of composite stones are particularly effective. Notes on chemical composition and on infra red spectra are also given. M.O'D.

GODOVIKOV, A.A., RIPINEN, O.I., 1991. Wunderschine Achate von den Fundstellen der Mongolei. *Lapis*, **16**, 12, 35-9, 11 photos (9 in colour).

Among minerals reported from the north-western Gobi, Mongolia, are ornamental quality agates. From the photographs the specimens include a wide range of colours. M.O'D.

GÜBELIN, E., 1991. Dans la vallee des rubis. *Revue de Gemmologie*, **109**, 7-9, 1 map, 3 photos (1 in colour).

The first part of a review of the ruby deposits of Myanmar (Burma) covering the journey to the site and the area geology. M.O'D.

GURNEY, J.J., LEVINSON, A.A., SMITH, H.S., 1991. Marine mining of diamonds off the West Coast of southern Africa. *Gems & Gemology*, **27**, 4, 206-19, 16 figs.

The raised beaches of marine deposits inland in this area have already yielded about 100 million carats of mostly gem quality diamond. Similar deposits are known to exist off-shore and new techniques have been developed to exploit these at depths of up to 100 metres and are expected to increase in yield. The deposits have been swept northward by prevailing coastal currents for millions of years and extend far along the shores of Namibia where they are also exploited under lease mainly by South African based companies. The off-shore leases on the South African coast extend north from a point above Lamberts Bay to the present mouth of the Orange River. These southerly beaches were deposited at a time when that river reached the sea at what is now the mouth of the Olifants River. The source of these stones is the vast Orange River basin which eroded most of the region's known diamond bearing kimberlite pipes some thousand miles to the east over the past millions of years.

Submarine deposits of diamonds in potholes at shallow depths enable them to be worked with vacuum hoses operated by divers, while deposits up to 100 metres deep are vacuumed up by a large machine known [amusingly] as a 'robotic bottom crawler', which can raise up to 100 cubic metres of suspended solids an hour. There is no significant production from deep water yet, but that is expected to change if the Namaqualand (SA) De Beers sampling is successful. These off-shore diamond reserves are probably the largest known - 1.5 billion carats are estimated - but large scale recovery from the sea- bed presents major engineering problems, although prognosis would appear to be good. R.K.M.

HANNI, H.A., 1992. Blue-green emerald from Nigeria. (A consideration of terminology.) *Australian Gemmologist*, **18**, 1, 16-18, 4 figs.

Discusses the distinction between green beryl and blue-green emerald from Nigeria, which contains iron as well as chromium and vanadium, altering the colour from the normally expected green of emerald. Dr Hanni justifies calling these stones by the more prestigious name on several counts. He suggests 'blue-green emerald' is sufficient distinction. R.K.M.

HARDER, H., 1992. Vom Steinbeil bis zur Smaragde - Jade ('Imperial - Jade'). *Aufschluss*, **43**, 65-82, 16 photos (14 in colour).

Despite the title, the paper deals with both jadeite and nephrite, reviewing the colour varieties, mineralogy and substances imitating jade. The imitations are conveniently listed together in a table which gives composition, specific gravity and refractive index. M.O'D.

HENN, U., BANK, H., 1991. Geschliffener, klar durchsichtiger Hackmanit von Mount St. Hilaire in Kanada. *Zeitschrift der Deutschen Gemmologischen Gesellschaft*, **40**, 2-3, 93-7, 4 photomicrographs, 1 table, 1 graph, bibl.

The hackmanites were found at Mount St Hilaire in Quebec; the same locality has yielded blue willemite in the past as well as beloeilite, a sodalite with albite and nepheline. The examined ten faceted hackmanites vary in weight from 0.27ct to 31ct. They are Cl-sodalites and show distinctive photochroism. RI 1.485-1.487, SG 2.30- 2.32. E.S.

HENN, U., BANK, H., 1991. Sternbronzit aus Sri Lanka. *Zeitschrift der Deutschen Gemmologischen Gesellschaft*, **40**, 2/3, 145-8, 2 photomicrographs, (one in colour) 1 graph, bibl.

Bronzite is an orthopyroxene, between enstatite and orthoferrosilite. The star bronzite cabochon from Sri Lanka weighed 0.79ct and showed a six-rayed star caused by needle-like inclusions filled with a liquid. RI 1.680-1.693, DR 0.013, SG 3.41. E.S.

HENN, U., BANK, H., 1992. Examination of an unusual alexandrite. *Australian Gemmologist*, **18**, 1, 13-15, 5 figs.

Underlines problems of distinguishing natural Brazilian alexandrite from the synthetic product since inclusions and growth patterns are similar in each. Present stone was first thought to be synthetic on the evidence of a triangular tabular inclusion. Further investigation by infrared spectrum proved it was genuine, and the inclusion was identified as hematite, typically natural. [Difficult] R.K.M.

HURWIT, K.N., REINITZ, I., MOSES, T., KAMMERLING, R.C., 1991. Untersuchung von Salzwasserzuchtperlen mit künstlichen, farbigen Kernen. *Zeitschrift der Deutschen Gemmologischen Gesellschaft*, **40**, 2/3, 81-8, 1 photograph, 4 photomicrographs, 4 graphs, bibl.

The nucleus seems to have been produced from powdered oyster shells and an inorganic pigment. The 'beads' are dark grey-green and have a diameter of 8mm. Other pearls were found to have a nucleus of some synthetic substances which started to melt when drilled. Comparative X-rays illustrate the difference. E.S.

JOHNSTON, C.L., GUNTER, M.E., KNOWLES, C.R., 1991. Sunstone labradorite from the Ponderosa mine, Oregon. *Gems & Gemology*, 27, 4, 220-33, 17 figs.

This mine produces labradorite sunstone in colours ranging from yellow through orange, pink to deep red, with green as the rarest colour. Yield of cuttable quality seems high but much is pale in colour and the best stones are generally small in size. Mining, in summer and autumn only, is open-cast by a small staff using a back-hoe and bulldozer; estimated ore reserves so far mined is 1.5 tonnes; high grade material about 500 grams a day in small sizes. Spangling is due to copper platelets distributed randomly parallel to two possible crystal directions (001) and (010). RIs 1.563-1.572; SG av. 2.71, as expected for labradorite. Ponderosa claims to be the premier location for this type of sunstone. There appear to be considerable reserves. R.K.M.

KAMMERLING, R.C., KOIVULA, J.I., KANE, R.E., FRITSCH, E., MUHLMEISTER, S., MCCLURE, S.F., 1991. An examination of nontransparent 'CZ' from Russia. *Gems & Gemology*, 27, 4, 240-6, 6 figs.

CZ is available in a wide variety of transparent colours and is now coming from Russia in opaque white, pink and black forms, the first two being cabochon cut and marketed as 'Pearl CZ'. Under intense lighting all are to some extent translucent with evidence of a banded or striated growth. Lustre of polished specimens was high and a faceted black stone resembled black diamond. Pink exhibited a fine line spectrum suggesting a rare-earth dopant. RI beyond the range of the refractometer, SG from 5.93 black, to 6.15 pink, probably varying with different stabilizer percentages. R.K.M.

KAMMERLING, R.C., KOIVULA, J.I., WELDON, R., 1991. Identificación de ghemas sintéticas fabricadas por fusión a la llama (método Verneüil). *Boletin del Instituto Gemológico Espanol*, 33, 32-7, 8 photos and 2 figs in colour.

Features of the Verneuil flame-fusion growth process are illustrated and discussed with particular attention paid to inclusions and absorption spectra. The coverage is limited to corundum and spinel. M.O'D.

KAMMERLING, R.C., KOIVULA, J.I., 1992. Novel assembled opals from Mexico. *Australian Gemmologist*, 18, 1, 19-21, 5 figs.

Assembled opal made by part filling cabochon shaped mould with acrylic resin before placing a sliver of black-backed opal face down and completing the filling. Bubbles were apparent in plastic, and viewed from side these looked like triplets. R.K.M.

KAMPF, A.R., 1991. Taaffeite crystals. *Mineralogical Record*, 22, 5, 343-7, 6 photos in colour, 2 figs.

Taaffeite has been reported from five places on earth. Most crystals are pyramidal or bipyramidal and are often truncated by basal pedions. Taaffeite crystals from Sri Lanka (the only ones of gem potential so far found) are most commonly mono-pyramidal (the mineral is hemimorphic). Crystals from the Pitkäranta district, Karelian USSR, are reported to occur as epitactic overgrowths on spinel; bipyramidal crystals from Sianghwaling, China, appear to be twinned by reflection on {0001}. Bipyramidal crystals from eastern Siberia and from Mount Painter, South Australia have not yet been described in detail but may also represent twins on {0001}. M.O'D.

KOHOUT, K., 1991. Die Mineralien des Hartsteinbruchs Rockenhausen in der Nordpfalz. *Lapis*, 16, 10, 41-4, 8 photos in colour.

Fine agates and other minerals are found in the Hartsteinbruch area of the German Nordpfalz. M.O'D.

KOIVULA, J.I., FRYER, C.W., KAMMERLING, R.C., 1991. Almandine garnet in Montana sapphire. *Zeitschrift der Deutschen Gemmologischen Gesellschaft*, 40, 2/3, 89-92, 4 photos, bibl.

Sapphire crystals with a slightly brownish-orange inclusion of almandine garnet are found in Dry Cottonwood Creek in Deerlodge County northwest of Butte in Montana, along the Continental divide. The alluvial corundum found here varies from colourless to yellow, blue, purple and red. They are of gem quality. The host sapphire crystal is yellowish, 3.55ct and measures 9.81 x 9.11 x 3.74mm. The inclusion measures 0.8mm in diameter and is of brownish-orange colour. Identification was made by X-ray diffraction analyses. E.S.

KOIVULA, J.I., KAMMERLING, R.C., 1991. Gem news. *Gems & Gemology*, 27, 4, 254-65, 20 figs.

DIAMONDS

News of diamond cutting in Botswana; a large diamond found in China; proposed diamond cutting in Shanghai. Diamond demand in U.S. remains strong in 1991 exported stones rose 16 per cent, imports also

increased; a diamond factory is to open in Dubai for melee up to half carat sizes. General Electric announce synthesis of large carbon-13 crystals, expected to be harder than normal diamond and of exceptional structural perfection suggesting uses for new electronic devices; Indonesian Diamond Corp reports a yield of 1 carat per $10m^3$ of treated gravel with substantial reserves; low-calcium/high- chrome garnet has been used as an indicator of diamond potential in exploration, but the nickel content of high calcium pyrope now seems to be more reliable. Raphaeli- Stschik, Israeli diamond cutters have unveiled their Royal Line diamond cuts - the Duchess, the Baroness and the Empress - reported to take advantage of flatter rough, giving straight-edged well-spread shapes [remarkably similar to the Maico 'Dream-cuts' illustrated in this column in the last issue of *Gems & Gemology*].

COLOURED STONES

A 'hairy bug' in amber is described and illustrated; Czechoslovakian Conference revealed recently discovered ruby deposit north of Magnitogorsk, Russia, high quality expected; synthetic malachite displayed and synthetic opal from Russia discussed. Dr Edward Gübelin has a 'cross' chrysoberyl cat's-eye, the normal eye being crossed by a growth band of different colour; an attractive Tanzanian green diopside is illustrated and described; Mike Ridding draws attention to finds of large emerald and green beryl crystals at Jos, Nigeria, in 1990; demantoid garnets are being mined again in the Urals; yellow manganese garnets are reported from Tanzania and a 23.56ct tsavorite is illustrated. The ban on ivory and tortoiseshell has led to search for suitable substitutes, including 'fossil' mastodon and mammoth tusks and vegetable ivory; 'recycled' ivory was said to be from old tusks but proved to be thin veneers from old piano-keys. Peruvian opal in blue and pink self-colours is coming from a mine near Arequipa - a copper mining area.

A 19th Century chalcedony ring had a sepia portrait of George Washington printed or stained on it by a photographic process.

Five out of six fragmentary rubies bought as natural in Vietnam proved to be synthetic when cut; several instances of synthetics from that country have been reported but these were the first synthetic 'rough' examined; terrorism is hampering exploration in Sri Lanka but good deep red corundum has been found at Hambatota and at Matara; good red star spinels from Ratnapura; yellow-green andradite and sundry colour-change stones and kornerupine and sillimanite also found, cat's-eye kornerupine is becoming scarce.

Intergrowths of sunstone and iolite are reported from India, the iolite usually of the 'bloodshot' type [which I named in 1955]; an update on tanzanite mining reports competition for workable zones over the gem rich area; a pink-yellow bi-colour tourmaline is reported as unusual.

SYNTHETICS AND SIMULANTS

Laser '91 exhibition in Los Angeles included chrome-doped alexandrite, padparadscha colour synthetic corundum, erbium-doped YAG and erbium-doped yttrium lithium fluoride; saturated emerald green YAG doped with chromium, thulium or holmium; chrome-doped LiCaF and chrome-neodymium gallium scandium gadolinium garnet; a star sapphire with a centre void in its star is illustrated.

ENHANCEMENTS

Editors have experimented with Opticon filled cracks in quartz and report all were low relief needing careful microscopy to detect them; dark-field showed characteristic violet/blue flashes, probably the most reliable diagnostic feature. An emerald crystal was found to contain cavernous oil-filled areas; cracks in synthetic emeralds from Swat, Pakistan were filled with a substance which fluoresced strong yellow under LUV; demand for yellow sapphire in Sri Lanka has led to heat treatment of pale stones and the import of synthetic yellows, surface coating with organic compounds, boiling with vegetable dyes which are then covered by wax to defeat the acid immersion test. Pink sapphire is similarly faked; some are chewed with a local berry [betel nut?] and then a cigarette is smoked to improve the colour. Paraiba tourmalines continue to be simulated; Drs Henn and Bank list apatite, irradiated topaz, beryl triplets, tourmaline and glass doublets and blue apatite cat's-eyes all offered as Paraiba tourmalines. R.K.M.

KOSHIL, I.M., VASILISHIN, I.S., PAVLISHIN, V.I., PANCHENKO, V.I., 1991. Wolodarsk-Wolynskii: geologischer Aufbau und Mineralogie der Pegmatite in Wolynien, Ukraine. *Lapis*, **16**, 10, 24-40, 2 maps, 5 figs, 30 photos (27 in colour).

The pegmatites of the Wolodarsk area of the Ukraine, USSR, are remarkable both for their green (non-emerald), yellow and blue beryl crystals and for equally fine crystals of topaz.

The beryl crystals display characteristic etching. A list of the other minerals found in the area is given with notes on the pegmatites and their formation. M.O'D.

NOACK, R., 1991. Die Achate aus den sekundären Fundstellen der Lausitz. *Lapis*, **16**, 12, 22-4, 1 map, 5 photos in colour.

Fine ornamental agates are found at Lausitz in the eastern part of Germany. The agates are locally known as 'Elbe-agates'. M.O'D.

O'DONOGHUE, M., 1991. Industrial review - Gemstones. *Britannica Book of the Year* 1991, p. 217.

Retail, production and saleroom details of the gemstone market are reviewed with notes on new species and varieties and on further developments in colour alteration and gemstone enhancement. Sales in the retail sector held up reasonably well in the period under review. M.O'D.

OSTROOUMOV, M.N., 1991. L'amazonite. *Revue de Gemmologie*, **108**, 8-12, 1 map, 2 figs, 1 photo in colour.

Occurrences of amazonite throughout the world are reviewed with observations on the cause of colour, ascribed to a colour centre including Pb and Fe ions. M.O'D.

PONAHLO, J., 1991. Diferenciación entre piedras preciosas naturales ysinteticas por catodoluminiscencia. *Boletin del Instituto Gemológico Espanol*, **33**, 47-52, 7 figs in colour.

Cathodoluminescence is advocated as a means of distinguishing between natural and synthetic gemstones. Corundum and chrysoberyl varieties are discussed together with Afghan and Chilean lapis lazuli. M.O'D.

READ, P.G., 1990. The threat of the look-alikes. *Canadian Jeweller*. October 1990, 34, 1 fig.

Although the main thrust of gemmological research is to do with methods of identifying the latest synthetic gem products, and we are alert to the possibility of a synthetic when checking out the potentially more valuable stones, when it comes to the 'semi-precious' materials we may not exercise the same degree of suspicion. The article instances amethyst, and various composite look-alike stones, including garnet-topped doublets (which were still being listed in Swarovski's catalogue in the 1970s). Details of simple identification methods are included. (Author's abstract) P.G.R.

ROBERT, D., 1991. La zircone, pourquoi cubique? *Revue de Gemmologie*, **108**, 14-17, 2 photos in colour, 2 figs.

The relationship between natural monoclinic zirconia and the cubic artificial product is described. M.O'D.

RÖTTERMANN, C., 1991. Argyle Diamonds - Ein australisches Abenteuer. *Zeitschrift der Deutschen Gemmologischen Gesellschaft*, **40**, 2/3, 155-6.

A short survey of the development and production of the world's largest diamond mine. The Argyle mine, situated in the Kimberley region in the north of Western Australia, is named after an artificial lake nearby. It started full production in 1986 (29.2 million carats) yielding in 1990 35 million carats. 5% are of gem quality, amounting to 3% of world gem production. The best of the gem diamonds are pink and very expensive. 75% of the production is marketed by the CSO. E.S.

SAADI, J.A., 1991. Monumento geológico: diatremas, únicas en el mundo, portadoras de formaciones estalactíticas de rodocrosita. *Boletin del Instituto Gemológico Espanol*, **33**, 38-43, 19 photos in colour, 1 map.

The rhodochrosite mine at Minas Capillita, Andalgala, Catamarca, Argentina, is described with notes on the geology and mineralogy. Photographs graphically illustrate the rhodochrosite occurrence as stalactites. M.O'D.

SCHWARZ, D., 1991. Die chemischen Eigenschaften der Smaragde. III. Habachtal/ôsterreich und Uralgebirge/UdSSR. *Zeitschrift der Deutschen Gemmologischen Gesellschaft*, **40**, 2/3, 103-43, 12 graphs, 1 table, 2 geological maps, bibl.

The regional, geological and genetic aspects of the Habachtal, Austria, and the Urals, USSR, are discussed, as are the chemical properties of emeralds from both localities. Variations and average concentrations of chromium, iron, magnesium and sodium are analysed. E.S.

SCOVILL, J.A., 1992. The Gillette quarry, Haddam Neck, Connecticut. *Mineralogical Record*, **23**, 1, 19-28, 3 maps, 14 photos (11 in colour).

Gem quality crystals of elbaite and beryl have been recovered over the years from the Gillette quarry, Haddam Neck Connecticut, USA. Prospects for future collecting are not good. M.O'D.

SUN, X.R., 1992. A note on corundum veinlets

in rubies from China and Australia. *Australian Gemmologist*, **18**, 1, 22-3, 3 figs.

In rubies from Huo Shan, China and Harts Range, Australia, geological conditions have caused shatter-like cracks which have subsequently been healed by darker corundum infillings, or at a later date by sericite [a fibrous form of mica]. Such inclusions may affect quality and value. R.K.M.

TOWNSEND, I.J., 1992. The Mintabie opalfield. *Australian Gemmologist*, 18, 1, 7-12, 9 figs and map.

A remote area of South Australia 290km from Coober Pedy and 450km from Alice Springs, first discovered about 1920 but too arid (rainfall average 10" per annum) and too difficult of access to be worked seriously until 1976 when bull-dozers and pneumatic drills were brought in. Matrix is a hard quartz sandstone and mechanical open cast mining and explosives are used until opal traces found when hand working is employed. Some Mintabie opal tends to crack if mined from below the water table, shallow drier veins are said to be free from this defect. Since 1985 output, including fine black, has increased dramatically. R.K.M.

TOGNONI, C., 1990. An automatic procedure for computing the optimum cut properties of gems. *La Gemmologia*, 15, 3/4, 23-32, 2 figs.

The optimum ray path inside a simple shaped transparent body is evaluated by an automatic computing method. M.O'D.

TROSSARELLI, C., 1990. Use of the inverted microscope in gemmology. *La gemmologia*, 15, 3/4, 7-21, 2 figs, 24 photos in colour.

Microscopes which display the underside of metallurgical, biological or opaque mineral specimens can be adapted for the examination of inclusions in gemstones. Examples of some uses are given. M.O'D.

WALMSLEY, J.C., LANG, A.R., 1992. Oriented biotite inclusions in diamond coat. *Mineralogical Magazine*, **56**, 108-11, 3 photos, 1 fig.

Coated diamonds have a clear, often gem-quality octahedral core with a coat shell in which the diamond matrix is densely populated by sub-micrometre-size non-diamond bodies. Flakes of brown biotite mica have been discovered in the coat of some diamonds from Zaire, and may have a preferred orientation with biotite (001) parallel to a diamond octahedral plane, for example (111) with diamond [110] parallel to biotite [110] or to an equivalent direction. M.O'D.

WATERMEYER, B., 1990. Colour retention and distribution. *Diamond International*, 4, March-April, 97-101, 4 figs.

Summarizes the principles of the passage and absorption of light in a polished diamond, and outlines the steps which can be taken to solve problems of colour concentration and colour dilution. Taking into account the relationship between colour concentration and the geometry of the stone, it is shown how the quality of colour in a number of diamond cutting styles can be improved. This can result in an upgrade from a normal to a fancy colour. Colour distribution can also be improved; pale stones can be deepened in colour, and darker colours can be enriched by introducing more light. P.G.R.

WEERTH, A., 1991. Neufunde aus dem Himalaya und Karakorum. *Lapis*, **16**, 10, 45-6, 4 photos (3 in colour).

Some recently reported minerals from the Pakistan Karakoram/Himalaya include emerald from Gujar Killi where crystals up to 5cm length have been found; spessartine from Haramosh, hematite from Skardu, epidote from Turmik near Skardu, aquamarine, apatite and herderite from the Dusso area. M.O'D.

YACOOT, A., MOORE, M., 1992. An unusual octahedral diamond. *Mineralogical Magazine*, **56**, 111-13, 6 photos.

A clear colourless diamond weighing 0.35ct showed small dodecahedra on the six vertices of the octahedron and laue pictures showed that the specimen was a single crystal. X-ray topographs show that crystal growth started from an imperfect and highly strained nucleus, growth banding confirms that growth was on {111} planes. A history of the crystal's mode of growth is suggested. M.O'D.

I.C.A. Laboratory Alerts. 1992. *Australian Gemmologist*, **18**, 1, 18.

Valuable warnings of 'Swat emerald rough' which yielded two synthetic cabochon emeralds; synthetic flux-grown red and blue spinels from Sri Lanka; 'Malaya Jade' which is green dyed quartzite; and crackle quenched red-dyed natural corundum which resembles some East African rubies, no trace of chromium spectrum and a yellow fluorescence under LUV betray. R.K.M.

Proceedings of The Gemmological Association and Gem Testing Laboratory of Great Britain and Notices

OBITUARIES

Denis Inkersole, FGA, for a generation the leading gemmology evening class teacher, died after a short illness on 11 August 1992. Living all his life in the East London borough of Hackney it was fitting that his teaching work took place at what is now the City Polytechnic whose premises are in an adjacent borough.

Born in 1931, Denis took a Higher National Certificate in a variety of subjects but worked mainly as an industrial chemist until the early 1970's when the move of his then employers out of London gave him the chance to set up on his own as a mineral dealer, lapidary and, later on, lapidary teacher. His firm, Mineral Associates, dealt in a wide range of the less expensive but more commercial gem and ornamental minerals and his lapidary work complemented his dealing, using similar species.

As the years went on, however, Denis was increasingly asked to provide faceted and sawn materials for some important commissions; his skills and patience as a lapidary teacher were recognized by other countries and he instituted lapidary classes in more than one. While all this was going on his Polytechnic classes continued in his characteristically chatty and friendly way.

Denis was always ready to take on the bread-and-butter work associated with class teaching and this perhaps unspectacular consistency marked his whole life; outside gemstones he worked with the Scout movement and must have given an inspiring start in life to many boys from a poor area of London.

We extend love and sympathy towards his wife and children who will sadly miss so kind and unassuming a man, as we do. M.O'D.

R.W. (Ron) Yeo, FGA, on Wednesday 26 February 1992 aged 81.

Ron Yeo's career as a jeweller and gemmologist spanned six decades, Ron himself qualifying as a Fellow of the Gemmological Association in 1929, passing with Distinction. Later he assisted I.G. Jardine with his gemmological lectures at Chelsea Polytechnic.

The opening of the Tech. in March 1963. The 'usher' on the right is the late Robert (Bobby) Blott of Waters & Blott; probably at one time the biggest jobbing jewellers around. R.W. worked there for a time.

In the early thirties Ron worked for Barnetts in the Burlington Arcade and later he established his own business in the same arcade.

During the war the business suffered badly when Burlington Arcade was bombed. On 10 September 1940 a 500lb bomb scored a direct hit on the shop. Ron always said that he was the first jeweller in the country to suffer bomb damage. He was always very proud of the fact that he and the staff sorted through the remains of the business and managed to salvage about 40% of the total stock themselves during a 12 week 'sweep up'. Later Ron was in great demand from jew-

ellers elsewhere in the country whose businesses had suffered similar fates during the bombing of provincial towns and cities. His practical advice enabled many to resurrect their companies.

After the war Ron ran two shops in the West End of London and then opened another shop in Burlington Arcade. The Company which bore his name expanded to own a number of businesses from Penzance to London, and is still in existence today with its head office in Exeter.

His passion for gemmology remained with him throughout his life and his lasting legacy is the South Western Trust in Exeter. He started the Trust in 1962 and developed a museum, a gem testing laboratory and a teaching centre. In its own premises near the centre of Exeter, the Trust runs the courses of both the Gemmological Association and the National Association of Goldsmiths.

He is survived by his wife and children and those who knew the larger than life personality of Ron will surely miss him. D.G.

Elma H. Evans, FGA (D.1988), Spring Valley, California, USA, died recently.

Kenneth Holmes, FGA (D.1969), Edgware, died on 31 August 1992.

James Walter Hudspith, FGA (D.1976), Leatherhead, died recently.

Janet A. Marriott, FGA (D.1988), died recently.

Father John W. O'Rourke, FGA (D.1973), Australia, died recently.

GIFTS TO THE GAGTL

The Association is most grateful for gifts of gems and gem materials for research and teaching purposes donated by the following:

Mr L.J. Fifield, FGA, of A. Sechaud & Co Ltd., London for two specimens of synthetic quartz;

John Kessler for emeralds from various localities;

Marcus McCallum, FGA, for spessartine garnet from Namibia;

Elizabeth MacGregor, FGA, of Teresopolis, Brazil, for crystal specimens and gem gravels;

Mrs C.M. Ou Yang, FGA, for peridot from China;

Professor Chen Zhonghui and Vice Professor Yan Weixuan, FGA, for turquoise from China;

Professor Guoping Zhou and Mr Huang Sheng for feldspar (moonstone) and saussurite from China.

MEMBERS' MEETINGS

London

On 22 September 1992 at the Ironmongers' Hall, London EC2, the annual Trade Luncheon was held.

On 30 September 1992 at 27 Greville Street, London EC1N 8SU, the Annual General Meeting of GAGTL was held. A full report will be published in the next issue of *The Journal*.

Midlands Branch

On 25 September 1992 at Dr Johnson House, Bull Street, Birmingham, an Open Forum was held, at which questions were answered by a panel.

North West Branch

On 16 September 1992 at Church House, Hanover Street, Liverpool 1, Adrian Klein gave a talk on emeralds.

GEM DIAMOND EXAMINATION 1992

In the 1992 Gem Diamond Examination 39 candidates sat for the Gem Diamond Diploma examination. Of these 31 (79%) passed, 1 with Distinction. The names of the successful candidates are as follows:

Qualified with Distinction

Tees, Audrey, Glasgow.

Qualified

Argyrakou, Joulia, London.
Baker, Paul Ronald, Ringmer, Lewes.
Barratt, Claire A., Gillingham.
Fromming, David Erwin, Gerrards Cross.
Georgiadou, Elizabeth, London.
Ghisi, Maria K., Athens, Greece.
Hall, David James, London.
Houseago, James A., Lowestoft.
Jordan, Lynn Pamela, Manchester.
Kejriwal, Bindu, London.
King, Margaret A., Scotland.
Levine, Richard John, Leeds.
Lilley, Elaine, London.
Lupton, Elaine, Paddock Wood.
MacLennan, David Jack, Glasgow.
Martin, Julie, Glasgow.
McConnachie, David Charles, Glasgow.
Ng, Soon Hoh, London.
Patel, Jagdish Ishverbhai, Wimbledon Village.
Patel, Pankaj, London.
Pattison, Rebecca Ann, Meopham.
Scott, Michael A., London.
Thatcher, Alison, Woking.
Thomas, Richard, Bridgend.
Vannet, Mary A., Dundee.

MEMBERSHIP '93

The new magazine *Gem and Jewellery News* has been well received by members during 1992. Also many have now taken the opportunity to apply for use of the Coat of Arms or Laboratory logo on their business stationery.

Overseas members benefit from the new arrangements to pay by credit card or sterling draft and will pay less in 1993 than in 1992; also in 1993 their *Journals* will be sent by airmail. All other membership rates are held at 1992 levels, as set out below:

Subscription Rates 1993

	UK	Overseas
Ordinary Member Fellow Diamond Member	£45.00	£65.00
Laboratory Member	£210.00 +VAT	
Gold Laboratory Member	£525.00 +VAT	£525.00

Members, Fellows and Diamond Members receive *The Journal of Gemmology* and the *Gem and Jewellery News* quarterly. Fellows may use FGA after their name and Diamond Members the title DGA, and both may also apply for use of the Coat of Arms on their stationery.

Laboratory Members receive *The Journal of Gemmology* and *Gem and Jewellery News* quarterly, and may apply for use of the Laboratory logo on their business stationery. Gold Laboratory Members may enjoy the benefits of Laboratory Members together with lower fees for diamond reports, assistance with temporary import of stones for testing, and special facilities on pearl and coloured stone reports.

Walter, Keith David, Peebles.
Young, Gabrielle E.M. Wareham.

EXAMINATIONS IN GEMMOLOGY 1992

In the 1992 Examination in Gemmology 515 candidates sat the Preliminary examination, 338 (66%) of whom qualified, 420 candidates sat the Diploma examination and 191 (45%) qualified, 16 with Distinction.

The **Tully Medal** for the candidate who submits the best set of answers in the Diploma examination which, in the opinion of the Examiners are of sufficiently high standard, was awarded to Mr Michael Tse Kwok Wing from Hong Kong.

The **Anderson/Bank Prize** for the best non-trade candidate of the year in the Diploma examination was awarded to Mr Michael Tse Kwok Wing from Hong Kong.

The **Rayner Diploma Prize** for the best candidate of the year who derives her main income from activities essentially connected with the Jewellery trade, was awarded to Miss Anne Bailey from Rugby, UK.

The **Anderson Medal** for the best candidate of the year in the Preliminary examination was awarded to Miss Sarah Hue-Williams from London, UK.

The **Preliminary Trade Prize** for the best candidate under the age of 21 years on 1st June 1991 who derives his main income from activities essentially connected with the Jewellery trade was awarded to Mr Alexander Hammond from Sandy, UK.

DIPLOMA

Qualified with Distinction

Bailey, Anne Margaret, Rugby.
Beckett, Shona-Maria Ferguson, London.
Boote, Caroline Marguerite Elizabeth, London.
Cheung Chi Ho, Hong Kong.
Dharmaratne, Pannipitiye Gamaathi Ralalage, Colombo, Sri Lanka.
Drowley, Brigitte, London.
Goddard, Valerie J., Alfold.
Grossman, Julie Frances, London.
Kesheng, Chen, Guilin, P.R. China.
Lang, Bernard, Basel, Switzerland.
Magara, Yoshiaki, Fukui Pref., Japan.
Marsh, Leona Claire, Harare, Zimbabwe.
Patel, Rekha Mahesh, Nairobi, Kenya.
Tse Kwok Wing, Michael, Hong Kong.
Tucker, William J., Douglas, Isle of Man.
Tun, Maung Win Myint, Bangkok, Thailand.

Qualified - UK

Balter, Jonathon, London.
Barrie, Lindsay, London.
Bedwell, Victoria Lynsee, London.
Bendel, Helle, London.
Bindon, Julie Ann, Taunton,
Birrell, Andrew Tierney, Edinburgh.
Bradford, Nikki, Hassocks.
Burrow, Denis, Gravesend.
Christian, Helen Elizabeth, Bolton.
Clayton, Josephine A., London.
Cooper, Carolyn, London, England
Day, Brynley John, Oldham.
Downing, Lucy N., London.
Emslie, Gail, Harrogate.
Fox, Rosemary, London.
Gemmell, James, Durham.
Geoghegan, Noel R., Wellesbourne.
Hardeman, Sonia L., Alton.
Harper, Jonathan, London.
Henn, C. John W., Wolverhampton.
Hering, Peter, Cambridge.
Hopper, Geoffrey C., Harrow.
Hughes, Helen, London.
Kneebone, Garfield David, Penzance.
Koetsier, Anya Kristina, London.
Ku, Sarah Joy, London.
Larkins, Barry, London.
Leathley, A.B.D.A., York.
Lodge, Sara Anne-Marie, Birmingham.
Lowe, David J., London.
Ludlow, Andrew Philip, London.
McDonald, Suzanne M., Edinburgh.
McFarlane, Neil R., Alloa.
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Mildenhall, Caroline, Brighton.
Nandha, Manoj, Nottingham.
Ng, Soon Hoh, London.
O'Brien, Gillian M., North Berwick.
Oldfield, Gemma, London.
Panlilio, Regina S., London.
Patel, Jagdish Ishverbhai, Wimbledon Village.
Prior, Louise Charlotte, London.
Quinton, Sarah, Oxford.
Read, Julian, Goole.
Reffell, Keith C., Rainham.
Sancroft-Baker, Raymond, London.
Spanbok, Gary, London.
Stewart, Robert Miller, Bishops Waltham.
Strachan, Elizabeth, London.
Taylor, David John, Isle of Wight.
Travis, Peter John Booth Charles, London.
Van Papen, Lorraine F.M., Guildford.
Vannet, Mary A., Dundee.
Vaughan, Michael, Chester.
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Qualified - Overseas

Alwicher, Terrence, Nijmegen, The Netherlands.
Anantwatanapong, Angkana, Bangkok, Thailand.
Araki, Kazuo, Hyogo Pref., Japan.
Arnau Graus, Concepcion, Barcelona, Spain.
Asanis Nikolaos, Athens, Greece.
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Ball, Pamela, Hong Kong.
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Cheng Chi Chung, Hong Kong.
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Chow, Kenickie Tze Joak, Hong Kong.
Chow Chun Hung, William, Hong Kong.
Chow Shui Wah, Hong Kong.
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de Jongh, Laurentia Melissa, Den Haag, The Netherlands.
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de Ruiter, J.E., Waddinxveen, The Netherlands.
de Wit, Lambertus, Den Haag, The Netherlands.
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Dharmaratne, Rosemary Olivia, Colombo, Sri Lanka.
Eguchi, Yukio, Osaka, Japan.
Engel, Nora, Geneva, Switzerland.
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Kariya, Tomoko, Tokyo, Japan.
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See Yat Sun, Hong Kong.
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Yu Yim Tong, Hong Kong.
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Yumoto, Atsuko, Osaka, Japan.
Yung Tak Yi, Hong Kong.
Zaveri, Pragnesh H., Bombay, India.
Zhao, Liu, Harbin, P.R. China.
Zinzuvadia, Jaydeep Amritlal, Bombay, India.

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Bertorelli, Andrea Elsbeth Louisa, London.
Bladbjerg, Tine, Rochester.
Boote, Caroline Marguerite Elizabeth, London.
Boulding, Philip, London.
Boyd, Derek Stephen, Didsbury.
Brown, Elizabeth, Lindford.
Campbell Pedersen, Maggie, Chiswick.
Carson, Michael Joseph, Boston.
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Clay, Gretchen Fleur, Boston.
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Cook, Stewart, Maidstone.
Cooper, Simon Paul, Hadfield via Hyde.
D'Arcy-Evans, Julie Anne, Little Chalfont.
Dale, Sharon Jean, Sutton.
Daniels, Razia, Chester.
Davidson, Clare Jane, Newcastle-upon-Tyne.
Day, James, Royal Tunbridge Wells.
de Villiers, Patricia Aileen, London.
Dinnis, Simon John, Burton on Trent.
Donkin, Jeffrey John, Surbiton.
Drowley, Brigitte, London.
Earby-McFarlane, Iain Scott, Chesham.
Fielding, Catherine, Avon.
Forrest, Jacqueline Alison, Bishopsbriggs.
Fox, Nigel Timothy, Leeds.
Fox, Rosemary, London.
Godfrey, Irmfried Adelheid, Glasgow.
Goliama, Teddy Francis, London.
Graham, Jennifer J., Glasgow.
Green, Kimberly Helen, Melton Mowbray.
Grossman, Julie Frances, London.

Gunnigan, Jane Carmel, Dartford.
Haddock, Brendan, Edinburgh.
Hammond, Alexander Malcolm, Sandy.
Hanna, Margaret Ann, London.
Hardeman, Sonia L., Alton.
Hardman, Joyce, Preston.
Harper, Jonathan, London.
Hawes, Rona Margaret, Redhill.
Hue Williams, Sarah Georgina, London.
Humphrey, Mary Sylvia, London.
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Johnson, Philip, Pensby.
Joly, Sandra Elizabeth, Rochester.
Jones, Amanda Melanie, Stourbridge.
Jones, Jason, Hull.
Joseph, Denise Taouk, London.
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Yasin, Abdel Nasser, St. Albans.

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Astrom, Mikko Tapani, Helsinki, Finland.
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Batis, David, Athens, Greece.
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Berruex, Cedric, La Chaux-de-Fonds, Switzerland.
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Chan W.K., Sunny, Hong Kong.
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Chedta-Thaiyawong, Kanitha, Bangkok, Thailand.
Cheng, Chi Chung, Hong Kong.
Cheng, Sau Chun, Hemans, Hong Kong.
Cheung, Chi Keung, Hong Kong.
Cheung, Shuk Mei, Hong Kong.

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Choi, Gyeng Hye, Seoul, Korea.
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Choy, Wai Ping, Daisy, Hong Kong.
Chui, Wai Chun, William, Hong Kong.
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Fowle, Michael John, Nairobi, Kenya.
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Jegge, Erich Peter, Zurich, Switzerland.
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Jeong, Seok-Ran, Busan, Korea.
Jewitt, Laura Kathleen, Vancouver, Canada.
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Ju, Young Ok, Pusan, Korea.
Jun, Huang, Hubei, China.
Kandamulla, Anuruddhika Priyadarshani, Colombo, Sri Lanka.
Kang, So Yean, Daejon, Korea.
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Kiji, Michio, Osaka, Japan.
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Kim, Kyoung-Soo, Taegu, Korea.
Kim, Kyung Sook, Pusan, Korea.
Kim, Meong Hee, Kyunggi-do, Korea.
Kim, Mi Jung, Pusan, Korea.
Kim, Mi-Ae, Busan, Korea.
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Kim, Young Ju, Daejon, Korea.
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Ko, Kyung Hai, Seoul, Korea.
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Lau, Teresa Sauwan, Hong Kong.
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Lee, Eun-Ju, Busan, Korea.
Lee, Gang-Ho, Daejon, Korea.
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Lee, Mi Kyung, Seoul, Korea.
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Lo Shuk Lan, Hong Kong.
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Sharma, Rashmi, Lusaka, Zambia.
Shouguo, Guo, Hubei, China.
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Sillanpaa, Heli Marianne, Kaustinen, Finland.
Silvonen, Nanna Kaarina, Helsinki, Finland.
Sivakumar, Periyasamy, Colombo, Sri Lanka.
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Suh, Dae-Yeol, Seoul, Korea.
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Syren, Riitta Anneli, Tampere, Finland.
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Tanabe, Hiroko, Toronto, Canada.
Tanaka, Kazuhide, Osaka, Japan.
Tarkkanen, Mika, Helsinki, Finland.
Toft, Peter Christian, Copenhagen, Denmark.
Tonn, Heleen, Rotterdam, The Netherlands.
Trifaud, Guillaume Nicolas, Bangkok, Thailand.
Tse Siu Ling, Hong Kong.
Tsui, Vincent Kam Luen, Hong Kong.
Tun, Maung Win Myint, Bangkok, Thailand.
Tuovinen, Annikki, Aanekoski, Finland.
Tzerbou, Helen, Athens, Greece.
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van Gils, Heleen, Overveen, The Netherlands.
van Vliet, Wim, Haastrecht, The Netherlands.
Vinkka, Susanna, Hameenlinna, Finland.
von Redlich, Anna Britta Andrea, Den Haag, The Netherlands.
Vreeling, Jacqueline, Schoonhoven, The Netherlands.
Wilcox, Kimberly Anne, New York, USA.
Wong, Queenie, Hong Kong.
Wong Chi Wing, Hong Kong.
Wong Chun Kwong, Hong Kong.
Wong Lai Fun, Alice, Hong Kong.
Wong Nim Chi, Phyllis, Hong Kong.
Xianfeng, Zhang, Hubei, China.
Yamasuga, Ryoji, Hyogo Pref., Japan.
Yan, Gao, Hubei, China.
Yan, Kam Tim, Hong Kong.
Yang, Hye Keong, Pusan, Korea.
Yip Man Loong, Hong Kong.
Yun, Sun-Whoa, Seoul, Korea.
Zaveri, Pragnesh H., Bombay, India.
Zhang Ziang Dong, Hong Kong.
Zhi, Zhan, Hubei, China.
Zinzuvadia, Jaydeep Amritlal, Bombay, India.

MEETINGS OF THE COUNCIL OF MANAGEMENT

At a meeting of the Council of Management held on 20 May 1992 at Chapel House, Hatton Place, London EC1N 8RX, the business transacted included the election of the following:

Fellowship
Flint, Sara E., Leeds. D.1991

Ordinary Membership
Almudallal, Mohammad, Abu Dhabi, UAE.
Bosey, Pauline M., Eton.
Dansereau, Eva M., Anola, Manitoba, Canada.
Fricker, Rowena, Dulwich, S Australia.

Jones, Michael, Bournemouth.
Mifsud, Ivan, Sliema, Malta.
Nilaratanakul, Chiraphong, Bangkok, Thailand.
Pash, A., London.

Laboratory Membership
Nash Broad Wesson, 42 Upper Berkeley Street, London WlH 8AB.

At a meeting of the Council of Management held on 24 June 1992 at Chapel House, Hatton Place, London EClN 8RX, the business transacted included the election of the following:

Ordinary Membership
Quinton, Sarah E., Byfield. 1992
Read, Julian, Goole. 1992
Sancroft-Baker, Raymond, London. 1992

Ordinary Membership
Ayles, Catherine, Edinburgh.
Branch, John Robertson, London.
Goh, Kok Chin Eric, Kuala Lumpur, Malaysia.
Hanna, David Mark, Inverness.
Jarek, Raymond Vincent, London.
Jindrich, Patricia Lynn, Trevor, USA.
McCormack, Susan, Liverpool.
Ronnie, Brenda, Leith, Edinburgh.
Saxton, Carol Anne Lesley, Alton.

Transfers to Fellowship and Diamond Membership
Barratt, Claire, Gillingham. 1992 (FGA, DGA)
Beckett, Shona-Maria F., London. 1992 (FGA)
Bendel, Helle, London. 1992 (FGA)
Blanch, Gloria, Barcelona, Spain. 1992 (FGA, DGA)
Boote, Caroline Margaret, London. 1992 (FGA)
Bradford, Nikki, Hassocks. 1992 (FGA)
Burrow, Denis, Gravesend. 1992 (FGA)
Day, Brynley John, Oldham. 1992 (FGA)
Drowley, Brigitte, London. 1992 (FGA)
Fox, Rosemary, London. 1992 (FGA)
Fromming, David Erwin, Gerrards Cross. 1992 (FGA, DGA)
Galopim de Carvalho, Rui, Portugal. 1992 (FGA)
Gemmel, James, Durham. 1992 (FGA)
Georgiadou, Elizabeth, London. 1992 (FGA, DGA)
Ghisi, Maria, Athens, Greece. 1992 (FGA, DGA)
Goddard, Valerie J., Alfold, Cranleigh. 1992 (FGA)
Grossman, Julie Frances, London. 1992 (FGA)
Hardeman, Sonia L., Alton. 1992 (FGA)
Harper, Jonathon, London. 1992 (FGA)
Hering, Peter, Cambridge. 1992 (FGA)
Houseago, James A., Lowestoft. 1992 (FGA, DGA)
Jordan, Lynn Pamela, Manchester. 1992 (FGA, DGA)
Kejriwal, Bindu, London. 1992 (FGA, DGA)
King, Margaret, Scotland. 1992 (FGA, DGA)
Kneebone, Garfield David, Penzance. 1992 (FGA)
Koundouros, Radka Lalovaska, Athens, Greece. 1992 (FGA, DGA)
Larkins, Barry, London. 1992 (FGA)
Lilley, Elaine, London. 1992 (FGA, DGA)
McConnachie, David Charles, Glasgow. 1992 (FGA, DGA)
McFarlane, Neil R., Alloa. 1992 (FGA)
Mildenhall, Caroline, Brighton. 1992 (FGA)
Ng, Soon Hoh, London. 1992 (FGA, DGA)
O'Brien, Gillian M., North Berwick. 1992 (FGA)
Oldfield, Gemma, London. 1992 (FGA)
Patel, Jagdish, Wimbledon Village. 1992 (DGA, FGA)
Patel, Pankaj, London. 1992 (FGA, DGA)
Prior, Louise Charlotte, London. 1992 (FGA)
Sergoulopoulos, Alexandros, Athens. 1992 (FGA, DGA)
Stather, Memory, Hong Kong. 1992 (FGA, DGA)
Stewart, Robert Miller, Bishops Waltham. 1992 (FGA)
Taylor, David John, Isle of Wight. 1992 (FGA)
Tees, Audrey, Glasgow, 1992 (FGA, DGA)
Travis, Peter J.B.C., London. 1992 (FGA)
Tucker, William J., Isle of Man. 1992 (FGA)
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CORRIGENDA

On p.133 above, second column the Figure 7 illustration was omitted; a reprint of the page complete with Figure 7 is included with this issue so that it may be inserted in the correct place

On p.151 above, Figure 1, line 1, after 'system' add 'show prism (A), pinacoid (c), bipyramid (w, z, n) and rhombohedral (r) faces'; Figure 1, line 4, for 'c and d' read 'parts c and d'

On p.152 above, first column line 5, for 'Figure 1b' read 'Figures 1c and 1d'; line 21, for 'Vichit *et al* 1979' read 'Vichit *et al*, 1978'

On pp.153, 154, 155, 157 and 158, because of a printing error illustrations are shown as negatives; replacement pages are included with this issue.

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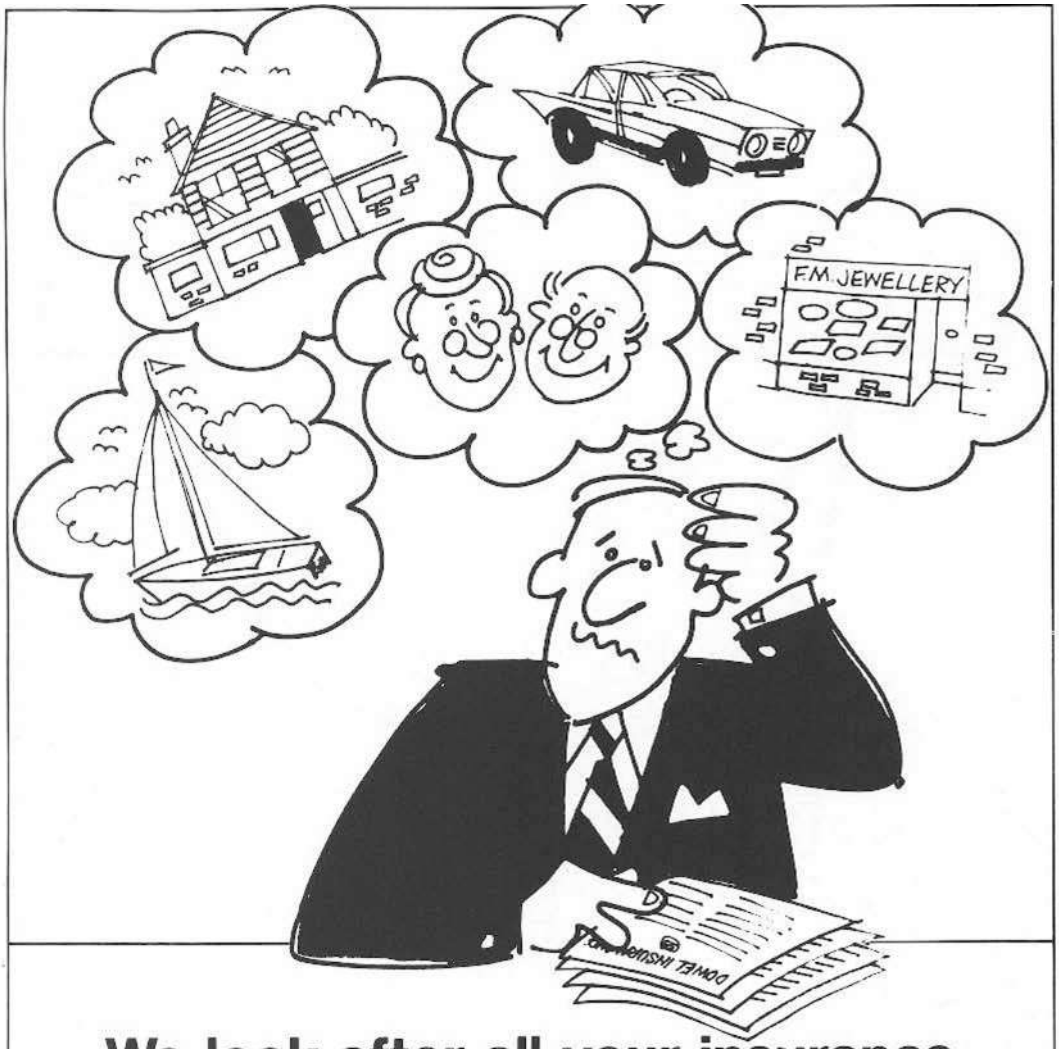

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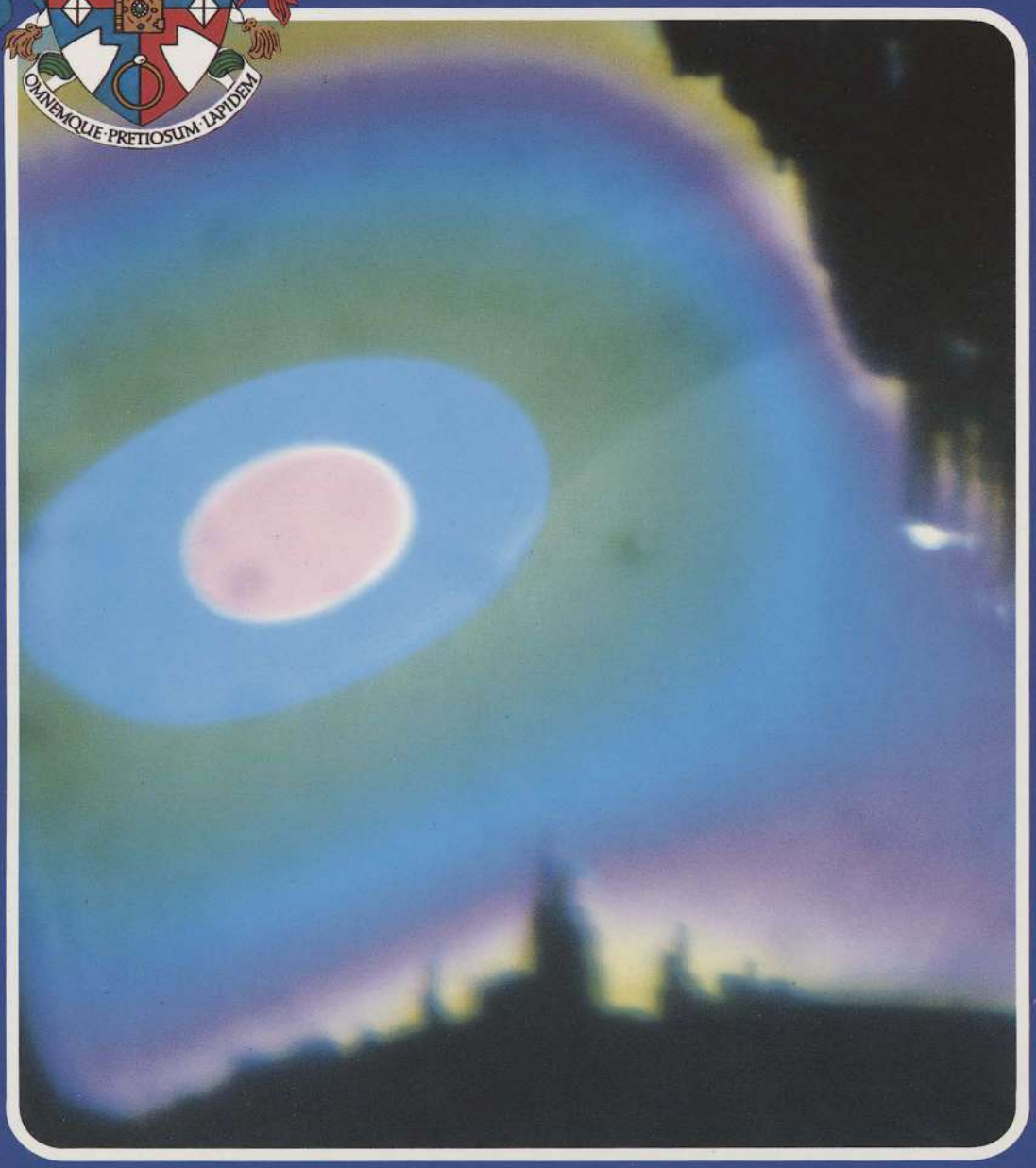

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Cover Picture

A thin film inclusion in an aquamarine from Pakistan. x22.

(See 'Unusual inclusion in an aquamarine' pp. 286)

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A notable red-brown diamond

James E. Shigley and Emmanuel Fritsch

Gemological Institute of America, Santa Monica, California, USA

Abstract

A 5.03 ct red-brown diamond in the Smithsonian Institution in Washington DC, USA (referred to as the 'DeYoung Red'), has attracted public and media attention as one of the only diamonds of its kind on museum display. Faceted diamonds having the hue term 'red' as any part of their colour description are extremely rare. Gemmological examination of this round-brilliant cut stone reveals it has internal features and a visible absorption spectrum typical of both brown and other pink-to-red diamonds. This correspondence supports the belief of a similar cause of pink and some brown colours that is thought to be related to deformation of the structure of these diamonds while they were still in the earth. The 5.03 ct stone described here is an example of a relationship in colour origin among brown and pink diamonds.

Introduction

In May 1989, we had the opportunity to examine a faceted red-brown diamond that had been donated to the Smithsonian Institution of Washington DC, USA in 1987 (Figure 1). Very little is known of the prior history of this 5.03 ct diamond, except that it had been owned by the late S. Sydney DeYoung, a well-known Boston gem dealer, who reportedly acquired it about 50 years ago and subsequently kept it locked in a vault. Gill (1978) suggested that this diamond may have come from India, but provided no further details. On Mr. DeYoung's death in 1986, the diamond was given to the Smithsonian as a bequest from his estate by the firm J. and S.S. DeYoung, Inc. It was delivered to the Smithsonian in November 1987, and was placed on public display in February 1988 in the National Museum of Natural History (Moser, 1987; Andrews, 1988; Federman, 1988).

Although the terminology used by the GIA Gem Trade Laboratory on reports describes this particular natural-colour diamond as a 'fancy, very dark, orangy red-brown', it has commonly but incorrectly been referred to as simply a 'red' diamond by the public and the press (Moser, 1987; Andrews, 1988; Federman, 1988). Diamonds that can be described as actually being 'pure red', or containing red as a principal (e.g. red-brown) or significant modifying (e.g. reddish-brown, reddish-purple) colour hue, are extremely rare in nature. Few diamonds of this colour have ever been examined or described in the gemmological literature; whatever information is available is often incomplete, or is included along with descriptions of other coloured diamonds. The GIA Gem Trade Laboratory has never issued a report on a diamond whose colour falls in the pure 'red' category, although recently a 0.95 ct diamond was described on the report as being purplish-red (Kane, 1987).

As part of our ongoing study of the gemmological properties of coloured diamonds, GIA Research staff examined this 5.03 ct stone to learn more about its coloration and other features. In this article, we briefly describe the gemmological properties and origin of colour of this notable coloured diamond (News Release, Smithsonian Institution, February 2, 1988, 'Colored Diamonds at the Smithsonian').

Instrumentation and Methods

Our examination was conducted using standard gemmological testing equipment, as well as more sophisticated instruments to record both the visible and infrared absorption spectra. The former included a GIA Gem Instruments binocular gemmological microscope, a Beck prism hand spectroscope, and a DISCAN digital-scanning, diffraction-grating hand spectroscope. The latter included a PYE-UNICAM Model 8800 ultraviolet-visible spectrophotometer, and a NICOLET Model 60SX Fourier-Transform spectrometer to record infrared spectra.

Results

Gemmological properties

Some quality-grading characteristics of this coloured diamond are summarized in Table 1. When examined under overhead fluorescent lighting, the diamond appears a very dark orangy-brown with a few bright red-brown reflections; the primary impression, however, is that of a brown diamond.

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Fig. 1. This 5.03 ct diamond, now on display at the National Museum of Natural History, Smithsonian Institution, is a very dark, orangy-red brown. *Photo by Robert Weldon, copyright by the Gemological Institute of America.*

When examined using directional lighting from, for example, a fibre-optic light source, the orangy red-brown bodycolour is more apparent. The overall appearance of this diamond has been described as similar to that of a red-brown garnet (Federman, 1988).

Because of its size and dark colour, it was difficult to transmit sufficient light through the diamond to observe some of its internal features with a microscope. Nonetheless, the bodycolour appears to be uniformly distributed when the diamond is viewed face-up with overhead fluorescent or incandescent lighting. The presence of red-brown coloured graining of moderately strong intensity could be seen when the stone was viewed through the pavilion (Figure 2). Such graining is evident throughout the diamond along octahedral planes of red-brown colour. Considering the orientation of this graining relative to that of polished table of the stone, the table appears to be approximately parallel to the cube {100} crystallographic plane. Such a stone is called in the trade a 'four-point diamond' (Gaal, 1977, p.109). This suggests the stone was fashioned from a primarily octahedral rough crystal.

When observed with a microscope using cross-polarized light, the diamond also displays strong anomalous birefringence ('strain') in the form of interference colours in either a banded or mottled pattern (depending upon the stone's orientation). This birefringence is seen throughout the diamond, and exactly replicates the pattern of graining. Both of these visual features – internal graining and anomalous birefringence – are typical of a number of natural yellow-to-brown, pink-to-red, and purple diamonds that we have examined during the past several years.

The diamond fluoresces a weak yellow to both long-wave and short-wave ultraviolet radiation. The fluorescence is chalky or turbid, and is evenly distributed except for one area under the table facet about 3mm in diameter which is inert. There is no phosphorescence after either ultraviolet lamp is turned off.

Spectroscopy

When viewed with a hand-held spectroscope, the spectrum of the diamond exhibits a broad region of absorption up to about 480 nm and a pair of weak but sharp lines at 496 and 503 nm. The diamond luminesces a moderately strong, turbid or chalky green colour when exposed to the intense transmitted light on the stage of the spectroscope unit (Figure 3). The luminescence to visible light (referred to by gemmologists as a 'green transmission' or 'transmission luminescence') is zoned, with some of the emission of green light observed to come specifically from the planes of coloured graining. This type of luminescence is common in natural brown to orangy-brown diamonds, and is believed to be associated with the H3 centre (503 nm; see Collins, 1982).

It was difficult to record absorption spectra obtained with the ultraviolet-visible spectrophotometer and the Fourier-Transform infrared spectrometer, again because of the strong absorption of the diamond due to its size and dark colour. The visible-range spectrum curve exhibits a continuously increasing absorption toward the violet (Figure 4, spectrum A). The curve levels off at wavelengths below 500 nm because the amount of absorption reaches the upper detection limit of our spectrophotometer (this is also the reason for the absence of the 496 nm absorption band in this curve that could be seen with a hand spectroscope). This kind of absorption curve gives rise to the 'brown' component of the colour of this diamond (Collins,

TABLE 1. Quality-grading characteristics

Dimensions	11.55 – 11.84 x 6.36 mm
Cut	Round brilliant with horizontally-split bezel facets
Weight	5.03 ct
Proportions	Table width percentage (54%), depth percentage (54.4%), medium culet size, and thin girdle width
Finish	Good symmetry and polish
Clarity	(VS2) with several small chips in the girdle, and a small needle-shaped inclusion under the table

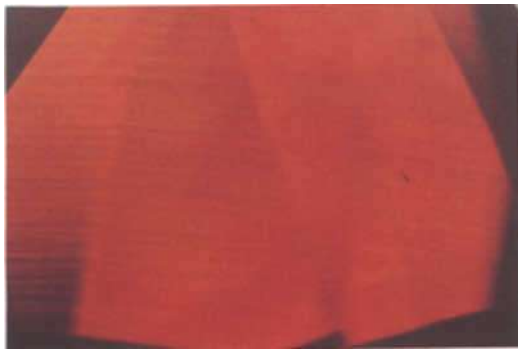

Fig. 2. When examined with 20X magnification through the pavilion, the strong red-brown graining that occurs throughout the diamond can be seen. *Photo by John Koivula, copyright by the Gemological Institute of America.*

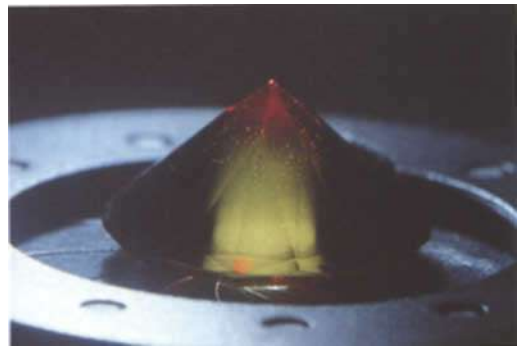

Fig. 3. When placed over a strong visible light source (such as from the hand spectroscope unit shown here), the diamond exhibits green luminescence. The numerous bright specks on the pavilion facets are dust particles on the surface. *Photo by John Koivula, magnified 2X, copyright by the Gemological Institute of America.*

1982). Superimposed upon this rising curve is a broad region of moderate-strength absorption between 500 and 600 nm that is centred at about 550 nm (that cannot be seen with a hand spectroscope). This broad-band absorption is characteristic of natural pink or purple diamonds (Collins, 1982), and its presence explains the 'red' component of the colour of this particular diamond. This can be seen by the comparison of the visible absorption spectra of this diamond with those for the 0.95 ct purplish-red and a 0.59 ct purple-pink diamonds (Figure 4, spectra B and C, respectively). The possible origin of these several absorption features is discussed below in the section entitled 'Cause of Colour'.

The infrared spectrum reveals that this diamond is of type Ia with a relatively high nitrogen content (Figure 5). The spectrum is unusual, however, because it shows a rarely-seen absorption feature referred to as the 'amber centre' (DuPreez, 1965, p.83), with a principal absorption band at about 4150cm^{-1} and many smaller bands at higher energy (Figure 5). Since the DuPreez thesis, there have been no further original data published on this unusual and complex absorption system. We have observed it in six out of about 1300 diamonds that we have recorded spectra for during the course of our ongoing coloured diamond research project. These six include four type Ia and two type Ib diamonds (one of the latter laboratory-treated to a red-brown colour (Landreau, 1986)). Our observations contradict the statement made by DuPreez that this absorption system was 'very common' in diamonds with paramagnetic nitrogen (e.g. type Ib diamonds). DuPreez named this system the 'amber centre' from the colour of the diamonds in which it was first found. However, one of the four type Ia diamonds with this centre that we examined has a light greyish-pink colour, and two of the other type Ia diamonds have a pinkish or reddish component to their colour. Interestingly enough, DuPreez associated the 'amber centre' with a broad absorption band at 550 nm, similar to that giving a pink colour (Collins, 1982), but he reported that the latter band behaved differently on cooling or exposure to X-rays than has since been noted elsewhere.

Discussion

Only a small number of diamonds with 'red' as a principal hue component of their colour have ever been mentioned in the gemmological literature. With few exceptions, these reports contain little, if any, detailed information on gemmological properties. There is also little specific information on their geographic origin of these diamonds. Ball (1934) lists the following sources: India, Borneo, Brazil, and South Africa. Gill (1978) mentions these same sources, but also includes Venezuela. The Alto Paranaiba area around Uberlandia (known as the 'Triangulo Mineiro', or the miner's triangle) in western Minas Gerais, Brazil, was reportedly a source of red and pink diamonds earlier in this century (Svisero *et al.*, 1984; K. Scarratt, pers. comm., 1989; Cassedanne, 1989).

Besides the diamond described here, the GIA Gem Trade Laboratory has issued reports on only three faceted diamonds in the recent past that contain the terms 'red' or 'reddish' as part of the colour description on their report.

* 2.33 ct cushion antique brilliant, fancy brownish orange-red, known as the 'Raj Red'.
* 0.95 ct round brilliant, fancy purplish red, known as the 'Hancock Red' (Kane, 1987; Federman, 1992).
* 0.54 ct round brilliant, fancy reddish-purple (Kane, 1987).

No coloured diamonds have ever been described

TABLE 2. 'Red' diamonds reported in the gemmological literature or by our colleagues, but not examined by GIA

Weight (ct)	Faceting style	Reported colour	Reference
10.26	Pear brilliant	'Chinese Red'	Gem Catalogue of the Duke of Brunswick-Luneburg (1860, pp.126-7)
8.00	Not reported	'Red'	Kunz (1926, p.596)
7.44	Round brilliant	'Garnet'	Gem Catalogue of the Duke of Brunswick-Luneburg (1860, pp.108-9)
6.00	Cushion cut	'Red'	Kunz (1926, p.596); Gill (1978, p.85); reportedly from South Africa
5.05	Emerald cut	'Blood red'	Drukker (1971); Gaal (1977, p.241); Gill (1978, p.85); 'De Beers Red'; reportedly from Lichtenburg, South Africa
5	Not reported	'Ruby red'	Shepard (1934); Monnickendam (1955, p.154)
5	Round brilliant	'Port wine red'	Gill (1978, p.86)
3.98	Round brilliant	'Brownish red'	Gem Catalogue of the Duke of Brunswick-Luneburg (1860, pp.94-5)
2.50	Round brilliant	'Port wine red'	Gill (1978, p.86)
2.50	Marquise	'Deep cherry red'	Gill (1978, p.86)
2.50	Round brilliant	'Red'	Gill (1978, p.85); reportedly from Brazil (?)
2.00	Not reported	'Red'	Kunz (1926, p.596)
1.64	Not reported	'Deep red'	K. Scarratt (per. comm., 1989; Gem Testing Lab of Great Britain report)
1.28	Marquise brilliant	'Red/pink'	C. Schiffmann (per. comm., 1989)
1.15	Not reported	'Bright red'	Eclat (1984, p.119)
1.14	Not reported	'Red/brown'	K. Scarratt (per. comm., 1989; Gem Testing Lab of Great Britain report)
1.13	Round brilliant	'Purplish-red'	T. Horovitz (per. comm., 1989; Gübelin Lab and SSEF Lab reports)
1.00	Not reported	'Red'	Streeter (1884, p.141); Gill (1978, p.85); 'Halphen'; reportedly from Borneo (?)
1	Cushion cut	'Ruby red'	Gübelin (per. comm., 1989)
0.80	Not reported	'Red'	Zucker (1984, p.93)
0.60	Round brilliant	'True red'	Crowningshield (1965, p.362)
0.52	Marquise	'Purplish red'	Eclat (1984, p.117)
0.46	Cushion brilliant	'Purple red'	C. Schiffmann (per. comm., 1989)
0.46	Marquise brilliant	'Reddish-pink'	T. Horovitz (per. comm., 1989; Colored Diamond Lab Services report)
0.37	Not reported	'Red'	Kunz (1926, p.596)
0.29	Not reported	'Red'	K. Scarratt (per. comm., 1989; Gem Testing Lab of Great Britain report)
0.28	Not reported	'Rose red'	K. Scarratt (per. comm., 1989; Gem Testing Lab of Great Britain report)

Notes:
1. The colour description of these diamonds using current GIA terminology is unknown.
2. Additional diamonds with these colours are cited in Fersman and Goldschmidt (1911, crystal drawings #55, 91, 92, 105, 120), Kunz (1926, p.596; 1927, p.567, and 1929, p.515), Drukker (1971, pp.140-1), Pyplev (1896; cited in Orlov, 1977, p.121), and Gill (1978, p.85).

by them as being 'pure red'. Considering the great number of coloured diamonds seen over the years in the GIA Gem Trade Laboratory, this very small number demonstrates how extremely rare coloured diamonds that would be described by experts as being 'red' or 'reddish' actually are.

Given the widely-held perception and reported experience of professional diamond gemmologists as to the great rarity of these coloured diamonds, we thought it would be interesting to try to find references to diamonds of this colour. Table 2 presents a list of other alleged 'red-orange' (i.e. 'red-brown'), 'red' and 'red-purple' faceted diamonds that have either been reported in the gemmological literature, or by our colleagues who are involved in the gemmological study of colored diamonds. Our purpose for compiling this table was to find reports of apparent 'red', 'reddish' or 'red-brown' diamonds. We chose not to mention pink or brown diamonds because of their much greater relative abundance and corresponding wider recognition among gemmologists. Literature citations also exist for rough diamond crystals, but they are given in Table 2 only as a footnote because it was impossible for us to be certain if their reported colour is a true bodycolour or just a surface colour (due to staining, for example).

In compiling Table 2, we sought references that mentioned a polished diamond in terms of its weight, faceted shape, and colour. Anyone familiar with the gemmological and trade literature recognizes that it is often incomplete, as can be seen for some citations in Table 2 where even this basic information was not reported. Some of these refer-

ences, such as the Brunswick gem catalogue (1860) and the personal communications from our colleagues, are without doubt first-hand reports of specific diamonds. Others, such as the citations from Kunz and Gill, appear to merely be repetitions of information apparently reported elsewhere, and thus, their accuracy is more doubtful. Nonetheless, we have no reason to suspect that there is not some degree of truth in all these citations of actual diamonds with some form of reddish appearance. It should be emphasized, however, that we have no accurate current colour description of the diamonds beyond what is shown in Table 2, since none have been examined by GIA. Neither can we be certain in all cases that the diamonds shown in Table 2 each represent a different diamond, nor whether or not they had been artificially colour-enhanced for the more recent references (since gemmologists have long recognized that red-brown diamonds are occasionally produced by laboratory irradiation treatment [Crowningshield, 1959, 1966]).

Our literature search encompassed many documents available in GIA's Richard T. Liddicoat Library and Information Centre, but we found citations of only 27 such faceted coloured diamonds in literature references in the last century. This small number further substantiates the great rarity of truly 'red' diamonds.

Cause of Colour

The visible absorption spectrum of a 'red' diamond has not been published before. The few natural-colour 'reddish' diamonds for which some data have been reported suggest that the red component of the colour is due to a strong, broad band centred around 550 nm ('2.2 eV band'), the same that contributes to a pink or purple colour when the band is less intense. This is illustrated by the comparison of visible spectra of the three diamonds (Figure 4) which each exhibit the 550 nm broad band of varying intensity. Preliminary work has shown this broad band to be a vibronic band (Raal, 1958;, Collins, 1982). This hypothesis has been confirmed by our ongoing study of coloured diamonds. In Figure 4, three weak oscillations (sidebands) on the low-energy side of the 550nm broad band at approximately 590, 605, and 610 nm, are seen in the spectrum (C) of the purple-pink diamond, and two of them (590 and 600 nm) are seen in the spectrum (B) of the purplish-red diamond. It has been speculated that the origin of this 550 nm broad-band absorption, as well as the absorption rising toward the violet that gives rise to the brown coloration, is plastic deformation (a small displacement of atoms) along gliding planes in the diamond crystal structure (Harris *et al.*, 1984).

Other causes of pink-to-red colour in diamond have been suggested. The early idea that the pink colour is related to traces of manganese was totally discredited as long ago as 1965 (DuPreez, 1965, p.79). Neither does there appear to be any correlation between a pink or red coloration and the nitrogen content of the diamond as is sometimes suggested (e.g. Christie's auction catalogue, 28 April 1987, p.292). It has been our experience that the nitrogen content of pink-to-red diamonds can vary. In some instances, the amount of nitrogen seems to be quite high, as evidenced by the mid-infrared spectrum of the 5.03 ct diamond (Figure 5). In fact, the 0.95 ct purplish-red diamond (described by Kane, 1987) and the 5.03 ct stone are both type Ia diamonds containing relatively large amounts of nitrogen. Research is currently being carried out to better understand the exact nature of the atomic-level plastic deformation that is now generally thought to produce the pink-to-red coloration in diamonds.

The visible spectrum of the 5.03 ct diamond in Figure 4 (spectrum A) also displays a weak, sharp band at 503 nm (the H3 centre). As mentioned above, this band is responsible for the green luminescence seen when the diamond is exposed to intense visible light, as well as the yellow ultraviolet fluorescence.

Summary

This 5.03 ct red-brown diamond exhibits gemmological features that we find are characteristic of a number of natural-colour yellow-to-brown and pink-to-red or purple diamonds. These include prominent red-brown graining, green luminescence in visible light, and a visible spectrum with an increasing absorption toward the violet and a broad band located at about 550 nm. This particular diamond also displays the rare 'amber centre' in its infrared spectrum.

Some individuals consider this diamond unattractive due to its dark colour (which is further compounded by its large size). However, it sometimes happens that much can be learned from the study of such a diamond where certain features are more prominently developed than is normally the case in a lighter-coloured stone. In this diamond, the unusual feature is the hue and intensity of the colour. We propose that the colour – mainly brown and some red – can be explained in terms of the visible absorption spectrum where the causes of both colour components are evident. Furthermore, visual examination indicates that the red-brown colour is concentrated along planar octahedral graining. When considered with the reported occurrence of some pink-brown diamonds from the Argyle mine (see Hofer, 1985), the presence of red (or pink) and brown in the same diamond suggests a

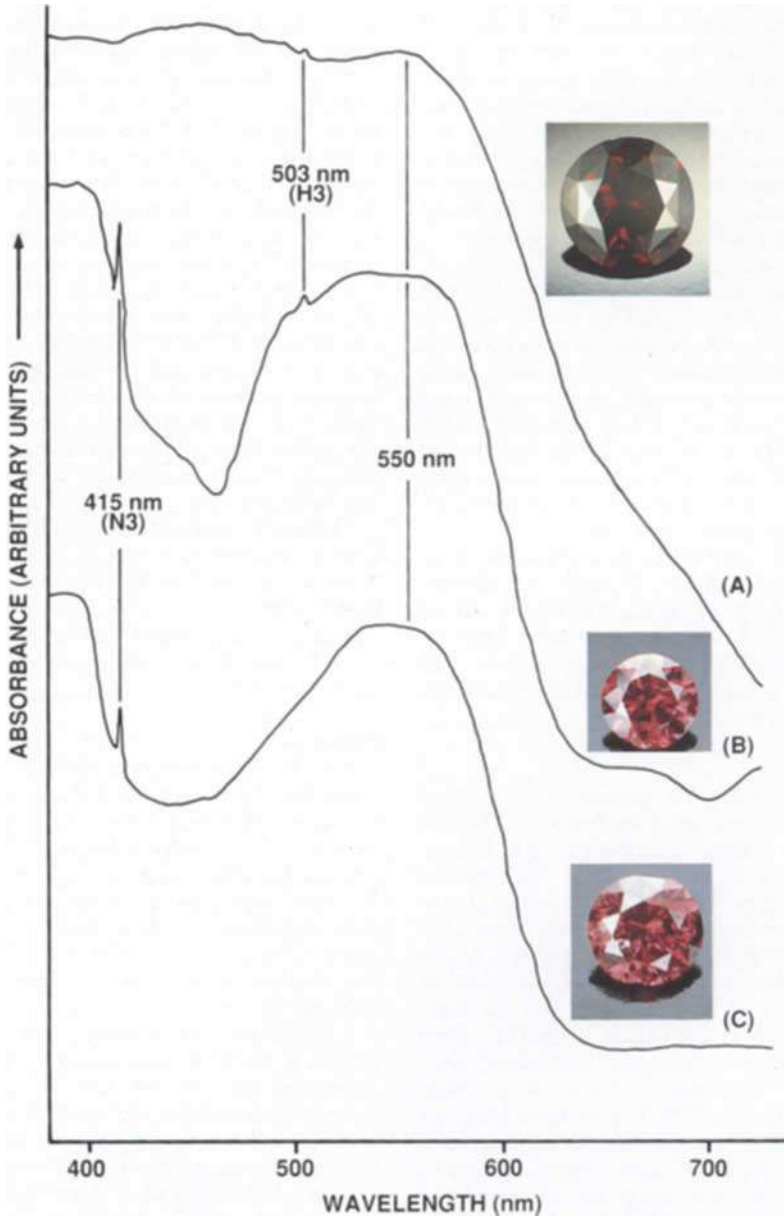

Fig. 4. These three visible absorption spectra were recorded at liquid nitrogen temperature (80 degrees K). The top spectrum (A) is that of the 5.03 ct diamond described in this article. The middle spectrum (B) is that of a 0.95 ct purplish red diamond, and the lower spectrum (C) is that of a 0.59 ct purple-pink diamond. Several features are present in these spectra;
(1) An increasing absorption toward the violet that gives rise to the brown component of the colour – this feature is only seen in (A). The 415 nm band (N3 centre), very common in type Ia diamonds as part of the 'Cape series' of absorption lines, can be seen in (B) and (C).
(2) A broad band centred at about 550 nm is responsible for the pink or red component of the colour. This band is visible in all three spectra in varying intensity. Associated weaker bands at approximately 590, 600, and 610 nm are visible in (B) and (C).
(3) The upper two spectra show a sharp band at 503 nm (the H3 centre); this band gives rise to the green luminescence of the 5.03 ct diamond. The 496 nm band observed with the hand spectroscope in the same diamond is not resolved in spectrum (A).

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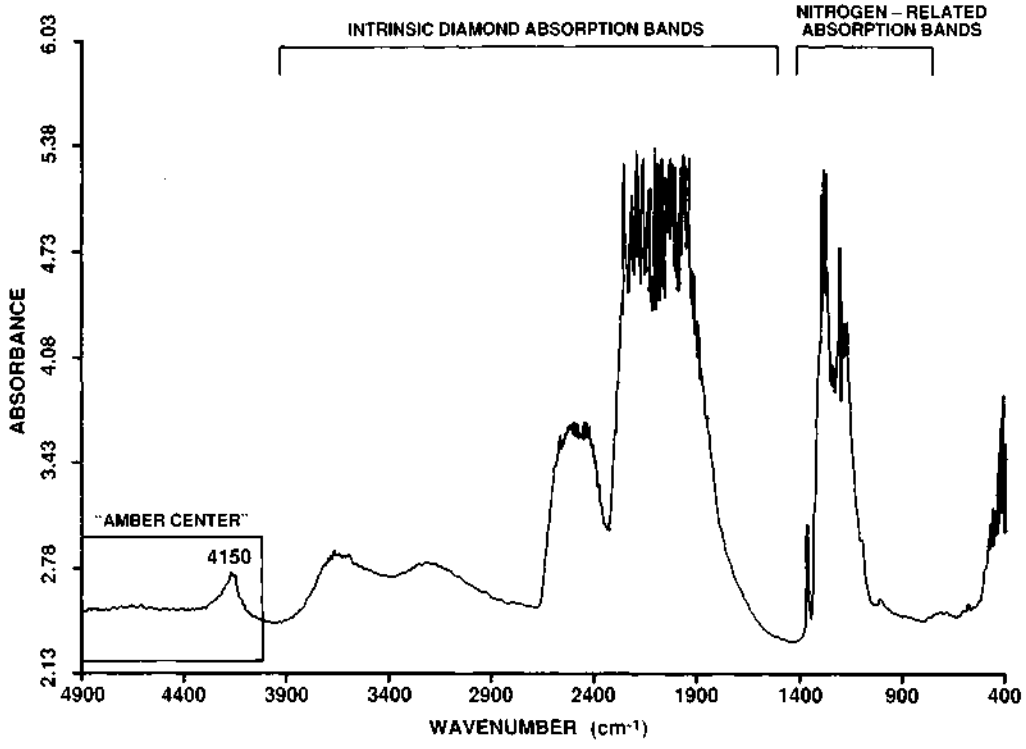

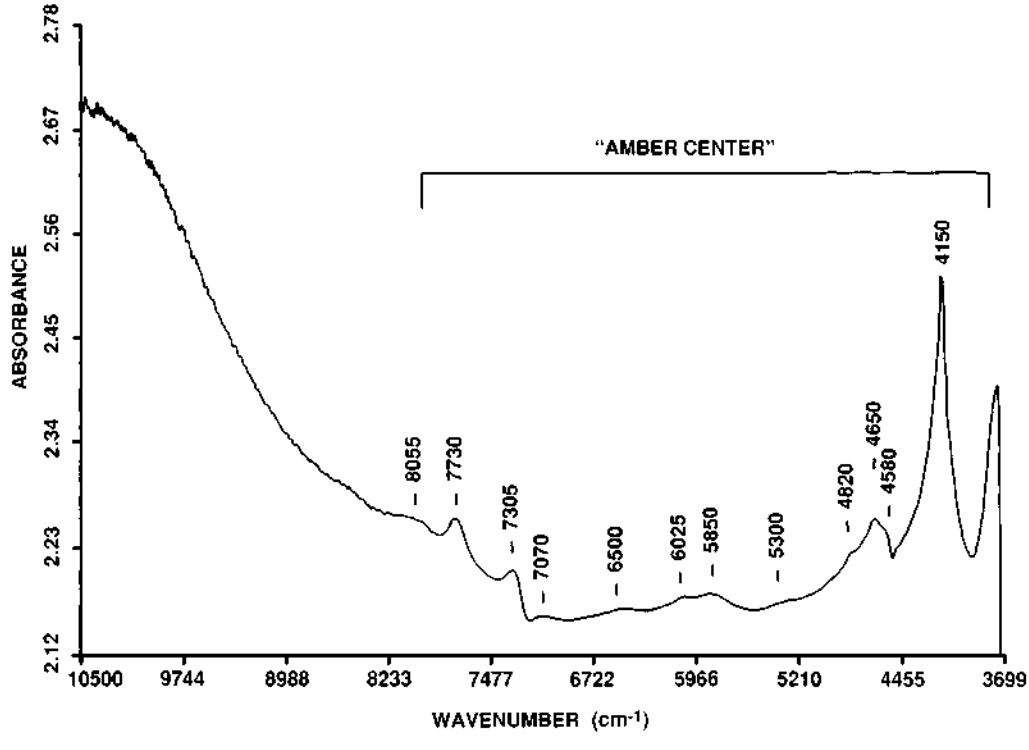

Fig. 5. The near- and mid-infrared absorption spectra of the type Ia 5.03 ct diamond. Note the 'amber centre' starting at 4150cm^{-1} (top spectrum) with further details at higher energies (bottom spectrum).

related cause of these colours. In such cases, deformation of the diamond during its long history in the earth may account for the formation of a colour centre along graining planes that would be responsible for brown, pink, and even 'red' colours.

Acknowledgements

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Possible prehistoric glasses in the gem trade of Sri Lanka

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Abstract

Variously-coloured glasses are found in Sri Lanka in different geological environments; at or near the surface (hence the Singalese name 'ground glass'), in some gravels of recent rivers and in some gem pits (hence the English name 'pit glass'). If these glasses were really deposited in the Pleistocene times together with the gem gravels, were they tektites? However, the chemical compositions of these glass samples are different from that of real tektites. The very high content of sodium in all samples and the lead content in some samples are strong arguments for an artificial formation of these glasses. These multi-coloured glasses are man-made materials, which were probably produced in prehistoric times. After the mining activity was finished the gem pits were always filled up with overburden and any kind of waste. The waste, which is found during modern gem mining, consists of old bricks, old pottery and other useless things, for instance gem gravel from older mining activities such as geuda, which did not have any value in former times. The gem pit could also be filled up with waste from glass production. Glass was an important article of trade on the old maritime silk route.

Introduction

In the gem trade glass is normally a man-made material. But in some cases glass is of natural origin such as obsidian from volcanic activity or tektite glass which has been formed from sediments on the earth surface which have been fused by heat generated through the impact of enormous meteorites (Preuss, 1935, Heide, 1934 and 1988).

Multi-coloured glasses are well-known in Sri Lanka. Most of them will be sold to tourists after cutting. Some rough uncut glasses will be exported to Thailand as carving material for the production of Buddha images and other articles. Gem dealers think that this glass is of natural origin and locally they call this material in the Singalese language '*Bin vitro*' which may be translated as ground glass. A. Church (1924) mentions that 'moldavite' (glass from Moldavia, Czechoslovakia; today sometimes called tektite (Greek: smelted)) 'occasionally occurs in the gem gravel of Ceylon'. In the English literature this material is called 'pit glass'. Webster (1970), mentions 'there has been no clear confirmation but a number of pieces of so-called 'pit glass' which is mostly brown or green have been credibly reported', but it seems for Webster 'so far be considered unproven?'. The question whether this glass was probably man-made in prehistoric time, has no room in the gem trade of Sri Lanka. Even well reputed gem dealers, who never touch this cheap stuff (which is mostly dealt with in the street) think that it is of natural origin. Some geologists and gemmologists of Sri Lanka with a very good knowledge of Sri Lankan gems consider this material as tektites coming from the gem gravel – the 'Illam'. If this conclusion is correct, it has an important consequence. Since the 'Illam' was probably deposited in the late Pleistocene, this pit glass could not be an artificial product. The multi-coloured appearance of this pit glass is, however, very unusual for a tektite or for similar material of meteoritic origin. This pit glass occurs in red, green, orange, violet and yellow colours, but most pieces which are on the market are colourless or with a very faint shade. Some of the colouring elements, such as cobalt, iron, etc., are enriched in some meteorites. On the other hand these colouring elements were well known in the various prehistoric glass-making factories. Glassy slags from prehistoric metal smelting works may assist in the study of man-made glass. Further information may be obtained by comparing the local pit glass with material from other places with an undisputed origin.

Description of the pit glass material

Glass in Sri Lanka may be found in the gem gravel (illam), in the river load or in some soils. For genetic questions – whether the material is man-made or of natural origin – the size, the shape, the surface, the colour and the chemical composition of the glass are very important.

The size of the Sri Lanka pit glass specimens varies considerably. Small pieces below one gram are to be found among pieces of several kilograms in weight. Even single pieces over 50kg are not uncommon. Real tektites from elsewhere, which were transported through the air, are mostly of

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Fig. 1. Two samples, which are common in Sri Lanka, show a very faint green tint. The surface of the larger glass sample is scarred and pock-marked; the weight of this sample is 940g, size 135 x 75 x 64mm (only part is visible). The smaller sample was collected from a river sediment. The surface of this sample is different from the bigger piece; weight 235g, size 85 x 55 x 45mm. The small blue sample is coloured by cobalt. Weight 50g, size 35 x 35 x 30mm.

Fig. 2. A similar glass sample (to Figure 1) on the illuminated viewing box.

Fig. 3. A prehistoric glass sample with a cut and polished surface. The window allows internal viewing and shows a clear glass body without any bubbles.

hazelnut sizes, but pieces of up to several kilograms have been found. However, tektites of several tens of kilograms are not known, whereas pit glass of this size has been found.

The shape of the pit glass is irregular but more or less isometric. Never have I seen in Sri Lanka pit glass shapes which are found in tektites such as balls (partly hollow), button shapes, drops, peas, ellipsoids, discs, dumb-bells, cones similar to pine cones, etc., which are well-known to collectors of tektites.

The surface of some pit glass is scarred, pock-marked or with cavernous or other weathering marks, but the pit-glass from the river or from the Illam does not show this characteristic surface. The surface markings of tektites may be explained by supersonic and rotational flight through the earth's atmosphere; weathering surfaces are not known from tektites.

As mentioned before, pit glasses from Sri Lanka are of various colours. Most tektites from other localities are black or dark coloured and opaque but colourless and various shades of transparent olive green, bottle green and yellowish-grey are found in some well-known 'tektite' localities such as Moldavia. However, the colours at one locality usually differ only in a relatively small degree. In contrast to these more or less uniform colours of the tektites the pit glasses from Sri Lanka are very different. Red, orange, light blue, deep blue, violet, green, brown and yellow are common in the local trade. But never have I seen a black pit glass, which is normal for most tektites.

Chemical composition

The chemical composition of some glasses may be helpful for the differentiation between man-made material and tektites.

Chemically glass, being a melt, can be produced by the fusion of an acidic oxide with a basic oxide to reduce the melting point of the glass. The acidic

Fig. 6. Cut prehistoric green glass with 0.2% chromium and 0.1% copper. Size: 15 x 15 x 10mm.

Fig. 4. Different coloured glass samples from Sri Lanka, probably of prehistoric origin. The green sample is coloured by chromium, the deep blue by cobalt, the light blue by copper, the deep red is a lead glass.

Fig. 5. Cut prehistoric glasses from Sri Lanka. The red triangular specimen is a lead glass. The small blue (copper) cabochon is not such a clear glass material. Cobalt-blue and chromium-green pieces. The large cut glass piece with a very faint tint is a most important prehistoric glass material in Sri Lanka.

Table 1: Chemical compositions of possible prehistoric glasses ('pit-glass') of different colours from Sri Lanka

	Colourless faint green tint	Cobalt blue	Emerald green	Aquamarine pale blue	Orange	Ruby-red
SiO_2	68.9	69.1	67.6	58.4	70.1	53.4
Al_2O_3	1.7	2.6	2.8	15.0	1.6	2.0
TiO_2	0.03	0.05	0.01	0.2	0.03	0.006
Fe_2O_3	0.2	0.06	0.07	0.2	0.06	0.12
MnO	0.02	0.06	0.02	0.2	0.09	0.18
P_2O_5	0.03	0.05	0.07	0.11	0.08	0.22
CaO	12.5	7.7	11.5	1.3	10.1	0.8
MgO	2.06	0.02	0.02	0.05	0.04	0.02
Na_2O	11.9	14.3	13.6	9.16	10.88	14.8
K_2O	0.86	0.91	2.07	1.28	4.99	0.22
BaO	0.02	0.002	0.005		0.01	
H_2O	0.10	0.15	0.16	0.56	0.34	1.26
ZnO	0.3	3.2	0.03	0.09	0.12	0.06
PbO	0.34		0.04	11.2	0.16	26.2
ZrO_2	0.1	0.03		0.1		
As_2O_3	0.05	0.3	0.4	0.65	0.3	0.5
Cu		0.60	0.14	0.25	0.06	0.07
Co		0.07				
Cr			0.2			
Se					0.15	
Cd					0.02	
	99.11	99.19	98.74	98.95	99.13	99.86
RI	1.510	1.535	1.518	1.524	1.51	1.56

Several single glass samples have been analyzed. The SiO_2 and partly the Al_2O_3 have been analyzed in the classical wet chemical way. Na_2O, K_2O, CaO, MgO, P_2O_5 and PbO by atomic absorption. Fe and Al by spectrophotometric methods. The other trace elements by X-ray fluorescence.

oxide is commonly quartz with a very high melting point. The basic oxides are commonly soda (in prehistoric times from Egypt) or potash (most commonly vegetable ash) together with limestone and possibly with basic lead, barium, zinc, thallium, zirconium or aluminium; glass has an immense range of chemical composition. Artificial glass normally has a much higher content of Na_2O and CaO than is found in tektites (varying between 0.65 and 3.8% Na_2O, 1.85 and 3.16% K_2O, 0.1 and 3.5% CaO). Preuss (1935) showed that the chief constituents and the trace elements of the tektites are similar to those of sandstones, graywackes or loess. Tektites are much higher in aluminium (6-15% Al_2O_3) and to some extent higher in SiO_2 (70-90% SiO_2) than the normal man-made glass. Antique glasses are very rich in sodium and lime, which lowers the melting point. Bezborodov (1975) published an extensive collection of chemical analyses of antique prehistoric glasses. The content of the different elements varied considerably: Na_2O 0.2-30%, CaO 1-25%, K_2O 1-19%, Al_2O_3 0.47-10%, SiO_2 49-72%. These prehistoric glasses were produced during different cultural times; Egyptian, Roman (from different places in Germany), ancient Russian (Ukraine) and Arabic cultures and even from different prehistoric localities in India. Most prehistoric glasses are Na and Ca-rich. The glass samples from India are mostly Na and Ca-rich and Arikamedu (South India) glass is rich in K_2O.

Our analyses of pit glass from Sri Lanka are presented in Table 1. All samples are very rich in sodium (9-15% Na_2O) and CaO (0.8-13% CaO). Pit glass shows a low content of Al_2O_3 (1.8-2.9%, one sample 15% Al_2O_3). The water content (0.09-1.5% H_2O) in these samples is too high for tektites (0.0003-0.01% H_2O). Even the content of all other elements shows very clearly that this so-called pit glass from Sri Lanka is a man-made glass and not a tektite. Another important constituent of some pit glasses is lead (varying in different analysed samples from 0.00-27% PbO). This element gives credence to the opinion that this material is man-made. Even the high content of antimony (up to several %), arsenic (0.0-4.3%), barium (0.2%) and sulphur (in some samples up to 2%) are unexpected elements and have not been found in true tektites in this amount. Even modern glasses normally have different chemical compositions from these prehistoric glasses from Sri Lanka.

Refractive index of glass

The refractive index and the density of pit glass vary over a considerable range and in some cases overlap those of natural stones. Moldavites have a refractive index n near 1.5 – the analysed pit glasses from Sri Lanka varied in this index n = 1.501 – 1.535 and up to 1.56 for lead glass. Some values are given in Table 1 together with the chemical composition.

Table 2: Colouring agents in possible prehistoric glass samples (pit glass) from Sri Lanka by X-ray flourescence analysis

Colour of the glasses	Trade name Imitation	Colouring Trace elements mean value of several samples
Red*	'Ruby'	Copper Cu^{I+} 0.1-0.0X% Gold probably + but very low
Brown red*		Copper with iron Fe^{3+} 0.0X-0.4%
Orange**	'Padparadsha'	Selenium 0.1 Se + 0.0X Cu%
Yellow	'Chrysoberyl'	Cadmium or iron Fe^{3+} 0.0X-0.2%
Blue	'Sapphire'	Cobalt 0.07% Co + 0.2% Cu^{2+}
Pale blue*	'Aquamarine'	Copper 0.0X-0.7% Cu^{2+}
Blue-green	'Aquamarine'	Iron 0.1-0.7% Fe^{2+}
Green**	'Emerald'	Chromium 0.2% Cr + 0.1% Cu
Blue-violet**	'Amethyst'	Cobalt 0.05% Co + 0.4% Cu
Dirty green		Manganese + iron 0.3% Mn + 0.4% Fe

* Partly lead glasses up to 27% PbO
** Partly potash glass
X Varying values in this range

Different types of pit glass

From the historical point of view it is very interesting to note that in the early days very different glass qualities were produced. The varying chemical analyses, densities and the refractive indices of the samples indicate that the pit glasses from Sri Lanka represent different special glass types. In modern glass nomenclature the pit glass is comparable with the following types:
bottle glass or window glass, crown glass (lime – soda – potash) and flint glass (crystal or lead crystal glass – with a high content of lead).

Pit glasses of different colours

Simple glass, made of pure ingredients such as silica and alkali oxides, are colourless, but natural sand is not chemically pure and has a varying content of heavy minerals. These different minerals may give the glass a very faint colour. If a stronger shade of colour is to be present colour-producing agents must be added. Many shades of colour could be attained even in prehistoric glasses. In normal glass, iron is the most important tinctorial agent, some yellow, some green, some brown colours reflect a certain iron content and a different oxidation state. Apart from iron a large number of metallic elements (as oxides) are used for imparting colour into glasses such as Cr, Co, Ni, Cd, Mn, Se and Au. Many of these elements are found in some specially coloured pit glass samples from Sri Lanka, as X-ray fluorescence analyses show (Table 2). The precise colour shades do not depend merely upon the amount of colouring matter, nor upon the overall glass composition, but the conditions of melting, for instance copper under oxidation conditions give a blue colour to the glass and a red colour under reducing conditions.

It is a mixture of different colouring elements, which has been analyzed in the pit glass and not a defined composition, which could be produced by chemically purer elements during modern melting procedures. The fact that the colouring trace elements (compounds) used are not chemically pure is also an argument that this material is made in prehistoric time and probably in most cases not recently man-made material.

The colouring oxides are used in a similar manner today. Blue was the popular colour in Egyptian times. Even in Sri Lanka, copper, cobalt and iron were found in different blue glass samples. Unusual in the analyzed glass samples was the use of selenium. The orange tint of this glass is to be found in some samples together with a high content of aluminium, which is unusual in antique glasses and more common in glasses from the Middle Ages and from modern production.

Glass as imitation of gems

Glass is one of the oldest imitations or substitutes of gems and has been manufactured for thousands of years. Glass-making was considered a great art by the ancient Egyptians and in Greek and Roman times, when glass was so rare that it was considered more precious than natural gem stones. Even today antique glass beads are more expensive in the local trade in Egypt than antique natural gemstones, like agate, onyx, amber and turquoise. In the gem area of Sri Lanka beads of glass are very uncommon.

Interpretation of the results

The Singalese name for this so-called pit glass is 'Bin vitro', which may be translated as 'ground glass'. This name implies that this material is found in the soil. The present investigation indicates that this glass is man-made material and not a tektite or obsidian, neither of which are found in Sri Lanka. A

plausible theory was put forward that the pit glasses of Sri Lanka are material that had been left behind on the sites of prehistoric glass factories which had to be abandoned. The prehistoric factory may coincide with the locality in which some pit glass can be found in larger quantities. Prehistoric glass is known not only from India (Bezborodova, 1975) but also from Sri Lanka. Francis (1990), mentions the locality Mantai in the north of Sri Lanka near the 'Adams Bridge' to South India (see Figure 1). From local information, which is difficult to get, glass may come from various localities in Sri Lanka: green and red glass may be found to the east of Matale. Dambulla (60km north of Matale) is famous for red glass. Yellow glass comes from Ginigathene. Various coloured glasses can be found among colourless glasses 35km south east of Anuradhapura. Blue glass comes from Nawalaptya, (100km east of Colombo). Green and pink glasses can be found near Kalawana (near Ratnapura). Very large glass pieces came from Bagawantalawo (near Nuwara Eliya). The route from the exact sources of gems to the market place is mostly secret. Even glass marketed in Ratnapura is mostly found elsewhere.

The gem gravel (illam) bed is mined in Sri Lanka in the dry season. The pit and the underground working may be filled up after the mining activity with overburden and even with any waste. For instance, in some mines in Elahera old pottery, bricks and old Singalese coins were found during modern gem mining activity. Even gems which were not in use in former days, such as star stones and geudas, were discarded and put back in the mined-out pit. Star stones, such as star rubies and star sapphire have come in fashion in the last century. Geuda, the nowadays highly valued poorly coloured corundum, which can be heated and turned into blue sapphire (H. Harder, 1990), was in old days without any value and can be found today in larger quantities in old mining areas. The waste of former days can include glass and this was probably produced in prehistoric times. Later new gem mining started again without knowledge of the previous mining activity and the old areas will be dug over again.

Only part of this new working will be in untouched illam. The other part is overburden and waste from the previous mining activity. During the new mining they may encounter the old workings and even the waste and other useful things of previous time, such as old Singalese coins. In the same way it could explain the possibility that man-made glass was mined from the illam. Only a completely untouched illam could show that no glass would be found in the Pleistocene horizon. An investigation in some newly opened gem mining areas might give some information but as nowadays (1989) travelling in some remote areas is difficult, this project could not be carried out.

The question of glass manufacture in Sri Lanka or imported glass

More than 2000 years ago when South India and even Sri Lanka were in close contact with the Mediterranean and even with the Chinese world, Mantei (now known as Mannar) was an ancient port of the maritime silk route. Beads of glass and gems were one of the important trade products. A further question is whether the rough glass was imported from elsewhere or whether the people of the Far East had their own glass production. The very large pieces of prehistoric glass may be a hint that the glass manufacture was in Sri Lanka itself. Another hint may be the unusually high content of zirconium and titanium in the glass. The mineral zircon is an important heavy mineral in the sands of Sri Lanka. Most glass analyses from Sri Lanka (Table 1) show a high content of Na_2O. Imported soda from Egypt or elsewhere or imported glass from the Mediterranean area or even sodium-rich plant ashes could be the source. The analyses also show a very unusually low content of magnesium for prehistoric glasses.

All these questions need further investigation but at the present time (1989) a visit to remote places in the northern part of Sri Lanka is impossible for political reasons. Francis (1990) says 'the South East Asian branch of glass industry died out in 1200'. It may be that in those times in Sri Lanka the glass factory became uninteresting and the people may have forgotten that glass was produced in this area. The deficiency of fuel seems, as in other places, also to be a reason why the glass production came to an end. This may apply also in the north of Sri Lanka since the production of 1kg glass needs two cubic metres of solid timber.

Prehistoric glasses as valuable collector pieces

In the past 'pit glass' stood in the shadow of the local gem business; only some poor tourists were happy to buy the rough or the attractive cut glass pieces. These glass pieces resembled sapphire, ruby, chrysoberyl, aquamarine and other gems. Prehistoric glasses are highly esteemed all over the world nowadays. The poor broker who deals on the gem market in Ratnapura with this glass material will not complain that it is not a tektite. As prehistoric glass this material is more valuable for collectors than the tektites, which are mostly found in larger quantities.

Acknowledgements

I express my thanks to Dr Kaboth from Deutsche Glastechnische Gesellschaft in Frankfurt for in-

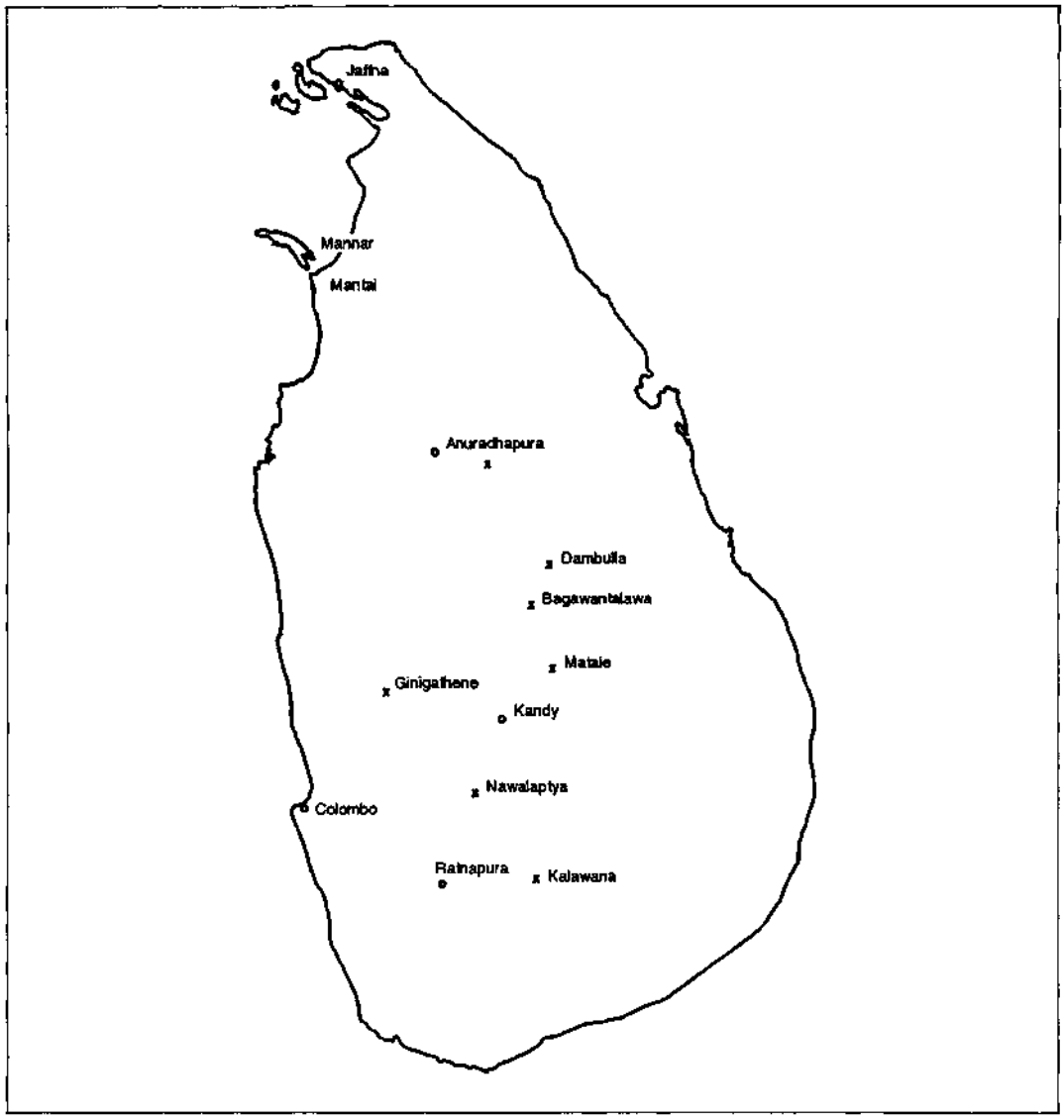

Fig. 7. Outline map of Sri Lanka showing some 'pit glass' localities.

formation on helpful literature. Mrs Cierny made the chemical analyses, which were very important for the scientific interpretation. Some friends in Sri Lanka, especially Mr Leslie J. Punchihewa, gave some information on local glasses.

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Notes from the Laboratory – 17

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The Gemmological Association and Gem Testing Laboratory of Great Britain

Three unusual Diamonds

The laboratory is involved with four areas of diamond activity – distinguishing diamond from its simulants; in the grading of the quality of gem diamonds, through the issuing of Diamond Grading Reports; and with respect to fancy coloured diamonds, grading the colour and identifying the origin of colour (whether this is of natural occurrence or whether it has been enhanced by irradiation and in some cases subsequent annealing).

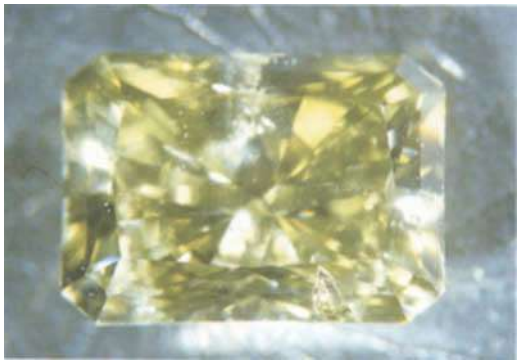

Fig. 1. The 0.49 ct chameleon diamond showing its 'stable' colour.

Coloured diamonds are rare – of the estimated 110 million carats of diamonds mined in 1992, a minute proportion will be graded as 'Fancy' in colour. Consequently few gemmologists and retail jewellers see many such fancies in the course of their working year. Those of us working in the laboratory are fortunate in seeing and identifying a great many such stones. However it is indeed exceptional for us to see three unusual fancy coloured diamonds pass through the laboratory at the same time.

The first stone (Figure 1) was submitted by a diamond cutter who had noticed that while polishing from the rough, the diamond glowed a bright orange-yellow on the polishing wheel and continued to glow for a few minutes after the stone came off the wheel. He found the finished gem diamond had 'stabilized' to a sufficiently interesting colour to warrant a laboratory report.

The rectangular, modified brilliant-cut stone, weighing 0.49 carats and measuring 5.13 x 3.70 x 2.90mm, was seen under our colour grading light to have an underlying yellow coloration somewhat modified by a less saturated secondary green colour. The overall saturation of colour when viewed through the crown of the stone ('face-up' position) was of such intensity that the stone was graded as 'Fancy'. When it was subjected to long-wave ultraviolet light, an intense yellow fluorescence and persistent (over five minutes) yellow phosphorescence was noted. After the diamond had been kept in a dark safe overnight and then exposed to light the following day, an intense yellow coloration was immediately apparent which slowly changed over the next few minutes to the normal 'stable' colour of greenish-yellow.

The characteristic colour and fluorescence indicated that the diamond could be a so-called 'chameleon' diamond – a diamond that changes its colour according to prevailing temperature and light conditions (Nassau, 1983). Our suspicions were confirmed when a gentle, careful heating of the stone in the flame of a spirit lamp once again induced the unstable yellow colour which decayed upon cooling to the stable colour. The ultraviolet/visible (UV-Vis) spectrum was similar to other chameleon spectra we have recorded (Scarratt, 1984), and the infrared (I-R) curve proved the diamond to be of Type IaA (with nitrogen in the A-aggregate form) with moderate to high amounts of hydrogen present (see major peak at 3107cm^{-1} in Figure 2). Hydrogen is seen in the I-R spectrum of other types of diamonds (see below) so its presence cannot be considered to be the cause of the chameleon effect.

We were indeed fortunate to have Dr Kurt Nassau, an acknowledged authority on the causes of colour, visiting the laboratory at the time of our examination (see 'Conference 1992' and 'Presentation of Awards') and it was a pleasure to discuss with him the possible causes of the unstable nature of the colour change in such diamonds.

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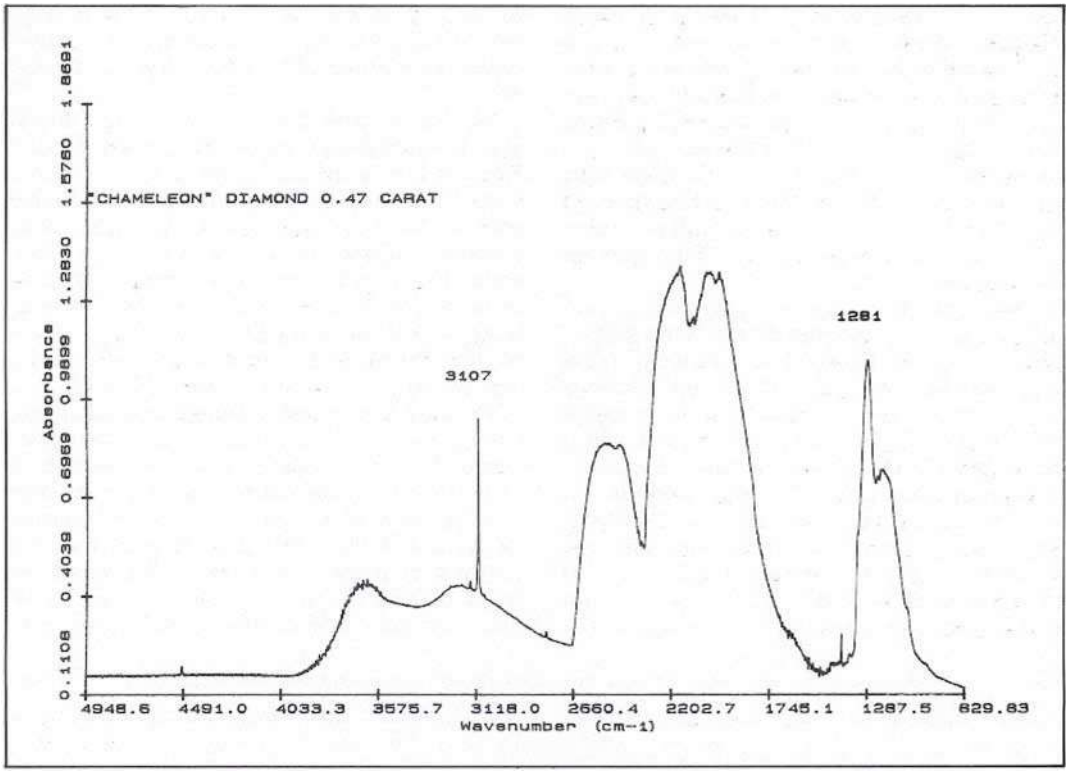

Fig. 2. The I-R spectrum of the chameleon diamond. Note the A-aggregate peak at 1281cm^{-1} and the major hydrogen peak at 3107cm^{-1}.

The second unusual coloured diamond we saw was a parti-coloured tapered baguette weighing 0.04 carats. One part of the diamond was colourless and the other part pink. The pink coloration was confined to parallel zones (Figure 3). We could find no evidence of artificial coloration. Very many pink diamonds we have examined, such as those from Argyle in Australia, exhibit strong internal pink 'grain' lines, visible in many cases to the un-aided eye.

The causes of pink coloration in diamond are not known for certain – it may well be produced by deformation of the diamond structure by stresses during growth in the Earth's upper mantle before the stone's ascent to the surface. Such plastic deformation may cause slippage of the lattice along the octahedral direction producing so-called 'grain lines' visible both within and on the surface of the polished gem.

Perhaps the reader would like to speculate on the

Fig. 3. The 0.04 ct parti-coloured pink diamond. Note the coloration in parallel zones.

Fig. 4. The 0.24 ct non-conductive blue diamond showing a high saturation of grey.

cause of the parti-coloration. If we reason that in this diamond plastic deformation is the cause of pink coloration then presumably only a part of the rough crystal was deformed and so only a part was coloured. Incorporation of that deformed coloured area together with an area of undeformed colourless diamond into the finished stone would produce the parti-coloured effect. Other workers (Chapman and Humble, 1991) have suggested that parti-coloration of pink diamonds may be due to a diffusion process involving an impurity.

The subject of pink coloration and colour instability reminds us of the pink diamonds that fade on exposure to bright light and heat. In the past, the Laboratory has graded several large pink diamonds of over forty carats, of pleasant colour saturation and graded as 'Fancy Light Pink'. When examined for clarity under the bright illumination and inevitable heat of a microscope, the colour soon faded to colourless literally before our very eyes! Happily for the diamond grader, the pink coloration soon returned at normal room temperature. We have also noted that many pink diamonds temporarily turn brown after brief exposure to X-ray irradiation. Again, the pink colour is soon restored. Presumably the cause of colour in these diamonds is an unstable colour centre susceptible to bleaching and irradiation.

Most of the pink diamonds we examine are of Type Ia – nitrogen present in the aggregated form. However it is interesting to note that, in contrast, many larger pink diamonds, including the fading ones we have examined are of Type IIa. These diamonds exhibit fugitive 'whitish' grain lines under 10x magnification. The famous Agra diamond mined in India exhibits whitish graining (Emms, 1990) and it would be fascinating to learn whether the Agra temporarily fades under strong light and whether it is, as I suspect, of Type IIa.

The third unusual rare coloured diamond to pass our way was an example of a non-conductive 'blue' diamond. The vast majority of blue diamonds are of Type IIb – the diamond lattice lacks nitrogen but contains boron as a single substitutional impurity (Wilks and Wilks, 1991). It is believed that the presence of boron causes the coloration and is responsible for the electro-conductive property of blue diamonds. Non-electroconductive blue dia-

Fig. 5. The I-R spectrum of the non-conductive blue diamond. The high hydrogen content is revealed as peaks at 3107, 3237 and 4496cm^{-1}.

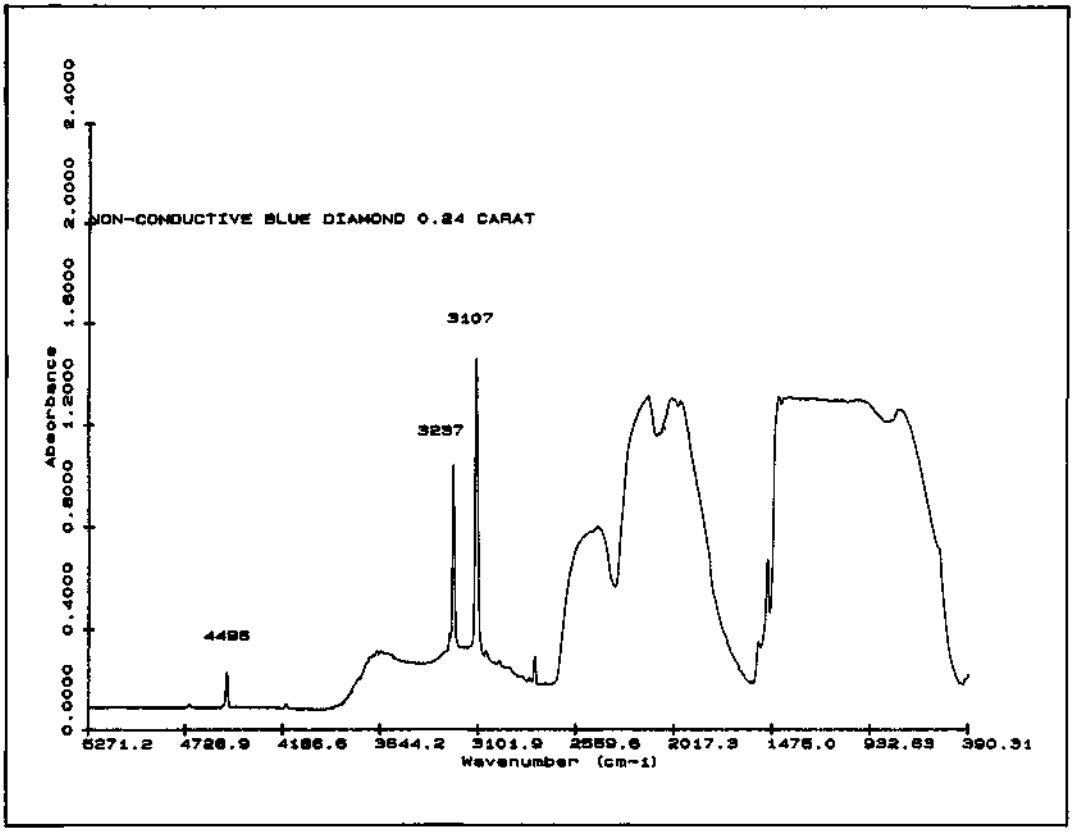

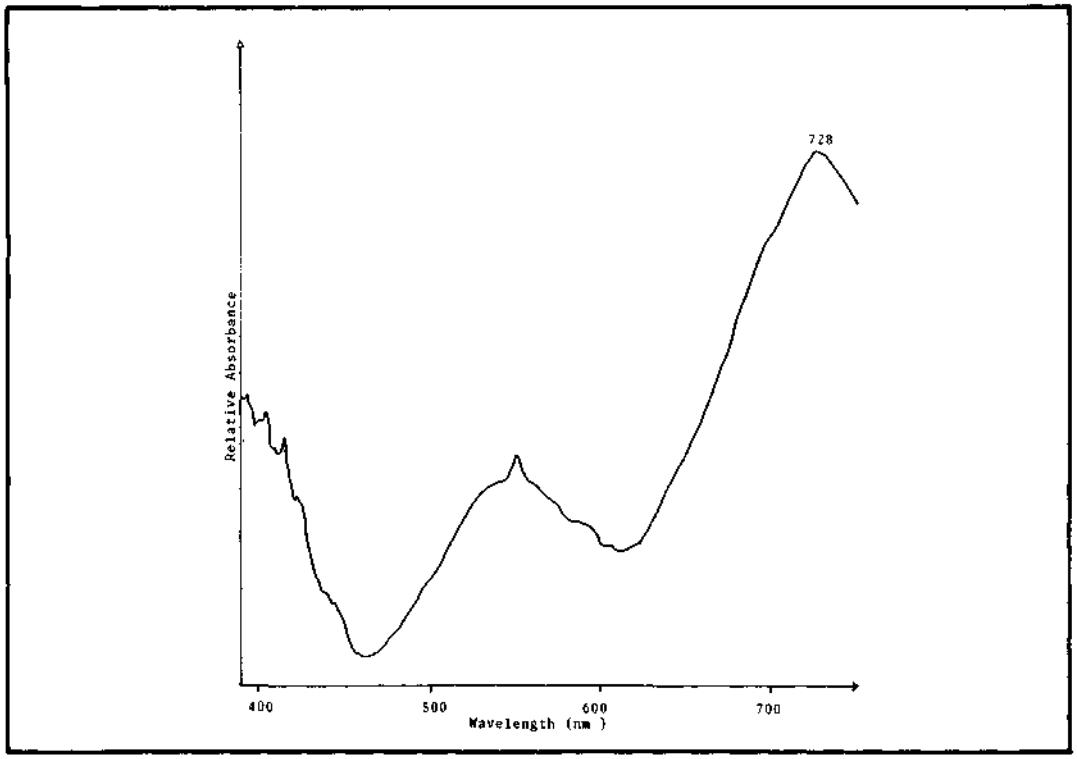

Fig. 6. The UV-Vis spectrum of the non-conductive blue diamond. Note the broad absorption in the red end (728nm) of the spectrum.

monds do not contain boron and may have nitrogen in both the A-aggregate and B-aggregate form (Type IaAB). Those diamonds we have examined have a violet, in addition to the blue component, together with a varying saturation of a grey tone.

This third unusual diamond was a round brilliant-cut (Figure 4) weighing 0.24 carats. Under LWUV light the stone fluoresced a strong yellowish-green colour; a somewhat weaker intensity of similar colour was seen under SWUV light. A prolonged greenish-yellow phosphorescence of up to ten seconds was observed after exposure to LWUV and SWUV light. The I-R curve confirmed the diamond to be Type IaAB with high hydrogen content (Figure 5) and the broad absorption in the red end of the UV-Vis spectrum (Figure 6) may account for the violet-blue colour component. Again the cause of the coloration of this type of stone is unknown, although hydrogen has been proposed tentatively as the impurity responsible (Fritsch and Scarratt, 1992).

These three fancy diamonds we have examined were all of natural colour yet they illustrate the uncertainty of the cause of the coloration in each type of diamond. We shall endeavour to collect more data in each case as part of our continuing programme of diamond colour research.

Acknowledgements

The author has pleasure in thanking Dr Kurt Nassau for a stimulating discussion on chameleon diamonds and thanks his colleagues at the Gem Testing Laboratory, namely Ana Castro, Steve Kennedy, Alan Clark, Louise Prior and Riitta Spencer, for their help. The author would also like to thank Dr Roger Harding for his helpful advice and is grateful to Ian Day and Richard Vainer for bringing these diamonds to our notice.

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Microscopic studies of Burmese jadeite jade – 1*

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Introduction

The 102 specimens used in this study were selected on the basis of their colour variation, differing grain size and appearance, and also taking into account the classification used by the Hong Kong jade dealers from whom a large proportion of the specimens was obtained. In this paper some of the results of the microscopic examination are described.

The rock types of Burmese jadeite jade

Based on the constituent minerals and textural features as seen under the microscope, Burmese jadeite jade can be divided into the following rock types:

(A) Pure jadeite rock (Jadeite)

This is an essentially monomineralic jadeite rock which may contain a little diopside and albite also. Examined samples are granoblastic in texture with measured grain sizes in the range 0.8 x 0.2mm – 1.76 x 0.3mm. Jadeite is colourless with long to short prismatic form, it has typical 2-direction pyroxene cleavages (at angles of about 87° and 93°). Under crossed polars the interference colour is 1st order grey to 1st order yellow. The extinction angles range from 32° to 44°. The optical sign is positive with 2V=70°-75° and the elongation is positive. Diopside is also colourless, but usually of short prismatic form, with two-direction cleavages. But the interference colour is higher than jadeite, usually of second order and the maximum extinction angle of longitudinal sections (010) is larger than jadeite, usually jadeite is 33° and diopside is 41°.

Apparently, this type of jadeite jade has not been subjected to alteration. The colour is usually white, but in some cases lavender and (Figures 1, 2) pale green.

(B) Crushed jadeite jade

Although this type of jadeite jade is also composed of jadeite mineral, its texture is quite complex. The grain size is quite uneven, larger grains are crushed into smaller grains. The larger grains may be up to 2mm and surrounded by a border of fine granular grains (0.001 to 0.05mm) produced by the grinding down of the crystal itself and its neighbour. This is called mortar structure (Harker, 1964).

* Part of a thesis submitted to the University of Hong Kong for the degree of M.Phil. Burma is now known as Myanmar.

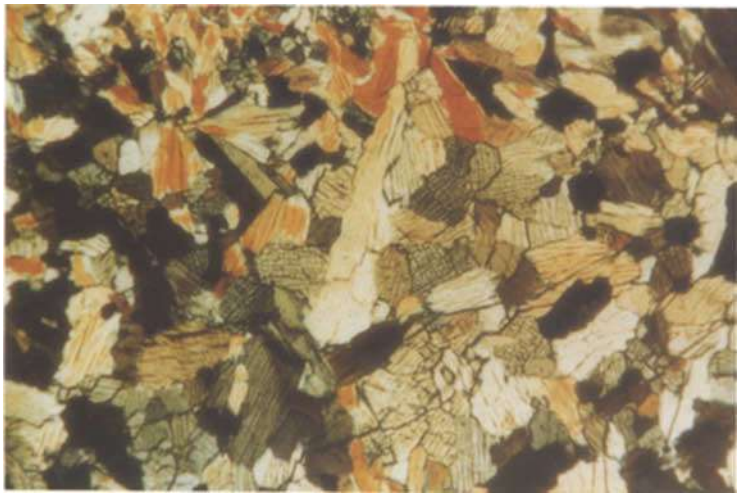

Fig. 1. Pure jadeite jade. Crossed polars. x35.

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Fig. 2. Pure jadeite jade. Plane polarized light. x30.

Fig. 3. Crushed jadeite jade. Crossed polars. x35.

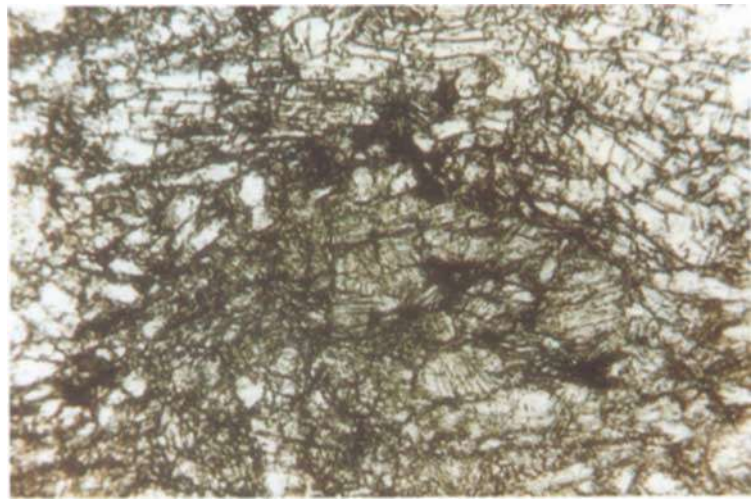

Fig. 4. Crushed jadeite jade. Plane polarized light. x35.

Under ordinary or plane polarized light, the smaller grain boundaries are not easily observed, they seem to be within the larger grain. Under crossed polars, however, they differ in extinction position so the boundaries between smaller and larger grains can easily be observed. This is evidence that the smaller grains are the result of crushing of larger grains (Figures 3, 4).

According to the degree of crushing, crushed jadeite jade can be divided into the following groups:

i. Composed mainly of coarse grains, which are surrounded by a few crushed fine grains as a result of the grinding along the grain boundaries.

ii. Large grains and crushed fine grains in equal proportion, e.g. the larger grains of jadeite are surrounded by about an equal amount of fine grains resulting from more grinding down of the larger grains.

iii. Essentially composed of fine granular grains resulting from the grinding and rolling processes. A small amount of uncrushed larger grains are isolated and separated by the finer groundmass, just like 'eyes' in mylonite rock.

Sometimes, under ordinary or plane polarized light, the uneven distribution of colour can be observed. Most of the larger grains are colourless, while the finer grains are slightly green. The result of electron-microprobe analysis of different grains shows that the average chemical composition of larger grains is:
$(Na_{0.87}Ca_{0.02}Mg_{0.02})_{0.91}(Al_{0.99}Fe_{0.01})_{1.0}Si_2O_6$ and that of the finer grains is $(Na_{0.99}Ca_{0.07})_{1.06}$-$(Al_{0.89}Mg_{0.06}Cr_{0.05})_{1.00}Si_{1.98}O_6$.
It is clear that they are both jadeite but the white large grains do not contain Cr (chromium) while the smaller grains contain chromium and have a green colour.

This explains why some of the samples of Burmese jade show different patterns of green colour on a white background.

(C) Actinolitized/tremolitized jadeite jade

This type of jadeite jade was originally composed of jadeite mineral but has been subjected to slight or strong alteration, so that part of the jadeite has been converted to tremolite/actinolite.

The actinolite and tremolite are of fibrous, acicular form, with lower relief than jadeite. Their interference colour ranges from 2nd order yellow to 2nd order blue and extinction angle from 10° to 20°. Their optical sign is negative with 2V=79° to 85°. Tremolite is white in colour while actinolite is green in colour. They can easily be distinguished from jadeite mineral under the microscope.

The different stages of replacement of jadeite by actinolite/tremolite can also easily be observed under the microscope, based on the degree of alteration (proportion of actinolite/tremolite present). The types of rock can be grouped into slightly altered, moderately altered and strongly altered jadeite jade.

i. Slightly altered jadeite jade

In the primary stage of alteration, the jadeite crystals are replaced only along the cleavage planes and grain boundaries (Figure 5). The proportion of actinolite/tremolite is small, about 15-20%. The granoblastic texture of the rock and the optical properties of jadeite remain unchanged.

ii. Moderately altered jadeite jade

The rock shows relict porphyroblastic texture. The short prismatic form of the jadeite crystal is largely replaced by the fibrous form of tremolite/actinolite. Isolated spots of jadeite embedded in fibrous amphibole give rise to the porphyroblastic texture. The tremolite/actinolite constitutes up to about 50-60% of the material; it is of acicular or fibrous form with grain size 0.2 x 0.002mm to 0.4 x 0.1mm. Sometimes, muscovite and/or chlorite may be observed as associated minerals. Microveins of quartz with comb structure can also be observed.

iii. Strongly altered jadeite jade

The rock has fibroblastic texture, and may be 80-98% composed of tremolite/actinolite, which has replaced the original jadeite. Relict texture of jadeite can be observed (Figure 6). The tremolite/actinolite occurs as fibres from 0.05 to 0.2mm in length. Samples which consist mainly of tremolite are white to grey colour, while those consisting mainly of actinolite are dark green, characterized by the oily lustre of their polished surface and greater transparency than jadeite jade.

(D) Ureyite jade*

The samples which were identified as ureyite are opaque, and dark green to bright green in colour. They are compact polycrystalline aggregates with grain sizes between 0.03 and 2mm.

Under the microscope, the ureyite jade shows a granular and/or fibrous texture. The samples examined contain 90-95% ureyite, the remainder being mostly chromite. The ureyite occurs both as tiny fibrous (Figures 7, 8) and short prismatic crystals with lengths up to 2mm. It has perfect cleavage in two directions parallel to {110}, intersecting in 85° or 95°, and a pronounced parting parallel to (001).

The refractive indices for monochromatic light (Na) are $\alpha=1.722\pm0.003$, $\beta=1.734\pm0.002$, $\gamma=1.745\pm0.003$. The mineral is strongly pleochroic

*Under the rules of priority, ureyite is now properly known as kosmochlor.

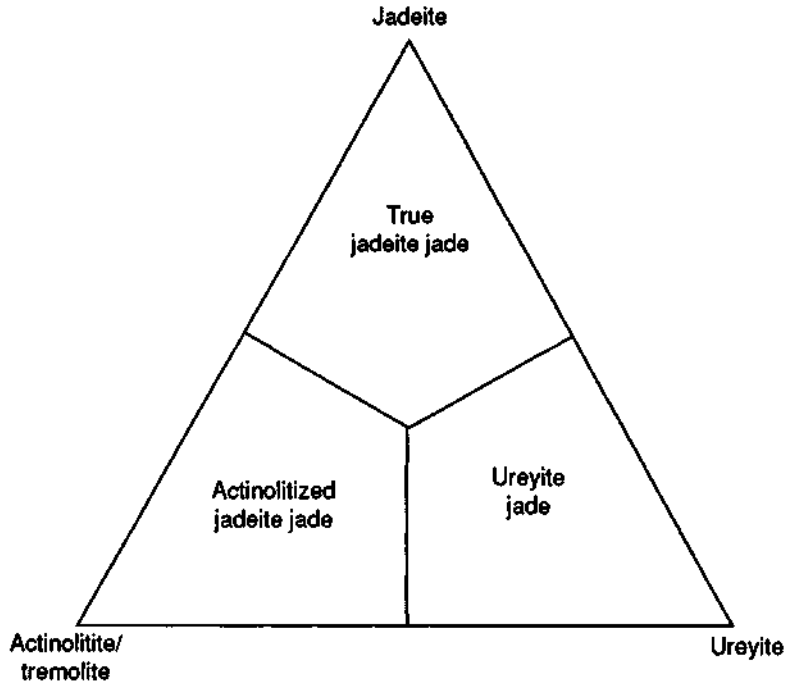

Fig. 11. The major mineral composition of Burmese jade.

with α yellow, β blue-green, γ bright emerald green. It is optically negative with 2V=70° (measured on the universal stage); the extinction angle, C equals 28°-30°. Some prismatic ureyite shows an exsolution texture with jadeite (Figure 9). This suggests that at very high temperature/pressure ureyite and jadeite mix more completely together; while at low temperature/pressure, they tend to separate. This finding is quite similar to that of Abs-Wurmbach and Neuhaus in 1976. The aggregate of tiny fibres, which can be seen from the extinction pattern; have replaced original grains. Wavy extinction is quite common. This indicates that the ureyite was subjected to stress during its formation.

The remaining minerals (associated minerals) are chromite and/or amphibole group minerals, feldspar and chlorite.

The process responsible for the paragenetic relation between the ureyite and the chromite is still under investigation. A mesh texture between chromite and ureyite can be observed (Figure 10), but in some cases chromite can also be observed surrounding the margins of the ureyite grains. In general, the texture of the chromite gives some hints that it may be the result of alteration of a Cr-rich mineral which has been largely replaced by ureyite.

At least two generations of an amphibole group mineral can be observed, as shown in Figure 8. One is of coarsely fibrous form, yellowish-green in colour and strongly pleochroic, which is found surrounding the ureyite. This amphibole is formed by direct alteration of the ureyite; this replacement phenomenon can be observed very easily. The other is of fine fibrous form, white to pale green in colour and weakly pleochroic, it comprises tiny veins intruding or enclosing the former (Ou Yang, 1984).

Conclusion

(1) The microscopic study of Burmese jade reveals that although it is composed mainly of jadeite, it is not pure. It has been subjected to alteration under stress. This gives rise to complicated compositions. The alteration product of jadeite is tremolite/actinolite (Kerr, 1977) and the rock contains some other pyroxene minerals. One characteristic of Burmese jade is that it is composed of mainly sodium rather than calcium pyroxene minerals. It is also very significant that ureyite, hitherto not known to occur in nature except in meteorites, is also present in Burmese jade.

(2) The microscope study shows that none of the determined optical properties fall in the aegirine field. It is suggested that there is not enough iron to form aegirine ($NaFeSi_2O_6$). This agrees with the results of chemical analyses.

(3) The major mineral components of Burmese jade are jadeite, ureyite and tremolite/actinolite (Figure 11).

(4) The relationship between jadeite and ureyite is an isomorphic one. The relationship between

Fig. 5. Replacement of jadeite by actinolite along cleavage planes and boundaries. Crossed polars. x35.

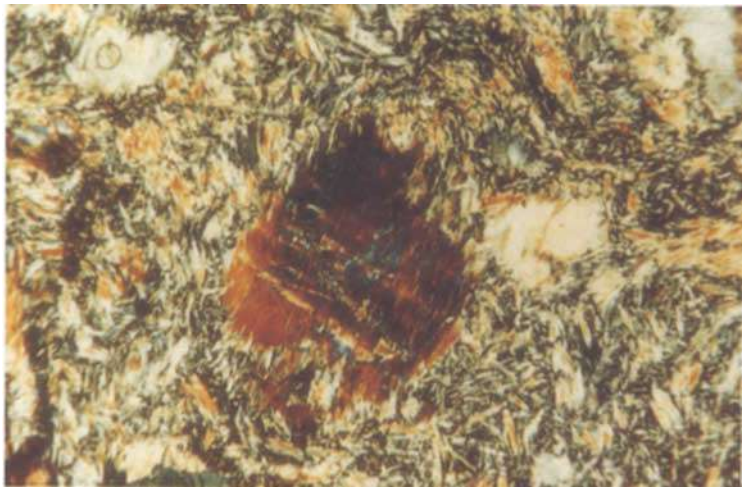

Fig. 6. Strong replacement of short prismatic form of jadeite by fibrous form of actinolite resulting in porphyroblastic texture. Crossed polars. x35.

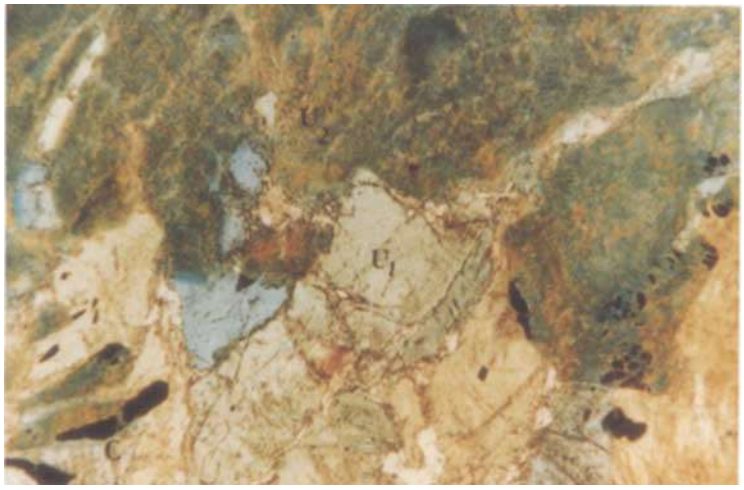

Fig. 7. Ureyite jade. Plane polarized light. x35. U_1 – granular ureyite; U_2 – fibrous ureyite; C – chromite.

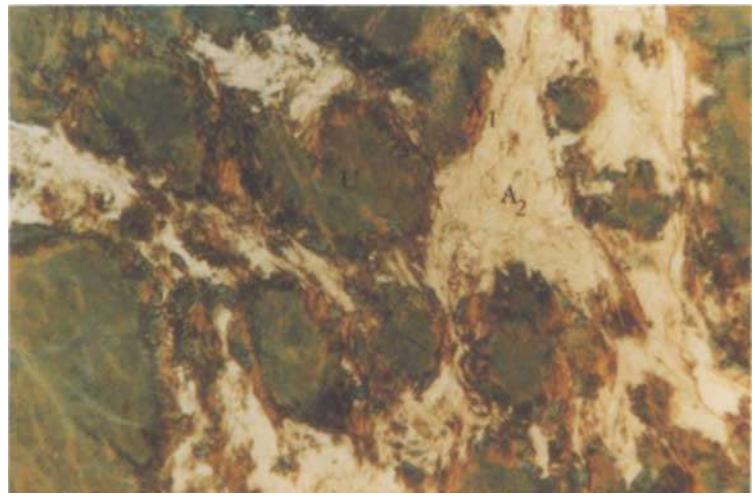

Fig. 8. Ureyite jade. Plane polarized light. x35. U – ureyite; A_1 – amphibole; A_2 – amphibole (see text).

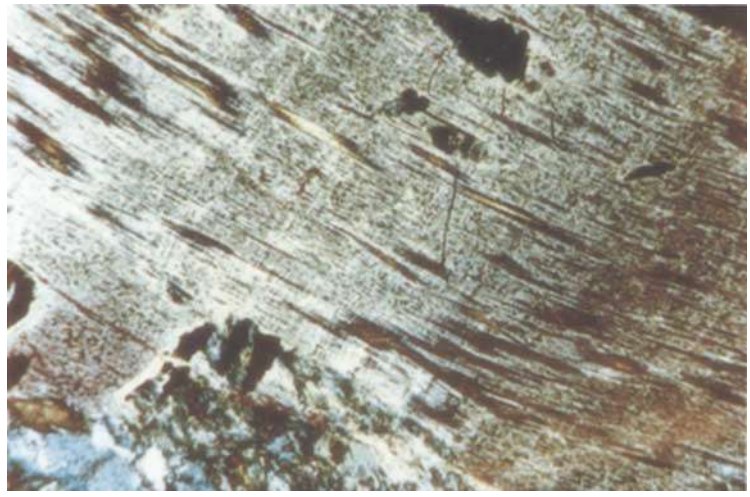

Fig. 9. Exsolution lamellae of jadeite in ureyite. Crossed polars. x70.

Fig. 10. Chromite and ureyite. Plane polarized light. x70. Chromite (black), ureyite (green).

jadeite and tremolite/actinolite is replacement. That between ureyite and tremolite/actinolite is also replacement.

(5) According to the constituent minerals Burmese jade can be classified into the following groups:

A. Jadeite jade (major);
B. Tremolitized jade/actinolitized jade (common);
C. Ureyite jade (comparatively rare);

(6) The different mineral compositions of jade affect properties such as colour, lustre, transparency and specific gravity, and thus gem quality. By means of their appearance and some physical properties, the three types of Burmese jade can be recognized.

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[*Manuscript received 5 January 1991, revised 15 October 1992*]

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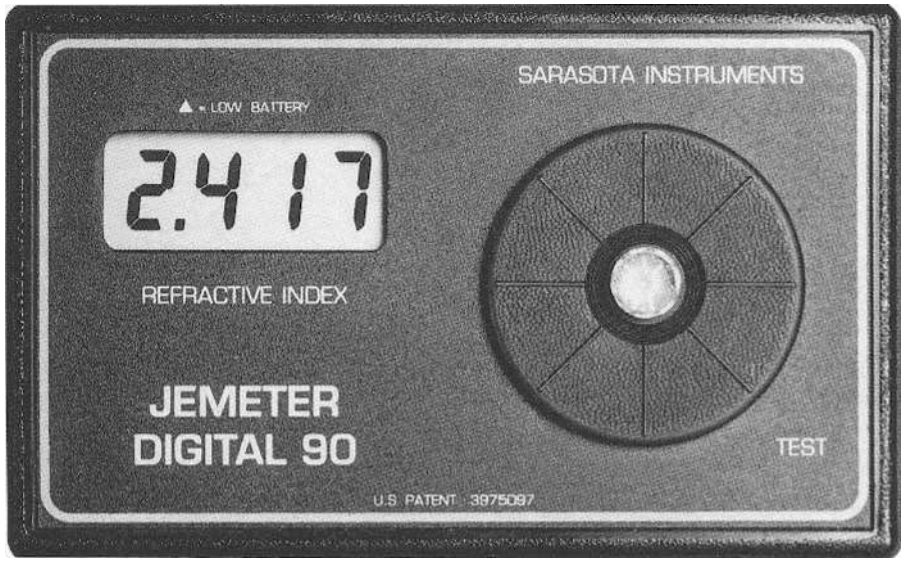

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Unusual inclusion in an aquamarine

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As a gemmologist with a passion for photomicrographing gemstone inclusions, (we are sometimes referred to as 'inclusionists'), it is always exciting to find something new in a specimen that perhaps has not been previously photographed.

Because this thin film inclusion was obviously three phase I decided to test it for reaction to a heat probe and was rewarded with the results shown in the accompanying photomicrographs:

Figure 1 is the inclusion at room temperature and the following three sequential photos illustrate the changes that take place as the specimen is warmed to a maximum of approximately 31.5°C. It is rather like watching a solar eclipse in miniature and the whole effect is enhanced by the beautiful interference colours.

It is also unusual in that the reaction to the thermal probe is quite slow. The oval liquid and gaseous phase appear almost viscous as it moves about. Occasionally, when the heat is first applied three or four small pink bubbles slowly rise from the black appearing spires and coalesce with the central pink oval.

Figs 1 to 4. A series of Photomicrographs showing the effects of warming an inclusion in aquamarine to a temperature of 31.5°C. Oblique illumination (without polars) using a fibre-optic pin-point illuminator. x22.

Fig 1

Fig 2

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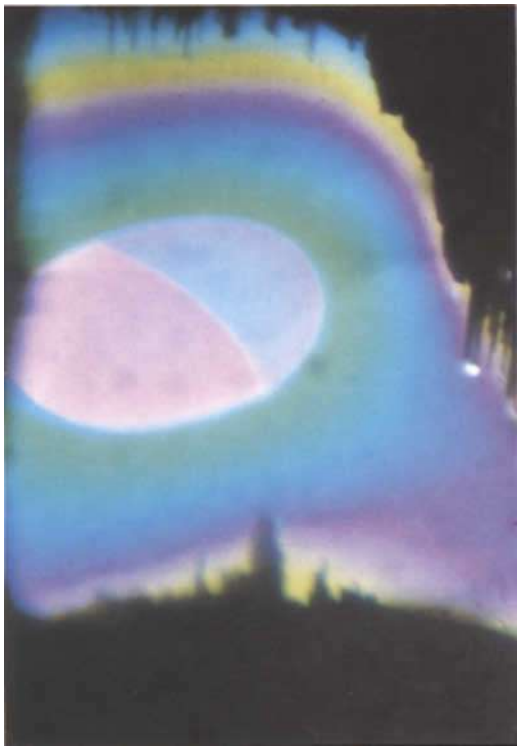

Fig 3

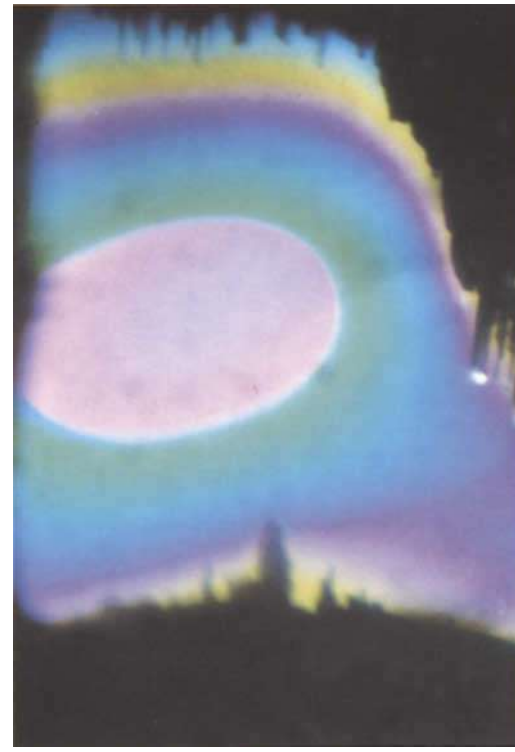

Fig 4

This is the second of two specimens of this material I have had the opportunity to examine. The first crystal also had several of the same type of slow moving heat-sensitive thin-film inclusions [1]. It would be interesting to ascertain if this is a characteristic of aquamarines from Pakistan.

I sent the first specimen to Dr Edwin Roedder at Harvard University and he describes the reaction of this type of fluid inclusion as a combination of several effects happening simultaneously. For example: Changes in surface tension from temperature differences may make bubbles move and in this case surface tension may also change due to compositional changes from CO_2 moving from a gaseous to a liquid phase and vice versa [2].

The photomicrographs (Figures 1 to 4) were taken using an Olympus OM2 SLR camera coupled to a Wetzlar trinocular microscope mounted on an Eickhorst Gemmaster base. Oblique lighting using a fibre-optic pin-point illuminator.

References:

(1) de Goutiere, A. 1991, Into the abyss: Inclusion Photos, *Gemological Digest*, 3, 2, 43.

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Radiation-induced colour change in natural and synthetic emerald

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Abstract

Radiation-induced colour changes in natural emeralds from different sources, in hydrothermally-grown synthetic emeralds, and in flux-grown synthetic emeralds are described. Irradiation experiments were performed by an X-ray fluorescence facility, in a cobalt 60 gamma cell, by a linear accelerator, and in a nuclear reactor. Two types of yellow colour centres are induced which turn natural emeralds yellowish-green or greenish-yellow and synthetic emeralds greenish-black or black. A first type of yellow colour centre with low thermal stability is produced by all types of treatment, mainly in hydrothermally grown and flux-grown synthetic emeralds. A second type of yellow colour centre with higher thermal stability, which is most probably confined to iron, is mainly observed in natural emeralds. The applicability of irradiation experiments in combination with absorption spectroscopy as a method for the distinction of natural and synthetic emeralds is discussed.

Introduction

A remarkable colour change of synthetic emeralds from green to smoky black or violet after irradiation treatment with X-rays, gamma-rays and neutrons is mentioned by various authors (Bank, 1982; Lind *et al.*, 1985; Schrader, 1987, 1988). According to the absorption spectra of irradiated and non-irradiated samples, which are published in some of the papers cited above, these colour changes are caused by a strong absorption band centred in the ultraviolet, the low energy tail of which is extending to the whole visible area, and/or by an additional absorption band in the green range between 520 and 530 nm. These absorption bands are due to different colour centres which are designated yellow and violet colour centres respectively.

The assignment of irradiation induced colour centres in natural and synthetic beryl is discussed by Schmetzer (1989). Most probably, the absorption band of the violet colour centre with an absorption maximum in the green and low thermal stability is assigned to an oxygen electron hole centre confined to Al^{3+} substituting for Si^{4+} in tetrahedral sites, and at least part of the yellow colour centres with an absorption maximum in the ultraviolet are related to traces of iron. This was later confirmed by Rink *et al.* (1990), who assigned the yellow colour centres of electron irradiated beryl to an iron related colour centre, which is produced by oxidation of Fe^{2+} to Fe^{3+} by irradiation.

Although the possibility of inducing different colour centres in natural and synthetic beryl and emerald by X-rays, gamma rays, electrons and neutrons has been known to the present author for more than ten years, only a limited application of radiation induced colour centres to problems of the distinction of natural and synthetic emeralds was performed. Occasionally, colour causing trace element contents of emeralds of known or unknown origin were examined by X-ray fluorescence analysis. According to the fact, that the colour of synthetic emeralds of known origin was, in general, altered to black or greenish-black after exposure to X-rays, a similar colour change in samples of unknown origin was used as an indication of synthetic emerald. In addition, irradiation experiments of a limited number of natural emeralds of known sources were performed by the author at the request of the trade in order to evaluate a possible stable colour enhancement of these stones. However, a systematic examination of possible irradiation induced colour changes of known natural and synthetic emeralds was neither performed until now, nor is described in gemmological literature. In other words, it was unknown if the colour of all synthetic emeralds is altered by different irradiation treatments in the same way and if, in addition, the colour of stones from different natural sources remains more or less unchanged upon irradiation treatment.

To overcome these disadvantages, the present paper describes some systematic irradiation experiments on natural and synthetic emeralds in order to evaluate the significance of the presence or absence of colour changes in emeralds after irradiation treatment for the distinction of natural

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and synthetic emeralds. Although the spectroscopic examination of the samples -performed for this study can also indicate some new aspects towards an assignment of the irradiation induced absorption bands to distinct colour centres, these special topics are not discussed in great detail in this publication.

Experimental details

Two series of irradiation experiments will be described in the present paper.

In the first series of experiments, six natural emeralds from different sources with low, medium and high iron contents, three hydrothermally-grown synthetic emeralds, and three flux-grown synthetic emeralds were sawn into four slices each. Three of the four slices of each sample were irradiated in a gamma cell, by a linear accelerator or in a nuclear reactor using the following experimental conditions:

a) cobalt 60 gamma cell, gamma dose 100 megarads, temperature in the gamma cell approx. 110°C;
b) linear accelerator, energy of the electrons 4.5 MeV, electron dose approx. 4 gigarads, cooling of the samples with running water;
c) nuclear reactor, thermal fluence rate 8.10^{13} n cm^{-2} sec^{-1}, irradiation time 1 h, gamma dose approx. 1.2 gigarads.

After exposure to gamma rays, electrons and/or neutrons, the colours of the three irradiated samples were visually compared with the colour of the remaining untreated slices of the twelve samples. Absorption spectra in the visible and ultraviolet area were measured of all untreated and all gamma and electron irradiated samples, but not of those emeralds treated in the nuclear reactor because of the high induced radioactivity of those slices.

In the second series of experiments, absorption spectra in the visible and UV were first recorded for 228 natural emeralds from different sources, 31 hydrothermally-grown synthetic emeralds and 41 flux-grown synthetic emeralds. Subsequently. each stone of these 300 samples was exposed to X-rays for 20 minutes using a commercially available Siemens SRS 300 X-ray fluorescence analysis facility with a Ru/Rh X-ray tube (operating conditions 40 mA at 50 kV). Subsequently, the colour of the samples was visually examined and absorption spectra were recorded of all irradiated natural and synthetic emeralds. The data collection within this second series of experiments was performed during a period of about four years.

Results

The results of the irradiation experiments are presented in Tables 1 and 2. Surprisingly, visual inspection and absorption spectroscopy did not indicate any production of violet colour centres, either in the experiments of the first series or in those of the second series. For the first series, this result is explained by the low thermal stability of violet colour centres in beryl, which are easily bleached in sunlight (Schrader 1987, 1988). As indicated by Solntsev (1981), the stability of these violet colour centres in beryl is in the range of 80°C.

Thus, according to the temperature in the gamma cell used for the cobalt 60 experiments, violet colour centres are immediately bleached.

Using the experimental conditions in a nuclear reactor as described above for the irradiation of topaz, exclusively blue topaz is produced. This indicates, that the brown colour centres of topaz, the stability limit of which is in the range of 200°C (cf. Schmetzer, 1987), are also faded by the radiation induced heat due to the extremely high gamma dose rate. Consequently, it is not expected that violet colour centres can be formed in beryl under these experimental conditions.

If topaz is treated in a linear accelerator under the circumstances described for the present experiments, most topaz crystals turn brown. This indicates that, due to water cooling, the radiation induced heat is lower than approx. 200°C. According to the fact, however, that no violet colour centres in beryl were formed under the experimental conditions applied, the violet colour centres must have been bleached by radiation induced heat, too.

Using X-rays for the irradiation of natural and synthetic emeralds, no violet colour centres were observed. This effect is not explained by radiation induced heat, but, obviously, the energy of X-rays was not sufficient for the production of violet colour centres in beryl.

At least two different types of yellow colour centres were formed in natural and synthetic emeralds upon exposure to X-rays, gamma rays, electrons and neutrons. Both types of yellow colour centres, designated type A and type B yellow colour centres, reveal a strong absorption band in the ultraviolet, the low energy tail of which extends to at least parts of the visible area. In natural and synthetic emerald, this absorption is superimposed upon the chromium-vanadium-iron spectrum of natural emerald and, depending on the type of synthesis, to the chromium-vanadium-iron-copper-nickel spectrum of synthetic emerald (cf. Schmetzer, 1988). Due to the intensity of the ultraviolet absorption band caused by irradiation

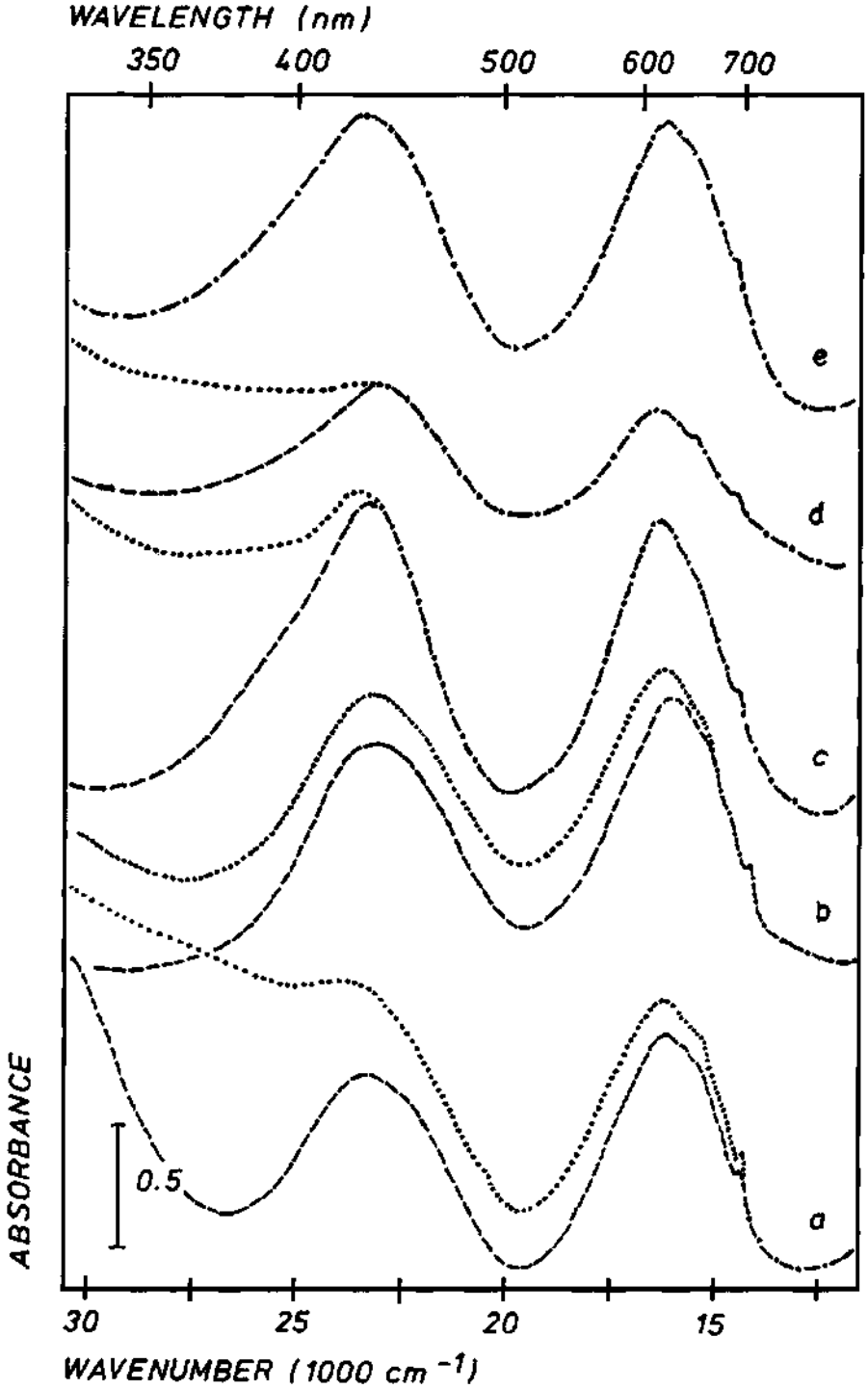

Fig. 1: Absorption spectra of untreated and X-ray irradiated natural and synthetic emeralds; —·— absorption spectrum or part of an absorption spectrum, which is identical for untreated and treated samples, — spectrum before treatment, ··· spectrum after treatment;
a Inamori flux-grown synthetic emerald, b Regency hydrothermally-grown synthetic emerald, c Biron hydrothermally-grown synthetic emerald, d Colombian emerald, e Colombian emerald.

Table 1: Radiation induced colour changes of natural and synthetic emeralds

	Iron content	Irradiation treatment: Gamma cell	Linear accelerator	Nuclear reactor
Natural samples, localities				
Colombia	low		yellowish-green	yellowish-green
Colombia	low	a slight yellowish-green colour tone is superimposed on the natural colour of the samples	yellowish-green	yellowish-green
Habachtal, Austria	medium		yellow-green	yellow-green
Gravelotte, South Africa	medium		yellow-green	yellow-green
Maria Mine, Mozambique	high		greenish-yellow	greenish-yellow
Zambia	high		greenish-yellow	greenish-yellow
Hydrothermally-grown synthetic emeralds				
Lechleitner, type D	low	greenish-black	greyish-green	greyish-green
Linde	not obs.	greenish-black	greyish-green	greyish-green
Russian sample	high	greenish-black	blackish-green	blackish-green
Flux-grown synthetic emeralds				
Gilson, Cr-bearing	not obs.	black	black	black
Chatham	not obs.	black	greenish-black	greenish-black
Lennix	not obs.	black	greenish-black	greenish-black

induced yellow colour centres in emerald, this additional absorption can more or less strongly alter the transparency of the absorption minimum of emerald in the green range and, thus, produces a yellowish-green, greenish-yellow, greenish-black or 'smoky' black coloration of the irradiated samples (Figures 1 a, b). If the intensity of the radiation induced ultraviolet absorption is somewhat weaker, the absorption minimum in the green is not affected and, consequently, no visual colour change is observed after irradiation treatment (Figures 1 c, d).

Type A yellow colour centres are produced by all types of irradiation, even by X-rays, and in all types of synthesis as well as in part of the Colombian emeralds examined (Tables 1, 2). After exposure to X-rays, all types of synthetic emeralds with the exception of Biron synthetic emeralds turn black or greenish-black (Table 2). Upon irradiation with gamma rays, electrons or neutrons, the six synthetic emeralds also turned greenish-black or black (type A, table 1). The stability of these type A yellow colour centres is relatively low. Part of them are already bleached in daylight or on exposure to ultraviolet radiation using a commercially available UV lamp. After heat treatment at 300°C for 1 hour no remaining colour change was visible. This low thermal stability of type A yellow colour centres explains the somewhat weaker coloration of electron and neutron exposed samples compared with the slices of the same crystals treated in the gamma cell (Table 1) by fading of type A yellow colour centres due to the high radiation doses applied to these samples.

Type B yellow colour centres, which are most probably confined to iron, are not produced by X-rays (Table 2). Subsequent to an exposure to a dose of 100 megarads of cobalt 60 in the gamma cell, all natural emeralds revealed a weak yellow colour tone, which was superimposed on the natural colour of the samples (Table 1). This shade of yellow was intensified by higher radiation doses, e.g. after exposure to 500 megarads of

cobalt 60. The irradiation experiments performed with a linear accelerator or in the nuclear reactor with extremely high doses also produced type B yellow colour centres in the samples and indicated, that the absorption band in the ultraviolet due to irradiation induced yellow colour centres is correlated with the iron content of the samples (Table 1). The thermal stability of type B radiation induced yellow colour centres in emerald is relatively high, i.e. this type of colour centre is not bleached by daylight, on exposure to UV radiation or upon heat treatment at 300°C for 1 hour.

Applicability of irradiation experiments for the distinction of natural and synthetic emeralds?

Although distinct differences in colour change between natural and synthetic emeralds were observed on exposure to gamma rays, electrons and neutrons (Table 1), this procedure has strong disadvantages and therefore is not practicable in a gemmological laboratory. Neutron exposed samples reveal irradiation induced radioactivity and cannot be returned to the customer within a short period of time. Electron treated emeralds may reveal radiation induced defects, e.g. cracks, which is also not acceptable. In addition, natural emeralds exposed to cobalt 60, electrons and/or neutrons turn yellowish-green or greenish-yellow. A complete bleaching of these iron related yellow colour centres is possible by heat treatment at temperatures higher than 300°C, which can also produce cracks in heat-treated samples.

Compared with the disadvantages described above, an application of a combination of X-ray irradiation experiments with absorption spectroscopy has certain advantages. Although such a procedure is not expected to become a routine procedure for emerald testing, every gemmologist working in a laboratory should be aware of the possibilities of this method and of the overlaps of properties between natural and synthetic emeralds:

Colour and absorption spectrum of most natural emeralds were not affected upon exposure to X-rays (Table 2, group I; Figure 1e).

In a small group of samples, the colour was unchanged upon X-ray irradiation, though yellow colour centres of low concentration were formed (Table 2, group II; Figure 1 c, d). This is the only overlap in this testing procedure between natural and synthetic emeralds observed so far. This second group consists of some of natural Colombian emeralds and of all Biron synthetic emeralds tested. Although a great number of 82 different Colombian emeralds were examined for this study, which were made available by different trade persons and from various collections, the author is unable to indicate the particular sources or mines of Colombian emeralds, the samples of which belong to groups I or II, respectively. If at least some of the samples examined were labelled correctly, both types of emeralds, samples belonging to group I and group II, emanate from both important Colombian mining areas, Muzo and Chivor.

Table 2: Reaction of natural and synthetic emeralds to X-ray irradiation *

Group I: colour visually not affected, absorption spectrum unchanged:
Gravelotte, Transvaal, South Africa (9);
Sandawana, Zimbabwe (8);
Filabusi, Zimbabwe (3);
Machingwe, Zimbabwe (6);
Maria Mine, Morrua, Mozambique (7);
Tauá, Ceará, Brazil (3);
Santa Terezinha, Goiás, Brazil (12);
Socotó, Bahia, Brazil (7);
Carnaiba, Bahia, Brazil (9);
Bom Jesus das Meiras, Bahia, Brazil (l);
Itabira, Minas Gerais, Brazil (7);
Ferros, Minas Gerais, Brazil (2);
Salininha, Bahia, Brazil (6);
Takovaya, Ural mountains, Russia (7);
Habachtal, Austria (8);
Ankadilalana, Madagascar (4);
Lake Manyara, Tanzania (6);
Swat, Pakistan (8);
Charbagh, Pakistan (2);
Makad, Pakistan (3);
Afghanistan (2);
Zambia, different localities (19);
Jos, Nigeria (7);
Colombia, different localities (38);
Group II: colour visually not affected, absorption spectrum changed in the blue and ultraviolet area:
Colombia, different localities (44);
Biron hydrothermally-grown synthetic emeralds (8);
Group III: colour visually affected, absorption spectrum changed in the visible and ultraviolet area, green samples turn greenish-black or black ('smoky'):
hydrothermally-grown synthetic emeralds:
Linde (3);
Regency (2);
Swarovski (2);
Russian samples (7);
Lechleitner, synthetic overgrowth, type B (5);
Lechleitner, fully synthetic, type D (4);
flux-grown synthetic emeralds:
Inamori (4);
Russian samples (6);
Lennix (4);
Seiko (2);
Chatham (8);
Gilson, Cr-Ni-bearing (2);
Gilson, Cr-Fe-bearing (2);
Gilson, Cr-bearing (10);
Lechleitner, fully synthetic, type F (3)

* numbers of samples examined are given in parentheses.

Colours and absorption spectra of most synthetic emeralds were strongly affected upon exposure to X-rays (Table 2, group III; Figure 1 a, b). The colour of these samples turns 'smoky' black or greenish-black. The yellow colour centres induced by X-rays are extremely unstable. Most of them fade in daylight or on exposure to UV radiation and only part of these samples need heat treatment to remove the influence of X-ray induced colour centres on the visual coloration of the synthetic emeralds.

Since spectrophotometers and X-ray fluorescence facilities are available in some of the greater gemmological laboratories in Europe, USA, and Japan, or are at least available to gemmologists, a combination of absorption spectroscopy and X-ray irradiation is generally performable. Consequently, every gemmologist should be familiar with the possibilities of the method and, in addition, every gemmologist should be aware of the fact, that a colour change is possible in synthetic emeralds after X-ray fluorescence analysis, e.g. for the determination of colour causing trace elements or for the detection of residual flux components. Consequently, these procedures should be applied to samples of unknown origin only by permission of the customer as a last possible diagnostic step, if all other diagnostic possibilities, e.g. microscopy or absorption spectroscopy in the visible or infrared, did not lead to an unambiguous identification of the emerald.

However, a possible application of X-ray irradiation in emerald identification procedures is the quick testing of larger parcels of rough or faceted stones for admixtures of synthetics.

Acknowledgement

The author is grateful to numerous colleagues and trade persons who kindly supplied samples of natural and synthetic emerald for the present study.

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[Manuscript received 22 July 1992]

1992 Annual Conference

Mary Burland

The second GAGTL Annual Conference held on 8 and 9 November at the Great Western Hotel, Paddington, London, was a truly international event with delegates attending from Canada, Hong Kong, Sri Lanka, Thailand and the USA, as well as from many European countries. There was a relaxed atmosphere as delegates had the opportunity to meet informally between lectures, and to examine various treated gemstones.

The theme was gemstone enhancement and the keynote speaker, Dr Kurt Nassau, launched the conference with a lecture on the history of gem treatments. Ancient literature dating back to Pliny contains many interesting recipes for the enhancement of gemstones and pearls, and Dr Nassau gave a fascinating account of some that he had tested in his laboratory. He then went on to review the history of various treatments, including the dyeing of agate, foil-backed stones, sugared opal, oiling of emeralds, heating of rubies and sapphires, irradiation of such stones as aquamarine, sapphire, topaz and tourmaline, and plastic impregnated opal. He also reported that it had been found that freshwater pearls became black when irradiated.

Dr Nassau described many of the current techniques used, the methods of identification of treated stones, the stability of the resulting colour and long-lasting radioactivity in irradiated specimens.

DEMONSTRATIONS

Between sessions delegates had the opportunity to microscopically examine, under the expert guidance of laboratory staff, some of the treated gemstones that had been discussed during lectures. Samples included laser drilled diamonds, diffusion treated corundum, fissure filled emeralds, cavity filled rubies and Yehuda and Koss glass filled fractures in diamond.

Also on display was a scintillation device made by Dr J. Nelson for demonstrating the separate contributions of lustre, fire, brilliance and sparkliness towards a stone's liveliness. A multi-faceted YAG doped with neodymium, which had been cut by Dr George Harrison Jones, was used for the demonstration.

Delegates examining treated and fracture filled specimens.

Dr Jamie Nelson explains his scintillation device.

Valuation and appraisal

Methods of valuation and appraisal, both British and American, were discussed by Terry Davidson of Cartier and Ann Dale from the USA.

Terry Davidson of Cartier speaking on appraisals.

Terry Davidson stressed that an item '... is worth what an individual is willing to pay for it'. He cited a number of examples of factors affecting the value, such as its antiquity, fashion trends, or the history of the piece.

Also consideration should be given to the difficulty in replacing items, particularly matching sets of rare stones such as Burma sapphires. Appraisers should be aware of fakes, and be able to identify reproduction pieces, and always consult experts if in any doubt. As much information as possible should be given in the descriptions of pieces.

Ann Dale then gave an account of methods used in America. As well as the fascination of the items she appraised, Ann often found the stories behind pieces and the personalities involved to be very interesting.

Ann Dale speaking on valuations in the USA.

Fees charged in the USA are based on an hourly rate, rather than a percentage of the value which is the custom in Britain. Approximately 80 per cent of appraisals are for insurance purposes, but estate parcels and the valuation of goods belonging to separated or divorced people were also discussed.

The Windsor Jewels

After lunch David Callaghan gave a talk on the Windsor Jewels. As well as giving fascinating details of lives of the Duke and Duchess of Windsor, he also recounted the background stories and disclosed hidden meanings associated with the pieces of jewellery. In a number of cases the code 'WE [Wallis and Edward] are two' was used. David went on to describe a number of the pieces in the collection in detail.

Gem certification

Ana Castro of the GAGTL gave a talk emphasizing the necessity for gem certification. It is essential that anyone connected with the jewellery trade should have knowledge of the exact nature of the gemstones being traded. It is possible to keep up- to-date with modern synthetics and treatments by reading gemmological journals and other literature, and by attending lectures and workshops on the subject. However, with the increasingly deceptive synthetic materials and ingenious treatments being developed it is essential that the expertise of the GAGTL Laboratory is available to be called upon. If you are in doubt about a material it should be submitted to the Gem Testing Department for a report.

Ana gave examples of various stones submitted to the laboratory, and described methods used in testing before a report is issued. In the case of a blue faceted stone, for example, the laboratory is asked to make the following determinations:

1. Is it sapphire or not?
2. Is it natural, treated or synthetic?
3. Is the sapphire's colour natural or a result of diffusion treatment?
4. Have any of the sapphire's surface-reaching features been infilled with artificial material?
5. Has the sapphire been artificially heat treated to enhance its appearance?
6. What is the sapphire's country of origin?

The main body of the report consists of a brief yet exact description of the material submitted for testing, including the predominant colour of the gemstone together with any notable optical effects, its shape and cut, and the millimetre size and the weight.

Ana concluded by emphasizing the importance of knowing the exact nature of the gemstones that you are dealing with.

Disclosure of fracture filling

Continuing the theme of gemstone enhancement, the final session of the day was a panel discussion on the need for disclosure of fracture filling. The panel, chaired by Ken Scarratt, comprised Steven Kennedy, John Kessler, Jeff Monnickendam, Dr Kurt Nassau and Eric Poyser, representing all aspects of the gemstone trade.

Steve Kennedy of the GAGTL opened the discussion with a brief explanation of the fracture filling process. Panellists then expressed their differing views before the subject was thrown open to the meeting when a lively debate ensued.

Thin diamond films

The proceedings began on the second day with a talk by Dr Kurt Nassau on thin diamond films. After giving a brief history of diamond synthesis, Dr Nassau described the process for producing thin diamond films. When tested many of the stones were found to have diamond-like films, such as amorphous carbon, hydrocarbon, super hard carbon and glassy carbon, which are easier to produce than the single crystal diamond film which will grow until it is 5-10 microns and then, for reasons not yet known, stop growing.

Keynote lecturer Dr Kurt Nassau (right) with David Callaghan.

The thin diamond film can be grown on silicon and silicon carbide but it does not adhere to other surfaces. An illustration was shown of a cubic zirconia from which part of the thin film had peeled off. Dr Nassau listed the various types of synthetic diamond, their commercial viability, and means by which they could be identified.

Gemstone treatments

The final talk on the theme of gemstone enhancement was given by Ken Scarratt, who gave an up-date on fracture filling.

Fractures in emeralds have for some time been filled with oil, and Ken pointed out that under CIBJO rules colourless oil is not declarable but coloured oil is. He went on to explain the process used in Opticon filled fractures, which can be identified by the yellow flash which changes to blue when the stone is turned. Large cavities common in rubies from Thailand and Burma are filled with plastic and then glass, which may give a considerable difference in weight before and after treatment. These fillings can be seen in reflected light.

Fracture Filled diamonds

Diamonds treated by Yehuda are filled with a yellowish glass, which reduces the colour grade of the stone. The London laboratory does not grade such treated stones.

The first stones treated could be identified by the bright blue flash from the substance in the fracture, changing colour as the stone was turned, but now flashes can be seen in various colours, for example blue changing to orange, blue to green or purple to red. It is also possible that bubbles can be seen in the fracture.

Very low quality material is now being treated, whereas previously the stones contained only one or two fractures.

Diamonds are now being treated in Israel. It is being claimed that a new colourless glass with an RI close to that of diamond, which gives no colour flash has been introduced. Stones tested did show a colour flash, but as could be seen from slides shown before and after treatment, visibility of the fractures was vastly reduced. On X- ray the glass appears opaque.

Ken concluded by describing an 'oscillation' treatment by which process fractures changed from black to white. After acid oscillation the surface is sealed with an organic hardener.

Diamond certification

An increasingly important aspect of the work of the GAGTL laboratory is that of diamond grading and the production of diamond grading reports.

Eric Emms of GAGTL told delegates of the work involved in producing a report. He stressed that a thorough knowledge of gemmology is essential for a competent diamond grader, as it is necessary to know whether a stone is a diamond - not synthetic or a simulant - and whether it has been treated to alter the colour or had its clarity 'enhanced'. 'Whereas gemmology and gem testing is *identification*, diamond grading is, in addition, an analysis of *quality*, and a diamond grading report is the written description of a stone's quality'.

Eric went on to explain the methods used in

grading the 'Four C's' - carat weight, colour, clarity and cut.

A particularly important area of diamond grading is that of control. At least three graders examine each stone - the first person will grade the stone and the second and third check their work. Because the GAGTL issues CIBJO and GIA reports that are produced by other laboratories around the world, it is essential that our grades should accord with those of other laboratories. To this end stones are exchanged on a regular basis and the resultant grades monitored. In addition grading philosophy and procedure is shared by an exchange of grading staff with other laboratories.

With the increasing awareness of the public of the quality of diamonds, many retailers now appreciate the advantage of highlighting diamond quality and necessity for grading reports to instill confidence at the point of sale.

'Quality is the essence of a diamond', concluded Eric. 'The word I have used most frequently today is 'diamond' followed by 'quality'. That has been my intention'.

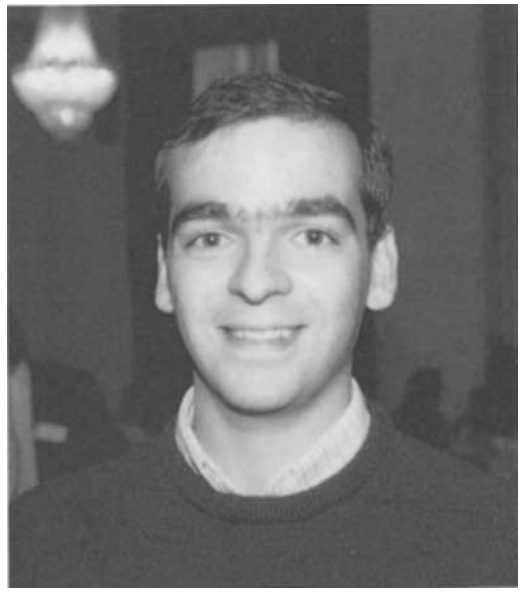

Diploma winner Rui Galopim de Carvalho from Lisbon, Portugal.

Burma and Vietnam

The afternoon session was devoted to Alan Jobbins and Ken Scarratt of GAGTL who spoke about their recent trip to South East Asia, a report of which was published in *Gem & Jewellery News*, Vol. 2, No.1, December 1992. Together with Edward Gübelin and Adolf Peretti of the Gübelin Laboratory, they spent five weeks visiting new gemstone deposits, at the invitation of Henry Ho of the Jewelry Trade Center in Bangkok.

As well as describing the various deposits, geology of the areas, methods of mining and recovery of the gemstones, they treated delegates to a marvellous 'travelogue' of the countries visited.

Sean O'Connell from Ireland with Vice President David Kent.

Ken dealt with the journey into Vietnam, describing the country as a 'gemstone paradise'. The ruby deposits at Luc Yen in north Vietnam were the first to be visited. Here the deposits are essentially alluvial, the BH Mining Co. exploiting concessions along a river valley. The rubies are associated with limestones and pegmatites, but the associated alluvial deposits are the main source of gemstones. The overburden is removed before the gem-bearing gravels can be recovered. The gravels are then washed and the gems extracted. The rubies are sorted at open windows on a mirrored surface allowing the light to pass through them.

Unfortunately, because of torrential rains and flooding in the area, it had been impossible to inspect the ruby deposit at Quy Chau, north west of Vinh, where rubies are recovered from beneath a thick whitish clay.

The party then stayed in the hill town of Dalat and visited a small sapphire working in Lam Dong province. In this region dark blue sapphires characteristic of lava deposits are found.

The visit to Burma was then discussed by Alan Jobbins. He described in detail the geology of the areas visited, as well as the mining methods used to extract the many minerals, including sapphire, ruby, peridot and spinel.

NEW SYNTHETICS

Dr Nassau reported briefly on synthetic forsterite and synthetic peridot which are now commercially available for laser work.

Gemmological Abstracts

ALEKSANDROV, V.I., VISHNJAKOVA, M.A., KALABUKHOVA, V.F., LOMONOVA, E.E., PANOV, V.A., 1991. Growth of zirconia single crystals by direct crystallization in a cold container. *Advances in Crystallography and Crystal Growth, 1991*, 17-28, 5 figs.

Problems of zirconia growth by RF heating in a cold container are reviewed. Solid solution composition, dopants and impurities, thermal conditions and growth regime all affect size and perfection of the crystals. M.O'D.

BANK, H., HENN, U., 1991. Smaragde und ihre Vorkommen in Nigeria. *Mineralientage München 1991, Messekatalog*, 29-31, 6 photos (3 in colour), 1 fig.

Gem quality emerald is reported from the pegmatites of the Jos plateau, Nigeria. Crystals up to 10cm long are recorded. Two- and three-phase inclusions have been noted together with zoning normal to the *c*-axis. M.O'D.

BAROT, N.R., BOEHM, E.W., 1992. Gem-quality green zoisite. *Gems & Gemology*, **28**, 1, 4-15, 17 figs.

Green zoisite has hitherto been known as a sugary-textured opaque aggregate associated with large low-grade ruby crystals at Longido, Tanzania. In the 1960s an important facetable violet-blue version, which was named tanzanite, was found in the Merelani Hills some 150km south of Longido. Since then brown and yellow versions have been found. Now a transparent faceted green version is reported, again from the Merelani Hills. Gemmological properties are identical with those of the blue gems and the new materials is here referred to as 'green tanzanite'. Chromium absorption seen in well-coloured stones, pleochroism naturally differs from that of the blue variety while inclusions consist of finger-print healed cracks, two- and three-phase cavities, and zircons with expansion haloes; some acicular inclusions provide cat's-eyes when cabochon cut. Heating finer green material produces no colour change, but some green-browns do change to blue when heated. Authors suggest that this new version of tanzanite should be specifically named. R.K.M.

BRACEWELL, H., 1992. Gems around Australia 7. *Australian Gemmologist*, **18**, 2, 38- 9, 4 figs.

Tour continues from Broome WA via Eighty Mile Beach to Port Hedland area for tiger-iron jaspilite; Marble Bar for ancient minerals, with gold and metallic ores. Lionel yields a chlorite marketed as 'Pilbara Jade'. R.K.M.

BROWN, G., 1992. Vietnamese ruby: a discriminatory problem for gemmologists. *Australian Gemmologist*, **18**, 2, 43-6, 13 figs.

Rubies discovered in 1987 near Luc Yen and Quy Chau in Vietnam are similar in colour and character to Burmese ruby. Some parcels have been salted with look-alike Verneuil synthetic rough or cut stones and identification of these and provenance of the natural stones is difficult, needing careful study of immersed stones under magnification if mistakes are not to occur. Burmese and Vietnamese rubies are closely similar in their inclusions, although blue zoning, pyrrhotite rods, orange rutile, bluish clouds of fine rutile and orange flux-like masses of the rare aluminium hydroxide, nordstrandite, are unique to those from Vietnam. The synthetics have been heat-treated to eliminate curved striae, and may have developed natural looking fissures due to prolonged treatment. R.K.M.

BROWN, G., 1992. Mintabie opal. *South African Gemmologist*, **6**, 1, 10-15, 4 photos in colour, 2 maps and 1 fig. in colour.

In 1990 28% of the production of the world's gem quality opal came from the Mintabie field, approximately 1,000km north-west of Adelaide. The history and geology of the field are described. M.O'D.

BROWN, G., KELLY, S.M.B., 1992. Fiber-eye: a gemmological study club report. *Australian Gemmologist*, **18**, 2, 52-3, 7 figs.

A new cat's-eye imitation made from fused cubic packed glass fibres. H about 6, brittle, RI estimated at 1.86 [high for a comparatively hard glass. More research needed?]. R.K.M.

BROWN, G., KELLY, S.M.B., 1992. Gemmology study club lab reports. *Australian*

Gemmologist, 18, 2, 56-60, 21 figs.

New pyrope/almandine from Northern territory described; four- and six-rayed blue star spinel illustrated; golden zircons submitted to determine whether they were heat- treated or not, evoked information on the heating methods but could not test whether they had been so treated [the heat-treated colour is usually far better than that of natural golden zircons]; a laser carved turquoise-blue cameo on a black base is thought to be imitation, granular appearance under magnification should identify; a 'pippin' shaped cultured pearl is described as a 'twin'; three stones with dendritic inclusions are identified by RIs as quartz, chalcedony and opal; two blue-green Egyptian faience scarabs were alleged to be of New Kingdom period, about 1400BC [Their apparent excellent condition suggests to abstracter that these may have been reglazed in modern times, a not unusual practice in Egypt]. R.K.M.

CAMPBELL, I.C.C., 1992. Another two examples of uncut simulated emeralds. *South African Gemmologist*, 6, 1, 23-6, 6 photos in colour.

A simulant of rough emerald proved to be a piece of flux-grown Chatham emerald within a matrix of Zambian host. The matrix was natural and not glued in place. Two further hoaxes involved dyed quartz crystals and glass emerald simulants offered in a sealed capsule. M.O'D.

CLACKSON, S., MORETON MOORE, 1992. An X-ray study of some Argyle diamonds. *Industrial Diamond Review*, 52, 551, 192-4. 1 table, 1 graph, 4 electron micrographs, 9 Laue photographs, bibl.

The Argyle diamond mine produces one third of the world output. The diamonds occur in lamproite, the sample examined by the authors showed a wide range of qualities, mostly irregularly shaped, the next common morphology was octahedral. Most diamonds were grey or brown, a small number were pink. 70% had black inclusions. Examination by Laue X-rays showed that most Argyle diamonds have a mosaic structure, i.e. the crystal is composed of many misorientated constituent crystals. This might account for their high wear resistance as experienced by diamond polishers and in industry. E.S.

CODY, A., BROWN, G., 1992. Robotic opal cutting: an Australian solution to an old problem. *Australian Gemmologist*, 18, 2, 40-1, 4 figs.

Automatic cutting of small calibrated opals requiring preform and colour selection before robot takes over. Polished by tumbling. R.K.M.

FRITSCH, E., SCARRATT, K., 1992. Natural colour non-conductive grey-to-blue diamonds. *Gems & Gemology*, 28, 1, 35-42, 5 figs.

To date all natural blue diamonds tested have been Type IIb and have conducted electricity. Now grey to greyish-blue diamonds of unknown origin tested by the London Laboratory were found to have a coating of Type IIa diamond and to be non-conducting, but became conducting once they were cut. Four greyish-blue faceted stones from the Argyle mine in Australia were tested at Santa Monica Lab and found to be non- conducting. An N3 absorption was seen which identified these as Type Ia rather than IIb. The infrared spectrum was also unusual in type and intensity. Lack of electrical conductivity cannot now be regarded as proof that a diamond has been artificially blued, although luminescence of yellow to yellowish-green, stronger in LUV than in SUV, will indicate that the blue colour is probably natural. R.K.M.

FRYER, C.W., CROWNINGSHIELD, R., HARGETT, D., MOSES, T., HURWIT., KANE, R.E., 1992. Gem Trade lab notes. *Gems & Gemology*, 28, 1, 52-57, 19 figs.

A large brownish-yellow non-nacreous concretion exhibiting 'flame' structure similar to that in conch and clam pearls was thought to be from a Bailer mollusc from Indo-Pacific waters.

A conjoined pair of dodecahedral diamonds is described and illustrated, as are two dice cut from black diamond with inserted gem diamond spots, and two square-cut brilliant grey diamonds exhibiting central dark grey clouds of particles in the form of matched crosses; a severely burnt diamond is depicted 'before and after' recutting to a fine stone half the original weight; a green-coated diamond was cleverly faceted to give two stones retaining the green colour and 91% of the uncut weight by using octahedral faces as main pavilion facets.

Two emeralds had very similar capped spicule inclusions, one with phenakite caps which identified a hydrothermal synthetic, the other with opaque yellow caps (calcite?) which confirmed it as natural, infrared spectrum also confirmed; a cylindrical imitation of lapis was recognized as ceramic but the colouring agent is not known. Black opal is illustrated which has

brilliant play-of-colour in saw-edged patches separated by fine lines of black potch; a large bead Polynesian naturally black cultured pearl necklace had two pearls which were non-nucleated; a green bead, sold as jade, was identified by X-ray diffraction as the muscovite mica mineral pinite (RI 1.57, SG 2.80, H 3 1/2, chrome absorption). R.K.M.

FUHRBACH, J.R., 1992. Kilbourne Hole peridot. *Gems & Gemology*, **28**, 1, 16-27, 20 figs.

This volcanic crater located in SW New Mexico near Las Cruces, was described in 1975, and Mr Fuhrbach has recently carried out an investigation which revealed a number of cuttable nodules capable of yielding reasonably sized faceted gems, although most of the gem quality pieces were under two carats but still capable of giving small stones of good colour and clarity. Constants and inclusions as for terrestrial peridot but lily-pad formations centred by black hercynite are new; chrome diopside, biotite and glass bleb inclusions were also found. The deposit is not actively worked. R.K.M.

GRAMACCIOLI, C.M., 1991. Application of mineralogical techniques to gemmology. *European Journal of Mineralogy*, **3**, 703-6.

The paper gives an undetailed overview of some of the techniques used by mineralogists which may also be useful in gem testing. M.O'D.

GRUNDMANN, G. Smaragd. Grünes Feuer unterm Eis. *Extra Lapis* no 1, pp. 96, illus. in black and white and in colour.

Habachtal emerald and other minerals associated with them are described in this first special issue of the journal *Lapis*. Mineralogy, geology and characterization are all discussed in an attractively produced large format book. M.O'D.

GRUNDMANN, G., 1991. Der grüne Schatz der Hohen Tauern. Mineralientage München 1991, *Messekatalog*, 33-47, 22 photos (16 in colour), 7 figs.

Emerald from the Austrian Habachtal is described with notes on the general geology and mineralogy of the area. The use of Habachtal emerald in jewellery is reviewed. Characteristic inclusions are illustrated and listed. M.O'D.

HAPUARACHCHI, D.J.A.C., 1989. Some observations on the origin of gem corundum in Sri Lanka. *Journal of the Geological Society of Sri Lanka*, **2**, 5-9, 4 figs, 2 maps.

Silica-deficient rocks of pelitic composition with corundum, biotite, sillimanite, perthitic K-feldspar, plagioclase, spinel, cordierite and garnet are described from the Sri Lanka Highland Series at Talatu Oya, Haldamulla and Gangoda. It is postulated that the textures of the corundum-bearing gneisses suggest a reaction between biotite and sillimanite to give corundum and K-feldspar, with cordierite, spinel and rutile. M.O'D.

KERREMAN, Y., WANTEN, E., 1992. Material loss when sawing gem diamond. *Australian Gemmologist*, **18**, 2, 49-51, 5 figs.

Compares weight loss between stones sawn mechanically by disc saw and those sawn by laser beam. In general the former is cleaner and a little less wasteful, but restricted in direction, while the laser gives less smooth surfaces with slightly more wastage but cuts equally well in any direction. Laser is twenty times faster. Differences in weight loss are not large and laser can be made less wasteful. R.K.M.

KOIVULA, J.I., KAMMERLING, R.C., 1991. Gemmological properties of emeralds from the Panjshir Valley, Afghanistan. *South African Gemmologist*, **5**, 3, 9-14, 1991, 7 photos in colour.

Small rough emerald crystals from the Panjshir Valley in Afghanistan with the longest measuring 14.62 x 4.01 x 3.03mm and weighing 1.48ct were examined for optical and physical properties. RI is recorded at 1.571 and 1.578 for the extraordinary and ordinary rays respectively with a birefringence of 0.007. Specific gravity falls in the range 2.69-2.72. Though two apparently treated crystals gave a whitish-yellow response to LWUV the remainder were inert to ultra-violet radiations. Two- and three-phase inclusions were noticed: also included were random crystals of beryl and possibly albite. Possible pyrite crystals are also noted. M.O'D.

KOIVULA, J.I., KAMMERLING, R.C., FRITSCH, E., 1992. Gem news. *Gems & Gemology*, **28**, 1, 58-67, 19 figs.

The Tucson Show came round again in February and this excellent report reflects highlights of this great annual event.

Diamonds

Coloured diamonds abundant in small sizes, mainly yellows and browns, plus one show of

pinks, and another of white 'opalescent' diamonds from Panna in India.

Coloured Stones

A fire agate with built-in 'frame' of clear chalcedony; fine blue-green amazonite from Minas Gerais, Brazil; Baltic amber; Madagascan green-blue apatites; deep blue aquamarines from Mozambique; specimen beryl crystals from Nigeria; greyish-blue aquamarines from Zambia; chalcedonies coloured by chrysocolla from Mexico were porous and improved with immersion in water. Cat's-eye emerald, normally rare, were on show in quantity by two exhibitors; moldavite from Czechoslovakia; fire-opal from Querétaro, Mexico; large peridots from newly exploited San Carlos deposits and from China and Ethiopia; pietersite hawk's-eye from Namibia; rubies and sapphires from Vietnam; a newly found ruby deposit in Namibia similar in type to Longido rubies; rubies from Central Australia; rubies and pink sapphires from Azad Kashmir, Pakistan; ruby in green zoisite from Longido; blue Chinese spinel; green and green-blue tourmaline from Paraiba scarcer this year; fine pink and red tourmalines from Namibia and from Madagascar; the new faceted green tanzanite and a number of rare gems from Mont St-Hilaire, Quebec are all described and most are illustrated.

Enhancements

Quantities of blue diffusion-treated sapphires in calibrated sizes available, no other colours seen; white hydrophane opal dyed dark blue with potassium-ferrocyanide and sealed with plasticizing liquid, detectable by light weight, plastic feel and blue translucency to strong light; irradiated green topaz from Sri Lanka also seen.

Synthetics and Simulants

Synthetic alexandrites by J.O. Crystals now being promoted as 'Nicholas Created Alexandrite', these Czochralski-pulled rods have negative crystal inclusions at their cores which are used for cabochons, faceted stones of good quality are from the outer parts of the rods; a range of colours in hydrothermal synthetic beryls from Russia and Australia were seen; cubic zirconia plentiful in many colours some of which were opaque; rare laboratory grown crystals were again available; earstuds held in place magnetically were an innovation; chatoyant fibre-optic glass gems; glass embedded natural opal; several colours of Russian synthetic sapphire grown primarily for laser use; opaque materials imitating sugilite, coral, turquoise, malachite azur-malachite and black onyx were evidently plastic based; faceted YAG in various colours and desk ornaments made from pulled rods of neodymium-doped YAG were all seen and illustrated.

Instrumentation

An illuminated immersion cell has been made to facilitate testing for diffusion treatment in sapphires. R.K.M.

KRIJGER, B., 1978. Fluoriet als edelsteen. *GEA*, **11**, 1, 17-18, 4 figs.

The possibilities of fluorite as an ornamental material are discussed with particular reference to the Blue John variety. M.O'D.

LINTON, T., BROWN, G., 1992. Gemmology study club lab reports. *Australian Gemmologist*, **18**, 2, 56-60, 21 figs.

An assessment of four filters marketed by Hanneman Gemological Instruments, Calif., arrives at conclusions rather similar to my own when I reviewed these in 1990. Use with caution. [*Journal of Gemmology*, 22, 4, 212-14]. R.K.M.

MOXON, T.J., 1991. On the origin of agate with particular reference to fortification agate found in the Midland Valley, Scotland. *Chemie der Erde*, **51**, 4, pp 251-60, maps.

SEM and TEM photographs show that the translucent white and blue-white bands in fortification agate (a variety of banded chalcedony whose pattern is reminiscent of the plan view of a castle) from Scottish andesites and basalts of Devonian age have a plate-like structure. The edges of plates scatter transmitted white light, causing the bands to appear red-brown; the blue-white bands also contain dusty inclusions which scatter white reflected light. The banding in agate can only form after the residue is full of silica. Recent theories of spherulitic growth combined with EM photographs support ideas first proposed by Jessop [*Proc. Geol. Assoc.*, 42, 1930, 29-43] which allow a rhythmic deposition of different impurities. R.A.H.

MULLIS, J., 1991. Bergkristall. *Schweizer Strahler*, **9**, 3, 127-61, 27 photos in colour, 22 figs.

The occurrence and crystallization of rock crystal is examined with particular reference to Alpine localities, and especially those in

Switzerland. The nature of twinning in quartz is discussed and variation in crystal habit from one locality to another is also described. The paper ends with a bibliography of 65 references.
M.O'D.

NIEDERMAYR, G., 1992. Die Bestimmung von geschliffenen Edel-und Schmuck-steinen mit einfachen Hilfsmitteln. *Mineralien Welt*, **3**, 1, 47-50, 1 photo in colour.

A brief overview of some of the simpler methods of gem testing. M.O'D.

O'DONOGHUE, M., 1992. Industrial review-Gemstones. *Britannica book of the Year*, p.188.

The expected swift upturn in the developed world's economies did not materialize and the gemstone and jewellery trade continues depressed with fewer major auction sales and small firms ceasing to trade. Few new gem varieties are reported but the question of alteration/enhancement of colour continues to occupy regulatory bodies.
[Author's abstract M.O'D.].

PEARSON, G., 1992. Torrington emerald. *Australian Gemmologist*, **18**, 2, 47-9, 7 figs.

Discusses prolific three-phase inclusions in stones from near Glen Innes, NSW. Absorption suggest that vanadium is the dominant chromophore but evidence of chromium justifies calling this material emerald although it is green through the emerald filter. Narrow colour zoning parallel to the basal pinacoid is common.
R.K.M.

PETRUSENKO, S., 1991. Kamienie szlachetne i ozdobne Bulgarii. *Mineralogia Polonica*, **22**, 1, 81-7, 1 map, 4 photos.

Gem minerals found in Bulgaria include aquamarine, emerald, quartz (amethyst, agate, jasper), garnet (almandine-spessartine), epidote, rhodonite, corundum (ruby), turquoise, malachite and fluorite. A bibliography is appended. M.O'D.

READ, P.G., 1992. Recent innovations refine effectiveness of reflectance meter. *Canadian Jeweller*, June 1992. 26-7, 2 figs.

Describes the Sarasota Jemeter Digital 90 reflectance meter and its innovative features, which include the ability to provide a direct digital readout of a gem's RI and to measure double refraction down to 0.01. Included in the article are details of the pocket-size Rosgem refractometer which uses a pen torch source of illumination. (Author's abstract) P.G.R.

ROSSMAN, G.R., FRITSCH, E., SHIGLEY, J.E., 1991. Origin of color in cuprian elbaite from Sao Jose de Batalha, Paraiba, Brazil. *American Mineralogist*, **76**, 1479-84, 3 figs.

Gem quality elbaite containing up to 1.4wt% Cu is reported from Mina da Batalha, close to Sao Jose de Batalha, north-eastern Brazil. Optical absorption bands for divalent Cu have maxima in the 940-695nm region and are more intense in the E⊥c direction. Colour can be modified to violet-blue and violet by increasing absorptions from trivalent Mn. M.O'D.

SANGEETA, SABHARWAL, S.C., GUPTA, M.K., 1991. On the growth of single crystal $Y_3Al_5O_{12}$. *Advances in Crystallography and Crystal Growth*, 1991, 37-41, 2 figs.

Crystals of YAG grown by the Czochralski method have their morphology affected by flow of ambient gas in the vicinity of solid/melt interface. The oxygen fraction in the ambient is found to affect crystal transparency. M.O'D.

SINKANKAS, J., KOIVULA, J.I., BECKER, G., 1992. Peridot as an interplanetary gemstone. *Gems & Gemology*, **28**, 1, 43-51, 10 figs.

Peridot is a common constituent of the stony meteorites called pallasites. They were first faceted early this century but it has only now become possible to examine specimens in detail. In 1990 Gerhard Becker identified several promising olivines in slices of the Esquel meteorite, which fell in Argentina, and took them back to Idar where Andreas Becker very carefully extracted and cut them to give small faceted stones. Eight of these and one from the Eagle Station pallasite were examined by the authors, confirming that their physical constants were in complete accord with those of terrestrial peridots, but that small included fragments, believed to be nickel-iron, are specific to stones from such sources. Faceted meteoric peridots are rare. R.K.M.

SOBOL, A.A., 1991. New easy melted laser garnet crystals: structural defects, spectroscopic and laser action study. *Advances in Crystallography and Crystal Growth*, 1991, 9-16, 6 figs.

Garnets doped with trivalent Nd are grown by Czochralski pulling from Pt crucibles. Raman spectroscopy is used to study structural defects. M.O'D.

SPENCER, R.J., LEVINSON, A.A., KOIVULA, J.I., 1992. Opal from Querétaro, Mexico: fluid inclusion study. *Gems & Gemology*, **28**, 1, 28-34, 6 figs.

Three-phase, two-phase and single-phase inclusions are known in these opals and this paper describes the chemical nature of the gases and liquids by freezing or heating them to establish the temperatures achieving solid or gaseous stages. Results suggest that liquids are hydrated silica gel rather than water. Solids are trapped inclusions rather than crystals grown from inherent impurities. Parent opals probably formed at about 160°C. Salt crystals were tentatively identified. Included air was not found. R.K.M.

STALDER, H.A., 1992. Edel-und Schmucksteine aus der Schweiz. Teil 2: Die Mineralien der Quarzgruppe. *Schweizer Strahler*, **9**, 6, 305-26, 22 photos (8 in colour).

Quartz group minerals are dealt with in this second part of a review of Swiss gemstones. Occurrence and use are described with some comments on inclusions and other gemmological features. M.O'D.

STALDER, H.A., VOLLENWEIDER, P., HÜGI, M., OFFERMANN, E., 1991. Edel-und schmucksteine aus der Schweiz. *Schweizer Strahler*, **9**, 4, 173-268.

The entire issue is devoted to a review of the gem minerals found in Switzerland. Among the species described are kyanite, corundum, axinite, cordierite, tourmaline, aquamarine, anhydrite, dolomite, epidote, grossular and demantoid. A list of references is appended. M.O'D.

STATHER, M., 1992. The care and cleaning of gem materials. *Australian Gemmologist*, **18**, 2, 34-8.

Cautious advice. R.K.M.

SURY, E., 1992. Synthetische Kristalle, synthetische Steine, weshalf, wie, wozu? *Lapis*, **17**, 13-23, 16 photos, 13 in colour, 9 figs.

Simple but well-illustrated account of the manufacture of artificial gem crystals by the main methods. M.O'D.

THOMAS, A., 1991. 'Blue-green emerald'. *South African Gemmologist*, **5**, 3, 26-32, 3 photos in colour.

A rambling account of emerald from the Miku deposit in Zambia and of green beryl from the Jos area of Nigeria. M.O'D.

TIN, HLAING, 1992. A deposit of greenstone, Shan State, Myanmar. *Australian Gemmologist*, **18**, 2, 42, map.

Nephritic material identified as a mixture of quartz, calcite, tremolite and diopside. R.K.M.

WANG, A., WANG, W., ZHANG, A., 1991. Microstructural variations of a pyrope inclusion in diamond as revealed by a micro-Raman spectroscopic study. *Canadian Mineralogist*, **29**, 517-24, 6 figs.

Two microstructural variations of a syngenetic pyrope inclusion in a diamond from Liaoning, China, are described. A micro-Raman technique was used for the investigation. M.O'D.

WILSON, W.E., BARTSCH, J.A., 1992. Minerals of the Houston Museum of Natural Science. *Mineralogical Record*, **23**, 1, [33 pages in separately paged bound-in supplement], 64 photos in colour.

The mineral collection of the Houston Museum of Natural Science, Texas, USA, contains a number of gem-quality specimens, some of which are illustrated. M.O'D.

Book Reviews

DOWNING, P.B., 1992. *Opal identification and value.* Majestic Press, Tallahassee. pp. x, 210. Illus. in colour. Price US$ 38.95.

Although there have been several books on opal valuation in recent years this is larger and includes information on opal from a number of countries other than Australia (where most previous accounts have been published). The first chapter introduces the factors influencing value and the second outlines the techniques used and gives a guide to simple equipment needed by the valuer. The reader is then introduced to opal types, which are well illustrated and then to the dangers offered by synthetic and imitation stones.

The book then turns to the classification of colour base and play of colour. In a sense, this is entirely subjective but the book makes a gallant attempt to simplify types and nomenclature; it certainly illustrates many of the main colour patterns very well. There are remarks on deficiencies and then the topic of valuation is introduced. The remarks are clear and sensible but some of the pictures in this section are not well reproduced - a pity, since the quality of the stones is apparent. Opal from the USA, Brazil, Java [i.e. Indonesia], Honduras, Mexico and Hungary [i.e. Czechoslovakia] is also valued. The author suggests that some Brazilian opal is sent to Australia and sold there as native material. Much Brazilian opal I have seen is not very like Australian material, having a characteristic pinfire effect.

The next section deals with synthetic opal valuation and with the valuation of rough opal. There is a useful bibliography and a glossary. The effort to keep the text simple and the exclusion of unnecessary terms has produced a good book which I can recommend. M.O'D.

FIELD, L., 1992. *The Jewels of Queen Elizabeth II - her personal collection.* Thames & Hudson. Paperback edition. Price £12.95.

This is an extremely well produced catalogue of some of the Queen's jewellery, giving a potted history of each piece with photographs of the Queen or another Royal wearing it. It includes such valued pieces as the Cullinan, a brooch belonging to the Empress Marie Feodorovna of Russia, Queen Mary's Stomacher and the Delhi Durbar Parure. The jewellery is sub-divided into tiara, necklaces, ear-rings, bracelets, brooches, watches and rings. A number of anecdotes make for amusing reading. E.S.

KAZMI, A.H., AND SNEE, L.W., Eds. *Emeralds of Pakistan: Geology, Gemology and Genesis.* Pakistan (Geological Survey of Pakistan) & New York (Van Nostrand Reinhold Co.), 1990. xii + 269pp., 90 colour photos., 49 maps. Price £29.00.

This attractively presented book, with a foreword by Edward Gübelin, contains nine chapters by a variety of international experts. Each chapter has its own references but there is also a selected bibliography on worldwide emerald occurrences, with some 530 references.

In northern Pakistan the spectacularly rugged Himalayan ranges dissected by the awe-inspiring canyon of the Indus River, which reaches over 6100m of relief in places, provide a fascinating background to the discovery and working of the emerald deposits in the Surat-Malakand-Mohmand area.

The gemmological characteristics of the Pakistan emeralds are fully documented by a chapter by E. Gübelin, who notes that they have refractive indices rather high for gem-quality emeralds, but which are in agreement with emeralds containing appreciable iron. This chapter also deals with both primary and secondary fluid inclusions from the petrographic viewpoint. In a later chapter, the chemistry of these inclusions is considered by R.R. Seal, who concludes that they were probably entrapped at 250-449°C at a confining pressure of 900 bars. A joint contribution from staff of the U.S. Geological survey and of the Geology Department of Oregon State University deals in detail with the major, minor and trace element composition of the emeralds from several Pakistan localities and also their host rocks; most of the emeralds owe their colour to the substitution of chromium for aluminium in the

beryl structure (though a green beryl from Gandao has 13300 ppm V but only 340 ppm Cr). A further chapter by Jane Hammarstrom of the U.S.G.S. reports on the colour zoning shown by some of the emeralds and also demonstrates that the substitution of magnesium for aluminium in the octahedral site is charge-balanced by the entry of sodium into the channel site (these emeralds are notably poor in Rb and Cs).

The remaining five chapters are concerned with the geology and genesis of these emerald deposits, and in these the work of A.H. Kazmi, Director General of the Geological Survey of Pakistan, and of L.W. Snee of the USGS, point the way to a more fundamental understanding of the genesis of emeralds. In Pakistan all the emerald deposits are located in the Indus suture zone; most are associated with the Mingora ophiolitic mélange which has provided the chromium, whereas the beryllium came from later mineralizing fluids from the younger granitic rocks. In a wider consideration of all known emerald occurrences worldwide, a possible classification takes into account the geochemical incompatibility of Cr and Be and lists emerald deposits according to the source of the chromium (suture zones, granite-greenstone terrain or shale (metashale) and of the beryllium (generally pegmatitic or hydrothermal fluids but more rarely metamorphic fluids). With the exception of the Colombian occurrences, most emeralds exist as a result of crustal plate movements that juxtaposed chromium-bearing ultramafic oceanic plate movements with beryllium-bearing felsic continental rocks. Thus as the Editors suggest, we may marvel at each emerald crystal not only for its intrinsic beauty, but also for its untold tale of continental collisions. R.A.H.

MITCHELL, R.H., BERGMAN, S.C., 1991. *Petrology of lamproites.* Plenum Press, New York and London. pp. xvi, 447, illus. in black-and-white and in colour. US$ 75.00.

Only in recent years have lamproites been distinguished from kimberlites as a source of diamond, though this is not their only petrological and mineralogical significance. Recent surveys have found that several diamond deposits, once thought to be kimberlitic, are in fact lamproitic; they include the very important fields in Western Australia as well as some in Africa and on all the other continents.

Lamproites are igneous rocks characterized by high levels of K_2O and MgO and the history of the definition forms the first part of the book. The next section discusses potassic rocks and the lamproite clan and this is followed by a survey of lamproite occurrences and of the tectonic framework of lamproite genesis. A chapter on petrological facies and igneous forms of the lamproite clan prefaces a major section on lamproite mineralogy and geochemistry. Gemmologists will find the later part of the book particularly interesting as there is an examination of diamonds, xenoliths and exploration techniques. Diamonds in lamproites are considered to be xenocrysts and derived from parts of the lithospheric mantle lying above the regions of lamproite genesis. This section contains a very useful resumé of diamond types and inclusions. Lamproitic diamonds show similarities with and differences from kimberlitic stones, though Argyle stones (Western Australia) are richer in K, Al and Fe. In general lamproite diamonds are of poorer quality, the majority being grey, yellow, brown or of industrial quality. They show no morphological characteristics or colours which would unambiguously distinguish them from kimberlite diamonds.

This is a most useful book and the data presented is backed up by an excellent bibliography. M.O'D.

NICKEL, E.H., NICHOLS, M.C., 1991. *Mineral reference manual.* Van Nostrand, New York. pp. iv, 250. £10.95.

This is an alphabetical list of all mineral names available from extant literature to May 1990. No attempt is made to give mineral groupings; though the names of groups appear in sequence, group membership is not amplified. Entries give composition, status according to the Commission on New Minerals and Mineral Names, crystal system, lustre, main colour, type locality, hardness, measured and calculated densities. Major references are given, including re-descriptions; papers descriptive of crystal structure are cited where the senior paper needs amplification. Those familiar with Fleischer's Glossary of mineral species (various editions) will find the present work equally useful and complementary; it is well presented and lies open fairly well. The text is broken in one or two places by crystal diagrams and an appendix gives a synonymy of non-species names. Over 3800 entries are given in the book as a whole. M.O'D.

PECKETT, A., 1992. *The colours of opaque minerals.* Wiley, Chichester. pp. xxxviii, 471, illus. in black-and-white and in colour. Price £95.00.

Though the main purpose of this book is to

aid the microscopist in the identification of ore minerals on the basis of their colour, there is a great deal of interest to anyone dealing with natural specimens with only colour upon which to base an identification. The early chapters give a rigorous treatment on the nature of light and of colour with notes on the operation of the eye. Several of the various colour evaluation systems are fully described and the inevitable mathematical treatment is at least explained in an appendix which pays particular attention to complex numbers and matrix algebra.

The book is divided almost into two halves; the first part deals with the theoretical aspect of opaque mineral colour description, the second with the minerals themselves. In this section each mineral is described as seen in polished mounts with the reflected light microscope in plane polarized light and between crossed polars. The colours seen depend upon the crystal structure and the electronic structure of the minerals. Each mineral description includes name and composition, crystal structure and optical properties, quantitative colour description, IMA approved name, X-ray diffraction data and atomic co-ordinates, with much other useful material and latest abstract in mineralogical abstracts where available. M.O'D.

RAILTON, G.T., WATTERS, W.A., 1990. *Minerals of New Zealand.* New Zealand Geological Survey, Lower Hutt. pp. 89, Illus. in black-and-white and in colour. Price on application. (New Zealand Geological Survey Bulletin 104).

New Zealand is not especially noted for its gem minerals but green nephrite is highly prized on the islands. The entry for nephrite correctly states that nephrite is now discouraged as a mineral name, most nephrite being a variety of actinolite or tremolite (IMA advice) but localities and references are given for this and for other minerals in alphabetical order. Each entry gives name, chemical composition, localities and references, with notes on synonyms. There is a really excellent bibliography and some attractive mineral photographs showing both hand specimens and thin sections in polarized light.

M.O'D.

SCHUMANN, W., 1992. *Edle Steine.* BLV Verlagsgesellschaft, München. pp. 159, Illus. in colour. Price on application.

Many years ago this author produced a book Gemstones of the world in which several serious errors escaped the editor (and the translator) thus rendering the text unreliable for any professional purpose. The pictures were good, however, and they are good this time too, accompanying a general survey of gem and ornamental materials with a good deal of historical data. I can recommend the book for its excellent standard of production. M.O'D.

WARD, F., 1992. *Rubies and sapphires.* Gem Book Publishers, Bethesda MD. pp. 64, Illus. in colour. Price to be announced.

First in a promised series that is to include diamond, jade, pearl and emerald, this very attractive book should be a part of every gemmological library. The simple and lucid text deals with the main occurrences of corundum, methods of mining and cutting, synthesis and colour alteration, enlivened by high-quality colour pictures, some of which have previously been published in the author's National Geographic article on corundum in October 1991. Final text covers buying corundum, looking after it and a brief note on gem and jewellery journals. This book should be a pleasing gift to turn almost anyone into a gemmologist. M.O'D.

Gold, Mineral, Macht und Illusion: 500 Jahre Goldrausch. Extra Lapis no 2. 1992. Christian Weise Verlag, München. pp. 96. Illus. in black-and-white and in colour. Price DM 29.80 exclusive of postage.

Gemmologists will find an interesting mixture of topics covered by this colourful book. The contents range from the geology and mineralogy of gold to gold assaying, gold rushes and amateur prospecting. It is worth noting that many journals have supplements like this and the subscription does not always cover them (it hardly ever does, in fact). M.O'D.

Association Française de Gemmologie, 1992. *Gemmes.* Paris. Unpaged. Price on application.

A useful and pleasantly printed alphabetical list of the major gem materials, one to a double page, giving (in rough order) colour and occurrence, a typical crystal where appropriate, chemical composition, physical and optical constants, general remarks, likely simulants and a space for the reader's own notes. A short bibliography ends the book which many will find handy. It is perhaps too tightly bound and may not stand up to heavy wear; space could have been found for 'best reference' (in whatever language!) and there are some trifling inconsistencies but nonetheless a pleasing and acceptable topical guide. M.O'D.

Proceedings of The Gemmological Association and Gem Testing Laboratory of Great Britain and Notices

NEWS OF FELLOWS

After some 19 years with the Gem Testing Laboratory, **Ken Scarratt** has left GAGTL to take up a position as a Director of GIA Gem Trade Laboratory Inc. in New York. Ken joined the London laboratory in 1974 shortly after the retirement of B.W. Anderson, C.J. Payne and R. Webster. He worked under the direction of Alec Farn until 1981, and was then appointed Director on Farn's retirement.

In his years with the laboratory Ken has supervised the move to the present premises in Greville Street and, more importantly, has masterminded the introduction of new techniques and equipment. His initial work with low temperature spectroscopy to detect artificially coloured diamonds gained the London laboratory great international respect and this was complemented by the subsequent introduction of the UV/visible spectrophotometer, which was provided by the Anderson appeal to Fellows and members. The infrared spectrometer (FTIR). the latest of the sophisticated tools acquired by the laboratory through Ken's influence, has proved of immense assistance in diamond identification, distinguishing between natural and synthetic gems and detection of plastic treatments. His world-wide reputation resulted in constant requests for lectures - in some twenty different countries. He has written papers for *The Journal of Gemmology* and other publications.

His enterprise also resulted in service contracts between the laboratory and organizations in Qatar and India and in the establishment of an excellent gem testing laboratory in Bahrain, where new designs of X-ray equipment for pearl testing were developed.

Following the decision in 1989 to amalgamate the London Gem Testing Laboratory with the Gemmological Association of Great Britain, it was Ken Scarratt who instituted the modernizing and computerizing of the administration. The successful progress of the Diamond Nomenclature Harmonization talks are largely due to Ken's chairmanship. His enthusiasm and expertise will undoubtedly greatly benefit his future work with GIA and the Asian Institute of Gemological Sciences in Bangkok where he has been appointed to the Board of Governors.

During the period 21 September to 6 October 1992 **Alan Hodgkinson, FGA**, gave a series of lectures, workshops and update courses in Kowloon, which were co-sponsored by the Gemmological Association of Hong Kong and the GIA Alumni Association (Hong Kong Chapter). He also presented a paper entitled 'Scottish view of gemmology' at the Hong Kong Gemmological Symposium 1992 on 22 September at the Hong Kong Convention and Exhibition Centre.

At the Canadian Gemmological Association's Gem Conference '92 held at the Park Plaza Hotel, Avenue Road at Bloor Street, Toronto, on 24 and 25 October 1992, Alan Hodgkinson gave two lectures entitled 'Gemmology! What good will that do you?' and 'A small taste of Scottish gemmology', as well as running a workshop on gem identification techniques. Following the lectures, he was made an Honorary Member of the Canadian Gemmological Association.

OBITUARIES

Mr John Edwards (D.1952 with Dist.), died suddenly at the beginning of December 1992. He was for many years a tutor for our correspondence course students worldwide. He has helped very many students obtain their Diploma in Gemmology through both the home study and Central Manchester College courses. Following his retirement from work as a jewellery retail Senior Manager, during which he ran company training, John was employed at the College to teach gemmology, gem diamond and retail jewellery courses and was in charge of the gemmology section until his retirement from the College two years ago.

We greatly regret the loss to this organization of

John Edwards as an able and willing correspondence course tutor.

As John is well remembered as a practical gemmologist, the College (now South Manchester College) is arranging in his memory a specially inscribed gem testing instrument for use in gemmology practical courses. Donations for this commemoration should be addressed c/o Mrs Sharon Longden and sent to her direct at South Manchester College, Arden Centre, Sale Road, Northenden, Manchester M23 ODD.

Mr Paul Ruppenthal of A. Ruppenthal GmbH & Co KG, passed away peacefully on 11 November 1992. He will be dearly missed by all.

GIFTS TO THE GAGTL

The GAGTL is most grateful for the gifts of gemstones and gem materials for research and teaching purposes from the following:

David J. Callaghan, FGA, for the following items for the Gem Tutorial Centre workshops: colourless topaz (44 x 39mm), a set of four 'Famous diamond' models, and a set of Gilson synthetic and simulant materials.

Christopher Cavey, FGA, for a modern carving in precious serpentine for the Gem Tutorial Centre.

Mr A. Ebelthite of A. & J. Ebelthite for a green paste.

M. Jhaveri of Precitone for a silver nitrate stained natural American freshwater pearl.

N.K. Lambrinides, FGA, President of the Gemmological Association of Greece, for dyed and varnished coral, black coral and horn specimens.

Marcus McCallum, FGA, for plastic imitation shell cameos.

Beverley Mitchell, FGA, of A. & G. Landesberg Ltd. for synthetic emeralds.

MEMBERS' MEETINGS

London

On 24 November 1992 at the City Conference Centre, Mark Lane, London EC3R 7JN, Dr Roger Harding and Howard Vaughan gave lectures on the gemstones of Africa.

Midlands Branch

On 30 October 1992 at Dr Johnson House, Bull Street, Birmingham, a Bring and Buy sale was held.

On 1 November 1992 at the Cobden Hotel, Birmingham, the Annual Practical Gemmology Seminar was held.

On 27 November 1992 at Dr Johnson House, Mark Jackson gave a talk on his experiences of working in jewellery factories abroad as a production consultant and discussed the social and working attitudes predominating in the countries concerned.

On 5 December 1992 the Fortieth Anniversary Dinner was held.

North West Branch

On 21 October 1992 at Church House, Hanover Street, Liverpool 1, Dr Jamie Nelson gave a lecture entitled 'The four optical attributes of a diamond'. One demonstration unit was used to help visualize the ray paths traced out in each of four simulated diamond profiles. Another device showed how each of the four attributes could be separately distinguished by means of three rotating parallel light beams falling on a brilliant-faceted stone.

On 18 November 1992 at Church House the Annual General Meeting was held at which Irene Knight, FGA, DGA, and Joe Azzopardi, FGA, were elected Chairman and Secretary/Treasurer respectively.

ANNUAL GENERAL MEETING

The Annual General Meeting of the Gemmological Association and Gem Testing Laboratory of Great Britain was held on 30 September 1992 at 27 Greville Street, London EC1N 8SU.

David Callaghan chaired the meeting and began by welcoming those present. He announced that this was the first meeting to be held in the newly acquired second floor accommodation at Greville Street, which was to be used for teaching purposes and lectures, as well as housing the library.

Nigel Israel was thanked for his work in packing the books that were transported from the library at Saint Dunstan's House. David Callaghan then thanked all those who worked in a voluntary capacity for the GAGTL and also the staff for their work, particularly during the difficult period when alterations were being made to the building.

Thanks were expressed to the Council of Management who spent considerable hours working on behalf of the Company, and to Noel Deeks who had been appointed overall administrator and has proved a tremendous asset.

The Annual Report and Accounts were approved and signed.

Alec Farn and David Kent were elected and R. Keith Mitchell re-elected as Vice Presidents.

D. Callaghan, R.R. Harding and E.A. Jobbins were re-elected to the Council of Management.

All members of the Members' Council were re-elected.

Messrs Hazlems Fenton were re-appointed Auditors.

This concluded the business of the meeting.

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Gem Diamond Diploma

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Telphone: 071 404 3334 Fax 071 404 8843

PRESENTATION OF AWARDS

The Presentation of Awards gained in the 1992 examinations was held on 9 November at Goldsmiths' Hall, Foster Lane, London EC2. Mr David J. Callaghan presided and welcomed those present. 1142 candidates had taken the Association's examinations in 1992 and among those present were award winners from Canada, Finland, Greece, Hong Kong, Kenya, Malaysia, The Netherlands, Portugal, the People's Republic of China, Singapore, Spain and Thailand, as well as from the UK. Mr Callaghan paid tribute to the education team and the Examiners for the tremendous amount of work they do in organizing the annual worldwide examinations.

Dr Kurt Nassau - awarded Honorary FGA.

Following the presentation of the awards by Dr Kurt Nassau, the two newly elected Vice Presidents, Alec Farn and David Kent, were presented with framed certificates. 'They are both remarkable men', said David Callaghan, 'and have served the Association for many years, one as a Director of the Gem Testing Laboratory and the other as a stalwart of the jewellery industry.

'David worked for Bravingtons and has for many years given considerable help to the GA. He is widely travelled and he has our grateful thanks for all he has done. Alec has written many articles as well as his book on pearls. He was a member of the team that worked together for many years at the gem testing laboratory, becoming Director in 1972, and is the last of what B.W. Anderson referred to as the 'phalanx of four' [B.W. Anderson, A.E. Farn, C.W. Payne and R. Webster].'

Anderson Medal winner Sarah Hue-Williams, London.

The Chairman then came to what he explained as a rare event. 'From time to time an Honorary Fellowship is awarded to someone who has made a great contribution to the world of gemmology - Dr Kurt Nassau is such a man'. A chemist who specialized in colour and the reasons for colour, Dr Nassau was awarded an Honorary Fellowship

Diploma Trade Prize winner Anne Bailey, Rugby.

in recognition of his extensive contributions to understanding in the field of gemmology.

David Callaghan then introduced Dr Kurt Nassau who gave the address. His interest in gemmology began when, as a research scientist at the Bell Telephone Laboratories in New Jersey, he was asked to work on laser materials and began to grow crystals. Over the years he investigated many aspects of gemmology, including synthetic and enhanced gemstones, and the causes of colour in gemstones, and has published a number of books on the subject. He told those present about many of the specimens he had seen over the years, and methods he had employed to test them.

'Do not believe everything you have read', Dr Nassau advised. 'Much of it is wrong, incomplete or misleading. Do question things - if something does not make sense to you, think about it, read up on it in many sources, and try some experiments. Do not limit yourself to the field in which you are working. Combine gemmology with physics, chemistry and mineralogy. Interest and enthusiasm are the best things to have and will further your understanding and professionalism'.

A vote of thanks was given by Alan Jobbins.

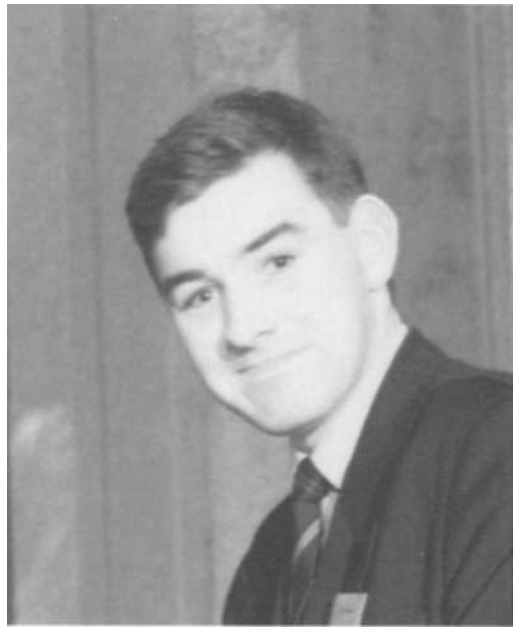

Preliminary Trade Prize winner Alexander Hammond, Sandy.

David Callaghan with the newly elected Vice Presidents, David Kent (left) and Alec Farn.

MEETINGS OF THE COUNCIL OF MANAGEMENT

At the meeting of the Council of Management held on 21 October 1992 at 27 Greville Street, London EC1N 8SU, the business transacted included the election of the following:

Diamond Membership

Baker, Paul, Ringmer. 1992

Fellowship and Diamond Membership

Amor Cubeiro, Carmen, Barcelona, Spain. 1974/5
Blasi Casal, Juan, Barcelona, Spain. 1974/5.
Sancho de Gelaberto, Ma Pilar, Barcelona, Spain.

Fellowship

Anantwatanapong, Angkana, Bangkok, Thailand. 1992
Ball, Pamela, Hong Kong. 1992
Bierlein, Chari, Paris, Tex., USA. 1992
Chan, Lily Siu Chan, Hong Kong. 1992
Cheang, Chong Nun, Macua, Via Hong Kong. 1992
Cheng, Chi Chung, Hong Kong. 1992
Cheung, Chi Ho, Hong Kong. 1992
Chow, Shui Wah, Hong Kong. 1992
Chow Tze Joak, Kenickie, Hong Kong. 1992
De Gruyter, Barbara, Tielt-Winge, Belgium. 1992
De La Torre Lopez, Luisa, Tarragona, Spain. 1992
De Wit, Lambertus, Den Haag, The Netherlands. 1992
Dharmaratne, D. Rosemary O., Rajagiriya, Sri Lanka. 1992
Downing, Lucy Nicola, London. 1992
Emslie, Gail, Harrogate. 1992
Falco, Joaquim, Llanca, Spain. 1992
Groeneveld, Pauline, Giessenburg, The Netherlands. 1992
Harjula, Katri, Helsinki, Finland. 1992
Hawrelko, Donna P., West Vancouver, Canada. 1992
Ho, Po Mi, Avis, Hong Kong. 1992
Hui, Chak Lun, Hong Kong. 1992
Itoh, Yasuhiro, Osaka, Japan. 1984
Jewitt, Laura Kathleen, West Vancouver, Canada. 1992
Karkkainen, Niilo Kalevi, Espoo, Finland. 1992
Khudhairy-Gaylani, Bann, Toronto, Canada. 1992
Klumpes, Eric, Ag Veere, The Netherlands. 1992
Lau, Sau-Kuen, Heddy, Hong Kong. 1992
Lau, Ying Chi, Hong Kong. 1992
Lau, Yuen Mee, Hong Kong. 1992
Leung, Chee Wing, Hong Kong. 1992
Li, Chi Man, Hong Kong. 1992
Lum, Yin Kew, Samantha, Hong Kong. 1992
McCrary Weinberg, Dianna, Madrid, Spain. 1992
Nadal Cerezo, Antonio, Barcelona, Spain. 1970
Ng, Kwok Yin, Hong Kong. 1992
Ohira, Shino, Calif., USA. 1992
Quek, Cho Siang, Jessie, Hong Kong. 1992
See, Yat Sun, Hong Kong. 1992
Siu, Wai Chung, Norman, Hong Kong. 1992
Slui, Cornelis, Krimpen A/D Yssel, The Netherlands. 1992
Strachan, Elizabeth, Finchley. 1992
Takarada, Michiko, Hong Kong. 1992
Tse, Kwok Wing, Hong Kong. 1992
Tse, On Na, Anna, Hong Kong. 1992
Tsui, Kam Luen, Vincent, Hong Kong. 1992
Tun, Maung Win Myint, Bangkok, Thailand. 1992
Van Hillo, Geertruida J., Almere-Buiten, The Netherlands. 1992
Van Lamoen, Hans Thom, Rosmalen, The Netherlands. 1992
Williams, Georgette, Bangkok, Thailand. 1992
Wong, Queenie, Hong Kong. 1992
Yu, Sum Pui, Frankie, Hong Kong. 1992

Transfer to Fellowship

Friedland, Melissa, Omaha, Nebr., USA. 1992

Ordinary Membership

Adamson, Mary Joan Ariane Sheila, London.
Bark, David, London.
Bevers-Reinders, L.M., Rotterdam, The Netherlands.
Eggington, Roy, Bournemouth.
Joseph, Denise Taouk, Kensington, London.
Ma, Siu Lam, Hong Kong.
McCarthy, Emily, Hornsey, London.
Mohamed Hamza, Mohamed Hassan, Kandy, Sri Lanka.
Paul, Neelam, Northwood.
Pegg, Delia, Petts Wood.
Ruts, Willem G., Den Helder, The Netherlands.
Sana, Atisa Julie, London.
Tonn, Heleen, Rotterdam, The Netherlands.
Whistance, Mary Margaret Nancy Tolladay, Exmouth, Devon.
Yip, Man Loong, Hong Kong.

Gold Laboratory Membership

Bae's Gem Testing Laboratory, 30-7 Namdaemunro-3 ka, Chung-ku, Seoul, Korea.

At a meeting of the Council of Management held on 16 November 1992 at GAGTL, 27 Greville Street, London EC1N 8SU, the business

transacted included the election of the following:

Fellowship
Asanis, Nikolaos, Athens, Greece. 1992
Barker, Maxwell, Johannesburg, South Africa. 1979
Barrie, Lindsay M.O., London. 1992
Cheung, Mei Ping Liann, Hong Kong. 1992
Cooper, Carolyn, Hong Kong. 1992
Dharmaratne, Pannipitiye Gamathi Ralalage, Rajagiriya, Sri Lanka. 1992
Karlsson, Andreas, Malmo, Sweden. 1992
Kim, Gum Jo, Pusan, Korea. 1992
Kuwabara, Rie, Hong Kong. 1992
Marsh, Leona Claire, Harare, Zimbabwe, South Africa. 1992
Patel, Rekha Mahesh, Nairobi, Kenya. 1992
Yung, Tak Yi, Hong Kong. 1992

Transfer to Fellowship
Bevoort-Alwicher, Terrence, Numegen, The Netherlands. 1992
De Jongh, Laurentia Melissa, The Hague, The Netherlands. 1992
Lang, Bernard, Basel, Switzerland. 1992
Liu, Zhao, Harbin, China. 1992
Zhang, Yabin, Harbin, China. 1992

Ordinary
Chedta-Thaiyawong, Kanitha, Bangkok, Thailand
Cho, Yong-Sang, Seoul, Korea
Daniels, Razia, Chester
Furze, Cindy Jane, Cheshunt
Lee, Tonny Song, Taiwan, China
Levy-Thomas, Katherine, Woking
Lu, Jei-Chih, Chelsea, London
Maclean, Hamish Donald, Seamill, Ayrshire
Micheli, Annika, London
Pelham Burn, Kate Ruth, London
Perera, Christel S.A., Colombo, Sri Lanka
Robinson, Zoe Lavinia, London
Takahashi, Masumi, Kanagawa, Japan
Williams, John Harold, Manchester
Zhang, Beili, Beijing, China

At a meeting of the Council of Management held on 16 December 1992 at GAGTL, 27 Greville Street, London EC1N 8SU, the business transacted included:

(a) election of T.J. Davidson, FGA, to the Council of Management;
(b) election to membership of the following:

Fellowship
Cheng, Sau Chun Hemans, Hong Kong. 1992
Chow, Chun Hung William, Hong Kong. 1992
Haberli, Sabine, Bottmingen, Switzerland. 1992
Lee, Siu Yin Ann, Hong Kong. 1992
Safar, Ali, Manama, Bahrain. 1992
Yuen, Chai Hung Teresa, Hong Kong. 1992

Ordinary Membership
Archutowski, Victor, London
Debrah, Kwame, London
Erilena, Cian Seren, Vicenza, Italy
Gregory, Fiona, Chalfont St. Peter
Hamissi, Ismail Djuma Shabah, London
Jo, Yoon-Hee, Wimbledon, London
Kabanda, Lolo-Manunga, Romford
Kang, Joo-Youn, Seoul, Korea
Rabstein, Wolf Isidore, London
Rodriguez, Lourdes, West Hampstead, London
Rose, Neil Robert, Stockport
Takamura, Hiyori, London
Violati Tescari, Ottaviano, Vicenza, Italy
Watanabe, Tatsuo, Kanagawahen, Japan

GEM DIAMOND EXAMINATIONS 1992 OVERSEAS

In the 1992 Gem Diamond Examination held overseas, the names of the successful candidates are as follows:

Qualified
Koundourou, Radka Lalovska, Athens, Greece.
Sergoulopoulos, Alexandros, Athens, Greece.
Stather, Memory, Hong Kong.

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CORRIGENDA

On p.197 above, under 'Congratulations to the Deutsche Gemmologische Gesellschaft E.V. on the occasion of their 60th Anniversary', second column, first line, for 'DDG' read 'DGG'

On p.202 above, first column, line 9, for 'diamond and corundum are' read 'corundum is'; on line 12 after 'Kane, 1984' add 'Scarratt *et al* 1984'

On p.204 above, first column, Line 21, for 'Organic fillers,' read 'Most organic fillers'

On p.205 above, second column, under References add: 'Kane, R., 1984. Natural rubies with glass-filled cavities. *Gems & Gemology*, Winter, 187-99'

On p.250 above, first column, line 12, for 'Ordinary Membership' read 'Fellowship'

On p.251 above, first column, the following were elected to Ordinary Membership on 24 June 1992 and not Fellowship as stated:
Jehu, A.G., Virginia Water.
Jones, Lloyd E., Gold Coast, Australia.
Kiernan, Janeien E., Cheddar Gorge.
Porter, Mark A., Hartley Wintney.
Sandy, Paul R., Bournemouth.
Smith, Richard S.N., Exmouth.
Van't Hooft, Jacobus A., Uught, The Netherlands.

We apologize for the above errors.

FORTHCOMING MEETINGS

London

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The programme until May is as follows:

8 February	'Emeralds in the Laboratory'.	Ana I. Castro & Stephen Kennedy
24 February	'New Gem Testing Instruments'.	Peter Read
8 March	'Colour in Diamonds'.	Dr Alan Collins
31 March	'From the Gem to the Jewel'.	David Callaghan
14 April	'Fluorescence Effects in Gemstones'.	Dr Jamie Nelson
27 April	'Rubies in the Laboratory'.	Ana I. Castro & Stephen Kennedy
11 May	'Engraved Gems'.	Christopher Cavey

Midlands Branch

26 February	'The Art of Engraver'.	Robert Campbell-Legg
26 March	'Crystal Healing'.	Peggy Stock
30 April	Annual General Meeting followed by a gem collection talk	

Meetings will be held at Dr Johnson House, Bull Street, Birmingham. Further details from Gwyn Green on 021-445 5359.

North West Branch

17 February	Video viewing 'Gemstones of America'.	
17 March	'Cameos and intaglios in antique jewellery'.	Richard Digby
19 May	'Lalique jewels from the 1992 Paris Exhibition'.	Dr J. Franks
16 June	Members and friends evening. Bring and Buy: crystals, books and instruments, and exchange of views.	

Meetings will be held at Church House, Hanover Street, Liverpool 1. Further details from Joe Azzopardi on 0270-628251.

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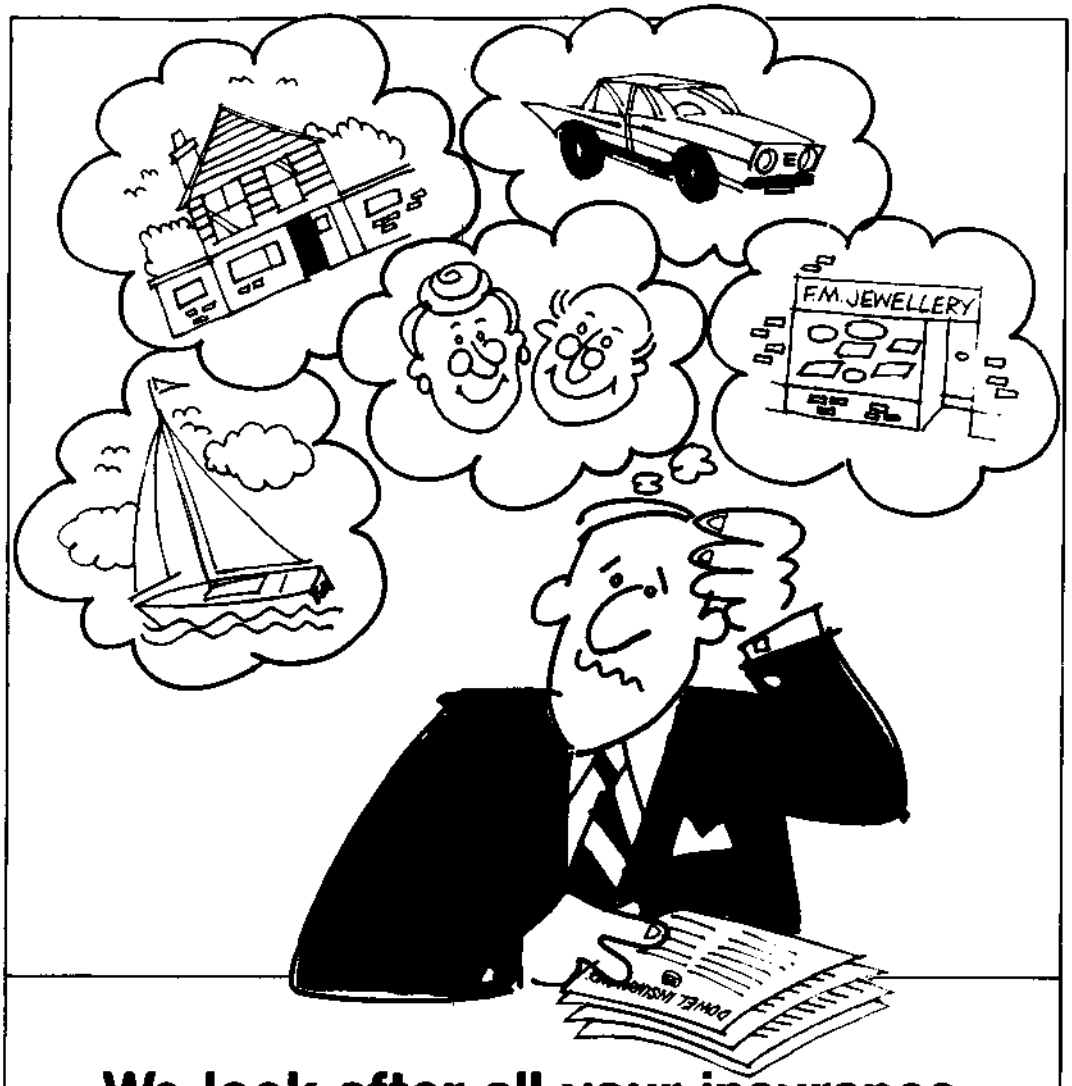

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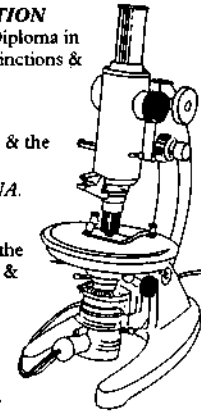

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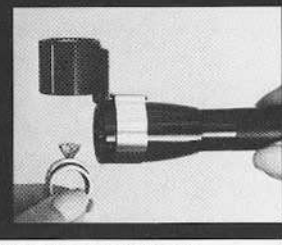

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The Journal of Gemmology

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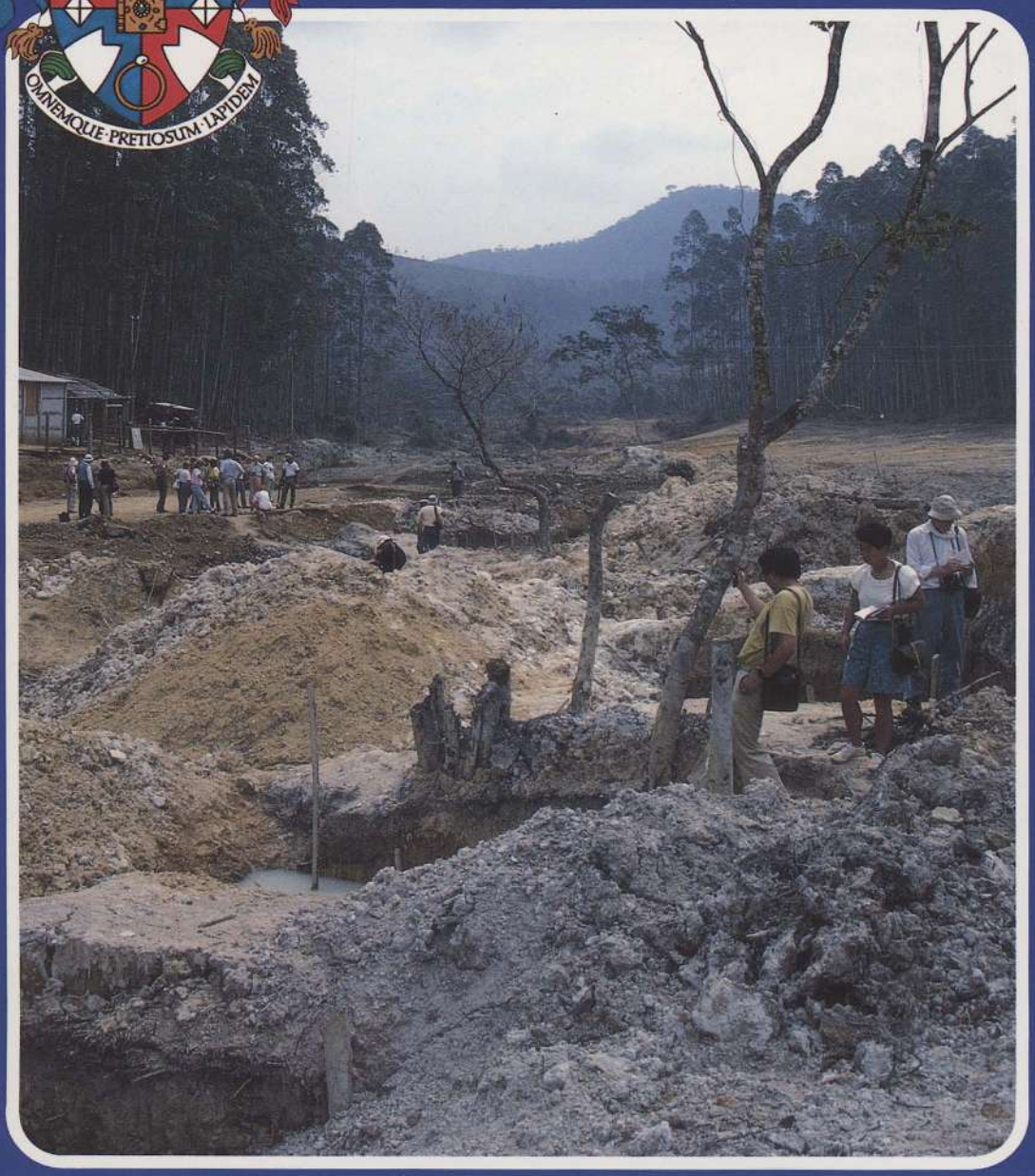

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Cover Picture

The Hematita mine in Minas Gerais in 1987 – probably the richest alexandrite concentration ever known. Note the whitish kaolinitic gravel (which carries the gem material) in the foreground, the soil profile in the centre and the valley confluence in the background. (See 'The location, geology, mineralogy and gem deposits of alexandrite, cat's-eye and chrysoberyl in Brazil' pp. 333-54)

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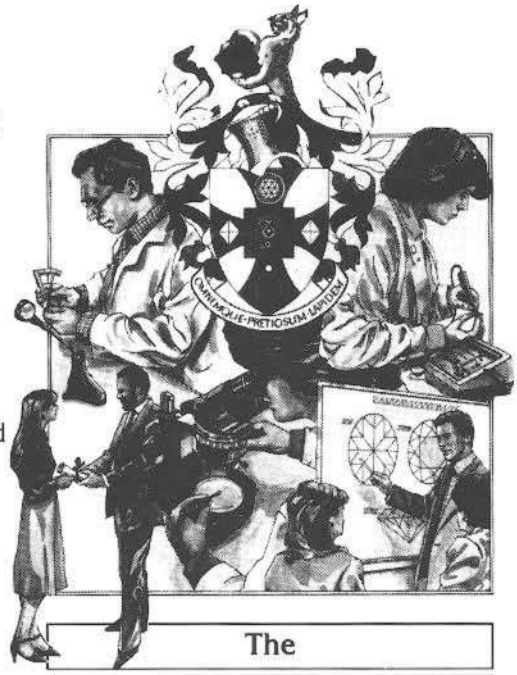

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A method for obtaining optic figures from inclusions

John I. Koivula

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Abstract

A method for obtaining optic figures from doubly refractive inclusions in transparent gems using a standard gemmological microscope is introduced. Some useful equipment and the limitations of this technique are discussed.

Introduction

In gemmology, non-destructive testing is the norm. The vast majority of the gems encountered cannot be examined in a manner that is destructive or even potentially destructive to their appearance. The microscopic study of inclusions plays a major role in non-destructive gem identification.

Fig. 1. The stoneholder-conoscope made by Harold Oates used to resolve optic figures from inclusions. Note the six different-sized interchangeable spherical lenses. *Photograph by Robert Weldon*

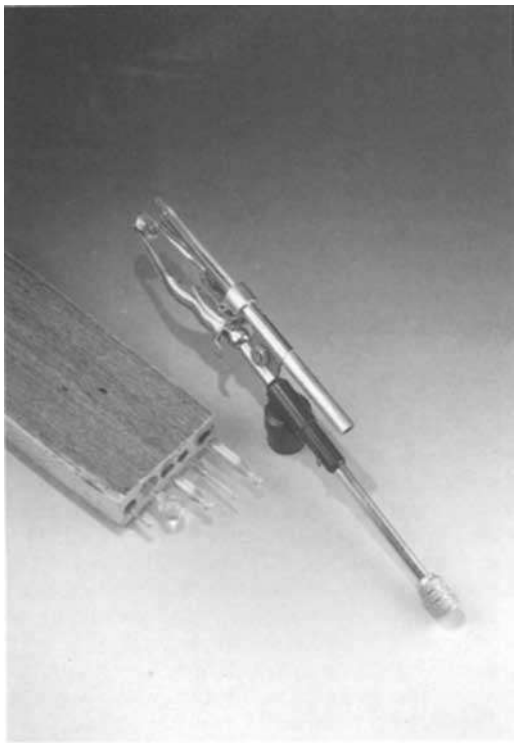

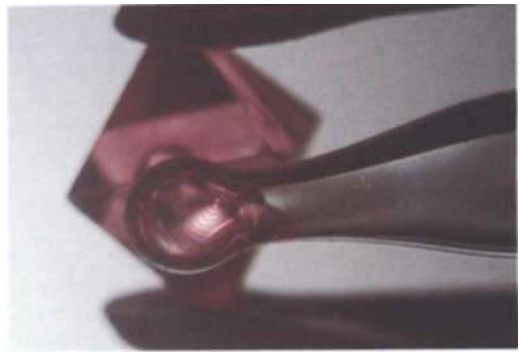

Fig. 2. One axis of a biaxial optic figure obtained by this method from an inclusion in a pink spinel octahedron from Sri Lanka. *Photomicrograph by John I. Koivula*

Inclusions exposed at the surface during the initial cutting process are ideally suited for detailed examination. However, it is rarely possible to actually grind down a gem to expose an inclusion at the surface for X-ray diffraction or chemical analysis. Yet inclusion recognition and identification is one of the more important scientific disciplines in modern gemmology. In this arena most gemmologists must work 'with their hands tied'. Although it is very important to be able to determine if a gem is natural or synthetic, and treated or untreated, this must be accomplished in ways which are not harmful to the gem itself.

At the retail and wholesale level where a great many gem identifications are done, gemmologists and appraisers do not have immediate access to testing instruments such as X-ray diffractometers, electron microprobes and Raman laser probes. Inclusion identification is generally accomplished by means of the gemmological microscope. Certain patterns and types of inclusions that have been seen before are recognized again when they are encountered. In many cases, although the overall inclusion scene presents testimony that a

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gem is natural, individual mineral inclusions within the scene remain unidentified. If such inclusions are well formed, then their external morphology gives evidence of their identity. Colour and degree of transparency are also useful in this regard. In short, any information that can be gleaned from an inclusion by means of the microscope is useful in gem identification.

With this in mind, it is apparent that polarized light would be useful in determining if an inclusion is isotropic or anisotropic. In certain cases perhaps even an inclusion's pleochroism could be ascertained.

During a polarized light examination of the inclusions in a faceted Burmese ruby, it was noticed that in a certain direction a semi-transparent inclusion that appeared to be calcite displayed ring-like patterns of bright interference colours. When a conoscope (consisting of a handle with a small glass sphere on the end) was placed over the inclusion, in contact with the surface of the ruby, a partial uniaxial optic figure was observed.

This may have gone unnoticed because ruby is also uniaxial. But it was unusual because the optic axis direction of the host ruby itself had already been determined and was approximately 40 degrees away from this viewing direction. So it was concluded that the uniaxial figure must have been generated by the inclusion and not by the ruby. Immersion in methylene iodide was then used to negate facet interference and a complete uniaxial figure was readily seen. However, an attempt at photomicrography of the effect, with the available equipment, proved to be so awkward as to be impossible.

Method

This observation and the problem with photomicrography were discussed with gemmologist Harold A. Oates of Glen Ellyn, Illinois, USA. Being a machinist as well as a gemmologist, Mr Oates manufactured a special stoneholder-condensing lens combination that secured both the gem and lens, making photomicrography of the effect possible.

The device, pictured in Figure 1, consists of a stoneholder with a flexible arm piggy-backed above it. The flexible arm can hold any one of six strain-free glass sphere-lenses. To conform to a wide range of gem and inclusion sizes, the spherical lenses themselves are of variable size (from 1 to 6 millimetres in diameter). When total immersion is not being used, a small droplet of suitable immersion oil is placed between the lens and the gem to facilitate good optical contact.

For illustration of this technique, a natural pink Sri Lankan spinel crystal containing a transparent, apparently colourless, doubly refractive crystal that measured approximately 1.5 x 1.0 millimetres was used, rather than the calcite-in-ruby described above. This was done because spinel is isotropic and there is no chance of interference from the spinel. Therefore, an optic figure resolved would have to come from the inclusion.

First the inclusion in the spinel was examined in polarized light (total extinction) to determine the most appropriate angle for conoscopic examination. Then the lens was placed in contact with the spinel immediately above the inclusion (good contact was made using a drop of methylene iodide). After a few moments of manipulation of the crystal one axis of a biaxial figure with its interference rings was noted (Figure 2). This observation immediately eliminated all uniaxial and isotropic minerals as possibilities in the identification of this inclusion and yielded information about this crystal that we would not have had otherwise.

In addition to the inclusion in this spinel, and in the ruby previously discussed, a number of other known inclusions in transparent gems have also been examined by this method. These include muscovite in topaz, apatite in spinel and corundum, and biotite in quartz.

Conclusion

Although the inclusion in spinel focused on in this paper had no recognizable external shape, its transparency, apparent lack of colour and its biaxial nature suggested that perhaps it might be albite feldspar. Albite is biaxial and has been previously identified by chemical analysis and X-ray means as a comparatively common inclusion in Sri Lankan spinels (Gübelin and Koivula, 1986).

This technique of obtaining optic figures from inclusions will not work in many cases. There are certain limitations that should be noted. First of all the host gem must be transparent, as should the inclusion (although some limited success has been had with semi-transparent gems and inclusions). The external morphology of the crystal or cut gem must not be so complex as to interfere with the spherical condensing lenses' ability to resolve an optic figure (total immersion in a properly selected liquid will help in such cases). The inclusion cannot be too deep within the host. The nearer to the surface the better. All of the inclusions successfully examined by this method so far have been within 2 millimetres of the surface of their hosts. The inclusion's orientation in the host material must be such that its optic axis (or one of its optic axes in the case of biaxial materials) can be lined up by the spherical condensing lens. The inclusion must also have some size to it (1x1 mil-

limetre or larger is suggested). The smaller the inclusion the more difficult it is to work with. In doubly refractive host materials the optic axis of the inclusion must be sufficiently off-orientation from the optic axis of the host in order to avoid interference. Partial optic figures must be interpreted with caution. It should also be noted that this method can be very time consuming in many cases, although it is an excellent exercise for increasing microscopic skill.

One final thought concerns the possible accidental discovery of this effect by a student of gemmology. If perhaps a student were examining a gem and noticed an optic figure from an inclusion they might erroneously think that the optic figure they were observing was a property of the host material itself, and a mistake in identification could result. While this possibility is remote, it is nonetheless possible. This is in fact the way that the author discovered this effect, i.e. by accident.

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[*Manuscript recieved 28 October 1992*]

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Freshwater pearl cultivation in Vietnam

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Fig. 1. Street scene in Hanoi.

Abstract

During a visit to Hanoi, the capital city of Vietnam, the authors became aware of a freshwater pearl culturing operation on Ho Tay, a lake situated in the north-west of the capital. Whilst the industry is still young, it is self-sufficient, and further farms are planned to come into operation in the near future.

The Ho Tay farm utilizes the wild mussels found in the lake and mother-of-pearl bead nuclei cut from a species of *Unio* found in the northern rivers of Vietnam. Pearl colours are natural and are, pink, orange, brown, white, light grey, and black.

Introduction

During the authors' visits to south-east Asia in the latter three months of 1992, we heard from several sources that there was some production of 'pearls', both natural and cultured, within, and in the waters surrounding, Vietnam. A further opportunity to enter Vietnam, principally to update the situation in the Luc Yen and Quy Chau ruby deposits, arose for the authors in early January 1993. Prior to, and in between the visits to the Luc Yen and Quy Chau districts the authors stayed in an hotel on Hanoi's West Lake (Ho Tay). Whilst there, they made enquiries about pearl production in general, and were surprised to learn of a freshwater culturing farm less than a kilometre away.

It may be difficult to understand how or why it is possible for a pearl farm to exist in the centre of a city with a population of three million. However, as

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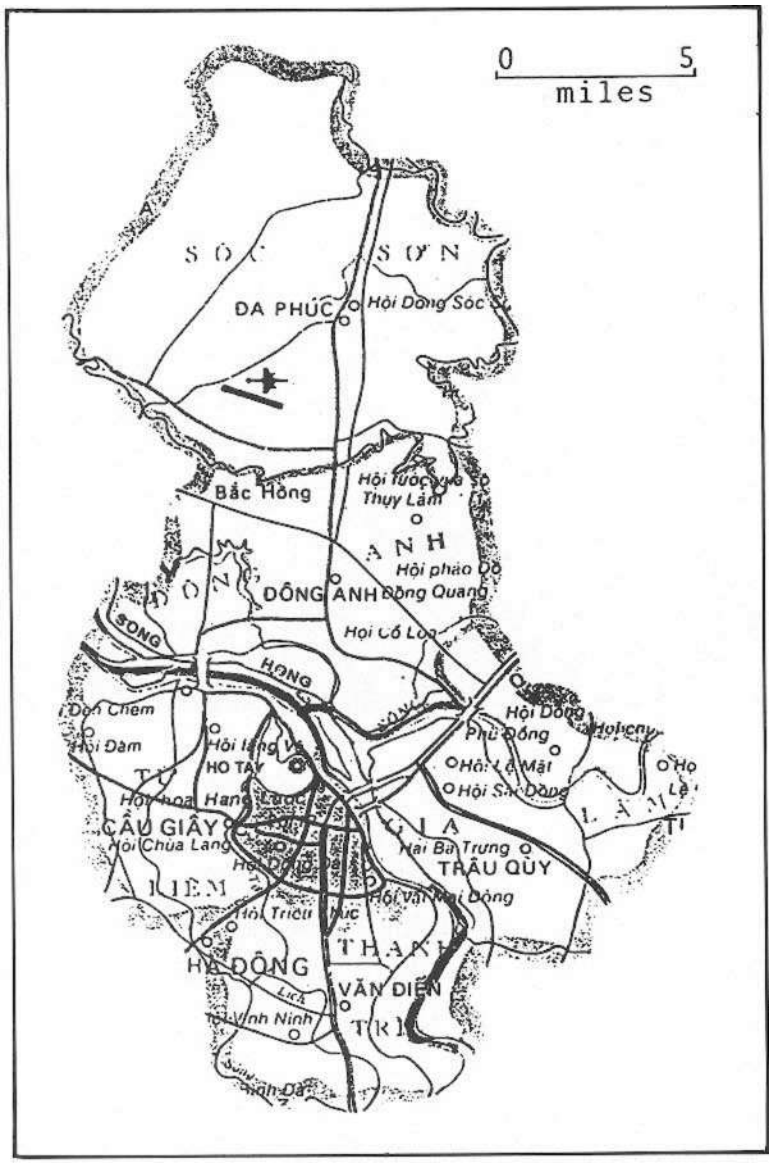

Fig. 2. Section of Hanoi city map showing the location of the Ho Tay pearl farm (shown by the 'flower' symbol) on the eastern banks of the West Lake.

is clearly evident from Figure 1, there is relatively little use of the motor car, and with the bicycle being the predominant mode of transport, not only the country, but also the capital city, is still largely unaffected by environmental pollution.

Other enquiries confirmed the possibility of orange conch (type) pearls (Scarratt, 1992) being found off shore, as well as saltwater culturing. Details concerning the saltwater culturing were difficult to obtain, and time constraints prevented the authors from visiting the locality. However, the information gained pointed to one culturing centre east of the port city of Haiphong, located either in the Ha Long bay or in the Fai Tsi Long archipelago off the north-eastern coast of Vietnam. It was further indicated that there was some involvement by a Japanese firm, although in what capacity was not made clear.

Freshwater pearl culturing in Hanoi

Enquiries about freshwater pearl farming revealed a young but blossoming industry. Apart from small operations in a number of (unidentified) Vietnamese lakes, two operations were mentioned in particular: these were in the estuary of the Red River (Song Hong) and a station in Hanoi city itself

Fig. 3. Snail harvesting in Ho Tay Lake.

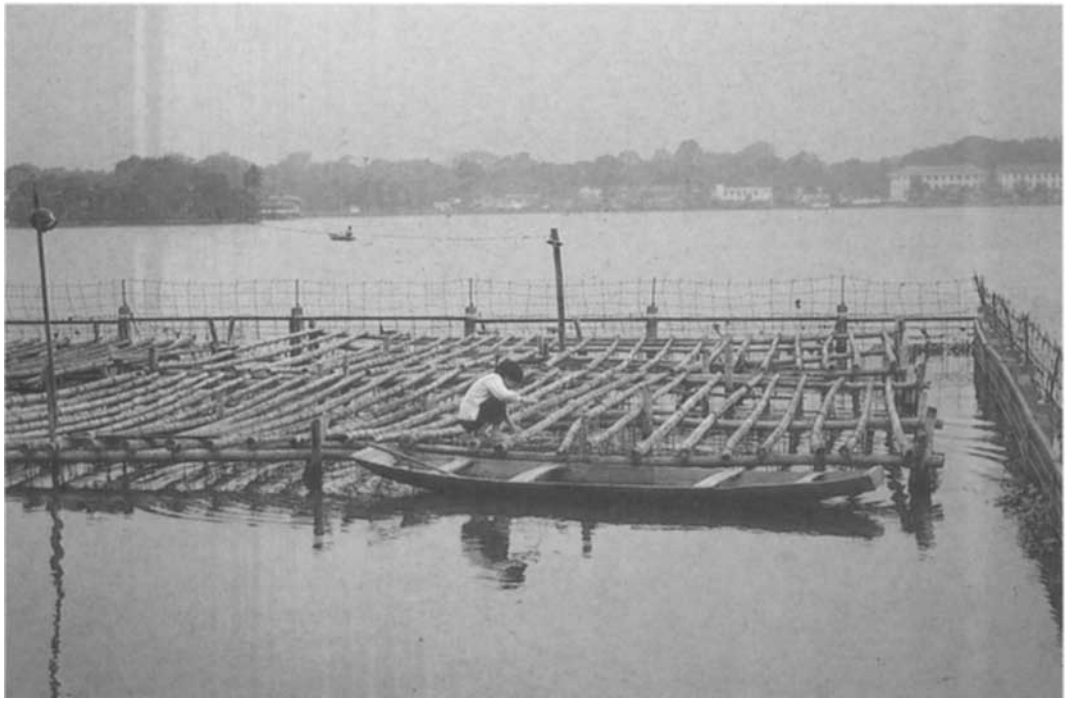

Fig. 4. View across Hanoi's West Lake with the fenced-in rafts of the Ho Tay pearl farm, as seen from the main building of the Ho Tay Fish Development and Investment Company.

on Ho Tay.

At very short notice the authors were granted a visit to the facilities of the Ho Tay Fish Development and Investment Company (the company responsible for the development of pearl culturing on Ho Tay) which are located on the banks of the lake (Figure 2). This lake is situated in the north-west of the capital and is isolated from the Red River by a high-water protection dam. The water quality of the lake is apparently good since pearls appear to be farmed successfully and fishing and snail harvesting can be observed daily (Figure 3).

Development and production of the Ho Tay enterprises

The Ho Tay Fish Development and Investment Company, formerly solely occupied with fishing and fish breeding, began feasibility studies on pearl farming in 1986, consulting Japanese experts on the matter. Mr Vu Dang Khoa, director of the company, revealed to the authors that by 1989 these studies were completed.

Actual production began in 1990 when 500 pearls were produced. In 1991, 1000 pearls were harvested, followed by 3000 in 1992. It is hoped to produce 8000 pearls in 1993. The cultured pearls have only been exported to Asian countries to date. The operation witnessed by the authors is run by a small crew. The mollusc processing team consists of two individuals. The plant has several office buildings as well as a fenced-in farm containing an anchored bamboo raft of about 15 by 10 metres floating approximately 15 metres off the lakeshore (Figure 4). In each of the round wire baskets, suspended to a water depth of less than two metres from the raft, are about ten bivalves.

The Ho Tay freshwater culturing technique

The standard technique of the Ho Tay enterprise utilizes fashioned mother-of-pearl beads from freshwater shells. The use of beads in freshwater culturing is not a new technique, indeed examples are known as far back as 1761, but in modern times (post World War II) it has not been the accepted practice, ie., in the mass market product cultured in China. However, recent years have seen an increase in the use of this technique – beading appears to be applied today in some North-American and certain larger Chinese freshwater cultured pearls using Japanese-made nuclei (Man Sang, 1992). The beads used for culturing in China are often dyed and their dark colour is visible through the mostly thin nacreous coating – compare Japanese saltwater cultured pearls of low quality (Hänni, 1993).

The Ho Tay bead material used for insertion is locally cut out of the small (dimensions approximately 80 x 45 x 15mm), but comparatively thick shell of a *Unio* species found in rivers of the northern provinces. The shape of the nuclei varies from nearly spherical to elliptical or button-shaped, their hue is white, cream or light orange, and the diameters range from roughly 3 to 5mm. The non-spherical shapes were stated to be desirable for the creation of natural-looking end products and the bead colours were said to be unaltered.

The living molluscs employed for pearl culturing are of the *Cristaria plicata* species (Figure 5), reported by Jobbins & Scarratt (1990), to be used also in Chinese farms. Some authors have placed this species in the *Anodonta* genus, but this is rejected by others who retain *Cristaria*. The supply of new molluscs is provided by collecting native animals from the Ho Tay. Spatting has not been used to date. The shells roughly measure 150 x 110 x 20mm at the time of harvest and most exhibit an elegantly greyish-purple mother-of-pearl interior and large, lobular orange-brown areas of variable size.

Epithelium strips are cut from the mantle tissue of sacrificed *Cristaria* animals, fashioned into squares of approximately 3 x 3mm and dipped in an orange antibiotic liquid to prevent infection of the molluscs to be operated on. Subsequently, six to eight short cuts are placed in the epithelium of the mantle tissue (3 to 4 on each side) of the living bivalves and a corresponding number of beads inserted. To initiate nacre growth around the beads, the epithelium squares are placed on top of the already inserted nuclei.

Success rates/Production time

The success rate at present is three nucleated, nacre-coated pearls out of six to eight beads per implanted mollusc. Whilst this may appear modest the rejection of an inserted bead normally results in the production of a non-nucleated cultured pearl from the tissue implant placed with the bead. The growth period of 18 to 24 months is long in comparison with the 9 months needed for non-nucleated pearls in Chinese waters but short compared to the reported Lake Biwa conditions (up to 36 months for the first harvest). No indications were made regarding re-use of the *Cristaria* clams for a second crop (*Hyriopsis schlegeli*, for example, continue to produce pearls when returned to the waters of Lake Biwa, not requiring implantation of new tissue material, Muller-port, 1981). Nacre thickness, also being a measure of success, is discussed below.

The Ho Tay cultured pearls and their properties

Three lots of cultured pearls were shown to the authors for examination. The assemblage of these fourteen pearls looked so varied and pleasing that it

was deemed worth a more detailed description. The specimens were supplemented by the addition of one yellow-banded white specimen to the top right-hand row (no.4 in Figure 6).

The nearly spherical shape of the largest pearl of the batch (no.1, upper left) is in contrast to the more familiar shapes associated with tissue-graft freshwater cultured pearls from other sources.

Typically the latter are 'semi-round' (roundish) to baroque. In fact, as can be seen from the radiograph of the fifteen undrilled pearls, only two are bead-nucleated (again no.1 on the top left in Figure 7 and no.4. All others are tissue-grafted or non-nucleated cultured pearls*. The fifteen pearls exhibit a mostly smooth surface, good lustre and a fair to good orient.

considered unacceptable by standards developed for the grading of cultured pearls by the Gem Testing Laboratory in London and the CISGEM Laboratory in Milan. The nacre coat of pearl no.4, however, has an acceptable minimum thickness of about 0.65mm.

Depending upon the structure differences of the tested pearls, there is a wide range of densities. The spherical *Unio* bead pictured in the lower right corner of Figures 6 and 7 gave a hydrostatically determined value of 2.80g/cm^3. The bead-nucleated pearls no.1 (2.56 ct) and no.4 (2.05 ct) showed densities of 2.78 and 2.65g/cm^3 respectively. These lower values can be explained by the thin nacre coat of the first and a void on one side of the bead inside the second pearl.

Fig. 5. *Cristaria plicata* shell with two encapsulated nuclei displaying the colour of the underlying shell (orangy pigment on the left and pinkish pigment on the right) together with the pearl batch examined.

The bead-nucleated pearls grow in 5 to 7mm sizes, with rare maximum diameters up to 12mm. The non-beaded pearls are generally smaller. The weight range of the pearl sample examined is from 2.56 ct (no.1) to 0.51 ct (no.6).

Pearl no.1 shows a nacre thickness of approximately 0.1 to 0.3mm, the lower figure being

The densities of the non-nucleated pearls ranged from 2.71 to 2.53g/cm^3. In this group, pearls nos. 6, 2 and 12 are the most dense (in this sequence). The two lowest figures, 2.62 and 2.53g/cm^3, are caused by the biggest cavities per volume visible in pearls no.10 and no.15. There is a definite relationship between the size of the central void or tissue remainder and the pearl density: the more compact the pearl, the higher density value, as subsequently confirmed by the internal structures displayed in the X-radiograph (Figure 7).

* The terms 'non-nucleated' and 'tissue grafted' have the same meaning and refer to the same type of cultured pearl. The term 'keshi' is not used in the text, but it should be made clear that it does not apply to the non-nucleated or tissue-graft pearls referred to in the text above.

Fig. 6. The fifteen freshwater cultured pearls examined from the West Lake (Ho Tay) in Hanoi, Vietnam, lined up according to colour types (orange, white, pink, fancy). Identical arrangement as in Figure 7 for direct comparison, with one spherical *Unio* mother-of-pearl bead in the lower right corner.

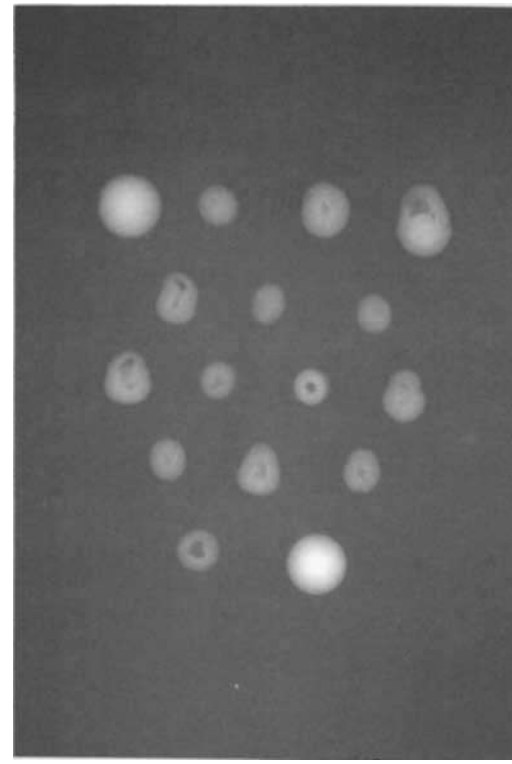

Fig. 7. X-radiograph of the fifteen Ho Tay cultured pearls and one bead, arranged as in Figure 6. Numbering in rows from top left, pearls nos. 1 and 4 are nucleated, all others are tissue-grafted or contain a void.

The colour of Ho Tay cultured pearls

As in most gem materials, colour is the outstanding property of the pearls examined. These come in a considerable range of hues, pure orange being the most unusual one. Ho Tay pearl colours were reported to be mostly pink, orange, brown and more occasionally white, light grey and almost black. This is in contrast with the three lots shown, white and pink being the predominant hues.

The present colours were measured in the reflectance mode of the Zeiss MCS 311 Multi-channel Spectrometer. This technique has been applied for many years, especially in Japan (Komatsu, 1991), for the separation of natural black cultured pearls from those dyed black with silver nitrate, ie., 'black-lip absorption' versus dyestuff absorption. Though only a preliminary colorimetric study of the Ho Tay and other known freshwater cultured pearls was conducted, it became evident that there is a positive correlation between the following hues and approximate absorption band positions:

orange	500	>	440nm
pink	440	>	550nm
purplish-pink	440	=	550nm
white	440	>	680nm

Mixed colours show the listed absorption bands roughly in the ratio of their contributing hues. It is known that the organic colouring components (porphyrine and conchiolin) of the mantle tissue as well as the aragonite platelet thickness (0.9mm in Chinese *Cristaria*, Gutmannsbauer, 1992) influence the pearl colours but the exact causes need further study.

No evidence was found to indicate other than natural colours for the examined undrilled Ho Tay pearls. This confirms the official claim that the pearls were not enhanced (i.e. not dyed, heated or irradiated). However, white and black being the preferred colours, Hanoi sources state that dying has been tested for application to off-coloured cultured pearls.

Outlook

Vietnam has the potential to become an important source of freshwater cultured pearls. It has been pointed out that there are at least three operations in various lakes, the waters of which are still largely unaffected by pollution problems, most likely because agriculture predominates over industry in all but a few urban areas.

The Ho Tay Fish Development and Investment Company plans for the Ho Tay station to become the largest such operation in Vietnam in 1993. Three additional farms will go into production this year; one in Hanoi, one in Ha Nam Ninh Province and another in Hai Hung Province, the latter two are both in the Red River delta. With increasing output figures, the Vietnamese freshwater pearls may become an important addition to the Chinese products in the future, especially if they are grown with thicker than normal nacre, as evidenced by those examined by the authors.

To encounter a pearl farm in a major metropolitan area was a great surprise. Pearls, not only from freshwater molluscs, appear to be symptomatic of the specialities and treasures that Vietnam holds in store for the world market. Conch pearl fishing in Vietnamese coastal waters, for instance, has existed for a long period, but is still not widely known. Flame-structured, natural conch-type pearls of nearly pure orange colour and sizes up to over 200 ct have come from Phu Quoc Island near the Cambodian border (Repetto, 1992, 1993) and compete with those from Thai and Burmese waters.

Acknowledgements

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The location, geology, mineralogy and gem deposits of alexandrite, cat's-eye and chrysoberyl in Brazil

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Abstract

Alexandrite, cat's-eye and transparent chrysoberyl are the gem chrysoberyl varieties sought after in Brazil. Primary chrysoberyl deposits are a few differentiated thin granitic pegmatites emplaced in granite, gneiss and mica-schists, presently abandoned, and granitic pegmatites cutting mafic and/or ultra-mafic rocks. In the last case, a few alexandrites are associated with emeralds which are found near the contact pegmatite/wall rock (Bahia and Minas Gerais States). Currently worked chrysoberyl deposits are detrital: eluvial, high and low colluvial terraces and alluvial, the latter being the most important. These deposits are located in the Minas Gerais, Bahia and Espírito Santo States; the biggest prospects are: Córrego do Fogo, Córrego da Faisca and Hematita in the State of Minas Gerais and Córrego Alegre in the State of Espirito Santo. A detailed formation description is provided for each deposit type, and the heavy minerals associated with chrysoberyl in the fine gravel fraction are listed. Associated with chrysoberyl in the coarse gravel fractions are: amethyst, aquamarine, garnet, smoky quartz, topaz, tourmaline and, in lesser amount: andalusite, rose quartz, moonstone, rutile, sapphire and zircon. Locally chrysoberyl is a by-product of the alluvial working of other gems such as diamond, aquamarine or andalusite.

Two maps (Figures 1 and 2) show the locations of the chrysoberyl deposits, an idealized diagram illustrates the types of deposit (Figure 7) and sections are shown of a series of alluvial deposits (Figure 8).

All chrysoberyl prospects are rudimentarily worked, by means of hand dug small pits or irregular open pits, and sometimes by means of a gravel pump (dredge).

Physical properties and gemmological characteristics of Brazilian gem chrysoberyl are reported, as are the significant inclusions.

Introduction

Chrysoberyl ($BeAl_2O_4$) holds a first class position between the rarer and higher priced Brazilian gems. Owing to a hardness of 8.5 and an average density of 3.75g/cm^3, it occurs as prismatic or platy, single or twinned crystals and as sharp or rounded fragments, pebbles and gravels. The fine specimens are eagerly sought after by mineral collectors. Without industrial importance, chrysoberyl is only sought for its gem crystals of which three types are distinguished:

- chrysoberyl, golden yellow (known as 'crisolita' in Brazil). It should not be mistaken for peridot, whose local name is the same
- cat's-eye or cymophane with chatoyancy of a bright line in the translucent stones cut en cabochon
- alexandrite, greenish-blue in colour in daylight and turning red in incandescent light.

Large faceted gems and cabochons can be made from chrysoberyl and cat's-eye and samples of several tens of carats in weight are known. On the other hand, alexandrite always produces smaller cut gems.

Chrysoberyl essentially occurs in the granitic suite, that is to say: pegmatites and aplites. It sometimes occurs in mica schists and, rarely, in dolomitic or calcic skarns. Chrysoberyl deposits belong to pegmatitic, pneumatolytic-hydrothermal and hydrothermal types (Smirnov, 1977).

In Brazil, chrysoberyl is prospected for in the States of Minas Gerais, Bahia and Espirito Santo and, nowadays, only in detrital deposits. These result from the partial or total destruction of primary deposits which are granitic pegmatites, locally intruded into ultramafic rocks. Our purpose, therefore, is to describe the various types of chrysoberyl deposits (cat's-eye and alexandrite varieties being specified as appropriate), their location, the associated minerals and the produced gems, today or in the past.

Pegmatite deposits

Granite pegmatites without ultramafic rocks association

Few deposits are accessible for research and at the present time none are worked. Deposits mined in the past were few in number and frequently caved in. Records of them are kept, state by state (see the location map, Figure 1):

Espirito Santo. The Triunfo prospect (Santa Teresa township) lies 1.5 kilometres to the ESE of Itarana town. A subvertical pegmatite, one metre wide, running NW-SE and outcropping as a gossan resulting from biotite weathering, was worked

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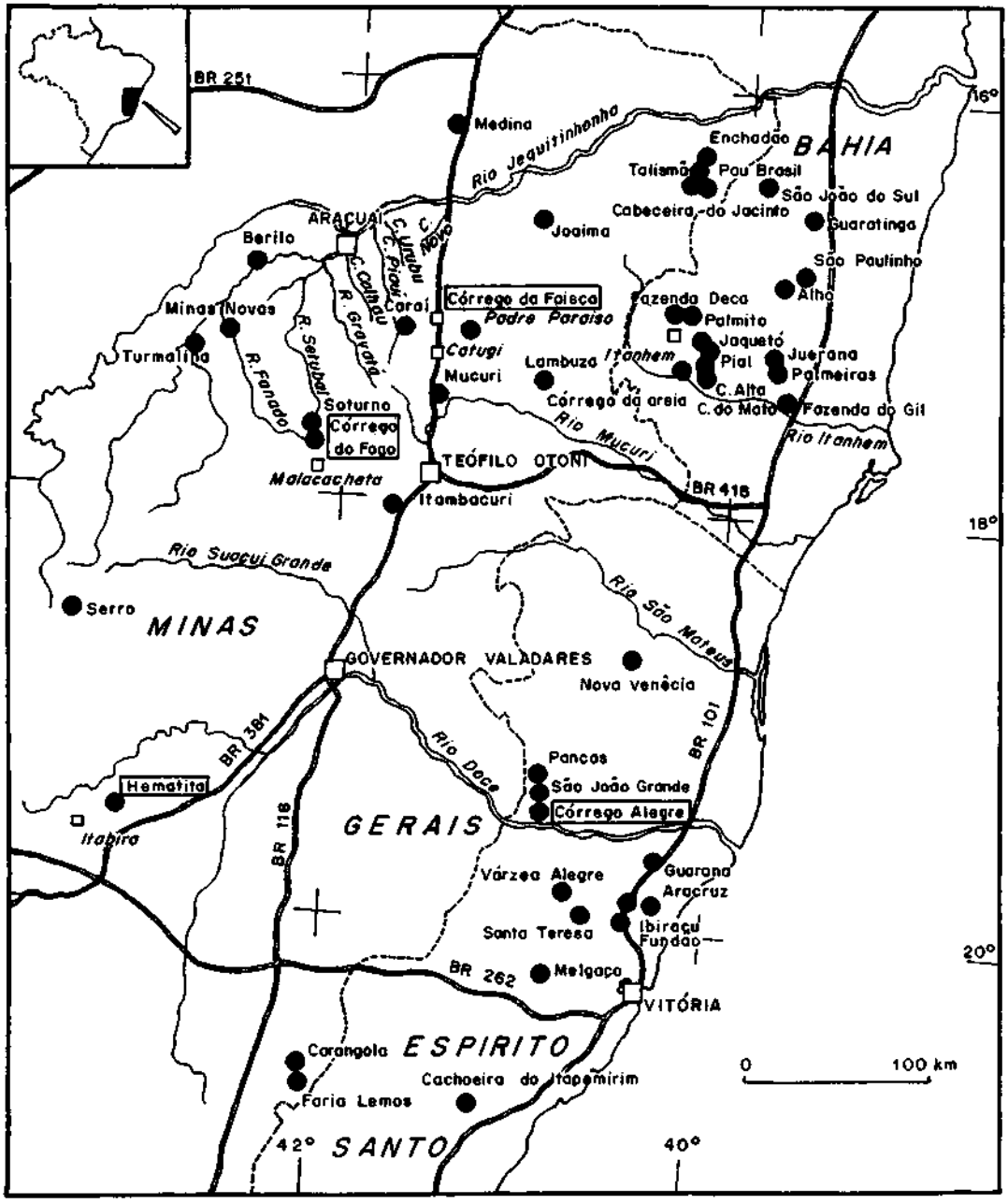

Fig. 1. Location map of the chrysoberyl deposits in Brazil.

between 240 and 270 metres in elevation. The pegmatite is zoned with a biotite-feldspar zone along the wall-rock (a granitic gneiss with feldspar phenocrysts) and a milky quartz core containing small cavities from which chrysoberyl was recovered. An 8 kilograms almost opaque V-twin is reported from this deposit.

Near Santa Leopoldina, another excavation in pegmatite produced chrysoberyl crystals reaching up to 1.5 kilograms in weight (J. Gomes, personal information). During 1940, trilling twins, several centimetres in diameter, were collected by Kaplan (Interview, 1980), from a weathered pegmatite (or its eluvium?), located in the Lavra (= mine) of Antônio Coelho (M. Luque property). These crystals are famous worldwide and commonly labelled

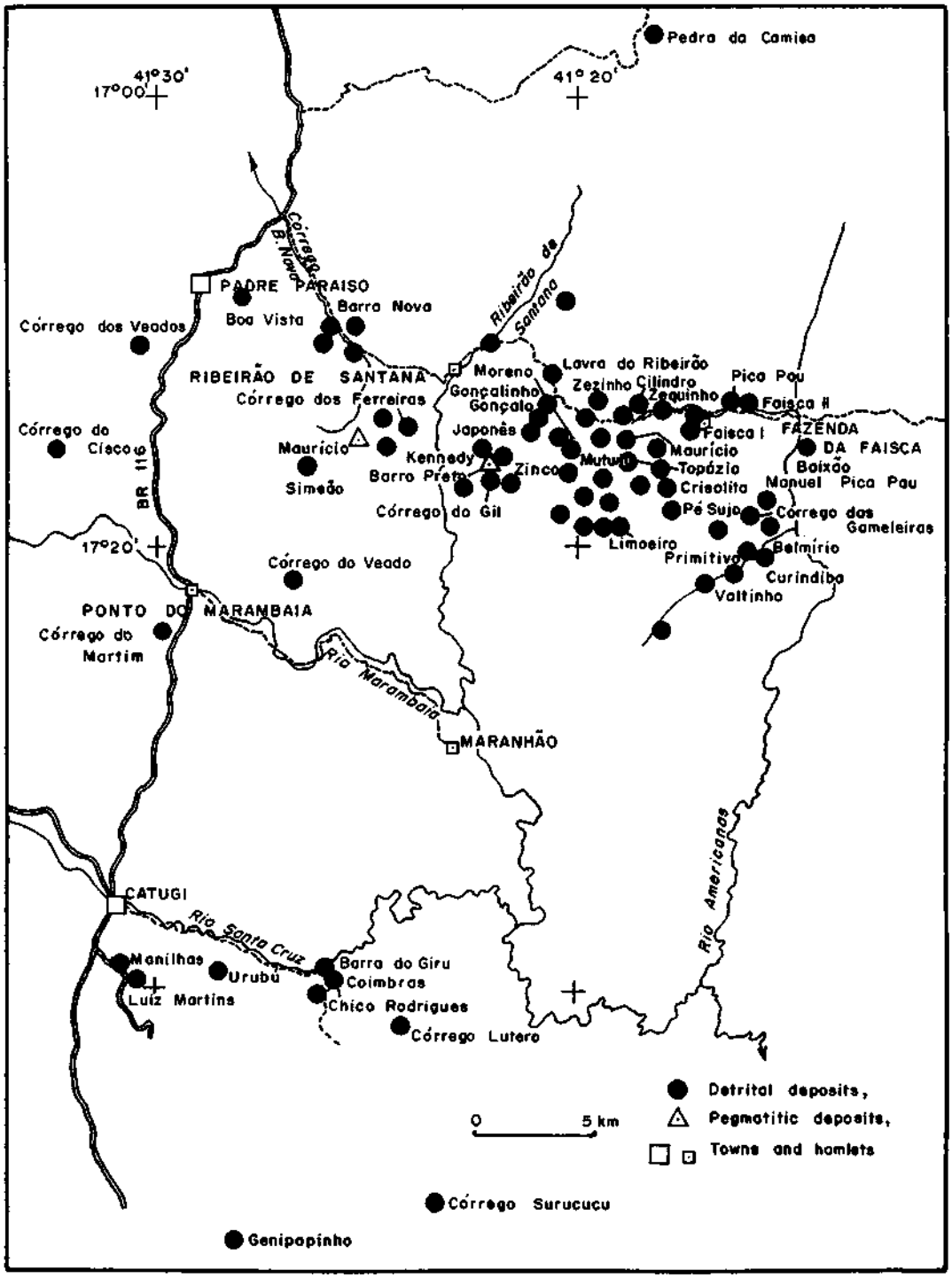

Fig. 2. Detailed map of the chrysoberyl deposits in Córrego da Faisca area.

as coming from Itaguaçu.

Chrysoberyl in quartz, near Castelinho (Cachoeiro do Itapemirim township) is briefly reported by Leonardos (1945a), and by Wohlers (1941) as being near Santa Teresa.

Minas Gerais. During 1990, on the right side of the Córrego (= creek) Barro Preto, a thin pegmatite was prospected by a trench, 50 metres in length, at the elevation of 740 metres. The occurrence is located 14 kilometres to the ESE of Padre Paraiso town (see detailed map, Figure 2), and near the top of a bald inselberg made of kinzigite with large garnets and platy sekaninaite crystals. The unzoned pegmatite, crossed by aplite veins, running N30°E and dipping 75°NW to vertical, is some centimetres wide with swellings reaching up to 0.5 metre in width. The pegmatite is composed of grey xenomorphic quartz, K-feldspar with some crystals reaching up to 15 centimetres in length, large biotite plates, green and pink fluorapatite, garnet and chrysoberyl crystals which are honey yellow to dark green in colour, thin, frequently flattened, commonly V-twinned. It is an exception if they reach up to 5 centimetres in length.

In the neighbourhood, 9 kilometres to the SSE of Padre Paraiso, another pegmatite, known as Lavra do Maurício, was partially worked in open pit on the top of a long hill made of biotitic granite, at the elevation of 800 metres. In the open pit, partially caved in, the weathered pegmatite involving many xenoliths, appears vertical, running EW and 5 to 6 metres wide. Typical minerals of the aquamarine deposits may be observed in the dumps: quartz crystals formed by three pyramids, biotite with hematite layers (Cassedanne *et al.*, 1992), muscovite, black quartz and colourless topaz. According to A. Tavares (personal communication), the pegmatite (or its eluvium?) would have produced some kilograms of greenish-yellow to greenish-grey, highly shredded, chrysoberyl crystals.

Until 1980, nine kilometres to the ESE of Coroaci town, that is to say 40 kilometres to the WNW of Governador Valadares, the Escadinha prospect was worked by small trenches and rooms, 60 metres in length along the outcrop. The deposit, located on the left side of the Grota (= gulch) do Xuxú, at an elevation of 450 metres, is a rosary-shaped pegmatite, 0 to 0.3 metre in width, running SSE-NNW and dipping 20°NE. The wall-rock is a garnetiferous mica schist. The unzoned pegmatite is made of malodorous grey quartz, kaolinized feldspar, abundant muscovite, garnet and flattened chrysoberyl crystals, frequently occurring in the quartz. Fine cat's-eyes are recorded from this deposit.

Leonardos (1945b) referred to yellow chrysoberyl in a beryl-bearing pegmatite located in the Córrego Surucucu; in Sebastião Ferreira (30 kilometres to the south of Itaipé town) and 'in various beryl-bearing pegmatites', in the Rio Mucuri basin. To the south of the State, near Manhumirim town, another pegmatite was reported as having produced chrysoberyl twenty years ago (J. Gomes, personal communication).

Bahia. Misi *et al.* (1975) report, without more information, 'simple pegmatites' chrysoberyl-bearing, in the southern part of the State. The deposits are caved in.

Rio de Janeiro. Menezes (1982) reported chrysoberyl in the Faraó de Baixo pegmatite (Conceição do Macacú township). Panning the dumps of various caved in adits, none produced chrysoberyl.

Ceará. Near the town of Fortaleza, capital of the State, and 1.6 kilometres to the east of the Cristais town, gem chrysoberyl was reported as having been found in the Caboquinho pegmatite. The deposit, running N30°W, was worked by an open pit, 120 metres in length, 40 metres in width and 20m in depth. Associated minerals are: albite, beryl, cassiterite, columbite, muscovite and spodumene (Limaverde, 1980).

From a more general standpoint, Costa Sena (1881) wrote that chrysoberyl proceeds from quartz veins and Leonardos (1945a) observed the same mineral 'in feldspar'.

The scarcity of the known deposits in rocks is highly disconcerting, even when, as it will be seen later on, chrysoberyl is broadly scattered in the detrital deposits where it is worked from many occurrences. It must be pointed out that chrysoberyl is not reported from aquamarine deposits, while the near alluvium, sometimes only several hundreds of metres away, frequently contain variable amounts of it. In order to explain this observation it was pleaded that the small size of many chrysoberyl crystals included in quartz or feldspar make them almost unperceivable, that beryl would have a different distribution in the pegmatite bodies or, in the old prospects, the belief that chrysoberyl brought bad luck caused it not to be mentioned (Elawar, 1974).

Research in numerous aquamarine-bearing pegmatites (Cassedanne *et al.*, 1992) confirmed that chrysoberyl does not coexist with aquamarine in its Brazilian primary deposits. Therefore, it may be concluded that chrysoberyl occurs in quartz (with feldspar and mica) veins and in thin pegmatites, devoid of aquamarine and judged almost without economic interest in outcrop, on account of their narrowness. According to the textural-paragenetic evolution scheme of Vlasov (1952 – modified in Cassedanne, 1990), the chrysoberyl-bearing pegmatites occur close to the base of the aquamarine producing zone.

Gem-bearing pegmatites were dated to 450-520

Fig. 3. Trilling twinned crystal (4.5 centimetres in diameter) from the Itaguaçu area (Espirito Santo State).

Fig. 4. V-twinned partly gemmy crystal (3 centimetres in length) from the Córrego da Faisca area (Minas Gerais State).

Fig. 5. Waterworn chrysoberyl crystal weighing 325 grams from Pancas area (Espirito Santo State).

Fig. 6. Large V-twinned crystals from a recent find in Córrego Alegre (Espirito Santo State). From left to right the samples weigh 1730, 830 and 880 grams. K. Elawar collection.

my old in the east centre of Minas Gerais State. They are always considered as belonging to the last phase of the Brazilian tectonic cycle, when emplaced in granites or its wall-rocks, or may have been slightly later (Correia Neves *et al.*, 1986).

Granite pegmatites associated with ultramafic rocks

Chrysoberyl (alexandrite) from these deposits is a by-product of emerald mining. See Schwarz (1987) for more details regarding this gem and its deposits.

In the large Carnaiba mine, 30 kilometres to the south of Campo Formoso town (Pindobaçu township, State of Bahia) located on the western slope of the Serra de Jacobina, alexandrite is associated with emerald mainly in the Marota and Lagarto prospects. In another, called Mundeú, chrysoberyl is found in biotite schist lenses in which it occurs as flattened trilling twins measuring up to 5 centimetres in diameter, but almost without translucent parts (Bruni, 1976). The Serra de Jacobina is made of a quartzite sequence with schist intercalations and ultramafic rocks sills (where chromite deposits are worked), intruded by a granite batholith and its pegmatite vein satellites. Emerald is found near the contact of the pegmatites. It is in a micaceous rock called sludite made of phlogopite, a little quartz, apatite, biotite, molybdenite and minor scheelite and alexandrite. The deposit, the production of which reaches some hundreds of tons of emerald of greatly variable quality, is hand worked by means of shafts and adits. The scattered prospects cover several square kilometres.

In the Socotó mine, to the NE of Campo Formoso town, a steeply dipping, running NNE-SSW sequence is made of gneiss, quartzites and talc-schists associated with peridotites and serpentinites, cut by thin granite pegmatites. As is done in Carnaiba, emerald is worked in the sludite lenses. Alexandrite and chrysoberyl are rare, sometimes associated with large rounded milky phenakite crystals.

Lastly, a very little alexandrite sporadically appears in the Belmont emerald mine, near Itabira (State of Minas Gerais).

Detrital deposits

A series of physical and chemical superficial phenomena take place in the primary deposits which lead to the formation of gem-bearing alluvium. Various types of deposits may be correlated to intermediate stages during this formation.

In tropical countries a number of pegmatite minerals are unstable under superficial conditions, at least on geological time scale. Some minerals change into clay (feldspars, spodumene), others decompose (biotite, magnetite, garnet) leading to the disintegration of the pegmatite body, while chemically stable or practically insoluble compounds such as chrysoberyl, beryl, topaz or tourmaline, remain unaltered and concentrate with heavy minerals such as cassiterite, ilmenite, monazite, niobotantalite, rutile and zircon. When the weathering-resistant products stay plumb with or very near to the pegmatite, they are either scattered in a reddish-brown sandy clay or are submitted to a light grade increase, by elimination of fine particles, caused by meteoritic water action, forming the so-called *eluvial deposits*. The previous detritus may

slide down the slopes, forming *colluvium* deposits before reaching the bottom of the valley, where they are picked up, transported and deposited several times by the running waters. This process allows gems and resistant heavy minerals to concentrate, by elimination of light particles, and leads to the formation of *alluvial deposits* (placers or flats). If the preceding cycle is repeated at different levels, distinct in time, its result will be the construction of superimposed *terraces* (see Figure 7).

The chrysoberyl detrital deposits are remarkably developed in the north-east of the Minas Gerais State, south of the Bahia State and west of Espirito Santo State, the area belonging to the 'Eastern pegmatite Province' of Paiva (1946).

Outliers of an old peneplain occur at the summit of some inselbergs to the north of Teófilo Otoni town and near the frontier with the State of Bahia, as extensive high plains preserved in clayey and sandy Cenozoic sediments. The peneplain, that culminates between 800 and 900 metres in elevation, belongs to the South American erosion cycle, dated lower Cenozoic (King, 1956) and extends to the south of the State of Bahia and near the frontier between the States of Minas Gerais and Espirito Santo.

The South American peneplain was dissected during new erosion cycles, with steeply sided valleys more than 300 metres in depth. The down cutting, related to the Rio das Velhas (Upper Cenozoic) and Paraguaçu (Pleistocene) cycles, was spasmodic with short accretion and planation periods. The accretion phases are marked by shreds of terraces remaining perched upon the high slopes. Commonly these very old terraces are buried by colluvium and only appear by chance, when artificial work cuts the slope. Other lower, but very extensive, terraces occur in the Rio Doce tributaries and various small coastal rivers (Rio Mucuri, for instance). The important preceding morphological features commonly are dated Upper Pleistocene – Lower Holocene (Meis *et al.*, 1981) and explain the importance of erosion in the dismantling of the primary chrysoberyl deposits.

In the south of the Bahia State, the newer erosion cycle appears as vast pediments gently sloping down towards the Atlantic ocean, but lightly rising up from south towards north. Broad valleys, where almost all chrysoberyl prospects are located, gashed the preceding pediments before being partly filled. In the interior, hanging valleys, sited upstream were thresholds of resistant granitic rocks which produced waterfalls and acted as traps for the chrysoberyl and heavy minerals (Cachoeira do Mato,

Fig. 7. Types of chrysoberyl deposits in an idealized section.

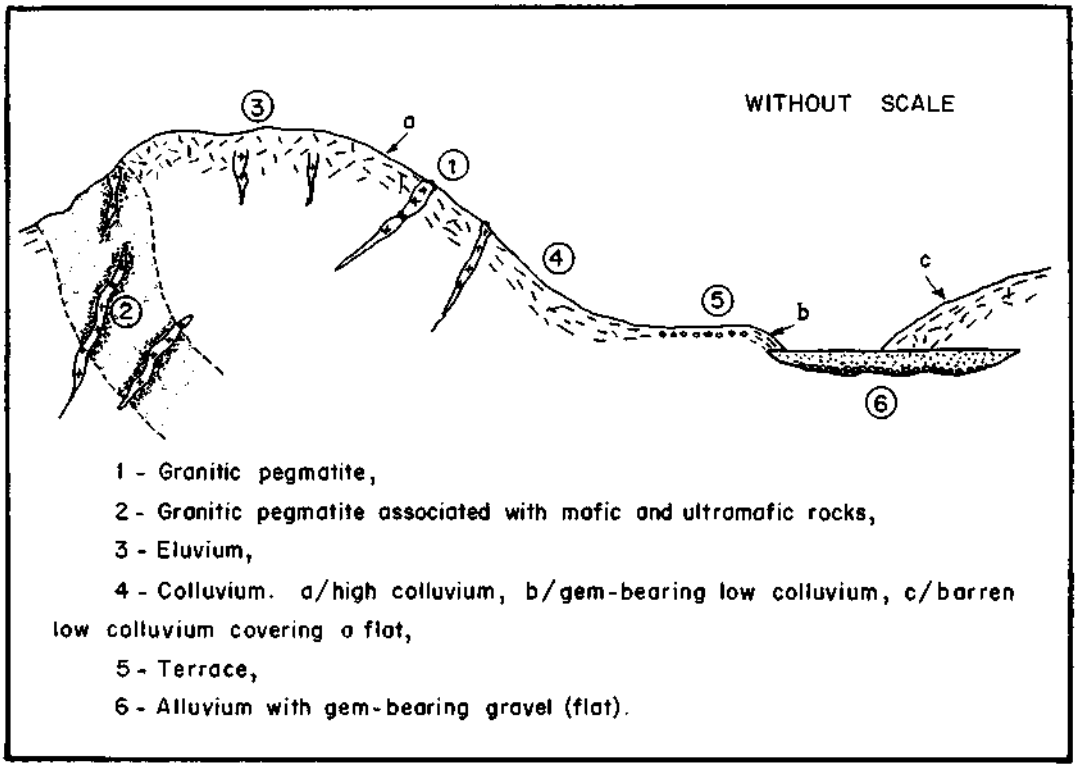

Jaquetó, Pau Brasil, etc.): erosion migrating towards the heads of the rivers did not have sufficient time to level the streams after the falling to the last base level.

Eluvial deposits

In the eluvium, commonly lateritic, the rough or slightly rounded gems are preserved in the soil, their surfaces being coated by ferriferous plastic reddish clay. The deposits, also called 'Chapada' (= high plain or plateau), as well as those of the high colluvium, are located upon the outliers of the South American peneplain or upon later piedmont slopes or planation surfaces. These deposits, of which superficial extension may reach tens of hectares, were extensively worked by means of irregular pits, small shafts of variable section and large irregular excavations. All were haphazardly dug because no superficial clue exists to guide the research. No well defined mineralized horizon occurs, but deposits of variable thickness composed of brown to reddish, sandy argillaceous layers with erratically distributed gems, associated with many milky quartz fragments, are found (Córrego da Faisca). Locally gem bearing layers become individualized in the eluvium, as thin discontinuous lenses. Mineralogically speaking, the eluvium deposits are poor, with some variably martitized magnetite granules, limonitic pisolites and quartz, associated with the chrysoberyl in the coarse fraction of the soil. The mass of the fine heavy fraction is made of magnetite and its alteration products, associated with ilmenite and a very small amount of biotite, garnet, leucoxene, monazite, muscovite, niobotantalite, tourmaline, xenotime and zircon.

It is impossible to date precisely the eluvial deposits, all old in age, because their formation continued after the peneplanation of the surface development which characterize them. This very long exposure to superficial weathering explains their broad extension, caused by multiple very small lateral movements of their resistant components, as well as their mineralogical paucity resulting from an exhaustive chemical weathering. Discovery of eluvial deposits is always fortuitous: loose gem chrysoberyl collected during a road or trench opening, fitting up of a wire fence, etc. Without delay a garimpeiros' (= diggers) rush follows the discovery, sometimes involving hundreds of diggers. They turn the soil of the deposit upside down before leaving it, regarding it as a worked out area. It remains, at first sight, a lunar or undulating bombarded landscape. The excavations are almost always hand dug, with vertical walls dependent on the eluvium stability. The brown to red colour of their wastes is typical, contrasting with the white or pale grey colour of pegmatite dumps. Sorting of the gems is made during the excavating, sometimes with screening of the finer sized overburden.

Colluvial deposits

By slow creep eluvium imperceptibly passes to *high slope colluvium*. The limit between the two types is merely conventional and only founded on their topographic situation. Mineralized high slope colluvium is always hand worked.

Colluvium is generally of low economic importance, the gems becoming diluted among a great deal of barren detritus sliding down the slope.

The *low slope colluvium* represents, in the vicinity of the alluvium, the result of the slight creep phenomena. This creep is accompanied by important mineralogical changes: the reddish-brown to reddish soil of the high slopes changes in the foothills to ochre or light brown in colour. Likewise, decrease of the magnetite and its alteration products, is counterbalanced by increase of ilmenite and/or monazite percentage in the heavy minerals fraction. Resistant mineral reloading occurs locally. In a sandy argillaceous soil reaching up to 10 metres in thickness, with some detrital quartz fragments, the chrysoberyl crystals and fragments are disseminated and worked by way of large irregular excavations, with vertical walls, always hand dug, as in the Curindiba prospect.

When no chrysoberyl occurs in the upper layers, barren colluvium of variable thickness may cover the gem-bearing outer alluvium (Córregos do Gil and do Fogo, Belmírio, etc.). For instance, at the Dimão prospect and vicinity, near São João Grande (Espirito Santo State), working of the mineralized gravel leads the diggers to search for its lateral extension until the riverside of the early creek is reached, that is to say below the slipped barren colluvium. This, 6 to 8 metres thick, was stripped with the help of a bulldozer during 1990 and 1991, allowing the discovery of magnificent large, partly gem-quality, V-twinned chrysoberyl crystals, some of them reaching up to 2 kilograms in weight.

Alluvial deposits

The so-called 'brejo' (= food plain) deposits are located at the bottoms of valleys, frequently occurring as swampy plains where the streams meander. The alluvial deposits vary from a few hundred metres to more than 2 kilometres in length, with a width of from some tens to some hundreds of metres. They are oval-shaped and may succeed one another, like a string, along one stream. Crosswise, the valleys show a flat bottom leaning by a nick against the lower slopes. In section, the alluvial deposits are usually characterized by a gravel bed lying upon the bedrock and overlaid by fine grained sediments. See some sections of alluvial deposits as

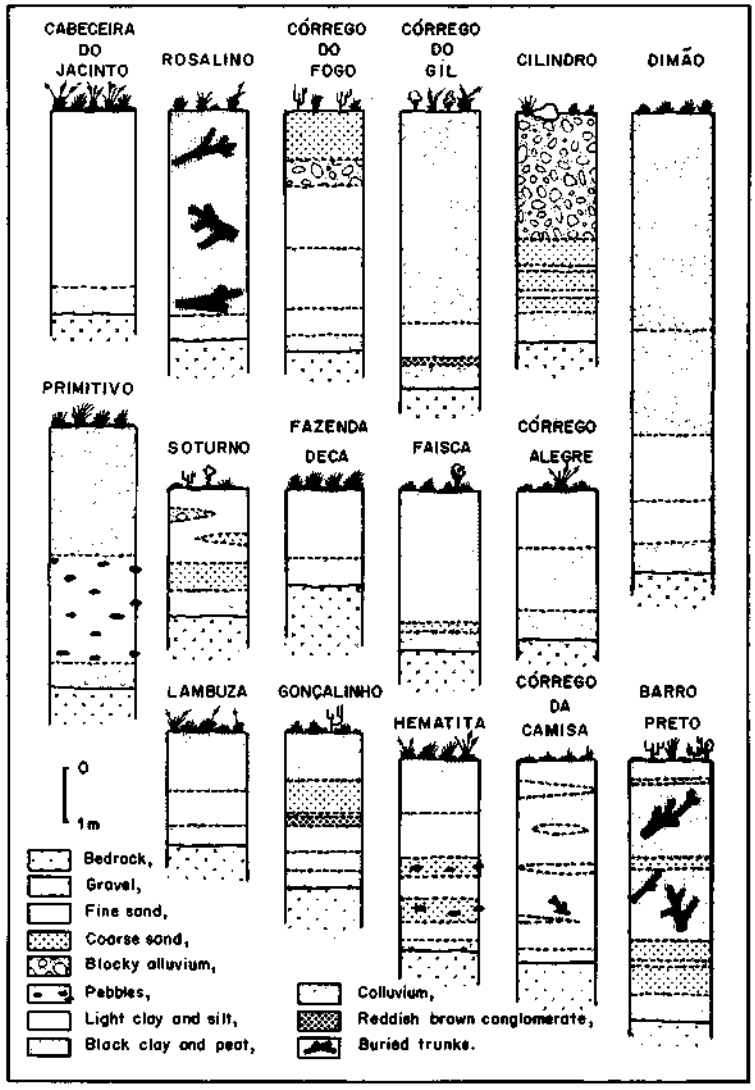

Fig. 8. Sections through various alluvial chrysoberyl deposits.

are shown in Figure 8.

The bedrock is variable, but invariably weathered below the placers and altered into a more or less plastic grey, beige or yellowish mass. The bedrock surface is undulating, showing pot holes, canyons more than 2 metres in depth (Córrego do Fogo) and large transverse ridges, or is asymmetrical, compared with the valley axis. Frequently, at both flat ends, the sole plate rises, forming a series of large elongated basins, where gravel was deposited, between rock thresholds which are passed by cascades and waterfalls. The resulting morphology leads to a series of high steps where hanging gravel beds are preserved. After gravel sedimentation, weathering of the bedrock took place. In order to explain this observation it must be kept in mind that the bedrock morphology is typical of hard rock river erosion. The argilization took place later, below the alluvial overburden resulting from weathering under a tropical climate.

The gravel, commonly fairly rounded, frequently contains medium to small sized, rare to abundant pebbles. It is an exception for multi-decimetre sized boulders to occur (Cilindro, southern tributaries of the Córrego do Fogo). After a few kilometres, the gravel grain-size distribution downstream quickly decreases and the fragile components disappear. Sometimes small boulders or coarse sand beds occur in the gravel. Moreover, what may be observed locally is a partial or entire iron hydroxide concretion of ferricrust type resulting from a tropical climate (Belmiro, Soturno) or a marked silicifica-

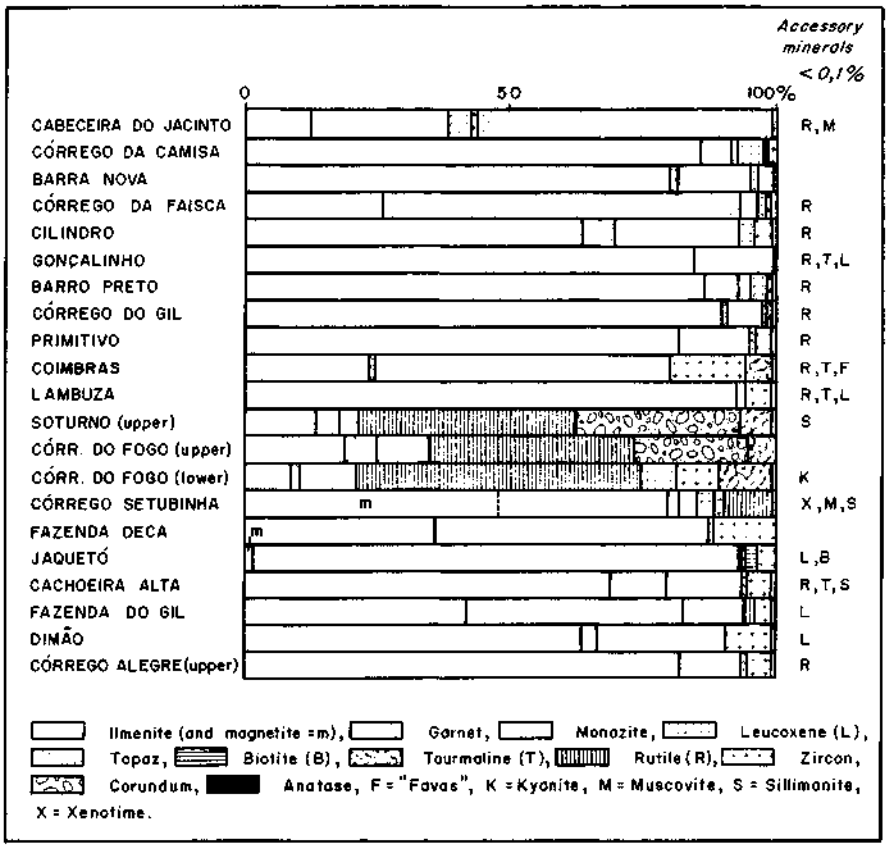

Fig. 9. Heavy minerals in some Brazilian chrysoberyl-bearing gravels.

tion corresponding to paleosoils (Primitivo, Córrego do Gil). The gravel is a few decimetres thick and it is an exception for it to reach up to 0.8 metre.

The gravel is invariably made of milky quartz, some of it being translucent to transparent or smoky quartz, associated with rock fragments, clay galls, feldspar in very variable amounts and, sometimes, a little muscovite and pisolites, in a poorly developed sand and clay matrix. In the coarse fraction (more than 2 millimetres in size) the chrysoberyl is associated with: aquamarine, garnet, schorl (locally with indicolite or rubellite), topaz, amethyst, smoky quartz, rose quartz and, in lesser amount, andalusite, iron oxides, niobotantalite, rutile, sapphire, zircon and moonstone. Research upon the fine fraction of panned heavy minerals (Figure 9) resulted in the finding of: anatase, andalusite, apatite, biotite, beryl, cassiterite, chrysoberyl, chrysocolla, cordierite, corundum, gahnite, garnet, hematite, hornblende, ilmenite, kyanite, leucoxene, 'limonite', magnetite, malachite, muscovite, nontronite, niobotantalite, pyrite, rutile, sillimanite, staurolite, rare-earths coatings, topaz, tourmaline, wolframite, xenotime and zircon. See for more details Cassedanne *et al.* (1984).

The overburden, barren and always fine grained in contradistinction to the gravel, lies abruptly upon the gravel. It is made of greyish, beige, yellowish or whitish coloured, more or less sandy clay, argillaceous sand and silt, irregularly superimposed, typical of flood plains. Interbedded locally are rich bluish-grey to blackish organic matter, plastic layers (Soturno, Barro Preto) with or without buried trunks, testifying to old turf-moors established in ox-bows (Rosalino) where pyrite neoformation sporadically occurs (Córrego do Fogo). Sometimes thin beds of cross-bedded coarse sand attest to short renewed torrential erosion periods (Barro Preto). Sandy or sand-free, kaolin layers and beige argillaceous brown mottled horizons evoke paleosoils. A mantle of large boulders descending from the steep slopes overhanging the streams, is rarely present (Cilindro). The overburden is always thicker than the gravel, reaching up to 4 metres in thickness. It grows thinner towards the heads.

Thus, the alluvial deposits correspond to more or less sorted torrential layers belonging to an old erosion period, abruptly overlain by finer sediments of a more even regime. Frequently the proximity of the gem-bearing source rocks may be inferred from field observation: large chrysoberyl crystals point out the proximity of more or less broken down

pegmatites which, apparently, have never been sought after by prospectors (São João Grande, Jaquetó or Córrego da Faisca). Frequently the nearness of pegmatites may even be inferred by: the abundance of sharp-edged topaz and muscovite crystals (Cabeceira do Jacinto), metre sized blocks of roze quartz (Alto Lagoa), almost unaltered biotite (Pau Brasil) or quartz from the graphic pegmatitic zone (Rosalino). However, it must be pointed out that, frequently, the chrysoberyl and some associated minerals are more rounded than the rest of the gravel. This observation demonstrates the importance of the relatively long transit creeping, accompanied by the red clay abrasion between the source rocks and the alluvium.

The main geomorphological features of the present relief were in the same position from the beginning of the alluvial deposits formation. In the valleys subjected to tropical and arid climates, in potholes, canyons and basins developed between the falls, which were remainders of former erosion cycles. From turbulent mud flows, the gravel deposition probably took place during local violent floods of short duration. Unsorted fragments coming down from the sparsely wooded adjacent slopes, or resultant from previous floods, were transported a short distance. Towards the end of every flood, a vanning of the finer particles took place. During this period, mechanical erosion augmented a weak chemical erosion. As consequence of a rapid climatic change, the earlier conditions were reversed: a predominantly dry climate may follow a tropical one where, under a thick forest, the chemical erosion predominates. Assisted by a deep rock weathering, this erosion will supply fine and argillaceous sediments to the valleys. During this period, marshes settle in the bottoms, where important terrigenous sedimentation and euxenic lens formation takes place, after the sudden decrease of the stream flow. Locally, temporary accidents disturb the terrigenous sedimentation. The chrysoberyl-bearing gravels probably were deposited during a dry climatic period approximately 40,000 years ago (Turcq *et al.*, 1987).

The search for alluvial deposits empirically is made by means of short pits haphazardly sunk in the flats. If gems are unearthed, the swampy or uninhabited valley converts into a diggers ant hill after a garimpeiro's rush. They turn the flat of the new deposit upside down before leaving it, regarding it as a worked (or not) area. Commonly working is done by a reduced garimpeiros team. A timbered square pit, a few metres in size, is sunk down to the bedrock, the overburden being indiscriminately dumped roundabout. When the gravel is reached, it is piled up on the flat surface, near the pit, the argilized bedrock being carefully cleaned up. Ever

Fig. 10. Two stage excavation of a pit. Soturno alluvial deposit (Minas Gerais State).

present seeping water is removed by small motor pumps. Finally, the gravel is washed upon a coarse sieve and the residue thrown into the now flooded pit. The sorting by hand of the highly coloured gems, among the prevailing milky quartz, is easy. Sometimes, part of the overburden is scraped by bulldozer (Córrego da Faisca, Córrego do Fogo, São João Grande), after draining of the flat by some deep trenches, or diverting the stream. Ground sluicing is rarely used (Córrego Topázio, tributary of the Córrego da Faisca).

Locally, working is done using a 'dredge', a small horizontal gravel pump set upon a steel pontoon. After building a dam, part of the deposit is flooded, then the overburden is pumped out as mud and rejected downstream below the dam, where a new flat is reconstituted. Locally buried trunks make dredging difficult. When the gravel is almost outcropping, a pit is sunk to the bedrock and water supplied by a stream deviation. The gravel is shovelled into the pit and mixed with a lot of water, before pumping and discharging upon a tilted sieve with a 3 to 5 millimetre aperture. The undersize passes through the sieve towards the dumps, but gravel and pebbles are secured and hand sorted. When gravel cannot be exposed, because water is too abundant, it is directly pumped out from the

Fig. 11. Removing a peat horizon in the overburden. Córrego do Fogo alluvial deposit (Minas Gerais State).

Fig. 12. Washing and sorting the chrysoberyl-bearing gravel. Rosalino prospect in the Córrego do Fogo alluvial deposit (Minas Gerais State).

Fig. 13. Working an alluvial deposit by means of a small dredge, near Teófilo Otoni town (Minas Gerais State).

bottom of the flooded excavation. This way leads to a variable loss of gems during the gravel dredging and consequently to a lower chrysoberyl recovery.

There are no reliable reports upon possible reserves, production or chrysoberyl gravel grade, whatever the prospect type. However, the chrysoberyl must be valued roughly as a few grams at most per cubic metre of gravel, of which gemmological properties are highly variable. Frequently eluvial and colluvial grades are far lower. Locally some coloured gemstones are recovered as by-products of the alluvium treatment: aquamarine, garnet, tourmaline; but industrial mineral is never recovered, although locally comprising a substantial part of the heavy undersize, particularly rutile (Córrego do Fogo) or monazite.

Location of the chrysoberyl detrital deposits

Minas Gerais

This State was the first chrysoberyl producer. From the eighteenth century the gem has been worked in the Rio Araçuaí basin, near the town of the same name (formerly Calhau) and in the tributaries of the river: Calhau, Gravatá, Lufá, Rabelo, Urubu, dos Neves (Costa Sena, 1881), Novo (Leonardos, 1945a) and Santa Maria (Arena, 1956). Presently these deposits, where chrysoberyl was associated with andalusite, sillimanite, spodumene and coloured tourmalines, have been worked out or abandoned and are mainly of historical interest.

The actual output proceeds from the Padre Paraiso-Americanas, Malacacheta and Itabira areas, where almost all active prospects are located.

Between *Padre Paraiso and Americanas*, about 90 kilometres to the NNE of Teófilo Otoni town, a great number of prospects, some worked for more than 50 years, comprise the larger concentration of chrysoberyl workings in Brazil, making out a WNW-ESE trend. The Córrego Barra Nova flows to the east, the Córrego da Faisca to the west and the Ribeirão de Santana in the centre, the last two being tributaries of the Rio Mucuri. The main deposit, near the elevation of 550 metres, is located at the Córrego da Faisca Fazenda (= farm) de R. Zimmer and its small tributaries, with various prospects: Cachoeira do Gato, Crisolita, Filuca, Córregos do Marcolino, Limoeiro and Topázio; Gameleira, Topazinho and Topazão. The area is mountainous with bald garnet-rich kinzigite inselbergs, looking down on deep valleys. The deposit produces chry-

Fig. 14. Discharging the pumped chrysoberyl-bearing gravel. Gravel and pebbles are retained by the sieve before hand sorting. Medina alluvial deposit (Minas Gerais State).

soberyl and cat's-eye associated with aquamarine, amethyst, smoky quartz (= morion), topaz and tourmaline with a little andalusite and very rare alexandrite. Garnet is abundant in the heavy panned fraction.

Towards the west a series of prospects exists, part of which is abandoned (see Figure 2 – in part after Vargas, 1992): Barra Nova 1 and 2, Boa Vista, Argimírio Gonçalves, Fazenda A. Tavares (Lavra do Bejú), Antônio Ramos, Córrego dos Veados, Córrego do Cisco, Córrego do Martim, Simião, Córrego do Veado, Córrego do Gil (more than 2 kilometres long flat located ESE of the Ribeirão de Santana hamlet and worked for twenty years), Barro Preto (working alluvium caught between kinzigite fallen blocks, in one Córrego do Gil affluent), Lavra do Ribeirão, Gonçalinho, Mutum, Moreno, Zinco, Cilindro and Zequinha (working a long narrow flat between blocks fallen in from the surrounding steep slopes). To the east and south are: Faisca 1 and 2, Baixão, Crisolita, Manoel Pica Pau, Fazenda João Edilberto (Córrego das Gameleiras), Belmírio Poaiá, Curindiba (Arlindo Miranda and Abílio Preto), Primitivo Moreira and Valtinho. This region, where many gems were produced in the past from alluvium, terraces and low colluvium, is also known as Americanas or Americaninhas, the name of a nearby hamlet. (See Proctor (1988) for historical data and detailed description of some deposits.) Output was mainly of chrysoberyl, with a lesser amount of cat's-eye, both associated with aquamarine, morion, topaz and tourmaline with rare garnet and andalusite. It is an exception to find alexandrite in this area.

About twenty kilometres to the ENE of Padro Paraiso, in the important outlying Pedra (or Córrego) da Camisa prospect, more than 300 diggers were actively working during 1990. The flat extends about 800 metres along the stream, a little before its junction with the Rio Anta Podre, and produces chrysoberyl and cat's-eye associated with much schorl, morion and topaz, with a little garnet, andalusite, amethyst and moonstone.

Fig. 15. After removing the thick reddish barren colluvium caused by sliding, workers found large V-twinned chrysoberyl crystals in the alluvial gravel of this flat in the Córrego Alegre (Dimão prospect – Espirito Santo State). See the 3 crystals in Figure 6.

In the south, after an hiatus corresponding to the Córregos Marambaia and Santa Cruz basins, famous world-wide for their great aquamarine production, exists another series of prospects, almost all abandoned. The Lavra dos Coimbras which produced fine small alexandrites from a wide flat of the Rio Comprido must be noted. The Chico Rodrigues, Córrego Lútero and Genipapinho prospects are located nearby.

The *Córrego do Fogo* deposit, 15 or so kilometres to the NNW of Malacacheta town, discovered about 1975, is one of the more important in Brazil. There, between 830 and 870 metres in elevation, along the

full length of the stream which runs ESE-WNW in a narrow valley, as in its southern tributaries and the Córrego Setubinha (to which flows the Córrego do Fogo), a series of prospects succeed one another (Garimpos Rosalino, da Safira, João Rodrigues, do Baiano, Abel, etc.). The deposit produces chrysoberyl and alexandrite and a few small sapphires associated with aquamarine, rubellite and some garnet and andalusite. Alluvium is rutile-rich, with large rose quartz boulders and, locally, pyritic peat horizons.

About 10 kilometres to the north, still in the Rio Setubal basin, the Soturno prospect works, at nearly 830 metres in elevation, in a narrow valley, a WNW-ESE running flat, one kilometre in length. The production is the same as that at the Córrego do Fogo. Small hematite roses are common in the gravel.

Approximately 20 kilometres to the north-west of the Santo Antônio do Jacinto town, various prospects are almost abandoned: Pau Brasil, Cabeceira do Jacinto, Talismã and Enchadão. They produced chrysoberyl associated with much colourless topaz with a few cat's-eyes and aquamarines.

The Lambuza prospect, to the SSW of Pavão town, is re-working a wide flat which produced aquamarine in the past (while chrysoberyl was not sought). Cat's-eye and alexandrite associated with the same minerals occurring in other nearby prospects are recovered.

The *Hematita mine* (also called Nova Era and Itabira), 4 kilometres to the SSW of the homonymous hamlet and 20 kilometres to the ESE of the Itabira town, is probably the richest alexandrite concentration in the world, located near the junction of two creeks that flow into the Córrego da Liberdade. The flat, 200 metres in length and 150 metres wide, encloses a kaolinitic gravel, probably an eluvium or colluvium almost unsorted, in which the alexandrite grade is exceptionally high. The alexandrite fragments, with many faces, subangular, are frequently centimetre sized. After two diggers invasions following the discovery in 1986, the deposit is presently mechanically worked by a sole mining society, but is in the process of closing because of the exhaustion of the detrital reserves. A few occurrences are sited in the neighbourhood.

Fig. 16. Córrego da Camisa alluvial deposit, near Padre Paraiso town (Minas Gerais State).

Various other chrysoberyl localities are mentioned, without details, and commonly lost: Serro (Ferraz, 1929), Rio Mucuri tributaries (Leonardos, 1945b), Caraí, Itambacuri, Joaima, Medina, Mucuri (Abreu, 1963), Santa Luzia de Carangola (Serra dos Arrependidos) and Fária Lemos (Franco *et al.*, 1972), Pouso Alegre (Rio Sapucaia Mirim), Rio Suaçuí Grande, Minas Novas, Turmalina (Rio Itamarandiba) and Berilo (Schobbenhaus *et al.*, 1984).

Fig. 17. Working a chrysoberyl-bearing pegmatite, during 1990, near Barro Preto (Minas Gerais State). The pegmatite may be seen along the small brown step in the foreground.

Bahia

Chrysoberyl deposits are smaller than those of Minas Gerais State, mostly abandoned and located in the south-eastern region of the State (see Cassedanne, 1984, for more details). In the northern area of the aforesaid region, the prospects of São João do Sul (Olavo, Fazenda E. Motta), Guaratinga (Lavra da Libidinosa, Fazenda Monte Carmelo), São Paulinho, Alho (Fojó Velho, Cacheado), Imbauba (near São João da Prata), Córrego da Queixadá, Lavra da Copacabana and Lavra do Corró (Itanhém) are practically abandoned, and the Jaquetó prospect (Salomão, where a very pale V-twinned alexandrite crystal, 6250 grams in weight, was unearthed) is in the process of closing.

Near Itamaraju, to the east of the São João da Prata hamlet, small prospects in the flats of the Fazenda Deca (Bom Jesus) and Palmito, between 90 and 100 metres in elevation, are located along tributaries of the Rio do Sul. There chrysoberyl and alexandrite are associated with a few cat's-eyes, aquamarine, garnet, andalusite, tourmaline, rose quartz, amethyst and zircon.

To the ENE, near Medeiros Neto town, two prospects are in reduced activity: Cachoeira do Mato at an elevation of 290 metres and Cachoeira Alta at 330 metres, both in hanging valleys overlooked by inselbergs. The output is made up of chrysoberyl with very little alexandrite, associated with aquamarine and tourmaline and a little garnet and rose quartz. The prospects of Pial (São José do Prado), Córrego da Areia (Medeiros Neto) and Juerana (Teixeira de Freitas) are abandoned. The latter two produced aquamarine and chrysoberyl.

In the neighbourhood of Santo Antônio de Alcobaça, the Palmeiras prospect, in process of closing, worked at an elevation of nearly 150 metres, a 2 kilometres long flat cut into a broad pediment. There, alexandrite and chrysoberyl are found in association with garnet and amethyst and rare aquamarine. The nearby prospects of Coité and Cachoeira are abandoned.

A deposit discovered in 1983, in the Fazenda do Gil, 500 metres from the riverside of the Rio Alcobaça, works a flat more than 1 kilometre in length, and produces chrysoberyl and alexandrite associated with aquamarine, garnet, tourmaline and rose quartz.

Chrysoberyl is also reported, without details, in Jacunda and Mata Verde.

Espirito Santo

The greatest deposit is that of the Córrego Alegre (Dimão, Minguinho, Nelson Costa, etc.), near São João Grande, 20 or so kilometres to the northwest of the Colatina town. There, a string-shaped flat, more than 3 kilometres in length, occurs through low hills with inselbergs above, between 100 and 120 metres in elevation. The production is made up of chrysoberyl and cat's-eye. Crystals of the former with numerous faces, frequently V-twinned and reaching more than 2 kilograms in weight, characterize the output of this region, where the medium size of the crystals, as a whole, is always greater than in the aforesaid prospects. Moonstone fragments are common in the gravel as are aquamarine, garnet and amethyst. In the neighbourhood, the São João Pequeno prospect is abandoned as is that of Pancas which produced chrysoberyl and fine cat's-eye.

The other prospects: Vargem Alta (Franco & Campos, 1965), Santa Teresa area (Tancredo), Vargem Alegre, Ibiraçu, Fundão (Córrego das Piabas), Cachoeiro do Itapemirim and Córrego Melgaço (Putzer, 1956), are practically abandoned.

Sao Paulo

This is the only other State where alluvial chrysoberyl is reported, but without details. In the Serra de Taquaxiara (near São Paulo city), it occurs in the gulches that flow into the Rio M'Boi Mirim (Knecht, 1934).

Fig. 18. Partial view of the Córrego do Fogo alluvial deposit (Rosalino prospect) where chrysoberyl is associated with some sapphire (Minas Gerais State).

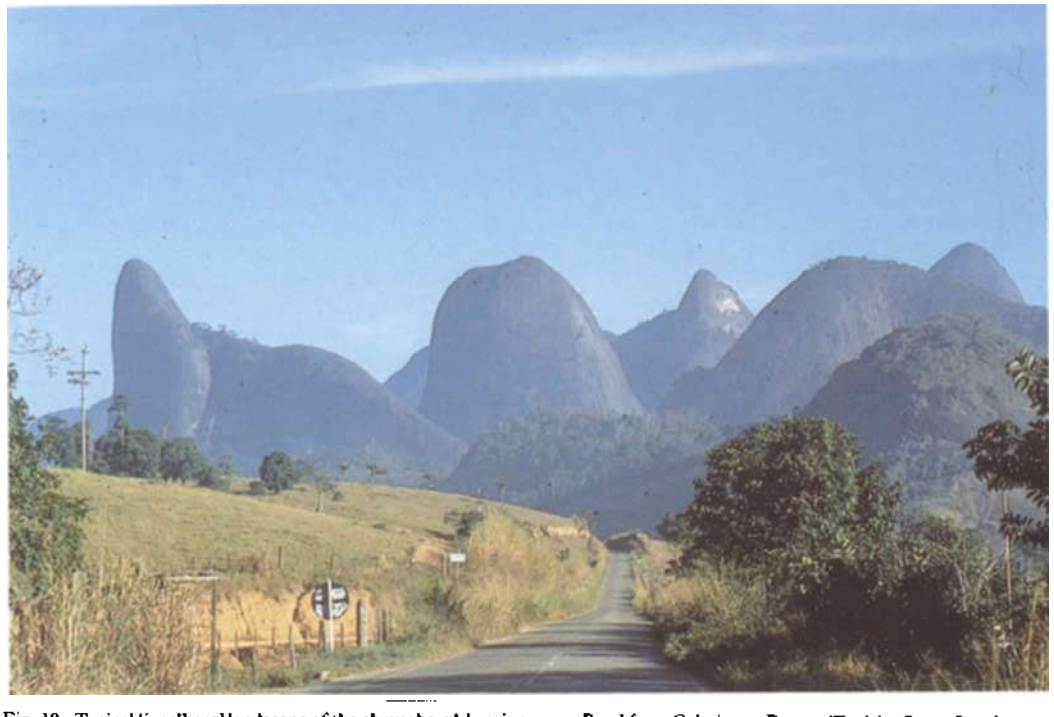

Fig. 19. Typical 'inselberg' landscape of the chrysoberyl-bearing areas. Road from Colatina to Pancas (Espirito Santo State).

Chrysoberyl associated with other gems

Chrysoberyl is frequently associated with other gems worked in alluvium, such as diamond, beryl and andalusite. It is locally recovered as a by-product.

Chrysoberyl from the diamond-bearing gravels is considered a common fellow-traveller mineral (Arena, 1956). It is reported from the State of Bahia in Lençois, Andaraí, Rio Paraguaçu (near Bandeira de Melo town) and Camaçari (cat's-eye) by Hussack (1917) and in Limões (Arena, op. cit.). In the State of Minas Gerais, chrysoberyl was observed in several flats in the Jequitinhonha valley, associated with andalusite, pyrope and hessonite (Bastos, 1962), particularly near Diamantina (Hussak, op. cit.), Lavrinhas (Cassedanne, 1971) and Três Ilhas. Chrysoberyl is reported from the São Paulo State by Hussak (1917) in the Patrocínio do Sapucaí township (Rios Santa Bárbara and Canoas, tributaries of the Rio Grande), in the Goiás State (Rio Claro) and in the Mato Grosso State (Rio Coxim, associated with sapphire). Limaverde (1980) reports chrysoberyl in the diamond gravel of the Rio Jauru, in the same State.

A little chrysoberyl is commonly associated with the aquamarine in its alluvial deposits, mainly in the State of Minas Gerais: Serrinha near Medina (with some alexandrite), Rios Marambaia (Córrego do Felipe) and Santa Cruz (Lavra das Manilhas, Urubu) valleys, among others. Chrysoberyl is also scattered in the aquamarine-bearing gravel of Juerana and Jaquetó deposits, in the far southern Bahia State, as in Fazenda Antônio Boffi (near Guaraná) and near Nova Venécia, both in Espirito Santo State.

Lastly, chrysoberyl is an accessory component of the gem andalusite-bearing gravels in the neighbourhood of Santa Teresa town (Serra do Prego, Ribeirão Caldeirão) in the Espirito Santo State.

The gems

Chrysoberyl belongs to the orthorhombic system. In alluvium it occurs as rounded or sub-rounded grains, chips and variably sized fragments, sometimes as crystals. These are long or wide with right-angled or sub-square section, or else platy, with longitudinal grooves upon the larger faces. Twins are common, frequently V-shaped with or without re-entrant angles, formed by two prisms or flat crystals. Hexagonal wheel-twins, crenellated or not, are not rare, but quite often small. In the gravel, crystals are millimetric to centimetric in size, rarely reaching up to 10 centimetres in length, partly rounded (head of the Córrego da Faisca), in elongated prisms or V-twinned. The Córrego Alegre deposit near Colatina town (Espirito Santo State), has been world famous for a long time for its large, partly gem quality, crystals many reaching more than one kilogram in weight. Recently a series of V-twinned crystals, with marked grooves, lightly rounded with sides exceeding 15 centimetres in length, olive green to dark green, were unearthed at São João Grande. The splendid, wonderful, translucent crenellated wheel-twins, yellow to olive green in colour, reaching up to 8 centimetres in diameter, from Ituaçu (Espirito Santo State), belong unfortunately to history. The Carnaiba emerald deposit produced flat opaque hexagonal twinned crystals, several centimetres in diameter.

Crystals found in pegmatites are commonly platy or V-twinned (Padre Paraiso), many being heavily shredded as a result of growing among micaceous minerals.

Hardness is 8.5. The fracture is conchoidal to uneven and the single poor cleavage is seldom observed.

Chrysoberyl is transparent to translucent, sometimes turning opaque due to very small black or brown inclusions. It is colourless (Barra Nova), milky (if so, not collected), pale yellow, vivid yellow, golden yellow, greenish-yellow, greenish, greenish-grey, dark green, beige or brown, sometimes grey, bluish-grey or blackish. The last three shades are common in the sand fraction, but infrequent in the gravel, and seldom collected. Locally opalescent (tributaries of the Ribeirão Americanas), the chrysoberyl often displays chatoyancy with a sharp line, occurring as cat's-eye with a more or less dark colour, golden and honey hues being the most sought after. Alexandrite appears greenish-blue, bluish-grey, dark green or brown in daylight, turning pale pink, reddish, reddish-brown or purple when examined for transparency before an incandescent light. The Hematita alexandrite shows a 'fabulous' colour-change according to Koivula (1987): bluish-green to greenish-blue passing to pink, raspberry, 'rhodolite' or ruby in colour, while other Brazilian alexandrites recovered in the past change only from green to violet or pink.

Lustre is vitreous to almost pearly, the streak colourless to pale beige. As crystals are frequently large and partly transparent, faceted chrysoberyl may be more than 100 carats in weight, as compared to the usually small faceted alexandrites. Yellow cat's-eye may weigh more than 40 carats, whereas cat's-eye alexandrites are extremely rare and seldom weigh a few carats.

Mean density of yellow chrysoberyl and cat's-eye is 3.68g/cm^3, higher and lower measured densities being 3.72 and 3.62g/cm^3. Density of brown chrysoberyl showing various shades varies from 3.75 to 3.80g/cm^3. Alexandrite density is 3.68 to 3.70g/cm^3.

Chrysoberyl is biaxial (+) with 2V near 70°. Typical refractive indices of pale yellow, golden and

greenish chrysoberyl are: α = 1.744-1.745 β = 1.746-1.749 γ = 1.753-1.754. Exceptionally, samples associated with gem andalusite, from the Santa Teresa area (Espirito Santo State), gave: α = 1.747 β = 1.749 γ = 1.757. Typical indices of alexandrite are: α = 1.745-1.747 β = 1.748-1.749 γ = 1.755-1.756. Some pale alexandrites from Córrego do Fogo show: α = 1.745-1.746 β = 1.748-1.749 γ = 1.754-1.755, and a sample from Carnaiba gave: α = 1.747 β = 1.748 γ = 1.756. A 0.008 to 0.010 birefringence is deduced from the previously reported indices.

Chrysoberyl and cat's-eye show a distinct pleochroism in the yellow and brown shades. Alexandrite, on the other hand, displays a marked pleochroism: dark red/orange to yellow/green.

The gravel grain surfaces are frequently pitted or show impact figures from which wavy cracks commonly diverge. Triangular positive (Pau Brasil) or negative marks may be observed upon some crystal faces. Gravel fracture is sometimes furrowed by parallel or divergent scratches. Because of their alluvial transport, many grains show large, impact, divergent, undulated, flat or conchoidal cracks and fissures, frequently producing iridescence, or are invaded by iron oxides. The latter, under microscopic examination and an adequate incident angle, present a golden gleam. Some small bayonet or grid-shaped fissures occur in some crystals (Santa Teresa).

Many pale yellow, golden yellow or greenish chrysoberyl grains are totally free of inclusions or imperfections under microscopic examination. In other grains, the most frequent inclusions are fissures with very small bubbles (Córrego do Gil) or, more often, finger prints (Córrego da Faisca). Small negative crystals are scattered or concentrated in parallel lines upon the inner crystal planes (Belmírio). When very small inclusions are thickly gathered upon conchoidal inner fractures, the crystal turns milky. Large two-phase inclusions are locally present (Lambuza). Unusable parts of many crystals are due to regular or no alternation of thick milky bands (caused by very small inclusions arranged in strips) and thinner transparent ones.

Little grey metallic plates, probably ilmenite, are common just underneath the faces of some crystals, and are easily eliminated during the cutting process. When present throughout the rough, the crystals turn opaque and are therefore useless as gems (Barro Preto).

Golden rutile needles, irregularly distributed and without preferential orientation are sometimes abundant (São João Grande), recalling those occurring in quartz crystals. Gübelin *et al.* (1986) reported goethite fibres in chrysoberyl from Bahia State.

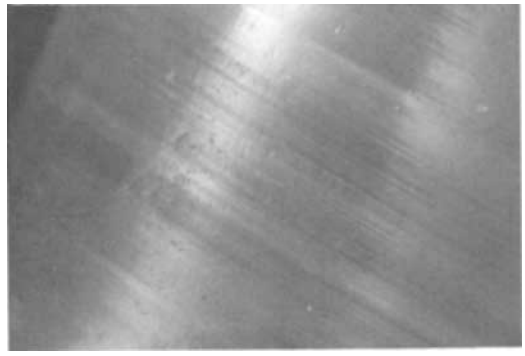

Fig. 20. Fine tubes in a cat's-eye from the Córrego da Faisca area (Minas Gerais State).

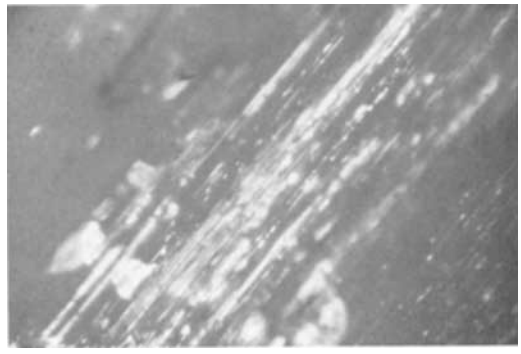

Fig. 21. Large tubes in a cat's-eye from the Córrego Alegre area (Espirito Santo State).

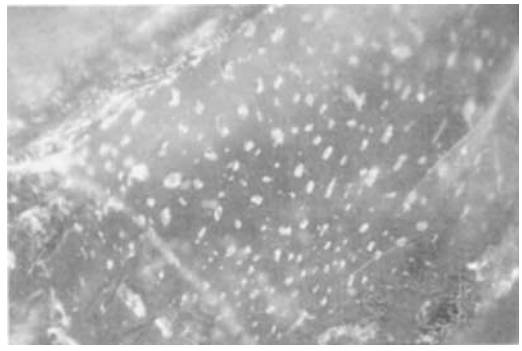

Fig. 22. Small two phase inclusions forming veils in a chrysoberyl from the Córrego da Faisca area (Minas Gerais State).

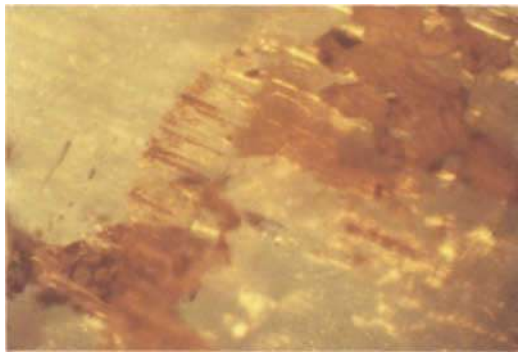

Fig. 23. Iron oxides filling a fissure in a chrysoberyl from the Córrego da Faisca area (Minas Gerais area).

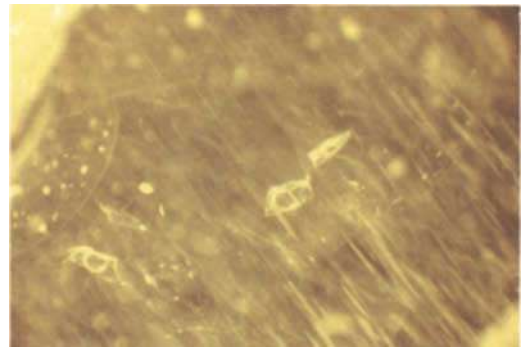

Fig. 24. Two phase inclusions in a cat's-eye from Lambuza (Minas Gerais State).

Fig. 25. A fine cat's-eye cabochon from Córrego da Faisca (Minas Gerais State).

Fig. 26. A fine banded cat's-eye cabochon, 23.51 cts in weight.

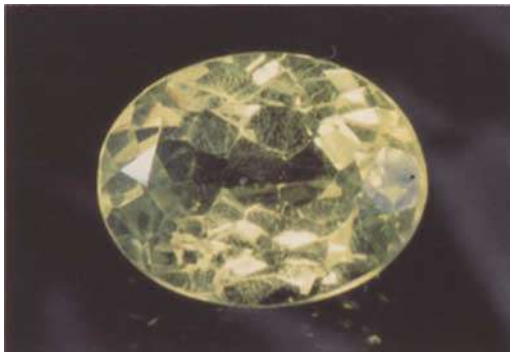

Fig. 27. Large faceted transparent chrysoberyl.

Fig. 28. Fine faceted Hematita alexandrite seen in incandescent light.

Fig. 29. Large two phase inclusions in a chrysoberyl from Lambuza (Minas Gerais State).

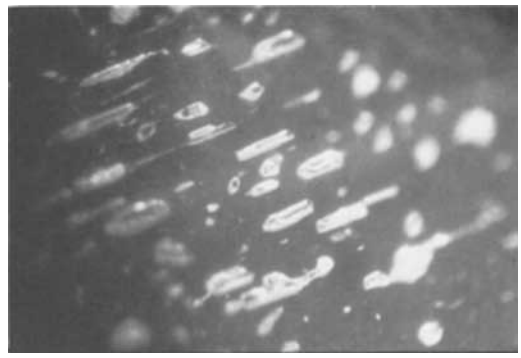

Fig. 30. Rutile needles in a chrysoberyl from São João Grande area (Espirito Santo State).

With the exception of Hematita, no deposit has revealed characteristic inclusions, although small crystals may be commonly observed in many gems under microscopic examination (the aforesaid cited prospects were only a few examples among many). According to Koivula *et al.* (1988) fluorite would be typical of the Hematita alexandrite, associated with apatite. Henn (1985) determined the following inclusions, for which chemical analyses are reported, in Brazilian chrysoberyls of imprecise location (because various prospects are known in each location): muscovite, andalusite and orthoclase at Três Barras; orthoclase and albite at Malacacheta; actinolite, talc and anthophyllite at Córrego do Fogo; albite, oligoclase, anorthite and andalusite at Água Fria; andalusite at Jaquetó; the examined samples from Colatina were inclusion-free. Lastly, Gübelin (1974) records radiating amiant fibres, sea-urchin like and biotite plates (Gübelin *et al.*, 1986) in Brazilian alexandrites of unknown origin.

Growth zones appear as narrow stripes with different hues (Juerana). Twin planes may be sporadically observed.

Tubes varying in length and diameter, hollow or not, are constantly present in cat's-eye and sometimes in yellow or greenish chrysoberyls, but very rarely in alexandrite; they are parallel to the crystal elongation.

All chrysoberyl varieties are free of radioactivity and are subject to very little deterioration. That property explains the easy preservation in alluvial gravels.

Colourless, yellow and greenish chrysoberyls and cat's-eyes are not fluorescent. Alexandrite, when light coloured, is inert under UV light (Córrego do Fogo), but has a weak orange/red when its body colour is darker (Carnaiba).

Yellow and greenish chrysoberyls and cat's-eye show a wide absorption band centred at 445 nm (440-450) and weak lines at 485 and sporadically at 505 nm (Lambuza). Light alexandrite from Córrego do Fogo shows a band between 680-690 (doublet), a partial absorption between 620 and 545 nm and total absorption beyond 470 nm. The weak additional lines reported by Anderson (1971) were not registered.

Trace elements (Ti, Sn, Fe) of the Americanas area chrysoberyls, are identical to those of the Trivandrum chrysoberyls (India – Soman *et al.*, 1986). It must be pointed out that in four Brazilian alexandrites analyzed by Otteman *et al.* (1978) gallium reaches up to 1200 ppm associated with tin which diadochically substitutes for aluminium following the equation: $2\ Al^{+3} \rightarrow Sn^{+4} + Fe^{+2}$. Like alexandrite, colourless chrysoberyl contains gallium (Vogler, 1986), although Schmetzer (1985) reports otherwise. A partial analysis of Hematita alexandrite gave 0.30-0.44 wt% Cr_2O_3, 1.11-1.59 wt% Fe_2O_3 and 0.01-0.03 wt% V_2O_3 (Proctor, 1988 – quoting Bank & Schmetzer).

Conclusion

According to Elawar (1974) the total monthly Brazilian chrysoberyl output would be in the order of 10 kilograms in weight, only 10% of which is gem quality grade: 1% top, 3% average commercial and 6% lower commercial grades. The remainder is sold as by-product. Production probably increased with the opening of new prospects, as was the case of the Córrego do Fogo, before decreasing to the current one kilogram monthly (Elawar, personal communication, 1992) as a result of the abandoning and closing of many workings. No official record of the present or recent output is available, but it is possible to warrant that the exhaustion of Brazilian chrysoberyl reserves is not to be foreseen in the near future.

Acknowledgements

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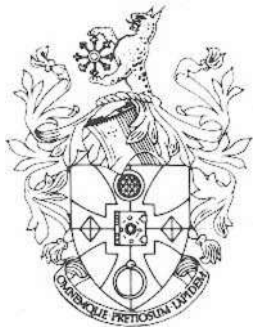

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Jaspers from Swierki near Nowa Ruda, Lower Silesia, Poland

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Abstract

The paper presents the results of mineralogical-petrographical and geochemical studies of jaspers occurring among Permian melaphyres (weathered basalts, often amygdaloidal (mandelstones)) and porphyries in the vicinity of Swierki near Nowa Ruda. Jaspers form a layer up to 1.8m thick. They mainly consist of silica represented by chalcedony, opal and quartz, as well as some admixtures of dolomite and micas. They are very interesting as a decorative material. Their origin appears related to low-temperature hydrothermal silification of sedimentary rocks occurring among melaphyres.

Introduction

Jasper is one of the more attractive and fairly common ornamental stones. This fine-grained massive rock contains marked amounts of iron oxides admixtures which may, in extreme cases, well exceed 20%. Its principal constituent silica is developed as chalcedony – either fibrous or spherulitic. Jaspers have a smooth and even fracture and their colour ranges from brick-red to blue. Besides occasional idiomorphic quartz concentrations, chlorite and opaque mineral inclusions are very frequent.

Fig. 1. Occurrence of rocks in the vicinity of Swierki: 1. gneisses; 2. serpentinites, gabbros and amphibolites; 3. old crystalline series.

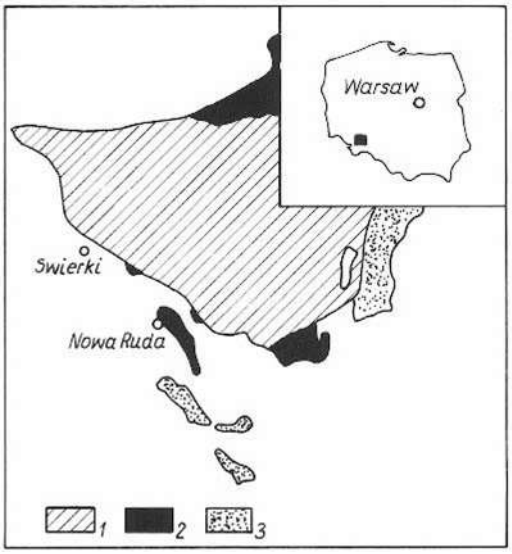

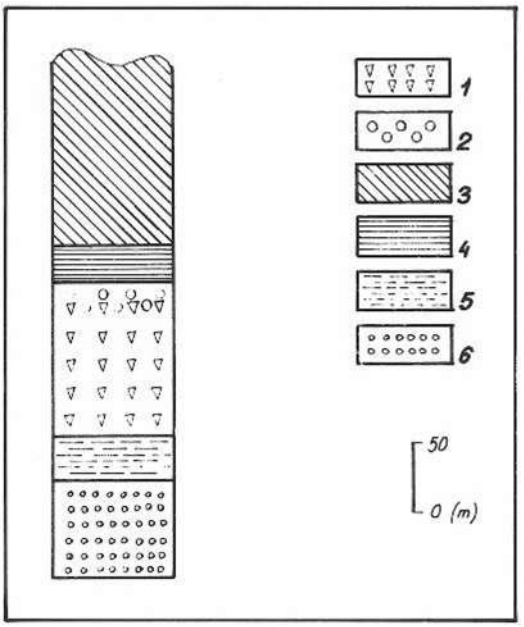

Fig. 2. Lithological profile of Permian rocks from the vicinity of Swierki: 1. compact melaphyres; 2. mandelstone; 3. porphyries; 4. schists intercalated with jasper layer; 5. clay shales; 6. sandstones.

Geology of the deposit

The jasper occurrence at Swierki near Nowa Ruda (Figure 1) is associated with melaphyres classified into the lower portion of the eruptive complex. This complex is underlain by shales occurring in the top part of the sandstone series (Figure 2). The melaphyre complex of Swierki is about 80m thick and composed of extensive lava flows partly of sub-volcanic nature. An amygdaloid-

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al zone has been identified in its upper part on the contact with the overlying shales above which a porphyry complex occurs classified into the second magmatic cycle.

Jasper occurring on the first level in the quarry forms a thick bed up to 1.5m dipping to the north at angles of 3-15° and showing distinct tectonic disturbances. The accompanying shales are thermally metamorphosed and distintegrated and the melaphyre is heavily fractured and altered. On the second exploitation level jasper is best exposed in the uppermost portion of the southern wall where it appears as a regular bed up to 1.8m thick. Also in this part of the quarry jasper is surrounded by thermally metamorphosed shale. The jasper bed is fairly compact and can be easily worked into blocks. Large blocks the size of several cubic metres are found at the foot of the wall on level two.

Jasper varieties found in the deposit

Varieties found in the jasper deposit at Swierki are cherry-red, red-grey, brick-red, creamy-green and green. They all have streaky hematite concentrations visible in hand specimens. The individual colour varieties form streaks or nest-like concentrations imparting an attractive colour pattern to the entire rock mass. The most common are red-grey jaspers while the green ones belong to the rarest and most prized varieties.

The red-grey jasper is dense and can be easily polished. Under the microscope it reveals a parallel, fluidal or unoriented texture. Its main chemical constituent is silica (Table 1) reaching up to 77% by weight and usually developed as chalcedony, usually fine-grained. Locally it is accompanied by spherulitic or fibrous forms. The rock also contains opal and quartz sometimes filling fissures and voids. The quartz is very often idiomorphic and then forms druses. All the constituents described above are unevenly scattered throughout the rock.

A constituent second in quantity is dolomite occurring in single rhombohedrons or filling fissure. Its amount does not exceed 15% by weight. Iron minerals are represented chiefly by hematite dispersed throughout the rock. Sometimes, however, their individuals, up to 0.01mm in size, show a linear arrangement accentuating the wavy structure. The amount of iron calculated as Fe_2O_3 does not exceed 0.6% by weight. But this amount is sufficient to impart to the rock a distinct coloration. Locally, in some voids and fissures the actual mineral succession can be easily traced: chalcedony attached to the wall is overgrown by quartz which in turn is overgrown by dolomite. As evidenced by the fact that dolomite veinlets cut all the other mineral concentrations this mineral is the final crystallization product.

Most often larger occurrences of green jasper are found close to the contact between the jasper bed and melaphyre. It is dense and uniformly coloured and can be polished easily. Under the microscope it is homogenous, fine-grained and shows an unoriented texture. Occasionally it contains minor dolomite amounts in the form of veinlets or rhombohedral individuals. Small opal concentrations are also present. In this variety the quartz content is 77,89% by weight (Table 1). Chemical results reveal the presence of 0.002% copper which is likely to be responsible for the green colouring. Rare mica scales and iron in the form of minute goethite pigment have also been identified under the microscope.

X-ray analysis

X-ray data were obtained from TUR 61 equipment within 0-25° range, with filtered CoKα radiation, goniometer and recorder speeds being 2°/min. and 600mm/h respectively.

X-ray data (Figure 3) reveal that both colour varieties differ only slightly in their chemical composition. In the X-ray diffraction patterns quartz reflections predominate for d_{hkl} = 4,25, 3,34, 2,45, 2,28, 2,24 and 2,13 Å. Also, as evidenced by reflections for d_{hkl} = 2,57 and 2,39 Å, minor

Table 1: Chemical composition (average) of jaspers from Swierki near Nowa Ruda in % by weight.

	Red-grey jasper	Green jasper
Fe_2O_3	0.59	1.85
SiO_2	77.79	77.89
TiO_2	0.12	0.34
CaO	4.15	0.43
MgO	3.29	2.05
Al_2O_3	4.44	8.96
Na_2O	0.28	0.34
K_2O	1.95	3.48
H_2O^+	0.39	1.97
H_2O^-	0.34	1.19
Loss of mass	7.01	3.63
Total	100.35	101.86

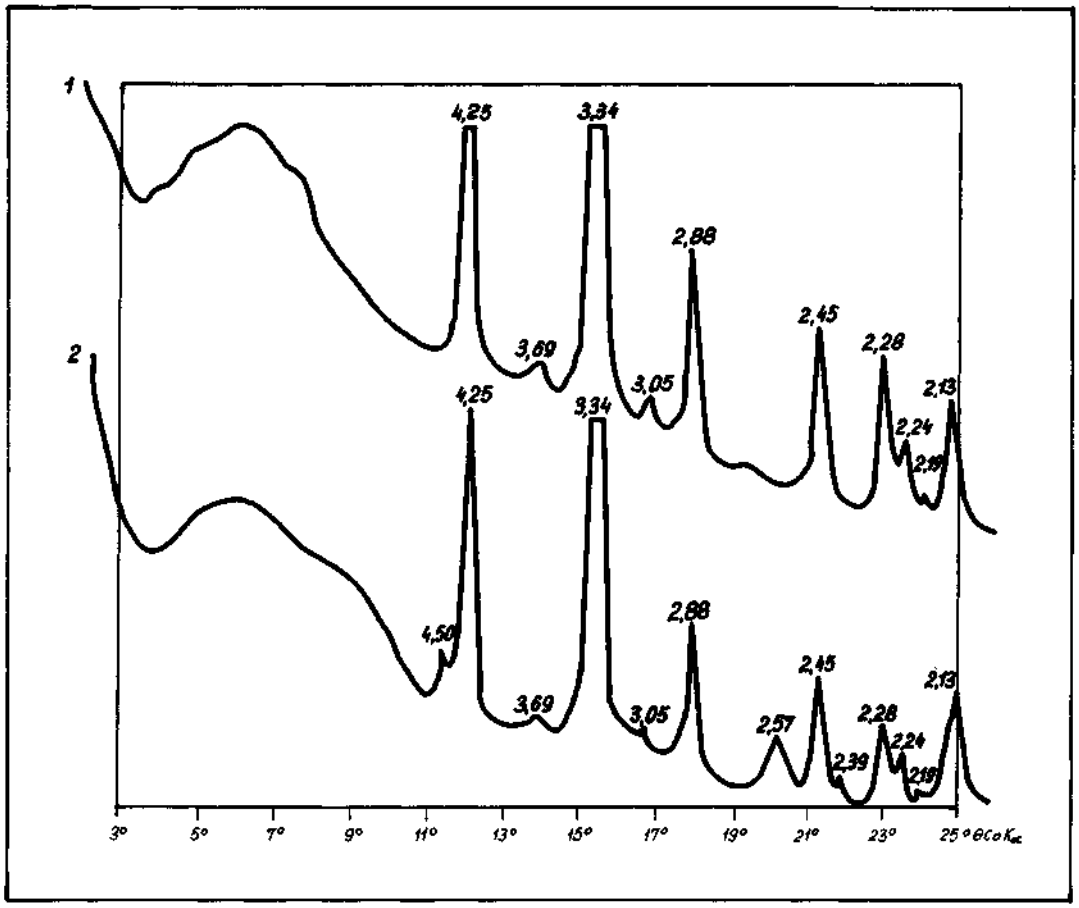

Fig. 3. X-ray diffractographs of jaspers: 1. red-grey; 2. green.

Fig. 4. DTA curves of cherry-red-grey jasper.

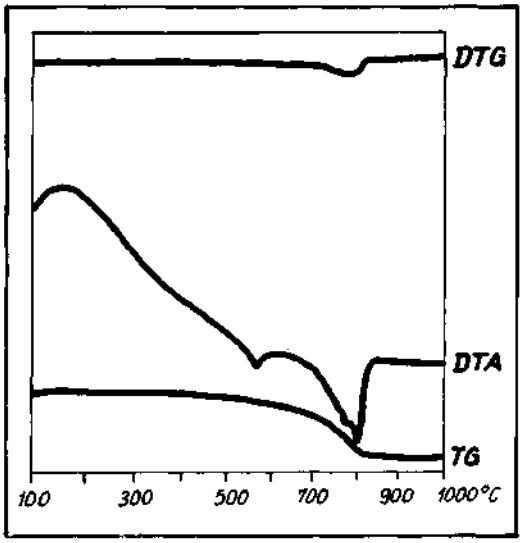

tenorite amounts may be present. The X-ray diffraction patterns for both coloured varieties show an elevated background within the 5-10 Å interval due to the presence of poorly ordered opal silica. The occurrence of poorly crystallized mixed-layer aluminosilicates cannot be excluded.

Thermal analysis

The thermal analysis was conducted within the 20-1000°C range using a Hungarian-made derivatograph, with 500mg samples and sensitivities DTG 1/3, DTA 1/3 and TG 100.

Thermal data (Figure 4) confirmed the presence of minerals identified previously. The DTA curve shows a weak endothermal effect at about 570°C related to polymorphic quartz transformation. The approximate 3% weight loss of the sample is due to dolomite dissociation as confirmed by two endothermal effects on the DTA curve at 780 and 800°C respectively.

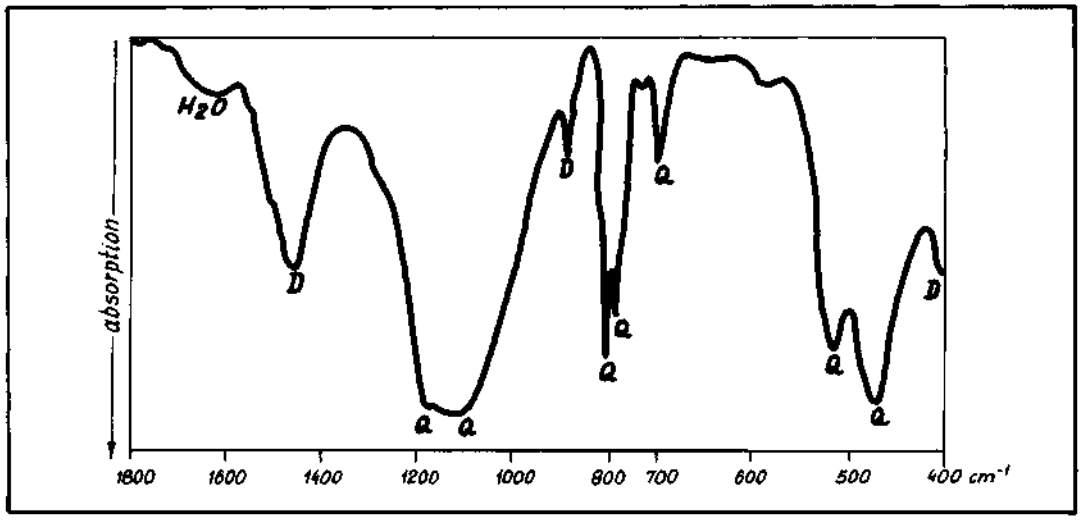

Fig. 5. IR absorption curve of cherry-red-grey jasper: D-dolomite; Q-silica (quartz and chalcedony).

IR spectrophotometric analysis

For IR spectrophotometric determinations within the 400-1800cm^{-1} range tabletized samples with KBr were used.

IR spectrophotometric data (Figure 5) for the jaspers examined point to the presence of small amounts of water with vibrations around 1650cm^{-1}. In addition, the absorption curve shows maxima distinctive of quartz (Q) and of dolomite (D). Vibrations around 1100cm^{-1} confirm the presence of opal. A small aluminosilicates admixture is indicated by vibrations within the 580-600cm^{-1} range.

Summary

Examinations discussed above revealed that jaspers from Swierki, Lower Silesia are built chiefly of silica developed as chalcedony and accompanied by minor amounts of opal and quartz. The rock also contains dolomite, hematite, aluminosilicates and trace amounts of copper minerals. Genetically the jaspers are connected with low-temperature silicification of shaly sediments by fluids migrating from the underlying melaphyres. Most probably silicification was accompanied by simultaneous hematitization, while the crystallization of dolomite and minor quartz amounts occurred after silicification.

Test Report on the Hanneman Mini-cube II

Peter G. Read, C.Eng., MIEE, FGA, DGA.

Bournemouth

The benefits gained by the immersion inspection of gemstones have been well documented[1]. To summarize, when a gem is immersed in a liquid whose refractive index is close to that of the gem, surface reflections are much reduced and light is able to penetrate the stone and reveal internal features. Immersion also helps in the identification of composite stones, as the differing refractive indices of the component parts of, for example, a garnet topped doublet will show contrasting outlines.

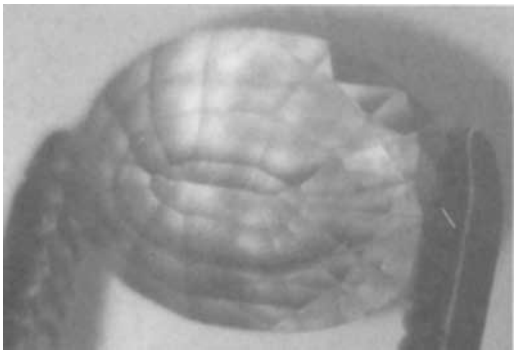

Fig. 1. Diffusion-treated Sri Lankan sapphire showing the spider-web effect produced by the concentration of colour at the facet edges

While in Sri Lanka in 1980, I was shown a sapphire which had come under suspicion because of its unusual evenness of colour. When immersed in water the colour concentration along the faceted edge became apparent (Figure 1), revealing the stone as one of the early diffusion-treated corundums. This effect, sometimes referred to as a spider-web, is made more obvious if the stone is immersed in a high-RI contact fluid such as di-iodomethane (methylene iodide).

With the increased production of diffusion-treated sapphires[2], immersion inspection has become one of several important screening methods in the detection of these stones. To meet this requirement, W.W. Hanneman, a pioneer in the production of inexpensive gemmological test equipment, has produced the Mini-cube II. This instrument consists of a small glass cell with a screw top, a block of acrylic plastic milled out to take both the diameter of the cell and any suitable light source (e.g. a pen torch - see Figure 2). The milled surface of the plastic cell holder is left unpolished and acts as a diffuser for the light source.

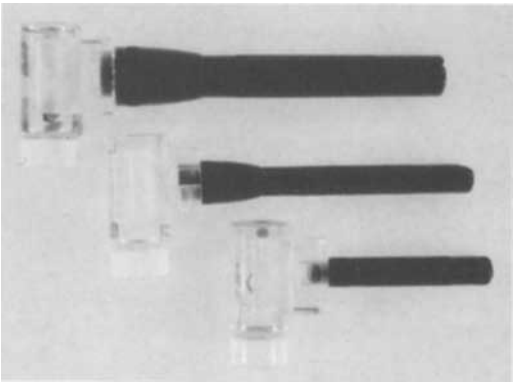

Fig. 2. Versions of the Mini-cube II designed for specific Mag-lite flashlamps. In the basic model, a black plastic mounting ring is fitted which has a 13mm diameter hole for a standard pen torch (the hole can be enlarged for other light sources)

Fig. 3. The immersion cell, illuminated from the rear by a pen torch fitted in the plastic mount, contains a sapphire immersed in di-iodomethane (the copper wire ring is to prevent discoloration of the liquid)

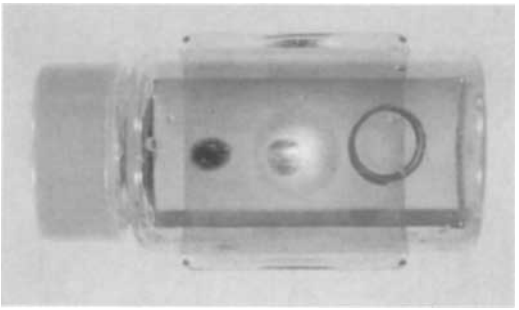

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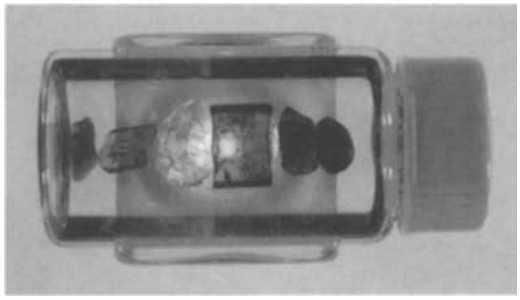

Fig. 4. Pieces of faceting-grade rough gem material being evaluated while immersed in baby oil

Figure 3 shows a horizontally positioned mini-cube containing a sapphire immersed in di-iodomethane. The coil of copper wire is provided to prevent darkening of the immersion liquid. In Figure 4, several pieces of faceting rough have been immersed for evaluation purposes, this time using baby oil as an alternative to the less pleasant high RI liquids (a concept introduced by A. Hodgkinson).

When used in conjunction with a pen torch and a 10X hand lens, the Mini-cube II forms a useful portable means of immersion inspection of quite sizeable gems (the cell neck diameter is 16mm) and immersion liquids can be safely left in the cell without danger of leakage. The Mini-cube II is marketed by Hanneman Gemological Instruments of PO Box 2453, Castro Valley, CA 94546, USA.

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Notes from Tucson '93

Eric C. Emms, B.Sc., FGA, DGA

Gemmological Association and Gem Testing Laboratory of Great Britain, London

Each year some 20,000 gemstone enthusiasts from around the world congregate in the city of Tucson, Arizona, in the south west of the United States. Starting in the mid-1950s with a small group of Tucson mineral dealers exhibiting their stock, the Tucson Gem Show is now not one but twenty different shows of varying size located at different hotel sites scattered around the city. The first fortnight of February is designated 'Tucson Gem and Mineral Days'.

Each show is organized by a different committee catering in the main for a particular market - for example fossil and mineral dealers would choose to exhibit at one show, while gemstone merchants would be attracted to another show. At the busy budget motels strung along a road close to the freeway, individual dealers, specializing in one type of gemstone, occupied the small bedrooms where they lived, slept, exhibited and dealt. A Hungarian would be dealing in East European minerals in one room, next door an Afghan would be selling his lapis lazuli, whilst a dealer showing his Baltic and Dominican amber would be in the next room. Such is the scale of the event that a visitor cannot hope to see and take in all that is on offer at Tucson.

The GAGTL decided to return to Tucson by exhibiting at the American Gem Trade Association (AGTA) GemFair - the prestigious coloured stone show housed in the modern, spacious Convention Center. Our aim was to promote our overseas membership and market our ever popular Diploma in Gemmology leading to the FGA. It was gratifying to learn from American gemmologists that the FGA is considered the pinnacle of gemmological education and that many Graduate Gemmologists wish to continue their studies by taking the FGA. The Gem Diamond Diploma leading to the DGA aroused interest, particularly in gemmologists from Canada and South East Asia. The Gem Testing Laboratory was highlighted by an illustrated talk I gave on gemstones recently seen in the Laboratory.

The topic of gemstone treatments was much discussed at the GemFair, especially diffusion treated sapphires, the prevalence and durability of fracture filling of emeralds and how these treatments should be explained and described to the consumer.

The shows appeared well attended and although some exhibitors were disappointed with the business conducted, others reported good sales. I was impressed with the quantity, quality and popularity of tourmalines on display, especially the red variety. The Paraíba tourmalines in a wide range of colours were more in evidence than I expected, accompanied by the similar colours of apatite. Tanzanite in strong to deep saturation and large sizes (over 10ct) was abundant, as were good-coloured peridot from the US and Burma. Peridot from China and Kenya was also in evidence.

The large number of red spinels from Burma impressed, at attractive prices in comparison to fine coloured Burma rubies on display. Pinkish-red Vietnamese rubies were for sale, one certified at over 8ct, although most dealers I spoke to indicated that Burmese material is currently easier to obtain than stones from Vietnam.

It was interesting to learn more of the present state of the mining of Montana sapphires and to see recent production of unheated and heat-treated stones. Three sources in the state are said to be producing small, flat crystals in many colours. The stones I saw had a light saturation of blue and were of good clarity. With large reserves rumoured to exist, the future for this native US gem looks encouraging.

Turning to synthetic stones, I was struck by the absence of anything new and exciting at the shows. Coloured cubic zirconia continues to be popular, with much rough in various colours being abundant. I was able to secure examples of recent US production of flux grown rubies and sapphires. Current Moscow production of flux grown syn-

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thetic spinel, synthetic opal and green GGG, together with Russian hydrothermal synthetic emerald, were obtained.

Garnet was the theme of the Tucson Gem and Mineral Show. Here nomenclature of the six gem garnets was well explained and illustrated by exhibitors displaying large crystal specimens of each species; large uvarovite crystals from Finland, orange spessartine garnets from Namibia and iridescent andradite from a new source in Mexico were particularly striking. A twenty kilogramme example of Libyan glass (the natural silica glass found in North Africa) and the Thompson diamonds (three pear-shaped brown diamonds cut from a 264ct rough stone) attracted the eye. Unusual quartzes included cabochon-cut transparent pink quartz (not to be confused with rose quartz) and crystals of ametrine (quartz with purple, colourless and brown colour zones), reputedly from Bolivia, characterized by the rhombohedral faces meeting at the basal pinacoid.

GAGTL is committed to expanding the opportunities for home and overseas students to study our FGA and DGA courses, and each year more of our Allied Teaching Centres are established for this purpose. The Tucson gem shows provide the opportunity to discuss with our overseas friends matters of interest and mutual concern, to emphasize our educational plans and to clarify perceptions of our future strategy.

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Gemmological Abstracts

ASHBAUGH III, C.E., 1992. Gamma-ray spectroscopy to measure radioactivity in gemstones. *Gems & Gemology*, **28**, 2, 104-111, 8 figs.

Gamma-ray spectroscopy to determine the radionuclides used to colour a yellow-green diamond (bought as radium-treated) and a deep blue topaz. The diamond had been treated with americium-241, a product of bombarded uranium-238 which coloured the surface and left radio-activity which would decline to a legally acceptable level for sale in rather more than three thousand years [not a very sound commercial proposition!]. The (London blue) topaz is a better bet and should reach a safe level in about two years. [Tests for radionuclides obviously call for expensive equipment and the ethics and sense of such treatment are highly questionable]. The author gives the half life of cobalt-60 gamma-ray signatures as 5.27 years and europeum-152 as 13.5 years (both have been used to colour diamonds), and says that it would take decades for even these fast faders to decline to a point where they were undetectable. Not all radiation, however, leaves such prolonged radio-active signatures. R.K.M.

BANK, H., 1991. In Partien natürlicher Rohedelsteine synthetische Rohsteine beobachtet. (Synthetic rough found in natural rough gemstone lots.) *Zeitschrift der Deutschen Gemmologischen Gesellschaft*, 40, 4, 253-5, bibl.

The author enumerates a number of instances where synthetics have been found amongst rough gem lots. In a lot of emeralds from Zambia, Chatham emeralds were found, a lot from Colombia contained glass, a lot from Nigeria yellowish fluorites. Rubies contained Verneuil products, alexandrite from Brazil some synthetic Russian alexandrite, glass masqueraded as tourmaline and aquamarine as well as amethyst which also contained some synthetic amethyst. The author also warns of quartzes which have been treated with green oil and sold as emeralds, and glass instead of diamond crystals. E.S.

BIANCHI POTENZA, B., DE MICHELE, V., LOBORIO, G., RIZZO, R., 1991. Le olivine della Sardegna: un materiale di interesse gemmologico. *La gemmologica*, **16**, 1, 17-28, 13 photos in colour, 2 figs, 1 map.

Green transparent olivines from Sardinian alkali basalts have gem potential. All major properties are described with a note on their occurrence. The basalts are of Plio- Pleistocene age and occur near Pozzomaggiore, Sassari, Sardinia. M.O'D.

BLANKENBURG, H.-J., LOTTNER, S., 1991. Achate aus einem temporären Ignimbritaufschluss bei Chemnitz. *Aufschluss*, 42, 275-383, 7 photos (5 in colour), 3 figs.

Agate is found in a disintegrated ignimbrite near Chemnitz, Germany. M.O'D.

BLANKENSHIP, D., 1992. The color of jade. *Bulletin of the Friends of Jade*, 7, 48-55.

The cause of colour in both nephrite and jadeite is reviewed; several areas where jade is found are covered. M.O'D.

BLANKENSHIP, D., 1992. Two stones. *Bulletin of the Friends of Jade*, 7, 24-8.

A short review of the two jade minerals with notes on some of their commoner imitations. M.O'D

BODE, R., KLAUS, D., 1992. Neue Rhodochrosit-Funde in der Sweet Home Mine bei Alma/Colorado. *Mineralien Welt*, 3, 6, 43-5, 13 photos (12 in colour), 1 map.

Further production of rhodochrosite at the Sweet Home Mine, Alma, Colorado, USA, is reported. M.O'D.

CAMPBELL, I.C.C., 1992. A short note on the appearance of some inclusions seen in a number of blue sapphires from Bo Ploi, Thailand. *South African Gemmologist*, 6, 2, 24-5, 4 photos in colour.

Blue sapphires from Bo Ploi, Thailand, were found to contain liquid feathers and possible plagioclase crystals as well as wool-like rutile

crystals and negative inclusions. The inclusions distinguish the sapphires from their Burmese counterparts. M.O'D.

CASSEDANNE, J-P., ALVES, J-N., 1992. L'aigue marine au Brésil (part 2). *Revue de gemmologie*, **111**, 11-14, 2 photos (1 in colour).

The second part of the paper discusses the classification and formation of pegmatites containing aquamarine. Simple, complex and intermediate types are postulated and described. M.O'D.

CASSEDANNE, J-P., ALVES, J-N., 1992. L'aigue marine au Brésil (part 2). *Revue de gemmologie*, **112**, 7-11, 2 photos (1 in colour).

The paper describes prospecting for aquamarine in the pegmatites of Brazil and discusses pegmatite age and formation. M.O'D.

COZAR, J.S., GARZON, J., 1992. Fluoruro de magnesio sintetico, en esmeralda sintética hidrotermal rusa. *Boletin del Instituto Gemológico Español*, **34**, 70-2, 5 photos in colour.

Tetragonal crystals of MgF_2 have been found in Russian hydrothermal emeralds. Energy-dispersive X-rays are used to demonstrate their presence. M.O'D.

COZAR, J.S., IBARRA, A., 1992. Centros de color en espinelas. *Boletin del Instituto Gemólogico Español*, **34**, 42-52, 8 figs (1 in colour), 5 photos in colour.

Defects and impurities in $MgAl_2O_4$ are discussed with reference to natural and synthetic stones. M.O'D.

CURTO MILA, C., FABRE FORNAGUERA, J., 1992. Fluorite and associated minerals from Asturias, Spain. *Mineralogical Record*, **23**, 1, 69-76, 14 photos (12 in colour), 1 map.

Some of the fluorites from a number of mines in Asturias, Spain, are of gem or ornamental quality. Details of the geology, mineralogy and associated minerals are given. M.O'D.

DE ALDECOA, M.A.I., SAPALSKI, C., 1992. Joyas españolas en la historia: siglos XVII y XVIII. *Boletin del Instituto Gemológico Español*, **34**, 63-9, 13 photos in colour.

Spanish jewels of the 17th and 18th centuries are described, examples being taken from a number of museums in Spain and abroad. M.O'D.

DIRLAM, D.M., MISIOROWSKI, E.B., TOZER, R., START, K.B., BASSETT, A.M., 1992. Gem wealth of Tanzania. *Gems & Gemology*, **28**, 2, 80-102, 27 figs.

Deals in some detail with diamond, Mwadui (formerly Williamson) Mine; ruby: Longido, Umba River and Morogoro; sapphire: all colours and change of colour, Umba River; zoisite: Merelani Hills, the purplish blue tanzanite and some yellow, reddish-brown and recently transparent green zoisite from the same area; garnet, including malaia (reddish orange) from Umba valley; tsavorite from the Tsavo National park in Kenya and from several Tanzanian sites including the Merelani Hills; rhodolite from many localities and colour-change pyrope/spessartine (blue-green daylight and purple-red in incandescent light) from Umba, other colour changes also known and illustrated; tourmaline in various types and many colours including the 'chrome' green now known to be due to vanadium, from various northern and eastern sites including Umba; emerald from Lake Manyara and Sumbawanga.

Other gems listed are actinolite, *alexandrite*, amblygonite, *amethyst*, andalusite, apatite, aquamarine, bronzite, chrysoberyl cat's-eye, chrysoprase, agates, etc., diopside, enstatite, epidote, euclase, feldspar, fluorite, hypersthene, idocrase, iolite, kornerupine, kyanite, malachite, pearls, peridot, phenakite, prase opal, quartz, rhodonite, *scapolite*, sillimanite, sinhalite, sphene, *spinel*, topaz, turquoise and *zircon*. Those italicized are dealt with briefly in this paper.

Writers suggest that the considerable gem potential could build to the great benefit of this impoverished country, but the health problem of the spread of HIV virus and AIDS challenges that effort. R.K.M.

DUCARRE, C-J., 1992. Gemmologie en Savoie (part 1). *Revue de gemmologie*, **111**, 3-4, 1 map, 4 figs.

Mineralization of the French Savoy Alps is discussed with particular reference to geological processes and mountain building. M.O'D.

DUCARRE, C-J., 1992. Gemmologie en Savoie (part 2). *Revue de gemmologie*, **112**, 3-6, 3 photos in colour, 1 fig.

Blue beryl, axinite, epidote and quartz from the Savoy area of France are described. M.O'D.

FREY, R., 1992. Jade and science. *Bulletin of the Friends of Jade*, 7, 56-69.

The development of modern methods of gem

testing is described with particular reference to the two jade minerals and their commoner simulants. M.O'D.

FRITSCH, E., WU, S-T., MOSES, T., MCCLURE, S.E., MOON, M., 1992. Identification of bleached and polymer-impregnated jadeite. *Gems & Gemology*, **28**, 3, 176-87, 14 figs.

Jadeite, bleached of iron-staining and impregnated with acrylic resin, possibly with added colour, to conceal cracks, is being offered in quantity in Taiwan and Hong Kong as natural coloured, RI and spectrum are right for jadeite, SG rather low and most treated stones will float in 3.32 liquid, while most untreated stones sink. Heat probe melts or burns filler. A spot of hydrochloric acid on an untreated stone will produce sweating near that spot.

Treated stones fluoresce faint bluish-white in LUV, white areas of untreated stone fluoresce yellow. Infrared spectrometry provides definitive test since acrylic filler gives sharp lines at 2900cm^{-1} and in the near infrared. Bleached/filled stones may fade. R.K.M.

FRYER, C.W., CROWNINGSHIELD, R., MOSES, T., HURWIT, K., KANE, R.E., 1992. Gem Trade lab notes. *Gems & Gemology*, **28**, 2, 123-8, 19 figs.

A fracture-filled diamond damaged by mount-repair heat confirmed prediction that sooner or later someone would fall into this trap. Diamonds without fillings may take repair heat but filled ones can suffer disastrously; this stone still had tell-tale 'flash-effect' even after it was damaged; filling material contains lead which is opaque to X- rays.

A 22.28 carat stone was the largest example of a chameleon type diamond (temporary change of colour on moderate heating) so far seen in the NY lab. A 'black' diamond with good polish proved to be an irradiated very dark green stone, polish too perfect for a natural black one, residual radio-activity would need some 36 years to reduce to US Nuclear Regulatory Commissions's low level requirement for legal sale.

A 5.56 carat 'emerald' with 'jardin' inclusions was a green YAG synthetic, singly refractive off-the-scale RI and SG 4.55 should have made the fraud obvious, 'jardin' was a mass of bubbles; crown glass imitations of crystals have been offered as 'healing stones' ['Crystal healing' is a health fad probably with little basis in fact]; a 'turquoise' with pitted surface was shown to be glass; a parcel of amethysts was found to contain a significant proportion of good paste, chalky-blue fluorescing, imitations with RI close to those of quartz (which did not fluoresce).

A black natural pearl was found off the coast of Baja California (La Paz, Mexico, formerly noted for such pearls, but not recently - the return of this type of oyster is obviously welcome); black dyed mabe blister pearls were proved by lifting colour with a swab of very weak nitric acid, LUV gave dull orange-red fluorescence, silver bromide was the colourant; nine large 'Geneva rubies' (early flame-fusion synthetics) were an unusual find for the NY lab; a sapphire with rubbed facet edges was a diffusion treated stone which would lose colour if repolished - the heat process is thought to make the surface brittle and more prone to wear, successive heatings, which are common with this treatment could increase this tendency; curved striae in synthetic orange or yellow sapphires, normally difficult to see, can be made more obvious by using a blue filter on the microscope light. R.K.M.

FRYER, C.W., CROWNINGSHIELD, R., MOSES, T., HURWIT, K., MCCLURE, S.F., 1992. Gem trade Lab Notes. *Gems & Gemology*, **28**, 3, 192-7, 18 figs.

Polymer-filled cavity in pavilion facet of alexandrite described and illustrated; in up-date of fracture filling in diamond new flash colours are noted; 6.90ct diamond, fractured in cutting, was filled but needed second and third treatment before polishing was complete, then two hour spell in ultra-sonic cleaner shattered and removed most of the filling, leaving flaw extremely visible; light pink diamond had ribbon-like etch features similar to laser holes but entrances were square, not round like laser drilling, and had to be inherent to the stone [transverse striation of holes also argues natural origin], stone graded I2 for lack of clarity.

A pair of jadeite earclips splice-repaired, cement fluoresced under UV; cat's-eye yellow opal had anomalous RIs of 1.45 and 1.47, X-ray diffraction showed cristobalite with amorphous background.

A shark pin made from an odd-shaped blister pearl was probably unbacked; large drop pearl was also hollow, filled with composite material; another large hollow pearl was the body of a gold and diamond owl pendant-seal; a black mabe pearl had been dyed with silver nitrate and had a crystalline filling.

A three-row necklace of 'ruby' beads was low-

grade sapphire, crackle-dyed red, no chromium absorption, but sapphire bands at 450 and 380nm were seen and another at 560 probably due to dye; a 125 carat greyish-green cabochon zircon, claimed to be world's largest, had a superbly sharp cat's-eye and exceptionally strong absorption spectrum. R.K.M.

GENDRON, F., 1992. 1492-1992 Les El Dorados gemmologiques américains. *Revue de gemmologie*, **110**, 15-16.

Materials used for ornament in the Americas from the 16th century are briefly discussed. M.O'D.

GROAT, L.A., HAWTHORNE, F.C., ERCIT, T.S., 1992. The chemistry of vesuvianite. *Canadian mineralogist*, **30**, 19-48, 23 figs.

Crystal chemistry and chemical variations in vesuvianite are studied from 76 samples from 54 different localities. A proposed general formula for boron-free vesuvianite is given as $X_{19}Y_{13}Z_{18}O_{68}W_{10}$ where X are cations occupying [8]- co-ordinate sites, Y are cations occupying [6]- and [5]- co-ordinate sites, Z are cations occupying [4]- co-ordinate sites and W are monovalent and divalent anions. M.O'D.

GÜBELIN, E., 1992. Dans la vallée des rubis. *Revue de gemmologie*, **111**, 5-8, 4 photos (2 in colour).

Mining operations in the Mogok region of Myanmar and details of rubies are discussed. M.O'D.

GÜBELIN, E., 1992. Green zoisite. (Letter). *Gems & Gemology*, **28**, 2, 140.

An objection to the use of the name 'green tanzanite' for the facetable green zoisite, reported in the Spring issue of The Journal, rightly points out that the Tiffany name 'tanzanite' belongs exclusively to the blue zoisite, and 'green tanzanite' is a horrible confusion of names. 'Green zoisite' is sufficient. R.K.M.

HÄNNI, H.A., 1992. Identification des fissures traitées. *Revue de gemmologie*, **110**, 10-12, 4 photos in colour.

Filled fissures in emeralds can be detected by a variety of tests which are summarized and illustrated. [Translated from the English]. M.O'D.

der Deutschen Gemmologischen Gesellschaft, **41**, 1, 17-19, 3 photomicrographs, 1 table, bibl.

The red garnets from Malawi (exact location of occurrence not known) were shown to be almandine-spessartine-pyrope-grossular mixed crystals. The garnets had unusual spherical aggregates as inclusions in the centre of the crystal, which were identified with the help of a scanning electron microscope as quartz and ilmenite. E.S.

HENN, U., BANK, H., 1991. Aussergewöhnliche Smaragde aus Nigeria. Exceptional emeralds from Nigeria. *Zeitschrift der Deutschen Gemmologischen Gesellschaft*, **40**, 4, 181-7, 1 photo in colour, 4 photomicrographs, 1 graph, bibl.

The emerald crystals from Nigeria are unusually well crystallized, some examples being crystallized at both ends. RI 1.569-1.576, DR 0.005-0.006, SG 2.65-2.67. chromium content of 0.06-0.11 weight % Cr_2O_3. The green colour is caused by a broad absorption spectrum band of Cr^{3+} as well as Fe^{2+} and Fe^{3+}. Beside distinct growth zoning two and three phase inclusions have been observed, the latter similar to those in Colombian emeralds. E.S.

HENN, U., BANK, H., 1992. Über die Eigenschaften von im Flussmittelverfahren hergestellten synthetischen roten und blauen Spinellen aus Russland. (About the properties of flux-grown synthetic red and blue spinels from Russia.) *Zeitschrift der Deutschen Gemmologischen Gesellschaft*, **41**, 1, 1-6, 8 photomicrographs, 1 table, 1 graph, bibl.

The values for RI are 1.716-1.719 and SG = 3.58-3.62, well within the limits of natural magnesium spinels. The colour is caused in the red stones by Cr^{3+}, in the blue by Co^{2+} which can be seen in the spectra. Microscopic studies show growth lines and tabby extinction as well as flux residues of different types and arrangements, some being of metallic origin, some being similar to the Lechtleitner and some producing two-phase inclusions. E.S.

HENN, U., BANK, H.,1992. Klar durchsichtiger, roter Labradorit aus Oregon, USA. (Clear transparent red labradorite from Oregon, USA.) *Zeitschrift der Deutschen Gemmologischen Gesellschaft*, **41**, 1, 49-51, 1

yellow, or yellow-red to reddish-brown and red. RII n_o =1.558, n_z=1.563, n_y=1.555, DR 0.008. SG 2.70. The chemical composition is 50.5% anorthite, 46.5% albite, 3% orthoclase. The deep red colour is caused by Fe, absorption band at 565nm. E.S.

HENN, U., REDMANN, M., 1991. Geschliffener, klar durchsichtiger, farbloser Katapleit von Mont Saint Hilaire, Kanada. (Cut transparent colourless katapleite from Mount St. Hilaire, Canada.) *Zeitschrift der Deutschen Gemmologischen Gesellschaft*, **40**, 4, 197-200, 1 photo under crossed nicols, 2 tables, bibl.

Katapleite is a hydrous sodium zirconium silicate which under normal temperatures crystallizes monoclinically and at 139°C hexagonally, Hardness 6, perfect cleavage; if calcium rich the colour is light yellow to brown, otherwise colourless to bluish. SG 2.72. RI 1.590-1.629, DR 0.039. Has an oily appearance under the microscope and shows irregular interference under crossed nicols. E.S.

HYRS, I.J., 1992. Die Mineralien der Alpin-Paragenese aus dem Nordural/Russlang. *Mineralien Welt*, **3**, 6, 59-62, 8 photos in colour, 1 map.

Minerals from Pripoljarnyi in the Urals include gem quality sphene and axinite as well as large specimens of phantom quartz. M.O'D.

KANE, R.E., KAMMERLING, R.C., 1992. Status of ruby and sapphire mining in the Mogok stone tract. *Gems & Gemology*, **28**, 3, 152-74, 26 figs.

A well illustrated account of this important source of gem corundum, dealing with history, geology, geographic location, nationalization, mining techniques (twinlons {narrow pits}, hmyawdwins {trenches}, loodwins {cavities in marble}), mechanisation including tunnelling, recovery, central crushing plant, production, manufacture and distribution, and other ruby occurrences in Myanmar. A valuable paper. R.K.M.

KOIVULA, J.I., KAMMERLING, R.C., FRITSCH, E., 1992. Gem news. *Gems & Gemology*, **28**, 2, 129-39, 17 figs.

Diamonds

Reports on diamond-claim rush at Lac de Gras in Canada's Northwest Territories; a diamond technical symposium in Israel; diamond bearing kimberlite pipes in Ukraine; small industrials near Tashkent; De Beers/Republic of Sakha (Yakutia) sales agreement; R.E. Kane's visit to alluvial diamond mines at Longlands, SA; agreement on prospecting and mining between De Beers and Tanzania; Zaire output reduced by a third, regulations tightened to reduce smuggling.

Coloured Stones

Californian exhibit of exotic beetles showed 107 different iridescent species which may be used in jewellery in one part of the world or another; cat's-eye golden beryl, possibly irradiated, is illustrated; a Cairo museum exhibits garnet-set Greco-Roman jewellery; largest jadeite boulder weighing estimated 33 tonnes is displayed outside Myanmar Gems Enterprise in Yangon (Rangoon); further reports on Vietnam rubies; iron nickel meteorite is sliced, etched and mounted as jewellery; black mabe 'pearls' made from nautilus shell are again on offer; a visit to Mont St Hilaire quarry, near Montreal, for red-brown villiaumite, carletonite, hackmanite, natrolite, sphalerite, catapleiites, orange serandites, albites, pectolites, burbankite, shortite, cryolite, and colourless vesuvianite [idocrase]; Tajikistan, (Pamirs), now independent, is to develop gem potential, including fine marble, spinel and lapis lazuli.

Enhancements

Acrylic spray coating for stones which do not take a good shine results in unnatural glassiness especially in recessed carving, coatings can be scraped off or dissolved by acetone; massive beryl/quartz is being heat-quench dyed to resemble charoite, sugilite, turquoise or coral, dye concentrated in surface fissures easily seen; aquamarine and other beads enhanced by dyeing the string and the stringing hole and by heat-quench dyeing; a 'concrete' Andamooka sandstone opal is blacked by sugar/acid treatment and then toughened with a plastic; silver nitrate, smoke and black plastic have also been used to give a black ground to porous opal; a local preference in Egypt for greenish turquoise is met by oiling the blue material to the required colour.

Synthetics and Simulants

Another sawn and hollowed beryl crystal (from Bogota) filled with green liquid and cemented together again, was detected when a cutter tried to saw it and it bled green; more information on Russian opaque CZ gives RIs about 2.14 to 2.165; bicolour red CZ is described and illustrated; many glass imitations of Paraiba tourmaline crystals have been

encountered, one from Bogota is illustrated; Vietnamese parcels of blue sapphire rough have been found to contain large crystals of blue spinel, and parcels of ruby rough continue to be found with significant admixtures of 'water-worn' Verneuil synthetics, immersion tests are essential for both rough and cut parcels; synthetic sodalite was among several synthetics from Academia Sinica (China), this is colourless but irradiates to a good blue.

Instrumentation

Hanneman Gemological Instruments are offering a cheaper simulant of the expensive quartz wedge used to determine optic sign in microscopic work. R.K.M.

KOIVULA, J.I., KAMMERLING, R.C., FRITSCH, E., 1992. Gem news. *Gems & Gemology*, **28**, 3, 198-209, 22 figs.

Diamonds

New extraction plant near Alexander Bay, S. Africa, operates on sea-water; at Lac de Gras, Canada, a 160 ton sample of ore yielded 101 carats of diamond, 25 per cent gem quality; British Crown Jewels, including Cullinan I [and II] and Koh-i-Noor diamonds, are to be brought up to ground floor level in the Tower of London in 1994; India is to increase diamond mining in collaboration with Australia; mining at Jwangeng, Botswana, is to expand; alluvial diamonds found near Momeik and Theindaw, Myanmar, are being cut in Yangon; Venetia mine, N. Transvaal, is operating and forecasts 5 million carats of rough a year; Belgian owned Hai Duong diamond factory, Vietnam, is polishing ready-sawn rough for return to Antwerp.

Coloured Stones

An amber is illustrated with 'insect inclusion' engraved on its base; Russians marketing heat-improved Baltic amber in Hong Kong; 'Glory Blue' chalcedony is reported from Montana; a Madagascan crystal had a corundum centre covered concentrically with green spinel and blue sapphirine; green crystals from Merelani Hills, home of tanzanite and green zoisite, were chrome diopside; opalized iron-stone is being used for carvings; an egg of rare mansfieldite, a new ornamental rock from Algeria, has been cut in Germany, looks like variscite.

Pearl shell is reported from Baja, California; also pearls from a Spanish galleon, badly damaged by long immersion; a liquid-filled cultured pearl reported earlier is now illustrated; Venezuelan investigations towards pearl cultivation have begun, using good nacre producing *P. radiata* oysters.

Longido ruby from Tanzania usually suitable only for cabochons, but a small deep red faceted brilliant is illustrated, about 6 carats of such stones may be expected from 20 tons of rough; Iankaroka, Madagascar, is producing parti-coloured sapphires in pale blue and orange-brown, some of them magnetic; small crystals of green sphalerite [blende] were found in Pennsylvania; a green tourmaline from Paraíba had a cascade of metallic yellow inclusions.

Enhancements

Large Thai parcels of 'natural coloured' cabochon sapphires are being salted with diffusion treated stones; at Tucson a kit was offered for fracture-filling emeralds with green dye; update on crackle-dyed emerald-green quartz reports they are convincing table-up but cracks easy to see base-up over white card, test as quartz, dye thought to be green Opticon which gives absorption from 660-690nm, no chromium lines; a ruby crystal was coated with amorphous red spinel, SG about 3.75, strong red luminescence in UV, RI and spectrum [surprisingly] typical of corundum.

Synthetics and Simulants

A new Czochralski-pulled 'alexandrite' is marketed as Allexite, colour-change bluish-green to reddish-purple similar to fine Brazilian alexandrite, curved striae seen, RI 1.740-1.749, SG 3.72, red luminescence very marked; green glass made from fused rock from Mt St Helens with added colorants is still being offered; scratched assembled stone looked like badly oriented alexandrite, had red centre enclosed by green glass; flame-fusion synthetic rubies, offered as natural stones at Mae Sot on the Thai/Burma border, have been quench-fractured and crudely cut to aid deception; an imitation opal with moulded plastic 'faceted' crown, backed by patterned diffraction foil was offered at recent gem show; about 100 specimens were seen in Germany of a composite crystal consisting of a zoned tourmaline slice cemented to coloured glass. R.K.M.

KUMARATILAKE, W.L.D.R.A., RANASINGHE, U.N., 1992. Unusual corundum bearing gem pockets at Avissawella and Getahetta, Sri Lanka. *Zeitschrift der Deutschen Gemmologischen Gesellschaft*, **41**, 1, 7-16. 2

maps, 2 photos, 4 diagrams, bibl.

For the last four decades peculiar kinds of corundum bearing pockets have been found in various localities, the main one being at Thalduwa in Avissawella in church premises. Extraction is primitive. There are two types of these pockets, corundum bearing pockets and hollow type pockets, the former yielding mainly patchy sapphires (which could probably be heat treated and turned into blue), some yellow and a few blue sapphires, while the latter only yields iron pyrite. The corundum bearing pockets also yield iron pyrite and dark orange brown tourmaline crystals. E.S.

LAFON, J-M., COLLYER, T.A., SCHELLER, T., 1991. Datierung der Smaragdmineralisationen der Granite von Campo Formoso und Carnaíba, Bahia. (Dating of emerald mineralization of the granites of campo Formoso and Carnaíba, Bahia. First results). *Zeitschrift der Deutschen Gemmologischen Gesellschaft*, **40**, 4, 241-6, 2 maps, 1 graph, 1 table, bibl.

An age of 1851 +/- 48 Ma has been obtained for five samples of phlogopites associated with the emerald mineralization of Campo Formoso and Carnaíba granitic bodies. This agrees with the radiometric ages obtained from these granitic rocks. Furthermore, the age of the phlogopites represents a cooling temperature of about 400°C which is the maximum temperature for the crystallization of gem quality emeralds. E.S.

LASNIER R., POIROT, J-P., VIDAL P., 1992. Essais de datation et détermination de l'origine des eméraudes par la méthode rubidium-strontium. *Revue de gemmologie*, **110**, 27-9, 1 fig.

Rubidium-strontium dating techniques are applied to the identification and characterization of emerald from different localities and of synthetic emerald. M.O'D.

LI YINGPING, 1992. Jade mining at Khotan from Chinese historical records. *Bulletin of the Friends of Jade*, 7, 29-39.

Jade mining at Khotan has taken place over the centuries and Chinese records have been used for this short study. Mining goes back at least 3,000 years; a list of references is given. M.O'D.

LYCKBERG, P., 1992. Eine reise zu den klassischen Edelstein-pegmatiten von Mursinka und Alabaska sowie zu den Smaragdvorkommen im Bereich von Takovaja im Ural. *Mineralien Welt*, **3**, 6, 68-79, 18 photos (10 in colour), 1 map.

As Russian gem-bearing areas are gradually opened up once more, details are given of some of the locations and of the species that are found at them. They include beryl, topaz, tourmaline, amethyst as well as a variety of minerals for the collector. Geological details are briefly given. M.O'D.

NASSAU, K., 1991. The seven types of yellow sapphire and the proposed Ponahlo test. *Zeitschrift der Deutschen Gemmologischen Gesellschaft*, 40, 4, 247- 51, bibl.

The fading behaviour of yellow sapphire with respect to light can be quite variable, depending on the nature of material and origin of colour. The author lists the seven different types of sapphires and shows that the cathodoluminescent test proposed by J. Ponahlo can only predict the fading behaviour of some types of yellow sapphire. E.S.

NASSAU, K., ROSSMAN, G.R., WOOD, D.L., 1992. Unstable radiation-induced yellow-green colour in grossular garnet. *Gems & Gemology*, **28**, 3, 188-91, 3 figs.

Pale grossularites from a few African localities were irradiated to a light to medium yellowish-green, a colour which faded rapidly in daylight and in about two months in the dark. Mechanics of the fade are explained. Colour too fugitive to have commercial significance. R.K.M.

NIEDERMAYR, G., 1992. Das Einschlussbild von Smaragden aus Serpentinit-Randgesteinsserien (Smaragde vom Typus Habachtal). *Mineralien Welt*, **3**, 5, 46-7, 4 photos in colour.

Habachtal emerald contains hornblende and biotite crystals as well as a variety of colour patterns and cracks. The relationship between the emerald and its host rock is discussed. M.O'D.

PERNY, B., EBERHARDT, P., RAMSEYER, K., MULLIS, J., PANKRATH, R., 1992. Microdistribution of Al, Li and Na in quartz: possible causes and correlation with short-lived cathodoluminescence. *American mineralogist*, 77, 534-44, 5 photos (3 in colour), 8 figs.

Secondary ion mass spectrometry has been used to identify the distribution of Al, Li and Na in natural quartz crystals looking at individual growth layers which are identified by cathodoluminescence and artificial γ irradiation.

Changes of trace element concentration by more than 3 orders of magnitude were observed on a scale of a few tens of micrometres. Zones showing intense but short-lived blue luminescence contain the highest Al and Li concentrations with no luminescence shown by regions with low concentrations. The pronounced variability in the phenomena is attributed to conditions of growth (fluctuations of temperature, pressure, pH and composition of growth fluids during growth). M.O'D.

PLATONOV, A.N., SACHANBINSKI, M., WROBLEWSKI, P., IGNATOV, S.I., 1992. Natural prasiolite from Lower Silesia, Poland. *Zeitschrift der Deutschen Gemmologischen Gesellschaft*, **41**, 1, 21-7, 1 photo, 4 graphs, bibl.

Prasiolite is the green, transparent holocrystalline variety which can be obtained by heating certain varieties of quartz up to 400-600°C. Naturally occurring prasiolites were discovered in quartz agate geodes in trachybasalts in the sedimentary-volcanic complex of Lower Silesia. The green colour is distributed unevenly throughout the stone and is caused by Fe seen in the absorption band at 725nm. When heated to 400-500°C the green colour turns to brown. The authors suggest that the colour is primary as a result of specific physico-chemical parameters in the quartz forming solution. E.S.

POIROT, J-P., 1992. Spectrometrie et fluorescence X, des aides pour la détermination de types de gisement de saphirs. *Revue de gemmologie*, **110**, 7-9, 15 figs.

X-ray spectroscopy and X-ray fluorescence have been used to determine the origin of sapphires from different localities, which include Burma, Sri Lanka, Kashmir, Vietnam, Madagascar, Thailand, Australia and France. Heated sapphires are also cited. [Translated from the English]. M.O'D.

PONZONE, A., 1991. Studi termici sulle inclusioni fluide in corindoni di Sri Lanka. *La gemmologia*, **16**, 1, 7-16, 10 photos in colour.

Chemical composition and physico-chemical properties of Sri Lanka corundum are investigated on the basis of thermal treatment of inclusions. M.O'D.

READ, P.G., 1991 - 1992. A four-part series of articles on gemstone enhancement methods. *Canadian Jeweller*.

Part 1 - Foiling, dyeing and impregnation. October 1991. 24. Covers historic enhancement techniques, and more recent wax, plastic and oil impregnation methods.

Part 2 - Heat treatments can enhance color. January/February 1992. 24-5. Describes the standard centuries-old heat treatment processes and the more recent high-temperature methods employed with geuda corundum and its detection.

Part 3 - Not all enhancement techniques are equal. March 1992. 24-5, 1 fig. This section includes the less permanent colour enhancement techniques employed with surface-diffused and irradiated corundum. Permanent irradiation methods including those used for topaz and diamond are also discussed.

Part 4 - Artificially-coloured diamonds can be detected. April/May 1992. The final part of the series deals with the irradiation/heat treatment, glass filling and lasering of diamonds, and its detection. (Author's abstracts) P.G.R.

ROBERT, D., 1992. Reseau cristallin des grénats. *Revue de gemmologie*, **110**, 23-4, 1 fig., 2 photos in colour.

A synthetic garnet with the trade name Oulongolite is discussed. Specimens have the YAG or GGG composition with various dopants. M.O'D.

SALERNO, S., 1992. Minéraux et pierres de Madagascar. *Revue de gemmologie*, **111**, 9-10, 1 photo in colour.

Polychrome sapphires are reported from Madagascar. First thought to be alexandrite, the zoned crystals (green and red) had RI 1.770-1.778 and 1.762-1.770 for the ordinary and extraordinary rays respectively with a birefringence of 0.008-0.009, and a specific gravity of 4.0. The mine is in the Betroka area; the corundum occurs with cordierite, tourmaline and biotite. Extraction of the corundum crystals without damage is said to be very difficult. M.O'D.

SAPALSKI, C., GOMEZ, F., 1992. Estudio de la esfalerita de la mina de Aliva, Santander (España). *Boletin del Instituto Gemólogico Español*, **34**, 29-39, 27 photos in colour, 2 maps.

Sphalerite of gem quality in colours ranging from light yellow and green to red is found at the Aliva Refuge mine, Camaleño, Cantabria, Spain. The sphalerite occurs with calcite.

Gemmological tests are used to identify the material which very frequently contains colour zoning, negative crystals and a variety of liquid inclusions. M.O'D.

SCHÄFER, W., HENN, U., SCHWARZ, D., 1992. Smaragde aus de Kesselklamm, Untersulzbachtal, Osterreich: Vorkommen und Eigenschaften. *Aufschluss*, **43**, 231-40, 3 maps, 4 figs, 3 photos in colour.

The Untersulzbachtal, celebrated for many years for fine crystals of epidote from Knappenwand, has produced some emerald. It was found in 1988 in a serpentine-talc lying to the south west of an already known beryl-producing area (Leckbachrinne). It is accompanied by biotite and muscovite and actinolite/tremolite crystals appear as inclusions together with them. Constants are given as n_e 1.580-1.582, n_o 1.588-1.590, DR 0.008, SG 2.72-2.73. Cr_2O_3 content varies from 0.01 to 0.38. M.O'D.

SCHLEE, D., PHEN HOCK CHAN, DORANI, J., FOOK KUNG VOONG, 1992. Riesenbernsteine in Sarawak, Nord-Borneo. *Lapis*, **17**, 9, 13-23, 23 photos (19 in colour).

Ornamental quality amber has been found with coal deposits in Sarawak, North Borneo, Malaysia. Specimens illustrated show long subparallel flow lines and colours range from white through colourless, pink, orange, red, yellowish-green, blue, violet, brown and black. Between 5-10% of the amber recovered is suitable for fashioning. M.O'D.

SCHLÜSSEL, R., 1991. Die Saphir-Lagerstätte von Bo Ploi in der Provinz Kanschanaburi, Thailand. (The sapphire occurrence at Bo Ploi in the Province of Kanchanaburi, Thailand.) *Zeitschrift der Deutschen Gemmologischen Gesellschaft*, **40**, 4, 165-80, 2 maps, 4 photographs, 10 photomicrographs, 1 table, bibl.

The occurrence of sapphires in Bo Ploi has been known since 1920; these were worked in small scale workings rarely larger than 15-15 sq.m. and varying in depth from 4 to 20 metres using similar methods to those used in most primitive gem producing countries. In the last fifteen years, however, the district has been worked more mechanically and the sapphires are found over an area of 100 sq.km. Today this is the most important production of sapphires in Thailand. Bo Ploi lies roughly 120km east-north east of Bangkok, near the border and near to the River Kwai bridge. The sapphires are dark to middle blue and do not require heat treatment. They are found together with black spinel. 46 rough and 135 faceted stones were examined. Mineral inclusions were mainly of colourless, tabular prismatic elongated crystals of feldspar surrounded by a halo; partly recrystallised healing fissures produce triangle shaped patterns; healing fissures and liquid-filled feathers can show interference colours. Oriented rutile needles have also been observed. E.S.

SCHLÜSSEL, R., 1992. L'identification au microscope des diamants aux cavités artificiellement colmatées à l'aide d'une substance vitreuse. *Revue de gemmologie*, **111**, 15-17, 5 photos in colour.

Methods of identifying glass-filled cavities in diamonds are discussed. M.O'D.

SCHMETZER, K., HÄNNI, H.A., JEGGE, E.P., SCHUPP, F-J., 1992. Dyed natural corundum as ruby imitation. *Gems & Gemology*, **28**, 2, 112-15, 6 figs.

A new imitation ruby was made from pale or colourless natural corundum with dye-filled heat and quench cracks. Early examples had colourless areas easily seen by eye; improved specimens need immersion and magnification to detect colour in cracks, and uncoloured areas.

No fluorescent line at 695nm, but iron bands were seen in the blue and ultraviolet regions; dye fluoresced a strong orange-yellow in LUV but was inert in SUV; acetone swab did not lift it. Corundum probably from Umba in Tanzania. R.K.M.

SCHWARZ, D., 1991. Geologie und Genese der Smaragdvorkommen in der Cordillera Oriental/Kolumbien. (Geology and genesis of the emerald occurrences in the Eastern Cordilleras, Colombia). *Zeitschrift der Deutschen Gemmologischen Gesellschaft*, **40**, 4, 201-31. 2 maps, 2 schematic sketches, bibl.

The author gives a detailed description of the regional and local geological conditions of the eastern Cordilleras in Colombia. Different genetic models of the emerald mineralisation are discussed. There are still some questions open for discussion, i.e. the temperature and composition of the mother solution and the origin of the element Be or of the Be-carrying solution (syn- or epigenetic). E.S.

SCHWARZ, D., 1992. Die chemischen Eigenschaften der Smaragde IV. Kolumbien. (The chemical properties of emeralds IV. Colombia). *Zeitschrift der Deutschen Gemmologischen Gesellschaft*, **41**, 1, 29-47, 7

tables, 6 graphs, bibl.

The emeralds examined were from Muzo, Coscuez, Yacopi, Chivor, Gachala and some other not specified occurrences. Ninety emeralds were subjected to a microprobe. The results of the chemical analyses are discussed and correlated. The amount in variation and concentration of chromium, vanadium, iron, magnesium and sodium in these Colombian emeralds are summarised. They seem to have the lowest iron and magnesium content of all examined emeralds. E.S.

SHERNAKOW, W.I., LASKOWENKOW, A.F., 1991. Grosse Smaragdkristalle aus den Gruben des Ural, UdSSR. (Large emerald crystals from the mines in the Urals, USSR). *Zeitschrift der Deutschen Gemmologischen Gesellschaft*, 40, 4, 189-95, 1 photo, 1 geological map, 1 crystallographic diagram, bibl.

The Ural emeralds usually have a hexagonal, prismatic habit - the hexagonal crystals being somewhat distorted. The colour is a rich green with bluish and yellowish hues, the intensity of the colour being dependent on the chromium content. A few especially large and beautiful emerald crystals are described in details, such as the 3369.5 ct. weighing 'Slavnyi Uralaski', eighty per cent of which are of gem quality; the 6.55 kg heavy crystal group 'Miner's Glory', the particularly beautiful 'Nowogodni' and 'Swesdar' and a number of other famous emeralds. Together with the emeralds alexandrites, phenakites and chrysoberyls are found. There are also some rare minerals such as brommelite, euclase, bertrandite and bowenite. E.S.

SHIGLEY, J.E., FRITSCH, E., REINITZ, I., MOON, M., 1992. An update on Sumitomo gem-quality synthetic diamonds. *Gems & Gemology*, **28**, 2, 116-22, 9 figs.

Two 5 carat slices of Sumitomo synthetic diamond, from cube and octahedral crystals respectively, revealed colour zoning, graining, strain and luminescence reflecting their initial crystal habits. Crystal morphology is thought to affect the properties. Material is used for industrial heat-sinks, etc., and is not intended for jewellery use. Both samples were inert to LUV but gave weak orange-yellow under SUV, a reaction which may be seen in type Ib natural diamonds. Cathodoluminescence emphasizes growth patterns. The cube sample was type Ib. The octahedral sample was found to be a mixture of types Ib+IIa+IIb diamond, so far not seen in natural diamond. R.K.M.

SOSSO, F., ROMAN E., 1002. Les améthystes d'Artigas (Uruguay). *Revue de gemmologie*, **110**, 13-14, 3 photos (2 in colour).

Amethyst from Artigas, Uruguay, is described with notes on its occurrence and properties. [Translated from the English]. M.O'D.

SUPERCHI, M., 1992. Trésors de l'art italien. Analyse gemmologique. *Revue de gemmologie*, **110**, 17-19, 4 photos in colour.

Three jewelled artefacts made in Italy are discussed gemmologically. M.O'D.

TOURET, L., 1992. Les pegmatites de Volhynie (Ukraine). *Revue de gemmologie*, **110**, 25-6.

Pegmatites of the Volhynie area of the Ukraine produce feldspar, quartz, yellow beryl and blue and pink topaz. M.O'D.

WANG TAO, 1992. Recent discoveries and research of ancient jade in PR China. *Bulletin of the Friends of Jade*, 7, 38-41.

A report that suggested that jadeite may have been found in Eastern Zhou tombs in Luoyang but a loose usage of the Chinese word yu shows that this is not the case. Poor documentation of sites hinders work on mineral or artefact occurrences. M.O'D.

WEIDINGER, W.A., 1992. More on alcohol damage to amber (Letter). *Gems & Gemology*, **28**, 2, 140.

Provides three further references to amber damaged by alcohol, ether and similar solvents (hair-sprays, perfume, etc.). R.K.M.

ZABINSKI, W., 1991. Transvaal 'Jade'. *Zeitschrift der Deutschen Gemmologischen Gesellschaft*, **40**, 4, 233-9, 2 tables, 1 graph, bibl.

The name Transvaal jade is given to a green grossular/hydrogrossular with some vesuvianite; the pink material consists also of grossular/hydrogrossular with different lattice parameters. The green is caused by the presence of Cr, the pink by Mn. E.S.

ZWAAN, P-C., 1992. La kornerupine d'Embilipitiya, Sri Lanka. *Revue de gemmologie*, **110**, 5-6, 2 photos in colour, 1 map.

Kornerupine is found at Embilipitiya in the south of Sri Lanka. SG=3.284, RI=1.660, 1.672. Black and red rutile crystals are found as inclusions in cut stones. [Translated from the English.] M.O'D.

Book Reviews

BALFOUR, I., 1992. *Famous diamonds.* Second edn. NAG Press, Colchester. pp. 245, illus. in black-and-white and in colour. £29.00.

The first edition of this book was well received and as so often happens sparked off the discovery of several more outstanding stones! Considerable attention is given to the superb Centenary diamond, weighing in its cut form 273.85ct and the largest diamond to be cut by the application of the most modern techniques. The colour picture of the faceted stone shows, as few diamond photographs do, some of the dispersion of this beautiful stone. It was found in 1986 at the Premier mine and weighed 599ct in the rough.

Other stones, such as the pink Kirti-noor have only recently come to public attention (it is a Golconda stone and has been in a private collection in India until recently). Some, such as the 'Unnamed Brown' have no name (this stone is now a modern fire-rose cushion shape of 545.67ct from a rough crystal weighing 755.50ct; the cut stone is a very high 72.2 per cent of the original weight).

As in the previous edition the text surrounds black-and-white and coloured photographs and the price is most reasonable for so interesting a book. M.O'D.

HOOVER, D.B., 1992. *Topaz.* [Butterworths Gem Books.] Butterworth-Heinemann, Oxford. pp. xiv, 207, illus. in black-and-white and in colour. £35.00.

Some topaz may be triclinic and some physical and optical values may be more dependent on locality and formation than upon colour. This study of topaz is particularly readable with a lucid style and very extensive references. Many new concepts similar to those opening this review are presented with sustainable evidence.

The book opens with a study of the derivation of the word 'topaz' and of the occurrence of the mineral in historical accounts. Large and notable topaz gemstones and crystals are described before an account of topaz chemistry, crystal structure, optical properties, physical properties, colour and luminescence. Next comes a description of topaz crystal morphology and of inclusions. Topaz geology and a summary of world sources complete the book.

Early on the author discovered that the substitution of the hydroxyl ion for fluorine in the topaz structure affects the crystallography and properties in hitherto unrealized ways and this theme is followed throughout this book which all gemmologists should possess.

M.O'D.

JOYCE, K., ADDISON, S., 1992. *Pearls, ornament and obsession.* Thames and Hudson, London. pp. 253, illus. in black-and-white and in colour. £38.00.

An uninformative introduction by Sumiko Mikimoto precedes a very attractive, illustrated book with a fairly general text. The survey covers the use of pearls in a variety of contexts with emphasis on costume; this is well illustrated by a number of reproductions of portraits in which pearls are prominent. The historical material has to be selective but is well put together and interesting to read. There is a reasonably useful bibliography and a much less useful glossary. Read the book for the pictures at least; the flowery style disguises quite a lot of valuable information and has to be waded through.

M.O'D.

KOCKELBERGH, I., VLEESCHDRAGER, E., WALGRAVE, J., 1992. *The brilliant story of Antwerp diamonds.* MIM n.v., Antwerp. pp. 303, illus. in black-and-white and in colour. BF2,895.

A book illustrating the history of Antwerp in celebration of its position as Cultural Capital of Europe 1993 and forming part of the 'Ortelius' series gives a great deal of information on the history of the city. The text is easy to read, with several pictures on each page: they include reproductions of significant documents and of portraits with many illustrations of famous diamonds. The diamond trade has done much to maintain Antwerp's favourable trading position and although work on small goods has

largely moved to India the presence in the city of the Diamond High Council will help to ensure the continuance of Antwerp's domination of the European diamond handling and polishing trade. M.O'D.

MARSHALL, D.J., 1988. *Cathodoluminescence of geological materials.* Unwin Hyman, Boston. pp. xiv, 146, illus. in black-and-white and in colour. £65.00.

Over the past few years cathodoluminescence has been advocated as a useful gemmological test. Here the whole range of geological materials, including gemstones, has been subjected to energetic electrons and the most significant results are detailed in a way which is easy to understand. History and instrumentation of the method are outlined first with definitions and a survey of the results obtained from some common minerals arranged by classes. The cathodoluminescence of the feldspar and quartz group is extensively described, each group having a chapter of its own; the carbonates are similarly treated. The cathodoluminescence of gemstones has a page of its own; there is an appendix outlining the photographic methods used in the various tests. An excellent bibliography completes the book.

Even though the treatment of gemstone cathodoluminescence is small, the general text contains much to interest the gemmologist. Not least in importance is the description of the ways in which different types of luminescence are caused and the review of a large number of individual species under test. M.O'D.

NABARRO, F.R.N. (ed.), 1992. *Dislocations and disinclinations. Dislocations in solids.* North-Holland, Amsterdam. Vol. 9, pp. x, 424, illus. in black-and-white. US$208.50.

With chapter numeration continuing from the first eight of the series, this volume deals with a summary of the advances in the electron microscopy of dislocations, the study of internal friction derived from kinks in dislocations lying in Peierls valleys, dislocation dynamics in face-centred cubic and body-centred cubic metals. An overview of rotational deformation is given with an exhaustive bibliography. Many of the topics discussed will be of great interest to crystal growers. M.O'D.

ROCK, N.M.S., 1991. *Lamprophyres.* Blackie, Glasgow. pp. viii, 285, illus. in black-and-white. Approximately £60.00.

From a gemmological point of view lamprophyres sprang into prominence with the discovery that the supposed kimberlite pipe, which provides many gem and industrial quality diamonds at Kimberley, Western Australia, is a lamprophyre now known as the Argyle pipe.

The first section of the book offers a history of the term lamprophyre; the suffix -phyre is correctly used in this context to denote a porphyritic character. The term was first used in 1874 for a rock characterized by glistening phenocrysts first described from the German Fichtelgebirge. Recent studies have begun to suggest that lamprophyres form a vital insight into the deep mantle and mantle processes and thus into the formation of materials such as diamond and gold. The term lamproite was coined in 1923 to describe extrusive rocks of lamprophyric aspect. Lively discussion of the nature of lamprophyres continues and several classifications have been postulated; in one hierarchical scheme kimberlites are placed with four other rock types in the first order, within which many other smaller categories are distinguished. From the mineralogical aspect the assemblage of minerals is probably that part of the lamprophyre topic of greatest interest; lamprophyres carry essential amphibole and/or biotite-phlogopite and also abnormal amounts of minerals rich in F, Cl, SO_3, CO_2 and H_2O. Mg-rich mafic minerals such as diopside and forsterite are found with Na-K feldspars and some quartz. Tremolite actinolite phases, for example, found in some igneous rocks, are not found in lamprophyres. Chapter 9, dealing with economic geology, will be found particulary interesting to gemmologists as it includes a table of diamondiferous lamprophyres excluding kimberlites. At the time of writing, some kimberlites at least, had been reclassified as lamproites and the premise made that lamprophyric rocks are the only confirmed magmatic sources of diamond.

There are other chapters of interest but the main feature is a very extensive bibliography. There is also a table of confirmed occurrences of different types of lamprophyres. This type of work, which will inevitably attract considerable discussion and amendment, is the type of study upon which our gemmological investigations ultimately depend, particularly at the prospecting and recovery end. M.O'D.

Proceedings of The Gemmological Association and Gem Testing Laboratory of Great Britain and Notices

GIFTS TO THE GAGTL

The Association is most grateful for gifts of gems and gem materials for research and teaching purposes from the following:

Miss Mary J. St Amand, FGA, of Sausalito, California, for moonstone from Mexico.

Mary Burland for synthetic rubies.

MEMBERS' MEETINGS

London

The following meetings, that have been held in the GAGTL's new Gem Tutorial Centre on the second floor at 27 Greville Street, London EC1N 8SU, have proved very successful and have attracted a 'full house' on every occasion.

On 25 January 1993 Michael O'Donoghue gave a talk on 'Gems of Pakistan'. A number of the gems mentioned were on display for the evening.

On 8 February 1993 Ana I. Castro and Stephen Kennedy gave an illustrated talk on 'Emeralds in the Laboratory'.

On 24 February Peter Read gave a talk entitled 'New gem testing instruments'.

On 8 March 1993 Dr Alan Collins gave an illustrated talk on the 'Colour in diamonds', bringing those present up-to-date with current research on the subject.

On 31 March 1993 David Callaghan gave a talk entitled 'From gem to jewel'.

Midlands Branch

On 27 January 1993 at Dr Johnson House, Bull Street, Birmingham, Edgar Taylor gave a talk entitled 'Fossicking in Wales'.

On 26 February 1993 at Dr Johnson House, Robert Campbell-Legg spoke to members on 'The art of the engraver'.

On 26 March 1993 at Dr Johnson House, Peggy Stock gave a talk entitled 'Crystal healing'.

North West Branch

On 20 January 1993 at Church House, Hanover Street, Liverpool 1, David Pelham gave a talk on 'Mines and mineral deposits of South Africa'.

On 17 February 1993 at Church House the video 'Gemstones of America' was shown.

On 17 March 1993 at Church House, Richard Digby gave an illustrated talk on 'Cameos and intaglios'.

GEMSTONE INCLUSIONS

A set of 30 display pictures of gemstone inclusions is available for sale. Recently they formed a travelling exhibition and consist of 40 x 29 cm prints mounted in glass/hardwood frames (67 x 54 cm) with explanatory captions.

For full details contact C.R. Burch, FGA, at 4 West Moor Drive, Cleadon, Nr Sunderland, Tyne and Wear SR6 7TW. Telephone 091-536 2386.

MEETINGS OF THE COUNCIL OF MANAGEMENT

At a meeting of the Council of Management held on 13 January 1993 at 27 Greville Street, London EC1N 8SU, the business transacted included the election of the following:

Fellowship

Bakker, Frederik C.S., Zwaagdijkwest, The Netherlands. 1992
Leung, Florence Lai Ping, Hong Kong. 1992
Spanbok, Gary, Edgware. 1992
Winkelmolen, Karin, Beesel, The Netherlands. 1992
Zaveri, Pragnesh, Bombay, India. 1992

Ordinary Membership

Cho, Eun-Kyung, Seoul, Korea.
Crane, Simone, London.
Kalischer, Janice, London.
McIntosh, Robert P., Penicuik.
Ruhmer, Fiona, Brackenbury Village, London.
Woodbridge, Roger, Upminster.

At a meeting of the Council of Management held on 17 February 1993 at 27 Greville Street,

GAGTL GEM TUTORIAL CENTRE

27 Greville Street, London EC1N 8SU

Diamond Grading Weekend Course
8-9 May 1993
For retailers, valuers and those involved in trading diamonds, who need an insight into gem diamond grading, simulants and treatments.
Price £210.00 + VAT

Identifying hardstone carvings
11 May 1993
Price £90.00 + VAT

A day of pearls
12 May 1993
Price £90.00 + VAT

Preliminary questions and answers
14 May 1993
The chance for Preliminary examination candidates to find out from tutors and examiners what is required of them in the examination.
Price £15.00 including VAT

A day of beads and stringing
20 May and 8 July 1993
For anyone who wishes to investigate the great variety of beads, natural or artificial, and the intricate methods for stringing beads or pearls.
Price £90.00 + VAT (inclusive of materials)

Diploma Workshop
1-2, 5-6, 8-9 and 19-20 June 1993
Two days of intensive practical tuition for students approaching examinations, with a mock exam; also suitable for those who need intensive gem therapy.
Price £125.00 + VAT for two days
GAGTL students £85.00 + VAT

Enquire within - Ornamental rocks
15 July 1993
A day looking at all aspects of ornamental rocks. Includes a short walk around the Hatton Garden area discovering materials used in buildings.
Price £90.00 + VAT

Enquire within - Organic gem materials
22 July 1993
A day looking at all aspects of organic gems, natural, treated and imitation.
Price £90.00 + VAT

Two days of diamonds
15-16 September 1993
For an insight into the gem diamond origins, grading, simulants and treatment.
Price £190.00 + VAT

Preliminary Workshop
12-14 October 1993
One-day practical tuition for Preliminary students and anyone who needs a start with instruments, stones and crystals.
Price £38.00 + VAT
GAGTL students £27.00 + VAT

For further information contact the GAGTL Education Department on 071-404 3334.

London EC1N 8SU, the business transacted included the election of the following:

Fellowship

Bruciak, Thomas M., Venice, Fla., USA. 1986
De Ruiter, Jacoba E., Waddinxveen, The Netherlands. 1992
Kim, Jong Pil, Seoul, Korea. 1992
Lu, Milton R.K., Taipei, Taiwan. 1983
Sohn, Jeong Sun, Seoul, Korea. 1992
Tenhagen, Joseph W., Miami, Fla., USA. 1969
Wong, Min Wan, Kowloon, Hong Kong. 1992

Ordinary Membership

Aikawa, Atsuko, Heusenstamm, Germany.
Beesley, C.R., New York, NY., USA.
Bell, Martin, Albuquerque, N.Mex., USA.
Bendingham, Michiko, Tokyo, Japan.
Boehm, Edward, Carlsbad, Calif., USA.
Bruns, Frederik H., Tucson, Ariz., USA.
Crevoshay, George, Upton, Mass., USA.
Gaskell, Benjamin H., London.
Guest, Vanessa A., Arnold, Nottingham.
Harada, Kayoko, Kanagawa Pref, Japan.
Ikuta, Miwa, Kyoto, Japan.
Inoue, Keiko, Osaka, Japan.
Ishida, Masako, Osaka, Japan.
Kanamori, Tomohiro, Osaka, Japan.
Kaneda, Kenichiro, Hyogo Pref, Japan.
Kashi, Kenya, Osaka, Japan.

FORTHCOMING MEETINGS

London

Throughout 1993 there is a programme of meetings on the second floor at 27 Greville Street. Refreshments will be available from 6.00 p.m. and lectures will start at 6.30 p.m.; these will be followed by discussion and closing about 7.45 p.m. The charge for a member will be £3.50 and, as places are limited to 55, entry will be by ticket only, obtainable from GAGTL.

11 May	'Engraved Gems'	Christopher Cavey
14 June	Reunion of Members, AGM and 'Bring and Buy'	
20 September	'Photographing minerals and gems'	Frank Greenaway
6 October*	'Diamonds in the Laboratory'	Eric C. Emms
8 November	'Thai evening'	Amanda Good and Martin Issacharoff
22 November	'CIBJO matters' - the gem trade in Europe	Harry Levy
7 December*	'Pearls in the Laboratory'	Ana I. Castro and Stephen Kennedy

* PLEASE NOTE: 'Diamonds in the Laboratory' is one week later and 'Pearls in the Laboratory' is one day earlier than previously scheduled.

Midlands Branch

30 April	Annual General Meeting followed by a gem collection talk

The meeting will be held at Dr Johnson House, Bull Street, Birmingham. Further details from Gwyn Green on 021-445 5359.

North West Branch

19 May	'Lalique jewels, from the 1992 Paris Exhibition'	Dr J. Franks
16 June	Members and friends evening. Bring and buy: crystals, books and instruments, and exchange of views	
15 September	Jonathan Condrup from Sotheby's	
20 October	'Minerals in the Bronze Age'. The Great Orme Mine.	Tony Hammond
17 November	Annual General Meeting	

Meetings will be held at Church House, Hanover Street, Liverpool 1. Further details from Joe Azzopardi on 0270-628251.

Kimura, Michihoko, Hiroshima Pref, Japan.
Kitawaki, Hiroshi, Saitama Pref, Japan.
Kitawaki, Junko, Osaka, Japan.
Kobayashi, Masahide, Osaka, Japan.
Kodama, Aki, Osaka, Japan.
Kokubu, Ozusa, Tokyo, Japan.
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Lee, Kyung Hae, Fukuoka Pref, Japan.
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At a meeting of the Council of Management held on 17 March 1993 at 27 Greville Street, London EC1N 8SU, the business transacted included the election of the following:

Transfer to Fellowship and Diamond Membership
Bakagianni-Sabou, Aristea, Nikea-Piraeus, Greece. 1993
Gofa, Sophia, Athens, Greece. 1993
Hare, Rebecca, Fleet. 1993
Prior, Louise, London. 1993
Scott, Kenneth M., Cleghorn. 1993
Diamond Membership
Lupton, Elaine, Paddock Wood. 1992

Fellowship
Koetsier, Anya, Maida Vale, London. 1992
Van Keulen, Simone J.C., Amsterdam, The Netherlands. 1992

Ordinary Membership
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Bollack, Josee, Strasbourg, France.
Carson, Michael J., Boston.
Jones, Donald, London.
Karmali, Amin, Wembley.
Levinson, Alfred A., Calgary, Alberta, Canada.
Pattni, Himat H., Chilwell, Nottingham.
Proudlove, David, Ardfern, Argyll.
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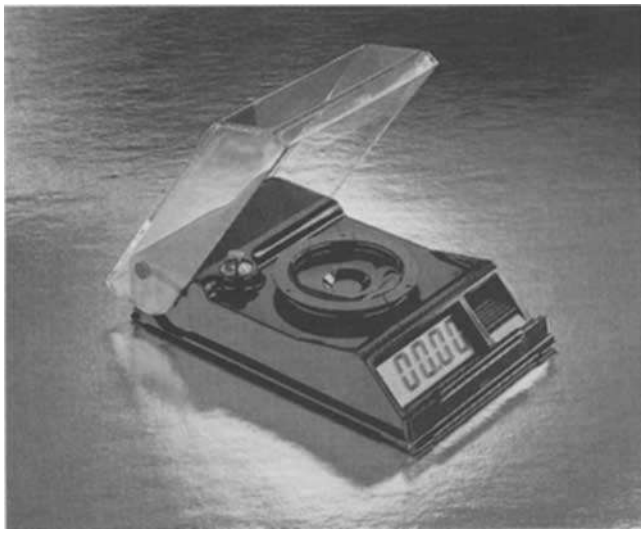

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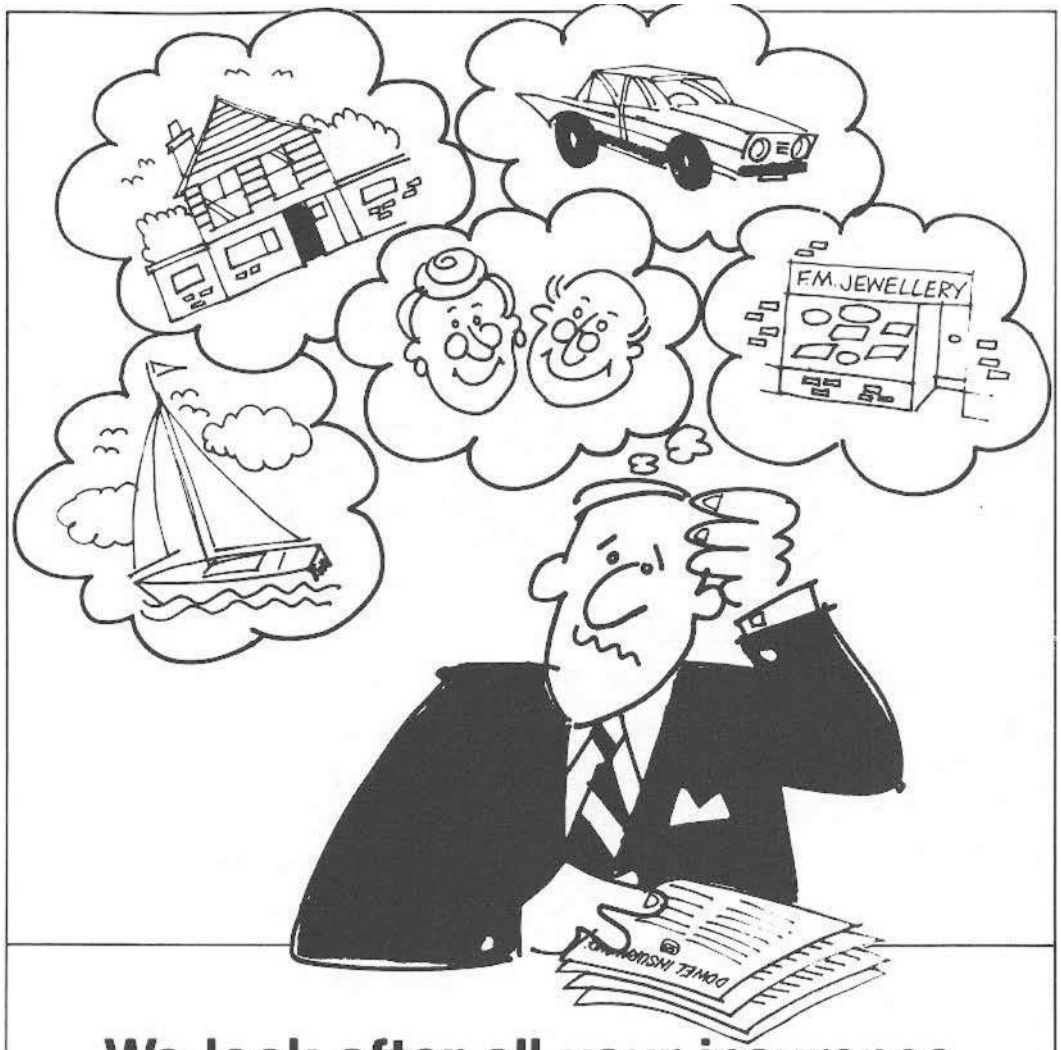

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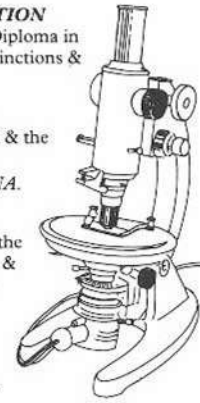

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The Editors are glad to consider original articles shedding new light on subjects of gemmological interest for publication in the *Journal*. Articles are not normally accepted which have already been published elsewhere in English, and an article is accepted only on the understanding that (1) full information as to any previous publication (whether in English or another language) has been given, (2) it is not under consideration for publication elsewhere and (3) it will not be published elsewhere without the consent of the Editors.

Papers should be submitted in duplicate on A4 paper. They should be typed with double line spacing with ample margins of at least 25mm all round. The title should be as brief as is consistent with clear indication of the content of the paper. It should be followed by the names (with initials) of the authors and by their addresses. A short abstract of 50–100 words should be provided. Papers may be of any length, but long papers of more than 10 000 words (unless capable of division into parts or of exceptional importance) are unlikely to be acceptable, whereas a short paper of 400–500 words may achieve early publication.

Twenty five copies of individual papers are provided on request free of charge; additional copies may be supplied, but they must be ordered at first proof stage or earlier.

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The Editors of the *Journal* invite advertisements from gemstone and mineral dealers, scientific instrument makers, publishers and others with interests in the gemmological, mineralogical, lapidary and jewellery fields.

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Enquiries to Mrs M. Burland, Advertising Manager, Gemmological Association, 27 Greville Street, London EC1N 8SU.

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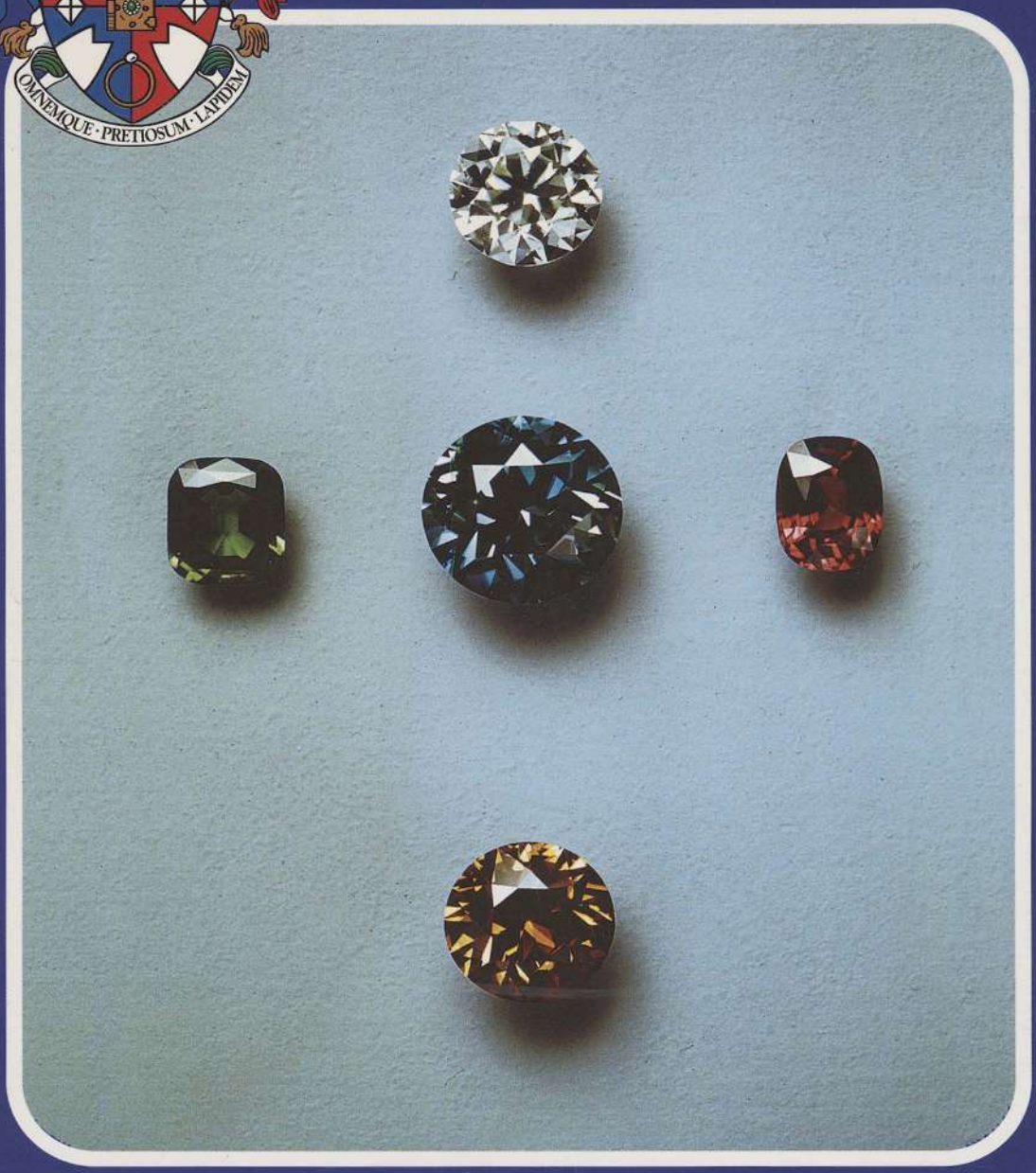

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The Journal of Gemmology

VOLUME 23

NUMBER SEVEN JULY 1993

Cover Picture

A series of cut zircons; the heat-treated stones are from Indo-China and weigh 21.32 ct (colourless), 33.34 ct (blue) and 27.58 ct (brownish-orange). They have been on exhibition for many decades and have not changed colour. The other stones are from Sri Lanka and are not treated; they weigh 9.85 ct (green) and 12.34 ct ('red'). All are on exhibition in the former Geological Museum, London. *Photo E.A. Jobbins.*

ISSN: 0022-1252

GAGTL ANNUAL CONFERENCE

24 October 1993

Great Western Royal Hotel,
Paddington, London

Inclusions

The theme of the Annual Conference this year is 'Inclusions' and we are pleased to announce that Dr E. Gübelin will deliver the keynote lecture. This will include newly discovered inclusions in gemstones and also a discussion on treated diamonds.

The theme will be continued with reports of recent work on Burmese and Vietnamese rubies and sapphires by Alan Jobbins, also of the range of Montana sapphires, treated and untreated, by Michael O'Donoghue. Both speakers have made recent visits to these producing areas.

Other items include lectures by Philip Sadler, who will outline the part played by gems in his investigations as a forensic scientist, and by Stephen Kennedy who will be talking about pearls and pearl fishing in the Arabian Gulf.

Throughout the day delegates will have the opportunity to view displays and participate in practical demonstrations.

GAGTL Open Day

The conference will be followed on Monday 25 October by an Open Day at the GAGTL Gem Tutorial Centre.

For further details and a booking form please contact:

Miss Linda Shreeves at GAGTL on 071 404 3334
(Fax 071 404 8843)

Zircon: a study of material donated by Mr W.C. Buckingham from various localities (mainly Indo-China)

Edinburgh Gemmological Group[1]

Introduction

In 1988 Mr W.C. Buckingham, FGA, donated his fine collection of rough and preformed zircons to the Gemmological Association of Great Britain. These zircons were to be made available to FGAs for research purposes, provided researchers complied with stipulated criteria namely:

1. the rough specimens originate from various localities, mostly Indo-China, and the research might be directed towards determining any variation in properties from the different localities. However, other research topics would be considered;
2. having carried out the research programme, the Fellow must present the results in the form of a paper which would, in the opinion of the Editor, be worthy of publication in *The Journal of Gemmology*.

This paper outlines investigations directed towards determining possible variation in properties of the zircons.

There were 12 packets of zircons which, in toto, weighed 1420.4 grams and a further 36.9 grams of selected material. The latter was mostly marked as having been worked on by Basil Anderson.

Ten stones were randomly selected from each packet. These constituted the samples. To help investigations and RI measurements windows were polished on the stones. The descriptions and results are set out in Table I.

Optical Data and Specific Gravity

Refractive indices were measured using a Rayner Diamond Table Refractometer with West's Solution as the contact liquid. Difficulties arose because of the liquid's viscous nature and toxicity. Table II details results, each of which is the sample average. Samples 2, 5, 7 and 12, had been heat-treated once. Samples 3, 4, 8, 10 and 11 had been heat-treated twice. Samples 1, 6 and 9 were untreated. Apart from samples 4, 5 and 12, all fell within the range for high zircon (1.925 - 1.984).

Specific gravity was determined by hydrostatic weighing. Anomalous specific gravity readings were queried and it was noted that the results had

Table I: Location and appearance of zircons tested

Packet No.	Mine & location	Notes
1	Looi mine, Kha district	Natural state as found
2	Looi mine, Kha district	Blue-coloured after initial heating
3	Looi mine, Kha district	Bleached white after second heating
4	Looi mine, Kha district	Tending to golden after initial heating
5	Hau Tek mine, Kha district	Finest. Only white after initial heating
6	Various, Champasak district	White stones after full heating
7	Various, Champasak district	Pre-heated to facilitate inspection for cracks and inclusions before main heating
8	Various, Champasak district	As above (packet 7) after final heating
9	Pailin district	Natural colour as found. Produces only white after heating
10	Looi mine, Kha district	After heating roughly shaped for faceting
11	Looi mine, Kha district	Bleached white after heating: roughly shaped for faceting
12	Various, Champasak district	After heating roughly shaped for faceting

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Table II: Properties of zircons from various localities in Indo-china

Mine/ District	Sample No.	Colour	RI	DR	SG	Dichroism	SWUV	LWUV	Phosphor-escence	Heat-treated	Observed absorption spectrum
Looi/Kha	1	strong gold	1.923-1.983	0.060	4.670	gold - light gold	None	None	None	No	General absorption of the red and blue/violet. Two specimens displayed an absorption line near 660 nm.
Looi/Kha	2	mid blue	1.923-1.969	0.046	4.719	blue - colourless	None	None	None	Yes	Produced absorption lines in the red at 590nm and single line or pair at 653 nm. Four examples showed a line at 525nm.
Looi/Kha	3	colourless	1.923-1.984	0.061	4.657	nil	None	Mustard	None	Yes	Pairs of absorption lines at 653 nm and a single line at 600 nm. In 80% of the packet there was a line at 525 nm present.
Looi/Kha	4	golden	1.922-1.982	0.060	4.555	nil	Mustard	None	None	Yes	General absorption of the red, but also showed a vague line at 653 nm. There was also a general absorption of the blue/violet.
Looi/Kha	10	blue	1.922-1.973	0.051	4.615	sky blue - colourless	None	None	None	Yes	600 nm line and pairs or single lines at 653 nm with further absorption lines at 525 nm.
Looi/Kha	11	colourless	1.922-1.979	0.056	4.593	nil	Mustard	Mustard	None	Yes	Persistent absorption line at 600 nm. There was also a single or double line at 550 nm, 500 nm and in 5 cases a single line at 490 nm .
Hau Tek/Kha	5	gold tinged white	1.922-1.982	0.060	4.45	nil	Orange	Orange	None	Yes	Showed a line or group of lines at 653 nm, 600 nm, and 5 stones showed a line at 525 nm. There was also a general absorption of the blue/violet.
Various Champasak	6	red	1.922-1.982	0.060	4.679	red - light red	Dull orange	None	None	No	No distinct absorption lines although there was general absorption of the blue/violet.
Various Champasak	7	orangy-white	1.922-1.982	0.060	4.695	nil	None	Orange	None	Yes	Line at 653 nm and, in four specimens, general absorption of the blue/violet.
Various Champasak	8	colourless	1.923-1.983	0.060	4.654	nil	None	Orange	None	Yes	General absorption of the blue/violet region. All specimens showed a doublet at 653 nm, a single line at 660 nm and a single line at 640 nm. In addition, all samples gave a single line 600 nm in the orange and a line at 550 nm. All specimens showed a line in the green area at 525 nm but four stones showed multiple lines in that region. Two stones displayed a doublet in the blue at 475 nm while four others only showed a single line.
Various Champasak	12	colourless	1.922-1.982	0.060	4.334	nil	Orange	Orange	None	Yes	General absorption of the blue/violet region. A distinctive line at 653 nm could be seen in most specimens as well as additional lines in the red. All samples displayed a line at 600 nm in the orange and most stones showed a line at 580 nm in the yellow region. All stones gave a line at 630 nm with a few stones giving additional lines in that area. With the exception of one specimen all samples showed lines in the blue region at 465 and 470nm.
Various Pailin	9	pale brown	1.921-1.982	0.061	4.649	pale brown-faint brown	Orange	Orange	None	No	No visible spectrum

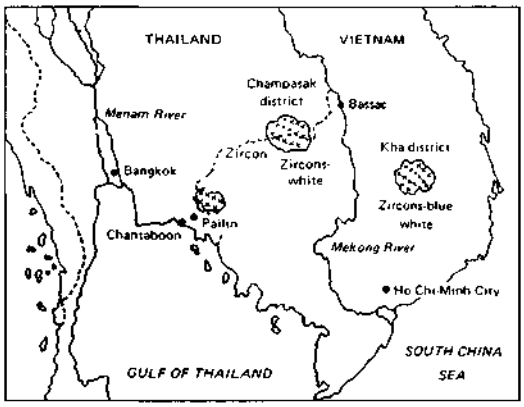

Map 1. Location of zircon mines (after Anderson, 1990).

been influenced, primarily, by the presence of adhering matrix or, to a minor extent, by inclusions. The results were within the general range for both high and intermediate zircons.

Heat treatment did not materially affect the refractive index or specific gravity of the stones.

Fluorescence and phosphorescent effects

The samples were examined in long-wave ultraviolet light (LWUV) and short-wave ultraviolet light (SWUV) to determine any fluorescent and/or phosphorescent effects. The results are compared with those in the literature and recorded in Table II.

Locality and amount of heat treatment were the only known variables. The Looi mine zircons gave mixed results. Untreated stones (sample l) showed no fluorescence . After initial heat treatment stones that turned blue (samples 2 and 10) did not fluoresce, whilst those that turned yellow fluoresced mustard under SWUV (sample 4). Stones that had been heat-treated twice, thereby rendering them colourless (samples 3 and 11), fluoresced mustard under LWUV, whilst sample 11 also fluoresced mustard under SWUV. The effects of heat treatment and fluorescence are clearly linked.

The other Kha district stones (sample 5) were recorded as turning colourless after a single heat treatment. These fluoresced orange under both long- and short-wave UV.

Champasak district stones also showed a link between fluorescence and heat treatment. Untreated stones did not fluoresce whilst those heat-treated once (sample 7) or twice (samples 8 and 12) fluoresced orange under LWUV. Only sample 12 showed additional orange fluorescence under SWUV.

Untreated Pailin district stones showed an orange fluorescence in both long- and short-wave UV.

Some of the heat treated stones had a skin that phosphoresced bright yellow. When this was removed by grinding no phosphorescence was observed. The skin was attributed to the surface fusion of phosphorescent material during heat treatment.

These results are similar to those recorded by Anderson (1964) and Webster (1983); the varying intensity of the fluorescence influencing the colour tone.

Spectroscope results

The assignment of a band or line to an exact wavelength is not possible, given the variable resolution of the prism spectroscope. The wavelengths cited in Table II are, therefore, a combination of accurately measured values reported by Anderson (1964), Webster (1983) and O'Donoghue (1988) and those estimated by the Edinburgh Gemmological Group. The results are set out in Table II.

Zircons are known to possess some of the most varied absorption spectra of all gemstones. The most persistent line is in the red at 653.5nm and the number of lines increases with the uranium content. In his study of Ceylon (Sri Lanka) zircons Anderson (1964) noted that the breakdown of the crystal structure can be clearly followed by the gradual deterioration of the uranium absorption bands. Sharp lines displayed by normal, fully crystallized zircon are replaced by weaker and vaguer development of the same bands until, with complete structural breakdown, metamict zircon displays merely a vague band in the red near 650nm sometimes accompanied by a narrow band in the green at 520nm. The latter band is not seen in normal zircon. Heat treatment of intermediate zircons will enhance the sharpness of the spectrum lines. Samples 8, 11 and 12 exhibited similarities to the anomalous spectrum produced by heat-treated low zircons (Anderson, 1990).

Infrared spectra of zircon

Variation in the infrared spectrum of zircon correlates directly with the degree of ordering of the atomic lattice. High zircons, which are well-ordered, display several sharp absorption bands (Figure l). The three strong, sharp absorptions at 434, 386, and 318cm^{-1} represent crystal lattice vibration while those at 980 and 902cm^{-1} represent stretching modes of the $[SiO_4]^{4-}$ anion and at 610cm^{-1}, a bending mode of the $[SiO_4]^{4-}$ anion. Metamict stones, which have poor ordering, display two broad absorption curves (Figure l).

All IR spectra were consistent with a well-ordered atomic structure. There were, however, small but significant differences between the

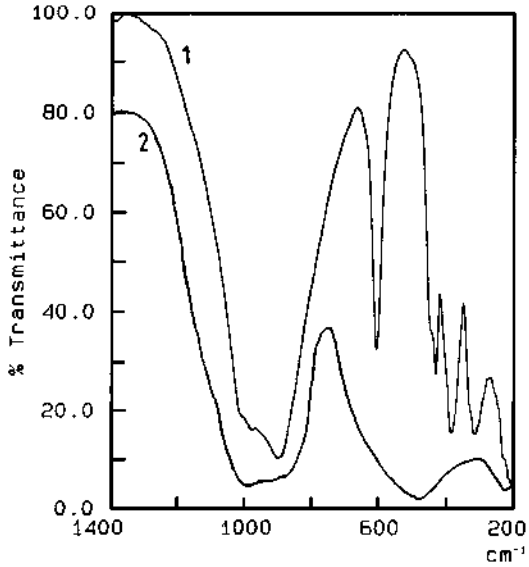

Fig. 1. 1. Infrared spectrum of zircon with well crystallized atomic structure.
2. Metamict zircon spectrum constructed from examples in the literature.

spectra of untreated and heat-treated stones.

Between 340cm^{-1} and 260cm^{-1} heat-treated stones showed a series of subtle absorptions of variable intensity superimposed upon the fundamental absorptions seen in untreated stones (Figure 2). This was attributed to crystal lattice absorption effects resulting from enhanced ordering following heat treatment. The subtle absorptions occurred at 330, 320, 308, 294 and 284cm^{-1}. Confirmation of heat treatment of colourless, blue and red zircon is not normally attempted, it being automatically assumed that such material has been heat-treated (Nassau, 1984). The IR spectrum of zircon provides confirmatory evidence of heat treatment in the absence of the anomalous visible spectrum described by Anderson (1990).

Inclusions

Tension fractures form the major internal feature of all the zircons. In many cases these were filled with secondary iron oxide staining which, in one specimen where the staining reached the surface and could be removed, was identified by X-ray diffraction as goethite. Curved and healing fractures were also common.

Colour zoning parallel to the prism faces {100} and {010} was only rarely seen (Figure 3) and only in untreated stones.

A dark brown inclusion extending to the surface proved, on X-ray analysis, to be ferrian spinel (specimen 2/10) (Figure 4). A specimen from the Looi mine was broken in order to expose a similar opaque inclusion. Unexpectedly, this revealed a

Fig. 2. Infrared spectra of: 1. heat-treated zircon from the Looi Mine; 2. untreated zircon from the Looi mine.

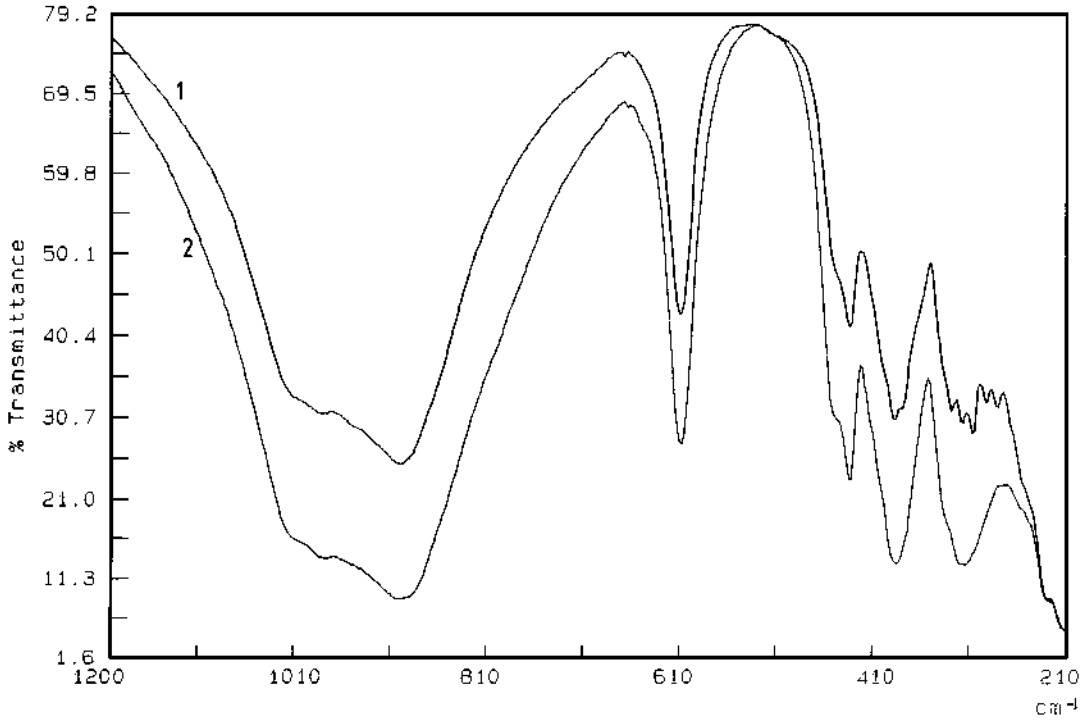

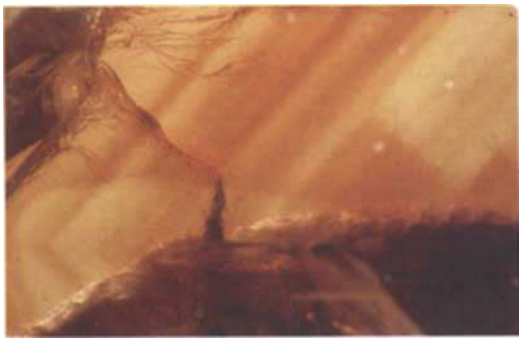

Fig. 3. Colour zoning intersecting at 90°.

Fig. 4. Distorted crystal of ferrian spinel in highly fractured blue zircon.

cavity the walls of which were covered by a dark coating. Inside, partially filling the cavity, was a dark grey mineral debris* (Figure 5). Spot analyses of the debris gave varying ratios of iron, aluminium and silicon which could not be assigned to any particular mineral species. Several grains (100μm to 150μm) contained only zirconium and therefore thought to be baddeleyite (ZrO_2). The baddeleyite occurs close to the zircon host and suggests a possible reaction phenomenon. High magnification of the dark-grey mineral debris revealed a sponge-like matrix,the voids of which contained light coloured partial-spheres <1μm across (Figure 6). Analyses*, detailed in Table III, could not be readily assigned to any known mineral and it is possible that more than one phase may be present. A search of an interactive mineral identification program (MinIdent-PC) using the matrix analysis in Table III gave 85.6% and 83.8% probability match for

Fig. 7. Heat-treated zircon showing bubbles around thermally decomposed inclusion.

* Analysed using a Link Systems AN100000 system with energy dispersive Si(Li) detector on a CamScan scanning electron microscope (SEM).

Fig. 5. Scanning electron microscope (SEM) photograph of debris-filled cavity in fractured zircon.

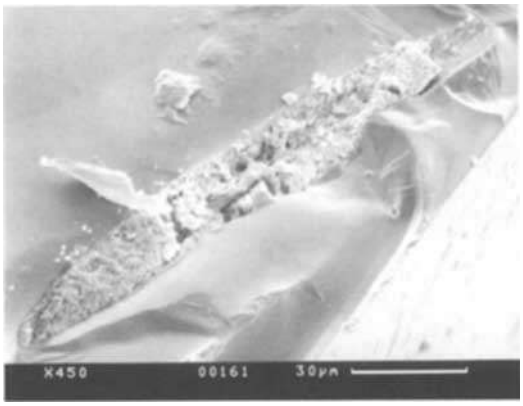

Fig. 6. Scanning electron microscope (SEM) photograph of the groundmass showing sponge-like form with white spheres.

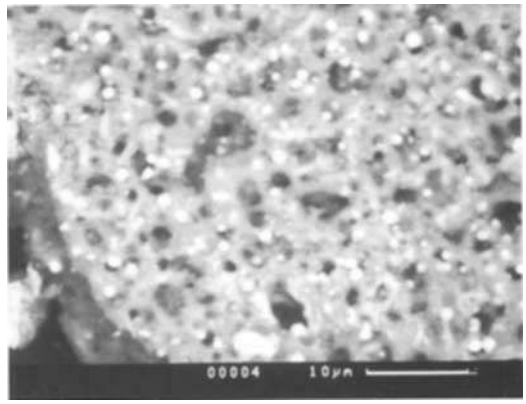

Table III: Analyses of inclusion material

	Partial-spheres	Spongiform matrix
SiO_2	13.12	47.65
TiO_2	00.98	03.16
ZrO_2	00.00	00.00
Al_2O_3	13.69	37.69
Cr_2O_3	00.05	00.23
FeO*	62.49	08.89
CaO	00.18	00.69
K_2O	00.05	00.21
P_2O_5	09.15	01.41
Cl	00.28	00.07
-O=Cl	0.06	0.02
Total	99.93	99.98

* The valence state of iron is assumed be 2+

cordierite and minerals in the cordierite-sekaninaite [$Mg_2Al_4Si_5O_{18}$-$(Fe,Mg)_2Al_4Si_5O_{18}$] series respectively. The partial spheres could not be identified with confidence. The frothy, sponge-like appearance of the dark grey matter suggested the emission of gases. This supports the view that there has been a reaction between the inclusion and the host zircon probably brought about by thermal decomposition during heat treatment. The elements present in ferrian spinel and zircon are also those contained in baddeleyite and cordierite-sekaninaite. Such reaction features (Figure 7) can show bubbles around the inclusion.

Other inclusions were black, distorted hexagonal plates of biotite and apatite crystals.

Conclusions

Application of the various tests failed to establish the existence of locality specific criteria.

Whilst there is evidence to support a correlation between fluorescence, locality and degree of heat treatment, the anomalies dictate that caution should be exercised. Fluorescence should be used neither as a clear-cut test for locality assignment nor, because of the anomaly shown by sample 9 under LWUV, as categorical evidence of heat treatment. Fluorescent effects of zircons from other localities would also have to be examined before refining views on fluorescence as a potential locality or heat treatment indicator.

Whilst the extent of heat treatment on the Indo-China samples clearly influenced the absorption spectra (colourless stones showing the strongest spectra), no correlation between spectra and location could be established. There was no discernible difference in the absorption spectra between the Indo-China zircons and those described by Anderson (1964) from Sri Lanka..

Infrared spectra could not be used to provenance the zircons although its use in heat treatment determination may prove useful.

It was not possible to assign particular inclusions to any specific locality.

Acknowledgements

The authors would like to thank Mr W. C. Buckingham and the Gemmological Association and Gem Testing Laboratory of Great Britain for allowing us to work on the specimens and their patience during the course of this study. Thanks are also due to Mr Paul Wilthew of the Conservation and Analytical Research Laboratory of the National Museums of Scotland for all SEM and analytical work. Karl Bank is thanked for his contributions at an early stage in the work.

Note

1. The Edinburgh Gemmological Group (EGG) is an informal group of FGAs who meet to discuss and investigate gemmological topics. The EGG members who collaborated in the preparation of this paper are: James 'Mac' Heatlie, Yvonne Holton, Brian Jackson, Alistir Tait, Euan Taylor, James Walker, Margery Watson and Tom Watson.

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[*Manuscript received 1 January 1993*]

Flux-grown synthetic rubies from Russia

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Introduction

Russia and some other states of the former Soviet Union are well known as producers of various synthetic stones, e.g. synthetic amethyst, emerald, alexandrite, spinel and diamond. Synthetic ruby was first mentioned by the authors in 1990. The dark red synthetic material (Figure 1) showed an aggregate-like, grained texture with few homogeneous parts which are facetable. The largest piece of rough weighed 30 ct. Microscopical studies yielded black bubble-like residues of the flux (Figure 2).

The existence of synthetic rubies of Russian production permitted the supposition that gem quality material would come up very soon. Finally in 1992, the first cut synthetic rubies from Russia were observed. Peretti and Smith (1993a) mentioned faceted specimens up to 1. 69 ct. and reported that the synthetic rubies were hydrothermally-grown. A detailed description of that material together with the chemical and physical properties was published by the same authors (Peretti and Smith, 1993b). Also in 1992, the authors of this article saw a faceted synthetic ruby said to be flux-grown from Russia and in January 1993 they received two rough crystals of synthetic ruby. The supplier, a colleague from the Academy of Sciences of Novosibirsk, where the synthetic specimens are produced, stated that the synthetic rubies were produced by using a flux technique.

The present article summarizes the properties of these flux-grown synthetic rubies of Russian production and emphasizes the important distinguishing features from natural rubies.

General appearance

The two rough crystals of synthetic ruby are quite different in visual appearance in both crystal habit and colour.

Type 1 (Figure 3) has an elongated, tabular prismatic habit and weighs 63.8 ct. The colour is pale red with a high homogeneity.

Type 2 (Figure 4) possesses a rhombohedral crystal habit, weighs 22.6 ct. and has a dark red colour.

Crystallographic description

The type 1 synthetic ruby crystal (tabular prismatic) shows a well-developed second-order hexagonal prism $a(11\bar{2}0)$ and less distinct positive rhombohedron $r(10\bar{1}1)$ and basal pinacoid $c(0001)$.

The rhombohedral type 2 synthetic ruby shows well-developed crystal faces with the positive rhombohedron $r(10\bar{1}1)$, second-order hexagonal prism $a(11\bar{2}0)$, second-order hexagonal bipyramid $n(22\bar{4}3)$ and basal pinacoid $c(0001)$.

Chemical composition

Chemical analyses carried out by EDAX-eds system fitted on a scanning electron-microscope proved the two synthetic ruby crystals from Russia to contain aluminium oxide and chromium oxide as main components. The tabular prismatic type 1 synthetic crystal shows 99.72 wt. % Al_2O_3 and 0.28 wt. % Cr_2O_3 and the rhomhohedral type 2 synthetic ruby 98.48 wt. % Al_2O_3 and 1.52 wt. % Cr_2O_3.

Refractive indices, birefringence and density

Using a standard gemmological refractometer, the refractive indices have heen determined for both type 1 and type 2 synthetic ruby: type 1: n_e=1.760 and n_o=1.768; type 2: n_e=1.762 and n_o=1.770. The birefringence of both specimens is 0.008. The optic sign is uniaxial negative.

The density has been measured by using a hydrostatic balance. The data determined vary between 3.98 and 4.01 g/cm^3. It must be remembered that the inclusions (flux residues) substantially influence the values of the density.

Absorption spectrum and pleochroism

The synthetic ruby crystals of Russian production show typical absorption spectra of Cr^{3+}. The

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Fig.1. Aggregate-like, polycrystalline synthetic ruby from Russia, first described in 1990 (weight of the large piece 28 ct).

Fig.4. Rhombohedral synthetic ruby crystal of Russian production (type 2), weighing 22.6 ct.

Fig.2. Black, bubble-like flux residues in the polycrystalline synthetic Russian ruby material. x20.

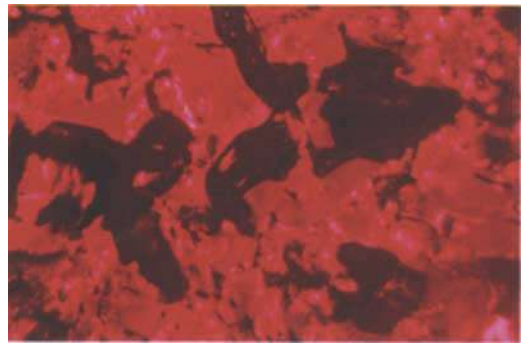

Fig.3. Elongated, tabular prismatic synthetic ruby crystal (type 1) from Russia, weighing 68.8 ct.

Fig.5. Black, opaque flux residues in a synthetic ruby from Russia. x10.

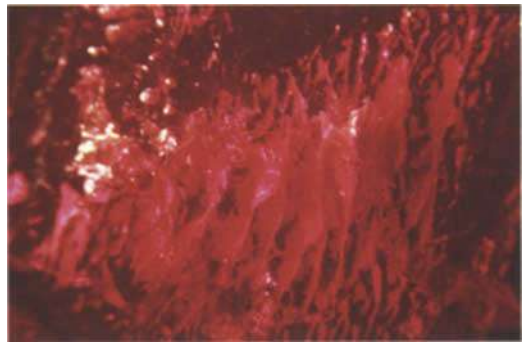

Fig.6. The flux residues of Figure 5 under darkfield illumination.

Fig.7. Flux residues in a synthetic ruby from Russia. x15.

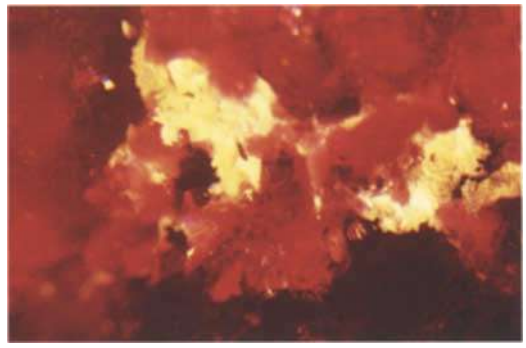

Fig.8. Yellow residues of the lithium tungstate flux at the surface of the type 2 synthetic ruby crystal from Russia. x10.

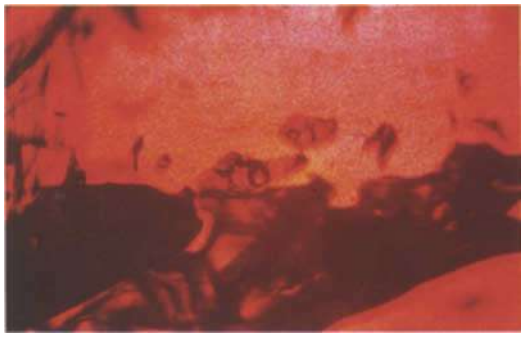

Fig.9. Cavities filled by flux residues. x20.

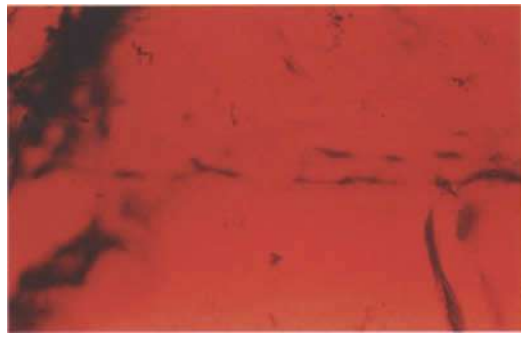

Fig.10. Tiny triangular platelet as a residue from the crucible (probably platinum). x30.

Table 1: Properties of flux-grown synthetic rubies from Russia

		Type 1	Type 2
Crystal habit		Tabular	Rhombohedral
Chemical composition (wt.%)	Al_2O_3 Cr_2O_3	99.72 0.28	98.48 1.52
Colour		Pale red	Dark red
Pleochroism	o e	Violet-red Yellowish-red	Purplish-red Orange-red
Absorption spectrum		Typical Cr^{3+} -spectrum Cr^{3+}-absorption line: 692 nm Cr^{3+}-absorption bands maxima: E // c: 545 and 409 nm E⊥c: 554 and 400 nm	
Refractive indices	n_e n_o	1.760 1.768	1.762 1.770
Birefringence		0.008	0.008
Density (g/cm^3)		3.98	4.01
UV luminescence long-wave UV short-wave UV		Strong red Weak red	
Internal features	Black, opaque residues of the flux (tungsten oxide has been determined as a component of the flux by chemical analyses), cavities partly filled with a flux bubble (the flux material has contracted during the cooling of the synthetic ruby crystals), small triangular residues from the crucible (probably platinum), distinct growth structures.		

Cr^{3+} absorption line is located at 692 nm. The pleochroic absorption bands are in the green and violet spectral range and possess maxima at 554 and 400 nm for E⊥c and 545 and 409 nm for E//c.

The pleochroism is distinct: violet-red (o) and yellowish-red (e) for type 1 and purplish-red (o) and orange-red (e) for type 2.

Ultraviolet luminescence

When exposed to ultraviolet (UV) radiation the synthetic ruby crystals both show strong red fluorescence under longwave-UV and weak red under short-wave UV.

Internal features

Microscopic investigations showed black, opaque residues of the flux (Figures 5,6,7). Chemical analyses of residues at the surface of the synthetic ruby crystals (Figure 8) proved the flux to contain tungsten as a main component. According to information from the producer, the synthetic rubies are produced in a lithium tungstate melt (Li_2O-WO_3) at temperatures of 1100°C . Flux residues are also found as residual fillings of cavities (Figure 9). Triangular residues of the crucible material (probably platinum) are also found as typical inclusions of flux-grown synthetic rubies (Figure 10).

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Notes from the Gem and Pearl Testing Laboratory, Bahrain – 2

A. Bubshait, FGA, and N.P.G. Sturman, FGA, DGA

Pressed amber

In our first Bahrain Laboratory notes (in Scarratt, 1992, 223-4) we made reference briefly to characteristic strain patterns normally associated with some forms of pressed amber. The strain patterns referred to were those sometimes observed between crossed polars and typical of materials subjected to some form of internal structural strain.

Interestingly, shortly after the publication of this article, a yellow heart-shaped cabochon (Figure 1) was submitted for a verbal opinion. The properties of the cabochon indicated that it was amber: it floated in brine, had an RI of 1.54 (direct and distant vision) and when a hot point was used extremely carefully, it gave off a characteristic resinous odour. However, unlike the necklace in our first report, when examined between crossed polars the cabochon displayed strain patterns typical of some forms of pressed amber (Figure 2). Microscopic examination revealed clear boundaries between some of the individual amber pieces making up the cabochon and the fluorescence exhibited under short wave ultra-violet light, although weak, was a patchy chalky whitish green colour. On closer examination the uneven fluorescence appeared to be related to the different fluorescent characteristics of the amber pieces within the cabochon.

Fig. 1. The pressed amber cabochon.

Fig. 2. The interference colours exhibited by the cabochon seen in Fig. 1, when examined through a polariscope.

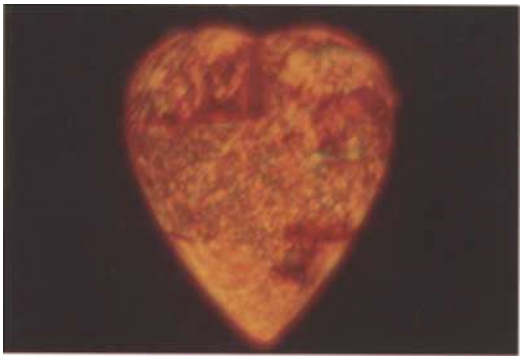

Surface colour enhanced amber

A string of 'worry beads' comprising 45 spherical, one cylindrically-shaped and two disc-shaped yellow brown beads was submitted recently with a request to check that the beads were amber. The usual testing procedures used on materials suspected of being amber all indicated that samples from the beads were amber, but the colour of the beads looked 'odd' when examined through the microscope. This oddity took the form of transparent lighter yellow patches of various sizes, scattered across the mainly darker orangish brown surface of the beads (Figure 3). These lighter areas

Fig. 3. One of the lighter yellow areas acting as a 'window' to reveal the underlying colour of the beads.

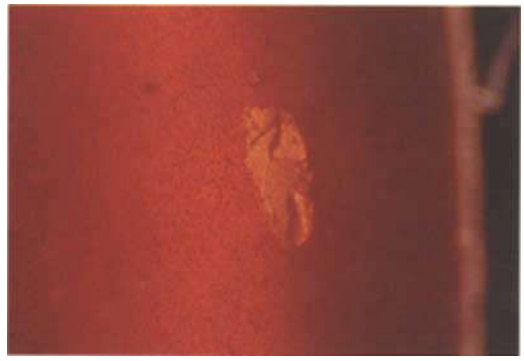

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Fig. 4. The spangles observed in some beads.

appeared to resemble gaps in an uneven coating of some type (rather like a decorator painting a wall but missing small areas), but no signs of any coating could be detected. Higher magnification showed that many of the lighter areas were slightly raised above the surface. In order to check that these areas were not due to spots of some separate substance which had been dropped onto the surface and solidified, we very carefully levelled one with a knife. This showed that the underlying colour was still a lighter yellow and that the raised area was not formed from another substance. As an extra check, the underlying area revealed by the knife and the top of another raised area which had not been examined previously were lightly touched with a thermal probe. Both gave a resinous odour typical of amber.

At this point we began to note the similarities between these beads and those examined in our first 'Note from the Bahrain Laboratory' (in Scarratt, 1992, 223-4). In UV radiation the darker coloured surface areas of the beads fluoresced a weak chalky orange, whilst the small lighter yellow areas within the darker body showed a distinct moderate to strong whitish/blue fluorescence. Pursuing this relationship between colour and fluorescence further, we gently scraped away the darker surface colour of one bead in a small inconspicuous area. Not only did the underlying colour of this particular area turn out to be light yellow, but when this previously dull orange fluorescent area was examined with UV light once more, a strong whitish-blue fluorescence was observed. It would appear that the body colour of the beads, in both this necklace and that described in the previous 'Note' (1992), is pale yellow and gives rise to whitish- blue fluorescence. The greenish-brown fluorescence of the more strongly coloured areas in the faceted bead necklace and the orange fluorescence of the necklace just described, probably indicate either slightly different starting materials or different degrees of heating.

Numerous spangles seen in some of the beads (Figure 4) are typical of some examples of clarified amber (Fraquet, 1987) and add credence to the idea that the beads have been heat-treated.

Surface cavity filled natural rubies

Today, gemmologists are not only faced with identifying a wide range of gemstones, but also a wide range of treatments used to improve the colour, clarity and, hence, the apparent value of these stones.

One of the most frequently encountered treatments is the artificial filling of cavities and fractures in natural rubies and, to a lesser extent, natural sapphires (Hughes, 1990). Figures 5 and 6 show the type of filling that the gemmologist needs to be aware of. These features were observed in two natural Thai rubies that were mounted in a necklace containing 32 oval faceted rubies of approximately 0.60 - 0.70ct each. Three more rubies in the necklace revealed narrow fillings in deeper fractures.

Stones with shallow filled surface cavities may be repolished to remove the material, but if, as in this case, any of the material present is in a deep fracture or feather the potential of the stone is not so good, as no amount of repolishing will remove all the material.

Fig. 5. The larger filled surface cavity in a ruby.

Fig. 6. Surface-reaching fracture in another ruby showing that part of the stone (top right) is filled.

Waxed filled cavities in coral

'Worry beads' are a part of Bahraini life and as such are used as a fashion accessory. Because of their popularity we inevitably see a large number pass through the Laboratory for examination. Figure 7 shows some 'worry beads that were tested recently. The concentric/radial branch-like structure of the beads and the other gemmological properties proved them to be coral, but what was more interesting was that some cavities and surface–reaching fractures appeared to have been filled. The material filling the surface features became very apparent under reflected light (Figure 8), as the lustre of the filler was notably different from the surrounding coral. In addition to the difference in lustre, some filled areas contained one or more bubbles, were easily marked with a metal pointer and flowed when a hot-point was placed near them. All this evidence led us to believe that the material used to fill the cavities was probably wax that had been used in part to improve the surface appearance of the beads by hiding the cavities.

Nineteen rows of mixed natural and non-nucleated cultured pearls

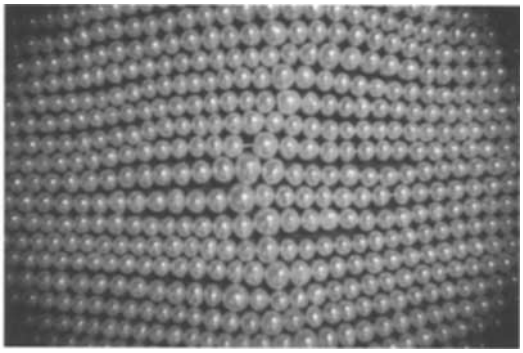

Fig. 9. Nineteen rows of pearls containing a mixture of non-nucleated cultured pearls and natural pearls.

Nineteen graduated single rows of pearls were recently submitted for a sample test and the largest pearls (up to 8.0 mm) are shown in Figure 9. We were informed that the pearls were thought to come from the Gulf and, since being found, had been sent to India for drilling, sorting and stringing. Gulf pearls have been sent to India to be incorporated in Bombay bunches for hundreds of years, so this account came as no surprise. The pearls were duly tested, and, when the radiographs of the pearls were examined, it became clear that the rows contained a mixture of natural and non-nucleated cultured pearls. Ever since the introduction of non-nucleated cultured pearls in the late 1950s, those dealing in natural pearls have had to be wary of this type of cultured pearl. These rows show just how careful dealers have to be, especially with the improved techniques used to culture pearls today. Nowadays, most of the non-nucleated cultured pearls no longer have a 'Rice-Crispie' shape, hitherto so characteristic of the freshwater culturing method, and many pearls resulting from freshwater and marine culturing methods may closely resemble natural pearls in external appearance.

Although these mixed rows are not the first to have been tested by the Bahrain Laboratory, they have proved to be the most mixed seen to date. In most previous rows we have examined, the non-nucleated cultured pearls have been small to medium sized, whereas the non-nucleated cultured pearls illustrated in Figure 9 are of numerous sizes, including many that are large. We know of no commercial cultured pearl farming in the Gulf so, although the natural pearls may well have a Gulf origin, the non-nucleated cultured pearls must come from elsewhere.

Two pearls with interesting drill-holes

In February 1993 a customer brought us two button-shaped pearls for testing. It was not their radiographic structure that interested us, but rather how they were drilled. The drilling methods used on each pearl were different, as the radiograph in Figure 10 shows. One showed the 'Chinese-drilling' method where two part-drilled holes are angled to meet one another to form a 'curved' drill-hole and the other showed a very large part-drilled hole in the base with a separate

Fig. 10. Radiograph and diagram of the two pearls showing the drilling methods applied to each. 15 minutes exposure, short development.

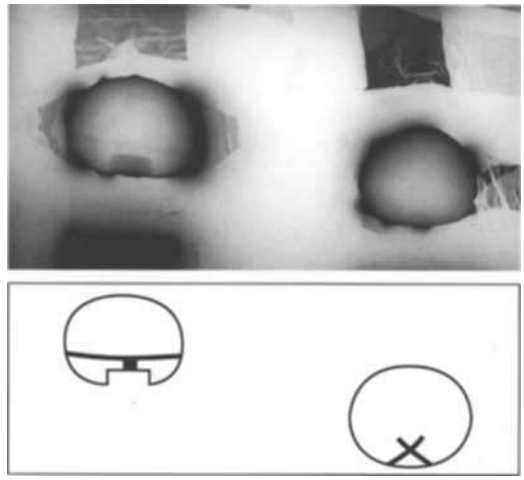

Fig. 7. The coral 'worry beads'.

drill-hole at right angles, running across the diameter of the pearl.

Both methods of drilling are often associated with natural pearls and, in our experience, a pearl with either form of drilling often proves to be natural. That this is not always the case is demonstrated by the pearl with the 'T' drilling which proved to be cultured. Such drilling clues, therefore, cannot be taken as proof of identity.

Chinese-drilling was so named because the Chinese often drilled pearls in this way for use as buttons and decorations on Mandarins' clothes (J. Taburiaux, 1985).

Acknowledgements

The authors acknowledge with thanks the assistance of both the Bahrain and London Laboratory staff.

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[*Manuscript received 7 March 1993*]

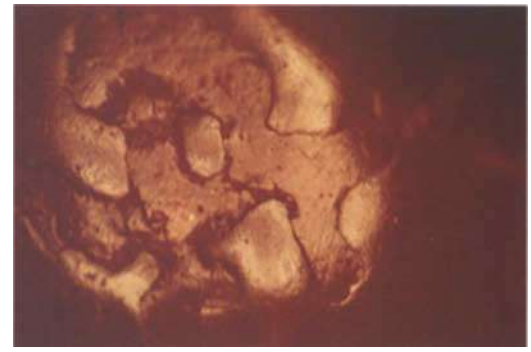

Fig. 8. The difference in surface lustre seen when a filled area is examined by reflected light. Note the dull lustre of the soft wax and the brighter lustre of the coral.

Emerald mineralization of Barang, Bajaur Agency, Pakistan

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Abstract

This is the first account of emerald mineralization from Barang, Bajaur Agency, NW Pakistan. Emerald mineralization is associated with talc carbonate host of the Indus suture ophiolitic melange. The mineralization is pneumatolytic and hydrothermal, late to post tectonic and structurally controlled. For the first time it is being recognized and proposed that the source of beryllium bearing fluids responsible for emerald mineralization are the Tertiary minor granites of S-type occurring in the area. This is contrary to the already held views that beryllium fluids emanated from a trench or arc source. The colour of Barang emerald varies from light bluish-green to deep green and the crystals range from minute to 2.5cm. This paper for the first time presents cell dimension of emerald from Pakistan by using an advanced computer program and four cycles of refinement.

Introduction

A variety of gemstones including emerald, ruby, pink and golden topaz, bi-colour tourmaline and aquamarine are being mined in northern Pakistan, mostly by the public sector. Amongst them, the top quality Swat emeralds are considered to be among the best in the world. For long these had been sold in the world market as 'Afghanistan' emeralds. The recent efforts of the Gemstone Corporation of Pakistan have introduced this emerald in the world market and because of its properties it is in great demand nowadays.

The main emerald-producing areas in the Swat district are Mingora (Gübelin, 1968, 1982; Jan, 1968, Jan *et al.*, 1981; Kazmi *et al.*, 1984, 1986) and Gujar Kili (Hussain *et al.*, 1982). Khazana (Shamozai area) is a newly discovered locality in Swat, the potential of which is still to be ascertained.

Emerald from Amankot, Bajaur Agency (longitude 71° 36.68′ and latitude 34° 39.25′), has been produced by the locals since early 1970s. The location of the area is given in Figure 1. Because of the tribal and hostile attitude of the locals, no outsider could visit the mining areas of this agency and hence nothing was reported about the nature of these deposits. After protracted efforts, it became possible to carry out investigations of the Amankot emerald mines in 1984.

A brief account of the geology and emerald mineralization of Amankot mines in Bajaur Agency is given below.

Geology and petrography of the host rocks of emerald

The geological map of the area is given as Figure 2. The lithostratigraphic sequence and broad tectonic units of the area are as follows:

Kohistan sequence	Amphibolite, etc.	Cretaceous
----- Main Mantle Thrust (MMT, Indus suture) ------		
Indus suture melange	Talc carbonate Ultramafics Gabbro Green schist/stone Amphibolite Metasediments	Cretaceous to Palaeocene
---------- Thrust ----------		
Indian Plate	Carbonatite Minor S-type Granite	Tertiary
	Graphitic schist Garnetiferous-calcareous rock Quartzite/quartz-mica schist	Precambrian
	Granite gneiss	Proterozoic

Talc carbonate blocks which host emerald mineralization in Barang, Bajaur Agency, are part of the Indus suture melange which marks the line of closure of the Tethys. This tectonic melange occurs between the Indian plate composed mainly of Precambrian metasediments and S-type granite gneisses cut at places by Tertiary garnet and tourmaline bearing leucogranites of S-type and associated beryl bearing pegmatites to the south and the Kohistan island arc complex of Creto-Tertiary age to the north.

A general north-south stretching Indus suture ophiolitic melange comprising lenses and blocks of greenstone, talc carbonate, gabbro, serpentinized peridotite, amphibolite, calcareous rock and

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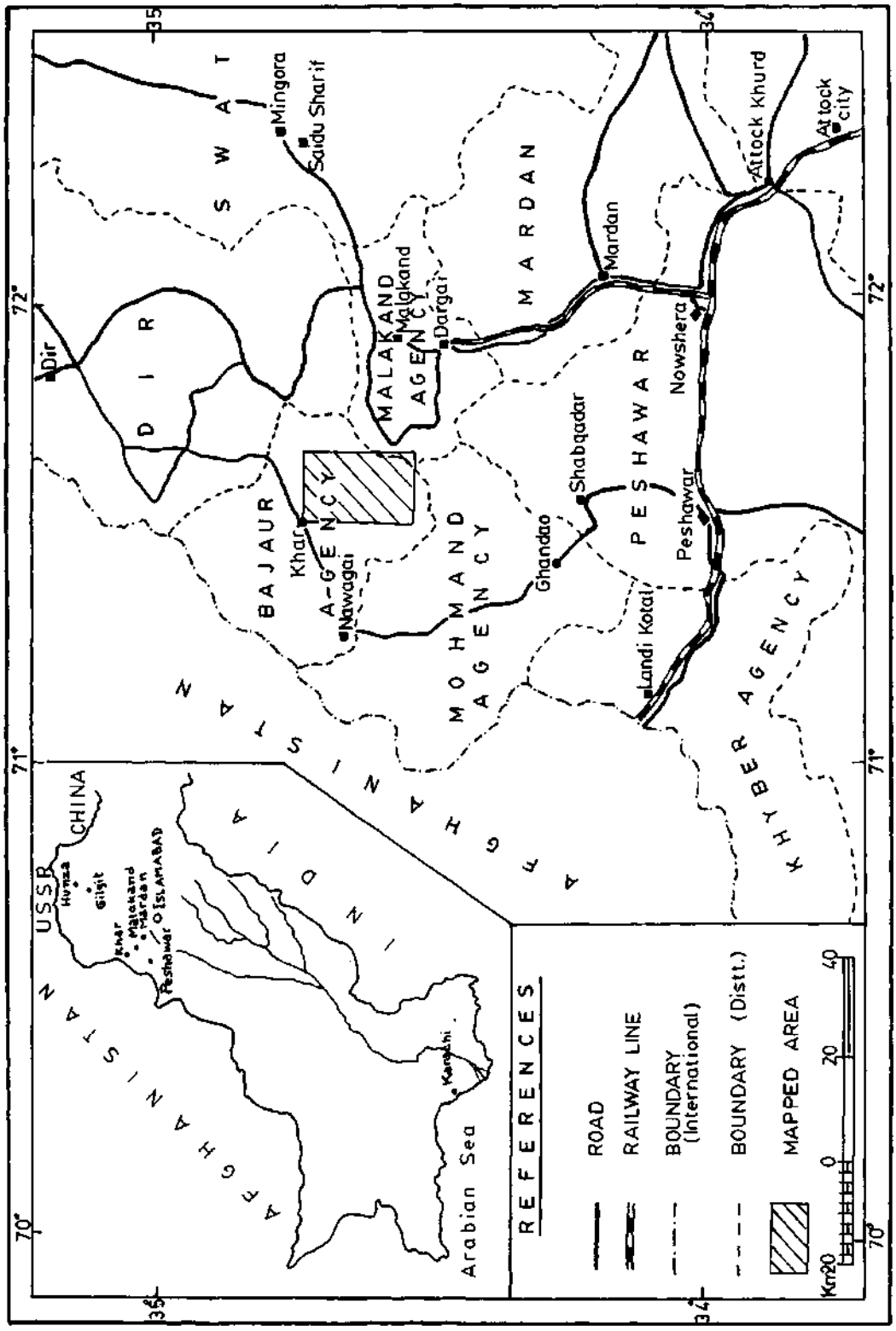

Fig. 1. Location map.

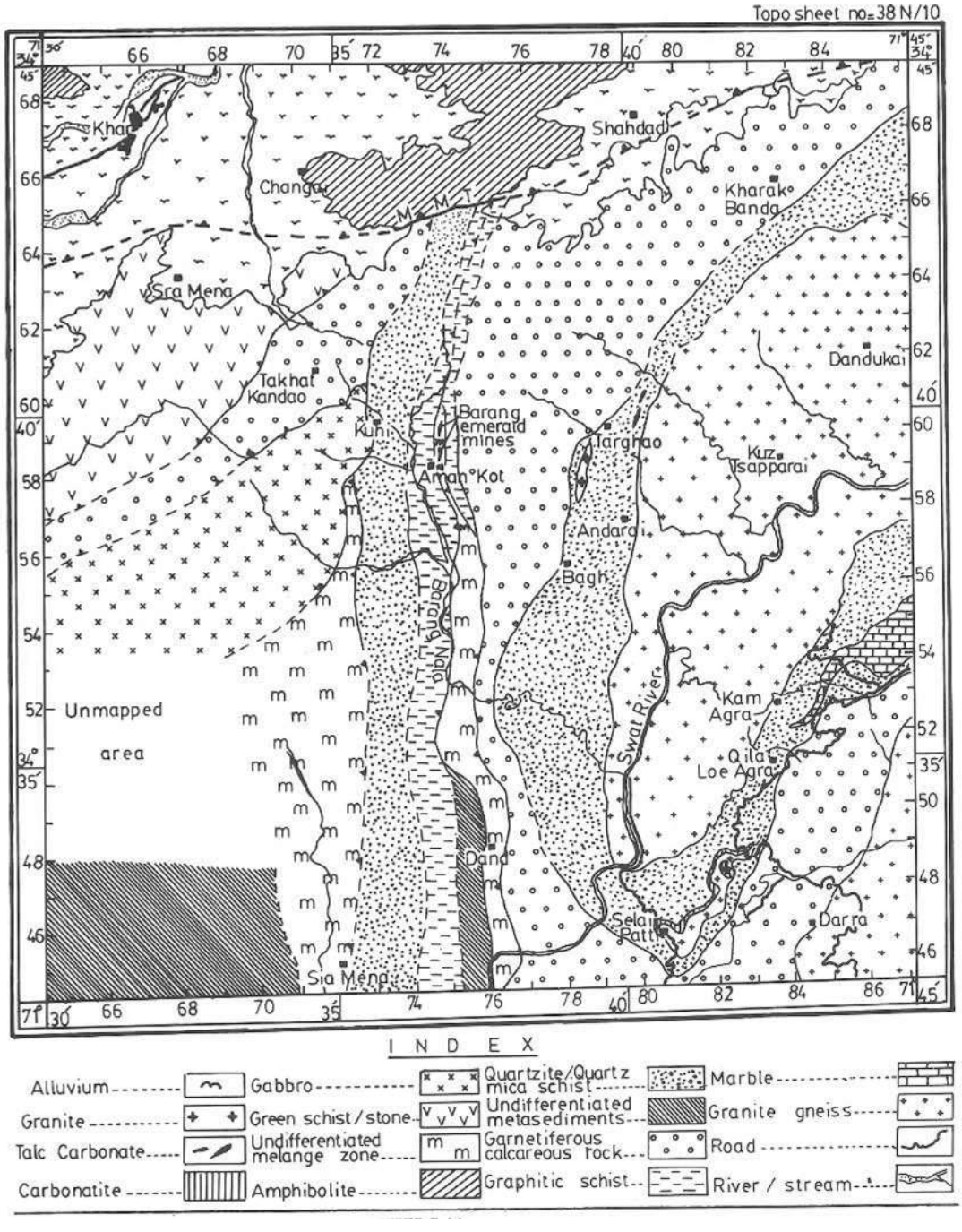

Fig. 2. Geological map of Barang-Turghao area, NWFP, Pakistan.

metachert has been briefly described by Hussain *et al.* (1984).

The larger outcrops of talc carbonate, greenstone and gabbro melange have been shown on the map (Figure 2). The melange with smaller unmappable blocks has been shown as undifferentiated melange (Figure 2). Towards the north it is truncated by Indus suture or Main Mantle Thrust (MMT). Ophiolitic melange has been emplaced along a number of faults which are usually marked by talcose rocks.

Rocks of the melange zone have an angular

relationship with overlying older calcareous schists. The rock fragments or blocks in the melange zone vary in size usually from a few metres to thousands of metres across. These rocks have been subjected to deformation resulting in the formation of tight folds, fractures and faults. Talc carbonate rocks which host emerald mineralization are described below. The other rock types in the melange have been excluded since they are not directly related to the emerald mineralization.

Talc Carbonate Rocks

Field and laboratory studies indicate that these rocks are the altered ultrabasics. They occur as lenses, patches and sheets of various sizes and are composed of talc, carbonates (mainly magnesite), quartz, actinolite, iron ore, etc.

The schistosed zones are talc-rich and exhibit tight drag folding. Talc carbonate schists contain almost equal quantities of talc and carbonate. Soapstone is also associated with talc carbonate schist. Massive rocks are carbonate (dominantly magnesite) with a small quantity of talc. These are well jointed and contain abundant quartz and calcite veins. Lenses and nodular quartz veins and stockwork are sometimes lined by chlorite and fuchsite.

Talcosed rocks may contain phacoids (concordant lenses) of green schist. Actinolite is developed in talc carbonates at their contacts with metasediments. At these places talc carbonates appear to be metasomatically altered. This is indicated by the presence of feldspar which is not strongly altered. Some of the altered bodies are highly feldspathic with chlorite, actinolite, muscovite and quartz as accessory or minor minerals. These patches are up to a few metres across in size.

Emerald mineralization is found in talc carbonate rocks towards the north of Amankot. Silicification of these rocks is observed and emerald has been mineralized in the silicified parts. These quartz schorl and somewhat feldspathized quartz schorl rocks are closely associated with the talc carbonates in the mine area of Amankot. The silicified and metasomatized areas (quartz-schorl-feldspar and quartz-schorl rocks) may contain tiny beryl crystals.

In Barang-Turghao area both S-type Proterozoic granite gneiss and younger anatectites (Tertiary in age and associated with the Himalayan orogeny) are present. The small acid minor bodies of Tertiary age are late to post tectonic.

Kot granite gneiss and Agra-Turghao granite gneiss of the surrounding area are S-type. Both these bodies have younger (Tertiary) acid minor bodies. They also include beryl- and tourmaline-bearing pegmatites. The beryl is bluish-green in colour.

Emerald mineralization

About an 80 metre wide zone in talc carbonates to the north of Amankot village has emerald mineralization. The talcose rocks are emplaced along a fault within graphitic schists.

The Amankot mineralized area consists of three emerald mines over a linear extension of about 0.80km. The emerald mineralization noted in these mines is described below:

1. Hydrothermal veins, consisting mainly of quartz with a small quantity of carbonates, in places contain emerald crystals. Talcose rocks adjacent to these veins are also mineralized. The quality of this emerald, especially in the host talc carbonates, is the best. The emerald crystals are usually well developed, inclusion free and have good transparency.
2. Tourmalinized meta-cherts overlying the mineralized talc carbonates are cut by pneumatolytic/hydrothermal veins. Sometimes these veins contain small sized, poor to medium quality emerald crystals. The host tourmalinized meta-cherts may also be mineralized with the same quality emeralds.
3. Silicification of the talc carbonates has taken place over smaller areas up to a few metres across. Occasionally these contain sporadic emerald crystals. The quality of these emeralds is also not good.
4. Sheared zones are developed along the faults in talc carbonate rocks. Hydrothermal veins have filled some of these weak zones. Within such zones emerald crystals are found in pockets as well as disseminations.

Optics and chemistry of emerald

The colour of emerald crystals of Amankot area is bluish-green, green, grass green and deep green. Some crystals are light greenish-blue with green edges. Transparency varies from poor to excellent. High quality emeralds of the Amankot area are bluish-green, clear and transparent.

Single crystals are usually well developed, hexagonal and may have small sized inclusions. The size of emerald varies from 1mm to a maximum of 2.5cm in the longer dimension. The largest stones weigh up to 150 carats.

The RIs of Amankot emeralds are higher than those of pure beryl due to a high quantity of iron and chromium. The values are comparable to the emeralds of Bucha, NW Pakistan (Rafiq *et al.*, 1985) but higher than those of Mingora emeralds, Swat, due to higher FeO.

Absorption bands and refractive indices of one beryl and two emerald crystals from Amankot are listed in Table I, together with similar data for Bucha (Mohmand) beryl and emeralds (Rafiq *et al.*, 1985) as well as Mingora (Swat) emerald (Gübelin, 1982). The RI values were determined by immersion method on powdered grains. The listed values are accurate to ± 0.002. The absorption spectra of

emeralds contain distinct chromium absorption lines in the red region at 682.7-683.9 nm for beryl and 682.5-683.8 nm for emeralds. There are also weak broad bands for Fe absorption for both beryl and emeralds in the yellow region between 585-584 nm. These are due to significant Fe contents. Optically the emeralds of Amankot area, Bajaur Agency, are very similar to the Bucha emeralds, Mohmand Agency, reported by Rafiq and Jan (1985).

Two chemical analyses of Amankot emeralds and one analysis of beryl for the same area are given in Table II. In addition to major elements, the amounts of Cr_2O_3, MnO, CuO and NiO have also been determined. For the sake of comparison the analyses of Amankot, Bucha (Rafiq *et al.*, 1985) and Swat emeralds (Gübelin, 1982; Schrader, 1983) and Barang emeralds and green vanadium beryls of Gandao (Snee *et al.*, 1989; Hammerstrom, 1989) have been arranged as Table II.

The analyses of Barang and Gandao emeralds have been discussed by Snee *et al.* (1989) and Hammerstrom (1989). However, they have wrongly grouped these analyses with Mohmand as constituting a single district. This grouping is erroneous since host rocks in the case of Barang (Bajaur Agency) are different from that of Gandao (Mohmand Agency) and the two deposits are separated by a considerable distance. The main Mohmand deposit occurs in meta-limestone whereas the host rock in case of Barang is talc-carbonate.

Schrader (1983) has suggested that the green colour in emeralds may be due to Cr, Mn, Ni, V and Fe. A comparison of the chemical analyses of emerald of the Amankot area with beryl of the same area shows that the values of Mn, Fe, Ni and V are similar. The only colouring factor may, therefore, be Cr. This fact has been pointed out by Rafiq and Jan (1985) for Bucha emeralds.

Cell dimensions of bluish-green emerald from Amankot (analysis 3 in Table I) were determined. The diffraction pattern was obtained on Ragaku automated powder X-ray diffractometer (Model D-MAX/IIA). The cell dimensions were calculated by using the advanced programme of Benoit (1987). Four cycles of refinement were used. The cell dimensions are:

$$a = 9.2548 \pm 0.0036$$
$$c = 9.1905 \pm 0.0075$$

This is the first determination of cell parameters of emeralds from Pakistan using an advanced computer program.

Paragenesis

Talc carbonates host emerald mineralization not only in Barang, Bajaur Agency (this account), but also in Mingora, Swat (Gübelin, 1968, 1982; Jan, 1968; Jan *et al.*, 1981, and Kazmi *et al.*, 1984, 1986). Talc carbonates also host emerald mineralization in

Table I: Physical properties of Amankot, Bucha and Swat emeralds

Specimen	Absorption (in nm)	Strength of absorption	Chelsea Colour Filter	Refractive Indices ε	Refractive Indices ω	Inclusions
Light pale green beryl (Amankot)	682.7 683.9 585.0	Weak to moderate Weak broad bands	Light brownish-red	1.576	1.586	Fluid inclusions mica and Fe-oxides
Bluish-green emeralds (Amankot)	682.6 683.8 584.0	Strong Weak broad bands	Deep brownish-red	1.592	1.604	Fluid inclusions, talc fibres, mica plates, Fe-oxides
	682.5 683.7 585.0	"	"	1.592	1.604	"
Light green beryl (Bucha)*	682.8 683.9 585.0	Weak to moderate Weak broad bands	Light brownish-red	1.575	1.583	Fluid inclusions, feathers of Fe-oxides, siderite, tremolite/mica
Bluish-green emerald (Bucha)*	682.8 683.9 585.0	Strong	Dark brownish-red	1.590	1.600	Fluid inclusions, talc fibres, mica plates
Emerald (Swat)**	683-680 662, 646, 637	Strong Distinct to strong	red to pink	1.588 to 1.593	1.595 to 1.600	Two phase inclusions, colour banding and zoning, calcite, dolomite
	477, 472 472	Weak				

* Rafiq and Jan, 1985

** Swat emerald values cover the range for seven stones (for details, see Gübelin, 1983)

Table II: Analyses of beryls, emeralds and green vanadium beryls from Pakistan.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
SiO_2	63.74	–	62.41	63.05	–	–	64.2	63.7	–	N.D.	–	63.8	N.D.	63.1	62.1	63.2
TiO_2	0.04	–	0.03	0.02	–	–	–	–	–	0.12	<0.02	<0.07	0.13	<0.05	0.01	0.02
Al_2O_3	13.28	–	15.26	14.20	–	–	14.8	13.7	–	14.5	14.8	14.5	14.7	12.7	14.1	14.0
Cr_2O_3	0.10	0.27	0.85	0.76	0.83	0.66	0.8	1.4	0.2	–	0.03	0.03	–	0.45	0.17	0.04
Fe_2O_3	2.52	2.25	2.47	2.18	2.10	0.9	0.4	1.4	0.7	–	1.6	1.4	–	1.2	0.94	1.40
BeO	12.95	–	12.08	13.07	–	–	–	–	–	–	–	11.41	–	10.96	–	–
MnO	0.08	0.10	0.10	0.10	0.10	–	0.0	0.1	0.002	–	–	–	–	–	0.02	0.00
MgO	1.26	2.18	2.15	2.34	1.91	2.6	2.7	2.4	0.6	2.0	2.4	2.2	2.5	4.8	2.77	2.14
CaO	0.69	–	0.41	0.34	–	–	–	–	–	0.3	<0.04	0.53	<0.3	0.13	0.02	–
Na_2O	2.29	1.87	1.91	1.82	2.14	2.1	2.1	1.9	2.0	2.30	2.49	–	2.22	–	2.19	1.75
K_2O	0.18	0.27	0.16	0.13	0.08	–	–	–	–	–	–	<0.5	–	<0.04	0.02	0.03
CuO	0.18	0.41	0.21	0.19	0.11	–	–	–	–	–	–	–	–	–	–	–
NiO	0.04	0.04	0.05	0.06	0.02	–	–	–	<0.02	0.00	–	–	–	–	–	–
V	0.04	–	0.06	0.04	–	–	0.1	–	>0.05 Sc=0.14	–	1.33	0.53	0.02	0.04	0.02 (as V_2O_3)	0.66 (as V_2O_3)
H_2O^+	1.70	–	1.50	1.67	–	–	–	–	–							
H_2O^-	0.14	–	0.11	0.08	–	–	–	–	–							

1. Light pale green beryl from Kot, Malakand Agency
2. Light green beryl from Bucha, Mohmand Agency. *Analyst M. Tahir Shah* (Rafiq and Jan 1985)
3 & 4. Bluish-green emerald from Amankot area, Bajaur Agency
5. Deep bluish-green emerald from Bucha, Mohmand Agency. *Analyst M. Tahir Shah* (Rafiq and Jan, 1985)
6. Emerald from Mingora, Swat. *Analyst M. Weibel* (Gübelin, 1982)
7 & 8. Microprobe analyses of two emeralds from (Swat?) Pakistan, (Hänni, 1982)
9. Neutron activation analysis of emerald from (Swat?) Pakistan. Average oxide values calculated from element percentages of two samples by Rafiq and Jan (1985) from Schrader (1983)
10 & 13. Neutron activation analyses of emeralds from Barang (Snee *et al.*, 1989)
11. Neutron activation analysis of green vanadium beryl from Gandao (Snee *et al.*, 1989)
12. & 14. Induced coupled Argon Plasma-Atomic Emission Spectrometry analyses of green vanadium beryl from Gandao and of emerald from Barang respectively (Snee *et al.*, 1989)
15 & 16. Microprobe analyses of emerald from Barang and of green vanadium beryl from Gandao respectively (Hammerstrom, 1989)

Gujar Kili, Makad and Charbagh areas of Swat (Hussain, 1982).

Gübelin (1982) suggested a dolomitic host for emerald mineralization in Mingora, Swat. However, detailed petrological and geochemical studies of talc carbonates and associated ultramafics from Indus suture melanges in Swat area clearly show that the talc carbonate rocks are strongly carbonatized serpentinites and serpentinized peridotites. Chaudhry *et al.* (1980) and Jan *et al.* (1968, 1980, 1981) also considered talc carbonate rocks as derivatives from an igneous (ultramafic) parentage.

Prior to this presentation no direct evidence was available to relate emerald mineralization to its source. Jan *et al.* (1981) ruled out the possibility that a granite source may have been responsible for emerald mineralization. They suggested the trench related fluids as a possible source of Be responsible for emerald mineralization in talc carbonates and related ultrabasic blocks of the Mingora melange. They ruled out a granite source of Be on the grounds that while the emerald host of Shangla-Mingora (talc carbonates and related rocks) are Mesozoic, the associated granites are Palaeozoic.

In the Barang-Turghao area the granites and granite gneisses are predominantly S-type, garnet and (at places) tourmaline bearing granite gneisses and amphibole bearing (I-type) granite gneisses. In addition there are minor post tectonic granite bodies of S-type as well as I-type. Kot granite gneiss and Agra-Turghao granite gneiss are S-type. Both have younger Tertiary minor acid bodies including some beryl-bearing pegmatites. The Kot granite gneiss is an extension of Malakand granite gneiss studied by Chaudhry *et al.* (1974, 1976) and Hamidullah *et al.* (1986).

The younger magmatic phases show blue beryl mineralization and some tourmalinization. The Selai Patti amphibole bearing granite gneiss and associated minor acid bodies are as yet not known to contain beryl mineralization or tourmaline of their own. It is, therefore, not possible to relate emerald mineralization with amphibole bearing granite/granodiorite or equivalent gneisses (arc related).

The emerald mineralization in the talc carbonates of the melange zone is characterized by its association with post obduction pneumatolytic and hydrothermal activity. This activity is manifested by silicification and development of emerald and tourmaline. Blue tinges and bluish-green colour of emerald are common. But green and grass green colours also occur.

It is important to note that blue or bluish-green beryl is also mineralized in acid minor bodies associated with Kot granite gneiss and Agra-Turghao granite gneiss. The emerald mineralization

can, therefore, be related to post obduction Tertiary pneumatolytic phases related to acid magmatism. This Tertiary acid minor magmatism is associated with the S-type granite gneisses and is a product of anatexis related to the thrust stacking and crustal thickening at the leading edge of the Indo-Pak shield just south of the melange zone containing talc carbonates, some of which are mineralized by emerald. Ghazanfar *et al.* (1986) and Chaudhry *et al.* (1987, 1990) have discussed the Tertiary anatexis at the leading edge of the Indo-Pak plate (just south of the Indus suture melange).

It is in these zones that younger Be-B bearing minor acid bodies (mainly pegmatites) are present. Here melange ultrabasics (bearing Cr) and Tertiary anatectites (Be-B) interact to give rise to emerald mineralization.

Emerald mineralization is therefore, regarded mainly as a product of the interaction of Be-B-Si-Al pneumatolytic activity associated with the emplacement of nearly post obduction younger granites (Tertiary) described earlier. This mineralization is structurally controlled, post obduction and most probably late to post tectonic. Chromium has been imparted by the host talc carbonates which are themselves altered ultrabasics.

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Observations of red beryl crystals from the Wah Wah mountains, Utah

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Abstract

Physical, optical and other properties of red beryl crystals from the Wah Wah mountains, Utah, were studied using spectroscopy, electron spin resonance (ESR) and usual instruments of identification.

1. Introduction

The colour-causing element and mineralogical data of red beryl from Wah Wah mountains, Utah, has already been reported (Nassau *et al.*, 1968; Shigley *et al.*, 1984). Both the Mn^{+2} ion (Nassau *et al.*, 1968) and the Mn^{+3} ion (Shigley *et al.*, 1984) have been suggested as the origin of the colour. In this report, the near infra-red spectrum due to vibrations of the H_2O in Type I and Type II sites (Wood *et al.*, 1967) in a beryl crystal with spectra in the visible region and ESR spectrum for observing the valence state of manganese have been measured with the other gemmological characteristics.

2. Results and discussion

The specimens tested were transparent, one having a modified brilliant-cut style, and were large enough to measure the ESR spectrum without crushing, the weight being 0.200-0.300 ct. The other properties were as follows:

SG	2.63-2.72 using specific-gravity bottle
RI	$\varepsilon = 1.561$-1.565, $\omega = 1.567$-1.571
Birefringence	0.004
Pleochroism	Orange red-purplish red
UV fluorescence	Inert to LW and SW
Chelsea colour filter	Inert
Content of Mn and Fe	0.23 wt% and 1.3 wt% respectively by atomic absorption analysis

Fig. 1. A component image and X-ray line profiles of Fe Kα and Mn Kα for the solid inclusion that appeared on the surface of a rough red beryl. Black bar on the left side represents 100 μm.

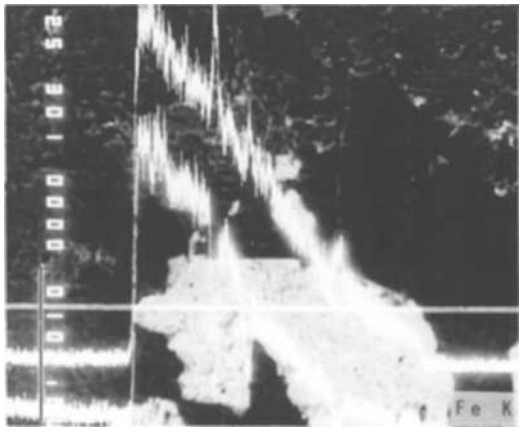

Inclusions

Liquid inclusions, minute fractures and black solid inclusions were observed under the microscope. Figure 1 shows X-ray line profiles of Fe Kα and Mn Kα for the solid inclusion which appeared on the surface of a beryl by EPMA. This analysis found the inclusion to be black bixbyite [$(Mn, Fe)_2O_3$].

Spectroscopy

Figures 2A, 2B, shows the absorption spectra of Utah faceted red beryl, natural Colombian emerald and Russian hydrothermally-grown synthetic emerald. The absorption peaks of natural Colombian emerald assigned to one, two and three vibration modes of H_2O molecular in the Type-I site or the Type-II site are observed Figure 2A, spectrum b, at 953, 1145, 1398, 1460, 1833, 1897, 1958 and above 2000 cm^{-1}. Of the absorptions shown in Figure 2A, spectrum b, the strong peak of 1897 cm^{-1} is associated with H_2O in the Type-II site, and the other to H_2O in the Type-I site or free H_2O molecular (Wood *et al.*, 1967). According to Wood and Nassau, H_2O of the Type-I site has two-fold symmetrical axes perpendicular to the *c*-axis of emerald crystals and has no alkali ions nearby. On the other hand, H_2O in the Type-II site has two-fold symmetrical axes parallel to the *c*-axis and has alkali

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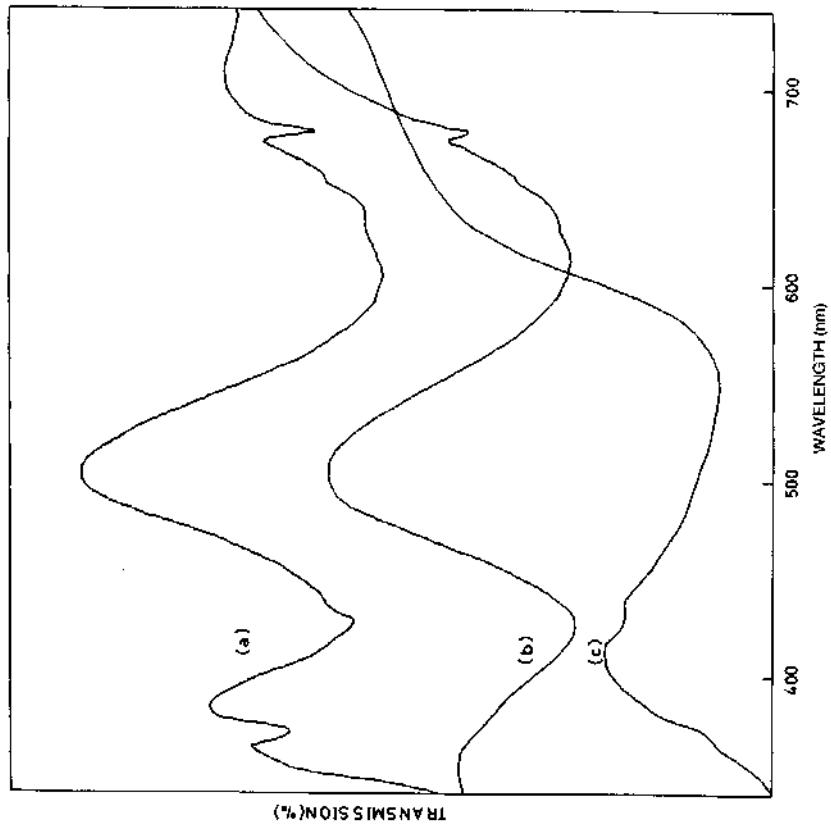

Fig. 2B

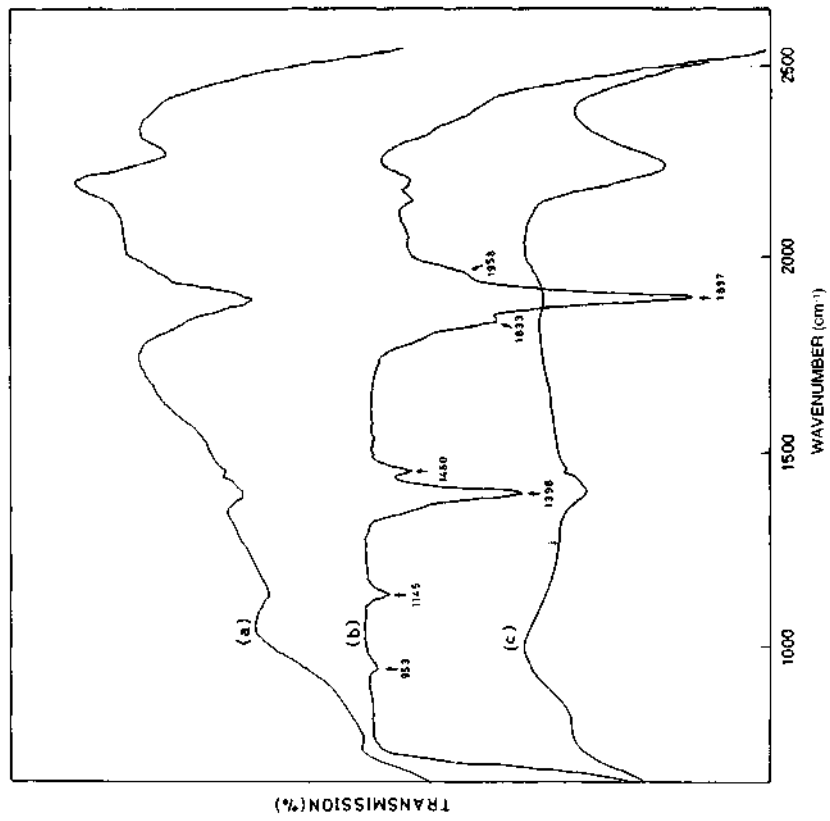

Fig. 2A

Fig. 2A,2B. Absorption spectra of Russian hydrothermally-grown synthetic emerald(a), natural Colombian emerald(b), and Utah faceted red beryl(c).

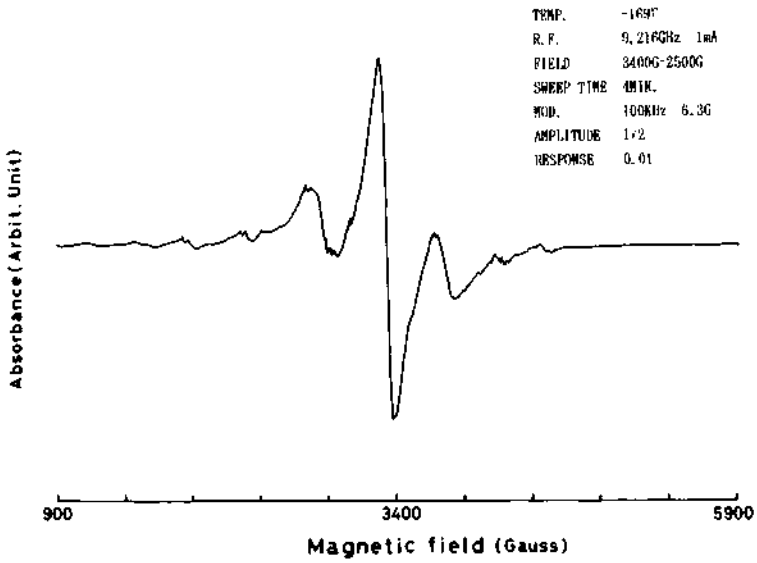

Fig. 3. ESR spectrum perpendicular to hexagonal axis.

ions adjacent to H_2O. The form of the whole absorption spectrum of red beryl (Figure 2A, spectrum c) was similar to that of the natural Colombian emerald, in which both types of H_2O are included, although the absorption of red beryl having its centre at about 1900 cm^{-1} is very weak and broad in comparison with that of natural Colombian emerald. Consequently, the red beryl has both types of H_2O. In the Russian hydrothermally-grown emerald, Figure 2A, spectrum a, the quantity of Type-II water might be more than the Type-I water, as in the case of natural Colombian emerald. The variety and amount of alkali ion adjacent to Type-II H_2O could be strongly influenced by the surrounding environment in which the respective crystals have been grown. It has been reported that a considerable amount of iron is contained in Utah red beryl (Wood *et al.*, 1967; Shigley *et al.*, 1984). The content of iron ion in this red beryl was 1.3 wt% as already shown above. The iron ion has the absorptions in the visible region. In the spectrum of Utah red beryl shown in Figure 2B, spectrum c, the two broad bands of 370 and 426 nm correspond to the absorptions due to the iron ion. These are assigned to Fe^{+3} ion in octahedral sites in beryl crystals (Wood *et al.*, 1968). The same absorption bands were observed in the visible region of Russian hydrothermally-grown emerald spectrum (Figure 2B, spectrum a). The red is caused by a broad absorption band of 540-560 nm and a fairly broad absorption band in the vicinity of 480 nm.

ESR spectrum

Figure 3 shows the ESR spectrum (at −169°C) of the red beryl from the Wah Wah mountains, Utah, for the field perpendicular to the hexagonal axis. A sharp spectrum line (Fe^{3+}) and wave-like spectra were obtained, but 'hyperfine splitting' due to the Mn^{+2} ion (S=5/2) was not observed. However, the Mn^{+2} ion could be expected to exist in the red beryl, because on the basis of the ESR data, in which 'hyperfine splitting' due to Mn^{+2} ion was observed in synthesized pink beryl crystals (Flamini *et al.*, 1986), it is considered that Mn^{2+} ion ought to give pink-red colours to natural red beryl crystals. Thus the apparent absence of distinct 'hyperfine splitting' in our natural red beryl, which includes 0.23 wt% manganese ion, may be attributed to the interference of the Fe^{3+} ESR spectrum with the ESR spectrum of Mn^{2+}. The ESR spectrum of Mn^{2+} is probably concealed by the wave-like spectra on both sides of the Fe^{3+} line (3325G region, g=1.980).

Acknowledgements

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An examination of garnets from the Sinai Peninsula, Egypt

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Abstract

Dark brownish-red garnets reported to be from the Sinai Peninsula, Egypt, were identified as almandine-spessartine, based upon their gemmological properties, chemistry and current criteria for distinguishing between the different gem garnets.

Introduction

Although garnets occur in a great range of colours, those of a predominantly red hue are no doubt the best known. Such garnets may be essentially pyrope or almandine, or they may be pyrope-almandine or almandine-spessartine mixtures (Stockton and Manson, 1985). Among the sources for one or more of these gems are Austria, Australia, Brazil, Canada, Czechoslovakia, India, Madagascar, Russia, Sri Lanka, United Kingdom (Scotland), USA, Zambia and Zimbabwe (Webster, 1983); Argentina, Japan, Norway, Sweden and Uruguay (Arem, 1987); Afghanistan (Bowersox, 1985); China (Keller and Wang, 1986); Tanzania (Jobbins, 1978); Mexico, Myanmar (Burma), Pakistan, Thailand and Greenland (Rouse, 1986). A review of the mineralogy of garnets can be found in Deer *et al.* (1982).

Egypt has also been a source of red garnets. Pliny mentions 'carbuncles'–a gem name now thought to have referred to garnets coming from an area near Thebes, although Rouse (1986) states this may be a reference to a trading station rather than a mining area. It is known that garnets have been recovered near Aswan in Upper Egypt, at the same locality from which the ancient Egyptians obtained much of their amethyst. Other Egyptian sources are in the Eastern Desert inland from Quseir and northeast of Qena (Andrews, 1991). More relevant to this report, larger stones–more appropriate for fashioning as gems– came from Western Sinai (Aldred, 1978). These reports, however, do not classify the garnets using current gemmological criteria.

It is also known that garnets were used by the ancient Egyptians for personal adornment. Garnets were fashioned for jewellery use as early as the Predynastic Period; a diadem that includes garnets was found in place on the head of a woman buried at Abydos and dating to the time of the Naqada II culture (*c.* 3200 BC). This gem material was most popular during the Middle Kingdom (*c.* 2133-1786 BC) (Andrews, 1991), possibly due to intensive exploitation of Sinai mineral deposits during this period. In the Cairo Museum is a gold collar inlaid with several species of gemstone, one of which is garnet. It is part of a parure of the Princess Khnumet who was buried in the vicinity of the pyramid of Ammenemes II (early XIIth Dynasty) (Aldred, 1978).

Background to study

Fig. 1. These garnets, reportedly from the Sinai Peninsula of Egypt, are part of a 36-bead necklace. *Photo by Maha Smith-DeMaggio.*

While on a trip to Egypt in late 1991, one of the authors (RCK) visited a gem dealer in Luxor who displayed a necklace of dark brownish-red beads represented as garnets (Figure 1). These were said to have been recovered from the south-central area of the Sinai Peninsula, 'two mountains over from Gebel Musa' (Mt. Sinai). According to the merchant, his father obtained the garnets at the mine site several years before, but the exact location was no longer known (unsuccessful efforts had been made to relocate the source). The necklace was subsequently acquired for gemmological examination.

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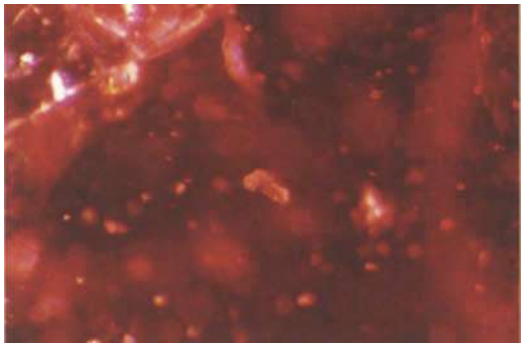

Fig. 2. What appear to be apatite crystals were noted in many of the garnets in this investigation. *Photomicrograph by John I. Koivula. 50X.*

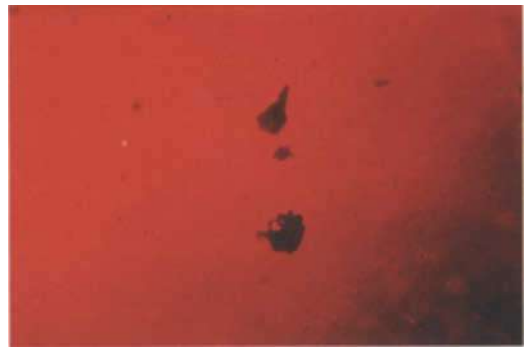

Fig. 3. Black opaque inclusions with the appearance of ilmenite were also detected in many of the garnets described herein. *Photomicrograph by John I. Koivula. 50X.*

Fig. 4. EDXRF analysis detected the presence of both iron and manganese in the garnets in this study. Analysis performed by Sam Muhlmeister using a Spectrace 5000 X-ray unit (tube voltage 20 KV, tube current 0.15mA, atmosphere–vacuum, aluminium filter, livetime 100 seconds.

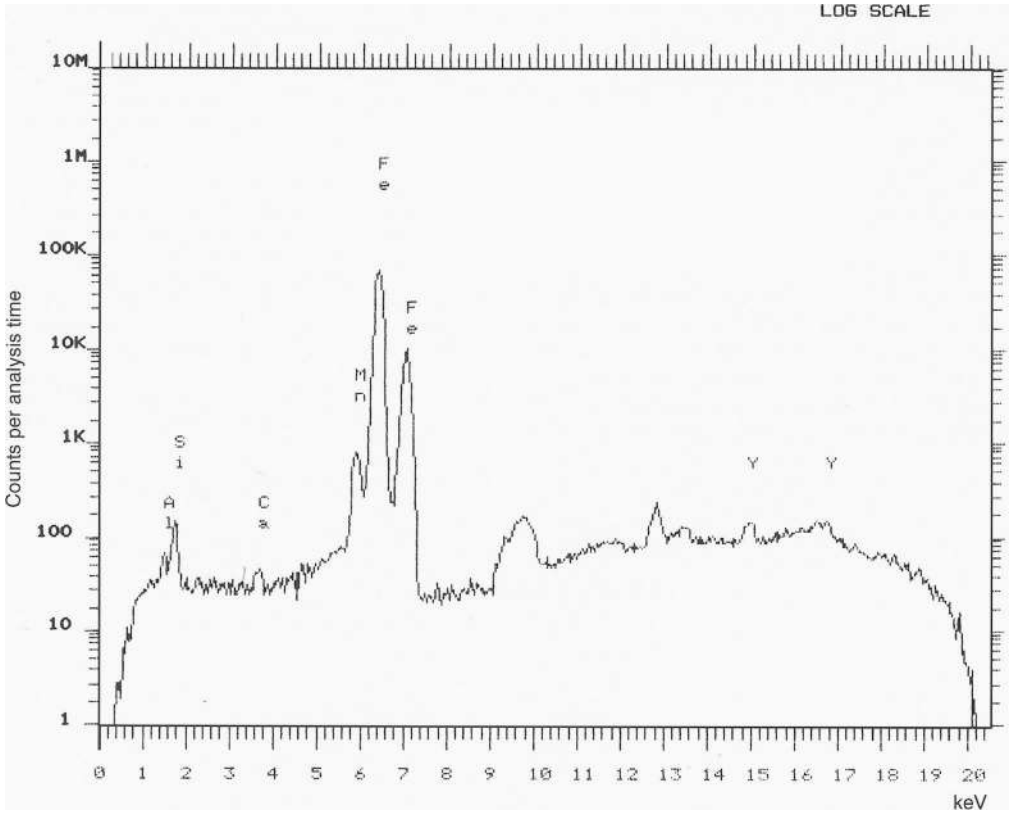

Gemmological examination

Description:

A necklace consisting of 36 off-round drilled beads ranging in diameter from approximately 12.3 to 13.0 mm.

Colour/appearance:

In reflected light, the beads were very dark brown (almost black) and nearly opaque due to their very dark colouration. In strong transmitted light, however, they were brownish-red and transparent.

Microscopic features:

Magnification revealed numerous partially healed fractures located throughout all of the beads. Crystalline inclusions were also noted and visually identified as apatite (Figure 2) and ilmenite (Figure 3) which are known to occur in garnets of this type (Gübelin and Koivula, 1986).

Refractive index:

Spot refractive index readings were taken using a Duplex II refractometer and white light source. This produced readings from approximately 1.81 to over-the-limits of the instrument.

Chelsea Filter reaction:

The beads appeared yellowish-green.

Ultraviolet luminescence:

All of the beads were inert to both long- and short-wave ultraviolet radiation when examined with 4-watt UV light sources.

Absorption spectrum:

Examination was carried out using both a Beck prism spectroscope mounted on a GIA GEM Instruments spectroscope illuminator base and a GIA GEM DISCAN diffraction-grating spectroscope unit. This revealed absorption bands at approximately 410, 430, 460, 500, 525, and 575 nm.

Chemistry

Energy-dispersive X-ray fluorescence (EDXRF) analysis was carried out by the GIA Research Department using a Spectrace 5000 X-ray unit. This revealed aluminium and silicon as major components, a high iron content with lesser amounts of manganese, and traces of calcium and yttrium (Figure 4). This chemistry is consistent with that of garnets in the almandine-spessartine solid solution series (see Deer *et al.*, 1982).

Conclusion

Based on the gemmological properties and using the criteria established by Stockton and Manson (1985), the garnets in the necklace were identified as almandine-spessartine. The chemical analysis, showing a significant iron component as well as lesser amounts of manganese, further substantiates this identification.

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Gemstone enhancement - detection of polymer-treated jadeite

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During a discussion in 1992 with Emmanuel Fritsch and Ken Scarratt, I was privileged to learn of a forthcoming paper on the treatment and detection of jadeite which had been enhanced using a polymer impregnation process (Fritsch *et al.*, 1992).

The paper divides jadeite into three categories used in Hong Kong:

(A) jadeite which has not been treated other than by traditional surface waxing;

(B) jadeite, the sub-surface of which has been filled by polymer impregnation. The process is preceded by bleaching by immersion in acid;

(C) jadeite which has been impregnated by a staining process.

The paper examines the detection of the 'B' treatment via various visual clues, and concludes that identification is positively achieved by infrared spectroscopic confirmation of the polymer used.

I was delighted to be able to lend to Dr Fritsch three transparencies which showed how the basically equipped gemmologist could tackle and identify such bleached jadeite using an acid testing technique. The test procedure is described in my forthcoming book, but sufficient interest was aroused during lectures in Hong Kong, Canada and Tucson, to relate the procedure in slightly more detail.

Figure 1 shows a trio of:

(a) an untreated slice of green and white jadeite (note the brownish outer skin due to natural iron staining),

(b) a slice which has been acid bleached and polymer filled (note the absence of iron discoloration); and

(c) a cabochon fashioned from the (b) material.

To carry out the test technique, position the specimen so that it presents a flat (or near to flat) portion uppermost – Blu-tak always makes a good anchorage. Use the head of a new domestic pin (held by tongs or a similar tool) to dip and retrieve a droplet of concentrated hydrochloric acid. Touch the acid down as a standing droplet on the jadeite surface, previously wiped clean. It is advisable to add a second or even a third droplet to sustain the acid supply.

Figure 2 shows a 20mm jadeite drilled bead specimen known to have been fashioned at least thirty years ago.

The applied acid droplet can just be seen across the edge of the window reflection. Down the centre of the specimen, it can be seen that the acid has reappeared at the surface of an internal fracture and away from the original applied droplet.

Figure 3 shows a close-up of the acid weeping from below to accentuate two internal fractures which form a diagonal cross. The evidence took some two to three minutes to surface. It is evident that in untreated jadeite ('A' type) the acid is drawn under the surface by the capillary action of the jadeite's cryptocrystalline grain boundaries and/or open fractures. Where there are no evident fractures, a 'perspiration' aureole of acid is seen surrounding the droplet several minutes after the acid application.

When the acid is placed on a specimen of bleached 'B' type jadeite, the acid sits on the surface until it evaporates and cannot reappear elsewherel since the polymer has in fact sealed the micro-porous structure.

My photographs appeared to be at odds with the findings of the GIA Lab which had observed no such diagnostic response. I discussed the discrepancy with Fritsch by telephone and he kindly forwarded one of the GIA specimens which had not responded to their own acid tests.

At first the GIA specimen resisted the hydrochloric acid, but I determined this was due in part to the fine grain texture of the translucent white jadeite specimen. I could see the first glistening response of the acid on the pyroxene but not sufficient to capture by camera. I added a second and third drop of acid at one minute intervals on the same spot and slowly the acid

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Fig. 1. From left to right: (a) untreated green and white jadeite with a brown iron-stained skin; (b) jadeite which has been bleached and polymer-resin treated; (c) a cabochon fashioned from the polymer-impregnated material.

Fig. 2. A 30 year old untreated jadeite bead showing an applied acid droplet across the edge of the window reflection and near the centre of the specimen, also droplets which have re-appeared at the surface of an internal fracture.

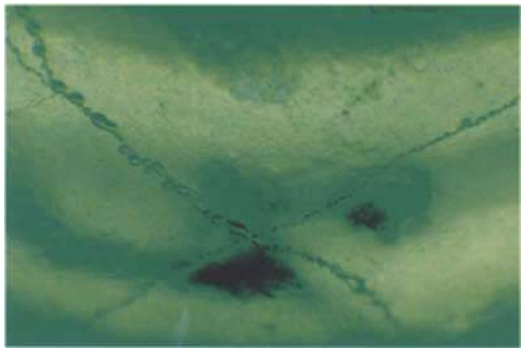

Fig. 3. Close-up of the acid droplets which have migrated up along two internal fractures in untreated jadeite.

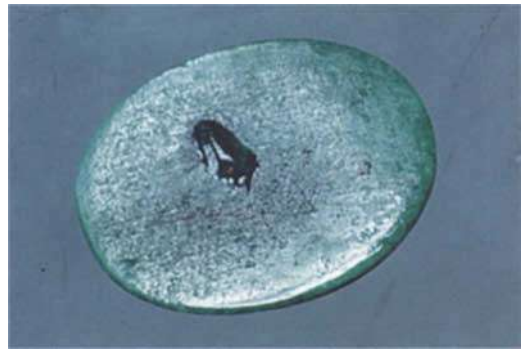

Fig. 4. Cabochon of stained jadeite ('C' type) made from more porous material. The centrally applied acid drop has sweated profusely over a surrounding aureole which covers the whole surface of the cabochon.

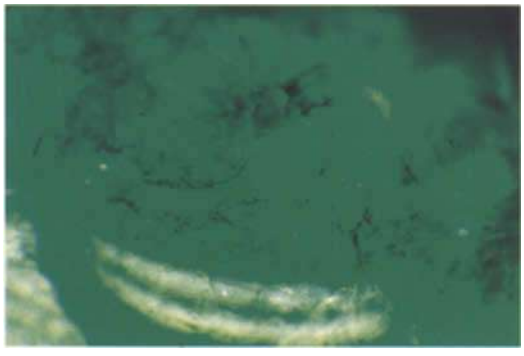

Fig. 5. Stained jadeite with an acid drop on the surface; the drop acts as a lens and reveals the staining pattern more clearly.

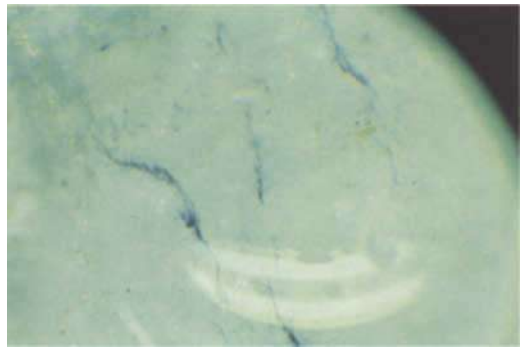

Fig. 6. Traces of the initial mauve stain agent in a green stained jadeite.

reappeared elsewhere, but the effect was somewhat thwarted by the decorative grooving which patterned the carved leaf design of the surface as shown by Fritsch *et al.* (1992).

A further telephone conversation pointed to opposing results until I happened to ask the temperature in Los Angeles. The 100°F+ temperature with air conditioning contrasted with the temperate Scottish climate in which I was domiciled and the discrepancy was explained by the rapid evaporation at higher temperatures with air conditioning. I also found mixed results in Hong Kong with their ubiquitous air conditioning.

Dr W. Hanneman of California was quick to point out an inexpensive solution (doesn't he always!). Place a glass cell or dish over the specimen subsequent to the acid drop application, and include under the glass a small receptacle or water to maintain normal conditions.

A further confirmation of an untreated surface also came to light. After the concentrated hydrochloric acid had sat on the untreated surface (type 'A' jadeite) for several minutes, the action of wiping away the acid droplet with a white tissue revealed a brown iron stain, though this was not apparent to the eye in the droplet itself. Such staining would be removed as part of the deep cleansing acid action prior to polymer treatment of type 'B' jadeite.

Figure 4 shows a green stained jadeite. The 'C' type relies on a more porous type of jadeite to gain access by the stain agency. As a result, the drop of hydrochloric acid quickly reveals the nature of such a porous material as it sweats profusely in a surrounding aureole, in this case covering the whole underside of the cabochon.

Polymer treatment of stained jadeite would no doubt seal and prevent such a result, but it is relatively easy to spot the staining of jadeite. The waxing of jadeite is a long standing practice to present the best polished surface (lustre). It was found that even freshly waxed jadeite did not interfere with the above acid tests.

In the course of acid testing the stained jadeite type 'C', the applied droplet of acid acted as a lens which resolved the stain agencies more distinctly (see Figure 5). A water droplet does the same of course, as also does a 10X lens.

The green staining of jadeite is actually a two-part process, the earlier part often involving a purple staining agent. Sometimes the purple stain is still in evidence after the final staining process (see Figure 6).

I trust this will be found to be a helpful adjunct to the main paper researched and reported in such detail by Dr Emmanuel Fritsch and his colleagues.

Reference

Fritsch, E., *et al.*, 1992. Identification of bleached and polymer impregnated jadeite. *Gems Gemol.*, 28, 3, 176-87.

[*Manuscript received 19 March 1993*]

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Microscopic estimation of refractive index using a dial test indicator and a personal equation

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Abstract

Fitting a dial test indicator to a microscope and its use combined with a personal equation, enables reasonably accurate measures of RI to be made in mounted and unmounted stones: some examples are given.

A modification is shown of engineers' digital calipers which facilitate the measurement of depth in mounted stones.

It is often useful to know the approximate value for the refractive index of a gemstone before using the refractometer, particularly for stones with RIs in the region of 1.8 and above. The measurement of real and apparent depth provides a quick way of achieving this, particularly if the microscope is adapted to use a dial test indicator (DTI). With care it is possible to obtain a reasonably good evaluation of the RI of a gemstone using the microscope in place of the refractometer.

Fig. 1. Dial test indicator 0.50mm, X0.01mm.

For this, the relatively inexpensive biological microscope is ideal. It is preferable to have a mechanical stage so that the stone may be moved laterally with its table still remaining parallel to the microscope stage. However, if the microscope does not have a mechanical stage, adjustment of position can still be accomplished manually if care is taken not to touch the stone but only the slide on which it is mounted. The DTI method is both more convenient and more accurate than using a vernier scale mounted to the microscope. The gauge used in this report has a range from 0 to 50mm with scale divisions of 0.01mm. This allows estimations of a fifth part of a scale division (i.e. to an accuracy of about 0.002mm). The gauge is easy to read; a dial size should be selected which enables it to fit comfortably on the microscope (in this case the dial shown in Figure 1 measures 70mm in diameter).

A simple brass mounting bracket with two locating screws may be constructed as shown in Figure 2. It is bored to take the stem of the gauge which is located by means of a 3mm grub screw. The vertical position of the gauge is adjusted by sliding it up or down in the bracket so that when its probe is touching the stage, the dial shows a mid-scale reading with the microscope in focus. This ensures that as the stage is raised or lowered, continuous readings are obtained on the gauge. Once set in position the gauge becomes an integral part of the microscope and may be used for making a variety of measurements. When focusing on a gemstone mounted with its table uppermost, it is safer to focus on the culet first; subsequent focusing may then be accomplished without the risk of damage to the objective. When focusing on the dome of a cabochon (via its base) care is needed to check that the 'surface details' focused on are not dust specks on the substage condenser.

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Moving the condenser downwards slightly removes the problem.

A useful accessory shown in Figures 3 and 4, is a small plate about the size of a microscope slide (75 x 25mm) made of 1.6 or 2mm thick aluminium sheet. This has a series of holes of different sizes drilled in it to accommodate stones of different diameters. A slit is cut to take a gemstone mounted in a ring. This slit is also ideal for mounting trap-cut stones and cabochons. The stones should be checked to ensure that their tables lie parallel to the microscope stage.

The following results were obtained using a 0.52 ct round faceted pyrope garnet. Measurements were repeated 10 times and RIs calculated as follows:

$$\frac{\text{Depth of stone}}{\text{Apparent depth of stone}} = \text{RI}$$

Mean RI (x) = 1.772 Standard deviation of the sample (δ^{n-1}) =0.009

The maximum and minimum values of the ten readings were 1.787 and 1. 756 respectively. The value of RI for the garnet, obtained by a refractometer, was 1.756.

As it stands, the method gives a reasonably good approximation of the stone' s RI but its accuracy may be improved. The values obtained vary with the technique used in focusing on the table and culet so that some practice is needed to ensure consistency. Individuals will have their own method, resulting in possible over-estimation or under-estimation and, just as astronomers used a personal equation for measuring the transit of a star, so an equation may be calculated for the microscope. In this case, the personal equation is found as follows:

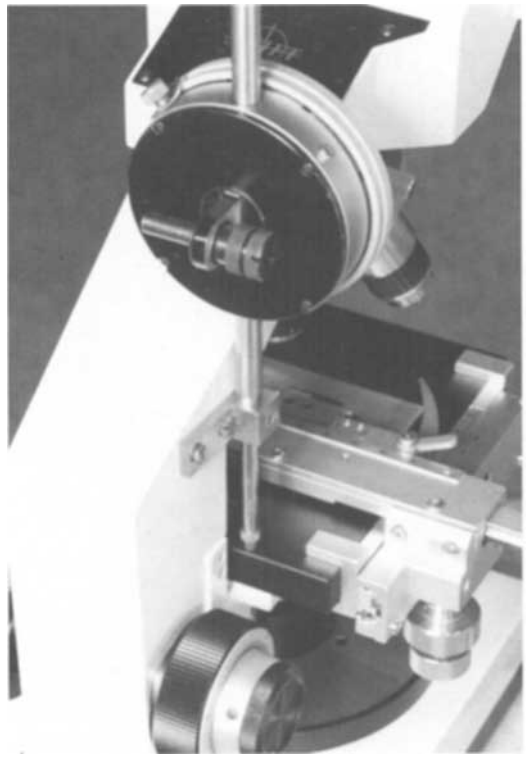

Fig. 2. Probe of mounted dial test indicator (DTI) in contact with stage.

Obtained value of RI 1. 772 (10 readings)
True value of RI 1. 756
error = 0.016 over-estimation

As a percentage of the true value, this is

$$\frac{0.016}{1.756} \times 100 = 0.9\%,$$

over-estimation which should be corrected in all measurements.

Fig. 3. Mounted stone held in slot of slide.

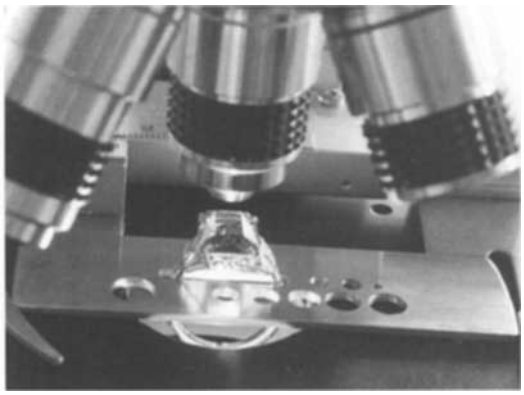

Fig. 4. Unmounted stone, culet down, in slot.

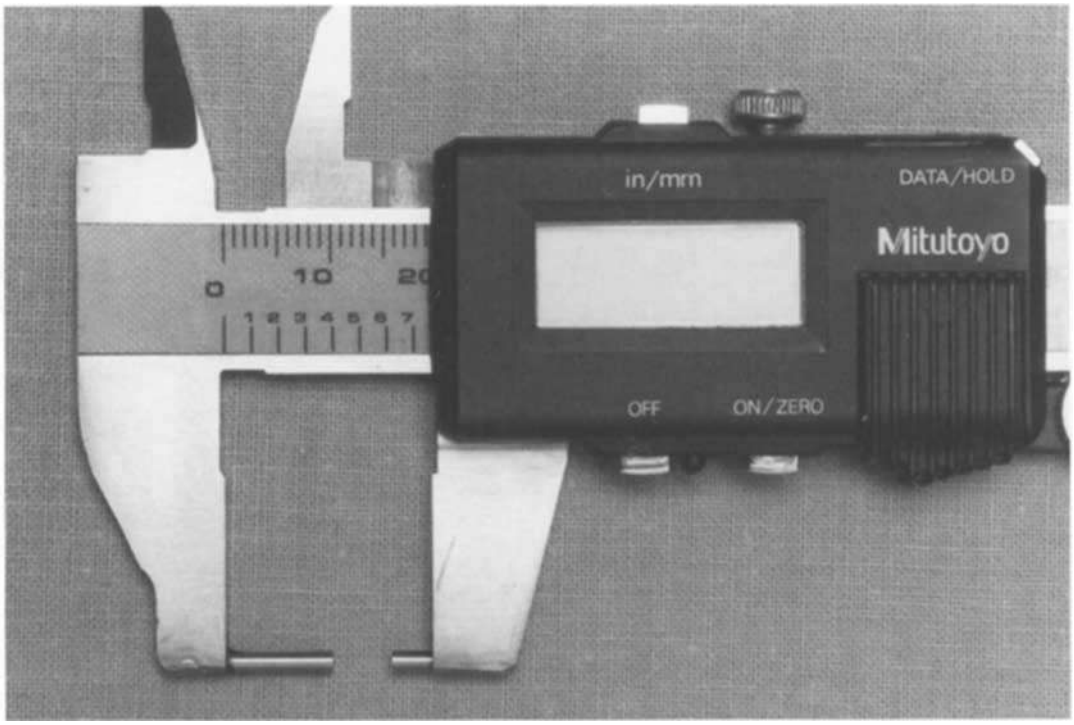

Fig. 5. Electronic calipers with attached, odd-leg 2mm diameter pins.

Applying this correction factor to the measurement of the RI of a trap-cut 2.6ct synthetic yellow sapphire gave the following values:

Microscope value of RI	1.780 (average of 3 readings)
Take off 0. 9% (Personal Error)	0.016
This gives the RI as	1.764

This is within the published range

$$\frac{o + e}{2} = 1.761 - 1.774$$

Other uses of the gauge included the measurement of the depth of an inclusion inside a stone, also the determination of the size of the inclusion (applying, of course, the appropriate correction for the optical effect of 'shallowness' caused by the RI of the stone). When testing ring-mounted stones, it is usually possible to use the transmitted light from the sub-stage condenser, but for some rings side lighting may be needed. In most cases it is easier to measure the true depth of the mounted stones using a Leveridge type gauge.

It is possible to modify (or have modified) engineers' electronic calipers as shown in Figure 5, by grinding down the tips of the calipers and mounting two 2mm diameter pins, one 4mm long, the other 10mm. The electronic calipers give readings to an accuracy of 0.01mm with values displayed digitally and the calipers may still be used after modification for normal measurements since they are self-zeroing.

Second-hand electronic calipers may sometimes be found which have a problem (due to wear) with accurate self-zeroing in the closed position. When pins are attached so that closure occurs at a point 14mm greater than before, the problem disappears as the worn area is not now being used. The second-hand Mitutoyo calipers which were modified cost the equivalent of just under £17. To measure the depth of an unmounted stone optically may be most easily accomplished by placing the stone with its table down over a small hole in the aluminium slide. Sufficient illumination is usually available from the substage condenser so that after focusing on the culet and taking a reading, the slide may be moved laterally to bring an adjacent hole into view and a second reading obtained by focusing on the machining marks around the hole.

Some examples of RIs obtained on different stones are as follows:

(a) This sample was a ring with an 8.8ct yellowish-green synthetic sapphire. Physical

depth determined by using calipers was 5.98mm. Three apparent depth readings showed a variability of 3.368, 3.360 and 3.360 (At 100X magnification). Taking the average as 3.3626 gives an RI of 1.778. Subtracting the personal equation factor of 0.9% gives an RI of 1.762.

(b) In the case of a 9.7ct mounted red tourmaline, 8.38 mm deep, internal detail was less clear, therefore a magnification of only 40X was used. Based on three readings and after applying the correction factor of 0.9% the RI value was 1.628.

(c) A 1.5ct diamond, mounted in a ring, gave three readings with an average apparent depth of 1.740. The physical depth was 4.29mm. The calculated RI value less the 0.9% correction factor gave a value of 2.42.

(d) A synthetic ruby cabochon, depth 6.36 mm, viewed with transmitted light, the dome of the cabochon facing the substage condenser (stone mounted in the slit on the aluminium slide). A few specks of dust on both surfaces aid the observations. Apparent depth values at 40X magnification are 3.575 and 3.577. RI value = 1.778 - 0.016 = 1.762

It is necessary in making all the above observations to focus on the *same* details each time, selecting a point in the centre of the stone and focusing via the table, or base in the case of the cabochon, at the deepest portion of the apex. Readings should be continued until consistent values are obtained. If the microscope is binocular, the appropriate eyepiece should be carefully adjusted to ensure that both left and right views show identical sharpness. If polarizing filters are fitted in the oculars (as in this microscope) they should be rotated, in the case of a birefringent stone, to show only one image (the *same* image in both oculars). Objectives with 4X and 10X magnification combined with a 10X eyepiece usually give sufficient clearance between objective and stone (15 and 7mm respectively) at magnifications of 40 and 100 times. When testing a cabochon which is mounted dome downwards in the slit on the microscope slide, its centre can be ascertained by viewing the dark edges of the slit, which appear as two curved lines. The centre is at the point where the two lines are closest together and also symmetrically positioned in the microscope field. It could be advantageous to construct specific correction factors for different sizes and shapes of stones and also for the various magnifications used. In this way, the microscope becomes a convenient tool for the measurement of refractive indices without any restriction on the magnitude of the RI.

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Towards a mathematical gemmology. Thinking in terms of ratios makes a difference

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Abstract

The author analyses the separation of light rays in doubling and 'fire' in terms of Snell's Law, and shows that the amount of separation varies inversely with the product of the highest and lowest RIs. Doubling strength and a new index that the author calls 'dispersing strength' are therefore recommended as being more accurate than birefringence and dispersion, respectively, whenever gemmologists wish to quantitatively discuss visual effects based on divergent light rays. Finally, fresh insight is given into the problem of colour fringes appearing during readings of a refractometer in white light, with the author suggesting that a comparison of the gem/hemicylinder critical angles in violet and red light is more useful than a comparison of the respective dispersions of gem and hemicylinder.

Introduction

One of the simplest observations that a gemmology student learns to make is the recognition of the doubled images of the back facets of a cut gemstone. This 'doubling' effect is positive proof that a stone is doubly refractive (DR), and therefore it is a useful test for separating diamond from some of its simulants.

Gemmology instructors typically explain that the amount of doubling depends on two factors: the path length of the light inside the gem and the gem's birefringence. Birefringence is the difference between the highest and lowest RIs of a DR material. Subtracting the two RIs is generally assumed to indicate the amount of separation between the two images: a gem which has high birefringence (e.g. zircon or peridot) will show more doubling than a gem which has low birefringence (e.g. topaz or quartz), if all other factors are equal.

However, in the ninth edition of *Gem Testing*, B. W. Anderson added a parenthetical comment to his discussion on the doubling effect of gems that have high birefringence: 'J.-P. Poirot, Director of the Paris gem-testing laboratory, has made the important observation that for a given birefringence the doubling effect is more marked in stones of low RI than in those of high index' (Anderson, 1980).

This article explains Monsieur Poirot's qualitative observation in quantitative terms, thereby revealing a fresh approach to understanding the amount of doubling that we see in gems that have high birefringence. The same analysis is then applied to our observation of dispersion and a new type of index is presented to quantify our understanding of a gem's ability to split white light into the colours of the rainbow.

Background concept

When a ray of light travels from a rarefied medium (such as air) into a denser medium (such as a gemstone), it generally undergoes several changes: it slows down, it bends towards the 'normal' (an imaginary line perpendicular to the interface) and sometimes it splits. The refractive index (RI) of a gem is the ratio of the speed of light in air to the speed of light in the gem. The higher the refractive index, the more the light slows down.

Snell's Law states that there is a fixed relationship between the angle at which a light ray strikes an object's surface and the angle at which the light ray is bent ('refracted') while it travels through the object. Measuring both the incident and refracted angles outward from the normal, Willebrord Snell (1591 - 1626) determined their relationship to be:

$$(1)\quad \frac{\sin i}{\sin r} = n \quad \text{where n is the object's refractive index}$$

Therefore, the higher the refractive index, the more sharply a light ray is bent when it enters the object.

When an incident ray of light splits into two rays inside a gem (double refraction), each ray slows and bends by a different amount. As a result, it becomes necessary to refer to *two* refractive indices. Subtracting the lowest RI reading from the highest RI reading gives us the gem's birefringence.

Isaac Newton discovered that a material's RI

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varies according to the wavelength of the incident light. Each of the component wavelengths of white light slows and bends by a different amount. Because the sides of a prism are not parallel, we are able to see the colours of the spectrum distinctly as they each bend by their characteristic amount.

The variation of RI with wavelength is called dispersion. The numerical value of dispersion is usually given as the difference between the RI of the Fraunhofer B line (686.7 nm) in the red part of the spectrum and the RI of the Fraunhofer G line (430.8 nm) in the violet part of the spectrum.

Do the simple subtractions involved in determining a gem's birefringence and dispersion describe any quantity that is mathematically meaningful? Generally speaking, the answer is 'no'.[1] Only by looking closely at Snell's Law can we accurately relate a gem's birefringence and dispersion to the *separation of light rays* that we observe in doubling and prismatic effects. Snell's Law views RI not as a single piece of data (i.e. speed of light in a gem) but rather as a *relationship* between measurements (i.e. a fixed ratio between two sines at *all possible* angles of refraction).

Separation, as perceived by the eye and as depicted in drawings of light ray paths, depends entirely upon *angular* separation and path length. Angular separation depends on the angle of incidence and the refractive indices, while path length is determined by the size and cut of the gem as well as the facet and angle through which the gem is viewed. Of all these factors, only the refractive indices are related to the nature of the gem material itself - the RIs are what we are referring to when we say 'diamond has a lot of fire' or 'peridot shows strong doubling'.

Another Approach

Although double refraction is the splitting of a *single* incident ray while dispersion is the separation of an *infinite number* of superimposed incident rays (i.e. the various wavelengths of white light), the two phenomena are mathematically equivalent; from one angle of incidence come two (or more) angles of refraction.

In both dispersion and birefringence, the angular separation is the arithmetic difference between the angle of refraction of one ray and the angle of refraction of another ray. Thus, an *exact* answer to 'How much divergence is there between the two rays?' can be achieved by subtracting the two angles of refraction. Subtracting the two RIs gives only a *rough approximation* of the divergence.

In Figure 1, the angular separation between

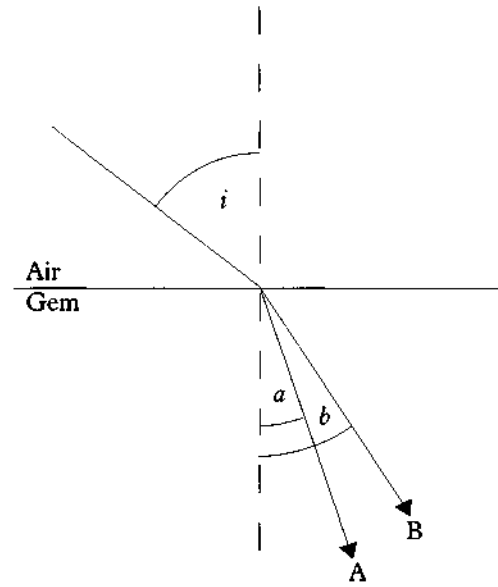

Fig. 1. Splitting of an incident light ray

refracted rays A and B can be expressed as b - a. We can derive an exact formula for this divergence by using Snell's Law (with the RIs of A and B represented as n_a and n_b, respectively):

$$(2) \quad n_a = \frac{\sin i}{\sin a} \quad \text{therefore} \quad \sin_a = \frac{\sin i}{n_a}$$

and similarly:

$$n_b = \frac{\sin i}{\sin b} \quad \text{therefore} \quad \sin_b = \frac{\sin i}{n_b}$$

The formula for an exact calculation of divergence is therefore:

$$(3) \quad b - a = \arcsin \frac{\sin i}{n_b} - \arcsin \frac{\sin i}{n_a}$$

However, a *close approximation* of divergence can be found by simplifying the exact formula, based on the fact that the divergence of rays is nearly always very small. (The dispersion of diamond and the birefringence of high zircon each produce an angular separation that is less than 1°.)

According to Maclaurin's theorem, the relationship between a small angle and its sine is nearly linear (Jenkins and White, 1976). Therefore, we can make a reasonable approximation of a small angular separation by replacing the quantity b - a with the quantity sin*b* - sin*a*. The formula then becomes:

$$(4)\ b - a \approx \sin b - \sin a \approx \frac{\sin i}{n_b} - \frac{\sin i}{n_a} \approx \sin_i \left(\frac{1}{n_b} - \frac{1}{n_a}\right)$$

As can be seen from formulae 3 and 4, the angular separation between two refracted rays varies directly with their angle of incidence. Discussions that compare materials of different optical density in terms of their refracting power generally assume a constant angle of incidence. If we therefore remove the quantity sini from formula 4, we arrive at the following formula which provides us with a highly accurate index of the 'diverging power' of any mineral (relative to other minerals of known RI):

$$(5)\quad \text{diverging power} \approx \frac{1}{n_b} - \frac{1}{n_a} \approx \frac{n_a - n_b}{n_a \times n_b}$$

Doubling Strength

The doubling strength of a gem is understood as the degree to which the gem material produces a doubling of the images of its back facets (relative to other gems illuminated at the same angle of incidence and viewed with equal path length).[2]

How does formula 5 compare with birefringence in determining doubling strength? The quantity $n_a - n_b$ can be recognized as the birefringence, which formula 5 states must be divided by the quantity $n_a \times n_b$ (the product of the gem's highest and lowest refractive indices) to give a close approximation of the doubling strength. In other words, the doubling strength produced by a given birefringence varies inversely with the two RIs (i.e. *roughly* in inverse proportion to the square of the mean RI).[3]

Table 1 compares the birefringence of 14 common gem materials with their doubling strength as derived from formula 5. The doubling strengths of two gems *can* be compared linearly: the fact that calcite has about 1.8 times the doubling strength of sphene means that the angular separation between the two rays of the former will be approximately 1.8 times the size of the angular separation between the two rays of the latter for any given angle of incidence (see Tables 2a, 2b and 2c).

Formula 5 explains why calcite shows 85 per cent *more* doubling than synthetic rutile, even though calcite's birefringence is only 60 per cent as large. Similarly, we find that the doubling strength of synthetic rutile is *less* than that of sphene, despite its birefringence being nearly twice as much as sphene's. Compared to zircon, peridot has 61 per cent of the birefringence and 83 per cent of the doubling strength. Dioptase has lower birefringence than zircon but *higher* doubling strength.

Table 1: Birefringence and doubling strength

Gem	Lowest RI	Highest RI	Birefringence	Doubling Strength
Syn Rutile	2.616	2.903	0.287	0.0378
Calcite	1.486	1.658	0.172	0.0698
Sphene	1.900	2.050	0.150	0.0385
High Zircon	1.925	1.984	0.059	0.0155
Dioptase	1.655	1.708	0.053	0.0187
Benitoite	1.757	1.804	0.047	0.0148
Sinhalite	1.668	1.707	0.039	0.0137
Peridot	1.654	1.690	0.036	0.0129
Diopside	1.675	1.701	0.026	0.0091
Tourmaline	1.624	1.644	0.020	0.0075
Spodumene	1.660	1.676	0.016	0.0058
Quartz	1.544	1.553	0.009	0.0038
Topaz	1.619	1.627	0.008	0.0030
Corundum	1.762	1.770	0.008	0.0026

Table 2a: Double refraction in calcite

Incident angle	Refracted angle of o-ray	Refracted angle of e-ray	Angular separation
15°	8.98°	10.03°	1.05°
30°	17.55°	19.66°	2.11°
45°	25.24°	28.41°	3.17°
60°	31.49°	35.65°	4.16°
75°	35.63°	40.54°	4.91°

Table 2b: Double refraction in sphene

Incident angle	Refracted angle for n_α	Refracted angle for n_γ	Angular separation
15°	7.83°	7.25°	0.58°
30°	15.26°	14.12°	1.14°
45°	21.85°	20.18°	1.67°
60°	27.12°	24.99°	2.13°
75°	30.56°	28.11°	2.45°

Table 2c: Comparison of calcite and sphene

Incident angle	Angular separation in calcite	Angular separation in sphene	Ratio of separations (calcite/sphene)
15°	1.05°	0.58°	1.81 : 1
30°	2.11°	1.14°	1.85 : 1
45°	3.17°	1.67°	1.90 : 1
60°	4.16°	2.13°	1.95 : 1
75°	4.91°	2.45°	2.00 : 1

Dispersing strength

Formula 5 can also be used to clarify our understanding of dispersion in a gem. The fire that we see in a diamond is a result of its cut (crown height and crown angle) and carat weight (path length). However, when we compare a diamond with other gems of similar size and ideal cut, their differences

in fire depend entirely on their ability to produce angular separation between the various wavelengths undergoing refractions.

As explained above, formula 5 gives a close approximation for angular separation-better than simple subtraction of RIs. Making a distinction analogous to the contrast between doubling strength and birefringence, we can use formula 5 to calculate a 'dispersing strength' which is more accurate than simple dispersion.

Table 3 compares the dispersion of five SR gems with their dispersing strength as derived from formula 5. Estimates had to be made for the red and violet RIs, because all of the numerous reference sources available to me list net dispersion without indicating the actual B and G RIs (except for diamond).

The dispersing strength of strontium titanate is about 4 times that of diamond, a fact stated in numerous gemmological texts. In comparing these two gems, dispersing strength gives nearly the same answer as dispersion, because the RIs are so close.

However, as the RI decreases, a given dispersion acquires more dispersing strength. Thus, compared to diamond, cubic zirconia's dispersion is 36 per cent higher but its dispersing strength is 69 per cent higher. GGG's dispersion is only 2 per cent higher than diamond's, but its dispersing strength is 54 per cent higher. The fire of GGG is thus closer to that of CZ than to that of diamond.

Furthermore, the dispersing strength of YAG is *greater* than that of diamond (approximately 0.0083 vs 0.0075). I suggest that the reason a piece of YAG does not show as much fire as a diamond is because the ideal proportions for diamond simulants have not been calculated with as much precision as Tolkowsky and others devoted to the cutting of the diamond. If cut to its own specific ideal proportions, YAG could show as much fire as diamond.[4]

Table 3: Dispersion and dispersing strength

Gem	Red (B) RI	Violet (G) RI	Dispersion	Dispersing strength
Strontium Titanate	2.36 (est.)	2.55 (est.)	0.190	0.0316
Cubic Zirconia	2.14 (est.)	2.20 (est.)	0.060	0.0127
GGG	1.950 (est.)	1.995 (est.)	0.045	0.0116
Diamond	2.407	2.451	0.044	0.0075
YAG	1.820 (est.)	1.848 (est.)	0.028	0.0083

I hope that a reader who has access to the exact B and G RIs for the various diamond simulants (including natural zircon) will be avid enough to calculate their dispersing strength from formula 5.

Dispersion on a hemicylinder

The problem of colour fringes at the shadow edge when reading a refractometer in white light is due to a 'difference' in dispersion between the gem and the refractometer's hemicylinder. What is the difference? Again, it is not a simple subtraction.

Recall that the shadow edge is determined by the critical angle between the hemicylinder and the gem. The critical angle is directly related to the *ratio* between the RI of the hemicylinder (n_{hemi}) and the RI of the gem (n_{gem}):

$$(6)\quad \text{critical angle} = \arcsin \frac{n_{gem}}{n_{hemi}}$$

The appearance of colour fringes at the shadow edge means that the critical angle between hemicylinder and gem varies slightly for different wavelengths of light. Therefore, the influence of dispersion on the sharpness of a refractometer reading should be calculated by comparing the critical angle in red light to the critical angle in violet light. If the two critical angles are nearly equal, the effect of dispersion will be almost nil (i.e. colour fringes will be difficult or impossible to see).

To minimize the colour fringes, we need to produce a situation that can be expressed as follows:

$$(7)\quad \arcsin \frac{n_{gemR}}{n_{hemiR}} \approx \arcsin \frac{n_{gemV}}{n_{hemiV}}$$

Formula 7 is approximately equivalent to:

$$(8)\quad \frac{n_{gemR}}{n_{hemiR}} \approx \frac{n_{gemV}}{n_{hemiV}}$$

Therefore, the important consideration in determining the effect of dispersion on colour fringes is *division*, not subtraction. That is, we should not be comparing the dispersion of the gem (n_{gemV} - n_{gemR}) and the dispersion of the hemicylinder (n_{hemiV} - n_{hemiR}), but rather the *ratio* between the two RIs in red light and the *ratio* between the two RIs in violet light.

For example, an ideal ('colour-fringe free') shadow edge would be present on a hemicylinder that has n_v = 1.92 and n_R = 1.88 (dispersion = 0.040) if the gem being tested has n_v = 1.550 and n_R = 1.518 (dispersion = 0.032)

In this case,

$$\frac{n_{gemR}}{n_{hemiR}} = 0.8074 \text{ and } \frac{n_{gemV}}{n_{hemiV}} = 0.8073.$$

The 'match' is therefore nearly perfect (assuming that the ratio remains the same for all of the wavelengths between red and violet), despite the 'difference' between the dispersion of the hemicylinder (0.040) and the dispersion of the gem (0.032).

Conclusion

The formulae presented in this article are not 'news' to those who are acquainted with the field of optics. Old mineralogy textbooks such as Dana's *A Textbook of Mineralogy* contain numerous formulae that are far more complex than those of this article. Indeed, many mathematical analyses of optical phenomena dating back to the nineteenth century remain valid (e.g. the optical indicatrix was presented by L. Fletcher in 1892).

Therefore, this article is not about the discovery of a new formula. Rather, it is about the application of old formulas to a new field of science called 'gemmology'. I am writing to encourage gemmologists to get in step with the mathematical concepts that optical mineralogists have been using for the past hundred years.

The simple subtraction involved in determining birefringence and dispersion is, to put it bluntly, a simplistic approach. As a rule of thumb, we can say that when the birefringence or dispersion equals at least 2 per cent of a gem's RI, a gemmologist's interpretation of visual observations (i.e. angular separations) will become distorted unless he or she has been trained to think in terms of ratios (doubling strength and dispersing strength) rather than differences.

Notes

1 The subtraction of RIs *is* meaningful when a mineralogist estimates birefringence from the observation of interference colours in a specimen of known thickness. Here it is useful to view the difference between high and low RIs as the different speeds of the two rays. When the thickness is constant, the difference in speed causes a 'retardation' (i.e lag) between the two rays. The exact distance of any retardation corresponds to one of 'Newton's colours', which are shown in sequence on a Michel-Levy chart (Hurlbut and Klein, 1977). A mineral's birefringence can be estimated from the chart, according to the following formula (Phillips, 1971):

retardation = thickness x birefringence.

2 Recalling the formula that is the basis for the Duc de Chaulnes method (Webster, 1983), it should be noted that the doubled images do not lie in the same plane. Because the two rays have different RIs, the two facet images produced by them have different apparent depths.

3 The term 'mean RI' is commonly encountered in mineralogy texts. It should be recognized as an abstract concept that does not have a specific relationship with crystal structure. For example, averaging the highest and lowest RIs of a biaxial stone generally does *not* give the beta RI.
Using 'mean RI' in the formula for doubling strength increases the number of steps involved in the calculation and gives results that are slightly too low in cases of very high birefringence: synthetic rutile = .0377 and calcite = .0696 (compare these figures with the corresponding figures in Table 1).

4 The amount of fire that one sees in a well-cut diamond depends on both the crown angle and the crown height. An ideal crown angle maximizes the 'fanning out' of the various wavelengths when they exit the gem (i.e. the spectral colours are easier to see because their rays are spread more). A large crown height increases the size of the crown facets relative to the table (i.e. it increases the *proportion* of internally reflected light that has its component wavelengths spread enough to be easily seen) (Pagel-Theisen, 1989).

References

Anderson, B.W. *Gem testing*, 9th edn, p.51 (1980) and 10th edn (1990) p.43 on Poirot.

Hurlbut, C.S. and Klein, C., 1977. *Manual of mineralogy* 19th edn, p.206 on Michel-Levy.

Jenkins, F.A. and White, E., 1976. *Fundamentals of optics*, 4th edn, pp. 150-1 on Maclaurin's theorem.

Pagel-Theisen, V., 1989. *Diamond grading ABC*, 9th edn, pp.145-6 on dispersion.

Phillips, F.C., 1971. *Mineral optics: principles and techniques*, pp. 91-2 on retardation, chart of interference colours folds out after p.100.

Webster, R.,1983. *Gems*, 4th edn, p.714 on refractometer colour fringes, p.724 on de Chaulnes formula.

Gemmological Abstracts

BANK, H., 1992. Demonstrationsobjekt 'Gemmologische Brosche' als pädagogisches Anschauungsmaterial. ('Gemmological brooch' as educational material.) *Zeitschrift der Deutschen Gemmologischen Gesellschaft* **41**, 2/3, 101-5, 1 photograph, bibl.

The brooch contains twenty-one gemstones, all somewhat deviating from 'normal' colour. Dr Bank had this brooch made up to demonstrate to students the difficulties of determining the gem materials in set pieces. E.S.

BENNETT, D., KEELING, J.L., 1992. Imitation lapis lazuli, charoite and azurite malachite. *Australian Gemmologist*, **18**, 3, 83-5, 6 figs.

Rough specimens obtained at Loxton Gemboree, South Australia, are described. Cabochons were cut from these. In general one needs imagination to associate these materials with the natural stones they are supposed to imitate [natural charoite is violet or lilac in colour, not Royal blue as the imitation, and not orange-brown as in the natural stone, illustrated]. Described as not very attractive, intended for cheap jewellery only. SEM showed them to be made of powdered barite and gibbsite plus colouring in an organic cement containing perspex. R.K.M.

BROWN, G., 1992. The elephant and its ivory. *Wahroongai News*, **26**, 10, 19-16, 18 figs.

An interesting listing of elephant species (proboscidae) from the Eocene era to the present day, illustrated by photocopies of line drawings including mammoths, mastodons and earlier fossil species, some of which might well be represented in 'fossil' ivories extant today. R.K.M.

BROWN, G., BEATTIE, R., 1992. Vietnamese ruby fakes: a problem requiring urgent solution. *Australian Gemmologist*, **18**, 4, 108-14, 36 figs.

Arrival of good quality rubies from Luc Yen and other Vietnam localities in 1990 occasioned much excitement, but many parcels, whether rough or cut, were and still are, heavily adulterated with stones from other sources, or with fragmented Verneuil type synthetics which had been tumbled to a water-worn appearance. More elaborate fakes were also found; synthetic material shaped to crystal habit with quench-cracking and lateral striation to increase deception, often heat-treated to reduce curved striae, oiled or waxed, impregnated with blue-dye, or infilled with fragments of real stones. Many natural stones painted with red nail varnish. Composites of either ruby or sapphire could contain both natural and synthetic material.

When cut, most of these are easily identified by conventional gemmological testing, but the rough parcels are much more difficult and it is advisable to polish a 'window' before arriving at a final decision.

Adulterated sapphire rough could be tested for the absence of a 450nm band in the synthetic material spectrum.

Natural rubies share inclusion types with those from Burma, with additional features of blue zoning, pyrrhotite rods (brassy or black), or colourless rods of calcite, orange rutile, fine bluish clouds of rutile needles and flux-like masses of orange norstrandite.

Writers say that to survive, the Vietnam ruby and sapphire industry must eliminate these practices at once. [Otherwise parcels from these sources may be rejected as untrustworthy.] Some fakes were crude but surprisingly ingenuous.

A valuable paper! R.K.M.

CAVENEY, R.J., 1992. De Beers Diamond Research Laboratory Report 1992. *Indiaqua Annual 1992/3*, 275-7, 9 photos in colour.

The main gem interest in this report is a brief account of the cutting of the shield-shaped 273 Centenary diamond. The diamond was cut, under conditions of high-level security, in the DRL premises, scientists and engineers of the laboratory developing the necessary specialized equipment. This included the scaife and special dops fed with a liquid coolant. A thermocouple attached to the stone monitored its temperature during cutting and, with the aid of a sophisticated control system, ensured that the gem was not subjected to any abnormal or sudden forces or to thermal variations.

In the Mineral Processing Division, work progressed during the year on the development of a fully integrated sorthouse for diamond recovery. New designs of X-ray machine, optics and ejector technologies were introduced to improve the efficiency of sorting. P.G.R.

COENRAADS, R.R., 1992. Sapphire and rubies associated with volcanic provinces: inclusions and surface features throw light on their origin. *Australian Gemmologist*, **18**, 3, 70-8, 11 figs, 1 map.

Like many other sources worldwide, the alluvial sapphires of New England, NSW, are of volcanic origin, in this case from the Central Province region. The paper describes these and other fields, crystal habit, inclusions, mining methods and many other matters in considerable detail. R.K.M.

COLDHAM, T.C., 1992. The Australian sapphire industry. *Australian Gemmologist*, **18**, 4, 104-7.

A history of sapphire mining and processing in Queensland and New South Wales, with problems and possible future. R.K.M.

COOPER, M.P., 1993. Letter from Europe. *Mineralogical Record*, **24**, 3, 231-7, 8 photos (5 in colour).

European mineral shows during 1993 have featured transparent gem-quality green zoisite from Pakistan (one crystal at least displaying pronounced dichroism); very large spessartine crystals from the Shagar valley, Pakistan; gem-quality emerald crystals from Nigeria; fine deep-coloured aquamarine crystals from Jos, Nigeria (the reporter feels that the deep colour is natural). M.O'D.

DISSANAYAKE, C.B., RUPASINGHE, M.S., DHARMARATNE T., 1992. Fluorine hydrochemistry in a topaz-rich area in Sri Lanka. *Zeitschrift der Deutschen Gemmologischen Gesellschaft*, **41**, 2/3, 111-16, 2 maps, 1 table, bibl.

Halogens are often used in geochemical exploration for mineral deposits. Fluorine, the most reactive of the halogens, is useful for the exploration of F-bearing gem minerals such as topaz, fluorspar and tourmaline. A study of the Elahera gem deposits in Sri Lanka shows that the geochemistry of F in ground-water could be used to locate areas of F-bearing gem materials. E.S.

DOMENECH, M.V., 1992. Les gemmes singulars del Tresor Imperial de Viena. *Gemologia*, **34**, 89, 4-8, 3 photos in colour.

Brief description of a fine emerald, a garnet and an agate plate, with other gems, forming part of the Imperial Treasures of the Hapsburgs, held in the Hofburg, Vienna. M.O'D.

DUCHAMP, M., 1992. Deux sommets de la gravure sur cristal de roche: les portraits de l'amiral de Ruyter et de l'empereur Leopold 1er. *Revue de gemmologie*, **113**, 5-7, 3 photos (1 in colour).

Two celebrated engraved rock crystal portraits are described. M.O'D.

FM-TGMS-MSA Symposium on garnet, 1993. [Short papers from the Symposium]. *Mineralogical record*, **24**, 61-8, 4 photos in colour, 13 figs.

The short papers cover: nomenclature and classification of garnets; the causes of colour in garnets; crystal structures, chemistry and properties of garnets; inclusions in garnets; geological occurrence of minerals in the garnet group; chemical and physical properties of vanadium-, chromium-, and iron-bearing garnets; garnets in architectural paints; garnets in the gem-bearing pegmatite dikes of San Diego County, California; garnets of Magnet cove, Arkansas; a new garnet locality in Connecticut; the McBride property [Hull County, Quebec]. M.O'D.

FRITSCH, E., MUHLMEISTER, S., BIRKNER, A., 1992. A preliminary spectroscopic study of the Biron synthetic pink titanium beryl. *Australian Gemmologist*, **18**, 3, 81-2, 3 figs.

UV visible and infrared were used, giving similar results to those for other Biron synthetic beryls. G. Brown has said that this material is easily identified by normal gemmological tests. R.K.M.

GODOVIKOV, A.A., BULGAK, L.V., 1993. Die Malchansker Elbait-Lagerstätte im russischen Transbaikalien. *Lapis*, **18**, 1, 13-15, 5 photos in colour, 1 map.

Gem-quality pink and green elbaite is found in the Malchansk pegmatites in Russian Transbaikalia. An interesting feature of some of the tourmaline is the high content of Bi_2O_3; the Malchansk pegmatites contain several bismuth compounds. M.O'D.

HANNAFORD, R., 1992. The carat: the unit of weight. *Australian Gemmologist*, **18**, **4**, 117-18, 1 fig. used as cover design.

An antique scale bought by Mr Hannaford for gold weighing had an incomplete set of weights in old English fractional carats which

means the scale is for gems and must predate 1914, when the British ratified the new weight. He quotes Herbert Smith's *Gemstones* in which the varying gram values worldwide are given. Such fractions were recorded separately and not added together. [Abstracter has a Moe diamond gauge booklet which quotes weights similarly.] The English carat was 0.2053 grams until 1914 when the standard carat of 0.200 grams was adopted. [The maker of the scale is quoted as De Crave, but I suspect that this is in fact De Grave, a well known maker in Victorian times.]

R.K.M.

HÄNNI, H.A., 1992. Considérations terminologiques au sujet des émeraudes du Nigéria de couleur bleu-vert. *Revue de gemmologie*, **113**, 2-4, 1 photo and 3 figs in colour.

Bluish-green emeralds from Nigeria offer a problem in nomenclature. However, a Cr absorption line can be seen at 683nm and the stones thus fulfil the Cr-content criteria for emerald despite their strong blue component.

M.O'D.

HARDER, H., 1992. Rauchmondsteine, eine neue Mondstein-Varietät. (Smoky moonstones, a new moonstone variety.) *Zeitschrift der Deutschen Gemmologischen Gesellschaft*, **41**, 2/3, 69-84, 8 photographs, 3 tables, 1 maps, 1 schematic drawing, bibl.

Underneath the colourless and white moonstones near Implube, east of Ratnapura in Sri Lanka, 'smoky moonstones' have recently been found. They exhibit a flash of blue or white from a dark body. The blue, semi-blue and white moonstones have different alkali contents. The white quality is richer in potassium, the blue in sodium. In the top blue more than half of the alkali position in the lattice of the feldspar is occupied by sodium, so it is more of an albite than an orthoclase. A higher Fe^{2+} content is the chemical reason for the smoky moonstone quality which makes the blue shine better visible.

E.S.

HENN, U., 1992. Uber die diagnostischen Merkmale von synthetischen Alexandriten aus der Gemeinschaft Unabhängiger Staaten (GUS). (About the diagnostic characteristics of synthetic alexandrites from the former Soviet Independent States.) *Zeitschrift der Deutschen Gemmologischen Gesellschaft*, **41**, 2/3, 85-93, 10 photomicrographs, 2 graphs, 1 table, bibl.

The identification of the synthetic alexandrites produced by flux-pulling or hydrothermal method are the absorption spectra and some microscopic features. These do not appear in all examples, as the products are very clean and only sometimes leave traces of their production processes.

E.S.

HENN, U., BANK, H., 1992. Aquamarine aus Moçambique. (Aquamarine from Mozambique). *Zeitschrift der Deutschen Gemmologischen Gesellschaft*, **41**, 2/3, 107-10, 1 photograph, 1 graph, bibl.

Aquamarines of fine colour (Santa Maria) were found in the sixties in primary deposits at Mocuba in Mozambique. RI 1.572-1.580, to 1.582-1.589, DR 0.009. SG 2.70-2.73. The colour is caused by Fe. Microscopic studies show tiny fluid inclusions and hollow tubes. Analysis shows the iron content to be between 2.06-2.55 weight % FeO.

E.S.

HENN, U., BANK, H., 1992. Gemmologische Kurzinformationen. (Short gemmological notes.) *Zeitschrift der Deutschen Gemmologischen Gesellschaft*, **41**, 2/3, 63-7, 6 photographs.

A De Beers synthetic diamond of 0.43ct is discussed. It is a yellow, of Type Ib, fluorescent under long- but inert under short-wave UV. Under the microscope one could see definite colour zoning, hollow tubes which were the remnants of the catalyst and some very fine clouding.

In November 1991 some cut black diamonds were offered in the trade which turned out to be radio-active; high radiation made these stones unsafe. This also applied to some radio-active blue topazes. According to German law, stones which have been treated and exceed certain limits of radio-activity cannot be traded.

The article then deals with some synthetic zinc oxide from Poland, colourless beryl crystals covered with synthetic emerald film, green glass from Zambia traded as emerald crystal and a faceted cut tourmaline from Brazil with the zoning at right angles to the *c*-axis; the pink colour was caused by Mn^{3+} and the yellow by Mn^{2+}.

A green material with brown specks was found in New South Wales; it is a mixture of plagioclase and jadeite and can be used as an ornamental stone called 'nunderite'.

E.S.

HLAING, U.T., 1992. Myanmar jade: an update. *Australian Gemmologist*, **18**, 3, 79-80, 4 figs.

Deals with legend of jade discovery in the thirteenth century, although regular trade did not start until late in the eighteenth century. Natural resources and gems are State owned,

but exploited jointly with private companies. Finest gems are sold abroad by Myanmar Gems Enterprise to bring foreign currency, but smuggling has led to a jade centre in Bangkok, Thailand. Sales have improved since jadeite was sawn to disclose its quality. R.K.M.

HOLZHEY, G., 1992. Praktische Gemmologie am Beispiel historischer Pretiosen. (Practical gemmology as applied to historical sculpture.) *Zeitschrift der Deutschen Gemmologischen Gesellschaft*, **41**, 2/3, 95-100, 3 photographs, bibl.

The sculpture discussed is a silver-gilt elephant produced by the goldsmith and jeweller J.M. Dinglinger in Dresden in the first quarter of the 18th century. The dimensions are 17.5 x 12 cm, height 13.5 cm; it is listed in the inventory of 1725 of the 'Gruenen Gewoelbe'. The saddle of the elephant is studded with precious stones, 21 emerald cabochons, but only 22 of the 41 rose-cut stones are diamonds, the remainder are rock crystal or colourless topaz. The quality of the emeralds is variable. E.S.

HUTTON, D.R., TROUP, G.J., 1992. Magnetic resonance spectrum of Torrington emerald. *Australian Gemmologist*, **18**, 3, 89-90, 2 figs.

An investigation of electron-spin resonance of emerald from another Australian locality, identifying a greatly reduced content of vanadium in comparison with stones from Poona or with Colombian emerald. Comparison with Biron synthetic emerald also made. R.K.M.

JACKOWSKA-POLEWCZAK, A., 1991. Kamienie szlachetne i ozdobne Madagaskaru. *Mineralogia polonica*, **22**, 3, 79-87, 1 map.

Gem minerals are described and brief geological and mining details are given for Madagascar. M.O'D.

JANOSZCZYK, B., 1992. Problem otrzymywania syntetycznych opali szlachetnych. *Mineralogia polonica*, **23**, 1, 89-93.

Some considerations of the Gilson synthetic opal are offered with theories on the possible methods of manufacture. M.O'D.

KEELING, J.L., FLINT, R.B., 1992. Almandine garnet crystals from the Prydz Bay area, Antarctica. *Australian Gemmologist*, **18**, 3, 85-8, 8 figs, 2 maps.

Red to brownish-red almandine crystal fragments found on Vikoy Island, near Davis, were examined and found to be of expected habits with trapezohedron predominant, usually heavily striated. R.K.M.

KOIVULA, J.I., 1992. The gemmological properties of extraterrestrial peridots. *South African Gemmologist*, **6**, 10-16, 5 photos in colour.

Transparent to translucent nodules of peridot have been found in pallasites, meteorites with a metallic network of nickel and iron. Properties are within the range for gem peridot but stones show acicular inclusions caused possibly by stress- and heat-caused exsolution. M.O'D.

LASNIER, B., POIROT, J-P., SMITH, D.C., 1992. Intercroissances de jadéite de différentes compositions dans les jades révelées par cathodoluminescence. *Revue de gemmologie*, **113**, 8-11, 5 photos in colour, 4 figs.

Zoned cathodoluminescence can be seen in crystals of jadeite and provides a means of distinguishing compositional variations. M.O'D.

LIEBER, W., 1993. Farbzonen in Kristallen: Beobachtungen im Mineralreich. *Lapis*, **18**, 1, 29-48, 15 photos in colour.

Among the examples of zoned minerals discussed are rock crystal, amethyst and tourmaline; the paper includes a discussion of chemical reasons for the phenomenon. M.O'D.

LINTON, T., BROWN, G., 1992. Hofer gemstone colorcard. *Australian Gemmologist*, **18**, 4, 122-4, 1 fig.

Despite its name this is intended to determine the colour temperature of light available in which to judge stones. It does not define the colour of stones. R.K.M.

MENZIES, M.A., BOGGS, R.C., 1993. Minerals of the Sawtooth batholith, Idaho. *Mineralogical Record*, **24**, 3, 185-202, 20 photos (6 in colour), 1 map.

Among the minerals found in miarolitic cavities and pegmatite dikes in the granite of the Sawtooth batholith in south-central Idaho are gem-quality aquamarine and colourless topaz. Smaller crystals of spessartine are also reported. Some aquamarine crystals reach over 10cm in length. M.O'D.

PASTERNAK, A., 1993. Rock star. *ES*, the *Evening Standard* magazine, June 1993, 2 photos in colour.

Reporter's interview with London merchant Laurence Graff. M.O'D.

PETERSEN, O.V., SECHER, K., 1993. The minerals of Greenland. *Mineralogical Record*, **24**, 2, 4-67. 76 photos (colour and black-and-white), 6 maps, 22 figs.

Among the minerals of Greenland with ornamental application are tugtupite, sphene, garnet, ruby and sapphirine though few can be counted gem quality apart from the first two named. The paper is a welcome and exhaustive up-to-date descriptive summary of one of the world's major mineralized areas. M.O'D.

PLASZYNSKA, M., 1992. Some remarks on the applications of Baltic amber today and in ancient and medieval times. *Mineralogia polonica*, **23**, 2, 75-6.

A brief account of the use of amber through the ages. M.O'D.

POIROT, J-P., 1992. Ambre naturel, ambre pressé, ambre synthetique. *Revue de gemmologie*, **113**, 25-6, 1 photo in colour, 1 fig.

A brief resumé of the various types of amber and amber simulants with details of some manufacturing processes where appropriate. M.O'D.

READ, P.G., 1993. Diamonds in the desert. *Canadian Jeweller*, April 1993, 27-8, 1 photo in colour.

Covers the history of the discovery of diamonds along the Namibian coastal desert in what was then German South West Africa, to the development of the CDM mining operation after World War I and its incorporation into the De Beers group. (Author's abstract) P.G.R.

ROBERT, D., 1992. La coloration artificielle du béryl. *Revue de gemmologie*, **113**, 23-4, 4 photos in colour, 1 fig.

Various ways of colouring beryl are briefly described. M.O'D.

ROBERTSON, A.D.C., SUTHERLAND, F.L., 1992. Possible origins and ages for sapphire and diamond from the central Queensland gem fields. *Records of the Australian Museum, Suppl.*, **15**, 45-54, 1 map, 1 photo.

Mining of sapphire has been carried out for over 100 years in this area, the classic grains of sapphire reputedly derived from the local basalt. New work has shown, however, that the sapphires originate in pyroclastic rocks and are associated with zircons. The zircons are of two types: older low-uranium zircon and younger high-uranium zircon. The occurrence of low-uranium zircon suggests that conditions may have been appropriate for the emplacement of diamondiferous material during this period. R.A.H.

SAADI, J.A., GRASSO, J.C., 1992. Rhodochrosite from Argentina. *Australian Gemmologist*, **18**, 4, 125-32, 26 figs.

Describes the Capillitas mines, which yield this beautiful pink to red ornamental mineral, in considerable detail. In a region producing much superlative material, it seems that the Ortiz mine is top in quality, some of which would appear to be facetable. The major output is slabbed for decorative use, carved or used for cabochons. R.K.M.

SCHUBNEL, H-J., 1992. Les gemmes et l'histoire de la minéralogie de Louis XIII à Charles X. *Revue de gemmologie*, **113**, 14-18, 14 photos (7 in colour).

Mineral and gem collections at the Muséum National d'Histoire Naturelle, Paris, reflect the collecting activities of several French kings. The three main collections are the Jardin du Roy (1626-1730) with an emphasis on the medicinal use of minerals; the Cabinet Royal d'Histoire Naturelle, (1739-1793), displayed in 99 showcases and Le Muséum National d'Histoire Naturelle (1793 to the present). Approximately 243,000 specimens are now in the collections. M.O'D.

THOMAS, A.E., THOMAS, C.A., 1992. Garnets of the alluvial diamond diggings, pt 2. *South African gemmologist*, **6**, 3, 5-9, 3 photos in colour.

Garnets from two areas are examined and described with details given of their weight, colour, RI, SG, fluorescence, absorption spectrum and inclusions. The two areas are: diggings in the Vaal River catchment from Boskuil through Bloemhof and Christiana to Warrenton in the western Transvaal; and an area in the northern Cape between Schmidtsdrift, Douglas, Higg's Hope and Prieska, including the confluence of the Orange and Vaal Rivers. Attempts are made to place the stones on a garnet colour scale. M.O'D.

VOYNICK, S., 1993. Synthetic gemstones: high fashion, higher tech. *Compressed air*, **98**, 4, 8-15, 9 photos in colour.

A brief resumé of the use of man-made crystals as gemstones with notes on the problems of identification. M.O'D.

WILLIAMSON, L., 1992. A new theory of archaic jades. *Bulletin of the Friends of Jade*, 7, 42-7.

Drawing on the development of ideographs some idea of the use of Chinese jade artefacts can be obtained. Diagrams are taken from Karlgren, Grammata Serica Recensa, Stockholm, 1957. M.O'D.

ZHANG, P., 1992. Gem-quality scapolite from Sinjiang region, West China. *Australian Gemmologist*, **18**, 4, 115-17, 2 figs.

Prospects appear to be good for purplish pink scapolite found in association with sphene in this region, both as facetable and as cat's-eye material. R.K.M.

What's new in minerals? 1993. [various authors]. *Mineralogical Record*, **24**, 3, 219-30, 1993. 32 photos (31 in colour).

Shows at Tucson and Pasadena are reviewed. Among the gem-quality species observed were yellow beryl from Skardu, Pakistan; rhodochrosite from the Sweet Home mine, Colorado; green zoisite from Skardu; very fine etched heliodor from Ukrainia and etched sherry-coloured topaz from the same country; diamond crystals from north- western Hunan province, China; also from China were light blue aquamarine crystals; orange clinohumite from Kukh-i-Lal, Pamir mountains of Tajikistan; brazilianite from Baixo, Guandu, Minas Gerais, Brazil; large pale bluish-green datolite, also danburite and axinite from Dal'negorsk; emerald and alexandrite from the Malysheva mine, Takavaya, Urals; topaz from Mursinka, Russia; sillimanite from Rakwana-Deniyara, Sabaragamuwa province, Sri Lanka (one crystal seen measured 1.8cm); chrysoberyl twins from Teixeira da Freitas, Bahia, Brazil and from Medeiros Neto in the same state; near gem-quality sapphirine from Androy, Malagasy Republic. M.O'D.

ANON, 1992. Opal theft. *Australian Gemmologist*, **18**, 4, 115, 1 fig.

A short note on a split pair of red pin-flash boulder opals (4.5 x 3.5cm each) stolen from the Museum of Victoria. Finder to inform Dr Bill Birch of that Museum (010 61 03 669 9878). R.K.M.

Zeitschrift der Deutschen Gemmologischen Gesellschaft, 1992. **41**, 4, 121-97.

This issue of the *Zeitschrift* is dedicated to the 60th anniversary of the German Gemmological Association. It starts with a short history and aims of the Association illustrated with photographs of past and present presidents. The anniversary was celebrated with a two-day symposium on 27 and 28 September 1992 and the inaugural speech by Professor Dr Bank is reprinted. There were 27 contributions which are reprinted in condensed versions, both in German and English. The subject matter of the lectures was varied, from new observations on the origin of tiger's-eye dealing mainly with the crocidolite from Griqualand West, to various production methods of producing synthetics in Japan. Antique Roman gemstones including mosaics were discussed. Two extremely interesting lectures on diamonds dealt with diamond and diamond-like thin film coatings and a review of the Argyle mines. Other subjects were: heat-treated pink spinel from Sri Lanka; trace elements and conditions for heat-treatment as factors of the gem quality of corundums; colour and causes of colour in green beryls and their nomenclatural delimitation; polymers as gemstone-relevant materials; identification of fissure treatment in gemstones; new occurrences of precious stones in Bohemia (opal- hyalite, aragonite and natrolite, smoky quartz, cassiterite and fluorite); gemstones in Nepal; a new device for obtaining a reflected IR spectrum; spectrometry and X-ray fluorescence of sapphires; cathodoluminescence of precious stones and minerals; fresnoite, a new synthetic ornamental stone (fresnoite was found in metamorphic sanborite-quartzite zone near Fresco, California); first catalogue of Raman spectra of gemstones; the present condition for ruby (in Japan and including rubies from Vietnam which, according to the author, might come from other localities); contributions to the crystal growth analysis of natural and synthetic rubies; identification of a dominant negative rhombohedral 'd' plane $(01\bar{1}2)$ in natural ruby; morphological aspects of diamonds, natural and synthetic, stable and metastable growth; new gemmological materials analyzed by CISGEM (pearl, mother-of-pearl, doublets and imitations); beauty grades of gemstones (ruby, tourmaline and tanzanite); analysis of Burmese and Thai rubies by PIXE; gemstones of the Swiss Alps; Embilipitiya, an interesting gem deposit in Sri Lanka (almandine garnet, spinel, cordierite and kornerupine). The contributions are illustrated by 20 photographs, 2 maps, numerous graphs and tables. E.S.

Book Reviews

CLARK, A.M. 1993. *Hey's Mineral Index*. Chapman & Hall, London. pp. xi, [852]. £50.00. ISBN 0 412 39950 4.

First a bibliographical note on the history of this major work. It began life in 1950 as the first edition of *An index of mineral species and varieties arranged chemically* [spine title and familiarly known as *Chemical index to minerals*]. The second edition with the same title appeared in 1955; thereafter the work was continued in two appendices published in 1963 and 1974, the latter with P.G. Embrey as co-author. The main work was also reprinted with minor corrections.

The work was compiled by, and is a memorial to Max Hey whose name is fittingly commemorated in the present title. This is one of the three or four mineralogy texts forming the foundation of all serious study.

The first two editions listed minerals in chemical order with elements first and rarer compounds last; it also included organic materials and substances inadequately characterized at the time. Mineral classes were assigned a number with species given a running number within the class. These numbers also included doubtful species and varieties; it was and still is difficult to distinguish between these two categories. The present work is arranged alphabetically but still includes the chemical order listing which is given in a concise form at the end of the main text. The names are all published and the sequence also contains some of the commoner mis-spellings, some meteorite and rock names which often resemble names of minerals and some trade names where they resemble mineral names. Each entry contains the chemical composition, group name where applicable [the groupings are much the same as those set out in Fleischer & Mandarino's *Glossary of mineral species*. There is a reference where possible to the description of the original mineral and references are also given for many old names and synonyms. Cyrillic characters are given for Russian language names, so often a cause of contention. It is interesting to find that citations are made in this edition to earlier editions of Dana's *System of mineralogy*; in previous editions of the present work only the sixth edition was used; this is now a rare book and references have been tracked down to their original appearance so that Dana editions 1-5 once more have work to do. Most name variants in Germanic languages are taken from the very rare and very expensive *Handbuch der Mineralogie* series, established by Carl Hintze. Details of crystal system, unit cell dimensions, and formula unit contents [Z] are given; there is also a two- or three-part number related to the previous Hey numbers but not identical to them. PDF (*Powder Diffraction file*) numbers are given for those entries where the unit cell data are held in that file.

An important new feature is the inclusion of type locality for species and well-defined varieties, when this is known. Gemmologists may like to know that the type locality provides the specimen from which the mineral or varietal description is first made. Although some politico-geographical changes have been made since original papers were written, this book still manages to be up-to-date, taking into account the unification of Germany (but not the disintegration of the former USSR and Yugoslavia). The remainder of the entry gives the origin of the name, reference to important chemical redefinitions that have occurred during the history of a species, synonyms and varietal names - these may be based on habit, colour or chemical differences. Data concerning unnamed species is not given in this edition, nor is the pronunciation table, since the author admits that even in a single laboratory (and even more in the field) two people rarely agree on this topic - perhaps there was something to be said for the Oxbridge accent when shouted against the wind!

The book is amazing value for its price and a superb, long-awaited work. M.O'D.

KAZMI, A. H. and O'DONOGHUE, M. 1990. *Gemstones of Pakistan: Geology and Gemmology*. Gemstone Corporation of Pakistan, Peshawar. pp. viii + 146, 24 black and white figs. 72 colour plates, 19 tables, Price £35.

This book might easily be considered as the sister publication of the earlier work *Emeralds of Pakistan*, especially since A. H. Kazmi is a co-author of both texts. Both have a geological bias, but this work has the avowed intention of stimulating budding gem geologists and jewellers to go out and make more gem discoveries. To this end the authors provide a twenty page general introduction to gemstone composition, properties and distribution; this includes the use of testing instruments, cutting and polishing and the procurement of rough. A list showing worldwide distribution of gemstones by countries is also provided.

The physical and geological features of Pakistan are described in the next chapter, which includes useful maps and sections explaining the tectonic setting. The latter is used as a basis for describing gemstones according to their various tectonic associations. Pakistan emeralds are described in some detail under the 'Indus suture associated gemstones' heading and are compared with their synthetic counterparts.

Ruby and spinel (often blue) are among the gems found in an extensive belt of crystalline marble found in the Hunza valley and elsewhere which forms part of the 'Karakoram suture associated gemstones' chapter. Pegmatites are widely distributed in Pakistan and this is reflected in the variety of gemstones in the chapter on 'Pegmatite associated gemstones'. The descriptions of aquamarine, tourmaline, feldspar, quartz, topaz and others are accompanied by good colour photographs and useful diagrams. The chapter on 'Gemstones in hydrothermal veins' deals with zircon, rutile, agate and the notable pink topaz from Katlang which merits a detailed description. The book concludes with a brief section on miscellaneous gems and the gem market in Pakistan. There is a comprehensive bibliography.

A major feature of the book is the excellent colour photography; largely the painstaking work of Dr Edward Gübelin on the inclusions and A. H. Kazmi on the mineral specimens and the good topographical pictures. The contents pages are reasonably informative, but there is no index. It is unfortunate that Photo No. 1 of an engraved emerald is the colour of a blue sapphire. Despite its geological bias, the book is very readable and should be on the shelves of those gemmologists who are curious about the origins of the gemstones they admire, collect, test, sell or incorporate into beautiful artifacts.

E.A.J.

SINKANKAS, J., 1993. *Gemology. An annotated bibliography.* 2 vol. Scarecrow Press, Metuchen NJ. pp. xxxiii, 1179, illus. in black-and-white. ISBN 0 8108 2652 6. £179.50.

At last gemmology has a worthy bibliography, and if one single event helps a subject to come of age this must be it. This is a bibliography in the sense of a catalogue raisonné rather than a list of books, with many old problems now at last laid to rest, freeing the student for other work and perhaps even building upon this one since the output of books and papers shows no sign of lessening.

The book opens with a foreword by Richard T. Liddicoat and continues with a preface in which the parameters of the book are described. It is certain that no previous bibliography exists and when Sinkankas began a literature search for his first book, published in 1955, he found that it was necessary not only to consult a very large number of existing books for their citations but also to acquire many of them and, at the same time, recording their bibliographical details as fully as possible. From these careful beginnings the present work has sprung; the library of books acquired now graces the Gemological Institute of America. It has taken something like forty years to bring this project to fruition.

During the compilation of the bibliography many books were consulted and recorded, perhaps for the last time since some were printed on so poor a paper that they cannot now be repaired. For this reason Sinkankas has provided as much detail as possible, including cloth types, colours, lettering, ornamentation, bevelled edges and endpapers. Such details are also provided for most of the other entries as well so that there will always be a record in the event of disaster.

The scope of the bibliography is based on size and relevance of the subject- matter. Thus many works are included which are peripheral to the main study of gemstones; such books include works on engraved gems, regalia, gem lore and biographies, with other topics. A limit of 15 pages was set for inclusion but shorter pieces of importance are included. Most entries are in English, with European languages covered to a lesser (but still considerable) extent. Books and papers must be in the Roman alphabet but this of course includes the romanization of works in Cyrillic and oriental scripts.

Numbered entries are under author where possible and follow accepted bibliographical practice. The preface explains this is some detail; entries may be abbreviated for short articles and full when a major work is cited. In such cases the entry begins where possible with a brief biographical sketch of the author so that important contributors to the literature of gemmology are highlighted; such treatment is

especially useful for historical and classical figures; today's major writers will be tracked down in their turn. Among British figures are Anderson, Webster, Herbert Smith, Blakemore, Bruton and the present reviewer.

Physical details of the book cited are very full and enable the student to distinguish editions, re-issues and variants from one another - this is not always easy since in the earlier part of this century dates of publication were not always given and there was no ISBN. Notes on illustrations are also very valuable since these may vary a great deal within a particular work which is printed more than once. Some very large books were published or re-issued for a particular small, wealthy group of collectors. Even large library catalogues do not always show this type of thing. Those interested can look up such entries as Heber R. Bishop's *The Bishop collection: investigations and studies in jade*, where full details of a celebrated limited circulation work will be found. In my years as a curator at The British Museum I passed this enormous two-volume book in its glass case many hundreds of times - now I know its contents!

However, this is not the only kind of book whose contents are described since Sinkankas provides descriptions of the text of virtually all the monographs cited. He also gives details of major reviews. Much of the small detail pertaining to an entry is abbreviated and a table sets these out over four pages. This section is followed by a list of serial publications and by a list of bibliographies and references consulted. These are listed alphabetically by compiler. It is remarkable and says much for the skill of the author that all this preliminary matter occupies only 33 pages.

At many openings title pages of important books are reproduced; this not only makes an attractive and useful break in the text but helps the student to see quickly which edition he has or wishes to know about. A superb work with quite a reasonable price for the amount of information contained and a credit to our science. M.O'D.

THEMELIS, T., 1992. *The heat treatment of ruby and sapphire*. Gemlab Inc. pp. xviii, 236, illus. in black-and-white and in colour. £65.00. ISBN 0 940 965 10 0.

The book is sub-headed 'An account of the most commonly practised heat treatment methods and apparatuses which alter the appearance of the ruby and sapphire; their occurrences, descriptions, inclusion characteristics, identification and other features'. This aim has been comprehensively achieved and the text must be in the hands of all gemmologists and students, although the price may seem a little high to some. The book is described as a limited edition, so a quick purchase may be advised. After an introduction to corundum in which the main characteristics, including cause of colour, are described, the effects of heat are outlined, to be more exhaustively covered later in the text where specimens from individual locations are discussed. At this point the author is content to list and describe heat and diffusion processes for the various colours of corundum. Fourteen different processes are considered; they include darkening and lightening of colour, development of colour change, production of asterism and removal of excess silk, diffusion treatment and some experimental treatments. Next comes a section on how inclusions may be affected by treatment, followed by general notes on corundum identification.

By chapter five the author embarks on as full an account of heat treatment as can be found anywhere. Particularly welcome are the notes on the types of equipment required and on the ways in which the stones are prepared for treatment. A 70-page chapter then describes corundum by country of origin, giving details where known of whether or not the stones are routinely treated. The amount of detail is very large and much of it is of the greatest use to workers not primarily interested in colour alteration as well as to those working directly in this area. The vexed questions of disclosure of treatment, of country of origin and of value form the final chapter, though there is a bibliography and index. As so much of the material in this excellent book is newly-acquired, the reader will find it a vital adjunct to existing modern books on gemstones: much of the information will filter through papers and bulletins supplemented where necessary by even more up-to-date accounts since this is the most important development area of gemmological investigation. The details seem to be correct; there are some misprints of names and some papers mentioned in the text are not found in the bibliography, but these are not important points when so much of the material is new to the literature. Colour pictures, which are grouped together, show interesting and hitherto unpublished examples and are of good quality. M.O'D.

Proceedings of The Gemmological Association and Gem Testing Laboratory of Great Britain and Notices

GIFTS TO THE GAGTL

The GAGTL is most grateful to Mr Fawcett of the Cultured Pearl Co. Ltd for the gift of a cultured Mabe pearl.

NEWS OF FELLOWS

Dr Roger Key, who is on secondment from the British Geological Survey, will be in Botswana for the next two years as Principal Geologist in charge of field mapping.

On 25 April 1993 Peter Read gave a talk on gem instruments to students of the Queensland Branch of the Australian Gemmological Association at their headquarters in 20 Rosslyn Street, East Brisbane. He was also invited by the President, Roy Beattie, to be guest speaker at the Branch's Diploma Dinner in Brisbane on 1 May, and gave a talk on 'Diamonds and De Beers'. Before his talk he presented GAA diplomas to that year's successful Queensland candidates.

Peter Read in Brisbane presenting a GAA Certificate to successful Queensland candidate Bradley Kearton. On the left is Roy Beattie, President of the Queensland branch of the Gemmological Association of Australia.

MEMBERS' MEETINGS

London

The following meets were held at the GAGTL's new Gem Tutorial Centre situated on the second floor at 27 Greville Street, London EC1N 8SU:

On 1 April 1993 Dr E. Gübelin gave a lecture

Dr E. Gübelin at GAGTL lecture

entitled 'The significance of natural and artificial inclusions in diamonds'. Those present were treated to a show of many excellent slides that Dr Gübelin used to illustrate his lecture.

On 14 April 1993 Dr Jamie Nelson gave an illustrated talk on 'Light scattering effects in gemstones'. Much of the talk dealt with recent developments in Raman scattering spectrometry. This is the ultimate laboratory tool for non-destructively characterizing those gemstone inclusions which lie below the polished surface of a stone.

On 27 April 1993 an illustrated talk was given by Stephen Kennedy entitled 'Rubies in the laboratory'.

On 11 May 1993 Christopher Cavey gave an illustrated talk on 'Engraved gems'.

On 14 June 1993 the Annual General Meeting was held (a full report of which is given below) fol-

GAGTL GEM TUTORIAL CENTRE

27 Greville Street, London EC1N 8SU

Gems for retailers
8-9 September
Two full days of practical experience with mounted stones. Investigate and test the stones you are likely to handle in the retail environment. Discuss suitable selling and talking points with gemmologists who have an extensive knowledge of the retail jewellry trade.
Price £164.50

Two days of diamonds
15-16 September
For an insight into gem diamond origins, grading, simulants and treatments.
Price £223.25

Synthetics and enhancements today
22-23 September
Are you aware of the various treated and synthetic materials that are likely to be masquerading alongside the gemstones you are buying and selling? Whether you are valuing, repairing or dealing, can you afford to miss these two days of investigation?
Price £223.35

Precious stones and crystals
Evening course commencing 28 September
The University of London's Centre for Extra-Mural Studies will run a course of ten evening classes at the GAGTL Gem Tutorial Centre to be held on each Tuesday from 28 September to 30 November, from 6.30 to 8.30 p.m.
Each week Ian Mercer, B.Sc., FGA, the GAGTL's Director of Education and a University Extra-Mural geology lecturer, will introduce a different aspect of these fascinating materials.
The course will appeal to beginners as well as qualified gemmologists.
For an application form and further information contact Alison Sutton at the University of London Centre for Extra-Mural Studies, 26 Russell Square, London WC1B 5DQ, or telephone Alison on 071-631 6654.
Price £50.00

DIY Laboratory
30 September
Spend a day finding out about the basic gem testing instruments. You will be looking at the principles by which these instruments work and the results you should obtain. You will also be constructing some instruments of your own.
Price £111.63 (includes materials)

Preliminary workshop
12-14 October
One-day practical tuition for Preliminary students and anyone who needs a start with instruments, stones and crystals; student discount
Price £44.65; GAGTL students £31.73

Jade
10 November
An unrivalled opportunity to handle jade, under the guidance of Alan Jobbins and Christopher Cavey.
Observe the great variety of jades, their simulants, artificial treatments and 'accidental' alterations.
Where are the limits to identification?
Price £111.63 (including lunch)

Photographing gemstones
23 November
Spend the day in the company of Frank Greenaway, one of the leading photographers of gemstones. A rare opportunity for you to enhance your photography.
Price £111.63 (including materials and lunch)

ALL PRICES INCLUSIVE OF VAT AT 17.5%

lowed by a Reunion of Members and a 'Bring and Buy' sale.

Midlands Branch

On 30 April 1993 at Dr Johnson House, Bull Street, Birmingham, the Annual General Meeting was held, at which David Larcher and Gwyn Green were re-elected Chairman and Secretary respectively.

On 13 June 1993 a trip to Castleton and Treak Cliff Caverns Ollerenshaw Collection, Derbyshire, was arranged for members.

North West Branch

On 19 May 1993 at Church House, Hanover Street, Liverpool 1, Dr J. Franks gave an illustrated talk entitled '"Lalique" jewels, from 1992 Paris Exhibition'.

On 16 June 1993 at Church House a 'Members and Friends' evening was held, which included a 'Bring and Buy' sale.

ANNUAL GENERAL MEETING

On 14 June 1993 the Annual General Meeting of the Gemmological Association and Gem Testing Laboratory of Great Britain was held at 27 Greville Street, London EC1N 8SU.

David Callaghan chaired the meeting and opened by saying how pleased he was that so many had attended. Although the previous AGM had been held on the second floor of 27 Greville Street, David stated that this was the first to be held in the newly completed Gem Tutorial Centre. The whole aspect of gemmology has now become very much more involved with the modern synthetics and gemstone treatments now appearing. The Centre is now able to offer an increasing number of courses to enable those with an interest in gemmology, either as a hobby or within the trade, to identify such gemstones. 'So it is now possible', David continued, 'to buy books and gem testing instruments, then take a course to find our how to use them - all in the same building'.

David Callaghan then announced that he was to retire from the Council of Management and from the position of Chairman at this meeting. He said that he had very much enjoyed his term as Chairman and thanked all those who had given him help and support over the years. It had been agreed that the Office of Chairman should not be filled immediately. Because of the changes in the company as a result of the merger between the Gemmological Association of Great Britain and the Gem Testing Laboratory, it was decided to seek the opinions of members on how they see the roles of Chairman and President of the merged company before any new elections are made.

The Annual Report and Accounts of GAGTL for 1992 were approved and signed.

Messrs A. E. Farn, D.G. Kent and R.K. Mitchell were re-elected as Vice-Presidents and, in recognition of his work for the Association over many years, Mr E. Bruton elected as Vice-President.

Mr I. Thomson was re-elected to the Council of Management; the election of Mr T.J. Davidson was confirmed and Mr N.W. Deeks was elected.

Messrs H. Levy and E.A. Thomson retired from the Members' Council. Messrs J. Kessler. G. Monnickendam, L. Music, J.B. Nelson and P.G. Read were re-elected and Messrs P. Dwyer-Hickey and R. Shepherd elected to the Members' Council.

Messrs Hazlems Fenton were re-appointed Auditors.

This concluded the business of the meeting.

Retirement of David Callaghan

Mr Ted Thomson then gave the following vote of thanks to David Callaghan on his retirement as Chairman of the GAGTL.

'I stand to say a few words on your behalf on the occasion of David Callaghan's retirement from the Chairmanship of the GAGTL and the Council of Management. If anyone ever deserved a long and happy retirement from public service it is David. It is quite amazing how long and comprehensive his service is and how early he started.

'David joined Hancocks as an apprentice at the age of sixteen and has worked for them all his life so far. He took his FGA in 1958 as part of his apprenticeship under the guidance of Miss Willis, who inspired his love of opals. Miss Willis, incidently, was one of the first ladies to qualify for the FGA and is now living in Leigh-on-Sea at the ripe age of ninety-four.

'During his career at Hancocks David has become an authority on gemstones, silver, high class jewellery and especially Victoria crosses, and has lectured worldwide on these topics. In the '60s he became a Director of Hancocks, a Freeman of the City of London, a Liveryman of the Clockmakers Company, a Freeman of the Wax Chandlers and in 1983 a Liveryman of the Goldsmiths Company. This latter shows an appreciation of his services to the trade.

'He was Chairman of the Precious Stone Diamond and Pearl Section of the London Chamber of Commerce from 1977-80. At that time this committee was the main connection between the trade and Government, and had many responsibilities in addition to running the Laboratory. He was a sucker for punishment as he

FORTHCOMING MEETINGS

London

Throughout 1993 there is a programme of meetings on the second floor at 27 Greville Street. Refreshments will be available from 6.00 p.m. and lectures will start at 6.30 p.m.; these will be followed by discussion and closing about 7.45 p.m. The charge for a member will be £3.50 and, as places are limited to 55, entry will be by ticket only, obtainable from GAGTL.

20 September	'Photographing minerals and gems'	Frank Greenaway
6 October*	'Diamonds in the Laboratory'	Eric C. Emms
18 October	'The distinction of natural from synthetic diamonds.'	Professor I. Sunagawa
8 November	'Thai evening'	Amanda Good and Martin Issacharoff
22 November	'CIBJO matters' - the gem trade in Europe	Harry Levy
7 December*	'Pearls in the Laboratory'	Ana I. Castro and Stephen Kennedy

The GAGTL Annual Conference is to be held on 24 October 1993 at the Great Western Royal Hotel, Paddington. This will be followed on 25 October by a GAGTL Open Day and the Presentation of Awards. Full details of these events are given on p. 386.

Midlands Branch

24 September	'Deep diamonds.'	Dr Jeff Harris
29 October	'Rescued from the scrap box.'	David Wilkins
26 November	A practical demonstration of light behaviour in gemstones.	Dr Jamie Nelson

The meetings will be held at Dr Johnson House, Bull Street, Birmingham. Further details from Gwyn Green on 021-445 5359.

North West Branch

15 September	Jonathan Condrup from Sotheby's, London	
20 October	'Minerals in the Bronze Age'.	Tony Hammond
17 November	Annual General Meeting	

Meetings will be held at Church House, Hanover Street, Liverpool 1. Further details from Joe Azzopardi on 0270-628251.

* Please note change of date: make a note in your programme card.

was also Chairman of the National Association of Goldsmiths from 1976-78 as well as an Examiner for the Retail Jewellers Diploma.

'I have a feeling, however, that his real love has always been the GA and the Laboratory. When Doug King had to retire from the Chair of the GA in 1980 David stepped in and since then has headed the Association with skill and enthusiasm. He was instrumental in seeing through the merger with the Laboratory in 1990 - which was no mean feat. It was very appropriate that he should lead the merged organization since his support for the Laboratory over so many years has been very significant in establishing continued development of its activities and resources - both through support from the Trade and acquisition of new instruments. In particular he did a lot of the background work to enable the Laboratory to acquire the UV-VIS spectrophotometer - appropriately named the Basil Anderson spectrophotometer - in 1984.

'So on behalf of his old colleagues at the Chamber of Commerce and more especially his many friends and colleagues at the GAGTL, I would like to thank you David for the many things you have done for the Trade in so many facets and would ask you to accept our gift as a small token of appreciation of your contribution and in the hope that you will have many years of enjoyment from it'.

MEETING OF THE TRADE LIAISON COMMITTEE

At a meeting of the Trade Liaison Committee held on 25 March 1993 at 27 Greville Street, London EC1N 8SU, the business transacted included the election of the following:

Gold Laboratory Membership

J. & B. Cousins & Sons Ltd., 8,9,9a Sun Street, Canterbury, Kent.
Graff Diamonds Ltd., 16 Greville Street, Hatton Garden, London EC1N 8SQ.
Gruet, 52 Rue La Fayette, 75009-Paris, France.
King's Diamond Trading Company, Rm 701-5 Lane Crawford House, 70 Queen's Road, Central Hong Kong.

Ordinary Laboratory Membership

Gold Arts, 7 Brighton Place, Brighton BN1 1HD.

MEETINGS OF THE COUNCIL OF MANAGEMENT

At a meeting of the Council of Management held on 21 April 1993 at Hancocks & Co., 1 Burlington Gardens, London W1X 2HP, the business transacted included the election of the following:

Ordinary Membership

Bastians, Indramal Chitranganie, London.
Bray, Betty A., Abilene, Tex, USA.
Brown, Symon, Cockermouth, Cumbria.
Cliff, Graham, Eltham, London.
Everest, Andrew, London.
Kleiser, Alwen, Holyhead, Gwynedd, Llgsidis.
Smith, Ian Hobden, Thatcham.

At a meeting of the Council of Management held on 19 May 1993 at GAGTL, 27 Greville Street, London EC1N 8SU, the business transacted included the election of the following:

Ordinary Membership

Bae, Sang-Kea, Seoul, Korea.
Bonnyarak, Orapin, Johor Bahru, West Malaysia.
De Narvaez, Mauricio, Bogota, Colombia.
Devon, Jill, Felstead.
Howard, Stanley, Mill Hill, London.
Nolens-Verhamme, Paule, Sint Truiden, Belgium.
Wood, Victor, Ilford.

At a meeting of the Council of the Management held on Wednesday 16 June 1993 at GAGTL 27 Greville Street, London EC1N 8SU, the business transacted included the election of the following:

Fellowship

Balter, Jonathan, London. 1992.

Ordinary Membership

Booth, Diane, Cromer.
Branco, Rui Jose Portela Jorge, Viseu, Portugal.
Gangsted, Anne, Bangkok, Thailand.
Keen, Paul, London.
Pellas, Isabelle, London.
Schmid, Huldrych, Bachenbulach, Switzerland.
Tandjung-Teo, Liti M., London.
Targiello, Barbara, Lublin, Poland.
Zanettrin-Barbin, Fabrizia, Geneva, Switzerland.

Gold Laboratory Membership

Chatila & Sons Ltd, 22 Old Bond Street, London W1X 3DA.

Ordinary Laboratory Membership

Eugenios Petrides, GG, FGA, London NW3 3AX.

CORRIGENDUM

On p. 353 above, the illustrations for Figures 29 and 30 were transposed

Letters to the Editor

From Kurt Nassau, Hon. FGA

Dear Sir,

I feel somewhat hesitant in submitting comments to no less than three of the articles in the October 1992 issue of *The Journal of Gemmology* (Vol. 23, No. 4). Perhaps I can be excused this momentary excess in view of the many other issues where I have not had any comments at all!

The determination of the ages of emeralds by rubidium-strontium analysis (Vidal, Lasnier and Poirot, p. 198) is certainly an original way of distinguishing natural emeralds. If this test were to come into professional use, however, I believe that it would not be too difficult to subvert. Emerald synthesizers could merely add controlled amounts of rubidium and strontium isotopes to their growth medium and so simulate any age desired in their synthetic material!

In his otherwise excellent article on symmetrical polyhedra for gemstones (pp 207- 14), Lurie uses the correct term 'vertex' interchangeably with the term 'quoin'. I have consulted several dictionaries and believe that 'quoin' is an incorrect usage. The multivolume *Oxford English Dictionary* (1933 on to the most recent 1987 supplement), for example, defines 'quoin' as applying to the 'external *angle* of a wall or building' or to the 'internal *angle* or corner, as of a room' or an '*angle* or an angular object', among other less relevant meanings. When an author employs an inappropriate usage such as 'quoin' for 'vertex' ('an angular *point*, as of a triangle or polygon' in *OED*; plural vertexes or vertices), then he needs to supply justification for such a usage lest he mislead others.

Finally, the author of the interesting article on the electrolytic oxidation treatment of sapphires (Wang Chuanfu, pp. 195-7) does not appear to be familiar with the many variables applicable to sapphire heat treatments, such as temperature, time, and precise oxidation-reduction conditions. The failure of his single attempt at heat treatment does not demonstrate that his material could not be changed to a desirable blue under more appropriate conditions. His explanation for the observed colours in terms of simple Fe^{2+}, Fe^{3+} and Ti^{3+} absorptions also omits consideration of the most important absorption, that of Fe-Ti charge transfer. Finally, he suggests that his electrolysis causes Ti to diffuse into the sapphire, without checking (or at least without reporting) whether this produced a colour concentration layer at the surface. Were this to be the case, his process would no longer be a heat or oxidation treatment but would become a surface diffusion process, with quite different implications for disclosure.

Yours etc.,
Kurt Nassau
21 December 1992
Lebanon, NJ, USA.

From Jos Lurie

Dear Sir,

In regard to Dr Nassau's comments I wish to reply as follows:

Dr Nassau is perfectly correct; having now carefully consulted numerous works I acknowledge that in my paper 'quoin' should read 'vertex' in all cases. I regret the error but trust that my meaning was clear.

Yours etc.,
Jos Lurie
9 March 1993
School of Mines, Technikon Witwatersrand,
PO Box 3293, Johannesburg 2000.

From Wang Chuanfu

Dear Sir,

Many heat-treatment methods of sapphire have been used for Chinese sapphires and many variable factors such as temperature, time, atmosphere conditions, etc., were investigated. Although heat-treatment method is very simple, it is not suitable for Chinese sapphire (containing high content of Fe (1-5wt% Fe_2O_3)). Owing to the high content of Fe the absorption of Fe-Ti biparticle is difficult to form a peak.

Now this method has a great commercial value and it is a pity that my paper only simply reports as above.

Yours etc.,
Wang Chuanfu
Vice Director
General Research Institute for
Non-Ferrous Metals, Beijing 100088, PR China.
15 March 1993

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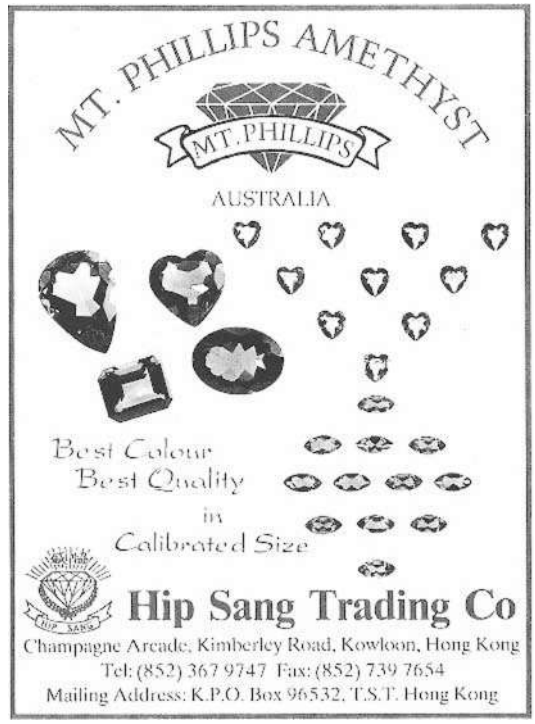

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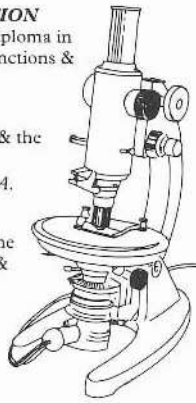

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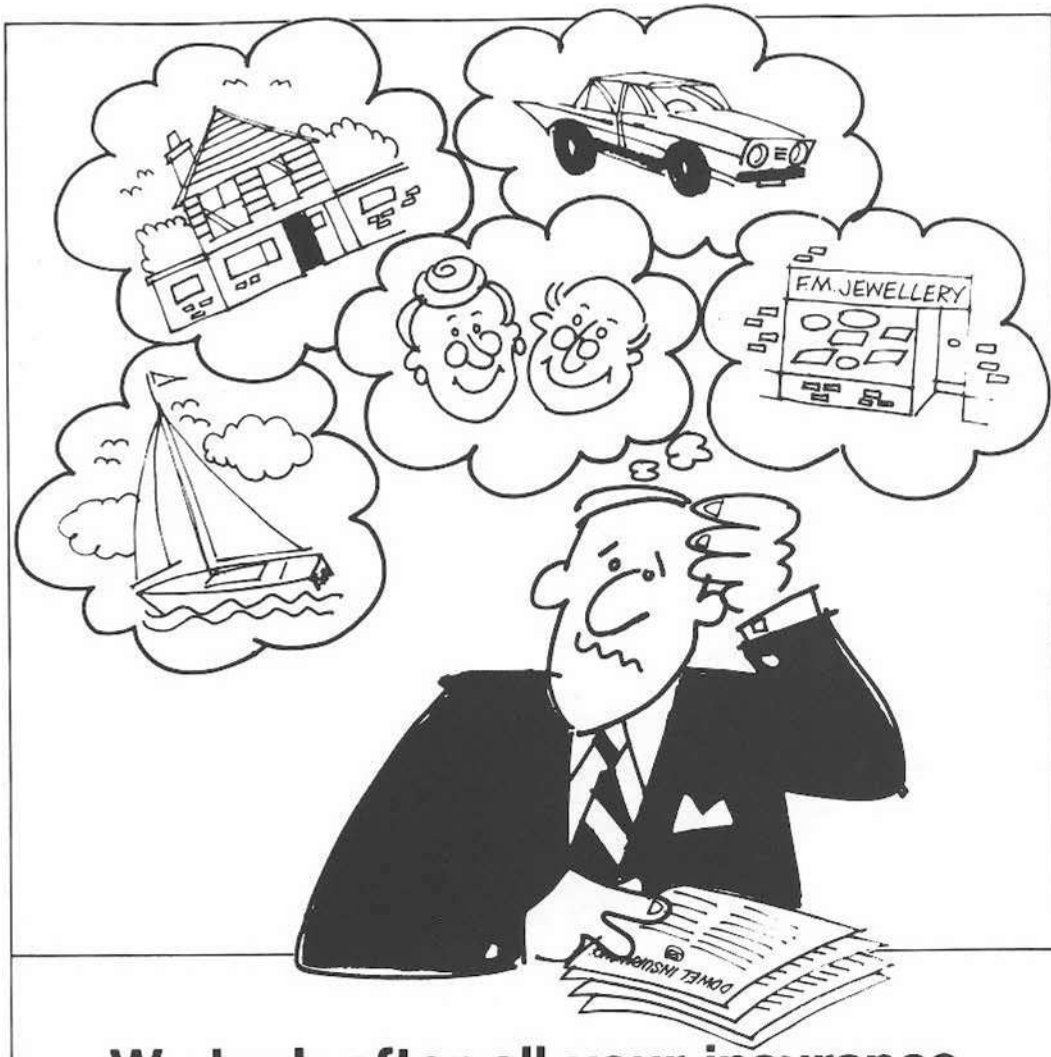

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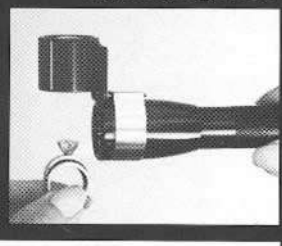

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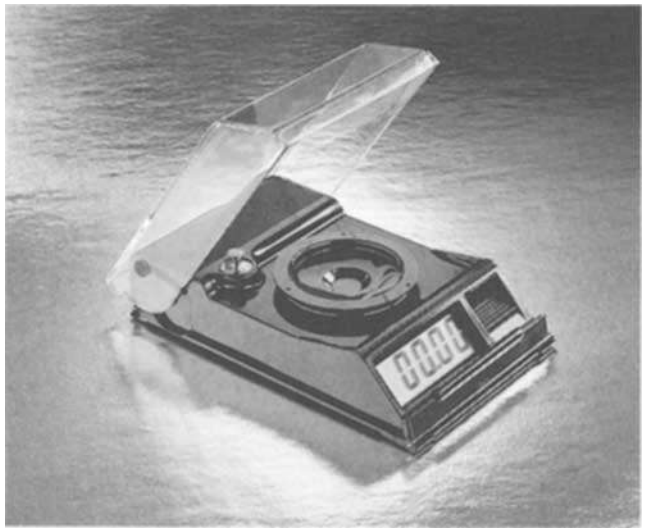

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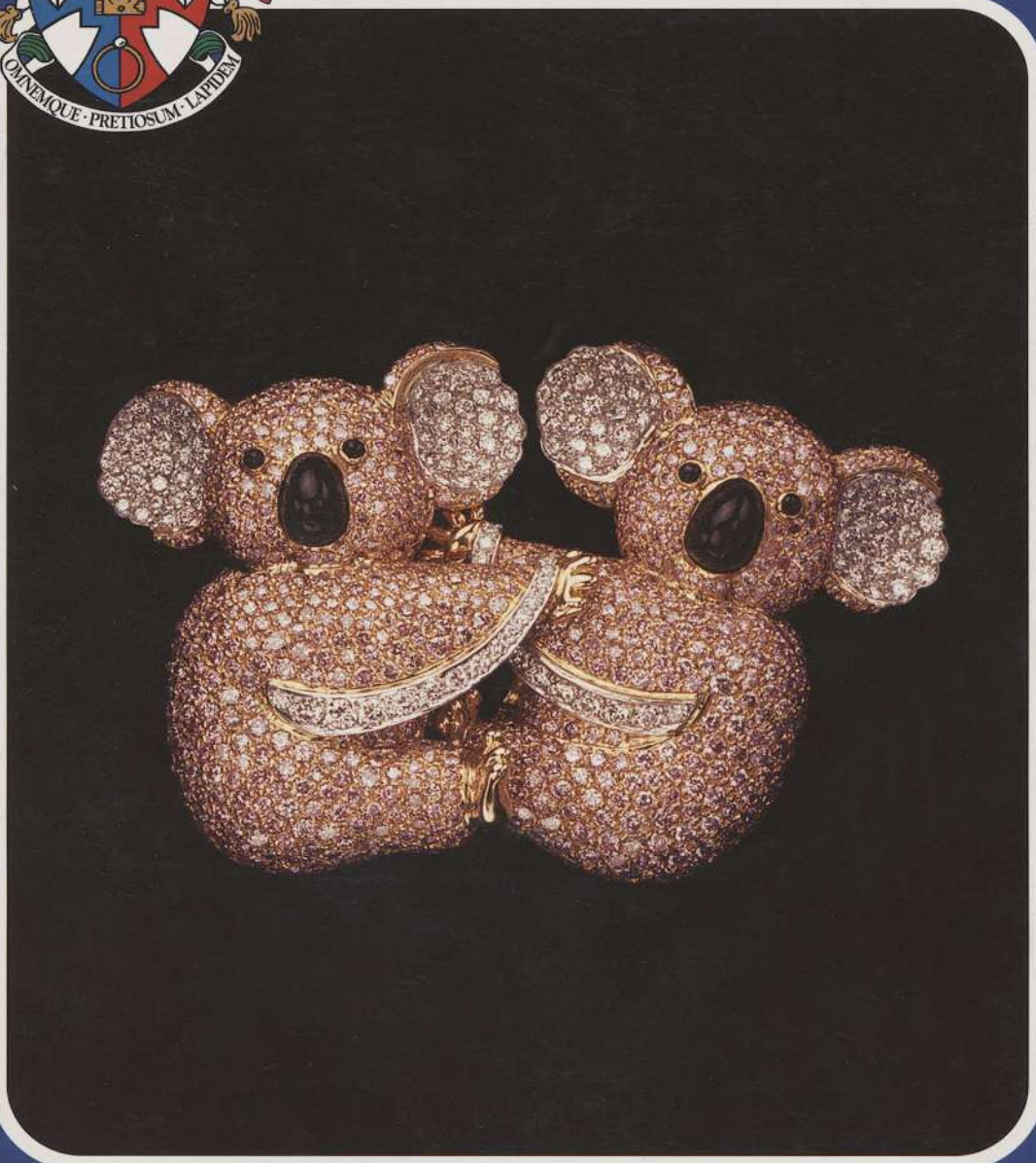

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Cover Picture

Brooch set with pink Argyle diamonds, maximum width approx 7cm; 1068 pink diamonds and 160 white diamonds weighing a total of 16.31 ct and 3.45 ct respectively. See 'Gemmological properties of Type Ia diamonds with an unusually high hydrogen content' pp.451-60.

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Gemmological properties of Type Ia diamonds with an unusually high hydrogen content

Emmanuel Fritsch and Ken Scarratt†*

*GIA Research, Santa Monica, CA, USA
†GIA Gem Trade Laboratory, New York, NY, USA

Abstract

One hundred and thirty-nine Type Ia diamonds that showed unusually intense hydrogen-related absorptions in the infrared range were studied; they are referred to as 'H-rich diamonds' for brevity. We demonstrate that the various kinds of H-rich diamonds often have a number of gemmological and physical properties in common, for example a yellow luminescence, certains types of colour zoning and clouds of sub-microscopic inclusions. We also report the discovery of several new hydrogen-related absorptions in the infrared and the visible ranges, some giving rise to a violet colour never described before in coloured diamonds.

Key words: Diamond, Hydrogen, Infrared, Colour centre.

Introduction

In recent years hydrogen has been recognized as a common impurity in natural Type Ia diamonds (Woods and Collins, 1983), in addition to the well-known nitrogen (and possibly boron) impurities. Little is known, however, of the influence that this hydrogen impurity may have on the optical properties of such diamonds, in particular their colour. In the course of the coloured diamond project, undertaken at GIA Research since 1986 in order to better understand the properties of natural and treated coloured diamonds, we have studied a number of diamonds with unusual characteristics. For example, we recently reported on a greyish-blue coloration in diamond believed to be caused by hydrogen-related colour centres (Fritsch and Scarratt, 1992). The presence of hydrogen in diamond can be detected by a series of sharp absorptions in the infrared region, especially at 1405 and 3107 cm^{-1}, which have been known since 1961 and attributed by Charette to C-H bonds (Charette, 1961). These two frequencies are also known as $h_{\omega}b$ (1405 cm^{-1}), the elementary frequency for the bending motion of the C-H bond, and $h_{\omega}s$ (3107 cm^{-1}) the elementary frequency for the stretching motion of the C-H bond.

Over the last five years, a number of gem-quality diamonds exhibiting strong C-H bands at 3107 cm^{-1} have become available. For convenience, these diamonds are hereafter called 'H-rich diamonds' but, strictly speaking, they only are diamonds with unusually intense hydrogen-related infrared absorptions. These diamonds, although they may have different appearances, present a number of gemmological properties in common. The large number of samples we

Fig. 1. Four typical H-rich diamonds, ranging in colour from greyish-yellow (0.28 ct, left), to light brownish-yellow (1.02 ct, centre) to light grey (0.09 and 0.15 ct, right). Stones courtesy Davenport Jewelry Company, Dallas, Texas. *Photo by Robert Weldon*

Fig. 2. Greyish-violet 0.88 ct pear-shaped diamond and brown-yellow 1.20 ct round brilliant-cut, both from the Argyle mine in western Australia. They represent typical examples of H-rich diamonds described in detail in this paper. Stones courtesy of Argyle Diamonds. *Photo by Robert Weldon*

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Fig. 3. The vast majority of 'white' or 'opalescent' diamonds, such as these three round brilliant-cuts from the Panna mine in India ranging from 0.30 to 0.33 ct, are also H-rich diamonds. Stones courtesy Malhotra Inc., New York. *Photo by R. Weldon*

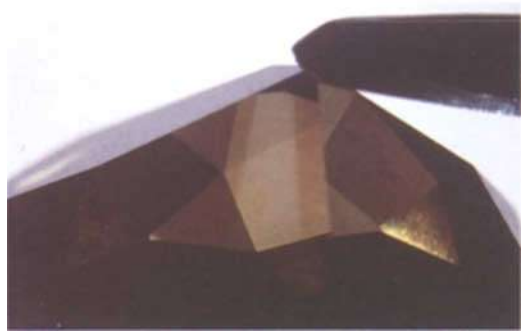

Fig. 5. Brownish colour zones limited by planar borders in a greyish-green chameleon diamond. Magnification 10x. *Photomicrograph J.I. Koivula*

studied (over one hundred) has enabled us to document a number of absorptions in the infrared and visible ranges related to the presence of the hydrogen impurity, some of which had never been described before. In particular, some rare hydrogen-rich diamonds from Argyle in western Australia exhibit a violetish-grey to greyish-violet colour never described before in coloured diamonds.

Materials and methods

The 139 samples examined in this study were all faceted gem-quality diamonds, on loan from private parties. They represent a wide range of colour with essentially yellow, grey (Figure 1) or brown as the main component (for 78 of them), but also bluish-grey to greyish-violet (for 6 of them), white (also called 'opalescent diamonds' in the trade; 8 samples) and blue and green (47 samples). Their geographical origin is generally unknown, as is unfortunately the case with most diamonds. However, the bluish-grey to greyish-violet stones are all from Argyle, as well as one brown-yellow (Figure 2) and one greenish-yellow stone. A series of three white diamonds is from the Panna mine, India (Figure 3).

This sampling includes 31 stones either known to be treated, or established to be so based on criteria explained elsewhere (Fritsch and Shigley, 1989 and 1991). Although most of these treated, hydrogen-rich stones were essentially green or blue (sample 8; Fritsch and Shigley, 1989), we documented also some that were essentially yellow (sample 2; ibid.).

All data collection was done at GIA Research. Ultraviolet-visible absorption spectroscopy was performed on a Pye Unicam 8800 spectrophotometer, using a band-width of 0.5 to 1 nm. The sample is cooled to 80 K using a pour-fill dewar cooling unit. Infrared absorption was recorded on a Nicolet 60SX FTIR spectrometer at a resolution of 4 cm^{-1} in the range 400-25000 cm^{-1}. Use of a microbeam chamber allowed for maximum energy output.

All samples were selected because they exhibit an absorption band at 3107 cm^{-1} that is particularly intense, generally comparable or superior in intensity to the intrinsic two-phonon diamond absorption around 2450 cm^{-1} (Figure 4. We indicate on this figure a position of 3105 cm^{-1}, not 3107, because our spectra are done at a resolution of 4 cm^{-1} only).

For this report, we have tentatively distinguished four types of H-rich diamonds on the basis of their properties: the 'brown to greyish-yellow family' (66 samples), the 'grey to violet family' (14), white diamonds (8) and finally 'chameleon diamonds' (36). 15 samples could not be classified because the necessary data were not available for various reasons. We call 'chameleon diamonds' those that typically change reversibly from a grey-green to a brighter yellow colour when heated in the flame of an alcohol lamp. Such photochromic behaviour was formerly described by Raal and Robinson (1982) in treated Type Ia diamonds and in some natural green diamonds from the South African gold mines (Raal, 1969). Brief gemmological reports on chameleon diamond behaviour can be found in Crowningshield (1975) and Fryer (1981, 1982).

Gemmological properties

Microscopic examination

Sixty-four of the 131 H-rich diamonds that are not white show colour zoning under low magnification. Generally, one or more distinct sectors having a brown or grey component to their colour are visible, limited by clearly defined, often planar, and sometimes smoothly curved surfaces (Figure 5). Some greyish-yellow diamonds show a grey-to-

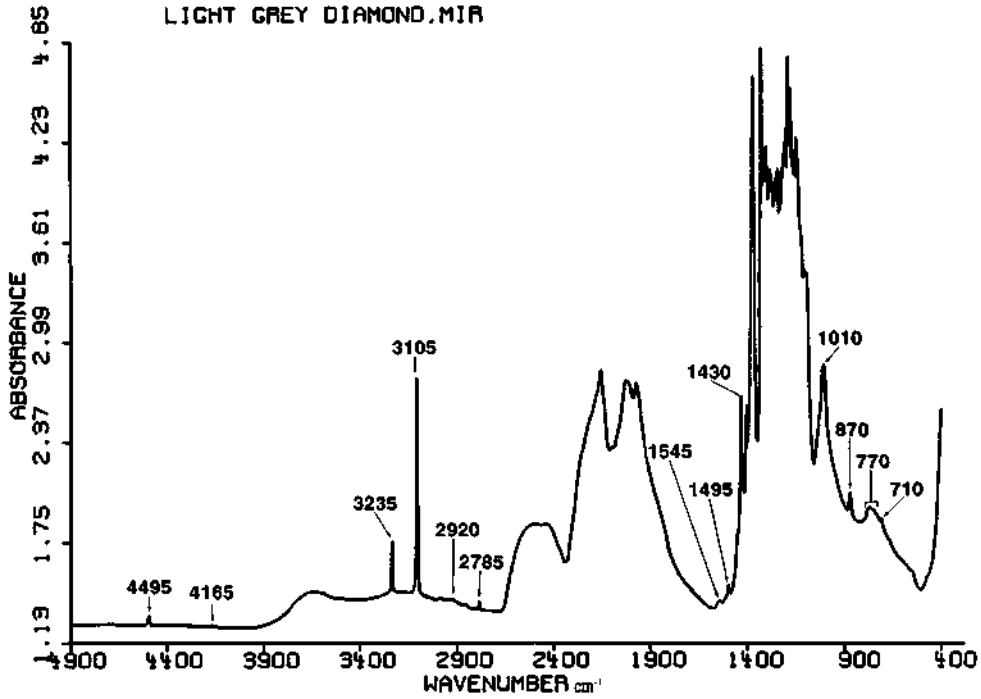

Fig. 4. Mid-infrared absorption of a light grey 'H-rich' diamond showing the intense H-related absorption at about 3105 and 3235 cm⁻¹

yellow colour zoning, also clearly limited by planar boundaries (Figure 6a). In some instances, a thin colourless layer can be observed between the two coloured zones (Figure 6b).

These brown or grey sectors contain clouds of sub-microscopic inclusions of unknown nature (Figure 6c). These clouds often occupy the entire colour zone. Sometimes, they form a petal-like pattern in certain directions (Figure 7), with more or less convoluted contours. Clouds of similar light-scattering inclusions are observed throughout the eight white diamonds, to which they impart their white colour. Rarely, white diamonds show some hint of sectorial growth as well.

There is generally no prominent graining in H-rich diamonds. When present, it is visible at the limit of the various colour zones.

Between crossed polarizers, H-rich diamonds show typically little anomalous birefringence ('strain'), usually producing interference colours of the first order and beginning of the second order. The pattern follows that of the colour zoning and is referred to as 'sectorial strain' (Figure 8).

Ultraviolet luminescence

With the exception of white diamonds, which tend to fluoresce blue to green, untreated, H-rich diamonds typically fluoresce yellow, more strongly in long-wave ultraviolet light than in short-wave. The luminescence colour might show a nuance of green or orange, but this nuance in colour description might simply be due to different colour perceptions by different observers. This ultraviolet luminescence is often followed by a yellow phosphorescence, which varies in intensity and duration from sample to sample. We have observed this phosphorescence in 70 per cent of the non-white samples. It is extremely strong and long-lasting (longer than one minute, in some cases longer than five minutes) for chameleon diamonds; this unusual luminescence behaviour is actually one of the most efficient ways to recognize chameleon diamonds.

Forty of our H-rich diamonds show a zonation of their luminescence. This zonation can take two different appearances. First, the luminescence zonation may follow the sectorial colour zoning. The most spectacular pattern is observed in some diamonds zoned yellow and grey: the grey areas fluoresce and phosphoresce yellow, while the yellow areas fluoresce blue (Figure 9a). Secondly, the luminescence may follow the clouds and the cloud area will fluoresce a strong yellow, in contrast with the rest of the stone (Figure 9b).

Gemmological spectroscopy

In most cases, the spectrum observed with the hand-held spectroscope at room temperature or

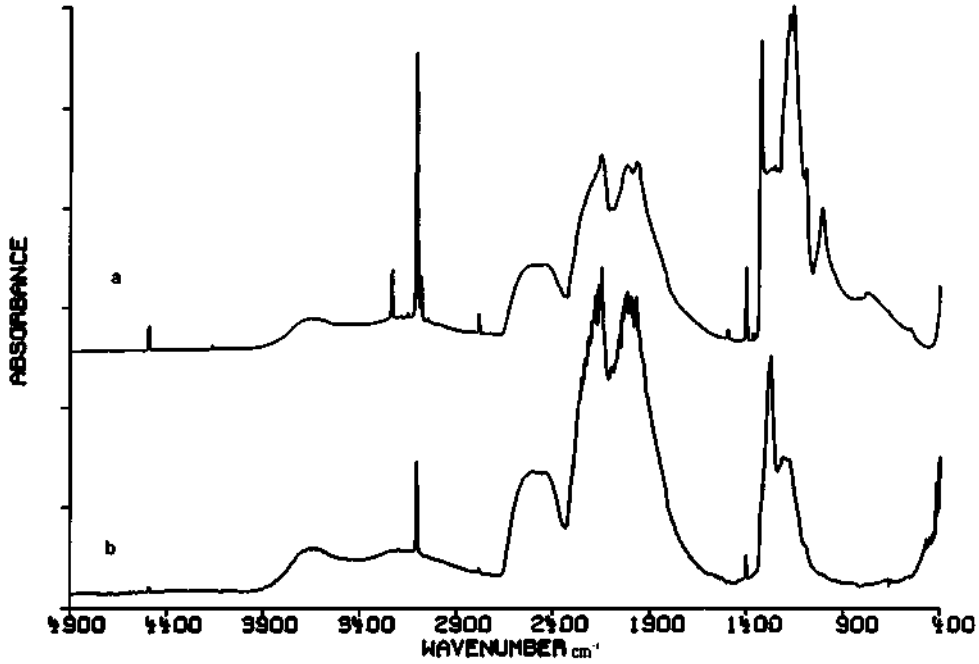

Fig. 10. Typical mid-infrared absorption spectra of (a) white and (b) chameleon diamonds. White diamonds are generally pure Type IaB, while 'chameleon diamonds' are pure Type IaA.

with cryogenic cooling is not helpful in identifying the diamond as containing large amounts of hydrogen, since it generally shows Cape lines at about 415 and 478 nm, common in all Type Ia diamonds. Crowningshield (1969) reported a 4.28 ct dark bluish-grey diamond with a sharp absorption at about 548 nm and a zoned blue and yellow luminescence, which might very well have been an H-rich diamond. We have observed on three stones (out of 97) an absorption line at about 545 nm of medium width (which may correspond to Crowningshield's observation) and in two stones a sharp line slightly above 560 nm. Only in these rare instances can gemmological spectroscopy help recognize an H-rich diamond.

Infrared absorption spectroscopy

Infrared absorption results show that all H-rich diamonds examined in this study are Type Ia, that is they contain aggregated nitrogen (for a detailed discussion of diamond types, see Fritsch and Scarratt, 1992). All chameleon diamonds we examined were pure Type IaA stones, whereas all of our white diamonds were pure Type IaB diamonds (Figure 10). It should be noted that we have encountered on occasions chameleon and white diamonds that did not show quite intense enough a 3107 cm^{-1} band to satisfy our criterion, although they were always close.

In correlation with the presence of intense H-related absorptions at 3107 cm^{-1} and 1405 cm^{-1} (the latter often masked by nitrogen-related absorptions) and their overtones, combinations and companion lines described previously (Davies *et al.*, 1984), we have also observed:

(1) three sharp bands around 6070, 5880 and 5555 cm^{-1} (Figure 11a);
(2) up to four bands of decreasing intensity centered around 7500, 7850, 8255 and 8615 cm^{-1}, forming possibly a vibronic structure (again, see Figure 11a); and
(3) a number of strong, broad absorptions of complex shape between 9000 and 11000 cm^{-1} (roughly 900 to 1100 nm; Figure 11b).

The newly discovered sharp bands at 6070, 5880 and 5555 cm^{-1} are believed to be, respectively, an overtone (2 $h_{\omega}s$), a new combination ($h_{\omega}s + 2h_{\omega}b$) and another overtone (4 $h_{\omega}b$) of the fundamental 'C-H' vibrations at 1405 ($h_{\omega}b$) and 3107 cm^{-1} ($h_{\omega}s$). It appears that Woods and others reported at the 1987 De Beers Diamond Research Conference the discovery of a new line at 6072 cm^{-1}, which they attributed to the first overtone of the 3107 cm^{-1} line, however these results were never formally published.

The well-known H-related absorption at 3235 cm^{-1} seems to be systematically more intense for diamonds belonging to the grey to violet family. In

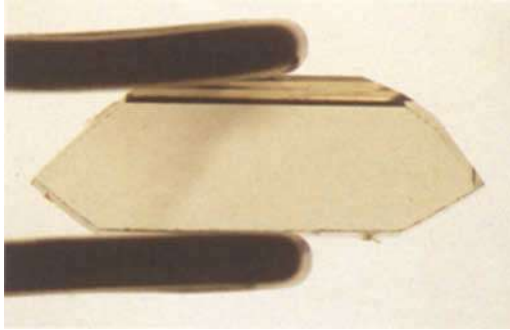

Fig. 6. (a) Yellow-and-grey planar colour zoning is seen using diffused light in a slab cut from the 0.28 ct greyish-yellow H-rich diamond illustrated in Figure 1. Magnification 4x.

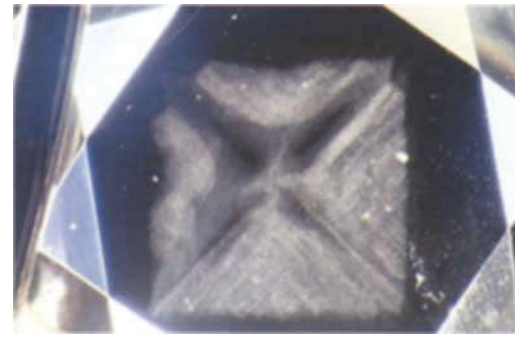

Fig. 7. The square cloud observed in a slab of the 1.02 ct light brownish-yellow diamond shown in Figure 1 exhibits four less-included lobes forming a pattern reminiscent of a flower. Magnification 7x. *Photomicrograph Emmanuel Fritsch*

Fig. 6. (b) Observation at higher magnification demonstrates that a thin colourless layer exists between the yellow and grey colour zones seen in (a). Magnification 10x.

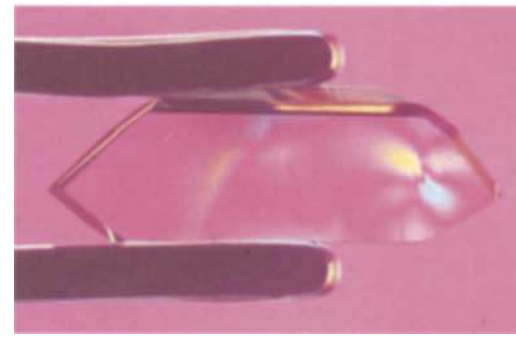

Fig. 8. The 'strain' observed between crossed polarizers in H-rich diamonds is generally weak. It also follows the pattern of colour zoning, as seen in this slab cut from the 0.28 ct greyish-yellow diamond shown in Figure 1 (compare also with Figure 6 a, b and c). The contrast of interference colours has been enhanced using a first order red compensator. A small, atypical strain centre is also present in this stone. Magnification 4x. *Photomicrograph Emmanuel Fritsch*

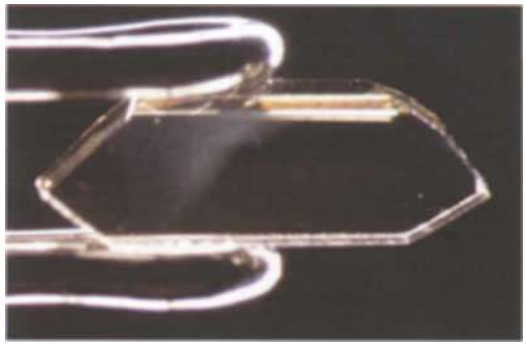

Fig. 6. (c) Observation in dark-field show that the grey colour zone seen in (a) corresponds to a cloud. Magnification 4x. *Photomicrographs Emmanuel Fritsch*

the very few cases when the shape of the faceted stone permitted, it was possible to demonstrate that H-related infrared absorptions in general are more intense in the grey or brown sectors of the stones (which also correspond to the clouds).

Using vacuum fusion analysis, Chrenko and Strong measured in a stone with 'very strong' hydrogen absorptions a hydrogen concentration of 400 at. ppm (Chrenko and Strong, 1975). One can therefore speculate that the hydrogen concentration in 'H-rich' diamonds would be of the order of 100 to 1000 ppm. Attempts to quantify the amount of hydrogen present in 'H-rich' stones studied in this report have so far been unsuccessful. This is because most non-destructive experimental techniques available today to

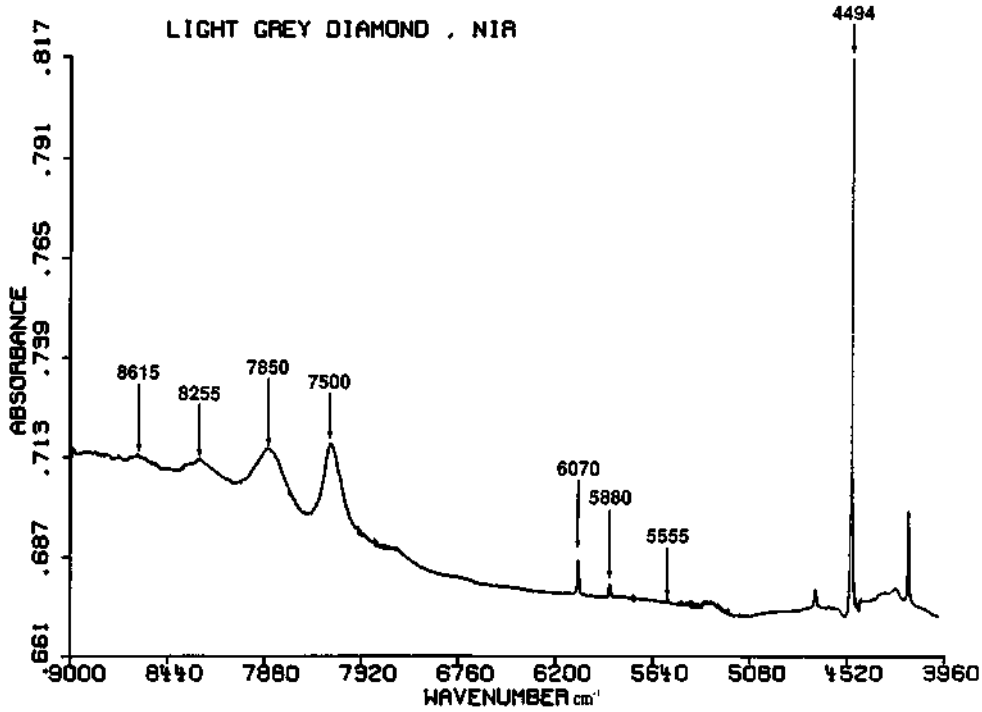

Fig. 11a

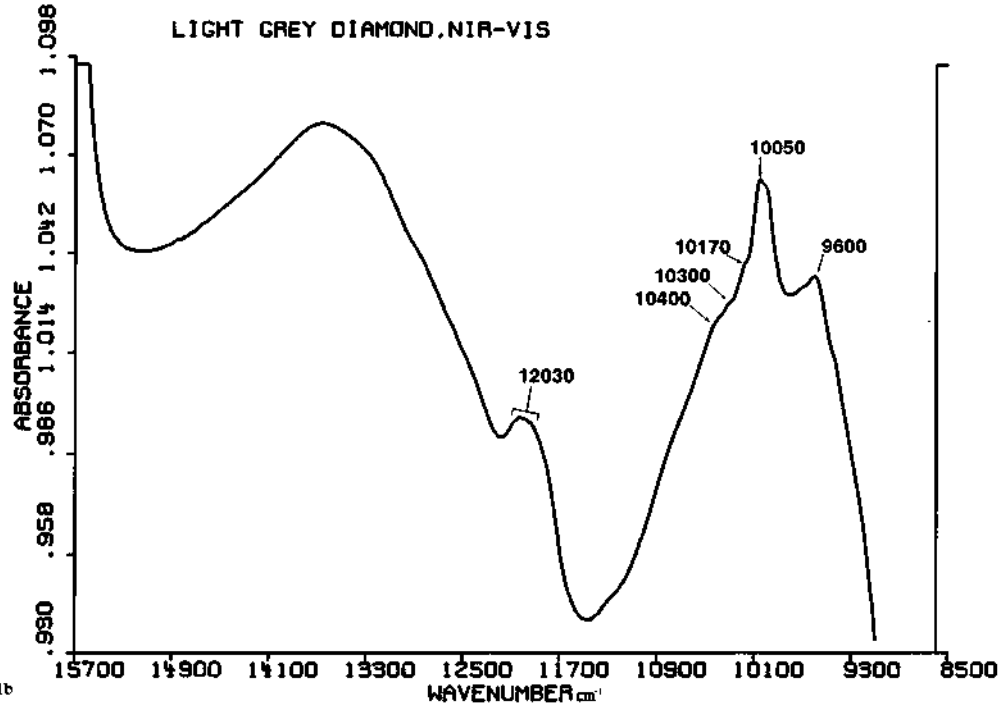

Fig. 11b

Fig. 11. Near-infrared (a) and near-infrared-visible (b) absorption spectra of a light grey H-rich diamond showing some of the newly discovered hydrogen-related bands, for example at 6070, 5880 and 5555 cm⁻¹.

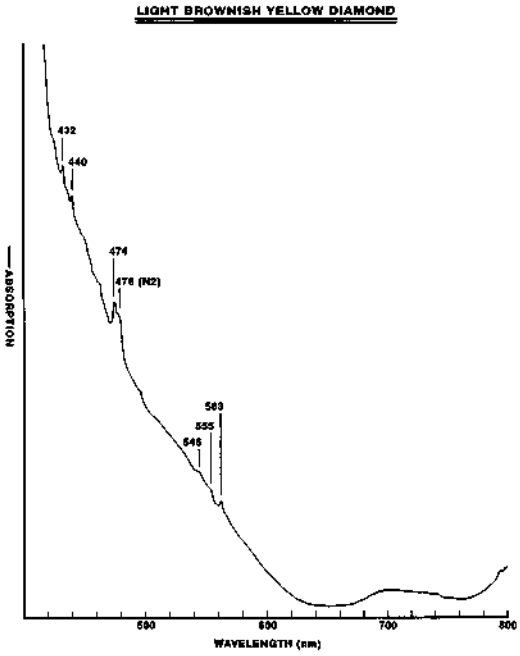

Fig. 12. Ultraviolet-visible absorption spectrum taken at liquid-nitrogen temperature of a 1.02 ct light brownish-yellow diamond illustrated in Figure 1, typical of the 'brown to greyish-yellow family' of H-rich diamond, shows a sharp absorption band at 563 nm and other associated bands (see text) believed to be due to hydrogen-related defects.

measure the concentration of hydrogen in diamonds are not suited to measure concentrations of the order of magnitude expected in our samples.

Ultraviolet-visible absorption spectroscopy

Since all these stones are Type Ia diamonds, the N2 and N3 centres (with major absorptions at 478 and 415 nm respectively), corresponding to nitrogen aggregates, have often been found associated with the features described below.

A typical spectrum of diamonds belonging to the 'brown to greyish yellow family', first described by Scarratt (1986) and illustrated in Figure 12, is characterized by a regular increase of the absorption from the red toward the violet, which is responsible for the dominant brown to greyish-yellow coloration. On this major absorption feature are superimposed a very broad band centred around 700 nm, a weak but sharp band at about 563 nm accompanied by wider bands (possibly phonon side bands) at 555 and especially 545 nm, a moderate to strong band at 474 nm and two sharp bands at 440 and 432 nm. On one occasion, the broad 700 nm band, which absorbs mostly the red end of the visible spectrum, was strong enough compared to the other features to give rise to a primarily green coloration (with yellow and grey overtones).

The 'grey to violet family' of H-rich diamonds shows a typical spectrum (Figure 13) containing a broad band centred around 700 to 730 nm, a broad, composite absorption feature located between 500 and 600 nm, and weak, sharp bands at 448, 444, 425, 415, 404 and 380 nm. In bluish-grey stones (see Fritsch and Scarratt, 1992), a broad maximum around 550 nm is always well individualized and a band at about 590 nm is present in greyish-violet stones.

The two categories of absorption features described above have been observed to our knowledge exclusively in H-rich diamonds, and not in other kinds of diamond. Therefore we suggest that H-related defects are responsible for such absorptions in the visible range, which affect the colour of diamonds. The exact nature of these defects is still unknown.

Chameleon diamonds display a typical spectrum (Figure 14) with a weak, broad feature centred around 700 nm, a broad band centred around 480 nm and a sharp band at 425 nm, which from our experience is a companion line to the 480 nm band. The 480 nm band is also known as the 2.6 eV band, and is commonly accompanied by a bright yellow luminescence and phosphorescence (Collins, 1982), as is the case for chameleon diamonds. The differences in absorption in one chameleon diamond between room and low temperature has been reported by Scarratt (1984) and demonstrates the importance of the reduction in the absorption of a very broad band centred in the near-infrared at about 800 nm to obtain the yellow colour. The difference in absorption between the stable, greener colour at room temperature and the yellow colour immediately after heating has not yet been recorded because of technical problems.

White diamonds show an apparent absorption increasing regularly toward the ultraviolet. This feature is not a true absorption and is actually the result of light scattering due to the 'cloud' of microscopic inclusions observed in such stones.

Discussion

There is no doubt that hydrogen-rich diamonds have been mined occasionally over the years. For example, we documented a hydrogen-rich diamond of unknown origin from the British Museum coloured green (by natural irradiation) that had been catalogued in 1934 (Shigley and Fritsch, 1990). We also report here on three H-rich stones from India, the major

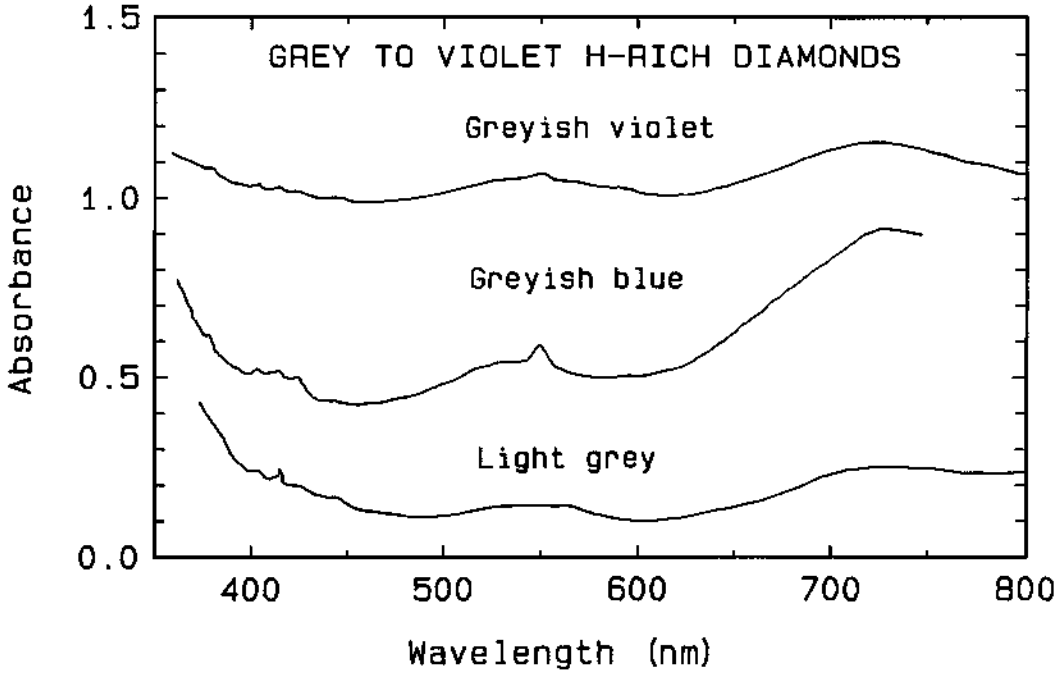

Fig. 13. Ultraviolet-visible absorption spectra taken at liquid-nitrogen temperature of three H-rich diamonds from the 'grey to violet family', all exhibit a broad band at about 550 nm.

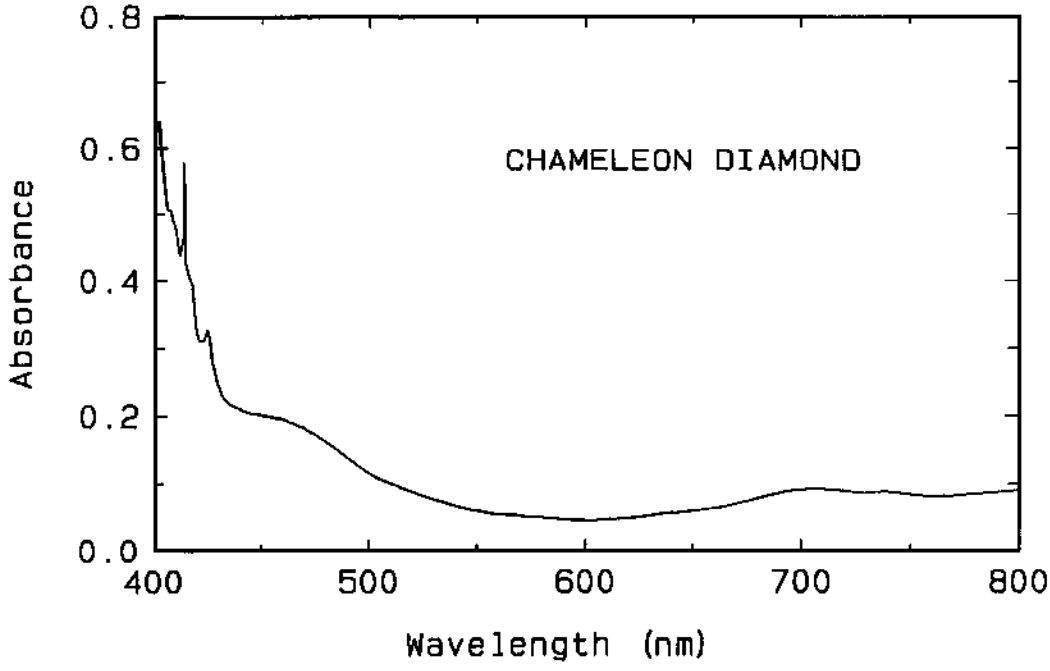

Fig. 14. Typical ultraviolet-visible absorption spectrum taken at liquid-nitrogen temperature of a chameleon diamond, showing the typical broad band centred around 480 nm and its sharper companion band at about 425 nm.

diamond-producing country until the eighteenth century. Thus, there is a strong likelihood that this locality produced more such diamonds over the centuries.

However, the number of hydrogen-rich diamonds present in the gem market has greatly increased, starting in the mid-1980s. One wonders what might be the cause of this sudden abundance. A number of our samples are known to come from the Argyle mine in north-west Australia. This mine became fully operational only in 1985. In addition, hydrogen-rich diamonds have been reported from the Jwaneng mine in Botswana, where commercial recovery of diamonds started in 1982 (Welbourn *et al.*, 1989). Therefore, these two relatively recent mines could be the source of these suddenly common H-rich diamonds.

The pattern of colour zones and clouds observed in H-rich diamonds, as well as their luminescence behaviour and infrared absorption spectra, is similar to that of cuboid internal growth sectors observed in rough diamonds of cube or cube-related shape from the Jwaneng mine in Botswana (Welbourn *et al.*, 1989). Cuboid growth in diamond is a nonfaceted growth along non-crystallographic surfaces of mean {100} orientation (Lang, 1974). It is interesting to note also that the luminescence and colour zonation described above have a symmetry consistent with the grey to brown sectors being cuboid growth sectors. The greenish-yellow luminescence of Jwaneng diamonds is attributed, at least in part, to the S1 and S3 centres (Welbourn *et al.*, 1989) and the same centres could be the source of the yellow luminescence observed in our samples. Welbourn and his co-workers also observed in some cases the zoned yellow and blue luminescence we described above. The clouds in their samples were formed by light-scattering defects in the form of thin discs, about one micrometre in diameter, lying on the {111} planes (Walmsley *et al.*, 1987). These defects could be the physical location of the hydrogen impurity.

The singular fact that none of our samples was a Type II diamond merits comment. To date, no natural Type II diamond has been documented as showing any H-related absorption. One pragmatic explanation is that the presence of nitrogen is necessary for the incorporation of hydrogen in diamond (Fritsch and Scarratt, 1989). But the hydrogen-related absorptions we observe have been proved conclusively by isotopic studies to be due to C-H vibrations (Woods and Collins, 1983) and the same authors identified N-H-related absorptions at different energies between 3300 and 3400 cm^{-1}. In addition, one should note that the $\delta^{13}C$ of Type IIa diamonds in several localities tends to be on average much lower than that of Type I diamonds (Harris, 1989). This difference in carbon isotope ratio suggests that Type II diamonds may have a somewhat different geological origin from Type Ia diamonds. Consequently, hydrogen might be found only in the environment in which Type I diamonds grow.

Conclusion

We have demonstrated that in natural diamonds, hydrogen induces absorptions in both the infrared and the visible range, some of which had never been described before. Some of those absorptions result in a fairly intense coloration, to include a greyish-blue colour formerly thought typical of Type IIb diamonds and a violet colour never before encountered in natural diamonds. In addition, broad, prominent H-related absorptions are found in the near-infrared, a spectral region in

Fig. 9a. Zoning of the ultraviolet luminescence has been observed in a number of H-rich diamonds, and can take two different appearances: (a) in H-rich diamonds showing a yellow and grey planar colour zoning, the yellow zone fluoresces blue and the grey zone yellow, as in this slab from a 0.28 ct greyish-yellow diamond already illustrated in Figures 1, 6 and 8.

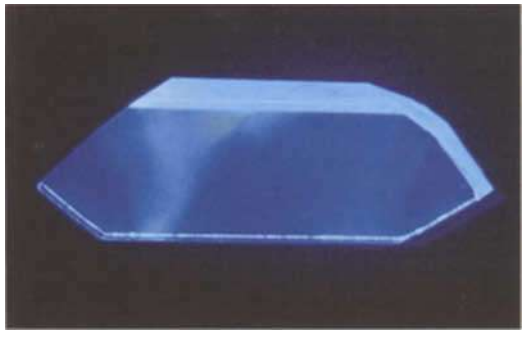

Fig. 9b. The cloud in this slab from a brownish-yellow 1.02 ct diamond – already illustrated in Figures 1 and 7 – fluoresces a strong yellow in long-wave, in contrast with the rest of the stone, which in this case fluoresces blue. *Photomicrographs John Koivula*

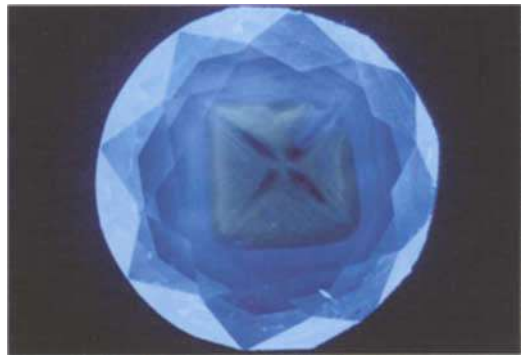

which diamonds are generally considered perfectly transparent. Our observations suggest that these diamonds result from mixed growth, with both octahedral and cuboid growth sectors.

In many cases, H-rich diamonds can be easily identified by classical gemmological observations on the basis of their colour appearance, combined with their internal zonation, type of inclusions and typical ultraviolet luminescence. Rarely hand-held absorption spectroscopy can help. Because those H-rich diamonds belonging to the 'brown to greyish-yellow' and 'grey to violet' families present body colours generally judged unattractive, they have commonly been treated to produce green and yellow colours deemed more attractive.

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The glass filling of diamonds
Part 1: an explanation of the colour flashes

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Abstract

An explanation is given for the appearance of bright colour flashes associated with regions bordering the fissure-fillings of diamonds and other gemstones. A procedure is outlined for determining the exact spectral wavelength at which the infilling glass and the diamond possess the same refractive index.

The diamond colour flashes

As with emeralds, brilliant colour flashes are associated with diamond fissure filling. Compared with Opticon-filled emeralds, the situation is different for diamonds. Apart from the coloured fancies, those of the Cape series increase in value as they approach the entirely colourless state. Any mechanism contributing to an enhanced body colour would lower their commercial attractiveness. The colour-flashing is such a mechanism. An understanding of the mechanism responsible for this optical phenomenon is the first step towards its management.

The cause of the flashes

Some months before this paper was submitted for publication, the writer had attended a slide-illustrated lecture by E.A. Jobbins[1] on the microscopical observations on fissure-filled diamonds. It was during this lecture that the writer immediately recognized the cause of this hitherto unexplained effect. It was clear to him that its mechanism was identical to that of an optical effect of which he had made regular use for the past twenty-five years! He has to confess that while he had read the seminal paper published in 1989[2] by members of the laboratories of the Gemological Institute of America, he had totally failed to appreciate the connection at that time.

This laboratory procedure was one which allowed the positive identification of small particles or fibres of different substances which had been immersed in suitable microscopical slide preparations. Its analytical principle was derived from a monochromatizing light filter invented by Christiansen in 1884[3]. The principle was first transformed into a polarized light microscope unit by Crossmon in 1948[4]. Further improvements were made later by Cherkasov in 1957[5] and by Schmidt in 1958[6]. It was finally worked up into a commercially-available system by Brown and McCrone in 1963[7], who named it *'optical dispersion staining'* for the systematic identification of all transparent substances, whether crystalline or not. It has since been a much-used technique and is employed world-wide, now mainly in the identification of all asbestos minerals and their substitutes.

The dispersion staining analytical system

Without doubt, the least painful way to explain the cause of the diamond colour flashes is to describe the workings of the dispersion staining system. There is no uncertainty whatever that the optical mechanisms involved are identical.

The system comprises four elements. The first is a polarized light microscope on to the nosepiece of which can be coupled the Brown-McCrone *dispersion staining objective*. The second is a set of calibrated high refractive index immersion liquids, and the third a data bank of refractive index and dispersion data on many hundreds of the commoner minerals and chemical compounds. The fourth element consists of a graphical procedure for converting the observed dispersion staining colours into numerical statements on the refractive index and dispersion of the unknown particle or fibre.

Dispersion staining colours

To produce the brightest colour effects, the particle and immersion liquid must have different dispersion curves which should have as disparate slopes as possible in the visible region. Referring to Figure 1, two hypothetical curves are shown as linear plots of refractive index (n) against wavelength (λ). It is seen that only at a single wavelength (termed λ_0), does the solid particle and the immersion liquid have the same refractive index. At λ_0, a clear, colourless, inclusion-free, solid particle, of whatever shape, will be perfectly

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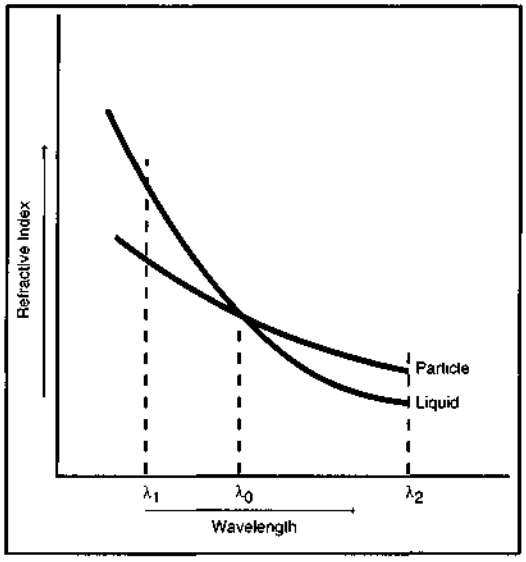

Fig. 1. Hypothetical dispersion curves for particle and liquid showing a match in refractive index at λ_0.

invisible in a colourless liquid. However, on either side of λ_0, say at λ_1 and λ_2, optical discontinuities will exist and the particle's boundaries will be clearly visible.

The microscopy of dispersion staining

Consider the situation illustrated in Figure 2. This is a representation of the microscopical dispersion staining of a lens-shaped colourless particle or small crystal immersed in a thin layer of liquid enclosed between a microscope slide and a cover slip.

A parallel beam of white light from the microscope's condenser-and-iris illuminator (not shown) is directed upwards to the slide preparation. The liquid has been chosen so that it has the same refractive index as the particle at a wavelength of 580 nanometres. This wavelength corresponds approximately to a yellow light. While all visible spectral wavelengths are present in the white light beam, for the purpose of clarifying the dispersion colour-staining mechanism, only three are considered, namely red (650nm), yellow (580nm) and blue (470nm).

In Figure 2A, a small annular diaphragm or stop is shown lying in the back focal plane of the microscope's objective. Its purpose is to allow the yellow unrefracted rays to pass through to the imaging plane. Because of the wavelength dispersing behaviour of the prism-like structure of the particle, the mismatching blue and red rays are bent away in opposite directions from the undeviated yellow rays. The annular stop prevents them from reaching the imaging plane. *As a consequence, the particle is perceived as a white image having a yellow boundary and is seen against a white background.*

In Figure 2B, a central stop diaphragm is placed in the back focal plane. Its effect is to stop the unrefracted yellow rays from the particle and the unscattered white light from the source from passing into the image space. Instead, the mismatching red and blue rays are allowed to pass through. *Thus when a central stop is used, the particle appears as a dark image with purple (i.e. a mixture*

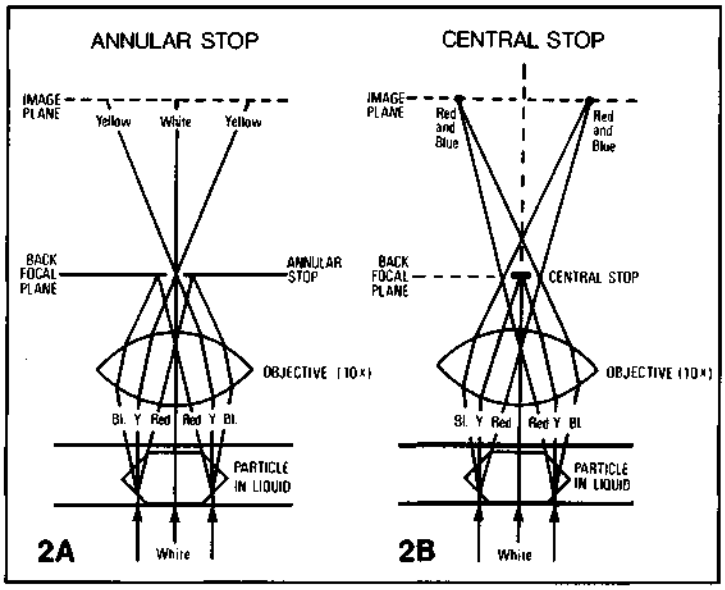

Fig. 2. Schematic representation of dispersion staining for three colours, red (λ = 650nm), yellow (λ = 580nm) and blue (λ = 470nm).

Fig. 3. The McCrone dispersion staining microscope objective.

of red and blue rays) borders, seen against a dark background.

The dispersion staining microscope objective (Figure 3) is equipped with a 10 times magnification objective lens and a rotating-disc which permits the insertion into the objective's back focal plane of either an *annular stop* or a *central stop*. A third click- stop setting allows both to be moved aside so that the full aperture of the back focal plane can be inspected for alignment purposes. Thus the colours seen at the borders of the uncoloured body of the particle are quite different for the two kinds of stops.

The purpose of both stops is to generate the 'staining' colours at the particle's boundaries. From the kind of colours seen, an estimate can be made of the matching wavelength (λ_o) when the n values of the particle and that of a chosen immersion liquid are identical. The liquids most often used in routine particle identifications are available in a convenient set of 31 Cargille Certified High Refractive Index Liquids ranging in n_D values from 1.500 to 1.800 in 0.010 steps.

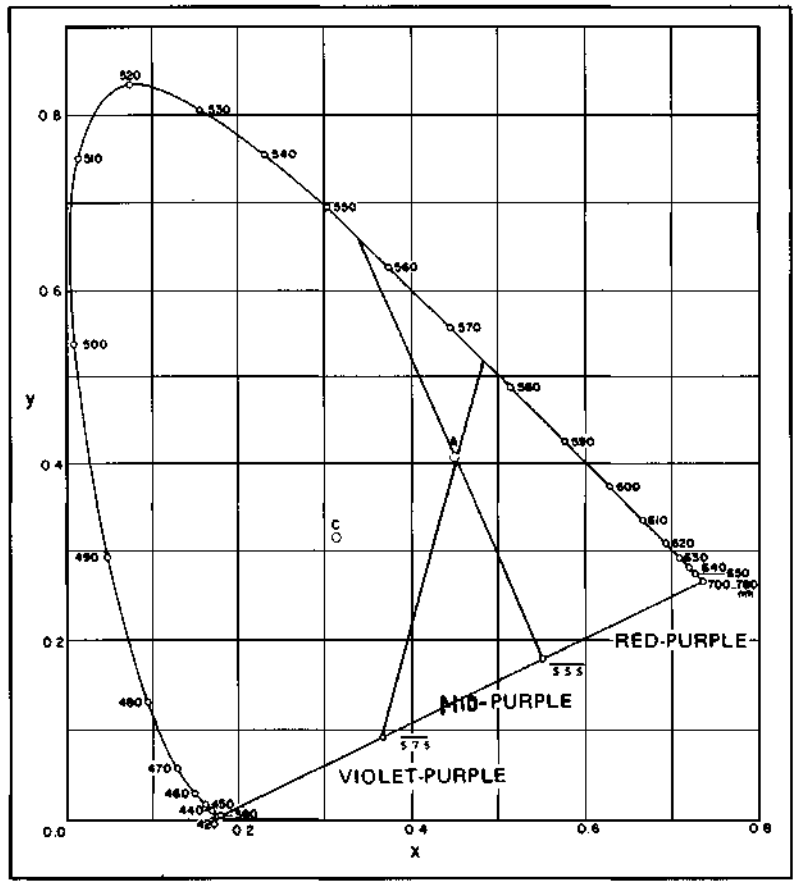

Fig. 4. The CIE (1931) Chromaticity Diagram.

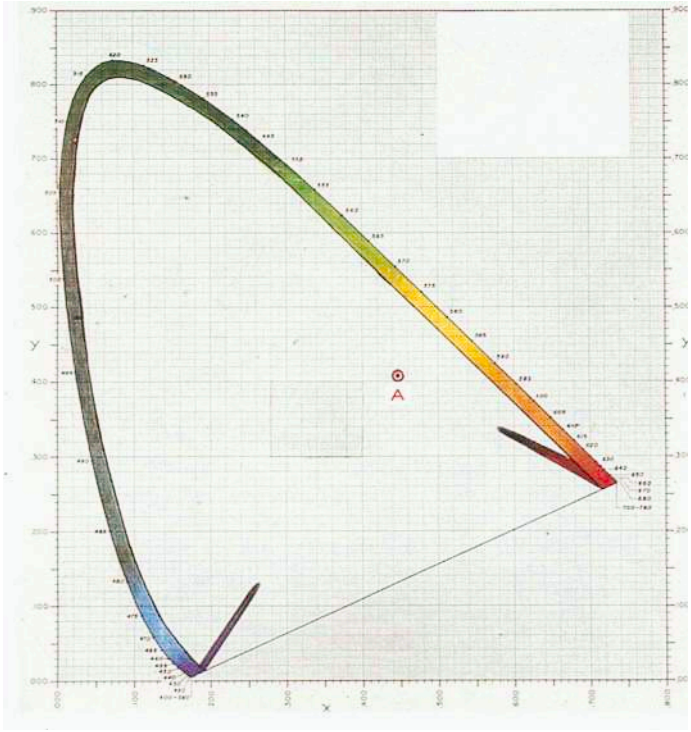

Fig. 5. The CIE Chromaticity Diagram showing the idealized dispersion staining colours for the annular stop mode. CIE Illuminant 'A'.

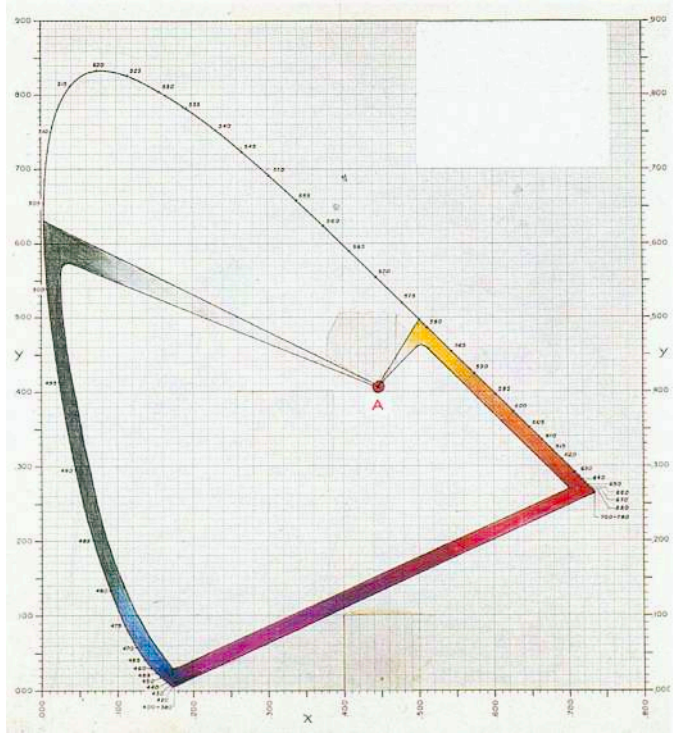

Fig. 6. The CIE Chromaticity Diagram showing the idealized dispersion staining colours for the central stop mode. CIE Illuminant 'A'.

They are stable liquids whose n values have been accurately calibrated at three wavelengths (the C, D and F lines of the solar spectrum).

The kind of microscope illumination used is important, as reproducible dispersion colours depend on the colour temperature of the light source. A 20 watt condensed tungsten filament lamp is preferred. It is operated slightly above the normal rated voltage. Such a white light source corresponds closely to the C.I.E. Standard Illuminant 'A', having a colour temperature of 2855K. [8,9] The central stop is the one most frequently used. However, inspection of the annular stop colours can yield a second judgement of the λ_0 value of the particle or fibre. The dispersion staining colours observed for both annular and central stops are shown in Table 1.

The CIE Chromaticity Diagram

The CIE (1931) Chromaticity Diagram[8,9] is a helpful way of visualizing dispersion staining colours and in assigning λ_0 values to them. The diagram shown in Figure 4 represents the spectral colours as a curved distorted triangle with their wavelengths marked around it. Spectral mixtures of violet and red are known as the spectral purples and these all fall on the straight line joining the violet and red end-members. The purples are arbitrarily divided into three sections, namely the violet-purples, the mid-purples and the red-purples. The divisions are made at values of λ at $\overline{575}$and $\overline{555}$. The 'purple bar' placed over the numbers indicate that these colours are complementary to the spectral colours at 575 (yellow) and 555 (green-yellow) respectively. They are linked through the white point, here taken as the CIE Illuminant 'A'. A particular advantage of this diagram is its ability to show corresponding annular and central stop colours, i.e. complementary colours at opposite spectral ends of a straight line passing through the chosen white source.

A Chromaticity Diagram showing the idealized dispersion staining colours for the annular stop mode is shown in Figure 5. It can be seen that all the spectral colours are represented except the spectral purples.

The corresponding diagram for the central stop mode is shown in Figure 6. All the purples are present, but the spectral colours in the continuous region between the blue-green at λ = 504nm and the yellow at λ = 579 are absent (see Table 1).

Dispersion Staining Charts

The most convenient way of presenting and using dispersion colour information is not by plotting the usual direct *dispersion curves* (Figure 7A, left-hand graph), but as *dispersion staining curves* (Figure 7B, right-hand graph). In the latter graph, the refractive index for the sodium D line of the matching Cargille liquid (n_D^{25}) is plotted against a function of the matching wavelength (λ_0).

Table 1: Dispersion staining colours using a CIE Standard Illuminant 'A' (colour temperature of 2855K)

Spectral Colours*			Annular Stop Colours		Central Stop Colours	
Colour	*λ range in nm*	*λ (mean) in nm*	*Colour*	*λ in nm*	*Colour*	*λ in nm*
Violet	400-450	440	Dark violet to violet	440	Pale yellow†	579
Blue	450-480	470	Blue	470	Yellow	581
Blue-green	480-510	495	Blue-green	495	Orange	$\overline{594}$
Green	510-550	530	Green	530	Red-purple	$\overline{530}$
Green-yellow	550-570	560	Green-yellow	560	Mid-purple	$\overline{560}$
Yellow	570-590	580	Yellow	580	Blue	460
Orange	590-630	605	Orange	605	Blue-green	500
Red	630-700	650	Red to dark red	650	Pale blue- green†	504

* These are the spectral colours according to Wright[9]. The boundaries between the colours are arbitrary since no sharp upper or lower limits can be assigned in the continuous white spectrum.

† The dispersion colours are virtually pure spectral colours in the annular stop mode. This is also so for the central stop mode, except for the λ values above about 485nm and below 595nm when desaturation begins to increase gradually. No dispersion colours will be seen in either mode if the n values of the particle and liquid are too far apart to match at any wavelength in the visible region. Also, in principle of course, no dispersion colours would ever be seen if the n values and dispersions of the particle and liquid were identical. This would be an unlikely occurrence.

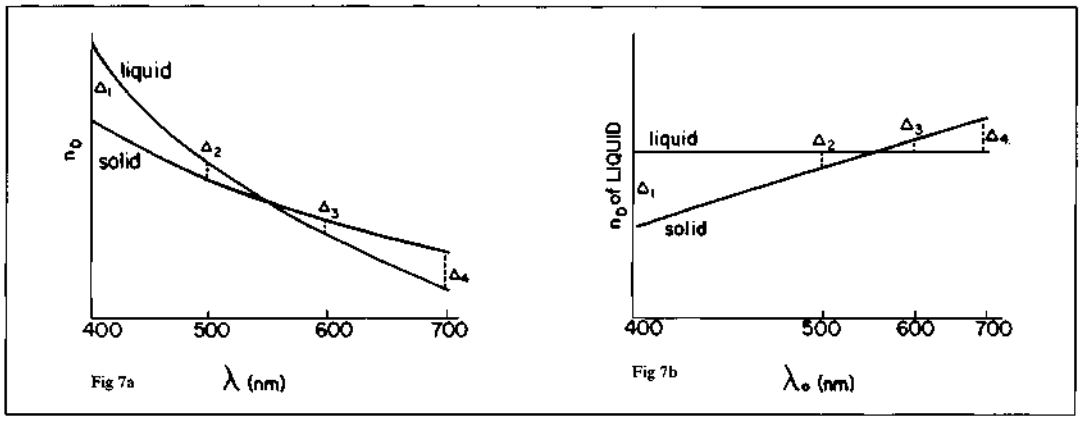

Fig. 7. The derivation of the analytical dispersion staining graphs of (7B) from the conventional dispersion graphs of (7A).

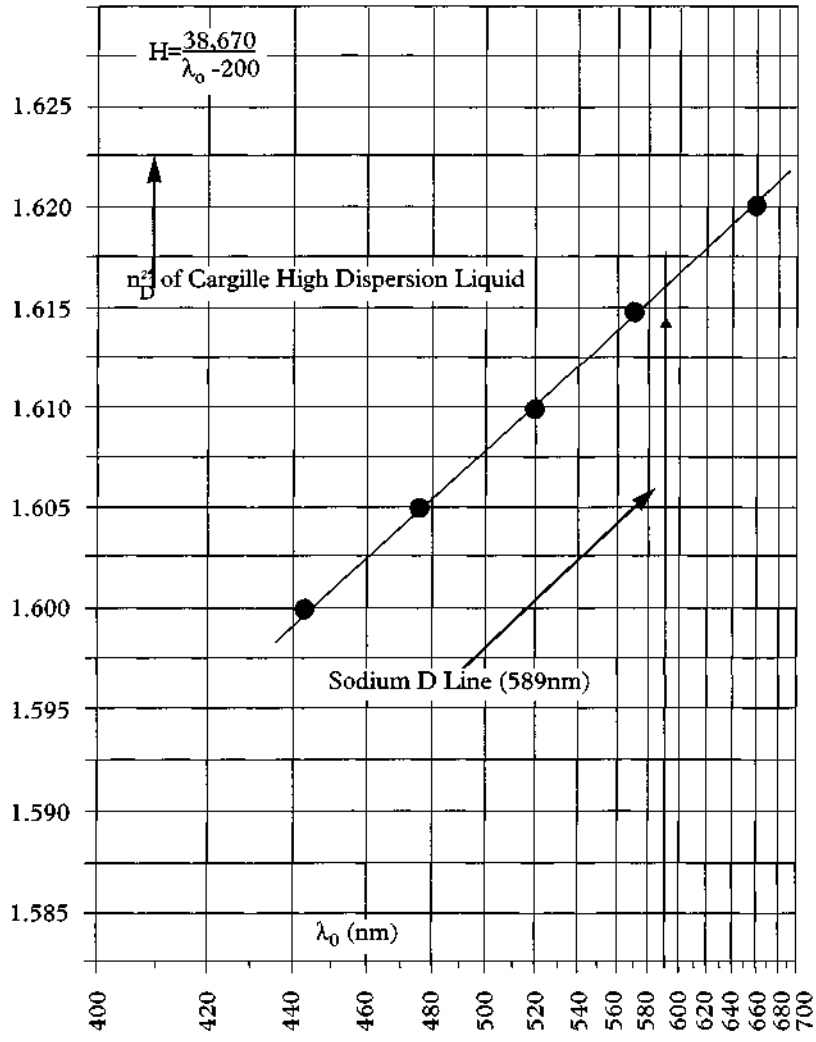

Fig. 8. The dispersion staining chart for an unknown crystal, showing the smoothed graph of estimated λ_0 plots. Central stop. CIE Illuminant 'A'. The n_D value for the crystal is seen to be 1.616.

The wavelength scale adopted is that used in the Hartmann dispersion relationship:†

$$H = \frac{K}{\lambda - 200}$$

where λ = wavelength (nm),
K = a constant,
and H = distance (mm) along the scale corresponding to a given value of λ.

[For a λ range from 400 to 700nm, corresponding to a scale length of 180 mm, K has a value of 60 000.]

In this way, the dispersion staining curves of materials plot almost invariably as straight inclined lines, with the Cargille liquids plotting as horizontal straight lines. Thus the dispersion staining curve gives directly the matching wavelength (λ_o) in each liquid (identified by its n_D^{25} as ordinate). The prefix '25' is the calibration temperature in °C of the Cargille liquid.

An example is given here of the dispersion staining analysis of an unknown white crystalline powder. The central stop mode and Illuminant 'A' were used. The dispersion staining colours were noted for microscope slide preparations in which the powder was immersed in five different Cargille High Dispersion Liquids. The matching wavelength, λ_o, was estimated from the observed dispersion staining colours using the relationships listed in Table 1. The immersion liquids used were the Cargille (n_D^{25}) liquids 1.600, 1.605, 1.610, 1.615 and 1.620.

The estimated λ_o values were plotted on a Hartmann chart and the best straight line drawn through the plots. In this way, the n_D for the crystals was determined by interpolation at the point where the inclined dispersion staining graph intersected the vertical line corresponding to λ_o = 589nm. A value of n_D = 1.616 was found. A quick search through the comprehensive dispersion staining data tables[10] showed the crystals to be sodium bromate ($NaBrO_3$). The plot is shown in Figure 8.

As well as obtaining the actual n value at λ = 589nm for the crystals, it is possible from the same chart to find their n values for any of the other visible wavelengths. The procedure takes a little longer [11], but the results are just as accurate as for λ = 589nm. Thus the n values found for the standard (i.e. Cargille calibrations) solar spectrum lines 'C', 'D' and 'F' were n_{656} = 1.613; n_{589} = 1.616 and n_{486} = 1.624, respectively.

†This relationship provides a simple means of approximating the conventional optical dispersion curves (i.e., change in n with λ) from two points only. A straight line connecting the two points permits interpolation, and perhaps even extrapolation, with considerable accuracy.

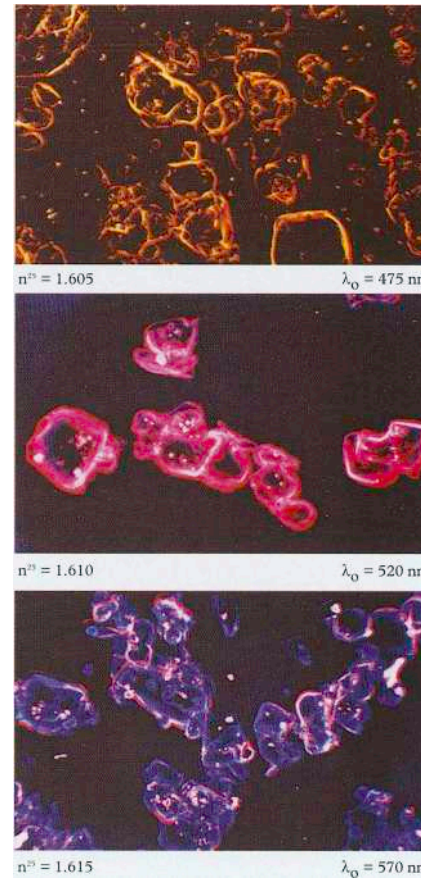

Fig. 9. Photomicrographs of unknown crystals mounted in High Dispersion Cargille Liquids of n_D = 1.605, 1.610 and 1.615. Central stop. CIE Illuminant 'A'. Magnification X80.

Three of the preparations were photographed and the results are shown in Figure 9.

The dispersion staining colours of diamond fillings

By now it is apparent that the spectral colour flashes seen by *darkfield examination in a gemmological microscope* are indeed identical to those seen in the central stop mode of the dispersion staining objective of a polarized light microscope. They are the colours listed in Table 1 and shown in the chromaticity diagram of Figure 6.

As to be expected from a consideration of Figure 2B, the most intense colours will be seen in the extreme angular darkfield mode of a gemmological microscope and *only at a particular orientation* of the infilled diamond. This is the reason for the sudden brilliant flashes. These will occur when the planes of the cleavage infillings bisect the small angle formed by the narrow beam

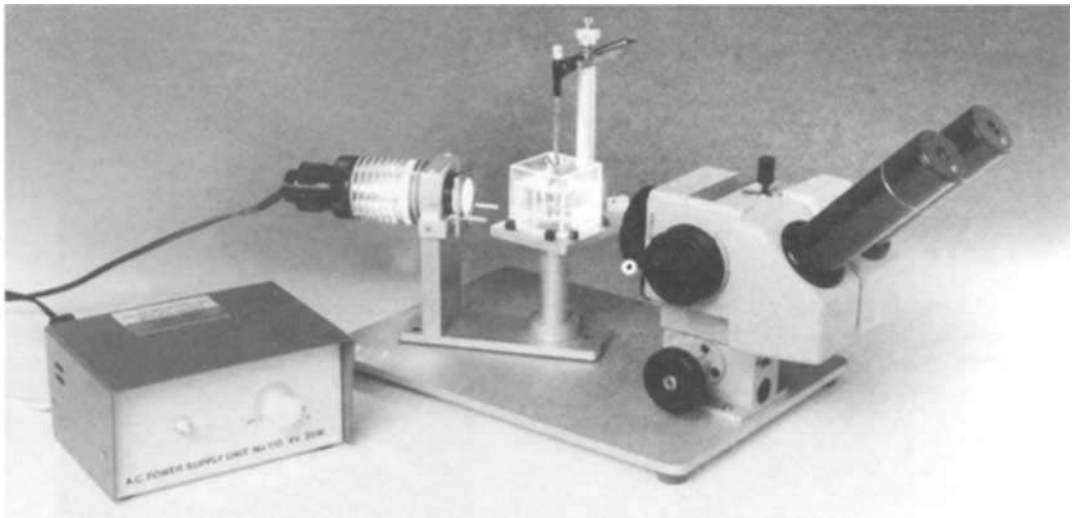

Fig. 10. A horizontal gemstone immersion microscope suitable for the determination of the λ_o value of the glass phase in filled diamonds.

of the light source and the optic axis of the microscope.

On the other hand, the examination of the infillings by the *brightfield (transmission) mode with a gemmological microscope*, the most intense spectral colours will be seen when the plane of the cleavage infillings lie parallel to the common direction of the light beam and the optic axis of the microscope's objective. As with the annular stop mode of the dispersion staining objective, the spectral purples are never seen. Instead, as shown in Table 1 and Figure 5, only the unmixed spectral colours are observed, and of these, the predominant colour flashes will be green and greenish-yellow.

In both darkfield and brightfield microscope images, the spectral colours will be rendered more monochromatic (i.e. unmixed with neighbouring wavelengths) if a nearly parallel beam of light from the illuminating source is employed. This is the equivalent of using a narrow slit in gemmological spectroscopes, whether prism or diffraction grating.

The optimum conditions for λ_o estimations

To specify these conditions, it is necessary to consider first the geometry and optics of a faceted diamond. This stone, like other gemstones, is designed to be an efficient retroreflector. It is similar to a motorway 'cat's-eye'. Direct transmission viewing of its interior is virtually impossible, either with unaided or magnified vision. In fact, the direct viewing in air of a stone using a single parallel beam of light in a back-reflection mode (darkfield) is not too simple a matter. Constant changing of the orientation of the stone in its holder is needed to inspect its whole interior. One conventional American gemmological microscope overcomes this need for excessive stone manipulation by using an extended diffuse light source. Such an illuminant is not suitable for the detection of faint or narrow colour flashes.

Moreover, this light source invariably consists of a tubular fluorescent lamp having a colour temperature approaching and often exceeding that of the CIE daylight simulant Source 'C' (6775K). A glance at Figure 4 demonstrates the importance of the choice of illuminant. For a λ_o = 495nm, the darkfield colour with Source 'A' (2855K) is orange (λ = 593nm). With Source 'C', it is red-purple (λ = 495). Indeed, there are only two matching wavelengths where the 'A' and 'C' darkfield colours are identical. It can be seen that these occur at λ_o = 583nm and λ_o = 482nm.

It is the multiple total internal reflections which makes gemstone microscopy so different and troublesome. However, it is quite simple to frustrate or nearly eliminate these reflections by immersing the stone in a colourless liquid of even a moderate refractive index. The evident attractiveness of also using a single *directed*, rather than a strongly *diffused* light source, is testified by the rising popularity of horizontal immersion microscopes. With these, much more of a stone's interior can be seen at a single chosen orientation.

The ideal design requirement for a microscope suited to the present purpose is now clear. The desiderata are:

1. A condensed filament tungsten (non-halogen) lamp operated only at a colour temperature corresponding to Source 'A'. [A Source 'C' illumination yields no greater colour discrimination than Source 'A'. It is

more costly to ensure that it is indeed an accurate Source 'C'.]

2. The lamp to be coupled to a condenser lens so as to be capable of producing a broad parallel, or near-parallel beam of white light (i.e. without filters of any kind).
3. This source-assembly to be capable of being swung around an angle from a direct transmission (brightfield) mode to a back-reflection (darkfield) mode with the gemstone as the centre of rotation.
4. The stone in its holder to be capable of being easily manipulated and viewed in either air or in a square, parallel-sided, glass cell containing a suitable colourless immersion liquid.

It so happens that a microscope meeting these ideal requirements will also perform all or more of the tasks needed for routine and research gemmological microscopy.

It should be stated here that all compound gemmological microscopes can detect strong colour flashes, but for accurate quantitative results, a parallel or near-parallel light beam and a standard illuminant are essential. Even a simple 10x loupe can be used to see the colour of the flashes, but it must be remembered that examinations in daylight will result in wrong estimates of λ_o.

The darkfield mode is the one preferred by the writer. Here, the colour flashes are seen against a black background. With the brightfield mode, the flashes are seen against a white background and therefore appear to be less contrasty and more desaturated than they really are. Nevertheless, a note of the brightfield dispersion staining colours serves as a useful check on the λ_o estimation made by the darkfield mode.

The darkfield mode has also a surprising and valuable feature. It was discovered when trying to detect minute fibres of asbestos found in air samples using the central stop mode. With the 10x microscope objective in use, it was found to be almost impossible to see the true, resolved images of chrysotile-asbestos fibres less than about one micrometre in diameter. Despite this, the true dispersion staining colours of chrysotile fibres of down to 0.1 micrometre diameter were vividly seen in their full strength and saturation.

This behaviour seems to be a universal phenomenon. For example, although the true images of stars can never be resolved in even the largest telescopes, stars still show their own characteristic colours. For this reason, while not yet in a position to test this experimentally with the glass infillings, it is quite likely to hold good. If so, it means that if the molten glass manages to penetrate to the root of the thinnest fissure, colour flashes will reveal it. Here again, brightfield will not be nearly so sensitive.

Experimental Observations

Two Yehuda-filled diamonds of 0.37 and 0.39 carats were examined with a horizontal immersion microscope of the kind shown in Figure 10. Colourless benzyl benzoate (n_D = 1.57) was used as the immersion liquid, and the four optimum viewing conditions were followed.

Both stones displayed the same dispersion colours. The darkfield mode colours gave a λ_o value of about 560nm (mid-purple). This was confirmed by the brightfield mode, which showed a green-yellow flash. This meant that the glass and the diamond possessed the same n value at 560nm. A glance at the Hartmann dispersion chart of diamond (in Figure 11) shows diamond, and therefore the glass, to have an n value of 2.421_5 at λ = 560nm. Of course, no conclusion could be reached as to the magnitude of the dispersion of the n values of the glass. This could only be determined by the methods described in Part 2 (to be published in a future issue of the *Journal*). It is, of course, much greater than that of diamond.

When the stones were examined in air in the darkfield mode, the results were found to be identical to those of the immersed stones. However, still using this mode, but now in air, when the stones were slowly turned, sudden green-yellow colour flashes were seen against a bright background. This was indeed a puzzling behaviour, but the reason for this 'forbidden' colour flash was not difficult to uncover.

With the immersion cell, the diamond's total internal reflections were eliminated, but in air they played their normal, intended role in returning the light to the viewer. In this way, and at certain angles, they converted the back-reflection (darkfield mode) light beam into a transmission (brightfield) beam. As will be recalled, this green-yellow colour is the A-Source complementary colour to mid-purple.

These observations with the two Yehuda-filled diamonds confirmed all the experimental observations already reported[2]. In this Reference, the complementary colours seen however, were not those found during the present observations. The difference could well have arisen from the use by the six authors of the daylight fluorescent tube illumination. This explanation is entirely consistent with the facts as shown in Figure 4. It is also supported by a later note in 'Gem News' by two of the authors[12] who reported colours identical to those seen by the writer. Here they made use of a

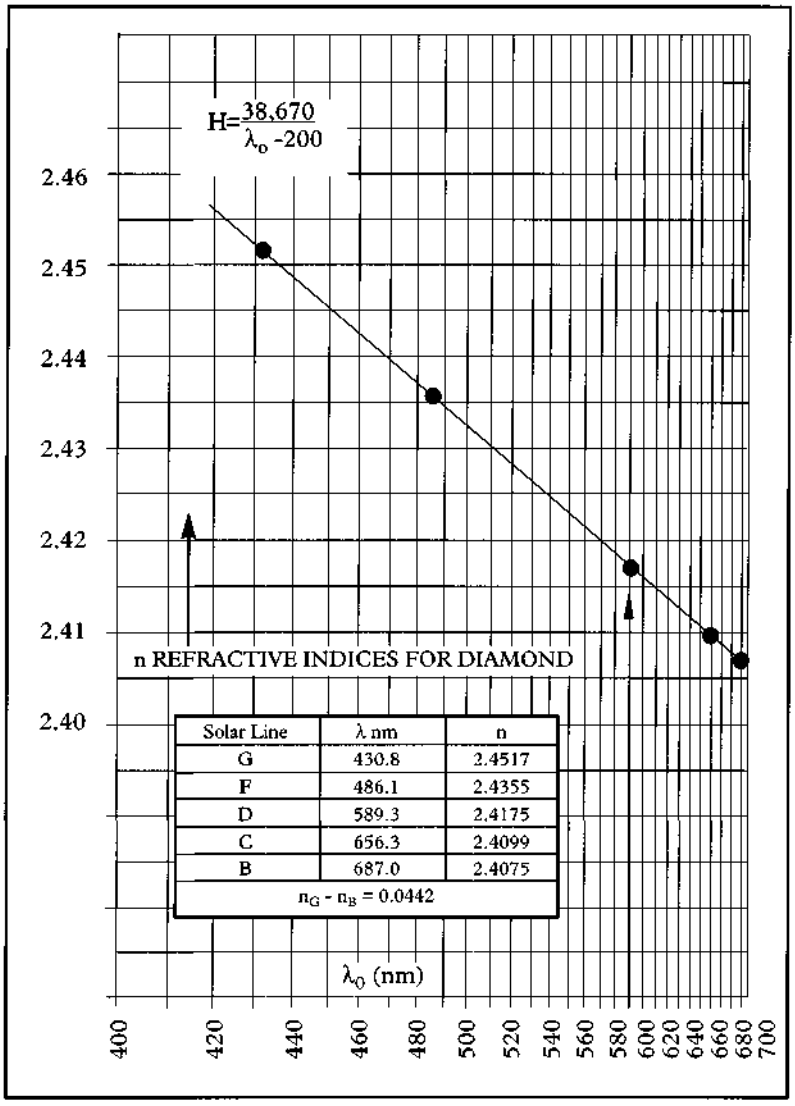

Solar Line	λ nm	n
G	430.8	2.4517
F	486.1	2.4355
D	589.3	2.4175
C	656.3	2.4099
B	687.0	2.4075
$n_G - n_B = 0.0442$		

Fig. 11. The Hartmann dispersion chart for diamond.

fibre-optics 'light wand', which has a colour temperature very close to that of Source A.

In References 2 and 13, the authors state that the complementary colour flashes are interference colours. This is not so. The writer demonstrated this by inserting single and crossed polarizing filters into the illuminating and viewing light paths. The colour flashes were identical to those seen without polars.

With some stones, when the fissure roots are narrow and unfilled, the use of crossed polars allows one to distinguish with certainty between dispersion staining colours and the classical Newtonian interference colours. Interference colours are quite different from those of the fully saturated colours arising from dispersion staining.

The CIE Chromaticity Diagram of Figure 12 shows the locus of three orders of interference colours. It can be seen that the petrologist's *first order sensitive tint plate*[14] (having an optical retardation of 550nm) shows a mid-purple colour of considerable desaturation. A petrologist's quartz wedge inserted at 45° between crossed polars shows these progressively desaturating orders perfectly.

Dispersion colours (the 'fire' of diamonds [15]) pose no problem even with immersion viewing. These do not 'flash' and they display the entire spectral range of colours at the same orientation. This is why it is always necessary to state clearly in any discussion of this subject whether it is a *dispersion colour* or a *dispersion staining colour*. With

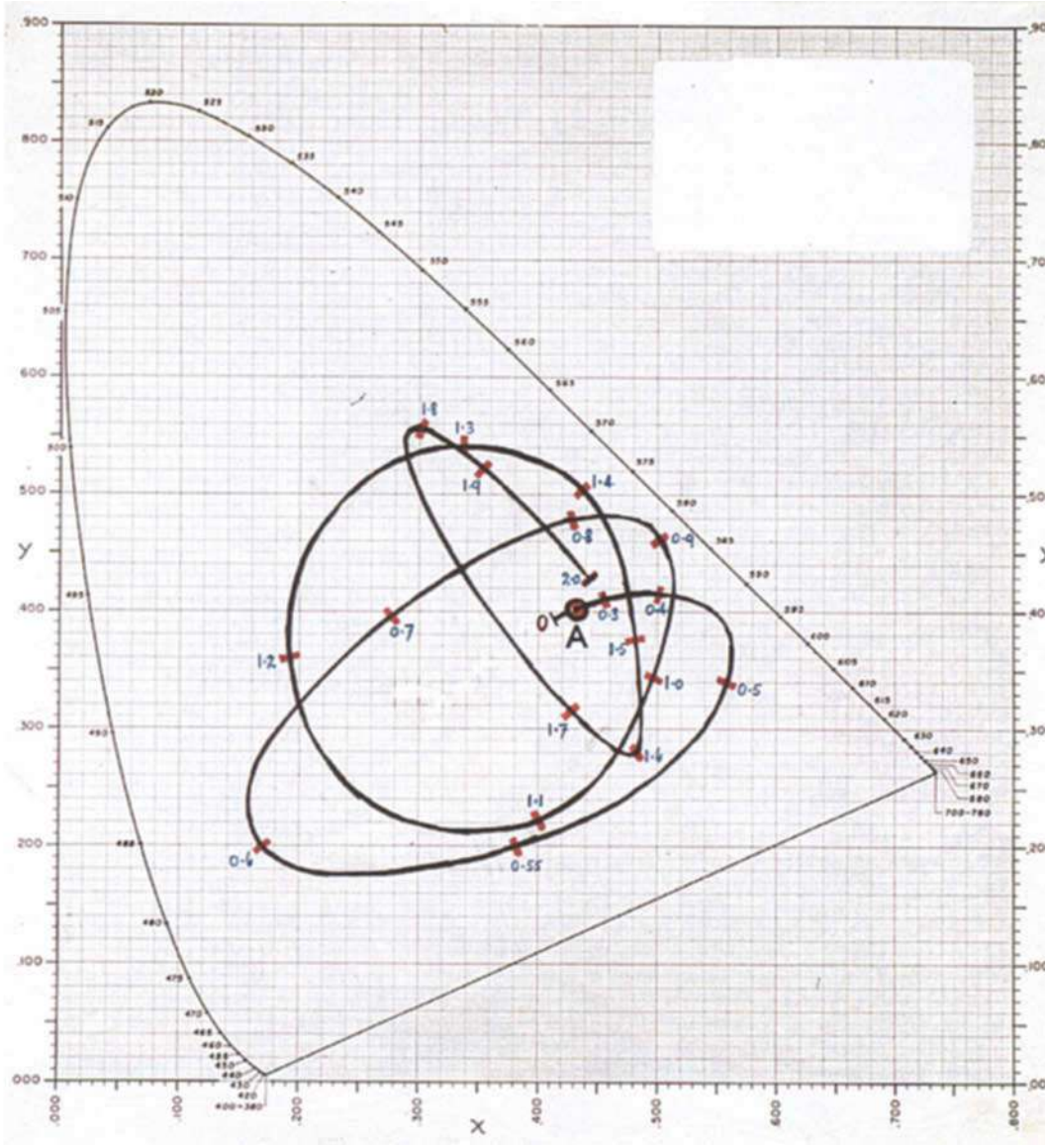

Fig. 12. The CIE Chromaticity Diagram showing the locus of three orders of the Newton Series interference colours. CIE Illuminant 'A'.

experience, optimum viewing conditions and a good reference table of λ_o colours, the writer has found it possible to estimate λ_o values to within ±6nm.

Concluding Remarks

From the preceding discussion, it is clear that if the dispersions of the host gemstone and that of its inclusion become farther apart, then the dispersion staining colours become more intense. If both coincide, the colours vanish and perhaps the inclusion boundary images as well. Remembering that λ_o is the wavelength at which the glass and diamond have the same refractive index, it is also clear that with λ_o values lying just beyond either end of the visible range (400nm to 700nm), no spectral colour flashes will be seen. It follows that if it were decided to eliminate the colour flashes, then the price to be paid for this change would be an increased visibility of the glass-diamond inter-

faces. Just how much will not be known until it is tried.

The thought may also have occurred that a λ_0 glass showing a darkfield blue dispersion staining colour would be an improvement over the Yehuda mid-purple one. The intention would be to help cancel out the yellow body colour of the less valuable of the Cape series stones. This is not a viable stratagem as the brightfield colour for such a glass is yellow. Perhaps this idea may have been tried out in a more recent Israeli enhancement attempt by Koss [16]. It would be of interest to examine these stones in the future.

It is impossible to imagine that a 'runny', wettable, low melting-point glass would ever be discovered which would possess an identical dispersion to diamond. Only a monocrystalline diamond filling will do. The only conceivable process would involve enclosing a batch of the fissured stones in the high-temperature, high-pressure cell of that used in diamond synthesis. Even this exotic repair scenario could only result in yellow fissure fillings. In any case, costs would certainly rule it out.

There is only one small improvement which the writer can think of. It is to incorporate pure, colourless particles of diamond (say less than 10 000 grit size) into the batch of glass used for infilling, hoping that an effective de-gassing stage will help to entice a substantial amount of them into the larger fissures.

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[Manuscript received 19 April 1993]

Opalite triplets - new imitations of opal

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Abstract

Significant quantities of a reportedly new production of the imitation opal known as 'Opalite' or 'Opal Essence' which was on display at the 1993 Tucson Gem Shows, is described. The refractive index and SG were found to be 1.50 and 1.17 respectively. Also on display at the shows were triplets and mosaic triplets made with central layers of Opalite under a clear dome and a wax-like base. A key non-destructive method of identification for the unassembled Opalite is the recognition of the clear plastic coating, whilst observations made on a microscopic level, both in terms of internal structures and phosphorescence effects are important in the identification of the triplets and mosaic triplets.

Key words: Mosaic, Opal, Opal Essence, Opalite, Plastic, Triplet

Introduction

In the late 1970s and early 80s reports were published (Horiuchi, 1978 and 1982) concerning the introduction of a new opal simulant. This simulant, which has in latter years been marketed as 'Opalite' (Koivula and Kammerling, 1989), may be described as a plastic imitation of opal in which the play-of-colour is caused by the same mechanism as that which causes the visual effect in natural opal (*see for example* Nassau, 1980).

The 1993 AGTA Tucson Gem Show saw the introduction of a new production of 'Opalite' made in Japan (Koivula and Kammerling, 1989, report a US marketing effort at that time and state that it was also being promoted as 'Opal Essence'). Further, the company displaying the new production, Universal Canal Jewelry, also produced doublets, triplets and mosaic triplets made by making use of thin layers of the same material.

Whilst there are no difficulties in terms of differentiating between the 'Opalite triplet' (or indeed any other triplet) and natural solid opal, problems are forecast for the separation of the new composite with plastic imitation opal from the natural opal triplets. The following report outlines in a brief format (for comparison with the triplet material) the properties of two samples of the new Opalite production obtained at the 1993 AGTA show and in a more detailed format, the properties of six Opalite triplets and four Opalite mosaic triplets provided for research by Universal Canal Jewelry.

Working methods

During the examination of the new production of 'Opalite', as well as the triplets and mosaic triplets assembled from this material, priority was given to basic gemmological testing techniques that might produce simple identification criteria. The instrumentation used was limited to the GemoLite microscope, standard refractometer, ultraviolet lamps, plus sectility and thermal reaction testing equipment.

Standard microscopic observations were made using a GemoLite microscope at magnifications of between 10 and 60x. A variety of illumination techniques were used including darkfield, brightfield (diffused and transmitted) and variable incident lighting through an optical fibre.

A GIA GEM Instruments Duplex II refractometer was used to obtain both 'distant vision' refractive indices (from curved surfaces) and normal flat surface readings from the bases of cabochons. The GIA GEM Instruments Thermal Reaction Tester was used on setting '90' and the reactions observed under magnification with the microscope.

A non-standard variation in the use of the equipment was employed in the observation of the *'detail'* of the luminescence effects. A GIA GEM dual long-wave/short-wave ultraviolet lamp was placed in the position normally occupied on the GemoLite by the standard double tube overhead fluorescent light. Observations were made in a 'darkroom' at magnifications of between 10 to 30x, after the observers eyes had become dark adapted (1 to 2 minutes). The effects were otherwise observed in the standard 1:1 at approximately 12 inches distance, but again in a darkroom with dark adapted eyes.

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Fig. 1. Two Opalite samples, illustrating the different sizes/appearances the colour patches may show. *Photo by Maha DeMaggio.*

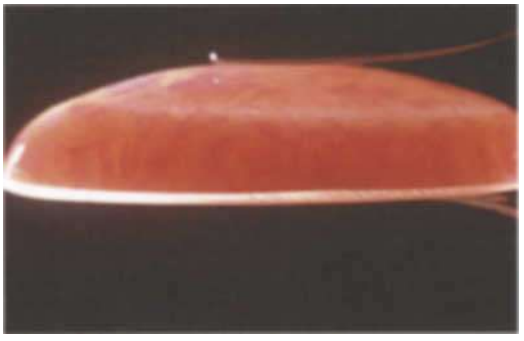

Fig. 2. This edge-on view of a solid Opalite cabochon in transmitted light clearly reveals the transparent colourless coating on the base. Note also the material's salmon pink body coloration when so illuminated with islands of deeper colour. 7x. *Photo by John I. Koivula.*

Opalite

Since the CSIRO concluded their investigations in 1964 (Jones *et al.*, 1964) and the true cause of the play-of-colour in opal became known, several attempts have been made to synthesize or imitate the 'opal effect'. By the mid 1970s Pierre Gilson had produced his 'synthetic opal' (Liddicoat, 1974; Jobbins *et al.*, 1976; Scarratt, 1986) and by the end of the decade an all-plastic 'play-of-colour' material, 'Opalite', had been produced (Horiuchi, 1978).

The two examples of the latest production of Opalite obtained at the 1993 Tucson Gem Show, and described here, are similar in their characteristic features to those described for the 1988 production by Koivula and Kammerling (1989).

The two samples, which closely resemble natural white opal, or more particularly the Gilson synthetic white opal, in general appearance, are of similar size, 3.70ct (19.22 x 14.12 x 3.93mm) and 3.84ct (19.2 x 14.35 x 4.21mm),but were chosen for their slightly differing structural appearance. The 3.70ct example displays mostly small pin-point colour segments whilst the 3.84ct example displays broader colour segments (Figure 1).

Both samples are perfectly oval with good proportions and, contrary to the appearance of natural opal which is cut with weight as an important consideration, the backs are flat and free from any indentations, cavities, etc.

Both display irregular columnar structures when viewed in profile (Figure 2) and, as previously reported, show what appears to be a clear layer 0.4mm in depth on their bases (see also Figure 2). Upon closer examination the clear coating on the 'base' is revealed to be one that covers the entire surface of the 'opal effect' layer. Figure 3 shows that when the examples are viewed 'base on' a clear rim, similar in proportions to the layer seen across the base in profile, is seen (cf Figure 2). Also, when viewed from the top,there appears to be a significant clear portion which has to be 'focused through' before the play-of-colour portion is reached.

Under magnification and in reflected light (directly overhead and at approximately 90° to the

Fig. 3. When viewed base-on and illuminated with horizontal fibre-optic illumination, this Opalite cabochon reveals the thickness of the clear coating covering its upper surface. 7x *Photo by John I. Koivula.*

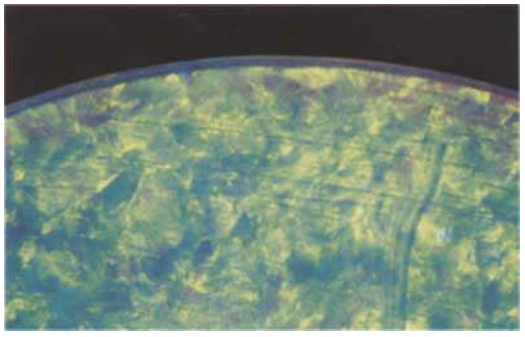

Fig. 4. The cracked or 'dried mud' structure - also referred to as the 'honeycomb' appearance - of the Opalite is seen here when examined in transmitted light down the length of the columnar structure. 20x. *Photo by John I. Koivula.*

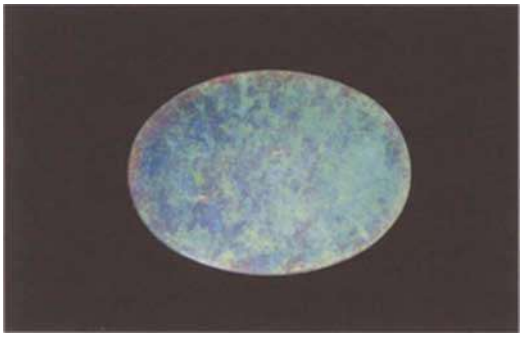

Fig. 5. A brightly reflecting, green metallic 'foil-like' effect is noted here when viewing the flat base of this Opalite cabochon using overhead illumination. *Photo by Maha DeMaggio.*

Fig. 6. The six Opalite triplets examined in this investigation. *Photo by Maha DeMaggio.*

surface of the specimen), the colour segments appear to change through blue, green and orange. The blue and green colours have a dull two-dimensional appearance whilst the orange, which may be mixed with yellow, has a bright three-dimensional appearance. In brightfield illumination and viewing directly through the top of the cabochon, the basic overall colour is an orange-yellow with islands of pink contained within structures that may be described alternatively as having the appearance of 'cracked and dried mud' or a 'honeycomb structure' (Figure 4). When viewed through the side, again in transmitted light, the overall colour is of a salmon pink that contains deeper pink islands.

An unusual feature is seen principally when the flat back of the cabochon is viewed. As the cabochon is moved slowly in reflected light, a brightly reflecting green layer with a metallic foil-like appearance becomes evident (Figure 5). To some extent, this 'foil-like' effect may be observed in the top of the cabochon as a stripe moving across the top as the specimen is rocked.

Whilst the overall face-up colour-effect in these plastic imitations is blue in either incandescent or fluorescent overhead light, when the cabochons are rocked so that the view becomes close to 'edge-on', the colour effect is predominately orange. Thus far, the authors have not noted a similar effect in natural white opal.

The refractive index, determined both by the distant vision and flat contact techniques, was found to be 1.50. The SG was determined by hydrostatic weighing as 1.17 . Under long-wave ultraviolet light the specimens fluoresced a strong bluish-white, with the acrylic on the base (where it is most distinctive) reacting more strongly than the remainder of the cabochon. No phosphorescence was observed. The specimens were also found to be easily sectile and melted in contact with a 'hot point'.

In order to make the comparison with previous productions complete, the infrared spectrum of the latest production was taken. The resulting curve was found to be similar to those previously published (see Koivula and Kammerling, 1989, Figure 5).

Fig. 7. Examined with horizontal fibre-optic illumination, the bright edges of bubbles both above and below the Opalite layer are noted. 10x. *Photo by John I. Koivula.*

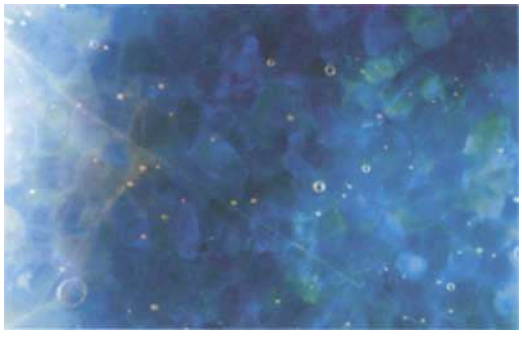

Fig. 8. The three-dimensional pinpoint (or pinfire) colour segments of the Opalite layer in this triplet display a characteristic 'brush stroke' or 'ploughed field' effect. 10x. *Photo by John I. Koivula.*

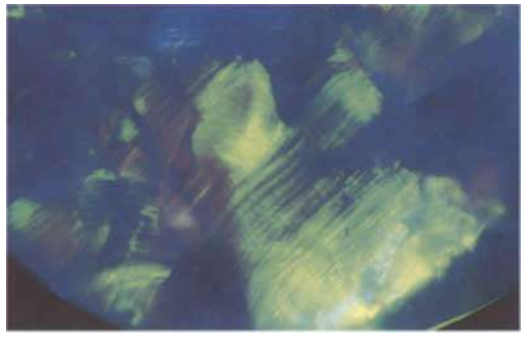

Opalite triplets

Six Opalite triplets (Figure 6) were examined for general appearance, microscopic clues to identification, refractive index, UV fluorescence, hot point reaction and sectility. The specimens ranged from 1.77 to 2.03 ct.

Appearance

When viewed from the top and without magnification the Opalite triplets have a similar appearance to natural or synthetic opal triplets in that one appears to be looking through a 'lens' at the 'opal' layer below. The phenomenal colours seen are mainly blue to green and these change as the stone is moved ('roll over') as might be expected for natural or synthetic opal. A side view reveals an unusually thick (compared with what might be expected for a natural opal triplet) layer of Opalite (0.40 to 0.80mm) under a colourless dome of a slightly greater circumference and above a black base of lesser proportions. It should be noted that not all the Opalite layers were of a uniform thickness; rather, in several specimens these were wedge shaped.

Microscope

The specimens were chosen for their variation in colour segment size and type (see Figure 6). Observed under low magnification (15x) and in reflected light, the basic appearance is again similar to that which is expected for a natural or synthetic opal triplet. However, because of the high nature (2.4 to 2.5mm) and lens-like rounding of the dome as well as its somewhat greater circumference than the Opalite layer, the play-of-colour towards the edges appears 'blurred' by internal reflections (see Figure 6). Bubbles are clearly visible in the junction layers and these stand out with 'bright' edges in horizontal fibre-optic illumination (Figure 7).

As with the whole Opalite specimens, the colour of each segment changes through blue, green and orange, but unlike the whole Opalite each of the colours and segments in the 'pinpoint segment' type have a three dimensional appearance. Some colour segments in the 'pinpoint' type revealed the 'ploughed field' or 'brush stroke' effect (Figure 8) seen in some natural opal, but this was not generally the case. On the other hand this effect was very evident in the Opalite triplets with the larger colour segments.

Upon focusing through the Opalite layer to the junction below, a metallic 'foil effect' similar to that described for the whole Opalite, seemed to be present in small areas, but with generally a mauve colour. The base, whilst appearing black, is translucent and grey with a multitude of included black spots. As with the whole Opalite the slice present in the triplet appears as an overall 'salmon pink' with deeper pink islands when viewed side-on in transmitted light (Figure 9). The junction adhesive layers above and below the Opalite layer have a similar appearance to each other and are probably the same substance.

Refractive Index

Distant vision readings for the dome of the triplet produced a reading in the region of 1.50, which is the same as that recorded for the Opalite itself, whilst the readings from the flat backs revealed readings of 1.49. In the authors' experience these are within the ranges of the glass and plastic substances sometimes used to produce colourless caps and black backs for natural opal triplets. However, conclusive identification of these materials was not carried out.

UV Fluorescence

The six triplets were examined under both long-wave and short-wave ultraviolet light for possible fluorescence and phosphorescence reactions. Under long-wave, the only part of the triplet that could be said to fluoresce is the adhesive in the upper and lower junctions. Here the adhesive layers have a bright blue fluorescence which is followed by a distinctive mottled yellow-green phosphorescence when the ultraviolet light is turned off. This effect is best seen under magnification as misinterpretation may result from 1:1 observation (i.e. when viewed through the dome, as will be the case when the stone is set), the same bright blue fluorescence will be seen as well as the continuing mottled phosphorescence, as appearing (incorrectly) to come from the 'opal' or 'Opalite' layer. Note: to obtain the phosphorescence reaction, this material must be held close to the UV lamp (25-50mm) for a minimum of 30 seconds.

Under short-wave ultraviolet light the adhesive layers fluoresce similarly to the long-wave effect, but of a lesser intensity. Under this wavelength there is no perceptible phosphorescence. The colourless dome fluoresced with a yellow/chalky effect of a moderate strength under this wavelength.

Thermal reaction/sectility

With the prior knowledge that we were dealing with a plastic opal-like material, it was decided to carry out two potentially destructive testing procedures under controlled conditions. These were the point reaction to heat of the various compo-

nents of the triplets and also the ability of the various parts to 'peel' when a sharp blade is applied.

Both the base and the Opalite layers were found to be easily sectile - the base slightly more so. When the probe of the thermal reaction tester was placed lightly on a small portion of the exposed area of the Opalite layer, the part touched was found to melt very quickly. The same test on the black base layer revealed that this portion of the triplet melted extremely quickly and on a par with what might be expected if the material were a wax candle. The transparent colourless dome was found to be neither sectile nor did it react to the thermal reaction tester.

Opalite Mosaic Triplets

Two oval Opalite mosaic triplets (Figure 10) were examined and compared with a single natural opal mosaic triplet also obtained at the 1993 Tucson Gem Show. The sizes of all three samples were similar: the natural mosaic measuring 17.99 x 13.05 x 3.8mm and weighing 6.63ct, and the Opalite mosaics measuring 16.5 x 12.49 x 5.15 and 16.45 x 12.3 x 4.91mm and weighing 6.79 and 6.13ct respectively. Each specimen was examined for general appearance, microscopic clues to identification, refractive index, UV fluorescence, hot point reaction and sectility.

Appearance

When viewed from the top and without magnification the Opalite mosaic triplets were similar in appearance to the natural opal mosaic triplet. The sectional nature of the opal or Opalite mosaics can be seen clearly, and without magnification, through the transparent colourless domes. Also clearly visible without magnification are the shapes of the various sections of the mosaics. In the case of the Opalite these could be seen as being triangular whilst in the case of the natural opal the shapes are more irregular, i.e. truncated triangular and trapezoid generally with chipped and rounded points.

As with the Opalite triplets discussed earlier, the colours seen in the Opalite mosaics are mostly blue to green and the 'roll-over' effect is similar to that which occurs in the natural opal mosaic specimen. However, the colours of the natural specimen, whilst tending to have a greater presence of orange/red, were a little duller in appearance.

When viewed side-on the Opalite mosaics revealed a somewhat thinner section of Opalite than is used in the Opalite triplet and the thickness is also variable as the cabochon is turned (from 0.3 to 0.4mm), but is of a similar thickness to the opal used in the natural opal mosaic triplet (the latter varying from 0.3 to 0.4mm). However, the curvature of the clear dome on the natural mosaic triplet begins more closely to the opal layer than it does for the Opalite mosaic triplet, which has a steep rise before the curvature begins (Figure 11). Both the natural opal and the Opalite mosaic triplets have black material bases but the base of the natural is somewhat thinner than in the Opalite assemblage.

Microscope

Observed under low power (15x) magnification, and in reflected light, both the natural opal and the Opalite versions of the mosaic triplets reveal substantial gaps between the mosaic sections in which can be seen the clear adhesive and bubbles therein. It is also confirmed that the mosaic sections in the natural version vary more in their shape than do those in the Opalite version, all of which are triangular with truncation only occurring at the edges of the triplet.

The mosaic sections used in the Opalite version appear to have been selected from the type of Opalite in which the colour segments are wide rather than the pinpoint type and, as a result, the 'ploughed field' or 'brush stroke' effect is evident in most of the sections (Figure 12).

The blurring of the edges observed in the Opalite triplets does not seem to be as great a factor in the Opalite mosaic version. This is probably due to the differing profiles of the domes of each type. The triplet being more rounded and having a greater 'overhang' beyond the outer edge of the Opalite layer, in comparison with the mosaic version.

The sections in the natural opal mosaic, as might be expected, are made from a variety of types (from the pinpoint play-of-colour to wider colour patch versions (Figure 13)), and many individual sections may also contain included matrix material.

In transmitted light the natural opal version loses virtually all of its play-of-colour effect and the near transparent and grey (rather than black) nature of the base is revealed (Figure 14). In this situation the bubbles in the adhesive layers stand out with black rims. Due to the greater opacity of the backing, in contrast the Opalite version appears much darker and still exhibits much of its play-of-colour.

Refractive Index

Distant vision refractive index measurements were recorded for the domes and direct refractive

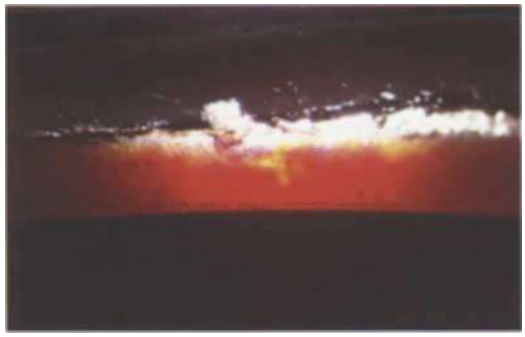

Fig. 9. The salmon pink transmitted-light appearance of Opalite is clearly seen in the triplets as well when viewed side-on. 7x. *Photo by John I. Koivula.*

Fig. 10. The two Opalite mosaic triplets examined in this investigation. *Photo by Maha DeMaggio.*

index readings were taken from the bases of both the natural opal and Opalite versions of the mosaic triplets. For the Opalite version the RI of the dome was found to be 1.51 and the base 1.49, whilst for the opal version the dome was found to have a refractive index of 1.52 and the base 1.53.

Fluorescence

The two Opalite mosaic triplets and the natural opal mosaic triplet were all examined for their reactions to ultraviolet light.

In common with the Opalite triplets, under long-wave ultraviolet light the adhesive layers of the Opalite mosaic triplets were found to have a bright blue fluorescence which was followed by a distinct phosphorescence. This effect is best seen under magnification when the true nature of the fluorescence and the phosphorescence, i.e. coming from the adhesive rather than the Opalite, can be seen.When viewed through the clear dome with the unaided eye (1:1), the fluorescence effect of one of the Opalite versions appeared to be coming from between the Opalite mosaic sections, i.e. from the adhesive, but the other sample appeared to show an overall effect, probably due to the fact that its upper adhesive layer is thicker.

Under short-wave ultraviolet light the transparent domes of the Opalite versions fluoresced with a 'chalky' appearance which interfered with any effect the adhesive or Opalite might have. However, the sample with the thicker upper adhesive layer phosphoresced (from the adhesive) whilst for the sample with the thinner layer no phosphorescence was seen.

The reaction of the natural opal mosaic triplet was as could be expected from a material made with a natural 'white' opal component (see Jobbins *et al.*, 1976). Under long-wave ultraviolet light, viewed from the side, the upper adhesive layer fluoresced as with the Opalite version. This was also confirmed when the triplet was viewed through the clear dome, when the fluorescence of the adhesive could be seen in between the opal sections (Figure 15). However, and as can be

Fig. 11. When examined from the side, the two Opalite mosaic triplets on the right are seen to have thicker colourless caps than does the typical natural opal mosaic triplet, as illustrated by the one assemblage on the left. *Photo by Maha DeMaggio.*

Fig. 12. As seen here, magnification reveals the typical 'brush stroke' or 'ploughed field' appearance of some of the chips in this Opalite mosaic triplet. Note also the very sharp edges of the individual chips as compared with those of the natural opal mosaic triplet shown in Figure 13. 7x. *Photo by John I. Koivula.*

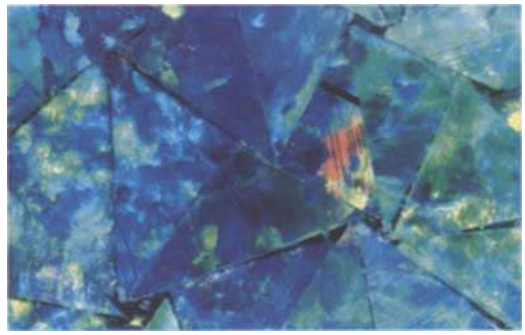

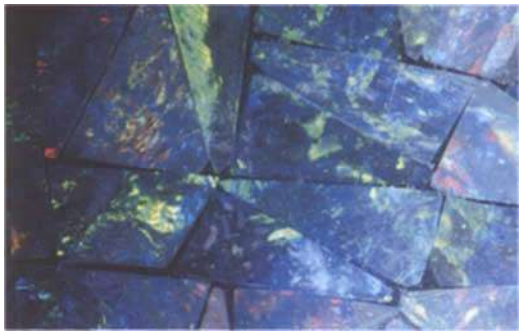

Fig. 13. Careful observation reveals the varying phenomenal colour types in the opal typically used to produce natural opal mosaics. Note also the blunted and other irregular terminations to the individual opal fragments. 7x. *Photo by John I. Koivula.*

expected with white opal, it was noted that the opal sections also fluoresced and when examined under magnification the distinct phosphorescence effect, which could be seen at 1:1, was found to come from the opal sections rather than the adhesive between them.

Thermal reaction/sectility

Only the adhesive layer of the natural opal mosaic triplet reacted to the thermal reaction tester in that it melted at the point of contact. In the case of the Opalite assemblage, however, both the base and the Opalite layer melted at the point of contact - the base extremely fast and on a par with a wax-like substance.

The transparent domes of the Opalite assemblages were found to have no reaction to the thermal reaction tester and nor were they sectile. However, both the Opalite layer and the base were found to be sectile, the base more so that the Opalite. The natural opal version was found to be non-sectile apart from the adhesive layer.

Fig. 14. The same natural opal mosaic triplet illustrated in Figure 13, seen here in transmitted light. 10x. *Photo by John I. Koivula.*

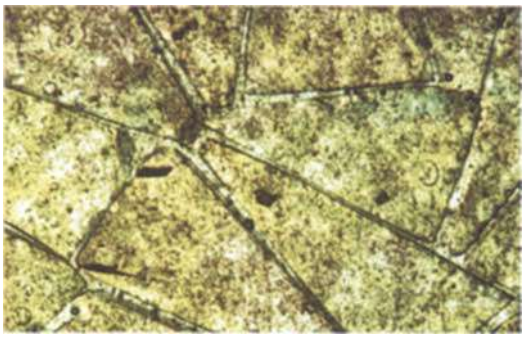

Discussion

The authors hope that the foregoing report assists, first in warning gemmologists of the presence of Opalite triplets and mosaic triplets on the market and, secondly, in giving some basis for their identification. However, in the discussion below it should be remembered that it is the nature of 'composite' stones and particularly those composed of natural opal, that the components may and do vary (differing types of opal, adhesive, backing and domes) from those discussed here (see Anderson/Jobbins, 1990; Nassau, 1980).

The reportedly new production of Opalite is similar to, if not the same as, previous productions and reference should be made to Koivula and Kammerling (1989) for useful identification features. However, the observation of the clear plastic/acrylic layer which covers the entire surface of the Opalite cabochon, together with the refractive index of 1.50 (cf. natural opal - at 1.44) and lack of phosphorescence (white opal usually phosphoreses strongly) should be sufficient to identify the material, particularly when set in jewellery. If the flat back of the Opalite is visible through a setting, observation of the green foil-like flash should also indicate that the substance is not natural opal, although similar effects have been noted with synthetic opal. Any damage marks on a suspect stone, such as chips and sharp edged scratches, would tend to indicate a natural or synthetic stone rather than the plastic imitation, where damage would have a much softer or smoother appearance.

The Opalite triplets and mosaic triplets create a number of problems for the unwary. The clear domes are made of a material (most likely clear glass) sometimes used for natural opal triplets and the Opalite structures seen through the dome are

Fig. 15. A natural opal mosaic triplet under long-wave ultraviolet radiation. Note the fluorescence of the adhesive between the opal sections. Under this magnification phosphorescence is seen to come from the opal sections and not the adhesive - the reverse was the case for the Opalite mosaic triplets. *Photo by John I. Koivula.*

similar to those observed in natural opal. However, such natural opal layers may contain matrix material which should not be present in Opalite or mosaic Opalite layers. The Opalite layers in the Opalite triplets were also noted to be somewhat thicker than might be expected for the opal in a natural opal triplet, an observation that would be particularly useful when examining loose stones.

The natural opal mosaic triplet examined for comparison purposes was produced from irregularly-shaped pieces of opal whilst the Opalite version was made from essentially all triangular pieces. A useful identification technique is the observation of fluorescence and phosphorescence effects under magnification. During this investigation it was found that the adhesive used in the Opalite mosaic type phosphoresced whilst the Opalite did not, whereas in the natural opal version the opal phosphoresced whilst the adhesive did not or was not perceptible positioned next to the opal sections. This observation would also apply in the case of the triplets if white opal were used in the natural version.

Whilst destructive testing is not recommended, the observation of the surface area of the wax-like base of the Opalite triplets as a 'hot point' is brought close, will undoubtedly reveal a movement of the surface even before contact is made.

Undoubtedly, gemmologists must now be far more critical in their examination of assembled stones which appear to include opal as one of their components. Those which are set in closed back/bezel settings will be particularly difficult to identify.

Acknowledgements

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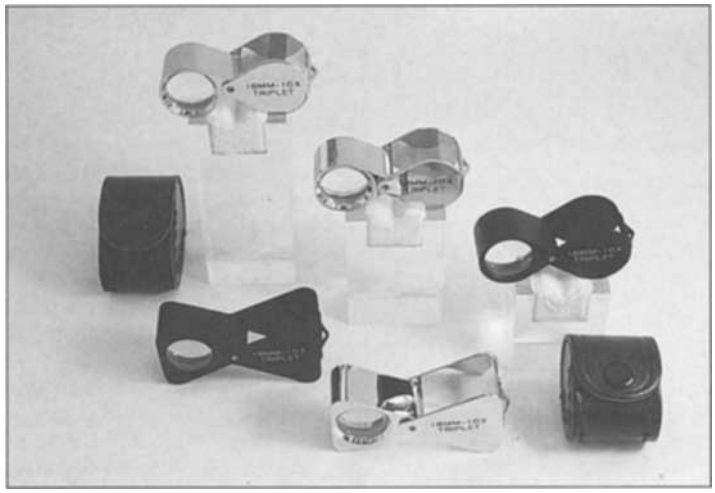

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The first occurrence of musgravite as a faceted gemstone

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Abstract

Two pale greyish-mauve faceted stones (weighing 0.30 and 0.37 ct), described as 'taaffeite', very probably from Sri Lanka, show X-ray diffraction data which are in entire agreement with musgravite, a rare beryllium-magnesium-aluminium oxide related to taaffeite but not identical with it, and which has never been found previously in nature in gem quality. Apart from the colour, which seems to be paler than for most taaffeite specimens, and with a greenish cast, the physical properties of musgravite are not sufficiently different from those of taaffeite to permit distinction between the two species using traditional gemmological equipment; here X-ray diffraction seems to be essential for reliable identification.

Introduction

Taaffeite and related minerals were considered as extremely rare stones until about a decade ago, when the number of positively identified specimens in public and private collections was of the order of twenty (Anderson *et al.*, 1951; Kampf, 1991).

In the 1950s one of the authors (C.M.G.) was little more than a boy and on visiting London he had the opportunity of seeing one of these stones exhibited in the 'new acquisition' glasscase of the British Museum (Natural History), together with sinhalite. Needless to say, having a taaffeite specimen was considered as a very remote (and rewarding) possibility by a private collector and in particular it has been a kind of 'youth dream' for some of us.

Around 1980, a bright red stone of about 1 carat in weight was sold as 'red taaffeite' to Dr E. Gübelin by a gem dealer in Sri Lanka; the physical properties of this stone were almost identical with those of taaffeite, but the colour was quite unusual. A detailed investigation on this stone was carried out by Moor, Oberholzer and Gübelin (1981); mainly on the grounds of chemical analysis and crystal-structure determination, these authors ascribed the stone to a new mineral species, 'taprobanite'. However, the supposed differences between taaffeite and 'taprobanite' were shown not to be real, mainly because of an error in the chemical formula originally proposed for taaffeite (Schmetzer, 1983a; Nuber and Schmetzer, 1983); therefore, in spite of its better characterization, 'taprobanite' was discredited by the Commission on New Minerals and Mineral Names of the International Mineralogical Association in favour of taaffeite, because of priority (Schmetzer, 1983b).

In the last few years (McDowell, 1984; Kampf, 1991; Jarry *et al.*, 1992; Gunawardene, 1984a,b) taaffeite gem specimens have been found in considerable number (exceeding 1000) in several localities in Sri Lanka, and also from at least one locality in Burma (Spengler, 1983). In Sri Lanka a zincian variety with relatively high refractive indices and density has also been discovered (Schmetzer and Bank, 1985), and a second specimen of the very rare red variety has been found quite recently (Koivula and Kammerling, 1991).

Some taaffeite crystals have been preserved in their natural state, as waterworn hexagonal prisms with different terminations at each end of the sixfold axis, in agreement with their crystallographic symmetry (polar point group 6mm): in at least one case goniometric measurements could be carried out (Saul and Poirot, 1984; Kampf, 1991).

In May 1992, Dr Domenico Nicita, a friend of the authors and a gem dealer, showed us a brilliant-cut stone which had been identified as 'taaffeite' and whose origin was thought to be Sri Lanka. This stone is rather small (0.30ct in weight) and its colour is a pale greyish-mauve with faint but definite change to light mauve on passing from daylight to artificial light, similar to what happens in some taaffeite specimens (Bank and Henn, 1989); the colour is however definitely paler than for most taaffeite specimens.

Following our interest in rare stones and beryllium minerals, and in particular for taaffeite, one of the authors (C.M.G.) bought it for his collection, planning to check it adequately, as for all unusual stones in general.

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Experimental results

The physical properties of the first stone studied by us are reported in the first column of Table 1: they show close analogy with those of taaffeite, to the point that using ordinary gemmological equipment the stone could indeed be classified as 'taaffeite'. However, because of the peculiar colour, we wanted to complete our investigation using X-ray diffraction. For this purpose a four-circle single-crystal X-ray diffractometer was employed without difficulty, in spite of the large size of the specimen (Pilati *et al.*, 1988).

The unit-cell data obtained using a Enraf-Nonius CAD4 diffractometer are reported in

Table 1: Physical data for taaffeite-group minerals

	Musgravite[1] *first stone*	*Musgravite*[1] *second stone*	*Musgravite Australia*[2]	*Musgravite Antarctica*[3]	*Musgravite Greenland*[4]	*Pehrmanite-18R Finland*[5]
Weight (ct)	0.30	0.37				
Lattice	Hexagonal-R	Hexagonal-R	Hexagonal-R	Hexagonal-R	Hexagonal-R	Hexagonal-R
a (Å)	5.665(3)	5.670(1)	5.675(2)	5.6804(2)	5.687(2)	5.70
c (Å)	41.07(3)	41.019(7)	41.096(5)	41.104(2)	41.16(2)	41.16
Extinction rule:	hkl: -h+k+l=3n	hkl: -h+k+l=3n	hkl: -h+k+l=3n	hkl: -h+k+l=3n	hkl: -h+k+l=3n	hkl: -h+k+l=3n
ω	1.726(1)	1.725(1)	1.739(2)			mean index 1.79
ε	1.720(1)	1.719(1)	1.735(2)			
Optical charact.	uniax.(-)	uniax.(-)	uniax.(-)		uniax.(-)	uniax.(-)
Density (g/cm³)	3.64	3.62	3.68			4.07

	Taaffeite-8H Sri Lanka	*Taaffeite*[1]	*Taaffeite*[1]	*Taaffeite*[1]	*Taaffeite*[1]
Colour		mauve	pink	mauve	mauve
Weight (ct)		0.39	0.45	0.63	0.84
Lattice	Hexagonal-P	Hexagonal-P	Hexagonal-P	Hexagonal-P	Hexagonal-P
a (Å)	5.684(1)[6]	5.685(3)	5.685(2)	5.686(3)	5.687(1)
c (Å)	18.332(7)[6]	18.332(7)	18.314(4)	18.313(4)	18.325(5)
Extinction rule:	hhl: l=2n	hhl: l=2n	hhl: l=2n	hhl: l=2n	hhl: l=2n
ω	1.721-1.724(2)[7] zincian 1.730(1)[8]	1.725(2)	1.722(2)	1.726(2)	1.726(2)
ε	1.717-1.720(2)[7] zincian 1.726(1)[8]	1.719(2)	1.718(2)	1.720(2)	1.721(2)
Optical charact.	uniax.(-)	uniax.(-)	uniax.(-)	uniax.(-)	uniax.(-)
Density (g/cm³)	3.59-3.62[7] zincian 3.71(2)[8]	3.63	3.62	3.65	3.63

Sources: 1. Present work 2. Hudson *et al.*, 1967 3. Grew., 1981 4. Chadwick *et al.*, 1993 5. Burke and Lustenhouwer, 1981 6. Moor *et al.*,1981 7. Range of values reported in the literature 8. Schmetzer and Bank, 1985. For our samples the refractive indices have been measured using a total refractometer with sodium light (569 nm); the density has been determined using a hydrostatic balance.

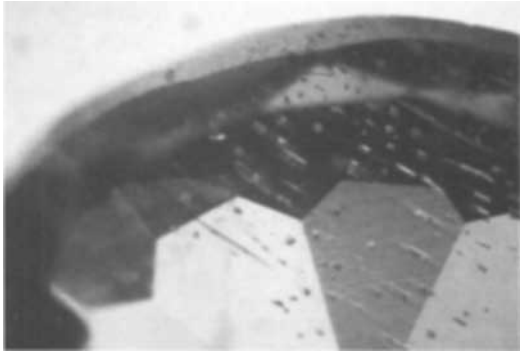

Fig. 1. Inclusions in musgravite, first stone, reflected light (50x).

Table 1, together with the corresponding results obtained by other authors for minerals of the taaffeite group. On comparing our crystallographic data with those of the other minerals, it is clear that the gem is not taaffeite, but it should be ascribed instead to musgravite, a closely related but distinct species.

Musgravite is indeed very similar to taaffeite, although it has never been found in gem quality specimens previously. It was first discovered in the Musgrave Range, Australia (Hudson *et al.*, 1967) and it was considered to be only a polytype of taaffeite ('taaffeite-9R'); later a second occurrence was found in Antarctica (Grew, 1981) and using material from both these localities the crystal structure of musgravite was established with good accuracy and compared with that of taaffeite (Nuber and Schmetzer, 1983). From this study, the chemical formula of these two phases were shown to be different ($BeMg_2Al_6O_{12}$ and $BeMg_3Al_8O_{16}$, respectively); therefore, the two minerals are not polytypes in the strict sense but are polytypoids, and the distinct name of musgravite could be assigned to the rhombohedral modification. Meanwhile, pehrmanite, the iron equivalent of musgravite, was discovered in Finland (Burke *et al.*, 1981), but the crystals are very small and of no gemmological interest. A very recent discovery of musgravite has been made in Greenland (Chadwick *et al.*, 1993).

Fig. 2. Inclusions in musgravite, first stone, transmitted polarized light (50x).

Consequently, it seems that some of the supposed 'taaffeites' on the gem market which in all probability come from Sri Lanka are actually musgravite. Following our discovery, five additional stones were obtained by courtesy of Dr Nicita: four show unit-cell data virtually identical with those of taaffeite and one is musgravite. These data and their physical properties are also reported in Table 1.

On account of these results, musgravite seems therefore to be rarer than taaffeite. As we have said, the colour of the 'true' taaffeite stones we have examined is in all cases deeper than that of musgravite, ranging from a decided rose to mauve, sometimes with a distinct colour change on passing from daylight to artificial light, whereas musgravite is paler with a more decided greenish cast; however, two stones only are not very significant statistically, and on this basis the existence of darker musgravite cannot be excluded. In his works on taaffeite (1984a,b), Gunawardene lists a number of occurrences in Sri Lanka, and only one locality (Balangoda) seems to provide nearly colourless stones; this might be an interesting point to follow up.

Since the point-group symmetry of musgravite is $\bar{3}m$ and that of taaffeite is 6mm, the crystal habit should be appreciably different in the two cases. For instance, most of the pictures and the drawing published by Kampf (1991) of crystals from Sri Lanka clearly show polar symmetry, since they are clearly pyramidal; on the other hand, musgravite is centrosymmetric and its crystals should be equally terminated at both extremities, like corundum. This is confirmed by the crystal shape of the musgravite found in Greenland, which is clearly rhombohedral (see Figure 2 in Chadwick *et al.*, 1993)

On examining the stone with the immersion microscope, the pavilion shows swarms of polyhedral birefringent inclusions (see Figures 1-2), which are in association with disc-shaped groups of smaller, possibly two-phase inclusions. The crystalline inclusions, which are protogenetic in nature, are grouped along parallel planes and can be ascribed to alternation of two different minerals: the former appears as brown tabular crystals and is with all probability identical with phlogopite, which has been already identified with certainty in taaffeite inclusions by Gunawardene

(1984); the latter mineral forms bipyramidal crystals with high interference colours between crossed polarizers. Like the original taaffeite specimens, the mineral is neither fluorescent under shortwave (254nm) nor longwave (365nm) ultraviolet radiation.

The optical absorption spectrum, examined through a direct-vision prism spectroscope, shows a weak absorption band centred at 475nm.

Conclusions

Our observations show that some of the gemstones sold as 'taaffeite' may be of a much rarer mineral, musgravite, the presence of which has never been noticed so far in the gem fields. It would be interesting to have some material of absolutely certain origin, not only to confirm the country of origin, but also to know whether these stones are actually found together with taaffeite (as seems quite probable), or they come instead from another locality.

Acknowledgements

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Diamond replicas - possible but just

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Abstract

The author describes some of the problems encountered when making models or replicas of famous diamonds.

This paper is about replicas of some of the world's most important diamonds and the problems of making them, so perhaps I should start off by saying what a replica is and what it is not. For this we have to make a distinction between a replica and a model.

When a cutter gets a very large diamond rough, one of the first things he does is make models of it. Nowadays this modelling can be done on a computer but when, for example, in 1935 Lazare Kaplan received the 726 ct diamond rough called the Jonker he made real models of the stone. The models were then cut in various ways to decide the best way in which to saw and cleave the diamond. The result was an amazingly accurate prediction of what he would get out of the actual cutting (see Balfour, 1992).

In such cases, of course, the absolute accuracy of the model is of paramount importance. They can be made of many materials. A model of the rough for the Regent diamond in the Natural History Museum in London, for example, is made of lead.

Sometimes, however, we are concerned with the appearance of a cut stone and while ideally we would like to have the same exactness as a 'model', generally this is not possible. Very few diamonds have been studied with the exactness necessary and, as we shall see, even when a certificate from a testing laboratory has been issued it is woefully inadequate for the real model maker. One can only concentrate on making the stone *look* as much like the original as possible. These I call 'replicas'.

One of the earliest models/replicas of a cut diamond to which I have found a reference was that presented to the Natural History Museum in London by the famous (infamous?) British mineralogist, James Gregory. (Gregory had reported that no diamonds would ever be found in South Africa and any that were had obviously been dropped there by ostriches!)

The 'replica' that Gregory presented at the turn of the century was of a stone called the Pigot, which has now disappeared. George Pigot had brought the rough back to England in about 1770 and after his death his heirs continued to try to sell it. At some 48 ct it was one of the largest - and hence most expensive - diamonds in Europe at the time. No buyer could be found and in 1800 the British Parliament gave permission for the family to dispose of it by lottery. The diamond finally got into the hands of Rundell and Bridges, the Crown Jewellers, who did not find a buyer until 1822.

When trying to sell a large diamond it was the custom to make 'models' of the stone to show potential customers and it was one of these 'models' that Gregory had presented to the Natural History Museum. In the best traditions of modern advertising 'hype', the more desperate Rundell and Bridges became to sell, the bigger these 'models' became. Anyone taking measurements from Gregory's 'model' would have assumed the diamond weighed 93.30 ct!

The sad end to this story was that, when the purchaser of the Pigot, Ali Pasha, realized that he was dying, he ordered that the two things he loved most in the world - his wife and his diamond - should not out-last him. The diamond was destroyed, but fortunately his wife was spared!

Much more in the nature of a replica is a glass copy of the diamond named the Dresden Green from the collection of Sir Hans Sloane, acquired by the Natural History Museum in 1753. The diamond had probably been cut in London and sold to Frederick Augustus II, Elector of Saxony and King of Poland, in 1741, but was almost certainly available for study when the replica was made.

Therefore the history of replicas of cut diamonds goes back at least 250 years. The earliest material was, of course, glass - hardly what one

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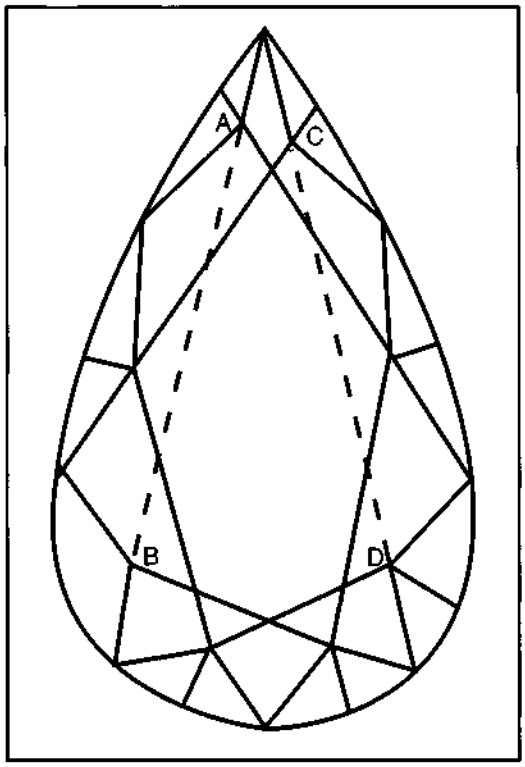

Fig. 2. The crown of a pear-shaped diamond; by making AB and CD straight the eye is carried to the point and the diamond made to appear slimmer and more elegant

would call a satisfactory diamond simulant. However, it was good enough at the time for the collection of diamond replicas made of glass on show at the Great Exhibition of 1851 to cause a considerable stir. Other materials that are still used are quartz, synthetic spinel and synthetic sapphire (also not exactly satisfactory simulants) and, further 'up market', yttrium aluminium garnet (YAG) and cubic zirconia (CZ), the most realistic of all and unlikely to be improved upon. If the material used for the replica does not have a sufficiently high refractive index, instead of light being bounced around the stone by total internal reflection and coming out of the crown, it will pass straight through the stone and out of the back. The stone will look dead, particularly in the centre, where it is acting like a window. This is why quartz (RI 1.55) can never be cut as a satisfactory diamond simulant. YAG (RI 1.83) and CZ (RI 2.15) are both much nearer to diamond (RI 2.41).

The replica of the Dresden Green referred to above was almost certainly made under the ideal conditions of having the original available to refer to. But so often one reads in the descriptions of large diamonds 'present whereabouts unknown' or 'stolen without trace', that for a replica maker like myself these ideal conditions remain only a dream. I do not expect anybody to send me their 80 ct diamond to study, even if I knew who to ask. For many reasons including security, insurance, tax and currency, most of these owners do not advertise their possessions.

The extremely high prices being paid recently for large diamonds have caused many of the old and famous diamonds, such as the Agra and the Tereschenko, to appear in the sales-rooms of Sotheby's and Christie's. The diamonds are then normally submitted to one of the major testing laboratories* for a certificate. Unfortunately these certificates are not always published in the sale catalogue and the laboratories take the view that these are confidential papers available only to the owner, even for historically important stones. Figure 1 shows what is missing for people such as myself, even when the certificate is published.

Fortunately the sale catalogues do provide life-size photographs of such diamonds which help to fill in much of the information missing from the certificate. They also help to supply what I call the 'design factors' of the cut - the ways in which the cutter has adapted the standard brilliant-cut to emphasize features he considers to be of importance.

Figure 2 illustrates this point better than words. Although this may look like a normal pear-shape crown, by making AB and CD straight the eye is carried to the point and the diamond is made to appear slimmer and more elegant. Bent lines would emphasize the 'roundness' rather than the length.

There are, of course, sources other than sales catalogues, and one which I cannot recommend highly enough for its illustrations and information is Lord Balfour's book *Famous diamonds*, a new edition of which has just appeared (1992). Unfortunately this book gives the dimensions of very few of the stones. For this information, there is no alternative to 'scattergun' research - it is buried in old books and journals and only weeks in museum libraries will find it. There is no bibliography or central source of information available.

Some famous stones have been studied, particularly by Herbert Tillander from Finland, and this information can quickly be found by a search through the indexes of the major gemmological publications.

However, the great time for writing about large diamonds was in the late 1800s when so many were being found in South Africa. (Sadly, a major

* in New York, Antwerp, Lucerne or London

Information given on a typical diamond grading report

SHAPE AND CUT	Cushion antique mod. brill.
Measurements	21.10 x 19.94 x 11.59 mm[1]
Weight	32.24 ct
PROPORTIONS	
Depth	58.1%[1]
Table	53%[2]
Girdle	Extremely thin to medium[3] faceted
Culet	Slightly large[4]
FINISH	
Polish	Good
Symmetry	Good
CLARITY GRADE	VS1
COLOUR GRADE	Fancy light pink[5], natural colour, whitish graining is present

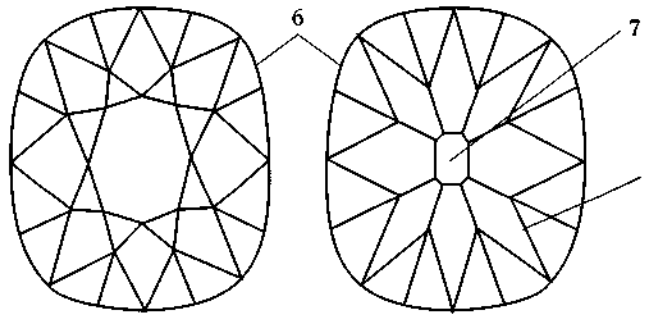

Explanation

1. This gives the total depth but not how much is above or how much is below the girdle.
2. This is a percentage of the width. The length of the table is not given.
3. How thick is 'medium' ? Slight extra thickness in the girdle can make a big difference to the weight.
4. Given how enormous some of the old culets were, this is hardly an exact description!
5. Colouring in diamonds can be very subtle and light colours can need a lot of imagination to see. No comparison stones exist. 'Fancy' here means only that the stone is a definite colour and not just 'off white'. (Although reports may grade yellow stones from K to Z, nowhere have I seen comparison stones for colours in this range. Also, this type of scale exists only for yellow diamonds and not for other fancy colours.)
6. This shape is indicative only. All pear-shapes, for example, would look the same in this section of a report. This is a standard stamp, not the shape of the stone.
7. In reality there may or may not be a culet and it may or may not be this shape.
8. This indicates only that there are girdle facets, not how long they are or if they are visible through the table.

Fig. 1. Information given on a typical diamond grading report with comments by the author.

find no longer generates the same excitement - perhaps there have been too many.)

An interesting area of what, perhaps, should be called reconstructions rather than replicas is the old French Crown Jewels. When the inventory was made the stones were pressed into wax. These impressions still exist and, thanks to Bernard Morel, many have been published. This information, combined with a knowledge of cutting of the time, has allowed a 'reconstruction' of the eighteen diamonds known as The Mazarins. They might not be up to the accuracy demanded of other replicas but for the first time people can have an idea of what these stones looked like.

Let us look at some of the situations that can arise:

(1) *All information available*
This is undoubtedly the rarest situation and I can think of only one instance when this almost applies. Kane *et al.* (1990) in their paper on the Dresden Green quote a different paper which gave the inclination and azimuth angle of most facets. (Some of the lower girdle facets could not be measured because of the setting.) Here one can obviously expect a high level of accuracy - a model rather than a replica.

(2) *Some angles available*
Typical are the Regent and the Wittelsbach, for both of which Tillander measured the angles of the mains. By making a replica with these angles correct and the facet diagram fitting the photograph, one can expect a very high degree of accuracy.

(3) *Photograph and certificate available*
This will give sufficient information to enable a replica to be made which is very realistic from the top but, as the certificate (see for example Figure 1) does not indicate how the depth is divided between the crown, girdle and pavilion, one cannot be totally sure about angles. There are various hints in the photograph and if the depth is unusual this can be built into the replica as, for example, the exceptional depth of the Premier Rose.

(4) *Photograph only available from a sales catalogue*
As many people buy on the strength of photographs in catalogues such as those produced by Christie's and Sotheby's, the auctioneers go to tremendous pains to make sure that they show the stones at the exact size. One can, therefore, measure their height and width. Calculations based on these dimensions and the weight give a fairly accurate value for the depth. As in (3) above, one can get a good 'face-up' replica (i.e. as when viewed through the table). What one sees should be very close to the original.

(5) *Line diagrams of correct size or dimensions given*
For stones not recently put up for sale or historical stones which have disappeared, replicas can be made from these details but one cannot have as much reliance on the accuracy of the dimensions. Typical of these is the Florentine, which was stolen from the Emperor of Austria after he went into exile in 1918 and has never been heard of since. This jewel is of great historical importance and had been recorded by that extraordinary diamond dealer/traveller, Jean Baptiste Tavernier, in 1657. A replica which might be at maximum 10 per cent out in size is surely better than no replica at all for such a stone. Often one comes across a line diagram and the dimensions, then one has to trust only the accuracy of the line diagram, especially on such features as lower girdle length. Again a sound knowledge of the history of cutting provides a useful check.

I give below some other factors or considerations which affect the making of a replica or model:

Shape:
Either from photographs or from line diagrams, mostly published at the turn of the century. *Not* from certificates. Beware - some diamonds have been deliberately photographed not face on (see for example the Premier Rose in *Famous diamonds* (Balfour, 1992)).

Dimensions:
From certificates when available, but many of the big South African stones were written about at the time of their first cutting. Also from photographs in sales catalogues. At some point in cutting the replica, a decision based on one's own knowledge must be made about where the girdle comes so one can calculate mains angles.

Facet arrangements:
For the crown these can be taken from a photograph if available. The biggest problem on the pavilion is the girdle facets when they do not appear through the table. Here a knowledge of the history of faceting helps one to make an educated guess.

Colour:
Perhaps the single biggest problem. Few important diamonds are on display and descriptions of colour are at best vague and colour balance will

vary from one published photograph to another. An additional factor is the availability of material - coloured CZ is made to be attractive in its own right and not to imitate the often very subtle tones of coloured diamonds. A run of a special colour from one of the CZ manufacturers must usually be for a minimum of 50 kg costing perhaps $5000 and hence out of the question for just one replica. Sometimes one is forced to use material the colour of which is a little more intense than the original diamond.

Sometimes one searches hard to find the information one wants but fails. And sometimes one gets too much! I hope one day to make a replica of a stone called the Cumberland which is usually described as a *round* stone. However, Lord Twining, expert on European crown jewels and writer of heavy tomes, identified it as a *triangular* stone which came up for sale at Christie's in London in 1953. On a carousel of diamond replicas originally presented to Queen Victoria by the East India Company, probably for her Diamond Jubilee, now in the store rooms of the Natural History Museum in London, sits a 'replica' of the Cumberland - it is *cushion-shaped*!

Given the problems outlined here and on the certificate, are replicas possible? If one demands one hundred per cent accuracy in every factor, what I call a model, then the answer is almost invariably 'No'. If one wants something that face-up looks like the real thing even to the owner, and would be indistinguishable to most of us if put side by side with the real thing, the answer is definitely 'Yes'. And if any more justification is necessary, they give a lot of pleasure to a lot of people. What more can one ask?

References

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Kane, R.E., McClure, S.F., Menzhausen, J., 1990. The legendary Dresden Green diamond. *Gems & Gemology*, 26, 4, 248-66.

[*Manuscript received 18 May 1993*]

Gem Diamond Diploma

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Gemmological Abstracts

BANK, H., HENN, U., 1993. Gemmologische Kurzinformationen. (Short gemmological notes.) *Zeitschrift der Deutschen Gemmologischen Gesellschaft*, **42**, 1-6, 10 photographs, bibl.

An article composed of the following short notes. A green zoisite from Tanzania; the authors feel that this material should be called green zoisite not green tanzanite or chrome tanzanite. A 5-7cm, 3mm thick tourmaline 'melon' from Madagascar was identified as a tourmaline-glass doublet. Also from Tanzania a ruby-quartz doublet. A yellow-brown star corundum was found to be a synthetic/natural doublet with good asterism. Rubies with cracks were treated either with oil/paraffin or resin or, in faceted stones, a glass-like substance was used as a filler. Many more diffusion-treated sapphires were noticed on the market. Other examples included a dyed star-sapphire of 12.5ct from Sri Lanka; various filled cracks in emeralds; dyed quartzes imitating fire opals; and the name 'aqualite' used in the trade (Thailand) for apatite. A synthetic emerald from Russia (produced by hydrothermal synthesis and sold under the trade name 'Vasar') showing unusually strong pleochroism and a definite blue colour at right angles to the optic axis: physical values as for synthetic emeralds. E.S.

BRANDSTÄTTER F., NIEDERMAYR, G., 1993. Einschlüsse von gediegen Kupfer in Cu-Elbait von São José da Batalha in Paraíba, Brasilien. (Inclusions of native copper in elbaite of São José da Batalha in Paraiba, Brazil.) *Zeitschrift der Deutschen Gemmologischen Gesellschaft*, **42**, 37-41. 1 photograph, 1 photomicrograph, 1 X-ray picture, 1 table, bibl.

The native copper inclusions were found in grey-green tourmalines of São José da Batalha. They form typical dendritic platelets (80-100μm in size, 1μm thick), orientated parallel to the *c*-axis of the host crystal. Electron probe analysis showed the tourmaline to be cuprian elbaite with significant iron and magnesium content. E.S.

BROWN, G., 1993. Paraiba tourmaline. *South African Gemmologist*, **7**, 1, 4-6.

Bright blue tourmalines from Mina da Batalha, Paraiba, Brazil, contains up to 2.38% CuO and/or 2.88% MnO. Blue colour is ascribed to the presence of up to 1.4% Cu^{2+}: a green colour is ascribed to intervalence charge transfer between adjacent Mn^{2+} and Ti^{4+} sites. Cut stones are very expensive. M.O'D.

CUIF, J-P., DAUPHIN, Y., STOPPA, C., BEECK, S., 1993. Forme, structure et couleurs des perles de Polynésie. *Revue de Gemmologie*, **114**, 3-6, 10 photos (3 in colour).

The colour, shape and structure of Polynesian pearls are described in this first part of a general survey paper. M.O'D.

DA CUNHA, C., 1993. Gemmes en lumière. *Revue de gemmologie*, **114**, 11-14, 2 photos (2 in colour), 1 fig.

Quartz with blue inclusions, rhodochrosite, green chrome chalcedony, chrysoprase and green dyed quartz are highlighted. M.O'D.

DELÉ-DUBOIS, M-L., FOURNIER, J., PERETTI, A., 1993. Rubis du Vietnam. *Revue de Gemmologie*, **114**, 7-10, 5 photos (4 in colour), 2 figs.

Ruby from various Vietnam sources are compared with those from Myanmar and other classic locations. Inclusions reported in the Vietnam stones are apatite, quartz, amphibole and rutile. M.O'D.

DHARMARATNE, P.G.R., 1993. Gemmological examination of a colour changing cobalt spinel. *Zeitschrift der Deutschen Gemmologischen Gesellschaft*, **42**, 47-50. 1 graph, bibl.

The author examined a 41.65ct mixed-cut blue stone from the Nilani Gem Museum in Ratnapura, Sri Lanka, which showed a colour-change from blue in daylight to violet in tungsten light. The stone was identified as spinel with cobalt as trace element. E.S.

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DUCHI, D., FRANZINI, M., GIAMELLO, M., ORLANDI, P., RICCOBONO, F., 1993. The iron-rich beryls of Alpi Apuane. Mineralogy, chemistry and fluid inclusions. *Neues Jahrbuch für Mineralogie. Monatshefte*, **5**, 193-207, 3 photos, 5 figs.

Beryls from the Alpi Apuane show unusually high Fe^{2+} content and include emerald and aquamarine. Fluid inclusions are found in both green and blue varieties and three-phase inclusions are illustrated. Crystals show a low *c/a* ratio and are characterized by elongated prism and pinacoid, the largest examples reaching about 1cm in length. Blue beryl comes from the Calcaferro and Buca della Vena mines, emerald from the latter. All come from late-Alpine veins and seem to have avoided any appreciable strain event. At Buca della Vena aquamarine samples occur in quartz veins associated with microcrystalline hematite and magnetite. Emerald occurs in dolomite veins with pyrite, in a dolomitic limestone. M.O'D.

GEBHARD, G., SCHLÜTER, J., 1993. Natrolith von St. Hilaire, Quebec, Kanada. (Natrolite from St Hilaire, Quebec, Canada.) *Zeitschrift der Deutschen Gemmologischen Gesellschaft*, **42**, 43-5, 1 photograph, 1 table, bibl.

Cut, clear transparent, colourless natrolite from St Hilaire, Quebec, shows fine orientated cracks, moss-like inclusions of brown to bright-yellow as well as fine needle-like inclusions parallel to the *c*-axis. SG 2.26, RI 1.477-1.490, DR 0.013. E.S.

HARDER, H., 1993. Prähistorische Gläser aus Sri Lanka. (Pre-historic glasses from Sri Lanka.) *Zeitschrift der Deutschen Gemmologischen Gesellschaft*, **42**, 27-36, 1 map, 2 tables, 4 photographs, bibl.

Multi-coloured glasses are found in Sri Lanka in varying geological environments, at the surface (ground glass), in river gravels, in gem pits (called pit glass). The chemical composition is different from tektites - they have a high sodium and lead content - so it could be that they are man-made, possibly in pre-historic times. After the finish of any mining activity the pit is generally filled with overburden and other waste. The waste is rediscovered during modern mining and can consist of bricks, pottery, gem gravel from other mines and waste from glass production. Glass was an important trade article on the maritime silk road. E.S.

KAMMERLING, R.C., KOIVULA, J.I., 1993. Examination of an interesting assembled imitation of emerald. *South African Gemmologist*, **7**, 1, 20-5, 6 photos in colour.

An imitation emerald crystal purchased in Colombia contained a green fluid which escaped on cutting. The specimen, in the form of a 6.59ct hollowed-out hexagonal prism, appeared a medium-dark green and consisted of a 'water-worn' core fitted inside a hollow crystal of poor quality emerald or pale beryl. The internal cored surfaces were the chief source of the colour which concentrated in patches and was apparently a dyestuff. The core, though displaying a water-worn appearance, seemed to be some form of plastic as it had a very low heft and was very soft. The two pieces, when fitted together, were capped by a grey metal plug covered with a mixture of what might have been a mixture of ground-up mineral matter in a polymer. The grey metal may have been lead and the groundmass melted at the gentle touch of the thermal reaction tester. M.O'D.

KARFUNKEL, J., WEGNER, R., 1993. Das Alexandritvorkommen von Esmeraldas de Ferros, Minas Gerais, Brasilien. (The alexandrite occurrence of Esmeraldas de Ferros, Minas Gerais, Brazil.) *Zeitschrift der Deutschen Gemmologischen Gesellschaft*, **42**, 7-15, 1 map, 2 photographs, bibl.

The alexandrite occurrence of Esmeraldas de Ferros is compared to the neighbouring occurrence at Hematita. The physical properties of both are similar but the geological and tectonic settings are different. The alexandrites of Esmeraldas de Ferros have been affected by tectonic movements and are strongly fractured. The quality is good but they are rarely more than 0.10ct when cut. The colour change is distinct to good. E.S.

KONEV, A.A., VOROBJOV, E.I., BULACH, A., 1993. Charoit- der Schmuckstein aus Sibirien und seine seltenen Begleitminerale. *Lapis*, **18**, 4, 13-20, 14 in colour, 2 maps.

Charoite and its accompanying minerals tinaksite, tausonite (strontium titanate) and others is described from its type location in Siberia. M.O'D.

LEES, B., 1993. Die Wahrheit Åber die neuen Rhodochrosite von der Sweet Home Mine, Alma, Colorado. *Lapis*, **18**, 2, 30-5, 16 photos in colour, 1 map.

Fresh discoveries of gem-quality rhodochrosite have been made at the Sweet Home mine, Alma, Colorado, USA. Details of

some of the more spectacular discoveries are given. M.O'D.

LIEBER, W., 1993. Frabzonen in Fluorit-Kristallen. *Lapis*, **18**, 6, 39-48. 15 photos in colour.

Reworked paper from Lapis 1/93 discussing and describing colour zoning in fluorite. A revised list of references is provided. M.O'D.

LURIE, J., 1993. Polyhedra and gemmology. *South African Gemmologist*, 7, 1, 7-19, 12 figs (5 in colour).

A survey of equidimensional symmetrical polyhedra is presented with remarks on space-filling in solids. M.O'D.

LYCKBERG, P., 1993. Eine Reise zu den Smaragd-Vorkommen im Bereich von Takovaja im Ural. *Mineralien Welt*, 4, 3, 53-9, 21 photos (16 in colour).

The emerald-bearing area of Takovaja in the Urals is described with notes on the history, geology and mining of the area, as well as on emerald, phenakite, tourmaline, garnet, alexandrite and topaz, with other minerals. M.O'D.

MAY, M., MAITRALLET, P., 1993. Etude d'un spinelle synthétique rouge par dissolution anhydre, de fabrication russe. *Revue de gemmologie*, **114**, 15, 2 photos (1 in colour), 2 figs.

A flux-grown red spinel octahedron weighing 4.01 ct and manufactured in Russia had SG 3.56 and RI 1.718. A black fingerprint inclusion was observed. M.O'D.

NIEDERMAYR, G., 1993. Das Einschlussbild synthetischer, nach dem Verneuil- Verfahren hergestellter Korunde. *Mineralien Welt*, **4**, 3, 14, 2 photos in colour.

Well-illustrated short piece on the growth and characterization of flame-fusion corundum. M.O'D.

REDMANN, M., HENN, U., 1993. Smaragde mit künstlich behandelten Rissen und deren Erkennung. (Emeralds with treated cracks and their identification.) *Zeitschrift der Deutschen Gemmologischen Gesellschaft*, **42**, 17-25, 1 table, 3 graphs, 2 photographs, 4 photomicrographs, bibl.

Emeralds with cracks can be enhanced in transparency by colourless oiling. According to CIBJO (1991) this is an established trade practice and need not be declared. Cracks filled with artificial resin must be declared. The article gives a survey of today's processes in emerald crack-filling and their identification and distinction between different filling substances. A table gives the various colours and RIs of oils used for these purposes. There are three main methods of identification: (a) with the help of a microscope, especially when the stone is immersed, (resin often shows small bubbles, and is frequently iridescent); (b) examination under UV; however, some resins fluoresce only slightly and, in cases where the cracks have been sealed at the surface, not at all; (c) by infrared spectroscopy which allows a definite identification of the filling substance. E.S.

RYKART, R., 1993. Quarze mit inhomogen verteilten Rauchquarzfarbzentren aus dem Rheinischen Schiefergebirge. *Aufschluss*, **44**, 151-7, 8 photos in colour.

The paper discusses the colour of smoky quartz and its cause with particular reference to fine crystals from the Schiefergebirge in the German Rhineland. M.O'D.

SCOVIL, J., 1993. Neues aus den USA: Die Tucson Gem & Mineral Show 1993. *Lapis*, **18**, 28-32, 8 photos in colour.

Among the gem-quality minerals on show at the 1993 Tucson Gem & Mineral show were orange spessartine from the Kunene river, Namibia; brazilianite from Baixo, Minas Gerais, Brazil; transparent orange clinohumite from Kukh-i-Lal in the Pamirs; demantoid from the Bobrovka river in the Urals; chrysoberyl trillings from Medeiros Neto, Bahia, Brazil; aquamarine from the north-east of Minas Gerais, Brazil; tourmaline from Krasny-Chikoy in the Baikal area of Siberia and amethyst from a number of places. M.O'D.

STALDER, H.A., 199?. Edel- und Schmucksteine aus der Schweiz. Teil 3:Undurchsichtige-Mineralien. *Schweizer Strahler*, **9**, 10, 473-524. 29 photos (15 in colour). Includes German and French versions.

Opaque gem and ornamental materials are covered in the third part of a survey of Swiss gemstones. Species included are jadeite, nephrite, andalusite, kyanite, lazulite, vesuvianite, rhodonite, rhodochrosite and uvarovite. M.O'D.

Book Reviews

ARIYARATNA, D.H., 1993. *Gems of Sri Lanka.* Fifth revised edition. D.H. Ariyaratna, London. pp 109. Illus. in black-and-white and in colour. £9.99.

The gem minerals of Sri Lanka deserve better than this muddled book whose best feature is the coloured photograph depicting faceted stones from the Natural History Museum on the front cover. The naïveté of the text would be hard to beat though the mixture of science, astrology and folk-lore has its own charm. The text cannot be relied on for scientific accuracy and this is a pity since no comparable book on the subject exists in English. This reviewer is not equipped to say whether or not the accounts of gem mining and trading in Sri Lanka are soundly based although they are interesting to read. The whole book is disordered, unconsciously whimsical and at the same time echoes the ponderous didacticism of the British gem textbooks of not so long ago. In no sense can the book be regarded as even moderately worthy of its subject. With revision under the careful eye of a serious scientist the text could one day approach a moderate usefulness but the lack of such supervision is sadly obvious this time. M.O'D.

FAIRBAIRN, R.A., 1993. *The mines of Alston Moor.* Northern Mine Research Society, Keighley. pp 191. Illus. in black-and-white (British mining. no 47).

Though primarily a monograph of the mines and mining of this famous district of the northern Pennines of England this should be required reading for those interested in fluorite deposits (on the mineral side) and in the development and decline of a mining area (on the socio-historical side). M.O'D.

FEDERMAN, D., 1992. *Modern Jeweler's Gem profile/2: the second 60.* Modern Jeweler, Shawnee Mission, KS. pp. 143, illus. in colour. US$ 39.95.

The second (131) tome of gem photographs by Tino Hammid and descriptions aimed at the readers of *Modern Jeweler* and at modern jewellers, this is an attractive book describing a variety of gemstones which include sugilite, blue Paraiba tourmaline and the 'Hancock' red diamond. Notes on history and provenance are interesting, as are the speculations on values. Readers completing a close study of the book (in which the standard of colour photography varies from the very good to the not-so-good) may like to work out how 60 becomes 131, but all will welcome the larger number! M.O'D.

FIELD, J.E. (ed.), 1992. *The properties of natural and synthetic diamond.* Academic Press, London. pp xiv. 710. Illus. in black-and-white and in colour. £90.00.

Though not described as a third edition, the recent work really began with Berman's *Physical properties of diamond* (1965) and Field's *The properties of diamond* (1979), both being, as the present work, multi-author exhaustive studies of diamond. In the preface the reader is warned that further studies will be necessary before very long. While covering all the areas dealt with by the previous books, advances in investigative techniques have compelled the enlargement of the text and in addition some knotty points have come at least closer to resolution; these recent thoughts can be found in the sections on nitrogen aggregation and geology. Diamond growth is strongly covered but the platelet story, even with the new conception of voidites, is still not settled.

It can be seen, therefore, that this is a very wide-ranging text and a look at the extensive lists of references provided in each section shows that it is also up-to-date. A small colour-plate section is devoted to synthetic diamonds which are described in a lengthy section of text. The book also deals with the many applications of diamond, many of which have some relevance to the properties which make diamond unique as a gemstone. Although expensive, gemmologists with a special interest in diamond should at least endeavour to see the text in a major library, since so much current thinking is included and little of this shows up in gemmological texts, for space, relevance and cost reasons. M.O'D.

FIELD, L., 1992. *The jewels of Queen Elizabeth II: her personal collection.* Thames & Hudson, London. pp 120. Illus. in black-and-white and in colour. £12.95.

This well-designed and easily readable book is a revised and shortened paperback version of the author's *The Queen's jewels*, Harry N. Abrams Inc, New York, 1987. Based on a selection of photographs, the main items in the Queen's personal jewellery collection are described with some general historical notes. Some stones shown are important and have rarely been illustrated before. The book is highly recommended. M.O'D.

KELLER, P.C., 1992. *Gemstones of East Africa.* Arizona. Geoscience Press, Phoenix, pp. xiv, 144, illus. in black-and-white and in colour. Price on application.

The gemstone deposits of Kenya and Tanzania are described from the point of view of the geologist and gem prospector. Chapters, each with lists of references and accompanied by some previously unpublished maps, deal with Kenya and Tanzania only: they cover diamond deposits of Tanzania; ruby and sapphire of East Africa; emerald and alexandrite from Tanzania; tanzanite from Merelani, Tanzania; garnets of East Africa; tourmaline of East Africa and prase opal from Haneti Hill, Tanzania. A prefatory chapter discusses East African geology and appendices deal with noteworthy localities of East African gemstones, East African gemstones in the Los Angeles County Museum of Natural History. The matter is very readable and well-presented; the colour photographs are nearly outstanding but show some slight blurring in my copy at least. A most welcome book and one of the forerunners of a new generation of gemmological studies departing from the over-trodden and repetitive path of gem testing.

M.O'D.

POINAR, G.O., Jr, 1992. *Life in amber.* Stanford University Press, Stanford, CA. pp. xiii, 350, illus. in black-and-white and in colour. £40.00.

With 30 citations in the field of amber inclusions, a full-length study from this author is particularly welcome since very few gemmologists will have access to the mostly biological sources covered. Leaving the often vexed arena of taxonomy aside, this survey of plant and animal inclusions in amber will provide an invaluable source of information on the types most likely to occur in natural amber.

The opening chapter gives an excellent summary of the formation and occurrence of amber and this is followed by an account of world amber deposits with maps, charts and tables. The next chapter describes the world's major collections of fossiliferous amber and precedes the descriptions, by kingdom, of the major inclusions. This account begins with bacteria, moulds and fungi, going on to bryophyta (mosses and liverworts) and the higher plants gymnosperms and angiosperms. The next section (approximately 200 pages) covers the various animal kingdoms and most readers will be astonished at the variety of creatures that have been found in amber. With so exhaustive a listing, it is clear that many more species remain to be discovered. The descriptions and taxonomic arrangement make this section of the book useful for biologists working in these fields.

The next section of the book gives a reasoned study of the importance of amber inclusions for biological research. This is especially useful when we consider that many of the species found as inclusions are now extinct so that evolution studies are aided as well as work on biogeography. The chapter ends with a speculation that DNA might be cloned from amber inclusions; the implications here are enormous.

Appendices give useful regional summaries: one lists arthropod classes, orders and families reported from Mexican amber and the other covers the same area for the Dominican Republic. There is a 30-page bibliography and a well-constructed index. The price is very reasonable for so original a book which will be found essential for many biologists as well as the wide public interested in amber. M.O'D.

SCHIFFER, N.N., 1993. *Rhinestones.* Schiffer Publishing Co., Atglen, PA. pp. 156. Illus. in colour. £16.95.

This is good value for money as there is a price guide to the items illustrated. The text describes the history of rhinestones (named from Rheinkiesel - Rhine pebbles) a term describing coloured glass moulded in Bohemia and sold at shops on the banks of the Rhine early in this century. The stones and the artefacts made from them are described in order of colour; there are a few references and the price guide at the end of the book. The colour photographs are quite good and the range of objects illustrated very wide. Publication date is 1993 and the ISBN 0 88740 457 X. M.O'D.

Proceedings of The Gemmological Association and Gem Testing Laboratory of Great Britain and Notices

GIFTS TO THE GAGTL

The Association is most grateful for gifts of gems and gem material for research and teaching purposes from the following:

Mrs Ameena Kaleel, FGA, Mt Lavinia, Sri Lanka, for smoky quartz, garnets, zircons (with very good spectra), corundum crystals, rutilated quartz and kornerupine cat's-eyes.

He Ok Chang, FGA, Brazil, for new decorative stones from Brazil.

Mr H. Stern, Rio de Janeiro, Brazil, for a parcel of emeralds from Brazil.

MEETINGS OF THE COUNCIL OF MANAGEMENT

At a meeting of the Council of Management held on 14 July 1993 at 27 Greville Street, London EC1N 8SU, the business transacted included the election of the following:

Fellowship

Fitzmaurice, Karl M., Castlerea, Ireland. 1990.

Ordinary Membership

Cadby, John H.V., Trowbridge.
Finlayson, James C., Stoke-on-Trent.
Jayarajah, Aravandy P., Colombo, Sri Lanka.
MacArthur, Iain, Barnes, London.
Sison-Jones, Maria D., London.
Torenvlied, Pieter, Stonehaven.

Gold Laboratory Membership

Cry for the Moon, 31 High Street, Godalming, Surrey GU7 1AU.

At a meeting of the Council of Management held on 11 August 1993 also at 27 Greville Street the business transacted included the election of the following:

Transfer to Diamond Membership

Kassam, Salim S., London. 1993.
Papadopoylos-Fatalos, Costas, Athens, Greece. 1993.

Transfer to Fellowship and Diamond Membership

Beckett, Shona-Maria Ferguson, London. 1993.
Cooper, Carolyn, Hong Kong. 1993.
De Silva, Gamini, London. 1993.
Garrod, Douglas J., Torquay. 1993.
Gellini, Delio, Harrogate. 1993.
Harper, Jonathan, London. 1993.
Mallett, Gillian E., Cambridge. 1993.
Spencer, Riitta M., Helsinki, Finland. 1993.
Strachan, Elizabeth, London. 1993.
Triantaphyllides, Zoe M., Athens, Greece. 1993.
Wates, Peter J., Coulsdon. 1993.
Wu, Chao-Ming, Taipei, Taiwan. 1993.

Fellowship

Chen, Kesheng, Guangxi, China. 1992.
Harris, Richard J., Carlisle. 1993.
Lewis, Rob, Dunstable. 1993.
Maharaj, Rajendra K., Toronto, Ont., Canada. 1988.
Moyersoen, Jean-Francois, Monaco. 1978.
Muigai, Mumbi, Nairobi, Kenya. 1973.
O'Connell, Helen M., Chessington. 1993.
Thomson, Joanna L., Peebles. 1993.

Transfer to Fellowship

Campbell-Pedersen, Maggie, London. 1993.
Daniels, Razia, Chester. 1993.
Day, James P.M., Royal Tunbridge Wells. 1993.
Embleton, Michelle L., Basildon. 1993.
Finlayson, James C., Alsager, Stoke-on-Trent. 1993.
Hue-Williams, Sarah, London. 1993.
Humphrey, Mary S., London, 1993.
Lu, Jei-Chih, London. 1993.
Massow, Kenneth J., Rochford. 1993.
McCormack, Susan L., Liverpool. 1993.
Preece, Susanne L., Bath. 1993.
Proudlove, David, Lochgilphead. 1993.
Robinson, Zoe L., London. 1993.
Ruhmer, Fiona J., London. 1993.
Sandum, Mark A., Ramsgate. 1993.
Saxton, Carol A.L., Alton. 1993.

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FORTHCOMING MEETINGS

London

Meetings will be held on the second floor at 27 Greville Street. Refreshments will be available from 6.00 p.m. and lectures will start at 6.30 p.m.; these will be followed by discussion and closing about 7.45 p.m. The charge for a member will be £3.50 and, as places are limited to 55, entry will be by ticket only, obtainable from GAGTL.

8 November	'Thai evening'	Amanda Good FGA and Martin Issacharoff
22 November	'CIBJO matters' - the gem trade in Europe	Harry Levy FGA
7 December	'Pearls in the Laboratory'	Stephen Kennedy FGA, DGA, and Ana I. Castro FGA
24 January 1994	'Overview of world diamond producer sources'	Robin Walker
7 February	'The independent gemmologist's workshop'	Patrick Daly, FGA
23 February	'Decorative and collectors' minerals from southwest England'	Dr Robert Symes
7 March	'The history of Garrards, the Crown Jewellers'	William Summers
30 March	'Jewellery at auction'	David Lancaster, FGA

The GAGTL Annual Conference is to be held on 24 October 1993 at the Great Western Royal Hotel, Paddington. This will be followed on 25 October by a GAGTL Open Day and the Presentation of Awards.

Midlands Branch

29 October	'Rescued from the scrap box'	David Wilkins
26 November	A practical demonstration of light behaviour in gemstones	Dr Jamie Nelson
11 December	41st Anniversary Dinner	
28 January 1994	'The Cheapside Hoard'	James Gosling
25 February	'Jewellery through the ages'	Nigel Dunn
25 March	'Platinum - design and technology in the workshop'	Dr John Wright
29 April	Annual General Meeting followed by 'The gems of Sri Lanka'	C. & N. Gems

The meetings will be held at Dr Johnson House, Bull Street, Birmingham. Further details from Gwyn Green on 021-445 5359.

North West Branch

17 November	Annual General Meeting	
16 February 1994	'A contemporary use of pearls'	Jane Sarginson
16 March	'Current trends in gem testing'	Dr Roger Harding

Meetings will be held at Church House, Hanover Street, Liverpool 1. Further details from Joe Azzopardi on 0270-628251.

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23 November 1993
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Benefit from his experience, pick up valuable tips and enjoy the spectacle.
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Preliminary questions and answers
13 January 1994
The chance for Preliminary students taking their examination at the end of January to find out from tutors and examiners what is required of them.
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Diploma Workshop
15-16 January 1994
Two days of practical tuition for students taking the Diploma Examination at the beginning of February. Also suitable for those who need intensive gem therapy.
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GAGTL students £105.75

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For further information contact the GAGTL Education Department on 071-404 3334.

Scott, Damian T.F.C., London. 1993.
Slater, Richard M., Bath. 1993.
Sondack, Julia, London. 1993.
Vuillet A. Ciles, Pierre, London. 1993.
Walker, Averil S., London. 1993.
Withers, Justine M., Redhill. 1993.

Ordinary Membership
Jefferson, Gareth, London.
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Kent, Tricia, Princes Risborough.
Sadow, Tanja M., Singapore.
Simpson, David C., Devizes.
Van Der Kemp, Francina M., The Hague, The Netherlands.
Wilson, Deborah T., Boston.

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GAGTL LONDON LECTURES 1994

The following lectures will be held in the GAGTL Gem Tutorial Centre at 27 Greville Street, London EC1N 8SU, entry by ticket only. For further details see Forthcoming Meetings on p. 497.

Monday 24 January
'Overview of world diamond producer sources'
Robin Walker

Robin Walker is the only member of staff of the De Beers Central Selling Organization in London who has had experience in the field as a prospector. He spent fourteen years in West Africa, rising to General Manager of the Sierra Leone operation. Altogether, he has been with the CSO for thirty-four years and is now a Manager with the Marketing Liaison Department.

Monday 7 February
'The Independent Gemmologist's Workshop'
Patrick Daly, FGA

Pat Daly entered the jewellery trade in 1970, working in retail and manufacturing before becoming independent in 1984. He has taught gemmology since 1982 with Alan Hodgkinson, at Sir John Cass College, at the GA and at Regents College, taking a particular interest in the ways in which jewellers and gemmologists of

slender means may make the best possible use of the instruments they have and also make their own instruments. He is now working as a freelance jewellery valuer and teacher of gemmology and geology.

Wednesday 23 February
'Decorative and Collectors' Minerals from Southwest England'
Dr Robert Symes

Dr Bob Symes is currently Deputy Keeper in the Department of Mineralogy, Natural History Museum. He has written and co-authored many books on minerals, specializing in British occurrences and is a recent President of the Russell Society. He is currently writing Minerals of Northern England.

Monday 7 March
'The History of Garrards, the Crown Jewellers'
William Summers

William H. Summers, LVO, retired recently from Garrard & Co Ltd, the Crown Jewellers, which he joined in 1950. During the last thirty years he represented them as Crown Jeweller and as a director. He has travelled extensively throughout the world, particularly in the USA, the Far East and Australia to promote the company and British jewellery and silver.

Wednesday 30 March
'Jewellery at Auction'
David Lancaster, FGA

David Lancaster joined the Garrards - Mappin and Webb group in 1970 and spent nine years in South Africa at their Johannesburg branch. On his return to the UK he joined Christie's and has since specialized in period jewellery at Christie's South Kensington. He is also a keen collector of minerals.

Wednesday 13 April
'Ancient Gems and Jewellery'
Dr Jack Ogden, FGA

Dr Jack Ogden is a specialist in the history of the materials and technology of jewellery. He has written and lectured widely on the subject and is editor of *Jewellery Studies*, the Journal of the Society of Jewellery Historians, which he helped found in 1977, and a co-editor of *Gem and Jewellery News*. As a director of the Cambridge Centre for Precious Metal Research, he undertakes consultancy work for museums, dealers and collectors.

Tuesday 26 April
'Cutting it Fine'
Dr George Harrison Jones, FGA

Dr George Harrison Jones has been an Examiner for the GA and GAGTL since 1975 and is on the Members' Council. He specializes in cutting unusual gem species to make the best of their inherent properties and has many examples of his work on display in the Earth Galleries of the Natural History Museum.

Wednesday 11 May
'Spreading Gem Knowledge'
Ian Mercer, FGA

Ian Mercer is Director of Education in GAGTL. He joined the staff of the Association after more than twenty years with the Geological Museum at South Kensington working as a geologist in the Earth science exhibitions team. He headed the team for the 'Treasures of the Earth' exhibition, pioneered videodisc technology in London museums and investigated educational aspects of exhibit use. With a particular interest in gem crystallization, Ian wrote the highly successful Museum book *Crystals*.

Monday 13 June
AGM and Reunion of members

GEM DIAMOND EXAMINATIONS 1993

In 1993 5 candidates sat in January and 45 in June for the Gem Diamond Diploma Examination. Of these 30 passed including one with Distinction. The names of the successful candidates are as follows:

Qualified with Distinction
Papadopoylos-Fatalas, Costas, Athens, Greece.

Qualified - January Examination
Bakayianni-Sabou, Aristea, Athens, Greece.
Gofa, Sophia, Athens, Greece.
Hare, Rebecca M.A., Fleet.
Prior, Louise C., London.
Scott, Kenneth MacDonald, Carluke.

Qualified - June Examination
Beal, Michael R., London.
Beckett, Shona-Maria Ferguson, London.

Burgess, Timothy R., London.
Cooke, Eva-Maria, London.
Cooper, Carolyn, London.
De Silva, Gamini, London.
Duncan, Andrew, Liverpool.
Garrod, Douglas J., Torquay.
Gellini, Delio, Harrogate.
Godfrey, Irmfried A., Glasgow.
Harper, Jonathan, London.
Jackson, Coralyn D., Rosyth.
Jeffrey, Vivian, London.
Kassam, Salim S., London.
Mallett, Gillian E., Cambridge.
Norman, Andrew J., London.
Orr, Caroline, London.
Spencer, Riitta M., Helsinki, Finland.
Strachan, Elizabeth, London.
Triantaphyllides, Zoe M., Athens, Greece.
Turner, Gaynor J., Edinburgh.
Turner, Stephen J., Edinburgh.
Wates, Peter J., London.
Wu, Chao-Ming, Taipei, Taiwan.

EXAMINATIONS IN GEMMOLOGY 1993

In the 1993 Examinations in Gemmology 485 candidates sat the Preliminary examination (65 in January and 420 in June) 321 of whom qualified, and 425 sat the Diploma examination and 201 qualified, 18 with Distinction.

The **Tully Medal** for the candidate who submits the best set of answers in the Diploma examination, which in the opinion of the Examiners are of sufficiently high standard, was awarded to Mrs Guo Tao of Wuhan, P.R. China.

The **Anderson Bank Price** for the best non-trade candidate of the year in the Diploma examination was awarded to Mr Pierre Vuillet à Ciles of Villards d'Heria, France.

The **Diploma Trade Prize** for the best candidate of the year who derives his main income from activities essentially connected with the jewellery trade was awarded to Mr Guo Xiaoming of Wuhan, P.R. China.

The **Anderson Medal** for the best candidate of the year in the Preliminary examination was awarded to Mrs Guo Tao of Wuhan, P.R. China.

The **Preliminary Trade Prize** for the best candidate under the age of 21 years on 1 June 1993 who derives his main income from activities essentially connected with the jewellery trade was awarded to Mr Yip Ngai of Kowloon, Hong Kong.

DIPLOMA

Qualified with Distinction

Astrom, Mikko, Helsinki, Finland.
Bertorelli, Andrea E.L., London.
Chellew, Ross, London.
Forrest, Jacqueline, Glasgow.
Guo, Tao, Wuhan, P.R. China.
Guo, Xiaoming, Wuhan, P.R. China.
Hue Williams, Sarah, London.
Ibanez de Aldecoa, M. Angeles, Madrid, Spain.
Jegge, Erich P., Zurich, Switzerland.
Kitawaki, Hiroshi, Saitama Pref., Japan.
Leong, Margaret, Bandar Seri Begawan, Brunei.
Mani, Heida, Mississauga, Ont., Canada.
Proudlove, David, Lochgilphead.
Saxton, Carol A.L., Alton.
Scott, Damian T.F.C., London.
Vuillet À Ciles, Pierre, London.
Walker, Averil S., London.
Wang, Shengzhong, Wuhan, P.R. China.

Qualified

Alexanders, David, Toronto, Ont., Canada.
Alonso Florentino, Jose Maria, Madrid, Spain.
Balducci, Annette, Neston.
Berreux, Cedric, La Chaux-de-Fonds, Switzerland.
Bombeke, S., Schoonhoven, The Netherlands.
Buxani Naina Mahesh, Hong Kong.
Campbell Pedersen, Maggie, London.
Cavelti, Christian G., Vancouver, BC, Canada.
Chan Mei Wah, Carol, Hong Kong.
Chan Seung Yuen, Samuel, Hong Kong.
Chedta-Thaiyawong, Kanitha, Bangkok, Thailand.
Chen, Meihua, Wuhan, P.R. China.
Chenevix-Trench, Susannah, London.
Cheung Shuk Mei, Hong Kong.
Choi Dong-Geun, Seoul, Korea.
Choi Pui Ho, Eddie, Hong Kong.
Chow Wing Yuen, William, Hong Kong.
Chown, Philip, Sevenoaks.
Crabbe, Jeremy P., Hong Kong.
Daniels, Razia, Chester.
Dansereau, Eva M., Winnipeg, Man., Canada.
Day, James P.M., Royal Tunbridge Wells.
de Chamerlat, Marie, Paris, France.
de Granville, Francesca, Oklahoma City, Okla., USA.
Del Barrio Lazaro, Pedro A., Valencia, Spain.
Donkin, Jeffrey J., London.
Duigan, Ingeborg, Hong Kong.
Earnshaw, Alison, Tonbridge.
Embleton, Michelle L.E., Basildon.
Ettila, Annamari, Helsinki, Finland.
Farrimond, Thomas, Cambridge, New Zealand.

MEMBERSHIP '94

Members, Fellows and Diamond Members receive an annual membership card, *The Journal of Gemmology* and the *Gem and Jewellery News* quarterly. Fellows (members who hold our Diploma in Gemmology) may use FGA after their name and Diamond Members (members who hold the Gem Diamond Diploma) the title DGA, and both may also apply for the use of the Coat of Arms on their stationery.

Laboratory Members receive a membership certificate for display, *The Journal of Gemmology* and *Gem and Jewellery News* quarterly, and may apply for use of the Laboratory logo on their business stationery. Gold Laboratory Members may enjoy the benefits of Laboratory Members together with lower fees for diamond reports, assistance with temporary import of stones for testing, and special facilities on pearl and coloured stone reports.

All members are eligible for a 10% discount on the retail price of instruments and specimens, and a 5% discount on books purchased from Gemmological Instruments Limited and Overseas Members benefit from arrangements to pay by credit card and all their journals will be sent by airmail.

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Gold Laboratory Member	£525.00 + VAT	£525.00

Ferguson, Neil, Balloch.
Finlayson, J.C., Alsager.
Fowle, Michael J., Nairobi, Kenya.
Fry, Suzy, London.
Fung Lai Yi, Hong Kong.
Gibson, William M., Highland, Md., USA.
Gillies, Bronwyn, London.
Gisbert Garcia, Ana M., Madrid, Spain.
Godfrey, Irmfried A., Glasgow.
Goyal, Hariprasad, Jaipur, India.
Graham, Jennifer J., Glasgow.
Granlund Jarvinen, Ingalill, Kasnas, Finland.
Green, Janette F., Leamington Spa.
Guo, Shouguo, Wuhan, P.R. China.
Gutierrez Martinez, Jose A., Madrid, Spain.
Haddock, Brendan, Edinburgh.
Hamp-Gopsill, David, Burton-on-Trent.
Hanna, Margaret A., London.
Harada, Kayoko, Kanagawa Pref., Japan.
Harris, Richard J., Carlisle.
Hawes, Rona M., Redhill.
Hui Wing Chiu, Ernest, Hong Kong.
Humphrey, Mary S., London.
Hung Ching Ting, Hong Kong.
Hung Suet Fung, Hong Kong.
Indiano Iglesias, Natividad, Madrid, Spain.
James, Cary S., Woodstock, Ont., Canada.
Jeong, Seok-Ran, Busan, Korea.
Jones, Amanda, Birmingham.
Joshi, Vikas, Jaipur, India.
Jun, Huang, Wuhan, P.R. China.
Kang, Joo-Youn, Seoul, Korea.
Keating, Martina, London.
Kelloniemi, Katri, Helsinki, Finland.
Kennedy, Lisa, London.
Kiji, Michio, Osaka, Japan.
Kim, Gye Hong, Taejon, Korea.
Kim, In-Kyu, Seoul, Korea.
Kim, Jee-Eun, London.
Kim, So Won, Kyungido Kuri, Korea.
Kinda, Yumiko, Osaka, Japan.
Kitawaki, Jyunko, Osaka, Japan.
Kiviluoto, Raija, Helsinki, Finland.
Kohn, Peter A., Oxford.
Krommenhoek, Celine, Amsterdam, The Netherlands.
Kruise, B.J., Schoonhoven, The Netherlands.
Kuosmanen, Jussi, Helsinki, Finland.
Lai Yi Oi, Hong Kong.
Lanko, Jantine, Amsterdam, The Netherlands.
Lasry, Veronique, Madrid, Spain.
Lau, Paul, Hong Kong.
Lau Heung Ping, Linda, Hong Kong.
Lau Hok Keung, Hong Kong.
Law Yiu Sing, Hong Kong.
Lee, Han Yun, Seoul, Korea.
Lee, Heui-Yeol, Seoul, Korea.
Lee, Jin Young, London.
Lee, Myoung-Hee, Seoul, Korea.
Lee, Sang Yen, Taejon, Korea.
Lee, Sook Jin, Taejon, Korea.
Lee Choi Kan, Franky, Hong Kong.
Lee Fung Kiu, Hong Kong.
Leinonen, Ossi, Kemi, Finland.
Lewis, Robert, Totternhoe.
Li, Jingzhi, Wuhan, P.R. China.
Lin, Songshan, Wuhan, P.R. China.
Linde, Pamela A., Crewe.
Lu, Jei-Chih, London.
Luke Ting Cho Lin, Arlene, Hong Kong.
McCormack, Susan L., Liverpool.
McLean, Grace L., Dundee.
Ma Siu Lam, Hong Kong.
Margolis, Paul H., Vancouver, BC, Canada.
Martin, Jennifer F., Bristol.
Massow, Kenneth J., Rochford.
Mathiopoulou, Regina, Athens, Greece.
Molloy, Theresa A., Vancouver, BC, Canada.
Moon, Sang Rok, Seoul, Korea.
Morris, Patricia E.J., Crewe.
Nam, Song-Ja, Daejun, Korea.
Nicholson, Charles J.R., London.
Nicoll, Douglas J., Haddington.
O'Connell, Helen M., Kingston-upon-Thames.
Odawara, Hiroko, Osaka, Japan.
Oele, Kees, Schoonhoven, The Netherlands.
Okuta, Etsuko, Osaka, Japan.
Ortega Marin, Antonio J., Murcia, Spain.
Paakkari, Petri William, Lahti, Finland.
Preece, Susanne L., Bath.
Rijkelijkhuizen, C.J., Schoonhoven, The Netherlands.
Roberts, Keri J., Bath.
Robinson, Zoe L., London.
Romero Paya, Oscar, Valencia, Spain.
Roskin, Gary A., Marion, Indiana, USA.
Roubin, Ernest, Athens, Greece.
Rouleau, Jocelyne, Quebec, Canada.
Ruhmer, Fiona J., London.
Sagir, Yoram, Israel.
Sandum, Mark A., Ramsgate.
Saorin Penalva, Jose A., Murcia, Spain.
Sapalski Rosello, Cristina, Madrid, Spain.
Sarma, Sunil, Jaipur, India.
Schuivens, C., Geleen, The Netherlands.
Seo, Joung Hee, Taejon, Korea.
Shibata, Hitoshi, Osaka, Jana.
Silvonen, Nanna K., Vantaa, Finland.
Slater, Richard M., Bath.
So Chak Tong, Anthony, Hong Kong.
Sondack, Julia, London.
Stahl, Elone, Lannavaara, Sweden.

Stamatiadis, Nick B., Athens, Greece.
Suh, Young-Hye, Kyeongnam-Do, Korea.
Summanen, Sari, Helsinki, Finland.
Ta'eed, Amelia, Apeldoorn, The Netherlands.
Tanaka, Kazuhide, Osaka, Japan.
Tang, Yuanjun, Wuhan, P.R. China.
Tarkkanen, Mika Olavi, Helsinki, Finland.
Thompson, Jane D., Woodbridge.
Thomson, Joanna, Peebles.
Tonn, Heleen A., Rotterdam, The Netherlands.
Trifaud, Guillaume N., Bangkok, Thailand.
Tripathi, Rajesh, Jaipur, India.
Tuovinen, Annikki, Aanekoski, Finland.
Turner, David B., Newcastle-Upon-Tyne.
Turner, Stephen J., Edinburgh.
van Opstal, Wilma, Tilburg, The Netherlands.
Vinkka-Keskinen, Susanna, Hameenlinna, Finland.
Welsh, Alexis L., Bangkok, Thailand.
Whang, Kyu-Young, Seoul, Korea.
White, Isabel H., Tunbridge Wells.
Wilcox, Kimberly A., London.
Williams, Jason F., Cobham.
Withers, Justine M., Redhill.
Wong Chi Wing, Hong Kong.
Wong Lai Fun, Alice, Hong Kong.
Wong Man Yee, Bess, Hong Kong.
Wong Ming Kin, Hong Kong.
Wu, Chao-Ming, Taipei, Taiwan.
Yamasuga, Ryoji, Hyogo Pref, Japan.
Yan, Gao, Wuhan, P.R. China.
Yang, Hye Keong, Pusan, Korea.
Yasuda, Kiyotaka, Osaka, Japan.
Yi, Young Mee, Taejon, Korea.
Yokote, Hideki, Fukuoka Pref, Japan.
Yu, Peter K.N., Hong Kong.
Yun, Sun-Whoa, Seoul, Korea.
Zanettin Barbin, Fabrizia, Geneva, Switzerland.
Zhang, Beili, Wuhan, P.R. China.
Zhang, Congsen, Wuhan, P.R. China.
Zhang, Xianfeng, Wuhan, P.R. China.
Zhang, Xiang Dong, Hong Kóng.
Zhi, Zhan, Wuhan, P.R. China.

PRELIMINARY

Qualified - January Examination

Baik Bong Jun, Yaesu, Korea.
Bok Hee Ahn, Seoul, Korea.
Chen, Meihua, Wuhan, P.R. China.
Ettema, Johan A., Barendrecht, The Netherlands.
Guo, Tao, Wuhan, P.R. China.
Guo, Xiaoming, Wuhan, P.R. China.
Jung, Gwang Gyo, Daejon, Korea.
Kang, Han Yong, Chungnam-Do, Korea.
Kang, Seung Ho, Pusan, Korea.
Kim, Hee Kyung, Seoul, Korea,
Kim, In-Kyu, Seoul, Korea.
Ko, Hyo-Chong, Seoul, Korea.
Kuiphuis, H.H., Schoonhoven, The Netherlands.
Lee, Chang-Hun, Kyung B K-Do, Korea.
Lee, Han Yun, Seoul, Korea.
Lee, Jae-Yeol, Daejon, Korea.
Li, Zhaocong, Wuhan, P.R. China.
Lin, Songshan, Wuhan, P.R. China.
Moon, Sang Rok, Seoul, Korea.
Shim, Hoo Joung, Daejon, Korea.
Sin, Tea Sun, Seoul, Korea.
Sung, Hee Jin, Chung Nam-Do, Korea.
Tang, Yuanjun, Wuhan, P.R. China.
Verhoef, L., Gouda, The Netherlands.
Wang, Shengzhong, Wuhan, P.R. China.
Yang, Sung-Ja, Seoul, Korea.
Yun, Young Harn, Pusan, Korea.
Zhang, Congsen, Wuhan, P.R. China.

Qualified - June Examination

Ahamed, Omar Faiz, Gillingham.
Alexanders, David, Toronto, Ont., Canada.
Allum, Jason P., Shaftesbury.
Andrews, Peter W., Reading.
Au Ming Cheung, Hong Kong.
Au Yang So-Wah, Natasha, Hong Kong.
Ayles, Catherine R., Edinburgh.
Bae, Eun Jeung, Taegu, Korea.
Bao, Deqing, Wuhan, P.R. China.
Barnes, Matthew J., Rochester.
Benes, Alexandra, London.
Bishop, Heather M., Ipswich.
Blaauw, Pauline P., Rotterdam, The Netherlands.
Bosma, Elizabeth J.A., Amsterdam, The Netherlands.
Bossenbroek, Anna E.H., Doorn, The Netherlands.
Brady Moloney, Zoe D., Camberley.
Bronger, Kimberly K., Sheppey.
Bruce, Rachel M., Edinburgh.
Bryan, William L., Surrey.
Butcher, Anna R., London.
Cai, Cuihua, Wuhan, P.R. China.
Campbell, Robert D., Surrey.
Carr, Rachel J., Blackburn.
Carr, Simon D.P., Garstang.
Carroll Marshall, Anne E., Hong Kong.
Carvalho, Roberta Melo De, London.
Cavelti, Christian G., Vancouver, BC, Canada.
Chan, Kin-Chung J., Hong Kong.
Chan Kwok Keung, Hong Kong.
Chan Shiu Fai, Hong Kong.
Chan Yuk Victoria, Hong Kong.

Chan Zen Iu, Hong Kong.
Chau Kit Yee, Fion, Hong Kong.
Chellew, Ross, London.
Chen, Pauline Lian Bee, Hong Kong.
Cheng Fung Kei, Hong Kong.
Cheng Yuen Yi, Hong Kong.
Cheung, Hoi Ying, Kowloon, Hong Kong.
Cheung, Kit Ching, Kowloon, Hong Kong.
Chew Lee Lee, Hong Kong.
Choi, Jae Hee, Inchon, Korea.
Choi, Lai Na, Lina, Hong Kong.
Choi Pui Ho, Eddie, Hong Kong.
Chow Chun Wai, Hong Kong.
Chua, Virna Ngo, Taikoo Shing, Hong Kong.
Chui Yee Hung, Hong Kong.
Chung Yam Ming, Daly, Kowloon, Hong Kong.
Cliff, Graham O., London.
Cookson, Ian P., Sheffield.
Cooper, Shaun P., Wickhambreaux.
Corbett, Heather R., Bury St Edmunds.
Crook, Gary A.G., London.
Cunningham, Ruth, Edinburgh.
Curtis, Mary E., Auckland, New Zealand.
Cyriac, Joseph J., Worksop.
Dalla Libera, Natalie A., London.
Davis, Shelagh M., Andover.
Deba Kiladi Wa Deba, Manchester.
de Chamerlat, Marie, Paris, France.
Devon, Jill V., Felsted.
Dickinson, Barry E., Blackburn.
Dragland, Frode R., Sortland, Norway.
Drummond, Michelen, Toronto, Ont., Canada.
Egginton, Roy, Bournemouth.
Eggleston, Avrina, London.
Elstgeest, Audrey C., Schoonhoven, The Netherlands.
Evans, Sara J., Somerset.
Farion, Jean-Christopher, Shepton Mallet.
Feingold, Lorna M., London.
Feng, Jiansen, Wuhan, P.R. China.
Ferraro, Benedicta, London.
Fok, Paulyanna, Kowloon, Hong Kong.
Freyer, Nina, Hong Kong.
Fung Yuk Fung, Hong Kong.
Gamst, Terje, Breivikbotn, Norway.
Garvik, Beate K., Oslo, Norway.
Gerrits, Marioes A.A.J., The Netherlands.
Ghurahoo, Julien M.B., Utrecht, The Netherlands.
Gibson, William M., Highland, Md., USA.
Gillies, Bronwyn, London.
Goldschmidt-Husein, Asli, Bangkok, Thailand.
Goss, Sanya L., Aldershot.
Graff, Elliott M., London.
Guillotel, Corinne, London.
Gulliani, Narinder, West Midlands.
Gunell, Carola Merete, Kirjala, Finland.
Hajimihail, Michael, Athens, Greece.
Hamidulla, Suzan, Helsinki, Finland.
Hammer, Sharon, Ont., Canada.
Harootouniun, Katrina, London.
Hartford, Katrina D., Maple Ridge, BC, Canada.
Hellenbrand, Chagay M., Willowdale, Ont., Canada.
Henderson, Stephen M., West Ferry, Dundee.
Hindley, Stuart W., Worksop.
Hindmarsh, Andrew, London.
Ho Tung Tak, Hong Kong.
Hoefsloot, Marlou M.L.J., The Netherlands.
Hong, Ji Hyun, Choongbuk-do, Korea.
How, Sarah J., Shaftesbury.
Hui Sze Wai, Hong Kong.
Hui Wai Yee, Wendy, Hong Kong.
Human, Tracey D., Toronto, Ont., Canada.
Ikuta, Miwa, Kyoto, Japan.
Ispan, Karlo, London.
Jack, Johanne C., Montreal, Que., Canada.
Jansen, Edwin T.D.M.L., Schoonhoven, The Netherlands.
Janssen, Maurice, Schoonhoven, The Netherlands.
Je, Soung Soo, Inchon, Korea.
Johansson, Ingvor, Stockholm, Sweden.
Joshi, Vikas, Jaipur, India.
Kan, Wing Lok, Kowloon, Hong Kong.
Karppijarvi, Karina Pirjatta, Raisio, Finland.
Karunarathne (Buddadasa), K.A., Colombo, Sri Lanka.
Kashi, Kenya, Osaka, Japan.
Keating, Martina, London.
Kennedy, Karen Fiona, Berks.
Ketomaki, Tapio, Jokela, Finland.
KienHuis, Anne-Marie A.M., Wierden, The Netherlands.
Kilby, Linda E., Lancashire.
Kilger, Flavia L.M., Schoonhoven, The Netherlands.
Kim, Eun-Joo, Busan, Korea.
Kim, Jee-Eun, London.
Kim, Kyoung Jin, Chungnam, Korea.
Kim, So Won, Kyungido Kuri, Korea.
Kim, Sung Ju, Pusan, Korea.
Kim, Sung-Mo, Seoul, Korea.
Kim, Young-Suk, Seoul, Korea.
Kim, Sung-Mo, Seoul, Korea.
Kimani, Marjory Nyakiago, Nairobi, Kenya.
King, Andrew, Northants.
Kit Ching Cynthia, Lai, Hong Kong.
Ko Kwai Chun, Hong Kong.
Kobayashi, Masahide, Osaka, Japan.
Kodama, Aki, Osaka, Japan.

Kon Kiang Fung, Hong Kong.
Konst-Kurstjens, Monique A.M., The Netherlands.
Ku Chun Lan, Hong Kong.
Lai, Suet Ling, Hong Kong.
Lake, Richard J., Gorey, Jersey.
Lam, Christina, Ont., Canada.
Lam, Francine, Hong Kong.
Lam, Siu Wing, Hong Kong.
Lam Lai Ping, N.T., Hong Kong.
Lambert, Wendy C., Glasgow.
Lau Heung Ping, Linda, Hong Kong.
Law Yiu Sing, Hong Kong.
Lee, Hyeon-Joo, Seoul, Korea.
Lee, Jin Young, London.
Lee, Mi-Suk, Chonbuk-do, Korea.
Lee Choi Kan, Franky, Hong Kong.
Lee Fung Kiu, Hong Kong.
Legrand Cox, Veronique, Hong Kong.
Leong, Margaret, Bandar Seri Begawan, Brunei.
Leung Yuet Shim, Stella, Hong Kong.
Liang, Tao, Wuhan, P.R. China.
Lo Poi Man, Polly, Kowloon, Hong Kong.
Louis, Eugene, Athens, Greece.
Luo, Weixing, Wuhan, P.R. China.
Macdonald, Louise C., Suffolk.
Ma Cho Pan, N.T., Hong Kong.
McIntosh, Robert P., Penicuik.
McKay, Euan S., Fife.
Mackenzie, Nicola-Jane, Hong Kong.
McKeown, Nicola, Plymouth.
Mak, Judy, Hong Kong.
Mak, So Yi, Hong Kong.
Mann, William M., Gloucester.
Marshall, Michael R., West Midlands.
Mathon-Clark, M.V.J., London.
Mayor Lopez, Enrique, Spain.
Meghji, Gulzar S., Nairobi, Kenya.
Mensink, Indra J., Lemelerveld, The Netherlands.
Mhatre, Vaishali, Bombay, India.
Michaelides, Artemios, Athens, Greece.
Molloy, Nicola, Ipswich.
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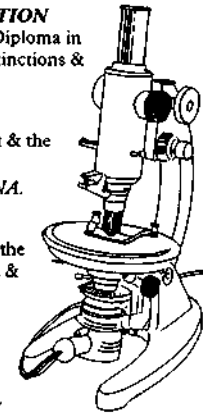

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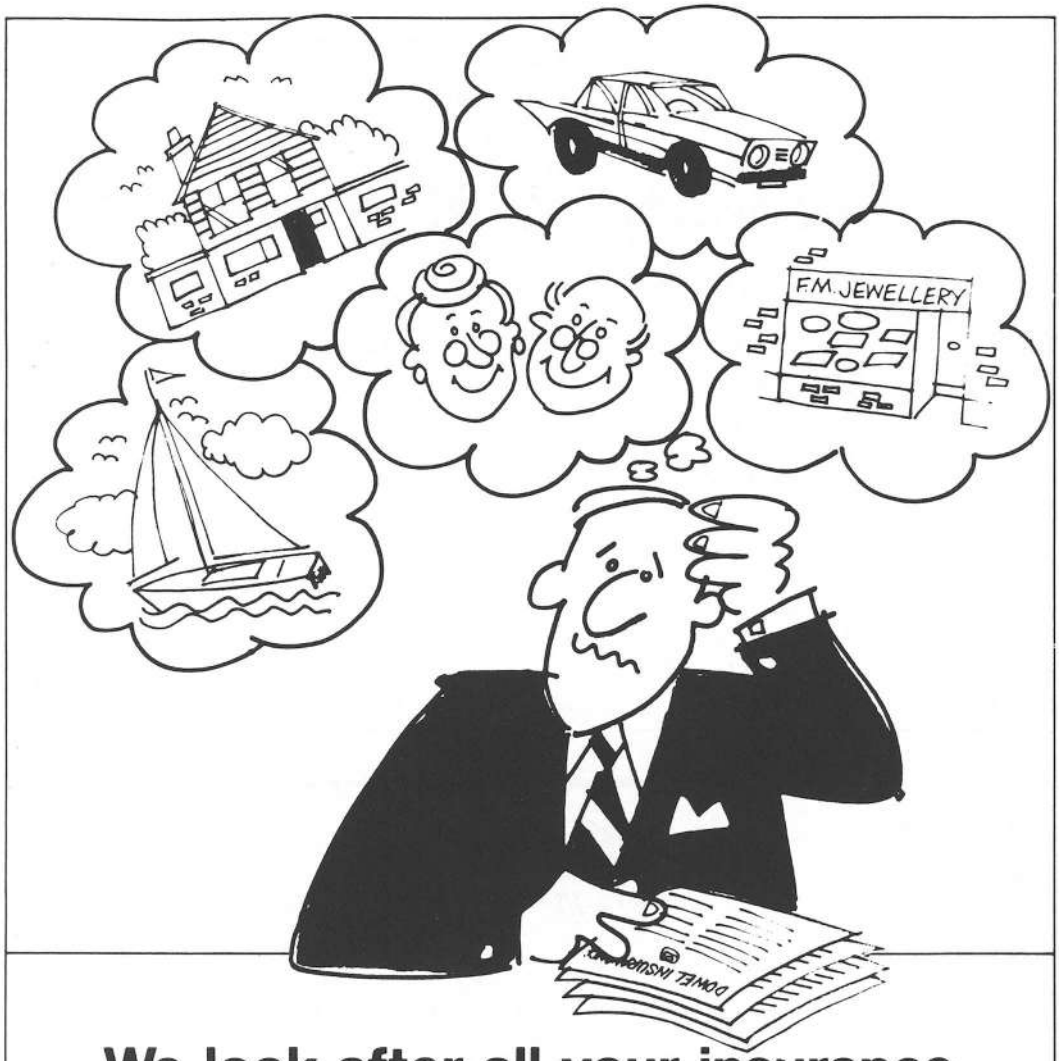

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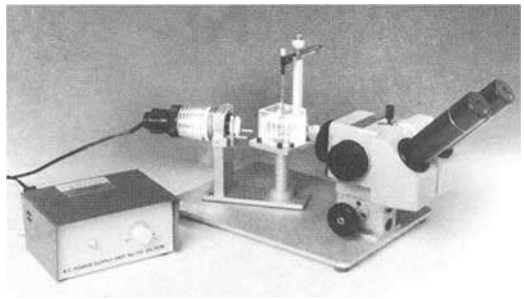

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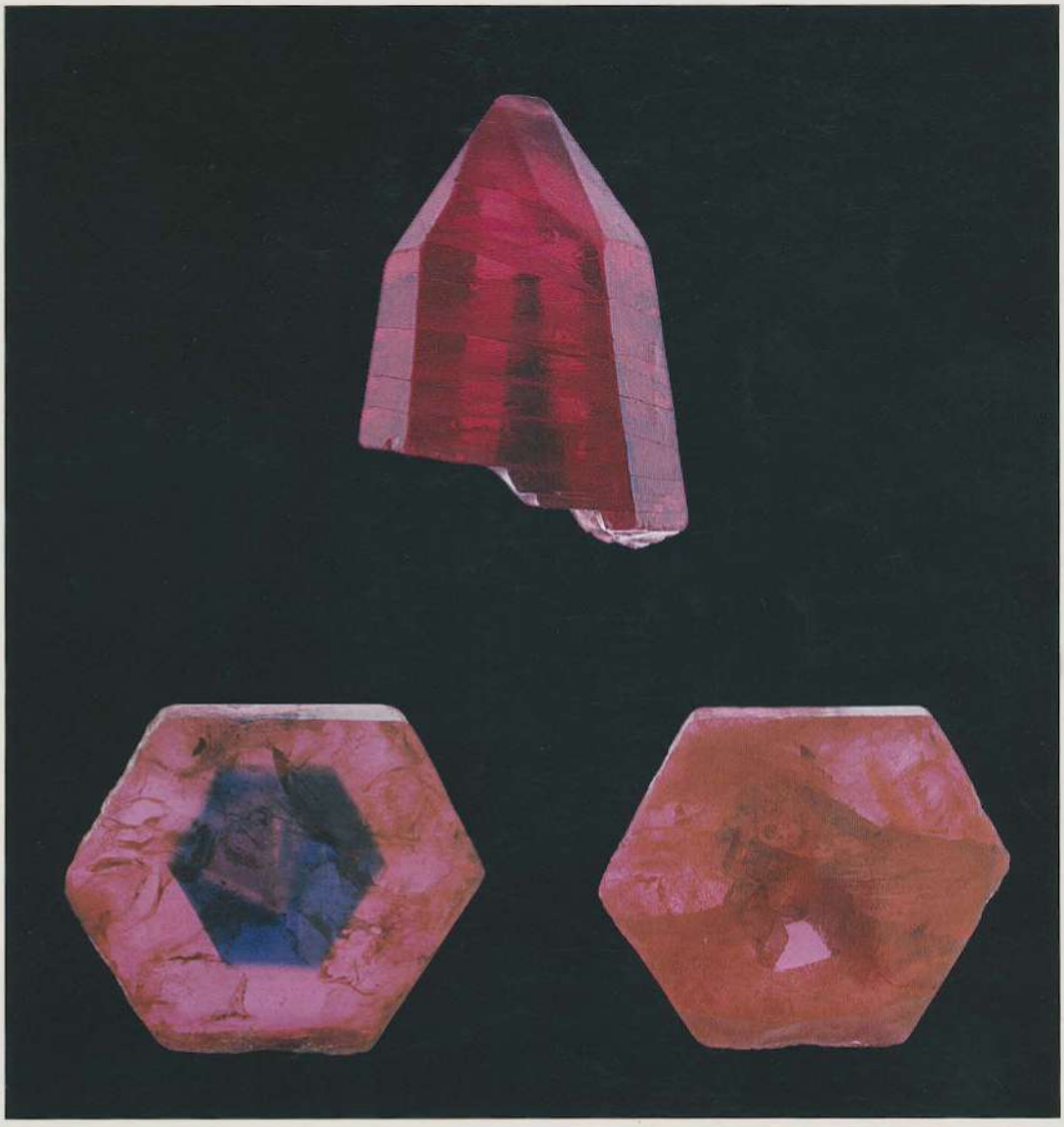

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Cover Picture

Ruby crystals from Mong Hsu, Myanmar (Burma): the terminated crystal (9mm high) is not heat treated. The hexagonal blue zoning characteristic of natural (not heat treated) Mong Hsu ruby rough is prominently visible in this partly polished crystal fragment (7mm across) on the lower left, while the view on the lower right is the same crystal after heat treatment at 1350°C in an oxidizing atmosphere for seven hours (see 'Myanmar and its gems – an update' p.3)

Upper photo by Shane F. McClure and lower photos by John L. Emmett. Crystals courtesy of Robert E. Kane.

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Myanmar* and its gems - an update

Robert C. Kammerling[1], Kenneth Scarratt[2], George Bosshart[3], E. Alan Jobbins[4], Robert E. Kane[5], Edward J. Gübelin[6] and Alfred A. Levinson[7]

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Fig. 1. The Kingdoms of Pagan in central Myanmar go back almost to the beginning of the Christian era, but the golden periods during the eleventh and twelfth centuries saw an extraordinary explosion of building which resulted in many hundreds of temples and pagodas (many now in ruins) squeezed into an area of only around 40 sq. km. *Photo by E.A. Jobbins*

Abstract

This paper up-dates and expands upon the information contained in Kane and Kammerling (1992) in relation to the gemstone production in the area of Mogok and goes further in that it relates the information gained on other important producing areas within Myanmar during several visits to the country by the majority of the authors. However, many of the areas referred to still remain unvisited by the non-Burmese and the information contained here is a compilation of published data and verbal information gained both within and without Myanmar.

Key words: Burma, gemstones, geology, Myanmar

*Myanmar - formerly Burma

Introduction

It is clear that over the past three years more information has become available about the current operations of the Myanma Gems Enterprise (MGE) and its joint-ventures. This follows a period that has lasted from the early 1960s in which little was revealed to the outside world about any gemstone production, prospecting, or any other related research that was being carried out in Myanmar [note: both Myanmar and Burma are used interchangeably throughout this paper depending upon historic preference]. One of the first indications of the increase in the availability of information was the paper published by Kane and Kammerling (1992) entitled *Status of ruby and sapphire mining in the Mogok Stone Tract.*

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The situation in Myanmar is such that certain areas remain within the designation 'not recommended for travel', a warning that westerners would be most unwise to disregard. Certainly the country is rugged and there is a need for expert guides. The survey map (Figure 2) shows the positions of the diamond and jade deposits in the north, through the corundum deposits in the Mogok area (Figure 3) and the diamond deposits and pearl farms in the south.

Myanmar's gemstone wealth is set out in Table 1 in the form of 'Economically important gemstones', 'Economically less important gemstones' and 'Rare gemstones'. Table 1 reads like the index to a gemmological textbook, with very few stones missing, and this attests to the enormous gemstone wealth possessed by this country.

History

Myanmar (Burma) is regarded as one of the earliest sources of fine rubies, sapphires and spinels. Mining was first recorded in the sixth century (Chhibber, 1934). These gemstones continued to be mined through the centuries with the Monarchy taking control of the mines towards the end of the sixteenth century. A number of historically important stones may be dated back to this period. Indeed, Burmese rubies, sapphires and spinels have been set in royal regalia and aristocratic jewellery for many centuries and probably back to the sixth century.

Some of these important stones figure prominently in several of the treasures in the royal regalia of a number of countries, including England. Two of the authors have recently enjoyed the privilege of examining most of the historic English Royal Regalia which is housed in the Tower of London. Possibly the earliest stone is the Black Prince's Ruby (actually an orange-red spinel) which can, with a reasonable degree of certainty, be dated back to 1367. This large spinel is set in the front of the Imperial State Crown. From its properties and inclusions it would appear to be of Burmese origin. The Timur Ruby (also a spinel) in the British Royal collection would also appear to be of Burmese origin. Superb rubies with Burmese characteristics are liberally distributed in the various coronation rings and sceptres, and are prominent in the Imperial Crown of India.

'When Upper Burma was annexed to the Empire in 1886 negotiations were opened with commercial firms for the working of the ruby mines near Mogok', so stated Gordon (1888) at a meeting of the Royal Geographical Society held on the evening of 27 February 1888. His report published in the proceedings of that meeting, goes on to state that a concession was granted to Messrs Streeter & Co. of London. He also reports that he was asked to survey and report on the mining district by the concessionaires. The map he produced at the time shows the Mogok area in great detail with even at that time a considerable amount of cultivated land.

Gordon's report for the period he spent surveying the ruby deposits is probably the most useful of its type for evaluating the differences that have occurred over the last 100 years. He describes not only the mines and mining methods in simple terms but also the inhabitants of the numerous villages in the area. He states that in this period the mines were of three types, the first, which was the least important at that time, consisted of

'working in fissure veins of soft material which are found embedded in the crevices of hard rock. ... The crevices in the older rocks give origin to cave mines, which are called "Loos" [also known as "loodwins"] where the soft earth is excavated in a primitive fashion and on a small scale. ... Pingu-toung, a steep hill overlooking Bama (spelt Panma in Figure 3), is rich in such mines.

'The second class of mine is called "Myaw" [also known as "Hmyawdwins"] or washing. The clay is cut into thin slices with a gardener's spade and washed from the funnel shaped excavations through the flumes or open timber channels, where the clay is dissolved away, or carefully examined for the stones.'

The third and most important at that time was the class of mines found in the flatter lands of the valleys. These were referred to as 'twinlons' (narrow circular pits) and their variants the 'lebins' (reinforced pits) which were normally only 60cm wide, the 'cobin' 1 to 1.5m deep and the 'imbye' 6 to 9m deep (Chikayama, 1987, 9, 4). At depths varying from 3 to 9 metres there is found a layer of corundum from a few centimetres to a few metres in thickness.

Messrs Streeter & Co. formed the Burma Ruby Mines Ltd. This company operated the mines from 1887 until 1925 with their operation centred around the area now known as the Mogok Stone Tract. Much modernization of mining methods took place during this period with the introduction of hydroelectric power to run the plant and

Fig. 2. Map of Myanmar showing gemstone and some mineral occurrences. See Table 1 for explanation of codes. *Map compiled by G. Bosshart*

Table 1: Gem minerals reported from Myanmar (Burma), including organic gem materials (compare with Figures 2 and 3) - Myanma names (in italics) after Chikayama (1988)

Material	*Description*	*Code*	*Locality*
1. Economically important gemstones			
Ruby (*Pa Ta Mya*)	red, purplish-red, also asteriated	R1	Mogok Stone Tract (MST)[1]
		R2	Momeik (Mongmit)[2]
		R3, 4	Nawarat and Namhsa Stone Tract[2]
		R5	Mong Hsu Stone Tract[2]
		R6	Nanyaseik (Nanyazeik)[3]
		R7	Sagyin Hills[4]
		R8	Belin Thandaung[5]
Sapphire (*Ni La*)	blue, also asteriated	S1	Mogok Stone Tract[1]
		S2	Momeik[2]
		S3	Mong Hkak[2]
		S4	Twingire area[4]
Fancy sapphire	pink, purple, violet, light yellow, colourless, green (rare)	S	Mogok Stone Tract[1]
Jadeite jade (*Kyauk sein*)	green, yellowish-green,white, purple to violet, brown, yellow and black	J1	Hpakant-Tawmaw Jade Tract (JT)[1]
		J2	Mawhan hills[3]
		J3	Hkamti hills[4]
		J4	Putao area[3]
		J5	Laisai area[3]
		J6, 7	Mandawng and Shangaw[3]
Maw-sit-sit	yellowish-green and black (opaque)	J8	Maw-sit-sit[3]
Greenstone (nephritic)	green, yellowish-green, brownish-green	J9	Langhko area[2]
Peridot (olivine) (*Pyaunggaung sein*)	yellowish-green, green	PD	Pyaunggaung (Pyaung Gaung)[4]
Spinel (*Am nyant*)	red, pink, purple, orange-brown, red-brown, violet-blue, greyish-violet, greenish-blue	SP	Mogok Stone Tract[1]
Cultured pearl (*Pa le*)	white, golden, bluish (saltwater, beaded and tissue graft)	CP1	Sir Malcolm Island[11]
		CP2	Mergui Peninsula[11]
2. Economically less important gemstones			
Amber (*Pa yin*)	light yellow, reddish brown, orange-brown	AM1	Maingkwan hills[3]
		AM2	Hukawng Valley[3]
		AM3	Kalewa hills[4]
Beryl	colourless	BE	Sakangyi (MST)[1]
	Aquamarine (*Mya pya*) – light blue, greenish-blue	BE	Sakangyi (MST)[1]
Diamond (*Sein*)	yellowish to colourless (Cape series)	D1	Tenasserim/Taninthari River[8]
		D2	Tavoy area[8]
		D3	Toungoo area[6]
		D4	Momeik area[2]
		D5	Putao area[3]
Feldspar (*Myaw myo kyauk*)	Albite – colourless, white, yellow, also chatoyant	FS	Kyaukpyatthat and Kyatpyin (MST)[1]
	Moonstone (*Myaw*) – white, light yellow, light brown, with bluish or white sheen (adularescent, also chatoyant)		

Material	*Description*	*Code*	*Locality*
Garnet (*U Daung*)	Almandine (*Zee*) – red-brown, dark red	GA	Kyatpyin (MST)[1]
	Spessartine (*Lein maw yi daung*) – yellowish-orange, brown-orange		
Lapis lazuli	blue, light blue (sodalite, lazurite)	LL1	Dattaw (MST)[1]
(*Pa la dote Hta*)		LL2	Kabaing (MST)[1]
		LL3	Thapanbin (MST)[1]
Natural pearls	white, golden (marine)	NP1	Mergui archipelago[6]
		NP2	Bay of Bengal coast[7]
Quartz (*Sa lin*)	Rock crystal - colourless	QU1	Sakangyi (MST)[1]
	Amethyst (*Sa lin swe*) – purple		
	Smoky quartz (*Sa lin nyo*) – brownish		
	Citrine (*Sa lin wa*) – light yellow		
	Agate – various types	QU2	Pagan hills[4]
	Chrysoprase – green	QU3	Tagaung hills[4]
Scapolite (*Thu Yaung*)	colourless, pink, yellow, violet, also bluish, pink and white (chatoyant)	SC	Mogok Stone Tract [1]
Topaz (*Halat ta ya*)	colourless, light yellowish-brown, light blue	TO	Sakangyi (MST)[1]
Tourmaline (*Pa ye u*)	yellow, orange-brown, brown, red, pink, black, green,	TM1	Mogok Stone Tract[1]
	greenish-brown, colourless	TM2	Monglong (Mainglon)[2]
Zircon (*Gaw Meik*)	green, greyish-green, brownish-green, brownish-yellow, orange, orange-brown, red-brown	ZR	Mogok Stone Tract[1]
3. Rare gemstones			
Amblygonite	colourless, yellow	RM	Sakangyi (MST)[1]
Andalusite	red-brown, dull green, orange; chiastolite crosses	RM	Kyaukse hills[1]
Apatite	blue, green, also chatoyant, colourless, yellow	RM	Kyaukpyatthat (MST)[1]
Chrysoberyl	colourless, yellow	RM	Mogok Stone Tract[1]
	Alexandrite (rare) – green		
Conch pearl	orange, flame structured (very rare)	RM	Mergui archipelago[6]
Cordierite (iolite)	violet-blue	RM	Mogok Stone Tract[1]
Danburite	brownish-yellow, colourless, yellow-orange, pink, greenish-yellow, green	RM	Kyauksataung and Thapanbin (MST)[1]
Diopside	light greenish-yellow, green, also chatoyant	RM	Mogok Stone Tract[1]
Enstatite	greenish-brown, dark red-brown, light yellow-green	RM	Mogok Stone Tract[1]
Epidote	green (*tawmawite*)	RM	Tawmaw (JT)[5]
Fluorite	purple, violet, green, yellow	RM	Mogok Stone Tract[1]
Kornerupine	yellow-brown, greenish-yellow, green, blue, also asteriated	RM	Mogok Stone Tract[1]
Kyanite (disthene)	light blue, blue	RM	Mogok Stone Tract[1]
Painite	dark red-brown (extremely rare)	RM	Ohngaing (MST)[1]
Phenakite	colourless	RM	Myanmar
Sillimanite (fibrolite)	violet-blue, green, grey-blue, also chatoyant	RM	Mogok Stone Tract[1]
Sinhalite	yellow-brown (very rare)	RM	Mogok Stone Tract[1]
Sphene (titanite)	orange-brown	RM	Mogok Stone Tract[1]
Spodumene	colourless	RM	Mogok Stone Tract[1]
Taaffeite	colourless, light violet (very rare)	RM	Mogok Stone Tract[1]
Tremolite	green chatoyant (amphibole)	RM	Myanmar
Vesuvianite (idocrase)	brown	RM	Myanmar

Note: All gem materials listed in Table 1 occur in the Mogok Stone Tract, with the following exceptions only: jade, andalusite*, epidote, phenakite, tremolite, vesuvianite, pearls and amber. (*Hughes, 1990, reports orange andalusite from MST, unconfirmed.)
Legend: 1 Mandalay District, 2 Shan State, 3 Kachin State, 4 Sagaing State, 5 Karen State, 6 Pegu State, 7 Arakan State, 8 Taninthari/Tenasserim State

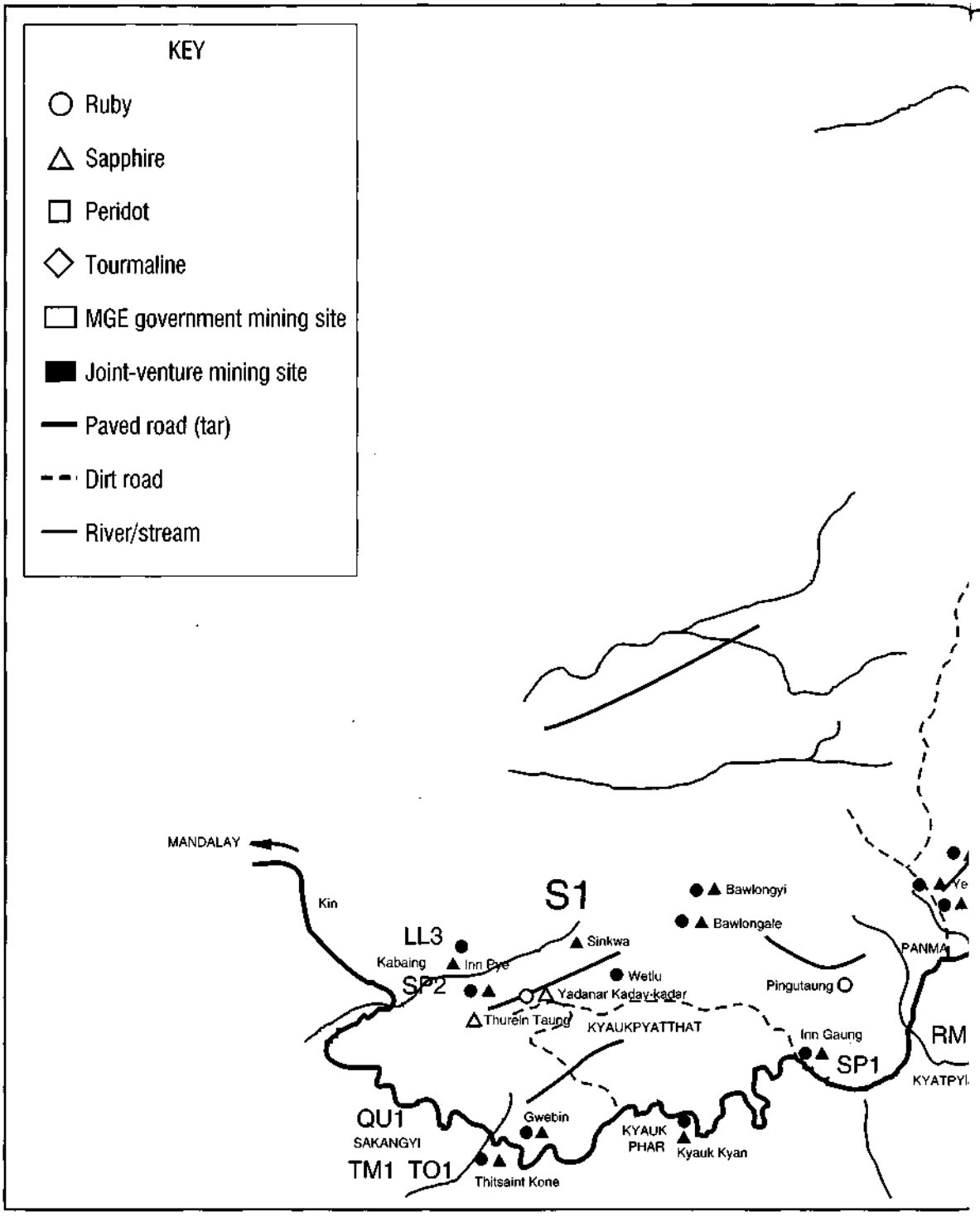

Fig. 3. Map showing gemstone workings in the Mogok Stone Tract. *Expanded and revised by G. Bosshart from Kane and Kammerling (1992)* 'Status of ruby and sapphire mining in the Mogok Stone Tract', *Gems & Gemology*, **28**, 3, 152-74, Fig. 4.

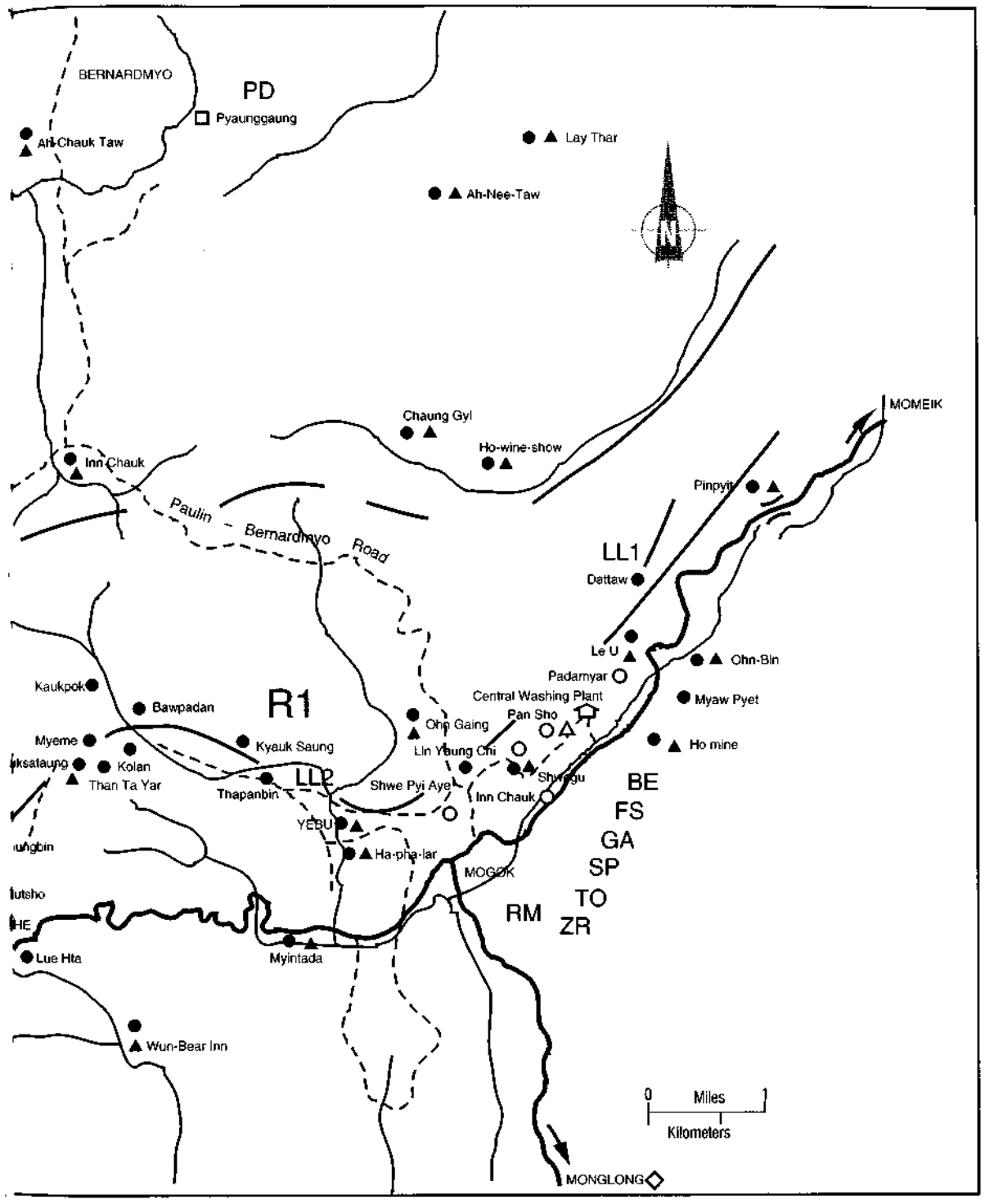
BERNARDMYO
PD
Pyaunggaung
Ah-Chauk Taw
Lay Thar
Ah-Nee-Taw
N
Chaung Gyi
Ho-wine-show
MOMEIK
Inn Chauk
Pinpyit
Paulin
Bernardmyo
Road
LL1
Dattaw
Le U
Ohn-Bin
Padamyar
Central Washing Plant
Myaw Pyet
Kaukpok
Bawpadan
R1
Pan Sho
Ohn Gaing
Myeme
Kyauk Saung
Lin Yaung Chi
Ho mine
Kolan
Than Ta Yar
LL2
Thapanbin
Shwe Pyi Aye
Inn Chauk
BE
FS
GA
SP
TO
ZR
RM
YEBU
Ha-pha-lar
MOGOK
Lue Hta
Myintada
Wun-Bear Inn
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MONGLONG

Fig. 4. This view of the town of Mogok shows part of the artificial lake in what was formerly an area worked by the Burma Ruby Mines Company. *Photo by R.C. Kammerling*

pump drainage water from the mine sites. The lake around which Mogok town is now built is witness to these former days for it is artificially produced from the former open cast workings of Burma Ruby Mines Ltd (Figure 4).

A series of events during the early part of this century caused the eventual collapse of Burma Ruby Mines Ltd; the introduction of commercial synthetic ruby, the First World War and the Great Depression. The company surrendered its leases to the Government in 1931 and mining reverted to the effective traditional indigenous methods. These methods continued to be used up until the early 1960s, when the mines were nationalized and the last reports, prior to the recent events, were available.

Fig. 5. Two of the three known crystals of painite recovered at Ohngaing in the Mogok Stone Tract. The larger crystal weighs 1.477 grams.

Returning to other exceptional gemstones, we should mention the [Pain] collection assembled by A.C.D. Pain during the period between the Second World War and 1963. Pain lived in Mogok and his interest in unusual stones was well known to the local miners who brought him 'difficult' stones for identification and possible purchase. His unique collection of rare and unusual stones was presented to the Natural History Museum, London, upon his death in 1971 and these Burmese stones were amalgamated with those of the former Geological Museum, London, in the 80s. Over the centuries Burma has produced almost every known gemstone. Of special note is the very rare mineral painite (only three crystals are known) which was named after A.C.D. Pain (Figure 5). Today, owing to the active participation of the Myanma government, gemstone mining and exploration is once again mechanized and modern techniques

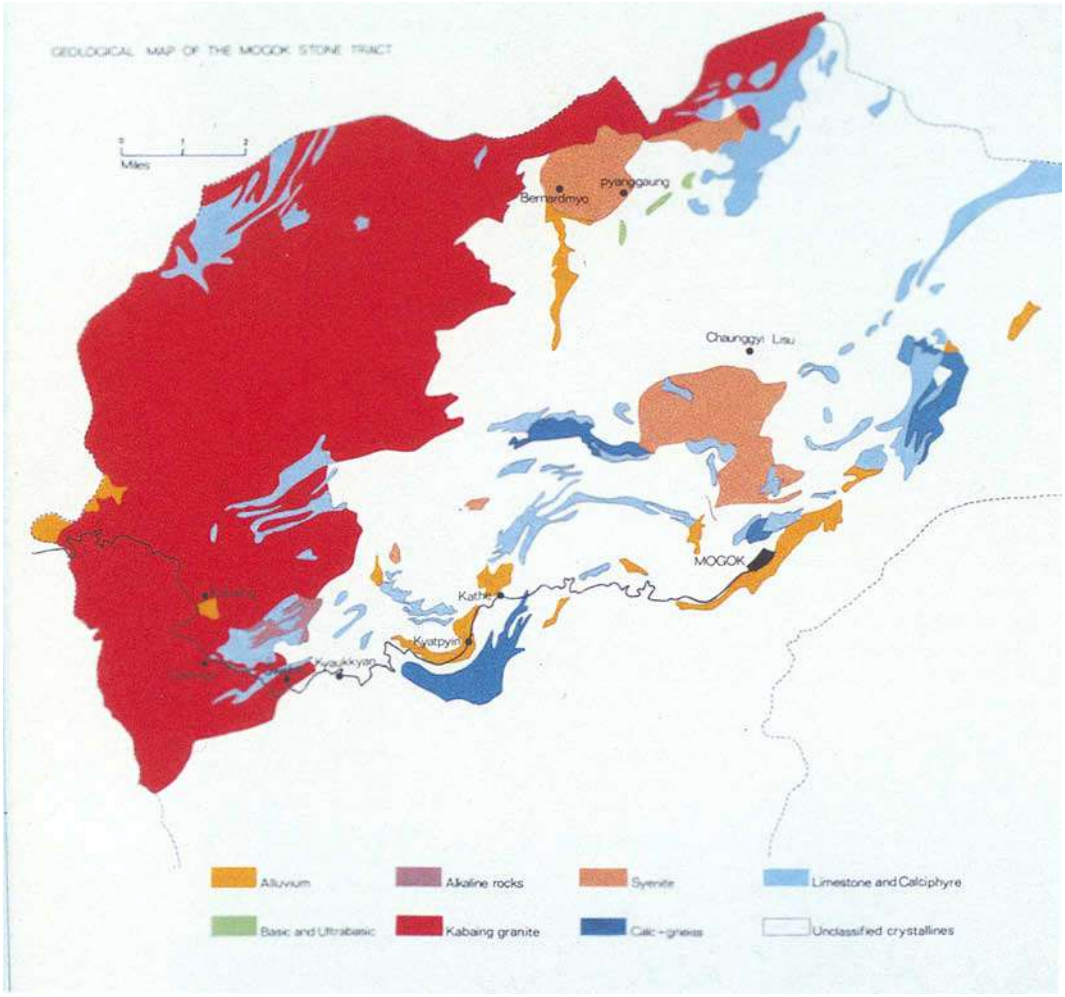

Fig. 6. Geological map of the Mogok Stone Tract, simplified after Iyer (1953)

are being employed. This has led to a marked increase in production.

General geological and tectonic survey

The country is traversed by roughly north/south trending mountains and hills belonging to the Eastern Himalayan orogenic system which sharply bends westwards just outside the country's northern-most tip. This morphology is the result of the Indian subcontinent drifting into the Asian continent, a mountain building process going on since early Tertiary times. This led to the juxtaposition of completely different rock types and to mineralizations having gem potential (e.g. the albite-jadeite dykes in Upper Burma, centred at J1 in the survey map (Figure 2).

In Myanmar, the suture zone (an active seismic collision belt) defining where the Indian plate is subducted under the huge Asian continent is delineated by the arc-shaped margin between the Indoburman mountain ranges in the west, and the Chindwin, Minbu and Irrawaddy Delta Basins in the centre of the country (a subduction thrust accompanied by a stringer of serpentinite bodies). Other expressions of the general tectonic structure can be seen in the line up of volcanic and plutonic rocks along the well defined western edge of the Shan Highland Plateau (Thin, 1985) or even in the diamond occurrences lined up from the Tenasserim State in the south, all the way through to Northern Kachin State

(locations D1 to D5 in Figure 2). Additional detail on the tectonic history of Myanmar and Mogok is given by Bender (1983) and more recently by Mitchell (1993).

In general terms, it can be stated that western Myanmar is a high-pressure/low temperature area with ultrabasic rocks in the north-west and sediments, metamorphosed sediments and igneous rocks in the south-west (Chin and Arakan States). In contrast, the east of the country (Shan State) is a high-temperature zone composed of uplifted metasediments intruded by granites and diorites. The south is mostly made up of granites and Paleozoic rock types (Bender, 1983).

Mineral resources

Southern Myanmar (as well as the entire Malayan peninsula) is renowned for its productive tin (Sn) and tungsten (W) deposits. Going north, Sn and W ores are again found south-west of Bhamo. Inside the slightly curved western edge of the Shan Plateau, lead (Pb), zinc (Zn) and silver (Ag) ores are encountered. On a concentric line west of this ore belt (i.e. closer to the suture zone), nickel (Ni) and chromium (Cr) mineralizations have been detected in peridotites (south of the jade belt centre J1 - Figure 2). Antimony, bismuth, molybdenum, uranium and manganese ore as well as baryte, chromite, ilmenite, columbite, tantalite, monazite (rare earths), graphite, albite, gypsum and asbestos occurrences have also been reported.

Bawdwin near Namtu (east of the Mogok Stone Tract) is known for its Pb, Zn, Cu and Ni assemblage, boasting the most important silver deposit in Myanmar. Alluvial platinum (Pt) in small quantities is found north of Madaya/Mattaya (Mandalay district). To complete the picture, gold is exploited in a considerable number of mainly alluvial deposits, gold nuggets being extracted from the important Kawlin-Wuntho area placers. Production figures of present-day official and private (illicit) mining activities, however, are difficult to procure.

Following the south-central banks of the Irrawaddy river, oil fields are lined up, showing that the fossil energy deposits obey the same general tectonic pattern. Oil and natural gas are also drilled off-shore (Montgomery, 1993). Oil production is said to cover the domestic needs. Coal reserves are located near Kalewa and in the Hukawng Valley, in western and northern Myanmar.

How did the primary ruby deposits at Mogok form?

The origin of the primary ruby deposits at Mogok is still controversial. There are two reasonable alternative explanations: (1) contact metamorphism and (2) regional metamorphism. Proponents of both explanations agree on all the important facts, e.g. that the rubies occur in a coarse-grained marble (metamorphosed limestone); that associated minerals include spinel and numerous silicates (diopside, phlogopite, etc.); that the ruby-bearing marbles form more or less continuous bands and lenses interbedded with gneisses; and that there are many types of igneous intrusions (e.g. granites, pegmatites, syenites) in the area. All proponents also agree that for the corundum (Al_2O_3) varieties to form in either of the two metamorphic situations listed above, an unusually enhanced Al_2O_3 content must be present. This is in contrast to rocks of normal Al_2O_3 content, in which the Al_2O_3 is taken up by common aluminium silicates such as feldspar, garnet, clinozoisite and the Al_2SiO_5minerals (andalusite, kyanite and sillimanite). Ideally, the best starting material for the formation of corundum would be one of the mineral forms of AlO(OH) (boehmite or diaspore) or $Al(OH)_3$ (gibbsite), as the metamorphic conversion would merely involve the loss of OH (effectively, H_2O) at geologically reasonable temperatures (less than 600°C) and low pressures.

Contact metamorphism involves mineralogical and textural changes in rocks resulting from the heat of nearby igneous intrusions. In certain circumstances, hydrothermal fluids may be introduced and these will have a major effect on the types of minerals formed (e.g. skarn minerals); this type of contact metamorphism involving the introduction of new material is called 'metasomatism'. Pressure does not vary significantly in contact zones around intrusions. Temperature is the dominant factor. The width of zones of contact metamorphism varies greatly ranging from a few centimetres to several kilometres.

Iyer (1953), who spent three seasons mapping in the Mogok area, was convinced that the ruby deposits formed by the contact metasomatic reaction of late magmatic pegmatitic fluids with the limestones, which were subsequently metamorphosed to marbles. Eventually, an aluminium-rich, silica-depleted environment was created from which Al_2O_3 formed. The sequence of events summarized from Iyer (1953, p.36) apparently involve the removal of SiO_2 (desilication) and other constituents from the magmatic solutions by means of chemical reactions

with the limestones in stages: (1) diopside, forsterite (olivine) and certain other minerals formed due to contact metamorphism initially when CaO, MgO (originally from magnesium in the limestones) and SiO_2 were present in sufficient quantities; (2) when SiO_2 and CaO became depleted, MgO combined with Al_2O_3 to form spinel, and when MgO became exhausted the remaining Al_2O_3 in the magmatic fluids crystallized as corundum. This mechanism also explains the occurrence of spinel, which is significantly more abundant than corundum at Mogok. It should be noted, however, that many modern experts in metamorpic rocks would prefer a mechanism by which corundum and associated minerals were formed by desilication of the limestones (rocks) rather than by desilication of the fluids as was proposed by Iyer (1953).

Regional metamorphism occurs over a large area and is caused by deep burial of rocks or by tectonic (i.e. deformational) forces in the crust; moderate-high temperatures and low-high pressures may be involved. Keller (1990) advocates regional metamorphism (with high temperatures and low pressures) as the cause of the primary ruby deposits at Mogok, because the ruby-containing marbles are interbedded with gneisses of unquestionably regional metamorphic origin.

In order to explain the regional metamorphic origin of the rubies, it is necessary to invoke some set of circumstances by which Al_2O_3 contents became elevated in limestones before they were metamorphosed to marbles, at which time the rubies (corundum) would have been formed. One such mechanism can be envisaged by intense (lateritic) weathering of an impure limestone (containing clay minerals, for example), perhaps in a karst environment, leading to the formation of boehmite, diaspore or gibbsite. After the surface weathering, the rocks would have been overlain by a great thickness of other rocks (shales, etc.) and deeply buried. In response to regional metamorphism limestone would change to marble, shale to schist and gneiss, and the aluminum-rich limestone impurities (e.g. boehmite) to corundum (ruby). The equation for the formation of corundum would be:

$$\underset{\text{(boehmite, diaspore)}}{2AlO(OH)} \longrightarrow \underset{\text{(corundum)}}{Al_2O_3 + H_2O}$$

This same mechanism was proposed for the formation of the ruby deposit in the Hunza Valley, Kashmir, Pakistan, which is very similar geologically to the deposits at Mogok (Okrusch *et al.*, 1976; Gübelin, 1982). Based on experimental data, Okrusch *et al.* (1976) determined that the formation of the rubies at Hunza took place at about 600°C and the pressure was about 7kb (equivalent to about 23 km depth).

The important emery (corundum with admixed spinel, magnetite, etc.) deposits of Naxos, Greece, which have been mined for centuries, are explained by a similar regional metamorphic mechanism. With respect to these deposits, Dixon *et al.* (1987, p.515) observed:

'Most of the deposits form part of discontinuous horizons, which are more or less conformable with the surrounding marbles and can be followed laterally over several kilometers. Such horizons are the metamorphosed equivalents of fossil weathering crusts [e.g. laterites] in a tropical climate.'

From the above discussion it is clear that either of the two possible geological processes, i.e. contact or regional metamorphism, could explain the origin of the Mogok ruby deposits. In fact, it is possible that *both* contact and regional metamorphism could have affected the rocks containing the rubies at Mogok. Rubies could initially be formed by contact metamorphism in the zone around an igneous intrusion and these rubies could have survived subsequent regional metamorphism during which additional rubies, occurring over a much larger area, would be formed. It is also possible to envisage situations in which regional metamorphism would precede contact metamorphism and rubies would be formed by both processes. Detailed geological mapping, and gemmological and mineralogical studies, should be able to recognize the two metamorphic events. For example, groupings of rubies could be made on the basis of their mineral inclusions and trace elements and the physicochemical characteristics (e.g. temperature of their formation) of their fluid inclusions could be determined. The spatial distribution of the rubies with respect to the igneous and metamorphic bodies might enable a distinction to be made between the two processes. Interestingly, Hänni and Schmetzer (1991) reported that two different types of rubies, one of which also occurs in marbles, have been recognized from the Morogoro area, Tanzania, based on gemmological properties; one of the types has properties similar to those from Myanmar. No explanation for the difference was offered.

Finally, it must be emphasized that this discussion is not applicable to rubies and other corundum varieties that are found in certain other localities, such as Thailand and Australia, because these occur in basalts.

The gemstone deposits

Outline

Given that the Government of Myanmar do not recommend journeys into certain areas at the present time the following description of the various gem deposits is a compilation of personal visits to the sites by the authors and information gained from sources both inside and outside Myanmar, and the verification of earlier published references.

The reference maps consulted are those listed in the map reference section. The Mogok Stone Tract map of Kane and Kammerling (1992) has been revised and expanded. A simplified version of the geological map of Iyer (1953) is included here (despite its age) since it still gives a good idea of the local distribution of the various rock types - note especially the sinuous outcrops of limestone (marble) which traverse the area in a generally east-west alignment (see Figure 6). However, it should be noted that, as in many other countries in the area, names change with time or after political upheavals, or may vary due to different official and local spelling (Mong Mit of earlier times became Momeik; Mong Hsu in Shan dialect is Maing Su in official Myanma language and Mai Suu is the Thai pronunciation in the gem exchange town of Mae Sai, northern Thailand; Hpakant, the name of the jade mining centre, can also be encountered as Hpakan and Phakant). Where not obviously wrong or outdated, two name or spelling versions are accepted with the more common one leading. For the Western hemisphere, rubies and sapphires still originate from Burma, not Myanmar (the country's official name since 1990), therefore, both names are used here equivalently. (NB. Myanma is the correct adjectival form describing Myanmar.)

The following indications on the survey map (Figure 2) and MST map (Figure 3) are (1) approximate for R3-R4, R6, R8, S3, J3-J4, CP2, AM2, D1, D4, TM2, and/or (2) unconfirmed for S4, J5,-J7, AM3, D2, D5, LL2-LL3, NP2, QU2, QU3. Productive areas are: R1-R2, R5, S1-S2, J1, PD, SP, CP1-2; (D1), (LL1), (NP1), (RM). (See Table 1 for explanation of the codes and localities.)

Mines and mining in the Mogok Stone Tract

Access to the historic Mogok Stone Tract in upper Myanmar was severely restricted for approximately 30 years, beginning in the early 1960s. Taking a more pragmatic approach, the Myanma government began to permit a limited number of foreign nationals to visit this important mining area at the beginning of this decade (Figure 3). Within the period February 1991 through February 1993, one or more of the authors took part in a total of four such visits, among the first by western gemmologists in recent years. The following information was gathered on these visits through personal observations and briefing documents provided by government officials and is presented for each of the mines seen. Also described is the Central Washing Plant, a facility that processes gem gravels recovered from several MGE-operated mines and the Zay Kyaung Buddhist Monastery, which displays several important gem-encrusted Buddhist images.

General Access

The famed Mogok Township is located about 100 air kilometres north-east of the city of Mandalay. On all of the authors' trips, Mogok was reached by road from Mandalay. In addition to the authors and their MGE hosts, the groups included an armed Myanma security detachment. The drive, which takes approximately six hours in good weather, is on a 200km and somewhat sinuous poorly paved road that is less than two lanes wide. About half-way through the journey one comes across individuals 'panning' for gold and the occasional ruby in several streams along the road. As we drove through this land of farming villages and teak, bamboo and banana plantations, we passed many ox-driven carts, the main mode of transportation for many of the inhabitants. Approximately 26km north of Mandalay one passes close to the Sagyin hills where an important and still active marble quarry is located. Interestingly some gemstones - including rubies and sapphires – are recovered as a by-product of the marble recovery process (Bauer, 1937; Chikayama, 1987, 9, 5).

In all instances, four-wheel drive vehicles were used. Although it was not needed between Mandalay and Mogok, it would have been difficult, and in some cases impossible, to reach some of the mine sites without the four-wheel drive capability, especially during those visits when the access roads were quite muddy due to monsoon rains. While the drive is somewhat long and dusty, the scenery is very impressive so the time seems to pass fairly quickly.

Fig. 7. An enormous broken boulder of jade (with polished areas showing 'Imperial Jade') on display at the headquarters of the Myanma Gems Enterprise, Yangon. *Photo by E.A. Jobbins*

The mining operations

From the nationalization of gem mining in 1963 until April 1990, all legal mining activity in the Mogok Stone Tract was conducted by the Myanma government. The Myanma Ministry of Mines still controls all legal mining and exploration in the Union of Myanmar. The Ministry founded the Myanma Gems Corporation on 1 April 1976, to oversee the Mogok gems project, the Pharkant Jade Project of the Mineral Development Corporation, and the Trade Corporation No. 19 (Gems) of the Ministry of Trade. In 1989, the Myanma Gems Corporation was renamed the Myanma Gems Enterprise (Figure 7).

Today, in addition to MGE mining, there are also government-authorized joint ventures between the MGE and private individuals or groups, as well as illicit mining activities. Although both the MGE and joint-venture operations (and even some unauthorized concerns) now mine a small number of primary deposits, most of the mining by all parties at Mogok today continues to be in secondary (byon) deposits.

MGE Mogok Gems Mining Department

All government mining in the Mogok Stone Tract is handled by the MGE's subsidiary, the Mogok Gems Mining Department, which has several geologists and mining engineers on staff. Eight mines are currently being worked exclusively by the government: one for peridot and seven for ruby and/or sapphire. All are well organized, mechanized operations that use various methods of mining such as ground sluicing, open pit, and underground tunnels into the host rock, depending on the type and nature of a particular deposit. The number of MGE-operated mines is limited only by budgetary constraints - additional deposits have been identified (MGE officials, 1991).

Joint - Venture Mining Contracts

On 9 March 1990, in an attempt to drastically curtail illegal gem mining, the Myanma government announced the availability to Myanma nationals of joint-venture mining leases on both the ruby and sapphire districts and jadeite mining areas (*Working People's Daily*, 1990) .

From this initial offering, the government

allowed 159 joint-venture projects to begin mining in June and July 1990. According to Yong (1990), the one acre plots were all located within a total of 230 acres in the areas of Mogok, Momeik, Mattaya and Thabeikkyin. Each approved operator reportedly paid at least 'a six figure' amount (in Myanma kyats).

All gems found at joint-venture mines have to be turned over to the MGE for quality grading and first quality stones have to be sold through the MGE at jewellery shops or the Gems, Jade and Pearls Emporium in Yangon (see below). Lesser quality stones are returned to the joint-venture operator after 10 per cent of the value is charged as a mineral tax, and 50 per cent of the value is paid to MGE (*Working People's Daily*, 1990). No gem mining joint-ventures between the MGE and non-Myanma nationals are presently in operation, but MGE officials have stated that they are being considered.

Independent (illicit) mining

In Mogok, citizens have found gems even while drilling water wells, leading to the mandate that anyone in the area who wants to dig in the earth must first seek approval from the government (*Working People's Daily*, 1990). Yong (1990) estimated that the government of Myanmar may have controlled as little as 5 per cent of the total gem production before the first joint ventures were established, with the rest being smuggled to Thailand and India. MGE officials believe that the many joint ventures now in operation have greatly reduced the amount of illegal mining. However, on a small scale simple washing of gem gravels with rattan baskets is still common in the streams and rivers in and around Mogok. Illicit miners also use age-old methods that are still practical today.

Mogok mines

Yadanar Kaday-kadar

This MGE-operated mine is located about 22 km south-west of Mogok township. It is a large, open-cast mine (Figure 8) whose importance is noted in its name, which roughly translates as 'billions of precious stones'. At the time of the authors' visits in 1991, 1992 and 1993, it was described by local officials as the most productive of the MGE-operated sapphire mines.

The site, at the base of Thurein Taung and Katheyaike hills, is a natural basin of about 180m diameter and with an area of about 29 800 sq.m forming the western end of an elongated lowland that runs from north of Kyaukpyatthat village to Sinkwa (Yadanar Kaday-kadar Camp, 1991). A mass of limestone bands outcrop on the floor of the valley, forming the western rim of the lowland area. This rim serves as a structural barrier, trapping material that has washed down into the basin from surrounding high ground—including the two above-mentioned hills that are known to be sapphire-bearing. This basin had been worked by private miners until confiscation in the mid 60s, followed by a cooperative effort between local miners and military personnel. The current operation, under direct MGE supervision, began in May 1985 after geological surveying indicated the basin had very good potential.

It is interesting here to note that, although the current name of the mine has a positive connotation, an earlier designation tells of past difficulties in working the area. The local miners used to call this basin Lok Khet (meaning 'difficult to work') because of both the considerable overburden – averaging 18m deep – that had to be removed as well as the seasonal flooding. As the basin was not drained regularly, it eventually filled with water producing a small artificial lake. This problem with flooding was solved after the MGE took over the operation, by cutting a 270m long, 1.2m square drainage tunnel through the brecciated marble hillside, a project that took three years (MGE, 1992).

The majority of the production at this mine, which may be both eluvial and alluvial, is blue sapphire (Figure 9), with lesser amounts of ruby, pink sapphire and other gems also being recovered. The mining observed by the authors is basically of the hmyawdwin type, with labourers using simple hand tools to cut trenches into the sides of the open pit. With water flowing rapidly from a pipe at the top of the trench, workers along its slope excavate gravels along its sides, pushing them into the stream of water.

The gravity-propelled water, mud and gravel mixture collects in a pit at the base of the trench, from which it is pumped upward to a wooden holding tank. At this stage in the operation larger rock fragments are removed by hand and the gravels washed with clean water. The gravels then travel through a series of sluices (Figure 8), with final hand-sorting taking place at the mine site.

Although not observed by the authors, some underground mining has also reportedly taken place at this site. These were reported in 1991 to

have included the following: a 27m main shaft that connects to the 180m drainage tunnel, a 17m cross-cut and a 12m minor shaft (Yadanar Kadaykadar Camp, 1991).

Shwe Pyi Aye (meaning 'Golden land of peace')

This large open-cast mine is located within the township of Mogok. A secondary deposit, this site had been worked by military cooperatives from 1965 to 1987. Mining by the MGE began in December of 1987 and since then Shwe Pyi Aye has become known as a source of fine-quality rubies. Several years ago, a magnificent 5.56ct oval faceted ruby, known as the Crown of Mogok, was cut from a 10.95ct crystal recovered at Shwe Pyi Aye. Also recovered are pink sapphires, a significant amount of red spinels, minor amounts of blue sapphire, and other gem minerals.

Here, the gem-bearing gravel layer – typically 1.8 to 2.4m thick – is reached by removing the 12m to 24m deep overburden with a bulldozer of Japanese manufacture (Figure 10). The overburden itself consists of topsoil and 'red soil' (i.e. laterite). During a visit in March 1991, the exposed gravel was being removed through the use of labourers and simple hand tools, then pumped to an on-site processing centre that included the use of 2.5cm and 1.9cm screens and a series of sluices. At the time of these visits, on-site staff consisted of a mine manager, three engineers, a geologist and thirty-seven other personnel (Shwe Pyi Aye Camp, 1991).

When visited one year later, the exposed area of the mine had increased significantly, with much additional overburden having been removed. Mechanization now also included the use of an excavator to remove the gem-bearing gravels which were loaded onto a truck for transporting to the Central Washing Plant: on-site processing was no longer taking place. During the rainy season, when the Central Washing Plant apparently is not in operation, the gravels are accumulated at the mine site in a large, fenced-in holding area. At the time of this visit, the on-site work force had been reduced by ten men, a 'force reduction' due, no doubt, to the increase in mechanization (Shwe Pyi Aye Camp, 1992). The operation was essentially the same when visited in February 1993 (Shwe Pyi Aye Camp, 1993), but there was a significant enlargement of the excavated area compared with the previous year.

Pan Sho

Operated by the MGE, this open-pit mine is located only 1.5km north-east from the centre of Mogok. Here, production from secondary sources includes rubies, pink and blue sapphires, and on a percentage basis significant amounts of other gem materials as well. During a visit in March 1991 a bulldozer was being used to remove the overburden, after which an excavator was employed to extract the gem gravels. These were loaded onto trucks for transport to the Central Washing Plant which is only about 0.5km away.

Than Ta Yar

Operated by the MGE until the latter part of 1991 when it became a joint-venture entity, Than Ta Yar is located about 5km to the north-west of Mogok and less than 1.5km from the Kyauk Saung mining area. At this locality hard-rock mining techniques are used to expose loodwins, chemically weathered cavities, fissures and even large cavernous areas in the host marble in which the more resistant heavy minerals such as corundum have concentrated. Pneumatic drilling and blasting were being used at the mine to widen openings in the marble so as to reach the often very rich gem deposits. Production at this site is predominantly ruby, with lesser amounts of other gem materials such as fine red spinels and moonstones. MGE officials stated that Than Ta Yar is one of the more important joint-venture operations at Mogok in terms of total carats of ruby rough produced.

Entrance to the Than Ta Yar mine is through a steep, downward sloping tunnel that intersects a deep (approximately 100m) vertical shaft. Near this point of intersection was a winch, used to extract larger waste rock from below. The bottom of the shaft was reached via wooden ladders and scaffolding. This lowest level of the mine contained roughly a metre of water, from which point workers placed waste rock and debris into a bucket which was winched by hand to the surface of the mine. This shaft was located about 2.5m higher than the bottom of and leading off from the main vertical shaft. The gem-bearing byon was pumped from the bottom of the mine to an on-site processing plant.

This recovery operation was located within a fenced-in compound no more than 50m from the mine's entrance. The gem-laden gravels and water being pumped from the mine showered out of a pipe like a fountain and onto an inclined trough (Figure 11), where workers with long-handled rakes manually pushed larger rock

Fig. 8. The large open-pit mine at Yadanar Kaday-kadar in October 1992. The 'byon' (gem gravel) is being washed down by the water jet (upper left); the gravel is concentrated in the sluices or 'hymadwin' (centre); the vertical drainage shaft is capped by the black 'tent' (bottom left); see text. *Photo by E.A. Jobbins*

fragments over the side. The remaining gem-bearing material collected in a heap on the ground at the opposite side of the trough, where it was loaded into small circular sieves. These, in turn, were placed in a small vibrator jig used to concentrate the heavy minerals on the bottoms of the sieves. Adjacent to the vibrator jig was a sorting table, onto which the sieves were quickly inverted. The final step was the hand removal of gemmy material, which was placed in a sealed container with a 'one-way' opening. At Than Ta Yar we also saw 'kanase' women pursuing their traditional function of working the discarded gravels from the mine, hoping to find rubies and other gems that may have been overlooked in the original recovery operation.

Fig. 9. Rough sapphire (some grading to ruby) from the Yadanar Kaday-kadar mine. *Photo by E.A. Jobbins*

Thurein Taung ('Sun Mountain')

Operated directly by the MGE since December of 1987, this hard-rock mine produces sapphires almost exclusively. The site is reached by driving about 23km west from Mogok, followed by a brisk fifteen minute walk along 900m of a steep and narrow, often barely discernible footpath from the Yadanar Kaday-Kadar mine site. Here the geology consists of alkali-rich basic igneous rocks that have been intruded into the marble. The gems are recovered from this intruded igneous rock and biotite-bearing gneiss. Conventional tunnelling along the sapphire-bearing vein is accomplished through the use of pneumatic drilling and blasting with dynamite (Figure 12). Electricity to power the compressor as well as lighting within the mine is provided by an on-site generator. When first visited by one of the authors in March of 1991, the on-site staff

Fig. 10. Removing reddish-brown overburden (from 12-24m thick) to reach the gem gravels at Shwe Pyi Aye. *Photo by R.E. Kane*

Fig. 11. Gem-laden gravels from the Than Ta Yar mine are pumped to this on-site processing plant where they shower out of a pipe and on to an inclined trough. *Photo by R.C. Kammerling*

consisted of twenty-five employees: a site manager, an assistant manager, a geologist, two mining engineers and twenty other personnel (Thurein Taung Camp, 1991) (Figure 13).

Located a short distance from, and visible *en route* to, the MGE mine, is a similar operation that is operated as a joint venture. Both operations are within a few hundred metres of the spectacular Kyaukpyatthat Pagoda which sits atop a promontory that dominates the area.

Lin Yaung Chi

This MGE mine, surrounded by the Let Nye, Shwe Taing, and Yekan mountains, is located due north of Mogok on the east side of the Panlin Bernardmyo road. Lin Yaung Chi is known for its occasional production of exceptionally fine gem rubies, such as a piece of rough that was faceted into a 4.70ct stone that sold for US$282,000 ($60,000 per ct) in the February 1992 Emporium in Yangon. Accessory minerals, including spinel, garnet, apatite, green tourmaline and mica are also encountered while mining for ruby (Lin Yaung Chi Camp, 1992).

Prior to it coming under MGE control, this site was worked by local miners who recovered the gems by removing the topsoil to reach gem-bearing gravels that concentrated in weathered and fractured areas within the marble; these gem-rich gravels are known as 'let kya byon'. Rubies were found *in situ* in 1970 and MGE mining of this primary source began in April 1977 (Lin Yaung Chi Camp, 1991; 1992).

The current hard-rock mining cuts through brecciated marble associated with veins in a fault zone. The veins, which strike N64°E and dip at an angle of 30°, occur between a massive marble and a diopsidic marble (Lin Yaung Chi Camp, 1991; 1992). Tunnelling follows the fault zone between the two marble types, with sawn timbers used for shoring.

During all of our visits, rubies were being recovered from the main tunnel which at the time was roughly 150m long. A 30m-long secondary shaft, called lateral cut number 1, runs perpendicular to the main tunnel and is located about 50m down from its entrance; a second 50m long lateral cut (number 2) occurs a further 50m down the main tunnel. Both lateral cuts were made for the purposes of ventilation and water drainage, the latter accomplished through the use of generator-driven pumps; in addition, number 2 is also used to transport men and materials into and out of the mine.

As with all of the hard-rock mines visited by the authors, drilling and blasting were being used. At the time of our visits on-site staffing consisted of a mine manager, three assistant mining engineers and forty-four other personnel. Gem processing takes place on-site, just beneath the entrance to the main tunnel. Sorting begins with the use of large-mesh screens to remove larger rock fragments, followed by sluicing and then hand-removal of the gems from the gravels.

We were told by MGE officials that on the other side of the hill a secondary deposit was being worked (Shwegu, '*Golden cave*'). By the description provided, the mining technique resembles a hmyawdwin: using water gravity force (from a 135 000 litre reservoir), the gem-bearing gravel is forced down the hill into a sluice. This operation produces large sapphires of good habit, as well as the associated gem minerals of spinel, garnet, apatite, green tourmaline, and topaz (Lin Yaung Chi Camp, 1991; 1992). It is interesting to note that Lin Yaung Chi was in ancient times known as 'vulture hill'. According to a local legend vultures, who would rest on the hill when searching for food in the area, would mistake rubies lying on the ground for pieces of meat. It is possible, therefore, that the legend about vultures plucking rubies from a deep valley at Mogok traces to this very site.

Dattaw

A joint-venture mine, Dattaw is located approximately 5km to the north-east of Mogok. It is reached by driving along a narrow dirt road, followed by a rather steep climb by foot that takes approximately one hour. During the early stages of the climb we noted a number of areas where independent miners were working gravels along narrow streams.

The area where the Dattaw mine itself is located becomes apparent long before it is reached, as it reveals itself at a distance by its stark white marble tailings that flow down the side of the mountain. Some of this marble, still *in situ*, is also exposed on the face of the mountain where a number of tunnels have been excavated at various levels (Figure 14). The mine is entered through an excavated tunnel that leads into a natural limestone cave, the latter as high as 10m in some areas. Additional excavated tunnels lead off from this natural cavern. As with other hard-rock mining at Mogok, pneumatic drilling and blasting are used. Although we did not enter it, we were also shown the tunnel entrance that

leads to where the SLORC (State Law and Order Restoration Council) ruby had been uncovered. At the time of the March 1992 visit an area in front of this entrance was being used to prepare blasting charges.

Dattaw is known as a reliable source of some very large ruby crystals, as well as one of the more important producers in terms of total caratage, although some of the other mines typically produce higher quality stones. One of the large stones recovered at Dattaw was the Nawata ruby, later renamed the SLORC ruby. Found in early 1990, it weighed 504.5 carats and measured 43 mm x 37 mm x 33 mm before it was trimmed to 496.5 carats. Another large stone, reported to weigh 560 carats, was shown to two of the authors at the mine a few days after it was found in March 1992. In early 1993, the Dattaw mine produced yet another large specimen; this 1743ct crystal was examined by three of the authors during the February 1993 visit. Dattaw was also the source of a rare green danburite rough (58ct) which yielded a magnificent oval gemstone of 24.98ct (Figure 15).

Kyauk Saung

Located about 3km north-west of Mogok centre, this mining area hosts a number of separate joint-venture mines. Here primary mines are located along one side of the access road, stretching roughly 1.5km along a ruby-rich marble contact zone (Figure 16). The authors were told by MGE officials that underground water is diverted for working these mines. As elsewhere, drilling and blasting are used. MGE officials also indicated that the operations at Kyauk Saung were among the most productive joint ventures in terms of total caratage produced.

Although all the primary mining was concentrated on one side of the road, secondary mining was in progress on the other side. Here, within easy view of the joint-venture mining, some secondary mining, mostly of the 'lebin' type, was being carried out. In addition, there were many local people – mostly women – who were hammering on marble that had been discarded from the primary mines in hopes of recovering any rubies or spinels that may have been missed (Figure 17). This searching of the tailings by the 'kanase' women is an age-old custom.

Central Washing Plant

The Central Washing Plant is a facility constructed and operated by the MGE to process gem-bearing gravels from government owned and operated mines that do not have such on-site facilities. It lies approximately 1.5km to the north-east of Mogok centre, very near the MGE operated Pan Sho mine. Construction of the plant began in May 1989 and was completed about six months later, with production starting during the last week of November. The plant has a capacity to process 100 tonnes of material a day (Central Washing Plant, 1991; 1992; 1993).

Gem-bearing earth removed from some of the MGE-operated mines is brought by trucks to this facility. The trucks back onto a concrete slab, dump their load onto a large metal grate and high-pressure water cannons are then directed onto the material (Figure 18). Larger rocks and debris are trapped by the sturdy grating and discarded by labourers, while the dirt and gem-bearing gravels are washed into a concrete pen that is at a somewhat lower level than the grate. From platforms on either side of the pen, additional water cannons are used to wash the gravels, causing the lighter soil to be washed away, this muddy waste water flowing down a chute. Simultaneously, the water cannons cause the gem-bearing gravels to travel into the first of a series of vibrating screens and concrete chutes. One of these screens separates out all stones larger than 1.9cm, which are then collected and hand-sorted on a table. A second screen separates out stones smaller than 1.9cm but larger than 0.6cm for similar hand-sorting. Finally, the smaller gravels continue down the system until they reach a large, concrete holding tank, near the bottom of which is a drain pipe of approximately 8cm diameter. Gravel removed through this pipe flows into shallow, circular metal pans that have bases fabricated from fine-mesh screening. Each filled pan is placed in a small vibrating jig for several minutes, the vibration causing the heavier minerals, including the corundum, spinels and zircons, to settle to the bottom centre of the pans. The pans are then taken to a sorting table where they are quickly overturned, thereby leaving the denser materials at the top centre of the piles. The gems are then picked out by sorters using stone tongs and placed in locked metal containers. Although all gem-quality materials were placed into the containers without sorting by type, the sorters showed the authors their expertise in separating ruby from red spinel on the basis of crystal morphology and slight differences in colour.

During the 1993 visit we were told that the

Fig. 12. Miner preparing for blasting in the 'hard-rock' mine at Thurein Taung. *Photo by R.E. Kane*

Fig. 13. Sorting sapphire at the primary tunnel mine at Thurein Taung. The blue sapphire is visible in matrix (bottom right) and in the concentrate (centre). *Photo by E.A. Jobbins*

Fig. 15. This very rare green danburite (24.98ct) was cut from rough (58 ct) found in a Dattaw mine. *Photo by E.A. Jobbins*

Fig. 14. In the primary mine at Dattaw, a worker uses a drill in the excavation of the marble. *Photo by R.C. Kammerling*

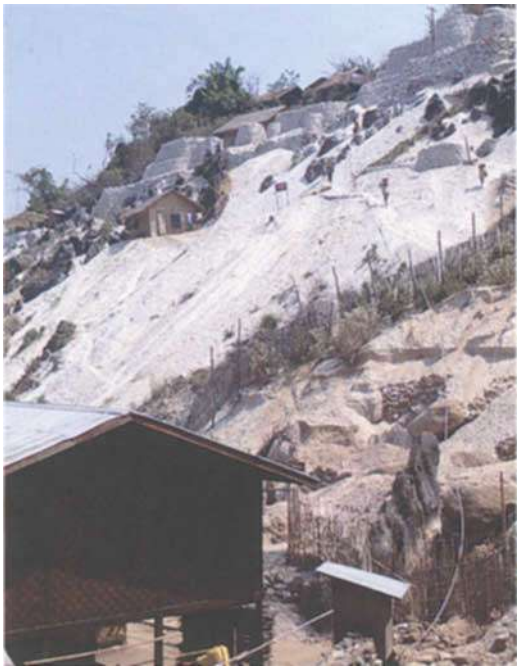

Fig. 16. At Mogok, the primary (*in situ*) occurrences of rubies is in a coarse-grained marble. Here at Kyauk Saung, white marble tailings cover a large portion of the hillside. *Photo by R.E. Kane*

Fig. 17. Here a 'kanase' woman hammers on marble discarded from the primary mines at Kyauk Saung in the Mogok Stone Tract in hopes of recovering any rubies or spinels that may bave been missed. *Photo by R.C. Kammerling*

Fig. 18. Central Washing Plant. From platforms on either side of a pen, water cannons are used to wash the gravels brought to the facility for processing. *Photo by R.C. Kammerling*

Central Washing Plant was processing gem gravels from several mines, including Pan Sho, Shwe Pyi Aye, Padamyar and Pingu Taung. The considerable amounts of water required for the washing operation are pumped from a dirt reservoir located just below the washing plant. To increase the efficiency and capacity of the plant an additional, larger reservoir was being constructed of concrete during the 1993 visit. This new on-site source of water will be uphill and adjacent to where the trucks initially deposit the gravels.

Zay Kyaung Monastery

This Buddhist monastery (Figure 19) is of gemmological significance since it houses some important gem-set Buddhist icons. These are reported to have been produced with funds and gem materials donated by pious individuals. One such icon is a roughly 8cm tall image of the Buddha carved from what appears to be an opaque ruby. This is mounted on a 30cm high moulded plaster (?) dome that is completely covered with uncut, predominantly red stones which the authors believe to include both rubies and garnets (gemmological testing was not possible). Another such icon seen was also of Lord Buddha, this one fabricated of gold and ornately decorated with faceted gems, among them many that appeared to be rubies of very good colour. A smaller dome of unfashioned red gems was surmounted with another Buddha image approximately 7.5cm high (Figure 20), this one transparent and bluish-green in colour. We were told that this had been carved from an aquamarine crystal that was recovered locally. During our visit to the monastery in March 1992 we had an audience with the head monk, who granted us permission to photograph the icons.

Another point of interest in the Mogok area is Beedaw Hill, site of a Buddhist shrine (Figure 1). Our primary purpose in visiting this site, however, was for the spectacular view it provides of Mogok and the man-made lake below.

Mong Hsu

In July of 1992 the Government of Myanmar declared the Mong Hsu Gemstone Tract (R5 in Figure 2) and, in doing so, the country recognized yet another important source of gem quality ruby. 'Mong Hsu', as its spelling and pronunciation (Hsu = Soo) is becoming internationally recognized, may also be spelt and pronounced in a variety of other ways, including 'Mine Shu' as it was first spelt and pronounced to a number of the authors by Myanma Gems Enterprise (MGE) staff in September of 1992.

The ruby mining area is near the Shan State town of Mong Hsu, an area of Myanmar which the government advise foreigners not to enter at this time. The authors, therefore, experienced some difficulty in obtaining first hand descriptions of the situation there. However, enough reliable and verifiable second-hand information was obtained through the MGE and dealers in Thailand for a reasonably accurate account of the situation to be recorded here.

The town of Mong Hsu is located approximately 250km east of Mandalay and the mining is said from information gained in November 1993 to take place at a site known as 'Sia laing'. Hlaing (1993) reports that this primary deposit occur between the peaks of Loi Hsawnshtoa (approximately 16km south-east of Mong Hsu) and Loi Paning, and secondary deposits are mined in the river terraces of Nam Hsu, just 5km south east of Mong Hsu. Hlaing also reports that primary Mong Hsu ruby occurs *in situ* in marbles and associated minerals include quartz, green tourmaline, red-brown garnet, staurolite, pyrite and acicular tremolite. He further states that the ruby-bearing gravels of the secondary alluvial deposit at the village of Loi Kham (about 8km south-west of Mong Hsu) are of a quartz-hematite-rock pebble type and that these lie below a yellowish-brown soil about 32-64m thick.

Whilst the alluvial Mong Hsu ruby tends to be water worn, the primary mining area yields euhedral crystals that are prismatic combined with series of dominant and subordinate bipyramidal faces and positive rhombohedral and/or small pinacoidal terminations (Smith and Surdez, 1993). Most Mong Hsu rubies contain distinct blue cores and/or zoning when mined (see cover picture) and these need to be removed by heat treatment. Whilst some heat treatment of this material is now taking place in Myanmar (as evidenced in the last two Emporiums), most stones are treated in Thailand. The Mong Hsu ruby is now one of the most common ruby 'varieties' available on the market and yet it has been conspicuously under represented at the Yangon Emporiums since its discovery. At the October1993 Emporium only four small lots of stones identified as having come from this area and described as 'heat-treated cut ruby' in the Emporium catalogue were offered at auction.

Inclusions in Myanma rubies and sapphires

It is well known in the gem world that for certain gemstones geographic origin – the provenance – can have a significant impact on its value. This is especially true with the most costly of coloured stones, among them ruby, sapphire and emerald. As rubies and sapphires from Myanmar have long been held in high esteem, their gemmological properties, in particular those that would help to separate them from natural stones from other localities, as well as their synthetic counterparts, have been studied in some detail.

Although more 'high-tech' methods – trace element analysis, optical absorption spectra, etc. – are being called upon increasingly in making such distinctions, internal features as noted through the microscope remain the most relied-upon characteristic to say whether a given stone is or is not of Burmese origin. Furthermore, this is the only diagnostic test available to the vast majority of gemmologists.

In the past it was not particularly difficult to recognize Myanma rubies on account of their inclusions and to distinguish them with relative certainty from rubies originating from other localities. Commercially suitable rubies used to originate from Myanmar, Sri Lanka or Thailand, whereas other localities were more or less unimportant and their rubies did not appear on the market in sufficiently important quantities. The formation mechanisms and the geological conditions of the three most important ruby deposits are so completely different from each other that their rubies' growth features also differ quite conspicuously.

Exquisite rubies of the coveted pigeon blood red colour were very rare and hardly ever occurred in Thailand or Sri Lanka. Therefore, the colour already served as a certain indicator. However, the inclusions offered considerably more certainty. Although the individual mineral inclusions and their associations were characteristic for Myanma (Mogok) rubies, it was the general appearance and *distribution* of the internal features which typified them. In order to gain a relative certainty, three internal features were necessary to coexist (Figure 21):

1. Relatively local concentrations, so-called *nests* or also zones, of short rutile needles (silk), of which many would display the unusual *arrow twins* (Figure 22).
2. In addition, more or less well-shaped calcite crystals (Figure 23) which could usually be identified by their twinning lamellae or the rhombohedral cleavage planes. The calcite crystals are often accompanied by reddish-brown phlogopite or dark reddish-black prisms of rutile and sometimes by dolomite and spinel. However, no margarite has been observed as in rubies from the Hunza valley.
3. Further telltale features are the roiled structure of swirl-like treacle (Figure 25), resulting from inhomogeneities and optical distortions. Irregularly spaced polysynthetic twin lamellae may be present.

Fluid inclusions forming fingerprint feathers are relatively uncommon and certainly less frequent than in rubies from Sri Lanka. In contrast to the general appearance of the above-mentioned principal elements forming the inclusion scene in Myanma rubies, Thai rubies reveal themselves by the so-called rosettes, which consist of a negative crystal or a crystal of apatite or garnet surrounded by the typical decrepitation halo.

In the 1960s, rubies from East Africa (Longido, Umba Valley and Nganga, to name just the most important) started appearing on the market. However, due to their entirely different geological background and mode of formation, the internal features had nothing in common with Myanma rubies.

When, however, more recently rubies originating from the Hunza Valley and deposits in Vietnam made their début on the gem market, it was immediately obvious that it would be much more difficult to distinguish these from Myanma rubies, for all three deposits are composed of very similar mother-rocks (dolomitic marble) with comparable geological histories. While a highly experienced gemmologist, who is accustomed to scrutinizing inclusion scenes and their individual elements, might be able to discern them, in most cases gemmologists have to take recourse to more elaborate methods. So far, experience teaches that rubies from the Hunza Valley in Pakistan and those from Vietnam contain a less diverse variety of mineral inclusions than the rubies from Myanmar, apart from other usually

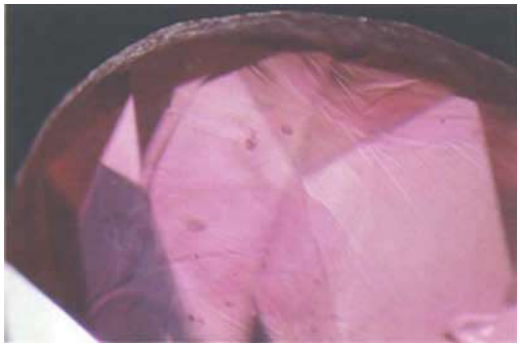

Fig. 21. Swirled 'treacle' or 'roiled' effect in a Mogok ruby. 15x. *Photomicrograph by J.I. Koivula*

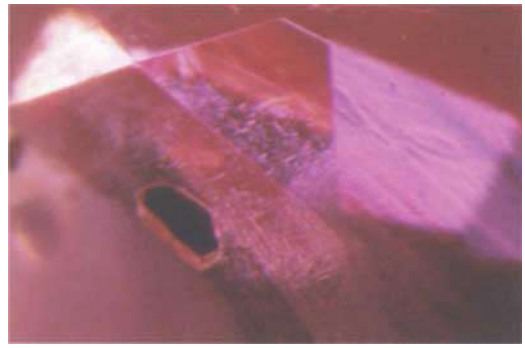

Fig. 22. A black crystal of graphite surrounded by short rutile needles and a 'roiled' or 'treacle' structure in a Mogok ruby. Graphite flakes also occur quite abundantly in the dolomitic marble mother-rock. 9x. *Photomicrograph by E.J. Gübelin*

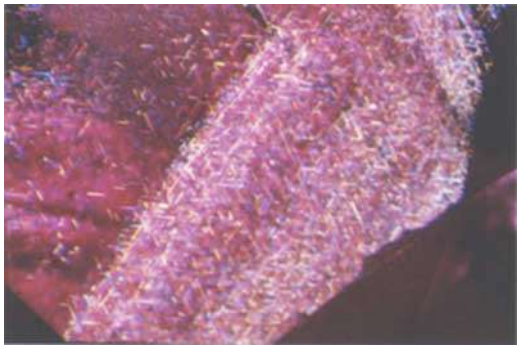

Fig. 23. Dense net of iridescent epigenetic rutile needles in a Mogok ruby. 60x. *Photomicrograph by J.I. Koivula*

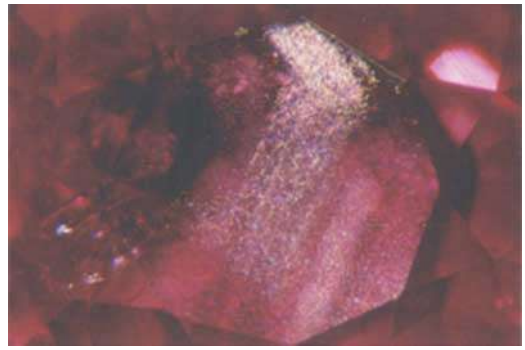

Fig. 24. Dense silk consisting of short rutile needles forming zones parallel to the prism faces in a Mogok ruby. They reflect the impinging light. 18x. *Photomicrograph by E.J. Gübelin*

Fig. 25. Strongly corroded calcite crystal displaying the typical rhombohedral pattern of twinning in a Mogok ruby. 64x. *Photomicrograph by E.J. Gübelin*

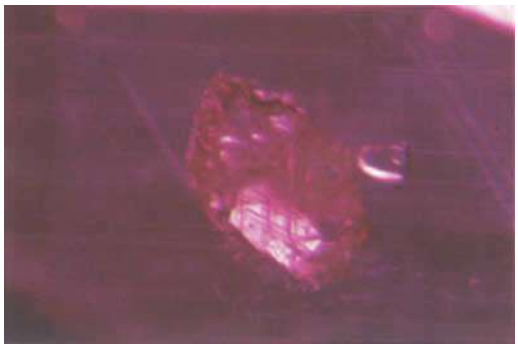

Fig. 26. Locally typical inclusion association, embracing a loose group of calcite crystals, as well as loosely woven silk (cloud) of rutile needles, and a black prism of rutile. 25x. *Photomicrograph by E.J. Gübelin*

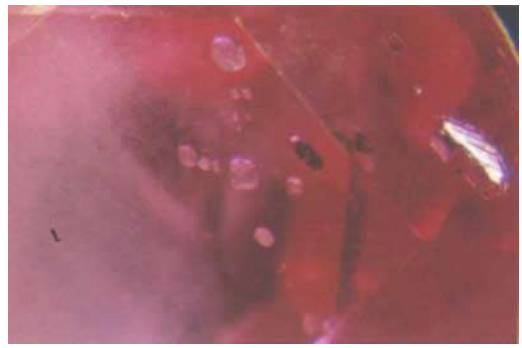

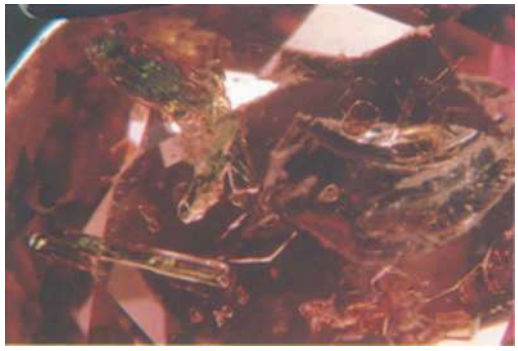

Fig. 27. New association of inclusions discovered: green pargasite crystals accompanied by strongly corroded brown spinel crystals. This association forms a particularly characteristic combination in Mogok rubies. 9x. *Photomicrograph by E.J. Gübelin*

Fig. 28. A recently identified slightly resorbed crystal of sphene displays typical striation as an individual peculiarity in a Mogok ruby. 8x. *Photomicrograph by E.J. Gübelin*

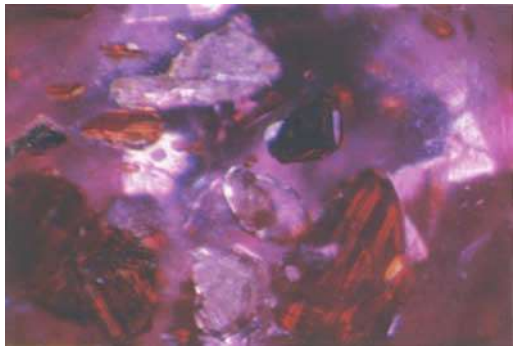

Fig. 29. Very dark brownish-red crystals of rutile, epigenetic rutile needles, and whitish and near-colourless calcite crystals in a Mogok ruby. 50x. *Photomicrograph by J.I. Koivula*

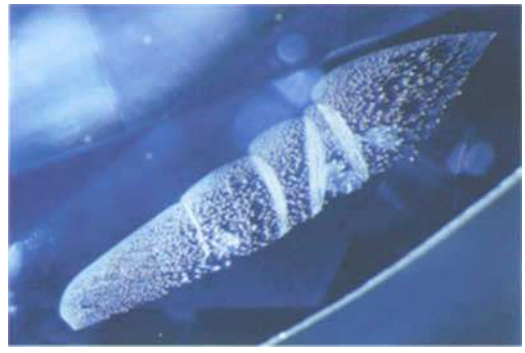

Fig. 30. A partially healed fracture system with some 'folding' in a Mogok sapphire. 25x. *Photomicrograph by J.I. Koivula*

Fig. 31. A white cloud of epigenetic rutile needles, some of which are iridescent, in a Mogok sapphire. 40x. *Photomicrograph by J.I. Koivula*

Fig. 32. Fine 'silk' of rutile needles and a corroded yellowish apatite in a Mogok ruby. 20x. *Photomicrograph by E.J. Gübelin*

trivial but, in certain cases, quite important differences.

During the two excursions to Myanmar (1992, 1993), in order to visit the gem mines around Mogok and to attend the Gem Emporium in Yangon two lots of rubies were purchased by one of the authors, containing 21 and 22 rubies respectively. Upon examination of these rubies, the fact that *all* 43 rubies displayed an absolutely characteristic inclusion scene containing the above and some additional features was met with reassuring satisfaction. (Figures 21 and 22 reliably attest to this fact.) Some of these rubies were surprising as they contained mineral inclusions which have never before been identified. By means of electron microprobe, energy dispersive X-ray fluorescence or X-ray diffraction they could be identified as being a yellowish, typically corroded apatite, a flake of graphite, a well-shaped scapolite crystal, a slightly resorbed sphene crystal and an emerald-green pargasite, as well as strongly corroded brown spinel (see Figures 25 to 28). So far it has been noticed that apatite in Myanma rubies is normally resorbed to a rounded shape, whereas in Sri Lankan gemstones apatite usually displays euhedral, prismatic crystals. Some of these mineral inclusions have not yet been observed in either Hunza or Vietnam rubies.

Some of the inclusions seen in Myanma rubies also occur in the sapphires. Fluid inclusions in the form of partially healed feathers often with a 'folded' or fingerprint-like appearance are not uncommon in Myanma sapphires (Figure 30).

This relatively short report about the investigation of the above-mentioned 43 rubies, which took almost a whole year, reveals that a thorough study of the internal features of rubies from the various commercially important mines is always enlightening.

Very recent work has shown that inclusion patterns of Mong Hsu rubies differ markedly from those of Mogok rubies. Apart from occasional apatite or dolomite crystals, mineral inclusions are typically absent from Mong Hsu rubies. Instead they commonly display cloud and dust stringer patterns as well as prominent growth structures and colour zoning (see cover picture).

Furthermore, an examination of these stones by one of the authors revealed that the stones still exhibited their distinctive blue cores, in contrast to the Thai treated stones.

However, rubies from Mong Hsu are readily available in Mae Sai, the northernmost town in Thailand, just across the small Moei Kok River from the town of Tachileik, Myanmar. In Mae Sai, only a few hundred metres south of the border, rough, untreated rubies from Mong Hsu are openly traded in shops and at street-side tables along what has come to be known locally as 'Soi Tab Teem', or Ruby Lane (Figure 33). Here Thai dealers, mostly from the south-eastern city of Chanthaburi, purchase stones from Burmese who daily cross the bridge between Mae Sai and Tachileik. According to one such Thai dealer, the cost of setting up shop here is quite reasonable: roughly $US 400 to rent a shop, $80 for a table on the main soi (lane) and $40 for a table on one of the smaller side lanes. While visiting this market in early November 1993, one of the authors was able to observe transactions taking place. Parcels may range from one or two small pieces to parcels weighing over 1kg (5000 ct). Stones are examined and, if agreement is reached, goods and money (in Thai baht) exchanged.

From discussions with individuals both in Myanmar and Thailand, the route from mine to market is as follows: the rubies are taken from the mine site to the town of Mong Hsu; they are then taken 275km (by road) to the city of Taunggyi where there is a government (i.e. legal) market at which, for a fee, dealers can trade their stones (interestingly, when one of the authors asked some Burmese dealers the source of their stones, some replied 'Taunggyi' rather than Mong Hsu). However, rather than then going to Yangon, the vast majority of the rough travels east to the town of Keng Tung and from there to Tachileik and across the border into Thailand. Typically the next stop is Chanthaburi where the stones are heat-treated to remove the blue colour core (see cover picture) and are then fashioned, after which they go to Bangkok for marketing throughout the world. In some cases it is reported that the blue cores become needle or flake-like inclusions on heating.

At the time of a visit by one of the authors to Mae Sai in late 1993, several individuals reported that the number of dealers had decreased significantly from a few months' previously. This was

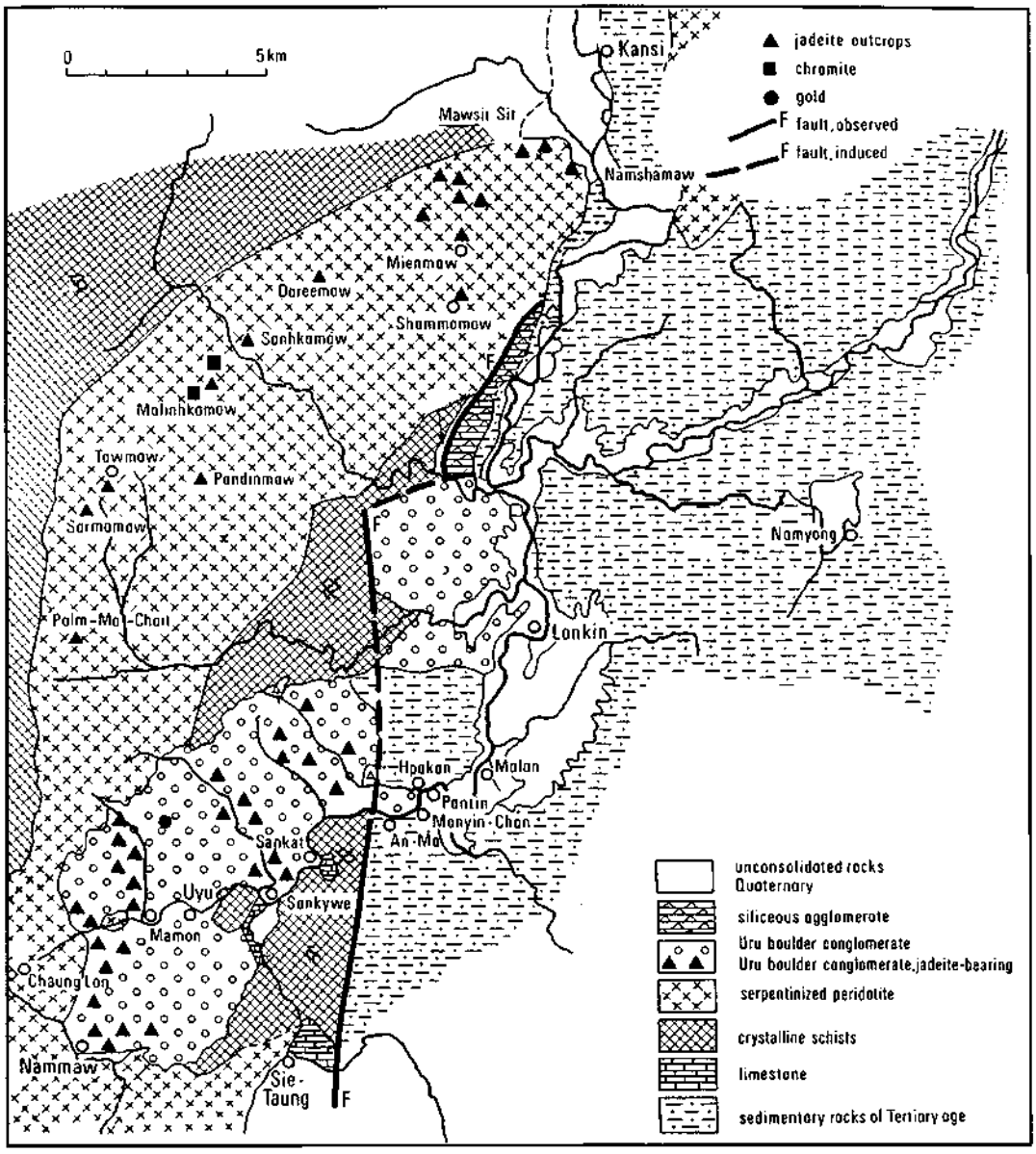

Fig. 34. Geological map showing jade occurrences. Modified after Chhiber (1934) and Bender (1983)

attributed to some controversy surrounding Mong Hsu rubies and a subsequent drop in price. Apparently fluid inclusions in the material result in some fracturing during heat treatment. The fractures in turn are invaded by the fire-coating substance(s) with which the stones are prepared before heat treatment, resulting in inclusions very reminiscent of secondary partial healing planes in some flux-grown synthetic rubies. Unconfirmed reports in both Mae Sai and Bangkok suggest that some stones from Mong Hsu sent to Europe and the Far East were returned after being misidentified as flux-grown synthetics. It was further stated that, whereas heat treatment is generally an accepted – and expected – practice, the presence of such glassy, flux-like fillings deep in fractures was much less acceptable, especially in larger stones.

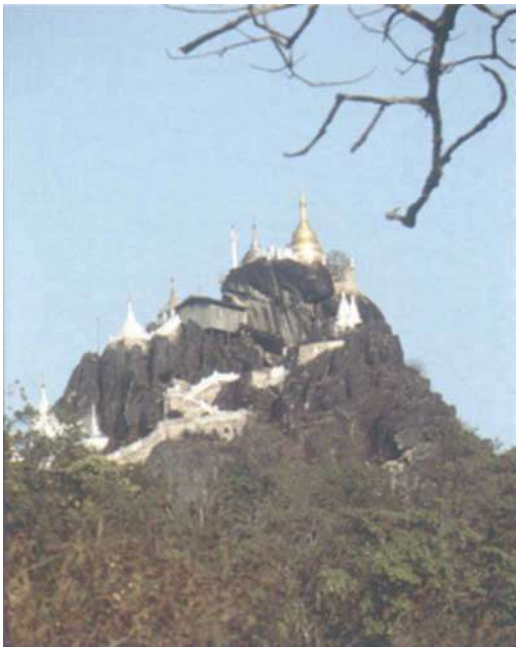

Fig. 19. The spectacular Kyaukpyatthat Pagoda sits atop a promontory only a short distance from the Thurein Taung mine near Mogok. *Photo by R.C. Kammerling*

Fig. 20. At Zay Kyaung Monastery, one of the important gem-set Buddhist icons. *Photo by R.C. Kammerling*

Fig. 33. Gem dealers examine ruby rough from Mong Hsu in the gem market at Mae Sai, northern Thailand. *Photo by R.C. Kammerling*

Jadeite

In 1893 Warry, who was an employee of the British Consulate, gave an account of the discovery of jadeite in Burma: a party of Chinese traders on their way back to China, were passing through what is now the northern part of the Kachin State sometime during the thirteenth century. They picked up some stones to help balance their baskets on the donkeys' backs. When they returned to China they found that the stones were top quality jadeite. Many Chinese went back to the area in search of the jadeite, but none was found. Another story, and one told by the local Kachin people recalls a girl doing her laundry in the Uru river. A passing group of Chinese traders, noticing the wonderful green hue of the rock she was using as her laundry board took it from her (Chikayama, 1988, 10, 1). Following a very hostile period that lasted up to 1784 a survey party from China located the occurrence of jade by the Uru River and from that time on jadeite was carried through the mountains and into Yunnan.

The so-called 'jade belt' of Upper Burma stretches from Hweka north of Indawgyi Lake to Singkaling Hkamti on the Chindwin river

Fig. 35. Sectioned boulder showing veins of 'Imperial jade' at the October 1992 Gem Emporium, Yangon. *Photo by E.A. Jobbins*

Fig. 36. Sectioned boulder of 'maw sit sit' jade at the October 1992 Gem Emporium, Yangon. *Photo by E.A. Jobbins*

(Figure 34). The main mining area being situated between Hpakan (about 105km or four hours by jeep from Mogaung Station) and Tawmaw near the Uru river (Lintner, 1989). Jade is also found in Mandawng and Shangaw east of the Nmai Hka river, as well as in the Kachin State. However, it is said that the deposits yield a jadeite of an inferior quality.

A broad area of serpentinized peridotite intrudes a country rock of crystalline schist to the north-west of Hpakan. In between this and the large expanse of Tertiary deposits to the east of the river Uru lies an area of conglomerate, the Uru Boulder Conglomerate, which is the source of most of the jadeite (Chikayama, 1988, **10**, 3/4). In the Mamon jadeite mining area the Uru Boulder Conglomerate has a maximum width of 6.4km. The alluvial deposits along the river Uru are conjectured to exceed 300m in thickness, and it is said that from Mamon to Hpakan, the banks of the Uru are solid Boulder Conglomerate with jadeite sizes ranging from pebbles of 10cm to boulders of several metres width. Chikayama (1988, **10**, 3/4) gives other occurrences of jadeite in this area as (a) outcrop/lode, (b) degradation gravel, (c) Tertiary conglomerate and (d) Uru riverbed deposits.

The government of Myanmar reportedly allows mining in only three places: Hpakan and the neighbouring villages of Waje Maw and Sanchyoi, the workers at these mines are government employees and they receive a monthly wage plus a 10 to 20 per cent commission on the value of any higher quality jade they may find (Frey and Lintner, 1991). Outside Myanmar this mining region is often referred to as 'Mogaung' after a town about 80km south-east of the mining area on the major north-south Ledo Road. However, Hpakan is the jade capital of Myanmar's Kachin State and has been described as a 'mini Hong Kong' by many of its visitors with thousands of fortune seekers entering the area every year (Lintner, 1989).

Whilst in 1962 jadeite mining was put under government control, anti-government Kachin forces have prevented the full enforcement of this monopoly and much of the jadeite is smuggled out to Thailand through the border town of Mae Sai and on to the city of Chiang Mai. It is said that blocks are tied to rafts and taken down river to Hmalin. The jade then continues by steamer down the Chindwin, hidden in such places as paddy baskets, to the railhead at Monywa when the journey continues on to Mandalay and Taunggyi and on to the border with Thailand (Lintner, 1989). Whilst a small amount of this jadeite goes to India, the majority crosses into Thailand adding to the prosperity of Chiang Mai. There are also at least two jade-cutting factories in the town of Mai Sai of which the authors' are aware. In addition to fashioning jade other ornamental stones are cut in these facilities.

There are three main qualities of jade (Chikayama, 1988, **10**, 5):

(1) Imperial jade (*Ah ye Kyauk sein*) (Figure 35) – the highest quality of chrome-green material. Used almost exclusively to produce small gemstones, e.g. cabochons, small pendant pieces.

(2) Commercial jade (*Ah hte Kyauk*) – gem-quality material suitable for producing jewellery items such as bracelets and less valuable gemstones.

(3) Utility jade (*Ah tha Kyauk*) – material typically

used for carving ornamental objects such as figurines and functional objects like bowls.

China appears to have become an important jade buyer again. The old jade route from the Kachin State to the former jade trading centres of Baoshan and Kunming in Yunnan is being revived. A significant portion of the Burmese jade still reportedly goes to Hong Kong but much is cut and carved in the areas of southern China neighbouring Hong Kong's Northern Territories. The Emporium sales of the major Burmese gem materials, including jade boulders by the MGE in Yangon, appear to be comparatively modest in terms of total dollar sales although they do typically represent a significant percentage of total Emporium sales. The great majority of the attendees for the jade portion of the Emporiums are ethnic Chinese. At the most recent Emporium these included, in addition to buyers from the People's Republic of China and Hong Kong, others from Taiwan, Thailand, Singapore, Indonesia and South Korea. It was remarked that the contingent from Taiwan was becoming increasingly important.

Maw-sit-sit (named after its locality) (J8 in Figure 2), which was at one time mistakenly sold all over Europe as chloromelanite (a form of jadeite of dark green to black colour), is a brilliant green rock often found with dark, almost black veins and spots (Figure 36). It was found, collected and studied by Dr Edward Gübelin in 1963. The black spots (chromite) are often surrounded by dark green kosmochlor (ureyite), a chrome-rich analogue of jadeite, with bright green jadeite and a chromian amphibole with minor albite (Anderson, 1990; Hänni, 1993).

Peridot

The mines in the Pyaunggaung mountains

The mining for peridot takes place on the northern slopes of Kyaukpon mountain (Webster, 1983) near Pyaunggaung in an area approximately 19.5km north-north-west of the town of Mogok. The peridot is found in association with ultrabasic rock in talc/olivine veins, and also in actinolite, phlogopite, talc, olivine and chrysotile pockets. The area was a significant producer of peridot after the Second World War. It is probable that the ancient kingdom of Pegu supplied gems from these mines to the outside world and that they were among those that were so appreciated before the Renaissance (Bariand and Poirot, 1985).

Travelling to the mining area from Mogok entails a four-wheel-drive journey of one or two hours, depending upon the weather conditions, along the unpaved Panlin-Bernardmyo road that in places is no more than a mule track. The route winds through the mountains from an elevation of 1500m in Mogok to approximately 2150-2250 m at the mine sites. It is a route extensively used by mule trains which take farm produce from the mountain villages down to be sold in Mogok, and other goods on the return journeys. Onions and rice appear to be the main items transported on the downward journey.

During the early stages of the journey several instances of what appeared to be unauthorized ruby mining were observed, but this became less evident as the elevation increased. The MGE operated peridot mine sits on Kyaukpon mountain and overlooks the town of Bernardmyo (originally a sanitorium named after the first Chief Commissioner of the province following annexation to the British Empire in 1886 (Gordon, 1888)). It is approached by turning off the main two-vehicle-wide track on to a smaller single-vehicle track and through a small onion farming village and terraced rice fields. It is interesting to note that there are a number of villages of ethnic Nepalese in the area. Once through this area the large open pit mine with associated buildings comes into view (Figure 37), here drilling and blasting are used in the recovery operation. The mine area is also used as a military post situated above the mine buildings. A ten minute hike from this mine brings one to a joint-venture mine, a primary deposit worked as an open pit. Local miners used simple hand tools and blasting to break away the host rock in search of peridot. More joint-venture operated peridot mines, involving a further one-hour journey by foot, were visited by two of the authors in March 1992. These were two separate but closely spaced tunneling operations being worked with hand tools and explosives.

The largest peridot produced as of October 1992 is a cabochon cut stone of 319ct that was on display at the second Emporium of the same year. In the authors' experience, the vast majority of very large (50ct plus) peridots seen in the market-place today originate in Myanmar (Webb, 1993) and one is, therefore, not surprised to come across cut stones in the 100ct range at the Emporium (Figure 38). The two largest peridots offered at the Mid Year Emporium in late 1993 were a 147.50ct faceted free form and a 101.55ct faceted oval.

Spinel

Spinel in assorted colours and perfect to distorted octahedra is widely found in certain marble bands throughout the Mogok belt. It occurs in large quantities and outnumbers ruby in places. Kabaing is known for 'hot pink' spinels and Kyatpyin for the finest red spinels.

Diamond production

On 9 June 1971 the *Financial Times* Correspondent in Rangoon reported to his newspaper that diamond finds in Mongmit township of northern Shan State had prompted the Mineral Development Corporation, the State mining concern, to send a seventeen-man exploration team to the area. The finds were taken seriously in view of a report made by an official geological survey team in 1958 about the presence of kimberlite in this area. Mongmit lies in the region noted for rubies and sapphires but since about the middle of 1992 there have been reports of some diamonds being picked up by some villagers there (as reported in Chikayama, 1987, **9**, 6).

At the October 1992 Mid Year Emporium 27 cut Myanma diamond lots totaling 101 stones were offered for sale. Eleven lots were sold with the largest stone, which was 3.56ct, reaching US$10470 (US$2941 per carat). Similar prices were reached for a few other lots, but many stones were of a lesser quality with prices in the region of US$500 per carat. Whilst this may not indicate a large production of diamond from Myanmar (and indeed there was some question at the Mid Year 1993 Emporium about whether all of the diamonds offered actually originated in Myanmar), Emporium sales are not necessarily a good indicator of the country's total production. Indeed, in view of its tectonic position, athwart major suture zones there would appear to be some doubt as to whether Myanmar might become a really major source of diamonds.

Diamonds are found in three regions (Hlaing, 1990), in the areas of Mong Mit in the northern Shan State and Toungoo in central Myanmar, and to the east of Mergui (D1, D3 and D4 in Figure 2). The diamond crystals are found in octahedral, trisoctahedral, and hexoctahedral forms, some being distorted. The deposits are all secondary and of the river terrace type, the diamonds being found in the gravels and in association with rubies and sapphires in Mong Mit and with gold and other heavy minerals in the other two areas (Figure 39).

Diamond production is a small scale side-line of the alluvial tin mining in Tenasserim State (east of Mergui) and is in its infancy still. The MGE hopes to locate the primary diamond sources in the mainly forested areas by applying geophysical prospecting methods. The stones recovered in Myanmar are all faceted (as round brilliants) at a facility within the MGE Headquarters in Yangon. The finished stones reportedly average 0.30-1.00ct, with the largest to date being about 10ct (Koivula *et al.*, 1992).

Pearl production

Up until the late '70s Myanmar produced fine quality large cultured pearls in crops varying from 6000 to 8000 mommes. However, in more recent years both the quality and production have decreased to such a level that it has reportedly discouraged pearl buyers from attending the Emporiums. Of the 180 lots offered at the October 1992 Emporium very few were of a quality that would interest the discerning buyer (Figure 40). The sizes were not large, colours generally poor, and surfaces spotted and cracked. A similar situation was true of the following Emporium in February 1993, pearls were then undersized, and poor in colour and shape ('Burma: pearling hits rock bottom',1993).

Whilst it is stated that the situation should improve with the implementation of a new joint venture scheme with a Japanese company, it is reported that few dealers have confidence that this might become a reality ('Burma: pearling hits rock bottom', 1993). This situation is somewhat disappointing given the enthusiasm which started the project with the 'Burma Pearl Fishing and Culturing Syndicate' in 1954. It was a few years prior to this that a customs official living in Mergui began to realize the potential of the shell harvest in the area (Mynt, 1992). The shell harvesting lead to the production of cultured blister pearls off Malcolm Island (an island among 800 others in the Mergui Archipelago, the group stretch for some 530km through the Andaman Sea) and later also off Owen Island. Whole cultured pearl production began shortly after with the marketing of the results in 1958 (CP1 in Figure 2). In 1964 the farms were nationalized.

Today, in addition to the cultured blister pearls and the whole and beaded cultured pearls, many non-nucleated (tissue grafted) cultured pearls are produced and offered for sale at the Emporiums.

Fig. 37. A peridot quarry in fragmentary ultrabasic rocks at Pyaunggaung. *Photo by E.A. Jobbins*

Fig. 38. Exceptional gemstones in the collection of the Myanma Gems Enterprise: red spinel (20.60ct), 'sleepy' green peridot (143ct), pale brownish-pink topaz (123ct), pale green diopside (29.22ct), orange spessartine (14.20ct), aquamarine (27.40ct), pale yellow danburite (19.50ct) and a purplish-blue fluorite (25.55ct). *Photo by E.A. Jobbins*

Fig. 39. Twenty diamond crystals recovered from alluvial deposits in Myanmar, ranging in weight from 3.50 to 10.13ct. *Photo by R.E. Kane*

Malcolm Island is still the centre of the Burmese pearl fishing area. More than 300 people are employed in the cultivation industry. As there is no mollusc cultivation programme, the molluscs at approximately three years of age are collected wild by divers known locally as 'Salons' (sea gypsies). About ten locally-produced nuclei are implanted in one mollusc (*Pinctada maxima*) and it takes about three years to produce one pearl. Harvesting takes place four times a year and one mollusc may be re-implanted up to three times. Rather than following the practices of other farms the molluscs are not suspended from a raft, but the baskets are left 10m down on the sea bed (Chikayama, 1988, **10**, 3). New pearling stations exist along the Mergui Penninsula and are planned to increase up to fifteen farms. Natural pearls may also be fished in the area of Mergui and in 1960 a 200mm orange conch pearl was discovered in a muddy bottom in the same area (Scarratt *et al.*, 1994).

Fig. 40. Four of the best lots of cultured pearls offered at the October 1992 Gem Emporium, Yangon. *Photo by E.A. Jobbins*

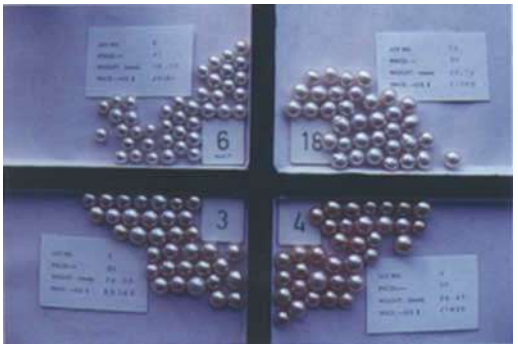

Amber

Burmese amber (burmite) has been mined for centuries, not only as a gemstone but also as a medicine. It is said to be more durable than other amber and to contain only one quarter to one half the amount of acid that Baltic amber (succinite) does (Chikayama, 1987, **9**, 7).

Amber is found in Myanmar's northern-most areas in a straight line from the border with Assam (India) in the west to Myitkyina and the Yunnan (Chinese) border. The Hukawng Valley in Myitkina District was, at least in the past, a major source (Ehrmann, 1957). The mines are located in the Chindwin district and at Maingkwan (just north of the jade deposits near Hpakan, AM1 in Figure 2) (Fraquet, 1987; Lintner, 1989). One other specific Hukawng Valley locality mentioned in the literature is Nango-tai-maw hill, 5km south-west of Maingkwan (Bauer, 1937). The material occurs typically in lenticular, fist-size pieces within Tertiary blue shale and sandstone, experience showing that thin seams of coal were indicators of good amber (Ehrmann, 1957). Fraquet (1987), describing a typical working, states that the pits were 'only about 1/3 metre square', and that after working through 4 to 6 metres of dry clay containing small pieces of lignite, there appeared a grey, slatey clay, and imperfectly formed lignite. At this layer the amber occurred in irregular pockets. At Khanjamaw ('maw' means mine) the amber level is at 13-15m, at Ladammaw it lies at 10m and at Lajamaw a mere 30cm below the surface (Chikayama, 1987, **9**, 7).

At some earlier Emporiums, Burmese amber from the banks of the upper Chindwin River was

Fig. 41. A 5.7cm diameter orb showing typical swirl structure, alongside a lenticular rough fragment (7.1cm wide); both of reddish-brown Burmese amber (see text). *Photo by E.A. Jobbins*

offered for sale (Gübelin, 1974). Most recently – at the 1993 Mid Year Emporium – one minor lot of predominantly dark, rather small pieces was offered. Ehrmann (1957) reported that larger blocks of material were traditionally purchased by Chinese for fashioning. Unfortunately, in recent years large 'carvings' composed of dark reddish-brown plastic and believed to originate in China or Hong Kong have been offered for sale as 'Burmese amber'.

Burmese amber is often referred to as 'burmite'; Baltic amber that has been imported into Myanmar was in the past labelled 'Indian amber' (Bauer, 1937). According to Vavra (1982), burmite from various sources includes resins of different geological ages, from Cretaceous to post-Eocene. This same author states that included material has been identified as copal. Fraquet (1987), however, states that burmite is of Eocene age, i.e. from 38 to 54 million years old.

Burmite is generally from a dark rich brown to a pale sherry colour and is never of the yellow shades seen in the amber from the Baltic region. However, the most sought-after colour for Burmite is a rich cherry red, a colour that does occur naturally but is more often produced by the plastic imitations mentioned above that are so often misrepresented as burmite.

Two historically important pieces of Burmese amber are described by Fraquet (1987), the latter of which was examined by two of the authors in 1992. Both pieces are said to have been originally part of the Burmese Royal Regalia dating back to the Dynasty prior to Kings Mindon Min and Theebaw (who reigned from 1853-1878 and 1878-1885 respectively). The first piece is described as carved in the duck-like symbol of Burma, the 'hinta', measuring 28cm in length and 15cm wide it is today on display at the National Museum in Yangon. There are now only faint traces of the gold leaf design, and the eye sockets, which it is assumed once contained rubies, are now empty. This is a good example of what can be done with opaque Burmese amber. The second piece which is much less well known is an orb of clear reddish brown amber (some 6cm in diameter - described by Fraquet (1987) as 10cm in diameter) which is presently held in private hands and might have formed part of the 'Burmese Royal Regalia'. The orb was given to an Englishman by the King 'following the death of the King's wife' and still remains within that family. The orb was said to sit in a carved hand within the Regalia and was presented to the King to signify the birth of a male child (Figure 41).

Marketing

The primary official outlets for Myanmar's gem wealth are the Gems, Jade and Pearl Emporiums held in Yangon. The first was held in December 1964 and they became annual events occurring in late January to mid-February. In 1992 a second 'Mid Year' Emporium was instituted for the autumn. Sales at these MGE-organized events, which were held up until late 1993 at the Inya Lake Hotel, total in the millions of US dollars. At the February 1991 Emporium sales totalled slightly over US$11 030 000: approximately $6.9 million in jade, $2.8 million in pearls and $1.3 million in 'gems'. This latter category, although primarily consisting of corundum, also includes peridot, zircon, aquamarine, garnet, amethyst and even some diamonds. Sales at the February 1992 Emporium totalled about US$8 million, including $4.5 million in jade, $0.8 million in pearls and $2.7 for gems (Clark, 1992). The October 1992 Emporium produced over $8.9 million in sales, including about $6.37 million in jade, $0.47 million in pearls, $1.76 million in gems and $0.3 million for jewellery and jade carvings. Sales at the February 1993 Emporium registered a significant increase over those of February 1992, totalling $14.66 million. This included $11.47 million in jadeite, $1 million in gemstones, $0.64 million in pearls, $0.48 million for jewellery and $0.12 in jade carvings. There was also a special sale of utility jadeite which brought in an additional $0.62 million ('Sales at emporium rise 153%', 1993).

In 1993 the Mid Year Emporium was held over a nine day period in late October and early November. A description of this event follows, as it most probably represents the venue and format for Emporiums in the immediate future and also provides a more detailed look at the types of goods offered.

The first two days of this most recent event were allotted for the viewing of goods, followed by seven days of competitive bidding (four days for jade, one day for pearls and two days of gems). There were 614 lots of jade, 198 pearl lots and 318 lots of gems offered. However, the 1993 Mid Year Emporium was notable historically in that it was held for the first time in the new MGE exhibition hall, built adjacent to the MGE headquarters and solely for these bi-annual sales. On the ground floor of the new facility, consisting

primarily of a large open room known as the jade display room, lots of rough jade were shown on small tables while fashioned items (carvings, cabochons and 'semi-fashioned' pieces) were in display cases. Also offered were fashioned items at fixed prices. These included all jade-related items priced under $US 3000, the lowest reserve price for jade at the auction. In addition to the material presented inside the building there were jade lots along the sides and back of the exhibition hall. These included the largest jadeite boulders and large lots (some weighing over 1500 kg) of 'utility jade', i.e. lower quality carving material.

The second storey of the new exhibition hall is where the auction takes place. Here bidders sit at tables in a large room reminiscent of a banquet hall. The auctioning is conducted by five MGE officials from a raised dais at the front of the hall. As each lot was presented for bidding, the pertinent information – lot number, category of material (e.g. utility jade) and reserve price – was projected on to a large screen. Simultaneously, a previously recorded short videotape, showing the actual lot being offered, is shown on the right side of the screen. When a winning bid is announced, the price paid and name of the purchasing firm is also projected. Actual bidding takes place by registered buyers who fill out bid forms (for the jade auction these are on green paper). The bidder then signals to one of several Burmese bid collectors who briefly check the form and then place it into one of two silver bowls sitting on pedestals to either side of the raised dais. When the auctioneer has determined that no more bids will be made, the two silver bowls are brought up to the dais and their contents emptied on to the tables. The bids are then inspected and the winning bid (assumingly the largest offer) announced and projected.

Gems, pearls and jewellery were displayed in cases on a balcony above the second storey. As with jade, items below a certain reserve price (approximately $3000 for gems and $1500 for pearls at the Mid Year 1993 Emporium) were sold at fixed prices; all of the jewellery was sold at fixed prices. The latter included various types of jewellery items being sold on consignment to the MGE as well as gem-set gold rings produced and marketed by the Myanma VES Joint Venture Company Ltd. The joint-venture firm sold its products at its own booth on this balcony level. This was the third Emporium at which they have offered their goods.

Although rubies and sapphires were the most abundant coloured stones being offered, as at past Emporiums, other gems were also available either through competitive bidding or fixed price. These included amethyst, citrine, kyanite, danburite, spinel, topaz, zircon, diopside, scapolite, apatite, aquamarine and peridot. There was also one small boulder with a yellowish-brown weathered surface and one exposed area of dark blue that was labelled 'lapis lazuli'.

Total sales of approximately $15.53 million were reported for this most recent Emporium, with 506 lots having been sold. This figure includes both items sold through competitive bidding (jade – 264 lots/$5.49 million; pearls – 75 lots/$0.67 million; gems – 77 lots/$1.43 million); additional sales of roughly $0.70 million in jewellery; $69 000 in jade carvings; $9000 in fixed price jade; $5.95 million in fixed price gems; $0.15 million for special sale jade; $61 000 for special sale gems. It is important to note that the disproportionately large figure for fixed price gems includes $5.86 million paid for a 38.12ct ruby for which bids were accepted from a select group of invitees.

There are additional legal outlets for Myanmar's gems. According to a report in *JewelSiam* ('Neighborly Burma', 1990), other sanctioned sales have been made through special arrangement with the Myanma government. The MGE also accepts inventory from the private sector and sells it on a consignment basis, both at the Emporiums and in its retail shops (Montgomery, 1993a). In addition, in August 1992 the MGE entered into a joint venture with Thailand's VES Group of companies to produce and market jewellery. This operation, which moved into its new factory in January 1993, has been set up to cut and polish the gems as well as produce the jewellery in which they will be set. While initial production has been of inexpensive items for the tourist (and perhaps local Myanma) trade, the ultimate goal is to offer higher-quality goods on the international market in the near future. Two hundred fifty pieces of the joint venture's early production were offered at the Emporium in October 1992 ('Burma signs joint ventures for pearls, jewelry', 1993; 'Thai-Myanmar Joint Venture', 1993; ' Thai-Burma factory opens in Rangoon', 1993). Sales increased at the February 1993 event and more than doubled (in both total value and number of pieces) at the October/November 1993 Emporium (Montgomery, 1993b).

Yet in spite of on-going efforts of the Myanma government to increase their control over the mining and marketing of their nation's wealth, significant quantities of gemstones are believed to still leave the country through extra-legal avenues. It is widely reported in Bangkok that the cross-border trade continues at a steady pace, with major transit points occurring in the areas near the Thai towns of Mae Sai (see above) and, to a lesser extent, Mae Sot. This illicit trade appears to have increased in the Mae Sai region in the past year or two with the discovery of the significant new ruby source at Mong Hsu. In the early part of 1993, several of the authors were queried by members of the jewellery industry about a reportedly new south-east Asian ruby source described as 'Mae Sai' or 'Mae Sar'. It is believed these references were to Mae Sai in northern Thailand, a town later confirmed as being a centre for the trade in rubies from this new Myanma source (see Mong Hsu above). Goods are also reported to enter India and China through illicit channels.

Chikayama reported to the 24th International Gemmological Conference (1993) that there was in fact a new route for Myanmar's gemstone production entering China. He stated that this was through a 'Free Trade Area' at Rui Li, north-west of Mandalay.

It is also interesting to note in this regard that in 1993 a Thai firm based in Mae Hong Son had received approval from the Myanma government to build and operate a road linking Chaing Rai in Thailand with eastern Myanmar ('Northern Thailand set for Burma route', 1993). This road could easily help to increase the cross-border traffic in goods, both legal and otherwise.

Regardless of how it is marketed, all indications are that the gem wealth of Myanmar will almost certainly continue to be in great demand, bringing exceptional prices in the international market. As one example, the third highest price paid for a lot at a Sotheby's, Geneva, auction in May 1993 was for a ring set with a 16.51ct Myanma ruby. This single item, lot 537, went for US$ 3.03 million ('53 carat diamond—$3.7m; 11 carat blue—$3.6m', 1993). Another relevant example is the 38.12ct ruby that fetched over $5 million at the most recent Emporium (see above).

Summary

The occurrences of jadeite in Kachin State still have no competitors anywhere in the world, both in terms of the quantity and quality of the jadeite mined. The deposits appear to be far from exhaustion. Myanma deposits of rubies, sapphires and many other gemstones are at their richest and most concentrated in the Mogok Stone Tract (MST) which is situated at the western border of the Shan State and is generally understood to include the alluvial deposits in the wider vicinity of Mongmit, north of Mogok, as well. There seems to be no sign of exhaustion in the MST for any of the gem species mined. Recent and very productive additions are the important Mong Hsu ruby fields and the even more recently discovered Mong Hkak sapphire deposit which is also situated in the eastern Shan State. Several diamond placers in Myanmar are known today but no primary diamond pipes or sills. Production is very modest but might increase.

Pearl fishing and culturing is centred in the Mergui Archipelago (Tenasserim (Taninthari) State). Sea water pollution has not been mentioned as one of the factors having possibly impaired the quality of the Burmese cultured pearl.

Considering Burma's amazing wealth in many different types of mineral resources and considering the presence of a long collision belt reminiscent of the one forming the north-west bend of the Himalayas in Pakistan, the pertinent question might be asked, '*Where do Burma's hidden emeralds lie?*' As postulated by Kazmi and Snee (1989), the contact of chromium-bearing oceanic rocks (ophiolites, etc.) and beryllium-bearing continental rocks (granitic intrusions, pegmatites) in the Himalayan suture zone generated 'the essential combination of elements needed' for emeralds to form in Pakistan. In Myanmar, rocks of both ultramafic and acid types are present as well, possibly even in the proximity required for emerald growth. The find of these green wonders would complete the colour spectrum of Burmese gemstones.

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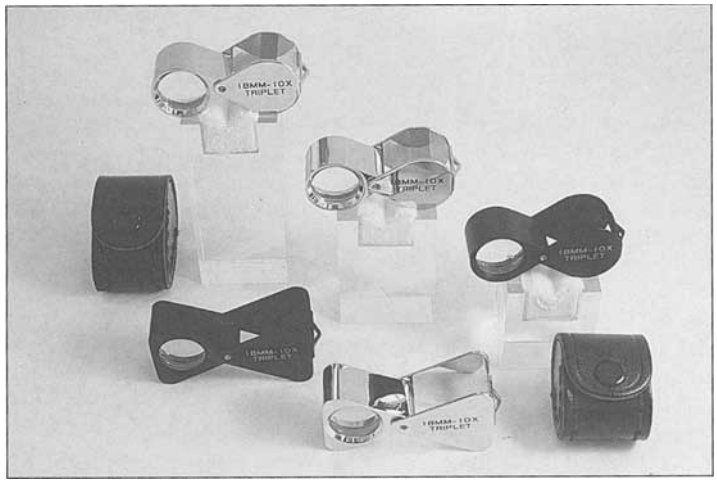

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Notes from the Gem and Pearl Testing Laboratory Bahrain – 3

Ahmed Bubshait, B.Sc., FGA, and Nick Sturman, FGA, DGA

Abstract

Our third contribution deals with 'filled' natural and synthetic rubies and with natural and cultured pearls.

Natural rubies with 'filled' fissures

In our last notes from the Laboratory - 2 (J. Gemm., 1993, 23, 7) we reported on some filled natural rubies mounted in a necklace. Since then we have examined a number of new rubies submitted for routine testing and, of these, one group of stones also revealed glass fillings of the type that laboratories often encounter these days. Three faceted stones in this group (weighing 1.79 ct, 1.98 ct and 2.04 ct) contained filled surface-reaching fissures (Figure 1).

Whether fillings such as these are the accidental result of the heat treatment process or are the result of a fraudulent attempt to improve the appearance and weight of the stones, the fact is that the fillings are not produced by nature and are a result of man's interference. Therefore, our policy is to inform customers about this and any other enhancements/treatments that we observe, so that they in turn are able to pass the information on to their customers. In this way all our customers can be better 'prepared' for the future.

Distinguishing a natural inclusion from a filling in a natural ruby

When examining any ruby for evidence of 'fillings', all gemmologists have to be careful not to mistake a natural inclusion (such as a crystal that has been exposed at the surface during cutting) for an artificial filling. Recently, we had the chance to examine a cabochon-cut stone weighing 7.32 ct with such an inclusion. The inclusion (Figure 2) occupied a considerable area at the base of the stone, was visible to the naked eye and, unlike the artificial fillings, showed a distinct white cast.

We pursued our investigation further to try and identify the inclusion and rule out the possibility that it may be another type of unusual filling not previously encountered in natural rubies. A distant vision reading of the RI of the area gave a value in the region of 1.6 and microscopic examination revealed some small crystals and feathers, as well as at least one distinct cleavage direction. With this information we considered which natural mineral it might be. Our conclusion was that calcite was the most likely contender and so we tested this idea by placing a small amount of dilute hydrochloric acid on a small area and noted its strong effer-

Fig. 1. Glass filling in one of the three natural rubies tested.

Fig. 2. The probable calcite inclusion seen in the 7.32 ct. natural ruby, as seen in overhead fluorescent lighting.

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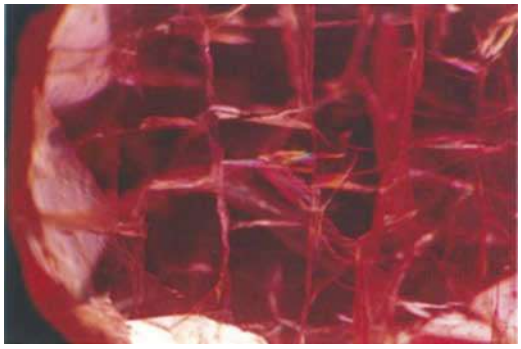

Fig. 3. Some unusual flashes of colour within the induced fractures of this crackled Verneuil synthetic ruby.

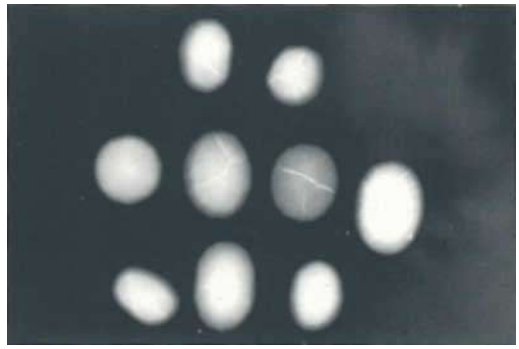

Fig. 4. The radio-opaque filler is clearly visible in the induced fractures in these crackled Verneuil synthetic rubies.

vescent reaction. Additionally, we placed the stone under UV radiation to see if any fluorescence could be observed in the area of the inclusion. A moderate orange fluorescence was noted in the red background fluorescence of the ruby, which is also consistent with the behaviour of calcite.

Filled synthetic rubies

One of our regular customers recently asked us to check a few assorted stones on a verbal assessment basis. Amongst them were some red stones that on preliminary testing gave results expected for rubies. We then turned to the microscope and it was quickly evident that a majority of the stones showed features characteristic of crackled synthetic Verneuil ruby. However, some of the fractures, induced by heating and then rapid cooling of the stones (Hughes, 1990), were the source of uncharacteristic flashes of a variety of colours (Figure 3). This prompted us to examine the fractures in more detail, with the result that

Fig. 5. The pearls submitted by Custom officers, shown with a loupe for scale.

we recognized a similarity with the filled fractures seen in resin-treated emeralds and glass-filled feathers in diamonds. As in many filled diamonds and emeralds, the filler is very difficult to detect at the surface (unlike most rubies where the difference in surface lustre is more apparent). The colours seen within the

Fig. 6. Some of the small 'demi-like' pearls that were selected from the largest group of pearls.

Fig. 7. One of the 'demi-like' pearls shown in Figure 5. The fibrous structure of the broken non-nacreous half of the pearl is shown.

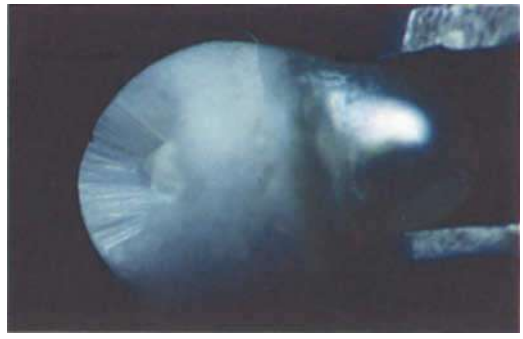

induced fractures are similar to those seen in resin-filled emeralds, but not as distinct as those seen in filled diamonds. A weak blue 'flash', similar to the effect sometimes seen in filled emeralds, could be seen in some of the stones when observing the fractures at the right angle.

Diamond can tolerate fairly high temperatures and it is known that the material used to fill fractures is often a lead- or bismuth-based glass (Koivula *et al.*, 1989). So because corundum is also known to tolerate high temperatures, we reasoned that a similar radio-opaque material may have been used to fill the fractures and hence might show up as opaque areas on the X-ray film. The series of opaque white lines running throughout some of the stones on the radiograph (Figure 4) confirmed our reasoning. In order to determine that this result was not the 'norm' for crackled synthetic rubies, two stones without unusual flashes of colour within their fractures were obtained and radiographed. both stones showed no evidence of material opaque to X-rays within the fractures.

An unusual lot of pearls

Many of the pearls examined by the laboratory are submitted by Customs and Ports Directorate, since Bahraini law requires that all pearls coming into the state have to be checked to eliminate any cultured pearls that may be amongst them.

The pearls shown in Figure 5 are typical of the consignments received from Customs. The pearls were split into two groups, the larger weighing 5000 ct and consisting of mostly small rounded pearls and the smaller group weighing just under 2500 ct, consisting mainly of larger irregularly-shaped pearls. When radiographed the latter group showed that a majority of the pearls had non-nucleated cultured pearl structures, whilst a minority had natural pearl structures. The larger group consisted of a mixture of natural and non-nucleated cultured pearls and both groups had a few nucleated cultured pearls. In addition to natural pearls, non-nucleated and nucleated cultured pearls, a small number of 'demi-like' pearls, which are half nacreous and half non-nacreous (Hurwit, 1989 and 1991), and some completely non-nacreous pearls were also observed amongst the larger group. Some of the 'demi-pearls' (Figure 6), and one in particular, showed damaged non-nacreous areas that clearly revealed a fibrous, more columnar structure (Figure 7), typical of some freshwater pearls (Scarratt, 1987). However, they did not produce the fluorescence in X-rays typical of freshwater pearls.

The fluorescence of some of the remaining pearls did match the sample test results that we obtained. For instance, some pearls that we determined had fairly convincing non-nucleated cultured pearl structures and emitted a very strong fluorescence and phosphorescence when exposed to X-rays (typical of freshwater cultured pearls such as those from Lake Biwa), whilst others that had good natural structure were inert under X-rays.

In normal circumstances, these pearls would have been returned to Customs' officers who would have then returned them to the original supplier, in this case a company in Pakistan. This, however, was not a normal circumstance, as the importer informed us that these pearls were not destined for the jewellery trade (the area covered by the cultured pearl law in Bahrain) but for medicinal purposes. Like many Asian countries and some Middle Eastern countries, Bahrain has an active alternative medicine trade that, amongst other things, uses pearls, lapis lazuli, orpiment and sulphur to treat a variety of ailments.

Given this explanation about the destiny of these particular pearls and after consultation with various authorities including Customs' officers, two members of the laboratory staff visited the premises of the importer and witnessed him crush all the pearls shown in Figure 5. Needless to say, the pearls described in this last section are no longer in the form they arrived in, but we hope that their medicinal properties help cure eye problems and cases of cystitis and impotency which, we were informed, are the most common problems for which pearls in their powdered form are prescribed.

Acknowledgements

The assistance offered by staff from both the Bahrain and London Laboratories is acknowledged with thanks.

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1993 Annual Conference

Mary Burland

The 1993 GAGTL Annual Conference was held on 24 October at the Great Western Royal Hotel, Paddington, London, followed by an Open Day at the GAGTL Gem Tutorial Centre in Greville Street on 25 October. Once again, there were many delegates from overseas including representatives from Australia, Bahrain, Canada, Malaysia, Sri Lanka, Taiwan and the USA as well as from many European countries. Delegates were able to view the displays and examine, with the expert assistance of laboratory staff, some of the stones discussed during lectures.

The theme of the conference was 'Inclusions' and the Conference opened with the keynote lecture by Dr E. Gübelin entitled 'New gem inclusions'.

New gem inclusions

With the aid of many magnificent slides, a selection of which is shown on p.46 Dr Gübelin discussed some of the new inclusions he had found since the publication of the *Photoatlas* (Gübelin and Koivula, 1986). The 'portraits' of the inclusions were accompanied by chemical analyses shown simultaneously on a second screen. The methods used for the identification of each inclusion (for example energy dispersive X- ray fluorescence, electron microscopy or Raman laser spectroscopy) were explained in detail.

Gemstones illustrated included kyanite, euclase, demantoid and pyrope garnet, moonstone, peridot, rock crystal, sapphirine, ruby, sapphire, taaffeite, spinel and natural and artificial glass.

Dr Gübelin explained how it was possible to speculate on the place of origin of gemstones by identification of the inclusions. Not only are particular mineral inclusions typical of certain areas, but also the shape of the crystal inclusion can provide clues as to the host's origin.

In conclusion, Dr Gübelin referred to the 'nostalgic' and traditional method of identifying inclusions' that had been used before the sophisticated instruments, such as those he had been

Fig. 1. Keynote speaker Dr E. Gübelin with Miss Pat Lapworth who has been responsible for the English translation of his books.

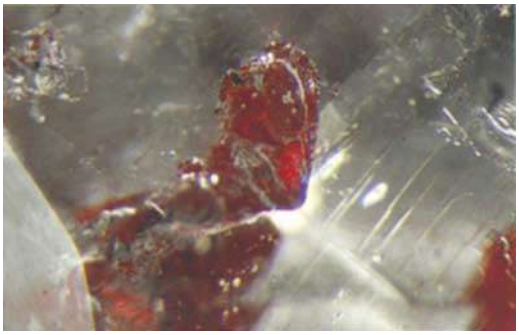

Fig. 2. Colourless faceted baryte from Chauwai, Kirghisia. Red, more or less corroded crystals of cinnabar, HgS, ornate the interior of this rare collector's gemstone. 9x

Fig.3. Goshenite (colourless beryl), Minas Gerais, Brazil. A beautifully shaped, euhedral crystal of yellowish brown spessartine, $Mn_3Al_2(SiO_4)_3$, presents itself in correct position to the beholder. 20x

Fig.4. Colourless beryl from Hagendorf, Bavaria, Germany. A group of intergrown slightly resorbed crystals of zwieselite, $(Fe^{+2},Mn^{+2},Mg,Ca)_2(PO_4)(F,OH)$, accompany their host for its lifetime. 8x

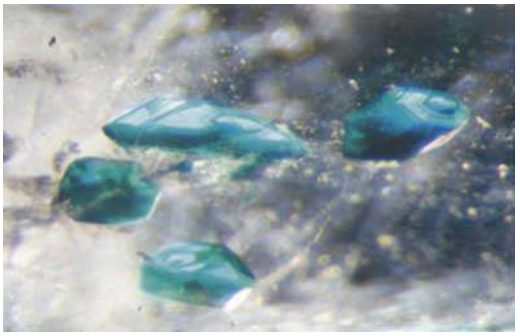

Fig.5. Calcite, Congo, Africa. A small loose group of well-shaped dioptase, $CuSiO_2(OH)_2$, crystals aligned parallel to the host crystal's direction have found a permanent resting place. 20x

Fig.6. Rock crystal from Sri Lanka. Distinctly shaped tabular crystals of muscovite mica, $KAl_2(Si_3Al)O_{10}(OH,F)_2$, strung on rutile fibres (TiO_2) shine with kaleidoscopic colours between crossed polars. 30x

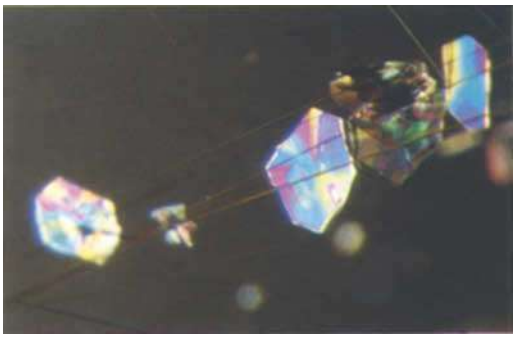

Fig. 7. Rock crystal from Ajo, Arizona, USA. A divergent radial arrangement of fibrous papagoite, $CaCuAlSi_2O_6(OH)_3$, and ajoite crystals, $(K,Na)Cu_7AlSi_9O_{24}(OH)_6.3H_2O$, impart delightful coloration to an otherwise colourless quartz. 15x

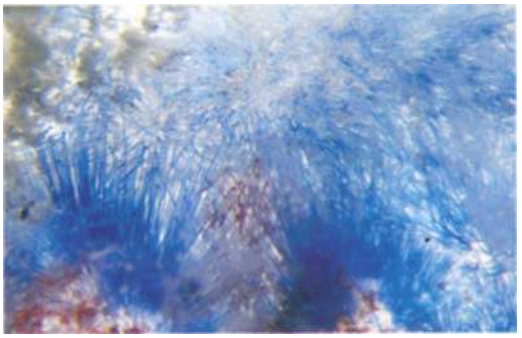

discussing, were invented. Gemmologists had to identify inclusions 'using visual methods,' he explained, 'by their colour, appearance and characteristic habit, and some knowledge of the genetical conditions of the host gem itself'. A pink sapphire from Sri Lanka was illustrated, showing an inclusion of a diaspore crystal on a graphite flake which, under magnification, Dr Gübelin had been able to identify from the individual faces and shape of the crystal.

Burmese and Vietnamese gem inclusions

The second lecture of the day was by Alan Jobbins who spoke about his visits earlier in the year to Burma and Vietnam. He described in detail the geology and topography of the areas, and illustrated a number of the mines visited. The methods by which the rubies and sapphires are extracted, sorted and marketed were also discussed.

Rubies from Burma and Vietnam were compared, showing many similarities. As well as discussing the inclusions to be found in the rubies, Alan also described colours typical of stones from the areas visited, zoning and other characteristics that could indicate the origin of the stones.

Fillings in diamonds and coloured gemstones

Following lunch, Dr Gübelin gave a second lecture, this time on the filling of diamonds and other gemstones.

He discussed and illustrated laser drilled diamonds in which the laser canals which had been filled, as well as diamonds in which cracks that reached the surface of the stone had been filled.

Illustrations of stones before and after treatment indicated the degree of invisibility that could be achieved when flaws were filled. Dr Gübelin went on to describe ways in which such fillings could be identified.

In addition to diamond, the filling of coloured gemstones such as emerald, aquamarine, tourmaline and corundum (including diffusion treated sapphire) was discussed and methods of identification suggested.

Montana sapphires

Michael O'Donoghue spoke on the sapphires of Montana, giving a general history of the mining in the area. It is unique in that it is the only place in which you can find corundums in situ as well as gravel type deposits. He described

Fig. 8. Michael O'Donoghue who spoke on Montana sapphires.

the methods of mining at the Yogo mine and various deposits along the Missouri River. The sapphires are generally small and the colour pale blue, green or yellow – bluish-green stones with an orange spot inside are particularly typical of the area. All stones, with the possible exception of those from Yogo, are heat treated.

Michael illustrated a number of stones including a mauve star sapphire (star stones are not usually found in the area) and a stone reputed to have been mined as a colourless sapphire in the 1920s which had only recently been heated to an attractive yellow colour.

Unusual gems in forensic science

Philip Sadler gave us an insight into the work of the forensic laboratory of the Metropolitan Police.

A number of items associated with the gem and jewellery trade passed through the laboratory. Philip described a number of these and their case histories, as well as the techniques used to identify a range of substances.

Pearls in the Arabian Gulf

In the final lecture of the day, Stephen Kennedy of the Association's Laboratory commenced with a summary of the history of the pearls in the Gulf, dating back to *c.* 2000 BC.

In 1988 Stephen went to Bahrain to assist the

Fig. 9. Stephen Kennedy who spoke on the Gulf pearls.

Ministry of Commerce and Agriculture in setting up their own pearl and gem testing laboratory to monitor their large and expanding pearl trade. Stephen discussed the past and present pearl trade in Bahrain and illustrated examples of modern jewellery now sold in the Gulf.

In London, the Laboratory recently had the opportunity to examine two exceptional pearls. These were the Pearl of Asia and the Hope Pearl. With a number of illustrations of the pearls and their mounts, he outlined their histories and then described them in detail, explaining methods used to test them and displaying the results.

OPEN DAY

On Monday 25 October an Open Day was held at the GAGTL Gem Tutorial Centre in Greville Street, London. Members of the laboratory staff were available to discuss any problems with delegates. One subject that concerned delegates was the issuing of origin reports on gemstones. It was explained that, as a service to Laboratory Members and only in cases where there was no reasonable doubt of the origin of a gemstone, a letter giving an opinion of origin could be issued to accompany an Identity Report.

A number of delegates asked about the colour grading of coloured gemstones (excluding diamonds). Although there are systems available for colour grading, no one system has outstanding advantages over any other or has been considered sufficiently satisfactory for use by this Laboratory.

Fig. 10. Ali Safar and Ahmed Bubshait from the Gem and Pearl Testing Laboratory, Bahrain.

STUDENT STARTER SET ORDER FORM

To: Gemmological Instruments Ltd.,
27 Greville Street,
London EC1N 8SU

Name: _____

Address: _____

_____

_____ Post Code: _____

Daytime Telephone Number: _____

Membership Number if applicable: _____

VAT Number if applicable: _____

Quantity		Total
	Student Starter Set @ £60.00 each * chrome/matt black finish Loupe	
	Less Members' Discount	
Postage and Packing	Sub total	
UK – £4.50	Plus Postage & Packing	
EU – £6.00	Plus VAT @ 17.5%	
OS – £7.50	Total Amount Due	

Payment Methods:

1. By cheque/bank draft drawn on a British Bank and made payable to Gemmological Instruments Ltd.
2. By Credit Card – Visa, Mastercard, American Express or Diners Club.

I wish to pay by * Visa/Mastercard/American Express/Diners

Please charge to account number: Expiry Date:

Name on Card _____ Signature _____

* (delete as applicable)

DISPLAYS

Specimens under the microscope

Delegates had the opportunity to examine, with the expert assistance of laboratory staff, a number of specimens discussed during lectures. These included untreated Burma rubies, referred to by both Dr Gübelin and Alan Jobbins during the morning lectures, showing typical inclusions for the older stones, but delegates were advised that the newer rubies coming from the area showed very different inclusions as a result, among other things, of heat-treatment. Also exhibited were diamonds showing inclusions such as crystals, clouds, feathers and indented naturals, and it was explained how these related to clarity grading.

Fig. 11. Joris C. Höfelt, Utrecht, The Netherlands, examining a Burma ruby with Riitta Spencer, Clive Burch in background.

Following the talk by Michael O'Donoghue, a selection of Montana sapphires was on display as well as a book of memorabilia from the mines, and delegates were able to compare heat-treated and untreated specimens from Rock Creek under the microscope.

Replicas

Replicas of famous diamonds were exhibited by Richard Willmott. As well as replicas of the cut stones, in some cases there were also models of the rough crystals before cutting. (For further information on Richard Willmott's replicas see Willmott, 1993.)

Glass filling of diamonds

There was also a display by Dr Jamie Nelson of the production of colours which appear as dispersion staining colours in glass infilled diamonds (see Nelson, 1993). This was in the form of a practical hands-on demonstration of spectra.

Gem identification

Delegates were able to microscopically examine rough and cut samples of the two types of synthetic emerald most likely to be encountered in the trade today. The first was a hydrothermal synthetic emerald from Russia showing typical inclusions and marked zoning. This type of synthetic is particularly difficult to distinguish from the natural because it often contains two-phase and sometimes three-phase inclusions. The second was a Chatham synthetic emerald grown by the flux method.

Diamond

The methodology of diamond grading was explained and demonstrated.

Delegates were able also to examine diamonds that had been fracture-filled and laser drilled, as discussed by Dr Gübelin during his second lecture. Filled diamonds are now circulating and it is vital that members of the trade can recognise such treatment.

References

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XXIV International Gemmological Conference Paris 1993

E. Alan Jobbins

At this conference, which was admirably organized by Jean-Paul Poirot and his helpers, the excursions (1-9 October) preceded the scientific sessions. Delegates visited Lyons, the Chessy St-Bel copper mines, and synthetic corundum and jewellery factories near Grenoble. In the Auvergne they visited classic areas of volcanicity, sapphire and tourmaline localities. At Bourges Cathedral they studied architectural and decorative building stones. The scientific sessions (11-15 October) were held in Paris under the auspices of the Paris Chamber of Commerce and Industry. The papers presented are listed below:

G. Bosshart	'Cut diamonds of natural green coloration.'
E. Fritsch	'New and useful criteria for the separation of natural and treated colour green to blue diamonds.'
C. Sapalski and L. Sarmiento	'Relationship between colour grade, N3 absorption and response to ultra-violet light in diamonds.'
H. Tillander	'The revised history of diamond cuts.'
H.O. Meyer	'Diamonds in North America.'
A.A. Levinson	'Diamond exploration in Canada; current status.'
N.L.E. Haralyi	'Big sized diamonds in Brazil.'
J.M. Saul and A. Mercier	'Thermobarometry applied to deposits of crystalline coloured gemstones.'
D. Schwarz	'Some news on emeralds and their occurences.'
J. Kanis	'Zimbabwe revisited - Orissa gems updated.'
A. Chikayama	'About a new route for Myanma gemstones.'
R.E. Kane	'Selected Burmese gems.'
R.R. Harding and N. Barot	'Pink corundum from Kitui (Kenya).'
H.A. Hänni and K. Schmetzer	'First results on a new flux-grown synthetic ruby (Douros) produced in Greece.'
K. Schmetzer	'Growth structures as means for the characterization of new types of high quality

Attending a reception at the Pierre and Marie Curie University in honour of delegates to the XXIV International Gemmological Conference are Jean-Paul Poirot, the organizer (far left), Pascal Entremont (third from left), Pierre Bariand (arms folded) and, addressing the gathering, the Vice President of the University, M. Lemerle.

	natural and synthetic rubies.'
G. Brown	'Australian synthetic periclase.'
V.S. Balitsky, I Makhina	'Man-made rose quartz.'
V. Prygov and A. Mar'in	
G.V. Bukin	'Siberian synthetic gemstones.'
U. Henn and H. Bank	'An update on synthetic stones manufactured in Russia; properties and distinguishing features.'
H.S. Pienaar and D. Glenister	'Studies on gem zircon.'
G.F. Becker	'Utah red beryl.'
C. Arps	'Museum specimens and nomenclature.'
C. Sapalski and J. Saadi	'Geologic monument of unique diatremes bearing stalactitic formations of rhodochrosite (Capillita Mine, Catamarca, Rep. Argentina).'
F. Payette	'Rare gem-quality minerals from Mont Saint-Hilaire, Province of Quebec, Canada.'
H. Bank	'Gemmological news.'
I.Z. Eliezri	'New spessartite garnet occurrence in Namibia.'
E. Buhtiarova and T. Bublikova	'Main gemmological characteristics of charoite from eastern Siberia.'
F.H. Pough	'Phenomenal obsidians.'
R. Segnit	'A colour change sapphire from Queensland (Australia).'
J. Ponahlo	'Cathodoluminescence of some rare and of colourless gemstones.'
H.J. Schubnel	'Historical synthetic stones of corundum, beryl, chrysoberyl, phenacite in the collection of synthetic minerals in the Museum d'Histoire Naturelle (1824-1900).'
E.A. Jobbins	'Sapphires and rubies in Vietnam - an update.'
K. Scarratt	'The pearls of the Melo volutes.'
R. Cusi	'Conch pearls: a review on the Strombus gigas production and its use.'
M. Superchi	'Conch pearls: a technical note on the Strombus gigas production.'
A. Bouquillon, J.P. Poirot and G. Querré	'Natural stones and man-made materials used in Egyptian jewellery: example of three pectorals of the Louvre Museum.'
G. Graziani, P. Evangelista and M. Martini	'A gem collection never before published: the dactilyotheca of Pope Leo the XIIth.'
J. Koivula	'Inclusion research update.'
E. Gübelin	'New inclusions observed.'
G. Tombs and M. Ducan	'Opal. Safe or unsafe. A guide to recognition.'
G. Brown, J. Townsend and K. Endor	'Lambina opal field.'
M. Sevdermisch	'Three lapidaries: skill versus technology.'
V.S. Balitsky	'Current situation and new gemmological tendencies in contemporary Russia.'
G. Zoysa	'New developments in Geuda corundum and its technology.'
N.L.E. Haralyi	'Comments on the magnetic properties of gemstones.'
J.M. Dereppe and C. Moreaux	'Application of Nuclear Magnetic Resonance to the study of gemstones.'
T. Tay (to be read by G. Zoysa)	'A study of natural and synthetic rubies by PIXE.'
M.L. Delé, J.M. Dereppe, P. Dhamelincourt, P. Sombret and J.P. Poirot	'Use of spectroscopic techniques for the study of natural and synthetic gems; application to rubies.'
P. Zecchini, K. Yamni and C. Aurisicchio	'Determination of the composition of natural garnets by using infrared reflectance spectroscopy and multivariate calibration.'
J.M. Nogués-Carulla and N. Ferrer	'Characterization of cut diamonds by FTIR analysis: possibilities and limitations.'
B. Lasnier	'A new Raman probe specially adapted for gemmological laboratories.'
J. Shida	'Observation of rubies by LASER tomograph; effects of heating.'
H. Merigoux, B. Astric and P. Zecchini	'Variation of the appearance of a faceted stone according to its refractive index.'

Members having gained their Diploma in Gemmology or the Gem Diamond Diploma (FGA or DGA) may now apply for use of the Coat of Arms on their stationery or within advertisements.

Laboratory members are also invited to apply for use of the Laboratory Logo.

It is still a requirement of GAGTL, in accordance with the Bye Laws, that written permission be granted by the Council of Management before use.

Members interested in further information please contact:

Linda Shreeves

Gemmological Association and Gem Testing Laboratory of Great Britain

♦ 27 Greville street, (Saffron Hill Entrance), London EC1N 8SU ♦

Tel: (071) 404 3334 Fax: (071) 404 8843

Book Reviews

HENIG, M., 1990. *The Content cameos*. Derek J. Content Inc. in association with the Ashmolean Museum, Oxford. Hardbound with dust wrapper, 200 pp, 228 monochrome and 93 colour illustrations, bibl., indexes. £52.00.

The Content Family Collection contains what appears to be the largest assemblage of Ancient Cameos outside the major European museums. Now on display in the Ashmolean Museum, Oxford. Every stone in a holding of over two hundred is discussed and its significance assessed: in addition all the gems have been illustrated in monochrome and many of them in colour as well. N.B.I.

HENIG, M., VICKERS, M. (eds), 1993. *Cameos in context*. Derek J. Content Inc. in association with the Ashmolean Museum, Oxford. 102 pp. Hardbound with dust wrapper. £27.50.

The record of six lectures given at the Ashmolean Museum, Oxford in the Summer of 1990 to celebrate the arrival of Ruben's painting of the Grand Camée de France (the 'Cameo of Tiberius') bequeathed by Christopher Norris, and the deposit on loan of the Content Family Collection of Ancient and Later Cameos. The lectures were sponsored by Benjamin Zucker.

Six chapters, each on a different aspect of cameos by renowned experts on their fields.

'The Portland Vase: an aspect of Roman cameo cutting' by David Whitehouse (Director, Corning Museum of Glass, USA) and Kenneth Painter (Formerly Deputy Keeper, Greek and Roman Department, British Museum).

'Ancient cameos in the Content Family Collection' by Martin Henig (Research Associate, Institute of Archaeology, University of Oxford).

'Late antique cameos *c.* AD 250-600' by Jeffrey Spier (Research Associate, University College, London).

'Cameos in Byzantium' by Cyril Mango (Bywater and Sotheby Professor of Byzantine and Modern Greek, University of Oxford) and Marlia Mundell Mango (Research Associate, Institute of Archaeology, University of Oxford).

'Rubens and the Cameo of Tiberius' by Christopher White (Director, Ashmolean Museum, University of Oxford).

'Portrait cameos: aspects of their history and function' by Gertrud Seidmann (Research Associate, Institute of Archaeology, University of Oxford).

Each chapter has an extensive bibliography. A beautifully produced, well illustrated book.

N.B.I.

KARLIN, E.Z., 1993. *Jewelry and metalwork in the arts and crafts tradition*. Schiffer Publishing, Atglen, PA. pp 272, illus. in colour. £69.95.

This is an excellent survey of Arts and Crafts jewellery which is enjoying a well-deserved popularity at the time of writing. It is colourful and imaginative; both these qualities are brought out by this not-unreasonably-expensive book which is well illustrated in colour. The text opens with a survey of work done in England: this is followed by accounts of Scottish and Irish work. The effects of British training of Australian craftsmen are described next before the European arts and crafts interpretation is examined. American work comes last. After these regional descriptions modern studio jewellery is spotlighted. There is a glossary, hallmarks table, lists of dealers and auction houses, notes on major museums, bibliography and notes on values. The text is easy to read and the whole makes an attractive and useful book. M.O'D.

PECKETT, A., 1992. *The colours of opaque minerals*. Wiley, Chichester. pp. xxxviii, 471, illus. in black-and-white and in colour. £95.00.

Though the main purpose of this book is to aid the microscopist in the identification of ore minerals on the basis of their colour, there is a great deal of interest to anyone dealing with natural specimens with a rigorous treatment on the nature of light and of colour with notes on the operation of the eye. Several of the various colour evaluation systems are fully described and the inevitably mathematical treatment is at least explained in an appendix which pays particular attention to complex numbers and matrix algebra.

The book is divided almost into two halves; the first part deals with the theoretical aspect of opaque

mineral colour description, the second with the minerals themselves. In the latter each mineral is described as seen in polished mounts with the reflected light microscope in plane polarized light and between crossed polars. The colours seen depend upon the crystal structure and the electronic structure of the minerals. Each mineral description includes name and composition, crystal structure and optical properties, quantitative colour description, IMA approved name, X-ray diffraction data and atomic co-ordinates, with much other useful material and latest abstract in *Mineralogical Abstracts* where available. M.O'D.

PINET, M., SMITH, D.C., LASNIER, B., 1992. La Microsonde Raman en Gemmologie. *Revue de Gemmologie a.f.g.* numero hors series. pp. 60, 50 figs. FF200.

A special volume illustrating the Raman spectra (and other data) of a selected series of gemstones. E.A.J.

SURY, E., 1991. *Mineralien richtig reinigen.* 2 Auflage Sektion Basel SVSM, Basel. pp 68. DM18.00.

A useful ring-backed guide to the cleaning and conservation of minerals including some gem species. Various liquids are suggested for the cleaning process. M.O'D.

WARD, F., 1993. *Emeralds.* Gem Book Publishers, Bethesda MD. pp. 64, illus. in colour. US$ 14.95.

The second of the Fred Ward Gem Book Series (the first was *Ruby and sapphire*) is equally well-produced and succeeds in giving a great deal of information in a very small compass. Depending for its initial impact on the number and quality of the coloured photographs, the book covers emerald in history, present-day mining and commerce, oiling and treatment, synthesis and imitation, with details of emerald mining in the main producing countries. I recommend the book for all interested in this beautiful stone. M.O'D.

WEBER, I.S., 1992. *Kostbare Steine: die Gemmensammlung des Kurfürsten Johann Wilhelm von der Pfalz.* Deutscher Kunstverlag, Munich. pp. 287, illus. in black-and-white and in colour. DM 148.00.

More than 400 engraved gems from the classical period (two examples) up to the end of the eighteenth century form part of the collection of Johann Wilhelm von der Pfalz, housed in the Staatlichen Münzsammlung in Munich. This scholarly book is a catalogue of the collection, entries giving place of manufacture, date, subject, physical description, dimensions, inventory numbers, references to the literature and notes on provenance. A section of eleven colour plates illustrates a cross-section of the collection while a twelfth plate depicts the special cabinets which contain it. The standard of reproduction in black-and-white is particularly high while the colour plates are excellent. There is a very useful bibliography and tables in which items are listed by inventory number and catalogue number successively, one table forming a concordance to the other. Provenance is given in both tables. M.O'D.

WEISE, C., 1993. *Jade, Juwel des Himmels.* Christian Weise Verlag, Munich. Unpaginated, illus. in colour. DM16.00.

Ninety-one jade artefacts from the Chinese Xing [1644-1911] dynasty are described and some of them illustrated in this catalogue of an exhibition held at the publisher's gallery in Munich during 1993. Short notes on jade and its importance to the Chinese are given and in the catalogue entries the purpose, size and colour of the artefacts are provided. The colour reproduction is good for so inexpensive a work. M.O'D.

WIGHT, Q., 1993. *The complete book of micromounting.* The Mineralogical Record, Tucson. pp. 283, illus. in black-and-white and in colour. Price on application.

It is some years since a book on micromounting was published in English and there has never been a history of this particular way of studying minerals. Micromounting has always been a North American preoccupation and the text reflects this geographical bias. After an interesting account of the earliest micromounters the text goes on to give a step-by-step description of the techniques involved. A hall of fame gives biographies of figures of recent years and the book concludes with a photo album in which 165 coloured photographs of fine-quality micromounts are arranged alphabetically. Since many rare species are found only in small sizes this is one of the only ways in which many can be shown. There is a useful bibliography and appendices in which various micromounting activities are described.

The author has, in fact, completed the text prepared by the late Neal Yedlin and Paul Desautels: the former often said 'buy and use a good mineral book' – this is one. M.O'D.

Proceedings of the Gemmological Association and Gem Testing Laboratory of Great Britain

PHOTO COMPETITION

The GAGTL are pleased to announce their first ever Photographic Competition.

The theme for the competition is 'The ins and outs of gemstones'. The photographs, which must be of gemmological interest and visually attractive, can be of any form of gem material, rough or cut, and can be of the exterior or interior of the subject. Entry is free to members of GAGTL and there will be two categories - Macro and Micro - with a prize for each category to the value of £100.00.

The closing date for the competition will be 30 April 1994. Selected entries will be exhibited at the GAGTL Annual General Meeting to be held on 13 June 1994 in London.

For rules of entry and an entry form contact Doug Garrod in the Education Department at GAGTL on 071 404-3334.

GIFTS TO THE GAGTL

The Association is most grateful for gifts of gems and gem materials for research and teaching purposes from the following:

D.H. Ariyaratna, London, for his book *Gems of Sri Lanka* published by the author.

Clive R. Burch, B.Sc., Cleadon, Tyne and Wear, for an exhibition collection of pictures of inclusions in gemstones, captioned and framed. The collection will be on display at 27 Greville Street, London.

Rui Galopim de Carvalho of Lisbon, Portugal, for the book *Royal treasures of the Portuguese Crown* by Isabel Silveira Godinho, Ana Maria Batalha Reis. Trans. Peter Ingham. Clube do Coleccionador dos Correios, 1993.

Garrard & Co., Regent Street, London, for a green composite stone from the 1920s imitating emerald.

J.A. Kessler Ltd, London, for six natural emeralds.

Tonny S. Lee, Taipei Co., Taiwan, for two actinolite cat's-eyes from Taiwan.

Harry Levy of Levy Gems for a collection of glass cabochons imitating cat's-eyes of various colours.

Pauline Matthews for an emerald in pegmatite and mica schist from the Menzies Mine, Western Australia.

K. Narayanamurthy, Kuala Lumpur, Malaysia, for rough topaz from Malaysia.

Professor David C. Smith of the Museum National d'Histoire Naturelle, Paris, France, for books on gems and Raman spectroscopy for the library.

M.H.M. Suhaib, B.Sc., Akurana, Sri Lanka for a range of untreated, treated and cut and polished geuda sapphires from Sri Lanka. The GAGTL also wishes to thank the Sri Lankan Government and the State Gem Corporation of Sri Lanka for kindly permitting the export of geuda gem samples.

NEWS OF FELLOWS

Alan Jobbins will resign from the Editorship of the *Journal of Gemmology* with the publication of this number. He wishes to thank all the authors and others who have helped him over the years; he owes a particular debt to Mary Burland for her unstinting editorial assistance and wise counsel.

He resigned from the Council of Management in September 1993.

Peter Read was invited to speak at the Canadian Institute of Gemmology's Gem Forum 1993 held in Vancouver over the weekend of 22-24 October. He gave two talks entitled 'GEMDATA Update 5' and 'The Brewster-angle refractometer'. These talks were followed by a slide presentation 'Gemscapes' at the Gala Dinner.

Whilst in Vancouver, Peter Read also ran an examination preparation course, in conjunction with **Geoffrey Dominy**, for the Canadian Institute of Gemmology students taking the GAGTL examinations.

MEMBERS' MEETINGS

London

The following meetings were held at the GAGTL's Gem Tutorial Centre at 27 Greville Street, London EC1N 8SU:

On 20 September 1993 Frank Greenaway gave a lecture on photographing minerals and gems.

On 6 October Eric Emms gave an illustrated lecture entitled 'Diamonds in the Laboratory'.

On 8 November Amanda Good and Martin Issacharoff spoke on the gemstones of Thailand.

On 22 November Harry Levy gave a lecture entitled 'CIBJO matters - the gem trade in Europe'.

On 7 December Stephen Kennedy and Ana I. Castro gave an illustrated lecture entitled 'Pearls in the Laboratory'.

Midlands Branch

On 24 September 1993 at Dr Johnson House, Bull Street, Birmingham, Dr Jeff Harris gave an illustrated lecture entitled 'Deep diamonds'.

On 29 October at Dr Johnson House, David Wilkins gave an illustrated lecture entitled 'Rescued from the scrap box'.

On 26 November at Dr Johnson House, Dr Jamie Nelson demonstrated three new gemmological teaching aids. The 'hands-on' exhibits were a two-spectra comparison spectroscope, two optical light-path units and a teaching apparatus embodying elementary 'first-principles' gemstone physics.

The Branch's 41st Anniversary Dinner was held on 11 December.

North West Branch

On 15 September at Church House, Hanover Street, Liverpool 1, a talk was given by Jonathan Condrup from Sotheby's, London.

On 20 October at Church House, Tony Hammond gave an illustrated lecture entitled 'Minerals of the Bronze Age'.

On 17 November at Church House the Annual General Meeting of the Branch was held, at which Irene Knight and Joe Azzopardi were re-elected Chairman and Secretary respectively.

MEETINGS OF THE COUNCIL OF MANAGEMENT

At a meeting of the Council of Management held on 8 September 1993 at 27 Greville Street, London EC1N 8SU, the business transacted included the election of the following:

Diamond Membership and Fellowship

Ferguson, Neil Fleming, Balloch, Dunbartonshire. 1990/1993
Godfrey, Irmfried Adelheid, Milngavie, Glasgow. 1993

Fellowship

Balducci, Annette, Neston, S. Wirral. 1993
Bertorelli, Andrea Elsbeth Louisa, London. 1993
Bombeke, Sonja, Zoeterwoude Rijndijk, The Netherlands. 1993
Cavelti, Christian G., Vancouver, Canada. 1993
Chan, Seung Yuen, Samuel, Quarry Bay, Hong Kong. 1993
Chow, Wing Yuen, William, Shatin, N.T., Hong Kong. 1993
Chown, Philip John, Sevenoaks. 1993
Earnshaw, Alison, Tonbridge. 1993
Graham, Jennifer J., Glasgow. 1993
Green, Janette Frances, Leamington Spa. 1993
Hamp-Gopsill, David, Burton-on-Trent. 1993
Hanna, Margaret, Grayshott. 1993
Hawes, Rona M., Redhill. 1993
Jegge, Erich Peter, Zurich, Switzerland. 1993
Jones, Amanda Melanie, Stourbridge. 1993
Kennedy, Lisa, Bexley. 1993
Lai, Yi Oi, Kowloon, Hong Kong. 1993
Lee, Fung Kiu, Kowloon, Hong Kong. 1993
Linde, Pamela Ann, Crewe. 1993
McLean, Grace, Dundee. 1993
Martin, Jennifer Frances, Hanham. 1993
Mathiopoulou, Regina M., Athens, Greece. 1993
Morris, Patricia E.J., Crewe. 1993
Nicholson, Charles James Rupert, Hackney, London. 1993
Nicoll, Douglas John, Haddington, East Lothian. 1993
Roberts, Keri Jane, Radstock, Nr Bath, Avon. 1993
Roskin, Gary A., Los Angeles, Calif., USA. 1993
Sagir, Yoram, Ramat-Hasharon, Israel. 1993
Schuivens, Chantalle Martine Ernestine Wilhelmine, Geleen, The Netherlands. 1993
Spencer-Haddock, Brendan, Edinburgh. 1993
Welsh, Alexis, L., Bangkok, Thailand. 1993
White, Isabel Howard, Tunbridge Wells. 1993
Williams, Jason F., West Byfleet. 1993
Wong, Chi-Wing, Kowloon, Hong Kong. 1993
Wong, Man Yee, Bess, Hong Kong. 1993
Yu, Peter K.N., Kowloon, Hong Kong. 1993.

Transfers from Ordinary Membership to Fellowship

Berruex, Cedric, La Chaux-de-Fonds, Switzerland. 1993

Chedta-Thaiyawong, Kanitha, Bangkok, Thailand. 1993
Dansereau, Eva M., Winnipeg, Canada. 1993
De Granville, Francesca, Oklahoma City, Okla., USA. 1993
Duigan, Ingeborg, Hong Kong. 1993
Farrimond, Thomas, Cambridge, New Zealand. 1993
Harada, Kayoko, Kanagawa Pref., Japan. 1993
Kang, Joo-Youn, Seoul, Korea. 1993
Kiji, Michio, Osaka, Japan. 1993
Kinda, Yumiko, Osaka, Japan. 1993
Kitawaki, Hitoshi, Saitama Pref, Japan. 1993
Kitawaki, Jyunko, Osaka, Japan. 1993
Luke, Ting Cho Lin, Arlene, Hong Kong. 1993
Ma, Siu Lam, Hong Kong. 1993
Odawara, Hiroko, Osaka, Japan. 1993
Okuta, Etsuko, Osaka, Japan. 1993
Shibata, Hitoshi, Osaka, Japan. 1993
Tanaka, Kazuhide, Osaka, Japan. 1993
Tonn, Heleen Antoinette, Rotterdam, The Netherlands. 1993
Van Opstal, Wilma, Tilburg, The Netherlands. 1993
Yamasuga, Ryoji, Hyogo Pref, Japan. 1993
Yasuda, Kiyotaka, Osaka, Japan. 1993
Yokote, Hideki, Fukuoka Pref, Japan. 1993
Zanettin-Barbin, Fabrizia, Geneva, Switzerland. 1993
Zhang, Beili, Wuhan, P.R. China. 1993

Ordinary Membership
Ahamed, Omar Faiz, Gillingham
Anderson-Slight, Jamie Gordon, Horsham
Bruguera de la Pena, Jorge, Barcelona, Spain
Butcher, Anna, London
Edwards, Kenneth Frank, Luton
Fraser-Harris, Malcolm, Lewes
Gunn, Sapphire, Harrow Weald
Hultberg, Stefan, Copenhagen, Denmark
Jackson, Stephen, Redruth
Jones, Stephen David, Hong Kong
King, Carolyn Jane, Richmond
Kumar, Visuvalingham Krishna, Morden
Ma, Hon Kit, Jonathan, Hong Kong
Marshall, Michael Robert, Solihull
Ooka, Yoshiyuki, Kraainem, Belgium
Randall, Gary Marshall, Lowestoft
Saaf, Judith Heselton, Groisy, France
Seegobin, Wendy, Walthamstow
Sutton, Daniella Nicola, Cheltenham
Wren, Amanda, Edinburgh

GAGTL GEM TUTORIAL CENTRE

27 Greville Street, London EC1N 8SU

Identification of Beads & Necklaces
15 February
How often do you need to identify a gemstone with a curved surface or an opaque substance that you cannot place on the refractometer?
This is the course for you. Spend a day studying a variety of beads and other items.
Price £35.25 (including sandwich lunch)

Weekend Diamond Grading Course
5-6 March
This successful course concentrates on the practical aspects of clarity and colour grading of polished diamonds, using 10x lens, microscope and colour comparison stones. Mounted stones, simulants and clarity enhanced stones will be seen. Of great value to all involved in diamond trading and appraisal, the course is taught by Laboratory staff.
Price £246.75

Preliminary Workshop
6 April
A day of practical tuition for Preliminary students and anyone who needs a start with instruments, stones and crystals.
Price £44.65; GAGTL students £31.73 (including sandwich lunch)

Synthetics & Enhancements Today
19-20 April
How aware are you of the various treated and synthetic materials that are likely to be masquerading alongside the gemstones you are buying and selling? Whether you are valuing, repairing or dealing, can you afford to miss these two days of investigation into the Laboratory's important collection?
Price £223.35 (including sandwich lunch)

ALL PRICES INCLUSIVE OF VAT AT 17.5%

At a meeting of the Council of Management held on 20 October 1993 at 27 Greville Street, London EC1N 8SU, the business transacted included the election of the following:

Diamond Membership
Turner, Gaynor Jane, Edinburgh. 1993

Diamond Membership and Fellowship
Turner, Stephen Jeffrey, Edinburgh. 1993

Fellowship
Chan, Mei Wah, Carol, Hong Kong. 1993
Chenevix-Trench, Susannah, Hong Kong. 1993
Cheung, Shuk Mei, Hong Kong. 1993
Crabbe, Jeremy Paul, Hong Kong. 1993
De Chamerlat, Marie, Paris, France. 1993
Donkin, Jeffrey John, Surbiton. 1993
Ettila, Annamari, Helsinki, Finland. 1993
Forrest, Jacqueline, Charing Cross, Glasgow. 1993
Fowle, Michael John, Nairobi, Kenya. 1993
Fung, Lai Yi, Kowloon, Hong Kong. 1993
Gibson, William Michael, Highland, Md., USA. 1993
Gisbert, Ana Maria, Madrid, Spain. 1993
Hung, Ching Ting Cara, Quarry Bay, Hong Kong. 1993
Hung, Suet Fung Josephine, Hong Kong. 1993
Indiano, Natividad, Madrid, Spain. 1993
Keating, Martina, Waterford, Ireland. 1993
Kelloniemi, Katri Irene, Helsinki, Finland. 1993
Kim, Jee-Eun, New Malden. 1993
Kruise, Berendina Jantje, Zwolle, The Netherlands. 1993
Lasry, Veronique, Madrid, Spain. 1993
Lau, Paul, Kowloon, Hong Kong. 1993
Lee, Choi Kan Franky, Kwun Tong, Hong Kong. 1993
Lee, Jin-Young, Potters Bar. 1993
Leong, Margaret, Gadong, Brunei. 1993
Mani, Heida, Ontario, Canada. 1993
Nam, Song-Ja, Daejon, Korea. 1993.
Paakkari, Petri William, Lahti, Finland. 1993
So, Chak Tong Anthony, Hong Kong. 1993
Stahl, Elone, Tygelsjo, Sweden. 1993
Thompson, Jane Devereux, Woodbridge. 1993
Turner, David Barry, Newcastle-upon-Tyne. 1993
Wong, Lai Fun Alice, Hong Kong. 1993

Ordinary Membership
Aarden-Kilger, Flavia L.M., Bemmel, The Netherlands
Carr, Simon Damian Peter, Garstang
Chong, Seok-Ran, Busan, Korea
Damiao, Luisa Isabel Gomes, Mitcham
Doumbouya, Mohamed, St John's Wood
Frey, Robert, London
Gordon, Tanya, London
Green, Nicholas Philip, London
Hare, Judy, Finchley
Hill, Letitia, Birminghan
Hill, Lisa Juliet, Queens Park
Jack, Johanne C., Khon Kaen Thailand
Kilby, Linda Elaine, Great Harwood
Lam, Siu-Wing, Hong Kong.
Lubowa, Ngoy, Forest Gate
Pomicter, Leonard John, Santa Monica, Calif., USA
Purkiss, Karen Ann, Colchester
Quintner, Flora, Grays
Raphael, Menachem, Alwoodley
Sotolongo, Sachiko, London
Tanaka, Keiko, East Finchley
Tinnyunt, Emma Judy, Torquay
Von Manussis, Veronica, London
Yip, Ngai, Kowloon, Hong Kong

At a meeting of the Council of Management held on 17 November 1993 at 27 Greville Street, London EC1N 8SU, the business transacted included the election of the following:

Diamond Membership
Cooke, Eva-Maria, North Cheam. 1993

Fellowship
Chellew, Ross Jasper, London. 1993
Fung, Kam Man, Hong Kong. 1989
Gillies, Bronwyn Joy, Wanaka, New Zealand. 1993
Leinonen, Ossi Antero, Viantie, Finland. 1993
Margolis, Paul Howard, Vancouver, B.C., Canada. 1993
Park, Kyong Ok, Seoul, Korea. 1992
Roubin, Ernest, Athens, Greece. 1993
Wilcox, Kimberly Anne, Delmar, NY, USA. 1993
Wong, Ming Kin, Hong Kong. 1993
Yang, Hye Kyeong, Houston, Tex., USA. 1993

Ordinary Membership
Ashton, David, Homerton
Baker, David M., Dublin, Ohio, USA
Dapper, Sylvia, Catford
Davis, Shelagh Mary, Andover, Hants.
Dyer, Elaine, Compton Dundon
Fields, Catherine, London
Hatiris, Michael, Athens, Greece
Hatzimihael, Michael, Athens, Greece
Hoi, Tyng Siew, Kuala Lumpur, Malaysia

Kaskara, Tatiana, Pimlico
Kimani, Marjory Nyakiago, Nairobi, Kenya
Maulud, Mat Ruzlin Bin, Leicester
Maxwell, Gary, London
Nakane, Chie, Hyogo Pref., Japan
Pearce, Nigel Robert Williams, St. Helier, Jersey
Schieser, Andrea Louise, Austin, Tex., USA
Sinton, Sarah Kristine, Wandsworth
White, Malcolm John, Kingston-upon-Thames

PRESENTATION OF AWARDS

The Presentation of Awards gained in the 1993 examinations was held on 25 October at Goldsmiths' Hall, London. Mr Ian Thomson presided and congratulated the successful candidates. Among those present were award winners from Finland, France, Greece, Hong Kong, Japan, The Netherlands and Switzerland, as well as those from the UK.

Following the presentation of awards for the Gem Diamond and Gemmology examinations, a Research Diploma was awarded to Dr Jamie Nelson for his thesis entitled 'The glass filling of diamonds'. A certificate was presented to Eric Bruton, who had been elected as Vice President of the GAGTL at the Annual General Meeting held on 14 June 1993.

The awards were presented by Lord Ian Balfour. In his address Lord Balfour referred to his career in the diamond trade. He started as a diamond sorter, which was very good experience, and very early in his career he was shown a pamphlet on famous diamonds. This was the beginning of his interest in the subject which led eventually to the publication of his book *Famous Diamonds of the World*. A second edition of the book was published in 1992 and a third is in prospect.

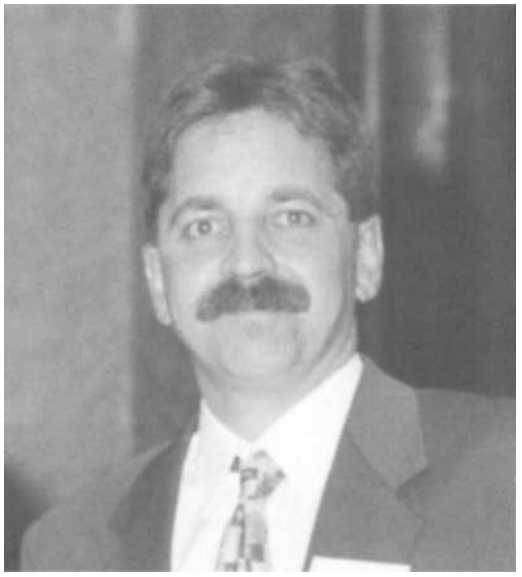

Fig. 2. Anderson Bank Prize winner Pierre Vuillet à Ciles of Villards d'Heria, France.

Fig. 1. Lord Balfour.

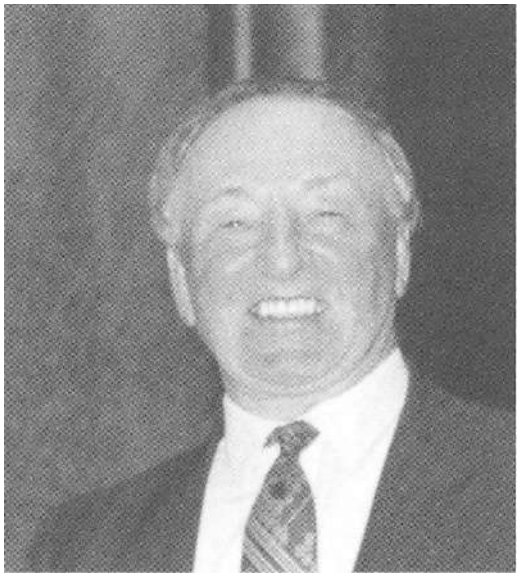

Fig. 3. Dr Jamie Nelson awarded the Research Diploma.

'Diamonds', said Lord Balfour, 'are only one facet of gemmology.' He stressed that knowledge does not stand still and those that had qualified should consider the Diploma as a major step on their quest for excellence in gemmology.

The vote of thanks was given by Christopher Cavey.

In conclusion Ian Thomson thanked the Goldsmiths' Company for allowing the GAGTL to hold the presentation ceremony at the Hall. He also thanked the Examiners and the education team for their work during the year.

Awards ceremony in China

During a visit to Hong Kong and China, Eric C. Emms was guest of honour at the awards ceremony at the annual Gemmological Conference of the China University of Geosciences in Wuhan. The University is an Allied Teaching Centre (ATC) of the GAGTL and has taught the Diploma course in gemmology leading to the FGA status for many years. Vice Minister of Geology, Mr Zhang Wenye, presented successful candidates in the Diploma examinations with their Diplomas and Eric Emms presented the three awards. The Tully Medal and the Anderson Prize were presented to Ms Guo Tao. The Diploma Trade Prize was presented to Mr Guo Xiaoming.

Fig. 4. Vice-President Eric Bruton.

In his speech following the presentation, Mr Emms described GAGTL plans to teach the Gem Diamond Diploma course leading toDGA status in China and other ATCs in East Asia. A report on the launch of the Gem Diamond Diploma course in China will appear in the next issue of the Journal.

Letters to the Editor

From Dr A. Peretti and Christopher P. Smith

Dear Sir,

Concerning new synthetic rubies in Russia and the recent article of Dr Henn and Professor Bank in the *Journal of Gemmology*.

We feel it is necessary to clarify certain statements made by Dr Henn and Prof. Bank in the July 1993 issue of the *Journal of Gemmology* (**23**, 7) in their article on new synthetic rubies from Russia. According to their introduction, the reader may be led into thinking that the material which we have described as being of hydrothermal origin, is the same material which Dr Henn and Prof. Bank have described in their paper. Therefore, we would like to clear up any possible misconceptions by supplying proof of the hydrothermal origin of the synthetic rubies we

Fig. 1. Infrared absorption spectrum in the region of 2500 to 4000 wavenumbers, of a flux-grown synthetic ruby produced by the Academy of Sciences in Novosibirsk, displaying the relatively featureless IR spectrum of a synthetic ruby grown by a flux process. Path length approx. 4mm

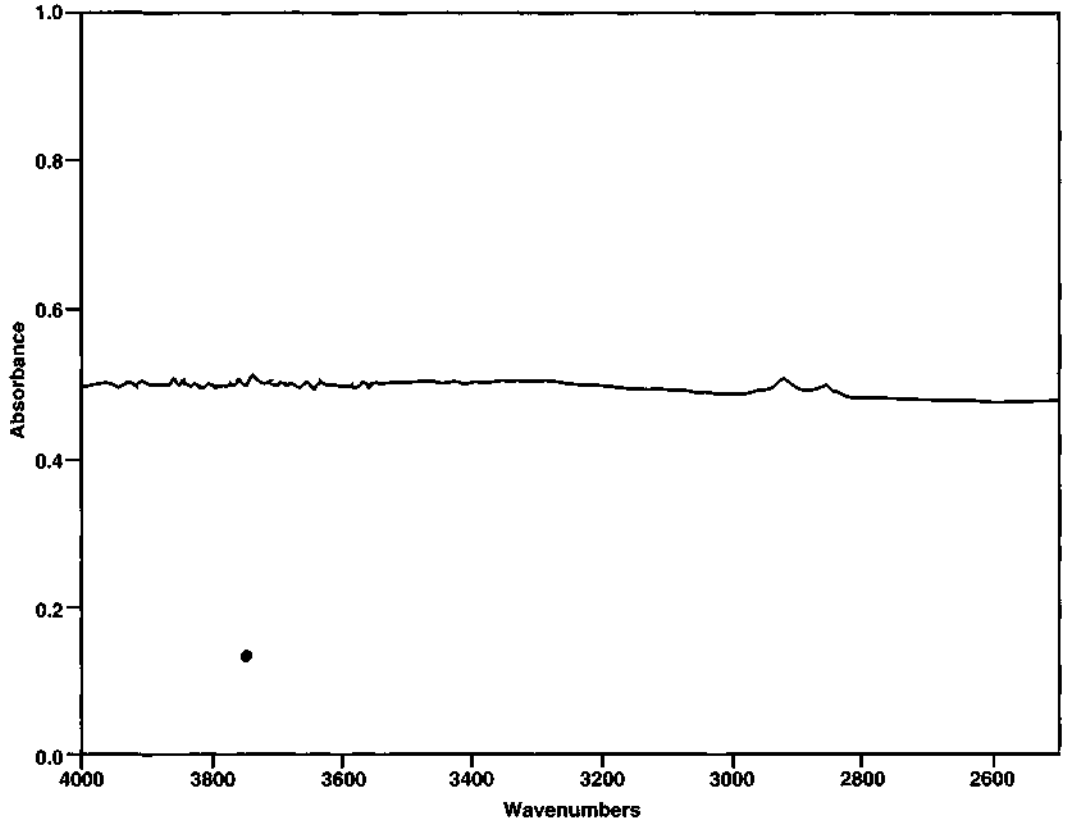

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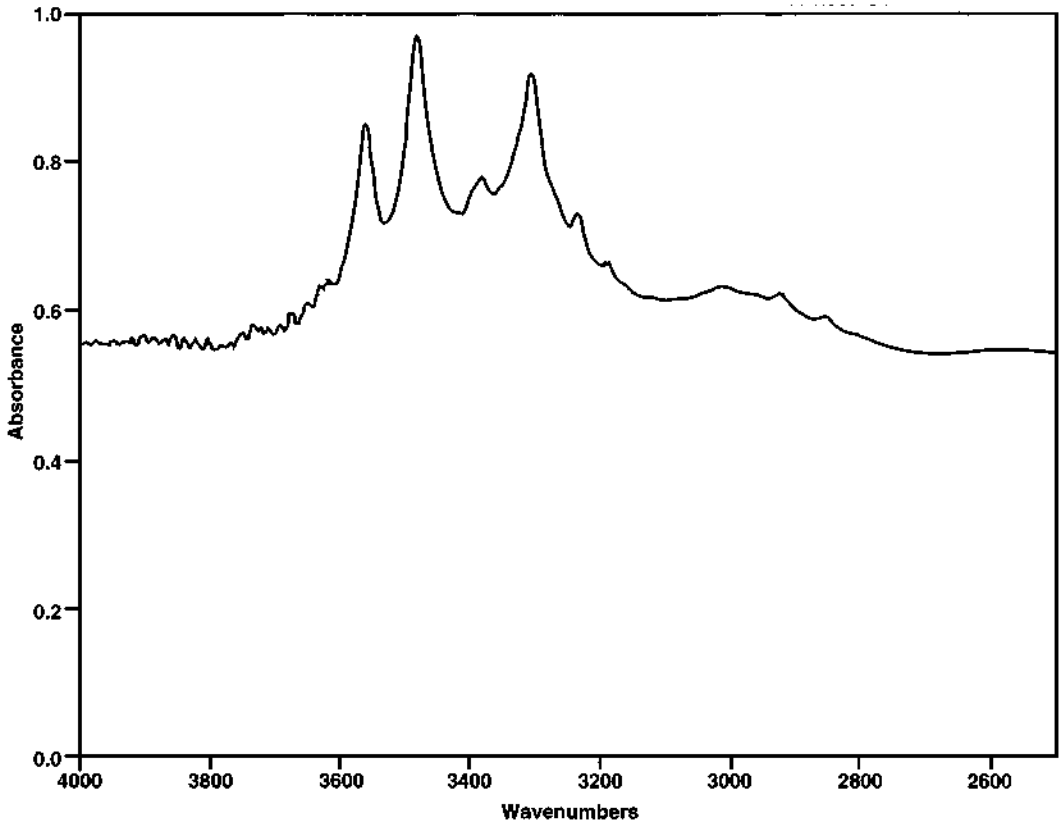

Fig. 2. Infrared absorption spectrum in the region of 2500 to 4000 wavenumbers, of a hydrothermally-grown synthetic ruby produced by the Institute of Geology and Geophysics in Novosibirsk. Exhibiting the typical series of sharp absorption peaks located at 3561, 3483, 3382, 3305, 3235 and 3191 wavenumbers, related to structural OH groups. Path length approx. 4 mm

have investigated, through infrared spectroscopy and scanning electron microscopy.

To begin with, we have also examined the material which Dr Henn and Prof. Bank detailed in their paper. The samples were given to Dr Dietmar Schwartz, of the Gübelin Gemmological Laboratory, directly by Dr Bukin, of the Academy of Sciences in Novosibirsk. This included rough crystals with the identical morphology as those pictured in the *Journal of Gemmology* article, p. 394. Dr Henn and Prof. Bank are indeed correct in reporting that this material is grown by a flux-melt process. However, this is not the material which we have presented in ICA Laboratory Alert No. 66 or the article published in the *Australian Gemmologist* (18, 5, 149-56), describing hydrothermally-grown synthetic rubies. The material we have reported on, is produced by the Institute of Geology and Geophysics, another of the several research laboratories under the Academy of Sciences in Novosibirsk and marketed by the Tairus joint-venture through Pinky Trading Co. Ltd in Bangkok (Thailand) directed by Mr W. Barshai (a competitor of Dr Bukin). There is more than one research facility producing synthetic rubies in Russia for various techniques including pulled (Czochralski), flux-grown, floating-zone as well as hydrothermal. As we have been informed, the Tairus joint-venture is only marketing floating-zone and hydrothermally-grown synthetic rubies.

For comparison purposes, we have enclosed infrared spectra for both types of synthetic ruby under discussion. Typical of flux-grown synthetic rubies, the material from Dr Bukin is free of

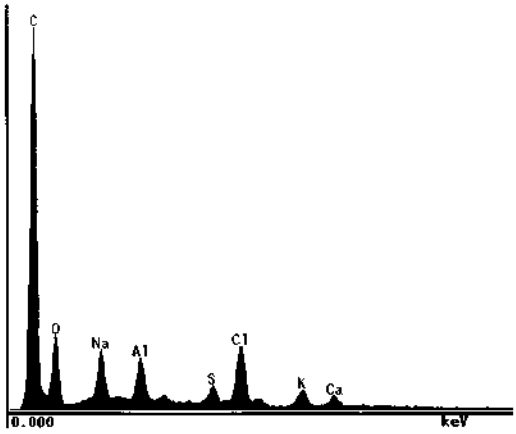

Fig. 3. SEM-EDX analyses of the whitish crusts found on rough rubies reportedly produced by the hydrothermal process in Novosibirsk (Russia). Note the presence of Ca, K, and Na and C evidencing the presence of alkali carbonates in the whitish crusts. Such materials are used as nutrients for complexing alumina in hydrothermal ruby productions. Note no signatures for transition or heavy metal elements.

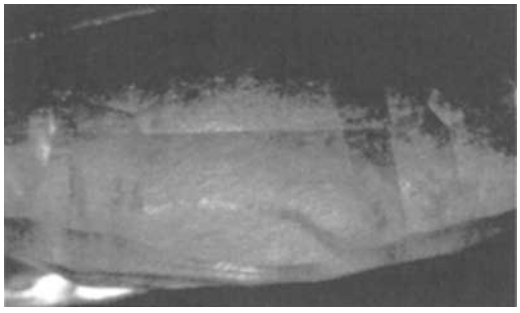

Fig. 4. The most distinctive inclusion feature of the hydrothermal synthetic rubies described to date, consists of heavily disturbed growth characteristics. 35x

significant absorption features in the region of 2500 to 4000 wavenumbers (Figure 1). In contrast, the hydrothermally-grown synthetic rubies display a series of absorption peaks, within the same region of 2500 to 4000 wavenumbers, which are related to structural OH groups (Figure 2). These spectral characteristics are consistent with what has been reported for experimentally-grown hydrothermal synthetic rubies, by Russian and American researchers. About this topic we will soon report in detail.

In addition, we have analysed by scanning electron microscopy, metallic inclusions as well as whitish crusts which were coating some of the rough crystal fragments of the material we have described as hydrothermal rubies. The metallic inclusions were identified as two different types of copper alloys, it is important to note that copper is not used in the flux-growth process because it is not resistant enough to the high temperatures necessary for this process. The whitish crusts were identified as alkali and potassium carbonates (Figure 3). These materials have been described as nutrients in the literature for the production of hydrothermal rubies. No platinum was detected in the metallic alloys and no lithium or tungsten was detected in the whitish crusts. Such elements would have been expected if we were analysing the same material as described by Dr Henn and Prof. Bank.

Lastly, we've included a photo-micrograph of the most distinctive and identifiable inclusion feature observed in the hydrothermal synthetic rubies we have reported on to date. This consists of heavily disturbed growth characteristics (Figure 4), which are very reminiscent of the growth characteristics seen in the hydrothermal synthetic emeralds produced in Russia (see e.g. Schmetzer, 1988; Characterization of Russian hydrothermally-grown synthetic emeralds, *Journal of Gemmology*, **21**, 145-64). They are not present in the material described by Dr Henn and Prof. Bank.

We hope this will prevent any possible misconceptions between these two materials. Continued research of the hydrothermally-grown synthetic rubies has provided more interesting results, which will be forthcoming in the gemmological literature.

Yours etc.

Adolf Peretti and Christopher P. Smith
1. Peretti Gemlab, Adligenswil, Switzerland
2. Gübelin Gemmological Laboratory, Lucerne, Switzerland

Reference

Peretti, A., Smith, C.P., 1993. 'A new type of synthetic ruby on the market: offered as hydrothermal rubies from Novosibirsk.' *The Australian Gemmologist*, 18, 5, 149-57

From Patricia B. Lapworth

Dear Sir

It seems a pity that the Japanese have chosen to call their new *imitation* opal by the name 'Opalite' (see Scarratt et al. 'Opalite triplets - new imitations of opal', *Journal of Gemmology*, 1993, **23**, 8, 473-80), which has been used for over 25 years at least in Australia, to my knowledge, for decorative *natural* common opal (usually yellow with black dendrites) much used by lapidaries. It appears in a number of authoritative Australian texts on ornamental, etc., stones and appears in Peter Read's *Dictionary of gemmology*.

Surely there are already enough examples of confusion in gemstone nomenclature already without inventing new ones!

Yours etc.,
Patricia Lapworth
Guildford GU1 3RR
23 November 1993

Corrigenda

In *J. Gemm.*, 1993, **23**, 8, p. 465, Table 1, fifth column heading for 'λ' read 'λ_0'

On p. 466, Figure 8, formula at top left, for '38 670' read '30 730'

On p. 467, left hand caption on each of the three photomicrographs, for 'n^{25}' read 'n_D^{25}'

On p. 468, second column, line 14, for '495' read '$\overline{495}$'

On p. 470, Figure 11, formula at top left, for '38 670' read '27 830'

Gem Diamond Diploma

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23 February	'Decorative and collectors' minerals from southwest England'	Dr Robert Symes
7 March	'The history of Garrards, the Crown Jewellers'	William Summers
30 March	'Jewellery at auction'	David Lancaster
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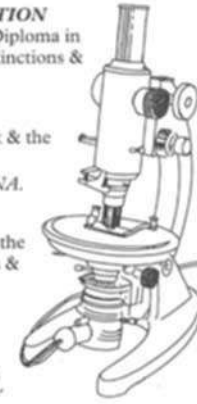

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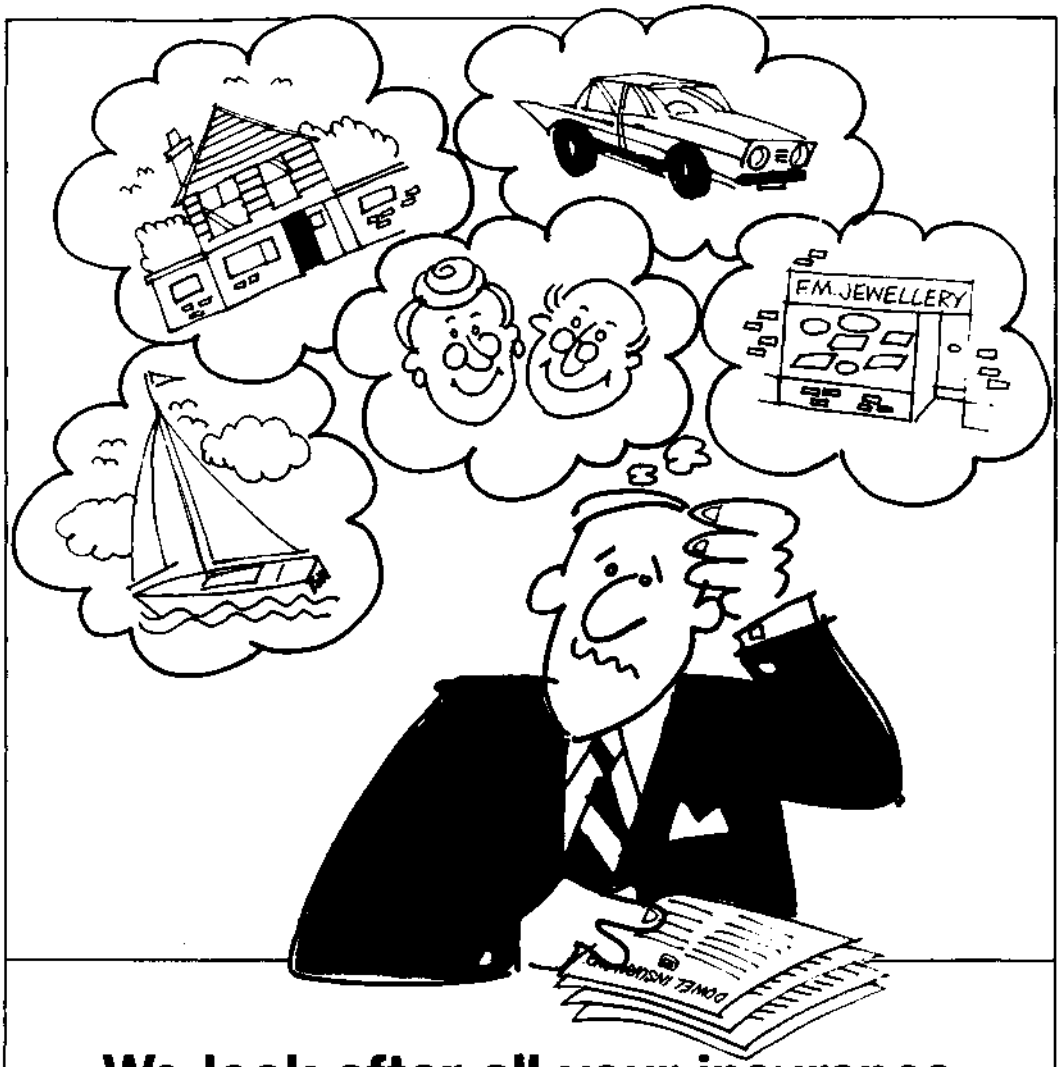

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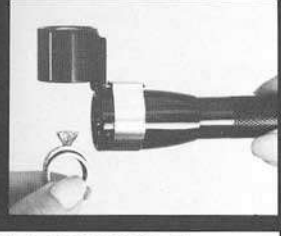

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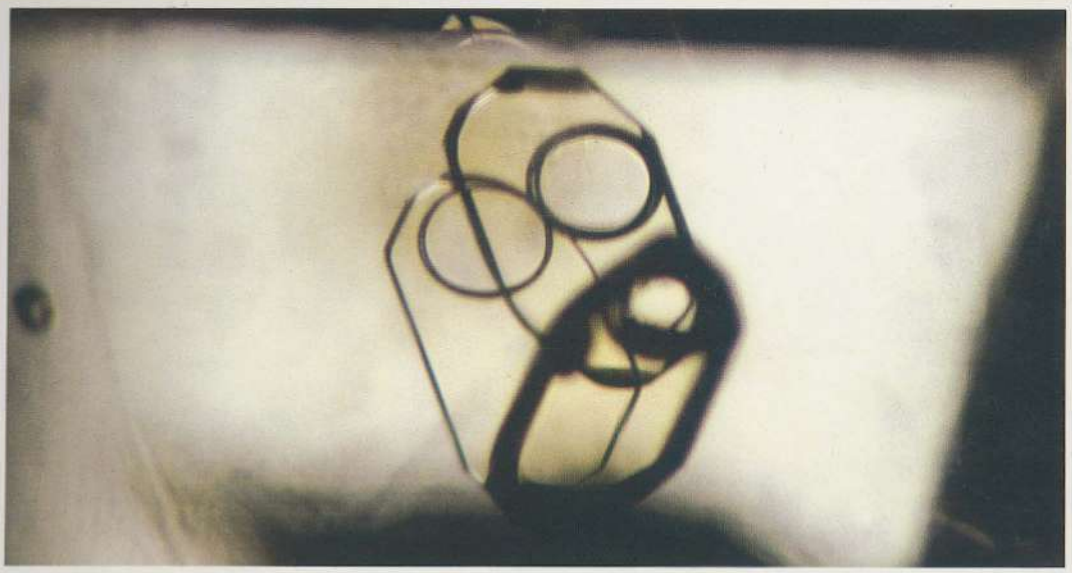

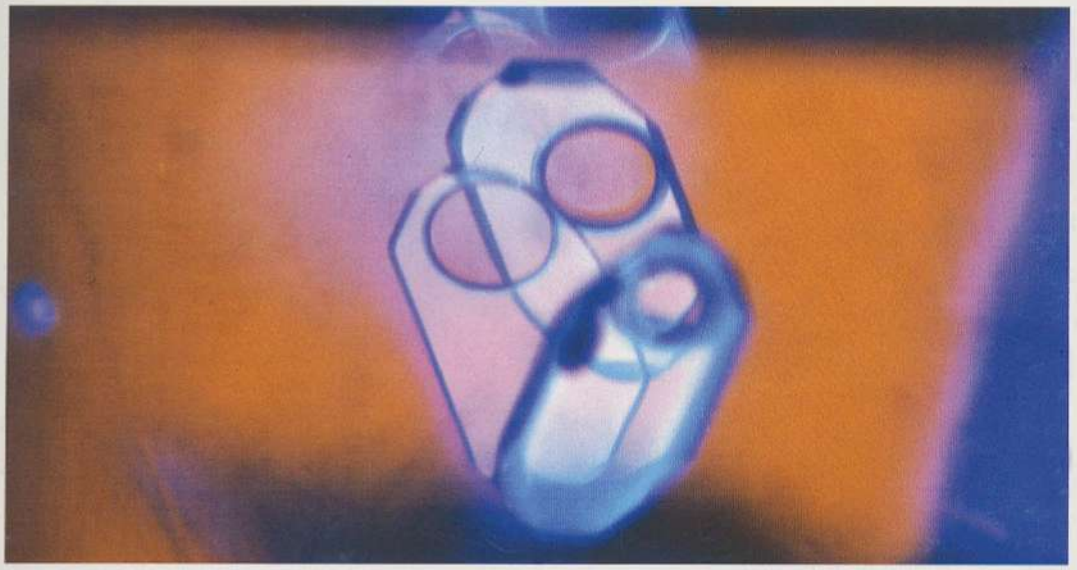

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The Journal of Gemmology

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Cover Picture

Three-phase inclusions in quartz consisting of oil, a gas bubble and a small black particle of bitumen. Transmitted light (top) and long-wave ultraviolet light plus low intensity transmitted illumination below. 14x.

(See 'Fluorescent oil inclusions in quartz' pp. 84-5)

Photo by Anthony de Goutière

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Alan Jobbins
Editor 1986-93

Alan Jobbins resigned from the editorship of the *Journal* at the end of 1993. The Council of Management has appointed Dr Roger Harding to succeed him.

In 1985 Alan became joint Editor of the *Journal* with J.R.H. Chisholm and took over completely in 1986. In that year he launched a new design, of increased size, which incorporated more colour illustrations of better quality and enhanced the already world-wide reputation of the *Journal*.

Gemmology is a constantly changing and expanding subject, and we intend that the *Journal* should develop to reflect, record and be part of these changes. To this end, an editorial structure including Assistant and Associate Editors is planned and will involve a wide range of expertise. This will enable a thoroughly professional assessment of new manuscripts describing the latest gemmological developments.

The *Journal* will continue to be a major magazine for original papers on topics of significance for gemmologists whether they be in production, manufacturing, distribution, testing or research sectors of the profession. We invite accounts of new gemstone research and stimulating reviews of recent advances for publication. We aim to achieve publication in twelve months or less from date of reception of a satisfactory manuscript.

For many years and throughout his editorship Alan supplied a constant stream of colour illustrations for the *Journal* - they were superb and have been a major feature in his articles and lectures on gemmology. We hope that Alan will continue to delight us all with his pictures and with the fruits of his gemmological travels throughout the world. We would also like to wish him good health and many more years of enjoyment in his gemmological activities.

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Four hessonite occurrences in Orissa, India

Dr J. Kanis[1] and M. Redmann[2]

1. Veitsrodt, Germany
2. Idar-Oberstein, Germany

Abstract

Hessonite garnets from the villages of Ghatpara, Dahikbala, Budhido and Burubura in Orissa, India, are located in the high-grade metamorphic khondalite suite and occur either in calc-silicate lenses or in quartzite-amphibolite contact zones. The paragenesis of Orissa's hessonite is linked to regional metamorphic processes, probably during Middle Proterozoic times. The colours of the stones are pale yellowish, orange to brown and the ranges of the refractive index and density from each locality are:

Ghatpara:	n=1.738-1.752	D=3.56-3.64 g/cm^3
Dahikbala:	n=1.750-1.756	D=3.58-3.64 g/cm^3
Budhido:	n=1.751-1.758	D=3.60-3.63 g/cm^3
Burubura:	n=1.759-1.763	D=3.60-3.66 g/cm^3

In addition to calcium, aluminium and silicon, the chemical analyses also show a distinct content of iron and traces of both manganese and titanium.

Microscopical study shows that the hessonite from Ghatpara is characterized by mineral inclusions, healing cracks with two- or three-phase inclusions and growth marks which sometimes show strong interference colours under crossed polarizers. The inclusions in the stones from Burubura are mainly healing cracks with two- or three-phase inclusions and growth marks. The hessonite from Budhido shows a strong oily appearance and mineral inclusions, and the stones from Dahikbala are characterized by needle-like inclusions, growth marks and some mineral inclusions.

Introduction

India is an important producer of gemstones and rare collectors' specimens, and well known for its abundant gemstone occurrences. There are many valuable garnet occurrences, not only of very fine rhodolite, almandine and pyrope-almandine but also of the hessonite variety of grossular.

Indian hessonite has been found near Madras in the Coimbatore district; in the State of Orissa, near Boirani in the Genjam district and near Daolathgarh in Rajasthan (Rouse, 1986).

During a United Nations Development Programme (UNDP) exploration mission in Orissa (India) recently one of the authors (J.K.) collected light yellowish to brownish hessonite samples from the Ghatpara deposit, south of the Tel river. Later, in November 1992, hessonite samples in yellowish-brown and orange to brownish colours were collected from three other occurrences near Dahikbala, Budhido and Burubura, all in the State of Orissa.

The physical, chemical and microscopic characteristics of hessonites from these four different occurrences are interesting to compare. Grossular is chemically a calcium aluminium silicate ($Ca_3Al_2(SiO_4)_3$) and forms with andradite and uvarovite the ugrandite series (Deer *et al.*, 1982). Two kinds of decorative grossular can be distinguished: a transparent and an opaque type. Opaque green grossular variety, which is known in the trade as 'Transvaal Jade', is a mixture of grossular with vesuvianite. The green colour depends on the chromium (Cr^{3+}) content (Bank, 1982). Opaque pink grossular is a mixture of grossular and hydrogrossular, now know as hibschite where SiO_4 is partly replaced by $(OH)_4$, and the colour is caused by manganese (Bank, 1982).

Transparent grossular is known in colourless, green, yellowish and orange to brown colours. It is the vanadium (V^{3+}) and/or chromium (Cr^{3+}) content which is responsible for the green colour, and this green grossular is well known under the name tsavorite, from East Africa. The yellowish and orange to brownish colour is caused by iron (Fe^{3+}) and this grossular variety is known as hes-

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Table I. Refractive indices and densities of transparent grossular from previous literature

Literature	*Colour*	*Refractive index*	*Density: g/cm³*
Eppler (1984)	pure synthetic grossular	1.734	3.594
Bank, H. (1971)	colourless	1.732	3.65
Bank, H. and Henn, U. (1988)	yellowish-green - dark green (contains vanadium)	1.735-1.759	3.55-3.64
Eppler (1984)	light green	1.734-1.738	
Eppler (1984)	tsavorite (green)	1.739-1.744	3.61 (mostly)
Bank, H. *et al.* (1969)	yellow	1.745	3.60
Bank, H. *et al.* (1969)	brown	1.749	3.73
Webster (1983)	hessonite	1.728-1.748	3.65
Eppler (1984)	hessonite	1.742-1.748	3.65 (mostly)
Manson and Stockton (1982)	hessonite	1.733-1.760	3.59-3.66

sonite. The refractive indices and density in the transparent varieties vary considerably, depending on the contents of different elements. For instance, in the green vanadian grossular the aluminium (Al^{3+}) is partly replaced by vanadium (V^{3+}) and chromium (Cr^{3+}). The higher the percentage of vanadium (V^{3+}), the more intense is the green colour and the higher are the refractive indices and the density (Bank and Henn, 1988). In the yellowish to brown grossulars there is a partial replacement of aluminium (Al^{3+}) by iron (Fe^{3+}). Similarly, the refractive indices and the density are higher with increased iron content.

Strongly corroded apatite and calcite have been found as inclusions in hessonite, as well as diopside and zircon. Typical internal features in hessonite are oily-looking streaks, often called 'treacle'. According to Gübelin and Koivula (1986) this is due to a colloid separation of calcite in the hessonite from Sri Lanka. Also lamellar growth marks are observed.

During the International Gemmological Conference meeting in Rio de Janeiro (1987) Gübelin reported inclusions in the orange, brownish-orange to brownish-yellow grossular from Orissa. These inclusions are orthoclase crystals with twinning, small prismatic apatite crystals and well formed quartz crystals. Gübelin also mentioned three-phase inclusions (watery fluid, gas bubbles and halite crystals) and multiphase inclusions (watery fluid, drops of oil, gas bubbles, halite crystals and a not yet identified black amorphous substance, which could be bitumen).

Federal State of Orissa

Geography

The State of Orissa is situated on the east coast of India, along the Gulf of Bengal and south-west of Calcutta.

The Mahanadi river flows through the Eastern Ghats and has a length of 885km. This mighty river has been known for the occurrence of alluvial diamonds for more than 200 years. The hills and mountains of the Eastern Ghats dominate the morphology of Orissa; the average elevation is about 750m, but a few peaks rise to over 1500m.

Geology

Geologically the Eastern Ghats consist largely of high grade Precambrian metamorphic rocks with a distinct structural-geomorphological trend parallel to the north-north-east to south-south-west elongation of the Eastern Ghats. The principal lithologies are khondalite, charnockite, leptynite and gneiss, with a very complex structure, indicating a zone of intense deformation (Figure 1).

The high degree of regional metamorphism (granulite and amphibolite facies) in the western part of Orissa has been responsible for developments of garnets, rubies, sapphires and

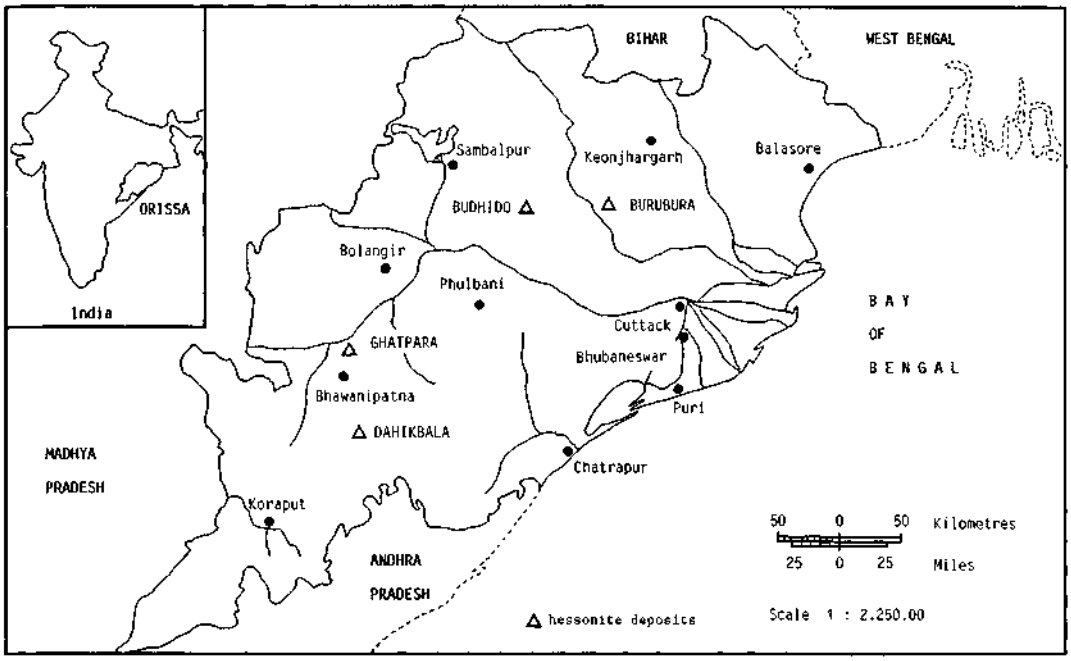

Fig. 1. Geographical location of Orissa hessonite occurrences.

cordierite, whilst younger granite intrusions and their related granitic pegmatites are the source for gemstones like aquamarine, chrysoberyl cat's-eye and tourmaline. These occur in a number of extensive pegmatite belts throughout western Orissa. The two principal rock suites of the Eastern Ghats are:

Khondalites and related rocks, which consist of calc-silicates, a metamorphosed sequence of sediments and limestones. In addition to sillimanite and garnet, other minerals indicative of the high metamorphic grade are cordierite and sapphirine.

Charnockites are silica-rich, quartzo-feldspathic assemblages containing hypersthene.

Khondalites and charnockites were first recognized in India in the Khalahandi district of Orissa (khondalite) and near Pallavaram in Tamilnadu (charnockite). Subsequently, these rocks were identified in other parts of India and Sri Lanka.

The khondalites are intimately interbedded with calc-silicate rocks and represent a series of argillaceous sediments formed in an environment that also permitted the deposition of

Fig. 2. Erratic hessonite 'pockets' in calc-silicate formation (khondalite). (*Photo J. Kanis*)

Fig. 3. Illegal hessonite mining near the village of Singjharan in calc-silicate formation (khondalite). (*Photo J. Kanis*)

carbonate rocks. These calc-silicates form lenticular bodies 50 to 800m long and 5 to 200m wide, often associated with manganese-bearing rocks. These interbedded lenses always contain K-feldspar, wollastonite, calcite and quartz. Other characteristic minerals are grossular, scapolite, diopside and sphene.

The mineralogy is largely a result of prograde metamorphism, but some retrogressive effects have been found, e.g. Choudhuri and Banerji (1974) described an assemblage of grossular and quartz formed by retrogressive reaction of anorthite and wollastonite. Cordierite is present in areas of a lower metamorphic grade than the common sillimanite-garnet rocks which do not contain cordierite. Naqvi and Rogers (1987) mention that an inverse correlation between the abundance of orthopyroxene and garnet implies a reaction relationship. The garnets in khondalite are generally high in grossular and low in pyrope components, in contrast with the almandine-pyrope garnets of associated charnockites. Garnets tend to be paragenetically young, showing inclusions of all other surrounding minerals.

The ages of deformation of the Eastern Ghats granulite suites are unknown, but they may have coincided with emplacement of granites in the Middle Proterozoic, or perhaps a collisional event might have been a principal cause.

Table II. Refractive indices and densities of Orissa hessonites

Locality	*Refractive indices*	*Density: g/cm³*
Ghatpara	1.738-1.752	3.56-3.64
Dahikbala	1.750-1.756	3.58-3.64*
Budhido	1.751-1.758	3.60-3.63
Burubura	1.759-1.763	3.60-3.66

* Some samples were too small to justify more precise density values.

Hessonite occurrences in Orissa and their localities

It is unusual that the exact location and geological source of gemstones examined in the laboratory are known to the gemmologist. It is fortunate, therefore, that the four hessonite localities, mentioned below, were visited by one of the authors (J.K.) during field trips as consultant for the current UNDP gemstone project in Orissa.

Ghatpara

North-east of the railway town of Kesinga in the Bolangir District is the village of Ghatpara, near the south bank of the Tel river. Between Ghatpara and the small village Singjhran, about 3km south-east of Ghatpara, are various calc-silicate lenses embedded in khondalite rocks. These

Table III. Chemical analyses (in wt.%) of hessonite from Ghatpara and Burubura in Orissa, India

	Gh 01	*Gh 02*	*Gh 03*	*Bu 01*	*Bu 02*	*Bu 03*
SiO_2	38.15	38.31	37.48	37.32	38.50	37.14
Al_2O_3	20.43	19.55	18.46	17.12	17.78	17.20
CaO	39.59	37.53	37.10	38.12	36.24	36.15
Fe_2O_{3tot}*	1.10	4.17	6.15	6.75	6.93	8.20
MnO	0.37	0.44	0.66	0.26	0.22	0.80
TiO_2	-	-	0.15	0.44	0.33	0.51
Total	100.00	100.00	100.00	100.00	100.00	100.00
n:	1.738	1.746	1.752	1.759	1.760	1.763
D g/cm³	3.56	3.60	3.64	3.60	3.61	3.66

* total iron content measured as Fe_2O_3

NB The Edax programme processes these oxide values to total 100%.

Gh 01:	hessonite, light yellowish	Ghatpara, Orissa
Gh 02:	hessonite, yellowish-brown	Ghatpara, Orissa
Gh 03:	hessonite, yellowish-brown	Ghatpara, Orissa
Bu 01:	hessonite, yellowish-brown	Burubura, Orissa
Bu 02:	hessonite, yellowish-brown	Burubura, Orissa
Bu 03:	hessonite, brown	Burubura, Orissa

Table IV. Chemical analyses (in wt.%) of hessonite from Budhido and Dahikbala in Orissa, India

	Bh 01	*Bh 02*	*Bh 03*	*Di 01*	*Di 02*	*Di 03*
SiO_2	36.75	34.63	35.97	35.97	36.39	36.17
Al_2O_3	18.95	17.59	17.64	18.84	18.85	18.62
CaO	37.82	39.81	38.73	37.62	36.45	36.12
Fe_2O_{3tot}*	5.54	6.38	6.67	5.89	6.68	7.09
MnO	0.67	1.26	0.73	1.30	1.21	1.60
TiO_2	0.27	0.33	0.26	0.37	0.42	0.41
Total	100.00	100.00	100.00	100.00	100.00	100.00
n:	1.751	1.756	1.758	1.750	1.753	1.756
D g/cm³	3.60	3.60	3.63	3.58	3.61	3.64

* total iron content measured as Fe_2O_3
NB The Edax programme processes these oxide values to total 100%.

Bh 01: hessonite, light yellowish — Budhido, Orissa
Bh 02: hessonite, yellowish-brown — Budhido, Orissa
Bh 03: hessonite, yellowish-brown — Budhido, Orissa
Di 01: hessonite, yellowish-brown — Dahikbala, Orissa
Di 02: hessonite, yellowish-brown — Dahikbala, Orissa
Di 03: hessonite, brown — Dahikbala, Orissa

lenses contain concentrations of hessonite crystals in 'pockets', together with calcite and small diopside crystals (Figures 2 and 3). The lenses are between 60 and 250m long and about 20m wide. Wollastonite is another important constituent and, due to its hardness, it shows pronounced bands within these lenses. The markings of deformation patterns in wollastonite bands are clearly visible. A significant percentage of hessonite from Ghatpara is of gem quality and from some crystals stones of 5 to 6ct can be cut. The coordinates of this occurrence are lat. 20°16′N and long. 83°16′E.

Dahikbala

A hessonite occurrence was recently discovered by digging foundations for a power line 9km from Ambadola in the direction of Mumiguda in the Koraput District. Shallow pits expose khondalite quartzites with small fractured crystals of transparent orange-brown coloured hessonite. The coordinates are lat. 19°45′N and long. 83°29′E.

Budhido

This relatively large hessonite occurrence was discovered in 1991. Local villagers dug (illegally) many pits over an area of about 300m long and 50m wide. The hessonite crystals occur in a garnetiferous gneiss, in contact with amphibolite.

Although the hessonite crystals found on the dumps are large and show a strong brownish-orange colour, the crystals are translucent rather than transparent and the interior appears 'treacly', a common feature in hessonite garnets. At the time Budhido was visited, local villagers had abandoned the occurrence, probably due to the fact that not sufficient gem quality hessonite crystals were found.

The coordinates are lat. 21°15′42″N and long. 84°55′E. Budhido is about 2km north-east of the village Riamal in the Sambalpur District.

Table V. Absorption maxima of Orissa hessonites and their assignment

Orissa	*Amthauer (1975)*	*Assignment*
432-433 nm (23 148–23 094 cm⁻¹)	434 nm (23 041 cm⁻¹)	Fe^{3+} / oct.
408-409 nm (24 509–24 400 cm⁻¹)	409 nm (24 449 cm⁻¹)	Mn^{2+} / cub.
370 nm (27 027 cm⁻¹)	371 nm (26 954 cm⁻¹)	Fe^{3+} / oct.

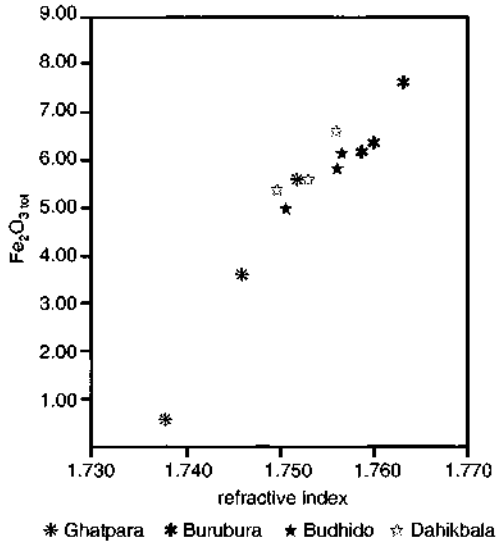

Fig. 4. Correlation diagram of iron content (Fe_2O_3) and refractive indices.

Burubura

About 1km south-south-east of the village of Burubura in the Dhenkanal District is an exposed hessonite occurrence in a contact zone between khondalite quartzite and amphibolite. The colour of the hessonite crystals is a pleasing dark orange. The coordinates are lat. 21°15'05''N and long. 85°14'50'E.

Physical properties

The values of RI and density obtained from hessonite from the four Orissa occurrences (Table II) fall in the ranges reported by previous authors.

The light yellowish hessonite from Ghatpara has the lowest refractive index, n= 1.738 (1.10 wt.% $Fe_2O_{3\,tot}$) whilst the highest value belongs to the brown hessonite from Burubura, namely n= 1.763 (8.20 wt.% $Fe_2O_{3\,tot}$).

These figures proved that an increase in iron content is linked to a higher refractive index. Figure 4 shows the relationship between refractive indices and iron content for the four Orissa hessonite occurrences.

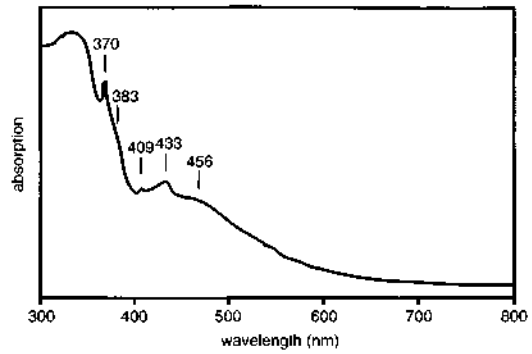

Fig. 5. Absorption spectrum of yellowish-brown Budhido hessonite (Orissa).

Chemical data

The chemical analyses of the hessonite crystals were carried out on a Philips Raster electron-microscope, type XL 30. They indicated, besides calcium, aluminium and silicon, small quantities of iron and traces of manganese and titanium.

Absorption spectra results

The spectrophotometer examination was carried out with a Perkin Elmer instrument (Lambda 9, UV/VIS/NIR) in the 800 - 300 nm range (see Figure 5). The Orissa samples showed three absorption bands at ca. 434nm (23 041 cm^{-1}),

Fig. 6. Mineral inclusions with a strongly corroded surface in Ghatpara hessonite. Immersion, 20x. (*Photo M. Redmann*)

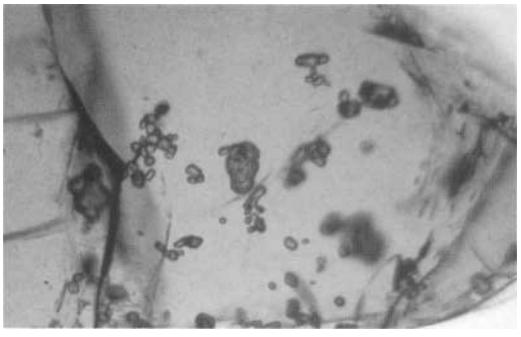

Fig. 7. Strongly corroded, long prismatic inclusions in Ghatpara hessonite. Immersion, 40x. (*Photo M. Redmann*)

409nm (24 449 cm^{-1}) and 371 nm (26 954 cm^{-1}) which are identical to the results of Amthauer (1975) for the brown grossular from Tanzania.

Other absorption bands between 383–387 nm (26 109–25 839 cm^{-1}) and 456–460 nm (21 929–21 739 cm^{-1}) have been observed which, according to Manning (1969), are also due to iron (Fe^{3+}).

Amthauer (1975) mentioned the three absorption bands of 434 nm (23 041 cm^{-1}), 409 nm (24 449 cm^{-1}) and 371 nm (26 954 cm^{-1}) as the origin for the brown colour in hessonite and in contrast to green grossular, a strong Ligandfield absorption near the UV range.

Microscopical features

The hessonite samples from Ghatpara are rich in different types of mineral inclusions. Some of the mineral inclusions are strongly corroded (Figures 6 and 7), which in parts show tension fractures and interference colours under crossed polars, indicating an optically anisotropic crystal. Other mineral inclusions are idiomorphic, hexagonal, long prismatic crystals well terminated, which also show interference colours under crossed polars and are, therefore, also optically anisotropic (Figure 8). These are probably euhedral crystals of apatite. One sample contained fibrous mineral inclusions, but their identity has not yet been established. Some of the hessonite showed healing cracks with undefined contours and two-phase inclusions (lg) in some parts. Various samples showed strong growth marks and zones. Under crossed polars a double refractive effect indicating strain is noticeable at the growth marks and some samples show an intense interference picture, also caused by the strong growth structures (Figures 9 and 10). The 'oily' internal feature typical of many hessonites was observed in only a few of the Ghatpara hessonite samples.

Compared with the Ghatpara samples the Burubura hessonite is relatively poor in inclusions. Healing cracks with two-phase (lg) and three-phase inclusions (slg) can be seen. Different mineral inclusions can also be seen in the multiphase inclusions (Figures 11 and 12). Furthermore, growth marks are visible which, under crossed polars, show patchy double refraction. All the examined Budhido samples have a strong 'oily' appearance, which, of course, influences the transparency of the hessonite (Figure 13). In addition strongly corroded mineral inclusions can be seen which, under

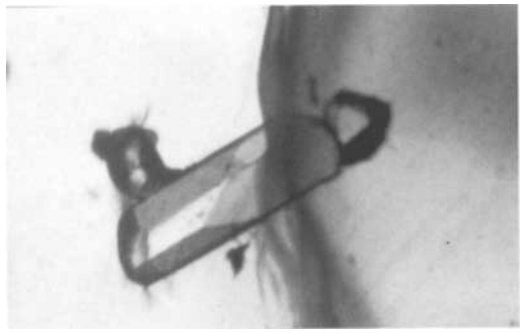

Fig. 8. Idiomorphic, long prismatic, hexagonal mineral inclusions, well terminated, in Ghatpara hessonite. Immersion, 40x. (*Photo M. Redmann*)

Fig. 9. Growth marks showing strong interference of light under crossed polars in Ghatpara hessonite. Immersion, 25x. (*Photo M. Redmann*)

Fig. 10. 'Schlieren' growth marks under crossed polars in Ghatpara hessonite. Immersion, 10x. (*Photo M. Redmann*)

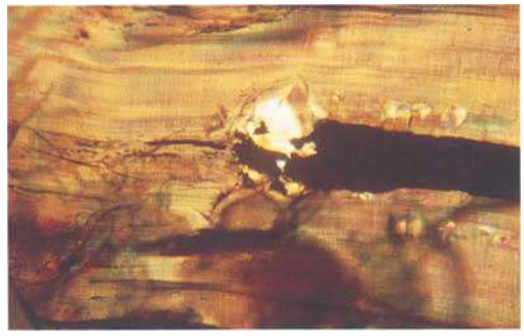

Fig. 11. Multi-phase inclusion (slg) in Burubura hessonite. Immersion, 50x. (*Photo M. Redmann*)

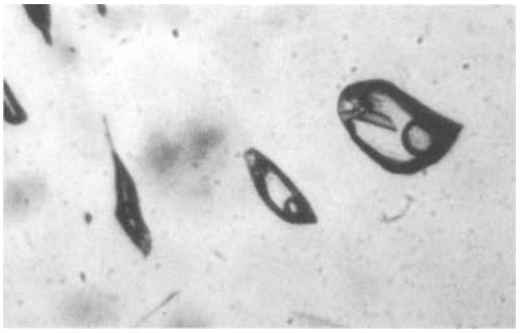

Fig. 12. Multi-phase inclusion (slg) in Burubura hessonite. Immersion, 25x. (*Photo M. Redmann*)

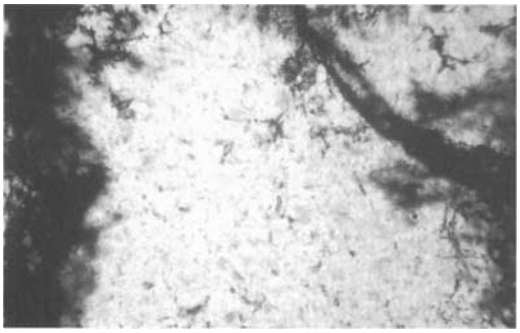

Fig. 13. 'Oily' appearance with small corroded mineral inclusions in Budhido hessonite. Immersion, 40x. (*Photo M. Redmann*)

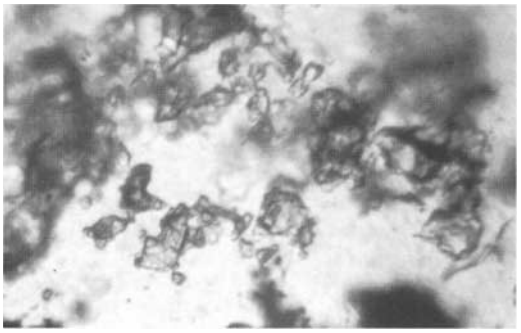

Fig. 14. Strongly corroded mineral inclusion, 'oily' appearance, in Budhido hessonite. Immersion, 10x. (*Photo M. Redmann*)

Fig. 15. Long, needle shaped mineral inclusions, which are partly bent, in Dahikbala hessonite. Immersion, 10x. (*Photo M. Redmann*)

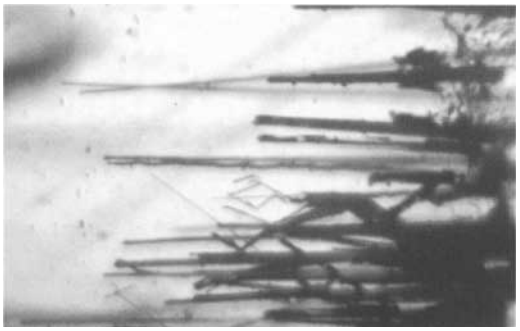

Fig. 16. Growth marks in Dahikbala hessonite. Immersion, 10x. (*Photo M. Redmann*)

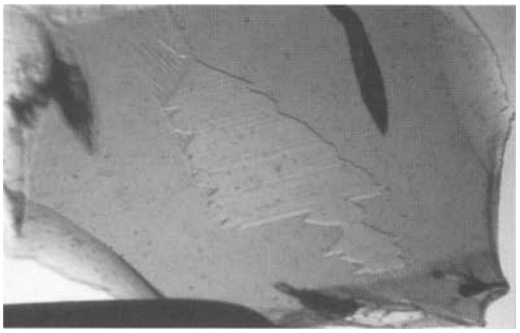

crossed polars, show interference colours (Figure 14). The microscopic study of all Dahikbala samples showed long needle-like mineral inclusions, which are in part parallel and often bent (Figure 15).

Rarer are mineral inclusions with a corroded surface, which are doubly refractive. Also rare at Dahikbala are healing cracks with liquid inclusions. However, growth marks in parallel stripes, as 'schlieren' features, or in grotesque shapes are common (Figure 16). All samples with these complex growth marks show distinct double refraction.

Acknowledgement

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Fluorescent oil inclusions in quartz

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Fig. 1. This is a photograph taken of the two crystal specimens described as they appeared in the ultraviolet light unit.

The accompanying photomicrographs are of fluorescent oil inclusions found in two quartz crystal specimens purportedly from Herkimer, New York (Figure 1). Both crystals are doubly terminated and weigh 13.06 grams and 3.54 grams respectively. I have examined quite a number of small quartz crystals from this source over the last few years but these are the first specimens containing oil inclusions that I have had the opportunity to photograph.

Figures 2, 3 and 4 show a three-phase inclusion containing a fairly large globule of petroleum, which in turn contains a gas bubble. The third phase in this inclusion is a brine solution. There is actually a fourth phase consisting of small particles of a tar-like substance (bitumen). The gas bubble moves freely about in the oil when the specimen is tilted. The oil fluoresces very strongly under long-wave ultraviolet light.

The trio of included crystals shown in the cover

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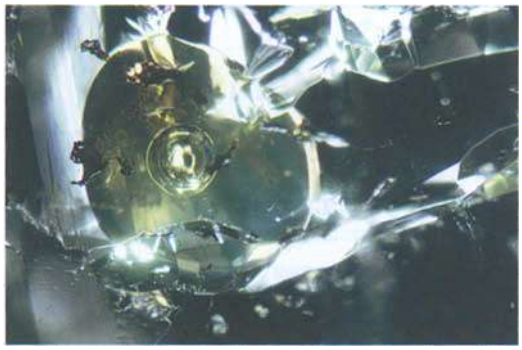

Fig. 2. Transmitted illumination. 8x

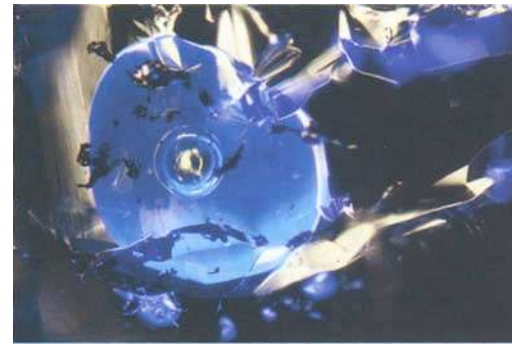

Fig. 3 Long-wave ultraviolet light plus low intensity transmitted illumination. 8x.

picture are all three-phase and consist of oil, a gas bubble and a small black particle of bitumen. The oil in these inclusions doesn't fluoresce quite as strongly as in the other inclusion, but once again the gas bubble moves about as the specimen is tilted.

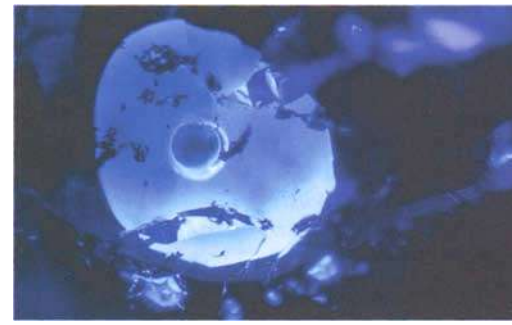

Fig. 4 Long-wave ultraviolet light only. 8x.

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Twinning in Ramaura synthetic rubies

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Abstract

Twinned individuals of Ramaura synthetic rubies were examined. The crystals are penetration twins, the two components of which are symmetrically related by a 180° rotation about the *c*-axis or by a reflection across one of the first-order hexagonal prisms $\{10\bar{1}0\}$ or across the basal pinacoid (0001). The twins are in contact along four twin boundaries which are oriented parallel to the twin planes. This form of penetration twinning has never been encountered before in either natural or synthetic corundum.

Each twin crystal reveals one planar surface which represents the contact of the ruby with the floor of the crucible in which the growth procedure was performed. These planar surfaces of the twins are subdivided into different sectors by the four twin planes, which intersect at one central point. Triangular growth structures on basal planes are related by the symmetry elements of the twin, i.e. by a two-fold axis parallel to [0001] or by mirror planes parallel to $\{10\bar{1}0\}$.

Introduction

Ramaura flux-grown synthetic rubies have been commercially available since early 1983 (Kane, 1983; Bosshart, 1983). Although details of the commercial growth process of these high quality synthetic rubies produced by Judith A. Osmer, J.O. Crystal Company, Long Beach, California, are kept secret, the study of morphological properties of rough crystals (Kane, 1983; Schmetzer, 1986a, 1986b) as well as the chemical examination of residual flux remnants trapped in faceted and rough crystals (Schmetzer, 1986a, 1986c), clearly indicate a perfect correlation between the Ramaura synthetic rubies and those of flux-grown synthetic rubies described by Janowski *et al.* (1965), Chase, (1966) and Chase and Osmer (1967, 1970). Consequently, it can be assumed that at least the basic principles of the commercial production process of Ramaura synthetic rubies are consistent with the processes described in the four papers just mentioned.

According to these publications, rubies are grown by spontaneous nucleation without seed crystals from solvents with Bi_2O_3 and PbF_2 as dominant and La_2O_3 as subordinate components of the flux material. Slow programmed cooling of the flux from 1250°C to 1000°C with constant cooling intervals between 2°C and 8°C per hour is applied during the growth process. Perfect crystals of high transparency and purity are obtained by the application of an additional temperature gradient in the growth medium by localized cooling of the platinum crucible by means of an air flow (Chase and Osmer, 1967).

The habit of the flux-grown synthetic ruby crystals varies with the content of La_2O_3 in the melt. In general, only three crystal faces are observed: the basal pinacoid *c*, the positive rhombohedron *r* and the negative rhombohedron *d**. Crystals grown from Bi_2O_3 - PbF_2 fluxes without La_2O_3 result in flat, tabular plates with dominant basal faces c and smaller positive rhombohedra *r*. If small amounts of La_2O_3 are added to the melt, the habit of the crystals changes from tabular to rhombohedral (more equidimensional), with larger positive and negative rhombohedral faces, *r* and *d*. With La_2O_3 contents of the melt up to approx. 0.5 mole %, only the positive rhombohedron *r* is present. With La_2O_3 contents between 0.6 and 1.0 mole %, the negative rhombohedron *d* begins to develop and becomes the more predominant crystal face at 1.0 mole % La_2O_3 (Chase,

* CRYSTAL FACES:

basal pinacoid	*c*	(0001)
first-order hexagonal prism		$(10\bar{1}0)$
second-order hexagonal prism	*a*	$(11\bar{2}0)$
positive rhombohedron	*r*	$(10\bar{1}1)$
negative rhombohedron	*d*	$(01\bar{1}2)$

This nomenclature is used throughout this publication.

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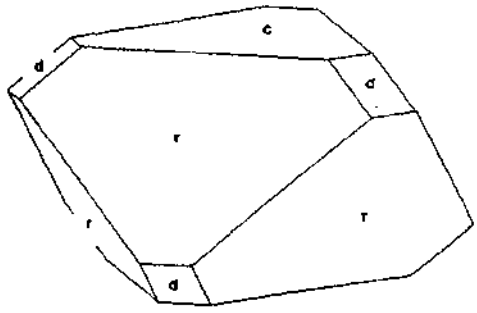

a) clinographic projection of an untwinned crystal with basal pinacoid *c* (0001), positive rhombohedron *r* $(10\bar{1}1)$ and negative rhombohedron *d* $(01\bar{1}2)$

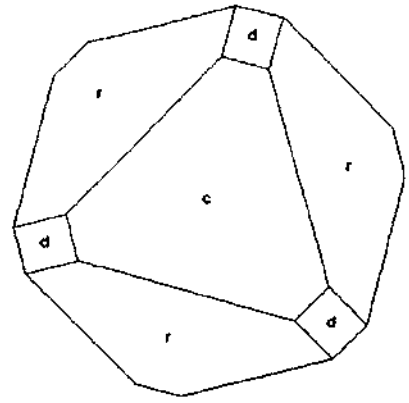

b) *c*-axis projection of an untwinned crystal with *c*, *r* and *d* faces

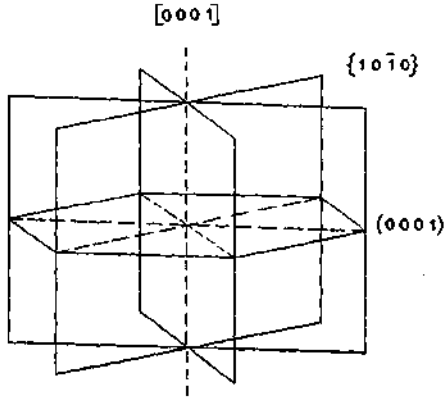

c) clinographic projection of equivalent symmetry elements in crystal class $\bar{3}2/m$, a two-fold axis parallel to [0001] as twin axis is equivalent to three mirror planes parallel to $\{10\bar{1}0\}$ and one mirror plane parallel to (0001) as twin planes

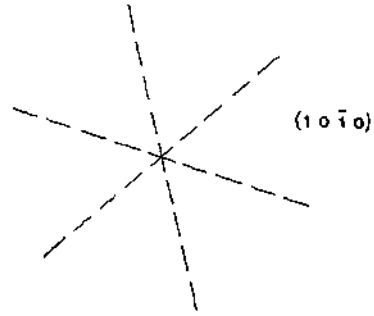

d) *c*-axis projection of mirror planes parallel to $\{10\bar{1}0\}$ as twin planes

Fig. 1. Twinning in Ramaura synthetic ruby

1966). Equidimensional Ramaura synthetic ruby crystals with such rhombohedral habits are described in Kane (1983). In Figure 1 of that paper, a rough Ramaura synthetic ruby crystal is shown with predominant *r* and more subordinate *d* rhombohedral faces, whereas Figure 2 of the same paper portrays a clinographic projection of a Ramaura synthetic ruby with dominant *d* and more subordinate *r* faces.

Twinning in synthetic ruby crystals grown from Bi_2O_3 - PbF_2 fluxes was described by Janowski *et al.* (1965). After etching the rubies in molten potassium bisulphate, the study of the resulting etch pits located on basal *c* faces indicated that the composition planes between twinned individuals were approximately normal to the same basal faces. The traces of composition planes between twinned individuals did not strictly follow any particular plane, but tended to favour the $(11\bar{2}0)$ and $(10\bar{1}0)$ prism planes. In general, only a single straight line was found as trace of the twin boundary between twinned individuals, but more complex twin structures were also rarely observed.

Up to now, twinning characteristics have been described in Ramaura synthetic rubies only according to microscopic observations of faceted samples (Schmetzer, 1986a, 1986b, 1987). Consequently, no description of macroscopic twinning characteristics is available in the litera-

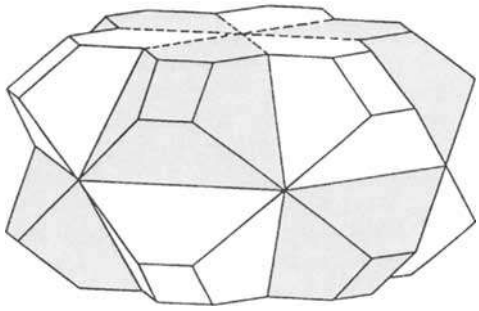

e) clinographic projection of a penetration twin consisting of two equally sized twin components, dashed lines are traces of twin planes and twin boundaries parallel to $\{10\bar{1}0\}$

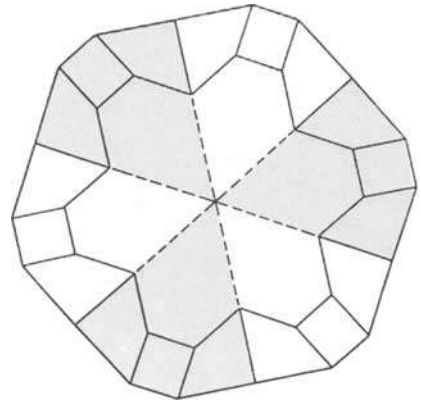

f) *c*-axis projection of a penetration twin consisting of two equally sized twin components, dashed lines are traces of twin planes and twin boundaries parallel to $\{10\bar{1}0\}$

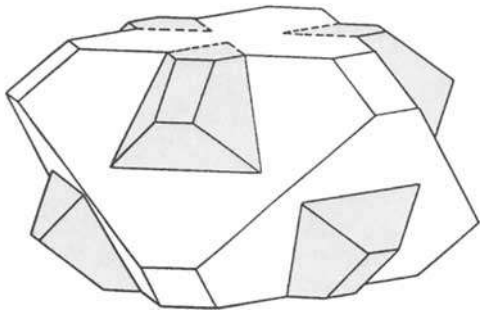

g) clinographic projection of a penetration twin consisting of two differently sized twin components, dashed lines are traces of twin planes and twin boundaries parallel to $\{10\bar{1}0\}$

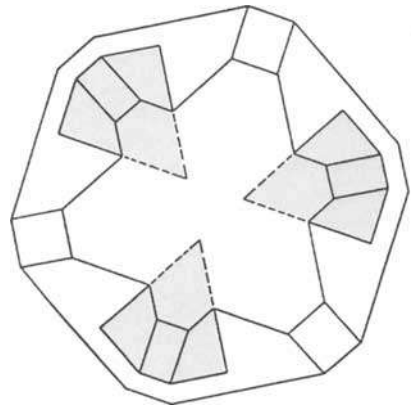

h) *c*-axis projection of a penetration twin consisting of two differently sized twin components, dashed lines are traces of twin planes and twin boundaries parallel to $\{10\bar{1}0\}$.

Fig. 1. Twinning in Ramaura synthetic ruby

ture to date. It is, therefore, the aim of the present study to complete this information and to compare these twinning features with flux-grown synthetic rubies from various other producers and those observed in natural ruby crystals.

Materials and methods

The present study is based upon the examination of five macroscopically twinned Ramaura synthetic rubies (Figures 2, 3, 4). Two crystals (6.03 and 4.41 ct) were submitted by Judith A. Osmer of J.O. Crystal Company, Long Beach, California, producer of Ramaura synthetic rubies, while three of the twinned individuals (59.14, 8.00 and 3.69 ct) were available from the reference stone collection of the Gübelin Gemmological Laboratory, Lucerne, Switzerland. Several single crystal, non-twinned Ramaura synthetic ruby crystals were also used for comparison purposes. The rubies were examined using conventional gemmological and mineralogical methods. The identification of crystal faces and growth structures were performed using a standard goniometer and by immersion microscopy using the techniques described by Schmetzer (1986b) and Kiefert and Schmetzer (1991).

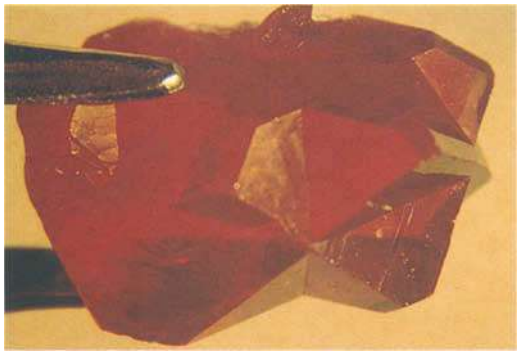

Fig. 2. Penetration twin viewed in a direction almost identical to that of the clinographic projection of Fig. 1, 18x.

Gemmological properties

The standard gemmological properties of the five Ramaura synthetic rubies examined were determined to be consistent with those observed during previous studies (Kane, 1983; Bosshart, 1983; Schmetzer, 1986a). These include refractive indices (e = 1.760, o = 1.768), birefringence (0.008), optic character (uniaxial negative), pleochroism (e = orange-red, o = purplish-red), spectral characteristics through the UV-VISIBLE-NIR regions, fluorescence (LW-UV strong red, SW-UV weak to medium red), density (3.99 g/cm^3) and inclusion features consisting of white and 'golden' coloured flux remnants occurring isolated or in fingerprint patterns of various sizes, along with transparent internal growth structures reflecting the external crystal morphology.

Twinning characteristics

The crystal faces identified in both twinned and untwinned individuals of Ramaura synthetic rubies (Figure 1), were the basal pinacoid *c*, the positive rhombohedron *r* and the negative rhombohedron *d*. The habit of all the crystals examined consisted of dominant *c* and *r* faces with subordinate d faces (Figure 1 a, b). Synthetic ruby crystals consisting of dominant *d* and subordinate *r* faces, as pictured in Kane (1983), were not observed.

Corundum crystallizes in the trigonal/rhombohedral system and belongs to crystal class $\bar{3}2/m$. In this crystal class, the three following symmetry operations are equivalent:

- 180° rotation about the *c*-axis [0001],
- reflection across the first-order hexagonal prism $\{10\bar{1}0\}$, and
- reflection across the basal pinacoid *c* (0001).

The orientation of the symmetry elements characterizing these symmetry operations, i.e. the two-fold twin axis and the four $\{10\bar{1}0\}$ and (0001) twin planes (mirror planes), is shown in Figure 1 c,d. It is important to mention that these symmetry operations do not occur in untwinned ruby crystals. By the application of one of these symmetry operations to a single crystal of an untwinned ruby, a twinned crystal is formed (Figure 1 e-h).

These theoretical considerations are consistent with the observations on the twinned Ramaura synthetic rubies. All five twins in this study (Figure 1 e-h, Figures 2-4) are penetration twins formed from a single, untwinned ruby crystal (Figure 1 a, b) by a rotation about the twin axis or by a reflection across one of the four twin planes. Each Ramaura penetration twin was found to reveal four contact surfaces as twin boundaries. Three of these contact surfaces are planes parallel to the first-order hexagonal prism. The

Figs 3, 4. Penetration twin viewed in a direction perpendicular to the *c*-axis: the two figures are related by a small rotation about the *c*-axis, 18x.

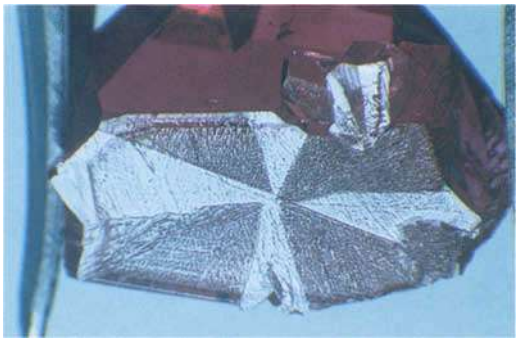

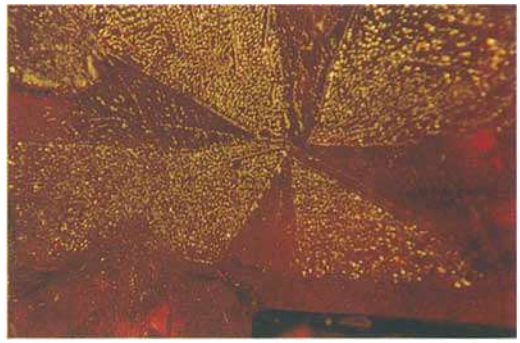

Figs 5, 6. Planar surface of a penetration twin confined to the floor of the crucible, with two groups of four growth sectors subdivided by traces of three twin planes parallel to $\{10\bar{1}0\}$ prism faces and one twin plane parallel to the (0001) basal face. Portrayed here is a nearly undistorted twin consisting of two almost equally sized twin components. View nearly perpendicular to the *c*-axis. Fig. 5, 16x; Fig. 6, 32x.

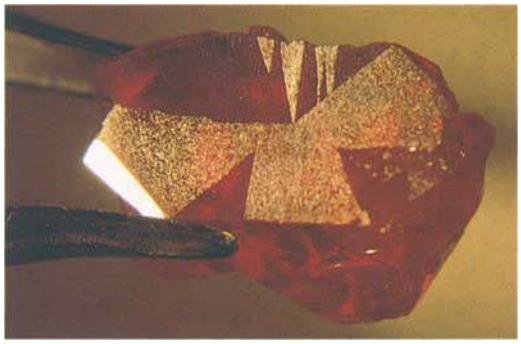

Fig. 7. Planar surface of a penetration twin confined to the floor of the crucible, with two groups of three dominant sectors subdivided by traces of three twin planes parallel to $\{10\bar{1}0\}$ prism faces and one twin plane parallel to the (0001) basal face. Portrayed here is a distorted twin with four subordinate sectors within one of the dominant sectors. View nearly perpendicular to the *c*-axis, 16x.

remaining fourth twin boundary is a slightly irregular plane which tends to run more or less parallel to the basal pinacoid *c* (Figure 1 e-h). The two components of the penetration twin may be of equal size (Figure 1 e, f) or of different sizes, with one being dominant and the other subordinate (Figure 1 g, h). The observed re-entrant angles are formed by the meeting of two positive rhombohedral faces, *r* and *r'*, of the two twin components (refer to Figure 1 e-h, Figures 2-4).

All of the twinned crystals revealed one planar surface which did not follow any of the crystal faces *c*, *r* or *d*. It was felt that this plane represented the 'contact surface' of the growing crystal with the floor of the crucible. This interpretation was confirmed by the producer. The planar surface of each twin is subdivided into two groups of growth sectors, with all the related sectors within one individual group displaying optical reflectivity in the same orientation.

Figs 8, 9. Triangular growth structures parallel to traces of the twin planes $\{10\bar{1}0\}$ on the basal pinacoid *c* (0001) of a penetration twin.
Fig. 8: A twin boundary extends from the lower middle to the upper right of the photograph, 20x.
Fig. 9: A twin boundary extends from the lower right to the upper middle of the photograph, 30x.

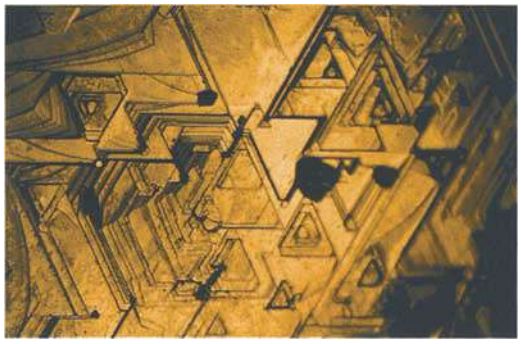

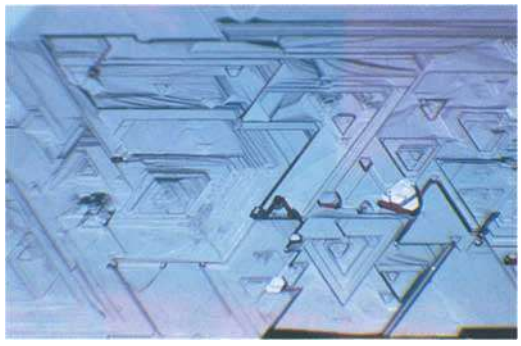

Collectively, the sectors belonging to different groups of growth sectors displayed optical reflectivity in differing orientations (Figures 5-7). The traces of the boundaries between these sectors correspond to the four composition planes of the two twin components (Figure 1 c, d) and intersect at one central point. Ideally, in twins such as these, each group consists of four essentially equal sectors (Figures 5, 6). In twinned crystals which are distorted to varying degrees, different numbers of dominant sectors with additional subordinate sectors can also be observed (Figure 7).

The different sectors of the twin can also be seen in the subtle surface topography characteristics of the basal faces (Figures 8, 9). These trigonal growth structures located on basal faces were observed on two of the five Ramaura synthetic twins examined. Within one of the two components of the twin, these growth triangles have the same orientation. Different orientations of the triangles within different sectors located on the basal planes *c* and *c'* of the twin components (again refer to Figure 1 f, h), are the result of twinning, i.e. the result of a 180° rotation about the *c*-axis or of a reflection across the first-order hexagonal prism. The three sides composing these growth triangles were found to follow the traces of the three twin boundaries $\{10\bar{1}0\}$. These observations in Ramaura synthetic rubies are consistent with the previous results obtained from the study of etch pits in twinned flux-grown synthetic corundum (Stephens and Alford, 1964; Janowski *et al.*, 1965; Champion and Clemence, 1967; Lillicrap and White, 1976).

Discussion

The rough Ramaura synthetic ruby crystals examined by the authors in the past several years were found to be single crystals without any indication of interpenetrant twinning. The five Ramaura synthetic rubies examined in this study are penetration twins, involving the three equivalent symmetry operations described previously, with three twin boundaries along first-order hexagonal prism planes and one slightly irregular twin boundary essentially parallel to the basal pinacoid *c*. These crystals were grown by a process of spontaneous nucleation in a flux environment, possessing a single planar surface which was in contact with the floor of the surrounding crucible. This form of interpenetrant twinning in corundum has never been observed by the authors or reported in the literature before.

In the various papers mentioned previously, twinning was described in flux-grown synthetic corundum (both rubies and sapphires) according to the examination of etch pits, which in most cases were intentionally created by etching the basal faces of the crystals involved. For all these corundums, the twinning was described as a 180° rotation about the *c*-axis or as a reflection on the first-order hexagonal prism, which is also consistent with the twinning observed here in Ramaura synthetic rubies. According to the references cited above, the twin boundaries were found to run along the first-order hexagonal prism or along the second-order prism *a*. It is important to mention that in the crystal class of corundum $\bar{3}2/m$, the prism *a* is parallel to a mirror plane and therefore cannot be a twin plane but rather a composition plane of two twinned individuals.

In flux-grown synthetic rubies and sapphires produced by Chatham, the typical twinning observed consists of a $(10\bar{1}0)$ face as twin plane (mirror plane) and a $(11\bar{2}0)$ face as contact plane (twin boundary) (Schmetzer, 1986a, b, 1987; Kiefert and Schmetzer, 1987). Simple contact twins consisting of two twin components are known, which are related by a reflection across the first-order hexagonal prism and intergrown along the second-order hexagonal prism *a*, and cyclic twinning has also been observed (Kiefert and Schmetzer, 1987).

In natural rubies and sapphires, contact or penetration twins possessing one of the prism faces $(10\bar{1}0)$ or $(11\bar{2}0)$ as twin boundaries have never been described. In extremely rare cases, contact twins consisting of two twin components which are twinned by a reflection across the basal pinacoid *c*, with the *c* face as twin plane and composition plane, have been identified (cf. Goldschmidt, 1918; Schmetzer, 1986a, 1987). The most common form of twinning observed in natural rubies and sapphires, however, consists of rhombohedral twinning along the positive rhombohedron *r*, commonly referred to as 'laminated' twinning in gemmology. This type of twinning has not been observed in Ramaura synthetic rubies to date. For a more detailed description of rhombohedral twinning in natural and synthetic rubies, the reader is referred to the detailed descriptions of Schmetzer (1987).

Acknowledgement

The authors are grateful to Judith A. Osmer of Long Beach, California, for submitting two twinned crystals for the present study.

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The glass filling of diamonds Part 2: a possible filling process

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Abstract

Diamonds are now appearing in the market place with a greatly enhanced appearance caused by fissure-filling glass. No patent disclosures have been made on the filling method or glass composition, but much useful information has now been published on the nature of the glass.

A possible practical process is outlined for the filling of outcropping cleavages, fractures and fissures in cut diamonds. This scheme is based on reports in the gemmological literature since 1987, describing the characterization and identification of filled diamonds. It embodies all the requirements which would have to be met for successful batch productions.

Introduction

Diamonds and coloured gemstones often have fractures and cleavage fissures which outcrop on the polished surfaces. These optical discontinuities lower a stone's brilliance and sparkliness. To improve the appearance of poor quality, or even unsaleable gemstones, various impregnation techniques have been used in attempts to conceal the defects.

If the refractive indices of the filling materials approach or match those of the host stone, they are usually quite successful in helping to mask the original optical discontinuities. However, this apparent improvement in the stone's clarity also results in unwanted 'colour flashes'. These appear as streaks or patches of high intensity spectral colours of fairly fixed hues and are seen only at particular orientations of the stone. While these flashes are not obvious in stones having strong body colours, such as rubies, sapphires and emeralds, they can be very visible in diamonds of the Cape Series. Here, significant enhancements in the degree of perceived clarity from say, SI to VS, could be accompanied by reductions in the colour grade, by as much as one point (for example from E to F, H to I or L to M).

The existence of the colour flashes has been treated at some length in the current gemmological literature, but no account has been given of the basic cause of this phenomenon.

Part 1 of this article (*J. Gemm.*, **23**, 8, 461-72) now offers an explanation of the optical mechanism responsible for the flashes. However, the nature of this explanation obliges one to speculate on the physical mechanisms of the clarity enhancement process for diamonds and on the physico-chemical properties of their fillings. This is mainly the substance of Part 2.

Emerald clarity enhancement

Emeralds are notoriously prone to show surfacing fissures and cracks and were probably the first stones to be subject to improvements in clarity. Very early on, it was found that these arrived in the form of low viscosity oils chosen to have a refractive index which matched the mean refractive index of the emerald as closely as possible. Liquids having also low surface tensions enabled them to penetrate almost to the very roots of the fissures (Ringsrud [1]).

The colour flashes seen when the refractive indices were matched did not present any great problem as the strong green colour of the stone tended to obscure them. If the emerald possessed only a pale green colour, then the use of oils tinctured with an intense, green, oil-soluble dyestuff also served to dampen the non-green colour flashes.

This remedy was often short-lived. In time, the liquid tended to seep out or even evaporate and the stone reverted to its original state. The treatment had then to be repeated.

Recently, an epoxy resin-type filling liquid having all the desired properties was introduced. After impregnation, in order to seal off this mobile, unpolymerized liquid, the stone's surface was lightly smeared with a liquid polymerizing agent. After a brief gelling period to harden the

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Fig. 1. Opticon filled emerald: 5.71ct. Before treatment. After treatment. Reproduced from the article of Reference 2, with the kind permission of the Editor of *Gems and Gemology*. © Gemological Institute of America and Tino Hammid.

resin at the outcropping surface only, the surplus polymerizing liquid was wiped away with a solvent. In this way a solid, impermeable plug of fully-polymerized resin prevented the outward flow of the totally unpolymerized liquid resin.

The most successful of these preparations is now marketed as a stone improvement kit under the trade name 'Opticon 224'. Figure 1 shows a typical 'before-and-after' treatment of an emerald upon which this kit has been used. [2]

While not readily apparent to unaided vision (i.e. 1x magnification), an examination with a 10x loupe or a compound microscope reveals the presence of muted colour flashes bordering the defects, enabling the stone to be classed as 'liquid-filled'.

The now more common use of the horizontal axis immersion microscope means that a suspect emerald must first be examined in air before being transferred to the glass immersion cell. Benzyl benzoate is a much favoured immersion liquid, partly because it has a refractive index almost identical to that of the ordinary ray of emerald. If an emerald has not been subjected to any filling treatment, this liquid will readily penetrate into any outcropping fissure networks. The stone would therefore be wrongly pronounced as 'fissure-filled' because of the resulting colour flashes.

It is clear that the Opticon emerald treatment has little effect on the body colour and that any observed colour flashes serve only as a useful diagnostic aid.

Diamond clarity enhancement

The new form of diamond enhancement was first encountered by the GIA in January 1987. Developed by Mr Zvi Yehuda of Ramat Gan, Israel, it can increase the apparent clarity of many faceted diamonds.

An exhaustive and elegant study describing the characterization and identification of some eighteen filled stones from this source was reported in 1989 by a group of six research gemmologists at the GIA.[3] This research, particularly that part touching upon their analyses of the filling material, provided much insight into the whole process. Apart from a brief reference to a note by Rapaport [4], the actual nature of the filling process was not considered. However, from the details outlined and from several subsequent articles and bulletins published since 1989, it is possible to outline some of the parameters of the filling glass and filling procedure.

A possible filling glass

A low melting-point glass would first have to be formulated. It would have to have a low contact angle with diamond (i.e. it would 'wet' diamond), a low viscosity slightly above its melting point (i.e. 'runny') and a refractive index at room temperature close to that of diamond itself. These combined requirements are quite a tall order, but Yehuda seems to have achieved them.

The GIA's scanning electron microscope with its X-ray energy-dispersive spectrometer was able to demonstrate that the major elemental ions present in the *in-situ* fillings were lead (Pb^{2+}), bismuth (Bi^{3+}) and chlorine (Cl^-). The Pb^{2+}:Bi^{3+} concentration ratio was generally around 2:1, while the Cl^- concentration consistently seemed 'to approximate the sum of the Pb^{2+} and Bi^{3+} concen-

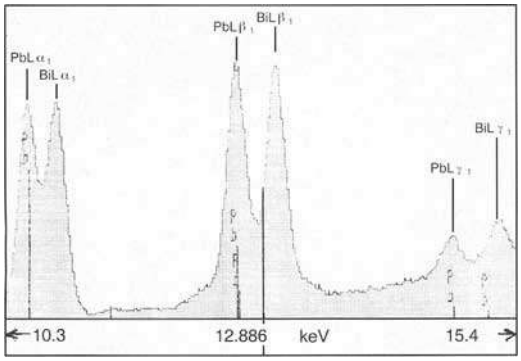

Fig. 2. Electron microprobe chart of an outcrop of a Yehuda glass filling.
Source: Scarratt[5]

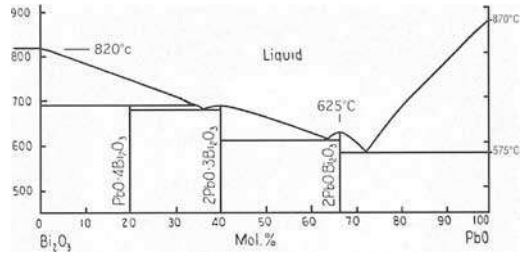

Fig. 3. The phase diagram of the Bi_2O_3-PbO system.

trations'. A separate electron microprobe equipped with an X-ray wavelength-dispersive spectrometer showed that oxygen ions (O^{2-}) were also a major constituent. X-radiography of many filled stones confirmed that the fillings must contain one or more very heavy elemental ions, while an X-ray powder diffraction analysis of the scrapings of an adhering droplet of the filling material established it to be that of an oxide glass.

In a current study of filled diamonds by Scarratt and Jobbins [5], the high concentrations of Pb^{2+} and Bi^{3+} were confirmed for a Yehuda-filled stone. Another new diamond-filling Israeli producer, Koss by name, has followed Yehuda, but the analyses of the fillings in Koss stones have not yet been reported. Figure 2 shows an electron microprobe chart of the filling in a Yehuda-treated stone.

In the light of these studies, it is instructive to examine the phase equilibrium diagram of the binary component system, bismuth oxide (Bi_2O_3) and lead oxide (PbO). This is shown in Figure 3. It is a rather unusual binary diagram, having five phases, three eutectics and showing no mutual solid solubility of any of the neighbouring phases. The lowest freezing point of the system occurs at the third eutectic point at a temperature of about 575°C and at a composition of around 72 mole % PbO. This corresponds to a weight % PbO of 55.2 and a weight % Bi_2O_3 of 44.8.

If a melt of this composition was to be cooled rapidly to well below 575°C, it is highly probable that it would remain as an *extremely* viscous liquid, that is to say, a glass. If this glass phase was held at a temperature not too far below 575°C for some time, then this uniform glass phase would decompose (i.e. devitrify) into two different polycrystalline phases. It would consist of a mixture of about 82 mole % of the phase $2PbO.Bi_2O_3$ and about 18 mole % of the pure mineral phase massicot (PbO); these phases have melting points of about 625°C and 870°C respectively. Both are soluble in nitric acid, as would be

Table 1: Properties of the possible third melt component

Mineral name	*None*	*Cotunnite*	*Bismoclite*	*Mendipite*
Formula	$BiCl_3$	$PbCl_2$	BiOCl	$Pb_3O_2Cl_2$
Crystal system	Cubic	Orthorhombic	Tetragonal	Orthorhombic
Refractive indices, λ = 589nm	n = unknown	α= 2.199 β= 2.217 γ= 2.260	ω= 2.15 ε= unknown	α= 2.24 β= 2.27 γ= 2.31
Melting Point	232°C	501°C	'Red heat'	'Red heat'
Density, g/ml	3.86	5.81	7.70	7.24
Colour	Colourless	Colourless	Pale Yellow	Colourless
Soluble in dilute nitric acid	Yes	Yes	Yes	Yes

the glass phase itself.

Both crystalline phases have refractive indices for sodium light (λ = 589nm) well above that of diamond. For example, massicot has α= 2.51, β= 2.61 and γ= 2.71. No indices are available for $2PbO.Bi_2O_3$, but undoubtedly they will be higher than that of diamond (2.418). It would therefore be safe to conclude that the optically homogeneous glass phase, although having a slightly lower refractive index than that of the mean refractive indices of the mixed crystalline phases, would still have an index greater than 2.418.

It is now obvious that a third component having much lower indices than diamond will have to be added to the two-component melt to bring down the index to near that of diamond. There are many candidates for this role, but the most suitable by far are the chlorides of bismuth and lead. Their properties are given in Table 1.

It should be mentioned here that the presence of relatively large amounts of chloride ions might result in a mainly oxide mixture being more susceptible to devitrification. The photomicrographs shown in Figures 13, 14 and 15 of Reference 3 do show some evidence, not so much as incomplete fillings but as microcrystalline (devitrified) fillings.

$BiCl_3$ has probably the greatest attraction because a modest concentration of it would dramatically lower the binary eutectic point of 575°C down to a ternary eutectic point perhaps as low as 450°C.

The melting of the three components;

(1) bismite, α - Bi_2O_3, melting point 820°C
(2) massicot, PbO, melting point 870°C
(3) taking, say, $BiCl_3$ with a melting point about 230°C

in the correct proportions to make a yellow tinted but clear glass should be quite straightforward. A prolonged stirring of the melt following complete fusion would be necessary to ensure optical homogeneity and freedom from bubbles. The molten mass would then be poured directly into a large quenching bath of cold mineral oil in order to retain the solid glassy state. The shattered fragments would be recovered, cleaned with a solvent and dried, ready for the infilling step.

Measurement of the optical properties of the glass

It is necessary to ensure that the correct amount of the third component has been added to the 575°C eutectic composition. This would be most easily accomplished for exploration batches by using a gemstone infrared reflectance meter. Although the refractive index (n) is actually measured at the peak of a broad band at about 950nm and not for sodium light at 589nm, the calibration of the meter with a polished diamond should ensure sufficient accuracy.

The measurement of the dispersion of the glass would not prove so simple. The conventional method of employing several monochromatic filters in conjunction with the minimum-deviation method on a goniometer, using a cut-and-polished prism of the glass, could be troublesome. If the prism was strongly absorbing in the blue-to-green region, then accurate dispersion measurements would not be possible.

Unfortunately, there does not yet exist a total reflection refractometer capable of measuring indices higher than about 2.10 for the 589nm line, let alone for other wavelengths.

Liquids of high enough indices do not exist for use with the well-known Becke line technique for small particles. However, even if some such liquids could be found, the difficulty of ensuring even the short-term stability of the liquid dispersion calibrations, awkward as they would be, again rules out this approach.

The best course of action is to measure the optical reflectances (R), at normal incidence of a flat, scratch-free, polished surface of a quenched glass fragment using a suitable photometer. These vary in pattern from a simple selenium-cell device to the more sophisticated microphotometers equipped with a stabilized power supply, a photomultiplier photosensor and a set of monochromatizing interference filters. An example of this latter instrument is shown in Figure 4. With the aid of calibrated reflectance standards, it is capable of measuring the R values of circular areas down to a diameter of ten micrometres. An oil immersion objective on its microscope stand yields values of 'oil reflectance' at four different fixed wavelengths (λ = 470, 546, 589 and 650nm). These values are designated '$^{oil}R_\lambda$'. The procedure for translating these into refractive indices (n_λ) has been described by Galopin and Henry.[6] This makes use of the classical Fresnel optical relationship:-

$$n_\lambda = \frac{1 + \sqrt{^{oil}R_\lambda}}{1 - \sqrt{^{oil}R_\lambda}}$$

An example of the dispersion of the refractive indices (n versus λ) for four reflectance standards

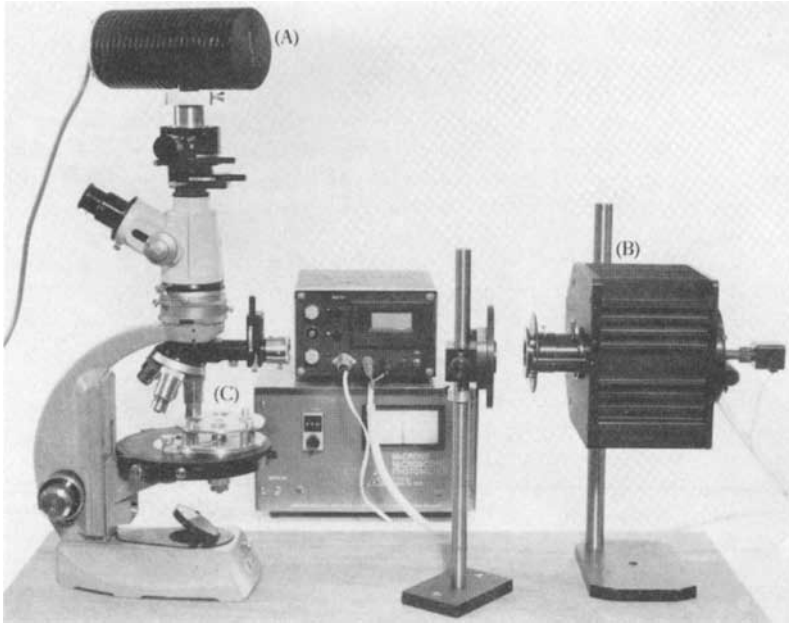

Fig. 4. The McCrone microreflectance photometer.

is given in Figure 5. Made, calibrated and marketed by the writer's company, they all possess flat, isotropic surfaces and are free from the smallest scratches, pits and other light-scattering centres. They are alpha-SiC (omega ray), CZ, GGG and YAG.

If the wavelength, λ, is drawn on a linear scale, the graphs are always curved lines. When drawn on a Hartmann chart the graphs always plot as straight lines, including those of immersion liquids such as methylene iodide (di-iodomethane).

In theory, it should be quite possible to measure *in situ* the actual dispersion of the infilling glass using the microphotometer of Figure 4.

Two conditions would be necessary. A substantial filled crack or 'nick' or a fissure larger than about 10 micrometres would have to be found. As the acid used to remove the surplus melt also penetrates quite deeply into the surface-reaching cracks and fissures, it would be necessary to repolish that particular facet to render the glass infilling exactly co-planar with the diamond surface. Moreover, both the new glass and diamond surfaces would require to be rigorously free from any light-scattering artefacts such as minute sleek-like defects or gas bubbles. An expert diamond polisher should have no difficulty in executing the kind of repolishing required for this measurement, so long as overheating was avoided. This could result in glass devitrification.

Fig. 6. Facet polishing required for the 'in-situ' dispersion measurement of the infilling glass.

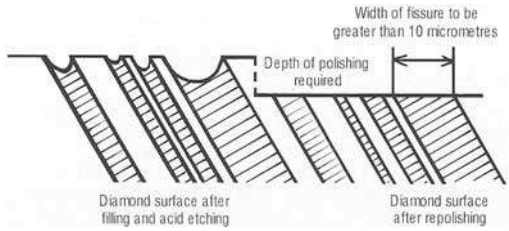

The sketch in Figure 6 illustrates the repolishing geometry.

It is always necessary to employ an external reflectance standard to convert the photometer reflectance values into the required absolute values ($^{\omega}R_{\lambda}$). An alpha-SiC standard represented in the dispersion chart of Figure 5, would serve admirably for this purpose. However, there is an unexpected bonus in using the reflectance method for the n_{λ} dispersion measurements. It is this. It is seen in Figure 6 that a built-in standard already exists in the shape of the co-planar, juxtaposed, repolished surface of the diamond itself. The Hartmann plot for diamond is shown in Figure 7.

Other physical properties of the glass

It should be emphasized that the viscosity,

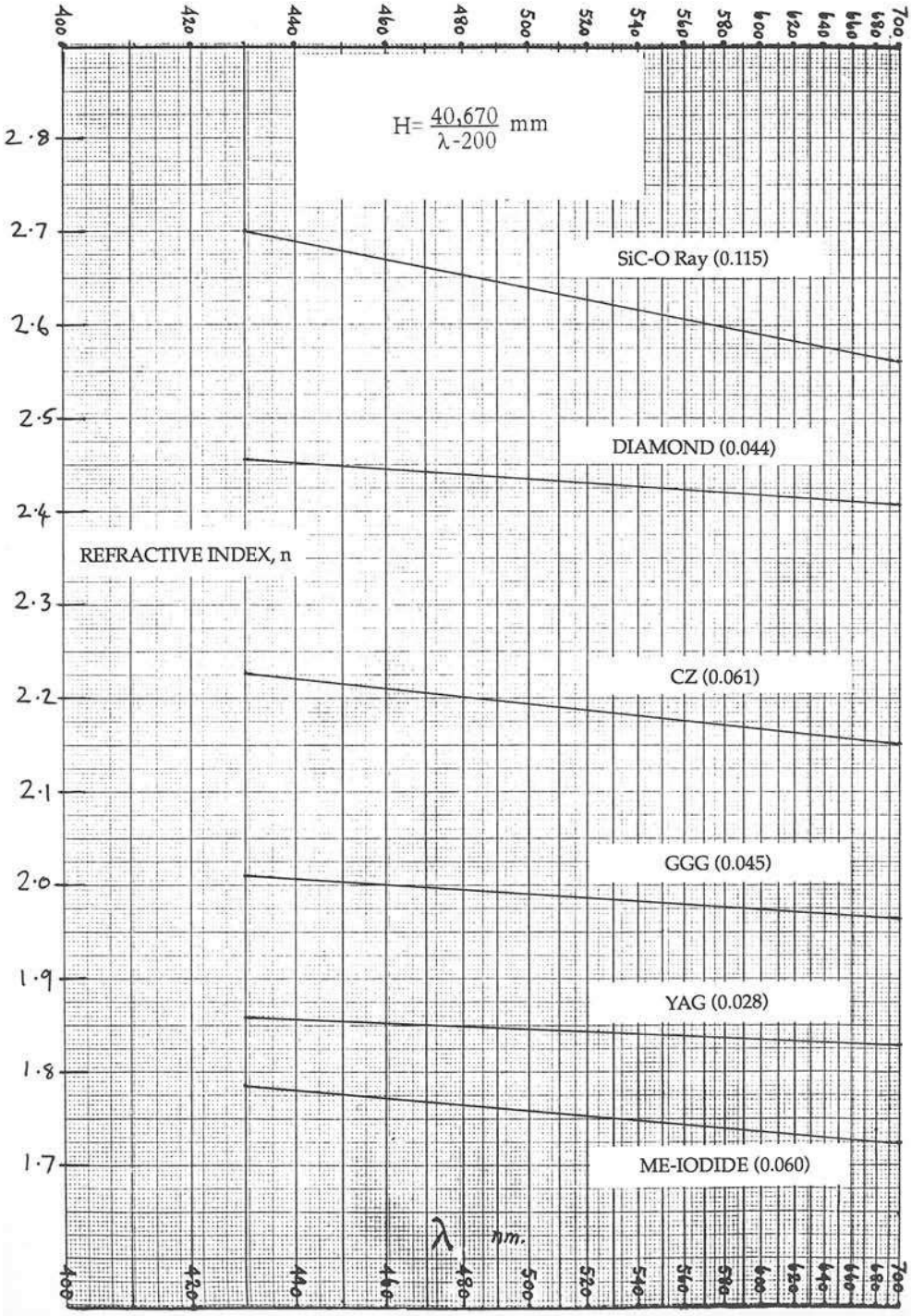

Fig. 5. Hartmann plots of the dispersions of four calibrated reflectance standards, diamond and methylene iodide. The numbers in brackets are those of the n_c - n_s dispersions.

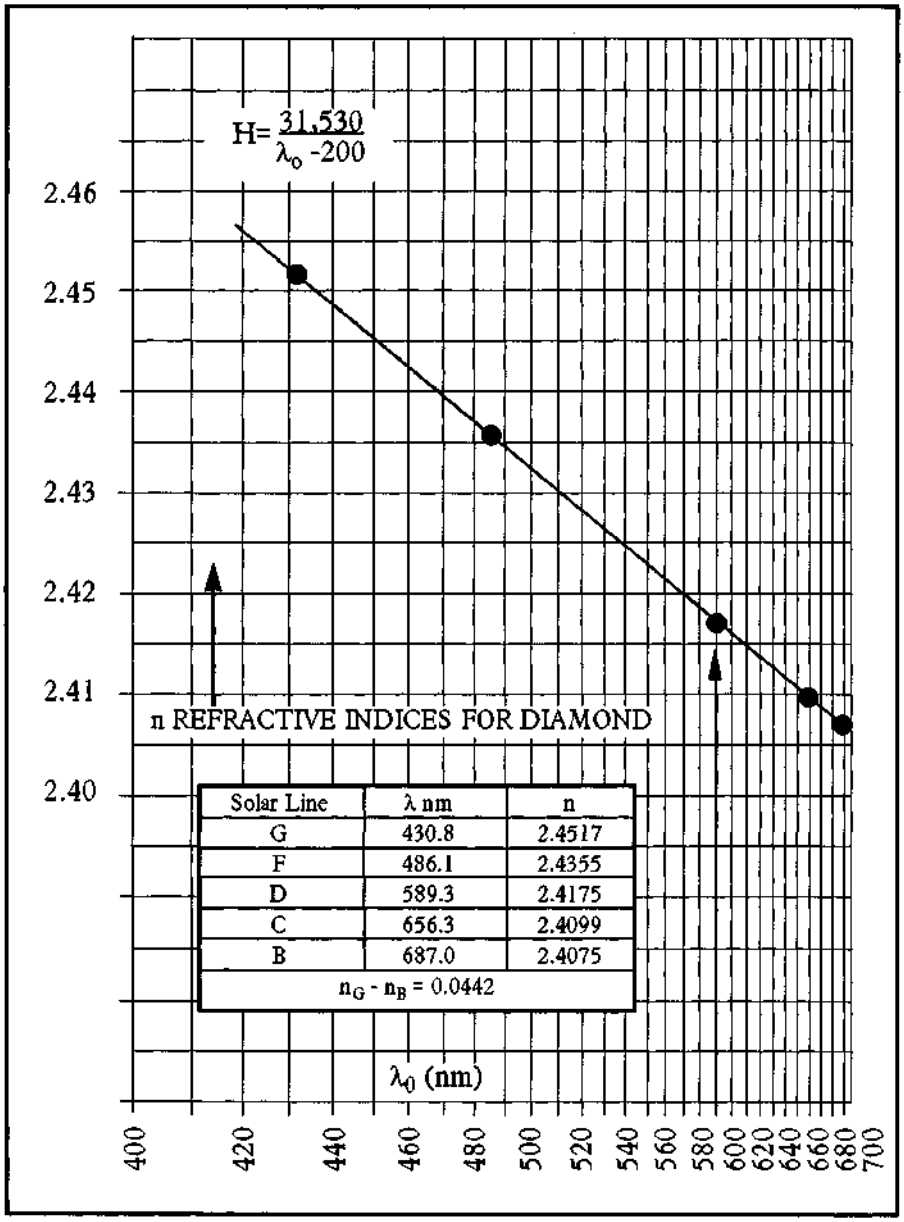

Solar Line	λ nm	n
G	430.8	2.4517
F	486.1	2.4355
D	589.3	2.4175
C	656.3	2.4099
B	687.0	2.4075
$n_G - n_B = 0.0442$		

Fig. 7. The Hartmann dispersion chart for diamond.

diamond wettability and stability (resistance to devitrification) are features of the proposed glass which cannot even be guessed at. Certainly, Yehuda's glass must possess the requisite low viscosity. From the appearance of the beads of glass which had bled out from the infillings during torching (Figure 21 of Reference 3), their low profile contact angles show it to be a very good wetting agent. His glass too seems to possess the physical elastic properties which are compatible with diamond. If they were not, the resultant tensile or compressive stresses would render the filled diamond very unstable, leading to failure during any rough mechanical handling.

A possible filling process

If an engineer was asked to construct a batch production unit for filling stones, he would prob-

ably design a unit which might not be too different from that concocted on paper by the writer. The scheme is illustrated in Figures 8, 9, 10 and 11.

While seemingly rather complex, it is a proposed practical solution to the air- evacuation of the fissure roots. In a single cycle it could treat a batch of diamonds weighing up to 100 carats.

It consists of a rotatable, evacuable cylinder with internal heating units where three successive stages of operation can be carried out. One side of the cylinder supports the electrical wire resistance ovens together with their power control and temperature measuring connecting leads. It is removable and is sealed to the drum with a rubber O-ring. On the other side is a metal plate containing the vacuum pipe outlet together with a glass observation port for monitoring the various cycles. A cross-sectional sketch of the unit is shown in Figure 8.

It is vital that all open fissures are emptied completely of occluded or absorbed air. This operation is far from the simple process it appears to be. As air-filled channels in any porous solid become narrower, the rate at which air molecules can be removed from them by evacuation with even the fastest vacuum pump, becomes ever slower. Their complete removal, and particularly the multiple layers of air molecules which are strongly absorbed on the fissure walls and roots, is a very time-consuming process. It could take hours or even days of continuous pumping. If the air is not fully removed, then certainly it cannot be forced out, ferret-wise, by any liquid entering the wide mouths of the fissures, no matter how small the size of the molecules of the liquid itself. The still entrapped air cells and 'lakes' [3] will continue to behave as before the filling, as small but effective light-scattering, brilliance-robbing centres.

The reason for the long duration of the evacuation is related to the 'mean-free-path' of air molecules. These are in constant motion and they impact on each other less frequently when pressures and temperatures are low. This situation can be imagined as the average straight path distance travelled by a molecule where no collision occurs with neighbouring molecules. When the opposite-facing walls of a fissure are separated by a distance which is commensurable with the mean-free-path of the air molecules, then these are less able to move towards the vacuum pump. Heating the fissure walls enormously decreases the mean-free-paths and so accelerates the molecular drift towards the pump.

In Figure 9, the polycrystalline pure alumina refractory tube containing the batch of fissured diamonds is heated in the oven 'A', with its temperature monitored by a thermocouple. The clean glass fragments, held in oven 'B', would not be heated to above the melting point until the vacuum de-airing phase was near to completion.

The second stage is shown in Figure 10. The cylindrical evacuated drum is rotated on its axis until the melt contents of the alumina tube in oven 'B' have been emptied into the tube of oven 'A'. The drum is rocked slightly to ensure that all the stones floating in the melt have had an opportunity to be bathed in the melt. Unlike the de-airing stage, the filling stage should be almost instantaneous if the views about the melt's viscosity and wetting powers are correct.

At the end of this stage, the vacuum pump and oven 'B' are switched off. Air is admitted to the chamber and the observation port is removed. A diamond recovery metal cup with a stone-retaining drainage screen is clamped in place.

This cup is shown in Figure 11 where the diamond and melt recovery stage ends. After the cup has been released, the diamonds are removed from the screen and cooled as quickly as possible to prevent glass devitrification.

The removal of the residual frozen melt on the diamonds' facets would be accomplished by a solvent treatment with dilute hydrochloric or dilute nitric acids. Sulphuric acid must be avoided as it leads to the chalky formation of highly insoluble lead sulphate ($PbSO_4$). A strong solution of caustic soda (NaOH) might also be effective if strong acids were unacceptable.

Conclusions

This tightly-specified proposed scheme for the fissure filling of diamonds is an amalgam of what is already known and what is thought to be desirable for a repeatable working process.

It could be argued that the filling procedure is unduly elaborate but the complexity of the apparatus arises from the need to remove the air completely from the fissure roots *before* immersing the stones in the molten glass. This longish vacuum 'baking-out' step is believed to be vital for really successful results.

One can also question the need to measure dispersion accurately, but it is likely that further improvements will be sought to preserve the

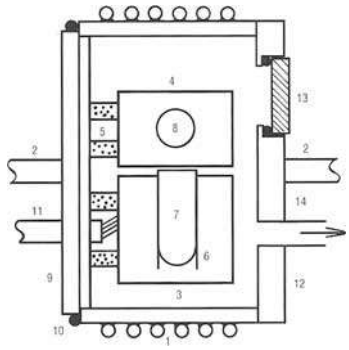

1. Cylindrical steel chamber with soldered-on water cooling tube.
2. Axial rotation spindle (V-block bearing not shown).
3. Electrically heated oven 'A'
4. Electrically heated oven 'B'
5. Heat-insulating standoff pillars.
6. Resistance heaters wound on insulated metal sleeves ('A' and 'B').
7. Sintered alumina reusable tube for holding the glass melt.
8. Sintered alumina reusable tube for holding the untreated cut diamonds.
9. Removable aluminium alloy end-plate.
10. Stretched rubber O-ring vacuum seal.
11. Vacuum-sealed electrical conduit for conducting both the independent power leads to each oven and the leads to each thermocouple temperature sensor.
12. Vacuum-tight fixed end-plate.
13. Glass-disc observation port with rubber O-ring seal.
14. Vacuum pipe showing the direction to the vacuum pump.

Fig.8. A cross-sectional sketch of the glass filling unit

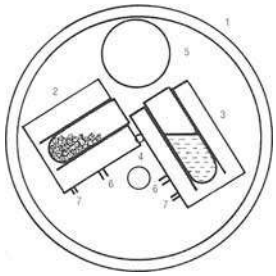

1. Thick-walled steel chamber.
2. Oven A showing the diamond batch under the air evacuation of fissures.
3. Oven B showing the molten glass after the completion of the air evacuation.
4. Vacuum pipe.
5. Observation port.
6. Power supply terminals.
7. Thermocouple terminals.

Conditions: Oven A on. Oven B off. Vacuum pump on.

Fig.9. The first stage of filling: fissure evacuation.

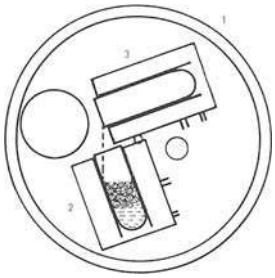

1. Chamber rotated to the glass pouring position.
2. Oven A.
3. Oven B.

Conditions: Oven A on. Oven B on. Vacuum pump on.
At the end of the second stage: Oven A on. Oven B off. Vacuum pump off. Air admitted to the chamber. Observation port off. Diamond recovery cup with its integral screen clamped on in place. (see Fig. 11).

Fig.10. The second stage of filling: fissure filling.

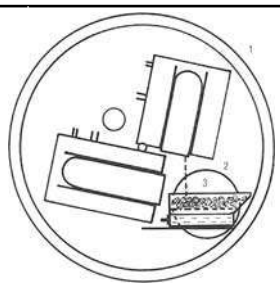

1. Chamber rotated to the position for discharging the diamonds and melt into the recovery cup.
2. Open observation port.
3. Recovery cup with diamond retaining screen.

Conditions: Oven A on. Oven B off.
The recovery cup is unclamped and removed from the chamber. The diamonds are removed from the screen as rapidly as possible to prevent devitrification. Molten glass is recovered for recycling.

Fig.11. The last stage of filling: recovery of diamonds and melt.

original body colour and increase the brightness of the enhanced stones. These efforts would certainly require dispersion control.

In this technical and theoretical account, it has been felt inappropriate to touch upon the market aspects. These are best discussed by members of the stone trade. However, it is interesting to note that the CIBJO rules require the disclosure of the glass filling of any gemstone, and some consider (e.g. Hänni[7]) that the requirement should be mandatory.

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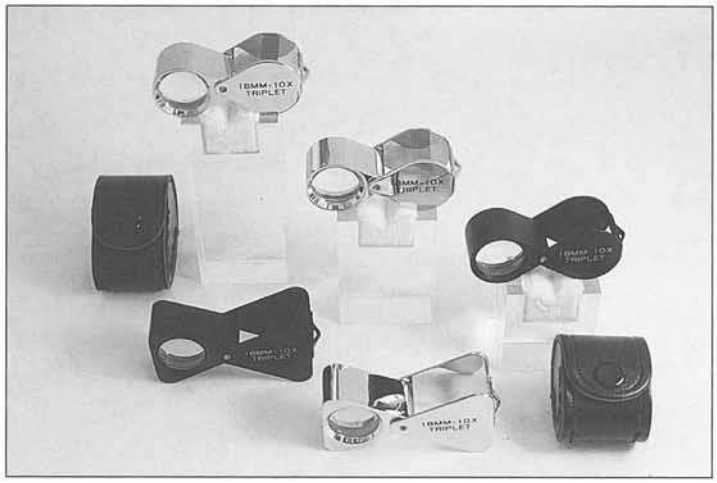

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A device to facilitate the measurement of birefringence in gemstones

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Introduction

When discussing birefringence in gemstones, as measured on a refractometer, Anderson (1990) states:- 'for the purposes of identification maximum and minimum readings are all that are normally necessary. It can be stressed that for all stones, uniaxial or biaxial, the difference between the maximum and minimum readings obtainable on any facet must always represent the full birefringence for that stone'.

The technique which Anderson describes for obtaining birefringence is to select one edge and, using the forefingers of each hand, slowly rotate the stone on the table of the refractometer by gentle nudges. The upper shadow edge is chased to its highest limit and recorded; the lower edge is then chased to its lowest limit and also recorded. The difference between the two values is the birefringence of the stone. Anderson also describes another technique in which the stone is rotated and both lower and higher edge readings are recorded for each orientation of the stone; finally the lowest value is subtracted from the highest to give the birefringence.

This paper describes the construction of a simple device, which could be modified to suit most refractometers*. It enables a stone to be rotated by means of a 'twiddler rod' with the refractometer lid in the closed position, whilst at the same time observing the movements of the shadow edges via the eye piece[1]. First, the high reading shadow edge is selected using the polarizer and, as the stone is rotated, the edge is observed until it reaches its maximum value and begins to reverse. This peak reading is marked with the cursor (in the Dialdex) and recorded. The lower edge is dealt with in a similar fashion to obtain the point where its value is minimal. The point of reversal is obtained just as easily as when focusing a single lens reflex camera, i.e. first going beyond the point of focus in both directions and then returning to a position intermediate between the two. It is, therefore, possible to measure birefringence in just a few seconds since only two values need be recorded and both are accurate. In comparison, using a discontinuous procedure involving writing down a series of values is time-consuming and prone to error and the true value may in fact be in a position intermediate between successive stone orientations. Additionally, since the lid is in the closed position, the operator is not troubled by fumes from the contact liquid, nor does the liquid dry up so quickly.

When using the 'spot' or 'distant vision' test with cabochons, the spot of liquid may be progressively reduced in size quite easily by first retracting the twiddler-rod, so lifting the stone vertically and therefore safely off the table. The liquid remaining on the table is then removed with tissue so that on closing the lid and allowing the stone to descend, the liquid still adhering to the cabochon provides contact with the table, but now the spot has been reduced to approximately half its original size. (The rod stays in its retracted position since the Blu Tack sticks to the top of the hood.) The procedure is repeated until a suitably small image is obtained which gives greater accuracy. Optic sign determinations are also facilitated since the movement of both shadow edges related to each other may be observed directly as the stone is rotated. Mechanical rotation of the stone ensures that, provided the stone is placed at the centre of the table initially, it rotates about the same centre each time and is not laterally displaced as it would be if fingers were used to effect movement. This reduces the possibility of scratching the table and readings are accurately repeatable at any particular orientation of the stone.

Instructions for making the device are given

*A ready-made device for the Dialdex (with mounting instructions) is available from the writer's address for £20 for those who may wish to construct their own.

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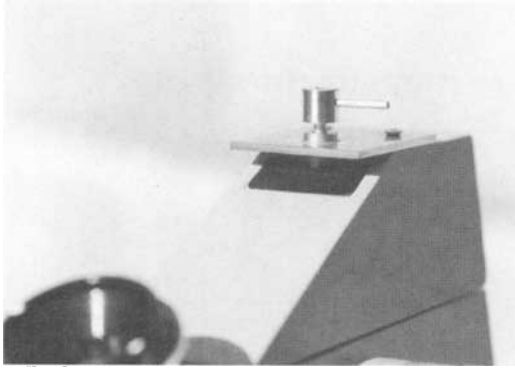

Fig. 1. The rod is shown down in its position of contact with the stone.

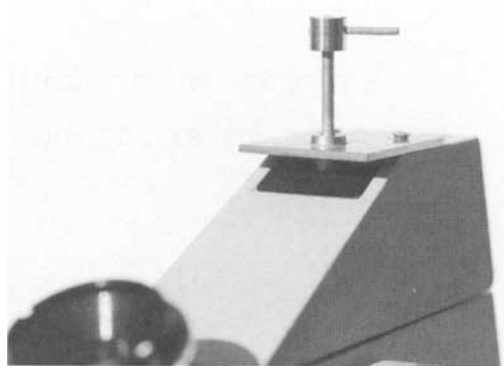

Fig. 2. The rod is shown retracted as when a ring-mounted stone is tested, or when an unmounted stone is withdrawn from contact with the table.

below for the Dialdex refractometer, but only a slight modification would be necessary to adapt it for other instruments.

Basically the device consists of a drilled bush which is inserted into the hood of the refractometer directly above the centre of the table. The bush is mounted on a brass plate which projects over the sloping part of the hood as shown in Figure 1. The bush is of such a length as to steady the rod which passes down its centre hole, but short enough to allow the rod to be retracted as shown in Figure 2. This enables ring-mounted stones to be tested. The rod has a pointer which acts as a handle on its upper end. On its lower end, inside the hood, is a blob of Blu-Tack or some similar substance (Figure 3) which contacts the stone and enables it to be rotated and also lifted from the surface of the table when necessary.

In use, no downward pressure is required once contact has been made with the stone, and the accuracy of the system is such that the same readings are obtained at the same orientation of the pointer each time. With the simple addition of a disc, calibrated in degrees, below the pointer, it would be possible to draw a continuous curve showing the RI of the stone at any specific angle of orientation.

Fig. 3. A blob of Blu-Tack is shown fixed to the end of the rod for rotation of the stone or the shank of a ring.

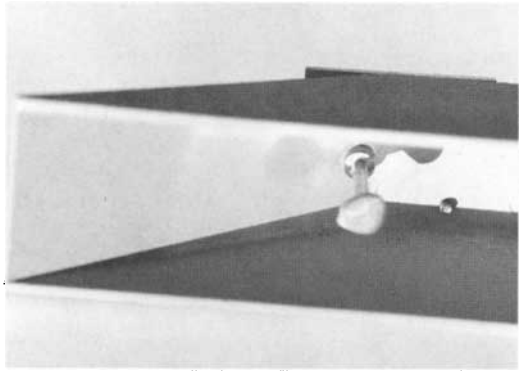

Construction

The plate

The first item to be made is the mounting plate for the bush. This plate in effect lengthens the top surface of the hood so that the bush, which it holds, is perpendicular to the table surface. This is necessary because the hood slopes at the point where the bush must be inserted. Cut a 27 x 30 mm plate from 1.6 mm brass sheet. Scribe the positions of the two mounting screw holes 6 mm in from the edge on a 27 mm side and drill to take the screws to be used. Mark the position of the hole for the bush on the centre line and 9 mm from the edge on the side opposite the screw mounting holes. Mount the plate in a vice in a drill press and using a centre finder (or as accurately as possible by eye) position a 5 mm drill over the mark and drill the hole.

The bush

Mount a short length of 6.5 mm diameter brass rod in a lathe chuck. Turn down a 6 mm length to a diameter of just under 5 mm so that it makes a good sliding fit in the hole in the plate. Drill through with a 2.4 mm drill (or to suit the diameter of the rod to be used). Part off to leave a flange approximately 2 mm thick and fix the

Fig. 4. Another version of the device is shown mounted on the Jemeter, with a spacer designed to accommodate ring-mounted stones.

bush into the plate, using Araldite, high-strength Loctite or solder, etc.

Marking the position for the hole in the hood

It is important to drill the hole in the hood vertically above the centre of the refractometer table. The easiest way of doing this is to mark the centre of the table by drawing diagonals across the rectangular glass area, using a sharp grease pencil which will not damage the glass. Remove the hood and mount the body of the refractometer in a drill press vice, taking care not to overtighten it. Place a centre finder (or fine drill) in the drill chuck and position it accurately above the centre-mark on the table. Now replace the hood (after backing off the drill chuck) and,using a Slocombe centre drill, make a mark on top of the hood. An ordinary drill is too flexible for this job since the mark has to be made on a sloping surface. When the centre mark has been made, remove the refractometer to a safe place and mount the hood only in the vice. Reposition it so that the drill is now directly above the mark previously made and drill a 5 mm hole through it. (It helps to start the hole first with a stiff centre drill.)

The bush in the plate made earlier should fit snugly through the hole in the hood. With the bush in position in the hood, rotate the plate until it lies with its sides parallel with the sides of the hood, then, holding it firmly in place, use a scriber to transfer the position of the screw holes onto the hood. Remove the plate and drill and tap the two holes which are to take the screws. If tapping is a problem, simply drill two holes which just clear the threaded shanks of the two screws and secure them with nuts inside the hood. Mount the plate on the hood.

The twiddler rod

A 30 mm long piece of 2.4 mm diameter aluminium tube is mounted in a brass head with about 27 mm projecting. (The diameter may be varied to suit the material available.) The handle is a clock pin or similar small-diameter rod. The finishing touch is to insert the rod into the bush and fix a pea-sized blob of Blu-Tack on the end. It was found helpful when using the device to mould the Blu-Tack on the rod so that it rotates concentrically with it. In this way, the culet of the stone seats neatly in line with the rod. A little practice is all that is needed to achieve RI and DR measurements in a fraction of the time taken previously.

Jemeter Digital 90

Figure 4 shows a similar device which has been constructed for the Jemeter Digital 90 obtainable from Gemmological Instruments Ltd.

Note

1. The device was sent to Reg Peace. a GAGTL Tutor, who reports as follows:
   'Once the lid of the refractometer has had suitable holes drilled (a relatively simple job), the stone is easily attached to the vertical rotator by Blu-Tack. This procedure avoids scratching the glass prism.
   'Observation of shadow edges while rotating the stone is easily done and repeatable. This is particularly valid in the case of biaxial stones where both shadow edges have to be observed and the maximum and minimum positions do not occur in the same position. By noting the position of the horizontal arm at these stages the refractive indices of each can be checked (a protractor in the form of an adhesive plastic disc on the top of the hood would be an advantage). The relative positions have no significance as they depend on the relationship of the table facet to the optic axes, whilst the numerical values of the refractive indices determine the double refraction.
   'I have found the "twiddler" to be an excellent addition to the refractometer and so easy to use. It can even be used where the stone is set in a ring.'

Reference

Anderson, B.W., revised by E.A. Jobbins, 1990. *Gem Testing* 10th edn. Butterworth & Co., London, p. 23.

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More on the antiquity of emerald oiling

Kurt Nassau, Ph.D.
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In a recent article I pointed out that the usual 2000 year antiquity attributed to emerald oiling cannot be supported (Nassau, 1991). Pliny's description, as discussed in detail, does not apply to emerald but to the oiling of turquoise to turn it from blue to green. It is amusing that Koivula, *et al.* (1992) have recently reported that turquoise is still oiled in Luxor, Egypt, to obtain the green colour preferred by the local population, while blue material is preferred by tourists. All the usually cited sources on emerald oiling since Pliny appeared to be merely restatements of Pliny's account. Tracing emerald oiling backward from today, I was then only able to go back to about 1910.

I am very grateful to Dr John Sinkankas for drawing my attention to two sources, both in the fourteenth century, which give a definite history of at least 650 years to emerald oiling.

The first of the two is a brief mention in *The book of nature* by Konrad von Megenburg (1299-1374). This was written about 1350, widely circulated in manuscript form but not published until 1475, with a facsimile version edited by Pfeiffer (1962). In discussing emerald he says:

> '*Smaragd*... But the best is that which one finds in Scythia, and which is taken from the nest of the griffin bird, which guards the nest with great ferocity... And if one washes it and smears it with palm oil so improves its green.' (Translation by Sinkankas)

Were this the only evidence, however, one would be concerned whether this mix of myth and apparent fact might not still be merely repeated from Pliny. This is particularly likely, since many of the names Megenburg used for stones are unidentifiable because they were taken from Pliny according to Sinkankas. And was oil actually used to the same extent that emeralds were found in griffin nests?

All doubt, however, is removed by a report published by Oskar Schneider (1892) on 'The Egyptian emerald' which includes many historical citations. Among these is one taken from the report of an Arab traveller (p.68):

> 'Schehab ed-din Abul Abbas Achmed in his work "Mesa-lek-al-absar" gives the following more exact description, which he obtained from Abder-rahim, who was employed as a notary at the mine. "The emerald mine is located in the desert which borders on the town of Aswan... When an emerald is found, it is thrown into hot oil, then placed into cotton [wool], which is then wrapped in a piece of linen or other such material."' (Translation by Nassau)

Also included is a detailed description of the mine, with problems of water supply, financing by the Sultan, thieving by the workers, and the rarity of good quality emeralds.

I am greatly indebted to Dr Hedi Benaicha, Arabic Bibliographer at the Princeton University Library, for locating the following information: Abu'l-ᶜAbbās A. b. Ya. b. Fadlallāh al-ᶜOmarī Šihābaddīn was a member of a famous family of government officials. He died in 1349. The work in question was titled *Masālik al-abṣār fi manālik al-amṣār*. This poetic sounding title can be literally translated as 'The Road of the eyes to the kingdoms of the world', being a detailed account of his wide-ranging travels. Its date is not certain, but it was already cited in 1331.

With this realistic description we can clearly accept emerald oiling early in the fourteenth century. Particularly convincing is the use of oil that is hot, since this reduces the viscosity to enable it to penetrate more readily, as well as causing air to expand in fractures and draw in the oil as the air shrinks on cooling. Whether additional convincing evidence for an even earlier occurrence of emerald oiling (not derived from Pliny) will turn up remains to be seen.

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Nassau, K., 1991. Two types of historical traps: on 'diamond softening' and the 'antiquity of emerald oiling'. *Journal of Gemmology*, **22**, 7, 399.

Pfeiffer, F. (Ed.), 1962. *Das Buch der Natur Von Konrad Von Megenburg*. 1861 Stuttgart, Facsimile reprint, Olms, Hildsheim.

Schneider, O., 1892. Der Aegyptische Smaragd. *Zeitschrift für Ethnologie*, **24**, 41.

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Gemmological Abstracts

ARROUAS, S., 1993. Rubis du Vietnam, mythe ou réalité. *Revue de Gemmologie*, 115, 7-8, 6 photos (3 in colour).

A brief survey and statistical report on ruby from the Luc Yen area of Vietnam.

Average size of cut stones ranges from 0.15-1.80ct and the largest stone found so far weighed 57.6ct. Only 6 per cent of the production is suitable for faceting. M.O'D.

ARTIOLI, G., RINALDI, R., STÅHL, K., ZANAZZI, P.F., 1993. Structure refinements of beryl by single-crystal neutron and X-ray diffraction. *American Mineralogist*, **78**, 7/8, 762-8, 3 figs.

Single-crystal neutron and X-ray data of two samples of beryl with different alkali and water contents (gem varieties morganite and aquamarine) confirm existing theories of site occupancy. M.O'D.

ASTRIC, B., MERIGOUX, H., ZECCHINI, P., 1993. Studio della variazione dell'aspetto delle gemme con l'aiuto di immagini di sintesi. *La gemmologia*, **16**, 7-31, **4** photos, 11 figs.

Computer-aided image synthesis is used to build up a picture of various possible shapes for a faceted brilliant-cut diamond. The part played by the source and type of light used for illumination is also studied. M.O'D.

BEDOGNÉ, F., SCIESA, E., 1993. Die Demantoide vom Val Malenco, Sandrio/Italien. *Mineralien Welt*, **4**, 6, 25-8, 8 photos in colour, 1 map.

Well-shaped crystals of demantoid are described from the classic location of Val Malenco, Italy. From the photographs the colour is the expected yellow to brownish- green. Some material is of faceting quality and size. M.O'D.

BOVENKERK, H.P., BUNDY, F.P., CHRENKO, R.M., CODELLA, P.J., STRONG, H.M., WENTORF, R.H.Jr., 1993. Errors in diamond synthesis. *Nature*, **365**, 19, 1 fig.

A natural diamond is reported to have got into the diamond synthesis run 151 carried out in 1955 by some of the present authors while working on diamond synthesis at General Electric. The pressure attained is now believed to have been not much above 42kbar, insufficient to synthesize diamond. Examination of the run 151 specimen to obtain an IR absorption spectrum showed coincidences with a natural N-containing Type Ia diamond. M.O'D.

BROWN, G., 1993. Value enhanced jadeite. *South African Gemmologist*, **7**, 2, 27-32, 5 photos in colour.

A brief survey of the various methods used to enhance the colour of jadeite with notes on identification. M.O'D.

BROWN, G., 1993. Vietnamese ruby. *South African Gemmologist*, **7**, 2, 14-20, 6 photos

A description of ruby from Vietnam is combined with a warning on the presence of Verneuil-type synthetic ruby in parcels of natural stones. M.O'D.

BROWN, G., 1993. Lapis lazuli – a long used gemstone. *South African Gemmologist*, **7**, 3, 12-18, 7 figs in colour.

A brief account of lapis lazuli and its main imitations with notes on simple identification methods. M.O'D.

CUIF, J-P., DAUPHIN, Y., STOPPA, C., BEECK, S., 1993. Forme, structure et couleurs des perles de Polynésie (suite). *Revue de gemmologie*, 115, 9-11, 3 figs.

Spectral analysis of dark pearls from Polynesia is reviewed as part of a general programme to improve the appearance of cultured material from the region. M.O'D.

DE JENLIS, M., 1993. Les mines de rubis de Bolaí. *Revue de gemmologie*, 116, 10-11, 2 photos.

Ruby mines at Bolaí in the former Cambodia are now closed but this brief account describes the method of working that took place. M.O'D.

DEREPPE, J.-M., MOREAUX, C., 1993. Application gemmologique de la résonance magnétique nucléaire. *Revue de gemmologie*, **117**, 8-10, 4 figs.

NMR techniques have a number of gemmological applications including identification of some synthetic emeralds and resolution of diamond types. M.O'D.

DUCHAMP, M., 1993. Les richesses du cristal de roche. *Revue de gemmologie*, 116, 2- 5, 7 photos (1 in colour).

An account of the various uses to which rock crystal has been put in the manufacture of historical artefacts. Objects discussed come from different named museums. M.O'D.

DUCHAMP, M., 1993. Les intailles en cristal de roche et en agates. (Part 1) *Revue de gemmologie*, 117, 4-7, 7 photos (2 in colour).

The use of rock crystal as a medium for engraving is described with reference to a number of artefacts of the sixteenth and seventeenth centuries held in the Karlsruhe Museum and in Vienna. M.O'D.

ENDERS, J., KEJM, T., NOHL, U., 1993. Farbwechselnder Hackmanit aus Kanada-ein überraschender Edelstein. *Lapis*, **18**, 7/8, 26, 5 photos in colour.

A variety of hackmanite showing distinct photochroism is reported from Canada. A variety of sodalite, this type of transparent hackmanite may be found near-colourless, turn purplish during UV-irradiation and remain reddish-orange for a while after the irradiation before reverting to the original near-colourless state. The nature of the colour centre responsible is discussed. M.O'D.

FOLIE, K., 1993. 150 Jahre Burgum-eine klassische Fundstelle für Zirkon in Südtirol. *Mineralien Welt*, **4**, 6, 29-38, 15 photos and 1 map in colour, 2 figs.

Zircon, sphene and vesuvianite are among the minerals found at Burgum in the southern Tirol, Austria. Crystals of all three minerals are well-formed though small. M.O'D.

FORD, T.D., 1992. Postscript to the largest Blue John vases ever made. *Bulletin of the Peak District Mines Historical Society*, **11**, 6, 282.

A large Blue John vase is reported from Renishaw Hall near Sheffield, the home of the Sitwell family. The vase measures 22 inches from base (excluding the plinth) to the top of the handles, thus making it one inch taller than a similar Blue John vase at Chatsworth. Notes on other pieces are given; some of them appear to have been lost. M.O'D.

FORD, T.D., SARJEANT, W.A.S., SMITH, M.E., 1993. The minerals of the Peak District of Derbyshire. *UK Journal of Mines and Minerals*, 13 [jointly with] *Bulletin of the Peak District Mines Historical Society*, **12**, 1, 68pp., illus. in black-and-white and in colour.

The full description of all minerals so far recorded from the Peak District of Derbyshire includes an account of fluorite covering occurrence, production, varieties and properties. The paper, in which the minerals are listed in chemical order, concludes with an excellent bibliography. M.O'D.

GAUTHIER, J-P., 1993. Une mission à Takapoto, 'l'Ile des perles'. *Revue de gemmologie*, 115, 2-6, 4 photos (3 in colour).

Pinctada margaritifera and the smaller *P. maculata* are used for the culture of pearls on the island of Takapoto, situated east of Tahiti in the southern Pacific. M.O'D.

GRIFFIN, W.L., SOBOLEV, N.V., RYAN, C.G., POKHILENKO, N.P., WIN, T.T., YEFIMOVA, E.S., 1993. Trace elements in garnets and chromites: diamond formation in the Siberian lithosphere. *Lithos*, **29**, 235-56.

Trace elements in garnet and chromite inclusions in diamonds from some Siberian kimberlites are studied by proton-microprobe analysis. The kimberlites studied are the Mir, Udachnaya, Aikhal and Sytykanskaya mines in the Yakutia area of the CIS. Examinations of garnet and chromite concentrates from the same pipes have provided information on the thermal state and chemical stratification of the Siberian lithosphere. Diamonds from the peridotite-suite have formed over a temperature interval of about 600°C (Yakutia specimens), this information being obtained from Ni and Zn thermometry. Similar data from other diamond pipes are given. M.O'D.

GRUNDMANN, G., MORTEANI, G., 1993. 'Smaragdminen der Cleopatra': Zabara, Sikait und Umm Kabo in Ägypten. *Lapis*, **18**,

7/8, 27-39, 22 photos (17 in colour), 5 maps, 6 figs.

Several emerald mines in the south-east of Egypt are reviewed. Some may have produced emerald crystals used in the jewellery from the time of the Pharaohs and intermittent work is carried on today though on a very small scale. The three main emerald-producing areas are Wadi Sikait, Zabara and Umm Kabo; the emerald is found in a variety of assemblages: at Sikait it occurs with biotite, plagioclase, muscovite and other minerals and at Zabara, the source of the finest crystals, with biotite schists. At Umm Kabo the emerald is found with carbonate-chlorite schists in association with quartz. An inclusion of columbite is reported in an emerald crystal from Sikait.

M.O'D.

HENN, J., LIEBER, W., 1993. Amethyst vom Brandberg, Namibia. *Lapis*, **18**, 10, 44-8, 11 photos (6 in colour), 3 maps.

Sceptre and phantom varieties of amethyst are found at Brandberg, Namibia. General details of the location are given. M.O'D.

JERDE, E.A., TAYLOR, L.A., CROZAZ, G., SOBOLEV, N.V., SOBOLEV, V.N., 1993. Diamondiferous eclogites from Yakutia, Siberia: evidence for a diversity of protoliths. *Contributions to Mineralogy and Petrology*, **114**, 2, 189-2-2, 9 figs.

The compositions of 14 diamondiferous eclogites from the Udachnaya kimberlite, Yakutia, Siberia are examined with particular reference to major-element and rare earth element factors. Tests involving the electron microprobe and secondary ion mass spectrometer were used in the determination of compositions. While these Siberian eclogites have roughly similar compositions to those in southern Africa there are significant differences which are extensively discussed. M.O'D.

JONES, G.C., 1993. Amber. *Mineralogical Society Bulletin*, **100**, 3.

Short and authoritative account of the formation, distribution, properties and care of amber.

M.O'D.

KAMMERLING, R.C., KANE, R.E., 1993. Die Rubine- und Saphir-Abbaue von Mogok. *Lapis*, **18**, 7/8, 40-56, 27 photos (22 in colour), 2 maps.

The paper, a revised and updated version of that appearing in *Gems & Gemology*, **28**, 3, 152-74, 1992, describes the traditional and more up-to-date methods of mining for ruby and sapphire in the area. Details of some of the geology and mineralization are given and a full list of gem-quality minerals appended. M.O'D.

KAMMERLING, R.C., KOIVULA, J.I., 1993. The role of fashioning in effective gemstone substitutes. *South African Gemmologist*, **7**, 3, 19-29, 7 figs in colour.

Cutting styles used for synthetic and imitation gemstones are discussed with reference to such features as colour distribution, pleochroism and inclusions, as well as to the cutting itself.

M.O'D.

KANEKO, K., LANG, A.R., 1993. CL and optical microtopographic studies of Argyle diamonds. *Industrial Diamond Review*, **53**, 6, 334-7, 6 photomicrographs, bibl.

External surfaces and polished sections of Argyle stones have been examined by cathodoluminescence (CL) topography and optical microtopographic techniques, revealing radiation damage on natural surfaces, complex growth histories and post-growth plastic deformation. Spatially fine-scale variations in nitrogen impurity content correlate closely with differences in abrasion resistance. E.S.

KAZACHENKO, V.T., BUTSIK, L.A., SAPIN, V.I., KITAEV, I.V., BARINOV, N.N., NARNOV, G.A., 1993. Vanadian-chromian tourmaline and vanadian muscovite in contact-metamorphosed carbonaceous rocks, Primorye, Russia. *Canadian Mineralogist*, **31**, 347-56, 7 photos, 1 map, 5 figs.

Vanadian-chromian tourmaline with up to 4.06wt% V_2O_3 and 2.38wt% Cr_2O_3 is reported from contact-metamorphosed carbonaceous metasediments of the Pribrezhnaya anticlinal zone in Primorye, Russia. Crystals show compositional zoning with depletion in Cr and V and enrichment in Al, Mg and Fe from core to rim. The Cr and V enter via the mechanisms $Cr^{3+} \leftrightarrow Al^{3+}$ and $V^{3+} \leftrightarrow (Mg^{2+}, Fe^{2+}, Mn^{2+})$. The second exchange necessitates a charge increase and this is thought to be resolved via substitution of ^{IV}Al for Si and by the appearance of vacancies in the X site. M.O'D.

KOSHIL, I.M., VASILISHIN, I.S., PANCHENKO, V.I., 1993. Bernstein aus der Ukraine. *Lapis*, **18**, 10, 34-7, 4 photos in colour, 1 map, 1 fig.

Ukrainian amber has been known for at least 1200 years. Artefacts are described and there are notes on characteristic inclusions. M.O'D.

KRAPPMANN, M., DREES, H-H., 1993. Mineraliensuche im Süden Afrikas. *Lapis*, **18**, 10, 41-3, 5 photos (4 in colour).

Particular reference to amethyst, beryl and tourmaline is made in a general survey of South African minerals. M.O'D.

MAGNORI, L., 1993. Brevi osservazioni sull'anfibolite zoisitica a corindone della Tanzania. *La gemmologia*, **16**, 33-5, 4 figs in colour.

Ruby in zoisite from Tanzania is briefly reported with notes on some petrographic characteristics. M.O'D.

MATHEZ, E.A., BLACIC, J.D., MAGGIORE, C., MITCHELL, T.E., FOGEL, R.A., 1993. The determination of the O content of diamond by microactivation. *American Mineralogist*, **78**, 7/8, 753-61, 4 figs.

Microactivation techniques have been used to determine the oxygen content of diamond. The specimen is bombarded with an energetic beam of $^{3}H^{2+}$ from a tandem accelerator giving the reaction $^{16}O(^{3}He,p)^{18}F$. The ^{18}F decays to ^{18}O (half life of 109.8 min) by positron emission and the decay activity is measured by coincidence counting. In 28 diamond samples most showed 10-100ppm O (atomic) in spots. These were later found to be inclusion-, crack- and defect-free. It is not thought that the O is present in submicroscopic mineral inclusions. Samples tested came from some unknown locations and also from the Monastery and Finsch kimberlites, South Africa, from Orapa, Botswana and from Muji Mayi, Zaire. M.O'D.

MITCHELL, A.H.G., 1993. Cretaceous-Cenozoic tectonic events in the western Myanmar (Burma)-Assam region. *Journal of the Geological Society, London*, **150**, 1089-102, 11 figs.

Late Mesozoic mafic and ophiolitic rocks when correlated may imply that a NE-facing mafic arc was emplaced on to SE Borneo, western Sumatra, western Myanmar (then 1100 km S of its position today), the Mogok belt and the Denquen-Bangong Co-ophiolite zone in Tibet in the late Lower Cretaceous. These sites were at that time situated on the SW margin of Asia. Subsequent reversal of tectonic polarity and other events were implicated in the mineralization of several important gem-bearing areas, including the Mogok Stone Tract. M.O'D.

MONAT, P., MERIGOUX, H., 1993. Marbode. Poème des pierres précieuses. (part 1) *Revue de gemmologie*, 117, 2-3.

Prologue, diamond, agate, amber, jasper, sapphire and chalcedony are reviewed in this first part of a commentary on Marbodius, *Libellus de lapidibus*, a poem tentatively dated between 1067 and 1101. M.O'D.

MUNTYAN, B.L., 1993. 10 interessante Mineralienfundstellen in Colorado, USA. *Mineralien Welt*, **4**, 4, 17-23, 10 photos (8 in colour), 1 map.

Among the ten sites are the Sweet Home mine, celebrated for gem-quality rhodochrosite and Crystal Peak where good quality amazonite is found. M.O'D.

NEUBAUER, D., 1993. Olivinkristalle aus Hawaii. *Aufschluss*, **44**, 347-8, 1 fig., 1 photo in colour.

A near gem-quality green olivine crystal found at Mauna-Lani on the west coast of Hawaii measured approximately 2 x 1.5mm and 1mm in height. Predominating faces were (001), (102), (011), (012) and (110): SG was 3.35. M.O'D.

NIEDERMAYR, G., 1993. Saphir. *Mineralien Welt*, 4, 4, 29, 3 photos (2 in colour).

Characteristic inclusions in Sri Lanka blue sapphire are illustrated and described. M.O'D.

NIEDERMAYR, G., 1993. Diffusions-behandelte Korunde. *Mineralien Welt*, 4, 5, 15, 1 photo in colour.

Brief review of diffusion-treated corundum with notes on identification. M.O'D.

NOVAGA, M., 1993. La vesuviana di Bellecombe e Montjovet (AO) come materiale di interesse gemmologico. *La gemmologia*, **16**, 36-40, 6 photos in colour, 1 map.

Gem quality vesuvianite is reported from Bellecombe and Montjovet in the province of Aosta, northern Italy. SG and RI ranges are given. M.O'D.

O'DONOGHUE, M., 1993. Gemmology towards the 21st century. *Mineralogical Society Bulletin*, **191**, 3-4.

A survey of some of the problems facing gemmologists towards the end of the twentieth century includes alteration of colour by various means and the related question of disclosure; new gem species and varieties and changes in mining, supply and marketing methods. Gem-quality synthetic diamond bids to occupy gemmological attention very soon.

(Author's abstract) M.O'D.

PICKER, H., 1993. Granite International. *International Diamond Review*, **53**, 557, 4, 218-22, 3 tables, 4 photographs.

Reprint of a lecture by H. Picker at the international seminar *Dimension Stone Afrika 1993* earlier this year in Johannesburg. He surveyed the growth of the granite industry, which covers the use of granite in memorials and tombstones; in construction for wall cladding, flooring, in pedestrian areas and as tiles and veneer tiles and for technical application as surface plates and basins for acids and as pillars. The main producing countries are India, South Africa, China, Spain, Brazil, Norway, Korea and Finland, although sizeable quantities are also produced in Sweden, Italy, Portugal, France, Germany, the former Eastern bloc, USA and Canada. The industry is growing rapidly in China as well as in Taiwan and a big diamond sawing capacity is being built up in Thailand, Malaysia, Singapore and Indonesia. E.S.

RENDELL, H.M., KHANLARY, M-R., TOWNSEND, P.D., CALDERON, T., LUFF, B.J., 1993. Thermoluminescence spectra of minerals. *Mineralogical Magazine*, **57**, 2, 217-22, 6 figs.

Though most TL measurements are obtained by examining light emission during heating, using broad-band optical filters and blue-sensitive photomultiplier tubes, more useful information can be gained by an examination of the emission spectrum displayed during the time that the TL is occurring. Crystal purity, radiation dose, dose rate and thermal history all affect the TL spectra of minerals. The paper describes TL spectra of calcite, fluorite, zircon and feldspars. M.O'D.

RIZZI, F., WEISS, S., 1993. Grösster Apatitkristall aus einer Schweizer Zerrkluft. *Lapis*, **18**, 12, 21-6, 11 photos (7 in colour), 1 fig.

Large crystals of apatite, some with a moonstone-like sheen and others apparently with sections sufficiently transparent to be faceted, are found in Alpine clefts in the area of Naret, Ticino, Switzerland. The colour is predominantly pale yellow. M.O'D.

ROBERT, D., 1993. Gemmes irradiées et radioactivité, *Revue de gemmologie*, 116, 6-9, 1 photo in colour.

The irradiation of gemstones and the problems associated with radio-activity are briefly discussed with particular reference to topaz. M.O'D.

ROBINSON, G.W., KING, V.T., 1993. What's new in minerals? *Mineralogical Record*, **24**, 5, 381-95, 18 photos in colour.

The paper includes the annual world summary of mineral discoveries covering April 1992 through April 1993. Gem-quality and ornamental species described include: rhodochrosite from the Sweet Home mine, Alma, Colorado; fluorite from the classic locality of the Minerva no. 1 mine, Cave-in-Rock, Illinois; purple fluorapatite and variously coloured tourmalines from several different sites in Maine; very fine opal from Opal Butte, Morrow County, Oregon. Outside the United States there are reports of kunzite and lazurite from Afghanistan, brazilianite from Minas Gerais, Brazil, a state also producing fine-coloured tourmaline of different colours, chrysoberyl from Medeiros Neto, Bahia, Brazil. Spectacular crystals of red spinel in white quartz are reported from Burma and bluish-green fluorite crystals from Shang Bao, Leiyang County, Hunan, China. Fine emerald crystals from Colombia have been on the market as have gem-quality golden beryl crystals from Wolodarsk-Wolynski, Wolhynien, Ukraine. Large red elbaite crystals have come from the Otjua mine near Karibib, Namibia and transparent green gem-quality zoisite from the Northern Areas of Pakistan. M.O'D.

SCHÄFFER, W., 1993. 'Tsavorite', der grüne Grossular aus Kenya. *Lapis*, **18**, 7/8, 57-66, 23 photos (18 in colour), 3 maps, 1 fig.

Transparent gem-quality green grossular is found in the Taita Hills near Voi, Kenya. Details of the occurrence and of the sporadic mining operations are given. The garnet occurs in a graphitic gneiss. M.O'D.

SCHELLHORN, S., 1993. Bitterfeld: Sächsischer Bernstein aus dem Braunkohlen- Tagebau, *Lapis*, **18**, 10, 32-3, 3 photos in colour.

Amber is found in brown coal measures at Bitterfeld, Saxony, Germany. The current working site, Gute Hoffnung I, is described.

M.O'D.

SCHRAUDER, M., NAVON, O., 1993. Solid carbon dioxide in a natural diamond. *Nature*, 365, 42-4, 1 photo., 2 figs.

Solid CO_2 is reported from a natural diamond. The specimen was a brownish- yellow diamond composed of two intergrown crystals with the larger crystal displaying a zoning with slight colour in the centre and a more intense colour at the outer zone. The smaller crystal is colourless. IR spectra for the different zones show the common type IaA bands with low N and H content, (1282 and 3107cm^{-1}). Four additional bands (at 650, 2376, 3620 and 3752cm^{-1}) can be observed in the coloured zones. The bands at 2376 and 650cm^{-1} dominate the remainder of the spectrum and show an intensity exceeding that of the diamond absorption bands. These dominating bands are the v_3 and v_2 bands of CO_2; the bands at 3620 and 3752cm^{-1} correspond to the combination bands (v_3+2v_2 and v_3+v1) of CO_2. The lines are shifted from the positions where they occur at one atmosphere pressure and comparison with high-pressure spectral data of CO_2 shows that the position of three of the peaks in the spectrum of the diamond closely fit the spectrum of solid CO_2 at a pressure of 5±0.5GPa.

M.O'D.

SCHUBNEL, H-J., 1993. Les collections de synthèses anciennes du Muséum National d'Histoire Naturelle. *Revue de gemmologie*, 117, 11-14, 9 photos (5 in colour).

A number of early syntheses of gem materials, particularly corundum, spinel and emerald, are held in the collections of the Muséum National d'Histoire Naturelle, Paris. M.O'D.

SEIFERT, T., RIEDRICH, G., 1993. Die Achate im Melaphyr von Gröppendorf bei Hubertusberg in Sachsen. *Mineralien Welt*, 4, 4, 15-16, 5 photos (3 in colour), 1 map.

Ornamental agate is described from the area of the Huberstusberg near Gröppendorf, Saxony. The agate occurs in a melaphyre.

M.O'D.

SIRAKIAN, D., 1993. Gemmes en lumière. *Revue de gemmologie*, 115, 12.

A pink stone with an RI of 1.732 and weighing less than one carat was tentatively identified as a garnet in the pyrope-almandine series despite the low RI which suggested spinel in the first instance. Semi-quantatitive chemical analysis was used to establish the identity of the Sri Lankan specimen. M.O'D.

SKOBEL, L.S., NEKHANENKO, I.I., POPOVA, N.P., 1993. Axinitfunde in der Lagerstätte Puiva, Polarural. *Mineralien Welt*, 4, 5, 33-7, 5 photos (4 in colour), 1 fig.

Axinite, some crystals of gem quality, are reported from the area of Puiva in the extreme north of the Urals in Russia. Occurring with and on quartz, the axinite shows strong pleochroism with predominantly violet and cinnamon colours and has RI 1.688, 1.685, 1.678. M.O'D.

SOUZA, J.L., MENDES, J.C., BELLO, R.M.S., SVISERO, D.P., VALARELLI, J.V., 1992. Petrographic and microthermometrical studies of emeralds in the 'Garimpo' of Capoeirana, Nova Era, Minas Gerais State, Brazil. *Mineralium Deposita*, **27**, 2, 161-8.

Studies in this area have revealed two main lithostructural units. The first consists of gneissic rocks of granitic composition belonging to the basement complex and the second of a highly weathered metasedimentary-metavolcanic sequence represented by metapelitic schists, amphibolites, schists derived from ultramafic rocks, and quartzites. Quartz and pegmatitic veins appear near the contacts between the gneissic rocks and the mineralized metasedimentary-metavolcanic sequence. The emerald mineralization is mainly concentrated within the intercalations of meta-ultramafic schists near the contact with the pegmatitic veins. Microthermometric studies of the fluid inclusions in the emerald grains indicate that crystallization occurred in the P-T range 2000 - 2750 bar and 450 - 650°C. The data suggest that the mineralizing solutions had a late hydrothermal-pneumatolytic origin characterized by low P, suggestive of the paragenesis talc + tremolite + carbonate + biotite-phlogopite + chlorite in the emerald wall rocks.

R.A.H.

SURY, E., 1993. Wie der Schein doch trügen: Edelsteine aus Glas und Klebstoff. *Lapis*, **18**,

7/8, 71-6, 7 photos (6 in colour).

A review of synthetic and imitation gemstones with notes on their manufacture.

M.O'D

THOMAS, A., 1993. The emerald mines of Madagascar. *South African Gemmologist*, 7, 3, 3-11, 3 photos in colour.

Emeralds from the Mananjary mine are compared with specimens from other world localities, but with no conclusive evidence to distinguish them. The crystals occur in a biotite schist and although predominating inclusions of tremolite and actinolite are reported from this area in the literature stones recovered on the occasion of the visit of the author did not show these minerals. The solid inclusions are not identified. Most of the article is devoted to travel reminiscences. M.O'D.

VAN PRAAGH, G., 1993. Growing crystals of quartz. *Mineralogical Society Bulletin*, **101**, 7-9, 2 figs.

The writer recalls his work in investigating German crystal growth activities immediately after the Second World War. In particular he recalls meetings with Professor Richard Nacken and discussing hydrothermal growth of quartz. Details of methods used at the time are given.

M.O'D.

WEERTH, A., 1993. Neuheiten aus Asiens Schatzkammer. *Lapis*, **18**, 9, 28-30, 5 photos in colour.

Gem-quality mineral finds from Asia over the past few years are reviewed. Particular attention is paid to the northern Pakistan pegmatites with spessartine, green transparent zoisite, aquamarine, scheelite and epidote. M.O'D.

WEERTH, A., 1993. Milarit und Danburit aus Südtirol. *Lapis*, **18**, 10, 26-31, 15 photos (14 in colour).

Danburite, some of good gem quality, is found with milarite in clefts at various places in the southern Tirol, Austria. Crystals are fairly small, however. M.O'D.

WEISS, S., 1993. Schörl, Rubellit und Mohrenköpfe aus Sachsen. *Lapis*, **18**, 7/8, 13-17, 12 photos (11 in colour), 2 figs, 2 maps.

Gem quality red tourmaline and specimen-quality schorl, with some characteristic dark-topped crystals, occur in the Granulitgebirge in Saxony, Germany. The nearest town to the major deposits is Penig. Other minerals reported from the area include apatite, quartz, dark red garnet and amblygonite. M.O'D.

JADES IMPÉRIAUX. *Revue de gemmologie*, 1993, 116, 12-16, 5 photos in colour.

Photographs illustrate some jade artefacts to be shown at an exhibition in Paris in late 1993.

M.O'D.

A unique diamond exhibition. *Industrial Diamond Review*, 1993, **53**, 557, 4, 204-5, 7 photographs.

Short description of the *From the Treasury* exhibition in June 1993 organized by the HRD (Diamond High Council) to commemorate Antwerp's selection as the cultural capital of Europe. The exhibits included the Eureka diamond, the first diamond ever found in South Africa, and jewellery and stones from the Romanov Tsars, the Thurn and Taxis, the Duchess of Windsor and many other celebrities. De Beers loaned their Rainbow collection and Argyle diamonds the Argyle Library Egg by Kutchinsky, 70cm high and studded with 20 000 pink and white diamonds. E.S.

Book Reviews

ASSELBORN, E., FOLIE, K., GEIPEL, R., GRAMACCIOLI, C.M., GRUNDMANN, G., HOCHLEITNER, R., MAISSEN, F., MULLIS, J., NIEDERMAYR, G., STRUNZ, H., WEISS, S., 1993. *Kristall alpin.* Christian Weise Verlag, Munich. pp. 95, illus. in black-and-white and in colour (*extraLapis* 5). ISBN 3 921656 28 1.

A multi-author survey of the Alpine environment and its minerals forms the fifth in the *extraLapis* series. Though the series is not covered by a subscription to *Lapis* itself, those issues so far published are well worth the attention of gemmologists. In this number each of the major minerals is extensively described with some crystal drawings and high-quality colour photography. Rarities get similar but shorter treatment. Early chapters describe geology, inclusions, mineral formation and tectonics. A more comprehensive bibliography would have been welcome but, to be fair, this area has been well covered by other works. M.O'D.

AYERS, J., 1993. *A jade menagerie: creatures real and imaginary from the Worrell collection.* Azimuth Editions, London. pp. 72, illus. in colour. Price on application.

Jade animals, few later than the Ming dynasty, form the nucleus of the collection formed by T. Eugene Worrell of Charlottesville, Virginia. The book has chosen 41 items for description but the text takes second place to the photographs, all in colour and all showing the subtle yellow, brown and cream colours characteristic of nephrite. The text is more narrative than scientific but loses nothing by this. Items are succinctly dealt with in catalogue style at the end of the book while the main section describes the real and mythical creatures, their styles and dates. M.O'D.

BURNS, R.G., 1993. *Mineralogical applications of crystal field theory.* 2nd edn. Cambridge University Press, Cambridge. pp. xxiii, 551, £50.00.

Forming volume 5 of the series *Cambridge topics in mineral physics and chemistry*, this book first began life as a series of lectures given at Cambridge and Oxford during 1966, the lectures themselves being based on material collected for a thesis submitted to the University of California at Berkeley. Since the publication of the first edition the amount of data relating to visible to near-IR spectroscopic measurements of minerals containing cations of the first-series transition elements has greatly increased and this edition, while reviewing the data, also introduces newer applications of them, particularly in the context of the occurrence of transition metal-bearing minerals on planetary surfaces and of the applications of remote-sensed reflectance spectra in their identification.

For the mineralogist and gemmologist the chapters on measurements of absorption spectra of minerals and crystal field spectra of transition metal ions in minerals will be turned to first although other sections of the book are just as absorbing. Apart from the explanations and observations provided, the extensive reviews of work covered not only by the text but also by end-of-chapter references and a 43-page bibliography at the end of the book are just as useful. Read in conjunction with *The physics and chemistry of colour* (Nassau, 1983) the combined texts provide the best possible introduction and explanation of some of the problems faced by mineralogists and gemmologists and those persisting with the text will admire the lucidity of style excellently complementing the elegance of the conceptions.

For the price this is a most valuable bargain; the text appears to have been set and in any case is not camera-ready copy. I had been looking forward to this edition since I first saw its announcement at the beginning of 1993. M.O'D.

CHRONIC, H., 1990. *Roadside geology of Utah.* Mountain Press, Missoula, MT. pp. x, 326, illus. in black-and-white; maps in 2 colours. US$14.00.

As usual with the *Roadside geology* series, the geological features of a particular region are discussed from the point of view of those travelling along major US highways. Preliminary chapters

give general geological details of the whole area covered. Similar treatment is given to Montana (1991), US$14.95; Idaho (1991), US$15.00 and Colorado (1991) US$11.95. All are recommended to those with interest in field work. M.O'D.

De CERVAL, M., 1992. *Mauboussin*. Editions du Regard, Paris. pp. 274, illus. in black-and-white and in colour. £98.00.

The celebrated Paris firm of Mauboussin grew from a business established by M. Rocher in 1827. Six generations on the firm has branches outside France, most notably in New York. This account, well-presented in a large and heavy volume without an index, relates the story of the firm's development and describes the most celebrated pieces with photographs and some designers' drawings. A section at the end of the book covers automata and there is a useful bibliography. This is an expensive book but invaluable for students of jewellery history. M.O'D.

ENTREMONT, P., 1992. *Chasseur de pierres*. Robert Laffont, Paris. pp. 212, illus. in colour. [Series *L'aventure continue*]. Price on application.

Excellent and cheerful account of the author's travels world-wide in search of gemstones. Several classic localities are described, together with good-quality colour photographs and the author's reported dialogue is lively and full of useful information. From the accounts given, he has a notable gemstone collection. I can recommend the book which does not need high-level French to understand. M.O'D.

FALK, F., 1985. *Europäischer Schmuck*. Verlag Hans Schöner, Königsbach-Stein. pp. 201, illus in colour. Price on application.

205 items from the Pforzheim jewellery museum are well illustrated in colour with notes in German and English. A short introduction by the museum curator opens the text. M.O'D.

FRONLICH, F., SCHUBNEL, H-J., 1991. *L'Age du silicium*. Muséum National d'Histoire Naturelle, Paris. pp. 92, 115 figs. Price on application.

The catalogue to an exhibition of the same title. A series of 36 papers follows silicon from its atomic structure, its mineralogical and petrological associations through its role in stained glass to silicon chips, silica glass fibres and amorphous silica layers. The role of silicon in contemporary society is examined and it is suggested that we are now in the middle of the Silicon Age. E.A.J.

GERE, C., CULME, J., SUMMERS, W., 1993. *Garrard: the Crown Jewellers for 150 years*. Quartet Books, London. pp. 216, illus. in black-and-white and in colour. £50.00. ISBN 0 7043 7055 7.

Many people know that when the crown jewels are cleaned or from time to time altered it is the London firm of Garrard which carries out the work. This well-produced survey begins with the first Royal Appointment in 1843. Very fortunately the archives of the firm are preserved and the book draws freely on them in its description of the wide variety of artefacts produced over 150 years.

Coronations, the personal jewellery of sovereigns and the care of important pieces, all form separate sections which follow an introduction giving the history of the firm. There is free use of anecdotal material and several pages from the archives are reproduced together with photographs of plate, presentation objects, pieces of jewellery and the crown jewels. Of particular interest to many readers will be the description of the care of the crowns and regalia, and the section describing the crown jewels and their situation in the Tower of London. There is a short bibliography and the standard of illustration is excellent. Altogether there must be a great deal in Garrard's archives which has yet to be revealed and a further book, once a theme has been found, would be welcome. M.O'D.

GRIFFEN, D.T., 1992. *Silicate crystal chemistry*. Oxford University Press, New York. pp. ix, 442, illus. in black-and-white. £45.00.

Some of the main groups of silicate minerals are discussed in the context of undergraduate one-semester courses. The groups covered are arranged in decreasing order of tetrahedral polymerization; thus framework silicates come first and orthosilicates last. A single chapter covering amphiboles and non-classical biopyriboles (this word is a coinage from biotites, pyroxenes and amphiboles) is placed out of sequence to emphasize some important points made by the author. Readers with an interest in gem minerals will find some of the chapters particularly valuable, especially those discussing the garnet group, the pyroxenes, the amphiboles, the aluminium silicate polymorphs and the olivines. The chapter on the feldspars should also be consulted. The main trend of the book is the relationship between

chemical composition and structure and many useful concepts are brought out. Each chapter has its own list of references (there are, for example, 54 for the garnet chapter) and a careful reading will greatly increase the size and depth of the intellectual base on which gemmological studies are founded. M.O'D.

HURLE, D.T.J., 1993. *Crystal pulling from the melt.* Springer-Verlag, Berlin. pp. ix, 148, illus. in black-and-white. DM 78.00. ISBN 3 540 56676 7.

Donald Hurle is the *doyen* of crystal pulling techniques and it is good to see much if not most of the work so long pursued at Bell Labs, New Jersey, and elsewhere appear as a monograph. Naturally gemmologists will be interested in trying the book out as so many important materials with ornamental application are grown in this way (notably ruby and synthetic garnets). The method originated at the beginning of the present century, Czochralski's paper appearing in 1918, but it took the growth of the semi-conductor industry after the Second World War to underline its importance: the invention of the laser meant that ruby rods of exceptional purity were needed and this method was the only way in which they could be grown (though very recent work on tight temperature control with the Verneuil method has greatly enhanced the purity of materials grown by it).

Treatment of the subject is largely mathematical since the author's aim is to help the grower to improve the process and also to enhance the system modelling capabilities of the applied mathematician, rather than to give a guide to crystal pulling technology.

The first chapter summarizes the advantages of the method which are that the crystal is unconstrained as it cools so that a high degree of structural perfection can be obtained, the rotation of the crystal ensures an even distribution of solute and the growing crystal can be observed at all stages of growth. The remainder of the book examines all parts of the process in detail and provides a 268-entry list of references. M.O'D.

KELLER, A.S. (ed.), 1992. *International Gemological Symposium, Los Angeles, 1991. Proceedings of the International Gemological Symposium 1991.* Gemological Institute of America, Santa Monica. pp. xvi, 192, illus. in colour. Price on application.

Under the title Facing the future 70 full presentations and 90 poster sessions, with panel discussions and exhibitions made up a useful conference at which developments were rounded up and set out in a pleasingly-produced volume. Though most of what was contributed can be found elsewhere, the book provides a useful starting point for discussion and is also very suitable for counter display as the text is fairly general in tone. As always the colour photographs are excellent. M.O'D.

LIDDICOAT, R.T., KELLER, A.S. (eds.), 1990. *Gems & Gemology: a retrospective of the '80's.* Gemological Institute of America, Santa Monica. pp. 110, illus. in colour. Price on application.

This beautiful volume described as 'limited edition' reproduces in hardback form the contents and illustrations of Gems & Gemology, 26, 1, Spring 1990. This is a very good idea since the book is more portable and easier to display than the flimsier journal issue and in any case most gemmologists will want to keep their journal sets together. Few books and few periods show a greater range of gemmological developments and techniques and this item is particularly suitable as an introduction to our science for the student and customer. As always with GIA, quite first-rate production. M.O'D.

MARKEL, S. (ed.), 1992. *The world of jade.* Marg Publications, Bombay. pp. 124, illus. in black-and-white and in colour. £45.00

A multi-author book with chapters on early Chinese jades; the working of jade in the Ming and Qing dynasties; jades from the Islamic world; inception and maturation in Mogul jades; jades in the treasuries and palaces of Europe; historical implications of the jade trade between the Maya lowlands and Costa Rica during the early classic period; jades of the New Zealand Maori and scientific description and technical analysis.

Each chapter is well illustrated and has extensive lists of references. The colour photographs are generally quite good; some are excellent. With a large page size helping the illustrations, this is a useful and wide-ranging treatment of the jades. M.O'D.

MATLINS, A.L., BONANNO, A.C., 1993. *Jewelry and gems: the buying guide.* 3rd edn. Gemstone Press, Woodstock, Vermont. pp. xx, 26,. illus.

in black-and-white and in colour. US$16.95. ISBN 0 943763 11 8.

With a sprightly text and two sections of colour photographs showing gemstones and set jewellery respectively, it is easy to see why this simple book appeals to all connected with gemstones. While the text is aimed at the customer and dealer there is plenty for the gemmologist to praise: an excellent common-sense approach to tricky sales situations, a useful table of prices with plenty of comments advising the reader to use it with caution, usually up-to-date information on gem species currently used in jewellery and a section covering mounting, metals, buying and selling, appraising and insuring. On the debit side is the odd way in which some of the stones have come out in the colour section (look at Paraiba tourmaline and a very red topaz), the too-short list of references and the use of both 'red emerald' and bixbite for red beryl from Utah. Yes, these are pretty small criticisms and the book is recommended, especially for the student who needs a commercial source as well as a scientific one. M.O.D.

NEWMAN, R., 1992. *The pearl buying guide.* International Jewelry Publications, Los Angeles. pp 186. Illus. in black-and-white and in colour. US$18.95. ISBN 0 929975 17 0.

The greatest weakness in the literature of gemmology is the lack of even an adequate coverage of pearl in English. This comes close to being the ideal although, like other books from this publisher, it is aimed primarily at the customer. Even so, there is a sound treatment of the gemmological and zoological aspects of pearl with questions following each chapter and a good bibliography. This book makes a timely appearance and will be welcomed by students as well as by a wide range of the jewellery-buying public. M.O'D.

NEWMAN, R., 1993. *The diamond ring buying guide.* 4th edn. International Jewelry Publications, Los Angeles. pp. 151, illus. in black-and-white. US$12.95. ISBN 0 929975 20 0.

This excellent text makes a welcome reappearance as a fourth edition, though 'reprint' would perhaps be more accurate. Nevertheless, anyone connected with gemstones or jewellery should have the book – by far the best coverage of the subject around. M.O'D.

NEWMAN, R., 1994. *The ruby and sapphire buying guide.* 2nd edn. International Jewelry Publications, Los Angeles. pp. 204, illus. in black-and-white and in colour. US$19.95. ISBN 0 929975 21 9.

This useful book, accurately written, well-produced and illustrated, contains 14 additional pages of colour photographs. It also describes the present role of the GAGTL, depicting one of its certificates (as a sample only). While the pictures are very good indeed, there is little coverage as yet of ruby from Vietnam and no reference is made to the now routine heating of Montana sapphires (other than Yogo material). Nevertheless, the book can be highly recommended and at the price should be in the library of every gemmologist as well as in jewellery shops. M.O'D.

PETRUSSENKO, S.I., KOSTOV, R.I., 1992. *Gem and decorative minerals of Bulgaria.* Sofia (publishing house of the Bulgarian Academy of Sciences). pp. 90, 2 maps, Leva 17.00. [Bulgarian with Russian and English summaries]

The first part of this booklet gives an historical account of the use of precious stones and carvings in Bulgaria. Enhanced activity since 1944 led to the discovery of gemmological materials such as emerald, garnet, amethyst, jasper, turquoise, etc. In the second part some details are given of chrysoberyl, spinel, ruby and sapphire, fluorite, rose quartz, citrine, agate, amethyst, opal, amazonite, scapolite, actinolite, rhodonite, heliodor, emerald, aquamarine, kyanite, topaz, zircon, zoisite, garnet, tourmaline, apatite, turquoise and malachite. In the final part, genetic types of gem materials are discussed. The Rhodope region is the most important area for the size of deposits and their variety. R.A.H.

VOYNICK, S., 1992. *Colorado gold.* Mountain Press, Missoula, MT. pp. ix, 206, illus. in black-and-white and in colour. US$12.00.

The author of books on hard rock mining and on Yogo sapphires gives an equally readable and accurate survey of gold mining in the state of Colorado, beginning with the gold rush at Pike's Peak in 1859 to present day working. While the stories of the various enterprises are most interesting there are also many technical and mineralogical details of the mining itself which make the book useful to a wide variety of readers. There are many good black-and-white pictures and a colour section with photographs of gold specimens. Much more information will

be obtainable from the large number of sources listed at the end of the main text. M.O'D.

WARD, F., 1993. *Diamonds.* Gem Book Publishers, Bethesda, MD. pp. 64, illus. in colour. Price on application.

Another welcome book in the *Gem Books* series, this gives an excellent introduction to diamonds, covering every aspect of diamond mining, grading, sale and synthesis in a very compact text. There is also room for photographs and brief accounts of famous diamonds and jewellery. This series should be in every store; no other books that I know give a better overview of the gem world. It is good to see that the pictures are fresh and well-reproduced. M. O'D.

WHITE, J.S., 1991. *The Smithsonian treasury: minerals and gems.* Smithsonian Institution Press, Washington DC. pp. 96, illus. in colour. £9.95.

A short and reasonably-priced guide to some of the major specimens in the National Museum of Natural History, Smithsonian Institution, with some account of the scientific work carried out there. Several named gemstones and pieces of jewellery are illustrated as well as mineral specimens; the photographs do not quite do some of them justice. M.O'D.

ZAPATA, J., 1993. The jewelry and enamels of Louis Comfort Tiffany. Thames and Hudson, London. pp. 176, illus. in black-and-white and in colour. £25.00. ISBN 0500 23664 X.

Louis Tiffany, the son of Charles, founder of the celebrated New York firm, was born in 1848. He is particularly associated with lamps, glass and ceramics, but he also produced effective and distinctive jewellery. The book opens with a history of the family and goes on to describe the early enamels. Chapter 3 describes the jewellery: it is established that Louis did not begin his jewellery production until 1902, the year of his father's death. Sadly, there are no extant record books of the earliest items up to 1907 but identified pieces show the wild flower motifs typical of the early years. Also typical is the experimenting with metals and stones; the latter include demantoid, opal (particuarly varieties from Mexico) and coral. Byzantine designs were used in some pieces.

In 1907 Tiffany & Co. began to manufacture his designs which became more stylized with, for example, platinum fashioned to resemble antique work. Early in this period the first source book was produced, the 1909 Tiffany blue book. This is an alphabetical catalogue in which the jewellery is listed under the heading Tiffany art jewelry and held separate from the Tiffany & Co. stock. In this jewellery we can note the rare use of white diamonds and the growing use of motifs taken from the impressionist-style paintings he made during his earlier life. Zircon, peridot, amethyst and tourmaline are frequently used; one early example of the period is a pink pearl brooch. Many pieces use Egyptian designs: scarab motifs were particular favourites. In general, Tiffany preferred opaque or translucent stones to transparent ones and he also preferred deeper tones in opaque materials. Since George F. Kunz and Tiffany both sat on the Tiffany & Co. board, there were many opportunities for gemmologist and designer to collaborate and it may be from this source of new gem species and varieties that Tiffany developed some of his more unusual pieces. The association of Kunz with Tiffany & Co. lasted from 1879 to his death in 1932.

The book provides many good-quality photographs both of pieces of jewellery and of pages from workbooks. There is a useful bibliography and the price is most reasonable. M.O'D.

Een Eeuw van Schittering (A sparkling age): 17th century diamond jewellery. Diamantmuseum, Antwerp, 1993. 00 223. Illus. in black-and-white and in colour. £36.00. [Text in Flemish and English]

As part of the Antwerp '93 celebrations, the Diamantmuseum put on an exhibition of diamond jewellery of the seventeenth century, featuring pieces from museums and private collectors. Opening essays introduce tendencies in seventeenth-century jewellery; seventeenth-century diamond jewellery and the ornamental print; diamond cuts in the seventeenth century and a piece describing the miniature case of Louis XIV. The catalogue entries give a description with measurements, details of provenance and citations from the literature where appropriate. In many cases the cut is illustrated by a diagram, a very useful feature as in some of the pieces the cut is obscured by the setting. M.O'D.

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Proceedings of The Gemmological Association and Gem Testing Laboratory of Great Britain and Notices

OBITUARY

Mr Donald D. Baird, FGA (D.1976), London, died in 1994.

Mr Hector M. MacLeod, FGA (D.1957), Glasgow, died in May 1993.

Mr Peter G. Meakin, FGA (D.1948), London, died in 1993.

GIFTS TO THE GAGTL

The Association is most grateful for gifts of gems and gem materials for research and teaching purposes from the following:

Rod Beattie of Access Asia, Thailand, for a tourmaline crystal from Luc Yen, Vietnam.

Ing. Ludek Hubrt, M.Sc., of Gem Servis, Prague, Czech Republic, for fine moldavite pieces in six different shapes and a collection of cut pyrope garnets, all from the Czech Republic.

Mark Jobin, London, for new gem materials for research.

John Kessler, London, for a fracture filled Brazilian emerald.

Paragon Jewellery Design, for 150 rough blue sapphire crystals.

Sarah Petre, London, for sapphire rough.

Ted Themelis of Gemlab Inc., Florida, for a sapphire crystal, one half of which had been heat treated.

Professor Chen Zonghui and the staff of the Gemmological Institute, China University of Geosciences, Wuhan, for the following samples from China: pyrope garnets from Heilongjian Province, sapphire from Shandong Province, peridot from Hebei Province, zircon from Fujian Province and amethyst from Jiangxi Province.

NEWS OF FELLOWS

Norman Harding was awarded an OBE in the New Year's Honours for service to the City of London Corporation, in particular for work on the restoration of the interior of the Mansion House over the past twelve years.

Alan Hodgkinson has just returned from an extensive lecture tour. He visited Bangkok, Singapore and Tucson, giving four lectures at each location. He was also the keynote speaker at the prize giving conference weekend of the Canadian Gemmological Association, guest speaker at the Golden Jubilee of the Australian Gemmological Association and visiting speaker in all of the six Australian states.

Antonio Bonanno

A special tribute

Antonio 'Tony' Bonanno's retirement at the end of 1993 was honoured by a Gala Tribute during which he was presented with a special award from the GAGTL in recognition of his great contribution to gemmology and his long association with GAGB and GAGTL. The Award was presented by Ann Dale, GAGTL's liaison gemmologist in the United States. Ann writes:

'How do you say "Goodbye" to a master in his field, an author, admired mentor of thousands, and good friend to all? The spirit which filled Bethesda, Maryland's Positano Restaurant, seemed to answer this question, as many enthusiasts gathered to pay homage to Tony Bonanno, an outstanding leader of the nation's gemmological community, who had announced his retirement after sixty years of service. This remarkable man is credited with having personally trained over 3000 students in the field of gemmology, 1000 of whom have become professional gemmologists. His commitment to expanding knowledge and upholding the highest professional and ethical standards has been a guiding force in the industry and continues its influence through his students. I am proud to be one of these and remember fondly my student days at the National Gem Appraising Laboratory and Columbia School of Gemology, both established by Tony Bonanno as centres for specialized studies over four decades ago.

Fig. 1. Tony Bonanno listening to Ann Dale before she presented him with a Certificate of Appreciation on behalf of the GAGTL.

'It was a special pleasure for me to have been selected to represent the GAGTL as a key speaker at Tony Bonanno's retirement gala. It was an opportunity to express my appreciation for all he has done for so many for so long and proved that one needn't ever say "goodbye" to Tony, who has so generously shared time, talent and wisdom with others, because he will always be a part of them.'

DIAMOND COURSE LAUNCHED IN CHINA

In November 1993 the GAGTL launched its Gem Diamond Diploma Course in China. The course, leading to the DGA qualification, is a comprehensive study of the formation, mining, sorting, cutting, grading and trading of diamonds and was held at the GAGTL's Allied Teaching Centre at the Gemmological Institute, China University of Geosciences in Wuhan, Hubei Province.

Students, mostly managers drawn from the diamond and jewellery trade, from Beijing, Shanghai, Shenzhen and Guangzhou, Changsha in Hunan Province, Harbin in Helongjian Province, Dalian in Liaoning Province and Guangxi Province, attended the intensive two-week practical part of the course and sat the examination in Wuhan.

Eric Emms travelled to Wuhan to teach the practical course which covered elementary sorting of rough; detailed grading of loose and mounted polished diamonds using the 10x loupe, microscope and colour comparison stones; detection and description of lasered and fracture-filled diamonds and identification of diamond simulants.

Mr Emms commented that the students displayed a quick grasp of grading principles and an intense desire to learn as much as possible about diamond quality.

Through its Allied Teaching Centres, the GAGTL will be offering more FGA and DGA courses throughout Asia in 1994.

Fig. 2. Professor Chen Zhonghui, Vice-President of the China University of Geosciences, receiving a gift presented by Eric Emms on behalf of the GAGTL.

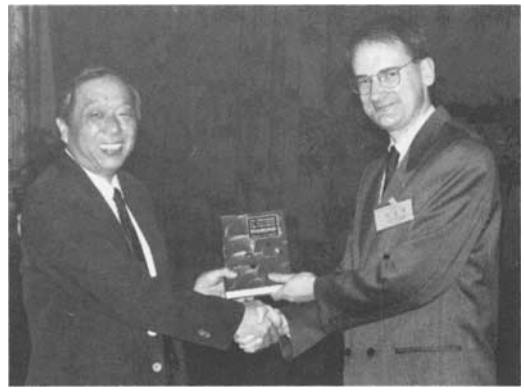

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MEMBERS' MEETINGS

London

The following meetings were held at the GAGTL's Gem Tutorial Centre at 27 Greville Street, London EC1N 8SU.

On 24 January 1994 Robin Walker of De Beers' Central Selling Organisation gave an illustrated lecture entitled 'Overview of world diamond producer sources'. (A full report of the lecture was published in *Gem & Jewellery News* **3**, 2, 17.)

On 7 February Patrick Daly gave a lecture entitled 'The independent gemmologist's workshop'.

On 23 February Dr Robert Symes spoke on 'Decorative and collectors' minerals from south-west England'.

On 7 March William Summers gave a lecture on 'The history of Garrards, the Crown jewellers'.

On 30 March David Lancaster spoke on 'Jewellery at auction'.

Midlands Branch

On 28 January 1994 at Dr Johnson House, Bull Street, Birmingham, James Gosling gave a lecture entitled 'The Cheapside Hoard'. The Hoard was treasure dated between 1580 and 1620, part of a Jacobean goldsmith's stock-in-trade, that was found under a cellar floor in Cheapside, London, in 1912.

On 25 February at Dr Johnson House Nigel Dunn gave a lecture entitled 'Jewellery through the ages'.

On 25 March at Dr Johnson House Dr John Wright gave a talk on 'Platinum - design and technology in the workshop'.

North West Branch

On 16 February 1994 at Church House, Hanover Street, Liverpool 1, Mr D.H. Ariyaratna gave a talk on 'Gems and gem industry of Sri Lanka'.

On 16 March at Church House Dr Roger Harding gave a talk on 'Current trends in gem testing'.

The talk on 15 September 1993 was given by Mr M. Downer of Sotheby's, London, and not Jonathan Condrup as stated previously (*Journal of Gemmology*, 1994, **24**, 1, 56).

MEETINGS OF THE COUNCIL OF MANAGEMENT

At a meeting of the Council of Management held on 15 December 1993 at 27 Greville Street, London EC1N 8SU, the business transacted included the election of the following:

Fellowship

Gao, Yan, Beijing, China. 1993
Gutierrez Martinez, Jose A., Madrid, Spain. 1993
Guo, Shouguo, Wuhan, China. 1993
Ibanez de Aldecoa, M. Angeles, Madrid, Spain. 1993
James, Cary S., Woodstock, Ont., Canada. 1993
Jun, Huang, Wuhan, China. 1993
Lanko, Jantine, Amsterdam, The Netherlands. 1993
Li, Jingzhi, Beijing, China. 1993
Molloy, Theresa A., Burnaby, BC, Canada. 1993
Sarma, Sunil, Rajasthan, India. 1993
Summanen, Sari I., Helsinki, Finland. 1993
Zhang, Xianfeng, Wuhan, China. 1993

Ordinary Membership

Blackman, Barry N., Whetston, London.
Bordat, Mark, New Southgate, London.
Briginshaw, Richard C., Hampstead, London.
Desprat, Anne-Sophie, London.
Franks, Nicola, London.
Goss, Sanya L., Aldershot.
Hardman, Joce, Preston.
Michaelides, Artemios, Athens, Greece.
Su, Bin, Wuhan, China.
Walker, Albert, New York, NY, USA.
Wang, Zhong Hui, Beijing, China.
Yu, Guimei, Wuhan, China.

Ordinary Laboratory Membership

Tim Watkins Ltd, 19 Burlington Arcade, London W1.

At a meeting of the Council of Management held on 26 January 1994 at 27 Greville Street, London EC1N 8SU, the business transacted included the election of the following:

Diamond Membership

Kassam, Salim Sultanali, Kensington, London. 1993

Fellowship

Chen, Meihua, Wuhan, China. 1993
Choi, Eddie Pui Ho, Hong Kong. 1993
Guo, Tao, Wuhan, China. 1993
Hui, Wing Chiu Ernest, Hong Kong. 1993
Krommenhoek, Celine, Amsterdam, The Netherlands. 1993
Sapalski Rosello, Cristina, Madrid, Spain. 1993
Stamatiadis, Nick, Athens, Greece. 1993
Tang, Yuanjun, Wuhan, China. 1993
Zhang, Xiang Dong, Hong Kong. 1993

Ordinary Membership

Agnew, Michael A., Cambridge.
Arai, Naoko, Japan.
Bennett, Shawn, Bexleyheath.
De Carvalho, Roberta, London.
Delaney, Patrick, Teresopolis, RJ, Brazil.
Ferrell, Ronald L., Deland, Fla., USA.
Fukuda, Kenji, Japan.
Fukushima, Yuko, Japan.
Ichimura, Kozue, Japan.
Imamura, Naoki, Japan.
Isaka, Masahiro, Japan.
Ives, Juleen, Shoeburyness.
Kamata, Mariko, Japan.
Karino, Masae, Japan.
Kataoka, Noriko, Japan.
Kato, Ayako, Japan.
Kawabe, Tadayuki, Japan.
Kelly, Christel E., London.
Kobayashi, Akihito, Japan.
Kukagawa, Hiroko, Japan.
Matsuoka, Satoru, Japan.
Mine, Mayumi, Japan.
Morioka, Akiko, Japan.
Nakano, Yasuyoshi, Japan.
Nii, Miwa, Japan.
Nishiyama, Fumie, Japan.
Ogino, Takashi, Japan.
Ohhara, Reiko, Japan.
Ohki, Toshie, Japan.
Ramos-Gonzalez, Stephen, Dalston, London.
Sada, Shinsaku, Japan.
Sakai, Takeo, Japan.
Sapkas, Panayatis, Larissa, Greece.
Shimakura, Toshiyuki, Japan.
Shimizu, Takayuki, Japan.
Shorter, David J., Diss.
Smith, Andrew, West Malling.
Tada, Michiko, Japan.
Toyoda, K.B.S., Weybridge.
Wakatsuki, Reiko, Japan.
Yamanaka, Kazue, Japan.
Yoshimura, Shinya, Japan.
Zhao, Rugong, Wuhan, China.

FORTHCOMING MEETINGS

London

Meetings will be held on the second floor at 27 Greville Street. Refreshments will be available from 6.00 p.m. and lectures will start at 6.30 p.m.; these will be followed by discussion and closing about 7.45 p.m. The charge for a member is £3.50 and, as places are limited to 55, entry will be by ticket only, obtainable from GAGTL.

11 May	'Spreading gem knowledge'	Ian Mercer
13 June	Annual General Meeting and Reunion of members; Bring and Buy	
19 September	'The gem materials of Zimbabwe'	Susan Anderson
28 September	'Diamonds and the retail trade'	Alan Clark
22 November	'Gem collections in the United Kingdom'	Christine Woodward
5 December	'Sapphires in the Laboratory'	Stephen Kennedy

Annual Conference and Presentation of Awards

The 1994 GAGTL Annual Conference is to be held on 23 October 1994 at the Great Western Royal Hotel, Paddington. The theme of the Conference will be 'Diamonds and modern gem developments'. A full programme of lectures and demonstrations is planned and details will be published in the July issue of the *Journal*.

The Presentation of Awards will be held on 24 October at Goldsmiths' Hall, Foster Lane, London EC2.

Midlands Branch

29 April	Annual General Meeting followed by 'The gems of Sri Lanka'	C. & N. Gems

The meeting will be held at Dr Johnson House, Bull Street, Birmingham.

A gemmological training day is to be held on 8 May, full details of which are available from Gwyn Green on 021-445 5359.

North West Branch

18 May	'Touching gold and silver'	David Callaghan
15 June	Exchange and Mart - a members and friends get together. Bring and buy, and business buzz.	
21 September	'Pearls in the Arabian Gulf'	Stephen Kennedy
19 October	A visit to the Liverpool Museum of Geology, specimen minerals and instruments.	
16 November	Annual General Meeting.	

Meetings will be held at Church House, Hanover Street, Liverpool 1. Further details from Joe Azzopardi on 0270 628251.

Ordinary Laboratory Membership
Elizabeth Gage Ltd, 20 Albemarle Street, London W1X 3HA.
Pucci of 205 King's Road, London SW3.

At a meeting of the Council of Management held on 23 February 1994 at 27 Greville Street, London EC1N 8SU, the business transacted included the election of the following:

Ordinary Membership
Adler, Allen, Geneva, Switzerland.
Austin-Kaye, Anthony M., Chester.
Barrett, Robin N., Gwynedd.
El Manawi, Abdel Hamid Wagdi Abdel Aziz, Abu Dhabi, UAE.
Farion, Jean-Christophe, London.
Fisher, Dorothy A., Tolworth, Surbiton.
Gurney, Charles R., London.
Haske, Martin D., Woburn, Mass, USA.
Johnson, Michael C., Eastbourne.
Van Goethem-Tytgadt, Anne, Johannesburg, S. Africa.
Vanson, Robert F., Bromley.
Walker, Peter L., Christchurch, New Zealand.

Gold Laboratory Membership
V. Barsamian Diamants sa, Pelikaanstraat 62, 2018 Antwerp, Belgium.
Cartier Joaillerie Internationale, 13 Rue de la Paix, 75002 Paris, France.

Ordinary Laboratory Membership
House of Antiques, 17 Prince Albert Street, Brighton.
M. Kaye Ltd, 9 St Michaels Row, Chester.
The Burlingon Jewellers Ltd, 56-57 Burlington Arcade, Piccadilly, London W1V 9AF.

Corrigenda
On p. 25 above, columns 1 and 2, and p.28 above, column 1, several of the Figure numbers given in the text are incorrect. Details are as follows:
Figure 21 should read 26
Figure 22 should read 23
Figure 23 should read 25
Figure 25 should read 32
Figure 26 should read 22
Figure 27 should read 28
Figure 28 should read 27

Letter to the Editor

From D.H. Ariyaratna, FGA, DGA, FGS

Dear Sir,
I refer to the review by Mr M.J. O'Donoghue in the October issue of the *Journal of Gemmology* (1993, **23**, 8, 494) about *Gems of Sri Lanka* (5th revised and enlarged edition). It was a surprise to read such an unfavourable review as I believe the book is well presented.

In view of the remark that 'the whole book is disordered', I would remind the reviewer that he stated that the 3rd edition is 'a pleasantly-written book whose main value is in the account of gem working in Sri Lanka' (*J. Gemm.*, 1980, **XVII**, 47).

Basically, the chapter names, line drawings, some black and white photographs and the order of the contents have remained the same from the first to the latest editions of the book.

Even though no book on gemmology can be expected to be perfect, my efforts concerning Sri Lanka's gems have been accepted by the Government of Sri Lanka (Ministry of Education) as a school library book.

Yours etc.,
D.H. Ariyaratna
London
7 February 1994

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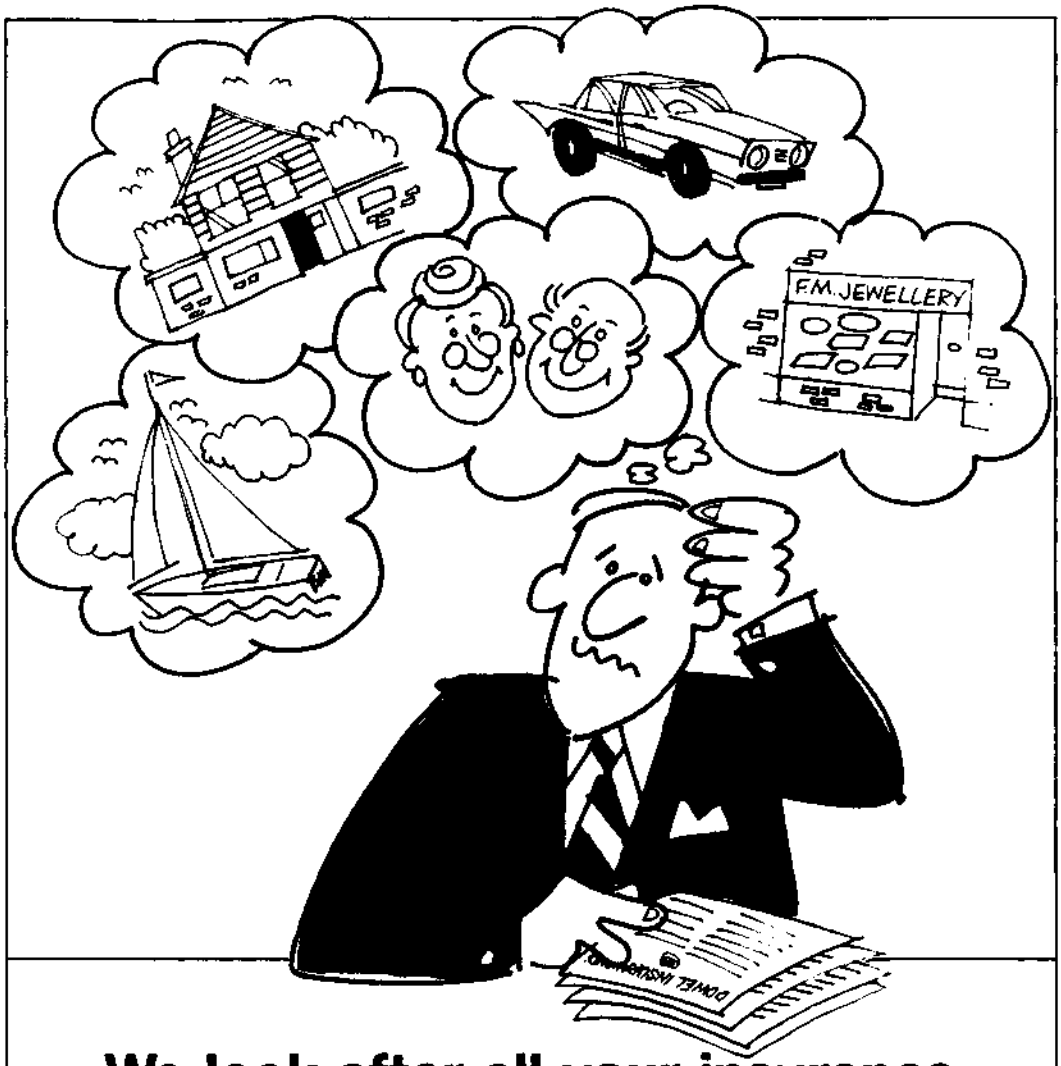

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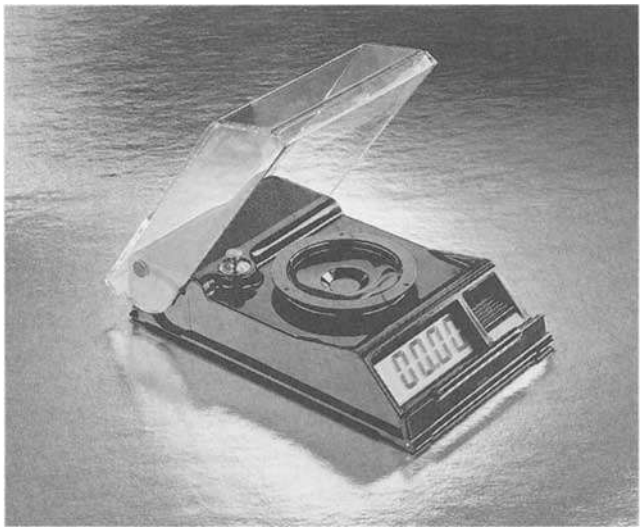

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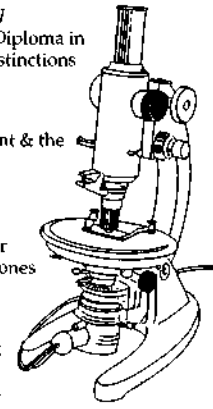

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Guide to the preparation of typescripts for publication in *The Journal of Gemmology*

The Editor is glad to consider original articles shedding new light on subjects of gemmological interest for publication in *The Journal*. Articles are not normally accepted which have already been published elsewhere in English, and an article is accepted only on the understanding that (1) full information as to any previous publication (whether in English or another language) has been given, (2) it is not under consideration for publication elsewhere and (3) it will not be published elsewhere without the consent of the Editor.

Typescripts Two copies of all papers should be submitted on A4 paper (or USA equivalent) to the Editor. Typescripts should be double spaced with margins of at least 25mm. They should be set out in the manner of recent issues of *The Journal* and in conformity with the information set out below. Papers may be of any length, but long papers of more than 10 000 words (unless capable of division into parts or of exceptional importance) are unlikely to be acceptable, whereas a short paper of 400-500 words may achieve early publication.

The abstract, references, notes, captions and tables should be typed double spaced on separate sheets.

On matters of style and rendering, please consult *The Oxford dictionary for writers and editors* (Oxford University Press, 1981).

Title page The title should be as brief as is consistent with clear indication of the content of the paper. It should be followed by the names (with initials) of the authors and by their addresses.

Abstract A short abstract of 50-100 words is required.

Key Words Up to six key words indicating the subject matter of the article should be supplied.

Headings In all headings only the first letter and proper names are capitalized.

A **This is a first level heading**

First level headings are in bold and are flush left on a separate line. The first text line following is flush left.

B *This is a second level heading*

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Illustrations Either transparencies or photographs of good quality can be submitted for both coloured and black-and-white illustrations. It is recommended that authors retain copies of all illustrations because of the risk of loss or damage either during the printing process or in transit.

Diagrams must be of a professional quality and prepared in *dense* black ink on a good quality surface. Original illustrations will not be returned unless specifically requested.

All illustrations (maps, diagrams and pictures) are numbered consecutively with Arabic numerals and labelled Figure 1, Figure 2, etc. All illustrations are referred to as 'Figures'.

Tables Must be typed double spaced, using few horizontal rules and no vertical rules. They are numbered consecutively with Roman numerals (Table IV, etc.). Titles should be concise, but as independently informative as possible. The approximate position of the Table in the text should be marked in the margin of the typescript.

Notes and References Authors may choose one of two systems:

(1) The Harvard system in which authors' names (no initials) and dates (and specific pages, only in the case of quotations) are given in the main body of the text, e.g. (Gübelin and Koivula, 1986, 29). References are listed alphabetically at the end of the paper under the heading References.

(2) The system in which superscript numbers are inserted in the text (e.g. ... to which Gübelin refers.[1]) and referred to in numerical order at the end of the paper under the heading Notes. Informational notes must be restricted to the minimum; usually the material can be incorporated in the text. If absolutely necessary both systems may be used.

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Papers Hurwit, K., 1991. Gem Trade Lab notes. *Gems & Gemology*, **27**, 2, 110-11

Books Hughes, R.W., 1990. *Corundum*. Butterworth-Heinemann, London. p. 162

Abbreviations for titles of periodicals are those sanctioned by the *World List of scientific periodicals* 4th edn. The place of publication should always be given when books are referred to.

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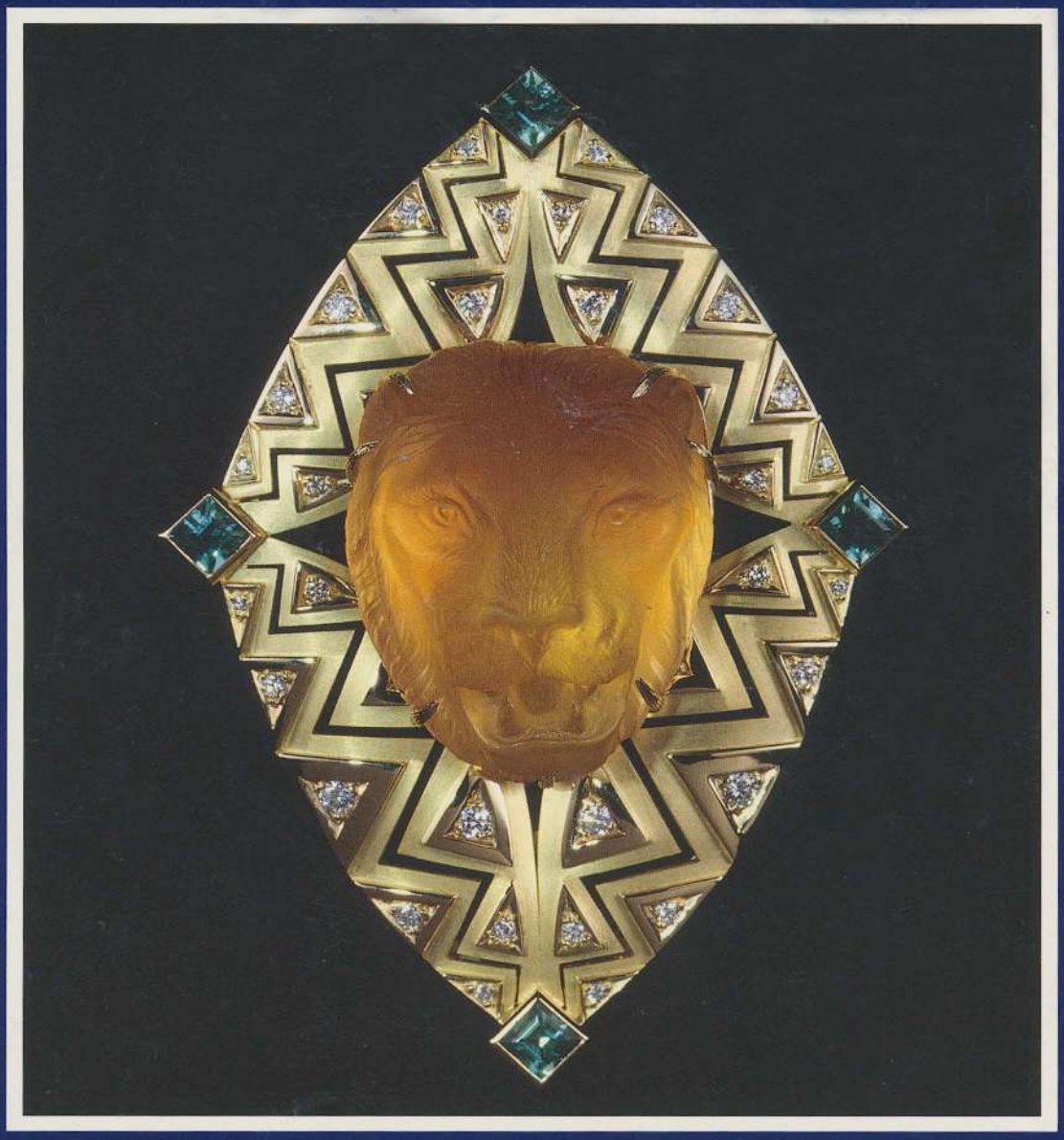

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Carved citrine lion face set in an 18ct gold and diamond brooch by Stephen Webster.
Photograph by Bob J. Maurer, FGA, DGA (See 'Photographic Competition' p.216)

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Editorial

Following the announcements in the April issue of the Journal the new editorial structure is now in place and I am very pleased to have the support of Michael O'Donoghue and Peter Read as Assistant Editors. They will oversee book reviews and abstracts respectively. For assessing new manuscripts submitted for publication we are at once honoured and pleased to welcome a distinguished group of Associate Editors. They hail from many parts of the world and cover a wide range of gem, diamond, pearl and trade expertise, some of which has already been put to good use in appraising the contributions in this issue.

The opening paper deals with the question of origins of gems and with the factors important in assessing how reliable origin information might be. The precise description of features in gems is paramount if there is to be clear communication, and this applies as much to origins as to the descriptions of new synthetic sapphires, moonstones, vesuvianite and the pink sapphires covered in the other contributions. A prospect of life in the wild is provided by a paper on how to pan for gem minerals and, when you bring your concentrates back to base, just apply specific gravity techniques explained by Dr Farrimond to help distinguish the gems.

It is a long-recognized fact that in order to identify gems you should have access to the most up-to-date comparative information. But there is so much information available that it can be difficult to find what is relevant to a particular problem in a reasonable length of time. Nevertheless, we hope to assist readers in this process with an increased coverage of abstracts. To this end permission has been obtained from colleagues in related fields to reprint abstracts not normally seen by many of our members. Further, the abstracts will be arranged in the following categories: diamonds, gems, instruments, jewellery and synthetics.

The most noteworthy change of all in this issue, however, is the appearance on the inside front cover of Eric Bruton's name as President. For over three years since the death of Sir Frank Claringbull the GAGTL has been without a President and we are delighted that, on the invitation of the Council of Management, Eric Bruton agreed to become our next President and was elected at the Annual General Meeting on 13 June. A man of many talents, his gemmological contributions include the standard textbook on diamonds and it is partly in recognition of this that the GAGTL Conference in October incorporates a major diamond theme under the title 'Diamonds and modern gem developments'.

R.R.H.

Origin determination for gemstones: possibilities, restrictions and reliability

Dr H. A. Hänni, FGA

SSEF Swiss Gemmological Institute, Zurich, Switzerland

Abstract

The gemmological 'origin' means the geographical locality of a gemstone deposit. Origin names should neither be used as a description of a colour type nor to express a certain quality. For the determination of origin in a gemmological laboratory different chemical and physical properties are considered, e.g. inclusions, colour zoning, chemical composition and spectral characteristics. Therefore, sophisticated equipment is essential and instrumentation such as spectrophotometers (UV-VIS-IR), EDXRF, SEM and optical microscopy should be applied. Some of the determined properties may be diagnostic for a definite source of gemstones. For a reliable interpretation a large collection of comparison samples of known origin and reference data are necessary. Furthermore, the knowledge has to be updated repeatedly by adding new information through research, the latest literature and by exchange of experience. Where data released from a stone are insufficient or ambiguous an opinion of origin should not be given.

Introduction

A definition of the term 'origin' as used in gemmology should logically be the starting point of this paper. 'Origin' should indicate the geographical origin of a gemstone. This is either in the primary deposit in the parent rock or in a secondary deposit resulting from transport and accumulation of gemstones after decomposition of the parent rock.

In the trade the terms Burma, Pailin and Kashmir have been applied to what are perceived as the most desirable gems to own but since they have a geographical meaning, they should *not* be used to express a particular colour of gemstone. It is common knowledge that one deposit produces a range of colours, some of which may be found in other deposits, too.

The need in the gem trade for certification of origin seems restricted to a few varieties of gemstones only and to a small number of deposits with a high reputation. For many people the origin 'Burma' may be commercially meaningful, whereas 'Malawi' as an origin for a ruby does not create an increased interest. It should again be stressed that a certain origin does not necessarily mean that all crystals from that source are of high quality.

Some gemstones can indicate their place of origin through their physical and chemical properties, and by their inclusions and growth structures if these are clearly distinguishable from all other types. Thus, these properties must be unique by themselves or in combination. The greater the number of individual and characteristic properties found in a certain stone, the more reliable is a determination of origin. Valuable characteristics should not only positively testify a certain origin but at the same time exclude other possibilities.

Consequently in determining the origin of a gemstone the expert must be aware not only of the properties of similar stones from the locality in question, but of the whole set of properties of similar stones from all other localities (Figure 1). Only the

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Fig. 1. A large collection of reference material is an important tool for recording and comparison of gemstone characteristics. It is indispensable for laboratories doing origin determination.

exclusive features, unique for a particular deposit, are called diagnostic properties! Depending on the complexity of the formation of the gemstone crystals, the geological environment, the type and number of characteristics can be quite varied.

Gemstone formation

The formation of a gemstone crystal requires a number of more or less important conditions. Some of the main conditions, causing general or individual properties of gemstones are the following:

Basic conditions pertaining to gemstone crystal formation

- availability of main constituent chemical elements, speed of growth
- type and concentration of available trace elements, variation in their concentration and relative ratio
- transport process and transport medium involved for gemstone constituents
- type of energy source for the formation (intruding pegmatite, metamorphosis)
- partial pressure of free oxygen, redox situation
- cooling rate and behaviour of pressure (static or oscillating) during or after formation
- deformation history of parent rock and crystal during its period of growth

All these factors affect the individual characteristics of a gemstone crystal, and result in differences regarding the following:

Features which may impart individual characteristics to gemstones

- size and shape of crystals, growth zoning

- twinning
- colour, colour homogeneity, colour variation
- trace element mixture (including 'invisible' trace elements)
- solid inclusions (e.g. protogenetic inclusions, reflecting parent rock)
- fluid inclusions (e.g. syngenetic inclusions, reflecting transport medium and genetics of formation)
- state of healed fissures, geometry and degree of restoring
- nature of fillings in negative crystal voids

Cut Gemstones

What sort of definitive information can we collect from a cut gemstone (in respect of a determination of origin) ? The following features could be studied:

Characteristic features in cut gemstones:

Microscopic features (Figure 2): colour- and growth-zoning relative to crystallography, colour inhomogeneity, twinning type, internal strain, observation of type and distribution of solid and fluid/gas inclusions, type of healing fissures temperature and pressure during formation of fluid inclusions by microthermometric measurements.

Physical and optical features: determinations of specific gravity, refractive indices, double refraction, fluorescence behaviour, cathodoluminescence reaction, absorption spectroscopy (UV,VIS,IR, see Figure 3), magnetic resonance spectroscopy.

Chemical features: main composition, trace element determination by EDSXFA, amount or relative ratio of trace elements present (e.g. Ti, Fe, Cr, V, compare Figure 4), chemical analysis of inclusions by an electron beam instrument (scanning electron microscope, or electron microprobe) or Raman spectroscopy.

The determination of origin of a cut gemstone is thus a matter which requires a number of (expensive) instruments, and a lot of experience in their use and interpretation of the results. A collection of comparison stones (from all deposits, showing the variability within a population) for reference, files containing the analytical results measured over the years and a library with books and periodicals for old and new information are also very important requirements (compare list of references at the end of the article).

Analytical techniques

To register all the different features listed above requires the knowledge and application of analytical steps based on a wide field of analytical techniques. I will give a brief summary of the most recent or most important publications in this respect.

Microscopic investigation is most often done in dark field lighting, and inclusions are 'identified' by morphological comparison. *The Photoatlas of inclusions in gemstones* (Gübelin and Koivula, 1986) and *Pierres précieuses dans le monde* (Schubnel, 1972) are considered as the most important general books for inclusion reference. Growth peculiarities such as colour zoning are easier to observe in immersion, and an indication of the encountered crystal faces is possible by using a special attachment

Fig. 2. Using a Leica M8 stereo microscope for identification of internal characteristics in a gemstone. A binocular microscope with different lighting possibilities, working in air and in immersion is essential for a safe gemstone identification. An adaptor enables recording of inclusion pictures by photography or video for research and education purposes .

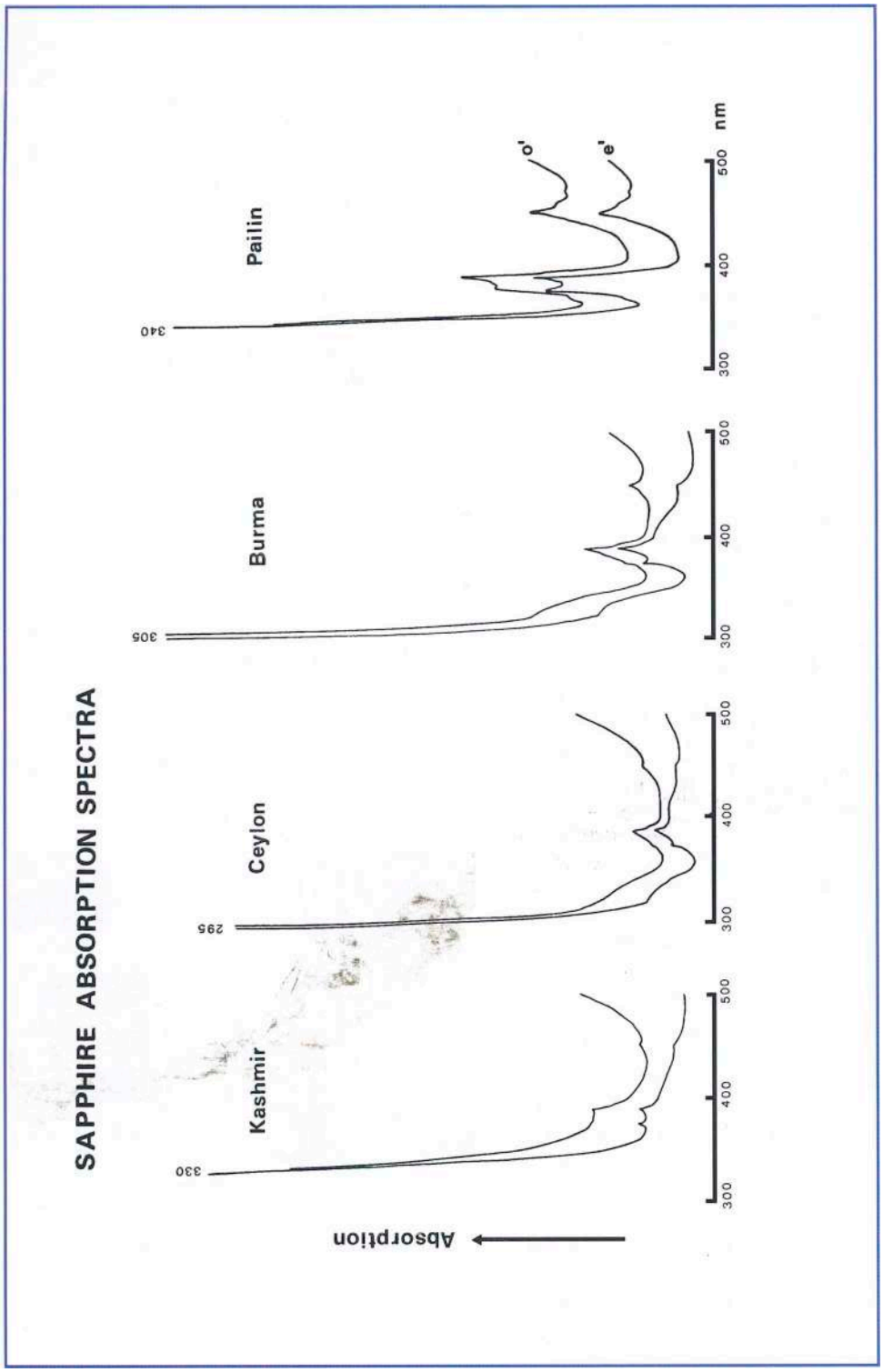

Fig. 3. Absorption spectra recording and measurement, e.g. of the Fe^{2+} features at 450 nm, furnishes important characteristics when a possible origin or heat treatment is being discussed. The above spectra may be taken as standard types for the respective origins and stones of approx. 8 mm thickness in the direction of the recorded light path.

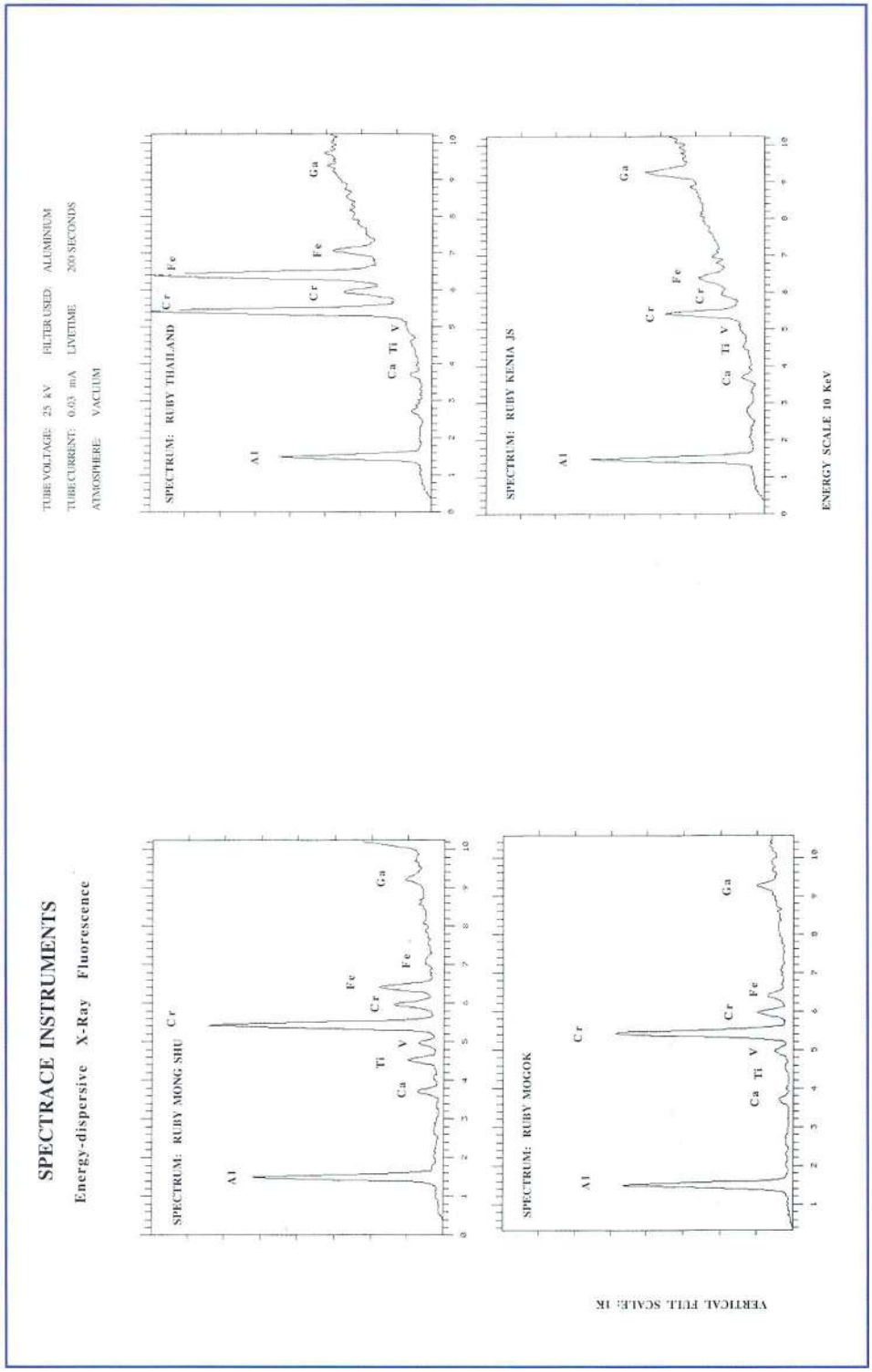

Fig. 4. EDXRF spectra reflect chemical composition for main and trace elements and allow a comparison among stones of different deposits. The above spectra **are typical for rubies from Myanmar (Burma), (Mogok and Mong Hsu)** Thailand and Kenya (John Saul Mine). A programmed calculation process may **transform the peak intensities into semiquantitative results.**

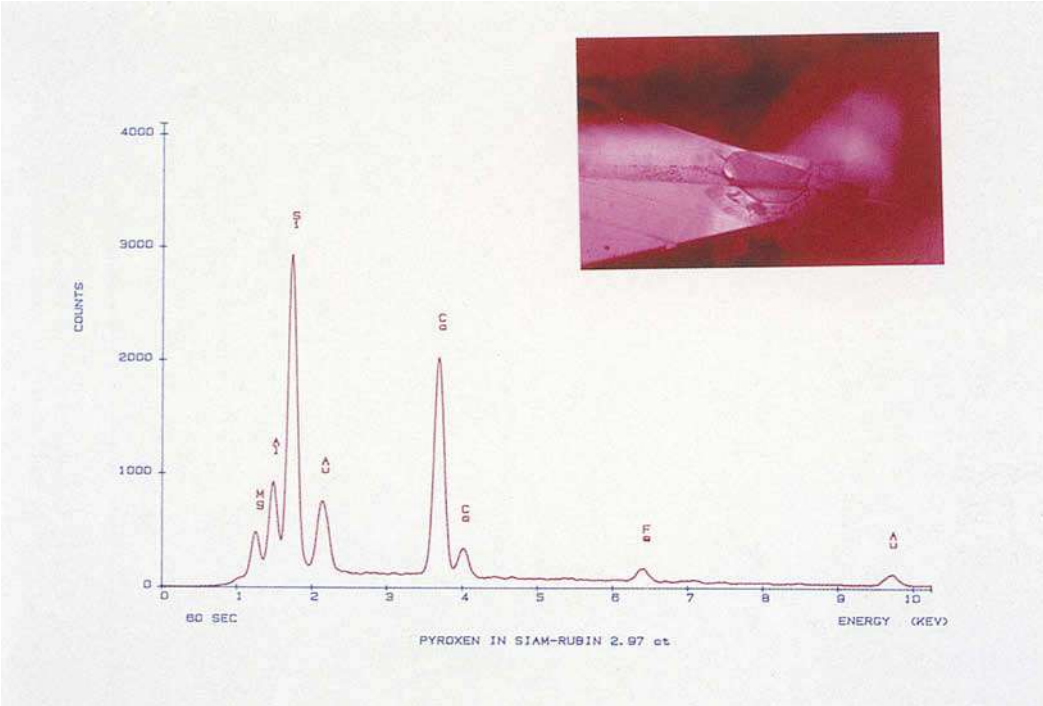

Fig. 5. The chemical composition of the inclusion in the pictured ruby has been analysed by use of the electron micro-beam of a SEM. An energy spectrum of the constituents of the inclusion has been produced and the crystal was identified as fassaite (pyroxene). This mineral is quite common as an inclusion in Thai rubies (compare Schubnel, 1972).

described by Schmetzer (1985). The application of this method is demonstrated by a characterization of sapphires from different occurrences by Kiefert (1988) and Kiefert and Schmetzer (1991). Growth characteristics may also become visible as fluorescence phenomena by cathodoluminescence as published by Lasnier *et al.* (1992) in the case of jadeite. Primary or pseudo-secondary fluid inclusions (i.e. negative crystals and fingerprints) provide important information about the conditions during the formation of a crystal. By microthermometry the fillings in these voids are analysed by their contents of gases, vapours and salts. A section by Roedder in *Photoatlas of inclusions in gemstones* (Gübelin and Koivula, 1986) is devoted to this method. For a characterization of sapphires from Kashmir, this method was used by Peretti *et al.* (1990).

Spectroscopic features are useful since they can be gathered from a very wide field of the electromagnetic wave spectrum, from the short X-rays through to the long infrared waves (Hänni, 1993). Every spectral section provides a lot of diagnostic information regarding the analyzed crystals. In their synopsis on the developments in the 1980s, Fritsch and Rossman (1990) gave a short introduction to the instrumental possibilities regarding gemstone testing.

Energy dispersive X-ray fluorescence analysis gives rapid information about surface elemental composition of a gemstone, down to trace element levels (Muhlmeister and Devouard, 1991). For a quantitative determination of major elements the electron microprobe is generally used (Dunn, 1977), a complex instrument where a fine electron beam causes an X-ray line spectrum of the excited sample ele-

ments. Microprobe analyses were used by Hänni (1982) and Stockton (1984) to differentiate chemically between the various natural and synthetic emeralds.

A related instrument is the scanning electron microscope SEM (Stockton and Manson, 1981). Although the SEM is primarily used to create highly magnified pictures of a sample surface, this instrument is also capable of producing compositional information, if it is equipped with energy dispersive system (Figure 5).

The visible and ultraviolet part of the spectrum was successfully used both for distinction of natural from synthetic rubies as well as for distinction of rubies from different localities by Bosshart (1982). Similar applications are valid for sapphire (Hänni, 1990) and emerald (Bosshart, 1991), where different types can be separated if absorption curves recorded by a spectrophotometer are investigated.

Infrared spectroscopy is a spectroscopic technique which can give information about molecules and radicals in gemstones. An introduction to the method as used in gemmology is given by Fritsch and Stockton (1987). Its applicability for emeralds is especially well demonstrated by Wood and Nassau (1968) or Goldman *et al.* (1978).

Raman spectroscopy is a very powerful and relatively new technique in its application to gemmology (Delé *et al.*, 1980). A Raman laser probe is able to identify by comparison with reference spectra not only totally included mineral guests, but also liquid and gaseous inclusions. Plinet *et al.* (1992) have recently published a brochure with the most important Raman spectra of minerals encountered as inclusions in gemstones.

Nuclear magnetic resonance (NMR) is another non-destructive testing method but it is rarely used in gemmology (Dereppe and Moreau, 1986). Electron spin resonance (ESR) spectra can provide information about the type and position within the crystal lattice of distinct ions. The method was successfully applied in the characterization of sapphires of different types (Troup and Hutton, 1983).

Some of the observed and registered characteristics in a gemstone may not be restricted to one deposit alone. As an example, three-phase inclusions in emeralds were regarded as characteristic for a Colombian origin for a long time. Today, such inclusions are also known in emeralds from Australia and Nigeria. Chemical information is also needed for a discrimination; together with this the inclusions may - in combination - be of diagnostic value. Those observations which are unique for a special deposit are the important diagnostic features in respect of an origin determination. For a successful determination the following steps must be taken:

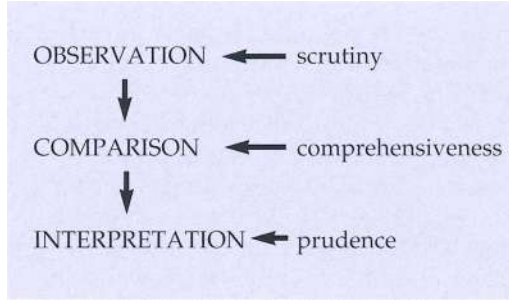

Although experience, prudence and honesty are crucial in the determination of origin for cut gemstones, the result is not absolute and still expresses the opinion of the analyst. The result should reflect the most probable conclusion based on the background of the comparison stone collection and reference data. It seems clear that the education, scientific equipment and actual knowledge of the laboratory gemmologist are major points in the reliability of the origin determination. Not many laboratories have the necessary facilities in terms of equipment and staff to

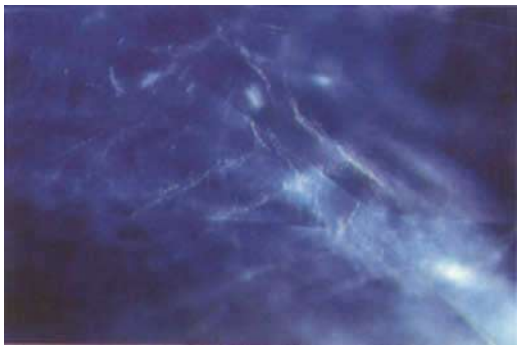

Fig. 6. Vietnamese blue sapphires from the northern deposits are still new gemstones to the market and their characteristics have been discussed by only a few gemmologists. Such sapphires may exhibit a complex colour zoning, very fine and short rutile needles and they may have almost no trivalent iron, as evidenced by the absence of the 450 nm line in the spectrum.

produce consistent results over many years in this particular field. This may be one reason why CIBJO has not approved the issue of origin certificates.

How can we get reliable basic knowledge on material from a particular origin ?

The ideal procedure is to personally collect the rough gems from their geological source. In many cases this is not possible, since the source is exhausted or not accessible. Therefore we must do the next best thing and collect our reference material from a reliable source such as a museum or a well-curated old collection. Information on gemstone sources can also be obtained from books and publications. Many historical gemstone sources are treated in reference books. Geological maps give specific information on the type of deposit, and scientific publications contain the properties (including chemical analyses and inclusions) of the relevant gemstones. To be usable, all observations should be in agreement or consistent with the different facts known, e.g. trace elements with spectroscopy, inclusions with geology. A selection of books and articles with valuable information regarding origin determination is given under 'References' at the end of this paper.

From all this information we may gain a very complex view of a gemstone deposit and its products. The more material we investigate, the denser our network becomes. New observations will always be added to the formerly restricted set of information (Figure 6). Sharing and discussing new information with colleagues in gemmology can bring a higher degree of safety into our determinations of origin. But it is fundamental to revise and recheck our primary data regularly by basic research and literature study of publications on new sources or techniques. Stagnation is dangerous.

Limitations in the determination of origin

As pointed out at the beginning, we use differences in properties as a means of discrimination. Properties which are found in stones from more than one source are not valued as diagnostic characteristics. But they can nevertheless be helpful to exclude other localities which do not produce stones with these properties. As an example, sapphires of a particular shade of blue may not prove a certain origin, nor do those with a misty turbidity. But the misty turbidity in combination with the absence

Fig. 7. The recently discovered second mining area for corundum in Myanmar (Burma) is producing rubies with a peculiar growth pattern. A primarily blue core shows colour zoning parallel to the basal face, whereas the mantle around is formed by growth layers parallel to pyramidal faces r, n and ω (Schmetzer, 1993)

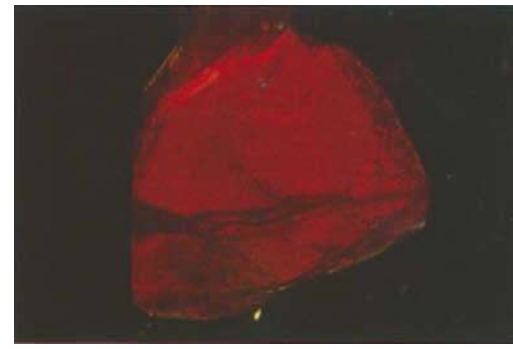

of rutile needles points towards a group of possible origins while excluding others. Within the group of possible origins we may arrive at only one, if the stone itself contains further diagnostic characteristics. It may for instance exhibit a distinct absorption curve, not seen in stones from other places. At the same time it may show included crystals (identified by an electron beam instrument) which are typical for that source only. These inclusions therefore exclude all other possibilities.

Origin determinations established do not depend on one typical characteristic only, but on at least three independent diagnostic features preferably concerning inclusions, spectroscopy and trace element contents.

The possibilities for determining an identification of origin are restricted if:

- properties observed occur in stones from several sources (they are not diagnostic)
- stones are free of diagnostic features
- the stones are set in jewellery
- not enough information about possible sources is available
- features which may be diagnostic are destroyed by heat treatment.

Sometimes gemstone deposits and therefore mining areas cross international borders, e.g. Kenya/Tanzania, Thailand/Cambodia and, conversely, large countries may contain more than one source of a particular species, e.g. Burma (Figure 7), Sri Lanka, Vietnam, Brazil. Designation of origin, therefore, must be worded appropriately.

Certain people from the gem trade seem to have rather narrow opinions on the type of material coming from one definite source. In one source the stones can vary in size, colour and transparency quite considerably, a fact that we must keep in mind when associating a certain stone with a particular group. It is certainly not the overall aspect visible to the eye or the hand lens which is critical in determining the origin of a stone. On the contrary, origin can only be assigned following the most careful investigation of all properties by an experienced gemmologist using modern scientific equipment. And if there is any doubt or ambiguity, an independent and serious scientist would not give a definite result. When the characteristics of the stone are not diagnostic for a particular locality a report of origin cannot be issued, and it would help laboratory staff considerably if this situation could be understood by many more members of the trade.

Acknowledgements

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An examination of Chatham flux-grown synthetic pink sapphires

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Abstract

This article reports on the gemmological, spectroscopic and chemical characteristics of the new flux-grown synthetic pink sapphires produced by the firm Chatham, Inc. of San Francisco, California, USA. The material is essentially a lighter-toned version of the firm's well-known synthetic ruby that has been available for many years. Gemmologically, the pink synthetic sapphires differ from the synthetic ruby in their ultraviolet fluorescence behaviour and in the presence of a grid-like flux inclusion pattern not previously documented in the synthetic rubies.

Introduction

Synthetic ruby is one of the more important of the commercially-produced man-made gem materials. It is also the one that has been produced by perhaps more methods of synthesis than any other. In terms of quantity, the vast majority of material is produced by the melt techniques of flame-fusion and Czochralski 'pulling' (Nassau, 1980). Another melt technique that has been used is floating zone. This was used briefly in the early- to mid-1980s by Suwa Seikosha (Seiko Watch) Company Ltd. of Japan (Koivula, 1984). More recently, a variation of this method, described by the producers as 'horizontal growth' has begun to be employed commercially in Russia (W. Barshai, *pers. comm.*, 1993). Russia is also the source of hydrothermal synthetic rubies that are now available in small quantities (Peretti and Smith, 1993).

Flux-growth methods have also been used by a number of manufacturers to synthesize ruby; among them (both past and present) are Chatham (Reinecke, 1959), Kashan (Huffer, 1981), Knischka (Gübelin, 1982) and Ramaura (Kane, 1983); among the more recent entries are the Douros product from Greece (Smith and Bosshart, 1993) and one from Russia (Henn and Bank, 1993).

In spite of the many manufacturers of flux-grown synthetic rubies, until recently none of these firms has marketed flux-grown synthetic pink sapphires (although some of the material marketed in the past as synthetic ruby, for example, some of the lower-quality Kashan material has lacked sufficient depth of colour to be called ruby). This has changed recently with the introduction of a synthetic pink sapphire by Chatham, Inc., of San Francisco, California, USA, a firm that produces and markets flux-grown synthetic rubies, emeralds and sapphires (both blue and orange). This report will describe the authors' recent examination of samples of this new flux-grown product.

Materials and methods

The test sample consisted of four faceted stones ranging in weight from 2.73 to 4.19 ct (Figure 1). Also examined for microscopic features was an 884 ct crystal (Figure 2).

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Fig. 1. These four faceted flux-grown synthetic pink sapphires comprised the test sample on which complete gemmological testing was performed for this study. *Photo by Maha DeMaggio © GIA*

Fig. 2. Also examined for microscopic features was this 884 ct crystal. *Photo by Maha DeMaggio © GIA*

The microscopic examination was performed using GIA GEM Instruments Mark VII binocular gemmological microscopes in conjunction with darkfield and supplemental fibre-optic illuminators. Refractive indices were determined using a Duplex II refractometer and a near sodium-equivalent light source. Ultraviolet luminescent reactions were observed under a dual, 4-watt long-wave/short-wave unit in a viewing cabinet at distances of approximately 5 to 10 cm from light source to test sample. Absorption features were observed with a Beck prism spectroscope mounted on a GIA GEM illuminator base. Pleochroism was documented using a calcite dichroscope. Specific gravity determinations were made through the hydrostatic weighing method on a Mettler AM 100 electronic balance equipped with suitable attachments. Chemical analyses were performed using a Tracor X-ray Spectrace 5000 energy-dispersive X-ray fluorescence (EDXRF) system.

Gemmological properties

Appearance:

All four faceted specimens are transparent. Their body colours range from medium light to medium purplish pink of fairly high saturation, with the colour quite evenly distributed in all samples. The crystal has comparable hue and saturation but due to its very large size is medium dark in tone. Two of the faceted pieces as well as the crystal exhibit some eye-visible inclusions.

Refractive indices:

RI values are very constant from one faceted stone to another, all exhibiting 1.768 for the ordinary ray and 1.759 for the extraordinary ray, with a birefringence of 0.009.

Pleochroism:

The dichroic colours are purplish pink for the ordinary ray and orange-pink for the extraordinary ray.

UV Luminescence:

All specimens fluoresced when exposed to both long- and short-wave ultraviolet radiation. The reaction was essentially identical under both wavelengths: a strong orange-red that was evenly distributed and possessed a weak to moderately chalky overtone. There was no phosphorescence after exposure to either wavelength.

In the crystal, large flux inclusions located near the surface fluoresced green, while those located deeper within the crystal appeared to fluoresce yellow. This

latter reaction is probably the result of the inclusion's inherent green fluorescence being observed through the red-fluorescence of the host material, as green light combined with red light results in yellow light.

Chelsea colour filter:
All test samples appeared a strong red when viewed through the colour filter.

Optical absorption spectra:
Absorption features observed with a desk-model prism spectroscope were consistent with those previously reported in the literature for rubies and pink sapphires, both natural and synthetic, with lines at 468.5, 475-476.5 (doublet), 659.2, 668, 692.8 and 694.2 nm (see, e.g., Liddicoat, 1989).

Specific gravity:
Three of the faceted stones had SG values of 3.99; a value of 4.00 was determined on the fourth.

Microscopic features:
Magnification revealed a number of internal features in the sample specimens. Most prevalent were flux inclusions, both primary and secondary. Primary flux inclusions ranged from large masses revealing their distinctly granular texture and white to light brown body colour (Figure 3) to series of many minute droplets arranged in rows along growth steps (Figure 4). In two of the faceted stones what appeared to be minute primary flux inclusions were delicately arranged in neat, intersecting rows that formed a grid-like pattern and created an unusual inclusion scene (Figure 5). This is a type of inclusion pattern that to our knowledge has not previously been observed in any synthetic gem material. It is, however, very similar to the patterns of tiny negative crystals observed in some natural spinels (Gübelin and Koivula, 1986). Secondary flux inclusions noted

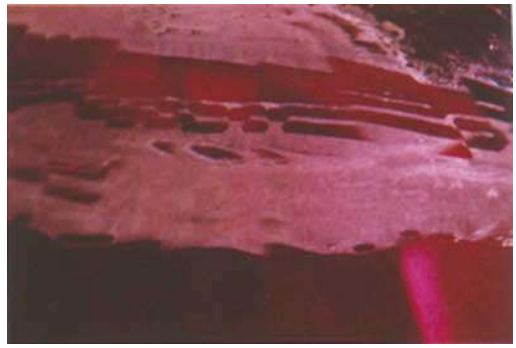

Fig. 3. These large primary flux inclusions in a Chatham flux-grown synthetic pink sapphire exhibit a distinctly granular texture. *Photomicrograph by John I. Koivula © GIA.* 10x

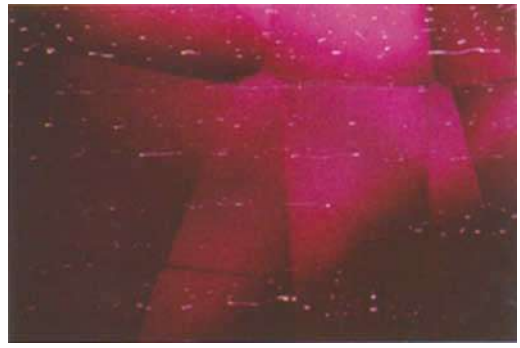

Fig. 4. Some of the primary flux trapped in the synthetic pink sapphires occurred as rows of minute particles trapped along growth steps. *Photomicrograph by John I. Koivula © GIA.* 10x

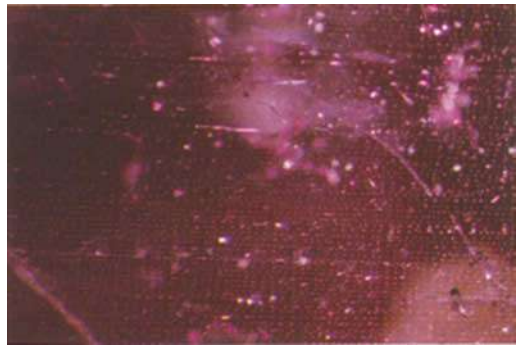

Fig. 5. Delicately arranged in neat intersecting rows producing a grid-like pattern, what appear to be minute primary flux inclusions created an unusual inclusion scene in two of the flux-grown synthetic pink sapphires. *Photomicrograph by John I. Koivula © GIA.* 10x.

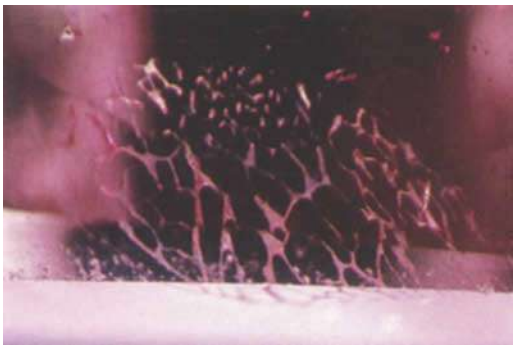

Fig. 6. **This planar flux 'fingerprint' inclusion provides evidence of partial fracture healing.** *Photomicrograph by John I. Koivula © GIA.* 30x

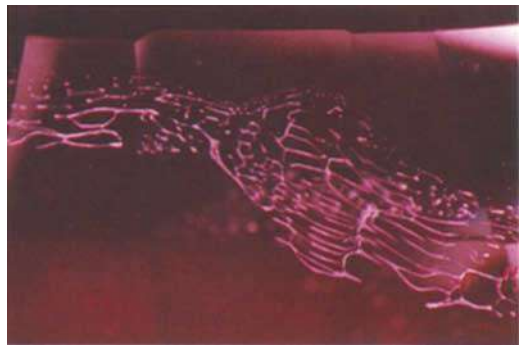

Fig. 7. Secondary flux inclusions in the specimens commonly exhibited an undulating form, as seen here. *Photomicrograph by John I. Koivula © GIA.* 25x

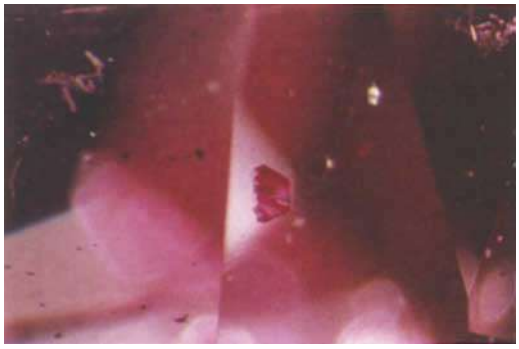

Fig. 8. A small number of relatively large, individual platelets of platinum like those seen here were observed in the test samples. *Photomicrograph by John I. Koivula © GIA.* 20x

Fig. 9. Dense clusters of small rods and platelets were typical of the platinum inclusions noted. *Photomicrograph by John I Koivula © GIA.* 35x

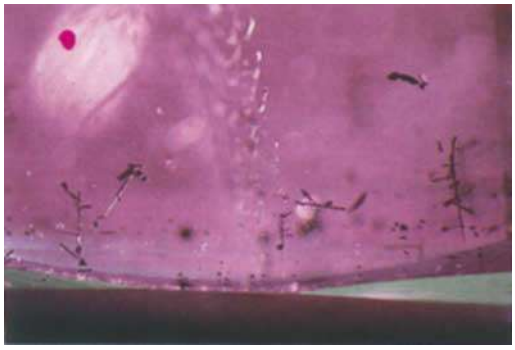

Fig. 10. Dendritic formations were another typical pattern noted for the platinum inclusions. *Photomicrograph by John I. Koivula © GIA.* 25x

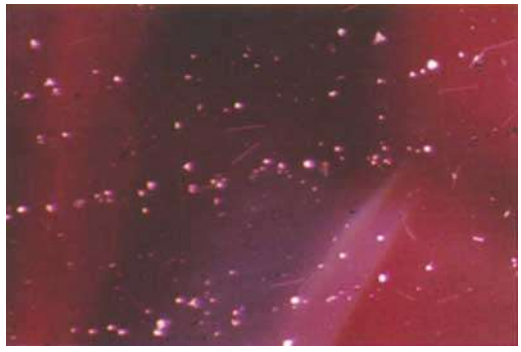

Fig.11. One of the test samples contained this phantom layer of tiny triangular and hexagonal platelets just under the table facet. *Photomicrograph by John I. Koivula © GIA.* 30x

Table I: Summary of gemmological properties

Diaphaneity	Transparent
Colour	Medium light to medium purplish pink of fairly high saturation (faceted stones); medium dark purplish pink (large crystal)
RI	1.768 (ω), 1.759 (ε); 0.009 birefringence
Pleochroism	Purplish pink (ε) and orangey-pink (ω)
UV luminescence	Weakly to moderately chalky, strong orangey-red (LW and SW); no phosphorescence
Chelsea filter	Strong red
Absorption spectrum	Lines at 468.5, 475, 476.5, 659.2, 668, 692.8 and 694.2 nm
SG	3.99-4.00
Inclusions	Primary flux as large, granular masses and lines of small droplets; secondary flux in 'fingerprint' patterns, both planar and undulating; platinum as large, individual platelets, clusters of small rods and platelets and complex dendritic formations

were in the form of partially healed 'fingerprints'. While some of these were quite planar in attitude (Figure 6), the majority showed an undulating form (Figure 7).

Angular metallic inclusions tentatively identified as platinum on the basis of their morphology were also noted in a number of forms. Least common were large, single platelets (Figure 8). Relatively common, however, were both dense clusters of small rods and platelets (Figure 9) and complex dendritic formations (Figure 10). In addition, one of the four faceted specimens contained a phantom layer of minute, triangular to hexagonal platelets under its table facet (Figure 11).

The gemmological properties noted are summarised in Table I.

Chemistry

As with Chatham flux-grown synthetic rubies, the synthetic pink sapphires contain very little in addition to the corundum's aluminium and the chromium colouring agent. The only other elements detected were a trace of iron and a weak to moderate amount of platinum. This latter element can most likely be attributed to the crucible in which the material was grown and confirms the identification of the metallic-appearing inclusions (see '*Microscopic features*,' above).

The chromium concentration varies widely from one test specimen to another, ranging from 0.027 to 0.200 % wt. Cr_2O_3. There did not appear to be any obvious correlation between the colour of the samples and their chromium content, even when variations in size are taken into account. Examination of additional specimens in the future may shed additional light on this issue.

Discussion and conclusion

The refractive indices, birefringence, specific gravity and inclusions of the four faceted specimens of Chatham flux-grown synthetic pink sapphires were generally consistent with those of other flux-grown synthetic corundums produced by this firm, including their synthetic blue sapphires and synthetic orange sapphires as reported by Kane (1982). These properties were also generally consistent with those

noted by the authors in Chatham flux-grown synthetic rubies. Additionally, the optical absorption features noted in the test sample were consistent with those previously observed in both Chatham flux-grown synthetic orange sapphires and synthetic rubies.

One interesting property noted in the pink material was its reactions to long- and short-wave ultraviolet radiation which were of essentially equal intensity. This is unlike the reactions of Chatham flux-grown synthetic rubies which typically luminesce more strongly to the long-wave than to the short-wave lamp. We have noted a similar luminescence behaviour in Czochralski 'pulled' synthetic pink sapphires coloured by chromium, reactions we therefore surmise are due to the presence of a moderate amount of chromium in an otherwise pure corundum. Also of note in the synthetic pink sapphires were the grid-like patterns of flux inclusions which the authors have not previously documented in any of the other Chatham flux-grown products or those of other flux-grown synthetics.

As is the case with other flux-grown synthetics–both those of the Chatham and of other firms–inclusions prove diagnostic in separating them from their natural counterparts.

Acknowledgements

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Exploration gemmology

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Fig. 1 Prospectors recovering pan concentrates from small stream in the Bell Hill Exploration Licence Area, Westland, New Zealand.

Abstract

Microscopic examination of heavy mineral samples from stream sediments is a quick method for initially assessing the mineral potential of selected watersheds. Application of gemmological techniques provides a check on conventional geochemical prospecting and gives information not otherwise obtainable. The collection and study of pan concentrates is a novel occupation for the gemmologist.

Introduction

The gold pan used with a couple of screens (6 and 3 mm) is the gear of the prospector. It is effective for mineral prospecting in areas where there is running water.

In geologically youthful terrains, e.g New Zealand and Southern Chile, mining companies sometimes use a 'pan concentrate' method to explore a large area, often several 100 sq km, that may include many watersheds (Bates, 1987; Taylor and Utting, 1984, 1988). Samples of the screenings and/or heavy residue are systematically recovered from the stream

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bed at regular intervals of a kilometre or less, and all tributaries are sampled.

The samples may be analysed for a few or for a dozen or more metals and elements by an appropriate chemical or physical method, e.g. XRF (X-ray fluorescence), AA (atomic absorption), NAA (neutron activation analysis).

The analytical results are plotted on a map of the area to give an overall picture of the survey and show up any anomalies from background levels.

The role of the microscope

Most rock-types have distinctive accessory minerals, or heavy minerals, of a few per cent or less down to mere traces. Often they are characteristic of the particular rock. Sandstones and arkoses may have magnetite with garnet, zircon and xenotime. The weathering of granite will produce its suite of heavy minerals and so too will gneiss, schist and volcanics.

When streams join up to form rivers you get a blend of heavy minerals from all the rock-types occurring in the watershed that have been subject to erosion. By using a binocular microscope to examine the pan concentrates, you can test what rocks might lie ahead. Hopefully, with luck and skill, you may detect traces of an orebody undiscovered in your licence area.

When prospecting, black sand is a welcome sight as it shows there is heavy residue in the sample of gravel; if not present, you may have to dig deeper.

Black sand is usually composed of tiny grains of the opaque iron minerals, magnetite and ilmenite, either one or the other or both; sometimes chromite is encountered. It is useful to know the ratio of magnetite to ilmenite since they tend to originate from different rock-types. When the black sand is dry, run a magnet through it (covered with tissue paper). If the black grains all leap to the magnet then it is composed of magnetite (Fe_3O_4); if only a few are strongly attracted, the bulk of it could possibly be ilmenite ($FeTiO_3$), the titanite of iron, which is almost nonmagnetic. Chromite ($FeCr_2O_4$) is feebly magnetic. Next examine the black sand with a binocular microscope and see for yourself what it is.

Magnetite belongs to the cubic system and commonly occurs as tiny octahedra, either alone or as crystal intergrowths. On the other hand, ilmenite is trigonal and like sapphire may occur as shiny, hexagonal platelets or thicker, rounded tablets.

Examination under the microscope (up to x40) confirms which mineral is which and use of the magnet is a quick way to test roughly the ratio of these two iron minerals.

The black sand can be the result of erosion of the rocks contained in the watershed being prospected, but not always! In recent volcanic terrains there is the possible source from weathering of soils, having wind-blown volcanic ash, which invisibly coats the landscape.

When prospecting, it is advantageous to get quick results and so direct the field activity to concentrate on regions of greatest promise. This is where the binocular microscope comes into its own for producing important initial information with later assay results being used as valuable supplementary information.

The detection and estimation of gold, tin (cassiterite) and tungsten (scheelite) in a pan concentrate is quickly and reliably done using a binocular microscope (Taylor and Utting, 1988).

The tail sands of a pan concentrate usually range in grain size from 0.1 to 1 or 2mm. Optically, there are two extremes in mineral grains - the transparent and the opaque when viewed with oblique lighting. The grains may be single or multi-mineralic (rock fragments), single crystals, or poly-, micro- or cryptocrystalline as with conventional gem material. All the physical properties of minerals (e.g habit, cleavage, refractive index, colour, dichroism, etc) are important in order to identify what is present. This is

where a knowledge of gemmology is an advantage. But with the ore minerals, such as cassiterite and scheelite, you have to be certain of a correct identification and with these minerals it is necessary to do simple microchemical tests to prove their presence (Hutton, 1950).

The sparkly white crystals often encountered in the tail sands are usually tiny (0.2mm) prisms of zircon, which occur as tetragonal prisms capped with pyramid faces; they have a high RI and sparkle well if the faces are not water-worn. The purple/pink variety of zircon is often found. The prismatic habit of zircon distinguishes it from the pink/red/orange garnets, which are isometric (isotropic) and may occur as very angular fragments or broken parts of a dodecahedron. The deep red pyrope garnet is an important indicator mineral used in diamond prospecting as its source is usually the kimberlite pipes or lamproite dykes that produce diamonds.

The tail sands of your gold pan are like a jeweller's window; with the binocular microscope you may find apatite, epidote, tourmaline, zircon, rutile, topaz, sapphire, diopside, pyrite, hematite and a host of other gem materials (but not beryl or emerald), all in miniature.

Just as the source rock for diamond is associated with distinctive indicator minerals that are more abundant and therefore easier to find than diamond, e.g. pyrope garnet, chrome diopside, picroilmenite (Atkinson *et al.*, 1990), so too can the metals

Fig. 2. Geologists use an old bathtub to pan-off concentrates at small alluvial goldmine at Bell Hill, Westland, NZ

Fig. 3. Typical one-man operation of a deep lead alluvial goldmine at Bell Hill, Westland, NZ. A backhoe is used to feed a rotating trommel, which screens the gravel and allows the fines to flow over inclined tables to trap the heavy minerals and gold. Concentrates from such operations are worth studying closely because of the great quantity of gravels processed.

Fig. 4. Aluminium sluice box used to recover gold from the heavy mineral concentrate accumulated at an alluvial gold mine, Bell Hill, Westland, NZ. After a week's operation of the gold recovery plant, there is always an interested audience to see how much gold is produced.

and ores (gold, platinum, cassiterite, scheelite, etc) be associated with a suite of minerals distinctive of a particular occurrence or rock-type. Once on the trail of gold, tin or whatever, you have to study all the clues and trace the metal or mineral to its source to see whether its occurrence is significant.

Today, undiscovered ore bodies are hidden and not easily found. A mineralised zone may be well weathered and covered by soil and forest, or sometimes may exist beneath later surface deposits such as river gravels, glacial till, loess, lava flows and volcanic ash beds. Erosion of these superficial deposits will also contribute a heavy mineral residue to the streams, and this source must be recognized as being distinct from the bedrock. Perhaps the watershed being prospected does not penetrate deep enough to gain erosion products from the bedrock? In this case, pan concentrate prospecting is not suitable, or your objective needs changing. Maybe the overlying material contains something of value?

On gold

Gold, once seen in the pan is easily recognized, even the tiniest yellow speck of 0.1mm size or less. The binocular microscope allows you to pry deeply into its varied forms and so read its history. A gold particle has much to tell about itself which may hopefully reveal its source, and a possible economic deposit.

One scenario for a hard-rock gold deposit is to contain irregularly shaped or granular gold particles of 0.1 to 1mm size. Erosion of the mineralised zone will shed the gold into the stream gravels.

In an active mountain stream it takes only 2 or 3 km of buffeting travel to result in the flattening of the grains to larger flakes. A further 30 to 100 km of travel may shred the gold to small flakes until eventually, on reaching the sea, it may concentrate on the beaches. The very fine flaky beach gold is difficult to pan off from the black sand, and amalgamation is usually resorted to for recovery.

Besides this mechanical abrasion and battering of the gold particles, there are also the processes of solution and crystal growth of gold by reaction with the groundwater, particularly when the particles stop travelling. A solution surface tends to be dull and rounded, whereas a growth surface is often bright, with shiny faces and sharp edges. When gold particles become stagnated in a terrace or deep lead occurrence, it is possible for the larger particles to grow at the expense of the small ones. It may take

thousands of years to produce detectable results.

In the Victorian goldfields, the deep leads have existed for many tens of millions of years. Although much of the original reef gold was coarse, the frequent occurrence of nuggety alluvial gold in Victoria and West Australia is exceptional by world standards (Flett, 1979).

In New Zealand, where the alluvial goldfields are probably no more than a few million years old, since the topography is so youthful, gold nuggets are rare. Even so, microscopic evidence can be found of growth surfaces on gold particles found in terraces and deep leads.

Gold particles may have quartz or some other gangue mineral attached to them, which is indicative of their origin.

A few red herrings

It is not unusual to find in the pan silvery particles, like platinum, that are as heavy as gold. This is amalgamated gold or gold particles coated with mercury. Heating the sample in a flame will drive off the mercury and reveal the true gold; so too will heating in nitric acid.

Mercury may originate from some goldmining or battery site contamination located upstream. However, natural amalgamated gold is sometimes found, particularly if cinnabar is known to occur in the vicinity.

Metallic lead pellets from shotguns are often found in heavy residues. If you assay samples without microscopic tests, your lead anomalies could be misleading. Pellets are now also made from steel and bismuth in order to prevent lead pollution of the environment.

Tiny spheres of metallic iron, highly magnetic, can be found in heavy residues. These are not micrometeorites from outer space - but quite probably upstream someone has been welding a bridge girder or iron pipe and the welding sparks have contaminated the stream sediments.

Detecting cassiterite

Cassiterite, or tinstone (SnO_2), is often black and opaque, sometimes brown to deep red. It is a heavy mineral (SG 6.8), usually exhibiting no crystal form, when encountered in the pan. It is not recognizable for sure on sight, when present in small amounts or as small grains. So how do you identify cassiterite?

A simple chemical test for cassiterite is to place the specimen in a beaker with dilute hydrochloric acid and a piece of metallic zinc. The nascent hydrogen produced by the zinc dissolving in the acid reacts with the tin oxide and reduces it to metallic tin. Thus your cassiterite specimen becomes tin-coated and 'silvery' in appearance (Hutton, 1950; Lever, 1965).

To check pan concentrates for tin, a microchemical test based on this reaction was used successfully to show the presence of even one grain of 0.1mm size in a pan of gravel. The tail residue was put into a zinc beaker (made from half a dry cell battery) and dilute hydrochloric acid added for *c.* 30 seconds. Any cassiterite grains present develop a tin coating. The residue is then transferred to a specially prepared 'iodine paper' in order to pinpoint the tin-coated grains, since they produce a noticeable white spot on the blue paper. The iodine paper was prepared by spraying KI and iodine solution onto a filter paper soaked in starch, hence it is a dark blue colour. When in contact with metallic tin, the iodine in the paper is reduced to colourless iodide and makes a white spot much larger than the original grain, which is immediately noticeable.

Detecting scheelite

Scheelite is the ore of tungsten, composition calcium tungstate, $CaWO_4$, a heavy mineral (SG about 6.0). It may be found in the heavy residues of river sands and even sea beaches, at quite some distant from its original source, but in tiny grains of 0.2mm size or less.

It is important to be able to positively identify scheelite in a pan concentrate. The grains tend to be translucent to transparent, either colourless or white to creamy, so they do not stand out when the residue has appreciable milky or clear quartz grains present.

The method used by CRA Exploration Ltd in their prospecting for scheelite in the Southern Alps of New Zealand was to examine the residues with a short-wave ultraviolet light, whereupon any scheelite grains were detected by their natural bluish fluorescence. This requires a special dark box for operation in the day time.

Alternatively, a microchemical test can be used. The heavy residue tail contained in a glass beaker can be carefully heated on a hot plate with aqua regia (a mixture of nitric and hydrochloric acid this will dissolve any gold hence it is the last test to be done). Any scheelite present develops a bright yellow coating of tungstic oxide, which will dissolve in ammonia solution, thus confirming the presence of tungsten.

The results of these chemical reactions are studied with the binocular microscope - hence the name 'microchemical test'.

Conclusions

Pan concentrate surveys are an effective way of evaluating the mineral potential of areas that are subject to active erosion by running water. Use of the binocular microscope to examine the heavy concentrates enhances the information obtained and provides a check on the geochemical assay data.

The collection and study of pan concentrates is within the broad scope of gemmology, it may be seen as dealing with micro-jewels, rather than macro-jewels.

Wherever you live, be it England, Zimbabwe or Patagonia, get out your pan or kitchen dish and recover a sample of the heavy residue from a nearby stream (with the permission of the landowner of course!). Examine it with your binocular microscope. You will be surprised. You will enter a new World and learn much. Maybe you will find clues to a mineral deposit hidden nearby.

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Hydrostatic measurement of specific gravity

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Abstract

The hydrostatic method has been found to give reasonably accurate specific gravity values for stones down to about five points. A major advantage of the method is its speed and convenience, and the fact that, as opposed to heavy liquids, there is no upper limit to the value of SG which may be determined.

According to Webster (1983) 'even with an accurate balance, the method of hydrostatic weighing is hardly worth using with stones of a carat or under and heavy liquids have to be pressed into service'. Anderson (1990) states that 'if it is desired to obtain the best possible results with small stones (say under 3 carats), it is desirable not to use water but some other fluid having a lower surface tension. Toluene is a stable and fairly inexpensive liquid which can be recommended for the purpose'. In view of the above comments, it might be supposed that the hydrostatic method involving water is of little value for stones of less than 3 carats. In this paper, the practicability of using water for determining the SGs of stones down to 0.035 ct is considered. It is axiomatic that knowing the SG of a stone is of considerable value; it is also evident that using heavy liquids is an unpleasant and often noxious way of establishing SG. If the relatively innocuous hydrostatic method is to be used, it is important to know its limitations and benefits.

Method

Stones ranging from 0.035 ct to 2.62 ct were tested to determine the smallest weights which would give reasonable accuracy. Tests were carried out using the following equipment:

1. a Sartorius single pan balance weighing to 0.0001 gm (0.0005 ct).
2. a 9 ct gold stone carrier in the form of a small dish to which is attached a suspension wire of 0.6mm diameter (Figure 1).

Fig. 1. The 9ct gold dish constructed to hold the stones; it remains relatively bubble-free in water with detergent.

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This carrier was used in preference to a wire cage, since cages are notorious bubble traps; the dished surface of the carrier is remarkably free from bubbles in comparison. The water used was drawn from the mains supply and not boiled or distilled. However, it was left to stand for several hours to reach room temperature and occasionally stirred to remove dissolved air bubbles before use. A non-foaming carpet shampoo of the type used in wet and dry vacuum cleaners was found to be an ideal detergent, but five drops were used rather than the one drop often recommended in the literature. The water container had a working volume of 450mls. Since the balance had a tare weight facility, the scale could be adjusted to read zero with the carrier suspended in the water. Six stones were used in the SG determinations, two diamonds of 0.035 and 0.053 ct and four synthetic corundum stones of 0.25, 0.46, 0.91 and 2.62 ct respectively. They were first tested without detergent and then with detergent. The values obtained are shown in Table I.

Results

As a check on the test-retest variation to be expected in the weighing technique, the SG of a twinned quartz cut stone of 3.42 carats was obtained in ten successive weighings. The stone was tested, dried and retested (and inevitably dropped on occasion) in order to determine the variations created by dust particles, air bubbles, response of the balance, etc. The results were:- mean SG 2.662, standard deviation $\sigma^{N-1} = .0065$. This shows that the technique is reasonably consistent. Using the same procedure, ten measurements of SG, using an untwinned quartz cut stone of 6.707 ct, gave a mean SG of 2.650, and $\sigma^{N-1} = .0029$.

Comments

With heavy liquids it is of course possible, when stones of particular SGs are to be detected, to make up a liquid of the same SG as the stone (providing that a sufficiently dense liquid is available), but when a number of different stones are to be tested it is necessary to use a series of liquids with SGs such as 2.65, 3.06, 3.33 (and 4 if you have a fume cupboard and suitable equipment to deal with Clerici solution - it is not recommended for use outside the laboratory). In this case, unless the stone happens to remain suspended in the liquid, since its SG coincides with that of the liquid, it is only possible to locate its SG somewhere between two values, for example 4.0 and 3.3, corresponding to the liquid in which it floats and that in which it sinks. For stones down to 0.053 ct, such approximate estimations of SG are also obtainable, using the hydrostatic method. The 0.053 ct diamond would be credited with an approximate SG of 3.45 similar to

Table I. Weights, SGs and errors in measurements of stones tested.

		With detergent		*Without detergent*	
Stone	*Weight in carats*	*SG*	*% Error*	*SG*	*% Error*
Diamond	0.035	3.12	-11.4	3.0	-14.8
Diamond	0.053	3.45	-2.0	3.16	-10.2
Corundum	0.25	3.94	-1.2	3.87	-3.0
Corundum	0.46	4.01	+0.5	4.04	+1.2
Corundum	0.91	3.97	-0.5	3.99	0
Corundum	2.62	3.97	-0.5	3.96	-0.75

NB: Errors are related to theoretical SG values of 3.52 for diamond and 3.99 for Corundum (Arem)

that provided by the four heavy liquids.

For stones in excess of 0.25 ct hydrostatic determinations become more accurate and at about 0.46 ct the error is only 0.5 per cent. The advantage of using the hydrostatic method for such stones is that there is no upper SG limit as for heavy liquids, and for the determination of accurate SGs the hydrostatic method is far quicker than modifying the SG of a heavy liquid to obtain a match.

The water used in the tests was relatively pure, but water samples from other localities may require greater quantities of detergent for the best results. Water has a surface tension of 74 dynes per cm and in tests carried out by the writer using a platinum wire loop, it was found possible to reduce the surface tension (by adding detergent) to a value approaching that of toluene at 28 dynes per cm. There is thus apparently little point in using toluene, particularly since it varies in SG as its temperature changes and temperature correction tables would have to be used; for example at 5°C its SG is 0.8787, but at 25° it has fallen to 0.8587, representing a change of 2.3 per cent. Since water only changes by about 0.02 per cent between 4° and 70°C, no compensation needs to be made.

Surface tension increases proportionally with the contact made by the suspension at the water's surface. Therefore the results could have been improved by using a thinner wire. The wire used in these tests was 0.6mm in diameter. If the diameter had been reduced to 0.05 mm the surface tension would fall to about one tenth, so improving accuracy, particularly for smaller stones. However, the thicker wire was used since it provided greater rigidity and made removal of stones from the dish much easier.

Conclusions

Hydrostatic measures of specific gravity, using a sensitive balance, appear to be suitable for obtaining accurate values of SG for stones over 0.25 ct. For stones down to 0.05 ct, the method still gives approximate values such as are obtained when using a series of heavy liquids. The hydrostatic method, using water, was found to be quicker and more pleasant and, in contrast with heavy liquids, there is no upper limit to the value of SG which may be determined.

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[Manuscript received 18 August 1993]

TABLE POLARISCOPE

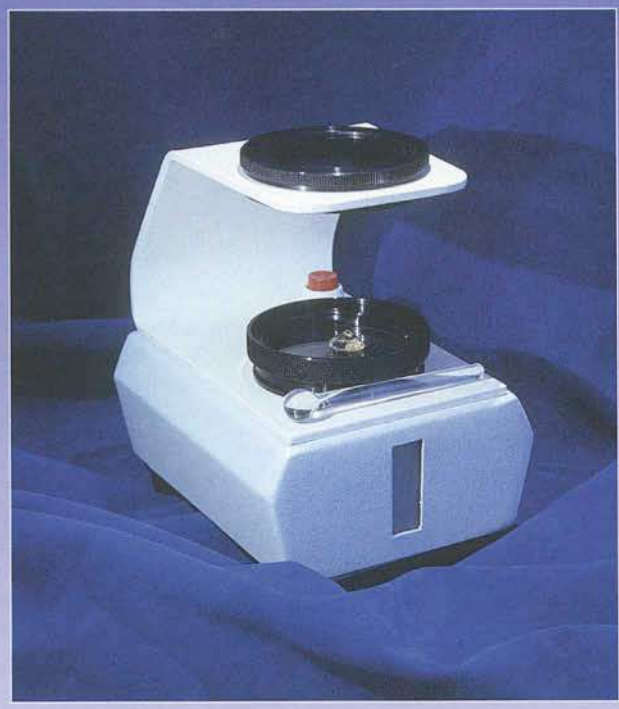

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Pink corundum from Kitui, Kenya

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Abstract

A new source of pink corundum in the eastern foothills of Mount Kenya is described. The corundum occurs in gravels overlying rocks of the Mozambique orogenic belt which comprises ancient basement and metamorphosed volcanic and sedimentary rocks.

Corundum has been extracted since 1989 using simple open-pit mining techniques with a work force of 30 to 50. After sieving and washing, about 50-100 kilograms of corundum are recovered each week.

The corundum is light to medium pink, translucent, and suitable for cabochons and beads. Most material is exported to India but 1-5 per cent of the yield is good quality and the stones are cut in Kenya or in Germany.

Corundum beads dyed red in India could well have been fashioned from material obtained from the new deposit at Kitui.

Introduction

The north end of the East African gemstone belt lies in northern Somalia next to the Red Sea. The belt extends southwards through Ethiopia, through north-west to south-east Kenya and across Tanzania to Mozambique. In geological terms this assemblage of rocks is known as the Mozambique orogenic belt and here it forms the eastern margin of the great rift valley.

The gemstones from this region of East Africa are as ancient and spectacular as their environment. They occur in and are derived from ancient basement rocks and overlying volcanic and sedimentary rocks which have been modified by several episodes of metamorphism. Some of these episodes involved intense heat and pressure leading to partial melting, and the resulting movement of these fluids caused reaction, dissolution and recrystallization of new mineral assemblages, some containing gem species.

The concentration of gem materials is such that now this East African 'gem belt' is blessed with proven producing areas such as the following: Lodwar and Garbatula for sapphire; Taita Taveta and Kasigau for ruby, tsavorite, tourmaline and garnet; Arusha-Moshi for tanzanite, tsavorite, chrome tourmaline and rhodolite; Longido for ruby in zoisite; the Umba River valley for fancy sapphire, garnet and other gems; Mpwapwa near Dodoma for scapolite and kyanite; and Mgorogoro for ruby and spinel.

The latest addition to this catalogue of gem localities is a hitherto unknown area east of Mount Kenya. Preliminary investigations have indicated deposits of pink corundum and this paper outlines the geology, gemmological investigations, and potential for production, marketing and manufacturing.

Location and access

The north Kitui area broadly covers the area just south of the equator, 50 miles east of Mount Kenya and about the same distance north of Mwingi.

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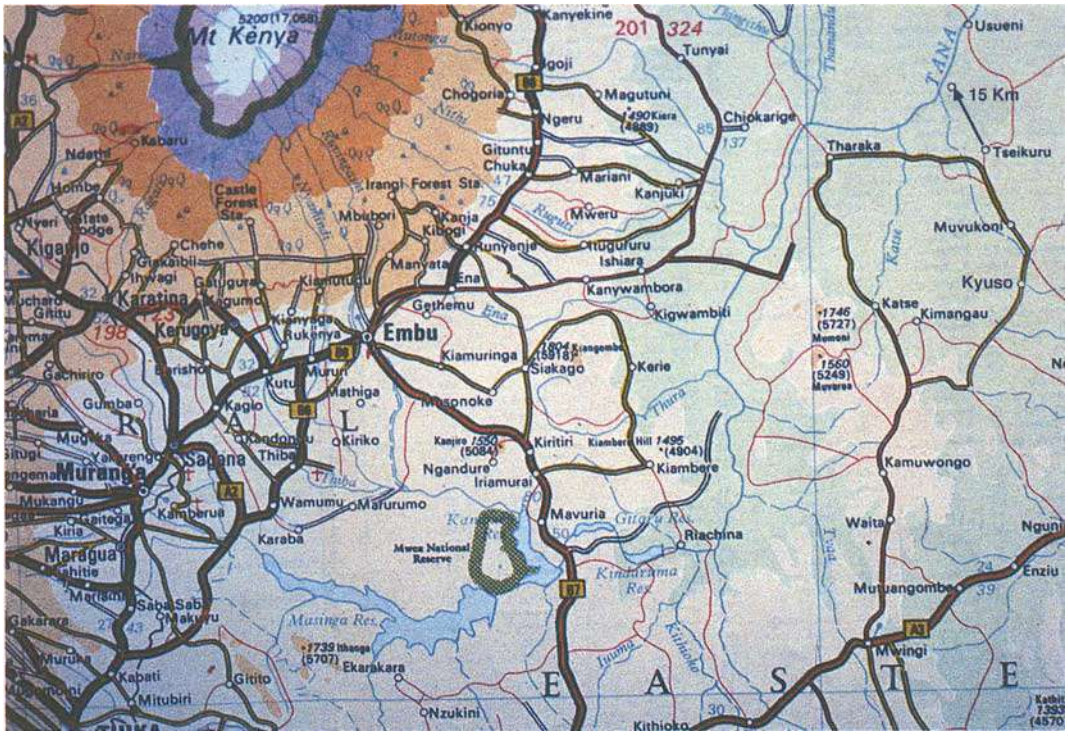

Fig. 1. Map and localities.

The claim known as Taawajah (0°13′S, 38°11′E) (shown on Figure 1) is at an elevation of about 1900 metres above sea level and situated in the eastern foothills of Mount Kenya (elevation 5200 metres). The River Tana (500 metres west of the claim) flows all year round providing a good source for permanent water. Tsaikuru is the nearest village with a population of about 500 people.

In order to reach Taawajah, take the Thika road from Nairobi and then the A3 highway to Mwingi (approximate time 2 hours). From Mwingi turn left (Marrom Road) and pass through Waita, Kamuwongo (approximately 15 kms) then turn right to pass through Kyuso, Mavukoni and on to Tsaikuru. After that turn left onto a bush track in a north-west direction for about 15 kms to arrive at the claim Taawajah (three hours from Mwingi).

Geology

The geological succession in the north Kitui area consists of the Basement System (Precambrian in age) overlain by younger sediments and volcanics of Tertiary and Recent age.

The Basement System consists of an assemblage of quartzites, marbles, calc-silicate rocks, amphibolites and heterogeneous gneisses, some graphitic, with minor granitic and basic intrusive rocks. The quartzites typically contain magnetite, epidote, diopside, wollastonite and garnet. The marbles are generally salmon-coloured. In the alumina-rich rocks, metamorphism was sufficiently intense to produce sillimanite. The intrusive rocks include pegmatites and peridotites.

Near Kitui, 120 miles east of Nairobi, the Mutito fault zone, in which the rocks are intensely sheared and crushed, was devel-

Fig. 2. Crystals and cabochons of reddish-pink sapphire from Kitui, Kenya. *Photo: N. R. Barot*

Fig. 3. Crystals, cabochons and necklace of reddish-pink sapphire. *Photo: N. R. Barot*

oped first in the early Precambrian (Archean) along a north-north-westerly direction, and then was probably rejuvenated in Lower or Middle Pleistocene times about 2 million years ago. This produced what is now known as the Mutito escarpment and is part of the African Rift System. Further details of the geology of this area may be found in Dodson (1955) and McConnell (1972). Dodson reports (1955, p.26) the alleged recovery from the Giluni river bed of a corundum crystal weighing about 3.5 kg but subsequent search revealed no further evidence of corundum.

Mining and production

In 1969 prospecting in the Taawajah area revealed pink corundum but due to the

Fig. 4. Cabochon weighing 7 ct of Kitui reddish-pink sapphire showing colour zoning. *Photo: R. R. Harding*

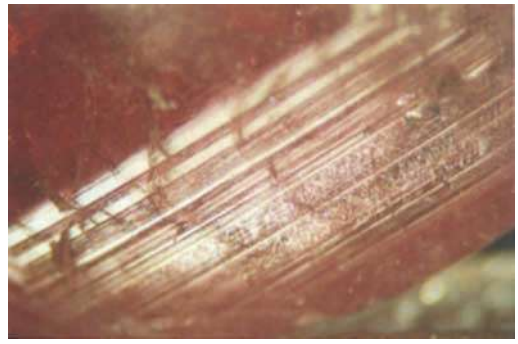

Fig. 5. Close up of colour zoning in cabochon illustrated in Figure 4 showing variation in coarseness of rutile needle inclusions. *Photo: R. R. Harding*

lack of demand the area was not developed. In 1988 the area was again surveyed and was registered in 1989.

Since then open-pit mining using simple techniques has been employed.

The deposit is processed using compressor and pneumatic drills, picks and shovels, and the ore is washed and sieved before hand picking of the gem material. Most gem corundum comes from the top 30 cm of gravel but depths up to 4.5 m have been exploited. There is a work force of between 30 and 50.

Weekly production of gem corundum generally varies between 50 and 100 kg but occasionally reaches 200 kg if a favourable area is being worked. More than 2 tonnes of corundum were extracted during 1989-1991, and from early 1992 to September 1993 a further 2 tonnes have been mined.

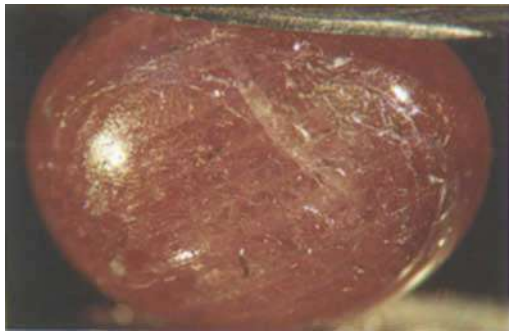

Fig. 6. Parting and fissures in a cabochon, 4.10 ct. *Photo: R. R. Harding*

Most of the gem corundum is pink or reddish-pink and is recovered from the upper levels of the deposit,largely free of decomposed host rock. Below 1.5m the corundum forms part of composite rocks with white, grey, dark green or black minerals. This profile indicates that much, if not all, the corundum is eluvial in origin, derived from rocks in the immediate area, with probably some local re-working.

Marketing and manufacturing

Most of the rough corundum is sold and exported to India through various Kenyan dealers. Between 1 and 5 per cent of production is of good quality and is either sold to Germany or cut and polished into cabochons in Kenya (Figure 2). The cabochons are usually light to medium pink, translucent with a good polish and range from 2 to 20 carats.

In India the corundum rough is cut and polished into cabochons or beads; some of these are dyed red and sold locally or exported to various parts of the world (Figure 3).

Gemmological investigation

a) Description of material

Samples of rough weighing 1080g and comprising crystals and mineral aggregates up to 30 mm across were examined in London. Representative selections from the

range of material were made for detailed analysis.

The samples examined comprise small prismatic crystals with basal parting, rhombohedral parting or both, and chipped or broken to some degree. Some crystals remain undamaged but most have been abraded and now show rounded edges and impact fractures. Abrasion, however, has not removed all traces of host rock and about 10 per cent of the crystals have dark green chlorite, amphibole or mica, or white feldspar or margarite adhering. The crystals range in weight up to 20g (including partial skins of the above minerals).

Iron oxide or hydroxide stains which penetrate along cracks in the crystals, give rise to an orange or brown cast to the colour

Most crystals are bright reddish-pink overall but sections can reveal some complexity in an apparently homogeneous overall colour. Colour zoning inside the crystals is common and often discontinuous in shades of red. Some crystals contain regions of blue which have gradational edges where they merge through purple into the red host.

Cut and polished samples of natural corundum examined in this survey comprise cabochons ranging from purplish-pink to reddish-pink. They range in weight from 3 to 7 carats and are up to 12 mm in length. Rutile silk is present in some crystals and cabochons and it may show a considerable range in coarseness between colour zones (Figures 4 and 5). They contain numerous fissures (Figure 6), twin planes and some contain small sub-rounded colourless crystal inclusions (Figure 7). In addition, dyed corundum cabochons and faceted beads were examined. The cabochons are a bright red and range from 1.2 to 2.7 ct in weight and up to 9 mm in length (Figure 8). The faceted beads are a deeper duller red up to 9 mm across and weigh between 2.7 and 5.9 ct; they are crudely drilled inwards from two

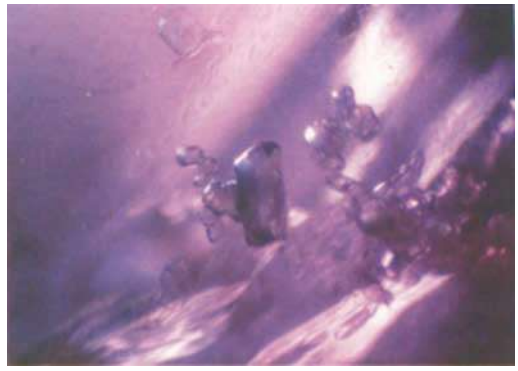

Fig. 7. Colourless crystal (?apatite) inclusions in Kitui pink corundum. *Photo: N.R. Barot*

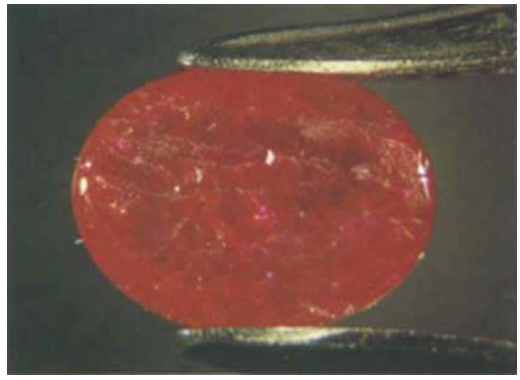

Fig. 8. Treated corundum cabochon, 1.22 ct. *Photo: R. R. Harding*

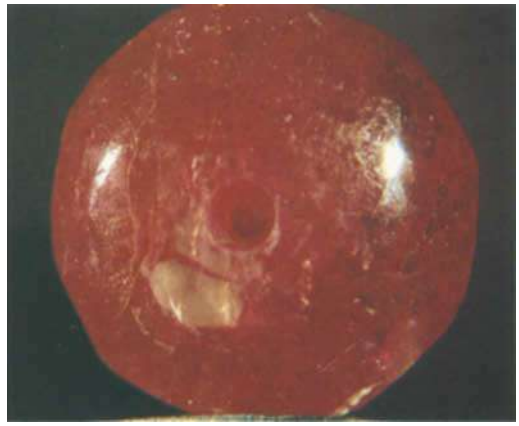

Fig. 9. Treated corundum faceted bead, 2.85 ct. *Photo: R.R. Harding*

directions (Figure 9).

(b) Dichroism and fluorescence

The reddish-pink crystals and cabochons show moderate dichroism from a purplish-red to red with an orange tinge. In many samples, however, the numerous fissures and some twin planes make it difficult to see. Paler crystals and cut stones have correspondingly less distinct dichroism.

Dichroism is very faint or absent in the dyed cabochons examined but in the dyed faceted beads there appeared to be faint purplish-orange dichroism in some samples.

Fluorescence of untreated crystals and cabochons under long-wave ultraviolet radiation (LWUV) at 365 nm is orangey-red and strongest in the most translucent crystals. Increasing degrees of opacity or of blueness in colour correspondingly dampen the fluorescence. Behaviour of any of the rubies under short-wave ultraviolet (254 nm) is a duller version of that under LWUV.

In both the dyed cabochons and faceted beads the response under long- and short-wave ultraviolet is orange-red. It comes mainly from the fissures and is more obvious in the beads than in the cabochons.

(c) Chemical analyses

Analyses by Geoscan electron microprobe at the British Geological Survey were carried out to determine the composition of the ruby in its various shades of colour and to identify the black, dark green, grey and off-white minerals adjacent to the ruby in the mineral aggregates.

The compositions of eight positions on a red cabochon showed major aluminium and minor chromium and iron; total iron reported as FeO, ranged from 0.26 per cent to 0.44 per cent while chromium (as Cr_2O_3) varied between <0.10 per cent and 0.16 per cent. In a purplish-pink cabochon the FeO range was 0.18 per cent to 0.39 per cent, and Cr_2O_3 <0.10 per cent to 0.21 per cent. Analyses of a polished section across a ruby prism showed similar ranges of values. Some round polished and faceted beads have been stained to resemble better quality ruby (see below). One was analysed and contained no detectable chromium (<0.10 per cent Cr_2O_3) and between 0.44 per cent and 0.75 per cent FeO.

Two orange-red fragments in the ruby concentrate were found to be garnet with approximately equal contents of almandine and pyrope; there are also minor grossular and trace spessartine components. Analyses of seven spots on the two fragments gave a mean composition for the garnet of $Py_{45}\ Al_{42}\ Gr_{11}\ Sp_2$.

The mineral aggregates from deeper levels of the deposit consist of red corundum, grey-brown corundum, amphibole, feldspar and micaceous minerals. The grey-brown corundum contains no detectable chromium and up to 0.7 per cent FeO. The black lustrous amphiboles are the calcic variety hornblende with the composition $(Na_{0.41}\ K_{0.05}\ Ca_{1.54})\ (Fe_{1.01}\ Mg_{3.11}\ Ti_{0.03}\ Al_{1.13})\ (Si_{6.37}\ Al_{1.63})\ O_{23}\ (OH)$. The off-white minerals sampled are oligoclase fieldspar $(An_{26}\ Ab_{73}\ Or_1)$ and quartz. Dark green minerals, probably largely chlorite, form at the margins of the hornblende.

(d) Spectral features

Spectra in the range 250-750 nm (UV-VIS) were measured on specimens of natural corundum (two pink cabochons, one purplish-pink cabochon and a polished slice) and five treated specimens (two cabochons, one half-cabochon and two faceted beads).

The natural untreated corundum displays a small peak at 692 nm, a broad absorption between 490 and 600 nm centred about 550 nm, very small peaks at 474 nm, 466 nm and 448 nm, and a major sharp peak at 386 nm. Each specimen also showed total absorption at wavelengths which ranged from 310 nm in the pale corundum to 350 nm for the more intensely

coloured purplish~pink cabochon. In comparison with published spectra for rubies and sapphires (see for example Schmetzer et al., 1992, and Themelis, 1992) the preliminary work on the Kenyan stones has revealed no obvious distinguishing characteristics.

The spectra of the treated stones can be considered in two groups. The cabochons and half-cabochon display spectra similar to the untreated stones except that peaks recorded for untreated stones at 474, 466 and 448 nm are weak or non-existent. The second group comprises the faceted beads. They display no absorption at 692 nm, a broad peak centred about 550 nm and a distinct peak at 450 nm with a minor peak on the longer wavelength shoulder at 458 nm.

This preliminary survey has thus shown that the treated cabochons have spectra similar to those of Kenyan rubies, but at the same time have not shown obvious spectral differences between untreated and treated stones. However, the differences between the spectra of the treated cabochons and treated beads indicate that the beads are made from corundum with no detectable chromium.

(e) The dyed corundum

At first glance the dyed cabochons and faceted beads look like ruby (Figures 8 and 9) but careful examination under a microscope in appropriate lighting conditions reveals patchy and sometimes dense concentrations of colour in the fissures. The dye is orange red in transmitted light but tends to have a purplish hue if the fissure/polished surface intersection is viewed in reflected light, perhaps because the dye has reacted with the air.

Immersion of the cabochons (Figure 10) and faceted beads (Figure 11) in water did not appear to affect the dye, but there is some dissolution in benzyl benzoate which is easily seen as a pink residue when the dyed material is dried with white tissue. In ethyl alcohol and amyl acetate the dye in the cabochons was slightly soluble, and that in the faceted beads was readily soluble, making the white tissue distinctly pink. The dye in both kinds of stone appeared to be less soluble in methylene iodide (di-iodomethane) with only faint tinges of pink on the tissue resulting. The apparently 'stronger' behaviour of the faceted beads in the solvents may merely be an indication of a higher density of dye-filled fissures.

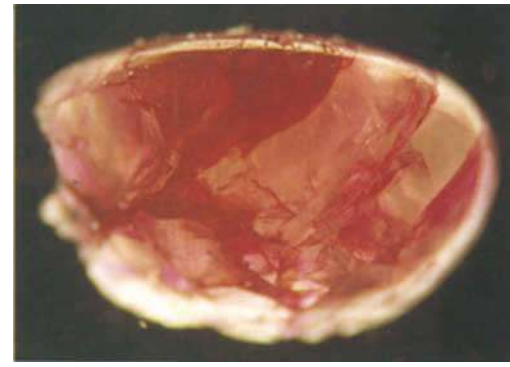

Fig. 10. Treated corundum cabochon immersed in water; red dye along fractures is easily visible. *Photo: R. R. Harding*

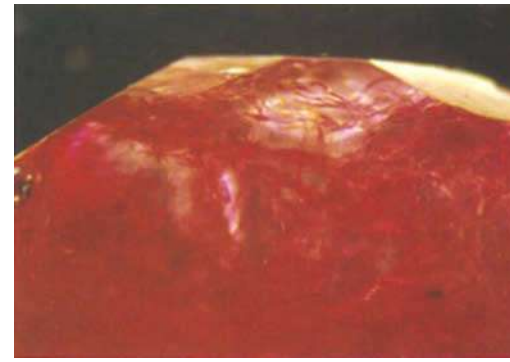

Fig. 11. Treated corundum bead immersed in water; red dye along fractures may be seen near the facet surfaces. *Photo: R. R. Harding*

We can conclude that it is a simple matter to detect dyed faceted beads using ethyl alcohol or amyl acetate where a rapid appearance of colour on white material might be expected. A little more perseverance may be necessary to check the

cabochons if they have relatively few fissures.

In addition to the above organic solvent test, Schmetzer *et al.* (1992) have discussed a method of detecting dye in a dyed corundum using ultraviolet spectroscopy and microphotography.

Discussion

We may draw the following conclusions:

(a) pink and reddish-pink gem quality corundum from a new locality at Kitui in Kenya has been described. The best material is a bright attractive colour but the stones contain numerous fissures and to date the production has been most suitable for cutting into cabochons;

(b) chemically, the corundum contains small amounts of chromium and slightly higher contents of iron, features confirmed in the spectra obtained from a sample of cabochons and crystals;

(c) samples of corundum cabochons, dyed red and emanating from India, yield identical spectra to those from untreated corundum from Kitui. Kitui is therefore a possible source for this Indian material. Samples of faceted beads, also dyed red and emanating from India, are cut from corundum with different spectra from those of the examined Kitui material and the source of the corundum is not known;

(d) both dyed cabochons and dyed faceted beads may be detected and distinguished from un-dyed ruby and sapphire by application of a solvent such as ethyl alcohol or amyl acetate on a white tissue and observing the colour of the residue when it dries.

Acknowledgements

We would like to thank Ana Castro and Stephen Kennedy for assistance in the Laboratory and for useful discussions. Thanks also go to Dr M. T. Styles of the British Geological Survey for use of the Geoscan electron microprobe, and to him, D. Bland and Paul D. Wetton for technical assistance.

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[Revised maniscript received 5 January 1994]

Vesuvianite from Bellecombe and Montjovet (AO Italy): a material of gemmological interest

Massimo Novaga

Milan, Italy

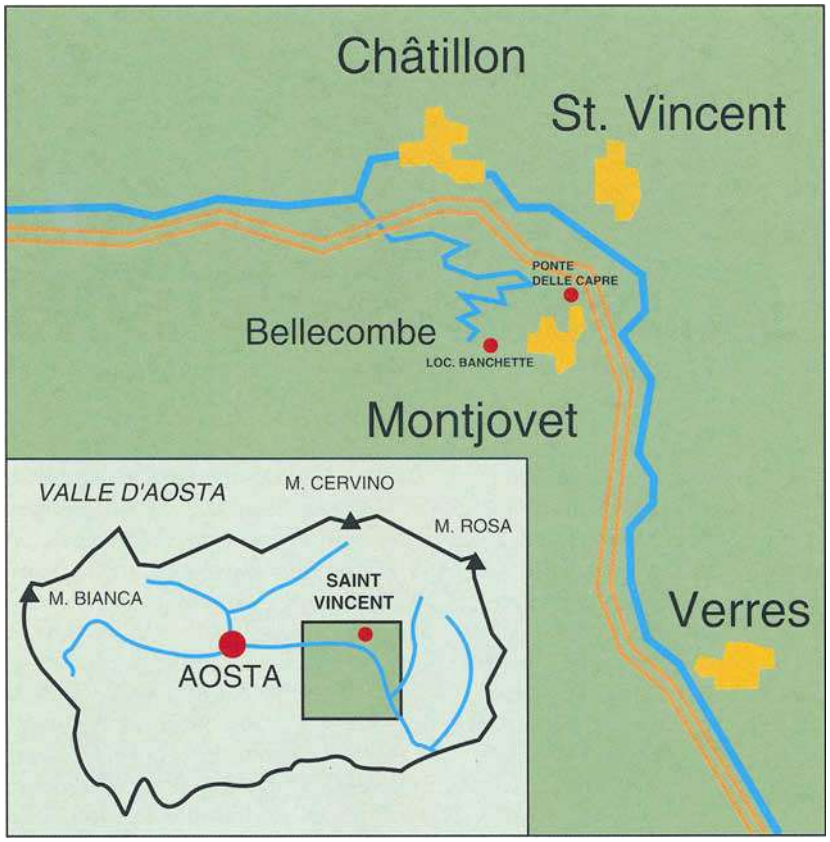

Fig. 1. Map showing the vesuvianite research area in the Valle d'Aosta region, Italy.

Abstract

Gem quality vesuvianites from Cretaceous rodingite veins near Bellecombe and Montjovet (AO Italy) have been analysed. Chemical analyses and refractive index measurements allow distinction of two kinds of vesuvianite: type A with n=1.724-1.736 and type B with n=1.715-1.720; densities between 3.35 and 3.40 g/cm^3 were recorded. Transparent vesuvianite from this locality is good gem material but, because the vesuvianite is not uniformly distributed in the rodingite rock, the occurrence is not an economic prospect.

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Fig. 2. Massive vesuvianite rock and serpentinites in the Bellecombe area

Introduction

Vesuvianite or idocrase is a calcium aluminium silicate classed as a sorosilicate and is present generally in rodingite rock. Rodingites, which are common in Liguria (Voltri group) at Bric Camula and in other parts of the Valle d'Aosta, are associated with peridotites and serpentinites (Dal Piaz, 1966). The aim of this work, comprising, geological fieldwork and laboratory analysis, is the study of the petrology and gemmology of vesuvianite and an investigation of its economic potential.

Fig. 3. Veins of vesuvianite rodingite rock near the road from Ussell to Bellecombe.

Location and petrology

The area studied covers 12 square kilometres lying north-east and north-west of Bellecombe, and is occupied by massive serpentines (Figure 1). The metamorphic rodingite-vesuvianite rocks from Bellecombe are of Cretaceous age and were formed as a result of the action of serpentinizing fluids on ultrabasic massifs (see Dal Piaz, 1966) (Figure 2). Generally the rodingite-vesuvianite rocks are present as brown or pink fine-grained veins and lenses. These calc-silicate rocks consist of diopside and augite, epidote, garnet and chlorite, with vesuvianite enclosed in a garnet matrix: indeed the rodingite rock has been called 'garnetite'.

Veins of rodingite rock are easily visible in the serpentines, both in the mines and quarries near Montjovet (Figure 3) and in outcrops near the road from Ussel to Bellecombe. Massive rodingites also occur at Banchette. A characteristic feature of rodingite veins in these localities is the chlorite border at each margin which effectively defines the veins.

Table I. Chemical analyses of vesuvianite from Bellecombe and Montjovet, Valle d'Aosta, Italy

Weight per cent	*Range*	*Mean*
SiO_2	36.53 - 37.40	36.95
Al_2O_3	15.12 - 17.74	16.43
FeO	2.66 - 3.94	3.3
MgO	2.04 - 2.62	2.33
CaO	35.78 - 36.50	36.14
Na_2O	abs - 0.09	0.02
TiO_2	0.035 - 2.05	1.04
MnO	abs - 0.12	0.06
Cr_2O_3	0.02 - 0.06	0.04
Total		96.85

N.B. 'abs' means below the detection limits of this method of analysis

Table II. Optical and physical analyses of vesuvianite from Valle d'Aosta, Italy

IGI inventory number	*Locality*	*Indices* ε	ω	*Bire-fringence*	*Density g/cm³*
Type A					
2909	Ponte delle Capre	1.724	1.728	-0.004	3.35±0.025
2910	Ponte delle Capre	1.731	1.736	-0.005	3.38±0.045
2911	Ponte delle Capre	1.731	1.736	-0.005	3.36±0.020
Type B					
2760	Loc. Banchette	1.715	1.718	-0.003	3.40±0.055
2761	Loc. Banchette	1.714	1.717	-0.003	3.38±0.050
2904	Bellecombe	1.719	1.722	-0.003	3.39±0.050
4119	Bellecombe	1.718	1.720	-0.002	3.36±0.035

Unit cell parameters

Sample	1	2	3	4	5
a (Å)	15.566	15.538	15.588	15.533	15.546
c (Å)	11.859	11.816	11.848	11.878	11.831

Fig. 4. Vesuvianite crystal.

Characteristics of vesuvianite

Vesuvianite from Banchette and Bellecombe has prismatic habit, is greenish-brown (DIN 24,5:4:6) and reaches 3 cm in length (Figure 4) that from Ponte delle Capre is yellowish-brown. Chemical analyses of vesuvianite crystals were performed by Scanning Electron Microscope with energy dispersive attachment (Table I). Since minor elements and water were not determined, the oxides do not total 100 per cent. Optical data and density measurements are given in Table II.

Refractive indices and densities

Gemmological examinations were performed on seven cut samples (two of which are illustrated in Figures 5 and 6), which weighed between 1.2 and 3.1 ct. These samples have been divided into two types designated 'A' and 'B'. Type A presents refractive indices in the range 1.724-1.736 and densities 3.35±0.025 - 3.36±0.020 g/cm^3; type B is characterized by refractive indices of 1.714-1.722 and densities of 3.36±0.035 - 3.40±0.055 g/cm^3. The reasons for these differences probably lie in chemistry related to the diversity of the host rodingite rock.

Spectra

Using a Zeiss prism spectroscope, the spectra of all samples showed an absorption line at 471 nm, which is the most important identification feature of vesuvianite (Anderson, 1987).

Inclusions

Under the immersion microscope, the gems may be seen to contain abundant inclusions, the most frequent of which are fluid inclusions in small tubes or channels and in negative crystals (Figure 7).

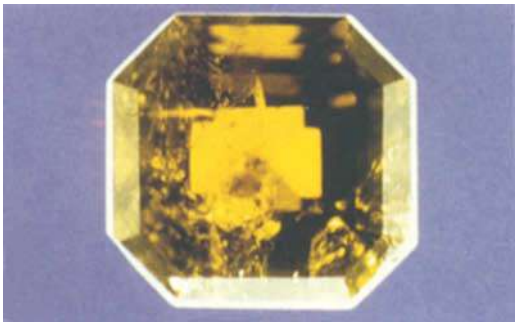

Figs. 5 and 6. Samples of faceted vesuvianite.

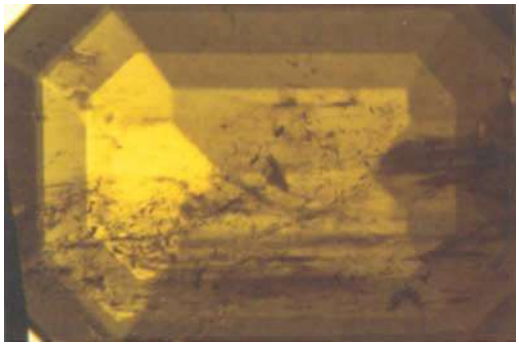

Fig. 7. Fluid inclusions in small tubes and fractures, and various crystals. Immersion microscope.

Dichroism

Dichroism, observed with a calcite dichroscope, indicates that the Ponte delle Capre samples range from brown to yellow or green, while the Loc. Banchette and Bellecombe samples tend to show a yellow to green range.

Conclusions

The rodingite veins in the serpentinites around Bellecombe and Montjovet have yielded some gem quality vesuvianite. However, the rodingites are heterogeneous rocks (Vuagnat, 1965; Dal Piaz, 1966) and economic extraction of vesuvianite from this area of Valle d'Aosta is not feasible. Moreover this area is now protected by the Valle d'Aosta regional authority.

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[Revised manuscript received 8 April 1994]

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Smoky moonstone: a new moonstone variety

H. Harder

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Abstract

The blue sheen of moonstone is enhanced by a dark body colour. It is proposed to call moonstones with a grey body colour 'smoky moonstone'. The colour can be attributed to divalent iron content.

Introduction

The beauty of moonstones is due to both the body colour and the blue or white sheen (adularescence). The moonstone sheen is mobile and is best seen in particular crystallographic directions.

Moonstones are generally colourless but can also occur in many colour shades. Some south Indian moonstones, for instance, have a strong body colour in green, yellow, beige, pink, red or brown and even in black or grey, but most Sri Lankan moonstones are colourless and transparent or white and translucent.

The blue sheen in some Sri Lankan moonstones is well known (Spencer, 1930) and is caused by a high sodium content (Harder, 1992a). Only a small proportion of stones show a strong sheen, but a weak sheen may be emphasized by a darker body colour and appear much more beautiful.

Location

Moonstones with a dark body colour have been found in the last few years in

Table I. Moonstone qualities of Sri Lanka with different body colours and sheens

		Colourless moonstones	*Smoky moonstones*
Moonstone body colour		Water clear	Smoky clear or
		Colourless cloudy	Cloudy translucent
Moonstone sheen	Blue	Crystal blue[1]	'Royal blue'[2]
		Normal blue	Normal blue
		Muddy blue	Muddy blue
	Semi blue	Top semi blue[1]	Crystal semi blue
		Normal semi blue	Normal semi blue
		Muddy semi blue	Muddy semi blue
	White	Crystal white[1]	Crystal white
		Silvery/pearly white[3]	
		Normal white	Normal white
		Muddy white	Muddy white

1 Only in Metiyagoda
2 Only in Imbulpe
3. Less in Metiyagoda and more from Embilipitiya, a new moonstone locality on a bank of the river Walawe Ganga in south Sri Lanka

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Table II. Chemical composition of colourless and smoky moonstones from Sri Lanka

Weight %	*Colourless – Metiyagoda* *semi-blue sheen*	*Smoky – Imbulpe* *blue sheen* *dark smoky*	*Smoky – Imbulpe* *semi-blue sheen* *light smoky*
SiO_2	66.2	66.5	66.4
TiO_2	0.004	0.02	0.02
Al_2O_3	18.8	19.0	19.1
Fe_2O_3	0.007	0.014	0.003
FeO	0.014	0.094	0.06
MgO	<0.00	<0.00	0.005
PbO	≈0.02	0.00	0.00
BaO	0.004	0.04	0.03
CaO	0.3	0.74	0.64
SrO	0.02	0.05	0.05
Na_2O	3.7	5.9	5.34
Rb_2O	≈0.07	≈0.013	≈0.009
K_2O	10.1	7.7	8.41
Ign. loss at 950°C	0.16	0.0	0.03
Total	99.399%	100.071%	100.097%
Other trace elements:	Cr_2O_3 0.02-0.003	MnO 0.03-0.01	Ga 0.002
Feldspar components:			
Orthoclase	63	45	49
Albite	35	52	48
Anorthite	2	3	3

the Central Mountains of Sri Lanka near Imbulpe, east of Ratnapura (Harder, 1992b), and in the region of Balangoda, near the road to Haputale in the Sabaragumuba Provinces. The flash of the blue or white sheen emanating from the dark smoky body makes the beauty more apparent. It is proposed to call this new variety of moonstone 'smoky moonstone'.

In the Sri Lankan trade, there is now a much greater variety of moonstones. Qualities from a number of new mines are cut together with the well-known moonstone from Metiyagoda (see Table I). The locality in Imbulpe has produced some smoky moonstones with an unusually strong blue sheen and locally this top quality is called 'royal blue'.

Composition

Top blue moonstones even in smoky qualities are albite rich; i.e. an albite, which contains only up to 45 per cent potassium feldspar (orthoclase). The chemical composition of two smoky moonstones from Imbulpe are presented in Table II and are compared with an analysis of a moonstone from Metiyagoda with a quality called 'semi-blue'. The SiO_2 and Al_2O_3 contents were determined by means of gravimetric analyses. The K_2O, Na_2O, CaO and MgO contents were analysed by atomic absorption, Fe by spectralphotometric investigation and the trace elements Mn, Ba, Sr, Rb and Cr by X-ray fluorescence.

Although the values of the main and trace element contents between samples

Fig. 1. The strong blue moonstone sheen is visible from a smoky body colour. The stones range from 2 to 10 cts and are of reasonable quality.

Fig. 2. Range of qualities of cut smoky moonstone from Imbulpe.

Fig. 3. Poor quality smoky moonstone from Imbulpe with cleavages, cracks and inclusions; cut as a paper weight. Size 50/30mm.

Fig. 4. The smoky body colour of this moonstone is apparent in front of a white sheet.

are very similar, the Fe_2O_3 and especially the total iron content of the smoky moonstone samples are distinctly higher than in colourless Metiyagoda moonstones. A higher Fe^{3+} content and the charge transfer of Fe^{2+} to Fe^{3+} is the chemical reason for the smoky body colour of the moonstone. The blue sheen is more visible the darker the stone.

In the smoky moonstone deposits in Imbulpe a range of qualities is recovered from pegmatites. The moonstones are mined from the pegmatite surface on the slopes of the mountains and show some weathering. Some of these moonstones present brownish or yellow colours, which probably formed through recent weathering processes. Although these muddy colours are not appreciated in the trade, the most important defects which affect gem quality are the numerous mineral inclusions. Most inclusions are clay minerals, such as swelling chlorite, which is probably a recent result of weathering of biotite. The inclusion-rich moonstones may have some interest for collectors but for the moonstone dealers this 'quality' is a disadvantage. The first smoky moonstones were cut at the end of 1990 and their intensive blue sheen has attracted some Sri Lankan sapphire dealers. The trade in sapphires has tolerated inclusions, indeed they are a useful indication of natural origin. The prices of the new variety of smoky moonstones are extremely high even though they are difficult to sell.

Moonstones on the market

The mining in Imbulpe is illegal and the activity is not regular. In the years 1992 and 1993 better material with a stronger blue was cut. But most cut stones contain inclusions, and only a small percentage is inclusion-free. This inclusion-free material with a strong blue sheen should be expensive, but it is not sufficiently well-known in the jewellery trade so the clear Metiyagoda moonstones are preferred. The present market situation of smoky moonstones may be compared with the introduction to the trade of black opals. At first the beauty of black opals was not recognized by the public, but now their prices are extremely high compared to white opals. It is the author's opinion that the trade and public will grow to accept smoky moonstones and that values will rise.

Other localities

John Sinkankas (1959) describes the body colour of 'the finest moonstones in North America' (Black Range in Grant County, New Mexico) as 'a very distinctive smoky grey or brown'.

> 'The strong bright blue adularescence ... rivals that observed in Ceylon moonstones. Most of the material is cracked and veiled with inclusions and large flawless gems are impossible to obtain.'

The material from New Mexico seems to be similar to the smoky moonstones of Imbulpe. But in Sri Lanka a few cut stones are free of inclusions and possibly the Sri Lankan quality may be slightly higher.

It is to be hoped that more smoky moonstones in other parts of the world can be found in qualities which the gem trade will accept.

Acknowledgements

It is a pleasure for me to express my thanks to several friends in Sri Lanka. Talks with well-informed moonstone merchants were very helpful in preparations for this paper, especially the information from S.H.M. Mohideen (Jeiser), Hajee M.T.M. Nazurdeen and John Sinkankas of San Diego, USA.

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[Manuscript received 27 March 1993]

Letters

From Dr Kurt Nassau, PhD, FGA

Dear Sir

On Diamond-filling Glasses and Nelson's Speculations

I was surprised by the speculations of J.B. Nelson[1] on the possible nature of the glasses used in the fracture filling of diamonds and on a possible apparatus for performing this operation. First, Nelson ignored the stated limitation of the analyses used by Koivula *et al.*[2] and therefore missed the important boron content of these glasses. Secondly, he also ignored the large literature on low melting glasses, including solder glasses. And, thirdly, he hypothesized a possible £5000 apparatus for fracture filling when a £5.00 arrangement would do as good a job. As a result, while his discussion is actually not often wrong, much of it is irrelevant.

The type of analyses used by Koivula *et al.*[2] as well as that shown in Figure 2 of Nelson's paper is not able to detect the presence of boron, as was clearly stated by Koivula *et al.* (ref. 2, p.79). They also reported that the chloride content seemed to approximate the sum of lead and bismuth and that a major amount of oxygen was also present. Nelson[1] repeated these statements but ignored their logical consequence, namely that there must be present another cation in major amounts to correspond to the oxygen content and that boron is the only practicable (and indeed expected) candidate. Since Koivula *et al.*[2] reported that bismuth was present in some, but not all, of the analyzed fillings and E. Fritsch (unpublished data) observed the presence of bromine in one fracture-filled diamond, the fracture-filling glasses are thus quite variable, including both lead-boron-oxyhalides and lead-boron-bismuth-oxyhalides.

Lead-boron-oxide glasses are well known, with melting temperatures as low as 500°C, and so are lead-boron-bismuth-oxide glasses (ref. 3 p.169; ref. 4 pp 447, 465-9; ref. 5, pp 177, 185, 218, 251). The addition to oxide glasses of halides, such as bismuth and lead chlorides and bromides are also widely described (ref. 3 pp 225-6; ref. 4 pp 562-5; ref. 5 p.183).

Multicomponent oxyhalide glasses can have extremely low melting points (even lower than 300°C) and are widely used, e.g. as 'solder glasses' to seal glass covers to digital (alphanumeric) semiconductor displays. Such glasses do not usually show devitrification unless specifically designed and processed to do so, thus allaying one of Nelson's concerns.

Incidentally, Nelson's suggestion of pouring molten glass into mineral oil should not be tried - such a process is an extreme explosion and fire hazard! Why not merely pour the melted glass onto a cold metal plate in the customary manner?

A very simple apparatus often used by scientists to mix substances in vacuum is shown at *a* in Figure 1.

Since the fracture-filling glasses are so low melting, a fused silica (or even pyrex?) container is suitable for their melting. The diamonds are placed at A, the glass at B, and a vacuum is applied at a temperature less than the flow temperature of the glass for baking out. The temperature is then raised and rotation about the ground glass joint C into the dashed position now causes the glass to flow onto the diamonds. After fracture filling, a further rotation permits draining the excess glass through screen D. To remove the diamonds, one merely breaks the inexpensive tube (if it has not fractured by itself on

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cooling).

If one does not insist on performing the draining step in vacuum, then the even simpler test-tube arrangement at *b* in Figure 1 can be used, where lumps of glass E are placed on top of the diamond F. After baking out at a lower temperature, the glass is melted to flow over the diamonds. For this arrangement a furnace is not needed since a gas burner will do; the excess glass is melted away on a wire screen in the ambient atmosphere.

Finally, one should point out the impossibility of the precision polishing required

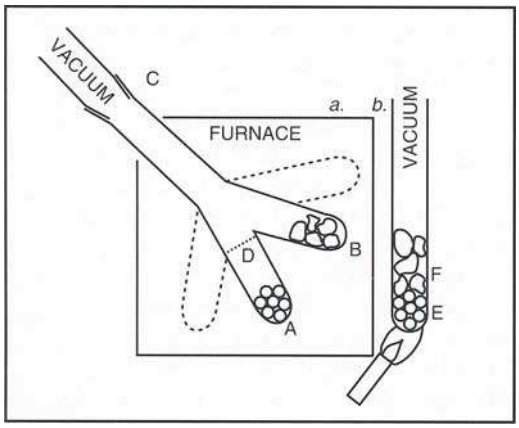

Fig. 1. Two ways of filling fractures in diamonds with low melting glass in a fused silica (or pyrex?) apparatus.

by Nelson[1] in his Figure 6. When a soft glass is adjacent to extremely hard diamond, the well-known 'undercutting' just cannot be avoided, even if the heat of cutting does not cause the glass to ooze.

My aim here has been to caution the reader and to provide Nelson with additional data and some entry references into the glass literature[1,5], where he will find many additional relevant references; this should give him a factual basis for his speculations.

Yours etc.
Kurt Nassau
Nassau Consultants,
Lebanon, NJ 08833, USA.

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From Professor Cornelius S. Hurlbut

Dear Sir

I write in reference to the article by T. Farrimond in the *Journal of Gemmology* (1994, 24, 2), 'A device to facilitate the measurement of birefringence in gemstones'. This paper was of particular interest to me for several years ago I constructed, for my own use, an almost identical device for use with a GIA GEM Duplex II refractometer.

However, the device itself is not what prompted this letter but rather the reference to the Gemeter Digital 90. It is perfectly correct that the difference between the highest and lowest readings determined on any facet with a Dialdex is the birefringence. Since a similar device is mentioned, and illustrated, for the Gemeter, it implies that the birefringence can also be measured with this instrument. Assuming accurate readings, only with special crystallographic orientations of the table can birefringence of a gemstone be determined with a Gemeter. The special condition for uniaxial gemstones is when the table is parallel to the optic axis. If the table were perpendicular to the optic axis, all readings would be the same as the stone is rotated. For biaxial gemstones the rarely encountered special condition is that the vibration directions of both the alpha and gamma indices lie in the table. For a random crystallographic orientation of the table of both uniaxial and biaxial gemstones different readings would be obtained on turning the stone, but the dif-

ference of the maximum and minimum would never be the full birefringence.

Yours etc.
Cornelius S. Hurlbut
Professor of Mineralogy, Emeritus
Department of Earth and Planetary Sciences, Harvard University, Cambridge, Mass 02138, USA

Response from Dr T. Farrimond

20 May 1994
Dear Sir

I appreciate the comments made by Professor Hurlbut pointing out the problems of measuring birefringence using a device such as the Jemeter Digital 90. In my article, the reference I made to it en passant was simply to illustrate the convenience of using a mechanical rotation device for the Jemeter. I find it much easier, when using mechanical rotation, to retain a stone balanced on the 4.5mm diameter truncated cone platform of the Jemeter. My reference was not intended to imply similarity of function to critical angle refractometers.

I am pleased Professor Hurlbut has drawn attention to my footnote since the distinction between the different types of instruments is made clearer.

Yours etc.
Tom Farrimond
Thornton Road, Cambridge, New Zealand
11 June 1994

From Richard M. Hughes

Dear Sir

I would like to comment on two articles in the *Journal of Gemmology*. First, 'A Note from the Bahrain Laboratory' (1992, 23, 4, pp 223-4), featuring a discussion of treated amber. In this article, the authors noticed a concentration of colour at the surface of a necklace of amber beads, and came to the logical conclusion that the beads had been treated to darken their colour.

In the mid-1980s I had occasion to cut some rough amber (probably of Baltic or Dominican Republic origin) in Bangkok. In the rough, the colour was a rich golden brown, but the resulting cabochons came out a pale yellow, similar to the colour of the average, tasteless, American beer. The stones were put into a stone paper and promptly forgotten. Several years later I examined those same stones and was surprised to discover that their colour had darkened considerably, despite the fact that they had remained in pitch darkness the whole time.

From the above experience I was able to conclude one thing without doubt ...

* The colour of amber may darken over time.

However, being the good scientist I pretend to be, I must consider mitigating factors. These lead me to the following postulate ...

* The colour of amber may very well darken over time. But with the paint-warping pollution levels what they are in Bangkok, it is entirely possible that such a colour change should be seen as a form of providential treatment (er, enhancement).

Perhaps this is the real secret to Thailand's success at gem treatments. Not to worry though. If pollution is found to influence the colour of gemstones, I am sure CIBJO can find a historical precedent, so customers need not be informed.

The second item is 'Myanmar and its gems - an update' (1994, 24, 1, pp 3-40). In this article (which was excellent), the Black Prince's Ruby and the Timur Ruby are said to possibly be of Burmese origin (p.4). I would like to point out the existence of historical evidence which suggests that most of the red spinels of yore were actually mined in Badakshan, along what is now the Afghanistan-Tajikistan border. The terms balas ruby, formerly used to describe spinel, is a garbled version of Balakhsh, an old pro-

nunciation of Badakshan.[1] To me, Timur is an obvious reference to King Timur, who ruled over Samarkand early in the fifteenth century. And the Timur ruby does feature Persian inscriptions on it.

While the above evidence is circumstantial, it is no more than the inclusion evidence. Until such a time as documented specimens are collected from the Badakshan mines, and inclusion studies performed, it is impossible to say whether or not their inclusions are similar to those of Burmese spinels.

In closing, I would like to leave you with the following from one of Ireland's finest, Valentine Ball [1843-1895], former head of the Geological Survey of India and Tavernier biographer ...

> 'There is good reason for thinking that many of the large historical spinels, both of the East and Europe, may have come from the locality in Badakshan, or possibly even from Afghanistan, rather than from the better known localities of Ceylon and Burmah.'
>
> Valentine Ball (1893)

A description of two large spinel rubies, with Persian characters engraved upon them. Proceedings of the Royal Irish Academy, Third Series, 3, 1, pp 380-401. Reprinted in *Gemological Digest*, 1990, **3**, 1, pp 57-68.

Yours etc.
Richard W. Hughes
Boulder, CO 80301-3980, USA
28 May 1994

1. For an excellent description of this term, see Yule, H. and Cordier, H. (1921) *The Book of Ser Marco Polo*. Reprinted by Dover, 1993, London, Murray, 3 vols.

Abstracts

Diamonds | Gems and Minerals | Instruments and Techniques | Jewellery | Synthetics

Diamonds

Possibly diamond-bearing mantle peridotites and podiform chromitites in the Luobusa and Donqiao ophiolites, Tibet.

W.-J. Bai, M.-F. Zhou and P.T. Robinson. *Canadian Journal of Earth Science*, **30** (8), 1993, pp 1650-9, 3 maps.

The Luobusa ophiolite of the Yarlung–Zangbo (S Tibet) suture zone and the Donqiao ophiolite of the Bangong–Nujiang (N Tibet) suture zone are allochthonous bodies that contain possible diamond-bearing mantle peridotites and podiform chromitites. The mantle sections in both massifs consist chiefly of harzburgite and diopside-bearing harzburgite with abundant lenses of dunite and chromitite. These ultramafic rocks are more strongly depleted than typical abyssal peridotites and their geochemistry suggests formation above a subduction zone. An unusual mineral association (diamond, SiC, graphite, native chromium, Ni-Fe alloy, Cr^{2+}- bearing chromite), indicating a high-*P*, reducing environment, occurs in both the peridotites and chromitites. To date, > 100 diamond grains have been recovered from the two massifs; most are 0.1—0.2 mm in diameter but some are > 0.5 mm. Those in the Luobusa massif are colourless, whereas those from the Donqiao massif are yellowish green to dark green. It is suggested that these ophiolites were generated originally in a suprasubduction zone environment and were later carried deep into the mantle along a second subduction zone, at which time the diamonds and other high-*P* minerals were formed. It is not yet clear whether the diamonds formed by high-*P* metamorphism of the oceanic crust or by crystallization from mantle melts, but their occurrence in chromitites and harzburgites suggests a metamorphic origin. During the collision of India with the Eurasian plate, the mantle sections were tectonically emplaced at shallow crustal levels rapidly enough to preserve the diamonds. R.A.H.

Find of eclogite with two diamond generations in the Udachnay kimberlite pipe.

A. M. Bezborodov, V. K. Garanin, G. P. Kudryavtseva, J. Ponahlo and E. Yagouts. *Akademia Nauk USSR, Doklady Earth Sciences Section*, **317**(3), 1993, pp 190-3.

The problem is defined and the diamond-bearing rocks are described. The chemical data are tabulated. CL curves and IR spectra are shown. The authors conclude that natural diamond formation is a discrete process. K.A.R.

Low-calcium garnet harzburgites from southern Africa: their relations to craton structure and diamond crystallization.

F. R Boyd, D. G. Pearson, P. H. Nixon and S. A. Mertzman. *Contributions to Mineralogy &*

ABSTRACTORS

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For further information of many of the topics referred to consult *Mineralogical Abstracts* or *Industrial Diamond Review*.

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Petrology, **113**(3), 1993, pp 352-66.

Low-Ca garnet harzburgite xenoliths contain garnets that are deficient in Ca relative to those that have equilibrated with diopside in the lherzolite assemblage. Minor proportions of these harzburgites are of widespread occurrence in xenolith suites from the Kaapvaal craton and are of particular interest because of their relation to diamond host rocks. The harzburgite xenoliths are predominantly coarse, but one specimen from Jagersfontein and another from Premier have deformed textures similar to those of high-*T* peridotites. Equilibration *T* and depths calculated for the harzburgites have the ranges 60-1400°C and 50-200km. Garnets and associated minerals in harzburgite xenoliths differ from minerals of the same assemblage that are included in diamonds in that the latter are more Cr-rich, Mg-rich and Ca-poor. Coarse crystals of low-Ca pyrope with the compositional characteristics of diamond inclusions commonly occur as disaggregated grains in diamondiferous kimberlites. Their host rocks are presumed to have been harzburgites and dunites. The differences in composition between the disaggregated grains that are similar to diamond inclusions and those comprising xenoliths imply some differences in origin. P.Br.

A graphite-cohenite-iron mineral association in the core of a diamond from the Twenty Third Soviet Communist Party Congress Pipe.

G. P. Bulonava and N. V. Zayakina. *Akademia Nauk USSR, Doklady Earth Sciences Section*, **317A**(3), 1993 pp 126-30.

The diamond was studied with optical, X-ray, and EPMA methods. The X-ray powder data are tabulated and five photomicrographs are shown. The data are discussed in detail. It is concluded that the diamond was formed in nature from graphite. K.A.R.

Thin film diamond growth mechanisms.

J. E. Butler and R. L. Woodin. *Philosophical Transactions of the Royal Society: Physical Sciences and Engineering*, **342**(1664), 1993, pp 209-24.

The principal chemical mechanisms relevant to the growth of diamond from gaseous hydrogen and hydrocarbon species are discussed. The kinetic processes during activation and transport of the gaseous species to the growing surface are described, with the key processes being the generation and subsequent reactions of gaseous atomic hydrogen. R.K.H.

Evidence of kimberlite magmatism in the eastern part of the East European craton.

V. G. Chaykin and A. V. Tuluzakova. *Akademia Nauk USSR, Doklady Earth Sciences Section*, **314**(1-6), 1992, pp 62-4, 1 map.

Most believed that kimberlite magmatism is confined to cratons. The widespread rifting caused widespread mafic and ultramafic activity including traprock, trachybasalt, and kimberlite(?). This is confined to the west Urals where diamonds are found in Palaeogene deposits. However, all attempts to find bedrock sources of diamonds in the Urals have failed. The authors reinterpret aeromagnetic data to derive a sequence of events for the Urals, and conclude that known and presumed kimberlite bodies are in areas E of the White Sea and W of Timan as well as in the Timan and Cisural region. K.A.R.

Diamondiferous kimberlite in Saskatchewan, Canada – a biogeochemical study.

C. E. Dunn. *Journal of Geochemical Exploration*, **47**(1-3),1993, pp 131-41,1 map.

Kimberlite was first reported in this area in 1988. Subsequently more kimberlite pipes have been discovered and the total diamond yield is now 160, of which some are macro-diamonds of gem quality. An investigation was made in 1989 of the kimberlite outcrop at Sturgeon Lake, at that time the only known kimberlite in central Canada, to characterize its biogeochemical signature and assess the value of biogeochemistry in future exploration activities. The vegetation is dominated by *Populus tremuloides*, *Cornus stolonifera*, and *Corylus cornuta*. Although no geobotanical expression of the kimberlite was found, tissue samples of the three species showed a spatial relationship to the kimberlite in enrichment in Ni, Rb, Sr, Cr, Nb, Mg and P, and depletion in Mn and Ba The Ni content of C *stolonifera* twigs was much higher than that of twigs of the other species near the kimberlite; all three species were enriched in Rb and Sr relative

to sites on the surrounding Cretaceous and Quaternary deposits. It is suggested that Rb may be derived from the phlogopites within the kimberlite, and mobilized during weathering as its highly soluble carbonate. It seems that biogeochemical studies of the distribution patterns of, especially, Ni, Rb and Sr, may help in locating kimberlite at shallow depth, particularly if there is upward movement of groundwaters to bring these elements to the root systems of the plants.

R.E.S.

Gem Trade lab notes.

C.W. Fryer, G.R. Crowningshield, T. Moses, K. Hurwit and S.F. McClure. *Gems & Gemology*, **28**(4), 1992, pp 262-7, 15 figs.

A diamond with zig-zag etched dislocation channels is described and illustrated; an Argyle yellow diamond exhibited characteristic etch feature rather like a wheel abrasion; another diamond had long blade-like parallel inclusions reflecting kaleidoscopically when stone was face up; a deep brown octahedral diamond crystal was set in a medieval ring mount. R.K.M.

[Spectroscopic characteristics of yellow and green fancy colour diamond prepared by Koss.] (Japanese)

M. Hayashi. *Journal of The Gemmological Society of Japan*, 17 (1-4), 1992, pp 43-4, 4 figs.

FTIR spectroscopic investigations of yellow and green fancy colour diamond prepared by Koss Co. have been made. Based on the results, the annealing temperature of yellow diamond was evaluated to be 900°C, and that of green diamond a slightly higher temperature. FTIR spectroscopy reveals characteristic peaks more clearly than ordinary spectroscopy. I.S.

[Characterization of diamond synthesized from gas phase.] (Japanese with English abstract)

M. Kamo. *Journal of The Gemmological Society of Japan*, **17** (1-4), 1992, pp 24-30, 10 figs.

This paper reports an outline of diamond synthesis from a gas phase and some properties of diamond prepared by the microwave plasma method, based on the results of Raman, absorption and cathodoluminescence spectroscopies, and secondary ion mass spectroscopy (SIMS) analyses. Single crystals of diamond grown from the gas phase have good crystalline quality, but polycrystalline films grown under the same conditions contain an appreciable amount of double bonds and strains. Contamination of elements from substrate holder can not be neglected for the diamond obtained. Hydrogen and oxygen contents are negligibly small. Other impurities in higher concentration than those found in natural diamond were not detected. I.S.

[Recent studies on impurities in large synthetic diamonds.] (Japanese with English abstract)

J. Kanda. *Journal of The Gemmological Society of Japan*, **17** (1-4), 1992, pp 16-23, 9 figs., 1 table.

This paper summarizes the results of recent studies on the synthesis of large gem quality diamond crystals (the largest in the world so far reported is 15mm across) and on atomic scale impurities, which may influence the colour and optical properties) in both natural and synthetic diamonds. Large diamond crystals of gem quality can be synthesized by temperature gradient method using a seed crystal. By adding appropriate metals, such as Ti, into the solvent metal system, which act as a nitrogen getter, colourless diamond can be synthesized. Growth temperature and annealing temperature are also parameters which control the concentration and state of nitrogen in diamond structure. Boron is easily incorporated into diamond, producing a blue colour whose intensity depends on the type of metals used and the boron concentration. Nickel is also incorporated in the crystal, inducing green and brown colours. These impurities are located selectively depending on growth directions, thus producing growth sectors discernible even by the naked eye. The concentrations of these impurity elements are in general the highest in the {111} growth sectors, followed by the {100}, and then by {110} and {113}. The morphology of large synthetic crystals is principally cubo-octahedral, but often associated with {110}, {113}. I.S.

CL and optical microtopographic studies of Argyle diamonds.

K. Kaneko and H.R. Lang. *Industrial Diamond Review*, **53** (6), 1993, pp 334-7.

External surfaces and polished sections of dia-

monds from the Argyle deposit, Western Australia, have been examined by cathodoluminescence topography and optical micrographic techniques, revealing radiation damage on natural surfaces, complex growth histories and post-growth plastic deformation. Spatially fine-scale variations in nitrogen impurity content correlate closely with differences in abrasion resistance. Lattice misorientations may result from the lattice distortions and rotations generated when closely-spaced slip bands lying on different octahedral planes intersect. R.A.H.

Gem News.

J.I. KOIVULA, R.C. KAMMERLING AND E. FRITSCH. *Gems & Gemology*, **28** (4), 1992, pp 268-79, 14 figs.

Potential diamondiferous pipe found at Giralia, W. Australia; a deep etch cavity in a small diamond resembled a statue of President Lincoln, trigons were present; an update on gem diamond synthesis is given; Tanzania is exploring Lake Victoria region for diamonds; Zimbabwe diamond processing plant at River Ranch reports 5000 carats in three month test. R.K.M.

Gem News.

J.I. KOIVULA, R.C. KAMMERLING AND E. FRITSCH. *Gems & Gemology*, **29** (1), 1993, pp 52-64, 24 figs.

Headed Tucson '93, this paper reports on:-

Diamonds: including natural green transmitters; chameleon stones (colour changes with temperature); Indian briolettes and diamonds with clarity enhancement disclosed. A Swiss company is offering fine five-pointed star-cut diamonds in a variety of colours. R.K.M.

Gem News.

J.I. KOIVULA, R.C. KAMMERLING AND E. FRITSCH. *Gems & Gemology*, **29** (2), 1993, pp 130-41, 24 figs.

Diamonds: a 446ct diamond is reported from Botswana; De Beers market quality high- pressure industrial diamonds with numerous metallic inclusions, 1 to 4ct cost effective, largest 34.80ct, 600 hours in production; quality synthetic diamond films also reported; the Flanders brilliant, a new octagonal-cut, is described and illustrated; Sakha (Yakutia) is building diamond reserves independent of Moscow; Venezuelan diamond production up almost 50 per cent. R.K.M.

Diamond nucleation by hydrogenation of the edges of graphitic precursors.

W. R. L. LAMBRECHT, C. H. LEE, B. SEGALL, J. C. ANGUS, Z. LI AND M. SUNKARA. *Nature*, **364**(6438),1993, pp 607-10.

Calculations suggest that diamond films can nucleate by the initial condensation of graphite and subsequent hydrogenation of the (1100) prism planes along the edge of the graphite particles. R.K.H.

Diamond sources and production: past, present and future.

A.A. LEVINSON, J.J. GURNEY AND M.B. KIRKLEY. *Gems & Gemology*. **28**(4), 1992, pp 234-54. 19 figs.

An exhaustive account of diamond availability from 1600 to 1990, amply illustrated by maps and tables to provide a fascinating paper heavy with significance of vast craton areas as yet scarcely touched. Some figures are rather dark and detail has suffered. R.K.M.

[Identification of natural and synthetic diamonds by a cathodoluminescence method.] (In Japanese with English abstract)

T. MINYATA AND M. KITAMURA. *Journal of The Gemmological Society of Japan*, **17** (1-4), 1992, pp 10-15, 9 figs., 1 table.

Cathodoluminescence topography using scanning electron microscopy has been applied to visualize internal heterogeneity of both rough and brilliant-cut natural diamonds and Sumitomo synthetic rough diamonds. It has been shown that (1) growth sectors of natural diamond consist of flat {111} with or without curved {100} faces, whereas those of synthetic diamond are characterized by flat {111} and {100} faces, and (2) each stone exhibits different patterns of growth sectors, and growth banding indicating the applicability of the method for both identification of natural and synthetic diamonds and finger printing of a cut stone. A convenient index system to arrange the zoning patterns is also presented. I.S.

Two treated-colour synthetic red diamonds seen in the trade.

T.M. MOSES, I. REINITZ, E. FRITSCH AND J.E. SHIGLEY. *Gems & Gemology*, **29**(3), 1993, pp 182-90,

1 table, 10 illus. in colour.

Microscopic examination revealed distinct colour zoning showing square shaped and superimposed yellow areas surrounded by large red areas. The narrow light zones were seen at four locations around the girdle separated by ninety degrees when viewed through the girdle. Metallic opaque inclusions were identified as nickel and iron by EDXRF chemical analysis. Both diamonds were attracted by a simple magnet. Ultraviolet luminescence was striking both in the long- and short-wave. An intense green fluorescence corresponding to the narrow yellow areas showed squares and crosses which phosphoresced the same colour when the short wave UV lamp was turned off. Under long-wave UV radiation there is only a small reddish orange fluorescence at an isolated point near the girdle but this extends to all the large dark red areas under short-wave UV.

Spectroscopy in the visible region showed numerous sharp absorption bands at liquid nitrogen temperatures, several of which could be seen by hand held spectroscope, particularly at 637 and 658nm. In addition there was increased absorption towards the violet and a broad absorption region extending from 500-640nm. Mid-infrared spectra showed that both diamonds were a mixture of types Ib + IaA + IaB and bands at 1050, 1450 and 1502cm^{-1} were present, the latter two due to annealing.

Examination of the visible and infrared spectra showed the lines were due to nickel, iron and nitrogen aggregates. The cause of the colour is almost certainly due to increased absorption towards the UV and the broad absorption band between 450 and 650nm (due to the 'N-V' centre) is a result of laboratory treatment. The orange UV luminescence is most likely due to irradiation and heating. Previous reports of a yellow to greenish- yellow fluorescence to short wave UV radiation refers to yellow untreated synthetic diamonds of pure type Ib in contrast to natural yellow Ib diamonds which rarely show this reaction.

In comparison with natural diamonds, some natural pink diamonds are type IIa with orange fluorescence; no known treated pink diamonds are of this type. Increasing number of pink/red natural diamonds are of type Ia with blue UV fluorescence but none of these showed any type Ib character. Thus all known natural pink to red natural diamonds are readily distinguishable from the stones described. (Unfortunately there is no evidence as to where they might have been treated.) R.J.P.

[Inclusions of sodium fluoride and high-alkali silicate glasses within a xenogenic diamond from granitoids.] (Russian with English abstract)

M. I. Novgorodova, N. V. Trubkin, M. A. Akhmedov and M. Kh. Satvaldiev. *Proceedings of the Russian Mineralogical Society*, **122**(1), 1993, pp 88-96.

Inclusions of silicate glass are reported in diamonds from a pipe-like body (100-150 m diameter) with siliceous cement, cutting through granitic rocks of the Badaytagsky massif, Kuramin Mts, central Tien Shan. The chemical composition of the silicate glass inclusions are tabulated; Na_2O ranges 2.90-20.86, and K_2O ranges 0.69-4.36 wt.%. The alteration of villiaumite under the electron microdiffraction beam is recorded. Comparisons are made with glasses from other diamonds from Zambia, Botswana and Yakutia. R.A.H.

Petrology of a diamond and coesite-bearing metamorphic terrain: Dabie Shan, China.

A.I. Okay. *European Journal of Mineralogy*, **5**(4), 1993, pp 659-75, 2 maps.

The Dabie Shan complex is a large gneiss-granite terrain in the E part of the Qinling orogen in central China; it represents part of the lower continental crust of the Yangtze plate subducted during the Triassic continental collision and consists of several welded gneiss terrains with different metamorphic grades. An eclogite zone is sandwiched between two amphibolite-facies terrains, and consists of a >25 km thick sequence of leucocratic, granoblastic gneiss with eclogite, marble and minor ultramafic bands and lenses. Two subzones with different *P-T* regimes are tentatively distinguished in the eclogite zone. In the hot eclogite zone in the N the eclogites contain garnet, omphacite, zoisite, kyanite, phengite ± Ca-amphibole ± quartz, rutile and very rare coesite as inclusions in garnet. Eclogites also

occur in marble bands where they contain diopsidic pyroxene and grossular-rich garnet with coesite, K-feldspar and diamond inclusions. The eclogite mineral assemblages record *T* of 800 ± 50°C and *P* 18-34 kbar; the presence of coesite and diamond indicate minimum *P* of 29 and 38 kbar, respectively. The ultra-high *P* metamorphism appears to have been regional and to have affected both the eclogites and the host gneisses. The coesite and diamond-free cold eclogite terrain in the S tectonically overlies the hot eclogite terrain and is characterized by the absence of marble-eclogite horizons and by the presence of eclogites with sodic amphiboles (crossite). The mineral assemblage indicates *P-T* conditions of 635 ± 40°C and 18-26 kbar. The retrograde *P-T* path of the hot eclogite terrain appears to be very steep down to < 10 kbar when it was juxtaposed with the cold eclogite terrain R.A.H.

Diamonds and associated minerals in kimberlites and loose sediments of Tersky shore (Kola Peninsula). (Russian with English abstract)

I. V. POLYAKOV AND M. M. KALINKIN. *Proceedings of the Russian Mineralogical Society*, **122**(1), 1993, pp 96-101, 1 map.

Diamond-bearing kimberlite pipes have been discovered on the Tersky shore of the White Sea. Haloes of diamond-associated minerals were found by prospecting in unconsolidated sediments of the area. Chemical compositions for garnets from kimberlites, melilitites and the sediments are reported (Cr_2O_3 < 6.97%). An estimate is made of possible diamond mineralization being of more widespread occurrence in the terrain. R.A.H.

Catodoluminiscencia (CL) y espectros de catodoluminiscencia de diamantes sintéticos experimentales De Beers.

J. PONAHLO. *Boletin del Instituto Gemológico Español*, **35**, 1993, pp 25-38, 8 figs (21 col.), 2 tables.

Synthetic gem-quality diamonds manufactured by De Beers show geometrically-patterned colour zoning under cathodoluminescence. Polarization figures induced by stress have been observed as well as large euhedral crystals of unknown composition. Colours induced by cathodoluminescence are a greenish yellow and blue. Growth lines can be seen in different sectors of the stones. M.O'D.

Famous diamonds.

K.T. RAMCHANDRAN AND B. PORWAL. *Indian Gemmologist*, **4**(1), 1994, pp 20-3.

Thirty-three of the world's most celebrated diamonds are briefly described. M.O'D.

De Beers near colourless-to-blue experimental gem-quality synthetic diamonds.

T. ROONEY, C.M. WELBOURN, J.E. SHIGLEY, E. FRITSCH, I. REINITZ. *Gems & Gemology*, **29**(1), 1993, pp 38-45, 10 figs.

Five small boron-doped diamonds had diagnostic features not previously reported in synthetic diamond, internal zones of blue, yellow and near colourless gave near colourless to greenish-blue and blue face-up tints in faceted stones. Could be confused with natural diamond if made commercially, but fluorescence and inclusions should detect them. R.K.M.

Diamond growth history from in situ measurement of Pb and S isotopic compositions of sulfide inclusions.

R. L. RUDNICK, C. S. ELDRIDGE AND G. P. BULANOVA. *Geology*, **21**(1), 1993, pp 13-16.

The S and Pb isotopic compositions of mantle sulphide encapsulated within diamonds from under the Siberian craton were determined and the results compared with those of African counterparts. $\delta^{34}S$ values of the Siberian sulphides do not deviate significantly from the mantle value, but Pb isotopic compositions are highly variable confirming the compositional differences between peridotitic and eclogitic suite inclusions in African diamond inclusions. The large variation in Pb isotopic compositions of sulphides within a single peridotitic suite diamond documented three stages of diamond growth: 1) crystallization of the core near 2000 m.y., 2) growth of its outer zone in an environment with high U/Pb ratio similar to that of eclogitic diamond, 3) growth of the rim near the time of kimberlite emplacement. L.C.H.

Relación del grado de color de los diamantes con la banda de absorción N3 (415.5nm) y con

su respuesta a la luz ultravioleta.

L. SARMIENTO AND C. SAPALSKI. *Boletin del Instituto Gemológico Español*, **35**, 1993, pp 50-6, 9 tables.

5298 faceted gem-quality diamonds examined gave rise to the conclusions that nitrogen was present in 88 per cent of the specimens. The N absorption was the N3 type with absorption at 415.5nm and showed in 53 per cent of D grade stones and in more than 90 per cent of stones graded G or lower. There was evidence of a direct relationship between the intensity of the yellow colour and the intensity of the N3 absorption. Only 32 per cent of the specimens responded to UV and no clear relationship between colour grade and fluorescence was established. M.O'D.

Contrasting kimberlites and lamproites.

B. H. SCOTT SMITH, *Exploration & Mining Geology*, 1(4), 1992, pp 371-381, 1 map.

Over the past 20 years lamproites have joined kimberlites as the only two known primary sources of economic quantities of diamonds. Here the petrography, primary and xenocrystic mineralogy, and pipe geology of these petrogenetically separate rocks types is contrasted. The petrographic discrimination of kimberlites and lamproites from each other, as well as from other rock types found during prospecting, is discussed. Kimberlites and lamproites can be classified texturally and mineralogically, highlighting the differences between, and among, lamproites and kimberlites. The implications of these differences for diamond exploration programmes are discussed, with particular emphasis on the application of petrography. R.E.S.

Two near-colourless General Electric type-IIA synthetic diamond crystals.

J.E. SHIGLEY, E. FRITSCH AND I. REINITZ. *Gems & Gemology*, **29**(3), 1993, pp 191-7, 7 illus. in colour.

Isotopically pure ^{12}C diamonds were synthesized for use as heat sinks in telecommunications and integrated circuits. Unlike previous synthetic diamonds the source material was a thin polycrystalline layer of synthetic diamond grown from ^{12}C methane gas by a low pressure chemical vapour deposition. This new method also uses a transition metal flux which removes nitrogen and boron impurities.

The colour was L-M a faint yellow. No colour zoning was seen. Microscopy revealed clusters of tiny triangular or lozenge shaped tabular inclusions. These are possibly metallic as the stones were attracted to a simple magnet. Such inclusions are virtually unknown in the natural stones. The stones showed anomalous strain birefringence between crossed polars, and although the stones were inert to long-wave UV radiation, they fluoresced a weak yellowish orange to short-wave UV. This greater response to short wave UV is a distinctive property of some synthetic diamonds. Both stones showed cathodoluminescence when exposed to X-rays in a vacuum chamber.

Further studies on type IIa diamonds will be required to confirm these preliminary identification criteria. R.J.P.

The gemological properties of Russian gem-quality synthetic yellow diamonds.

J.E. SHIGLEY, E. FRITSCH, J.I. KOIVULA, N.V. SOBOLEV, I.Y. MALINOVSKY, Y.N. PALYANOV. *Gems & Gemology*, **29**(4), 1993, pp 228-47, 2 tables, 24 illus. in colour.

Seven as-grown samples and three treated by post-growth annealing at high pressure and high temperature (HPHT) revealed distinctive gemmological properties including colour and luminescence zoning, metallic inclusions, graining and sharp absorption bands in the visible. Although easily identifiable some properties differed from previous yellow synthetics *viz*. UV luminescence and optical absorption spectra. All but one fluoresced to long-wave UV and the HPHT-treated stones fluoresced stronger to long-wave UV radiation than to short-wave UV radiation (typical of fluorescing natural diamonds). Thus UV luminescence (i.e. short wave stronger than long wave) can no longer be considered diagnostic for synthetic yellow diamonds. Additionally HPHT treated stones showed a moderate to strong yellow phosphorescence to UV radiation. Most of the samples showed a green luminescence to visible light. These synthetic diamonds showed a distinctive spectrum, and HPHT treated stones showed additional

sharp bands visible at low temperature with a handheld spectroscope. It may be difficult to establish simple identification criteria for gem-quality Russian synthetic diamonds. R.J.P.

Dependence of the cathodoluminescence of diamond films on deposition temperature.

Y. H. SHING *ET AL. Journal of Applied Physics*, **71** (12), 1992, pp 6036-8 (Jun 15), 4 figs.

The deposition temperature dependence of the cathodoluminescence (CL) of diamond thin films grown by microwave plasma-assisted CVD has been investigated. Depositions were made in the temperature range of 400 to 750°C at a pressure of 10 Ton, with a gas mixture of 5% CH_4 and 5% O_2 in hydrogen. The intensity of the luminescent peak at 430nm was used as a measure of diamond quality for the film. This peak was found to be a maximum above 600°C. Examination of the intensities of CL emissions associated with nitrogen and silicon impurities at 530, 560 and 740nm indicate incorporation of these impurities is more efficient at temperatures above 600°C. Film quality was thus found to be an optimisation of competing mechanisms, i.e. improvement of diamond quality as evidenced by the intensity of the 430nm peak, with the apparent activation of impurities and vacancy defects at elevated temperatures. J.H.

[Kimberlite magma evolution and diamond genesis.] (Russian with English abstract)

V.S. SHKODZINSKII AND V.V. BESKROVANOV. *Zapiski Vses. Min. Obsheh*, **121** (6), 1992, pp 21-32.

Results of quantitive modelling of the evolution of kimberlite indicate that: (1) it was formed by compression-dissipative remelting with the squeezing and extrusion of a substratum of sub-melted kimberlite composition from asthenospheric depth through tectonic fault zones; (2) the formation of the diatreme and most of the kimberlite breccia is a result of explosive disintegration of the upper part of the magmatic column under the influence of excessive P in the fluid phase preserved by decompression hardening of the melt during its ascent; (3) the best conditions for diamond conservation are in the explosive breccia because of the rapid decrease in *T* (through several hundred degrees) due to adiabatic dilation of gas and heat expansion within xenoliths of sedimentary rocks; (4) diamond crystallizes as a solid-phase product of incongruent melting during the ascent of the kimberlite magma, according to a reaction of the type CO_2 + CH_4 + solid phases →melt + C. This mechanism of diamond genesis is confirmed by the presence of three zones (central, intermediate, peripheral) within most of the diamond crystals. The parameters of these zones testify to the gradual dilution of the media during the growth of the crystals, with a decrease in its oversaturation with carbon and increase in *T*. R.A.H.

Nd and Sr isotopes from diamondiferous eclogites, Udachnaya Kimberlite Pipe, Yakutia, Siberia: evidence of differentiation in the early Earth?

G. A. SNYDER, E. A. JERDE, L A. TAYLOR, A. N. HALLIDAY, V. N. SOBOLEV AND N. V. SOBOLEV. *Earth & Planetary Science Letters*, **118**(1-4), 1993, pp 91-100.

Nd and Sr isotopic data from diamond bearing eclogites in the Udachnaya Kimberlite are interpreted as indicating an early (> 4000 m. y.) differentiation event, whereby the mantle split into complementary depleted and enriched reservoirs. Reconstructed whole-rock $^{87}Sr/^{86}Sr$ ratios (present-day) range from 0.70151 to 0.70315 and are-consistent with a mantle origin for these rocks. The Nd isotopic evolution lines of four samples (U-5, U37, U-41 and U-79) converge at 2200-2700 m.y. Sample U-5 is unique in exhibiting the most enriched signature of any of the samples (present-day ε_{Nd} of -20), and this sample points unequivocally to an old, enriched component. A complementary depleted mantle component is suggested by samples U-86 and U-25 which yield ε_{Nd} values (at 2200 m. y.) of +13 and +7, respectively. The two mantle reservoirs may have formed before 4000 m.y., and evolved separately until 2200-2700 m.y. At that time, the reservoirs were melted, forming eclogites both as residues (from the enriched reservoir) and as partial melts of peridotite (from the depleted reservoir), resulting in demonstrably different histories for eclogites from the same locality. R.A.H.

A diamond-bearing xenolith of garnet peridotite from the 'Mir' kimberlite pipe.

Z. V. SPETSIUS, *Akademia Nauk USSR, Doklady Earth Sciences Section*, **313**(1-6), 1992, pp 200-203.

The xenolith nodule is described, and its mineralogy is given and discussed. The chemical composition is tabulated, and two electron micrographs are shown. The diamonds are described. The work supports the hypothesis that diamonds in kimberlites are xenogenic. K.A.R.

[Basic concept for the identification of natural and synthetic diamonds.] (Japanese with English abstract)

I. SUNAGAWA. *Journal of the Gemmological Society of Japan*, **17** (1-4), 1992, pp 3-9, 8 figs., 1 table.

This is a paper discussing the fundamental concept to be based in the forthcoming necessity of identification between natural and synthetic diamonds. The main difference between natural and synthetic diamonds is the difference of solvents in which diamond single crystals grow; natural diamond grew from silicate solution, whereas synthetic diamond grows from metallic solution. The difference leads to a distinct difference in their morphological characteristics and growth processes. Spiral and layer growth can occur only on {111} surface and never on {100} in the case of natural diamond, whereas they can be expected on both {111} and {100} surfaces in synthetic diamonds. The difference comes from the difference of solvents, which may modify solid-solution interface structure. Due to this difference, natural and synthetic crystals exhibit different internal morphologies, i.e. growth sectors, growth banding etc., which can be used as diagnostic features to differentiate between the two, if appropriate methods are used to visualize such heterogeneities and imperfections in single crystalline cut stones. Polarization microscopy, cathodoluminescence tomography, laser beam tomography, X-ray topography, etc., are useful methods for such purposes. I.S.

The diamond deposits of the Mandala Basin, SE Guinea, West Africa.

D.G. SUTHERLAND. *Transactions of the Royal Society of Edinburgh*, **84**(2), 1993, pp 137-49, 4 maps.

This drainage basin in the central part of the West African craton, immediately to the S of the regional watershed contains numerous intrusions of kimberlite dykes. The kimberlites range in grade from being apparently barren to having a high diamond content. The presence of other undiscovered kimberlites can be inferred from the distribution, chemistry and abundance of kimberlite indicator minerals and variations in diamond size and character. Secondary diamond deposits are widespread with the main concentrations in the present and former Mandala valley bottoms; tributaries have lower diamond contents. Systematic variations in the alluvial diamond characteristics can be explained in terms of diamond sources as well as transport of the diamonds away from these sources. Since the Pliocene or early Pleistocene the Mandala has been rejuvenated with incision of the main channel by < 26m, which has led to flushing of the tributaries and storage of sediment, including diamonds, in the principal channel. The abundance of diamonds ranges from 1 to 37 stones/m^3, with average weights of 0.18ct but with individual stones > 1ct constituting > 17 per cent of the diamonds, e.g. where the Mandala crosses the Bouro dyke zone. R.A.H.

[Reactor irradiation and heat treatment examinations on diamonds.] (Japanese with English abstract)

I. UMEDA AND K. IIDA. *Journal of the Gemmological Society of Japan*, **17** (1-4), 1992, pp 31-6, 7 figs.

Absorption spectroscopic investigations were made to trace how spectrographs of sample diamond crystals changed by irradiating the samples in a research reactor, and the subsequent heat treatment so that the optimum conditions for dose intensity and annealing temperature may be found quantitatively. A range of dose, 10^{14} ~10^{16} fast neutrons/cm^2, and of annealing temperature, 300 ~700°C were investigated. An experiment of very high dose irradiation (10^{16} 10^{17} fast neutrons/cm^2), which changes the colour to black was also performed. In this case, the black colour changed to orange, through light red, and brown by subsequent heat treatment at 600 ~700°C. I.S.

Nano-structures on polished diamond surfaces.

W.J.P. VAN ENCKEVORT, M.S. COUTO AND M. SEAL. *Industrial Diamond Review*, **53**(6), 1993, pp 323-7.

Despite many debates in the past, the actual mechanism of diamond polishing is still unclear. To obtain more information on this, the morphologies of polished surfaces of several semiconducting diamonds have been examined by scanning tunnelling microscopy. The results of this topographic study are presented and provide essential new insights into the process of diamond polishing, but further questions arise. Abrasion along the hard directions proceeds via fracture and chipping on a nanometre scale; material removal in the softer directions seems to take place by single pass grooving by diamond particles at supercritical loads followed by a polishing action by particles at subcritical loads. Problems to be solved include the actual mechanism of 'plastic' grooving and how the extreme dependence of polishing rate on crystal orientation can be explained now that the Tolkowsky cleavage model must be abandoned. R.A.H.

Micas in diamond-bearing metamorphic rocks of northern Kazakhstan.

M. A. VAVILOV, N. V. SOBOLEV AND V. S. SHATSKIY. *Akademia Nauk USSR, Doklady Earth Sciences Section*, **319A**(6), 1993, pp 177-182.

The petrography and mineralogy of these diamond-bearing, metamorphic rocks are described. Representative chemical analyses are tabulated and plotted. It is concluded that the data on the micas support the earlier conclusion that diamond in some metamorphic rocks crystallized in the thermodynamic stability range with $P > 40$ kbar. K.A.R.

Implanted radiogenic and other noble gases in crustal diamonds from northern Kazakhstan.

A.B. VERCHOVSKY, U. OTT AND F. BEGEMANN. *Earth and Planetary Science Letters*, **120**(3-4), 1993, pp 87-102.

Noble gases were extracted in steps from grain-size fractions of microdiamonds (< 100 μm) from the Kokchetav Massif, N Kazakhstan, by pyrolysis and combustion. The amount of ^{4}He in the diamonds themselves (liberated by combustion) shows a $1/r$ dependence on grain size (r). For grain diameters > 15 μm, the amount also decreases with the combustion step. Both results are evidence that ^{4}He was implanted into the diamonds from α-decaying elements in the surrounding matrix. The saturation concentration of ^{4}He (5.6×10^{-4} cm^3 STP/g) is among the highest observed in any terrestrial diamonds. Fission xenon from the spontaneous fission of ^{238}U accompanies the radiogenic ^{4}He; the ^{136}Xe$_f$/^{4}He ratio of $(2.5 \pm 0.3) \times 10^{-9}$ agrees well with the production ratio of 2.3×10^{-9} expected in a reservoir where Th/U ~ 3.3. Radiogenic ^{40}Ar is predominantly (> 90%) set free upon combustion; it also resides in the diamonds and appears to have been incorporated into the diamonds on formation. On the other hand, ^{3}He is mainly released during pyrolysis and hence is apparently carried by 'contaminants'. The amount in the diamonds proper is of the order of 4×10^{-12} cm^3 STP/g, with a ^{3}He/^{4}HE ratio of 1×10^{-8}. Excess ^{21}Ne, similarly, appears to be present in contaminants as well as in the diamonds themselves. These two nuclides in the contaminants must have a nucleogenic origin, but it is difficult to explain their abundance. R.A.H.

Dynamics of the crystal lattice of lonsdaleite.

M. F. VIGASINA. *Akademia Nauk USSR, Doklady Earth Sciences Section*, **317**(2), 1993, pp 188-90.

This is a hexagonal wurtzite-like polymorph of diamond. The vibrational frequencies are tabulated and the unit cell is sketched The Raman spectra are plotted. The measurements were done on a synthetic specimen prepared by explosion. The results permit the identification of fine lamellae in diamond monocrystals. Also the study leads to physical models for the force fields of other compounds similar to diamond. K.A.R.

Large <110>-segmented helical dislocations in natural diamond.

J.C. WALMSLEY AND A.R. LANG. *Philosophical Magazine Letters*, **65**(3), 1992, pp 159-65.

Helical dislocations composed of very straight <110> line segments (helical shape due to climb from original screw orientation) have been observed by TEM in a region of diamond where

growth had occurred on non-faceted, near -{100} orientation surfaces. Of the six <110> segments forming each turn of the helix, the two which are pure edge segments normal to the helix axial Burgers vector are 10x longer than the others, thereby producing strong flattening of the helix in the cube plane containing the axis of the helix. Detailed study of one of 30 such helices revealed that the axis of the helix was marked by a line of vesicles, diameters 20-130nm, producing matrix strain contrast attributed to fluid under pressure within the vesicles. R.A.H.

Carbon in the core.

B. J. Wood. *Earth and Planetary Science Letters*, **117**(34), 1993, pp 593-607.

Although C is extremely abundant in the solar system (10 x Si, 20 x S) and in C1 carbonaceous chondrites (3.2 wt.%) and it dissolves readily in liquid Fe at low *P* (4.3 wt.% at 1420 K), it is rarely considered as a potential light element in the Fe-rich core, because it is volatile even at low *T* as CO. Carbon volatility is shown to be a strongly *P*-dependent phenomenon that is important only during condensation from a solar gas (~10^{-3} atm), and not at the *P* and *T* generated during planetary accretion and differentiation (0.01-5 GPa). Thus, impact heating and degassing of the protoearth should have led to an Fe-rich melt with ~ 2-4 wt.% C, compared to the 0.01-0.6 wt.% in iron meteorites and 0.3-3 ppm C predicted to be present in Fe condensed from the solar gas. Experiments (to 9 GPa) and thermodynamic calculations on the systems Fe-C and Fe-C-S show that C solubility in Fe melt increases slightly with *P* but that C could not conceivably constitute more than half the light element content of the core. However, the addition of even very small amounts of C (< 1%) to liquids containing Fe and a light element such as S has a dramatic effect on the properties of the system. At 330 GPa (inner core – outer core boundary) 0.3% of C is sufficient to stabilize Fe_3C, rather than ε-Fe, as the first phase to crystallize in melts with ~ 10% S. Given probable inner core *T* of ~5000-6000 K, both ~ε–Fe and the higher P α'-Fe are too dense to explain the inner core *D* of 12.85 g/cm^3. The stability of iron carbide provides a possible solution and is shown to acquire the inner core *D* in the right *P-T* range. R.A.H.

Gems and Minerals

Reactor-irradiated green topaz.

C.E. Ashbough III and J.E. Shigley. *Gems & Gemology*, **29**(2), 1993, pp 119-21, 6 figs.

So-called 'Ocean Green' topaz is identified as reactor irradiated, probably at higher temperatures than the 'London blue' material. These green stones have residual radio- activity and are prone to fade rapidly in bright sunlight. R.K.M.

L'aigue-marine au Brésil [final part].

J.-P. Cassedanne and J.-N. Alves. *Revue de gemmologie*, **118**, 1994, pp 21-3.

Appendix in the form of a table listing occurrences and related properties of Brazilian aquamarine. Entries are arranged by state then by individual mine. Notable years of production are given as well as geographical coordinates, size of deposit, type of working and host rock. M.O'D.

Emerald dating through $^{40}Ar/^{39}Ar$ step-heating and laser spot analysis of syngenetic phlogopite.

A. Cheilletz, G. Féraud, G. Giuliani and G. Ruffet. *Earth and Planetary Science Letters*, **120** (3-4), 1993, pp 473-85, 1 map.

Emerald in K-metasomatic rocks at the contact of the Carnaíba leucogranite with serpentinite, Bahia State, Brazil, gave ages of 1951 ± 8 and 1934 ± 8 m.y. for the Trecho Velho and Braulia occurrences, respectively. The procedure combines step- heating and spot fusion on two types of phlogopite crystals: (1) bulk samples and individual grains extracted from the enclosing metasomatic host rocks and (2) syngenetic solid inclusions precipitated along growing zones of the emerald host crystals. A second procedure uses in situ laser probe measurements on rock sections. Chemical analysis of an emerald crystal from Trecho Velho gave SiO_2 64.52, TiO_2 < 0.01, Al_2O_3 16.80, Fe_2O_3 0.57, MnO < 0.01, MgO 1.18, CaO 0.25, Na_2O 1.20, K_2O 0.038, Rb_2O 0.0038, H_2O 2.42, BeO 13.26, Li 0.0684, Cs 0.1045, V 0.0068, Cr

0.0480, Zn 0.0050, = 100.47; EPMA results are given for a muscovite and for phlogopites both outside and inside emerald. All these results are consistent with the fast cooling of the whole granite hydrothermal system and place the age of the Carnaíba granite-related emerald deposits as being within the Transamazonian orogenesis.

R.A.H.

Single-crystal NMR studies of low-concentration hydrous species in minerals: grossular garnet.

H. Cho and G.R. Rossman. *American Mineralogist*, **78** (11-12), 1993, pp 1149-64, 4 tables, 16 figs. in black-and-white.

Garnets containing low (OH) levels were examined by detailed solid-state proton NMR. Stones examined included a colourless and a pale orange grossular from Asbestos, Quebec, and a colourless grossular from the Lelatema Hills, Tanzania. These crystals showed a broad line at 40kHz with a weaker feature superimposed. Examination of multiple-quantum spectra shows that in the asbestos specimen the dominant cluster size is two protons whereas in the Tanzanian specimen there was a mixture of two proton and four proton clusters. An average interproton separation for the grossular samples was 1.69Å; the low levels of (OH) were 0.2-0.3wt% as H_2O.

M.O'D.

Rainbow Garnet: Das Geheimnis der irisierenden Andradite aus Mexico.

G. Clark. *Lapis*, **19** (4), 1994, pp 23-6, 6 illus. in colour.

A variety of andradite displaying colourful iridescence is reported from the Sierra Madre area of Mexico. The andradite is found in schists in the western part of the Sierra Madre. Cut stones show iridescent colours against a blue-green or yellow-orange background. One star stone is illustrated and comparisons with spectrolite are made.

M.O'D.

Aplicación de técnicas de microanálisis de rayos X al estudio de inclusiones en gemas.

J.S. Cózar. *Boletin del Instituto Gemológico Español*, **35**, 1993, pp 40-8, 13 illus. in black-and-white, 20 in colour, 7 figs.

Inclusions in sapphire, quartz, emerald, topaz and ruby were studied by various X-ray techniques applied to microanalysis. The analysis of F, O, N and C was made possible by the use of an ultrafine window in the detector. Sapphire from Sri Lanka was found to contain negative crystals filled with iron hydroxides, aluminium hydroxides and colloidal silica: quartz from La Unión, Cartagena, was found to contain manganoan calcite in radiating fibres and dendritic sulphur compounds with Fe, Pb and Sb: Brazil emerald showed spearhead-like twinned crystals of rutile: Brazilian colourless topaz showed almandine-spessartine: Thai ruby was found to contain microcavities in veils, the cavities filled with concretions of calcium carbonate.

M.O'D.

A prospector's guide map to the gem deposits of Sri Lanka.

C.B. Dissanayake and M.S. Rupasinghe. *Gems & Gemology*, **29**(3), 1993, pp 173-81, 2 tables, 6 illus. in colour.

Sri Lanka has probably the widest variety of gem minerals of any country and the greatest proportion of land underlain by gem deposits. Although haphazard prospecting has been reasonably successful for over two thousand years, this is the first occasion when a scientific map has been compiled. Criteria include lithology and topography, stream-drainage density, presence of alluvium and the nature and abundance of heavy metals. Gem potential was divided into four classes. As expected most of the new probable areas surround existing known deposits. Analysis of heavy minerals in stream sediments showed that garnets, spinels and zircons were the most useful indicators of gem potential.

It is suggested that large amounts of gem minerals have been washed into the sea particularly in the south west regions and future targets should be the mouths of rivers and their near-shore regions.

R.J.P.

Heat treating the sapphires of Rock Creek, Montana.

J.L. Emmett and T.R. Douthit. *Gems & Gemology*, **29**(4), 1993, pp 250-71, 2 tables, 25 illus. in colour.

A large percentage of pale blue, pale green or

near-colourless sapphires could be converted into well saturated blue and yellow colours. Oxidizing conditions which were tolerant of time and temperature easily produced yellow hues. Blue colours resulted under reducing conditions but high iron concentrations increased the possibility of hercynite precipitation. Samples of exact size with parallel polished sides were specially produced to enable accurate before and after treatment studies to be carried out. The theoretical background to reduction/oxidation conditions was very thoroughly covered.

The strong yellow colours produced under oxidising conditions previously thought to be due to Fe^{3+} absorption was shown to be the result of a broad absorption band extending from 600nm to the shortest visible wavelengths. The suggested cause is divalent ion-hole pairs or colour centres in the crystal. Blue coloration was due to rutile dissolution in the presence of dissolved iron, followed by reduction of some of the iron.

The authors concluded with a timely warning of the explosive nature of reducing gases when mixed with air or oxygen. R.J.P.

Gem trade lab notes.

C.W. Fryer, G.R. Crowningshield, T. Moses, K. Hurwit, R.C. Kammerling and S.F. McClure. *Gems & Gemology*, **28**(4), 1992, pp 262-7, 15 figs.

Lechleitner type 'emeralds' in a brooch had been polished very lightly if at all, characteristic reticulation seen at junction layer. A pink cabochon of hydro-grossular had low RI (1.69) and SG (3.30); a black opal with a truly black background, and a 12mm pinkish purple pearl from Chattahoochee River, Alabama, are illustrated and described synthetic green quartz, purporting to be natural from Brazil, submitted for testing.

An unusual sapphire zoned in pink and orange is illustrated and described; a heat- diffusion treated sapphire had abraded facet edges as if paper-worn, does this treatment leave some stones more prone to wear? A heat-treated yellow sapphire showed yellow fluorescence to SUV, due to complex combination of orange and blue fluorescence; a synthetic purple star sapphire was unusually translucent; a bi-colour green and blue zoisite owed green to Cr and blue to V. R.K.M.

Gem trade lab notes.

C.W. Fryer, G.R. Crowningshield, T. Moses, K. Hurwit, R.C. Kammerling and S.F. McClure. *Gems & Gemology*, **29**(1), 1993, pp 46-51, 17 figs.

A synthetic alexandrite with slightly curved colour banding and short acicular inclusions was thought to be Czochralski-pulled; a green beryl gave a red reaction through the emerald filter but colour was due to a coating on the pavilion facets; yellow-green beryls had Maxixe-type absorption suggesting irradiation; a black fingerprint-like inclusion was seen in a blue electrically-conducting diamond; another diamond had laser drilled holes to provide for setting; other diamonds had been notched below their girdles to allow invisible setting; another had been laser drilled to facilitate filling a fracture; a greenish- yellow diamond was found to have been irradiated with americium and has a legal safety date in the States some 4500 years in the future.

A possibly Russian synthetic emerald had been cut unusually as a cabochon; an earlier report on a phlogopite ceramic imitation of lapis lazuli is updated; and a large faceted lazulite and a yellow cat's-eye orthoclase are reported, as was an unusually metallic lustred pair of abalone pearls. R.K.M.

Gem trade lab notes.

C.W. Fryer, G.R. Crowningshield, T. Moses, K. Hurwit, R.C. Kammerling and S.F. McClure. *Gems & Gemology*, **29**(2), 1993, pp 122-8, 19 figs.

Clarified amber, heat-treated to improve surface colour, faded under strong light and fluoresced unusually orange; a diamond had extensive difficult-to-see filled fractures like low-relief fingerprints; an unusual V-shaped iridescence seen in another diamond; small diamonds set in plastic gave 'simulant' readings on thermal conductivity meter, UV fluorescence proved them real; an irradiated green diamond was radio-active and illegal for US sale until 2192.

A carved head of Emperor Nero as a child was identified as emerald by SG and chrome absorption; a deep blue-green euclase gave chrome

absorption lines; a fine suite of turquoise jewellery contained some examples of the rare 'bone turquoise' odontolite.

A natural black cultured pearl had a dimpled surface like a golf ball [or an orange]; a badly eroded cultured earstud gives rise to advice on pearl care; the back of a large half pearl illustrated the natural concentric layer structure very effectively. R.K.M.

Gem trade lab notes.

C.W. Fryer, G.R. Crowningshield, K. Hurwit, R.C. Kammerling and S.F. McClure. *Gems & Gemology*, 29(3), 1993, pp 198-205, 19 illus. in colour.

A necklace of baroque amber 'nuggets' showing heat induced spangles which darkened on exposure to strong light possibly due to oxidation; a brown-pink diamond showing rare 'green graining' was shown to be natural by its spectrum; a light violet-grey diamond explained as an optical combination of grey and pink zones shown to be of type IIa and IIb; a light yellow diamond showing a clear octahedral strain phantom defined by first- order interference colours; an unusual tablet reminiscent of a mass of actinolite crystals proved to be devitrified glass; a treated jadeite pendant was shown to have natural colouring but an infra-red spectrum denoting polymer treatment; a grey pearl set as a brooch with a bird motif was shown to be natural-colour cultured pearl containing two beads; a string of cultured pearls showed severe erosion by skin contact and lack of after-wear care; a colour-zoned pink quartz showing a UV absorption spectrum similar to that of amethyst and traces of iron by EDXRF analysis was simply reported as pink quartz; an imitation of a water-worn ruby crystal was shown to be synthetic by EDXRF analysis which showed a typical melt-produced trace element composition; a pair of earrings set with invisibly mounted square cut-rubies were shown to be flame-fusion synthetics. R.J.P.

Gem trade lab notes.

C.W. Fryer, G.R. Crowningshield, K. Hurwit, R.C. Kammerling and S.F. McClure. *Gems & Gemology*, 29(4), 1993, pp 278-84, 17 illus. in colour.

A brownish-yellow carving allegedly sixteenth century proved to be cubic zirconia; A cyclotron-treated round diamond showed an asymmetric umbrella effect which was thought due to treatment by an old cyclotron at Columbia University; a natural fancy dark yellowish-brown diamond showed unusual brown radiation stains; a greyish-green diamond showed numerous brown radiation stains and an unusual 'melted' cavity; a faceted yellow synthetic diamond exhibited features of a synthetic and suggested a Russian origin; an emerald with large filled etch channels had been treated with a synthetic resin and an attempt made to polymerize the surface but the interior was fluid as shown by a movable bubble; filled fractures in garnets were detected by the careful use of a hot point needle; a necklace of iridescent beads was shown to be orthoamphibole 'Nuummite'; a carved mask in rock contained one or more orthopyroxenes. A multi-stranded necklace containing both natural and cultured pearls showed 'hammering' effects on the natural pearls which appeared to have been inflicted with a ball pein hammer; synthetic ruby rough was easily identified by the curved striae shown using a brightfield/immersion technique; a set sapphire appeared to show curved striae on exposure to short-wave UV radiation but its uniform colour caused a re- examination of the unset stone which then showed evidence of altered silk and the striae under immersion were normal parallel growth planes. Another sapphire showed diffusion treatment obscured by the mounting; a dark green YAG showed elongated gas bubbles sheathed in fine layers of blue colouration with slightly curved parallel graining and scattered small crystals with stress fractures. R.J.P.

Les perles rouges de Pinna nobilis.

J.-P. Gauthier, J. Caseiro and B. Lasnier. *Revue de gemmologie*, 118, 2-4, 1994, 6 photos, 4 in colour.

Pearls of a pinkish-red colour are retrieved from Pinna nobilis, a bivalve found at depths between 3 and 30m in the Mediterranean. Specimens may reach nearly 20mm in length and have a mainly calcitic content. Sections of the

pearls show a radiating fibrous structure.

M.O'D.

The difference between the solubility of quartz and chalcedony: the cause?

S. R. GÍSLASON, P. J. HEANEY, D. R. VEBLEN AND L. K. T. LIVI. *Chemical Geology including Isotope Geology*, **107**(3-4), 1993, pp 363-6.

Chalcedony is a mixture of quartz and moganite, a little known silica polymorph. Possible causes for the enhanced solubility of chalcedony include small crystal size, high defect concentration due to pervasive Brazil twinning and the incorporation of moganite. The solubility of moganite and its surface free energy are unknown, but indirect evidence suggests that it is more soluble than quartz. R.A. H.

Die aussergewoehnlichen Eigenschaften von Kascholong-Opal aus einem Neuentdeckten Vorkommen im Oman.

I. GUBA. *Zeitschrift der Deutschen Gemmologischen Gesellschaft*, **42**(4), 1993, pp 141-8, 1 diagram, 6 illus. in colour, bibl.

A new deposit of rare opal varieties cashalong and prasopal has recently been discovered in the ophiolites of the Oman mountains near Muscat/Oman. Similar but smaller deposits have been known in Poland and Mexico. Both varieties are intergrown and grading into each other. The extraordinary characteristic of cashalong in particular is its high porosity and capillary wettability. The stone is easily polished and engraved and its use for cameos and in composition stones is suggested. Because of its porosity it will retain perfumes for a long time and can be used as a combined piece of jewellery and perfume flask. It is easily dyed and can therefore be used as simulant for turquoise, malachite, amber, coral, etc. Other uses suggested are in aromatherapy, filter or absorption medium, slow coolant and possibly as implant (?). E.S.

A cobalt-rich spinel inclusion in a sapphire from Bo Ploi, Thailand.

J. GUO, W.L. GRIFFIN AND S.Y. O'REILLY. *Mineralogical Magazine*, **58**(2), 1994, pp 247-58, 1 map.

A gem-quality blue sapphire from Bo Ploi contains a composite inclusion consisting of Co-rich spinel (~200 μm) and a glassy phase. A combination of EPMA and proton microprobe techniques gave the composition of this spinel as Al_2O_3 48.18—61.27, CoO 19.7—22.84, Cr_2O_3 0—12.28, FeO 8.64—9.67, MgO 6.04—6.89, TiO_2 0.49—0.73%, Ni 2251—2532, Zn 335-371, Mn < 177—849, Ga 113—153, Nb 24—1252, Zr < 4—167, Sn 22—428, As < 4—56, Sr < 4—59, Ag 13—64 ppm. Transitional elements decrease in abundance from core to rim of the spinel while the other elements increase. Crystal chemical considerations suggest that a vacancy-creating substitution mechanism may be operative in the Co-rich spinel: $3\,Co^{2+} = 2\,Al^{3+} + {}^{[4]}[\ ]$. The coexisting glassy phase may be the product of heating by the host basaltic magma. This unusual spinel [with average composition near $(Co_{0.89}Mg_{0.27}Fe_{0.26})(Al_{1.8}Cr_{0.2})O_4$] is considered to be the result of a complex magma mixing process in the lower crust. R.A.H.

Sapphires from Changle in Shandong Province, China.

J. GUO, F. WANG, G. YAKOUMELOS. *Gems & Gemology*, **28**(4), 1992, pp 255-60, 7 figs.

Significant quantities of sapphire have been found in situ in basalt in Changle [Chang- Lee?] county, colours ranging through dark blue, blue, greenish-blue and yellow. Area has produced alluvial sapphire for some time but this basalt deposit is considered to be unique in size. Some stones strongly zoned. At present a small operation, mining is largely by hand, but mechanization is planned and potential appears to be large. Constants as normal for sapphire, little dichroism, red zircon, columbite, feldspar, ilmenite and spinel were seen as inclusions.

R.K.M.

Gemmologische Kurzinformationen.

U. HENN AND H. BANK. *Zeitschrift der Deutschen Gemmologischen Gesellschaft*, **42**(2-3), 1993, pp 163-67, 1 table, 4 illus. in colour, bibl.

The first note deals with a new ruby find in Myanmar, in the Mogok district, at Mong Hsu, east of Mandalay. The rough is on the dark side and may be lightened by heating with borax and sodium hydrogen phosphate, remains of which can be found in cracks and fractures, RI 1.762-

1.770, DR 0.008, SG 3.98.

The second note describes spessartines from Namibia, which were offered in Tucson as 'hollandine' (because of their orange colour). The stones are found as rhombdodecahedra near a river on the border with Angola. They have RI 1.790-1.796, SG 4.04-4.15. The largest cut stone weighed 55.4ct.

The rest of the notes mention triphylite and triplite from Brazil (the first being greenish-blue lithium phosphate, the second a complex phosphate black with blue sheen and cat's-eye effect); synthetic diamonds from Russia (yellow rough, the largest crystal weighing 0.86ct); synthetic rubies from Russia and beryl/beryl triplets and blue adhesive layer as imitation for Paraíba tourmalines, found in a parcel of tourmalines. E.S.

Geschliffene grünlich-braune Hornblende aus Sri Lanka.

U. HENN AND H. BANK. *Zeitschrift der Deutschen Gemmologischen Gesellschaft*, **42**(4), 1993, pp 163-9, 1 table, 4 illus. in colour, bibl.

Three transparent, greenish-brown specimens came from a district about 75km south-east of Ratnapura in Sri Lanka and were identified as pargasitic hornblende. RI 1.620-1.642, birefringence 0.022, SG 3.12. The colour is caused by iron; inclusions are healing cracks, hollow tubes and mica platelets as well as growth structures. Some crystals show cat's-eye effect. E.S.

Gemmologische Kurzinformationen.

U. HENN, H. BANK AND C.C. MILISENDA. *Zeitschrift der Deutschen Gemmologischen Gesellschaft*, **42**(4), 1993, pp 137-40, 4 photomicrographs in colour.

The most detailed note of this report deals with filled diamonds and how to recognize these treated stones.

A new synthetic ruby from Greece is now commercially available under the name of 'Douros'; RI 1.762-1.770, DR 0.008, SG 3.98. There is also a new synthetic ruby from Russia that can be identified by dendritic remains of the flux.

A new occurrence of dendritic opals has been found on lake Kariba, Zambia. The material is brownish-yellow and shows definitive dendritic inclusions; RI 1.459, SG 2.15.

From the Kola peninsula in Russia comes a quartz with a stick-like bronze-coloured inclusion which has been shown to be astrophyllite (a type of complex layered silicate). E.S.

Aquamarin aus Irfersgruen; Sachsen.

G. HOLZHEY. *Zeitschrift der Deutschen Gemmologischen Gesellschaft*, **42**(2-3), 1993, pp 123-7, 4 photomicrographs, 1 table, 1 graph, bibl.

The only known German source of aquamarine in Irfersgruen in Saxony occurs in local pegmatites. The aquamarines have low RIs of 1.565-1.570. The absorption spectra can be seen at 810nm and 225nm and there is a transmission maxima at 485nm. Two-phase inclusions can be seen parallel to the crystallographic *c*-axis. E.S.

Das strahlende Blau der behandelten Topase.

M.F. HUEGI. *Zeitschrift der Deutschen Gemmologischen Gesellschaft*, **42**(2-3), 1993, pp 91-9, 6 photographs, bibl.

A review of the colour and its causes by different treatment methods of blue topaz. The blue colour is due to structural defects which radiation can turn into colour centres. In natural blue topaz the radioactivity of the host rock causes colour saturation. The artificial colour can be caused either by irradiation by gamma-rays or electrons or bombardment with neutrons. The risks of transformation of trace elements into radioactive isotopes are explained. Reliable proof of treatment is only possible by laboratory methods. E.S.

Rare stones.

A. JAVERI. *Indian Gemmologist*, **4**(1), 1994, pp 15-16.

Stones chosen for a brief description are rhodochrosite and thomsonite. M.O'D.

Emeralds and green beryls from Upper Egypt.

R.H. JENNINGS, R.C. KAMMERLING, A. KOVALTCHOUK, G.P. CALDERON, M.K. EL BAZ AND J.I. KOIVULA. *Gems & Gemology*, **29**(2), 1993, pp 100-15, 19 figs.

A report on a visit to the Red Sea Hills near Marsa Alam and the examination of historic mine sites and emeralds. Believed to be the oldest known sources of emerald, these are worked only sporadically today. A radio navigation

system enabled the accurate mapping of these difficult wadis during the expedition. Quality of emerald mined today is generally low. R.K.M.

Examination of a glass imitation of jade from Vietnam.

R.C. KAMMERLING AND G.P. CALDERON. *Zeitschrift der Deutschen Gemmologischen Gesellschaft*, **42**(4), 1993, pp 171-7, 2 illus. in black-and-white, 2 in colour, bibl.

The bowl of yellowish-green (apple-jade) with semi-translucent, whitish areas was obtained in Ho Chi Minh City, Vietnam. RI 1.51 and found to be partially devitrified glass, but distinct from the Japanese product known as 'Meta-Jade'. The material was shown to be not entirely amorphous. E.S.

Identifación de zafiros tratados por difusión.

R.E. KANE, R.C. KAMMERLING, J.I. KOIVULA, J.E. SHIGLEY AND E. FRITSCH. *Boletin del Instituto Gemológico Español*, **35**, 1993, pp 7-23, 2 tables, 27 illus. in colour, 3 figs.

Paper on the identification of blue diffusion-treated sapphires first published in *Gems & Gemology*. M.O'D.

Testa Nera: die trauernden Turmaline von Elba.

D. KLAUS. *Lapis*, **19**(1), 1994, pp 54-5, 4 photos in colour.

Tourmaline crystals of various colours but with black or dark tops are characteristic of Elba. Some examples and locations are described. M.O'D.

Gem News.

J.I. KOIVULA, R.C. KAMMERLING AND E. FRITSCH. *Gems & Gemology*, **28**(4), 1992, pp 268-279, 14 figs.

Uruguay has large deposits of agate and amethyst at Artigas; reports on blue amber from Dominican Republic and on Baltic amber, including plan to pump direct from seabed at Gdansk; an unusual aragonite from south Peru resembled blue pectolite; a faceted remondite–Ce had colour change from greenish-yellow (day) to yellowish orange (incandescent) due possibly to neodymium; dumortierite quartz beads from S. Africa are illustrated; a turquoise simulant seen in Egypt was mixture of amphibole and feldspar, colour due to copper. Fine golden cultured pearls, reportedly from Okinawa, are illustrated and described; individual gem mining continues on a small scale at Elahera, Sri Lanka; another update on Sri Lanka from Gordon Black says that decline in production is due to threat of terrorism, some pink sapphires have been irradiated to padparadscha colour but change is unstable, chatoyant kornerupines, rutiles and a 114 carat chrysoberyl twin also reported, an iron-rich chrysoberyl had high RIs; a 33 carat taaffeite was seen in Hong Kong; an update from Vietnam reports increased production of pink sapphire/ruby at Luc Yen, various finds reported; green zoisite reported from Skardu, Pakistan.

Enhancements: Filled pique diamonds offered in Perth W. Australia without clear statement that they are filled; rough diamonds are being fracture filled to defraud, since glass fillings will not stand heat of cutting; black irradiated diamonds said to become non-radioactive after boiling in acid; a sandstone teapot stained by tea is illustrated. R.K.M.

Gem News.

J.I. KOIVULA, R.C. KAMMERLING AND E. FRITSCH. *Gems & Gemology*, **29**(1), 1993, pp 52-64, 24 figs.

Headed Tucson '93, this paper reports on unusual multi-coloured iris agates; Baltic amber; Uraguayan amethyst; amethyst-citrine from Bolivia; dark blue and blue-green apatite from Bahia and bright green-blue apatite from Madagascar; a 10.90ct alexandrite from Brazil and another of 7.55ct from Orissa were seen. Various materials cut to display natural surfaces are described; yellow-green beryl from Ukraine; deep yellowish-green Zambian emeralds with fewer inclusions than usual; gem materials ranging from pallasitic meteorite to moldavite and other tektites and silica glass were shown. Among large stones exhibited were a 240ct sinhalite and several Sri Lankan sphenes; a 673ct pink fluorite; iolites up to 110ct and a 600ct opal from Tintenbar, NSW. Some Siberian jadeite was shown; and a strangely aventurescent zircon. Basaltic opal from British Columbia; cultured pearls from Tahiti, Australia and China were offered. Chinese reported to be trying to develop

spherical pearls by tissue nucleation. Natural river Unio pearls were shown from a Quebec source which can reach -40°C in winter; one man exhibited peeled black cultured pearls which had been worked on with little more than a knife [does this expose the dyed conchiolin layer?]. Opaque red quartz owed its colour to included chalcotrichite; small Ethiopian peridots similar to those from Arizona and China were seen; briefly described but not illustrated were faceted ezcurrite, probertite, mooreite, brucite and leifite; Colorado yielded some spectacular large faceted rhodochrosites.

Updates on rubies and sapphires from a number of sources are given; intense orange spessartine garnets from Namibia were offered as 'Hollandine'. Paraíba blue-green tourmalines were again offered and some from minas Gerais which do not heat-treat so well; parti-coloured green/blue zoisites were also seen.

Enhancements: An apparatus for filling emerald fractures with coloured oil was offered from Israel. R.K.M.

Gem News.

J.I. Koivula, R.C. Kammerling and E. Fritsch. *Gems & Gemology*, **29**(2), 1993, pp 130-41, 24 figs.

Coloured stones: Blue cancrinite reported from Greenland (RI 1.499-1.493, SG 2.43, H 5-6, fluoresces red to dark purple); Big Crab-Tree Mountain, N. Carolina, 'only source US emeralds', now mining matrix material for cabochons and quartz-topped doublets; a 30cm globe using gem slabs of representative minerals for countries was seen at Tucson, also a large quartz cabochon had been cut to include 3-phase 'fingerprint'; Tucson also offered volcanic glass with striking range of iridescent colours.

Orissa, India, is now a significant gems source with rhodolite garnet, alexandrite, aquamarine, ruby, tourmaline, hessonite and chatoyant sillimanite seen at Tucson; cultured freshwater pearls in various colours are reported from Ho Tay Lake, Hanoi; a small quantity of Zabargad peridot was shown at Tucson, as were an ornamental porphyry from British Columbia and a natural fossil resin from Colombia, S. America, containing numerous insect and plant inclusions; alluvial ruby workings at Ruvu, near Mahenge, Tanzania, by Thai companies, producing mainly cabochon material.

Enhancements: RI of opticon filler varies between 1.545 and 1.560 giving variable optical relief as RI of host also differs; turquoise oiled to improve colour may fade as oil evaporates.

Announcements: The S.R. Perren Gem and Gold Room at the Royal Ontario Museum, Toronto, opened in July featuring a 1625ct peach-coloured beryl, a 193ct star sapphire and a natural blue topaz of some 3000ct, among nearly 1000 gem and gold exhibits. R.K.M.

[Amethyst. A geological-mineralogical and gemmological essay.] (Bulgarian with English abstract)

R. I. Kostov. Sofia (Private Edition), Price 29 Levs, 1992, 250 pp.

The book consists of the following chapters: Etymology, Historical notes, Crystal morphology (structure, morphology, polycrystalline varieties and ontogenetic studies), Physical properties (specific gravity, permitivity, magnetic susceptibility, refractive index, nature of colour and hues, homogeneity, zonality, optical spectroscopy, thermoluminescence, X-ray and gamma luminescence, thermal influences, IR spectroscopy, e.p.r. and nuclear magnetic resonance), Chemical composition and inclusions, Geographical distribution and production (Europe, Asia, Africa, America, Australia and Oceania), Genetic types of the deposits, Synthesis, and Role in human culture. The rich literature cited serves as a specific to amethyst bibliography with sources in different languages. R.K.

A new gem beryl locality: Luumäki, Finland.

S.I. Lahti and K.A. Kinnunen. *Gems & Gemology*, **29**(1), 1993, pp 30-7, 12 figs.

Pale yellow, green and (rarely) blue, heavily etched crystals of beryl have been found in a pegmatite quarry. Decrepitated fluid inclusions are characteristic. Constants typical of beryl. Greens are not emerald. R.K.M.

U-disequilibrium dating of corals in southern Taiwan by mass spectrometry.

T. Lee, J. H. Chen, C. F. Dai & J. J. Shen, *Journal of the Geological Society of China*, **36**(1), 1993, pp 57-

6, 1map.

Uplifted corals in this area were dated by $^{230}Th/^{234}U$ using MS. For Holocene samples the results are in agreement with earlier studies but with better precision than conventional nuclear counting, and better than ^{14}C dating. There is the potential to date samples as young as 30 yr and as old as 500,000 yr, though careful selection of samples and thorough field studies are required. To investigate the possibility of dating palaeoseismic activity four coral samples from Hou-Bi-Hu, Kenting, were analysed. The results suggest that complex coral assemblages and the studied samples may not be suitable for dating such activity. The dating of other samples is discussed. R.E.S.

Spessartine aus Namibia.

T. Lind, H. Bank and U. Henn. *Neues Jahrbuch für Mineralogie. Monatshefte*, **12**, 1993, pp 569-76, 3 figs.

Gem-quality spessartine from Namibia has SG 4.09-4.15 and RI 1.790-1.797. The specimens are ascribed to a near-binary solid solution series pyrope-spessartine with spessartine content between 80 and 90 per cent. With the spectroscope a nearly pure spessartine composition is indicated with bands corresponding to Mn^{2+}, the only ones found in the visual spectrum. A small amount of hydrospessartine is found by using NIR spectroscopy. M.O'D.

Stable-isotope, fluid-inclusion, and mineralogical studies relating to the genesis of amethyst, Thunder Bay Amethyst mine, Ontario.

J.R. McArthur, E.A. Jennings, S.A. Kissin and R.L. Sherlock. *Canadian Journal of Earth Sciences*, **30**(9), 1993, pp 1955-69, 1 map.

This mine exploits a vein system in which the main zoned sequence consists of chalcedony, colourless quartz and three to four stages of amethyst. The main sequence surrounds fragments of a brecciated earlier sequence with chalcedony, colourless quartz and prasiolite, which appears to be thermally bleached amethyst. The vein system is in a fault in Archaean granodiorite and is associated with a zone of chloritic and hematite alteration. Main-stage fluid inclusion T_h are in the range 91.2 to 40.9°C (mean 68.4°C) in amethyst, whereas in colourless quartz the T_h range is 146.5—114.7°C (mean 132.1°C); eutectic T indicate an NaCl—$CaCl_2$—H_2O system and salinities are 22.9 to 15.3 eq.wt.% NaCl. trace sulphide and other mineral inclusions indicate a trend of decreasing Eh and pH from a rather oxidized (sulphate stable) to a reduced (sulphide stable) condition during deposition. The ^{34}S values for pyrite and chalcopyrite are -0.4 to $1.4_{0/00}$; $\delta^{18}O$ in quartz range + 12 to + $17.1_{0/00}$, corresponding with $\delta^{18}O(H_2O)$ - 2.1 to - $12.8_{0/00}$ using fluid-inclusion T. The quartz monzonite wall rock does not appear to have been involved isotopically; rather, mixing of local meteoric water with a basinal brine appears to explain the observed trend. The amethyst deposits are believed to have been formed by basinal brines expelled from Proterozoic Sibley group sediments; the brines dissolved silica by alteration processes accompanying their passage through granitic basement rocks. The T interval for amethyst formation appears to be restricted to < 90°C; T for thermal bleaching of amethyst are as low as 145°C. R.A.H.

Update on diffusion treated corundum: red and other colours.

S.F. McClure, R.C. Kammerling and E. Fritsch. *Gems & Gemology*, **29**(1), 1993, pp 16-28, 20 figs.

Diffusion-treated red and pink corundums were examined prior to commercial release. Such stones cannot be assumed to start as rubies and so must not be called 'diffusion- treated rubies'. Of 43 stones examined only 12 were 'ruby colour' while a further 15 were light pink or purple. These 27 stones were examined gemmologically in detail. The remaining 16 stones were unsatisfactory products of earlier experiments, patchy or wrong in colour.

RIs were abnormally high in many stones and some showed a second set above 1.80 when tested on a cubic zirconia refractometer. Some pleochroism and luminescences were unusual, the latter particularly in SUV; absorption spectra weak for colours tested. Magnification showed disrupted inclusions expected in heat-treated stones; uneven patchy colour due to thin colour layer or to excessive polishing more obvious

when stones immersed. In methylene iodide these stones showed greater facet relief than similar naturally coloured stones or synthetics, some gave blue or purple outlines. [There appears to be an element of coating in some specimens which surely needs to be declared.]

An important paper which suggests that these experimental reds are detectable. Experiments are continuing in an endeavour to improve the products. R.K.M.

Achate aus dem Geschiebe der nordischen Vereisungen.

R. MENDE. *Aufschluss*, **45**, 1994, pp 43-7, 8 photos.

Some examples of agate from the northern area of Germany are described and illustrated. M.O'D.

Application of structural geology in the exploration for residual gem deposits of Sri Lanka.

D.P.J. MENDIS, M.S. RUPASINGHE AND C.B. DISSANAYAKE. *Bulletin Geological Society of Finland*, **65**(1), 1993, pp 31-40, 4 maps.

Geological investigations have shown that corundum deposits are generally associated with axial plane areas of tight, doubly plunging synclinoria and anticlinoria where crystalline limestones and pegmatites occur. Corundum deposits also occur at sites of heavy structural disturbances such as discontinuities, faults, folds, joints, lensing and necking zones, etc. if marbles and/or intrusions of granite and pegmatites are present. Alluvial gem deposits do not necessarily exist close to their place of origin, though most concentrations of alluvial gem beds still remain close to their source. Examples are given of areas of high potential (Opanayake and Hattota Amuna), moderate potential (Bogawantalawa and Pubbiliya) and areas with significant potential. Sketch maps are given of the four areas mentioned, which in addition to sapphire yield spinel, tourmaline, zircon and garnet. R.A.H.

What's new in minerals?

T. MOORE. *Mineralogical Record*, **25**(1), 1994, pp 57-63, 1 illus. in black-and-white, 9 in colour.

Gem minerals reported from a number of shows include fine elbaite from Pakistan, a country which also provided specimens of aquamarine, spessartine and epidote. Orange sphene has also been reported from Pakistan, the actual location being Alchuri village, Shigar Valley, Baltistan. Some green-pink water-melon tourmaline is reported from Pakistan. Gem-quality datolite has been found at Dalnegorsk in the far eastern part of Russia and fine rhodochrosite continues to appear from the Sweet Home mine in Colorado. Fine green uvite from a site 'near Mogok', Myanmar, is reported to be found about 15km from the Thai border. M.O'D.

Rb-Sr dating of sphalerites from Mississippi Valley-type (MVT) ore deposits.

S.NAKAI, A.N. HALLIDAY, S. E. KESLER, H. D. JONES, J. R. KYLE AND T. E. LANE. *Geochemica et Cosmochimica Acta*, **57**(2). 1993, pp 417-427, 1 map.

Rb-Sr elemental and isotopic data are presented for sphalerites and their fluid indusions from NW Territories and Newfoundland, Canada, and E Tennessee and N Arkansas, USA. The value of the Rb-Sr method for dating sphalerites is assessed and can be useful in elucidating the genesis of MVT and other types of ore deposits. But isotopic inhomogeneity of ore brines limits the accuracy of sphalerite dating. Rb and Sr appear to be hosted mainly in the sphalerites rather than in silicate indusions the sites of Rb and Sr atoms in the sphalerites are uncertain but they are probably associated with crystal defects. Sphalerites with very low Sr contents are difficult to date since their Sr isotopic compositions are affected by minor silicate inclusions. Results for the four groups of samples are discussed. R.K.H.

Edel-und Schmucksteinvorkommen in Nepal.

G. NIEDERMAYR, F. BRANDSTAETTER AND V.M.F. HAMMER. *Zeitschrift der Deutschen Gemmologischen Gesellschaft*, **42**, 1993, pp 69-89, 1 map, 7 photographs, 4 tables, 5 graphs, bibl.

Gemstones found in Nepal include corundum (ruby and sapphire), dravite, almandine garnet, iolite, alkali feldspar-moonstone, rock crystal and smoky quartz, aquamarine, tourmaline, spessartine garnet, amazonite, danburite and hambergite. Most of these are not commercially mined, partly because of their local situation.

The corundums are mainly pink and violet sapphires from Ganesh Himal, north-west of Kathmandu. The aquamarines are often light blue, the dravite dark brown to orange-brown. The high quality tourmalines are in shades of pink, green, brown to orange and pure yellow; these come from the pegmatites near Manang, the rough crystals being up to 16cm long. The Mn content of these tourmalines can be as much as 9.2 per cent of their weight. Mining is difficult. One of the promising tourmaline mines in eastern Nepal can only be reached after three days on foot. Explosives cannot legally be used by private persons. E.S.

Almandin.

G. NIEDERMAYR. *Mineralien Welt.* **5**(1), 1994, p.17, 2 illus. in colour.

Short account of the occurrence of almandine in metamorphic rocks with notes on characteristic inclusions. M.O'D.

Comparative study of beryl from various Indian occurrences - beryl from Jammu and Kashmir.

J. PANJIKAR. *Indian gemmologist.* **4**(1), 1994, pp 3-8, 3 tables, 10 figs, 1 map.

The structure and properties of the beryl varieties are described with particular reference to beryl from Jammu and Kashmir. M.O'D.

Fluid evolution in the H_2O-CH_4-CO_2-NaCl system during emerald mineralization at Gravelotte, Murchison Greenstone Belt, north-east Transvaal, South Africa.

Y. Y NWE AND G. MORTEANI. *Geochemica et Cosmochimica Acta,* **57**(1), 1993, pp 89-103, 1 map.

Microthermometry and laser Raman microprobe spectrometry are used to study complex fluid inclusions present during the formation of emeralds and associated phenakites. In the system, $H_2O + CH_4$ were dominant in the earliest stages of formation; minor C_2H_6, N_2 and H_2S were also detected. The early type 1 fluids, trapped in the phenakites and beryls, which are low-salinity with <18 mol.% CH_4, developed during albitization/alkali metasomatism of a pegmatite body. With increasing interaction with the host rocks, progressive crystallization of the emeralds occurred, the fluids becoming less CH_4-rich and more saline. *P-T* conditions for the earliest inclusions in the phenakites were ~450-500°C and 4 kbar. Phenakite was converted to emerald as Al_2O_3 activities in the system increased. R.K.H.

A study of gem varieties of corundum from parts of Tumkur and Mysore Districts, Karnataka.

J. PANJIKAR, H. CHANDRASHEKHAR, M. MUNISWAMIAH AND N. AHMED. *Journal of the Geological Society of India.* **43**, 1994, pp 311-15.

A brief account of gem corundum occurrences in southern Karnataka, India, is given with notes on the complex geological environments involved, specially referring to the margins of the Clospet pluton. Geological and gemmological characteristics of gem corundum from parts of Tumkur and Mysore districts are given. M.O'D.

A tentative classification of heat-treatable corundum (Geuda) stones.

M.S. RUPASINGHE, R.A.P. RUPASINGHE, C.B. DISSANAYAKE AND O.A. ILEPERUMA. *Zeitschrift der Deutschen Gemmologischen Gesellschaft.* **42**(2-3), 1993, pp 115-21, 4 photographs, 1 table, bibl.

Heat-treatable low quality corundum (Geuda) exhibit a wide range of properties and the local gem trade (Sri Lanka) identifies these stones mainly on the basis of their appearance. Local names for the different varieties are explained, including such names as diesel geuda (oily), milky geuda (these include blue milky, red milky and yellow milky), silky geuda, ottu geuda (indicator for other stones probably to be found, i.e. unevenly developed, patchy or spotted stones) and dhum geuda (smoky). E.S.

[Structural-mineralogical peculiarities of lazurite from the South-Western Pamirs.] (Russian with English abstract)

A. N. SAPOZHNIKOV, V. G. IVANOV, V. L LEVITSKY AND L. F. PISKUNOVA. *Proceedings of the Russian Mineralogical Society,* **122**(1),1993,pp 108-115.

Associated isotropic and anisotropic lazurites from the Luadzhvardarite lazurite deposit, together with an isotropic lazurite from near the town of Ishkashima (SW Pamirs) have been studied. The commensurate and incommensurate modulations of the lazurite structure were

established by XRD; they are related to non-stoichiometry, causing local changes in occupation of structural sites. This, in turn, seems to be related to changes during secondary crystallization after the primary phase of growth. EPMA data, n values and XRD powder reflections are tabulated for three Pamir lazurites and compared with lazurites from Baikal and Afghanistan. Indexed powder data are given for an anisotropic lazurite; this has a reflection at d=12.2Å. R.A.H.

Saphir vom Seufzergründel in Sachsen.

F. WAGENKNECHT. *Lapis.* **18**(12), 1993, p.46, 1 fig., 1 photograph in colour.

Ruby and sapphire, not of gem quality, are reported from the Seufzergründel near Hinterhermsdorf, Saxony, Germany. Associated minerals include almandine, zircon (high type) and apatite. M.O'D.

Garnets from Altay, China.

F. WANG AND Y. LIU. *Gems & Gemology.* **29**(4), 1993, pp 273-7, 1 table, 9 illus. in colour.

Spessartine (wrongly described as spessartite in this paper) and grossular garnets of gem-quality are being mined commercially. The material is cut in China and sold internationally through Hong Kong. Chemical composition and physical constants are normal for these species. The deposits are in mountainous terrain close to the borders of Kazakhstan and Mongolia. Access is limited to six months each year and is difficult. R.J.P.

Queensland boulder opal.

R.W. WISE. *Gems & Gemology.* **29**(1), 1993, pp 4-15, 16 figs.

An exhaustive account of black opal found in ironstone in Central Queensland, a variety largely disregarded at first but now increasingly valued. Impressively illustrated and well written. R.K.M.

[Gem scapolite from the Eastern Pamirs and some general constitutional features of scapolites.] (Russian with English abstract)

A.A. ZOLOTAREV. *Zapiski Vsesoyuznogu Mineralogicheskogo Obchestra,* **122**(2), 1993, pp 90-102.

Gem scapolite from the Kukurt deposit, E Pamirs, can be distinguished from other scapolites by its chemical composition, cell parameters and other properties. Chemical analyses and cell parameters are given for eight scapolites with Me % 5.4—34.0. IR, optical absorption and EPR spectra are presented. The data suggest the existence of a hitherto unrecognized solid solution between marialite and Ca-marialite. The nature and cause of the lilac colour of the Kukurt scapolite is of particular interest, but additional investigations are needed. R.A.H.

Instruments and Techniques

Radioactivity revisited (Letter).

W.W. HANNEMAN. *Gems & Gemology.* 29(2), 1993, p.80.

Points out inconsistencies in US regulations affecting irradiated gems, and suggests that the restrictions are political rather than practical. R.K.M.

[The weight of a round brilliant cut by calculation] (Japanese with English abstract).

M. HAYASHI AND Y. HORIKAWA. *Journal of The Gemmological Society of Japan.* 17(1-4), 1992, pp 37-42, 9 figs.

A new equation is proposed to calculate the weight of a round brilliant cut diamond, which is applicable under less limited conditions than any of the hitherto proposed equations. For this calculation, the diameter of the girdle, D, the depth of the pavilion, P, the thickness of the girdle, G, the height of the crown, H, the length between the vertical point of the star facet and the girdle, U, that between the vertical point of the lower girdle facet, L, and the diameter of the table, T, are necessary factors. The equation appears rather complicated, but the calculation is easy with the help of a calculator. I.S.

Kathodolumineszenz (KL) und KL-Spektren von Edelsteinen. (Ausgewaehte Beispiele) Teil II.

J. PONAHLO. *Zeitschrift der Deutschen Gemmologischen Gesellschaft,* **42**(2-3), 1993, pp 101-13, 6 photomicrographs, 6 graphs, 1 illus., 2 tables, bibl.

The article describes some CL phenomena and results of CL microspectrophotometric measurements to differentiate between natural and synthetic coloured stones. The following examples are given: blue sapphire, red topaz and spinel, natural and synthetic emerald, red and violet taaffeite. E.S.

Kathodolumineszenz (KL) und KL-Spektren von Edelsteinen. (Ausgewaehte Beispiele) Teil II.

J. PONAHLO. *Zeitschrift der Deutschen Gemmologischen Gesellschaft*, **42**(4), 1993, pp 149-162, 6 illus. in colour, bibl.

In the second part of his paper the author describes the cathodoluminescence of red and violet spinels, chrome-containing taaffeites, feldspars, apatite cat's-eye and a leuco sapphire from Sri Lanka. E.S.

Magnetic field-induced rotation of diamagnetic gem crystals.

C. UYEDA. *Science Reports of the College of General Education, Osaka University*. **41**(1-2), 1992, pp 23-8.

The rotation induced by a magnetic field is reported for natural gem-quality crystals of quartz, topaz, beryl, olivine and spodumene. This rotation was observed when the restoring force of the string suspending the crystal became negligible compared to the diamagnetic anisotropic energy. The diamagnetic principal axis of the crystal gradually changed its orientation towards the direction of the applied magnetic field. The values of diamagnetic anisotropy (ΔX) estimated ($\times 10^{-}$ emu/mol) were: quartz 0.12, (*b-c* axis) 16.4, beryl 58.3, olivine (*a-c* axis) 4.50 and spodumene (*a-b* axis) 4.33. R.A.H.

Stone polishing – measurement of surface finish.

D. N. WRIGHT AND C. ROUSE. *Industrial Diamond Review*, **53**(1), 1993, p 10-13.

Values obtained for different types of polished granite using a portable instrument, where a stylus measures the surface texture, and a gloss meter are compared. The effects of mineral grain size and 'pull-out' have to be taken into consideration when analysing the results. R.A.H.

Monodite used in engraving jewellery.

Industrial Diamond Review, **53**(6), 1993, p. 316, 5 photos, 1 diagram, bibl.

Single point diamond cutting tools made from De Beers blank monodite, a single crystal, synthetic diamond product, are used by a Birmingham manufacturer of rings, bracelets, earrings, clock faces and picture frames, which are engraved with intricate patterns. E.S.

Jewellery

Methods of determining the gold content of jewelry metals.

M.E. MERCER. *Gems & Gemology*, **28**(4), 1992, pp 222-33, 11 figs.

Without a rigorous hallmarking system, the assessment of gold quality in the USA presents many difficulties. Officially they have 10 carat, 14 carat, 18 carat and 22 carat, but these can apparently be interpreted somewhat widely.

Ms Mercer has investigated four methods of assessment; density (the least reliable since lead is also a heavy metal); touch-stone and acid (complicated by acid dilution, but more reliable); testing with a pen-like detector (not usable on curved surfaces); and X-ray fluorescence (an expensive test which still does not come within their legal requirement (known rather quaintly as Plumb Laws) of ±3 parts per thousand accuracy. Plated or colour flashed goods could be deceptive. Author says much more research is needed. [In abstractor's opinion the time is ripe to institute a proper hallmarking procedure, perhaps on British lines.] R.K.M.

Jewels of the Edwardians.

E.B. MISIOROWSKI AND N.K. HAYS. *Gems & Gemology*, **29**(3), 1993, pp 152-71, 20 illus. in colour.

This detailed review covers the period 1880-1915 and records the introduction of platinum as a precious metal. With its non-tarnishable nature together with its great strength and hardness compared with silver it led to the creation of the light

and lacy garland style. Women from the uppermost echelons of society favoured extravagant jewellery to demonstrate their wealth and rank with the tiara as an essential item.

The Edwardian age was shattered by World War I which not only changed the social structure in Europe but paralysed both the gem and jewellery trades. The former by De Beers who closed down diamond production and the latter by platinum being classified as a strategic metal [a chemist could argue that without platinum, explosives production would have been insufficient to continue the conflict]. When the war was over it was impossible for society to revert to the self-indulgent lifestyle of the Belle Epoque. R.J.P.

Synthetics

Growth of crystals of beryllium oxides and silicates using fluxes.

G.V. Bukin. *Growth of crystals.* **19**, 1993, pp 95-110, 8 illus. in black-and-white, 8 figs.

Work over 25 years at the Institute of Geology and Geophysics and the Special Design and Technology Office of Single Crystals of the Siberian Branch of the USSR Academy of Sciences has dealt with the experimental mineralogy of Be oxides and silicates. The present paper deals particularly with the synthesis and crystallization conditions of analogues of natural beryllium minerals. Work on emerald and chrysoberyl is described and there are also notes on bromellite. Further investigation may enable crystal growers to accomplish the growth of taaffeite and cordierite. M.O'D.

Gem News.

J.I. Koivula, R.C. Kammerling and E. Fritsch. *Gems & Gemology.* **28**(4), 1992, pp 268-79, 14 figs.

An update on crystal synthesis reports fluoride crystals of more than 100kg, combined flux and pulling methods improve size and quality of crystals, yttrium silicate and yttrium vanadates, etc., have been produced for laser and super-conductor purposes; attractive three part gem of rhodolite, topaz and iolite was offered as 'rhodiolopaz'; Durafourge of Switzerland are cutting CZs in sizes down to 500 per carat; Bifra of Vicenza are marketing synthetic stones ready set in gold findings; possibly the largest hydrothermal synthetic ruby weighs 1930 carats; an imitation of water melon tourmaline proved to be stained red quartz surrounded by other mineral fragments and cement encased in slices of blue/green tourmaline. R.K.M.

Gem News.

J.I. Koivula, R.C. Kammerling and E. Fritsch. *Gems & Gemology.* **29**(1), 1993, pp 52-64, 24 figs.

Headed 'Tucson '93' this paper reports on: Synthetics and simulants: reconstituted amber (pressed); several 'pulled' synthetic materials; miscellaneous emerald simulants are described and discussed. R.K.M.

Gem News.

J.I. Koivula, R.C. Kammerling and E. Fritsch. *Gems & Gemology.* **29**(2), 1993, pp 130-41, 24 figs.

Synthetics and simulants: synthetic corundum marketed as Imperial topaz simulant; Russian flux-synthetic emerald cut in Bangkok under name 'Crystural-created emerald'; opal simulants using holography image or interference imaged film to give play of colour, and other plastic imitation opals; triplet apatite and tourmaline simulants of Paraíba tourmaline; blue synthetic quartz; non-transparent synthetic quartz and German synthetic spinel are all described and illustrated. R.K.M.

Flux-grown synthetic red and blue spinels from Russia.

S. Muhlmeister, J.I. Koivula, R.C. Kammerling, C.P. Smith and E. Fritsch. *Gems & Gemology,* **29**(2), 1993, pp 81-98, 19 figs.

An in-depth investigation of these relatively new synthetics with suggestions for identifying them by absorption spectra, flux inclusions when present, or by detection of more zinc in natural spinels by energy dispersive X-ray fluorescence. Other colours have been made. R.K.M.

Flux growth and properties of oxide crystals.

V.I. Voronkova, V.K. Yanovskii, I.V. Vodolazskaya and E.S. Shlbentsova. *Growth of*

crystals. **19**, 1993, pp 111-27, 2 illus. in black-and-white, 7 figs.

Growth of crystals using low-temperature fluxes allows crystals to be prepared from compounds melting with decomposition. Choice of an appropriate flux has always been an important part of crystal growth work and this paper outlines growth methods of a number of materials including corundum and lithium niobate. Crystallization of ruby from a flux of alkali and alkaline-earth tungstates and molybdates enables isometric single crystals to be prepared with hexagonal bipyramidal shape. Growth from these solvents takes place most effectively in a fixed temperature gradient on seeds when rates of about 0.5mm/day give single crystals up to 25mm in size from 50-100ml of melt. For large single corundum crystals the Verneuil or Czochralski methods are still the most efficient.

M.O'D.

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Book Reviews

Beautiful Australian opals

L. Cram. 1994. Robert Brown & Associates, Coorparoo, Queensland. pp 80. Illus. in black-and-white and colour. Soft cover. Price AUS$9.95. ISBN 1 86273 075 X.

Len Cram is now well-known as a writer of most attractive books on Australian opal, very competitively priced and with a good deal of information not published previously. The text is divided into three parts, dealing with black opal, boulder opal and light opal with illustrations of some fine stones and of mining scenes and methods. The text includes mining anecdotes, folk-lore and details of present-day mining and exploitation. I have rarely seen such good opal photographs and I recommend all opal lovers to buy the book. M.O'D.

Gemstones.

C. Hall. 1994. Dorling Kindersley, London. p.160. Illus. in colour. Soft cover. Price £10.99. ISBN 0 7513 1026 3.

Part of the publishers' Eyewitness handbooks this book is most attractively produced with colour photographs on virtually every page. I would certainly recommend it as a starter and present and since stimulus of the imagination is the essential first part of learning it could even be used in the early stages of a gemmology course. Material is arranged with the usual introductory chapters followed by separate descriptive sections covering major and rarer species. There are tables and a glossary but no bibliography which would have been useful for the next stage of learning. But this is a small point in a book which ought to spend a lot of its life on the bedside table. M.O'D.

The new alchemists: breaking through the barriers of high pressure.

R.M. Hazen. 1993. Times Books, New York. pp xvi.286. Price US$22.50. ISBN 0 8129 2275 1.

So much of this excellent semi-popular study of how scientists have been able to overcome the difficulties of high pressure experiments deal with the successful synthesis of diamond that it should be required reading for all gemmologists. In fact it would be fair to say that this is at least two-thirds a study of diamond synthesis since the last part of the text is a more cursory survey of the structure and nature of the earth, of superconductivity and of the very recent discovery of buckminster-fullerene, a new form of carbon with the possibility of transforming to diamond at room temperatures under pressures of 200,000 atmospheres. The material is so lucidly presented that it is easy to read and easy to (think you) understand! Beginning with the famous peanut butter to diamond transformation by Wentorf in 1955, the book goes on to outline the ways in which high pressures were achieved and their subsequent employment in materials structure analysis. On the way we stop at early attempts at diamond synthesis, the work of Percy Bridgman, the final harnessing of high pressure and the manufacture and application of diamond thin films grown by chemical vapour deposition. These topics are given sufficient detail to make them both a stimulus to the imagination and a source of information. Anecdotal material is well-chosen and not overdone; the occasional black-and-white picture helps the text along as do the diagrams, especially those depicting diamond synthesis.

The text, once fully read, brings the participants to life as well as to work. The workers on diamond synthesis were as subject to human emotions and jealousies as anyone else; scientists also need the trappings of peer recognition and our brief acquaintance with the characters in this particular play makes us feel that we know them well. M.O'D.

Antero aquamarines: minerals from the Mount Antero-White Mountain region, Chaffee County, Colorado.

M.I. Jacobson. 1993. L.R. Ream Publishing, Coeur d'Alene, Idaho. pp xvi.126. Price US$19.85 (paper) US$34.95 (cloth). ISBN 0 928693 07 4.

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Interesting geological-mineralogical-anecdotal account of the pegmatites of Mount Antero, Colorado and their contents, the most significant of which is aquamarine. Crystals reach gem quality in some instances and some faceted stones are illustrated in colour. There is a really useful bibliography and chapters deal with the genesis of pegmatites and with geochemistry as well as with local conditions. A model of a local specialized guide which will appeal to several classes of reader. M.O'D.

Designer jewellery.

C. MAZLOUM. 1993. Gremese International, Rome. p.189. Price £12.95. ISBN 88 7301 021 0.

A review of some of the work of currently-operating Western-style jewellery designers, chosen apparently at random, this book, while quite attractively produced and certainly well illustrated, comes close to advertising the products displayed and their designers. The text is inflated, containing little more than platitudes, and there is no attempt at any kind of critical review. As the 'collaborators' listed on the title-page are the same as the designers whose work is included, perhaps this is to be expected. A number of mistakes in the lists of journals and museums does not increase confidence. M.O'D.

International Conference [on] New Diamond Science and Technology, Washington DC, 1990.

R. MESSIER, J.T. GLASS, J.E. BUTLER, R.ROY (eds). 1991. Materials Research Society, Pittsburgh, PA. pp xx, 1128. Illus. in black-and-white. Price £58.00.

This very stout but reasonably-priced book covers a wide field of diamond research, beginning with an account of the resurgence in work on diamond synthesis (together with cubic boron nitride (BN) and related materials): chemical vapour deposition techniques have initiated considerable advances in the synthesis of very hard materials. The text is divided into 13 parts and most of these deal with various aspects of vapour-grown diamond crystals and films. Gemmologists will probably find most to interest them in part 8 which deals with properties: optical, vibrational, Raman. Here there is a paper by Collins on optical centres in synthetic diamond; this is a review paper and is followed by Fritsch, Scarratt and Collins on optical properties of diamond with an unusually high hydrogen content. Other papers in this section cover cathodoluminescence, spectroscopic studies and features of diamond films. Part 10 describes the effect of doping with boron and with various electrical properties. The final two parts deal with diamond-like materials and with cubic boron nitride.

There is a very large amount of information in this book and as each chapter has its own list of references readers will find pointers in any direction of further study. Perhaps this is not a book for the general gemmologist but all should know of its existence. M.O'D.

Diamond grading ABC (11th revised, enlarged edition).

V. PAGEL-THEISEN. 1993. Rubin & Son bvba, Antwerp. p.308. Illus. in black-and-white and colour. Soft cover. Price £25.00. ISBN 3 9800434 1 1.

Since its first appearance in the early 1970s this book has deservedly become a useful handbook for the diamond grader. Over the years production and presentation have kept pace with improving standards and the clarity grading text is illustrated in eye- catching black and red, making the inclusions much easier to see.

Chapters deal with colour first, followed by clarity, cut and weight. The last section deals with diamond imitations. A good deal of attention is paid to instruments and styles of cutting are clearly described; this section has been updated to take new styles into account; other additions to the text include details of filling practices and the lasering of stones.

There is a useful bibliography and the book is very reasonably priced. M.O'D.

The Coronation ceremony of the kings and queens of England and the crown jewels.

T. ROSE. 1992. HMSO, London. p.134. Illus. in colour. Hardback. Price £9.95. ISBN 0 11 7013617.

The varying rituals of English coronations are briefly described with passing notes on items of the regalia. Though the pictures of the regalia and the reproductions of pictures and MSS are

very well done the text jumps about rather uncomfortably, mingling accounts of the most recent coronation with those of earlier ones so that the reader does not always know which one is meant. Accounts of the various items are not always accurate; for example, the colobium resembles the present-day alb rather than the dalmatic; though a pair of gloves is said to be worn for the reception of the two sceptres, the photograph on page 112 shows only one being worn; after retiring the sovereign removes the mantle as well as the dalmatic and supertunica - if this is not done she would be wearing two heavy robes! On page 95 the white shift worn for the anointing is worn over the dress, not beneath the Parliamentary robes which have been removed before this point. The bracelets worn by the Sovereign are known as armills rather than armillas, however correct the latter name may be. The illustration on page 53, showing the two ends of the stole, is not captioned clearly.

Despite the support of 'seven distinguished scholars' the author appears to have no real depth of knowledge of her subject and the whole text reads as a hasty throw-together of items from popular journals. It is a pity that so ancient a ceremony and magnificent paraphernalia are not better served. For gemmologists, the text is of no greater value than previous accounts. M.O'D.

La microsonde Raman en gemmologie.

H.-J. Schubnel, M. Pinet, D.C. Smith and B. Lasnier. 1992. Association française de gemmologié, Paris. p.60. Illus. in black-and- white and in colour. Price FFr100.00. ISBN none: uses ISSN of *Revue de gemmologie* which is 0396-9011.

Raman microprobe techniques enable non-destructive testing of gemstones to be carried out by comparison with established mineral and gemstone standards. Using a laser beam Raman-diffused light is converted to a computerized spectrum with peaks denoting specific atoms in vibration within specific molecular environments. After an introductory section by Schubnel describing developments in Raman techniques with particular reference to inclusion determination the remainder of the book details gem minerals in chemical order with their Raman spectra, notes on major inclusions and other properties and constants. The book is well illustrated and will be a very useful laboratory tool, giving the first set of examples to serve as standards in the future. M.O'D.

Fabergé: imperial jeweller.

G. von Habsburg, M. Lopato. 1993. State Hermitage Museum, Fabergé Arts Foundation, St Petersburg and Washington DC and St Petersburg. p.476. Illus. in black-and-white and colour. Paperback. Price £30.00. ISBN 0 88397 110 0.

This is a well-produced catalogue of an exhibition of Fabergé pieces ranging from enamels to gold to large silver presentation pieces. Though few pieces of jewellery are included, readers will find the text most useful as it gives a considerable amount of the history of the Romanov royal family as well as many details of the Fabergé workshop, its masters and its methods of production. Those readers who then visit the exhibition will find especially fine examples of nephrite and at least two fine aquamarines.

The exhibition was shown in London and Paris during 1993-94 and began at the State Hermitage Museum in St Petersburg, whose staff contributed considerably toward the compilation of the catalogue. With many reproductions of Fabergé working drawings, photographs of the Romanov family and notes on marks, added to a useful bibliography, the catalogue should be required reading for all Fabergé students.

M.O'D.

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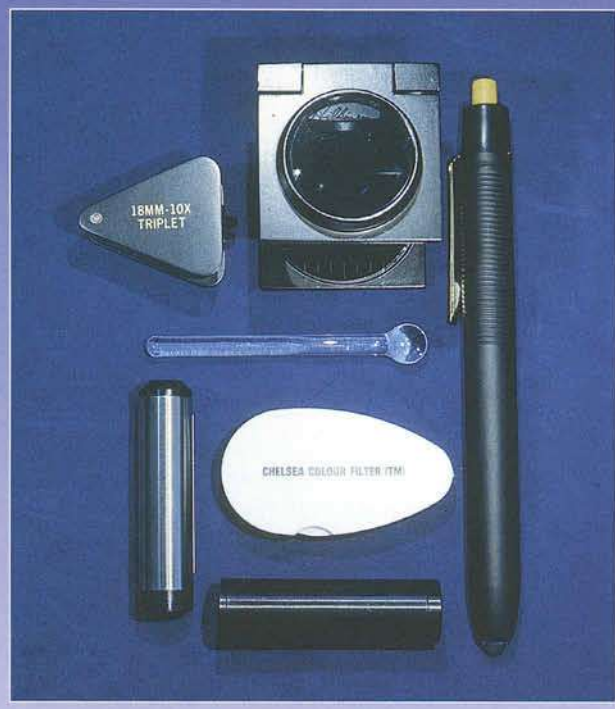

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Proceedings of the Gemmological Association and Gem Testing Laboratory of Great Britain and Notices

PHOTOGRAPHIC COMPETITION

The Association's first photographic competition for members attracted 18 entrants and a total of 93 prints or transparencies in the two categories 'Macro' and 'Micro'.

The winner of the 'Macro' category is Mr Bob J. Maurer of Redhill, Surrey, with a fine picture of a gold and diamond brooch with a carved citrine in the centre (designer Stephen Webster). The brooch is shown on the front cover of this issue of the Journal.

In the 'Micro' category, the winner is Mr Anthony de Goutiére of Victoria, British Columbia, and his picture of an inclusion (?cavity) in quartz is reproduced opposite.

Each winner receives a prize of £100.00. The entries covered a wide range of aspects of gemmology, from the mechanical effects of magnification in gems, to interference effects of light both on surfaces and through crossed polars, to gemmologically informative or artistically attractive inclusions, to rare gem minerals and cameos. A selection will be published in future issues of the *Journal*.

OBITUARY

Claire Elizabeth Parker, FGA, DGA, GG, jewellery expert and cataloguer, died on 10 April aged 36.

Everyone who met Claire admired her impeccable manner, her warm, selfless composure, as well as her professional expertise.

She will be greatly missed by her colleagues at Sotheby's and all her friends in the Laboratory and jewellery trade.

A rare pure spirit. *Requiescat in Pacem.*

Ana I. Castro

Mr Yoshio Asano, FGA (D.1976), Tokyo, Japan, died recently.

Mr N.P. Jameson Bennett, FGA (D.1967), Plymouth, died recently.

GIFTS TO THE GAGTL

The Association is most grateful for gifts or gems and gem materials for research and teaching purposes from the following:

Vanessa Guest for 15 cut tourmalines.

R. Holt & Co. Ltd, London, for cut zircons and garnet-topped doublets for teaching purposes.

John Kessler, London, for a parcel of rough emeralds from Brazil.

Pentti Merranto, Kalhonkyla, Finland, for spectrolite and hypersthene with a sheen from Mantyharjo (per Riitta Spencer).

Bernard Silver, FGA, London, for a stained cultured 'black' pearl.

NEWS OF FELLOWS

Peter Read was invited to speak at the Swedish Gemmological Association's Annual Meeting held in Stockholm on 19 and 20 March 1994. He gave two talks entitled 'The Brewster Angle Refractometer' and 'GEMDATA Update 5'. Following the talks he made provision for participants to try out an experimental refractometer (using a miniature solid-state laser in a Dialdex case) and to use his latest GEMDATA computer program.

Michael O'Donoghue gave a talk to the Wessex Branch of the National Association of Goldsmiths on 27 May 1994. The subject was 'Gemstones of Pakistan' and a number of stones and maps were on display.

Michael O'Donoghue also leads the Wednesday group which meets in the evenings at the GAGTL. Members of the group choose their own subjects of study and several useful projects are under way, backed by GAGTL and outside resources.

ANNUAL GENERAL MEETING

The Annual General Meeting of the GAGTL was held on 13 June 1994 at 27 Greville Street, London EC1N 8SU.

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Photographic Competition - Winner of the Micro category.
Inclusion in quartz showing a combination of flat and rounded boundaries to a cavity. *Photograph by Anthony de Goutière.*

The meeting was chaired by Ian Thomson who opened by welcoming those present. The Annual Report and Accounts were approved and signed.

Memorandum and Articles

It was reported that when the merger between the Gemmological Association of Great Britain and the Gem Testing Laboratory of Great Britain took place, the Memorandum and Articles had been assembled from those of the two organizations. Most requirements for the new Association were satisfactorily dealt with but a few aspects were not covered. The following amendments to the Memorandum and Articles were proposed and approved:

1. Article 10 states 'No business shall be transacted at any General Meeting unless a quorum of members is present at the time when the meeting proceeds to business; save as herein otherwise provided, two members present in person shall be a quorum.'

It was agreed to delete 'two' and insert 'ten'.

2. The wording in Articles 26 and 27 concerning the proxy forms relate to companies; it was agreed that the following wording would also apply to single members:

'I/We... of (address or company)... in the County of... being a member/members, hereby appoint (name)... of (address or company)... as my/our proxy to vote for me/us or my/our behalf at the Annual/Extraordinary General Meeting of the Company to be held on the... day of , 19 , and at any adjournment thereof. Signed... this day of , 19 .'

3. Amendment concerning the President and Vice-president:

President

'32 - On the nomination of the Council of Management, the President shall be elected by the members of the Association at a General Meeting. The term of office of the President shall run from the election at a General Meeting for two years until the re-election or a successor is elected at the appropriate General Meeting. Subject to the discretion of the Council of Management and the membership, a President would not normally be re-elected more than once. The President shall, ex officio, be entitled to attend meetings of the Council of Management and be entitled to vote.'

Vice-President

'33 - On the nomination of the Council of Management a member may be elected a Vice-president of GAGTL at a General Meeting, provided however that at no time shall the number of Vice-presidents exceed six. A Vice-president, duly elected, shall be entitled to hold that office so long as he or she continues to be a member of the Association.'

To take account of these two additional Articles, the following Articles should be renumbered accordingly.

4. The wording of Article 32 stated that the General Meeting could determine the salaries of members of Council. It is felt that the spirit of the Article is to reimburse Council members for necessary expenses and not to restrict the management function of the Council, which must always have a majority of non-executive members. It was agreed therefore to reword the Article thus:

'34 - The members of the Council shall be paid all reasonable travelling, hotel and other expenses properly incurred by them in attending and returning from meetings of the Council or any committee of the Council or General Meetings of the Company or in connection with the business of the Company.'

5. Since members receive at least 21 days notice of the General Meeting, it was agreed that if a member wishes to nominate a member for the Council of Management, notice should be registered with the office of the Association 35 days before the Meeting; it was also agreed that the notice should contain the names and signatures of the proposer, the seconder and a statement of willingness to stand of the proposed. The agreed wording replacing Article 43 is:

'45 - No person not being an officer or other member of the Council of Management retiring at the meeting shall, unless recommended by the Council for election, be eligible for office on the Council of any General Meeting, unless at least thirty five days before the day appointed for the meeting, there shall have been delivered to the office notice in writing by members duly qualified to be present and vote at the meeting for which such notice is given, of the intention to propose and second such person for election, and also notice in writing, signed by the person to be proposed, of their willingness to be elected.'

FORTHCOMING MEETINGS

London

Meetings are held in the GAGTL Gem Tutorial Centre, 2nd Floor, 27 Greville Street, London EC1N 8SU (entrance in Saffron Hill).
The charge for a member is £3.50. Entry will be by ticket only, obtainable from GAGTL.

19 September	'The gem materials of Zimbabwe'	Susan Anderson
28 September	'Diamonds and the retail trade'	Alan Clarke
22 November	To be announced.	
5 December	'Sapphires in the Laboratory'	Stephen Kennedy

GAGTL Annual Conference

Diamonds and Modern Gem Developments

The 1994 GAGTL Annual Conference is to be held on Sunday 23 October at the Great Western Royal Hotel, Paddington, London. A full programme has been arranged to include lectures by Professor I. Sunagawa from Japan, A.T. Collins, David Callaghan, Peter Read and Eric Emms, as well as a Forum to discuss 'Implications for the trade of gemstone treatments'.
For further details and a booking form contact Roger Harding at the GAGTL on 071-404 3334.

Midlands Branch

30 September	'Poking about in gemmological corners'	Alan Hodgkinson
28 October	Bring and Buy - rock swap, instrument demonstration, 'Do-it-Yourself'	
6 November	Autumn Seminar at the Cobden Hotel, Hadley Road, Birmingham	
25 November	'How to buy gemstones'	Grenville Millington
3 December	Annual Dinner	

The meetings will be held at Dr Johnson House, Bull Street, Birmingham. Further details from Mandy MacKinnon on 021-444 7337.

North West Branch

21 September	'Pearls in the Arabian Gulf'	Stephen Kennedy
19 October	A visit to the Liverpool Museum of Geology, specimen mineral and instruments	
16 November	Annual General Meeting	

Meetings will be held at Church House, Hanover Street, Liverpool 1. Further details from Joe Azzopardi on 0270 628251.

6. At the meeting of the Members' Council on 8 April 1994 it was agreed that to fulfil the functions summarized in Article 56a section (f) the current arrangement for a quorum could sensibly be reduced from half the membership of the Members' Council to that of four members. Membership of the Members' Council was determined to be a maximum of twenty and a minimum of twelve. In view of the change to the quorum it would be appropriate to reduce the minimum membership to eight.

It was therefore agreed that in Article 58a (the revised 56a), section (a) the minimum number of 'twelve' be replaced by 'eight'; and 58a section (f) should read: '(f) A quorum for any meeting of the Members' Council shall be four.'

7. In order to make Article 64 consistent with Article 67 and to eliminate irrelevant wording, clarification concerning UK members and deletion of references to debenture holders was agreed, the Article to read:

'66 - A copy of every balance sheet (including every document required by law to be annexed thereto) which is to be laid before the Company in General Meeting, together with a copy of the auditor's report, and Council's report, shall not less than twenty-one days before the date of the meeting be sent to every member of the Company with an address in the UK. Provided that this article shall not require a copy of those documents to be sent to any person whose address is unknown to the Company.'

Roger Harding and Vivian Watson were re-elected to the Council of Management and the election of Eric Emms was confirmed.

The Chairman announced that Adrian Klein had retired from the position of Company Secretary and had been succeeded by Roger Harding. He expressed the Association's gratitude to Adrian for holding the post, which is an important job with many responsibilities laid down by law.

It was announced that George Harrison Jones and D. Warren had expressed their wish to retire from the Members' Council. Keith Penton was elected and I. Roberts, R. Velden and C. Winter were re-elected to the Members' Council.

Messrs Hazlems Fenton were re-appointed Auditors.

Election of President

Ian Thomson outlined the desirability and

Eric Bruton, FGA, DGA (right) being congratulated on his election to the Presidency of GAGTL by Ian Thomson, Chairman at the AGM.

prestige of having a President. It had been decided, when the merger between the Gemmological Association and the Gem Testing Laboratory took place in 1990, that the Chairmanship of the Council of Management meetings would rotate alphabetically, whilst David Callaghan would retain the title of Chairman. When David retired from Council in 1993 it was decided that the position of President, which had been vacant since the death of Sir Frank Claringbull in 1990, should now be filled. The criteria for the position were that the candidates should be internationally recognized, to have contributed to gemmology in a significant way and be someone that the Association would be proud to have as its figurehead. The position would be primarily ceremonial, and would be held for two years, renewable for a further two years by agreement, after which a successor must be appointed. The position may again be held by the retiring President at some time in the future.

'We are fortunate in our organization', Ian continued, 'to have many internationally renowned personalities which have been recommended by the membership to fulfil this post, but after much heart-searching the Council agreed that Eric Bruton should be approached to become President, and I am very pleased to say that he is willing to be nominated.'

The nomination was unanimously carried and Eric Bruton was presented with the Presidential Badge of Office.

Eric thanked the Chairman for his kind words and said that he had been both surprised and delighted to be nominated and that he felt it was a great honour to have been elected.

Eric concluded, 'When John Major was elected as Prime Minister he said "Who would have thought it!" - I feel a bit like that myself!'

Photographic Competition and Bring and Buy

The AGM was following by a Bring and Buy sale, with many members bringing along an assortment of items including mineral specimens, beads, books and second-hand instruments.

During the evening a selection of the entries for the Photographic Competition was displayed as well as the two prizewinning photographs (see details on p.216).

MEMBERS' MEETINGS

London

The following meetings were held at 27 Greville Street, London EC1N 8SU:

On 13 April 1994 Dr Jack Ogden gave a lecture entitled 'Time and money: natural and deliberate alteration of ancient gem materials'.

On 26 April Dr George Harrison Jones gave a lecture on 'Cutting it fine'.

On 11 May, Ian Mercer gave a lecture entitled 'Spreading gem knowledge'.

On 13 June the Annual General Meeting was held, a report of which appears on p.218.

Midlands Branch

On 29 April 1994 the Annual Meeting of the Branch was held at Dr Johnson House, Bull Street, Birmingham, at which Jim Porter and Mandy MacKinnon were elected Chairman and Secretary respectively. The AGM was followed by a talk by Richard Taylor entitled 'Diamonds and their value'.

On 8 May a practical seminar was held for students.

North West Branch

On 18 May 1994 at Church House, Hanover Street, Liverpool 1, David Callaghan gave a lecture entitled 'Touching gold and silver'.

On 15 June at Church House a 'Bring and buy' and a business buzz were held.

GEM DIAMOND EXAMINATIONS

In January 1994 13 candidates sat the Gem Diamond Examination worldwide, of whom 3 qualified. The names of the successful candidates are as follows:

Larkins, Barry, London.
Mistry, Dharmesh, London.
Stratigos, Harry G., Pittsburgh, Pa., USA.

EXAMINATIONS IN GEMMOLOGY

In the Examinations in Gemmology held in January 1994 126 candidates sat for the Preliminary examination of whom 71 qualified, and 120 for the Diploma examination of whom 52 qualified, 3 with Distinction. The names of the successful candidates are as follows:

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Naresh, Deora, Jaipur, India.
Hong, Ji-Youn, Seoul, Korea.
LeRose, David Charles, Redondo Beach, CA, USA.

Qualified

Ahn, Eun Sook, Seoul, Korea.
Bao, Deqing, Wuhan, P.R. China.
Bartfai, Tunde, Schoonhoven, The Netherlands.
Batis, David, Athens, Greece.
Blancardi-de Jong, Iris, Schoonhoven, The Netherlands.
Brom, Reinier W., Schoonhoven, The Netherlands.
Brown, Elizabeth Anne, Lindford.
Capper, Beverley Anne, Bath.
Chau Kit Yee, Fion, Hong Kong.
Conley, Curtis D., Fairplay, Co, USA.
Guptill, Martin, Los Angeles, Ca, USA.
Hui, King Chuen, Hong Kong.
Human, Tracey D., Toronto, Ont, Canada.
Im, Un San, Seoul, Korea.
Jack, Johanne C., Bangkok, Thailand.
Johnson, Philip F., Wirral.
Jordan, Steven L., Boston.
Kim, Byung-Bae, Kyung Gd-do, Korea.
Kim, Kyoung-Soo, Taegu, Korea.
Kim, Taek Joong, Seoul, Korea.
Kim, Jin-Gu, Kyung Gi-Do, Korea.
Kim, Sang Hee, Seoul, Korea.
Kim, Sung-Mo, Seoul, Korea.
Ko, Hyun Seung, Seoul, Korea.
Kweon, Hyun Jun, Seoul, Korea.
Lam, Denys Tai Sing, Hong Kong.
Lee, Chang-Hun, Kyung B K-Do, Korea.
Leung, Irene Yuk Ping, Hong Kong.
Li, Zhaocong, Wuhan, P.R. China.
Livingstone, Sheena S., Dundee.
McCarthy, Edward J., Cambridge.
McLelland, Jonathan Neil, Bradford.
Meropi, Kaminara, Athens, Greece.
Michaelides, Maria G., Athens, Greece.
Mitchell, Gisela Charlotte, London.
Nayer, Ranjit Kaur, Nairobi, Kenya.
Oh, Sook-Hoe, Pusan, Korea.
Orner, Miri, London.
Park, Mi Kyeong, Pusan, Korea.
Rodrigues, Lourdes, London.
Saito, Masumi, Bangkok, Thailand.
Seong, Wun-Mo, Daejon, Korea.
Shin, Jae-Hyuk, Seoul, Korea.
Stratmann, Rudolf W., The Hague, The Netherlands.
Takahashi, Yasushi, Kofu, Japan.
Utagawa, Sayuki, London.
van Gils, Heleen, Overveen, The Netherlands.
Vaughan, John W., London.

Preliminary

Qualified

Ahn, Eun Sook, Seoul, Korea.
Anastasiou, Pavlos, Athens, Greece.
Bowman, Helene, Epping.
Carpenter, Emma, Gillingham.
Chakravarti, Lisa M., Hong Kong.
Ching, Joanne Chan Wai, Kowloon, Hong Kong.
Chang Jin Han, Seoul, Korea.
Chao, Tan-Chi, Taipei, Taiwan.
Chen, Chin-Ho, Taipei, Taiwan.
Chen, Debbie Chu-Jueh, Taipei, Taiwan.
Cheng, Lap Fan, Hong Kong.
Cheng, Su Chen, Taipei, Taiwan.
Cheung, Losanna Lai Ha , Hong Kong.
Choi, Gyoung-Ho, Seoul, Korea.
Choi, Ik Jin, Seoul, Korea.
Chow, Kam Lun, Kowloon, Hong Kong.
Chui, May Mui-Ching, Kowloon, Hong Kong.
Chung, Luk-Mui (Ivy), Kowloon, Hong Kong.
Deora, Naresh, Jaipur, India.
Florian, Claudia, New York, NY, USA.
He, Wei, Wuhan, P.R. China.
Ho, Jolanda Cheuk-Wah, Kowloon, Hong Kong.
Hong, Ji-Youn, Seoul, Korea.
Hu, Hai, Wuhan, P.R. China.
Huang, Yin-Ching, Taipei, Taiwan.
Im, Un San, Seoul, Korea.
Jin, Yi, Wuhan, P.R. China.
Johnston, Dale Raymond, Durham.
Kam, Roma Mei Lin, Hong Kong.
Kaushik, Suresh Kumar, Jaipur, India.
Kim, Byung-Bae, Kyung Gd-do, Korea.
Kim, Hyun Ok, Daejon, Korea.
Kim, Hyang-Mi, Kyung Ki-do, Korea.
Kim, Jin-Gu, Kyung Gi-do, Korea.
Kim, Nam Soon, Kyung Di-do, Korea.
Kim, Sang Hee, Seoul, Korea.
Ko, Hyun Seung, Seoul, Korea.
Kong, Pill Je, Seoul, Korea.
Kweon, Hyun Jun, Seoul, Korea.

Lam, Yiu Ming, Hong Kong.
Lamahewa, Nilanthi, Colombo, Sri Lanka.
Lee, Jae Yong, Seoul, Korea.
Lin, Hsin-Pei, Taipei, Taiwan.
Lord, Karen Wendy, Lutterworth.
Louie, Miu Man, Hong Kong.
Lu, Yi, Wuhan, P.R. China.
Lu, Yung Ching, Taipei, Taiwan.
Mourtzanos, S., London.
Mun, Eun Kyung, Kyunggi-do, Korea.
Nisell, Ann, Lidingo, Sweden.
Pit, Tino, Groningen, The Netherlands.
Sarkinen, Marianne, Stockholm, Sweden.
Shi, Dan, Wuhan, P.R. China.
Shin, Kyoung-Ok, Seoul, Korea.
Shu, Xingying, Wuhan, P.R. China.
Stather, Lorne Francis, Hong Kong.
Sung, Min Jun, Taegu, Korea.
Tao, Du, Wuhan, P.R. China.
Tzung, Chiu-Yen, Taipei Hsien, Taiwan.
Vingback, Roland, Vittangi, Sweden.
Wang, Tai-Hwan, Taipei, Taiwan.
Weng, Li Li, Taipei, Taiwan.
Wong, Gary Ming Leung, Hong Kong.
Woo, Jee, Seoul, Korea.
Xu, Hong, Wuhan, P.R. China.
Yoo, Bo-Young, Seoul, Korea.
Yu, Ni Wen, Taiwan.
Yuen, Flora Tsz Wai, Hong Kong.
Zhang, Bing, Wuhan, P.R. China.
Zhou, Jie, Wuhan, P.R. China.
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MEETINGS OF THE COUNCIL OF MANAGEMENT

At a meeting of the Council of Management held on 23 March 1994 at 27 Greville Street, London EC1N 8SU, the business transacted included the election of the following:

Transfer DGA
Mistry, Dharmesh, London, 1994.

Transfer FGA/DGA
Larkins, Barry, London, 1994.

Transfer FGA
Brown, Elizabeth A., Lindford, 1994.
Jack, Johanne C., Bangkok, Thailand, 1994.
Jordan, Steven L., Boston, Lincs., 1994.
McCarthy, Edward J., Cambridge, 1994.
Rodrigues, Lourdes, London, 1994.
Stratmann, Rudolf W., The Hague, The Netherlands, 1994.
Vaughan, John W., London, 1994.

Fellowship
Parsons, Richard F., Chorleywood, 1970.

Ordinary Membership
Ambrose, Steven J., Uxbridge.
Anastassopoulou, Angeliki, London.
Bahrani, David John, Abu Dhabi, UAE.
Bhaskar, Brajesh Nandan, New Delhi, India.
Bowman, Helen Olga, Epping.
Cham, Ansumana Ali, London.
Cooper, Tamasin Louise, Oxford.
Fantis, Charoulla, London.
Habern Jr., Michael Wayne, Tx, USA.
Lin, Shung-Shan, Taipei, Taiwan.
Mamo, Charles, Wanstead.
Perera, Sreemal, Hounslow.
Prince, John L.N., Westbury on Severn.
Sanderson, Michael David, London.
Whipp, David T., Chipstead.

Ordinary Laboratory Membership
E W Hopkins Ltd of 26-27 Hatton Garden, London EC1.

At a meeting of the Council of Management held on 27 April 1994 at 27 Greville Street, London EC1N 8SU, the business transacted included the election of the following:

Fellowship
Andersson, Ekaterini, Piraeus, Greece, 1991.
Bartfai, Tunde, The Hague, The Netherlands, 1994.
Batis, David, Athens, Greece, 1994.
Chau, Kit Yee, Fion, Hong Kong, 1994.
Conley, Curtis, Fairplay, Ca, USA, 1994.
Duguid, Keith Bruce, Kadoma, Zimbabwe, 1984.
Guptill, Martin, Los Angeles, Ca, USA, 1994.
Hui, King Chuen, Hong Kong, 1994.
Johnson, Philip Frederick, Pensby, Wirral, 1994.
Kim, Taek Joong, Seoul, Korea, 1994.
Le Rose, David, Redondo Beach, Ca, USA, 1994.
Livingstone, Sheena S., Dundee, 1994.
McLelland, Jonathan Neil, Thackley, Bradford, 1994.
Mitchell, Gisela, Hong Kong, 1994.
Nayer, Ranjit Kaur, Nairobi, Kenya, 1994.
Takahashi, Yasushi, Kofu, Japan, 1994.
Utagawa, Sayuki, Tokyo, Japan, 1994.
van Gils, Heleen, Santpoort Noord, The Netherlands, 1994.

Ordinary Membership
Boocock, Allan, Shepley, Huddersfield.
Duggan, Rory, Phetchabun, Thailand.
Dykhuis, Luella Woods, Tucson, Az, USA.
Fawcitt, Tony, London.
Govindasamy, Paramasivam, Selangor Darul Ensan, Malaysia.
Hughes, Nicholas, Stevenage.
Huston, Jane, Kilkenny, Ireland.
Kwon, Ho Kim, Chonbuk-do, Korea.
Novaga, Massimo, Milan, Italy.
Onyema, Oge, London.
Rapp, Kenneth, Ohio, USA.
Seabrook, Vivienne, Eden Hills, Australia.
Stather, Lorne, Hong Kong.
Wasinski, Simon Mark, London.
Yuen, Flora, Hong Kong.

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At a meeting of the Council of Management held on 25 May 1994 at 27 Greville Street, London EC1N 8SU, the business transacted included the election of the following:

Fellowship
Boyadjian, Liza Artin, Isleworth, 1989.
Boyd, Warren, Ontario, Canada, 1979.
Saito, Masumi, Bangkok, Thailand, 1994.
Sinclair, Anne Louise, London, 1988.

Ordinary Membership
Appleton, Susan, Wineanon, Somerset.
Butler, Aiko Sato, Silver Spring, USA.
Byworth, Margaret, Old Knebworth.
Chen, Chin-Ho, Taipei, Taiwan.
Cheng, Su Chen, Taipei, Taiwan.
Deba, Kiladi Wa, Longsight, Manchester.
Gorriceta, Felix, Quezon City, Philippines.
Horne, Timothy, Aylesbury, Bucks.
Ip, Joao Jose, Kowloon, Hong Kong.
Khon, Edgar, Miami, Fla, USA.
Sarkinen, Marianne, Stockholm, Sweden.
Siu, Kenneth, Bangkok, Thailand.
Thornton, Timothy, Kettering.
Tzung, Chiu-Yen, Taipei, Taiwan.
Wang, Tai-Hwan, Taipei, Taiwan.
Weinberg, Richard, London.

Ordinary Laboratory Membership
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At a meeting of the Council of Management held on 16 June 1994 at 27 Greville Street, London EC1N 8SU the business transacted included the election of the following:

Fellowship
Athauda, Nanda S.K., Uxbridge, 1982.
Brom, Reinier W., Wassenaar, The Netherlands, 1994.
Kim, Kyoung-Soo, Taegu, Korea, 1994.
Leung, Irene Yuk-Ping, Chaiwan, Hong Kong, 1994.

Ordinary Membership
Chao, Tan-Chi (Dandy), Taipei, Taiwan.
Chen, Pauline, Lian Bee, Hong Kong.
Chow, Michelle, Epsom.
Cullinane, Anthony, Bushey Heath, Watford.
Lin, Hsin-Pei, Taipei, Taiwan.
Lu, Yung-Ching, Taipei, Taiwan.
Mackenzie, Nicola-Jane, Southport.
Medcraft, Joseph, Windsor.
Middleton, Mary, Southampton.
Orner, Miri, Finchley, London.
Schellehens, B., Capelle a/d Yssel, The Netherlands.
Simoes, Margarida, S. Mamede de Infesta, Portugal.

Ordinary Laboratory Membership
Clark Diamonds Ltd, 62 Tenby Street North, Birmingham, B1 3EG.

CORRIGENDA

On p.91 above the captions to Figures 8 and 9 should read as follows:

Fig. 8: A twin boundary extends from the lower left to the upper middle of the photograph, 20x.

Fig. 9: A twin boundary extends from the lower middle to the upper left of the photograph, 30x.

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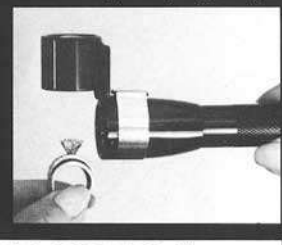

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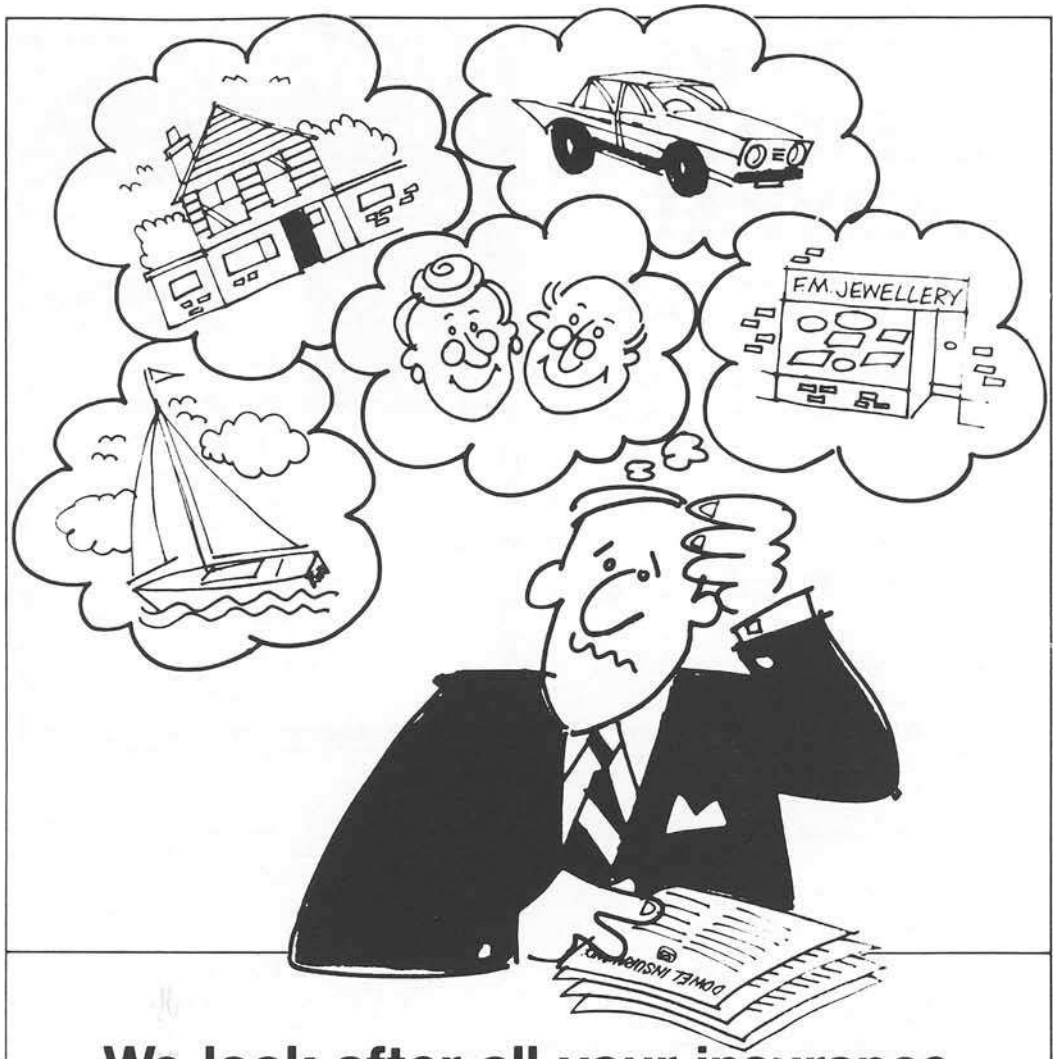

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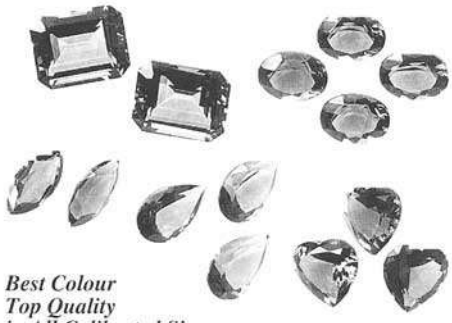

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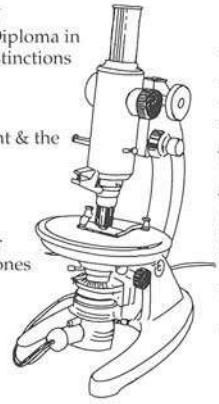

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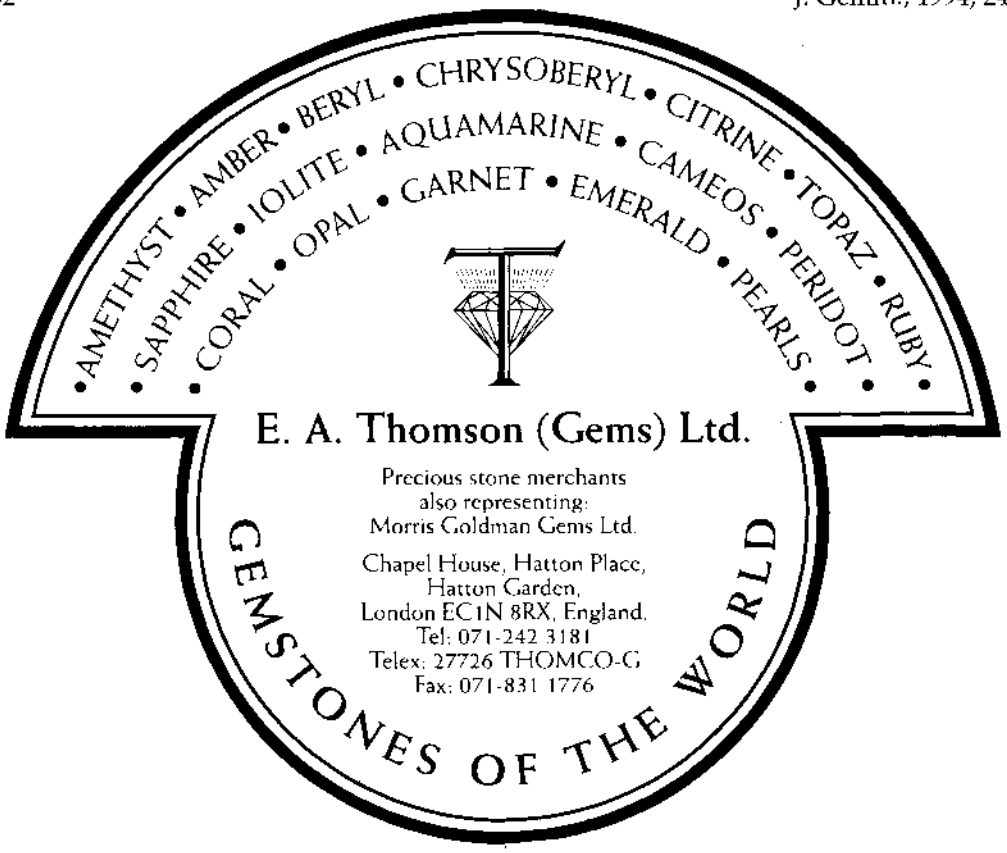

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Cover Picture

The Hope Pearl in its crown setting. *Photograph: Mikimoto.*
(See The Hope Pearl p. 235)

ISSN: 1355-4565

Editorial

The first two papers in this issue of the *Journal* concern pearls. The Hope Pearl is famous through a connection with Tavernier in 1669 and derives its name from being part of the Hope collection of gems in the 1830s.

Over time this collection has been dispersed but parts are still identifiable notably in the Smithsonian Institution and in the Natural History Museum, London. This is the first modern professional gemmological description of the Hope Pearl to appear in print.

The roots of gemmology lie in the application of mineralogical, physical or chemical techniques to the solution of gem problems and the second pearl paper extends this concept to the discipline of biomineralization. There is considerable research today into how organic tissues secrete and deposit solid matter and the application of some of these ideas has led the authors to conclusions of importance to the future of the cultured pearl industry.

The third paper takes us from sea level (or below) to high in the western Himalayas where the gems of Afghanistan are the subject of renewed exploration and development. To date, however, their historical background has been the result of much speculation and a thorough summary of the known records, long overdue, is published in this issue. Some famous gems in the world's regalia may well have their origins in northern Afghanistan and the evidence is assessed.

Papers on Burmese gems have been increasing in frequency in the past few years and here the first of two accounts of the jades of Myanmar by two authors on the spot in Yangon deals with their composition. The constituent minerals and chemistry of a representative range of different coloured jades are described and related to an extensive set of illustrations.

Two short papers complete the contents of this issue: new dendritic opals are described from Zambia and a new appearance in the trade of a star ruby imitation is reported by Dr Schmetzer. The latter material is dyed star corundum and is plainly being produced to tempt the unwary public; however, advice on how to recognize these treated stones is clearly outlined.

R.R.H.

The Hope Pearl

*Stephen J. Kennedy**

*Shigeru Akamatsu and Yasunori Iwahashi***

* Gemmological Association and Gem Testing Laboratory of Great Britain
** Pearl Research Laboratory, K. Mikimoto & Co. Ltd, Japan

Abstract

The Hope Pearl and its crown setting is described and the history of the item is reviewed. The pearl was examined by fluorescence emission spectrometry, reflection spectrophotometry, X-ray fluorescence analysis and X-ray radiography. Surface features and the X-ray radiograph proved it to be a natural blister pearl. A peak at 620nm in the fluorescence emission spectrum indicates the presence of porphyrin in the coloured base of the pearl. The reflection spectrum confirms the presence of porphyrin as well as displaying a trough at 700nm characteristic for a black pigment found in Black-lip pearls from the *Pinctada margaritifera* oyster.

Introduction

In 1993 the London Laboratory was privileged to examine one of the larger pearls known to exist. The Hope Pearl was purchased by H.E. Mohammed Mahdi Al-Tajir in 1974 from Gerards, the Paris jewellers (personal communication). The pearl formed part of the Christie's exhibition in 1989 called *The glory of the goldsmith - magnificent gold and silver from the Al-Tajir collection*. Last year, under a loan agreement, the pearl was to be taken from London to Tokyo to be the centrepiece of an exhibition arranged by K. Mikimoto & Company. The pearl was examined by X-ray radiography and its surface was closely inspected before departure, and the laboratory was asked to assess whether any

Fig. 1. The Hope Pearl, viewed from the front (left), from the right-hand side (centre) and from the back (right). *Photos: Mikimoto.*

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damage had been suffered by the pearl when it was returned to London. Once in Japan much more extensive research was carried out at the Mikimoto Pearl Research Laboratory at Toba, Toba-shi, Mie-ken.

Description and History

The Hope Pearl (Figure 1 and cover picture) is roughly drop-shaped with irregular channels on the surface around the base. The narrower top of the pearl is white in colour with a bright orient whereas the broader base graduates to an iridescent greyish-purple. The narrow top end of the pearl is capped with a gem-set, red-enamelled, gold-coloured metal arched crown pendant fitting. The item measures approximately 9cm in length from the top of the crown fitting to the base of the pearl. The broader base of the pearl varies in width between approximately 3cm to 4cm (Figure 2). The whole item of jewellery weighs 134.6 grams.

The crown fitting has been set with 70 diamonds in the arches and the pendant ring part of the fitting, and three rectangular natural emeralds, four round natural rubies and two blue lozenge-shaped pastes are set in the front part of the band of the crown fitting. The blue, orange, and green 'gem-shapes' on the reverse part of the crown band (Figure 3) are small enamelled geometric shapes giving an appearance of set gems. In addition to these small areas of enamel there is also a large area of red enamel on the cap underneath the arches of the crown.

The pearl itself is reputed to weigh 450ct or 1800 grains. As its name implies, the pearl formed part of the famed collection of the London banker Henry Philip Hope, which was assembled in the early 1800s. The collection, which was catalogued by Bram Hertz in 1839, is probably best known for the 45.52ct deep-blue Hope Diamond. The previous history of the pearl is sketchy but reference (Dickinson, 1968) is made to it having been purchased in India by Jean Baptiste Tavernier, the jewel merchant, in the mid-seventeenth century. The pearl is believed to have been sold to Louis XIV, possibly when the two met in 1669 (Tavernier, J.B., English translation 1889).

Henry Philip Hope died in 1839 and the pearl was passed down through the family. Mr A.J. Beresford-Hope loaned the pearl to the South Kensington Museum (Streeter, 1886) at some stage subsequent to its opening in 1881. The pearl was sold with other gemstones from the Hope collection in 1886 by the auctioneers Christie & Manson. Garrard & Co. of London purchased the pearl and it is known that it was being offered for sale in 1908 at £9000 (Kunz and Stevenson, 1908). As mentioned above the pearl was purchased in 1974 for a figure that has been quoted at $200,000 (Newman, 1981). At some time prior to this the pearl had been exhibited at the Smithsonian Institution in Washington (Taburiaux, 1985).

Investigation methods

In addition to microscopic and fibrescope examination the following techniques were also used in examining the pearl:

Ultra-violet fluorescence

The fluorescent colours emitted by a pearl when irradiated by ultra-violet light may yield information concerning the species of the mother oyster (Sawada, 1958; Miyoshi *et al.*, 1987 a and b).

Fluorescence emission spectrometry

The different fluorescent colours emitted by pearls originating from certain oysters can produce characteristic fluorescence emission spectra. Black pearls from the black-lipped *Pinctada margaritifera* (Miyoshi *et al.*, 1987 a and b) and pearls from the Mabe *Pteria penguin* can be distinguished from other pearls by the presence of a peak at 620nm in their fluorescence emission spectra (Figure 4), which is due to the presence of porphyrin. The fluorescent

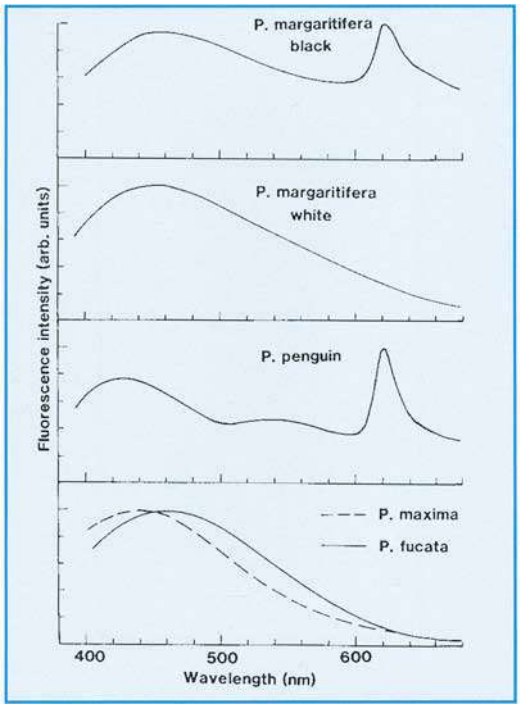

Fig. 4. Fluorescence emission spectra of the nacre from different types of oysters, showing how the nacre from *Pteria penguin* and the black nacred *Pinctada margaritifera* differ from the nacre of other oysters by the presence of a peak at 620nm.

emission characteristics of the coloured base of the Hope Pearl were measured with a Nihon Bunko spectrofluorophotometer Model FP770 at an excitation wavelength of 400 nanometres.

Reflection spectrophotometry

The pigmentation of coloured pearls can also give rise to specific reflection spectra in the visible region for particular pearl-producing oysters (Wada, 1983). The reflection spectra for grey *Pinctada margaritifera* pearls display a trough at 700nm whereas the spectra for *Pteria penguin* pearls do not show the trough (Figure 5). A reflection spectrum was obtained from the iridescent greyish-purple base of the Hope Pearl using a CMS-35sp spectrophotometer from the Murakami Color Research Laboratory.

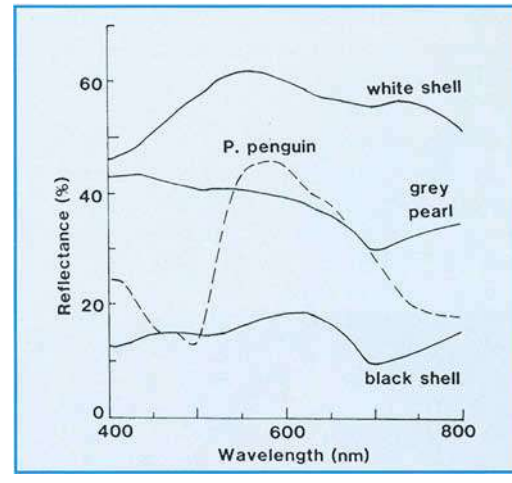

Fig. 5. Optical reflection spectra of a pearl and the shells of *Pinctada margaritifera* (solid curves) and the reddish-brown shell of *Pteria penguin* (dashed curve), which can be differentiated on the basis of a trough at 700nm in the spectra for *Pinctada margaritifera*.

X-ray fluorescence analysis

The main inorganic component of pearl is calcium carbonate. The chemical composition also includes some minor elements, of which the relative amounts of manganese and strontium have been found to be an important indicator of the species of the pearl-producing mother oyster.

Freshwater pearls can be differentiated from marine oyster pearls on the basis that the latter have lower concentrations of manganese and higher concentrations of strontium (Wada and Fujinuki, 1988). Amongst seawater pearls strontium is found in slightly greater concentrations in Black-lip *(Pinctada margaritifera)* and White-lip *(Pinctada maxima)* pearls than in Akoya *(Pinctada fucata)* pearls. The Hope Pearl was analysed for calcium, manganese and strontium by Energy Dispersive X-ray spectrometry using Seiko Model SEA 2001.

X-ray radiography

The internal structure of the Hope Pearl was revealed by X-ray radiography. In Japan the radiographs were obtained using a SOFTEX CMB-2 set. In London the spe-

cially designed X-ray set uses a Machlett fine focus diffraction tube with a molybdenum anode target.

Results and discussion

Visual examination of the reverse side of the Hope Pearl reveals the growth lines that prove the pearl was attached to the shell (Figure 6) and should therefore be

Fig. 6. Surface growth lines on the back of the Hope Pearl indicating its blister origin. 5x.

Fig. 7. Overlapping platy crystal structure on the surface of the Hope Pearl typical of pearls from nacreous bivalves. 25x.

described as a natural blister pearl. At higher magnification the striped pattern of overlapping platelets (Figure 7) characteristic of nacreous bivalves can be seen. The fact that light from the fibrescope could not penetrate very far through the surface of the pearl indicates that it consists mainly of solid calcium carbonate, and this was confirmed by the X-ray radiographs (Figure 8).

The presence of the organic component

Fig. 8. Positive photograph of the X-radiograph taken of the Hope Pearl.

conchiolin is recorded on the radiograph negative (not shown) by a series of faint growth lines sweeping across the body of the pearl to its edge; this pattern is typical for a natural blister pearl which has grown away from the inner surface of the shell.

The coloured base of the pearl fluoresces a reddish colour under ultra-violet light, and this suggests the presence of porphyrin pigment known to exist in Black-lip (Iwahashi and Akamatsu, 1994) and Mabe pearls (Comfort, 1949).

The fluorescence emission spectra recorded under 400nm radiation contain a peak at 620nm (Figure 9), confirming that the pigment is porphyrin, which can be found in both Black-lip and Mabe pearls.

Porphyrin also gives rise to the troughs at 400nm and 500nm in the reflection spectra (Figure 10a and b). More importantly the trough at 700nm (Figure 10c) is characteristic for a black pigment contained in the Black-lip pearl.

The X-ray fluorescence analysis reveals concentrations (cation %) of 99.54% for

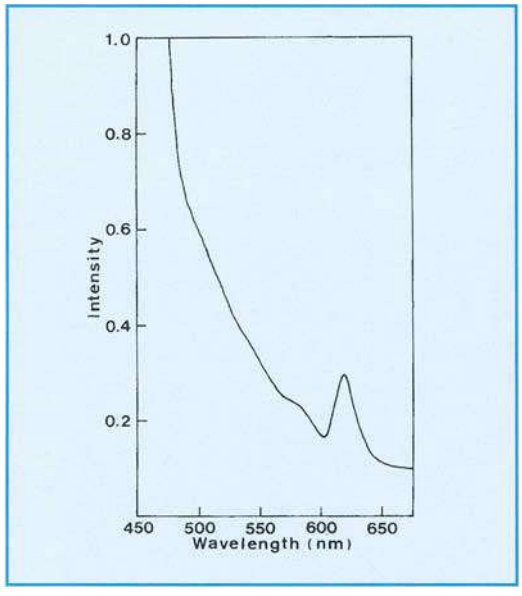

Fig. 9. Fluorescence emission spectrum of the Hope Pearl showing the presence of the peak at 620nm.

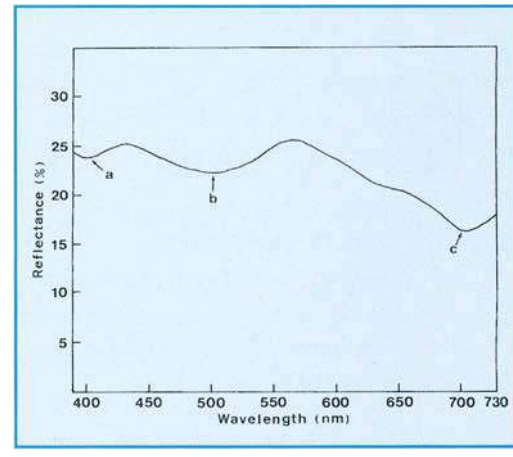

Fig. 10. Optical reflection spectrum of the Hope Pearl. The troughs at (a) and (b) relate to porphyrin, the trough (c) at 700nm is typical for a black pigment contained in *Pinctada margaritifera*.

calcium, 0.42% for strontium, and 0.04% for manganese. The relatively low concentration of manganese and high concentration of strontium point to a marine origin for the Hope Pearl.

Conclusions

The Hope Pearl is a natural blister pearl of solid nacre. The pigments present in the bronzed area indicate that the Black-lip oyster *(Pinctada margaritifera)* is the most likely source of the pearl.

Acknowledgements

The authors wish to convey their thanks to the owner, H.E. Mahdi Mohammed Al-Tajir, for his permission to publish this article.

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Structural and chemical investigations on shells and pearls of nacre forming salt- and fresh-water bivalve molluscs

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Abstract

To investigate the shell structure of some pearl-forming bivalve molluscs the following techniques were used: light microscopy, scanning electron microscopy (SEM), X-ray diffraction (XRD), texture goniometry, scanning force microscopy (SFM), energy dispersive X-ray fluorescence (EDXRF) and fourier transform infrared spectroscopy (FT-IR).

X-ray diffractograms were taken to determine the identity of the minerals forming the shell. They were identified as aragonite in the mother-of-pearl layer and as calcite in the prismatic layer.

The X-ray diffractograms also showed that the orientation of the crystallites forming the nacreous layer of freshwater mussels is different from those of saltwater oysters. In pictures taken by SEM the aragonite crystals of all the investigated mussels except *Hyriopsis schlegeli* show a pseudo-hexagonal shape. Investigations by texture goniometry indicate the crystals to be single crystals, so they are not twins like their inorganically grown counterparts.

A theory of nacre growth is proposed and its application would help to decrease the amount of waste pearls. It was found to be possible to influence the colour of the pearls without using artificial treatment.

Attempts were made to explain the crystal growth by means of high resolution scanning force microscopy (SFM) which enables examination of the surface of the aragonite microcrystals. The observed structures on top of these crystals could be the so-called organic matrix that strongly influences nacre growth.

The chemical investigations showed that there is little difference in the amount of minor and trace elements in the nacre and pearls from different localities. However, it is possible to distinguish between the origins of freshwater mussels due to their contents of manganese and potassium. The strontium contents of some saltwater oysters are presented but are not a diagnostic feature.

Introduction

Investigating the shell and shell growth of nacre forming molluscs (e.g. bivalvia (mussels)) is not only of gemmological interest because of their capability to form pearls. The shell growth is a biomineralization process which is related to similar processes in the human body (skeleton) (Handschin and Stern, 1992). Compared to human bones, the shell of a mussel is a simple model where mineralization processes can easily be studied (see also

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Caseiro, 1993). The aim of this study was to perform a structural and chemical comparison of shells and pearls from different origins. In order that one may understand the observed structures it is important to know how the mussel grows and to recognize the main parts of the shell.

Because the growth process is essentially the same in shells and pearls, the results of the shell investigations can be used to supplement the knowledge of the process of pearl formation, but this work does not attempt to explain the initiation of pearl growth.

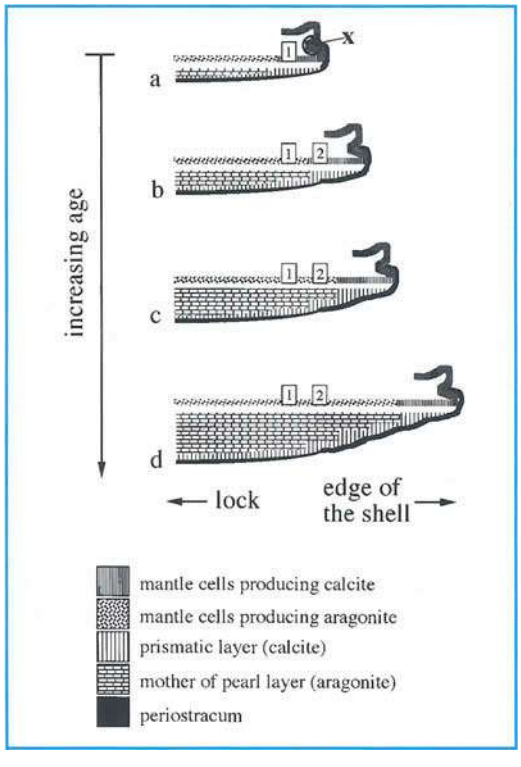

Fig. 1. Schematic cross-section through the shell, showing the mineral components of the shell and the soft parts of the animal (mantle tissue, periostracum) that produces them. From a to d the cross-sections represent increasing ages.

Background

This section includes not only the results of earlier work but also some of our own new results which should enable the reader to understand the following text.

Figure 1d shows a schematic cross-section through the type of shell used in this study. The bottom of the sketch represents the outer surface of the shell. This is a hydrophobic organic skin called the periostracum. It covers the hard parts of the shell and serves as a defence against erosion and enemies. On the inside of the periostracum is the prismatic layer, the first inorganic part of the shell. It is formed by small prisms of calcite crystals ($CaCO_3$, trigonal). The prismatic layer is followed by the mother-of-pearl layer, or nacreous layer, which is formed from tabular aragonite crystals ($CaCO_3$, orthorhombic).

All these components of the shell are produced by a soft part called the mantle (Figure 1), the part of the animal next to the shell. On the opposite side of the hinge (that is where the two shells are connected) the mantle forms a fold (x in Figure 1a). The cells in this fold produce molecules which grow to form the periostracum (Lowenstam and Weiner, 1989) which is the first part of the shell that is formed. It builds the substrate on which the prismatic and mother-of-pearl layers grow. There is also evidence for another organic phase besides the periostracum playing an important role in the formation of the shell. It is called an organic matrix (Weiner and Traub, 1984) and may influence strongly the crystallization of the calcite and aragonite crystals. More details follow in the section 'Morphological structures'.

Figure 1 shows the growth stages of the type of shell investigated. The shell always grows from the centre towards the edge. At the hinge the shell does not spread but thickens with increasing age. The growth of the shell is a consequence of the growth of the inner soft parts, in other words of the animal itself whose growth centre is the mantle. There are two types of mantle cell that secrete the Ca^{2+} and CO_3^{2-} ions (1 and 2 in Figure 1). The formation of the crystals as calcite or aragonite is determined by the

age of the cells. Young cells (1) near the border of the shell produce calcite and older cells (2) towards the inner part of the shell form aragonite.

This means that young cells situated on the inner side of the shell always produce calcite (type 1 cells). These young cells are followed by older cells (type 2 cells), which were former type 1 cells. Because the cells do not change their places relative to the shell, but change the mineral phase they produce, there will be a certain time when they deposit aragonite over calcite (Gutmannsbauer, 1992). This growth behaviour is summarized in Figure 1.

The knowledge of this theory could be of great importance for the cultured pearl industry. The production of large amounts of reject cultured pearls, e.g. – pearls that consist of, or are partly overgrown by, calcite – could be prevented. Since cultured pearls will have the same colour as the mother-of-pearl grown by the original mantle cells, pearl culturers can influence the colour of the end product by carefully choosing the mantle cells from the right location in the bivalve sacrificed for its mantle tissue.

Material and methods

In this study the shells and pearls of the main pearl-forming oysters and mussels were of interest. Cultured as well as natural pearls were investigated and a main point for our sample acquisition was that the shells and pearls were not treated in any way, so that there could be no falsification of the chemical and structural data. The examined shells and pearls are listed with their origins in Table I.

The following techniques were used to investigate the structures of the shells: light microscopy (LM), scanning electron microscopy (SEM), X-ray diffraction (XRD), texture goniometry and scanning force microscopy (SFM).

Chemical analyses were carried out by energy dispersive X-ray fluorescence (ED-XRF). Fourier transform infrared spectroscopy (FT-IR) was used for struc-

Table I. Shells and pearls examined in the present study.

Saltwater oysters	*Quantity*	*Origin*	*Pearls*
Pinctada margaritifera	10	Tahiti	yes
Pinctada martensii	8	Japan	yes
Pinctada maxima goldlipped	3	Philippines	no
Pinctada maxima goldlipped	4	Australia	no
Pinctada maxima goldlipped	1	Thailand	no
Pinctada maxima silverlipped	1	Burma	no
Pinctada maxima silverlipped	12	Australia	no
Pteria penguin	2	Okinawa	yes
Pteria penguin	2	Philippines	yes
Pteria penguin	3	Australia	yes
Pteria penguin	3	Thailand	yes
Freshwater mussels	*Quantity*	*Origin*	*Pearls*
Anodonta plicata	5	China	yes
Hyriopsis schlegeli	6	Japan	yes
Unio margaritifera	1	USA	yes

Fig. 2. Cross-section through the shell of the saltwater oyster *Pinctada margaritifera* (Tahiti). The components from the bottom to the top are: prismatic layer (calcite), mother-of-pearl layer (black-and-white, aragonite). 27x

tural as well as chemical investigations.

We will not give any technical details of the well-established methods such as SEM, FT-IR, XRD and texture goniometry, (a further development of XRD), but a short introduction is given to the less well-known method of energy dispersive X-ray fluorescence (EDXRF) and to scanning force microscopy (SFM), which is relatively new.

Morphological structures

Light microscopy (LM)

The essential observations were made with normal light microscopy, which led us to the theory of shell growth outlined above in the 'Background'. The pictures were taken on polished cross-sections of shells and pearls, both natural and cultured. Figure 2 shows a cross-section through the shell of the saltwater oyster *Pinctada margaritifera* from Tahiti. The layers seen compare favourably with those in Figure 1d. The black colour is due to the organic phases, conchiolin and porphyrin (Miyoshi *et al.*, 1987, 1989). The difference of colour in the aragonite layer may be caused by either a seasonal change or variation in food availability.

The influence of the age of the tissue causing the growth of a pearl is shown in Figure 3 (cf. Figure 1). The bead of the cultivated Japanese saltwater pearl (the oyster *Pinctada martensii*) in Figure 3a is the nucleus for a deposit of a thin layer of calcite prisms. Figure 3b shows a large core of calcite prisms in a natural saltwater pearl. In both cases, the calcite layers are followed by aragonite layers. The identity of the calcite prisms was checked by FT-IR (Farmer, 1974).

What do we learn from the structures of these pearls?

The piece of mantle that was inserted with the bead, to build up the tabular aragonite crystals (nacre) around it, was cut from a little too near the edge of the victim bivalve. It was not old enough to produce aragonite from the beginning. After producing calcite prisms for a while, it switched to aragonite. This explains the calcite rim around the bead followed by the aragonite layer.

Initial growth of the natural pearl also took place near the edge of the shell in very young mantle cells which deposited calcite for a long time before changing to aragonite production. Like others (e.g. Scarratt, 1987), we also have observed both natural and cultivated pearls built totally out of calcite prisms. These pearls show none of the desired optical iridescence effects and most are of no commercial value.

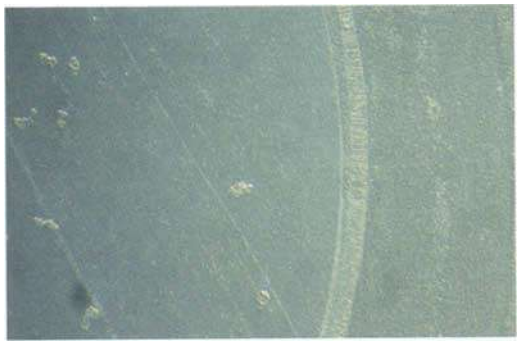

Fig. 3a. Cross-section through a Japanese bead-nucleated pearl cultured in saltwater (Akoya). The bead (left) is followed by a small layer of calcite prisms that is followed by the mother-of-pearl layers (aragonite). 40x

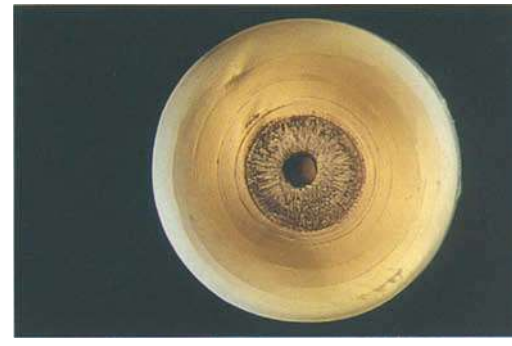

Fig. 3b. Cross-section through a natural saltwater pearl with a large core formed of calcite prisms. The prismatic layer is followed by the mother-of-pearl layers. 30x

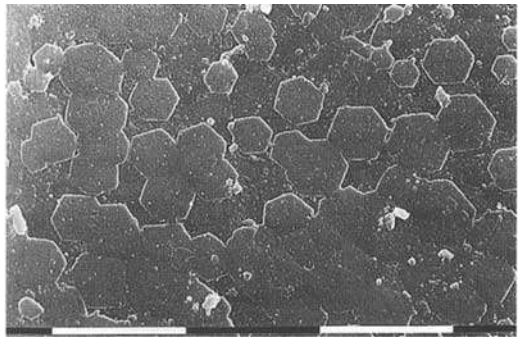

Fig. 4. SEM micrograph of the pseudo-hexagonal aragonite crystals forming the mother-of-pearl layer in the shell of the saltwater oyster *Pinctada maxima* (Australia). Length of one white line segment: d = 10µm.

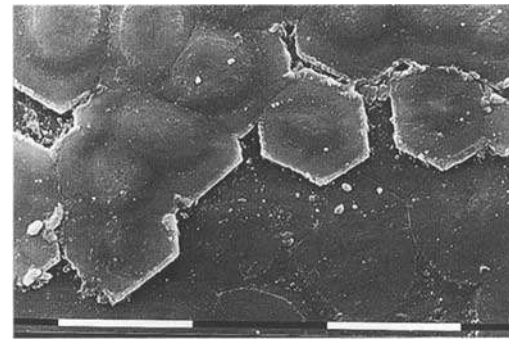

Fig. 5. SEM micrograph of the aragonite crystals forming the mother-of-pearl layer in the shell of the freshwater mussel *Hyriopsis schlegeli* (Japan, Lake Biwa). Nearly all crystals show screw dislocations. Length of one white line segment: d = 10µm.

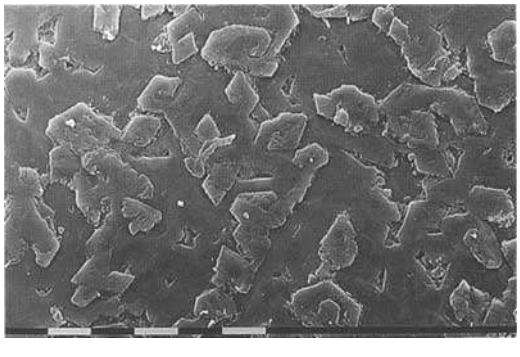

Fig. 6. SEM micrograph of the pseudo-hexagonal aragonite crystals forming the mother-of-pearl layer in the shell of the saltwater oyster *Pinctada margaritifera*. The crystals show hillocks on their surfaces. Length of one white line segment: d = 10µm

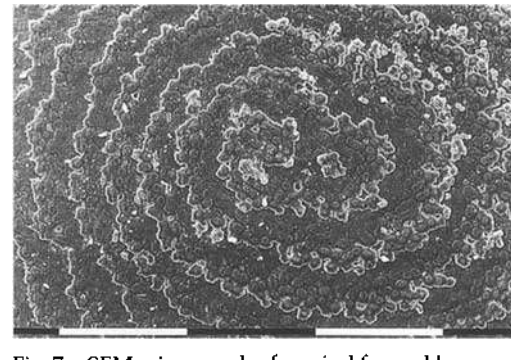

Fig. 7. SEM micrograph of a spiral formed by many aragonite crystals in the mother-of-pearl layer of the saltwater oyster *Pinctada margaritifera* (Tahiti). Length of one white line segment: d = 0.1mm

Scanning electron microscopy (SEM)

The aim of the SEM investigation was to characterize the aragonite and calcite crystals and perhaps some organic relics such as the organic matrix mentioned in the introduction (for a short review of SEM see Postek *et al.*, 1980).

For the SEM investigations three specimens of each species were chosen. At least three samples were taken from every single shell. In this way, we hoped to gain an overview of the internal diversity of the shell. Indeed, we observed that the habits of the aragonite crystals vary between the different species and in the shells themselves. However, there is one particular habit of the aragonite crystals that can be found in every species. These are tabular crystals with a thickness of 400 nm to 1500 nm that have a pseudo-hexagonal shape (see also Mutvei, 1980, and Erben, 1970). Figure 4 shows a top view on the mother-of-pearl layer which is built of these pseudo-hexagonal aragonite crystals, from the shell of the saltwater oyster *Pinctada maxima* (Australia).

The nacreous layers from the shell of the freshwater mussel *Hyriopsis schlegeli* (Biwa pearls, Japan) and the saltwater oyster *Pinctada margaritifera* (Polynesian black pearls, Tahiti) show some features that distinguish them from the other shells. Figures 5 and 6 show SEM micrographs which exhibit two totally different kinds of growth. The *Hyriopsis schlegeli* grows by adding carbonate in spirals initiated by structural dislocations. The term dislocations describes changes in the symmetry of the array of atoms as they adhere to a crystal at its growing surface. Nearly every aragonite crystal in the nacreous layer shows this phenomenon. In contrast, the aragonite crystals of the *Pinctada margaritifera* (Figure 6) exhibit a kind of hillock on every crystal. We think that these 'growth hills' could be the initial stages of the crystals forming the next nacreous layer.

Screw dislocations can be observed in nearly all shells, but to a much lesser extent than in the *Hyriopsis schlegeli*. Only a few crystals in the whole of the *Pinctada margaritifera* (Tahiti) shell have such dislocations, but these are transmitted to the overlying crystals, giving rise to a large spiral involving many single aragonite crystals without dislocations (Figure 7). The reason why the aragonite crystals of some shells have many dislocations while others have very few is not yet clear, but it will be an interesting subject for our further investigation.

The calcite crystals of the prismatic layer in the shells are quite uniform in shape through all the investigated species. They only vary in size. For SEM images of the prismatic layer see Doumenge *et al.* (1991).

X-Ray diffraction (XRD) and texture goniometry

Shell material of every species was investigated by XRD. It confirmed that the nacreous layer of every shell consisted of aragonite and the prismatic layer of calcite. Fibrous aragonite as described by Caseiro (1993) was not found in our samples.

More astonishing was the fact that the diffractograms of the nacreous layer of saltwater oysters looked different from those of freshwater mussels. The diffractograms of the aragonitic layers in freshwater mussels had some reflections that did not appear, or only to a much lesser extent, in those of saltwater oysters. We concluded that the orientations of the aragonite crystals in the nacreous layer of saltwater oysters are slightly different from those in the nacreous layer of freshwater mussels.

To confirm this theory, we used the method of texture goniometry, with which it is possible to determine the orientations of the crystal axes in a polycrystalline material. This very useful method works on the basis of X-ray diffraction, and a detailed description is given by Wenk (1985). These investigations showed that the *c*-axes of all aragonite crystals forming the nacreous layer are aligned perfectly

parallel to each other, and perpendicular to the inner surface. But the lateral axes of the aragonite crystals of the saltwater oysters were better aligned than those of the freshwater mussels. The reason for these different orientations are not known, but the factors of water temperature and concentrations of dissolved elements (which for freshwater mussels are usually lower than for saltwater oysters) may play a role.

Studies carried out by texture goniometry revealed other even more interesting results. It was clearly shown that the aragonite crystals forming the mother-of-pearl layer in all our investigated shells are single crystals. This is in agreement with some earlier studies (Towe and Hamilton, 1968; Wise 1970). However, it contradicts the findings of other authors who postulated that the pseudo-hexagonal habit of the aragonite crystals, arose as a result of twinning (Mutvei, 1970; Hänni, 1982).

Although one query has been solved a new one arises: how can an aragonite crystal with orthorhombic crystal symmetry have a hexagonal shape? The hexagonal shape and the spatial arrangement of the aragonite crystals in nacre has been described by Erben (1970) and Mutvei (1970) using SEM. Theoretically it is possible to have aragonite single crystals with orthorhombic crystal symmetry displaying a 'pseudo-hexagonal' habit (Graeser, 1992), and the question of whether these crystals are twins can possibly be answered by another result of the texture goniometry study. We detected a highly ordered phase in the mother-of-pearl layer that could not be correlated with any of the modifications of $CaCO_3$, (calcite, aragonite or vaterite) or with strontianite. This highly ordered phase may not be crystalline at all and the reflection could come from the organic matrix (Weiner and Traub, 1984) mentioned in the 'Background'. The exact nature of the organic matrix, which presumably covers every single crystal in the shell, could not be observed on the SEM.

Scanning force microscopy (SFM)

With scanning force microscopy (SFM), whose lateral and vertical resolution is high enough to distinguish atoms, we were able to depict the surface of single aragonite crystals forming the nacreous layer in the shell of the Australian oyster *Pinctada maxima.*

Scanning force microscopy is essentially a further development of the scanning tunnelling microscope (STM) invented by Binnig *et al.* (1982). In contrast to the STM, which senses a tunnelling current, the force microscope senses forces between the probing tip and the sample surface. With the SFM it is possible to study surfaces of insulators as well as conductors, whereas the STM is restricted to conducting samples. Figure 8 shows a scheme for a scanning force microscope that is based on a force sensor, a displacement sensor, a feedback system which monitors and regulates the deflection of the cantilever, a mechanical scanning system and a computer system for acquisition of data and image processing. For recent reviews see Rugar and Hansma (1990) and Meyer (1992).

Two general modes of operation have been developed for SFM to sense short-range forces as well as long-range forces: the contact mode and the non-contact mode.

In this study only the contact mode was applied; therefore the description is restricted to this method. Using the contact mode, the probing tip (2) is brought close to the repulsive force range of the sample surface (3) (tenths of nanometers). In response to the repulsive short-range interatomic forces, which act on the probing tip, the cantilever (1) is bent. While scanning the sample surface with piezoelectric transducers, the deflection of the cantilever is kept constant by a feedback loop that adjusts the relative distance between sample surface and probing tip. The feedback signal is monitored as a func-

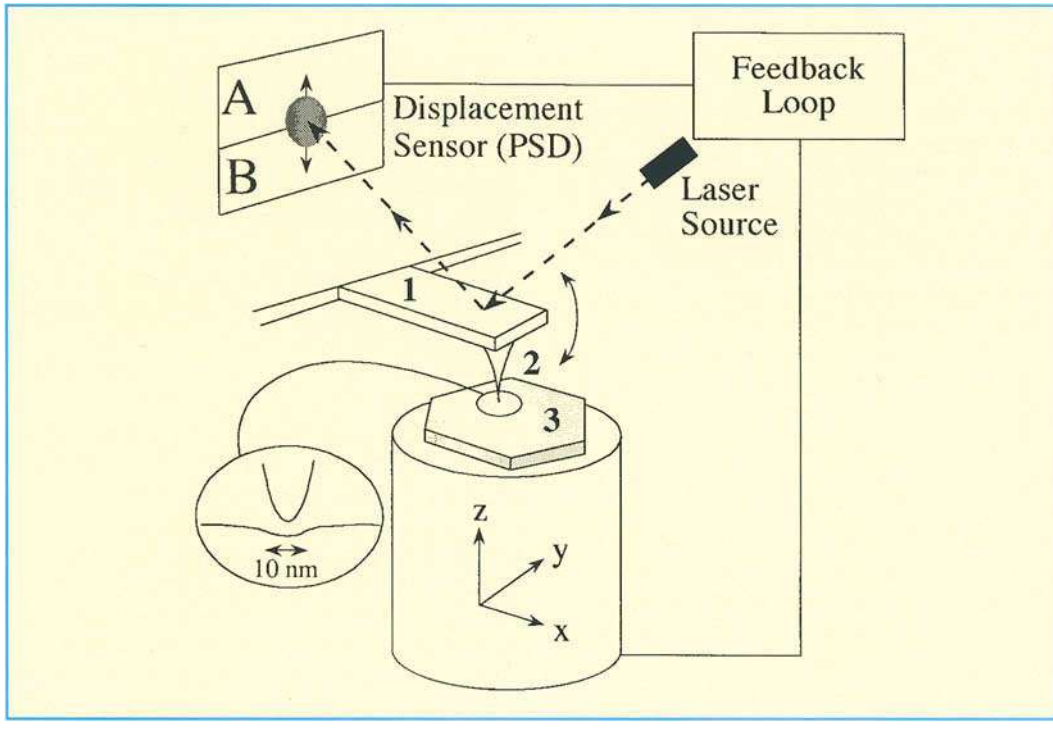

Fig. 8. Schematic diagram of a scanning force microscope (SFM). (1) Cantilever, (2) probing tip, (3) sample surface.

tion of the lateral position of the probe and the image of equiforce contours (termed force micrograph) is obtained. This relief is interpreted as the topography of the sample surface.

In this study a commercially available scanning force microscope, equipped with a beam deflection system for measuring the cantilever displacement was used. This system is widely used in commercially available microscopes because of its simplicity. A laser beam is collimated and focused on the rear side of the cantilever and there reflected off to a segment photo diode acting as a position sensitive detector (PSD). Due to the interaction between probing tip and sample surface, the cantilever is deflected elastically and thereby changes the reflection angle of the laser beam detected by the PSD (Figure 8).

Figure 9 shows a force micrograph of a single aragonite crystal from the nacreous layer. The crystal shows no re-entrant angles as twins sometimes do (Hurlbut, 1977). It has a thickness of about 600 nm and a diameter of about 5000 nm (5μm). According to Weiner and Traub (1984), the growth of these aragonite hexagons is strongly influenced by an organic matrix covering every single crystal. In confirmation of this theory, the crystals of the mother-of-pearl layer all look as if they are covered with organic matter. Figure 10 is a top view of the crystal in Figure 9. Particles with diameters of 80 to 100 nm can be seen. These particles probably form the organic matrix. They also often show hexagonal shapes which are taken on by the subsequent growth of aragonite crystals (Gutmannsbauer, 1993). It is also known that organic compounds can influence the shape of inorganic crystals. Uric acid causes NaCl crystals to crystallize as octahedra instead of the cubes usually seen. It is possible that a similar process between the organic matter and the arago-

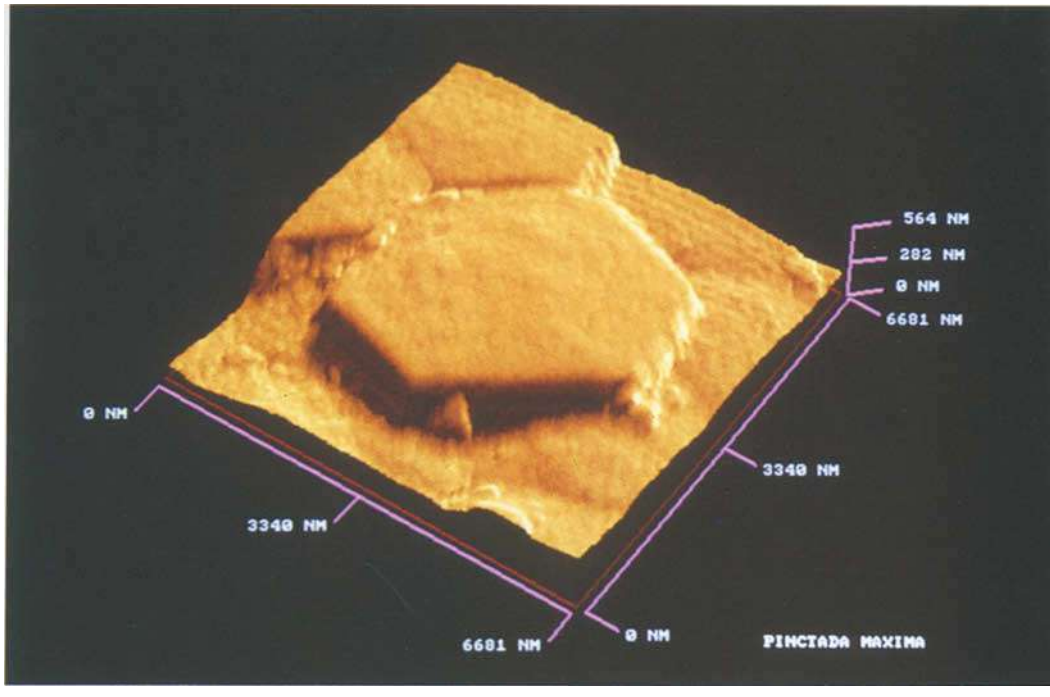

Fig. 9. Scanning force micrograph of an aragonite crystal forming the mother-of-pearl layer in the shell of the salt-water oyster *Pinctada maxima* (Australia). Diameter of the crystal: d≈5µm

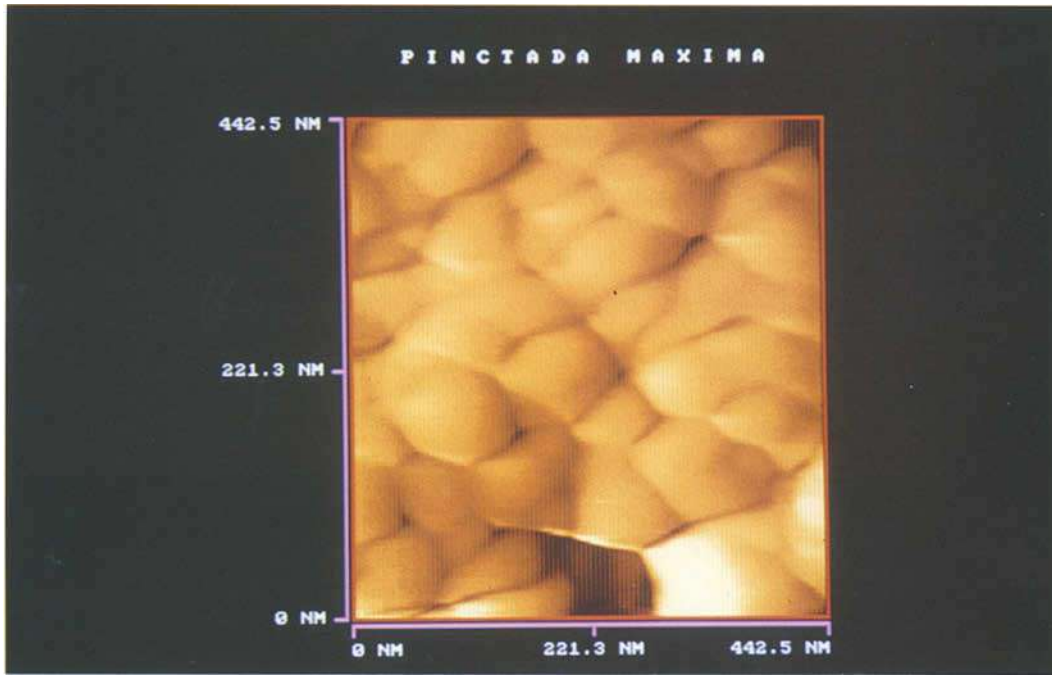

Fig. 10. Scanning force micrograph of the top of the crystal in Figure 9. This is probably the organic matrix that covers every crystal in the shell. Diameter of the polygonal domed areas forming the matrix: d≈80 nm.

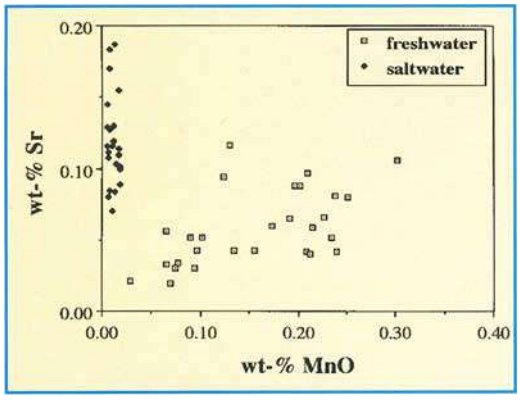

Fig. 11. EDXRF analysis of the Mn and Sr contents in the mother-of-pearl layers of saltwater and freshwater shells.

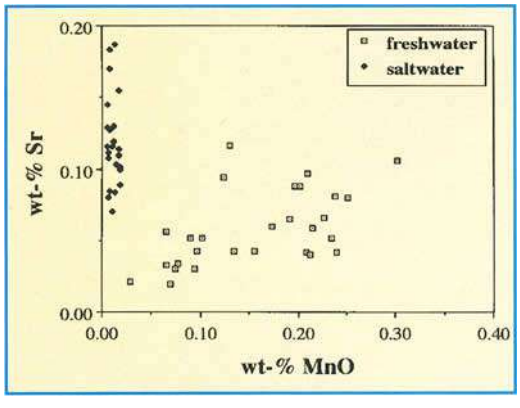

Fig. 12. EDXRF analysis of the Mn and Sr contents in the mother-of-pearl layers of the shells of the freshwater mussels *Hyriopsis schlegeli* and *Anodonta plicata*.

nite crystals influences the growth of the aragonite crystals. According to Lowenstam and Weiner (1989), there is evidence of organic matter inside the crystals.

The thicknesses of these aragonite microcrystals are within the range of wavelengths of visible light, which suggests that the rainbow colours seen on nacre are due to interference.

Chemistry

Energy dispersive X-ray fluorescence (EDXRF)

The chemical analyses of the shells were carried out by EDXRF. This is a spectrometric analysis method for the determination of the chemical composition of usually solid matter. The sample is supplied with radiation energy from an X-ray tube. Due to this irradiation the atoms in the sample also emit X-rays of characteristic wavelength (line spectra) that are typical for every element. The fluorescence or energy is registered by a detector. The detection records simultaneously all major and minor elements with the atomic numbers from Z=11 (Na) to Z=92 (U). Because the power of the X-ray tube is not very high, no radiation damage is caused. For a detailed description see Hahn-Weinheimer *et al.* (1984).

With EDXRF we studied the chemical composition of the periostracum, the mother-of-pearl layers and the pearls of the different species that were available.

The results showed that the composition of the periostracum of all shell material contains a greater number of different elements and in higher concentrations than the corresponding mother-of-pearl layers and pearls. Among the elements found were Na, Mg, S, Cl, K and P. We suggest that these elements give some indication of the composition of the water the animals lived in, but because there is no gemmological relevance for these elements in the periostracum, we will not go into further details.

As earlier investigations have already shown (Farn, 1986), saltwater shells and pearls contain significant lower Mn than those from freshwater. Sr can easily be incorporated in the structure of aragonite instead of Ca, and all of the investigated mussels do incorporate Sr in their shell but not enough for the formation of the mineral strontianite. However, there is no significant difference in the concentration of Sr between salt- and fresh-water shells (Figure 11). The concentration of Mn differs even among the freshwater mussels themselves. The mother-of-pearl layer and pearls of the mussel *Anodonta plicata*

contain significantly less Mn than the mother-of-pearl layer and pearls of the mussel *Hyriopsis schlegeli* (Figure 12). There is no statistically demonstrable difference between these two species with regard to Sr content.

The mother-of-pearl layer and the pearls of the freshwater mussel *Hyriopsis schlegeli* are the only freshwater mussels that contain no K.

The chemical analyses of mother-of-pearl and pearls of the freshwater mussels originating from the Mississippi (*Unio margaritifera*) showed that it is not possible to characterize these in terms of their trace elements. The values of the element concentrations overlap the values found from all other investigated species. This can be explained by considering the vast extent of the Mississippi river system. The river passes through many different geological environments and the element concentrations of the water will vary to a large degree.

It was not possible to find any difference between the element concentrations in the mother-of-pearl layers in shells from different saltwater oysters. However, the pearls of the saltwater oyster *Pinctada martensii* have lower Sr concentrations than the other saltwater pearls.

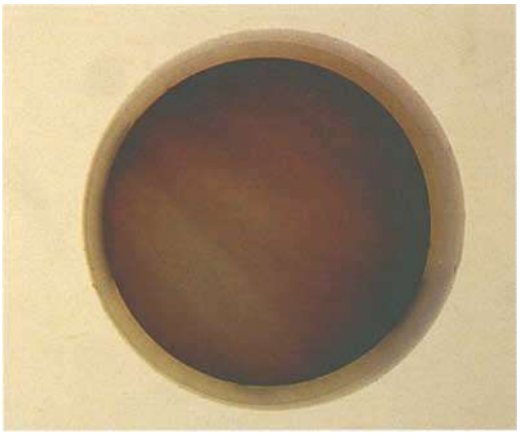

Fig. 13. Akoya cultured pearl with a bead that is treated with an organic dye. 30x

Fourier transform infrared spectroscopy (FT-IR)

All the shells and pearls we received were described as untreated. However, nearly all Japanese saltwater grey to black cultured pearls contained beads coloured with an organic dye. Figure 13 shows an Akoya cultured pearl of this kind. The dye causes a series of peaks in the infrared range between 2000 and 1300cm^{-1}.

All our samples were tested using FT-IR to determine the presence of calcite or aragonite. A quick identification is possible (Speer, 1983) by checking the spectrum for peaks either at 1492-1432, 879 and 706cm^{-1} (calcite) or 1504, 1492, 1080, 866, 711 and 706cm^{-1} (aragonite).

Conclusions

This study shows that formation of mother-of-pearl and pearl is complex and can only be investigated with the use of specialized instruments. Although this study took one year of research for one of the authors (W.G.), many unsolved problems remain and some new questions have arisen.

The study showed that it is not possible to identify shell species and pearls using only one method. On the contrary, only a combination of techniques can lead to realistic interpretations. For example, the determination of the bivalve that formed a pearl is only possible by a combination of results gained from structural and chemical investigations.

To detect and confirm any treatments (e.g. dyeing) even more techniques are required (e.g. FT-IR).

The investigation of mother-of-pearl is not only of gemmological interest: the growth process itself, including biomineralization is also of great importance in medical research. The nacreous layer of the bivalve molluscs makes available a relatively simple model in which biomineralization processes can be studied.

Acknowledgements

The large amount of data and the many different analytical methods used mean that this work could not have been done by one single person.

Grateful thanks are extended to Prof. Dr W.B. Stern for supporting this work with his great experience using the XRD and EDXRF, Prof. Dr R. Guggenheim, D. Mathys and M. Düggelin for the professional work on the SEM and Dr H. Stünitz for the investigations with the texture goniometer. Further thanks are extended to Prof. Dr H.- J. Güntherodt and to Dr P. Reimann who enabled the SFM investigations. For fruitful discussions we want to thank Prof. Dr S. Graeser, Dr R. Handschin and R. Lüthi.

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One of the authors (W.G.) wants to thank his co-author and 'diploma father' for guiding him so well during his diploma thesis; and last but not least his fiancée Carmen for bearing with him during this year of research.

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[Manuscript received 4 February 1994]

Dyed natural star corundum as a ruby imitation

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Fig. 1. Dyed natural star corundums; the middle cabochon in the front measures 11.4mm in diameter. *(Photo by H.A. Hänni, Basel)*

Abstract

Natural star corundum which is treated with a red dye, most probably in India, is described. The star ruby imitation is easily identified by an uneven colour concentration in fissures or cracks, which irregularly traverse the corundum cabochons. The asterism is caused by orientated inclusions of rutile needles.

Introduction

Dyed natural corundum as a ruby imitation was recently described by several authors (Schmetzer *et al.*, 1992; Schmetzer and Schupp, 1992; Crowningshield and Reinitz, 1992). For the dyeing procedure yellowish or nearly colourless corundum crystals, probably from East Africa, were used. Microscopic examination of dyed beads as well as cabochon-cut and faceted specimens revealed various natural inclusions and an uneven colour distribution within the samples. The red dye was con-

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Fig. 2. Treated natural star corundum cabochon revealing growth zoning confined to prism faces or hexagonal dipyramids; the sample measures 10 x 12mm. *(Photo by H.A. Hänni, Basel)*

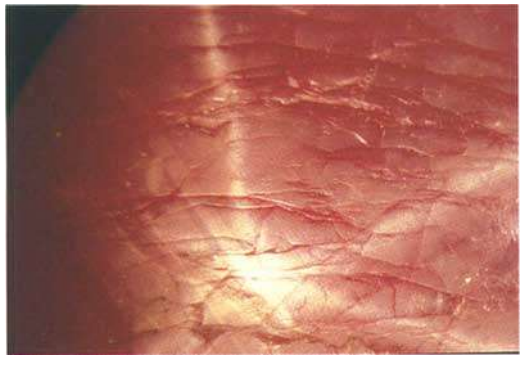

Fig. 3. Growth zoning and concentration of red dye in fissures of treated natural star corundum; the figure represents an area of about 0.4 x 0.6mm.

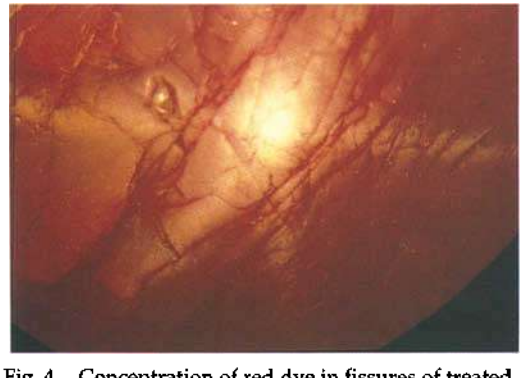

Fig. 4. Concentration of red dye in fissures of treated natural star corundum; the figure represents an area of about 0.4 x 0.6mm.

fined only to irregular fissures and cracks, which showed an extraordinarily intense yellow-orange fluorescence under long-wave ultraviolet radiation. Similar dyed specimens were mentioned by Barot and Harding (1993, 1994), who quoted Kitui in southern Kenya, a new locality for mostly pale-coloured stones, as a possible source for material dyed in India as a ruby imitation.

Gemmology

Recently 16 cabochon-cut asteriated gemstones were purchased by one of the authors from a dealer in Germany as natural star rubies. The samples ranging from about 7mm to 12mm in size (Figures 1, 2) revealed an intense red body colour and possessed sharp six-rayed stars. From information given by the supplier, these samples were probably imported from India.

Standard gemmological tests identified the cabochon-cut stones as corundum. In several samples the rays of the stars were found to run perpendicular to traces of growth planes parallel to{11$\bar{2}$0} prism faces and/or parallel to hexagonal dipyramids (Figures 2, 3). This orientation of the six-rayed star is typical for Indian star corundum, the asterism of which is caused by inclusion of rutile needles (cf. Weibel, 1985). The concentration of rutile needles in different growth sectors of the cabochons described in this paper is sometimes variable, which is indicated by different intensities of the milky-white appearance of various growth zones in reflected light (Figure 3).

The characteristic features mentioned above in addition to the observation of natural inclusions and parting planes parallel to the positive rhombohedron (10$\bar{1}$1), which were also present in some of the samples, indicate a natural origin for the cabochons.

During microscopic examination, however, it was observed that the colour of the samples was concentrated in fissures

or cracks, which irregularly traversed the corundum crystals (Figures 3, 4). Under long- or short-wave ultraviolet radiation no fluorescence was observed, neither from the corundum cabochons themselves nor from the dye concentrated in fissures. When a stone was immersed in acetone, part of the red coloration was removed and, subsequent to this test, red spots were visible even on the wrapping material of the stone.

Consequently, the samples were identified as artificially dyed natural star corundum. The lack of a pronounced yellow fluorescence of the red colouring agent in fissures and cracks indicated a different dye compared with the beads and faceted stones described recently in gemmological literature.

Discussion

A possible source of the natural corundum specimens used for the dyeing process is the Mysore-Karnataka area in southern India, which supplied a great quantity of pale-coloured star corundum in the past. Artificially dyed material from this locality was mentioned by Hughes (1990), although material similar to the star ruby imitation described in this paper has not previously been observed in the trade by the present authors.

Treated star corundum cabochons can be identified by microscopic examination or even with a hand lens by observation of the uneven colour concentration in fissures or cracks.

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The rubies and spinels of Afghanistan – a brief history

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Abstract

While ruby is one of the most important gems, in the twentieth century little has been written about one of the premier sources of antiquity—Afghanistan. The following article is divided into two parts. The first describes the history of Afghanistan's ruby/spinel deposits. Important mines are located near Jagdalek and Gharan (Badakhshan). The latter is believed to be the original source of the balas ruby (spinel); many of the most famous spinels, such as the Timur Ruby and Black Prince's Ruby, possibly originated there. The second part deals with the gemmological characteristics of Jagdalek rubies.

Keywords

Afghanistan, Tajikistan, ruby, spinel, gems, history

Notes on methodology

Whenever possible, quotations found throughout this article have been faithfully transcribed from the original source. The only corrections made have been minor changes in punctuation. As a result, readers may encounter inconsistencies in spelling, etc. My approach has been that, when doubt existed, the original would stand as printed.

Certain quotations are quite lengthy. Rather than rewriting or paraphrasing what others have found (and, in the process, claiming it as his own), the author believes that history is better served by repeating their words exactly. Hence the extensive use of quotations from the primary literature (including the original footnotes). In so doing, the danger of misinterpretation is lessened. My own thoughts on the meaning of such quotes follow. This approach allows readers reach their own conclusions on the original authors' intent.

Some may question the need for such extensive historical detail. I include it in an attempt to show the threads of wisdom connecting us with our past. In today's modern world it is easy to believe that anything worth knowing has resulted from recent study. Such is not the case and I hope that this article can open readers' eyes to the glories (and excesses) of human tradition and history.

The great enigma: Afghanistan's ruby/spinel mines

Afghanistan's ruby/spinel mines are one of the great mysteries of gemmology. Historically, rubies and red spinels have been produced from four areas: Myanmar (Burma), Sri Lanka, the Thai/Cambodian border (ruby only; no red spinel) and Afghanistan. While extensive accounts exist regarding the other deposits, in the twentieth century little has been written about the rubies/spinels of Afghanistan. Indeed, many are totally unaware of the Afghan occurrences.

While I have visited Afghanistan and have personally examined many rubies

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from Jagdalek, I have not visited either of the two major deposits described. Thus the following has been assembled from a number of historical sources, with much of the primary research on inclusions in Jagdalek stones coming from the author's own research.

In terms of historical data, rather than rewriting or paraphrasing what others have found and, in the process, claiming it as his own, the author believes history is better served by repeating their words exactly, warts and all. Hence the extensive use of quotations from primary literature (including the original footnotes from those sources).[1]

Early history: AD1000–1895

Afghanistan's ruby/spinel mines were mentioned in the Arabic writings of many early travellers, including al-Muqaddasi (c. tenth century), al-Biruni (b. 973; d. c. AD1050), Teifaschi (AD1240), and Ibn Battuta (AD1325–1354).

Mohammed Ben Mansur, writing in the twelfth century, stated during the time of Abbaside (caliphs who ruled from AD750 to AD1258), a hill at Chatlan was broken open by an earthquake and within a white rock in the fracture was found the 'Laal-Bedaschan' (balas ruby). Women of the neighbourhood apparently tried to extract dye[2] from the red stones and, failing, threw them away. Later a jeweller recognized their value (Ball, 1931).

Although Marco Polo (c. AD1254–1324) apparently did not visit the mines, he passed nearby. In Henry Yule's definitive version (1920) of Marco Polo's travels is the following (with Yule's and Henri Cordier's notes following a translation of Polo's text):

Polo's text

BADASHAN is a Province inhabited by people who worship Mahommet, and have a peculiar language. It forms a very great kingdom, and the royalty is hereditary...

...It is in this province that those fine and valuable gems the Balas Rubies are found. They are got in certain rocks among the mountains, and in the search for them the people dig great caves underground, just as is done by miners for silver. There is but one special mountain that produces them, and it is called SYGHINAN. The stones are dug on the king's account, and no one else dares dig in that mountain on pain of forfeiture of life as well as goods; nor may any one carry the stones out of the kingdom. But the king amasses them all, and sends them to other kings when he has tribute to render, or when he desires to offer a friendly present; and such only as he pleases he causes to be sold. Thus he acts in order to keep the Balas at a high value; for if he were to allow everybody to dig, they would extract so many that the world would be glutted with them, and they would cease to bear any value. Hence it is that he allows so few to be taken out, and is so strict in the matter.*

Yule's annotation

* I have adopted in the text for the name of the country that one of the several forms in the G. Text which comes nearest to the correct name, viz. *Badascian*. But *Balacian* also appears both in that and in Pauthier's text. This represents *Balakhshán*, a form also sometimes used in the East. Hayton has *Balaxcen*, Clavijo Balaxia, the Catalan Map *Baldassia*. From the form *Balakhsh* the Balas Ruby got its name. As Ibn Batuta says: 'The Mountains of Badakhshan have given their name to the Badakhshi Ruby, vulgarly called *Al Balaksh*.' Albertus Magnus says the *Balagius* is the female of the Carbuncle or Ruby Proper, 'and some say it is his house, and hath thereby got the name, quasi *Palatium* Carbunculi!' The Balais or Balas Ruby is, like the Spinel, a kind inferior to the real Ruby of Ava. The author of the *Masálak al Absár* says the finest Balas ever seen in the Arab countries was one presented to Malek 'Adil Ketboga, at Damascus; it was of a triangular form and weighed 50 drachms. The prices of *Balasci* in Europe in that age may be found in Pegolotti, but the needful problems are hard to solve.

> No sapphire in Inde, no Rubie rich of price,
> There lacked than, nor Emeraud so grene,
> Balès, Turkès, ne thing to my device.
> (Chaucer, 'Court of Love.')

> L'altra letizia, che m'era già nota,
> Preclara cosa me si fece in vista,
> Qual fin *balascio* in che lo Sol percuoto.
> (*Paradiso*, ix. 67)

1. All footnotes attached to quotations are those of the original authors and are indicated with symbols (*, †, etc.). My own footnotes are at the bottom of the page and are numbered – RWH.

2. Lapis lazuli, also from Badakshan, was an important source of pigment in ancient times (*viz.* ultramarine, which is made by crushing lapis). Thus the actions of these women are understandable. However, corundum and spinel, unlike lapis, are coloured by impurities. Thus their streak, and their colour when crushed, is colourless.

Cordier's annotations

['...d'Ohsson translates a short account of Badakhshan by Yakut (+1229), stating that this mountainous country is famed for its precious stones, and especially rubies, called *Balakhsh.*' (Bretschneider, *Med. Res.* II. p. 66.)—H.C.]

The account of the royal monopoly in working the mines, etc., has continued accurate down to our day. When Murad Beg of Kunduz conquered Badakhshan some forty years ago, in disgust at the small produce of the mines, he abandoned working them, and sold nearly all the population into slavery! They continue to remain unworked, unless clandestinely. In 1866 the reigning Mír had one of them opened at the request of Pandit Manphul, but without much result.

The locality of the mines is on the right bank of the Oxus, in the district of Ish Káshm and on the borders of SHIGNAN, the *Syghinan* of the text. (*P. Manph.; Wood*, 206; *N. Ann. des.* V. xxvi. 300.)

[The ruby mines are really in the Gháran country, which extends along both banks of the Oxus. Barshar is one of the deserted villages; the boundary between Gháran and Shignán is the Kuguz Parin (in Shighai dialect means 'holes in the rock'); the Persian equivalent is 'Rafak-i-Soumakh.' (Cf. Captain Trotter, *Forsyth's Mission*, p. 277.)—H.C.]

Henry Yule, 1920,
The Book of Ser Marco Polo

The famous Moorish traveller, Ibn Battuta (Batuta) (AD1325–1354), mentioned the following:

People generally attribute the lapis-stone [lapis lazuli; Arabic *lazward*] to Khurasan, but in reality it is imported from the mountains of [the province of] Badakhshan, which has given its name also to the ruby called *badakhshi* (pronounced by the vulgar *balakhshi*)...

H.A.R. Gibb,
The Travels of Ibn Battuta, Vol. 3, 1971

In 1832, James Prinsep published a fascinating paper in the *Journal of the Asiatic Society of Bengal*. This contained abstracts of three different oriental works, translated into English by Raja Kalíkishen[3], some of which covered the ruby/spinel deposit of Badakhshan:

DODECAHEDRAL CORUNDUM
OR SPINELLE RUBY

Persian: *lâl*; HINDU: *manik?* or *lâl*.

'The mine of this gem was not discovered until after a sudden shock of an earthquake, in *Badakshan**, had rent asunder a mountain in that country, which exhibited to the astonished spectators a number of sparkling pink gems of the size of eggs. The women of the neighbourhood thought them to possess a tingent quality, but finding they yielded no colouring matter, they threw them away. Some jewellers, discovering their worth, delivered them to the lapidaries to be worked up, but owing to their softness the workmen could not at first polish them, until they found out the method of doing so with *mark-i-shisá*, marcasite or iron pyrites. This gem was first esteemed more than the *yaqút*,[4] but as its colour and hardness were found to be inferior to the latter, it became less prized. ...'

In a manuscript history of Cashmír and the countries adjacent, by Abdúl Qádir Khan, Benares, 1830, is the following description of the manner of extracting rubies from the *Badakshan* mines: it professes to be taken from an oral account by Mirza Nazar Báki Bég Khán, a native of Badakshán, settled at Benares.

Having collected a party of miners, a spot is pointed out by experienced workmen, where an adit is commenced. The aperture is cut in the rock large enough to admit a man upright: the passage is lighted at intervals by cotton mashúls placed in niches; as they proceed with the excavation, the rock is examined until a vein of reddish appearance is discovered, which is recognized as the matrix of the precious gem. This red coloured rock or vein is called *rag-i-lál*, or, the vein of rubies; the miners set to work upon this with much art, following all its ramifications through the parent rock. The first rubies that present themselves are small, and of bad colour: these the miners called *piadehs* (foot soldiers): further on some larger and of better colour are found, which are called *sawars* (horse soldiers); the next, as they still progress in improvement, are called *amirs, bakshis*, and *vazirs*, until at last they come to the *king jewel*, after finding which, they give up working the vein: and this is always polished and presented to the king. The author proceeds to describe the finest ruby of this kind that had ever fallen under his observation. It belonged to the Oude family, and was carried off by Vizir Ali; he was afterwards employed in recovering it from the latter: it was of the size of a pigeon's egg, and the colour very brilliant; weight, about two tolas; there was a flaw in it, and to hide it, the name of *Julál-ud-dín* was engraved over the part; hence the jewel was called the *lál-i-jaláli*. A similar ruby to this, but considerably larger, is in the possession of *Runjit Sinh*, and has the names of five emperors engraved upon it.

James Prinsep and Raja Kalíkishen, 1832

*The *Manaif-ul-ahjár* dates this occurrence '350 years ago', but the date of the work is not given: the lâl is not mentioned by *Zakarya*. Since the above was written, Mr. H.H. Wilson has favoured me with a sight of another work on jewels, entitled *Khawás-ul-*

[3]The information was extracted from three books, of different eras: 1, the *Ajáib-ul-makhlukát o Gharáib-ul-moujudát*, an ancient Persion work on natural history, written by *Zakaya*, a native of *Kufa*, date unknown; 2, the *Aqul-i-ashreh*, a work on science, by Mahomed of Berar, An Hej. 1084 (AD1673;) and 3, the *Jawáhir-námeh*, a modern anonymous compilation, containing much useful matter in a condensed form: it was probably written at one of the native courts, either Delhi or Hyderabad, since it mentions the opening of [then] recent mines in India (Prinsep and Kalikishen, 1832).

[4] *Yaqut* is a Persian-Arabic term for corundum. Ancient Arab minerologists placed all colours of ruby-sapphire under *yaqut* (Princep, 1832).

Famous balas rubies— blood-red souvenirs of conquest

Among the most storied stones of history are the large balas rubies found in museums and gem collections throughout the world. The Diamond Fund in Russia has a number of representative examples. Noted Russian gemmologist/mineralogist, Alexander Fersman, remarked '...in the Diamond Fund these spinels have a significant place. One of such stones, weighing 100 carats, speaks to us of the sands of Ceylon, but the majority of them come from Afghanistan, from the mountains of the province of Badakhshan. In old Russian manuscripts it was called "lal Badakhshan" (Fersman, 1946, p. 374).

Prominent among spinels in the Diamond Fund is the massive red orb atop the Imperial Russian Crown. This crimson colossus tips the scales at 414.30 ct (Twining, 1960). A rather fanciful description of this stone's history has been given by Yevdokimov (1991). It was said to have been found by Chun Li, a Chinese-mercenary member of Timur's army that looted Samarkand. Unfortunately for Chun Li, he failed to turn in some of the booty, and so was exiled in slavery to the ruby mines of Badakhshan. Finding the stone, he crept away in the night and made his escape. But his attempt to present it to the Chinese emperor was thwarted when a palace guard found the stone and killed him for it. This guard was similarly killed when a jeweller he tried to sell the stone to, informed on him. Thus the gem passed to the emperors. In 1676, the ruby was purchased 'at a pretty price' from emperor Kon Khan by Nikolai Spafari, at the behest of Alexei Mikhailovich, second tsar of the Romanov dynasty. Upon the ascendancy of Catherine II ('the great') to the throne in 1762, she had the stone mounted on the top of her crown, where it remains today (Yevdokimov, 1991).

The Black Prince's Ruby is perhaps the most famous balas ruby in existence (Figure 4). Since its story has been told so many times before (see Hughes, 1990) I will not tell it again. Less well-known among spinels, but no less interesting, is the Timur Ruby, or Khiraj-i-alam ('Tribute to the World'). The last of the great nomad kings to overrun the world, when not conquering far-off lands, Timur [also known as Shah Qiran; b. 1336?; d. 1405] made his base at Samarkand, where legendary feasts and orgies were held (Collins, 1968).

The Timur Ruby weighs 352.50 ct and is currently in the collection of HM Queen Elizabeth II. The stone carries several Persian inscriptions written in Arabic, the longest of which reads: 'This is the ruby among the twenty-five thousand jewels of the King of Kings, the Sultan Sahib Qiran.' The Ruby is said to have passed into his hands when he sacked Delhi in 1398 and, after the usual pillage and extortion, was later obtained by Ranjit Singh, the 'Lion of the Punjab'. The British annexed the Punjab in 1849. Along with the province, they also 'annexed' both the Koh-i-Nur diamond and the Timur Ruby, which were later presented to Queen Victoria (Twining, 1960).

Fig. 4. The Black Prince's Ruby, a historic red spinel set in the Imperial State Crown and displayed in the Tower of London. A ruby, set in gold, is secured to the top of the spinel. *(Photo by F. Greenaway, by kind permission of H.M. The Queen. Crown copyright reserved)*

hejár, translated by himself, in which the *lâl* is treated of under the name of *balaksh* (*Balakshan* being synonymous with *Badakshan*). This leaves no doubt as to the origin of the word Balas...

The inscriptions mentioned on the ruby owned by Ranjit Singh ('Runjit Sinh') suggest that this was the Timur Ruby now in the collection of the British monarch (see p.259).

In 1836, Captain John Wood began an epic journey to trace the headwaters of the Oxus river. He did attempt to visit the ruby mines in Badakhshan, but due to inclement weather was unsuccessful. The following is his account:

The ruby mines are within twenty miles of Ishkashm, in a district called Gharan, which word signifies caves or mines, and on the right bank of the river Oxus. They face the stream, and their entrance is said to be 1200 feet [366 m] above its level. The formation of the mountain is either red sandstone or limestone largely impregnated with magnesia. The mines are easily worked, the operation being more like digging a hole in sand, than quarrying rocks.... The galleries are described as being numerous, and running directly in from the river. The labourers are greatly incommoded by water filtering into the mine from above, and by the smoke from their lamps, for which there is no exit. Wherever a seam or whitish blotch is discovered, the miners set to work; and when a ruby is found it is always encased in a round nodule of considerable size. The mines have not been worked since Badakhshan fell into the hands of the Kunduz chief, who, irritated, it is supposed, at the small profit they yielded, marched the inhabitants of the district, then numbering about five hundred families, to Kunduz, and disposed of them in the slave market. The inhabitants of Gharan were Rafizies, or Shiah Mohamedans, and so are the few families which still remain there.

John Wood, 1841
A Journey to the Source of the River Oxus

A mention of the Badakhshan mines was made by Pandit Manphúl, in a report dated 1867. His report is important for, unlike most others, he seems to have examined actual specimens. Manphúl said:

The Ruby Mines are situated in *Ishkásham*, bordering on *Shighnán*.... The Ruby mines have not been worked for the last twenty years and upwards. They were then given up in consequence of the labour spent on them not having been sufficiently rewarded; whether the mines had been exhausted, or whether the workers were unskilful, or managed to steal the more precious stones, is not certain. The present Mír, who had one of the mines worked last year (AD1866), at my request, made over to me some of the best specimens brought to him. They are not the best of their kinds, unless the one encased in a nodule turn out to be so. The Mír, depreciating the skill of the present workers, who are natives of the country, and, according to an established usage, labour for nothing, is anxious to secure the services of competent miners... It is believed that the mines are still stealthily worked by the people living near them, with, or without the countenance and connivance of the servants of the Mír charged with their management. The mines are known to have yielded rubies of six different colours, viz. red, green, white, yellow, violet, and rosy. The specimens with me are white, violet, and rosy. The ruby (*lál*) has given Badakhshan a lasting celebrity in the world of Oriental poetry. The Sohanmakkhi* also comes out of the Ruby Mines.

*Corundum?

Pandit Manphúl,
Badakhshán and the Countries around it
(see Yule, 1872)

Valentine Ball (1881), Irishman *extraordinaire*, former head of the Geological Survey of India and author of *Tavernier's Travels in India*, also remarked on the mines, under the topic of spinel:

Afghanistan —In the year 1879 the so-called ruby mines of the late Amir of Afghanistan, Shir Ali, which are situated near the village of Jagdalak in Kabul, were visited by Major Stewart of the Guides. Two specimens of stones, called *yakut* by the natives, and samples of the matrix, were forwarded to the office of the Geological Survey for examination. The stones proved to be spinel, and the matrix a crystalline micaceous limestone. Major Stewart* states that the Amir kept a strict guard over the mines and only allowed particular friends of his own to work them.

Badakshan —The balas ruby mines of Badakshan are situated on the banks of the Shighnan, a tributary of the Oxus. They have been known by reputation for very many centuries, and the name balas is derived from Balakshan, another form of writing the name of the country or from Balkh the capital town.† This may possibly be the origin of the common mistake made in English works on precious stones, namely, that these mines are situated in Balochistan! ...

*Proc. As. Soc. Bengal, 1880, p. 4.
†Prinsep J. Jour. As. Soc. Bengal, Vol. I, p. 359

Valentine Ball, 1881
A Manual of the Geology of India, Part III: Economic Geology, pp 429-30

Ball claimed that the Jagdalek stones were spinel. While spinel could possibly also occur there, a later analysis reported by F.R. Mallet (1887) proved that the two

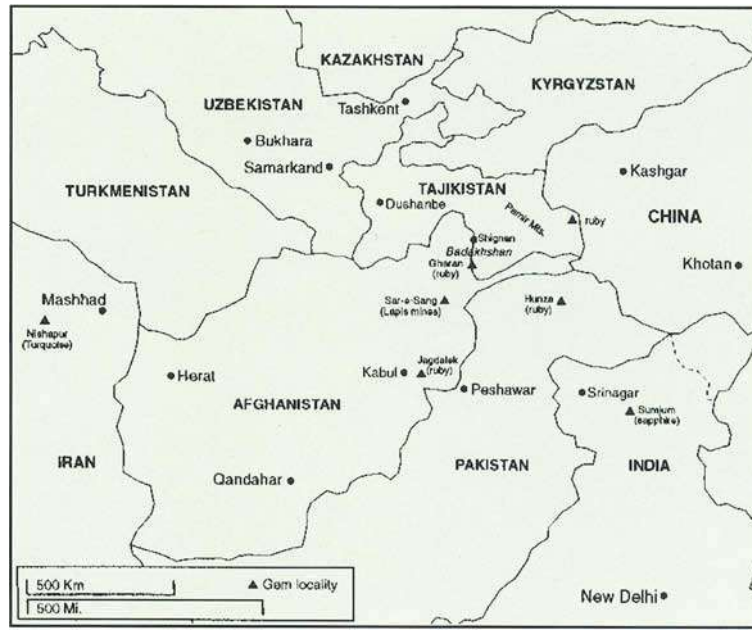

Fig. 1. Major gem deposits of central Asia. Corundum is found at Sumjum (India), Hunza (Pakistan), Jagdalek (Afghanistan) and Gharan (Afghanistan/Tajikistan), as well as along the China/Tajikistan border.

specimens collected were, in fact, rubies.

An early mention of the rubies of Badakhshan is found in the writings of the Spaniard, Ruy Gonzalez de Clavijo, who visited the court of Timur[5], at Samarkand in the years AD1403–06 .

> The lord [Timour] caused all the Meerzas and nobles in the land of Samarcand to come to this festival; amongst whom was the lord of Balaxia, which is a great city, where rubies are procured; and he came with a large troop of knights and followers.
>
> The ambassadors went to this lord of Balaxia, and asked him how he got the rubies; and he replied that near the city, there was a mountain whence they brought them, and that every day they broke up a rock in search of them. He said that when they found a vein, they got out the rubies skilfully, by breaking the rock all round with chisels. During the work, a great guard was set by order of Timour Beg; and Balaxia is ten days journey from Samarcand, in the direction of India.
>
> C.R. Markham, 1859
> *Embassy of Ruy Gonzalez de Clavijo to the Court of Timour, at Samarcand*, AD 1403–6

Bauer (1904) describes both the Jagdalek and Badakhshan deposits. Of the latter, Bauer said:

> The ruby mines of Badakshan were famous in olden times, and they supplied some of the vast store of treasure amassed by the Great Mogul. They are situated in Shignan, on the bend of the Oxus river, which is directed to the south-west, in latitude about 37°N. and longitude 71.5°E. They lie between the upper course of the Oxus and its right tributary the Turt, near Gharan, a place the name of which is said to signify 'mine,' sixteen miles [26 km] below the town of Barshar, in the lower, not the higher, mountain ranges…
>
> It is possible that the rubies and spinels which have recently come into the market through Tashkent, and which, according to the merchants, were mined in the Tian-Shan Mountains, are in reality from these same mines. There is no reliable information as to the existence of ruby mines in the Tian-Shan Mountains or in Tibet, so that the 2000 carat ruby recently received by Streeter, and said to come from Tibet, may also have been found in these mines on the Oxus.
>
> Max Bauer, 1904
> *Precious Stones*

There is little mention of the Badakhshan mines after Bauer, possibly because they lie on the border of, or inside, Tajikistan, a region of the former USSR little visited by foreigners. Barthoux (1933) discussed the mines, stating that they lay near the village of Siz, in the area of *Ghâran*, on the right

5. Tamerlane is an English corruption of *Timur i leng* ('Timur the lame'), as Timur was crippled in battle when about 27 years old (Collins, 1968).

Fig. 2. View overlooking the Jagdalek ruby mines, Afghanistan. The mines are located in a limestone band which appears as a thin white line on the most distant hills at the rear of the picture. *(Photo by Gary Bowersox)*

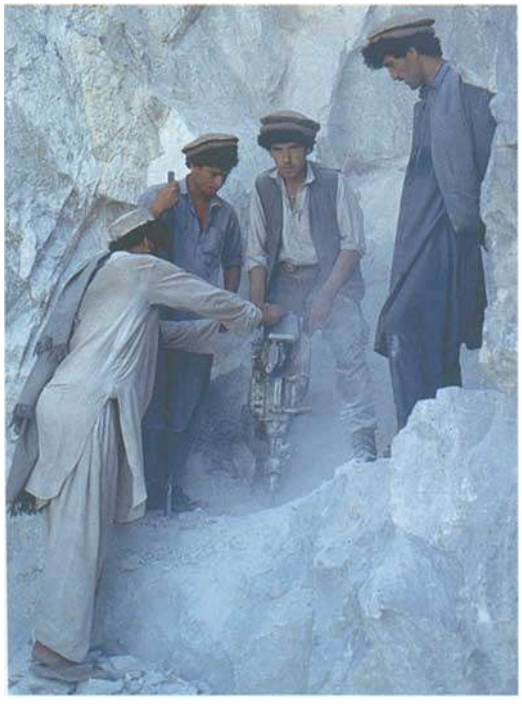

Fig. 3. Afghan miners drilling the limestone for rubies at Jagdalek, Afghanistan. *(Photo by Gary Bowersox)*

bank of the Oxus. He reported that huge, translucent, purplish pink octahedrons (*'le rubis balais'*) over 20 cm in size were extracted at that locality. Almandine garnet was said to occur on the left bank. Barthoux also stated that a more important occurrence of ruby was at Jagdalek ('Djagdalik'). The larger pieces were mostly massive, but smaller pieces showed traces of '*p* {10$\bar{1}$1}, *a* {0001}, *d* {11$\bar{2}$0} and *e* {22$\bar{4}$3}'. They were found with spinel and most were pink in colour. Also occurring with the rubies were humite, chondrodite, phlogopite, fuchsite, rutile, sphene, hematite and pyrite (Barthoux, 1933; trans. for the author by Olivier Galibert, 3 June 1994).

After Barthoux, discussion of Afghan rubies was restricted to the Jagdalek mines. During the Soviet occupation, mining of all Afghan gem and mineral deposits was controlled by the state (Boa, 1987). However, since many mines lay in inaccessible areas, such mining became an important source of income for the rebels. With the Soviet withdrawal, modern exploration and

Badakhshan ruby/spinel: myth or reality?

From the historical record, it is clear that the Badakhshan mines were of great importance during the period from AD1000–1900 . While it is impossible to speculate about ruby, it is safe to say that, based on the numerous historical accounts, the Badakhshan mines were the source of many of the finest early red spinels in gem collections around the world, such as those in the crown jewels of Iran, the collection in Istanbul's Topkapi, Russia's Kremlin and Diamond Fund, and England's Tower of London.

Unfortunately, in modern times, such mines are largely overlooked. Twentieth-century gemmologists persist in the belief that the only source of big red spinels is Myanmar (Kammerling, *et al.*, 1994). This is not based upon any particular evidence, such as inclusion studies; for these studies do not exist, either for Myanma spinels or for those from Badakhshan.* Instead, it simply rests upon the belief that what is today, has always been.

While evidence for the existence of the Badakhshan mines is not direct, it is substantial. We have the name *balas ruby*, which is apparently derived from an ancient word for Badakhshan, we have numerous detailed accounts of the mining, we have spinels with Arabic inscriptions and we have historical names, such as the *Timur* ruby. Circumstantial? Indeed. But if circumstantial evidence was of no value, the world's jails would be empty.

*Occasional photos of inclusions in Burmese and Sri Lankan spinel have been published. But since no *in situ* collecting has been done at the Badakhshan mine, and little in Burma, it is impossible to say whether similar inclusions will be found at each deposit. Remember, rutile silk has been found in rubies from virtually every deposit except Thailand/Cambodia. Similar inclusions are often found in stones from different mines.

exploitation might become possible, thus increasing the output from Afghanistan.

Other Afghanistan localities

Streeter (1892) did mention a ruby of 10.50 ct brought to England from mines at Gandamak, about 20 miles (32 km) from Jagdalek. Due to the proximity of these localities, it is possible that the stone actually came from Jagdalek. Griesbach (1892) reported rubies 20 miles (32 km) west of Tatang in a coarse, micaceous marble.

Gary Bowersox reported that gem-quality ruby had been found north-east of Kabul (Koivula, 1987). No further details are available. Ghaggi has also been reported as a source of ruby. About 1986, American dealer Dudley Blauwet purchased a large, euhedral yellow sapphire crystal said to have originated from Dharipiche, Kunar Province, north-eastern Afghanistan (pers. comm., 19 Sept 1994).

Tajikistan

In the late 1980s, large reddish spinels were reported from the Pamir mountains of what is now Tajikistan. One 532 ct rough yielded cut gems of 146.43 and 27.81 ct (Bancroft, 1989, 1990). It is not known if the mine that produced these specimens is the same as the Badakhshan mine described above (Peter Bancroft, pers. comm., June 1994). Ruby was also reported in eastern Tajikistan, near the border with China, in the early 1980s (Bank and Henn, 1990; Henn, *et al.*, 1990). The mine is said to be located at Turakuloma, some 40 km north-west of Murgap, at 4500 m above sea level, in a mineralized zone of marbles. However, this deposit is far from the Afghan border.

Summary

The above accounts clearly describe two separate mines for ruby and/or spinel.

One, located at Jagdalek (spelled variously, *Jagdalak* or *Jegdalek*), 51.5 km (32 miles) east of Kabul, and another further north in Badakhshan, on the banks of the Shignan, a tributary of the Oxus (Amu Darya), near Gharan, just north of Ishkásham. According to Alexander Fersman (1946–47), noted Russian mineralogist/gemmologist, 'From the mines at the mouth of the Kuga–Lial River, the East for a thousand years has been getting its red stones—bright rubies and pinkish-red spinels, called *lal*.'[6] Gary Bowersox has told the author that the Afghan name of the Badakhshan mine is *Kuh-i-lal* ['the place of ruby/spinel'] (pers. comm., 1 July 1994). Undoubtedly the localities described by Fersman and Bowersox are identical.

Political difficulties and rugged terrain make Afghanistan a difficult country to explore, and Tajikistan is no better. Until someone manages to visit the Badakhshan mines, and lives to tell the tale, we must be content with mere speculation.

Characteristics of Afghanistan ruby (Jagdalek)

Nothing exists in the literature regarding the gemmological characteristics of rubies or spinels from Badakhshan, primarily because no twentieth-century eyewitness accounts exist of the mines. In addition, gemmological descriptions of the important specimens of history, such as the Timur ruby and the Black Prince's ruby, have never been published.

The situation at Jagdalek is somewhat better. Material has filtered out throughout the 1980s. In the early part of that decade, the author acquired a number of faceted and rough specimens from Jagdalek. The following is based on his first-hand studies, supplemented by those of Bowersox (1985), Barthoux (1933), Beesley (1986), Brückl (1937) and Themelis (1988).

6. *Lal* is the Persian word for balas ruby. In Chinese, it is *la* (Bretschneider, 1887).

Occurrence:

Afzali (1981) has reported the Jagdalek mine to lie in Kabul province at 34° 26′ N, 69° 49′ E. For those who read German, the most complete description of the mine is that of Brückl (1937). The rubies are said to occur embedded in a regionally-metamorphosed marble cut by granitic intrusions of Oligocene age.

Colour range:

Rubies from Jagdalek are only rarely encountered in faceting quality, but when clean can be magnificent. In terms of colour, Jagdalek rubies resemble most the gems of Vietnam, Burma and Sri Lanka, being strongly fluorescent and often of a slightly pinkish or raspberry-red hue similar to rubellite tourmaline. A small percentage are of violet hue.

Solid inclusions:

Various types have been found in Afghan rubies. Common are colourless blocks displaying rhombohedral cleavage, most likely of calcite. Inclusions of calcite are not surprising, considering the fact that Jagdalek rubies are found in a marble matrix, just as in Burma. Transparent plates and books of hexagonal outline are also seen. Due to their anisotropic character between crossed polars and prominent basal cleavage, they are most likely mica. Other plate-like inclusions consist of irregular distorted shingles which are opaque and black or slightly gold in color. These also display a somewhat micaceous appearance. Additional solid inclusions seen were rounded colourless grains of low relief and, in one specimen, corroded blocks of a yellow colour. Several specimens examined by the author contained deep red-orange prisms of square outline and submetallic luster. Some were knee-shaped twins with obvious re-entrant angles, indicating rutile.

Table I: Properties of Jagdalek (Afghanistan) ruby

Property	*Description*
Colour range/phenomena	• Near colourless to a deep red, often slightly purplish, strongly fluorescent. Violet stones are seen on occasion.
Geological formation	• Ruby is found embedded in a regionally metamorphosed marble cut by granitic intrusions of Oligocene age.
Crystal habit	• Most crystals are hexagonal prisms (short or long) with development of rhombohedron and pinacoid faces. Spindle-shaped bipyramids are also sometimes seen.
RI and birefringence	$n_\varepsilon = 1.762$; $n_\omega = 1.770$; birefringence = 0.008
Specific gravity	~4.00
Spectra	**Visible region** • Strong Cr spectrum (similar to rubies from other localities)
Fluorescence	UV • Strong reddish to reddish-orange fluorescence (LW stronger than SW).
Other features	May be dyed or heat treated.
Inclusion types	*Description*
Solids	• Calcite; rhombs • Phlogopite mica; books • Rutile; prisms and knee-shaped twins • Garnet • Chondrodite • Apatite • Pyrite • Spinel • Graphite • Hornblende • Dolomite
Cavities (liquids/gases/solids)	• Primary negative crystals. • Secondary healed fractures are common. They occur in a variety of patterns and thicknesses. • Iron oxide stains are common in cracks (these stains can be eliminated during heat treatment).
Growth zoning	• Straight, angular growth zoning parallel to the faces along which it formed; irregular 'treacle'-like swirls in other directions. Distinctive are the blue colour zones intermingled in most stones, similar to Vietnamese rubies. Growth zoning is extremely sharp and prominent.
Twin development	• Growth twins of unknown orientation. • Polysynthetic glide twinning on the rhombohedron.
Exsolved solids	• Dense zoned clouds of (often, but not always) tiny particles (probably rutile), parallel to the hexagonal prism (3 directions at 60/120°) in the basal plane. • Boehmite, long white needles along intersecting rhombohedral twin planes (3 directions, 2 in one plane, at 86.1 and 93.9°).

Cavities:

Both primary and secondary liquid inclusions are seen, the latter being responsible for the lack of clarity which most of these rubies display. Irregular, liquid-filled cavities with jagged edges (much like those in Colombian emeralds) are also found. However, the cavities of the Jagdalek rubies are somewhat thicker. The fingerprints and feathers which fill these stones often show a ragged appearance, with coarse tubes that can easily be confused with the flux inclusions in flux-grown synthetic rubies.

Growth zoning:

Colour zoning in Jagdalek rubies is extremely sharp and narrow, forming in the typical hexagonal pattern when viewed parallel to the *c* axis. The most distinctive feature of Jagdalek rubies are the small spots or zones of a sapphire-blue colour. At times, these blue zones may be hexagonal in outline while in other cases they consist of narrow bands, but all show a sharp division between red and blue. Similar blue zoning is seen in Vietnamese rubies and in Myanma rubies from Mong Hsu.

Twin development:

Rhombohedral polysynthetic twin lamellae are seen in most specimens, inevitably accompanied by long white boehmite needles meeting at 86.1/93.9°.

Exsolved inclusions:

While exsolved rutile needles have not been found, clouds of tiny exsolved particles of what may be rutile have been seen. The lack of true silk means that star rubies are not produced. Cabochons may show a silvery sheen though, from reflection off the particles. Exsolved boehmite needles are common at the junctions of intersecting rhombohedral twin lamellae.

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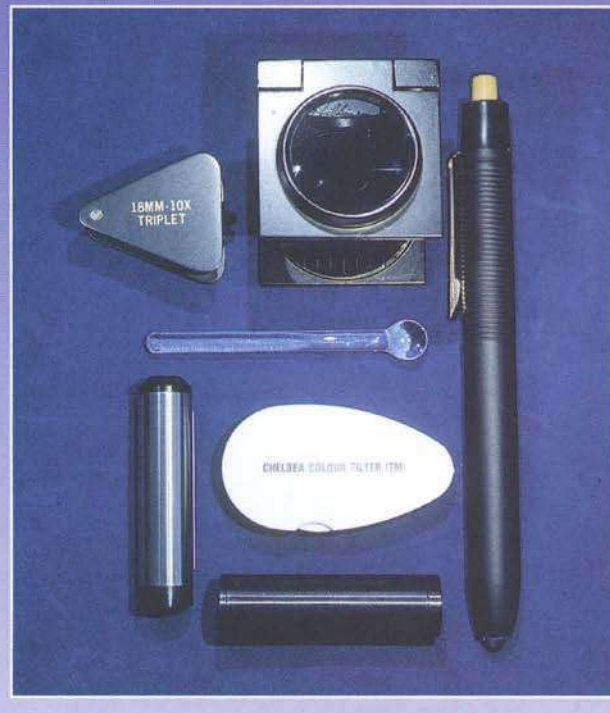

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Mineral and chemical compositions of jadeite jade of Myanmar

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Abstract

This research work contributes mineralogical and chemical data for jade varieties of Myanmar (Burma). From petrographic examination and XRD analysis, jade of Myanmar can be defined as a monomineralic (pure jade) or polymineralic (impure jade) rock. Twenty five specimens were studied and about two thirds consist essentially of jadeite and one third of jadeite plus amphiboles and/or other pyroxenes. Edenite, richterite and tremolite are major associated minerals; kosmochlor, enstatite and chromite/ magnesiochromite are minor associated minerals. Rutile/ilmenorutile are frequently present as acicular inclusions in jadeite. No albite was observed in any of the jade specimens studied. XRF analyses demonstrated a wide range in bulk chemical compositions from a pure jadeite to impure jade compositions depending upon the content of amphiboles and/or other pyroxenes.

Introduction

Literature on jade and its counterfeits is abundant, but that specifically on jade of Myanmar is less well known. Mineralogical and chemical data are scarce or not available for the different varieties of jade of Myanmar. As used in this paper the term jade of Myanmar refers to jadeite.

The earliest geological accounts of the jade mine areas in northern Myanmar are due to Noetling (1892). The occurrences of jade have been reported by Bleeck (1908), Coggin Brown (1921), Chhibber (1932; 1934). General descriptions of jade colours and qualities have been given by many authors such as Webster (1948; 1949; 1975) and Coggin Brown (1948). The mineral constituents and chemical compositions (not bulk composition) of very limited specimens of jade of Myanmar can be found in the papers by Lacroix (1930), Yoder (1950), Bauer (1969), Coleman (1961) and Mével et al. (1986). Analytical data are mainly for jadeite itself.

Jade rocks or jade pieces used in the jade trade may be monomineralic or polymineralic. It was, therefore, considered that the mineralogical and chemical characteristics would be required for a more representative study of different varieties of jade of Myanmar.

Some discrepancies between previous data on jade of Myanmar and present results were encountered. For instance, the locally called 'maw-sit-sit' is technically neither jade because of lack of jadeite nor albite-jadeite rock as has been described before (e.g. Gübelin, 1965).

The term 'jade' normally refers to one of two mineral species - jadeite or nephrite. Jade counterfeits have usually been named with prefixes, such as, 'South African jade', 'British Columbian jade' for grossular and hydrogrossular, 'Swiss jade' for chalcedony, etc. On the other hand, a jeweller

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may use the terms 'Chinese jade' and 'New Zealand jade' to refer to the true jades, jadeite and nephrite respectively, with a justifiable indication of locality. Thus, the use of this kind of locality prefix may cause confusion. Therefore, we propose that the term 'Jade of Myanmar (or Burma)' is preferable to 'Myanma jade' in order to differentiate between true jade and pseudo-jade.

Sampling and sample preparation

For this research work the Myanma Gem Enterprise has provided jade specimens in many different colours and varieties. Some specimens were collected from the Geological Museum, Geology Department of Yangon (formerly Rangoon) University and from personal collections. These specimens were from the following mining centres: Hpakan, Lonkin, Tawmaw, Nantmaw, Whay Khar Maw, Haungpa and Knamti.

Assorted samples were carefully selected for appropriate analyses on the basis of variation in colour, texture, transparency and weathered crust. The colours of jade samples under investigation ranged from white through grey to almost black, shades of green, dark green, emerald green, lavender, yellowish through brown to reddish-brown, bluish and greyish blue-green. Textures vary from almost glassy to coarse grained as seen in hand specimen. The weathered crusts in some specimens may be thick or thin, rough or smooth and compact or porous; some specimens lack crusts.

In sample preparation, care was taken to obtain representative results of mineral and chemical compositions. For X-ray diffraction analysis each sample was crushed and roughly sorted by hand-picking under a stereo-zoom microscope.

Mineral compositions determined by optical and XRD methods

Each jade specimen was sectioned for petrographic examination before and after XRD identification of the mineral constituents. A computer controlled Rigaku X-ray diffractometer 'Geigerflex' D/Max III B was used for mineral identification.

In the panel below are mineral assemblages identified by both XRD analysis and optical examination in the jade of Myanmar.

In a collection of 25 specimens of assorted jade varieties (see Figures 1-4) about two thirds are essentially composed of jadeite and about one third consist of two or more essential minerals. Acicular rutile and ilmenorutile, as confirmed by XRD occur occasionally as tiny inclusions in some grains of jadeite.

Pure jade is almost white in the absence of colouring agents and the emerald-green colour in jadeite-jade is due to chromium. On the other hand, kosmochlor in impure jade specimens gives a similar or even a deeper green. For example, the bright-green colour of maw-sit-sit from the Tawmaw area is due to kosmochlor. Unlike Gübelin's (1965) samples, our three

Monomineralic *(pure jade)*	- Jadeite
	- Jadeite ± rutile/ilmenorutile
	- Jadeite ± chromite/magnesiochromite ± rutile
Polymineralic *(impure jade)*	- Jadeite + edenite + richterite ± chromite
	- Jadeite + kosmochlor ± ilmenorutile
	- Jadeite + enstatite + tremolite
	- Jadeite + tremolite + edenite + richterite + kosmochlor ± ilmenorutile

Note: The sign ± denotes minor accessory mineral.

maw-sit-sit samples (two from Myanma Gems Enterprise (MGE) and one from Mandalay jade market) do not contain jadeite or albite. (A mineralogical account of maw-sit-sit is in preparation.) The amphiboles are largely responsible for greenish grey, dark green and black colours.

Chemical composition determined by XRF analysis

A wavelength dispersive X-ray fluorescence spectrometer (model: RIGAKU 3060 P) was used for analysis of major and trace elements in various jade specimens. The international igneous rock standards – AG V.1, BCR-1, G-2, W-1 and BR – were employed in the determination of all major elements except Na, Mg and Cr where synthetic jade mixtures were used. The concentration ranges of the oxides in these standard mixtures are: for SiO_2 10.69 - 71.11%, for Al_2O_3 10 - 40%, for Na_2O 2 - 18%, for Cr_2O_3 0.10 - 12%, for Fe_2O_3 0.10 - 7%, for MgO 0.05 - 4%, for CaO 0.05 - 4% and for K_2O 0.01 - 2%.

XRF analyses of 15 jade specimens are given in Table I. The measured values for Na and Mg may be slightly low due to the use of a tungsten X-ray target; also Mn and water were not determined. These factors, although small in magnitude, probably account for the low totals in Table I. Nevertheless, these compositions are believed to be representative of the jade varieties of Myanmar.

In Table I, the specimens 1 (mauve) and 2 (white) are pure jadeite. The specimens 3-11 contain considerable amounts of calcium and iron, although they are still essentially monomineralic.

The excess components of calcium and

Table I. XRF Analysis of jadeite-jade of Myanmar

	1	2	3	4	5	6	7	8
SiO_2	59.80	59.67	59.42	59.79	59.50	59.65	59.55	59.08
Cr_2O_3	0.22	n.d.	0.17	0.03	0.23	0.21	0.20	0.28
Al_2O_3	24.18	23.04	22.56	23.11	23.66	23.16	23.58	22.24
Fe_2O_3	0.93	0.98	1.74	1.37	1.11	1.32	1.06	1.44
MgO	0.01	0.05	0.66	0.75	0.29	0.33	0.36	0.80
CaO	0.33	0.72	1.79	1.71	1.21	1.22	1.22	1.82
Na_2O	13.44	15.52	12.35	12.48	12.93	12.93	13.28	12.86
K_2O	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
	98.92	99.99	98.70	99.25	98.94	98.83	99.26	98.53

	9	10	11	12	13	14	15
SiO_2	59.45	59.16	58.95	56.14	59.79	58.67	58.64
Cr_2O_3	0.03	0.19	1.16	0.70	0.10	0.17	0.12
Al_2O_3	23.27	23.79	22.16	15.34	22.80	20.67	17.51
Fe_2O_3	1.12	1.12	1.40	1.42	1.13	2.34	1.97
MgO	0.50	0.26	0.85	9.88	0.60	1.72	3.17
CaO	1.32	1.10	1.90	10.84	1.47	2.59	5.40
Na_2O	13.02	13.04	12.99	5.66	12.56	12.61	11.65
K_2O	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
	98.72	98.67	99.42	99.99	98.46	98.78	98.47

Fig. 1. Photographs of jade varieties of Myanmar.*
(a,1) Jadeite. Mar-sar Maw. (b,3) Jadeite + ilmenorutile + rutile + magnesiochromite. Phakangyi Maw. (c,4) Jadeite + ilmenorutile. Nant Maw. (d,5) Jadeite. Chauk-oo Maw. (e,7) Jadeite. Chauk-oo Maw. (f) Jadeite + richterite + rutile + chromite. Phakan-gyi Maw. (g) Jadeite + ilmenorutile. Chauk-oo Maw.
* Numbers in brackets refer to the sample no. in Table I.

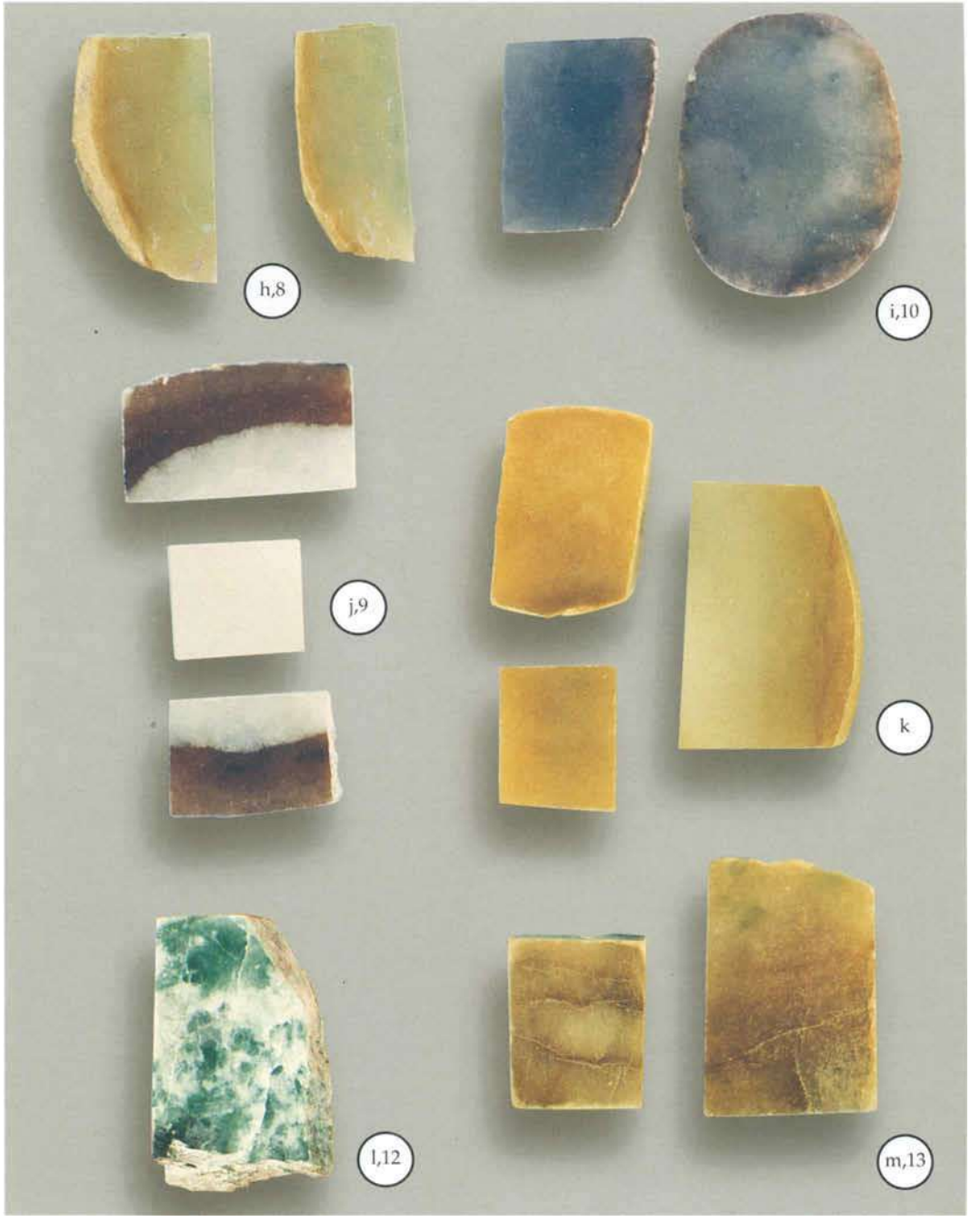

Fig. 2. Photographs of jade varieties of Myanmar.*
(h,8) Jadeite + rutile. Phakan-gyi Maw. (i,10) Jadeite + rutile + magnesiochromite. Tar-ma-khan Maw. (j,9) Jadeite + rutile. Whay-khar Maw. (k) Jadeite + rutile. Whay-khar Maw. (l,12) Jadeite + richterite + tremolite + kosmochlor + ilmenorutile. Nant Maw. (m,13) Jadeite + edenite + kosmochlor + rutile. Maw-maung Maw.
* Numbers in brackets refer to the sample no. in Table I.

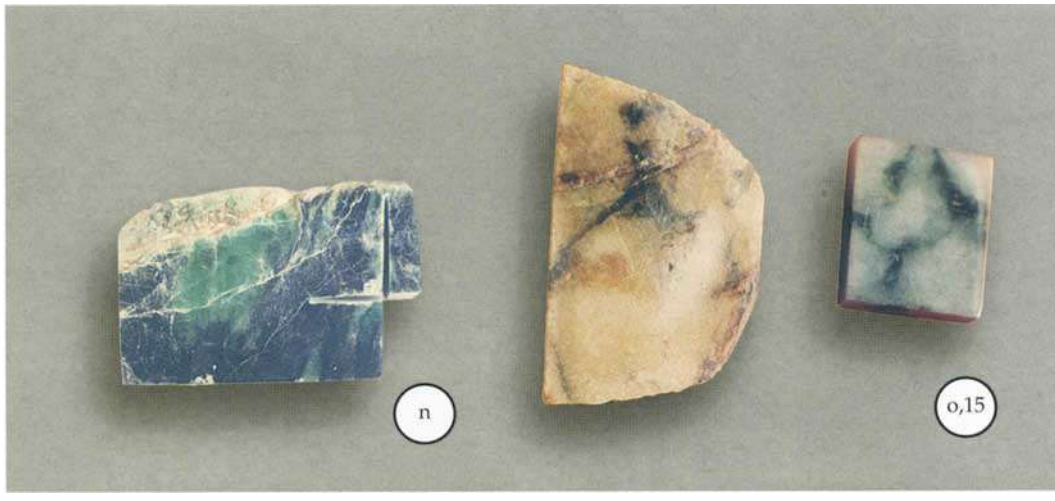

Fig. 3. Photographs of jade varieties of Myanmar.*
(n) Jadeite + richterite + kosmochlor + tremolite. Whay-khar Maw. (o,15) Jadeite + enstatite + tremolite. Ka-tone-yat Maw.
* Numbers in brackets refer to the sample no. in Table I.

iron may be attributed partly to chemical impurities and tiny crystal inclusions in jadeite itself and/or partly to a small molecular component of augite.

From optical and XRD examination the specimens 12-15 were found to be pyroxene-amphibole jades and a considerable range of chemical variation was to be expected.

Qualitative XRF analyses of 9 selected samples were also made to provide a general survey of trace elements present in the various jades of Myanmar. Ti, Sr, Zr, + Nb, + Ni and +Zn are present, in addition to Cr and Fe as shown in Table I. The + sign indicates that the element may be present or absent in some specimens.

Conclusions

The present study demonstrates that jade of Myanmar may include a much wider range in mineral constituents and chemical composition than was previously recognized. All the jade varieties in a range of colours may be either monomineralic or polymineralic. The monomineralic type is entirely made up of jadeite, whereas edenite, richterite, tremolite, kosmochlor and enstatite are characteristic associates of jadeite in polymineralic varieties. Chromite, magnesiochromite, rutile and ilmenorutile are frequent accessories; no albite has yet been found among the true jade samples studied.

XRF analyses of the bulk chemical compositions of various jades showed that there was a significant range of chemical variation from almost pure jadeite to impure jade compositions. The impure varieties contain more Ca, Mg, Fe and sometimes Cr, and less Al and Na. These variations are mainly due to the contents of amphiboles and/or other pyroxenes.

The jade specimens studied are believed to be fairly representative. Therefore, based on the present evidence, it is suggested that jade of Myanmar should be defined as a rock consisting essentially of jadeite with or without interlocking amphiboles and/or other pyroxenes.

Acknowledgements

The authors are grateful to the former geology Professors U Ba Than Haq and U

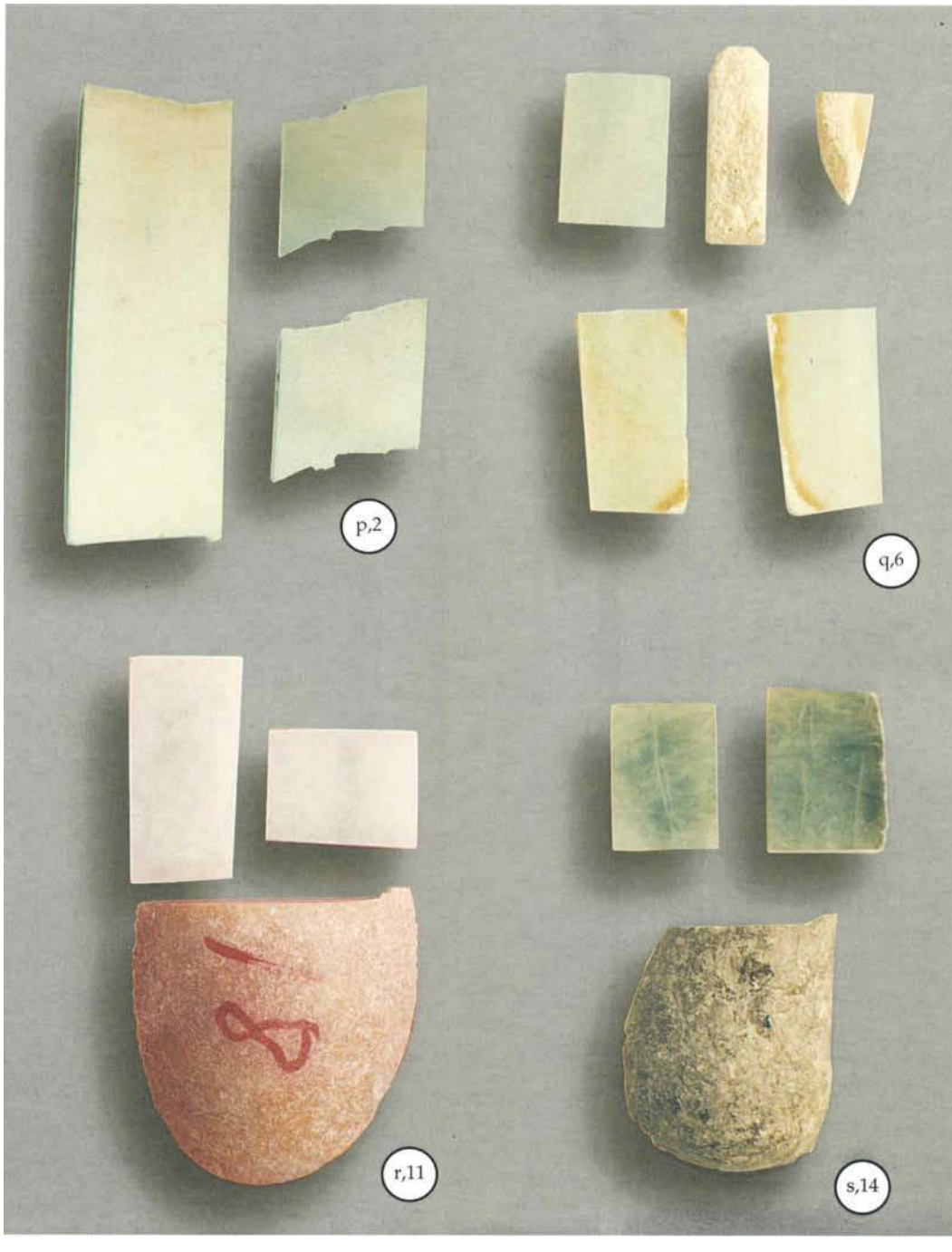

Fig. 4. Photographs of jade varieties of Myanmar.*
(p,2) Jadeite. Nant Maw. (q,6) Jadeite + rutile. Chauk-oo Maw. (r,11) Jadeite. Met-lin Maw. (s,14) Jadeite + kosmochlor + ilmenorutile. Tar-ma-khan Maw. .
* Numbers in brackets refer to the sample no. in Table I.

Clarence Thacpaw and Professor Dr Maung Thein, who permitted them to carry out this research project. The authors are also indebted to Dr Zin Aung, former Associate Professor of Physics and Head of Universities' Research Centre, for laboratory facilities provided for this study. Grateful acknowledgement is made to the Managing Director and the staff of Jade Section, Myanma Gems Enterprise for providing the valuable jade specimens.

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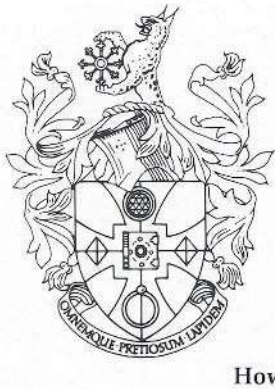

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A new occurrence of dendritic opal in south-eastern Zambia

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Abstract

Gem-quality dendritic opal from a newly discovered deposit in south-eastern Zambia is transparent to translucent, yellow to brownish-yellow and is found in fractures and cavities of sedimentary rocks. Chemical analyses suggest that the dendrites consist of the manganese oxide psilomelane.

Introduction

Besides amethyst and malachite occurrences, it was the rediscovery and new finds of emerald in the 1970s and their consequent massive exploitation which formed the basis of Zambia's dramatic entry into the gemstone supply scene. This led to widespread exploration and, as a result, gemstones such as aquamarine, garnet and tourmaline have been found and there is certainly more potential not yet realized. Most recently, yellow to brownish-yellow, gem-quality dendritic opal has been discovered in south-eastern Zambia.

Opal as such is a non-crystalline, colloidal substance consisting of very minute spheres of silica gel with various amounts of water, mostly between 3 and 5 wt% H_2O. In contrast to precious opal, where the silica spheres are relatively consistent in size and are regularly stacked thereby causing a three-dimensional diffraction grating and, as a result, a play of colour, no such diffraction of light occurs in common opal because the silica spheres vary in size and are randomly stacked. White and multi-coloured common opal often contains inclusions of other minerals with tree-like forms which are termed dendrites. Such is the case with dendritic opal known from Zimbabwe, South Africa, Tanzania, various places in the United States (Webster, 1983; Gübelin and Koivula, 1986) and, most recently, from Zambia.

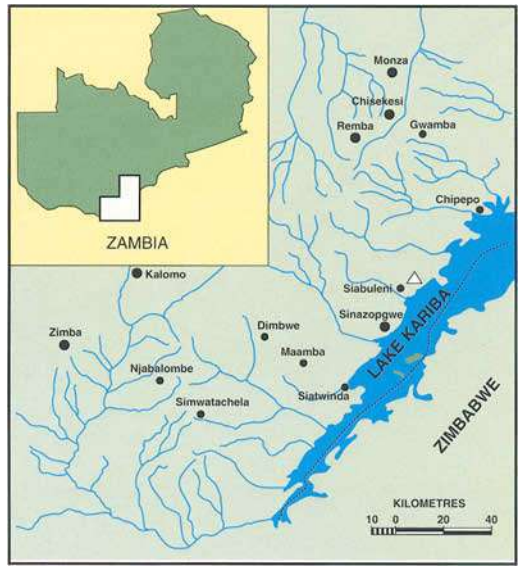

Fig. 1. Simplified geographical map of south-eastern Zambia showing sample location (triangle)

The new Zambian opal find is located approximately 40km north-east of the town Maamba at Lake Kariba in south-eastern

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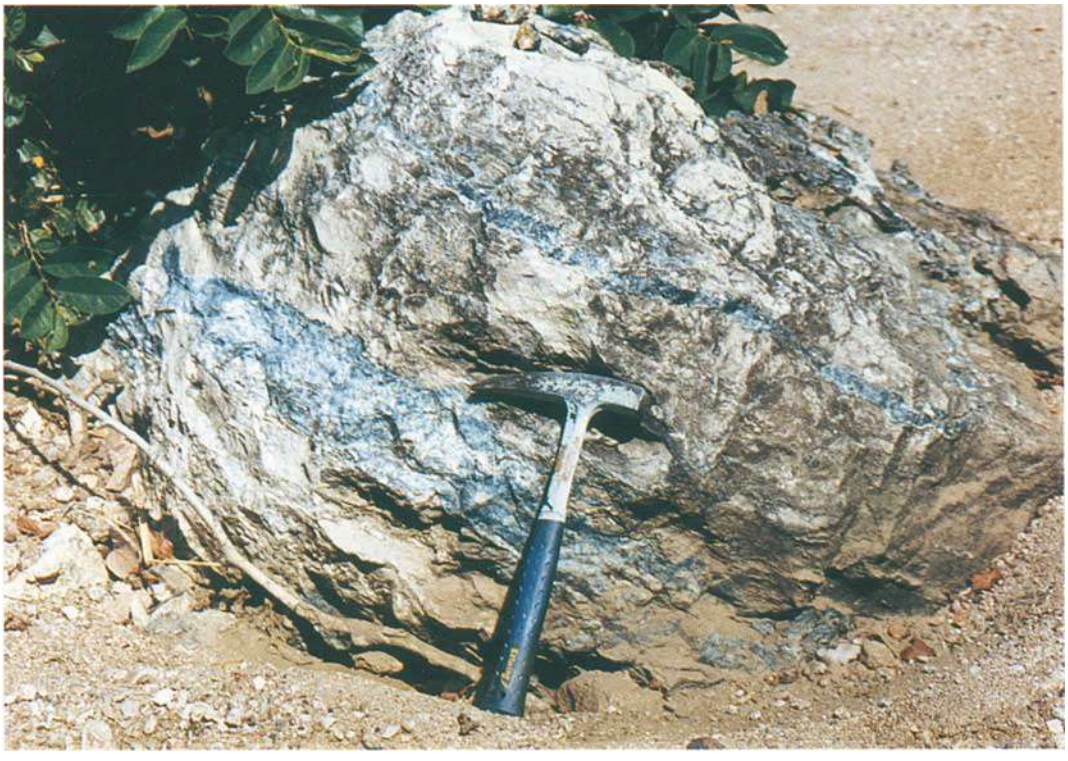

Fig. 2. The Zambian opal occurs in veins in Karroo sandstones

Table I. Properties of dendritic opal from Zambia

Colour	Yellowish to brownish-yellow	
Diaphaneity	Transparent to translucent	
Fracture	Conchoidal	
Refractive index	1.459	
Specific gravity	2.15	
UV luminescence	Distinct	
Long-wave UV	Yellowish	
Short-wave UV	Greenish-yellow	
NIR-Absorption Spectrum	Typical opal-spectrum	
	Absorption maxima	Assignment
	1420-1460 nm	vibrations of H_2O
	1915 nm	vibrations of H_2O
	2213 nm	vibrations of SiOH
	2315 nm	vibrations of SiOH

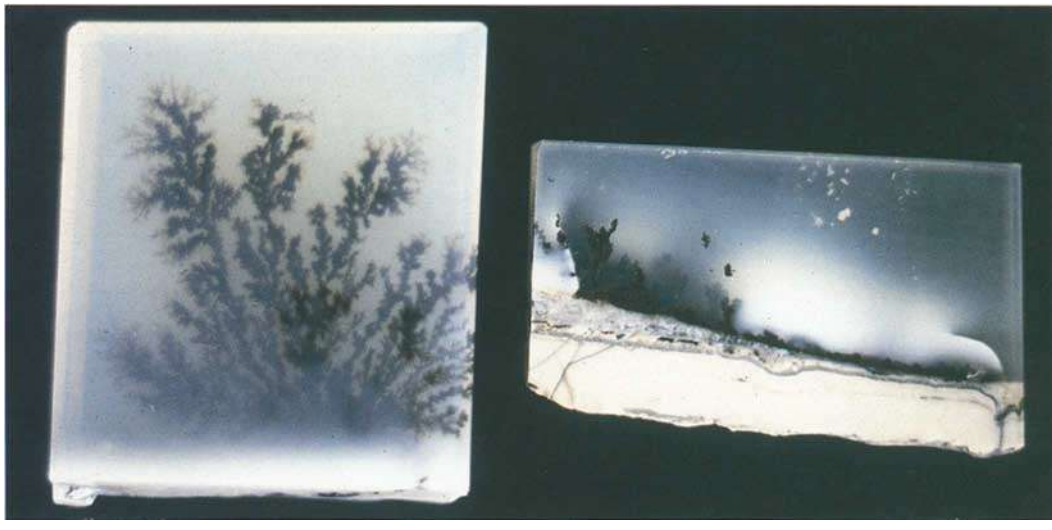

Fig. 3. Two cut opals with dendritic inclusions from south-eastern Zambia. Width of photograph 3.5cm

Zambia (Figure 1). The material occurs in veins and cavities in sandstones (Figure 2) which belong to the upper Carboniferous to Jurassic Karroo Suite as indicated on the Geological Map of Zambia.

The standard gemmological properties of the Zambian material, as well as the results of chemical analyses are given below.

Gemmological Properties

The gemmological properties are listed in Table I. The colour of the opal samples examined is yellow to brownish-yellow and their diaphaneity ranges from transparent in small samples to translucent mostly in larger specimens. They typically show a conchoidal fracture. In some cases the opals contain black, dendritic inclusions which originate from veins and form patterns resembling trees or even landscapes (Figure 3).

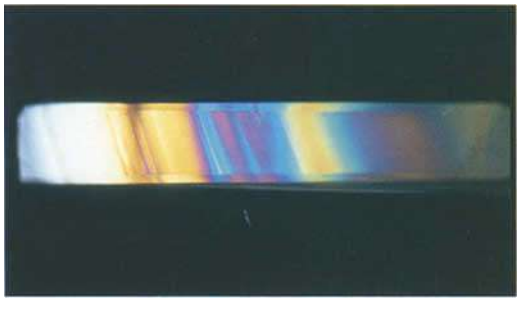

Fig. 4. Interference effect of a cut opal under crossed polars. Width of photograph 3.5cm

Refractive index and specific gravity

Using a standard gemmological refractometer, the RI was determined to be n = 1.459. Some samples show a strain induced birefringence and, as a result, an iridescent effect when examined under crossed polars (Figure 4). The SG was measured using a hydrostatic balance and yielded a value of 2.15.

Ultraviolet luminescence

When exposed to ultraviolet (UV) radiation, the opal samples show a distinct yellowish fluorescence with long-wave UV radiation and a distinct greenish-yellow under short- wave UV.

Spectroscopic analysis

The infrared spectrum is plotted in Figure 5. The sample displays a near-infrared (NIR) spectrum which is consistent with the general patterns found in natural opal (e.g. Langer and Flörke,

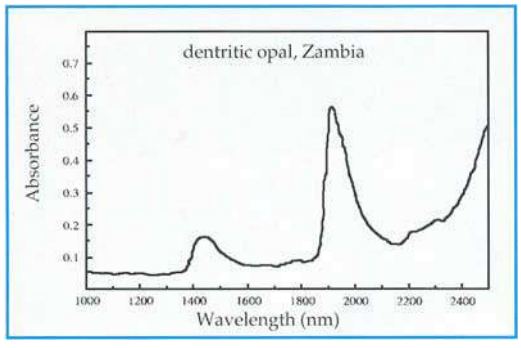

Fig. 5. Infrared absorption spectrum for an opal specimen from south-eastern Zambia (for explanation see text)

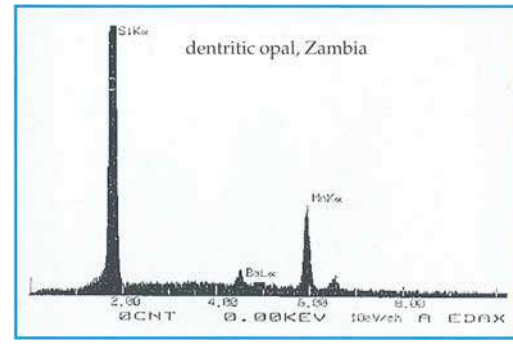

Fig. 6. Energy dispersive X-ray fluorescence spectrum of the dendritic inclusions (for explanation see text)

1974; Fritsch and Stockton, 1987). The opals tested show combination vibrations of molecular water (H_2O) between 1420 and 1460nm and at 1915nm. Additional absorption maxima occur at 2213 and 2315nm, both caused by combination vibrations of SiOH groups.

Chemical analysis

The dendritic mineral inclusions were chemically analyzed using an EDAX energy dispersive analytical system fitted on a scanning electron-microscope. The spectrum is shown in Figure 6. The strong Si-peak results from the opal-host, whereas both Ba and Mn are present in the inclusions. It is thus probable that the inclusions are psilomelane, a colloidal manganese oxide including barium oxide and water[$(Ba,Mn^{3+})_3Mn_8O_{16}(O,OH)_6$].

Conclusions

The gemmological properties of this common opal correspond to those described for other common opal occurrences. The beautifully arranged psilomelane inclusions make this new Zambian material interesting for the gem trade. Large quantities of dendritic opal are apparently available and there are good prospects for commercial exploitation.

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[Manuscript received 13 December 1993]

Letters

From J.B. Nelson, PhD, FGA Research Diploma

Dear Sir

On diamond-filling glasses and Nelson's speculations

I was not surprised to see from his Letter to the Editor in the July issue of the *Journal*[1] that my favourite curmudgeon, Kurt Nassau, has followed up the two salvos[2,3] from his Lebanese battlements at a previous paper of mine[4], by yet another one.

His judgement of the currently offending paper[5] is that '...while [Nelson's] discussion is actually not often wrong, much of it is irrelevant ...'.

I am grateful to Dr Nassau for allowing me the further opportunity for expanding on matters related to this topical subject.[1,2]

After the submission of a thesis to the GAGTL on 'The glass filling of diamonds', the writer was awarded the title of FGA Research Diploma. The articles in the *Journal* are based on this thesis. It appears that Nassau's comment on the irrelevancy of the ideas does not accord with the verdicts of the thesis examiners.

He begins by stating '... [Nelson] has therefore missed the important boron content of these [Yehuda] glasses ...'

This wording wrongly conveys to the reader that a quantitative boron analysis was reported in the GIA laboratory's elegant paper of 1989.[3] Not even a qualitative detection of boron was claimed. Nor, I feel sure, has its presence in Yehuda glasses been reported in the literature since that date.

He was therefore careless in failing to insert the essential word 'possible' between the words 'important' and 'boron'. His firm belief that boron is the missing element probably stems from:

a) his familiarity with the composition of low flow-point and solder glasses where boron oxide is an important additive,
b) the results of an X-ray elemental analysis with the GIA's energy-dispersive X-ray fluorescence spectrometer attachment to a scanning electron microscope (SEM-EDS).[4] These were semi-quantitative analyses of spot areas lying along various outcropping glass-filled fractures on the same stone.[3] Chlorine, along with lead and bismuth, was detected. The results were reported as '... The chlorine concentration consistently *seemed* [emphasis added] to approximate the sum of the lead and bismuth concentrations ...' Because of the 'semi-quantitative' nature of the observations, the cautious GIA analyst chose to express the chlorine content in the less precise terms which the less-cautious Nassau would prefer us to ignore.

From these two viewpoints, he firmly concludes '... that boron is the only practicable (and indeed expected) candidate ...'

There have always been great doubts by analysts on the quality of X-ray spectrochemical results which attempted to measure the percentage of a very light element occurring in a matrix of a very heavy element. The inverse situation, e.g. a small percentage of say lead (Z=82)* or bismuth (Z=83) occurring in a predominantly boron (Z=5) matrix, would invariably yield results of high accuracy.

For this reason only, I declined to pursue the 'logic' of the GIA analysis, as Nassau feels that I should have done.

It is really not sensible to speculate on missing elements on such flimsy evidence. Is it not far better to actually determine their concentration? Why indeed has this

* Z is the characteristic number of an element. It is the number of protons in its nucleus.

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not been done? If it had, it is not beyond belief that lithium (Z=3) or beryllium (Z=4) could equally well have been found to serve as Nassau's missing element.**

Quite unwittingly, he has drawn attention to one of the more intractable problems facing present-day inorganic analytical chemistry. The low atomic number elements, lithium (Z=3), beryllium (Z=4), boron (Z=5), carbon (Z=6) and nitrogen (Z=7) cannot be detected, let alone measured, by X-ray fluorescence energy-dispersive spectrometers (XRF-EDS). These instruments, of the non-destructive kind still in use at the GIA laboratory,[4] have been the mainstay of modern elemental analysis. However, they are quite unable to detect and measure elements of lower Z number than sodium (Z=11).

In general, the light elements play an as yet little understood role in gemmological science. I have recently completed a brief account of the historical developments of the analytical methods used to determine them. A different scene is now emerging. It is now possible with a new generation of X-ray fluorescence, wavelength dispersive spectrometers (XRF-WDS) to measure, accurately and non-destructively, all the elements from uranium (Z=92) to beryllium (Z=4), except lithium (Z=3). It is quite likely that this too, will soon yield to the instrument engineer. The account, under the title '... The troublesome trio; boron, beryllium and lithium', will hopefully appear in a future issue of the Journal.

It is now necessary to return to Nassau's other comments.

Glass formulations. He has advised me to look up his list of references on lead, bismuth and boron oxide glasses. This is not a task which I feel obliged to do as I have no intention of starting up a fracture-filling station.

As mentioned in my paper, no analyses of the glasses of any diamond enhancer other than Yehuda had been reported. Nassau's later, undated and unpublished personal communication from Fritsch of the GIA, stating that bromine had been found in one fracture-filled diamond of unstated origin, comes as no surprise. Following Yehuda's trail-blazing invention, it would be astonishing if other entrepreneurs had not tried out various cocktails. I would find it easy to accept that a Koss or other glass consisted of PbO and $PbBr_2$ with a small addition of B_2O_3 or Li_2O to adjust for a low flow point, better glass stability and the desired RI.

Laboratory safety. As to his warnings about the oil-quenching process being '...an extreme explosion and fire hazard! ...', may I ask him to perform the following experiment? Take a teaspoonful of motor engine oil and heat it with an alcohol lamp. He will find that it is quite difficult to set alight. After all, engine oil has had all the volatiles distilled off, otherwise it would be a fuel and not a cylinder lubricant. He will discover that it has to be heated to smoking temperatures before it becomes a laboratory hazard. The alcohol lamp itself is much more dangerous!

My suggestion for dribbling the molten glass into a large bath of cold motor engine oil has long been the preferred quenching method in phase equilibrium studies of alloys and inorganic compounds. It has the advantage of thermally-shocking the glass into small fragments which are ideal for rapid remelting. It is by far the most effective way of ensuring that there is no devitrification. Sodium chloride in the glassy state can be produced only in this way. The 'splat' method by which the molten sodium chloride is poured on to a cold, thick, polished copper plate does not work. Alas, I cannot share Nassau's belief that glasses do not devitrify easily. They do, and often quite unexpectedly. He must surely have been aware of the devitrification at 250°C of the 90 per cent silica glass ('Corex') envelopes of halogen lamps. Only a touch of moist fingers containing

** For carrying out X-ray powder diffraction studies of organic substances sensitive to H_2O, CO_2 and O_2, the writer has made and used thin-walled capillary tubes of 'Lindemann Glass'.[5] This X-ray transparent glass has the approximate composition $5Li_2O.BeO.6B_2O_3$.

sodium chloride traces is enough to catalyse the conversion to cristobalite.

Glass-filling apparatus. As to a real laboratory hazard, I was horrified at the suggestion that his DIY test-tube apparatus as shown in his Figure 1b could be used for fracture filling. I would not dream of asking anyone to attempt these experiments without a large, thick Perspex screen placed in front of the hot evacuated glassware. Vacuum implosions are almost as devastating as pressure explosions. Flying molten glass, solid hot glass splinters and incandescent diamonds are much to be avoided.

His costings make interesting reading. His test-tube arrangement of Figure 1b 'could be purchased for £5.00 ...' A Pyrex test-tube, yes, but not a Bunsen burner. As for a suitable two-stage, ballasted, oil vacuum pump such as the Edwards RV3, it would cost him about £1300. Again, his estimate of the cost of about £5000 for my suggested filling unit is quite far out. I could not expect to have it made for less than £20 000.

Precision diamond polishing. Finally, he states that it would not be possible to polish diamond-glass surfaces without undercutting. A diamond polishing friend in the trade had assured me that it could be done, but not as in the routine manner. A thin film of some coolant or lubricant such as a light mineral oil or isopropyl alcohol would be required to be maintained on the scaife. With a very light load and a long polishing period, it should be possible to prepare good, polished, strictly-coplanar flat surfaces without any undercutting or heating.

I would put it to Nassau that his own letter is totally irrelevant. His rebuttal of my rebuttal, which is sure to follow, will be eagerly awaited as they say.

Yours etc.
James B. Nelson
Nelson Gemmological Instruments
Hampstead, London.
25 July 1994

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Response from Dr Kurt Nassau, PhD, FGA

Dear Sir

More on diamond-filling glasses and Nelson's speculations

I fully agree with James B. Nelson[1] that boron has not yet been demonstrated to be present in the fracture-filling glasses used on diamonds; I thought I had made this clear in my letter[2]. Perhaps instead of saying that 'boron is the only *practicable* (and indeed expected) candidate' for the missing cation component, I really should have said *possible* or *probable* there and elsewhere in my letter[2] commenting on Nelson's article[3].

No - I was not 'unwitting', as Nelson puts it[1], when it comes to the difficulty of analyzing for the presence of low atomic weight cations in small samples: this well-known limitation always presents a problem. Yet a 'glass-former' needs to be present, and the lithium or beryllium Nelson suggests as alternatives just will not do. In my opinion, boron is the only possible candidate, a conclusion not grounded merely on the limited basis Nelson[1] attributes to me. As neither the GIA, Nelson, I, nor anyone else who has analyzed these glasses has had access to the special capability needed to determine boron, certainty will only result from such an analysis. But the possibility of the presence of boron cannot be ignored.

Yet Nelson has missed the essential point of my letter[2] which was intended as a polite and, I hoped, gentle reminder for him to

familiarize himself adequately with the literature on glasses before attempting to draw subtle conclusions. He may indeed be well acquainted with the physical properties of glass, yet reading his article[3] and his subsequent letter[1] makes it clear to me that his knowledge of possible glass-forming compositions and glass preparation techniques does not have the necessary depth.

And I am totally baffled by Nelson's stated[1] unwillingness to look up the references I suggested because he has 'no intention of starting up a fracture-filling station'. Should not a scientist feel the obligation to consult suggested new sources before deciding on their irrelevance?

I might note that over the last 20 years I have studied the preparation and properties of a wide variety of glasses (fused silica, silicates, other mixed oxide, heavy metal and halide glasses, also including rapid quenching and crystallization studies), with over 50 publications on glasses in recognized journals. Based on this experience I can assure Nelson of the following.

One can definitely work with low-melting glasses in fused silica with only minimal contamination. I have done this many times, even making my own tubes - I picked up glass-blowing in my youth. I have frequently used vacuum without ever experiencing an implosion. Of course I used safety shields and goggles, as does any prudent experimenter. And I did not include the cost of these, of the bunsen burner, vacuum pump, or glass-blowing torch in my £5.00 estimate, because every laboratory I have ever worked in contained such standard equipment. I accept Nelson's estimate of £20 000 for building his apparatus as being reasonable; my £5000 was obviously just an order of magnitude guess.

Dropping a red-hot glass into oil is definitely not the same as Nelson's[1] heating a teaspoon of it over an alcohol lamp! I too have dropped red hot phase diagram samples into oil and other fluids on many occasions, but this is usually done with very small quantities. For the topic under discussion however, the preparation of bulk glass, I can guarantee at least a minor eruption on dropping a hundred grams of molten glass into oil and a definite major explosion if this were done with a kilogram amount. What happens is that the oil is 'cracked' on contact with the high temperature glass to yield volatile and flammable low molecular weight fragments. Please do not try it!

Incidentally, I did not say that glasses do not devitrify easily, as stated by Nelson[1]. I did say that solder glasses do not usually do so unless specifically designed and processed to do so[2]. And I ignore comments of Nelson irrelevant to the topic at hand such as those on X-ray diffraction, the devitrification of 'Corex', and so on.

My deduction of the probable presence of boron was based on a consideration of the nature of known glass-forming systems, on the usual necessity for the presence of a good 'glass-former', combined with the missing cations (all of Nelson's speculations notwithstanding, these cannot be ignored). In my judgement, a non-crystallizing glass consistent with the available analyses with enough fluidity to penetrate thin fractures in a reasonable time at a reasonable temperature just does not seem plausible in the absence of significant boron.

I am also quite unimpressed by the assurance given to Nelson[1] by his diamond-polishing friend of his ability to avoid undercutting *totally* and to achieve the 'exactly coplanar' surface required for Nelson's measurement[1]. I shall believe this one only when it has actually been demonstrated.

Feedback that helps to put facts into a meaningful perspective is considered to be part of the scientific approach. None of us can know everything, however expert. I myself have found comments on my own reports useful and therefore assume that so

would others.

Yours etc.
Kurt Nassau
Nassau Consultants
Lebanon, NJ 08833, USA
24 August 1994

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From Professor Cornelius S. Hurlbut

Dear Sir

I write in reference to the article by T. Farrimond in the *Journal of Gemmology* (1994, 24, 3, 161-3,), 'Hydrostatic measurement of specific gravity'. In this article Dr Farrimond concludes that accurate determinations of specific gravity can be made on gemstones 0.25ct or greater by the hydrostatic method using water.

Because of it low surface tension, toluene has been used in place of water as an immersion liquid for specific gravity measurements of small stones. By adding a detergent the surface tension of water can be lowered to a point approaching that of toluene. For this reason Dr Farrimond feels there is little point in using toluene. He mentions as a disadvantage the rather large variation in its density with changes in temperature and the necessity of making a density/temperature correction.

It is stated that the density of toluene at 25°C is 2.3 per cent less than at 5°C, whereas the density of water changes only about 0.02 per cent between 4°C and 70°C making compensation unnecessary. There is an error in this last percentage figure. The density of water at 4°C is of course 1.0; at 70°C it is 0.9778 a difference of 0.0222 or 2.22 per cent, more than 100 times greater than stated. We are not told the temperature at which Dr Farrimond made his determinations but if it were 25°C (at which water has a density of 0.9971) a downward correction of 0.29 per cent should have been made to obtain more accurate values. The SG of diamond measured as 3.45 would be 3.44 and the 4.01 for corundum lowered to 4.00.

These differences are not large and probably no greater than other experimental error. However, since in using toluene a correction *must* be made, the reported values are probably more accurate than those obtained in using water with no correction. When a specific gravity is reported correct to the third decimal place (as that given for quartz in this article) without a density/temperature correction, it is suspect.

Yours etc.
Cornelius S. Hurlbut,
Professor of Mineralogy, Emeritus,
Department of Earth and Planetary Sciences,
Harvard University, Cambridge,
Mass 02138, USA.
29 August 1994

Response from Dr T. Farrimond

Dear Sir

I should like to express my appreciation to Professor Hurlbut who correctly points out an error in my article entitled 'Hydrostatic measurement of specific gravity' (*J. Gemm.*, 1994, **24**, 3, 161-3). On page 163, the sentence referring to the effects of temperature on the density of water should read: 'Since water only changes by about 0.2 per cent between 4°C and 20°C no compensation need be made.' Although the figures are different, the rationale remains unaltered, since at normal temperatures up to 20°C, the density of water is little different from unity. All SG determinations were made at 17°C.

Professor Hurlbut notes that temperature correction for water at 25°C would change the SG value for a diamond of 0.053ct from 3.45 to 3.44 and for a corundum of 0.46ct from 4.01 to 4.00. At lower temperatures the difference made by temperature correction could also be made for water if thought necessary.

Although it is true that the low surface tension of toluene brings benefits, its 13 per cent lower density of 0.867 at 20°C relative to water (0.998) would decrease the magnitude of the balance readings, so exacerbating the influence of other factors including surface tension.

Professor Hurlbut also refers to the quoted SG for quartz questionable if standing alone, but the standard deviation of the sample places the value between 2.64 and 2.66.

The term 'accuracy' used in the article is qualified by the statement that:

'For stones in excess of 0.25ct hydrostatic determinations become more accurate and at about 0.46ct the error is only 0.5 per cent.'

Given the above limitations of hydrostatic measures of SG using water, the method is quick, convenient and sufficiently accurate to make it a means of obtaining useful ancillary information for stone identification.

Toluene, if used regularly, requires controlled conditions so that the fumes are not breathed in by the operator. I encountered at first-hand the effects of olfactory adaption brought about by the regular use of the chemical carbon tetrachloride. Some members of the staff at a coal research laboratory, where I was employed for a short time when a student, used the liquid for washing samples of coal prior to analysis. One hot summer's day, they did not turn up for lunch as usual and upon investigation they were all found to be unconscious on the floor.

Damage to lungs, nervous system and liver, as well as changes in behaviour involving slurred speech and uncoordinated movements resembling drunkenness, have all been reported as a result of inhalation of toluene fumes.

The avoidance of health hazards such as these by using water whenever practicable, instead of toluene, is largely an exercise in prudence.

Yours etc.
Dr T. Farrimond,
Thornton Road, Cambridge, New Zealand
12 September 1994

From Alec E. Farn

Dear Sir

John M. Jerwood MC FGA

I was surprised when my wife, who was reading the Review section of the *Sunday Telegraph* of 12 June, looked up and asked me if I knew a John Jerwood. I replied that I did (past tense) and enquired why the question?

She passed to me the full page Arts Review portraying artists and their style of work.

A write-up described the Jerwood Painting Prize of £30 000 to be awarded annually. The criterion being 'excellence in Modern British Painting' the only condition required that entrants must have lived and worked in this country for the past ten years. It was an aspect of John Jerwood who gained his Diploma in Gemmology in 1937 which was new to me as was his Military Cross won in the Italian Campaign. His firm featured in the early days of the Laboratory of the Diamond Pearl and Precious Stone (trade section) of the London Chamber of Commerce holding positions of deputy chairman of the Standing Committee 1931 and Hon Secretary to the section. John Jerwood was well known to Basil Anderson in laboratory terms of pearl testing. I personally made contact with him by correspondence towards the end of my time at the labora-

tory on matters concerning the Japanese production of non-nucleated cultured pearls from Lake Biwa.

He was a fount of first hand information having cultured pearl farms in Japan and Australia. He sent me a report on the decline of pearl fishing in Australia and of cultured pearl production of Mabe pearls in the *Pinctada maxima* oyster. I had often wondered why these expensive oysters which were in fairly short supply were used to produce Mabe cultured blister pearls*. He gave me important addresses to which to write to in Japan for production figures and dollar earnings. It seems ironic that it was not until November 1983 when I started (in retirement) to write Pearls Natural, Cultured and Imitation that I met him personally. He had then lived in Japan for many years. In my early days at the laboratory I seldom dealt with the pearl trade. Coloured stones and gem set jewellery were my metier. Few gemmologists today will have heard or known of John Jerwood.

Yours etc.
A.E. Farn,
Seaford, E. Sussex.

* See A.E. Farn, 1986. *Pearls natural, cultured and imitation*, Butterworth, London. pp 79-80.

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ABSTRACTS

Diamonds | Gems and Minerals

Instruments and Techniques | Synthetics and Dimulants

Diamonds

[Morphogenetic peculiarities of placer diamonds from Anabar River alluvial deposits and a problem of their genesis.] (Russian with English abstract)

A.I. DEGTJAREVA, T.V. POSUKHOVA AND V.K. GARANIN. *Proc. Russian Mineralogical Society*, **123** (1), 1994, pp 71-80.

Data are presented from the morphological analysis of diamond crystals found in a total of six alluvial deposits in tributaries on both banks of the Anabar River and on the coast of the Laptevs' Sea. The degree of mechanical wear and some other hypogene alteration of these diamonds were investigated by SEM. The weight of the diamond crystals ranges from 3.3 to 52.7 mg. The typomorphic peculiarities of the crystals lead to the suggestion that the diamonds have reached these placer deposits from different sources; the nature of these sources is discussed in the light of the reported observation. R.A.H.

Superkimberlites: a geodynamic diamond window to the Earth's core.

S.E. HAGGERTY. *Earth & Planetary Science Letters*, **122** (1-2), 1994, pp 57-69.

Diamonds are geologically ancient (3300 m.y.) and originate deep in the mantle (> 180km); rare diamonds are from the transition zone (400–670km) and others possibly nucleated in the lower mantle (>670km). Transport to the surface is via volatile (C-O- H-N-S)-charged highly explosive kimberlite and lamproite volcanoes, sited exclusively in the oldest (> 1700 m.y.), tectonically most stable and thickest (~200km) regions of crust and upper mantle lithosphere. The energies required for volcanism are so exceptional and the sources so deep that possible connections between and among the core, geomagnetism, plumes and diamonds are explored; some correlations are established and others are implied. The results are sufficient to allow the author to suggest that kimberlites and the geographically and temporally associated carbonatites are continental recorders of plumes dating back to ≥ 2800 m.y., and that some diamonds may have recorded core events dating back to 3300 m.y., or possibly earlier. Peaks in kimberlite magmatic activity correlate, on average, with normal and reverse superchron and subchron behaviour of the geomagnetic field. The time lag between magnetohydrodynamic activity in the core and kimberlite eruptive cycles at the Earth's surface is of the order of 25 to 50 m.y., consistent with the travel times modelled for the passage of plumes from the D″ layer to the subcontinental lithosphere. Although the existence of plumes and the nature of D″ are debated, the correlations established for the past 500 m.y. between and among superchrons, subchrons, kimberlites and entrained diamonds are considered to weigh heavily in favour of the following scenario: solid core growth, the consequent release of Si, O, C, H, S, K and possibly N and B to D″, disruption of D″ at some critically unstable threshold thickness (200-300km), enhanced core convection and the stabilization of a constant non-reversing magnetic dipole field, rising plumes and subsequent volcanism. If protokimberlitic magma and entrainment begin at the core-mantle boundary, a number of geochemical and mineralogical anomalies in diamonds are at present best satisfied if D″ is invoked. These include, but are not limited to, intensely reduced (i.e. oxygen deficient) SiC, metallic Fe, an abundance of sulphides, silicate perovskite and wüstite-periclase mineral inclusions in diamonds. The most abundant source of diamonds is unequivocally from cratonic root zones with C possibly implanted by ancient plumes; eclogitic suite dia-

ABSTRACTORS

R.A. Howie	**R.A.H.**	**P.G. Read**	**P.G.R.**
M. O'Donoghue	**M.O'D.**	**R.E. Samson**	**R.E.S.**
R.J. Peace	**R.J.P.**	**I. Sunagawa**	**I.S.**

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monds are equivocal, and diamonds transported from the transition zone and the lower mantle are best explained by entrainment in highly reduced plumes. Carbon in the great majority of diamonds appears to be primordial. By analogy with a chondritic Earth and chondrites, carbon was acquired during accretion in gaseous complexes, in the form of nanometre-size amorphous C, and as hydrocarbon particles; it may also have been added as crystalline nanodiamonds that served as seeds for subsequent diamond growth. R.A.H.

'Primary' diamond deposits. What controls their size, grade and location? Giant ore deposits.

H.H. HELMSTAEDT. *Society of Exploration Geologists*, special publication no. 2, 1993, pp 13-81, 26 figs.

Kimberlites and lamproites are shown not to be primary deposits for diamond in the sense that diamond originated within them, although they are principal source rocks for diamond. These rocks were transporting agents for diamonds forming in harzburgitic and eclogitic source rocks in the subcontinental lithosphere. The 'primary' deposits are analysed to show sources, modes of transportation and deposit locations. It is not possible to distinguish between 'giant' deposits which may have arisen from different processes and smaller deposits. A notable dilution in diamond grade between source rocks and 'primary' deposits suggests that 'giant' deposits may be those represented by concentrations of eclogitic source rocks in the upper mantle and that these would be far larger than any known 'primary' deposits. M.O'D.

Gem Trade Lab Notes.

R.C. KAMMERLING, C.W. FRYER, G.R. CROWNINGSHIELD, T. MOSES, K. HURWIT AND S.F. MCCLURE. *Gems and Gemology*, **30** (1), 1994, pp 39-46, 20 illus. in colour.

The Centenary diamond was graded on site in London and at 273.85ct was declared the largest 'D' colour, flawless or internally flawless diamond graded to date; a colour report was made on the 545.65ct diamond known as 'Unnamed Brown' and shown to be fancy yellowish-brown of natural colour; a fancy coloured orange to brown rough diamond was shown to be natural although cutting produced a near colourless stone; clusters of fine dark needles in fancy intense yellow diamonds strongly suggested a type-Ib stone; orientated platelets appeared to be unique to type -IaA fancy yellow diamonds. R.J.P.

Diamond radiation detectors.

R.J. KEDDY, T.L. NAM. *Radiation Physics & Chemistry*, **41** (4-5), 1993, pp 767-73 (Apr-May), 10 figs, 28 refs.

A review to date is given of the status of diamond as a detector of ionising radiations. The use of diamond as a thermo-luminescence device, as an ionisation chamber (pulse and dc modes), as a scintillation counter for α–particles and for high dose applications using radiophotoluminescence is discussed. Some of the data obtained have also led to a better understanding of physics and crystallographic structures of the diamond lattice. Appropriate examples and references are given. Particular attention is paid to the role played by the impurity atoms within the lattice. (Author's abstract). R.J.K.

[Clastogenic* pyropes and diamonds of northern Karelia.] (Russian with English abstract)

S.F. KLJUNIN AND A.A. ZAKHAROV. Proc. Russian Min. Soc., 122 (6), 1993, pp 43-7.

New data on the composition, morphology and types of crystal surface are presented for chrome-pyropes and diamonds found in heavy-mineral concentrates obtained by sampling the 'pyrope aureole' in N. Karelia. EPMA results are reported for 19 pyropes. Photomicrographs are given of the surface textures of grains of garnet and diamond; their morphology and the stepped development of faces on diamond bear witness to the short distance of transportation undergone by these minerals. It is concluded that prospecting for diamond deposits in this area should be promising. R.A.H.

*Editor's note: the term 'clastogenic' is generally used in connection with fire fountains and may be considered in a kimberlite volcanic context thus: fallout from a fire fountain produces a spatter rampart around the vent and if the accumulation rate is high the molten spatter may coagulate to form a flow of lava known as a clastogenic flow.

Rb-Sr ages of Proterozoic kimberlites of India: evidence for contemporaneous emplacement.

A. KUMAR, V.M. PADMA KUMARI, A.M. DAYAL, D.S.N. MURTHY AND K. GOPALAN. *Precambrian Research*, **62** (3), 1993, pp 227-37, 2 maps.

Rb-Sr analyses of leached phlogopite macrocrysts from kimberlite pipes 1, 2, 5 and 7 in S India give concordant ages of 1091 ± 20, 1092 ±15, 1093 ± 20 and 1091 ± 10 m.y., respectively, indicating contemporaneous emplacement. The present results contradict earlier measurements. Groundmass mineral assemblages with low Rb/Sr ratios give a tight set of initial Sr ratios at 0.7029 ± 0.0002, 0.7019 ± 0.0002, 0.7029 ± 0.0002 and 0.7030 ± 0.0004, suggesting derivation of the

primary kimberlite magma from a relatively uniform and depleted mantle source. A similar age and initial Sr isotopic ratio of one sample of the Majhgawan lamproite from central India imply that the Proterozoic kimberlite/lamproite activities in India, although widely separated in space, were almost contemporaneous. R.E.S.

A high-chromium corundum (ruby) inclusion in diamond from the Sao Luiz alluvial mine, Brazil.

G.R. WATT, J.W. HARRIS, B. HARTE AND S.R. BOYD. *Mineralogical Magazine*, **58** (3), 1994, pp 488-91.

A highly chromian, red corundum inclusion (~100 μm long) was found in a type II diamond with a variable $\delta^{13}C$ (-11.56 to -15.21 vs PDB). Electron microprobe analyses gave SiO_2 0.58, TiO_2 0.10, Al_2O_3 90.37, Cr_2O_3 8.58, FeO 0.28, MnO 0.04, MgO 0.40, CaO 0.01, Na_2O 0.01, = 100.39. The high Cr content of the São Luis corundum relative to corundum from eclogitic xenoliths may reflect formation at sub-lithospheric depths, analogous to increased Cr partitioning in kyanite with pressure. R.A.H.

Comments on 'An unusual octahedral diamond' by A. Yacoot and M. Moore.

A.R. LANG. *Mineralogical Magazine*, **58** (3), 1994, pp 506-510.

A recent application of X-ray topography to a natural diamond [*Min.Mag.* **56**, 1992, 111-13] is considered to have incorrectly interpreted the evidence. A new interpretation is put forward, with the emphasis on the cuboid protuberances, and a possible explanation for the present shape of this diamond is proposed. R.A.H.

Gems and Minerals

Structural changes of nephrites at elevated temperatures as revealed by their IR-spectra.

A. BANERJEE AND P. WANG. *Neues Jahrbuch für Mineralogie Monatschefte*, 1994 (7), pp 317-27.

Correlation between the Fe and Mg contents of two nephrites [no localities given] and their IR absorption bands was investigated. The more magnesian nephrite had one absorption band at 3674cm^{-1} due to OH-stretching vibration; this band splits to give an additional absorption band at 3660cm^{-1} for the more iron-rich sample. The changes in the IR spectra with heating to 900°C were also studied. R.A.H.

L'amazonite de Santa Maria de Itabira (Minas Gerais, Brésil) (part 1)

J.-P. CASSEDANNE. *Revue de gemmologie*, **119**, 1994, pp 5-6, 2 illus. in colour.

Amazonite from the iron-bearing area of Itabira is described. The region is 100km east-nor-east of Belo Horizonte, Minas Gerais, Brazil, specifically in the Fazenda de Geraldo Duarte on the left bank of the Corrego do Patrimìnio. Amazonite occurs in a granite pegmatite cutting a granite gneiss and is associated with quartz, albite and biotite. M.O'D.

Cordiérites à effets spéciaux.

C. DA CUNHA. *Revue de gemmologie*, **119**, 1994, pp 11-14, 2 illus. in black-and-white, 2 in colour, 2 figs.

Chatoyant and star cordierites are described, both 4- and 6-ray versions of the latter being recorded. Though hematite and/or lepidocrocite are proposed as the cause of the chatoyancy the minerals responsible for the asterism were not identified. A note on a cordierite showing aventurescence identifies the presence of biotite and muscovite in the literature and these may be the cause of some of the aventurescence observed in the author's studies but this is uncertain. M.O'D.

Gravure sur pierres précieuses: les saphirs.

M. DUCHAMP. *Revue de gemmologie*, **119**, 1994, pp 7-10, 6 illus. in black-and-white, 3 in colour.

Engraving on sapphire is traced from early times with notes on specimens from a number of collections. M.O'D.

The Indaia sapphire deposits of Minas Gerais, Brazil.

D.S. EPSTEIN, W. BRENNAN AND J.C. MENDES, *Gems & Gemology*, **30** (1), 1994, pp 24-32, 11 illus. in colour.

Although the total amounts of sapphire mined during the last three years have been relatively small, the discovery of deposits in this region may be of major significance. The sapphires are recovered from alluvium. Spectroscopy is consistent with iron-rich sapphires from other localities. Optical characteristics and microscopy are given in detail with a high percentage of stones showing colour change. Whether more sophisticated mining methods will be practical and economical remain questionable. R.J.P.

Les perles rouges de Pinna noblis (continued).

J.-P. GAUTHIER, J. CASEIRO AND B. LASNIER. *Revue de gemmologie*, **119**, 1994, pp 2-4, 3 illus. in black-and-white, 2 in colour, 1 fig.

Pearls with aragonite composition are a little rarer than those composed of calcite and usually measure from 1-4mm. A section of one pearl

showed seven distinct growth stages. Some specimens apparently owed their nucleation to the presence of a 'nodule' placed at the base of the mantle close to the viscera. The structure of the nodule shows a fibrous and radiating picture with concentric growth zones. The material was found to be calcite with some aragonite. M.O'D.

The name game.

R.W. HUGHES. *The Australian Gemmologist*, **18** (10), 1994, pp 311-15.

Although written in a light-hearted style, the author nevertheless gives the reader much to think about and is master of his topic. The whole system for naming varieties is in need of serious overhaul and will require a concerted effort by all concerned bodies. R.J.P.

A combined magnetic resonance and gamma-irradiation study of some green beryls.

D.R. HUTTON AND G.J. TROUP. *The Australian Gemmologist*, **18** (10), 1994, pp 315- 317, 7 illus. in black-and-white.

Part of a continuing series, the article shows how a combined Electron Spin Resonance technique (ESR) with gamma-irradiation can detect vanadium in the presence of both iron and chromium providing that the Fe^{3+} and/or Cr^{3+} lines are not too broad. In the study, Colombian emeralds from the Chivor and Muzo mines contained vanadium whilst Brazilian and Zambian emeralds together with Torrington emerald showed an absence of vanadium. The role of the radiation is to produce paramagnetic vanadium ions which can then be detected by the ESR method. R.J.P.

Gem Trade Lab Notes.

R.C. KAMMERLING, C.W. FRYER, G.R. CROWNINGSHIELD, T. MOSES, K. HURWIT AND S.F. MCCLURE. *Gems and Gemology*, **30** (1), 1994, pp 39-46, 20 illus. in colour.

A snuff bottle was shown to be primarily plagioclase feldspar with garnet of the grossular-andradite-uvarovite series; a black stone which was highly magnetic was shown to be about 75 per cent hercynite and 25 per cent spinel; a lavender-coloured jadeite had been polymer impregnated; several translucent greenish-blue carved pendants with the appearance of finest Mexican chalcedony were confirmed as opal by X-ray diffraction; assembled cultured blister pearls were shown to be early Japanese; a pearl necklace was proved to be cultured with one pearl having a distinctive plastic nucleus; a star sapphire with a buff-top cut was found to be natural; a colour change synthetic sapphire had its red colour enhanced by red foil or paint on the pavilion facets in a closed setting. R.J.P.

World gemstone market invaded by sizeable amount of Burma ruby.

C. KREMKOW. *Israel Diamonds and Precious Stones*, **136** (May), 1994, p. 64,68 (2 pages), 1 illus. in colour.

A newly developed ruby mine at Mong Hsu in western Myanmar is now producing sizeable quantities of commercial-quality ruby, and significant quantities of fine-quality goods particularly in sizes up to one carat. Larger sizes are rare and only available in the lower qualities. The deposit was first discovered in 1991, with commercial quantities being produced from 1992 when the Myanma government officially declared the area a gemstone tract. The supply of rough has enabled dealers to offer calibrated sizes up to 8 x 6mm, including rounds up to 5mm. Virtually all Mong Hsu ruby is heated to eliminate blue zoning. P.G.R.

Der Blue John-Fluorit. Ein Besuch in den Flusspatgruben von Castleton, Derbyshire, England.

W. LIEBER. *Lapis*, **19** (6), 1994, pp 13-22, 1 illus. in black-and-white, 14 in colour, 3 maps.

A useful description with historical notes of the Blue John fluorite occurrences in Derbyshire, England. Many artefacts are illustrated. M.O'D.

Edel- und Schmucksteine aus Österreich.

G. NIEDERMAYR. *Mineralien Welt*, **5** (4), 1994, pp 17-23, 1 illus. in black-and-white, 16 in colour.

The gem minerals of Austria include emerald, garnet, quartz, nephrite, fluorite, lazulite, corundum, diopside, topaz, sphene, feldspars and phenakite, all occurring with reasonable frequency. Rarer species include datolite, sphalerite, apatite, scheelite, cordierite, scapolite, vesuvianite and rutile. All are briefly described. M.O'D.

Comparative study of beryl from various Indian occurrences - beryl from Jammu & Kashmir [continued from vol. 4. no. 1.].

J. PANJIKAR. *Indian gemmologist*, **2** (2), 1994, pp 3-7, 6 tables, 2 figs in black-and-white, 6 in colour.

Kashmir beryls show protogenetic solid inclusions identified as biotite and three types of syngenetic single phase solid inclusions identified as quartz, fluorite and tourmaline. Primary and secondary fluid inclusions occur frequently in all observed specimens. Two- phase (gaseous and liquid) and three-phase inclusions are also reported. Multiphase inclusions including variously-shaped crystals (one identified as hematite)

are also observed. Colour zoning is reflected in the arrangement of the inclusions, both features being syngenetic. Chemical analyses are given. [To be continued.] M.O'D.

Synthèse du rubis en phase gazeuse.

D. ROBERT. *Revue de gemmologie*, **119**, 1994, pp 15-18, 1 table, 1 fig.

A short review of the principles observed for crystal growth from the gaseous phase with particular reference to ruby. M.O'D.

Torrington emerald update.

K. SCHMETZER. *The Australian Gemmologist*, **18** (10), 1994, pp 318-19, 1 table, 2 illus. in black-and-white.

Evidence was cited for this green-coloured beryl from Torrington, New South Wales, to be described as emerald. This included spectrophotometric examination which confirmed the presence of chromium. Chemical analysis by electron microprobe and wet chemical determinations showed extreme zoning with alternating green emerald and colourless beryl. Vanadium intensified the green colour due to chromium. Microscopic examination of the crystals showed intense colour zoning parallel to the basal pinacoid. R.J.P.

On the presence of OH⁻ groups in Zabargad olivine gems.

P.F. SCIUTO. *Neues Jahrbuch für Mineralogie, Monatshefte*, **4**, 1994, pp 145-56, 5 tables.

Single-crystal XRD study of an olivine from Zabargad shows a structure suggesting that an essentially hydrous phase is present. Hydrogen content is not measurable by this technique. The crystal examined was gem quality. Internal disorder evaluation showed that inter-crystalline exchanges ceased at an upper limit of approximately 600°C. M.O'D.

Lepidolith und Heliodor aus Rozná in Westmähren/CR.

J. STANEK. *Lapis*, **19** (6), 1994, pp 49-50, 1 illus. in black-and-white, 2 in colour.

Gem-quality yellow to yellow-green beryl is found in pegmatites in the neighbourhood of Rozná, Czech Republic. M.O'D.

Moçambique emerald.

A. THOMAS. *South African Gemmologist*, **6** (1), 1994, pp 10-11.

Brief note on the present status of mining of emerald in Moçambique reports that the Cabral enterprise is in ruins though sporadically worked, with other deposits, by itinerant garimpeiros. Light green crystals were recovered in the vicinity of pegmatite veins in the metamorphosed Moçambique belt. The mines at Morrua have worked lenses of emerald-bearing schist in the contact zone of the pegmatite veins. The Maria I, Maria II and Maria III mines have produced the bulk of emerald from the area. M.O'D.

The Anahí Ametrine Mine, Bolivia.

P.M. VASCONCELOS, H. WENK AND G.R. ROSSMAN. *Gems and Gemology*, **30** (1), 1994, pp 4-23, 23 illus. in colour.

Ametrine (intergrown amethyst and citrine) only appeared commercially from this source in 1978 and its natural nature was challenged. The authors studied its nature at source and suggested that the sharp colour distribution was crystallographically controlled. Theories of colour formation were suggested and one involving quenching of the amethyst colour by natural radiolysis of the higher water content in citrine areas was not borne out by analysis of crystals from a different source. The geology and mineralogy were thoroughly discussed. The difficult access to the mine and former mining restrictions imposed by the authorities accounted in part for the mystery surrounding this deposit. R.J.P.

Blauer Kluftberyll aus der Südschweiz.

S. WEISS. *Lapis*, **19** (6), 1994, pp 25-40, 1 illus. in black-and-white, 5 in colour.

Blue beryl crystals, some appearing to be gem quality, are found as cleft minerals near the Basïdino Glacier, Ticino, Switzerland. Some crystals reach 1.25cm in length. M.O'D.

Mineralogy of the Bennett pegmatite, Oxford County, Maine.

M.A. WISE, T.R. ROSE AND R.E. HOLDEN JR. *Mineralogical record*, **25** (3), 1994, pp 175-184, 2 tables, 9 illus. in black-and-white, 1 fig., 1 map.

Fine crystals of morganite, tourmaline and fluorapatite are among the minerals found at the Bennett pegmatite in western Maine, USA. Aquamarine of gem quality is also known from this location. A fine morganite crystal known as the 'Rose of Maine' was discovered in 1989 and was cut into gems. The original weight was approximately 23kg. Some elbaite is of gem quality and is found as water-melon and 'cucumber' [water melon reversed] crystals, though examples are relatively rare. Dark to pale green and pink crystals are also found. M.O'D.

Mikro-Achate aus Ost-Thüringen.

H. ZYPRIAN. *Mineralien Welt*, **5** (3), 1994, pp 44-6, 2 illus. in black-and-white, 5 in colour.

Small but attractive specimens of banded agate are described from eastern Thuringia, Germany. The sizes are around 3mm in general. M.O'D.

Schöne Mineralien aus dem Setesdal Minal Park. [No author given]

Mineralien Welt, **5** (3), 1994, pp 16-24, 19 illus. in colour.

Crystals of gem minerals are exhibited at a newly-established Mineral Park in Setesdal, Norway. Some of the examples are illustrated. M.O'D.

Instruments and Techniques

Visual optics–the Hodgkinson method: an update.

A. HODGKINSON. *The Australian Gemmologist*, **18** (10), 1994, pp 320-2, 4 illus. in colour.

In this welcome up-date the author acknowledges the contributions by Dr Hanneman to amplify the quantitative aspects of the technique and it is hoped that the proposed kit will enable the technique to be separated from the word 'instrumentless' which has hitherto been applied. R.J.P.

Synthetics and Simulants

Density-driven liquid-liquid phase separation in the system Al_2O_3 -Y_2O_3.

S. AASLAND AND P.F. MCMILLAN. *Nature*, **369**, 1994, pp 633-6, 1 table, 4 illus. in black-and-white, 3 figs.

The sluggishness of crystallization of yttrium aluminium garnet, host material for Nd^{3+} ions in YAG lasers, may be due to the existence of two coexisting liquid phases in the supercooled melt of Al_2O_3-Y_2O_3 both with the same composition and existing just above the glass transition at ambient pressure. It is proposed that the two phases differ only in density and that the transition is entropically driven. M.O'D.

Fraudulent use of synthetic sapphire.

R. MACKENZIE. *South African Gemmologist*, **8** (1), 1994, pp 7-9, 3 illus. in colour.

Synthetic ruby rough is reported to have been offered as natural ruby in some south-east Asian markets. Material shows diffused colour banding (curved striae), rounded to elongate gas bubbles and masses of partly fused whitish alumina originating at the point of attachment between boule and refractory pedestal. Rough synthetic sapphire has also appeared on the South African market. Both blue and pink to purple colour-change varieties are reported; both show characteristic signs of flame-fusion growth. M.O'D.

Doubletten und Tripletten.

G. NIEDERMAYR. *Mineralien Welt*, **5** (3), 1994, pp 15-16, 5 illus. in colour.

Brief survey with excellent photographs of the various types of gemstone composites with emphasis on emerald imitation. M.O'D.

Synthetische, nach dem Schmelz-diffusionsverfahren hergestellte Smaragde.

G. NIEDERMAYR. *Mineralien Welt*, **5** (4), 1994, pp 15-16, 5 illus. in colour.

Brief, useful description of the flux-melt method of emerald synthesis with photographs of characteristic inclusion. M.O'D.

New developments in synthesis of gemstones.

J. PANJIKAR AND K.T. RAMCHANDRAN. *Indian Gemmologist*, **2** (2), 1994, pp 14- 16.

Brief overview of some of the commoner synthetic gemstones covering ruby, emerald, spinel and alexandrite. M.O'D.

[Nucleation and growth of diamond.] (Japanese with English abstract)

M. WAKATSUKI. *Journal of the Japanese Association of Crystal Growth*, **16** (2), 1989, pp 106-17.

The characteristic behaviour exhibited during the nucleation process of synthetic diamonds in a metal-carbon system under high-*P*, high-*T* conditions was explained by a reaction model in which the nucleation of diamond and recrystallization of graphite compete with each other. From the model, it became possible to deduce a suitable *P-T* cycle for obtaining well-crystallized particles and a new method of growing single crystals using seeds, which is different from the conventional temperature-gradient method. The formation of surface dendrites, commonly observed on synthetic diamonds, was prevented by slow cooling at the end of growth. I.S.

Book Reviews

Führer durch das Deutsche Edelsteinmuseum.

H. BANK, 1994. Vereinigung der Freunde der Mineralogie und Geologie, Heidelberg. pp 128, illus. in black-and-white and in colour. [Forms *Der Aufschluss* 45, 4/5, 1994: ISSN 0004-7856.]

While Idar-Oberstein has more than one publicly-displayed gemstone collection, over the past 25 years the Deutsche Edelsteinmuseum, housed in the Diamant- und Edelsteinbörse and thus conspicuously easy to find, has taken pride of place. It has long needed a comprehensive guide and now has one in this monographic issue of *Aufschluss*.

The guide opens with a short history of the museum which took up its present quarters in 1973, occupying one of the lower floors of the multi-storey bourse building. Movement towards the establishment of a gemstone museum in the town began as long ago as 1853 and before the latest move the collection was housed in the Gewerbehalle, familiar to all who have taken courses with the Deutsche Gemmologische Gesellschaft. The present quarters are superbly arranged as I have found on many visits and the new guide takes the visitor through the display systematically, having discussed the establishment of the gemstone industry in Idar-Oberstein - this dates at least from the fourteenth century.

The descriptive part of the text begins with a discussion of the nature of gemstones and their properties, the main gemstone-producing locations with brief notes on their geology, on rarities and on the use of gemstones and ornamental minerals in history. The book then describes the gemstones in chemical order, following the arrangement of the traditional mineral cabinet, giving chemical composition, crystal system, physical and optical properties, details of geological occurrence and main producing locations. Details of the major synthetic and imitation products follow.

Since Idar-Oberstein is one of the world's cutting and carving centres, it is welcome to find a short section on these topics (there is room for an up-to-date book on gemstone carving); this is followed by a discussion on nomenclature and by notes on gemstones found in the present century which form a separate display. Tables list numerical data for the major species and also list stones which might be confused with diamond, ruby, blue sapphire and emerald. More useful is a chronological table giving the dates when the more important synthetic gemstones appeared. A final table gives the names of gem species first found in the present century.

The text is accompanied by first-class colour photographs by Gerd Becker and although the text is gemmological rather than popular there seems no reason why the guide, while part of a specialist scientific journal, should not become the standard for other collections. M.O'D.

Natural Glasses.

V. BOUSKA, Z. BOROVEC, A. CIMBALNIKOVA, I. KRAUS, A. LAJCAKOVA AND M. PACESOVA, 1993. Ellis Horwood, New York and London. pp 354. Price £45.00.

This book considers natural glasses in terms of the time required to form them. Classified according to their mechanisms of formation, they include fulgurites, dialectic glasses formed by impact, impact glasses formed by thermal melting of the parent minerals and rocks during the impact event, tektites, and volcanic glasses (on Earth, Moon or the planets). The physical properties and chemical compositions of the various glasses are described and there is a final chapter on the practical uses of these glasses. R.A.H.

Gemstone enhancement: history, science and state of the art. Second edition.

K. NASSAU, 1994. Butterworth Heinemann, Oxford. pp xii, 252, illus. in black-and- white and colour, softcover. Price £30.00. ISBN 0 7506 1797 7.

Few texts have been as eagerly awaited as this one which appears at a time when gemstone treatment is now affecting most of the major gem species and thence to the dealer and customer. Conferences have been devoted to this difficult topic and the publication of the first edition of this book in 1984 served to shed light on events which many in the trade had never considered.

While the main text is presented in the same way as in 1984, there have inevitably been amendments and these are considerable in some areas. The spread of fracture filling and the near-flooding of the blue stone sector of the market by treated topaz are two places which the author highlights in the preface - there are at least four

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different techniques by which blue topaz can be irradiated. Even more alarming is the identification of seven (at the time of writing) types of treated yellow sapphires, a species which has now laboured under considerable disadvantage commercially for many years. The diamond story is no less complex though the references appended to this section of the book show the amount of work being carried out.

As in the first edition the author gives us much of the knowledge we might need to treat our own stones while showing us how dangerous and unpredictable such an activity would be. While many gemmologists will be interested in the chapters describing the practice and history of the different treatments, more (especially in gem testing laboratories) will turn to the alphabetical descriptive section where species are described in turn with prefatory summaries introducing the major species and references closing each description. Tables, useful addresses and amplification of the earlier chapters on heating and irradiation complete the text - or nearly: readers will be pleased to hear that in normal conditions of wear the Maxixe and Maxixe-type blue beryls will not fade for at least 20 to 40 years. This is just what student gemmologists in particular like to know and it is characteristic of this superb text that they can find out. Somehow this says it all!

M.O'D.

Fluorescence: gems and minerals under ultraviolet light.

M. ROBBINS, 1994. Geoscience Press, Phoenix, AZ. pp ix, 374, illus. in black-and-white and in colour. Price US$40.00. ISBN 0 945005 13 X.

Books on luminescence are not too easy to come by and several years have passed since one appeared on the market. Geoscience Press have built up a reputation for good- quality books in the earth science field and this example is worth buying. Some of the material is taken from articles in *Rocks and minerals* and some of the text is updated from the author's previous book *The Collector's book of fluorescent minerals* (1983).

Beginning with an account of fluorescence the book continues with descriptions of two major localities, Mont St Hilaire, Quebec, Canada, and Franklin, New Jersey, USA. Both sites produce such fine specimens of fluorescent minerals that they are felt to merit a chapter to themselves. Lists of minerals are given for both places. The next chapter describes how fluorescence is activated and from this point the book deals with mineral species or groups one by one, each having its own chapter.

One chapter is dedicated to gemstones and provides useful information conveniently brought together from various sources. It is followed by an account of fluorescent faces and zones in minerals and then by a catalogue, with descriptions, of fluorescent minerals, in chemical order and including gem minerals. The text concludes with a table of activators, a set of experiments that the reader can try out and an excellent bibliography.

This is a useful book and fills a serious gap. While largely concerned with minerals that few people will ever see, there is enough on better-known and gem species to guarantee wide sales and gemmologists will do well to have a copy handy. The colour photographs, grouped in a single section, are the best I have seen so far in a book on this topic.

M.O'D.

Fundamentals of crystals. Second, enlarged edition.

B.K. Vainshtein, 1994. Springer-Verlag, Berlin. pp xxi, 480, illus. in black-and-white and in colour, hardback. Price DM119.00. ISBN 3 540 56558 2.

Covering (and subtitled) symmetry and methods of structural crystallography, this revised edition of what quickly became a standard work is welcome. While revising the original text and updating it where necessary, the author has added quasicrystals, developments in molecular-beam epitaxy, surface melting, improper ferroelectrics and incommensurate phases, with other topics. New techniques included are tunnelling microscopy, extended X-ray absorption fine structures (EXAFS) and position-sensitive detectors for X-rays. The excellent bibliography has also been extended and revised. For the interest of readers quasicrystals were 'discovered' when the structure of rapidly cooled $Al_{86}Mn_{14}$ alloy was investigated by electron diffraction. The diffraction patterns gave a system of reflections which in reciprocal space had icosahedral *m5m* symmetry, previously considered impossible as 5-fold rotation axes were incompatible with 3-dimensional translation symmetry in crystal structure. But don't amend your textbooks yet!

As in the first edition coloured diagrams of important crystal symmetry patterns make a welcome and useful addition to what is a complex subject, lucidly treated.

M.O'D.

Proceedings of the Gemmological Association and Gem Testing Laboratory of Great Britain and Notices

OBITUARY

Professor Igor S. Loupekine (D.1963 with Distinction), Santa Julia de Loria, Principality of Andorra, died recently.

David Wilkins, Yeovil, died on 1 September 1994. A full obituary will be published in a future issue of *The Journal.*

GIFTS TO THE ASSOCIATION

The Association is most grateful to David Callaghan of Hancocks & Co., London, for the gift of synthetic ruby beads for research and teaching purposes.

NEWS OF FELLOWS

On 6 July 1994 **Peter Read** gave an illustrated talk to the Bournemouth Natural Science Society in their Christchurch Road premises on the subject of 'Gem mining in Sri Lanka'. Included in his presentation was a display of gemmology books and a selection of Sri Lankan rough and polished gemstone specimens in which thirteen species were represented.

MEMBERS' MEETINGS

London

On 19 September 1994 at the Gem Tutorial Centre at 27 Greville Street, London EC1N 8SU, Susan Anderson gave an illustrated lecture entitled 'The gem materials of Zimbabwe'.

Midlands Branch

On 30 September 1994 at Dr Johnson House, Bull Street, Birmingham, Alan Hodgkinson gave a talk entitled 'Poking about in gemmological corners'.

North West Branch

On 21 September 1994 at Church House, Hanover Street, Liverpool 1, Stephen Kennedy gave an illustrated talk entitled 'Pearls in the Arabian Gulf'.

GEM DIAMOND EXAMINATIONS

In June 1994 97 candidates sat the Gem Diamond Examination worldwide, of whom 66 qualified including four with Distinction. The names of the successful candidates are as follows:

Qualified with Distinction

Haddock, Brendan, Edinburgh.
Kneebone, David G., Penzance.
Scott, Damian T., London.
Stossel, Hillary, London.

Qualified

Baddoo, Alfred A., London.
Bailey, Anne M., London.
Bailey, Lisa J., Birmingham.
Balducci, Annette, Neston.
Ball, Pamela, Hong Kong.
Bao, Chunhui, Wuhan, China.
Bastians, Indramal, London.
Brady, Deanna M., Wirral.
Bray, Betty A., Abilene, Tex., USA.
Brown, Allen G., Birmingham.
Carvalho, Rui Galopim de., Lisbon, Portugal.
Chan Ka Fung, Louisa, Hong Kong
Chen Shulan, Wuhan, China.
Chew Lee Lee, Hong Kong.
Christian, Helen E., Bolton.
Clover, Wai Ying, Birmingham.
Crabbe, Jeremy P., Hong Kong.
Di Jingru, Wuhan, China.
Everitt, Sally A., London.
Fu Yun Long, Wuhan, China.
Galloway, Linda L. Vacca-, Hong Kong.

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Geoghegan, Noel R., Wellesbourne.
Griffin, Anthony, Godalming.
Guo Shougou, Wuhan, China.
Han Hui, Wuhan, China.
Henn, C. John W., Wolverhampton.
Hughes, Helen, London.
Huong Jun, Wuhan, China.
Jackson, Brian, Edinburgh.
Jhaveri, Devang, London.
Jones, Amanda, Hagley.
Kilby Hunt, Judith A.F., London.
Krikos, Alexandra, London.
Lee, Jin Young, London.
Lewis, Rob, Totternhoe.
Lian Bee Chen, Pauline, Hong Kong.
Lowe, David J., London.
Lu, Jei-Chih, London.
Ludlow, Andrew P., London.
Massow, Kenneth J., Rochford.
Mathiopoulou, Regina, Athens, Greece.
O'Brien, Gillian M., North Berwick.
Page, Christopher, Newmarket.
Parker, David T., Sunderland.
Penton, Keith, London.
Pratt, James, London.
Qi Lijian, Wuhan, China.
Saxton, Carol A.L., Alton.
Siu Lam Ma, Hong Kong.
Sondack, Julia, London.
Sum-Pui F. Yu, Kowloon, Hong Kong
Sutton, Daniela N., Cheltenham.
Tarazi, Mirna Y., London.
Taylor, Roger J., Bordesley Green.
Thomson, Joanna, Peebles.
Walker, Averil S., London.
Wong Nim Chi, Phyllis, N.T., Hong Kong
Xu Shirong, Wuhan, China.
Yan Weixuan, Wuhan, China.
Yang Mingxing, Wuhan, China.
Zhang Shuyun, Wuhan, China.
Zhou Min, Wuhan, China.

EXAMINATIONS IN GEMMOLOGY

In the June 1994 Examinations in Gemmology 366 candidates sat the Preliminary examination, 255 of whom qualified; 354 sat the Diploma Examination and 148 qualified including four with Distinction.

The Tully Medal for the candidate who submits the best set of answers in the Diploma examination which, in the opinion of the Examiners, are of sufficiently high standard, was awarded to Mr Neil Rose of Stockport.

The Anderson Bank Prize for the best non-trade candidate of the year in the Diploma examination was awarded to Miss Hiroko Fukagawa of Osaka, Japan.

The Diploma Trade Prize for the best candidate of the year who derives his main income from activities essentially connected with the jewellery trade was awarded to Mr Neil Rose of Stockport.

The Anderson Medal for the best candidate of the year in the Preliminary examination was awarded to Miss Deborah Wilson of Boston, Lincolnshire.

The Preliminary Trade Prize for the best candidate under the age of 21 years on 1 June 1994 who derives her main income from activities essentially connected with the jewellery trade was awarded to Miss Alicia Arnold of London.

DIPLOMA

Qualified with Distinction

Fukagawa, Hiroko, Osaka, Japan.
McIntosh, Robert P., Edinburgh.
Rose, Neil R., Stockport.
Watatsuki, Reiko, Kawasaki, Japan.

Qualified

Alaniva, Orvokki, Helsinki, Finland.
Alexander, Maria K., London.
Antzoulakos, George, Athens, Greece.
Armstrong, Michael J., Whitley Bay.
Au Ming Cheung, Hong Kong.
Au Yang So-Wah, Natasha, Hong Kong.
Audichya, Pradeep, Jaipur, India.
Barcados, Alexander J., Toronto, Ont., Canada.
Bastians, Indramal, London.
Bevers-Reinders, L.M., Rotterdam, The Netherlands.
Bezeredi, Svetlana, W. Vancouver, BC, Canada.
Bishop, Heather M., Ipswich.
Bollack, Josee, Strasbourg, France.

FORTHCOMING MEETINGS

London

Meetings are held in the GAGTL Gem Tutorial Centre, 2nd Floor, 27 Greville Street, London EC1N 8SU (entrance in Saffron Hill).

The charge for a member is £3.50. Entry will be by ticket only, obtainable from the GAGTL.

22 November	**Gemstones on display at the Natural History Museum: past, present and future**	Cally Hall
5 December	**Sapphires in the Laboratory**	Stephen Kennedy

Midlands Branch

6 November	Autumn Seminar at the Cobden Hotel, Hadley Road, Birmingham	
25 November	**How to buy gemstones**	Grenville Millington
3 December	42nd Annual Dinner	
22 January 1995	Gem Club	
27 January	**The treatment of diamonds**	Eric Emms
19 February	Gem Club	
24 February	Clive Burch (subject to be announced)	
19 March	Gem Club	
31 March	**Jewellery through the ages**	Nigel Dunn

The meetings will be held at Dr Johnson House, Bull Street, Birmingham. Further details from Mandy MacKinnon on 021-444 7337.

North West Branch

16 November Annual General Meeting

Meetings will be held at Church House, Hanover Street, Liverpool 1. Further details from Joe Azzopardi on 0270 628251.

Bossenbroek, A.E.H., Doorn, The Netherlands.
Boyens, Christine P., Auckland, New Zealand.
Bruce, Rachel M., Edinburgh.
Butcher, Anna, London.
Carr, Simon D., Garstang.
Carroll Marshall, Anne E., Hong Kong.
Carvalho, Roberta Melo De, Rio de Janeiro, Brazil.
Chan, Kin-Chung, John, Hong Kong.
Chan Kwok Keung, Hong Kong.
Chan Wai Ching, Joanne, Kowloon, Hong Kong.
Chan Yuk Victoria, Hong Kong.
Chao, Tan-Chi, Dandy, Taipei, Taiwan.
Chen, Pauline Lian Bee, Hong Kong.
Chen Chin-Ho, Taipei, Taiwan.
Cheng Fung Kei, Hong Kong.
Cheng Lap Fan, Hong Kong.
Chokhani, Shiv Vishwanath, Bombay, India.
Chua, Virna Ngo, Hong Kong.
Chung Yam Ming, Hong Kong.
Cliff, Graham, Greenwich.
Coghlan, Karen, Exeter.
Cooke, Joanne T., Petchburi, Thailand.
Cookson, Ian P., Sheffield.
Cracco, Alexia, London.
Devon, Jill V., Felsted.
Dickinson, Barry E., Blackburn.
Diserens, Myriam, London.
Dragland, Frode, Sortland, Norway.
Eames, Lucy, London.
Farion, Jean-Christophe, London.
Fung Yuk Fung, Hong Kong.
Gamst, Terje, Breivikbotn, Norway.
Gemin Cherkaoui, Nadine, Geneva, Switzerland.
Goldschmidt-Husein, Asli, St. Ingbert-Owb, Germany.
Goss, Sanya L., Aldershot.
Graff, Elliott M., London.
Green, Kimberly H., Birmingham.
Gunell, Carola, Kirjala, Finland.
Hamidulla, Suzan, Helsinki, Finland.
Hamza, Mohamed Hassan, Colombo, Sri Lanka.
Hasler, Christian S., Toronto, Ont., Canada.
He, Wei, Wuhan, China.
Hindley, Stuart W., Worksop.
Hu Hai, Wuhan, China.
Hui Sze Wai, Hong Kong.
Hui Wai Yee, Wendy, Hong Kong.
Jang Sool Cho, Seoul, Korea.
Jansen, E.T.D.M.L., Wijchen, The Netherlands.
Jargiello, Barbara A., Lublin, Poland.
Jin, Yi, Wuhan, China.
Jung, Gwang-Gyo, Seoul, Korea.
Kam Siu Tong, John, Hong Kong.
Kato, Ayako, Tokyo, Japan.
Kervezee, R., Berkel-Rodenrys, The Netherlands.
Ketomaki, Tapio, Helsinki, Finland.
Kilby, Linda E., Blackburn.
Kim Sang Sun, Seoul, Korea.
Kiszel, Elisabeth M., Vancouver, BC, Canada.
Kobayashi, Masahide, Osaka, Japan.
Kon Kiang Fung, Hong Kong.
Kumar, V. Krishna, London.
Kwan Wai Shun, Hong Kong.
Lakhtaria, Yashwin, London.
Lam, Christina, Toronto, Ont., Canada.
Leventopoulou, Ageliki-Loudovika, Athens, Greece.
Liang, Tao, Wuhan, China.
Lin, Hsin-Pei, Taipei, Taiwan.
Lord, Karen, Lutterworth.
Louie Miu Man, Hong Kong.
Lu, Yi, Wuhan, China.
Lu, Yung Ching, Taipei, Taiwan.
Mackenzie, Nicola-Jane, Hong Kong.
Mak, So Yi, Hong Kong.
Mann, William M., Gloucester.
McCarthy, Emily, Dublin, Ireland.
McKay, Euan S., Newport-on-Tay.
Molloy, Nicola, Ipswich.
Ng Lok Chung, Angela, Hong Kong.
Okada, Takayuki, Osaka, Japan.
Or Chi Ching, Hong Kong.
Pan, Huijin, Wuhan, China.
Papadopoulos, Iraklis, London.
Paredes Quevedo, Juan, Madrid, Spain.
Park, In-Sook, Seoul, Korea.
Park Young Ah, Seoul, Korea.
Pavlides, Vassilis, Athens, Greece.
Pegg, Delia, Petts Wood.
Perez Munoz, Jorge, Madrid, Spain.
Picallo Rodriguez, Ma Teresa, Santiago De Compostela, Spain.

Proffitt, Graham S., Liverpool.
Pulkkinen, Kari T., Helsinki, Finland.
Purkiss, Christopher R., London.
Ramos-Gonzalez, Stephen P., London.
Ranasinghe, L.D.S., Eheliyagoda, Sri Lanka.
Randall, Gary M., Lowestoft.
Reilly, Clare, Birmingham.
Rubin, Maria, Lannavaara, Sweden.
Sakai, Takeo, Chiba Pref., Japan.
Schroetter, Ralph E., Whitby, Ont., Canada.
Shi, Dan, Wuhan, China.
Sinton, Sarah K., Newcastle-upon-Tyne.
Smyth, Lesley J., London.
Song, Jun-Ho, Seoul, Korea.
Sorrill, Rachel, London.
Stather, Lorne F., Hong Kong.
Stilwell, Lesley, Berkhamsted.
Stoner, Jonathon P., Bradford.
Sutton, Daniela N., Cheltenham.
Syren, Riitta, Helsinki, Finland.
Tang Man Wah, Connie, Hong Kong.
Tang Wai Chun, Hong Kong.
Tao, Du, Wuhan, China.
Terras, Fay, Newton Abbot.
To An You, Peter, Hong Kong.
Tse, Pauline Lai-Kiu, Hong Kong.
Tse Woon Lam, Hong Kong.
Varey, Irena Maria, Leicester.
Wang Tai-Hwan, Taipei, Taiwan.
Welton, Andrew, London.
Wilson, Deborah T., London.
Windwick, William, Elgin.
Xu, Hong, Wuhan, China.
Yeom, Chang-Woo, Pusan, Korea.
Ying Kai Yiu, Hong Kong.
Yip Ngai, Hong Kong.
Yuen, Flora Tsz Wai, Hong Kong.
Zhao, Hechun, Wuhan, China.
Zhao, Rugong, Wuhan, China.
Zhou, Jie, Wuhan, China.
Zhu, Wenhui, Wuhan, China.

GAGTL GEM TUTORIAL CENTRE

Recognizing Treatments and Synthetics
2-3 November
An opportunity for you to handle treated and synthetic gem materials currently encountered in the trade, plus materials which have recently appeared. Improve your technique for detection work on these materials.
Price £223.25 (including sandwich lunch)

The Gem Diamond Practical Tutorial
9-11 and 14-16 November
Limited places are available to anyone requiring basic practical training or a practical review for trade purposes. This is a tutorial structured over six days and is designed to give home study students a complete grounding in practical aspects. It will cover clarity and colour grading of polished diamonds, using 10x lens, microscope and colour comparison stones. You will also handle simulants and clarity-enhanced stones, rough and crystals.
Price £658.00 (including sandwich lunches)

Two-day Diploma Practical Workshop
7-8 January 1995
The long-established intensive practical course to help students prepare for the Diploma practical examination or for non-students to brush up on technique. This is the course to help you practice the methods required to coax results from instruments which can be difficult or awkward to use. The course includes a half-length mock exam for you to mark yourself.
Price £160.39 (£111.04 for GAGTL registered students)
includes sandwich lunches

Just phone, fax or write for details to Doug Garrod at the
GAGTL Education Office - 27 Greville Street, London EC1N 8SU
Tel: 071-404 3334 Fax: 071-404 8843
All prices include VAT at 17.5%

PRELIMINARY
Qualified

Abbott, Debra, Harrogate.
Adams, Victoria, London.
Aiken, Glenn, Tunstall.
Akerblom, Tom E., Helsinki, Finland.
Ambrose, Steven J., London.
Anderson-Slight, Jamie, London.
Ankh, Catrin M., Stockholm, Sweden.
Arnold, Alicia M., London.
Au Yeung Kwok Ho, Hong Kong.
Audichya, Pradeep, Jaipur, India.
Badibanga Bialusambo, Carine, Brussels, Belgium.
Bailey, Alison, Hong Kong.
Baolin, Ma, Wuhan, China.
Baxter, Richard P., Birmingham.
Beesley, Wendy D., Birmingham.
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Bray, Betty A., Abilene, Tex., USA.
Briginshaw, Richard C., London.
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Chan, Ka Mei, Cynthia, Hong Kong.
Chan, Tony Chung Sing, Toronto, Ont., Canada.
Chan, Yik Pun, Hong Kong.
Chan, Yuk, Christine, Kowloon, Hong Kong.
Chan Chi Ling, Phyllis, Hong Kong.
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Cheng, Po Wah, Kowloon, Hong Kong.
Cheng, Yau-Cheong, Hong Kong.
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Cheung, Kam Wah, Hong Kong.
Cheung, Doris Chow Tong, Toronto, Ont., Canada.
Chik, Wing Sheung, Hong Kong.
Chino, Izumi, London.
Choi Yong Dog, Seoul, Korea.
Cho, Jang Sool, Seoul, Korea.
Chonan, Rie, London.
Chong, Shan Shan Elisa, Hong Kong.
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Cracco, Alexia, London.
Dalsplass, Line, Oslo, Norway.
Davies, Paul B., Great Missenden.
de Reus, Leonard, Oisterwijk, The Netherlands.
Dempster, Stuart, Glasgow.
Desai, Hema, Nairobi, Kenya.
Desprat, Anne-Sophie, London.
Disereus, Myriam, London.
Do, Thao Phuong Trung, Melbourne, Vic., Australia.
Dodge, Sarah R., Halesowen.
Downes, Michael D., Morden.
Duann, Teresa, Taichung, Taiwan.
Eriksen, Sissel E., Malvik, Norway.
Fleischner-Zois, Krista, Athens, Greece.
Fong Ming Ho Philips, Hong Kong.
Fong Wai Ko, Raymond, Hong Kong.
Foskolou, Frankiska-Agni, Athens, Greece.
Frankland, Sean C.E., Worth, Crawley.
Fu, Ming Ho, Hong Kong.
Getgood, Fiona J., St Leonards-on-Sea.
Gil Perez, Nuria, Valencia, Spain.
Gitau, Albert G., Kiambu, Nairobi, Kenya.
Gorriceta III, Felix Sarabia, London.
Gregori Enguix, Rafael, Valencia, Spain.
Guest, Vanessa A., Arnold, Nottingham.
Guo, Xiaodan, Wuhan, China.
Hahn, Dieter, Toronto, Ont., Canada.
Haittoniemi, Mia Maria, Kuusankoski, Finland.
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Harvey, Kirsty L., Oxford.
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Hongwei, Tan, Wuhan, China.
Hoopman, Jeffrey B., Akersloot, The Netherlands.
Houben, Sanne, Schoonhoven, The Netherlands.
Hsu, Ming Hung, Tapei, Taiwan.
Hughes, Nicholas B., Stevenage.
Hui Yuk Lum, Isabel, Kowloon, Hong Kong.
Hung, Yvonne, Hong Kong.

MEMBERSHIP '95

Members, Fellows and Diamond Members receive an annual membership card, *The Journal of Gemmology* and the *Gem and Jewellery News* quarterly. Fellows (members who hold our Diploma in Gemmology) may use FGA after their name and Diamond Members (members who hold the Gem Diamond Diploma) the title DGA, and both may also apply for the use of the Coat of Arms on their stationery.

Laboratory Members receive an annual membership certificate for display, *The Journal of Gemmology* and *Gem and Jewellery News* quarterly, discounted testing and grading fees, and may apply for use of the Laboratory logo on their business stationery. Gold Laboratory Members may enjoy similar benefits together with lower fees for diamond grading reports and assistance with the temporary importation of gemstones for grading or testing.

All members are eligible for a 10 per cent discount on the retail price of most instruments and specimens, and a 5 per cent discount on books purchased from Gemmological Instruments Limited. Overseas Members benefit from arrangements to pay membership fees by credit card and all their journals will be sent by airmail.

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Kim Sang Sun, Seoul, Korea.
Kleiser, Alwen, Holyhead.
Kou, Wai Hung, Taipei, Taiwan.
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Kwok, Chi Kwong, Kowloon, Hong Kong.
Lai, Chit Ying, Hong Kong.
Lai Chuen Cheung, Kowloon, Hong Kong.
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Lee Yun Jeong, Seoul, Korea.
Leung, Siu Ha, Kowloon, Hong Kong.
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Lim, Sau Kuen, Hong Kong.
Liming, Zhao, Wuhan, China.

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Metaxa, Ioulia, London.
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Morey, Helene J., Manchester.
Morris, Anthony P., Liverpool.
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Multon, Diana L., Fleet.
Naeder, Karin, Nairobi, Kenya.
Naing, Aye Myo, Yangon, Myanmar.
Ng, Alsion, Kai-Chuen, Kowloon, Hong Kong.
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Nicas, Styliana, P. Pendeli, Greece.
Nip, Yeun Moo, Hong Kong.
Oja, Tonis, Tallinn, Estonia.
Oo, Zaw, Yangon, Myanmar.
Or Chi Ching, Hong Kong.
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Park Young Ah, Seoul, Korea.
Pattni, Jilesh Hirji, Wembley Park.
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Porter, Simon D., Lichfield.
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Pugh, Anthony, Huddersfield.
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Rogers, Mark, South Auckland, New Zealand.
Ronkko, Veera Victoria, London.
Rose, Christina, Wrexham.
Rosier, Wendy J., Hong Kong.
Rosse, Shaun C., London.
Ruxton, Ian T., Winsford.
Sallinen, Virpi H., Helsinki, Finland.
Sammoon, Sarrah, Colombo, Sri Lanka.
Samson, Ma. Teresita, Quezon City, Philippines.
Sanzo, Manuela, Sanremo, Italy.
Sapkas, Panagiotis, Larissa, Greece.
Sark, Kenny, Kowloon, Hong Kong.
Shah, Sudha, Nairobi, Kenya.
Sharma, Animesh, Jaipur, India.
Shen, Yu-Lin, Taipei, Taiwan.
Shende Vivekanand Vasant, Bombay, India.
Shepherd, Louis, Birmingham.
Sherzman, Suthita, Makati, Philippines.
Shuzhen, Zhou, Wuhan, China.
Siegfried, Andreas Balthasar, London.
Simmons, Mary A., London.
Sinton, Sarah K., Newcastle-Upon-Tyne.
Siu, Chun Nei, Hong Kong.
Slattery, Bo, London.
Smallenburg, M.A., Amsterdam, The Netherlands.
Soskin, Marie-Joan, London.
Sotolongo, Sachiko, London.
Suninmaki, Virpi K.A., Helsinki, Finland.
Susan-Roet, Violet E., Naarden, The Netherlands.
Takiguchi, Naomi, Macclesfield.
Tang, Shun Man Catherine, Hong Kong.
Teofanidis, Elefteria, Athens, Greece.
Testler, Jeffrey, Ilford.
Tinnyunt, Emma J., Torquay.
Tompkins, Alison L., Birmingham.
Tripaathi, Naagesha, Jaipur, India.
Tsai, Pei-Lun, Taipei, Taiwan.
Turner, Caroline, Thorpe Bay.
Turula, Suvi A.K., Raahe, Finland.
Tuson, Jonathan L., Romford.
Tzou, Jyh-Jeng, Kee Lung City, Taiwan.

Ueng, Chi-Hong, Taipei, Taiwan.
Vaja, Pravin, London.
van der Wijk, Anneke, Schoonhoven, The Netherlands.
van Doorn, M.R.A., Maarssenbroek, The Netherlands.
van Duijnen, Anna M., Bergen aan Zee, The Netherlands.
van Essen, Elma I., Schoonhoven, The Netherlands.
Verma, Hitesh, Jaipur, India.
Wang, Congyou, Wuhan, China.
Welton, Andrew, London.
Westbury, Victoria L.H., Byfleet.
Whipp, David, Chipstead.
White, Michele Lynne, Birmingham.
Whiteson, Sarah J., London.
Whiting, Sarah K., London.
Wilkinson, Calley P., Nuneaton.
Williams, Edward D., Edinburgh.
Wilson, Deborah T., Boston.
Win, Mai Mu Mu, Yangon, Myanmar.
Winegarten, Robert, London.
Wong, Kam Wah Steven, Kowloon, Hong Kong.
Woods, Mark H., Faversham.
Wu, Ching-Lin, Taipei, Taiwan.
Wu, Chiu Shek, Kowloon, Hong Kong.
Wunna, Kyaw, Yangon, Myanmar.
Xuefang, Lin, Wuhan, China.
Yamanaka, Kazue, Osaka, Japan.
Yan, Chun Wai Danny, Hong Kong.
Yates, David Hayman, Matlock.
Yen, Mun Ching Liza, Hong Kong.
Yim Pik Wa, Hong Kong.
Yoo, Sun Ah, Chonbuk-do, Korea.
Yoshida, Miyuki, Hong Kong.
Yoshimura, Shinya, Osaka, Japan.
Yuyan, Yuan, Osaka, Japan.

MEETINGS OF THE COUNCIL OF MANAGEMENT

At a meeting of the Council of Management held on 20 July 1994 at 27 Greville Street, London EC1N 8SU, the business transacted included the election of the following:

Fellowship

Deora, Naresh, Jaipur, India.

Ordinary Membership

Branch, Henry C., Hampton.
Chu-Jueh Chen, Debbie, Taipei, Taiwan.
Sulub, Abdirizak M., London.
Webb, Christine, London.
Weng, Li Li, Taipei, Taiwan.

At a meeting of the Council of Management held on 7 September 1994 at 27 Greville Street, the business transacted included the election of the following:

Transfers - Ordinary Membership to DGA

Bray, Betty A.

Transfers - Ordinary Membership to FGA

Bevers-Reinders, L.M., Rotterdam, The Netherlands.
Bollack, Josee, Strasbourg, France.
Butcher, Anna, London.
Carr, Damien P., Preston.
Chao, Tan-Chi, Dandy, London.
Chen, Chin-Ho, Taipei, Taiwan.
Cheng, Su Chen, Taipei, Taiwan.
Cliff, Graham, London.
Devon, Jill, V., Felsted.
Eames, Lucy, Ljubljana, Slovenia.
Farion, Jean-Christophe, London.
Fukagawa, Hiroko, Osaka, Japan.
Goss, Sanya Lisa, Aldershot.
Kato, Ayako, Tokyo, Japan.
Kervezee, R., Berkel-Rodenrys, The Netherlands.
Kilby, Linda E., Great Harwood.
Kobayashi, Masahide, Osaka, Japan.
Kumar, V. Krishna, Morden.
Lakhtaria, Yashwin, London.
Lin, Hsin-Pei, Taipei, Taiwan.
Lu, Yung Ching, Taipei, Taiwan.
Mackenzie, Nicola-Jane, Southport.
McCarthy, Emily, London.
McIntosh, Robert P., Penicuik.
Okada, Takayuki, Osaka, Japan.
Pegg, Delia, Petts Wood.
Purkiss, Christopher R., London.
Ramos-Gonzalez, Stephen P., London.
Randall, Gary M., Lowestoft.
Rose, Neil R., Stockport.
Sakai, Takeo, Chiba, Japan.

Stather, Lorne F., Hong Kong.
Stilwell, Lesley, Tring.
Wang, Tai-Hwan, Taipei, Taiwan.
Watatsuki, Reiko, Kawasaki, Japan.
Windwick, William, Lhanbryde.
Yip, Ngai, Hong Kong.
Yeun, Flora Tsz Wai, Hong Kong.
Zhao, Rugong, Wuhan, China.

Transfers - FGA to FGA/DGA

Bailey, Anne M., London.
Bailey, Lisa J., Birmingham.
Balducci, Annette, Neston.
Ball, Pamela, Hong Kong.
Bastians, Indramal, London.
Brady, Deanna M., Wirral.
Carvalho, Rui Galopim de, Lisbon, Portugal.
Christian, Helen F., Bolton.
Clover, Wai Ying, Solihull.
Crabbe, Jeremy P., Hong Kong.
Galloway, Linda L. Vacca, Hong Kong.
Geoghegan, Noel R., Wellesbourne.
Haddock, Brendan, Edinburgh.
Henn, C. John W., Tong.
Hughes, Helen, London.
Jackson, Brian, Edinburgh.
Jones, Amanda, Stourbridge.
Kneebone, Garfield D., Penzance.
Krikos, Alexandra, Birmingham.
Lewis, Rob, Dunstable.
Lowe, David J., London.
Lu, Jui-Chih, London.
Ludlow, Andrew P., Buckhurst Hill.
Ma, Siu Lam, Hong Kong.
Massow, Kenneth J., Rochford.
Mathiopoulou, Regina, Athens, Greece.
O'Brien, Gillian M., North Berwick.
Page, Christopher, Newmarket.
Penton, Keith, London.
Saxton, Carol A.L., Alton.
Scott, Damian T., London.
Sondack, Julia, London.
Sutton, Daniela N., Evesham.
Thomson, Joanna, Peebles.
Walker, Averil S., Kingston-on-Thames.
Yu, Frankie Sum Pui, Hong Kong.

Diamond Membership

Baddoo, Alfred A., London. 1994
Chew, Lee Lee, Hong Kong. 1994
Everitt, Sally A., South Kensington. 1994
Parker, David T., Roker. 1994

Fellowship

Bishop, Heather M., Ipswich. 1994
Carroll Marshall, Anne, Hong Kong. 1994
Cheng, Fung Kei, Hong Kong. 1994
Coghlan, Karen A., Weston-Super-mare. 1994
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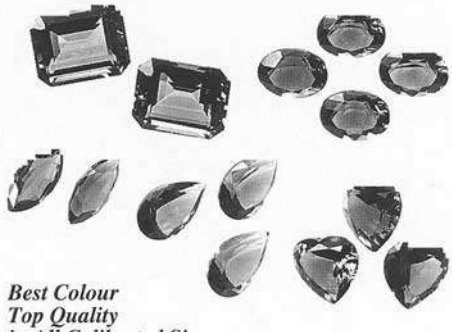

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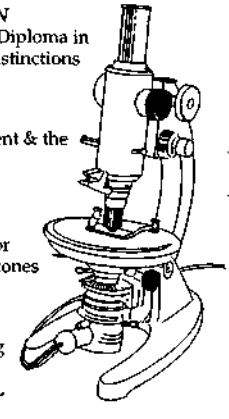

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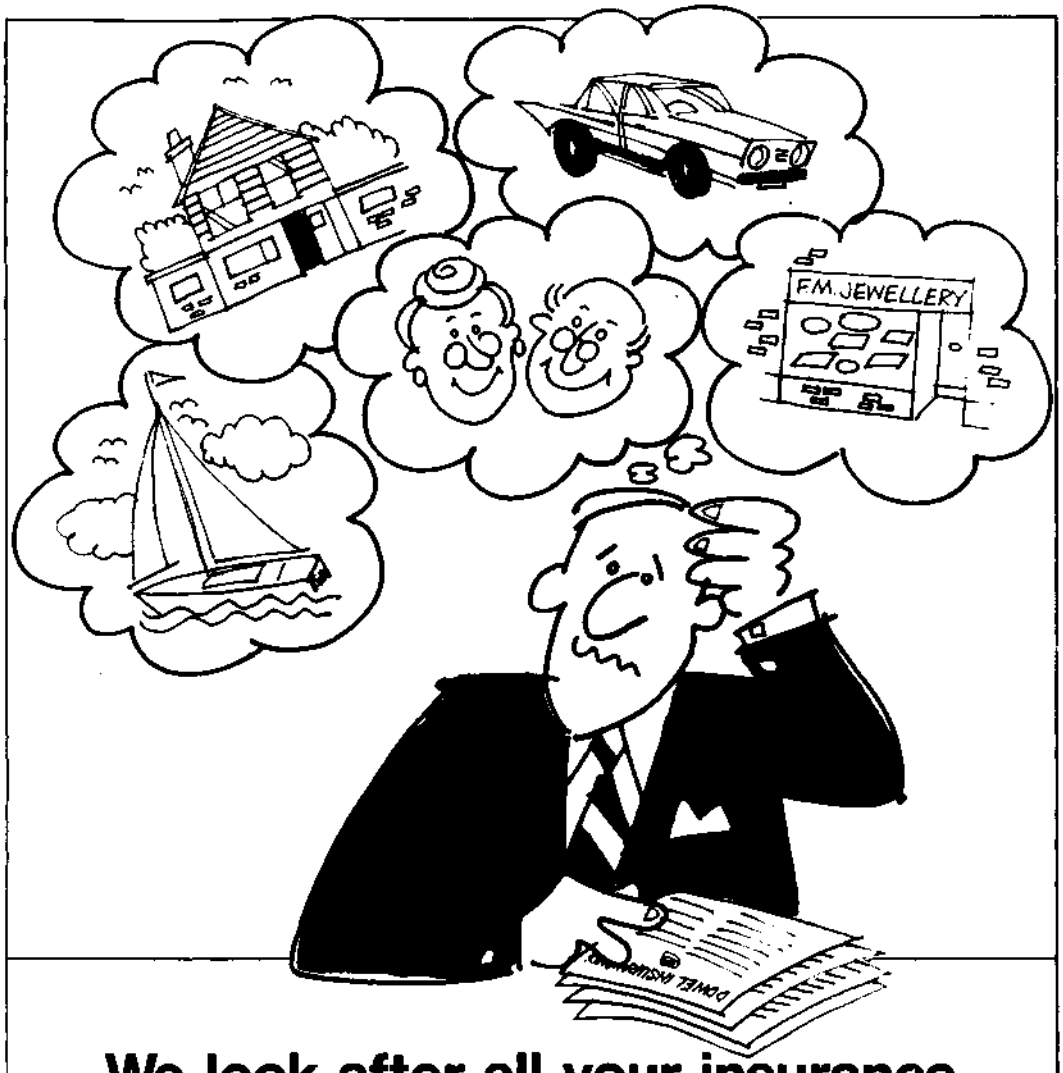

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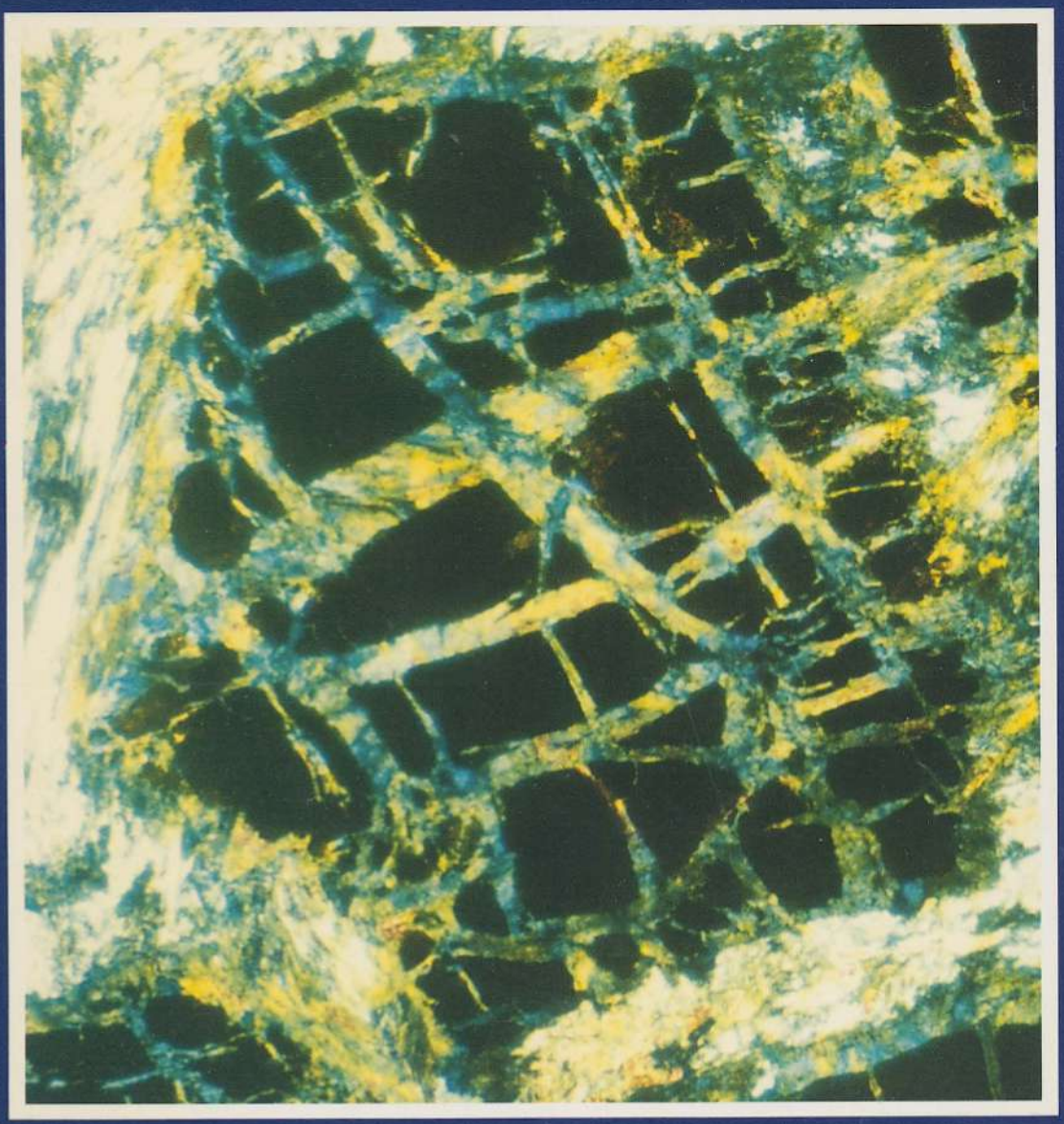

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Cover Picture

Photomicrograph of maw-sit-sit (MSS1) in plane polarized light. Kosmochlor (bluish-green and yellow, due to different orientation), amphibole (white) and chromite/magnesiochromite (black, opaque).
(See Studies on kosmochlor, jadeite and associated minerals in jade of Myanmar, p.315)

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In this issue...

The Far East again figures strongly in the papers published in this issue and there is new information on gems from Myanmar, Vietnam, Sri Lanka and Siberia.

The first paper deals with the relationship of jadeite with kosmochlor - the intense green mineral now found in maw-sit-sit but first identified in extra-terrestrial rocks. The composition of maw-sit-sit is discussed and the authors present the case for calling it jade.

The recent development of deposits of ruby at Mong Hsu, again in Myanmar, has been extremely rapid - amazingly so when one contrasts it with the several centuries of painstaking output from Mogok. However, this is a result not only of market hunger for the fine stones from this locality, but also of the improvement in communications, the removal of 'procedural' obstacles and the availability of new technologies. With such technologies it is possible at one end to quickly extract gem gravel by the ton and at the other to use a higher percentage of the product by heat-treating stones to improve their colour. Many rubies from Mong Hsu are heat-treated and the methods of distinguishing them from untreated stones, using – yes – new technology, are outlined by C.P. Smith.

The third paper deals with the history of pearl production in the Gulf of Mannar and Sri Lanka. A fascinating insight is given into how pearls were traded and who controlled the trade from the earliest times. An account of the fluctuations in production culminating in its cessation in the 1950s implicates misguided, if well-meaning, government interference.

Over the past thirty years Siberia has been best known in the gem world as the source of Russian diamonds. But over the centuries it has provided a wide range of gem and decorative materials, many of which were utilized in the Fabergé workshops and became well known. Not so well known, perhaps, are the reserves of Siberian jet, which was also a popular material for carving. The paper by S. Glushnev fills a gap in the general appreciation of the history and development of Siberian jet and comes at a time when interest in the potential of Siberian materials is reawakening.

Finally two papers on peridot and synthetic diamond provide topical information on stones that may well become more significant in the trade.

R.R.H.

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Studies on kosmochlor, jadeite and associated minerals in jade of Myanmar

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Abstract

Physical, optical and X-ray data are given for jadeite, kosmochlor and other associated minerals in various jades of Myanmar. Jadeite jade is a monomineralic or polymineralic crystalline aggregate. In the polymineralic variety, jadeite occurs in intimate associations with edenite, richterite, tremolite, kosmochlor and enstatite. Maw-sit-sit is essentially composed of kosmochlor and chromite/magnesiochromite with or without amphiboles and enstatite, but devoid of pure jadeite.

The occurrence of kosmochlor is confirmed as a terrestrial mineral. Jadeite-kosmochlor solid solution suggests that the term 'jade' could be extended to include kosmochlor as a jade mineral in the gemmological sense.

Introduction

Jade of Myanmar (Burma) has a worldwide reputation for its fine quality. There are various jade types differing in colour, transparency and mineral association, and many quality grades including Imperial, commercial and utility, are produced from Myanmar. They are subdivided into subgrades in the jade trade. These qualities and varieties of jade may be directly related to the mineralogical and chemical characters of jadeite, pure or impure.

By petrographic and X-ray diffraction studies, some amphiboles and pyroxenes including kosmochlor (previously known as ureyite, Fleischer, 1965) were found (Figures 1 and 2) in association with jadeite in some jade specimens (Naing, 1990). The present work has also confirmed the occurrence of kosmochlor as a terrestrial mineral (Ou Yang; 1984, Harlow and Olds, 1987) and supported the probable existence of jadeite-kosmochlor solid solution (Mével and Kiénast, 1986). However, the amphiboles associated with jadeite and described in the present work are different from those described by Mével and Kiénast.

In addition, neither albite nor quartz has yet been found in any of the true jade specimens studied, but some jade-like rocks do occur in the jade mine areas, for instance the locally called 'pa-lwan' resembles jade but contains albite, quartz and minor epidote. 'Maw-sit-sit' from Tawmaw is regarded as a kind of jade-like material (not real jade) by most jade dealers and by Myanma Gems Enterprise, but the specimens shown in Figures 3, 4 and cover picture do not contain pure jadeite.

Nomenclature of jade

Gemmologically the term 'jade' is applied to only two mineral species - jadeite and nephrite. For some jades of Myanmar, the term jade will refer not only

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Fig. 1. Sp. No. J4 consisting of jadeite, richterite/edenite, tremolite and kosmochlor.

Fig. 2. Sp. No. J13 consisting of jadeite, richterite/edenite, kosmochlor and tremolite.

Fig. 3. Sp. No. MSS 2. Maw-sit-sit consisting of kosmochlor, tremolite, edenite/richterite and chromite.

Fig. 4. Sp. No. MSS 3. Maw-sit-sit consisting of kosmochlor, enstatite, chromite and magnesiochromite.

to jades composed only of jadeite but also to jadeite plus other associated mineral or minerals. When a jade specimen is essentially monomineralic, the term 'jadeite jade' or 'pure jade' will be used. If the specimen is polymineralic the term 'impure jade' will be applied in the present work.

Mével and Kiénast have demonstrated by electron probe microanalysis that a wide range of solid solution exists between pure jadeite and nearly pure kosmochlor (i.e. kosmochlor 85 jadeite 15).

Physical characteristics of jade

Texture

Well formed, individual crystals of jadeite have not yet been found in Myanmar. All the jade samples are compact, massive and generally granular aggregates. The states of aggregation may be different from one specimen to another. Commonly, fine- and coarse-grained aggregates are associated in a single jade specimen. Lath-shaped, elongated or fibrous aggregates of prismatic crystals can be seen in hand specimens. The constituent crystals may be subparallel or randomly oriented and their textures are commonly best displayed on weathered crusts. X-ray diffraction (XRD) and X-ray fluorescence (XRF) analyses showed that the mineral and chemical compositions of crusts were not significantly different from those of fresher parts of the rock.

Lustre

Vitreous to subvitreous.

Diaphaneity

Ranging from transparent (highest degree of diaphaneity) through translucent to semi-opaque (lowest), except included grains of chromite/magnesiochromite which are opaque even at the thickness of petrographic thin sections (0.03mm).

Colour

Jades of Myanmar can be found in many hues ranging from almost white through purple, blue, green, yellow, red and pink in variable saturations to nearly black.

Qualitative point analysis on vividly coloured specimens by JEOL JXA 840A electron probe micro-analyzer provided the following information on the chemical constituents which may be causing the colour:

Emerald-green to light green:
Cr(colour saturation depends upon Cr concentration). Kosmochlor itself is deep emerald-green especially in maw-sit-sit

Greyish-green and greenish-grey:
Fe, Mg, + Cr

Yellowish, brownish and reddish:
Fe (Ti, V, Cr and Mn were not detected in jades of these colours)

Mauve and pinkish:
Manganese

Dark green and greenish black:
Mg, Ca, Fe (constituent elements of amphiboles which may be responsible for these colours)

Hardness

The relative hardness varies in practice from slightly greater than 6 (coarse-grained aggregate) to 7 (for fine-grained aggregate).

Specific gravity

Ranges from 3.30 to 3.36 with a mean value 3.327 (by hydrostatic weighing method). The lower values are due to the presence of amphiboles.

Refractive index

Mineral grains from each specimen were immersed in liquid and the immersion liquid was adjusted to the RI of the grains. Thus, only a single mean value for each specimen could be measured on the Abbe

Refractometer with a sodium light source. The results from 21 specimens range from 1.6530 to 1.6556. The mean value is 1.6545.

Optical characteristics

Jade of Myanmar is either a monomineralic aggregate of jadeite or a polymineralic pyroxene-amphibole rock with some oxides. In polymineralic jades, edenite, richterite, tremolite, kosmochlor and enstatite may be intimately intergrown with jadeite.

Jadeite

In thin sections jadeite is colourless in plane polarized light (PPL), but some grains appear dusty with streaks mainly due to oriented, fine acicular inclusions. XRD methods indicate that these inclusions are probably rutile and ilmenorutile. Some jadeite grains also contain liquid inclusions, noticeably in wedge-shaped spherical and dumb-bell forms.

Crystal habit varies, stout prismatic granular forms are common, but columnar and fibrous aggregates also occur, sometimes bent and radiated like a cock's tail. Simple and lamellar twins are not uncommon. In thin section under a polarizing microscope the coarse grains usually show wavy extinction. Jadeite is distinguished from associated amphiboles by its pronounced pyroxene cleavages, higher extinction angles, lower birefringence and positive optic sign.

Kosmochlor (previously known as ureyite)

Kosmochlor occurs in some jadeite jades and in all maw-sit-sit specimens studied. In jadeite jade it is intimately intergrown with jadeite and with amphiboles. In maw-sit-sit it occurs as a replacing mineral around grain boundaries and along fractures of both chromite/magnesiochromite (Cover picture) and enstatite.

Its body colour ranges remarkably from vivid green in maw-sit-sit where chromite/magnesiochromite is predominant to less deep green where amphiboles and kosmochlor are predominant over chromite/magnesiochromite, to light green when associated with jadeite. The deeply coloured kosmochlor (in maw-sit-sit) shows strong pleochroism from bluish-green, deep green to yellow, whereas the light green variety is weakly pleochroic from light green to light greenish-yellow (in jadeite jade).

Kosmochlor occurs as lozenge-shaped, rectangular or tabular square or as columnar crystals. In thin sections, its relief is higher than jadeite and associated amphiboles. It has characteristic pyroxene cleavages, one set being good while the other set is poor. Parting is common.

Edenite and richterite

Edenite and richterite are calcic and sodic-calcic amphiboles (Leake, 1978). In impure jades they are intimately intergrown with tremolite, jadeite and kosmochlor, but the amphiboles can be distinguished easily from pyroxenes in thin sections.

Both minerals are usually colourless in plane polarized light (PPL), but they show pleochroism from colourless to greenish-yellow when associated with chromite/magnesiochromite. They occur as rectangular, six-sided, tabular, bladed or fibrous forms and simple twins are sometimes present. Edenite and richterite show characteristic amphibole cleavages and moderately strong interference colours in thin sections. It is extremely difficult to differentiate between edenite and richterite and mineral species identification was based on XRD analysis, even though this is not entirely satisfactory.

X-ray powder diffraction data

Using a computer controlled Rigaku X-ray diffractometer intensities were measured between 10° to 70° 2θ at a scanning speed of 8°/min. The X-ray patterns of jadeite and kosmochlor were compared with the JCPDS(1986) standard data (Table I). Due to the high scanning speed of the

goniometer, very weak lines are not detected and are not listed in Table I.

Specimen J21 is a mineralogically pure jadeite and J14 is a polymineralic specimen containing jadeite, kosmochlor and amphiboles. The jadeite results for J21 and J14 are almost the same within the accuracy limits of the method.

The X-ray patterns of kosmochlor occurring in maw-sit-sit (MSS) and jadeite jade (J13) are compared with those of natural ureyite (Fleischer, 1965) and synthetic kosmochlor (JCPDS, 1986). Six out of seven diffraction lines given in Fleischer's report are almost the same as the present data, but their intensity ratios are different.

Compared with the JCPDS data, the presence and absence of diffraction lines and their intensities differ slightly as the compositions vary from MSS1 to J13. Some of the diffraction lines of kosmochlor overlap those of jadeite, and this tends to confirm that solid solution is possible between kosmochlor and jadeite as described by Mével and Kiénast (1986). Similarly, edenite, richterite and tremolite have overlapping

Table I. X-ray powder diffraction data

Jadeite						*Kosmochlor*							
JCPDF 22-1338		J21		J14		JCPDF 26-1484		MSS1		MSS2		J13	
d(Å)	Int	d(Å)	Int	d(Å)	Int	d(Å)	Int	d(Å)	Int	d(Å)	Int	d(Å)	Int
6.22	15	6.232	11	6.267	12	6.3	29	6.311	29	6.258	18	6.293	11
4.5	5					4.57	3	4.458	31				
4.35	5	4.371	5			4.39	18	4.378	27	4.401	12		
4.29	45	4.304	29	4.3	26	4.35	25			4.362	13	4.354	19
3.25	5	3.262	7	3.25	10	4.06	15						
3.1	30	3.112	27	3.11	31	3.58	7						
2.922	75	2.928	73	2.926	76	3.15	5	3.14	83	3.133	100	3.144	62
2.831	100	2.836	100	2.838	100	2.958	100	2.963	90	2.984	24	2.992	87
2.527	2					2.87	65	2.87	69	2.875	33	2.861	48
2.49	20	2.499	17	2.495	27	2.519	28	2.518	100	2.52	24		
2.417	25	2.424	19	2.424	29	2.511	40					2.511	20
2.206	10	2.206	9	2.212	12	2.451	35	2.462	27	2.45	9		
2.161	5	2.164	8	2.16	11	2.235	5						
2.046	10	2.046	6			2.182	18						
1.993	2			1.998	6	2.1	22	2.105	32	2.101	11		
1.968	15	1.971	11	1.972	16	2.073	12	2.065	26	2.079	11	2.081	23
1.93	2					2.017	10						
1.887	5	1.889	5	1.891	6	1.965	6					1.977	19
1.839	2					1.915	9			1.9	15		
1.761	10	1.761	11	1.764	12	1.866	3						
1.684	10	1.685	10	1.687	11	1.809	5						
1.651	2			1.652	5	1.781	2					1.768	17
1.624	5			1.627	6	1.71	10	1.712	30	1.713	9		
1.611	5	1.613	6	1.611	8	1.708	8					1.691	15
1.572	20	1.573	15	1.574	18	1.671	5						
1.552	15	1.552	14	1.554	12	1.667	5			1.654	13		
1.499	10	1.5	8	1.5	10	1.646	6	1.652	35	1.652	13		
1.488	10	1.488	10	1.492	10	1.625	25	1.625	29	1.629	7		
						1.596	15	1.599	46	1.601	12		
						1.576	5	1.577	31	1.573	10	1.576	28
						1.52	6	1.523	27	1.523	6		
						1.512	2	1.51	35	1.508	7		
						1.494	10					1.496	15
						1.482	4	1.472	39				
						1.466	2						
						1.452	7			1.432	15		
						1.391	4						
						1.382	12			1.378	9	1.369	23

J21 - Jadeite jade, almost pure
J14 - Jadeite associated with amphiboles and kosmochlor
MSS1 - Vivid green kosmochlor
MSS2 - Green kosmochlor
J13 - Light green kosmochlor associated with jadeite

diffraction lines since their mineral structures are very similar.

Conclusions

The jades of Myanmar may be defined as jadeite/kosmochlor-bearing rocks with or without other minerals. Jadeite occurs as a monomineralic aggregate or frequently in association with edenite, richterite, tremolite, enstatite and kosmochlor. As described by Mével and Kiénast (1986), kosmochlor and jadeite form a solid solution series, and so kosmochlor could be classed as a jade mineral. Maw-sit-sit is a jade variety essentially composed of kosmochlor and magnesiochromite/chromite with or without the associated minerals enstatite, edenite, richterite and jadeite.

The quality of a jade specimen mainly depends on colour, transparency and lustre. The emerald-green colour is due to Cr which is an essential component of chrome jadeite and kosmochlor. Other colours depend on impurity elements (colouring agents) and associated minerals present. Fine- to medium-grained texture with fused or sutured boundaries of granular jadeite commonly provide high degrees of transparency and glassy lustre.

The optical properties and X-ray diffraction patterns of kosmochlor occurring in jade and maw-sit-sit vary in such a way as to suggest a wide range of solid solution between jadeite and kosmochlor. This is consistent with the work of Mével and Kiénast (1986) and for gemmological purposes the term 'jade' should be extended to include kosmochlor as a jade mineral.

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A contribution to understanding the infrared spectra of rubies from Mong Hsu, Myanmar

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Abstract

The infrared absorption of the rubies from Mong Hsu was analyzed in order to classify the absorption features recorded. In the mid-infrared region, it was possible to distinguish two separate types of spectra. The first type was recorded in non-heat-treated ruby samples in the region from 1900 to 3400 cm^{-1}, identifying inclusions of diaspore. The second type was recorded in heat-treated ruby samples in the region from 3100 to 3600 cm^{-1}, indicating structurally bonded OH groups. Detailed for the first time in corundum, the building of OH groups is accomplished as a direct result of the dehydration of diaspore inclusions, demonstrated through heat treatment experiments.

Key words

Corundum, Ruby, Infrared spectroscopy, Diaspore, Heat treatment, Structural OH groups

Introduction

Ever since its development in 1991, the mining region near the town of Mong Hsu (in Shan state, north-east Burma) has provided an intriguing new source of gem-quality rubies for the jewellery, gemmological and scientific communities. As a result, these rubies have received a lot of attention in the gemmological literature (see for example Hlaing, 1991, 1993, 1994; Laughter, 1993a,b; Clark, 1993; Henn and Bank, 1993; Peretti, 1993; Kammerling *et al.*, 1994; Smith and Surdez, 1994). The rough ruby crystals from this source are characterized by unique dark blue to violet core colour zones. These blue to violet colour zones can be readily removed with heat treatment, resulting in attractive, richly coloured rubies. However, within some crystals dense whitish clouds may form during heat treatment, reducing the transparency of the gemstones. In addition, various other forms of cross-hatch and flake-like cloud patterns as well as stringer formations and prominent sequences of growth structures, are the most typically observed internal features. For a further description of the inclusions observed in Mong Hsu rubies, the reader is referred to the publications listed above.

Hlaing (1991, 1993) indicated a primary marble source and secondary deposits with associated minerals including tourmaline, red-brown garnet, staurolite, pyrite, tremolite and quartz. The primary and secondary source minerals can provide important insights into the geology surrounding Mong Hsu. Mineral inclusions such as apatite (microprobe), dolomite (scanning electron microscope - energy dispersive system (SEM-EDS)), fuchsite and muscovite micas (SEM-EDS and X-ray diffraction (XRD)), serpentine (XRD), kaolinite (microprobe) and diaspore (SEM-EDS in combination with XRD), have been identified in the rubies from Mong Hsu and the initial findings have been published by Smith and Surdez (1994). In this paper, the absorption features present in the mid-infrared spectrum were also briefly

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described. During subsequent research, it became possible to identify the causes of these absorption features as well as an interactive alteration which takes place as a result of heat treatment. It is the purpose of this paper to present this new information to aid in understanding the infrared spectral characteristics in rubies from Mong Hsu.

Infrared spectroscopy has been an important method of analysis for classification in mineralogy for several decades (see for example Frederickson, 1954; Farmer, 1974; Suhner, 1984; Rossman, 1988). Recently, it has also become an increasingly valuable tool in gemmology and is successfully applied for the identification of gem materials, the distinction between natural and synthetic gemstones, and identifying various treatments (see for example Suhner, 1979; Lind and Schmetzer, 1983; Fritsch and Stockton, 1987; Martin *et al.*, 1989; Schmetzer, 1989; Fritsch and Rossman, 1990; Schmetzer and Kiefert, 1990). The part of the spectrum of most interest to gemmologists is the region above 400 cm^{-1}, the mid-infrared region. This region is particularly useful because it is here that absorption features relating to structural OH groups and water stretching frequencies are located (Farmer, 1974; Fritsch and Stockton, 1987).

The infrared spectrum of corundum is dominated by absorption features resulting from Al-O stretch frequencies and lattice absorption, with peaks located at approximately 760, 642, 602 and 450 cm^{-1} (Wefers and Bell, 1972), while the mid-infrared region, where hydroxyl bands are typically located, is generally free of absorption features (see for example Rossman and Smyth, 1990).

The rubies from Mong Hsu possess the dominant absorption features typical of corundum, in the region of approximately 300 to 1000 cm^{-1}. In addition, they frequently display absorption bands in the region between 1900 and 4000 cm^{-1}. Two distinct combinations of bands in this latter region were recorded and could be distinguished, with only slight variations occurring within the individual types. These two types of absorption spectra are distinctly separate, dependent upon the presence of certain mineral inclusions in non-heat-treated rubies and the influence of heat treatment.

Methods and materials

A total of 31 Mong Hsu rubies were examined in the near- to mid-infrared spectral region (approx. 200 to 7000 cm^{-1}). A Unicam 9624 FTIR spectrophotometer, utilizing a beam condenser and diffused reflectance unit for sample measurement, with a straight transmitted and internally reflected beam path, respectively (4.0 cm^{-1} increments, 200 scans), were used to test nine non-heated, partly polished crystals, eight heat-treated, partly polished crystals and 14 heat-treated faceted rubies. Polarized infrared spectral analysis was made with a Perkin-Elmer 1720 spectrophotometer equipped with stationary filters and a rotatable sample holder (4.0 cm^{-1} increments, 15 scans). Heat treatment experiments were performed in a Thermal Technology Group 1000A graphite hot zone furnace with temperatures of 1500°C in a pure O_2 atmosphere, without the use of 'Borax'-related coatings, for a period of five hours.

Non-heat-treated samples

A series of absorption bands in the mid-infrared range 1900 to 3400 cm^{-1} were recorded in several of the non-heat-treated Mong Hsu rubies. These included typically a series of peaks; one was located between approximately 1990 and 2040 and another slightly broader peak with the maximum positioned between 2120 and 2145 cm^{-1}; in addition to two absorption bands with maxima located at approximately 2885, 3025 cm^{-1} (Figure 1). Polarized spectral analysis revealed a pleochroic effect which consisted of more prominent absorption peaks recorded

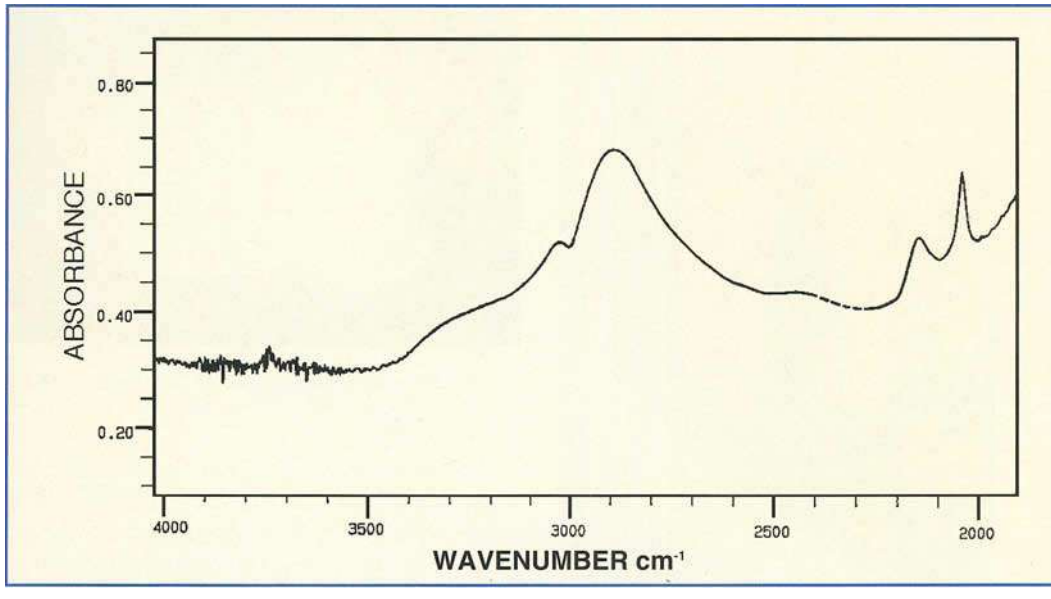

Fig. 1. The non-heat-treated Mong Hsu ruby samples commonly possess OH bending and stretching frequencies assigned to diaspore (αAlOOH), with absorption peaks in the infrared region from approximately 1900 to 3400 cm^{-1} superimposed on the spectrum of corundum. The dashed line indicates an area of the spectrum corrected for a spurious peak attributed to CO_2.

along the vibrational path parallel to the *c*-axis of the corundum crystal and a weaker, yet identical, spectrum recorded along the vibrational path perpendicular to the *c*-axis of the corundum crystal. Features in this spectral area are commonly related to OH group absorptions (Farmer, 1974). Such absorption features are not generally seen in pure corundum, which is anhydrous (i.e. a mineral which does not possess water or hydroxyl groups in its structure).

For the identification of this additional mineral phase, only the spectral range above approximately 2000 cm^{-1} was available because of the dominant Al-O and lattice absorption which masks much of the region necessary to properly identify a mineral by this method. However, the mid-infrared region, which contains the structural OH stretching frequencies, has long been used as a means to identify and distinguish the several hydrous alumina phases (Frederickson, 1954). Therefore, it was possible to positively identify the secondary mineral phase as the aluminium oxyhydroxide diaspore (see for example Farmer, 1974; p. 148, figure 9.8). As described in the introduction, diaspore was independently identified in the rubies from Mong Hsu by scanning electron microscopy in combination with XRD micro-sampling techniques, recorded with a Gandolfi camera. The diaspore occurred as 'veins' which penetrated and traversed the stones (Figure 3), as well as coatings at the surface of the crystals (Figure 4). It is very important to mention, however, that this infrared absorption spectrum was also recorded in crystals with polished parallel windows and no sizeable mineral inclusions, veins or external coatings (Figure 2). These absorption peaks were even recorded when the spectral analysis was taken through areas which were specially isolated (i.e. 'masked' in order to ensure that the areas measured were free of the inclusion features just described).

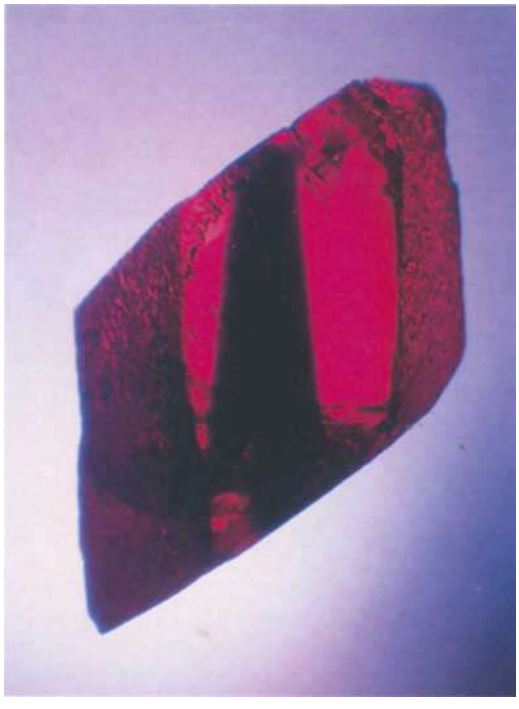

Fig. 2. The spectrum shown in Figure 1 was obtained from this high quality, partly polished, 2.21 ct Mong Hsu ruby crystal. This crystal possessed the unique dark violet core colour zone which is typical of the corundum crystals from this deposit, while no diaspore was found as coatings, in twin lamellae or in veins. Transmitted fibre-optic illumination, 9x.

Fig. 3. Mong Hsu ruby crystal (2.54 ct) traversed by irregular veins of diaspore. Overhead illumination, 22x.

A subordinate presence of boehmite was also indicated in the mid-infrared spectrum, with absorption bands centred at approximately 3080 and 3290 cm^{-1} (see for example Frederickson, 1954; Suhner, 1984; Häger and Greiff, 1994). Boehmite has been identified as an inclusion in corundum by other researchers (Sahama *et al.*, 1973; White, 1979), however, the identification of boehmite in the rubies from Mong Hsu has not yet been verified by X-ray diffraction.

Heat-treated samples

In contrast, many heat-treated Mong Hsu rubies were found to possess a more

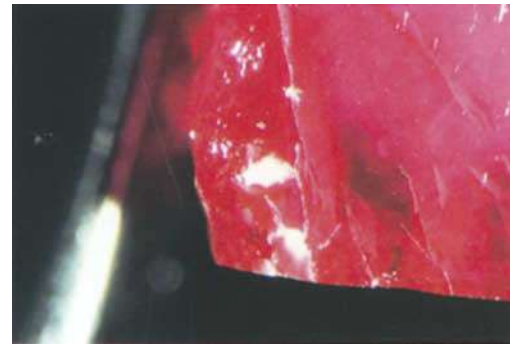

Fig. 4(a) and (b). Many Mong Hsu ruby crystals are coated with diaspore

a) A transparent essentially colourless coating of diaspore filling recesses at the surface of this 2.75 ct Mong Hsu ruby crystal prior to heat treatment. Overhead illumination, 20x.

b) The same area of the 2.75 ct ruby crystal after heat treatment, where the diaspore coating has gone through a dehydration process and transformed into a translucent, whitish, polycrystalline mass. Oblique fibre-optic illumination, 20x.

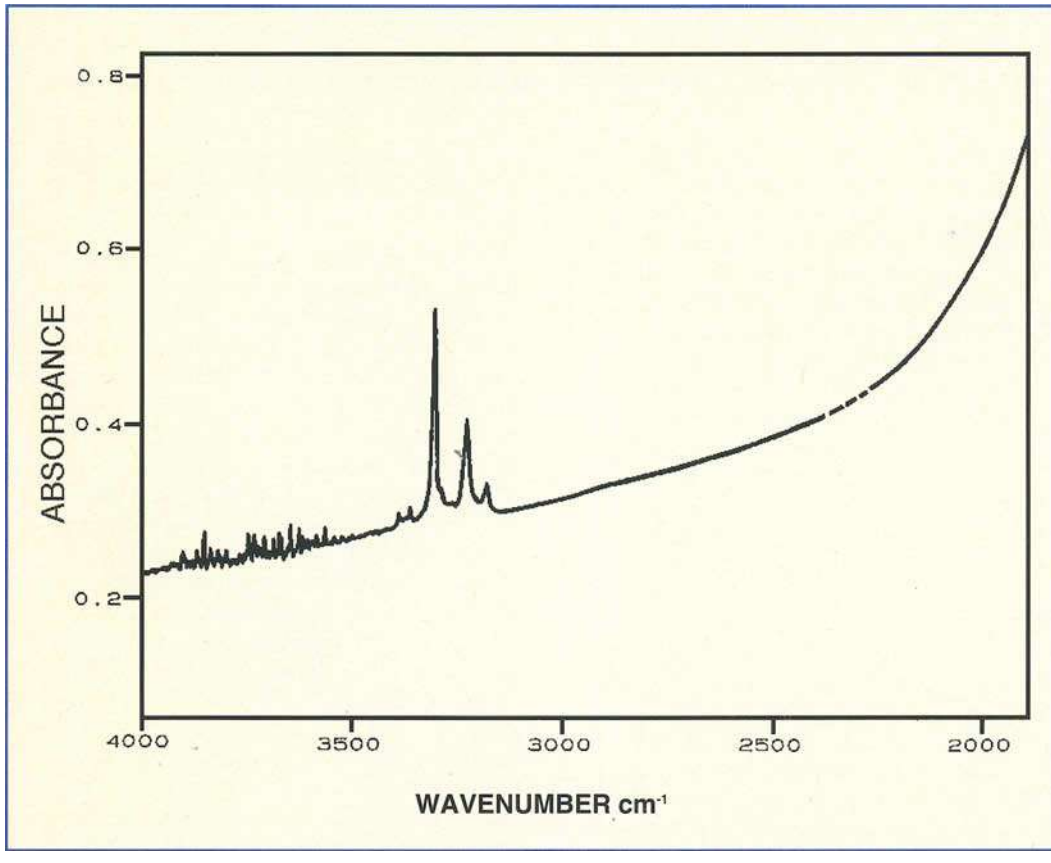

Fig. 5. Heat-treated Mong Hsu ruby samples typically display absorption peaks ascribed to structural OH groups bonded within the corundum lattice, in the infrared region between approximately 3100 and 3600 cm^{-1}. The dashed line indicates an area of the spectrum corrected for a spurious peak attributed to CO_2.

localized concentration of absorption features in the region from approximately 3100 to 3600 cm^{-1}. These consisted of a series of sharp peaks, with the primary peak located at approximately 3310 cm^{-1}, accompanied by a shoulder at approximately 3292 cm^{-1} and weaker peaks at approximately 3232, 3187 and 3368 cm^{-1} (Figure 5). Polarized spectral analysis revealed these absorption peaks to be of a strongly pleochroic nature, with maximum peak intensity recorded when the vibrational path was perpendicular to the *c*-axis of the corundum crystal, while they were very weak when the vibrational path was parallel to the *c*-axis of the corundum crystal. These peaks were rarely superimposed on an underlying absorption band. The series of sharp peaks observed here are related to structural OH groups bonded within the corundum lattice (Eigenmann and Günthard, 1971; Eigenmann *et al.*, 1972; Volynets *et al.*, 1972, 1974; Beran, 1991; Moon and Phillips, 1994; Häger and Greiff, 1994; also refer to the panel on pages 326-8).

Not all heat-treated samples possessed the complete series of absorption peaks, while other samples indicated a complete lack of structural OH. OH was recorded in the translucent whitish clouds which had formed during the heat-treatment process and additionally in transparent areas of some rubies (Figure 7). Dependent on the

Additional comments on the structural bonding of OH in corundum

Although the incorporation of hydrogen in the structure of corundum is a subject not well known to many gemmologists, it has been a topic studied in great detail by past researchers, especially in Austria, Australia, the former Soviet Union and Switzerland. Most of the previous work detailing the structural bonding of OH groups in corundum has been carried out on Verneuil-grown synthetics of various colours and composition (see for example Eigenmann and Günthard, 1971, 1972; Eigenmann *et al.*, 1972; Volynets *et al.*, 1972, 1974; Beran, 1991). In addition, structural OH absorption peaks have been recorded in hydrothermally grown synthetic rubies (Belt, 1967; Peretti and Smith, 1993, 1994) and in natural corundums, including a ruby from Sri Lanka and a sapphire from Montana (Beran, 1991), sapphires from Australia (Moon and Phillips, 1994), sapphires from southern Vietnam (Smith *et al.*, 1994), rubies from the Mong Hsu mining region in Burma (Smith and Surdez, 1994), as well as corundums from various other sources (Häger and Greiff, 1994).

Past researchers have indicated that hydrogen atoms are typically incorporated within the structure of corundum as a charge compensation mechanism bound to various transitional metal ions present as trace elements, occupying an interstitial site between two oxygen atoms (O^{2-}) or also possibly trapped by cation vacancies (Eigenmann and Günthard, 1971, 1972; Eigenmann *et al.*, 1972; Volynets *et al.*, 1974; Beran, 1991; Moon and Phillips, 1994). Similar replacements have also been identified in other principally anhydrous minerals (see for example Martin and Donnay, 1972). The influence these traces of hydrogen have on the corundum's spectral properties is observed as a series of sharp absorption peaks which are present in the mid-infrared region of the spectrum.

The prominence and number of absorption peaks recorded in the mid-infrared spectrum are dependent on the concentration of OH bonding. The individual wave number positions of the absorption peaks are dependent, either singly or in combination, upon which trace element the OH has bonded to; such as titanium (Ti), vanadium (V), magnesium (Mg), iron (Fe), silicon (Si), nickel (Ni) or cobalt (Co). The most typically encountered structural OH groups recorded in corundum are those attributed Ti, V, or Fe bonds, as illustrated in Figures 5 and 6 (Eigenmann and Günthard, 1971; Eigenmann *et al.*, 1972; Volynets *et al.*, 1972, 1974; Moon and Phillips, 1994; Häger and Greiff, 1994). Polarized infrared spectral analysis has shown these absorption traits to be highly pleochroic, indicating a crystallographic orientation of OH bonding, dependent on the element, either in a direction perpendicular or parallel to the *c*-axis (Eigenmann and Günthard, 1971, 1972; Eigenmann *et al.*, 1972; Volynets *et al.*, 1972, 1974; Beran, 1991; Moon and Phillips, 1994).

The rubies from Mong Hsu described in the present paper were found to possess structural OH groups only after heat treatment; however, non-heat-treated natural and synthetic corundums may possess similar structural OH groups. Verneuil synthetic corundum typically contains structural OH groups (see for example Eigenmann *et al.*, 1972; Volynets *et al.*, 1974). This is attributed to the high hydrogen supply involved with the Verneuil growth technique (Beran, 1991; see also for example Nassau, 1980). While Häger and Greiff (1994) and the present author have observed structural OH absorption in the

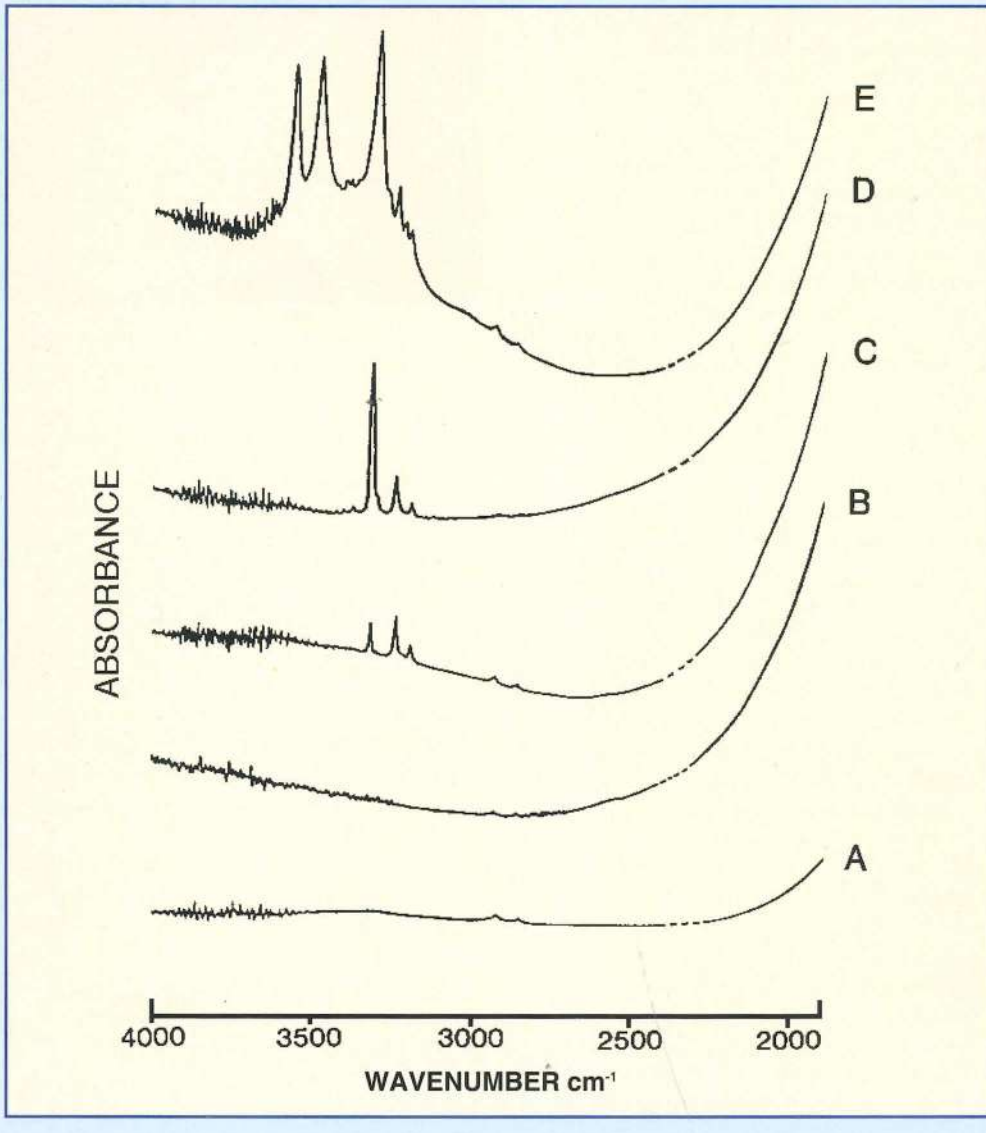

Fig 6: The structural OH absorption peaks illustrated here are attributed bonds occurring with metal ions (Ti,V or Fe) in a transitional state. Although they may be observed in non-heat-treated natural and synthetic corundum, more typically they are recorded in natural sapphires from basaltic sources, as well as in synthetic corundums grown by the Verneuil (flame-fusion) or hydrothermal growth methods. Non-heat-treated natural corundums from metamorphic sources typically do not show evidence of OH groups in the mid-infrared region of the spectrum, while unaltered flux-grown synthetic corundums are always free of structural OH. (A) Flux-grown synthetic ruby; (B) natural ruby from the Mogok stone-tract, Burma (Myanmar); (C) flame-fusion synthetic ruby; (D) natural blue sapphire from Thailand; (E) hydrothermally-grown synthetic ruby. Also note the difference in the intensity of the structural OH absorption peaks present in hydrothermally-grown synthetic corundum, compared with the pattern in natural corundum or flame-fusion synthetic corundum. The dashed line indicates an area of the spectrum corrected for a spurious peak attributed to CO_2.

mid-infrared spectra of non-heat-treated natural corundums as well, in the present author's experience the occurrence of structural OH in non-heat-treated natural corundum is more restricted than this general statement might at first imply. The structural OH groups attributed to Ti, V or Fe bonds are much more typically recorded in non-heat-treated blue sapphires from basaltic sources (for example Australia, Cambodia, Thailand, southern Vietnam, etc.) than in non-heat-treated rubies or sapphires from other types of sources (i.e. metamorphic). Additionally, structural OH is readily observed in non-heat-treated hydrothermal synthetic corundum; however, the concentration and intensity of the OH bonding and its absorption features are considerably stronger than those recorded in either natural or other synthetically grown corundum (Figure 6).

Heat-treatment experiments with both natural and synthetic corundums have shown that OH bonding can be increased or decreased depending on the precise conditions (see for example Eigenmann and Günthard, 1971; Eigenmann *et al.*, 1972; Moon and Phillips, 1994). The results of the work reported above indicate that hydrogen can be diffused into the corundum structure, forming OH groups, through annealing in a hydrogen atmosphere under different conditions, thereby producing or intensifying the respective absorption peaks. Whereas annealing in an oxygen atmosphere under certain conditions may reduce or eliminate structural OH bonding and its absorption features.

While the mid-infrared region of the spectrum for corundum has not been of great interest to gemmologists in the past, recent work has proved this to be a fruitful research area for rubies and sapphires.

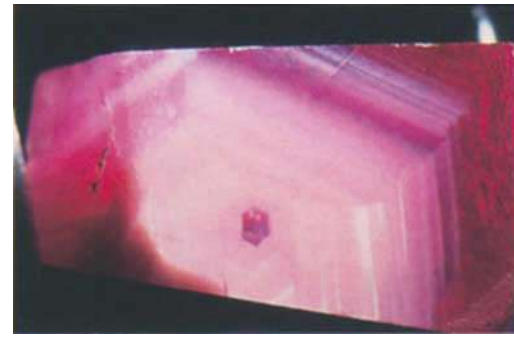

Fig 7. Whitish clouds in a partly polished 1.21 ct Mong Hsu ruby. Heat-treated Mong Hsu rubies frequently develop dense whitish clouds, which form along certain growth areas. Structural OH absorption peaks are typically present when a spectral analysis is taken through these clouds, and they may also be recorded in transparent areas of these stones. Oblique fibre-optic illumination, 12x.

concentration of OH, several samples possessed only a single peak located at approximately 3310 cm^{-1}; others showed this in combination with a second peak at approximately 3232 cm^{-1}, while the most intense spectra also possessed an additional small peak located at approximately 3393 cm^{-1}. In all the tested samples of heat-treated rubies from Mong Hsu, the peak at approximately 3310 cm^{-1} was the strongest, with the next most prominent peak at approximately 3232 cm^{-1} being one fourth to one half the intensity of the first. The relative intensity of the peaks located at approximately 3187 and 3368 cm^{-1} varied depending on the sample, while the peak occasionally observed at approximately 3393 cm^{-1} was the weakest in all cases. Other researchers, however, have indicated different sequences of peak intensity recorded in various synthetic corundum samples (Eigenmann and Günthard, 1971; Eigenmann *et al.*, 1972; Volynets *et al.*, 1972, 1974; Beran, 1991; Peretti and Smith, 1993, 1994).

Experimental results

Once the two different types of mid-infrared absorption spectra had been

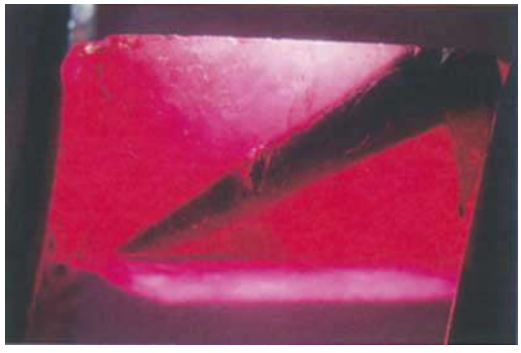

Fig. 8a. A 2.75 ct, partly polished Mong Hsu ruby crystal prior to heat treatment, possessing a dark violet core colour zone and a mid-infrared absorption spectrum related to diaspore. Oblique fibre optic illumination, 10x.

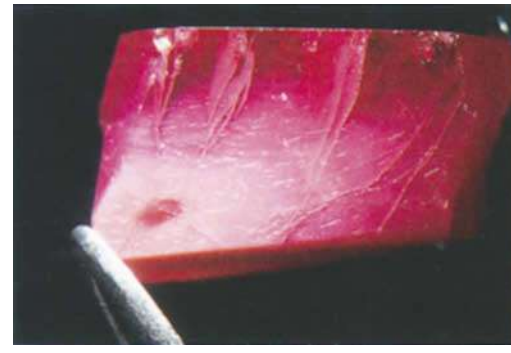

Fig 8b. The same crystal after heat treatment at 1500°C in a pure O_2 atmosphere, for a period of five hours. As can be readily seen, although the dark violet core colour zones were successfully eliminated, dense, whitish, clouds formed during heat treatment and greatly reduced the transparency and quality of this crystal. Structural OH groups are now present in the mid-infrared spectrum, while the spectrum related to diaspore is no longer present. Oblique fibre-optic illumination, 10x.

identified, it was concluded that the structural OH groups present in the heat-treated samples were being formed as a consequence of the alteration and dehydroxylation (dehydration) of diaspore particles within the 'host' corundum crystal. In order to verify and demonstrate this occurrence, specially selected Mong Hsu ruby crystals possessing the additional infrared spectral absorption features related to diaspore (from 1900 to 3400 cm^{-1}) were selected for heat-treatment experiments (Figure 8). Before the heat-treatment process was conducted, the partly polished crystals contained dark blue to violet core colour zones. In addition, one of the crystals possessed coatings of diaspore (Figure 4a). Upon completion of the heat-treatment process, the blue to violet colour zones had disappeared while in the areas just outside the original position of the core colour zones, dense whitish clouds had formed, drastically reducing the transparency of the crystals. Another special phenonemon noted on the surface polished prior to heat treatment and examined after heat treatment without repolishing, included the presence of shallow surface cracks or crazing. This surface crazing was associated with the whitish clouds which had become apparent upon heat treatment

Fig 8c. Evidence of the stress such rubies may experience during the formation of these clouds can be seen by a special feature noted on the surfaces polished prior to heat treatment: the presence of very fine, shallow cracking or crazing which was most concentrated in the areas where the densest clouds reached the surface and was less concentrated where the clouds were less dense. Crazing is absent where there are no clouds, as can be seen when comparing the b and c images of this figure. Overhead illumination, 14x.

and present in higher concentrations when associated with the densest cloud formations reaching the surface, while more sparse when the clouds were less dense.

No surface crazing was present where no clouds had formed (Figure 8). In addition, the transparent, colourless coatings of diaspore had transformed into translucent, whitish polycrystalline masses (Figure 4b).

After heat treatment, the infrared spectra of these crystals were taken again under the same conditions as previously tested. The resulting spectra confirmed the formation of newly bonded OH groups within the structure of the corundum crystal with peaks in the mid-infrared spectrum, from 3100 to 3600 cm^{-1}, while the mid-infrared absorption relating to diaspore had disappeared. A pure oxygen atmosphere was essential during these heat-treatment experiments. This proves conclusively that the building of structural OH groups within these ruby samples is solely related to the alteration and dehydration of diaspore. Even though the concentration of OH may be decreased under these conditions, it is not possible for hydrogen to be diffused into the corundum lattice from such an atmospheric source (see also the panel on pages 326-8).

Discussion of non-heat-treated Mong Hsu rubies

In order to discuss and understand the simultaneous occurrence of corundum and diaspore together in these samples, a brief description of their interwoven nature and relationship is in order. To begin with, aluminium is an element which can be present in many different minerals, one of which is corundum, the alpha form of aluminium oxide (Al_2O_3). Additionally, there are several hydroxide forms of aluminium (oxyhydroxides and trihydroxides), including boehmite, diaspore, nordstrandite, bayerite, gibbsite, etc. (see for example Wefers and Bell, 1972). The similarity in structure between corundum (αAl_2O_3) and diaspore ($\alpha AlOOH$), with a close-packed hexagonal arrangement of aluminium and oxygen in the lattice, allows for a relatively easy transformation to occur between these two minerals due to the small rearrangement necessary in the (Al) and (O) positions. Perkins *et al.* (1979) indicate the reaction as follows:

2 Diaspore = Corundum + Water

expressed in chemical formula as

$$2(AlOOH) \leftrightarrow Al_2O_3 + H_2O$$

This is a process which can take place in either direction, with alteration and reverse alteration occurring as conditions fluctuate above and below the equilibrium curve (Haas, 1972; Perkins *et al.*, 1979), diaspore being the stable phase within the lower temperature field at similar pressures (Figure 9). The result of this alteration process is commonly observed in nature, where diaspore is frequently found as a coating on corundum crystals (see for example Haas, 1972; Wefers and Bell, 1972; Klein and Hurlbut, 1985; Deer *et al*, 1993). An early description detailing this phenomenon was given more than a century ago by Kenngott (1866). Inclusions of diaspore in corundum have also been identified, occurring along irregular fractures (Schmetzer, 1987) and as a daughter mineral in three-phase inclusions (Schmetzer and Medenbach, 1988). It is important to mention that diaspore also forms as an independent mineral in several deposits around the world, in particular as a minor to major constituent of bauxite ores.

Once this relationship is understood, it is easier to discuss the coexistence of both minerals in the rubies from Mong Hsu. In general, the different formation conditions of these two minerals do not typically allow for the mineral diaspore to exist while corundum is still growing, with diaspore having formed either prior to or simultaneously with corundum. As described above, it is easy to explain the presence of diaspore as a coating on the ruby crystals from Mong Hsu, as an alteration product due to corrosion of the corundum crystal in the presence of water

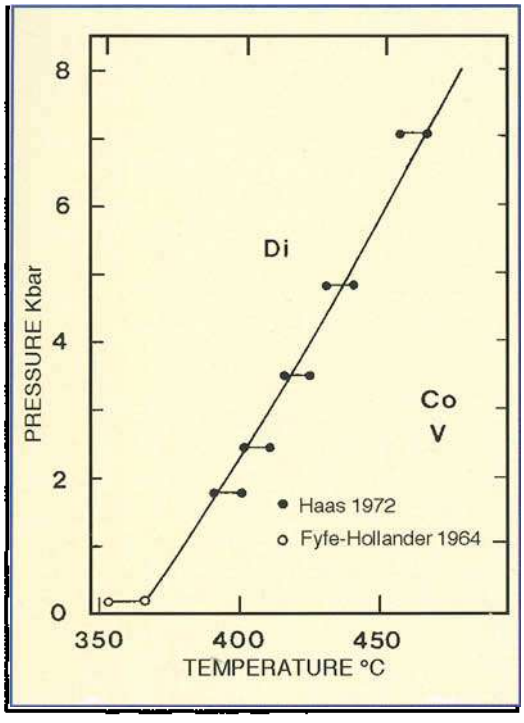

Fig. 9. The phase equilibrium between diaspore and corundum has been a topic studied in great detail by past researchers. This is a reversible reaction which is commonly encountered in nature. The phase trajectory indicated here, is shown as an example, in the presence of a pure water solution, between the temperatures of 350°C to 500°C and pressures of 0 to 8 kilobars. However, more complex fluids are typically encountered in nature. The relative concentrations of these mixtures will have a significant effect on the position of the phase boundary. Di = diaspore, Co = corundum and V = water vapour (H_2O) (reprinted from Perkins *et al*, 1979)

at pressures and temperatures within the diaspore stability field. It is also possible to explain the presence of diaspore in veins penetrating cracks and narrow channels within the corundum crystal, by this same process (similar to the occurrence described by Schmetzer, 1987).

However, diaspore was additionally identified intergrown within the corundum 'host' as an inclusion at a presumably tiny microscopic to sub-microscopic level (i.e. visible as tiny pinpoint inclusions or not visible, with a standard gemmological microscope). This can be explained by a growth in which a fluid is trapped within the corundum in the form of tiny inclusions. It has not been possible yet to determine whether the fluids were Al-rich (for an essentially primary formation of diaspore) or were a mixture containing water (for an essentially secondary formation of diaspore). Tiny particles of diaspore may form through a reaction taking place internally as the corundum crystal enters a new pressure/temperature environment within the stability field of diaspore. This reaction occurring in Mong Hsu is similar to that described by Schmetzer and Medenbach (1988) for sapphires but with a much smaller particle size and a higher concentration of diaspore. Polarized infrared spectroscopy of non-heated samples indicate a preferred orientation of diaspore within the corundum 'host'. Although a detailed discussion of this pleochroic effect is outside the scope of this paper, the degree of pleochroism signifies an epitaxial growth of diaspore and the 'host' corundum crystal.

The presence of diaspore in association with the corundum crystals of Mong Hsu plays a vital role in the subsequent presence of OH groups in the corundum structure resulting from heat treatment.

Discussion of heat-treated Mong Hsu rubies

In this section a brief description is given of the changes which occur in diaspore upon exposure to heat. In 1801 R.J. Haüy first described the mineral which he named diaspore, taken from the Greek word for 'scatter', because the mineral shattered when heated (Wefers and Bell, 1972). When exposed to temperatures and pressures above its stability field, diaspore will go through an alteration process, as explained in the previous section. This is a reactionary process where the temperature

plays a more critical role than the pressure (Weber, 1966). The mineral decomposition which takes place is a process of 'dehydroxylation' (dehydration) producing the alpha form of aluminium oxide (corundum), while releasing the hydroxyl components in the form of water vapour. When the process is complete, the original diaspore crystal can lose up to 15 per cent of its original weight (see for example Fyfe and Hollander, 1964; Wefers and Bell, 1972). The resulting contraction of the remaining crystalline material causes cracks to develop and is responsible for the shattering of the specimens described by Haüy.

As is common practice with rubies from virtually all sources around the world, the rubies from Mong Hsu are typically heat treated. This is performed in order to remove the blue to violet colour zones as well as improve the apparent clarity. For non-heat-treated Mong Hsu rubies which possess inclusions of diaspore, this can be considered as a strong indication for the presence of structural OH groups after heat treatment. When the diaspore has access to the atmosphere (such as is the case when present as a coating on the corundum's surface or areas of the veins in close proximity to the surface), the excess atoms of hydrogen and oxygen released during the alteration process, form a water vapour (H_2O) which will enter the atmosphere. However, for the deeper recesses of the veins which penetrate the corundum crystals, as well as the inclusions of diaspore within the corundum crystals, there is no such avenue of direct escape for these molecules into the atmosphere and so it is considered that a slightly different alteration process takes place. Internally, diaspore particles alter to aluminium-oxide (corundum) and hydrogen is bonded within the corundum structure forming OH groups. In samples tested in this study, the concentration of structural OH bonding is apparently defined by the amount of diaspore present within the crystal prior to heat treatment (in pure O_2).

The highly pleochroic nature of the OH groups measured in the heat-treated samples and the presence of OH groups in transparent areas of these crystals, supports the conclusion of not only a formation of OH groups within the newly formed aluminium-oxide particles, but also, and more intriguingly, an assimilation into structurally bonded sites within the surrounding 'host' ruby. The diffusion of hydrogen into the structure with the subsequent building of OH groups, during heat treatment experiments with both natural and synthetic corundums has been demonstrated by Eigenmann and Günthard, 1971; Eigenmann *et al.*, 1972; Moon and Phillips, 1994. OH groups in natural and synthetic corundum have been attributed to structural bonds occurring with various trace elements, such as Ti, V or Fe (Eigenmann and Günthard, 1971; Eigenmann *et al.*, 1972; Volynets *et al.*, 1972, 1974; Moon and Phillips, 1994; Häger and Greiff, 1994; also refer to the panel on pages 326-8). The rubies from Mong Hsu are evidently suitable for the transition of the aluminium hydroxide phase to structural OH bonding. The cause for this may be found in their major to trace element chemical composition. This is a unique source of corundum, where the rubies commonly possess high trace element concentrations of chromium, titanium and potentially vanadium, while iron is typically incorporated in only negligible amounts (Smith and Surdez, 1994).

An additional point of interest for gemmologists and people within the gemstone trade who are familiar with the rubies from Mong Hsu, has been the nature of the clouds which form during the heat treatment of the rubies from this source. From this work it seems likely that within the corundum crystals, concentrations of diaspore particles alter during exposure to elevated temperatures and form tiny whitish particles of aluminium-oxide, which in high concentrations, scatter the

light to cause the appearance of the clouds. Similarly, it has been noted in rubies from the Morogoro area, Tanzania, that planar lamellae of AlOOH (both diaspore and boehmite) became translucent and whitish in appearance during heat treatment (Dr K. Schmetzer pers. comm., 1994).

Conclusion

The rubies from Mong Hsu are a new source of corundum which is intriguing for several reasons. One such area of interest has involved the infrared spectrum. Although corundum is a typically anhydrous mineral, these rubies commonly possess absorption features in the mid-infrared region of the spectrum. Two distinctly different types of mid-infrared absorption spectra were distinguished: the non-heat-treated Mong Hsu rubies were found to possess associations of the aluminium oxyhydroxide diaspore by the presence of their OH bending and stretching frequencies in the region of the spectrum from 1900 to 3400 cm^{-1}; and the heat-treated Mong Hsu rubies typically possessed absorption features from 3100 to 3600 cm^{-1}, related to structural OH groups bonded within the corundum structure.

Diaspore was found with the ruby crystals from Mong Hsu in a variety of associations including coatings on the exterior surfaces, irregular veins penetrating the ruby crystals and as tiny included crystals. Microscopic to sub-microscopic diaspore inclusions intergrown within the corundum crystals were also indicated by the mid-infrared spectra of samples, when no visible coatings, twin lamellae, veins or sizeable mineral inclusions were present.

The bonding of structural OH is occurring as a charge compensation mechanism for various transition elements present in trace quantities in the chemical make-up of the rubies from Mong Hsu. The building of structurally bonded OH groups in corundum, as a direct result of the dehydroxylation (dehydration) of diaspore inclusions was identified and subsequently demonstrated through heat-treatment experiments for the first time in the gemmological literature. Recent work with other minerals (i.e. fluorite) lends support to this process for the formation of structurally bonded OH groups (Götzinger, 1992).

In this study of Mong Hsu rubies, the mid-infrared absorption related to diaspore has only been recorded in non-heat-treated samples, while the absorption features related to structural OH groups have only been recorded in heat-treated samples. This is also true for Mong Hsu ruby samples which have only received a slight degree of heat treatment, still possessing a pale blue to violet colour zone. This point could be of importance, because, although the blue to violet colour zones may be removed with temperatures as low as 900°C (R.E. Kane pers. comm., 1993), diaspore will go through the dehydration process at temperatures well below this (see for example Haas, 1972; Perkins *et al.*, 1979). Therefore, it would be incorrect to assume that a Mong Hsu ruby crystal is not heat treated simply because a pale blue to violet core remains; an infrared analysis may reveal that a low-temperature heat treatment has been performed.

It should be emphasized that although a large percentage of rubies from Mong Hsu (roughly 75 per cent of a random selection) possess diaspore or structural OH, the mere presence of these mid-infrared spectral features should not be used to indicate the place of origin of a particular stone.

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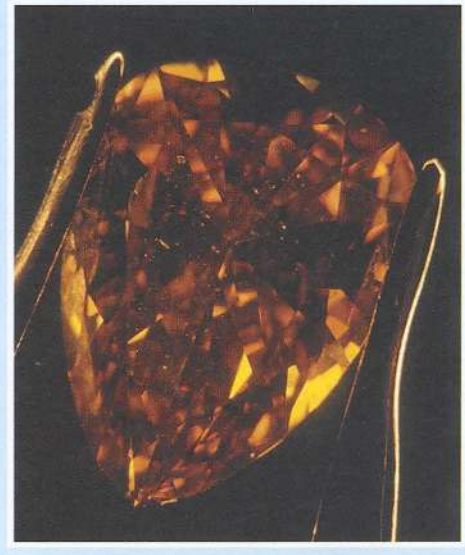

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The story of the Sri Lankan pearl

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Abstract

Sri Lankan pearling has had a history of over two millennia, though it is no longer commercially viable. In addition to their intrinsic value, pearls were considered auspicious objects in ancient and medieval Sri Lanka. Hence, kings gave pearls great importance. When Portugal, the Netherlands and Britain, successively became paramount powers in Sri Lanka, the auspicious qualities of pearls declined in favour of their economic value which feature had always been dominant in international trade. Pearls were classified according to their size, shape and purity. The failure of the pearl industry in Sri Lanka is due to well-meaning attempts of Government to rationalize and place it on a scientific basis in the first part of the twentieth century.

Introduction

Today the pearls of Sri Lanka are a part of history, as pearling no longer takes place.[1] However, Sri Lankan pearls surface occasionally when old collections are dispersed or when new settings replace older ones or heirlooms go on exhibition. Yet, for a thousand years and more, the Sri Lankan pearl was well-known and much in demand. Referring to the period 500BC to AD400, usually known as 'the civilization of the early Anuradhapura period', the standard history of Sri Lanka says,

> 'The pearls found on the north-western coast, the chanks* found in the sea further north and the precious stones which were the products of the southern regions of the Island attracted merchants to Ceylon from ancient times. The pearls of Ceylon are referred to as kauleya in an ancient Sanskrit text and are said to have been produced in a river near the village *Mayura* (*Modaragam*)!'[2]

These pearls would have been riverine pearls not considered in the trade as equivalent to pelagic (sea) pearls either in size or colour. They fetched lower prices.

During the late Anuradhapura period, usually the years between circa AD400 and AD1000, the Sinhalese kings, who ruled Ceylon, sent embassies to China between the years 405 and 762. Trade was one of its purposes. Among the gifts of the Sinhalese kings to the Chinese Emperors were pearls, filigreed gold, gems and ivory.[3] By that time, the skill of Ceylonese craftsmen was well-known to Asia and the world beyond - the Chinese, the Indians and the Japanese of the early Middle Ages recognized and valued their fine craftsmanship. Admiring comments, for instance, are found in Chinese works such as *Kao-Seng-Chuan, Liang-Shu, Kuang-Ming-Ming-Shih*.[4] Since pearls formed an essential item of the clothes of royalty and the aristocracy, pearl enhancement and adornment in clothes were established technologies.

* A large kind of shell, Tarbinella rapa, prized by the Hindus, found especially in the Gulf of Mannar.

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Incidentally, the usual mode of transporting pearls at that time was to ensconce them in very fine fabrics and carry them on the person.

Status and role of the classical Ceylon pearl

Apart from its intrinsic value, the pearl has been admired in medieval Ceylon and even today. For instance, some place-names in Sri Lanka have 'pearl' in their names.[5] 'Muthu', the term for pearl in Sinhala and Tamil, the indigenous languages of Sri Lanka, also means 'acme' or 'excellence' in these languages.[6] Many members of the Sinhala and Tamil communities in Sri Lanka have 'muthu' prefixed to their names. This term also finds its place in the Hindu pantheon.[7]

The pearl is also a symbol of good luck in classical Ceylon. That perhaps is why we get so many references to pearls in ancient and medieval literature of Sinhala and Tamil. Like the lotus and the peacock, but at a higher level, the pearl is or was, an auspicious object.

Ancient Ceylonese chronicles associated auspicious events such as the coronation of kings or the births of princes with the 'serendipitous' finding of pearls. For instance, the 'Mahavamsa' ('the Great Chronicle'), a work in the Pali language written by the Buddhist monk Mahanama in the sixth century and which tells the history of Sri Lanka from 483BC onwards, records such events. Describing the coronation (really the consecration) of King Devanampiya Tissa (247-207BC), an exact contemporary of the Buddhist Emperor Asoka of India, the Mahavamsa records,

> 'Pearls of the eight kinds, namely horse-pearl, elephant-pearl, wagon-pearl, myrobalan-pearl, bracelet-pearl, ring-pearl, kakuda fruit-pearl and common (pearls) came forth out of the ocean and lay upon the shore in heaps.'[8]

Further, detailing the desire of King Duttha Gamini (101-77BC) to build a 'thupa' to house the relics of the Buddha, the Mahavamsa writes,

> 'In a westerly direction from the city, at a distance of five "yojanas", near the landing-place Uruvela, pearls in size like to great myrobalan fruits mingled with coral, six waggon-loads, came forth to the dry land. Fishermen who saw them piled them together in a heap and taking the pearls together with coral in a vessel they went to the king and told him of this matter.'[9]

From a review of the detailed descriptions of pearls in the ancient chronicles, it is possible to sketch in some of the principles of pearl classification in classical (i.e. medieval) Ceylon. The classification was based mainly on size and, often but not always, colour gradations.

Basic to the classification was the definition of a pearl of the best kind in Sanskrit literature.[10] They usually call those pearls 'muthu' (first class) and see them as perfectly rounded globes of dazzling white colour. That tradition came down to Sri Lanka and entered the lexicons and thesauri of the Sinhala language.[11] The Tamil language, working on a tradition from South India equally well-known for its pearls, calls them 'aani-muthu' (literally 'nail or tap-root pearl'). Such splendid pearls were rare, however.

The normal pearl was called the common pearl, that is from the point of view of poets who habitually lived in the world of the imagination. Human biology forms a useful yard-stick in the taxonomy of the pearl in classical Ceylon, for several parts of the body were expressed in 'pearly' terms. In those days a Beauty Queen, or any excellence in feminine shapeliness, was called 'pancha kalyani' (a Sanskrit word meaning 'the five excellences'). These were long, lustrous, dark hair reaching down to the hips; reddish, perfectly shaped lips; soft skin; youth; and 'white, regular teeth'.[12] Since very small, white, regular teeth were compared to grains of

rice, it is fair to conclude that the modal pearl in the market of ancient and medieval Ceylon approximated to the size of female, regular teeth, white and sparkling.[13] However, very small pearls are not impressive by themselves in a tropical climate; even 'en pave', they tend to look 'shabby-genteel'. Incidentally, the most expensive rice in Sri Lanka is called 'muthu samba' (pearl collection).

Ancient and medieval Ceylonese jewellers and goldsmiths (and the upper-class and upper-caste elite who were their regular and often their only customers) divided other pearls into regular ones for ornaments such as ring-pearls and bracelet-pearls. The biggest, most lustrous and (almost) perfectly shaped pearls were used for necklaces (specially for royals) and diadems and plate-crowns.

Two ornaments need special mention. One was the 'sacred' royal necklace composed of the largest available pearls of very good quality, 'corded' on gold thread, in descending order of size with the largest pearl in the centre as the pendant. The antipodal pearl of the pendant was the next largest pearl in the necklace. This necklace was 'sacred' in the sense that it was the insignia or the most important part of it and could only be used by the sovereign.[14] (It also came in handy when a long-lost heir to the throne had to prove his legitimacy.)

Another important ornament usually worn by kings was the golden breast-plate which covered the upper part of the chest. Buffered on a thick plate of gold and encrusted with corundums of different colours and with spinels, it was as much a protective device as an ornament. Pearls formed a part of this ornament mainly for the purpose of setting off the splendour of the other gems.

Misshaped pearls of limited size and small pearls of dull colour were often used as leg and foot ornaments by upper-class (and so mainly upper-caste) women. These pearls were enclosed in the hollow tubes of gold anklets. These tinkled as the women walked and at least on one occasion were the source of great tragedy and a great literary masterpiece.[15] Irregular pearls were generally large and human ingenuity found for them similarities with horses, waggons and elephants in their suggestive shapes. These pelagic elephant pearls should not be confused with real elephant pearl, a roundish encrustation rarely found in the tusks of elephants.[16] Its value is purely exotic.

The myrobalan-pearl is of more interest. It is frequently mentioned in the ancient *Chronicles*. For instance, the Mahavamsa recounting the building of the relic chamber of the 'thupa' as directed by king Duttha Gamini, said that the platform of the Bodhi tree was paved with great myrobalan-pearls.[17] The myrobalan is a fruit, used extensively in Sinhala traditional medicine and is one of the three 'panacea' herbs.[18] It is an auspicious article and a recognized royal gift in ancient times.[19]

The sanctity of myrobalan attached quite naturally to the pearls of that name and shape. The myrobalan pearl or 'pearl the size of Amalka fruit' is a large pearl, often the size of three ordinary pearls. Some ancient and medieval poets in the East, with poetic licence, describe these as pearls 'exceeding the size of ducks' eggs'. These descriptions seem to have got into several stories in the Arabian Nights as well.

The median myrobalan-pearl was 'yellowish' and imperfectly rounded, like those of the South Indian coast. A perfectly-shaped myrobalan pearl, with good texture, was rare. A string of such pearls cost much. Even in the second century BC, according to the Mahavamsa, a string was worth nine-hundred-thousand pieces of money.[20] Even assuming that the chronicler was referring to the copper coin rather than the silver coin in use at that time, the price was high enough.[21] These strings of pearls also had another royal purpose. A king or some other royal taking refuge in

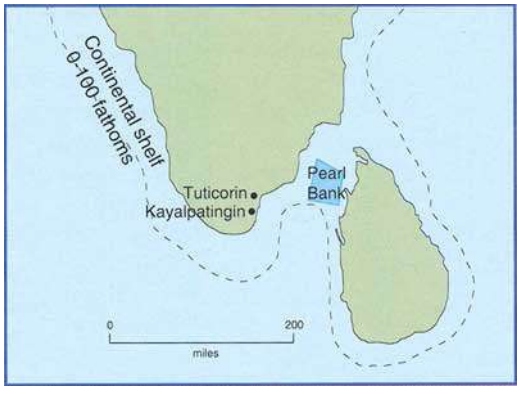

Fig. 1. Continental Shelf between S. India and Sri Lanka: pearling locations

another king's territory could always placate his host with a few strings of pearls.

The organization of pearling in classical Ceylon

Pearling differs from gemming of terrestrial stones in four ways. Pearling is confined to some specific off-shore sites; pearling takes place at irregular intervals and sometimes, such as currently in Sri Lanka, ceases altogether; there are seasonal variations in the supply and quality of pearls; and pearl-diving is a hazardous activity.

In classical Ceylon, pearls had some in-built advantages. Only the divers and pearl merchants came into contact with the pearl in its original condition. From them, by sale, gift or transfer, it passed into the hands of the royalty, the aristocracy and the rich, all of them belonging to the upper-castes. Naturally, its use was limited to these people. Sumptuary rules denied the use of the pearl to the ordinary man, assuming that he ever came into contact with one. While it was possible for the ordinary man to come across precious stones by chance, that did not happen in the case of pearls. Such a chance 'discoverer' could secrete the gem - even bury it - hoping for better times. Such entombment of pearls in a tropical country like Sri Lanka, would dry them out to the equivalent of fish-eyes.

The traditional people involved in the pearling industry could be classified as follows:

a) the owners and members of the fishing fleet;
b) the pearl divers - local and foreign;
c) the officers of the king, whose duty was to delineate, organize and distribute the shares of the pearl oysters and be in charge of the administration and security of the area. Also, they would take charge of the king's share;
d) the king's administrator under whom the pearling territory came;
e) the pearl merchant at the spot;
f) the final pearl merchant who exported the pearls.

Incidentally, the pearl divers received the least reward and the final pearl merchant the highest.

Pearling was carried out on the north-west part of the continental shelf (Figure 1), (that is, where the depth of the sea averages a hundred fathoms or less) which surrounds Sri Lanka and South India.[22] The continental shelf fans out from Cape Comorin (India) and surrounds Sri Lanka as a fairly narrow strip. The area was usually called the Pearl Banks of Sri Lanka (Ceylon), currently known as the Gulf of Mannar and Puttalam (i.e. to the north-west of Sri Lanka).[23]

The shallow waters and the consequent high solar heating seem to have brought about a great increase in marine micro-flora and micro-fauna which benefited the pearl-oyster. While, the pearl-oyster was pervasive throughout this marine zone, there were also specific concentrations. The oysters were more abundant on rocky 'paars' in five to six fathoms.[24] Apparently the food-chain of the waters, in which the oyster was a part, fluctuated throughout the years. And this meant that pearling could take place only when the oysters were plentiful. The pearl-oyster (*Pinctada*) 'which is more nearly related to the mussel than to the edible oyster' is (or really was)

an erratic breeder of pearls, as Leonard Woolf, colonial administrator in Ceylon in 1907 and later a writer and publicist, noted.[25]

When the seat of the Sinhala kings of Ceylon was in Anuradhapura between 555BC and AD1000, the government had close control of pearling (Figure 2). This was so because the pearl banks were only 60 miles north-west of Anuradhapura. However, the incursions of invaders from South India forced the Sinhala kings to shift their capital away from the north. Thus in medieval Ceylon the capital shifted in turn to Pollanaruwa (25 miles south of Anuradhapura), Kurunegala (40 miles south of Anuradhapura), Gampola (50 miles south of Anuradhapura) and Kandy (close to Gampola), the last three being in fairly hilly areas. At each shift of the capital, the central authority moved further away from the pearl banks.

Thus, as time went on, more intermediaries were interposed between the pearl-divers and the royal authority.

It was in exceptional circumstances, if ever, that pearl-oysters were cast on the shore. Hence, government had to organize or let others organize the pearling. The medieval governments of Sri Lanka, constrained by considerations of distance, preferred to do the latter, regulating those who actually organized the pearling. In the later Anuradhapura period, state officials called 'danda-nayaka' were appointed and established near pearl banks with civil powers of administration as well as with coercive authority, as their title of office 'Masters of Punishment' indicates. This was intended to be a corrective to the the tendency of some divers or pearl extractors to hide or secrete some very large pearls.

In a later period, largely owing to the strength and dynamism of King Parakrama Bahu I (AD1153-86), pearling as well as terrestrial gem development came under a royal official close to the King. His official title was 'antaranga-dhura' (confidential secretary or head of secret service).[26] This official had his servants all over the environs of the pearl banks and so could have a rough tally of the number and value of the pearls after each pearling. Parakrama Bahu I was a worldly-wise king and realized that pearls not under his control were against his interests.

Whatever might have been the chain of control over pearling, the most important aspect of Sri Lankan pearling was its export significance. The ancient and medieval trade routes which carried Sri Lankan pearls to Europe, the Middle East and the Far East were frequently changing, subject as they were to natural obstacles such as floods, pestilence and political problems like the oppression of kings and princes. Still, some traditional trade routes can be traced. There was the overland route which, though encroached upon by the sea route from Europe to the lands of the Indian Ocean later, continued to be significant. This route connected Mannar or Mantai, the township on the Mannar mainland, through the narrow sea channel between India and Sri Lanka, to the Indian sub-continent.

The overland route pushed west through Kerala, Gujerat (both districts and now

Fig. 2. Sri Lanka: pearling location and principle merchandising centres (towns).

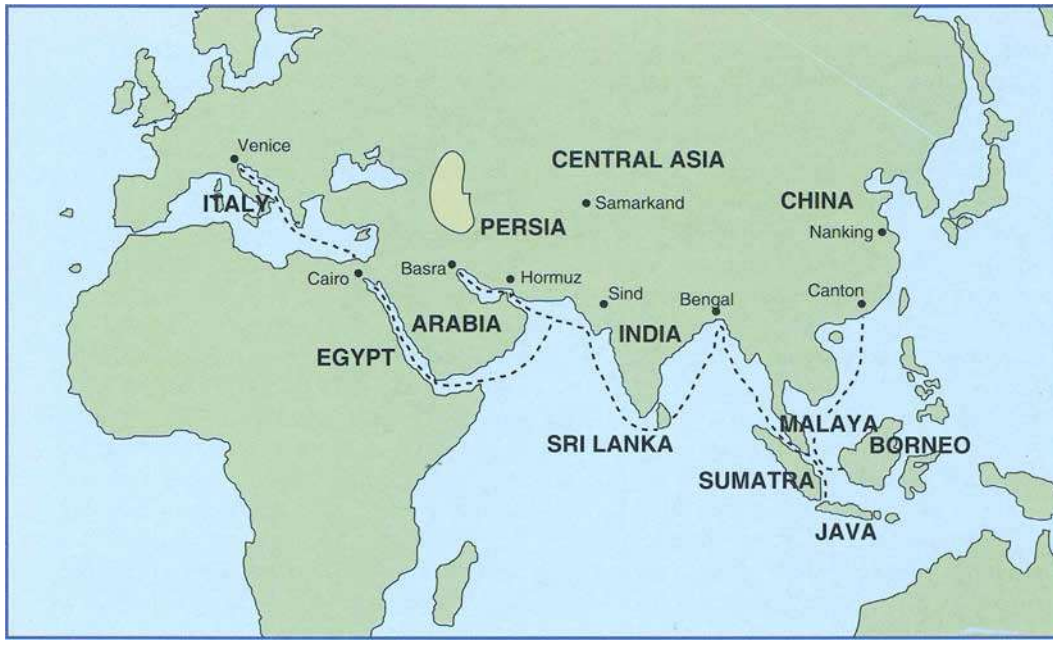

Fig. 3. Pearl route up to *circa* 1500

states of India), Sind (now in Pakistan) and continued west to Persia, Iraq and into Turkey, and then either joined the sea route to Venice and thus into Europe, or it branched to the east through Central Asia and became part of the Silk Route to China. Another branch of the overland route moved east from Kerala and joined up to Bengal and then again to a branch of the Silk Route to China. However, there was great scope for the sale of Ceylon pearls among the kings and rulers of principalities in India itself, theirs being an insatiable demand. Pearls, however, were not highest among gems from the Chinese point of view - they prized jade above all. At any rate, the overland route was not disadvantageous to the pearl trade. Pearls were easily concealable on the person and traders could sell stock either to the other merchants in the locality or to the potentates of the area.

The importance of pearls to the sea route linking Europe to the countries of the Indian Ocean, which Barolomea Dias and Vasco Da Gama pioneered following Arab navigational procedures, only came as one among the luxury articles (with high value/weight differential) including cinnamon, gems, cloves and pepper which European adventurers and merchants either purchased or commandeered from the indigenes of Asia.

In the early part of the Middle Ages, the Arabs were perhaps central to the pearl trade in Ceylon and associated countries of the region. Mannar, the base of pearling operations, soon became an important junction for the Arab trade. A well-informed observer who was also Chief Justice of the Supreme Court of Ceylon in 1811 wrote of Mannar in the Middle Ages that it was the great emporium of all the trade of the Arabs (Muslims) with Egypt, Arabia, Persia, the coasts of Malabar on the west side and of Coromandel, the eastern shores of the Bay of Bengal, Mallaccas, Sumatra, Java, the Moluccas and China on the east.[27] The Mannar merchants obtained pearls from their agents at Cooderamale.[28] The majority of the pearl trade reached the Middle East, Europe and many Asian

countries through their hands.

Ibn Battuta, the Moroccan jurist and traveller who visited Sri Lanka after 1325, gives an insight into the nature of the pearl trade and administration of those days. Though Ibn Battuta was not a professional student of pearls or a jeweller, he had the practical knowledge of the cultivated man of his time. Speaking of the Prince who controlled the region in which pearling took place, he wrote,

> 'One day I went to him [the Prince] while there lay about him a large number of pearls which had been brought to him from the pearl fishery in his dominion. His employees were busy sorting out and classifying the best pearls from the rest. "Have you seen any pearl-fishery in the countries you come from?" he enquired of me. "Yes," said I, "I saw them in the islands of Qais and Kish, which belong to Ibn-us-Sawamli." "I have heard about," said he. Then he picked up a few pearls out of the lot and said, "Are the pearls in those islands like these?" "The pearls I saw," I replied, "were inferior to these." He was delighted at this and said, "These pearls are yours; do not be shy. You can demand of me whatever you desire." '[29]

The translator notes that the islands of Qais and Kish later became the sites of Hormuz and Bandar Abbas.[30]

The excerpt, perhaps, brings out the presence of the nagging anxiety of the rulers and pearl merchants of Ceylon that pearls from the Persian Gulf were frequently larger and more rounded than those from Ceylon. Some people believed that the tiny detritus which entered the pearl-oyster and caused the pearl to form, was more abrasive in the Gulf than in the waters off Mannar.

When the central authority of Ceylon was strong, the government share of pearling was dutifully forthcoming. Sometimes an energetic sub-king took the initiative. For instance, in the middle of the fifteenth century, when King Vikrama Parakrama Bahu III was reigning in Gampola, he authorized the sub-king Alagakonnara III to regulate the foreign trade that was being carried out at Colombo, then (and now) the principal port of Sri Lanka.[31] Alagakonnara was equally strict and unforgiving to his craft vassals. Hence, the pearl fishers of Chilaw, among purveyors of exotic products, delivered the government's share to the sub-king's palace.[32]

When the central authority was weak, even merchants and adventurers from South India were not averse to interfering in the pearling in Sri Lanka. The *Rajavaliya* (meaning, in the Sinhala language, 'Dynastic History') is a chronicle written in the seventeenth century, and is of high historical authority. It says of an incident early in the sixteenth century:

> 'During the reign of Dharma Parakrama Bahu, a Moorish pirate, Kadiriyana by name, coming from the seaport Kayala, landed at Chilaw, accompanied by a large body of Moors, for the purpose of forcibly fishing for pearls at Chilaw and capturing elephants. Dharma Prakrama Bahu sent for Prince Sakala kala walla, entrusted to him a large army and gave him permission to attack.'[33]

From this excerpt, the following suppositions could be drawn. Kayala (today called Kayalpattinam) is a South Indian town in the Tinnevelli district (of present-day Tamil Nadu), directly facing Mannar across the Gulf of Mannar. It was and is a town traditionally known for its expertise on pearl and terrestrial gems, having a solid body of pearl and gem merchants with a great deal of capital. That a body of merchants could mount an attack was an indication of their resources and resource. It was widely believed that the pearl merchants of Kayalpattinam amalgamated Ceylon pearls with South Indian ones and sold these off to the many princes and princelings of the Indian sub-continent. Incidentally, the exotically named Sakala

kala walla (it means 'an expert in all arts and sciences' in Sanskrit) stood up to his name and put down the Kayalpattinam incursion.

Ceylon pearling under the European Dispensation

Ceylon, or at least its littoral, came under European colonial powers from 1505 to 1948. The Portuguese ruled from 1505 to 1656 when they were replaced by the Dutch - really the VOC, the Dutch East Indies Company. In 1796 the VOC was replaced by conquest by another company - the British East Indies Company. The British Crown assumed responsibility in 1802 and by annexing the Kingdom of Kandy, the surviving indigenous monarchy in 1815 brought Ceylon under a single rule. Ceylon became independent in 1948.

The three colonial Powers looked upon pearling as sometimes lucrative but essentially an adventitious source. They preferred cinnamon, which had great demand in Europe. The Portuguese army which controlled the littoral and which was officered by a few hidalgos on a base of Portuguese landless labourers and lumpen-proletariat, did not have much expertise on pearls. Further, the frequent incursions into the Gulf of Mannar by the fleets of the Zamorin, the indigenous Prince of Calicut, often disrupted pearling. The Zamorin, of course, was a declared enemy of the Portuguese. The VOC, whose senior officials were styled 'over-merchants', 'merchants' and 'under-merchants' in Dutch, were more business-like. But they preferred to use Ceylon more as a transit station for cloves, pepper and other spices they garnered from the Dutch East Indies.

However, information of pearl and pearl trading in Ceylon during that period is available in the histories, the annals and diaries which European travellers to Ceylon wrote after their sojourn in that country. An important figure in this regard is Caesar Fredericke, the Venetian merchant-adventurer who visited Ceylon after 1563. He has left a full account.

Caesar Fredericke noted that pearling in Ceylon was done in the sea between Cape Comorin (in India) and off Chilaw.[34] All the fishermen, that is those who plied the boats, were Christians (Roman Catholics) of the fisher caste and they paid dues to the King of Portugal and the Churches of the Friars of St Paul. The pearl-fishing boats were usually guarded by three or four fursts (i.e. lightly-armed sloops). Three or four fishing vessels, which he calls barkes and 'are like to our little Pilot boates' go out to the sea and anchor. The depth of water in those parts is only fifteen to eighteen fathoms. There are seven or eight men in each barke and they comprise the entire crew involved in this operation.

Caesar Fredericke saw the actual pearling which he described. Each barke cast a rope with a big stone at its end into the sea. The diver descends into the sea along this rope. The diver has his ears and nose stopped and 'anointed with oil'. He has a basket about his neck or under his left arm. Within the limited time he is under water, he collects the oysters into the bag and tugs at the rope. He is pulled up and into the barke. In the evening, the barkes sail back to the shore. Fredericke noted that each barke dumped its oysters into a heap, separated from the others. These heaps lie till the end of the fishing season when each crew opens its heap. Sometimes there are more pearls in one season and sometimes less. Caesar Fredericke, explained the matter of grading.

> 'There are certain experts in the pearls whom they call Chitini which set and make the price of pearls according to their carats, beauty and goodness, making four sorts of them. The first sort are the round pearls and they are called Aia of Portugal, because the Portuguese do buy them. The second sort which are not round, are called Aia of Bengal. The third sort which are not so good as the second, they call Aia of Canara, that is to say the Kingdom of Bezenegar. The fourth and the last sort which are the least and worst sort, are

> called Aia of Cambaia. Thus the price being set, there are merchants of every country which are ready with their money in their hands, so that in a few days all is bought up at the prices set according to the goodness and carats of the pearles.'[35]

The grading of the pearls had the exotic Indian names because the merchants involved in pearling and substantive purchasers of pearls were Indian potentates.

The finest kind of pearls were so called because the Portuguese officers in control of the area of pearling had the pick of the best pearls. It is not clear how much of this went to the Royal Portuguese treasury maintained by the Captain-General, the head of the Portuguese establishment in Ceylon, and how much to private hands. The Bengala in the second variety probably refers to Bengala (Bengal in India), traditionally known for its high level of craftsmanship. The third sort are those named after 'Canara' or 'Bezeneger'. These, presumably, stand for Kannada and Vijayanagar, respectively. The eponymous capital of the Vijayanagar empire, founded by the two brothers, Bukka and Harihara in 1336, was situated in the Deccan region of India and inhabited by people who spoke the Kannada (Canarese) language, one of the Dravidian group of languages which includes Tamil.[36] The Vijayanagar empire was famous for promotion of fine arts and a delight in jewellery.

Cambaia has the dubious honour of being named for the worst sort of pearls in Caesar Fredericke's estimation. It is presently called Diu and is in the Gulf of Cambay, about 150 miles north-west of Bombay. In Caesar Fredericke's time it was a small town, a place where Portuguese influence was felt.[37]

In spite of the Indian 'naming of pearls', a correlation could be made between this classification and that of the medieval chroniclers of Sri Lanka. The Aia of Portugal is the first-class pearl or the 'ani-muthu' in Tamil. The Aia of Bengal is the myrobalan- pearl. The Aia of Canara is the common-pearl. The Aia of Cambaia are those malformed pearls defying all classification.

Caesar Fredericke's Chitini, the experts who classified pearls, were obviously the present- day Chetty community, found in South India and Sri Lanka. They are a sub-group of the Vaisyas who are held to be the third group of the Indian caste-structure engaging themselves in agriculture, cattle-breeding and trade.[38] Sometimes called Nattu kottai Chetties in Tamil Nadu (South India), they were market-leaders in the import-export business, banking and gold, and the gemstones and pearl trade. They were businessmen of the utmost integrity. This is an essential requirement as the pearl-trade is largely carried out without recourse to legal documents. The actual crafts of the goldsmith, the silversmith and of pearl-enhancement jewellery, however, are practised by the caste-groups, called asari.[39]

Caesar Fredericke was a well-informed observer. He himself says that he 'has sold rubies well there [in Sri Lanka] brought with [him] from Pegu'.[40] After Caesar Fredericke's time a large number of Aia of Cambai (Caesar Fredericke's term for Ceylon pearls) including the poor grades of bluish-greys went into South India. This was after the middle-1700s, when the colonial wars between Britain and France had pushed up a client-population of feudatories, called 'poligars'. When the British had settled the situation in their favour and had disbanded the levies of the poligars, forcing the poligars into simple land-ownerships as 'zamindars' and wealthy 'country gentlemen', these men took to conspicuous expenditure to keep up their status. And pearls were an important part of such aspirations.

Throughout the centuries, a large number of pearls from Ceylon went to the Middle East and not Europe. Some of these pearls were taken up by Arab traders who bought the oysters, either by them-

selves or through their agents. Another group of pearls were those bought by merchants of Indian towns such as Kayalpattinam and sold, together with those of South Indian pearls, to Middle East traders. The divers, a large number of whom were Arabs, took pearls from their share of the oysters to their native towns. (Since they knew the trade, they could get good prices.) For instance, during the pearling in Sri Lanka in 1906, which lasted from 20 February to 3 April, there were 4090 Arab divers from the Persian Gulf out of a total of 8667 divers.

A persistent feature of pearl-fishing is the hazardous nature of the occupation, and Caesar Fredericke's description of diving continued to be true all along. This lack of change was a result of several factors. First, governments did not see the point in rationalizing an uncertain trade. Secondly the pearl traders and middlemen did not care to add to their prime costs. This was understandable since the British Government insisted on dividing the whole harvest of oysters into three equal parts, taking two parts which it subsequently auctioned off at the site.

Thirdly, the strongest opposition to any reform of diving came from the divers themselves. Divers were hardy, whip-cord-like individuals with ice-cold nerves and proud of their powers of endurance. James Steuart, Master Attendant during the first part of the nineteenth century and well-informed in matters of pearl-fishing, noted that the divers remained under water for only 53-57 seconds, if they were working at a depth of nine fathoms.[41]

During the nineteenth and twentieth centuries there was increasing centralization in the trade of pearls and the decreasing number of leaders in the trade became correspondingly more important. They became the ultimate possessors of all good-quality pearls resulting from Ceylon pearling. Questions of economics and geography determined this situation in the following way: outsiders lacked the expertise and the ability to hold on to pearls for a long time. And further, every mile away from the pearling area added to the chances of the outsider being robbed or questioned about how he got the pearl. So most outsiders disposed of their finds as soon as they could, receiving only one to ten per cent of the actual value of the pearls.

The strangulation of the Ceylon pearl fishing

The end of the pearl fisheries in Ceylon was the result of apparently excellent motives. The Government of Ceylon, at that time under the *de facto* authority of the British Governor and subject ultimately to the Secretary of State for Colonies at Westminster, decided to apply science to this field of activity. The declared purpose was the development of the pearling area in the north-west of Ceylon,

> 'to make it a busy scene of scientific operation in pearl-fishery economy, to locate pearls in live oysters without opening them, and to induce those oysters which are barren, to produce pearls.'[42]

Reviewing the official and private documents in this matter, four strands in the Government's thinking could be traced. First, there seemed to be a time correlation in the barren periods (i.e. when no pearling took place or when the 'harvest' was negligible). For instance, during the British period, after the pearl-fishing of 1815 there was a gap of 13 years which ended in 1827. There followed further gaps between 1837 and 1854, 1864 and 1873, and 1892 and 1902. 1903 signalled very successful pearl-fishing which in 1905 netted the Government a sum of Rs. 3,500,000 which would be an astronomical sum in today's money.

Secondly, these time gaps could be ascribed to biological and geo-thermal (really, marine-thermal) conditions such as the availability of nutrients to oysters, lack

or plenitude of predators and with this knowledge remedial action could be taken. Provision of salt-water lagoons appeared to be one solution.

Thirdly, there was a widely held belief that pearling in Ceylon was over-extended, that too many individuals were concerned with it, and that this had led to the subsequent pollution of the beaches and the surrounding area of the pearling zone. Fourthly, some rationalization should be introduced into pearling, an occupation which had been unchanged for upwards of two millennia.

Hence the Government of Ceylon wished to privatize pearling. A former Surveyor-General of Ceylon, an expert on geography and geographical systematics, wrote that in the early years of this century, the Government of Ceylon sold its monopoly of pearling in the Gulf of Mannar and Portugal Bay to the Ceylon Company of Pearl Fishers.[43] It was believed that the highest officers in the country took a part in the floating of the company and that two Americans, Mr John I. Solomon and Mr Dale, were the financiers. On the recommendation of James Hornell, the Government Marine Biologist, it was decided to appoint Louis Siedle, then a famous gemmologist, to 'pioneer the implementation of their plans'.[44]

These plans were not successful and some thought that the main cause was the step which the company took of cleaning the fishery banks which 'resulted in the disturbance of the oysters'.[45] The Marine Biologist, it was reported, however, was of the view 'that the dearth of oysters is due to premature decay of oysters'.[46]

The Pearl Fisheries of Sri Lanka never recovered from this project. Since pearl-fishing has taken place for two thousand years on the South Indian part of the Gulf of Mannar, it is fair to postulate that it was the cleansing efforts of the company that had upset permanently the ecology of the pearl banks of Mannar. (In Tuticorin, in the Chidambaran district of Tamil Nadu, pearl fishing has been noticeably flourishing since 1955 and about 2000 persons are engaged in the industry.)[47]

At a social level, the loss of the pearl industry in Sri Lanka did not seem to have had much impact on those who would normally buy and wear pearls. After the disappearance of the Kandyan kingdom in 1815, pearls as articles of ornamentation and ceremonial decoration of the elites, declined in importance. In modern times, the pearl has been an article of feminine wear. However, it does not go well with the sari, and most women in Sri Lanka wear the 'thali', the chunky gold necklace as a symbol of marriage. This obviates the wearing of a string of pearls about the neck.

Despite the low-profile of pearls in the jewellery of Sri Lanka and its tragic end as an industry, pearls in Sri Lanka have had 'a storied past undreamt in history'.[48]

Notes

1. Sri Lanka, the island lying off the tip of South India, was known as Ceylon till 1972 when it became a republic. In this article, 'Ceylon' and 'Sri Lanka' are used according to context.
2. C.W. Nicholas and S. Paranavitana, *A concise history of Ceylon from the earliest times ... 1505* (Ceylon University Press, Colombo, 1961) p. 102. I have discussed relevant gemmological topics in M.M.M. Mahroof (a) 'The Muslim lapidary; some aspects of the gem folkways in Sri Lanka' *Journal of Gemmology* 1989, 21, 7, 405 (b) 'The Sri Lankan ruby; fact or fable' in *Journal of Gemmology* 1992, 23, 1, 20.
3. Nicholas and Paranavitana, ibid., p. 164.
4. Sylvain Levi, 'Chino-Sinhalese Relations in the Early and Medieval Ages' tr. John M. Seneviratne in *Journal of the Royal Asiatic Society*, Ceylon Branch (JRASCB), Colombo (1915/1916) xxiv, 74.
5. 'Muthu' is the term for pearl in the Sinhala and Tamil languages which are indigenous to Sri Lanka. The thirteenth century Sinhala thesaurus, the *Amarakhosha* Ven. Meddepola Wimalajothi ed., Bastian & Co., Colombo 1934, gives the Sanskrit form 'mowkthikam' as equivalent to 'muthu' in Sanskrit (p. 149). This *Amarakhosha* is thought to be a particular revision or version of the work of the same name by the Sanskrit writer of the sixth century, Amarasinha.
6. For instance, 'muthu mandapaya' (in Sinhala) and 'muthu mandapam' (in Tamil) stand for 'grand palace'. 'Muthu Silavam' (NW coast of Sri Lanka) and 'Muthu Raja wela' (SW coast, close to Colombo) are among the 'pearly' geographical names.
7. 'Muthu Kumaran' (pearl prince) is one of the names of Skanda, the younger son of Siva in the Hindu pantheon.
8. Ven. Mahanama, *The Mahavamsa or the Great Chronicle of Ceylon*, tr. and ed. Wilhelm Geiger and M.H. Bode.

Government Information Department, Colombo. 1950 reprint of original 1912 edition, p. 78.
9. Ibid. p. 189. Uruvela was a port about forty miles away from Anuradhapura, the capital of ancient Ceylon.
10. Kalidasa, one of the greatest of Sanskrit poets, lived in the fifth century. (All dates unmarked in this article are AD.)
11. *Amarakhosha*[5], p. 149.
12. R.L. Brohier, *Discovering Ceylon*, Lake House Investments, Colombo, 1973, p. 82.
13. The rice grain averages one-seventeenth inch in width. Perhaps the 'pancha kalyani' tooth is twice that width.
14. From the sixth century, 'ekavali' or string of pearls was one of the five items of the Sri Lankan royal insignia. (Nicholas and Paranavitana, p. 166).
15. The 'Silappadikaram' (which means in Tamil 'the chronicle of the ankle[4]'), a classic Tamil epic of the fourth century, is based on such an event. The hero is accused of stealing the queen's anklets, when he was really trying to sell his wife's anklets. The king in the story orders the hero killed. The hero's wife smashes her remaining anklet in the presence of the king. Sapphires in it leap out - the queen's anklets had pearls. The king dies in mortification, as does the queen. V. Chelvanayakam, *Thamil Ilakiyya Varalaru* ('History of Tamil Literature'), Sri Lanka Achakam, Jaffna, Sri Lanka, 1965, ff. 66.
16. There is a photograph of an elephant pearl (ivory pearl) with the caption 'the elephant pearls are more expensive than oyster-pearls and hence very highly prized in the East' in S.E.N. Nicholas *Commercial Ceylon*, Times of Ceylon, Colombo, 1933, p. 29.
17. *Mahavamsa*[8], p. 203.
18. Myrobalan is called 'kadukkai' in Tamil, literally 'bitter fruit'. Tamil literary works, either in Sri Lanka or South India, never compared pearls with 'kadukkai'. This information came from Mr M.A. Othman of Schofield Place, Colombo, who specializes in the literature on medical herbs.
19. *Mahavamsa*[8], p. 80.
20. *Mahavamsa*[8], p. 203.
21. Nicholas and Paranavitana[2], p. 102. H.W. Codrington, *Ceylon coins and currency*, Colombo Museum Series no. 3, Government Printer, Colombo 1924, *passim*.
22. P.G. Cooray, *An introduction to the geology of Ceylon*, National Museums of Ceylon, Colombo 1967, p. 73.
23. L.J.B. Turner (Superintendent of Census and Director of Statistics, Ceylon), *Handbook of commercial and general information for Ceylon*, Government Printer, Colombo 1922, p. 89.
24. Ibid.
25. Leonard Woolf, *Growing: an autobiography of the years 1904 to 1911*, Hogarth Press, London 1977, p. 86.
26. Nicholas and Paranavitana,[2] p. 250.
27. Sir Alexander Johnston CJ, 'Letter to the Secretary ...' *Transactions of the Royal Asiatic Society of Gt. Britain*, 1827, i, ff. 537, reprinted in I.L.M. Abdul Aziz, *Ethnology ...*, MICH, Colombo, 1957 reprint, p. 57. Also, M.M.M. Mahroof and M. Azeez, *An ethnological survey of the Muslims of Sri Lanka*, Sir Razik Fareed Foundation, Colombo 1986, Chap I (by M. Azeez).
28. Ibid., Sir Alexander, Coodera malle is a town south of Mannar. It means in Tamil, 'horse mountain'.
29. Mahdi Hussain, *The Rehla of Ibn Battuta (India, Maldive Islands and Ceylon)* (translation and commentary), Orient Institute, Baroda, India, 1976, p. 218.
30. See notes 3 and 4.
31. Nicholas and Paranavitana,[2] p. 299
32. B. Gunasekera (ed.), *Rajavaliya, or A historical narrative of Sinhalese Kings ...*, Government Printer, Colombo 1900, p. 212. Chilaw is a port some forty miles north of Colombo; Wanni is north of Anuradhapura; Sabaragamuwa is a province east of Colombo.
33. Ibid. The Rajavaliya is a sixteenth century work, in historical authority next to the *Mahavamsa*[8].
34. 'The voyage and travell of M. Caesar Fredericke, Marchant of Venice, into the East India and beyond the Indies ...' in Hakluyt's Voyages (with an introduction by John Masefield, Everyman's Library, Dent/Dutton, London, vol. iii, p. 224. Where necessary, the English spelling of the original has been modernized in this article.
35. Ibid.
36. Nicholas and Paranavitana,[2] p. 308.
37. Caesar Fredericke[34], p. 205.
38. Nicholas and Paranavitana[2], p. 36.
39. Goldsmiths including pearl enhancers are called 'asar' in the Tamil language; meaning 'artificer'. They are called 'naide' in Sinhala caste-structure. See the two lists of caste-stratification in Ralph Pieris, *Sinhalese social organization; the Kandyan Period*, University Press, Colombo, 1956.
40. Caesar Fredericke[34], p. 227.
41. Cited in R.L. Brohier[12], p. 49.
42. Ibid. p. 46.
43. Ibid.
44. Ibid.
45. S.E.N. Nicholas[16], p. 49.
46. Ibid.
47. L. Thamilvaanan, *Thamilaka Mavatta Nool Varisai; Chidambaranar Mavattam* (in Tamil) (District Gazeteers of Tamil Nadu Series; Chidambaram District), Manimekalai Publications, Madras, 1986, p. 68.
48. The present writer is working on an extensive history of gems and gemcrafts in Sri Lanka from which the present article is an excerpt.

[Manuscript received 28 May 1993]

Siberian sapropelic coal: a unique type of workable jet

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Abstract

The composition and workable properties of sapropelic coal from Eastern Siberia and referred to as 'jet', is discussed. Apart from Eastern Siberia, jet is found in other parts of the former USSR, in the Crimea, the Caucasus, Kamchatka, Sakhalin and Central Asia. Jet from the Caucasus, the Crimea and Eastern Siberia was used mainly for the manufacture of artifacts. In the 1930s, for about ten years, a jet industry existed in the USSR aimed at the production of consumer and industrial goods from Siberian sapropelic coal. Interest in certain types of jet for the manufacture of artifacts has now reawakened.

Introduction

In 1987 a book by Helen Muller entitled *Jet* was published by Butterworths[1] and was translated into Russian by the author. Muller collected information on jet from the UK, France, Spain, Germany and the USA but did not have access to information on Russian jet. This is the reason why the present author, a senior scientist of the Institute of Fossil Fuels, decided to study the history of jet working in the former USSR. In Moscow and Irkutsk a jet industry using the workable jet from deposits of Siberian sapropelic coal was organized, which operated for ten years. At other times jet-working centres existed in the Caucasus and the Crimea. The industry was engaged in the production of consumer goods, industrial goods and jewellery.

Terminology

In 1934 the Russian petrologist Y. Zhemchuzhnikov wrote the following about jet:

> Perhaps it is difficult to find another fossil fuel, which is associated with so many false and vague concepts as jet. Even the definitions of this 'mineral' in the various encyclopedias, reference books and handbooks are very different and often contradictory. The essential characteristics of this type of coal are hardly ever given. Therefore, this material under the name 'jet' (author: Siberian sapropelic coal), which is used in industry, has nothing in common with the jet known for many centuries in different countries.[2]

The Siberian sapropelic coal having the characteristics of workable jet, is basically different from true jet. Classical jet is a compact, hydrocarbon impregnated black wood (vitrain would be more precise petrologically) having a conchoidal fracture and an attractive lustre. It is easily worked and polished. These properties may be due to the bituminization of the original raw material.

True jet consists of carbonaceous fragments of the ancient conifer genus Araucarioxylon subjected to bituminization[3,4]. The wood had been bituminized by the permeation of hydrocarbons. In the Siberian sapropelic coal referred to as 'jet', there are virtually no traces of any woody

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structure and it consists entirely of components of sapropelic origin.

Sapropel is an unconsolidated mud or mire with the consistency of jelly and is composed of plant remains, chiefly algae, which have putrefied in anaerobic conditions on the beds of shallow lakes or seas. Sapropelic coal (or sapropelite) is a coal originating from these muds and includes the varieties cannel, boghead and torbanite. Among the vast deposits of sapropelic coal in eastern Siberia are the jet-sapropelites which differ from the coals in their compact texture, low ash content, conchoidal fracture, brownish colour and brown streak.

Some characteristics of Siberian jet or jet-sapropelite.

Pieces of Siberian jet had been found in the vicinity of Irkutsk for many years, and by the end of the nineteenth century several dozen tons had been taken to Irkutsk. Here the cathedral of the Virgin of Kazan was built, containing a remarkable icon. Its panels were decorated with jet and adorned with gold and silver. Carved ornamentations of jet embellished the interior and also some exterior parts of the cathedral. Skilful local craftsmen fashioned chibouks (long Turkish tobacco pipes), spoons and food bowls from jet, and the peasants took chips of jet and burnt them as substitutes for candles and kerosene lamps. The first deposit of workable sapropelic coal - Siberian jet - was discovered in the Irkutsk coal basin near the settlement of Matagan in 1931.

The 'jet' in the deposit rarely consisted of the finest material. There were significant components of sapropelic coals of different kinds, heterogeneous carbonaceous rocks, combustible shales, and bogheads of different ash contents, cleavages and densities. In a sizeable lump of good quality Matagan jet it was not possible to distinguish any signs of cleavage or any other break in its uniform structure.

The jet-bearing beds occurred in two main horizons in the sedimentary succession - an upper and a lower. Both upper and lower jet-bearing beds consisted of sapropelic formations different in density and hardness and presented a gradual transition from a hard and compact mass to an evidently shaly structure. Jet suitable for working was excavated from the Matagan field and freed from adhering shaly material with an axe. The jet occurred in the form of plates, 20 to 25cm thick, up to 1m wide and 2m long. After some time, a dried slab of jet became so hard that it could not be cut with an axe, but only broken into irregular pieces displaying conchoidal fracture and a dull lustre.

The Siberian jet is generally a beautiful black and leaves not a black but light brown, almost yellow streak on a porcelain plate. In places pieces of blackish-brown and brown jets with spots have been found in the coal beds.

Siberian jet is characterized by a plasticity eminently suitable for working. Thin plates were easily folded. Such a plate when heated to 90-100°C was so soft, that under slight pressure it could be folded into a ring or turned into a spiral. Heated jet-sapropelite was very easily worked with various cutting, planing and drilling tools. The characteristic plasticity and elasticity were especially valued by the master craftsmen because they could cut and turn the finest sculptures and bas-reliefs from the heated jet, and their tools for such fine work were specially adapted for these properties.

Siberian jet appears to be resistant to air and water and was not affected by 50 per cent sodium hydroxide at room temperature, nor by 35 per cent hydrochloric acid at 80°C. Sulphuric acid began to react with it at concentrations above 50 per cent. Nitric acid reacted with it below 0°C at concentrations above 20 per cent. Ethanol and acetone did not react with the jet below zero, but benzene, toluene, ether and chloroform dissolved it.

Plates of jet could be glued together and

also to wood and similar materials by the use of simple joiner's glue or waterproof adhesive. Jet could also be decorated with many paints or lacquers, and some glazes adhered to it very firmly. Thus Siberian jet has shown itself to be an extremely adaptable material.

Chemistry and petrography of Siberian jet

The Siberian jet is an end member of a series of sapropelic coals. Simple and approximate analyses of jet samples have given the following results: moisture 0.94-1.4%; volatiles 71.3-73.7%, coke 14.0-15.3%, ash 11.8-12.0%. The composition of the organic matter of Matagan jet was: carbon 61.5-72.7%, hydrogen 9.1-9.6%, oxygen 15.5-25.4%, and nitrogen 2.4-3.0%.

Some physical properties of Siberian jet are as follows: density 1.1-1.22g/cm^3, Mohs' hardness 2.5-3.0, limit of durability (kg/cm^2) on compression 650-1100, on expansion 110-154, on winding 100-325. The shock velocity (kg cm/cm^2) is 5-6.

In a transparent microscopic section, the Matagan jet shows a basic mass of horizontally orientated clots of sapropel of flattened lenticular shape and slices of dispersed thin threads of darker organic matter. In the basic material indistinct, yellow bodies without sharp contours were observed, but their identity is unknown. They are probably algae of the genus Pila, which had undergone partial decomposition. Perhaps the yellow, oval bodies were a product of coagulation of the sapropelic constituent. In any case, the pure, sapropelic character of the Matagan jet is evident.

It is interesting that Y. Zhemchzhnikov, who recognized the useful qualities of Matagan sapropelic coal, was disinclined to call it 'jet', because the former had been closely associated with algae and not with trees. Incidentally, as regards technological properties, foreign as well as Russian jets of mixed humus-sapropelic nature are quite different from Siberian jet, because the former are more fragile and not suitable for the manufacture of large items. (Jet had been imported to Russia from England during the New Economic Policy (NEP), before the Siberian jet deposits had been discovered.)

Articles made from Siberian jet

Fig.1. Cigarette case of Siberian jet which belonged to V. Petrov. *c.* 1933

Matagan sapropelic coal has received its reputation as an important workable material as a result of the work of a group of engineer-innovators headed by the mining engineer V. Petrov[5]. They laid the foundation of the jet industry based on the Siberian sapropelic coals of the Matagan deposits. In consequence, the factory 'Gagat' (Jet) was built in Moscow, and several 'Artels' (Association for common work) such as 1st May, Medsanlabor, Universalnye izdeliya and Utiltokar sprang up. At these enterprises a large range of more than 70 different artifacts was produced. These included inkstands (Figure 2), caskets, tobacco pipes, cigarette cases (Figure 1), soap containers, buttons, vases, candlesticks, chess sets, salt cellars (Figure 3), knife handles, forks, walking sticks and umbrella handles. In addition, master engravers also made from Siberian jet a range of ornaments including rings, beads, pendants, cameos and gems (Figures 4a, b and c).

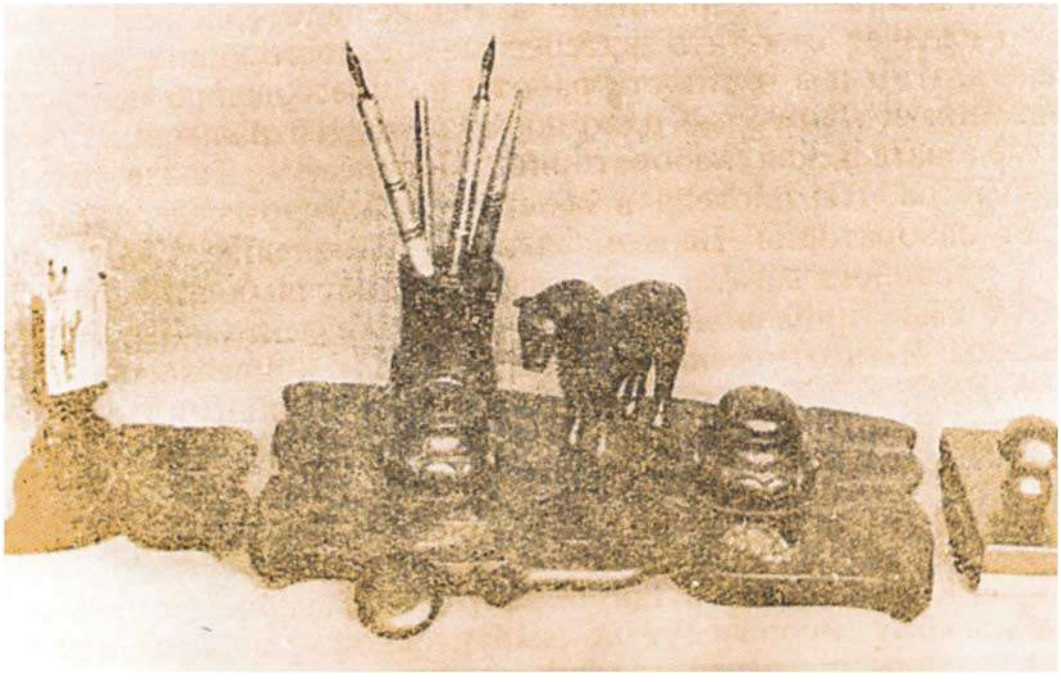

Fig.2. Inkstand of Siberian jet made by the factory 'Gagat'

The Artel '1st May' manufactured jet ornaments which found a ready market with fashionable women in France, Germany and the USA. Francs, marks, and dollars to the total sum of 50 000 roubles were transferred quarterly to the Artel account. Such a sum in the 1930s was very considerable.

Fig.3. Salt cellar of Siberian jet

Siberian jet has attracted the attention of scientists and engineers because of its resistance to acids and alkalis and its dielectric properties. Research teams have studied the replacement by jet of non-ferrous metals and their alloys such as copper, aluminium, type metal, brass and Babbit's metal.

The industrial concern 'Metallob'edinenie' succeeded in saving several dozen tons of pure copper by using jet in the manufacture of 300 000 door handles. The concern 'Poligraphob'edinenie' ordered 600 tons of jet to produce print type. The workshops of the trust 'Promsviaz' produced jet panels for radio equipment. In addition to Moscow, there were jet factories in the Siberian towns of Irkutsk and Cheremkhovo.

Unfortunately, by 1939 the jet supplies in the Matagan deposit were completely exhausted, and the jet industry had to find other raw material. The Burtin jet deposit situated 70km to the North-West of Irkutsk

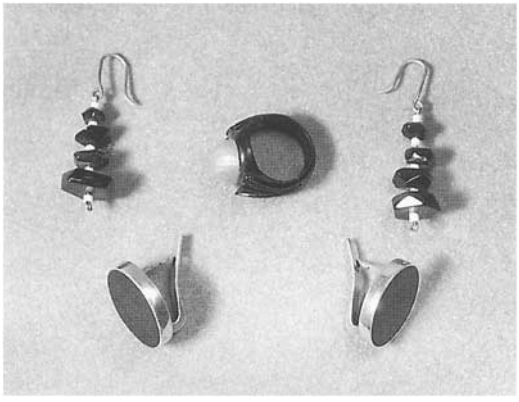

Fig.4a. Jet jewellery. Jet ring with agate and two types of earrings

Fig.4b. Siberian jet ring with agate

was urgently inspected and geologists estimated its jet supplies to be 30 000 tons. Jet in this new deposit differed from the Matagan jet in hardness, but nevertheless yielded good quality articles.

Beds of excellent jet were also found in the Khakharei deposit in the Irkutsk coal basin. However, the Second World War started soon after, and put an end to the jet industry on a large scale in the USSR.

Fig.4c. Two bracelets with Caucasian jet

Conclusion

Over half a century has passed since Russian jet workshops ceased to function and in the popular domain the kind of artifact once made in jet is now made with synthetic polymers. Nowadays it is expedient to use the Siberian jets only in the traditional way for a specialized market in personal ornaments and other carved items[6], although there is enormous potential for new sources of jet-sapropelite among the coals in the remote regions of eastern Siberia.

Acknowledgements

The author is greatly indebted to Mrs Helen Muller who showed great interest in the history of Siberian jet, and to Yaroslavna Petrova, the daughter of the mining engineer V. Petrov. She presented the material about the Siberian jet, which belonged to her late fathers to the photographer Serge Ivanov, who took the photographs.

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A preliminary investigation of peridot from Vietnam

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Abstract

Gem-quality peridot is being obtained from two areas in Vietnam. This article reports on the gemmology of that material being mined in Lam Dong Province. Classical gem testing procedures reveal properties consistent with those reported in the gemmological literature for peridot from other sources and none was found to be diagnostic of this particular locality.

Introduction

Peridot is a gem material whose use dates back to antiquity. It is first documented from the island in the Red Sea known variously as Zeberget, Zabargad or the Island of Saint John (Webster, 1983). A very good and fairly recent report on this deposit and the gemmology of its peridot can be found in Gübelin (1981). Although small amounts of this material still occasionally appear in gem markets, apparently no commercial mining has been undertaken since nationalization in Egypt under Nasser in the 1950s (Koivula *et al.*, 1993a). In terms of volume, today's major commercial sources are the San Carlos Apache Reservation in Arizona, USA (Koivula, 1981; Koivula *et al.*, 1992a) and China (Koivula and Fryer, 1986), while Myanmar (Burma) continues to produce limited quantities of stones that are exceptional both in size and quality (Kammerling *et al.*, 1994). Other commercial or potentially commercial sources of peridot include Ethiopia (Koivula *et al.*, 1993b), New Mexico, USA (Fuhrbach, 1992), Sri Lanka (Gunawardene, 1985) and Tanzania (Stockton and Manson, 1983). Peridot from other localities is occasionally cut into gemstones, including material from pallasitic meteorites (Sinkankas *et al.*, 1992).

Background to study

While on a visit to Vietnam in November 1992, one of the authors (RCK) visited the gemmology department of the Research Centre for Industrial Mineralogy, Hanoi University. Here he was shown a wide assortment of gem materials that had been recovered from areas throughout the country and that were felt by university staff members to have commercial potential. Among this collection of rough gemstones were what appeared to be several hundred carats of rough peridot.

Additional information about Vietnamese peridot was subsequently provided in July 1993 by Saverio Repetto of the Gemological Institute of Vietnam (GIV), a Hanoi-based joint venture firm involved in the purchasing, cutting and marketing of gem materials. According to Saverio Repetto, two deposits were discovered in mid-1993, one in Lam Dong Province, southern Vietnam, and another in Gia Lai Province, central Vietnam, near the Cambodian border (Figure 1). In their first few weeks of operation, the two localities reportedly produced an estimated 100-200kg of peridot.

On a subsequent visit to Vietnam in

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Fig. 1. Local miners remove peridot from what would appear to be a gem-encrusted nodule of basalt in Gia Lai Province, central Vietnam, near the border with Cambodia. *Photo courtesy of Saverio Repetto.*

November 1993, one of the authors (RCK) learned that the deposit near the Cambodian border was at the time being mined by the local populace. The rough peridot was reportedly taken by vehicle over rough roads from the mining area to the city of Pleiku where, the author was told, Thai buyers were coming to make purchases.

Current investigation

The test sample for this investigation consists of five faceted peridots ranging from 1.60 to 5.56 carats (Figure 2). These were provided by Saverio Repetto and are reported to come from the Lam Dong locality. Their properties, determined using standard gem testing equipment, are described below.

Appearance

All five stones were transparent. They ranged in hue from yellowish-green to brownish-green of low to moderate saturation in medium light to medium dark tones.

Refractive indices

RI readings were taken using a GIA GEM Instruments Duplex II refractometer and near-sodium equivalent light source. The values determined were α= 1.650, ß= 1.665-1.667 and γ= 1.687-1.688, with resulting birefringence of 0.037 to 0.038.

Pleochroism

Using a calcite dichroscope with a fibre-optic illuminator, weak pleochroism in very slightly brownish-green and yellowish-green was observed.

Absorption spectrum

A Beck desk-model prism spectroscope revealed iron-related absorption bands typical for peridot at approximately 453, 473 and 493nm.

Fig. 2. These five faceted peridots, ranging from 1.60 to 5.56ct are the study sample used in the current investigation. *Photo by Maha DeMaggio, GIA.*

Chelsea colour filter

When viewed through the Chelsea filter, all stones appeared yellowish-green.

Specific gravity

SG determinations by the hydrostatic weighing technique produced values ranging from 3.33 to 3.35.

Inclusions

The five specimens were examined microscopically in order to document their suite of internal features. As with peridots from other localities such as Egypt (Gübelin, 1981), Arizona (Koivula, 1981), China (Koivula and Fryer, 1986) and New Mexico (Fuhrbach, 1992), the geological mode of formation of Vietnamese peridot limits the types of possible inclusions that may be found therein. While not diagnostic of their Vietnamese source, some of these internal features may be considered gemmologically diagnostic of peridot in general. Following are descriptions of all those internal features noted in the present investigation.

'Lily pads': The one type of inclusion that is most characteristic for peridot from most localities is often referred to by gemmologists as a 'lily pad' inclusion. All five specimens in the test sample displayed these highly diagnostic inclusions (Figure 3).

'Lily pad' inclusions are actually cleavages that result from the rupturing of minute fluid-filled negative crystals, the filling usually being carbon dioxide and natural glass. They form as circular to ovoid planar discs, known as decrepitation halos, surrounding tiny whitish to transparent negative crystals that may appear dark brown to black under certain methods of illumination. These 'lily pads' form along the directions of imperfect cleavage in peridot and quite often behave as thin films, appearing brightly iridescent if illuminated from above (Koivula, 1981).

The majority of 'lily pad' inclusions observed in the Vietnamese peridots exhibited sufficiently high relief to be detected relatively easily using darkfield illumination. However, some had such low relief that they could go virtually unnoticed

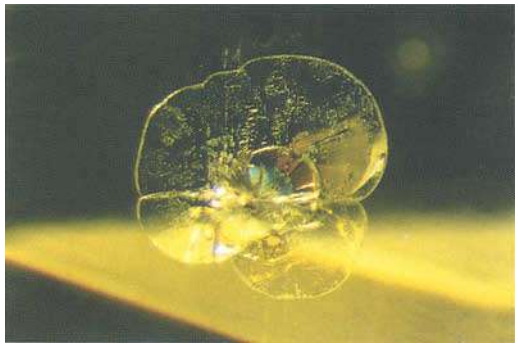

Fig. 3. This 1.1-mm 'lily pad' inclusion is typical of those found in Vietnamese peridots. *Photomicrograph by John I. Koivula, GIA.*

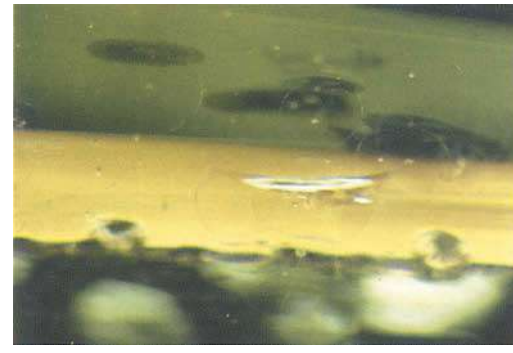

Fig. 4. These 'lily pad' inclusions are so thin as to be almost unnoticeable in darkfield illumination. Field of view approximately 3mm. *Photomicrograph by John I. Koivula, GIA.*

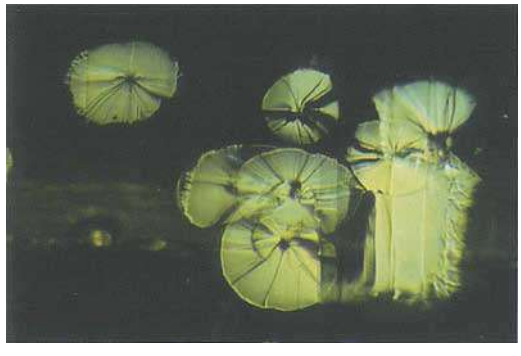

Fig. 5. In reflected fibre-optic light the 'lily pad' inclusions shown in Figure 4 behave as thin films, becoming very easy to see. Field of view approximately 3mm. *Photomicrograph by John I. Koivula, GIA.*

Fig. 6. White, smoke-like veiling is one of the internal characteristics noted in Vietnamese peridot. Field of view approximately 2.5mm. *Photomicrograph by John I. Koivula, GIA.*

(Figure 4) unless incident fibre-optic illumination was employed to take advantage of their thin-film reflectivity (Figure 5).

Smoke-like veiling: An internal feature perhaps best described as smoke-like veiling and already noted in peridots from San Carlos, Arizona (Koivula, 1981), Hebei Province, China (Koivula and Fryer, 1986), and Kilbourne Hole, New Mexico (Fuhrbach, 1992) was found in four of the test stones (see Figure 6). This feature is believed to result from incomplete solid solution-unmixing which occurs as the peridot is brought to the earth's surface and cools in the host (basalt?) – and visible strain caused by decorated dislocations (Kohlstedt *et al.*, 1976). These inclusions are easily recognized, always appearing as ghostly white flowing streamers when viewed with a combination of darkfield and pinpoint fibre-optic illumination.

One of the test samples, a 2.77ct pear-shaped stone of distinctly brownish-green colour (again, see Figure 2) contains sub-parallel dark brown bands (Figure 7). These are similar in appearance to some of the white veil structures described above, differing only in their colour. Their distinctly brown coloration may result from iron concentrated along dislocation zones, or from chemical alteration of the peridot.

Chromian spinel: Chromian spinel is a rel-

atively common type of solid mineral inclusion in peridot (Dunn, 1974). It crystallizes in the isometric crystal system and when seen as an inclusion generally appears as opaque, black octahedra or anhedral, rounded masses exhibiting reddish-brown coloration at thin edges. Distorted octahedra, some flattened to an almost tabular habit, are also encountered. These crystalline inclusions are typically surrounded by tension fractures that result from the expansion of the spinel against the host peridot. One such inclusion was noted in our test sample, exhibiting a slightly rounded but still recognizable isometric habit (Figure 8).

Biotite: The mineral biotite has been documented previously as an inclusion in peridots from other localities, for example, Myanmar (Burma) (Gübelin, 1974), San Carlos, Arizona (Koivula, 1981) and Hebei Province, China (Koivula and Fryer, 1986). In our test sample of Vietnamese peridots, two very small, translucent brown, euhedral, micaceous-appearing inclusions tentatively identified as biotite were observed.

Optically active intergrowth: In the 2.77ct sample, an elongated, sharp-edged intergrowth zone was detected which was virtually undetectable in darkfield illumination, but was clearly visible in polarized light, displaying vivid interference colours (Figure 9). The extremely low relief exhibited in darkfield lighting indicates that the zone has similar if not identical optical properties to those of the surrounding peridot. The image noted in polarized light, however, proves that the optical orientation of the intergrowth zone differs from that of the host. The specific nature of this intergrowth zone is unknown. It is possible that it resulted from solid solution unmixing or chemical alteration, dendritic intergrowth or perhaps a form of twinning. Similar optically active areas have been observed in peridot nodules from Arizona although the authors are not aware of this feature having been documented previ-

Fig. 7. Subparallel dark brown bands, similar to some of the white veil structures shown in Figure 6, were observed in one of the test samples. Field of view approximately 2mm. *Photomicrograph by John I. Koivula, GIA.*

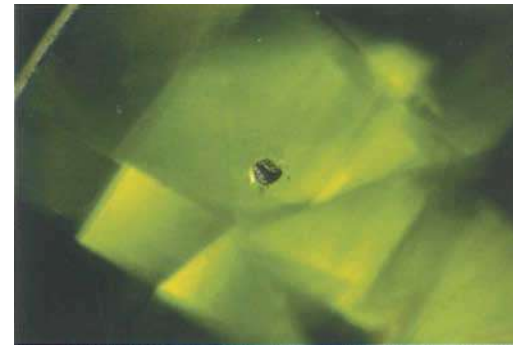

Fig. 8. Only one rounded octahedron (0.15mm) of what appears to be chromian spinel was noted in the Vietnamese peridots. Note the slightly reddish-brown colour at the edges of the inclusion. *Photomicrograph by John I. Koivula, GIA.*

Fig. 9. An optically active intergrowth zone, displaying vivid interference colours in polarized light, was observed in one of the test stones. Field of view approximately 4mm. *Photomicrograph by John I. Koivula, GIA.*

Table I: Gemmological properties of Vietnamese peridot[1]

Diaphaneity:	Transparent
Colour:	Medium light to medium dark, yellowish-green to brownish- green of low to moderate saturation
RI:	α= 1.650 β= 1.665-1.667 γ= 1.687-1.688
Birefringence:	0.037 - 0.038
Pleochroism:	Weak, very slightly brownish-green and yellowish-green
Chelsea filter:	Yellowish green (negative reaction)
Absorption spectrum:	Diffuse bands at 453, 473 and 493nm
SG:	3.34 ± 0.01
Magnification:	'Lily pad' inclusions surrounding negative crystals; smoke-like veiling; chromian spinel(?); biotite mica(?); optically active intergrowth.

[1]Based upon examination of five faceted stones from Lam Dong Province, ranging from 1.60 to 5.56ct.

ously in photographs.

The gemmological properties are summarized in Table I.

Chemical analysis

Quantitative chemical analysis by energy-dispersive X-ray fluorescence (EDXRF) was performed on one specimen. This indicated the presence of magnesium, iron and silicon – essential components of peridot $(Mg,Fe)_2SiO_4$ – as well as nickel, chromium, manganese and calcium. This chemistry is consistent with that of peridot from other localities (see, for example, Fuhrbach, 1992).

Based on the refractive indices and the direct correlation of RI and chemical composition in this material (Mg- and Fe-contents) (see Deer *et al.*, 1992), the Vietnamese peridots consist of approximately 10 per cent fayalite (Fe_2SiO_4) and 90 per cent forsterite (Mg_2SiO_4).

Discussion

Vietnam has been widely recognized as a commercial source of gemstones only in the past few years, first entering this arena with its rubies and pink to purple sapphires (Kane *et al.*, 1991) and holding potential as an economically viable source of other gems including sapphires (Koivula *et al.*, 1992b; 1993c) and now peridot.

The peridot from Lam Dong Province in southern Vietnam exhibits gemmological properties that are similar to those of peridot from other localities around the world and their internal features are typical of peridots from basaltic volcanic environments. We have not as yet discovered any features or properties which are unique to the peridots from Lam Dong Province.

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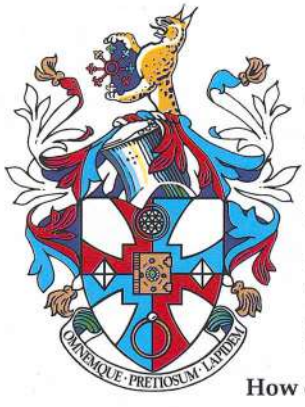

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Some observations on a gem-quality synthetic yellow diamond produced in the region of Vladimir (Russia)

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Abstract

The gemmological properties of a synthetic yellow diamond reported to come from Vladimir, east of Moscow, Russia, are described. The infrared spectrum of the synthetic resembles that of a natural yellow diamond but growth patterns revealed by fluorescence in ultraviolet radiation are distinctive.

Introduction

In December 1993 the Istituto Gemmologico Italiano (IGI) was presented with a faceted synthetic yellow diamond weighing 0.15ct by Fabio Pignataro, a gemstone dealer. The diamond was stated to come from the region of Vladimir east of Moscow in Russia. This is a possible new source of synthetic diamonds and a brief summary of our gemmological investigation is given below.

Colour and colour-zoning

The colour of the stone is an intense brownish-yellow when observed in both reflected and transmitted daylight and in strong fibre optic light (Figure 1). When exposed to a mercury lamp, the diamond displayed a strong green overtone, evenly distributed on the pavilion facets (Figure 2). Probably such a colour arises in response to the intense green emission component of the mercury lighting.

This phenomenon has also been observed in many natural yellow (fancy) diamonds and is not a distinctive property of synthetics.

Using a gemmological microscope, an angular grain line separating a narrow colourless zone from another yellowish-brown area may be seen (Figure 3). The intensity of colour in the brown zone varies when the diamond is rotated around an imaginary axis perpendicular to the table of the stone (Figure 4). The simple pattern of two intersecting graining lines, corresponding with the distribution of the colour zoning, is different from the graining seen in Russian diamonds from Novosibirsk by Shigley *et al.* (1993). However this simple pattern has been observed in natural yellow diamonds in our laboratory.

Inclusions

The Russian synthetic diamond contains a cloud of tiny, grey, poorly-reflecting 'pinpoint' inclusions (Figure 5), not obviously oriented. Some of these small inclusions intersecting the table facet of the diamond were analyzed using a SEM-EDS system with quite surprising results (Figure 6). In addition to iron and nickel, a small quantity of caesium was detected. (The chlorine recorded in the EDS spectrum is probably the result of contamination.) Both iron and nickel have been previously reported (Shigley *et al.*, 1987, 1993; Moses *et al.*, 1993) and derive from flux material used in the crystal synthesis. The origin of the caesium is not clear. It may have been a component of the metal alloy, or it may be a contaminant from a previous experiment

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Fig. 1. The 0.15 ct diamond of intense brownish-yellow colour from Vladimir, east of Moscow. Magnification 5x.

Fig. 4. As the stone is slightly rotated (compared to the position of Fig. 3) the longer grain line appears to be masked by a dark brown rectangular area. Diffuse and oblique illumination, magnification 6x.

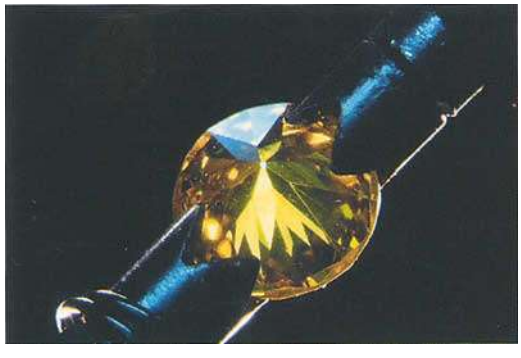

Fig. 2. When illuminated with the mercury light, the diamond exhibits a green overtone over the pavilion facets. Oblique illumination, magnification 5x.

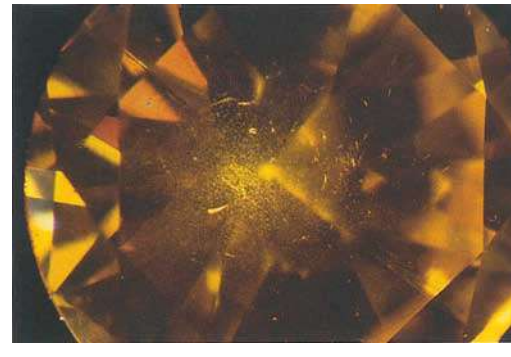

Fig. 5. Inside the diamond, a cloud of tiny greyish pinpoint inclusions is visible. Dark-field illumination, magnification 10x.

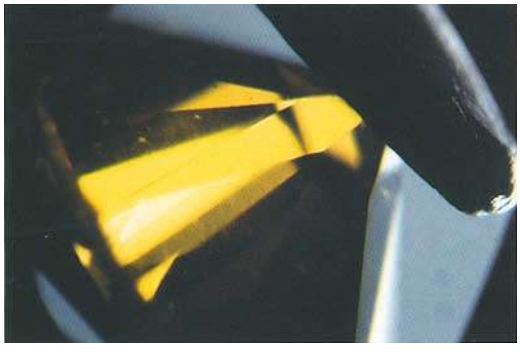

Fig. 3. Near colourless zone limited by two intersecting grain lines is visible through the pavilion facets. Diffused-transmitted light, magnification 8x.

in the high pressure cell. Or again, since the small metal inclusions intersecting the diamond table are softer, their surfaces lie slightly below the table, and as small 'pits' they may have trapped some possible coating material. It does not seem likely that a rare element like caesium was a component of the solutions used to release the diamond from the flux-alloy or during its cutting and polishing.

In spite of the presence of a cloud of metallic inclusions the diamond was not attracted by a simple magnet, suggesting that the magnetic attraction, previously reported in the General Electric (Koivula *et al.*, 1984), Sumitomo (Shigley *et al.*, 1986)

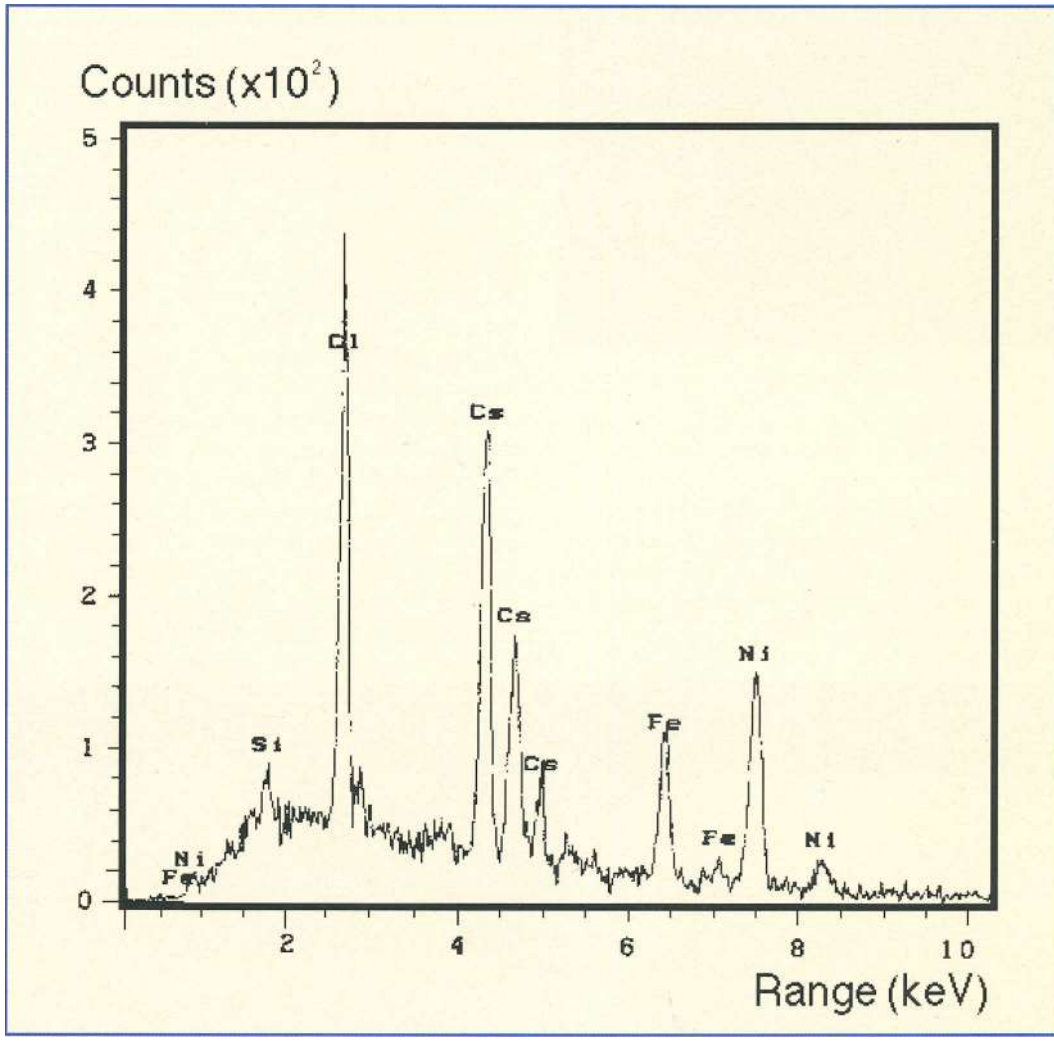

Fig. 6. SEM energy-dispersion graph showing the peaks of iron, nickel and caesium present in the metallic inclusions. (The peak on the left – chlorine – is due to contamination.)

and De Beers (Shigley *et al.*, 1987) synthetic diamonds, does not depend solely on the presence of metallic inclusions.

Luminescence phenomena

One of the most prominent characteristics of this Russian synthetic yellow diamond, which is useful in distinguishing it from natural diamonds, is the arrangement of distinct growth sectors which strongly luminesce when exposed to ultraviolet rays or to an electron beam (see Ponahlo, 1992). Through the table of the diamond it is possible to see a cross-shaped area which fluoresces greenish-yellow to both long- and short-wave UV radiations (Figure 7), the response to long wave UV being slightly stronger. Outside the central cross-shaped area the stone is inert and no other growth sectors are visible.

The cathodoluminescence pattern (Figure 8), matches the UV fluorescence in the central zone of the stone but also reveals lines in a square pattern arranged

Fig. 7. The square sectors and the four arms arranged to form a cross pattern are clearly visible due to their intense fluorescence in UV radiation. Magnification 5x, ten minutes exposure.

at forty-five degrees with respect to the main arms of the central cross. It was not possible to determine which of the visible lines or arms represented cubic or octahedral growth zones.

In conclusion, cathodoluminescence analysis indicates the presence and shapes of different growth sectors (Shigley *et al.*, 1993) and helps to indicate the crystal as synthetic. Also the UV luminescence pattern of this diamond leads to the same conclusion.

Spectroscopy

The diamond was cooled to 273K and then to the spray refrigerant temperature (240K), but no absorption bands or lines were visible with a hand-held spectroscope.

Measurement of the infrared spectra in a Fourier Transform infrared (FT-IR) spectrophotometer (see Figures 9 and 10) revealed that the diamond is a mixture of Types Ib and IaA, with the following absorption features in the 'nitrogen region': 1132cm^{-1}, 1344cm^{-1}, (related to Ib nitrogen impurities) and 1282cm^{-1} (related to IaA

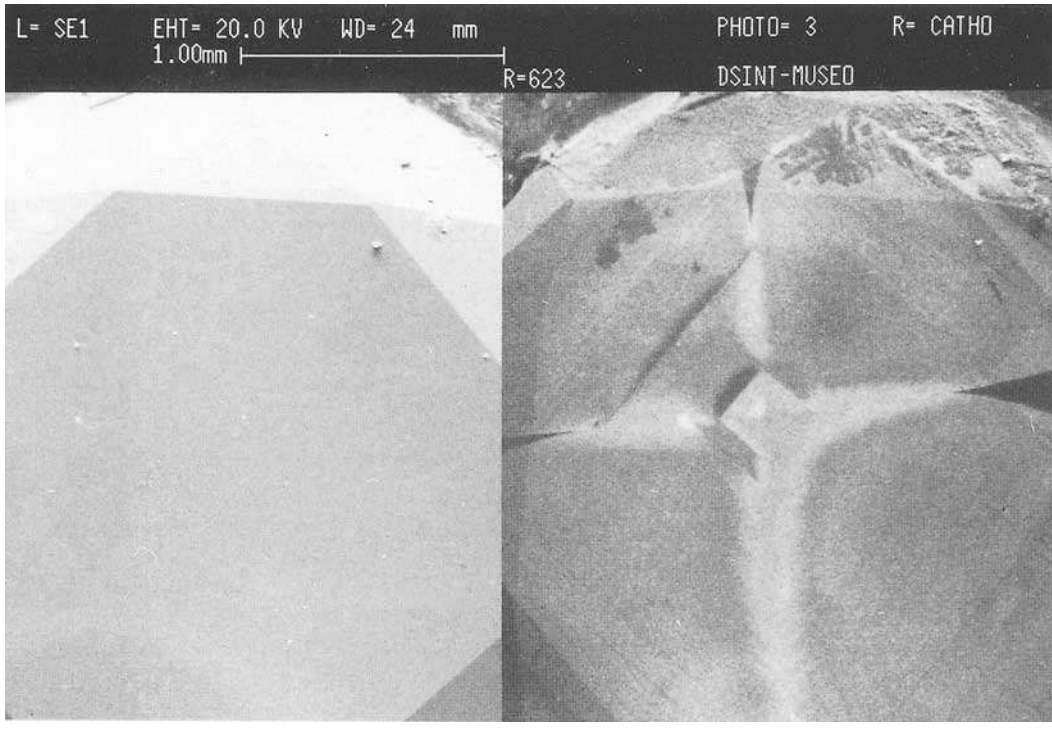

Fig. 8. Two SEM images of the synthetic diamond: (left) secondary electron image of the diamond table; (right) cathodoluminescence topograph: symmetric arrangement of square growth-sectors. The brightest central 'cross-shaped' area closely matches the UV luminescence pattern.

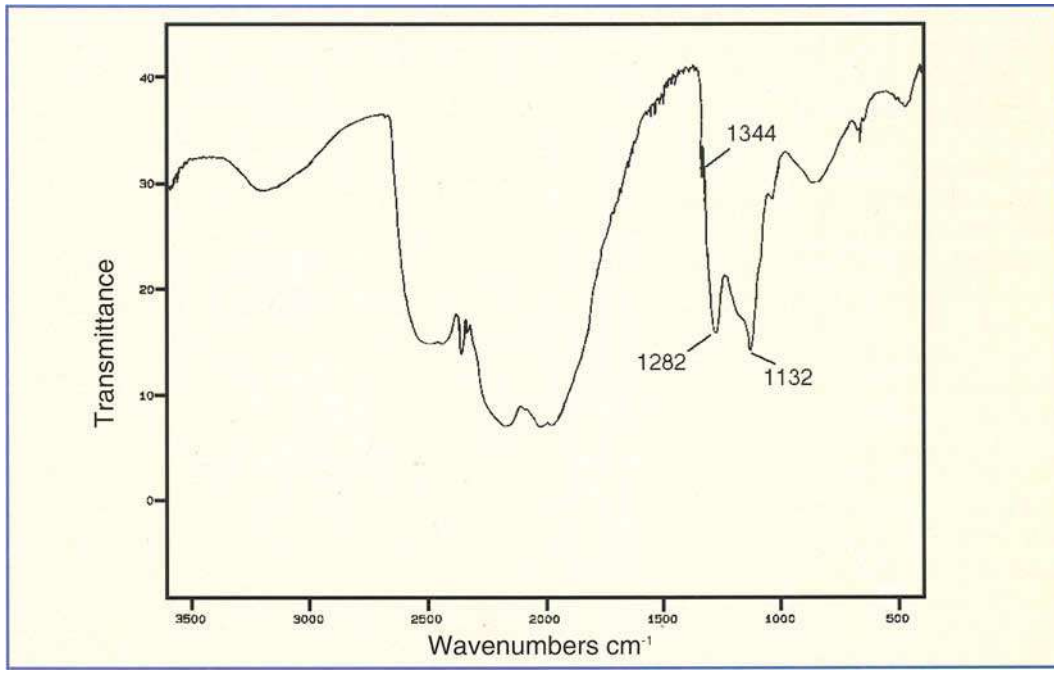

Fig. 9. Mid-infrared absorption of the yellow synthetic diamond showing the Ib and IaA N-related features.

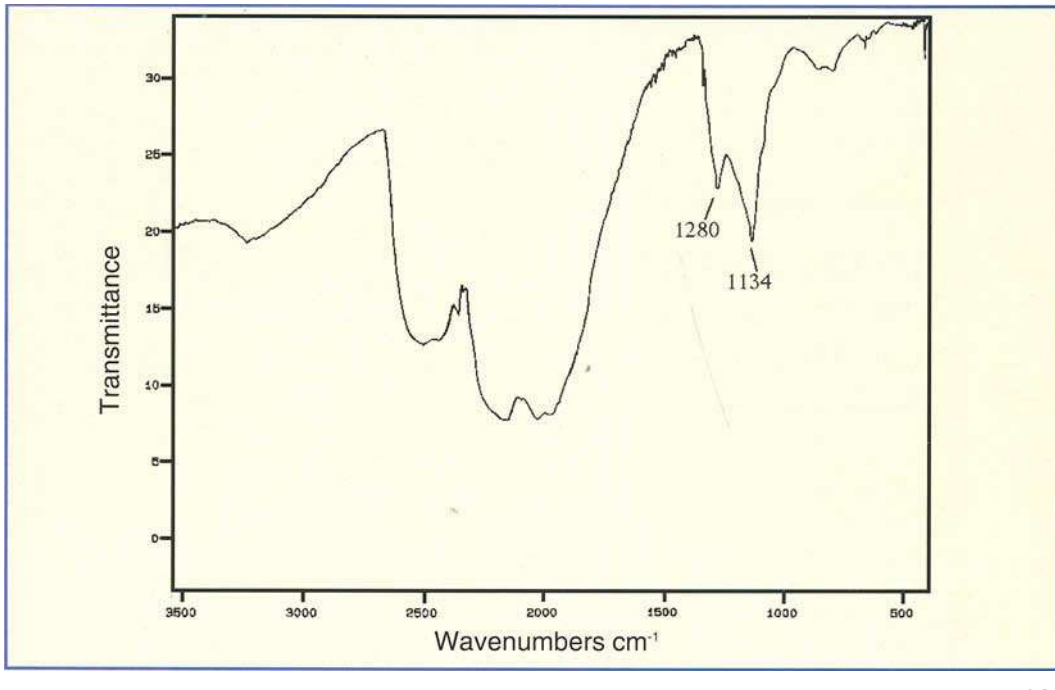

Fig. 10. Mid-infrared absorption of a natural yellow diamond. Note the strong similarity with the spectrum of the studied diamond.

nitrogen impurities). This pattern is very similar to those reported by Shigley *et al.* (1993) and Moses *et al.* (1993), for synthetic diamonds grown in Novosibirsk.

Conclusions

Although the Russian gem-quality synthetic diamonds coming essentially from Novosibirsk (Southern Siberia) have been known since 1991 (Koivula and Kammerling, 1991), this is the first gemmological examination of a synthetic diamond produced in the Region of Vladimir, east of Moscow.

Documentation of the properties of this synthetic diamond - e.g. pinpoint metal inclusions, colour zoning, UV fluorescence and infrared absorption spectrum - indicates that the diamond was manufactured by a process very similar to that used in Novosibirsk.

Perhaps the most important and diagnostic gemmological property of this diamond is the strongly zoned UV fluorescence related to the different growth sectors which does not resemble anything seen in natural stones.

Acknowledgements

The author wishes to thank Willy Andergassen for all the FT-IR work. Thanks are also due to Benito Piacenza and to R. Giomo who tested the specimen with the SEM. The pictures in this paper are due to the kindness of Armando Piana.

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Letters

From N.P.G. Sturman

Dear Sir

Treated amber

With reference to the Letter from Richard Hughes (*J. Gemm.*, **24**(3), 185-6) regarding the article 'A note from the Bahrain Laboratory - 3' (*J. Gemm.*, **24**(1), 42-4), I quite agree with his observation that 'the colour of amber may darken over time' as I have seen some examples of amber with a darker surface colour and lighter interior colour that I most probably would not call surface-treated amber. All these examples have been what I would consider as old, possibly even antique, pieces (by this I mean the period that has passed since the pieces were fashioned, as all amber is antique in age!) and, as such, I believe the exposed (surface) colour has indeed altered without intentional interference. In other words, the colour was not altered on purpose to improve the appearance.

However, the visual gemmological features of the amber we discussed in the article were so different from untreated amber examined in both this laboratory and the Gem Testing Laboratory of Great Britain and of a type that was evidently fashioned recently that, in our opinion, we had no alternative but to call it surface colour enhanced (treated) amber. I certainly would not have purchased it as natural *untreated* amber, if it was offered to me as a potential customer. Therefore, it is our opinion that in this case and in some other examples we have seen (see *J. Gemm.*, **23**(7), 398-9), the surface colour has in some way been artificially altered on purpose.

We would appreciate receiving any information about this subject from individuals or companies involved in modern enhancement methods and would be interested in purchasing samples of treated material, modern synthetics, etc., for our reference collection.

Yours etc.
Nick Sturman
Advisor, Bahrain Laboratory
1 October 1994

From W.W. Hanneman

Dear Sir

On the glass filling of diamonds

In his interesting two-part article on diamond-filling glasses (*J. Gemm.*: Part I, 1993, **23**(8), 461-72; Part 2, 1994, **24**(2), 94-103), Dr Nelson spoke of the difficulty of measuring the optical properties of exploration batches of these materials. These problems also hold true for high RI gem materials. I would like to offer a simple solution.

Take a small piece of the specimen, polish two facets meeting at an angle of 25 or 30 degrees and, using a Hanneman-Hodgkinson refractometer, determine the index of refraction for any wavelength of visible light that one might wish. It will also allow one to measure dispersion and the magnitude of birefringence in doubly refracting materials. Details are available from the address below.

Yours etc.
W.W. Hanneman
Hanneman Gemological Instruments,
Castro Valley, CA 94546, USA
13 September 1994

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Abstracts

Diamonds | Gems and Minerals

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Diamonds

Characterisation study of diamond and diamond-like carbon.

D.P. DOWLING *et al.* *Surface & Coatings Technology*, **53** (2), 1992, pp 177-83 (Sep 15), 11 figs, 1 table, 19 refs.

A comparative characterization study of diamond and diamond-like carbon films deposited using plasma-enhanced CVD is presented. The films were examined using scanning electron microscopy (SEM), X-ray diffraction, X-ray photoelectron spectroscopy (XPS), Auger electron spectroscopy and Raman spectroscopy. As a result of these studies structural and chemical information was obtained on the carbon films. The SEM examination indicated the presence of high levels of stress in the diamond films. The ability of XPS and Raman spectroscopy to distinguish between diamond-type carbon (sp^3 hybridised) and graphitic carbon (sp^2 hybridised) is demonstrated. (Author's abstract) D.P.D.

Potassium in clinopyroxene inclusions from diamonds.

G.E. HARLOW AND D.R. VEBLEN. *Science*, **251** (8), 1991, pp 652-5.

Analytical TEM, EPMA and single-crystal XRD data support the conclusion that high K contents, ≤ 1.5 wt.% K_2O, of some diopside and omphacite inclusions from diamonds represent valid clinopyroxene compositions with K in solid solution. This conclusion contradicts the traditional view which holds that K is too large to be incorporated in the pyroxene structure. These diopside and omphacite inclusions have a high degree of crystal perfection and anomalously large unit-cell volumes, and a defect-free structure is observed by TEM on K-bearing regions. These results imply that clinopyroxene can be a significant host for K in the mantle and that some clinopyroxene inclusions and their diamond hosts may have grown in a highly K-enriched environment. R.A.H.

Gem News.

J.I. KOIVULA, R.C. KAMMERLING AND E. FRITSCH. *Gems & Gemology*, **30** (1), 1994, pp 47-57, illus. in colour.

The International Colored Stone Association reported two attempts to pass cubic zirconia as diamonds; in one case the imitation was in a parcel of rough diamonds and was in the form of an octahedron and even had etched 'trigons'; the other case involved CZ baguettes and round brilliants salted in a parcel of similarly sized and cut diamonds.

Enhancements

Care is required with filled diamonds as heat from repairs can damage the filling as can also prolonged ultra-sonic cleaning. Long exposure to short-wave ultraviolet radiation caused discoloration. R.J.P.

ABSTRACTORS

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Diamonds and their sources in the Venezuelan portion of the Guyana Shield.

H.O.A. MEYER AND M.E. MCCALLUM. *Economic Geology*, **88** (5), 1993, pp 989-98, 5 maps.

Two sources are suggested for the diamonds. The secondary source is the 2000m thick Roraima group of Proterozoic age. The main sources probably are unknown Proterozoic kimberlites or lamproites in the Guyana Shield of the Amazonian craton. No evidence exists to support an African source. K.A.R.

Three generations of diamonds from old continental mantle.

S.H. RICHARDSON, C.D. CANHAM AND S.R. PUGH. *Nature*, **366** (6452), 1993, pp 256-8.

Major elements, Rb, Sr and Rb-Sr, Sm-Nd isotopic data are presented of peridotitic garnet, clinopyroxene inclusions in diamonds and macrocrysts from the Proterozoic Premier kimberlite. The peridotitic inclusion minerals have compositions reflecting an origin in harzburgite (clinopyroxene-bearing) assemblages. The harzburgitic garnet inclusions and kimberlite have Nd and Sr isotopic features consistent with an Archaean age (> 3000 m.y.) and a metasomatized mantle source. Lherzolitic garnet and clinopyroxene inclusions gave a preferred Sm-Nd isochron age of 1930 m.y. (~100 m.y. less than that of the nearby Bushveld complex) suggesting a link analogous to that between harzburgitic diamond formation and komatiitic magmatism in the Archaean. The last generation of diamonds (with eclogitic inclusions) was formed ~1150 m.y. ago prior to the kimberlite emplacement. R.K.H.

Solid carbon dioxide in a natural diamond.

M. SCHRAUDER AND O. NAVON. *Nature*, **365** (6441), 1993, pp 42-4.

The discovery of solid CO_2 in the IR spectrum of brown-yellow diamond of unknown location is reported. The CO_2 is presently at 5 GPa and must have been trapped at even greater *P* in the mantle corresponding with depths of ~220-270km. At these *P* free CO_2 should react with olivine and pyroxene. The survival of free CO_2 at depth indicates the presence of an environment of different mineralogy such as a fully carbonated metasomatic vein or a block of subducted sediment. R.K.H.

A new find of microscopic diamonds in metamorphic rocks: evidence that the high- pressure metamorphism in the Kokchetav massif was regional in scope.

V.S. SHATSKIY, N.V. SOBOLEV, A.A. ZAYACHKOVSKIY, Y.M. ZORIN AND M.A. VAVILOV. *Doklady*, Russian Academy of Sciences, Earth Sciences Section. **322** (1), 1992, pp 128-32.

The literature is reviewed and the geology is discussed. Chemical data are tabulated for garnets, pyroxenes and amphiboles. Two microphotos are shown, and the Raman spectrum of the diamond is given. The authors conclude that probably the Kokchetav massif was submerged in the mantle in a manner similar to the Dora Maira coesite-bearing rocks of the Alps. K.A.R.

Diamond inclusions in the rock-forming minerals of metamorphic rocks.

T.Y. YEKIMOVA, L.D. LAVROVA AND M.A. PETROVA. *Doklady*, Russian Academy of Sciences, Earth Sciences Section. **323** (2), 1992, pp 101-3.

The previous work is reviewed. The diamonds commonly occur in garnet, quartz, biotite, pyroxene, etc. The petrography and mineralogy are discussed. Four microphotos are shown. The work suggests that diamonds can be formed in the crust as well as the mantle. K.A.R.

Gems and Minerals

[On the mineralogical characteristics of ruby and sapphire of Xinjiang, China.] (Chinese with English abstract)

P. ABDUKADER AND L. WANG. *Journal of Mineralogy & Petrology (Kuangwu Yanshi)*, **13** (4), 1993, pp 68-74, 1 map.

Detailed mineralogical examination of rubies and sapphires from Xinjiang is reported. They have *D* 3.96-3.99 g/cm^3; hardness parallel to *c* 2034-2570 kg/mm^2 (Mohs 8.8-9.24), perpendicular to *c* 1947-2392 kg/mm^2 (Mohs 8.5-9.0); ε1.761-1.762, ω1.768-1.771; and unit cell parameters *a* 0.4756, *c* 1.2960 nm. Electron microprobe analyses gave SiO_2 0.06, 0.11; Al_2O_3 99.28, 98.71; Cr_2O_3 0.16, 0.70; TiO_2 0.02, 0.03; FeO 0.40, 0.37; MnO 0.06, 0.02; MgO 0.01, 0.05; CaO 0.00, 0.00; Na_2O 0.01, 0.00; K_2O 0.02, 0.01; Co 0.02, 0.01; Ni 0.01, 0.01; Totals 100.05, 100.02. Analyses are also reported for inclusions of rutile. Comparisons are made with ruby and sapphire from other localities. R.A.H.

Specific surface area and ultramicroporosity in polymorphs of silica.

M.A. BUSTILLO, R. FORT AND M. BUSTILLO. *European Journal of Mineralogy*, **5** (6), 1993, pp 1195-1204.

A detailed study of the specific surface area (SSA) and the volume of pores between 10 and 400 Å (ultramicroporosity or UMP) in different types of silica phases from different localities and geological settings is reported. It was found that small proportions of other minerals in the siliceous rocks can alter the SSA and UMP substantially. Opal-A (diatomite) has SSA 23.87m²/g and UMP 9.90%; opal-CT has 7.76-14.05 m²/g and 6.68- 8.50%; α-cristobalite has 1.93-2.43 m²/g and 1.27-1.52%; α-tridymite has 1.93-2.56m²/g and 1.05-1.62%. There is a loss of SSA and UMP in the diagenetic transformation opal A→opal-CT →opal-C (α-cristobalite). The host rock in which the silica phase is formed may play an important role in the SSA: e.g. opal-CT formed in a sepiolite rock has a greater SSA than opal-CT formed in a limestone. The UMP is characteristic of the silica phase, though in opal-CT this may vary in relation to the texture. R.A.H.

Jade in Switzerland.

H. GIESS. *Bull. Friends of Jade*, **8**, 1994, pp 1-46, 3 photos, 10 figs, 3 maps.

Nephrite sites in Switzerland are described with notes on early settlements and the artefacts they produced. No jadeite has been found *in situ*. M.O'D.

A gem collection never before published. The Dactyliotheca of H.H. Pope Leo XII.

G. GRAZIANI, M. MARTINI AND P. EVANGELISTA. *Zeitschrift der Deutschen Gemmologischen Gesellschaft*, **43** (1/2), 1994, pp 49-72, 2 tables, 2 illus. in black-and- white, 3 in colour, bibl.

The collection containing 388 gems, ornamental stones and rings was given by H.H. Pope Leo XII to the Mineralogical Laboratory of the 'Archiginnasio' of the ancient Rome University 'La Sapienza' in 1824. Details have not been published before. The items have been divided on basis of cut and shape, later identified in contemporary catalogues. Precise description has shown some differences between the antique and modern identification. Some theories concerning interpretation of some marks in a ring and two collets are discussed, as are country of origin of the rings and of the collection as a whole. E.S.

Achat als Nebenproduct der Tonmineralbilding.

H. HARDER. *Zeitschrift der Deutschen Gemmologischen Gesellschaft*, **43** (1/2), 1994, pp 19-37, 2 tables, 7 illus. in colour, bibl.

Worldwide agate occurrences have been extensively discussed in the literature, and their origin by high or low temperature processes compared. Recent isotope investigations suggest agate formation at lower temperatures. The author explains agate formation as a by-product of clay mineral formation at low temperatures.

Experiments at low temperatures with solutions containing up to 1000x more silicon than aluminium and iron can lead to a water-rich precipitate with gel-like texture, chemically similar to agates. Agates are mostly found in strongly decomposed volcanic rocks. During the weathering process Fe-rich clay minerals are formed. The remaining solution contains ions not incorporated into the clay mineral structure; these have a relatively high Si content and a low Fe and Al content. Contents of sodium and potassium were probably high. Acid surface water will neutralise the basic solution in the cavities and thus precipitate the SiO_2. Numerous rotations of different fillings and precipitation of hydroxide silicate led to the banded and layered agate structure during geological times.

Larger quartz crystals contain less iron and aluminium than the surrounding agates. These crystals are grown from purer solution which existed during formation of the agate gels from which diagenetically the chalcedony fibres grow. E.S.

Zur Entstehung von verkieselten Hölzern.

H. HARDER. *Aufschluss*, **44** (1), 1993, pp 23-31.

Silicified wood ('woodstone') predominantly consists of fine-grained or fibrous quartz with some larger idiomorphic quartz crystals; opal is rare. The quartz must have grown from only slightly supersaturated solutions. Silicified wood contains up to 0.9% Fe_2O_3 and ≤ 0.4% Al_2O_3 concentrated in the fine-grained parts. This indicates that weakly basic weathering solutions were neutralized by acid solutions formed by wood decay, precipitating e.g. Al hydroxides, which then absorbed colloidal silica which slowly silicified the wood. In the pore space of the hydroxide-silica precipitates, diagenetic quartz crystallization took place, with the larger quartz grains growing from genuine solutions. The results of experiments of colloidal silica enrichment are reported. K.v.G.

Jadeitites, albitites and related rocks from the Motagua Fault Zone, Guatemala.

G.E. HARLOW. *Journal of Metamorphic Geology*, **12** (1), 1994, pp 49-68, 1 map.

Jadeitites are found as weathered blocks in tectonized serpentinite in a 15-km zone N of the Motagua fault zone; they occur with albitites, albite-mica rocks, omphacite/taramitic amphibole-bearing metabasites, chlorite-actinolite schists, talc- carbonate rocks and antigorite schists. In addition to jadeite, the jadeitites also contain micas, omphacite, albite, titanite ± zircon, apatite and graphite. Conditions of jadeite formation are 100-400°C and 5-11 kbar. Fluid inclusions, coarse textures, vein structures and rhythmic zoning of pyroxene indicate that an aqueous fluid was involved. Jadeitites are either: (1) metasomatic modifications of former felsic-to-pelitic inclusions that underwent silica depletion plus Na exchange and enrichment, or (2) solution precipitations derived from such a source. They may have formed in a relatively high-*P/T* setting with substantial flow of sodic fluid in a tectonized zone. Most Guatemalan jadeitites are extensively altered to analcite, albite, taramitic amphibole, (clino)zoisite ± nepheline and preiswerkite; this alteration reflects depressurization + heating to below the jadeite ± fluid = analcite reaction at high a_{Na}. With progressive alteration, analcite and nepheline are replaced by albite. R.A.H.

Gemmologische Kurzinformation.

U. HENN, H. BANK AND C.C. MILISENDA. *Zeitschrift der Deutschen Gemmologischen Gesellschaft*, **43** (1/2), 1994, pp 1-4, 6 illus. in colour, bibl.

In the south-east of Finland, about 130km north of Helsinki, some yellow, yellowish- green, green and pale blue beryls of gem quality were found by a Finnish mineral collector. In the region of Eskishehir in Turkey, a district known for the occurrences of meerschaum and beryls, some cuttable emeralds were found. The crystals were up to 2cm long in a matrix of quartz, feldspar and black mica. Details of constants are given. Amethysts from the Auvergne, France, are mentioned. The crystals are relatively small and full of inclusions, but have a very good colour. Also from France, near St. Leger the rare stolzite (lead tungstate) hardness 3, SG 8.37, the cut sample weighs 2.15ct. Under the name of 'Nicholas created alexandrite' the firm J.O. Crystal markets faceted synthetic alexandrites with definite colour change blue-green to violet-red. Also by the firm J.O. Crystal, synthetic emeralds under the name of 'Empress culture emeralds'. Lastly a synthetic blue sodalite from China weighing 32.98 ct, SG 2.42. E.S.

Transparenter, schleifwuerdiger, gruener Barium-Orthoklas aus Minas Gerais, Brasilien.

J. KARFUNKEL AND M.L.S.C. CHAVES. *Zeitschrift der Deutschen Gemmologischen Gesellschaft*, **43** (1/2), 1994, pp 5-13, 1 map, 1 table, 3 graphs, 1 illus. in black-and-white, bibl.

The green, transparent, cuttable mineral was found south of Felicio dos Santos, Minas Gerais, Brazil, and was identified as barium-orthoclase, a feldspar variety previously unknown in this colour; it is found in small veins in quartz-mica schist. It is to be hoped that mining will prove economically viable. The light green colour with perfect transparency could lead to a future demand as an ornamental stone or collector's item. E.S.

A photo essay dedicated to Bill Hicks.

J.I. KOIVULA. *Australian Gemmologist*, **18** (10), 1994, pp 323-6, 12 illus. in colour.

This set of photomicrographs taken with Nomarski Differential Interference Contrast shows the beauty of surface patterns on 'rough' crystals. Some faces may show superficial growth features while others may reveal dissolution or etching of previously formed faces. These features reflect a crystal's internal symmetry. Thus identical crystal faces display similar forms. From these superficial 'imperfections' the author poses a question on the nature of perfection itself. R.J.P.

Gem News.

J.I. KOIVULA, R.C. KAMMERLING AND E. FRITSCH. *Gems & Gemology*, **30** (1), 1994, pp 47-57, illus. in colour.

A jade cutting factory on the Myanmar-Thai border was described. At the time of the visit nephrite from British Columbia was being carved.

Tucson '94

Gem materials from Arizona were well represented and included turquoise and a bright greenish-blue chrysocolla chalcedony; emeralds from Brazil were offered by several dealers. A pleasing aroma emanating from rough emerald

from the Carnaíba area in Bahia state was due to the natural oil from the peroba tree. Carved amber both from the Dominican Republic and the Baltic states was often in the form of dinosaurs (presumably due to the success of the film *Jurassic Park*). Materials from Madagascar included emeralds from Tulear, aquamarine, morganite, colourless phenakite, apatite and a wide range of garnets. Rubies from the new mining area of Mong Hsu in Myanmar were notable for their bright consistent colour.

There was greater availability of Mexican obsidian with striking iridescent colours. An intertwined 'rope' from a single piece of obsidian was an unusual carving shown. Cat's-eye opal from Brazil was plentiful with fine fibres and readily absorbed water which improved the transparency as well as causing the body colour to become browner. These effects were reversible as the water evaporated. Opal from Ethiopia was of two types: pale yellow, orange and brown with either weak or no play-of-colour visually similar to Mexican fire opal; a dark brown to reddish-brown body colour with strong play-of-colour in a mosaic pattern of rectangular to rounded patches. Russian goods were offered by many dealers including drusy uvarovite garnet on a chromite matrix and hessonite and demantoid garnets.

From the state of Orissa in India were shown bright brownish-orange hessonite garnets together with rhodolite garnets of a very purple hue. R.J.P.

Leuchtend orangefarbige Spessartine aus einem neuen Vorkommen In Namibia.

T.H. LIND, U. HENN, H. BANK. *Zeitschrift der Deutschen Gemmologischen Gesellschaft*, **43** (1/2), 1994, 39-47, 3 tables, 3 graphs, 1 illus. in black-and-white, 1 illus. in colour, bibl.

The new occurrence was found in 1992 in the north of Namibia near the confluence of the river Maria with the river Kunene, very close to the Angolan border. It was first called Kunene spessartine, then Dutch spessartine (because of its orange colour); it has also been marketed as mandarin spessartine. The occurrence is of primary nature, the crystals often rhombdodecahedra. The orange colour is evenly distributed. The largest stone found weighted 55.4 ct, but normally stones up to 15 ct were found. SG 4.09-4.15; RI 1.790-1.797. It was found to be a pyrope spessartine, the spessartine content being 80-90 per cent, with visible absorption spectra near to pure spessartine. NIR absorption spectra revealed a small quantity of hydrospessartine. E.S.

Nature and cause of colour in Indian beryls.

J. PANJIKAR. *National Academy Science Letters*, **16** (1), 1993, pp 13-15.

The blue in Kashmir beryls is due to Fe^{2+} occupying the channel portions in the lattice with absorption spectra of 32 000 to 11 500cm^{-1}. Beryls from Rajasthan have absorption bands due to Fe^{2+} and Fe^{3+} in the octahedral and tetrahedral sites, respectively. It is assumed that some replacement of Fe^{3+} for Al^{3+} also occurs at the octahedral site. Orissa beryls also have absorption peaks || or ⊥ the *c*-axis, both of which are related to Fe^{2+} in tetrahedral and octahedral sites. In the case of beryl from Andhra Pradesh, Fe sorption has been observed in the IR region. Gujarat beryl shows absorption with the polarization || *c*-axis due to Fe^{2+}/Fe^{3+} charge transfer. It shows an absorption band due to the presence of Fe^{3+} in the octahedral site. R.E.S.

Campolungo, Schweiz: Neufund der grössten Korund-Kristalle der Alpen.

A. ROVETTI, R. ROVETTI AND M. PACCIORINI. *Lapis*, **19** (9), 1994, pp 35-6, 11 photos (7 in colour), 4 figs., 2 maps.

A rose-violet corundum crystal measuring 5cm in length and found in a dolomite matrix with similar but smaller crystals at Campolungo, Ticino, Switzerland, is believed to be the largest crystal of corundum so far to be found in the Alps. M.O'D.

Emeralds from the Mananjary Region, Madagascar: internal features.

D. SCHWARZ. *Gems & Gemology*, **30** (2), 1994, pp 88-101, 19 illus. in colour.

This excellent review is the first of its kind about emeralds from the Mananjary region in eastern Madagascar. Inclusions are reported and compared with those in emeralds from other localities especially from Africa. Although most of the internal features are similar to other emeralds from schist-type deposits, Mananjary emeralds can be separated by association of certain mineral inclusions with specific liquid inclusions. These minerals include talc, carbonates, amphiboles (mostly of the actinolite/tremolite series) and quartz. However, the latter is a common constituent of emeralds from most African localities so is of little diagnostic significance. The presence of talc - especially when it appears in a fibrous or sheaf-

like form - is a good diagnostic feature for Mananjary emeralds. R.J.P.

What's new in minerals?

J.A. SCOVIL. *Mineralogical record*, **25** (5), 1994, pp 377-82, 15 photos (12 in colour).

Among gem-quality minerals noted are emerald from Hiddenite, North Carolina, green dravite from the Mikhaylovskoye mine, Chita Oblast, Russia, peridot (as a crystal 3.2cm high) from Pyaung Guang, Myanmar, elbaite from the Bennett mine, Buckfield, Maine, and red beryl from the Violet claims, Wah Wah Mountains, Utah. M.O'D.

The incorporation of alkalis in beryl: multi-nuclear MAS NMR and crystal-structure study.

B.L. SHERRIFF, H.D. GRUNDY, J.S. HARTMAN, F.C. HAWTHORNE AND P. CERNY. *Canadian Mineralogist*, **29** (2), 1991, pp 271-85.

The stereochemical details of the incorporation of alkali ions into the beryl structure were examined by multi-nuclear MAS NMR spectroscopy and single-crystal structure refinement. The ^{29}Si signal is narrow in alkali-poor beryl, and broadens with increasing alkali content, a result of the different short-range next-nearest-neighbour configurations produced by the incorporation of alkalis into the structure; the value of this substitutional broadening is calculated from the proposed local configurations and the method of Sherriff & Grundy (1988). Substitutional broadening is observed in the ^{27}Al spectra that also show only [6]-coordinate Al to be present, in agreement with the current and earlier X-ray results. Two ^{7}Li signals are observed, indicating that Li occurs both as a framework constituent and as a channel species. The crystal structures of the four samples were refined, to R indices of 2-3 per cent using Mo[Kα] radiation. The <Be-O> distance expands linearly with increasing Li = Be substitution at this site, but the O-Be-O bond angles remain unchanged. This substitution produces a bond-valence deficiency at the O(2) anion. This is compensated by lengthening of Si-O(1) and Si- O(1)a, and contraction of Si-O(2) with increasing Li = Be substitution. All samples of alkali-bearing beryl examined show residual electron density in the channels due to occupancy by alkali ions; all show more density at the 2a site than at the 2b site. Comparison of these residual densities with known alkali contents confirms previous work that assigned Cs to the 2a position. The electron density observed at the 2b position correlates well with the Na contents and is insufficient to account for the H_2O; thus Na is assigned to 2b and H_2O to 2a. Local stereochemistry and analytical results suggest that Na is bonded to two H_2O groups in the channel. L.T.T.

Jades of North America.

J. SINKANKAS. *Bull. Friends of Jade*, **8**, 1994, pp 67-104.

This is a major revision of the jade section of volume 2 of *Gemstones of North America*. Additional material is given for the states of the USA and for other north and central American countries. Each country or state description has its own list of references. M.O'D.

Fluorite from Seiles, Andenne, Belgium: Coloration, fluorescence, and a remarkable crystal geometric discoloration phenomenon.

R.F. VOCHTEN, M.D. VAN DOORSELAER AND H. DILLEN. *Zeitschrift der Deutschen Gemmologischen Gesellschaft*, **43** (1/2), 1994, pp 73-84, 2 tables, 3 graphs, 5 diagrams, 6 illus. in colour, bibl.

A study of experimental and literature data reveals that the violet and blue coloration of fluorite from Seiles, Belgium, cannot be caused by the mere presence of rare earth elements but should be attributed mainly to high energy radiation. The fluorescence which typifies some of the coloured fluorite samples could be caused by specific colour centres which are not present in non-fluorescing samples. A particular discoloration phenomenon with a trigonal pattern is described and tentatively related to enhanced oxygen diffusion along disturbed boundaries of penetration twin crystals. E.S.

Instruments and Techniques

Miniature fibre optics.

T. LINTON. *Australian Gemmologist*, **18** (10), 1994, pp 329-31, 2 illus. in black-and- white.

This informative article will be welcomed by practising gemmologists who have to examine set stones. The miniature fibres are usually hand held and ensure quick, effective and simple illumination. They can be used with the microscope and many other instruments. R.J.P.

Computer assisted gem identification.

P. READ. *Australian Gemmologist*, **18** (10), 1994, pp 332-3, 4 illus. in black-and-white.

The history and development of this topic were amply covered and showed how the increased

capacity of the personal computer allowed a much wider scope for gemstone identification as well as enabling the textual data to be expanded. The GEMDATA programme is now in its fifth update enabling the most recent advances in gemmology to be incorporated. R.J.P.

Synthetics and Simulants

Crystallization of diamond from a silicate melt of kimberlite composition in high-pressure and high-temperature experiments.

M. ARIMA, K. NAKAYAMA, M. AKAISHI, S. YAMAOKA AND H. KANDA. *Geology*, **21** (11), 1993, pp 968-70.

A series of experiments was carried out at high *P* (7.0 and 7.7 GPa) and high *T* (1800- 2000°C) using a modified belt-type high-*P* apparatus with a 32mm bore diameter. Diamond crystallized and grew in a volatile-rich kimberlite melt of an aphanitic group 1 kimberlite from Wesselton mine, South Africa. The diamond has well-developed {111} faces and its morphological characteristics resemble those of natural diamond but differ from those of synthetic diamond grown from metallic solvent-catalysts. The kimberlite melt has a strong solvent-catalytic effect on diamond formation, supporting the view that some natural diamond crystallized from volatile-rich melt in the upper mantle. L.C.H.

Synthetic rubies by Douros: a new challenge for gemologists.

H.A. HÄNNI, K. SCHMETZER AND H. BERNHARDT. *Gems & Gemology*, **30** (2), 1994, pp 72-86, 3 tables, 23 illus. in colour.

Introduced in 1993, these synthetic rubies are produced by controlled spontaneous nucleation and slow cooling techniques by unseeded flux growth. Although conventional methods may show the synthetic nature of these stones, sophisticated methods such as energy-dispersive X-ray fluorescence (EDXRF) and UV visible spectrophotometry may have to be employed. EDXRF spectra showed chromium, titanium and iron in varying amounts together with lead. The Douros product most closely resembles the Ramaura synthetic ruby and the presence of yellow flux particles often associated with rounded bubbles are easily recognized. Without these, chemical analysis and immersion microscopy (to reveal characteristic crystal-growth patterns and colour zoning) should provide the necessary distinguishing evidence. The crystallography of the new synthetic is thoroughly discussed including the marked colour zoning seen in crystal specimens. R.J.P.

Synthetische Rubine aus Griechenland.

U. HENN AND C.C. MILISENDA. *Zeitschrift der Deutschen Gemmologischen Gesellschaft*, **43** (1/2), 1994, pp 15-17, 2 illus. in black-and-white, 2 in colour, bibl.

A new type of synthetic ruby from Greece has come on to the market. It is manufactured by the firm Douros in Piraeus and is known under the name of Douros. Physical properties are those of corundum and under the microscope flux residues can be seen, typical for a flux growth environment. E.S.

Gem News.

J.I. KOIVULA, R.C. KAMMERLING AND E. FRITSCH. *Gems and Gemology*, **30** (1), 1994, pp 47-57, illus. in colour.

Synthetic sapphires had been diffusion-treated with a cobalt compound. The Chelsea colour filter, spectroscopic and UV examinations readily confirmed the cobalt whilst microscopic examination revealed gas bubbles and/or curved colour banding of the synthetic.

Beryl triplets were offered as emerald simulants. Chatham introduced a new pink synthetic sapphire with less than 0.2 per cent w/w chromium trioxide. Apart from having an orangey-red fluorescence to short wave UV of equal intensity to the red fluorescence under long-wave UV, it showed all the gemmological characteristics of a Chatham flux-grown synthetic ruby. Synthetic material from Russia included hydrothermal emeralds, synthetic rubies by a number of techniques, flux-grown red and blue spinels, numerous quartzes including a new pink quartz, and synthetic malachite and turquoise. Cubic zirconia was available in many colours together with a yellow-green which would make an effective simulant for peridot. R.J.P.

Book Reviews

Jades from China.

A. FORSYTH AND B. MCELNEY, 1994. Museum of East Asian Art, Bath. pp 422, illus. in black-and-white and in colour, hardcover. Price £105.00. ISBN 1 897734 03 4.

The Museum of East Asian Art in Bath opened in April 1993 and the present catalogue describes and illustrates jade objects at present in the Museum's custody. About 50 per cent of the artefacts come from the collection of the second author, presented to the Museum by him as founder. The remainder of the objects come from two collections on long-term loan to the Museum, the Peony and Rannerdale collections.

The book opens with a note by the authors particularly concerning the difficulty of dating jade objects. This topic is constantly under discussion. A chronological table, short glossary with illustrations and maps follow, the text and labelling in English and Chinese. Introductory essays cover jade as a raw material, jade supplies to China and working with jade. Then come jade culture and dynastic essays before the catalogue itself begins. The introductory essays are in English and Chinese.

The chief feature and one seldom seen today is that each object is illustrated in colour. As there are 354 objects and some have more than one photograph more than 400 colour photographs are included. Each description of an artefact includes descriptive name, place of origin and period, description and note of publication where applicable. If similar pieces exist in the collection these are referred to. This main section is arranged chronologically and each division has a short essay in English and Chinese. The book ends with a bibliography of 100 entries which could perhaps have been extended to match the importance of the text.

In a book of this kind reviewed in a journal dealing with the scientific background of the production of worked specimens, we first need to ensure that the coverage of the mineralogical and gemmological area is correct and balanced. The essay on jade as a raw material tells us surprisingly little about the mineralogy of the jades though what there is seems adequate enough. The account of how various characters have been used to denote jade (or 'precious stone') is interesting but there is little new information.

These are small points or would be if this was a smaller catalogue. Clearly the promise of further work on the background of so excellent a collection remains and it would be unfair to expect everything to go in one volume, especially one in which the illustration is the main aim - and in this the book succeeds admirably. The price is not unreasonable for today and serious students will welcome so prodigal a display of illustrations. M.O'D.

Red coral, jewel of the sea.

B. LIVERINO, translated [from the Italian] by J.H. Johnson, 1989. Analisi-Trend, Bologna. pp 208, illus. in black-and-white and in colour (Industrial history series) Price £31.50.

Books on coral are rare and though several books in Italian have been published since the early 1970s the major texts have not been translated. For this reason the present work is to be welcomed, with its profusion of good-quality colour photographs which, given the warm colour of most coral artefacts, make a pleasing effect. The aim of the book is to present not only the artistic but also the historical, social and economic importance of coral recovery and fashioning to the people of the area round Torre del Greco: in this town the author has established a Museum of Coral and Cameos.

Early chapters describe the origin, zoology and formation of coral and early methods of fishing, both in the Mediterranean and elsewhere, particularly in the Pacific. The history of coral working is examined from archaeological sources and then by centuries. Other uses of coral – in pharmacology and as ornament - are outlined before an account of the present state of the industry. The final chapter concentrates on the centre of Torre del Greco and its importance in the history of coral. Despite the absence of a bibliography which would have been especially welcome the book can be recommended for students and for everyone with an interest in this particular material. M.O'D.

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OBITUARIES

Malcolm (Mac) James Hanslip (D. 1950) died on 16 July 1994 aged 68.

When Mac left school, he trained as an engine fitter in Devonport dockyard, completing his apprenticeship in 1946. Mac then left the dockyard and joined his father's watchmaking business, qualifying as a fellow of the Gemmological Association in 1950. One year later he joined the firm of Conroy Couch Jewellers in Torquay, part of the R.W. Yeo group of companies, as the Senior Sales Assistant.

Promotion within the company took Mac back to Plymouth as manager of Samuel Edgecombe Ltd., where he remained until the mid 1960s when he transferred to the Technical Centre in Exeter, the head office for Ron Yeo's group of companies. As well as a training centre where students could learn all aspects of the jewellery trade, Exeter was the head office from which Mac travelled to all the company's shops, his expertise and enthusiasm taking him to the position of Chairman of R.W. Yeo (Associated Companies) Ltd.

Mac enjoyed being involved with the staff of his shops. Always passionate about gemstones and jewellery, he loved being behind the counter meeting people, and relished the opportunity of working on the sales floor of the company's various shops when covering for holidays or helping out at Christmas.

Mac is survived by his wife, two daughters and two grandchildren. A man who loved 'people', Mac will be missed by all those who knew him. D. Garrod

Keith Richard Willmott MA (Oxon) (D. 1990 with Distinction) died on 29 October 1994.

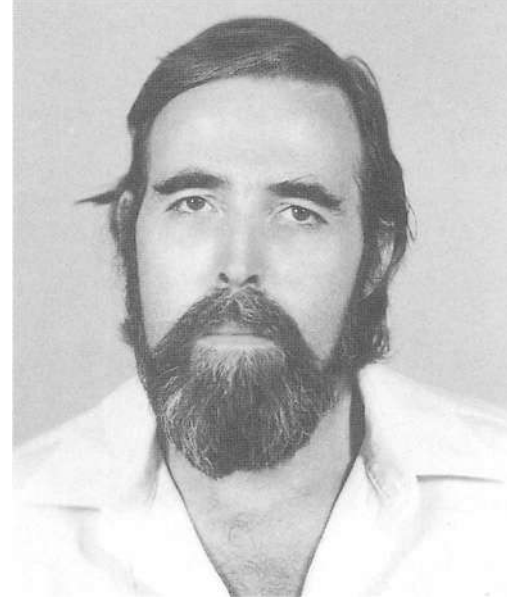

Richard Willmott

Richard Willmott started his career after graduating with a first class honours degree in mathematics from Oxford University followed by two years' research at Cambridge. From there he embarked on various teaching and journalism assignments around the world. However, his interest in gemmology started in his twenties when he collected books on famous gems. He often joked about his early disastrous attempts at buying rough gems from the mines in Sri Lanka.

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At the age of 45 he realized his long term interest in gemmology and obtained his FGA with distinction in 1990. He also found time to travel across the Australian Nullabor Plain by train, stopping at all the gem mines along the way, and started his Gem Technical Services business in the free trade zone in Sri Lanka. Among other things, he employed local gem cutters to produce replicas of crown jewels and celebrity jewellery (such as the Taylor Burton necklace) made from cubic zirconia. His article 'Diamond replicas - possible but just' (*J. Gemm.*, 1993, **23** (8), 486) dealt with the history of making replicas and the practical problems he encountered in obtaining accurate information on famous originals. During the last few years he started 'The Diamond Extravaganza' to produce and promote his CZ replicas to the jewellery trade and to various museums*. His clients included famous names such as Christies, Garrards and De Beers. Replicas made by Richard have been the subject of recent articles in various trade publications including *The Retail Jeweller* and were featured on a BBC television programme *The Diamond Empire* earlier in 1994.

Sadly, Richard became ill during this time and was not able to reap fully the benefits of his unique enterprise or to realize his long-term ambition of starting a London Diamond Museum and he died aged 50 years. He is sadly missed by his numerous friends and colleagues around the world.

Lynda Thorn

GIFTS TO THE ASSOCIATION

The Association is most grateful to Thor Johne of the Geologisk Museum, Oslo, Norway, for the gifts of ruby crystals in matrix and feldspar variety sunstone, both of which are from Norway.

* The CZ replicas and museum artefacts are now being sold. For information, please fax 0171 258 1810 or write to Diamond Extravaganza, c/o PO Box 1041, London W2 3ZW.

NEWS OF FELLOWS

On 24 October 1994 **Michael O'Donoghue** gave an address to Gemmologia Europa V in Milan. His subject was *Ruby and sapphire: treatment, synthetics and imitations*, and special emphasis was given to the heat-treated sapphires from Montana, USA, specimens of which were demonstrated. A display of rare books on ruby synthesis and mineral colour alteration was also provided and slides shown by courtesy of Eric Emms of the GAGTL.

Alan Jobbins and **Ken Scarratt** also contributed lectures in this series concerning the natural origins and resources of ruby and sapphire.

MEMBERS' MEETINGS

London

The 1994 Annual Conference was held on 23 October at the Great Western Royal Hotel, Paddington. A full report of the Conference was published in the December 1994 issue of *Gem and Jewellery News*.

The following meetings were held at 27 Greville Street, London EC1N 8SU:

On 28 September Alan Clark gave a talk entitled *Diamonds in the retail trade*.

On 22 November Cally Hall gave a talk entitled *Gemstones on display at the Natural History Museum: past, present and future*.

On 5 December Stephen Kennedy spoke on *Sapphires in the Laboratory*.

Midlands Branch

On 28 October at Dr Johnson House, Bull Street, Birmingham, a Bring-and-Buy Sale was held.

On 6 November the Autumn Seminar was held at the Cobden Hotel, Hadley Road, Birmingham.

On 25 November at Dr Johnson House Grenville Millington gave a talk entitled *How to buy gemstones*.

The Branch's Annual Dinner was held on 3 December.

North West Branch

A visit to the Liverpool Museum of Geology was organized on 19 October.

On 16 November at Church House, Hanover Street, Liverpool 1, the Annual General Meeting was held at which Irene Knight and Joe Azzopardi were re-elected Chairman and Secretary respectively.

PRESENTATION OF AWARDS

The Presentation of Awards gained in the 1994 examinations was held at Goldsmiths' Hall, London, on 25 October.

The President, Mr Eric Bruton, presided and welcomed those present. He announced that a total of 1059 students had taken the gemmology and gem diamond examinations in 1994, 599 of whom had been successful. The 197 students who had passed the Diploma examination came from a total of 26 countries representing all five continents. Award winners from 14 countries attended the Presentation, from as far away as Brazil, the People's Republic of China, the Republic of China and the USA.

The awards were presented by Vice-President Alec Farn and his address is set out below.

The vote of thanks was given by Vivian Watson and in conclusion Eric Bruton thanked the Goldsmiths' Company for once again allowing the GAGTL to hold the ceremony at the Hall.

Address by Alec Farn

'Ladies, Gentlemen and Fellow Gemmologists, it gives me considerable pleasure to be here this evening to talk to you and present the awards. I hope that you will enjoy your visit.

'We are extremely fortunate in having this great hall for our annual awards ceremony. It is to the Worshipful Company of Goldsmiths that we address our thanks.

'Although I am a retired director of the original pearl testing station founded in Hatton Garden in 1925, I am not going to talk about pearls. It is fatal to ask someone of my age to talk at a Presentation of Awards Ceremony. The opportunity to reminisce is too great an offer to miss. I must remember that some of you are not only younger than myself but come from countries hundreds – if not thousands – of miles away. That in itself is a compliment

Prize Winners at Goldsmiths' Hall: from left Alicia Arnold (Preliminary Trade Prize), Neil Rose (Tully Medal) and Deborah Wilson (Anderson Medal).

to the London scene.

'I like to think of myself essentially as a trades person. My father was the manager of a pawnbroker and retail jewellers shop in south east London. The well known sign of a pawnbroking establishment together with a public clock hung outside my bedroom window. I was employed in four other pawnbroking shops in various parts of London and lived-in at two of them, the last of which was the most important. At that time I knew very little about gemstones and gemmology was a new word in my vocabulary.

'My own introduction to the Goldsmiths' Hall was of a non-gemmological nature in the mid-thirties. I was working and living-in as a member of staff in an old established jewellers in London's Oxford Street. We held a fine stock of both antique and modern silver as well as important jewellery. Occasionally our silver buyer would obtain tickets to lectures at the Goldsmiths' Hall on silversmiths, their work and like matters of historical interest. These lectures were very popular. A colleague and myself always attended - there was a free buffet and claret. This *may* have been a reason for the popularity of the lectures, especially to young men in their twenties earning quite modest salaries!

'I specifically mention my colleague whose name was George E. Ratcliffe, FGA. He obtained his diploma in that very impressive and important year (1934) when R. Keith Mitchell beat Robert Webster for the Tully Medal – you had to be extremely good to do that. It may have been the claret at one of the lectures or just genuine friendship which inspired George Ratcliffe to say to me: "You know, you are really ignorant about gems and gemmology. You ought to go to evening classes at Chelsea Polytechnic." I did in fact go to Chelsea Poly. The instructor was a tall, fair haired young man over six feet tall. His name was Basil Anderson. You may have heard of him.

Vice President Alec Farn

'I passed the first year exam and received a certificate from Chelsea Polytechnic. Then the war intervened. Some six years later in 1946 I was demobbed but my pre-war job no longer existed. I was ex-service and unemployed. I wrote to Basil Anderson, hoping that he might know of a vacancy in the retail jewellery trade. He replied promptly and asked me to go to see him. He offered me a job in the laboratory. I was considerably taken aback – all I had was a first year certificate nearly seven years old and a brand new demob suit. I thought he must have mistaken me for someone else. A week or two later I joined the Laboratory of the Diamond Pearl and Precious Stone Trade Section of the London Chamber of Commerce. This evening I am wearing their tie in their honour and as a compliment to all of you successful FGAs.

'My first year at the laboratory was trade gem testing with a vengeance. We had monocular microscopes which were back-

aching to use standing up and awkward to use sitting down. Monobromonaphthalene was the main immersion liquid. Each stone and pearl was tested individually. In that year we tested 104 849 rubies and sapphires, 62 616 natural pearls and 7553 cultured pearls. We worked together as a team for 25 years before successive retirements began to take their toll. With B.W. Anderson's retirement I changed from junior to senior in all-too-swift escalation and found myself with young faces around me. It was quite a contrast when you consider the birth years of that first foursome – Robert Webster 1899, Basil Anderson 1901, C.J. Payne 1905 and myself, the youngest, 1916.

'I would like to dwell a little upon the history of this magnificent building, its Livery hall and the Goldsmiths' Company. As early as 1339 the Company acquired a site and building in the goldsmiths' quarter of the City of London. King Edward I in 1300 required that all silver articles were to be of the same sterling standard as the coins of the realm and that they were to be assayed by the wardens of the Goldsmiths' Guild. Before they left the workers they had to be marked with a leopard's head which signified London. The Sterling Standard was 11 ounces 2 pennyweights in the pound Troy, or as it is recognized today, 925 parts per thousand pure.

'The Goldsmiths' Company has a link with gemmology from the year 1666, the date of the Great Fire of London when the Goldsmiths' Hall was burned to the ground. In that same year Isaac Newton proved that white light has a composite nature. Sir Isaac Newton, as he later became, was appointed Warden of the Mint in 1696. Lord Montague, the Chancellor of the Exchequer at the time, had authorized a new coinage because the old coins had been badly clipped around the edges by the populace who used the clippings as a source of income as scrap silver, etc. He was obviously very efficient as he became Master of the Mint three years later.

'The Trial of the Pyx was an annual event at the Goldsmiths' Hall when silver coins were tested by a jury composed of members of the Goldsmiths' Guild. There was a strong link between the Goldsmiths' Company and the Royal Mint in the Tower of London.

'This present Hall was completed in 1835 following a commission by the Goldsmiths' Company to their surveyor, Stephen Hardwicke. It followed a reconstruction of the previous hall which was built after the Great Fire in 1666. This in time had become dilapidated and needed propping up. It was eventually demolished in 1829.

'On the opening day of the present Hall in 1835 words described it as "marked by an air of palatial grandeur not exceeded by any other piece of interior architecture in the metropolis". The Duke of Wellington, victor of the Battle of Waterloo (1815), was the Goldsmiths' Company's principal guest at the celebratory dinner since the King, William IV, was indisposed.

'The recent refurbishment of this hall is interestingly described in the Goldsmiths' Review of 1989/90. Many unexpected problems arose requiring long consultations with technicians with a wide range of skills. The day fixed for the official opening by HM Queen Elizabeth and the Duke of Edinburgh was fast approaching. In an article describing the tension experienced in the run up to this, the Clerk of the Goldsmiths' Company had the comments by the Duke of Wellington on the result of the Battle of Waterloo in mind when he quoted: "It was a damned nice thing - the nearest run thing you ever saw in your life."

'It is interesting to note how the word "hallmark" has entered our vocabulary. After 700 years of assaying we can truly say that the Goldsmiths' Company has left its mark upon the trade.

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22 February
Baffled by beads? Artificial, artistic, mineral, organic - a survey and discussion led by the Bead Society, with an opportunity to bring your own enigmas, gather tips on identification, detection, relative values and on cataloguing your collection. Learn from experts in gemmology and archaeology, people who appreciate beads of all kinds.
Price £35.25 (including sandwich lunch)

Enquire Within : Emerald
1 March
A valuable and concentrated look at all aspects of emerald: natural rough and cut stones, treated, synthetic and imitation stones.
Price £111.63 (not including lunch)

Weekend Diamond Grading Course
4-5 March
This successful course concentrates on the practical aspects of polished diamonds, using 10x lens, microscope and colour comparison stones. Mounted stones, simulants and clarity enhanced stones will be seen. Of great value to all involved in diamond trading and appraisal, the course is taught by Laboratory staff.
Price £246.75 (not including lunch)

Preliminary Workshop
15 March
A day of practical tuition for Preliminary students and anyone who needs a start with instruments, stones and crystals. You can learn to use the 10x lens at maximum efficiency, to observe the effects and results from the main gem testing instruments and to understand important aspects of crystals in gemmology.
Price £47.00; GAGTL students £33.49 (including sandwich lunch)

Enquire Within : Ruby and Sapphire
4 April
A concentrated look at all aspects of these gems: natural rough and cut stones; treated, synthetic and imitation stones.
Price £111.63 (including sandwich lunch)

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Just phone, fax or write for details to Doug Garrod at the GAGTL Education Office - 27 Greville Street, London EC1N 8SU. Tel: 0171-404 3334 Fax: 0171-404 8843

'When the mathematician Archimedes was called upon to prove the quality of gold in a crown he was literally "out of his depth". The gold could have been alloyed during manufacture. Still pondering the problem he stepped into his rather full bath. As he sat down water poured over the sides. Observing this he realized that a body must displace its own volume or bulk when immersed. Excited by this revelation and its portent he shouted Eureka meaning "I have it", and dashed naked to verify the experiment. It is doubtful whether many gemmologists today will be carried away with such enthusiasm, but who knows whether from among our present successful students we may yet read of similar excitements.

'The excitement, though, this evening is the presentation to you of your well-earned diplomas. These are your hallmarks as qualified gemmologists.

'During my thirteen years in retirement the gemmological world has moved on apace. I look back now with pleasurable nostalgia to that small intimate laboratory where we used to speak of Angstroms and the familiar names were Burma, Ceylon, Siam, the Persian Gulf and the Gulf of Mannar.

'On that retrospective note I will conclude and say "thank you" to you all for listening so patiently to my reminiscences.'

MEETING OF THE COUNCIL OF MANAGEMENT

At a meeting of the Council of Management held on 7 September 1994 at 27 Greville Street, London EC1N 8SU, the business of the meeting included the election of the following:

Gold Laboratory Membership
Clive Ranger Ltd, Cardiff

Ordinary Laboratory Membership
Chard (1964) Ltd, Blackpool
Cranbrook (Jewellers) Ltd, Basildon
Dianoor Jewels Ltd, London W1

MEETING OF THE COUNCIL OF MANAGEMENT

At a meeting of the Council of Management held on 26 October 1994 at 27 Greville Street, London EC1N 8SU, the business transacted included the election of the following:

Transfers from Ordinary Membership to Fellowship
Jargiello, Barbara, London. 1994
Hamza, Mohamed Hassan, Kandy, Sri Lanka. 1994

Diamond Membership
Zhang, Shuyun, Shanghai, China. 1994
Stossel, Hilary, London. 1994

Fellowship
Alexander, Maria K., Buenos Aires, Argentina. 1994
Armstrong, Michael J., Whitley Bay. 1994
Au Yang So Wah, Natasha, Kowloon, Hong Kong. 1994
Bao, Deqing, Hubei, Hong Kong. 1994
Barcados, Alexander J., Toronto, Ont., Canada. 1994
Bossenbroek, Anna E.H., Doorn, The Netherlands. 1994
Chan Kin-Chung, John, Chai Wan, Hong Kong. 1994
Chan, Kwok Keung, Kowloon, Hong Kong. 1994
Chan Wai Ching, Joanne, Kowloon, Hong Kong. 1994
Chan, Yuk Victoria, Burnaby, BC., Canada. 1994
Chua, Virna Ngo, New Territories, Hong Kong. 1994
Chung, Yam Ming, Kowloon, Hong Kong. 1994
Cooke, Joanne T., Petchburi, Thailand. 1994
Cookson, Ian P., Sheffield. 1994
Dragland, Frode R., Sortland, Norway. 1994
Gamst, Terje, Lannavaara, Sweden. 1994
Goldschmidt-Husein, Asli, St. Ingbert, Germany. 1994

Gunell, Carola M., Kirjala, Finland. 1994
Hasler, Christian, Toronto, Ont., Canada. 1994
Hindley, Stuart W., Worksop. 1994
Hui, Sze Wai, Kowloon, Hong Kong. 1994
Kam Siu Tong, John, Tsuen Wan, Hong Kong. 1994
Kon, Kiang Fung, North Point, Hong Kong. 1994
Kwan, Wai Shun, Kowloon, Hong Kong. 1994
Louie, Miu Man, Kowloon, Hong Kong. 1994
Mann, William M., Gloucester. 1994
Ng, Lok Chung Angela, North Point, Hong Kong. 1994
Or, Chi Ching, New Territories, Hong Kong. 1994
Paredes Quevedo, Juan C., Madrid, Spain. 1994
Smyth, Lesley J., London. 1994
Syren, Riitta A., Pirkkala, Finland. 1994
Tang Man Wah, Connie, Kwai Chung, Hong Kong. 1994
Tang, Wai Chun, Kowloon, Hong Kong. 1994
To, An You, Kowloon, Hong Kong. 1994
Varey, Irena M., Leicester, 1994
Welton, Andrew V., Hayes. 1994
Ying, Kai Yiu, Kowloon, Hong Kong. 1994
Young, Patrick Pak-chee, Taipei, Taiwan. 1994
Zhao, Xinmin, Wuhan, China. 1991

Ordinary Membership

Abbott, Deborah, Harrogate.
Abrmian, Levon, London.
Ankh, Catrin, Arsta, Sweden.
Au, Ming Cheung, Wanchai, Hong Kong.
Bailey, Alison, Hong Kong.
Bailey, Henry, London.
Barker, Cyrine, London.
Cadby, Sarah L., London.
Chan, Hsiu-Yin, London.
Churchill, David, Halifax, Nova-Scotia, Canada.
Crowley, Mark, Dunkineely, Co. Donegal, Ireland.
Duann, Teresa, Taichung, Taiwan.
Glaser, Sonja, Zurich, Switzerland.
Greenbank, Patricia, Kendal.
Hill, Rebecca Mary, Edinburgh.
Ho, Mary Malai, London.
Hopkinson, Barrie, Nottingham.
Horniblow, Kathy, Henfield.
Hsu, Ming-Hung, Taipei, Taiwan.
Hui, Mu-Cheng, Taipei, Taiwan.
Iwata, Kaoru, Kingston-upon-Thames.
Jensen, Brenda, Nesbru, Norway.
Jiranek, Jaroslav, Ostrava-Svinov, Czech Repub.
Kathoon, June S., Holte, Denmark.
Koneru, Suresh, London.
Kou, Wai Hung, Taipei, Taiwan.
Lee, Chiu-Hsia, Taipei, Taiwan.
Lin, Kuei-Yu, Fiona, Taipei, Taiwan.
Loughran, Anna, London.
Lundsrud, Berit, Sandvika, Norway.
Makri, Hariklia, Thessaloniki, Greece.
McInnes, John, Edinburgh.
Merrigan, Noel J.P., Cambridge.
Messent, Judith A., Colchester.
Mittel, Rita, Lusaka, Zambia.
Moreland, Lena, London.
Mourtzanos, Stefanos, Kensington.
Nakamura, Shukubin, London.
Obles, Maria Angeles, Madrid, Spain.
Quintin-Baxendale, Brian W., Rickmansworth.
Shu, Xingying, Wuhan, China.
Smith, T.J., Dartmouth.
Sugg, Duncan, High Wycombe.
Sugiyama, Shigeru, Cambridge.
Susan-Roet, Violet E., HD Naarden, The Netherlands.
Tsai, Pei-Lun, Taipei, Taiwan.
Turner, Caroline, Southwold.
Tzou, Jyh-Jeng, Taipei, Taiwan.
Webster, Paul Timothy, Greenford.
Wu, Ching-Lin, Taipei, Taiwan.

BACK ISSUES OF THE JOURNAL

The family of one of our late members on the Belgian/Dutch border has some bound copies of *The Journal of Gemmology* for sale at £2.00 per issue. From 1965-75 they are bound in red and from 1975-85 they are

bound in grey; subsequent issues are loose.

A member in Wales has a set of *The Journal of Gemmology* (January 1972 to date) for sale at £2.00 per issue, as well as back numbers of *Boletin del Instituto Gemologico Espanol, Revue de Gemmologie and the Indian Genmologist.*

Please contact Mary Burland at the GAGTL who will forward enquiries.

CORRIGENDA

On p. 285 above, first column, letter from Professor Hurlbut, second paragraph, first line, for 'it low surface tension' read 'its low surface tension'

On p. 270 above, under *Sampling and sample preparation*, first paragraph, last line, for 'Knamti' read 'Khamti'

On p. 276 above, second column under *References*, for 'Noeting, F.' read 'Noetling, F.'

FORTHCOMING MEETINGS

London

Meetings are held in the GAGTL Gem Tutorial Centre, 2nd Floor, 27 Greville Street, London EC1N 8SU (entrance in Saffron Hill).

The charge for a member is £3.50. Entry will be by ticket only, obtainable from the GAGTL.

20 March	**Jewellery at Sotheby's**	Alexandra Rhodes
12 June	**Annual General Meeting**	
16 October	**Recent developments in the diamond industry**	Howard Vaughan

Midlands Branch

19 February	**Gem Club - Composite gems**	
24 February	**Inclusions in silica gems**	Clive Burch
19 March	**Gem Club**	
31 March	**Jewellery through the ages**	Nigel Dunn

Meetings will be held at Dr Johnson House, Bull Street, Birmingham. Further details from Mandy MacKinnon on 0121-444 7337.

North West Branch

15 March	**A taste of Scottish gemmology***	Alan Hodgkinson
17 May	**Diamonds in the Laboratory**	Eric Emms

* Please note that this meeting will start at 7.00 p.m.

Meetings will be held at Church House, Hanover Street, Liverpool 1. Further details from Joe Azzopardi on 01270 628251.

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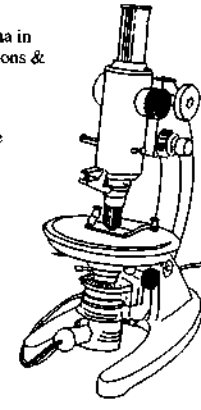

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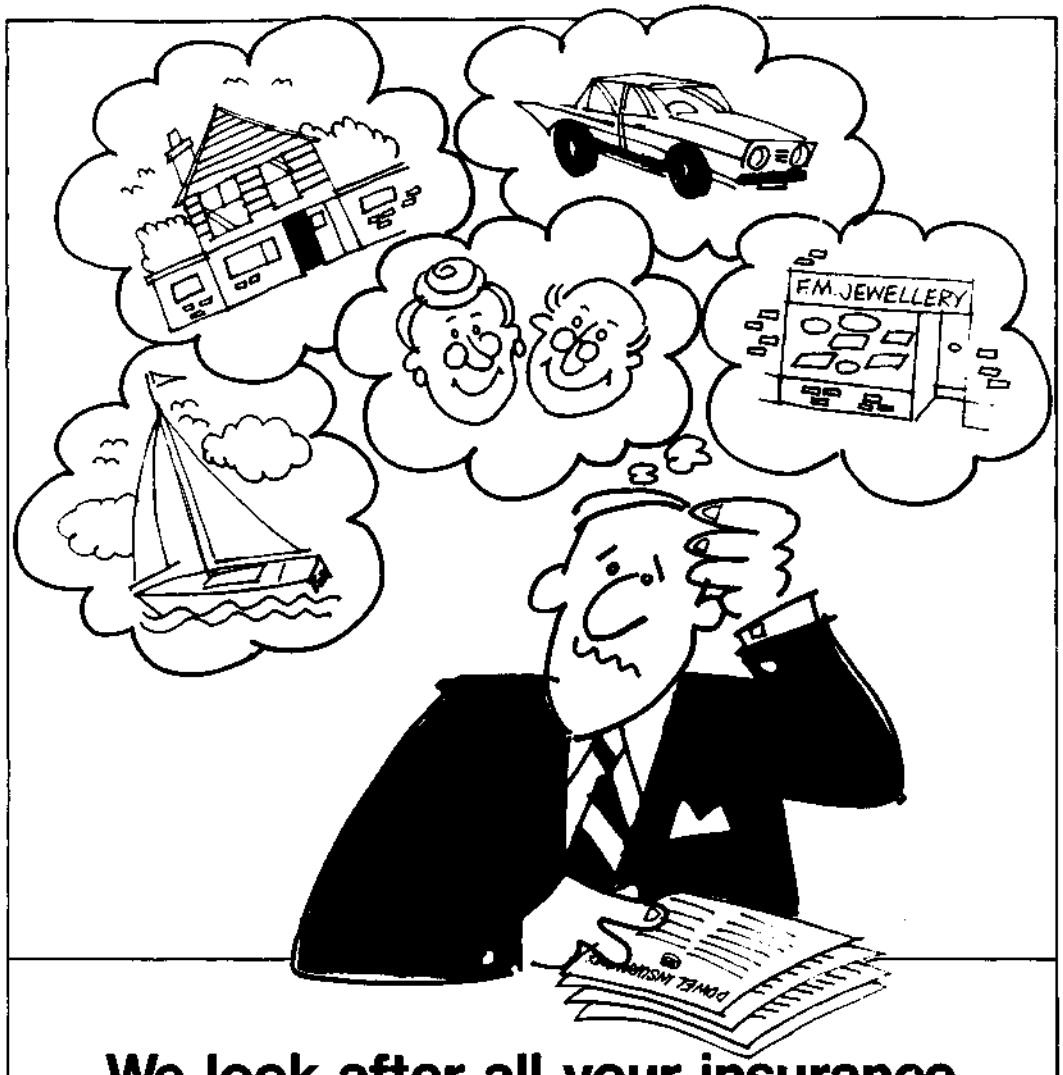

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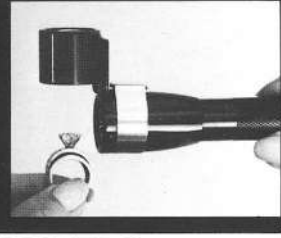

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Typescripts Two copies of all papers should be submitted on A4 paper (or USA equivalent) to the Editor. Typescripts should be double spaced with margins of at least 25mm. They should be set out in the manner of recent issues of *The Journal* and in conformity with the information set out below. Papers may be of any length, but long papers of more than 10 000 words (unless capable of division into parts or of exceptional importance) are unlikely to be acceptable, whereas a short paper of 400-500 words may achieve early publication.

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Cover Picture

Watch set in a crystal of Colombian emerald found during excavations in Cheapside in the City of London in 1912. The crystal measures 42mm deep and 20mm across (see 'The Cheapside Hoard confusion', page 395)
Photo: courtesy of the Museum of London.

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In this issue...

The topics covered in this issue of *The Journal of Gemmology* again comprise a range from the historical to the modern. The first paper concerns a rather enigmatic hoard of jewellery and jewellers' materials discovered in London in 1912. Mystery still surrounds the precise origin and recovery of the cheapside Hoard, but most of it is now on display in the Museum of London. The Hoard has been attributed to the early seventeenth century and is a fascinating assemblage of precious stones and decorative materials in a wide range of different qualities. The gemmological identities of some exceptional items augment the historical account of the discovery of the Hoard and perhaps, with the continued development of historical analysis techniques, answers may yet be forthcoming for the still unsolved aspects of the Hoard's origin.

Another source of continued speculation concerning its origin is the gem material moldavite. It is now more or less agreed that the spread of specimens over areas formerly known as Bohemia and Moravia is the result of a massive meteorite impact with the Earth in an area to the east of Stuttgart in Germany. The energy released on impact melted the local materials and in the glasses generated some very beautiful inclusions which were preserved by the quenching process. These unusual phenomena are illustrated in the paper by Anthony de Goutière.

Glass of a different nature turned up in the form of a cat's-eye cabochon among the items submitted for testing at the Bahrain Laboratory. Different synthetic corundums are also described and, considering that much of the Laboratory's work concerns natural and cultured pearls, the rather rare incidence of X-ray radiographs which depict perfect pearl structure is discussed.

Two papers on instruments highlight the continuing quest towards more reliable gem identification. One concerns development of an accessory on the well-established gem refractometer and should lead to improved speed and accuracy of refractive index readings. The second paper describes the infrared microscope and its application to certain problems difficult to solve by standard gemmological techniques.

With the rapid growth of information it becomes increasingly difficult to find the time to absorb the information of most relevance. But to absorb relevant information one must first find it or be made aware of it. After that come the processes of assimilation and assessment as to its reliability. The compilation of abstracts of current investigations can speed this process enormously and in this issue more than a hundred abstracts relating both to important aspects of gemmology and to related topics are printed.

Diamonds continue to fascinate investigators of the depths of the earth and there are abstracts of significant papers on the variety of ages of diamond and of their chemical and isotopic variation. At first sight these investigations may seem of marginal interest to gemmologists but with the increasing possibilities of encountering treatments, synthetics and imitations on the market, fundamental information of this kind could give rise to effective methods for identifying natural untreated stones.

Journals not normally seen by gemmologists from time to time contain papers of considerable gemmological interest and potential and one abstract printed here offers hope of being able to determine the origins of different ambers. *The World of Stones* is a new journal from Russia abstracted by Michael O'Donoghue and this is beginning to reflect the increased activity in gemmology in the area of the former USSR. Some of the secrets of polishing are also starting to come to light with detailed analysis of surfaces and it seems that to obtain the best results for certain stones it is crucial to find the best recipes. R.R.H.

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The Cheapside Hoard confusion

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Abstract

A summary of the accounts of when and how the Cheapside Hoard, a collection of jewellery found in London in 1912, is given. The role of G.F. Lawrence is described but some details are shrouded in mystery. Most of the Hoard is displayed in the Museum of London and gemmological details of some exceptional items are described.

Introduction

In the summer of 1912 a unique treasure of some 340 items was unearthed in Cheapside near St. Paul's Cathedral in London. The Hoard is believed to be the 'stock in trade' of a Jacobean goldsmith, pawnbroker or perhaps a fence who buried it, in unknown circumstances, in about 1630 and presumably was unable to return to claim it.

Most of the collection, known as the Cheapside Hoard, is now on display at the Museum of London in the Barbican, but in 1916 the treasure was divided largely between the London Museum and the Guildhall Museum - with some items going to the British Museum and some to the Victoria and Albert Museum. In 1976 the Museum of London was formed by the amalgamation of the London Museum and the Guildhall Museum which presented the opportunity of bringing together most of the Cheapside Hoard. The Hoard contains elaborate gold and enamel chains, a rock crystal chalice, polished gems and watches (see Figures 1-4), one of which is set in an emerald crystal (see also cover illustration). The collection gives a wonderful insight into the social background of the period and also raises many questions.

Previous accounts

There appears to be no eye-witness account of the actual discovery, no record of the date nor details of the find itself. The 1928 catalogue[1] prepared by the then new director of the London Museum, Dr Mortimer Wheeler (later Sir Mortimer Wheeler, the charismatic participant of the 1950s television programme Animal, Vegetable, Mineral) has been out of print for decades and is now virtually unobtainable. However, in that catalogue reference is made to workmen digging on the site of Wakefield House at the corner of Friday Street and Cheapside, the property of the Lord Mayor of London, in 1912. A workman put his pick through a box which lay, it is said, below a chalk floor. Although the box was much decayed, it was thought to have been fitted with trays, but further details of the recovery of the treasure are lacking.

In her book *History of jewellery*[2] published in 1953, Joan Evans refers to 'The hoard from a jeweller's shop of about 1615 found beneath the floor of a cellar between St. Paul's Cathedral and the London Central Post Office in 1912.'

Another publication that refers to the Cheapside Hoard is the *Handbook of the Museum of London*[3] published in 1985. This refers to workmen demolishing an old

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The watch (A14162) shown on the front cover has been dated to *c.* 1610. The mechanism is badly corroded and cannot be removed without the risk of damage. The enveloping crystal (and the cover) contain the typical spiky Colombian emerald inclusions with halite cubes, liquid and gas bubbles. Colombian emeralds only became available in Europe around 1500 and this sets the earliest date for the completion of the watch.

Fig. 1. Watch set in a Colombian emerald crystal. *Photo: by courtesy of the Museum of London*

shop in Cheapside, opposite the church of St. Mary le Bow, a considerable distance from the site mentioned in Wheeler's catalogue of 1928. The workmen discovered the remains of a wooden box filled with jewellery in 1912 and the jewellery was recovered by George Lawrence visiting the public houses frequented by these workmen and buying back from them 'at a modest price' the whole collection.

The only book that deals in any detail with the Cheapside Hoard is *The treasury of London's past*[4] by Francis Sheppard published in 1991. He gives a date for the find of about 18 June 1912 when workmen were excavating a building site at the corner of Friday Street and Cheapside. They discovered 'a bucket' - rather than a box - containing what was thought by the finders to be a collection of beads. George Lawrence managed to buy 'the greater part of the find' from the men for ready cash but there appear to be no details of how this was achieved.

It appears that the initial discovery was not given any publicity. Indeed, a bitter wrangle broke out between the London Museum, which had opened to the public in April 1912, the Guildhall Museum and the Corporation of the City of London concerning the laws of Treasure Trove[5] as applied by the Corporation of the City of London. This dispute was not settled until 1916.

In his book *In search of London*[6], H.V. Morton introduces another account which has to be considered in relation to the vexed question of Treasure Trove. He states that he believed Lawrence declared the Hoard as Treasure Trove, was awarded around £ 1000 and astonished two navvies by giving them something like £100 each. Morton also gives an eye-witness account of the same two navvies handing over an immense mass of clay found in Cheapside.

> 'It was like an iron football and they said there was a lot more of it. Sticking in the clay were bright gleams of gold. When they had gone, we went to the bathroom and turned the water onto the clay. Out fell pearl earrings and pendants and all kinds of crumpled jewellery. That was how the famous hoard of Tudor jewellery which occupied a room to itself in the London Museum was discovered.'

The only public announcement that I have been able to trace appeared in *The Times* in 1914. This referred to the sudden exhibition in the London Museum of the

Cheapside Hoard which was described as having been found in the City of London.

In 1991 an exhibition entitled 'Treasures and trinkets' opened at the Museum of London and in the catalogue[7] it is stated that the Cheapside Hoard was discovered in the foundations of a house in Cheapside near St. Paul's Cathedral in 1912. Many of the pieces are described in detail with illustrations. The only other major work on the Cheapside Hoard is by E.A. Jobbins[8] in which a scientific and scholarly account of some of the major items in the collection is given. Surprisingly there is no modern catalogue of this national treasure.

G.F. Lawrence

The key person in this mystery seems to be a vague and shadowy figure - George F. Lawrence who, with a delightful touch of nineteenth-century pedantry, called himself an 'antiquary'.

I was fortunate enough to be shown a copy of an article which was printed in the *Daily Express*[9] dated 1928 and written by H.V. Morton as a personal tribute to George F. Lawrence on his retirement, aged 67, as Inspector of Excavations from the London Museum.

It would appear that this quiet, gentle man, victimized by asthma, contributed some 15 000 objects out of the soil in the years he worked for the London Museum. He instructed the London navvies how to save anything of archaeological interest and with his capacious carpet bag and ready supply of half crowns he had become a familiar figure at all the London building sites and was affectionately known as 'Stony Jack'. The secret of his success with the navvies was that he was kindly, honest and sincere and never sent them away empty-handed. Even if they brought him something worthless he

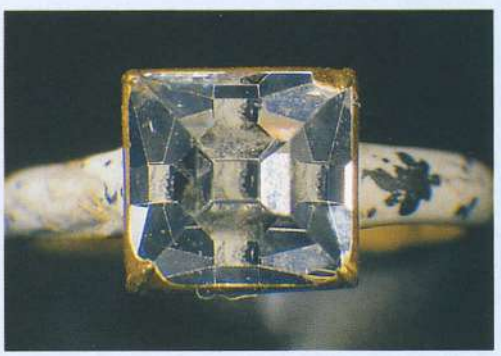

Figs. 2a and b. Table-cut diamond. *Photo by E.A. Jobbins by courtesy of the Museum of London*

The diamond in the ring (A14244) measures 8.4 x 8.0mm with the table approximately 3.4 x 2.8mm. Although the nature of the setting makes weight estimation difficult, the stone is probably between three and four carats. The crown is table cut and the pavilion a modified 'scissors cut', but the detail was difficult to establish because of dominating reflections and the short time available for study. This stone is possibly an exceptional survivor of the old scissors cut many of which had been recut by about 1700 (personal communication, H. Tillander, 1991). The date of burial of the Hoard is commonly believed to be in the second quarter of the seventeenth century which makes it virtually certain that the diamond is of Indian origin.

would always give them the price of a pint of beer. He might have been a character created by Dickens and Morton also creates a picture of this delightful man who, in his old age, became a spiritualist to be in even more intimate contact with former ages.

Morton goes on to explain that George Lawrence had an antique shop on West Hill, Wandsworth, and many of London's workmen brought their finds to him after work. He relates that a most sensational event took place one Saturday night a few years before the 1914-18 War, when workmen arrived with a sack and spilt on the floor many great lumps of caked earth: 'We've struck a toy shop I think guv-nor!' was the comment of one navvy as he indicated various bright streaks in the earth. When the men had gone Lawrence took the earth to the kitchen and washed it. To his astonishment he saw tangled chains of Tudor design and other delicate objects. Morton then goes on to explain that the workmen returned over a period of the next month carrying knotted handkerchiefs full of jewels.

In 1937 when George Lawrence was 76 years old there was a further tribute to him by H.V. Morton in the *Daily Herald*[10] when he refers to the famous hoard of Tudor jewellery which was passed over the counter at Wandsworth wrapped in newspaper and embedded in clay.

It would certainly seem that G.F. Lawrence is one of London's unrecognized benefactors. In his article, H.V. Morton declares it was his belief that

> 'when the archaeological history of the last forty years is written "Stony Jack" will stand in this period as Roach Smith did in Victorian London. No other man has saved so many relics of ancient London for the education and pleasure of future ages.'

In his book *Still digging*[11] Sir Mortimer Wheeler - who was appointed Keeper of the London Museum in 1926 - had some harsh words to say about the general conditions of the Museum.

> 'It had to be cleaned, expurgated and catalogued; in general, turned from a junk shop into a tolerable, rational institution.'

The catalogues were published from 1927 and *The Cheapside Hoard of Elizabethan and Jacobean jewellery*[1] appeared in 1928. As late

The blue sapphire in the ring (A14245) has a hexagonal outline in a rub-over setting and measures 12.3 x 8.4mm. It displays a most unusual cut; the curved edges to the girdle facets lend support to the suggestion that it was originally cut as a cabochon. The remainder of the crown is covered with a series of small (mostly triangular) facets; the pavilion is step cut. Internally there is abundant rutile silk and pronounced hexagonal zoning at angles of 120°.

The shape, style of cutting and the mounting of this stone show a marked resemblance to the Stuart Sapphire in the English royal regalia.

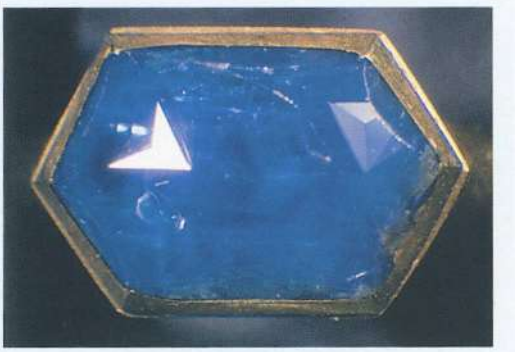

Fig. 3. Hexagonal sapphire in rub-over setting. *Photo by E.A. Jobbins by courtesy of the Museum of London*

Fig. 4a. Amethyst and emerald grape pendants. *Photo courtesy of the Museum of London*

The bunches of grapes are fashioned from amethyst (A14063-4) and emerald (A14112). At a distance the appearance is very realistic; close examination reveals an ingenious method of manufacture. It would appear that annular drills have been used to 'attack' a roughly conical or ellipsoidal piece of gem material from many angles ensuring that all the margins of the resultant borings were in close contact with each other. The material between the cylinders so-produced was then removed and the shallow cylinder ends were rounded off to produce the closely packed 'hemispherical' grapes. This method of manufacture is clearly demonstrated in Figure 4b.

Fig. 4b. Detail of the amethyst 'grapes'. *Photo by E.A. Jobbins by courtesy of the Museum of London*

as 1927 F.L. Lawrence, the son of George Lawrence, presented the London Museum with two amethysts from the Cheapside Hoard.

Discussion

George Lawrence had been employed at the Guildhall Museum part-time, when his main job was the revision and condensation of the manuscript catalogue. In 1911 Lawrence was invited to join the staff of the London Museum to acquire newly discovered archaeological material on site for the museum. It is clear that when he joined the museum in 1926 Dr Mortimer Wheeler held George Lawrence in high regard.

It would seem reasonable to assume that in the year Lawrence retired he would have assisted Dr Wheeler with the catalogue on *The Cheapside Hoard of Elizabethan and Jacobean jewellery* and given some first-hand account of the discovery.

References to the chalk floor of unknown thickness in the cellar and to the treasures buried in the clay would seem to be quite feasible. There were a considerable number of bore holes in that area and they would have penetrated London clay before encountering any chalk, and chalk may well have been brought to the surface as a result. Alternatively it could have been transported to London as ballast in barges from chalk outcrops further down the Thames and then used to cover the cellar floor. The London clay would act as an impervious layer and keep the surface material quite wet. This would probably hasten the decay of the box and some of its contents and allow the treasure to mingle with the silty clay below the chalk floor.

Conclusion

Clearly there is a considerable case for a new illustrated, authoritative catalogue of the Cheapside Hoard and perhaps a need to bring the whole collection together. The items of the Hoard that are in the British Museum were back on display in the summer of 1994. In the Victoria and Albert Museum seven items of the Hoard are elegantly exhibited in the Jewellery Gallery. Of these seven items the necklace was purchased by the Museum in 1921 and the other six pieces of the Hoard have been on loan from the Museum of London since that time. There are many questions still to be answered about this national treasure and some confusion to be settled but we are fortunate that the major part of the Cheapside Hoard is beautifully displayed at the Museum of London in the Barbican.

Acknowledgements

The research for this article was undertaken by the author in response to an invitation to prepare a lecture for the Bewdley Festival. The author would like to gratefully acknowledge the contribution of illustrations and their captions by Mr E.A. Jobbins and for his assistance in discussions throughout the project.

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Further Reading

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Notes from the Gem and Pearl Testing Laboratory Bahrain - 4

Ahmed Bubshait, B.Sc., FGA, and Nick Sturman, FGA, DGA

Abstract

Much of the work of the Bahrain laboratory concerns pearls but only a small number show clearly defined growth structure on radiographs. Synthetic corundum of emerald colour and a filled synthetic ruby are described, emeralds offered for a suspiciously low price turned out to be synthetic, and a greenish-grey cat's-eye was found to be made of glass.

Natural pearl structure

Considering that 95 per cent of the laboratory's work is related to pearl testing, it is surprising that natural pearls with very good to extremely good concentric growth structures are not seen more often on the radiographs we examine. The radiograph shown in Figure 1, however, is of a pearl submitted to us in 1994, which shows extremely good growth structure. It is the clearest example we have seen to date of the concentric structure of a natural pearl in fine detail.

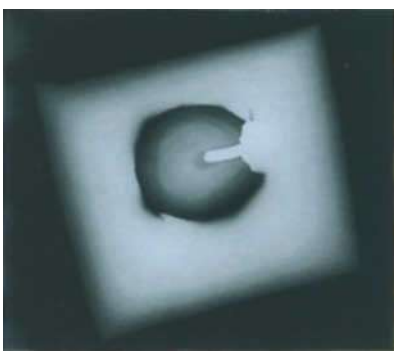

Fig. 1. This radiograph clearly shows the excellent concentric structure of a natural pearl.

It is unclear why some pearls show such good structure and others so little structure on radiographs, but perhaps the conditions experienced by the oyster during the period the pearl formed within it are the most likely cause. These conditions include such factors as water temperature, availability and type of food, disease and locality. All these factors are interrelated to some degree. The species of oyster, its age and the position of the pearl in the oyster (Gutmannsbauer and Hänni, 1994) will also influence the formation of the pearl and probably its radiographic structure. It is thought that natural pearls with very fine to extremely fine structures that are not readily visible on a radiograph, are formed under 'ideal conditions' (Farn, 1986) whereas pearls formed under less than 'ideal conditions' show more pronounced structure. This implies that a pearl with fine structure formed under conditions that changed little over many seasons, whereas a pearl with more pronounced structure reacted to seasonal changes and variation by depositing more conchiolin than calcium carbonate at certain times. Being less radio-opaque and more transparent to X-rays than calcium carbonate, it is the conchiolin that shows up as the dark concentric rings on radiographs.

Synthetic corundum

On a recent trip to a local jeweller, one of

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the authors noticed a box of loose faceted stones being sold as glass. Amongst these variously coloured stones was one 'emerald- green' 'emerald-cut' stone weighing 1.05ct, that looked just like an emerald at first glance. On closer examination with a loupe it looked even more like an emerald, as it was faintly doubly refractive and, although clean, displayed what appeared to be green colour zoning. After informing the owner of the shop that his

Fig. 2. The curved colour bands in the synthetic green sapphire become readily apparent when the stone is immersed in methylene iodide.

'glass' was not glass, but could be something more valuable, he was only too willing to let the laboratory examine the stone on a verbal assessment basis and wait to hear the result at a later date. Back in the laboratory the identification proved to be straightforward. After obtaining refractive indices of 1.760-1.768 (birefringence 0.008, uniaxial negative), a specific gravity of 3.99, a weak but noticeable line in the red of the absorption spectrum (Hughes, 1990, p. 58), and observing minute to small bubbles and curved colour bands through the microscope (Figure 2), it was clearly apparent that, although not an emerald as hoped, the stone was not glass, but synthetic corundum. Although this colour is available in synthetic corundum, it is certainly a shade of green that is rarely encountered in normal day-to-day laboratory testing and probably even in the market place.

A treated synthetic ruby

In our last report from the laboratory (*J.Genm.*, 1994, 24(1), 42-4) we mentioned a group of crackled synthetic Verneuil rubies that had some solid radio-opaque material, most probably glass, filling their surface-reaching fractures. Since examining these stones, another customer has submitted a filled crackled synthetic Verneuil ruby. The fractures in this particular stone were very interesting for two specific reasons: first the fractures showed numerous clear flattened bubbles trapped within them (Figure 3) and secondly the characteristic difference in surface lustre between the corundum and filler was very evident in virtually all the surface-reaching fractures.

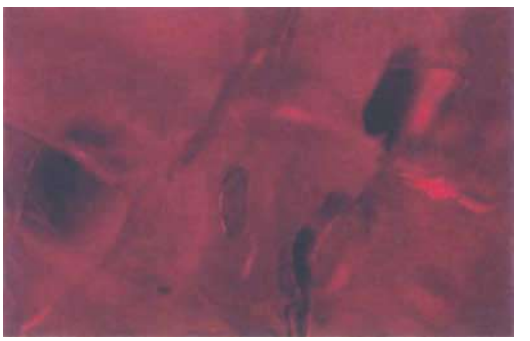

Fig. 3. A large flattened bubble trapped within one of the induced fractures in a Verneuil synthetic ruby.

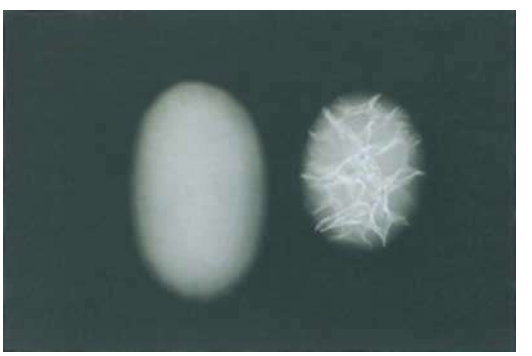

Fig. 4. This comparison radiograph clearly shows the opaque white lines running through the induced fractures of the treated synthetic ruby and the absence of these white lines in the untreated synthetic ruby.

Just for interest, we radiographed this stone with an untreated crackled Verneuil ruby for comparison (as we did with the previous stones) and the resulting image (Figure 4) clearly shows the difference between the two stones. The opaque filler can be seen as bright lines in the treated stone.

The customer who submitted this stone informed us that he purchased it on a trip to Thailand, but the stone was actually obtained in Burma, brought across the border for him to look at by the seller, and negotiations went from there.

It is not clear why some crackled synthetic Verneuil rubies have had their fractures filled. Does it really matter? With a natural stone certainly, but with a synthetic? It seems strange to think that it could have been done on purpose, unless as a trial run with a greater goal in view, maybe in order to treat more natural rubies! However, on the basis of our customer's story, it may be that someone thought the stone was a natural ruby and tried to heat-treat it in order to improve its appearance. It is already known that some natural rubies have their surface cavities and surface reaching-fractures filled with glass and, although this is thought to be an accidental result of the heat treatment process (Hughes, 1990, p. 120) in some cases, it is still considered to be an unacceptable form of enhancement. How this stone and the others we previously examined became treated in this way and whether such treatment occurred by accident is not known, but no doubt we will find out exactly how and why one day.

Hydrothermal synthetic emeralds

Five loose green faceted stones ranging from 0.22ct to 1.00ct were submitted to us by a customer because his suspicions were aroused when the seller asked a price per carat for them as natural emeralds that was 'too good to be true'. When the customer informed us that the dealer selling the stones wanted US$650 per carat for the stones, we too had doubts about their origin. A price of US$1500 per carat or more would have been more realistic in our view. Like most if not all laboratories we know, our laboratory does not give opinions on the values of stones or items of jewellery we examine, but we do try to keep up to date with all aspects of the trade, including market values.

During routine gemmological testing we obtained RIs of 1.569-1.575 for four of the stones and 1.565-1.570 for the fifth, a mean SG of 2.68 for all the stones and very clear spectra diagnostic of emerald. As a result there was no doubt that they were emeralds, so it only remained to determine whether they were natural or synthetic. Owing to the information given to us by the customer, the slightly low RI readings on four of the stones, the very low RI reading on the fifth stone and the low SGs obtained, we were not expecting to find any inclusions that would prove the stones were natural and indeed this was the case.

The four stones with identical RI readings all contained very similar inclusions. The main features seen were chevron type zoning (a characteristic of hydrothermal synthetics), minute white pinpoints running in trails throughout the stones (these were especially clear when immersed in benzyl benzoate and examined in dark-field lighting), clear two-phase feathers and in one particular

Fig. 5. The minute nail-head inclusion seen in one of the synthetic emeralds.

Fig. 6. The distinct zoning noted in all but one of the synthetic emeralds.

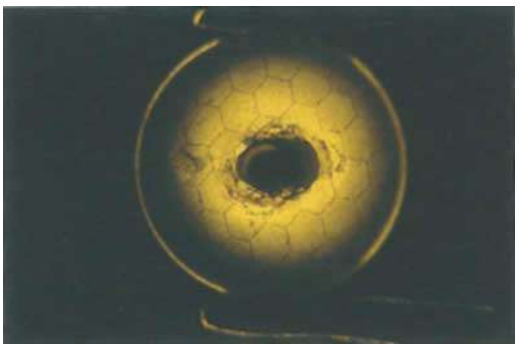

Fig. 8. The very pronounced hexagonal pattern seen down the length of the fibres.

stone a very clear (although extremely small) nail-head or spicule inclusion (Figure 5). When the chevron zoning was observed down its length rather than parallel to it, a distinct V-shaped or wedged pattern was observed (Figure 6). The fifth stone with the lowest RI reading did not contain the same types of inclusions as the other four. Instead the most obvious features were two groups of small acicular colourless crystals that each formed 'stars' (one distorted) and zoning that was more banded than chevron in form. The inclusions in this last stone are similar in some respects to those noted in some Seiko synthetic emeralds (Kennedy, 1986), whilst the features observed in the first four stones are more characteristic of Biron or Russian hydrothermal synthetic emeralds.

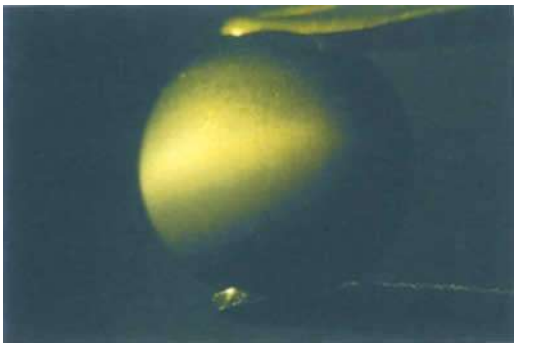

Fig. 7. The chatoyant drilled bead.

Fibre optic glass bead

Recently we were asked to examine a drilled, greenish-grey chatoyant bead (Figure 7) that turned out to be fibre optic glass. Although the RI was very indistinct by the distant vision technique, a vague reading of about 1.62 was obtained. The SG of the bead was obtained with a great deal more accuracy and was found to be 3.33. A very pronounced hexagonal pattern (Figure 8) was seen when the bead was examined in the direction of the drill-hole and, as in the natural stone ulexite and other examples of fibre optic glass, print placed in contact with one end of the fibres was transmitted the length of the fibres and clearly reproduced on the surface at the opposite end. Coincidentally, the week after examining this bead we received the Summer issue of *Gems and Gemology* (Vol. 30 (2)) which contains the account (p.127) of a comparison between a fibre-optic glass cabochon and a sillimanite cat's-eye. The glass described and the bead we examined appear to be very similar.

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The declinometer for refractometers : the latest developments

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Abstract

The declinometer is the best mechanical accessory for any gemmological refractometer because it enables the user to obtain the maximum amount of information about the stone being examined.

The following is an analysis of the modifications introduced in the current model of the declinometer and their possible uses.

The new declinometer

A detailed description of the declinometer and its operation has been published previously (Moliné Sala, 1985). During recent years several parts of the declinometer have undergone modification in order to enhance its features. In the course of this process, the opinions and suggestions contributed by its users have been invaluable. This discussion will be limited to changes made in the current model of the declinometer.

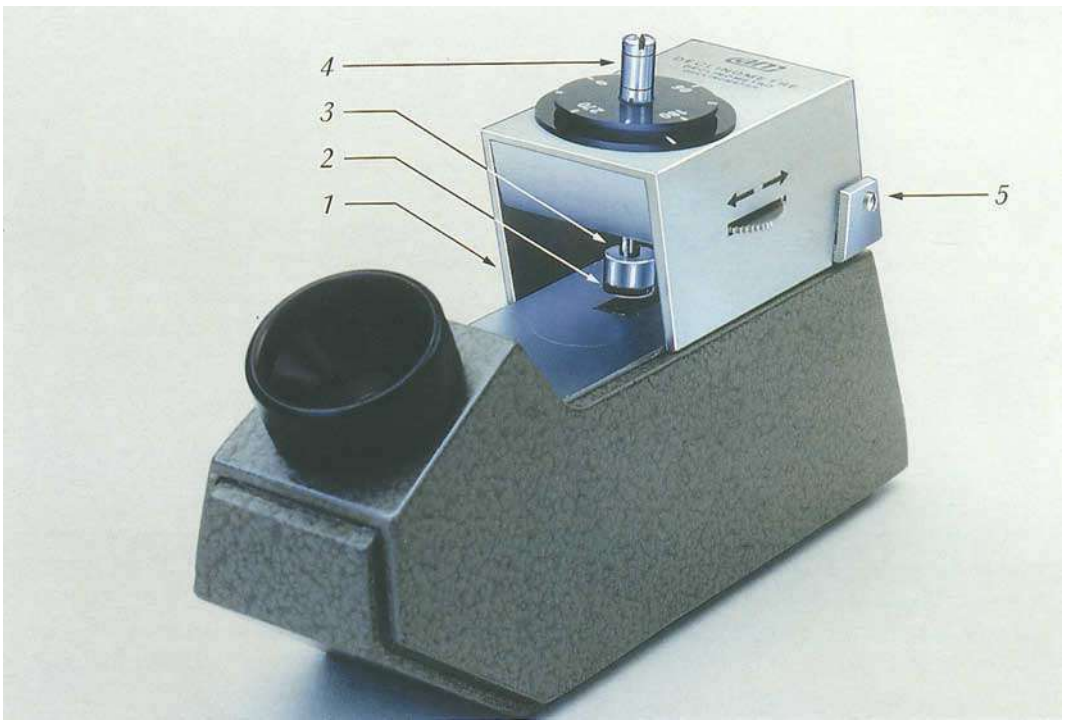

Fig. 1. The current model of the declinometer fitted on a Topcon refractometer. The numbers refer to the parts that have been modified (see the text).

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Fig. 2. The declinometer is fitted on a Rayner refractometer by means of an additional base-piece.

The improvements introduced are the following (Figure 1):

1. the sleeve/flange of the front part has been lengthened to avoid the consequences of lateral light falling on the stone being examined;
2. a new elastic pad with a grooved surface adapts better to the pavilions of the stones and makes them easier to rotate. The material used in the pad is cross- linked polyethylene foam, which is far more compact and is highly resistant to a range of chemical substances and solvents;
3. the position of the cup with the elastic pad may be vertically adjusted to adapt it for the study of very small or very flat stones. It is also advisable to readjust the height of this cup when the declinometer is attached to Rayner refractometers;
4. a small spring has been added to the main vertical shaft to strengthen the traction movement on the stone and to improve the contact between the stone and the glass of the refractometer prism;
5. the piece that attaches the declinometer to the refractometer, one of the most important parts of the device, has been completely redesigned. Each declinometer of the preceding model could only be attached to one specific type of refractometer and that was a serious drawback when the user was equipped with several different refractometers. The new piece has adjustable lugs that allow the user to fit the declinometer with equal ease on the three most frequently used types of refractometers, such as the Rayner, the Shibuya (which includes Fuji, Kyowa, System Eickhorst, Krüss, etc.) and the Topcon;
6. the middle base-piece that enables the attachment of the declinometer to the Rayner refractometer has been simplified (Figure 2). This additional piece is necessary since the hinge of the cover of

the Rayner has no vertical slots to fit the declinometer.

Main applications of the declinometer

The declinometer is a mechanical precision instrument which was designed, first and foremost, so that the user of a gemmological refractometer could avoid the disadvantages resulting from the movement of the stone on the refractometer prism. Any direct handling of a stone on the prism of a refractometer entails a number of problems which must be taken into account, principally related to the contact, centring and rotation. To avoid them, the user must work with extreme care. In addition, he must combine the handling of the stone with the rotation of the polarizer and also note the readings. Carrying out these processes carefully is time-consuming and, even when every precaution is taken, the results obtained with very small stones may be inaccurate.

Besides overcoming all these mechanical obstacles, the declinometer provides direct data on the optical properties of the stone. However, often the user will not need such complete information and will opt for a simplified manipulation of the declinometer using only some of its features. Two very different applications of the declinometer can be outlined, depending on the requirements of the user.

a) A 'practical' application

When different stones must be separated as quickly as possible, as is the situation with parcels of mixed stones, the declinometer can be used to control the movement of the stone, utilizing the three-fold feature of turning it centred, quickly and with complete contact maintained during the entire revolution. This allows gemmologists to devote their full concentration to the eyepiece. It is obvious that in such a case it is advisable to use a refractometer with an internal scale, allowing direct reading through that eyepiece. In the vast majority of situations the gemmologist will easily obtain approximate values of the refractive indices and birefringences. The optical character and indications of the optical sign can also be detected, since the use of the declinometer eliminates the possibility that the oscillations of the shadowy lines observed are in reality due to an unsatisfactory displacement of the stone on the prism of the refractometer. The data obtained in this manner, although approximate, are sufficient for an initial selection of the stones.

b) An 'analytical' application

The declinometer can demonstrate its full potential for providing more accurate and more detailed data than can be obtained by any conventional procedure in which this device is not used. For this application the declinometer has two wheels positioned at the top. The main wheel is graded in sexagesimal degrees and turns together with the shaft of the device in such a way that each reading on the refractometer scale, corresponding to a direction (or 'declination') of the facet of the stone being examined, is associated with a reading in that graded wheel. The other wheel serves as the reset, zeroing or reference for the main wheel and allows the user to note the readings that are optically significant (i.e. the 'optical declinations'), corresponding to the maximum and minimum values and the inflection points of the refractive index and to the maximum birefringence. It also enables the user to take as many repeated and revised readings as are considered necessary.

The theoretical concept and the possibilities of a declinometer for refractometers have already been described by Figueras (1976). Utilizing a declinometer model, Figueras made a study of what are described as refractometric graphics. A refractometric graphic is the graphic representation of

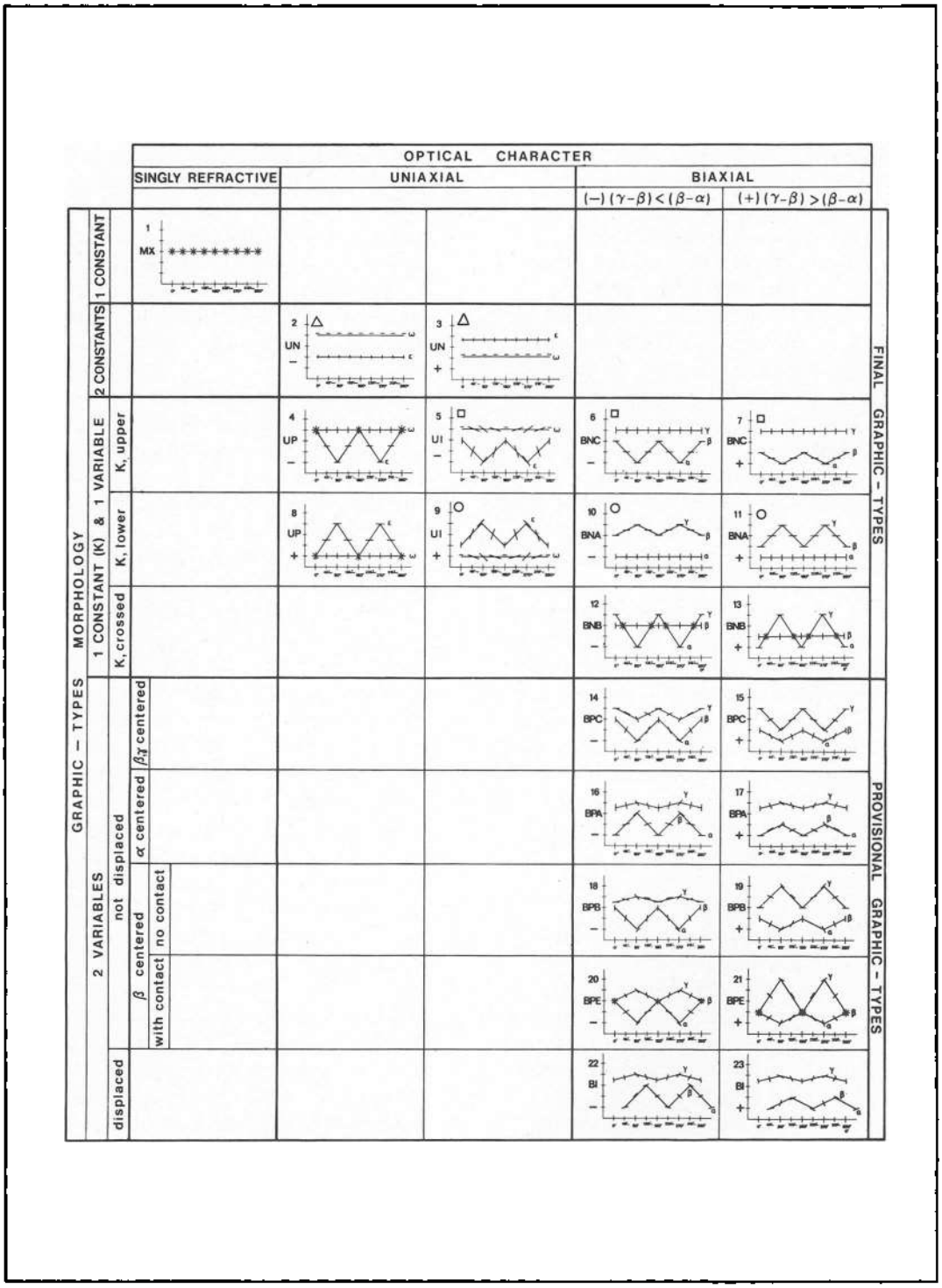

Fig. 3. Diagram of the graphic types established by J. Figueras.

the refractive indices and of the polarization traces corresponding to all the optical declinations of a facet. The polarization traces are the graphic expression of the polarization plane of the rays that determine the reading of a refractive index.

Each refractometric graphic is formed by one or two refractometric curves, deduced from a sequence of readings on rotation of the stone and through calculations with stereographic projection. Although the theoretical and real form of refractometric graphics is a continuous curve, it is easier and more functional to represent them by broken lines linking their measured points of inflexion and of single refraction. The author has established the existence of 23 types or patterns of refractometric graphics (Figure 3). This is believed to be comprehensive and that, whatever stone is being studied and whatever facet is chosen, a refractometric graphic will be obtained which is comparable to one and only one of these 23 graphic types. Further work with the declinometer is continuing.

Acknowledgement

The author is grateful to Mr Jordi Figueras, Director of Courses of Asociacion Española de Gemologia, for his assistance and critical reviewing of this article concerning the subject of his refractometrical theory.

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The infrared microscope and rapid identification of gemstones

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Abstract

Infrared spectroscopy is now widely used in gem laboratories to characterize natural, treated and synthetic stones. Because of technical limitations the method is not appropriate for all gems but use of the infrared microscope can widen this application. The spectrum is obtained from a beam of reflected light and characteristic spectra in the mid-infrared region analyzed. It is an important method of gem identification for stones difficult to determine with classical gem testing methods and results for diopside, kornerupine and sillimanite are discussed.

Introduction

Infrared spectroscopy was first used in mineralogy during the 1950s. With the development of Fourier transform infrared (FT-IR) spectrometers the study of minerals became faster and easier. Initially only a few research laboratories used infrared methods for identifying gems, concentrating more on methods for distinguishing natural from treated or synthetic stones. Many of the original experimental procedures involved measurement of powders or thin slabs of material, but development of reflectance accessories enabled gems with at least one polished face to be analyzed (Martin *et al.*, 1989). The above methods are of limited use in gem identification but the infrared microscope has wider application and can provide results on gems difficult to identify by other means. The method can be used on uncut or polished gems, loose or mounted in jewellery, and is non-destructive. The reader is also referred to the reviews by Fritsch and Stockton (1987) and Fritsch and Rossman (1990).

Principles of the method

The infrared (IR) spectrum is an indication of vibration energy levels in the atomic structure of a substance and may display a characteristic pattern for a particular substance. The fundamental vibration energies in the structures of many gemstones are located in the mid infrared region, typically between 1500 and 400cm^{-1} (i.e. between wavelengths 6.67 and 25 μm) and use of reflectance techniques can detect these. The infrared absorption caused by structural vibrations is determined by bond lengths and bond angles between the atoms and has been described as the 'fingerprint zone'.

Because of the directional arrangement of atoms in many minerals, the absorption of infrared radiation may be directional. So, although the locations of the absorption peaks in the spectra should remain constant in different directions, the degree of absorption may vary. So the characteristic absorption pattern and the presence or absence of infrared pleochroism are important features of a mineral or gem.

Most natural minerals, and particularly silicates, are opaque to infrared radiation between 1500 and 400cm^{-1} when of significant thickness; thus investigation of

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transmitted infrared radiation in this critical region is not possible. However with reflected radiation and the infrared microscope it is possible to obtain spectra which can be diagnostic for certain minerals. Although this science is young, infrared spectra for many substances have been published and form the basis for this method of identification.

Instrumentation and experimental procedures

For this study the Nicolet Magna-IR 750 infrared spectrometer, an IR-plan infrared microscope and a 486 computer system were used (Figure 1). The gem to be tested was cleaned and dried and stuck with plasticine to a sample board so that it could be examined face (table facet) up on the microscope stage (Figure 2). Large samples can be placed directly on the microscope stage.

The microscope contains two light systems, one visible and one infrared. The visible system is used first to locate the sample and focus on the face or facet to be investigated. Then the infrared system is switched in and the data are collected

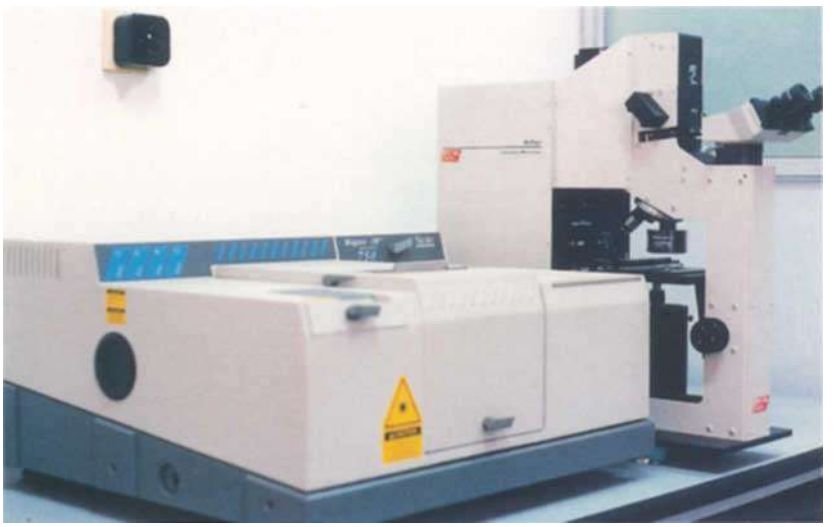

Fig. 1.
The infrared spectrometer and the infrared microscope.

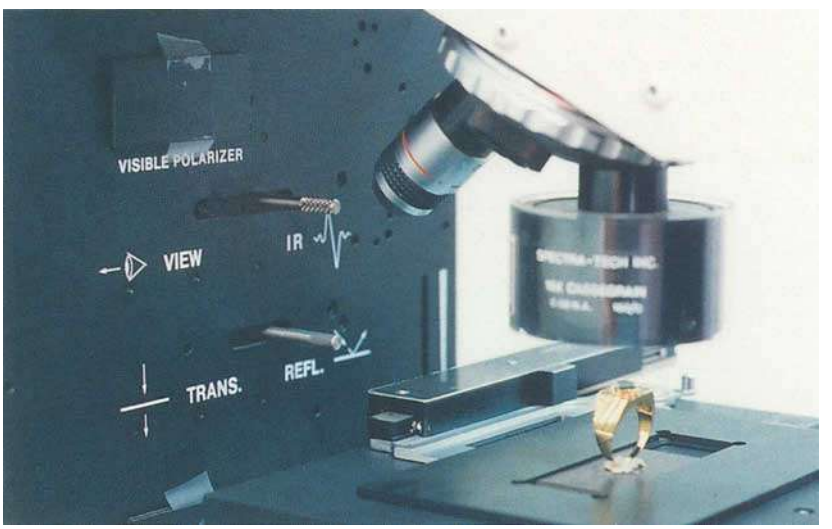

Fig. 2.
The sample stage of the infrared microscope and the jewellery stuck to the sample board with plasticine. The visible light objective lens is used to find and focus a sample and the infrared light objective is used to measure the spectrum.

using the computer. Normally the range 2000 to 400cm^{-1} is scanned 64 times for each sample. Resolution is 8cm^{-1} and it takes 30 seconds to measure each sample.

Application of the method: distinction of three cat's-eyes composed of diopside, kornerupine and sillimanite

Diopside, kornerupine and sillimanite cut and polished as cabochons may all show chatoyancy (Figure 3). Using classical gemmological methods it is very difficult to distinguish these three gems, especially if they are mounted in jewellery.

Nevertheless, they are three different minerals with different chemical compositions and structures. Diopside is $CaMgSi_2O_6$ and belongs to the monoclinic crystal system, kornerupine is Mg_3Al_6 (Si, Al, B)$_5O_{21}$(OH) and is orthorhombic, and sillimanite is Al_2SiO_5 and orthorhombic. The features of these three gems are listed in Table I, and the infrared spectra are

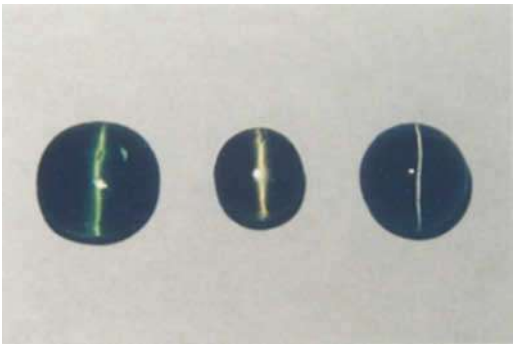

Fig. 3. The samples (from left) are diopside, kornerupine and sillimanite. All are chatoyant and similar in appearance.

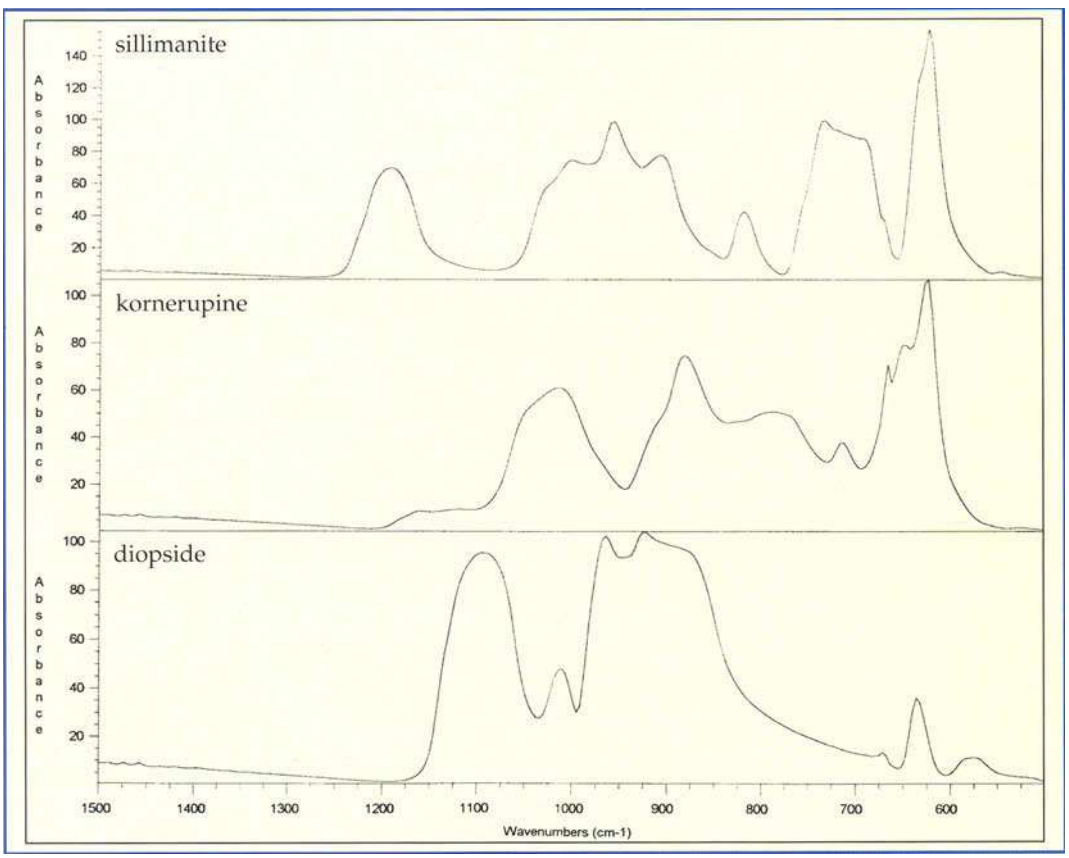

Fig. 4. The infrared reflectance absorption spectra of diopside, kornerupine and sillimanite (non-directional).

Table I: Properties of samples of diopside, kornerupine and sillimanite

Mineral name	*Diopside*	*Kornerupine*	*Sillimanite*
Colour	Dark green	Dark brown	Brownish-purple
Phenomena	Chatoyancy	Chatoyancy	Chatoyancy
Refractive Index (spot reading)	1.68	1.68	1.67
Specific Gravity	3.33	3.37	3.28
Absorption Spectra	Not diagnostic	Not diagnostic	Not diagnostic
Ultraviolet Fluorescence			
LW	Inert	Inert	Inert
SW	Inert	Inert	Inert
Semiquantitative analysis by energy dispersive X-ray fluorescence (EDXRF)			
Main composition	CaO,MgO,SiO_2	MgO,Al_2O_3,SiO_2	Al_2O_3,SiO_2
Trace element	Fe	Ca	Mn

shown in Figure 4.

It is apparent from Table I that the gemmological properties of the three gems are very similar. However the different chemical compositions and structures give rise to distinctive infrared spectra which, together with the gemmological properties, are diagnostic for these gems. It is concluded that the infrared microscope is a very useful instrument for gem identification and may provide diagnostic information for gems whose other properties are similar.

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Photogenic inclusions in moldavite

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Abstract

Natural glasses in the form of tektites are found in many regions around the world. This article with accompanying photographs is intended to acquaint the reader with the unusual and very photogenic inclusions and occasional occlusions that occur in the moldavite tektites from two southern areas of former Czechoslovakia. This article also looks briefly at tektite specimens from Thailand.

Introduction

It has been predominantly agreed that tektites were formed when large meteorites struck the earth's surface (Horn, 1985). The extremely high pressures and temperatures that were generated at the point of impact melted the hard rocks, loose overburden and soils and ejected the molten material in a direction dependent on the angle and direction of the impacting body (Bouška, 1993). The hot gases and vapour from the impact explosion threw the molten, congealing material into (and in some cases above) the atmosphere where it was fragmented into small pieces (tektites) by turbulence. Tektites have been found on most of the continents around the world and their landing sites are referred to as 'strewn fields'. The most important of these sites are: the Australian strewn field, 750 thousand years old; the North American strewn field, 35 million years old; the Ivory Coast strewn field, 1 million years old.

About 15 million years ago a massive meteorite travelling from a westerly direction struck the earth about 85 kilometres east of Stuttgart in southern Germany, forming the Nördlinger-Ries crater (Chao, 1977; Chao *et al.*, 1992). In the case of the moldavite tektites (named after the river Moldau), the molten masses that were formed as a result of this impact were thrown into the atmosphere and rained down as tektites over the southern Czech Republic in areas formerly known as Bohemia and Moravia, about 320km and 450km respectively, east of the impact site (Horn, 1985).

Historical aspects

Moldavites have been recovered in archaeological sites in Austria and the Czech Republic, and these sites have been dated back to 30 000 BC (Hrabanek and Malley, 1988). It can be assumed that prehistoric man used these moldavites as implements and also probably as jewellery. Most of the moldavites that appear on the jewellery market today are of the strongly corroded or 'sculptured' variety. They can resemble leaves and ferns and can even look like chipped stone arrow heads (see Figure 1). Their colour can be described as translucent bottle-green. Although these sculptured specimens are heavily textured with ridges and grooves they are quite lustrous and can be made into attractive jewellery. Moldavite was quite popular in jewellery up to the end of the last century and in recent years has enjoyed a minor renaissance. Some of the sculptured mol-

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Fig. 1. Various shapes of moldavite tektites and a faceted specimen. Note the difference in the texture - in some specimens the ridges and grooves are quite deep and others have a pock-marked texture. Some of the shapes are very attractive and lend themselves to modern jewellery design.
The arrows point to the two specimens described in this paper. The length of the faceted oval stone is **14mm.** *Photo: A. de Goutière.*

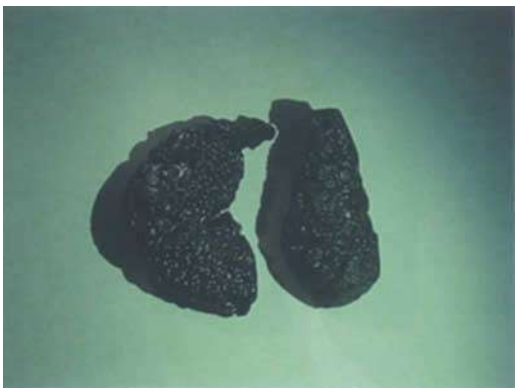

Fig. 2. Two tektite specimens, purportedly from Thailand, are not as delicate looking as the moldavite specimens, but are distinctive nevertheless. The larger specimen measures **50 x 27 x 17mm.** *Photo: A. de Goutière.*

davite has been cut into cameos, effectively combining nature's sculpting with that done by gemstone carvers. Recently, sculptured moldavite has appeared on the market as a cult talisman with attributed 'magical healing powers'.

Some moldavites have been faceted and it was just such a stone that came into the author's hands recently. It is an oval modified brilliant-cut measuring 14.0 x 12.0 x 9.2mm, and weighs 6.40ct. Its colour could be described as translucent bottle-green and as a gemstone is not very attractive. However, it is the interior of this specimen that is beautiful as the accompanying photomicrographs illustrate.

Some tektite specimens purportedly from Thailand were also examined. These particular tektites were found by miners who screen alluvial gravels in their search for rubies. The material is very dark blackish-brown with a faint translucency at the thin edges. They are more massive than moldavites and have a distinctive pock-marked surface, see Figure 2.

A 4mm thick polished slice revealed swirls in parts of the specimen and variously shaped 'Schlieren' containing small gas bubbles. Examination using crossed polarizers revealed strain but only faint interference colours when combined with the first-order red compensating filter. Figures 10 and 11 illustrate the inclusions.

Inclusions

The most fascinating inclusions in moldavite glasses are the lechatelierites with their strange spiral and meandering shapes. These lechatelierite glasses are composed of pure silica and because of their higher melting point did not homogenize with the surrounding glass although they did become fluid to the extent that they were influenced by the flow of the molten glass (Bouška, 1993). Other inclusions found in moldavites are gas bubbles of various sizes, both oval and spherical in shape, and the 'Schlieren' which are elongated inclusions with a treacly appearance (Schliere is German for treacle.) These combinations of inclusions are not necessarily found in all moldavites but when present they indicate the source as probably the České Budějovice-Třebon region in southern Bohemia or the Třebic area in Southern Moravia.

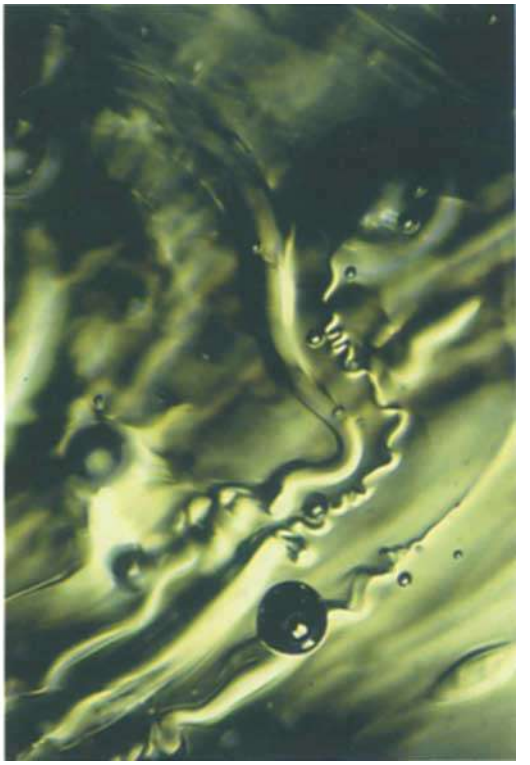

Figs 3, 4 and 5.
Spiral and meandering lechatelierite inclusions and gas bubbles in moldavite. The vermicular lechatelierite inclusions resemble tendrils on a grape vine. In Figure 4 one can imagine a small bird among the vines. These three photomicrographs were taken using transmitted plus side illumination. The magnifications are 60x, 50x and 50x respectively. *Photos: A. de Goutière.*

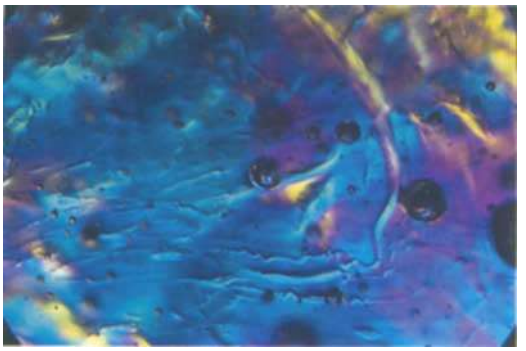

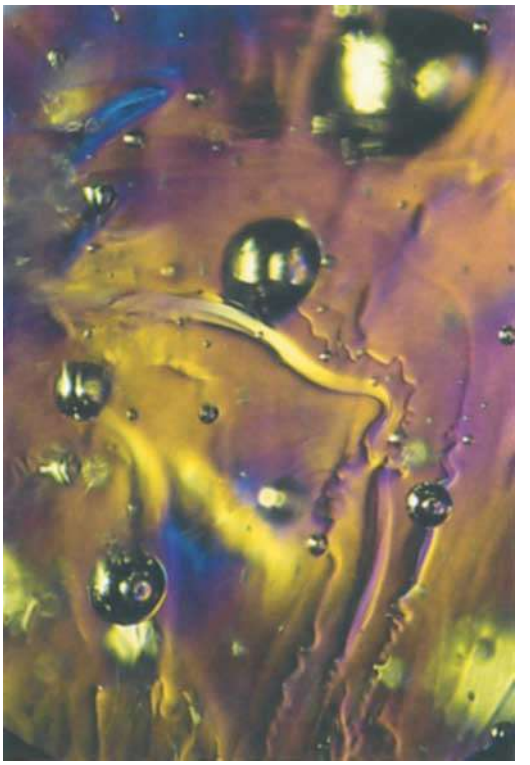

Figs 6 and 7.
Internal strain is present in most moldavites and was obvious in this specimen under crossed polaroids. As an experiment the author inserted a first-order red compensating filter between the specimen and the lower polarizer and produced these spectacular interference colours. Slide magnifications are 14x and 40x respectively. *Photos: A. de Goutière.*

According to Boŭska (1993), the refractive index of moldavite ranges from approximately 1.485 to 1.491 and the specific gravity varies from approximately 2.31 to 2.37. The hardness is approximately 5 on Mohs' hardness scale. However, the 6.40ct oval faceted specimen described in this paper has a refractive index of 1.498, higher than the figures quoted. The specific gravity, determined using the hydrostatic method and taking the average of three measurements, worked out to

Fig. 8. Hook-shaped lechatelierite occlusion on the surface of a moldavite. Dark field illumination, magnified 30x. *Photo: A. de Goutière.*

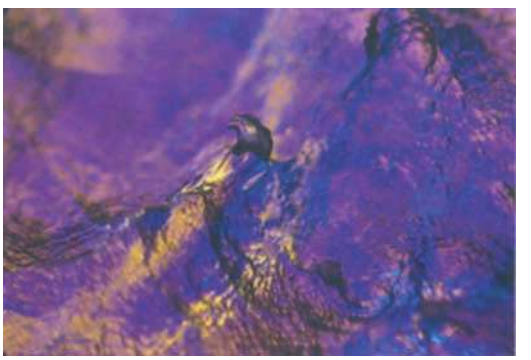

Fig. 9. Occlusion pictured in Fig. 8 from a slightly different angle. Transmitted polarized illumination plus a first-order red compensating filter. Magnified 30x. *Photo: A. de Goutière.*

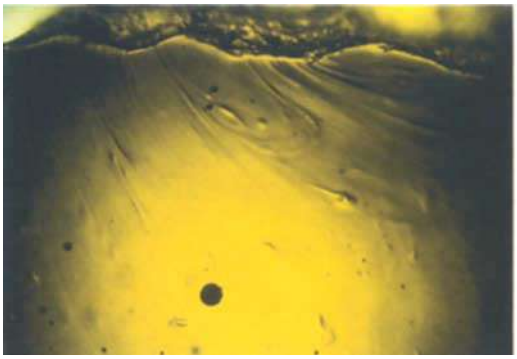

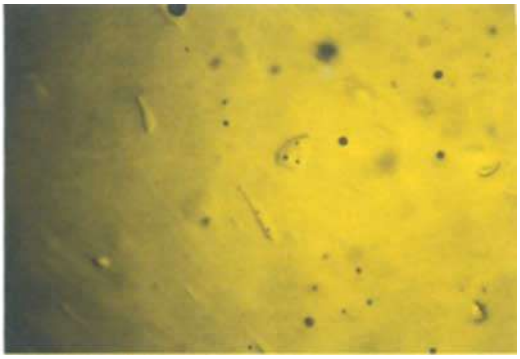

Figs 10 and 11.These two photomicrographs illustrate the inclusions occurring in tektites from Thailand. There is a slight resemblance to the inclusions in moldavite especially in Fig. 10. In Fig. 11 two of the included 'Schlieren' appear to contain small gas bubbles Fig. 10 magnified 17x; Fig. 11 32x. *Photos: A. de Goutière.*

2.356 and falls within the range reported above.

The polished slice of tektite from Thailand described in this paper has a refractive index of 1.50 and its specific gravity, determined using the hydrostatic method and taking the average of three measurements, worked out to 2.955.

Summary

Although moldavite will probably never be a particularly popular gemstone, it is a fascinating material for study. The endless variety of shapes in the sculptured specimens is intriguing and the fact that they are the direct result of a cataclysmic event that took place millions of years ago gives moldavite a certain aura of mystery.

Moldavites are readily obtainable and the author suggests that gemmologists interested in the study of inclusions should have at least one faceted (or windowed) specimen and one sculptured specimen in his/her collection. There is also the added bonus of observing the beautiful colour reactions when the moldavite is rotated between crossed polarizers in combination with the first-order red compensating filter.

Acknowledgements

The author would like to thank Rogerio Graca and Gerry Vaulkhard of Victoria BC, and also Stéphane Salerno of Edmonton, Alberta, for supplying the specimens used to illustrate this article.

A special thanks to Dr Vladimír Bouška, Professor of Geochemistry, Charles University, Prague, Czech Republic, for research advice and for his interest in the author's photomicrographs.

I would also like to thank my referee *inconnu* for his valuable comments and suggestions in the preparation of this paper.

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Abstracts

Diamonds | Gems and Minerals

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Diamonds

Interstellar grains in meteorites: I. Isolation of SiC, graphite, and diamond; size distributions of SiC and graphite.

A. AMARI, R.S. LEWIS AND E. ANDERS. *Geochimica et Cosmochimica Acta*, **58** (1), pp 459-70.

Isolation of these three minerals involved dissolution of silicates in HF-HCl, destruction of kerogen by $Cr_2O_7^{2-}$, KOH and H_2O_2, with recovery of the microdiamonds as colloids. Graphite is recovered by density and size separations. Spinel is dissolved in the residue in H_2SO_4 leaving SiC (~6 ppm), hibonite and corundum. Size distribution measurements of SiC (0.2-6 µm) show a mainly log-normal distribution. R.K.H.

Evaluation de la masse de Dresde Vert par calcul.

H. ASTRIC, B. ASTRIC, H. MERIGOUX AND P. ZECCHINI. *Revue de Gemmologie*, **120**, 1994, pp 13-14, 1 photo in colour, 2 figs (1 in colour).

The mass of the Dresden Green diamond is calculated and the stone weight is given as 40.67ct. Previous calculations are summarized. M.O'D.

Interstellar grains in primitive meteorites: diamond, silicon carbide, and graphite.

E. ANDERS AND E. ZINNER. *Meteoritics*, **28** (4), 1993, pp 490-514.

Primitive meteorites contain a few ppm of pristine interstellar grains that provide information on nuclear and chemical processes in stars. Their interstellar origin is proved by highly anomalous isotopic ratios, varying more than 1000-fold for elements such as C and N. Most grains isolated thus far are stable only under highly reducing conditions (C/O >1), and apparently are 'stardust' formed in stellar atmospheres. Microdiamonds, of median size ~10Å, are most abundant (~400-1800 ppm) but least understood. They contain anomalous noble gases including Xe-HL, which shows the signature of the *r* and *p*-processes and thus apparently are derived from supernovae. Silicon carbide, of grain size 0.2-10 µm and abundance ~6ppm, shows the signature of the *s*-process and apparently comes mainly from red giant carbon (AGB) stars of 1-3 solar masses. Some grains appear to be > 10^9 yr older than the Solar System. Graphite spherules, of grain size 0.8-7µm and abundance < 2ppm, contain highly anomalous C and noble gases, as well as large amounts of fossil ^{26}Mg from the decay of extinct ^{26}Al. They seem to come from at least three sources, probably AGB stars, novae and Wolf-Rayet stars. R.H.J.

Investigations modernes du diamant vert de Dresde et interprétation des résultats.

G. BOSSHART. *Revue de Gemmologie*, **121**, 1994, pp 4-12, 7 photos (5 in colour).

ABSTRACTORS

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For further information on many of the topics referred to consult *Mineralogical Abstracts* or *Industrial Diamond Review*.

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The Dresden Green diamond was subjected to laboratory examination, the full results of which are given. The stone is classified as Type IIa.

M.O'D.

A preliminary study of $^{15}N/^{14}N$ in octahedral growth form diamonds.

S.R. BOYD AND C.T. PILLINGER. *Chemical Geology*, **116** (1-2), 1994, pp 43-59.

The $\delta^{13}C$, $\delta^{15}N$ and N concentrations have been determined in 43 octahedral diamonds from South Africa, Australia and North America. The N in 'high-$\delta^{13}C$' diamonds was generally depleted in ^{15}N relative to atmospheric N, similar to the results obtained previously from fibrous diamond. It is believed that the volatiles from which these diamonds grew are primitive, being derived from a source located beneath the continental lithosphere. The 'low- $\delta^{13}C$' diamonds contained N generally enriched in ^{15}N relative to air. It is suggested that the major C isotope heterogeneity within the mantle, as represented by diamonds such as these, is located in deep, mechanically unstable regions of the continental lithosphere. The isotopic compositions of both C and N are consistent with this heterogeneity resulting from the subduction of crystal material, though isotope fractionation related directly to diamond growth cannot be ruled out. R.E.S.

The story of Russian diamond occurrences.

W.E. BOYD. *Canadian Gemmologist*, **15**(1), 1994, pp 8-13, 2 photos.

Report of a visit made to the Siberian diamond fields in 1993 with notes on production and occurrence. M.O'D.

On the importance of fluids for diamond growth.

P. DEINES AND J.W. HARRIS. *Mineralogical Magazine*, **58A**, 1994, pp 219-20.

A systematic investigation of carbon isotope geochemistry and sulphide inclusion chemistry is undertaken for diamonds from southern Africa. Specimens are taken from deposits at Koffiefontein, Orapa, Premier, Roberts Victor, Jagersfontein, Sierra Leone, Star mine, Mwadui and Alamasi. Data are used to determine the role of fluids in diamond formation. M.O'D.

[Mineralogical criteria for determination of diamond content in kimberlites.] (Chinese with English abstract)

Z. DONG, A. CONG AND Z. HAN. *Mineral Deposits*, **12 (1)**, 1993, pp 48-54.

In kimberlites diamond is associated with pyrope, picotite, ilmenite, clinopyroxene and olivine, whose physical and chemical properties partly reflect their high T-P formation conditions. The higher the *a*, D, Cr_2O_3, Cr/(Cr + Al), ($Mg_3Cr_2Si_3O_{12}$) and Cr component in pyrope, the higher the content of diamond in the kimberlites. Picotite from diamond-rich kimberlites contains higher Cr_2O_3, Cr/(Cr + Al), Cr/(Cr + Al + Fe^{3+}), $MgCr_2O_4$, and Cr than that from diamond-poor kimberlites. The lower the IR absorption frequencies of pyrope and spinel in kimberlites, the higher the content of diamond in kimberlites. With increasing MgO, $MgTiO_3$ and Cr_2O_3 in metacrystalline and coarsely-crystallized ilmenite, the diamond content of kimberlites tends to increase. Compared with clinopyroxene in diamond-poor kimberlites, clinopyroxene in diamond- rich kimberlites contains lower (Ca/(Ca + Mg), Ca/(Ca + Mg + Fe) and tschermak molecule, but higher Mg/(Ca + Mg + Fe), Cr_2O_3 and $Al^{[vi]}/Al^{[iv]}$. Olivine in diamond-bearing kimberlites is rich in MgO, Cr_2O_3 and NiO. R.E.S.

Isotopic composition of lead and its use to date Siberian kimberlites.

N.N. FEFELOV, S.I. KOSTRAVITSKIY AND N.V. ZARUDNEVA. *Akademia Nauk Russian Doklady, Earth Sciences Section*, **321A**(9), 1994, pp 186-9.

The isotopic data are tabulated, plotted and discussed. In the Malaya Botuobuya field the age of the Mir pipe is 362 m.y., the age of the Anomaliya-21 is 360 m.y. and the age of the Internatsionanalaya pipe is 450 m.y. The Aykhal pipe has an age of 344 m.y. The Udachnaya pipe has an age of 348 m.y. In the Daldyn-Alakit field the Lipa pipe has an age of 352 m.y. The veins of the Ingashi field have an age of ~1250 m.y. or a Rb-Sr age of 1268 m.y. K.A.R.

Carbon-isotope composition of diamonds from Arkhangel'sk-Region kimberlite pipes.

E.M. GALIMOV, O.D. ZAKHARCHENKO, K.A. MAL'TSEV, A.I. MALKIN AND T.A. PAVIENKO. *Geochemistry International*, **31**(8), 1994, pp 71-8, 3 figs.

The Arkhangel'sk diamond region in the north of European Russia is a recent discovery. The carbon isotope composition of diamonds obtained from kimberlite pipes in the region is examined and the value of $\delta^{13}C$ ranges from -2.9 to -22.2‰ but with most specimens showing values greater than -10‰. The $\delta^{13}C$ distribution is

similar to that for diamonds world-wide but is different in detail from those for diamonds in other regions. The carbon isotope composition is related to the morphology of the diamond with the widest range of $\delta^{13}C$ occurring in dodecahedroids. Stones containing inclusions characteristic of eclogite paragenesis are on average isotopically lighter than those containing ultrabasic paragenesis-type inclusions. The diamonds examined were found at the Zolotitsk kimberlite field. M.O'D.

The origin of diamonds in western Minas Gerais, Brazil.

G.M. GONZAGA, N.A. TEIXEIRA AND J.C. GASPAR. *Mineralium deposita*, **29**, 1994, pp 414-21, 3 maps.

Diamonds are found in an alluvium/colluvium in the Brasilia Orogenic Belt, western Minas Gerais, Brazil. The age of the Belt is estimated at 700-450 m.y. The relationship between diamonds and a variety of formations is discussed. Analysis of the field relations shows that the majority of the diamonds were transported by glacial events from the São Francisco craton further east.

M.O'D.

Lower mantle mineral associations preserved in diamonds.[1]

B. HARTE AND J.W. HARRIS. *Mineralogical Magazine*, **58A**, 1994, pp 384-6

Minerals with (Mg,Fe)O composition are found in inclusions in some natural diamonds and it is possible that these originated in the lower mantle. The question is discussed with reference to diamonds from São Luiz, Brazil.

M.O'D.

Trace element characteristics of the lower mantle: an ion probe study of inclusions in diamonds from São Luiz, Brazil.[1]

B. HARTE, M.T. HUTCHISON AND J.W. HARRIS. *Mineralogical Magazine*, **58A**, 1994, pp 386-7, 1 fig.

Diamonds are found in an alluvial deposit at São Luiz, Matto Grosso, Brazil. They contain syngenetic inclusions of 50-400 µm diameter, indicating parageneses stable at pressures corresponding to the transition zone and lower mantle. One suite of these inclusions shows majorite garnet coexisting with calcic pyroxene while another, discussed in the paper, shows periclase-wustite probably existing with $CaSiO_3$ and $(Mg,Fe)SiO_3$. M.O'D.

Diamondiferous eclogites from Udachnaya: a subducted component in the Siberian upper mantle.[1]

D.E. JACOB, E. JAGOUTZ, D. LOWRY, D. MATTEY, M. ROSENHAUER AND G.P. KUDRJAVTSEVA. *Mineralogical Magazine*, **58A**, 1994, pp 448-9, 1 fig.

Eight diamond-bearing bimineralic eclogite xenoliths from the Udachnaya mine, Yakutia, Siberia, were investigated to establish major element content and oxygen isotopic ratios with a view to extending knowledge of Siberian mantle history and to compare it with that of the South African craton. The aim was also to examine the homogeneity of eclogite-forming processes on a global scale. M.O'D.

Chemical properties of Central African carbonado and its genetic implications.

H. KAGI, K. TAKAHASHI, H. HIDAKA AND A. MASUDA. *Geochimica et Cosmochimica Acta*, **58**(12), 1994, pp 2629-38.

Analyses are reported of alluvial carbonado stones from the Central African Republic; these are aggregates of polycrystalline diamond particles with non-carbonaceous inclusions. The results include photoluminescence spectra, thermal (TG-DTA) data, IR spectra, *REE* elemental and isotopic analyses. On the basis of spectral profiles three groups are identified with very intense photoluminescence bands resulting from radiation-damaged defects. Group B carbonado has been exposed to a higher *T* than Group A; the transition from Group A to B arose between 400-500°C. Group A carbonado has a narrow exothermic peak at 800°C while Group B has a broad exothermic band at 790°C. An absorption band at 1384cm^{-1} in IR spectra indicates N_2 platelets in the diamond lattice. Crystallization of microdiamond by high *P* and *T* in the upper mantle was followed by binding of the microcrystals in the crust under U and Th irradiation, with hydrothermal etching causing a range of the physio chemical properties identified. R.K.H.

An update on filled diamonds: identification and durability.

R.C. KAMMERLING, S.F. MCCLURE, M.L. JOHNSON, J.I. KOIVULA, T.M. MOSES, E. FRITSCH AND J.E. SHIGLEY. *Gems & Gemology*, **30**(3), 1994, pp 142-77, 2 tables, 43 illus. in colour.

This is an important review with very impressive colour photomicrographs. It was centred on the products from Yehuda/Diascience, Koss & Shechter Diamonds (Genesis II), and Clarity Enhanced Diamond House (a subsidiary of

Goldman Oved Diamond Co.). Treated diamonds from all three firms were purposely damaged by direct heating and by repolishing facets intersected by filled breaks. Some stones were adversely affected by some standard cleaning procedures and wear conditions. Lead-containing filling materials could be detected by X-radiography and EDXRF spectroscopy but it was found that flash effects were the most distinctive characteristic of fracture filling. The increased proliferation of filled diamonds (as small as 0.02ct) is a cause of concern as detection is essential and the initial reported durability of these fillings has been challenged.

None of the Koss treated stones showed any signs of 'easily detected fluorescing filler' reported in the trade press. Treated by two differing fillers viz. halogen glasses and halogen-oxide glasses, the results showed that the apparent clarity improvement was of a variable nature. (Some doubt was thrown on the 'typical nature' of these stones from examination of stones obtained by a third party.) In brightfield illumination blue and green flashes predominated whilst in darkfield illumination orange and pink flashes predominated although other spectrum colours except green were seen.

Examination of Goldman Oved treated stones showed an improvement in apparent clarity in all cases and the apparent colour grade was not lowered as in some of the Koss stones. Flash colours typically of the Goldman Oved stones are bluish-green and yellow in brightfield illumination and for darkfield illumination violet, purple and pink.

Earlier Yehuda treated-diamonds showed the filler to have a light brown to brownish-yellow or orange-red colour. Later filled stones showed no such colouring but the most recent specimens showed a noticeable yellow body colour of the filler. This filling treatment was found to lower the apparent colour grade in some cases. Also encountered were areas of reduced transparency, a white cloud effect.

Fracture-filling treatments of all three firms could be detected by use of a normal binocular gemmological microscope together with suitable lighting techniques. Durability tests showed that commonly employed cleaning techniques could damage the filler as would direct heating. In view of the limited scope of the 'destructive testing' employed it was advised that filled stones be treated with due caution. R.J.P.

Zircon from the mantle: a new way to date old diamonds.

P.D. Kinny and H.O.A. Meyer. *Journal of Geology*, **102**, 1994, pp 475-81, 1 photo, 1 map.

A very small single inclusion of zircon in a diamond from a kimberlite at Mbuji Mayi, Zaire, was identified by the SHRIMP U-Pb method. Diamonds from this locality are a composite suite of contrasting compositions, ages and origins, including stones from characteristic ultramafic and eclogitic parageneses as well as diamonds with a fibrous coating which formed in equilibrium with a volatile-rich fluid phase. The zircon and diamond are thought to have formed together and the probable age (628±12Ma) is the youngest found so far from a diamond originating in the upper mantle. M.O'D.

Gem News.

J.I. Koivula, R.C. Kammerling and E. Fritsch. *Gems & Gemology*, **30**(2), 1994, pp 122-32, 1 table, 18 illus. in colour.

A second major upgrade will soon be completed at the Argyle mine. This is to maintain the level of diamond production over the remaining seven year life of the open-pit operation. Projected 1994 production is 39 million carats. Only 5 per cent is of gem quality but this generates 50 per cent of the revenue. De Beers' rough diamond sales were 41.5 per cent higher than the second half of 1993. Komdragmet, the Committee on Precious Metals and Gems of the Russian Federation offered 114 000 carats of rough for sale as part of the trading arrangement with De Beers. To double its production of polished diamonds several new units have been introduced by SKTB Kristall of Smolensk. Diamondiferous kimberlite pipes have been found in the North West Territories in Canada outside the 'Corridor of Hope' and should encourage further investigations. Although shallow alluvial reserves at the Ghana Consolidated Diamond Mines operation at Akwatia are nearing exhaustion there are substantial deep alluvial deposits being mined in the Birim River Valley.

In Zimbabwe the recovery plant at the River Ranch diamond mine will be upgraded to increase annual production from 130 000 carats to 300 000 carats for proven reserves of at least fifteen years. R.J.P.

Some facets of diamond research.

A.R. Lang. *Mineralogical Society Bulletin*, **104**, 1994, pp 3-6.

The paper reviews current thinking on the formation of diamond, diamond synthesis, the role of nitrogen impurities, electron microscopy of natural diamond coatings and the natural and artificial coloration of diamonds. There is a 22-item list of references. M.O'D.

Diamant-vorkommen und Diamant-Produktion.

A.A. LEVINSON, J.J. GURNEY AND M.B. KIRKLEY. *Mineralien Welt*, **5**(6), 1994, pp 17-38, 15 photos (12 in colour), 6 maps, 4 figs (1 in colour).

Survey of current diamond production with maps and discussion of world deposits. Crystals characteristic of some deposits are illustrated. M.O'D.

Evidence for stable isotope and chemical disequilibrium associated with diamond formation in the mantle.[1]

D. LOWRY, D.P.MATTEY, C.G. MACPHERSON AND J.W. HARRIS. *Mineralogical Magazine*, **58A**, 1994, pp 535-6.

A record of mantle conditions during diamond growth is preserved by syngenetic inclusions in the diamond. Very small samples of such inclusions can now be analysed by laser ablation techniques for the microanalysis of oxygen isotopes in silicates. M.O'D.

Die Russischen Diamanten.

V. NESENZEW. *Lapis*, **19**(11), 1994, pp 16-19, 7 photos (3 in colour), 1 fig.

Short account of the history and current conditions of diamond mining in the former USSR and in present-day Russia. At least one Siberian pipe mine extends to 1000m in depth. M.O'D.

The characterisation and origin of graphite in cratonic lithospheric mantle: a petrological carbon isotope and Raman spectroscopic study.

D.G. PEARSON, F.R. BOYD, S.E. HAGGERTY, J.D. PASTERIS, S.W. FIELD, P.H. NIXON AND N.P. POKHILENKO. *Contributions to Mineralogy & Petrology*, **115**(4), 1994, pp 449-66.

Graphite crystals in peridotites, pyroxenites and eclogite xenoliths from the Kaapvaal craton of southern Africa and the Siberian craton, Russia, have XRD patterns and Ramon spectra characteristics of highly crystalline graphite of high-*T* origin and are interpreted to have crystallized within the mantle. Thermobarometry on the graphite peridotite assemblages using a variety of elemental partitions and formulations yeild estimated equilibration conditions that plot at lower *T-P* than diamondiferous assemblages. Moreover, estimated *P-T* for the graphite peridotites fall almost exclusively within the experimentally determined graphite stability field, and thus no evidence is found for substantial graphite metastability. The C isotope composition of graphites in peridotites from this and other studies varies from $\delta^{13}C_{PCB}$ = -12.3 to -3.8‰ with a mean of -6.7‰; this mean is within one standard deviation of the -4‰ mean displayed by diamonds from peridotite xenoliths, and is identical to that of diamonds containing peridotite-suite inclusions. The C isotope range of graphite and diamonds in peridotites is more restricted than that observed for either phase in eclogites or pyroxenites. The isotopic range displayed by peridotite-suite graphite and diamond encompasses the C isotope range observed in mid-ocean ridge basalt (MORB) and ocean island basalt (OIB). Similarity between the isotopic compositions of C associated with cratonic peridotites and the carbon (as CO_2) in the oceanic magmas (MORB/OIB) indicates that the source of the fluids that deposited C, as graphite or diamond, in cratonic peridotites lies within the convecting mantle, below the lithosphere. Textural observations provide evidence that some of the graphite in cratonic peridotites is of sub-solidus metasomatic origin, probably deposited from a cooling C-H-O phase permeating the lithosphere along fractures. Graphite in mantle-derived xenoliths appears to be restricted to Archean cratons. P.Br.

Re-Os isotope evidence for a mid-Archaean age of diamondiferous eclogite xenoliths from the Udachnaya kimberlite, Siberia: constraints on eclogite petrogenesis and Archaean tectonics.[1]

D.G. PEARSON, G.A. SNYDER, S.B. SHIRLEY, L.A. TAYLOR AND N.V. SOBOLEV. *Mineralogical Magazine*, **58A**, 1994, pp 705-6, 1 fig.

The Re-Os isotope system has been used to define the age of a well-characterized suite of eclogites from the Udachnaya diamond kimberlite pipe in Yakutia, Siberia. M.O'D.

Kimberlites and diamond exploration in the Slave Structural Province, NWT.

J. PELL. *Canadian Gemmologist*, **15**(3), 1994, pp 67-73, 2 maps.

Diamonds and diamondiferous kimberlites are described from the Lac de Gras region in the central Slave Structural Province of the

Northwest Territories, Canada. Notes on the establishment of mines are given. M.O'D.

Diamonds and De Beers.

P.G. READ. *Mineralogical Society Bulletin*, **104**, 1994, pp 7-9, 4 photos.

A review of some of the instruments used by the Diamond Trading Company (part of the Central Selling Organization, a group of De Beers companies), with particular reference to apparatus used in the sorting, sizing, counting and weighing of rough diamonds. (A printing error gives the number of sorting staff as 5000 instead of 500.) M.O'D.

Trace element analysis of fluid-bearing fibrous diamonds from Jwaneng (Botswana) by neutron activation analysis.[1]

M. SCHRAUDER AND M. KOEBERL. *Mineralogical Magazine*, **58A**, 1994, pp 811-12.

Evidence given by diamonds on the fluid regime of the earth's mantle has been collected by means of NAA using specimens of fibrous fluid-bearing diamonds from the Jwaneng mine in Botswana. M.O'D.

Hydrous and carbonatitic mantle fluids in fibrous diamonds from Jwaneng, Botswana.

M. SCHRAUDER AND O. NAVON. *Geochemica et Cosmochimica Acta*, **58** (2), 1994, pp 761-71.

Fluid inclusions trapped in fibrous diamonds and coatings of octahedral diamonds sampled upper mantle fluids. The composition of the major oxides, volatile speciation and secondary phases of mantle fluids trapped in 13 diamonds are reported. The fluids range between two end-members - a carbonatitic fluid rich in carbonate, CaO, FeO, MgO and P_2O_5, and a hydrous fluid rich in H_2O, SiO_2 and Al_2O_3. K_2O is high in both end-members; Mg/(Mg+Fe) in the fluids is low and decreases to the hydrous end-member. Models of formation and evolution of fluids in the mantle are: mixing of hydrous and carbonatitic fluids, partial melting of a carbonate source-rock and fractional crystallization. R.K.H.

Fluids in Yakutian and Indian diamonds.[1]

M. SCHRAUDER, O. NAVON, D. SZAFRANEK, F.V. KAMINSKY AND E.M. GALIMOV. *Mineralogical Magazine*, **58A**, 1994, pp 813-14, 1 fig.

Fluids trapped in micro-inclusions in diamonds from Africa prove the existence of a range of fluid compositions from a carbonatitic end-member to a hydrous end-member. Compositions are given for major oxides and volatile fluid species from six diamonds from Yakutia and four from India. M.O'D.

Chemical zoning of garnets in peridotites and diamonds.[1]

N. SHIMIZU, F.R. BOYD, N.V. SOBOLEV AND N.P. POKHILENKO. *Mineralogical Magazine;* **58A**, 1994, pp 831-2, 2 figs.

Major and trace element data of zoned garnets from garnet harzburgite and dunite which show progressive chemical changes from diamond inclusion-like characteristics in the core to 'normal' lherzolitic features in the rim are examined and compared to chemically zoned diamond inclusion garnets. The data are used to improve knowledge of the nature and age of geochemical processes in the mantle. M.O'D.

Emplacement ages of kimberlite occurrences in the Prieska region, southwest border of the Kaapvaal craton, South Africa.

C.B. SMITH, T.C. CLARK, E.S. BARTON AND J.W. BRISTOW. *Chemical Geology*, **113**(1-2), 1994, pp 149-69, 2 maps.

Rb-Sr (mica) and U-Pb (perovskite) emplacement ages for kimberlites from the SW part of the Kaapvaal craton range from 170 to 74 m.y., similar to ages elsewhere in S Africa. Isotopically defined Group I and II kimberlites are found on the craton NE of the Doornberg and Brakbos lineaments with ages of 74, 108 and 118 - 125 m.y. Kimberlites in the craton margin area bounded by the two lineaments are exclusively Group II, with ages of 116-119 k.y. Kimberlites to the S of the craton boundary are of Group I affinity emplaced in two episodes at 74 and 100-103 m.y. The southernmost area is dominated by kimberlites petrographically, chemically and isotopically transitional between Groups I and II types, but with the oldest ages at 140 and possibly 170 m.y. Phlogopite from a peridotite xenolith from the Sanddrift kimberlite has retained an age of 2250 m.y., presumably the enrichment age of the nodule. R.E.S.

Diamondiferous eclogites from the Udachnaya kimberlite pipe, Yakutia.

V.N. SOBOLEV, L.A. TAYLOR, G.A. SNYDER AND N.V. SOBOLEV. *International Geology Review*, **36**, 1994, pp 42-64, 20 figs, 4 photos.

The mineralogy and petrography of 29 eclogite xenoliths from the Udachnaya kimberlite pipe,

Yakutia, Siberia, are examined and the data combined with those from previous studies of the eclogites by the same workers. Five different petrographic groups are defined, the criteria being based on texture, mineral colour and degree of alteration. Evidence indicates that the Udachnaya eclogites may have originated in the mantle and there are no definite indications of a crustal origin. M.O'D.

The origin, formation and emplacement of diamonds.

M. STATHER. *Australian Gemmologist*, **18**(11), 1994, pp 342-5.

The article is primarily aimed at the recently qualified gemmologist and reviews the major advances in knowledge over the last fifteen years. Quoted examples include South Africa's Finsch mine which contains 3300 million year old peridotitic diamonds and 1580 million year old eclogitic diamonds that were emplaced at the same time 90-100 million years ago. In kimberlite pipes the total time for the ascent through 100km of rock may have been only four to fifteen hours. It was suggested that the original Kimberley volcano was about 1400m above ground level and that erosion would have distributed 500 million carats of diamonds into the drainage systems of Namaqualand and Namibia. R.J.P.

L'analisi merceologia del diamante.

M. SUPERCHI AND A. DONINI. *Gemmologia Europa*, **IV**, 1994, pp 77-108, 16 photos (in colour), 10 figs. (In Italian and English.)

The role of diamond as a commodity is discussed with particular reference to sales and certification which is examined in detail with relevant illustrations. M.O'D.

Great Mogul: the largest diamond found in India.

I. VIKAMSEY. *Indian Gemmologist*, 4(3/4), 1994, pp 18-19, 1 fig, 1 map.

The Great Mogul diamond whose present identity is open to question was recovered from the Vindhayan system of deposits at Kollur, in the Krishna gorge, Andhra Pradesh, India. The stone is said to have been found in 1650 or earlier. Weighing 280ct, according to Tavernier, it may be identical with the Orloff since both stones are rose cut and show a faint tinge of blue. M.O'D.

A carbon-rich inclusion in a Chinese diamond and its geochemical implications.

A. WANG, P. DHAMELINCOURT, H.O.A. MEYER, L. GUO AND A. ZHANG. *Contributions to Mineralogy & Petrology*, **117** (1), 1994, pp 15-24.

A multiphase inclusion in a 2mm diamond from a kimberlite in the Fuxian area, Liaoning Province, China, consists of an olivine covered with relatively large (90-3600 μm) plates of graphite. Both phases are enclosed in a thin layer of glass that separates the multiphase inclusion from the host diamond. Microcrystallites of diamond and graphite are embedded in the olivine and graphite plates. The structural form and morphology of the microcrystallites of diamond and graphite in the olivine suggest that they formed contemporaneously with the olivine and host diamond. An alternative suggestion is that they formed from carbon previously dissolved in the olivine at high *P* and *T*. The genesis of the large graphite plates on the surface of the olivine and beneath the glass film is not fully understood. This is the first record of diamond and graphite occurring within a silicate inclusion in diamond. R.A.H.

Gems and Minerals

[Changes in the *Y* and *Z* octahedra of the tourmaline structure during heating from the X-ray powder patterns.] (Russian with English abstract.)

G.G. AFONINA, L.A. BOGDANOVA AND V.M. MAKAGON. *Proceedings of the Russian Mineralogical Society*, **122**(6), 1993, pp 89-98.

The change in ordering and the character of oxidation processes for cations in schorl, dravite, elbaite and ferritourmaline have been investigated using *dY-dZ* diagrams, under heating in different media. On heating in air, the degree of disorder in the tourmaline structure depends on two parameters; the number of cations in the *Y* position with valency > 2, and the abundance of cations whose valency increases on heating. The dimensions of unit cells and *Y* and *Z* octahedra of tourmalines heated in air for 15 min at 500-900°C are tabulated. R.A.H.

CO_2 contents and formation pressures of some Kilauean melt inclusions.

A.T. ANDERSON JR AND G.G. BROWN. *American Mineralogist*, **78** (7-8), 1993, pp 794-803.

Of 50 analyzed glass inclusions in olivine phenocrysts from the 1959 Kilauea Iki eruption, 41 formed at $P < 1$ kbar, 7 between 1 and 2 kbar, and two at $P > 2$ kbar. The surprisingly low formation

P suggest that most 1959 olivines, including most of those with pre-eruptive equilibration *T*>1200°C, crystallized in an upper part of Kilauea's summit magma storage reservoir.

J.A.Z.

Achate von den Feldern des Landkreises Birkenfeld.

G.ANDREE AND R. ANDREE. *Mineralien Welt*, **5** (4), 1994, pp 54-5, 4 illus. in colour.

All visitors to Idar-Oberstein know the Hunsrück and its potential for the agate-hunter. A selection of specimens from the Birkenfeld Kreis is shown with brief descriptive notes.

M.O'D.

Infrared spectroscopy and crystal chemistry of the beryl group.

C. AURISICCHIO, O. GRUBESSI AND P. ZECCHINI. *Canadian Mineralogist*, **32** (1), 1994, pp 55-68, 2 tables, 9 figs.

The IR spectra of 27 natural and 2 synthetic beryls were taken with the specimens in powdered form, the results showing water molecules in two different orientations (types I and II); it is shown that a positive correlation with Na content exists. The type II configuration is due to high alkali concentration. The presence of hydroxyl groups in a H_2O [type II]-Na-(OH) configuration is proposed for alkali-rich beryl and the absorption frequencies for different samples are correlated with structural and compositional parameters.

M.O'D.

Achate aus der Lausitz.

W. BECK. *Lapis*, **20**(1), 1995, pp 27-31, 14 photos (12 in colour), 1 map.

Good quality ornamental agate is found, together with tektite, in the Senftenberg area, north of Dresden, Germany. Various agate patterns are described.

M.O'D.

Copper and tenorite inclusions in cuprian-elbaite tourmaline from Paraíba, Brazil.

F. BRANDSTÄTTER AND G. NIEDERMAYR. *Gems & Gemology*, **30**(3), 1994, pp 178-83, 1 table, 8 illus. in colour.

The three specimens examined contained numerous yellow metallic specks which at higher magnification showed a dendritic form that is typical for native copper. The samples were a greyish-green with typical pleochroism and with gemmological properties consistent with reported values. The platelets were orientated parallel to the *c*-axis of tourmaline and revealed the trigonal symmetry of the species. A few irregularly scattered grains were identified by SEM–EDS and confirmed by microprobe as tenorite in the form of subhedral platy crystals. Analyses showed a higher iron content than previous reports. Electron microprobe analysis traversed perpendicular to the copper platelets and to the *c*-axis of the host tourmaline showed a decreasing copper content of the tourmaline in the direction of the inclusions. No such variation was found around the tenorite inclusions. The existence of these inclusions and the high copper content in these tourmalines indicated that the elbaites formed under unusual conditions for a granitic pegmatite environment; the tenorite inclusions were interpreted as possible remnants of pre-existing copper mineralization.

R.J.P.

An occurrence of sectored birefringence in almandine from the Gagon Terrane, Labrador.

D. BROWN AND R.A. MASON. *Canadian Mineralogist*, **32** (1), 1994, pp 105-10. 1 illus. in black-and-white.

Birefringent almandine with a composition of $Alm_{0.79}Grs_{0.173}Prp_{0.024}Sps_{0.013}$ is found in graphitic schists of the Gagnor Terrane, Grenville Front, south-western Labrador, Canada. Sectored extinction is observed in sections cut parallel to the X-Y plane, the birefringence estimated at 0.004-0.006. The garnets, which occur as grains, also show quartz intergrowths of cylindrical shape. X-ray diffraction analysis shows slight departure from cubic symmetry.

M.O'D.

Mon aventure Vietnamienne. Part I.

M. BRULEY. *Revue de Gemmologie*, **121**, 1994, pp 21-4.

Breezy account of a journey taking the writer through Kampuchea to Vietnam with observations on gemstones on the way.

M.O'D.

The crystal chemistry of manganese-bearing elbaite.

P.C. BURNS, D.J. MACDONALD AND F.C. HAWTHORNE. *Canadian Mineralogist*, **32** (1), 1994, pp 31-41. 7 tables, 5 figs.

A study of eight crystals of manganiferous elbaite showed both Mn and Fe to be completely in the divalent state in all the crystals. The conclusions were reached in the course of determining Li content in tourmaline by crystal structure refinement using an electron-counting technique with spatial resolution (SREF).

M.O'D.

L'amazonite de Santa Maria de Itabira (continued).

J.-P. CASSEDANNE. *Revue de Gemmologie*, **120**, 1994, pp 8-9, 2 photos in colour.

Details of amazonite from Itabira, Brazil, are given. Specimens have SG 2.55 and RI 1.519, 1.523, 1.526 with a birefringence of 0.007. Principal X-ray diffraction lines and their intensities are also given. M.O'D.

The Jaguaraçu pegmatite, Minas Gerais, Brazil.

J.-P. CASSEDANNE AND J.N. ALVES. *Mineralogical Record*, **25** (3), 1994, pp 165-70, 1 table, 8 illus. in colour, 1 map.

Some of the world's finest crystals of milarite (in the same family as sugilite) were found at the Jaguaraçu pegmatite in the Piracicaba river valley east of Belo Horizonte, Minas Gerais, Brazil. The finest crystals were transparent to translucent and tan coloured though a few exceptions were yellowish-green. Milarite has occasionally been faceted although it is brittle. Crystals occur as floaters (unattached to matrix). M.O'D.

Time-pressure and temperature constraints on the formation of Colombian emeralds: an $^{40}Ar/^{39}Ar$ laser microprobe and fluid inclusion study.

A. CHEILLETZ, G. FÉRAUD, G. GIULIANI AND C.T. RODRIGUEZ. *Economic geology*. **89**, 1994, pp 361-80, 4 tables, 11 figs.

$^{40}Ar/^{39}Ar$ induction and microprobe methods have been used to date two Colombian emerald deposits of the western emerald belt of the Eastern Cordillera, Coscuez and Quipama-Muzo. Studies were carried out on contemporaneous greenish Cr-V-rich potassium mica aggregates made up of muscovite as the dominant phase ± kaolinite, ± paragonite, ± quartz, ± albite, and ± chlorite, pyrite and calcite. Two distinct plateau and spot fusion ages of 35 to 38 Ma and 31.5 to 32.6 Ma were obtained for the Coscuez and Quipama samples respectively. Colombian emerald genesis is referred provisionally to a moderate-temperature epigenetic hydrothermal-sedimentary model. M.O'D.

The 'Gems' Museum.

V.S. CHERNAVTSEV. *World of Stones*, 4/94 , 1994, pp 58-60, 5 photos in colour.

Brief account of the State Museum of the Coloured Stones ('Gems Museum'), formed originally as the sectional exhibition of the 6th All-Union Industrial Association (Soyuzkvartssamotsvety-'Unionquarzgems') of the USSR Ministry of Geology. Some important specimens are described. M.O'D.

La perliculture polynésienne.

J.-P. CUIF, J.-P. DAUPHIN AND Y. DAUPHIN. *Revue de Gemmologie*, **120**, 1994, pp 2-5, 6 photos.

The formation and coloration of the pearls from *Pinctada margaritifera* var. *Cumengi* are described. Photographs illustrate characteristic surface structures. M.O'D.

Notes on alexandrite chrysoberyl.

S.J.A. CURRIE. *Australian Gemmologist*, **18** (10), 1994, pp 326-8, 4 illus. in black-and-white, 5 in colour.

Some personal observations are given including details of an alexandrite trilling twin from Brazil. R.J.P.

Crystal-field analysis of Cr^{3+} in grossular $Ca_3Al_2(SiO_4)_3$.

M. CZAJA AND Z. MAZURAK. *Optical Materials*, **3** (2), 1994, pp 95-8, 2 figs.

The spectra of trivalent chromium in a grossular garnet are analysed with a C_{3i} crystal-field Hamiltonian. Energy levels and crystal field parameters for the Cr^{3+} ion, including spin-orbit and ligand-field interactions are calculated and the crystal field parameters *Bnm* satisfactorily fit the crystal field interactions of trivalent Cr in grossular. M.O'D.

Budjet, budjet!

F. DAMASCHUN. *Lapis*, **19**/11, 1994, pp 46-53, 19 photos in colour.

An account with some remarks on current conditions of some of the areas in Russia visited by Alexander von Humboldt's expedition of 1829. The expedition was commissioned to explore the mineral wealth of distant parts of the Russian empire. M.O'D.

Mineralogical collection of the Mining Museum, St. Petersburg Mining Institute.

N.N. DEVNINA, N.A. KULIKOVA AND E.E. POPOVA. *World of Stones*, **3**/94, 1994, pp 16-33, 35 photos in colour.

The work of and major specimens in the Mining Museum of the St. Petersburg Mining Institute are described. M.O'D.

X-ray absorbtion spectroscopy of silicon dioxide (SiO_2) polymorphs: the structural characterization of opal.

DIEN LI, G.M. BANCROFT, M. KASRAI, M.E. FLEET, R.A. SECCO, X.H. FENG, K.H. TAN AND B.X. YANG. *American Mineralogist*, **79** (7-8), 1994, pp 622-32, 7 figs.

The structures of the silica polymorphs stishovite, alpha quartz, alpha cristobalite, coesite, amorphous silica and opal were investigated by Si*K* and Si*L*-edge X-ray absorption spectroscopy. The local structures of two opals were found to show a mixture of alpha SiO_2 and alpha cristobalite structural units. M.O'D.

Die ersten Edelopale Europas. Geschichte, Gewinnung, bedeutende Steine.

R. DUDA. *Mineralientage München, Messethemenheft*, 1994, pp 42-5, 7 photos in colour.

Opal from the Dubnik area is described with notes on workings for opal. The area has been called Vereswagas and Czerwenicza at different times. M.O'D.

The south Urals: a brief mineralogical guide.

A.A. EVSEEV. *World of Stones*, 1/93, 1993, pp 31-5, 3 photos in colour, 1 map in colour.

Major mineral localities in the southern Urals, Russia, are listed with names of the minerals occurring. These include agate, kyanite, euclase, grossular and topaz (colourless, rose and blue varieties). M.O'D.

Siberia's crystals and symmetry in the distribution of occurrences of minerals.

A.A. EVSEEV. *World of Stones*, 1/93, 1993, pp 11-20, 15 photos in colour, 2 maps in colour.

A survey of major mineral deposits in Siberia with lists of minerals pertaining to each. Beryl, tourmaline, quartz, danburite and scheelite are among gem minerals listed. M.O'D.

The Urals (from Middle to Polar): a brief mineralogical guide.

A.A. EVSEEV. *World of Stones*, 2/93, 1993, pp 35-9, 5 photos in colour, 1 map in colour.

Results of a literature search give details of mineral finds arranged in alphabetical order of locality name, covering the polar and middle Urals, Russia. Minerals known to have been deposited in museums are flagged, as are type localities and first finds in Russia. M.O'D.

North and east Europe. A brief review of mineral localities.

A.A. EVSEEV. *World of Stones*, 3/94, 1994, pp 43-54, 8 photos in colour, 2 maps.

Mineral localities in north and east Europe (including parts of the former USSR) are listed with major minerals found. Type localities, first finds in Russia and outstanding specimens are flagged. M.O'D.

Siberia and the Far East: a brief mineralogical guide.

A.A. EVSEEV. *World of Stones*, 4/94, 1994, pp 42-54, 10 photos in colour, 1 map, 1 loose insertion.

Mineral deposits of Siberia and the Russian far east are listed alphabetically with type localities, major specimens and first finds in Russia flagged. A loose insertion provides a numbered key to the map. M.O'D.

Accreted terranes and mineral deposits of Myanmar.

POW-FOON FAN AND KO KO. *Journal of Southeast Asian Earth Sciences*, **10**(1/2), 1994, pp 95-100, 3 maps.

Of the three identified terrains in Myanmar (Shan-West Malaysia-Sumatra, Central Burma Basin, Arakan Yoma) the first includes gem-quality jadeite and ruby. In the West Kachin subterrain jadeite occurs in boulders in late Tertiary conglomerates and alluviums and as dyke-like bodies in serpentine. It is associated with glaucophane schists formed probably by high-pressure metamorphism in Palaeozoic time. Jadeite can be found in serpentinized epidote, light green schist and in silicified amphibolite-albite. Jadeite may be formed as a result of desilication of albite. The serpentinite bodies intrude into Cretaceous limestone. Ruby associated with spinel and other gem minerals is found in the East Kachin subterrain, occurring in the vicinity of the contact of nepheline syenites and alaskites which intruded marble. M.O'D.

Alexei V. Sverdlov: one must love and understand stone.

V.S. FEODOROV. *World of Stones*, 1/93, 1993, pp 43-55, 21 photos (20 in colour).

Biography with examples of the work of the mineral photographer A.V. Sverdlov. M.O'D.

Causes of the purple and pink colours of manganoan sugilites from the Wessels Mine, South Africa.

E. FRITSCH AND J.E. SHIGLEY. *Mineralogical Magazine*, **58**(4), 1994, pp 681-5, 2 figs.

Purple and pink colours observed in manganoan sugilite from the Wessels mine,

South Africa, is ascribed to Mn with the two colours explained by different crystal fields resulting from two distinct compositions with pink as Al-rich, Fe-poor material compared to the purple variety. M.O'D.

Flat pearls from biofabrication of organized composites on inorganic substrates.

M. FRITZ ET AL. *Nature*, **371**(6492), 1994, pp 49-51.

It is shown that a highly organized composite 'flat pearl' can be biofabricated on discs of glass, mica and molybdenum sulphide inserted between the mantle and shell of *Haliotis rufescens* (red abalone). The implantation of inorganic surfaces recognized by mantle cells apparently governs a switch from aragonite to calcite biomineralization. After deposition of a partially oriented calcite-protein layer, there is a reversal to nucleation and assembly of columnar stacks of highly ordered aragonitic nacre. R.K.H.

K-Ar and $^{40}Ar/^{39}Ar$ evidence for a Transamazonian age (2030-1970 Ma) for the granites and emerald-bearing K-metasomatites from Campo Formoso and Carnaíba (Bahia, Brazil).

G. GIULIANI, J.-L. ZIMMERMAN AND R. MONTIGNY. *Journal of South American Earth Sciences*, 7 (2), 1994, pp 149-65, 5 tables, 7 figs.

The Campo Formoso and Carnaíba granites form part of a suite of middle Proterozoic magmatic rocks in the northern part of the São Francisco craton, Bahia, Brazil. They intrude the Archaean basement and Lower Proterozoic Jacobina volcanosedimentary series. Emeralds are developed by means of fluids percolating through serpentinites forming metasomatites at the contact with granite-related pegmatite veins. The Campo Formoso and Carnaíba mines exploit these deposits.

From the K-Ar and $^{40}Ar/^{39}Ar$ measurements it appears that emerald at the Carnaíba deposit is formed contemporaneously with pervasive muscovitization of the granite. M.O'D.

Zur Kathodolumineszenz von Achat-erste Ergebnisse.

J. GÖTZE AND H-J. BLANKENBURG. *Aufschluss*, **45**, 1994, pp 305-12, 13 photos (11 in colour).

Microphotographs of agate shown displaying cathodoluminescence are accompanied by a commentary discussing the varying responses of the layers. M.O'D.

Recent developments at the Benitoite Mine.

M. GRAY. *Canadian Gemmologist*, **13**(4), 1992, pp 118-20.

Processing techniques have enabled larger benitoite specimens to be recovered. Twinned crystals resembling six-rayed stars with sharp points and large neptunite crystals have been found. The largest cut benitoite known weighs 15.42ct. M.O'D.

On a remarkable topaz crystal with a lepidolite inclusion from the Tolstopjatov collection.

A.V. GROMOV. *World of Stones*, **1**/93, 1993, pp 5-6, 1 photo in colour.

Topaz with an inclusion of lepidolite is reported from the Tolstopjatov collection in the Vernadsky State Geological Museum (GGM). The lepidolite takes a platy form and it is assumed that lepidolite flakes became attached to the surface of a growing topaz crystal and hinders or even stops growth in some directions, thus altering the topaz form. M.O'D.

Rose corundum from the Khitostrov locality of north Karelia.

A.V. GROMOV. *World of Stones*, **2**/93, 1993, pp 2-4, 2 photos in colour.

Rose-coloured corundum crystals, not necessarily of gem quality, are reported from the oblasts Khitostrov, Diadina Gora, Varatskoe, Nigrozerskoe, Notozerskoe in North Karelia and from adjacent deposits in Murmansk oblast. Crystals, whose forms are fully described, occur in highly-metamorphosed rocks of amphibolite facies of the Belomorskii Archean complex but are confined to different stratigraphic series. Crystals have been found to contain garnet, plagioclase, biotite, hornblende, magnetite, rutile, ilmenite and wüstite. M.O'D.

Contribution à l'étude des caractéristiques distinctives des saphirs du Cachemire. Part 1.

H.A. HÄNNI. *Revue de Gemmologie*, **121**, 1994, pp 18-20, 2 photos, 1 fig.

Properties of Kashmir sapphire are discussed with notes on the history of the site and on the colour of the stones. The cause of the characteristic turbidity seen in many Kashmir sapphires is tentatively ascribed to rutile. The absorption spectrum is compared to spectra given by sapphires from Sri Lanka, Burma and Kampuchea. Some Kashmir stones contain small amounts of chromium, giving an emission line at 693nm. M.O'D.

Edelopal: der feurig funkelde Harlekin.

H. HARDER. *Mineraltage München, Messethemenheft*, **1994**, pp 34-41, 14 photos (11 in colour).

Notes on opal with the harlequin pattern and on other opals are given, with an explanation of the cause of the play-of-colour. M.O'D.

The structural redetermination and crystal chemistry of sinhalite, MgAlBO$_4$

C.L. HAYWARD, R.J. ANGEL AND N.L. ROSS. *European Journal of Mineralogy*, **6** (3), 1994, pp 313-21.

EPMA results for a suite of four gem-quality sinhalites indicate that this species can accommodate excess Al and small amounts of Fe at the expense of Mg. Single-crystal XRD data show that sinhalite is isostructural with forsterite, with space group *Pbnm*, *a* 4.3320, *b* 9.8819, *c* 5.6813 Å. The structure was refined to R_w 0.017, R_u 0.019 with 427 reflections. The assumed ordering scheme of $[Mg_{0.91}Fe_{0.015}Al_{0.05}\square_{0.025}]^{M2}Al^{M1}BO_4$ is deduced from the EPMA results. Visible absorption spectra are indicative of extremely low Fe^{3+} contents in these sinhalites, suggesting that the main substitutional mechanisms are $3Mg^{2+} \leftrightarrow 2Al^{3+} + \square$ and $Mg^{2+} \leftrightarrow Fe^{2+}$, where $\square$ represents a vacancy. R.A.H.

Structural disparities between chalcedony and macrocrystalline quartz.

P.J. HEANEY, D.R. VEBLEN AND J.E. POST. *American Mineralogist*, **79** (5/6), 1994, pp 452-460, 13 illus. in black-and-white, 2 figs.

Structural differences between chalcedony and bulk quartz are characterized by the nature of the individual crystals which form chalcedony. These are shown to be elongate along [110] and are twisted about the fibre axis. Under dark-field illumination the texture of a structural disorder shown by single fibres in the {100} and possibly the {011} planes appears dendritic. M.O'D.

Translucent nepheline from Norway.

U. HENN AND H. BANK. *Canadian Gemmologist*, **14**(2), 1993, pp 44-5.

Translucent reddish-brown nepheline is reported and described from Stalaker, near Tjolling, Sandefjord, south Norway. The area is noted for larvikite, itself associated with a nepheline syenite including pegmatite veins with rare minerals. M.O'D.

Yellowish-green herderite from Brazil - a second occurrence.

U. HENN AND H. BANK. *Canadian Gemmologist*, **15**(1), 1994, pp 40-2.

Transparent yellowish-green herderite up to 55ct was recovered during 1992 from Virgem da Lapa, Araçuai, Minas Gerais, Brazil. Notes on properties are given. M.O'D.

Petrology of a jadeite-quartz/coesite-almandine-phengite fels with retrograde ferronyböite from Dora-Maira Massif, Western Alps.

T. HIRAJIMA AND R. COMPAGNONI. *European Journal of Mineralogy*, **5** (5), 1993, pp 943-55, 1 map.

Ferronyböite is reported from a jadeite-bearing rock of the ultra high-*P* Brossasco-Isasca unit, S Dora-Maira Massif. At the ultra high-*P* climax, the rock was mainly composed of jadeite, garnet, phengite and coesite, then during an early stage of the retrograde path, omphacite, ferronyböite to katophorite, and albite developed at the expense of peak phases. As the retrograde process continued, omphacite changed via aegirine- augite to almost jadeite-free aegirine and the ferronyböite and katophorite rimmed by Si-poor katophorite and ferro-aluminotaramite. Ferronyböite and katophorite also occur as a reaction rim around garnet and as idioblastic tabular grains in the albite matrix. The most Fe-rich ferronyböite core has SiO_2 46.91, TiO_2 0.40, Al_2O_3 12.86, FeO' 20.06, MnO 0.00, MgO 5.61, CaO 3.60, Na_2O 7.85, K_2O 0.50, = 97.79, i.e. the richest so-far reported in Fe^{2+}. Garnet-omphacite geothermobarometry gives ~500-570°C and 12-15 kbar for the early retrogression stage. It is suggested that ferronyböite rather than ferroglaucophane is stable in the local Na-, Al- and Fe-rich bulk compositions under low-*T* eclogite-facies conditions. R.A.H.

On the morphology of malachite.

O.V. IL'IN. *World of Stones*, **4**/94, 1994, pp 3-9, 12 photos in colour.

Forms of malachite from Russian deposits are described with notes on their mode of occurrence. M.O'D.

Quasicrystals: novel forms of solid matter.

J.A. JASZCZAK. *Mineralogical Record*, **25** (2), 1994, pp 85-93, 13 illus. in black-and-white.

Solid matter in which there are no single unit cells and which shows no periodic repetition of local structures through the body have been given the name quasicrystal. Some examples have been found to possess rotational symme-

tries, including 5-fold, which have not been observed before. M.O'D.

Axinite: new finds in Russia.

V.N. KALACHEV. *World of Stones*, **1**/93, 1993, pp 3-4, 4 photos in colour, 3 figs.

Fine quality brown axinite is reported from cavities in the Puiva Mountains in the Polar Urals of Russia. Crystal forms are described and illustrated and specimens are notable for their brownish-lilac pleochroism. Greenish-brown axinite from the Dalnegorsk mine and brown axinite from the Pribrezhnoye locality in the Magadan region are also discussed. At Puiva the axinite vein is embedded in an essentially slate Puiva formation of the Proterozoic which is often intruded by numerous meridian and basic dikes. Quartz veins and axinite mineralizing in them are from the middle Carboniferous to Early Permian. The Pribrezhnoye locality is 35km to the north-west from the Inchoun Settlement. Here axinite occurs in the carbonate-terrigenous sediments of the Utaveem formation of the Early Carboniferous, skarned with leucocratic granite stocks of the Early Cretaceous. Here both reddish-brown and greyish-brown axinites occur at different places. M.O'D.

Update on mining rubies and fancy sapphires in northern Vietnam.

R.C. KAMMERLING, A.S. KELLER, K.V. SCARRATT AND S. REPETTO. *Gems & Gemology*, **30**(2), 1994, pp 109-14, 7 illus. in colour.

Since organized mining started in 1989 millions of carats of rubies and fancy sapphires have been produced. The two main locations are at Luc Yen and Quy Chau. At Luc Yen a tripartite venture with a one-year concession was centred on a 200 acre site at Khoan Thong using hydraulic cannon. When the site was exhausted the whole operation was moved to a fresh site at nearby Nuoc Ngap. The gems are fashioned in Hanoi and a further cutting factory has been built in Yen Bai.

At Quy Chau access is controlled by the military which is difficult during the rainy season. Originally worked by thousands of independent miners, after two years of operation an area of 740 acres is worked by four companies. Future prospects will depend upon Government policy as well as gem reserves which could last up to fifty years. R.J.P.

Gem News.

J.I. KOIVULA, R.C. KAMMERLING AND E. FRITSCH. *Gems & Gemology*, **30**(2), 1994, pp 122-32, 1 table, 18 illus. in colour.

Tucson Show

A round modified brilliant cut green fluorite of 30.67ct of very high clarity from the Felix fluorite mine above Azusa in Los Angeles county was subsequently donated to the San Bernardino County Museum. Green stones on offer included chrysoprase chalcedony from Queensland and gaspeite, a nickel, magnesium and iron carbonate which originated in Western Australia. Cat's-eye sillimanite from the state of Orissa in India was very similar in appearance to fibre-optic chatoyant glass marketed as 'Catseyte', 'Cathaystone' and 'Fiber Eye'. Down the length of the fibres the fibre-optic glass revealed the hexagonal packing of its fibres whilst no such effect was visible in cat's-eye sillimanite. Freshwater pearls from Bangladesh all exhibited a strong pink overtone with an exceptional almost metallic lustre. 'Zebra' stones from Australia proved to be two distinctly different ornamental stones. Dolomitic marble which presented a dark grey-white striped appearance. A second type consisting of alternating parallel layers of medium-dark reddish-brown and tan from the East Kimberley region of Western Australia were reported to be a fine-grained siliceous argillite which is a clay- or mud-containing sedimentary rock that has reacted with silica-rich fluids to form a harder material.

A 'wagon wheel' tanzanite was described in which a single needle-like inclusion running from the culet to the centre of the table facet produced a symmetrical pattern of spoke-like reflections.

Burma (Myanmar) authorities have relaxed their gem controls allowing foreigners to purchase privately owned gems. Tiger's-eye quartz production in South Africa reached a new record in 1992 of 620.8 tons.

Enhancements

A new emerald treatment system from Israel which could handle many stones in a batch and used a hand operated vacuum pump followed by fracture filling under pressure. A wide range of oils and resins could be used. R.J.P.

The Mining Museum in St. Petersburg.

V.D. KOLOMENSKY AND L.A. FAINSTEIN. *World of Stones*, **3**/94, 1994, pp 6-15, 15 photos in colour.

A short history of the Mining Museum in St. Petersburg with notes on some important specimens, including gem minerals, housed there. The Museum was founded in 1773 as the Mining Technical School. M.O'D.

Opal.

J. KOURIMSKY. *Mineralien Welt*, **5**/94, 1994, pp 32-40, 9 photos in colour, 1 fig.

The paper gives a general survey of opal with notes on the history and geology of the major world deposits. M.O'D.

Carcass skeletal quartz crystals from the Indigirka river.

V. KURBATOV. *World of Stones*, **3**/94, 1994, pp 62-4, 1 photo in colour, 2 figs. in colour.

Carcass-skeletal quartz crystals were first reported from the Indigirka river basin, eastern Siberia, in the early 1970s. The crystals are described with notes on their formation. M.O'D.

[Opal and magnesite veins in weathered serpentinites from the western Rhodope Mts.] (Russian with English abstracts.)

V. KURCHATOV AND P. PETROV. *Annual of the Mine and Geology University Sofia: Part 1: Geology*, **39**, 1993, pp 45-8.

Weathering of serpentinized ultrabasic bodies during the Pontian produced opal veins in the upper part of the weathering crust and magnesite veins in its lower part. The two minerals have been studied by optical and electron microscopy, spectral analysis, DTA and IR spectroscopy. Besides amorphous opal, the crystallization of silica gels has produced cristobalite and finally cristobalite-tridymite opals. I.V.

Abstraction and jade exchange in Precolumbian southern Mesoamerica and lower central America: Costa Rican considerations.

F.W. LANGE AND R.L. BISHOP. *Bull. Friends of Jade*, **8**, 1994, pp 105-24, 2 maps.

The paper examines the use of jade as a pre-currency trade medium with particular reference to central America and Costa Rica. There is an extensive bibliography. M.O'D.

Single-crystal spectra of garnets from diamondiferous high-pressure metamorphic rocks from Kazakhstan: indications for OH^-, H_2 and FeTi charge transfer.

K. LANGER, E. ROBARICK, N.V. SOBOLEV, V.S. SHATSKY AND W. WANG. *European Journal of Mineralogy*, **5** (6). 1993, pp 1091-1100.

Garnet crystals from the high-*P* metamorphic rocks of the Kokchetav Massif, Kazakhstan, were studied by EPMA and single-crystal spectrometry in the UV, visible and IR range. The crystals are $Gro_{48}Py_{33}Alm_{16}Sp_2$ (yellow) from garnet-pyroxene-carbonate rock and $Gro_{21}Py_{24}Alm_{49}Sp_5$ (deep red) from garnet-biotite gneiss. Their colour is produced by the position of the UV absorption edge and a broad $Fe^{2+[8]}$ $Ti^{4+[6]}$ charge-transfer band centred at 21 500 cm^{-1}. A high-*P* garnet, $Py_{70}Alm_{17}Uv_{13}$, from Liaoning-50 kimberlite, NE China, was included for comparison. All crystals studied contained defect OH-groups, corresponding with those in synthetic OH-bearing pyropes, giving a single absorption band in the range 3560-3610 cm^{-1}, the exact position depending on the type and site fractions of ions in the OH-coordinating metal sites, $A^{[8]}$ and $B^{[6]}$. This hydroxyl 'water' is not uniformly distributed in the garnet crystals; it amounts to 0.02-0.25 wt.%. In addition to υ_{OH} the IR spectra show a broad band at 3400cm^{-1}, characteristic of $(H_2O)_n$ clusters. R.A.H.

Lightning Ridge. Die Heimat des Schwarzopals.

W. LIEBER. *Mineralientage München, Messethemenheft*, 1994, pp 46-51, 11 photos in colour.

Description of the Lightning Ridge opal mining area in New South Wales, Australia, with notes on mining practice and illustrations of some notable specimens of opal recovered. M.O'D.

The Dal'Negorsk boron deposit: a unique mineralogical object.

A.E. LISITSYN AND S.V. MALINKO. *World of Stones*, **4**/94, 1994, pp 30-40, 20 photos (19 in colour), 1 map, 1 fig.

Fine crystals of danburite are among the minerals found at the Dal'Negorsk boron deposit in the Primor'ye region in the Russian far east. The mineralogy and geology of the deposit are described at length together with the minerals to which a classified list is also devoted. M.O'D.

Nanometre scale textures in agate and Beltane opal.

T. LU, X. ZHANG, I. SUNAGAWA AND G.W. GROVES. *Mineralogical Magazine*, **59**(1), 1995, pp 103-9.

Optically observable individual fibres in con-

centrically banded agates of geode origin are composed of much finer fibres, in which quartz crystallites 8-100 nm long are stacked together ‖ <11$\bar{2}$0> or <10$\bar{1}$0>. Brazil twin lamellae structures are frequently seen in grains > 30 nm long. Uniformly spaced systematic striations consist of a cyclic alternation in quartz grain sizes, the smallest size being 6nm. Coarse quartz or amethyst represent the final stage of agate (lining type) formation. In opal from Beltane, California, the fine fibrous textures observed are composed of cristobalite crystallites with sizes of 8-20nm stacked together. They appear as the rims surrounding quartz crystals, and grow into regions with free space. TEM results suggest that embryonic particles agglutinated to form fibres, possibly driven by electrophoresis. R.A.H.

Luminescence and exited state ^2E_g decay kinetics of Cr^{3+} in grossular $Ca_3Al_2(SiO_4)_3$.

Z. MAZURAK. *Optical materials*, **3** (2), 1994, pp 89-93, 6 figs.

Spectroscopic and luminescence measurements were carried out on a pale green grossular garnet in which a relatively large splitting of the ^2E_g state of Cr^{3+} was observed. M.O'D.

Gemstone mineralization in southern Kerala, India.

R.D. MENON, M. SANTOSH AND M. YOSHIDA. *Journal of the Geological Society of India*, **44** (3), 1994, pp 241-52, 2 maps.

Within the gem field extending over an area of 70 x 35km in S Kerala and the adjacent region of Tamil Nadu, a variety of gemstones occur, including chrysoberyl (cat's-eye and alexandrite varieties), ruby, sapphire, emerald, topaz, zircon and amethyst. The primary mineralization is in zoned, complex pegmatites of Pan-African age, emplaced in granulite-facies metapelites (khondalites) and variably weathered and laterized, secondary gemstone deposits are found in stream gravels and placers. Thermal decrepitation of fluid inclusions indicate the presence of variable amounts of CO_2 in quartz (72.7ppm), garnet (141.2 ppm) and chrysoberyl (51.6 ppm). The $\delta^{13}C$ value of CO_2 in quartz is -8‰. Gem recovery in Kerala has vast untapped potential, but is at present carried on by illegal means. A map of gem occurrences is given, together with photographs and brief details of chrysoberyl, sapphire, ruby, topaz and zircon. R.A.H.

Genesis of banded, fibrous and twisted quartz by 'catalysis', unstable crystallization fronts and substitution: self-organization in agates.[1]

E. MERINO, Y. WANG AND E. DELOULE. *Mineralogical Magazine*, **58A**, 1994, pp 597-8

Agates formed in basalts show bands of chalcedony fibres which contain low amounts of trace elements and which repeatedly alternate with bands consisting of twisted, very fine fibres with high trace element content. This is shown to be an example of self-organization, in which a system generates its characteristic features through its own dynamic. M.O'D.

A new discovery of early Cretaceous (Wealden) amber from the Isle of Wight.

C.J. NICHOLAS, A.E. HENWOOD AND M. SIMPSON. *Geological Magazine*, **130**(6), 1993, pp 847-50, 1 map.

The early Cretaceous amber nodules can be found within two thin, black lignite horizons which form a channel-lag deposit exposed in the cliffs of Chilton Chine. Examination of plant material above and below this site by other workers, combined with IR spectra of the amber in this study, implies a coniferous (possibly taxodiaceous) origin for this resin. Palaeoenvironmental interpretation of the Chilton Chine sites suggests the amber was exuded locally, and in some cases the globules have been partly replaced by iron pyrite. C.H.D.

Ein spektakulärer Fund von Rauchquarz und Morion aus der Wiesbachrinne im Habachtal, Land Salzburg, Österreich.

G. NIEDERMAYR AND A. STEINER. *Mineralien Welt*, **5** (4), 1994, pp 46-55, 4 illus. in black-and-white, 4 in colour, 1 fig.

Crystals of quartz (smoky quartz and morion) are reported to reach considerable size and excellent form at the Wiesbachrinne, Habachtal, Salzburg, Austria. Some specimens reach up to 13cm in length. M.O'D.

Formation of the Muzo hydrothermal emerald deposit in Colombia.

T.L. OTTAWAY, F.J. WICKS, L.T. BRYNDZIA, T.K. KYSER AND E.T.C. SPOONER. *Nature*, **369**(6481), 1994, pp 552-4.

Emerald-bearing veins are related to highly altered zones (cenicero) in host shales; the emeralds occur in distal parts of calcite-albite-pyrite veins radiating from cenicero zones. Analyses are presented of fluid inclusions in the emeralds and indicate that mineralizing solutions were resid-

ual brines from basinal fluids that interacted with evaporites. Hydrothermal brines transported evaporitic sulphate to structurally favourable sites where it was thermochemically reduced. S thus generated reacted with organic matter in the shales to release trapped Cr, V and Be enabling emerald formation. R.K.H.

Comparative study of beryl from various Indian occurrences: beryl from Rajasthan.

J. PANJIKAR. *Indian Gemmologist*, **4**(3/4), 1994, pp 5-10, 4 photos in colour, 5 figs.

Emerald is found in the area Kala Guman (Kaliguman) approximately 90 miles NNE of Udaipur. The country rock is a peridotite, partly talcose, tremolite-actinolite schist, biotite-schist and hornblende-schist invaded by veins of quartz pegmatites. Emeralds occur in the biotite schists which also contain alteration products, including chlorite. Crystals show prismatic habit with some examples of twinning. Colour is dark to watery green. Refractive index is found to be lower than previously quoted by Webster and others, values being 1.581 and 1.574 for the ordinary and extraordinary rays, with a birefringence of 0.007. SG is 2.7542. Biotite and phlogopite inclusions have been detected by EDS and quantitative microprobe analysis. Chlorapatite and beryl inclusions are also found with some talc and albite. Primary and secondary fluid inclusions were observed but very few three-phase inclusions. Growth tubes of large dimensions were seen and are classified as syngenetic. M.O'D.

A study of gem varieties of corundum from parts of Tumkur and Mysore districts, Karnataka.

J. PANJIKAR, H. CHANDRASHEKHAR, M. MUNISWAMAIAH AND N. AHMED. *Journal of the Geological Society of India*, **43**(3), 1994, pp 311-15.

The mineralogical and gemmological properties of rubies from three localities in Tumkur district and three localities in Mysore district of Karnataka are briefly summarized. Most of the rubies occur as detrital material or at the contacts between granitic pegmatite and schists or gneisses. They are translucent rather than transparent, due to inclusions of rutile ± mica and apatite. The deposit 1.5km NW of Chilkunda (12°20′45″N, 76°10′30″E), Hunsur Taluk, Mysore district, seems the most promising prospect for gem-quality rubies. R.A.H.

Remarkable finds of minerals of beryllium: from the Kola Peninsula to Primorie.

I.V. PEKOV. *World of Stones*, **4**/94, 1994, pp 10-26, 14 photos (13 in colour), 1 map.

Beryllium-bearing minerals found in the territories of the former USSR are described with notes on their geology, mineralogy and on the history of their discovery. M.O'D.

La microspectrométric Raman des grenats XYZ O II. La série alumineuse naturelle pyrope-almandin-spessartite. [French with English abstract.]

M. PINET AND D.C. SMITH. *Schweizerische Mineralogische und Petrographische Mitteilungen*, **74**, 1994, pp 161-79, 9 figs.

Raman spectra of 52 natural aluminian garnets in the pyrope-almandine and almandine-spessartine series are examined. The spectra are compared with each other and with the spectrum of grossular which is at once aluminian and calcic. M.O'D.

Notes on history of topaz and aeschynite finds in the Ilmeny mountains.

V.O. POLYAKOV. *World of Stones*, **2**/93, 1993, pp 31-4, 2 photos in colour, 1 fig. in colour.

Topaz crystals occurring in the amazonite pegmatites of the Ilmeny mountains are described. Fine topaz specimens from Ilmeny locations were first noted in 1832. M.O'D.

La pegmatite Urubu, Araçuai, Minas Gerais (Brésil), example de pegmatite complexe à pétalite: zonalité minéralogique et géochimie des micas et tourmalines. [French with abridged English version.]

J. QUÉMÉNEUR, M. LAGACHE AND J.M. CORREIA NEVES. *Comptes Rendus de l'Académie des Sciences, Série II*, **317** (11), 1993, pp 1425-31.

The Urubu pegmatite of Cambrian age, situated in the Eastern pegmatitic province of Minas Gerais, is a Li, Cs, B and Sn pegmatitie which exhibits a complex mineralogical zonation with lepidolite, petalite and pollucite at the centre. The pegmatite is surrounded by a contact metamorphic aureole containing zinnwaldite rich in Fe, Mg, Rb and Cs and Fe-Mg-rich tourmaline. Micas and tourmalines in the pegmatite are richer in Fe and Mg at the rim and in Li, Cs and F at the centre following the classical model of fractional crystallization. The contact aureole is considered to have been formed during the intrusion of the magma. M.L.

Isomorphic replacement of Al and Si in tetrahedral Be and Si sites of beryl from Torrington, NSW, Australia.

K. SCHMETZER AND H.-J. BERNHARDT. *Neues Jahrbuch für Mineralogie, Monatshefte*, **1994** (3), pp 121-29.

Chemical analysis of a crystal of emerald from Torrington (averages of results from EPMA + ICP determinations) gave SiO_2 67.23, Al_2O_3 18.99, Cr_2O_3 0.13, V_2O_3 0.02, FeO* 0.20, BeO 13.80, MnO 0.00, MgO 0.02, Li_2O 0.06, Na_2O 0.05, K_2O 0.03, H_2O 0.53 = 101.07. It has ε1.5654, ω1.5700; a 9.2127, c 9.1980 Å. The data from 353 point analyses by EPMA reveal a distinct chemical zoning and a negative correlation of Si with Σ(Al+Mg+V+Cr+Fe) in the formula unit. These results indicate a partial replacement of Be^{2+} by Al^{3+} and/or Si^{4+} and, in other zones of the crystal, a partial replacement of Si^{4+} by Al^{3+} according to heterovalent substitution schemes for both tetrahedral Be^{2+} and tetrahedral Si^{4+} sites. R.A.H.

Martin Leo Ehrmann, 1904-1972.

B. SMITH AND C. SMITH. *Mineralogical Record*, **25** (5), 1994, pp 347-70, 20 photos (12 in colour).

Martin Ehrmann, who began his life in the United States as a poor immigrant from Russia, eventually became one of the best-known mineral and gemstone dealers of this century. His rise to this position is given in detail with particular reference to his travels, trading at gemstone locations and his help in the formation of some of the world's greatest gemstone collections, including those at the Natural Museum of Natural History, Smithsonian Institution, Washington, DC, and the Los Angeles County Museum of Natural History. A fascinating sidelight into the ways of gemstone dealing is given along the way and many examples of specimens handled by Ehrmann are described, some being illustrated. M.O'D.

Earl Perovsky (1792-1856) and his beryl collection in the Mining Museum.

E.S. SVIRINA. *World of Stones*, **3**/94, 1994, pp 35-8, 7 photos in colour.

Beryl crystals from the Perovsky collection in the St. Petersburg Mining Museum include specimens of emerald and rose beryl. Notes on the formation of the collection are given. M.O'D.

Chemical composition and structural formula of manganoan sugilite from the Wessels Mine, Republic of South Africa.

J.E. TAGGART, E.E. FOORD AND J.E. SHIGLEY. *Mineralogical Magazine*, **58**(4), 1994, pp 679-81.

A structural formula for manganoan sugilite from the Wessels mine, South Africa, based on 30 oxygen atoms in the Si O portion of the formula, is given as

$^{(C)}K_{1.0}\ ^{(B)}(Na_{2.17}H_2O_{0.25})_{\Sigma 2.1}\ ^{(A)}(Fe^{3+}_{1.46}, Mn^{3+}_{0.28}, Fe^{3+}_{0.11}, Al_{0.08})_{\Sigma 1.3}\ ^{(T2)}Li_{3.05}\ ^{(T1)}Si_{12.0}O_{30}$ M.O'D.

Cristalli di fluorite rosa dal Poncione di Maniò, Val Bedretto, (TI).

A. TORINO AND E. OFFERMANN. *Schweizer Strahler*, **10**(4), 1994, pp 140-52, [Italian and German versions], 4 photos in colour, 6 figs.

Large pink fluorite crystals of gem quality, found at Poncione di Maniò, Canton of Ticino, Switzerland, show an unusual combination of forms for Alpine-type fluorite. A characteristic example is the formation of rhombdodecahedra at all points of an octahedron. Diagrams show how this phenomenon developed. M.O'D.

Ammolite, an organic gemstone from Alberta.

R. VANDERVELDE. *Canadian Gemmologist*, **14**(2), 1993, pp 53-7, 1 photo.

Ammolite, the nacreous layer of the ammonite shell, has been used ornamentally with interference colours providing an attractive material provided that adequate backing is used. Recovery is from the Bearpaw Formation in Alberta, Canada. M.O'D.

Chemical characterization of fossil resins ('amber') - a critical review of methods, problems and possibilities: determination of mineral species, botanical sources and geographical attribution.

N. VAVRA. *Abhandlungen der Geologischen Bundesanstalt*, **49**, 1993, pp 147-57.

Fossil resins were studied for two reasons: determination of the botanical origin and geographical attribution to a special area. Among chemical methods discussed, possibilities and applications for IR spectroscopy and MS are given. In addition advantages of different varieties of gas liquid chromatography are discussed in greater detail. Computer-aided combined gas-liquid chromatography/MS is shown to be the most promising method for the characterization of fossil resins at the moment. An exact distinction of single material species of fossil resins is still uncertain in some cases. H.E.

Der wilde Weg zu den Aquamarinen.

P. VOILLOT. *Lapis*, **19**(11), 1994, pp 38-45, 10 photos in colour.

Describes the aquamarine deposits in the Northern Areas of Pakistan with particular reference to mines at altitudes preventing working for six months of the year. Attention is paid to the geography of the area and to access difficulties for the miners. M.O'D.

A discernment of ruby by ESR.

O. WAKISHIMA. *Indian Gemmologist*, **4**(3/4), 1994, pp 21-9, 16 figs.

Electron spin resonance was used to distinguish Burma from Thai ruby, the former showing the Cr^{3+} absorption line (resonance field 7500e) and the latter the Fe^{3+} absorption line (resonance field 8500e). The figure for the Fe^{3+} absorption line varied in heat-treated ruby. M.O'D.

Essence and nomenclature of jade: a problem revisited.

CHUNYUN WANG. *Bull. Friends of Jade*, **8**, 1994, pp 55-66.

Short study of the significance of the Chinese word *yu* and its application to the jade minerals. While the word is sometimes used to denote any precious minerals, such features as a hard and compact texture have been inseparable from the concept of the word as far as Chinese use is concerned. M.O'D.

Krieg und Steine: Ein aktueller Situationsbericht und Neufunde aus Pakistan und Afghanistan.

A. WEERTH. *Lapis*, **19** (10), 1994, pp 27-30, 7 photos in colour.

Despite the hazards of war, crystals of ruby, aquamarine, purple apatite and peridot have been found by the author at locations in Pakistan and Afghanistan. M.O'D.

Lapis-Lazuli, die unendliche Geschichte.

A. WEERTH. *Lapis*, **19**(11), 1994, pp 20-7, 10 photos in colour.

Despite wars and economic conditions mining and sale of lapis lazuli continues in Afghanistan. Methods of mining or at least lapis recovery are described and there are notes on paragenesis and on present-day conditions in the traditional centre of Sar-e-Sang. Notes on lapis deposits in other countries are briefly mentioned. M.O'D.

Synthetische Amethyststufen und bestrahlter 'Rauchquarz'.

C. WEISE. *Lapis*, **19** (9), 1994, pp 33-4, 6 photos, (4 in colour).

Specimens of quartz irradiated to give amethyst colour and offered as crystal groups are reported from mineral fairs in Europe. The origin is believed to be Russia. M.O'D.

The fossil hydrocarbon jet.

M. WELLER AND CH. WERT. *Die Geowissenschaften*, **11**(9), 1993, pp 319-25.

Jet (Gagat) is a fossil hydrocarbon, with a composition close to that of bituminous coals, but free of mineral inclusions. It does not weather in a moist atmosphere and, because it carves well and takes a high polish, it has been used for jewellery at least as long as amber. Old carvings have been found in England and Scotland, largely made from jet found in Yorkshire. Samples from the Liassic Posidonia shale from Holzmaden (Germany), from the Yorkshire mines and from the deserts of the SW USA were studied especially for their mechanical loss spectra. K.v.G.

Chinese neolithic jade: a preliminary study of archaeological geology.

WEN GUANG, JING ZHICHUM, *Bull. Friends of Jade*, **8**, 1994, pp 125-47, 7 photos, 4 figs.

Analysis of jade artefacts from the neolithic period in China shows that nephrite was used extensively in the period. There is a review of jade mineralogy and an extensive list of references. M.O'D.

Der Sonnengott der Azteken. Die Opale der Neuen Welt: ein Überblick.

J.S. WHITE. *Mineralientage München, Messethemenheft*, 1994, pp 52-8, 11 photos in colour.

Brief review of opal with particular reference to specimens found on the American continent. M.O'D.

Check-list for rare gemstones: carletonite.

W. WIGHT. *Canadian Gemmologist*, **14**(1), 1993, pp 14-17, 1 fig.

Light blue transparent carletonite from Mont Saint-Hilaire, Rouville County, Quebec, Canada, has occasionally been faceted. Between 1982 and 1987 crystals recovered from the Poudrette Quarry reached 5cm in length. Notes on occurrence and properties are given. M.O'D.

Check-list for rare gemstones: villiaumite.

W. WIGHT. *Canadian Gemmologist*, **13**(4), 1992,

pp 110-13, 1 photo.

Note on the properties and ornamental possibilities of the sodium fluoride villiaumite. Most gem-quality material comes from Mont Saint-Hilaire, Rouville County, Quebec, Canada. M.O'D.

Check-list for rare gemstones: shortite.

W. WIGHT. *Canadian Gemmologist*, **14**(2), 1993, pp 46-9, 1 fig.

Shortite, in pale yellow transparent crystals has been found at Mont Saint-Hilaire, Rouville County, Quebec, Canada. The largest faceted stone recorded weighs 3.52ct. Occurrence and properties are described. M.O'D.

Check-list for rare gemstones: sodalite.

W. WIGHT. *Canadian Gemmologist*, **14**(3), 1993, pp 78-81, 1 fig.

The nepheline syenite quarries at Mont Saint-Hilaire, Rouville County, Quebec, Canada, have provided specimens of transparent hackmanite, a variety of sodalite which show tenebrescence, in this case occurring pink and reverting to colourless or achieving pink coloration after irradiation with UV, during which an orange fluorescence is seen. Some specimens remain magenta. Properties and details of the occurrence are given. M.O'D.

Check-list for rare gemstones: vlasovite.

W. WIGHT. *Canadian Gemmologist*, **14**(4), 1993, pp 110-13, 1 fig.

Facetable vlasovite is reported from the Kipawa alkaline complex beside Sheffield Lake, Villedieu Tp., Temiscamingue County, Quebec, Canada. Notes on the occurrence and properties are given. M.O'D.

Check-list for rare gemstones: eudialyte.

W. WIGHT. *Canadian Gemmologist*, **15**(1), 1994, pp 14-17, 1 fig.

Red transparent eudialyte from the Kipawa Alkaline Complex, Quebec, Canada, has been faceted. Notes on the occurrence and properties are given. M.O'D.

Check-list for rare gemstones: dolomite.

W. WIGHT. *Canadian Gemmologist*, **15**(1), 1994, pp 46-9, 1 fig.

Facetable transparent colourless dolomite is described from the Nanisivik mine, Baffin Island, Northwest Territories, Canada. A few pink stones have been found. M.O'D.

Check-list for rare gemstones: scheelite.

W. WIGHT. *Canadian Gemmologist*, **15**(3), 1994, pp 78-81, 1 fig.

Facetable yellow-orange scheelite has been found at Emerald Lake, Yukon Territory, and colourless material from Foley Mountain, Agassiz, New Westminster District, British Columbia, Canada. Properties are given. M.O'D.

Okanagan opal.

R.W. YORKE-HARDY. *Canadian Gemmologist*, **15**(1), 1994, pp 43-5, 1 photo.

Gem-quality opal has been found near Vernon, British Columbia, Canada, occurring as fracture and vesicle fillings in various Tertiary volcanic rocks. Stability appears to be good. M.O'D.

Neue Grossulare aus Dionboko/Mali.

J. ZANG. *Lapis*, **19** (10), 1994, pp 45-6, 2 photos (in colour), 1 fig.

Crystals of grossular garnet, some of facetable quality, are reported from the vicinity of Dionboko in the Kayes region of Mali. Specific gravity is given as 3.63-3.72 and refractive index as 1.756-1.769. The colour of the faceted stone illustrated is yellowish-green. Both iron and chromium have been identified in specimens recovered. M.O'D.

Fritz Klein: Smaragde unter dem Urwald.

ANON. *Lapis*, **19**(11), 1994, pp 28-37, 13 photos (12 in colour).

Fritz Klein wrote *Smaragde unter dem Urwald* in 1941 and his career as an emerald buyer in Brazil and Colombia is described. One of Klein's exploits led to the rediscovery of the Chivor mine. Photographs of current activity in some of the areas visited by Klein are included. M.O'D.

Instruments and Techniques

Spectrophotometry in gemmology.

J. ALLAMAN. *Cornerstone, Journal of the Accredited Gemologists Association*, **Autumn/Winter**, 1994, pp 1,3,4, 3 figs.

In gemmology the sensitivity and speed of spectral analysis afforded by the spectrophotometer is being increasingly used for the identification of gems and synthetics. Combined with computer software it is also used for colour analysis in the colour grading of diamonds, the comparison of diamond master stones and the detection of irradiated diamonds. P.G.R.

Le 'Pearlscop', un nouvel instrument gemmologique.

H. ATALAY. *Revue de Gemmologie*, **120**, 1994, pp 15-16, 1 photo, 2 figs.

Monochromatic light from a laser source is used to identify drilled or non-drilled pearls. The method works in a similar way to the endoscope. M.O'D.

Contouring with diamond wire.

G.L. BIASCO. *Industrial Diamond Review*, **54**(562), 1994, pp 114-16, 1 table, 4 diagrams, 5 illus. in colour.

Over the years the stone industry has seen many developments in processing techniques, all of which have contributed in ensuring the growth of a major area of diamond tool usage. Not least are the computer-controlled machines employing diamond wire. There are at present about fifty of these machines in use in Europe alone. The main uses are the production of tombstones, curved slabs for cladding and columns in the manufacture of modern and antique style accessories. The technique of producing stone profiles with the help of computer-controlled contouring machines is described. E.S.

Modelling the growth of natural diamonds.

S.R. BOYD, F. PINEAU AND M. JAVOY. *Chemical Geology*, **116**(1-2), 1994, pp 29-42.

Using available evidence it has been possible to construct a model for the growth of coated diamonds; using this model C isotope fractionation related directly to diamond formation is considered. In contrast, the comparative lack of knowledge of many aspects of the growth conditions of octahedral diamonds leads to uncertainty regarding the interpretation of the isotopic data. Detailed studies (particularly CL and FT-IR) of the internal zoning in isotopically distinct populations of diamonds may help, possibly revealing marked differences in the conditions of growth. R.E.S.

Penetrating diamonds with X-rays and a microscope.

A.R. LANG. *Industrial Diamond Review*, **54**(3), 1994, pp 141-6.

The information yielded by simple crystal assessment methods, such as birefringence microscopy, is much enhanced by the correlation of birefringence observations with cathodoluminescence and X-ray topography. In this article, the volume-imaging capabilities of birefringence microscopic and X-ray topographic techniques are described and illustrated, and are combined to give pictures of the internal strains in diamonds that are both comprehensive and capable of interpretation. Since no lenses are used with X-rays, it is not possible to focus observations on a selected layer in the crystal, as can be done in optical microscopy. However, equivalent results can be achieved by a variant of the projection topograph technique, the 'limited projection topograph'. R.A.H.

Optical anisotropy in the spinel group: a polishing effect.

E. LIBOWITZKY. *European Journal of Mineralogy*, **6**(2), 1994, pp 187-94.

Examination of > 100 polished sections of magnetite, chromite, franklinite and jacobsite from ~50 localities used two final polishing procedures. Using a 0.1 μm diamond suspension on 'microcloth' always led to weak optical anisotropy, except for {100} and {111} sections, whereas use of an alkaline silica solution on 'microcloth' gave sections which remained isotropic with the exception of five zoned magnetites. Electron channelling pattern images with SEM showed a strongly damaged surface for samples prepared with the diamond suspension and a perfect undisturbed surface for those prepared using an alkali silica solution. This convincingly indicates that the anomalous optical anisotropy effects in the spinel group are usually caused by mechanical polishing procedures. R.A.H.

Catodoluminiscencia (CL) y espectros de catodoluminiscencia de diamantes sintéticos experimentales De Beers.

J. PONAHLO. *Boletin del Instituto Gemológico Español*, **35**, pp 25-38, 2 tables, 21 illus. in colour, 8 figs.

Synthetic gem-quality diamonds manufactured by De Beers show geometrically-patterned colour zoning under cathodoluminescence. Polarization figures induced by stress have been observed as well as large euhedral crystals of unknown composition. Colours induced by cathodoluminescence are a greenish yellow and blue. Growth lines can be seen in different sectors of the stones. M.O'D.

An experimental optical Brewster-angle refractometer.

P.G. READ. *Gemmological Assoc. of New Zealand*

Newsletter, **Nov.**, 1994, pp 5-7, 4 figs.

The author traces his development work on Brewster-angle refractometers from the first simple optical model in 1979 through two fully electronic versions to a more recent optical model using a miniature visible red (670nm) solid-state polarized laser. This latest experimental unit is housed in a modified Dialdex refractometer case and the drum mechanism is used to drive the laser carriage through the 18 degrees of angular movement necessary to cover the RI range of 1.40 to 3.00. (Author's abstract) P.G.R.

Synthetics and Simulants

AGEE synthetic hydrothermal emerald.

S. FERNANDES, S. SARMA AND V. JOSHI. *Indian Gemmologist*, **4**(3/4), 1994, pp 30-1, 3 photos (in colour), 3 figs.

Emerald manufactured by AG Japan Ltd is grown hydrothermally, probably from low quality emerald feed material. RI is found to be 1.573-1.580 with DR 0.004-0.007, SG 2.67-2.72. A strong red is seen through the Chelsea filter and there is a variable fluorescence, weak red to inert. Promotional literature gives figures for RI as 1.569- 1.573. Stones showed partially spiral fingerprints, growth and angular zoning, parallel cavities, crystal structures and widely spaced colour zoning, indicating hydrothermal origin; the IR spectrum for water was also observed.

M.O'D.

Synthetic emerald overgrowths on colourless beryl crystals.

U. HENN AND H. BANK. *Canadian Gemmologist*, **14**(4), 1994, pp 102-3, 2 photos.

Colourless beryl crystals with an overgrowth of emerald have been produced in Russia. The natural seed contains inclusions which may deceive the gemmologist but the boundary between seed and overgrowth can be seen under magnification. M.O'D.

Microscopic features of synthetic rubies. Part 1: melt products.

R.C. KAMMERLING AND J.I. KOIVULA. *Canadian Gemmologist*, **15**(3), 1994, pp 82-5, 8 photos.

Details of inclusions likely to be found in melt-grown rubies are given with particular reference to Verneuil, Czochralski and floating-zone products. M.O'D.

The characteristics of Russian flux-grown synthetic red and blue spinels.

J.I. KOIVULA AND R.C. KAMMERLING. *South African Gemmologist*, **8**(2/3), 1994, pp 4-15, 8 photos in colour.

The presence of flux residues, air-filled fractures and particles of crucible wall material are the most characteristic features of flux-grown red and blue spinel manufactured in Russia.

M.O'D.

Gem News.

J.I. KOIVULA, R.C. KAMMERLING AND E. FRITSCH. *Gems & Gemology*, **30**(2), 1994, pp 122-32, 1 table, 18 illus. in colour.

A new emerald imitation 'Swarogreen' made by Swarowski of Austria had an RI range of 1.608-1.612 and an SG of 2.88-2.94. This glass had a reported dispersion of 0.030 and a Mohs' hardness of approximately 6.5. The higher-than-usual RI is due to the presence of both calcium and aluminium. Minute machine-cut synthetics as small as 1mm diameter were shown at Tucson and included emerald simulants consisting of green synthetic spinel triplets. Faceted synthetic opals by Gilson showed a slightly milky body colour and exhibited a full range of hues with green predominating. Manning International showed several Czochralski-pulled sapphires with a saturated slightly greenish-yellow colour. The main chromophore was nickel. Microscopic examination revealed curved growth lines. A near-colourless Russian synthetic diamond produced using a 'belt' apparatus was examined and the cuboctahedral crystal revealed large metallic inclusions and fluoresced yellow in short-wave ultraviolet radiation only. The crystal adhered to a simple magnet and the metallic inclusions contained iron. R.J.P.

Relationship between the crystallographic orientation and the 'alexandrite effect' in synthetic alexandrite.

Y. LIU, J.E. SHIGLEY, E. FRITSCH AND S. HEMPHILL. *Mineralogical Magazine*, **59**(1), 1995, pp 111-14.

The transmittance spectra of a synthetic alexandrite along the three crystallographic axes are in general similar, but the observed colour changes along these directions under different light sources are quite different. Calculated hue-angle changes for colours observed under different pairs of CIE standard illuminants are largest for light travelling || to the *a* axis. Therefore, alexandrite as a gemstone should be cut with the

top facet oriented ||(100) for it to show the most dramatic change in colour. R.A.H.

Synthetic forsterite and synthetic peridot.

K. NASSAU. *Gems & Gemology*, **30**(2), 1994, pp 102-8, 1 table, 6 illus. in colour.

Large crystals of forsterite doped with chromium are manufactured commercially for use as a laser material. Forsterite is an end member of the olivine series being magnesium silicate, whilst fayalite, iron (II) silicate is the other end member. Peridot is a silicate containing both iron and magnesium. It has only been produced in experimental amounts and the data so far are consistent with natural peridot, although inclusions are distinctive. The crystal formation used an image-furnace floating-zone technique with an atmosphere of carbon monoxide and carbon dioxide. Any oxygen leak resulted in a brown peridot.

The synthetic chromium-containing forsterite is usually of a different colour to peridot but a peridot-like colour is possible with some overlap of gemmological properties. However, the chromium compound has a distinctive visible spectrum and lower refractive index and specific gravity values than natural peridot. R.J.P.

Unusual synthetic.

K.T. RAMCHANDRAN AND J. PANJIKAR. *Indian Gemmologist*, **4**(3/4), 1994, p. 3, 3 photos in colour.

An apparently natural faceted ruby with solid-appearing inclusions beneath the crown facets showed Plato lines on immersion but no curved growth lines. The inclusions proved to be a concentration of chromium salt with aluminium oxide. M.O'D.

Synthesis, stability, and properties of $Al_2SiO_4(OH)_2$: a fully hydrated analogue of topaz.

B. WUNDER, D.C. RUBIE, C.R. ROSS II, O. MEDENBACH, F. SEIFERT AND W. SCHREYER. *American Mineralogist*, **78** (3-4), 1993 pp 285-97.

The OH end-member of the F-OH topaz solid-solution series, with a composition close to $Al_2SiO_4(OH)_2$, has been synthesized at *P* between 55 and 100 kbar and $T \leq 1000°C$) from gels and crystalline starting materials. The results of single-crystal X-ray diffraction (space group *Pbnm*, *a* 4.724, *b* 8.947, *c* 8.390 Å) are reported. J.A.Z

Note

1. These are short abstracts from extended abstracts published in *Mineralogical Magazine* **58A** (two parts), 1994. The volumes contain only the extended abstracts of papers from the V.M. Goldschmidt Conference, Edinburgh 1994.

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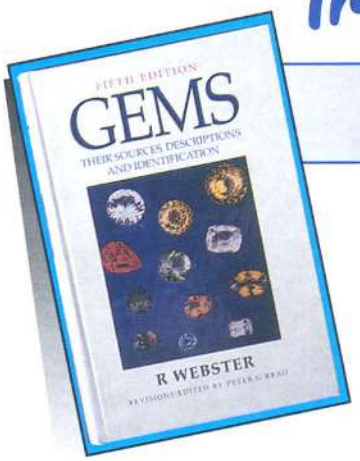

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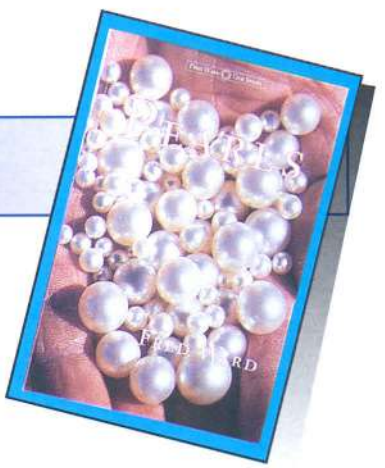

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Book Reviews

Versteinertes Holz. Aus Holz wird Stein: die Mineralogie der Holzversteinerung.

U. DERNBACH, M. GLAS, R. HOCHLEITNER, W. JUNG, M. LANDMESSER, H. MAYR AND A. SELMEIER, 1994. Christian Weise Verlag, Munich. pp 96, illus. in black-and-white and in colour. Price DM29.80. (*extraLapis* 7) ISBN 3 921656 32 X.

This seventh monographic issue of *extraLapis* has the theme of replacement and pseudomorphism with particular reference to the replacement of organic materials by silica. Among the topics discussed are opal and agate structure with notes on collectors and collections, mining and chemistry, and there is a useful bibliography on the formation of agates. Readers will find the coloured photographs both beautiful and informative and some notes on the history of solutions in agate formation will be hard to find elsewhere. M.O'D.

Brésil, terre de pierres. Mines, cristaux et garimpeiros.

C. DUFOUR AND J.-P. HÄNNI, 1994. Muséum d'histoire naturelle de Neuchâtel, Neuchâtel. pp 80, illus. in colour. Price SF 28.00. ISBN 2 940041 01 6.

A short but beautifully-produced account of the major gem minerals of Brazil with descriptions of geology, mining methods and geology. The photographs are original and particularly welcome on this account since so many pictures while excellent in themselves go the rounds once too often. Some of the photographs show mining techniques in operation. Gem minerals in the book include diamond, topaz, beryl, tourmaline and quartz, making up, in fact, the bulk of the text. There is a short bibliography. M.O'D.

Silica: physical behaviour, geochemistry and materials applications.

P.J. HEANEY, C.T. PREWITT AND G.V. GIBBS (eds), 1994. Mineralogical Society of America, Washington. pp xviii, 606, illus. in black-and-white (*Reviews in mineralogy*, vol. 29). ISBN 0 939950 35 9.

A comprehensive account of silica in all its forms. Gemmologists will find the chapter by Rossman, on coloured varieties of the silica minerals, very useful, though there is much else of interest in the rest of the book. As always in this series, the lists of references are very valuable. The level is undergraduate to post-graduate. M.O'D.

Visual optics: diamond and gem identification without instruments: the Hodgkinson method.

A. HODGKINSON, 1995. Gemworld International Inc., Northbrook IL. pp v, 50, illus. in colour. ISBN 0 96417331X. £16.50

While the term 'visual optics' may puzzle physicists and mineralogists, those gemmologists who have used Hodgkinson's method - and members of the general public who have stood amazed by its results - know that it means that anyone can identify a faceted gemstone, within limits, under controlled conditions.

This is, of course, not true and the book does not in any way claim that so simple a method of testing can produce results all the time in any hands. What it does claim is that trained operators can quite often, sometimes with unpromising material, identify an unknown with small risk of error. The book is very attractively produced and reads very well despite a few obscure sentences and unexplained technical terms, which I think would rule it out for universal use. The author's photographs and diagrams are well reproduced and the tests could be followed by any gemmologist or student.

Does the book succeed in its argument? Yes, since it does not over-claim and so far as I can see all the tests would work. I am sure that there will be counter-claims on a specific aspect of a particular test and I am also certain that developments will arise over the years. This is how a diagnostic science should work and this interesting and moderate overview of a way of gem testing should be welcomed in its context. The beautiful view of Arran from the author's laboratory will certainly make many diamonds rise a grade or two in colour! Buy the book to find out why! M.O'D.

Handbook of crystal growth.

D.T.J. HURLE, 1993. North-Holland, Amsterdam. Illus. in black-and-white and in colour, hardcover. Approx. 560 Dutch guilders per volume. 3 volumes [in 6]. ISBN [series] 0 444 89933 2.

This is the most important monograph on crystal growth yet to appear in any language and while most gemmologists will probably not have

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access to copies (costing something like £700-800 for the complete set) they will find a very large amount of information on the processes of crystallization and references to monographs and papers on all aspects of crystallization. The first part (in two volumes) deals with fundamentals, divided by volume into thermodynamics and kinetics and transport and stability. The second part, again in two volumes, covers bulk crystal growth, divided again into basic techniques and growth mechanisms and dynamics. The third part covers thin films and epitaxy, divided into basic techniques and growth mechanisms and dynamics.

Gemmologists will find the sections in volume 2 most relevant to their studies as they cover those types of crystal growth most appropriate for gemstones. There is a great deal of relevant material in the rest of the book but some skill is needed to find exactly what is wanted since the text is aimed at crystal growers and at those dealing with characterization rather than crystal applications. This is a book likely to be found only in the largest two or three university libraries but is a monument to the science and well worth looking through if and when encountered. M.O'D.

Das Diamanten-Imperium. Aufstieg und Macht der Dynastie Oppenheimer.

S. KANFER, 1994. Carl Hanser Verlag, Munich. pp 503, hardcover. Price DM45.00. ISBN 3 446 16075 2.

This is a German version of *The last empire: De Beers, diamonds and the world*, first published in 1993. The theme is the fairly well-tried one of the De Beers near-monopoly of diamond recovery and price maintenance with useful history of how the group of companies developed. Sidelights on South African politics are given and there are very useful lists of references for each chapter. M.O'D.

Manual of mineralogy 21st edition.

C. KLEIN AND C.S. HURLBUT JR, 1993. John Wiley & Sons Inc, New York. pp xii, 681, illus. in black-and-white, soft cover. Price £22.95. ISBN 0 471 59955 7.

This is an ideal text to read with that of Putnis, reviewed elsewhere. In the continuing absence of a completed (or better, a revised and completed *System of mineralogy*) the two texts, theoretical and taxonomic, complement each other excellently and in this new edition of the *Manual* chapters on crystal chemistry and mineral chemistry have been revised and a new chapter on mineral stability diagrams included. Such diagrams are now incorporated in the descriptive section where relevant. Crystal chemistry is the underlying theme in this edition, as with its more recent predecessors. Chapter 15 describes gem minerals briefly and many will find both the descriptive section and the tables useful. It is always important for gemmologists to keep up with current thinking in the wider earth science field, however fast or slowly it moves. M.O'D.

Mineralogical gemmology. The precious minerals through the centuries. [In Bulgarian.]

R.I. KOSTOV, 1993. Nauka i Izkustvo Publishing House, Sofia. 213 pp. Price Bulgarian Leva 32.00.

This book reviews the aesthetic attitude of mankind to the precious and decorative minerals and bio-objects used in different epochs and different countries and continents. A lot of mythological stories and ancient texts have been analyzed, as well as some works of well known writers and poets of the past. The first part of the book describes gemmology as a complex science, lists important contributions in the history of gemmology and gives the principles for classification of gemmological minerals. The second part is related to mythological texts, stories and legends about gemstones in primitive societies, in the Ancient and Medieval civilizations around the world. The third part deals with the miracles and reality about gem materials in the spectrum of knowledge, philosophy, astronomy, physics, chemistry, geosciences, medicine, ethnography and semantics. The last part is an attempt to give an art point of view on crystals and gemmological materials. A glossary of gemmological names (natural materials) has been added for the general reader. The book can be defined as a work on mineralogical folklore with a lot of new ideas and information after the pioneer works of G.F. Kunz in the USA and A.E. Fersman in Russia. R.A.H.

Amethyst: geschichte, eigenschaften, fundorte.

W. LIEBER, 1994. Christian Weise Verlag, Munich. pp 188, illus. in black-and-white and in colour, hardcover. Price DM98.00. ISBN 3 921656 33 8.

In a well-printed and beautifully illustrated book Werner Lieber, who has already written such mineral classics as *Kristalle unter der Lupe* and *Calcit, Baustein des Lebens*, introduces both the mineralogically-inclined and the more general reader to the history, geology, mineralogy and identification of amethyst. The

gemmologist, too, will find the text quite sufficiently extending and there is an excellent bibliography.

The book begins with the use of amethyst over the past 5000 years and then goes on to describe the form and structure, physical and optical properties, cause of colour, inclusions and synthesis. The remainder of the text, some 100 pages, is devoted to the main amethyst occurrences of the world and one of the indexes covers locality names. Here and there about the text are pictures of postage stamps and in some ways the main thrust of the book is towards the collector. The photographs are very well chosen and reproduced and the variations in colour are sufficiently distinguished to show how great they can be. Gemmologists will welcome the photographs of inclusions and the diagrams in the text, especially those depicting the forms of crystals and the ways in which twins occur, are especially well-drawn and clear. The price of the book is very reasonable and I strongly recommend readers to obtain a copy. M.O'D.

The crown jewels.

K. MEARS, 1994. Historic Royal Palaces Agency. pp 51, illus. in black-and-white and in colour, softcover. (Original text by K. Mears revised with additions by Simon Thurley and Clare Murphy.) £3.50.

Guides to the crown jewels have never equalled the importance of their subject either in text, illustration or standard of production. There has always been a sense of let-down over an unscholarly, breathless and hastily-written text or over indifferent photographs set out in an amateurish style. The present book, while one of the best of recent productions, does not go all the way to remedying a rather mysterious tradition. Here the text is harmless and the pictures nearly all good (some are very good, in fact): there is, though, too much white paper showing and the text of the captions is rather small. The cover, while boldly conceived, is too dark to be really successful and some of the other photographs also have too much shadow.

While I see no serious inaccuracies in the text, the dearth of information is sad: so much more could have been supplied and none of the information given would be new even to fairly well-read people, let alone to scholars. The book is, though an improvement on most others, another example of insufficient initiative or skill being brought to bear on a subject of major importance to the historian and gemmologist. Something in the crown jewels seems to stop serious effort either being initiated or, when started, carried on. Timidity has wrecked what have promised to be previous attempts to provide a useful survey. Perhaps the curse of the regalia will lift when a champion of adequate status presents himself. M.O'D.

Physics and chemistry of earth materials.

A. NAVROTSKY, 1994. Cambridge University Press, Cambridge. pp xiii, 417, illus. in black-and-white, softcover. (*Cambridge topics in mineral physics and chemistry. 6*) £22.95. ISBN 0 521 35894 9.

The book is intended for first-year and more senior undergraduates and is aimed to present crystal chemistry away from the rock-forming context and also to give an overview of chemical bonding in minerals. The author relates microscopic structural features to macroscopic thermodynamic behaviour and in doing so shows off the usefulness of modern tools, especially in spectroscopy. High-pressure phase transitions, solid-state reactions and amorphous materials are discussed in conclusion.

While gemmologists will probably find the general standard rather above diploma level, sections on spectroscopy and crystal structure may fill gaps in understanding left by standard gemmological texts: mineralogists will find the book an excellent overview of a topic much in discussion today. The long lists of references appended to each chapter are valuable in themselves.

M.O'D.

Introduction to mineral sciences.

A. PUTNIS, 1992. Cambridge University Press, Cambridge. pp xx, 457, illus. in black-and-white, softcover. Price £22.95. ISBN 0 521 42947 1.

Over the past few years there have been so many developments in techniques in the mineral sciences that the more customary taxonomic type of mineralogy text now needs a companion work in which these are described. Advances in techniques have made it possible for a greater understanding of mineral formation and behaviour to be developed and this aspect of mineralogy is a major theme in this book. While many of the concepts are perhaps a little too advanced and mathematical for the majority of gemmologists they should be aware of some of the current work and ideas in what is still seen as the parent science. M.O'D.

Dictionary of gemmology.

P.G. READ, 1994. Butterworth-Heinemann, Oxford. pp 266, illus. in black-and-white, soft-

cover. Second edition. £16.95. ISBN 0 7506 1675 X.

It is pleasing to meet an old friend in a new and cheaper issue, though the covers, like those of our real friends, conceal matter both good and questionable! This may be the time for an evaluation of the enterprise before a third edition appears.

A check of the some 3000 entries shows that approximately 30 per cent are little-used names of ' gem' materials. A sample of these tested against *Hey's mineral index* shows that approximately half are not included and are thus regenerated by the book under review (via some of the mostly British pundits of the 1960s whose uncritical work was unhelpful in this context). Further investigation shows that these entries include some misreadings (e.g. darlingtonite for darlingite [jasper]) and some names first making their appearance in the late eighteenth century.

Someone, sometime, needs to ask the question 'were these names ever in general currency?' I am quite sure that only a very few were used in the trade and that most originate from novels and the more fanciful mineralogical texts of the last century. Unless readers are engaged in serious mineralogical or gemmological taxonomy they perhaps do not need so many names?

This is a vexed question arising from the time when gemmology was little but an amateur and commercial aspect of mineralogy. Now that mineralogy itself is taken in some quarters to be inorganic natural products chemistry (with some geology) it seemed worthwhile to look at some of the chemistry in the *Dictionary*. The description of garnet as an isomorphous series of gem minerals' misses the point that 'garnet' is a group name and the remainder of that entry, somehow dragging in the feldspar group, repeating iron and omitting potassium, only confuses more. The tourmaline entry again omits the group name status (which explains the chemistry and properties much more easily). Uvite is stated to be a dravite-type tourmaline but is, in fact, an individual species within the tourmaline group. Fibrolite is said to be polymorphous with andalusite and kyanite but it would be more accurate to say that the three species are polymorphs of Al_2SiO_5. The entry for olivine is inaccurate in that no mention is made of the magnesium content nor of the isomorphous series existing between forsterite and fayalite, knowledge of which is important in gem testing.

On a lighter note, I was interested to encounter the concept of the 'rare collector' and hope that they form a club which I might one day join when sufficiently eminent. It is always good to have an ambition! Non-rare [common?] collectors have to be content with crocoite while their betters can have creedite (inexplicably, with other species, described as 'complex').

From the book itself it is not clear whether the text has been revised but a publisher's note accompanying the review copy calls it a 'revised paperback edition'. One of the adjectives must be incorrect but I do recommend the book even as it stands, as the only text of its kind. It would have been helpful if the publisher had included a short biography of the author who, after all, has made money for them: this type of omission is discourteous and unhelpful to later bibliographical scholarship. M.O'D.

Jade treasures of the Maori.

M. Riley, 1994. Viking Seven Seas Ltd, Paraparaumu, New Zealand. pp 63, illus. in black-and-white and in colour, softcover. Price NZ$6.25. ISBN 85467 090 4.

A really first-class small book covering one part of the jade story that gets less airing in proportion to that given to the Far Eastern scene. The bibliography alone, containing references to MS material in New Zealand and other libraries, is worth the very reasonable price. The book has beautiful photographs, a great deal of folk-lore pertaining to jade in New Zealand and notes on the ritual and other significance of the shapes of jade artefacts used by the Maori people. Maori names for the various colours of nephrite are listed, with notes on their origin. In many cases the names originated in descriptions of native creatures. This is one of the most interesting books I have seen for a long time. M.O'D.

Humboldt's travels in Siberia (1837-1842): the gemstones. Extracts and commentaries on Gustav Rose's Reise nach dem Ural, 1837-1842.

G. Rose [translation and commentary by John Sinkankas. Edited by George M. Sinkankas], 1994. Geoscience Press, Phoenix, AZ. pp 80, illus. in black-and-white, hardcover. Price on application. ISBN 0 945005 17 2.

The expedition mounted by Alexander von Humboldt to the then virtually unknown Siberian part of the Russian realm was intended to explore mineral possibilities. Count Cancrin, Minister of Finance to the Tsar, had a strong interest in minerals (cancrinite was later to be named after him) and was instrumental in establishing the expedition. Gustav Rose, the team's official geologist and later to be the namer of cancrinite, was the recorder and secretary. Rose eventually produced a two-volume description of the expedition's activities under the title

Mineralogische-geognostische Reise nach dem Ural, dem Altai und dem Kaspischen Meere - a title usually, as here, shortened to *Reise nach dem Ural*. Considerable attention was paid to the gemstones and the work has very great value on this account alone.

The travels began in Berlin and proceeded to St. Petersburg. Before the travellers had got very far they had their first experience of displayed gem materials (amber) in the mineral collection of the University of Königsberg in the then East Prussia. A good deal of detail about amber in general from the Königsberg area is given and the pattern of 'expedition stops somewhere - gemstone deposits, traders or collectors encountered - Rose writes about them' is maintained as the travellers passed from St. Petersburg to Ekaterinburg to the northern Urals, to the Altai, to Miask, Slatoust, Orenburg and elsewhere. In passing, extended details are given on such topics as the Orlov and Shah diamonds, the habits of topaz crystals from Mursinsk and chrysoberyl from the Uralian emerald mines. The amount of useful and unpublished material is very large and readers will be most grateful to Sinkankas for unearthing the treasures from the larger work. In passing, Sinkankas laments the poor acquaintance of British-American writers with German mineralogical works and after years of working with German and other continental language texts I can support his strictures with experience! The language barrier seems insurmountable to the insular and thus poorly-informed British gemmologist at least - perhaps a closer acquaintance with Europe over the next few years will put this right. M.O'D.

Crystal identification with the polarizing microscope.

R.E. Stoiber and S.A. Morse, 1994. Chapman & Hall, New York. pp xiv 358, illus. in black-and-white, softcover. Price £24.95 (paperback), £65.00 (hardback). ISBN 0 412 04831 0.

It is very pleasing to meet a new text on one of the most traditional methods of mineral identification. This is desert-island mineralogy with never a black (or grey) box in sight. The authors set themselves a difficult task when they state their aim is to make the text available and understandable to the widest range of readers from beginner to professional but my feeling is that they are largely successful. The opening chapters cover crystal identification and optical properties, the text then passing to the different types of effects shown by isotropic and anisotropic specimens. Gemmologists will be familiar with a good deal of this material and it is presented in such a way that diagrams and text complement each other satisfactorily. Perhaps many will find the account of the immersion method of obtaining refractive index particularly interesting while others will not be able to wait to get to grips with biaxial crystal optics. Appendix A gives the optical properties of common rock-forming minerals while Appendix B outlines the identification of fibrous asbestos, by now known to everyone as a notorious health hazard. There is an excellent bibliography which refers entries back to the pages on which they occur - a very useful feature.

I strongly recommend gemmologists to buy this book which is very reasonably priced. It will explain many aspects of optical mineralogy which cannot be followed, for space reasons, in specifically gemmology-oriented textbooks.

M.O'D.

Gem care.

F. Ward, 1995. Gem Book Publishers, Bethesda, MD. pp 32, illus. in colour, softcover. *(Fred Ward Gem Books.)* Price on application. ISBN 0 9633723 5 1.

Fred told me something I already knew - that there was no comparable book on the market! This short and pleasant-appearing guide tells the jeweller and customer about the way to handle (and not to handle) the major gemstones. Photographs accompany each gem section and the text concludes with Mohs' hardness figures for quite a lot of species. Matters dealt with include hardness, cleavage, cleaning (beware of ultrasonic cleaners for brittle stones, especially tanzanite and emerald), storage conditions and the effect of chemicals, including cosmetics. Each stone is also given a brief description. This is a book for everyone. M.O'D.

Pearls.

F. Ward, 1995. Gem Book Publishers, Bethesda, MD. pp 64, illus. in colour, softcover. £9.95. ISBN 0 9633723 3 5.

The literature of pearl is still far less exhaustive than that of inorganic gem materials and while there have been one or two books published in the last few years they have not attracted the eye so much as this short guide which succeeds in covering a difficult subject very well. The book opens with notes on the history and lore of pearl, then describes natural, cultured salt-water, and cultured freshwater pearls. Mother-of-pearl and shell products, imitation pearls and the purchase and care of pearls complete the book.

As with all the *Fred Ward Gem Books*, there are

photographs of a kind and quality never before seen and this reviewer, at least, is beginning to learn some of the pearl basics. Readers could turn to any opening to find stimulus but try pages 30-31 first - they show the inside of a cultured pearl. Notes on mother-of-pearl and shell are especially welcome since these have had scarcely any up-to-date treatment in the literature. A must for students and for presents!

M.O'D.

The art of diamond cutting.

B. WATERMEYER AND S.S. MICHELSEN, 1994. Chapman & Hall, New York. pp xxi 137, soft-cover. £19.99. ISBN 0 412 98411 3.

The difference between the work of the lapidary and that of the diamond polisher is not so great, say the authors, that a good lapidary may not learn how to polish diamonds successfully. The book is a simple manual designed to make just such a transformation and sensibly begins with a glossary which is worth reading before starting on the main text. After a short discussion on diamond formation and structure, the authors describe how rough material is selected for polishing and go on to exhibit the processes of bruting and girdle faceting. As in the remainder of the book, the text is accompanied by clear diagrams. Chapters 4 to 6 tell the reader about the mechanics of diamond polishing so that he may set up his own lap (levelling it is hard to do) and have all the equipment set up before turning to Chapters 7, which shows how to find the four-point grain direction, and 8, which deals with facet placement for the round brilliant-cut.

The repair and re-cutting of old-cut diamonds (sometimes a pity!) is dealt with in Chapter 9 and further discussion of equipment follows. An account of diamonds from various sources and the working of the diamond market in the United States completes the main text. Advice is then given to the aspiring home polisher and an appendix explains the pricing structure for rough diamonds.

I enjoyed reading the book and can certainly recommend it, not only to its intended readership but also to students who want to know the essentials of diamond polishing. The price is competitive by today's standards. M.O'D.

Australasian mining and metallurgy: the Sir Maurice Mawby memorial volume (second edition: in two volumes).

J.T. WOODCOOK AND J.K. HAMILTON, EDS., 1993. Australasian Inst. of Mining & Metallurgy, Parkville, Victoria, *Monograph 19*. pp xxxvi 1587. Price $A 325.00.

This is essentially an upgraded version of *Monograph 10*, published in 1980. Its aim is to reflect the technical, operational and general practices of the mining and metallurgical industry in Australasia after 100 years of activity. It contains 416 articles on current activities in Australia, New Zealand, Papua New Guinea and Fiji, in 20 chapters covering background, general practices, environmental management, research, education and training, statistics of mineral and metal production, iron ore, iron and steel, Pb-Zn-Ag, Cu, Al, Au, Sn-W-Ta, U, Ni-Co, other metals, mineral sands, industrial minerals, diamond and other gems, and coal; there are author and subject indexes. Listed below are the articles most likely to be of interest to gemmologists:

(1) Hard rock diamond mining at Argyle Diamond Mines Pty Limited, Argyle, WA. D. Yates, D. Matthews and S. Deakin, pp 1443-9, 2 maps.
(2) Diamond mining by Poseidon Bow River Diamond Mine Limited, Bow River, WA. M. McCracken and T. Major, pp 1449-52, 1 map. Alluvial gravels yielding 0.28 ct/t. Gem-quality 15-20 per cent, due to presumed concentration from Argyle source.
(3) Opal mining in Australia. I.J. Townsend and J.L. Keeling. pp 1472-6.
(4) Sapphire mining and production in the New England region, NSW. D.C. Lawrence, pp 1477-81.

R.A.H.

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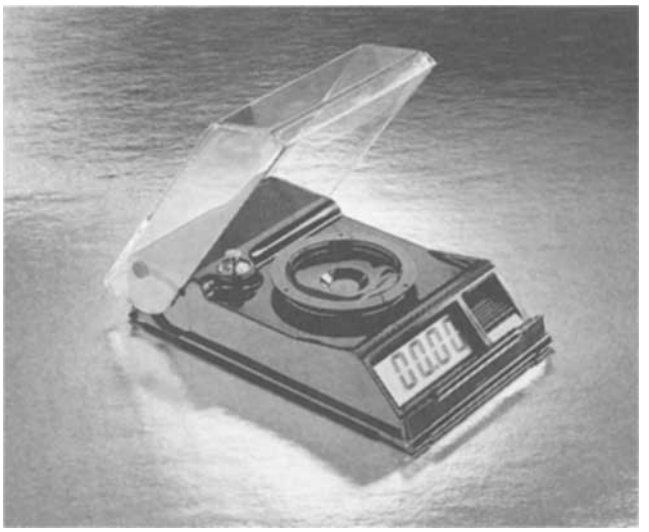

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Proceedings of the Gemmological Association and Gem Testing Laboratory of Great Britain and Notices

OBITUARIES

David Wilkins (D.1962), Chairman of the NAG Registered Valuers Committee, gemmologist and jeweller of Yeovil, died on 29 August 1994.

David had struggled bravely with his illness, working, advising, planning and helping the trade right up until a few weeks before his death.

David was a founder member of the Registered Valuers scheme; indeed its inception, fruition and success is something that he could certainly be very proud of; during his career he was able to see so many ideas realized which proved of great benefit to so many people.

David was apprenticed as a watchmaker and became a craft member of the British Horological Association. To study gemmology, he travelled the 34 miles to Bath from Cirencester to attend the study classes run at 1 Royal Crescent and spent his career furthering his knowledge and expertise, all the while sharing it with his colleagues.

He was a Council member of the National Association of Goldsmiths and made a particular contribution to the education activities. An examiner for the Retail Jewellers Diploma for 28 years, he wrote training articles and courses on gemstones, jewellery, silver and antiques. His enthusiasm for gemmology was immense; his collection included much that was unusual and reflected his taste for quality. Many students will remember his insistence on viewing 'asterism in sunshine' and the satisfaction of appreciation!

David's contribution to the trade was unique and his tireless enthusiasm will be irreplaceable. David's widow, Margaret, who was always involved and so supportive of his work, and all of us who enjoyed his friendship and kindness will miss his generous spirit. Michael Norman

Kenneth Norman Brohier (FGA 1979, DGA 1980 with Distinction), Kirby, Merseyside, aged 64.

Gordon Brohier died in a road accident in Sri Lanka in September 1994. He was a close personal friend and a popular and enthusiastic member of the North West Branch of the GAGTL. He had in the past few years spent a large part of his time in Sri Lanka where his family owned a hotel in Galle and part of a tea estate. It was while working on plans for the future of a hotel and estate that he was so tragically killed. He is survived by his wife and a son and daughter. J.W. Franks

Robert Anthony Buhl (D.1982), West Vancouver, Canada, died on 8 January 1995.

Thomas Reginald Shipster (FGA 1950, DGA 1970), Bergvliet, South Africa, died recently.

GIFTS TO THE ASSOCIATION

The Association is most grateful to the following for their gifts of gems and gem materials for research and teaching purposes:

Marie de Chamerlat, FGA, Paris, France,

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for buttons in shell, bone, horn and imitation materials.

Luella Woods Dykhuis, Tucson, Arizona, for sets of rough and cut sapphires from Montana.

Mrs M. F. M. Eliahoo, London, for two fine blue beryls.

Mrs Vanessa A. Guest, Nottingham, for specimens of rough and cut pectolite (larimar).

Steve Ryle, Dallas, Texas, for 21 cut Kashan synthetic rubies.

NEWS OF FELLOWS

Nick Sturman, FGA, DGA, of the Gem and Pearl Testing Laboratory of Bahrain, gave a talk entitled 'An introduction to the world of gemstones' to the American Women's Association, at the Diplomat Hotel, Bahrain, on 13 February 1995.

MEMBERS' MEETINGS

London

On 16 January in the Gem Tutorial Centre at 27 Greville Street, London EC1N 8SU, Stefany Tomalin gave a talk entitled *Miniature treasures and wearable works of art*. Slides and 'hands-on' examples illustrated the most famous collectable types of bead.

On 20 March at the Gem Tutorial Centre Alexandra Rhodes FGA, a Director of Sotheby's and Head of their Jewellery Department in London, gave an illustrated talk entitled *Jewellery at Sotheby's*.

Midlands Branch

On 24 February at Dr Johnson House, Bull Street, Birmingham, Clive Burch gave an illustrated talk entitled *Inclusions in silica gems*.

On 19 March a Gem Club was held, the subject of which was pearls.

On 31 March at Dr Johnson House Eric C. Emms gave a talk entitled *Diamond and its treatments*.

North West Branch

On 15 March at Church House, Hanover Street, Liverpool 1, Alan Hodgkinson gave an illustrated talk entitled *A taste of Scottish gemmology*.

ANNUAL TRADE LUNCHEON

The 1995 GAGTL Annual Trade Luncheon is to be held on Friday 16 June at the RAC Club, 89 Pall Mall, London SW1.

The Luncheon is open to all members and their guests and is an ideal opportunity to thank customers or suppliers for their support or to express appreciation to staff for their hard work. The speaker will be Jeremy Richdale, a Director of the Central Selling Organization.

As well as a buffet menu which has been carefully selected to suit all tastes, on this occasion we are also able to offer a Kosher menu at a small additional cost.

The price of the luncheon is £42.00 plus VAT (totalling £49.35) to include wine. Tickets for single and block bookings are now available from

Mary Burland at GAGTL,
27 Greville Street, London EC1N 8SU.
Telephone 0171-404 3334.
Fax 0171-404 8843.

SCOTTISH BRANCH

The first meeting of the newly formed Scottish Branch is to be held on Friday 19 May 1995 at the Assay Office, Goldsmiths Hall, 39 Manor Place, Edinburgh, when Ana I. Castro will give an illustrated talk entitled 'Gem Testing at the Laboratory'. All members in Scotland and the North of England are welcome to attend.

For further details please contact Joanna Thomson FGA DGA, PO Box 2, Peebles, Tweeddale, EH45 8BW. Telephone 01721 722936.

FORTHCOMING MEETINGS

London

12 June*	Annual General Meeting, Members' Reunion, and Bring and Buy Sale
16 June	Annual Trade Luncheon, the Royal Automobile Club, Pall Mall, London SW1
1 October	GAGTL Annual Conference to be held at the Scientific Societies Lecture Theatre, New Burlington Place, London W1. The theme will be *Gemmology in Britain.*
16 October*	**Recent developments in the diamond industry** Howard Vaughan

Weekly Meetings on Wednesdays

Regular practical gemmology evenings, held in the Gem Tutorial Centre, 27 Greville Street, London EC1N 8SU, are conducted by Michael O'Donoghue every Wednesday from 6.00 - 8.30 p.m. An opportunity to take part in individual or in group projects, or to pursue new paths in gemmology, the resources of the GAGTL are available and the fees are £25.00 per quarter or £90.00 annually.

* To be held in the GAGTL Gem Tutorial Centre, 2nd floor, 27 Greville Street, London EC1N 8SU (entrance in Saffron Hill). The charge for a member is £3.50. Entry will be by ticket only, obtainable from the GAGTL.

Midlands Branch

Full details from Mandy MacKinnon on 0121-444 7337.

21 May	Gem Club - **Jade in the contemporary world**. Rosamond Clayton Venue: 3 Denehurst Close, Barnt Green. 2.00 p.m. to 6.00 p.m.
18 June	Gem Club - subject to be announced

North West Branch

Meetings will be held at Church House, Hanover Street, Liverpool 1. Further details from Joe Azzopardi on 01270 628251.

17 May	**Diamonds in the laboratory**	Eric C. Emms
21 June	**Luminescence as a means of identification**	Geoffrey Simpson
20 September	**Natural history of jewellery**	Dr John Franks
18 October	A gemmology evening - no charge, open to members and friends	
15 November	Annual General Meeting	

MEETINGS OF THE COUNCIL OF MANAGEMENT

At a meeting of the Council of Management held on 15 February 1995 at 27 Greville Street, London EC1N 8SU, the business of the meeting included the election of the following:

Diamond Membership

Bao, Chunhui, Wuhan, China. 1994
Chen, Shulan, Wuhan, China. 1994
Di, Jingru, Wuhan, China. 1994
Fu, Yunlong, Wuhan, China. 1994
Han, Hui, Wuhan, China. 1994
McKearney, Michael Colin, Tring. 1986
Xu, Shirong, Wuhan, China. 1994
Zhou, Min, Wuhan, China. 1994

Fellowship

Abdeen, Mohammed, London. 1961
Basnayake, Senarath B., Katugastota, Sri Lanka. 1983
Collyer, Rodney Frederick, Rubery, Birmingham. 1953
Goodall, Andrew, London. 1986
Guo, Xiaming, Wuhan, China. 1993
Hai, Hu, Wuhan, China. 1994
He, Wei, Wuhan, China. 1994
Jackson, Mark, Birmingham, 1989
Jin, Yi, Wuhan, China. 1994
Liang, Tao, Wuhan, China. 1994
Lord, Karen, Lutterworth. 1994
Lu, Yi, Wuhan, China. 1994
Mitchell, Terence, Sydney, NSW, Australia. 1969
Pan, Huijin, Wuhan, China. 1994
Perez Munoz, Jorge Antonio, Madrid, Spain. 1994
Shi, Dan, Wuhan, China. 1994
Tao, Duo, Wuhan, China. 1994
Wilby, Christine Ann, Bromsgrove. 1985
Wilding, Peter, Liverpool. 1960
Zhang, Congsen, Wuhan, China. 1993
Zhao, Hechun, Wuhan, China. 1994
Zhou, Jie, Wuhan, China. 1994
Zhu, Wenhui, Wuhan, China. 1994

Ordinary Membership

Amarasinghe, Diwin, Hayes
Bak, Krystyna, London
Chawla, Harmeet, Los Angeles, CA., USA
Dokken, Aarrynne, D.C., Sutton
Ebata, Reiko, Tokyo, Japan
Endo, Masahiko, Osaka, Japan
Fujimoto, Eiichi, Yokohama City, Japan
Gerrard, Peter William, Sydney, NSW, Australia
Godwin, James George, Brighton
Hino, Toshiaki, Owase City, Japan
Hiroko, Shiomi, Tokyo, Japan
Honda, Takashi, Tokyo, Japan
Inoue, Daisuke, Osaka, Japan
Jo, Yoon-Hee, Twickenham
Kato, Junko, Osaka, Japan
Kawamura, Toshiko, Sakurai City, Japan
Kawarara, Tamami, Osaka, Japan
Kitamura, Yumia, Osaka, Japan
Kobayashi, Yukiko, Osaka, Japan
Kubota, Chiaki, Kobe City, Japan
Kudo, Kazuhiko, Hiroshima City, Japan
Kurahashi, Keiko, Tokyo, Japan
Macnish Porter, Frances Holly, Edinburgh
Maeda, Mariko, Ichikawa City, Japan
Maruyama, Kyoko, Kumagaya City, Japan
Maunga, Ntite Tito, London
Nagaoka, Mikage, Nishinomiya City, Japan
Nakata, Junko, Osaka, Japan
Nicita, D., Milan, Italy
Niroo, Sousan, London
Nishioka, Megumi, Osaka, Japan
Ogura, Yasumi, Osaka, Japan
Ohtsuka, Mayumi, Osaka, Japan
Osman, Naushad Daud, Wembley
Parker, Michael Anthony, Midhurst
Pierce, Jason, London
Purshottam, Vimay, London
Raben, Jonathan D., Boston, Mass., USA
Roultedge, Hylton, Bromsgrove
Sakulbenjayotin, Somchai, Bangkok, Thailand
Seki, Shoko, Osaka, Japan
Shibata, Yukari, Osaka, Japan
Takiguchi, Naomi, Osaka, Japan
Tanaka, Daisuke, Kobe City, Japan
Van Essen, Elma Irene, Ymuiden, The Netherlands
Wakefield, Sharon A., Boise, Idaho, USA

GAGTL GEM TUTORIAL CENTRE

Two-Day Diploma Practical Workshops
27-28 May, 6-7 June and 10-11 June
The long-established intensive practical course to help students prepare for the Diploma practical examination or for non-students to brush up on technique. This is the course to help you practise the methods required to coax results from instruments which can be difficult or awkward to use. The course includes a half-length mock exam for you to mark yourself.
Price £160.39 for two days (£111.04 for GAGTL registered students) - includes lunch

Diamond Grading Revision
10-11 June
Designed for students taking the Gem Diamond Diploma, this tutorial will cover information required for the practical examination and will include a mock examination to help students gain familiarity and confidence.
Price £129.25 for the two days (lunch will not be included)

Gem Detection - The Introduction
13-14 September
Spend two whole days mastering the basic methods of gem identification and detection. A commonsense approach aimed at helping you distinguish a variety of gem materials.
The price is only £105.75 (including lunch)

Visual Optics
29 September
This inexpensive method for gemstone identification is presented by Alan Hodgkinson who has developed its use over many years. Practise this fascinating and useful technique with a range of gems in the comfort of the Gem Tutorial Centre.
Price £58.75 (including lunch)

Preliminary Workshop
11 October
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At a meeting of the Council of Management held on 15 March 1995 at 27 Greville Street, London EC1N 8SU, the business of the meeting included the election of the following:

Fellowship
Alaniva, Orvokki, Pello, Finland. 1994
Daulatani, Shambhu Lal, Dubai, UAE. 1982
Dayasagara, Kalupahana L.D., Colombo, Sri Lanka. 1981
Kaminaras, Merope, Athens, Greece. 1994
Oh, Sook Hoe, Pusan, Korea. 1994
Park, Mi-Kyeong, Pusan, Korea. 1994
Vikamsey, Indira Jayantilal, Bombay, India. 1981

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Franquet, John Julian, London
McInnes, Catriona, Edinburgh
Peech, Rosalind Mary, Worksop

GEM DIAMOND EXAMINATIONS

In January 1995 32 candidates sat the Gem Diamond Examination worldwide, 23 of whom qualified. The names of the successful candidates are listed below:

Distinction
Li Yali, Wuhan, China.

Qualified
Bedwell, Victoria Lynsee, London.
Chan, Tony Chung Sing, Toronto, Ont., Canada.
Chan, Yik Pun, Hong Kong.
Chen Huilan, Wuhan, China.
Chen Kesheng, Wuhan, China.
Chen Meihua, Wuhan, China,
Chung, Yam Ming (Daly), Hong Kong.
Gedeon, Leila, London.
Kaskara, Tatiana, London.
King Chuen Hui, Hong Kong.
Liu Xu, Wuhan, China.
Liu Zhao, Wuhan, China.
Mei Gewei, Wuhan, China.
Mok, Dominic Wai Kei, Hong Kong.
Nottbusch, Jurgen Uwe, Appel, Germany.
Osmond, Catherine, London.
Qi Wie, Wuhan, China.
Yoshida, Miyuki, Hong Kong.
Xiong Xianzheng, Wuhan, China.
Xue Qinfang, Wuhan, China.
Zhang Jiewen, Wuhan, China.
Zhuang Zhenghua, Wuhan, China.

EXAMINATIONS IN GEMMOLOGY

In the Examinations in Gemmology held in January 1995 165 candidates sat for the Preliminary examination of whom 130 passed and 125 for the Diploma examination of whom 50 passed. The names of the successful candidates are as follows:

Diploma
Agarwal, Pooja, London.
Ayles, Catherine, Edinburgh.
Bae, Eun Jeung, Seoul, Korea.
Bagai, Deepak, Bombay, India.
Bowman, Helene, Epping.
Cai, Cuihua, Wuhan, China.
Campbell, Robert, Wallington.
Cheung Lai Ha, Losanna, Hong Kong.
Cho, Jin-Ho, Seoul, Korea.
Dalla Libera, Natalie, London.
Dinnis, Simon John, Swadlincote.
Eggleston, Avrina, London.
Fantis, Charoulla, Nicosia, Cyprus.
Feng, Jiansen, Wuhan, China.
Ferrell, Ronald L., Deland, Fla., USA.
Garvik, Beate Kielland, Oslo, Norway.
Gulliani, Narinder, Birmingham.
Kan, Wing Lok, Hong Kong.
Kim, Ki-Jung, Taegu, Korea.
Kim, Chul-Seung, Seoul, Korea.
Lee, Chiu-Hsia, Taipei, Taiwan.
Lee, Min Hi, Seoul, Korea.
Levonis, Helen, Toowoomba, Qld, Australia.
Lundsrud, Berit, Sandvika, Norway.

Macarthur, Iain, London.
Mangun, Colleen Chien, Manila, Philippines.
Mi Sun, Won, Buchon City, Korea.
Newman, Frances, London.
Park, Kinam, Seoul, Korea.
Rush, Laura, Edinburgh.
Ryu, Kyeong Won, Daejon, Korea.
Samson, Ma. Teresita Pelea, Quezon City, Philippines.
Seow, Meng Seh Francis, Hong Kong.
Sherman, Suthita, Makati, Philippines.
Shetty, Vaju Krishna, Bombay, India.
Shu, Xingying, Wuhan, China.
Simpson, David C., Devizes.
Sung, Min Jun, Taegu, Korea.
Tian, Baozhen, Wuhan, China.
Tripaathi, Naagesha, Jaipur, India.
Tsai, Pei-Lun, Taipei, Taiwan.
Tytgadt, Anne, Johannesburg, South Africa.
Tzou, Jyh-Jeng, Kee Lung City, Taiwan.
Vlahos, Nikolaos, Pireas, Greece.
Wei, Zhou, Wuhan, China.
Won, Dae-Kwon, Seoul, Korea.
Wren, Amanda, Edinburgh.
Zhang, Bing, Wuhan, China.
Zhu, Meidi, Wuhan, China.
Zou, Haiqing, Wuhan, China.

Preliminary
Abramian, Levon, London.
Agarwal, Pooja, London.
Allberg, Mauritz, London.
Bagai, Deepak, Bombay, India.
Balalis, Evagelos, Athens, Greece.
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Bolin, H. Christian, Stockholm, Sweden.
Cadby, Sarah Louise, London.
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Chan, Bo Kwan, Hong Kong.
Chan, Sally Yuk Wa, Kowloon, Hong Kong.
Chan, Wai Chu, Hong Kong.
Chan, Wai Keung, Hong Kong.
Chan, Yau Yin, Hong Kong.
Chan, Yue Kwan Joyce, Kowloon, Hong Kong.
Chan, Yuk Fan, Kowloon, Hong Kong.
Choi, Chan Wai, Hong Kong.
Chen, Jyh-Shyang, Taipei, Taiwan.
Chen, Shing Lin, Hong Kong.
Cheng, Ming Chi, Wanchai, Hong Kong.
Chung, Jae-Hak, Seoul, Korea.
Curtis, Simon James, Torquay.
Dang, Xiaoying, Wuhan, China.
De Groot, Olivier Robbert, Huizen, The Netherlands.
Ding, Weijun, Wuhan, China.
Fan, Wan Wah Andrew, Shaukeiwan, Hong Kong.
Fotsalis, Angelos, Nikea, Greece.
Fotsalis, Panayiotis, Nikea, Greece.
Galiatsatoy, Helen, Athens, Greece.
Gamage, Amitha K.U., Nugegoda, Sri Lanka.
Geerling, S.A., Rotterdam, The Netherlands.
Go, Jung-Hun, Kyungam-do, Korea.
Golad, Tanya, London.
Goransson, Mari E. P., Stockholm, Sweden.
Guo, Hui, Wuhan, China.
Haria, Aarti Vipul, Nairobi, Kenya.
Ho, Hsiung-Chien, Taipei, Taiwan.
Holt, Jr., Roosevelt, Nairobi, Kenya.
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Hui, Mu-Cheng, Chung-Li City, Taiwan.
Hunter, Rachel Suzanne, Bath.
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Iwata, Kaoru, London.
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Jayathilake, Salpadoru Thupphige Deepika, Colombo, Sri Lanka.
Ji, Ke Ke, Hong Kong.
Jiang, Xinshun, Wuhan, China.
Jo, Byung-Hyun, Kyungbuk-do, Korea.
Jones, Barry, London.
Jones, Maureen, Coventry.
Junaida, Kathoon, London.
Kim, Chul-Seung, Seoul, Korea.
Lam, Chiu-Hung, Kowloon, Hong Kong.
Lau, Chun Kit, Hong Kong.
Lee, Joong-Hyup, Kyunbuk-do, Korea.
Lee, Julia Siu Ying, Hong Kong.
Lee, Jun-Ah, Seoul, Korea.
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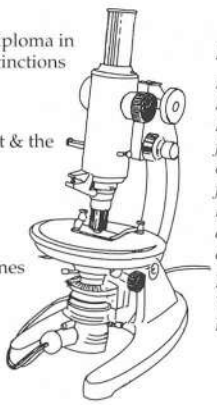

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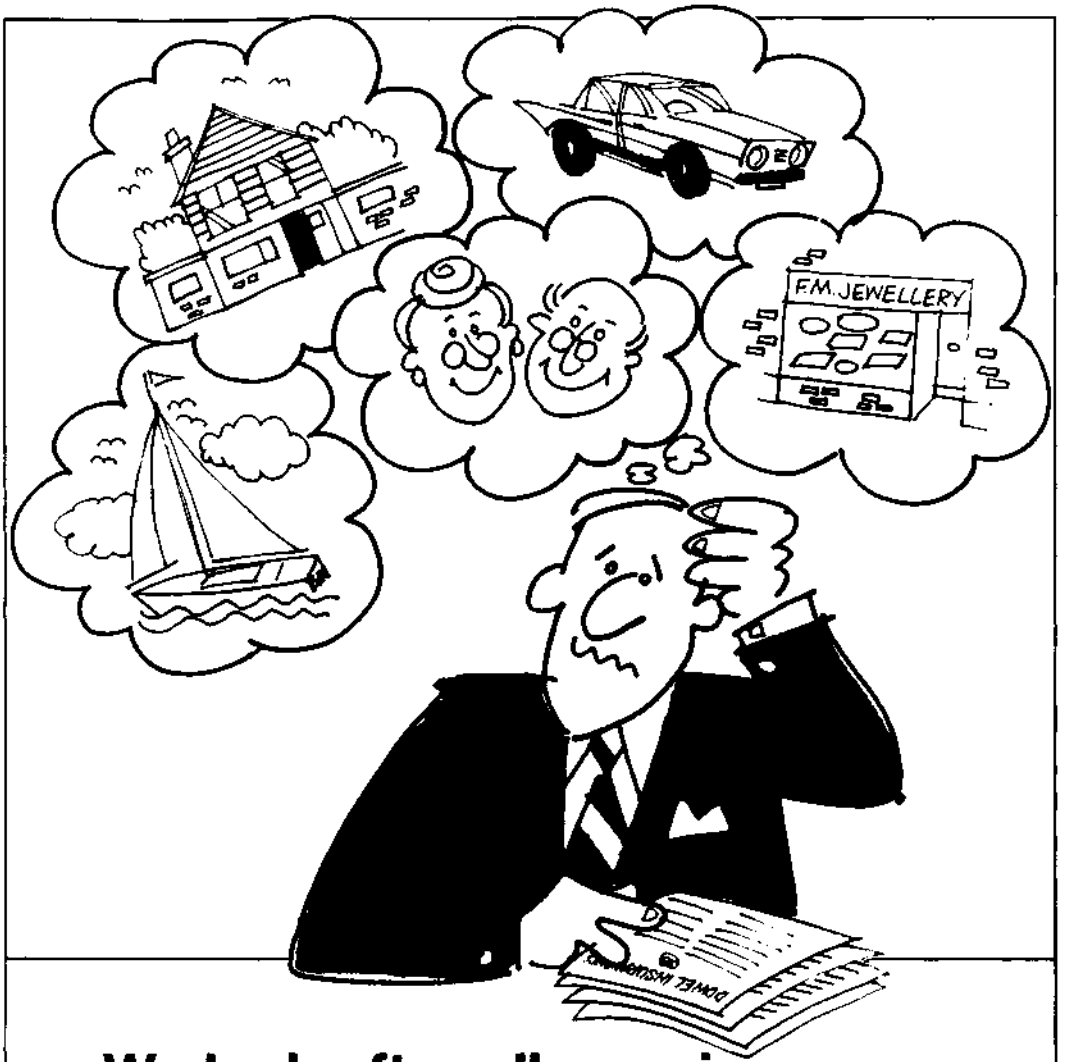

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On matters of style and rendering, please consult *The Oxford dictionary for writers and editors* (Oxford University Press, 1981).

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July 1995

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Cover Picture

Interference colours from cleavage in gem sphalerite.
Photograph by Wilma van Opstal, FGA **(see Photographic Competition, p.523)**

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In this issue...

The GAGTL Photographic Competition this year again drew from members some beautiful images. The competition theme was 'The spectrum of gemstones' and this allowed a wide choice of interpretation of the spectra displayed by gems, of interference phenomena, of multi-coloured jewellery or of the colour range shown by a particular gem species. It also allowed the demonstration of some newer techniques which enable initially more obscure features of a gem to be seen in greater detail, and one submission involving phase contrast photography gained second prize.

In a wide range of entries, many highlighted interference phenomena and one of these, reproduced on the front cover, won first prize. Another, depicting paua shell, won third prize and the three prizewinners together with a selection of other entries will appear in the 1996 calendar.

The papers in this issue cover ruby and sapphire deposits in China, composition and treatment of jadeite, the features of Russian synthetic emerald and a major contribution to the methods for distinguishing natural from synthetic diamond. This latter topic is of growing importance in the gem world and it formed the subject of Professor Sunagawa's keynote lecture at the last GAGTL Annual Conference. The distinctive features of natural and synthetic diamond are described and related to their origins and to how they may be recognized.

Treated jadeite is another important gem material which can stretch the capabilities of those with only basic gem testing equipment. However methods are now available in laboratory and university which enable the economic testing of important pieces, and the paper by Dr Tan and his colleagues outlines one which can yield quite definitive information on surface treatments. The location of the equipment used to provide this information may seem at first to be foreign to the habits of traditional professionals in the trade but with the rapid expansion of materials science - especially in such disciplines as semi-conductors and polymers - more and more universities throughout the world are installing the relevant equipment and we should be ready and able to make use of it on an economic basis.

R.R.H.

Chinese ruby and sapphire – a brief history

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Abstract

China is one of the largest countries in the world, with a rich cultural and scientific tradition. Yet for non-Chinese, until recently little was known of her mineral resources. A brief survey of China's ruby and sapphire deposits is given and an eyewitness account of one of the most important of China's sapphire deposits – Penglai, Hainan Island, – is described.

Keywords: China, ruby, sapphire, corundum, gems, Penglai, Hainan Island

History of Chinese corundum

Like Vietnam, China has never been considered a historical source of ruby or sapphire. Vague mentions of corundum in Tibet exist (Gregor, 1803), but none have been confirmed. The authors have been unable to find any evidence of historic deposits of gem corundum in China proper, but there are reports that impure corundum was used as a grinding material due to its hardness (Needham, 1959).

Still, the Chinese were aware of ruby and sapphire from outside the country. While the Chinese have never been noted as great travellers, historically they have ventured outside their borders on military or diplomatic missions, or for religious pilgrimage (Bretschneider, 1887). Fa Hien (Fa Hsien) was selected by the Chinese emperor to travel to India to obtain accurate information on Buddhism. In the account of his journey, which occurred during AD 399–414, he did mention the occurrence of many precious stones in Ceylon (Legge, 1965). One Chinese author, Thao Tsung-I, wrote a brief treatise on the precious stones known about AD1366. A short section of this was translated by Bretschneider (1887). In this, *la* (balas ruby, or spinel) is described, as well as *yakut (yaqut)*, which is Persian for corundum.[1] Thus it is apparent that some in China were aware of the corundum gems from abroad, but domestic occurrences were not reported until the late-1970s, when economic and political reforms made it possible to openly discuss 'bourgeois' subjects, such as gems.

Tu Wan's *Stone Catalogue of Cloudy Forest* dates from about AD1126 (Schafer, 1961). This book contains descriptions of various stones known to the Chinese in the twelfth century, but apart from the banded blue–green 'Stone of the Office of the White Horse' (*Ho-nan-fu*), none accurately describe corundum.

According to Liu Guobin (1981), the finest historical work on precious stones in China is the *Lapidarium Sinicum* of H-C Chang (1921). The authors have not seen this book. In the 1990s, gemmological periodicals have appeared in China but, as the authors cannot read Chinese, the following is drawn from sources using the Roman alphabet.

1. According to Bretschneider (1887), the Chinese word for ruby is *hung pao shi* (red precious stone), while that for blue sapphire is *lan pao shi* (blue precious stone).

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Fig. 1. Corundum localities of China. Gem deposits are found in Fujian, Hainan, Heilongjiang, Jiangsu, Qinghai, Shandong, Sichuan, Xinjiang and Yunnan Provinces. Note that the position of some localities is approximate only.

Corundum in China

Information on Chinese localities is difficult to come by, as access often involves obtaining permission from the Chinese military, which controls most mines. A second factor is location; many mines are in remote areas where travel is difficult. The following information is as accurate as present circumstances will allow.

Ruby and sapphire have been reported from a number of different areas in China. Of these, the most important are the sapphire occurrences of Shandong, Fujian and Hainan in eastern China. In each of these places, sapphires occur in alkali basalts as dark, inky-blue material similar to that mined in Australia.

Penglai (Hainan Island)

Getting there

Hainan Island is located in the South

China Sea, due east of Vietnam. Reached by air from Guangzhou (Canton) and by air or (irregular) boat from Hong Kong, Haikou, the island's provincial capital, is the jumping off point for trips to Penglai.

Access from the provincial capital of Haikou is typical for third-world backwaters; several hours on a livestock-infested bus along what the charitable term 'roads'. The December–February rainy-season flooding, which turns the Penglai area into a swamp, will give travellers further fuel for spinning porch-side yarns in the twilight of their lives ('I remember when I was on the road to Penglai ...').

Penglai's sapphire mines lie 2km south-east of the town of the same name, covering some 25km^2, in the north-east corner of Hainan Island. Due to the difficulty of getting there, few foreign gem dealers visit. Fortunately, the journey is not the only reward: the Penglai area produces some of China's finest sapphires.

Mining and cutting

Sapphire was first discovered on Hainan Island in the early 1960s by a local farmer, Zhang Changde, who found a beautiful stone on the ground near to where his animals were grazing. Fascinated, he began collecting more but apparently must seek his reward in heaven for, upon turning the gems over to the local geological team, he received just 1.6 yuan (~$1.00) (Wang Furui, 1988).

In 1982 an exploration team was sent to study the deposit (Wang Furui, 1988), but since Olivier Galibert's first trip to the area in 1987 only Hainan Island natives have been involved in mining. Digging generally takes place in the evenings by farmers (and even government officials), particularly after heavy rain. Excavation methods are primitive, along the lines of traditional corundum mining in south-east Asia. What sapphire is recovered is often kept in small bags sewn into the miners' trousers.

Among the reasons this deposit has not been worked on a larger scale are the policies of local officials, who hesitate to decide just who will be blessed with the appropriate permission. This is common among mining projects in some nations, where local officials do everything possible to both retain authority and sell it to the highest bidder.[2] At the time of Galibert's last visit in 1991, most production was being sold to Thai and Hong Kong dealers; no sapphire-cutting factories existed on the island.

Gemmology of Penglai sapphires

Alkali basalt is thought to be the source rock of the sapphires, which are recovered at a depth of 2–3m, with pyrope garnet, black spinel, pyroxene, olivine and zircon. Penglai sapphires tend to occur as small- to medium-sized hexagonal prisms and fragments. The average size is 2–5mm, with the largest reported at 35.5 ct. Colours are mostly blue, with stones varying through bluish-green, green and yellowish-green. Most are dark. Stones containing traces of Cr have also been found, but are rare.

Gemmological properties are typical for sapphire. Straight, angular colour zoning is common, with associated clouds of unidentified silk. Solid inclusions may be opaque and black; white crystals have also been found. Both types may be surrounded by tension haloes. Like most sapphire, Penglai stones are commonly heat-treated (Wang Furui, 1988).

Heat treatment

Attempts to heat treat Penglai material have met with varying degrees of success. Professor Qin Bingsheng of the Guangdong geological office has run experiments which resulted in increased transparency, but darkening of colour, thus reducing value. Similar results have been obtained by Thai burners.

While much of the Penglai material dis-

2. Or bidders. During one author's (RWH) residence in Vietnam, he heard of several cases where the 'exclusive' rights to mine a deposit did not 'exclude' native digging on the same land.

Fig. 2. Sapphire diggings at Penglai, Hainan Island, China. *Photo: Olivier Galibert*

plays the oily diesel effect common to Sri Lankan geuda sapphires, Sri Lankan sapphires contain silk which is relatively pure rutile (TiO_2). In contrast, the silk of basalt-sourced Fe-rich sapphires is generally mixed crystals of rutile and ilmenite ($FeTiO_3$). Due to its quadrivalent state, Ti^{4+} diffuses into corundum some 10 000 times faster than either iron or chromium (John Emmett, pers. comm., 11 July 1994). Thus when such crystals are heat treated, the Ti diffuses into the corundum, leaving the iron behind. The result is that, unless heating is performed for extended periods of time, some silk always remains.

Other Chinese localities

Fujian Province

The following is based on the report of Keller and Keller (1986). Sapphires were first discovered near the town of Mingxi in 1980, during diamond exploration. Mining takes place approximately 10km north-west of the town in secondary deposits derived from alkali basalts.

Colours of the material range from yellowish-green, green, through greenish-blue to blue, with rough averaging 2ct in weight. The largest faceted gem reported was 2.1ct. Virtually no information is available on the inclusions of this material. Crystal habits tend to be barrel and dog-tooth shapes, similar to sapphires from Australia (which the material strongly resembles).

Shandong Province

The following is based on the report of Jingfeng Guo *et al.* (1992). Sapphire was discovered near Wutu, Changle County, Shandong Province in the late 1980s, first in alluvial gravels, later *in situ* in alkali basalts. Mining is taking place in the secondary deposits, while primary deposits are worked for mineral specimens. Similar to other basaltic sapphires, crystals tend to be barrel-shaped. Many show rounded,

etched surfaces due to partial solution by magma during their eruptive trip to the surface.

Most stones are dark blue; some material ranges from greenish-blue to yellow in colour; material is often strongly zoned. While material ranges in size from 5–20mm, larger material tends to be too dark. Solid inclusions identified in Shandong sapphire include U- and Th-rich zircon crystals of orange-red colour, Ti-rich columbite (black, metallic), Na-feldspar, apatite, ilmenite and Mg-Fe spinel. Specimens with silk are found, but the identity of the silk has yet to be reported. Virtually all are heat treated.

Yunnan

Ruby in marble was discovered in the Ailao Mountains of Yunnan Province in the late 1980s, with placer deposits being mined (Qian Tianhong *et al.*, 1992). Vague reports regarding ruby deposits in Yunnan claim that this material is similar in colour to that from Myanmar and Vietnam (Anonymous, 1991a–b). These deposits are said to have potential, with clean rough as large as 8ct being found.

Shortly after the find was made, people descended on the area in droves, possessed with 'ruby fever'. This was not exactly the type of 'resettlement policy' the central government had in mind, and a quick halt was put to the proceedings.

In Yunnan, the Shunning Fu prefecture was described as a source of sapphire, ruby and green sapphire; these gems were said to occur in other parts of that province, as well (US Consular Reports, 1990).

Heilongjiang

Ruby and volcanic sapphire have been reported from Heilongjiang (Anonymous, 1989). Weather conditions are said to be difficult, allowing mining only 3–4 months of the year. The army is said to control the area and little is being recovered; most stones are of small sizes.

Fig. 3. Rough sapphires from Penglai, Hainan Island, China. *Photo: Olivier Galibert*

Jiangsu

Low-quality (dark) blue sapphire is said to occur in Jiangsu, but the reports of ruby are said to have been confused with garnet, which is of good quality.

Qinghai

Both ruby and sapphire have been reported from Qinghai (Dong Bingyu, 1993). Mining is said to be difficult due to the 3000m elevation of the Qinghai plateau. Translucent ruby of pale pink to medium red is said to occur in an oligoclase-biotite gneiss. Star rubies are said to be possible. (Anonymous, 1991b.)

Sichuan

Ruby has been reported from Nanjiang, Sichuan Province (Chikayama, 1986).

Xinjiang

Ruby has been reported from Kalpin, far western Xinjiang (Keller and Fuquan,

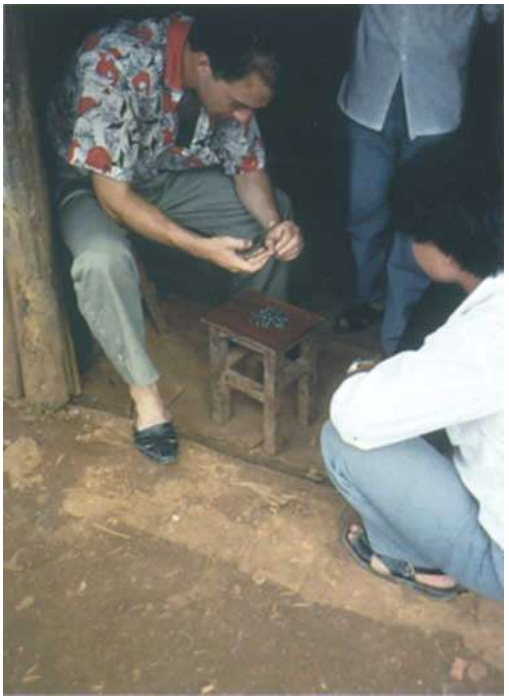

Fig. 4. French dealer, Olivier Galibert, examines sapphire rough from Penglai, Hainan Island, China. *Photo: Olivier Galibert*

1986). Sapphire has also been reported from Taxkorgan in Xinjiang (Chikayama, 1986).

Conclusion

Blessed with varied and plentiful natural resources, it is only a matter of time before China joins the ranks of major gem-producing nations. Already, corundums have been found in Fujian, Hainan, Heilongjiang, Jiangsu, Qinghai, Shandong, Sichuan and Xinjiang provinces. While China has yet to produce corundums of top quality, Hainan Island's sapphire deposits display promise, and rumours of quality ruby in Yunnan suggests that China could become an important force in the world market for ruby and sapphire.

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Identification of bleached wax- and polymer-impregnated jadeite by X-ray photoelectron spectroscopy

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Abstract

X-ray photoelectron spectroscopy (XPS) is found to be a useful non-destructive technique distinguishing unambiguously bleached impregnated jadeites (B-jade) from the natural and untreated ones. The impregnation substance can be identified by chemical analysis of the surface of the jadeite. Results of an XPS study on 16 jadeite samples show that some have been impregnated with wax, polymer or both. XPS results were further supported by basic gemmological tests and complemented with infrared absorption spectroscopy.

1. Introduction

The use of infrared absorption spectroscopy for the identification of bleached and polymer-impregnated jadeite or grade B jade (B-jade) was reported first by Fritsch *et al.* (1992). It was found that the presence of strong multiple absorption peaks in the 2800–3100cm^{-1} range indicate the presence of polymer, thus implying that the samples had been treated with polymer. As polymer can be quite easily detected using infrared spectroscopy in this frequency range, manufacturers may use alternative materials as fillers in the bleaching process, such as paraffin wax (Fritsch, 1993) or other substances which are not detectable by infrared absorption techniques. Indeed, recent findings of high concentrations of wax in some jadeites have created some controversy between laboratories (Tay, 1992). Some claim that wax has been part of the polishing agent used by manufacturers for centuries to improve the quality of polish on jadeite and that this process is considered to be an acceptable trade practice (Ehrmann, 1958; Crowningshield, 1972). In a quantitative way, infrared absorption peaks at 2852 and 2920cm^{-1} attributable to normal wax polish tend to be relatively low in comparison with the extremely high peaks found in some jadeites with modern treatments. However, the identification of treated jadeite using infrared spectroscopy is severely limited by its response in only certain parts of the mid- and near-infrared frequency ranges and by the restriction of this measurement to specimens of thin jadeite which is not opaque to infrared transmission.

The structure and texture of jadeites may reveal that they have been treated (Ou Yang, 1993). In the study carried out by Tay *et al.* (1993) using a scanning electron microscope, photomicrographs of some bleached jadeites showed both the interlocking crystal grain structure damaged by

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Fig. 1. Natural rough jadeites. For identification, the jadeites are numbered 1 to 4 (from top to bottom)

bleaching and the concentration of impurities between grain boundaries; but the proper interpretation of the photomicrographs requires a good understanding of the texture and structure of jadeite crystals. Although an energy dispersive X-ray fluorescence (EDXRF) spectrometer can be used to detect differences in iron content in jadeites, it is not capable of detecting light elements such as carbon, hydrogen, oxygen and nitrogen which constitute most polymers (Fritsch *et al.*, 1992). Thus the photomicrographs do not provide any information on the type of impregnation materials other than to indicate that they would be of low atomic number.

In this work, the X-ray photoelectron spectroscopic (XPS) technique was used to study the chemical compositions of the surfaces of treated jadeites for the first time. Our results show that such chemical analyses provide unambiguous information for discriminating between natural and B-jades, and between wax- and polymer-impregnated jadeites.

2. Materials, preliminary tests and results

Four unbleached weathered jadeites with newly-sawn rough surfaces (Figure 1), five natural-coloured polished jadeites and seven bleached wax- or polymer- impregnated coloured polished cabochons (Figure 2), were studied using basic gemmological instruments and an infrared absorption spectrometer. All the samples originated from Myanmar (Burma). The results of these preliminary investigations are summarized in Table I.

The 'spot' refractive index was found to be about 1.66 for all polished jadeites, which is within the jadeite range. It was not possible to measure the refractive index of the weathered jadeites because of their rough surfaces, but all were placed in di-iodomethane (specific gravity 3.32). As can be seen in Table I, it is not possible to discriminate between natural and treated jadeite on the basis of immersion in di-iodomethane. Both natural and treated jadeites showed very similar visible absorption lines using a prism spectroscope (Table I). Some but not all the treated jadeites fluoresced under long-wave or short-wave ultraviolet irradiation whereas all natural jadeites were completely inert to such irradiation.

For all the samples studied, infrared absorption spectra were recorded using a Bomem DA3.002 Fourier Transform Infrared (FT-IR) spectrophotometer (Tan *et al.*, 1992) to determine whether they were

Fig. 2. Five pieces of natural wax polished jadeite, numbered 5 to 9 (upper row, from left to right). Seven pieces of bleached wax- or polymer-impregnated jadeite, numbered 10 to 16 (lower row, from left to right)

wax-polished, wax- or polymer- impregnated, or untreated. The resolution of the spectra was 1cm^{-1}. The absorption peak values are listed in Table I. Typical weak peaks at 2852 and 2920cm^{-1} as illustrated in Figure 3(a) confirmed that jadeite samples 4 to 9 were polished with wax whereas strong peaks (Figure 3(b)) showed a high content of wax impregnated in samples 12 (off white) and 13 (red brown). No absorption peaks were observed for samples 1 to 3, showing that the presence of wax and polymer were negligible. On the other hand, if a spectrum contains several strong and distinct peaks in the 2800–3100cm^{-1} range, these are due to the absorption of polymer material and indicate that the sample was polymer-impregnated. A spectrum with peaks at 2875, 2931, 2966 and 3060cm^{-1} typical of samples 10, 11 and 14 to 16 is shown in Figure 3(c).

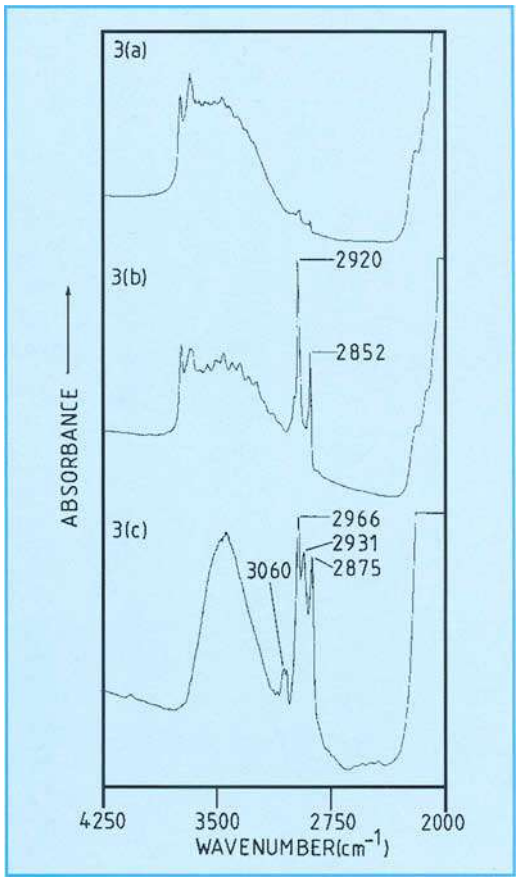

Fig. 3. Infrared absorption spectra of:
(a) natural jadeite with wax-polish (samples 4–9)
(b) bleached wax-impregnated jadeite (samples 12,13)
(c) bleached polymer-impregnated jadeite (samples 10,11, 14–16)

Table I. Gemmological and spectroscopic data on natural and impregnated jadeite

Sample	SG (3.32)	Ultraviolet fluorescence	Microscopic observations	Infrared peaks (cm^{-1})
1, 2	Sink	None	Rough and newly-sawn. Lavender colour with thick brown fissure.	None
3	Sink	None	Rough and newly-sawn. Very very light green.	None
4	Sink	None	Weathered with polished surface. Dark green.	2852, 2920 (very weak)
5	Sink	None	Light green oval shape cabochon. Several brown spots. Green veins.	2852, 2920 (weak)
6	Sink	None	Very light even green oval cabochon. No fissures. Some slight breaks.	2852, 2920 (weak)
7	Sink	None	Medium dark brown carved pendant showing cracked-like effect on surface. Suspected heat-treated.	2852, 2920 (weak)
8	Sink	None	Green oval cabochon with fine fissures. Green veins.	2852, 2920 (weak)
9	Sink	None	Light yellow carved pendant showing patches of white mineralization.	2852, 2920 (weak)
10	Float	Chalky blue (long-wave)	Very light green with large pit marks. Green veins.	2875, 2931 2966, 3060 (strong)
11	Sink	None	Light green patches with brown stains on face. Some pit marks and fine fissures.	2875, 2931 2966, 3060 (strong)
12	Sink	None	Very light green oval flat cabochon. Fine fissures.	2852, 2920 (very strong)
13	Sink	None	Medium brown oval flat cabochon with brown veins. Fine fissures throughout surface. Cracked-like appearance. Suspected heat-treated.	2852, 2920 (very strong)

14	Float	Weak chalky blue (long-wave)	Very light green cabochon. Green veins and pit marks on surface.	2875, 2931 2966, 3060 (very strong)
15	Float	Chalky blue and yellow patches (long-wave)	Light green cabochon. White patches and minute pits on surface.	2875, 2931 2966, 3060 (very strong)
16	Sink	Chalky yellow (long- and short-waves)	Green oval high dome cabochon. Green veins and patches. Fine polishing marks. Tinted slight yellow.	2875, 2931 2966, 3060 (strong)

3. X-ray photoelectron spectroscopy (XPS)

Surface analysis by XPS is accomplished by irradiating a sample with mono-energetic soft X-rays (photons) and detecting and analysing the energy of the emitted electrons. MgK_α (1253.6 eV) X-rays are commonly used. These photons have limited penetrating power in a solid, extending between 1 and 10 μm depending on their energy and the nature of the substance. They interact with atoms in the surface region, causing electrons to be emitted by the photoelectric effect. The emitted electron has a measured kinetic energy given by

$$K.E. = h\upsilon - B.E. - \phi_s$$

where $h\upsilon$ is the photon energy, *B.E.* is the binding energy of the atomic orbital from which the electrons originate, and ϕ_s is the spectrometer work function.

Each element has a unique set of binding energies, and as such XPS can be used to measure these energies and identify and determine the concentration of the elements on the surface. Variations in the elemental binding energies (chemical shifts) arise from the differences in the chemical potential and polarizability of compounds. These chemical shifts can be used to identify the chemical state of the compounds. Probabilities of electron interaction with matter far exceed those of the photons, so while the path length of the photons is of the order of micrometres, that of the electron is of the order of nanometres or tens of angströms. XPS is thus a surface-sensitive technique capable of the chemical characterization of the surface of a solid, in this case jadeite.

Technical details

XPS has been shown to be a useful tool for studies of chemical compositions of polymers (Loh *et al.*, 1993, 1994). The surfaces of all 16 samples as listed in Table I were thoroughly cleaned with a light dose of highly volatile propanol in order to remove any contaminant present due to handling immediately before they were placed in the evacuated analysis chamber. The XPS measurements were made on a VG ESCALAB MkII spectrometer with an MgK_α X-ray source (1253.6 eV photons). The X-ray source was run at a reduced power of 120W (12 kV and 10 mA). The core-level spectra were measured at a take-off angle of 75°. To compensate for surface charging effects, all binding energies were referenced to the C(1s) neutral carbon peak at 285 eV. Surface chemical compositions were determined from peak area ratios, corrected with appropriate experimentally-determined sensitivity factors, and were liable to a ±5% error. The normal

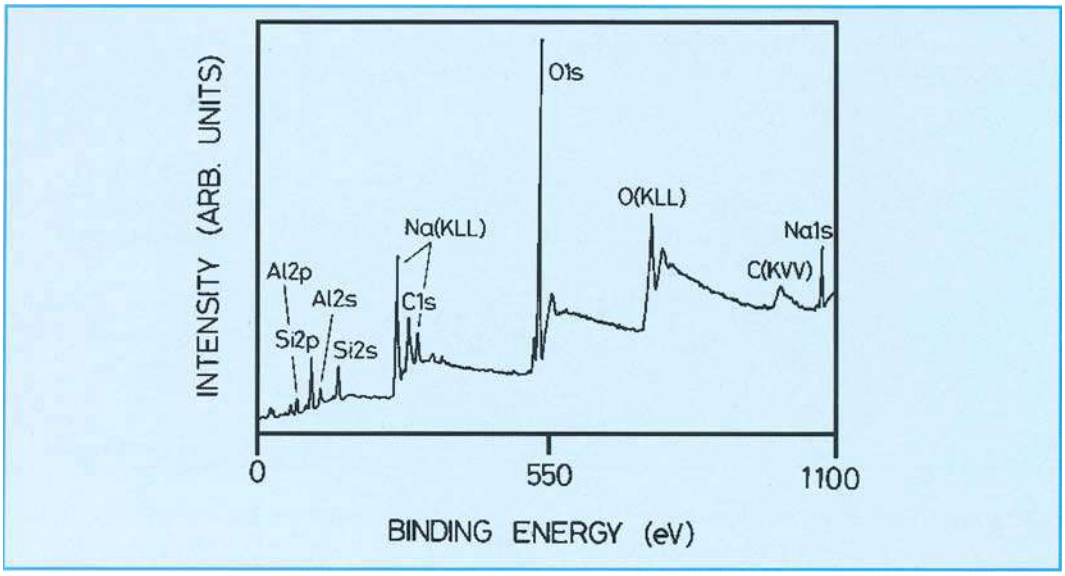

Fig. 4. XPS survey scan spectrum of natural jadeite (samples 1–3). KLL and KVV refer to the electronic levels at which the vacancy is created by the excitation source (electrons); the de-excited electron originate, and the Auger electron originate respectively.

operating pressure in the analysis chamber was less than $5x10^{-9}$ mbar.

Gemmologists will recall that the basic structure of the atom can be thought of in terms of shells of electron orbitals labelled in sequence from the nucleus outwards K, L, M and N. Photoelectron spectroscopy detects and measures the energy levels of electrons in the different orbits, s, p, d or f in the shells and the concentrations of each element can then be calculated.

4. Results and discussion

A typical XPS survey scan spectrum of the surface of a natural rough jadeite such as that obtained from samples 1 to 4, is shown in Figure 4. The spectrum recorded in the binding energy range of 0 to 1100 eV was able to provide identification of all the elements present on the surface of the jadeite. As shown in Figure 4, the main peaks are silicon (Si(2p) peaks at about 99 eV, as given by Moulder *et al.*, 1992), sodium (Na(ls) at about 1072 eV), aluminium (Al(2p) at about 73 eV), and oxygen (O(1s) at about 531 eV), consistent with the ideal composition of jadeite, $NaAlSi_2O_6$ (Deer *et al.*, 1978). Traces of carbon (C(1s) at about 285 eV), and calcium (Ca(2p) at about 347 eV) were also found. The relatively weak carbon (C(1s)) peak (Figure 4) can be attributed to a small amount of carbon (hydrocarbon) impurity (such as little traces of wax or grease) present on the surface of the jadeite which was detected by the highly sensitive XPS spectrometer. Due to the small sampling depth (approximately 50Å) of the XPS techique, bulk elements which may include Fe and Cr were not detected.

For the natural jadeite (samples 4 to 9) which were wax-polished, a higher C(1s)/Na(1s) ratio of about 12 was observed as compared to a ratio of about 2.5 for the unwaxed natural jadeite. The presence of a higher C(1s)/Na(1s) ratio is indicative of the presence of wax which consists mainly of carbon, hydrogen and a trace of oxygen, as shown in Figure 5(a). The XPS spectrum of wax is shown in Figure 5(b) and shows two significant peaks: a major C(1s) peak and an associated trace O(1s) peak. The C(1s)/Na(1s) ratio of about 11.0 (as shown in Figure 5(c))

for the wax-impregnated jadeite (samples 12 and 13) is comparable to that of the wax-polished jadeite. Since wax-impregnation would result in a higher carbon concentration in the bulk of the jadeite, it would not be possible to differentiate a wax-polished jadeite from that which is wax-impregnated from surface analysis using XPS. For the purpose of determining bulk analysis, it would be essential to measure a mid-infrared absorption spectrum in the range which shows wax peaks (Figure 3(a), (b)).

All of the bleached polymer-impregnated jadeites (samples 10, 11, 14–16) showed a very intense carbon peak with a C(1s)/Na(1s) ratio of about 35, as typically shown in Figure 6(a). The C(1s)/Na(1s) ratio for such jadeite was found to be much stronger than that of either wax-polished or wax-impregnated jadeite (Figures 5(a), 5(c)). The XPS spectrum of a polymer commonly used as a filler for jadeite showed intense peaks of C(1s) and O(1s) (Figure 6(b)) which were expected from the chemical composition of the polymer.

From the overall analysis of the XPS survey scans recorded, the intensity of the C(1s) peak appeared to be the most important determinant for the identification of B-jades. A closer examination of the C(1s) core-level spectra of both the wax- and polymer-impregnated jadeites revealed additional differences between the two treated jadeites. Figures 7(a) and 7(b) show the high resolution C(1s) core-level spectra of the wax- and polymer-impregnated jadeites respectively. By a process of peak-analysis, the C(1s) core-level peak envelope can be resolved into its peak components. As shown in Figure 7(a), the C(1s) peak is generated from three arrangements of bonds, namely, the aliphatic (-C-C-), the ether (C-O) and the ester (O=C-O). In contrast, as shown in Figure 7(b), the broader C(1s) core-level peak of the polymer-impregnated jadeite can be resolved into four components. They are the aliphatic, the aromatic/phenyl (O), the carbonyl (C=O) and the ester bond structures.

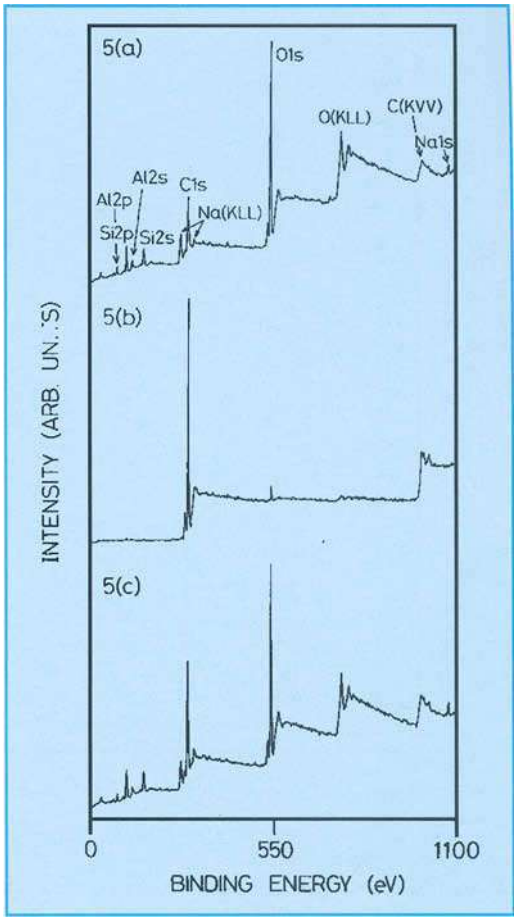

Fig. 5. XPS survey scan spectrum of:
(a) natural wax polished jadeite (samples 4–9)
(b) pure paraffin wax
(c) bleached wax-impregnated jadeite (samples 12, 13)
KLL and KVV refer to the electronic levels at which the vacancy is created by the excitation source (electrons); the de-excited electron originate, and the Auger electron originate respectively.

5. Conclusion

Basic gemmological tests such as the measurement of specific gravity and the observation of luminescence to ultraviolet radiation can only provide limited indications of any treatment to jadeites. Observations of damaged grain boundaries using scanning electron microscopy can give an indication of the extent of bleaching of the jadeite, but a more satis-

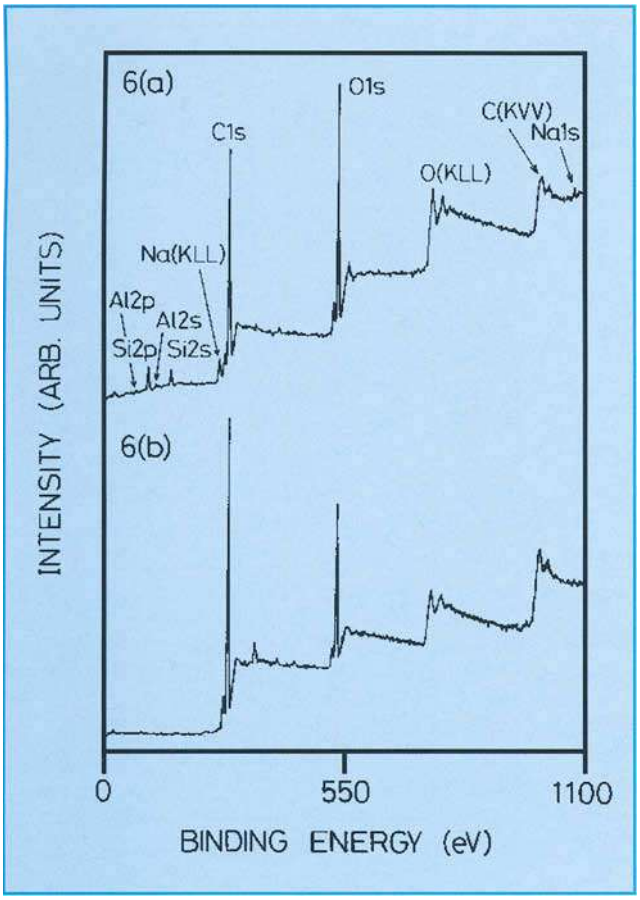

Fig. 6. XPS survey scan spectrum of:
(a) bleached polymer-impregnated jadeite (samples 10, 11, 14–16)
(b) a polymer.
KLL and KVV refer to the electronic levels at which the vacancy is created by the excitation source (electrons); the de-excited electron originate, and the Auger electron originate respectively.

factory test uses infrared absorption spectroscopy which identifies wax and polymers in certain infrared regions. However, even this advanced technique may not be able to detect impregnation materials other than wax and polymers. Furthermore the infrared absorption technique is limited to thin jadeite which allows the transmission of infrared radiation. These limitations can mostly be circumvented with the use of XPS. This non-destructive technique has been found to be capable of determining the chemical composition of the surface of the jadeite and thus can identify any foreign elements present. The surface analysis used in the XPS technique is complementary to determination of the bulk composition by infrared absorption spectroscopy.

From the results of our XPS study, the impregnation materials used in the bleached jadeite samples are paraffin wax and polymer. High C(1s)/Na(1s) ratios of about 11 indicate the presence of wax in jadeite. A C(1s)/Na(1s) ratio of about 35 is indicative of the presence of polymer. In addition, impregnation by wax or polymer can be further distinguished by analysing the differences in the carbon peaks. The ether carbon is characteristic of the wax whereas the phenyl and the carbonyl species are characteristic of the polymer used for impregnation. Hence, our work has shown that X-ray photoelectron spectroscopy is an independent and accurate technique for the identification of bleached wax- and polymer-impregnated jadeite.

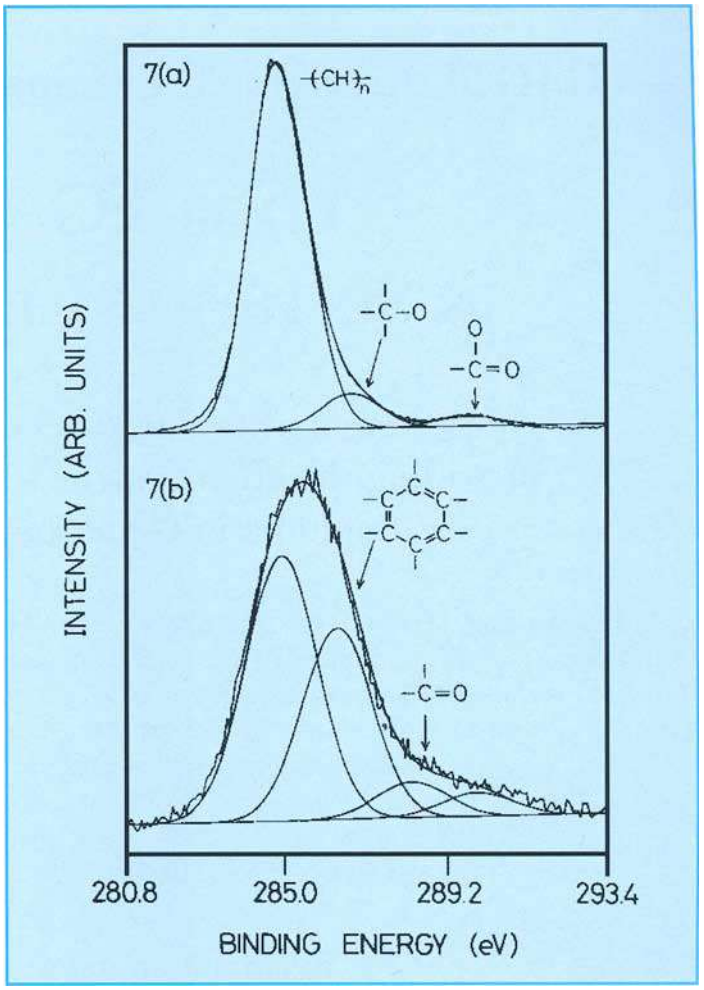

Fig. 7. XPS C(1s) core-level spectrum of:
(a) bleached wax-impregnated jadeite (samples 12, 13)
(b) bleached polymer-impregnated jadeite (samples 10, 11, 14–16).

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The distinction of natural from synthetic diamonds

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Abstract

Important concepts necessary to understand the mechanisms of crystal growth and the reasons why crystals of the same species can adopt a wide variety of morphologies are explained. This is followed by an explanation, based on thermodynamic analysis, of growth conditions of natural and synthetic diamond crystals in the diamond stable region, and of CVD diamonds in the diamond labile region. Due to differences in growth conditions and ambient phases, diamond crystals develop different morphological characteristics during their growth processes and may be considered as three types. The main difference between natural diamond and two types of synthetic diamond is found in the roughness at the growth surface of {100} faces. The {100} interface behaves as a rough interface, on which an adhesive type of growth mechanism operates, when diamond grows in a silicate solution (natural), whereas it behaves as a smooth interface when diamond grows in a solution of metal and carbon or by chemical vapour deposition; a two-dimensional nucleation growth mechanism or spiral growth mechanism is operative on {100} during synthetic growth.

Since these variations may be recorded in different single crystals as differences in growth sectors, growth banding, spatial distribution of dislocations and other lattice defects, they can be detected and visualized with the appropriate method even if a crystal is cut and polished. For this purpose the best method for use in gemmological laboratories is cathodoluminescence topography, combined with optical microscopy. Examples are given to demonstrate how CL images can differ between natural and synthetic diamonds of gem quality.

Introduction

In 1959, a research group of the General Electric Company in the USA published a paper in *Nature*, reporting, for the first time, how to synthesize diamond (Bovenkerk *et al.*, 1955). In this paper, they reported that there was no detectable difference between natural and synthetic diamonds. In issues of the same journal a few weeks later, Tolansky and Sunagawa (1959, 1960) published two papers, reporting that surface microtopographic observations revealed distinct differences between natural and synthetic diamonds. The authors inferred that these features resulted from differences in ambient phases and growth conditions experienced by the two kinds of diamond. It was possible to make such a comparison with confidence, because in Tolansky's laboratory a database on surface microtopograhic observations on natural diamond crystals had been accumulated.

They noticed the following differences between natural and synthetic diamonds.

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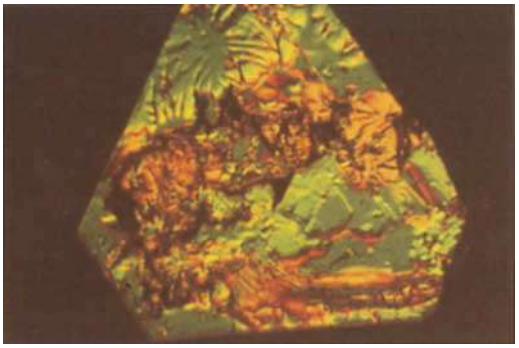

Fig. 1 (a). Differential interference photomicrographs of coralloid dendritic pattern commonly observed on a synthetic diamond face (111) (above) and (100) (left); the hopper nature of the face, growth steps, and surface dendritic pattern are seen.

1. Synthetic diamonds showed a cubo-octahedral habit bounded by {111} and {100} faces, which is not common among natural diamonds.
2. Dendritic or hopper crystals were commonly encountered among synthetic diamonds, which reflected growth under a higher driving force (supercooling or supersaturation). It is interesting to note that such crystals are no longer common among synthetic diamonds because modern crystal growth is better controlled.
3. Surface patterns resembling coralloid dendrites were universally seen on the surface of synthetic crystals, but were not observed on natural diamonds. These surface patterns are now understood to be due to quenched products from metal-carbon solutions. Figure 1a represents such a pattern.
4. The {100} faces of synthetic crystals showed either extremely flat and smooth surfaces, or growth spirals. The growth spiral shown in Figure 1b was the first to have been observed on diamond crystals. Growth spirals have also been observed on {111} faces of synthetic diamonds (Figure 1c). The relatively rare {100} faces of natural diamond show only a rugged surface, and neither growth spirals nor smooth surfaces are present.

Gemmological laboratories have to realize, whether they like it or not, that cut synthetic diamonds of gem quality have already been submitted for identification and certification. Some jewellers may pretend that synthetic diamonds of gem

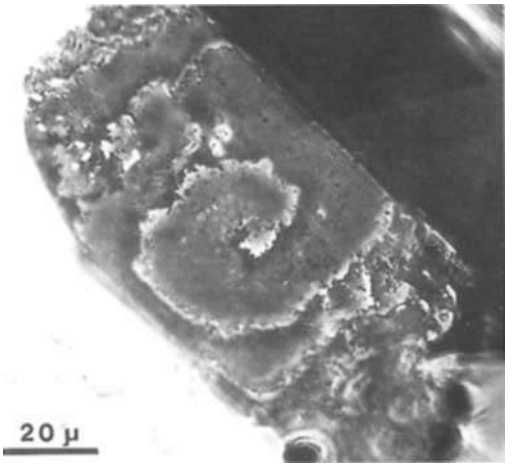

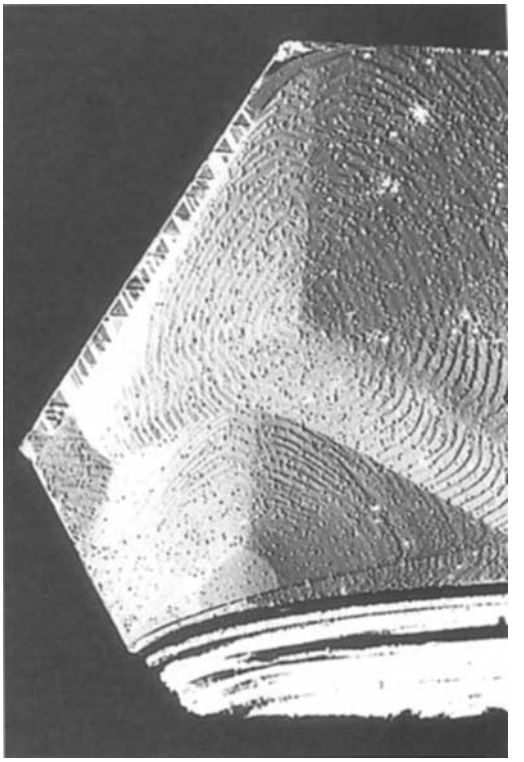

Fig. 1 (b) (above). Phase contrast photomicrograph of growth spirals observed on a (100) face; from Tolansky and Sunagawa, 1959.

Fig. 1 (c) (right). Growth spiral hillocks on (111) face of a synthetic diamond crystal. *Courtesy of Dr H. Kanda.*

quality will not come onto the market for many years because of higher production costs than natural diamond. But technological improvements have cut the cost of synthesizing gem quality diamonds, and control of colour is becoming easier, since we know which metal solvents act as getters of nitrogen, the main cause of colour in diamond. We should also note that natural diamond of near gem quality with various colours has already gained in popularity in the gem market. Under these circumstances, gemmological laboratories should prepare themselves to be able to distinguish between natural and synthetic diamonds with a high degree of confidence.

The two papers by Tolansky and Sunagawa provided an initial framework to distinguish natural from synthetic diamonds and it is the aim of this article to discuss the methods we should now adopt. If we can understand the mechanisms of crystal growth, which give rise to morphological characteristics, and the perfection and homogeneity of crystals during their growth, then that knowledge will provide a firm foundation when we try to distinguish between natural and synthetic gemstones, since each grows in different chemical and physical environments.

Physical properties such as specific gravity, specific heat, hardness, magnetic properties and optical properties, which are principally determined by the chemical composition and the structure of the crystal, do not vary much between samples of one crystal species. Such physical properties are called intrinsic properties and form a basis for identification of the different gem species. However, there are also physical properties which are greatly influenced by physical perfection, chemical purity or homogeneity of crystals, and thus vary greatly from sample to sample of the same crystal species. These so-called struc-

ture-sensitive properties include colour, and the electronic, spectroscopic and plastic properties of crystals. Such properties help to discriminate between natural and synthetic gemstones of the same mineral species, or between untreated and treated stones, since (1), the properties are influenced by the growth conditions, ambient phases and how conditions fluctuate during the growth process (through which imperfection and inhomogeneity are formed in the growing crystals) and (2) they are also modified by post-growth treatment. Distinction between natural and flux or hydrothermally grown emeralds by means of careful measurement of specific gravity, refractive indices and IR spectroscopy is based on the factors in (1), whereas distinction between natural and irradiated coloured diamonds is due to (2). The widely used gem identification method based on microscopic observations of syngenetic inclusion content also belongs to category (1), but this currently has only an empirical basis, lacking somewhat in theoretical understanding. However, inclusions represent only one aspect of the growth process of crystals and we shall concentrate in this article on explaining other more subtle growth features of crystals using diamond as an example.

Concepts and mechanisms of crystal growth

Much crystal growth takes place at the solid-liquid interface. Depending on how rough the interface is on an atomic scale, growth mechanisms are different. If atomistically rough and consisting only of kinks (which give rise to the rough interface), an adhesive type of growth mechanism operates. The interface advances continuously in a direction normal to the interface, since the atom or the growth unit arriving at the interface can immediately find a site to be incorporated into the crystal. If an interface is atomistically smooth (smooth interface, corresponding to a low index crystal face) and consists largely of a flat terrace with a few steps and kinks, an adhesive type of growth mechanism is not operative, since the growth unit arriving at or on the interface has difficulty immediately in finding an adhesive position on the crystal. The growth unit may be incorporated into the crystal only after surface migration to a kink or step. As a result, growth proceeds in a two-dimensional manner by spreading growth layers parallel to the interface, a mechanism called layer-by-layer growth. There can be two growth mechanisms in such a case; growth layers originating from a two-dimensional island-like nucleus (two- dimensional nucleation growth, the so-called 2DNG mechanism) and those originating from a step created on the surface through the outcrop of a screw dislocation giving rise to spiral growth (spiral growth mechanism). Depending on the growth mechanism, the relationships between the normal growth rate of the interface and the driving force (i.e. the degree of supersaturation or supercooling) are different. Since the morphology of crystals is determined by the relative growth rates in different crystallographic directions, the resultant morphology of crystals can differ depending on the interface roughness, the growth mechanism and the driving force, which are related to growth conditions, their fluctuation and ambient phases.

The morphology of a crystal can be related to crystal growth by various means. These can include surface microtopographs of crystal faces (morphology of growth steps on crystal faces), morphology of a bulk crystal (dendritic, hopper, polyhedral, or more normal crystal habits), internal morphology observed in a single crystal (growth sectors, sector boundaries, growth banding, spatial distribution of dislocations and other lattice defects) and textures of polycrystalline aggregates. All these can vary during the growth process. The science of crystal growth is concerned with how crystals nucleate and grow and how

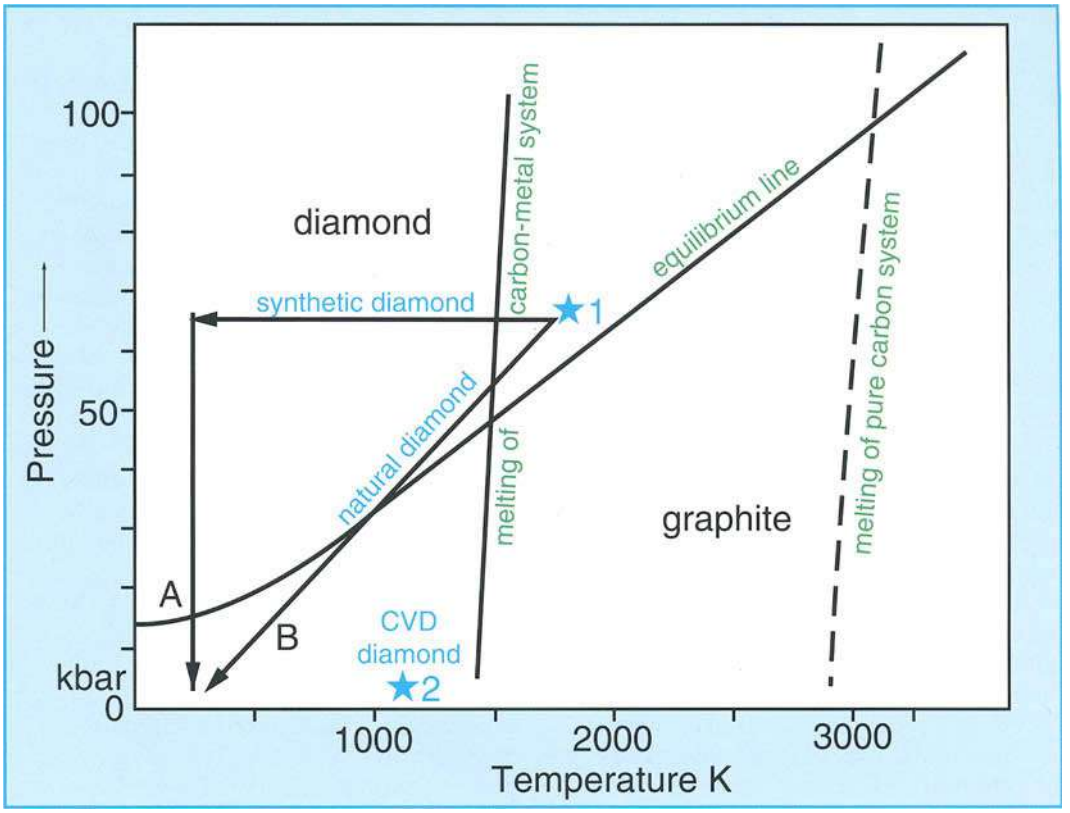

Fig. 2. Schematic phase diagram of diamond and graphite (see text for details). Star 1 corresponds to a point where diamond is expected to nucleate and grow in the stable region, whereas star 2 indicates diamond nucleation in the diamond labile region. Arrows A and B respectively indicate the routes whereby synthetic (A) and natural (B) diamond pass through the labile region.

morphologies, physical perfection and chemical homogeneity are determined by growth conditions, ambient phases and processes of crystal growth. Clearly, the knowledge achieved in these studies forms the basis of gemmology, since the main task of the gemmologist is to identify natural, synthetic and treated gemstones. Fortunately, since most of the important natural gemstones are obtained from well crystallized single crystals of high perfection, it is appropriate for the time being to consider polyhedral single crystals bounded by low index faces which grew by two-dimensional nucleation growth or spiral growth mechanisms on smooth solid-liquid interfaces.

Growth of diamond

Figure 2 shows a schematic phase diagram of diamond and graphite. In the region above the equilibrium line in the pressure-temperature diagram of Figure 2, diamond exists stably, whereas in the region below this line graphite is stable. On the equilibrium line diamond and graphite co-exist, but neither nucleation nor growth of diamond or graphite will ever take place if the thermodynamic condition on this line is unchanged. To nucleate and grow diamond, it is necessary to realize a condition away from the equilibrium line and into the diamond stable region. The difference between this condition and the equilibrium line provides a driving force to nucleate and grow diamond.

Thermodynamically, therefore, we expect that diamond can nucleate and grow in the *P-T* region above the equilibrium line.

When only pure carbon is used as a starting material in diamond synthesis, very high *P-T* conditions are required. This situation corresponds to crystal growth from a melt phase, similar to the synthesis of silicon single crystals by the Czochralski method or of ruby by the Verneuil method. Alternatively, if carbon is dissolved by a solvent to form a carbon- solvent solution, the *P-T* conditions of diamond growth are reduced to lower values. This is crystal growth from a solution phase and crystals grown in fluxes, hydrothermally or from aqueous solutions, as well as in magmas belong to this type. In Figure 2, the vertical solid straight line represents the line of melting of a hypothetical solution containing carbon and the dotted line is the melting line of pure carbon. The position of the first solid line depends on the nature of the solvent because interaction energies between solute and solvent components are different.

From the above circumstances, it is clear that the orthodox way to grow diamonds is to subject starting mixtures of carbon and solvent to higher temperature and pressure conditions than the region bounded by the solid straight line and equilibrium curve marked *1 in Figure 2. This position in the phase diagram is enough to allow the diamond to grow, but to ensure that the product is diamond and not graphite we initially drop the temperature rapidly to room temperature while keeping the pressure unchanged and follow this by releasing the pressure; route A in Figure 2. For natural diamond, the process is partly paralleled when crystals are brought up to the Earth's surface in a magma at speeds of as much as 100 km/h, and undergo an adiabatic quenching through volcanic eruption. Their path to the surface will follow route B in Figure 2. During this ascent, natural diamond crystals experience dissolution processes, which produce rounded crystals and surface etch features such as trigons.

Although the orthodox way of growing diamond crystals is to subject starting materials to high *P-T* conditions, it is also possible to nucleate and grow diamond crystals in conditions where diamond is thermodynamically not stable, such as from position (*2) in Figure 2 (see also Sunagawa, 1990). Such processes involve metastable nucleation and growth. Diamond synthesis by chemical vapour deposition (CVD), to create diamond- like films is one example occurring at atmospheric pressures and appropriate temperature conditions. An example of metastable growth in the natural world would be the formation of aragonite, normally a high pressure phase of $CaCO_3$ (Deer, Howie and Zussman, 1962, p. 308), by the biological activity of shellfish.

Table I summarizes our present understanding of the thermodynamic conditions of diamond growth and the ambient phases from which these crystals grew, both for natural and synthetic crystals. Clearly, diamond crystals grown under stable and metastable conditions can be distinguished. Among stable diamond growth we see a marked difference between natural and synthetic diamonds in the chemistries of their solvent components. Natural diamonds grew in silicate liquids of either eclogitic or ultramafic composition, whereas synthetic diamond grew from metal or alloy solutions. The difference in the growth solvent is important, because this may result in different morphological characteristics between the two systems about which a detailed explanation will be given later. Although tiny diamond crystals have recently been successfully synthesized using non-metallic solvents such as carbonates, sulphates (Akaishi *et al.*, 1990 a,b) and even silicates in the form of kimberlite powder (Arima *et al.*, 1993), the crystals are too small to be cut as gemstones (see Table I). Similarly, synthetic diamond crystals grown by CVD are

Table I. Conditions of diamond growth and ambient phases

	Temperature	Pressure	Ambient Phases
Thermodynamically Stable Conditions			
Natural	1000–1600°C	40–55 kbar	Silicate solution
		4–5.5 GPa	(ultramafic and eclogitic)
Synthetic	1400–1700°C	50–70 kbar	
		5–7 GPa	Metal and alloy solution
			carbonates (Akaishi *et al.*, 1990a)
			sulphates (Akaishi *et al.*, 1990b)
			silicates (kimberlites) (Arima *et al.*, 1993)
Thermodynamically Metastable Conditions			
Synthetic	800–1000°C	1 bar	Pyrolysis or chemical vapour deposition
		0.1 MPa	of hydrocarbons including CH_4 and
			C_2H_2

too small to cut. Thus the problem for gemmologists in the coming ten to twenty years will be to recognize those diamonds synthesized by the temperature gradient method, using seed crystals and metallic solvents. It must not be forgotten, however, that CVD diamond has a potential to be used as coating material to improve the colour grade of cut diamond or to enhance the hardness of other gemstones.

Review of morphology of crystals

The morphologies of crystals are controlled both by internal structural factors and by external factors. Theoretically, if one entirely neglects the effect of external factors, a crystal species should show a unique polyhedral morphology which is determined by the internal chemical bonding and crystal structure. Such a hypothetical morphology can be deduced from such concepts as Bravais' law, Donnay-Harker's extension of Bravais' law and a Hartman-Perdok's PBC (Periodic Bond Chain) analysis (for a reference, see below). This structural morphology does not necessarily relate to the thermodynamic parameters of pressure and temperature. In contrast, if a crystal attains equilibrium with the ambient phases, the morphology is uniquely determined for the given thermodynamic condition. Such a morphology is called the equilibrium form. The equilibrium form can be deduced theoretically for simple crystals from a basis of surface energy calculations. On the other hand, the morphology of crystals arising from a growth process which is not in equilibrium, are called growth forms, and these can be plural. What we need to understand is how growth forms of crystals change depending on growth conditions, and what the external controlling factors are to create morphological variations of crystals. This subject is discussed in a great detail in *Morphology of crystals, part A and B* edited by Sunagawa (1987a). Variations in crystal morphologies appear as the product of dif-

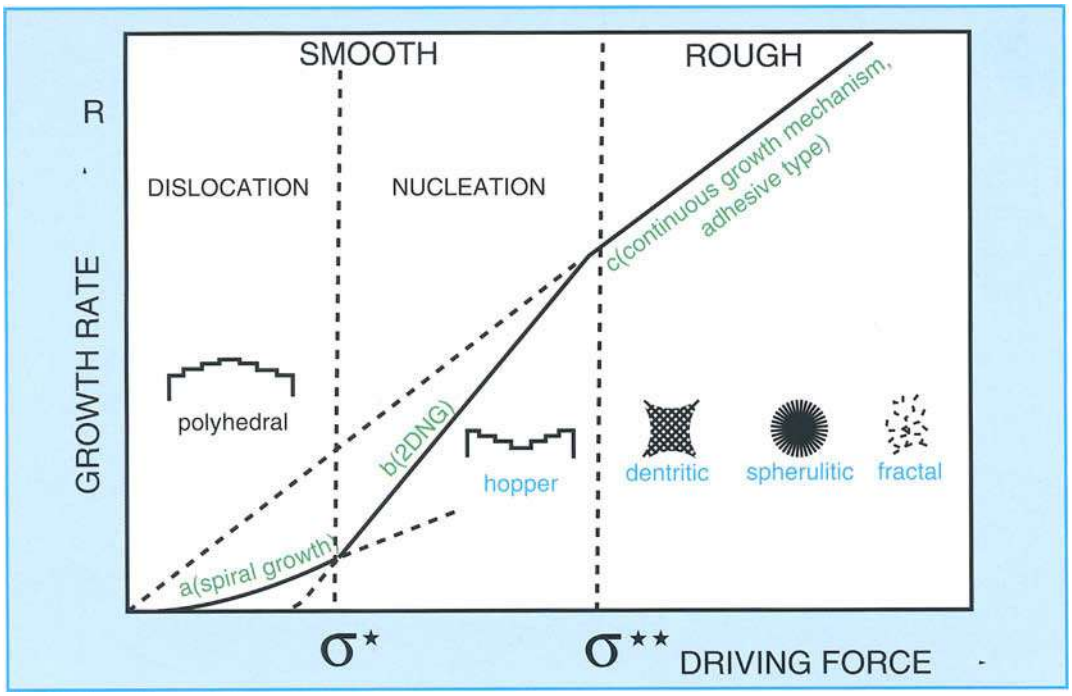

Fig. 3. Schematic diagram explaining the relationship of interface roughness (rough and smooth), growth mechanisms (a, spiral growth-line a; b, 2DNG-line b; c adhesive type continuous growth) and morphologies. The morphological variations of crystals are related by growth rate R versus driving force; from Sunagawa (1987b).

ferent growth rates of different crystal faces and because the growth rate relates to the roughness of the solid-liquid interface, the growth mechanism and the driving force, we shall now examine these problems on this basis.

Figure 3 illustrates the relation between growth rate (R) and the driving force for a theoretical crystal. Curve *a* corresponds to the R vs driving force relation expected for the spiral growth mechanism, *b* that of the 2DNG mechanism, and *c* to the adhesive type continuous growth mechanism. For further information on these mechanisms, the reader may refer to text books of crystal growth (e.g. Chernov, 1984; Sunagawa, 1984a, 1987a,b).

We see in Figure 3 two intersections of curves a,b and c respectively denoted by σ^* and σ^{**}. In the region to the right of σ^{**}, solid-liquid interfaces are expected to be atomistically rough, where a continuous growth mechanism will be operative, and dendritic, spherulitic and further fractal morphologies are expected. Dendrites appear because a growing rough interface becomes morphologically unstable, creating protrusions, which develop as dendritic branches. Spherulites appear when crystals grow in radial directions from centres much more quickly than and before morphological instability of the interface occurs. Fractal is a pattern due to self-analogous repetition of a smaller pattern, such as may be observed in dendrites of manganese oxide. In the region between σ^* and σ^{**}, where solid-liquid interfaces should be smooth and the 2DNG mechanism is principally operative, crystals will form hopper morphologies. In the region to the left of σ^*, the solid-liquid interface is also expected to be atomisti-

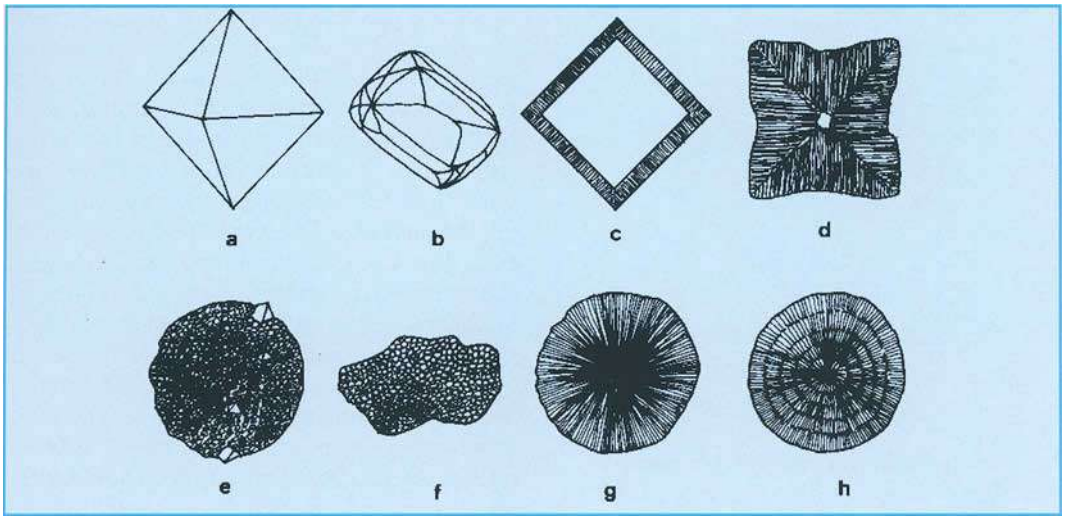

Fig. 4. Morphology of natural diamond crystals. Category 1, single crystals, a and b; category 2, polycrystalline, d to h; category 3, combined single crystalline and polycrystalline, c.

cally smooth, and a spiral growth mechanism will principally operate. In this region, the expected morphology of crystals is polyhedral bounded by flat low index crystal faces. We also note that in this region crystals of the same species may take a wide variety of crystal habits. From Figure 3 we also see that polyhedral crystals form when crystal growth occurs under a smaller driving force than σ^*, hopper crystals occur between σ^* and σ^{**}, whereas only dendritic crystals and polycrystalline spherulitic morphologies occur above σ^{**}.

Morphology of natural diamond

Natural diamonds have experienced a dissolution process whilst being transported from depths within the Earth. Evidence for such a process includes the rounded dodecahedroidal faces of diamond and the ubiquitous trigon observed on {111} faces. If we restore the original as-grown morphology (i.e. pre-dissolution), diamond crystals may be classified into three categories, schematically illustrated in Figure 4.

Figures 4a and b are single crystalline diamonds (category 1), which are the principal kinds used for gems, whereas Figures 4d to h depict polycrystalline diamonds (category 2), used only for industrial purposes. Figure 4c illustrates the texture of a coated stone, consisting of a single crystalline core and polycrystalline rim forming a combined type (category 3); the core portion is commonly of gem quality.

From Figure 3 and the discussion above, we can surmise that diamond crystals of category 1 grew under a driving force smaller than σ^*, (spiral growth mechanism), and those of category 2 were formed under a driving force larger than σ^{**}. Crystals of category 3, experienced two growth stages; they initially grew as single crystals under a driving force smaller than σ^*, followed by a driving force condition higher than σ^{**} giving rise to a polycrystalline overgrowth. Such a situation may occur if a magma containing single crystalline diamond of category 1 is uplifted to a shallower position in the mantle with consequent changes in pressure and temperature.

The major forms of single crystals of diamond are {111}, {110} and {100}. The hardness of diamond along these planes decreases in this order and corresponds to

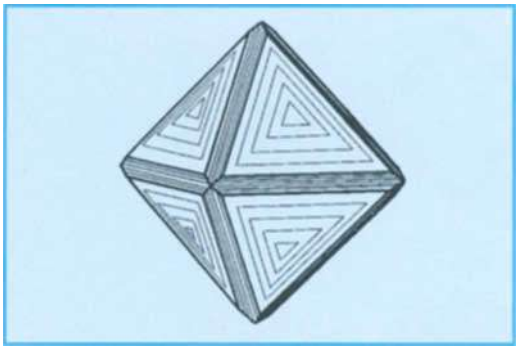

Fig. 5. Structural form of diamond as deduced from periodic bond chain (PBC) analysis.

the decreasing order of reticular density (number of atoms per unit area in a lattice plane) and the number of C-C covalent bonds per unit area.

Structural forms of diamond can also be deduced by means of Periodic Bond Chain (PBC) analysis and, according to Hartman and Perdok (1955), crystal faces are classified into an F (flat) face, which contains more than two PBCs, an S (stepped) face containing only one PBC and a K (kinked) face containing no PBC. If a crystal structure is examined in order to find directions with strong chemical bonding between the neighbouring atoms or ions, one can find more and stronger periodic bond chains on some faces than on others. Depending on the number of PBCs contained in crystallographic faces, Hartman and Perdok classified crystallographic faces into three types. Following the explanation given in the previous sections, an F face corresponds to a smooth interface, which grows by 2DNG or by the spiral growth mechanism and develops large faces, whereas a K face corresponds to a rough interface which grows by the adhesive type of growth mechanism and thus does usually not appear on growth forms. An S-face has an intermediate character between an F and a K face, and should show only striations.

According to PBC analysis of a diamond crystal, {111} is an F face, {110} an S face and {100} is a K face. The structural form of diamond is therefore an octahedron with small striated {110} faces. On the {111} faces, growth layers with triangular form in accordance with the triangle of the face should be expected, whereas no {100} faces will appear. Since {100} is a K face, no growth layers are expected to develop on this face. The structural form of diamond can therefore be drawn as shown in Figure 5. This morphology can be used as a criterion in analyzing growth forms exhibited by polyhedral crystals of diamond formed under different conditions. We shall in the following focus our attention on the morphological characteristics of the three faces, and compare them as they are developed in natural diamonds, synthetic diamonds grown in the thermodynamically stable region and those grown metastably.

Critically reviewing previous observations reported in many papers and also those made by the present author on bulk morphology, surface microtopography of crystal faces and internal morphology (growth sectors, growth banding, etc.) of natural diamond crystals, we can summarize the situation as follows.

1. Natural diamond crystals have experienced dissolution processes to varying degrees. However, there are crystals which have been little affected, preserving almost as-grown surfaces, like those from Siberia. Growth forms and their changes during growth history can also be revealed by visualizing the internal morphology, such as growth sectors and growth banding, by applying appropriate methods to be described later.
2. The {111} faces are the only ones on which layer-by-layer growth or spiral growth takes place. Evidence of spiral growth was obtained on crystals from Siberia which were only slightly dissolved, through a combined investigation of surface

microtopography and X-ray topography (Sunagawa *et al.*, 1984b). Observations of growth banding revealed by etching gem quality natural diamond crystals, reported by Seal (1965), showed clearly that {111} faces grew by a layer-by-layer growth mechanism throughout their growth history. Straight crystallographic growth banding in {111} growth sectors is a universally observed feature on X-ray topographs of natural diamonds, as witnessed by extensive X-ray topographic work carried out by Lang (e.g. 1965, 1979).

3. {110} faces usually appear on larger crystals due to dissolution of original octahedral crystals as reported by Seal (1965). On these crystals, the {110} faces are rounded and split into four curved {hhl} faces. They are not truly crystallographic dodecahedral faces, but dodecahedroidal faces. In contrast, on much smaller diamond crystals only a few micrometres across {110} faces often appear as flat and as true dodecahedral faces, their only obvious feature being striations parallel to an edge with the neighbouring {111} face. No growth layers have been observed on these faces, although they are considered to have appeared by a growth process through piling up of steps of growth layers developing on {111} faces (Sunagawa, 1984b) and not by a dissolution process.
4. {100} faces are always rugged, and never appear as flat crystallographic faces. They are not cubic faces, but cuboid faces. As seen in Figure 3d, cuboid crystals with depressed cuboid faces appear due to polycrystalline growth. Analysis of the so-called centre cross pattern sometimes detected by X-ray topography, cathodoluminescence or by etching methods at the centres of gem quality diamond crystals has indicated hummocky, non-straight growth banding in {100} growth sectors, in contrast to the straight banding seen in the {111} growth sectors of the same crystal. Rugged {100} surfaces were also reported on tiny diamond crystals occurring in eclogitic garnet by Sobolev *et al.* (1991).

Thus {111} faces are the only ones which provide a smooth interface during the growth of natural diamond and on which layer-by-layer or spiral growth operates. In contrast, {100} faces always behave as a rough interface on which layer-by-layer or spiral growth does not take place. {110} faces may appear either by growth or dissolution. During growth it behaves as an intermediate face between smooth and rough interfaces, on which layer-by-layer or spiral growth does not take place. During dissolution dodecahedroidal faces appear when the dissolution preferentially proceeds from the edges and corners of an as-grown octahedral crystal. It should be noted that morphological characteristics of natural diamond crystals are in accordance with those of structurally deduced morphologies shown in Figure 5.

Morphology of synthetic diamond

The morphological characteristics of diamonds synthesized in metal-carbon systems are markedly different from those of natural diamonds; see Figure 6 for the preferred conditions of formation of different faces. If the surface dendritic pattern due to quenched metal-carbon solution is removed from the surfaces of synthetic diamond, both {111} and {100} faces show growth spirals, indicating that both faces have grown as smooth solid-liquid interfaces. Growth spirals on the synthetic {111} faces take on a triangular form in accordance with the triangular outline of a {111} face (as is the case of natural diamond crystals), whilst synthetic {100} faces show a rectangular form, bounded by [011] steps.

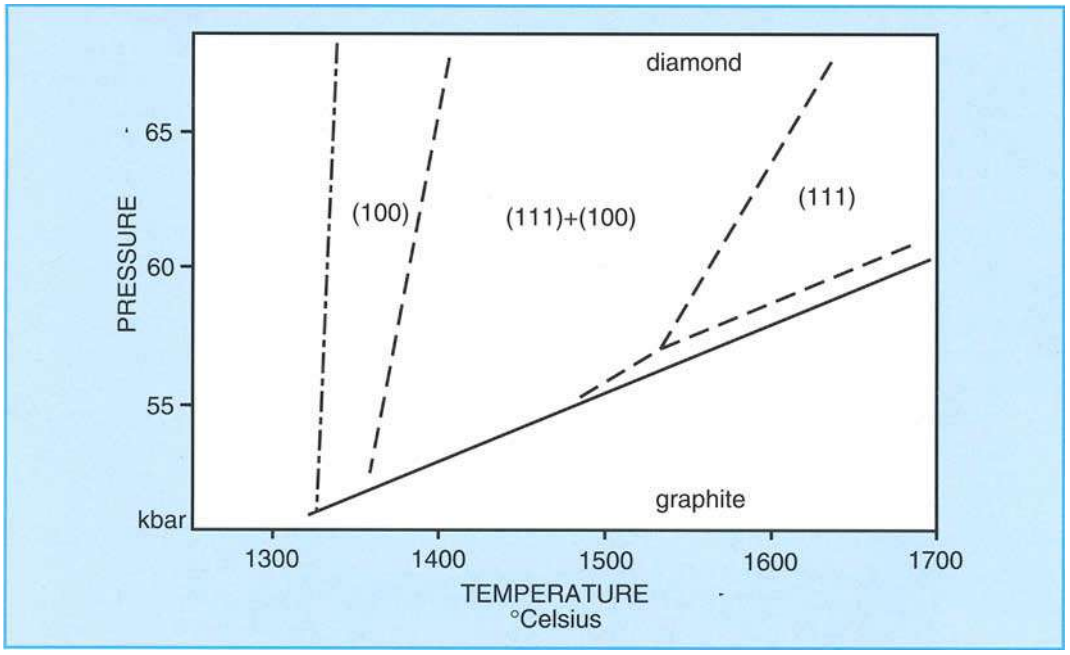

Fig. 6. Morphological phase diagram (morphodrom) of synthetic diamond growth in the diamond stable region; after Sunagawa (1984b).

The principal difference therefore between the surface characteristics of natural and synthetic diamond is that in natural diamond {100} behaves as a rough interface.

The origin of the contrasting behaviours of growth on {100} faces when both natural and synthetic diamond are grown in stable conditions can only lie in the different solvent components; natural crystals grow in silicate solutions, whereas synthetic crystals are derived from metallic solutions. In the silicate system it is possible that the presence of oxygen ions prevents the development of smooth {100} faces. Indeed, when diamond crystals were synthesized in a silicate solution using kimberlite powder as nutrient, crystals took a simple octahedral habit, no {100} faces being developed (Arima et al., 1993).

CVD diamond crystals show cubo-octahedral habit bounded by {111} and {100} faces, and both faces may exhibit growth spirals. This situation, therefore, is essentially the same as for other synthetic diamonds grown from metallic solutions in conditions stable for diamond. However, some distinctions have been observed and these are summarized below (see also Sunagawa, 1990).

1. Multiply twinned particles, which are considered to represent the morphology of crystalline particles in a metastable state, are commonly encountered among CVD diamonds. A twinned crystal is in a higher energy state than a single crystal, since interface energy is additionally required to join the two individuals to form a twin. Multiply twinned particles are ubiquitous among ultra-fine metal particles produced by evaporation and condensation; they collapse and rearrange themselves to form single crystals when they exceed a critical size.
2. On {111} faces triangular growth

spirals are oppositely oriented to the triangular outline of the face. This is in contrast to the morphology of growth spirals observed on {111} faces of both synthetic and natural diamond grown in the diamond stable region.

3. {111} faces become larger with increase in the driving force, an observation which contrasts with that observed on synthetic diamonds grown in the diamond stable region.
4. {100} interfaces are smoother than {111}, a situation which is opposite to that for synthetic diamonds grown in the diamond stable region.

Internal morphology

In gem identification, the characteristics of surface microtopographs and the bulk morphology of diamond crystals may appear to have no direct importance, since gemstones for investigation are cut and polished. Gemmologists may appreciate that the knowledge is fundamentally interesting but think that it is outside their field. However, this is not so.

During the growth history of a crystal, growth conditions may vary, resulting in the fluctuation of growth rate, which leads to morphological variations and the formation of physical imperfections and chemical inhomogeneities. Often these features are orientation-dependent and produce distinct differences in crystals from either similar or different starting materials. Growth sectors, sector boundaries, growth banding, dislocations and other lattice defects are such internal features. Even if a stone appears to be completely perfect, transparent and homogeneous to the naked eye or under ordinary magnification, the stone will show some inhomogeneity or imperfection, if appropriate methods are applied. Thus, if a crystal or cut stone appears to be perfectly homogeneous then the gemmologist should consider whether or not the analytical method applied was sensitive enough to detect imperfections and inhomogeneities.

Techniques, such as X-ray topography, cathodoluminescence topography and laser-beam tomography, plus the use of sensitive optical microscopy like phase contrast, differential interference contrast and polarization microscopy, may be mentioned and have been developed in recent years to characterize perfection and homogeneity of crystalline materials. Some of these methods ought to be in standard use in gemmological laboratories. For example

(a) X-ray topography is a powerful method to reveal dislocations and other lattice defects, as well as growth banding, although its use requires sophisticated knowledge and technique (Sunagawa, 1984);

(b) laser-beam tomography visualizes spatial distribution of light scattering centres on a submicron scale and identifies luminescent centres and dislocations in single crystals. Such a powerful technique could be used to distinguish natural, synthetic and treated stones in a gemmological laboratory;

(c) sensitive optical microscopy enables one to observe weak strain fields associated with various lattice defects and growth sector boundaries;

(d) cathodoluminescence; the most useful instrument, perhaps, for gemmological laboratories is a conventional CL system which is commercially available as a combination of optical microscopy with a vacuum system and electron gun. Ponahlo (1992) has pioneered this technique in the gemmological field. For research in universities, this method may be used in combination with a scanning electron microscope.

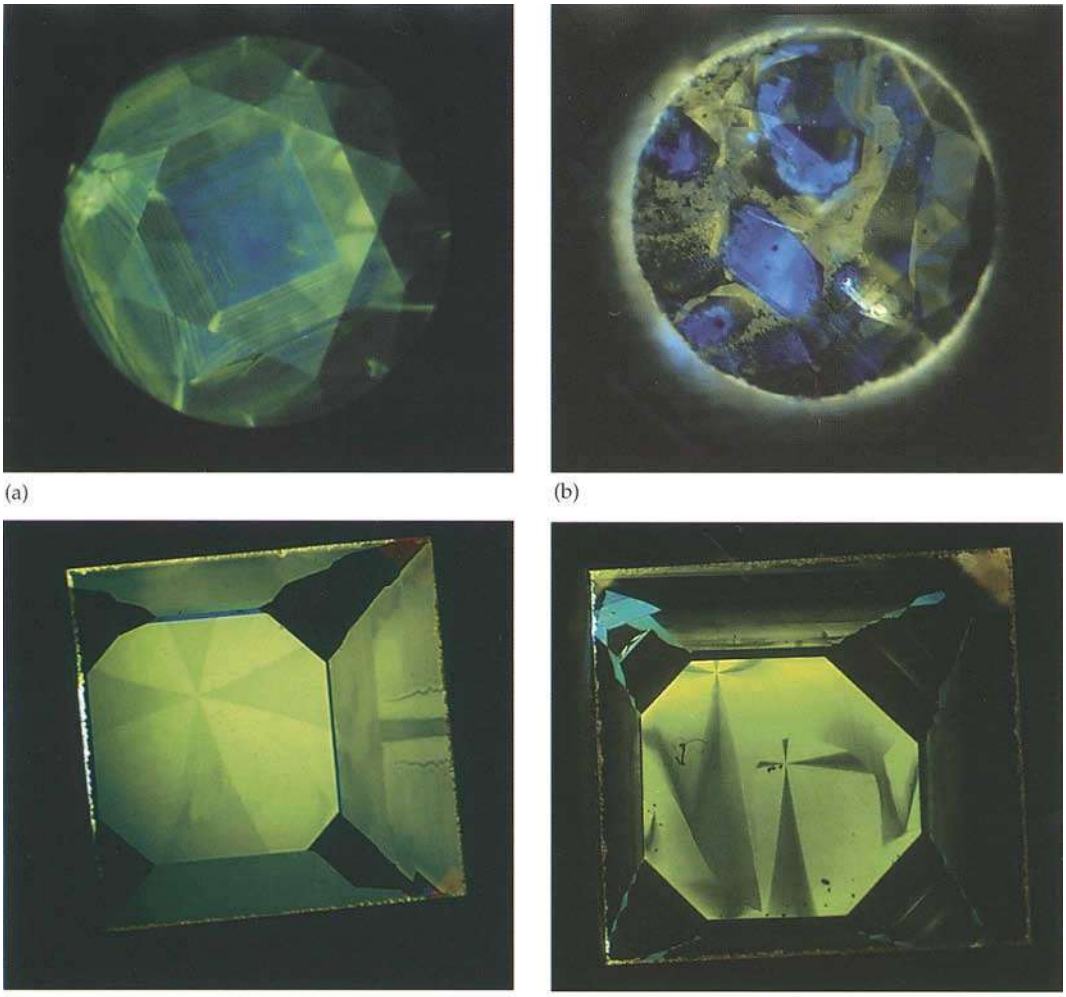

Fig. 7. Examples of CL images shown by round brilliant cut natural diamonds (a) and (b) and an as-grown synthetic Sumitomo diamond (c) and (d). *By courtesy of the Gemmological Association of All Japan.*

To demonstrate what sort of images can be obtained by a conventional cathodoluminescence microscope, four CL photographs are shown in Figure 7, taken by the Gemmological Association of All Japan. Figures 7a and 7b show CL photographs of natural round brilliant cut diamonds, which show {111} growth sectors with growth banding and a centre cross pattern consisting of {111} and {100} growth sectors. Figures 7c and 7d show CL photographs of a Sumitomo synthetic stone with platy habit parallel to the (100) face, which reveals {111} and {100} growth sectors originating from plural centres. Clearly there is a distinct difference between natural and synthetic stones, which is the result of differences in crystal growth.

Concluding remarks

This article has demonstrated how and why crystal growth and the resultant morphological characteristics can differ

between natural and synthetic crystals, taking diamond as a representative example. Using such knowledge, it is possible to distinguish between natural, synthetic and treated gemstones, even after they have been cut and polished. These arguments apply not only to diamond but also to other gemstones, such as emerald, ruby and sapphire. A knowledge of crystal growth, therefore, ought to be considered an important aspect of gemmological education.

Acknowledgements

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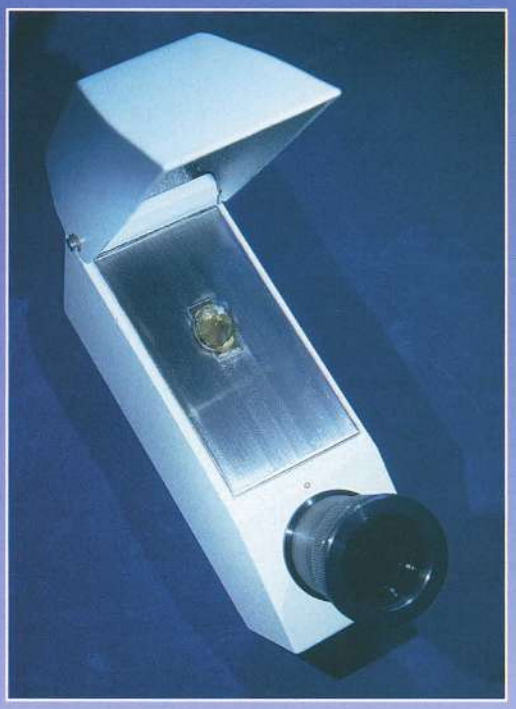

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Russian hydrothermal synthetic emeralds: characterization of the inclusions

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Abstract

This work contributes to the description of the internal features of Russian hydrothermal synthetic emeralds which have been produced recently. SEM-EDS analyses carried out on some metallic crystalline inclusions reveal that they consist mainly of Fe, Cr and Ti oxide or oxides of undetermined structure. Lanthanum and cerium were also found in one of these metallic inclusions.

Introduction

At present the Russian hydrothermally-grown synthetic emeralds are produced in many plants at several localities in Russia. Together they represent a significant share of the European commercial production of synthetic emeralds.

The physical and gemmological properties of Russian hydrothermal synthetic emeralds have been described by Fryer *et al.* (1983), Koivula (1984; 1985), Lind *et al.* (1987), Scarratt (1987), Schmetzer (1988), and Brown *et al.* (1989). In the emeralds investigated by these authors many typical inclusions were found and described: liquid veils and feathers, two- and three-phase inclusions, colour zoning, angular growth structures, irregular boundaries between sectors or subgrains as well as minute opaque grains or platelets. In particular Schmetzer (1988), provided much information on the presence of the seed-plate, its orientation with respect to the optic axis and its influence on colour zoning and growth inhomogeneities.

In the present paper the inclusions occurring inside numerous faceted samples of Russian hydrothermally-grown synthetic emeralds are described; they are believed to have been produced in the first half of 1994 but the manufacturing plant is not known. The object of the present study is also to investigate the chemical nature of the crystalline and opaque inclusions.

Materials and methods

A rough synthetic emerald weighing 39g, 8.2 x 2.7 x 1.2cm in size (Figure 1), with synthetically-grown portions symmetrically developed about a central seed plate approximately 1mm thick was cut and pol-

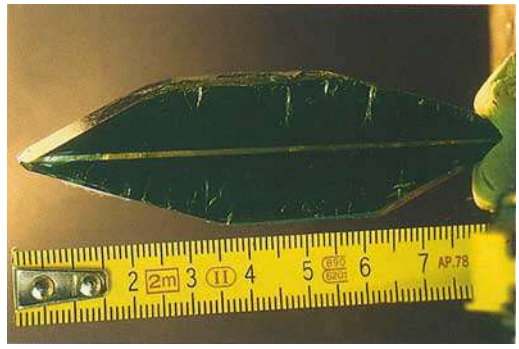

Fig. 1. The 39g rough of Russian hydrothermally-grown synthetic emerald, displaying the colourless beryl seed in the middle.

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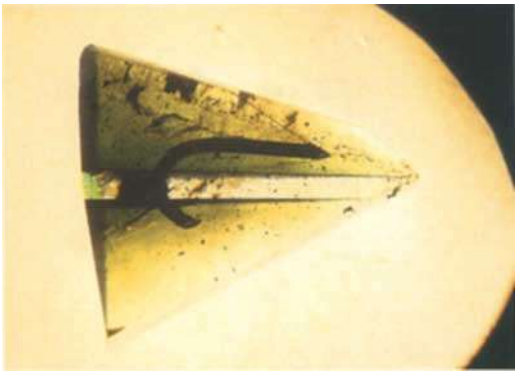

Fig. 2. Residual metallic wire on which the seed plate was suspended. 4x.

ished into seven stones ranging from 2.72 to 5.71ct. At the two ends of the rough, two stumps of the wire used to support the seed plate inside the growth vessel were visible (Figure 2).

The rough sample and the faceted emeralds obtained from it were observed under the optical microscope and the scanning electron microscope (SEM). The qualitative chemical analyses of the inclusions were carried out on a Leica-Cambridge Stereoscan-360 SEM equipped with a Link energy-dispersive system (SEM-EDS) belonging to the SGEL department of AGIP SpA.

Results

Description of the rough synthetic emerald

The original rough sample showed an intense green colour with a remarkable blue overtone; on the two longest parallel surfaces many 'shield-shaped' growth figures were present (Figure 3). On the same surfaces a complex system of superficial cracks was also noted (Figure 4). The fissures were completely eliminated after cutting and polishing.

In observing the seed plate sited in the middle of the rough, it was possible to see, at the two ends, where a hole of about 1cm in diameter containing a 'U'-shaped metallic wire (with a cross-section of 0.8mm) had been placed. In addition to growth on each side of the seed plate, synthetic emerald also filled the holes and came into direct contact with the metallic wire.

Metallic inclusions and their chemical composition

The qualitative chemical analysis (Figure 5) indicates that the wire is made of an iron, chromium and nickel alloy; the same elements that were also found everywhere in the 'bulk' of the investigated synthetic emeralds (Figure 6). These elements are responsible for the colour of the samples. It is therefore possible to suppose that the incorporation of a certain amount of Cr, Ni and Fe in the growth solution was due to the initial corrosion of the metallic wire next to the walls of the steel autoclave used during the industrial process.

Schmetzer (1988) and Cozar *et al.* (1992),

Fig. 3. Shield-shaped growth-figures on a surface of the 39g Russian synthetic emerald rough. 20x.

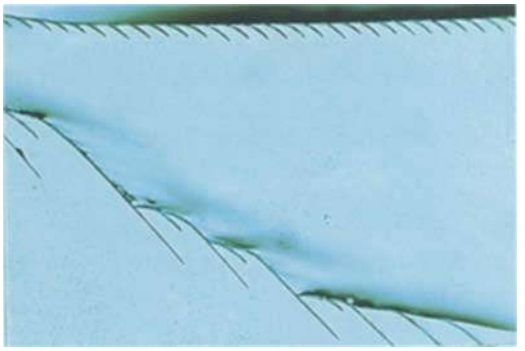

Fig. 4. On the surface of the rough-emerald different series of hook-shaped fissures are visible. 250x.

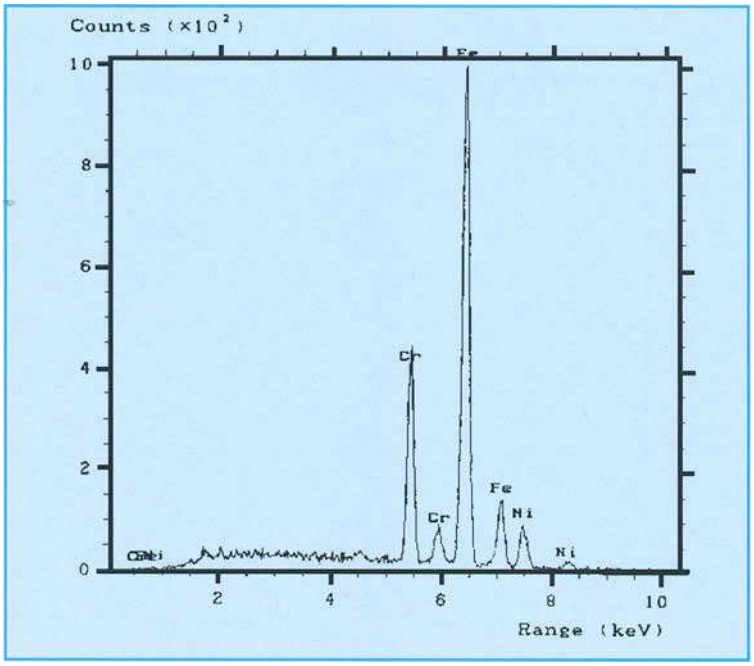

Fig. 5. SEM-EDS chart showing the characteristic peaks of the elements present in the metallic wire on which the beryl-seed was hooked (see Figure 2).

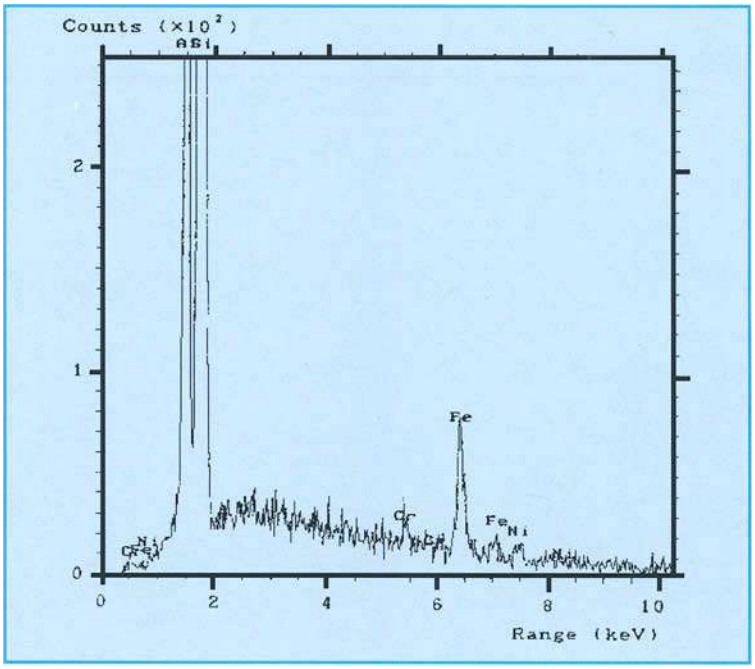

Fig. 6. SEM-EDS chart showing the chemical composition of the Russian hydrothermal synthetic emeralds examined.

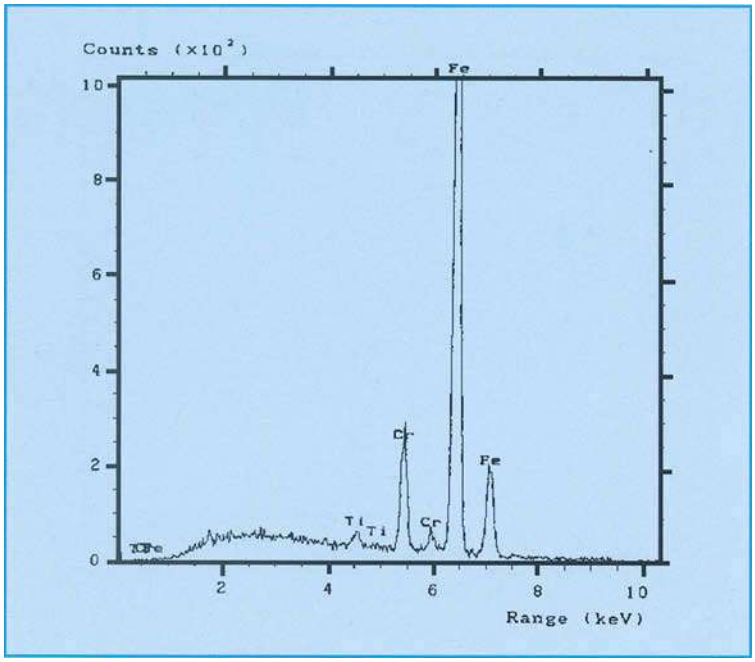

Fig. 9. SEM-EDS chart of the constituents of the pseudo-hexagonal, opaque metallic crystals (see Figure 8).

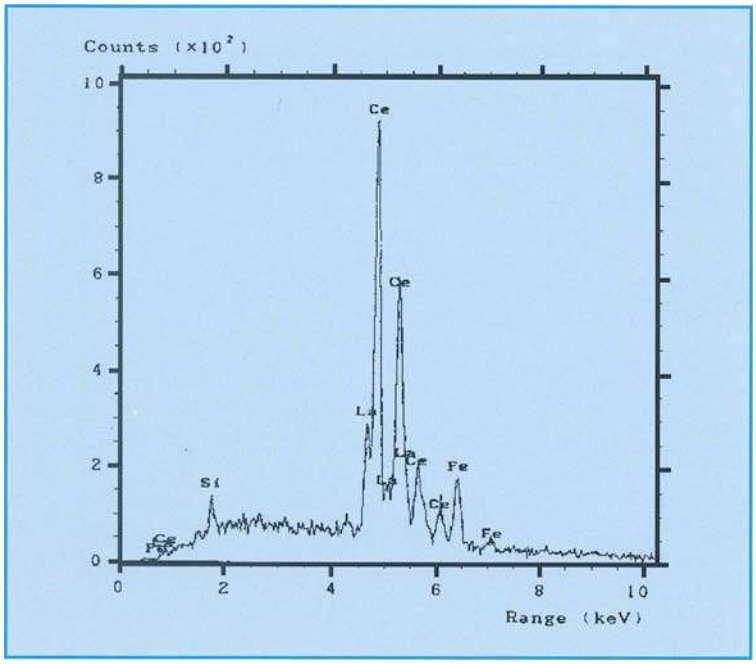

Fig. 11. SEM-EDS chart showing the presence of lanthanum and cerium inside an opaque metallic crystal (see Figure 10).

Fig. 7. Inclusion of an aggregate of black, opaque, lamellar metallic crystals. 400x.

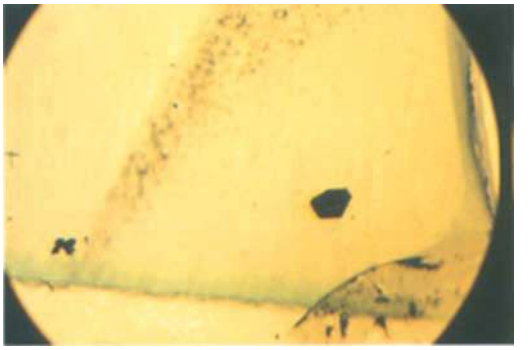

Fig. 8. Six-sided opaque lamellar crystal sited near the boundary of the colourless seed and synthetic emerald. Behind the focal plain many pin-point opaque inclusions are visible. 100x.

described hydrothermally-grown Russian synthetic emeralds containing copper in similar percentages to those of the other minor elements. Copper was not detected either in the metallic wire or inside the emerald described here.

Scattered inside the cut synthetic emeralds and particularly concentrated near the metallic wire of the original crystal, numerous crystalline, opaque pin-point and/or lamellar inclusions were found (Figures 7, 8). The lamellar inclusions show pseudo-hexagonal outline, are dark grey or black and have a metallic lustre. These small inclusions are composed of iron, chromium and titanium oxides (Figure 9). Titanium was not detected in the metallic wire and has not previously been reported in the literature as a component of the inclusions in hydrothermal synthetic emerald. In his 1988 paper, Schmetzer suggested that the metallic particles he described were hematite.

At this stage it seems reasonable to suggest that these inclusions are chromiferous hematite, the chromium and titanium forming a solid solution with iron in the hematite structure.

During examination of the various opaque inclusions one particular metallic crystal showed more reflecting portions, both under the optical microscope and on the secondary electron-image in the SEM (Figure 10). The reflecting portions are formed by crystalline micro-aggregates of rare earth elements lanthanum and cerium (Figure 11). The most likely explanation is that lanthanum and cerium were present as monazite or other rare-earth minerals in the colourless beryl used as a seed plate for growing the hydrothermal emeralds, transferred to the growth-solution and precipitated in their present form. The presence of a small silicon peak (Figure 11) may also be due to incorporation of that element from the seed plate.

Other microscopic features

Dissolution of the beryl seed during the initial stage of the growing process could have been the cause of the development of

Fig. 10. Secondary electron-image of a polished section of a synthetic emerald: an opaque metallic crystal with strongly reflecting zones is visible.

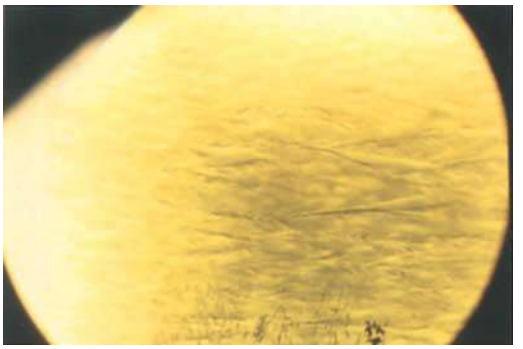

Fig. 12. Angular and spindle-shaped growth planes form an intersecting pattern. 5x.

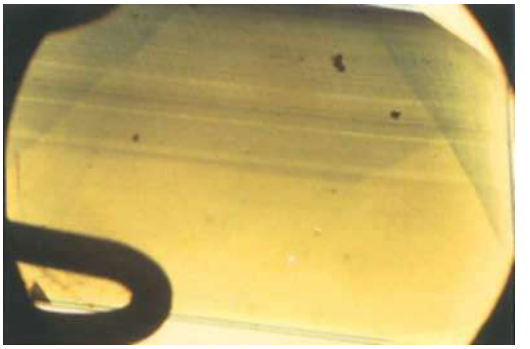

Fig. 13. Faint colour zoning parallel to the contact surface between the colourless seed plate and the synthetic emerald. 200x.

Fig. 14. Isolated phenakite crystal: around it many reflecting metallic inclusions are visible. 400x.

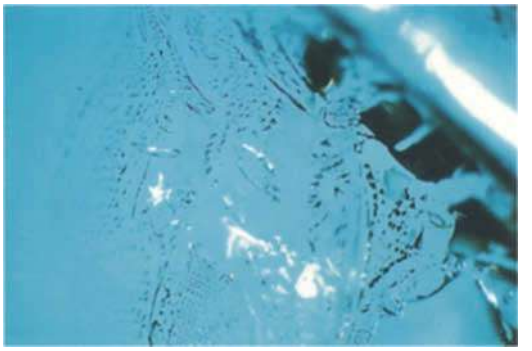

Fig. 15. Liquid feathers and films observed inside Russian synthetic emerald. 200x.

Fig. 16. Flat negative crystals having a shape very similar to that of the growth- figures seen on the surface of the emerald rough. 60x.

Fig. 17. This negative crystal hosts a two-phase inclusion. 100x.

the minute unevenness observed on the seed surfaces. These irregularities appear as a mosaic of microscopic reliefs which acted as nuclei for the growth of crystals of synthetic emerald similar to those described by Schmetzer in his paper of 1988.

The results are visible under the gem microscope, using an immersion liquid, as spindle-shaped growth lines arranged in an intersecting pattern (Figure 12). These angular growth patterns are the most striking and diagnostic features of Russian hydrothermal synthetic emeralds.

Other features seen in the examined emeralds include unusual colour-zoning with an orientation parallel to the seed plate (Figure 13), isolated phenakite crystals (Figure 14) and liquid feathers with two-phase inclusions inside minute negative crystals (Figure 15). Peculiar to the examined emeralds are quite large and flat cavities (negative crystals) whose walls are arranged in geometrical patterns similar to the growth figures observed on the surfaces of rough synthetic emerald (Figure 16). These cavities are also filled by two phase inclusions: liquid and gas or two immiscible liquids (Figure 17). The seed plate and the overgrowth have the same optic orientation, the length being inclined at 43° to the *c*-axis.

Conclusions

The latest Russian synthetic emeralds contain inclusions typical of Russian synthetic emeralds previously described by other authors: irregular step-like or angular growth lines, phenakite crystals, liquid feathers of mono and two-phase inclusions and minute, opaque granular or lamellar metallic particles. In addition, the stones described in this paper contain large and flattened negative crystals filled by two immiscible liquids.

Transition elements detected in the synthetic emeralds, in dispersed form or as metallic particles, are similar but not identical to those previously described and this is probably due to the different wire metal support and autoclave lining used in this production.

Acknowledgements

The authors are grateful to Mr E. Giomo of AGIP SpA for professional work on the SEM-EDS. Many thanks also go to Mr A. Piana who carried out the photographic work.

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Trace elements as colouring agents in jadeites

H. Harder

Göttingen

Abstract

Jadeite may be white, pink, lilac, brown, red, orange, blue, black or many shades of green, and contains different trace elements as colouring agents. Of these trace elements, iron shows the highest concentration and its oxidation states of ferrous or ferric iron produce different colours. In white jadeite nearly all iron is present as ferric (trivalent) iron, while in black jadeite half is ferrous (divalent) and half ferric. In the leaf green jadeites the Fe^{2+}/Fe^{3+} ratio ranges from 0.1 to 0.2.

The finest green Burmese jadeite, whose colour is caused by up to 0.3 per cent chromium, has been called 'Imperial jade' or 'emerald jade'. Contents of iron (up to 0.6% Fe) and nickel (0.04% Ni) can modify the rich chromium green of the jadeite. Lilac, mauve or lavender jade may contain manganese (up to 0.01% Mn), cobalt (up to 0.001% Co), chromium (up to 0.001% Cr) and iron (from 0.006 to 0.3% Fe).

Introduction

The term 'jade' (or 'green stone' as it was previously known) actually refers to different mineral assemblages. Today the definition covers only jadeite and nephrite. Nephrite was a valued material and was used as an 'axe-stone' by many prehistoric human communities for more than 7000 years. Even the famous old Chinese jade artefacts were made from nephrite; jadeite was introduced only in the eighteenth century. Jadeite was also known by the Indians in Central America and in pre-Spanish times they produced very impressive carvings (Foshag, 1955). In those times the Chinese used only nephrite. They called this material 'Chèn Yü', which can be translated as 'real jade'. These two cultural centres stimulated the work in jade and similar elements of craftsmanship were developed.

In the eighteenth century Burmese jadeite was brought to China as 'Yünnan jade'. After some time jadeite also was called 'Chèn Yü', i.e.'true' or 'real' jade. The beauty of some qualities of Burmese material significantly affected the market situation even in the older days. Today the colour is the most important feature of jade and not its toughness, which was its most valuable property in prehistoric times. When we look at the current jade market we must realize that even in China many of the real jade qualities have not the marvellous appeal they had in former times. Nephrite occurs throughout the world in relatively large quantities and is nowadays not an expensive gem material. Only some qualities of jadeite have preserved some of its glory. The rarity of jadeite itself and of its top colours are the major factors in its evaluation. The quality of the material is determined not only by its colour but also by the evenness of the colour distribution, translucency and fineness of grain.

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Fig. 1. Multi-coloured jadeites from Burma. The colour of the emerald-green jadeite, caused by chromium, can also be influenced by iron or nickel. The colour of the blue jadeite is probably due to its high content of titanium and iron. In the mauve jadeite cobalt and manganese may be acting as colouring agents.

The colour range of jadeite

Jadeite occurs without colour as white jade ('Pai-Yü' moon jade, the Chinese symbol also meaning white silk) or in a very wide range of colours, mostly in light shades, but also in stronger pinks, reds, oranges, browns, greens, blues and black. Many shades and hues between the different colours are possible. A single block of jadeite will display different colours in different parts of the block, so it is very difficult to set prices of raw jadeite boulders which have a grey weathering crust. For trading a small window is cut and polished on the surface of each boulder in order to see the quality underneath the weathering skin. The most highly valued colours are the finest emerald green and mauve or lavender. Translucent stones of the superb green colours are called in the trade 'Imperial jade', and this quality is most appreciated and the most expensive in the Far East.

Trace elements in jadeite

The colour range of jadeite indicates that it is an allochromatic mineral. Chemically pure jadeite is white and its colours are acquired from trace elements. The depth of colour in jadeite depends on the content of these trace elements. As jadeite is formed in the vicinity of metamorphic ultrabasic rocks, it is possible that iron, nickel and cobalt may be incorporated in the structure of the newly formed jadeite. Many natural minerals have more than one colouring agent while, in contrast, only one of these colouring elements is usually present in man-made materials.

In white, black and in some green

Table I: Trace elements in Burma jadeite

Colour	*Cr%*	*Ni%*	*Mn%*	*Ti%*	*Fe%*	Fe^{2+}/Fe^{3+}
White jadeite *Pai-Yü* (Moon jade)	0.00	0.00	0.001	0.00–0.02	0.03–0.3	0.01
Black jadeite *Hsi-Yü*	0.01	0.001	0.03	0.04–0.1	0.3–2.0	1.0
Leaf-green jadeite ('Chinese cabbage')	0.00	0.003	0.02	0.01	0.7–1.0	0.1–0.2
Brown jadeite ('Mouth jade')[1]	0.00	0.003	0.02	n.d.	0.7–1.0	0.2
Emerald green ('Imperal jade')						
chrome-rich	0.3–0.4	0.01–0.03	0.01–0.02	n.d.	0.3–0.05	n.d.
nickel-rich	0.01	0.04	0.02	n.d.	0.5	n.d.
iron-rich	0.01	0.01	0.001	n.d.	0.6–0.02	n.d.
Blue jadeite (very rare)[2]	0.03	0.00	0.00	0.16	0.18	n.d.
Mauve jadeite ('lavender jade')[3]	0.001	0.004	0.002–0.01	n.d.	0.006–0.3	0.5[4]

Notes:
1. Cremating gift jade will change colour from green to brown with heat.
2. Only one piece could be analysed by X-ray fluorescence.
3. Mauve jadeite contains 0.001% Co.
4. Only poor qualities could be analysed by wet chemical analyses.

n.d. not determined
Analyses by X-ray fluorescence with Si standard; valency state of iron determined by wet chemical methods.

jadeites iron is the only trace element. All iron ions in white jadeite are found in the trivalent state. In black jadeite – with a higher total iron content – half of the iron ions are in the divalent state. In leafgreen jadeite the ratio of Fe^{2+}/Fe^{3+} is 0.1–0.2. Iron alone does not provide the emerald-green shade of 'Imperial jade'. This is due mainly to chromium but also small quantities of iron and nickel can be found in the high value 'Imperial jade' qualities (Table I). Some high quality green jade samples look similar to the nickel-containing chalcedony, or chrysoprase. Others show a tint of leaf-green, which indicates the presence of iron. In all jadeite samples – even the different emerald-green ones – iron content is higher than that of chromium and nickel. But the colouring effectiveness of iron in jadeites depends very much on its oxidation state. Trivalent iron has little or no influence on the colour in low concentration. Only divalent iron can influence the green colour. So the natural colours are different from one piece to another and the 'beauty' cannot be measured only by the content of chromium

or other elements. In jadeite the lines in the absorption spectra are noticeably diffuse (Gübelin, 1974), probably because it is an assemblage of minerals rather than one single crystal. Chromium should produce a doublet, but the band at 691.5nm is not resolved. A spectral band at 437nm is related to the iron content. The Ni content in the analysed samples was not high enough to be detected as absorption bands in the violet part of the spectrum which was already showing low transmission due to the presence of iron. The subtleties of colours produced by chromium or iron can entail enormous differences in value and in beauty.

Not only emerald-green 'Imperial jade' is highly prized. Lavender jade is also sold at extremely high prices in the Far East. Webster (1970) and Gübelin (1974) speculated that manganese is the reason for the mauve colour and Rossman (1974) related the mauve colour of jadeite to charge transfer from Fe^{2+} to Fe^{3+}. My own analyses have revealed only small amounts of manganese and cobalt in mauve jadeite and it may be that this attractive colour is related to these elements. But with only a few analyses, the interpretation of the mauve colour remains uncertain and the cause of this colour is still a mystery.

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Letters

From Howard L. Blackmore, FGA, antiquary

Dear Sir

I was very interested to read James Gosling's intriguing account of the Cheapside Hoard (*Journal of Gemmology*, 1995, **24**, 6) as I knew George Fabian Lawrence (Stony Jack), the man who obtained the hoard for the London museums. He was, as Gosling says, a quiet gentle man and he did his best in the 1930s to encourage me as a schoolboy to take an interest in archaeological artefacts. Gosling kindly mentions the tributes to Stony Jack's work for the museum but why does he call him 'a vague and shadowy figure'? He was anything but that. He was a dedicated amateur archaeologist but in 1900–1903 he was entrusted with the task of arranging and cataloguing the collections at the Guildhall. He then became Director of Excavations for London until his retirement in 1928. He acted as assistant to the Directors of the London Museum, first to Sir Guy Laking and then to Sir Mortimer Wheeler. If ever a man deserved the description of antiquary it was Stony Jack. In his retirement from his shop in Wandsworth (open all day only on Saturday), he continued his work of rescuing historical remains from the excavations in London. When he died in 1939, Mortimer Wheeler (another antiquary) wrote:

'This Museum, like others, owed more to him than to any other individual and his name will always be associated with the formative period of the collections. Alas, no one has succeeded him. Indeed no one can.'

Yours etc.
Howard L. Blackmore
Caterham, Surrey
5 May 1995

Response from James G. Gosling

Dear Sir

Thank you very much for passing on the intriguing letter from Howard Blackmore. How fortunate to have known the man who could have answered all the questions about the Cheapside Hoard confusion.

In the world of the professional antiquarian George F. Lawrence (Stony Jack) was undoubtedly held in high esteem and clearly he was an important member of the London Museum but when it comes to the Cheapside Hoard discovery things are very different. There appears to be no eyewitness account of the actual discovery and there are at least four distinct versions of the actual find. In three of these the role of Lawrence is very different and unclear.

No – I stick to my phrase 'a vague and shadowy figure' certainly in connection with the Cheapside Hoard for every time I seemed to have the answer a new item of confusion would appear. If only Lawrence had left a diary or some notes – perhaps members of his family still have information about this great event.

I am very grateful to Howard Blackmore because he has focused attention on the remarkable character of Stony Jack. Perhaps this will encourage someone to write a biography of George Fabian Lawrence as, according to Morton, 'no other man has saved so many relics of ancient London for the education and pleasure of future ages'.

Yours etc.
James G. Gosling
Pattingham, Staffordshire
12 May 1995

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Abstracts

Diamonds | Gems and Minerals

Instruments and Techniques | Synthetics and Simulants

Diamonds

Radiolucency of diamond and its simulants.

R. COATES. *Australian Gemmologist*, **18**(11), 1994, 348–51, 8 illus. in black-and-white.

Although the difference in transparency to X-rays for diamond and its simulants has been well documented, unusual circumstances required comparisons to be made in conditions simulating the human stomach, bowel and bony pelvis.

R.J.P.

Gem Trade Lab notes.

R.C. KAMMERLING AND C.W. FRYER. *Gems & Gemology*, **30**(3), 1994, 184–90, 16 illus. in colour.

A yellow-green Old European-cut diamond was found to owe its colour to americium-241 and the stone should not legally be sold until the 50th century. A marquise-shaped brilliant cut diamond showed an unusual triangular inclusion filled with graphite. It was postulated that the inclusion was originally lonsdaleite which being less stable than (isometric) diamond later reverted to graphite. R.J.P.

Gem News.

J.I. KOIVULA, R.C. KAMMERLING AND E. FRITSCH. *Gems & Gemology*, **30**(3), 1994, 191–201, 17 illus. in colour.

Botswana. De Beers reported 15.9 million carats produced in 1993 compared with 17.5 million carats in 1992 due to negotiated agreements between Botswana and the CSO.

West Africa. Ghana Consolidated Diamonds plan to double output to 40 000 carats per month at the Akwatia mine.

South Africa. Production in 1993 was 9.8 million carats with Regional Resources, Canadian Overseas and Diamond Field Resources expanding their activities. The situations in other African countries are summarized.

Australia. In New South Wales the lack of lamproites or kimberlites has elicited a new model of formation for diamonds in this region by subduction of carbon-rich marine deposits followed by metamorphism and transport upwards by nephelinites or alkali basalts. The Argyle joint venture is upgrading plant at the Argyle open pit in the Kimberley region of Western Australia and hopes to increase diamond ore production to 8 million tons.

Former USSR. Almazy Rossii-Sakha (ARS) in agreement with De Beers sold its entire quota of diamonds in 1993 and $600 million worth of diamonds in the first half of 1994. R.J.P.

Les autres grands diamants de la Couronne de Saxe.

B. MOREL. *Revue de Gemmologie*, **122**, 1995, 3–5, 4 photos.

Following a paper on the Dresden green diamond in *Revue de Gemmologie* 121 the diamonds in the Crown of Saxony are described. They include the Dresden White and the Dresden yellow, weighing 49.71 and 39.46ct respectively. The Rose of Saxony diamond weighs 41.77ct and the Queen Eberhardine diamond 25.11ct. Brief notes are given on their settings. The stones form part of the collections of the Green Vaults, Dresden, Germany. M.O'D.

Fracture filled diamonds.

B. SECHOS. *Australian Gemmologist*, **18**(12), 1994,

ABSTRACTORS

M. O'Donoghue	M.O'D.	R.J. Peace	R.J.P.
E. Stern	E.S.		

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379–85, 13 illus. in colour.

After a brief introduction of existing treatments, clarity enhancement or fracture filling using a glass filler with refractive index very close to that of the diamond (Yehuda and Koss methods) was discussed. For the Yehuda treatment the flash effect, using dark ground illumination, a white line on the surface where the fracture emerged, flattened gas bubbles, finger-print inclusions and the cracked mud effect due to partial crystallization were listed whilst for the Koss treatment the purplish flash appeared to be the chief diagnostic feature. Both companies gave lifetime guarantees for their treated stones provided they are kept under normal conditions. Descriptions are given of treated diamonds subjected to extreme conditions including heating to 800°C to simulate jewellery repair conditions and thermal shock by immersion in liquid nitrogen at -185°C. Several examples were quoted of filler instability together with photographs. Declaration of fracture filling is not only important from the legal aspect but diamond jewellery repairers must be able to recognize the treatment. R.J.P.

Gems and Minerals

Tahiti cultured pearl.

M. COEROLI. *Australian Gemmologist*, **18**(12), 1994, 388–94, 6 illus. in black-and-white, 11 illus. in colour.

The Tahiti cultured pearl and its by-products are the most important exports from French Polynesia. Natural black pearls from the black lipped pearl oyster the bi-valve *Pinctada margaritifera* type cumingi were obtained by free-diving in 15–20m yielding only one pearl in 15–20 000 oysters. The first cultured pearls from French Polynesia appeared in 1972. Cultured production really commenced following the establishment of pearl farms in South Marutea and on the Gambier Islands. Advances in technique resulted in establishment of cooperatives during the 1980s. Details of pearl culture are illustrated. Harvest details showed that of 40 pearls obtained from 100 grafted oysters only 15 per cent were round or semi-round. Although the loose pearl market is dominated by Japan and Hong Kong, nevertheless progressive development of the French Polynesian pearl industry should add a prestigious product. R.J.P.

Das Ametrin-Vorkommen von Anay, Santa Cruz, Bolivien.

T. COLLYER, K. FUZIKAWA AND D. SCHWARZ. *Zeitschrift der Deutschen Gemmologischen Gesellschaft*, **43**(3/4), 1994, 117–26, 1 mpa, bibl., 3 illus. in black-and- white, 2 illus. in colour.

The Anay (Anahi) deposit, located in Santa Cruz along the eastern border of Bolivia near Brazil is the only known deposit of bicoloured purple and yellow quartz (ametrine) of economic interest. The mine is currently being worked by Minerales y Metales del Oriente SRL (M & M), a private Bolivian company, with a steady monthly production of about 400kg of gem quality rough. The amethyst and citrine are associated with hydrothermal quartz veins which cut across the dolomite and limestone formations of the Murcielago group. E.S.

La gravure sur pierres précieuses: les rubis et les spinelles.

M. DUCHAMP. *Revue de Gemmologie*, **122**, 1995, 10–15, 9 photos (3 in colour).

The history and techniques of engraving on ruby and spinel are described with reference to several museum pieces. M.O'D.

Flussperlen in Bayern und Böhmen.

H. HAHN. *Gemmologie – Zeitschrift der Deutschen Gemmologischen Gesellschaft*, **44**(1), 1995, 33–8.

River pearls have been found in Europe for many centuries in various rivers in Bavaria, Bohemia, Russia, Scandinavia, Spain, Lorraine (France) Brittany (France) Lüneburg Heath (Northern Germany) as well as Saxony. Because of growing pollution the European pearl fishing industry is very small; in Scotland a few rivers yield some mussel pearls. The author describes the propagation of the mussels and surveys the occurrences of freshwater pearls in Bavaria and Bohemia. Recently some 150 000 mussels from Russia have been placed into Bavarian rivers, not primarily for the production of pearls, but in the hope that the behaviour of the mussels may help to detect various types of pollution. E.S.

Contribution à l'étude des caractéristiques distinctives des saphires du Cachemire (second part).

H.A. HÄNNI. *Revue de Gemmologie*, **122**, 1995, 6–9, 10 photos (5 in colour).

Inclusions characteristic of Kashmir sapphire are described. Rutile needles, green tourmaline crystals, long crystals of zircon and crystals of

plagioclase, uraninite and allanite-(Ce) are also found, together with fine lamellae and zoning with exsolved material and fissures. Internal features noted by other writers are listed. M.O'D.

Makusanit – ein klar durchsichtiger Obsidian aus Peru.

U. HENN. *Gemmologie – Zeitschrift der Deutschen Gemmologischen Gesellschaft*, **44**(1), 1995, 25–8, 2 illus. in black-and-white, 1 in colour, bibl.

The material comes from Puno in Peru and is found in aluminosilicate bearing ignimbrites of Miocene to Pliocene age. It is a clear brownish transparent rhyolitic obsidian. RI 1.489, SG 2.36. Aluminium silicate inclusions were found in the shape of elongated prisms. E.S.

Saphire von Indaia, Minas Gerais, Brasilien.

U. HENN, H. BANK AND F.H. BANK. *Zeitschrift der Deutschen Gemmologischen Gesellschaft*, **43**(3/4), 1994, 111–16, 1 map, bibl., 4 illus. in black-and-white, 1 in colour.

A new corundum occurrence in Brazil near Indaia in Minas Gerais produces transparent blue sapphires. RI $n\varepsilon$ = 1.760–1.763 $n\omega$ = 1.768–1.771. DR = 0.008 SG = 3.99–4.02. The absorption spectrum shows typical bands of Fe^{2+}/Ti^{4+} and Fe^{3+}. Chemical analysis showed traces of iron and titanium besides aluminium. Mineral inclusions of mica and rutile, healing cracks and distinct growth and colour zoning could be seen under the microscope. E.S.

Gemmologische kurzinformationen.

U. HENN, H. BANK AND C.C. MILISENDA. *Zeitschrift der Deutschen Gemmologischen Gesellschaft*, **43**(3/4), 1994, 105–9, 3 illus. in black-and -white, 4 in colour.

Some cuttable peridots were said to come from a new occurrence in Pakistan. The tested faceted examples weighed from 1.99 to 12.41ct. There is also a report of grossular-andradite from Mali; the colour varied from pale to yellow green to brown with a relatively high RI of 1.755–1.774; the SG of the faceted stones was between 3.58 and 4.19. A translucent white beryllonite cat's-eye cabochon with definite cat's-eye effect was said to come from Afghanistan; RI about 1.55, SG 2.80. E.S.

Azurit-Malachit – Verwechslungsmîglichkeiten und Imitationen.

U. HENN AND B. SCHNEIDER. *Zeitschrift der Deutschen Gemmologischen Gesellschaft*, **43**(3/4), 1994, 127–32, 1 table, 2 graphs, bibl., 2 illus. in colour.

Azurite-malachite is the result of natural coalescence of the blue azurite and the green malachite, often with chrysocolla, turquoise, quartz and possibly some other components. Gemmological examination is difficult as the various components have varying RI and density. For the laboratory a method using infrared spectroscopy is advised. An imitation often found on the market consists of pressed products of azurite and malachite sometimes with the addition of chrysocolla. Another imitation is made of gibbsite, partially coloured by ultramarine. E.S.

Hsa-Taw green tourmaline.

U.T. HLAING. *Australian Gemmologist*, **18**(11), 1994, 352–3, 1 illus. in black-and-white, 3 in colour.

The Hsa-Taw tourmaline comes from south-east Myanmar (Burma) close to the Thailand border. Its gemmological properties are standard for elbaite tourmaline and display a variety of inclusions including trichites, colour zoning, possible mica and undetermined solid black inclusions. R.J.P.

Smaragdgrüne Chrom-Titanite aus dem Ural, Russland.

J. HYRSL AND C.C. MILISENDA. *Gemmologie – Zeitschrift der Deutschen Gemmologischen Gesellschaft*, **44**(1), 1995, 29–32, 1 illus. in black-and-white, bibl.

Faceted green titanites (sphene) were recently offered on the German market. These stones come from the Sarany chromium deposits in the Perm region in the central Urals. The sphenes occur as grass green to dark emerald green crystals up to 8cm in length with definite pleochroism. Transparent pieces are much smaller and cut samples are not bigger than 0.25ct. SG 3.54, RI 1.908–1.912 to 2.07–2.099, DR 0.16–0.19. E.S.

Gem Trade Lab notes.

R.C. KAMMERLING AND C.W. FRYER. *Gems & Gemology*, **30**(3), 1994, 184–90, 16 illus. in colour.

A 'carving' showed an unexplained hole in the base and parallel striations together with cracks which showed no vein-filling materials. X-ray diffraction analysis showed mullite, kalsilite and gehlenite which are rare minerals and not found together in nature, but are found in ceramics. A

modified rectangular step cut stone was identified as natural citrine containing a prominent well-formed first-order prism termination which proved to be quartz but of a different orientation to the host.

A handsome mottled white and green rock described as massive grossular garnet was shown to be dominantly white grossular with diopside, vesuvianite and clinochlore. A necklace of highly polished black beads, sold as black jadeite, showed a 'spot' RI of midway between 1.60 and 1.70 and an SG of 3.36 but with an unusual evenness of polish. X-ray diffraction analysis showed the beads to be ferrohornblende an iron-rich member of the amphibole group. Visible light spectroscopy of intense green jadeite beads showed natural colour whilst infrared spectroscopy showed they were not polymer impregnated. The fineness of the aggregate resulted in such high diaphaneity that the stringing cord was clearly visible even in the largest bead. An unusual barrel-shaped black pearl showed both a solid black appearance and distinctive banding. When exposed to long-wave ultraviolet radiation the dark areas fluoresced a very strong red as seen in other black pearls from the Gulf of California whilst X-ray radiography revealed a large dark central core which proved the pearl was natural. A treated-colour black pearl showed the visual damage to the nacre layers and iridescence. EDXRF analysis showed the presence of silver. A blue sapphire was proved to be free from heat treatment on the basis of inclusions which resolved into two phases on cooling. A colour zoned synthetic sapphire appeared a uniform yellow orange face up but from the side all but a small orange area appeared pink. Curved banding in the orange zone proved it was synthetic. An opaque mottled brown and white carving was shown to consist of serpentine and forsterite. A piece of partially polished blue rough was identified as turquoise and a colourless transparent substance on the surface shown to be a polymer by infrared spectroscopy.

R.J.P.

Almandine garnets from Vietnam.

R.C. KAMMERLING AND J.I. KOIVULA. *Australian Gemmologist*, **18**(11), 1994, 356– 8, 1 table, 4 illus. in colour.

A number of garnets from this source were examined referring to the criteria of Stockton and Manson and classed as almandine. Chemical analysis showed the stones to be essentially almandine with minor pyrope, grossular and spessartine components.

R.J.P.

Gem news.

J.I. KOIVULA, R.C. KAMMERLING AND E. FRITSCH. *Gems & Gemology*, **30**(3), 1994, 191–201, 17 illus. in colour.

'Caymanite' from the Grand Cayman Islands was shown by X-ray diffraction to be dolomite found as a banded rock with orange-brown and cream coloured layers. A carving of green beetles on a brown matrix is chrysoprase and chalcedony matrix from the Yerilla district in Western Australia. Iridescent demantoid garnet from Mexico was shown to be very pure andradite with no chromium and only a trace of manganese. 'Pearls' from the horse conch *(Pleuroploca gigantea)* showed a clearly visible flame structure. New sources of peridot from Pakistan and rhodonite from the Yukon were reported. The origin of satellite readings on the refractometer from a tourmaline was thought to be the result of thermal shock or overheating when the stone was polished.

Natural gem production in the USA reached a total value of $51 million in 1993 and synthetics were valued at $19 million. Freshwater pearls at $25 million headed the natural list whilst shell inserts for cultured pearls produced $53 million.

Enhancements: A coated jadeite with mottled green varnish together with a clear outer coating gave a positive hotpoint test. The strong chalky blue fluorescence to long-wave UV radiation contrasts with the normal spotty and yellowish-white fluorescence of natural jadeite.

R.J.P.

Schleifwürdige Granate (Grossulare) von einem neuen Vorkommen in Mali.

TH. LIND, H. BANK AND U. HENN. *Gemmologie – Zeitschrift der Deutschen Gemmologischen Gesellschaft*, **44**(1), 1995, 17–24, 2 tables, 3 graphs, five illus. in colour, bibl.

The article describes chemical and physical properties of a yellow-green to greenish- brown grossular from Mali, but details of the locality are not given. Distinct growth zoning and distinct anomalous double refraction under crossed polars can be observed. RI 1.758 to 1.785, SG 3.63 to 3.72. Spectra show absorption lines of Fe^{3+} superimposed on an intense absorption band with a maximum in the ultraviolet.

E.S.

Gemmologische Kurzinformationen. Short notes from the gemmological laboratory of the German Foundation for Gemstone Research.

C.C. MILISENDA. *Gemmologie – Zeitschrift der Deutschen Gemmologischen Gesellschaft*, **44**(1), 1995, 3–8, 8 illus. in colour.

A new occurrence of gem quality sapphires from Madagascar has been found in the south-west of the island, these are pale to dark blue, elongated ditrigonal bipyramids, between 0.49 and 1.32ct, RI 1.761–1.763 to 1.769–1.771, DR 0.008, SG 3.91 to 3.98. Distinct colour and growth zoning with swirls. The most striking inclusions are hollow tubes. Other stones submitted to the laboratory included two ruby cabochons and a rough sample of the same material from China, one of the stones showing distinct asterism due to rutile needles. Blue opals from Peru are greenish-blue to blue with black dendrite inclusions. Fine faceted fire opals from the Shaphane mountains in Turkey are reddish, orange and yellowish-red and comparable to the Mexican fire opals with RI between 1.442 and 1.446 and SG 2.00–2.02. Opal embedded in sandstone matrix from Andamooka in South Australia is similar to the opalised sandstone from Louisiana. The Andamooka material showed yellow, green and blue play of colour. E.S.

Seltene Edelsteine von St. Hilaire, Quebec, Canada.

C.C. MILISENDA, J. SCHLÜTER AND G. GEBHARD. *Zeitschrift der Deutschen Gemmologischen Gesellschaft*, **43**(3/4), **1994**, 133–42, 5 tables, 1 map, bibl., 2 illus. in black-and-white.

The Mont Saint-Hilaire in Quebec lies 20km east of Montreal and is part of the Monteregian Hills; Mont Saint-Hilaire has a diameter of about 3km and is roughly 350m above the St. Lawrence river plain. The most productive occurrence is the Poudrette open mine. Most of the gemstones are found in peralkaline syenites. Among the stones described are a 0.44ct transparent, faceted yellow shortite (a sodium calcium carbonate) and a 0.03ct faceted colourless leifite. Other cuttable gemstones found at Mont Saint- Hilaire include carletonite, eudialyte, hackmanite, katapleite, natrolite, remondite, rhodochrosite, serandite, siderite, sphalerite, villiaumite and willemite. E.S

Heat treated corundums of Sri Lanka; their heat treatment.

T.G. PEMADASA AND M.V. DANAPALA. *Australian Gemmologist*, **18**(11), 1994, 346–7, 1 table.

Before the 1970s the Sri Lankan corundum now known as geuda was often discarded by miners and gem dealers. Thai dealers purchased large amounts and successfully converted poor quality geuda into blue sapphire. Now heat treatment is carried out in over 200 furnaces in Sri Lanka by Sri Lankans. Many use a butane-oxygen mixture. The geuda is divided into two groups. Group I consisted of translucent smoky geuda and partially coloured clear blue corundum known as *otto* which is treated using a reducing flame. Precise temperatures and times are quoted. Group II consisted of bluish ruby and red geuda which yielded ruby and pink sapphire and a third member, Kowangu yellow sapphire, which is slightly yellowish in reflected light due to fine inclusions and yields either yellow or padparadscha sapphire. Oxidizing conditions were used for this group. R.J.P.

Instruments and Techniques

Das Diamond Colorimeter DC 200.

B. GÜNTHER. *Gemmologie – Zeitschrift der Deutschen Gemmologischen Gesellschaft*, **44**(1), 1995, 39–43, 4 graphs (1 coloured), 1 illus. in colour.

The Diamond Colorimeter by Gran Computer Industries Ltd is described. Its design is based on colour perception similar to that of the human eye. The diamond is subjected to three colours and those wavelengths which are absorbed by the diamond are measured. The author does not think that its performance matches that of the human eye but that it should be a useful complementary tool. E.S.

Gemlite polariscopes.

T. LINTON, B. NEVILLE AND A. Shields. *Australian Gemmologist*, **18**(12), 1994, 386–7, 1 illus. in black-and-white.

Two models were examined by the GAA Instrument Evaluation Committee. Both were considered good value for money and are of the conventional type. Addition of a X5 lens would have helped in the examination of small stones. Polarized reflections from the aluminium mounting holding the polariser caused some misleading ADR results and the tendency for one of the instruments to fall over in use showed some lack of basic design but all the faults were easily eliminated. The incorporation of an on/off switch would improve the safety aspects. R.J.P.

Synthetics and Simulants

Synthetische Opale aus China und Russland.

U. HENN, L. ACKERMANN AND K. SCHODER. *Gemmologie – Zeitschrift der Deutschen Gemmologischen Gesellschaft*, **44**(1), 1995, 9–15, 1 table, 3 illus. in black-and- white, 6 in colour, bibl.

Two new types of synthetic opals have come onto the market. First, green and pink opals from China show regular, sharply bounded colour patches with lizard-skin effects and columnar structures. The opals are composed of closely packed silica spheres about 320nm in diameter; there is an ignition loss of about 20 per cent at 1000°C; SG = 1.80– 1.90, RI = 1.450–1.468.

The second type is from Russia and looks very like natural opal. The material is composed of strongly distorted silica spheres with an approximate diameter of 240nm. Ignition loss at 1000°C is about 8 per cent; SG = 1.74–1.86; RI = 1.440–1.450. E.S.

Gemmologische kurzinformationen.

U. HENN, H. BANK AND C.C. MILISENDA. *Zeitschrift der Deutschen Gemmologischen Gesellschaft*, **43**(3/4), 1994, 105–9, 3 illus. in black-and-white, 4 in colour.

The Austrian firm Swarovski has marketed a new glass imitation of emerald under the name of 'Swarogreen'. The tested faceted stone weighed 0.22ct RI 1.600 (lower than Swarovski's figures of 1.605–1.615), SG 2.98 (higher than Swarovski's 2.88–2.94). No inclusions could be observed. An intensively yellow brilliant-cut diamond was tested and found to be synthetic. It weighed 0.34ct and was found to be Type Ib. No provenance was given. A new synthetic emerald from the USA was marketed under the name of 'Kimberley created emerald' by the firm Kimberley Inc. NY. The stones were produced by hydrothermal synthesis; the firm plans to produce in future also rubies, sapphires and alexandrites. Another synthetic emerald produced hydrothermally comes from China from the firm Techyears Industries Ltd; this shows very strong red fluorescence. Also from China, there is a new synthetic opal; RI 1.450–1.468 with a distinct lizard skin effect. Another synthetic opal, but without the lizard skin effect, came from Russia; these opals had an RI 1.44–1.45, and an SG 1.74–1.86 which is relatively low due to its obvious porosity. E.S.

Gem news.

J.I. KOIVULA, R.C. KAMMERLING AND E. FRITSCH. *Gems & Gemology*, **30**(3), 1994, 191–201, 17 illus. in colour.

Synthetic phenacite from Russia in the form of transparent bluish-green crystals produced by the flux growth method had the optical and physical properties associated with natural phenacite. Apart from its distinctive colour, flux inclusions provided the most obvious clue to its synthetic nature. These phantom structures appeared to be trapped along growth steps and varied in colour from colourless to a greenish-brown.

The firm Tairus, a joint venture between the Russian Academy of Sciences and Pinky Trading Co. of Bangkok, opened a new facility in Novosibirsk, Siberia, for synthetic gemstone production in late 1994. The prime activity is that of producing hydrothermal synthetic emerald. R.J.P.

Gemmologische kurzinformationen. Short notes from the gemmological laboratory of the German Foundation for Gemstone Research. (in German and English)

C.C. MILISENDA. *Gemmologie – Zeitschrift der Deutschen Gemmologischen Gesellschaft*, **44**(1), 1995, 3–8, 8 figs in colour.

Hydrothermally grown synthetic emeralds are marketed by A.G. Japan Ltd. under the name 'AGEE Emeralds, refined and recrystallized' – the rough emeralds are apparently crushed, purified using a laser technique and then recrystallized under hydrothermal conditions. This description is not in agreement with CIBJO nomenclature and the stones should be sold as synthetic emeralds; RI 1.569–1.575, DR 0.006, SG 2.69. Faceted artificial glasses are being marketed under the name of 'lazerite' imitating peridot, citrine, tanzanite, and a blue similar to tourmalines from Paraiba. RI 1.519 to 1.520, SG 2.47 to 2.53. Gas bubbles and swirl marks can be seen under a microscope. E.S.

BOOK REVIEWS

Properties and growth of diamond.

G.DAVIES (Ed.), 1994. INSPEC/Institution of Electrical Engineers, London. pp xv, 437, illus. in black-and-white, hardback. Price £135.00. ISBN 0 85296 875 2.

Forming no 9 of EMIS Data Reviews series the contents of this large book appeared at first glance to be a set of benchmark papers but the 90-plus papers are all freshly written. I cannot think of a more timely compilation and since, as the foreword says, all the important aspects of diamond science are contained in the volumes of articles edited by Berman (1965), Field (1979 and 1992) and Wilks & Wilks (1991) it has become vital to present the substance of those articles in a form giving the important parameters characterizing all the forms and conditions of diamond.

While most gemmologists will find the topics of diamond physics and diamond growth of great interest many will find the papers written in the rigorous language of physics and chemistry and may not attempt to find the many points which have a direct bearing on diamond as a gemstone. None the less, some will make the attempt and will probably find the most interesting sections to be those dealing with the growth of diamond by chemical vapour deposition, the high-pressure growth of diamond, the decay times of luminescence and laser action in diamond and the properties of nitrogen in diamond. Each paper has its own list of references and there is a subject index. The price is not unreasonable for a book of such size.

M.O'D.

Zeolites of the world.

R.W. TSCHERNICH, 1992. Geoscience Press, Phoenix, AZ. pp 563, illus. in black-and-white and in colour, hardback. Price £67.00. ISBN 0 945005 07 5.

Though by their nature few zeolite species are likely to find themselves used ornamentally, readers may none the less find this book useful for details of analcime, pollucite and yugawaralite (all of which I have seen in faceted form) but far more importantly as an example of what such a survey should be. Many gemmologists are mineral collectors too and they should certainly buy the book. The text is well-organized and as comprehensive as possible with references, in the excellent bibliography, up to 1991.

M.O'D.

The history of mineral collecting, 1530–1799, with notes on twelve hundred early mineral collectors.

W.E. WILSON, 1994. Mineralogical Record, 25(6), pp 1–264, illus. in black-and-white and in colour.

Priced at US$24.00, this monographic issue of the *Record* introduces mineral collectors from the mid-sixteenth century to the end of the eighteenth, with notes on their collections and reproductions, many in colour from their works where appropriate. Among the collectors celebrated for their cabinets of gem minerals are Jacob van der Näll, Abraham Gottlob Werner (Germany), Sir Hans Sloane and Alexander Crichton (Great Britain) René-Just Haüy and Jacques de Bournon (France). I know of no comparable account and details of European collectors and their specimens are especially hard to come by. There are several very full lists of references and the standard of colour reproduction from early books is particularly good. Title-pages of many of the books concerned are reproduced in black-and-white.

M.O'D.

Gem reference guide for the GIA colored stones, gem identification and colored stone grading courses.

Gemological Institute of America, 1993. Santa Monica. pp ix, 270, illus. in black-and-white and in colour, hardcover.

Stones forming part of the GIA identification courses are described with full listing of properties and coloured representations of absorption spectra where appropriate. Entries also include notes on care and cleaning, market availability, sources and recommended disclosures of treatment where applicable. Key separations point out the major possibilities of confusion with other species and with artificial products. Particularly welcome and shown in no comparable book are the colour photographs of specimens, mostly cut stones. Notes on mode of occurrence are not given but in all this is a most attractive and useful guide.

M.O'D.

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Hohe Tauern: Mineral & Erz.

1994. Naturhistorisches Museum, Wien. pp 149, illus. in black-and-white and in colour, soft-cover. Aus.Schg. 1,250. ISBN 3 900 27548 3.

Useful information on emerald from Habachtal is given in this survey of the Hohe Tauern area of Austria. The book deals not only with geology and mineralogy but also with fossils and with the National Park which occupies much of the area.

M.O'D.

Gems, their sources, descriptions and identification.

R. WEBSTER, 1994 (fifth edition). Butterworth-Heinemann Ltd, Oxford. pp xxviii, 1026, illus. in black-and-white and in colour. Price £75.00. ISBN 0 7506 1674 1.

The revision of a work such as this cannot be undertaken lightly. Those who accepted the challenge are to be congratulated for effectively and sympathetically updating a mammoth work.

The book has been revised by a number of specialist contributors under the able editorship of Peter Read and the text has a welcoming appearance as the former long paragraphs have been divided into more readable length. The bibliography contains a pleasingly high proportion of up-to-date gemmological literature of an authoritative nature. Additional specialist volumes are mentioned in the text where appropriate.

Revision has in general been conservative. However, the results of the latest research, newly discovered deposits, recently developed equipment and changes in techniques have been included, and some heaviness of historical detail has been reduced. Where substantial rewriting has occurred, it is mostly succinct and light in style.

Given that this weighty tome is a specimen well worth collecting, it is to be expected that at a cost of well under 1p per carat, there will be some imperfections.

Illustrations: Some of the black-and-white photographs can be said to be of historical interest but the continued use of others, now of poor definition, cannot be justified. Some changes are purely cosmetic: a photograph of a lone pearl fisher, standing in a Scottish river and peering into his glass-bottomed tub has been removed, and although of more pleasing artistic composition, the replacement photograph leaves much to the imagination! Unfortunately, in the same section, the Lauegram patterns produced by natural and cultured pearls have been printed above one another's captions.

The frontispiece neither excites nor educates and overall the selection of colour plates lacks imagination. Plates 9 to 14 inclusive are out of focus and the spectrum diagrams need updating for proportion and realism. Several photographs in the text intending to demonstrate relative sizes of items have no scale and are, therefore, of limited value. Students unacquainted with certain crystal specimens will not be enlightened by some photographs contained in the text. A good line drawing of a star sapphire would convey more than its dismal photograph.

Text: In the diamond chapter previous theories regarding its origin have been omitted, but unfortunately the results of important research still in progress during the preparation of this edition have not been included.

For the ruby and sapphire chapter the rearrangement of the presentation works well. Unfortunately, where additions have been made, colloquial expressions have been introduced. These will date and may be a problem where English is not the reader's first language. The review of this topic is a highly individual one and these passages do not blend sympathetically with the general tone of the work. A work of this nature is no place for political statements and the editor might usefully have wielded his blue pencil more heavily here. On the other hand, in this chapter, inclusions are now dealt with by type rather than provenance, and pertinent references are made, where confusion might arise between inclusions of similar appearance, in both natural and synthetic stones. This is a distinct improvement.

In places there is some inconsistency of information and for instance on the topic of trapiche emeralds, the 4th edition reported them as found in 1946, the 5th edition in 1964, while in *Emerald and other beryls* (Sinkankas, 1989) relates a detailed history beginning with their first notice in 1879.

In the chrysoberyl chapter, the spectrum of alexandrite is described as resulting from an anomaly. Not so. It has all the characteristics of a good chromium spectrum. Evenly balanced transmission of wavelengths, in the red and green, causes the characteristic colour change depending on the nature of the incident light. The ubiquitous use of fluorescent lighting today means that reference to colour-changes in gems could better be made using the words 'incandescent light', rather than 'artificial light'.

Some 24 extra items have been included in 'Lesser known ornamental and gem materials' but the generally available sogdianite is still only mentioned in passing under sugilite.

J.R.H. Chisholm would have been pleased to note that 33 years after his review of the first edition, the crystal axes of the monoclinic system have now been defined correctly. However, some picturesque errors from that edition are still evident. Those who expect to see the mean refractive index of malachite at 1.85 on the refractometer, are sure to be disappointed; likewise those who hope to see a single vagrant extraordinary ray shadow edge, when a dark brown tourmaline is rotated on the refractometer prism.

Strangely, there is still considerable emphasis on the use of Clerici solution. As this is not available for general testing, and should only be used at all in controlled laboratory conditions, the coverage of its use in such details seems inappropriate. Perhaps Rohrbach's solution could have been mentioned.

There are some inevitable inconsistencies of fact where different reviewers have dealt with the same subject under different headings. Calculations comparing the weight of a diamond and a strontium titanate of equal size could more usefully have been adapted for CZ. The expression 'in recent years', used variously throughout, seems to indicate, as far as could be ascertained, a span of anywhere between the mid-eighteenth century and the start of the present decade!

Some terms, such as 'Liesegang bands', explained in previous editions are now without explanation. Other terms, such as 'Nomarski interference contrast techniques', appear for the first time but without explanation or reference. Name-dropping of technical terms 'which are not our concern here' could have been eliminated without detriment to the text and a glossary of relevant specialist terms would be helpful. A few examples are banket, Joplin jig, aureole, aplite, coenosarc and tenebrescence. Some of the terms used are not even in standard geology, mineralogy, physics or science dictionaries.

Table 1 is a consolidation of the main gem constants in mean RI order. The other tables of separate constants are much as before, suitably updated, although the list of suggested permissible names has been omitted. An additional appendix giving all the causes of colour of gems, where known, would have been most welcome.

Compiling and revising an index is by no means the least of the tasks required for a new edition. An exhaustive test of the index has not been possible and although some headings are still ambiguous, so far all references sought have been found.

My copy of the work has had one careful owner and already the spine is beginning to separate from the body of the book. The board used for the cover is less substantial than that of previous editions. For a volume which will undoubtedly receive much use, this is a pity.

The content represents an extra 9.3 per cent in the text, having over 10 per cent more words to the page than the 4th edition. The weight has been reduced by just under 3 per cent and is about 1.94kg. All units of measurement now conform to international standards.

When not actually on the desk, this 5th edition of Webster's 'magnum opus' needs to be readily accessible as it will undoubtedly be indispensable to the enthusiastic gemmologist and voracious student alike. G.M. Green

Turmalin: der Edelstein des Regenbogens. Neueste Nachrichten von der Turmalin-Gruppe.

[extraLapis. no.5], 1994. Christian Weise Verlag, München. pp 96, illus., in black-and-white and in colour, softcover. Price DM 29.80. ISBN 3 921656 31 1.

At an absurdly low price here is one of the very finest illustrated books on a single gem species (a mineral group, of course) that I have yet seen. With colour photographs on nearly every page the book would delight anyone and especially the beginner in gemmology. Particular topics covered include early work on the properties of tourmaline, on its crystal forms, how the different colours are accounted for and details of historical and new discoveries. The book is designed to be read right through and I recommend readers to do so, as fresh stimuli to your gem studies will be received every time the page is turned. Everyone has their favourites but look at the blue Paraíba specimens on page 47 – even better are the Mount Mica crystals on page 78. Several illustrations from the mammoth book by Benesch (1990) are included. The book forms part of the series extraLapis and, like its five predecessors, is not included in the subscription to the main journal *Lapis*. M.O'D.

Proceedings of the Gemmological Association and Gem Testing Laboratory of Great Britain and Notices

PHOTOGRAPHIC COMPETITION

The second GAGTL Photographic Competition again stimulated some exceptional pictures on the theme 'The spectrum of gemstones'.

The winner, with a picture of the interference colours from cleavage in gem sphalerite (see cover picture), was Wilma van Opstal of Tilburg, The Netherlands. Second prize was won by Michael J. Crowder of Camberley, Surrey, for a phase-contrast picture of a diamond crystal (submitted while he was studying for the Gem Diamond Diploma). Third prize was won by David Minster of Pretoria, South Africa for a close-up of the iridescent colours of paua shell.

The three prize winners receive awards of £100.00, £75.00 and £50.00 respectively and plans are advanced to include these pictures and a selection of other fine entries in the 1996 GAGTL calendar.

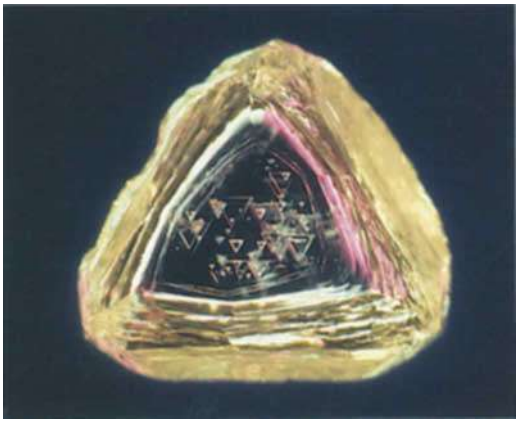

Second Prize. Trigons on a diamond crystal.
Photograph by Michael J. Crowder.

Third Prize. Paua shell from New Zealand.
Photograph by David Minster, FGA.

OBITUARY

Mr Claude B. Jones FGA, DGA (FGA 1972, DGA 1973), Northampton, died on 30 December 1994.

Mrs Marja L.A. Pitkanen FGA (D.1987), Kukkila, Finland, died on 1 January 1995.

Mr John Reginald Shaw, FGA (D.1968), Birstwith, near Harrogate, died suddenly on 4 May 1995.

Mr Douglas N. Wilson, FGA (D.1963), Paradise, South Australia, died recently.

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George Lindley & Co Ltd, London, for a parcel of mixed diamond simulants.

Thomas M. Schneider, San Diego, California, for rough samples of blue and greenish-blue apatite for teaching purposes.

The Scottish Branch of the GAGTL for the book *The Honours of Scotland* by C.J. Burnett and C.J. Tabraham (1993), Historic Scotland, Edinburgh.

Swarovski, Switzerland, for five synthetic rubies.

Wu Chao-Ming, Taiwan, for a garnet crystal and a piece of rough serpentine.

MEMBERS' MEETINGS

London

On 12 June in the Gem Tutorial Centre at 27 Greville Street, London EC1N 8SU, the Annual General Meeting was held, followed by the Reunion of Members and Bring and Buy Sale. A full report appears on page 527.

On 16 June at the Royal Automobile Club, Pall Mall, London SW1, the Annual Trade Luncheon was held. The speaker was Mr Jeremy Richdale, a Director of the Central Selling Organization, and a report of his address will appear in the September 1995 issue of *Gem and Jewellery News*.

Midlands Branch

On 28 April at Dr Johnson House, Bull Street, Birmingham, the Annual General Meeting of the Branch was held, at which Jim Porter was re-elected Chairman and Mandy MacKinnon and Neil Rose were elected to share the post of Secretary. The AGM was followed by a talk by Mrs Carson on the work of the Assay Office.

Gem Clubs were held on 16 April, 21 May and 18 June.

North West Branch

On 17 May at Church House, Hanover Street, Liverpool 1, Eric Emms gave an illustrated talk entitled 'Diamonds in the Laboratory'.

On 21 June at Church House, Dr John Franks gave an illustrated talk on 'Geological jewellery and souvenirs'.

Scottish Branch

On 19 May at the Assay Office, Goldsmiths Hall, 39 Manor Place, Edinburgh, the inaugural meeting of the new Branch was held, at which Joanna Thomson was elected Chairman. Ana I. Castro gave an illustrated talk entitled 'Gem testing in the Laboratory'.

ANNUAL REPORT

The following is the report of the Council of Management of the GAGTL for 1994.

The Gemmological Association and Gem Testing Laboratory of Great Britain (GAGTL) is a company limited by guarantee and is governed by the Council of Management. This year Eric Bruton was elected President at the Annual General Meeting in June. The activities of the company benefited enormously from the contribution of other major councils and committees and in September Dr G. Harrison Jones took over as Chairman of the Board of Examiners from E.A. Jobbins, C. Winter took over as Chairman of the Members' Council from R. Velden and J. Kessler continued as Chairman of the Trade Liaison Committee. In addition, the Education Review Meeting provided a very useful forum to exchange information between teachers, examiners and staff of the Association which helped in developing the path of gemmological education.

During 1994 the GAGTL continued to expand its major activities and can report a successful financial year. In the laboratory, growth in diamond grading continued and additional staff were recruited to deal with the extra work. In addition to CIBJO and GIA diamond reports, the Laboratory now

FORTHCOMING MEETINGS

London

1 October	GAGTL Annual Conference to be held at the Scientific Societies Lecture Theatre, New Burlington Place, London W1. The theme will be *Gemmology in Britain.*	
16 October	**Recent developments in the diamond industry.** Howard Vaughan. To be held in the GAGTL Gem Tutorial Centre, 2nd floor, 27 Greville Street (entrance in Saffron Hill), London EC1N 8SU. The charge for a member is £3.50. Entry will be by ticket only, obtainable from the GAGTL.	

Midlands Branch

29 September	**Jewellery valuations and their attendant problems**	Philip Stocker
27 October	**Pearls - production and identification**	Stephen Kennedy
24 November	**Jewels in the hand**	James Gosling

The meetings will be held at Dr Johnson House, Bull Street, Birmingham. Further details from Mandy MacKinnon on 0121-444 7337 or Neil Rose on 0161 832 2551

North West Branch

20 September	**Natural history of jewellery**	Dr John Franks
18 October	A gemmology evening – no charge, open to members and friends	
15 November	Annual General Meeting	

Meetings will be held at Church House, Hanover Street, Liverpool 1. Further details from Joe Azzopardi on 01270 628251.

Scottish Branch

19 September	A visit to the British Geological Survey, Edinburgh
20 October	A talk by Doug Garrod to be held at Newliston House, Edinburgh

Further details from Ruth Cunningham on 0131-225 4105

issues the London Diamond Report using harmonized colour and clarity grades. Pearl testing continues to be an important part of the Laboratory's work and after producing a report on the Hope Pearl a full description of this famous jewel was published in *The Journal of Gemmology*. On the coloured stone front, origin opinions on rubies and sapphires were much in demand. Laboratory staff also hosted the first CIBJO Recognized Laboratories meeting in London which provided an international forum to discuss identification and description of gemstone treatments.

The GAGTL staff member seconded to the Gem and Pearl Testing Laboratory of Bahrain also reports increased activity. A large proportion of the testing concerns pearls but other interesting gems are also encountered and 'Notes from the Bahrain Laboratory – 3' was published in *The Journal of Gemmology*.

For the first time, GAGTL offered its own on-site comprehensive courses leading to the Diploma in Gemmology and in September one course held on two full days per week and a second course held on two evenings per week were established. The former enables a student to obtain the Diploma in nine months and has proved attractive particularly to overseas students wishing to qualify quickly.

An increased programme of trade, student and general tutorials was held in the Gem Tutorial Centre – now expanded to two floors in the building – and courses were also held in Birmingham, at centres in Ireland and in Hong Kong.

The number of students entering the GAGTL examinations in gemmology increased by more than 20 per cent compared with 1993 and 45 per cent of candidates obtained the Diploma. The examinations were offered in seven languages and this opportunity was welcomed by many students. The Gem Diamond qualification is increasingly sought after worldwide and 67 per cent of the students who sat for the examination were successful in 1994.

Gemmological Instruments Ltd now occupies a designated area on the second floor of the Greville Street building where visitors can investigate and receive advice on the instruments, stones and books on display. Stock and records are now fully computerized and this will assist in better service both for visitors and for the mail order customers. The 1994 turnover was 8 per cent higher than that for 1993 and with further improvements in the instruments stocked the prospects are bright for the future.

The GAGTL again exhibited at the American Gem Trade Association Fair at Tucson and, for the first time, joined the British group of companies exhibiting at the International Jewellery Fair in Basle. At the GAGTL Annual Conference entitled 'Diamonds and modern gem developments', Professor I. Sunagawa was the keynote speaker in a full day's programme attended by members and visitors from over 20 countries. The following day, the President Eric Bruton chaired the Presentation of Awards in Goldsmiths' Hall where the successful gemmological and gem diamond students received their prizes and diplomas from Vice- President Alec Farn.

Both the Midlands and North West Branches of the GAGTL mounted successful programmes of lectures and meetings in 1994 and plan increased activities in 1995.

The first GAGTL photo competition produced a very good response and the best contributions were reproduced in the 1995 GAGTL calendar distributed free to all members. Membership increased in 1994 and the future prospects to expand the membership are good.

The Council of Management wish to pay tribute to the efforts of all the staff for their enthusiasm and professionalism in developing the activities of the organization throughout the year.

ANNUAL GENERAL MEETING

The Annual General Meeting of the GAGTL was held on 12 June 1995 at 27 Greville Street, London EC1N 8SU.

Terry Davidson chaired the meeting and welcomed those present. The Annual Report and Accounts were approved and signed.

It was reported that following approval of the amendments to the Memorandum and Articles at the 1994 Annual General Meeting, our solicitors, Paisner and Co., had further clarified the wording in some paragraphs and had recommended the addition of two paragraphs. Paisner and Co. pointed out that in the Memorandum and Articles it would be advisable to specify the right of the company to obtain insurance cover for certain categories of risk, including the legal responsibilities of directors (Council of Management). The following additions to the Memorandum and Articles were proposed and approved.

> Paragraph 3(t)
> To purchase and maintain insurance for the benefit of any person who is or was, within a period of six years, a member of the Council of Management of the Company or of any other company which is its holding company or in which the company or such holding company has any interest whether direct or indirect or which is in any way allied to or associated with the Company or of any subsidiary undertaking of the Company including (but without prejudice to the generality of the foregoing) insurance indemnifying such persons against liability for negligence, default, breach of duty or breach of trust or any other liabilities which may lawfully be insured against; for these purposes 'holding company' and 'subsidiary undertaking' shall have meanings ascribed to them in the Companies Acts.
>
> Article 71
> The members of the Council shall have power to purchase and maintain insurance for the benefit of any person who is or was, within a period of six years, a member of the Council or other officer of the Company or of any other company which is its holding company or in which the company or such holding company has any interest whether direct or indirect or which is in any way allied to or associated with the Company or of any subsidiary undertaking of the Company.

Christopher R. Cavey and Ian Thomson were re-elected to the Council of Management.

It was announced that R. Velden had expressed the wish to retire from the Members' Council. Tony Allnutt, Patrick Daly, Robert Fuller and Brian Jackson were re-elected to the Members' Council.

Messrs Hazlems Fenton were re-appointed Auditors.

Reunion of Members and Bring and Buy

The AGM was followed by the Reunion of Members and a Bring and Buy Sale. The sale proved very popular with a wide variety of new and second-hand books, gems, minerals and instruments being offered.

During the evening the winners of the 1995 Photographic Competition were announced (see p.523) and a selection of entries displayed.

MEETINGS OF THE COUNCIL OF MANAGEMENT

At a meeting of the Council of Management held on 12 April 1995 at 27 Greville Street, London EC1N 8SU, the business transacted included the election of the following:

Transfers – FGA to FGA, DGA

Bedwell, Victoria Lynsee, London, 1995
Chen, Kesheng, Wuhan, China, 1995
Chen, Meihua, Wuhan, China, 1995
Chung, Yam Ming (Daly), Hong Kong, 1995
Li, Yali, Wuhan, China, 1995
Liu, Zhoa, Wuhan, China, 1995

Mok, Dominic Wai Kei, Kowloon, Hong Kong, 1995
Osmond, Catherine, London, 1995
Xue, Qinfang, Wuhan, China, 1995

Transfers – Ordinary membership to DGA
Gedeon, Leila, London, 1995
Kaskara, Tatiana, London, 1995
Yoshida, Miyuki, Hong Kong, 1995

Fellowship
Bagai, Deepak, Bombay, India, 1995
Cheung, Losanna Lai Ha, Wan Chai, Hong Kong, 1995
Cracco, Alexia, London, 1994
Kan, Wing Lok, Kowloon, Hong Kong, 1995
Ki-Jung, Kim, Taegu, Korea, 1995
Levonis, Helen, Toowoomba, Qld, Australia, 1995
Mangun, Colleen C., Manila, Philippines, 1995

Transfers – Ordinary membership to FGA
Ferrell, Ronald L., Deland, Fla., USA, 1995
Lee, Chiu-Hsia, Taipei, Taiwan, 1995
Lundsrud, Berit, Sandvika, Norway, 1995
Shu, Xingying, Wuhan, China, 1995
Tsai, Pei-Lun, Taipei, Taiwan, 1995
Tzou, Jyh-Jeng, Keehung City, Taiwan, 1995
Van Goethem-Tytgadt, Anne, Johannesburg, S. Africa, 1995

Ordinary Membership
Booth, Roderick McKenzie, Greenwich, London
Chan, Wai Chu, Wan Chai, Hong Kong
Cheong, Stephanie Mun Fong, Kuala Lumpur, Malaysia
Davey, John Richard, Rainham
Head, Christopher, Bournemouth
Lim, Victor K.K., Singapore
Ma, Annie Yiu-Chu, Hong Kong
Owens, Suzanne, Dublin
Ryder, Peter Ian, Tunbridge Wells
Sakurai, Akane, London
Sunnak, Jugal Kishore, Bristol
Tai, Man Tak William, Hong Kong
Williams Jnr, Hodson Adeoye, London
Zilvold, Mirjam, Bridel, Luxembourg

At a meeting of the Council of Management held on 14 June 1995 at 27 Greville Street, London EC1N 8SU, the business transacted included the election of the following:

Diamond Membership
Chan, Tony Chung Sing, Kowloon, Hong Kong, 1995
Chan, Yik Pun, Hong Kong, 1995
Nottsbusch, Jürgen Uwe, Appel, Germany, 1995

Fellowship
Campbell, Robert Desmond, Wallington, 1995
Ketomaki, Tapio, Jokela, Finland, 1994
Park, In Sook, Seoul, Korea, 1994
Park, Kinam, Seoul, Korea, 1995
Samson, Ma Teresita, Quezon City, Philippines, 1995
Sherman, Suthita, Makati, Philippines, 1995
Sokhal, Baljender, Birmingham, 1987
Vlahos, Nikolaos, Pireas, Greece, 1995

Ordinary Membership
Chen, Jyh-Shyang, Taipei, Taiwan
Chonan, Rie, London
Daalmeyer, Trudy, Oegstgeest, The Netherlands
Ho, Hsiung-Chien, Taipei, Taiwan
Horne, Timothy, Aylesbury
Lam, Chui-Hung David, Kowloon, Hong Kong
Mackay, Colin Alexander, Edinburgh
Shaw, Gillian Ann, Nairobi, Kenya
Smallenburg, Maud Alice, Amsterdam, The Netherlands
Streit, Veronica, Manila, Philippines
Theodorou, Antonia, Limassol, Cyprus
Young, Sigrid, Billingshurst
Zini, Grazia, Ferrara, Italy

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29 September
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Preliminary Workshop
11 October
A day of practical tuition for Preliminary students and anyone who needs a start with instruments, stones and crystals. You can learn to use the 10x lens to gain the maximum benefit, to observe the effects and results from the main gem testing instruments and to understand important aspects of crystals in gemmology.
Price £47.00; GAGTL students £33.49 (including sandwich lunch)

Enquire Within : Pearls
19 October
A concentrated look at all aspects of the subject, including the origins and detection of natural, cultured and imitation pearls. Gain experience from the expert tutoring of the Laboratory staff.
Price £76.38 (including sandwich lunch)

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22–23 November
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ADDENDUM

Declinometer

Explanation of symbols shown in 'The declinometer for refractometers: the latest developments' by A. Moliné i Sala (*Journal of Gemmology*, 1995, **24**, 6, 405–9) Figure 3, p. 408.

The following symbols refer to the optic character of the gem and optic orientation of the facet of the gemstone being studied:

MX	:	Singly refractive, facet cut in any orientation	
UC	:	uniaxial, cut at 90° to the optic axis	
UP	:	"	cut parallel to the optic axis
UI	:	"	tilted facet
BNC	:	biaxial, cut at 90°	to γ
BNA	:	" "	to α
BNB	:	" "	to β
BPC	:	" cut parallel	to γ
BPA	:	" "	to α
BPB	:	" "	to β
BPE	:	" "	to an optic axis
BI	:	" facet tilted to every optic axis	

The geometric symbols draw attention to patterns where extra care should be taken in interpretation:

Δ : To determine the optic sign of a gem from a facet cut at 90° to the uniaxial optic axis

❑ : To distinguish the facet of a uniaxial negative gem from that of a biaxial gem cut at 90° to γ

O : To distinguish the facet of a uniaxial positive gem from that of a biaxial gem cut at 90° to α

For further information, the reader should consult the monograph by J. Figueras Calsina, details of which are given in the References section p. 409.

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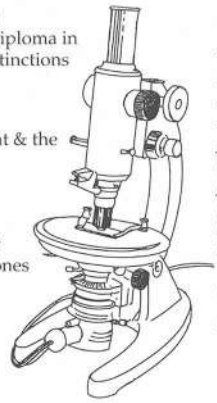

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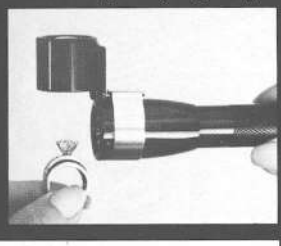

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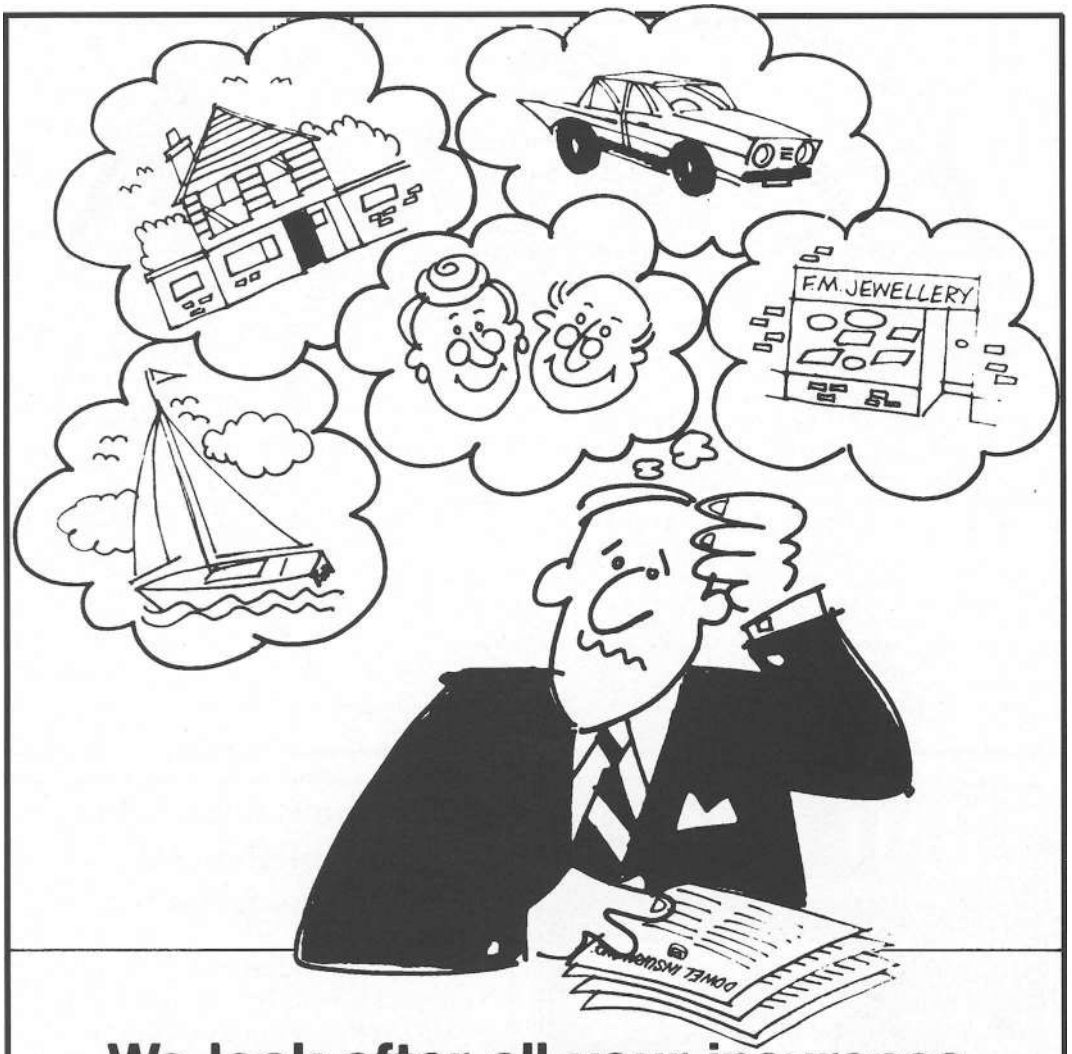

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The Editor is glad to consider original articles shedding new light on subjects of gemmological interest for publication in *The Journal*. Articles are not normally accepted which have already been published elsewhere in English, and an article is accepted only on the understanding that (1) full information as to any previous publication (whether in English or another language) has been given, (2) it is not under consideration for publication elsewhere and (3) it will not be published elsewhere without the consent of the Editor.

Typescripts Two copies of all papers should be submitted on A4 paper (or USA equivalent) to the Editor. Typescripts should be double spaced with margins of at least 25mm. They should be set out in the manner of recent issues of *The Journal* and in conformity with the information set out below. Papers may be of any length, but long papers of more than 10 000 words (unless capable of division into parts or of exceptional importance) are unlikely to be acceptable, whereas a short paper of 400-500 words may achieve early publication.

The abstract, references, notes, captions and tables should be typed double spaced on separate sheets.

On matters of style and rendering, please consult *The Oxford dictionary for writers and editors* (Oxford University Press, 1981).

Title page The title should be as brief as is consistent with clear indication of the content of the paper. It should be followed by the names (with initials) of the authors and by their addresses.

Abstract A short abstract of 50-100 words is required.

Key Words Up to six key words indicating the subject matter of the article should be supplied.

Headings In all headings only the first letter and proper names are capitalized.

A **This is a first level heading**

First level headings are in bold and are flush left on a separate line. The first text line following is flush left.

B *This is a second level heading*

Second level headings are in italics and are flush left on a separate line. The first text line following is flush left.

Illustrations Either transparencies or photographs of good quality can be submitted for both coloured and black-and-white illustrations. It is recommended that authors retain copies of all illustrations because of the risk of loss or damage either during the printing process or in transit.

Diagrams must be of a professional quality and prepared in *dense* black ink on a good quality surface. Original illustrations will not be returned unless specifically requested.

All illustrations (maps, diagrams and pictures) are numbered consecutively with Arabic numerals and labelled Figure 1, Figure 2, etc. All illustrations are referred to as 'Figures'.

Tables Must be typed double spaced, using few horizontal rules and no vertical rules. They are numbered consecutively with Roman numerals (Table IV, etc.). Titles should be concise, but as independently informative as possible. The approximate position of the Table in the text should be marked in the margin of the typescript.

Notes and References Authors may choose one of two systems:

(1) The Harvard system in which authors' names (no initials) and dates (and specific pages, only in the case of quotations) are given in the main body of the text, e.g. (Gübelin and Koivula, 1986, 29). References are listed alphabetically at the end of the paper under the heading References.

(2) The system in which superscript numbers are inserted in the text (e.g. ... to which Gübelin refers.[3]) and referred to in numerical order at the end of the paper under the heading Notes. Informational notes must be restricted to the minimum; usually the material can be incorporated in the text. If absolutely necessary both systems may be used.

References in both systems should be set out as follows, with *double spacing* for all lines.

Papers Hurwit, K., 1991. Gem Trade Lab notes. *Gems & Gemology*, **27**, 2, 110-11

Books Hughes, R.W., 1990. *Corundum*. Butterworth-Heinemann, London. p. 162

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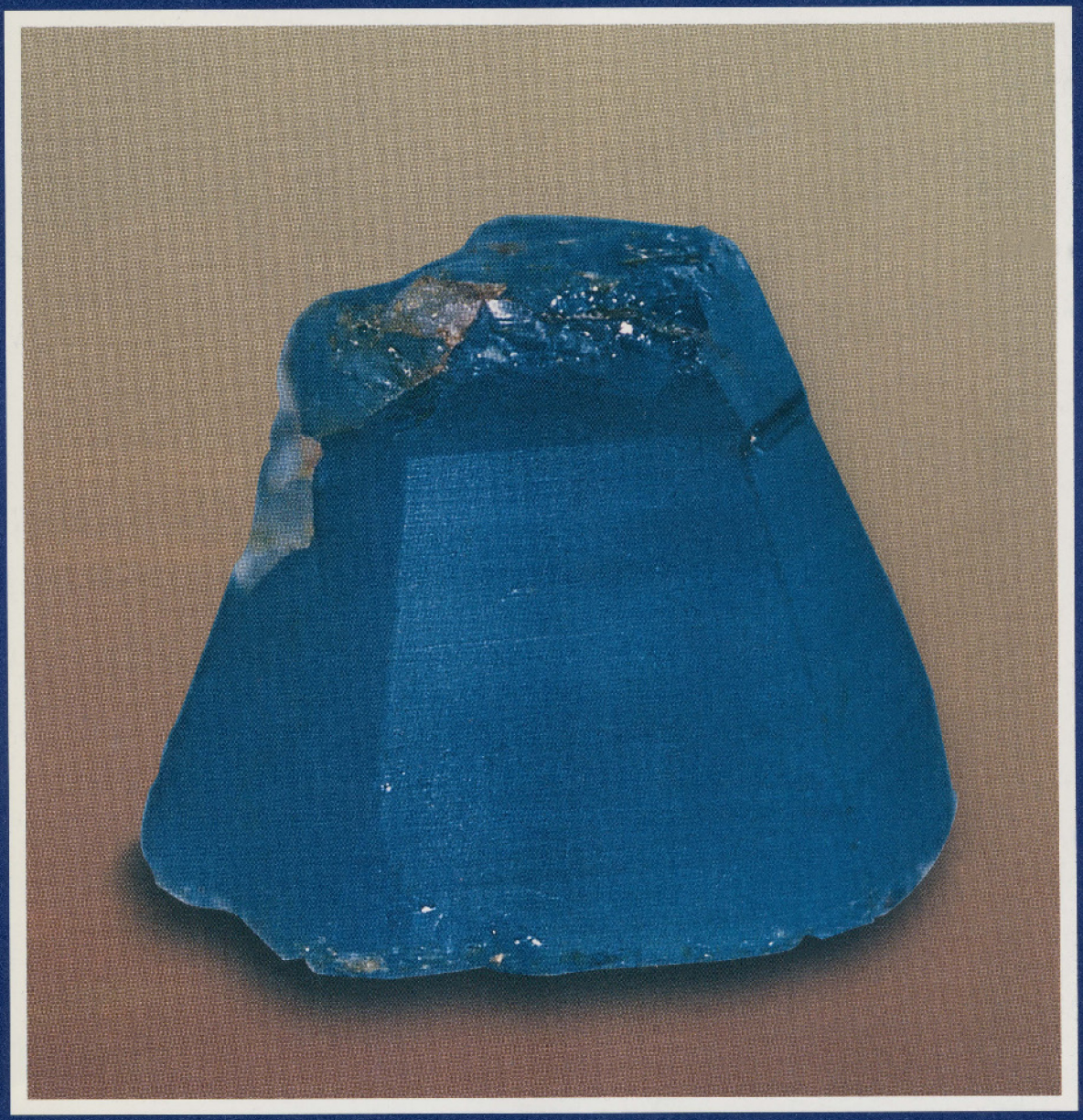

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Cover Picture

Burmese sapphire crystal weighing 502 ct, unearthed in 1994 at Khabine, near Gwebin, in Burma's Mogok Stone Tract. (See Burmese sapphire giants, p. 551)

Photo by U Khin Mg Win

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In this issue...

This issue completes volume 24 of the *Journal* in which 43 original papers from 58 authors in 21 countries have been published. Five hundred abstracts and 99 book reviews have also appeared and together these figures offer a convincing testimony to the expanding activity across the whole spectrum of gemmology. The papers in the *Journal* have ranged from a comprehensive review of gems from Myanmar to origin determination for cut gemstones, and from historical gemmology in Afghanistan, Sri Lanka or the UK to the criteria for distinguishing natural from synthetic diamond.

In this issue Dr Gübelin discusses a synthesis of recent practical study and theoretical ideas of pearl formation, reviewing the current position and indicating a possible sequence of formation not involving a grain of sand! This paper is followed by a comprehensive description of the nephrite jade produced at Chuncheon, Korea, since 1976.

As East Africa continues to yield more gems from different localities, thirteen gem species are recorded here as stars or cat's-eyes. Their properties are listed and the variety of inclusions, including those responsible for optical effects are described. As yet the region has not yielded a corundum crystal large enough to be included in the list of sapphire giants discussed in the Burmese sapphire paper. But with verified occurrences of large corundums in the Transvaal perhaps it is only a matter of time and recognition.

The world of materials science is of growing influence in the gem market and if it is not laser development or space research that is generating new and interesting crystals, it is some other branch of activity such as those concerned with insulators or fibre optics. The latest challenge to the gemmologist's testing skills reportedly comes from the chimney of a kiln used in paint manufacture, and the zincite which condensed on the chimney walls is now on the market in a range of yellow and orange crystals and cut stones. Features are described which should enable its rapid identification.

The final form of each of these papers and indeed of most of the contributions in this volume owes a great deal to the expertise and wisdom of the Associate Editors. With their constructive comments and pertinent advice they have contributed significantly to the value of the papers; it is a privilege to have their support. A brief look at the initials following an abstract or book review will remind readers of the dedicated hard work put in by a wide range of experts, and among those who supply such a readable source of condensed information I would particularly like to record our appreciation of the efforts of Michael O'Donoghue, Evelyne Stern, Peter Read, Professor Bob Howie and Reg Peace.

Papers for the new volume are already in preparation and will include important contributions on rubies, emeralds and collectors' gems. Plans are in hand for further improvements in the design of the *Journal* and we would welcome your comments on these or any other matters gemmological.

R.R.H.

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An attempt to explain the instigation of the formation of the natural pearl

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Abstract

Biological research discloses that the instigation of the formation of a natural pearl is based upon the excrescence of epithelial cells which, while accumulating and slowly forming a pearl bag, secrete substances to create pearl and shell in the same succession. During this process the organic substance *'conchin'* is continuously secreted to wrap the inorganic crystals of calcite and aragonite as a sponge embraces its voids. There is no evidence of a sand grain being the original stimulus of the formation of the natural pearl.

Keywords: Epithelium, nacre, periostracum, protein.

Introduction

The following article is based upon studies carried out in Germany between the two world wars, but not continued later, and first published by F. Haas (1931). The pearl is the most perfect of all jewels nature presents us with. Other than gemstones, which are caused to sparkle and shine only by the artistic styles of cut, the pearl does not require the help of human hands to obtain its fullest beauty. Already in its original form, the pearl is of accomplished splendour. In the same form as it is extracted from the mollusc – noble, promising and enigmatic – it is mounted onto a ring or strung onto a necklace, together with its sisters.

Where the play of water, the rise and fall of the waves, the teasing to and fro of the sunbeams, the roaring of the riverbed and the quiet trickle of sand on the bottom of the sea stir up everlasting motion – there lies the cradle of the pearl – the Aphrodite gift of the water.

Many legends have been spun about the origin of the pearl. The least romantic but most persistent yarn about its formation is that a sand grain is the instigator of the pearl's formation. This is as erroneous as another story nurtured by Christopher Columbus that during his third voyage, when he circumnavigated the island of Trinidad, one morning during low tide, he observed open shells lying among the roots of the mangrove trees. He thought that pearls were dew drops which had fallen off the mangrove leaves into the open shells where they 'crystallized', but of course we know that this idea is fantasy.

The anatomy of the mollusc and the formation of the shell

If one considers how the mollusc develops its shell, it is possible to understand how difficult it would be for a grain of sand to enter between the shell and the mantle. Figure 1 depicts a longitudinal cross section of an adult mollusc. The centre consists of the animal's body and three muscular wings on each side, of which the outer one is the *'mantle'*. The mantle is coated on the inner and outer side by a thin skin of epithelium, which has its origin in the mantle's fold, situated immediately below and inside the lip of the

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shell, whether the latter is tiny or large. From this fold two different types of epithelia wrap as a mono-cell layer all over the inside and outside of the mantle. On the mantle's inner surface is the endoderm, a passive mono-layered skin whose purpose it is to protect the inner side of the mantle. The outer monolayer is the active 'ectoderm', whose task it is to build up the shell. It covers the mantle from the fold to the hinge of the shell and from its cells the shell-forming substances are secreted in three subsequent phases (Figure 2).

The shell is composed of three layers of different substances: the first layer, the periostracum, consists of a dark leathery, protective matter composed of the organic substance conchiolin ($C_{32}H_{48}O_{11}$) whose correct biological term is now 'conchin'. It is a scleroprotein of the keratin type. The second layer of the shell is inorganic and is made up of oriented prismatic columns of crystalline calcium carbonate ($CaCO_3$), usually in the form of calcite. The prisms of this layer are perpendicular to the inner side of the periostracum. The correct name for this layer is the prismatic layer or 'calcite primer'. The third and innermost layer forms the internal surface of the shell. It is normally secreted by the entire length and width of the ectoderm epithelium and it increases during the entire span of the animal's life. This layer also consists of calcium carbonate ($CaCO_3$), but is the orthorhombic form 'aragonite'. The aragonite layer accumulates by crystallization of a large number of flakes and forms the smooth iridescent inside of the shell called 'nacre' or 'mother of pearl'. The principal axis of these flakes or platy crystals is orientated parallel to the *c*-axis of the calcite prisms, or in other words at right angles to the inner shell surface. Being the third and innermost part of the shell the nacre lies in direct contact with the secreting monocell ectoderm (Hänni, 1982).

During growth of the mollusc and its shell from its tiniest shape as a spat and from its hinge towards its rim, the youngest epithelial cells at the tip of the mantle secrete the periostracum (forming the outside of the shell), while the oldest are responsible for forming the aragonite (nacre) which lines the inside of the shell. In other words, the product of the epithelium changes with the latter's age from conchin via calcite to aragonite. This has been vaguely known for a long time, but only recently has it been precisely defined and explained by Gutmannsbauer (1992).

The switch from the prismatic calcite layer to the tabular aragonite nacre was investigated and explained by Fritz *et al.* (1994), in their description of biofabrication of highly organic composite flat pearls on synthetic materials, which they had inserted into abalone molluscs. Nevertheless, they did not gain knowledge of the nature of this process. They postulate a dynamic relationship at the cell-mineral interface in which cell recognition of the inorganic surface governs the genetic reversal controlling the structure of the new mineral (aragonite). This results first in the precipitation of a prismatic calcite layer succeeded by the tabular aragonite crystals.

Along its rim the shell is directly connected to the ectoderm – not only during the continued growth of the shell, but as long as the mollusc is alive. Consequently, the boundary between the ectoderm and the nacre has no gaps, and no passive substance, such as a sand grain, withered plant matter or dead animals can penetrate this region (Gübelin, 1987) unless forced by some external agency. It is possible that certain adhesive barnacles might drill a hole through the shell and thus irritate the ectoderm, which would react by secreting the three shell substances in the aforementioned sequence. In most cases the mollusc would be killed by the barnacle. However, an irritation caused by a barnacle is relatively rare and does not normally result in the formation of a baroque or spherical pearl, but rather in the attached so-called 'blister pearl'. The possible devastating

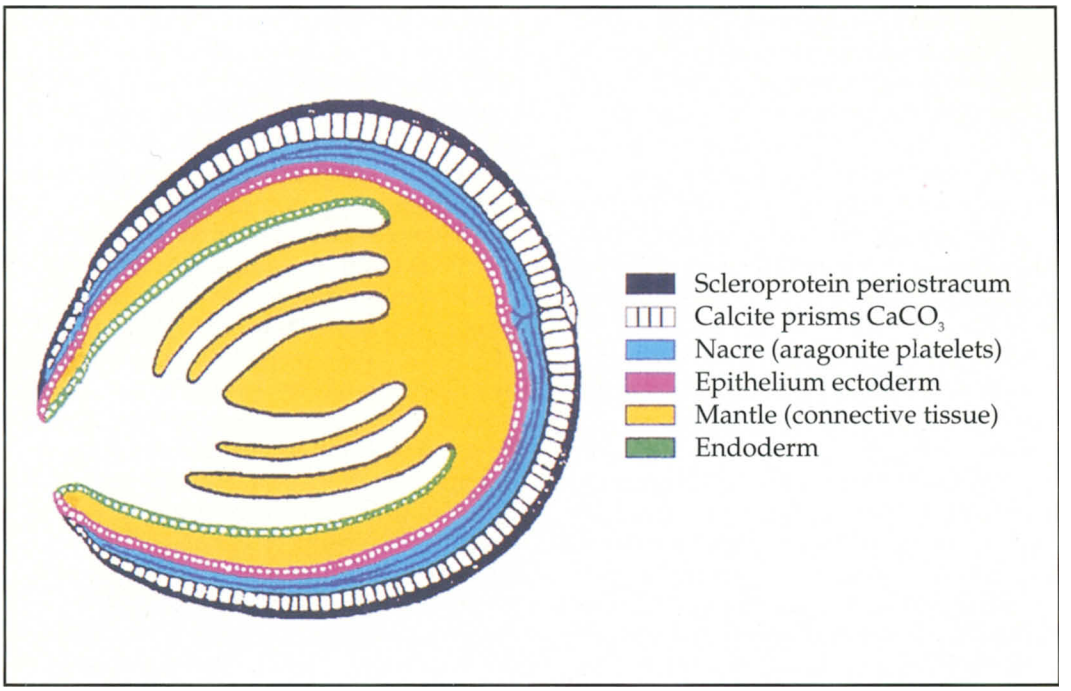

Fig. 1. A longitudinal cross section of an adult mollusc.

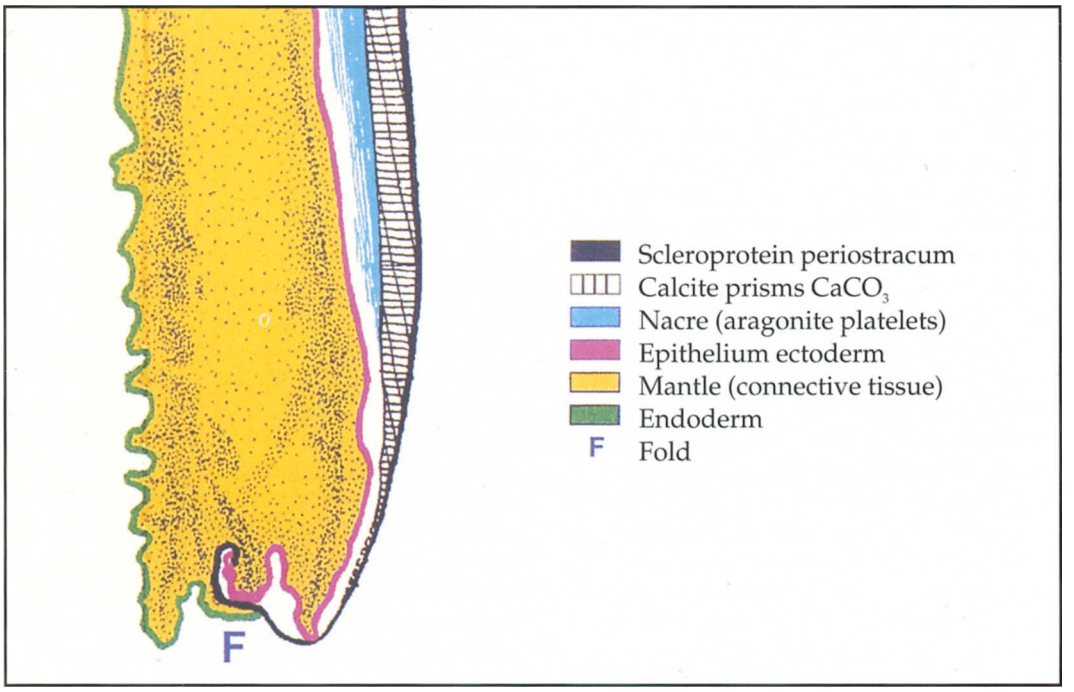

Fig. 2. Detail of the growth pattern of cells from the mantle fold.

action of barnacles however is well known to the cultivators of cultured pearls and is the reason why the molluscs used for cultivating pearls must be cleaned regularly while suspended in wire baskets from the rafts. The risk of obtaining a baroque, blister or freak pearl is the reason why the nucleus is implanted into a gonad of the Akoya bivalve by the cultivators instead of inserting it between the ectoderm and the shell.

In the pearl as well as in the shell, the inorganic elements (i.e. the calcite prisms as well as the aragonite platelets) are 'cemented' together by very thin films of conchin which forms a kind of mortar (Gutmannsbauer *et al.*, 1994). They call the conchin 'periostracum' (while the author of the present article limits this term to the conchin covering the outermost surface of the shell), whereas to the conchin 'scaffoldings', mortaring the inorganic carbonate crystals together, they give the name 'matrix'. The author of the present article likes to compare the conchin wrapping the carbonate crystals to a sponge, in the voids of which the calcite prisms and the aragonite platelets are embedded.

The effect of this sponge-like scleroprotein is to prevent the aragonite from lining the inner side of the shell as one large sheet-like crystal of aragonite, but rather to limit its size to innumerable tiny platelets.

The instigation of the formation of the natural pearl

All previous opinions published seem to agree about the stimulation of the natural pearl as a consequence of an intruded sand grain which somehow had penetrated the region between the shell and the shell-building ectoderm. The possibility of passive transfer of pieces of epithelium, or of the so-called 'yellow particles' (hardened grains of conchin) into the connective tissue of the mantle as growth nuclei for pearls has also been discussed.

Biological studies have revealed another possible cause of exciting epithelial cells; this is in the form of an excrescence, a kind of epithelial tumour resulting either from some injury or arising from a natural stimulus (benign tumour). The repeated permanent development of such benign tumours within the epithelium seems to be a genetic heritage of some species of marine molluscs and freshwater mussels.

Biologists still do not seem to know the precise cause whereby the ectoderm cells form monolayered tumours at certain places, although the molecular mechanisms of the process are known in principle. Very recent research has revealed that certain proteins bonding guanylnucleotides – called G-proteins – play a central role as converters, multipliers and messengers of signals. Disturbances of the normal functions of G-proteins are directly connected with diseases such as cholera and some forms of cancer (Brunner, 1994). The excrescences of the ectoderm cells can therefore be interpreted as a kind of benign cancer, and it may be feasible that ectoderm cells receive signals from G-proteins to excresce. Also nobody seems to have asked the question why these benign tumours expand as monolayers instead of accumulating clusters of cells. Modern laboratory experiments with tissue cultivation may yield the answer.

According to observations on the mechanisms of formation of the monolayered tumour, the substratum – i.e. the connective mantle tissue, upon which the ectoderm as well as the tumour cells spread – is essential in that it exerts an attractive, positively chemotactic stimulus upon the epithelial cells. This was perceived in the course of cultivation experiments.The two different tissues (mantle and epithelium) seem to act as competitors and force their own cells as well as the cells of the other tissue to differentiate in a manner characteristic of each tissue. Mono-cultivation causes proliferation, while mixed cultivation leads to a differentiation of the cells. Differentiation

is exactly what happens between the epithelium and the mantle tissue. The epithelial cells do not, therefore, form clumps, but on account of the competition from the mantle tissue, the epithelial cells can only multiply as a one-layered skin. The presence of the underlying tissue, mostly of mesodermal origin – as in our case the mantle tissue – exerts such an attractive positively chemotactic and stimulating influence upon the epithelial cells that these cannot help arranging themselves and settle with their bases upon the mantle tissue as a monolayered skin. Consequently, in view of the regularly flat, tabular shape of the individual ectoderm cells, the evenly arranged one-layered epithelium must spread on and over the outer surface of the mantle tissue.

The encystation of the natural pearl

Hence, while proliferating rampantly, the epithelial cells cannot form random accumulations of irregularly stacked cells, but are forced by nature to align themselves side by side to expand as a monocell layer over its substratum. The epithelial cells, however, cannot spread towards the hard shell, but must do so in the direction of the soft mantle tissue (see Figure 3a). As a result of continuous multiplication of the excrescent cells the original depression deepens into the connective tissue of the soft mantle, slowly forming a kind of bag – the so-called 'pearl bag', (see Figure 3b). Following nature's tendency to favour shapes with the largest volume but smallest surface – and simultaneously assisted by the accrescent pearl, the pearl bag, under ideal conditions, assumes the shape of a sphere which in biological terms is called a 'blastula' (see Figure 3c). The pearl itself consists of exactly the same substances as the shell and forms also in precisely the same sequence: first, conchin is secreted in a smaller or larger quantity by the excrescent ectoderm cells. This 'embryo' of a natural pearl is usually

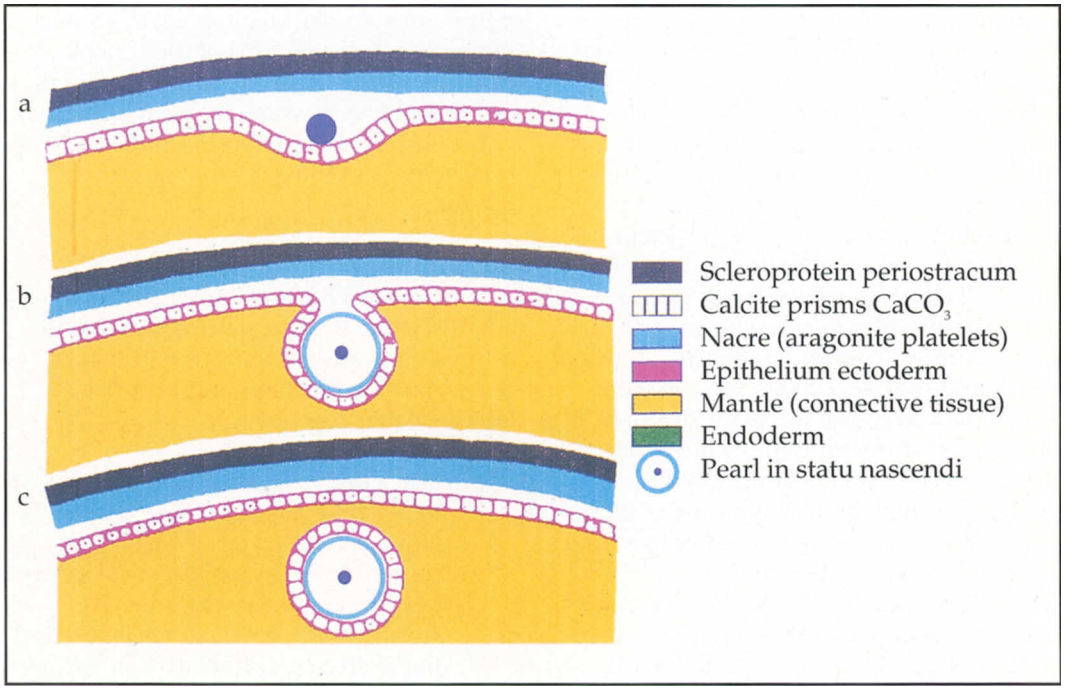

Fig. 3. The encystation of the natural pearl.

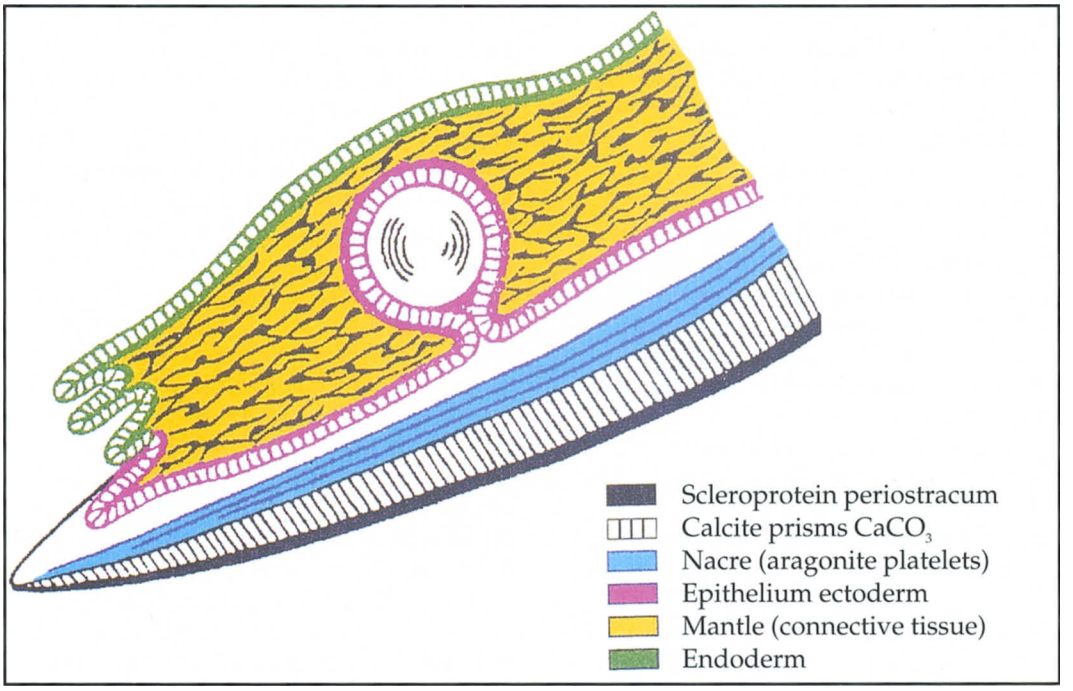

Fig. 4. The ideal result of the instigation of the natural pearl is a spherical product consisting of the three shell substances conchin, calcite primer and aragonite nacre.

extremely tiny and commonly not even visible by X-rays. Pearls containing a relatively large centre of conchin are called 'blue pearls' in the trade, and in X-ray shadowgraphs their centre appears darker than the surrounding body of the natural pearl. This 'core' is then overgrown by layers of prismatic calcite, which themselves are covered by layers of aragonite (nacre). However, the formation of the natural pearl does not take place as an uninterrupted, continuous process in that concentric spherical layers are deposited which may be compared to the layers of an onion, but rather through the intermittent deposits in the form of small calottes or skull caps which quite commonly overlap one another. This seems to testify to a regional activity of the ectoderm cells depending upon their age. The results may easily be observed when examining the walls of the drillhole of a natural pearl. These walls reveal an irregular, successive pattern of step-like semicircles, enhanced by the interlayered skins of the conchin. Yet, sometimes there are aragonite layers on natural pearls which may envelope the entire surface due to the simultaneous and total activity of the epithelial cells of the blastula.

Summary

In summarizing, we may now acknowledge that the natural pearl is the astonishing result of various natural processes, partly still enigmatic, occurring in logical sequences:

(a) first a secret signal seems to be given to certain ectoderm cells – maybe by G-proteins – to start excrescence;
(b) on account of a chemotactical, competitive correlation between the substratum – the mantle tissue – and the overlying epithelial cells, the latter do not form clumps but

expand as a monolayer, first forming an indentation in the mantle and later deepening and widening into a pearl bag;

(c) while multiplying, the epithelial cells secrete shell substances in exactly the same sequence in the pearl as in the shell, and in both, the inorganic components (calcite prisms and aragonite platelets) are wrapped by ultra-thin films of the scleroprotein conchin.

The author has based this article partly on actual experimentations and partly on theoretical reflections. Yet, until it is possible to film the actual process of pearl formation, we must depend upon this combination of practical experience and hypothesis to advance our understanding of one of the mysteries of nature.

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Nephrite from Chuncheon, Korea

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Abstract

Nephrite from Chuncheon, Korea, and traded under the name 'Chuncheon Ok' (meaning Chuncheon jade) or 'Baek Ok' (meaning white jade) has been produced since 1976. The high-quality nephrite is monomineralic consisting almost entirely of tremolite, whereas the poor-quality nephrite is polymineralic, containing small amounts of diopside, calcite and chlorite. Gemmological properties and electron microprobe analyses of the nephrite are given.

Keywords: Nephrite, Chuncheon jade, Korea jade, nephrite jade, Baek Ok

Introduction

Nephrite jade has been produced since 1976 from the Chuncheon area, north east of Seoul, in the Province of Kangwondo, which is in the central part of the Korean peninsula (in some atlases the name is spelt Ch'unch'on). Annual production of the nephrite mine (the Daeil Mine) is reported to be approximately 80 000–90 000kg. The nephrite has been fashioned mainly as rings, beads, bracelets, tabs, cabochons, brooches, drop earrings and carvings (Figure 1).

Fig. 1. Fashioned nephrite jade from Chuncheon, Korea. Bracelets, a string of prayer beads (top), curved ornaments for crowns, rings, and buttons (bottom).

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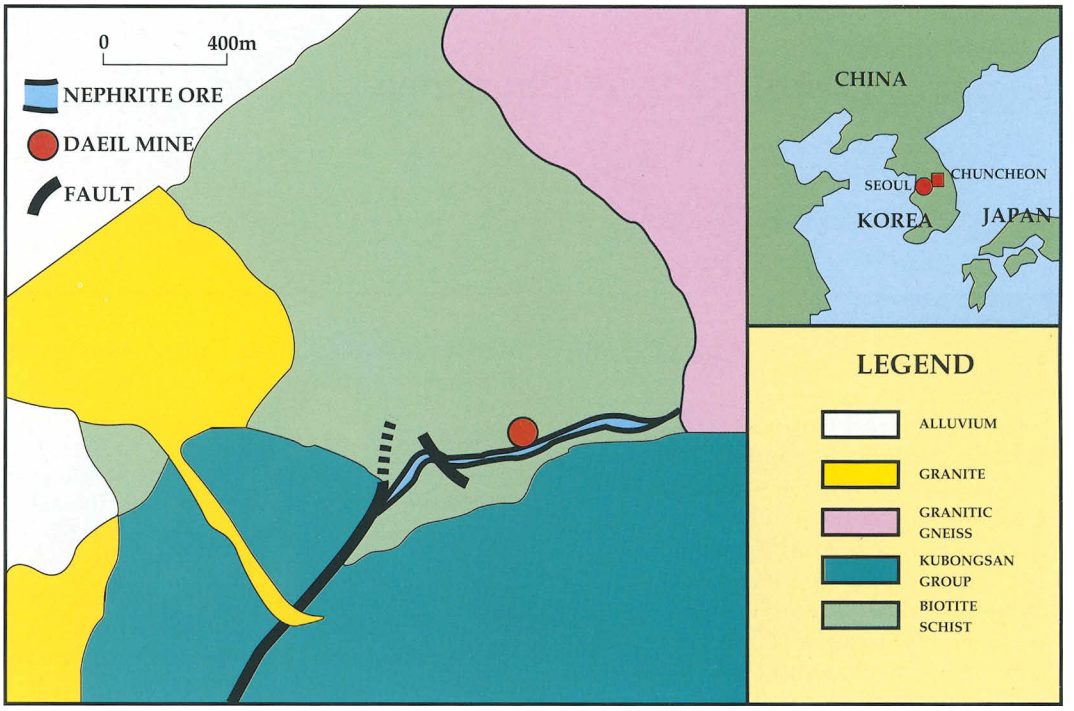

Fig. 2. Geological map of nephrite mine area, Chuncheon, Korea.

Occurrences

The geology of the nephrite mine area consists largely of Precambrian biotite schist (Youngduri Complex), amphibolite, limestone and quartzite (Kubongsan Group), granitic gneiss of unknown age and Jurassic granite (Figure 2). Nephrite has developed along the contact between the dolomitic marble lens and the enclosing biotite schist (Figure 3), and attains a maximum thickness of 3m with a confirmed extension of 1km at the surface. Investigations using polarizing microscopy, X-ray diffraction and electron microprobe analysis are reported also by Kim *et al.*, 1986; Noh *et al.*, 1993; see also Park *et al.*, 1974.

Gemmological properties

Colour, diaphaneity and lustre

The Chuncheon nephrite varies in colour from greenish-white and pale yellowish-green to pale green. It is rarely deep green. Colour distribution is quite uniform and the material is translucent. It shows a resinous or waxy lustre. Very recently, nephrite dyed green has appeared on the market.

Mineral composition of nephrite

Under a polarizing microscope, the pure (high-quality) nephrite is found to consist essentially of tremolite in the form of aggregates of minute fibres (Figure 4).

Tremolite aggregates are sometimes bounded by rounded or rhombic outlines, most clearly seen in plane polarized light, indicating that tremolite was formed by alteration of pre-existing diopside and calcite (Figure 5). However, impure (low-quality) nephrite is polymineralic, containing small amounts of calcite, diopside and chlorite in the nephrite matrix. All the mineral constituents described above were identified by X-ray diffraction analysis as well as from thin section observations. Depending upon the

Fig. 3.
Mine workers remove nephrite ore at the Daeil Mine, Chuncheon, Korea. The nephrite ore develops along the contact between the dolomite marble bed and the enclosing biotite schist.

amounts of accessory minerals present in the nephrite matrix, refractive indices, specific gravity and hardness may vary slightly.

It should be emphasized that the so-called 'Korean jade', referring to serpentine material, should not be confused with the Chuncheon jade.

Refractive indices

Owing to the aggregated nature of the microscopically small tremolite crystals, only a single reading of about 1.62 can be obtained on a standard gemmological refractometer.

Hardness and toughness

The hardness is measured at 6-6½ on Mohs' scale. Due to the felted nature of the crystal aggregates, it is extremely tough.

Specific gravity

The specific gravity determined by the hydrostatic weighing technique ranges from 2.96 to 3.01.

Absorption spectrum

No distinctive absorption spectrum is displayed by the natural nephrite. However, some nephrite dyed green shows a marked absorption band at 630 - 650nm.

Ultraviolet luminescence

The nephrite shows no luminescence under ultraviolet light.

Chemical composition

The general chemical formula $Ca_2(Mg, Fe)_5(Si_4O_{11})_2(OH)_2$ is assigned to the tremolite- actinolite solid solution series. Electron microprobe analyses of four nephrite specimens (Table I) each with slightly different colours show that all lie in the tremolite composition range. It is generally believed that a deepening of the green colour in nephrite is attributable to an increase in the amount of ferrous iron present. Although the Fe/Mg ratio for each analysis, 0.0178(1), 0.0167(2), 0.0196(3) and 0.0221(4), appears to be consistent with this assumption, it should be remembered that the iron contents shown in Table I are values calculated on the

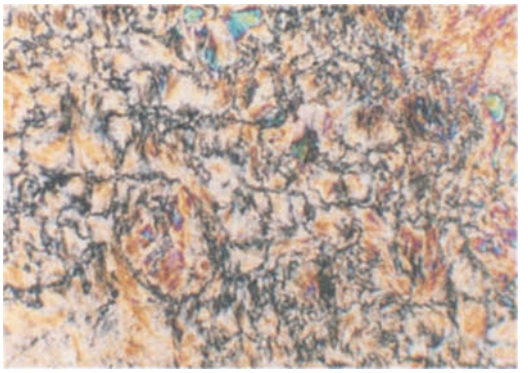

Fig. 4. Thin section photomicrograph of Chuncheon nephrite, Korea. It is made up of fibrous aggregates of tremolite. Crossed polars. x20.

Fig. 5. The same Chuncheon nephrite as Fig. 4, but taken under plane polarized light. Crystal shapes of pre-existing diopside, now replaced by tremolite, are visible. x20.

Table I. Electron microprobe analyses of nephrite from Chuncheon, Korea.

Wt % oxide	*1*	*2*	*3*	*4*
SiO_2	57.62	57.54	57.76	56.98
MgO	24.11	23.26	24.38	23.06
CaO	13.10	13.42	13.34	13.29
Al_2O_3	0.54	0.61	0.68	0.59
FeO	0.43	0.39	0.48	0.51
MnO	0.08	0.12	0.08	0.10
Na_2O	0.03	0.07	0.09	0.06
K_2O	0.03	0.05	0.01	0.03
TiO_2	0.01	0.02	0.03	0.01
Total	95.95	95.48	96.85	94.63

1. greenish-white
2. pale yellowish-green
3. pale green
4. pale green

assumption that all the iron present in the mineral exists in the ferrous state. This may not be so and the iron values reported in the Table may also represent some iron in the ferric state.

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Burmese sapphire giants

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Abstract

The Mogok area of Myanmar (Burma) has long been noted for producing some of the world's finest blue sapphires. Burmese sapphire mining is reviewed, along with some of the most important blue sapphires from Burma, particularly those of large size. Mention is also made of some giant corundum crystals from other localities. The article contains sections based upon eyewitness accounts and discussions with some of Mogok's long-time gem dealers.

Keywords: Burma, Myanmar, Mogok, sapphire, large gems, corundum, precious stones

Introduction to Burmese sapphires

Although it is rubies for which Burma is famous, some of the world's finest blue sapphires are also mined in the Mogok area. Today the world gem trade recognizes the quality of Burmese sapphires, but this was not always the case. Edwin Streeter (1892) described Burmese sapphires as being overly dark. Unfortunately this error was later repeated by Max Bauer and others. G. Herbert Smith wrote:

> While the Burma ruby is famed throughout the world as the finest of its kind the Burma sapphire has been ignominiously, but unjustly, dismissed as of poor quality. In actual fact nowhere in the world are such superb sapphires produced as in Burma.
>
> G.F. Herbert Smith, *Gemstones*, 1972

While this statement must be qualified by adding that the finest Kashmir sapphires are in a class by themselves, those from Burma are also magnificent. J. Coggin Brown (1955) said:

> It has been stated that Burmese sapphires as a whole are usually too dark for general approval, but this is quite incorrect; next to the Kashmir sapphires they are unsurpassed. Speaking generally, Ceylon sapphires are too light and Siamese sapphires too dark, and it is more than probable that many of the best 'Ceylon' stones first saw the light of day from the mountainsides of the Mogok Stone Tract.
>
> J. Coggin Brown and A.K. Dey, *India's mineral wealth*, 1955

Not all Burma sapphires are deep in colour. The best display a rich, intense, slightly violetish blue, but some are quite light, similar to those from Sri Lanka. The key difference between Burma and Sri Lankan sapphires is saturation, with those from Burma possessing much more colour in the stone. Colour banding, so prominent in Ceylon stones, may be entirely absent in Burma sapphires.

Burmese sapphires

Although rubies are found with much greater frequency at Mogok (rubies form about 80-90 per cent of the total output), sapphires may reach larger sizes. Cut gems of over 100 carats are not unknown. Large fine star sapphires are also found at Mogok, in addition to star rubies. Near

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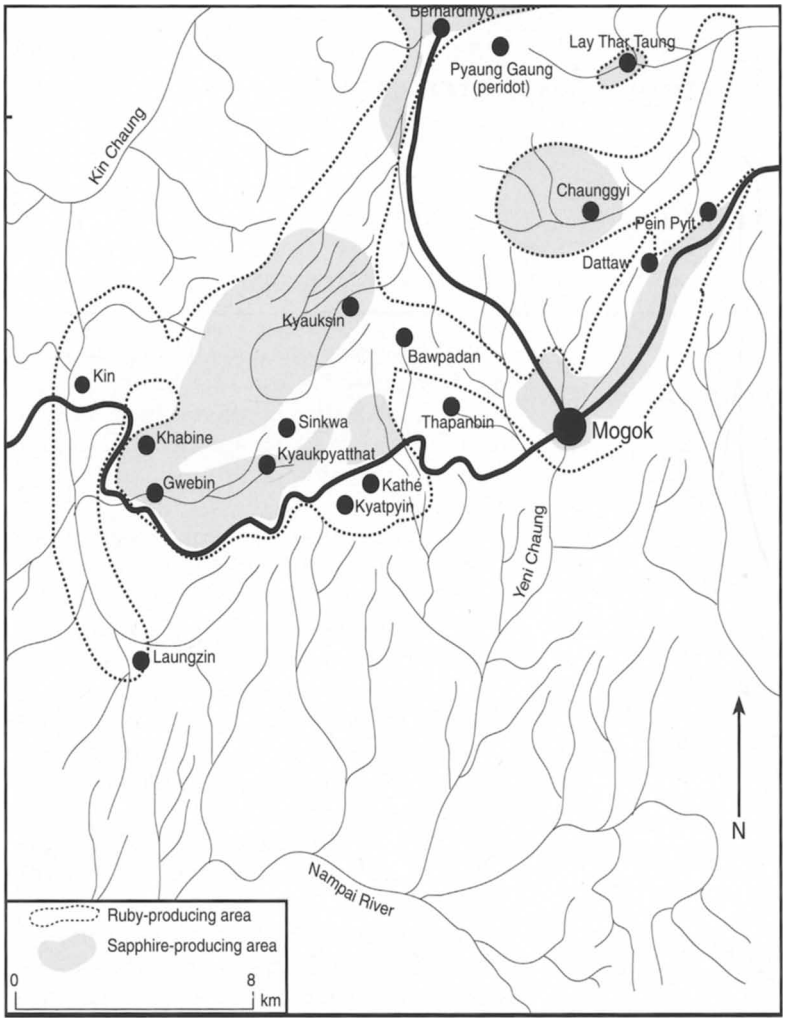

Fig. 1.
Map of the sapphire-producing regions of Burma's Mogok Stone Tract. (Modified from Halford-Watkins, 1935b).

Kabaing (Khabine), at Kin, is located a mine famous for star sapphires (see Figure 1).

The sapphires of Burma occur in intimate association with rubies in virtually all alluvial deposits throughout the Mogok area, but are found in quantity at only a few localities, particularly 8 miles (13 km) west of Mogok, near Kathé (Kathe). At Kyaungdwin, near Kathé, in 1926 a small pocket was discovered that yielded 'many thousand of pounds' [sterling] worth of magnificent sapphires within a few weeks' (Halford-Watkins, 1935b).

According to Halford-Watkins (1935b), the majority of fine sapphires were derived from the area between Ingaung and Gwebin. Sapphires have also been found near Bernardmyo.[1] According to Halford-Watkins (1935b):

> Bernardmyo itself at one time produced large quantities of sapphires, many of which

1. The plateau of Bernardmyo was chosen by the first British expedition to Mogok as a suitable place for a sanatorium for British troops. It was thought that the climate was more suitable for Europeans and that eventually the place would develop into the Simla of Burma. Bernardmyo was Christened after the first British Chief Commissioner of Upper Burma, Sir Charles Bernard (G.S. Streeter, 1887, 1889).

An interview with U Thu Daw

Longtime Mogok gem dealer, U Thu Daw, a contemporary of A.C.D. Pain (of *painite* fame), was interviewed by one of the authors (U Hla Win). The following are some of his edited comments on Burmese sapphires:

H Hla Win: 'Were there any big sapphires found in the pre- World War II days?'

U Thu Daw: 'Yes, including some famous stones. U Kyauk Lon from Gwebin village found one and sold it to Albert Ramsay for one lakh of kyats (US$13,000). [Ramsay later named the 958ct giant the *Gem of the Jungle*.]'

UHW: 'Isn't he the one who was famous for star sapphires?'

UTD: 'Yes. U Shwe Hlaing of Zegyi found one which weighed over 100ct after cutting. I saw it with my own eyes and it was quite beautiful.'

UHW: 'How much did it sell for?'

UTD: 'U Shwe Hlaing did not sell it in Mogok. After attempting to sell the gem in England, it was eventually sold to U Shwe Kin, owner of Rangoon's Kwan Louk Hotel, for under one lakh kyats. U Shwe Kin reportedly later sold it in Hong Kong.'

UHW: 'Any other sapphires?'

UTD: 'Of course. U Kan from Ze Haung (Old Market) had one which weighed 1450ct. U Shwe Kin also bought this one, for 70,000 kyats. But this time he wasn't so lucky. I think he cut it on a Saturday, U Shwe Kin's brother took it to Hong Kong. He was killed in a train wreck there and the stone lost. It was a fine sapphire and might have fetched 10,000 kyats.'

UHW: 'Were there any famous sapphires in the post-war period?'

UTD: I did not notice much. The famous sapphire mines are Loke Khat (Kaday-kadar), Chaunggyi (north of Mogok) and Lay Thar Taung. At Lay Thar Taung, the brothers, U Thein and U Ba Thaw, made a successful sapphire mine. There were so many sapphires mined that they had to be moved by horses. Those brothers were so kind-hearted that those who came to buy sapphires were sold bucketfuls. Many got rich because of those brothers.'

UHW: 'Were the sapphires of good quality?'

UTD: 'They were Lay Thar Taung sapphires are famous in Mogok.'

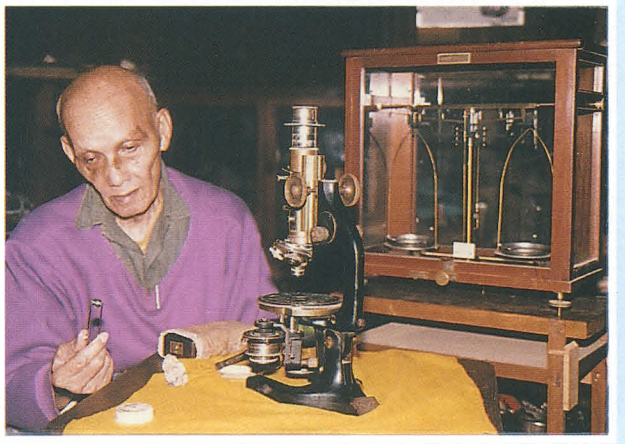

Fig. 2. U Thu Daw of Mogok with his microscope formerly owned by A.C.D. Pain
Photo by U Khin Mg Win

were of magnificent colour and quality, though a number were of a peculiar indigo shade, which appeared either very dark or an objectionable greenish tint by artificial light. During an extensive native mining rush to Bernardmyo in 1913 a number of these stones were placed on the London market.

Many of the stones found in this area were coated with a thin skin of almost opaque indigo colour which, on being ground off, revealed a centre sometimes of a fine gem quality, but in many cases of greenish shade. The method of occurrence was different from that anywhere else as the majority of stones were taken from a hard black iron-cemented conglomerate, which was found in layers a few inches thick, often only a few feet below the surface. This area now appears to be exhausted, and little mining is carried on there today except for peridots, which are abundant.

Another isolated local deposit which has produced some fine sapphires occurs at Chaunggyi, four miles north of Mogok, and about a thousand feet higher.

As well as blue, sapphires also occur in violet, purple, colourless and yellow colours at Mogok. The violet and purple stones may be fine; yellows tend to be on the light side and are not common. Green sapphires are known, but rare.

Orientation of sapphire rough

While stones from localities such as Kyauk Pyat That retain their rich blue hue in various orientations, those from Chaunggyi and Painpyit take on a greenish tint when the *c*-axis is not exactly perpendicular to the table so correct orientation for cutting is important. Many Mogok dealers attribute this phenomenon to 'invisible black silk' and currently (1994) pay strict attention to locality when buying sapphire rough.

Fig. 3. Sapphire mine of U Mya Mg at Khabine, near Gwebin, Mogok, Burma. In February of 1994 this mine yielded the 502ct sapphire crystal in Figure 6. *Photo by U Khin Mg Win.*

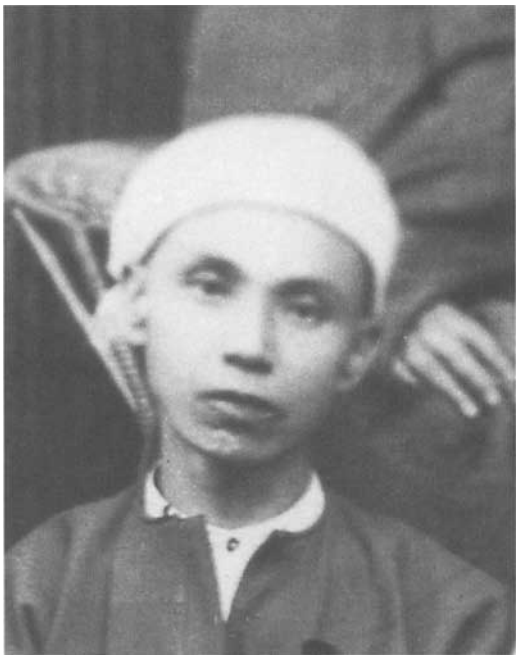

Fig.4. Left: U Tun, one of the most prominent sapphire dealers in Mogok in colonial times. Right: U Thein, one of the brothers who mined sapphires at Lay Thar Taung.
Photos by U Khin Mg Win, Mogok.

Famous Burmese sapphires

S.M. Tagore in his classic work, *Mani-Málá* (1879), described several celebrated sapphires. One of these was a fabulous stone of 951ct, and was seen by an English ambassador to the Court of Ava (Burma). Tagore also mentions a curious custom among the Hindus of India. They were said to have a prejudice against sapphires, believing the blue gem to be the bringer of misfortune.

> In consequence of this notion, some of them would invariably keep a stone on trial for several days before they would make final settlement with the sellers. Hence, perhaps, the paucity in the numbers of sapphires in their possession.
>
> S.M. Tagore, Mani-Málá, 1879

One magnificent Gwebin gem was scratched up from just below the grass in 1929 by miners preparing a site for digging. Found by U Kyauk Lon, it was a water-worn, doubly-truncated pyramid weighing an incredible 958ct. Purchased for $13,000 by Albert Ramsay, who dubbed it the *Gem of the Jungle*, the rough produced nine fine cut stones, weighing 66.53, 20.25, 20.00, 13.11, 12.25, 11.33, 11.11, 5.50 and 4.33ct. All stones were personally cut by Ramsay and were said to be of exceptional colour. A marvellous account of the purchase and cutting of the Gem of the Jungle was published in the *Saturday Evening Post* in 1934 (Ramsay and Sparkes, 1934).

About 1967, a 12.6kg (63,000 ct) crystal surfaced at Mogok. Today this sapphire colossus is on display at the Myanma Gems Enterprise (MGE) office. Like virtu-

Fig. 5. The 12.6kg sapphire giant owned by Myanma Gems Enterprise. Note the large central piece which was removed in an attempt to see if gem material might lie within. *Photos by U Khin Mg Win.*

ally all giant specimens, it is far from gem quality. In order to see if something of gem quality might be lurking within, MGE staff disembowelled it with drill and saw. Alas, the interior was just as opaque as the skin (see Figure 5). While this piece is billed by MGE as the 'world's largest sapphire crystal', in fact a number of much larger specimens are known, including a 40.3kg crystal from Sri Lanka which contains gemmy portions (see Table II).

On 22 February 1994, a large sapphire of 502ct was unearthed at Khabine, about 2.4kms from Gwebin. The crystal is a single pyramid of rich blue colour, and slightly silky (see Figure 6).

Table I is a first attempt to catalogue some of the more famous Burmese sapphires. Criteria for listing include titled specimens, specimens large or fine enough to merit mention in newspaper/magazine articles and those which have set auction records. Unfortunately, due to the secretive nature of the gem business, many fine specimens have never been publicly described. The authors would love to hear from readers with additional information.

Acknowledgements

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Fig. 6. Below: 502ct Burmese sapphire crystal. This was unearthed on 22 February 1994, at Khabine, near Gwebin, in Burma's Mogok Stone Tract. Right: the Base of the crystal, showing concentrations of silk. *Photos by U Khin Mg Win.*

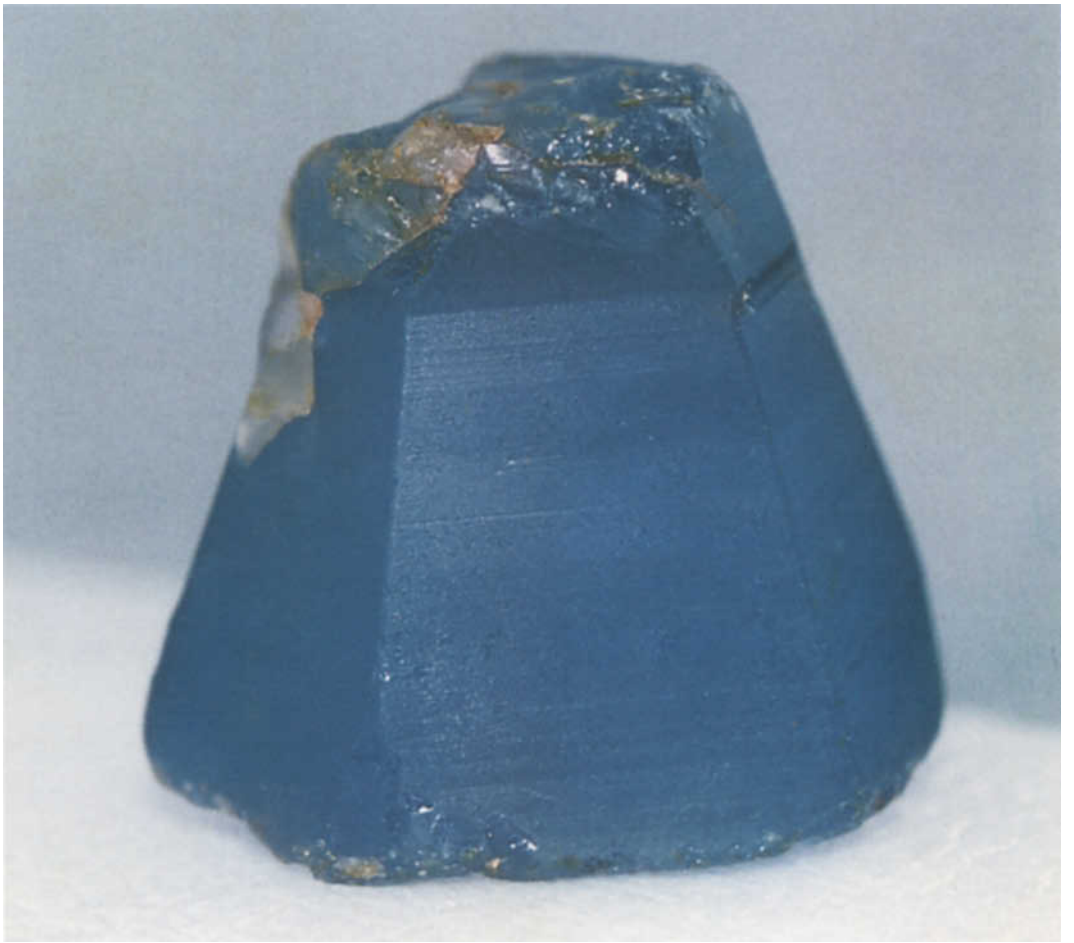

Table I: Summary of famous Burmese blue sapphires

Name, weight, description and sale price[a]	*Source & date found*	*Current location*	*Reference*
Ruspoli's Sapphire (*' Wooden spoon Seller's Sapphire' or ' Great Sapphire of Louis XIV'*) 135.8ct; faceted; rhomb shaped (only six facets); said to have been found by a wooden spoon seller in Bengal; sold by the House of Ruspoli (Rospoli?) of Rome to a German prince (salesman?), who in turn sold it to the French jeweller Perret for 170,000 francs. Later purchased by Louis XIV.	Said to be Bengal; probably Burma or Sri Lanka Date unknown	Muséum National D'Histoire Naturelle, Paris. Valued at 100,000 pounds in 1791	Tagore, 1879, 1881; Streeter, 1892; Bank, 1973; H.-J. Schubnel (pers. comm., 16 December 1994; 5 January 1995)
Unnamed 951 ct; rough or cut unknown; seen in 1827 in the treasury of the King of Ava	Unknown (Burma?) Date unknown	Unknown	Smith, 1913
Unnamed Rough, weight unknown; sold for Rs28,000 (£1,870)	Redhill Mine Mogok, Burma, 1917	Unknown	*Times of London*, 11 July 1917
Unnamed 113ct; rough; sold for Rs45,000	Bernardmyo, Mogok, Burma, 10 May 1919	Unknown	*Times of London*, 15 July 1919
Unnamed Weight unknown; rough; sold for Rs40,000	Mogok, Burma 1919	Unknown	*Times of London*, 15 July 1919
Unnamed 437ct; not stated whether rough or cut; valued at over £11,000	Mogok, Burma 1928	Unknown	*Mineral Industry*, 1929
Gem of the Jungle 958ct rough; cut stones of 66.50 (66.53?), 20.25, 20.00, 13.11, 12.25, 11.33, 11.11, 5.50 and 4.33ct; purchased by Albert Ramsay for over £13,000	Gwebin, Mogok, Burma August 1929 (or July 1930)	Unknown	*Mineral Industry*, 1930, 1931; Ramsay and Sparkes, 1934; Halford- Watkins, 1935a
Star of Asia 330ct; cabochon cut; blue-violet star sapphire; acquired in 1961 from Martin Ehrmann; once said to belong to the Maharajah of Jodhpur	Burma Date unknown	Smithsonian	Desautels, 1972; White, 1991
Unnamed 630ct rough (upon breaking up for cutting, it proved less valuable than expected)	Kathé, Mogok, Burma May 1930	Unknown	*Times of London*, 31 May 1930 *Mineral Industry*, 1930, 1932
Unnamed 293ct rough	Kathé, Mogok, Burma 1930	Unknown	Brown, 1933

Table I: Summary of famous Burmese blue sapphires (continued)

Name, weight, description and sale price[a]	*Source & date found*	*Current location*	*Reference*
Unnamed nearly 1000ct rough	Gwebin, Mogok, Burma 12 August 1932	Unknown	Brown 1933
Unnamed 514ct rough	Mogok, Burma December 1932	Unknown	Brown 1933
Unnamed star sapphire 435ct; not known whether rough or cut	Kathé, Mogok, Burma December 1932	Unknown	*Mineral Industry*, 1934
Unnamed 390ct; rough; sold for over £3,000	Mogok, Burma 1930s	Unknown	Halford-Watkins, 1935b
Unnamed about 99ct; faceted; round; offered for sale in Bangkok in early 1980s for $10,000/ct	Burma Date unknown	Unknown	Author, R.W.H.
Unnamed 41.04ct; faceted; emerald-cut; sold at Sotheby's New York, October 1986 for $924,000 ($22,515/ct)	Burma Date unknown	Purchased by American retailer	Anonymous, 1986
Rockefeller Sapphire 62.02ct; faceted, rectangular step-cut; mounted in diamond ring; sold at Sotheby's St. Moritz, 20 February 1988, for $2,828,546 ($45,607/ct). **Per carat and total price world record for a single blue sapphire**	Burma Date unknown	Unknown	Hughes and Sersen, 1988; Matthews, 1993
Unnamed 4145ct; rough; offered for sale at 1993 Myanma Gems Enterprise Emporium (Lot 95; reserve price $300,000)	Burma Date unknown	Unknown	Author, U H.W.
Unnamed 14,387ct; rough; offered for sale at 1993 Myanma Gems Enterprise Emporium (Lot 96; reserve price $50,000)	Burma Date unknown	Unknown	Author, U H.W.
Unnamed 251.60ct; star cabochon; offered for sale at 1993 Myanma Gems Enterprise Emporium (Lot 165; reserve price $300,000)	Burma Date unknown	Unknown	Author, U H.W.
Unnamed 502ct; rough, pyramid- shaped crystal, silky, of good colour	Kabaing, Mogok, Burma 22 February 1994	Unknown	Author, U H.W.

Table II: Summary of rough corundum giants (not gem quality)

Name, weight, description and sale price[a]	*Source & date found*	*Current location*	*Reference*
Unnamed 312lb (141.5kg; 707,500ct); opaque, red and blue crystal (not gem quality)	Franklin, NC Before 1882	Shepard Collection Amherst College, USA	Kunz, 1892
Unnamed Over 10lb (4.5kg); sapphire crystal	Mogok, Burma 1928	Unknown	*Mineral Industry*, 1929
Unnamed 335lb (152kg); hexagonal bipyramid crystal (not gem quality); 2ft 3in (68.58cm) in width. **This is the largest corundum crystal on record.**	Leydsdorp, Northern Transvaal, South Africa Date unknown	Geological Survey Museum, Pretoria, South Africa	Spencer, 1933 Anonymous, 1951
Unnamed 42lb (19kg); crystal said to be in the shape of the island of Sri Lanka	Sri Lanka Date unknown	American Museum of Natural History?	Anonymous, 1936 Wijesekera, 1980
Unnamed 136.5lb (61.92kg); crystal	18km from Santa Barbara, Minas Gerais, Brazil	Natural History Museum London	Personal communication
Unnamed 63,000 ct (12.6kg; 27.783lb); rough crystal, bluish-grey pyramid (not gem quality); 27 x 14.25 x 6.75 in (68.58 x 36.195 x 17.145 cm)	Mogok, Burma *ca.* 1967	Myanma Gems Enterprise, Burma	Anonymous, 1967
Unnamed 40.3kg; rough, doubly- terminated bipyramid crystal	Rakwana, Sri Lanka Date unknown	Unknown	Koivula and Kammerling, 1989
Unnamed 4.230ct; rough; bluish bipyramidal crystals, not gemmy	Lokekhet ('Kadegadar') Mogok, Burma September 1990	Myanma Gems Enterprise, Burma	*Working People's Daily*, 5 February 1991 Clark, 1991, p. 68

[a] On 1 April 1914, the carat was standardized as 200 milligrams. Weights before that date are approximate only. All dollar prices in US dollars unless stated otherwise.

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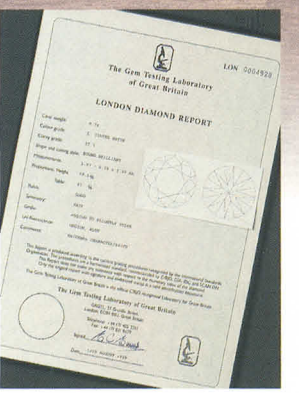

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An examination of 'serendipitous' synthetic zincite

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Abstract

This article describes the gemmological investigation of synthetic zincite from Poland. The material is reported to have formed as an accidental by-product of an industrial process.

Keywords: gem mineral, gemstone, mineral, synthetic, zincite.

Introduction

A *mineral* may be defined as a naturally occurring, crystallized chemical element or compound having either a definite chemical composition or range in composition and usually formed as a product of inorganic processes (Hurlbut and Kammerling, 1991). When a mineral is deemed to be sufficiently attractive and durable to be used for personal adornment, it may be referred to as a *gem material*, with the fashioned product generally called a *gemstone*. (Sometimes minerals with the requisite beauty but lacking in durability are also fashioned and are sometimes referred to as *collectors' gemstones*.)

A *synthetic mineral* or *gemstone*, on the other hand, is an artificial or manufactured (that is, non-natural) product. Unlike imitations which merely resemble a natural gem, synthetic gemstones duplicate their natural counterpart's chemical composition and crystal structure (resulting in the same optical and physical properties) (Nassau, 1980; Hurlbut and Kammerling, 1991).

Some natural minerals are formed under somewhat exotic conditions, including fumaroles and volcanic vents (e.g. cotunnite and scacchite: Palache *et al.*, 1951); in guano deposits (struvite, which was first found in bat deposits in a church basement, and newberryite: Palache *et al*, 1951; urea: Bridge, 1973); and in lichen colonies (moolooite: Chisholm *et al.*, 1987).

Isolated synthetic crystals or crystal aggregates may also form in artificial environments. However, in the absence of other considerations, these are not considered minerals (and, by extension, would not qualify in fashioned form as natural gemstones). For example, both mullite and brownmillerite crystals form in ceramics, but until they were found in natural environments, were not considered minerals (Bowen, 1924; Johnson *et al.*, 1994; Hentschel, 1964). Similarly, phases found only in weathered slags (e.g. barium sulphite, $BaSO_3$: Braithwaite *et al.*, 1993) are not currently accepted as minerals (Jambor, 1994).

Current study

In February 1995, while attending the many concurrent gem and mineral shows in Tucson, Arizona, USA, the authors encountered a considerable amount of synthetic zincite. (Small quantities had been noticed at the Tucson shows in previous years and have occasionally been submitted to the GIA Gem Trade Laboratory for examination, including material reported to be from Poland [Crowningshield, 1985].) Although the majority of this material was

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Fig. 1. These crystals (95.85 and 179.65ct) are accidental by-products of an industrial kiln in Silesia, Poland. *Photo by Maha DeMaggio © GIA*

Fig. 2. These three gems (1.35 to 3.26ct), fashioned from single crystals of synthetic zincite, were the subjects of the current investigation. *Photo by Maha DeMaggio © GIA*

in the form of single crystals up to 15cm in length and as complex crystal aggregates (Figure 1), faceted stones were also being sold. The colour of the material ranged from a medium-toned yellow through orange and dark orangey red, with a very few yellowish-green crystals seen as well.

Discussions with representatives of the Krakow Poland-based firm Minerals and Gemstones shed some light on this material (D. and J. Wachowiak, pers. comm., 1995). They reported that it was an accidental by-product of an industrial kiln in Silesia, Poland, used to produce zinc-based paint. The synthetic zincite would form spontaneously and randomly by vapour deposition in the kiln's chimney/air vents due to some undetermined error in the commercial production process.

Both rough and faceted samples were purchased for examination. Gemmological properties were determined for three modified round brilliant-cuts weighing 1.35, 3.18, and 3.26ct (Figure 2).

Gemmological Properties

Appearance

All three specimens have a sub-adamantine lustre and are transparent, as were others seen by the authors but not examined in detail. The colours of the three are medium-light yellow, medium orange and medium-dark reddish-orange, all of high saturation and even distribution. These samples were felt to be representative of the range of hues and depths of colour exhibited by the material being offered at the Tucson shows. These properties are generally consistent with those reported in the literature for the rare natural zincite

Table I. Ultraviolet fluorescence of samples

	Long wave	*Short wave*
Medium-light yellow specimen	Moderate yellow	Weak to moderate yellow
Medium orange specimen	Very weak yellowish-orange	Very weak orange
Medium-dark reddish-orange specimen	Very weak yellowish-orange	Inert

(Webster, 1983; Arem, 1987), although cuttable natural material is described as being slightly cloudy to translucent, and frequently darker or more brownish in colour.

Refractive indices

All three stones are over the limits of a standard Duplex II refractometer, i.e. with a refractive index of more than 1.80. Such a determination is consistent with the values $\omega = 2.013$, $\varepsilon = 2.029$ reported for natural zincite (Webster, 1983; Arem, 1987).

Optic character

The material was determined to be doubly refractive, by observing weak doubling of back facet edges under magnification and by the presence of weak pleochroism (see below). In addition, two of the three stones were confirmed to be uniaxial by resolving an optical interference figure between crossed polarizers. These data are consistent with those for natural zincite which crystallizes in the hexagonal crystal system and has a birefringence of 0.016 (Webster, 1983; Arem, 1987).

Pleochroism

Dichroism is very weak, in two tones of the body colour. It should be noted that both Webster (1983) and Arem (1987) report natural zincite as having no pleochroism. This apparent inconsistency may be explained by the very weak reaction of the synthetic material noted by the authors and by the fact that natural zincite is rarely transparent, for even minor scattering of light in the natural material could obscure a weak pleochroic reaction. Webster (1983) also reports that small crystals of synthetic zincite showed no apparent dichroism; here, the combination of a weak reaction in possibly pale-coloured specimens might account for the differences noted.

Ultraviolet fluorescence

In all three stones, the reaction to long wave was stronger than the reaction to short wave (see Table I).

Furthermore, the strengths of the reactions were inversely proportional to the depth of body colour. Both Webster (1983) and Arem (1987) report that natural zincite does not fluoresce. This lack of reaction in natural zincite is most likely caused by one or more fluorescence-quenching impurities. Webster (1983) reports a dull to bright yellow fluorescent reaction for small synthetic specimens, although the excitation wavelength(s) is not specified.

Chelsea filter reaction

The appearance through the Chelsea filter varied with the body colour of the test sample. The medium-light yellow stone gave no reaction (that is, it appeared yellowish- green, the colour of the filter).

Table II. Summary of gemmological properties of synthetic zincite

Colour	Medium-light yellow, medium orange, medium-dark reddish-orange
Diaphaneity	Transparent
Lustre	Sub-adamantine
RI	Over the limits of standard refractometer (1.80+)
Optic character	Doubly refractive, uniaxial
Pleochroism	Very weak, in two tones of body colour
UV Fluorescence:	
Long wave	Very weak to moderate, yellow to yellow-orange
Short wave	Inert to very weak to moderate, yellow to orange
	LWUV > SWUV; both inversely proportional to depth of body colour
Chelsea filter reaction	Yellow stone: no reaction (appears yellowish-green)
	Orange stone: weak pink
	Reddish-orange stone: moderate red
Absorption spectra	Weak general absorption to about 430nm and a weak band centred at 500nm (lightest-coloured stone); Weak general absorption to about 510 or 530nm (other two stones)
SG	5.70 ± 0.02
Electrical conduction	Non-conducting (two lighter-coloured stones)
	Conducting (darkest-coloured stone)
Magnification	Dislocations; cloud of small particles; small crystals, some acicular

The medium orange stone appeared weak pink while the medium-dark reddish-orange specimen appeared moderate red.

Absorption spectra

These were observed using a Beck prism-type spectroscope mounted on a GIA GEM transmitted/fibre-optic light base. The lightest-toned specimen showed weak general absorption from 400 to about 430nm plus a diffused band centred at approximately 500nm. The other two showed weak general absorption from 400 to 510 and 530nm respectively. Webster (1983) reports no distinctive absorption features for small specimens of synthetic material, although this may be due to their relatively light body colour (they are described as being yellow).

Specific gravity

This was determined through hydro-

static weighing on a Mettler AM100 electronic balance, with three separate sets of calculations performed for each stone. Values obtained were 5.70±0.02 and are consistent with the 5.68 value reported by Arem (1987) and close to the 5.66 value Webster (1983) reports for gem-quality natural material.

Electrical conduction

Electrical conduction was measured qualitatively using a GIA Gem Instruments electrical conductivity meter. The medium-light yellow and medium orange stones gave a negative reaction (i.e. did not conduct electricity), but the medium-dark reddish-orange stone gave a positive reaction (i.e. did conduct electricity).

Magnification

The lightest-toned stone contained only a cloud of small particles (Figure 3). The two darker stones showed dislocations and small included crystals that could only be seen under fairly high magnification (Figure 4). The darkest stone also contained acicular inclusions (Figure 5). As none of the inclusions broke the surface, they were not further characterized.

The gemmological properties are summarized in Table II.

Chemistry

Qualitative chemical analyses were performed using a Tracor X-ray Spectrace 5000 EDXRF spectrometer. The only element revealed was zinc (Zn), which is consistent with the chemistry of zincite (ZnO), as oxygen and other light elements are not detectable with this method of analysis.

For comparison purposes, a dark brownish red faceted natural zincite from Franklin, New Jersey, USA, was also tested using the EDXRF system; this stone contained manganese (Mn) as well as Zn. Microprobe analysis of a natural 'light green' zincite from Sterling Hill, New Jersey, USA, showed contents of 98.88% ZnO, 0.23% iron (Fe) as FeO, and 0.29% Mn as MnO (Dunn, 1979).

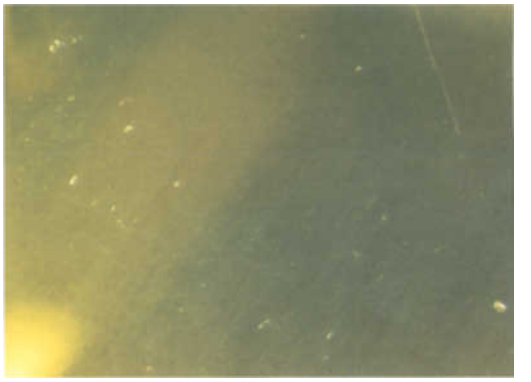

Fig. 3. A cloud of minute particles was noted in the 3.18ct light yellow specimen. 60x. *Photomicrograph by John I. Koivula © GIA*

Fig. 4. Veil-like dislocations and small included crystals of undetermined nature were detected in two of the test samples. 50x. *Photomicrograph by John I. Koivula © GIA*

Fig. 5. One of the three samples contained acicular inclusions. 60x. *Photomicrograph by John I. Koivula © GIA*

Discussion

The gemmological properties of the synthetic zincites described in this investigation were in their essentials consistent with those reported in the literature for the rare, gem-quality facetable natural zincite from Franklin, New Jersey, USA. The data obtained are also in agreement with what is documented in the literature for synthetic material.

Although the red colour in many natural zincites is thought to be due to Mn (Webster, 1983), none of the three faceted synthetic stones examined by the authors contained any detectable Mn. We suspect that the yellow, orange and reddish-orange colours, and corresponding absorption spectra, may be due to increasing amounts of band-gap absorption from defect states within zincite (see, for instance, Fritsch and Rossman, 1988); in agreement with this model, the darkest stone conducts electricity.

The synthetic zincite examined by the authors is unusual in that it is reported to have formed as an accidental by-product of a commercial manufacturing process, rather than having been grown for a specific gem or industrial application. However, *intent* is not a consideration in the definition of a synthetic gem material. For instance, additional synthetic crystals form under conditions meant to grow other materials including, for example, the synthetic phenakite crystals found in synthetic emeralds, and the synthetic acmite and eucryptite 'breadcrumb' inclusions sometimes found in synthetic quartz.

It is worth noting that this is not the first such occurrence of synthetic zincite crystallizing by accident. In an article titled 'A modern miracle' (Kennedy, 1983), the author describes yellow and red-orange amber-coloured crystals of synthetic zincite that were found at the Blackwell Zinc Smelter in Blackwell, Oklahoma, USA, when an old furnace used to produce zinc ore concentrates was torn down.

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Cat's-eye and asteriated gemstones from East Africa

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Abstract

The study was carried out on nineteen cat's-eye or asteriated cabochon-cut examples of the following gems from Tanzania and Kenya: almandine, apatite, aquamarine, beryl, grossular, kyanite, kornerupine, rhodolite, ruby, sapphire, scapolite, tourmaline and zoisite.

Optical observations, electron microprobe and X-ray analyses were carried out to investigate chemical compositions of the bulk crystals and the role of the inclusions.

Inclusions, responsible for the optical effects, i.e. tubes, acicular inclusions, lamellae, laminae and platelets, are described and some deductions about conditions of growth of the gems are made.

Keywords: Gemstones, cat's-eye, chatoyancy, asterism, cabochon, inclusions.

Introduction

Tanzania and Kenya now contribute significantly to the world market in supplying unusual gemstones which display chatoyancy and asterism.

For several years, cabochon-cut gemstones of different mineral species producing these optical phenomena have appeared on the Kenyan market.

A group of 19 cabochon-cut gemstones of different mineral species, selected according to their origin, weight, size and with evident cat's-eye or asterian effect, were examined.

This article describes the physical and chemical properties of the gems with particular emphasis on the inclusions responsible for the optical effects.

Sample location and geology

The samples were obtained by N.R. Barot from North Tanzania and South Kenya and are of known origin (Figure 1). The regional geology is complicated and has not been mapped in detail.

Sample 1 is from the Ngorongoro volcanic complex at Lake Manyara, in north central Tanzania. The erosion of the metamorphic rocks, which lie on the northern border of the Masai Steppe, produced the neogenic deposits in which the sample was found.

Samples 7, 12, 13, 14 and 15 are from the Dodoma area, 17, 18 and 19 from the Lelatema District and 2, 9 and 11 from the Pare and Usambara Mountains, all in Tanzania.

Samples 3, 6, 8, 10 and 16 are from the Taita Mountains and 4 and 5 from the Embu and Meru areas respectively, in Kenya.

These areas are part of the central system of the Rift Valley (Pangani Rift). The rocks are affected by extensive tensional tectonic events and consist of high grade gneisses (granulite facies) of Tertiary age, and lower grade metamorphic rocks (amphibolite

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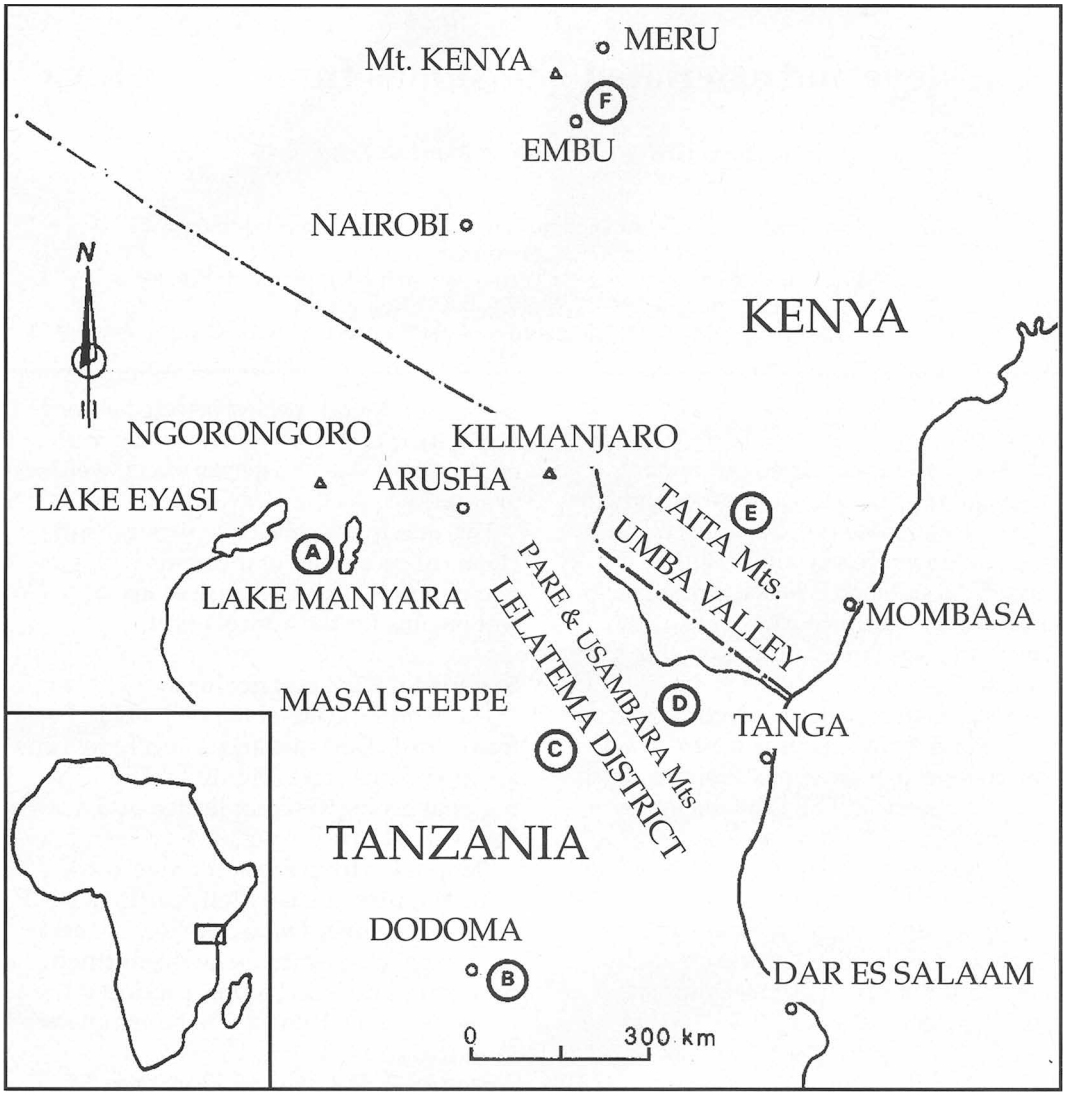

Fig. 1. The map shows the origin of the gemstones studied from East Africa. A: Sample 1; B: Samples 7, 12, 13, 14 and 15; C: Samples 17, 18 and 19; D: Samples 2, 9 and 11; E: Samples 3, 6, 8, 10 and 16; F: Samples 4 and 5

facies) of Precambrian age. In particular they comprise pyroxene granulites, gneisses with kyanite, amphibolites, crystalline limestones with graphite, serpentine and sporadic pegmatite complexes of syn-orogenic metasomatic or post-orogenic magmatic origin.

All the gems are oval cabochon-cuts, ranging in size from 5.40x5.20x4.90mm (sample 6) to 12.80x10.27x6.67mm (sample 15). Their weights vary between 0.58ct (sample 17) and 6.37ct (sample 15).

Elongate, thin inclusions parallel to the base of the cabochons cause the cat's-eye effect in samples 1, 2, 3, 4, 5, 6, 7, 8, 11, 12, 13, 14, 15, 16, 17, 18 and 19 and traverse the whole body of the host crystal (Figures 2, 3, 5 and 10). Also, a hazy six-pointed star, not

Fig. 2. Sample 2. This almandine from Mt. Pare (Tanzania) is decorated by syngenetic intergrowth of rutile needles with a crystallographically dictated arrangement along the edges of the rhombdodecahedral faces. 60x.

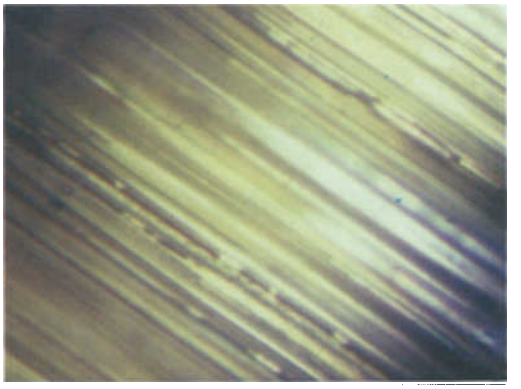

Fig. 3. Sample 3. In this yellow fluorapatite from Mt. Taita (Kenya), the tubes are parallel to the *c*-axis, partly filled with epigenetic laminae of iron compounds, and are considered to be mainly responsible for the cat's-eye. 50x.

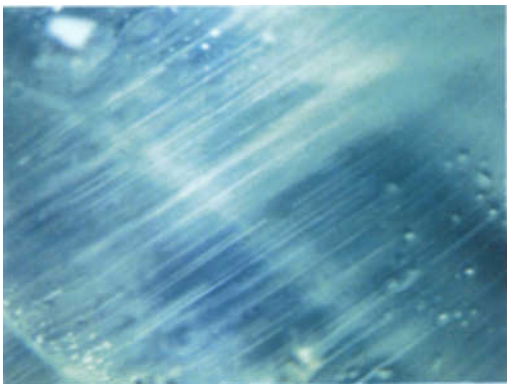

Fig. 4. Sample 4. In this aquamarine from Embu and Meru area (Kenya), the cat's-eye effect is caused by massed parallel, hair-like tubes. 20x.

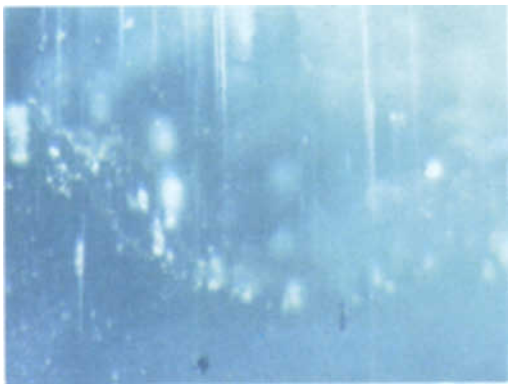

Fig. 5. Sample 8. Healing fissures of different patterns, narrow tubes and some crystals, with a vaporous appearance, decorate this green kornerupine from Mt. Taita (Kenya). 30x.

Fig. 6. Sample 10. The straight edged growth zoning, present in this ruby from Mt. Taita (Kenya), indicates many changes in the physico-chemical environment of the host gem. Inclusions of fine rutile needles were confined to growth zoning. 20x.

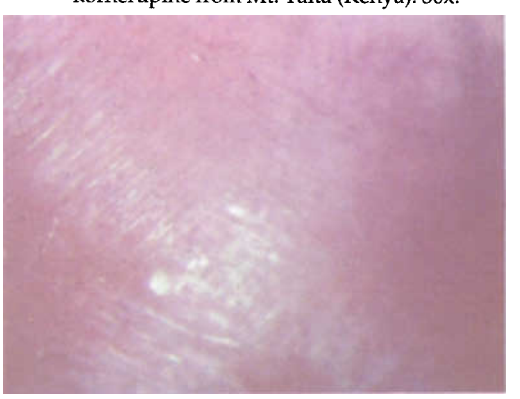

Fig. 7. Sample 10. In this ruby from Mt. Taita (Kenya), the crystallographically dictated arrangement of syngenetic rutile needles and lamellar structures cause the hazy asterism displayed by this cabochon. 10x.

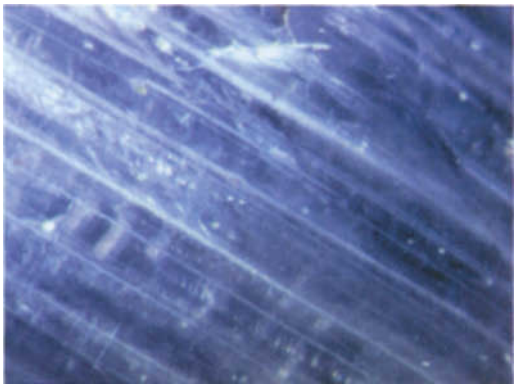

Fig. 8. Sample 11. Broad hollow tubes and boehmite laminae traverse this lilac sapphire from Mt. Pare (Tanzania), and produce the cat's-eye effect. 30x.

Fig. 9. Sample 13. In a yellowish scapolite, 45% Me content, from Dodoma (Tanzania), the filled cleavage laths are yellow, reddish-brown and black due to iron oxides and hydroxides. The opaque laminae consist of pyrrhotite and have the appearance of stripes. The laths and the laminae are parallel and crystallographically oriented. 20x.

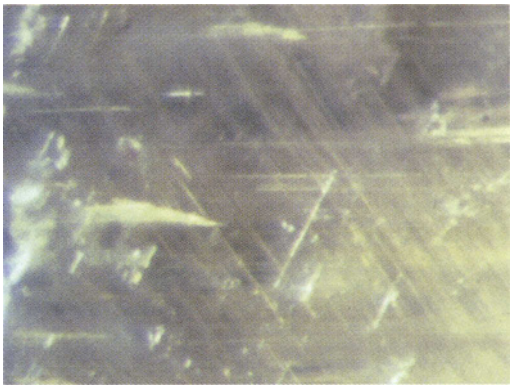

Fig. 10. Sample 17. Systems of parallel tubes and healing fissures cross this brownish-yellow zoisite from Lelatema District (Tanzania). 30x.

extending fully, is displayed by samples 9 and 10. The width and the shortness of these rays may be related to three factors.

First, many stones are quite transparent with patchy development of inclusions; secondly, some stones are poorly cut; and thirdly, variation of alignment of the elongate inclusions tends to make the chatoyancy or asterism less well-defined (Figure 6).

Gemmological and analytical tests

The cabochon-cut gemstones were submitted to standard gemmological and appropriate analytical tests (see Table I).

Visual appearance and absorption spectra

The samples present different grades of clarity and are classified as cabochon-cut gemstones either transparent (samples 3, 4, 5, 8, 9, 10, 11, 12, 13, 14, 15, 17, 18 and 19), semi-transparent (samples 1, 2, 6 and 7), or translucent (sample 16). To the unaided eye, the samples appear of medium hue, only one being dark (sample 16).

The visible-light absorption spectrum of all the cabochons was observed through the hand-held spectroscope and measured with the Cary 219 dual-beam spectrophotometer over the spectral range 400 to 800 nm.

Refractive index, pleochroism and luminescence

The refractive indices of the cabochons were assessed by means of a gemmological refractometer using the distant vision method. It was possible to determine only average values.

Pleochroism and luminescence under long and short wave were observed and evaluated.

Specific gravity

The specific gravity of all the samples was measured with a Berman balance. Due to the variable inclusion content of the cabochons, the results should be interpreted with caution.

Table I. Gemmological properties and mineralogical classification of the cat's-eye and asteriated gemstones from East Africa.

Sample number	*Refractive index (average value)*	*Pleochroism*	*Absorption (nm)*	*Luminescence (UV)*	*Specific gravity*	*Gem*
1	1.75	Reddish Greenish	Broad band: 430 Broad band: 450 Narrow lines: 488, 503	Long wave: faint Short wave: greenish	3.71	Alexandrite
2	1.76	—	Indistinct band: 420 Narrow line: 460 Bands: 500, 520, 576 Faint lines: 470, 605	—	3.96	Almandine
3	1.64	Blue Yellowish	Indistinct band: 450 Narrow line: 478 Faint bands: 520 Strong band: 580	Long wave: greenish Short wave: greenish	3.21	Apatite
4	1.57	Bluish Colourless	Broad band: 427 Diffuse band: 456 Narrow line: 537	—	2.68	Aqua-marine
5	1.58	Sea-green Yellowish	No characteristic	—	2.72	Beryl
6	1.74	—	Main bands: 410, 421, 435 Weak bands: 460, 480, 504 Weak line: 520 Broad band: 573	—	3.93	Grossular
7	1.72	Colourless Blue	Vague lines: 450-500 Vague line at 700	Long wave: dim red Short wave: inert	3.68	Kyanite
8	1.67	Greenish Reddish	Indistinct band: 430 Faint line: 445 Band: 503	Long wave: yellow glow Short wave: yellow glow	3.30	Korner-upine
9	1.75	—	Indistinct band: 460 Main band: 500 Broad bands: 520, 576	—	3.84	Rhodolite
10	1.77	Yellowish Purple	Indistinct band: 463 Narrow lines: 475, 469 Absorption area: 485-600 Weak line: 663 Strong line: 694	Long wave: crimson Short wave: weaker red	3.99	Ruby

Table I. continued

11	1.77	Yellowish Blue	Indistinct band: 435 Complex band: 450	—	4.00	Sapphire
12	1.56	Yellowish Colourless	Broad band: 530-590 Weak line: 650	Long wave: inert Short wave: vague pink	2.68	Scapolite
13	1.56	Yellow Colourless	Broad band: 530-590 Weak line: 650	Long wave: inert Short wave: vague pink	2.72	Scapolite
14	1.55	Yellow Yellowish	Broad band: 530-590 Weak line: 650	Long wave: inert Short wave: vague pink	2.63	Scapolite
15	1.56	Yellow Colourless	Broad band: 530-590 Weak line: 650	Long wave: inert Short wave: vague pink	2.68	Scapolite
16	1.63	Dark green Yellowish	Strong line: 498	Long wave: faint Short wave: yellow	3.04	Tourmaline
17	1.70	Blue Sage-green	Broad band: 590 Faint bands: 530, 455	—	3.36	Zoisite
18	1.70	Blue Sage-green	Broad band: 590 Faint bands: 530, 455	—	3.35	Zoisite
19	1.69	Blue Sage-green	Broad band: 590 Faint bands: 530, 455	— —	3.35	Zoisite

Note: – means no pleochroism or fluorescence was observed

Electron microprobe, X-ray diffraction and thermal analyses

Electron microprobe analyses and X-ray powder diffraction measurements were carried out on all samples to investigate any chemical variation and possible structural change of the host gems and of the inclusions, whenever they were exposed at the surface of the cabochons.

Electron microprobe analyses were carried out on a Jeol JMS-50A. Matrix corrections were made according to the EMPADR VII programme described by Rucklidge and Gasparrini (1969). Total iron was calculated as FeO; beryllium and boron were not detectable by the microprobe.

The unit cell parameters were calculated by means of X-ray powder diffractometry, using nickel-filtered copper K_α radiation with five oscillatory scans at 1/4° 2θ per minute from 10° to 80° 2θ. Pure semiconductor grade crystalline silicon metal (Jarrel Ash JM, spectroscopy impurity less than 300 ppm) was used as an internal standard. The lattice constants were estimated using a least-squares refinement (Appleman and Evans, 1973) of the X-ray data, indexed by comparison with the data listed by the JCPDS files.

Thermogravimetric analyses were performed with a TGS-2 Perkin Elmer system using about 0.10mg of material for each analysis. The H_2O content was estimated by assessing the difference between the thermogravimetric results and the chemical data for the other volatile components, i.e. CO_2, F, Cl and S.

The CO_2 content of the total gaseous phase emitted by the substance after

heating at 1000°C was determined by means of the high sensitivity analyzer of Scarano and Calcagno (1975), using an air current with constant CO_2 content as carrier.

Identification of the gems

The specimens were submitted to the standard gemmological tests, thus identifying the mineral species (Table I). Detailed analytical features are given in Table II and Appendix.

Sample 1 is a chrysoberyl. The iron content (1.36%) and the small amount of chromium are responsible for the dark greenish colour of the gem (Schmetzer, 1985). The reddish colour of the sample in transmitted light (Dana, 1944) and the X-ray powder diffraction data (Vlasov, 1966) suggest that it may be the alexandrite variety.

Samples 2, 6 and 9 are red, greenish-red and brownish-red garnets respectively. On the basis of the lattice constants, refractive index and specific gravity values, they are classified as almandine, grossular (Bank, 1979; Deer *et al.*, 1982) and rhodolite, a mixed crystal within the pyrope-almandine isomorphous series (Anderson, 1959; Bank and Henn, 1989) with a notable pyrope molecular percent end member (62.7%). The calculation was performed according to the dominant molecular content of the end- member components present in each garnet (Table II). The percentage of the andradite end-member was calculated on the basis of Fe^{3+} estimated according to Droop, 1987. The calculated Fe_2O_3 contents were: 0.34, 2.26 and 0.69 wt.% for samples 2, 6 and 9 respectively.

Sample 3 is a yellow apatite. The microchemical analyses, the amount of fluorine (3.15%) and the lattice constants values (c/a = 0.736) identify it as a fluorapatite (Deer et al., 1967; Altschuler *et al.*, 1953).

Samples 4 and 5 are beryls with very similar optical properties, specific gravity, microchemical and lattice constants (Deer *et al.*, 1986; Radcliffe, 1969; Winchell and Winchell, 1953). The relatively high content of MgO and the pale bluish appearance of sample number 4 allows its classification as an aquamarine (Schaller *et al.*, 1962).

Sample 7 is a moderately blue kyanite. The low iron and titanium content may be responsible for the faint colour of the host cabochon and consists of an aggregate of colour patches spread in a colourless matrix (Ghera *et al.*, 1986).

Sample 8 is a dark green kornerupine on the basis of the optical properties, microchemical analyses and lattice constants (Hey *et al.*, 1941; Girault, 1952).

Samples 10 and 11 are ruby and lilac sapphire, based on their appearance and the presence of chromium, iron and traces of titanium, respectively.

Samples 12, 13, 14 and 15, are colourless or yellowish scapolites. The microchemical analyses and lattice constants allow esti-

Table II. Molecular percentage end member and X-ray data of cat's-eye and asteriated garnets from East Africa

Sample number	*Lattice constant a (Å)*	*molecular percent end member*					
		Alm.	*Andr.*	*Gross*	*Pyr.*	*Spess.*	*Uv.*
2	11.566 ± 0.004	45.7	1.0	21.4	30.3	1.6	–
6	11.495 ± 0.005	32.6	4.3	55.6	5.7	1.8	–
9	11.495 ± 0.004	19.3	1.1	16.4	61.9	1.1	–

mates following the relationship proposed by Shaw (1960) and Burley *et al.* (1961), of the percentage of meionite, namely, 39, 48, 28 and 41%, respectively.

Sample 16 is a dark green tourmaline. The chemical data and the lattice constants (c/a = 0.451) indicate that it is a member of the schorl–dravite series (Dunn *et al.*, 1975; Epprecht, 1953; Sahama *et al.*, 1979).

Samples 17, 18 and 19 are brownish-yellow zoisites on the basis of their compositions and lattice constants (Deer *et al.*, 1986).

Examination of the inclusions

The cabochons were examined by means of a stereoscopic microscope and the inclusions were analyzed by the electron microprobe, wherever they intersected the surface.

The specimens were observed in immersion and often showed the presence of a colour pattern unevenly distributed in bands. Broader zones and colour areas are exhibited by the clustering of tiny needles.

A multitude of inclusions were observed and segregated into six main categories. The different types of inclusions are listed in Table III. Only the inclusions in groups 1, 2, 3 and 4 are involved in producing cat's-eyes or asterism.

1. Tube like inclusions

These inclusions are present in numerous cabochons of different mineral species and are the main cause of the chatoyancy (samples 3, 4, 8, 9, 11, 12, 13, 14, 15, 16, 17, 18 and 19).

They are primary cavities which are normally caused by irregularities in the growth process of the host crystal. Such tubes may be filled by scaly aggregates with a colour varying from brownish-red to yellow and variously mixed (Figures 3, 4, 5, 8, 9 and 10), by two-phase inclusions (Schmetzer *et al.*, 1977; Graziani and Gübelin, 1981; Schmetzer and Bank, 1983) or by powdery birefringent material (Graziani *et al.*, 1982).

Around these cavities, 'fingerprint' veils are often present, and also healing fractures, surrounded by brown or reddish-brown vague haloes which alter the appearance both of the cat's-eye or star effect.

Electron microprobe analyses indicate the presence of iron, therefore the haloes were attributed to iron oxides or hydroxides. This has been documented by Schmetzer and Bank, 1983; Ghera *et al.*, 1988, and is common to numerous minerals.

2. Acicular inclusions

Analysis of the fine (<30μm diameter) acicular inclusions is experimentally difficult and results are commonly similar to composition of the host crystal (samples 1, 2, 3, 6, 9, 10, 11 and 16).

Analyzing the acicular inclusions of maximum diameter, the semi-quantitative microprobe analyses showed small amounts of titanium. Considering the visually estimated high birefringence, the growth conditions and the high formation temperature, the inclusions are probably rutile.

The colour hue of the cabochons appears to be linked to these acicular inclusions which are responsible for the clear or for the opalescent appearance of the samples (Figures 2, 6 and 7).

Optical and electron microprobe observations showed the presence (samples 1 and 16) of bunches of yellowish brucite fibres (Koivula and Fryer, 1985) and (sample 3) of acicular goethite (Gübelin and Schmetzer, 1982).

3. Lamellae

Some specimens (samples 1, 2, 3, 6, 10, 11, 17, 18 and 19) showed planar textures. These are polysynthetic lamellar structures with the same microchemical composition of the host crystals and are either twinning or cleavage surfaces.

The individual lamellae are often limited both by an incipient decomposition along

Table III. Recognized inclusions in the cat's-eye and asteriated gemstones from East Africa

Sample number	*Host gem*	*Inclusions*					
		Tubes	*Lamellae*	*Laminae*	*Feathers*	*Minerals*	
						acicular	*other habits*
1	Alexandrite	---	Present	---	Present	Brucite Rutile	Diopside Unidentified
2	Almandine	---	Present	---	Present	Rutile	Unidentified
3	Apatite	Present	Present	---	---	Goethite Rutile	Unidentified
4	Aquamarine	Present	---	Biotite	---	---	---
5	Beryl	---	---	Hematite	---	---	Apatite
6	Grossular	---	Present	---	Present	Rutile	Diopside, Unidentified
7	Kyanite	---	---	Hematite	---	---	Unidentified
8	Kornerupine	Present	---	Graphite	Present	---	Apatite
9	Rhodolite	Present	---	---	Present	Rutile	Apatite, Unidentified
10	Ruby	---	Present	---	Present	Rutile	Apatite
11	Sapphire	Present	Boehmite	---	Present	Rutile	Apatite
12	Scapolite	Present	---	Muscovite	Present	---	---
13	Scapolite	Present	---	Pyrrhotite	Present	---	---
14	Scapolite	Present	---	Biotite	---	---	Unidentified-
15	Scapolite	Present	---	---	Present	---	---
16	Tourmaline	Present	---	Graphite	---	Brucite	---
17	Zoisite	Present	Present	Graphite	Present	---	---
18	Zoisite	Present	Present	Graphite Hematite	Present	---	---
19	Zoisite	Present	Present	Graphite	Present	---	---

these planes (samples 10 and 11), by parallel arrangements of laminae (samples 2, 3, 6, 17, 18 and 19), or may be covered with disseminated, lenticular, colourless lamellae, (sample 11), probably boehmite (Eppler, 1974; Hänni and Schmetzer, 1991) (Figure 8).

4. Laminae and platelets

Brown laminae of biotite and transparent, colourless platelets of biotite and muscovite occur in samples 4, 12 and 14.

Dark grey, pseudo-hexagonal laminae of hematite and pyrrhotite, often partially decomposed and surrounded by rings of yellow-orange iron hydroxides, represent common epigenetic inclusions (samples 5, 7, 13 and 18) and when present, darken the colour of the cabochon.

Rounded black platelets of graphite often forming groups, are present in some cabochons from East Africa (samples 8, 16, 17, 18 and 19) as a product of intense metamorphism.

5. Feathers and healed fractures

Healed fractures are indicated by cleavages or veil-like feathers of fluid remnants and by haloes of a yellow or brownish-red matter (samples 1, 2, 6, 8, 9, 10, 11, 12, 13, 15, 17, 18 and 19) and are generally unrelated to the cat's-eye or asterism effect.

Electron microprobe analyses of the fractures showed the almost exclusive presence of iron, and consequently the haloes were ascribed to iron oxides or hydroxides.

6. Mineral inclusions

Sporadic transparent and opaque inclusions are present in almost all the cabochon-cut gemstones (Figures 9 and 10). The crystals (approx. 0.03 x 0.06mm), are often elusive or difficult to study, they seem to disappear like vapour and occur singly (Figure 10). Careful optical observations may enable one to identify these peculiar inclusions (samples 1, 2, 3, 6, 7, 9 and 14), and so far, diopside (samples 1 and 6) and apatite (samples 5, 8, 9, 10 and 11) prismatic crystals have been recognized (diameter: min.: 0.01mm; max.: 0.2mm).

Discussion and conclusions

The cabochon-cut gemstones are remarkable for the presence in all samples of a multitude of inclusions, many of which are responsible for the chatoyancy or star effects (Table III).

The straight-edged colour bands and growth zoning (Figures 7 and 8) are due to the sporadic variations in the physico-chemical growth conditions and document intermittent episodes of the host crystal's growth (samples 10 and 19).

Tubes, acicular inclusions and lamellae, sometimes with a crystallographically dictated parallel arrangement of minute lines, decorate the host minerals and represent the main cause of these optical effects.

Laminae and platelets are related to the cat's-eye effect only if they are oriented perpendicularly to the base of an elliptical cabochon.

Feathers, healed fractures and mineral inclusions are not confined to stones with the cat's-eye or star effect and are present incidentally.

Nevertheless, tubes, acicular inclusions, healed fractures and feathers are responsible for the yellowish appearance of the cabochons. This colour is due to iron oxides or hydroxides and indicates that the latter iron minerals crystallized after a late-stage filling of these cavities. Sporadic alterations of the physico-chemical conditions probably produced fractures into which the mother fluid penetrated and where iron compounds segregated. The colour variability of the haloes, from yellowish to reddish, also probably indicate a possible sequence of transformation of iron hydroxides into iron oxides due to an increase of the environmental temperature.

The presence of hematite in samples 5, 7 and 18 shows that the temperature of crystallization was more than 500°C (Kulp *et al.*, 1951).

The frequent occurrence of graphite platelets (samples 8, 16, 17, 18 and 19) is witness to intense metamorphic events which characterized the East African geological situation.

The data obtained from the cabochon-cut gemstones and their identified inclusions are consistent with their derivation from medium- to high-grade metamorphic rocks which are common throughout the whole East African region.

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Appendix
Electron microprobe analyses of cat's-eye and asteriated gemstones from East Africa

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
SiO_2	0.50	39.48	-	65.40	65.92	38.00	37.70	32.10	41.31	0.22	0.20	52.85	52.58	57.12	52.67	37.38	40.10	41.10	41.76
TiO_2	0.00	tr.	-	0.00	0.00	0.00	0.05	0.16	0.00	0.06	0.03	0.04	0.04	0.04	0.05	0.23	0.05	0.09	0.14
Al_2O_3	78.76	21.48	-	18.25	18.90	21.80	61.79	44.43	24.17	98.65	98.46	24.81	24.07	22.05	23.46	31.39	33.40	32.47	32.95
FeO[1]	1.36	21.92	0.14	0.70	0.64	17.50	0.40	0.17	10.29	0.06	1.02	0.27	0.09	0.11	0.06	3.50	1.11	0.05	0.07
MnO	0.00	0.75	0.00	0.00	0.06	0.85	0.00	0.00	0.54	0.00	0.06	0.00	0.00	0.00	0.00	0.00	0.04	0.04	0.05
MgO	0.00	8.04	0.25	0.45	0.06	1.52	-	19.90	17.36	0.00	0.01	0.11	0.10	0.00	0.14	10.87	0.14	0.15	0.17
CaO	0.30	8.18	52.54	0.50	0.00	20.60	-	0.05	6.41	0.00	0.00	12.92	11.62	6.80	10.22	1.03	23.50	23.91	24.01
Na_2O	0.00	-	0.27	0.70	0.55	-	0.00	0.02	-	-	-	3.94	6.23	9.22	7.19	2.01	0.10	0.74	0.53
K_2O	0.00	-	0.00	0.30	0.09	-	0.10	0.03	0.00	-	-	1.08	1.25	0.86	1.25	0.08	tr.	0.21	0.20
P_2O_5	-	0.00	41.90	-	-	0.00	0.00	0.00	-	-	-	-	-	-	-	-	0.00	0.00	0.00
SO_3	-	-	-	-	-	-	tr.	tr.	-	-	-	0.57	0.76	0.05	0.72	-	-	-	-
Cr_2O_3	0.18	0.00	-	0.03	0.04	0.00	0.00	0.05	-	0.45	0.09	-	-	-	-	0.19	tr.	tr.	tr.
V_2O_5	tr.	0.00	-	0.00	0.00	0.00	0.00	0.00	-	0.05	0.02	-	-	-	-	tr.	tr.	tr.	tr.
Cl	tr.	-	1.15	-	-	-	tr.	0.18	-	-	-	1.56	1.70	3.03	1.85	-	-	-	-
F	0.00	-	3.15	0.00	-	-	0.00	0.00	-	-	-	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
BeO[1]	18.85	-	-	12.25	12.63	-	0.00	0.00	-	-	-	-	-	-	-	-	-	-	-
B_2O_3[2]	0.00	-	-	0.00	-	-	0.00	3.17	-	-	-	-	-	-	-	10.76	-	-	-
CO_2[3]	0.00	-	1.00	-	-	-	0.00	0.00	-	-	-	2.00	1.50	0.85	2.15	0.00	-	-	-
H_2O^+, H_2O^- [4]	0.00	0.00	0.00	1.47	1.47	0.00	0.00	0.00	0.00	-	-	0.10	0.19	0.15	0.15	3.30	1.10	1.13	0.14
	99.95	99.85	100.40	100.05	100.36	100.27	100.04	100.26	100.08	99.49	99.89	100.25	100.13	100.28	99.91	100.74	99.54	99.89	100.02
O≡Cl,F			0.13									0.35	0.38	0.68	0.42				
TOTAL	99.95	99.85	100.27	100.02	100.36	100.27	100.04	100.26	100.08	99.49	99.89	99.90	99.75	99.60	99.49	100.74	99.54	99.89	100.02

See Table I for sample identities 1-19

(1) Total iron recorded as FeO

(2) Calculated

(3) Measured with CO_2 analyser

(4) Determined with a thermogravimetric analyser

A note on red beryl

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Abstract

The gemmological characteristics of a 4.66ct cut red beryl are described. Electron microprobe analyses of the beryl indicate contents of 2.8 per cent FeO (total iron) and 0.8 per cent MnO, and a complex inclusion cluster of opaque minerals comprising bixbyite columbite and two unidentified species, one largely composed of manganese and cerium oxides, the other containing these two elements together with significant uranium and thorium.

Introduction

The recent publication of Hosaka, Tubokawa, Hatushika and Yamashita on red beryl crystals from Utah (*Journal of Gemmology*, July 1993) complements the earlier work of Shigley and Foord in 1984 (*Gems & Gemology*, Winter 1984). Recently Alan Hodgkinson provided the opportunity to examine one of the larger faceted red beryls in existence and it is appropriate to comment briefly on both the spectrum displayed by this stone and the complexity of its inclusions.

Gemmology and composition

The stone is a deep mixed-cut of fine colour (Figure 1) weighing 4.66ct, with RI of 1.568 – 1.572 and DR of 0.004. Through a hand–held spectroscope the absorption pattern appears as shown in Figure 2 with a wide absorption band from 590–500nm, a weak band at 455nm, a stronger band at 430nm, and general absorption from 420-400nm.

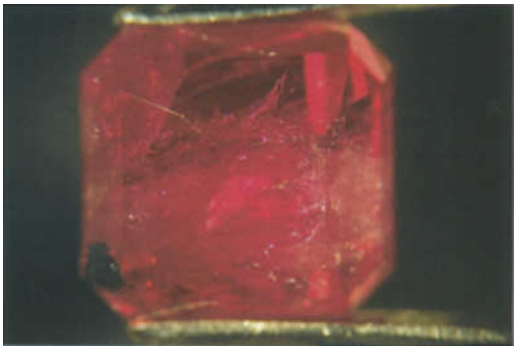

Fig. I. Red beryl of 4.66ct, viewed from pavilion side, with cluster of opaque inclusions located just below the girdle. *Photo: R.R. Harding*

These data are consistent with the spectrophotometer traces published by Shigley and Foord (1984) and by Hosaka *et al.* (1993), although the absorption peaks of the polarized spectra given by Shigley and Foord are slightly different in detail. This variability may be related to the differences in iron content between the stones measured (see below).

Analyses of the red beryl were carried out on a Hitachi scanning electron microscope (SEM) with Link Systems energy dispersive system (EDS) and the mean of 3 spot analyses is given in Table I, column 1. As indicated above, the main difference between the composition of this red beryl and of those reported in the papers cited is the iron content – 2.8 per cent compared with 1.3 per cent (Hosaka *et al.*) and 1.5 – 1.8 per cent (Shigley and Foord).

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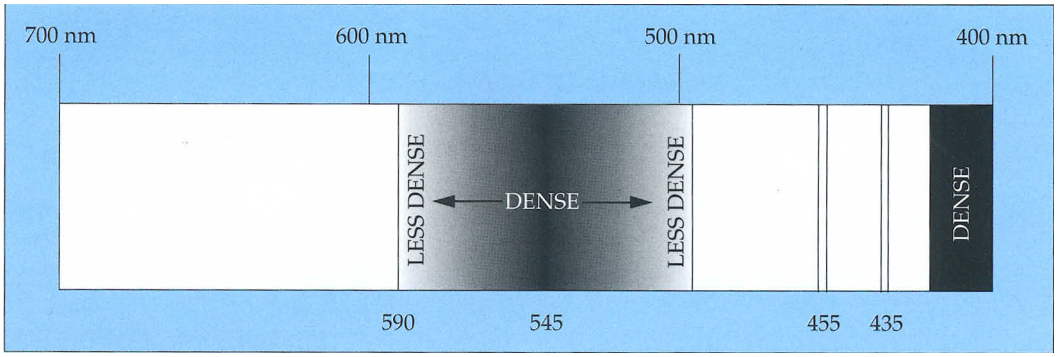

Fig. 2. Visible absorption spectrum of red beryl through diffraction grating spectroscope. The 455nm line is weak.

Manganese (0.8 per cent) is also higher in Alan Hodgkinson's stone and these higher minor element contents may be responsible for the appearance of a spectral absorption band at 455nm.

The red beryl contains a number of black inclusions and conveniently for SEM-EDS analysis, some intersect the surface close to the girdle (Figures 3 and 4). They are rounded or equant polygonal in polished section, and most consist of the iron manganese oxide bixbyite (Table I, column 2). However, not all the grains are bixbyite, and both within and at the rims of the bixbyite are opaque grains of other species, some not yet identified.

At the core of one bixbyite grain is ferrocolumbite whose composition is given in Table I, column 3; the high total may be a combination of some experimental error and perhaps different oxidation states of the niobium and tantalum. Within and at the edges of the bixbyite are unidentified minerals variably rich in cerium, uranium

Table I: Electron microprobe analyses of 4.66ct red beryl and inclusions

Red Beryl (mean of 3)		*Bixbyite (mean of 3)*		*Columbite*		*Unidentified mineral UA*		*Unidentified Mineral UB (mean of 5)*	
SiO_2	67.17	SiO_2	2.41	SiO_2	1.69	SiO_2	1.06	SiO_2	6.35
TiO_2	0.29	TiO_2	1.48	TiO_2	7.47	TiO_2	0.25	TiO_2	0.59
Al_2O_3	16.75	Al_2O_3	1.71	FeO	19.92	Al_2O_3	0.58	Al_2O_3	2.31
FeO	2.81	Fe_2O_3	44.37	MnO	8.21	FeO	3.50	FeO	5.50
MnO	0.82	Mn_2O_3	49.02	CaO	0.27	MnO	9.42	MnO	37.01
CaO	0.13	CaO	0.31	SrO	2.40	CaO	0.56	CaO	1.07
K_2O	0.10	Na_2O	0.40	ZrO_2	2.69	K_2O	0.40	K_2O	2.29
		ZrO_2	0.48	SnO_2	1.43	ZrO_2	3.55	SrO	0.90
		MgO	0.07	UO_2	0.89	UO_2	15.60	PbO	3.62
				Nb_2O_5	54.09	ThO_2	14.26	Ce_2O_3	22.05
				Ta_2O_5	4.08	Ce_2O_3	47.77	SO_3	0.85
						SO_3	0.23		
Total	88.07		100.25		103.14		97.18		82.54

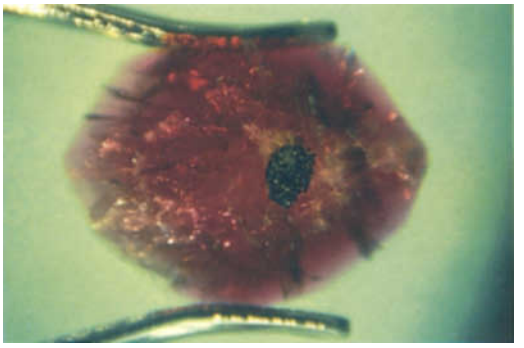

Fig. 3. Red beryl immersed in fluid with opaque inclusions visible just beneath the girdle. *Photo: A. Hodgkinson*

Fig. 4. Cluster of opaque inclusions intersecting the facets of the red beryl show a range of reflectivities. *Photo: R.R. Harding*

or thorium and two compositions are given in columns 4 and 5 of Table I. The composition given in column 5 is the mean of the analyses of 5 spots which gave consistently low totals; these may be due to the presence of low atomic number elements such as lithium or beryllium or hydrogen (water), none of which are detectable by this method of analysis.

Conclusion

Other methods of analysis would be needed to fully identify these minerals but the SEM-EDS has revealed some of the complexity that may be present among opaque inclusions in gemstones. The presence of cerium-bearing inclusions brings to mind the brown cerium carbonate parisite which is found in association with the Muzo emeralds in Colombia.

Acknowledgements

I would like to thank Alan Hodgkinson for the opportunity to examine this rare cut stone, and Ana Castro and Stephen Kennedy for discussion in the laboratory, and Frances Wall and Terry Williams, Natural History Museum, for assistance with micrprobe analyses.

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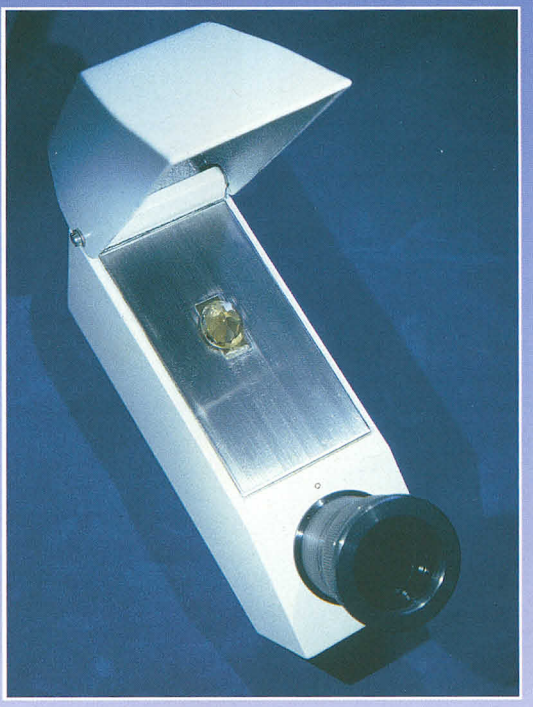

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Abstracts

Diamonds | Gems and Minerals

Instruments and Techniques | Synthetics and Simulants

Diamonds

Crystal morphology identification of diamond and ABN.

M.W. Bailey and L.K. Hedges. *Industrial Diamond Review*, **55**(1), 1995, 11-14.

The structures of diamond and cubic boron nitride are similar in that they are both strongly bonded covalently with tetrahedral bonding, but are dissimilar in that diamond has a centre of symmetry whereas cBN does not. Crystals of each can be described and distinguished by a simple crystallographic system referred to as the 'morphology index'. This index has been used by De Beers for many years to characterize the extensive range of diamond and ABN (abrasive boron nitride) offered on the market. The morphology index describes the basic characteristics of a crystal in terms of the growth of different crystal faces, which have different mechanical properties (indentation hardness, abrasion resistance and polishing rates, cleavage or fracture energy), and different chemical properties (absorption of chemical species and chemical reactions with oxygen or, for diamond, with carbon solvent metals or carbide formers).

R.A.H.

Carbon dioxide in strongly silica undersaturated melts and origin of kimberlite magmas.

G.P. Brey and I.D. Ryabchikov. *Neues Jahrbuch für Mineralogie, Monatshefte*, (10), 1994, pp 449-63.

The solubility of CO_2 in melts on the olivine-melilitite-($CaCO_3$-$MgCO_3$) join has been determined at 5-30 kbar. The CO_2 content of gas-saturated melts increases almost linearly with (Ca + Mg) from 9 to 37 wt.% at 30 kbar; at 10 kbar it increases non- linearly with (Ca + Mg), and more rapidly on the carbonate-rich side of the join. A simple thermodynamic model is proposed for CO_2 solubility, which takes into account the higher stability of $CaCO_3$ compared with $(Mg,Fe)CO_3$ complexes in the melt. The CO_2 solubility for compositions similar to type 1A kimberlites (characterized by high MgO and relatively low CaO levels) changes sharply in the *P*-range corresponding with the stability field of diamond. The vigorous degassing resulting in hydraulic fracturing of wall rocks may explain the diamondiferous character of these MgO-rich melts.

R.A.H.

Dating lower crust and upper mantle events: an ion microprobe study of xenoliths from kimberlitic pipes, South Australia.

Y.D. Chen, S.Y. O'Reilly, P.D. Kinny and W.L. Griffin. *Lithos*, **32**(1-2), 1994, pp 77-94.

Zircons separated from five xenoliths from the Calcutteroo kimberlitic pipes (167-174 m.y.) (three quartzofeldspathic granulites, one mafic granulite and one eclogite) were dated using the SHRIMP ion microprobe. The zircon data indicate that different types of xenoliths had different origins and formed at different times. The combined data-set of all zircon U-Pb ages from all the xenoliths records four major tectonic events associated with zircon formation, recrystallization or

ABSTRACTORS

R.K. Harrison	R.K.H.	R.J. Peace	R.J.P.	K.A. Riggs	K.A.R.
R.A. Howie	R.A.H.	G. Raade	G.R.	R.E. Samson	R.E.S.
M. O'Donoghue	M.O'D.	P.G. Read	P.G.R.		

For further information on many of the topics referred to consult *Mineralogical Abstracts* or *Industrial Diamond Review*.

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Pb loss. These events at about 1600-1500, 780, 620 or earlier and 330 m.y., correlate with large-scale tectonic events recorded in adjacent crustal and mantle rocks. The identification of multiple zircon-forming events and the inferred different times of formation of different xenolith assemblages show that Sm-Nd isochron ages based on an assumption of a cogenetic relationship are invalid. G.R.

Majhgawan diamondiferous pipe, Madhya Pradesh, India - a review.

A.K. CHATTERJEE AND K.S. RAO. *Journal of Geological Society of India*, **45**(2), 1995, 175-89, 2 maps.

The alkaline ultrabasic Majhgawan diatreme was intruded into the Kaimur sandstones of the Lower Vindhyan supergroup (1400–1100 m.y.) overlying the cratonic Bundelkhand granite basement (2550 m.y.), which is a typical archon; recent Rb/Sr age data indicate 1042–1067 m.y. for the Majhgawan pipe. This pipe has a surface dimension of 500 x 320m, and is a carrot-shaped body reminiscent of a typical kimberlite. The rock has been classified as an olivine lamproite lapilli tuff of crater facies. High TiO_2 (4-6%), less abundant heavy indicator minerals such as pyrope and ilmenite, and overall petrological character of the pipe reflect its lamproite nature, as do high amounts of Ba (3000 ppm), Sr (1000 ppm) and *REE*. On the other hand, the almost concentric distribution of diamonds, mode of occurrence of mantle-derived xenocrysts and overall geochemistry, with high MgO (25%), low K_2O (1%) and fair amounts of Cr and Ni, are characteristics of a kimberlite. The garnet population and composition are intermediate in character between kimberlite and lamproite. The Majhgawan diamonds (42% of gem grade) have predominantly curved faces and modified forms indicative of resorption. R.A.H.

Origin of vein graphite in high-grade metamorphic terrains. Role of organic matter and sediment subduction.

C.G. DISSANAYAKE. *Mineralium Deposita*, **29**(1), 1994, 57-67, 2 maps.

A voluminous source of mantle-derived CO_2 has been suggested for the phenomenon of granulite formation. Recent studies on the granulite terrain of Sri Lanka have clearly shown that it is only an upper crustal section and that it was subjected to a much smaller influx of CO_2 than previously envisaged. The close association of graphite with the granulites, and the recent discovery of grain-boundary graphite in the lower crust, implies graphite as a major source of CO_2. Recent reports on the discovery of alluvial diamonds within the granulite belt of the Highland complex of Sri Lanka, where graphite is abundant, may indicate penetration of the graphite-diamond inversion line. R.E.S.

Nitrogen aggregation in metamorphic diamonds from Kazakhstan.

K.S. FINNIE, D. FISHER, W.L. GRIFFIN, J.W. HARRIS AND N.V. SOBOLEV. *Geochimica Cosmochimica Acta*, **58**(23), 1994, 5173-77.

Proton-probe analyses are presented of diamonds separated from Tertiary sands 20km from the type locality of the diamondiferous rocks of the Kokchetav massif; for K, Ca, Ti, Cr, Cu, Zn, Zr and Fe the results are compared to those of diamonds from Zaire, South Africa and the Argyle field. IR and visible absorption spectra show ~48-63% aggregation of single N substitution to A centres. Calculated residence times assuming peak metamorphic *T* of 800-900°C are <0.5 m.y. to 40 m.y. These times, together with petrographical evidence, indicate that the diamonds formed during high-*P* metamorphism rather than being derived from pre-metamorphic sediments. R.K.H.

An atomistic model for stepped diamond growth.

M. FRANKLACH, S. SKOKOV AND B. WEINER. *Nature*, **372**(6506), 1994, 535-7.

Theoretically, bridging methylene (CH_2) groups on the {100} plane of diamond growing in the presence of hydrogen can migrate in a manner analogous to surface diffusion. It is shown that this theory can be developed into an atomistic model accounting for stepped growth in diamond through the formation of surface-bound species from gaseous precursors, followed by their migration through surface chemical reactions involving covalent bond breaking and formation. R.K.H.

Trace elements in garnets and chromites: diamond formation in the Siberian lithosphere.

W.L. GRIFFIN, N.V. SOBOLEV, C.G. RYAN, N.P. POKHILENKO, T.T. WIN AND E.S. YEFIMOVA. *Lithos*, 29(3-4), 1993, 235-56.

Proton EPMA of trace elements in garnet and

chromite inclusions in diamonds from the Mir, Udachnaya, Aikhal and Sytykanskaya kimberlites in Yakutia provide new insights into the processes that form diamond. Equivalent data on garnet and chromite concentrates from these pipes yield information on the thermal state and chemical stratification of the Siberian lithosphere. Peridotite-suite diamonds from Yakutia have formed over a *T* interval of ~600°C, as measured by Ni and Zn thermometry on garnet and chromite inclusions. Individual diamonds contain inclusions recording *T* intervals of >400°C; ranges of >100°C are common. Diamond formation followed a severe depletion event, and a separate enrichment in Sr. Comparison of *T* on garnet and spinel inclusions with *T* derived from diamondiferous harzburgites, exposed inclusions in boart and concentrate minerals suggest that the diamond-containing part of the lithosphere has cooled significantly since the Siberian diamonds crystallized. The peridotite-suite diamonds probably formed mainly in response to one or more relatively short-lived events, related to magmatic intrusion. The *N* part of the Daldyn-Alakit district may have had a typical cratonic geotherm at the time of diamond formation, and during kimberlite intrusion. The *S* part of the district, and the Malo-Botuobiya kimberlite field, probably had a relatively low geotherm (~35 mW/m^2). The vertical distribution of garnet and chromite types indicates that the mantle above 120km depth is dominated by lherzolites, whereas the deeper parts of the lithosphere are a mixture of lherzolite and more depleted harzburgites and dunites. G.R.

Trace elements in diamond inclusions from eclogites reveal link to Archean granites.

T.R. IRELAND, R.L. RUDNICK AND Z. SPETSIUS. *Earth & Planetary Science Letters*, **128**(3-4), 1994, 199-213.

Trace element data are reported for rare inclusions of garnet and clinopyroxene in diamonds in eclogite xenoliths from the Udachnaya pipe in the Daldyn-Alakit kimberlite field of Siberia. These inclusions are more depleted in incompatible trace elements and have lower *mg* numbers than the eclogite host minerals, reflecting metasomatic enrichment of the eclogites after diamond formation.

Experimental studies are interpreted as showing that eclogites of this type are in equilibrium with silicic melts such as tonalites or trondhjemites. Thus, both the trace element data and petrological considerations are consistent with the eclogites forming in equilibrium with Archaean tonalitic or trondhjemitic magmas. R.A.H.

Gem Trade Lab notes.

R.C. KAMMERLING AND C.W. FRYER. *Gems & Gemology*, **31**(1), 1995, pp 52-8, 15 illus. in colour.

A marquise-cut diamond showed an unusual fracture with thin film iridescence and natural colour staining which might be confused with the flash effect of a filled diamond. However, the 'feathery' appearance was typical of an unfilled break.

A new type triangular inclusion in a diamond is described. A triangular plane containing separate trigons was seen to be one of the octahedral faces of a phantom crystal within the host. The high relief of the trigons was attributed to gas trapped in the triangular voids formed at the interface of the phantom crystal and the host.

A dark red brilliant-cut diamond could be picked up with a hand magnet and contained inclusions with metallic lustre. Long wave UV revealed a cross-shaped area with green fluorescence whilst the rest of the stone remained inert; the stone fluoresced a faint orange under short wave UV. Visible spectroscopy revealed several absorption lines between 500 and 660nm including lines at 595 and 635nm with an emission line at 580nm. This pattern is typical of a treated stone. R.J.P.

Gem news.

J.I. KOIVULA, R.C. KAMMERLING AND E. FRITSCH. *Gems & Gemology*, **30**(4), 1994, pp 271-80, 16 illus. in colour.

The occasional diamond found in the Appalachian Mountains has been suggested to have local sources. Previous explanations include glacial transport and deposition by migratory birds.

Initial surveying on the Kahama/Shinyanga diamond leases in Tanzania by Serengeti Diamonds shows that diamond concentration in these secondary deposits is higher than that in the initial pipe due to wind action with an estimated deposit of 258 000ct. A US$8 million upgrade of the Mwadui mine discovered by Dr J. Williamson in 1940 is to be carried out since superficial reserves were exhausted in the 1980s.

United Reef Ltd of South Africa have reported results of valuations on diamonds from its Bamingui Project showing US$150 per carat

making this one of the world's highest in terms of dollars per carat.

Canadian diamond prospects received a major setback in August 1994 when sampling at the Tli Kwi Cho kimberlite pipe in the Lac de Gras area of the Northwest Territories showed unexpectedly low results. A further poor report from the Torrie pipe in the Yamba Lake area produced a crash in diamond stocks which hurt investor confidence. However encouraging results have been obtained from a cluster of pipes in the Corridor of Hope which cuts through the Lac De Gras area. BHP/Dia Met are starting a feasibility study and hope to start mining before the year 2000.

Prospecting in Finland has received increased interest after Ashton Mining (Australia) discovered 21 kimberlite pipes and recovered several diamonds over 2 carats. R.J.P.

Geoscience 1994 and beyond: thoughts on geology and exploration for world-class ore deposits.

P.J. LEGGE. *Australian Journal of Earth Sciences*, **42**(1), 1995, 1-10.

In this Presidential Address, the use of new technologies is highlighted in a summary of developing concepts for exploration criteria. By determining the Ni content of a suite of kimberlite pyropes, it is possible to estimate the *P-T* conditions of garnet formation and hence judge the probability of formation in the diamond window of 850-1200°C at 150-200km depth depending on the geotherm. This work has been extended to estimate maximum grade (carats/tonne) in a kimberlite, based on the mix of mantle rocks entrained and the degree of metasomatism as measured by the Zr content of a suite Cr- pyropes from a pipe. R.A.H.

Diamonds and their sources in the Venezuelan portion of the Guyana Shield.

H.O.A. MEYER AND M.E. MCCALLUM. *Economic Geology*, **88** (5), 1993, pp 989-98, 5 maps.

Two sources are suggested for the diamonds. The secondary source is the 2000m thick Roraima group of Proterozoic age. The main sources probably are unknown Proterozoic kimberlites or lamproites in the Guyana Shield of the Amazonian craton. No evidence exists to support an African source. K.A.R.

Paleomagnetism of some Indian kimberlites and lamproites.

K.C. MILLER AND R.B. HARGRAVES. *Precambrian Research*, **69**(1-4), 1994, pp 259-67, 1 map.

Consistent vectors have been isolated by AF demagnetization of 22 cores from two sites in Proterozoic kimberlites in the Wajrakarur district of the Dharwar craton (pole at 45.4°S, 121.5°W), and 12 cores from two sites from the mine at Majhgawan in the Panna district of the Aravalli craton (pole at 38.9°N, 216.5°E). Surprisingly, these 1200-1000 m.y. poles fall close to roughly coeval points on the APW curve for the Kalahari craton in a Gondwana reconstruction. If the poles and their ages are correct, these data constrain Mesoproterozoic supercontinental reconstructions. R.E.S.

Compositions of garnet and spinel from the Aries diamondiferous kimberlite pipe, central Kimberley block, Western Australia - implications for exploration.

R.R. RAMSAY, D. EDWARDS, W.R. TAYLOR, N.M.S. ROCK AND B.J. GRIFFIN. *Journal of Geochemical Exploration*, **51**(1), 1994, 59-78, 2 maps.

This weathered, micaceous kimberlite pipe is the largest and most diamondiferous of the few kimberlites currently known in Australia. It contains abundant country rock xenoliths, but the only mantle-type inclusions so far recovered are individual grains of Cr-spinel, rare chromian pyrope and diamond. Aries differs from other kimberlites of similar age in the block in the absence of megacrystic minerals. Chromian pyrope has compositions which indicate garnet lherzolite and garnet wehrlite in the upper mantle, but harzburgitic 'G10' garnets, considered the paramount indicator of diamondiferous kimberlite in S. Africa, have not been recovered at Aries where spinel has been the most important indicator mineral in the discovery. This can be distinguished, morphologically and compositionally, from spinel in local basaltic country rocks. The spinels in the pipe have a range of internal features which can be allocated to six types which in turn can be combined into two broader classes. Both Class 1 and 2 spinels may be associated with Ti-rich Cr-spinel which is compositionally similar to titaniferous Cr-spinel from the groundmass. R.E.S.

[Mineralogical and petrological features of alkali-ultramafic lamprophyres and kimberlites of Kola Peninsula.] (Russian with English Abstract.)

S.K. SIMAKOV, E.A. BAGDASAROV AND L.I.

LUKJANOVA. *Proceedings of the Russian Mineralogical Society*, **123**(1), 1994, 26-40.

Dykes and explosion pipes of alkali-ultramafic lamprophyres and kimberlites occur mainly in the S part of the Kola Peninsula, controlled by deep fault structures. Their formation corresponds with the final stage of alkali magmatism in the Palaeozoic Kandalaksha graben. Geochemically, these lamprophyres are rich in Fe and Ti, with high Na content. In kimberlites the Al_2O_3, ΣFe and SiO_2 decrease with increasing MgO content and K_2O/Na_2O ratio. Numerous EPMA results are reported for olivines, clinopyroxenes, garnets, chrome spinels, ilmenites and micas, together with clinopyroxenes, garnets and amphiboles from xenoliths in the explosion pipes, and native gold from a melteigite dyke, and native copper, solver, argentite, chalcocite and gersdorffite from a fine-grained kimberlite. The *P-T* conditions for lamprophyre magma formation are estimated to be in the range 10-40 kbar, 1425-1320°C, corresponding with a depth for the magma chamber of 40-130km. For kimberlitic magma, the formation *T* is estimated at 1360-1450°C, the *P* 30-51 kbar and the depth of magma chamber 110-160km. In general, there is a tendency for increase in chamber depth from W to E, towards the Archangelsky kimberlite province; this is reflected in the chemistry of the rocks and minerals, with increasing Mg, reduction in Ti and Na and a decrease of Ca in the olivines. R.A.H.

Story on the 'Cross of Asia' fancy yellow radiant cut diamond.

A. SZYMANSKI. *Archiwum Mineralogiczne*, **50**(1), 1994, 137-8.

An examination by the author of this diamond (fifteenth on the GIA list of clearly yellow coloured diamonds) is reported. Found in Jagersfontein mine, South Africa, in 1902, this stone originally weighed 280ct; it was cut first to 142ct and later recut three times to 112, 109.28 and finally to 79.12ct. It now has a rectangular shape (28.67 x 22.21 x 15.77mm) and the play of colours on the table facet create the outline of a Maltese cross. R.A.H.

The generation of kimberlites, lamproites and their source rocks.

K.M. TAINTON AND D. MCKENZIE. *Journal of Petrology*, **35**(3), 1994, 787-817, 1 map.

Measurements of the *REE* concentrations in South African kimberlites and in the Argyle lamproite from Western Australia constrain the composition of the source rocks from which these melts originate. To account for the amounts of Tm, Yb and Lu in these magmas, their sources must first have been strongly depleted by ~20% melting in the garnet stability field, and then enriched by a metasomatic melt rich in *LREE* and other incompatible elements. The calculated source compositions strongly resemble those of coarse, low-*T*, depleted peridotite nodules that are the commonest nodules in kimberlites. The *REE* composition of the metasomatic melt calculated from the diopsides and garnets in the sheared nodules, from the diopside megacrysts and from majorite garnet inclusions in diamonds is in excellent agreement with that expected for a melt produced by melting ~0.5% of the source region of ocean ridge basalts. The initial depletion event requires the extraction of ~20% melt from a region in which garnet and chrome-spinel were stable. The melt distribution obtained from the inversion of komatiite composition satisfies both these conditions. Kimberlite source rocks are shallower than the layer from which fertile nodules originate. Such nodules must therefore be transported by entrainment of the lower boundary of the layer that became unstable. R.A.H.

The Luanda diamond fields [Part 1].

A. THOMAS. *South African Gemmologist*, **9**(2), 1995, pp 10-23, 3 maps (2 in colour).

First part of an account of the author's study of the history of exploration for diamonds in north-east Angola giving notes on the history of diamond recovery, export and marketing from this area. The bibliography is less helpful than at first appears, with some citations mistranscribed. M.O'D.

UV-induced colour change in pink diamonds.

J. VAN ROYEN. *Antwerp facets*, March 1995, 21-4, 4 photos in colour, 3 figs. in colour.

This issue contains the 1994 annual report of the Diamond High Council.

Some pink diamonds have been found to change to a brown colour when exposed to intense UV radiation, the pink colour returning after a period of time. The absorption band near 550nm is reduced in strength by the irradiation. Heating to approximately 250°C will restore the original colour more quickly. M.O'D.

Analysis of diamonds and indicator minerals for diamond exploration by laser ablation inductively coupled plasma mass spectrometry.

R.J. WATLING, H.K. HERBERT, I.S. BARROW AND A.G. THOMAS. *Analyst*, **120**(5), 1995, pp 1357-64.

A method has been developed, using laser ablation – inductively coupled plasma – mass spectrometry (LA-ICP-MS), for the semiquantitative determination of 43 elements in diamonds, chromites and garnets. Samples of diamonds from five different countries and the interrelationship between their trace elements gives distinctive patterns for each source. This should allow the tracing of stolen diamonds and can also be used to establish the trace element distribution in indicator minerals for diamond exploration, such as garnets and chromites. The relative distributions of the REE, Ta and Hf indicate a consistent inter- element relationship for garnets associated with diamondiferous kimberlites; the trace element partitioning pattern of chromites can be used to establish a kimberlite or non-kimberlite provenance of this mineral. R.A.H.

Gems and Minerals

Die Cabochonsammlung, eine interessante Variante des Sammlung von Mineralien.

W. BECK. *Aufschluss*, **46**, 1995, pp 181-3, 6 photos (3 in colour).

A review of the fashioning and collecting of cabochon-cut gem and ornamental minerals, with particular reference to agate. M.O'D.

Gems around Australia - part 10.

H. BRACEWELL. *Australian Gemmologist*, **19**(1), 1995, pp 23-4, 6 illus. in colour.

This section describes a visit to the Marra Mamba tiger's-eye deposit 6km south of the majestic Hamersley Range main escarpment in the Pilbara area of Western Australia. Specimens range from a rich coppery coloured tiger's-eye to tiger's-eye with an attractive picture jasper. Although extensive deposits of blue asbestos or crocidolite are present, it takes a silica enrichment to leach into the seams to produce golden tiger's-eye. R.J.P.

A new variety of grossular garnet with extended gemmological constants.

R. BRIGHTMAN. *Australian Gemmologist*, **19**(1), 1995, pp 19-22, 1 table, 3 illus. in colour.

A new source of grossular garnet from Mali, West Africa, has produced specimens in a wide range of colour. X-ray diffraction and X-ray fluorescence analysis confirmed it as grossular but the refractive indices of a number of specimens ranged from 1.764 to 1.782 which are in excess of the range up to 1.760 quoted by Stockton and Manson (1985). Specific gravity determinations were within the quoted range of 3.65 to 3.67. All the specimens showed an absorption band at 440 - 445 nm (attributed to iron), which is not normally expected in grossular garnet. R.J.P.

A further update on value-enhanced jadeite.

G. BROWN. *South African Gemmologist*, **9**(1), 1995, pp 8, 17-18, 26-27, 30-31.

Notes on CIBJO rulings on value-enhanced jadeite, the enhancement commonly arising through waxing, resin coatings or epoxy-type fracture fillings. The writer feels that disclosure of enhancement should always be made. Details of some treatments and methods of identification are given. M.O'D.

An unusual sapphire-zircon-magnetite xenolith from the Chanthaburi gem province, Thailand.

R.R. COENRAADS, P. VICHIT AND F.L. SUTHERLAND. *Mineralogical Magazine*, **59**(3), 1995, pp 467-81.

A sapphire-, zircon- and magnetite-bearing xenolith is reported from alkali basalt at Khao Wua, near Chanthaburi, and is taken to demonstrate a common origin for sapphire, zircon and magnetite found in alluvial deposits in the Chanthaburi gem fields. The original Al- and Ti-rich octahedral magnetite crystal in the xenolith exsolved into hercynite, magnetite and hematite during cooling; it includes minor anhedral jarosite-alunite, possibly from an iron-sulphide-rich immiscible liquid. U-Pb dating of zircon in the xenolith gives an age of 1-2 ($\pm < 1$) m.y., falling within the fission-track ages for alluvial zircons (2.57 ± 0.20 m.y.) from the Chanthaburi-Trat gem fields and within the K-Ar ages of 0.44-3.0 m.y. for the alkali basalt volcanism in the Chanthaburi province. These data suggest a common origin for sapphire, zircon and magnetite, and link them with the processes involved in alkali basaltic magma generation. The high Fe and Zr, low Mg, and the inferred sulphides suggest pegmatite-like crystallization in an incompatible-element-enriched, silica-poor magma (partial melt or fractionation product) in the deep crust or upper mantle. Etch features on exposed surfaces of the xenolith indicate that it

was transported out of its equilibrium environment by the rise of later magma. R.A.H.

Alteración de las inclusiones de zircón, apatito y vidrio en el tratamiento térmico de rubies y zafiros.

J.S. CÓZAR AND I. DE VICENTE-MINGARRO. *Boletin del Instituto Gemologico Espanol,* **36,** 1995, pp 47-54, illus. in colour.

Alteration of mineral inclusions is one of the indications of the heat treatment of corundum. Features of the alteration of zircon, apatite and glass are discussed. M.O'D.

A la recherche de la glyptique moderne.

M. DUCHAMP. *Revue de Gemmologie,* **123,** 1995, pp 4-8, 8 photos (2 in colour).

Description of the work of some contemporary glyptic artists with notes on the ornamental materials used. M.O'D.

Pink topaz from the Thomas Range, Juab County, Utah.

E.E. FOORD, W. CHIRNSIDE, F.E. LICHTE AND P.H. BRIGGS. *Mineralogical Record,* **26**(1), 1995, 57-60, illus. in colour.

Topaz is found in lithophysal cavities in rhyolite in the Thomas Range, Juab County, Utah, USA. The geology and mineralogy of the area are described and there is a list of minerals identified from the Topaz Mountain rhyolite. Topaz crystals showing a sherry-brown colour typically fade to colourless within weeks: some other crystals show a more or less uniform pink colour and are of gem quality. Some crystals show a pink-red colour masked to some degree by a sherry-brown colour which fades on exposure to sunlight: the underlying pink-red colour in such cases does not fade. The topaz is extremely fluorine-rich and contains almost no water. The pink colour is not ascribed, as formerly, to Cr as a trace element but to the substitution of Al^{3+} by Mn^{3+}± Fe^{3+}. M.O'D.

Occurrences of boron-free and boron-poor kornerupine.

C.R.L. FRIEND. *Mineralogical Magazine,* **59**(1), 1995, pp 163-6.

The problem of kornerupine virtually free of B is discussed and a new analysis is reported of a cream-coloured kornerupine from an area of amphibolite-facies rocks 50km E of Fiskenæsset, SW Greenland; this mineral has B_2O_3 0.38 wt.%, equivalent to B 0.081 pfu. It is suggested that a new term 'boron-free' kornerupine be introduced to cover those samples with 0.2 B pfu. R.A.H.

An evaporitic origin of the parent brines of Colombian emeralds: fluid inclusion and sulphur isotope evidence.

G. GIULIANI, A. CHEILLETZ, C. ARBOLEDA, V. CARRILLO, F. RUEDA AND J.H. BAKER. *European Journal of Mineralogy,* **7**(1), 1995, 151-165.

The fluids trapped by emerald, dolomite and pyrite in the Colombian emerald deposits consist predominantly of Na-Ca brines with some KCl; the similarity of the fluid composition in the E and W emerald zones demonstrates the homogeneity of the parent fluids. The Na-Ca-K chemistry of the brines gives strong support for an evaporitic origin of the parent hydrothermal fluids. The $\delta^{34}S$ values of H_2S in solution in equilibrium with pyrite from six emerald deposits range from 14.8 to 19.4‰ whereas sedimentary pyrite from the enclosing black shales yield a $\delta^{34}S$ of -2.4‰. The narrow range in $\delta^{34}S_{H2S}$ between the different deposits suggests a uniform and probably unique source for the sulphide-sulphur. The high $\delta^{34}S_{H2S}$ values suggest the non-participation of magmatic or early Cretaceous black-shale sulphur sources. Saline diapirs occur in the emeraldiferous areas and the most likely explanation for high $\delta^{34}S$ involves the reduction of sedimentary marine evaporitic sulphates. This type of unique emerald deposit corresponds with mesothermal deposits (300°C), formed in a sedimentary environment and produced through thermochemical reaction of sulphate-rich brines to H_2S by interaction with organic-rich strata. R.A.H.

The symmetry of vesuvianite.

L.A. GROAT, F.C. HAWTHORNE, T.S. ERCIT AND A. PUTNIS. *Canadian Mineralogist,* **31**(3), 1993, pp 617-35.

Examination of the physical and chemical properties of 76 samples of vesuvianite from 50 localities is reported. On the basis of optical properties, three groups are recognized: 1) normal crystals which show uniform extinction and small (0-5o) 2V, 2) blocky crystals showing irregularly-shaped areas of variable birefringence in a (001) section, with 2V 5-35°, and 3) sector-zoned crystals showing {001}, {101} and {100} sectors with low (~5°), intermediate (20-35°) and high (40-60°) 2V, respectively. A combination of optical and XRD evidence indicates that the symmetry of vesuvianite is *P2/n* (or *Pn*). It is

suggested that there is a virtually continuous ferroelastic phase transition between a high-*T* *P4/nnc* structure and a low-*T* *P2/n* or *Pn* structure. The variety of optical types of vesuvianite results from different relationships between the *T* interval of crystallization and the T of the phase transition. R.A.H.

Precious layer opal with a complex sedimentary formation process as colloid chemical precipitation, sedimentation and evaporation.

H. HARDER. Neues Jahrbuch für Mineralogie, Monatshefte, (3), 1995, pp 121-6.

Experimental work leads to the conclusion that the formation of layer opal in desert conditions is controlled not only by evaporation but also by the enrichment and separation of SiO_2 from the primary alkaline weathering solutions. Neutralization by CO_2 vapour may result in an oversaturation and a slow precipitation of $Al(OH)_3$ together with a strong colloid chemical enrichment of SiO_2. After deposition as porous jelly opal, the primary water-rich layer opal can slowly dry out to a solid opal, which may rarely form a layer of precious opal. R.A.H.

Influence of chemistry on the pyroelectric effect in tourmaline.

K.D. HAWKINS, I.D.R. MACKINNON AND H. SCHNEEBERGER. *American Mineralogist*, **80**, 1995, pp 491-501, 5 figs.

In tourmaline the pyroelectric coefficient is variously affected by elements occupying the X, Y and Z cation sites in the structure. The effect is strong when Fe occupies the octahedral Y site since Fe prefers this position and the effect increases when Fe and Mg cations are added to the smaller Z octahedral site. Whether or not this indicates a determinable trend is hard to distinguish since in tourmaline in almost all samples Al occupies the Z site to the exclusion of other cations. Occupancy of the X site does not affect pyroelectricity. M.O'D.

Eindrücke und mineralogisch-geologische Notizien von der Tansanit-Grube in Mirerani bei Arusha/Tansania.

B. HERGARTEN AND M. HERGARTEN. *Aufschluss*, **46**, 1995, 43-6, 5 photos, 1 map.

Account of the tanzanite deposits of Mirerani in the area of Arusha, Tanzania, and their working. M.O'D.

Alexandrite chrysoberyl surprises.

A. HODGKINSON. *Australian Gemmologist*, **19**(1), 1995, pp 25-8, 1 illus. in black-and-white, 5 in colour.

Attention was drawn to the striking trichroism shown by natural alexandrite but refractive indices of alpha = 1.761, beta = 1.770 and gamma = 1.773 not only showed anomalously high values but also that it was biaxial negative rather than positive. These properties were attributed to a higher than normal iron content. Alexandrite and ruby absorption spectra are normally quite similar but in this stone there is a strong band at 444nm typical of chrysoberyl. Examination of a synthetic alexandrite showed that it possessed properties identical to those of natural alexandrite. Another stone, a Uralian alexandrite, appeared red in incandescent light but blue rather than green in daylight conditions. It has normal constants for chrysoberyl and its chromium content was confirmed by chemical analysis. In this case the iron content was greater than that of chromium. A synthetic green chrysoberyl with chromium provided additional interest and prompted the suggestion that despite a Cr spectrum its lack of colour change could be attributed to nickel and iron being leached from the walls of the growth cylinders. R.J.P.

Gem Trade Lab notes.

R.C. KAMMERLING AND C.W. FRYER. *Gems & Gemology*, **30**(4), 1994, 264-70, 17 illus. in colour.

A light yellow diamond was shown to have been treated by examination of the mid- infrared spectrum which revealed H1b and H1c lines. A carved emerald fetish from a pre-Columbian necklace was confirmed as natural with no clarity enhancement. A feldspar represented as sanidine was shown to be labradorite with refractive index values of 1.559-1.568. A simple test to distinguish some plagioclase feldspars from alkali feldspars is the appearance of brilliant multicoloured stripes showing polysynthetic twinning which only occurs in feldspars of the triclinic system, thus microcline and the plagioclases show twinning but not sanidine or orthoclase. A grossular-andradite garnet from Mali West Africa as yellow-green rough had a single RI value of 1.77 an SG of 3.65 and strong ADR. Microscopy showed an unusual pattern resembling dodecahedral growth and a wispy horse-tail inclusion. Its nature was confirmed by X-ray powder diffraction and EDXRF analysis. A

jadeite bracelet was shown to be bleached and impregnated. Removal of impurities with acid had left a honeycomb surface. A drop of hydrochloric acid remained intact and infra-red spectroscopy showed evidence of polymer treatment. A synthetic malachite necklace had a spot RI of 1.55 and only slight effervescence with hydrochloric acid. It showed a conchoidal fracture and fluoresced green to both long and short-wave UV. Destructive tests with a hot needle turned the material a chalky white with melting. A genuine malachite necklace showed a strong birefringent blink on the refractometer and effervesced strongly with hydrochloric acid. It was inert to both forms of UV and with a hot needle produced a brown spot with no melting.

Abalone 'Mabe' pearls made with blister pearls cultivated in the abalone shell showed a fine cellular structure in the blister portion while strong yellow fluorescence to long wave UV showed its derivation from abalone. A non-nacreous cultured pearl described as resembling a shiny black marble from the black-lipped oyster harvested in French Polynesia was thought to be the result of an unusual culture in which critical epithelial cells were missing.

A sapphire with an unusual reddish-brown colour, similar to that of alexandrite in incandescent light but with no colour change was due to pink and green-blue bands with some influence from the stone's dichroism. The high RI values of 1.775-1.784 still fell within the quoted limits for natural brown sapphire. A synthetic pink sapphire showed a strong red fluorescence but the typical bluish-white reaction to short-wave UV was uneven and confined to clearly defined curved colour bands. R.J.P.

Gem Trade Lab notes.

R.C. KAMMERLING AND C.W. FRYER. *Gems & Gemology*, **31**(1), 1995, pp 52-8, 15 illus. in colour.

An alexandrite with a green to purple colour change had optical properties typical of alexandrite but twinning was shown by brightly coloured irregularly-shaped worm-like areas under magnification and using a polar.

A filled emerald with unusual flash-effect colours showed orange to pinkish-purple in one direction and a blue and orange effect in another. The reason may be that emerald, being uniaxial with two distinct refractive indices, produced two crossing dispersion curves in conjunction with a non-crystalline filler. The flashes occur at the wavelength at which the refractive indices match. Bright field illumination produces blue whilst dark field illumination gives the complementary colour orange, these forming a colour pair. In the other orientation orange to pink forms the dark field colour. The expected bright field colour green to blue green was probably masked by the body colour.

A mottled green cabochon with typical jadeite properties was shown to be bleached and polymer impregnated. Microscopically, certain grains were shown to be eroded, whilst infrared spectroscopy confirmed the presence of a polymer. A jadeite necklace was shown to contain both natural and treated beads. Of the two jades, jadeite is much more commonly colour-enhanced, so it was unusual to come across nephrite cabochons dyed green. The visible spectrum showed a dye band in the red centred at 660nm. A purple sapphire cabochon with diffusion induced colour and star on immersion in methylene iodide showed a red colour confined to the surface and a number of red spots near the centre of the star which suggested that the original intention was to produce ruby.

A green star sapphire was described with an absorption line at 670nm attributed to cobalt and showing uneven asterism. Energy dispersive X-ray fluorescence spectroscopy (EDXRF) indicated cobalt as the colouring agent. A natural spinel with a dendritic iron stain which could be confused with yellowish-white or yellowish-brown flux was confirmed by EDXRF spectroscopy. In addition the stone had inclusions in the form of octahedral crystals as well as large feathers. In some flux-grown synthetic spinels pyramid-shaped phantoms in near perfect alignment with external faces and edges of the octahedra are present and could be confused with octahedral inclusions present in the natural stone. R.J.P.

Ruby and sapphire from the southern Ural Mountains, Russia.

A.J. KISSIN. *Gems & Gemology*, **30**(4), 243-52, 2 tables, 10 illus. in colour.

Ruby and sapphire have been known in the South Urals for over a century and were presumed to be in pegmatites. In 1978 the author postulated that these may have originated in the marbles which were widespread in the Kootchinskoye area. Ruby and sapphire mineralization is now known to occur in marbles within four metamorphic complexes in the Urals. These gemstones were found *in situ* as well as in alluvial deposits. From the known geology other

corundum bearing areas are believed to exist in the 600km linear belt including Ekaterinburg, Chelyabinsk and Plast. At present gem quality stones are being evaluated prior to commercial extraction.

A detailed examination of the Kootchinskoye marbles revealed that of three types only dolomitic calcite marble contained corundum. Rubies and sapphires could be grouped in three main classes but only two had good enough colour and clarity for faceting. One class consisted of ruby in thick platy well formed crystals with inclusions of pyrites and gas. The other consisted of rounded and acicular pink sapphires with pyrites, black rutile and gas inclusions.

Some corundum deposits in Myanmar, Pakistan, Afghanistan and Tanzania are similar. In the system corundum + dolomite = spinel + calcite + carbon changes in pressure and temperature are important and the magnesium content of the marble will have a major influence on whether spinel is the preferred (stable) mineral phase. R.J.P.

Inclusions in quartz.

J.I. Koivula and R.C. Kammerling. *South African Gemmologist*, **9**(1), 1995, pp 7-16, 12 photos in colour.

An illustrated summary of mineral and other inclusions in quartz with a table of minerals so far identified. M.O'D.

Inclusions in garnets.

J.I. Koivula and R.C. Kammerling. *South African Gemmologist*, **9**(2), 1995, pp 24-32, 12 photos in colour.

Illustrated general survey of the main inclusions in gemstones of the garnet group. The horsetail effect in the demantoid variety of andradite is now ascribed to tremolite-actinolite or to chrysotile. In orange spessartine recently found in Namibia black grains are identified as manganese oxide, and transparent virtually colourless needles as tremolite. M.O'D.

Gem news.

J.I. Koivula, R.C. Kammerling and E. Fritsch. *Gems & Gemology*, **30**(4), 1994, pp 271-80, 16 illus. in colour.

A new source of amethyst from North Namibia yields several tons annually but mining can only take place in the six-month dry season. An unusual chatoyant demantoid garnet had the horsetail inclusions orientated in a parallel fashion with some inclusions 'bending back' on themselves. A colour-change diaspore from Turkey showed a distinct colour change from brownish-pink in incandescent light to brownish-green in daylight. The brown colour was attributed to Fe^{3+} whilst Cr^{3+} caused the colour change. White translucent cabochons with red crystal inclusions from Myanmar were shown by X-ray diffraction analysis to be plagioclase feldspar with ruby. Gems from North Carolina included cabochons of emerald matrix and of kyanite of greenish- blue to blue with colourless areas. Peridot from Pakistan in the far western Himalayas has standard gemmological properties. On the basis of RI and SG values the material is 90 per cent forsterite and 10 per cent fayalite. Black rod-like inclusions present in the rough proved to be the magnesium iron borate mineral ludwigite. Large blue sapphire crystals were reported from the Isle of Lewis, Scotland, including one of 242 carats. A blue cobalt-coloured spinel from Burma showed abundant iron, a trace of manganese and unusually high nickel content; cobalt was not detected.

A general shortage of gems from Sri Lanka has been blamed on unusual weather conditions. Large reserves of 'zebra stone' are reported from Arizona consisting of actinolite or tremolite amphibole and plagioclase feldspar. R.J.P.

Gem corundum in alkali basalt: origin and occurrence.

A.A. Levinson and F.A. Cook. *Gems & Gemology*, **30**(4), 1994, 253-63, 1 table, 7 illus. in colour.

The majority of gem corundums in the jewellery industry are derived from secondary deposits in SE Asia and Australia, and are associated with alkali basalts which are uncommon geologically. The mineralogy and chemistry of the basalts are well reviewed; the basalts are silica-deficient and do not contain visible quartz. From the theory of plate tectonics the subduction of oceanic basalts beneath a continental plate may eventually give rise to tholeiite basalts and alkali basalts with the latter forming at depths greater than 50-60km. Although associated with alkali basalt, sapphires may not have crystallized from it, being xenocrysts derived from broken or molten xenoliths. Other xenocrysts in alkali basalts include zircon, some garnets and spinel. Two mechanisms of corundum formation each involving a different starting material are discussed. One mechanism involves subduction of

aluminium-rich shales with muscovite which breaks down to give orthoclase feldspar and corundum, providing that quartz is absent. A second mechanism involves hydrated aluminium oxides such as gibbsite and diaspore. Conditions for this may exist at depths as shallow as 24km. The mechanism for the transport of corundum to the surface is described in detail.

Alternative theories based on studies on Australian deposits attach great importance to associated inclusions such as zircon. A model involving two magmas was evolved by Coenraads. The first, a carbonate-enriched mafic magma containing metals not associated with common rock forming minerals, allows corundum to crystallize within it. The second magma of alkali basalt entrains the corundum on eruption. Guo developed a more complex multi-stage model involving four magmas and possibly too many special conditions to occur on a large scale. It is hoped that the use of such models will enable future sites of corundum deposits to be predicted. R.J.P.

Farbenstehung und -verteilung in fluorit.

W. LIEBER. *Aufschluss,* **46,** 1995, 1-11, 18 photos (15 in colour).

The cause of colour in fluorite is discussed with examples taken from a variety of locations. M.O'D.

Hanneman-Hodgkinson synthetic emerald filter.

T. LINTON AND A. SHIELDS. *Australian Gemmologist,* **19**(2), 1995, pp 65-8, 1 table, 5 illus. in black-and-white.

The Hanneman-Hodgkinson synthetic emerald filter (referred to as the H-H filter) holds two gelatin filters, one an orange-yellow and the other blue. These combined filters allow transmission of 3 per cent of the 480-560nm wavelengths and 66 per cent of all red wavelengths above 670nm. Essentially it transmits more red, yellow and green wavelengths than the Chelsea Filter. Whilst the Chelsea Filter spots most emeralds by a pink/red response, the H-H Filter distinguishes all synthetics from natural by the pinkish/reddish response of the synthetics (with stated exceptions of the Biron/Pool hydrothermal synthetic emeralds, unspecified Russian hydrothermal synthetics and Lechleitner coated beryl). The manufacturers suggest that the stone should have its optical properties checked to confirm its identity as an emerald and that a microscopic examination be made before a positive judgement is made. The Evaluation Committee coopted several competent students whose pooled results showed that the Chelsea Filter detected most emeralds and the H-H Filter reacted to most synthetics as the inventors suggested. It appears that 60 years after the introduction of the Chelsea Filter, emeralds still defy a definitive means of identification using filters of this type. R.J.P.

Mineralization and potential of the gemstone industry of Zambia.

S.H. MAMBWE AND C. SIKATALI. *In Industrial minerals in developing countries,* S.J. MATHERS AND A.J.G. NOTHOLT, eds. British Geological Survey/Association of Geoscientists for International Development: AGID Report Series No. 18, 1994, 265-72, 1 map.

Gemstones are found in all nine provinces of Zambia, hosted in pegmatites and veins in Pre-Karoo rocks. They include emerald, aquamarine, amethyst, beryl, tourmaline and garnet. There is some potential for ruby and sapphire, as well as for the recovery of rose quartz and other silica varieties. R.A.H.

The mineralogy, geology and occurrence of topaz.

M.A. MENZIES. *Mineralogical record,* **26**(1), 1995, 5-53, illus. in colour.

A major study of topaz, the paper discusses geology, mineralogy and occurrence of topaz with a good deal of comment on gem-quality crystals, a number of which are illustrated in colour. The major topaz-producing areas are described with historical notes on locations such as Schneckenstein. A table lists gem topaz deposits worldwide with references to the literature and there is also an 11-column bibliography. Among the coloured illustrations are reproductions from older mineralogical books, including Richard Braun's *The mineral kingdom* (1908). Figures in the text draw comprehensively from Goldschmidt's *Atlas der Krystallformen.* Maps and figures illustrate major deposits generally and particularly. M.O'D.

What's new in minerals?

T. MOORE. *Mineralogical Record,* **26**(2), 1995, 147-53, 14 photos in colour.

Among specimens on display at the 1995 Tucson Gem and Mineral Show were fine elbaites, with one crystal 8cm long, from the

Himalaya Mine, California; red beryl from the Wah Wah Mountains, Beaver County, Utah, with some crystals up to 6cm long; emerald crystals on a calcite matrix from the Coscuez Mine, Boyacł, Colombia. The matrix in which the crystals are found, in underground working at the Coscuez-Los Gavilanes mine, 12 miles from the Muzo mine, may be calcite or black shale or both. Orange scapolite from the Mpwampwe mine, Morogoro, Tanzania, and loose dodecahedrons of what is probably andradite from Mali, diaspore from what is said to be the Aydin-Mugla region of Turkey, golden beryl and blue beryl from Volodarsk, Ukraine, with reddish-brown vesuvianite from an as yet unspecified locality in Pakistan, complete the gem mineral portion of the report - apart from further praise for the Pakistan peridot. M.O'D.

What's new in minerals?

T. MOORE. *Mineralogical Record*, **26**(3), 1995, pp 215-30, 45 photos (42 in colour).

Minerals exhibited at the 1995 Tucson Gem & Mineral Show included peridot crystals from Pakistan: the locality is now placed as Suppatt, between Kamila and Naran, North West Frontier Province. The site is reported to be a string of prospect pits with Dasu the closest town. It is believed that some peridot hitherto attributed to China and to Afghanistan may come from this site in Pakistan. Colourless prisms of hambergite are reported from Drot, Gilgit-Skardu Road, Northern Areas of Pakistan. Fine rhodochrosite crystals were exhibited from the Sweet Home mine, Colorado, and yellow apatite crystals from the Sceptre Claims, Emerald Lake, Yukon, Canada. Reddish-pink grossular crystals from Sierra de las Cruces, Coahuila, Mexico, appear to be of gem quality and there was some attractive green smithsonite from the 79 mine in Arizona. Red beryl from the Maynard claim in the Thomas Range in Utah was prominent along with topaz crystals from the same area of the state. Diamond crystals in matrix were shown from both China and Russia: fine clear yellow beryl crystals were shown from mine no 2, Volodarsk-Volynsk, Zhitomir region, Ukraine. M.O'D.

The Yogo sapphire deposit.

K.A. MYCHALUK. *Gems & Gemology*, **31**(1), 1995, pp 28-41, 14 illus. in colour.

Sapphires were discovered at Yogo Gulch over a century ago and the deposit is one of four major sapphire producing areas in Montana, USA. The Yogo sapphires are noted for their uniform well-saturated blue colour ('corn flower' blue) and a relative absence of inclusions and zonation. They do not require heat treatment and their flat rough crystals generally weigh less than one carat. Unlike other Montana deposits the Yogo deposits are primary with the sapphires being mined directly from at least six parallel dykes of lamprophyre rock. In one hundred years the Yogo deposit has produced 18.2 million carats of rough which has yielded more than 0.5 million carats of cut stones.

The history of the deposit is described. Now the Vortex Mine is the only active underground mine and Yogo sapphires are marketed as the world's only sapphires guaranteed not to have been heat treated. An early theory of the origin of the sapphires was their direct formation from the Yogo magma as phenocrysts in which silica-deficient Yogo magma incorporated large amounts of Al-rich shales as it rose towards the surface. Later it was suggested that the Yogo magma incorporated fragments of kyanite bearing gneiss instead of shales. The kyanite, a source of aluminium, was then consumed by the magma and later crystallized as corundum. Observed inclusions such as carbon dioxide gas and analcime are consistent with the direct formation of sapphires from the magma. However it is also possible that the sapphires were incorporated as xenocrysts by a Yogo magma which captured fragments of the corundum-bearing gneiss and transported it upwards as xenoliths. Support for this theory has come from computer simulations of multi-component crystallization but additional research will be required to finally resolve the question. R.J.P.

Einschlusse-Phänomene im Quarz.

G. NIEDERMAYR. *Mineralien Welt*, **6**(4), 1995, pp 15-16, 3 photos (2 in colour).

The presence and types of mineral inclusion in quartz are discussed. Lepidocrocite, antimonite, rutile and ilmenite are illustrated. M.O'D.

Mineralogische Reise nach Pakistan.

P. PAULITSCH. *Aufschluss*, **46**, 1995, 37-41, 2 photos (1 in colour).

Short account of an excursion to Pakistan with particular reference to emerald deposits, emerald synthesis and tourmaline. M.O'D.

Rubies from Mong Hsu.

A. PERETTI, K. SCHMETZER, B. HEINZ-JÜRGEN AND

F. MOUAWAD. *Gems & Gemology*, **31**(1), 1995, pp 2-26, 4 tables, 4 illus. in black- and-white, 30 in colour.

Since 1992 a primary source of ruby has been Mong Hsu in north eastern Myanmar. Untreated samples showed a distinctive dark violet to almost black cores with ruby rims.

Geological studies in the Mong Hsu area showed that the ruby deposits occurred in upper Palaeozoic marbles. Other minerals found with the ruby rough include green and brown tourmaline, andalusite, almandine, quartz and tremolite and they indicate that the deposits are metamorphic. Associated secondary deposits occurred as gravels which are removed and processed for gems by using elaborate sluicing systems.

Cut stones are usually heat treated and many have glass fillings. The stones are heated to remove the violet colour and then in borax to fill any fissures. Typical crystals were well-terminated barrel shaped and the distinctive colour distribution was reflected in some of their gemmological properties. The commonest inclusions are whitish particles; rutile, fluorite and spinel were rarely found. Whitish streamers orientated perpendicularly to growth planes extend from the outermost edge of the violet core. Heat treatment not only removes the violet colour but may cause additional fractures due to decrepitation of entrapped solid matter which decreases the transparency of the stone. Second stage heating in the presence of borax can result in solution of alumina and healing of open fracture planes.

X-ray fluorescence analysis and electron probe analysis showed significant trace concentrations of chromium, iron, titanium, vanadium and gallium; refractive indices correlated with the total concentration of these.

Spectra of the violet cores showed a Cr^{3+} absorption spectrum with a superimposed broad Fe^{2+}/Ti^{4+} charge transfer absorption and an additional line at 675nm whose cause is unknown.

R.J.P.

Eudialyte crystals from the Kola Peninsula.

N.A. PEKOVA. *World of Stones*, **5/6**, 1995, pp 8-11, 5 photos in colour, 8 figs.

Near-gem quality eudialyte crystals have been recovered from underground mines in the Yukspor and Rasvumchorr mountains, Kola Peninsula, Russia. Crystals reach no more than 7mm in size but are a transparent red. Fine quality crystals are described from other locations in the same region and the properties and crystallography of eudialyte are discussed.

M.O'D.

En direct de Madagascar.

D. PIAT AND M.-P. BOUQUEAU. *Revue de Gemmologie*, **123**, 1995, pp 12-13, 3 photos (1 in colour), 1 map (in colour).

Brief account of a visit to a sapphire-bearing mine at Andranondambo, Malagasy Republic. Gem-bearing sites in the vicinity are reported to be controlled by Swiss, Thai and Israeli enterprises. M.O'D.

Euhedral sinhalite crystals from Sri Lanka.

L.C. PITMAN, C.S. HURLBUT AND C.A. FRANCIS. *Mineralogical Record*, **26**(2), 1995, 91-4, 3 photos (2 in colour) 1 fig.

Morphological details of two euhedral sinhalite crystals from Sri Lanka (the first recorded from this location) accord with data given for a crystal from Burma. There are 32 faces, giving 13 forms for one crystal and 31 faces and 9 forms for another. The pale brown colour is attributed to ferric iron. One specimen was a pale transparent pebble of 36ct and measuring 2.6 x 1.6 x 1.2cm, the other was one of a pair of transparent pale brown crystals. The location is reported to be Balangoda, about 25km east of Ratnapura.

M.O'D.

Porcelanite - ein neuer Landschaftsmarmor aus Tschechien.

L. REJL AND A. TUMA. *Lapis*, **20**(3), 1995, 42-4, 4 photos in colour, 1 map.

A marble with landscape patterning has been given the name porcelanite, the location being in the Bućník area of the Czech Republic. M.O'D.

Zur Entstehung der sternförmigen Achate in sauren Vulkaniten.

R. RYKART. *Aufschluss*, **46**, 1995, 33-6, 7 photos (6 in colour), 1 fig.

Formation of agate with a star-shaped interior is discussed with examples taken from acidic volcanic rocks. M.O'D.

Meerschaum from Eskisehir Province, Turkey.

K. SARIIZ AND I. ISIK. *Gems & Gemology*, **31**(1), 1995, pp 42-51, 11 illus. in colour.

Sepiolite, a hydrated magnesium silicate, is commonly known as meerschaum in its massive compact form. It has a very low specific gravity and hardness, and is easily carved and polished.

The Eskisehir deposits have been used since the eighteenth century and the meerschaum is mined using rudimentary mining methods. Examination of sepiolite nodules shows that many have a magnesite core indicating that magnesite formed first and was later replaced by sepiolite. The physico-chemical behaviour of Mg^{2+}, $SiO_{2(aq)}$ and H_2O has been thoroughly investigated and it is concluded that meerschaum nodules probably formed at shallow depths under alkaline conditions in the vicinity of paleo-shorelines of a large inland lake.

During carving the meerschaum has to be kept wet to maintain its softness. After carving it is slowly dried in the sun and finally for two hours in an oven at 110°C. After polishing with a fine abrasive it is immersed in liquid beeswax for a few minutes. The creamy-white colour of pipe bowls progressively turn yellow due to absorption of nicotine. Although the recent decline in smoking has affected the demand for pipe bowls, sepiolite has many other industrial uses including that of an ivory simulant. However, ivory is much harder than meerschaum and can bend without breaking. R.J.P.

Tucson 1995: Neues, Neues Altes, Altes.

J. SCOVIL AND C. WEISE. *Lapis*, **20**(4), 1995, 25-8, 8 photos in colour.

Among the minerals reported from the 1995 Tucson Gem & Mineral show were reddish grossular from Mexico, hambergite from Pakistan in crystals up to 1.8cm across and gem-quality olivine from Sopat, Pakistan, with a crystal 7.9cm in length pictured with a faceted stone: this material occurs in a white talc matrix. M.O'D.

[The pulse cathodoluminescence of corundums.] (Russian with English abstract)

V.I. SOLOMONOV, S.G. MIKHAILOV, V.V. OSIPOV, V.N. AVDONIN, M.F. VASILEVSKAYA AND V.I. YAKSHIN. *Proceedings of the Russian Mineralogical Society*, **123**(6), 1994, pp 39-51.

This proposed pulse cathodoluminescence (PCL) method uses nanosecond high-current, pulse-repeated e-beams, as an alternative to the usual continuous low-current electron streams. Measurements are taken in the 340-800nm range and do not involve destruction of the sample, or its previous heating. Spectra of natural and synthetic corundums (except for Vietnamese sapphires) have a strong red band with dominant chromium lines at 694.3 and 692.9nm; its maximum intensity was shown by synthetic rubies and the minimum intensity in grey-blue natural corundum. A long wave wing of this red band is formed by N-Cr lines; S-lines are fixed in the short wave wing of the spectrum. There are two new wide bands seen in the PCL spectrum of corundums: blue (482nm) and green (555nm); they dominate the PCL spectra of Vietnam sapphires. Some PCL spectra of spinels are also presented. R.A.H.

Granatfund aus dem Täschtal bei Zermatt (VS).

H.A. STALDER AND M. AUFDENBLATTEN. *Auschluss*, **10**(7), 1995, pp 267-79, 10 photos in colour, 4 figs.

Dark red crystals of garnet from which faceted stones have been cut are found in the Täschtal, close to Zermatt in canton Valais, Switzerland. Diopside and vesuvianite are found with the garnets which occur as combinations of rhombic dodecahedra and icositetrahedra and which are classified as the hessonite variety of grossular. M.O'D.

Texture formation of agate in geode.

L. TAIJING AND I. SUNAGAWA. *Mineralogical Journal*, **17**(2), 1994, 53-76.

Optically observable individual fibres in agate bands are shown by electron microscopy to be composed of much finer fibres in which quartz crystallites, 8-100nm in length, are aligned parallel to <11$\bar{2}$0> or <10$\bar{1}$0>, with the *c* axes perpendicular to the fibre elongation. Both uniformly spaced systematic striations and 'Runzelbänderung' in agate bands, and coarse quartz or amethyst crystals radiating inwards to the open space in a geode have essentially the same texture as that of ordinary agate bands, and were formed when growth conditions were stabilized. The coarse quartz represents the final stage in the formation of agate bands, whereas the strata-forming horizontal banding consists of only euhedral quartz grains 0.5-4 μm across, or spherulites with a diameter ≤ 100 μm, or both; they were precipitated due to gravity after the formation of agate bands and coarse quartz crystals. Based on these observations, it is suggested that the quartz crystallites in agate were precipitated from a hydrothermal solution invading a geode in which polymerized embryonic particles with a quartz structure with a size of ~10nm were already present. R.A.H.

Achatähnlicher Kalkstein aus Niederösterreich.

L. THALHAMMER. *Lapis*, **20**(3), 1995, 45-6, 3 photos (2 in colour).

A limestone with patterning and colour resembling agate is reported from the Piestingtal area of Lower Austria, close to the B21 road. M.O'D.

Heat treating sapphires from the Anakie District, Australia.

T. THEMELIS. *Australian Gemmologist*, **19**(2), 1995, pp 55-60, 5 illus. in black-and-white, 5 in colour.

The effects of heat on colour and clarity were systematically studied to determine the optimum conditions for maximizing the enhancement potential of sapphires. Regardless of the type of atmosphere used it was found that 'silk' was partially dissolved at 1400°C and was completely dissolved at 1650°C and upwards. This increased the clarity of the stones and increased their value. Green to yellow sapphires on heat treatment did not produce stones of significant value. Blue to green stones produced better results whereas near-colourless, silky and brown spotted sapphires produced the best results. Using carefully controlled rates of heating and cooling prevented cracking.

The sapphires were initially cleaned in dilute hydrofluoric acid after which orange to reddish-brown zircons were identified and removed. The sapphires were then classified into nine types according to colour and milkiness and subjected to a total of eight separate heating runs under specific conditions. From this it was deducted that four sets of conditions could satisfactorily deal with all the types.

A batch heating system was discussed and involved reheating in many cases. The author did not reveal details of the gas mixtures used but stressed their poisonous nature and highly explosive characteristics which required expert handling.

The author concluded that high quality sapphires should be treated by type whilst commercial and lower quality stones should be batch treated. The author followed a systematic approach but retained the mystique expected of such treatments. R.J.P.

Vanadian-chromian garnet in mafic pyroclastic rocks of the Malé Karpaty Mountains, western Carpathians, Slovakia.

P. UHER, M. CHOVAN AND J. MAJZIAN. *Canadian Mineralogist*, **32**(2), 1994, 319- 26, 2 maps.

Unusual examples of V-Cr garnets are described from Lower Palaeozoic metamorphosed mafic pyroclastic rocks enriched in V, Cr and C_{org}, in the Pezinok-Pernek complex of the Malé Karpaty Mts, NE of Bratislava. The garnet is emerald-green, 0.5mm in size with *a* 11.98 Å, *n* 1.810, *D* 3.75 g/cm^3 and contains V_2O_5 9.5-22.1, Cr_2O_3 5.5-10.9, Al_2O_3 0.4-7.6 wt.%, corresponding with goldmanite 27-65, uvarovite 19-34, grossular 1.5-33, yamatoite 2-5 mol.%. The associated hydromica contains $V_2O_3 \leq 9.2$, Cr_2O_3 0.5-7.2 wt.%; coexisting chlorite and tremolite also exhibit elevated levels of V and Cr. This assemblage of V, Cr-rich minerals formed at ~500°C as a result of thermal metamorphism induced by Hercynian granitic intrusions. R.A.H.

Die grosse Kluft am Planggenstock, UR.

F. VON ARX. *Schweizer Strahler*, **10**(6), 1995, pp 201-11, 15 photos (7 in colour).

Fine rose-coloured fluorite of gem quality is among the minerals found in the great cleft of the Planggenstock, Uri, Switzerland. Crystals range up to 3-4cm in size and occur as octahedra or twins. The most recent discovery was in 1994. M.O'D.

Das Kalahari-Manganerzfeld und seine Mineralien. 1.

L. VON BEZING, J. GUTZNER. *Mineralien Welt*, **5** (4), 1994, pp 24-43, 5 illus. in black-and-white, 28 in colour, 2 maps in black-and-white, 1 map in colour, 2 figs.

Though for the gemmologist rhodochrosite takes pride of place among the minerals of the Kalahari area of South Africa, green opal and fine well-crystallized hematite are also found, with many other non-ornamental species. This first part of a general geological and mineralogical survey of the Kalahari lists minerals in chemical order with notes on the geology and the present state of mining. M.O'D.

Ontario - Amethyst County.

J. ZENZ. *Lapis*, **20**(2), 1995, 35-40, 13 photos (9 in colour), 1 map.

Gem-quality amethyst is found at several sites in the Thunder Bay region of Ontario, Canada, The Panorama, Pearl Lake, Ontario gem amethyst mine, Diamond Willow mine and Blue Points mine have been involved in amethyst production which has been known from the region since the seventeenth century. M.O'D.

$^{23}Na^{27}Al^{9}Be^{29}Si$ solid state NMR study of tugtupite.

ZHI XU AND B.L. SHERRIFF. *Canadian Mineralogist*, **32**(4), 1994, 935-43, 9 figs.

Tugtupite was found to have a well-ordered structure with only one Si, Al, Na and Be environment when studied with the NMR techniques of MAS (magic angle spinning), DAS (dynamic angle spinning) and DOR (double rotation). Quadrupolar parameters C_Q (quadrupolar coupling constant) and τ (asymmetry parameter) of ^{23}Na and ^{27}Al were found by a comparison of a computer simulation of the MAS central transition lineshape at two different fields with experimental results. M.O'D.

FM-TGMS-MSA Symposium on topaz.

Mineralogical Record, **26**(1), 1995, pp 63-71, illus. in black-and- white.

Synopses or complete papers on topaz and other topics presented to the 16th Annual Symposium of the Friends of Mineralogy, the Tucson Gem & Mineral Society and the Mineralogical Society of America, held at Tucson 11 February 1995. Topics of papers are: the occurrence of topaz in northern New England pegmatites: the occurrence of topaz in the southeastern United States: Colorado topaz: notes on the occurrence of topaz in Idaho: geology and occurrence of well-crystallized topaz: where's the proton? – symmetry and structure variations in topaz: topaz – environments of crystallization, crystal chemistry and infrared spectra: items of North American mineralogical and gemmological note during 1994, covering a salmon-pink colour obtained by heating cornflower blue coloured benitoite, the development of diamond pipe mining in the Northwest Territories of Canada, an option taken by Kennecott Corporation [RTZ subsidiary] on the Utah red beryl deposits, and on further recovery of tourmaline from Mt Mica, Paris, Maine. Some of the crystal drawings accompanying the reports are taken from Goldschmidt, *Atlas der Krystallformen.* M.O'D.

Instruments and Techniques

Optical anisotropy of cuprite caused by polishing.

E. LIBOWITZKY. *Canadian Mineralogist*, **32**(2), 1994, 353-8.

Optical investigations on bulk samples of cuprite (Cu_2O, space group P_n3_m), as well as on oriented single crystals, confirm that all diamond-polished sections except (111) and (100) are anisotropic. Electron channelling patterns obtained by SEM reveal that these mechanically polished surfaces of cuprite are always extremely deformed. An alternative chemomechanical polishing procedure with alkaline silica solutions, however, results in isotropic sections without exceptions. R.A.H.

ROS/GEM Optics Model RFA 322 Refractometer; an instrument evaluation.

A. SHIELDS AND B. NEVILLE. *Australian Gemmologist*, **18**(11), 354-5, 3 illus. in black-and-white.

This new critical angle refractometer manufactured in the USA was considered to be a robust easily portable instrument due to its smaller than average dimensions. Graduations of 0.005 should increase the accuracy of the readings and appeal to many potential users. R.J.P.

GIA evaluates progress in color detection technology.

J.E. SHIGLEY, R.C. KAMMERLING AND T.M. MOSES. *Diamond World Review*, **85**, pp 96-8, 3 photos in colour.

The authors first list the variables involved in colour description, and then describe the technical problems which occur when using instrumentation to quantify the colour of gemstones. The principles used in the two main types of colour measuring instruments (colorimeters and spectrophotometers) are then discussed. Two of the newer colour-measurement instruments, the Hitachi U4001 spectrophotometer and the Gran colorimeter, have recently been evaluated. When used to check isotropic coloured gem material, the Hitachi produced colour hue measurements consistent with visual observations. The Gran colorimeter gave quite consistent results for non-fluorescent round brilliant-cut diamonds in the Cape series. However, observations on these and other commercial gemstone colour measuring instruments indicate that instrumentation of this type cannot yet be used in place of visual colour grading. P.G.R.

The fingerprinting of gold samples.

ANON. *Assay, magazine of the Johnson Matthey Group*, Autumn 1994, pp 21, 2 photos in colour.

A new technique, LA-ICP-MS (laser ablation -

inductively coupled plasma - mass spectrometry), is forecast to revolutionize tracing methods for the identification of stolen gold. The technique enables scientists to compare the elemental associations in any given sample of gold. The detailed analysis can be specific to precise locations and the gold sample can be related to a specific mineralising event, mine or bullion sample. Initial investigations also suggest that the technique could be equally successful in the fingerprinting of antique silver, and gold and platinum artefacts, facilitating positive identification of important stolen objects. LA-ICP-MS was pioneered by the Chemistry Centre, Western Australia in conjunction with Fisons Instruments Elemental Analysis. P.G.R.

Synthetics and Simulants

An interesting imitation opal.

G. Brown. *South African Gemmologist*, **9**(2), 1995, pp 7-9, 4 photos in colour.

An opal imitation in which the play-of-colour emanated from a holographic projection from an aluminised grating sandwiched between plastic covers gave an SG of 1.2, a single RI of 1.48 and felt very light. These values are taken from the plastic cover. The gemmological microscope enables the very thin grating to be observed. M.O'D.

Another flux-grown synthetic ruby.

I.C. Campbell. *South African Gemmologist*, **9**(1), 1995, pp 22-5, 5 photos in colour.

A ruby crystal offered as natural at a gem show in the United States was cut into three stones in which lead was discovered on analysis, thus proving artificial origin. M.O'D.

An examination of Swarogreen : a new imitation emerald from Austria.

E. Fritsch, R.C. Kammerling and J.I. Koivula. *Australian Gemmologist*, **19**(11), 1995, pp 15-18, 2 illus. in black-and-white, 3 in colour.

This was shown to be a silicate glass with a relatively high refractive index of 1.608-1.612 attributed to calcium and aluminium. The green colour is due to a transmission window formed by Pr^{3+} and Cu^{2+}. Although it is an attractive simulant almost all its gemmological properties are quite different from those of emerald. All the samples were of a medium dark bluish- green colour and were free from inclusions. R.J.P.

Gem news.

J.I. Koivula, R.C. Kammerling and E. Fritsch. *Gems & Gemology*, **30**(4), 1994, pp 271-80, 16 illus. in colour.

Described as a new man-made material from Russia 'Minkovite' is monoclinic synthetic yttrium silicate with neodymium providing the blue colouring agent. A visit to the Russian synthetic research facility at Alexandrov revealed an active concern with 2000 workers. The main products are synthetic quartz and synthetic calcite. Recent laboratory grown material include a medium-dark blue GGG and 'YAP' (yttrium aluminium perovskite). An interesting variety of hydrothermal synthetic quartz was predominantly brown with a shallow green layer offered as a simulant for andalusite. R.J.P.

The cathodoluminescence of synthetic periclase.

J. Ponahlo. *Australian Gemmologist*, **19**(1), 1995, pp 31-7, 1 table, 2 illus. in black-and-white, 4 in colour.

The author has presented a very detailed study of synthetic periclase (magnesium oxide) comparing its cathodoluminescence (CL) and analysis of CL spectra with trace element content. The causes of CL colour are discussed with reference to Ni, Cr, Fe and Mn contents. R.J.P.

BOOK REVIEWS

Handbook of mineralogy. Volume 2. Silica, silicates.

J.W. ANTHONY, R.A. BIDEAUX, K.W. BLADH AND M.C. NICHOLS, 1995. Mineral Data Publishing, Tucson, AZ. 2 vol. Hardcover. US$142.50 (including shipping). ISBN 0 9622097 0 8 [from vol. 1].

The first volume of this most welcome series covered the elements, sulphides and sulphosalts. With the silicates, on which so much reclassification has been postulated over recent years and to which so many new species have been added, two volumes have been found necessary to contain all the (highly edited) data available. As in the first volume the minerals are presented in alphabetical order; also following precedent there are no crystal drawings; locality information is strictly edited and based on specimens in major collections. The aim of the book is to present data rather than to give background information on how to use it.

Members of the silicate class have increased by about three times from the 1950s and growth in the sophistication of investigative techniques has been responsible for this as well as extensions in field work with consequent finds of new species. Many of the silicate species fall into groups and while these are not set out as in Fleischer and Mandarino's *Glossary of mineral species*, group membership is indicated by a note at the top of the page devoted to each species. For cross-referencing between names and compositions the program SEARCH is available from the publishers at PO Box 37072, Tucson AZ 85740. While many of the silicate groups are quite complicated the amphiboles have always given particular problems and for this reason a classification in diagram form is provided.

Some 'rogue' silicates such as thaumasite (cut stones exist) in which silicon occurs without oxygen to bond with are included as true members of the class, this membership depending, as conventionally agreed, on the presence in a mineral of mutually bonded silicon and oxygen atoms. Diadochic substitution of SiO_4 for PO_4 places a species in the phosphates when the atomic ratio of the silica is subordinate to that of the phosphate and in the silicates if the reverse is the case.

The convenience of having one species per page by far outweighs the slight inconvenience of having to look elsewhere for some classes of information; the readership for this excellent book will know how to do this already. M.O'D.

The properties of optical glass.

H. BACH AND N. NEUROTH (Eds), 1995. Springer, Berlin. pp xvii, 410, hardcover. DM268. ISBN 3 540 58357 2.

Forming part of the Schott series on glass and glass ceramics (the Schott Glasswerke in Mainz carries a large research group whose work is publicized in a series of *Forschungsberichte*), the book updates and consolidates material contained in the seminal *Beiträge zur angewandten Glasforschung* which began in 1959. Since that date there has been a great increase in the use of glass and glass ceramic substances.

The first part of the book describes the manufacture and use of optical glass with some historical material on its development. The bulk of the text, however, describes the optical properties, chemical composition, optical quality, mechanical and thermal properties, chemical durability, processing and applications of glass and gemmologists would expect to find a good deal of useful information in many of the sections. Probably most interest will come from the chapters on refraction and chemical composition though a later chapter on coloured glasses presents material which usefully adjoins what we know about the colouring of natural and synthetic inorganic substances. While the treatment (of dispersion, for example) is of necessity mathematical the text is quite easy to read and since each major section includes an extensive list of references the book forms a major reference tool for anyone using glass. Two further volumes, covering low thermal expansion glass ceramics and thin films on glass, will complete this part of the Schott series. M.O'D.

A century-plus of opal publications.

H.E.R. DE BOER, 1994. [Published by the author] c/o Middleton Post Office, Tasmania. pp 87 [81 of text, space for notes], AU$ 26, including air mail to Great Britain, AU$ 23 surface mail.

Published in an edition of 500 copies, this most

© Gemmological Association and Gem Testing Laboratory of Great Britain ISSN: 1355-4565

useful bibliography of opal includes both monographs and papers in journals. A careful comparison with other opal books has shown that there seem to be few omissions, at least with the monographs, and citations of papers are adequately done. This is a well-produced and essential guide to an important part of gemmological literature. Later editions might well include the pagination of monographs from which the reader will get some idea of the text size. M.O'D.

Gemstones of Afghanistan.

G.W. BOWERSOX AND B. CHAMBERLIN, 1995. Geoscience Press, Tucson, AZ. pp xx, 172, illus. in black-and-white and in colour, hardcover. Price on application. ISBN 0 945005 19 9.

Having co-authored the standard book on the gemstones of neighbouring and geologically-similar Pakistan, the present reviewer has been waiting a long time for this book since looking over the MS and photographs with the authors back in 1993. There have long been problems with placing the location of gem species from these countries and descriptions of the mines and their minerals have been long overdue. As always seems to happen, the finest specimens of emerald and ruby are found in places particularly difficult of access so that many attributions are merely to the name of the nearest settlement. Equally mystifying are the many travellers' tales, some dating back many centuries and prone to colourful exaggerations of the size and nature of gemstones seen in places which few readers would and few authors actually did visit.

The book opens with an account of how this area, a fruitful area for plate tectonic studies, came to produce such a wealth of major gem species. This is followed by a history of geological explorations in Afghanistan. These chapters, like those following, have their own lists of references. Major gem species of Afghanistan are then treated in fine detail, beginning with the lapis lazuli occurrences of Badakhshan and proceeding to the spinel deposits of the same area, to the ruby and sapphire deposits of Jegdalek and Gandamak, the emerald mines of the Panjshir Valley and the deposits of tourmaline, kunzite and aquamarine in Nuristan. The main text closes with an assessment of the mineral potential of Afghanistan: appendices give the properties of the gemstones described, the coordinates of the major occurrences (what a valuable feature and one increasingly necessary for a serious study), a glossary and a general bibliography. An introductory statement outlines the pitfalls of transliteration and gives examples of some important variations. Interestingly the words panjsher and panjshir have different meanings so it is easy to see how ambiguities occur!

Such a care over detail and indication of where accounts can appear to treat quite different places while in fact pertaining to the same site parallels the care taken with the whole text. Even more remarkable, it is easy to read for relaxation and of course vital for gemmological, mineralogical and geological reference. Each occurrence is set in its geological context and the authors have actually visited them, not always the case in the gem books of not so long ago. Even better, once there, they understood the nature of the deposits. I could not wait to get into the book and wish that I had written it. M.O'D.

The honours of Scotland: the story of the Scottish crown jewels.

C.J. BURNETT AND C.J. TABRAHAM, 1993. Historic Scotland, Edinburgh. pp 56, illus. in colour, softcover. ISBN 0 7480 0626 5.

The crown jewels of Scotland were re-discovered in a dramatic scene played in 1818. An oak chest, long believed to be empty and housed in a sealed room in Edinburgh Castle, was opened to reveal the Scottish regalia which had been left there in 1707, the year of the Act of Union.

On New Year's day 1651 Charles II was crowned King of Scots near Scone Palace. At this last Scottish coronation the king was presented with the Honours of Scotland, crown, sceptre and sword, with a pair of spurs. They date back at least to the reign of James IV (1488-1513) but it is believed that Scottish kings may have been crowned since the sixth century though no regalia are known to have survived for so long. When Robert the Bruce, who seized the Scottish throne in 1306 was crowned, an improvised gold circlet was used but this disappeared to the English conquerors very soon afterwards. Although legend suggests that the circlet forms part of the present Scottish crown, there is no backing for the story.

Returning to Scotland and victorious over the English at Bannockburn in 1314, Robert would have ordered new Honours to be made and the coronation of his only son David in 1331 would have included those items of regalia which later appeared at the coronation of James IV. The story

after this is unclear since the present displayed regalia took their place at some time during the reign of James IV or James V.

The present Italian-made sceptre was perhaps given to James IV by Pope Alexander VI. There had been a tradition of papal gifts to Kings of Scotland and the sceptre is said to have been presented to James in 1494. The sword of state was made in Edinburgh rather than in Italy and is known to have been ordered in 1502. In 1536 the sceptre was re-modelled by the Edinburgh goldsmith Adam Leys and includes a polished globe of rock crystal.

While the exact form of the crown inherited by James V is not known, his marriage in 1540 to Mary of Guise-Lorraine gave an impetus towards the remodelling of the crown and this was undertaken by John Mosman of Edinburgh.

These major items of regalia are fully described, together with other pieces which have joined them. The remainder of the book describes the later history of the Honours, the period during which their whereabouts was uncertain and their present state and display. There is, in addition, a great deal of ancillary material on Scottish history: there is also a short but useful bibliography. The book is a really first-class account, worthy of its unique subjects. M.O'D.

Ore microscopy and ore petrography.

J.R. CRAIG AND D.J. VAUGHAN. 1994. Wiley, New York. pp xiv, 434, illus. in black-and-white, softcover. £18.95. ISBN 0 471 11599 1.

Many gemmologists are mineral collectors too and by some chance many minerals most accessible to the collector are ore species. While this book would have been greatly enhanced by colour photographs the text is lucid and provides a wealth of detail on the operations of many types of microscope, with particular reference to specimen preparation, qualitative methods of mineral identification and reflected light optics. These sections occupy approximately half the text. The remainder is devoted to ore mineral paragenesis, formation and fluid inclusion geothermometry of ores, the nature of ore mineral assemblages in igneous rocks and vein deposits and in a variety of other environments. There are excellent lists of references and useful tables, making this a cheap and accessible text for the student. M.O'D.

Meisterwerke Sächsischer Minerale.

E. EQUIT, 1994. Eberhard Equit & Co., Berlin. pp 151, illus. in colour, hardcover. US$120.00. ISBN 3 930874 00 8.

Full-colour paintings of 98 mineral specimens and 11 mining landscapes from Saxony, together with a short bibliography and list of Saxon minerals in public and private German collections make up a superb album for the mineral collector. Since the edition is limited to 1500 copies the book will soon have scarcity value; more costly is a leather-bound edition with included maps but the gemmologist will be quite happy with the illustrations of fluorite, smoky quartz and yellow topaz from Schneckenstein, as well as with the many specimens of native silver that Saxony had always produced. Mineral paintings are becoming more popular and it is good that photographs do not always have it their own way; the artist may very well have a particular feature in view when the camera sees everything dispassionately. M.O'D.

Fabergé [Catalogue of an exhibition held at The Queen's Gallery, Buckingham Palace, 1995-96].

1995, Merrell Holberton, London. pp 80, illus. in colour, softcover, price on application.

The Carl Fabergé shop in London's Dover St was established in 1903 and Queen Alexandra was one of the first royal customers, receiving Fabergé artefacts as birthday presents at least by 1909. Since then various members of the royal family have been assiduous collectors and the present royal collection is one of the largest and finest in existence.

The present exhibition contains 543 items and covers many ornamental materials. Nephrite, as might be expected, takes pride of place but there are some magnificent examples of rhodonite, rock crystal, various colours of chalcedony and the small diamonds, often set in dark backgrounds, with which Fabergé so often decorated his pieces.

Items selected for the catalogue are given descriptive entries containing notes of materials used, date of manufacture and craftsman's name where known, dimensions, details and translations of inscriptions and notes on provenance. A number of items are known to have been purchased from particular shops and such transactions are given. The standard of illustration is well up to that now taken as customary and the catalogue should be added to the collections of all with an interest in these distinctive productions.

Handlist to the exhibition. While the illustrated catalogue has selected items for inclusion the visitor needing a quick overview of all the pieces on show has a first-class, well-printed list available without charge. Apart from the illustrations, it contains virtually all the information printed in the illustrated catalogue. M.O'D.

Classical gems. Ancient and modern intaglios and cameos in the Fitzwilliam Museum, Cambridge.

M. HENIG, 1994. Cambridge University Press, Cambridge. pp xxx, 538, illus. in black-and-white and in colour. £125.00. ISBN 0 521 23901 X.

This catalogue raisonné of one of the world's major collections of classical and modern intaglios and cameos was compiled by Martin Henig with major contributions by Diana Scarisbrick and Mary Whiting. The Fitzwilliam Museum is the university museum of Cambridge and the systematic acquisition of gems began in 1864 with the purchase of the Leake collection of Greek and Roman coins and antiquities, including a major collection of ancient gems. Since that time the museum has acquired many important items and even while the catalogue was in press another very large set of engraved gems was presented by the Trustees of the Wellcome Trust - this last being the largest single accession of engraved gems ever received by the museum. The present catalogue stops short of this gift but otherwise includes all artefacts acquired up to the early 1980s.

Problems of preparation are bound to be large in this kind of work and the original preface is dated 1990. An additional problem has been cost and the museum was enabled to proceed with the publication of the catalogue only after a major donation had been received from the J. Paul Getty Trust.

The history of the collections is given in the first prefatory chapter : the second gives an account of how engraved gemstones were appreciated in antiquity. Notes on English collectors of engraved gems occupy the nine pages of the third chapter while ring and ringstone typology is set out in chapter four. Extensive lists of references accompany all the introductory chapters.

The catalogue is arranged in Greek and Roman and Medieval and Modern sections. The classical collections are subdivided into intaglios, cameos and miniature sculpture in precious stones and into metal rings and stamps. The medieval and modern collections are arranged by gemstones in intaglios, cameos, gem carvings in the round, non-mineral recipients and forgeries of ancient intaglios. Appendices describe items from the Davis collection of Iranian seals and similar items from the [first] Wellcome Trust donation. The Burges Ewer and the Burn bequest (one item) conclude the catalogue, while the book closes with lists of inventory numbers, of donors and provenances, details of proper names in Greek, Latin, Etruscan, in transcribed oriental and ancient languages and in modern European languages. Previous publications (i.e. of individual items) are listed and there are subject and general indices.

Catalogue entries give number, brief description, materials used, dimensions, provenance, date and style, followed by a full description including references. The majority of the gem materials used are varieties of the silica gems (cornelian, jasper, sard, agate and amethyst) while garnet, sapphire and glass also appear.

It is rare today for this kind of catalogue to be published at all, let alone at what is really a reasonable price. While the illustrations are almost all in black-and-white the central colour section includes high-quality photographs of 19 of the finest items. The authors and their assistants are to be congratulated for their production of a catalogue of international and lasting worth. M.O'D.

Chinese snuff bottles in the collection of Mary and George Bloch.

R. KLEINER, 1995. British Museum Press, London. pp xxxix, 665, illus. in colour, hardcover. £65.00. ISBN 0 7141 14650.

The days of the sumptuous, fully-illustrated catalogue of artefacts are not over! For a very reasonable price the reader is admitted to one of the finest private collections of Chinese snuff-bottles presently extant and on view at the time of writing in The British Museum. The standard of photography and of reproduction is as high as could be expected today and all we need to establish is the importance of the snuff bottle to the gemmologist.

The Chinese snuff-bottle is often made of a material with which all gemmologists will be familiar: perhaps rock crystal, perhaps one of the opaque varieties of quartz, perhaps jade, glass, ivory, coral, enamel, shale, soapstone, turquoise, amber, horn or other things: where the bottle is not itself made from a notable ornamental substance the stopper may be good quality jade or, a popular choice, pink tourmaline: snuff-bottle

stoppers helped the Californian tourmaline mines to establish themselves.

Bottles in the collection are presented in colour together with notes on materials, size, period, details of publication where applicable, description of item and any notable points of design, fashioning, inscriptions, decoration or reign/date markings. Similar pieces are compared. There is a first-rate bibliography and introductory material gives a short biography of the owners of the collection, George and Mary Bloch. A chapter on Qing imperial glass by another author occupies 17 pages and includes its own coloured photographs, taken from another collection, not displayed at the Museum.

The charm of the small and easily-handled snuff-bottle will be appreciated by those who also admire the generally small size and beauty of jewellery and gemstones and I strongly recommend readers to take the opportunity to find out more about how these materials are worked and why they are so valued. M.O'D.

Standard catalog of gem values. Second edition.

A.M. MILLER AND J. SINKANKAS, 1994. Geoscience Press, Tucson, AZ. pp ix, 271. £15.99. ISBN 0 945005 16 4.

A clue to the sudden appearance of the *Catalog* came in an advertisement in the German journal *Lapis* and very soon afterwards it was upon us. I was particularly pleased to see a revised text of an old friend which was first published in 1968 and reissued with inserted price update pages in 1988. The format remains the same with tables of prices for rough, faceted, engraved and carved gem materials and a chapter devoted to pearls. Details of fashioning are among the best and clearest of any book and how prices are arrived at forms a section rarely attempted by any author.

The deadline for updated prices was 1993 so alexandrite from the Hematita mine, Brazil, the production of the Argyle diamond mine in Western Australia and the intense blue copper-bearing tourmalines from the state of Paraiba, Brazil, are not included. There will always be a new find just after a book is published so these and other examples will have to wait for a third edition. Nonetheless the information given is profuse and welcome and especially useful are the short introductions to each species, telling the reader what features establish the best quality material.

The book is well produced on the whole though there are many misprints - the first author appears to have been born in the year that the copy deadline expired, according to the cataloguing in progress entry on the verso of the title-page! I am delighted that a new edition has been attempted and very pleased with the result. M.O'D.

Emerald and tanzanite buying guide.

R. NEWMAN, 1995. International Jewelry Publications, Los Angeles. pp 155, illus. in colour, softcover. US$19.95. ISBN 0 929975 23 5.

This book forms part of an informal series which includes buyers' guides for ruby and sapphire, for pearl, diamond rings and gold jewellery. The present book reaches the high standard set by its companions and can be highly recommended both for buying stones and for many gemmological purposes.

While emerald and tanzanite may seem unlikely bedfellows they are both sought supremely for their colour rather than for any particular effect. Some of their properties are also similar: they are both brittle and so need extra care in setting and cleaning and they both have imitators which can cause the gemmologist difficulties. Emerald, of course has its synthetic counterpart too and to make identification even more difficult there are filled and treated stones.

For the student, each chapter ends with a short set of questions which form good examination revision materials, and there is also an extensive bibliography. The book deals with many topics from the standpoint of the beginner with a view to helping the jeweller to sell his stones and the notes on judging the colour of emerald and later of tanzanite. The reader is also shown how to evaluate the cut of a stone and is then told in some detail about the treatments now commonly used. Very sensibly the author gives advice on how disclosure of treatment should be presented. The customer is also helped in the questions that should be asked when buying emerald or tanzanite.

The chapter on synthetic emeralds neatly summarizes the present position and with the help of some excellent colour photographs gives an overview for the student and even for the practised gemmologist.

Where else can you find coloured photographs of tanzanite in different lighting conditions and of inclusions, composites and set pieces as good as any so far published in specialist books? All gemmologists should get a copy at the very reasonable price. M.O'D.

Gemstones in Australia: a review of the industry and the first Australian assessment of gemstone resources.

J.G. OLLIVER AND I.J. TOWNSEND, 1993. Australian Gemstone Industry Council, Sydney. pp x, 72, illus. in colour. A$50.00. ISBN 0 644 29617 8.

This most useful book reviews resources and production of Australia's major gemstones, opal, sapphire and ruby and diamond state by state, with shorter notes on the production of jade, chrysoprase, emerald and other gem beryl, agate, garnet, rhodonite, turquoise, topaz, tourmaline, zircon and chiastolite. In addition there is an historical review of the Australian gemstone industry and details of regulations on mining imposed by South Australia, as well as maps of the locations of major species. Tables give the values of Australian gemstone production, of actual and inferred opal resources in New South Wales and in western Queensland and similar details of sapphire and diamond production and resources. Chrysoprase production is also described and South Australian opal production 1978-1990 is summarized. Each section has its own list of references and the book is a most welcome addition to the rarely-covered topic of gemstone production. M.O'D.

Chinese jade from the Neolithic to the Qing.

J. RAWSON, 1995. British Museum Press for the British Museum, London. pp 463, illus. in black-and-white and in colour, hardcover. £66.00. ISBN 0 7141 1469 3.

Despite the near-reverence held by so many for artefacts cut and polished in the jade minerals there has been no serious study in Western languages for many years. Since the Oriental Ceramic Society published the catalogue to the exhibition *Chinese jade throughout the ages* in 1975 (in the compilation of which the present author collaborated with John Ayers) the reader has to assume (correctly, in the main) that most of the major jade works must have been published in Chinese if not in China itself. Fortunately this book has an excellent bibliography in which Chinese studies feature largely. Before 1975 the Oriental Ceramic Society had held an exhibition in 1948, *Chinese jades*, which, like its successor exhibition, was catalogued in the Transactions of the Society. *Chinese jade throughout the ages* is by chance the title of one of Stanley C. Nott's books, first published in 1936, reprinted in 1962, and as this is the only large text in English (there are some good but small ones) likely to have been available for years the present book can be seen to be very long overdue.

The book accompanies an exhibition of Sir Joseph Hotung's jade collection and opens with explanation not only of the nature of the jade minerals but of the high value invariably placed on them by the Chinese. It is customary to say that this is because jadeite in particular is pleasing to the touch but far greater importance attaches to the capability of jade, like bronze, for supporting and perpetually preserving inscriptions, a property which has always been of particular significance to the Chinese. The toughness and hardness of the jades suggests power, whether political or religious: it is no accident that the linguistic character for jade is the same as that indicating 'precious stone'. The introduction goes on to discuss those shapes of jade which have been fashioned since the earliest times, to describe known fashioning sites and something of the methods used in working the materials. The book then begins the period-by-period study which occupies the bulk of the text.

Over 300 artefacts from the Hotung collection are described and illustrated and where appropriate reference is made to similar objects in the major collections of The British Museum. Each chronological section has its own list of references: full descriptions, including details of publication, accompany the excellent colour and black-and-white photographs (which also give the size of the object). The descriptions also speculate on the possible uses of the objects, their shapes and the nature of the fabulous animals, as well as their provenance.

A chapter on jade mineralogy follows the catalogue and includes a map showing possible nephrite sources in China. The book ends with the bibliography and index.

In so many ways this is the book that the jade connoisseur has always wanted and perhaps it is not too serious that there has been so long a gap between the publication dates of the major English texts. Along with modern identification techniques has come a much greater familiarity with Chinese classical and later texts, so that a book published near the end of the century has been able to draw on far more material than its predecessors. We hope that more Chinese sources, geological, mineralogical and textual, will be available for a second edition. M.O'D.

The Peking diamonds. [A tale.]

P. READ, 1995. Gembooks, Bournemouth. pp 208, softcover. £7.95 including post & packing: £8.50 surface mail overseas. ISBN 0 9525315 O X.

Forming part of a planned trilogy (the first part was *Diamond mine**) this story is about the planned substitution of flux-grown spinel crystals for diamond in the pre-sight routines of the De Beers organization. Two large countries (read the book to find out which they are) are behind the operation and the whole thing is not entirely unrealistic. I found this a jolly good read, moving more quickly than *Diamond mine* and with the sort of detail which gemmologists at least will find familiar. With Dick Francis' *Straight* (1989), *The Peking diamonds* should be required reading for students who need some lighter books from time to time. Two small points of interest: flux-grown colourless corundum may also take octahedral form and show trigons; as with spinel grown in this way, the trigons echo the edges of the octahedron and diamond sorters would spot this, since in diamond crystals the trigons are reversed. While a single flux of lead fluoride might be used for spinel growth, the combination lead oxide-lead fluoride-boron oxide is perhaps preferred today. M.O'D.

Images of the Anakie sapphire fields, Queensland.

W.L. SCHOLLER, 1993. E & W Scholler, Anakie 4702, Queensland. pp viii 136, illus. in black-and-white and in colour, softcover. ISBN 0 9589968 2 2.

For a fairly short historical account of a major gemstone locality you could not do much better than this. The Anakie fields in Queensland have produced good quality sapphire with fine blue and yellow stones predominating. The author laments the diminution of activity in the fields today (most blue sapphires on the market come from Thailand and lately from China) and suggests a number of reasons why activity has slackened. The main portion of the book, though, describes the fields, the sapphires and the miners, drawing heavily upon local newspaper accounts which would not be available anywhere else and there is a great amount of detail on personalities of the fields and a very useful bibliography, again giving information quite impossible to obtain any other way. There are many black-and-white photographs and some major finds are shown in colour. This reviewer appeals to anyone with such a personal knowledge of a gemstone location to get the facts written down at once. If their accounts are as good as this one, gemmological history (where is it?) will start life as a subject of its own. M.O'D.

*Diamond mine was reviewed in *J. Gemm.*, **23** 3

Diamond cuts in historic jewellery 1381-1910.

H. TILLANDER, 1995. Art Books International, London. Illus. in black-and-white, hardcover. £52.00. ISBN 1 874044 07 4.

This study covers ground which has never been treated monographically before. Long-awaited and written by the acknowledged authority on the history of diamond cutting and its relation to jewellery styles, it will be welcomed by a wide readership, the gemmologist and the historian of jewellery design together with those interested in the applied arts in general who may find the study of diamond cutting of much greater interest than they could have imagined. The combination of art and technology which has led so many to undertake gemmology as a study has never been better shown than here. While the author admits that some of his conclusions are intuitive in the absence of much written material, he nevertheless manages to compile a most useful bibliography and to include many valuable citations in the text. While the illustrations are in black-and-white they none the less serve to illustrate points of argument and description at least adequately and often better than adequately.

The text is arranged by style of cutting, beginning with the use of the natural diamond point and progressing through ever more complicated cuts to the various ideal brilliants and to those cuts recently developed with a view to enhancing diamond's properties still further. Appendices describe proportioning, the rock crystal bowl of Queen Elizabeth I, the wedding ring of Albrecht V, early price lists and the relationship between artists and diamonds. Photographs are supplemented by diagrams and sketches: these are especially useful in displaying how a particular cut is obtained from the rough crystal, information which will be most useful for the student of diamonds. Particular attention is paid to some of the named diamonds such as the Sancy, Tiffany and Koh-i-Nor and the section dealing with what may be thought of as the modern brilliant discusses the various 'ideal' cuts at length, bringing in data which have either been unpublished before or which are making a welcome reappearance. It is good to see Frank B. Wade's 'finely cut diamond' with some of whose features

Tolkowsky later disagreed, rejecting Wade's table but retaining a very visible culet spurned by Wade. This kind of history is what makes the book unique and highly desirable at a very reasonable price. M.O'D.

Faszination Edelstein aus den Schatzkammern der Welt. Mythos, Kunst, Wissenschaft.

1992. Hessisches Landesmuseum, Darmstadt. pp 275, illus. in black-and-white and in colour, softcover. £36.00. ISBN 3 7165 0871 3.

Catalogue of an exhibition shown at the Hessisches Landesmuseum at Darmstadt in 1992, the book takes gemstones as its theme and describes exhibits in order of species, after some general introductory material on gemstones as ornament. Diverse topics are covered, including trade in gemstones in the Middle Ages, gemstones in the classical period and the synthesis and imitation of gemstones. The major gemstone families are described next and in all sections artefacts are shown and described. Each section too has its own list of references. Without saying that the catalogue contains enough substance to present a definite theme as thoroughly as might have been possible, a read-through shows a large number of interesting objects and commentary, with many of the exhibits getting a rare airing. M.O'D.

A private collection of early Chinese jade carvings 28 November to 9 December 1994. [Catalogue].

Weisbrod Chinese Art Ltd, Weisbrod, New York, 1994. pp 85, illus. in colour, softcover, £8.00.

Very well-illustrated catalogue of an exhibition of early Chinese jades with an introductory essay, chronology and bibliography. Entries include a full description with provenance where applicable as well as notes on publication. M.O'D.

Jade in Chinese culture.

Palm Springs Desert Museum, 8 February-29 April 1990 [The Museum] Palm Springs, 1990. pp 155, illus. in colour, softcover, £22.00.

With the sub-[or series] heading Magic, Art and Order this catalogue of Chinese jade artefacts illustrates an exhibition describing the development of jade working in Chinese culture from the neolithic period to 1911. Additional material covers ritual objects, animals, copies of objects in other media, objects of aesthetic delight and objects of ornament. The standard of the photographs is high and there is a useful bibliography. M.O'D.

Bärnsten. Guldet fran Östersjön. Bursztyn. Zloto Baltyku.

1992. Oficyna Wydawnicza Excalibur, Bydgoszcz. pp 77 [colour section unpaged], illus. in black-and-white, hardback. Price £40.00. ISBN 83-900152 6 9.

Magnificently illustrated by a series of colour photographs, the book forms the catalogue of an exhibition of Baltic amber artefacts assembled by two Swedish and two Polish museums and sent on tour during 1992/93. The short text (by Elzbieta Mierzwínska) is in Polish and Swedish and includes a short bibliography and a list of the objects, the best of which have been selected for reproduction in this catalogue (probably best ordered as *SHM utställningskatalog* no. 120 from the Statens Historiska Museum, Stockholm). Details of the history of amber recovery in the Baltic countries and a short account of the nature of amber form part of the text. Most readers will, however, turn straight to the illustrations; there are 122 and all forms of representation are included. M.O'D.

Gemme e Diamanti dal Kremlino. Gems and diamonds from the Kremlin.

1994, Musei Statali del Kremlino, Moscow, pp 208, illus. in black-and-white, hardback. Price £45.00.

The Kremlin Museum in cooperation with an Italian printer/publisher [Ferrero Editore] has produced a magnificently-illustrated selection of some of the artefacts in its care. Readers familiar with Moscow should note that the museum concerned is the Palace of the Armoury, not the Diamond Treasury (both are in the Kremlin). Both contain jewellery and both need to be visited (visits to the Diamond Treasury need to be arranged in advance). The Museum and its history are fully described in the introduction and it is good to learn that new objects are being made by Russian jewellers and goldsmiths and added to the collections. In the illustrated section 90 items are illustrated in colour, each photograph occupying a full page with facing text; as in the rest of the book Italian and English are used. M.O'D.

Proceedings of the Gemmological Association and Gem Testing Laboratory of Great Britain and Notices

The 1996 GAGTL Photo Competition

Images in Gems

In the competition this year members are asked to submit pictures of gems with colour shapes, structures or inclusions that suggest a particular item to the viewer - the more spectacular the better.

Develop the range of evocative names established by 'feather', 'fingerprint', 'Chinese aeroplane', 'jardin', etc. What images are suggested to you by an unusual cut or by an unconventional arrangement of gems in jewellery?

All entries will be judged for originality, beauty and gemmological interest.

The following prizes will be awarded:

First Prize:	**£100.00**
Second Prize:	**£75.00**
Third Prize:	**£50.00**

Entry forms and details of the rules of entry will be circulated to all members.

OBITUARY

Mr William J. Boxall, FGA (D.1952), Midcalder, West Lothian, died recently.

GIFTS TO THE ASSOCIATION

The Association is most grateful to the following for their gifts of gems and gem materials for research and teaching purposes:

Mr D.H. Ariyaratna, FGA, DGA, London, for a stained ruby crystal approximately 8mm in length.

Gina Latendresse, GG, President of the American Pearl Company, Nashville, Tennessee, for 'designer-shaped' cultured pearls.

Louise Sinclair, FGA, London, for a cubic zirconia weighing 3.22 ct.

Mr Wu Chao-Ming, Taiwan, for a piece of rough nephrite from Taiwan.

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FORTHCOMING MEETINGS

London

Dr Grahame Brown, Editor of *The Australian Gemmologist*, will be giving the following lecture during his visit to Britain in January 1996:

1996
4 January **Gemstones - Australia's national treasure.** Dr Grahame Brown.
Evening lecture, charge £3.50 for members and £5.00 for non-members.

To be held in the GAGTL Gem Tutorial Centre, 2nd Floor, 27 Greville Street (entrance in Saffron Hill), London EC1N 8SU. Entry will be by ticket only, obtainable from the GAGTL.

Midlands Branch

27 October **Pearls – production and identification** Stephen Kennedy

29 October **Practical Autumn Seminar**
Beginners/refresher day. To be held at the New Cobden Hotel.

24 November **Jewels in the hand** James Gosling

2 December **Annual Dinner**
To be held at Denehurst Close, Barnt Green

1996
21 January **Gem Club – Is it the real McCoy?**
Details of venue from Gwyn Green on 0121 445 5359

26 January **Bring and Buy, and Quiz Night**

Unless otherwise indicated meetings will be held at the new venue of the Discovery Centre, 77 Vyse Street, Birmingham 18. Further details from Mandy MacKinnon on 0121 624 3225 or Neil Rose on 0161 483 8919.

North West Branch

15 November **Annual General Meeting**
The meeting will be held at Church House, Hanover Street, Liverpool 1.

Further details from Joe Azzopardi on 01270 628251.

NEWS OF FELLOWS

Michael O'Donoghue has been appointed to the Editorial Board of the German mineral journal *Lapis* and also to the Editorial Board of the Russian journal *World of stones.*

GEM DIAMOND EXAMINATIONS

In June 1995 83 candidates sat the Gem Diamond Examination worldwide, of whom 64 qualified including seven with Distinction. The names of the successful candidates are as follows:

Qualified with Distinction

Auzmendi, Amaia Garin, Madrid, Spain.
Kassam, Sultan Mohamed S., London.
Nicholson, Charles J., London.
Pattni, Jilesh Hirji, Wembley Park.
Sheng, Beili, Wuhan, China.
Smyth, Lesley, London.
Wu, Zhanxia, Wuhan, China.

Qualified

Allberg, Mauritz, Stockholm, Sweden.
Arulnathan, Jayabalan, London.
Badibanga, Carine, Brussels, Belgium.
Bagchi, Debal N., Brentford.
Capisano, Eric, London.
Carroll Marshall, Anne E., Hong Kong.
Cassarino, Paul R., Rochester, NY, USA.
Chan, Yuk Fan, Kowloon, Hong Kong.
Chong, Gar Leok Grace, London.
Eggleston, Avrina, London.
Fan, Siu Kam, Hong Kong.
Fantis, Charoulla, London.
Farion, Jean-Christophe, South Kensington.
Fong, Tsz Pan, Kowloon, Hong Kong.
Fukushima, Katsue, London.
Fung, Wai Yin, Hong Kong.
Gantzidis, Adam, Athens, Greece.
Garland, Annette J., London.
Hamp-Gopsill, David, Burton-on-Trent.
Hofer, Peter M., Northwood.
Hui, Sze Wai, Kowloon, Hong Kong.
Hung, Vivian Chi Ling, Hong Kong.
Ji, Xiaoyan, Wuhan, China. Joey,
Leung Wing Yee, Kowloon, Hong Kong.
Kam, Chih, Hong Kong.
Kam, Ka Dung, Hong Kong.
Keating, Elaine, London.
Kwan, Wai Shun, Kowloon, Hong Kong.
Lai, Mui Guk Margaret, Hong Kong.
Lakhtaria, Yashwin, London.
Lam Chiu Hung, David, Kowloon, Hong Kong.
Mo Jing Lee, Grace, Wanchai, Hong Kong.
Lu, Yefei, Wuhan, China.
Mamo, Charles, London.
Papadopoulos, Iraklis, London.
Pattani, Shobna, London.
Pawlyna, Andrea G., Hong Kong.
Pegg, Delia, Petts Wood.
Poon, Loi Chuen, Hong Kong.
Ren, Jiakai, Wuhan, China.
Roca Massotti, Joaquin J., London.
Ruhmer, Fiona J., London.
Spooner, Carole, Wokingham.
Summerfield, Susan, London.
Tsoi, Chung Ho, Kowloon, Hong Kong.
Victor, Chau Tak Ming, Kong Kong.
Wakefield, Melanie, Horsham.
Wan, Stephen, Kowloon, Hong Kong.
Wang, Hui, Wuhan, China.
Wang, Xin, Wuhan, China.
Warrington, Jennifer L., Palmerston North, New Zealand.
Weng, Ping, Wuhan, China.
Williams, Jason, Cobham.
Wong, Mei Wai May, Kowloon, Hong Kong.
Xi, Bo, Wuhan, China.
Xu, Rupeng, Wuhan, China.
Zhang, Weichao, Wuhan, China.

EXAMINATIONS IN GEMMOLOGY

In the June 1995 Examinations in Gemmology 354 candidates sat the Prelminary Examination, 247 of whom qualified; 336 sat the Diploma Examination and 105 qualified.

The Anderson/Bank Prize for the best non-trade candidate of the year in the Diploma examination was awarded to Miss Zhou Shuzhen of Wuhan, China.

The Diploma Trade Prize for the best candidate of the year who derives her main income from activities essentially con-

nected with the jewellery trade was awarded to Miss Johanna Carlsson of London.

The Anderson Medal for the best candidate of the year in the Preliminary examination was awarded to Miss Sau Ping Pamela Cheung of Kowloon, Hong Kong.

The Preliminary Trade Prize for the best candidate under the age of 21 years on 1 June 1995 who derives her main income from activities essentially connected with the jewellery trade was awarded to Miss Seema Dayaldasani of Bombay, India.

This year no candidate was considered to be of sufficient merit for award of the Tully Medal.

The names of the successful candidates are as follows:

DIPLOMA

Qualified

Au, Yeung Kwok Ho, Hong Kong.
Baxter, Richard, Birmingham.
Bray, Betty A., Abilene, Tx, USA.
Cadby, John H.V., Trowbridge.
Cadby, Sarah, London.
Can, Cao, Wuhan, China.
Carlsson, Johanna A., London.
Carr, John R., Cheltenham.
Chen, Jyh-Shyang, Taipei, Taiwan, ROC.
Cheng, Ming Chi, Hong Kong.
Clay, Gretchen F., Boston.
Dang, Xiaoying, Wuhan, China.
Day, Stephen J., Peterborough, Ont., Canada.
Dayaldasani, Seema Kamlesh, Bombay, India.
Ding, Weijun, Wuhan, China.
Dokken, Aarrynne D.C., Sutton.
Everitt, Sally A., London.
Guo, Hui, Wuhan, China.
Guo, Xiaodan, Wuhan, China.
Haittoniemi, Mia, Helsinki, Finland.
Hawken, Diana B., Hong Kong.
Higo, Kenji, Osaka, Japan.
Ho, Hsiung-Chien, Taipei, Taiwan, ROC.
Ho, Shuk Ching Rebecca, Hong Kong.
Ho, Tung Tak, Hong Kong.
Iwata, Kaoru, London.
Javeri, Mitesh J., Bombay, India.
Jiang, Xinshun, Wuhan, China.
Kuixi, Jin, Wuhan, China.
Kathoon, Junaida, London.
Kawamura, Toshiko, Sakurai City, Japan.
Kennedy, Karen F., Egham.
Kenny, Sark, Kowloon, Hong Kong.
Kissoon, Sasha N., London.
Kleiser, Alwen M., Holyhead.
Lee, Angela Sau Mui, Kowloon, Hong Kong.
Leung, Stephen Ping-Kwong, Thornhill, Ont., Canada.
Li, Yuan, Wuhan, China.
Lin, Fiona, Taipei, Taiwan, ROC.
Lin, Bing, Wuhan, China.
Lo, Shuk Lan, Hong Kong.
Loungani, Jagdish, Jaipur, India.
Lu, Fude, Wuhan, China.
Luo, Yiguang, Wuhan, China.
Ma, Yugao, Wuhan, China.
Maheshwari, Ashoo, Jaipur, India.
Mallo Sanz, Maria Cristina, Madrid, Spain.
Marathe, Tanjua, Pune, India.
Moore, Julie L., Measham.
Nam, Chang Soo, Daejon, Korea.
Ng, Yee Mei Kathy, Hong Kong.
Owens, Suzanne, Dublin, Republic of Ireland.
Pachchigar, Dharmesh N., Bombay, India.
Papadopoulos, Dimitrios, Athens, Greece.
Pattni, Jilesh Hirji, Wembley Park.
Purkiss, Karen A., Colchester.
Qin, Shule, Wuhan, China.
Rabstein, Wolf I., London.
Rickard, Sarah V., Market Harborough.
Roca Massotti, Joaquin J., London.
Rose, Christina, Liverpool.
Rosier, Wendy, Hong Kong.
Rossiter, John T., Weston-Super-Mare.
Salm-Reifferscheidt, Sophie, London.
Sharma, Animesh, Jaipur, India.
Sharma, Rajeev, Jaipur, India.
Sim, Hoo Joung, Daejon, Korea.
Siu, Ming Wa, Hong Kong.
Smallenburg, M.A., Amsterdam, The Netherlands.
So, Che Shing, Hong Kong.

Solves Camara, Jose Daniel, Valencia, Spain.
Soo, Hoi Leung, Hong Kong.
Sotolongo,Sachiko Kashiba, London.
Stead, Graham Scott, Tillsonburg, Ont., Canada.
Sun, Yanling, Wuhan, China.
Sung, Soo Kyung, Taegu, Korea.
Tada, Reiko, Osaka, Japan.
Tan, Hongwei, Wuhan, China.
Tanaka, Daisuke, Kobe City, Japan.
Tang, Zhen Yi, Hong Kong.
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Corrigenda

On p.500 above, for '£115.00 plus VAT' read '£275.00 plus VAT'

On p.508 above, Abstract, first paragraph, last line, for '0.1 to 0.2' read '0.1 to 0.5'

On p.509 above, second column, under Trace elements in jadeite, first paragraph, line 8, add 'chromium,' before 'iron'

On p.510 above, Table I:Fe2+/Fe3+ content of leaf-green jadeite, for '0.1-0.2' read '0.1- 0.5'; Cr%, emerald green (chrome-rich), for '0.3-0.4' read '0.3-0.04'

On p.510 above, first column, line 6 of text, for '0.1-0.2' read '0.1-0.5'

On p.524 above, first column, last line in Gifts to the Association section, for 'serpentine' read 'nephrite from Taiwan'

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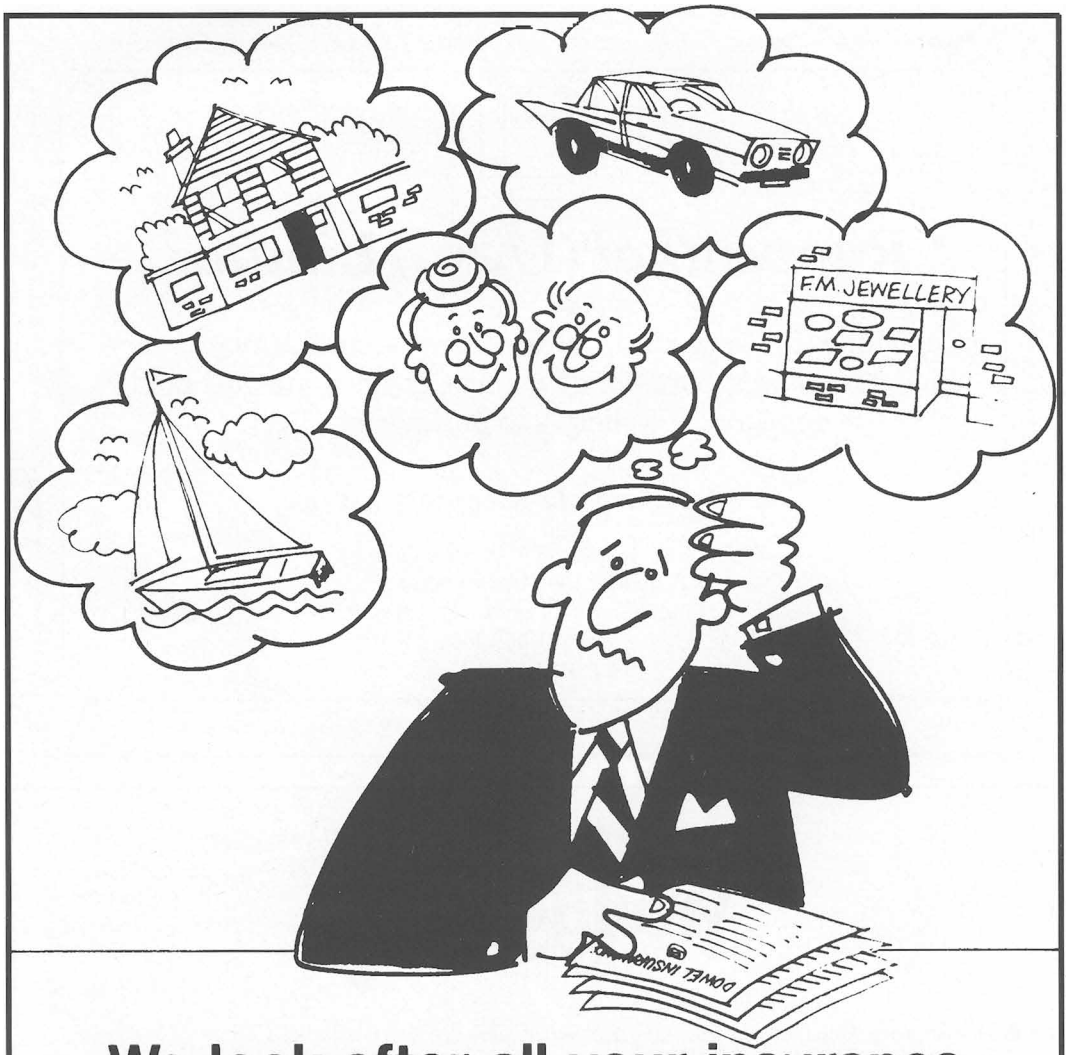

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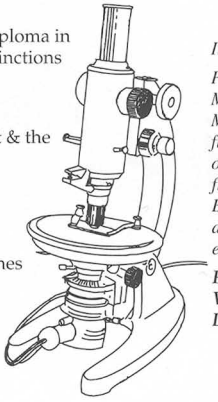

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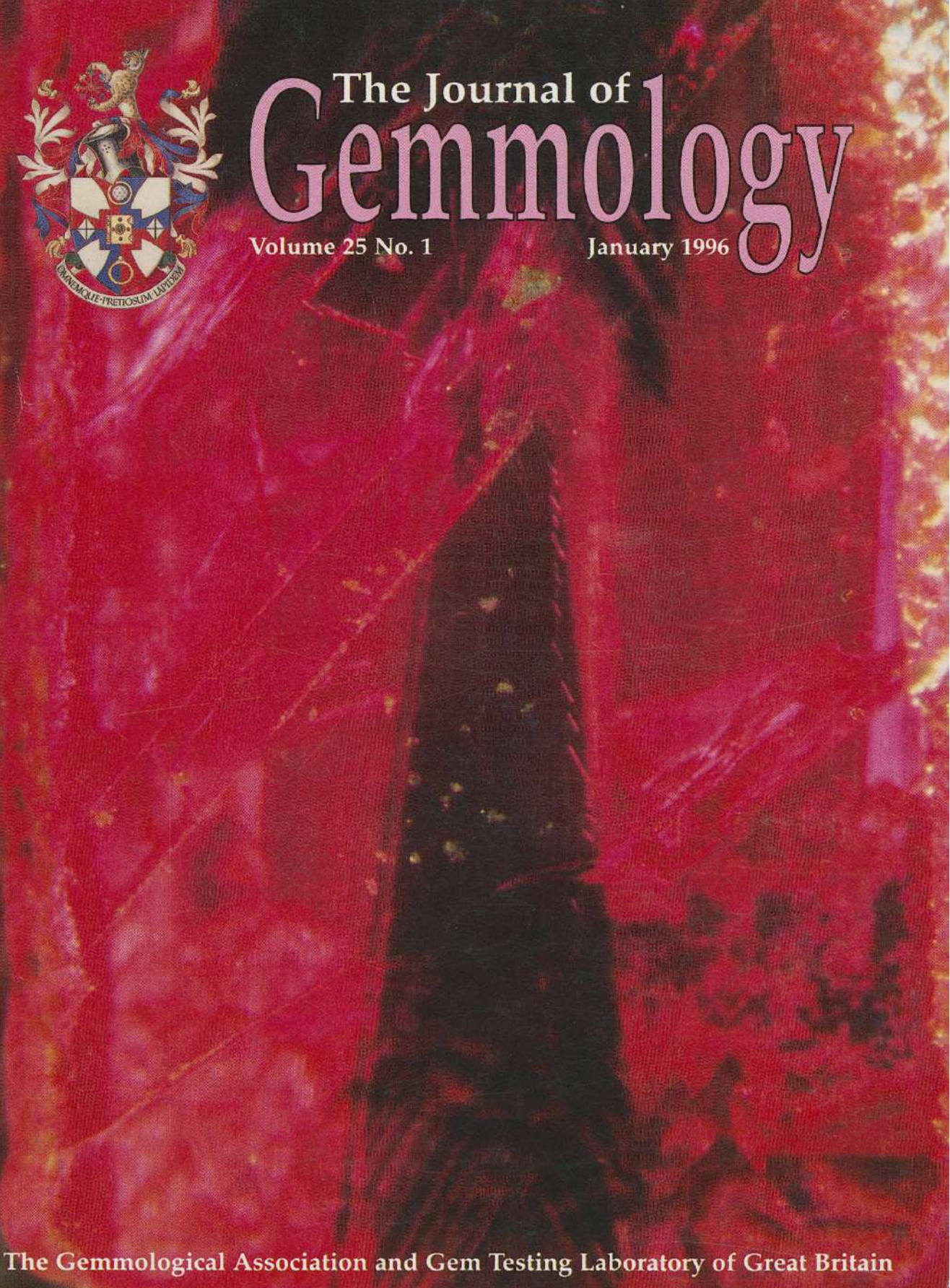

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Cover Picture

Typical colour zoning in a Mong Hsu ruby which has not been subjected to heat-treatment. Central violet to black zones are due to high concentrations of titanium and chromium. See 'The role of fluorine in the formation of colour zoning in rubies from Mong Hsu, Myanmar (Burma)' on pp 3–19.

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In this issue...

The first paper in this volume concerns the currently fashionable Mong Hsu rubies from Myanmar and aims at explaining some of the unusual features displayed by stones from this deposit. The rubies have become famous because of their fine colour and the common occurrence of a blue core in many samples. Not the least of their attractions was the fact that this blue core could be removed by heat treatment to leave a fine red stone!

The composition of the rubies and their inclusions, and of minerals associated with the rubies in the gem gravels, are considered in modelling how the particular features of the Mong Hsu stones originated and it is concluded that fluorine played an important role. In particular a sequence of fluids variably enriched in water, CO_2, F, Cr, and Ti, is thought to be responsible for the alternating zones of ruby and sapphire.

Mention has been made before in this *Journal* of the great potential of Russia for supply of gem materials, and amber possibly having come from this source is described in Notes from the Gem and Pearl Testing Laboratory, Bahrain. The composition of strings of prayer beads and fracture-filled emerald are other topics discussed in the Notes and reflect a wide diversity of work which must be of considerable reassurance to the jewellery trade in Bahrain.

Mont Saint-Hilaire, Quebec, is a twentieth century mineralogical and gemmological phenomenon. More than 300 different minerals have been found there, 27 of them new species. Not all the new species are large enough to cut into gems, but a total of 28 species have been cut, most for curiosity but some for collectors. Notwithstanding the original motive for cutting, all these stones become collectors' gems. An authoritative account combines the history of finds at Mont Saint-Hilaire with the major personalities involved in the discovery and cutting of the gems. With the growing economic significance in the market for specimens from some localities it is becoming more important to establish reliable and definitive criteria for their identification, and comprehensive pictures and tables provide a unique reference for the locality to mid-1995.

In the final paper, the author describes the occurrences of freshwater mussels and pearls in Bavaria and Bohemia. New interest in this subject has arisen not because a new productive strain of pearl mussel has been found but because these geologically long-lived animals are extremely sensitive to pollution and vast numbers are being studied to monitor the rivers of Europe. The fact that some of the shells will, in the fullness of time, produce pearls is a bonus!

R.R.H.

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The role of fluorine in the formation of colour zoning in rubies from Mong Hsu, Myanmar (Burma)

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Abstract
Mong Hsu rubies are characterized by a black sapphire core and a ruby rim. This colour zoning has been correlated with the presence of the trace elements Ti (violet to black) and Cr (red) (Peretti *et al.*, 1995a). Some examples of Mong Hsu rubies show a complex chemical zonation, which results in multiple zones of rubies, violet sapphires and black sapphires within one particular crystal. Rubies of this type have been studied by analyzing the solid and fluid inclusions as well as their chemical zoning. Minerals accompanying the rubies, such as tourmaline (dravite) and tremolite have also been analysed. The formation conditions of the rubies have been reconstructed following the study of mineral associations and fluid inclusion analyses. Mong Hsu rubies were formed at 2–2.5 kbars and at temperatures between 500° and 550°C. The fluids were found to be water-bearing and multi-volatile CO_2-rich (multivolatile = composed of CO_2, CH_4 and other components, possibly N_2, H_2S and HF). Fluorite inclusions in the rubies indicate that fluids must have contained some HF. During the study of the homogenization temperatures in different populations of fluid inclusions, it was concluded that no major variations in temperature and pressure occurred during the growth of Mong Hsu rubies. However, the chemical zonation patterns found in Mong Hsu rubies and accompanying tourmalines are indicative of variations in the composition of the fluids e.g. in contents of F, Ti and Cr. A preliminary model is proposed, which explains the cyclic growth of Mong Hsu rubies, with formation of alternating zones of ruby and sapphire by variation in HF concentration in the surrounding fluids. The possible multiple infiltration of fluids from metapelites into dolomites is discussed.

Introduction

A new source of rubies with commercial importance was declared in 1991 at Mong Hsu in the Shan state of Eastern Burma more than 200 kilometres from the classical ruby mine at Mogok (Hlaing, 1991; Jobbins, 1992; Jobbins *et al.*, 1994; Kane and Kammerling, 1992, Peretti *et al.*, 1995a). The main metamorphic rocks in the mining district are composed of metacarbonates (dolomites, marbles, calcsilicate rocks) and metapelitic rocks (schists, gneisses, phyllites) (Earth Sciences Research Division, 1977, Hlaing, 1991, 1993, 1994). Mong Hsu rubies are mined in secondary deposits (Figures 1 and 2) and in primary deposits in the dolomite marbles.

The most characteristic feature of the Mong Hsu rubies is their colour zoning, with a violet to black core (Figure 3) and a red rim. The cores consist of zones enriched in TiO_2 and Cr_2O_3 along with

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Fig. 1. Ruby deposits in the Mong Hsu region showing mining activities in the secondary deposits. The picture shows the separation of the larger crystals of tremolite by sieving before the rubies are washed from soil. *Photo by U Tin Hlaing, courtesy JewelSiam*

Fig. 2. River terraces at Mong Hsu with the alluvial deposits of the rubies. Primitive mining by local people before late 1993 is shown. *Photo: anonymous miner*

Fig. 3. Non-heat-treated Mong Hsu rubies, partly with polished facets, showing black to violet cores. Rubies between 0·50 and 2·00 ct.

Fig. 4a. Typical colour zoning in a Mong Hsu ruby which has not been subjected to heat-treatment. Central violet to black zones are correlated with high concentrations of titanium and chromium (Peretti *et al.*, 1995a). Ruby cut parallel to the *c*-axis. Magnification on slide is 40×. Ruby approx. 2 ct. *Photo by Dr E. Gübelin*

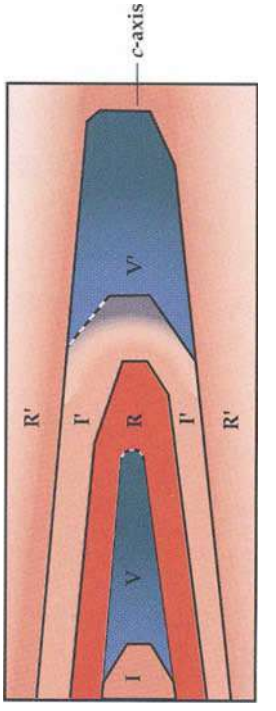

Fig. 4b. Classification of the colour zoning of the Mong Hsu ruby of Figure 4a. Growth phases are described as I, R and V. Compare with Figure 12. Sketch by Dr K. Schmetzer. Details on growth zones see Peretti *et al.* (1995a).

only small concentrations of FeO (Peretti *et al.*, 1995a). The colour zones in the Mong Hsu rubies occur in repeated cycles of violet/black and red along with changes in the crystal habit (see Peretti *et al.*, (1995a) and Figure 4a, b). The factor most relevant to the commercial importance of the Mong Hsu rubies is that the violet to black zones can be removed by heat-treatment (Figure 5) (Jobbins, 1992; Ho, 1993; Laughter, 1993). Typical examples of such heat-treated fine quality and faceted rubies are shown in Figure 6.

Fig. 5. Heat-treated Mong Hsu rubies. The original violet to black cores have been completely removed and transformed to intense red. Rubies between 1 and 3 ct.

This study concentrates on attempting to determine the conditions under which Mong Hsu rubies were formed and on the genetic reasons for the presence of violet to black zones in the Mong Hsu rubies. A more general gemmological investigation of the properties of the Mong Hsu rubies, including the heat-treated samples, can be found elsewhere (e.g. Peretti *et al.*, 1995a,b,c).

Minerals accompanying the Mong Hsu rubies in the alluvial deposits

The materials for this study were sampled during expeditions to Northern Thailand (Mae Sai) and Burma in the summers of 1993 and 1995 (Figure 7a). However, direct field work at the primary mine in Mong Hsu was not possible because of security risks which are still pertinent (see Thailand Stone Market Report, 1995). In order to obtain further information concerning associated minerals, large parcels of mineral concentrates from the Mong Hsu ruby deposits have been checked (Figure 7). Some of the results are shown in Figure 8,

Fig. 6. A set of cut stones showing different colour shades obtainable from Mong Hsu rubies after heat-treatment. Rubies heat-treated and cut by the authors. Sizes of rubies around 1 carat each. *Photo by Mouawad, Bangkok (Thailand).*

Fig. 7. (a) A Mong Hsu ruby in the host rock. The ruby is formed in a vein consisting of corundum, sapphire, ruby, calcite, Mg-chlorite, fuchsite and opaque minerals. The vein itself is embedded in a dolomite marble (area of lower left corner) which shows signs of metamorphic recrystallization (equal sized dolomite crystals, 2mm in size). A calcite crystal is shown in reflected light in the figure. It is formed at the border zone of the vein, in contact between the dolomite marble and the ruby. Minerals identified by SEM-EDS analyses. Length of Mong Hsu ruby is 8 mm. Collection A. Peretti.

Fig. 7. (b) Kilos of rough Mong Hsu rubies in Mae Sai displayed in the office of a major dealer for the selection of samples for this study (left-hand side). Mong Hsu ruby lots may contain various other minerals such as tourmaline, garnet, andalusite and tremolite.

Fig. 8. Minerals found in the lots of Mong Hsu rubies including one green chromium-dravite (top), three brownish dravites (middle), andalusite (lower left corner) and two almandines (lower right side). Note that the crystals are not water-worn; length of green chromium-dravite is 6 mm. Identification by XRD.

namely, the presence of brownish-green dravite, quartz, almandine intergrown with white mica, and andalusite. Garnet, green tourmaline, white mica and quartz have already been described by Hlaing (1993), but in addition he described staurolite as a mineral that can be found in the alluvial deposits. Green tourmaline was also reported to occur as an intergrowth with ruby (Hlaing 1993). Tremolite is particularly frequent in the alluvial deposits (Figure 1).

In general, neither the Mong Hsu rubies nor the minerals accompanying the Mong Hsu rubies are water-worn (Figure 8). It is therefore most likely that the minerals occurring with the rubies in the alluvial deposits originate from the primary ruby deposits or from country rocks close to them.

In order to obtain more information about their host rock types, dravite, almandine and tremolite crystals have been chemically analyzed by means of electron

Fig. 9. Fragments of greenish tremolite from the Mong Hsu ruby mine. The green is due to Cr- and V-concentrations in the tremolite (see Table I for these and F content). Transmitted light. Length of crystal is 2 mm (Crystals immersed in epoxy, polished on one side).

microprobe analyses (Table I). Mong Hsu tremolites show traces of chromium (Cr), vanadium (V) and fluorine (F), but iron (Fe) and nickel (Ni) were below detection levels. Green tremolite from Mong Hsu is chemically zoned with some areas more enriched in V and Cr than others; these elements seem to be responsible for the variable intensities of green found in the mineral (Figure 9). Increasing Cr-concentrations in the tremolites are correlated with increasing V-concentrations with a Cr/V atomic ratio of 10:1. Furthermore, considerable concentrations of fluorine were found in the Mong Hsu tremolites. Such tremolites may be typically found in

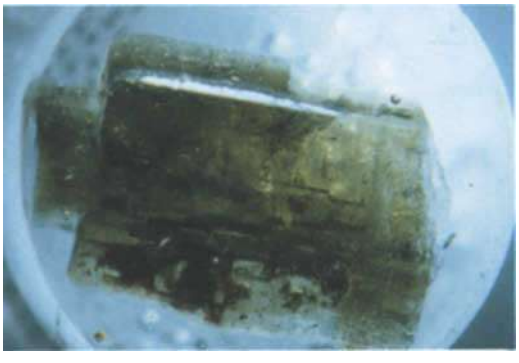

Fig. 10. Brownish-green dravite containing traces of Cr, V and F (see Table I). For the chemical profile with variations in Cr and F see Figure 11. Transmitted light. Length of crystal is 5 mm.

Table I: Chemical compositions of minerals associated with Mong Hsu rubies in comparison with those from other localities

	Tremolite (1)	*Tremolite (1)*	*Tremolite (2)*	*Almandine (1)*	*Dravite (1)*	*Dravite (1)*	*Dravite (3)*
MgO	24.05	24.32	24.83	1.09	12.65	13.26	13.67
CaO	13.55	13.43	12.61	0.50	2.82	1.89	2.41
Na_2O	0.95	1.01	0.21	0.00	1.55	1.96	1.63
K_2O	0.07	0.07	0.00	0.00	0.00	0.00	0.09
SiO_2	53.07	53.31	57.88	35.15	35.46	37.57	35.96
Al_2O_3	2.65	2.42	0.00	20.38	30.52	31.13	30.85
TiO_2	0.05	0.04	0.00	0.05	0.13	0.15	0.14
FeO	0.00	0.01	1.76	42.06	0.04	0.09	0.76
MnO	0.00	0.03	0.00	0.07	0.00	0.01	not det
Cr_2O_3	0.63	0.60	0.15	0.00	2.17	0.22	not det
V_2O_3	0.05	0.04	bd	0.00	0.00	0.06	not det
NiO	0.00	0.00	0.07	0.00	0.00	0.00	not det
Cl	0.01	0.01	bd	0.00	0.01	0.01	not det
F	3.49	3.50	bd	0.00	1.79	1.15	not det
Total	98.57	98.79	97.51	99.30	87.14	87.50	85.51
B_2O_3	not det	not det	not det	not det	not det	not det	10.73
H_2O	not det	not det	not det	not det	not det	not det	4.16

Notes
not det = not determined, bd = below detection limit
1 = Tremolite, dravite and almandine from Mong Hsu (Burma)
2 = Malenco serpentinite (amphibolite facies metamorphism)
3 = Brown dravite, dolomite marble, Deer Howie and Zussman (1986)

Analytical details for Mong Hsu minerals:

Electron microprobe laboratory, IMP, Swiss Federal Institute of Technology, Zürich, Switzerland. Electron microprobe CAMECA SX-50, 5 spectrometers (2 PET crystals for Ti, Ca, K, Cr and Mn, Cl; LIF crystal for Fe and Ni; PC1 crystal for F and TAP crystal for Si, Al, Mg and Na). Standards are natural silicates and oxides. Acceleration voltage was 10 kV and 20 kV. Measuring time for trace elements 200 sec.

metasomatic veins in dolomitic marbles such as those described by Mercolli *et al.*, (1987). Chemically different from tremolites originating from marble deposits are those from metamorphosed ultramafic rocks. Their chemical composition is characterized by traces of Ni and higher concentrations of Fe but without traces of F (Table I). The most common accessory mineral found in the lots of Mong Hsu rubies was brown to green dravite. These tourmalines contain trace amounts of Cr, V and F (Figure 10, Table I).

The chemical compositions of the associated minerals give some indication of their formation in different rock types. Almandine and white mica (as overgrowth on garnet) typically occur in a range of rocks including metapelites (metamorphosed gneisses or schists), while staurolite and andalusite occur almost exclusively in metapelites. This mineralogical assemblage is typical for regionally metamorphosed or contact metamorphosed metapelites which have undergone amphibolite facies conditions. Additionally, the formation of tremolite is consistent with this degree of metamorphism. It is also known that tremolite can be formed under these metamorphic conditions in veins within dolomites (e.g. see Mercolli *et al.*, 1987). Cr-, V- and F-bearing dravites also probably formed in the same or similar metasomatic veins. The observed intergrowth of tourmaline with Mong Hsu rubies (Hlaing and 1993 and 1995) and their typical occurrence in other ruby deposits (Hunstiger, 1990) supports this idea.

Chemical zoning in Mong Hsu tourmaline

Strong fluctuation of the chromium content occurred during the crystal growth of green dravite, ranging from 0.2 to 2.2 wt.%Cr_2O_3 (Table I). These variations are related to the colour zoning with light green indicating low Cr-concentrations

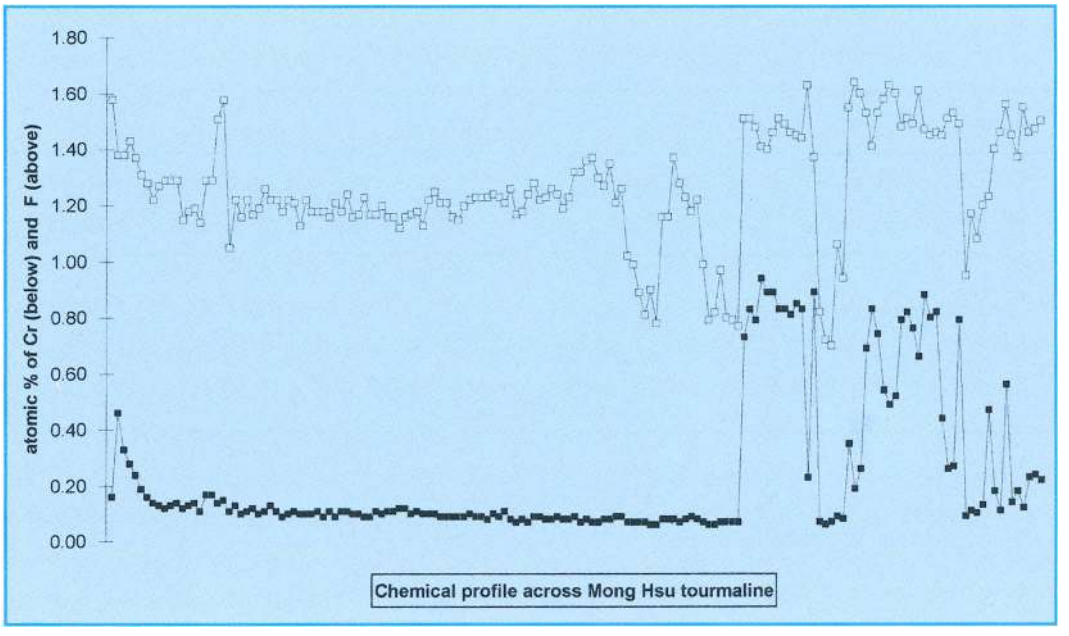

Fig. 11. Chemical profile across a green dravite originating from Mong Hsu (perpendicular to *c*-axis) showing F and Cr-concentrations. Note strong fluctuations of Cr along with F at distinct phases of growth towards the edge of the crystal. Increasing Cr-concentrations are correlated with increasing F-concentrations.

and intense green being related to relatively high Cr-concentrations. As shown in Figure 11, several abrupt changes in Cr-concentration occurred during the growth of the tourmaline crystal. Increasing Cr-concentration is correlated with increasing F-concentrations. They are also correlated with increasing V-concentrations.

Chemical zoning in Mong Hsu ruby

Figure 12 shows in an idealized way the chemical oscillations in a selected Mong Hsu ruby sample and its colour zoning as seen in the immersion microscope (Figure 4a). The concentrations of the trace elements are taken from Peretti *et al.*, (1995a). Many other samples showed a similar colour zoning, although the full sequence of growth shown in Figure 12 may not always be present. Colour zoning in Mong Hsu ruby is correlated with different growth phases of the crystal, designated as 'I' (intermediate), 'V' (violet), and 'R' (red) as defined in Peretti *et al.*, (1995a). Growth phase 'I' is characterized by relatively low to medium Cr_2O_3-concentrations, along with relatively low or absent TiO_2-concentrations; growth phase 'V' by relatively high TiO_2 and high Cr_2O_3-concentrations; growth phase 'R' by relatively high Cr_2O_3-concentrations with no presence of TiO_2. During phase 'I', pink or violet sapphire to ruby layers are formed; during growth phase 'V' violet to black sapphire layers are formed; and during phase 'R', ruby layers are formed. This successive growth is repeated at least twice during the formation of a typical Mong Hsu ruby. A dramatic habit change in the Mong Hsu ruby crystal occurs at

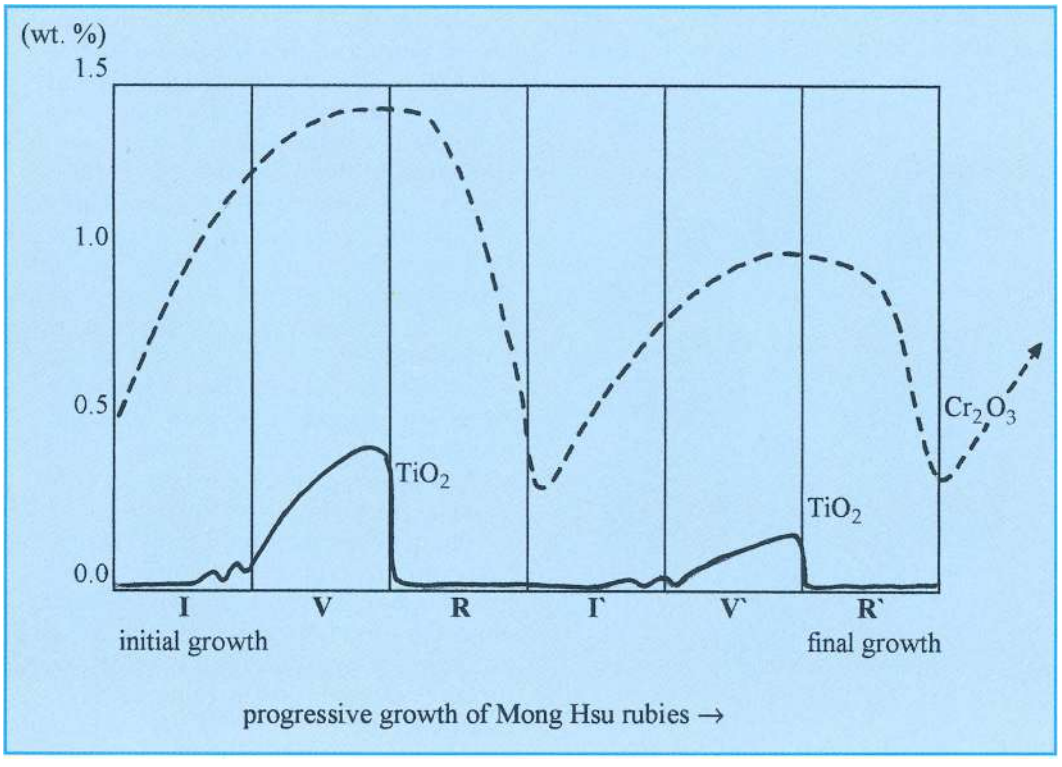

Fig. 12. Zoning patterns in Mong Hsu rubies as schematically reconstructed from colour zoning and chemical profiles; different growth stages are defined as I, V, R and are characterized by a typical trace element pattern and crystal habit (Peretti *et al.*, 1995a). I = alternation of pink sapphire and violet sapphire, V = black sapphire, R = ruby. Note the repeated oscillation of Cr and Ti during the growth history of the Mong Hsu ruby.

the transition of growth phase 'V' to 'R' and the highest vanadium concentrations are found in the 'V' zone (Peretti *et al.*, 1995a).

Solid inclusions in Mong Hsu rubies

Various minerals have been identified as inclusions in the ruby rough; these include layered silicates (white mica, fuchsite, Mg-chlorite, Figure 13), silicates (plagioclase and aluminosilicates), halides (fluorite, Figure 14a-c), oxides (rutile, Figure 15), carbonates (dolomite, see Smith and Surdez, 1994, and Peretti *et al.*, 1995a) and phosphates (apatite, see Smith and Surdez, 1994). Aluminium-hydroxide (boehmite or diaspore) has been identified as a daughter mineral in fluid inclusions and tiny dispersed diaspore inclusions occur elsewhere in the Mong Hsu rubies (Smith, 1995). Fluorite and rutile inclusions have been found in the sequence of crystal growth labelled 'R'. However, because fluorite and rutile are only found extremely rarely, it cannot yet be confirmed that they occur repeatedly in different 'R' zones in the crystals and never in the 'I' and 'V' zones. Fine dispersed diaspore occurs repeatedly in the 'R' to 'I' zones of the crystal (Figure 16 and Smith, 1995). Further study is necessary to indicate whether other hydrous silicates or even submicroscopic fluoride particles are located in these zones also. Examination of the occurrence of diaspore inclusions in the 'V' zones of Mong Hsu rubies is currently under re-examination (C.P. Smith, pers. comm.). Dolomite crystal inclusions occur in large numbers in some Mong Hsu ruby crystals and their distribution does not seem to be restricted to any particular zone.

Fig. 13. Mong Hsu rubies intergrown with fuchsite (top three crystals) and light green Mg-chlorite and white mica. Crystal length of lower left ruby is 9 mm (identified by means of XRD and SEM-EDS, see Peretti *et al.*, 1995a).

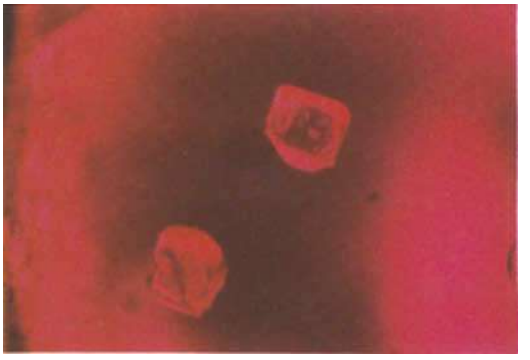

Fig. 14. (a) Fluorite inclusion, 0.2 mm across, lower left of centre occurring in a Mong Hsu ruby in transmitted and reflected light.

Fuchsite, Mg-chlorite and white mica have been detected as overgrowths on Mong Hsu rubies or as inclusions in the marginal parts of the rubies, in the outer 'R' to 'I' zones (Figures 13 and 16).

Hlaing (1994) pictured Mong Hsu rubies occurring in a matrix of dolomite, with greenish minerals occurring in the contact zone. Our investigation indicates that these minerals are hydrous silicates which were formed with the ruby in veins within dolomite (Figure 7a).

Fluid inclusion analyses

Fluid inclusions are frequently present throughout a ruby, from core to rim. The

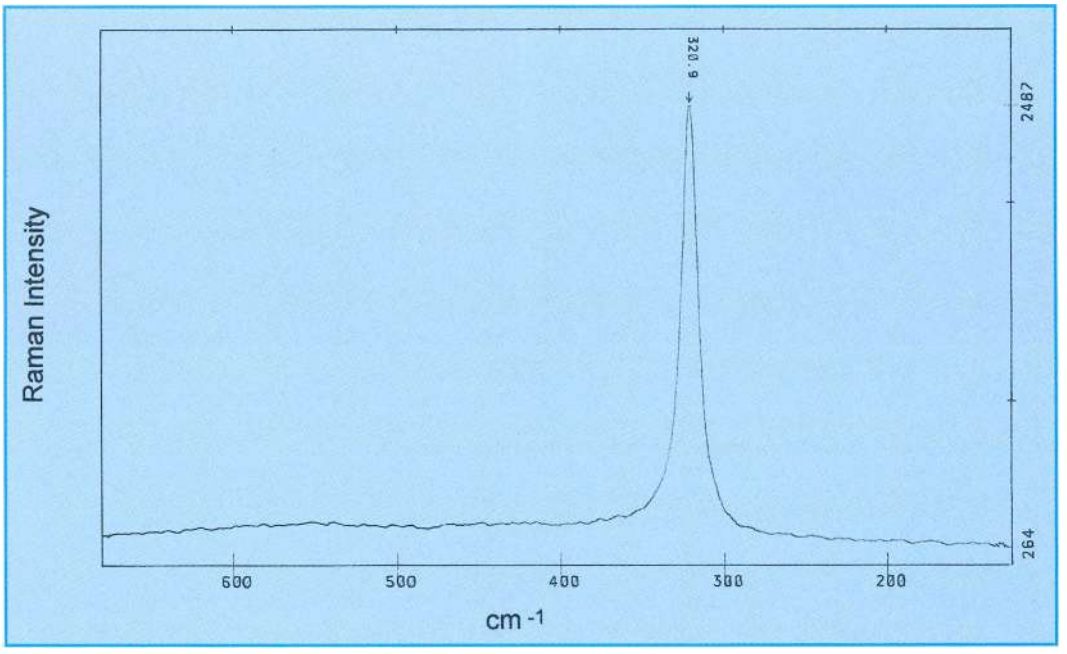

Fig. 14. (b) Raman spectrum of fluorite inclusion obtained from X–Y Dilor multichannel Raman spectrometer, Ar ion laser, 514.5nm, Type 2020 Spectra-Physics, by Dr J. Dubessy, CREGU, Nancy, France. For fluorite identification by Raman spectroscopy, see Griffith, 1987.

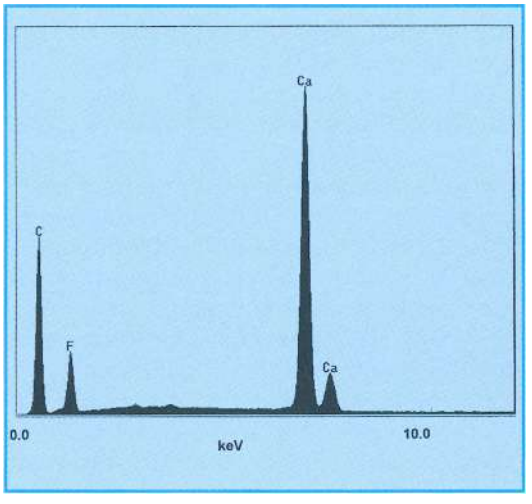

Fig. 14. (c) Analysis of fluorite by energy-dispersive technique on an electron microscope (SEM-EDX). The inclusion was exposed by recutting the ruby (C peak due to carbon coating). Analyst M. Düggelin, University of Basel, Switzerland.

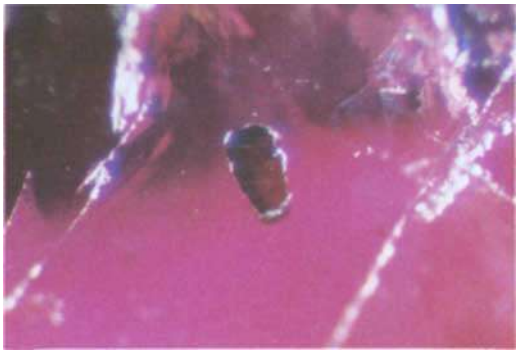

Fig. 15. Microphotograph of a rutile inclusion in a non-heat-treated Mong Hsu ruby. Note that this rutile inclusion is localized in the red portion of the ruby. Identified by Raman spectroscopy based on Capwell *et al.*, (1972). Magnification on 35 mm slide 105×.

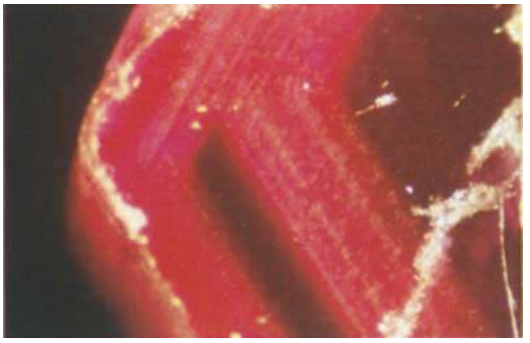

Fig. 16. Microphotograph of a non-heat-treated Mong Hsu ruby with alternating zones enriched in Ti and Cr (violet to black) and Cr (red). Note the presence of whitish reflecting inclusions in reddish zones which are most probably hydroxides such as diaspore but may possibly be hydrous silicates or fluorite. Reflected light. Fibre optic illumination. Magnification on 35 mm slide 60×.

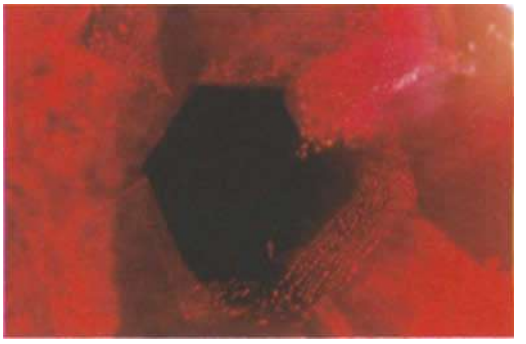

Fig. 17. Healing fissure in a rough ruby from Mong Hsu (not-heat-treated) containing fluid inclusion trails of various generations. Note 'hexagonal outline' of fluid inclusion trail around a black core in a Mong Hsu ruby. The formation of this trail is related to the early growth stage of the Mong Hsu ruby. Transmitted light, magnification on 35 mm slide 60×. *Photo by Dr E. Gübelin*

formation of fluid inclusion trails is related to cracking and subsequent healing of the ruby by fluids during its growth. Figure 17 shows an early formed fluid inclusion trail, which is located in the first 'R' growth phase of the ruby. As a result of continued growth, the secondary fluid trails are completely contained within the ruby core denoted by a hexagonal outline. This type of secondary inclusion is called pseudosecondary as the inclusions represent fluids present during a particular stage of the ruby growth. Different populations of pseudosecondary fluid inclusions have been detected; they are related to different growth stages of the rubies.

Fig. 18. Isolated fluid inclusion tubes in a secondary fluid inclusion feather of an untreated Mong Hsu ruby with a three phase inclusion (liquid, CO_2-rich multi-volatile vapour and diaspore). Microphotograph taken at approximately 25°C. Transmitted light. Size approx. 20 microns.

In the single isolated tube shown in Figure 18 there are three phases present at room temperature, including a CO_2-liquid, CO_2-rich multi-volatile vapour and one daughter mineral. The daughter mineral is most probably diaspore. This conclusion is based on the habit and intergrowth within corundum found in other samples which were identified by Raman spectroscopy. In all the fluid inclusion feathers studied, similar liquid/vapour ratios were found, showing that there had been a very homogeneous fluid population. Preliminary measurements on a freezing-heating stage were carried out, in order to obtain information about the chemical composition of the fluid inclusions. Forty-four fluid inclusions were investigated in four different pseudosecondary fluid inclusion trails of different ages. The heating runs showed that the volatile-rich fluid inclusions were homogenizing from the liquid and vapour to the liquid phase, between 24 and 31°C (temperature of homogenization = Th).

Melting of CO_2 at –61°C indicates possible contamination of CO_2 by CH_4, with one or more further components such as N_2 or

H_2S, showing that the concentration of CO_2 is greater or equal to 85 mol.% of the volatile part (Thiery *et al.*, 1994). HF may also be present as a component of the volatile part.

Because of the presence and size of Al-hydroxides as daughter minerals in the fluid inclusions, it was furthermore concluded, that minor contents of H_2O, approximately 5–10 vol.%, were also originally present in the fluids. Thus, in summary, the fluids involved in the formation of Mong Hsu rubies can be described as water-bearing multi-volatile CO_2-rich fluids.

Formation conditions

The minerals found in the alluvial deposits with the rubies, namely andalusite, almandine, white mica and staurolite can provide sensitive information concerning the metamorphic conditions in the Mong Hsu region. For the purpose of estimating these formation conditions, the stability field of almandine, andalusite and staurolite was calculated in the system FeO-Al_2O_3-SiO_2-H_2O using a computer programme of Connolly (1990). The mineral reactions that relate to the formation of almandine, staurolite and andalusite occur above 530°C. The stability field of andalusite limits the possible pressures up to approximately 4.5 kbars. Different micas + quartz are stable assemblages under these *P–T* conditions. The temperature required for tremolite to form in CO_2-rich conditions within dolomite marbles confirms the above temperature estimations (Mercolli *et al.*, 1987).

Further constraints on the formation conditions of the rubies are obtained from the fluid inclusion analyses. From the homogenization temperatures of the fluid inclusions, an isochore (Figure 19) was calculated (Bowers and Helgeson, 1983; based on Th = 24°C, assuming 5 vol.% of H_2O in a CO_2-rich fluid, whose density was 0.728 g/cm^{-3}). Other minor components present in the fluids will not considerably alter the position of the isochore. The isochore

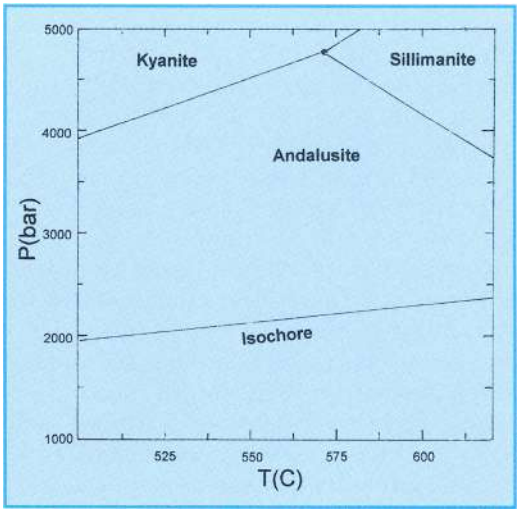

Fig. 19. *P–T*-diagram showing the stability field of andalusite, kyanite and sillimanite derived from thermodynamic data (Connolly, 1990) and the isochore determined from the fluid inclusion analyses (see text). The isochore indicates that the pressure at which the fluid inclusions formed in the rubies was 2.0 to 2.5 kbars at variable temperatures. Such conditions are within the stability field of andalusite.

defines a line in the *P* and *T* diagram (Figure 19) which indicates the possible pressures (*P*) and temperatures (*T*) under which the fluid inclusions were formed. For the estimation of the actual *P* and *T* conditions, either *P* or *T* must be determined independently. At *T* between 500 and 550°C, the likely *P* can be calculated as 2–2.5 kbars.

Titanium mobility

It has been shown by Peretti *et al.* (1995a) that the violet to black zones in the rubies are due to high concentrations of titanium (possibly Fe^{2+}–Ti^{4+} charge transfer) and chromium. Therefore, in determining how these colour zones were formed, it is essential to know how these transition metals are transported in the fluid systems during ruby formation.

Hydrothermal fluids in the Earth's crust contain a number of complex-forming ligands (or molecules) which are important for the transportation of metals in fluid.

Some of the most important are Cl^-, OH^-, HS^-, HCO_3^-, HSO_4^-, NH_3, F^-. Different metals tend to form ligands with different anions; Mn^{2+}, Fe^{2+}, V^{3+}, Cr^{3+}, Ti^{4+} for example, may preferably form ligands with F^-, Cl^- or OH^- (Crerar *et al.*, 1985; Brimhall and Crerar, 1987). Variations in temperature and pressure in fluid systems are also important factors. With increasing temperatures and pressures, transition metals will tend to form associated neutral metal- ligand-complexes rather than charged ionic species in the fluids (Seward, 1981). Variations in the formation conditions such as *P*, *T* or chemical composition of the fluids will influence the type of complexes and their concentrations in the fluids. Depending on the chemical system, the solubility of minerals in such fluids will be different and minerals may precipitate when formation conditions vary. In order to obtain detailed information on the speciation in the fluids, thermodynamic analyses are necessary (see Eugster and Baumgartner, 1987). However, because of the range of minerals occurring in the system related to the rubies, such calculations would have to be carried out in the chemical system *Si- Mg- Ca- Na- K- P- Al- Cr- Ti- V- Fe- B- C- O- H- F- N*. With so many components this is very complex and there are not yet enough thermodynamic data to do this accurately. The elements Si to P are found in the inclusions, Al to Fe are found in the ruby, and B to N occur in the fluid system.

The presence of fluorite inclusions in the 'R' growth phase of the rubies shows that F was present in the Mong Hsu solutions. From the analyses of the fluid inclusions, it was deduced that water was present in the fluids. Because there are rutile inclusions in the rubies, the concentrations of Ti in the fluids can be discussed in terms of the solubility of rutile. It is known from experiments that rutile is highly soluble in H_2O-HF fluids due to the formation of Ti-hydroxyfluoride complexes such as ($Ti(OH)_{2+X}F_{2-X}$) (Barshukova *et al.*, 1979; Ried, 1994). Variations in the solubility of rutile occur with variation in *P*, *T*, and HF-concentration in the fluids (Ayers and Watson, 1991; Passaret *et al.*, 1972; Kuznetsov and Panteleev, 1965; Barshukova *et al.*, 1979; Ried, 1994). In the *T* interval between 500 and 550°C and at *P* of 2–2.5 kbar, which are the deduced conditions for formation of the Mong Hsu rubies, the solubility of rutile in H_2O-HF-fluids increases strongly with increasing *T* and HF-concentrations in the fluid with only minor changes caused by variations in *P* (Ried, 1994). At very high *P* up to 30 kbars, the critical factors controlling the solubility of rutile are different (Ayers and Watson, 1991) but such conditions did not occur in the Mong Hsu area. Other complexes in the system C-O-H-S-Cl-F (Agapova *et al.*, 1989, Nabisvanet and Omel'chenko, 1986; Bright and Readey, 1987; Tolley and Testerm, 1989) may also be of importance but their presence cannot yet be proposed on the basis of our present analyses of the inclusions.

Discussion

The most characteristic feature of the Mong Hsu rubies is their colour zoning which is related to the trace contents of titanium along with small Fe-concentrations and chromium. The trace element concentrations in the Mong Hsu rubies change in a rhythmic pattern during growth and many ruby samples have Ti-rich zones with increasing Cr-concentrations as shown in Figure 12. The pattern of chemical zoning in the Mong Hsu rubies typically shows a strong phase of Cr-depletion ('I' zone) followed by an increase in Cr and this is followed by increasingly higher concentrations of Ti ('V' zone). At a certain stage of the ruby growth, mostly when the level of Cr is high, the Ti-concentrations in the ruby abruptly change to zero ('R' zone). The abrupt change may occur twice in one crystal and is always correlated with a sharp colour border between sapphire and ruby. The distinct

chemical change (from sapphire to ruby) is accompanied by a crystal habit change, as shown by Peretti *et al.* (1995a). In the different colour zones, some of the larger identifiable crystals were found to be fluorite and rutile and some of the submicroscopic minerals are hydrous (Smith, 1995).

The range of observations concerning inclusions and colour zones are interpreted as due to oscillations in the chemical composition of the fluids present during ruby formation. Indication for such variation in the chemical composition of the fluids was also obtained from the analysis of dravite from Mong Hsu. This mineral is characterized by strong oscillations in both chromium and fluorine. Based on the correlations of these elements in the tourmalines, it is concluded that the fluids which were relatively enriched in chromium were also relatively enriched in fluorine. The importance of fluorine in the system is further confirmed by the high concentrations found in the green tremolite associated with the Mong Hsu ruby and dravite.

Fluid inclusions in the Mong Hsu rubies are water-bearing, CO_2-rich and contain CH_4 with possibly N_2, H_2S and HF. Fluorine is known to play a vital role in the complexing of titanium, particularly at the *P* and *T* likely during formation of the Mong Hsu rubies, forming complexes such as $(Ti(OH)_{2+X}F_{2-X})$. Thermodynamic studies of the solubility of rutile, at such *P* and *T* conditions have shown that concentrations of Ti in the fluids are strongly influenced by variations in temperature and F-content. Based on experimental data, the range of concentration of Ti in the Mong Hsu fluids could be controlled by oscillations in fluorine content or by variations in temperature. However, no evidence for abrupt changes in temperature has yet been found, but indications for variations in the fluorine content are found in other minerals. So it is very possible that F is the controlling factor in the variable concentrations of Ti in the Mong Hsu rubies.

The reason for such strong variations in fluid composition in the Mong Hsu area may be related to the infiltration of fluids from metapelites into dolomites. Fluids which are equilibrated with metapelites may be rich in certain elements such as B, C, H, O, S, N, P, F, Al, Mg, Si, Ca, Na and K, as well as Cr, V and Ti, depending on the degree of metamorphism, the rock type and type of complexing agent present in the fluids. If such external fluids come into contact with dolomites, the fluid will re-equilibrate with minerals present in the dolomites and hence dramatic changes in the fluids may be expected (Korzhinsky, 1970). It is evident from the data now available from the Mong Hsu area minerals that the chemical conditions of their growth, in particular the compositions of the fluids varied and changed relatively rapidly. Repeated oscillation of Cr and Ti in the rubies as shown in Figure 12 is probably the result of the multiple influx of fluorine-bearing fluids from the metapelitic rocks into the dolomites where they reacted to the different chemical environment by precipitating at various stages hydroxides, hydrous silicates, corundum, fluorite and rutile.

It is thus proposed that *F* concentration of the metasomatising fluids migrating into the host carbonate rock was a major factor in the development of the colour zoning of the Mong Hsu rubies. According to our preliminary simplified model, relatively high F- and OH-concentrations induced complexing of Ti as well as high Ti-concentrations in the fluids. From such fluids Ti ± Fe and Cr-ions were incorporated in the corundum structure (Ti-rich Cr-rich violet to black coloured sapphire = 'V' growth phase). Decreasing F-concentrations, possibly by precipitation of fluorite, induced decreasing Ti-concentrations in the fluids (no Ti-ion incorporation in the corundum structure, medium to high Cr-bearing red ruby = 'R' growth phase). A modification of this model may be presented when more detailed data on the primary deposits become available and

thermodynamic modelling of complex systems becomes more advanced in the future.

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Notes from the Gem and Pearl Testing Laboratory, Bahrain – 5

Ahmed Bubshait and Nick Sturman

Abstract
Items of interest seen within the jewellery trade in Bahrain are discussed. An amber box and composite amber and plastic worry beads are described, and the problem of fissure filling is discussed, with a note about a fracture-filled emerald.

Amber box

Figures 1 and 2 show an amber box submitted for testing by a local customer. The box was being offered for sale as amber by a 'Russian' client.

On preliminary examination the majority of pieces used to construct the box appeared to be amber and this was duly confirmed by basic gemmological testing. However, the interesting point about this piece was that the orange-brown inlaid rectangular area and the scrolled area of the same colour on the lid of the box, proved to be fashioned from pressed amber. Proof that these two areas were not natural amber was obtained by using polarized light to inspect the internal structure under the microscope. Between cross polars a typical pattern of interference colours (Bubshait and Sturman, 1993) was seen and swirly smoke-like inclusions con-

Fig. 1. Side view of the amber box.

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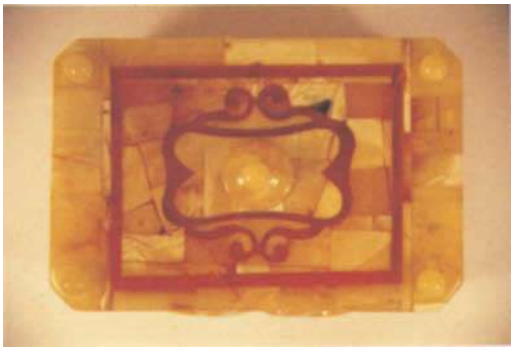

Fig. 2. View of the lid with darker orange-brown rectangular and central scrolled pressed amber areas showing.

sisting of minute brown to black impurities were seen in places; the latter structure is typical of some types of pressed amber. Although identification was fairly straightforward, it was made harder because the maker of the box had mixed a reddish-brown dye with the adhesive to fix the pressed amber pieces in position. This layer prevented most of the light from passing through the pressed amber freely and it was only in the patches where there were bubbles in the adhesive that we could observe the interference pattern between crossed polars and look at the inclusions with greater clarity. These bubble areas, being free of the reddish-brown dye, showed the true paler yellow colour of the pressed amber used and allowed the light to pass through with little obstruction.

Plastic and amber worry beads

Worry or prayer beads are widely used in the Middle East. Traditionally they were used in mosques and were made up of either 99, 66 or 33 beads, strung with two spacers and a long cylindrical terminating 'bead'. The number of beads corresponded to the number of times short Arabic phrases had to be recited after prayer. The Catholic faith's rosary beads are used in a similar fashion.

Today most strings of worry or prayer beads consist of 33 beads and are mainly used as fashion accessories. The bead in Figure 3 was one of 33 in a row of worry beads that we were asked to examine recently. The beads were being offered as amber and our customer decided to have them checked. Although not a member of the trade, he was aware that some materials sold as amber are not genuine and they looked suspicious to him. The identity of the beads was partly correct when described as amber but, as can be seen from the photograph, the beads used in this particular set of worry beads look 'wrong' on first impression and indeed they are. Each bead is actually made up of amber pieces, embedded within a plastic bead frame and clearly shows a central line (typical of some pieces of moulded plastic and glass) where the two adjacent pieces of plastic meet.

We have encountered worry beads such as these before, but it is the first time we have had the opportunity to photograph a set.

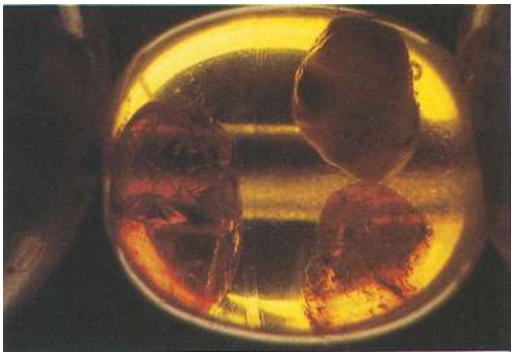

Fig. 3. One of the plastic beads with included amber pieces.

A resin-filled natural emerald

An ongoing concern in the international jewellery trade today is the fracture filling of various stones (Levy, 1995). Diamonds, corundum (mainly ruby) and emerald are the main stones to be treated in this way. However, some in the jewellery trade would appear to consider emerald separately and argue that oil (generally accepted by all) or resin (not so widely

accepted) should both be considered as accepted practices. On the other hand, some say any filling should be disclosed. The trade generally agrees that filled fractures and cavities in stones other than emerald should be disclosed. It is good to see that this problem is being addressed at various international meetings and whatever the reader's personal opinion, this will continue to be a matter for discussion (*Gem and Jewellery News*, 1993–94) until a firm stance is taken. Valid points have been made for and against disclosing oiled and resin-filled fractures in emeralds. Customers have the right to know and decide for themselves. In practice, many think that when they purchase a stone they are being told everything relevant to them at the time (*Gem and Jewellery News*, 1993). Should all filled stones, no matter what the filler is, be openly disclosed to customers so that they can decide for themselves? If you were the customer, would you like to be told the 'whole truth and nothing but the truth' wherever possible? In the laboratory, it is not yet possible to *prove* the identity of a specific filler, such as Opticon resin No. 224 (even with infrared spectrometers and other sophisticated equipment available to some of us) without destructive testing but it is possible to indicate in general terms whether oil or resin is present.

Recently a number of resin-filled natural emeralds have been examined in the laboratory and, although most of the stones appear to be of Colombian origin and show weak to distinct signs of resin filling, one stone described here is possibly of 'Russian origin' (customer's opinion) and contained quite distinct evidence of filling. The colour flashes within the fractures were very pronounced (even vivid at some angles) and the filler was easily visible throughout the fractures.

We believe that this particular stone was filled by a resin other than Opticon 224, possibly Araldite No. NU471, Dobeckot No. 505 or Novogen No. P40 (Nassau, 1994), first because the colours were extremely strong, comprising orange (Figure 4) which was the most distinct, blue (Figure 5) and yellow and purple (depending on the angle); and secondly due to its unusual reaction when examined under both long- and short-wave ultraviolet light. A fracture running parallel to the table fluoresced a moderate yellow/white and exhibited a fairly persistent yellowish phosphorescence when exposed to SWUV light, whilst another fracture produced a strong yellow/white fluorescence and a very short-lived phosphorescence under LWUV. This is the first time resin fillers exhibiting these fluorescent characteristics have been observed in this laboratory. Because no 'sweating' was observed from any of the surface-reaching fractures in the

Fig. 4. The distinct orange colour seen in the fractures of a resin-treated emerald.

Fig. 5. The blue colour seen in the fractures of the same emerald as Fig. 4.

stone, the filler in this stone was probably sealed in with a hardener. A Colombian stone examined earlier showed the more characteristic resin-filled features and also showed pronounced 'sweating' from some of its surface-reaching fractures, so therefore this stone probably had no hardener applied to it. As part of its disclosure policy, the Bahrain laboratory adds a final explanatory paragraph on emerald reports, to inform customers about the filling of fractures in emeralds with various substances. However, because precise identification of the fillers is not yet feasible, we also give the customer a verbal opinion (when all agree) as to whether the filling is a natural oil/resin or an artificial epoxy type resin. The two customers who owned the stones mentioned above chose to act on both the laboratory report and verbal opinion. One chose not to purchase the stone (he would have done so if it were oiled and not filled with artificial resin) and the other customer purchased the resin-filled stone to see whether he could sell it as a treated emerald in the market. In both cases the customer had all the relevant laboratory information available and the decisions were made accordingly.

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The gems of Mont Saint-Hilaire, Quebec, Canada

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Abstract
The quarries at Mont Saint-Hilaire, Rouville County, Quebec, have been visited by mineral collectors for over 30 years. The total number of minerals found there stands at over 300, with 27 new species described from the locality. Gems have been cut from at least 28 mineral species. Since many of the minerals are rare and difficult to identify even as crystals, there are significant problems in identifying the gems. There has also been confusion about which gems come from Mont Saint-Hilaire, and this has been exacerbated by an increasing demand and thus increasing prices put on these rare gems. Two tables list and describe all gems documented from Mont Saint-Hilaire as of April 1995.

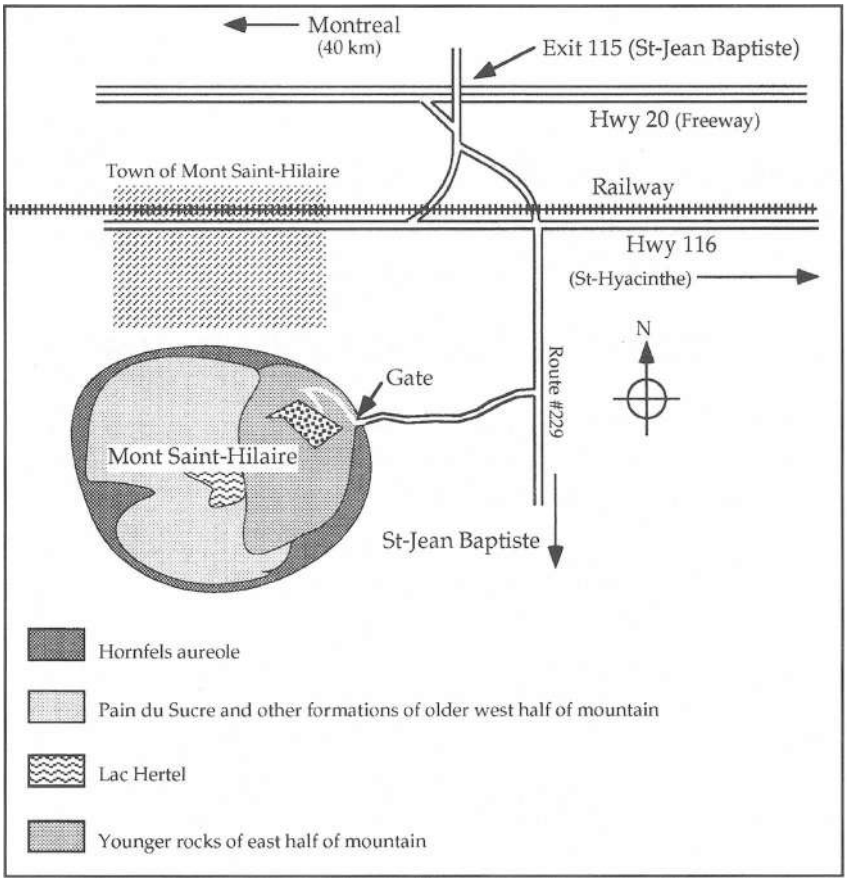

Fig. 1. Locality map of Mont Saint-Hilaire quarries. *Computer graphic by Q. Wight.*

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Fig. 2. Mont Saint-Hilaire from the north on highway 20, 28 May 1995. *Photo: Q. Wight.*

Fig. 3. Quarries on north-east side of Mont Saint-Hilaire from highway 229, 6 August 1994. *Photo: Q. Wight.*

Introduction

The quarries of Mont Saint-Hilaire, Quebec, have been a Mecca for mineral collectors, especially micromounters, for over thirty years. The number of minerals found at the locality now stands at over 300, with minerals new to science being described regularly. Mont Saint-Hilaire is the type locality for 27 mineral species, and there are still unknown species to be identified and described.

This large number of minerals, many of which are rare or unique, is even more remarkable considering the small size of the locality. The quarried area of Mont Saint-Hilaire is relatively small, a mere 30 or so hectares (<0.5 km^2). In contrast, the 340 minerals at the classic mineral locality of Franklin/Sterling Hill, New Jersey, came from mines spanning an area of at least 7 km^2.

Mont Saint-Hilaire lies about 40 km east of Montreal in Rouville County; it is one of the ten Monteregian Hills (see locality map, Figure 1). About 350 m in height and about 3km in diameter, the roughly circular pluton rises abruptly above the surrounding flat, St Lawrence lowlands (Figure 2). The nearby village on the bank of the Richelieu River is also called Mont Saint-Hilaire. At one time there were three adjoining quarries on the north-east face of the mountain – the Poudrette on the east and the Demix, formerly known as the Desourdy and Uni-Mix quarries, on the west – operating to provide crushed rock for construction and road work. Steady expansion over the years has resulted in one large pit, operated today by R. Poudrette Inc. (Figures 3 and 4).

Access for collecting in the quarry is strictly controlled, with regularly scheduled field trips being organized by the Club de Minéralogie de Montréal (usually five trips each summer).

Several comprehensive articles on Mont

Fig. 4. Looking into the south corner, 6 August 1994. Field trips are arranged for mineral collectors five times each year. Only about one-quarter of the quarry is visible here. *Photo: W. Wight.*

Saint-Hilaire and its minerals have been published, notably Horvath and Gault (1990), and Wight and Chao (1986, 1995). The book *Monteregian Treasures* was produced in 1989 by Mandarino and Anderson. References cited in these works will not usually be repeated here.

Geology

Mont Saint-Hilaire is a small, alkaline complex that intruded the Palaeozoic rocks of the St Lawrence Lowlands during the Cretaceous period; there were probably three intrusions, between 134 and 120 million years ago. Some indication of the geology is shown in Figure 1. The quarries are on the eastern side of the mountain, where the dominant rocks are nepheline syenite and sodalite syenite.

The complex contains some rare agpaitic rocks, those in which the alkali content is very high relative to aluminium. It is thought that the development of so many rare minerals at Mont Saint-Hilaire is related to the high alkalinity that allowed the liquid magma to incorporate more of the zirconium, titanium and rare earth elements that have been found in so many of the species. Furthermore, the material that makes up such rocks may have originated at great depth (perhaps 70 km) in the crust of the Earth, where the ratios of the elements to each other are not necessarily the same as those found in the relatively lighter rocks of the continental material above. The abundance of sodalite has been attributed to the reaction of the rising East Hill suite magmas with chlorine-bearing brines. Further geological information can be obtained from Horvath and Gault (1990), Wight and Chao (1995) or references in those comprehensive articles.

The minerals for which Mont Saint-Hilaire is famous occur in a large number of geological environments. Collectors refer to several readily recognizable host rocks, such as unaltered pegmatites, altered pegmatites, miarolitic cavities in nepheline syenite, marble xenoliths, sodalite xenoliths, igneous breccias, hornfels breccias and so on, in the three main rock types in the quarry – nepheline syenite, sodalite syenite and hornfels. Different environments, of course, foster the growth of different minerals.

History

When mineral collectors first began to visit the quarries in the early 1960s, Frank Melanson found an unusual orange-pink crystal about 5 cm long. Since he could not identify it, he took it to Dr Guy Perrault of the Ecole Polytechnique in Montreal. Perrault identified it as serandite, a rare sodium manganese silicate, previously found only as cleavage fragments from the island of Rouma, Los Archipelago, Guinea, off the west coast of Africa. Since then serandite has been found in other localities, but the crystals from Mont Saint-Hilaire are the best in the world (Figures 5 and 6). They have been found in sufficient quantities for almost every mineral museum in the world to have one. Three major finds in 1972, 1981 and 1988 are chronicled in detail in Horvath and Gault (1990).

The unusual and very attractive orange-pink colour of serandite led to the preparation of a cabochon by Sam Ronson of Montreal about 1964. Melanson kindly loaned this, the first polished serandite, for a photograph (Figure 7).

The first gems from Mont Saint-Hilaire

Over the years 'Canada's Magic Mountain' has become of great interest also to collectors of rare gemstones. This is partly because of the promotion of Canadian gemstones by the Canadian Museum of Nature (CMN). In 1975–76, the then National Museum of Natural Sciences mounted a temporary exhibit called 'Gemstones', consisting of 18 cases of minerals and gems, which was shown in Ottawa and then in Toronto at the Royal Ontario Museum (ROM). One case featured Canadian gemstones and included

Fig. 5. Superb large serandite crystal (CMN#37124; 22 x 10 cm) with the typical intense orange-pink colour, found in 1972. *Photo: CMN, G. Robinson.*

Fig. 6. Particularly lustrous pink serandite crystals were found in 1988 (CMN#54046; 6.0 x 3.5 cm). *Photo: CMN, G. Robinson.*

Fig. 7. The first polished serandite cabochon, 22.3 x 8.2 x 3.5 mm, loaned by F. Melanson. *Photo: Q. Wight.*

the four minerals from Mont Saint-Hilaire that had been faceted at that time: serandite, sphalerite, willemite and natrolite (Figure 8).

The serandite gem, on loan from the ROM, was the first faceted serandite. The 3.14 ct salmon-coloured, translucent, step-cut stone was faceted by G. Grant Waite of Toronto in 1974 from rough purchased by the ROM from Bernard Beaudin in 1973.

The natrolite and willemite in the exhibit were faceted from transparent pieces in the collection of the CMN by an amateur faceter, E.G. Letourneau of Ottawa. The 8.70 ct natrolite gem, largest of three that he produced in 1976, has still not been surpassed in beauty, although there are now slightly larger natrolite gems in the National Gem Collection. The blue willemite at 6.75 ct is the largest known; it is unlikely that any more will be found. Willemite of this blue colour is not found elsewhere (see Figures 9 and 10).

The sphalerite, a light green brilliant weighing 1.61 ct, was the gift of Wilfrid Jonasch of Montreal, who collected and faceted it himself.

The search for serandite

Serandite provided the same impetus for gem collectors as for mineral collectors.

Fig. 8. The first gems from Mont Saint-Hilaire exhibited by the CMN in 1976. Back, left to right, serandite (ROM; 3.14 ct), sphalerite (CMN#20045; 1.61 ct), willemite (CMN#20353; 6.75 ct) and in front, natrolite (CMN#20238; 8.70 ct). *Photo: CMN, G. Runnells.*

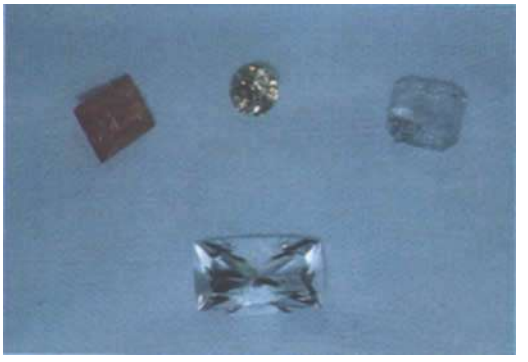

Fig. 9. Natrolite (CMN#20238; 8.70 ct) faceted from Museum rough in 1976 by E.G. Letourneau in a modified gavotte cut that brings out the best from this usually undistinguished looking material. *Photo: CMN, W. Wight.*

Fig. 10. Blue willemite (CMN#20353; 6.75 ct) was found only rarely in the 1970s at Mont Saint-Hilaire. This is the first and still largest gem, faceted in 1976 by E.G. Letourneau. *Photo: CMN, W. Wight.*

After the exhibition of the four gems in 1976, interest gradually grew with almost every collector looking for transparent pieces of the very attractive, orange-pink serandite. Some pieces tend to be more pink; others more orange. The CMN purchased its first serandite gem in 1981, a transparent orange beauty of 0.95 ct (Figure 11). Other stones were later faceted and cabochon-cut from Museum-collected rough by Art Grant. The National Gem Collection now has five gems, four being transparent, and one an exceptional orange translucent, pear-shaped cabochon of 19.65 ct (Figure 12).

A faceted serandite of 14.62 ct is known to exist in a private collection. Recent references to the species include Henn *et al.*, (1991) and Koivula *et al.*, (1992a and b).

Fig. 11. Faceted serandite acquired by the CMN in 1981, the first of several (CMN#20852; 0.95 ct). *Photo: CMN, W. Wight.*

Fig. 12. A large cabochon (CMN#22137; 18.65 ct) showing the pinkish orange colour typical of the best serandite, cut from rough already in the CMN by A. Grant in 1981. *Photo: CMN, W. Wight.*

Historical development

One of the important aspects of the production of gems from Mont Saint-Hilaire has been the role of the amateur faceter. The first gems were all cut by 'amateurs', who took the time to study these minerals, and found the proper angles and designs that would bring out their beauty. Skill and patience in the actual faceting are also very important, since many of these gemstones are soft, have cleavages and are difficult to polish. Special techniques were developed to facet water-soluble minerals such as villiaumite.

The great success in 1976 of Ernie Letourneau in providing attractive gems from the natrolite and willemite rough in the Museum's collection led to consideration of other possible gems from Mont Saint-Hilaire. The light blue colour of the willemite was attractive (and very unusual for willemite), but the natrolite gem, a modified gavotte cut, was truly surprising. It is remarkable that Letourneau was able to produce a beautiful gem (Figure 9) with a very bright appearance from natrolite, a colourless mineral with a very low refractive index, cleavages and a hardness of only 5. Attention to the proper angles and proportions are essential when working with such materials. Most natrolite gems appear dull and uninteresting.

Wilfrid Jonasch of Montreal faceted the first sphalerite gem on his own. He then produced four siderite gems in 1984 from Museum rough (Figure 13), the largest two weighing 2.25 and 2.60 ct.

Arthur Grant of Martville, NY, was at that time an amateur faceter very interested in soft and unusual gem materials (Wight and Wight, 1989). Over the years, his skills added villiaumite (1981) (Figures 14 and 15), rhodochrosite (1982) (Figures 16 and 17), catapleiite (1983), fluorite (1983), analcime (1987), microcline (1987) and narsarsukite (1987) to the National Gem Collection. Villiaumite (sodium fluoride) was a special challenge; it is water

soluble and required the development of special faceting techniques.

Gradually gem collectors interested in oddities learned about Mont Saint-Hilaire, and the demand for the faceted gems increased as had the demand for its rare and unusual minerals. Gems from Mont Saint-Hilaire now have a profitable, if limited, market. Table I gives details of the 28 minerals which we know to have been cut and polished as of April 1995. Table II gives a description of the gemstones with their properties and references that may be helpful in identification.

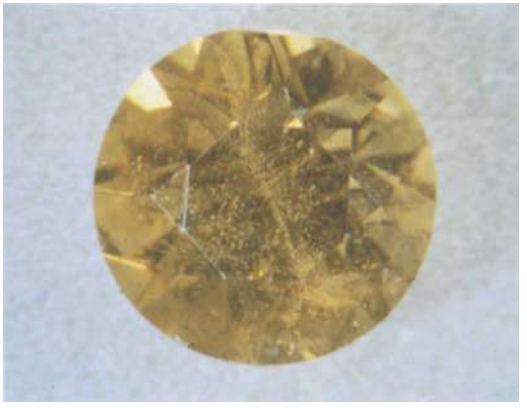

Fig. 13. Siderite (CMN#22201; 2.60 ct) faceted from rough already in the CMN in 1984 by W. Jonasch. *Photo: CMN, W. Wight.*

Fig. 15. Villiaumite (CMN#21544; 0.92 ct) faceted by B. Wilson in 1993. The first villiaumite was faceted from rough already in the CMN in 1981 by A. Grant (CMN#22134; 0.27 ct). *Photo: CMN, W. Wight.*

Fig. 14. Typical red cubes of villiaumite in white sodalite/analcime *Specimen and photomicrograph, Q. Wight.*

Table I: Some documented gems from Mont Saint-Hilaire

Mineral	*Gem sizes*	*Dates first cut*[1]	*Remarks*[1]
Albite	1 ct light pink	1987 (GH rough 1985)	only stone known Apr 1995
Analcime	0.82 ct 1 to 4.98 ct	1987 (CMN rough)	AG (list 95: 10 stones) BW 1994: 4.98 ct
Apophyllite	1.13 ct	1994	only stone known Apr 1995
Cancrinite	mauve cab 3.43 ct	1994 (CMN rough)	only stone known Apr 1995
Carletonite	0.04 to 1.48 ct	1988 (GH rough)	AG (list 95: 6 stones)
Catapleiite	0.45 to 2.48 ct	1983 (CMN rough 1972)	AG (list 95: 27 stones); BW 91
Cryolite	0.20 to 2.25 ct	1991	AG (list 95: 11 stones)
Eudialyte	0.19 ct	1991 (GH rough)	only stone known Apr 1995
Fluorite	G 0.38 ct; V 1.06, 1.23 ct; C 2.94 ct; lt B 3.47, 14.6 ct; lt G 26.90 ct	1983 green (CMN rough acquired 1972)	AG (list 95: 6 stones) BW 1992
Kogarkoite	0.34 ct	1993 (GH rough 1992)	only stone known Apr 1995
Leifite	0.72 to 2.82 ct	1992 (GH rough found 1989)	AG (list 95: 7 stones) BW (2 stones) only stones known Apr 1995
Leucophanite	lt G 1.49 ct; Y 0.30, 0.47 ct	1987 (GH rough found 1987)	AG (list 95: 3 stones) only stones known Apr 1995
Manganotychite	lt Y 0.16 to 0.32 ct; lt O 0.47 ct	1993 (GH rough found Sept 1992)	AG (list 95: 5 stones) only stones known Apr 1995
Microcline	0.56 ct; lt grey cab 16.26 ct	1987 (CMN rough collected 1984)	AG; BW cab only stones known Apr 1995
Narsarsukite	0.14 to 0.32 ct	1987 (CMN rough collected 1984)	AG (list 95: 3 stones) only stones known Apr 1995

Table I continued

Natrolite	8.70, 3.60, 3.05, 9.65; up to 10.60 ct	1976 (CMN rough collected 1973)	EL 1976 (3 stones) AG (list 95: 8 stones); BW
Pectolite	0.85 ct	1992 (GH rough)	only stone known Apr 1995
Quartz	0.22 ct	1994	AG (list 95: 1 stone)
Remondite-(Ce)	1.72 to 6.62 ct; 7.27 ct	1992 (GH rough 1991)	AG (list 95: 30 stones) BW 95
Rhodochrosite	0.21 to 1.16 ct; 3.91 to 5.66 ct	1982 (CMN rough 1972)	AG BW 95 (4 stones)
Serandite	0.95 to 2.80; cabs 6.40 to 18.65; others up to 14.62 ct	1964 cabochon 1974 Waite/ROM; 1981 (CMN rough)	AG (list 95: 37 stones)
Shortite	0.35 to 3.52 ct	1991 (CMN rough 1991)	AG (list 95: 16 stones)
Siderite	0.70, 0.95, 2.25, 2.60 ct	1984 (CMN rough 1972)	only stones known Apr 1995
Sodalite	cab; 0.12 ct transparent B	1978 cab 1994	BW 1994
Sodalite var. Hackmanite	3.32, 9.77 ct; up to 15.33 ct	1988 (GH rough found 1988)	AG (list 95: ~90 stones)
Sphalerite	G 1.61 to 24.74 ct; dk R 6.03 ct; dk G 42.16, 55.62 ct; Y 25.45 ct	1976 (WJ) 1984 (from CMN rough collected 1983)	AG (list 95: 31 stones) MG 1991 (red) BW 1994 (B-G) and others
Ussingite	0.11, 0.53 ct	1995 (GH rough)	AG (list 95: 2 stones) BW 1995 (3 small) only stones known Apr 1995
Villiaumite	0.27 to 35.0 ct 5.01 tricolour (1988)	1981 (CMN rough acquired 1972)	AG (list 95: 19 stones)
Willemite	0.30, 1.02, 6.75 ct	1976 (CMN rough collected 1971–72)	EL (6.75 ct, 1976) AG (list 95: 2 stones 1987) only stones known Apr 95

[1]Faceters; AG = Arthur T. Grant; BW = Bradley S. Wilson; EL = Ernest G. Letourneau; MG = Michael Gray; WJ = Wilfrid Jonasch

Collections: CMN = Canadian Museum of Nature; GH = Gilles Haineault

Abbreviations used for colour description: V = violet; B = blue; G = green; Y = yellow; O = orange; R = red; C = colourless; W = white; lt = light; dk = dark

Table II: Description and properties of gemstones from Mont Saint-Hilaire

Mineral	*Description*[1]	*Optical Properties*[2]	*Physical Properties*[2]	*Composition and Crystal System; Absorption Spectrum 0*	*Ref.*[3]
Albite	light pink (colourless)	B(+) $\alpha = 1.528$ $\beta = 1.532$ $\gamma = 1.539$	H: 6 to 6.5 SG: 2.59 Cleavage: perfect Fluoresces cherry R in SWUV	$NaAlSi_3O_8$ Triclinic	(1) (2)
Analcime	colourless Lustre: vitreous but less so than garnet	I n = 1.487 mean (meas.) (range 1.486 to 1.489) (may appear anisotropic)	H: 5 to 5.5 SG: 2.23 (meas.) May fluoresce G LW & SW UV	$Na(AlSi_2)O_6.H_2O$ Cubic	(1) (2)
Apophyllite (probably fluorapophyllite)	colourless (light grey, light green, light yellow, light pink) Lustre: vitreous, pearly on cleavage	U(+) $\omega = 1.530–1.536$ $\varepsilon = 1.532–1.538$ DR 0.001–0.002; may appear isotropic	H: 4.5 to 5 SG: 2.4 Cleavage: perfect May fluoresce Y LW, bright G SWUV	$KCa_4Si_8O_{20}(F,OH)8H_2O$ Tetragonal	(1) (2)
Cancrinite	light, greyish purple (yellow to orange, violet)	U(-) $\omega = 1.512$ $\varepsilon = 1.489$ (meas.) Opaque to transparent	H: 5 to 6 SG: 2.45 (meas.) Cleavage: perfect	$Na_6Ca_2Al_6Si_6O_{24}(CO_3)_2$ Hexagonal	(1) (2)
Carletonite	intense blue (blue, pink, white, grey, colourless; colour zoning common) Lustre: vitreous to pearly, slightly waxy on long exposure to air	U(-) $\omega = 1.521$ $\varepsilon = 1.517$ (meas.) Pleochroism: weak, blue/pinkish brown (in blue material)	H: 4 to 4.5 SG: 2.45 (meas.) Cleavage: perfect	$KNa_4Ca_4Si_8O_{18}(CO_3)_4(OH,F).H_2O$ Tetragonal	(1) (2) (3) (4)
Catapleiite	colourless, greyish (light brown)	B(+) $\alpha = 1.588$ $\beta = 1.591$ $\gamma = 1.624$ (meas.) DR 0.036 gems 1.593 - 1.629	H: 5.5 SG: 2.77 to 2.81 (meas.) Cleavage: perfect May fluoresce G LW & SW UV	$Na_2ZrSi_3O_9.2H_2O$ Monoclinic (pseudohexagonal)	(1) (2) (5) (6)

Cryolite	nearly colourless	B(+) $\alpha = 1.338$ $\beta = 1.338$ $\gamma = 1.339$ DR 0.001	H: 2.5 SG: 2.97	Na_3AlF_6 Monoclinic	(1) (2)
Datolite	gems not confirmed; (pale yellow, white)	B(-) $\alpha = 1.625$ $\beta = 1.653$ $\gamma = 1.670$	H: 5 to 5.5 SG: 3.00	$CaBSiO_4(OH)$ Monoclinic	(1) (2)
Eudialyte	brownish red (brown, red, orange)	U(+) $\omega = 1.598$ - 1.628 $\varepsilon = 1.605$ - 1.625 (meas.)	H: 5.5 SG: 2.88 to 3.07(meas.) Cleavage: indistinct	$Na_{16}(Ca)_6Fe_3Zr_3(Si_3O_9)_2(Si_9O_{27})_2(OH,Cl)_4$ Trigonal Abs. sp.: lines at 523, 527, 595nm	(1) (2) (7) (23)
Fluorite	colourless, violet, green, blue (pink, tan)	I n = 1.435(1) meas.	H: 4 SG: 3.08 meas. Cleavage: perfect octahedral. May fluoresce. V-B LW, weak B SWUV	CaF_2 Cubic	(1) (2) (5)
Genthelvite	gems not confirmed (colourless, light yellow, greenish yellow, orange-tan) Lustre: vitreous; greasy on broken surface	I n = 1.741 to 1.745 (meas.) Translucent	H: 6 SG: 3.63 to 3.66 (meas.) Cleavage: none Fluoresces bright G LW & SW UV; phosphoresces YG	$Zn_4Be_3(SiO_4)_3S$ Cubic	(1) (2)
Kogarkoite	light blue (pale blue, white) Lustre: vitreous to waxy after exposure to air	B(+) $\alpha = 1.439$ $\beta = 1.439$ $\gamma = 1.442$ DR (0.003) Translucent	H: 3.5 SG: 2.679 Slightly water soluble Fluoresces W LW, pale B SWUV	$Na_3(SO_4)F$ Monoclinic	(1) (24)
Leifite	light violet, (white to colourless, light yellow) Lustre: vitreous to silky	U(+) $\omega = 1.515$ $\varepsilon = 1.519$ (meas.) Translucent to transparent	H: 6 SG: 2.57 (meas.) Cleavage: distinct May fluoresce G SWUV	$Na_6K_1[Si_{12}(Si_3Al_3)(BeF)_2O_{39}]$ Trigonal	(1) (2) (8) (25)

Table II continued

Leucophanite	light yellow to light green (yellow, green and white)	B(-) α = 1.565 β = 1.590 γ = 1.593 (meas.)	H: 4 SG: 2.97 to 3.06 (meas.) Cleavage: perfect Some fluoresces pink or blue in LW & SW UV	$(Na,Ca)_2BeSi_2(O,OH,F)_7$ Orthorhombic	(1) (2)
Manganotychite	light rose	I n = 1.552 (meas.)	H: 4 SG: 2.83 (meas.) Water soluble	$Na_6(Mn,Fe)_2(CO_3)_4SO_4$ Cubic Abs. sp.: sharp band at 414 nm	(8) (9)
Microcline	colourless to greyish (white, grey)	B(-) α = 1.514 - 1.529 β = 1.518 - 1.533 γ = 1.521 - 1.539	H: 6 to 6.5 SG: 2.56 Cleavage: perfect	$KAlSi_3O_8$ Triclinic	(1) (2)
Narsarsukite	olive green (pale to bright yellow, green, grey, tan, brown)	U(+) ω = 1.610 - 1.614 ε = 1.644 - 1.647 (meas.) DR 0.033	H: 6 to 7 SG: 2.72 - 2.83 (meas.) Cleavage: perfect	$Na_2(Ti,Fe)Si_4(O,F)_{11}$ Tetragonal	(1) (2)
Natrolite	colourless, (light pink, yellowish brown)	B(+) α = 1.479 β = 1.485 γ = 1.491 (meas.) gems 1.478 - 1.490	H: 5 SG: 2.25 (meas.) Cleavage: perfect May fluoresce white LW & SW UV	$Na_2Al_2Si_3O_{10}.2H_2O$ Orthorhombic	(1) (2) (5) (10)
Pectolite	colourless	B(+) α = 1.592 - 1.610 β = 1.603 - 1.615 γ = 1.630 - 1.645	H: 4.5 to 5 SG: 2.91 (meas.) Cleavage: perfect May fluoresce pink, O-pink LW & weak pink SWUV	$NaCa_2Si_3O_8(OH)$ isomorphous series with serandite Triclinic	(1) (2)
Quartz	colourless to smoky	U(+) ω = 1.544 ε = 1.553	H: 7 SG: 2.65 May fluoresce Y-O LW & SW UV	SiO_2 Trigonal	(1) (2)

Remondite-(Ce)	orange (colour-change); greenish yellow in fluorescent light to yellowish orange in incandescent light	B(+) $\alpha = 1.632$ $\beta = 1.633$ $\gamma = 1.638$ (meas.) DR 0.006 gem 1.630 - 1.632 (0.002)	H: 3 to 3.5 SG: 3.43 (meas.), gem 3.53 (meas.) May fluoresce weak pink LW & SW UV	$Na_3(Ca,Ce,La,Na,Sr)_3(CO_3)_5$ Monoclinic UV/Visible transmission sp: sharp lines at 444, 488, 510, 522, 578 nm; others at 636, 678, 740, 800, 874 nm	(11) (12)
Rhodochrosite	pinkish red, orangish red	U(-) $\omega = 1.810$ $\varepsilon = 1.598$	H: 3.5 to 4 SG: 3.51 to 3.67 meas. Cleavage: perfect rhombohedral	$MnCO_3$ Trigonal	(1) (2) (5) (13)
Serandite	orange, pinkish orange, pink	B(+) $\alpha = 1.668$ $\beta = 1.671$ $\gamma = 1.703$ (meas.) DR 0.035 gems 1.674 - 1.708 Pleochroism: moderate pink/O	H: 5 to 5.5 SG: 3.34 (meas.) Cleavage: perfect	$Na(Mn,Ca)_2Si_3O_8(OH)$; isomorphous series with pectolite Triclinic Abs. sp.: absorbed up to ~420 nm, strong band centred at ~520 nm	(1) (2) (5) (8) (14)
Shortite	intense yellow, greenish yellow	B(-) $\alpha = 1.531$ $\beta = 1.555$ $\gamma = 1.570$ DR 0.039 Pleochroism: moderate Y/G/grey	H: 3 SG: 2.60 Cleavage: distinct Decomposed by water	$Na_2Ca_2(CO_3)_3$ Orthorhombic	(1) (8) (15)
Siderite	golden brown (light to dark brown)	U(-) $\omega = 1.816 - 1.875$ $\varepsilon = 1.592 - 1.633$; 1.623 (meas.) DR 0.240 gems $\varepsilon = 1.61 - 1.63$, $\omega > 1.81$	H: 4 SG: 3.92 (meas.) Cleavage: perfect rhombohedral	$FeCO_3$ Trigonal Abs. sp.: broad line 485 nm, weak bands 450 and 510–520 nm	(1) (2) (5) (16)
Sodalite	blue (white, grey)	I n=1.483 (meas.) Transparent to opaque	H: 5.5 to 6 SG: 2.22 (meas.) Some fluoresces bright O LW & SW UV; phosphoresces Y-W	$Na_4Al_3(SiO_4)_3Cl$ Cubic	(1) (2) (5) (17)

Table II continued

Sodalite var. hackmanite	Light yellow/pink after exposure to UV; rarely pink	as sodalite Transparent gems 1.483 (meas.)	as sodalite	$Na_4Al_3(SiO_4)_3Cl$ Cubic	(1) (2) (18) (19)
Sphalerite	yellow green, brownish green, green, dark red (colourless, brown, black) Lustre: resinous to adamantine	I n = 2.37 to 2.40 Dispersion: 0.156	H: 3.5 SG: 4.07 (meas.) Cleavage: perfect dodecahedral. May fluoresce Y-O LW, weak Y-O in SWUV	ZnS Cubic Abs. sp: sometimes 3 bands in red at at 690, 667, 651 nm	(1) (2) (5) (8) (20)
Sugilite	gems not confirmed (light purple)	U(-) ω = 1.595 - 1.611 ε = 1.590 - 1.607 Pleochroism: weak, shades of purple	H: 6 to 6.5 SG: 2.74 to 2.79 Inert to UV	$KNa_2(Fe,Mn,Al)_2Li_3Si_{12}O_{30}$ Hexagonal Abs. sp.: broad band at ~420 nm	(1) (8)
Ussingite	light pink (colourless)	B(+) α = 1.504 β = 1.508 γ = 1.543	H: 6.5 SG: 2.46 - 2.50 Cleavage: perfect 2 directions	$Na_2AlSi_3O_8(OH)$ Triclinic	(1) (2)
Villiaumite	colourless to pink to very dark red; some bi- or tri-coloured stones	I n = 1.326 (meas.)	H: 2 to 2.5 SG: 2.78(2) (meas.) Cleavage: perfect Very soluble in water May fluoresce weak R SWUV	NaF Cubic	(1) (2) (5) (21)
Willemite	light blue (grey, pale yellow, pink, colourless) Lustre: vitreous to resinous	U(+) ω = 1.689 ε = 1.716 (meas.) gem 1.693 - 1.722 (0.029)	H: 5.5 SG: 4.26 (calc.) Fluoresces G LW & bright G SWUV, phosphoresces G	Zn_2SiO_4 Trigonal	(1) (2) (5) (22)

[1] Colours in parentheses are also found at Mont Saint-Hilaire, but not known to be faceted.
[2] Whenever available, data are given for Mont Saint-Hilaire specimens, and designated (meas.).

References:

(1) Horvath and Gault, 1990 (2) Mandarino & Anderson, 1989 (3) Chao, 1971 (4) Wight, 1993a (5) Wight, 1986 (6) Wight, 1992b (7) Wight, 1994 (8) Kammerling *et al.*, 1995 (9) Khomyakov *et al.*, 1990 (10) Wight, 1992a (11) Koivula *et al.*, 1992c (12) Van Velthuizen *et al.*, 1995 (13) Wight, 1985 (14) Wight, 1991a (15) Wight, 1993b (16) Wight, 1992c (17) Wight, 1989 (18) Wight, 1993c (19) Koivula & Kammerling, 1989 (20) Wight, 1991b (21) Wight, 1992d (22) Wight, 1991c (23) Nickel & Nichols, 1991 (24) Pabst & Sharp, 1973 (25) Petersen *et al.*, 1994

Fig. 16. Rhodochrosite at Mont Saint-Hilaire may be rose pink (CMN#20894; 1.61 ct). *Photo: CMN, W. Wight.*

Fig. 17. Rhodochrosite may also be orange pink, similar in colour to some serandite (CMN#22136; 0.48 ct). *Photo: CMN, W. Wight.*

Fig. 18. Superlative yellowish green sphalerite (CMN#22212; 24.74 ct) faceted in 1980 by A. Grant. The combination of colour and cut has resulted in a stone whose true beauty is elusive and difficult to record in a photograph. *Photo: CMN, G. Robinson.*

Some gemstones will be discussed in more detail.

Sphalerite

The 1980 Rochester Mineralogical Symposium was considerably brightened by the sight of an exceptional gem sphalerite (Figure 18). It was faceted by Art Grant for Dr George Robinson, who had obtained the rough from someone who had collected it in the early 1970s. Previous sphalerite gems in shades of yellowish- to brownish-green had been attractive, but not large. This yellowish-green, 24.75 ct, pear-shaped, brilliant-cut gem was fashioned from an ugly, black-coated lump, showing that, indeed, the beauty of a gem owes much to the skill of the faceter. This glorious gem came to the CMN when Robinson took up an appointment as Associate Curator in 1982.

In 1991 a very rare, red sphalerite (6.5 ct step-cut) was acquired; it came from the rind of a green piece (see Figure 19).

Fig. 19. Very rare red sphalerite (CMN#21420; 6.03 ct) faceted in 1991 by M. Gray. *Photo: CMN, W. Wight.*

Recently larger greenish sphalerites have been cut by Art Grant for Gilles Haineault (25.45 ct yellow, 42.16 ct light green and 55.62 ct dark green) and others. The green of these stones is darker and not quite as attractive as the earlier 24.75 ct stone.

Carletonite

Carletonite is just one of the minerals first described from Mont Saint-Hilaire (Chao, 1971, 1972), which is so far the only known locality for the mineral. It was named after Carleton University in Ottawa, where Dr Chao is Professor of Mineralogy. In the period 1982–87, larger crystals up to about 5 cm in length were found. These vary in colour from colourless to light pink and from light to intense blue. Some small transparent pieces of a beautiful, intense blue colour have been faceted into stones weighing from as little as 0.02 ct up to 1.48 ct (Figures 20 and 21).

The first carletonite gem (0.34 ct) was shown at Tucson in 1988 and is pictured in the *Mineralogical Record* (Wilson, 1988).

Sodalite

Sodalite is a rock-forming mineral at Mont Saint-Hilaire. Nepheline syenite and sodalite syenite are common, and some sodalite containing rock was first cut as a cabochon showing blue crystal outlines in a white matrix. This rock has been called beloeilite, after the nearby town of Beloeil. Recently one tiny, transparent, blue gem was cut by Bradley S. Wilson for G. Langelier.

The hackmanite variety of sodalite, which can be yellow to pink to reddish-purple (photochromic), is also common at Mont Saint-Hilaire as massive, opaque material. In 1992, transparent light yellow hackmanite was found and some was faceted into amazing gems (Figures 22a, b, c). They become raspberry pink after about 15 minutes exposure to ultraviolet light. The colour fades gradually to the original light yellow, but the process is repeatable. These were first exhibited by Art Grant (who faceted them) and Gilles Haineault (who found the hackmanite) at Tucson and Rochester in 1989 (Koivula and Kammerling, 1989). Since then, a few pieces having a stable pink colour have been found.

The causes of colour, fluorescence and photochromatism in sodalite and its hackmanite variety are complex; some references are given in Wight, 1993c.

Fig. 20. Carletonite crystals, at 10x. *Specimen and photomicrograph: Q. Wight.*

Fig. 21. Carletonite gem (CMN#21464; 0.04 ct) at 20x. *Photomicrograph: CMN, W. Wight.*

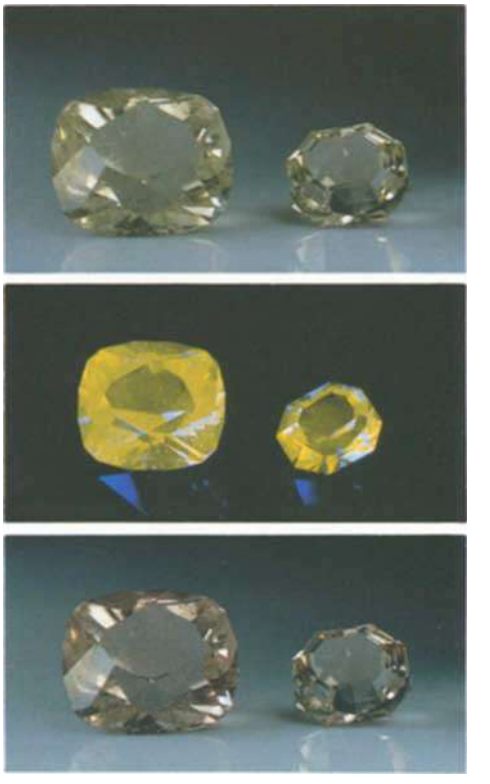

Fig. 22. Sodalite var. hackmanite gems (CMN#22363; 9.77 ct and CMN#22364; 3.32 ct) (a) light yellow in daylight; (b) showing orange fluorescence in ultraviolet light; (c) raspberry pink after irradiation with ultraviolet light. *Photos: CMN, G. Robinson.*

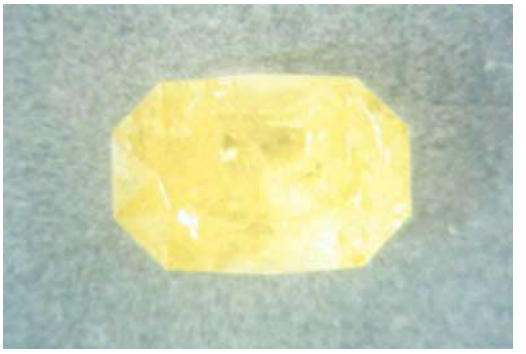

Fig. 23. The first shortite gem, faceted from rough already in the CMN by A. Grant in 1991 (CMN#21467; 1.04 ct). The intense yellow colour is distinctive. *Photo: CMN, W. Wight.*

Hackmanite from Mont Saint-Hilaire probably exhibits all possible reactions: some will appear bright pink when a rock is split open in the quarry and fade to white after a few minutes in daylight; some is found pink and remains pink; yet other pieces are white or light yellow until exposed to ultraviolet light, when they become pink temporarily, but fade in light.

Remondite-(Ce)

In 1991, Gilles Haineault found fragments of transparent orange crystals, which were first identified as burbankite. Small crystals of burbankite-group minerals had been found earlier, but these were large in comparison. The broken pieces were faceted by Art Grant into about 30 stones, weighing up to 6.62 ct. After being shown at the Tucson Show in February 1992, they were reported by Koivula *et al.*, 1992c. The most interesting property of these gems is their strong colour-change from orange or yellowish-orange in incandescent light to greenish-yellow in daylight. The colour-change is thought to be caused by the presence of rare-earth elements such as cerium and neodymium. New work on the burbankite group of minerals indicates that the gems are remondite-Ce, and not burbankite itself (Van Velthuizen *et al.*, 1995; see also Cesbron *et al.*, 1988). The name remondite-Ce indicates that cerium is the predominant rare-earth element.

Present situation

In the last few years, there has been a small but steady stream of new faceted rarities from Mont Saint-Hilaire: leucophanite (1987), cryolite (1991), shortite (1991) (Figure 23), leifite (1992), pectolite (1992), kogarkoite (1993) and manganotychite (1993). At the Rochester (New York) Mineralogical Symposium in April 1995, faceted ussingite (0.53 ct) was shown for the first time (Figure 24).

By April 1995, 28 mineral species from Mont Saint-Hilaire had been cut and polished. Transparent pieces of others have been collected (datolite, genthelvite and sugilite) and are awaiting the attention of a faceter. Despite the fact that the majority of the above species are not traditional gemstones, the demand for gems from Mont Saint-Hilaire has increased to the point where faceters (no longer amateurs) are competing for the very limited supply of facetable material.

Identification

It can be very difficult to identify the minerals of Mont Saint-Hilaire, especially since many of them are very small (microcrystals). In addition, the habit of a mineral from Mont Saint-Hilaire may be unlike the habit of that mineral from other localities. X-ray diffraction or electron microprobe analyses are often necessary to confirm identity. There have been many instances over the years of the incorrect identification of commercially available specimens, especially microcrystals.

Because of the fierce interest, and the resulting high price put on the limited number of gems available, it is very important to confirm the identity and true source of a gemstone. If one is paying a premium for a 'locality piece', there is the potential for misleading labelling. For instance, eudialyte gems labelled 'Canada' commonly come from Kipawa, Quebec, and

Fig. 24. Ussingite crystals, at 10x (CMN#54851). *Photomicrograph: Q. Wight.*

not Mont Saint-Hilaire. Although there is eudialyte at Mont Saint-Hilaire, it is not generally suitable for faceting. There is only one documented eudialyte gem (0.19 ct); it is in the collection of G. Haineault. Reports of gems cut from colourless scheelite, wulfenite and grossular are unconfirmed, and seem unlikely according to expert mineralogists and published literature. Scheelite and wulfenite do occur at Mont Saint-Hilaire, but only as a small number of microcrystals (Horvath and Gault, 1990).

It can be especially difficult to identify these rare gemstones since most of them are not described in the usual gemmology textbooks. And, of course, one must be aware of the existence of a gemstone in order to identify it. To help with that problem, some Mont Saint-Hilaire gemstones have been featured in the 'Check-list for Rare Gemstones' series published between 1985 and 1994 in *The Canadian Gemmologist* by W. Wight.

Conclusion

Mont Saint-Hilaire is a scientific treasure house of the rare and unusual. Only a few of its 311 identified mineral species have been cut and polished to date. The interest of mineralogists, mineral collectors and gem collectors in the treasures from this locality continues unabated.

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River pearls from Bavaria and Bohemia

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Translated and amended with the author's permission by Dr J Kanis from a paper published in *Zeitschrift der Deutschen Gemmologischen Gesellschaft*, March 1995.

Abstract

Freshwater pearls have been found in Europe for centuries and important sources of supply in the past have been various rivers in Bavaria, Bohemia, Russia, Scandinavia, Scotland, Spain, Lorraine and Brittany, as well as Lüneberg Heath and in Saxony. Because of increasing pollution, pearl fisheries in Europe are now unimportant and today it is only in Scotland where a few rivers yield a significant amount of mussel pearls.

The author describes the propagation of the mussels and gives a survey of the occurrences of freshwater pearls in Bavaria and Bohemia. In addition it is pointed out that, very recently, some 150 000 mussels derived from Russian sources have been placed in Bavarian rivers. The reason for this is not the production of pearls but for research into the behaviour of the mussels in response to various kinds of pollution.

Introduction

Since ancient times salt-water molluscs and their pearls have been widely known. In contrast our knowledge of pearls from the freshwater mussel *Margaritifera margaritifera* is relatively recent and much research has still to be done (Figure 1).

Some animals propagate very slowly, others much faster, and it is interesting to note that animals with a long life span normally produce fewer young than animals with a short life span.

Fig. 1. *Margaritifera margaritifera* (L.) with pearls, from a stream in Saxony.

With *M. margaritifera*, however, we have a different situation, and although they can grow to be a greater age than many other animals, they propagate in enormous numbers – an unusual process in the animal world.

During the Middle Ages freshwater pearls were fished in abundance from streams in Germany and other countries. For instance, according to interesting old documents (Reger, 1981), between 1814 and 1887 at least 158 000 pearls came from streams in the Bavarian Forest. Pearl fishing was of importance not only in Bavaria, but also in Bohemia, as well as in the

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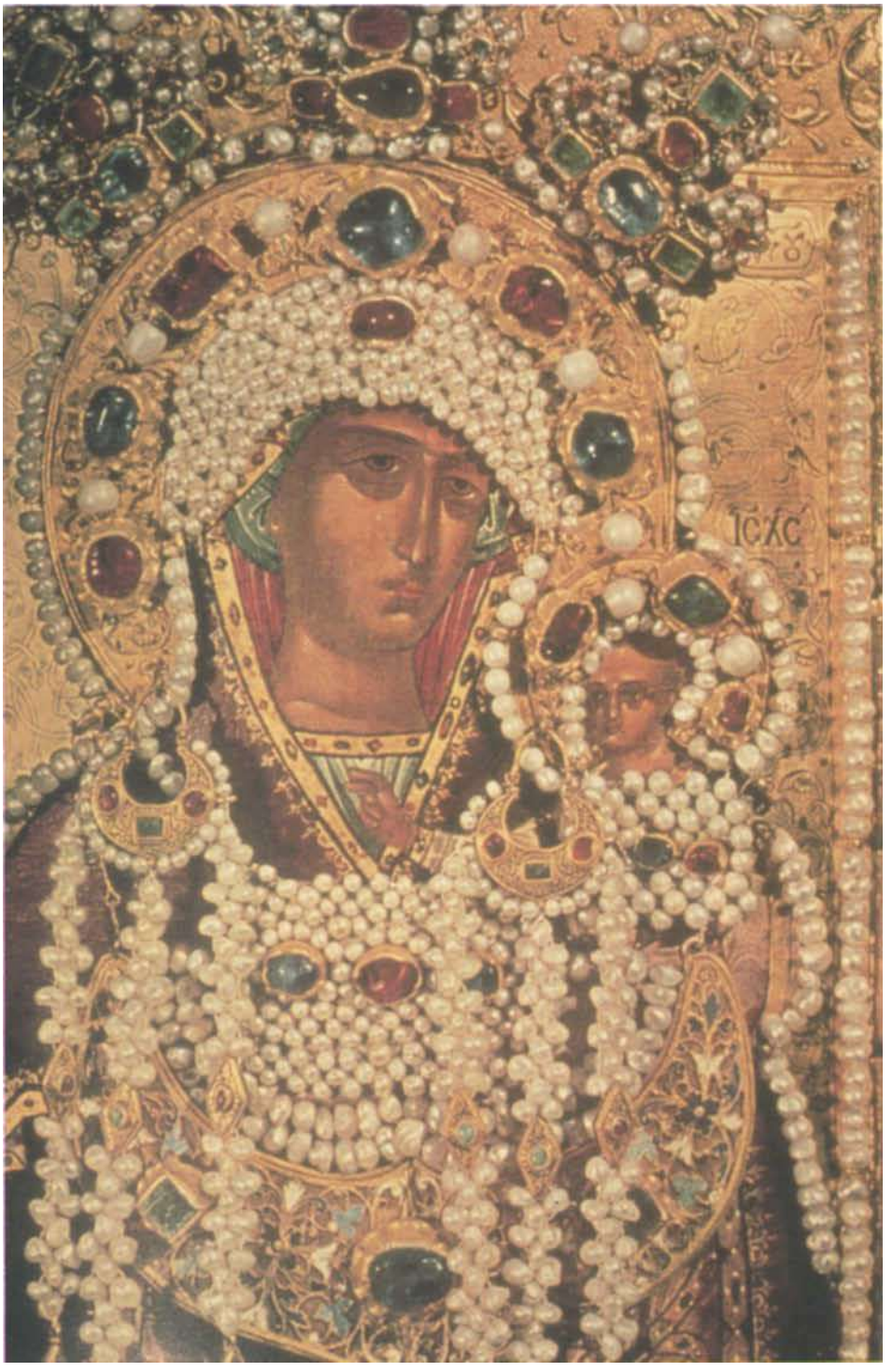

Fig. 2. Russian Maria Ikon (copy of Smolensk Madonna Ikon) embroidered in Munich in 1580 with 700 Bavarian river pearls. In Schatzkammer, Munich.

Lüneburg Heath district, Saxony, Lotharingen, Scandinavia, Spain, Brittany and Russia. In particular Scottish pearls should also be mentioned.

But where have all these freshwater pearls gone? High society, churches and monasteries obtained most of them and some beautiful specimens can now be admired in museums. To mention a few, the Schatzkammer of the Munich Residenz, the Bavarian National Museum (see Figure 2) and the Grüne Gewölbe in Dresden where a beautiful necklace from the time of August the Strong contains freshwater pearls from the River Elster (Figure 3).

In the St Petersburg Hermitage Museum a few valuable jewellery pieces with freshwater pearls are exhibited and in the Bavarian pilgrim village of Altötting there is an altar decorated with 3000 pearls.

Although some pieces are still in private hands and disappeared from the pearl trade long ago, the best and biggest freshwater pearls can be admired in the Hohenzollern jewellery. In particular the state crown with insignia (in the Schatzkammer in Vienna) and the Habsburg crown are richly decorated with pearls.

It is difficult to find out what has happened to the many pearls which were fished and recovered from Bohemian rivers and streams during the last few centuries. Until recently it was believed that nearly all river mussels in Europe yielding pearls had become extinct, but lately some interesting items of information have come to light.

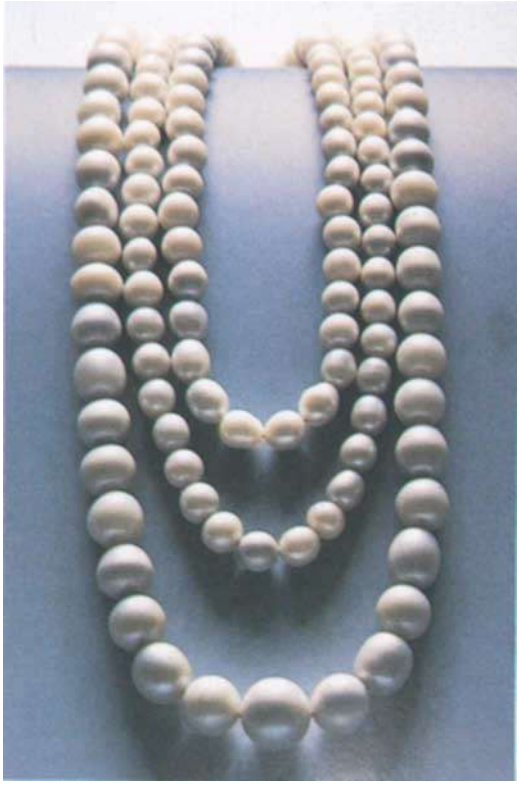

Fig. 3. Pearl necklace with 117 pearls from the Elster river in Saxony, eighteenth century. 'Grüne Gewölbe', Dresden.

Margaritifera margaritifera

The mussel *M. margaritifera* thrives only in very clean calcium-poor waters, but does not prosper in streams without any calcium. They are bisexual, which means that a sex change of the female mussel is possible. They can reach an age of 120 years and can grow up to 14 cm across. Their circulation system makes it possible for the animal to expand its foot up to 7–8 cm, to extend it from the shell and to move. This is, however, very slow at one metre a day. Their food consists of micro-organisms and algae, which are transported to the inner part of the mussel by millions of fast moving flagella. It is also known that this mussel variety has been with us for at least 130 million years and has outlived Dinosauria and many other animals.

Mussels of the species *M. margaritifera* are genetically identical everywhere and occur only in the northern hemisphere. They propagate as follows: during the spawn time in July–August up to four million eggs leave the ovary (the size of the eggs is approximately 0.04 mm) and move to the gill-leaves. Immediately thereafter – probably because of slight changes in

water temperature – the male mussels produce sperm which is then absorbed by the female mussel during the intake of water. During the course of evolution it would appear that the freshwater mussels must have developed some form of communication system because they appear to know whether they are alone, or whether other mussels occur upstream. In some environments the female mussel may change sex, perhaps where no males are present and reproduction is in danger.

Research in Sweden and by Dr Bauer of Bayreuth University proved that the larvae produced by the female mussel can only continue to grow in the gills of a particular variety of river trout 'Bachforellen' Salmo trutta fario (Reger, 1981). It takes three years for the young mussels to grow large enough to be recognized in the streams. The river trout are normally 'infected' only once with larvae and after that they develop an antibody which rejects the larvae.

It has also been established that among the millions of larvae are a few male mussels. The reason for this is that, although the female mussels are bisexual, a few male mussels in the group ensure that no degeneration takes place as a result of inbreeding which could occur if the female mussels exclusively depended upon self-fertilization. Male mussels cannot change sex (Reger, 1981).

Although this mussel variety has survived for millions of years through the complicated technique of survival outlined above, present ecological changes in water conditions and in general environmental pollution could eventually threaten the mussel's existence.

History

Recently the Förderverein Perlfischerei has obtained old documents from the former Bohemia, which are little known in western Europe; they include reports about river pearls in Bavaria in the sixteenth and seventeenth centuries in the Bavarian State Archives.

In 1560, the Swiss scientist Konrad Geszner wrote about the abundance of pearls in Bohemia and mentioned, among others, the rivers Moldau and Wottava. In particular good quality pearls in a range of colours were supposed to come from the Moldau. In the past, pearl dealers would specially mention Moldau pearls from Bohemia for their beautiful lustre. The author found this description in one of his grandfather's business books of 1888 of a grey-rosé coloured Moldau pearl of 9½ grains (4 grain equal 1 carat) that had been sold for 70 Gulden.

Most probably these pearls came from the upper course of the Moldau river because as rivers become larger downstream, the quantity of mussels diminishes, perhaps due to changes in plankton and other food, or to a lower calcium content of the water, or to a combination of factors.

The upper course of the small Bohemian river Schwarzach (Czech = Svarcavan) was well known for its abundance of mussels, but it is not known whether pearls have been found on the Bavarian side of the border. No pearls have yet been found in either Slovakia or Hungary, but during a trip to Hungary the author saw in the Schatzkammer of the Cathedral of Echtergom an old choir robe which was entirely embroidered with pearls. This is a Greek Byzantine piece of art, however, and the pearls came from the Orient.

Another piece of Greek-Byzantine origin in the famous Loretto church treasures in the Prague Hradschin, is the monstrance and this is decorated with large river pearls. Also, Bohemian pearls are found on a robe and a monstrance in the former monastery of Hohenfurt, and beautiful pearl-embroidered items can be admired in the Prague Cathedral Treasury.

Before the First World War most of the Bohemian river pearls were traded in the small town of Rosenberg where a large Jewish community has lived since the thirteenth century. The centre of the Bohemian pearl trade before the wars was, of course,

Prague, which has had a flourishing jewellery industry since the Middle Ages.

In 1933 a book on 'Pearl mussel and its occurrence' was published by a teacher named Ottokar Schubert, a Sudeten-German. Another local Sudeten-German, Arno Ritter, a textile merchant, studied river pearls and published various articles in magazines, and at the beginning of the 1930s he wrote:

'The industrialization of the last few years with its materialistic views has created conditions whereby these rare creatures are in danger of extinction. It is feared that all good intentions in Bohemia and Bavaria will disappear in bureaucratic paper and "paragraph-sausage" and that the biological gem will be totally extinct within a few decades.'

Pearl fishermen have also reported that, during the nineteenth century, the opening of mussels in certain streams was officially allowed only once in eight years.

Many an experienced fisherman believed that it was a good sign when many pearls came from mussels with curved and dented shell surfaces. They believed that rougher and more deformed shells promised larger pearls. However, the author does not believe that this is the case. For some time it has been known that natural pearls originate from an epithelial tumour and not due to pressure or injury. Arab and Indian pearl divers agree with this. Healthy, strong mussels normally carry more and better pearls, but in some rare cases deformed shells can produce a larger pearl which is often irregular and described as baroque.

Protection of the freshwater pearl mussel

Eight years ago a new society was founded with the assistance of the Bavarian Ministry of Agriculture, namely Förderverein Perlfischerei-Museum. The president, Karl-Heinz Reger, is the author of a book on pearl fisheries in Bavaria. In addition he started a data bank on freshwater pearls and their documentation. The honorary president, Otto von Habsburg, as a representative on a European committee for ecology and health, has with the help of committee members from Germany and other countries, stressed the importance of freshwater pearls as environmental indicators. Where they can survive the surroundings are still alright and other animals and plants can also flourish, which makes the need for other research and environmental improvements, possibly expensive, unnecessary.

The ecological problem of dying mussels is not confined to small regions and therefore the European Commission committee members have demanded immediate action to protect *M. margaritifera* from extinction. This is now the task of the Bavarian agriculture and forestry ministry and funds have been made available.

In particular, the newly founded Förderverein Perlfischerei is active and is, together with the University of Bayreuth, in contact with other European countries such as Sweden, France, Spain, Scotland and Russia.

During the last few years the present occurrences of *M. margaritifera* have been registered and one still finds these mussels in various streams in the Bavarian Forest, Scotland, Scandinavia, Spain and in a small area in Brittany. On the border of Saxony and the Czech Republic, in so-called no man's land, are two streams with healthy mussels, which shows that Nature can recuperate when people do not interfere! In Slovakia there are no recorded mussel occurrences, nor have pearls been used in the jewellery contained in museums or churches in that country.

During the 1980s a Czech-Bavarian border committee was formed, as some Czech scientists realized that freshwater pearl mussels are perhaps the best environmental indicators we have. This led to an agreement whereby some streams are cleaned and are not subject to untreated sewage from local establishments. This is perhaps not much, but it is a good start

and during the last two years there has been good cooperation.

Present status

Scientists are now making discoveries and collecting data which can form the basis for certain protection measures. Since 1991 the Bavarian agriculture ministry has been installing automatic equipment to check pH-values in streams and rivers. Some results are surprising: for example they found that during the cold season the mussels reduce their metabolism considerably and polluted waters cause less harm than in summer. A particularly harmful period seems to be spring when the melt waters from snow swell the rivers, but as a long research period is required to obtain reliable data (pers. comm.), no results have yet been published.

In one stream, Dr Bauer of Bayreuth University has discovered a potentially worrying situation. About 10 000 mussels live in this stream whose channel is completely covered with them. They are in a healthy condition, i.e. the females produce a very large amount of larvae every summer, which develop, thanks to the Bachforellen, into young mussels. But for the last few years the young mussels have been dying and therefore the mussel community is becoming too old. The remedy for this malaise has not yet been discovered.

In 1988–89 authorities in the former USSR offered their cooperation to the Bavarian authorities and informed them that they estimated that between 50 million to 150 000 million *M. margaritifera* mussels lived in Karelian streams. 150 000 mussels were then transported to Bavaria and placed in certain streams to complement low mussel populations; Bachforellen, essential for their reproduction, were also present.

However, this exercise was only partly successful, as not sufficient Bachforellen lived there. it took some time to realize that in addition to placing *M. margaritifera*, it is also necessary to introduce sufficient 'infected' Bachforellen at the same time. This was then done in a second trial, which now will be repeated in Bohemia, Saxony, Scotland, Spain and France. Again, these trials are being carried out because this mussel is a good indicator of the cleanliness of environmental conditions; it is considered a bonus that after 20–30 years they may produce pearls.

The Bavarian agriculture and environmental ministries have been able to keep the streams in question free from additional pollution. Further efforts at improvements will be made in the triangular area north of Rehau between Bavaria, Bohemia and Saxony.

Researchers at Bayreuth University and in particular Swedish scientists have described the presence of strontium and caesium in one of the latest year rings of the *M. margaritifera*; this is a result of the Chernobyl catastrophe and the consequent release of these elements into the atmosphere. Other Swedish investigations reveal that the fallout from large nuclear tests can be detected in mussels and convincing results will be published at a later date (pers. comm.). Future research on freshwater mussels is designed to provide important data regarding the mechanics of environmental catastrophies, and particularly to help solve problems concerning dying forests and the acidity of stream and river waters.

Reference

Reger, Karl Heinz, 1981. *Perlen aus bayerischen Gewässern.* Hugendubel Verlag, Munich.

Further reading

Woodward, Fred, 1994. *The Scottish pearl in its world context.* Diehard publ., Edinburgh.

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Abstracts

Diamonds | Gems and Minerals

Instruments and Techniques | Synthetics and Simulants

Diamonds

The formation of diamond.

G.P. BULANOVA. *Journal of Geochemical Exploration*, **53**, 1995, pp 1–23, 11 photos (10 in colour), 8 figs.

Study of the formation of commercial-sized diamonds from kimberlites has produced a very large amount of data which are summarized with fresh theories on the growth of diamond from kimberlites at Yakutia, Russia. It is proposed that all primary genetic information is collected from large single crystals and collated. Main primary features studied have been inclusion paragenesis, internal morphology, growth mechanism and evolution of the growth environment. Diamonds from kimberlitic rocks are concluded to have originated from a variety of mantle rock source environments. Photoluminescence photographs are used to show growth zones. M.O'D.

Vacancy-related centres in diamond.

G. DAVIES AND OTHERS. *Physical Review B*, **46**(20), 1992, pp 13157–70.

Vacancies in diamond migrate, during annealing, primarily in their neutral charge state, with an activation energy of 2.3 ± 0.3 eV. Negative vacancies are destroyed by first converting to neutral centres in a reversible charge transfer process. In relatively pure diamonds (type IIa) and in type I diamonds containing large concentrations of nitrogen, effectively all the vacancies in the samples after irradiation can be accounted for in their neutral (V^0) and negative (V^-) charge states. In nitrogen-rich diamonds, the vacancies are predominantly trapped during annealing at the nitrogen. In common natural (type Ia) diamonds, variations of absorption linewidths during annealing imply that ~40 per cent of the vacancies are created within a few atomic sites of the nitrogen impurity, and direct observation confirms that vacancy production is enhanced in these diamonds. About half of the vacancies, including those near the nitrogen, anneal at each T ~12 times faster than those vacancies whose creation is not correlated with the nitrogen. R.A.H.

Applications of the SHRIMP I ion microprobe to the understanding of processes and timing of diamond formation.

C.S. ELDRIDGE, W. COMPSTON, I.S. WILLIAMS, J.W. HARRIS, J.W. BRISTOW AND P.D. KINNY. *Economic Geology*, **90**, 1995, pp 271–80, 12 figs.

Using the ion microprobe, problems on the timing, materials, sources and processes involved in diamond formation in African kimberlites have been addressed in the course of a study combining uranium-lead isotope dating, rare earth element fingerprinting and sulphur plus lead isotope tracing. Results obtained are

ABSTRACTORS

R.K. Harrison	R.K.H.	M.O'Donoghue	M.O'D.	R.E. Samson	R.E.S.
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For further information on many of the topics referred to consult *Mineralogical Abstracts* or *Industrial Diamond Review*. For a further 9 papers concerning diamond sources the reader should consult the *Journal of geochemical exploration*, **53**, 1995.

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of value towards the study of carbon isotope heterogeneity of eclogitic diamonds. Data can be reconciled with a simple model in which the introduction of crustal material into the mantle triggers both generation of the kimberlite and diamond growth. Plate tectonic studies are vitally important in locating economic diamond reserves. M.O'D.

The origin of diamonds in western Minas Gerais, Brazil.

G.M. GONZAGA, N.A. TEIXEIRA AND J.C. GASPAR. *Mineralium Deposita*, **29**(5), 1994, pp 414–21, 2 maps.

Important diamond-mineralized alluvium/colluvium occurs in WMG in the 700–450 m.y. old Brasília orogenic belt. Diamonds are geographically related to glacial and periglacial sediments, wadi and debris flow conglomerates, and ultramafic alkaline rocks (intrusive and extrusive, including kimberlites, leucitites, kamafugites, carbonatites, etc.). Petrological data indicate that the rocks, originally classified petrographically as kimberlites, have mineralogical, chemical and isotopic differences from group I and II kimberlites, and more closely resemble kamafugites. The Brasília orogenic belt has features of a Wilson cycle, implying that WMG does not fulfil the geotectonic and geothermometric requisites to host primary diamond sources. An analysis of field relations and sedimentology in WMG shows that the majority of the diamonds have been transported by glacial events from the São Francisco craton further E. R.E.S.

Diamondiferous eclogites from Siberia: remnants of Archean oceanic crust.

D. JACOB, E. JAGOUTZ, D. LOWRY, D. MATTEY AND G. KUDRJAVTSEVA. *Geochimica et Cosmochimica Acta*, **58**(23), 1994, pp 5191–207.

Analyses by EMP are presented of mineral separates for major elements and trace elements, together with O, Sm-Nd and Rb-Sr isotopes from a suite of eight diamond-bearing eclogite xenoliths from the Udachnaya mine, Siberia. Chemically and petrographically these eclogites are similar to the eclogite suite from Roberts Victor or Bellsbank mines, South Africa, in age (2760 m.y.) and $\delta^{18}O$ values that deviate from mantle values. But no samples of eclogite with δ^{18} lower than mantle values have yet been found, and Cs contents of the Siberian eclogites are lower than those from Roberts Victor. A model indicates an origin of the Siberian eclogites from Archaean oceanic crust altered prior to subduction to mantle depths, and this is extrapolated to global eclogites from kimberlites despite the differences between samples from different cratons. R.K.H.

Catalogue of worldwide diamond and kimberlite occurrences: a selective and annotative approach.

A.J.A. JANSE AND P.A. SHEAHAN. *Journal of Geochemical Exploration*, **53**, 1995, pp 73–111, 9 maps.

Primary host rock occurrences of diamond on Earth are believed to number approximately 5000: 500 of these have been found to contain diamond with 50 being mined and 15 being large active mines. The validity of Clifford's Rule is upheld: this holds that economic kimberlites are found only on Archons (cratonic regions underlain by Archean basement) while economic lamproites occur on some Protons (Proterozoic mobile belts adjacent to Archons). Diamond and kimberlite occurrences are catalogued for all continents, the data including co-ordinates. M.O'D.

Gem trade lab notes.

R.C. KAMMERLING AND C.W. FRYER. *Gems & Gemology*, **31**(2), 1995, pp 120–27, 1 illus. in black-and-white, 17 illus. in colour.

A diamond showed high-order strain through crossed polars in the shape of an octahedron showing a dark line through the vertex and a dark plane perpendicular to it. The phantom did not affect the clarity (VVS) or the natural intense yellow colour.

Treated-colour pink diamonds. These have been found to have characteristic strong orange fluorescence to both LW and SW ultraviolet radiation. In addition they consistently show a diagnostic visible spectrum with sharp lines at 595, 617 and 658nm and an emission line at 575nm.

An unusual diamond crystal (13.24ct) of irregular shape with a large 'tunnel' etched through the centre was shown to be a single crystal. R.J.P.

A visual guide to the identification of filled diamonds.

S.F. MCCLURE AND R.C. KAMMERLING. *Gems & Gemology*, **31**(2), 1995, pp 114–19, 60 illus. in colour.

All filled diamonds to date have shown flash effects in a variety of colours. In addition there is evidence of flow structure, trapped bubbles, incomplete filling at the surface, crackled texture, an apparent colour to the filler, cloudy filled areas and surface residue. The authors have recognized the inadequacy of descriptive text in this subject and have resorted to the unusual step of providing a chart of over fifty photographs covering most aspects of diamond filling, together with photographs showing misleading features found in unfilled diamonds.

Emphasis is placed on the responsibility of jewellery professionals to be aware of diamond treatments as mistakes can be damaging both financially and to reputations. Lighting is important particularly in the use of darkfield and brightfield illumination where complementary colours are seen in the flashes. R.J.P.

Basic principles of alluvial diamond exploration.

T.R. MARSHALL AND R. BAXTER-BROWN. *Journal of Geochemical Exploration*, **53**, 1995, pp 277–92, 3 figs.

No single method of target selection for alluvial diamond deposits has yet been suggested. Data needed to be assimilated before field exploration is begun include regional geological features of the drainage basin, the constituent lithologies of the gravel being prospected for, geomorphic and climatic factors affecting the exploration area, the type of deposit sought and information on post-depositional processes which may have affected the deposit considered for exploration. M.O'D.

The role of petrography and lithogeochemistry in exploration for diamondiferous rocks.

R.H. MITCHELL. *Journal of Geochemical Exploration*, **53**, 1995, pp 339–50, 2 figs.

A combination of transmitted light petrography, back-scattered electron imagery and energy-dispersive X-ray spectrometry is used to assess rock samples collected during diamond exploration. M.O'D.

Pathfinder sampling techniques for locating primary sources of diamond: recovery of indicator minerals, diamonds and geochemical signatures.

M.T. MUGGERIDGE. *Journal of Geochemical Exploration*, **53**, 1995, pp 183–204, 8 figs.

Direct evidence of the presence of a diamond source may be given by other minerals (pathfinder minerals). Sampling techniques for the handling and identification of these minerals are described. M.O'D.

The morphology and nature of primary diamondiferous occurrences.

P.H. NIXON. *Journal of Geochemical Exploration*, **53**, 1995, pp 41–71, 4 maps, 13 photos, 10 figs.

The role of kimberlite and lamproite pipes as sources for diamond are reviewed together with notes on other types of occurrence, in particular the kimberlite pyroclastic ejecta deposits interstratified in the Albian Cretaceous sediments of Saskatchewan, Canada. Diamonds from Tibetan ophiolites are still being studied. M.O'D.

Sampling and statistical evaluation of diamond deposits.

L. ROMBOUTS. *Journal of Geochemical Exploration*, **53**, 1995, pp 351–67, 12 figs.

The statistical distribution found by a sampling programme of the average grade of deposit and average value of the diamonds found is an important item in the evaluation of a diamond deposit. Techniques are described. M.O'D.

Archean mantle heterogeneity and the origin of diamondiferous eclogites, Siberia: evidence from stable isotopes and hydroxyl in garnet.

G.A. SNYDER, L.A. TAYLOR, E.A. JERDE, R.N. CLAYTON, T.K. MAYEDA, P. DEINES, G.R. ROSSMAN AND N.V. SOBOLEV. *American Mineralogist*, **80**, 1995, pp 799–809, 9 figs.

The O isotopic composition of clinopyroxene and garnet, the C isotopic composition of diamond and the OH^- content of garnet from eclogite xenoliths transported to the surface in the Udachnaya kimberlite pipe, Yakutia, Siberia are presented as data which prompt the proposal that the eclogites may derive from an ultra-depleted mantle at approximately 2.9Ga. It is possible that ancient crustal material may have participated in the formation of the Udachnaya eclogites though the mantle C isotopic values of associated diamonds and the low OH^- content of the minerals suggest low or no participation of crustal material. M.O'D.

Occurrence of diamond in the mantle: a case study from the Siberian Platform.

Z.V. SPETSIUS. *Journal of Geochemical Exploration*, **53**, 1995, pp 25–39, 4 photos, 8 figs.

Diamond crystals from diamondiferous xenoliths and some kimberlite pipes at Yakutia, Russia, are described. Photoluminescence and infrared light absorption studies of crystals from mantle xenoliths, together with their morphology, allow differentiation to be made between diamonds from the peridotitic and eclogitic parageneses. Crystals from mantle xenoliths and from kimberlites are compared on the basis of their physical properties and morphology. It is shown that most diamonds in kimberlites are derived from mantle peridotite and eclogite, and were released into the kimberlite when the xenoliths disintegrated. M.O'D.

Thermal conductivity of isotopically modified single crystal diamond.
L. WEI, P.K. KUO, R.L. THOMAS, T.R. ANTHONY AND W.F. BANHOLZER. *Physical Review Letters*, **70**(24), 1993, pp 3764–67 (Jun 14), 3 figs, 1 table, 18 refs.

Experimental results on the thermal conductivity of isotopically enriched ^{12}C diamond crystals at low temperatures are presented. As far as is known, the measured value for a 99.9% ^{12}C crystal at 104 *K*, 410 *W/cm K*, is the highest measured thermal conductivity for a solid above liquid nitrogen temperature. The temperature dependent conductivities measured for the isotopically enriched diamond and natural abundance diamond specimens in the experiments are well described by Callaway's theoretical model. It is predicted that the thermal conductivity of a 99.999% ^{12}C diamond crystal should exceed 2000 *W/cm K* at ~80 *K*. J.H.

Infrared spectra of type IaB diamonds.
G.S. WOODS, I. KIFLAWI, W. LUTYEN AND G. VAN TENDELOO. *Philosophical Magazine Letters*, **67**(6), 1993, pp 405–11 (Jun), 6 figs, 18 refs.

It is shown that the infrared absorption spectra of pure type IaB diamonds, namely those that on cursory examination show only a B one-phonon component and neither A nor D, and the complete absence of a B′ localized-mode platelet absorption peak, may be divided into two subgroups. The defect content of specimens of one of these subgroups has been studied before and comprises slip dislocations and voidites in random homogeneous distributions unconnected with the transformation of platelets to dislocation loops. Electron microscopy of a specimen of the other subgroup, which may be recognised by the presence of weak additional one-phonon absorption near 1100cm^{-1}, shows a population of dislocation loops resulting from the complete transformation of a former platelet population, plus accompanying voidites. It is suggested that the extra absorption is caused by the dislocation loops. Observation of the way in which loops and voidites are distributed suggests that voidite production and platelet transformation may not, after all, be interlinked phenomena, but parallel independent processes both promoted by the same unknown conditions. J.H.

Gems

Fluorit. Liebling der Sammler.
ANON. *Mineralientage München. Offizieller Katalog 1995*, 1995, pp 30–110, illus. in colour.

Every year the Munich mineral fair has a theme mineral and fluorite fills the role in 1995. Fluorite's colour, geology, mineralogy, occurrence and recovery are described with notes on outstanding specimens, significant locations (including the Blue John site) and some paintings of fluorite crystals. M.O'D.

Pierres naturelles at matières synthétiques utilisées dans la joaillerie égyptienne.
A. BOUQUILLON, G. QUERRE AND J.-P. POIROT. *Revue de gemmologie*, **124**, 1995, pp 17–22. Illus. in colour.

Three pectorals in the collection of the Musée du Louvre, Paris contain natural and artificial stones whose identity was determined by a variety of techniques which are described. M.O'D.

History of pearling in La Paz Bay, South Baja, California.
M. CARINO AND M. MONTEFORTE. *Gems & Gemology*, **31**(2), 1995, pp 88–105, 16 illus. in colour.

The history of Baja California, the peninsula in North West Mexico, is closely linked to the exploitation of pearl resources for the past 400 years. Pearls from this source can be found in many religious treasures and royal jewellery collections. The two pearl oysters indigenous to the area are *Pinctada mazatlanica* giving typical baroque or semi-baroque pearls and *Pteria sterna* which produces smaller but rounder natural pearls.

Although pearling was known before the

arrival of the Spaniards in 1533, the area was exploited until the 1680s and for the next sixty years the grounds replenished themselves. Following thousands of oysters being cast onto the northern shores of the Gulf in 1740 the grounds were again exploited and a permanent settlement was established. By 1756 the grounds were again impoverished but the political independence of Mexico in 1821 coincided with a natural replenishment coupled with an influx of foreign investment. Combier, a French businessman started the export of oyster shell in 1836 and from 1840 the value of this was greater than that from pearls. During 1850–1925 pearl finishing increased and the pearl fleets were increasingly owned by local people. Later the Mangara Exploration Company became the main operator but did great damage to the grounds by routinely using explosives. Following the revoking of the Mangara Contract in 1912, the world's first pearling station was established by Gaston Vives and the C.C.C.P. company.

For spat collection wooden incubators were used and several million young oysters were harvested by hand. In San Gabriel Bay the inlet was transformed into a lagoon where the oysters were grown and protected from predators. After three years the oysters 16–18cm in diameter were collected and examined for pearls. Whereas Mikimoto's work pioneered pearl culturing, that of Vives was centred on pearl-oyster cultivation.

Today, cultivation techniques are being carried out by CIBNOR, a pearl-oyster research group incorporating many of the factors considered by Vives. Although on a limited scale the anticipated harvest by March 1996 is approximately 1000 cultured blister pearls of which 70 per cent should have the rich distinctive colours of Baja California pearls. R.J.P.

Eclogites and jades as prehistoric implements in Europe. A case of petrology applied to cultural heritage.

C. D'Amico, R. Campana, G. Felice and M. Ghedini. *European Journal of Mineralogy*, 7(1), 1995, pp 29–41, 1 map.

Eclogites and 'jades' [Na-pyroxenitic stones lacking garnet] are the raw material of many prehistoric polished axes found in N Italy and in a great part of the rest of Europe. In sites near the Western Alps, eclogites prevail over jades, whereas outside this region, jades become dominant. The petrography of European axes is similar to that of the N Italian axes and they were probably derived from the same source; only a few ceremonial jade axes of high quality in NW Europe do not correspond with a NW Alpine provenance. R.A.H.

The Merelani graphite-tanzanite deposit, Tanzania: an exploration case history.

C. Davies and R.J. Chase. *Exploration & Mining Geology*, 3(4), 1994, pp 371–82, 2 maps.

This deposit occurs in NE Tanzania, 14 km south of Kilimanjaro International Airport and close to the towns of Moshi and Arusha. The graphite mineralization is hosted by relatively undeformed linear Proterozoic metasedimentary gneisses, several of which have been subjected to hydrothermal alteration resulting in tanzanite mineralization. The graphite has been shown to be of unusually coarse flake-size, crystallinity and high purity. Studies have shown the deposit to be economically viable with a measured resource to 50m of > 9 x 10^6 t assaying at > 8 per cent graphitic C. Production was due to start at the end of the first quarter of 1994 with the processing plant design capacity initially set at 15 000 t/y. Tanzanite will also be produced by selective mining within the graphite open pit in the upper horizon and from underground workings within the lower horizon. This deposit will be the first major ore body to be exploited by private funding since Tanzania gained independence. R.E.S.

Zum Fluorit. Eigenschaften und genetische Aspekte.

M.A. Götzinger. *Mineralien Welt*, 6(6), 1995, pp 26–32, illus. in colour.

The structure, cause of colour, luminescence, geology, occurrence and internal world of fluorite are discussed. A list of references is provided. M.O'D.

Petrology of jadeite metagranite and associated orthogneiss from the Malpica-Tuy allochton (northwest Spain).

J.I. Gil-Ibarguchi. *European Journal of Mineralogy*, 7(2), 1995, pp 403–15, 2 maps.

Jadeite occurs in plagioclase pseudomorphs of porphyritic veins associated with corona-bearing granodioritic orthogneiss SW of Cabo Ortegal, NW Spain. Igneous textures and the igneous composition of plagioclase and biotite,

as well as high-*P* assemblages with sodic pyroxene, Ca-rich corona garnets, Si-rich phengite and rutile are preserved in the least deformed zones of jadeite-bearing and related rocks. Almandine- and grossular-rich coronitic garnets show conspicuous asymmetric zoning (e.g. $Alm_{76}Gro_{11}Pyr_{13}$ to $Alm_{54}Gro_{41}Pyr_{5}$ across a <100μm thick garnet rim). Estimated peak metamorphic conditions for jadeite-bearing and related rocks, ~640°C, >1.6 GPa, are consistent with those deduced from eclogites within the same structural unit. R.A.H.

Kristallglasschalen von Carl Fabergé.

J. GRAF VON FRANCKEN SIERSTORPFF. *Gemmologie – Zeitschrift der Deutschen Gemmologische Gesellschaft*, **44**(2/3), 1995, pp 61–3, 2 photos. in colour, bibl.

Two Carl Fabergé cut glass bowls with silver rims and round silver handles are described as are the typical hallmarks giving the silver content. The bowls are dated 1890. E.S.

Ein neues Vorkommen von Smaragd, Alexandrit, Rubin und Saphir in einem Topas-fuehrenden Phlogopit Fels von Poona, Cue District, West Australien.

G. GRUNDMANN AND G. MORTEANI. *Gemmologie – Zeitschrift der Deutschen Gemmologische Gesellschaft*, **44**(2/3), 1995, pp 11–31, 3 maps, 13 photos in colour, 2 diagrams, bibl.

In August 1994 first alexandrite then ruby was discovered in the Murchison Province, Western Australia. The green alexandrite and the ruby occur in tabular crystals or as strongly altered fragmented crystals together with deep blue sapphires, colourless topaz, light green emeralds, pink fluorite, margarite, muscovite and quartz in schists typical of those hosting the emerald deposits of Poona. The host rock is a medium grained phlopogite. Until now little cuttable material has been found, but further discoveries are likely. E.S.

Ein neues Vorkommen von Feueropalen in Brasilien.

U. HENN AND R. BALZER. *Gemmologie – Zeitschrift der Deutschen Gemmologische Gesellschaft*, **44**(2/3), 1995, pp 43–6, 3 photos in colour, bibl.

A new occurrence of fire opals has been discovered in the Brazilian state of Rio Grande do Sul, near the village of Campos Grande within the agate and amethyst mining areas of southern Brazil. The fire opal is found in a sedimentary layer just below the agate-bearing lavas. The rough is partly rounded and weighs up to 50–70 grams. They are orange-red to fire-red. RI 1.440 (±0.001), SG 2.01 (±0.02). Under the microscope one can see swirl-like structures and colour zoning. E.S.

Rote berylle aus Utah, USA-neue beobachtungen.

U. HENN AND G. BECKER. *Gemmologie – Zeitschrift der Deutschen Gemmologische Gesellschaft*, **44**(2/3), 1995, pp 55–60, 3 photos. in colour, 4 photomicrographs in colour, bibl.

The beryls come from south-western Utah, particularly the Wah Wah Mountains. They are found in so-called steam holes in rhyolites. The tubes which have penetrated the rhyolites and transported some post-volcanic gases are significant for the study of transportation of substances necessary for the formation of manganese containing red beryls. Fluid inclusions as well as interesting growth and colour zoning perpendicular and parallel to the *c*-axis of the beryls are shown. E.S.

Gem trade lab notes.

R.C. KAMMERLING AND C.W. FRYER. *Gems & Gemology*, **31**(2), 1995, pp 120–7, 1 illus. in black-and-white, 17 illus. in colour.

Azurite and antlerite rock. A variegated blue and green cabochon effervesced with dilute hydrochloric acid whilst a substance present in surface cavities melted on the approach of a hot needle suggesting azur-malachite. X-ray powder diffraction showed the blue and grey material to be azurite and quartz. The green material proved to be antlerite whilst the coloured foreign material was probably a polymer.

Jadeite with misleading inclusions. Small white crystals were seen in the white areas in an especially clear mottled green and white carving. All the properties were consistent with natural-colour jadeite.

An opaque mottled green and white carved mask gave only a vague RI reading of 1.62 and was inert both to LW and SW ultraviolet radiation. X-ray powder diffraction showed it to be omphacite, a pyroxene group mineral intermediate in composition between jadeite and diopside.

A cultured pearl showed on radiography a central void containing free pieces of a shattered bead.

A translucent mottled green cabochon resembling fine quality jade had a spot RI of 1.55 with dye in the fractures and a characteristic 'dye' band centred at about 650nm; it was dyed quartzite. Infra-red spectroscopy revealed a key absorption feature at 2900cm^{-1} similar to that of opticon resin.

A synthetic ruby with curved striae also showed fingerprint inclusions and a moderate star both of which must have been induced.

A green-blue sapphire showing chatoyancy which is described as rare had no acicular rutile needles but a series of nearly-planar, parallel, liquid-filled 'fingerprints'. Diffuse colour halos around the crystal inclusions showed that the stone had been heat treated. R.J.P.

An update on the Ural emerald mines.

A.F. LASKOVENKOV AND V.I. ZHERNAKOV. *Gems & Gemology*, **31**(2), 1995, pp 106–13, 12 colour illustrations.

The Ural emerald mines have been worked almost continuously since 1831; up to 1930 emerald and green beryl production sometimes reached 2.5 million carats annually and exceeded that of Colombia. During the 1939–45 War mining concentrated on beryllium ore production. Contrary to popular belief emerald production from this source has barely been interrupted.

During the 1940s and 1950s emerald production reached as high as 3–4 million carats as a by-product in beryllium production but the discovery of further beryllium deposits shifted attention back to emerald production with an annual production as high as 8–10 million carats. Malysheva Mines Management developed a sophisticated mining complex but cutting was not quite as sophisticated and only 20 000 carats of well cut emeralds were produced. After a cessation in cutting between 1987 and 1991, a Russian-Panamanian-Israeli venture ensured that Russian emeralds were cut using the latest technology.

Although there are significant reserves, only the Mariinsky deposit is currently being mined for emeralds using special low impact explosives. The deposits are located about 100km north-east of Ekaterinburg and are found in schists within amphibolite zones.

Uralian emeralds are mainly bluish-green, the intensity varying due to chromium content. Internal features are characterized by zoning, mineral and two-phase inclusions. The nature of the mineral inclusions depends on the nature of the enclosing rock. Several very large emeralds have been found including the 11 000 carat crystal named Kochubey's emerald found in 1831 and latterly the 3 370 carat emerald named Glorious Ural Stone found in 1978. In 1990 two rare beautiful emeralds were mined, the 4 400 carat New Year's stone and the 37.5 carat faceted Vitaly emerald. R.J.P.

Zinnober und antimonit: ausgezeichnete kristalle und ihre fundstellen in China.

G. LIN. *Lapis*, **20**(10), 1995, pp 33–43, 2 maps.

Included in the paper which describes Chinese locations for fine cinnabar and antimonite crystals is a list of gem minerals found in that country, giving species and province name only. M.O'D.

The crystal chemistry of Si ⇌ Al substitution in tourmaline.

D.J. MACDONALD AND F.C. HAWTHORNE. *Canadian Mineralogist*, **33**, 1995, 849–58.

The structure of nine gem-quality vanadian uvites on analysis with the electron microprobe proved to have a Si content of significantly less than 6 atoms per formula unit: assignment of $^{[4]}$Al sufficient to fill the *Si* site gives a linear relationship between {*Si*-O} and $^{[4]}$Al content. Recent work on tourmaline structure refinement shows no well-defined relationship between {Z-O} and constituent Z-cation radius. On the other hand there is a linear relationship between {*Y*-O} and constituent *Y*-cation radius. Site-scattering refinement shows F to be strongly to completely ordered at the O(1) site with no significant positional disorder at the O(1) or O(2) sites. M.O'D.

Metasomatism at a granitic pegmatite-dunite contact in Galicia: the Franqueira occurrence of chrysoberyl (alexandrite), emerald and phenakite.

A. MARTIN-IZARD, A. PANIAGUA, D. MOREIRAS, R. ACEVEDO AND C. MARCOS-PASCUAL. *Canadian Mineralogist*, **33**, 1995, pp 775–92, 2 maps.

The first documented example of a gem-quality chrysoberyl, emerald and phenakite deposit in western Europe is situated at Franqueira in the north-western part of the Iberian peninsula, Spain. The deposit is in the Galicia-Tras os Montes zone which is formed of two domains, one of schistose rocks and one of

granitic rocks. Granite pegmatite bodies intrude both schists and granite rocks. The geology and mineralization of the chrysoberyl (alexandrite) emerald and phenakite occurrences are discussed. The contact between a pegmatite body related to heterogeneous granites and ultramafic rock of dunitic character has developed a metasomatic zone in which the dunite has been almost completely altered to phlogopite at the contact. The phlogopite-rich metasomatic rocks contain the gem minerals. A genetic model is proposed in which emplacement of pegmatite and associated mobile elements (Be, B, P) into dunite takes place with subsequent metasomatism of the dunite into phlogopite and tremolite rocks near the pegmatite body. Chrysoberyl may be formed through its sharing structural features with the olivine so that epitactic nucleation on olivine relics could take place. Emerald is the last Be-bearing mineral to form, partially replacing chrysoberyl and phenakite, perhaps from the reaction chrysoberyl + phenakite + quartz → emerald, until exhaustion of the quartz occurs.

M.O'D.

Situation géologique des émeraudes de Ianapera, province de Tuléar (Madagascar).

P. MARCHAND. *Revue de gemmologie*, **124**, 1995, pp 13–16, illus. in colour, 3 maps.

Emerald has been discovered at Ianapera, Tuléar province, Malagasy Republic. The site is in the south of the island and crystals occur in tremolite-actinolite schists. The crystals are dark green in the main and reach 10g maximum. Most are heavily fractured and contain mica inclusions.

M.O'D.

Fluoritfundstellen in Kanada.

F. MELANSON. *Lapis*, **20**(11), 1995, pp 33–5, illus. in colour.

Fine examples of gem-quality fluorite have been found at a number of locations in Canada. Brief notes are given for the major locations.

M.O'D.

Peridot aus Pakistan.

C.C. MILISENDA, H. BANK AND A. HENN. *Gemmologie – Zeitschrift der Deutschen Gemmologische Gesellschaft*, **44**(2/3), 1995, pp 33–42, 3 photos in colour, 2 photomicrographs in colour, 1 map, 3 diagrams, 1 table, bibl.

The gem quality peridot is found 15 000 ft above sea level in the Nanga Parbat region of Pakistan Kashmir, most probably in veins in serpentinized peridotite. The crystals are in part well crystallized. There are some large crystals that are eye-clean and yield stones weighing more than 100ct. The authors examined a cut stone of 309.90ct. RIs range n_x1.648–1.653, n_y1.663–1.671 and n_z1.683–1.689, and birefringence from 0.035–0.038. SG 3.29–3.37. The absorption spectrum showed typical bands characteristic of Fe^{2+}. When immersed, feathers of small fluid inclusions as well as growth structures could be seen. Some rope-like inclusions of the Ludwigite-Vonsenite solid solution series were seen which have not been reported in peridot from other sources.

E.S.

Gemmologische kurzinformationen.

C.C. MILISENDA. *Gemmologie – Zeitschrift der Deutschen Gemmologische Gesellschaft*, **44**(2/3), 1995, pp 3–9, 8 photos in colour.

New gemstone finds in Afghanistan include golden beryls and brownish-yellow tourmalines from the Laghman district near Nuristan. The beryls show etch figures and have SG 2.7, RI 1.569–1.580, DR 0.008. Some cavansite was found near Poona, India, this is blue to bluish-green, turquoise-like and cut as cabochons; it has RI 1.54, SG 2.24–2.27, hardness 2½.

A massive natrolite was found in northern Bohemia; it is yellow-brown and looks like opalised wood; it has RI 1.48, SG 2.15, hardness 5.

An imitation of demantoid was offered on the market, but on examination turned out to be YGG (yttrium-gallium-garnet). A diffusion treated red corundum of 7.38ct was examined; it has RI 1.762–1.770, DR 0.008; the rim was relatively dark.

Some diamond beads on the market are yellow-brown, greenish-brown, weighing more than 10ct. The stones are bruted and show polishing marks. Weight loss is said to be about 50%. The technique was developed in Antwerp in 1989.

E.S.

Ammolite, ein organischer Schmuckstein aus Alberta, Kanada.

G. NIEDERMAYR. *Mineralien Welt*, **6**(6), 1995, pp 41–6, illus. in colour.

The name ammolite has been given to an ornamental fossil material with an opal-like play of colour, found in the area of St Mary's river in southern Alberta, Canada. Maps and details of the occurrence are given.

M.O'D.

Mondstein als Schmuckmaterial.
G. NIEDERMAYR. *Der Staoansuacher*, **9**(2), 1995, pp 18–24, illus. in colour.

A description of the feldspar gemstones with particular reference to the moonstone effect in orthoclase and other feldspar group members, to the coloration of labradorite and to the coloration and phenomenal effects in gemstones generally. M.O'D.

World review of mineral discoveries 1993–1994.
G.W. ROBINSON, V.T. KING, J. SCOVIL AND F. CURETON. *Mineralogical record*, **26**(5), 1995, pp 475–99, illus. in colour.

Among mineral discoveries reported during 1993–94 are bicoloured red and green elbaite from the Himalaya mine, Mesa Grande, California, where in 1994 a series of pockets were found: pale lilac to dark royal-purple amethyst from the Intergalactic mine, Maine and facetable blue-green elbaite from the Mount Mica quarry, Paris and multi-coloured green to crimson tourmaline crystals at the Bennett mine, Buckfield, in the same state: fine green facet-grade fluorite from the re-opened William Wise mine, Westmoreland, New Hampshire.

Outside the United States are reports of: lazurite from mines in the Kokscha Valley, Afghanistan and gem elbaite from the Gusalaka mines near Pech, Kunar in the same country; other gem quality tourmalines have been reported from the Kligal mine near Paprok and from another locality in the vicinity; many of the crystals reported from Afghanistan at this time are a fine blue; large morganites are reported from Resplendor, Minas Gerais, Brazil, the colour bleaching from a peachy-orange to pure pink; relatively few of the diamond crystals found near Lac de Gras, approx. 300 km NE of Yellowknife, NW Territories of Canada are of gem quality; gem quality opal has been found near Vernon, British Columbia; the Mengyin area of Shandong Province, China, is producing small diamond crystals in matrix; from Russia have come elbaite and liddicoatite but buyers are warned to check their specimens as there has been some indiscriminate labelling; Na-liddicoatite is reported from the Malchan pegmatite field [Kraznoy Chikoy]; some of the kimberlites found in eastern Finland contain diamonds; gemmy orthoclase is coming from South Betroka, Malagasy Republic; large yellow-green to brown grossular-andradite crystals are reported from a site near Sandara, Nioro du Sahel, Mali; fine peridot crystals are being found in Pyaung Gaung, Myanmar, as is bright green tourmaline (V-uvite is considered to be the appropriate name for this material); Namibia (the Otjua mine, Karibib) is continuing to produce large, often doubly-terminated rubellite crystals; red to green tourmaline is also reported from an alluvial ruby deposit at Thac Ba Lake, Yen Bai province, north Vietnam; pink beryl is reported from a site near Drot-Balachi, Shengus, Pakistan and the same country is producing peridot from Kohistan – quality is very fine. Also from Pakistan are blue crystals of phenakite (from Apaligun) and zircon crystals from Bulbin, Wazarat district. From Sri Lanka a 27 ct 2 cm crystal of sinhalite is reported from Nirialla near Ratnapura, Sabaragamuwa province and sharp sapphire crystals are coming from Galbkka, near Vallivaya, Uva province. Pink zircon occurs as terminated crystals at Amlilipitiya, near Kataragama. M.O'D.

Topas aus dem Untersulzbachtal, Österreich.
W. SCHÄFER, S.-A. JAKOBS AND R. HOCHLEITNER. *Lapis*, **20**(9), 1995, pp 13–19, illus. in colour, 1 map, 2 figs.

Well-formed colourless topaz crystals which could be fashioned into faceted stones are found in the Untersulzbachtal area of southern Austria, one of the main sites lying between the Stockeralm and Leutachkopf mountains. Quartz and sphene are sometimes found with the topaz as characteristic Alpine cleft minerals. M.O'D.

Gem minerals in early Arabic literature.
W.J. SERSEN. *Mineralogical Record*, **26**(4), 1995, pp 43–8, 3 figs.

While much Arabic writing on gemstones has not been translated, the original texts are mostly available in major libraries around the world. The author cites several topics dealt with in early Arabic literature, including the distinction of ruby from red spinel by specific gravity testing, the emerald versus peridot question as it concerns Egyptian sites, fluorescence in gem species from Afghanistan and Arab remarks on corundum. Brief details of early sources and their availability are given. M.O'D.

Regional mineralogies of the world.
A.E. SMITH. *Mineralogical record*, **26**(4), 1995, pp 113–134.

A bibliography of topographical mineralogies arranged in alphabetical order of country or

state, including citations of papers in journals as well as monographs. M.O'D.

Étude comparative sur les principaux traitements de l'émeraude.
D. SIRAKIAN AND D. RUSKONÉ. *Revue de gemmologie*, **124**, 1995, pp 6–8, illus. in colour.

Examples of different types of treated emeralds are presented with brief notes on identification. M.O'D.

Der Edelstein-Bergbau in Afrika.
K.C. TAUPITZ. *Gemmologie – Zeitschrift der Deutschen Gemmologische Gesellschaft*, **44**(2/3), 1995, pp 47–54, 3 maps, 1 diagram, 1 table.

Survey of gem mining in Africa, diamond being the most important, but during the last 10–15 years emerald, ruby, sapphire, tourmaline, aquamarine, amethysts, tanzanite, tsavolite and others have increased in importance. Easing of currency restrictions has had a positive effect on trading, as has also the diminishing influence of drug dealing combined with illegal dealing. Some geological interrelations are pointed out. E.S.

The saga of *Mineral digest*.
L. ZARA. *Mineralogical Record*, **26**(4), 1995, pp 135–42, 11 photos.

An account of the conception and publication of the journal *Mineral digest* which ran to eight issues only over an eight-year period from 1970 and which included many gemstones in its subject-matter and lavish colour photographs. Sets of the journal are keenly sought by collectors. All eight covers are reproduced. M.O'D.

Instruments and Techniques

Automated engraving with Syndite PCD.
B. AUGENSTEIN. *IDR*, **55**(2), 1995, pp 66–7, 5 illus. in colour.

The author describes an engraving machine suitable for mass production in the jewellery and coin stamping industry. Diamond tools work to extremely close tolerances, provide high surface finish and provide flexibility. As an example of an individual piece the author describes agate of diameter 100mm which was to be engraved with a wine-making scene; the tool used was a four-edged PCD cutter. The work was finished in approximately 48 hours. E.S.

Modelling the X-ray diffraction pattern of opal-CT.
G.D. GUTHRIE, JR., D.L. BISH AND R.C. REYNOLDS, JR. *American Mineralogist*, **80**, 1995, pp 869–72, 3 figs.

It is suggested that H_2O in opal is probably not present on a specific crystallographic site within the opal structure but may be located along the boundaries between the 10–35nm grains. This proposal is derived from the modelling of X-ray diffraction patterns of opal-CT [cristobalite/tridymite] using a recursive calculation technique allowing for ordered and disordered intergrowths of planar units. M.O'D.

Rho und Phi, Omega und Delta: die Winkelmessung in der Mineralogie.
O. MEDENBACH, P.W. MIRWALD AND P. KUBATH. *Mineralien Welt*, **6**(5), 1995, pp 16–25, 15 photos (14 in colour).

Short account of the part played by the goniometer in the history of mineral identification. Several models of instrument are illustrated. M.O'D.

Historische Entwicklung der Kristallmodelle.
L. TOURET. *Mineralientage München. Offizieller Katalog 1995*, 1995, pp 25–8.

Brief survey of the art of crystal model-making with particular reference to Haüy and other early crystallographers. M.O'D.

Diamond laboratory techniques.
N.J. TOWIE AND L.H. SEET. *Journal of Geochemical Exploration*, **53**, 1995, pp 205–12, 1 fig.

For the location of possible diamond sources discrete mineral grains need to be extracted from primary source rock. Grain size needs to be greater than 0.1mm in diameter: laboratory techniques for the handling of grains are described. M.O'D.

Synthetics

Premières études sur les émeraudes synthétiques hydrothermales japonaises AGEE.
H.A. HÄNNI AND L. KIEFERT. *Revue de gemmologie*, **124**, 1995, pp 9–12, illus. in colour.

Examination of hydrothermal emeralds produced by the Japanese firm AGEE shows that small liquid- and gas-filled inclusions and undulating veil-like structures are helpful in identification. Energy-dispersive XRF shows chlorine to be present. M.O'D.

Growth temperature effects of impurities in HP/HT diamonds.

H. KANDA AND S.C. LAWSON. *IDR*, **55**(2), 1995, pp 56–61, 1 table, 1 graph, 9 photomicrographs in colour, bibl.

Diamond crystals have been grown by the temperature gradient method under high temperature and pressure conditions, using Co and Ni catalysts with or without the use of Ti. A distinct green or brown coloured stripe caused by the incorporation of nickel appeared in sample regions formed during decreases in the growth temperature, but not in regions corresponding to increases in temperature. This suggests that the concentration of nickel depends on growth rate rather than on the growth temperature, in contrast to the case for nitrogen and boron. E.S.

New nickel-related optical absorption in high-pressure synthetic diamond.

S.C. LAWSON, H. KANDA AND M. SEKITA. *Philosophical Magazine B*, **68**(1), 1993, pp 39–46 (Jul), 4 figs, 10 refs.

Diamonds grown by the temperature-gradient method using a nickel catalyst and sufficient nitrogen getter to produce barely detectable nitrogen absorption in the defect-induced one-phonon region have a deep brown colour which has been found to result from continuum absorption whose threshold lies around 1.7 e*V*. In these diamonds, the presence of a zero-phonon structure lying between 1.2 and 1.25 e*V* has been observed for the first time in the near-infrared spectral region of the absorption spectrum. This structure exhibits interesting photochromic effects, and a correlation between partial decay of the 1.40 e*V* system (whose transition has previously been ascribed to nickel) and growth of the new zero-phonon structure has been observed. Like the 1.40 e*V* system, the new zero-phonon structure shows strong polarisation effects and is confined exclusively to the {111} growth sectors of diamond. From these results, it is proposed that the new structure results from a different charge state of the 1.40 e*V* nickel system. J.H.

Optical absorption spectroscopy of synthetic tourmalines.

M.N. TARAN, A.S. LEBEDEV AND A.N. PLATONOV. *Physics & Chemistry of Minerals*, **20**(3), 1993, pp 209–20.

The optical absorption spectra of tourmaline solid solutions containing Fe, Fe + Ti, Cr, Ni, Cu, Co, Mn chromophoric centres have been measured in the range 26316–5000cm^{-1} at 297K and in the range 26316–9090 cm^{-1} at 77K. In Fe^{2+}, Fe^{3+}-bearing specimens intense σ-polarized absorption bands caused by exchange-coupled Fe^{2+}, Fe^{3+} pairs in *Y*- and *Z*-sites occur. The colour and spectroscopic properties of the Fe^{3+}, Mn^{3+} and Cu^{2+} containing tourmalines are significantly affected by the presence of even the smallest Li-contents. The results suggest that Fe^{2+}, Cu^{2+}, Co^{2}, Ni^{2+} ions occupy, predominantly, *Y* sites of the tourmaline structure, whereas the Cr^{3+} ions enter the smaller *Z* octahedra.

S.A.T.R.

The effect of isotopic changes on the {001} platelet infrared absorption in diamond.

G.S. WOODS, I. KIFLAWI, H. KANDA AND T. EVANS. *Philosophical Magazine B*, **67**(5), 1993, pp 651–658 (May), 3 figs, 3 tables, 29 refs.

Normal synthetic diamonds consist of 99% ^{12}C with 1% ^{13}C in the host lattice, with dispersed ^{14}N as the main impurity. Two variants have been produced by changing natural isotopic abundances, in one case of the atoms of the host lattice and in the other of the nitrogen impurity. These, together with normal specimens, were treated under a stabilising pressure at a temperature sufficiently high to produce {001} platelets and the associated B' localized-mode infrared absorption peak. No isotopic effects were observed when B' peaks in ^{12}C diamonds with a substantial proportion of the nitrogen (up to about 67 per cent) present as the ^{15}N isotope (the balance being ^{14}N) were compared with the B' peaks in ^{12}C diamonds containing only ^{14}N. This implies either that nitrogen atoms, if present, are a minor constituent of the platelets or that such atoms, if a major species, remain stationary in the vibrational mode responsible for the B' absorption peak. Specimens consisting almost entirely of ^{13}C, with the nitrogen impurity present as ^{14}N, showed a shift in the wavenumber of the B' peak. Using simple harmonic theory, and taking into consideration the experiment described above which shows no influence of nitrogen atoms on the B' peak, this shift would be expected to be in the ratio of about $(12/13)^{1/2}$, caused by the change in the carbon mass only. The observed shift was, however, smaller than expected. It is suggested that this anomalous shift is caused by anharmonic effects, enhanced by the proximity of the B' local mode energy to the Raman energy. It would be valuable if a theoretical study could be made to test the validity of this suggestion. J.H.

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BOOK REVIEWS

Faux gems and jewels circa 1700 to 1930. An exhibition and sale [held by and at Sandra Cronan Ltd].

V. BECKER, 1994. Sandra Cronan Ltd, London. pp 36, illus. in colour, softcover.

A useful and attractive guide to a sale-exhibition held during 1994 with many colour photographs, some of which have reproduced rather darkly. The author speeds through the use of foiled and glass imitation gemstones and succeeds in making them objects of interest and desire, as indeed they were meant to be. There is a short list of references and the book in no sense aims at completeness, but anyone interested should try to get a copy before the print run is exhausted. M.O'D.

Ringe. Rings. Die Alice und Louis Koch Sammlung. Vierzig Jahrhunderte durch vier Generationen gesehen. The Alice and Louis Koch collection. Forty centuries seen by four generations.

A.B. CHADOUR, 1994. Maney, Leeds. pp 663, illus. in colour, hardcover, £200.00. ISBN 0 901286 45 1. In German and English. Slip case provided.

This very large book (it measures 35 x 25cm) is a full *catalogue raisonné* of the collection of rings formed by Alice and Louis Koch (1862–1930). The Kochs formed collections of other materials too, notably in the field of music, but antiquaries would place their collection of faience high in the list of major cabinets of that material. The Koch family were jewellers in Frankfurt am Main, Germany, and the firm was one of the leading German jewellery enterprises. Since the development of the business coincided with the rise of Art Nouveau, followed by Art Deco, the creations of the Kochs became important in those fields. The pieces made by Robert Koch (d.1902) are not often seen in the saleroom and when Louis Koch died in 1930 no one was left to carry on the name. The property was expropriated by the Nazi régime and, after the war when it had changed hands more than once, the business never regained its pre-eminence, closing down finally in 1987. The archives, mostly of jewellery designs, are in the Deutsches Goldschmiedehaus, Hanau.

The ring collection, now comprising 1980 items, is in the care of Louis Koch's great-grandchildren and contemporary jewellery designers have been helped by having their works included in it.

After a short biography of the Koch family and the formation of their art collections, the book devotes some pages to the history of the ring both in history and in the collection. The note covers the chronological development of the ring as an ornament, from classical antiquity up to the present. The descriptive portion of the catalogue then occupies the remainder of the text. Here items are arranged chronologically, each entry containing a colour photograph of good quality; most of necessity are small though there are short sections in the front of each volume for which larger photographs are selected. The rest of the entry gives inventory number, dimensions, description of metal and stone where appropriate, designer, publication and general comment. As in the remainder of the book both German and English are used side-by-side.

The book ends with an 18-page bibliography, notable for the inclusion of many rare German and European items; it is followed by a glossary, a general index and an index of firms and artists.

It is inevitable that most copies of this magnificent book will be purchased by libraries, since the price is naturally high for the private scholar. Nonetheless it will clearly be one of the most notable additions to ring scholarship for many years and will be of great interest to the historian of gemmology and its applications (a race yet to evolve). M.O'D.

Fifth international kimberlite conference, Araxá, Brazil, 1991.

COMPANHIA DE PESQUISA DE RECURSOS MINERALES-CPRM, RIO DE JANEIRO, 1994. pp 495, 388, 2 vol., illus. in black-and-white, softcover. Price on application to and available from the Mineralogical Society of America. CPRM *Special publication* 1/A.

The first volume of this major work on kimberlites and diamond sources deals with kimber-

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lites, related rocks and mantle xenoliths and contains papers on the Arkhangelsk diamond-kimberlite province as well as a great deal of material on other types of kimberlite, lamprophyre and carbonatite occurrences. The second volume is entirely devoted to diamonds, their characterization, genesis and exploration. The 29 papers in this volume will all be of interest to academic gemmologists and the student may also find at least some of the text a stimulus toward further study. Each paper has its own list of references. M.O'D.

100 famous diamonds.
DE BEERS, 1995. London. pp 18, illus. in colour, softcover.

Free publicity pamphlet describing and illustrating 100 of the best-known cut diamonds with notes on the weight, source of name, colour, date and source of discovery and weight of the original rough where known. The pamphlet is quite well produced but the text is marred by the recurring and sometimes mystifying reference to 'weight of original diamond' (not the rough) and by the use of unspecific adjectives ('extraordinary colour') where specific ones would have told the reader something useful. M.O'D.

Les grenats.
J. DEVILLE, 1995. *Minéraux et fossiles*, Paris. pp 67, illus. in colour, softcover. Price on application. ISSN (of the parent serial) 0335-6566. *Minéraux et fossiles.* Hors série no 1.

This is a very attractive, well-produced and informative guide to the garnet group, aimed primarily at the collector but of considerable use to the gemmologist. After a brief introduction to the mineralogy of the garnet group the group members are discussed in alphabetical order. Particular attention is paid in the remainder of the book to garnets from France, the relationship of garnets to metamorphism, the synthesis of garnets (this short item includes YAG but also true garnets, which have been synthesized in very small sizes) and garnets as gemstones. For those collectors interested in non-gem members of the garnet group there is some brief but useful information. The book lacks a bibliography but otherwise is an excellent production. M.O'D.

The Paris salons.
A. DUNCAN, 1994. Antique Collectors' Club, Woodbridge. pp 349, 305, illus. in black-and-white and in colour, hardcover. £45.00. ISBN 1 85149 159 7.

Consisting largely of black-and-white photographs, the book records about 3 000 pieces of jewellery displayed at the Paris Salons from 1895 to 1914. This period saw the development and growth of Art Nouveau, a style brought to an end by the start of the war and not revived afterwards. For this reason the period represents a spirit of decoration concentrated into a few years and perhaps because of this flowering more exotically than it might have done otherwise. Jewellers represented include Lalique, Fouquet, Gaillard and Boucheron as well as many other important designers. Four Salons including jewellery exhibits were held each year, those of the Société des Artistes Français, the Société Nationale des Beaux-Arts, the Société des Artistes Decorateurs and the Salon d'Automne. In addition the two major exhibitions, the Exposition Universelle of 1900 and the Exposition de la Parure of 1908 are also included in the survey.

The two volumes thus give a very full record of a major French design period and while most of the photographs are in black-and-white they show up well. Each piece is briefly described and the author has found it possible to provide attributions hitherto lost. Entry is in alphabetical order of artist and the major descriptive text follows a short general introduction in which trends perceived in Art Nouveau jewellery are elaborated. A short index of jewellery designers is given at the end of the second volume. Students of jewellery will need to have this book. M.O'D.

Jewelry in America 1600–1900.
M.G. FALES, 1995. Antique Collectors' Club, Woodbridge. pp 447, illus. in colour, hardcover. £35.00. ISBN 1 85149 223 2.

While the productions of this publisher are always attractive and informative, this book is particularly well-prepared and covers a subject which has often been attempted on a smaller scale. The top of the dust-cover shows a necklace of Maine tourmalines – I can think of nothing so calculated to draw out my interest – the necklace is in the Harvard Mineralogical Museum. The book, too, has a particularly useful bibliography.

Whether or not the pieces included were made in the United States or imported there, the author has attempted to identify and provide accurate descriptions of as many major items of

jewellery with an American connotation over the period 1600–1900 as can be found. The arrangement is in chronological order and many descriptions are taken from contemporary letters in which the jewels were mentioned by their owners or makers.

The book is arranged in four sections: colonial jewellery from 1600–1775; federal jewellery from 1775–1825; introduction [from outside the United States] 1825–1875; and introduction 1875–1900. Each of the four sections concludes with a discussion of the work and influence of individual jewellery of the time.

The illustrations are well-captioned and provide description, size, provenance and present location. The standard of the photography is high. For the gemmologist there is a good deal of relevant information with Kunz and Hamlin credited with many threads of influence; there is as much for the jewellery historian and the historian of costume. This is a first-class book and sells at a most reasonable price.

M.O'D.

Goldsmiths review 1994/95.

1995. Worshipful Company of Goldsmiths, London. pp 64, illus. in black-and-white and in colour.

Articles include silver in the National Museum of Wales, the career of Robert Welch, the new School of Jewellery, Birmingham, the jewellery designer Stephen Webster and his work, the making of fine jewellery, the Goldsmiths Group and its retail outlets, the arrangement of jewellery galleries in shops and the wine cups in the collection of the Court of Assistants, Company news occupies the last part of the issue.

M.O'D.

Edelsteine und Schmucksteine.

R. HOCHLEITNER, 1994. Gräfe und Unser Verlag, München. pp 160, illus. in colour [*GU Naturführer*]. ISBN 3 7742 2131 6.

Pocket-sized, beautifully illustrated guide to gem materials with sections on synthetics and imitation products. One or two of the chemical compositions given are not accurate; for example hydroxyl is omitted from the composition of topaz and feldspar group minerals are too simply presented in the chemical context. These are small points and the book can be highly recommended for the German-speaking gemstone student.

M.O'D.

Tangerine green. [A tale.]

W.D. JAMES, 1995. University Editions, Huntingdon, West Virginia. pp 303, softcover. US$10.00. ISBN 1 56002 529 8.

A set of assorted characters, few if any likely to be highly-placed on my dinner-party list, are involved in the search for a blue diamond reputedly stolen long ago from Shah Jahan in India. The search 'takes them through several continents' as such enterprises usually do and their miscellaneous adventures are described in a spirited if familiar railway-bookstall style. There are some accounts of gem centres and dealings. Division of the text into 55 chapters speeds the action along and the tale is a fair example of its genre.

M.O'D.

Gediegen Silber: das Erz der Münzen, das Metall des Schmuckes, das Element mit dem Glanz.

VARIOUS AUTHORS, *EXTRALAPIS 8*, 1995. Christian Weise Verlag, München. pp 96, illus. in colour, softcover. DM47 (including postage). ISBN 3 921656 34 6.

A set of papers dealing with the geology, mineralogy, current mining and mining history, fashioning and lore of native silver. The concluding paper lists and briefly describes the known silver compounds and lists are also given of the known silver mines in antiquity with dates of their period of production and notes of other elements found. The paper on major silver artefacts includes a list of references and the whole book is well up to the now-expected *extraLapis* standard.

M.O'D.

Granat. Die Mineralien der Granat-Gruppe: Edelsteine, Schmuck und Laser.

EXTRALAPIS 9, 1995. Christian Weise Verlag, München. pp 96, illus. in colour, softcover. DM 34.80. ISBN 3 921656 35 4.

The text covers all the garnet group minerals but pays most attention to the ornamental ones. In the first section group members are briefly described and illustrated: then comes a more detailed discussion of garnet minerals, their chemistry and structure, with the different species being taken in alphabetical rather than chemical order. As with the remainder of the sections, each page includes many colour photographs of the very highest quality, as readers of *Lapis* now expect. Look especially at the Pakistan spessartine!

Geological and mineralogical notes follow, special attention being paid to European deposits. Other sections include descriptions of Bohemian garnet, of some European garnet-set artefacts and a very useful and well-illustrated note on the synthetic garnets. The book ends (or nearly ends) with the question 'why are there no blue garnets?'. For an answer, get the book. In small letters could I add that a bibliography would have been welcome! M.O'D.

Il libro delle gemme.

E. LEONE, A. LEONE AND G. PROVERA, 1995. Edizioni AISG, Valenza. pp xv, 494, illus. in colour, hardcover. L290,000.

This is a beautifully-produced book with a comprehensive text arranged around a great number of high-quality colour photographs. So many of these show inclusions that the book might be used primarily as a source for some of the latest information about the internal inhabitants of gemstones. It is certainly time that fresh photographs appeared since the importance of inclusions grows daily.

The book begins with an introduction to petrology and mineralogy, dealing with the lithosphere, rocks and minerals, mineral formation and location types. Elementary crystallography follows with coverage of physical properties and the role played by chemistry in crystal formation. The fourth chapter introduces optical properties, including the use of the spectroscope and of ultra-violet sources in gem testing.

Chapter five introduces gemmology as a system of gemstone identification and includes such diverse topics as gemstone nomenclature, gem fashioning and treatment, the synthesis of gem materials and the nature of colour.

Much of the remainder of the book, from page 94 to the end, is devoted to gemstone descriptions. These are arranged in order of crystal class (see below for comment on this) so that diamond is the first material to be described. This section, of 54 pages, covers mining, the properties of diamond, fashioning and examples, with diagrams, of diamond grading. Diagrams of a number of celebrated diamonds are also provided. Descriptions of other gem materials follow the same form: synthetic counterparts of natural stones are included with them and very useful colour photographs of their inclusions, as well as those seen in treated stones need to be looked for under the name of the material. There is a lot to be said for including these features in one place. Imitation gemstones, where no particular major stone is simulated, are placed in their appropriate crystal families after the natural species have been covered. Thus we find YAG, strontium titanate and cubic zirconia in the cubic crystal system section. Glass is placed in the amorphous section. Altogether this arrangement works quite well since there is no ideal to be aimed at.

Those materials less often seen as fashioned gemstones appear in their appropriate crystal section. Quite a lot of species are described, making the book valuable for the growing number of collectors.

Organic materials are described after opal and glass and again the coverage is very thorough and the photographs original and arresting. Simple identification tables, quite a useful bibliography and both species and general indexes complete the book.

In so large a text there are bound to be some errors and areas less well handled than others. I found that the bibliography included some out-of-date items and some critical notes ought to be included in any bibliography today. Mere lists do not help. Rather more confusing is the arrangement of species by crystal system. Only three classes are used, monometric, dimetric and trimetric. Monometric is the cubic system while dimetric includes tetragonal, hexagonal and trigonal species: the rest are grouped under trimetric. This will appear eccentric to experienced gemmologists and beginners will find it hard to turn from this method of arrangement to more acceptable ones used elsewhere. I would strongly suggest that in a second edition an alphabetical arrangement is used.

Nonetheless, this is a very good, beautiful and important book, well in keeping with traditional Italian excellence of production. All serious gemmologists should buy it. M.O'D.

Fascination of gemstones.

H.J. MÜLLENMEISTER, 1995. [Published by the author] Markt Schwaben. pp 224, illus. in colour. DM49.50 plus postage. ISBN 3 9801925 1 2.

The author embarks on the perilous course of trying to explain or even justify his addiction to the study of gemstones, taking a number of different topics to illustrate those areas which he finds of greatest interest. He succeeds admirably, not least through the selection of subject areas but also in the choice of first-class colour photographs. Themes include historical diamonds, the physics of coloured diamonds, ruby, emerald

and their synthetic counterparts, details of stones in the crown jewels (in the Hofburg, Vienna) and a great deal on inclusions, well-illustrated by excellent photographs which in fact make the book worth recommending for inclusion study.

I found the addiction completely justified in terms of the book and would recommend it for general reading. For such a colourful production the price is reasonable for today. M.O'D.

La gemmologie, notions, principes, concepts. 2e édition.

F. PAYETTE, 1995. Fischer Presses, Sillery, Québec. pp 227, illus. in black-and-white.

This is a pleasantly-produced and simple book which would suit the student or beginner very well but will not attract the curious customer despite the attractive coloured front cover which depicts cut and rough villiaumite, of all rare stones! As villiaumite has been described as 'only partly water-soluble' it seems appropriate to describe the book as 'only partly satisfactory' for it is without colour photographs! Nonetheless the actual text is fair and the figures are notably clear and accurate. It can be recommended for the French-speaking gemmologist.

M.O'D.

Amber: the golden gem of the ages.

P.C. RICE, 1993. The Kosciuszko Foundation, New York (3rd printing with revisions). pp x, 289, illus. in black-and-white and in colour, softcover. £19.95. ISBN 0 917004 22 1.

This pleasant book was first published in 1980 by Van Nostrand Reinhold and the recent update takes into account the work of George O. Poinar Jr at the University of California, Berkeley, best known for providing some of the impetus for the film *Jurassic Park*. Other additions include some rather fruitless speculations on the present whereabouts of the Amber Room, formerly in St Petersburg, and, more usefully, additional entries to the bibliography. At the softcover price this is still a book gemmologists should possess. M.O'D.

Photo masters for diamond grading.

G. ROSKINS, 1994. Gemworld International Inc, Northbrook, IL, USA. pp 94, illus. US$95.00, £49.50.

This reviewer has been grading diamonds in a laboratory environment and teaching the subject since 1979. In that time he has seen few books published which cover the practical element of diamond grading and which can be used as teaching aids. The chapters covering grading in *Diamonds* by Bruton are a useful introduction but are now in need of revision *Diamonds and diamond grading* by Lenzen is out of print leaving *ABC of diamond grading* by Pagel-Theisen as the sole available text.

In this book Roskins draws on his experience as a diamond grader at the GIA Gem Trade Laboratory to review the history of the GIA clarity scale and provides a brief, rare glimpse of the workings of a grading laboratory. The value of the book to a diamond student lies in its presentation of over 200 excellent photomicrographs illustrating all the clarity grades accompanied by clear descriptions of the clarity characteristics responsible for the given grade. Common inclusions, symmetry and polish grades, girdle thicknesses and culet sizes are also illustrated.

Roskins correctly states that diamond grading is a subjective process with consistency only being achieved through the regular examination of many stones of different sizes. This book could help the tyro grader reach such a consistency. The author and publisher deserve much credit in producing such clear illustrations but the high cover price may deter all but serious students from acquiring this welcome book.

E.C.E.

Quartz-Monographie. Die Eigenheiten von Bergkritsall, Rauchquarz, Amethyst, Chalcedon, Opal und anderen Varietäten (2, überarbeitete auflage).

R. RYKART, 1995. Ott Verlag, Thun. pp 462, illus. in colour, hardcover. DM69.00. ISBN 3 7225 6204 X.

This now standard work on the occurrence and crystal forms of the major varieties of silica makes a welcome re-appearance with additional colour plates and a really exhaustive bibliography. As always the emphasis is upon quartz for the collector and a large amount of information has been compiled upon the wealth of crystal forms reported from locations worldwide. This is the book to consult if you want to know what quartz from a particularly celebrated site looks like and in covering this ground the author naturally brings in a wealth of data on inclusions, colour varieties and citations of papers with a slant towards those in German and other European languages.

Fine objets d'art in rock crystal are illustrated and some of the romantic side of crystal collecting in the Alps is included with notes on the life of the strahlers. Later sections describe the formation and colouration of chalcedony, the formation of opal and how its play of colour arises. A small separate section of colour photographs at the end of the text illustrates particularly notable specimens of the silica varieties covered by the book: the present location of the specimens is given along with their size (most if not all colour photographs in the main text of the book have the specimen size in their captions). A first-class book and don't let there be a language barrier!

M.O'D.

Tudor and Jacobean jewellery.

D. SCARISBRICK, 1995. Tate Publishing, London. pp 104, illus. in colour, softcover. £8.95. ISBN 1 85437 158 4.

Much of the evidence for the nature of jewellery from Tudor and Jacobean periods is derived from portraits and indeed the study of pictures for details of artefacts is rapidly becoming an independent branch of art scholarship. This short guide presents a series of portraits, very well reproduced in colour, each depicting items of jewellery and arranged in four sections, patrons, makers and materials, themes and the jewels themselves. There is a short bibliography and at the price the book is very good value. Perhaps the casual viewer of a portrait does not always understand the symbolism or other significance of a piece of jewellery; the choice of stone, where the jewel was worn and on what occasion, the choice of one item of jewellery rather than another. In its small compass this book is an excellent starting-point. M.O'D.

Structure of crystals.

B.K. VAINSHTEIN, V.M. FRIDKIN, V.L. INDENBOM, 1995. Springer-Verlag, Berlin. pp xx, 520, illus. in black-and-white and in colour, hardcover. Second, enlarged edition (*Modern crystallography*. 2). DM 119.00. ISBN 3 540 56848 4.

With the publication of the second volume of the second edition of *Modern crystallography* mineralogists and gemmologists again have an up-to-date text to back those areas of crystallographic importance in which work constantly continues to refine crystal structures once accepted as less complex than they now prove to be. While gemmologists will not often meet quasi-crystals and high-temperature superconductors, many will be interested in advances made in the study of crystal surfaces. From the first edition, published in 1982, the list of references has been greatly expanded and since the work is written by Russian crystallographers it is not surprising, though very welcome, that Russian and Soviet papers are strongly represented. In all, 21 pages are devoted to citations.

Gemmologists will probably find the sections on chemical bonding, the principal types of crystal structures and the advances in structural crystallography the most interesting though it must be said that the treatment, inevitably, is strongly mathematical. Nonetheless, since larger university libraries will have copies, the serious student will find many items of interest rigorously treated and some questions settled.

M.O'D.

Geology and mineralogy at Oxford 1860–1986: history and reminiscence.

E.A. VINCENT, 1994. Published by the author, Department of Earth Sciences, University of Oxford. pp 245, illus. in black-and-white, softcover. £10.50.

Gemmologists should take the opportunity to learn how one at least of its 'parent' sciences has been organized at a major university and how the specific subject of mineralogy has changed in emphasis during this century: up to 1941 it merited its own chair but from that date the Waynflete Professorship of Mineralogy and Crystallography was abolished, being then made part of the Department of Geology and Mineralogy. Both the work and the personalities of some of the leading Oxford earth science figures are described and, as always in academic history, there are accounts of making do with what accommodation was available and with the vagaries of temperament exhibited by some influential figures. Readers should visit the mineral display at the University Museum; the specimens are very well displayed and excellently curated and form an impressive background to one of the larger British earth science departments. M.O'D.

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Proceedings of the Gemmological Association and Gem Testing Laboratory of Great Britain and Notices

OBITUARY

Mr T.H. Bevis Smith, FGA (D.1936), Epsom, died suddenly on 22 October 1995. Mr Bevis Smith served as a member of the Council of the Gemmological Association from 1954 to 1976.

Mr Harold Cox, FGA (D.1934), Windsor, died recently.

Mr John J.W. Laurie, FGA (D.1988), Bluche, Switzerland, died on 25 September 1995 after a short illness.

Mr Aaron N. Levy, FGA (D.1990), London, died recently.

Mr Edward Arthur (Ted) Thomson, Hon. FGA, London, died in December 1995. A full obituary will appear in a future issue of the *Journal*.

Mr George Lindley, FGA (D.1937), Sutherland, Scotland, died on 27 November 1995. A full obituary will appear in a future issue of the *Journal*.

GIFTS TO THE ASSOCIATION

The Association is most grateful to the following for their gifts of gems and gem materials for research and teaching purposes:

Professor Yuri Aroutiounov, Moscow, Russia, for the illustrations of Russian lacquer boxes and a paste-set crown badge.

Dr Keglim Belloso-Laufer, London, for diamond crystals.

Biron International Ltd for synthetic emeralds.

Mr Tom Chatham of the USA for synthetic emeralds and rubies.

The Cultured Pearl Company, London, for a Tahitian cultured pearl, 18.73ct, 13.8mm, drilled.

Rak Hansawek, M.Sc., GG, Bangkok, Thailand, for tektites from NE Thailand, one faceted stone and one cabochon.

Mr John A. Kessler, London, for emerald crystals in matrix.

Ms Ou Yang C.M., Hong Kong Institute of Gemmology, for four cabochons of jet from Wusun, NE China, and a book on jade by Ms Ou Yang.

Mr Julius Petsch, Idar-Oberstein, for sapphire crystals from Madagascar.

Mr Xui Zhili, Zhongshan University, Guangzhou, China, for two gemmology textbooks by Mr Xui Zhili.

NEWS OF FELLOWS

Alan Hodgkinson carried out an extensive lecture programme during 1995. As well as speaking at the GAGTL Conference in London (as reported in *Gem and Jewellery News*, 1995, Vol. 5, No. 1) and other localities in the UK, Alan gave presentations in Australia, Canada, Hong Kong and New Zealand.

On 4 October 1995 Peter Read gave an illustrated talk to the Bournemouth Natural Science Society in their Christchurch Road premises on the subject of 'Diamonds and De Beers'. Included in his presentation was a display of gemmology books, diamond testing instruments and replicas of famous diamonds.

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FORTHCOMING MEETINGS

London
Meetings will be held at the GAGTL Gem Tutorial Centre, 2nd floor, 27 Greville Street (Saffron Hill entrance), London EC1N 8SU. Entry will be by ticket only at £3.50 for a member (£5.00 for a non-member) available from the GAGTL.

28 February	**The art and science of valuation**	Rosamond Clayton
3 April	**Bringing gems to the market place**	Arthur Woolgar
8 May	**Identifying inclusions within gemstones**	Jamie Nelson
10 June	Annual General Meeting and Reunion of Members	

Midlands Branch
Monthly meetings will be held at the Discovery Centre, 77 Vyse Street, Birmingham 18 (for directions to the Sunday Gem Club Venue contact Gwyn Green on 0121 445 5359). Further details from Mandy MacKinnon on 0121 624 3225 or Neil Rose on 0161 483 8919.

18 February	**Gem Club** – Talk on history of pearl buttons and bead-stringing workshop	
23 February	**Jades**	Alan Jobbins
4 March	**Visit to Birmingham Assay Office**	
24 March	**Gem Club** – Silversmithing activity day	
29 March	**Lavriotike: treasure house of Attika**	Edgar Taylor
14 April	**Gem Club**	
26 April	Annual General Meeting followed by a talk by D.H. Ariyaratna	
28 April	Preliminary Gemmology Seminar	
5 May	Diploma Gemmology Seminar	
19 May	**Gem Club** – day visit to Dolgellau Gold Mine	

North West Branch
Meetings will be held at Church House, Hanover Street, Liverpool 1. Further details from Joe Azzopardi on 01270 628251.

20 March	**Introduction to gemmology**	Deanna Brady
15 May	**Jade, past and present**	Rosamond Clayton
19 June	**Jewellery in the auction world**	David Lancaster

Scottish Branch
For details of Scottish Branch meetings contact Ruth Cunningham on 0131 225 4105.

7 February	**A Lab Night at Telford College, Edinburgh**
22 March	**Quiz Night and Bring and Buy**

MEMBERS' MEETINGS

London

On 1 October 1995 the GAGTL Annual Conference was held at the Scientific Societies Lecture Theatre, New Burlington Place, London W1. A full report was published in *Gem and Jewellery News*, 1995, Vol. 5, No. 1.

On 16 October at 27 Greville Street, London EC1N 8SU, Howard Vaughan gave a presentation illustrated by slides and a video entitled 'Recent developments in the diamond industry'.

On 30 November at 27 Greville Street, Dr John L. Emmett, a principal of Crystal Research, Pleasanton, California, gave an illustrated lecture entitled 'The heat treatment of corundum: a view from the laboratory'.

Midlands Branch

On 29 September 1995 at the Discovery Centre, 77 Vyse Street, Birmingham 18, Mr Philip Stocker gave an illustrated lecture entitled 'Jewellery valuations and their attendant problems'.

On 27 October at the Discovery Centre Mr Stephen Kennedy of the GAGTL laboratory gave an illustrated lecture entitled 'Pearls – production and identification'.

On 24 November at the Discovery Centre the speaker was Mr James Gosling. His topic was 'Jewels in the hand, a celebration of Elizabethan and Jacobean miniatures'.

On 2 December the forty-third anniversary dinner was held at Barnt Green.

North West Branch

On 20 September 1995 at Church House, Hanover Street, Liverpool 1, Dr John Franks gave an illustrated talk entitled 'Natural History of jewellery'.

On 18 October at Church House a gemmology evening was held for members and guests. Those attending were invited to bring along interesting items of jewellery for examination and discussion.

On 15 November at Church House the Annual General Meeting was held at which Irene Knight and Joe Azzopardi were re-elected Chairman and Secretary respectively.

Scottish Branch

On 19 September the Scottish Branch held its first outing which was a tour of the British Geological Survey unit in Edinburgh.

On 20 October at Newliston House, Newbridge, Edinburgh, Doug Garrod of the GAGTL gave a talk on traditions and superstitions connected with gemstones.

PRESENTATION OF AWARDS

The Presentation of Awards gained in the 1995 examinations was held at Goldsmiths' Hall, Foster Lane, London, on 6 November. The President, Mr Eric Bruton, presided and welcomed those present, including visitors from India, Japan, Korea, Norway and Taiwan. He reported that a total of 1095 students sat the Gemmology and Gem Diamond examinations in 1995, 619 of whom had been successful which represented a pass rate of just over 56 per cent. Students from 26 countries in all five continents qualified in this year's Diploma Examination.

The awards were presented by Peter Read and his address is set out below. The vote of thanks was given by Ian Thomson and in conclusion Eric Bruton thanked the Goldsmiths' Company for once again allowing the GAGTL to hold the ceremony at the Hall.

Address by Peter Read

It's a great pleasure to be here tonight addressing you in this impressive and historic Goldsmiths' Livery Hall. My greetings and congratulations are also especially directed to all those students who have just received their richly deserved diplomas – as a former student I'm well aware of the

effort you have made in achieving this goal.

Looking around the Hall earlier this evening reminded me of my own attendances here some twenty years ago. I'm not referring to those pleasant occasions when I too was the recipient of the Gemmological Association's Diplomas, but to the much more stressful hours I spent in this very Hall sitting the Association's theory and practical examinations under the watchful eye of Robert Webster. Among a group of around 45 other budding gemmologists, I still remember the rising tension during the final minutes of the three-hour practical exam as some of us literally ran between the various test instruments to identify the last few stones in the list. Inevitably the very last stone was dropped on the floor by a nervous student – this was not, surprisingly, yours truly – my speciality was knocking over the bottle of contact fluid! On this occasion Robert Webster was quickly on the scene and went down on his hands and knees to search for the missing gem. As you can appreciate, the lighting in the hall was not ideal for this task and someone offered a pen torch. By now the hands of the clock were indicating that the exam's three hours were up, and two of us were still waiting to test the missing stone. But with Robert in charge we need not have worried – the stone was quickly found and we were awarded an extra five minutes of 'injury time' to complete our tests! Little did I imagine then, that one day I would have the honour of returning to this same Hall and presenting the awards to another generation of graduate gemmologists.

Unlike many of my contemporaries who have been closely associated with the jewellery trade for most of their working lives, I discovered the fascinating world of gemmology much later in life. The main benefit of this tonight is that any reminiscences I might be tempted to indulge in will of necessity be reasonably brief.

Strictly speaking, my contact with the gem world only really started in 1970 when I joined De Beers Central Selling Organization in London to set up their first engineering development department. Prior to that time I had been a technical author and an electronics development engineer with companies such as the GEC, Iliffe publishers, Plessey, and Johnson Matthey the precious metals specialist.

Diploma Trade Prize winner, Johanna Carlsson, receiving her prize from Peter Read.

Some of you may be wondering at this point why De Beers were in need of an electronics engineer and a development department. Well, the sale of rough diamonds at the CSO had increased enormously in the post war years, and this had meant a similar increase in the number of diamond sorters. With more and more people handling the diamonds, De Beers decided that it made sense to begin automating some of

the less skilled sorting processes such as sieving and weighing.

One of my projects at Johnson Matthey had been the development of an automatic gold grain weighing system for the production of 10 tola currency bars. When I was offered the opportunity to move less than a hundred yards down Hatton Garden and take on the problems of automatic diamond weighing at De Beers, I readily agreed – a move from precious metals to gem diamonds was a chance not to be missed. As De Beers newly appointed Technical Manager my brief was first to set up a small development department. During the following years my department designed and installed computer-controlled automatic weighing systems in London, Kimberley and Botswana. We also introduced many other sorting aids including high-speed diamond counters, automatic diamond sieving machines and television shape sorting. During this period I became aware that evening classes in gemmology and gem diamond were being held in the Sir John Cass Institute at Aldgate (now called the London Guildhall University). As I was in the privileged position of seeing thousands of carats of rough diamonds passing through the various sorting departments each day, the gem diamond course seemed an ideal way to learn more about this stone. Unfortunately, it was not possible in those days to take the diamond course and sit the exam without first taking the gemmology course. Undaunted, I signed on for the gemmology course. Because of my lack of contact with gemstones other than uncut diamonds, I spent much of my exam preparation time in the Geological Museum's mineral gallery. So much time in fact that I had the feeling that the staff were beginning to follow me around – perhaps they thought I was casing the joint!

By 1976 my three years of evening study spent at the Cass Institute were finally over, and I was at last the proud possessor of both the gemmology and gem diamond diplomas. I must confess, however, that the amount of work I had to put in to ensure a comfortable pass far exceeded anything I had experienced in qualifying as a Chartered Engineer. This, of course, is why the FGA qualification is held in such high esteem around the world.

When I eventually left De Beers to start my own consultancy company, I also began writing articles for the trade magazines and for the *Journal of Gemmology*. The particular aspect of gemmology I chose to write about was one that as an engineer I found particularly interesting – gemmological instruments. Eventually I persuaded Butterworths to let me write a book on the subject. After this was published they suggested that I turned a series of articles I had written on gemmology into a paperback entitled *Beginner's guide to gemmology*. This slim volume appeared to find favour with students over the following years. In retrospect, perhaps this was because both author and reader were the 'Beginners'! The next book to be published was my *Dictionary of Gemmology* and, in 1991, after several reprints, *Beginner's guide* was finally replaced by my more comprehensive text book *Gemmology*.

Back in 1979 I had been fortunate enough to be chosen by the Rayner Optical Company as their consultant and over the next few years designed several gem test instruments for them. Perhaps the most important of these was the UK's first thermal diamond tester, in which endeavour I was encouraged by Harry Wheeler, who was secretary of the Gemmological Association from 1973 to 1982. With the introduction of cubic zirconium oxide as a diamond simulant, particularly in sizes smaller than the testing capability of the reflectance meter, Harry had foreseen the usefulness and the growing demand for such an instrument.

Because of my involvement with computers at De Beers, it seemed a logical step to write a computer program containing gemmological data. The result was GEMDATA, the world's first commercial computer pro-

gram for gemstone identification. This has just been released in its sixth update version.

Over the last two years, with the backing of the Gemmological Association, I have developed a new instrument using the Brewster angle of polarization. This has the advantage over the standard model of a range which covers refractive indices from 1.40 to around 3.3 – and without the need for contact liquid.

When, in 1986, I became a tutor for the Gemmological Association's correspondence courses, I was also running adult education courses in gems and gemmology at West Dean College near Chichester and in Bournemouth. This latter activity, of course, was all part of a cunning plan to introduce the general public to the exciting world of gemstones, and at the same time make them aware of the Gemmological Association's courses!

In an extension to this method of subliminal advertising, I have also followed the precedent set several years ago by our President Eric Bruton, and published two gemmological novels *Diamond mine* and *The Peking diamonds* – whoever said gemmology was dull!

I often find that memories are triggered by smells. Perhaps you do too. For me the smell of resin-cored solder takes me back to my electronic engineering days, while the all pervading smell of heavy liquids reminds me of happy evenings spent identifying gems at the Cass Institute. Unfortunately, the aroma of methylene iodide (or di-iodomethane as it's called today) is not so welcome in the home. Even with my study door firmly closed, it takes only a few minutes for my wife to become aware that I'm using my refractometer, or that I've unstoppered my heavy liquids to check the SG of a stone. If sodium polytungstate ever replaces the smelly organic liquids, gemmology will not seem the same!

In ending my reminiscences I will borrow part of one of Churchill's phrases and remind tonight's successful candidates that being awarded the Diploma is not the *end* of the learning process. It is not even the end of the beginning. For you the most exciting part of the great gemmological experience is just about to start, as it did for me twenty years ago.

Finally, I can do no better than quote the words that my De Beers friend and former colleague Jeremy Richdale used in his Keynote talk at the Italian GemFest '95... 'There has never been a better time to be a gemmologist or a student of gemmology, and the future for the science of gemmology has never been more promising.'

Thank you – and may I wish tonight's award winners the best of luck in their careers.

MEETINGS OF THE COUNCIL OF MANAGEMENT

At a meeting of the Council of Management held on 20 September 1995 at 27 Greville Street, London EC1N 8SU, the business transacted included the election of the following:

Transfers – DGA to FGA, DGA

Bray, Betty A., Abilene, Tex., USA. 1995
Everitt, Sally Ann, London. 1995
Yoshida, Miyuki, Hong Kong. 1995
Zhou, Min, Wuhan, China. 1995

Transfers – FGA to FGA, DGA

Carroll Marshall, Anne E., Hong Kong. 1995
Cassarino, Paul R., Rochester, NY, USA. 1995
Fan, Siu Kam, Kowloon, Hong Kong. 1995
Fantis, Charoulla, London. 1995
Farion, Jean-Christophe, South Kensington. 1995
Fung, Wai Yin, Hong Kong. 1995
Hamp-Gopsill, David, Burton-on-Trent. 1995
Hui, Sze Wai, Kowloon, Hong Kong. 1995

Hung, Vivian Chi Ling, Hong Kong. 1995
Kwan, Wai Shun, Kowloon, Hong Kong. 1995
Lai, Mui Guk Margaret, Hong Kong. 1995
Lakhtaria, Yashwin, London. 1995
Nicholson, Charles J.R., London. 1995
Papadopoulos, Iraklis, Athens, Greece. 1995
Pegg, Delia, Petts Wood. 1995
Ruhmer, Fiona J., Hammersmith. 1995
Smyth, Lesley J., London. 1995
Spooner, Carole, Wokingham. 1995
Wakefield, Melanie, Horsham. 1995
Williams, Jason F., West Byfleet. 1995

Transfers – Ordinary Membership to DGA
Hofer, Peter M., Northwood. 1995
Hung, David Lam Chiu, Kowloon, Hong Kong. 1995
Mamo, Charles, Wanstead. 1995

Transfer – Ordinary Membership to FGA
Cadby, John H.V., Trowbridge. 1995
Cadby, Sarah, London. 1995
Chen, Jyh-Shyang, Taipei, Taiwan, ROC. 1995
Dokken, Aarrynne D.C., Sutton. 1995
Ho, Hsiung-Chien, Taipei, Taiwan, ROC. 1995
Iwata, Kaoru, Kanagawa, Japan. 1995
Kathoon, Junaida, Singapore. 1995
Kawamura, Toshiko, Sakurai City. 1995
Kleiser, Alwen M., Holyhead. 1995
Lin, Fiona, Taipei, Taiwan, ROC. 1995
Owens, Suzanne, Dublin. 1995
Purkiss, Karen A., Colchester. 1995
Rabstein, Wolf Isidore, London. 1995
Smallenburg, M.A., Amsterdam, The Netherlands. 1995
Sotolongo, Sachiko Kashiba, London. 1995
Tada, Reiko, Osaka, Japan. 1995
Tanaka, Daisuke, Kobe City, Japan. 1995
Thornton, Timothy J., Kettering, 1995
Turner, Caroline, Southwold. 1995
Whipp, David, Thornton Heath. 1995
White, Michele, Moseley, Birmingham. 1995

Diamond Membership and Fellowship
Bratton, Tim, London. 1976/1977
Wilson, Andrew Robert, Worthing. 1980/1986

Diamond Membership
Allberg, Mauritz, Stockholm, Sweden. 1995
Badibanga, Carine, London. 1995
Garland, Annette Joy, London. 1995
Kassam, Sultan Mohamed, London. 1995
Keating, Elaine, London. 1995
Tsoi, Chung Ho, Hong Kong. 1995
Wan, Stephen, Hong Kong. 1995

Fellowship
Ajani, Shilpa Chetan, Bombay, India. 1985
Buxani, Naina Mahesh, Kowloon, Hong Kong. 1993
Carr, John Raymond, Cheltenham. 1995
Cheng, Ming Chi, Hong Kong. 1995
Day, Stephen J., Peterborough, Ont., Canada. 1995
Haitioniemi, Mia Maria, Kuusankoski, Finland. 1995
Ho, Tung Tak, Hong Kong. 1995
Leung, Stephen Ping-Kwong, Thornhill, Ont., Canada. 1995
Moore, Julie Lyn, Swadlincote. 1995
Rickard, Sarah, Market Harborough. 1995
Rosier, Wendy Julia, Stanley, Hong Kong. 1995
So, Che Shing, Kowloon, Hong Kong. 1995
Yates, David Hayman, Whatstandwell, Nr Matlock. 1995

Ordinary Membership
Aslanian, Mehran Artin, Tettenhall.
Battiscombe, Brigid, London.
Birtwhistle, John Percy, Telford.
Clarkson, James D., Reno, Nev, USA.
Dagermark, Sofa, London.
Fielding, Geoffrey Ian, Bury.
Foote, David Stuart, Reading.
Forbes, Victoria Elizabeth, Portadown.
Grondin, Daniel, Geneva, Switzerland.
Harvey, Mark Anthony, Hinckley.
Hegi, Matthieu M.M., Geneva, Switzerland.

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Kritikou, Eleni, London.
Lee, Dongjae, London.
Lorking, Derek, Walthamstow, London.
Matza, Eynat, London.
Mewani, Ashok, Montego Bay, Jamaica.
Mitchell, Christopher Hagon, Leigh-on-Sea.
Mitteregger, Unni, London.
Monje, Lucy, London.
Omine, Mitsunobu, Stanmore.
Pepprell, Eija-Liisa, London.
Riddell, Vanessa Stella, Harrow.
Rizwan, Babar, Ilford.
Schutt, Alan W., Bristol.
Silverio, Ma Rita, Mandaluyong City, Philippines.
Slattery, Bozenna, London.
Starreveld, Francis M.M., Hilversum, The Netherlands.
Stern, Sara, Arlington, Va, USA.
Swaffer, Hugh, Brighton.
Torrent, Denise, Geneva, Switzerland.
Torto, Augustine Bockaire, London.
Vernon, Penny Ann, High Wycombe.
Vivian Smith, Marina Lea, Quan, Vietnam.
Whiteson, Sarah Jane, London.
Yap, Hui Ling, Penang, Malaysia.
Yasuma, Kaori, Tokyo, Japan.

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Morelle Davidson Ltd., London.

At a meeting of the Council of Management held on 17 October 1995 at 27 Greville Street, the business transacted included the election of the following:

Diamond Membership
Chan, Yuk Fan Anna, Kowloon, Hong Kong. 1995

Fellowship and Diamond Membership
Eggleston, Avrina, London. 1995/95
Jones, Karen, Caernarfon, Gwynedd. 1985/86

Fellowship
Carlsson, Johanna A., London. 1995
Dillimuni, Dayananda, Colombo, Sri Lanka. 1978
Diserens, Myriam, Paudex, Switzerland. 1994
Hawken, Diana Blair, Hong Kong. 1995
Lee, Sau Mui Angela, Kowloon, Hong Kong. 1995
Mak, So Yi, Hong Kong. 1994
Papadopoulos, Dimitrios, Athens, Greece. 1995
Schmidt, Simon Peter, London. 1991
Shetty, Vaju Krishna, Bombay, India. 1995
Soo, Hoi Leung, Hong Kong. 1995
Stead, Graham Scott, Tillsonburg, Ont., Canada. 1995

Ordinary Membership
Caspi, Daniel R., London.
Davis, Roberta Kay, Harborne.
Hargreaves, David, London.
Haria, Aarti Vipul, Nairobi, Kenya.
Johnson, Helen Louise, Edinburgh.
Khashkovskaia, Tatiana, St Petersburg, Russia.
Patel, Ajay, Reading.
Rönkkö, Veera Viktoria, London.
Söderström, Jenny, Lannavaara, Sweden.
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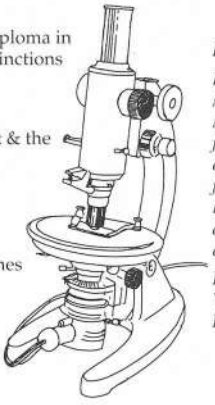

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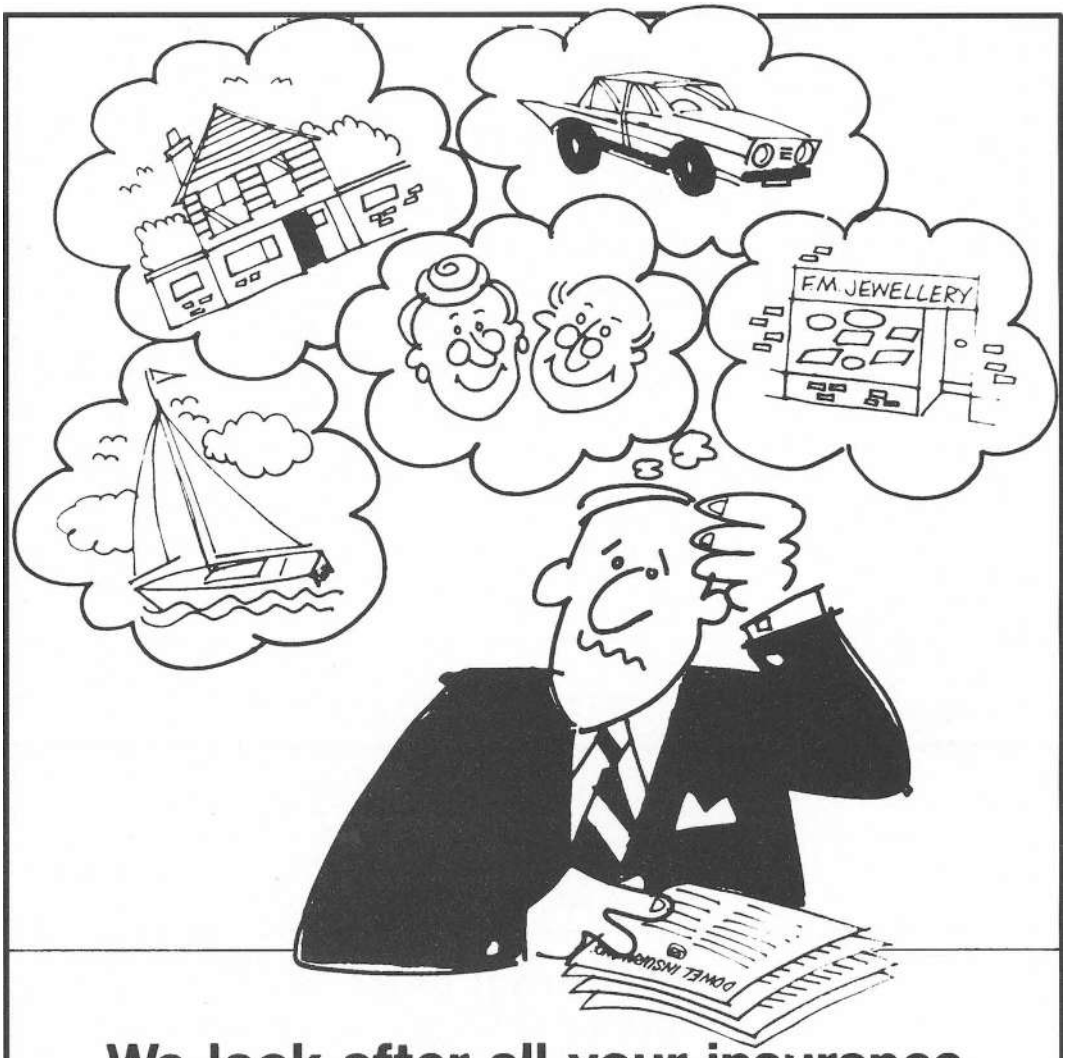

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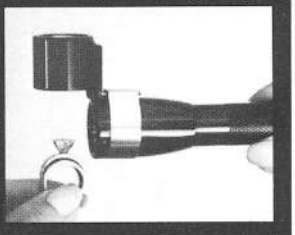

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Typescripts Two copies of all papers should be submitted on A4 paper (or USA equivalent) to the Editor. Typescripts should be double spaced with margins of at least 25mm. They should be set out in the manner of recent issues of *The Journal* and in conformity with the information set out below. Papers may be of any length, but long papers of more than 10 000 words (unless capable of division into parts or of exceptional importance) are unlikely to be acceptable, whereas a short paper of 400–500 words may achieve early publication.

The abstract, references, notes, captions and tables should be typed double spaced on separate sheets.

On matters of style and rendering, please consult *The Oxford dictionary for writers and editors* (Oxford University Press, 1981).

Title page The title should be as brief as is consistent with clear indication of the content of the paper. It should be followed by the names (with initials) of the authors and by their addresses.

Abstract A short abstract of 50–100 words is required.

Key Words Up to six key words indicating the subject matter of the article should be supplied.

Headings In all headings only the first letter and proper names are capitalized.

A **This is a first level heading**

First level headings are in bold and are flush left on a separate line. The first text line following is flush left.

B *This is a second level heading*

Second level headings are in italics and are flush left on a separate line. The first text line following is flush left.

Illustrations Either transparencies or photographs of good quality can be submitted for both coloured and black-and-white illustrations. It is recommended that authors retain copies of all illustrations because of the risk of loss or damage either during the printing process or in transit.

Diagrams must be of a professional quality and prepared in *dense* black ink on a good quality surface. Original illustrations will not be returned unless specifically requested.

All illustrations (maps, diagrams and pictures) are numbered consecutively with Arabic numerals and labelled Figure 1, Figure 2, etc. All illustrations are referred to as 'Figures'.

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Notes and References Authors may choose one of two systems:

(1) The Harvard system in which authors' names (no initials) and dates (and specific pages, only in the case of quotations) are given in the main body of the text, e.g. (Gübelin and Koivula, 1986, 29). References are listed alphabetically at the end of the paper under the heading References.

(2) The system in which superscript numbers are inserted in the text (e.g. ...to which Gübelin refers.[3]) and referred to in numerical order at the end of the paper under the heading Notes. Informational notes must be restricted to the minimum; usually the material can be incorporated in the text. If absolutely necessary both systems may be used.

References in both systems should be set out as follows, with *double spacing* for all lines.

Papers Hurwit, K., 1991. Gem Trade Lab notes. *Gems & Gemology*, **27**, 2, 110–11

Books Hughes, R.W., 1990. *Corundum*. Butterworth-Heinemann, London. p. 162

Abbreviations for titles of periodicals are those sanctioned by the *World List of scientific periodicals* 4th edn. The place of publication should always be given when books are referred to.

Volume 25 No. 1 January 1996

The Journal of Gemmology

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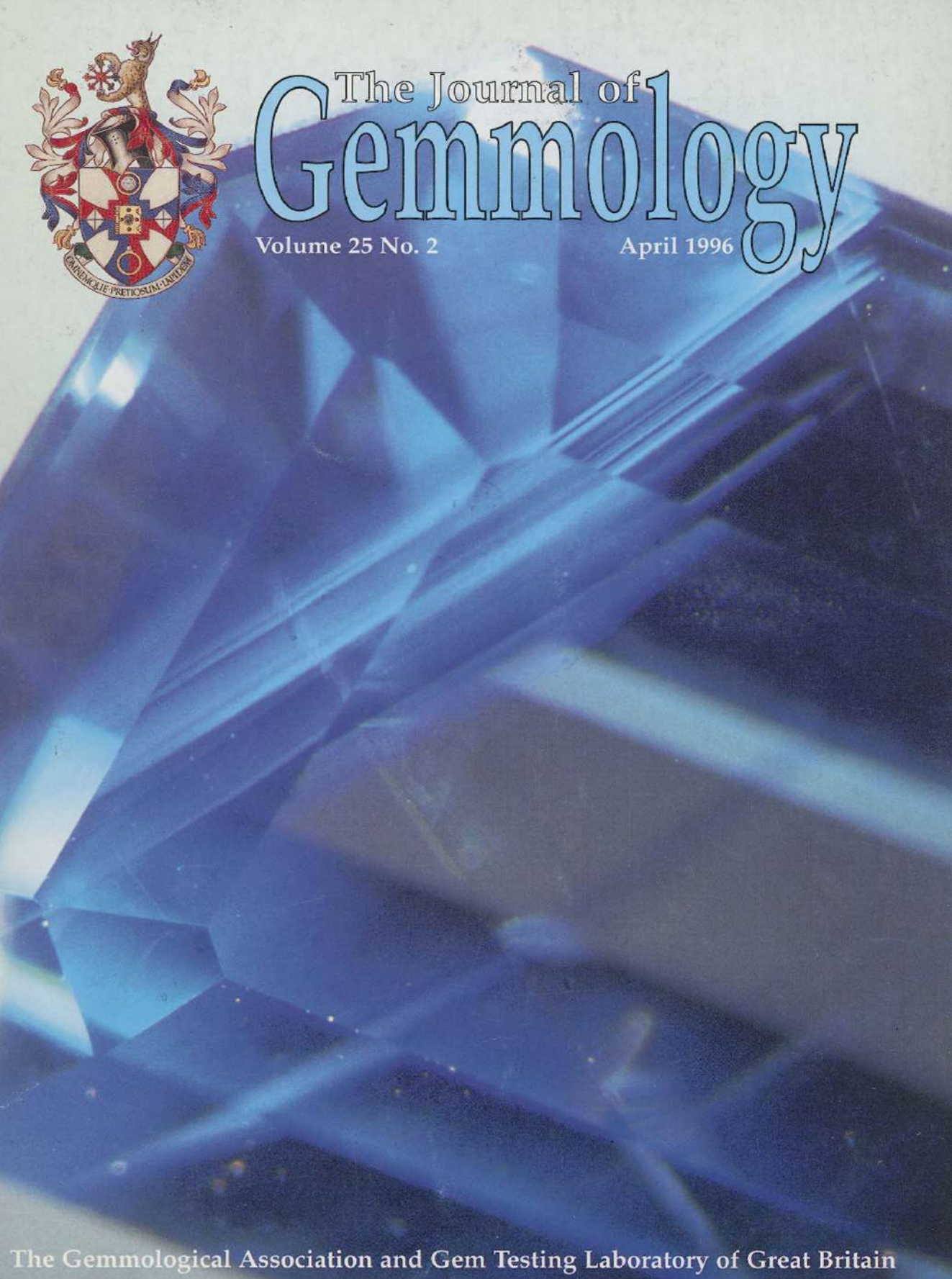

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Cover Picture

Faceted sapphire from Cyangugu district, SW Rwanda. See 'Investigations on sapphires from an alkali basalt, South West Rwanda' on pp 90–106.

In this issue...

We introduce this issue with an update of a collection started many years ago and first described in this *Journal* in 1987. Its original motive was to enlighten the student of gemmology with the number of stones that could be mistaken for diamond. But with increasing knowledge it led to appreciation on other levels with the fascinating range of gem materials that could appear in colourless form or with the subtleties of recognizing small variations in this 'colourlessness'. There are now 46 stones in the collection and they are listed with some basic gem parameters.

Rwanda has been in the news for all the wrong reasons in the past year so it is good to report a development of some potential for the local people. Sapphires have been discovered in the Cyangugu district in south-west Rwanda (bordering Zaire) and details of their source and gem characteristics are described. Most crystals are a deep blue but some show the milkiness characteristic of the Sri Lankan 'geuda' and these respond well to heat treatment. They contain a wide range of inclusions and a new texture found on some rough crystals, not previously reported, is described and discussed.

Ever since they were first discovered in 1917 the deep blue beryls from the Maxixe mine in Brazil have been a source of fascination both for those in the gem trade and for investigative gemmologists. Maxixe beryls, as they came to be known, are quite different from the commoner blue beryl, aquamarine, in that their colour has a different source within the crystal structure and it fades when exposed to sunlight. The third paper in this issue sets out some current thinking about Maxixe beryls and proposes suitable terminology and its limits of application in the beryl family.

The final paper presents the results of a thorough investigation (involving more than 1000 samples) of a range of emeralds and green beryls from Central Nigeria. Detailed work on inclusions, compositions of hosts and inclusions and on spectra are illustrated, and provide a reference to enable confident identification of emeralds from this locality. Some Nigerian emeralds do contain spiky three-phase inclusions and resemble Colombian emeralds, but again the means for distinguishing between stones from the two localities are indicated.

R.R.H.

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Common and rare colourless gemstones

David Kent FGA

London

Over the years I have compiled a collection of colourless gemstones which have been a source of fascination especially for students embarking on their gemmological studies. To a greater or lesser extent the stones may all be considered as diamond simulants and in 1987 a list of 39 stones was published (*J.Gemm.*, **20**(6), 344-5). Following some recent acquisitions (and one or two delightful presents!) I feel it is appropriate to bring the record of the collection up to date.

A new style Ever Ready P6 9-volt battery was fitted to the infrared reflectometer and all the specimens were measured again. This led to lower readings (compared with those in the 1987 table) for lithium niobate and smithsonite and a higher reading for the diamond/synthetic sapphire doublet. The higher meter reading for paste results from replacing the original stone with a much more lively lead-glass paste. Is the higher reading for the diamond/synthetic sapphire doublet due to deterioration of the adhesive?

Benitoite and beryllonite in the original list were on loan and have been returned to their owners, and the new additions comprise natrolite, oligoclase, sillimanite, kornerupine, spodumene, chrysoberyl, anglesite and scheelite. There are now 46 stones in the collection and the relevant data are given in Table I.

Table I: Revised list of the David Kent colourless stone collection with additions since 1987. Infrared reflectometer readings calibrated at 70 for diamond. In order of meter readings.

Meter reading	*Mean RI*	*Specimen*	*Carat weight*	*Hydrostatic SG*
17	1.434	Fluorite	2.91	3.18
17	1.440	Opal	1.96	2.00
17	1.487	Natrolite	0.21	
20	1.506	Petalite	2.06	2.39
20	1.510	Leucite	0.85	2.50
21	1.539	Oligoclase	0.79	2.63
22	1.549	Quartz	2.69	2.65
22	1.549	Synthetic quartz	4.67	2.65
23	1.540	Iolite	1.19	2.58
23	1.560	Scapolite	0.39	2.60
23	1.561	Labradorite	1.25	2.68
23	1.583	Beryl	1.48	2.74
24	1.613	Paste	1.63	3.54
25	1.615	Topaz	3.95	3.56
25	1.622	Amblygonite	2.58	3.03
25	1.629	Tourmaline	0.60	3.00
25	1.640	Baryte	8.00	4.49
25	1.647	Datolite	0.96	2.90
26	1.633	Danburite	1.59	2.98
26	1.675 (approx.)	Smithsonite	0.44	4.08
27	1.657	Jadeite	1.77	3.34
27	1.657	Enstatite	1.03	3.22
27	1.661	Euclase	0.43	3.08
28	1.661	Phenakite	0.85	2.98

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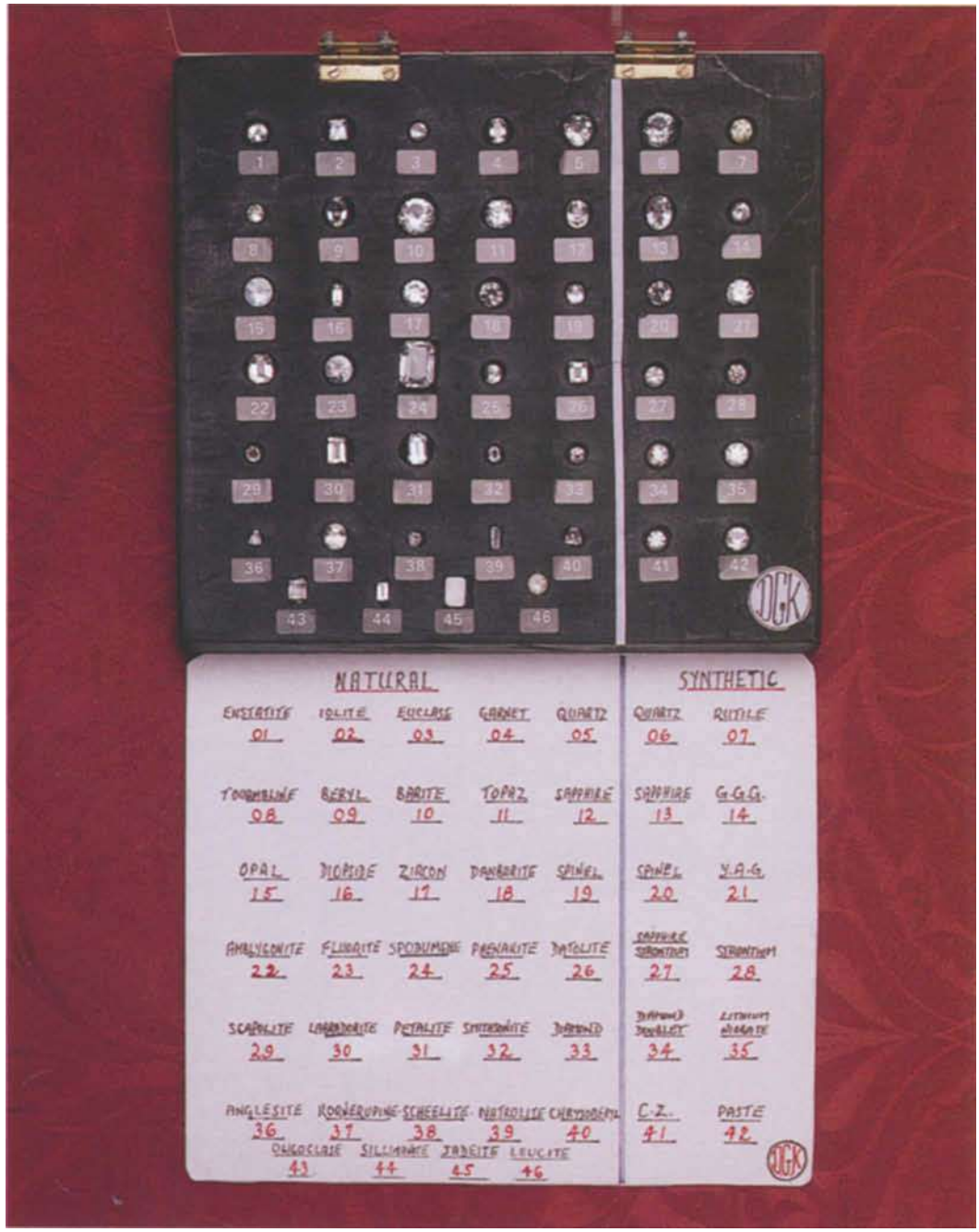

Fig. 1. The author's boxed collection of colourless stones.

Meter reading	Mean RI	Specimen	Carat weight	Hydro-static SG
28	1.668	Sillimanite	0.44	3.14
28	1.668	Kornerupine	1.96	3.26
28	1.668	Spodumene	10.44	3.19
29	1.678	Diopside	0.53	3.41
30	1.714	Spinel	0.96	3.61
30	1.725	Synthetic spinel	1.68	3.65
31	1.736	Garnet	1.26	3.60
32	1.746	Chrysoberyl	0.60	3.75
33	1.764	Sapphire	2.73	4.00
33	1.764	Synthetic sapphire	3.93	4.00
35	1.81	Anglesite	0.57	3.33
37	1.926	Scheelite	0.395	6.05
38	1.83	YAG	2.90	4.57

Meter reading	Mean RI	Specimen	Carat weight	Hydro-static SG
39	1.764	Synthetic sapphire/strontium titanate doublet	1.12	4.66
42	1.95	Zircon	2.52	4.66
42	2.03	GGG	1.67	7.10
56	2.17	CZ	1.51	5.80
58	2.25	Lithium niobate	2.36	4.63
64	2.41	Strontium titanate	1.21	5.14
70	2.42	Diamond	0.48	3.52
80	2.68	Synthetic rutile	1.56	4.20
90	2.42	Diamond/synthetic sapphire doublet	1.68	3.82

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Investigations on sapphires from an alkali basalt, South West Rwanda

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Abstract

A new deposit of sapphires in the Cyangugu district of SW Rwanda has been investigated. The sapphires are believed to have originated from a specific alkali basalt lava flow, extruded during the Tertiary extensional regime along the East African Rift. They exhibit mainly a deep blue colour, often showing so-called silk (inclusions of hematite or rutile) or a slight milkiness possibly due to submicroscopic exsolution of these minerals. Greyish 'geuda'-type crystals are known to convert to a blue colour by heat treatment. Values for the refractive indices and specific gravity are given, as well as VIS-IR data. Studies of the inclusions reveal the presence of Ti and Fe oxides, silicates, spinel, zircon and a complex Th-REE phosphate as solid inclusions; the presence of CO_2 in fluid inclusions was determined by microthermometric methods. Studies of crystal surfaces by SEM show corrosion or abrasion features, both primary and secondary. The primary corrosion occurred during the transport of the deep-crustal sapphires to the surface; it can be attributed to the high-temperature magma. Secondary abrasion took place during the erosion and weathering of the basalt and the subsequent formation of alluvial sapphire deposits.

Keywords: sapphire, alkali basalt, inclusions, corrosion, scanning electron microscopy

Introduction

East-Central Africa is well known for rich gemstone deposits. Extensive sapphire mining has been described from the Umba river (Tanzania), Garba Tula and Turkana (Kenya) (Hughes, 1990; Themelis, 1989; Hänni, 1986; Kanis and Harding, 1990; Barot and Harding, 1994).

Rwanda, at present in the political focus because of the tragic civil war, was until now barely known for gemstone deposits. One of the authors (MSK) recently had the opportunity to investigate a new sapphire deposit in a basalt province in the Cyangugu district, SW Rwanda (Figure 1). This investigation was made possible by kind support of J.F. Damon (Twin Gems, Washington DC).

After a geological field trip of two months which included trenching and sampling in a region of approximately 200km^2, some areas of major interest for sapphire mining were established (Figure 2). Due to the rapid decomposition of rocks in a tropical humid climate, the main sapphire deposits are of alluvial type. They are exploited mostly by the local population using traditional methods (Figure 3). Twenty representative sapphire samples from the Cyangugu district were selected for the laboratory and investigated by various methods, including spectrophotometry

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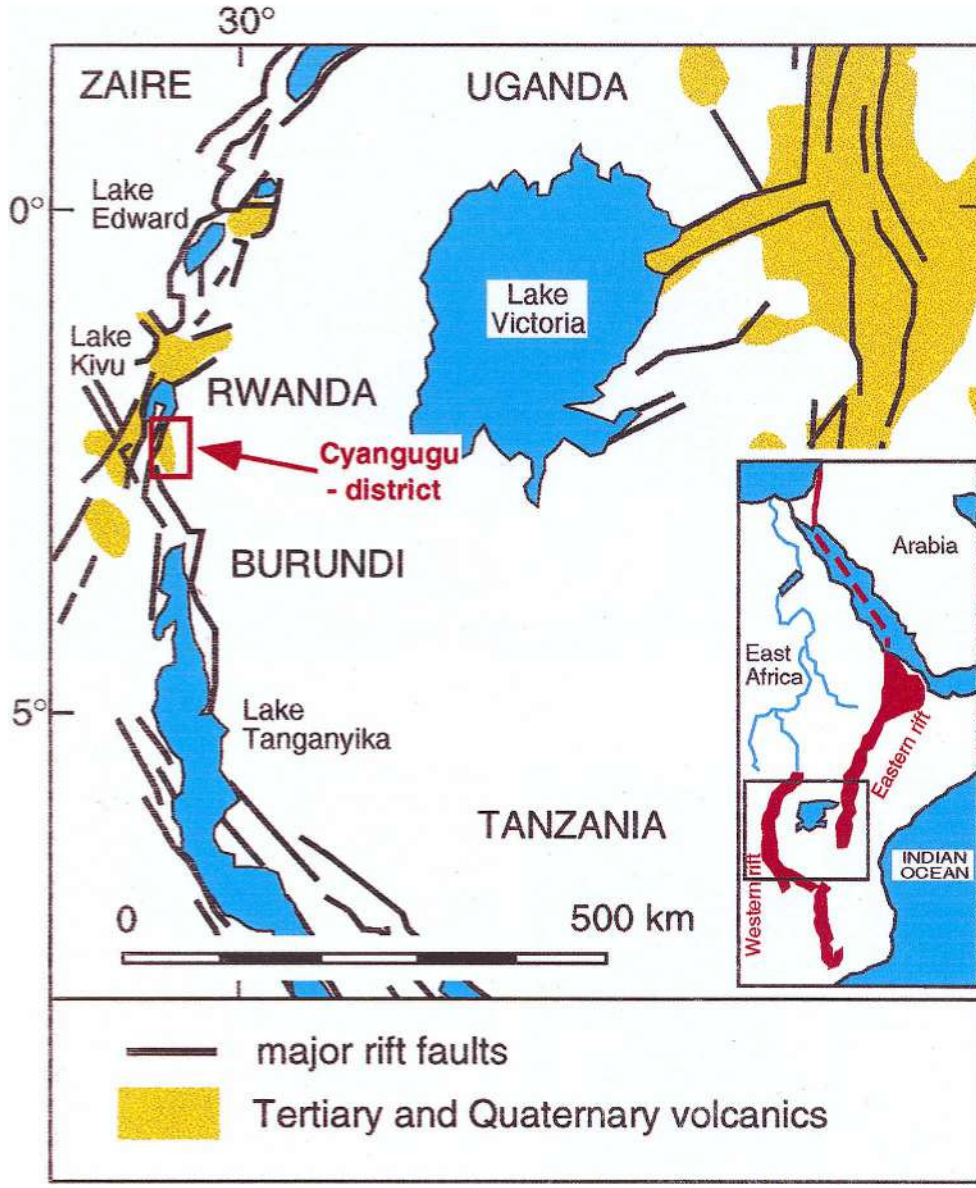

Fig. 1. Simplified geological map (after: Wilson, 1991).

(VIS-IR), SEM-EDX, ED-XFA, EMP-WDX, microthermometry and optical microscopy (OM) (Table I). During these analytical procedures information was gained about the trace elements responsible for colour, solid as well as fluid inclusions and surface features of sapphire crystals. In particular, a specific surface feature, which resulted from a shielding effect of plagioclase on sapphire and which influenced the primary corrosion in the basalt in a very spectacular way was observed.

Fig. 2. Prospecting trench in an alluvial deposit in the Cyangugu district.

Fig. 3. Local resident, working the alluvial deposit by traditional methods.

Geological setting

The western border of Rwanda follows the western branch of the East African rift (Figure 4), a continental rift zone, which has been tectonically active for the last 45 million years, i.e. since the early Tertiary. It forms a part of the Afro-Arabian rift system, which extends some 6500 km from Turkey to Mozambique. As a result of the extensional tectonics along this rift, the Red Sea opened in the northern part, whereas in the south, rifting occurred to a much lesser extent (Figure 1).

The western branch of the East African Rift has developed in a rather episodic way, accompanied by intense extensional faulting of the Precambrian basement. The basement is characterized by continental sedimentary rocks, i.e. sandstones and arkoses lying on a metamorphic substratum of gneisses and amphibolites. Upwelling of asthenosphere (upper mantle) caused a regional domal uplift

Table I: Gemmological properties of sapphires from Cyangugu district, SW Rwanda

Colour and visual appearance with unaided eye:	dark blue, transparent to semitransparent with microscopic and submicroscopic inclusions ('silk')
Refractive index:	n_o 1.770–1.771 n_e 1.761–1.762
Birefringence:	Δ_n –0.009
Specific gravity:	3.998–4.005
Dichroism:	greenish-blue and dark blue
Absorption spectrum:	absorption features at 375nm, 390nm, 450nm and a broad absorption band at 890nm
Reaction to long wave and short wave ultraviolet radiation:	no fluorescence

Fig. 4. The Ruizizi river in the western branch of the East African rift valley, SW Rwanda.

Fig. 5. Faceted sapphire from Cyangugu district, SW Rwanda.

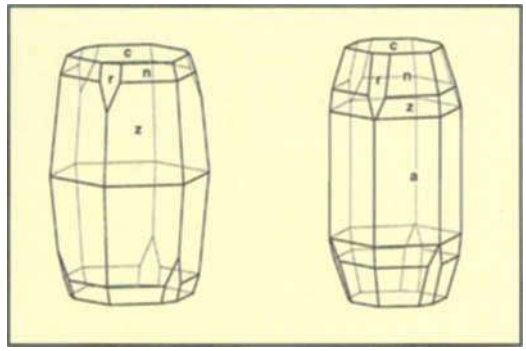

Fig. 7. Crystal habit of prismatic sapphires (after: Kiefert, 1987).

combined with intracontinental basaltic volcanism, which is typically dominated by alkali basalts (Cahen *et al.*, 1984; Wilson, 1991) (Figure 6).

The sapphire deposits in SW Rwanda are connected to this Tertiary-Quaternary volcanic activity. The sapphires have been brought to the surface by an alkali-basaltic magma, in which they were transported as xenoliths (alien crystals, separated in the upper mantle or deep crust from their original melt or rock). Alkali basaltic rocks as parent rocks of corundum are encountered in many places worldwide, and economically important deposits are exploited, e.g. in Australia, Thailand, Nigeria and China (Coenraads, 1992a; Guo *et al.*, 1992).

Due to the intense decomposition of volcanic rocks in the humid climate, sapphires have not been found in their host rock (embedded in alkali basalt), but by carefully examining the eluvial and alluvial gravel accumulations, the sapphire-bearing primary deposit could be assigned to a specific Tertiary alkali basalt. This coarse-grained, olivine-rich basalt flow always occurs near the contact between Tertiary basalt and the Precambrian basement. Therefore it is suggested that this coarse-grained alkali basalt had been erupted during an early stage of the Tertiary-Quaternary volcanic activity in south-western Rwanda.

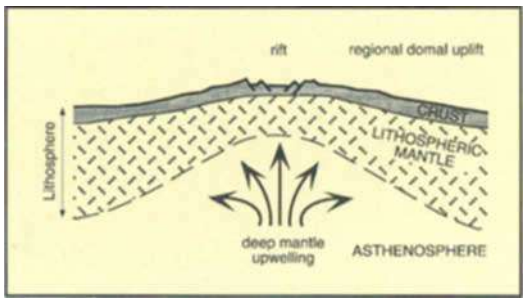

Fig. 6. Schematic profile through the intracontinental rift zone (after: Wilson, 1991).

The sapphires, concentrated in these eluvial and alluvial deposits are found together with zircon (red-brown and colourless transparent), magnetite, hematite, rutile, pyrite and quartz (originating from the Precambrian rocks).

The Cyangugu sapphires

Mineralogy

Sapphire, basically the blue variety of corundum Al_2O_3, occurs generally in high alkaline and silica-undersaturated rocks. Two types of geological settings are possible (Levinson and Cook, 1994); the sapphires originate from metamorphic rocks (e.g. dolomite marbles, gneisses) or from magmatic rocks (alkali basalts and pegmatites). Trace elements such as the transition metals Fe, Ti, Cr, V are known to cause a broad variety of colours in sapphires. Either alone or in combination, these ionic impurities may act as chromophores when substituting for Al^{3+} in the

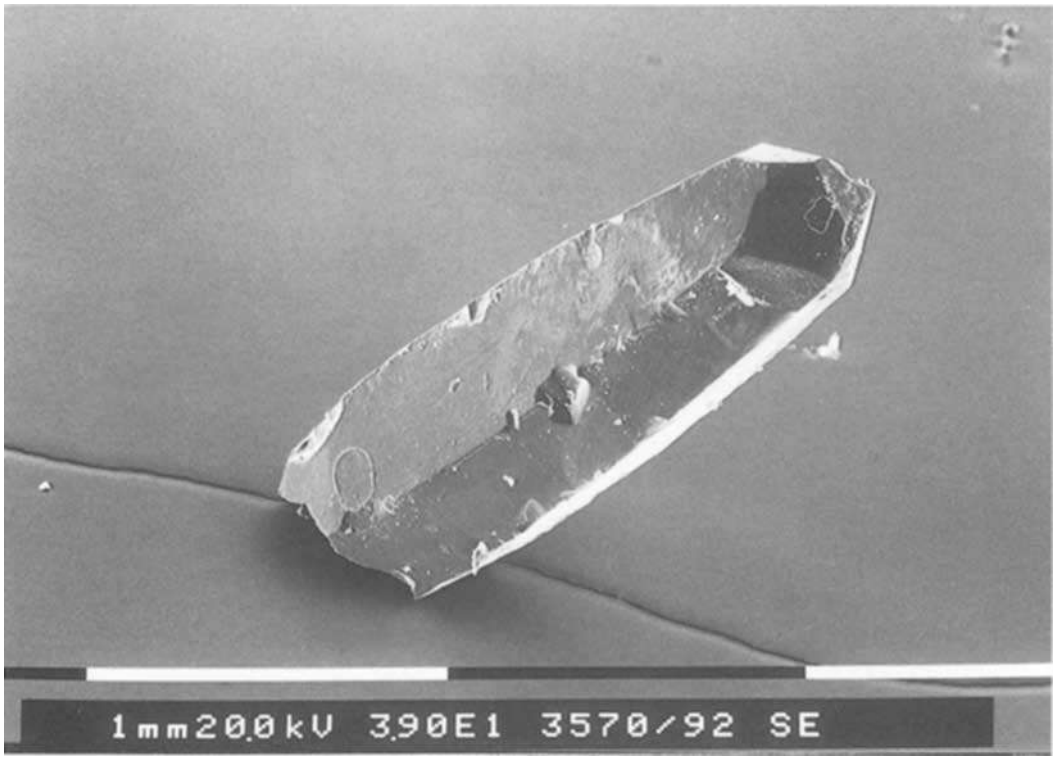

Fig. 8. Slender, prismatic, uncorroded sapphire from the Cyangugu district.

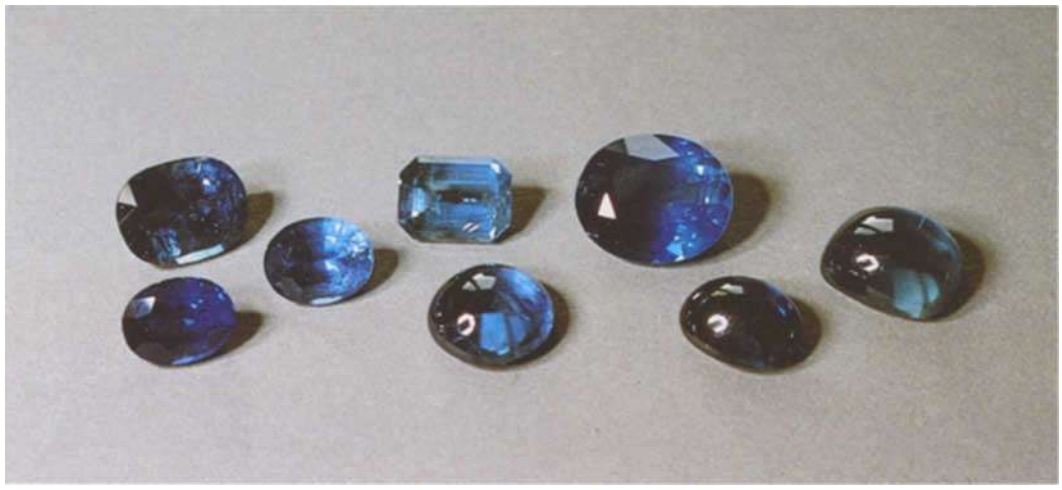

Fig. 9. Faceted and cabochon sapphires from the Cyangugu district. Largest stone is approx. 8 ct.

crystal structure. It has also been observed that these trace elements can actually quit their places in the corundum lattice and concentrate in individual inclusion minerals (Schmetzer, 1986) such as rutile (TiO_2), hematite (Fe_2O_3) or ilmenite ($FeTiO_3$). As many natural sapphires exhibit growth and colour inhomogeneities, experimental research concentrates on the improvement of the colour in lower quality sapphires by means of heat treatment (Themelis, 1992). During such treatment, former hematite or rutile inclusions may be re-dissolved and their Fe and Ti ions diffuse into the crystal lattice structure where they then may play the role of chromophore elements.

Morphology of rough sapphires

The Cyangugu sapphires are generally 1–8ct in weight and their habit is mostly prismatic-pyramidal. Rhombohedral crystals are much rarer. These observations are in agreement with those made by Kiefert (1987) on sapphire from other basaltic origins (e.g. Nigeria and Australia). She described as significant morphological faces, *a*, *r*, *n* and *z*, whose combination led to tabular, barrel-shaped prismatic and pyramidal crystals (Figure 7).

The surface morphology of the sapphires from the Cyangugu district is in general strongly affected by primary and secondary corrosion or abrasion effects and fractures. Normally the sapphires are broken into flat fragments along the basal plane (0001). Only a few small individuals have preserved their long prismatic shape (Figure 8).

Spectroscopy and chemical analyses

The sapphires from Cyangugu district (Figures 5 and 9) are mainly deep blue but greyish and yellowish tints are also found. The latter are suitable for colour modification by heat treatment (Themelis, 1992).

In sapphires from Rwanda, the blue colour is mainly caused by the Fe^{2+}/Fe^{3+} intervalence charge transfer (IVCT) (cf. Karr, 1975; Schmetzer and Bank, 1981; Schmetzer, 1987). A typical UV-visible-near IR-spectrum reveals three distinct peaks at 375nm, 390nm and 450nm and a broad absorption peak centred at 890nm, which correspond to Fe^{3+}, Fe^{3+}/Fe^{3+} ion-pairs and Fe^{2+}/Fe^{3+} -IVCT absorption (Figure 10, compare also Fritsch and Mercer, 1993).

In one specimen an absorption shoulder at 560nm (o-vibration spectrum) was observed, caused by the superposition of Fe^{2+}/Ti^{4+} -IVCT on the Fe^{2+}/Fe^{3+} -IVCT absorption band (Figure 11). But as most spectra reveal no distinct peak at this wavelength (560nm), normally the Fe^{2+}/Ti^{4+}-IVCT can be neglected as the cause of colour in these sapphires. The spectral absorption feature at 780nm as observed with o-vibration spectra in Figure 11 remains unexplained (see Schmetzer, 1987).

The strongly dichroic colour of sapphires from Cyangugu district is well illustrated by the different absorption curves in Figure 11.

Qualitative (ED-XFA) and quantitative chemical analyses by the electron microprobe (EMP-WDX) on the same sapphire samples confirmed the spectroscopic information about their trace element content (Table II). Fe is present at constant trace element levels (~0.5 wt% Fe_2O_3), whereas the distribution of Ga varies (~0.03 wt% Ga_2O_3). Ti (and V, Cr, Ca) is nearly at or below detection limit (~0.015 wt% TiO_2) and therefore the blue colour cannot solely be attributed to the Ti. Detection limits below 0.001 wt%, as seen in the literature (Schmetzer and Banks, 1981; Zwaan, 1974), seem quite astonishing in the present context, unless more sensitive analytical methods were used.

Microscopy

Rwanda sapphire samples often exhibit a so-called silk (crystallographically oriented inclusions of submicroscopic dimensions). According to various authors (compare Schmetzer, 1986) rutile needles are oriented parallel to the first order prism of the host corundum. The orientation of

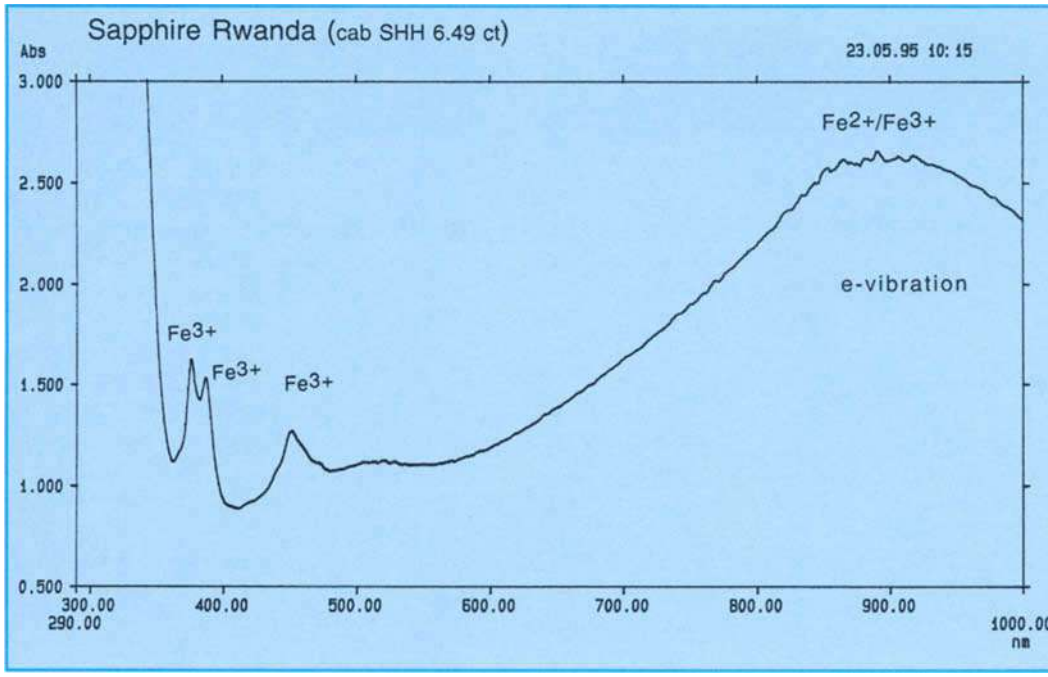

Fig. 10. Wavelength absorption spectra of a sapphire from the Cyangugu district (e-vibration spectrum).

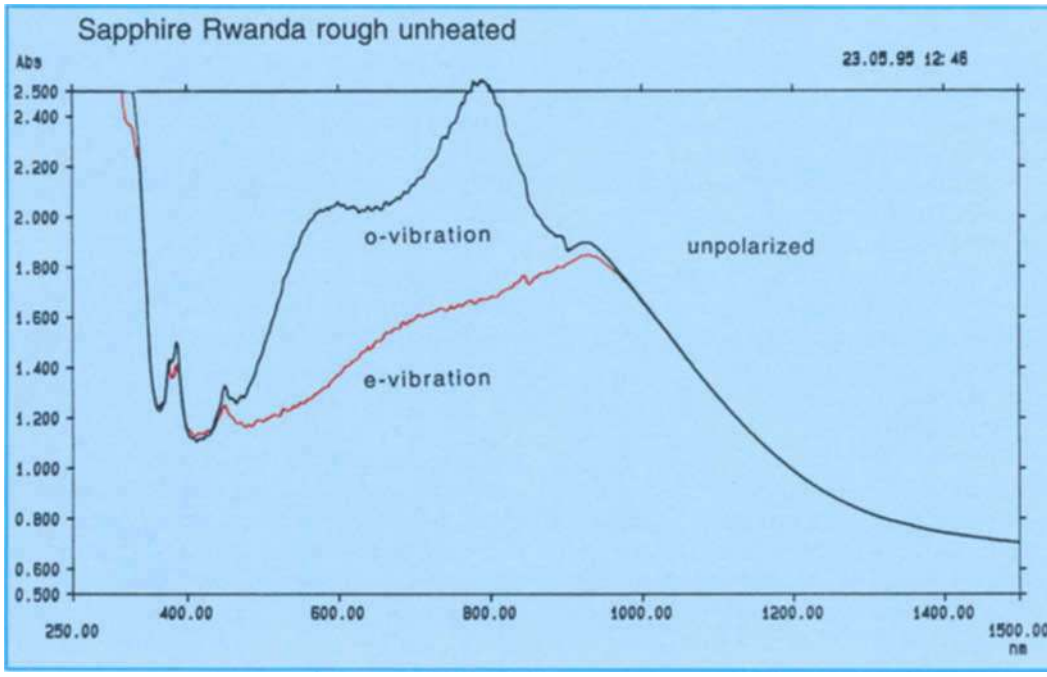

Fig. 11. Wavelength absorption spectra of a sapphire from the Cyangugu district (o- and e-vibration spectra).

Table II: Quantitative chemical analyses (EMP-WDX) of two sapphires from SW Rwanda

	Mean of 3 analyses	*Mean of 5 analyses*
Al_2O_3	99.31	99.53
Fe_2O_3	0.55	0.46
TiO_2	0.01	0.01
Cr_2O_3	n.d.	0.01
V_2O_3	n.d.	0.01
Ga_2O_3	n.d.	0.04
CaO	n.d.	n.d.
Total	99.87	100.06

n.d.: not detectable (below detection limit)

hematite tablets may be parallel to the first order prism, or to the basal plane. By heat treatment, this silk occasionally can be removed, and stones of better quality are obtained. The silk normally occurs in growth zones, thus reflecting a varying supply of Ti and Fe during sapphire formation. Growth inhomogeneities can usually be recognized using dark-field optical microscopic techniques.

Inclusion studies

Identification of inclusions in gemstones is of considerable importance, as the inclusions yield information about the genesis of the gemstones and therefore may be – with some restrictions – essential for determining authenticity or even the origin of a gemstone (Hänni, 1994).

A number of solid inclusions, randomly encountered in the sapphires, have been investigated by the SEM-EDX technique and also using back-scattered electron images (BSE); these have been compared with the results from inclusion studies in sapphires from other alkaline basaltic deposits (Gübelin and Koivula, 1986; Coenraads, 1992b; Guo *et al.*, 1992; Wang, 1988). Microthermometric studies revealed the presence of just one type of fluid inclusion which is CO_2-dominant.

Ti and Fe oxides: rutile, ilmenite and hematite

These inclusions are very common, typically with irregular shapes and dimensions of 0.1 to 2mm. They are not noticeably oriented along the trigonal crystal structure of the sapphire and generally consist of aggregates of at least two of the three oxides. Partial replacement of rutile (TiO_2) by ilmenite ($FeTiO_3$) at the grain rims can be observed (Figure 12).

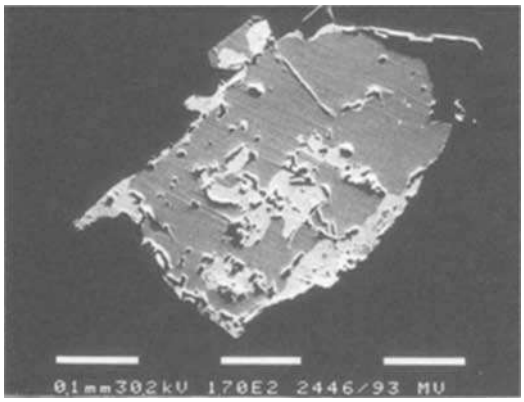

Fig. 12. BSE-micrograph (SEM) of a rutile inclusion, which is partly replaced by ilmenite (white).

Submicroscopic Ti and Fe oxides
As mentioned above, many sapphires from the Cyangugu district show distinct growth zones which contain varying amounts of submicroscopic inclusions – the cause of the translucent (silky) appearance of sapphires. Tiny hematite and rutile crystals may be responsible for this effect, which has been described by many authors from sapphire deposits throughout the world (Hughes, 1990; Gübelin and Koivula, 1986). In the Cyangugu sapphires hematite occurs as tiny brownish inclusions with a 'flaky' (ragged) shape, and rutile occurs as (sub)microscopic, white needle-shaped inclusions (Figure 13).

Genetically, the finely dispersed submicroscopic inclusions may be related to the microscopic Fe- and Ti-oxides. Both reflect the varying Ti and Fe supply during the growth of the sapphires (Figure 14). The relatively large Ti-Fe-oxide inclusions represent protogenetic crystals, enclosed by the growing sapphire. During the following cooling stage, they probably underwent an isochemical replacement reaction where ilmenite was formed from rutile + hematite. In contrast, the submicroscopic Fe-Ti-inclusions are probably a product of the cooling of the sapphires, during which the Fe and Ti ions, formerly dissolved in the corundum lattice, began to precipitate, forming tiny hematite and rutile inclusions, with orientation controlled by the crystal structure of the corundum.

Silicates: pyroxene, amphibole and chlorite
The shape of these inclusions normally is subidiomorphic. They are partially surrounded by a rim of chlorite, and their size normally does not exceed 0.1mm.

The Ca-Fe-pyroxenes and -amphiboles revealed similar EDX-spectra. They were distinguished, using their typical crystal shape in a thin section cut perpendicular to the c-axis of an inclusion of amphibole or pyroxene. The amphibole inclusions may represent retrograde products of primary pyroxene inclusions. During cooling, the pyroxene could have transformed to amphibole with the supply of H_2O from small scale fissures or diffusion processes within the sapphire. Such (healed) small scale fissures have been observed by OM and SEM-techniques. Mica inclusions are also present but are so fragile that they tend to disintegrate during the polishing of the sapphire samples.

Similar kinds of inclusions have been described from other alkali basalt derived sapphire deposits, e.g. in the Australian New England deposit (Coenraads, 1992b), from the Sri Lanka sapphires (Gübelin and Koivula, 1986) and in sapphires from the Shandong Province in China (Guo *et al.*, 1992).

Fig. 13. Crystallographically oriented microscopic rutile inclusions ('silk') in a sapphire from SW Rwanda.

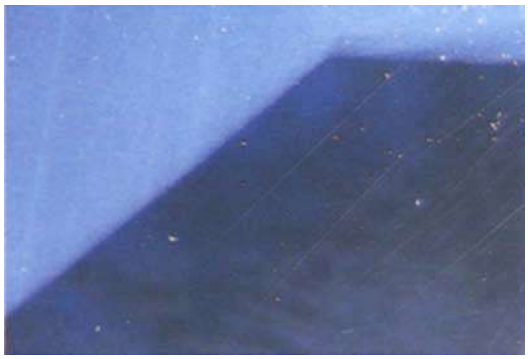

Fig. 14. Growth zoning, represented by submicroscopic inclusions.

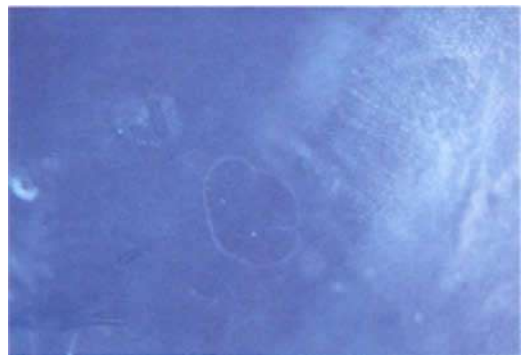

Fig. 17. Stress fissures (atoll-structure) around microscopic zircon inclusions.

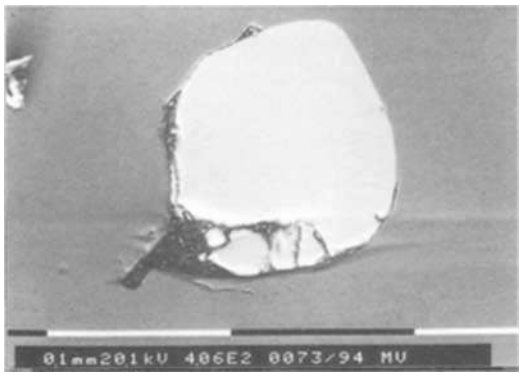

Fig. 15. BSE micrograph (SEM) of a syngenetic Fe-Zn-Al-spinel.

Spinel

In one sapphire sample a subidiomorphic solid inclusion, surrounded by a chlorite reaction rim was analysed by EDX-spectra and revealed a Mn-bearing intermediate member of the spinel solid solution series between hercynite ($Fe^{2+}Al_2O_4$) and gahnite ($ZnAl_2O_4$) (Figure 15).

Zircon and cheralite-(Ce)

Zircon and cheralite inclusions in the sapphires may be detected by back-scattered electron image investigations (SEM-BSE). Because they contain elements with high atomic weight (e.g. Zr, Th, REE...), they show a strong brightness contrast relative to the surrounding sapphire (Figure 16).

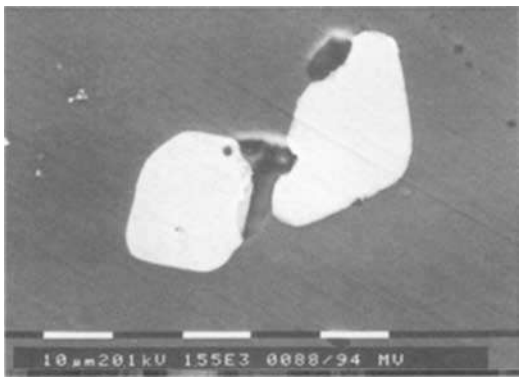

Fig. 16. BSE-micrograph (SEM) of idiomorphic zircon inclusions in sapphire.

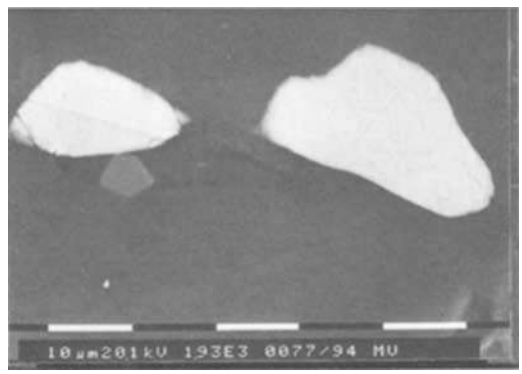

Fig. 18. BSE micrograph (SEM) of cheralite-(Ce) inclusions in sapphire.

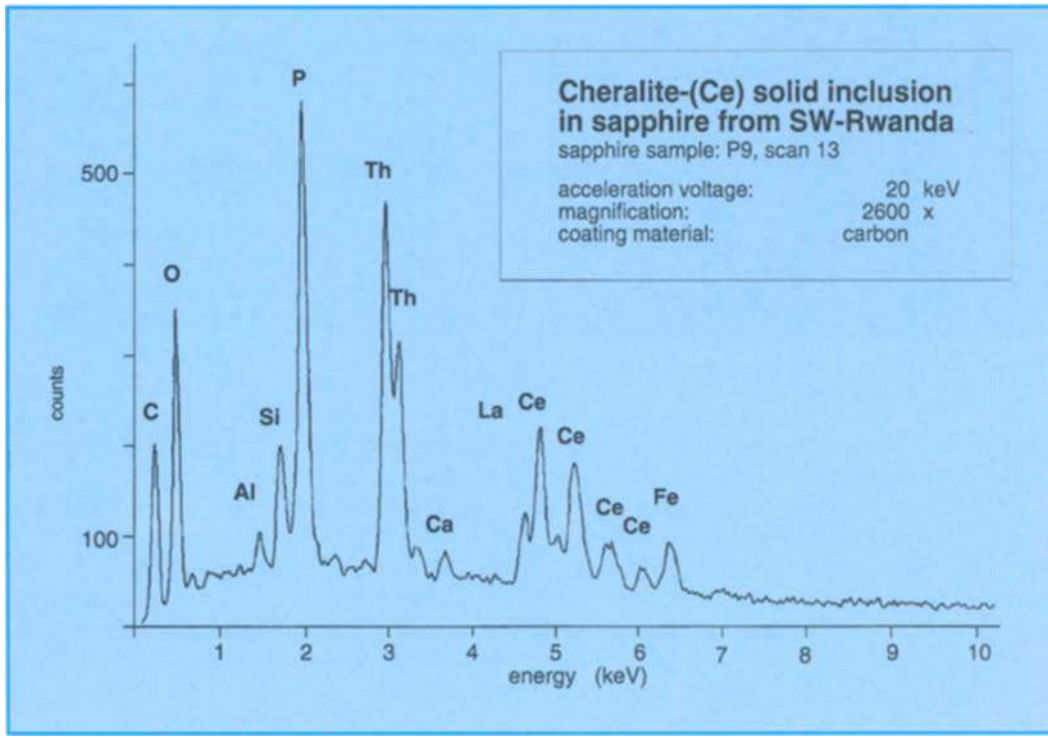

Fig. 19. EDX-spectrum of cheralite-(Ce), a complex phosphate (Ca,Ce,Th)(P,Si)O_4, of the monazite group.

The zircon inclusions (0.02 to 0.1mm) are characterized by a more or less idiomorphic shape, suggesting proto to syngenetic growth relative to the sapphire. They commonly occur in small groups and are surrounded by stress fissures in the host sapphire, typical for metamict inclusions (Gübelin and Koivula, 1986) (Figure 17).

One inclusion, adjacent to some zircon inclusions, was identified by SEM-EDX as cheralite-(Ce), a complex thorium-phosphate (Ca,Ce,Th)(P,Si)O_4, belonging to the monazite group (Figures 18 and 19).

Stress fissures around this inclusion are partially filled with a mineral (probably goethite α-FeO(OH), causing a pale brown halo (Figure 20).

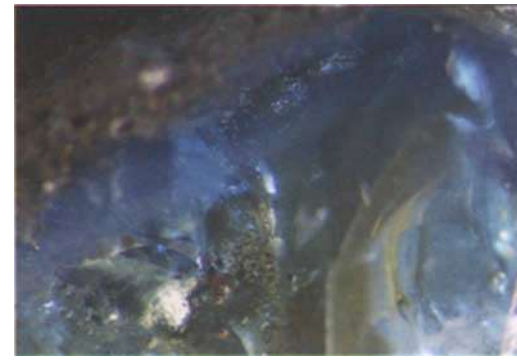

Fig. 20. Fe-hydroxide in fissures around cheralite-(Ce) inclusions.

Fluid inclusions

Microthermometric studies (by B. Bruder) of the sapphires revealed the presence of CO_2 dominated fluid inclusions as fillings of voids, negative crystals and 'fingerprints'. At room temperature, most of the fluid inclusions are monophase (pure CO_2 with a maximum density of 0.95g/cm^3). This is consistent with results from fluid inclusion studies on other volcanic sapphires. No distinctive fluid composition

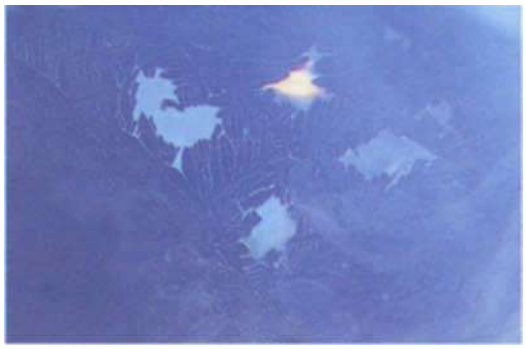

Fig. 21. Fluid inclusions along a healed fissure in a sapphire from the Cyangugu district.

and density was discovered for the Rwanda sapphires (Figure 21).

Inclusions similar to those observed in sapphires from the Cyangugu district have been described by many authors from analogous sapphire deposits in volcanic provinces. As Webster and Anderson (1983) and Hänni (1994) suggest, using the inclusions alone is insufficient to indicate the geographic origin of a gemstone. They merely give information about the geological and geochemical conditions during their genesis (for the Rwanda sapphires: during the continental volcanic activity along the western part of the East African rift suture).

Surface features

There are two main processes that have affected the surfaces of the Rwanda sapphires. *Primary corrosion*, a mainly chemical process during volcanic activity, and *secondary abrasion and fracturing*, mechanical impact processes which occurred during the erosion of basalts and subsequent transport of the sapphires to the alluvial deposit.

The primary corrosion features were studied with the SEM on eight randomly selected samples.

The genesis of sapphires from alkali basalts is still under debate. The model generally accepted is that they were formed at the conditions prevailing in the lower crust or upper mantle (high temperature and pressure) in a high aluminium environment. Most authors (Coenraads, 1992b; Guo *et al.*, 1992; Levinson and Cook, 1994) suggest, however, that the sapphires were not formed in the alkali basalt itself. The corrosion features on the surfaces of sapphires are interpreted as reactions of sapphire xenocrysts in disequilibrium with the basic magma (alkali basalt). If correct, this model implies that the basaltic magma acted merely as a transport medium and not as the parent magma of the sapphires. During the rise of the carrier magma, the sapphires were corroded by reactions with the melt.

Most Cyangugu sapphires show distinct primary corrosion features. The surface is typically rough and marked by many indentations (Figure 22). On the basal plane, there are triangular indentations, which are typical corrosion features of trigonal minerals.

One specimen is covered with a thin brownish layer (Figure 23), probably consisting of a Fe-hydroxide (α-FeO(OH)), which may have been derived originally from native iron.

Another specimen shows a very specific corrosion, not previously recorded. The whole surface is covered by a randomly oriented needle-like pattern (Figures 24 and 25), interpreted as due to long prismatic plagioclases, which covered the sapphire during its transport by and in the plagioclase-rich alkali basalt. The plagioclase partly protected the sapphire from primary corrosion in the magma (Figure 26) but due to the intense weathering of the basalt, it has since decomposed, and only the sapphire remains (cf. Coenraads, 1992a).

This specific corrosion feature sheds some light onto the relation between sapphire genesis and alkali basaltic magmatism. Plagioclases that are probably responsible for the needle-like surface pattern are virtually absent as solid inclusions within the sapphires from Cyangugu dis-

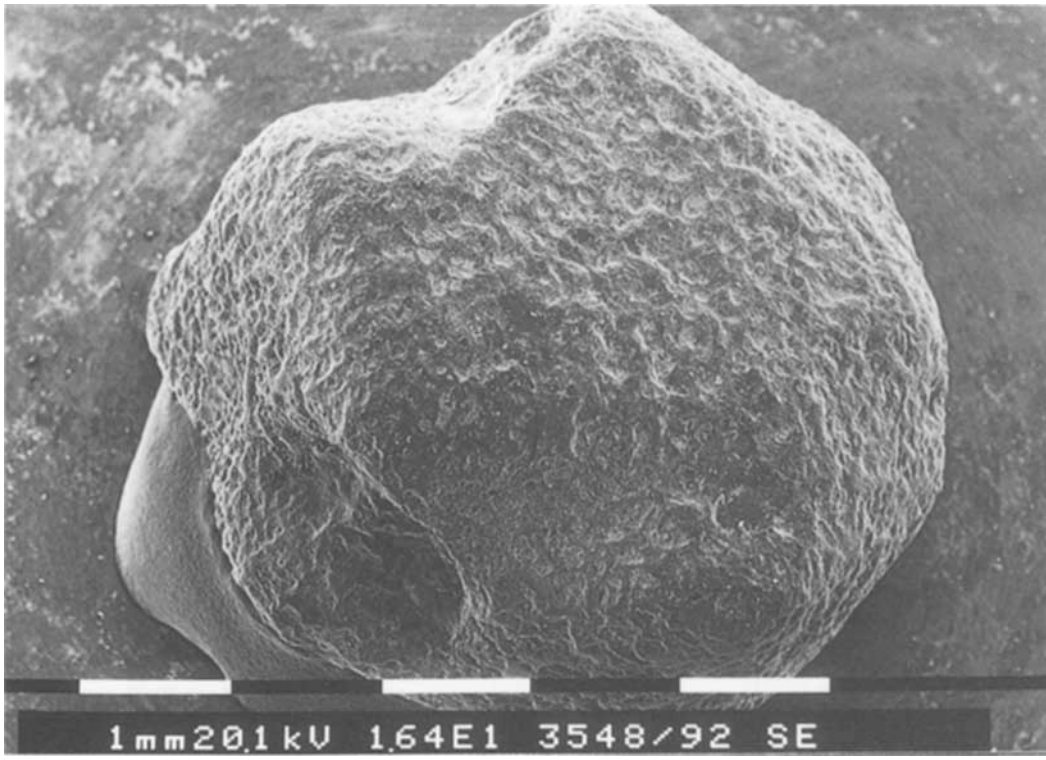

Fig. 22. SEM-micrograph of a strongly corroded sapphire from the Cyangugu district.

trict. Therefore it is suggested that these sapphires originate from a source other than the alkali basalt magma. Whether the incorporation of sapphires into the ascending alkali basalt occurred by magma mixing processes (magmatic origin of sapphires) or by supply of deep crustal rock fragments (metamorphic origin of sapphires) is not yet established (cf. Levinson and Cook, 1994). Radiometric age dating of both the alkali basalt and the sapphires (U-Pb-dating of zircon inclusions) could reveal further information on sapphire genesis (cf. Coenraads *et al.*, 1990).

Fig. 23. SEM-micrograph of a sapphire, partially protected by a Fe-hydroxide layer.

Conclusions

Sapphires from the Cyangugu district (SW Rwanda) originate from a specific alkali basalt, which has been erupted during Tertiary volcanic activity along the East African rift. Prospecting has established several alluvial-type sapphire deposits, which may have potential for future mining.

The sapphires normally are deep blue and commonly show a so-called 'silky' appearance. Three different types of solid inclusions which are typical for corundum

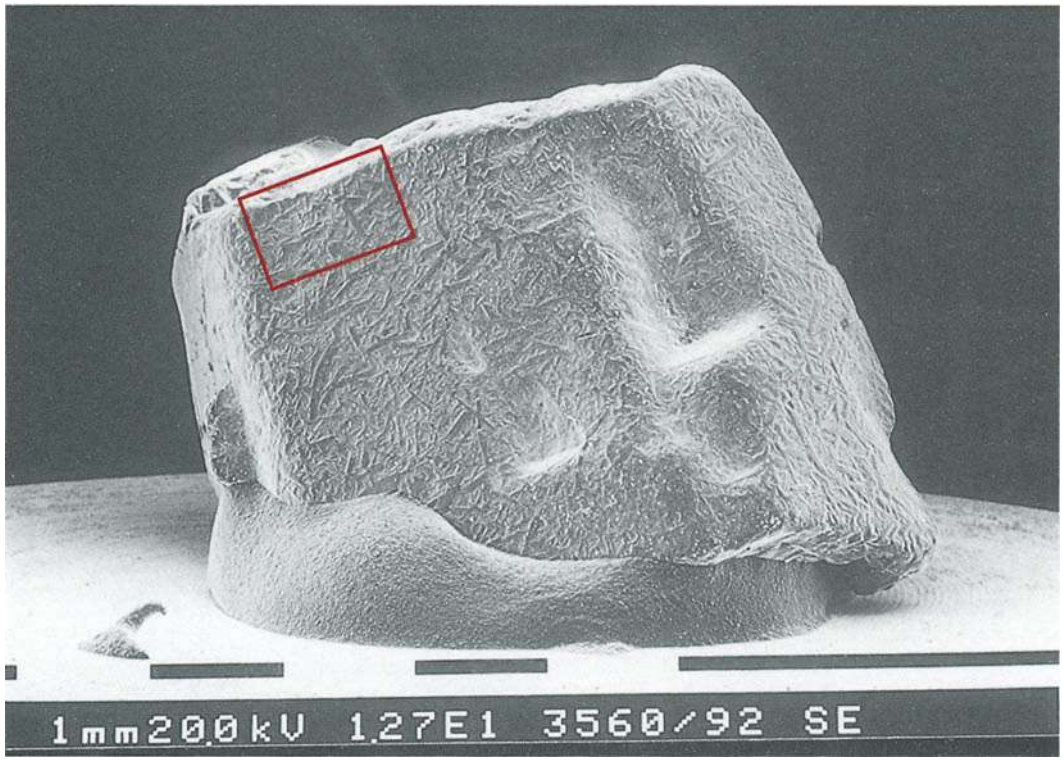

Fig. 24. SEM-micrograph of a specific needle-like corrosion feature on a sapphire of the Cyangugu district.

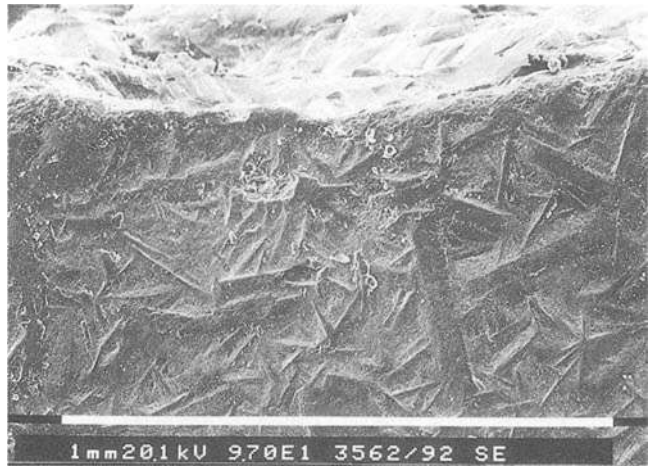

Fig. 25. SEM-micrograph of the marked area of the same sample under higher magnification.

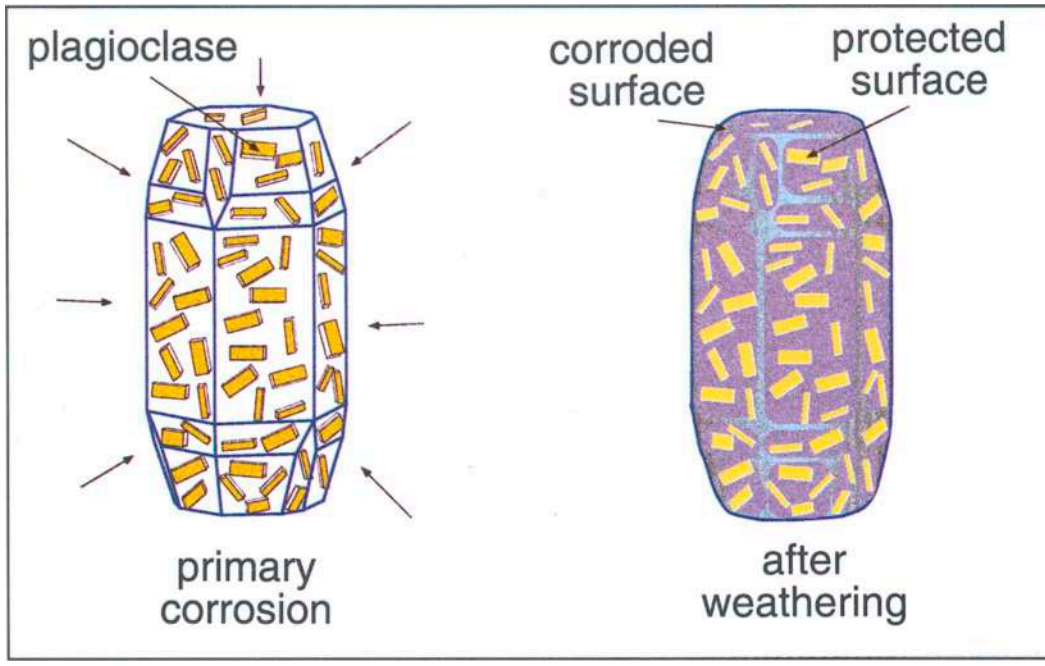

Fig. 26. Scenario explaining the genesis of the corrosion feature shown in Figures 24 and 25:
(a) the sapphire was covered by plagioclases in the ascending alkali basalt, protecting the gem stone partly from corrosion;
(b) subsequently, the plagioclases have been weathered during erosion of the erupted basalts.

from volcanic provinces have been distinguished. The sapphires often show signs of pronounced corrosion, and a needle-like pattern is interpreted as the relic of a former coating of plagioclase crystals. There is close similarity of these sapphires with those derived from other basaltic deposits, and an unambiguous identification of sapphires specifically from the Rwanda deposit is not possible.

Until now, sapphires from the Cyangugu district in SW Rwanda have not been well known on the gem market, but if the political situation stabilizes they may well become much more familiar to stone dealers and gemmologists.

Acknowledgements

We would like to thank Dr R Gieré (Min. Petrogr. Institute, University Basel) for his critical review of this paper, and Dr L. Kiefert (SSEF, Basel) for analytical assistance in taking both optical and ED-XRF-spectra and for useful discussions. Thanks also go to J.F. Damon (Twin Gems Co., Washington DC) for financial support and to J. Stähli (Bern) for the loan of faceted sapphires from SW Rwanda and for his encouragement

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Appendix

Analytical conditions

References for some of the analytical techniques applied are given in Hänni (1994). Two sapphire samples were cut and two faces polished parallel to the optic axis in order to record absorption spectra. With a Hitachi 4001 spectrophotometer the absorption features between 250 and 900nm (VIS-IR) were measured. Polarization filters were used in the visible part.

The scanning electron microscope, attached to an energy-dispersive X-ray spectrometer (SEM-EDX) is a powerful tool to obtain morphological and chemical information (Putnis, 1992). All the SEM investigations were performed on a Philips 515 instrument (20kV). Thin sections with randomly oriented, polished planes were prepared from ten samples to determine the nature of solid inclusions. The samples were coated with carbon for SEM-EDX analyses and back scattered electron imaging (BSE). Eight rough samples were sputtered with gold (20nm thickness) for SEM investigations of surface features.

Qualitative X-ray fluorescence analyses (ED-XRF) were carried out by a Philips combined Spectrace X-ray fluorescence spectrometer (25 kV, 0.3 mA, Al primary filter) in order to determine the trace elements present in the sapphires from SW Rwanda. For quantitative chemical information, two sapphires were analysed by a wavelength-dispersive electron microprobe (JEOL JXA-8600) operated at 20 kV and with a specimen current of 10 nA measured on a Faraday cage (EMP-WDX). Seven reference standards (Al, Fe, Ti, Cr, V, Ga, Ca) of well characterized natural and synthetic compounds were used and all the data were fully corrected for matrix effects by PROZA-computer program.

Two thin slices (approximately 0.3mm thick) of sapphires were investigated under a Leitz Ortholux microscope equipped with a Reynolds heating-freezing stage for microthermometry. The measurements were performed on 75 fluid inclusions by Bernard Bruder (Univ. Freiburg, Germany) who investigated fluid inclusions in corundum from various sources for his university diploma in mineralogy.

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On the identification and fade testing of Maxixe beryl, golden beryl and green aquamarine

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Abstract

Forty-three large (up to 126.66 ct) high quality faceted beryls of recent Brazilian origin were examined. Of these, 29 were intense blue Maxixe-type beryls, a material widely seen about 1970. The remaining five yellow and nine greenish beryls were found to be simply golden beryls and green aquamarines, respectively.

Heat and light exposure tests showed that an accelerated fading test must not use an excessively elevated temperature, say 50 °C (122 °F) maximum, since otherwise both aquamarines and golden beryls (which do not fade from light alone) would lose their yellow colour component from the heat and could then be misidentified as fading Maxixe beryls. This has indeed happened in one report in the recent gemmological literature, where a temperature of 100 °C was used as part of a fade test.

It is proposed that the gemmological distinction between the original 'Maxixe' and the later 'Maxixe-type' beryls be dropped, the term 'Maxixe' then covering both variants. While the distinction remains significant in mineralogy and other fields, it serves no useful purpose in gemmology.

Introduction

The early history and the gemmological characteristics of the original Maxixe beryls of 1917 and the later Maxixe-type beryls are well covered in the gemmological literature.[1–10] This includes their identification and distinction from aquamarine by the anomalous dichroism, unusual absorption spectra, and fading from exposure to light. These two variants differ somewhat in their absorption spectra and by the fact that the intense blue colour centre is associated with a nitrate impurity[8,11] in the original Maxixe beryl, or with a carbonate impurity[8,9,11] in the later Maxixe-type beryl.

It is often assumed that any intense blue original Maxixe beryl owes its colour to nature and that the equivalent colour of Maxixe-type beryl originates from man-induced irradiation as, for example, stated by Brown.[12] Yet it is clear from the literature reports that the colour of the original Maxixe beryl can also be produced or restored by irradiation by man,[4–6] and that the Maxixe-type blue beryl also occurs naturally.[10]

The distinction between these two variants is thus independent of the origin of the irradiation and depends only on the chemistry. Whether the colour derives from irradiation by nature or by man generally cannot be distinguished by gemmological or by any other form of testing. An exception occurs if an inappropriate irradiation technique has induced radioactivity, the residue of which may then be detectable, as happened at least once.[4]

Although I myself originally introduced these two variant designations,[4–6] I now believe that the distinction between the original 'Maxixe' beryl and the later

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'Maxixe-type' beryl serves no useful purpose in gemmology. It has never been used in GIA identification reports, for example. I believe it should be dropped because:

1. both variants generally occur in intense blue form in nature;
2. both can be produced by irradiation of pale colour beryl containing the necessary precursor impurities (nitrate or carbonate);
3. both fade in light in about the same time frame, although there is some variability;
4. both lose their colour on being heated, again with some variability;
5. lost colour can be restored by irradiation for both; and
6. routine gemmological testing using a hand spectroscope is not sufficient to distinguish these two variants, but this distinction is possible by using a research spectroscope.

In what follows, the designation 'Maxixe' beryl includes both variants except when specifically designated as 'original Maxixe' beryl or 'Maxixe-type' beryl.

On loss of colour by light and by heat

Experts prefer to reserve the term 'fading' for a loss of colour on exposure to light and use other terms such as 'destruction' or 'loss' of colour for the equivalent action of heat. A typical example is Herbert Smith, who in his *Gemstones*[13] describes the actions of light and heat on gemstones in separate paragraphs and uses the term 'fade' for the effects of light but not for those of heat. Again, Hunter and Harold[14] define: 'Fading: a colour change in a material that involves a weakening or lightening with time, usually as a result of exposure to light or weather.'

Rapid testing for fading uses illumination conditions much more intense than those to which a gemstone would be exposed in normal jewellery wear. In studies begun in 1973, I found[4–7,11] that Maxixe beryls faded rapidly under such conditions, losing essentially all colour in a few weeks, and stated that such material was therefore unsuitable for jewellery use. Some variability in behaviour was noted. The longer survival of this colour under normal (i.e. jewellery-wearing) illumination conditions was briefly mentioned in one of these reports.[11]

Accelerated fade testing often involves intense illumination combined with an elevated temperature to speed up the fading even more, typically less than 60 °C.

However, it is obvious that if an elevated temperature by itself changes the colour, then only such a temperature should be used for acceleration as does not itself have any effect. Nevertheless, the use of a temperature that might be present under normal illumination conditions, perhaps 50 °C (122 °F) maximum, would be reasonable.

Materials and experimental procedures

Examination of 40 beryls, the property of Dr al Gobaisi, was conducted under restricted access with limited time and equipment in January 1994 in Singapore, in part with the assistance of E. Wong and M. Stern. Conventional gemmological techniques were used, including particularly the nature and orientation of the dichroic colours and the absorption spectrum, the latter of these by use of the hand spectroscope on all 40 beryls (referred to hereafter as aG beryls).

Six of these beryls, two selected at random from each colour, were studied in more detail: intense blue, a 33.29 ct oval and a 40.59 ct cushion; yellow, a 33.77 ct oval and a 68.86 ct cushion; and greenish, a 33.85 ct cushion and a 63.23 ct pear. These tests confirmed that all were natural beryls of exceptional quality, being flawless under 10x magnification. The absorption spectra of these six beryls were also run on a BYK Gardner *Colorview* Spectrophotometer at Herberts South East Asia Pte Ltd in Singapore, using in-house software with

limited wavelength resolution, with the assistance of H. Gian and Wong. Each specimen was run three times in the geometry shown in Figure 1 and the results are shown in Figures 2 to 4.

The unusual geometry of Figure 1 had been worked out in preliminary experiments with a 25.85 ct intense blue cushion beryl, property of P. Hung, obtained by him from the same Brazilian source as the 40 aG beryls. The spectrum of this beryl was obtained by the author on a *Colorview* machine with much better wavelength resolution software at Colortech Associates, Inc. of Oldwick, New Jersey, USA, and is shown in Figure 5. The capability to run polarized spectra was not available with either of these instruments. While not as good as results from a research type instrument, these data were more than adequate to distinguish Maxixe beryl from aquamarine; both could also enable distinction between original Maxixe and Maxixe-type beryls.

Stones used for fading and heating tests included three beryls from the collections of P. Hung (hereafter designated 'PH'), obtained by him from the same source as the 40 aG beryls: the above-mentioned 25.85 ct intense blue cushion, a 13.90 ct yellow oval, and a 6.15 ct greenish oval. There were also five older beryls from the collections of the author (hereafter designated 'KN'): an 8.75 ct intense blue emerald-cut Maxixe-type beryl, a 1.55 ct greenish yellow round, a 1.75 ct greenish yellow emerald-cut, and yellow rounds of 2.20 and 2.28 ct.

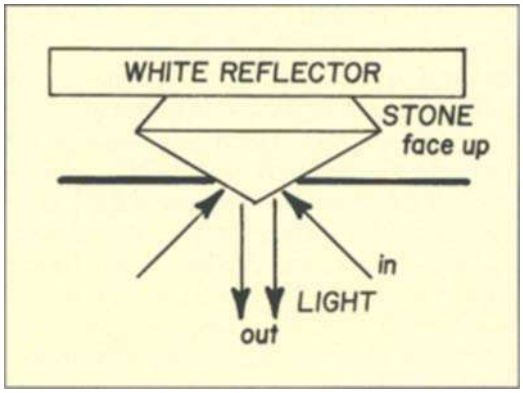

Fig. 1. The geometry used for spectral measurements on the two BYK Gardner *Colorview* Spectrophotometers to obtain the data of Figures 2 to 5.

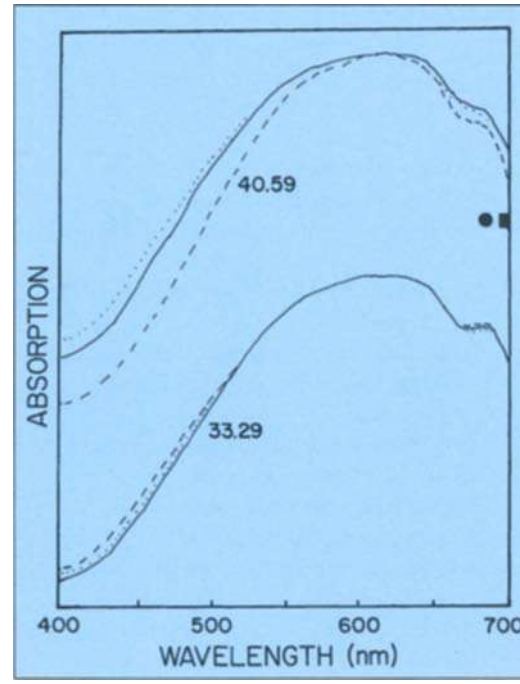

Fig. 2. Spectral curves of two intense blue aG beryls (33.29 and 40.59 ct) run in triplicate as in Figure 1; there is agreement with the position of the highest wavelength absorptions of the Maxixe-type beryl (circle), but not with that of the original Maxixe beryl (square), both taken from the 300K curves of Figure 2 of Reference 6.

The rapid fade test used in the restricted time available for this study employed incandescent light from a 150 watt internal reflector bulb for 43 hours with the face-up stone at 25 cm from the bulb as in Figure 6. Photometric measurements showed that this was approximately equivalent to a continuous (i.e. 24 hours per day) exposure to maximum (noon) sunlight for one week. A fan kept the temperature of the stone well below 50 °C, actually at a measured 44±2 °C. These conditions were different from those I had used previously[4] because of the limited time available and are not

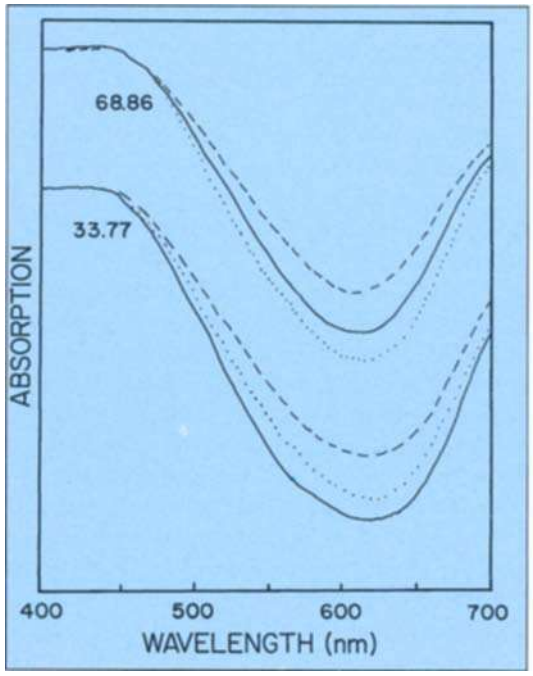

Fig. 3. Spectral curves of two yellow aG beryls (33.77 and 68.86 ct) run in triplicate as in Figure 1.

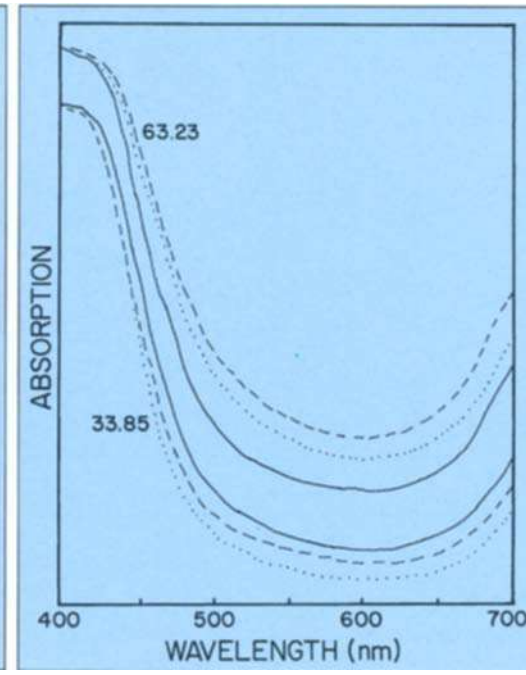

Fig. 4. Spectral curves of two greenish aG beryls (33.85 and 63.23 ct) run in triplicate as in Figure 1.

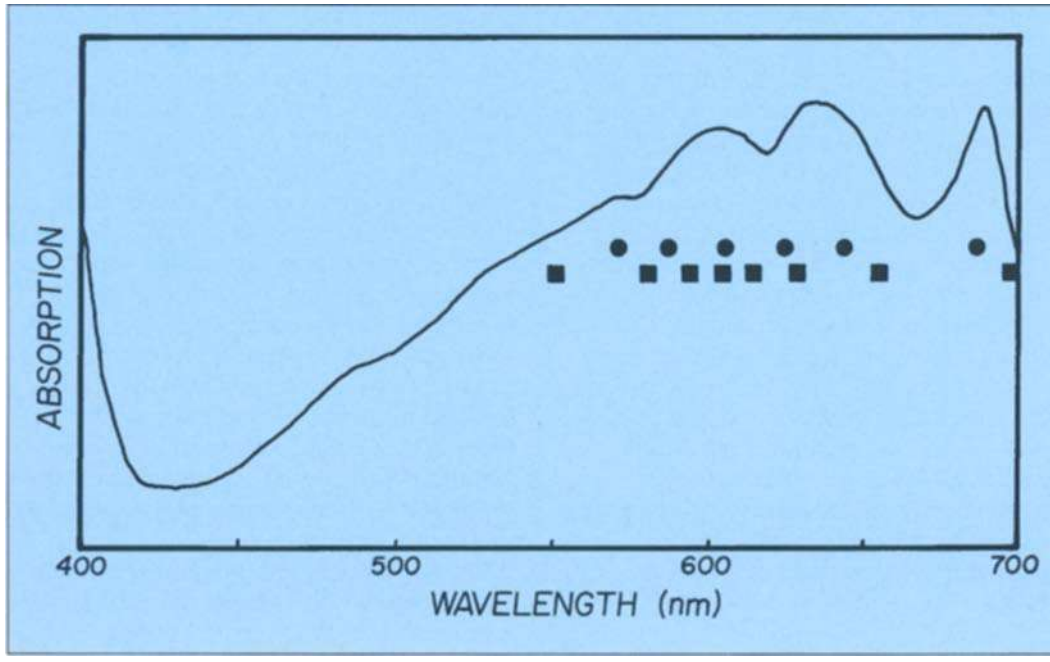

Fig. 5. Spectral curve of the 25.85 ct intense blue PH beryl run as in Figure 1 but with higher resolution software than that used for Figures 2 to 4; there is agreement with the absorptions of Maxixe-type beryl (circles) but not with those of the original Maxixe beryl (squares), both taken from the 300K curves of Figure 2 of Reference 6.

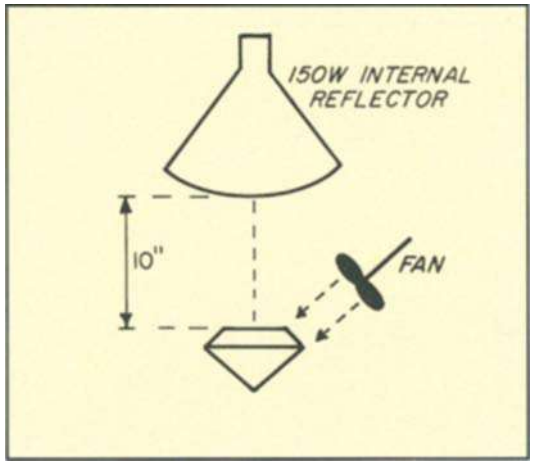

Fig. 6. The 43 hour accelerated fade testing arrangement used in this study.

necessarily preferred. This subject, as well as the question of the rapidity of fading will be discussed in detail elsewhere.

Some stones were also heated in the dark in an oven at 100±10 °C for one week, so that the effects of light and heat could be identified separately.

To avoid reliance on colour memory, which is notoriously fallible, or on equally difficult-to-reproduce photography, before and after colours were measured by comparison with the ISCC-NBS Centroid Color Charts[15]; such colours are given within quotation marks below.

The dichroism of Maxixe beryls shows the stronger blue colour in the ordinary ray, while the reverse is true for blue aquamarine. In using this test to identify Maxixe beryl, it is only the blue-producing absorption that is relevant. In the presence of much yellow, as in greenish aquamarine, a similar orientation of the dichroic yellow-causing absorption, which may also have this same dichroism orientation as described below, is not relevant for identifying Maxixe beryl.

Intense blue beryl

All the 28 large (20.10 to 41.70 ct), intense blue aG beryls were examined by the author, by Wong and by Stern with both the dichroscope and the hand spectroscope; these tests showed Maxixe beryl spectra[5–7] with the stronger dichroic colour in the ordinary ray. Since the two variants of Maxixe beryl are very similar in their spectroscopic absorptions, they cannot be distinguished with a hand-spectroscope.

With the assistance of Gian and Wong, the author was able to examine two of the intense blue aG beryls on the limited-capability BYK Gardner *Colorview* Spectrophotometer in Singapore. The results of Figure 2 confirmed that these were Maxixe beryls; the position of the absorption at about 680 nm indicated that this spectrum corresponded to Maxixe-type beryl. The higher resolution results of Figure 5, run in New Jersey on the intense blue PH beryl obtained from the same Brazilian source, supported this identification. On this basis, the intense blue aG and PH beryls match the later carbonate-containing Maxixe-type beryls; they do not match the earlier nitrate-containing original Maxixe beryls. Accelerated fading tests demonstrated the expected fading, albeit at a relatively slow rate; and the details of these tests will be reported elsewhere.

At this point it is pertinent to refer to Brown's report[12] concerning an intense blue rectangular cushion cut aG Maxixe beryl of 32.60 ct and his assumption that it had been irradiated by man; this was not supported by any observational or analytical data. Except in a fortuitous situation where inappropriate irradiation resulted in some residual radioactivity on a stone,[4] the author knows of no way to distinguish such blue beryls that have been irradiated naturally from those exposed to irradiation by man.

It can be concluded that all the intense blue aG and PH beryls are indeed Maxixe-type beryl and can therefore be expected to fade on exposure to light. It cannot be established whether the colour derives from irradiation by nature or by man.

Golden beryls

Golden beryl has a weak dichroism, basically a darker-yellow to lighter-yellow, often with brownish or greenish overtones, as described in gemmology texts.[e.g.16,17] The orientation of the darker colour is not usually given. Some published golden beryl spectra show a stronger absorption and therefore deeper colour in the ordinary ray.[e.g.18] Some texts, such as that of Hurlbut and Kammerling,[17] give the darker colour in the extraordinary ray. A recent check of a randomly chosen yellow beryl in the GIA collection by Kammerling (unpublished observation) gave the darker colour in the ordinary ray. It thus appears probable that the orientation of the stronger hue in dichroic yellow beryl can be either along the ordinary ray or extraordinary ray directions.

It is widely recognized that the colours of both golden beryls and green aquamarines are stable to light and that both lose their yellow component on being heated, turning colourless and blue, respectively.[e.g.13,16–19] Only a few minutes are required to complete this change at 500 °C; it takes hours at 250 °C.[16] This is the well-known process by which most aquamarine beryl is heated to convert it from the as-mined greenish colour into the more commercially desirable blue aquamarine.

To reconfirm this universally accepted behaviour and extend it to even lower temperatures, four yellow to greenish beryls (the PH13.90 ct 'pale orange yellow', the PH6.15 and KN1.55 ct 'light greenish yellows', and the KN2.28 ct 'light to brilliant yellow') were exposed to the 43 hour rapid fade test of Figure 6, where the fan kept the temperature of the stones at 44±2 °C. There was no change in colour, i.e. no fading, in any of these beryls. However, when held at 100±10 °C for one week in the dark, the 1.75 ct 'light greenish yellow to light yellowish green' beryls changed to 'light yellowish green' and the 2.20 ct 'light to brilliant yellow' beryl changed to 'light yellow'. Some yellow coloration was being slowly destroyed in both instances even at this low temperature.

The author and Wong and Stern examined four large (33.77, 37.71, 68.86 and 126.66 ct), high quality yellow aG beryls, one of which (37.71 ct) had also been examined in detail by Brown,[12] and was in Brown's 'after fading' (and heating) state when examined. The dichroism results agreed with that of Brown: it is the ordinary ray that carries the stronger yellow colour, but in contrast to Brown's results, no absorption lines for Maxixe beryl were detected using the hand spectroscope.

Instrumental spectra were again run, with the assistance of Gian and Wong, on two of the four yellow aG beryls in the arrangement of Figure 1, with the results shown in Figure 3. The spectra show an absorption minimum in the 600 to 650 nm region, this being the region where previously measured blue Maxixe beryls show a broad absorption band maximum, as seen in Figure 2 where similar experimental conditions obtained. Therefore these beryls totally lack Maxixe beryl absorptions, indicating ordinary golden beryl, which does not fade in light.

Thus, in the author's opinion, there is no reason to doubt that the four yellow aG beryls, as well as the related yellow pH beryl, are ordinary golden beryls. Here again, it cannot be established whether these golden beryls were coloured by irradiation by nature or by man.

Green aquamarine or Maxixe beryls?

A greenish beryl colour can originate in two different ways. First, it could result from a combination of the yellow of golden beryl with the light blue of aquamarine, together giving green aquamarine.[16,18] Here light does not produce fading but heat destroys the yellow component as discussed above and widely practised commercially.

Alternatively, a similar green could result from a combination of the yellow of golden beryls and the blue Maxixe beryl coloration as described by Nassau *et al.*[6] Such a combination was also reported by Crowningshield who noted the many narrow absorption lines in a research-type prism spectroscope;[20] these lines are clearly those of a Maxixe-type beryl spectrum.[4-6] Rink[21] produced such material by electron irradiation and was careful to distinguish the two colour components, also stating that the yellow component is stable to light. Here a fading of the blue component would be expected from light while heat would destroy both the blue (Maxixe) and the yellow (golden beryl) components.

Both types of greenish beryls may derive their yellow component (as well as their blue Maxixe beryl component, if present) from irradiation by nature or by man; again these cannot normally be distinguished by gemmological or by any other testing.

The eight large (33.85 to 74.20 ct) aG beryls with a colour range from light green to greenish-yellow were examined by the author, by Wong and by Stern. The stones closely resemble typical green aquamarines in their original as-mined state before such material is subjected to heat treatment to convert it to blue aquamarine. The possibility that irradiation had been used to intensify the yellow colour component, or restore it after it had been removed by a heating, cannot be ruled out.

Examination of the dichroism indicates that it is the ordinary ray that carries the stronger colour in all these aG greenish beryls. Such dichroism is reasonable for the yellow component and it would be expected for a Maxixe beryl blue component if present, but not for an aquamarine blue component. Dichroism by itself cannot normally be a reliable characteristic to distinguish the latter two possibilities. Indeed, we could not clearly establish the dichroic orientation of the blue-producing entity. In retrospect, it is possible that colour filters could perhaps have been used to separate the blue and yellow dichroisms but such an approach has not yet been investigated. Therefore, currently, only a detailed spectroscopic examination or a light-only fade test can help establish the presence or absence of Maxixe beryl. Hand spectroscope examination showed no absorptions in the Maxixe region in any of these aG beryls, and this was confirmed by results obtained from the spectrophotometer for two of the greenish aG beryls (Figure 4). The spectra are exactly those expected for the combination of golden beryl plus blue aquamarine. Again, there is a minimum in absorption in the region where the broad band Maxixe beryl absorption is seen in Figure 2. This conflicts with the results obtained by Brown[12] from one of the stones (50.35 ct rectangular cushion) in the aG collection.

On the basis of these results there is thus no reason to doubt that the eight greenish aG beryls, as well as the related greenish PH beryl, are anything other than ordinary green aquamarine beryls. Here again, it cannot be established whether the yellow-producing component in these greenish beryls derives from irradiation by nature or by man.

Conclusions

It is concluded that the 29 large, high quality intense blue aG and PH beryls of recent Brazilian origin are of the Maxixe-type carbonate variety, a material that was seen widely about 1970 (but never in such large sizes) and has been seen only occasionally since then. This conclusion agrees with that of Brown[12] on the 32.60 ct intense blue beryl.

The author also concludes that the five yellow and nine greenish large, high quality aG and PH beryls of recent Brazilian origin are non-fading golden beryls and non-fading greenish aquamarines, respectively. These conclusions conflict with the results reported by

Brown[12] for the 37.71 ct golden beryl and the 50.35 ct greenish beryl, which he examined by permission of Dr D.M.K. al Gobaisi.

It is worth emphasizing three points:

(i) yellow (golden) beryls do not fade on exposure to light but will lose colour slowly on exposure to a temperature of 100 °C and more rapidly at higher temperatures;

(ii) aquamarines do not fade on exposure to light, but any yellow component present in greenish aquamarines will again be lost slowly at 100 °C and more rapidly at higher temperatures; and

(iii) while Maxixe beryl has the stronger dichroic blue colour in the ordinary ray, it is only the blue-producing absorption that has been and is relevant for reaching such an attribution; the yellow-causing absorption in golden beryl, which is also present in greenish aquamarine and which may also have this same dichroism orientation as described above, is not relevant in deciding whether or not a beryl can be described as Maxixe.

For gemmological purposes, it is also recommended that the term 'Maxixe' beryl be used for both the original Maxixe and the later Maxixe-type variants, since this distinction is difficult to establish without spectrophotometers.

Acknowledgements

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Emerald and green beryl from Central Nigeria

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Abstract

Mineralogical and gemmological characteristics of emeralds and green beryls from the central Nigerian Kaduna and Plateau States are presented. A genetic model for the occurrence of these gemstones in greisen associations of Mesozoic alkali granite ring complexes has been established. Gemmologists should be able to distinguish between Nigerian emeralds and those from other localities. Distinction is based on the unique inclusions and the chemical features of the Nigerian emeralds and green beryls. For those Nigerian specimens that contain solid inclusions, the mineral association of albite + fluorides (fluorite, boldyrevite, ralstonite) + F-silicate + Fe-rich mica + ilmenite + monazite, is locality-specific. Growth structures and fluid inclusions are extremely common and the later ones show a large range of features including Colombian-type three-phase inclusions. For Nigerian emeralds that show an inclusion pattern similar to that of Colombian emeralds, the easiest distinction is by absorption spectroscopy. The Nigerian emeralds show 'mixed spectra' with peaks attributable to Cr^{3+}, Fe^{2+}, Fe^{3+} and Fe^{2+}/Fe^{3+}, whereas the spectra of Colombian emeralds, as a rule, are largely free of Fe-components.

Introduction

Since the beginning of the 1980s, Nigeria has become a country of special interest for the gem industry, with significant occurrences in the Kaduna and Plateau States of different coloured beryls, tourmalines and sapphires, some of a very good quality (Bank, 1984; Kanis and Harding, 1990). At the beginning of the 1980s and again at the beginning of 1991, probably a few thousand carats of Nigerian emeralds or green beryls entered the gem market for periods of a few months.

The beryl, tourmaline and topaz deposits of central Nigeria show a great variety in their modes of occurrence. Some may be related to pegmatites, quartz veins, stockworks and greisens within or near granite contacts. Others occur in fissures, joints and shear zones at the edges of granite bodies or in syngenetic miarolitic and schlieren formations.

Emeralds and green beryls in the Plateau and Kaduna States of central Nigeria are much less common than their blue counterpart, aquamarine. They occur in rocks of two distinct ages. The older occurrences are usually pegmatites, whereas the younger are in the 'roof' zones of granites. Although some beryls from both kinds of sources have an 'emerald colour', most are rather pale green and many dealers do not accept them as emeralds, classifying them as green beryl. Arps and Zwaan (1995) gave the source of the central Nigerian emeralds as east of Gwantu (south east Kaduna State) and north west of Nassarawa Eggon (Plateau State).

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This paper presents the first comprehensive study of the mineralogical and gemmological characteristics of Nigerian emeralds and green beryls and establishes a genetic model for the occurrences of these gemstones in central Nigeria.

Background and previous studies

Emeralds and green beryls (Figure 1) are found together with gem-quality beryls of various other colours in similar geological environments in the Kaduna and Plateau States of central Nigeria.

When the Nigerian emeralds and green beryls reached the gem market at the beginning of the 1990s, they attracted attention for their large size (up to 100 grams) and beauty of their well-formed crystals. They also provoked a revival of the old debate on emerald terminology i.e. on the dividing line between emeralds and 'normal' green beryls (Hänni, 1992). The physical and mineralogical properties of beryls from central Nigeria have been described by several authors (Lind *et al.*, 1984; Henn *et al.*, 1984; Kiefert and Schmetzer, 1990; see Table IV below).

Geology and genesis

The geological history of central Nigeria covers a long period, even in geological terms! The main geological events and associated rock types are summarised in Table I.

The Nigerian Basement Complex contains a variety of rock suites of different ages spanning a period from 3000–450 million years (m.y.) ago. The oldest rocks were originally sediments and intrusive bodies which have undergone periods of folding and metamorphism and have been altered to migmatite and granite gneiss. Younger sediments were deposited onto

Fig. 1. Well-formed crystals of emerald or green beryl (length about 4 cm) from the Kaduna and Plateau States, Central Nigeria. *Photo Gebr. Henn, Idar-Oberstein*

Table I: Summary of the geology of central Nigeria

Time divisions				*Age in million years*	*Geological events with ages in million years and associated rock types*	
PHANEROZOIC	CENOZOIC	Quaternary	RECENT	–0.2		
			PLEISTOCENE	–2	2	
		TERTIARY	PLIOCENE	–11		Well preserved volcanic cones and alkali olivine basalt flows.
			MIOCENE	–25		Sedimentary series with intercalated tholeiitic basalt lava flows, now largely eroded.
			OLIGOCENE	–40		
			EOCENE	–55		
			PALAEOCENE	–65	65	
	MESOZOIC	CRETACEOUS		–135	144	Alkaline basaltic and rhyolitic volcanism, alkaline granite intrusives with cassiterite, columbite, wolframite, sphalerite and beryl/emerald. Younger Granites
		JURASSIC		–180	190	
		TRIASSIC		–225		
	PALAEOZOIC	PERMIAN		–270		
		CARBONIFEROUS		–350		
		DEVONIAN		–395		
		SILURIAN		–440	450	Metasedimentary rocks and granitoid intrusives, pegmatite bodies with cassiterite, tantalite and beryl/emerald. Older Granites.
		ORDOVICIAN		–500	Pan-African	
		CAMBRIAN		–570		
PRECAMBRIAN	PROTEROZOIC	LATE		–1000	750	
		MIDDLE		–1800	Kibaran 1600	Granite gneisses of central and SW Nigeria
		EARLY		–2600	Eburnean 2400	Granite gneisses of central and SW Nigeria
	ARCHAEAN	LATE		–3300	Liberian 3000	Banded gneisses of SW Nigeria

the Basement and folded together with this granitized basement during the Pan-African orogeny from 750 to 450 m.y. ago, to form long north-south oriented linear schist belts of low grade metasedimentary rocks.

During the late Pan-African orogeny, from around 600 to 450 m.y. ago, there was a phase of granitoid magmatism. These granitoids were intruded into both the Basement Complex and the younger metasedimentary cover. The granitic rocks associated with the Pan-African orogeny generally have contrasting petrological and chemical compositions compared with the later Jurassic (Mesozoic) suite of alkaline ring complexes and are therefore called 'Older' Granites, in contrast to the 'Younger' Mesozoic Granites. The closing stages of the orogeny from 650–450 m.y. ago were marked by cooling, uplift and fracturing, by the eruption of volcanic rocks and the formation of pegmatitic lenses and dykes.

Within the Basement Complex is a zone in which this suite of pegmatites cut Old Eburnean rocks and early Pan-African metamorphic and igneous assemblages. The mineralized pegmatites are widely, but unevenly distributed within a broad zone, extending from the Ife area towards the Younger Granite province. It appears that the mineralized pegmatites occur within the north-south oriented younger metasedimentary belts composed of biotite schists and amphibolites. The pegmatites occur as dykes and sheets of varying dimensions – the dykes range from a few centimetres to tens of metres in width, with strike lengths of up to 2 km. The pegmatite sheets can have a considerable thickness of up to 40 m, and have been of economic interest because they contain cassiterite and columbo-tantalite. However the sheet-like pegmatites are of greater importance for the gems they contain. Many of the well mineralized pegmatites are characterized by pinch and swell structures. The swellings are generally very albitized and frequently correspond with centres of rich ore mineralization.

The younger granites of Nigeria, emplaced during the period 190 to 144 m.y. ago, form ring complexes typically 2–25 km in diameter and are composed of 95 per cent acid rocks. These Mesozoic ring complexes of Nigeria form part of a larger province of alkaline magmatism. They occur in a zone 200 km wide and 1600 km long, extending from northern Niger to south central Nigeria. This zone is related to the breakup of the Gondwana super continent during the Mesozoic era. According to Dickin *et al.* (1991), the ring complexes of the Jos Plateau are the product of mantle-derived magmas which have suffered a significant amount of crustal contamination during their ascent and differentiation in the crustal basement. There are three main granite types: hornblende biotite granite; biotite granite and alkali granite with Na-Fe pyroxenes and amphiboles.

In the ring complexes, a series of hydrothermal alteration processes with related mineralization can be recognized (Kinnaird, 1979). Early sodic metasomatism (albitization) may have modified all the granite types. The effects of the later processes beginning with potassic metasomatism are only well documented for the biotite granites. Each hydrothermal process is characterized by a distinct assemblage of silicate minerals and there is a clearly defined sequence of ore deposition associated with each of the hydrothermal processes. It is with albitization processes that the gem varieties of beryl are associated. The temperature interval of the emerald and green beryl crystallization is about 500–400 °C.

Beryl-bearing basement pegmatites

Pegmatites are common throughout the Kabba Province and, in addition to quartz and microcline, contain both biotite and muscovite and in many cases considerable amounts of albite with beryl and

tourmaline. Beryl crystals of the 'Basement' pegmatites can reach enormous sizes.

To the east of the Niger River and north of the Benue River, there is an important pegmatite belt which is apparently not related to major granite intrusions. The pegmatites occur in an area bounded to the east by the Jos Plateau, to the south by the Afu Hills, to the west by Nassarawa and to the north by Kafanchan (Figure 2). These pegmatites vary considerably in their mineralogy. The bulk of those which are metal-bearing are complex albitized pegmatites with important gem potential. Typical minerals of these pegmatites are microcline, albite, perthite, quartz and muscovite. Accessory minerals are, in addition to beryl, tourmaline varying from black to blue and green, apatite, gem-quality blue gahnite spinel, garnet, nigerite

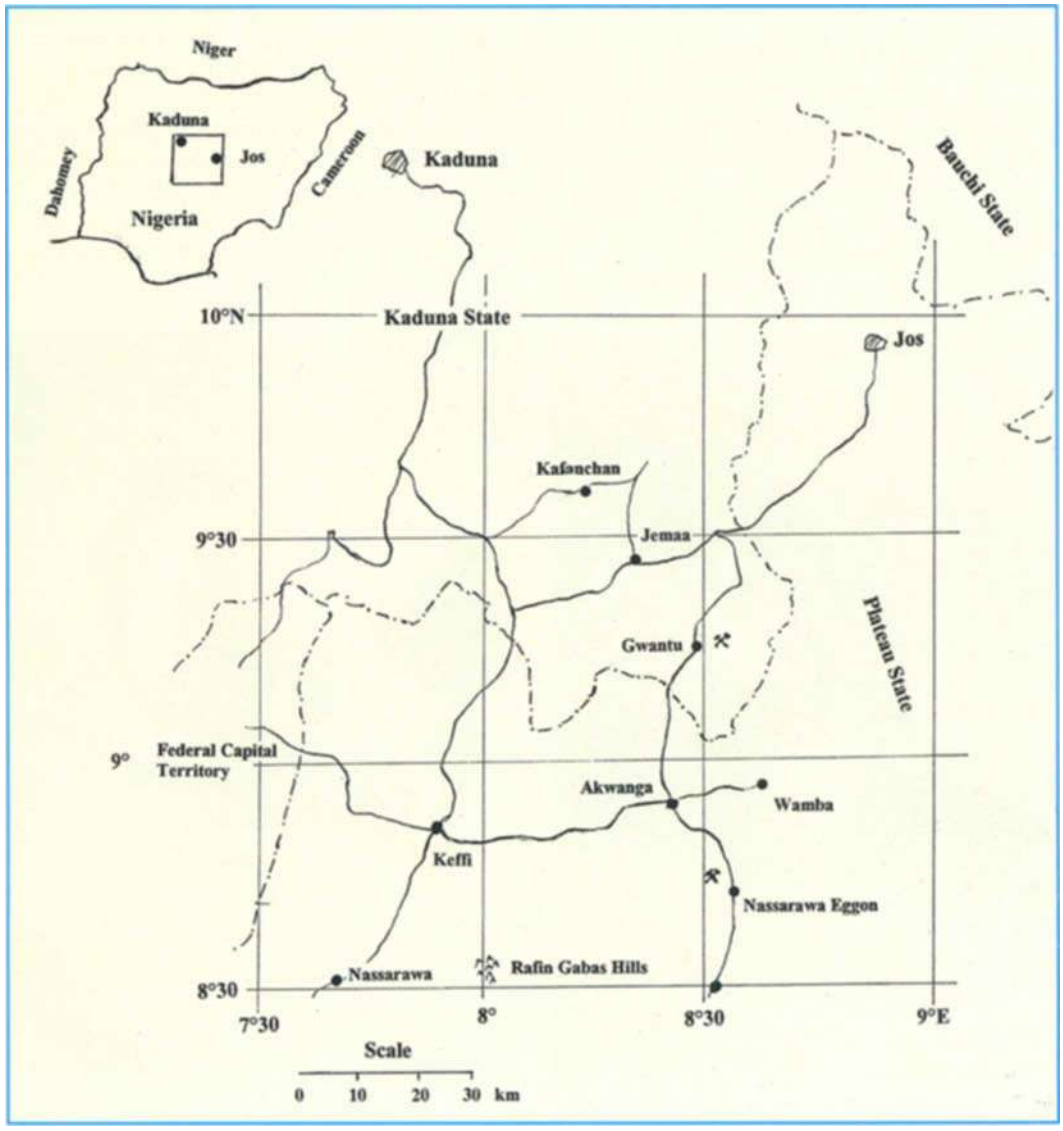

Fig. 2. Location map with the main beryl (emerald and green beryls) occurrences in the Kaduna and Plateau States, Central Nigeria

$(Zn,Mg,Fe^{2+})(Sn,Zn)_2(Al,Fe^{3+})_{12}O_{22}(OH)_2$, chrysoberyl, cassiterite and columbo-tantalite.

In the Wamba and Akwanga regions (Figure 2), the microcline-quartz-muscovite pegmatites are strongly albitized, dyke-shaped bodies. The albite contains abundant small crystals of alkali-tourmaline and other accessories, including cassiterite, garnet, apatite, beryl and a little columbo-tantalite. In the Egometi district, where pegmatite dykes are mainly of microcline-quartz-muscovite varieties, accessory minerals are biotite, tourmaline, albite, garnet, apatite, beryl and cassiterite.

Gem-quality aquamarines have been collected in the Nassarawa Eggon area from Sabon Wana and Tundun Delli and emeralds are known from Kwafam Gwari. These are likely to be the most important sources of gem quality beryls from the basement pegmatites, although there may be other localities not divulged by local gem dealers.

Beryl-bearing Younger Granites

In the Mesozoic ring complexes, gem quality beryl, topaz and smoky quartz are located in the 'roof' and contact zones of the latest intrusive stage of biotite alkali-feldspar granites, especially where the granite is in contact with the Basement Complex.

Gem quality beryl occurs as pale blue, greenish-blue or occasionally as pale green short stumpy hexagonal crystals often singly terminated. The gems occur in two settings, both formed in similar geological conditions.

Fig. 3a. Searching with a stick for miarolitic cavities with gemstones in a 'roof' zone of Younger biotite granite; Rafin Gabas Hills. *Photo J. Kanis*

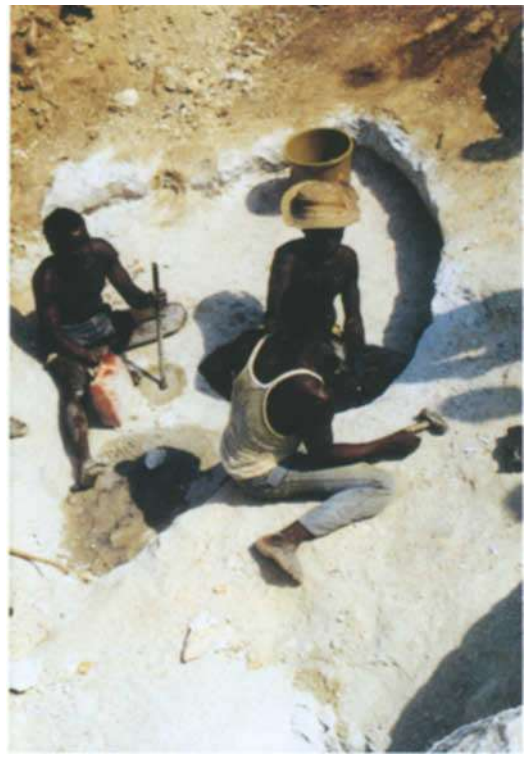

Fig. 3b. Drill holes being prepared for blasting to expose miarolitic cavities in the 'roof' zone of a Younger biotite granite; Rafin Gabas Hills. *Photo J. Kanis*

Fig. 4. Growth structures in a Nigerian emerald or green beryl (view perpendicular to the *c*-axis). The most dominant features run parallel and perpendicular to the *c*-axis. × 70

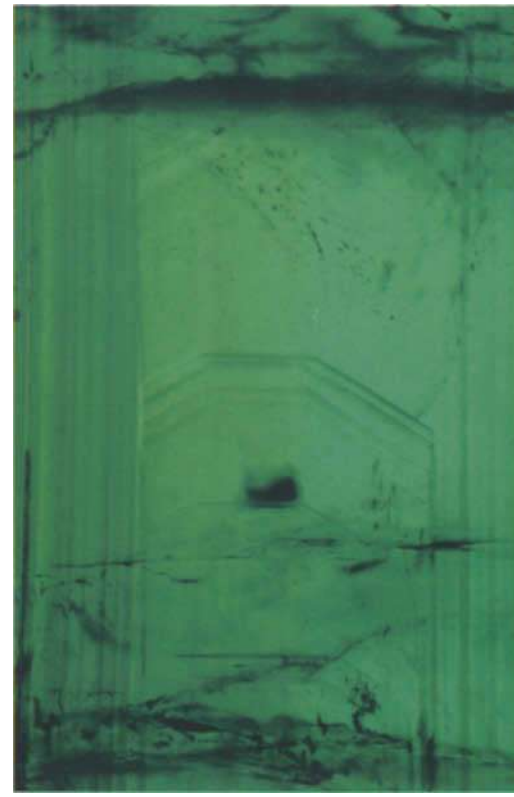

Fig. 5. Growth structures in a Nigerian emerald or green beryl (view perpendicular to the *c*-axis). Strongly developed features parallel to the hexagonal prism, the basal pinacoid and a hexagonal dipyramid. × 70

(i) The aquamarine and emerald may occur in small pegmatitic pockets in association with quartz, feldspar and topaz. These pegmatite pockets, which can be up to 8 cm in size, are found at the contact of a granite with basement rocks and represent cavities created by gas loss from the cooling magma. Localities of this type include the well known Timber Creek area near Rukuba, and the Barakin William occurrence in the Sha Kaleri Complex. In these pegmatitic pods crystals of more than 5 cm have been recorded. The stones from Barakin William, in particular, show distinctive colour variations within the crystal, either grading from colourless to deep blue or green along the *c*-axis of the crystal or with very dark colour bands, perpendicular to the *c*-axis, within otherwise pale crystals.

(ii) In the Janta area to the east of the Afu complex, 35 km SSW of Keffi, aquamarine and emerald have been found in soft decomposed granites. The crystals are pale blue, greenish or yellowish and less elongated than those from pegmatitic occurrences. Crystals have grown in small miarolitic cavities formed by gas loss in the 'roof' of the granite, within a zone of <20 m from its upper contact with the overlying rock type (Figures 3a and 3b). Fluid inclusion studies indicate crystallization at relatively high temperatures of 400–500 °C.

Fig. 6. Two beryl 'generations'. A distinctly visible 'core crystal' is surrounded by an 'envelope' with a different colour. × 35

Observations and results

Crystal growth and trapping of inclusions
Growth structures are extremely common in Nigerian emeralds (compare Figures 4 and 5). Strongly developed growth bands parallel to basal-pinacoid, prism, and pyramidal faces are the most frequent kind (Figures 4 and 5), and are consistent with the descriptions given by Lind *et al.* (1984, 1986) and by Kiefert and Schmetzer (1990).

During the growth of most crystals, numerous kinds of mineral and fluid inclusions have been incorporated. Also, interruptions of the growth process are commonly indicated by 'growth faces' on which different types of mineral inclusions have been deposited, and this results in phantom-like phenomena. These growth faces are generally parallel to the crystal faces observed macroscopically for each crystal. Those crystals that contain a distinctly visible 'core crystal' surrounded by an 'envelope' which has a different colour are considered to consist of different beryl generations (Figure 6). During the hiatus between the different growth phases, corrosion phenomena have commonly developed on the faces of the early-formed crystal. When the crystal growth re-started, large fluid inclusions were trapped along planes principally parallel to the prism faces. Another indication that crystal growth was not steady and continuous but took place in several phases ('pulses') is the distinct colour zoning visible when looking down the *c*-axis of the crystals.

An additional indication of relatively fast crystal growth is the presence of distinct anomalous birefringence. This is caused by internal stresses and can be observed under crossed polars in sections of emerald and green beryl perpendicular to the *c*-axis. What is rare in the Nigerian beryls compared with those from other localities is the so-called 'rain-effect' which is caused by the presence of minute growth tubes oriented parallel to the *c*-axis of the host crystal. Fractures are common. Many have been partially healed by growth nutrient-bearing fluids as indicated by the presence of secondary fluid inclusions, while others are not healed. Most of the fractures are normally unoriented with respect to the host crystal but some occur parallel to crystal faces. Epigenetic fracture fillings consist of Fe and Mn oxides.

Mineral inclusions
Mineral inclusions in Nigerian emeralds or green beryls have not been documented previously. This is understandable because they are not common; and only about 180–200 of the 1000 Nigerian emeralds/green beryls examined in this

study contain mineral inclusions. These have been studied in order to determine whether any inclusion features might be diagnostic in identifying the source of these emeralds or green beryls and might help in distinguishing them from synthetics.

The most common mineral inclusions in the Nigerian emeralds and green beryls are fluorite and albite which were identified in 80–100 samples (which is less than 10 per cent of the analyzed material). Tourmaline and K-feldspar inclusions only occur in a few samples, which means that their abundance is only a few tenths of a per cent, whilst other inclusion minerals have abundances of a few per cent.

The mineral inclusions vary in size with the largest up to 1–2 mm. Normally, there is no visible crystallographic orientation or control on the mineral inclusion distribution within the beryl host crystals. Only the minerals trapped on crystal faces during a period of growth interruption show a spatial distribution related to the emerald crystallography. Most of the mineral inclusions probably nucleated and grew only a short time before they were enclosed by the growing beryl crystals. Many are identifiable optically but some of the fluorides are not and these have been identified by microanalysis. The following list gives details of the mineral inclusions in approximate order of abundance.

Materials and methods of examination

For this study about 1000 emeralds and green beryl crystals and about 30 cut stones from the Kaduna and Plateau States in central Nigeria were examined. The description and the classification of the inclusions (using a binocular Schneider immersion microscope with Zeiss optics) was followed by photographic documentation of all the various inclusion types observed. In order to identify the mineral inclusions by microanalysis, the emeralds and green beryls were polished down until the inclusions to be analysed intersected the surface. Chemical analyses were carried out using scanning electron microscopes (Philips XL 30 and Zeiss DSM 962) fitted with an EDAX energy dispersive X-ray spectrometer. Chemical analyses of the beryl host crystals were performed on polished crystal faces in a CAMECA microprobe with WDS-spectrometer, using 15kV acceleration voltage, 10mA sample current and a raster size of 5 × 5 µm. The absorption spectra in the UV-VIS-NIR region were recorded with a Perkin Elmer Lambda 9 spectrometer.

(i) *Albite*

Albite, together with fluorite, is the most common mineral inclusion in Nigerian emeralds and green beryls. The albite crystals form colourless, transparent, angular to irregularly-shaped grains (Figure 7). In reflected light under a microscope, they generally appear translucent white because of their own numerous fine inclusions.

Feldspar inclusions of varying chemical composition have been described in African emeralds from different localities (Schwarz, 1994). They have also been encountered in emeralds from Colombia (Schwarz, 1995), Brazil (Hänni *et al.*, 1987; Schwarz and Eidt, 1989; Schwarz *et al.*, 1990), the Ural Mountains (Schwarz, 1991b), the Habachtal (Grundmann, 1991) and the Swat region in Pakistan (Schwarz, 1995). Consequently the identity and abundance of feldspar inclusions are of little diagnostic value when determining the origin of an emerald (Table II).

Table II: Mineral inclusions in emeralds from Kaduna and Plateau States, Central Nigeria, and from some other localities

Inclusion	*Locality of emerald host*	*Reported by*
Albite	Mananjary, Madagascar	Schwarz, 1994
	Cordillera Oriental, Colombia	Schwarz, 1995
	Sandawana, Zimbabwe	Fillmann, 1987
		Delé-Lasir and Poirot (pers. comm., 1991)
	Lake Manyara, Tanzania	Delé-Lasir and Poirot (pers. comm., 1991)
	Carnaíba/BA, Brazil	Schwarz and Eidt, 1989
	Socotó/BA, Brazil	Schwarz, 1987
	Khaltaro, Pakistan	Gübelin, in Kazmi and Snee, 1989
	Mingora-Swat, Pakistan	Schwarz, 1995
	Panjshir, Afghanistan	Schwarz, 1995
Fluorite	Colombia (?)	Roulet, 1956
	Madagascar	Delé-Lasir and Poirot (pers. comm., 1991)
	Pakistan	Eppler, 1984
	Ural Mountains	Shernakow and Laskowenkov, 1991
		Schwarz, 1995
	Emmaville/NSW	Stevens, 1980
		Brown, 1984
		Schwarz, 1995
Fe-rich mica	not reported	
Mg-biotite/ phlogopite	most occurrences worldwide, e.g. Belmont Mine/MG	Hänni *et al.*, 1987
	Capoeirana-Nova Era/MG	Schwarz *et al.*, 1988a
	Tauá/CE	Schwarz *et al.*, 1988b
	Carnaíba/BA	Schwarz and Eidt, 1989
	Socotó/BA	Schwarz *et al.*, 1990
	Santa Terezinha/GO	Schwarz, 1990
	Goiás State, Brazil	Barros and Kinnaird, 1987
	Western Australia (Poona, Menzies)	Schwarz, 1991a
	Ural Mountains	Schwarz, 1991b
	Habachtal	Grundmann, 1991

Inclusion	*Locality of emerald host*	*Reported by*
	Mananjary, Madagascar	Schwarz, 1995
	other African localities (Zambia, Zimbabwe, Tanzania, South Africa, Egypt)	Schwarz, 1995
Ilmenite	Mananjary, Madagascar	Hänni and Klein, 1982
	Sandawana/Machingwe	Schwarz, 1995
	Santa Terezinha/GO, Brazil	Cassedanne and Sauer, 1984 Barros and Kinnaird, 1987
	Ural Mountains	Shernakov and Laskovenkow, 1991
	Habachtal, Austria	Grundmann, 1991
	Poona, Australia	Graindorge, 1974
Boldyrevite	not reported	
Ralstonite	Belmont Mine/MG, Brazil (?)	Souza, 1988
Monazite	Habachtal	Grundmann, 1991
	Itaberaí/GO	Schwarz, 1995
Quartz	Many localities worldwide	
K-feldspar	Mananjary, Madagascar	Kleyenstüber, 1991 Schwarz, 1994
	Lake Manyara, Tanzania	Bank and Gübelin, 1976
	Socotó/BA, Brazil	Schwarz, 1987
	Capoeirana/MG, Brazil	Herrmann, 1991
	Salininha/BA, Brazil	Graziani and Lucchesi, 1979
Tourmaline	many occurrences worldwide, e.g. Zambia	Koivula, 1982, 1984 Schwarz, 1987
	Zimbabwe	Anderson, 1976 Schwarz, 1995
	Mananjary, Madagascar	Hänni and Klein, 1982 Schwarz, 1994
	Ural Mountains	Schwarz, 1995
	Habachtal	Grundmann, 1991
	Carnaíba/BA	Schwarz and Eidt, 1989
	Socotó/BA	Schwarz *et al.*, 1990
	Panjshir, Afghanistan	Schwarz, 1995
Emerald/beryl	Many occurrences worldwide	
Mg-Ca-Al-Na-Fluorosilicate	not reported	

(ii) *Fluorite*

Fluorite is one of the most frequent mineral inclusions; most are developed as perfect octahedra (Figure 8) but some are cubes and others have a more or less rounded or irregular shape (Figure 9), sometimes occurring as aggregates. Many fluorite crystals show a strong surface structure which may be an etching phenomenon. The fluorite inclusions are colourless but because of their low refractive index they show a very strong relief in the beryl host crystal and consequently appear very dark when immersed in fluid and examined under the gem microscope (Figures 8 and 9). In dark field illumination, they appear colourless-transparent or greyish-white.

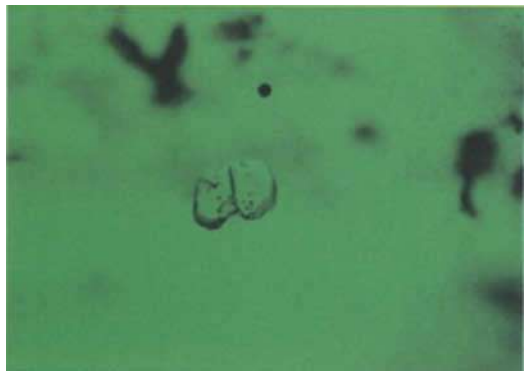

Fig. 7. Colourless, transparent, angular to irregularly shaped albite grains. × 100

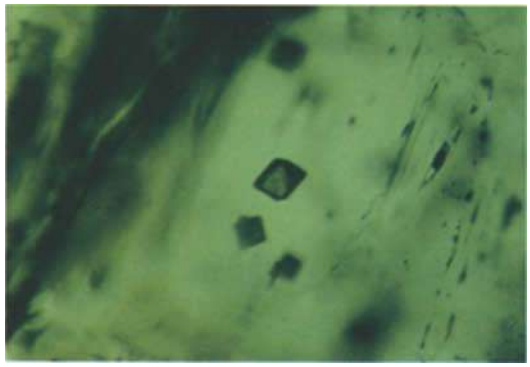

Fig. 8. Perfectly developed fluorite octahedra. × 100

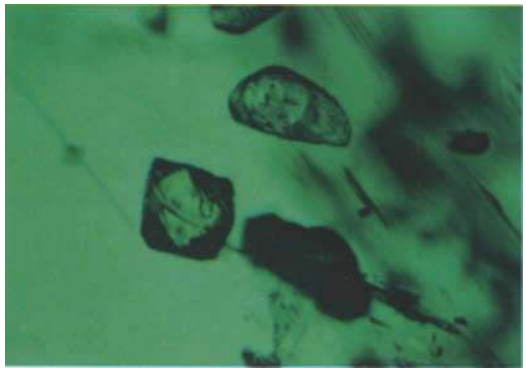

Fig. 9. Irregularly shaped fluorite crystals with very strong relief. × 140

Fluorite has been identified as an inclusion in emeralds from several localities. It was noted in Colombian emeralds by Roulet (1956), although it is not known by which method the inclusion mineral was identified and the identification has not been confirmed in subsequent studies on other Colombian emeralds. Fluorite has been noted in emeralds from Madagascar and Pakistan (Delé-Lasir and Poirot, pers. comm., 1991), the Ural Mountains (Eppler, 1984; Shernakow and Laskowenkow, 1991; Schwarz, 1995) and Emmaville, NSW, Australia (Stevens, 1980; Brown, 1984; Schwarz, 1995).

(iii) *Mica*

The mica inclusions in the Nigerian emeralds and green beryls are Fe-rich, most likely in the compositional range annite/siderophyllite or zinnwaldite. Energy dispersive X-ray spectrometry is insensitive to lithium and until this element content is measured it is not possible to fully identify the mica. The mica crystals are flaky or book-like in appearance, dark brown or reddish in colour with a strong pleochroism and basal cleavage (Figure 10).

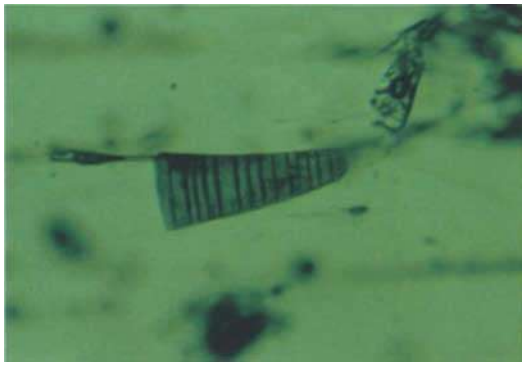

Fig. 10. 'Booklet' of dark brown to reddish mica (probable annite/siderophyllite). This Fe-rich mica is known as an inclusion mineral in emeralds or green beryls only from the Kaduna and Plateau States in central Nigeria. × 100

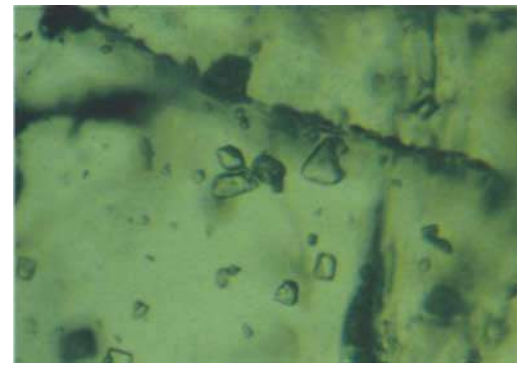

Fig. 11. Association of different fluoride inclusions such as fluorite, boldyrevite and ralstonite reflecting the very special genetic environment (related to a greisen process) in which the emeralds/beryls of central Nigeria were formed. × 50

Mica inclusions are common in emeralds from other localities but are usually of Mg-biotite or phlogopite composition. The occurrence of a Fe-rich mica in the Nigerian emeralds and green beryls is a distinctive feature and is a strong indication that these gems are from the alkali biotite granites of the ring complexes where Li-Fe biotites are the major mafic mineral (Kinnaird, 1985).

(iv) *Ilmenite*
Ilmenite occurs as opaque-black platelets, sometimes forming aggregates, or as irregularly shaped grains with a metallic lustre. This inclusion mineral has been identified in emeralds from several localities (see Table II).

(v) *Boldyrevite*
The occurrence of boldyrevite ($NaCaMgAl_3F_{14} . 4 H_2O$) was identified by chemical microanalysis. It cannot be distinguished optically from fluorite because their crystal habits and refractive indices are very similar. The association of different fluoride inclusions in a Nigerian emerald is shown in Figure 11.

(vi) *Ralstonite*
The identification of the fluoride ralstonite, $Na_x (Al_{2-x}Mg_x) (F,OH)_6 \times H_2O$ is also based on microanalysis. It also cannot be distinguished optically from fluorite on the basis of crystal form or refractive index.

(vii) *Monazite*
Monazite, $(Ce,La,Th)PO_4$, inclusions in Nigerian emeralds and green beryls show distinct relief as transparent prismatic crystals or aggregates which are transparent, colourless or of a weak yellowish colour. Analyses show that these monazites are very Th-rich.

Generally, monazite is a very rare mineral inclusion in emerald, having been found previously only in emeralds from the Habachtal (Grundmann, 1991) and the small occurrence at Itaberaí in the Goiás State of Brazil (Schwarz, 1995). The composition of the monazite at both these localities differs from that of the inclusions in the Nigerian stones, those of the Habachtal-emeralds being more Ce-rich (Grundmann, 1991), and the Itaberaí-emeralds being Ce/La-rich varieties (Schwarz, 1995).

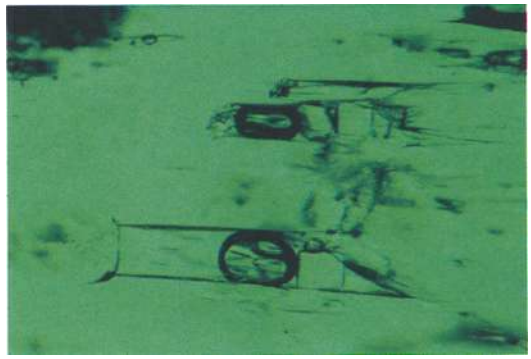

Fig. 12. Primary cavities with 's_x1g'-multiphase fluid inclusions. One of the inclusions 'originates' from an almost invisible beryl or emerald grain. × 70

(viii) *Quartz*
Colourless transparent quartz inclusions are prismatic, angular, or more or less elongated or rounded crystals. Because a surface structure is sometimes strongly developed, their relief in the emerald host crystal may be quite distinct. Quartz is a common inclusion in emeralds from different localities in the world and it is of little value in determining the source of an emerald (Table II).

(ix) *K-feldspar*
In contrast to albite, K-feldspar is a very rare inclusion in the Nigerian emeralds and green beryls. It occurs as colourless irregularly shaped grains. K-feldspar has been identified in emeralds from a number of other localities (Table II).

(x) *Tourmaline*
Tourmaline is a very rare inclusion in Nigerian emeralds and green beryls and only one, a Fe/Mg-tourmaline with a small Na component, was found. Lind *et al.* (1986), have reported a tourmaline intergrown with an aquamarine crystal from Nigeria. Since tourmaline does not occur in the Younger Granites but is common in basement pegmatites, the latter are the likely source of the Nigerian emeralds containing tourmaline inclusions. Tourmaline inclusions have been identified in emeralds from widely different occurrences (Table II).

(xi) *Emerald/beryl*
Inclusions of crystals or crystal fragments of beryl are almost invisible under normal transmitted light conditions (Figure 12). They occur in Nigerian emeralds and have also been identified as inclusions in emeralds from several other localities (Table II).

(xii) *Fluorosilicate*
It was not possible to identify precisely a Mg-Ca-Al-Na-fluorosilicate that was observed in one of the samples examined. The existence of fluorosilicates as daughter crystals in fluid inclusions in aquamarines from the Younger alkali granites of the Afu complex has been noted by Kinnaird (1985).

Comparing the association of the inclusion minerals in the emeralds and green beryls with the mineral associations in the different granite types of central Nigeria, there is a strong similarity to the mineral associations described by Kinnaird (1984) for the earliest mineralization stage in the alkali granites. In these, the most important accessories are U-pyrochlore, cryolite (Na-Al-fluoride), fluorite, thomsenolite (hydrated Na-Ca-Al-fluoride), zircon, Th-rich monazite and ilmenite. The minerals identified as inclusions in the Nigerian emeralds/green beryls are several fluorides, ilmenite, Th-rich monazite, quartz, feldspar (normally albite) and a Fe-rich representative of the mica group (probably annite/siderophyllite). All these minerals can be linked in terms of their origin to alkali granites. The micas of the alkali granites are characterized by very high Fe-contents (MacLeod *et al.*, 1971) and this is valid also for mica inclusions

in the emerald or green beryl. Potential inclusion minerals that may be found during further investigations of the emeralds are U-pyrochlore and zircon.

Fluid inclusions

Nigerian emeralds and green beryls show a large variety of fluid inclusions, some of which may exceed more than 1 mm in size. The primary cavities which contain the fluid inclusions show tubular, partly spiky, or irregularly shaped forms (Figure 12). Secondary cavities are irregularly shaped, normally with a rounded outline, sometimes, however, showing a 'jagged' outline (Figure 13). There is an enrichment of inclusions in certain more or less well-defined areas of the emerald host crystal, and this is considered to be a growth phenomenon. Such features include the more frequent appearance of fluid inclusions in the border zones of crystals or the common enrichment of growth tubes in the core of a crystal.

The fluid inclusion population of aquamarines, together with inclusions in topaz, fluorite and quartz from different localities in the younger granites of central Nigeria, have been described by Kinnaird (1985) who identified six different fluid inclusion-types, some of which have been found in the present study.

Most of the fluid inclusions in the Nigerian beryls have very strong relief and appear almost opaque in transmitted light; this is due either to the difference between the refractive index of the cavity filling and the surrounding emerald or to the irregularity of the cavity walls. Both of these features enhance reflection rather than transmission light and result in a dark image. The most abundant type of inclusion in emeralds and aquamarines from central Nigeria is one containing liquid, a vapour bubble and several solids (multiphase '$s_x lg$' inclusions[1] with several s-phases; Figures 12, 14, 15). Such multiphase inclusions are also known in

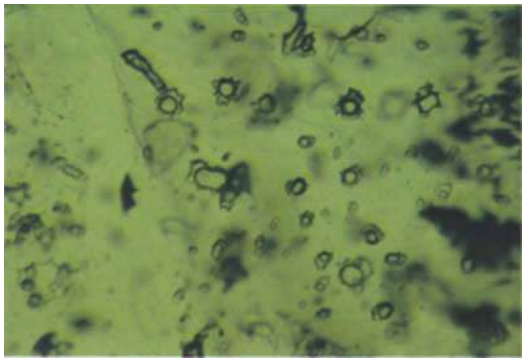

Fig. 13. Secondary cavities of Nigerian beryls are normally irregularly shaped or show rounded outlines. The cavities shown in this photo belong to a healing fissure that runs almost parallel to the basal face of the host emerald and show a 'jagged' outline. × 50

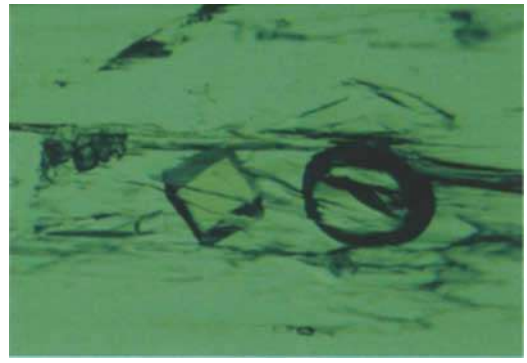

Fig. 14. Primary multiphase fluid inclusion of the '$s_x lg$' type with a large isotropic cube (probably halite). × 100

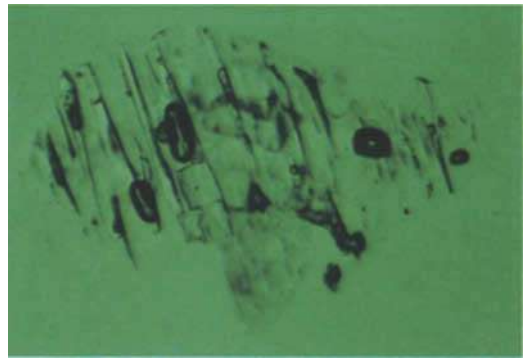

Fig. 15. Planar arrangement of multiphase fluid inclusions. × 70

Table III: Chemical compositions of emeralds and beryls from the Kaduna and Plateau States in Central Nigeria

	1	2 (a) (b)	3 (a) (b)	4 (a) (b) (c)	5	6	7	8	9	10	11
SiO_2	66.10–68.40	68.82/68.61	68.87/68.39	69.11/69.09/68.74	65.17	65.45	65.83	65.53	67.31	61.35–68.81	65.74–67.54
Al_2O_3	18.02–19.21	18.61/17.88	18.48/17.86	18.57/18.63/18.04	18.84	18.24	18.70	18.39	18.40	14.86–18.49	18.01–18.18
FeO_{tot}	0.11– 0.95	0.28/ 0.87	0.23/ 1.10	0.14/ 0.35/ 0.89	0.46	0.89	1.13	0.31	0.25	940* –12170*	0.06– 0.91
Cr_2O_3	< – 0.05	< / 0.06	< / 0.06	< / 0.02/ 0.21	0.01	<	0.02	0.08	0.07	< – 480*	0.06– 0.11
V_2O_3	< – 0.06	0.02/ 0.06	< / 0.09	< / 0.07/ 0.06	0.03	<	0.01	0.06	0.03	< – 280*	0.05– 0.07
TiO_2	< – 0.02	<	<	< < <	–	–	–	–	–	< – 0.04	0.07– 0.63
MgO	0.01– 0.20	0.02/ 0.06	0.03/ 0.06	0.08/ 0.03/ 0.05	0.03	0.04	0.02	0.20	0.03	0.03– 0.05	0.04– 0.06
Na_2O	0.04– 0.33	0.12/ 0.15	0.13/ 0.16	0.13/ 0.06/ 0.12	0.10	0.17	0.14	0.15	0.07	0.08– 0.57	0.09– 0.12
CaO	< – 0.01	<	0.01/ <	< < / 0.01	–	–	–	–	0.01	0.02– 0.05	0.00– 0.01
K_2O	< – 0.05	0.01/ <	< / 0.02	< / 0.01/ 0.05	–	–	–	–	–	0.04– 0.21	0.01– 0.02
CS_2O	< – 0.05	0.01/ <	0.02/ 0.02	0.01/ 0.02/ 0.03	–	–	–	–	–	–	–
MnO	< – 0.02	< / 0.01	0.01/ <	< < <	–	–	–	–	–	0.01– 0.05	–
Sc_2O_3	< – 0.03	<	0.01/ <	< < / 0.01	–	–	–	–	–	–	–
Li_2O	–	–	–	–	0.02	0.02	0.02	0.01	–	–	–

	12 (a) (b)	13 (a) (b)	14 (a) (b)
Cr	– / 290*	tr. / 1250*	tr. / 230*
V	tr. / 490*	tr. / 490*	– / 430*
Fe	178 / 588*	850 / 6380*	1090/ 6540*

Key:

< = contents below detection limit
– = not analyzed or range
* = element concentration in ppm
tr = traces

1: light to medium green and bluish-green (variation observed in 13 samples)
2–4: crystals with colour zoning; colour intensity c>b>a
5–8: Lind *et al.*, 1986;
5 = intense blue
6 = light blue
7 = light green
8 = intense green
9: Schrader, 1987
10: Henn *et al.*, 1984; range of 6 samples
11: Henn and Bank, 1991
12–14: J. Zang, pers. comm., 1992; crystals with colour zoning; colour intensity b>a

emeralds from other localities: for example, those from Colombia normally are three phase 'slg' inclusions with an isotropic daughter phase, usually halite.

Healed fractures are common in Nigerian emeralds and green beryls. Some are parallel to the hexagonal prism faces or to the basal pinacoid of the emerald host crystal (Figure 13) and are practically planar. More commonly, the healed fractures are undulating and without crystallographic orientation, often appearing as veil-like formations; some show a delicate net-like structure or contain larger flattened cavities whilst others contain numerous small rounded cavities resembling strings of pearls. Larger pseudo-secondary inclusions along healed fractures vary in type, some are multi-phase inclusions with or without birefringent solid phases. Three-phase inclusions of the 'Colombian type' (Figure 14) seem to be less frequent in the healed fractures than in primary cavities.

Chemistry

The chemical compositions of 32 beryls from central Nigeria are given in Table III. Since colourless, blue, blue-green and emerald-green beryls with varying intensities of colour may occur within the same paragenesis, their chemical characteristics will be discussed together.

The representative points of more than 100 emeralds from nine different localities in Africa are plotted in terms of their Al_2O_3 and MgO contents in Figure 16 (from Schwarz, 1995). The localities are:

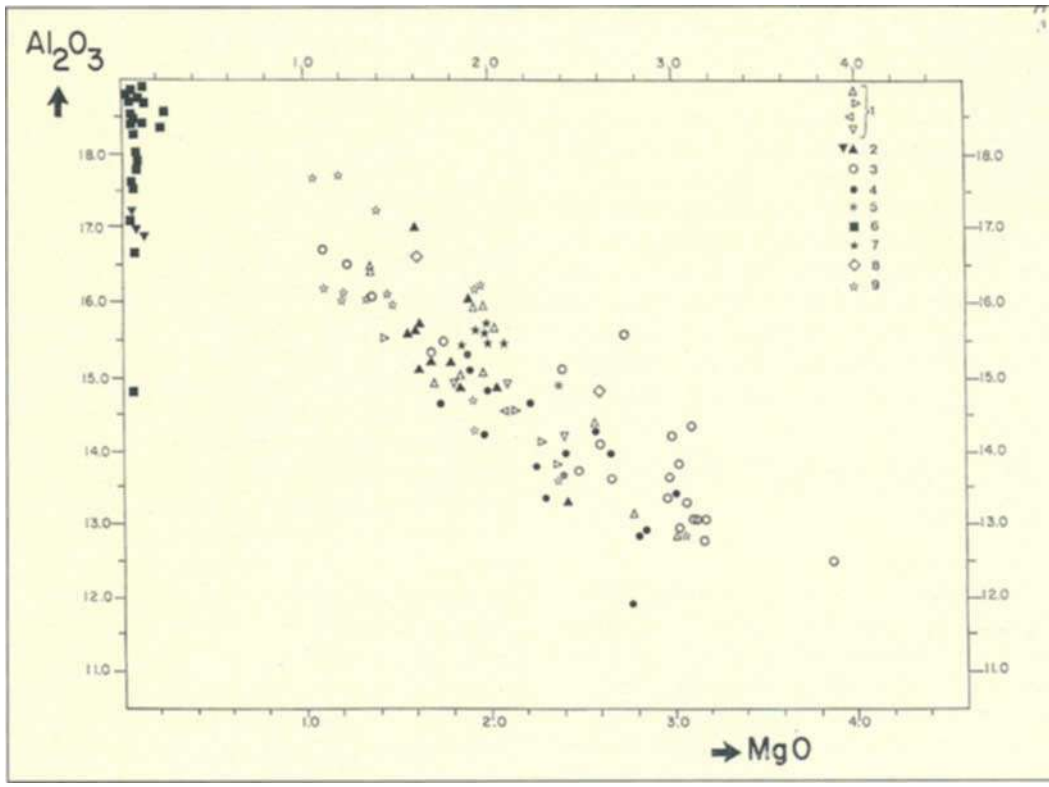

Fig. 16. Weight % Al_2O_3/MgO correlation diagram with representative points for emeralds from different African localities (1 = Ndola Rural District, Zambia; 2 = Alto Ligonha, Mozambique; 3 = Sandawana/Machingwe, Zimbabwe; 4 = Mananjary, Madagascar; 5 = 'Egypt'; 6 = Kaduna/Plateau States, Nigeria; 7 = Lake Manyara, Tanzania; 8 = 'South Africa'; 9 = Cobra Mine, South Africa

(1) Ndola Rural District (Kafube Belt), Zambia
(2) Alto Ligonha, Mozambique (including three pegmatite beryls)
(3) Sandawana-Machingwe mining area, Zimbabwe
(4) Mananjary mining region, Madagascar
(5) Eastern desert, Egypt
(6) Kaduna-Plateau State, Central Nigeria
(7) Lake Manyara, Tanzania
(8) 'South Africa' (exact locality not known)
(9) Cobra Mine, Transvaal, South Africa.

The emerald occurrences in Zambia, Zimbabwe, Mozambique, Madagascar, Egypt and South Africa all belong to 'schist-type' deposits; that is, they are associated with various schist rocks containing biotite or phlogopite, actinolite or tremolite and variable quantities of talc, chlorite or carbonates, probably derived essentially from a mafic-ultramafic protolith. Because of this environment, the MgO concentrations of emeralds from these rocks are generally between 1 and 3 wt%. The negative, approximately linear correlation between Al_2O_3 and MgO indicates that magnesium enters the beryl structure principally by substituting for aluminium. Such a substitution of Al^{3+} by bivalent ions such as Mg and/or Fe requires a coupled substitution to maintain a neutral charge balance, normally with Na in the following way:

$$Al^{3+,VI} = Mg^{2+,VI} + Na^{1+\,(channel)}$$

or

$$Al^{3+,VI} = Fe^{2+,VI} = Na^{1+\,(channel)}$$

In contrast to the emeralds from schist deposits, the Nigerian emeralds and green beryls are characterized by extremely low magnesium and sodium contents. This suggests that they are largely from the alkali granites of the Younger Granite suite which have extremely low contents of Mg. The suggestion made earlier that the majority of the Nigerian emeralds and green beryls containing fluorite and Fe-rich mica are probably of Younger Granite origin is consistent with this low Mg content.

Ferromagnesian minerals in the Nigerian alkali granites are always Fe or Na-Fe end members, so these elements must have been available during the albitization stage of alteration. Nevertheless, despite the availability of Na, the Na-contents of the Nigerian beryls are consistently low (see Table III and Figure 17). This is in accordance with observations on emeralds from other localities, especially in the Cordillera Oriental, Colombia where Schwarz (1995) has shown that Na is incorporated in the channels of the emerald structure only if there is some need for charge compensation caused by the entrance of bivalent cations (Me^{2+}) in the Al^{3+} positions. If there is no substitution of Al^{3+} by Me^{2+}, the emeralds show only low Na-contents, even if the mineralizing fluids are sodium-rich.

The iron-concentrations of the Nigerian emeralds and beryls show a strong variation, reaching FeO_{tot} values of up to 1.2 wt% (Figure 17, from Schwarz, 1995) and the high contents are consistent with iron being available during the beryl growth. As is shown by the absorption spectra (see below), at least part of the iron of the Nigerian emeralds or green beryls is present as Fe^{3+} (substituting for Al^{3+}) and therefore the beryl needs no sodium for charge compensation. The correlation diagram (Figure 17) shows that there is no correlation between the sodium and the iron contents for these emeralds.

In some of the analyzed samples that show colour-zoning, the concentration of the chromophore elements, especially iron, increases with the intensity of the bluish-green colour. Such colour variation is not related directly to the elements Mg and Na although they may be involved with chromophores in a charge-balancing role.

Comparing the values of optical data of emeralds from the schist-type deposits with those of the Nigerian emeralds and green beryls, the latter are low. The same is

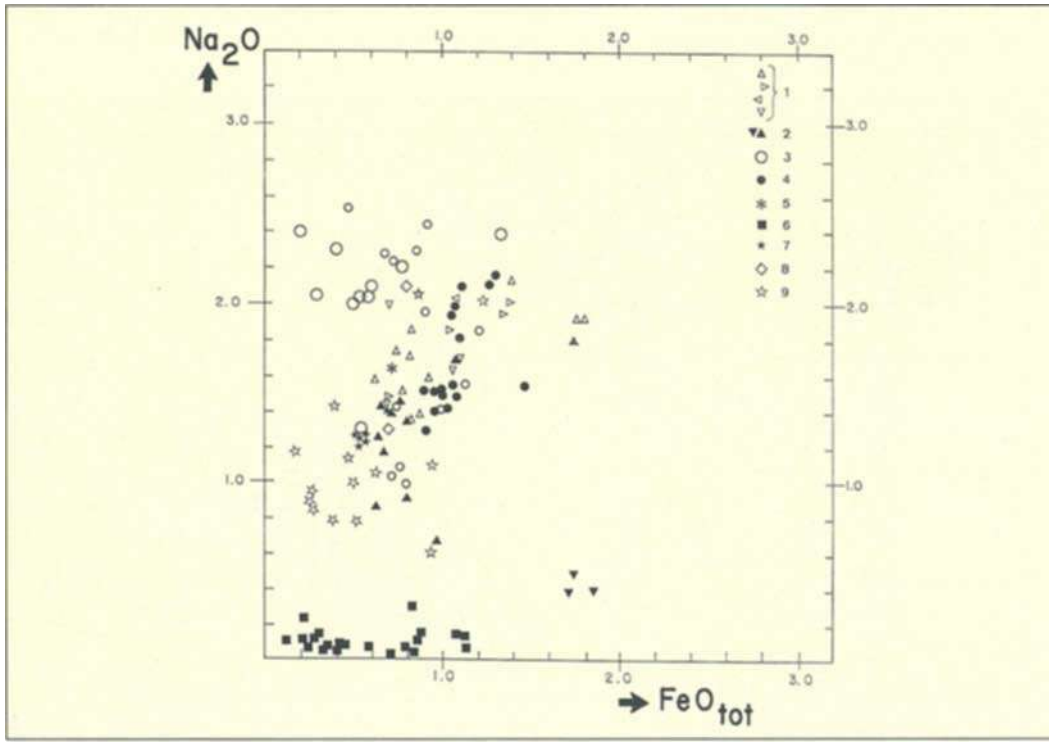

Fig. 17. Weight % Na_2O/FeO_{tot} correlation diagram with representative points for emeralds from different African localities (1–9 see Figure 16)

Table IV: Optical data of beryls/emeralds from the Kaduna/Plateau States, Central Nigeria.

n_e	n_o	*Birefringence*	*Reference*
1.566–1.568	1.572–1.575	0.006–0.007	Bank, 1984
1.565–1.567	1.570–1.572	0.005	Henn *et al.*, 1984
1.564–1.568	1.570–1.574	0.006	Lind *et al.*, 1986
1.569–1.570	1.574–1.576	0.005–0.006	Henn and Bank, 1991
1.560–1.569	1.566–1.574	0.005–0.006	This paper

Fig. 18. (a,b,c,d) Absorption spectra of emeralds and green beryls from the Kaduna and Plateau States in Central Nigeria. The spectra show different combinations and intensity ratios for the absorption bands of Fe^{2+}, Fe^{3+}, Fe^{2+}/Fe^{3+}, V^{3+} and Cr^{3+}.

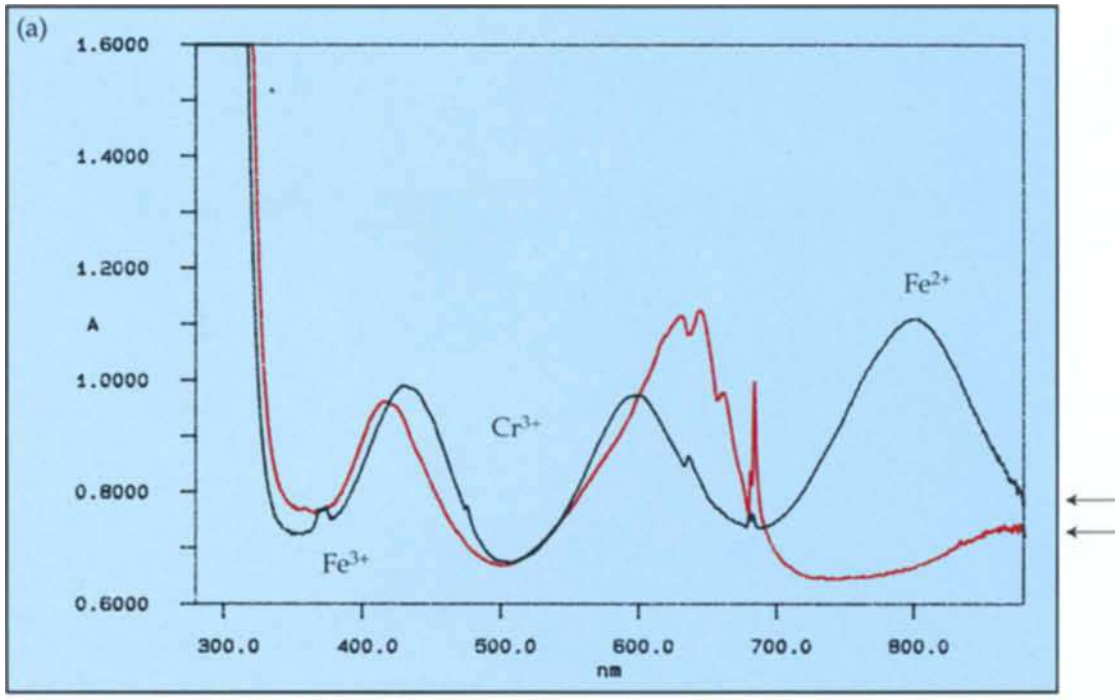

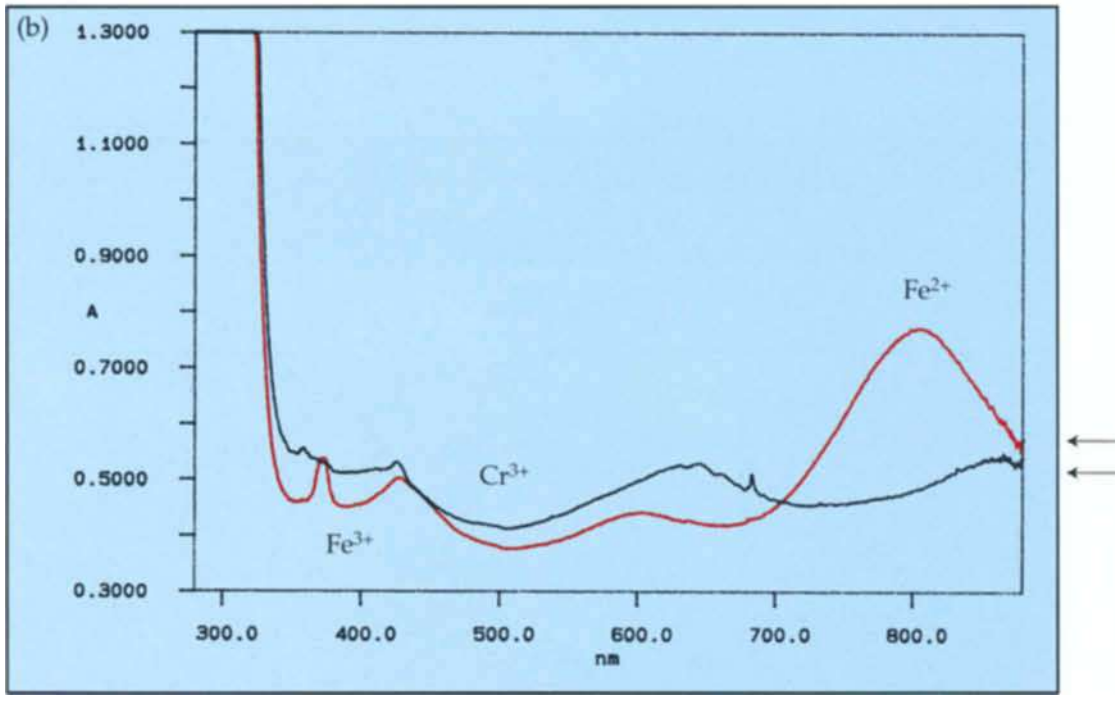

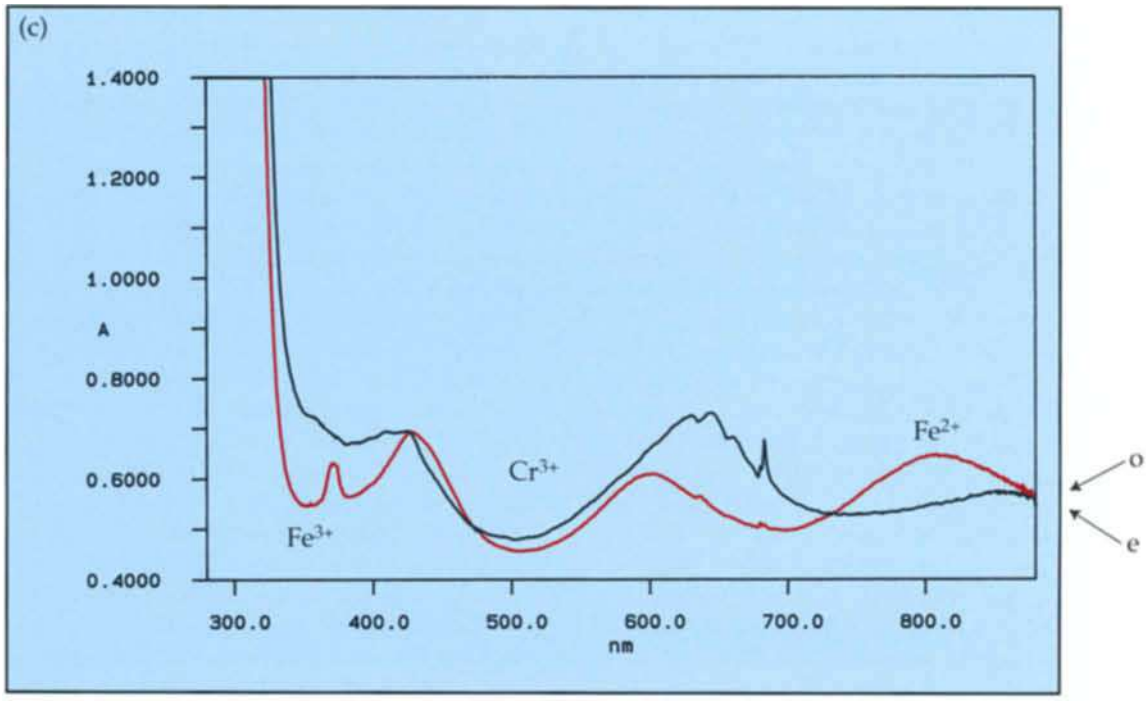
(c)
1.4000
1.2000
1.0000
A
0.8000
0.6000
0.4000
300.0
400.0
500.0
600.0
700.0
800.0
nm
Fe3+
Cr3+
Fe2+
o
e

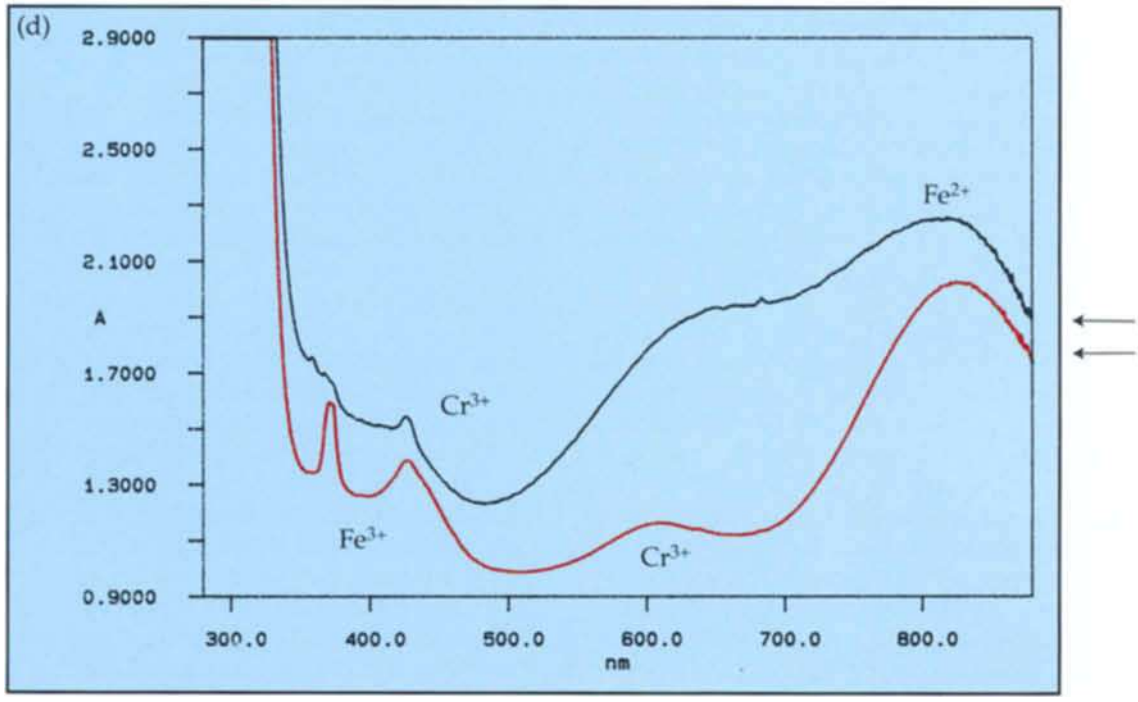
(d)
2.9000
2.5000
2.1000
A
1.7000
1.3000
0.9000
300.0
400.0
500.0
600.0
700.0
800.0
nm
Fe2+
Cr3+
Fe3+
Cr3+
e
o

true for the specific gravity values: 2.63–2.65 (Henn *et al.*, 1984), 2.66–2.68 (Lind *et al.*, 1986), 2.65–2.67 (Henn and Bank, 1991) and 2.64–2.68 (this paper).

After Henn and Bank (1991) and Lind *et al.* (1984), the absorption spectra of the Nigerian emeralds represent 'mixed types' with absorption patterns relating to an emerald component (Cr/V) and an aquamarine component (Fe^{2+} and Fe^{2+}/Fe^{3+}). Similar spectra have been reported for emeralds from Zambia (Schmetzer and Bank, 1980) and Madagascar (Hänni and Klein, 1982; Schwarz and Henn, 1992). The spectra of Figures 18a to 18d indicate that the Nigerian emeralds exhibit no consistent pattern. Almost all ratios of intensity between the different absorption bands of Cr, Fe^{2+}, Fe^{3+} and Fe^{2+}/Fe^{3+} have been seen in different Nigerian specimens (see also Schwarz, 1995), and the intense Cr^{3+} absorption bands observed in some samples show that the designation 'emerald' is justified at least for some of the beryls from the Kaduna and Plateau States.

Discussion and conclusions

There are two provenances for emeralds and green beryls in central Nigeria, one from pegmatites intrusive into the Basement complex, the other from Mesozoic alkali granite ring complexes. From their solid inclusions and chemistry, the large majority of the emeralds and green beryls in this study appear to have a granitic origin.

The very few beryls with tourmaline inclusions most likely originate from Basement pegmatites, whereas those which contain fluorite and Fe-rich mica originate from the Younger Granites.

The particular geological setting and the special genetic conditions result in a unique set of mineralogical-gemmological properties of the emeralds and green beryls from central Nigeria. These distinguish central Nigerian emeralds from all other main emerald deposits in the world. The association of mineral inclusions, comprising such 'exotic' representatives as boldyrevite-ralstonite-monazite-Fe-rich mica, together with the presence of a large variety of fluid inclusions, has no counterpart in beryls from other occurrences.

The presence of fluorite as a mineral inclusion in emeralds is consistent with the newest models postulated to explain emerald occurrences (Schwarz, 1995). Although it is likely that beryllium is transported in most cases as a complex with fluorine, fluorite (CaF_2) is apparently only a common mineral inclusion in emeralds if the emerald crystallization is related to greisenization processes (Schwarz, 1995). Th-rich monazite and the Fe-rich micas, also found in Nigerian beryls, are typical minerals of greisen associations. The occurrence of other fluorides (boldyrevite and ralstonite) and fluorosilicates indicates a specific genetic relationship for the emerald and green beryl mineralization in Nigeria. Boldyrevite and fluorosilicates have not been described as inclusions in emeralds from other localities, and the identification of ralstonite in one emerald from the Belmont Mine in Minas Gerais (Souza, 1988) has not been confirmed.

In the Younger Granites, emeralds and green beryls were probably formed during the late magmatic and early subsolidus hydrothermal stage, based on solid mineral inclusions and the nature of the fluid inclusion evidence. Early hydrothermal fluids associated with the granite magma were saline and of high temperature (about 400–500 °C) and the fluid inclusions in the emeralds and beryls normally contain several daughter minerals.

The unusual chemical properties, especially the very low Mg and Na concentrations of the emeralds and green beryls from central Nigeria, can also be explained considering the (geo-)chemical features of their host rocks. These are characterized by low Mg values. The incorporation of Na in the channels of the

emerald structure does not depend on the availability of this element in the mineralizing fluids. The controlling factor is the need for charge compensation caused by the entrance of bivalent cations. Consequently, the Na-concentration is low because $(Mg+Fe)^{2+}$ in the emeralds and green beryls is also low. The low Cr and V concentrations of the host rocks is reflected by low contents of these elements in the beryls. The large variation of the Fe-contents in the emeralds and green beryls is due to the possibility of incorporating iron as Fe^{2+} and/or Fe^{3+} in different lattice positions (including channel sites).

Both beryllium and fluorine are enriched in the alkali granites of Nigeria compared to 'average' values in granites worldwide, and both elements may occur in a range of minerals. The source of the chromophore elements, Cr and V, in the Nigerian beryls is problematic because both elements are scarce (0–10 ppm) in Nigerian granites. However, most beryl crystallization occurs close to the 'roof' of a granite in the region where granite fluids may react with surrounding country rocks. Thus Cr and V may have been incorporated from the basement schists or younger volcanic rocks both of which have higher Cr and V contents than many of the granites. The model calculations of Kozlowski *et al.* (1988) for the emerald occurrences of the Cordillera Oriental in Colombia, show that extremely low chromophore contents in the host rocks are sufficient to provide enough Cr and V for the crystallization of significantly coloured green beryls (emeralds). This suggests that it is not necessary to have exceptional enrichment of these elements in the country rocks of the Nigerian beryls.

The optical data for the beryls and emeralds from the Kaduna and Plateau States can be interpreted bearing in mind their chemical characteristics. The 'mixed type' spectra with almost all ratios of intensity between the different absorption bands of Cr, Fe^{2+}, Fe^{3+} and Fe^{2+}/Fe^{3+} are in accordance with the (crystal-) chemistry of the beryls.

Gemmologists should be able to distinguish between emeralds from central Nigeria and those from other localities. For those Nigerian beryls that contain solid inclusions, the mineral association of albite + fluorides + Fe-rich mica is unique. For those Nigerian beryls which are free of solid inclusions, the inclusion pattern may be similar to that of certain Colombian emeralds. However, the 'classic' fluid inclusions of the Colombian emeralds are 'slg'-three-phase-inclusions with a cubic halite crystal, whereas the emeralds and green beryls from central Nigeria are more commonly '$s_x$lg'-multiphase inclusions which, in addition, contain one or more (anisotropic) s-phases. Absorption spectra can also aid in origin identification. The 'mixed-type' spectra of the Nigerian beryls are quite different from the spectra of the Colombian emeralds which, as a rule, are free of iron bands (see also Schwarz, 1995).

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All photomicrographs are by D. Schwarz.

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Note

1. Examples for the fluid-inclusion nomenclature used in this paper:
   - lg – liquid-gas two-phase inclusion
   - llg – liquid-liquid-gas three-phase inclusion
   - slg – solid-liquid-gas three-phase inclusion
   - $s_x$lg – multi-phase inclusion with several different solid phases, one liquid phase and one gas phase

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Diamonds

Cathodoluminescence properties of CO_2-bearing and CO_2-free diamonds from the George Creek K1 kimberlite dike.

I.L. CHINN, J.J. GURNEY, H.J. MILLEDGE, W.R. TAYLOR AND P.A. WOODS. *International geology review*, **37**, 1995, pp 254–8.

CL properties of diamonds from the George Creek K1 kimberlite dike, in the State Line kimberlite district of Colorado-Wyoming, USA, are discussed. Diamonds shown by IR spectroscopy to contain sub-microscopic, high-pressure CO_2 inclusions show anomalous CL colours, including pink, pale violet, orange and brown, while CO_2-free diamonds show typically blue.

M.O'D.

Lab Notes.

R.C. KAMMERLING AND C.W. FRYER. *Gems & Gemology*, **31** (3), 1995, pp 196–203, 20 illus. in colour.

A very light green marquise diamond contained a row of included crystals most of which appeared to be diamond although at least one crystal was prismatic and yellow green suggesting pale diopside or enstatite. Testing showed that this inclusion was the sole cause of the colour. A visible spectrum showed absorption at 741 nm, the primary line of the GR1 centre, showing that the stone had not been exposed to ionising radiation. Small dark spots around some of the included crystals were graphite.

An eye-visible brownish-orange inclusion breaking the table surface of a fancy yellow diamond was shown to be almandine-spessartine garnet by EDXRF.

A yellow round brilliant diamond showed a natural iridescence in a fracture which had also been filled. In the iridescent area colours were seen simultaneously whereas the flash-effect colours were seen one at a time; green in bright-field and red in darkfield illumination. At high magnification the filling in the fracture showed small bubbles and flow lines. R.J.P.

Gem news.

R.C. KAMMERLING, J.I. KOIVULA AND E. FRITSCH. *Gems & Gemology*, **31** (2), 1995, pp 129–39, 16 illus. in colour.

Firms in Ramat Gan, Israel, have fracture-filled 30,000 ct of diamond in the last 30 months. All sizes and shapes of diamonds are being treated and the greatest demand is for those with an apparent clarity of SI after fracture filling.

Synthetic diamonds were misrepresented recently as Canadian rough. All the stones were about the same size, colour and shape (very atypical for a mine run sample) and showed evidence of metallic flux inclusions. R.J.P.

ABSTRACTORS

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For further information on many of the topics referred to consult *Mineralogical Abstracts* or *Industrial Diamond Review*.

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Gem news.
R.C. KAMMERLING, J.I. KOIVULA, M.L. JOHNSON AND E. FRITSCH. *Gems & Gemology*, **31** (3), 1995, pp 204–16, 22 illus. in colour.

A slightly brownish-grey diamond crystal contained a cavity with a mobile triangular inclusion which was of the same type (1a) as the host. The original material filling the cavity was thought to be gas which had escaped during the cutting of a window.

A visit to the kimberlite pipes in the Siberian Sakha (Yakutia) Republic showed that flooding was a serious problem. There was very little activity at two of the sites and both the international pit as well as the quarry-like Zarnitza prospect were inactive. Udachnya seemed to be the most productive and its large processing plant was in full production servicing not only its own but also the Aikhal and Jubilee sites. When winter temperatures reach ~45°C work stops because of an inversion layer which traps potentially deadly methane in the mine. R.J.P.

A diamondiferous lamprophyre dike, Gibson Lake area, North-west Territories.
N.D. MACRAE, A.E. ARMITAGE, A.L. JONES AND A.R. MILLER. *International geology review*, **37**, 1995, pp 212–29.

Diamonds are reported from the Akluilâk dyke in the Central Churchill Province, Gibson Lake area, Northwest Territories of Canada. The dyke is a narrow lamprophyre intrusion of ultrapotassic composition and has yielded a large number of diamonds, few of which are larger than 0.5 mm. Crystal forms are primarily octahedra and tetrahexahedroids though some macles, cubes, aggregates and fragments also occur. The dyke is situated approx. 120 km NW of Rankin Inlet. M.O'D.

[The apographitic impact diamonds from astroblemes Ries and Popigai.] (Russian with English abstract)
V.L. MASAITIS, G.I. SHAFRANOVSKY AND I.G. FEDOROVA. *Proc. Russian Min. Soc.*, **124** (4), 1995, PP 12–19.

A study of diamonds formed in the Popigai and Ries impact craters has shown that they are similar in their mode of occurrence, morphology, physical properties, crystalline structure, etc. They occur as polycrystalline aggregates of cubic and hexagonal phases and inherit the shape and some other features of the original graphite. Authigenic impact diamonds were established to exist in both craters in strongly shocked and partially fused fragments of graphite-bearing crystalline target rocks. After the solid transition from graphite at ~ 40–45 Gpa, impact diamonds were included in hot media and subjected to oxidation and graphitization. R.A.H.

Carbon isotopic composition and origin of SiC from kimberlites of Yakutia, Russia.
E.A. MATHEZ, R.A. FOGEL, I.D. HUTCHEON AND V.K. MARSHINTSEV. *Geochimica et Cosmochimica Acta*, **59** (4), 1995, pp 781–91.

Analyses are presented of carbon isotopic compositions of moissanite (SiC) from the Mir and Aikhal kimberlites. Yakutia Province. The mineralogy of moissanite is described and illustrated with an SEM image. Silicon metal is the most common inclusion and inclusions of ferrosilicate, Fe-Ti silicides, *REE* silicate and sinoite have been found. $\delta^{13}C$ ranges –22 to –29‰, and $\delta^{15}N$ + 9.7 ± 4.0 to +5.6 ± 2.0‰. Moissanite may be a relict of a reduced, primordial Earth and now present as a trace phase in an otherwise oxidized mantle. Alternatively there may be present-day global regions that are highly reduced with light C isotopic compositions. Other possibilities are discussed, including the formation of moissanite by metamorphism of reduced, carbonaceous sediments during subduction. R.K.H.

Distribution of the luminescent centres in Yakutian diamonds.
V. MIRONOV AND B. ANTONYUK. *Archiwum Mineralogiczne (Polska Akademia Nauk)*, **50** (2), 1994, pp 3–12.

The laser-luminescence tomography method for revealing crystal zoning is described and has been used to examine diamonds collected from the Malobotuobinskoe field in the Mirnyi region of Yakutia, Russia. This non-destructive method shows the distribution of luminescence centres in the crystals, usually arranged in zones formed during successive stages of crystal growth. 'Phantoms' inside crystals, i.e. luminescent outlines of the growth zones, even from the earliest stages, provide information on changes in diamond crystallization conditions in the parent rock matrix. The method has been developed for use in the classification of diamonds from both primary kimberlite and secondary alluvial deposits in the Mirnyi region. The paper is illustrated with nine colour photographs showing yellow, green or blue UV luminescence.
R.A.H.

The Luanda diamond fields. Part II.
A. THOMAS. *South African gemmologist*, **9** (3), 1995, pp 23–8.

Continuing account of a visit to the diamond-producing area of Luanda with some details of recovery methods. M.O'D.

[Heart and arrow shaped pattern observed in round brilliant-cut diamond.] (In Japanese with English abstract)
H. YANO. *Journal of the Gemmological Society of Japan*, **18**, 1993, pp 22–30, 14 figs., 2 tables.

A recent claim that gained popularity on the Japanese diamond market was that if a brilliant cut diamond exhibits a heart and arrow shaped pattern when illuminated under certain conditions, this proves that it has the highest grade of cut. Even an instrument to illuminate and record the pattern has appeared on the market. This paper reports the results of a mathematical analysis of the reliability of such a claim. It has been demonstrated that (1) such a pattern can be seen when a stone is illuminated in a range of inclination of 9 to 15 degrees to the axis, (2) the pattern is mainly due to the arrangements of pavillion facets and not to the crown facets, and so (3) this pattern does not automatically represent the highest cut grade. The appearance of the pattern is a necessary condition but not a sufficient condition to prove the cut grade. I.S.

Gems and Minerals

Detrital origin of fuchsite-bearing quartzites in the western Dharwar craton, Karnataka, India.
S. ARGAST, *Journal of the Geological Society of India*, **45**(5), 1995, pp 559–75.

Quartzites in the Nuggihalli, Holenarsipur, Javanhalli, Bababudan and Chitradurga schist belts all originated as clastic sandstones rather than as precipitated cherts. Detrital chromite occurs in the oldest quartzites and this gave rise to fuchsite during metamorphism; there is no evidence for significant contributions of hydrothermal Cr. There are secular trends in median Cr/Al_2O_3, Cr/Fe_2O_3, Cr/Zn and K_2O/Al_2O_3 ratios which are consistent with the gradual evolution of mafic and sialic sedimentary source terrains over the interval from ~ 3500–2500 m.y. ago. The compositions of the Javanhalli and Bababudan quartzites are sufficiently different to suspect, but not prove, that they are from different sources. R.A.H.

Charoite: a unique mineral from a unique occurrence.
M.D. EVDOKIMOV. *World of Stones*, **7**, 1995, pp 3–11, illus. in colour.

Details of the properties and occurrence of charoite are given, with notes on the geology of the occurrence and a list of references. The charoite-producing source (Sirenevyi Kamen [lilac stone]) is found on the meridian passing from the town of Olekminsk on the Lena River to Khani Station on the Baikal-Amur railway line, Russia. M.O'D.

Kazakhstan and Middle Asia. A brief mineralogical guide.
A.A. EVSEEV. *World of Stones*, **8**, 1995, pp 24–30, illus. in colour, 1 map.

List of mineral species found in Kazakhstan and Middle Asia, arranged in alphabetical order of location and including some gem minerals. M.O'D.

Recent colored gem stones from Russia. [In Japanese with English abstract]
M. HAYASHI, K. HARA AND A. YAMAZAKI. *Journal of the Gemmological Society of Japan*, **18**, 1993, pp 15–21, 15 figs, 6 tables.

Diamond, ruby, alexandrite, demantoid, topaz, emerald, aquamarine, tourmaline, diopside, jadeite and lapis-lazuli from Russia which have recently been encountered in the Japanese gem market are described. Chemical and analytical data obtained by electron dispersive spectroscopy, FT-IR charts, and XRD are given. Possible marketing routes of Russian emeralds are explained. I.S.

Gem identification by FT-IR–emerald, jadeite, sillimanite, etc. [In Japanese with English abstract]
M. HAYASHI AND Y. MANAKA. *Journal of the Gemmological Society of Japan*, **19**, 1994, pp 3–6, 15 figs., 1 table.

Fourier transform infrared (FT-IR) spectroscopy has been applied extensively to identify resin-impregnated emeralds and jadeites. FT-IR spectra show different features characteristic of natural, flux-grown, hydrothermally-grown emeralds and also resin impregnated emeralds, and jadeites, that can be used for diagnostic purposes. FT-IR spectroscopy is also useful to differentiate between gemstones whose refractive indices are similar, such as sillimanite, kornerupine, diopside and enstatite. I.S.

Rubis et saphirs de République Populaire de Chine.

R.W. HUGHES AND O. GALIBERT. *Revue de gemmologie*, **125**, 1995, pp 5–8, illus. in colour.

Adaptation of a chapter dealing with ruby and sapphire from China, to appear in a new edition of the first author's book on corundum. M.O'D.

Gem-quality grossular-andradite: a new garnet from Mali.

M.L. JOHNSON, E. BOEHM, H. KRUPP, J.W. ZANG AND R.C. KAMMERLING. *Gems & Gemology*, **31**(3), 1995, pp 152–67, 2 tables, 1 illus. in black-and-white, 17 illus. in colour.

Thousands of carats of these fashioned stones from the Republic of Mali are poised to enter the marketplace. In the trade these garnets are termed 'Mali garnet' or 'Mali grossular garnet'. The composition of this garnet is intermediate between grossular and andradite garnets and has been described by the GIA Gem Trade Laboratory as grossular-andradite. Quantitative chemical analysis using an electron microprobe and X-ray powder techniques revealed a composition 78% grossular and 20% andradite. Refractive indices for yellow-green and green stones are in the range of 1.752–1.769, whilst those of orange brown stones are 1.773–1.779 (RIs for grossular 1.73–1.76 and andradite 1.880–1.895).

The absorption spectra of yellow-green, and orange brown stones show an absorption band at 440 nm. The stacked parallel planes of growth zoning are always visible between crossed polars and together with moderate to strong ADR are diagnostic of grossular-andradite garnet.

Most of the gem quality grossular-andradite garnets from Mali are reminiscent of the pale greenish yellow to yellow-green grossular garnets from Tanzania, with some rare stones resembling peridot. Numerous brown to brownish-orange stones can be quite brilliant due to higher RIs and dispersion and may serve as inexpensive substitutes for 'cognac' diamonds. R.J.P.

Mosaic geographical map – a masterpiece of stonecutting art.

M.N. KALININA. *World of Stones*, **8**, 1995, pp 31–2, illus. in colour.

Brief account of a mosaic map in the Georgian Hall of the Hermitage Museum in St Petersburg, Russia. The map is constructed from hard ornamental stones. M.O'D.

Lab notes.

R.C. KAMMERLING AND C.W. FRYER. *Gems & Gemology*, **31**(3), 1995, pp 196–203, 20 illus. in colour.

A stone showing a colour change from dark bluish green in daylight to dark reddish purple in incandescent light was identified as natural alexandrite. It had atypically high RI values of 1.753–1.761 and was found to have unusually high concentrations of chromium, titanium and iron. Several surface-reaching fractures contained a transparent filler which easily melted.

Three purplish-red mixed-cut stones were identified as corundum but lacked distinctive absorption features. The facets had uneven surfaces with some slight rippling and many minute cracks. Immersion in di-iodomethane revealed concentration of the colour along the facet edges indicating that they were diffusion-treated corundums.

A translucent mottled-green carving in a closed pendant setting gave a spot RI reading of 1.66 and showed a series of 'chrome lines' in the red end of the spectrum which are consistent with natural-colour jadeite. However, the carving consisted of a thin hollow jadeite shell filled with a soft transparent colourless filler containing gas bubbles. FTIR spectroscopy of the filler indicated polymers known to have been used for jadeite impregnation. The thickness of the jadeite shell at the edge was only 0.05 to 0.10 mm. R.J.P.

Gem news.

R.C. KAMMERLING, J.I. KOIVULA AND E. FRITSCH. *Gems & Gemology*, **31**(2), 1995, pp 129–39, 16 illus. in colour.

Rare collector stones from the former Soviet Union were shown in Tucson in February 1995. These included small colourless crystals of leucophanite, colour-change clinochlore together with görgeyite, kaliborite and preobrazhenskite. The full constants of these were quoted.

Chatoyant moonstones with an atypical darker orange colour originated from Madras, India. Unusual opal carvings incorporating both opal and its matrix were cut from the back to produce a three-dimensional effect. Sapphires from Madagascar were well described. These had been heat treated and the blue colour was due to iron-titanium charge transfer. Details

were given of a chatoyant spessartine garnet from Namibia. R.J.P.

Gem news.
R.C. KAMMERLING, J. KOIVULA, M.L. JOHNSON AND E. FRITSCH. *Gems & Gemology*, **31**(3), pp 204–16, 22 illus. in colour.

A blue green apatite cabochon from Malagasy weighing 11.45 ct showed pronounced chatoyancy and an unusual colour. The chatoyancy was caused by barely visible white needles. 'Eilat stone' not from Israel but from Peru is now on the market. It is a by-product of copper mining. At 10.03 ct round cabochon-cut emerald from Brazil showed a well defined six-ray star. It showed strong pleochroism with intense blue-green colour parallel and a light yellowish-green colour perpendicular to the *c*-axis attributed to a distinct iron-bearing (aquamarine) component which was found in the spectrum together with chromium bands of emerald. Although there were channel-like inclusions orientated parallel to the *c*-axis, the star was caused by three sets of unidentified small elongated particles orientated perpendicular to the *c*-axis. A transparent purplish red-brown stone of 0.33 ct had RI 1.742, singly refractive, SG 3.68–3.70, inert to both long and short wave UV radiation. Unusually it showed a typical almandine-rhodolite visible-light absorption spectrum. It was confirmed as genthelvite, $Zn_4Be_3(SiO_4)_3S$, a member of the helvite group. X-ray powder diffraction analysis and energy dispersive X-ray fluorescence (EDXRF) spectrometry were used to identify the stone. A 'drusy' hausmannite cabochon showed an imposing architectural appearance with its natural crystalline surface. Green opal from Serbia appeared green through the Chelsea filter. Spot RI 1.46 and SG 2.10 values were obtained but were difficult to measure because the stone was porous. The stone was inert to short-wave UV radiation but fluoresced an even faint chalky green to long-wave UV. The spectrum showed cut-off edges at 450 and 620 nm. Some healed fractures and veining were visible under magnification. EDXRF analysis revealed the presence of nickel which was the probable cause of the colour. An Egyptian green quartz reportedly collected in the Eastern desert has a pseudo-fibrous structure. EDXRF analysis revealed a fairly large concentration of chromium which probably was the cause of the colour as finely disseminated chromium-coloured mineral inclusions. A spangled quartz is coloured by bright orange red flakes which are probably hematite. Although randomly orientated throughout the cabochon the flakes are concentrated in one layer parallel to a rhombohedral face and are unusual in that each grew outward from one corner in an elongated fashion to give an 'hour-glass' or 'cello' shape. An aromatic resin necklace sold as myrrh was thought not to be from the somewhat rare Commiphora myrrha of biblical fame. It showed RI 1.41(spot) SG 1.27, hardness less than 2.5 on Mohs' scale and on the approach of a hot needle easily melted emitting a characteristic sweet spicy odour. Purple scapolite from Tajikistan reputedly found in the Pamir mountains is mined at an altitude of 5000 m and miners wear oxygen masks when working. Specimens showed uniaxial negative character, RI 1.539 and 1.550, SG 2.61, inert to long wave UV and fluorescing a very weak pinkish orange to short wave UV. Another stone from this region was a spinel of 123 ct described as virtually flawless. An opticon-treated malachite showed enhanced lustre and depth of colour. The impregnation process consisted of repeated coatings and oven treatment at each stage so that finally the whole of the product was impregnated. R.J.P.

Spectrophotometric identification of emeralds. [In Japanese with English abstract]
H. KITAWAKI AND H. FUKUSHIMA. *Journal of the Gemmological Society of Japan*, **19**, 1994, pp 7–14, 18 figs, 1 table.

UV-VIS and NIR spectra have been obtained on some hundreds of emerald samples from different origins, both natural and synthetic. In UV-VIS spectra, dominant absorption due to Cr can be seen in natural Colombian emeralds, while the absorption peaks due to both Cr and Fe are seen in natural emeralds from other localities. Hydrothermally-grown synthetic emeralds show absorption due to Cr and high transmission of UV. In Russian synthetic emeralds, an absorption related to Ni is seen. In flux-grown synthetic emeralds, only Cr-related absorption can be recognized, and the transmission peak in the UV lies at a higher wavelength than that of Colombian samples. From NIR (1200–2700 nm) spectra, the origin of emeralds and the conditions of their growth can be conjectured from the absorption peaks, since they show the presence or absence and the nature of H_2O. I.S.

[A few unusual gemstones recently encountered.] (In Japanese)
Y. KITAWAKI. *Journal of the Gemmological Society of*

Japan, **19**, 1994, pp 32–3, 1 fig., 2 tables.

Natural bi-colour topaz, natural euclase, natural pink clinozoisite which were encountered in gem testing are described. I.S.

[A trial for grading black pearls.] (In Japanese with English abstract)

H. KOMATSU, C. SUZUKI AND M. HIRAKO. *Journal of the Gemmological Society of Japan*, **19**, 1994, pp 23–9, 10 figs., 3 tables.

Based on the quality elements of colour and brilliance, efforts have been made to establish a method to quantitatively grade the quality of black cultured pearls produced by *Pinctada margaritifera*. The method of grading, inherent mechanism of colour emission, and the difference in the emission mechanisms between black and white pearls are described and discussed. Reflectance is measured and RBG analysis is done by image analyser. The results showed that the measured values of four quality elements (blackness, body colour, interference colour and its intensity) on the image analyser, were almost identical to the grades obtained by visual grading. I.S.

Native copper in agates from Rudno near Krzeszowice.

W. KRAWCZYNSKI. *Mineralogia Polonica*, **26**(1), 1995, pp 27–32, 3 maps.

Copper is reported in agates from Rudno near Krzeszowice in Poland. Notes on the occurrence and on the agates are given and samples were taken from more than 300 agate specimens. Native copper was found to occur in secondary microfissures crossing agate layers obliquely, at the boundaries of individual agate layers in a tree-like form, and as dispersed grains independent of agate layers. M.O'D.

What's new in minerals?

T.P. MOORE. *Mineralogical Record*, **27**(1), 1996, pp 59–66, illus. in colour.

Gem-quality minerals and fashioned stones are reported from mineral and gem shows held in the United States. Species seen at the Denver show include fine rhodochrosite from the Sweet Home mine, Alma, Colorado: smoky quartz from the Calumet iron mine in the same state: twinned crystals of chrysoberyl from Santa Tereza, Espirito Santo, Brazil: very deep pink octahedral fluorite crystals from Mont Blanc, France: emerald from the Jos region of Nigeria: brown to green vesuvianite from Sandare, Diakon Arrondissement, Nioro du Sahel, Mali (this area also produces brown-green grossular): sceptre amethyst from Obman, Yakutia, Russia: blue topaz from Nura-Taldy, central Kazakhstan: emerald crystals from the mica schists of the Malysheva mine, central Urals, Russia (the crystals are not of gem quality): fine elbaite showing green, colourless and blue sections perpendicular to the *c*-axis, from the Asthor mine, near Shigar, Pakistan.

From the show held in Pretoria, South Africa, David Minster reports fine green tourmaline crystals from Mozambique: rhodochrosite crystals up to 3 cm long from the Kalahari manganese field, South Africa: gem-quality yellow orthoclase and rhodizite from the Malagasy Republic. M.O'D.

La saga peregrina, [first part].

B. MOREL. *Revue de gemmologie*, **125**, 1995, pp 15–17, illus.

Enquiry, with some proposals, into the present whereabouts of the Peregrina, a celebrated pearl once in the possession of the Kings of Spain. M.O'D.

The co-precipitation of Fe^{3+} and SiO_2 and its role in agate genesis.

T.J. MOXON. *Neues Jahrbuch für Mineralogie, Monatshefte*, **1996**(1), pp 21–36.

Detailed experimental work studying the use of Fe^{3+} and Mg^{2+} in removing H_4SiO_4 and colloidal silica from separate dilute silica solutions and sols over periods of 45 min to 14 years is reported. It is demonstrated that Mg^{2+}-SiO_2 gels in an alkaline saline environment at room temperature can develop signs of transformation into opal-CT after 14 years. The concentrations of Fe^{3+} found in some agates is considered to be coincidental and too low to precipitate silica from any silica sol or solution. R.A.H.

Ein trapiche-rubin aus Myanmar (Burma).

H.-J. MÜLLENMEISTER AND J. ZANG. *Lapis*, **20**(12), 1995, p. 50, 2 photos in colour.

A ruby crystal of 6 ct and 12 mm thick showed six sections of ruby divided from one another by spokes of a light-coloured carbonate material tentatively identified as either calcite or ankerite. The piece closely resembled the trapiche emerald long known from the Muzo mine in Colombia. M.O'D.

The degree of metamictization in zircons: a Raman spectroscopic study.
L. NASDALA, G. IRMER AND D. WOLF. *European Journal of Mineralogy*, 7(3), 1995, pp 471–8.

A series of natural zircons representing various degrees of metamictization were investigated by Raman microprobe analysis. Systematic changes in wavenumbers and half-widths of the Raman bands were shown to be caused by increasing irregularities of bond-lengths and bond-angles and a general breaking-up of the structure as a result of metamictization. The half-width of the antisymmetric stretching vibration band (B_{1g}) of the SiO_4 tetrahedra, which has a frequency of ~1007 cm^{-1} in well-crystallized and 1000 to 995 cm^{-1} in metamict zircons, is most suitable for estimating the degree of metamictization: its value increases from ~ 5 cm^{-1} in well-crystallized samples up to 30–55 cm^{-1} in highly metamict X-ray amorphous zircons, and is strongly dependent on the degree of lattice destruction by metamictization. In contrast, the Raman parameters seem to be almost uninfluenced by chemical variations. The potential value of such measurements, especially in radiometric age determinations, is discussed. R.A.H.

Antique cameos.
O.Y. NEVEROV. *World of Stones*, 7, 1995, pp 29–32, illus. in colour.

Descriptive paper introducing the classical motifs found in cameos, some of which are illustrated. Examples are taken from the collections of the Hermitage Museum, St Petersburg, Russia. M.O'D.

Optical and infrared spectroscopic studies of epidote group minerals from the Rhodope region.
S. PETRUSENKO, M. TARAN, A. PLATONOV AND S. GAVORKYAN. *Review of the Bulgarian Geological Society*, 53(1), 1992, pp 1–9.

Crystals of various colours, including Fe, Mn-bearing clinozoisites, Mn-bearing zoisite (thulite) and epidote from skarns of various Bulgarian deposits, have been studied. Oriented single-crystal platelets have been used to record optically polarized, α, β and γ spectra. The green colour of epidote is associated with Fe^{3+} occupying the *M*(3) sites in the crystal structure and is determined by a short-wave $O^{2-} \rightarrow Fe^{3+}$ transfer. The pink colour of Mn-clinozoisite and thulite is caused by Mn^{3+} in *M*(3) structural sites. The IR spectra of the two minerals show definite differences. The OH-group valency oscillation band at 210 cm^{-1} is most important for identification of zoisite. Mn-bearing specimens show three maxima in the 500–600 cm^{-1} interval whereas Fe-bearing ones show a single broad band which is explained with bond oscillations in the AlO_6-octahedra. A comparative analysis of infrared spectra of clinozoisite before and after its treatment with deuterium has shown that the OH-group band at 3370 cm^{-1} and the band at 1045 cm^{-1} (caused by Al-OH deformational oscillations) disappear. They are replaced by new bands at 2490 and 780 cm^{-1}. The absorption bands of the diorthogroups lined by *M*(3) octahedra are the most variable. This corroborates the assumption of preferable substitution of Al by Fe in the *M*(3) sites. A linear regression equation based on the valency frequency oscillations of diorthogroups is proposed for determining the Fe content. R.A.

Epitaxial overgrowths of marcasite on pyrite from the Tunnel and Reservoir Project, Chicago, Illinois, USA; implications for marcasite growth.
J. RAKOVAN, M.A.A. SCHOONEN, R.J. REEDER, P. TYRNA AND D.O. NELSON. *Geochimica et Cosmochimica Acta*, 59(2), 195, pp 343–6.

The marcasites occur as thin tabular crystals ≤ 300 µm on edge, dominated by {010}, and have grown around the {001} zone on pyrite octahedra. The marcasite has apparently grown around the pyrite by a layer growth mechanism as shown by macrosteps terminating partially developed layers on the marcasite {010}. Other forms on the marcasite are described and illustrated with SEM micrographs. A proposed reconstruction of the pyrite surface into a marcasite-like arrangement may be due to interactions of a protonated disulphide species with the pyrite during growth. R.K.H.

Luminescence in minerals.
J. RAKOVAN AND G. WAYCHUNAS. *Mineralogical Record*, 27(1), 1996, pp 7–19, illus. in colour.

The property of luminescence is explained with reference to mineral structure and chemistry, drawing examples from some of the commoner species. M.O'D.

Ruby and sapphire from Vietnam. (In Japanese)
J. SHIDA. *Journal of the Gemmological Society of Japan*, 18, 1993, pp 32–6, 17 figs.

Over 2400 samples of ruby and sapphire col-

lected from Luc Yen and Quy Chau, Vietnam were investigated. Crystal habits, inclusions, and internal features such as growth sectors and banding are described. I.S.

A guide to mineral localities in the former Soviet Union.
B. SMITH AND C. SMITH. *Mineralogical Record*, **26**(6), 1995, pp 517–49, illus. in colour, 1 map.

An alphabetical list of places where minerals have been found has been prepared for territories of the former Soviet Union. Each entry gives name in English with variants where appropriate, the name in Cyrillic characters, geographical co-ordinates, type of location (region, town, stream, village, bay, mountains and so on), location of the place of higher order (similar to state capital, province [Russian name *oblast*], local seat of government) and list of species found. Useful notes are given on how the table was compiled and the difficulties encountered, on how to transliterate and what scheme to use, and on the nature of Russian and non-Russian names in this specialized context. There is a table of useful terms and a transliteration table. M.O'D.

Sapphires from Southern Vietnam.
C.P. SMITH, R.C. KAMMERLING, A.S. KELLER, A. PERETTI, K.V. SCARRATT, N. KHOA AND S. REPETTO. *Gems & Gemology*, **31**(3), 1995, pp 168–85, 28 illus. in colour, 2 tables.

Gem quality blue to bluish-green sapphires from Southern Vietnam came on the market in the late 1980s. The sapphires occur in alkali basalts in the mining areas of Phan Thiet and Di Linh. Mining was carried out by hand at the former but relatively sophisticated equipment was used at Di Linh.

The properties and characteristics of these sapphires are similar to those from other basalt sources such as Australia, Cambodia, China, Nigeria and Thailand. The crystals show prominent growth structures and colour zoning in geometrical patterns. Sharply bordered blue bands alternate with narrow colourless or yellowish to brownish bands parallel to the crystal planes r and z; many stones showed a colourless 'core'.

The most common inclusions are various types of cloud with cross-hatch or lath-like patterns which have not been recorded from other sapphires. Although occasional dust-like 'snow-flake' inclusions have been noted in Kashmir sapphires, the very fine whitish needles presumed to be rutile or ilmenite lacked the well formed strongly iridescent appearance of rutile needles and plates observed in sapphires from metamorphic environments such as Sri Lanka and Burma. Inclusions of plagioclase feldspar, zircon, uranpyrochlore, columbite, ilmenite, pyrrhotite, chromite-hercynite, magnetite-hercynite and goethite were identified. The UV-VIS-NIR absorption spectra are typical of basaltic sapphires with absorption bands towards the near-infrared region due to $Fe^{2+} \leftrightarrow Fe^{3+}$ intervalence charge-transfer. Spectral curves in the 280–880 nm region might be used to identify the country of origin of sapphires but should be interpreted with caution. The high iron content of Southern Vietnamese sapphires allowed easy distinction from sapphires from a metamorphic source. Separation from other basaltic sapphires was more difficult but the cross-hatch and lath-like 'cloud' patterns coupled with distinctive colour zoning and a colourless 'core' are a unique combination. R.J.P.

Estructura cristallina, composició química I propietats físiques de les gemmes.5. La forma dels cristalls. (In Catalan and Spanish)
J. SOLANS AND M.V. DOMÈNECH. *Gemmologia*, **91**, 1995, pp 14–15, illus. in black-and-white.

The crystal structure of beryl is explained with diagrams showing the ring formation. M.O'D.

Brief chronicle of the formation of the Vernadsky State Geological Museum.
Y.Y. SOLOV'IEV, Z.A. BESSUDNOVA AND L.T. PRZHEDETSKAYA. *World of Stones*, **8**, 1995, pp 14–22, illus. in colour.

Account of the events preceding and accompanying the establishment of the Vernadsky State Geological Museum, Moscow, Russia, with illustrations of some notable specimens. M.O'D.

Larimar: blauer Pektolith aus der Dominikanischen Republik.
G. STEINER. *Lapis*, **21**(1), 1996, pp 39–41, 1 map.

The name Larimar has been given to an opaque blue ornamental variety of pectolite found in the Dominican Republic. The occurrence is on the south-west coast of the country. M.O'D.

Die türkisgrünen Steine' von Nagar in Nord-Pakistan.

W. TOROSSIAN-BRIGASKY AND V.M.F. HAMMER. *Mineralien Welt*, 7(1), 1996, pp 47–51, 1 map.

Quartz crystals with a turquoise-green colour have been found at 3400 m in the Nagar area of northern Pakistan. M.O'D.

Von Frankreich nach China: Münchner Mineralientage 1995.

S. WEISS. *Lapis*, **21**(2), 1996, pp 29–32, illus. in colour.

Among specimens shown at the 1995 Münchner Mineralientage in 1995 were emerald crystals from Mengdong, Yunnan Province, China and peridot crystals from Sopat, Kohistan, Pakistan. Fine orange-red rhodochrosite from southern Kazakhstan was also available, one specimen measuring 3.26 cm in width. While these specimens were illustrated, the text also mentions chrome cerussite from the Dundas Extended Mine, Tasmania; brazilianite crystals up to 4 cm long, from Minas Gerais and chrysoberyl trillings from Colatina, Espirito Santa, Brazil; these crystals are up to 2 cm. Pakistan has also produced morganite crystals up to 10–12 cm long. M.O'D.

Remarkable pyrite pseudomorphs after ammonites.

E.Y. ZAKREVSKAYA. *World of Stones*, **7**, 1995, pp 24–5, illus. in colour.

Fine ornamental specimens of pyrite pseudomorphs after ammonite are described from the collections of the Vernadsky State Geological Museum, Moscow, Russia. M.O'D.

Fluorescence and luminescence in minerals.

FM-MSA-TGMS-FMS Tucson mineralogical symposium. *Mineralogical Record*, **27**(1), 1996, pp 21–30, illus. in colour.

Short papers on luminescence in minerals are abstracted. Titles covered are luminescence zoning in minerals; fluorescent minerals – some answers, questions and enigmas; single-colour and multi-colour fluorescence in calcite; luminescence mechanisms and activators in Terlingua-type calcite and in benitoite and related silica minerals: the influence of heating on the luminescence of calcite: uranium-activated fluorescence in minerals of the Franklin-Sterling Hill area, Sussex County, New Jersey; fluorescent minerals of the Karnes uranium district, south Texas; cathodoluminescence in the study of rocks and minerals; activators for cathodoluminescence of charoite and associated minerals; illuminating gems with visible monochromatic lasers – what can it do for the gemmologist?; a combined microscope/fluorescence spectrometer system for mineralogical and gemmological applications; demonstration of mineral fluorescence excited by a 193-nm ArF excimer laser; the fluorescent characteristics of coal. M.O'D.

What's new in minerals?

[Various authors] *Mineralogical Record*, **26**(6), 1995, pp 575–83, illus. in colour.

A number of gem minerals have been seen at different mineral shows held in the United States during 1995. Examples include watermelon elbaite from the Otjua mine, Namibia, brown zircon from Lovozero, Kola Peninsula and golden-brown scheelite from Tenkergin, Chukotska, both Russia: fine green fluorite is coming in crystal sizes up to 13 cm on an edge from the Westmoreland mine, New Hampshire, USA, and peridot from the newly-discovered Pakistan location. Thumbnail-sized crystals of aquamarine and yellow beryl are coming from Cherlovaya Gora, Chita, Siberia and China continues to produce very high quality crystals of beryl, cassiterite and scheelite. It is reported that the violet red beryl claims in the Wah Wah mountains of Utah have been sold to a major mining company. A matrix group of crystals measuring 17.9 cm across, with about 25 crystals on it, has recently been recovered. Fine zoned elbaites in pastel blue, green and pink are coming from Pech, Kunar, Afghanistan.

Madagascar is producing more tourmaline: colourless crystals with ruby-red bands at each end have come from a small pocket south of the Mania river and liddicoatite crystals are coming from a site at Alakamisy, Anjanabonoina and from Ibity. Grass-green slabs with a perfectly symmetrical red-orange triangle in the centre have been found at old deposits in the Laondany area. Crystals of rhodizite are available as are hambergites: the export of both these species, with orthoclase, is forbidden. Some supposed hambergite on offer has turned out to be quartz or phenakite.

Crystals of rose- and peach-coloured morganite have been found in the past at the Bennet quarry, Buckfield, Maine, USA: New England beryl formed the theme of this year's Springfield show and a collection of Bennet beryls was shown by the Harvard Mineralogical Museum.

Very fine amethyst crystals are being found in opium-growing areas of Veracruz state, Mexico: this area is not recommended for visiting.

M.O'D.

Gemmologie.
Zeitschrift der Deutschen Gemmologische Gesellschaft, **44**(4), 1995, pp 1–112.

This issue comprises a booklet by U. Henn entitled 'Practical Gemmology' (Edelsteinkundliches Practicum). It is a survey of methods of differentiation between natural and synthetic diamonds, corundums, spinels, beryls (emeralds), chrysoberyls (alexandrites), quartzes (amethysts and citrines) and opals. The introductory part deals with a short history, describes in general the characteristics of gemstones and their imitations, and discusses their microscopic characteristics. In the specific, second section each of the gems mentioned is dealt with fully, listing origin of name, physical and chemical properties, inclusions, going on to list the various methods of synthesis and their characteristics. Each chapter has an extensive bibliography and many illustrations (145 illustrations in all) as well as numerous tables and graphs. E.S.

The Australian Gemmologist, **19**(3), Jubilee Edition, 1995.

This Golden Jubilee issue celebrates the 50th Anniversary of the formation of the GAA which was formed on the 29 October 1945. Fifty years on the aspirations of the founders have been amply fulfilled. This expanded reference edition traces the 50 year history of the association at both Federal and State Division levels as well as cataloguing the gemstone resources of each State in Australia. The survey includes biological gem materials such as pearl production in Western Australia and the Coburg Peninsula in the Northern Territory. The compact and comprehensive nature of this edition does not lend itself to conventional abstraction, and the reader is recommended to consult the original. R.J.P.

Instruments and Techniques

El conoscopi figueras 93.
M. Martínez, A Martínez, C. Báguena and A. Ruiz. *Gemmologia*, **91**, 1995, pp 8–12, illus. in black-and-white. In Catalan and Spanish.

Evaluation of a new model conoscope with remarks on the phenomena observed. M.O'D.

The SHAPE crystal-drawing computer program as an instrument in research.
I. Vesselinov. *Geochemistry, Mineralogy & Petrology (Bulgarian Academy of Sciences)*, **29**, 1994, pp 97–105.

The commercially available program of E. Dowty is shown to be a useful tool in solving morphological problems in mineralogy. Three groups of questions are discussed and exemplified: (1) identifying crystal forms on photographs of real crystals (e.g. zircon, monohydrocalcite and pyrite); (2) reproducing crystal cross-sections (e.g. pyrite), and (3) simulating crystal growth by successive growth forms (e.g. zoned arsenopyrite). I.V.

Jewellery

Joaillerie indienne. 5000 ans de tradition.
F. Brunel. *Revue de gemmologie*, **125**, 1995, pp 11–14, illus. in colour.

Several important pieces of Indian jewellery are illustrated in a short survey of the craft over the last 5000 years. M.O'D.

Synthetics and Simulants

'Ti-sapphire': Czochralski-pulled synthetic pink sapphire from Union Carbide.
M.L. Johnson, M.E. Mercer, E. Fritsch, P. Maddison and J.E. Shigley. *Gems & Gemology*, **31**(3), 1995, pp 188–95, 2 tables, 5 illus. in colour.

The pink 'Ti-sapphire' commercially available from Union Carbide by the Czochralski-pulling technique is used in laser applications as it produces a high-energy light over a wide range of frequencies in and near the visible range. It has also been made by flame fusion and melt techniques. Its gemmological properties are compared with natural and with other synthetic pink sapphires.

Separation from natural sapphire may be difficult but differences include no luminescence to long-wave UV radiation, chalky blue luminescence to short wave UV radiation (due to octahedral $Ti^{4+}O_6$ impurities, an interstitial oxidised titanium) and pinpoint inclusions some of which were resolvable as gas bubbles. However reliable separation can be done by means of its chemistry or UV-visible absorption spectrum. Natural pink sapphires owe their colour to

chromium, but with the 'Ti-sapphires' the colouring agent is trivalent titanium and a faint but different spectrum is seen with a spectroscope (the main difference is the lack of chromium lines in the red). R.J.P.

Lab notes.

R.C. KAMMERLING AND C.W. FRYER. *Gems & Gemology*, **31**(3), 1995, pp 196–203, 20 illus. in colour.

An imitation emerald necklace gave a chalky yellow reaction to long wave UV radiation (not unexpected from a heavily oiled stone) and appeared dullish red through the Chelsea colour filter; in the drill hole of one bead a dark green ring was observed containing flattened gas bubbles and it proved to be a natural beryl bead with a green plastic coating. A fine green carving gave a spot RI of 1.56, a weak mottled greenish blue fluorescence to short wave UV radiation and a spectrum showing general absorptions from 400 to 480 nm and 650 to 700 nm. The presence of gas bubbles, flow lines, mould marks and minute conchoidal fractures indicated a glass. An imitation lapis lazuli which looked more like sodalite was shown to be dyed feldspar by tests which included X-ray diffraction. A red stone with RI 1.552 and SG 2.64 and an orange stone with RI 1.480 and SG 2.39 imitating Mexican opal were examined. Both were singly refractive but gave anomalous effects in crossed polars in the form of snake-like bands. Both were inert to long wave radiation but gave a faint chalky yellow to short wave UV radiation. Magnification revealed small gas bubbles in both stones. EDXRF analysis revealed the presence of both selenium and cadmium, already known as constituents in orange and red glasses. A strand of silvery dark grey to black pearls was shown to consist of lead glass beads coated with bismoclite, a bismuth oxychloride which formed silvery layers (with elastic properties) and an outer layer of a transparent rubber-like substance containing gas bubbles.

A large Czochralski-pulled ruby weighing over 100 ct was transparent with a strong red colour with no purple or brown components. Some fine curved striae were seen but apart from these it was free from inclusions and colour variations. The manufacturer is reported to be aiming at pure crystals above 500 ct. R.J.P.

Gem news.

R.C. KAMMERLING, J.I. KOIVULA AND E. FRITSCH. *Gems & Gemology*, **31**(2), 1995, pp 129–39, 16 illus. in colour.

Amber simulants consisting of amber pieces embedded in plastic were recently shown from Poland. The material had a spot RI of 1.56 and an SG of 1.24. 'Recrystallized ruby and sapphire' marketed by the True Gem company of Las Vegas showed results consistent with a pulled synthetic product. All the stones had a laser inscription on a pavilion facet. Kyocera plastic-impregnated synthetic opals with different body colours were produced by impregnating the synthetic opal with various coloured polymers. Analysis by scanning electron microscopy with EDXRF instrumentation and Fourier-transform infrared (FTIR) spectroscopy was reported. A new ornamental material marketed as 'platigem' is an intermetallic compound of platinum, aluminium and copper. SGs were in the range 8.66 to 8.77 with RI values above 1.81. The colour was evenly distributed and varied from yellow to brownish pink. X-ray powder diffraction patterns suggested a cubic structure with approximately 21% copper. R.J.P.

Gem news.

R.C. KAMMERLING, J.I. KOIVULA, M.L. JOHNSON AND E. FRITSCH. *Gems & Gemology*, **31**(3), 1995, pp 204–16, 22 illus. in black-and-white.

An unusual colour-zoned synthetic amethyst from Russia showed exceptionally uneven 'speckled' or 'leopard' spot colour distribution attributed to the fact that the crystal grew on a seed plane cut perpendicular to the *c*-axis with darker-colour regions forming expanding rhombic pyramids. Tanzanite-coloured synthetic sapphire has been sold in India as tanzanite. Typical constants for corundum and obvious curved colour banding and pin point inclusions which were probably gas bubbles enabled easy identification. A constructed quartz containing both natural and synthetic quartz formed a multi-coloured gem and included a rutilated quartz 'termination'. R.J.P.

Synthetic red beryl.

Y. KITAWAKI. *Journal of the Gemmological Society of Japan*, **19**, 1994, pp 34–5, 5 figs.

Internal features and spectra in the range from UV to visible and the near infrared region are reported for a purplish red synthetic beryl. Absorption due to Mn is remarkable. I.S.

[So-called AGEE emeralds.] (In Japanese)

Y. KITAWAKI. *Journal of the Gemmological Society of*

Japan, **19**, 1994, pp 35–8, 10 figs., 1 table.

Synthetic emeralds appeared on the market a few years ago under the name of AGEE, and were supplied from A.G. Japan Ltd. Gemmological investigations indicated that there were several types; one type has the same gemmological properties as those of Biron synthetic emerald, other types showed similarity to Russian synthetics, flux-grown synthetics, and vanadium beryl. I.S.

Fraud at the source.

A. KLEYENSTÜBER. *South African Gemmologist*, **9**(3), 1995, pp 7–15, illus. in colour.

Useful account of various substances offered as natural gem materials from Namibia, Zambia and Zimbabwe. Most substitutes are glass of one form or another. M.O'D.

Crystal chemistry of non-stoichiometric Mg-Al synthetic spinels.

S. LUCCHESI AND A. DELLA GUISTA. *Zeitschrift für Kristallographie*, **209**(9), 1994, pp 714–19.

Twenty-seven single-crystal structural refinements were performed on synthetic spinels along the $MgAl_2O_4$-$Al_{8/3}\square_{1/3}O_4$ join. The number of vacancies (from 0.09 to 0.22) was determined by EPMA. Vacancies are limited to octahedral sites, with a vacancy-to-oxygen distance refined to 2.113(3) Å. Mg is ordered in the tetrahedral site, only for $a > 7.99$ Å are the amounts of octahedral Mg significant. The decrease in a for vacancy-rich spinels is essentially due to the decrease of the T-O distance because of large amounts of tetrahedral Al. A linear relation between a and vacancy content was derived fitting literature data, including end-members. K.v.G.

[Observations on synthetic emeralds by the scanning cathodoluminescence (SCL) method]. (in Japanese with English abstract)

T. MIYATA, K. TSUBOKAWA AND M. KITAMURA. *Journal of the Gemmological Society of Japan*, **18**, 1993, pp 3–10, 13 figs., 4 tables.

The internal inhomogeneities of ten faceted synthetic emeralds were investigated using scanning cathodoluminescence (SCL) methods. The origin of each specimen was established before SCL investigation by ordinary gemmological identification and by measurement of its NIR spectrum. The samples are from Lechleitner, Regency, Gilson, Saramandor and Chatham and include both flux and hydrothermal growths. Clear SCL images showed complex characteristics related to and depending on the methods of synthesis. Flux-grown emeralds are characterized by straight parallel growth banding or 'aurora-like' growth banding. Hydrothermally grown emeralds are characterized by the development of 'comet-like' luminaries arranged in one direction or unique rhombic patterns. SCL investigations are useful not only to distinguish between natural and synthetic emeralds but also between different synthetic methods. I.S.

Synthetische, nach dem Hydrothermalverfahren hergestellte Smaragde.

G. NIEDERMAYR. *Mineralien Welt*, **7**(1), 1996, p 14.

A hydrothermally-grown emerald is described and its inclusions illustrated. The specimen was grown at a temperature of 380°C. M.O'D.

[Growth of emerald crystals by cooling the high-temperature solutions using $PbO.V_2O_3$ flux.] (In Japanese with English abstract)

S. OISHI, N. NISHIZAWA AND M. HIRAO. *Journal of the Gemmological Society of Japan*, **18**, 1993, pp 11–14, 5 figs.

Transparent green emerald crystals up to 2.2 mm long were synthesized from $PbO.V_2O_3$ solution, using no seed crystals. The nutrient was heated at 1200°C for 10 hours, followed by cooling to 600°C at rates varying between 5 and 240°C/h to find the optimum conditions. The size of crystals decreased with increase in the cooling rate. The optimum cooling rate for obtaining larger crystals was 5°C/h. I.S.

[The present status of synthetic rubies.] (In Japanese with English abstract)

J. SHIDA, M. SHIGEOKA AND H. KITAWAKI. *Journal of the Gemmological Society of Japan*, **19**, 1994, pp 15–22, 26 figs.

General characteristics, UV spectra, internal features, inclusions, growth sector patterns and growth banding of 'Rubiante' synthesized by a flux method by Culture Crystal Inc., USA, 'Douros' synthesized by a flux method by O.E. Created Gems, Greece, and rubies supposed to be synthesized by hydrothermal methods in Russia are described. Growth banding seen in flux grown rubies can be mistaken for banding seen in natural rubies. Hydrothermally synthesized rubies are generally dark red in colour and contain many flaws. Their refractive indices are significantly higher than those of natural rubies. Internal features revealed by laser-beam tomography are also described. I.S.

BOOK REVIEWS

Blood stones [a tale].
E. ANTHONY, 1994. Bantam Press, London. pp 335, hardcover. £14.99. ISBN 0 593 036565.

Books on 'how the diamond market can be overturned' are not too uncommon and here is quite a readable tale whose thinly-disguised protagonist's battle with Russian diamond magnates over a possible move of Russian sales. Featuring as a prop to the complicated intrigues is a necklace of blood-red diamonds: whether or not they have been colour-enhanced forms an important part of the plot but I did not find out the answer! M.O'D.

Norsk Steinbok.
T.T. GARMO, 1995. 3rd edn. Universitetsforlaget, Postboks 2959 Toyen, Oslo. pp 300, hardcover. Price on application. ISBN 82 00 41693 3.

Norway has a rich mineralogy and a number of the species found have an ornamental application: these include emerald, peridot, sunstone and other gem-quality feldspar group members and some attractive colour-change and dark red garnets. The present book is arranged in traditional chemical order (beginning with elements), each entry including chemical composition, crystal system, common form and habit, mode of occurrence, and details of the particular site of recovery. Both mineral and rock species described are illustrated in colour, with welcome size details, and the quality of reproduction is good. There is a useful glossary, a bibliography and an identification table. While not everyone may be able to read Norwegian, the text is not too difficult for English-speaking students and in any case the photographs are sharp and chosen to be instructive. M.O'D.

Cornish mineral reference manual.
P. GOLLEY and R. WILLIAMS, 1995. Endsleigh Publications, Truro. pp 71, softcover. £9.20. ISBN 0 9519419 9 2.

Many gemmologists are mineral collectors too and this concise and well-produced guide to one of the world's best-known mineralized areas will be useful to them and also to those beginning to perceive a world a little away from faceted gemstones. After a short introduction to the mining history of Cornwall and a bibliography, minerals are described in alphabetical order with composition, details of type specimens where known and of major analytical work performed on the species. Blank sheets at the end allow for additions. M.O'D.

Fancy-color diamonds.
H. HARRIS, 1994. Fancoldi, Liechenstein. pp xv, 184, illus. in colour, hardcover. £115.

'Fancy-colored diamonds were virtually unknown to the general public and . . . I wanted to say "wow"!'

Harvey Harris is a diamond dealer specializing only in coloured diamonds and through his book, containing around 150 coloured photographs (many by leading gem photographer Tino Hammid), seeks to share his passion with the reader. The book is intended as a connoisseurs' guide to fancy-coloured diamonds, and is meant as much for enjoyment as for guidance. The diamonds illustrated are not simply fancy-coloured stones – they are the most intensely coloured prize-specimens from collections around the world and one's reaction is indeed 'wow'!

Before 1970 fancy-coloured diamonds were of little importance in the gem trade but, by the end of 1991, 19 of the top 20 price-per-carat records were held by fancy-coloured specimens. In the Introduction and in Chapter 9, the author chronicles some of these auction records, including the US$800 000 paid for a 0.95 carat round fancy purplish-red diamond in 1987.

The first two chapters of the book are largely historical, dealing with the evolution of the fancy-coloured diamond market and coloured diamond production through the ages – the deep blues and pastel pinks from India and Brazil, the Cape yellow stones from South Africa and, latterly, the pink and brown diamonds from Australia. Harris also believes that Brazil was the first significant source of green diamonds including, perhaps, the Dresden Green. The histories of other fancy-coloured diamonds are mentioned briefly and it is emphasized just how

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rare these strongly coloured diamonds are. Some are, indeed, the 'Old Master' of the gem world and, in an era when collectors are prepared to pay huge sums for unique works of art and unique works of Nature, this explains why prices of coloured diamonds have escalated a hundred-fold or more over the last 30 years.

Chapter 3 outlines the understanding and causes of colour in diamond and contains some excellent photographs. It clearly emerges that, while some colours (blue, green, yellow) are well-understood, there are no detailed explanations yet available for many other colours (brown, orange, pink). The specialist reader will find the treatment in this chapter, whilst mostly correct, rather shallow, whereas the general reader will encounter many unfamiliar concepts inadequately explained (especially the details and meaning of the various absorption spectra presented). However, an important point to emerge is that there *are* laboratories able to analyse the colours of diamonds and which are continually striving to understand in greater depth the origins of these colours. This information allows gem-testing laboratories to differentiate between naturally and artificially coloured diamonds (described in chapter 5) and between natural and synthetic diamond (described in chapter 6).

Chapter 4 presents interesting material on the cutting of fancy-coloured diamonds. A brilliant-cut, for example, washes out light-to-medium fancy-colours, while other shapes are devised to accentuate the colours of the stones.

The author is highly critical (Chapter 7) of the methods used by the GIA for colour-grading fancy-coloured diamonds. They use a subjective comparison technique and the lack of an adequate range of master stones can lead to diamonds with quite different colours being given the same description. Harris argues strongly for coloured diamonds to be measured objectively on equipment like that currently used by the Gübelin Gemmological Laboratory; it is claimed that this gives reproducible numerical values for the hue, tone and saturation which are the three key parameters in describing the colour of a gemstone.

The book has a Preface by François Curiel of Christie's and a Foreword by George Bosshart of the Gübelin Gemmological Laboratory. It has a very readable style, although the eye is continually diverted from the text by the magnificent illustrations, and there are relatively few misprints or layout errors in this first edition. Harris is not a scientist and, although he has consulted several diamond experts, the text contains a number of minor technical errors. Furthermore, readers who are not diamond dealers will probably find the author's obsession with the price-per-carat, of each stone described, rather tedious by the end of Chapter 10. Notwithstanding these criticisms, this is a book which anyone interested in coloured diamonds should have on the bookshelf. A.T.C.

Rare earth minerals. Chemistry, origin and ore deposits. (Mineralogical society series.)
A.P. JONES, F. WALL and C.T. WILLIAMS (Eds), 1996. Chapman & Hall, London. pp xi, 372, illus. in colour, softcover.
£29.99. ISBN 0 412 61030 2.

While gemmologists will inevitably associate rare earths with the attractive colours and absorption spectra produced in synthetic crystals when RE are used as dopants, these interesting and important minerals have a life outside gemmology. The present work consists of papers selected from those presented at the conference *Rare Earth Minerals: chemistry, origin and ore deposits*, held at the Natural History Museum [London] in April 1993.

The first chapter, introducing and reviewing the rare earth elements, should be required reading for serious gemmologists. For those who may not have a chance of reading the book, the rare earth elements [REE] form Group IIIa of the Periodic Table, that is scandium followed by yttrium and lanthanum through to lutetium. The name lanthanides is used for the 14 elements from cerium to lutetium. These names often crop up in mineralogy texts read by gemmologists who should establish their meaning.

After the introduction the chapters are devoted to RE minerals, their composition, formation and properties. Many of the species form crystals which are attractive to the mineral collector and readers will note that the papers are grouped into deposit types: these include carbonate-rich melts, hydrothermal systems, syenite pegmatites, peralkaline systems, carbonatites, laterites, karst-bauxites and karstic nickel deposits: other chapters cover RE deposits in China, in the Kola Peninsula, Russia, an analysis of RE minerals, and a revised classification scheme for an important RE host in alkaline rocks. There is a glossary (in this case a list of minerals with their composition and arranged in

chemical order). Chapters carry their own lists of references which are comprehensive in all cases.

With first-class illustrations in colour and well-presented tables and diagrams the book provides as useful an introduction to RE minerals as can be found. M.O'D.

Cameos old and new.

A.M. MILLER, 1991. Van Nostrand Reinhold, New York. pp xiv, 216, illus. in colour, hardback. £39.00. ISBN 0 442 00278 5.

Opening with an account of the history of the glyptic arts, followed by a discussion of the commoner cameo subjects, the book goes on to describe how cameos are made and how the collector may distinguish old from new artefacts. The various cameo imitations are described and there are suggestions on how a collection may be formed. Major collections are cited and there are useful sections comprising a bibliography, addresses of major auction houses, retail outlets and booksellers (confined to the United States). There is also a 'chronology of engraved stones and cameos in Europe'. The illustrations are placed together in the centre of the book.

While this is a perfectly reasonable structure and on the whole produced quite well, I found it hard to decide whether the book aimed at serious scholarship or whether it was merely a compilation of hastily-assembled facts. Some statements in the materials section are questionable: chalcedony will not disclose its cryptocrystalline structure under the microscope.

Although some facts need investigation, as a general guide the book succeeds quite well; it is easy to read and well-illustrated. The writer's interest comes through strongly and perhaps she could be described in her own words for Maxwell Sommerville as 'a curious and trusting scholar'. M.O'D.

Additions to the uniform polyhedra: recent unpublished papers.

P. TAYLOR, 1995. [The author] Nattygrafix, Ipswich. pp 38, illus, softcover. £5. ISBN 0 9516701 5.

The author introduces some interesting modifications and developments of uniform polyhedra (three dimensional bodies bounded by regular polygon faces arranged in an identical manner around each vertex). While the book is more in the field of geometry than crystallography the concepts are useful and give reasons for thought. Diagrams are well reproduced though the notation may be unfamiliar to many readers. M.O'D.

Jade.

F. WARD, 1996. Gem Book Publishers, Bethesda, MD. pp 64, illus. in colour, softcover. (Fred Ward gem series.) £9.95. ISBN 0 9633723 4 3.

It seems impossible for so much information to be packed into so small a compass, especially when the extensive and excellent picture coverage is included, but Fred Ward has done it again, this time with a notoriously difficult topic. A superbly coloured cabochon of Imperial jade arrests the eye as soon as it settles on the front cover and the same standard persists throughout the book which must be required reading for all sorts of gemmological and general readers.

The use of the jade minerals in different civilizations is covered first and the book then looks at the location and recovery of specimens, passing then to methods of working and to brief notes on valuation. Look out for the pictures of lavender jadeite, of jade from New Zealand and from Myanmar. The book is a delight and can stand with the already extensive jade literature without any loss of face. M.O'D.

Antwerp gemmological update.

December 1995. Antwerp facets. pp 772–83, illus. in colour.

Topics discussed include an exhibition celebrating the opening of the 'Treasury' in the Royal Museum of Arts and History and the Royal Museum for Central-Africa, Brussels, the exhibition including gemstones: inclusions in gemstones: orange 'mandarin' garnet from Namibia: details of diamond jewellery courses scheduled to be held during 1996. M.O'D.

Christie's jewellery review 1995.

Major items sold by the firm during 1995 are illustrated in colour and described, with notes on prices paid. A number of yellow diamonds are included and the review also contains a short account of the work of the De Beers group of companies and an introduction to blue diamonds. M.O'D.

HARDNESS PENCILS

Range 2 – 10 on Mohs' scale

- **Stones set in brass caps with wooden handles**
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Tel: 0171-404 3334 Fax: 0171-404 8843

Proceedings of the Gemmological Association and Gem Testing Laboratory of Great Britain and Notices

OBITUARY

Ted Thomson, Chairman of E.A. Thomson Gems Limited, died on 2 December 1995 aged 80. He will be remembered as the man who put more into the Gem Trade than he took out.

Ted Thomson

Ted, born on 2 March 1915, started his career by working for an insurance company after graduating from the Stationers School in North London. He decided that insurance was not for him and found a job with George Lindley & Co., gem dealers, a company known at the time as the Jade Dragon. It was there that Ted gained an interest in gemstones until the war interrupted his career. He joined the Royal Artillery in 1939 and rose up through the ranks to Captain. On demobilization he returned to his job with George Lindley where he worked until 1958 when he left to start up his own gem dealing company. His co-director, Eric Allen, joined shortly afterwards and together they built up the international business which constitutes E.A. Thomson Gems Ltd.

In 1971 E.A. Thomson Gems Ltd acquired the Birmingham stone dealing company of Morris Goldman Ltd and, predicting Great Britain's involvement in the EEC, an office was opened in Paris.

Not content with building a successful gemstone business, Ted devoted himself to enhancing the reputation of the trade. He served on the committee of the Diamond, Precious Stone and Pearl section of the London Chamber of Commerce and Industry, becoming Chairman of that section in 1984. Apart from dealing with many trade issues, liaising with the Treasury and HM Customs and Excise, the section also had the responsibility of running the British Gem Testing Laboratory, which subsequently merged with the Gemmological Association to form the GAGTL.

During his period of office, Ted was energetic in his promotion of the Laboratory and can claim credit for securing a contract with the State of Bahrain. The British Gem

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FORTHCOMING MEETINGS

London

Unless otherwise stated, meetings will be held at the GAGTL Gem Tutorial Centre, 27 Greville Street (Saffron Hill entrance), London EC1N 8SU. Entry will be by ticket only at £3.50 for a member (£5.00 for non-members) available from the GAGTL.

8 May	**Identifying inclusions within gemstones**	Jamie Nelson
5 June	**3-D slide presentation of gemstones and minerals**	David Minster
10 June	**Annual General Meeting, Reunion of Members and Bring and Buy** (There will be no charge for this event)	
14 June	**Annual Trade Luncheon.** The Langham Hilton, Portland Place, London, W1. The speaker will be Naim Attallah, former Chief Executive of Asprey.	

Midlands Branch

Monthly meetings will be held at the Discovery Centre, 77 Vyse Street, Birmingham 18 (for directions to the Sunday Gem Club venue contact Gwyn Green on 0121–445 5359). Further details from Mandy MacKinnon on 0121–624 3225.

26 April	Annual General Meeting followed by a talk by D.H. Ariyaratna
28 April	Preliminary Gemmology Seminar
5 May	Diploma Gemmology Seminar
19 May	**Gem Club** - visit to Dolgellau Gold Mine

North West Branch

Meetings will be held at Church House, Hanover Street, Liverpool 1. Further details from Joe Azzopardi on 01270 628251.

15 May	**Jade, past and present**	Rosamond Clayton
19 June	**Jewellery in the auction world**	David Lancaster

Scottish Branch

For details of Scottish Branch meetings contact Ruth Cunningham on 0131–225 4105.

19–21 April	**A weekend of Scottish gemmology**	Alan Hodgkinson

A three-day event to be held in Perth to include talks and practical workshops by Alan Hodgkinson, the Branch's first Annual General Meeting and a field trip to Ethiebeaton and Ardownie quarries near Dundee.

Testing Laboratory provided the equipment, trained the staff and seconded a senior staff member to set up what was to be the first laboratory in the Middle East working to international standards.

In addition to his duties at the LCCI, Ted Thomson was one of the founder representatives to CIBJO (the International Confederation of Jewellery, Silverware, Diamonds and Precious Stones). He was elected President of the Coloured Stone Commission in 1979 and served two terms in office. During this time Ted worked tirelessly on the production of the CIBJO *Gemstone Book* – the first definitive manual containing nomenclature and rules of application for the gem trade which, when combined with the Diamond and Pearl Books, became known as the *Blue Book*. Ted applied himself selflessly to the task and was not averse to telephoning Alec Farn, or latterly Ken Scarratt, at some unearthly late hour to clarify some arcane point regarding nomenclature. His charming approach never brought down the wrath of the awakened respondent. Ted's charm stood him in good stead when it came to the CIBJO Annual Conference. He would lobby all the major participants prior to the meeting to iron out any difficulties, and made sure of a clear path for his carefully prepared resolutions.

Ted prided himself on his knowledge of the Statute Book – an asset which would have an unprepared opponent slinking away in shame when confronted by chapter and verse. It was largely through Ted's drive and conference skills that the important second edition of the Blue Book was produced in 1982.

Apart from his skill in business and trade politics Ted also had an intense interest in gemmology on a personal level. As a tribute to his enthusiasm for gemmology and in recognition of his achievements in the trade, Ted was awarded an honorary FGA, one of only two non-academics to be granted this honour. He was invited to present the diplomas at the annual reunion of members of the Gemmological Association on 15 November 1982. By happy coincidence, one of the students to receive her award that evening was his daughter-in-law, Jenny Thomson.

Tragedy struck Ted when his wife of 44 years, Beryl, died after a long illness in 1983, after which Ted gradually handed over the running of the business to his two sons.

Although he was the head of a large company and an important official of several trade bodies, Ted Thomson never lost that common touch which earned him the respect and affection of his family, his loyal staff, his associates in the gem trade and all those people who had the good fortune to know him. He is survived by his second wife, Tuu, and his two sons, Ian and Peter.

Adrian Klein

George Lindley, FGA (D. 1937), died on 27 November 1995 aged 90. Born in Melitopol in 1905 of Russian-American parents he saw the early days of the 1917 Revolution while at school in Russia. At the age of 12 he made his own way, via Beijing, to the USA where he completed his education.

His early years in China inspired the love and knowledge of jade which became his life's work, accentuated by his appointment in 1926 as the buyer in Beijing for a major New York jade merchant. By 1929 he had resolved to open a business in London dealing in jade for jewellery, and as carvings and *objets d'art*. This flourished, despite the difficult trading conditions of the time, and he was ably partnered from 1935 by his late wife, Carol (neé Melville) (D. 1937).

The company was joined in 1936/37 by E.A. Thomson and W.C. Buckingham but business was inevitably slowed in the years immediately prior to the second World War. George Lindley served in the Auxiliary Fire Service in London, 1940/42, then the RAF Volunteer Reserve (Pathfinder Squadron) until 1945, when he restarted the business, being joined again by E.A. Thomson and W.C. Buckingham.

By now the work of the company had turned to coloured gemstones, in which George Lindley was a pioneer in careful

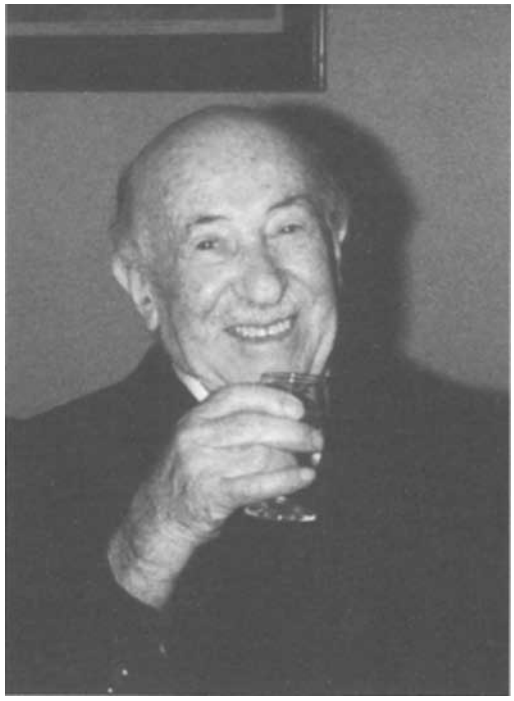

George Lindley

grading and calibration of original parcels, specifically for a demand generated by the centrifugal casting process. This gave the company a recognized place in the UK and international markets.

There was a steady flow of staff through the company in these years. Almost all attained their FGA. Some are still active with their own successful companies in the trade and would acknowledge the stern, but detailed guidance they had from George Lindley.

W.C. Buckingham

Mrs Deidre M.H. Inches Carr, MA FGA (D. 1982), Edinburgh, died on 12 December 1995.

Mr Juan C. Paredes Quevedo, FGA (D. 1994), Madrid, Spain, died in 1995.

GIFTS TO THE ASSOCIATION

The Association is most grateful to the following for their gifts of gems and gem materials for research and teaching purposes:

Dr J.L. Emmett, Pleasanton, California, for an illustrated summary of a lecture delivered to the GAGTL entitled 'The heat treatment of corundum: a view from the laboratory'.

Mrs Theresa Khairallah, London, for samples of amber, cornelian and coral.

Mrs Eynat Matza, London, for a specimen of eilat stone.

Professor E. Ralph Segnit, Melbourne, Australia, for a specimen of Opalus, an imitation opal from Melbourne.

D. Swarovski & Co., Wattens, Austria, for over 900 cut gemstones of various natural and synthetic material.

MEMBERS' MEETINGS

London

On 4 January 1996 at 27 Greville Street, London EC1N 8SU, Dr Grahame Brown from Albany Creek, Queensland, Australia, gave an evening lecture entitled 'Gemstones – Australia's national treasure'. On the following day Dr Brown led a half-day seminar entitled 'Hand lens characteristics of biological gem materials'.

On 28 February at 27 Greville Street Rosamond Clayton gave a lecture entitled 'The art and science of valuation'.

Midlands Branch

On 26 January at the Discovery Centre, 77 Vyse Street, Birmingham 18, members enjoyed a Bring and Buy, Quiz Night and Raffle.

On 23 February at the Discovery Centre E. Alan Jobbins gave an illustrated talk on jades.

On 4 March a visit was arranged for members to the Birmingham Assay Office.

On 29 March at the Discovery Centre Edgar Taylor gave a talk entitled 'Lavriotike: treasure house of Attika'.

Gem Clubs were held on 21 January, 18 February and 24 March.

North West Branch

On 20 March at Church House, Hanover

Your FGA in Nine Months!

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Tuition – basic instruments – examination fees
GAGTL membership for one year

Street, Liverpool 1, Deanna Brady gave a talk entitled 'Introduction to inclusions'.

Scottish Branch
On 7 February a Lab Night was held at Telford College, Edinburgh.

On 22 March at Newliston House, Newbridge, Edinburgh, members enjoyed a quiz and Bring and Buy sale.

GEM DIAMOND EXAMINATIONS

In January 1996 12 candidates sat the Gem Diamond Examinations in the UK of whom 8 qualified. The names of the successful candidates are listed below:

Atkin, Marie, Sheffield.
Cauchi, Savona, Louis, Malta.
Crowder, Michael J., London.
Gartery, Tania M., Christchurch.
Hill, Katia, Glasgow.
Johnson, Christopher W.R., Bickley, Nr Bromley.
Robinson, Zoe L., London.
Ryder, Peter Ian, London.

The overseas candidates who qualified will be published in the July issue of the *Journal*.

EXAMINATIONS IN GEMMOLOGY

In the Examinations in Gemmology held in January 1996 183 candidates sat for the Preliminary examination of whom 147 qualified; 116 candidates sat for the Diploma examination; 50 have qualified so far. The additional overseas candidates who qualified will be published in the July issue of the *Journal*.

The names of the successful candidates are as follows:

Qualified with Distinction
Grondin, Daniel, Geneva, Switzerland.

Qualified
Abramian, Levon, London.
Ahamed, Omar Faiz, Gillingham.
Ang, Zen Yi, Singapore.
Ayyar, Rajeshwari Narayan, Bombay, India.

Brangulis, Peters, Riga, Latvia.
Briginshaw, Richard Charles, London.
Brooke-Webb, Susannah, London.
Close, Helen Jane, Selby.
Cunningham, DeeDee Cecilia, Toronto, Ont., Canada.
Dempster, Stuart, Glasgow.
Fleischner-Zois, Krista, Athens, Greece.
Gil Perez, Nuria, Valencia, Spain.
Golad, Tanya, London.
Grondin, Magali, Geneva, Switzerland.
Horniblow, Kathy, Sherbourne.
Hyo-Jin, Choi, Tae-gu, Korea.
Jayasendil, J., Salem, India.
Kim, Yun-Hwa, Kyung Buk, Korea.
Kimber, Sarah, London.
Kuulman, Heli, Tallinn, Estonia.
Lake, Richard John, Gorey Village, Jersey.
Limaye, M.D., Calcutta, India.
McFarlane, Iain, Chesham.
MacNish Porter, Holly, Edinburgh.
Marr, Peter, Torquay.
Mathon, A.P.T., Oosterhout, The Netherlands.
McFarlane, Iain, Chesham.
Melego Canet, Merce, Valencia, Spain.
Michelson, Max J., Lincoln.
Mihama, Saki, London.
Naing, Aye Myo, Yangon, Myanmar.
Oja, Tonis, Tallinn, Estonia.
Parekh-Guastella, Rita, Pontedera, Italy.
Perkins, David J., Ayr.
Pierce, Jason Robert, Truro.
Pierce, Jill Fiona, Manchester.
Plomp, Jean Victoir, Rotterdam, The Netherlands.
Popov, Vladimir V., Tallinn, Estonia.
Prabhu, Miss Vaishali, Bombay, India.
Rai, Ashish, Jaipur, India.
Rege, Sonal, Bombay, India.
Shepherd, Louis, Nottingham.
Song, Gyu Bong, Ulsan, Korea.
Stopelli, Christopher J.D., Oakville, Ont., Canada.
Torrent, Denise, Geneva, Switzerland.
Vakil, Lakshmi H., Bombay, India.
van der Molen, W.N., Schoonhoven, The Netherlands.
Van Duijnen, A.M., Bergen aan Zee, The Netherlands.
Verma, Hitesh, Jaipur, India.
Vummidi, Nagaraj, Madras, India.
Withington, Terry, London.

Preliminary
Amrute, Rahul M., Bombay, India.
Andaluz Sanchez, Maria, London.
Anderson, Elizabeth Anne, Lewes.
Ayyar, Rajeshwari Narayan, Bombay, India.
Bagadia, Pavan Madanlal, Bombay, India.
Barbas, Constantinos, Athens, Greece.
Burden, Lorraine, Sawbridgeworth.
Cao, Shumin, Wuhan, China.
Chan, Hor Wai Pierre, Kowloon, Hong Kong.
Chan, Vivian S.F., N.T., Hong Kong.
Chan, Lam Ming, Hong Kong.
Chen, Kai-Wen, Taipei, Taiwan.
Chong, Yung Yung Sylvia, Toronto, Ont., Canada.
Chung, Wen-Hao, Taipei, Taiwan.
Coker, Olive Admira, London.
Cowley, Jacalyn Gloria, London.
Cucchiara, Carmelina, Wolverhampton.
D'Costa, Charles John, Thornton Heath.
Dai, Sulan, Wuhan, China.
Davidson, Simon J., Cookham.
Davies, Darryn Lewis, London.
Degermark, Sofia, London.
Dismore, Frances Jane, London.
Donald, Claire M., Perth.
Dong, Ping, Wuhan, China.
Du-Ri, Cho, Taegu, Korea.
Dykhuis, Luella Woods, Tucson, Arizona, USA.
Ebbs, Heather Alexandra, Bath.
Edery, Gabrielle Julietta, London.
Effendy, Jusak, Central, Hong Kong.
Fahller, Ingegerd, Lannavaara, Sweden.
Falcon, Lionel Michael, Craighall, S. Africa.
Feng, Allice, Taipei, Taiwan.
Foote, David Stuart, Reading.
Forbes, Victoria E., London.
Forward, Stephen, London.
Frick, Nola Ann, London.
Guest-Joste, Catherine Deanna, London.
Harvey, Mark Anthony, London.
Hazelius-Berglund, Wiveka, Lidingo, Sweden.
Hegi, Matthieu Manuel Marie, London.

Ho, Suk King Betty, Kowloon, Hong Kong.
Hobbs, Karen Lorraine, Bath.
Hsieh, Chia-Jung, London.
Hsieh, Hsiu-Hua, Katherine, Taipei, Taiwan.
Hsieh, Pao Lien, Evelyn, N.T., Hong Kong.
Huang, Tai Wen, Taipei, Taiwan.
Huijsser, Isabelle E., Vught, The Netherlands.
Hutton, Katie, London.
Jatoi, Faisal Zamman, London.
Jayasendil, J., Salem, India.
Kearton, Michael James, Eastbourne.
Kemp, Graham, London.
Khairallah, Theresa, London.
Kim, Yun-Hwa, Kyung Buk, Korea.
Kohler, Ghislaine L.M., London.
Kritikou, Eleni, London.
Lai, Li, Wuhan, China.
Lau, Joyce Pao-Ching, N.T., Hong Kong.
Lee, Dongjae, London.
Lee, Yow Hon, Tuen Mun, Hong Kong.
Li, Yin Ni, London.
Li, Li, Wuhan, China.
Liang, Zi, Guangzhou, China.
Limaye, M.D., Calcutta, India.
Lin, Chien Yu Joyce, Taipei, Taiwan.
Lin, Jiaqing, Wuhan, China.
Lin, Siu Pan, Kowloon, Hong Kong.
Lindgren, Maria, Lannavaara, Sweden.
Lindwall, Torbjorn, Lannavaara, Sweden.
Lui Pochoi, Tsuen Wan, Hong Kong.
Mackie, Karen Louise, Gillingham.
Mak, Tsui Sim, Hong Kong.
Matu, Sheila Gathii, Nairobi, Kenya.
Matza, Eynat, London.
Mitteregger, Unni, London.
Modi, Shivani, Delhi, India.
Monje, Lucy, London.
Monnar, Robert D., Nashua, New Hampshire, USA.
Nam, Chung-Chul, Taegu, Korea.
Newbould, Hans Peter Michael, Esher.
Nottbusch, Jurgen Uwe, Appel, Germany.
Oh, Mi Sun, Daejon, Korea.
Omine, Mitsunobu, London.
Pancratz, Mark Alan, Weybridge.
Pankaj, Nirmal Sethia, Bombay, India.
Parekh-Guastella, Rita, Pontedera, Italy.
Patel, Ajay, Reading.
Perks, Helen Elizabeth, Wolverhampton.
Prabhu, Vaishali, Bombay, India.
Prachi, Raghuwanshi, Bombay, India.
Rege, Sonal, Bombay, India.
Riddell, Vanessa Stella, Harrow.
Rijken, Yvonne A.W., Doorwerth, The Netherlands.
Rizwan, Babar, Ilford.
Rollings, Alexander Mark Baker, London.
Romero, Aniana Noguera, London.
Romero de Castilla, M.M. Solomon Castillui, Ilford.
Schellekens, Ben J., Rotterdam, The Netherlands.
Sequeira, Silvia W., Bombay, India.
Shen, Chen-Hua, Taipei, Taiwan.
Shih, Shu Chuan, London.
Shiue, Ling-yu, Taipei, Taiwan.
Smith, Sarah A., Bath.
Stossel, Hilary Jeanne, London.
Swaffer, Hugh Edward Thomas, Brighton.
Tang, Wong Wai, Manchester.
Tao, Hongwei, Wuhan, China.
Tao, Jinbo, Wuhan, China.
Todd, Anthony James, London.
Tolia, Ami Devendra, Bombay India.
Tong, Nicolette Tong, London.
Tsai, Shu Mei, Taipei, Taiwan.
Tsang, Wai Wan, Kowloon, Hong Kong.
Vafai, Khatereh, Teheran, Iran.
Vakil, Lakshmi H., Bombay, India.
Van Teeffelen, Cornelia Elizabeth, Bodegraven, The Netherlands.
Velliniati, Katerina, Athens, Greece.
Von Speyr, Lucy Jane Mountjoy, Cheltenham.
Wananabe, Hanaco, London.
Wang, Chien Ling, Taipei, Taiwan.
Wang, Liqun, Guangzhou, China.
Wang, Fenglan, Wuhan, China.
Watts, Emma Louise, London.
Watts-Rehman, Claudia, London.
Wavoo, Shahul Hameed, Kowloon, Hong Kong.
Wilson, Hollis, London.
Wisawayodhin, Kitiya, London.
Wong, Kevin Kwok Wing, NT Hong Kong.
Wu, Hsiu Tzu, Taiwan.
Wu, Ming Hsun, Taipei, Taiwan.
Wu, Xiaobing, Wuhan, China.

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25-26 May and 1-2 June	**Two-day Diploma Practical Workshop** *£160.39 (£111.04 for GAGTL registered students) includes sandwich lunch*
15-16 June	**Weekend Diamond Grading Revision** *£129.25*

Please contact the Education Office on 0171-404 3334 for further information

Xi, Bo, Wuhan, China.
Xie, Liming, Wuhan, China.
Xu, Xiaoxia, Wuhan, China.
Yang, Lixin, Wuhan, China.
Yeh, Chen-Mei, Taipei, Taiwan.
Yen, C.K., Taipei, Taiwan,
Yip, Nga Lai, NT Hong Kong.
Yip Yick Hing, Brenda, Aberdeen, Hong Kong.
Zakir, Aliasgher Fakhruddin, Nairobi, Kenya.
Zeng, Chunguang, Shanghai, China.
Zhang, Xueyun, Wuhan, China.
Zhang, Yanjun, Wuhan, China.
Zheng, Kaiwen, Wuhan, China.
Zhu, Xionghua, Wuhan, China.
Zou, Tao, Wuhan, China.

MEETINGS OF THE COUNCIL OF MANAGEMENT

At meetings of the Council of Management held at 27 Greville Street, London EC1N 8SU, the business transacted included the election of the following:

Meeting held 6 December 1995

Diamond Membership

Chen, Hui Lan, Shenzhen, China. 1995
Gantzidis, Adam, Athens, Greece. 1995
Garin, Auzmendi Amaia, Madrid, Spain. 1995

Fellowship

Au Yeung, Kwok Ho, Hong Kong. 1995
Chun-Li, Wu, Edgbaston. 1995
Dang, Xiao-Ying, Beijing, China. 1995
Heyes, Alan John, Stourbridge. 1970
Hui, Wai Yee Wendy, Hong Kong. 1994
Loungani, Jagdish, Jaipur, India. 1995
Maheshwari, Ashoo, Jaipur, India. 1995
Marathe, Tanuja, Pune, India. 1995
Salm-Reifferscheidt, Sophie, London. 1995
Siu, Ming Wa, Kowloon, Hong Kong, 1995.
Tang, Zhen Yi, Kowloon, Hong Kong. 1995
Rossiter, John Timothy, Weston Super Mare. 1995
Zheng, Bei, Beijing, China. 1995

Ordinary Membership

Anderson, Lesley Christine, Wivenhoe.
Ashton, David, London.

Bienemann, Andreas Martinus, Polsbroek, The Netherlands.
Brittain, Roger Anthony, Forncett St Peter, Norwich.
Burchell, Janet, Ravenstone.
Chang, Mei-Chu, Taipei, Taiwan.
Cuthbert, Richard Allen, London.
Dawson, Stewart, Aberdeen.
Dean, John Eldon, Bath.
Jessa, Alnasir R., Wembley.
Kuulman, Heli, Tallinn, Estonia.
Li, Long Hsing, Taichung, Taiwan.
Liu, Jian, Beijing, China.
Marshall, Andrew Paul, Gravesend.
Notari, Franck, Geneva, Switzerland.
Osundina, Olalekan, London.
Ronza, Antonella, Novara, Italy.
Rutter, Fay, Walsall.
Shibuya, Akemi, Tokyo, Japan.
Smith, Darrell Arthur, Haywards Heath.
Stopelli, Christopher John David, Brampton, Ont., Canada.
Tsai, Yao Chu, Kaoshung, Taiwan.
Yao, Teng Long, Taichung, Taiwan.

Laboratory Membership
Laboratórios G & M, Lisbon, Portugal
Bulgari Distribuzione, Rome, Italy
Escuela Internacional de Joyeria, Gemologia Y Tasaciones, Madrid, Spain
Richard Ogden Ltd, London W1V ONX
Spink & Son Ltd, London SW1Y 6QS

Meeting held 14 February 1996

Diamond Membership
Bagchi-Narayam, Debal, Brentford. 1995
Ji, Xiaoyan, Hubei, China. 1995
Lu, Yefei, Shanghai, China. 1995
Pattani, Shobna, London. 1995
Ren, Jiakai, Hubei, China. 1995
Wang, Hui, Shanghai, China. 1995
Wang, Xin, Shen Yang, China. 1995
Weng, Ping, Hubei, China. 1995
Xi, Bo, Hubei, China. 1995
Xu, Ru-peng, Shanghai, China. 1995
Zhang, Weichao, Hubei, China. 1995

Diamond Membership and Fellowship
Leese, Peter Francis, Croxley Green. 1953/1967

Fellowship
Bae, Eun Jeung, Seoul, Korea. 1995
Bishop, Lyndall Ann, Catterick Village. 1987
Bourke, Mary, Enniscorthy, Ireland. 1987
Harman, Bronwen, The Gap, Qld, Australia. 1992
Jiang, Xinshun, Shen Yang, China. 1995
Peryer, Keith George, London. 1987
Pluckrose, William Henry, St Mary's Platt. 1979
Qin, Shu-Le, Shanghai, China. 1995
Rydeng, Rig, Finnsnes, Norway. 1988
Sanson, Steven Nigel James, London. 1990
Sun, Yan Ling, Jiangsu Province, China. 1995
Sung, Min Jun, Taegu, Korea. 1995
Zhou, Shuzhen, Ningbo, China. 1995

Transfers from Ordinary Membership to FGA
Bowman, Helene, Epping. 1995

Ordinary Membership
Achten, Louisa Wendelina Wilhelmina, Horst, The Netherlands.
Adams, Victoria, Pimlico, London.
Akashi, Kazuko, Hyogo, Japan.
Akieda, Yumi, Hyogo, Japan.
Alessandro, Guastoni, Milan, Italy.
Beizer, Samuel, New York, NY, USA.
Bossi, Anna, Milan, Italy.
Cunningham, Ruth, Edinburgh.
Dodo, Naoko, Osaka, Japan.
Doyle, Ted, Bangkok, Thailand.
Drysdale, John G.S., Tiverton.
Egawa, Noriko, Osaka, Japan.
Endo, Yuko, Kanagawa, Japan.
Fisher, Claire Monica, London.
Fujii, Noburu, Nara, Japan.
Fukouka, Taishi, Kyoto, Japan.
Hill, Katia, Glasgow.
Ichikawa, Yoko, Hyogo, Japan.
Ishibe, Masahiko, Tokushima, Japan.
Ishijima, Juri, Hyogo, Japan.
Katoda, Yuka, Osaka, Japan.
Katagiri, Kumiko, Osaka, Japan.
Kitamon, Hideaki, Nara, Japan.
Kobayashi, Mitsuko, Hyogo, Japan.
Kokuho, Shigeko, Tokyo, Japan.
Kuroda, Chikako, Hyogo, Japan.
Matsui, Rie, Osaka, Japan.

Miyamoto, Takuya, Hyogo, Japan.
Miyamura, Kayoko, Shiga, Japan.
Murata, Sanae, Nara, Japan.
Myint Soe, Yangon, Myanmar.
Nakayama, Norio, Kyoto, Japan.
Nicolaou, Emmanuel George, Germiston, South Africa.
Nishikawa, Masako, Osaka, Japan.
Ogino, Takanori, Osaka, Japan.
Ohsumi, Yuichi, Kyoto, Japan.
Perks, Helen Elizabeth, Wolverhampton.
Porter, Simon Douglas, Glasgow.
Previn, Heather Mary, New York, NY, USA.
Ryuno, Yumiko, Kumamoto, Japan.
Shikazawa, Chiaki, Yamanashi, Japan.
Shiota, Mika, Osaka, Japan.
Smith, Sarah Jane, Erdington, Birmingham.
Sugawara, Yasuhiko, Tokyo, Japan.
Suzuki, Noriko, Nara, Japan.
Takahashi, Sachiyo, Nara, Japan.
Tanaka, Kiyomi, Osaka, Japan.
Tashiro, Hisami, Kyoto, Japan.
Wataya, Atsuto, Osaka, Japan.
Wiseman, Alan, Malden.
Yajima, Yuko, Saitama, Japan.
Jamashsita, Yuko, Osaka, Japan.
Yatohmaru, Hiroshi, Hyogo, Japan.

Laboratory Membership
Hattons, Gants Hill, Ilford

Meeting held 13 March 1996

Diamond Membership
Wu, Zhanxia, Shanghai, China, 1995.
Sheng, Beili, Shanghai, China. 1995
Summerfield, Susan Denise, London. 1995

Transfer – FGA to FGA, DGA
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Corrigenda

In the *Journal of Gemmology*, 1995, **24**(8), pp 543 and 544, the author was unfortunately inconsistent when drawing Figures 3 and 4 in that in Figure 3 he showed the pearl in cross section, while in Figure 4 the pearl is spherical, although shell and mollusc are drawn in cross section. The following Figures 3a and 4a now display the correct structure in the pearl consisting of the conchin nucleus, enveloped by the primary layer of calcite, coated by calotte shaped layers of aragonite platelets – all in cross section.

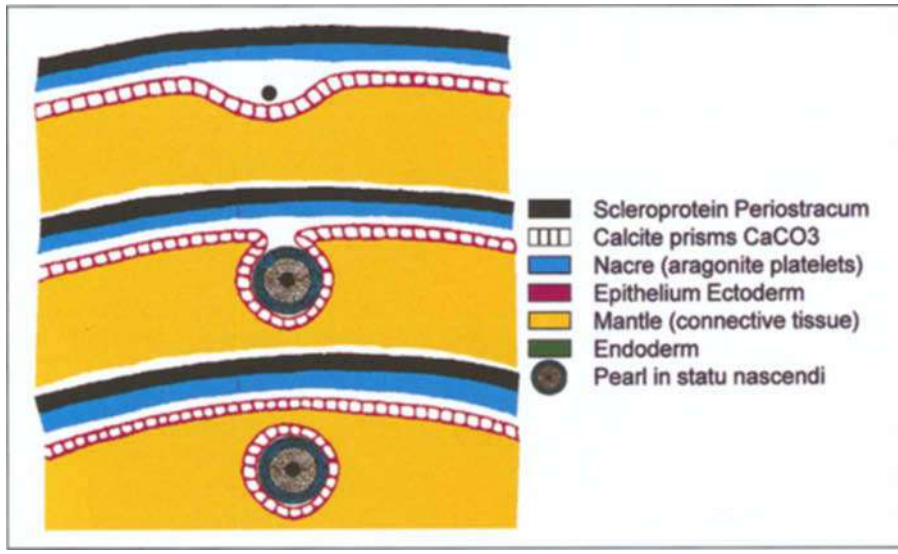

Fig. 3a

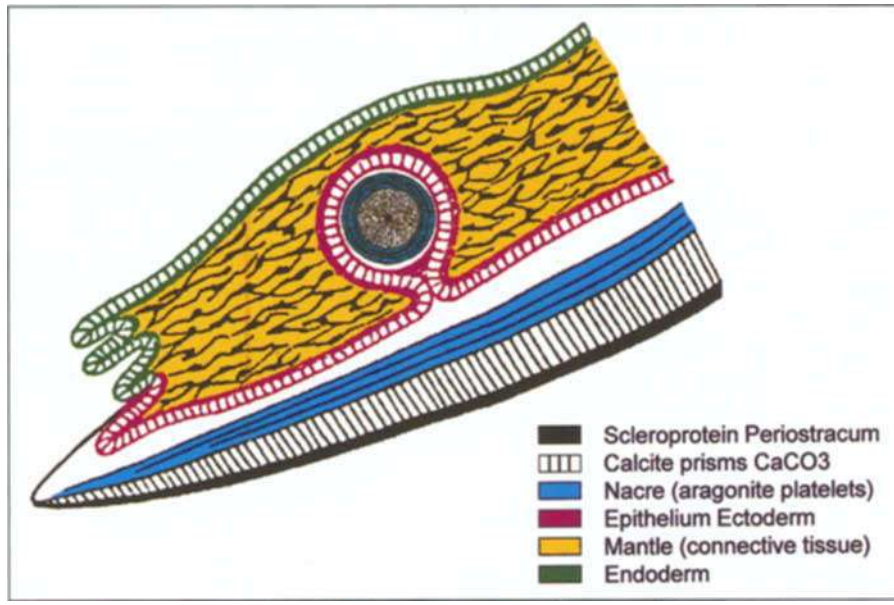

Fig. 4a

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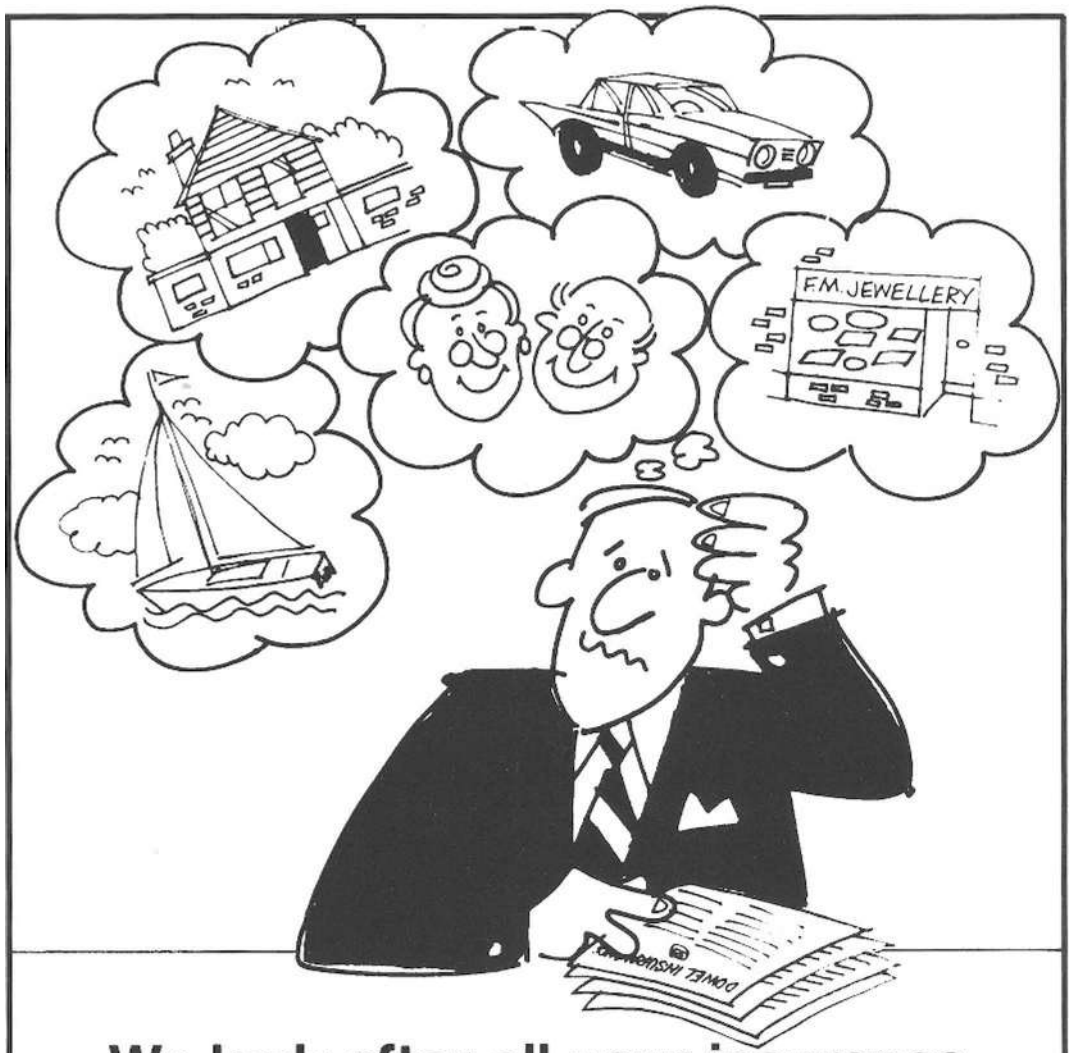

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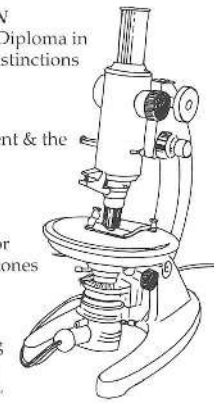

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Cover Picture

Images in Gems
'Square-eyed owl on a branch.' Partly healed cleavage in topaz.
Photograph by Spencer J.A. Currie, FGA, Auckland, New Zealand (see Photographic Competition, p. 246)

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In this issue . . .

A rarity in the gem and mineral world, euclase has sometimes fooled the unwary by its similarity to aquamarine, but its higher refractive indices and specific gravity enable one to distinguish it quite readily. An affinity with the beryl group however is not confined to its colour, and the first paper describes a cut euclase from Chivor, Colombia, that not only resembles greenish-blue aquamarine from Tongafeno (Madagascar) but also contains three-phase inclusions like those found in the more famous emeralds from the Chivor mine.

The next two papers reflect the growing importance of Madagascar and describe features of sapphires from a new locality about 350 miles from Tongafeno near the southern coast. Andranondambo is a new addition to the host of multisyllabic gem sources in that country and it has already impressed itself on our minds through efforts to establish its correct spelling!

The first sapphire paper describes their geological setting and summarizes their gemmological properties. The complexity of the patterns of colour-zoning in the sapphires is explored in more detail in the second paper and features concerning inclusions, heat treatment and chemical variation are described. The range in colour zoning has significant consequences for the trade in that resemblances have been found between Andranondambo crystals and sapphires from such diverse locations as Kashmir, Sri Lanka and Vietnam.

For nearly a century, goodletite has been a name used in New Zealand to describe an ornamental greenish rock containing variable amounts of ruby and sapphire. However, this was not the source for goodletite referred to by Webster in his glossary of unusual names where he alluded to a Burmese origin. His description of a marble forming the matrix of rubies does not coincide with the New Zealand rock, but at present the allusion remains elusive and its source has not been discovered, so any ideas of establishing historical priority for the name had to be put on one side. Meanwhile, the composition of the New Zealand goodletite is described and its gemmological properties listed.

The last paper is a review of the latest gem-identification program to come on the market. It is 'Windows' based and is a subset of a much larger Adamas Advantage program comprising gem identification with diamond and coloured stone analysis reporting. The program is wide ranging and a special section contains a wealth of information which should appeal to students.

On a personal note, the loss of Bob Kammerling earlier this year has left all who knew him with a deep sense of shock and bereavement. When I last saw him in Thailand in October 1995 he was as vital and intensely concerned about gemmological issues as he had been when I first met him in the eighties. I shall miss his ready understanding and willingness to discuss a whole range of topics and his departure is a great loss to gemmological publications and to the jewellery scene worldwide.

R.R.H.

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Euclase from Colombia showing three-phase inclusions

J.M. Duroc-Danner, FGA, GG

Geneva, Switzerland

Abstract

Gem quality euclase, a hydrated beryllium-aluminium silicate $BeAlSiO_4(OH)$, which crystallizes in the monoclinic system, may be fashioned into gemstones for collectors. The gemmological properties of a medium-dark greenish-blue euclase from Chivor, Colombia, are described and compared with the properties of other gemstones of similar colour with which it could be confused.

Fig. 1. Enlarged view of the 1.86 ct emerald-cut medium-dark greenish-blue transparent euclase.

Introduction

Recently the author was asked to identify a number of different faceted stones. All could be recognized from their aspect, colour and inclusions (e.g. beryl (aquamarine), trapiche emerald, parisite, peridot . . .). These were all confirmed by their gemmological properties, except for one medium-dark greenish-blue stone from Chivor, Colombia, which looked very similar to aquamarine from Tongafeno, Madagascar (Figure 1),[1] but which had different physical and optical properties.

Gemmological properties

The 1.86 ct emerald-cut medium-dark greenish-blue transparent gemstone (length 7.51 mm, width 6.60 mm, depth 1.92 mm) of vitreous lustre, is traversed by a few cleavage planes and abundant inclusions. Refractive index (RI) determinations were carried out using a Rayner Dialdex refractometer and monochromatic sodium light. The indices obtained were $\alpha = 1.654$, $\beta = 1.658$, $\gamma = 1.673$, giving a birefringence of 0.019, with optic sign (+). Under a calcite dichroscope with fibre optic illumination, a distinct to strong pleochroism in medium-dark blue; greenish-blue; colourless, was observed. When viewed through a Chelsea colour filter the stone appeared red.

The absorption spectrum was observed in dark conditions, through four spectroscopes (Aus Jena, Beck, DG-X, GEM CF), mounted on a GIA GEM spectroscope base set with a colour filter wheel, and revealed absorption bands typical of copper, iron and chromium, at 400–410, 412, 420, 453, 470, 616, 629, 641, 647, 660, 671, 684, 689, 706–708 nm. Of these absorptions, the easiest bands to locate and therefore most characteristic, were: 400–410, 412, 420, 453, 689, 706–708 nm.

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The stone was examined with a Multispec combined LW/SW ultraviolet unit and remained inert.

The specific gravity (SG) was obtained by hydrostatic weighing in distilled water using a Mettler electronic PL 300C carat scale, and the stone was found to have a value of 3.11. Since the stone tested was rather small (1.86 ct) and although great care was undertaken to obtain accurate weighings, it was decided to check the specific gravity obtained. In a liquid of SG 3.05 the stone sank slowly and this is consistent with the result from hydrostatic weighing.

The inclusions were examined using a Bausch & Lomb Mark V Gemolite binocular microscope using dark field illumination or overhead lighting as appropriate. The most characteristic inclusions (apart from the cleavage planes which are visible to the naked eye), are numerous well-shaped three-phase inclusions, very similar to the ones found in emeralds from Colombia (Figure 2).

Fig. 2. Some of the numerous three-phase inclusions observed under the microscope. Magnification 60x.

Conclusion

The physical and optical properties obtained are consistent with those for euclase.[2, 3, 4, 5, 6] Apart from the aquamarine from Tongafeno, Madagascar, which it resembles in appearance, there are two gemstones with similar properties with which this stone could be confused:

(1) green spodumene, RI 1.660–1.676(±0.005), biaxial positive, DR 0.014–0.016, and SG 3.18(±0.03);
(2) bluish-green sillimanite (fibrolite), RI 1.659–1.680(+0.004 to –0.006), biaxial positive, DR 0.015–0.021, and SG 3.24(±0.02).

Their perfect cleavages (two directions for spodumene, one direction for sillimanite), their fibrous aspect and two-phase inclusions, could also add to their confusion with euclase. The main differences between euclase and spodumene lie in the higher birefringence of euclase (0.019), and in its response to ultraviolet radiation: due to a trace content of iron it remains inert while spodumene often fluoresces.

Euclase may be distinguished from sillimanite only by its lower SG, 3.10(±0.01), compared with 3.24(±0.02) for sillimanite.

Acknowledgements

The author would like to thank Daniel Grondin for his assistance in the spectroscopic analysis.

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Compositional characteristics of sapphires from a new find in Madagascar

Claudio C. Milisenda and U. Henn***

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**German Gemmological Association, Idar-Oberstein, Germany

Abstract

Gem-quality blue sapphires from the Andranondambo area in south-eastern Madagascar have been recently entering the gemstone market in commercial quantities. The material is recovered from altered marbles and calc-silicate gneisses of the granulite facies. The physico-chemical properties of the samples investigated are similar to those found in metamorphic-type sapphires.

Keywords: Madagascar, sapphire, geological environment, physico-chemical properties

Introduction

The island of Madagascar has long been known in the gemstone supply scene and its formidable list of gem species and stones for collectors is comparable to those found in Sri Lanka. Even before World War I, people from Idar-Oberstein went to Madagascar in order to obtain gemstones for the industry in their home town (Falz, 1939). Since then gem species such as aquamarine, emerald and other beryls (e.g. morganite), garnets (e.g. rhodolite, spessartine), tourmaline, kunzite, quartz varieties (e.g. rock crystal, amethyst, citrine, agate), feldspars (e.g. amazonite, orthoclase, labradorite), corundum (ruby, sapphire) and a number of rare collector stones (e.g. kornerupine, epidote, kyanite, hambergite and many others) have appeared in the trade.

Lacroix (1922) summarized the island's mineralogy and showed that corundum is

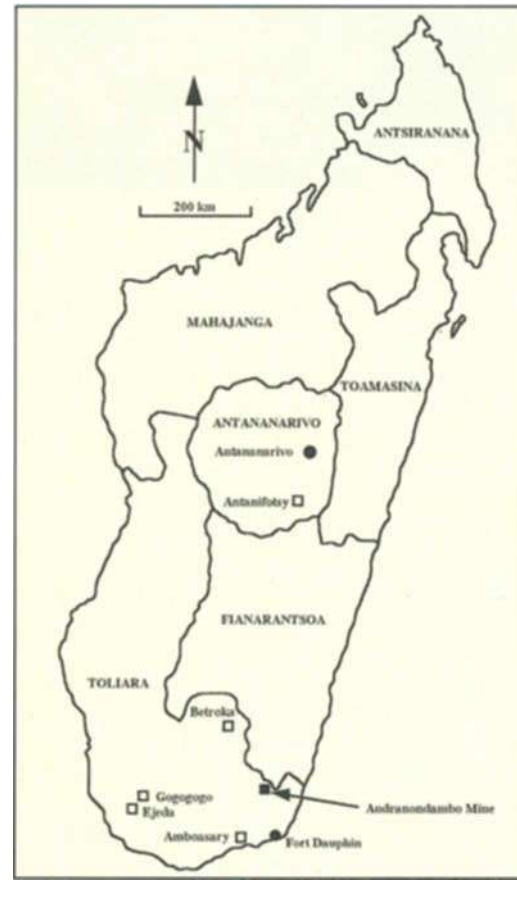

Fig. 1. Geographical map of Madagascar showing the known corundum occurrences (open squares) and the new find of blue sapphire (filled square) in the Andranondambo mine.

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Fig. 2. The Andranondambo mining area in the Toliara province, south-eastern Madagascar. *Photo by E.J. Petsch*

a common constituent of the metamorphic rocks in Madagascar. However, deposits of gem-quality ruby and sapphire are sparse and the production has been limited to relatively small and low-quality samples. According to Chikayama (1989) who presented a recent survey of the gemstone deposits in Madagascar, gem-quality corundum occurs in the south-western province of Toliara at Gogogogo (ruby), Ejeda (ruby), Amboasary (sapphire) and around Antanifotsy (ruby and sapphire), some 100 km south of the capital Antananarivo (Figure 1). An unusual type of multi-coloured (polychrome) sapphire is recovered from a mining area south-west of Betroka also located in the province of Toliara (Koivula *et al.*, 1992).

A recent discovery of blue sapphire in the south-eastern part of the Toliara province now raises the possibility of significant production of sapphire from Madagascar. The occurrence is located near the village of Andranondambo approximately 100 km North of Fort Dauphin (see Figure 1). There, the sapphires are recovered by using simple hand tools from numerous small square shaped gem-pits (Figure 2) which are located in residual gravels. Large quantities are apparently available and there are good prospects for commercial exploitation. In fact, a new company has been formed with investment from leading gem dealers from Thailand in order to develop the deposits in Madagascar (*ICA Gazette*, April 1995).

Geological environment

Granulite grade rocks crop out over a large area covering much of southern Madagascar. They form part of an Archaean crust which experienced its main thermo-tectonic evolution during the Pan-African event, which is known to have affected large parts of Africa, southern India and Sri Lanka (Kennedy, 1964; Kröner, 1980). In a Gondwana supercontinent notionally reassembled before conti-

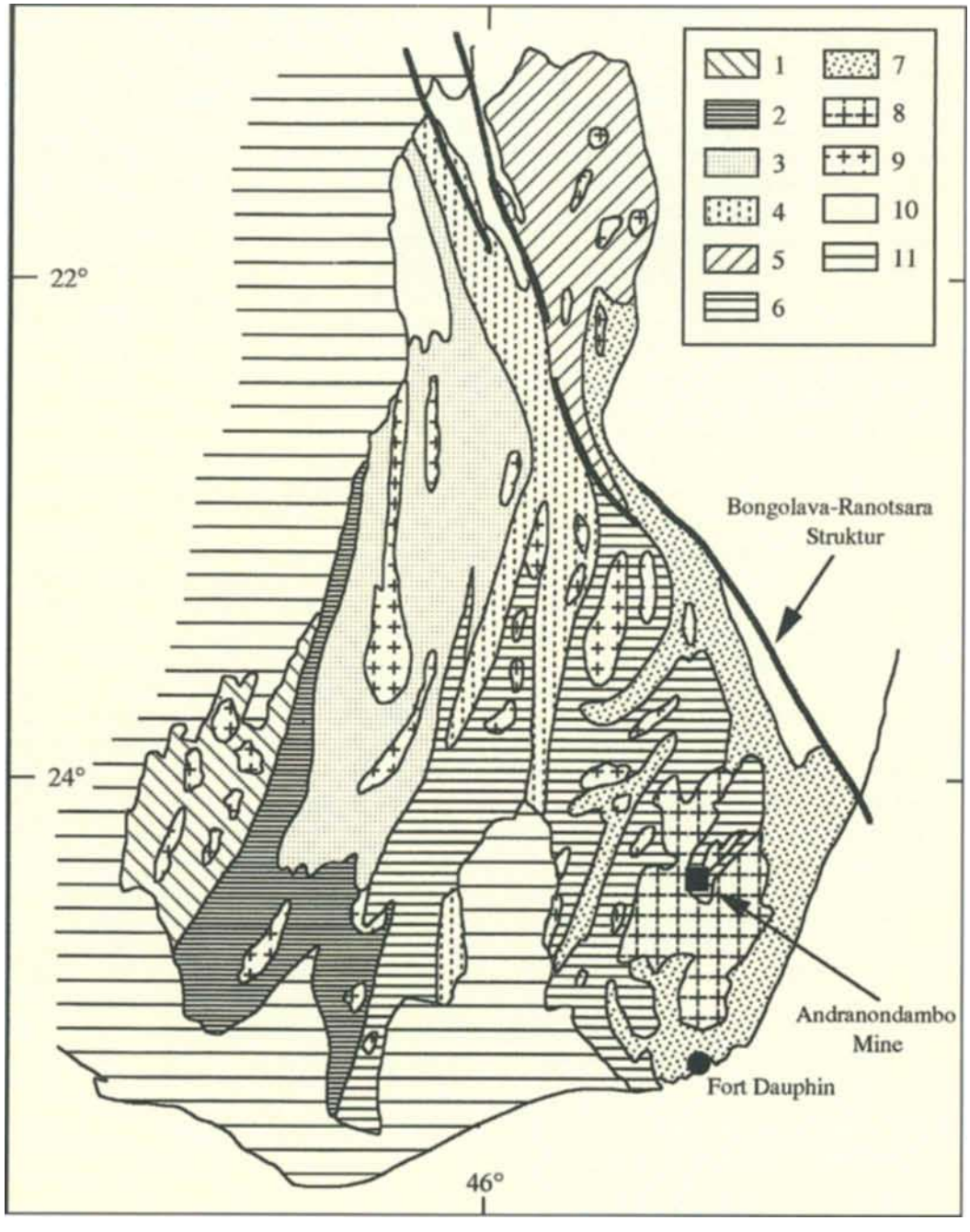

Fig. 3. Simplified geological map of southern Madagascar showing the main petrographic types (modified from Nicolett, 1990). Vohibory group: 1–Vohibory formation (amphibolite gneisses, amphibolites, marbles); Graphite group: 2–Ampanihy formation (graphite gneisses, leptynites, mafic granulites); Androyan group: 3–Horombe formation (leptynites); 4–Ihosy formation (anatectic gneisses, leptynites); 5–Tsitondroina formation (migmatites, leptynites); 6–Tranomaro formation (leptynites, cordierite gneisses, marbles, scapolite gneisses, charnockites); 7–Fort Dauphin formation (leptynites and gneisses); 8–charnockites and granites; 9–granites and orthogneisses; 10–undifferentiated Precambrian; 11–Phanerozoic.

nental drift separated the great landmasses we know today, these granulites are included in a broad belt of high-grade Precambrian rocks and marked the eastern limit of the Mozambique belt, which is regarded as a compression structure resulting from collision of East Gondwana (India-Antarctica-Australia) and West Gondwana (Africa-South America) some 600 Ma ago (Kröner, 1991; Milisenda, 1991).

Recently, Nicollet (1990) reviewed the geology and mineralogy of Madagascar. A simplified geological map is given in Figure 3. The south of Madagascar can be divided into three Archaean successions: from West to East, these are the Vohibory group which is predominantly composed of amphibolites and marbles, the Graphite group which is characterized by graphite-bearing gneisses and leptynites, a banded quartzofeldspathic granulite, as well as mafic granulites and the Androyan group which includes a large variety of granulite-facies ortho- and paragneisses (see Figure 3). Metamorphic grade increases from greenschist and amphibolite-facies in the Vohibory formation to intermediate and high pressure granulite-facies in the Androyan and Graphite group, respectively.

The new sapphire deposit is located south of the Bongolava-Ranotsara lineament (see Figure 3) which is most likely a suture that separates two chronologically distinct domains (Caen-Vachette, 1979). In the Andranondambo mining area, the sapphires are found in a suite of altered marbles and calc-silicate gneisses which form part of the 40–60 km wide Tranomaro formation, a subdivision of the Androyan group which in addition to marbles includes leptynites, banded cordierite-bearing gneisses, scapolite-bearing gneisses and charnockites (Nicollet, 1990). The Tranomaro formation or Tranomaro belt as it is alternatively called by Windley *et al.* (1994) closely resembles the supracrustal sequence of the Highland Complex in Sri Lanka (Milisenda *et al.*, 1988; 1994) and includes Archaean and Early Proterozoic rocks that have been extensively reworked in Pan-African times. Based on recent geochronological data (Andriamarofahatra *et al.*, 1990; Paquette *et al.*, 1993) obtained on rocks of the Tranomaro formation high-grade metamorphism took place in the Neoproterozoic ≈600 Ma ago. Because there is no evidence of either a significantly earlier or later high-grade metamorphic event in this rock unit, we conclude that this was also the time of corundum formation.

Visual appearance

The samples investigated were slightly to moderately included and commonly showed a strong, eye-visible colour zoning. In most cases an intense blue colour was concentrated in broad bands within the centre of the crystal fragments. Only a few crystals with a homogeneous colour distribution were observed. However, the distinct colour zoning can be largely obliterated and thus, the visual appearance of the sapphires can be strongly enhanced by heat-treatment.

Crystallographic properties

The Andranondambo mining area produces fragments of euhedral crystals (Figure 4) with rhombohedral and pyramidal habits. These crystal forms are typical for sapphires found in high-grade paragneisses such as marbles and are unlike the strongly etched or partly dissolved specimens that have been brought to the surface by alkali basalts. The most prominent growth planes are the hexagonal bipyramid $(11\bar{2}1)$ and the basal pinacoid (0001).

Physical properties

Refractive index and specific gravity

Using a standard gemmological refractometer, the refractive indices were determined to be n_e = 1.761–1.763 and n_o = 1.769–1.771 with a maximum birefrin-

Fig. 4. Crystal fragments of sapphires from the Andranondambo mining area, south-eastern Madagascar (weight of samples between 0.88 and 1.44 ct)

gence of–0.008. The specific gravity measured using a hydrostatic balance ranged from 3.91 to 3.98.

Pleochroism and ultraviolet fluorescence

The samples examined showed a distinct to strong dichroism with a green-blue hue perpendicular to the *c*-axis and violet-blue parallel to the *c*-axis.

All samples were inert when exposed to long wave ultraviolet (UV) radiation. Most of them were also inert to short wave UV. However, a few stones fluoresced a weak greenish-blue and one specimen a weak and uneven orange under short wave UV.

Spectroscopy

The polarized UV/VIS/NIR–spectrum of a representative sapphire specimen from the Andranondambo mining area is shown in Figure 5 and is typical for sapphires from high-grade metasedimentary sources (e.g. Poirot, 1992). They are dominated by two essential absorption mechanisms namely $Fe^{3+}$and the Fe^{2+}/Ti^{4+}charge transfer (e.g.

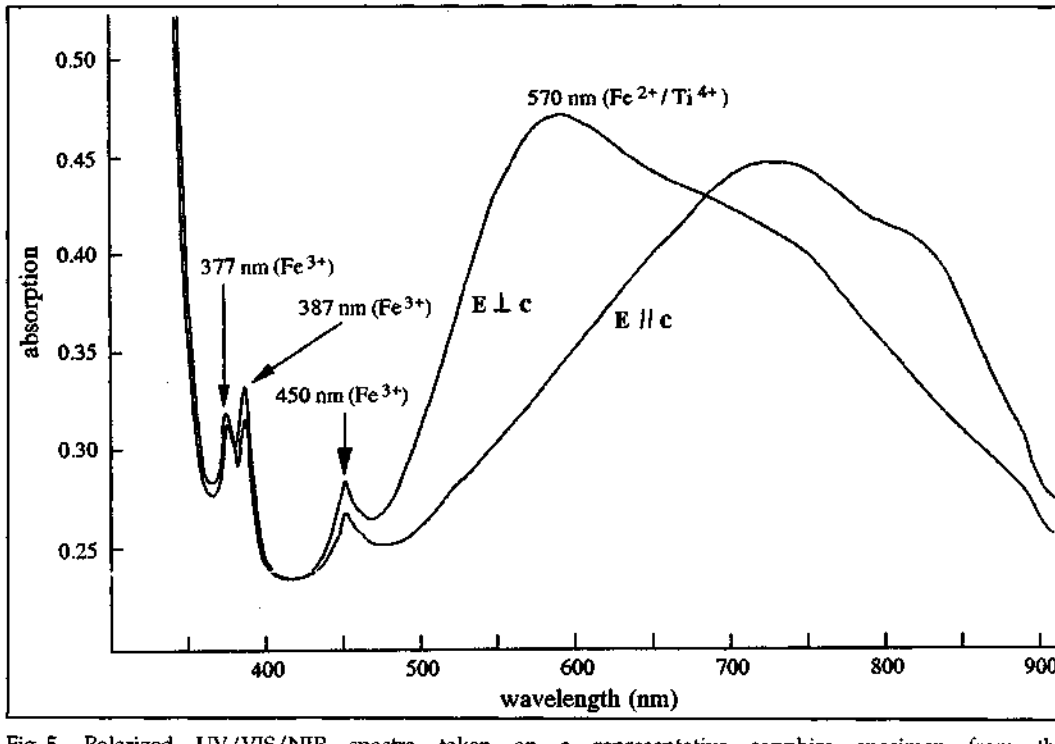

Fig. 5. Polarized UV/VIS/NIR—spectra taken on a representative sapphire specimen from the Andranondambo mining area in south-eastern Madagascar. E = vibration direction.

Schmetzer and Bank, 1980; 1981). The doublet in the ultraviolet region at 375 and 387, as well as the sharp band at 450 nm are the result of trivalent iron absorption. The broad absorption band with a maximum at 570 nm in the yellow part of the spectrum of the ordinary ray is due to an intervalence charge transfer process of the ion pair $Fe^{2+}$and Ti^{4+}. This absorption band is pleochroic and the maximum is closer to the near infrared in the spectrum of the extraordinary ray. It is worth noting that an absorption band in the near-infrared with a maximum at around 850 nm which is typically found in sapphires from basaltic sources (e.g. Poirot, 1992) was not detected.

Internal characteristics

As noted above, distinct colour zoning was present in the majority of the sapphires examined. In most cases, the samples showed an intense blue colour zone running parallel to the *c*-axis of the crystal (Figure 6). In addition, within the colour zones alternating deep to pale blue layers were observable which are oriented perpendicular to the *c*-axis. The colour zoning is accompanied by a strong growth zoning parallel to the basal pinacoid (0001) and/or parallel to the different bipyramidal faces of the sapphire crystal.

A number of crystalline inclusions were observed with an immersion-type microscope. Preliminary electron microprobe data indicate the presence of apatite, calcite, dolomite and a clay-mineral whose structure is yet to be determined. Apatite inclusions commonly possess a prismatic habit (Figure 7) but also occur in more equidimensional shapes which in places form a nucleus for hollow tubes oriented parallel to each other (Figure 8). Clusters of distinctly corroded, birefringent crystal

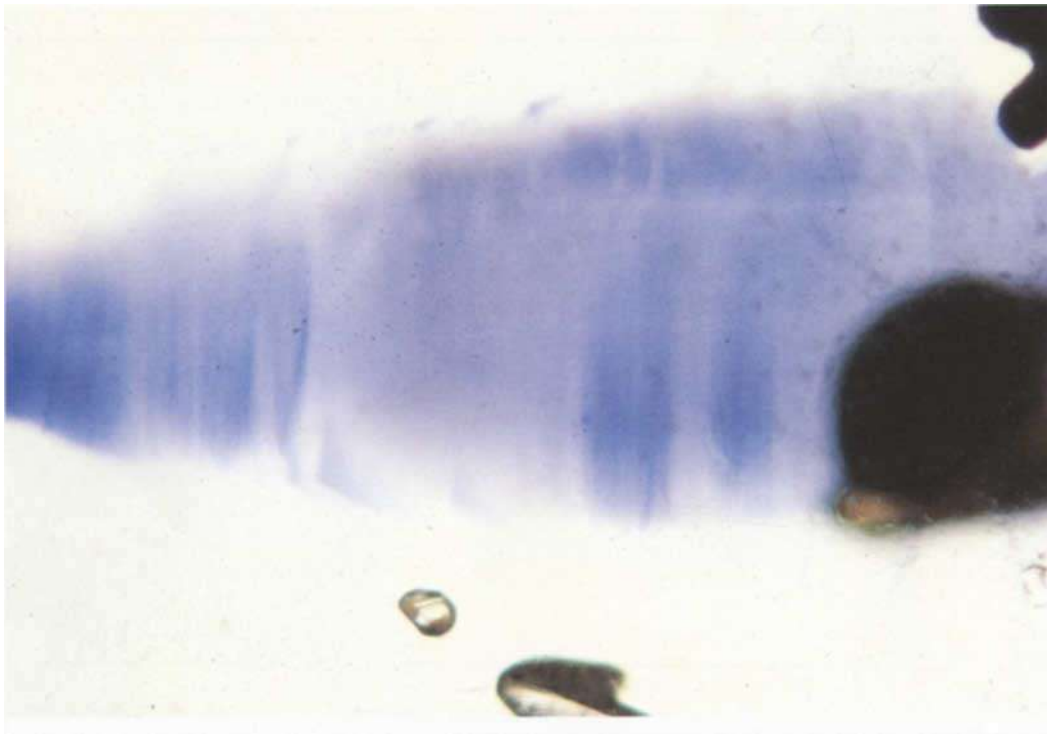

Fig. 6. An intense blue colour zone running parallel to the *c*-axis with alternating deep to pale blue layers oriented perpendicular to the *c*-axis is commonly observed in sapphires from south-eastern Madagascar. Immersion, transmitted light, 50x

Fig. 7. Euhedral apatite crystals are common inclusions in sapphires from the Andranondambo mining area. Immersion, transmitted light, 50x

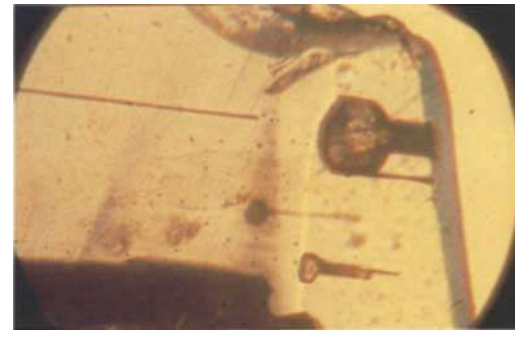

Fig. 8. Apatite inclusions located at the ends of hollow tubes which are oriented parallel to each other. Immersion, transmitted light, 40x

Fig. 9. Cluster of distinctly corroded, birefringent carbonate inclusions in front of a barely visible fingerprint-type healed crack. Immersion, transmitted light, 50x

Fig. 10. Transparent, colourless birefringent mineral platelets (probably mica) are typical inclusions in the sapphires from south-eastern Madagascar. Immersion, transmitted light, 50x

inclusions were identified as carbonates (Figure 9). Also common are transparent, colourless platelets displaying a pseudo-hexagonal habit (Figure 10); these are probably mica group minerals. In addition to the mineral inclusions mentioned above several other solid inclusions are present and probably include feldspar, diaspore, rutile and spinel. Microprobe work is continuing and a detailed chemical study of the large variety of solid inclusions in sapphires from south-eastern Madagascar will be presented in a separate paper.

A variety of negative crystals and fine networks of healed cracks (composed of minute fluid filled voids or two-phase inclusions) also form typical inclusion patterns. Lamellar twinning is present in some specimens.

Chemical properties

The chemical analyses of three sapphire specimens are listed in Table I. In addition to aluminium oxide (Al_2O_3) the electron-microprobe revealed iron oxide (FeO) as the most significant trace constituent followed by titanium oxide (TiO_2). Silicon (Si), gallium (Ga) and chromium (Cr) were also present in measurable concentrations, whereas manganese (Mn) and magnesium (Mg) were detectable in very small amounts in some crystals.

Conclusions

The compositional characteristics of the sapphires from the Andranondambo mining area in Madagascar were found to be very similar to those found in sapphires from Sri Lanka and Burma; these also were

Table I: Chemical compositions of three sapphires from the Andranondambo mine

Weight %	*Sapphire 1* Range (3 anals)	*Sapphire 1* Mean	*Sapphire 2* Range (3 anals)	*Sapphire 2* Mean	*Sapphire 3* Range (3 anals)	*Sapphire 3* Mean
SiO_2	0.02 – 0.04	0.03	0.02 – 0.04	0.04	0.02 – 0.05	0.04
TiO_2	0.06 – 0.08	0.07	0.07 – 0.14	0.10	0.03 – 0.10	0.05
Al_2O_3	99.84 – 100.28	100.09	99.48 – 100.05	99.81	99.58 – 100.35	99.93
Ga_2O_3	0.01 – 0.05	0.03	0.01 – 0.04	0.03	0.00 – 0.03	0.02
Cr_2O_3	0.00 – 0.05	0.03	0.00 – 0.07	0.02	0.00 – 0.06	0.02
FeO	0.26 – 0.30	0.29	0.45 – 0.59	0.50	0.30 – 0.31	0.31
MnO	0.01 – 0.02	0.02	0.00 – 0.03	0.01		0.00
MgO	0.00 – 0.01	0.01	<0.01	0.00		0.00
Total		100.57		100.51		100.37

formed in a sedimentary environment that underwent granulite-facies metamorphism. The new find will significantly increase the commercial importance of sapphires from Madagascar.

Acknowledgements

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Sapphires from Andranondambo area, Madagascar

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Abstract

Sapphires from a new deposit of commercial interest in the Andranondambo area, southern Madagascar, are described. The sapphires occur primarily in pegmatitic veins consisting mainly of calcite and plagioclase which intrude pyroxenites. The crystal habit as well as internal growth structures allow a subdivision of the sapphires into three types: type I shows a dipyramidal to barrel-shaped habit, type II is prismatic, and type III reveals a distorted tabular to short-prismatic-dipyramidal habit. The sapphires show distinct, sometimes extremely complex colour zoning between almost colourless, light blue, and dark blue to extremely blue areas. Some crystals contain brownish or whitish areas. The differently coloured zones may consist of core and rim, or narrow banding throughout the stones, or a combination of both.

Apatite inclusions are common and may be accompanied by rosette-like fissures in type I or by tubes perpendicular to the growth direction in type II sapphires. Calcite and spinel inclusions were also observed. Type III sapphires commonly show three-phase inclusions parallel to the basal pinacoid, consisting of liquid and gaseous CO_2 and diaspore.

Chemical analyses show that darker blue zones are richer in Fe_2O_3 than the lighter blue or almost colourless zones. They also show a somewhat increased TiO_2 content. Compared to the light blue areas, the brownish zones show significant enrichment in TiO_2 and slight enrichment in Fe_2O_3. Ultraviolet-spectra reveal absorption bands typical for sapphires of metamorphic origin. The absorption edge in heat-treated sapphires is shifted towards lower wavelengths.

Keywords: sapphire, Madagascar, pegmatite-like host rock, growth characteristics, inclusions, chemistry, spectroscopy

Introduction

Corundum from southern Madagascar was described in 1922 by Lacroix, and subsequently by Noizet and Delbos, 1955; Rafaranalisoa, 1968; Nicollet, 1986; and Ackermand *et al.*, 1989. However, only recently in 1994 have several gem companies and the local population begun to exploit sapphires in the region of Andranondambo, southern Madagascar. Now, more and more material from this source is coming onto the market (Figure 1), and there have been several brief reports about this new Madagascar mining area and its sapphires. Piat and Bouqueau (1995) and the *ICA Gazette* (Anon., 1995) described the property situation at the

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Fig. 1. Faceted and rough sapphires from Andranondambo area, SSE Madagascar. Weight of the second stone from left: 1.88 ct.

mining area, Milisenda (1995) gave a short description of the properties of sapphires found in the south-western part of Madagascar, and Kammerling *et al.* (1995) reported more gemmological data for these sapphires without specifying the mining area. The first detailed description of the mining area and gemmological properties of sapphires from southern Madagascar was given by Hänni *et al.* (1995) and a more detailed report is presented here.

Location and mining

The sapphires are mined in the region of Andranondambo (S.24°25′,E.46°35′, district of Amboasary, SSE-Madagascar, see Figure 2). The extraction of sapphires–mainly by rudimentary means–is carried out over a relatively large area of about 200 km^2. The occurrence of corundum in gem quality, however, is restricted to small areas within this large region. Several mining companies (from Thailand, Switzerland, Madagascar and Israel; compare Piat and Bouqueau, 1995) and a growing number of local residents are working in the district (Figure 3).

One of the authors (MSK) recently had the opportunity to investigate the geology of the mining area during two prospecting campaigns of one month each kindly supported by W. Spaltenstein and C. Ravomanana, Multicolour and Ste. Arc-en-Ciel Gem-Corp. The sapphires from the region of Andranondambo originate from primary deposits in small pegmatite-like veins (normally 0.05–0.2 m thick, 5–50 m long). Sapphires are found directly in these veins, or in alluvial accumulations, closely related to partly eroded pegmatite-like veins. Figure 4 shows a sapphire-bearing rock consisting mainly of calcite and feldspar. The mining, e.g. by the companies Multicolour (Thailand) and Ste. Arc-en-Ciel Gem-Corp. (Sri Lanka), concentrates on these pegmatite-like veins, digging exploitation trenches with simple equipment (Figure 5). The trench-gravel is passed over a jig to separate the sapphires from other rock components (Figure 6).

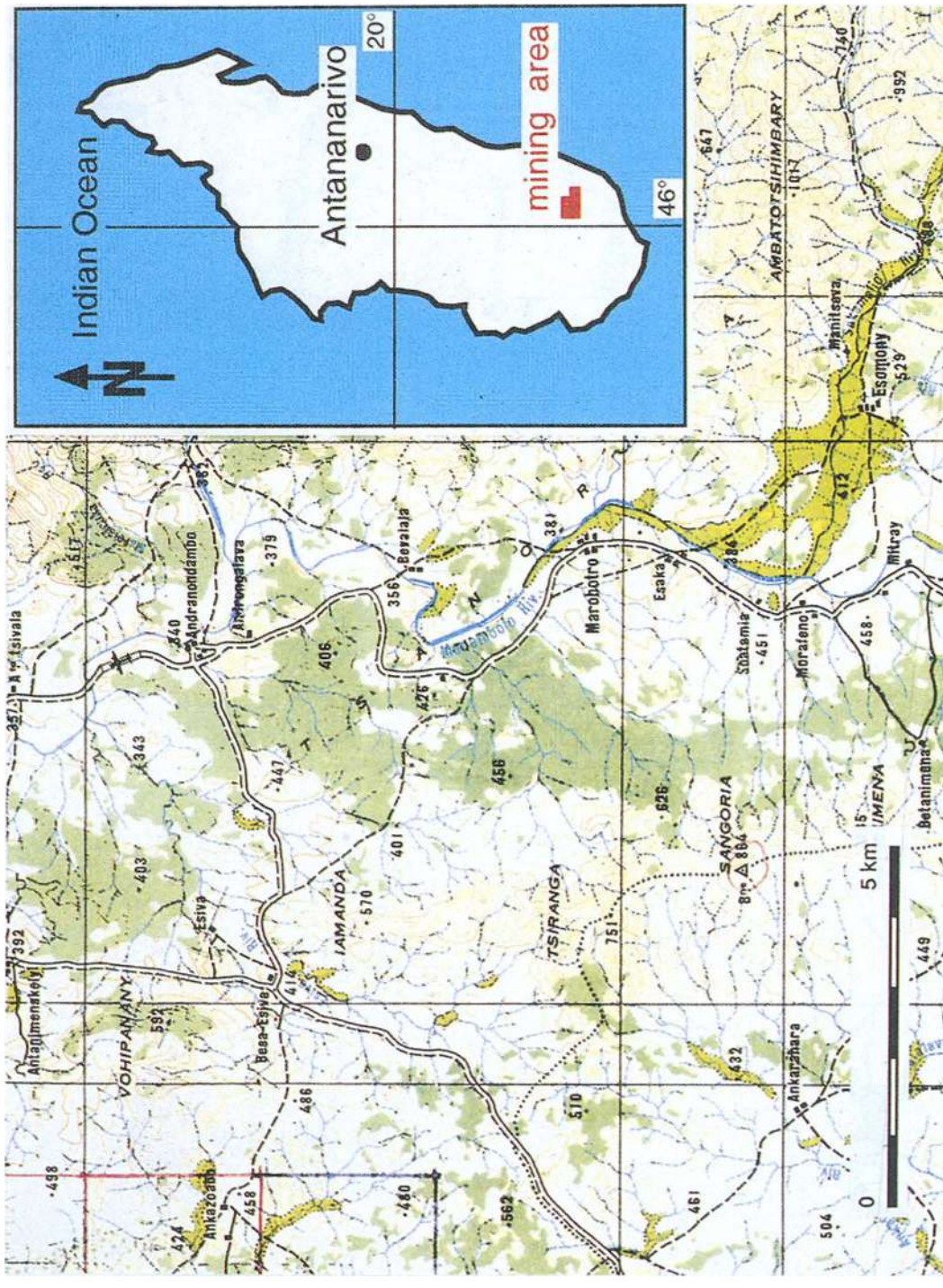

Fig. 2. Map of the sapphire mining area of Andranondambo in SSE Madagascar.

Fig. 3. Local residents dig for sapphires in the region of Andranondambo, SSE Madagascar.

Fig. 4. Sapphire-bearing calcareous host rock from the mining area of Andranondambo, SSE Madagascar. Length of the photographed area: 4.5 cm.

Due to evaporation in the semi-arid climate of southern Madagascar, massive limestone layers have developed on, or just below the soil-surface, and this complicates the mining operation. In addition, the development of this kind of deposit is often problematic, because the quantity of sapphires may be very unevenly distrib-

Fig. 5. The mining site in southern Madagascar, near Andranondambo, showing a trench worked by the companies Multicolour and Ste. Arc-en-Ciel Gem-Corp.

Fig. 6. The sapphire-containing gravel is treated by a jig in the working area of the companies Multicolour and Ste. Arc-en-Ciel Gem-Corp.

uted throughout small veins. Thus, it is difficult to predict if mining over a longer period of time will be economic.

Regional geology

The geology of Madagascar is closely related to the geological evolution of East Africa (Dixey, 1960; Cahen and Snelling, 1984). Southern Madagascar is characterized by Precambrian basement rocks, which mainly consist of medium- to high-grade metamorphosed gneisses and metasediments (Besairie, 1971; Ackermand *et al.*, 1989). These rocks represent terrains of continental sediments, which were accumulated and primarily metamorphosed in Archean times (~2600 Ma.). They were reactivated by the so-called Pan-African tectonothermal event (600–500 Ma.), a global phase of major metamorphic and tectonic activity. In southern Madagascar, that phase was associated with extensive magmatic activity, i.e. granitic intrusions, granitization and pegmatite formation (pegmatites of 550–480 Ma.; Besairie, 1971). The sapphire deposits in the mining area are obviously a product of this magmatic activity. The sapphires are found in pegmatite-like veins, which cut the Precambrian basement. Corundum from such primary deposits is geologically rather unusual, although some of the most famous gem corundum mines belong to this type of deposit; for example the sapphires from Kashmir (Atkinson and Kothavala, 1983; Hänni, 1990), and the rubies and sapphires from the Umba Valley in Tanzania (Solesbury, 1967; Hänni, 1986).

As a result of the field work of one of the authors (MSK), several types of veins with varying visual appearance, mineralogy and chemistry were distinguished in the mining area of southern Madagascar. Sapphires, however, only occur in one specific type of miarolitic pegmatite-like

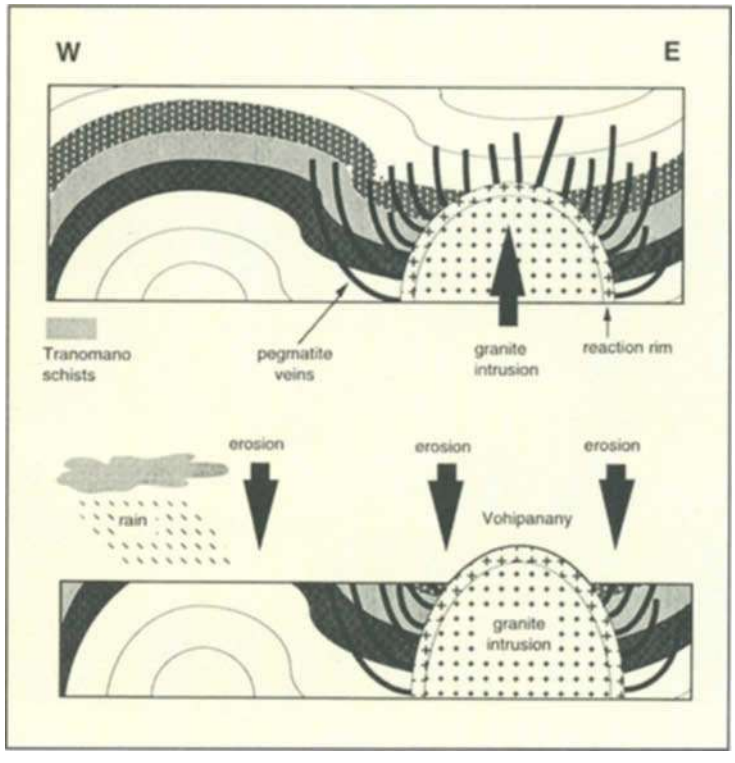

Fig. 7. Diagrammatic geological section at the mining area of Andranondambo, SSE Madagascar. Top: Pegmatites and granites intruded during the Pan-African tectonometamorphic event; bottom: situation today after 500 million years (Ma) of erosion.

host rock. This type of pegmatitic rock forms a net-like pattern of rather small veins which cut the Precambrian basic rocks here consisting mainly of pyroxenites with associated marble lenses. Sapphires were not found in these pyroxenites and marble lenses until now. On the basis of the form and abundance of the sapphire-bearing pegmatite-like rocks, we suggest that they are late-stage products of the Pan-African event, possibly originating from a highly differentiated granitic magma, with a high water content. Most petrologists agree that the aqueous-fluid phase plays an important role in the generation of pegmatites (London, 1986a). The pegmatitic rocks intruded the Precambrian basement in close proximity to larger granitic intrusions, e.g. the granite of Vohipanany, 1.5 km from the mining site (see Figure 7). The more acidic Precambrian gneisses and metasediments in the mining area contain comparable pegmatites which are, however, free of sapphires. The close connection of corundum-bearing pegmatitic rocks to basic-ultrabasic host rocks seem to be a common feature with geochemical relevance for the genesis of such a deposit (Larsen, 1928; Solesbury, 1967; Atkinson and Kothavala, 1983).

According to earlier work, the sapphire-bearing pegmatite consists mainly of calcium-rich plagioclases (bytownite-anorthite, Noizet and Delbos, 1955), and quartz only occurs in minor abundance. Hibonite ($CaAl_{12}O_{19}$), formerly only known in meteorites, has also been found in these pegmatites (Rafaranalisoa, 1968). Near the surface (at several metres depth), this plagioclase is strongly altered to a white powder consisting of fine-grained clay minerals (i.e. kaolinite, saponite and montmorillonite).

At the rim of the pegmatite-like veins in the mining area, we observed a distinct mineralogical zonation, consisting of mica (mainly phlogopite and biotite), epidote, amphibole and Fe-hydroxide (Figures 8 and 9). This zonation indicates extensive metasomatic processes between the intruding hydrous aluminium-rich pegmatite-like vein and the basic host rock of the vein. The precipitation of Al-rich minerals (i.e. corundum) in pockets in the central part of the pegmatite-like veins requires either a large water/rock ratio or extensive

Fig. 8. Sapphire-bearing pegmatite-like vein with mineral zoning at its rim at the mining site near Andranondambo in SSE Madagascar. The vein cuts across the pyroxenitic rock. The heavy weathering of the whole sequence near the surface is evident.

fluid recirculation during pocket formation in the pegmatite (London, 1986b). The formation of calcite within the pegmatite and as inclusions in the sapphires probably derives from the metasomatic fluid (calcium- and CO_2-enriched) originating from the basic host rock. With this mineral composition the genetic connection of the pegmatitic rock with the local granitic rocks mentioned above is admittedly tenuous. Generally, however, the observations are consistent with descriptions of similar corundum deposits in pegmatites from other parts of the world (e.g. Larsen, 1928; Heinrich, 1949; Solesbury, 1967; Atkinson and Kothavala, 1983).

Samples and analytical methods

The authors examined more than 300 sapphires from different suppliers. Of these, 34 were rough crystals, some of which were made available before and after heat treatment and/or faceting. The rough crystals weighed up to 10 ct and some examined in this study are shown in Figure 10. The colours range from dark blue to light blue with occasional uneven colour distributions.

Morphological and crystallographical properties of the samples were determined using a standard goniometer and microscopically by the method described by Schmetzer (1986) and Kiefert and Schmetzer (1991a). Inclusions in rough and faceted sapphires and constituents of the host rock were identified by scanning electron microscopy (SEM) with a JEOL 6300F Electron Microprobe and by Raman spectroscopy (RS) with a Renishaw Raman Microscope. X-ray diffractometry (XRD) was carried out on minerals adhering to the rough crystals. Qualitative chemical data

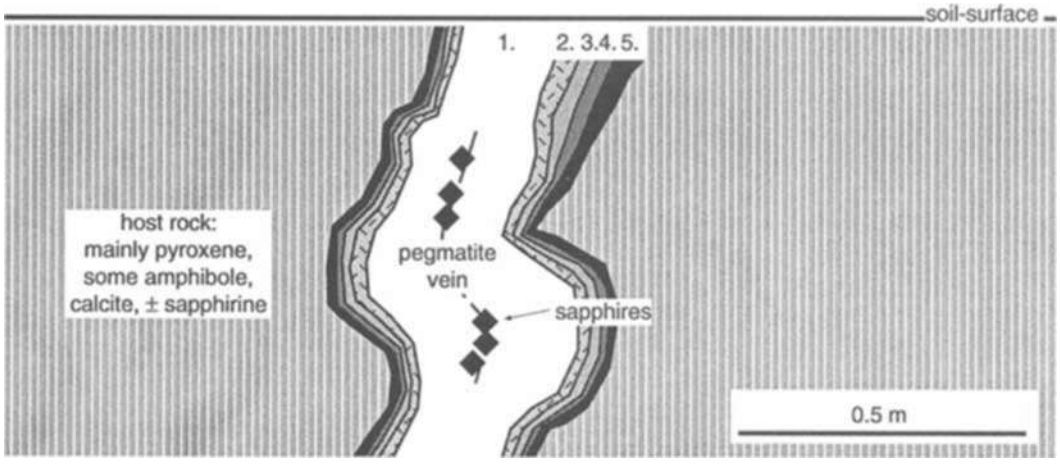

Fig. 9. Schematic diagram of a sapphire-bearing pegmatitic vein in pyroxenitic host rock from southern Madagascar. The mineral zones from vein centre to rim are (1) clay minerals (± feldspar) with some corundum in the central part of the pegmatite vein; (2) mica with clay minerals and some feldspar; (3) Fe-hydroxides, epidote and some clay minerals; (4) epidote, minor mica and clay minerals (± feldspar); (5) amphibole.

Fig. 10. Rough sapphires from Madagascar. Weight of the largest crystal: approximately 10 ct.

were obtained with a Phillips PV9500 X-ray fluorescence spectrometer with Tracor Northern Spectrace software (XRF). The chemical compositions of 13 stones with colour zoning were determined quantitatively by electron microprobe (CAMECA Camebax SX 50) by measuring between one and three traverses of 50 to 100 point analyses each across microscopically selected areas of the samples (EMP). Spectroscopical data were recorded with a Hitachi U4001 spectrophotometer and a Leitz-Unicam SP 800 spectrophotometer between 800 and 290 nm, the characteristic range of wavelengths where absorptions from chromophore elements in sapphires are observed. Infrared spectroscopy was carried out with a Phillips PU9800 spectrometer.

Visual appearance and crystallography

The crystallographic properties of the sapphires were determined by examining the morphology of the rough crystals and combining this with microscopic examination of internal growth structures of rough and faceted samples using methylene iodide as an immersion liquid. According to their morphology, the samples can be divided into three different types, namely (I) dipyramidal to barrel-shaped, (II) prismatic and (III) distorted tabular to short-prismatic-dipyramidal (see Figure 11). Indices of the crystal faces are given on the basis of the unit cell with a:c = 1:1.365.

Type I (dipyramidal to barrel-shaped habit): dipyramidal to barrel-shaped crystals are mostly blue, some are also whitish or greyish with a milky sheen (so-called geuda-type stones, which give nice blue colours after heat treatment). Violet stones are occasionally present, too. The crystal faces observed in this type of sapphire are the basal pinacoid *c* (0001), the positive rhombohedron *r* $(10\bar{1}1)$, and the hexagonal dipyramids *n* $(22\bar{4}3)$, *w* $(11\bar{2}1)$, *v* $(44\bar{8}3)$, and *z* $(22\bar{4}1)$. These crystal faces occur in various combinations (Figure 11 a-c). Colour zoning following any of these crystal faces is common.

Type II (prismatic habit): the crystal faces observed in this type of sapphire are the basal pinacoid *c* (0001), the positive rhombohedron *r* $(10\bar{1}1)$ and the hexagonal prism *a* $(11\bar{2}0)$ (Figure 11 d). Part of these crystals reveal only *c* (0001) and *a* $(11\bar{2}0)$ faces. Sapphires of the second type are often macroscopically colour zoned with a dark blue centre and a lighter blue rim. The rough stones investigated all showed a distinct whitish striation in the area confined to the rim of the basal plane with an orientation perpendicular to the hexagonal prism faces *a* (Figure 12).

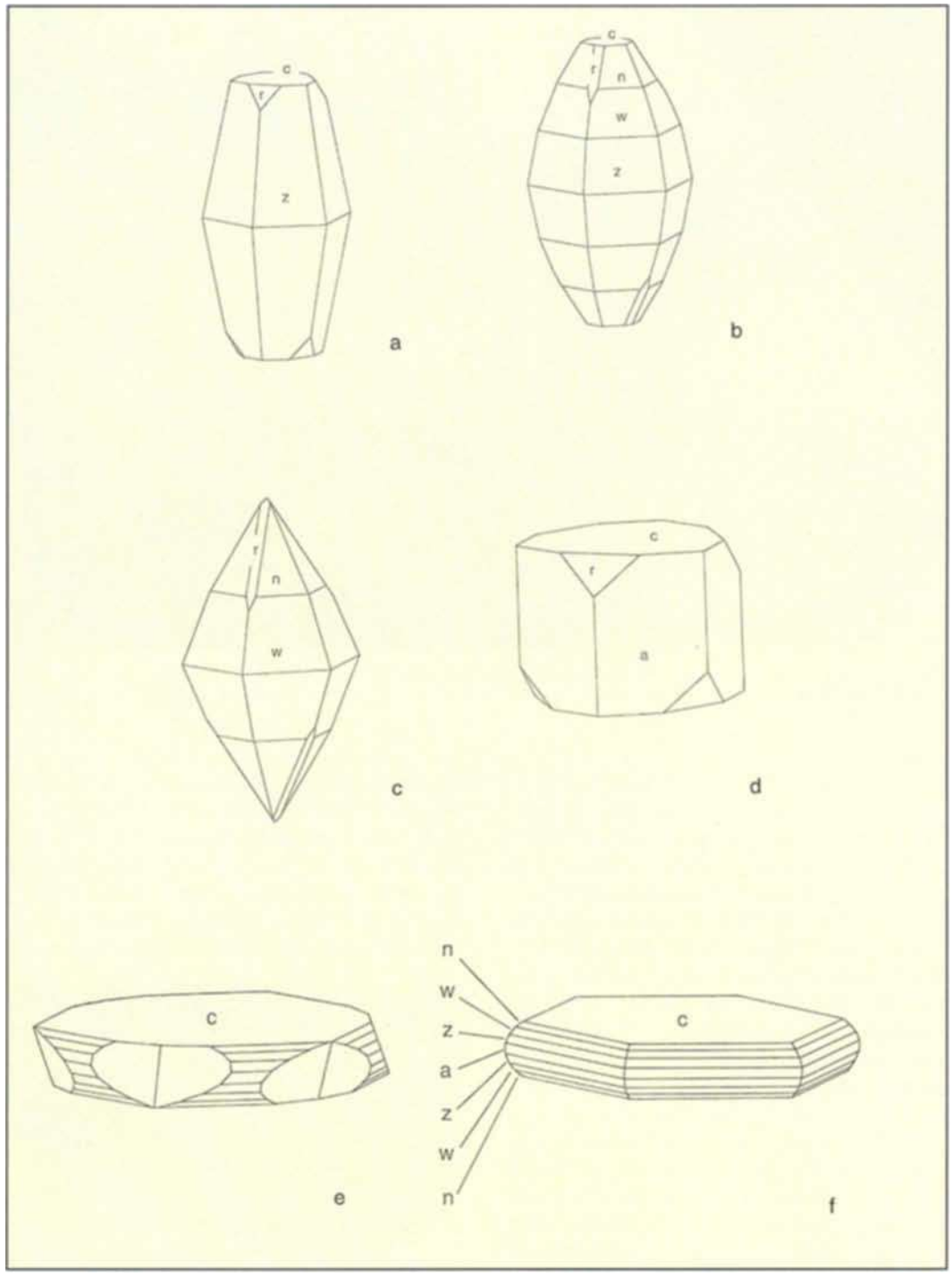

Fig. 11. Crystal forms observed in Madagascar sapphires: a-c dipyramidal to barrel-shaped habit; d prismatic habit; e distorted tabular to short-diprismatic-pyramidal habit showing a scalenohedron face; f distorted tabular to short-prismatic-dipyramidal habit.

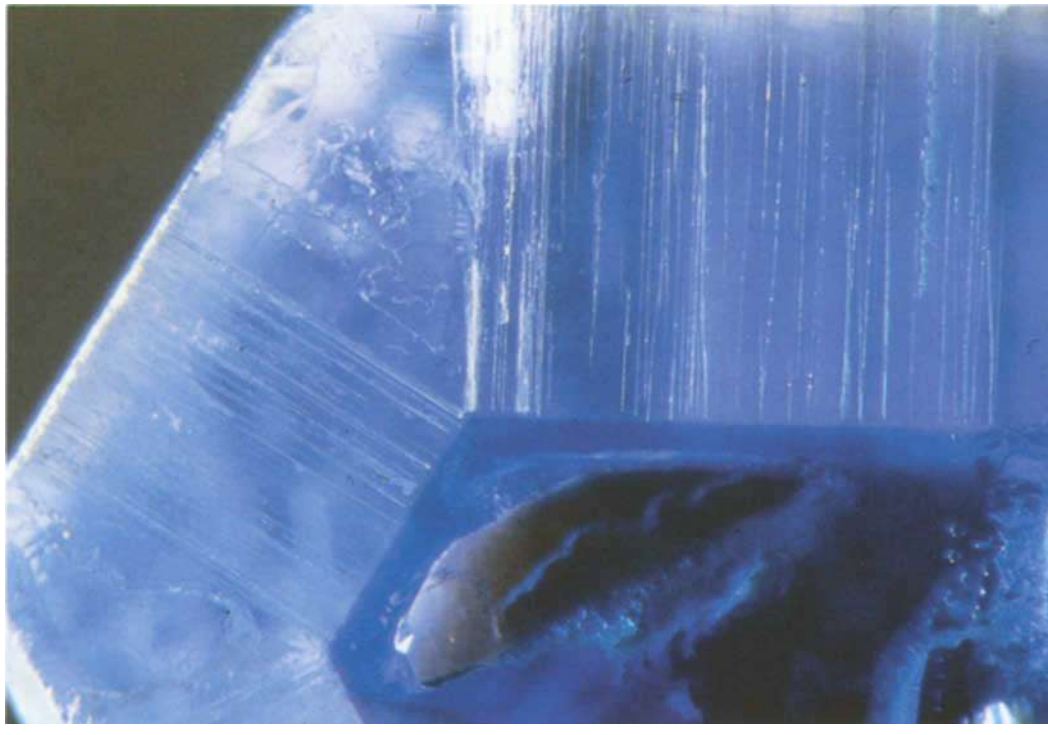

Fig. 12. Type II sapphire from Madagascar showing the dark blue core and lighter blue rim with white striations on the basal faces with an orientation perpendicular to the prismatic growth planes. View parallel to the *c*-axis. Magnification 4x.

Type III (distorted tabular to short-prismatic-dipyramidial habit): this type of sapphire shows the basal pinacoid *c* (0001) and the hexagonal prism *a* $(11\bar{2}0)$ in combination with several hexagonal dipyramids such as *n* $(22\bar{4}3)$, *w* $(11\bar{2}1)$, *v* $(44\bar{8}3)$, and *z* $(22\bar{4}1)$ (Figure 11 f). The growth of the hexagonal crystal faces may be completely subdued in one or two directions, while the basal pinacoid is very prominent. In these cases distorted rhomboidal-shaped sapphires with four prism faces, or crystals with five instead of six prism or dipyramidal faces are formed (see Figure 1). Some samples of this type also exhibit a ditrigonal scalenohedron, most probably $(10\ 2\ \bar{1}\bar{2}\ 3)$ as an additional crystal face (Figure 11 e). This type of crystal face is extremely rare in corundum (cf. Goldschmidt, 1918) and may therefore be considered a characteristic feature of type III sapphires from Madagascar. The crystals with distorted tabular to short-prismatic-dipyramidal habit are blue with a distinct colour zoning parallel to the basal pinacoid. The colour zoning may consist of only one thin, extremely dark blue stripe through the middle of the stone or

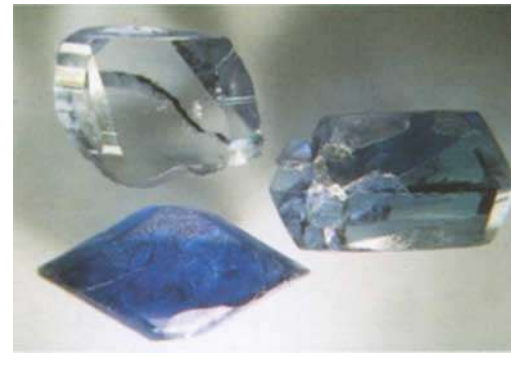

Fig. 13. Type III rough crystals showing different colour zoning. Magnification 2x.

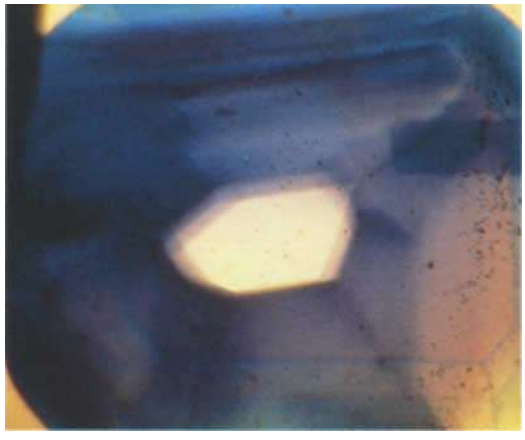

Fig. 14. Type I sapphire from Madagascar showing a colourless core and a blue rim. View nearly parallel to the *c*-axis. Immersion, magnification 30x.

a broad dark blue band with lighter blue rims (Figure 13). The bands and stripes are generally orientated parallel to the basal pinacoid.

Gemmological properties

Densities and refractive indices of all types of Madagascar sapphires do not differ from those of sapphires from other deposits. Measured densities vary between 3.99 and 4.01 g/cm^3. Refractive indices range from 1.761 to 1.763 for ε and 1.769 to 1.771 for ω, with a birefringence of 0.008. The blue sapphires are inert to short wave and long wave UV light, while the few purplish stones examined exhibit a distinct red fluorescence. Pleochroic colours of the blue sapphires are light greenish-blue parallel to the optic axis (ε-vibration) and dark violet-blue perpendicular to the optic axis (ω-vibration).

Microscopic features

Microscopic features can be studied in various kinds of lighting, in air or immersion. Therefore, the observed peculiarities may appear or be described differently, according to the illumination conditions. It is perhaps timely to point out that mineral dust appears different in dark-field and in transmitted light. What may be described as a zone of whitish dust in dark field illumination would probably appear to be brown in transmitted light in immersion (see Figures 21a and b). The Tyndall effect and scattering of light may explain the different appearance in relation to the observation technique.

Since the growth characteristics of the Madagascar sapphires were investigated in immersion (compare Schmetzer, 1986; Kiefert and Schmetzer, 1991a), in the following paragraphs growth sectors with mineral dust (rutile?) that appear whitish through a Gemolite binocular microscope with dark-field illumination, appear brown or brownish in immersion and are described accordingly.

Type I sapphires (dipyramidal to barrel-shaped habit)

Growth structures and colour zoning: The dipyramidal to barrel-shaped stones often vary in colour from core to rim. Three different types of colour variation were observed. Sapphires with: (a) a colourless core and a blue rim (Figure 14), (b) a dark blue, zoned core and a light blue rim (Figure 15) and (c) a brown (whitish) core with a blue rim (Figure 16). The cores are defined by various crystallographic planes

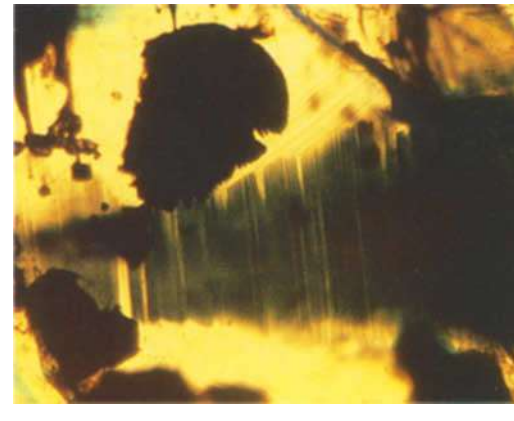

Fig. 15. Type I sapphire from Madagascar showing a dark blue inner core and nearly colourless rim. The zonation of the blue area is parallel to the basal plane. View perpendicular to the *c*-axis, the *c*-axis runs horizontically. Immersion, magnification 40x.

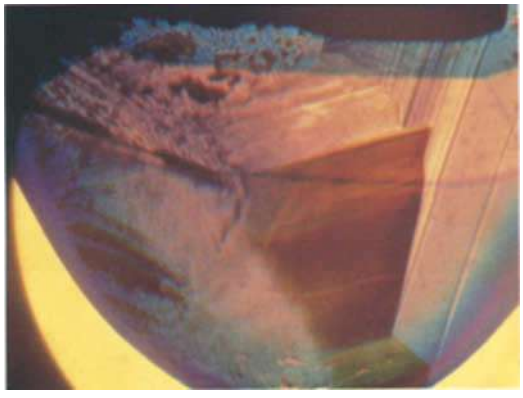

Fig. 16. Type I sapphire from Madagascar showing a brown core and light blue rim. View perpendicular to the *c*-axis, the *c*-axis runs almost vertically, the dark brown core is confined by one *c* and one *r* face. Immersion, magnification 50x.

which are parallel to the macroscopically observed crystal faces. The brown cores show mostly a homogeneous, unzoned colour, but in some cases minute particles were observed.

The zones around the cores and the complete samples (of stones without a distinct colour zoning between cores and rims) show strong light and dark blue, sometimes extremely complex colour zoning parallel to all macroscopically observed crystal faces *c*, *r*, *n*, *w*, *v*, and *z*

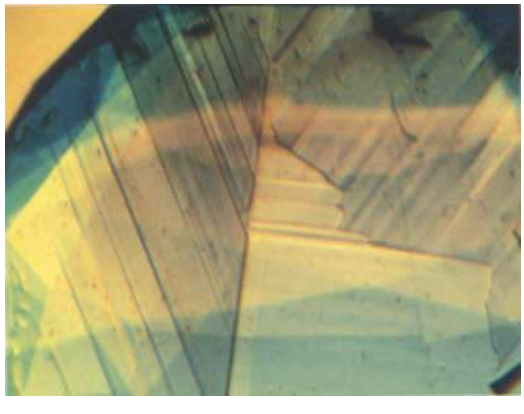

Fig. 17. Type I sapphire from Madagascar showing zones of lighter blue and darker blue. View almost perpendicular to the *c*-axis, the light blue zone is related to *c*-growth zones, the darker blue areas (left and right) are related to two *n* growth zones. Immersion, magnification 32x.

Fig. 19. Type I sapphire from Madagascar showing colour zoning related to two dipyramidal faces *n* and *n'* and the negative rhombohedron *r*. View inclined approximately 30° to the *c*-axis. Immersion, magnification 50x.

(Figures 17–19). In some crystals, oscillatory growth of different faces has formed mosaic-like patterns, occasionally throughout the crystals (Figure 20). These structures consist of various growth planes such as *c*, *r*, *n*, *w*, *v*, and *z*, sometimes in combination with crystal planes which are not observed macroscopically in this type of sapphire, e.g. the hexagonal prism *a*.

Brownish areas were not only observed in the core (Figure 16), but also as brown stripes in the outer rim of some sapphires. These brown stripes are usually very thin layers, and sometimes show a concentration of fine brownish particles. The brown colour is visible when the stone is viewed in transmitted light in immersion. Without

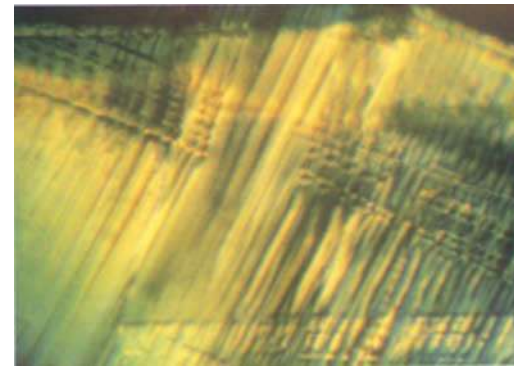

Fig. 20. Mosaic-like growth pattern in type I sapphires from Madagascar. Immersion, magnification 50x.

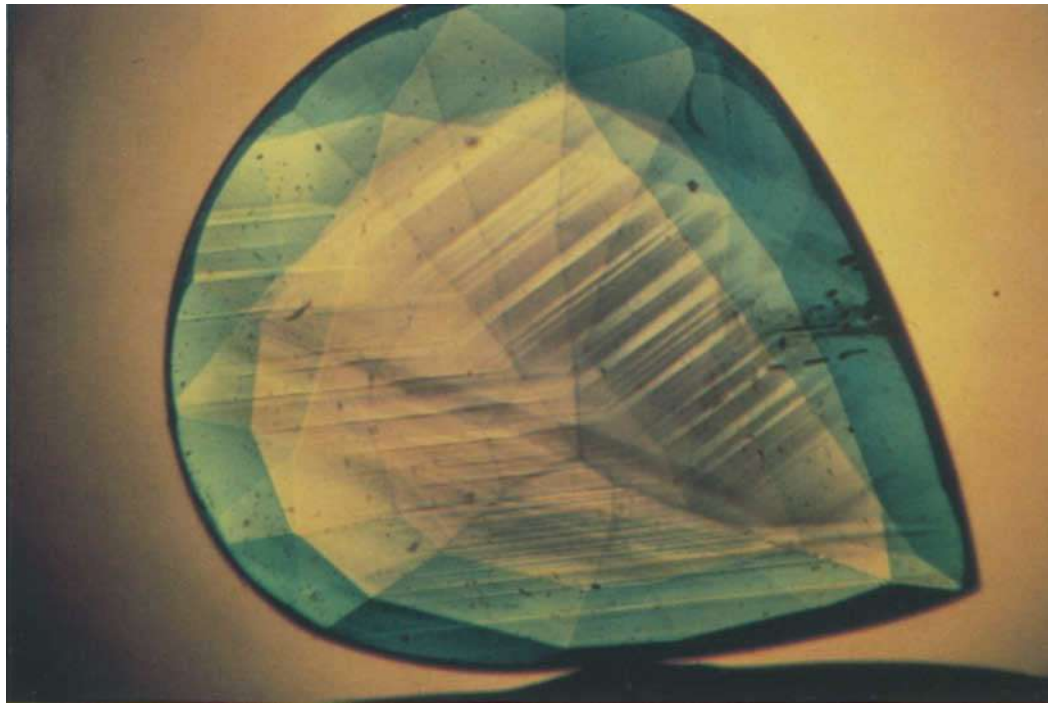

Fig. 18. Type I sapphire from Madagascar showing colour zoning related to the forms *r* and *n*. View inclined approximately 30° to the *c*-axis. Immersion, magnification 30x.

immersion, the brown areas appear white due to scattering of light by the small particles. In general, the thin brown stripes are orientated parallel to one single crystal face (Figures 21a and b, 22), but sapphires with brown stripes parallel to two or three crystal faces were also observed (Figure 23). These thin brown stripes were apparently formed by oscillating growth of one of the dominant faces such as *c*, *r*, *n*, *w*, *v*, and *z* with subordinate faces, which are not present macroscopically in this type of sapphire. Occasionally, this subordinate face was identified as the prism *a* (11$\bar{2}$0), and in

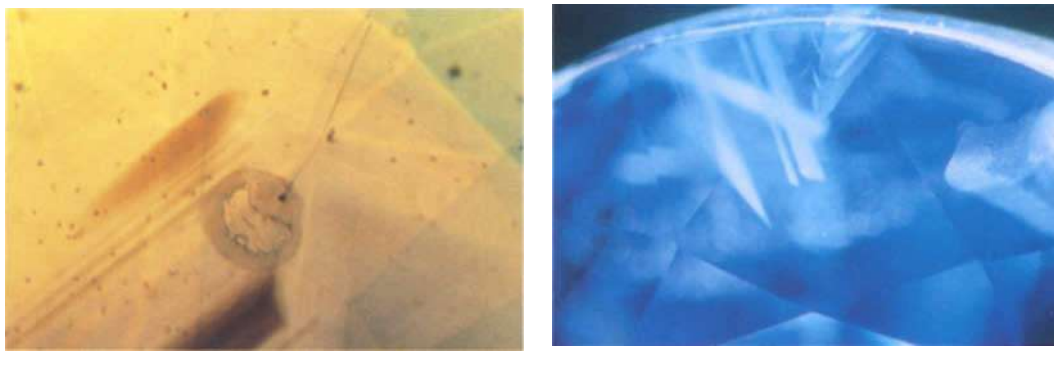

Fig. 21. (a) Parallel brown stripes in type I sapphire from Madagascar. At the centre of the photo is a tiny apatite crystal surrounded by a two-phase liquid/gas rosette, with the gaseous component in the centre of the rosette. Immersion, magnification 60x. (b) Similar stripes appearing white in reflected dark-field illumination. Magnification 30x.

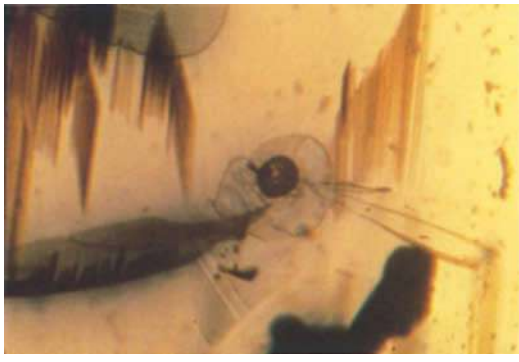

Fig. 22. Parallel brown stripes in type I sapphire from Madagascar. The centre of the photo shows a rounded calcite crystal with rosette-like fissure. Immersion, magnification 50x.

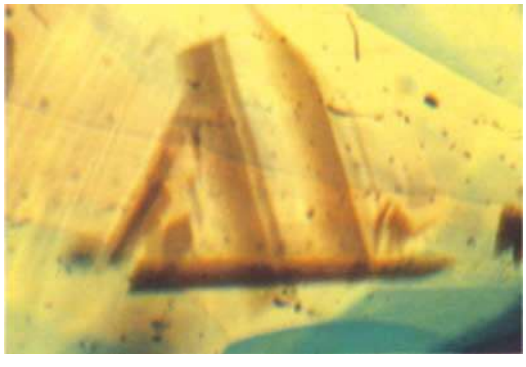

Fig. 23. Brown stripes parallel to three different growth planes in type I sapphire from Madagascar. Immersion, magnification 50x.

one crystal brown stripes were confined by the dominant dipyramid *n* (2243) and located in a growth area of a subordinate dipyramid *o* ($2\bar{2}45$). In all cases, the brown stripes were related to the growth area of the subordinate face e.g. parallel to *a* and *o*.

Twinning was not commonly observed in any of the examined sapphires.

Inclusions: Untreated as well as heat-treated type I sapphires from Madagascar frequently show rounded apatite crystals with rosette-like liquid/gas feathers (Figure 21a), which were determined with Raman Spectroscopy (RS) in the majority of the analysed samples. Further, calcite crystals with rosettes were also identified in some sapphires (Figure 22). Four calcite crystals which could be found on the surface of broken crystals were also identified by XRD. Typical solid inclusions in type I sapphires are therefore apatite, calcite, and small brown particles in cores and stripes. On the surface of a rough crystal which showed the basal pinacoid *c* and the negative rhombohedron *r* as dominant crystal faces, dark green spinel inclusions were identified by Raman Spectroscopy (Figure 24). Spinel was also identified in the host rock by SEM.

Healed feathers are commonly present in heat-treated and untreated stones (Figure 25). Some of the heat-treated sapphires obtained from the trade also show fissures with an unidentified foreign substance, which spreads into the fissures with a dendritic pattern (Figure 26).

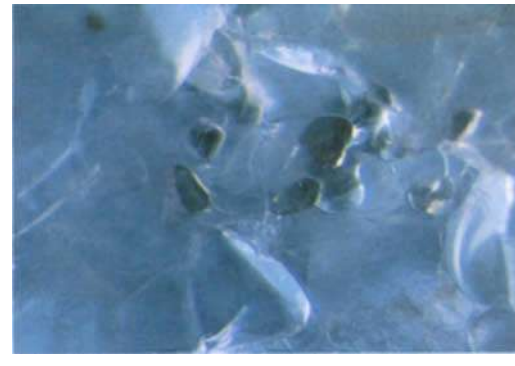

Fig. 24. Spinel inclusions on a broken surface of a type I sapphire from Madagascar. Magnification 30x.

Fig. 25. Healed feather in sapphire from Madagascar. Immersion, magnification 50x.

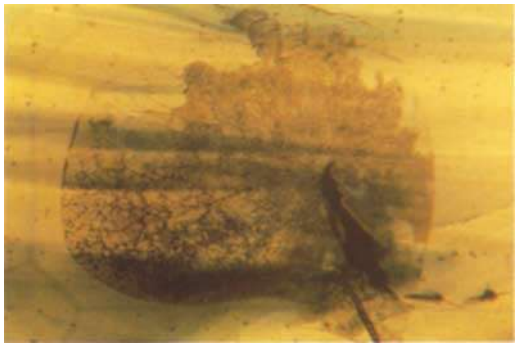

Fig. 26. Dendritic substance in healed feather in a heat-treated sapphire from Madagascar. Immersion, magnification 40x.

Similar looking patterns in emerald have been identified previously in the SSEF laboratory as organic fillers.

Type II sapphires (prismatic habit)

Growth structures and colour zoning: The crystals with prismatic habit possess an intense colour zoning with a dark blue core and a lighter blue outer zone (see Figure 12). There is a distinct boundary between the dark blue core and the light blue rim, which is generally orientated parallel to the hexagonal prism *a* $(11\bar{2}0)$, or occasionally in combination with the positive rhombohedron *r*. The core often shows narrow colour banding parallel to the basal pinacoid *c*. In some of the cores of this type of sapphire uniform dark blue trigonal pyramidal areas are observed which are terminated by the basal plane *c* and the rhombohedral faces. Within the rim colour zoning was observed parallel to the basal plane and to the prism faces. More complex zoning is also present and visible in oblique dark-field illumination.

Inclusions: Sapphires of the prismatic type frequently contain well rounded apatite crystals (RS) as solid inclusions accompanied by tubes (Figure 27). From their distribution (Figure 28) it is obvious that the apatite crystals were included first, and then subsequently, when the host sapphire continued growing, the tubes were formed in a direction perpendicular to the growth front (i.e. the prism face). Healed feathers were also observed in this type of sapphire. The contents of the tubes and the whitish substance forming striations on the basal planes of the rough crystals await identification.

Type III sapphires (distorted tabular to short-prismatic-dipyramidal habit)

Growth structures and colour zoning: This type of sapphire reveals a distinct growth and colour zoning parallel to the external growth planes. Blue and colourless zones alternate in narrow bands mostly parallel to the basal plane. Three different growth patterns were observed: (a) the whole stone shows thin alternating colour zones (Figure 29); (b) the centre of the crystal is

Fig. 27. Rounded apatite crystals with subsequent tubes in type II sapphires from Madagascar. Magnification 40x.

Fig. 28. Small rounded apatite crystal with a tube extending perpendicular to prismatic growth planes in type II sapphire from Madagascar. Immersion, magnification 50x.

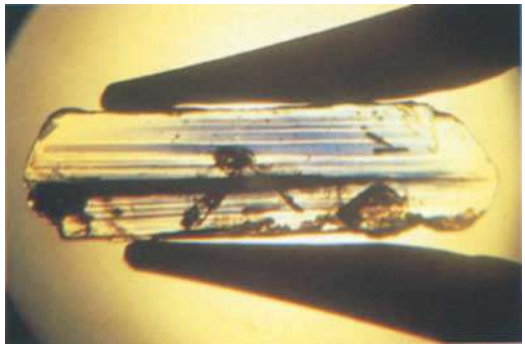

Fig. 29. Colour zoning parallel to the basal plane in type III sapphire from Madagascar showing a dark blue stripe in the centre. View perpendicular to the *c*-axis, the *c*-axis runs vertically. Immersion, magnification 20x.

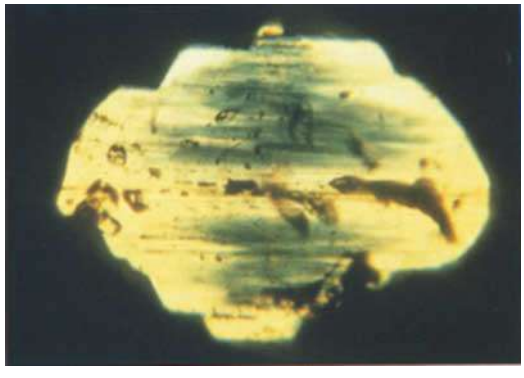

Fig. 30. Colour zoning with a colourless centre in type III sapphire from Madagascar. View perpendicular to the *c*-axis, the *c*-axis runs vertically. Immersion, crossed polarizers, magnification 25x.

more or less colourless and narrow alternating colour zones occur only at the basal pinacoid rim (Figure 30); and (c) the centre of the crystal shows alternating light blue to colourless banding while the outer zones are colourless.

In half of the stones, one additional extremely dark coloured layer parallel to the basal plane, which runs through the centre of the crystal, was observed (Figure 29). This thin colour zone gives the sapphires a medium blue colour when viewed parallel to the optic axis, even when the main body of the crystal is almost colourless. In addition to these different types of zoning parallel to the basal pinacoid *c*, colour zoning with alternating light blue to colourless areas was also observed parallel to other crystal faces, e.g. parallel to the prism *a* and/or parallel to dipyramidal faces.

Inclusions: These sapphire crystals often contain three-phase inclusions, which are oriented parallel to the basal faces. Due to improved analytical techniques, three-phase inclusions such as shown in Figure 31 can now be analysed on a non-destructive basis by Raman spectroscopy. The Raman spectra revealed that these inclusions consist of liquid and gaseous CO_2 and diaspore needles (Figure 31). Figure 32 shows a combined Raman spectrum of all phases contained in the inclusion. Similar inclusions have already been described in sapphires from Sri Lanka (Schmetzer and Medenbach, 1988). Flat calcite crystals with corroded edges (Figure 33), identified by Raman spectroscopy, are also oriented parallel to the basal plane of the sapphires. Other birefringent mineral inclusions (Figure 34) were identified as apatite and zircon by XRD and Raman spectroscopy.

Chemical composition

Qualitative chemical analyses by EDS-XRF of a range of samples from all three types

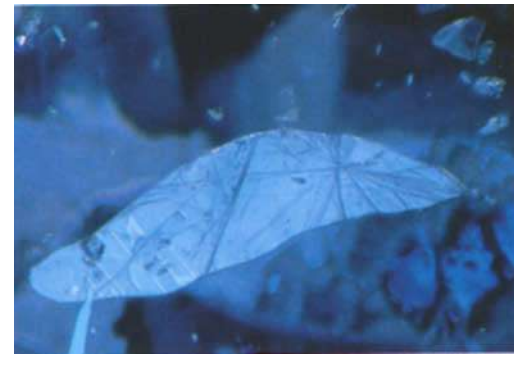

Fig. 31. Three-phase inclusions in type III sapphire from Madagascar oriented parallel to the basal plane and showing liquid and gaseous CO_2 and diaspore needles. View parallel to the *c*-axis. Magnification 50x.

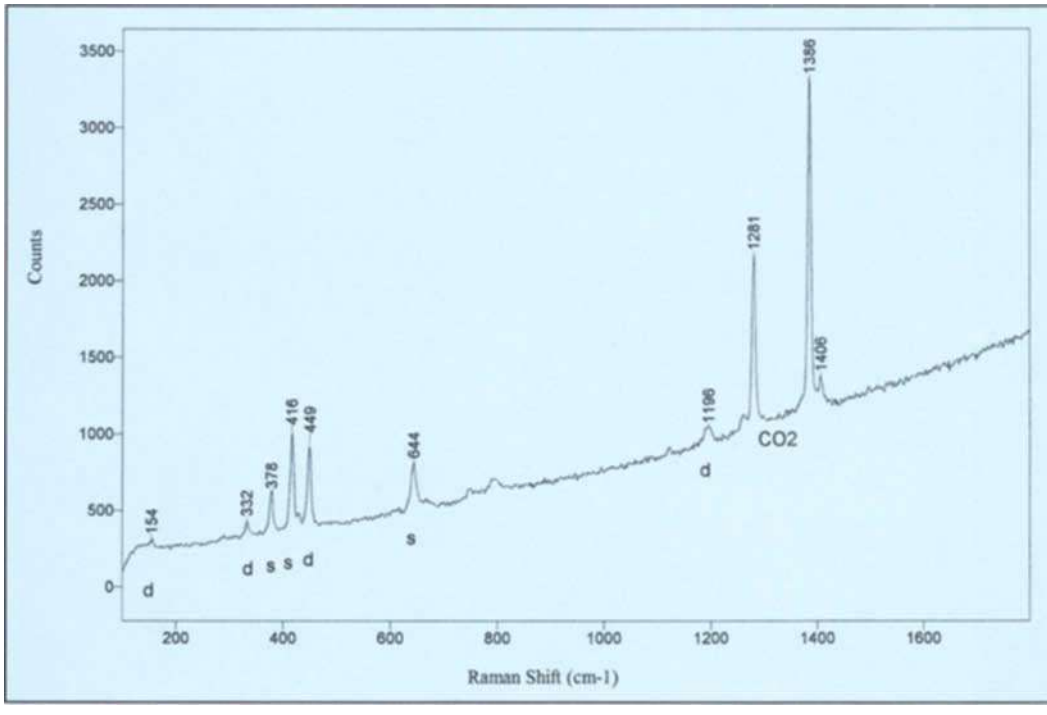

Fig. 32. Raman spectra of the phases in a three-phase inclusion in type III sapphire from Madagascar. The peaks are assigned to corundum (s), diaspore (d) and liquid and gaseous CO_2, and were obtained from a Renishaw Raman system.

of Madagascar sapphires show different bulk contents of the trace elements Fe and Ti. Differences in Fe- and Ti-concentrations were observed in detail between darker and lighter blue zones of macroscopically colour zoned samples, e.g. between a dark blue core and light blue rim of a type II sapphire (Figure 35). Distinct differences in different coloured areas have also been described from rubies from Mong Hsu, Myanmar (Peretti *et al.*, 1995). In order to quantify the chemical variations, 13 stones (8 of type I, 1 of type II and 4 of type III) were microscopically selected to cover the

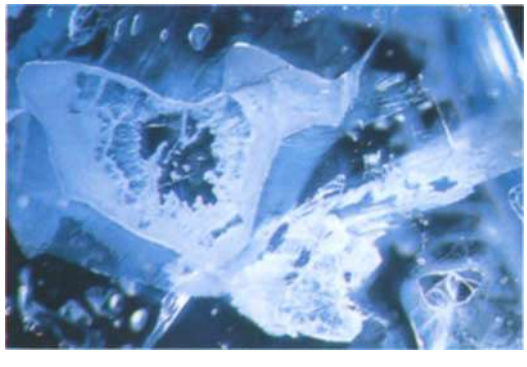

Fig. 33. Flat inclusion with calcite crystals parallel to the basal plane in a type III sapphire from Madagascar. View parallel to the *c*-axis. Magnification 40x.

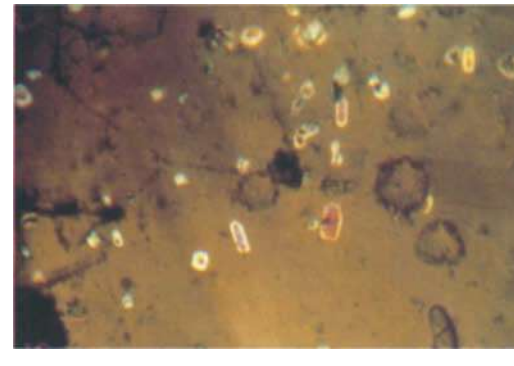

Fig. 34. Birefringent apatite inclusions in type III sapphire from Madagascar. Immersion, crossed polarizers, magnification 50x.

Table I: Chemical composition of sapphires from Madagascar

Sample number	*Sample description*	*Number of analysis points*	*Weight % oxides* Al_2O_3	V_2O_3	Cr_2O_3	MnO	Fe_2O_3	TiO_2
S1 (type I)	fine complex colour zoning, faceted, table ‖ basal plane, heat-treated	50	98.5–99.4	0.01–0.03	0.00–0.02	0.00–0.02	0.18–0.24	0.07–0.20
S4 (type I)	fine complex colour zoning, faceted, table ‖ basal plane, heat-treated	50	98.3–99.5	0.00–0.03	0.00–0.02	0.00–0.02	0.15–0.29	0.05–0.10
S9 (type I)	fine complex colour zoning, faceted, table ‖ basal plane, heat-treated	50 + 50	98.9–99.5	0.00–0.03	0.00–0.03	0.00–0.02	0.11–0.23	0.05–0.25
S20 (type I)	fine complex colour zoning, faceted, table ⊥ basal plane, heat-treated	50 + 50	98.5–99.3	0.01–0.03	0.00–0.02	0.00–0.02	0.43–0.62	0.03–0.16
H1.88 (type I)	faceted with dark blue core, lighter blue rim, table ‖ basal plane, heat-treated	29 (dark blue) 71 (lighter blue)	98.4–99.6	0.00–0.03	0.00–0.03	0.00–0.02	0.22–0.29 0.11–0.15	0.10–0.14 0.02–0.06
S27 (type I)	faceted with dark blue core, lighter blue rum, table ‖ basal plane, heat-treated	40 (dark blue) 10 (lighter blue)	98.7–99.4	0.00–0.03	0.00–0.02	0.00–0.02	0.31–0.40 0.24–0.26	0.05–0.10 0.04–0.06
S5 (type I)	faceted with brown core and blue rim, table ‖ basal plane, heat-treated	5 (brown) 45 (blue)	98.2–99.7	0.00–0.03	0.00–0.03	0.00–0.01	0.25–0.28 0.22–0.29	0.10–0.13 0.04–0.09

Table I: Chemical composition of sapphires from Madagascar (*Continued*)

Sample number	*Sample description*	*Number of analysis points*	*Weight % oxides* Al_2O_3	V_2O_3	Cr_2O_3	MnO	Fe_2O_3	TiO_2
S7 (type I)	faceted with brown core and blue rim with brown stripes, table ‖ basal plane, heat-treated	15 + 3 (br. core) 1+1+1 (br. stripe) 36 + 46 + 49 (blue)	98.4–99.7	0.01–0.03	0.00–0.02	0.00–0.02	0.28–0.34 0.26–0.29 0.24–0.33	0.09–0.15 0.22–0.27 0.04–0.09
H1 (type II)	rough piece, dark blue core and light blue rim, polished ‖ basal plane	12+20 (dark blue) 36+80 (light blue)	98.4–99.8	0.01–0.03	0.00–0.01	0.00–0.01	0.20–0.23 0.13–0.18	0.06–0.08 0.01–0.06
H3 (type III)	rough crystal, light blue core and colourless rim, polished ‖ basal plane	100+90	98.1–100.2	0.01–0.03	0.00–0.03	0.00–0.02	0.30–0.54*	0.00–0.04
H5 (type III)	rough piece, almost colourless	100+100	98.5–99.8	0.00–0.03	0.00–0.03	0.00–0.02	0.22–0.32	0.00–0.03
H2 (type III)	rough crystal, very intense blue layer ‖ c and almost colourless rim, polished ⊥ basal plane	2 (intense blue) 48+50 (colourless)	98.1–99.5	0.01–0.03	0.00–0.02	0.00–0.02	0.77–0.86 0.33–0.45	0.23–0.24 0.01–0.04
H4 (type III)	rough crystal, very intense blue layer ‖ c, almost colourless rim, polished ⊥ basal plane	2+3 (intense blue) 47+47 (colourless)	98.1–99.5	0.01–0.03	0.00–0.02	0.00–0.02	0.67–0.97 0.39–0.47	0.13–0.22 0.01–0.03

* Fe_2O_3 was somewhat higher in the light blue core compared to the almost colourless rim.

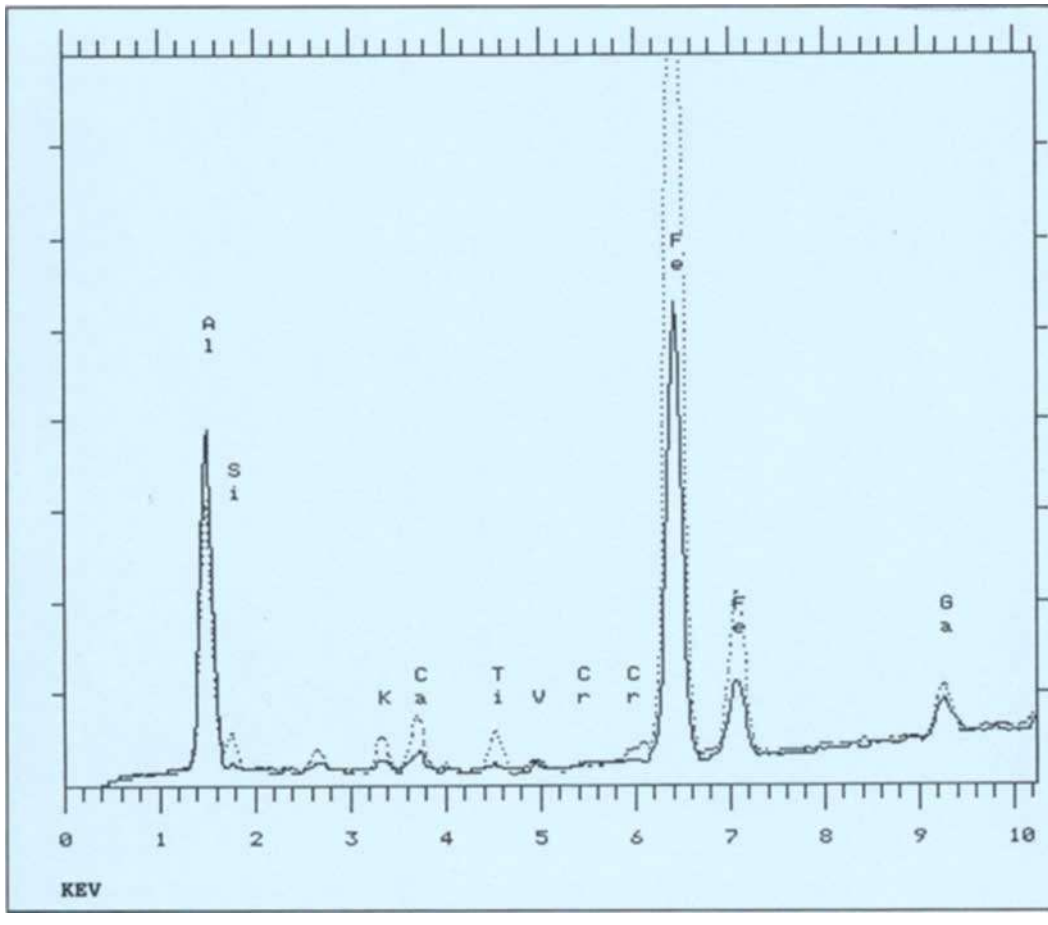

Fig. 35. Energy-dispersive X-ray fluorescence spectrum showing the chemical composition of a type II sapphire from Madagascar. Solid line, light blue prism face representing the rim of the crystal; dotted line, dark blue basal pinacoid representing the core.

different types of colour zoning and quantitatively analysed by electron microprobe. Between one and three traverses of 50 to 100 point analyses each were measured across the differently coloured areas of the samples. These analyses showed a marked zoning of Fe and Ti in all three types of stones, while the other elements showed a common range within differently coloured zones (Table I).

Type I sapphires (dipyramidal to barrel-shaped habit): The sapphires of Type I could be subdivided into three groups: 4 stones (samples S1, S4, S9 and S20) show a fine and, in places, an extremely complex colour zoning; 2 stones (samples H1.88 and S27) have dark blue cores with lighter blue rims; and 2 stones (samples S5 and S7) have brown cores with blue rims. One of the latter two stones also shows brown stripes in the rimming area around the blue core where some of the stripes were cut by the table of the faceted stone.

The samples with complex colour zoning show a wide range of Fe_2O_3 and especially of TiO_2 concentrations. Fe_2O_3 concentrations vary from a minimum of 0.11 wt.% in the lighter zones of the sample to a maximum of 0.62 wt.% in the darker blue zones of the sample. TiO_2 values range

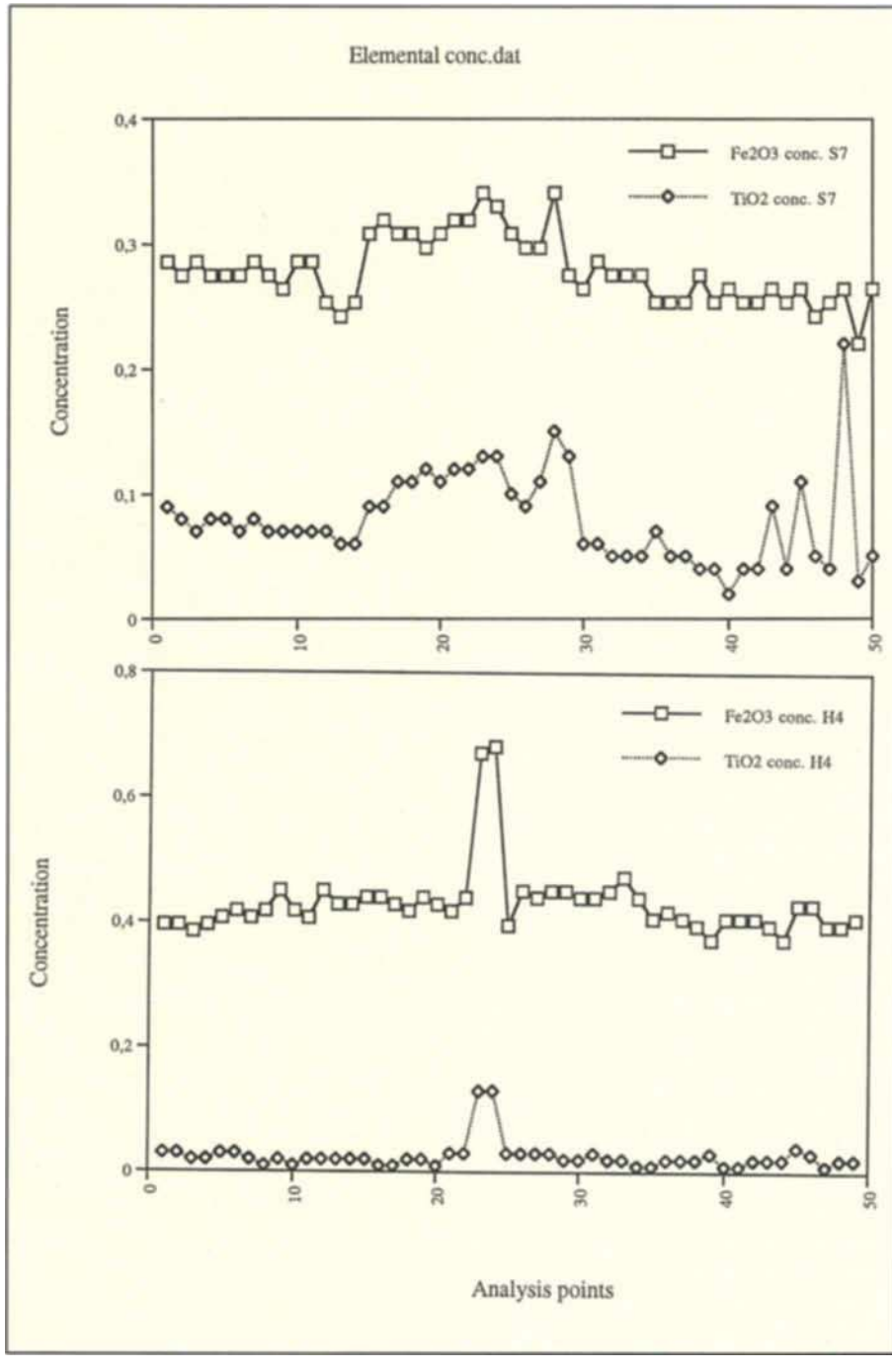

Fig. 36. Fe_2O_3 and TiO_2 contents of sapphires in traverses across colour zones: (a) type I sapphire: higher Fe_2O_3 and TiO_2 values are present in the brown core area, between analysis point No. 15 and 30. Analysis points 43, 45 and 48 show extremely high TiO_2 contents which are coincident with brown stripes in the rim of the stone; (b) type III sapphire: higher Fe_2O_3 and TiO_2 contents were measured across a thin, extremely dark blue stripe (analysis points 23 and 24).

from 0.03 to 0.25 wt.% in comparable zones (Table I).

The two samples with dark blue cores and lighter blue rims both contain higher Fe_2O_3 and TiO_2 in the darker cores compared to the lighter blue rims (Table I). While darker blue areas in the samples mentioned above are characterized by both higher Fe_2O_3 and TiO_2 values, the brown areas (cores and stripes) and blue rims of samples S5 and S7 show only minor differences in Fe_2O_3 content but there are marked differences in TiO_2 values (Table I and Figure 36a). The highest difference in TiO_2 content was found in the brown stripe outside the core which was high compared to that of the surrounding blue area (Table I). The high TiO_2 values are an indication that the composition of the fine particles is probably rutile, i.e. the brown zones with mineral dust are likely to contain extremely small rutile crystals.

Type II sapphires (prismatic habit): Only one of the type II sapphires (sample H1) was available for quantitative chemical analysis. The sample shows slightly higher values of both Fe_2O_3 and TiO_2 in the dark blue core compared to the outer light blue areas (Table I), which is in agreement with the qualitative chemical analyses (Figure 35).

Type III sapphires (distorted tabular to short-prismatic-dipyramidal habit): Sapphires of type III are characterized by medium Fe_2O_3 and very low TiO_2 concentrations in the lighter blue and almost colourless areas (samples H2, H3, H4 and H5). The very intense dark blue, extremely thin layers parallel to the basal pinacoid through the centres of the crystals show relatively high Fe_2O_3 concentrations (up to 0.87 wt.%), and TiO_2 concentrations are higher in these bands when compared to the dark blue areas of type I and II sapphires (Table I). Figure 36b shows the distribution of Fe and Ti content in a traverse through a sapphire with a dark blue stripe. In all three types of sapphires from Madagascar distinct amounts of Ga_2O_3 are present.

Spectroscopic data

Visible and ultraviolet (UV) spectroscopy. During the course of the study, UV-VIS spectra of 25 rough and three faceted sapphires were recorded. The rough, untreated samples show one common type of spectrum in the visible and UV range which can be considered characteristic for this occurrence. The Fe^{2+}/Ti^{4+}absorption bands resemble the ones observed in sapphires from Myanmar, Sri Lanka, Umba, Tanzania or Kashmir, all sapphires from pegmatitic or metamorphic sources (Figure 37a; see also Schmetzer and Kiefert, 1990). The absorption edge lies between 340 and 325 nm, which is a higher wavelength than usual for sapphires from metamorphic origins (see also Hänni, 1994). Violet stones show a distinct Cr^{3+}-component, which is superimposed on the blue sapphire spectrum.

Figure 37b shows a spectrum of a so-called geuda-type sapphire before heat-treatment. The sample shows a low Fe^{2+}/Ti^{4+}absorption, but bands in the Fe^{3+} area and the absorption edge are similar to the spectrum shown in Figure 37a. The spectra of heat-treated sapphires differ distinctly from untreated samples (Figure 37c). After heat treatment, the absorption spectra reveal a strong Fe^{2+}/Ti^{4+} absorption and a significant change in the 500 to 300 nm range. The Fe^{3+}absorption bands become very low and the absorption edge is stifled to a range below 300 nm. The low intensity of Fe^{3+}absorption bands in heat-treated samples may be explained by the conversion of trivalent iron to bivalent iron in connection with the dissolution of rutile particles as described by Schmetzer and Kiefert (1990). Absorption spectra of this type have so far been considered typical for heat-treated Sri Lankan sapphires (Schmetzer and Kiefert, 1990; Hänni, 1994).

Infrared spectroscopy: IR spectra of sapphires from Madagascar do not show the sharp OH-absorption lines in the 3000 to 3500 cm^{-1} range observed in some other corundum, e.g. in rubies from Mong Hsu,

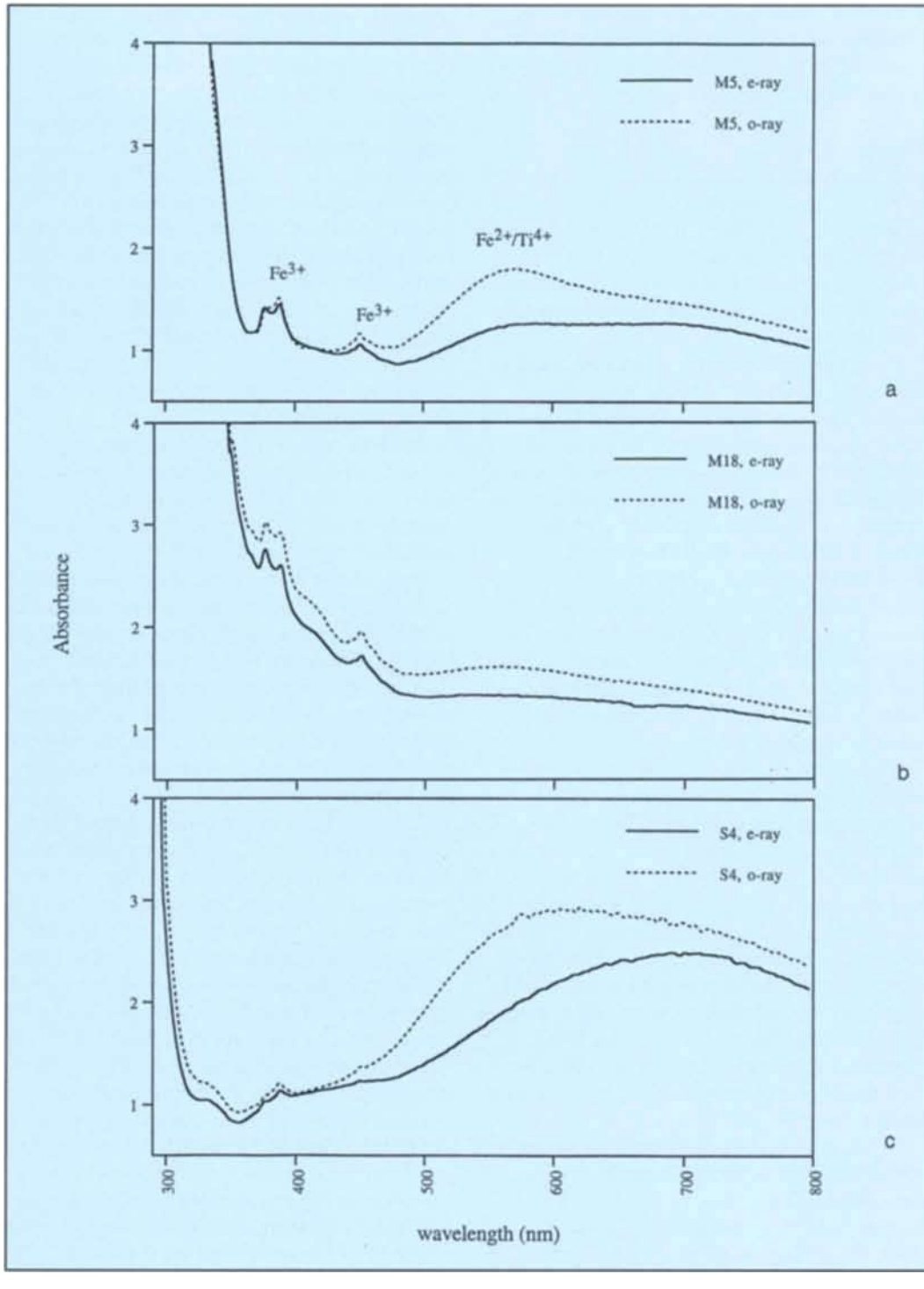

Fig. 37. UV-VIS spectra of sapphires from Madagascar: (a) untreated type II sapphire; (b) untreated type I sapphire (geuda-type); (c) heat-treated type I sapphire.

Myanmar (Peretti *et al.*, 1995; Smith, 1995). The samples only show the two absorption lines at 2930 and 2855 cm^{-1}, which are typical for corundum.

Conclusions

Sapphires from Madagascar show a variety of properties, most of which are also observed in sapphires from other deposits. A certain number of characteristics are, however, diagnostic for sapphires of the new deposit near Andranondambo, southern Madagascar.

The growth structures observed allow a division into three different types of stones. The first type is dipyramidal to barrel-shaped. Sapphires with this habit are observed at many other sapphire localities, e.g. Sri Lanka and Australia, while the second type with prismatic habit is frequently found in Montana, USA (Kiefert, 1987). The third type of sapphire from Madagascar varies in its morphology and consists mostly of distorted crystals which are formed of a prominent basal pinacoid and narrow dipyramidal and prismatic faces. Some of these crystals may also exhibit a scalenohedron.

Sapphires of all three types show strong colour zoning reflecting important fluctuations of growth conditions during the formation of the crystals. This colour zoning may be blocky and show a colourless core and blue rims, or a dark blue or brown core and light blue rims. Narrow colour zoning, sometimes irregular, is also present. Some of the colour zoning observed in cut stones may resemble colour zoning from Kashmir sapphires (Hänni, 1990), Vietnam sapphires (Smith *et al.*, 1995) or Sri Lankan sapphires (Kiefert, 1987; Kiefert and Schmetzer, 1991b).

Type I sapphires are the most abundant of the three types. Some contain fine particles, most likely rutile, in areas which appear brown in transmitted light, and these brownish areas may form the core or some small banded growth structures in the outer areas. This feature, especially the relation of the brown stripes to subordinate growth areas, can be considered as diagnostic for Madagascar sapphires. Although similar brown growth zones are also found in Sri Lankan sapphires, the brown areas in Sri Lankan sapphires are, however, always related to dominant growth zones. Diagnostic growth features of type II sapphires may be the dark blue cores confined by the hexagonal prism *a* and the basal pinacoid *c*, and, less commonly, the positive rhombohedron *r*. Type III sapphires generally contain extremely dark blue thin stripes, mostly parallel to the basal pinacoid *c*.

Solid inclusions in type I Madagascar sapphires are mainly calcite and apatite; the latter are commonly altered during heat treatment and surrounded by rosette-like feathers. The prismatic-type sapphires frequently show well rounded apatite crystals with hollow tubes extending perpendicular to the prismatic growth planes. Sapphires of type III contain apatite, zircon, and abundant three-phase inclusions or flat calcite crystals parallel to the basal plane. Similar three-phase inclusions with liquid and gaseous CO_2 and diaspore also occur in Sri Lankan sapphires.

The Madagascar sapphires contain a range of Fe_2O_3 and TiO_2 contents which cause different types of colour zoning and a variety of spectroscopic features. Light blue areas are generally low in Fe_2O_3 and TiO_2, while the dark blue areas show high Fe_2O_3 and TiO_2 contents. The brown cores and stripes contain Fe_2O_3 values almost comparable to the dark blue areas, but TiO_2 is enriched in these areas. The data observed lie within the range of compositions of sapphires from metamorphic origins and origin determination based only on chemical composition is not reliable unless other diagnostic features, such as the scalenohedron face, brown (resp. whitish) areas, or apatite crystals with tubes, can be taken into account.

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Goodletite – a beautiful ornamental material from New Zealand

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Abstract

Goodletite is an informal name used in New Zealand to describe a rare rock, of undetermined origin, that is found as small alluvial cobbles and pebbles in the gold-bearing alluvial gravels of rivers that drain the Westland district of the South Island of New Zealand. It is a greyish-green mottled ornamental rock consisting of a mixture of ruby (that in places grades into blue sapphire) and pinkish-grey corundum in a fine-grained greyish-green matrix of green tourmaline and translucent chrome-rich green micas. The literature is reviewed and the gemmological properties of goodletite are given.

Keywords: goodletite, New Zealand

Introduction

A collector of rare and exotic gem materials or a New Zealand gemmologist might be familiar with the existence of a rare and attractive New Zealand ornamental material called goodletite. A measure of goodletite's rarity is that for over a century after its discovery a comprehensive gemmological description of this ornamental rock has not been available.

Goodletite, sometimes called locally 'ruby rock' or 'treasure stone', is a rare ultrabasic rock that displays considerable potential as an ornamental material. When slabbed or carved its polished surfaces can be attractively patterned by a random mosaic of pink to purplish-red, pinkish-grey and occasional blue areas that contrast strongly with the dark greyish-green to green matrix of this rock (Figures 1 and 2).

Fig. 1. Sawn slab of New Zealand goodletite.

Goodletite in the literature

A literature search for previous descriptions of goodletite was not particularly rewarding. Older textbooks of gemmology such as Bauer's two volume *Precious stones* (1896),[1] Smith's *Gemstones* (1912),[2] Weinstein's *Precious and semi-precious stones* (1929),[3] and Spencer's *A key to precious stones* (1946),[4] failed to mention this material. However, in the Glossary [of unusual names] of the first (1962) edition of *Gems*, Robert Webster[5] did define goodletite as 'Marble forming the matrix of rubies (Burma)'. An attempt at tracing the source of Webster's definition by searching the available literature on the occurrence of ruby in Burma failed to find any reference to goodletite.

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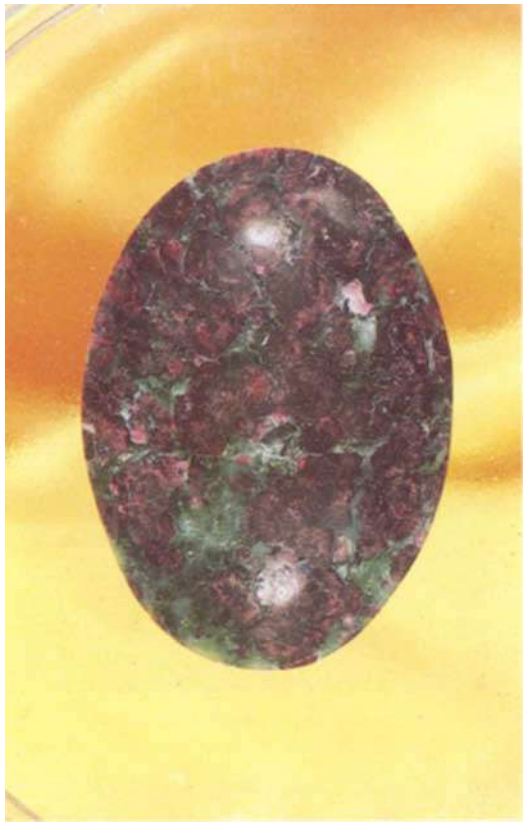

Fig. 2. Cabochon of New Zealand goodletite weighing 27.94 ct.

One of the few books published on the gemstones of New Zealand, L. and R. Cooper's *New Zealand gemstones* (1966),[6] was equally uninformative with respect to goodletite. However, the third (1967) edition of W.M. Campbell's *Minerals and gems of Maoriland*[7] contains the following entry on goodletite:

'Ruby: real ruby, dark red, H 9, SG 4, is found with dark green olivine crystals in goodletite or "treasure rock" at Rimu Flat, Westland. It is small and fragmentatious. Sir James Hector thought better quality awaited finding.'

However, a description of goodletite by A. Neithe, in B. Myatt's 1972 publication *Australian and New Zealand gemstones: how and where to find them*[8] stated that goodletite was:

'... not good lapidary rock because of the variable hardness of its composition, but its extreme rarity makes it a highly desired mineral specimen ... goodletite is so rare that it is not sold by any of the dealers, but is sometimes traded by fortunate owners.'

In addition Neithe suggested that goodletite was a rock which was formed from ruby and sapphire in a matrix of chrome mica (fuchsite) and tourmaline, but had never been found *in situ*. Instead, it is recovered 'as fragments' from gold sluicings at Rimu Flat, south of Greymouth on the west coast, in the rugged mountains to the east and in Whitcombe Pass (through which the Whitcombe River flows) (see Figure 3).

Further information on goodletite was obtained from Minerals of New Zealand, *New Zealand Geological Survey Bulletin*, **104**, 1990.[9] Railton and Watters state on p.53 that goodletite is an informal name given to a rock found as boulders at Rimu, Kaniere and Kaniere Forks (Westland), but not found *in situ* (see Figure 3). This attractively patterned rock also has been recorded as occurring in boulders of muscovite-serpentine rock at Olderog Creek, Arahua Valley (see Figure 3). In addition, Figure 34 (p.18) of *Bulletin* **104** illustrates a petrological thin section of goodletite (from a boulder in Whitcombe River, Westland). The caption of this colour photomicrograph states that the constituent minerals of goodletite are ruby grading into blue sapphire, green tourmaline and chromium-bearing muscovite.

A check of references cited in *Bulletin* **104** revealed that in Bell and Fraser's 1906 paper,[10] ruby rock, then already known as goodletite, had been found as loose boulders in the gold-bearing drifts of Rimu, Kaniere and Kaniere Forks, and in the Whitcombe Valley. Apparently a search had failed to locate any outcrops of the rock, so the authors postulated that it had been derived from serpentines located in the catchment area of the Hokitika River (see Figure 3).

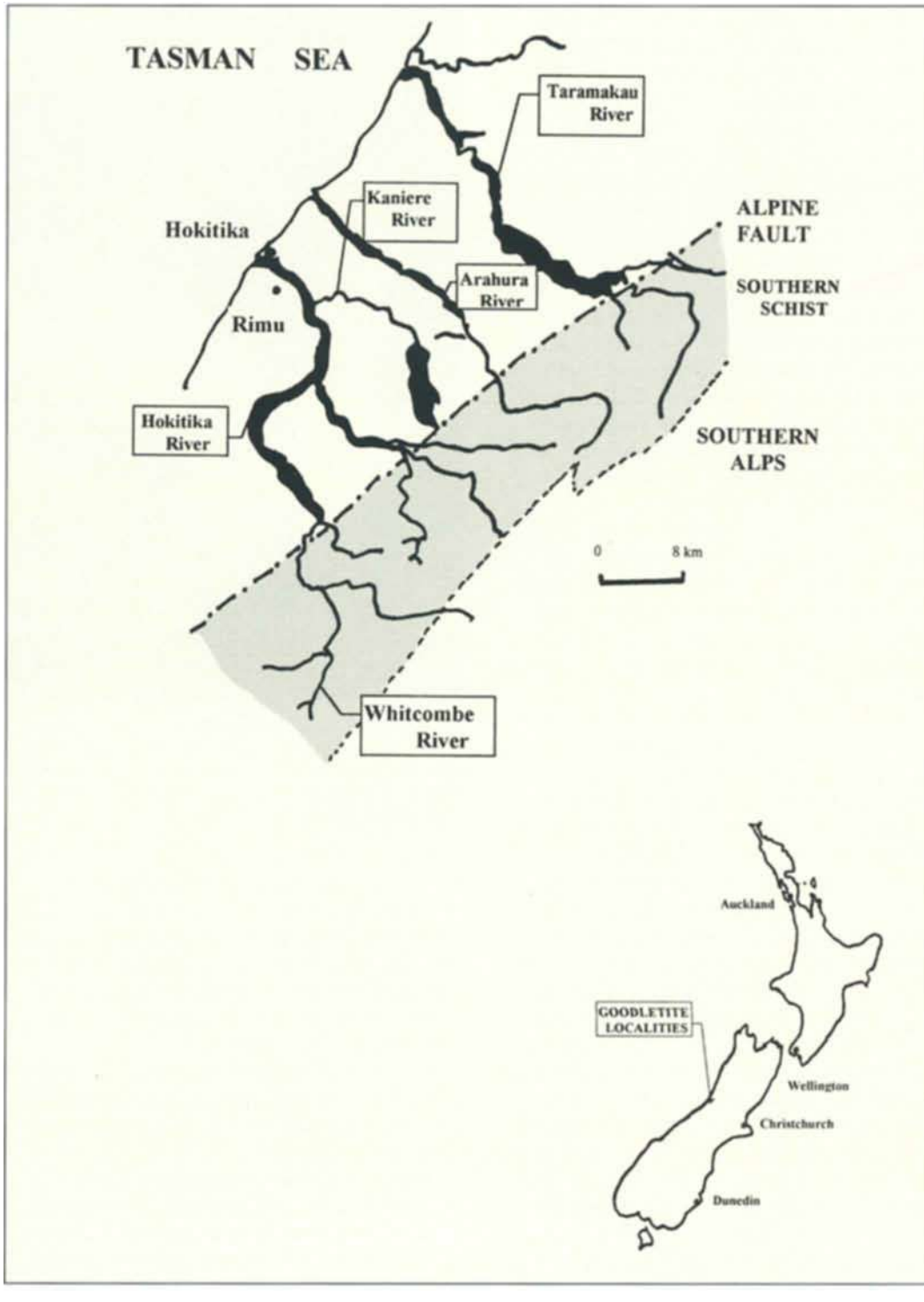

Fig. 3. Localities from which goodletite has been recovered (after Warren. G. (1967), Sheet 17, Hokitika[18]]

According to the same authors,[10] the first specimen of goodletite was obtained in 1891 by a geologist named A. McKay. According to McKay, [11] it was he who first submitted the rock for identification to the then Colonial Analyst William Skey. Subsequently Skey informed McKay that the rock contained ruby. Unfortunately (for McKay) the results of this analysis were never published.

Some time later William Goodlett, then a Laboratory Assistant in the Department of Geology, took specimens of this rock to Professor Ulrich, Professor of Geology at Otago University, Dunedin. Ulrich determined that the rock contained 'oriental rubies of fine colour', and it is likely that goodletite was named for William Goodlett (H.N. Jacobs, 1987).[12]

In 1908 Morgan[13] described the 'ruby rock' as dark green chrome mica and altered olivine containing fractured ruby that occasionally graded into blue sapphire. Morgan also suggested that the Hokitika Glacier was a possible transporter of the 'ruby rock'.

In 1976 Campbell[14] was well aware of the occurrence of ruby in green micaceous margarite and fuchsite at Rimu Flat (Hokitika), Kaniere Forks and Olderog Creek in Whitcombe Valley, but he did not identify the rock as goodletite.

Some eighty years after the first chemical analysis of goodletite was published, Mason[15] indicated that goodletite was a rock consisting of 'granular red and blue corundum intergrown with a green mica' that was 'a fine grained mixture of margarite and muscovite'. Mason's analysis was based on 'a fist-sized piece collected some years ago from the Rimu dredge tailings near South Beach, Hokitika' and he made no mention of the presence of green tourmaline in this rock. The specific gravity of 3.54 suggested to Mason that the rock consisted of about 70 per cent corundum and 30 per cent mica. In thin section, microprobe analyses of the corundum revealed Cr_2O_3 contents ranging from 0.93–3.36 wt % (mean 1.85 wt %), Fe_2O_3 contents of 1.0–2.0 wt %, and TiO_2 contents of 0.2–0.3 wt %. Mason further postulated that the rock originated from the Haast (Southern) Schist in probable association with the chromium-containing Pounamu Ultrabasics (see Figure 3).

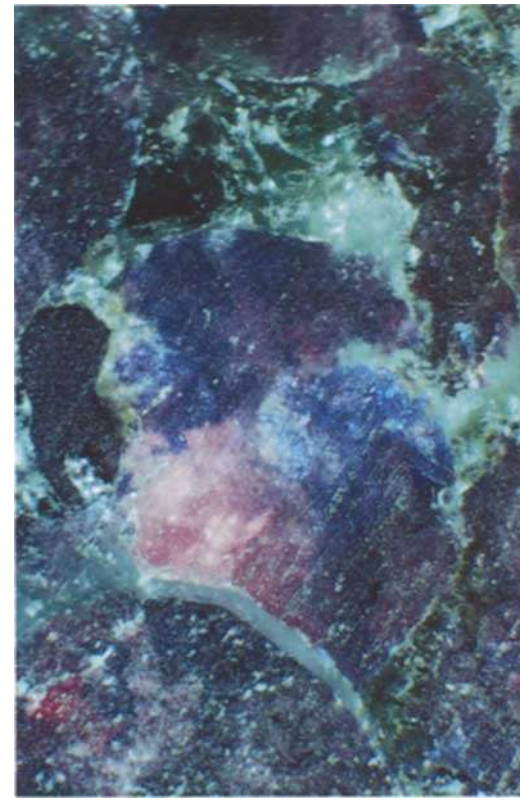

Fig. 4. Hand lens characteristics of goodletite illustrating an anhedral grain of ruby-blue sapphire and anhedral grains of corundum in a matrix probably consisting of a mixture of green chrome-rich micas and tourmaline.[17] Magnification 20×.

In response to Mason's paper, two New Zealand geologists, Grapes and Palmer, represented data in an article 'Goodletite further re-examined'.[16]

The authors' analyses showed that goodletite was a chrome-rich metasomatic rock, with a bulk rock content of 1.49 wt % Cr_2O_3. The rock was formed from green Cr-margarite, green Cr-muscovite, green tourmaline with a content of 1.9 wt %

Table I: Gemmological properties of goodletite	
Colour	Variegated, having a random pattern of dark pinkish-grey, pink, red, purplish and blue grains that are surrounded by anastomosing veins of light to dark green matrix.
Hardness (Mohs)	Variable: grey, purple or blue patches (9), green to greyish matrix (6 to 3). Polished surfaces undercut due to the comparative softness of the micaceous matrix.
Degree of transparency	Opaque
Lustre	Waxy
Specific gravity	3.53
'Spot' refractive index	Three relatively indistinct 'spot' refractive indices of 1.74, 1.64 and 1.57 were obtained from various areas on the cabochon.
Fluorescence: *LWUV* *SWUV*	 Pale yellow patches Few very small whitish specks

Cr_2O_3, ruby with an average content of 5 wt % Cr_2O_3 but containing thin lamellae with a very high Cr_2O_3 content of up to 10.2 wt %, and blue corundum with a maximum Cr_2O_3 content of 3.2 wt % and some TiO_2. The authors further postulated that, when eventually it was found in situ, goodletite was likely to occur in metasomatic muscovite zones developed within quartzofeldspathic schist near contacts with Pounamu ultramafic lenses.

In summary it would appear that goodletite is the informal name that, for over a century, has been used to describe small water-worn greenish-grey pebbles and cobbles that have been and still are occasionally recovered from gold-bearing alluvial gravels of the westerly flowing Hokitika, Kaniere and Whitcombe Rivers of the South Island of New Zealand. Goodletite is a coarsely granular rock poor in silica (SiO_2 = 20.90%), consisting of a mixture of anhedral grains and rarer euhedral crystals of red to blue and pinkish-grey corundum set in a fine-grained matrix of green chrome-rich margarite-muscovite mica and minor chromian tourmaline. The rock has not been found *in situ*.

The gemmology of goodletite

The gemmological features reported in this study of goodletite were determined on a thin slab (Figure 1), provided by the late Bryan Harford of Lightning Ridge, and a 30.5 × 21.8 mm low domed cabochon of 27.94 ct (Figure 2).

When examined with the naked eye, the slab of goodletite (Figures 1 and 2) has a very characteristic appearance. It is opaque, with globulose, decidedly mottled pinkish to dark grey (corundum) matrix that is attractively patterned by random 'specks'

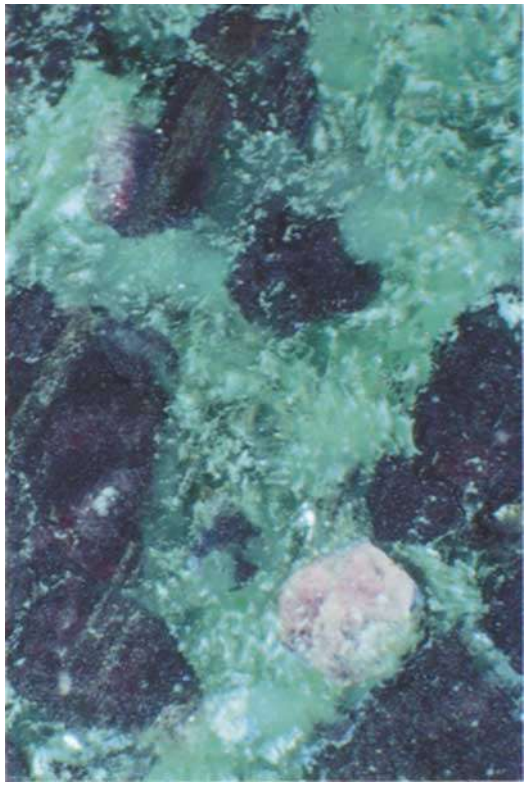

Fig. 5. Hand lens characteristics of goodletite illustrating the cross section of a ruby crystal and anhedral corundum in a matrix probably consisting of a mixture of green chrome-rich micas and tourmaline. Magnification 20×.

of pink to purplish corundum, and anastomosing veins of light green translucent mica and darker green tourmaline.

When examined at 10× magnification, goodletite was found to consist largely of a random mixture of anhedral grains of pink, pinkish-red, purplish-red ruby (some of which occasionally graded into blue sapphire), pinkish flecked dark grey corundum, and occasional euhedral crystals of opaque ruby of up to 1 mm cross-section. These occur as granular masses of various shapes and sizes, generally globulose, and set in a matrix of dark green tourmaline and fine-grained translucent emerald-green mica (Figures 4 and 5) which, in hand specimen, give the impression of sinuous veins.

Table I lists the properties of goodletite derived from the two specimens studied. It should be noted that the SG in other goodletite specimens may differ from that given in Table I because the mineral proportions of corundum, mica and tourmaline could be different.

As goodletite is a rock, for gemmologists outside the laboratory its identification must rely essentially on its distinctive hand specimen appearance. While superficially goodletite could be mistaken for other jade-like green to greyish materials – such as agalmatolite, serpentine, chalcedony, steatite or dyed calcite – none has either the gemmological properties (see Table I) or distinctive hand-lens characteristics (see Figures 1, 2, 4 and 5) of goodletite. For additional discriminatory data for possible imitations of goodletite readers are referred to Gübelin (1985).[17]

Discussion

Goodletite was named for William Goodlett, a Laboratory Assistant at Otago University, who in the early 1890s arranged for specimens of this rock to be analysed by Professor Ulrich, the Professor of Geology at Otago University, Dunedin.

Both the literature review that preceded this investigation and the investigation itself have confirmed that goodletite is a rock that has quite variable gemmological properties but with characteristics readily identifiable under the hand lens. The principal constituents of this coarse grained rock are ruby (some crystals of which grade into blue sapphire), pinkish-grey corundum, with lesser amounts of green chrome micas and green tourmaline.

Priority for the first use of the term appears to belong to McKay (1893).[11] The present authors could find no source, either in the literature or in terms of specimens, from which Webster might have derived the definition included in his book.

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J. Gemm., 1996, 25, 3, 219–224

The Adamas Advantage Gem Identification Kit 1.2e – a review

P.G. Read

Bournemouth

Abstract

The Adamas Advantage Gem Identification Kit 1.2e is a program requiring Windows 3.1, a 386 processor, 4Mb of RAM, 6Mb of free Hard Disk, a VGA/SVGA Monitor and a mouse. The program is excellent for students and suggestions for improving some aspects are made.

Introduction

When I was asked by Martin Haske of the Adamas Gemological Laboratory to review his gem identification computer program, I was pleasantly surprised as he knew that my own program GEMDATA, now in its sixth update, is a competitor in the same market. No doubt his reason for nominating me for this task was that I would be well aware of the necessary functions and programming complexities of such a product.

The program

The Adamas Advantage Gem Identification Kit 1.2e for Windows is a 'subset' of the much larger Adamas Advantage program, which is a DOS based package for gem identification, plus diamond and coloured stone analysis and reporting. The Kit is contained on two 3.5-inch diskettes. It is a Windows version with the minimum system requirements of Windows 3.1, a 386 processor, 4Mb of RAM, 6Mb of free Hard Disk, a VGA/SVGA Monitor, and a mouse.

Instructions for the installation of the program in the Windows environment are minimal and are easily implemented. Within a few minutes of my responding to the on-screen instructions, the Adamas icon appeared in the Main section of the Windows display and the program was ready for use.

On the title page of the program (Figure 1) there are six options (including Exit). Choosing 'Scan Data Base' gives direct access to data pages on each of the 524 gem materials in the database (selection is by double clicking the mouse on the chosen gem name). If 'Run Gem Identification' is chosen from the title page, the main ID menu is displayed (Figure 2).

Initially, the complexity of the menu screen seems rather daunting, as it contains some twenty-six input options for the various test parameters, all activated by clicking the mouse on the open box to the left of each parameter. However, it is only necessary to activate as many parameters as are relevant to the gem under test. For example, with a ring-mounted stone, colour, transparency, RI(s), and optic character (single/double refraction) may well be sufficient.

Before starting an identification, perhaps the most important choice to be made is how much of the database should be searched to find a match for the values of the chosen parameters. The first option labelled 'A Chart only', enables a search to be made for a match among a group of 66 of the more common gem materials. Unless the gem under test is thought to be

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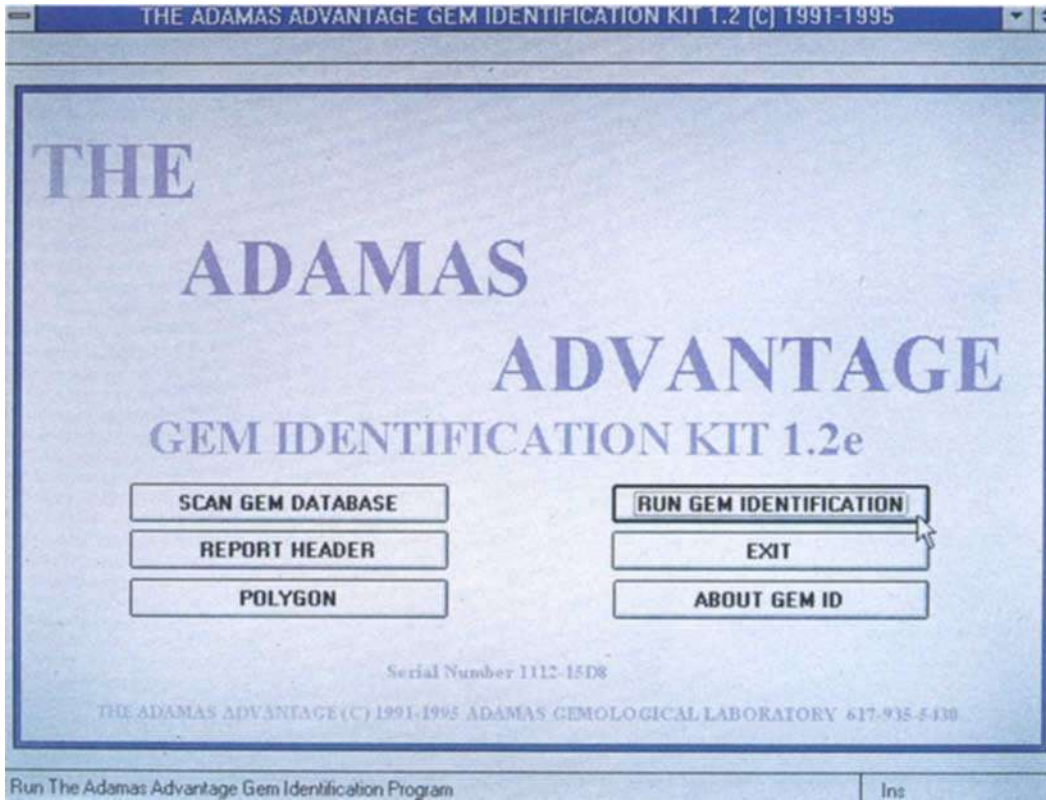

Fig. 1. Title page of the Adamas Advantage Gem Identification Kit.

something unusual, this is probably the best first choice. A second option labelled 'A + B Charts' adds in some less common gems to bring the total up to 133 materials, while the third option involves the complete database of 524 materials (many of these being minerals well outside my experience but no doubt forming a valuable asset to any mineralogist using the program!).

The next important decision is in the selection of the tolerance ranges for the search. These are set by clicking the mouse on 'Update Match Tolerances' to bring up a separate screen. For comparison purposes, I set the RI, DR and SG tolerances to my own program's 'Narrow Search' values of ±0.005, ±0.003 and ±0.02 respectively.

If a modest set of input parameters is chosen and entered (e.g. colour, transparency, optic character, lowest and highest RIs, and SG) and database option 'A' is chosen, the time taken by the program to search and find a match is around four seconds (the display box labelled 'Matched Table' then indicates those gems which fall within the tolerance ranges of the input values; if more than three gems are identified, these can be scrolled into view in the ID display box). However, if the complete database is chosen for the search, this can take up to thirty seconds. These items were logged on my 486SX based computer. (Slower processors such as the 386 specified as a minimum requirement would take proportionally longer.)

After the various test parameters have been keyed in, initiation of the search

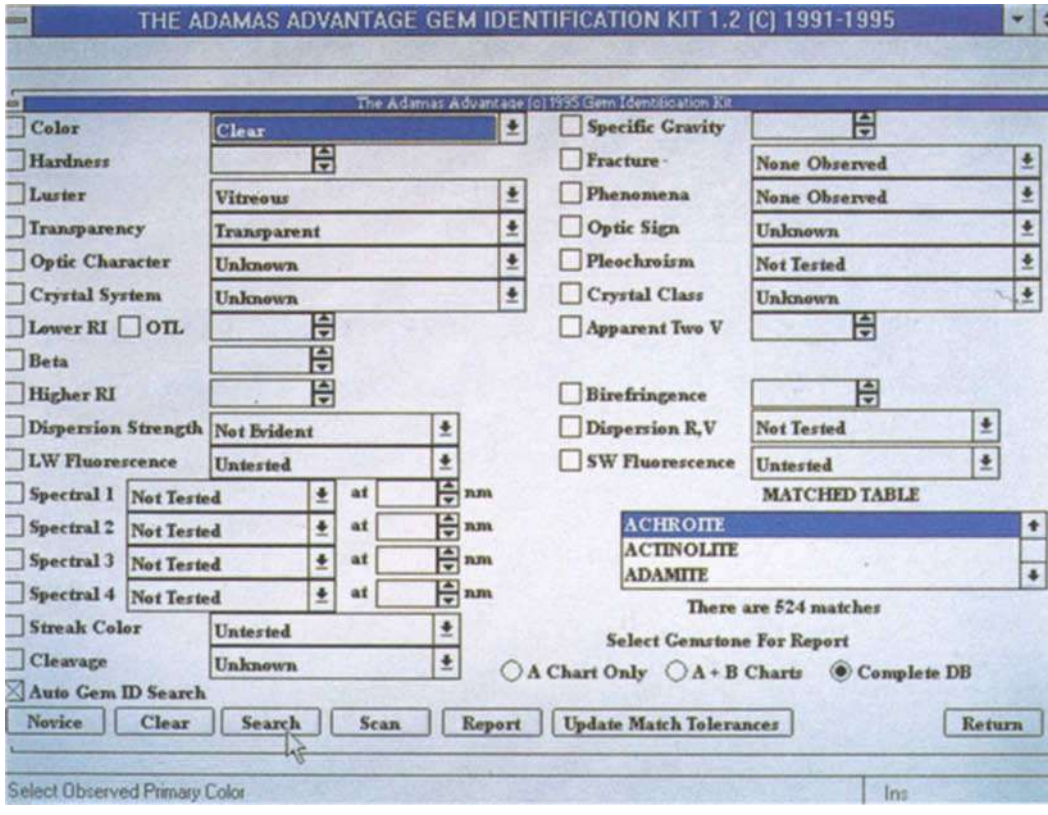

Fig. 2. The parameter menu page indicates the number of possible identifying constants and features which can be included in an identification search of the database.

process can be done either by clicking the mouse button on the 'Search' facility in the display, or by selecting the 'Auto Gem ID Search' facility. If the latter method is chosen, the program will search the database each time a parameter is modified, added or deleted – a useful feature when exploring alternative identifications.

If an identification becomes necessary on a gem whose RI is above the range of the standard critical-angle refractometer, the 'OTL' box alongside the 'Lower RI' parameter can be activated to exclude all gems with an RI lower than 1.81 from the identification (this is similar to an input option in GEMDATA). Information on any of the parameter boxes can be viewed by clicking on that box and data field with the mouse and then pressing key F1 on the computer (clicking on just the box will, with the exception of the 'OTL' feature, only display a standard message).

Evaluation of the program

During my evaluation of the program, I first checked out a few of the more common gem minerals such as quartz, corundum, topaz and diamond, all of which were promptly identified using the 'Chart A' section of the database. When employing the complete database, additional materials are often included in the ID. For example, Cape diamond, synthetic diamond and yellow diamond are listed in addition to diamond.

Feeling more adventurous, I set up the colour, transparency, optic character (DR) and RIs for meliphanite using the full database. It was here that I ran into my

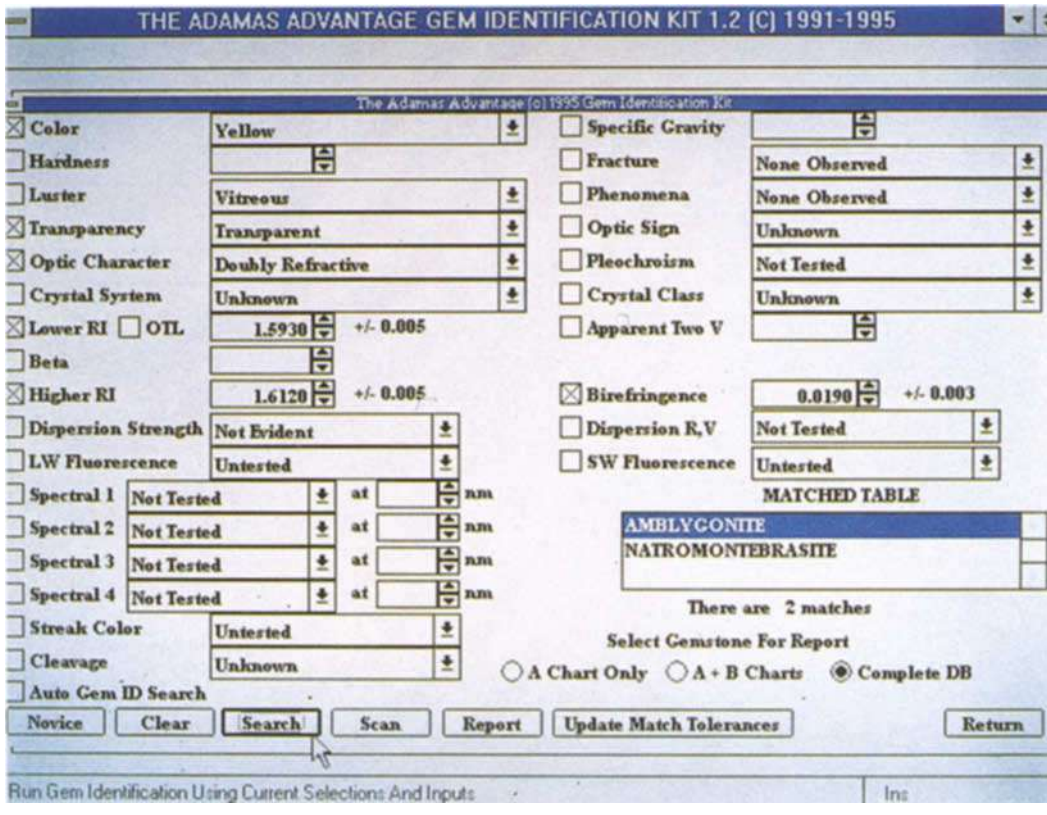

Fig. 3. When the constants for meliphanite are set up and optic character 'doubly refracting' is included, this gem is missing from the materials identified.

first problem when the 'Matched Table' display identified two gems, amblygonite and natromontebrasite, but omitted to list meliphanite (Figure 3). I activated the program's 'Scan' facility and checked out the constants of meliphanite (called melinophane) in the database. These were the same as the values I had input. Then I noticed that there was no mention of birefringence under the 'Optic Character' section of the database 'Scan' page, although the appropriate RI and DR values were listed.

When I went back to the Gem Identification screen and de-activated the 'Optic Character' input, melinophane was then displayed together with the other two gem materials (Figure 4). It seemed that melinophane was not being identified because its optic character (uniaxial positive) was missing from the database.

I then checked the optic character of all the gems from Achroite to Azurite in the database and found that five birefringent gems (albite feldspar, algodonite, andesine, anhydrite and ankerite) were also not listed as doubly refracting. Because of this, these gems could not be identified when this feature was included in the 'Optic Character' section of the parameter menu page. On a random browse through the rest of the alphabet, I found many other birefringent gems with this omission.

Although more irritating than major, this problem will need to be addressed in future versions of the Gem Identification Kit, as there are occasions when 'doubly refracting' becomes a necessary ID parameter (e.g. when a polariscope test indicates that a gem is birefringent, but

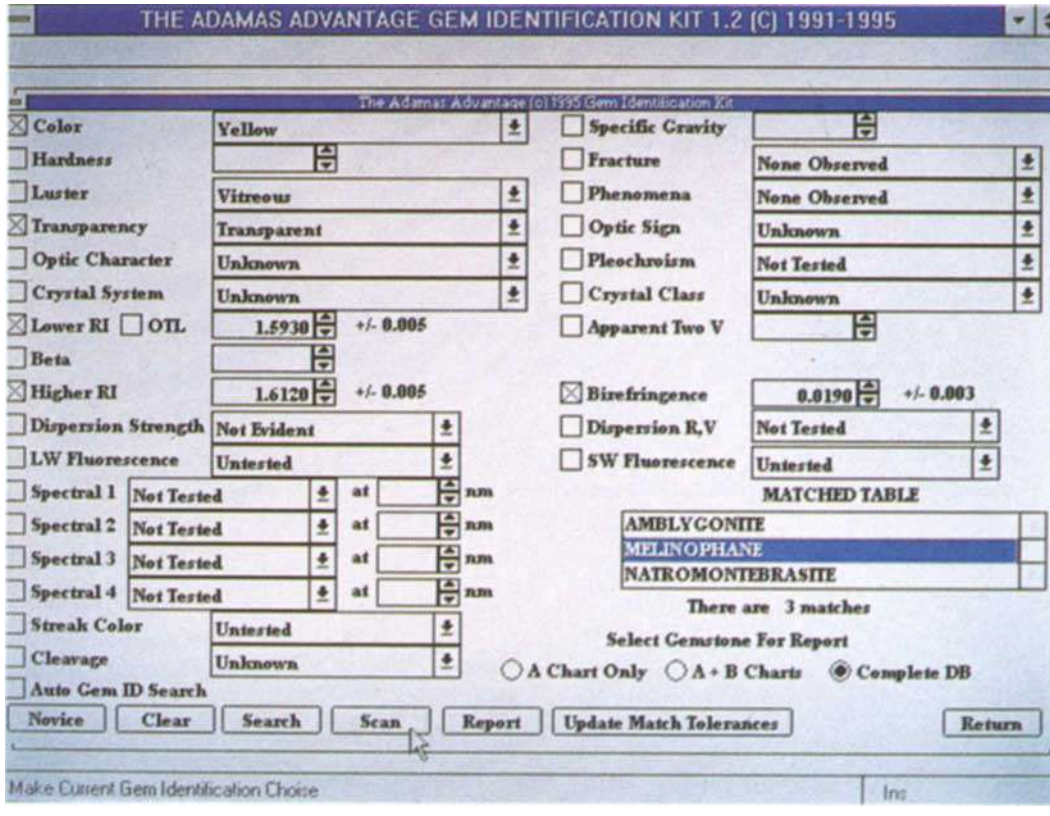

Fig. 4. If one optic character 'doubly refracting' is deleted (open parameter selection box near top on left-hand side), melinophane is included in the gems selected.

only one index can be measured on the refractometer).

Another characteristic of the program, which could easily be corrected, is the fact that when 'Run Gem Identification' is selected on the title screen, the program goes immediately into its search program. When the parameter menu page is finally displayed, the 'Auto Gem ID Search' feature is already activated (as can be seen in the bottom left-hand corner of Figure 2). It would be preferable if the user had the initial choice of selecting either the 'Auto' feature or the single 'Search' function.

Once a gem, or a set of gems, has been displayed in the 'Matched Table', it is then possible (as indicated earlier) to access the complete gem constants and characteristics on the selected material by clicking the mouse on the 'Scan' button (Figure 5). This information is derived from the database, and includes a 'View Gemstone Comments' feature which when activated displays further details including book references with page numbers.

After a gem identification, all of the selected parameters can be reset by activating the 'Clear' button. However, the first three gems in the selected section of the database remain displayed in the 'Matched Table' box. It would be more logical if this box was also cleared of any gem names prior to each ID operation.

Another aspect that could be reconsidered is that if the mouse indicator arrow is left on the 'Search' or 'Clear' button after this feature is chosen, the program stays in the search mode and displays its 'Computing' message until the

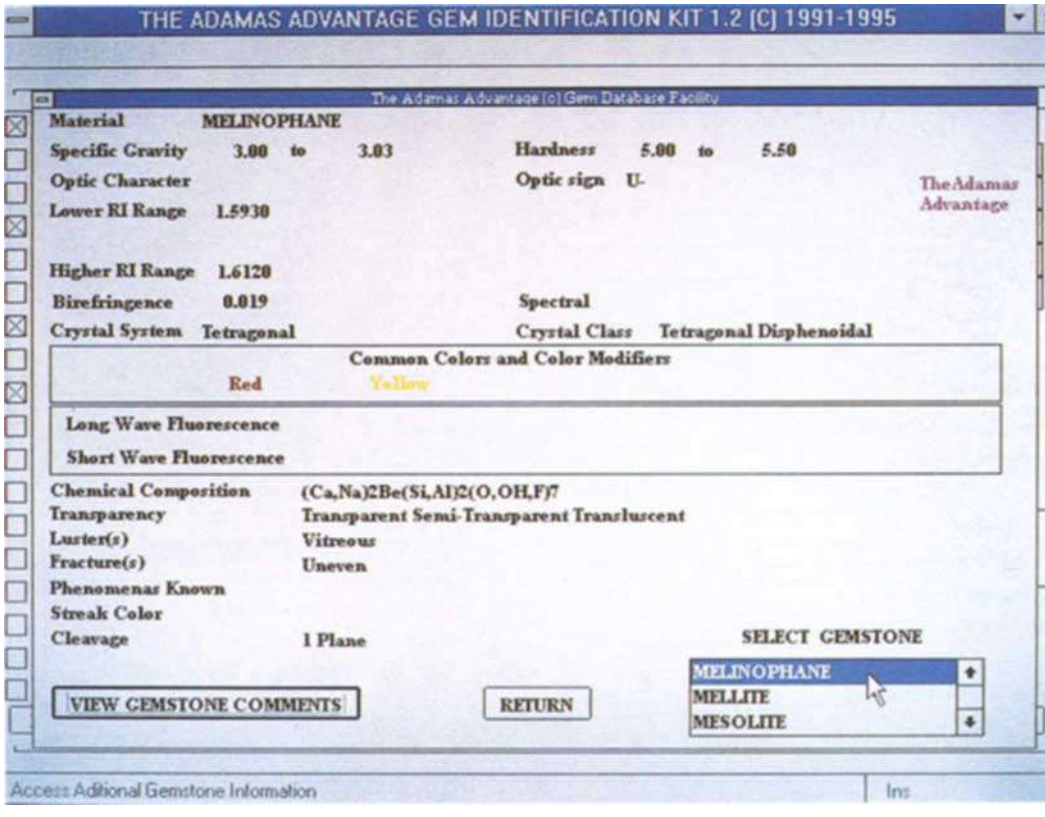

Fig. 5. After identification, further information on a gem is available from the database.

arrow is moved away. Under the colour selection parameter pink could be added to the colours to help separate highly saturated red gemstones from the pinks of smithsonite, kunzite, rhodochrosite, etc., and the term 'colourless' should replace 'clear'.

Conclusion

However, none of these criticisms detract from what is a very wide ranging and excellent gem identification program in which even the student is well catered for in a 'Novice' section containing a wealth of information. This ranges from a selection of basic equipment (including the yet to be marketed Brewster-angle meter) to a detailed description of the use of the critical-angle refractometer, plus a list of recommended gemmological text and reference books.

Both the Adamas Advantage program and the Gem Identification kit are available from the Adamas Gemological Laboratory, The Brook House C609, 77 Pond Avenue, Brookline, MA02146, USA.

Letters

From Dr T. Farrimond

Dear Sir

When making hydrostatic determinations of SG (*J. Gemm.*, 1994, **24**, 3) I also carried out a series of measurements of surface tension (ST), using initially the method advocated by most writers on the subject (e.g. Webster, R., 1983, *Gems*, p. 654; Sinkankas, J., *Gemstone and mineral data book*, p. 124.). For example, Sinkankas suggests adding a drop of detergent the size of a pin head to the surface of one litre of water. In my experiments I used de-ionized water with a temperature range between 16 and 17°C.

Ten ST readings were made in order to establish the accuracy of the procedure and gave the following values:- Mean 73.8 dynes/cm; standard deviation $\sigma_{(n-1)}$ 0.16 where n = number of measurements (in this case 10).

In the first series of tests, one drop of detergent of the *non-foaming variety* (supplied for wet or dry vacuum cleaners) was added to the surface of 150 ml of de-ionized water and ST readings were made at approximately 20 second intervals for a period of 50 minutes, giving a total of 150 readings. It was noticed that the readings were initially low, but showed a variation with time, producing a pattern resembling a damped oscillation.

Then the tests were repeated and the same effect occurred. The patterns were so similar that the results of the two tests were combined and a graph plotted for the total of 300 readings (Figure 1, Graph B). Adjacent readings were averaged to produce Graph B, which shows 45 ST values at approximately one minute intervals. Each point on the graph is, therefore, the average of about six readings.

From the $\sigma_{(n-1)}$ values for plain water, the variation due to experimental error should not be more than $\pm$ 1 dyne/cm. The effects shown in graph B do not appear to be random variations. It is noticeable when carrying out the measurements that each reading varies only slightly from the previous one and that the changes are progressive. The ST falls rapidly, after adding the detergent, to a value of 33 dynes/cm and then climbs slowly over a period of 20 minutes to 66 dynes/cm, after which a fluctuation occurs which gradually diminishes in amplitude over the next half hour.

When the liquid was allowed to stand for 15 hours, the first reading was low, at about 36 dynes/cm, but values rose rapidly so that after 8 minutes the levels were only slightly lower than for plain water. The 26 points shown in Figure 1 (Graph A) are based on 96 readings over a 50 minute period.

Figure 1 (Graph C) shows the effect of adding one drop of *concentrated dishwashing detergent* to the surface of 150 ml of de-ionized water. Surface tension falls abruptly to 29 dynes/cm but rises slowly to around 43 dynes/cm over a 20 minute period after which it settles down to a level of about 37 dynes/cm.

It seems from the graphs that hydrostatic measures of SG may reflect the variability of surface tension values. SG measurements obtained in the first minute after

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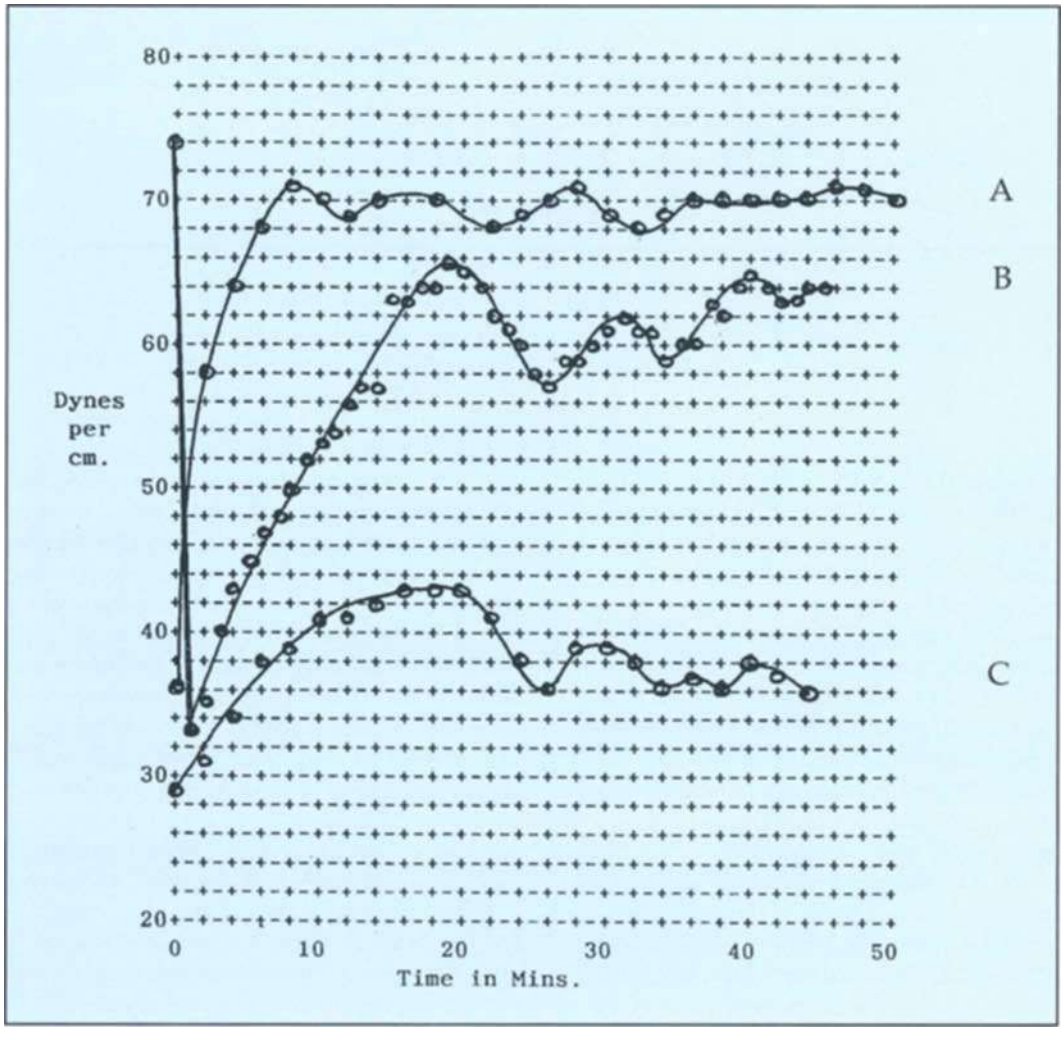

Figure 1

adding detergent may differ from those obtained after 20 minutes.

I am aware that ST would act not only on the suspension wire, but would also affect the tendency for bubbles to form on the stone and its holder beneath the surface. There appears to be a need to ascertain the percentage of detergent which should be added to water to determine what is optimal for the lowest values of ST at the surface and also beneath it.

Further tests were carried out with *non-foaming detergent* in which *increasing* amounts of detergent were added to 10 ml of water at 17°C followed by careful mixing and subsequent testing. The results are shown in Figure 2 (upper graph). The optimum concentration would seem to be a 10 per cent solution. An approximate ST level for toluene (dotted line) is also shown for comparison.

The lower graph in Figure 2 shows the effect of mixing *concentrated kitchen detergent* with 150 ml of de-ionized water. An amount of 2–3 drops appears to be optimal (that is about 14 drops per litre).

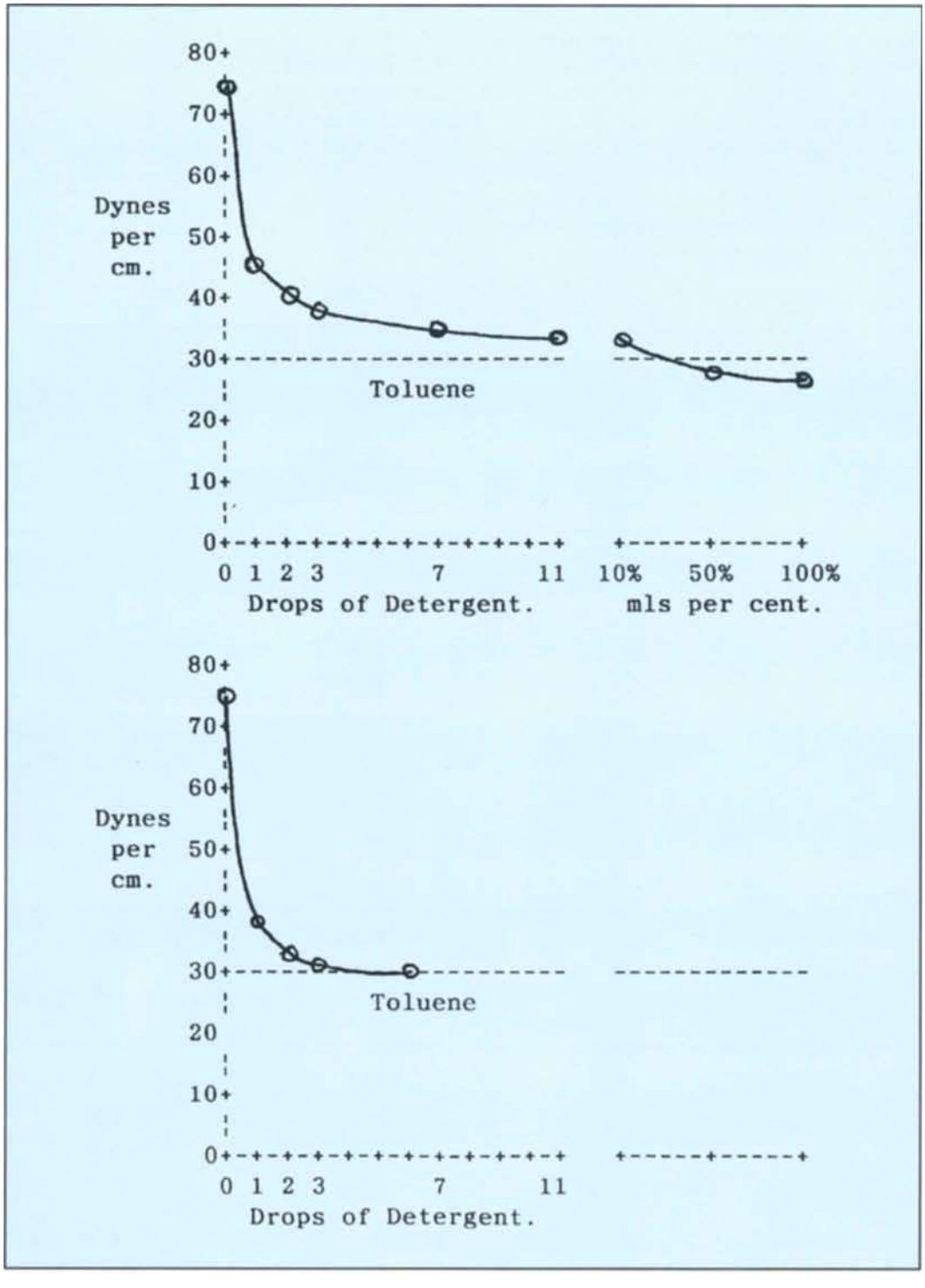
Dynes per cm.
80
70
60
50
40
30
20
10
0
Toluene
0 1 2 3 7 11
Drops of Detergent.
10% 50% 100%
mls per cent.
Dynes per cm.
80
70
60
50
40
30
20
10
0
Toluene
0 1 2 3 7 11
Drops of Detergent.

Figure 2

The values on which these graphs are based are shown in Table I. Each point on the two graphs is based on ten readings and the $\sigma_{(n-1)}$ values show the spread about the mean.

It is suggested that higher concentrations of detergent may be more effective (when measuring the SG of small stones hydrostatically) than the one drop on the surface previously advocated.

Yours etc.

Dr T. Farrimond
Cambridge R.D.1
New Zealand.
19 March 1996

Table I: Surface tension(ST) values for detergent mixed in 150 mls de-ionized water.

Non-foaming detergent added: drops	mls %	*Mean ST*	$\sigma_{(n-1)}$
0		74.6	0.18
1		46.2	0.26
2		39.2	0.21
3		36.9	0.46
7		35.0	0.16
11		34.0	0.14
	10	33.3	0.52
	50	28.5	0.25
	100	28.0	0.25
Concentrated kitchen detergent added: drops		*Mean ST*	$\sigma_{(n-1)}$
0		73.8	0.16
1		38.1	0.50
2		31.9	0.21
3		31.1	0.25
6		30.1	0.18

N.B. Each value based on 10 readings

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Abstracts

Diamonds | Gems and Minerals

Instruments and Techniques | Synthetics and Simulants

Diamonds

Conversion of platelets into dislocation loops and voidite formation in type IaB diamonds. T. EVANS, I. KIFLAWI, W. LUYTEN, G. VAN TENDELOO AND G.S. WOODS, *Proceedings of the Royal Society, Mathematics & Physical Sciences*, **449**(1936), 1995, 295–313.

Experiments are described in which platelets in natural diamonds are converted to dislocation loops by annealing at > 2400°C under high *P*. Conversion occurs most readily when the annealing conditions are in the graphite-stable region on the C phase diagram. At 2650°C there is an increase in the rate of conversion of about three orders of magnitude, attributed to the instability of the diamond structure. Linked to the conversion is the disappearance of the B local-mode platelet peak, the D spectrum and the X-ray spikes, which have been associated with platelets. Voidites on and inside the dislocation loops were produced, suggesting that voidites with these loops are formed during the conversion of platelets to dislocation loops. IR spectra and electron micrographs illustrate these results. TEM shows that platelets are converted to interstitial ½*a* (011) dislocation loops. R.K.H.

A history of diamond sources in Africa: part 1. A.J.A. JANSE. *Gems & Gemology*, **31**(4), 1995, pp 228–55, 25 illus., 7 in black-and-white, 18 in colour.

This review covers diamond and kimberlite discoveries in Africa spanning nearly 130 years from children playing with bright pebbles on the De Kalk farm to highly sophisticated exploration and mass excavation of desert sand at Orapa and Jwaneng in the Kalahari. During this time all but two of the largest economic kimberlite pipes in the world were discovered. In the period 1872–1959 Africa produced 98 per cent of the world's diamonds by weight and 96 per cent by value. Although most diamonds have been produced by alluvial diggings along waterways in South Africa, Angola and Zaire, and by large kimberlite pipes in the Kimberley area and in Botswana, diamonds from the coastal deposits off the Atlantic coasts of Namibia and Namaqualand promise to be the industry's greatest future resource.

The earliest official finds were made from 1867 in the sands and gravels of the Orange and Vaal Rivers in South Africa and subsequently in the hard rock kimberlites and more recently in offshore deposits along the western coast of South Africa and Namibia. Further important discoveries in many African countries such as Angola, Botswana, the Central African Republic, Ghana, Namibia and Zaire qualify them for inclusion with South Africa among the top diamond-producing countries in the world. The histories of these discoveries in southern and central Africa

ABSTRACTORS

R.K. Harrison	R.K.H.	M.O'Donoghue	M.O'D.	P.F. Schofield	P.F.S.
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M. Lagache	M.L.	G.W. Robinson	G.W.R.		

For further information on many of the topics referred to consult *Mineralogical Abstracts* or *Industrial Diamond Review*.

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from the nineteenth century to the present are examined in a systematic way.

The early history of diamond discovery has been well documented but not all the stones can be substantiated, and the reviewer has the advantage of hindsight to put these events into perspective. The result is a fascinating and authoritative review. R.J.P.

New find of diamond bearing gravel horizon in Payalkhand area of Raipur District, Madhya Pradesh.

S.K. NEWLAY AND J.K. PASHINE. *Journal of the Geological Society of India*, **45**(3), 1995, pp 309–12.

Some 200 kg of gravel from this area contained ~ 2% pyrope with minor quartz and two off-coloured diamonds (0.88 and 0.29 ct). R.A.H.

A chart for the separation of natural and synthetic diamonds.

J.E. SHIGLEY, E. FRITSCH, I. REINITZ AND T.M. MOSES. *Gems & Gemology*, **31**(4), 1995, pp 256–65, 1 table, 64 illus. in colour.

The chart itself is comprehensive, lucid and supplied with a profusion of coloured photographs. The information and testing is well within the scope of most gemmologists, and the recommended testing pattern uses everyday equipment. It was pleasing to note that where photomicrographs were shown the magnification was quoted.

The testing sequence was in the order (a) examination of the stone under magnification looking for inclusions, colour zoning and graining (b) ultraviolet radiation including both long and short wave (c) spectroscopic examination in the visible region (d) checking a suspected synthetic with a strong magnet and (e) observing possible strain patterns between crossed polarizers. The most useful gemmological properties of three groups of natural and synthetic stones were considered, yellow, blue and colourless to near colourless. The authors think that cathodoluminescence will soon be used routinely for examining diamonds.

Synthetic diamonds typically contain traces of flux metals such as iron or nickel both of which are ferromagnetic and will be attracted to a strong magnet (e.g. the neodymium-iron-boron magnet). Information was not included to cover cases where natural diamonds had a synthetic coating placed on them to change their colour or weight. R.J.P.

Analysis of diamonds and indicator minerals for diamond exploration by laser ablation-inductively coupled plasma mass spectrometry.

R.J. WATLING, H.K. HERBERT, I.S. BARROW AND A.G. THOMAS. *Analyst*, **120**(5), 1995, pp 1357–64.

A method has been developed, using LA-ICP-MS, for the semi-quantitative determination of 43 elements in diamonds, chromites and garnets. Samples of diamonds from five different countries and the interrelationship between their trace elements gives distinctive patterns for each source. This should allow the tracing of stolen diamonds and can also be used to establish the trace element distribution in indicator minerals for diamond exploration, such as garnets and chromites. The relative distribution of the *REE*, Ta and Hf indicate a consistent inter-element relationship for garnets associated with diamondiferous kimberlites; the trace element partitioning patterns of chromites can be used to establish a kimberlitic or non-kimberlitic provenance of this mineral. R.A.H.

Gems and Minerals

Gemmologie aktuell. Gemmological news.

H. BANK, U. HENN AND C.C. MILISENDA. (*Gemmologie – Zeitschrift der Gemmologischen Gesellschaft*, **45**(1), 1996, pp 1–4.

This deals with various items of gemmological interest. Green crystal fragments were submitted from an unknown source in Asia and were found to be demantoid garnet. An unusually large specimen of gahnite from Brazil weighing 8.54 ct and of intense green colour was examined, as were star-scheelite from Sri Lanka: yellowish-brown, weighing 61.73 ct, showing a distinct four-rayed star due to oriented needle-like inclusions. A larger variation of RI than previously described was found in garnets from Mali; some crystals can be as large as 15 cm in diameter; in cases of sufficient transparency it is possible to facet bicoloured stones.

Yellowish-green to yellowish-brown chatoyant specimens of opal cat's-eyes from Brazil are described—the cat's-eye effect is caused by parallel fibres of chrysotile. A new opal imitation is offered from Australia under the name of 'opalus'; it is composed of plastic foil in a colourless plastic material cemented onto a black background. Quartzes with a thin golden-yellow film were offered on the market as golden beryls; the layer could easily be removed by a solvent. E.S.

Amethysts and their occurrences.
H. BANK AND C.C. MILISENDA. *Australian Gemmologist*, **19**(4), 1995, pp 175–7, 6 illus. in colour.

Amethyst, the violet to purple variety of macrocrystalline quartz crystallizes in the trigonal system. Its colour is caused by a radiation-induced colour centre associated with an iron impurity. Pliny (AD 23–79) recounts amethyst amulets being used to protect their owner from excessive alcohol consumption and the word is derived from the Greek *amethustos* meaning 'not drunken'.

Since the fifteenth century amethyst has been mined and fashioned in Idar-Oberstein where it occurs as druses in mafic eruptive lava flows of Permian age (about 250 million years old). Brazilian amethyst also occurs in druses but from a slightly younger basaltic rock in the southernmost state of Rio Grande do Sul. These have been exploited commercially by traders and cutters from Idar-Oberstein since 1834. Amethysts from Bahia are transformed on heating into yellow citrine. Latterly another deposit from Minas Gerais has yielded amethyst which turns green (prasiolite) on heating. Bicoloured violet and yellow quartz (ametrine) comes from the Anay mine in Bolivia. In North America amethysts have been found in North Carolina, California, Colorado, Maine, Pennsylvania, Texas and Virginia. In Africa the largest occurrence was discovered in 1956 in the Kalomo district of Zambia where it occurs in hydrothermal veins in granulitic gneisses.

In France, amethyst has been mined since the seventeenth century from geodes in volcanic rocks in the Auvergne. Swiss alpine deposits are well known but the most important source in early times was Russia where amethyst was found in early Paleozoic quartz-chlorite and mica schists in the southern Polar Urals. Other deposits occur in many other countries including Japan, China and Australia. R.J.P.

Siberian jade.
R. BECK AND S. LEAMING. *Bulletin of the Friends of Jade*, **9**, 1996, pp 8–10, illus.

A short account of a visit paid to the (nephrite) jade fields in the East Sayan mountains of southern Siberia in August 1994, with notes on prospecting and occurrence of nephrite which is found as boulders. M.O'D.

Gems around Australia.
H. BRACEWELL. *Australian Gemmologist*, **19**(4), 1995, pp 182–4, 1 illus. in black-and-white, 6 in colour.

A visit to Western Australia's Wyloo amethyst deposit is described. A detailed description of the colourful history of the Great Australian Amethyst Mine makes interesting reading. So does the account of the author looking for complete crystals whilst fellow fossikers were intent only on obtaining faceting rough smashed crystals without concern. R.J.P.

La citrine de Campo Belo (second part).
J. CASSEDANNE. *Revue de gemmologie*, **126**, 1996, pp 7–9, illus. in colour.

Continues the description of citrine from Campo Belo, Minas Gerais, Brazil, with notes on the geology and mineralogy of the occurrence and on the gemmological properties of the citrine. Cut gemstones have been found to contain minute two-phase inclusions, dendritic crystals of goethite, various types of fissures and negative crystals. M.O'D.

Confucius. The essence of jade as told by Confucius in the *Li Ki*. Translated from the Couvreur's French translation by Herbert Geiss and Bob Frey with translations in French and Latin by Couvreur and the original Chinese text by Confucius. *Bulletin of the Friends of Jade*, **9**, 1996, pp 117–21, illus.

The *Li Ki* or *Memories on the propriety and the rites*, by Confucius, contains a definition of the essence of jade whose translation, with the original Chinese text, is given here. M.O'D.

What's new in minerals.
M.P. COOPER. *Mineralogical Record*, **27**, 1996, pp 137–48, illus. in colour.

Fluorite was a theme mineral at the 1995 Munich show and a wide range of specimens was exhibited from major museum collections. Crystals of particular interest and colour are described, with emphasis on British occurrences. An exhibit of crystal models also attracted considerable attention. Fine crystals of yellow beryl from Zelatoya Vada, Pamir mountains of Tajikistan and a group of brazilianite crystals on quartz, from near Mendes Pimentel, Minas Gerais, Brazil featured at other recent mineral shows. M.O'D.

Trois portraits du XVIIIe siècle en saphir.
M. DUCHAMP. *Revue de gemmologie*, **126**, 1996, pp 17–20, illus. in colour.

Portraits of Louis XIV, the Grand Dauphin and the Princess Palatine, fashioned as cameos in blue sapphire, are described with notes on their history. M.O'D.

The causes of color in garnets.
E. FRITSCH AND G.R. ROSSMAN. *Mineralogical Record*, **24**(1), 1993, p 63.

In most natural garnets colour is due to several superimposed absorption mechanisms. The common red colour in many garnets is caused by Fe^{2+} in a site with distorted cubic co-ordination. Mn^{2+} in this site produces the orange colour seen in many spessartines. Mn^{3+} in the octahedral site occasionally gives a pink colour to hydrogrossular, while Fe^{3+} in octahedral co-ordination produces the pale yellow-green colour of some andradites. Charge transfer absorptions involving Ti and Fe commonly contribute a yellow to orange to black colour component depending on Fe-Ti concentrations. Low concentrations of V^{3+} in octahedral co-ordination in grossular produce the yellowish green variety, tsavorite, and low concentrations of Cr^{3+} in andradite, also in octahedral co-ordination, produce the emerald-green variety, demantoid. Cr^{3+} in octahedral co-ordination gives the green colour to uvarovite and high-Cr content pyrope. Some purple garnets coloured by both Cr^{3+} and Fe^{2+} show a remarkable colour change to green when heated to about 200°C. An 'alexandrite effect' may be caused by Cr^{3+} and V^{3+} in octahedral co-ordination, generally in conjunction with Mn^{2+}. Occasionally, various physical mechanisms such as diffraction also cause colour in garnets. G.W.R.

Coraux (Coelenterata) australiens.
R. GARCÍA GIMÉNEZ, M.A. FERNÁNDEZ RODRÍGUEZ AND P. DA SILVA. *Revue de gemmologie*, **126**, 1996, pp 13–16.

Examples of corals from waters around Australia are briefly described and illustrated. M.O'D.

Nouvelle structure d'empilement compact dans de l'opale noble du Brésil.
J.-P. GAUTHIER, J. CASEIRO, S. RANTSORDAS AND D. BITTENCOURT ROSA. *Comptes Rendus de l'Académie des Sciences, Série II*, **320**(5), 1995, pp 373–9, (French with abridged English version).

A precious opal from Pedro II, NE, Brazil, shows a rare structure consisting of silica spheres of two different sizes regularly arranged, with a radius ratio $\gamma = r/R \sim 0.75$. From SEM images, it is possible to describe the periodic array, its stoichiometry, the unit cell including the 'atomic' positions and the symmetry group, $Fd\bar{3}m$. This cubic packing corresponds with a new AB_2 type structure, not described previously in bidisperse opals. The spheres of radius R occupy tetrahedral cavities of a face-centred cubic packing of spheres of radius r, and themselves display a diamond-like sublattice. The stability of the structure requires that the large spheres become slightly flattened, in order to eliminate 'rattling' of the structure. The large spheres are indeed flattened. M.L.

Structural mechanisms for light-element variations in tourmaline.
F.C. HAWTHORNE. *Canadian Mineralogist*, **34**, 1996, pp 123–32.

While Si, B and OH and F are well known to be variably present in minerals of the tourmaline group, their stereochemical details are still not fully understood. Proposals are made for the reallocation of site labelling. M.O'D.

Gemmologische Kurzinformationen. Short gemmological notes.
U. HENN, H. BANK, J. HYRSL AND C.C. MILISENDA. *Gemmologie – Zeitschrift der Deutschen Gemmologischen Gesellschaft*, **45**(1), 1996, pp 23–8.

The first item is by U. Henn and H. Bank and describes trapiche-like corundums from Myanmar. Red, blue and grey prismatic corundum crystals (ruby and sapphire) from Myanmar are described which showed a trapiche-like six-rayed inclusion pattern when viewed along the *c*-axis; the inclusions are probably carbonates.

The second item is by J. Hyrsl and C.C. Milisenda and describes eudialyte from the Kola peninsula in Russia. The specimens are intense red and of gem quality. Eudialyte is a complex trigonal cyclosilicate with RI n_e 1.614–1.615, n_o 1.610–1.611, DR 0.004, SG 2.91. There is colour and growth zoning and typical liquid feather inclusions.

The third and last item concerns new emerald manipulations and is by C.C. Milisenda. Two types of 'manipulations' are described. The first specimen, probably of Colombian origin, was

offered from Russia, weighed 5.62 ct and was overgrown with a 2.5 mm thick layer of green artificial glass. The second type concerned emerald crystals from Brazil which had been hollowed out and filled with a green plastic; strong tabby extinction under crossed nicols, swirl marks and air bubbles were also visible. E.S.

Inclusions in amethyst from Eonyang, Korea.
WON-SA KIM. *Canadian Gemmologist*, **17**(1), 1996, pp 8–13, illus.

Amethyst from Eonyang, Korea, has been found to contain acicular and dendritic crystals of hematite with two- and three-phase inclusions with gas bubbles, liquid and halite crystals. M.O'D.

Inclusions in garnets.
J.I. KOIVULA. *Mineralogical Record*, **24**(1), 1993, p.64.

Garnets are host to a variety of inclusions which reflect their somewhat diverse geological environments. The work required to correctly identify inclusions is time-consuming, specialized, and often difficult. Although 14 species are currently recognized as members in the garnet group, only five of these, almandine, andradite, grossular, pyrope and spessartine (and chemical solid solutions of these) have been studied for their inclusions. Almandine garnets are primarily a product of schists and gneisses. The most common mineral inclusions so far identified in almandine are apatite, biotite, ilmenite, monazite, rutile and zircon. Chromium-bearing transparent green andradite garnets, known by the name demantoid, are found in chlorite schists and serpentinites. These garnets often contain distinctive acicular groups of white-to-yellow tremolite-actinolite that radiate outward from a central crystalline core of chromite. Grossular garnets are produced by the contact and regional metamorphism of impure calcareous rocks. A wide variety of inclusions have been observed in these garnets such as actinolite, apatite, calcite, diopside, graphite, pyrite and scapolite. Peridotites and kimberlites are the chief source rocks of pyrope. Most of the pyrope that we see, however, is recovered from sands and gravels produced by weathering of these rocks. Inclusions recognized in pyrope garnets so far are diopside, forsterite and rutile. Diamond has even been noted as an inclusion in pyrope garnets from a kimberlite in South Africa. Granitic pegmatites are the primary source rocks for spessartine garnets. Spessartines reflect this environment in that they are the only garnet to commonly contain liquid and gaseous two-phase and three-phase fluid inclusions. G.W.R.

Nouvelles données sur la zincite synthétique.
E. LANDAIS AND J.-P. POIROT. *Revue de gemmologie*, **126**, 1996, pp 11–12, illus. in colour.

Synthetic zincite crystals in green and orange colours have been faceted as gemstones. Their formation is said to be a by-product of zinc oxide preparation at a location in Silesia, Poland. Properties are given. M.O'D.

Cu-bearing tourmaline from Paraíba, Brazil.
D.J. MACDONALD AND F.C. HAWTHORNE. *Acta Crystallographica*, **C51**(4), 1995, pp 555–7.

Two crystals of tourmaline, containing 0.81 and 0.38 wt.% CuO have been studied by single crystal XRD. The octahedrally co-ordinated *Z* site is completely occupied by Al, whereas the *X* and *Y* sites both contain more than two scattering species [(Na, Ca, □) and (Li, Mn, Cu, Al) respectively]. The occupancy of these two sites by cations of very different size and charge causes a significant degree of positional disorder, especially on O1 and O2. P.F.S.

Gems and gemmology in Sri Lanka: the early history.
M.M.M. MAHROOF. *Australian Gemmologist*, **19**(4), 1995, pp 169–74, 1 illus. in black-and-white.

Gems have been associated with the older name of Ceylon for many centuries and apart from emerald and diamond, examples of most gem species have been recovered from the island. The Roman historian Pliny wrote much about the gems in Sri Lanka and even Sinbad's narrative has connection with the island. The precious stones were under the direct control of royalty who underpinned the gem trade of ancient Ceylon.

Between the fifth and eleventh centuries AD gold jewellery became intricate and beautiful but the art of lapidary appears to have regressed. During the Middle Ages the gem trade was in the hands of the King and the great value of these gemstones ensured that the King retained his power. Nevertheless, in 1620 a Dutch admiral visiting Sri Lanka, landed at Trincomalee and reported the ready sale of gemstones before pro-

ceeding to the capital at Kandy. Evidently the King's edicts were not so effective since independent trading some distance from the capital was carried on. In medieval Ceylon a knowledge of gemstones was a necessary adjunct of the accomplished young man. R.J.P.

Minerals of the Sawtooth batholith, Idaho.
M.A. MENZIES AND R.C. BOGGS. *Mineralogical Record*, 24(3), 1993, pp 185–202.

The Sawtooth batholith is an anorogenic Tertiary granite pluton with miarolitic cavities, small pegmatite dykes and pegmatitic segregations containing both interesting and unusual minerals. Some of the miarolitic cavities have produced gem-quality crystals of aquamarine < 18 cm, topaz crystals < 12 cm and rare helvite crystals < 2.5 cm. Large crystals of smoky quartz, microcline and albite are abundant. The cores of some of the topaz crystals fluoresce bright yellow in long wave UV light; its cause is presently unknown. The predominant mica in the miaroles is a dramatically zoned zinnwaldite/masutomilite. The crystallization of spessartine is probably responsible for the abrupt change from zinnwaldite to masutomilite back to zinnwaldite. EPMA gave MnO 9.37%, making this the most Mn-rich masutomilite yet reported. The identification of carpholite from several pockets is the first reported from the USA. One of the carpholites has the unusual composition $(K_\chi(Mn^{2+}_{2-\chi},Li_\chi)Al_4Si_4O_{12}(OH,F)_8$, and may be a new mineral species. G.W.R.

Saphire aus einem neuen Vorkommen in Madagaskar.
C.C. MIUSENDA AND U. HENN. *Gemmologie—Zeitschrift der Deutschen Gemmologischen Gesellschaft*, **45**(1), 1996, pp 13–22, bibl. 2 tables.

The commercially available blue sapphires were recovered from the Andranondambo mining area in the south-east of Madagascar and occur in altered marbles and calc-silicate gneisses. The specimens were found to be similar to those from Sri Lanka and Myanmar. Most stones were colour zoned, and homogeneously coloured examples were extremely rare. The general appearance of many of these sapphires can be improved by heat treatment. E.S.

La saga peregrina (second part).
B. MOREL. *Revue de gemmologie*, 126, 1996, pp 4–6, illus.

•Continues the story of the celebrated pearl which formed part of the French crown jewels up to the time of the Revolution. M.O'D.

California jade: a geological heritage.
A. PASHIN. *California Geology*, **48**(6), 1995, pp 147–54, illus. in colour.

Both jadeite and nephrite occur in California and some of the principal deposits are briefly described with notes on specimen quality and local geology. M.O'D.

Blue quartz from the Antequera-Olvera ophite, Málaga, Spain.
J.C. SILVA ROMERO. *Mineralogical Record*, 27, 1996, pp 99–103, illus. in colour.

Crystals of blue quartz are reported from an ophite near Málaga, Spain. Some of the crystals appear large and translucent/transparent enough to facet: they occur in an ophite (diabase with ophitic texture) found in the Triassic rocks located between the Antequera and Olvera regions of Andalusia. The blue colour is attributed to inclusions of aerinite, a calcium aluminium iron magnesium silicate carbonate of hydrothermal formation. The blue quartz crystals show an apparently dipyramidal habit whose formation is not yet accounted for. M.O'D.

Mineraleinschlüsse—Indikatoren metamorpher Reaktionen. Mineral inclusions—a clue to metamorphic reactions.
W. SCHUBERT. *Gemmologie – Zeitscrift der Deutschen Gemmologischen Gesellschaft*, 45(1), 1996, pp 5–12, 8 photomicrographs, bibl.

Detailed studies of relict mineral inclusions can document the process of mineral-forming reactions during monometamorphic or polymetamorphic events. Petrological phase analyses and thermodynamic calculations will yield information about pressure and temperature conditions and activities of water and CO_2. Various examples are given, such as prograde formation of staurolite, garnet, kyanite and corundum + albite. E.S.

Water-rock interaction on Zabargad Island, Red Sea – A case study: II. From local equilibrium to irreversible exchanges.
P.F. SCIUTO AND G. OTTONELLO. *Geochimica et Cosmochimica Acta*, **59**(11), 1995, pp 2207–13.

Reaction kinetics in the quasistationary state of the alteration paragenesis of the peridotites in

this island are tentatively assessed. The highest (-ve) reaction rates of olivine gem formation occur in the zone of the thermal maximum coupled with a high (+ve) rate of chrysotile dissolution and (-ve) tremolite production; dolomite is near a balancing condition throughout the process. R.K.H.

To the problem of nephrite-bearing properties of folded areas.
A.P. SEKERIN, N.V. SEKERINA, Y.A. LASHCHENOV AND YU.V. MENSHAGIN. *Bulletin of the Friends of Jade*, **9**, 1996, pp 147–50, 1 map.

Commercial deposits of nephrite may be either apohyperbasite nephrite whose colours are various shades of green, or apocarbonate nephrite which shows white to light green colours. Notes are given on Russian nephrite deposits in the folded framework of the Siberian platform, accompanied by a nine-entry bibliography of Russian papers. M.O'D.

The light-coloured nephrite of East Sayany.
N.V. SEKERINA, A.P. SEKERIN, YU.V. MENSHAGIN, AND V.A. LASHENOV. *Bulletin of the Friends of Jade*, **9**, 1996, pp 143–6.

Light-coloured nephrite (white with various shades) occurs in the Sayan-Baikal Mountain area of Russia, in South Australia and in China, with a small deposit in the Kuraminski mountains of Uzbekistan. The alluvial deposits of China were once the main source of light-coloured material but they are now almost exhausted. Today the best qualities from the above locations are reported to be those specimens found in the Middle-Vitim Mountain area where deposits occur in the mid-flow of the Vitim River.

A promising nephrite source in Russia is East Sayan which is geologically favourable. Notes on this and on other Russian nephrite deposits are given, with a short bibliography including six papers in Russian. M.O'D.

Recent gemstone production in North America [first part].
J. SINKANKAS. *Canadian Gemmologist*, **17**(1), 1996, pp 18–22.

In a paper presented at the CGA Conference in Vancouver, Ontario, in October 1995, the author assesses the production and resources of gem material on the North American continent, including Mexico. In this portion of the paper amber, ammolite, azurite/malachite, benitoite, beryl, calcite, coral, corundum, diamond, feldspar, fluorite, garnet, ivory, the jade minerals and lapis lazuli are discussed. M.O'D.

Notes from a Singaporean laboratory.
TAY THYE SUN. *Australian Gemmologist*, 19(4), 1995, pp 178–81, 20 illus. in colour.

A white conch pearl known locally as a 'coconut pearl' displayed the typical 'flame' patterning on a smooth porcellanous surface. A rare elephant pearl (unattached denticle), claimed to have been recovered from inside the tusk of a Sri Lankan elephant, was 18.90 mm × 16.47 mm nearly void and weighing 24.93 ct. It had an SG 1.80, a spot RI value of 1.53 and showed a chalky white fluorescence of moderate intensity to long wave ultraviolet light. An amber imitation was readily recognized as plastic and even sported a modern ant as an inclusion. A polished water-worn pebble was an aggregate containing the rare Burmese jade-like mineral kosmochlor (formerly ureyite), spot RIs of 1.54 to 1.65 and an SG 2.72 were obtained and it was inert to ultraviolet light. A thin wafer of coloured jadeite had been coated with nail polish. A star sapphire looked natural but contained gas bubbles and curved colour banding indicating a Verneuil synthetic. Synthetic cubic zirconia melee resembled diamond but the single cut stones were chipped and poorly polished; a diamond probe gave a non-diamond reaction. A diffusion-coated ruby was claimed to be manufactured in Sri-Lanka. R.J.P.

A history of pietre dure.
T. TROIANI. *Australian Gemmologist*, **19**(4), 1995, pp 186–9, 8 illus. in colour.

Pietre dure (hard stones) are mosaic pictures or patterns made from gem materials commonly siliceous substances with a Mohs hardness of 6 or 7. Examples include jasper, chalcedony, quartz, agate, petrified wood, granite and porphyry, all of which were commonly used on Florentine mosaics. This art form was developed by the Opificio delle Pietre Dure which is now the National Museum in Florence, Italy.

At the time of the Renaissance, Florence was ruled by the Medici family who controlled the city from the fifteenth century to 1737 amassing a vast collection of jewels and works of art including mosaics. Mosaics from pre-Colombian Central America had turquoise as the favourite

working material, whilst one of the oldest modern mosaics, the 'Fight of the Macedonians and Persians' was found in Pompeii and identified as a copy of a lost painting by Philoxenus in about 300 BC. The Florentine mosaics reached such perfection that not only were the joins invisible but the finished product was sometimes indistinguishable from the brush strokes of an oil painter.

Created on 3 September 1588 the large building of the Opificio delle Pietre Dure is still in existence carrying on the operation of creating and restoring works in pietre dure. R.J.P.

Jade in China.
CHUNYUNG WANG. *Bulletin of the Friends of Jade*, **9**, 1996, pp 121–42, 3 maps.

Up-to-date survey of the nephrite deposits of China with notes on the history of nephrite use and fashioning followed by a survey of Chinese deposits which are listed and described as carbonate-type or serpentine-type. Details of current nephrite production are given with particular references to Khotan jade, Manus jade, Altun jade and other deposits. A number of occurrences are described in relation to their geology and mineralogy and there is a bibliography containing references to 35 papers in Chinese, many of which are as yet unpublished, as well as Western-language items. M.O'D.

Jade in Canada.
F. WARD. *Bulletin of the Friends of Jade*, **9**, 1996, pp 1–7.

A short survey of jade deposits in Canada with particular reference to deposits, recovery and sale of nephrite from British Colombia. Useful notes on marketing are given. M.O'D.

Check-list for rare gemstones: kämmererite.
W. WIGHT. *Canadian Gemmologist*, **17**(1), 1996, pp 14–17, illus.

Review of the composition, properties, mode of occurrence and locations for the chromian clinochlore, kämmererite, occasionally cut as a gemstone. M.O'D.

Zhou-Li.
References to jade in the *Zhou-Li* or Rites of Zhou, translated and assembled from the first French version . . . 1851, by Herbert Giess. *Bulletin of the Friends of Jade*, **9**, pp 58–117.

[This is an analytical entry, the name given to a complete separate work published within an issue of a journal.]

The title-page of volume 1 of the first French translation published by Edouard Biot in 1851, precedes the complete text of the book in which small editorial changes have been carried out by the Editor of the *Bulletin*. The text deals with religious rituals in which jade ornaments played a significant part. M.O'D.

Instruments and Techniques

The hazardous effects of refractometer contact fluid. A note.
T. LINTON. *Australian Gemmologist*, **19**(4), 1995, p. 185.

The recent replacement of the Anderson and Payne refractometer fluid in the UK and USA appears to be centred on the toxic and carcinogenic nature of the tetra-iodoethene component although di-iodomethane is also extremely toxic. Liquids containing halogeno-hydrocarbons must be treated with great care and this code of practice should be advertised and ideally learnt. A liquid with a refractive index of 1.81 is said to be stable and is currently undergoing evaluation tests in Victoria. R.J.P.

Australian (1.81) refractometer fluid.
T. LINTON AND B. NEVILLE. *Australian Gemmologist*, **19**(5), 1996, pp 221–3.

During the past two years many Australian gemmologists have had to use a refractive index fluid with RI 1.79 and the recent marketing of a liquid with RI 1.81 to the original Anderson and Payne formulation has led to this appraisal. The fluid is made by saturating di-iodomethane with sulphur followed by mixing with tetraiodoethene. The mixture is filtered and washed with sodium carbonate to remove any residual acidic component which reduces the risk of etching the refractometer glass. The present liquid is light-stabilized by the addition of copper to the mixture to prevent the liquid from turning black. The toxicity of both di-iodomethane and tetraiodoethene have been examined and a code of practice drawn up for the use of liquids containing these compounds. Correct handling techniques should be taught to all users and the recommended use of disposable protective gloves appears to be highly appropriate. R.J.P.

Synthetics and Simulants

Metastable diamond synthesis—principles and applications.
C.-P. KLAGES. *European Journal of Mineralogy*, 7(4), 1995, pp 767–74.

Diamond chemical vapour deposition (CVD) technology has progressed considerably in the last 30 years; a multitude of deposition processes are now available to grow diamond films, and textured and hetero-epitaxial (on Si) deposition also has been achieved. New technological applications of diamond films, making use of their outstanding physical properties, are continuing to emerge. Simultaneously, there has been rapid progress in the understanding of which molecular species and physicochemical processes are relevant for CVD growth in the metastable diamond phase, mainly due to the development of data-bases of chemical gas phase reactions in C-H-O systems using the results of research on flames and combustion. The various growth processes and different applications of diamond films are reviewed.

R.A.H.

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BOOK REVIEWS

Geology of Pakistan.
F.K. BENDER AND H.A. RAZA (eds), 1995. Gebrüder Borntraeger, Berlin. Distributed by E. Schweizerbart'sche Verlagsbuchhandlung, Johannesstr 3A, D–70176, Stuttgart. pp x, 414, illus. and with 5 loose folding maps in colour, hardcover. DM248.00, US$178.00. ISBN 3 443 11025 8. (*Beiträge zur regionalen Geologie der Erde*. 25.)

Following the excellent *Geology of Burma* (vol 16, 1983), Pakistan takes its place in this major series for whose outstanding components the publishers deserve great credit. While gemstones have their own section, [9.4] the text in general needs to be read to find out why Pakistan has produced so many gem-quality minerals. While the text is aimed at post-graduate level or at professional geologists rather than at undergraduates, and still less at gemmology students, nonetheless it is written sufficiently clearly for all to gain something useful on a slow and careful reading. The standard of illustration (incorporating Landsat images in colour) is first-class and the large-scale loose maps go a long way towards making up for the lack of Pakistan maps in the general market. The book is divided into eleven major chapters, each with its own author.

This type of overall country coverage falls into traditional order with mineral resources coming well after preceding chapters in which regional geology and tectonic units are described. Pakistan is uniquely blessed with dramatic beginnings, arising from the collisions of the Arabian plate in the south-west with the Eurasian plate in the north and north-west and the Indo-Pakistan plate in the south-east. From these tectonic events the Pakistan portions of the Karakorum, the western Himalaya, the Pamirs and the Hindu Kush mountain ranges were formed, giving the country some of the highest peaks in the world and surrounding areas particularly difficult to access.

The volcanic activity accompanying plate movement is the prime source of the mineralization in the Northern Areas of Pakistan and it is in these areas that emerald, aquamarine, ruby, spinel, tourmaline, garnet, epidote, turquoise, moonstone and some topaz are found. The very fine deep pink to purple topaz, a naturally occurring colour unique so far to Pakistan, is found in the North West Frontier Province. We can confidently expect further species to turn up, as did peridot a year or two ago, again from a very difficult site in the Northern Areas. The recovery of many species, particularly ruby, is still at a stage where fine-coloured but small crystals or larger heavily-included ones seem to be the rule: it is very likely that fine larger crystals will appear. The present reviewer, who in 1990 co-authored the standard book on Pakistan gemstones* with Dr Ali H. Kazmi, a major contributor to the present work, was very pleased to see mention of sites visited and explored at that time and also to note how many more sites had been worked.

A good guide to the usefulness of any book is the size and content of the bibliography. Here is an exceptionally good and welcome example, covering fifty pages and including many papers of gemmological interest. I strongly recommend visiting those (few) libraries which will buy this book. M.O'D.

Minerales de las comunidades autónomas del país Vasco y Navarra.
M. CALVO REBOLLAR, F. GASCÓN CUELLO AND J.M. CAVIA ORTEGA, 1993. Museo de Ciencias Naturales de Alava, Vitoria (Alava). pp 156, illus. in colour, hardcover. Price on application. ISBN 84 7821 145 4. (*Monografías del Museo de Ciencias Naturales de Alava*. 2.)

Not all locality mineral books provide much for the gemmologist but this example is not only beautifully produced and illustrated, but includes photographs of crystals of some minerals that ought to be familiar. The crystals are shown in a manner that a gemmology text will never have space for: those who can find a copy of the book should look for the sphalerite crystal groups, for the calcite crystals and for crystals of amethyst. Perhaps best of all are the dark crystal diagrams which are included to illustrate important forms.

*[Kazmi A.H. and O'Donoghue, M., *Gemstones of Pakistan*, 1990]

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The area covered lies in the eastern Pyrenees of Spain and the geology and mineralogy are fully described, with an excellent bibliography. M.O'D.

Platinum by Cartier: triumphs of the jeweler's art. (*Translation of Cartier: joaillier du platine*, 1995.)
F. COLOGNI AND E. NUSSBAUM, 1996. Harry N. Abrams Inc., New York. pp 279, illus. in colour, hardcover. £65.00. ISBN 0 8109 3738 7.

This large and heavy book somehow suggests large, ornate and heavy pieces of jewellery made from platinum and set with the finest gemstones. The suggestion is borne out by the useful text and very high-quality colour photographs which reproduce many Cartier pieces set in platinum. The text is arranged chronologically, beginning with the garland style from its origins to 1914 and continuing with Art Deco jewellery and its geometric forms from 1915 to 1925. The next chapter describes Cartier's development of the *tutti frutti* style and of white Art Deco, together with a synthesis of eastern and western forms.

From 1940 to 1967 Cartier made naturalism one of their major themes with jewellery representing flowers and animals. Finally the new era period from 1968 towards the end of the century is marked by Cartier's use of platinum to an even greater degree and by the firm's line of new jewellery and of watches.

The book is a beautiful production, with excellent layout: there is a most useful chronology and a short bibliography. Students of jewellery design will find the colour reproduction of many Cartier designs of particular interest. M.O'D.

Wonders within gemstones: the elusive beauty of gemstone inclusions.
A. DE GOUTIÈRE, 1996. Gemworld International Inc., 630 Dundee Road, Suite 235, Northbrook, IL 60062–2750. pp vii 135, illus. in colour, hardcover. US$49.95. ISBN 0 9641733 2 8.

There is a great deal of scope for many more books on inclusions and they do not all need to instruct. This one aims to delight and succeeds very well. Over 100 large colour photographs show inclusions in a variety of gem species. The arrangement appears to follow no particular pattern and since the captions are brief, readers need only turn through the pages to interpret the scenes in any way they like. Students in particular will find the book a lift to their imaginations, a pre-requisite for any learning.

Readers interested in gemstone photography will welcome the details given by the author, who gives magnification and type of illumination for each picture and an account of technique and instruments used at the end of the main text. A brief classification of inclusions is also provided but is not really much help as the true story is far more complicated than gemmologists imagine. The list of references takes the reader a little further. One or two careless misprints do not spoil the excellent general effect and very reasonable price. M.O'D.

New frontiers in diamonds: the diamond revolution.
D. DUVAL, T. GREEN AND R. LOUTHEAN, 1996. Rosendale Press, London. pp 175, hardcover. £30.00. ISBN 1 872803 21 0.

In recent years more areas have been prospected for diamonds than ever before and stories of 'the new boom locations' have proliferated, expanded and sometimes been denied. The book first considers diamond prospecting and recovery throughout the world and then turns to Canada, where new locations are being pursued with vigour. The third section is concerned with diamond prospecting and mining on the Australian continent and asks where the successors to the Argyle enterprise may be. Finally the authors ask about trends in diamond sales and project them to the year 2000. Appendices detail total rough diamond supply, diamond production at the major mines, a forecast of world diamond supply and demand, and Antwerp prices index.

This is a well-written and provocative book with clear signs of the journalistic background of the three authors. Co-operation among diamond producers is thought to be the way in which the diamond mining world will evolve over the next few years. On the marketing side the expansion of the Asian market is cited as one of the best things to have happened to the world diamond trade, which looks reasonably healthy to the authors in 1996. M.O'D.

Amber, window to the past.
D.A. GRIMALDI, 1996. Harry N. Abrams in association with the American Museum of Natural History, New York. pp 216, illus. in colour, hardcover. £36.00. ISBN 0 8109 1966 4.

Although in size and general appearance the

book might be assumed to have a slight and insignificant text, this is not the case and the book successfully combines zoological, botanical, palaeontological and gemmological information, most of which has been brought up-to-date by specialists in those fields. While not setting out to be a gemmological textbook, the student will be stimulated to find out more about a material which is often not well covered by standard texts and the connoisseur will find delight in the items depicted in the first-class colour and black-and-white photographs. The book first discusses the nature and properties of amber and introduces non-amber resins from the start: there is a good deal of information on contemporary resins and I found this part useful.

The text then describes the major amber deposits of the world covering Mesozoic, Tertiary, Baltic, Dominican Republic and Mexican material: the tree species involved in amber production, the insect and other populations of amber and the topical discussion of DNA from amber inclusions are all worked through before amber imitations and forgeries are described.

The second section describes the use of amber in art and proceeds in chronological order from the Mesolithic period through the Bronze Age to classical, medieval, renaissance and 17th–19th century artefacts. There are sections on the Amber Room and on Asian ambers.

The book ends with a quite useful bibliography. It can be recommended for a wide readership and the price is by no means high for a book of so high a standard. M.O'D.

Vases and volcanoes. Sir William Hamilton and his collection.

I. JENKINS AND K. SLOAN, 1996. British Museum Press for the Trustees of The British Museum, London. pp 320, illus. in colour, softcover. £25.00. ISBN 0 7141 1766 8.

Sir William Hamilton is known to connoisseurs for his collections, formed in Naples where he was British Ambassador, and to the public at large for his second wife Emma who eventually became the mistress of Horatio, Lord Nelson. Hamilton's time in Naples coincided with a flowering in that city of all kinds of cultural activities. At that time, too, eruptions of Vesuvius and the discovery of the buried city of Pompeii resulted in the discovery of antiquities on a large scale. Hamilton made collections which included objects recovered from Pompeii together with a large number of artefacts of all kinds: they were offered to the British Museum in 1772 for £8,400, a large sum for those days. So large an acquisition helped to broaden the collections of the Museum which had hitherto been richer in written and printed materials and in natural history. Hamilton's gifts to the Museum continued for many years and the objects he brought there became one of the sources of a growing interest in classical times and their artistic productions.

While the catalogue contains examples of polished rocks and lava from Vesuvius, gemmologists and historians of ornament will take considerable interest in the items of jewellery that Hamilton collected. His first bequest included a few cameos though more came to the Museum later on. From the latter group James Tassie selected some items for reproduction in both sulphur and white glass impressions: the catalogue illustrates some of the finest original cameos and also two trays of sulphur impressions attributed to Tassie. The collections also contained groups of Egyptian scarabs and sealstones as well as of hardstones set in rings and of intaglios.

Each item described in the catalogue is well illustrated with the expected high standard of photography and reproduction. Details of size, type and provenance are given and full references are made to supporting literature. The book ends with a glossary and a general bibliography. This is an excellent starting-point to any study of British interest in classical antiquities.

M.O'D.

Mineralogy of Maine. Vol. 1. Descriptive mineralogy.

V.T. KING AND E.E. FOORD, 1994. Maine Geological Survey, Department of Conservation, Station #22, Augusta, Maine 04333, USA. pp xi. 418, illus. in colour, softcover. US$40.00. inclusive of postage.

While this account of the minerals of Maine needs consideration as a location mineralogy, gemmologists will (or should) equate Maine with tourmaline and purple apatite and sure enough a photograph of apatite from the Pulsifer quarry at Auburn is on the front cover. Turning to the illustrated section, the book breaks new ground by including a set of excellent black-and-white pictures of mineral specimens, among which are crystals of a number of gem species. The colour photographs naturally include Mount Mica and Dunton quarry (Newry) tourmalines and show once more what beautiful

crystals they are. Gemmologists once having seen the pictures should look for a bibliography and here we have a very comprehensive one.

The bulk of the text is occupied by the descriptive section in which Maine mineral species are arranged and described in alphabetical order. While name and chemical composition are given, details of properties are not exhaustively covered, the text giving copious details of Maine occurrences and references instead. This is a wise decision since locality information of this quality might very well not find an alternative outlet and access to papers in which a particular species is fully described should not be too difficult. For elbaite there are 25 pages of occurrence description! Where crystal morphology is of particular interest, however, the entries include diagrams.

There is an index and an alphabetical list of townships down to the smallest identifiable places: the list is accompanied by a map on which the print is rather small – my only criticism of an excellent book whose second part I await eagerly. M.O'D.

Le diamant dans tout son éclat.
F. KOSTOLANY, 1992. Hachette, Paris. pp 159, illus. in colour, hardcover. £33.50. ISBN 2010166183.

A general survey of diamond with examples of set jewellery, loose stones and crystals, the whole book well-illustrated in colour but with an overall dark appearance which begins with the end-papers showing colourless faceted diamonds against a black background. From stories of diamond in the East the text ranges over the properties which make the stone desirable, famous diamonds and the diamond market, to accounts of important pieces of diamond-set jewellery. The last chapters deal briefly with imitations of diamond and ends with a quiz with interesting and useful questions. There is a very short bibliography.

While the book is one of many such, the presentation is attractive and the illustrations good. M.O'D.

Collectable beads: a universal aesthetic.
R.K. LIU. 1996. Ornament Inc, Vista, California [distributed in the UK by Thames and Hudson]. pp 256, illus. in colour, hardcover. £30.00. ISBN 0 9641023 0 7.

The study of beads has been helped by more than one book published in the last few years and while they have been of variable quality, all have contained useful text and attractive pictures. This example is particularly well illustrated and the text concise and carefully matched to the photographs. The coverage is arranged by area: thus Africa, China and Taiwan, the Indian sub-continent and its near neighbours, the Pacific countries, the Middle East and North Africa, Precolumbian Americas, the Americas and Europe. The book ends with illustrations of contemporary necklaces and beads, with fakes and simulations and with notes on bead collecting. There is a really first-class bibliography, a useful glossary and a short list of bead-collecting organizations, not confined to the United States.

At the price you could hardly do better than this: while the text is naturally not aimed at the scholar, some readers will be sufficiently inspired to take their studies further and while one or two entries in the glossary are not quite accurate, the mistakes are slight and the book as a whole is well worth buying. M.O'D.

The Amber Room. [A novel.]
C. MATTHEW, 1995. Sinclair-Stevenson, London. pp 390, hardcover. £14.99. ISBN 1 85619 447 7.

Some interesting and probably accurate details are given of the history of the Amber Room, once a feature of Pushkin, Russia. Included among descriptions of the fairly hectic activities taking place are notes on amber as an ornamental material, on its various imitations and how they may be detected. M.O'D.

Environmental geology.
B.W. MURCK, B.J. SKINNER AND S.C. PORTER, 1996. John Wiley & Sons Inc., New York. pp xviii, 535, illus. in colour, softcover. £19.99. ISBN 0 471 30356 9.

Gemmologists looking for a textbook which explains geological formations on Earth, the solar system and planetary evolution, the dynamic Earth, mineral formation and properties, volcanic eruptions, energy resources and how to make use of them and a whole range of allied topics will find an excellent coverage in this undergraduate-level textbook whose main theme is the environment. Readers should not be put off by the title: in the various sections, some at first sight not immediately applicable to minerals, let alone ornamental species, is a great deal of information of the 'I always wanted to know

what that meant' kind. As so often happens, consulting a foreign topic enlightens dark areas of your own field of study. The study of gemstones can easily become a parochial subject – there is an Earth outside. M.O'D.

Diamond ring buying guide. [fifth edition.]
R. NEWMAN, 1996. International Jewellery Publications, Los Angeles. pp 140, illus. in colour, softcover. US$14.95. ISBN 0 929975 24 3.

This book improves on its predecessors, which are also of high quality, by the inclusion of chapters on the filling of diamond and on synthetic gem-quality diamonds. The colour photographs, too, have been revised and now include examples showing how diamonds are graded – these are the best I have seen – and of a selection of setting styles. As always, chapters end with some pertinent questions (all placed together at the end this time), there is a useful bibliography and the author displays a genuine talent for spotting just the points you want to know, unlike most computer manuals which invariably miss just that one thing! M.O'D.

The gold jewelry buying guide.
R. NEWMAN, 1993. International Jewelry Publications, Los Angeles. pp 172, illus. in colour, softcover. US$19.75. ISBN 0 929975 19 7.

Another book by Renée Newman in the excellent *Newman's Gem guides* series, this study of the buying and selling of all types of gold jewellery should join its companions on the counter and in the loftiest of salerooms. Few books can be read from end-to-end but I found it possible to do so in this instance. Gemmologists will find the wealth of information on gold and on the setting of stones in and with gold fills a serious gap left by almost all gemmological texts.

The book begins with a survey of gold as a precious metal, describing systems of weighing, a brief note on hallmarks, a list of terms used for imitation gold, followed by descriptions of nugget gold jewellery and decorative finishes. The chapter ends with a quiz, an arrangement used in all the *Newman's Gem guides* and very useful.

The next chapter describes manufacturing methods, including lost-wax casting, stamping, electroforming, hand fabrication and handmade jewelry and succeeding chapters deal with judging the mounting and the setting and with gold chains. Gemmologists will be interested on 'real gold or fake?' and in determining carat value. Final sections of this first-rate book cover gold colours, gold coin jewellery, valuing gold jewellery and how to look after it. There is a short bibliography, and the coloured and black-and-white pictures are workmanlike. If you don't know which type of chain is the most difficult to repair properly (I didn't know) you should buy this book. Gemmologists should buy it anyway. M.O'D.

Chaumet, master jewellers since 1780.
D. SCARISBRICK, 1995. Alain de Gourcuff Editeur, Paris. Distributed by Art Books Distributors Ltd, P.O. Box 281, Lincoln, LN1 2AT. pp 366, illus. in colour, hardcover in lidded and hinged box. £125.00. ISBN 2 909838 10 2.

Drawing on the rich archives of the firm, this is the scholarly study *par excellence* of a major jewellery house. Chaumet's account books date back to 1836 and the archives also contain drawings, models and pieces of jewellery. The firm were jewellers to Napoleon, who enabled a slightly obscure jeweller and watchmaker, Marie-Etienne Nitot, to become one of Europe's greatest nineteenth-century craftsmen and retailers. Beginning with a commission to catalogue the jewels and other ornamental possessions of Marie-Antoinette, Nitot later asked that confiscated valuables should be kept as teaching examples for the jewellery makers. This successful suggestion shows Nitot's rise from a position of influence from 1793, the date of the commission, to that of the acknowledged Napoleonic jeweller: his commission to make the consular sword marked a point from which he never looked back. His parures, Scarisbrick tells us (and the illustrations emphasize the message) were outstanding for their brilliance, using gemstones and pearls in profusion: he was able to draw on the Trésor de la Couronne, formerly dispersed and later largely reunited on Napoleon's orders and he also acquired a number of stones, celebrated at the time, by shrewd bargaining with officials and trade rivals, his progress continuing to attract the interest and patronage of the Emperor.

This wonderful beginning sets the scene for a series of celebrated productions – the Consular Sword and jewels for the Empress Josephine and her successor the Empress Marie-Louise. But Nitot did not only create magnificent jewels for French Imperial and aristocratic wearers: his reputation led to commissions for a tiara for Pope Pius VII and for Maximilian I of Bavaria's crown.

Such progress could not have been possible without the recruitment of the best craftsmen and Nitot clearly recognized excellence in this field when he encountered it. With this and with judicial marriages the firm retained the premier position as jewellers to the Empire until it ended in 1814.

The end of the Empire also marked the firm's transfer by bequest to Fossin, the head of the workshop. Jean-Baptiste Fossin and his son Jean-Jules François Fossin continued to produce fine jewellery over the period from the Bourbon restoration to the fall of the July Monarchy. Sculptors as well as jewellers, the Fossons served the new aristocracy well and opened a branch in London which was to be visited by Queen Victoria in 1849 when some sales were made by its owner, Jean-Valentin Morel, who had followed his father Prosper, successor to Jules Fossin. The branching-out of the business away from France was due not only to London's pre-eminent position in the trading world but to a decline in French sales during and after the revolution of 1848.

In 1875 Marie Morel married Joseph Chaumet, thus introducing a name inevitably destined to become associated with the concept of the finest jewellery. Chaumet was a jewellery craftsman of the highest order who made a serious study of gemstones and pearls. The work of Chaumet quickly increased its sales world-wide and the firm prospered until the war of 1914 which slowed business down. After 1918 there were not many years in which to aim for pre-war levels of prosperity and the depression in 1929 forced the closure of the New York office which had opened only five years before. The London shop re-located to cheaper premises but gradually things improved, designs keeping in touch with changes of fashion and managing to achieve a simplicity which matched that of contemporary clothes.

A similar slow-down and regeneration followed the second world war. In 1987 Jacques and Pierre Chaumet resigned from their joint managing directorships and the company is now controlled by an international financial group: its present name is Chaumet International SA. Fine jewellery is still made and sold.

This is a magnificent account of one of the world's great jewellers. The text is uniformly lucid and the illustrations, depicting both jewels, designs and personages are the best quality possible today: the type-face is especially readable. There are exhaustive references to both pieces and archives and there is a good bibliography.

In its attractive lidded box, the book could almost be one of Marie-Etienne Nitot's own productions. M.O'D.

Exploring Australia's mining heritage. A visitor's guide.

W.G. SHACKLETON AND M.N. BINNIE, 1995. Osmond Earth Sciences, P.O. Box 658, Kent Town, South Australia 5071. pp 118, illus. in black-and-white, softcover. Overseas orders US$14.95 plus US$5.50 economy airmail or US$3.40 sea mail. ISBN 0 949116 05 X.

The title somewhat conceals a very useful directory of Australian mine sites and mining museums, arranged by state and then alphabetically. Each entry gives means of access, telephone number, contact names and telephone numbers, hours of opening and other facilities. Many sites are illustrated. Among those likely to be of interest to gemmologists are several in the Anakie sapphire district in Queensland, the Lightning Ridge and White Cliffs opal districts in New South Wales and the Andamooka and Coober Pedy opal mine sites in South Australia. Mineral collectors will find almost all the entries useful, many dealing with gold mines. The book concludes with a chronological table of significant dates in Australian mining history, a glossary of mining and mineral treatment terms and a short bibliography. A second edition is promised for mid–1996 and will certainly be welcome, since there must be far more sites to cover! This is a well-produced book and very competitively priced. M.O'D.

Jewelry in Europe and America: new times, new thinking.

R. TURNER, 1996. Thames and Hudson, London. pp 144, illus. in colour, softcover. £14.95. ISBN 0 500 27879 2.

Published to mark the occasion of the exhibition *Jewelry in Europe and America: new times, new thinking*, this book briskly covers the periods 1940–1980 in America, 1945–1970 in Europe (recovery and reconstruction), 1970–1980 (cross-currents in Europe) and finally the present time – 'in pursuit of savage luxury'. These headings suggest an idiosyncratic choice of pieces, a choice made all the more critical by the relatively small size of the book. A preliminary section introduces and explains the choice of items included, which are well reproduced. There is a

comprehensive bibliography and brief biographical notes on the artists whose work is included in the exhibition. As a study of jewellery trends this is a good starting-point. M.O'D.

Fabergé in America.
G. VON HABSBURG, 1996. Thames and Hudson, London. pp 366, illus. in colour, hardcover. £32.00. ISBN 0 500 01699 2.

An exhibition *Fabergé in America* was organized by the Fine Arts Museums of San Francisco and the Fabergé Company during 1995 and is scheduled to tour the United States during 1996. The present book is a catalogue of the exhibition (celebrating the 150th anniversary of the artist's birth) and contains a great deal of biographical and commercial information as well as the catalogue itself.

In the catalogue each item is illustrated in colour, the entry giving provenance, bibliography, exhibitions, details of the work and materials used, name of maker and workshop, date of manufacture and size. The quality of the illustrations is excellent. Two most valuable appendices deal with 'Fauxbergé' (forged artefacts) and how to recognize them (the New Brunswick Museum received a gift of 100 such items in the 1980s and was caught out, later displaying false and genuine items side-by-side as a courageous comeback). Some of the false objects are illustrated here. The second appendix describes acquisitions made by Americans at Fabergé's London shop 1907–1917.

American readers will of course find the book essential but at the very competitive price I can recommend it to all students of jewellery. M.O'D.

Fashion beads.
S. WITHERS, 1996. Thames and Hudson, London. pp 128, illus. in colour, hardcover. £12.95. ISBN 0 500 01697 6.

A pleasantly-written and well-illustrated book which covers its subject in a painless and imaginative way. The aim is that readers will learn to make their own decorative beadwork and jewellery on the basis of 45 designs taken from the jewelled artefacts of different periods and civilizations and in this the author succeeds. The standard of illustration is good, especially for the very reasonable price. M.O'D.

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J. Gemm., 1996, 25, 3. 246–250

Proceedings of the Gemmological Association and Gem Testing Laboratory of Great Britain and Notices

PHOTOGRAPHIC COMPETITION

The third GAGTL Photographic Competition on the theme 'Images in gems' attracted a record entry with a large number of beautiful pictures. After considerable deliberation the judges awarded the three prizes as follows:

First Prize – Mr S.J.A. Currie, FGA, of New Zealand
Square-eyed owl on a branch (see front cover)

Second Prize – Mrs H. Hubberstey, FGA, of Northern Ireland
'Hummingbird' in amber

Third Prize – Mr R.J. Maurer, FGA, DGA, of Redhill
Flower carved in amethyst

The three prize winners receive awards of £100.00, £75.00 and £50.00 respectively and plans are advanced to include these pictures and a selection of other fine entries in the 1997 GAGTL calendar.

Second prize

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ISSN: 1355-4565

Third prize

OBITUARY

Antonio C. Bonanno FGA, MSA, MGA

We are sad to report the death on 28 March of Antonio C. Bonanno after a long illness. He was 79 and for more than 50 of those years was a leader in the field of gemmology. 'Tony' Bonanno was one of America's best loved and most respected gemmologists.

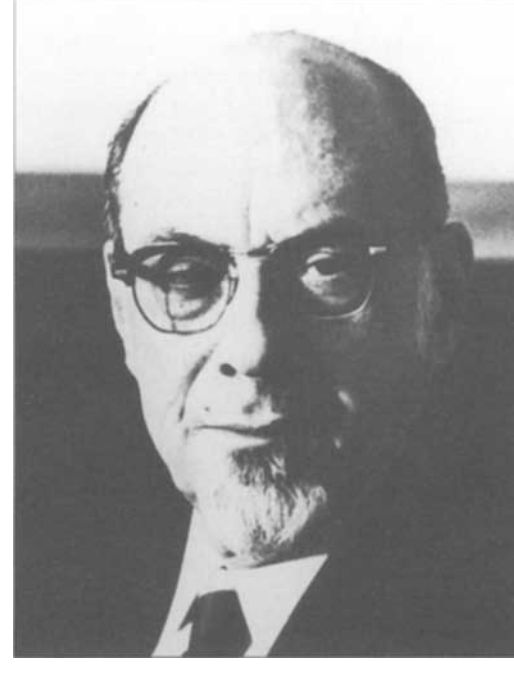

His accomplishments reflect a lifelong love of gems and jewellery, a passion for scientific research and education, and a commitment to honesty, integrity, and high standards. During World War II he created a special vocational training programme teaching lapidary and gemmology to disabled veterans. A native Washingtonian, he founded one of the country's first schools of gemmology over 40 years ago, Columbia School of Gemology in Washington, DC, and one of the country's first gem testing laboratories, National Gem Appraising

Laboratory. He served as Director of both until the onset of his illness. He appraised and taught beyond the call of duty, giving his precious, valuable knowledge to anyone who asked for it. In addition to the laboratory and school, he was Co-Editor of the Gemology Column for *National Jeweler* magazine from 1986–1994, and co-authored four highly acclaimed books in the field. He was a specialist in forensic gemmology and was active in many local, national, and international gem, mineral and lapidary organizations. In 1974 he founded the Accredited Gemologists Association (AGA), a national organization committed to expanding education and establishing standards of professional and ethical conduct in the field of gemmology. A distinguished Fellow of the Gemmological Association of Great Britain and Master Gemologist Appraiser of the American Society of Appraisers, he was also a chemist, photographer and appreciated the great outdoors.

He is survived by his wife Ruth Bonanno of Fredericksburg, VA, two sons, four daughters, one granddaughter, four grandsons and two great-granddaughters.

This tribute was assembled from contributions by Anne Ferrara Dale and Stuart Matlins.

Miss Jillian Glen, FGA, DGA (D. 1980, DGA 1981), London, died on 20 April 1996.

Mr Frederick E.J. Hewitt, FGA (D. 1956), Ormskirk, died on 1 May 1996.

GIFTS TO THE ASSOCIATION

The Association is most grateful to the following for their gifts for research and teaching purposes:

Joris Hofelt, FGA, of Utrecht, The Netherlands, for hyalite from the Czech Republic.

Mrs Ameena Kaleel, FGA, D.Gem.G., of Mount Lavinia, Sri Lanka, for specimens of corundum, sinhalite, rutile, kornerupine, spinel, quartz and tourmaline.

Yasushi Takahashi, FGA, Kofu, Japan, for anorthite crystals from Miyake Island, Tokyo, and Yoichi, Hokkaido, Japan.

Jesse Williams for garnet, rough and faceted, from northern Idaho, USA.

NEWS OF FELLOWS

After ten years working in the laboratory, Nick Sturman is leaving the GAGTL to take up a position with the Bahrain Government in their gem testing laboratory. For the past four years Nick has been seconded to the Bahraini laboratory from the GAGTL and has been a regular contributor to the *Journal* with his Notes from the 'Gem and Pearl Testing Laboratory, Bahrain'.

Michael O'Donoghue gave a talk on synthetic and treated gemstones to the Wessex branch of the National Association of Goldsmiths on 24 April 1996.

MEMBERS' MEETINGS

London

On 3 April 1996 at the Gem Tutorial Centre, 27 Greville Street, London EC1N 8SU, Arthur Woolgar gave an illustrated talk entitled 'Bringing gems to the market place'.

On 30 April at the Gem Tutorial Centre Mr S. Akamatsu of K. Mikimoto & Co. Ltd. gave an illustrated talk entitled 'Cultured pearls: past present and future'. A report of the talk was published in *Gem and Jewellery News*, 1996, 5, 3.

On 8 May at the Gem Tutorial Centre Dr Jamie Nelson gave a talk and demonstration entitled 'Identifying inclusions within gemstones'.

On 10 June at the Gem Tutorial Centre the Annual General Meeting was held, followed by a Reunion of Members and Bring and Buy. A full report of the AGM will be published in the October issue of the *Journal*.

On 14 June the Annual Trade Luncheon was held in the Portland Suite of the Langham Hilton Hotel, Portland Place, London W1. The speaker was Mr Naim Attallah, formerly Group Chief Executive of Asprey's. A report of his address will

appear in the September issue of *Gem and Jewellery News*.

Midlands Branch

On 26 April at the Discovery Centre, 77 Vyse Street, Birmingham 18, the Annual General Meeting was held at which Gwyn Green and Elizabeth Gosling were elected Chairman and Secretary respectively. The AGM was followed by a talk by Mr D.H. Ariyaratna.

On 19 May members visited the Dolgellau Gold Mine in north Wales.

Gem Clubs were held on 14 and 28 April and 5 May.

North West Branch

On 15 May at Church House, Hanover Street, Liverpool 1, Rosamond Clayton delivered an illustrated presentation entitled 'Jade past and present' to a packed house. The opening notes were on the ancient history of jade, its uses in acts of worship, power, status, ritual activities (4000 BC to AD 1000), and on the proper excavation of jadeite (eighteenth century). Amongst exceptional pieces of jewellery with fine carvings shown on slides were necklets, bangles, hair ornaments and brooches. Auction prices for some of the pieces ranged from £650 to above £120,000. Items dated from as early as 221 BC to the present time.

Retailers, registered valuers, students and other interested persons attended the talk. Some of those present had brought items to determine their authenticity, and some pieces were passed around for closer inspection of particular features.

Scottish Branch

A weekend of Scottish gemmology was held in Perth on 19 to 21 April. The Annual General Meeting was held on 20 April when Brian Jackson and Joanna Thomson were elected Chairman and Secretary respectively. Talks and practical sessions were given by Alan Hodgkinson and the weekend culminated in a field trip to quarries near Dundee where members were able to collect agates and quartz specimens. A full report of the weekend was published in *Gem and Jewellery News*, 1996, 5, 3.

On 19 May a lapidary session was held at the National Museum for Scotland Research Centre, Edinburgh, when members had the opportunity to cut the specimens they had collected on the field trip.

1996 CALENDAR

On the October page of the 1996 calendar we regret that an error occurred in the caption to the illustration, which should read 'Carved rubellite lip perch brooch by Stephen Webster. Photograph by Robert J. Maurer, FGA, DGA'. We apologize for this confusion.

ANNUAL REPORT

The following is the report of the Council of Management of the GAGTL for 1995.

The Gemmological Association and Gem Testing Laboratory of Great Britain (GAGTL) is a company limited by guarantee and is governed by the Council of Management. E.M. Bruton continued as President, and A.E. Farn, D.G. Kent and R.K. Mitchell are Vice Presidents. The activities of the company benefited greatly from the contribution of other major Councils and Committees; Dr G. Harrison Jones continued as Chairman of the Board of Examiners, D.G. Kent retired from the Board after sixteen years' service and three new appointments were made: Ms A. Good, Mrs C.J.E. Hall and Mrs G. Howe. C. Winter continued as Chairman of the Members' Council and D. Gann took over the Chair of the Trade Liaison Committee from J. Kessler. The annual Education Review Meeting provided a very useful forum to exchange information between teachers, examiners and staff of the Association and is of great benefit in monitoring progress.

During 1995 the GAGTL continued to grow and can report a successful financial year. The Laboratory was completely refurbished and a new X-ray machine was installed to maintain and develop its world-renowned expertise in pearl identification. The licence to issue GIA diamond grading reports came to an end in September and a programme to promote the London Diamond Report has commenced; in addition the Laboratory continues to issue CIBJO reports. Identification and origin reports for rubies, sapphires and emeralds continue to form a significant part of the Laboratory's work. After 16 years with the Laboratory E.C. Emms resigned from GAGTL at the end of November to pursue his own interests and the Council wishes him every success in the future.

The GAGTL staff member N. Sturman, seconded to the Gem and Pearl Testing Laboratory in Bahrain, continues to provide a valuable, fully active service and, in collaboration with staff of that Laboratory, produced an account of highlights of their work which was published in the *Journal of Gemmology*.

The gemmology courses established in 1994 at the Gem Tutorial Centre in Greville Street are fully subscribed for the academic year 1995–6. The members' evening study and research group, led by M.J. O'Donoghue, is also expanding and a very successful members' tour of Idar Oberstein was conducted in March. Travelling workshops were held in Scotland, Ireland and England, and an expanded programme is planned.

There was an increase of 8 per cent in students entering for the examinations in 1995 and pass rates in the preliminary Gemmology and Gem Diamond examinations were higher than in 1994. In contrast, the Diploma in Gemmology examinations produced lower than average results and the Tully Medal was not awarded.

Gemmological Instruments Limited occupies a designated area on the second floor of the Greville Street building where visitors can buy and receive advice on the instruments, stones and books on display. Turnover compared with 1994 showed a slight increase, and it is felt that there is room for expansion; a shop window has been installed at street level and efforts will be made to increase both home and overseas business by mail order.

The GAGTL again exhibited at the American Gem Trade Association Fair in Tucson, Arizona, and also at the International Jewellery Fair in Basle, Switzerland. Education staff also attended the Hong Kong jewellery Fair in September before visiting the Allied Teaching Centre in Wuhan, People's Republic of China, where I.F. Mercer presented diplomas to candidates successful in the GAGTL examinations.

The theme of the GAGTL annual conference in October was 'Gemmology in Britain'. Alan Hodgkinson opened the conference with 'The Gemstones of Scotland'

FORTHCOMING MEETINGS

London

Unless otherwise stated, meetings will be held at the GAGTL Gem Tutorial Centre, 27 Greville Street (Saffron Hill entrance), London EC1N 8SU. Entry will be by ticket only at £3.50 for a member (£5.00 for non-members) available from the GAGTL.

4 September	**The importance of gems in Brazil's development**	John Kessler
20 November	**The mystery of opal**	David Gallaghan
4 December	**Burmese gems at the Natural History Museum**	Cally Hall

GAGTL Conference
Exceptional Gems

The 1996 Annual Conference is to be held on Sunday 13 October at the Scientific Societies Lecture Theatre, New Burlington Place, London W1.

Extraordinarily beautiful and rare gemstones and methods of cutting to produce a truly outstanding specimen have inspired the theme of this year's Conference 'Exceptional gems'. The keynote speaker will be Dr H. Bank from Idar-Oberstein, Germany.

As well as a full programme of lectures, delegates will be able to enjoy displays of the gemmology of exceptional stones.

For further details contact Mary Burland on 0171–404 3334.

Midlands Branch

Monthly meetings will be held at the Discovery Centre, 77 Vyse Street, Birmingham 18 (directions to the Sunday Gem Club available on request). Further details available from Gwyn Green on 0121–445 5359.

27 September	**The Beta appraiser; a new computer program for valuers**	John Henn
25 October	Talk by Eric C. Emms	

North West Branch

Meetings will be held at Church House, Hanover Street, Liverpool 1. Further details from Joe Azzopardi on 01270 628251.

18 September	**Brush up your gemmology**	Deanna Brady
16 October	**Second-hand and antique jewellery, and all you need to know about it**	Richard Digby
20 November	**Annual General Meeting**	

Scottish Branch

For details of Scottish Branch meetings contact Joanna Thomson on 01721–722936 or Ruth Cunningham on 0131–225 4105.

and the British theme was continued by Helen Fraquet with the 'Amber of East Anglia' and then David Lancaster on 'Victorian gem-set jewellery'. Stephen Kennedy described the new X-ray set and its use in the London Laboratory and Ian Mercer reviewed the early days of gemmology in England. With 'Gemmological eye-openers', Alan Hodgkinson rounded off a full day's programme attended by members and visitors from 14 countries.

The presentation of awards was again held at the Goldsmiths' Hall by kind permission of the Worshipful Company of Goldsmiths. The President, E.M. Bruton, was in the chair, and the successful students in the gemmology and gem diamond examinations received their diplomas and prizes from the author and well-known gemmologist P.G. Read.

A revived Scottish Branch commenced its meetings programme in the spring and they, the Midlands and the North West Branches have all had a successful year.

Gem and Jewellery News, the joint production of GAGTL and the Society of Jewellery Historians, continues to be a lively forum for news of interest to our members, and the *Journal of Gemmology* continues to attract and publish papers on new materials and ideas in gemmology. Volume 24 was completed in October and with 624 pages is the largest to date.

The 1995 GAGTL photo competition produced a very good response and, again, what were judged to be the best contributions were reproduced in the calendar for 1996, which was distributed free to all members. Membership continues to increase and at 31 December stood at 3600.

The Council of Management wishes to thank all the staff for their dedication and hardwork throughout the year, and is indebted to all those who volunteered their time and expertise so willingly to serve on the many committees.

GEM DIAMOND EXAMINATIONS

In January 1996 19 candidates sat the Gem Diamond Examinations overseas of whom 12 qualified. The names of the successful candidates are listed below:

Chan Kwok Keung, Kowloon, Hong Kong.
Cheng Tak Min, Kowloon, Hong Kong.
Cheung Sung, NT, Hong Kong.
Francis Chow Chun Wai, Kowloon, Hong Kong.
Jin Lunwen, Wuhan, China.
Lam Kwai Fat, NT, Hong Kong.
Lee Yuan, Wuhan, China.
Li Liping, Wuhan, China.
Li Zihui, Wuhan, China.
Lo Lai Shan, Kowloon, Hong Kong.
Ng Wai Man, Kowloon, Hong Kong.
Yip Yick Hing, Brenda, Kowloon, Hong Kong.

The UK candidates who qualified were published in the April issue of the *Journal*.

EXAMINATIONS IN GEMMOLOGY

The names of the successful overseas candidates, additional to those published in the April issue of the Journal, who sat the Examinations in Gemmology held in January 1996, are as follows:

Qualified with Distinction

Ding Qian, Suzhou, China.
Liu Xu, Wuhan, China.
Mao Yanying, Wuhan, China.
Wu Yaoxing, Wuxi, China.

Qualified

Yik Pun Chan, Hong Kong.
Chan Kar Ming, Grace, Kowloon, Hong Kong.
Chan Yue Kwan, Joyce, NT, Hong Kong.
Binghui Chen, Guangzhou, China.
Chu, Terry, Kowloon, Hong Kong.
Guan Zichuan, Wuhan, China.
Hao Hui, Wuhan, China.
He Lin, Wuhan, China.
Ho Suk King, Betty, Kowloon, Hong Kong.
Hsieh, Chung Wei, Taipei, Taiwan, ROC.

GAGTL GEM TUTORIAL CENTRE

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Price £47.00; GAGTL students £33.49 (including sandwich lunch)

10 October **Introduction to Gemstones**
A day to look into the beautiful world of gemstones. Hold the gems in your hand and discover the individual qualities and characteristics that make them so prized.
The price is only £47.00 for the day (including sandwich lunch)

30 October **Enquire Within : Emerald**
A valuable and concentrated look at all aspects of emerald: natural rough and cut stones, treated, synthetic and imitation stones.
Price £111.63 (including sandwich lunch)

5 and 6 November **Synthetics and Enhancements Today**
Are you aware of the various treated and synthetic materials that are likely to be masquerading amongst the stones you are buying and selling? Whether you are valuing, repairing or dealing, can you afford to miss these two days of insights, tips and practical investigation?
Price £223.25 (including sandwich lunches)

20 November **Review of Diploma Theory**
A day for Gemmology Diploma students to review their theory work and to prepare for the Diploma theory examinations. Find out about our tips on the consolidation and revision of facts, figures, principles, practical techniques and instruments.
Let us help you to review your examination technique with the help of past questions. This review would help students who intend to enter the Diploma examination in 1997.
Price £33.49 (including sandwich lunch)

27 November **Enquire Within : Ruby and Sapphire**
A day looking at all aspects of these gems – natural, treated, synthetic and imitation.
Price £111.63 (including sandwich lunch)

7 and 8 December **Weekend Diamond Grading Revision**
This intensive weekend course has been designed for all students about to take the Gem Diamond Diploma. This workshop will include a mock examination to help students gain familiarity and confidence with examination conditions.
Price £129.25

NOTE: All prices include VAT at 17.5%

Please ring the Education Office (0171–404 3334) for further information

Lam Yiu Ming, Tsing Yi, Hong Kong.
Leung Siu Ha, Sue, Mongkok, Hong Kong.
Liao Zongting, Shanghai, China.
Lim Sau Kuen, Hong Kong.
Lin Xuefang, Wuhan, Hubei, China.
Luo Huabao, Wuhan, Hubei, China.
Ma, Annie Yiu-Chu, Hong Kong.
Ma, Sui Shan Tina, NT, Hong Kong.
Ma, Lien-Chen, Taiwan, ROC.
Qiu, Zhili, Guangzhou, China.
Tang, Deping, Wuhan, China.
Tian, Liangguang, Wuhan, China.
Xu, Hainan, Wuhan, Hubei, China.
Yan Chun Wai, Danny, NT, Hong Kong.
Yang, Ruzeng, Wuhan, China.
Yao, Teng-Long, Taipei, Taiwan, ROC.
Yeh, Chen-Mei, Taipei, Taiwan, ROC.
Yuyan, Yuan, Wuhan, Hubei, China.
Zeng, Chunguang, Shanghai, China.

MEETINGS OF THE COUNCIL OF MANAGEMENT

At a meeting of the Council of Management held on 10 April 1996 at 27 Greville Street, London EC1N 8SU, the business transacted included the election of the following:

Transfers – FGA to FGA/DGA

Chan, Kwok Keung, Kowloon, Hong Kong. 1994/1996
Lee, Yuan, Wuhan, Hubei, China. 1995/1996

Transfer – DGA to FGA/DGA

Chan, Yik Pun, Hong Kong. 1996/1995

Fellowship

Can, Cao, Anhui, China. 1995
Clay, Gretchen, Boston. 1995
Crawley, Annette, Thingwall,Wirral. 1975
Dempster, Stuart, Glasgow. 1996
Fleischner-Zois, Krista, Athens, Greece. 1996
Grondin, Magali, Geneva, Switzerland. 1996
Lam, Yiu Ming, Hong Kong. 1996
Luo, Yi Guang, Xi, China. 1995
Ma, Sui Shan, Tina, NT, Hong Kong, 1996
Mathon, Andries Petrus Theresia, Oosterhout, The Netherlands. 1996
Morris, Clive Raphael, Berkhamstead. 1961
Song, Gyu Bong, Kyungnam, Korea. 1996
Yan, Chun Wai, Danny, NT, Hong Kong. 1996

Transfers – Ordinary Membership to FGA

Ma, Annie Yiu-Chu, Hong Kong. 1996
Yao, Teng-Long, Taipei, Taiwan. 1996

Ordinary Membership

Chan, Lam Wing, Hong Kong.
Fahller, Ingegerd, Lulea, Sweden.
Hopley, Katharine, Coventry.
Huysser, Isabelle, Vught, The Netherlands.
Lodge, Tim, London.
Lundin, Margareta, Taby, Sweden.
Quintner, Flora, Grays.
Ramirez-Achinelli, Soledad, Skogas, Sweden.
Satariano, Lee, Msida, Malta.
Shaikh, Zakir, London.

Laboratory Membership

Marcus McCallum, London EC1N 8JY.

At a meeting of the Council of Management held on 15 May 1996 at 27 Greville Street, London EC1N 8SU, the business transacted included the election of the following:

Diamond Membership

Fukushima, Katsue, London. 1995
Lam, Kwai Fat, Hong Kong. 1996
Lo, Lai Shan, Kowloon, Hong Kong. 1996

Diamond Membership and Fellowship

Lewis, Rachel, Stockport. 1988/1989

Fellowship

Ang, Zen Yi, Singapore. 1996
Chan, Kar Ming, Grace, Kowloon, Hong Kong. 1996
Chan, Yue Kwan, Joyce, Hong Kong. 1996
Chu, Yin Yee, Terry, Kowloon, Hong Kong. 1996
Cunningham, DeeDee Cecilia, Toronto, Ont., Canada. 1996

Guo Xiaodan, Beijing, China. 1995
Leung, Siu Ha, Sue, Kowloon, Hong Kong. 1996
Lim, Sau Kuen, Hong Kong. 1996
Limaye, Mukund Dattatraya, Calcutta, India. 1996
McFarlane, Iain Scott, Chesham. 1996
Warren, Philip Arthur, Bolton-le-Sands. 1967
Welch, Lizanne, Taunton. 1991
Yeh, Chen Mei, Taipei, Taiwan. 1996
Zhang, Liangju, Guilin, China. 1990

Ordinary Membership

Batchelor, Philip Stephen, Dartford.
Campbell, Suzan, Morden.
Charles, Bruce, Llanelli, Dyfed.
Fenemore, Gerald, London.
Feng, Hsiu Yun, Taichung, Taiwan.
Godoy Ranirez, Aura, Madrid, Spain.
Hooke, Gina Marie, Cullompton.
Hoskins, Robert, Falls Church, VA, USA.
Hugo, Philippe Antoine M., Kortryk, Belgium.
Iannicelli, Marco, London.
Lin, Chief, Kaohsinng, Taiwan
López Sedó, Javier, Madrid, Spain.
Martini de Brum, Tania Mara, Rio Grande do Sul, Brazil.
Vafai, Khatereh, Tehran, Iran.
Wang, Chien-Ling, Taichung, Taiwan.

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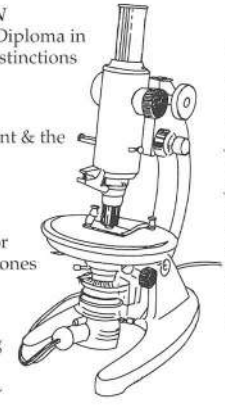

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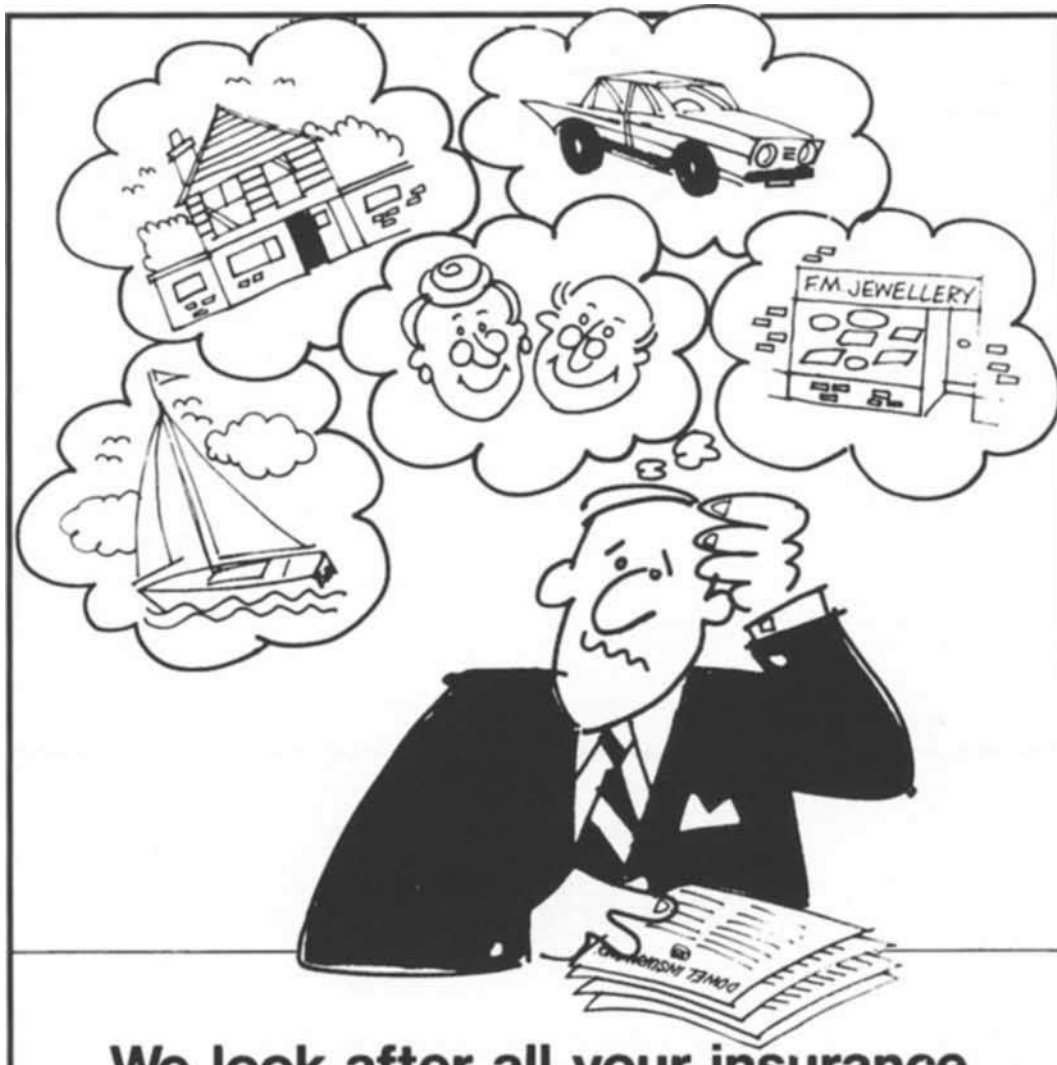

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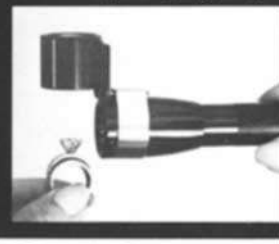

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GEMSTONES OF THE WORLD

Guide to the preparation of typescripts for publication in *The Journal of Gemmology*

The Editor is glad to consider original articles shedding new light on subjects of gemmological interest for publication in *The Journal*. Articles are not normally accepted which have already been published elsewhere in English, and an article is accepted only on the understanding that (1) full information as to any previous publication (whether in English or another language) has been given, (2) it is not under consideration for publication elsewhere and (3) it will not be published elsewhere without the consent of the Editor.

Typescripts Two copies of all papers should be submitted on A4 paper (or USA equivalent) to the Editor. Typescripts should be double spaced with margins of at least 25mm. They should be set out in the manner of recent issues of *The Journal* and in conformity with the information set out below. Papers may be of any length, but long papers of more than 10 000 words (unless capable of division into parts or of exceptional importance) are unlikely to be acceptable, whereas a short paper of 400–500 words may achieve early publication.

The abstract, references, notes, captions and tables should be typed double spaced on separate sheets.

On matters of style and rendering, please consult *The Oxford dictionary for writers and editors* (Oxford University Press, 1981).

Title page The title should be as brief as is consistent with clear indication of the content of the paper. It should be followed by the names (with initials) of the authors and by their addresses.

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Headings In all headings only the first letter and proper names are capitalized.

A **This is a first level heading**

First level headings are in bold and are flush left on a separate line. The first text line following is flush left.

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Illustrations Either transparencies or photographs of good quality can be submitted for both coloured and black-and-white illustrations. It is recommended that authors retain copies of all illustrations because of the risk of loss or damage either during the printing process or in transit.

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Tables Must be typed double spaced, using few horizontal rules and no vertical rules. They are numbered consecutively with Roman numerals (Table IV, etc.). Titles should be concise, but as independently informative as possible. The approximate position of the Table in the text should be marked in the margin of the typescript.

Notes and References Authors may choose one of two systems:

(1) The Harvard system in which authors' names (no initials) and dates (and specific pages, only in the case of quotations) are given in the main body of the text, e.g. (Gübelin and Koivula, 1986, 29). References are listed alphabetically at the end of the paper under the heading References.

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Cover Picture

Fine gem quality rubellite crystal, 75 mm long, from the Cruzeiro mine, Minas Gerais, Brazil. See 'The location, geology and mineralogy of gem tourmalines in Brazil' on pp. 263–98

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New President

Professor Howie receiving his Badge of Office from Vivian Watson, Chairman at the AGM.

At the Annual General Meeting of the Gemmological Association and Gem Testing Laboratory held on 10 June,* Eric Bruton stepped down from his two-year term as President and handed over his badge of office to the incoming President, Professor R.A. Howie.

Bob Howie graduated in Natural Sciences at Cambridge university and followed this with a doctorate on Indian metamorphic rocks, graduating in 1952. After a period at Manchester University, he moved to King's College, London, and was appointed to a personal chair in mineralogy in 1972. He was President of the mineralogical Society in 1978–80 and since 1966 has edited *Mineralogical Abstracts*, being responsible for a prodigious output of information in a digestible and relevant form appreciated throughout the world.

Countless students and professional geologists have perhaps most appreciated his involvement with W.A. Deer and J. Zussman in producing *Rock-Forming Minerals* and a condensed version *An introduction to rock forming minerals*. This work was published in five volumes in 1962 and with the later edition has been an integral part of the tremendous growth of activity in the earth sciences in the last three decades.

A lifelong interest in gemstones has found expression in lectures to a wide range of audiences and his presidency will reinforce the strong links that the Gemmological Association and the Laboratory have always had with King's College.

* A report of the Annual General Meeting and the President's address are published on pp 312–14.

The location, geology and mineralogy of gem tourmalines in Brazil

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Abstract

A comprehensive survey of Brazilian gem tourmalines, mainly green, blue, pink and red elbaite, including their gemmological properties and significant inclusions is given. The tourmalines are recovered from granitic pegmatites and detrital deposits. Tourmaline-bearing pegmatites, which commonly are lens-shaped, are variable in their strike and dip, and show a range of patterns of zoning and albitization. Wallrocks are mica schists, quartzites or rarely granite or gneiss, all Precambrian in age. The pegmatites occur either singly or in fields or clusters and belong to the Brazilian tectonic cycle (650–450 m.y.). Five types of gem-bearing pegmatites are described:

- poorly differentiated, almost homogeneous, with small albitic replacement bodies;
- poorly differentiated with strong albitization;
- zoned with small albitic replacement bodies;
- zoned with strong albitization;
- lithium-rich, very well zoned, with strong albitization.

Gem tourmalines occur in the inner parts of the pegmatites, on each side of a quartz core or concentrated in pockets, which are variable in shape and size, as are the crystals that they contain. The tourmaline-bearing pegmatites mainly consist of K-feldspar variably perthitized, albite, muscovite and milky quartz with some lepidolite, schorl and locally huge tabular crystals of spodumene. Accessory minerals are listed for different localities.

The main area producing tourmaline is the 'Eastern pegmatitic province' of Minas Gerais. One general and three detailed maps of specific areas show the location of the tourmaline deposits, and their regional zonation and age are briefly examined. Short descriptions are given for the most important pegmatites, and methods of prospecting and working, generally by hand, are discussed.

Weathering of tourmaline-bearing pegmatites produces detrital deposits, eluvial and alluvial. Only eluvial deposits sometimes yield deposits of economic worth and they also are worked by hand.

Non-pegmatitic deposits of tourmaline include the Brumado mine (Bahia) which produces fine red uvite crystals and the Serra Branca prospect (Paraíba) which produces large black dravite specimens.

Keywords: Tourmaline, pegmatite, eluvial deposits, gem mining, Brazil

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Introduction

Tourmaline is one of the most remarkable coloured gemstones mined in Brazil where, erroneously, for a long time it was marketed as Brazilian emerald, peridot, sapphire and chrysolite. Hardness, relatively high specific gravity and chemical resistance explain the abundance of its occurrence: tourmaline is found mainly in metamorphic rocks, quartz veins and granite pegmatites which produce the bulk of the gems. Therefore the deposits are many and have been the subject of a range of publications from old compilations to recent travel records (e.g. Ferraz, 1929; Calmbach, 1938; Putzer, 1956; Proctor, 1985a, 1985b). However, geological reports on the deposits are rare and as a result, our purpose is to summarize the main geological and mineralogical features of the tourmaline deposits, both primary and secondary, and to examine the gems produced.

Tourmaline has no industrial application and is mined only to recover crystals suitable for cutting and use in jewellery, or for other ornamental purposes, or less commonly for collectors. Tourmaline is the name given to a group of borosilicates of general formula: $WX_3Y_6(BO_3)_3Si_6O_{18}(O,OH,F)$ where W = Ca, K, Na; X = Al, Fe^{2+}, Fe^{3+}, Li, Mg, Mn^{2+}; Y = Al, Cr^{3+}, Fe^{3+}, V^{3+} (Fleischer and Mandarino, 1995). The most sought after varieties, green and blue (indicolite) or pink and red (rubellite), are traditionally referred to as elbaite $Na(Al,Li)_3Al_6(BO_3)_3Si_6O_{18}(OH)_4$; and the brown varieties are referred to as dravite $NaMg_3Al_6(BO_3)_3Si_6O_{18}(OH)_4$ or uvite $(Ca,Na)(Mg,Fe^{2+})_3Al_5Mg(BO_3)_3Si_6O_{18}(OH,F)_4$.

Tourmaline is the gem with the widest array of colours. This is due to the many isomorphic substitutions that occur and explains why only the colour is taken into account during transactions by miners, lapidaries and jewellers. Chemical analysis of a tourmaline sample aiming at an accurate mineralogical identification requires complex equipment which is neither accessible nor economically justifiable for daily trading. In this paper the mineralogical species will not be specified but, in common with daily use, the tourmaline will be described by means of its colour.

Tourmaline is trigonal hemimorphic and Brazilian elbaite (rubellite) was used by Ito and Sadanaga in order to determine its structure in 1951. Tourmaline commonly occurs as long, vertically striated prisms, with some crystals reaching up to one metre in length. Crystals show a rounded triangular cross-section with 3, 6 or 9 main faces, and flat or complex terminations with pyramids of 3, 6 or more faces, commonly irregularly developed or asymmetrical. Short crystals, thin tablets, needles, radiating parallel, stacked and irregular crystal groups are common as are compact or felty (asbestiform) masses (Coelho, 1948) (Figure 1) identical to those reported from California (Jahns and Wright, 1951). Tourmaline pebbles and gravels are common. Twins are rare, but some are reported by Madelung (1883) and Frondel (1948). Crystallographic reviews of tourmaline forms were published by Reimann (1907) and Goldschmidt (1923).

The streak is colourless and lustre is vitreous to waxy. Crystals are transparent, translucent or opaque. Elbaite is pink or green, also colourless, red, orange, yellow, blue, purple, white or black (which is smoky purple when strongly illuminated – Prescott and Nassau, 1978). Elbaite from Paraíba displays outstanding blue, purple, green and light purple colours. The colour is either homogeneous or shows variations within the crystal. Multicoloured tourmalines exhibit either one or more fairly regular patterns of colour zoning or irregular, patchy arrangements of their diverse hues. Regular patterns of zoning may be either perpendicular to the *c*-axis (roughly parallel to the pedion face) or parallel to *c* (roughly parallel to prism faces such as {1010} or {1120}. For example, along *c* green or blue may gradually pass to pink or dark blue, or a pink termination is separated from a green prism by a colourless zone.

Fig. 1. Fibrous tourmaline crystals upon quartz, from the São José da Safira region. Sample is 130 mm long.

Occasionally contrasting hues succeed one another as in the famous 'parrot' tourmalines from the Itatiaia deposit, near Conselheiro Pena (Minas Gerais), where up to five distinct colours occur along the main axis. Tourmaline exhibiting the zoning parallel to prism faces with pink centres and green rims are widely referred to as 'watermelon' tourmalines. The opposite arrangement also occurs. Zoning around the *c* axis may consist of repeated alternations of colour such as black-green-black-green or blue. Transitions between differently coloured zones have been reported to range from abrupt (Foord and Mills, 1978) to gradual over a few microns to a few millimetres, and these differences are possibly due to sudden changes in conditions of growth (Wagner *et al.*, 1971). Within individual pockets, all crystals, large and small, tend to exhibit zoning with essentially identical colour sequences.

Fracture is usually recorded as conchoidal to uneven, all specimens being brittle. The predominant fractures are roughly parallel, uneven, more or less perpendicular to the *c*-axis, but differ from the {0001} cleavage reported by Dunn *et al.* (1977) in liddicoatite. It is important for lapidaries to recognize the potential fracture locations because such fractures surround globular to subspherical zones called 'nodules'. They are essentially flawless and constitute especially valuable gemstone material. In some Brazilian deposits miners have found long crystals of tourmaline cracked in sections that can be broken apart with the fingers and then 'peeled' like an onion to obtain the small clear nodules present in the core of each section (Sinkankas cited by Dietrich, 1985). In the Barra da Salina area (Minas Gerais) where the nodules are common they have been called 'bolinhas' by the miners.

Cleavage is frequently reported as lacking in tourmaline. However, very poor (indistinct) cleavages may be present, one parallel to {1120} and another parallel to {1011} (Dietrich, 1985) in addition to that on {0001} mentioned above.

Hardness is 7 to 7.5. Specific gravity varies according to the colour, ranging

from 3.03 to 3.10 for elbaite. Values for particular colours are pink to reddish = 3.01–3.06, pale green = 3.05, dark green = 3.08–3.11 and blue = 3.05–3.11.

Tourmaline is uniaxial and optically negative. Refractive indices for elbaite are: α = 1.603 to 1.634 and β = 1.619 to 1.655, with a birefringence of 0.013 to 0.024 (Arem, 1987). Dispersion is 0.017. Dichroism is most pronounced in green crystals. Refractive indices of crystals from one deposit show a range depending on colour and probably on their place in the sequence of deposition within the pegmatite. Thus this property cannot be used to determine the source of a gem tourmaline. Commonly colour saturation correlates with indices of refraction for both pink and green elbaites, i.e. the more intense the colour, the higher the indices of refraction as previously noted by Dunn (1975b).

Foord and Mills (1978) reported that biaxiality occurs in deformed crystals and in strained and cracked zones with birefringence visible when the tourmaline was viewed along the *c*-axis; 2V values up to 20° and an extinction pattern similar to that shown by twinned microcline may be present. Some cut and faceted stones may exhibit more than two shadow edges on a refractometer; this is due to overheating or to thermal shock during polishing (Mitchell, 1976).

The spectrum is generally weak. In green crystals the red part of the spectrum is almost completely absorbed up to 640 nm and the yellow and green are freely transmitted except for a faint absorption region near 560 nm. There is a fairly strong and narrow band centred at 497–498 nm (due to ferrous iron) which is accompanied by a weaker band at 468 nm. In blue and in some green crystals a strong band is observed at 415 nm. Pink and red tourmalines show a broad absorption in the green region centred about 525 nm accompanied by a narrow band at 537 nm and two lines at 458 and 450 nm due to manganese (Webster, 1970). The turquoise-blue stones from São José da Batalha (Paraíba) exhibit two strong absorption bands at 698 and 524 nm, the first produced by Cu^{2+} and the second by Mn^{3+}. The green tourmaline from the same locality exhibits only two bands, both due to Cu^{2+} at 920 and 698 nm.

Some pink tourmalines fluoresce under short wave ultraviolet radiation. The fluorescence colour differs from specimen to specimen and has been recorded as ranging from inert to faint chalky blue (Beesley, 1975) but some pink and red crystals exhibit a lavender glow.

Some fibrous tourmalines exhibit chatoyancy. Those of a good quality and colour can be cut as cabochons to make fine cat's-eyes (Figure 2). The chatoyancy depends upon the presence of fibrous inclusions of other minerals or channels, hollow or filled with fluids, that are typically aligned parallel or subparallel to the *c*-axis. It is widely thought that the hollow tubes predominate. Bhaskara Rao and de Assis (1968) stated that the chatoyancy of some elbaites from north-eastern Brazil can be attributed to channel leaching.

Fig. 2. A set of cabochon tourmaline cat's-eyes. (*Photo: F.A. Becker*)

Pseudomorphs after tourmaline are relatively common and consist of partial to total replacement by lepidolite and/or muscovite, with or without a clay mineral. They have been reported from north-eastern Brazil (Bhaskara Rao and de Assis,

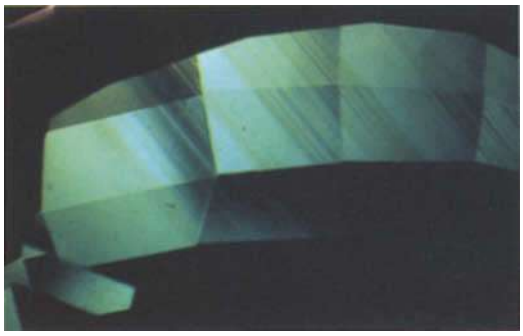

Fig. 3. Very fine channels in a transparent green cut tourmaline.

1968) and are plentiful in tourmaline deposits in Minas Gerais. In some occurrences the mica plates appear as if they were plastered on the tourmaline – they commonly have their basal planes parallel or nearly parallel to the faces of the underlying, typically partially replaced tourmaline.

As in beryl, the principal element of the crystal structure consists of rings of six SiO_4 tetrahedra which are connected by interstitial ions in a layered manner. The characteristic forms of the internal features arise from this structural architecture: as with beryl the tendency to develop growth tubes is based on the specific arrangement of the silica rings (Figure 3). The layered nature of the lattice on the other hand, leads to a tendency for the crystal to break and crack parallel to the basal plane (a poor cleavage), thus encouraging the formation of syngenetic, secondary liquid inclusions (Gübelin and Koivula, 1986). The syngenetic secondary fluid residues in the partially healed fractures form fibre-like capillaries plaited in nets, which have earned the name 'trichites' on account of their hair-fine appearance. These trichites are deemed as highly diagnostic characteristics of tourmaline and occur in all the varieties examined, but are particularly common in rubellite (Figures 4 and 5). Under strong magnification the tell-tale threadlike inclusions reveal themselves as two-phase inclusions consisting of a

Fig. 4. Trichites in a cut rubellite from the Laranjeira mine (Coronel Murta).

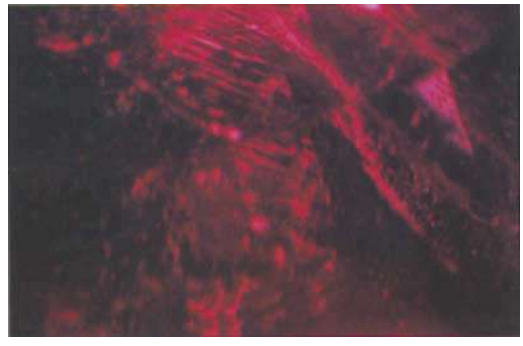

Fig. 5. Trichites in a cut rubellite from the Laranjeira mine (Coronel Murta).

watery phase with its vapour bubble. Otherwise trichites resemble undulating long and fine hairs, or inclusions consisting of very small triangular cavities with two predominant faces joined with a liquid network. The trichites occur either singly or in groups comprising interlaced net-

Fig. 6. Bicolour cut tourmaline with mica flakes in the green zone and fibres in the pink zone. Sample from the São José da Safira area.

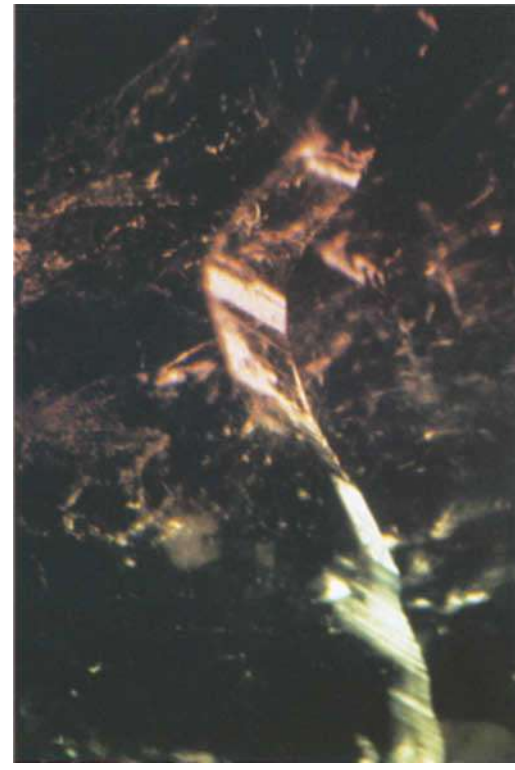

Fig. 7. Growth boundary intersecting colour zones in a cut tourmaline.

works; they commonly cross colour-zone boundaries with no interruption, as reported by Gübelin (1979). In watermelon specimens from the Minas Gerais deposits transitions between green zones with densely packed fibres and pink zones with irregular trichites are common (Figures 6, 7 and 8).

Remnants of the mother-fluid and/or secondary associated minerals (cookeite or actinolite for instance) commonly fill the growth channels running parallel to the *c*-axis, and can be considered as the cause of chatoyancy (Figure 9).

When present, fluorapatite occurs in euhedral transparent yellow or colourless crystals. It is a pegmatitic mineral and is a protogenetic or syngenetic inclusion in tourmaline.

Muscovite in pink tourmalines shows flashes of bright interference colours from its cleavages when illuminated obliquely from above.

Other solid inclusions are albite, hematite, hornblende, pyrite and rutile; quartz is rare. Small dendritic plates of native copper and tenorite are distinctive of the São José da Batalha tourmalines (Paraíba – Brandstätter and Niedermayr, 1994) (Figure 10).

Three-phase inclusions do occur in complex healed fractures but are not common. Some films or fractures displaying iridescence may appear opaque in transmitted light. Cracks and fissures perpendicular to the *c*-axis are common in crystals from all deposits (Figure 11). Cracks filled with gas and carbonaceous flakes occur sporadically in rubellite crystals.

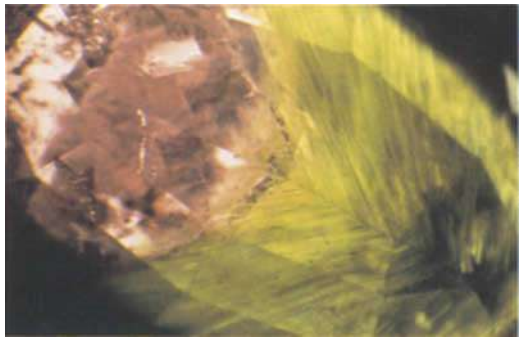

Fig. 8. Bicolour cut tourmaline with a channel-rich green section. Sample from Minas Gerais.

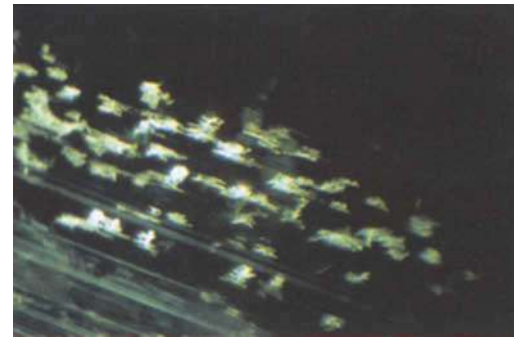

Fig. 10. Jagged plates of native copper in a green tourmaline crystal. These inclusions are characteristic of the tourmalines from the São José da Batalha mine (Paraíba).

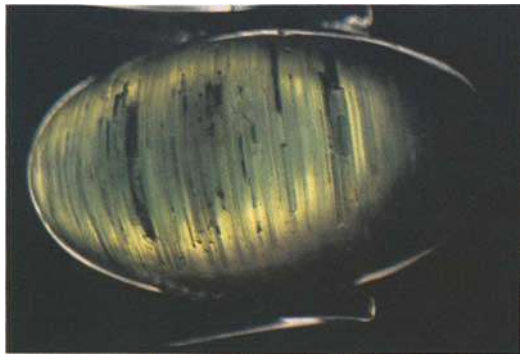

Fig. 9. Cat's-eye green tourmaline cabochon showing the many channels responsible for its chatoyancy.

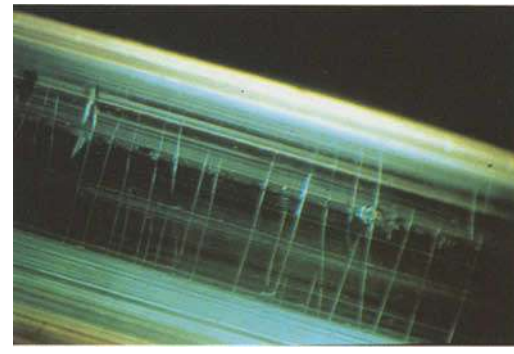

Fig. 11. Cracks perpendicular to the *c*-axis in a green gem quality tourmaline.

Tourmaline as an inclusion

Tourmaline is also a common inclusion in other minerals. In particular it has been reported in:

- quartz (called 'graphite' by miners). Milky or transparent, euhedral or anhedral, quartz occurs widely with clusters of needle-like tourmaline crystals or with tiny isolated tourmaline needles. This material is widely used for ornamental purposes and always originates from pegmatites. Both tourmalinated and rutilated quartz have been called 'Venus hairstone';
- quartz with helvite. Tourmalinated quartz from Governador Valadares contains helvite tetrahedrons which terminate some of the schorl filaments and grunerite needles (Dunn, 1975a; Gübelin, 1976);
- hydroxylherderite, in the Virgem da Lapa pegmatitic area (Cassedanne and Lowel, 1982);
- beryl; in the fine morganite crystals from the Urucum pegmatite (Cassedanne, 1986);
- various micas, as needles (Araçuaí area) or very thin large plates (Boa Vista pegmatite near Galiléia, Minas Gerais);
- apatite (Linópolis area, Minas Gerais);
- fluorite (Pedra Redonda pegmatite near Mantena, Minas Gerais);
- loellingite, as dark green tourmaline needles (Urucum pegmatite).

Fig. 12. Collection of mixed cut tourmalines, the largest piece weighing 17 ct.

Fig. 13. A lot of blue cut tourmalines from São José da Batalha (Paraíba). *(Photo: F.A. Becker)*

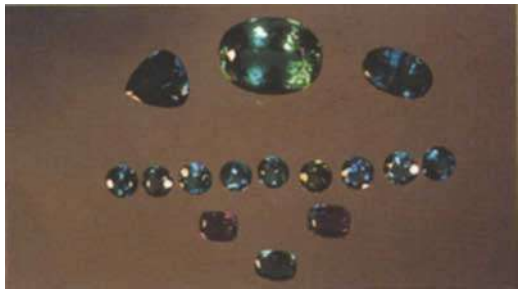

Fig. 14. A lot of mixed coloured tourmalines from São José da Batalha (Paraíba). *(Photo: F.A. Becker)*

As in aquamarine, the colour is commonly relatively even throughout a tourmaline crystal and may be heat treated to enhance the original shade. However, contrary to aquamarine, in the heat treatment process the maximum temperature is more important than the duration of the heating. The final colour becomes visible during cooling which may be controlled. For instance, tourmaline called 'batata roxa' (purple potato), purplish-brown to purplish-blue turns into a faint pink by heating between 250 and 400°C (or for some crystals up to 600°C). Green and blue tourmalines are heated up to 600–700°C in order to 'abrir a cor', that is to say to clarify them or to make them more lustrous. Because of its many inclusions rubellite cannot be treated in this manner. From the Barra da Salina area (Minas Gerais) brown crystals which are a mixture of bluish-green and rose hues are likely to turn light blue after heat treatment. Some tourmalines withstand heating up to 725–750°C, but this operation is hazardous due to partial recrystallization at 780°C, and the stones may require repolishing.

Irradiation

Irradiation changes the colour of many tourmalines. As early as 1926 Stamm noted that, after exposure for 25 days to 125 mg of radium bromide ($RaBr_2$), blue and green Brazilian tourmalines remained unaltered whilst the green and brown varieties became darker. In the same way, Newcomet (1941) reported that green tourmaline turns darker after exposure to Ra. Vargas and Tupinambá (1962) pointed out that the saturated green colour induced in the laboratory may be lightened by heating, as can be done for natural dark colours. Today irradiation is a routine procedure in changing the colour of many tourmalines: pale pink crystals turn into a very fine red (particularly the specimens from the Formiga deposit, Minas Gerais), blue and dark green crystals turn yellow, pink (peach blossom – Barra da Salina, for instance) or purplish (Nassau, 1984).

Relatively abundant and practically without cleavage, tourmaline is a very popular mineral. Nevertheless rough crystals are commonly cracked and gem material is rare, which explains why faceted stones of 10 ct and over are relatively scarce on the market. However some museums and private collections possess cut specimens of more than 100 ct. The darker shade of

this strongly dichroic mineral is generally oriented in the direction of the optic axis. Thus stones with their tables cut parallel to the *c*-axis are lighter than those where the table is perpendicular to the same axis. In a range of cutting styles, the commonest is the baguette cut, but emerald, round, oval, barrel-shaped, navette (drop and briolette) styles are used for the transparent stones. Chatoyant material is fashioned as cabochons, and translucent stones are polished into pearls and beads (Figures 12–16). Large pieces of rough containing some gem material are used for carving as sculptures, ashtrays, amulets and animals (Figure 17).

The large tourmaline deposits (in northern Minas Gerais) and the bulk of the smaller ones, all originating from pegmatites, are located in a narrow ellipse running NNW-SSE and bounded by the towns of Salinas in the north and Conselheiro Pena in the south (compare the aquamarine bearing area described by Cassedanne and Alves, 1992–1994). This ellipse, sometimes referred to as the 'tourmaline bearing basin' (Gonsalves, 1949), is centred upon the 18°S parallel and the 42°W meridian and limited by the Rio Araçuaí in the north-west, the boundary between the states of Minas Gerais and Bahia, the highway BR 116 to the north of Teófilo Otoni, the boundary between the states of Minas Gerais and Espirito Santo in the south-east, the Rio Doce to the south and finally the Rio Suaçuí to the south-west (Figure 18). The whole region belongs to the 'Oriental pegmatitic province' of Paiva (1946). Elsewhere deposits are either smaller (including the famous Paraíba pegmatite), not presently mined or abandoned. See Figures 25, 27 and 33 for locations of the mines and occurrences; the former have all been visited and the latter have in part been derived from the literature.

Resistant to weathering, tourmaline is commonly preserved in eluvial deposits, the soils overlying the pegmatites, which form from their weathering. Some workings exhausted the eluvium before entering the underlying pegmatite (Laranjeira and Poço d'Anta deposits near Taquaral, Santa Rosa, etc.), others are restricted to the eluvium (Ouro Fino deposit, Minas Gerais). The present output of this type of deposit is much lower than that from hard or weathered pegmatites. Some alluvial flats surrounding tourmaline-bearing pegmatites, are worked by garimpeiros

Fig. 15. Set of cut rubellites from the Ouro Fino mine, the largest weighing 5 ct *(Photo: ICA/Bart Curren)*

Fig. 16. Pendant of fine green tourmaline of 28 ct mounted with diamonds in 18 ct. gold.

Fig. 17. Two birds carved in multicoloured tourmaline. *(Photo: F.A. Becker)*

(prospectors), and they recover rounded fragments of tourmaline commonly associated with a little beryl, gahnite, topaz, amethyst and chrysoberyl (as in the Córrego do Fogo, near Malacacheta, Minas Gerais). But, compared to aquamarine (Cassedanne and Alves, 1991), tourmaline alluvial deposits are of little economic significance, probably because any large crystals that survive are always very cracked.

For a long time, the State of Minas Gerais has been famous both for the exceptional size of its gem quality tourmaline crystals (for example, in the Virgem da Lapa and Conselheiro Pena areas) and for the large number of tourmaline-bearing pegmatites and eluvium. Currently it is probably the foremost world producer of this gem. In contrast to aquamarine, large crystals are very rare, and prisms or pieces of prisms up to 0.3 metres long are commonest, albeit in large quantities. Named tourmaline crystals are rare and only the giant rubellites from the Jonas deposit, near Itatiaia (Conselheiro Pena, Minas Gerais), have been given names such as Flor de Lírio, Rosa do Itatiaia, etc. The discovery of a gem accumulation that may weigh up to hundreds of kilograms, either in pockets or in eluvium, leads to a temporary rush of garimpeiros to the new deposit. Legends, fabulous or perhaps exaggerated journalistic stories may arise from a succession of outstanding finds that sometimes degenerate into armed conflicts, as in the Golconda area near Governador Valadares, before World War II.

Tourmaline-bearing pegmatites

Most pegmatites are chemically and mineralogically similar to granites, and consequently are commonly known as granite or acid pegmatites.

In order to clarify subsequent descriptions, the evolution of a pegmatite crystallizing from a magma richer in volatile and rare elements than the original magma will be

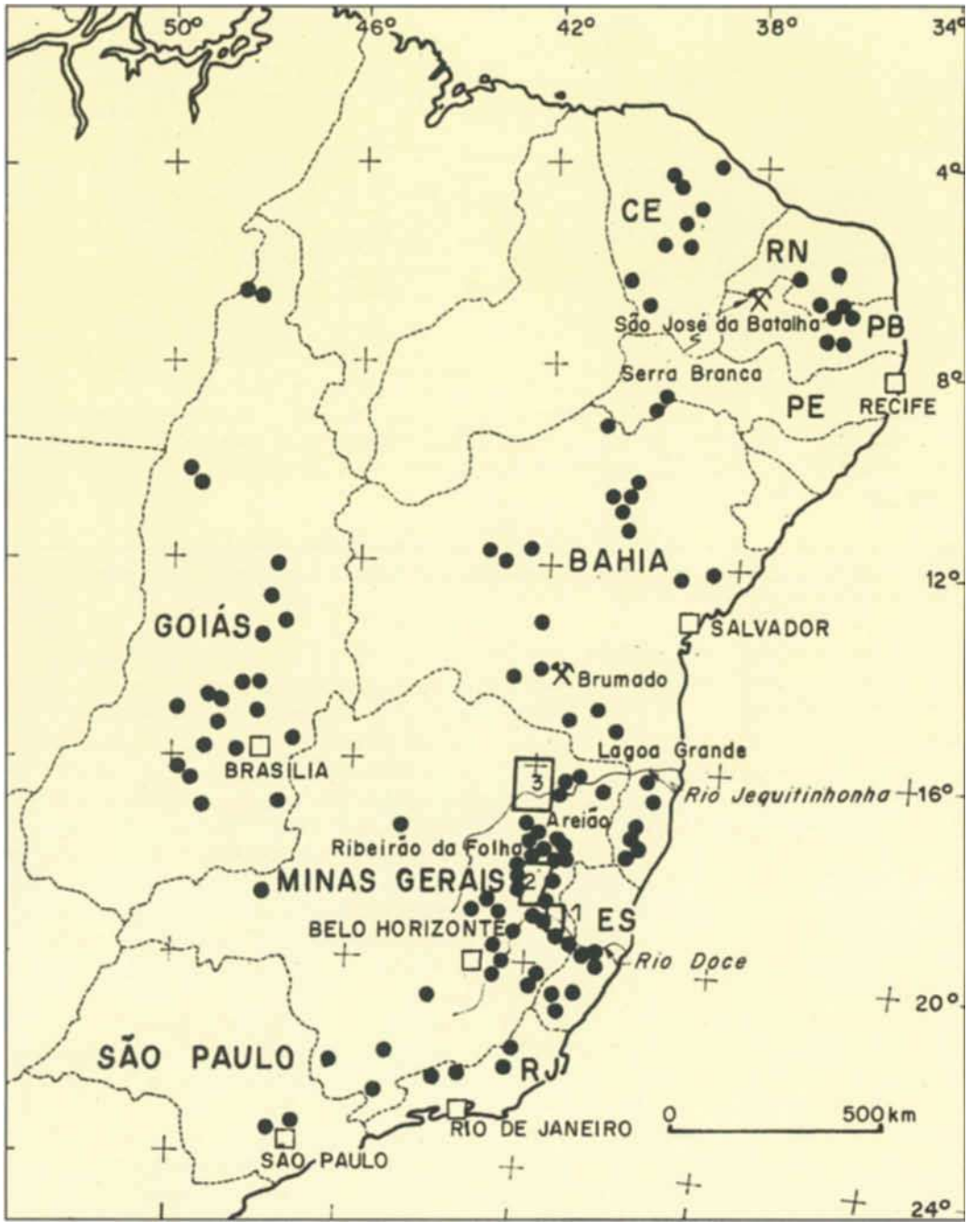

Fig. 18. Brazilian tourmaline occurrences and mines. Numbers refer to detailed area maps. Letter symbols for states are: CE = Ceará, ES = Espirito Santo, PE = Pernambuco, PB = Paraíba, RJ = Rio de Janeiro and RN = Rio Grande do Norte.

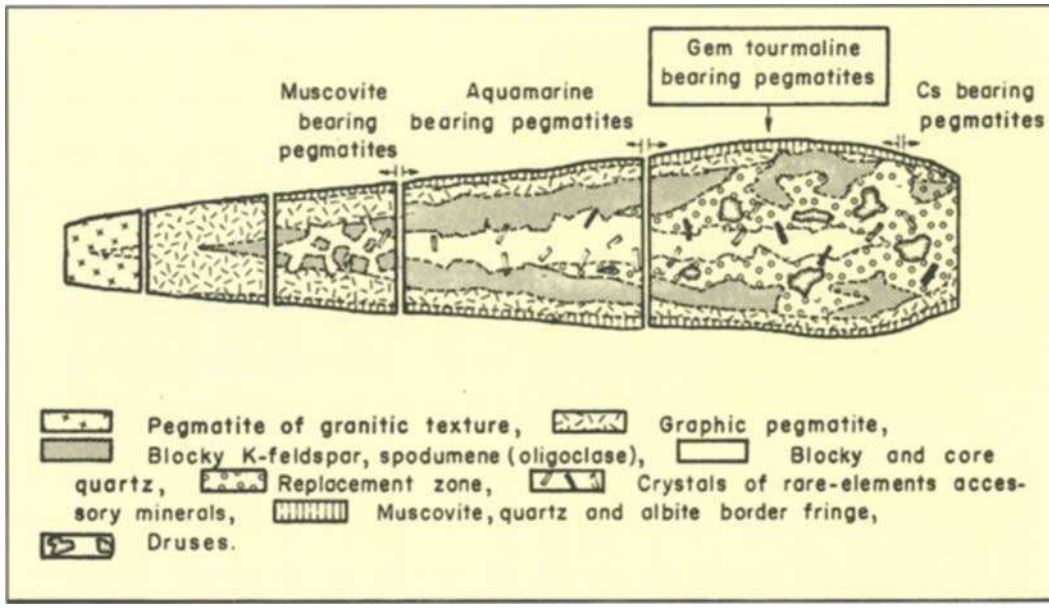

Fig. 19. Location of gem tourmaline bearing pegmatites in a schematic section of different textural-paragenetic types (modified from Vlasov, 1952).

briefly outlined (after Shigley and Kampf, 1984) and will be used as a basis for the proposed classification of the tourmaline deposits.

After the injection of pegmatite magma into fractured rocks and as the temperature falls, crystallization begins somewhat below 1000°C; first the minerals crystallize along the outer margin of the pegmatite chamber where plagioclase, quartz and muscovite form a fine grained border zone. Later these are joined in a coarser intermediate zone by microcline and sometimes by spodumene and beryl (Figure 19).

Because of their chemical and structural makeup, the early-formed minerals cannot, for the most part, incorporate the volatile or rare elements. As a result, these components are preferentially retained in the magma, where they become concentrated. As crystallization continues with further cooling, the water content of the magma eventually reaches saturation level. At this point an aqueous fluid, rich in volatiles and certain rare elements, separates from the remaining pegmatite magma between 750 and 650°C. The much lower viscosity of the aqueous fluid permits the rapid transport of chemical nutrients to the growing crystals, thereby promoting their growth in the innermost zones of the pegmatite. The greater concentration of volatiles and many of the rare elements contributes to the partitioning of elements between magma and fluid, and thereby to the segregation of minerals in separate zones. Aqueous fluids allow minerals to crystallize at lower temperatures and to reach greater sizes than do magmatic fluids. The aqueous fluid also may redissolve some earlier formed minerals and is responsible for much of the secondary mineral replacements occurring in the complex pegmatites. As crystallization proceeds, the aqueous fluid continues to exsolve from the silicic magmatic fluid which solidifies between 600 and 500°C. At this stage, the innermost portions of the pegmatite would be occupied by large crystals of feldspar and quartz (sometimes with spodumene and beryl) with a few isolated pockets of trapped fluid.

The formation of minerals in open pockets, the druses of Figure 19, is the final stage in the primary crystallization of the pegmatite. In this way, London (1986) showed that in pegmatites in Afghanistan and California, tourmaline pockets were formed between 475 and 425°C at pressures between 2800 and 2400 bars. With decreasing temperature to 400°C and rising internal pressure resulting from the release of volatilities, crystallization continues from the trapped fluid. Euhedral crystals of various minerals are able to form from the fluid within the open space of the pockets, and they may contain abundant liquid inclusions, attesting to their growth from an aqueous fluid. At this stage, the concentration of certain rare elements may reach sufficiently high levels of crystallization of unusual minerals. Some crystals projecting into the druses may start opaque and grow with addition of clearer zones of higher gem quality, ending in flawless terminations.

This continued mineral growth is accompanied by changes in the chemical composition of the fluid which, in turn, are reflected in corresponding changes in some minerals (e.g. colour zoning of tourmalines). The final temperature for mineral crystallization from this fluid may be as low as 250°C.

The changing fluid chemistry, coupled with decreasing temperature and increasing pressure, can eventually lead to the destruction of many pocket crystals. In addition, earlier formed minerals may become unstable in contact with this highly reactive fluid. As a result, some pockets are found to contain only the remnants of what may have been gem-quality crystals altered to secondary minerals such as lepidolite, cookeite or montmorillonite. If the leakage of volatiles is gradual, the pocket crystals will remain intact but, if the pocket fluid escapes rapidly, a very sudden drop in pressure has the same effect as a dramatic decrease in temperature. The resultant thermal shock may be responsible for many of the internal fractures observed in gem crystals (particularly tourmalines) and for the shattered fragments found on the floor or embedded in the pocket clay of many gem pockets.

It is thought that the aqueous fluid required for pocket formation is only able to exsolve from the magma under the lower confining pressures experienced by pegmatites formed at shallow depths. This would explain the lack of gem crystal druses in deeper pegmatites in many parts of the world, e.g. in north-east Brazil in the Borborema pegmatitic province. According to Jahns (1955) only one per cent of pegmatites are drusy and furthermore, the elements required for gem growth are not always present. Size, shape and filling of the pockets are highly variable.

The last hydrothermal stage of evolution may be deeper in any one pegmatite than indicated in the general model described above. This stage causes strong alteration by hydrolysis of the feldspars, commonly the main components of a pegmatite, and results in a white or off-white clay mixture irregularly mottled with quartz and other unaltered mineral fragments. This assemblage resembles, and may be confused with, the weathering product of many pegmatites. In tropical conditions a number of pegmatite minerals are unstable, at least on the geological time scale. Such minerals as feldspars and spodumene change into clays, while others (e.g. biotite and magnetite) decompose in other ways and lead to the disintegration of the pegmatite body; the chemically stable or practically insoluble minerals such as tourmaline, topaz, beryl and quartz remain unaltered. Kaolin is commonly the predominant component of the mixture resulting from pegmatite alteration, either by hydrothermal means or from weathering, and may be associated with montmorillonite, gibbsite, chlorite and other layered silicates in lesser quantities. Being commercialized under the name of 'kaolin' for ceramics purposes

(frequently without strict standards), the deposits from which it comes are commonly referred to as 'kaolinized'. Since chemical or other mineralogical determination of the clay, and identification of its cause as hydrothermal alteration or weathering, are generally lacking, in most deposits it would be regarded as right and proper to describe the mineral assemblage as an 'alteration product'.

Location of the deposits

Virtually all the tourmaline-bearing pegmatites in Brazil are located in metamorphic rocks such as micaschists with or without specific metamorphic minerals (staurolite, garnet, kyanite, andalusite) or, more rarely, in gneiss or quartzites (Cruzeiro, São José da Batalha deposits). Pegmatites cutting granites are rare (Valdete deposit near Coronel Murta, Minas Gerais). This observation is of geomorphological importance in areas where recent erosion has occurred in a very active way following doming, tilting and repeated uplift: the tourmaline-bearing pegmatites are more distant from the granite outcrops than are the beryl-bearing pegmatites. This observation is reflected by the regional morphology: the tourmaline bearing areas are commonly located in low hills overlooked by sporadic sugar loafs and inselbergs, topography that results from a high rate of chemical weathering accompanying the mechanical erosion (Figure 20). Although secondary deposits, mainly eluvial, were widely developed during the partial or almost complete destruction of the often kaolinized primary deposits, there are virtually no economic alluvial deposits of tourmaline. In contrast, 60 to 70 per cent of the Brazilian aquamarine output, comes from secondary deposits in which the alluvial type prevails (Cassedanne and Alves, 1991).

Tourmaline-bearing pegmatites occur singly or in groups (Černý, 1982). Single pegmatite bodies are frequently large (Veadinho, Minas Gerais) to very large (Golconda, Cruzeiro, Pederneira deposits, Minas Gerais), up to many hundreds of metres in length and tens of metres in width. Individual pegmatites in the groups

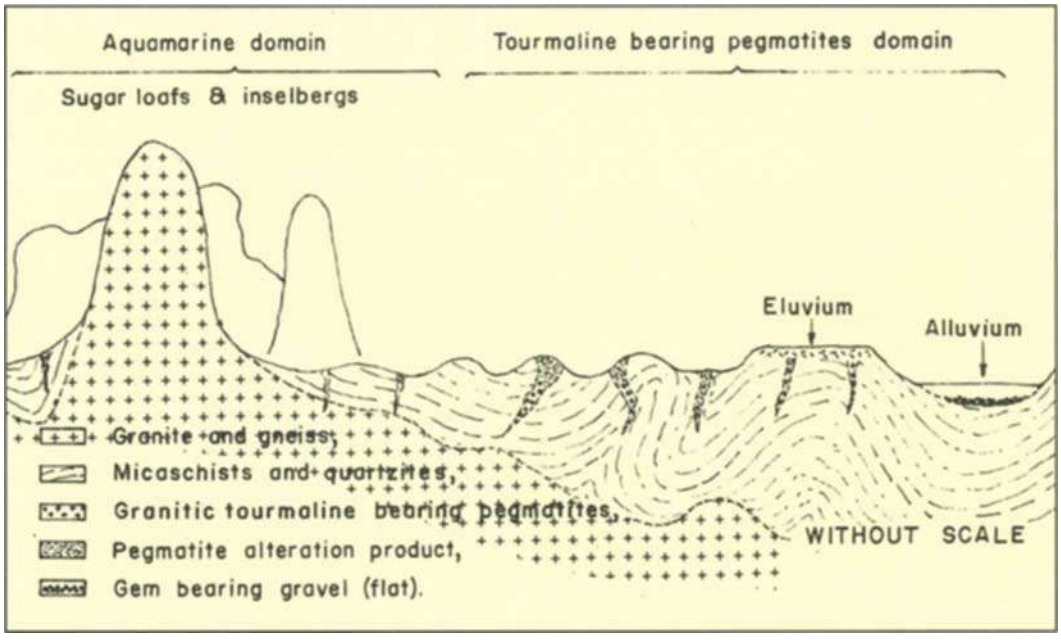

Fig. 20. Types of tourmaline deposits and their relationships with aquamarine deposits in an idealized section.

are always smaller, but the groups may comprise tens of pegmatite bodies with a range of sizes, strikes and dips (Taquaral, Barra da Salina near Araçuaí, Minas Gerais). Wall rocks, direction and dip may also change quickly in the same body, and such features are not of use as characteristic of any one deposit. The body of the pegmatite is commonly lens-shaped, sometimes tabular or dyke-like, and may be parallel to or cut across any banding or foliation of the wall rocks.

Typological classification of the deposits
Genetically, all tourmaline-bearing pegmatites show greater differentiation than aquamarine bearing pegmatites, which explains why the two gems do not occur together. Bearing in mind the above outline of pegmatite evolution, for practical purposes it is possible to distinguish two groups of pegmatites: homogeneous and heterogeneous.

Homogeneous pegmatites
Type 1 – single. These are K-feldspar pegmatites, commonly with well developed quartz-feldspar intergrowth textures (graphic granite), poorly evolved, with scattered albite and/or lepidolite-bearing substitution bodies where tourmalines are found. Pegmatite bodies of this type appear homogeneous on first examination, because zoning is not obvious, except in a few places where large K-feldspar crystals occur in the central zone.

The Humaitá deposit near Taquaral (Minas Gerais) may be used as an example: the vertical pegmatite, 6 to 8 metres in width, is irregularly worked along the 30 metres of its outcrop. Between the wallrock of staurolite schists and the pegmatite is a zone, 1 cm thick, of tourmaline. The texture of the pegmatite body is granitic to graphic and grain size ranges up to a few centimetres. The body consists of K-feldspar, some plagioclase, quartz and mica with much schorl, where albite replacement bodies containing small druses or pockets are erratically scattered. The pockets are coated with cleavelandite, decimetre-sized K-feldspar crystals, scarce lepidolite, window (= quartz à fenêtres or cathedral) quartz crystals and gem-quality blue and green tourmaline crystals, associated with a little crystallized rose quartz and fine moraesite needles (Cassedanne and Cassedanne, 1987).

Type 2 – albitized. This type may be distinguished from the single type by replacement of the large K-feldspar crystals by Na-feldspar. Again, some large K-feldspar crystals can occur in the central zone of the pegmatite.

The Gordura (or Zé Antônio) deposit, also near Taquaral, is a typical example. Running EW, with a small northerly dip in country rocks of biotite schist, ten metres or so wide, the pegmatite is worked along approximately 300 metres of its outcrop. A granitic fringe some cm in width, fine grained and schorl rich, occurs between the wallrocks and the pegmatite. The highly kaolinized body consists essentially of Na-feldspar with milky quartz, schorl, muscovite and a little garnet. Blue and green tourmalines also occur as small crystals disseminated in quartz, or less commonly in feldspar, or grouped in small pockets coated by cleavelandite and quartz with some muscovite. These pockets are commonest in the central part of the body where a string of milky quartz lenses and large microcline crystals may be developed.

Many pegmatites belong to this type in the neighbourhood of Taquaral and Barra da Salina, both hamlets in the state of Minas Gerais.

Heterogeneous pegmatites
The banding of the minerals is always conspicuous.

Type 3 – single. Part of the K-feldspar is substituted by small albite/lepidolite replacement bodies. With the exception

of banding, this type is similar to number one.

The Poço d'Anta pegmatite, in the vicinity of Taquaral, illustrates this type. The pegmatite body is horizontal, asymmetrical and has been worked along many hundreds of metres. From the roof to the floor, in a section of 2.5 metres, there may be seen:

- fine grained biotite schist;
- long flakes of muscovite perpendicular to the wallrock, embedded in granite (grain size about one centimetre);
- lens-shaped milky quartz core;
- microcline crystals up to 10 cm long with zones of albite substitution associated with lepidolite and pockets which are coated by cleavelandite, muscovite and window quartz with gem-quality green and blue, more rarely pink, tourmaline prisms up to 30 cm long;
- granite of medium grain size with a little muscovite;
- fine grained biotite schist.

The half-section of the symmetrical Xandá pegmatite, near Virgem da Lapa (Minas Gerais) will supplement the previous example. Dipping N20°E and 7 metres or so wide, the pegmatite was worked along its 150 metres outcrop. From the roof to the core may be seen:

- folded biotite schist;
- thin contact zone with perthite, plagioclase, quartz, muscovite and a little biotite;
- fine grained graphic granite with schorl, muscovite, biotite and pink garnet;
- a zone of very coarse to giant crystals of the above minerals associated also with some beryl. This zone is rich in substitution by albite and also contains pockets. The pockets are coated by cleavelandite, transparent and milky quartz crystals, lepidolite in a range of sizes, muscovite and/or zinnwaldite, blue transparent topaz (some crystals weigh 20 kilograms) and bluish and green tourmaline prisms which, exceptionally, may reach 80 cm in length. Less commonly present are bluish or greenish gem-quality apatite, microlite and large, sometimes gem, hydroxylherderite crystals;
- lens-shaped core of milky quartz (Cassedanne and Lowell, 1982).

Type 4 – albitized. This may be distinguished on the basis of higher substitution of the large K-feldspars by Na-feldspar. The half-section of a symmetrical pegmatite known as the Jonas deposit (Itatiaia) near Conselheiro Pena (Minas Gerais) will illustrate this type. The pegmatite body is vertical, ten metres or so in width and worked along the 70 metres of its outcrop. The zones from the biotite schist wallrocks to the core are:

- fine grained schorl-rich contact zone with granitic texture;
- medium grained graphic granite with schorl crystals perpendicular to the wallrock, biotite, some plagioclase and large muscovite flakes;
- coarse grained zone consisting mainly of albite with quartz, some muscovite, garnet and remnants of K-feldspar; pockets are scarce, but some are many cubic metres in size. These pockets are coated by transparent to pale yellow quartz crystals, commonly doubly terminated, lepidolite, cleavelandite, microcline and commonly pink (or green) gem tourmaline prisms, exceptionally more than one metre in length. Less common are microlite, arsenopyrite, monazite and gem quality apatite;
- milky quartz core and giant microcline crystals.

Type 5 – albitized with spodumene. The presence of spodumene crystals, commonly very altered and not of gem quality, some more than two metres in length, is the distinguishing feature of this type. Zoning is always conspicuous.

The half-section of a symmetrical vein from the Cruzeiro pegmatite field (Minas Gerais) will be outlined as an example. This pegmatite is vertical, approximately 12 metres wide, and has been partially

worked upon over a few hundred metres. The wallrock is a well banded, fine grained, white to grey quartzite, and from this to the core the zones are:

- coarse grained muscovite;
- granite consisting mainly of quartz and plagioclase with lenses of graphic texture;
- external intermediate zone, locally rich in large muscovite books (worked during World War II) with extensive graphic texture;
- internal intermediate zone, essentially of K-feldspar sporadically albitized;
- central zone: large quartz crystals which may or may not be idiomorphic (window), microcline, large tabular spodumenes and zones of albitic substitution bodies about 10 m wide, with cavities and pockets. The pockets are coated with cleavelandite and contain muscovite, lepidolite, quartz and commonly fine green or pink tourmaline prisms. Some iron and manganese phosphates may also be seen in the vicinity of the pockets;
- lens-shaped milky quartz core (Cassedanne *et al.*, 1980).

Identical sections may be observed in the Golconda and Barra da Salina (Cata Rica, Minas Gerais) deposits, where garnet is associated with the spodumene.

Minerals of the tourmaline deposits

From a mineralogical point of view, tourmaline-bearing pegmatites are simple: more or less albitized K-feldspar, albite, muscovite and milky quartz are always present. Lepidolite (Urubu, Limoeiro, Barra da Salina) and schorl (Sapo, Bananal, Caraíba) are commonly present and may be abundant. Niobotantalite and beryl (frequently as disc-shaped very pale blue, colourless or pink crystals) are also commonly present but always in small amounts. Finally, the following occur sporadically: apatite (gem quality fluorapatite at Jonas, Virgem da Lapa), amblygonite (Golconda, Palmeiras), cassiterite (Areião, Sebastião Dutra, Morro Redondo), citrine (Benedito), cookeite, some of which contains boron (Benedito, Eraco Teixeira), garnet (commonly with a composition near 50 per cent almandine and 50 per cent spessartine – see Cassedanne and Cassedanne, 1980; occurs at Veadinho, Golconda), hydroxylherderite (Urubu, Golconda, Virgem da Lapa), microlite (Jonas, Pederneira), morion (dark brown quartz at Manoel Teixeira, Baixão, Ouro Fino), nontronite (Itatiaia, Santa Rosa), petalite (Urubu), iron and manganese phosphates: triphyllite (Benedito), cyrilovite, eosphorite, ferrisicklerite (Manoel Teixeira), frondelite, graftonite, heterosite (Laranjeiras), hureaulite, mitridatite (Olho de Gato), phosphosiderite, strengite and vivianite; rarer phosphates: coeruleolactite (Cruzeiro), moraesite (Pirineú, Humaitá), wardite (Laranjeira), very fine rhodochrosite crystals (Pederneira), colourless or very pale pink gem spodumene (Benedito), thoreaulite (Urubu); secondary uranium minerals: autunite (Pederneira), phosphuranylite, saléeite (Olho de Gato) and torbernite (Cruzeiro), zinnwaldite and topaz. Topaz occurrences are restricted to the Laranjeira Velha deposit, Barra da Salina and Virgem da Lapa, and are almost always blue, yellow or green in contrast to the topaz in aquamarine-bearing pegmatites which is colourless. Manganese oxides, locally plentiful, stain the weathered pegmatites; commonly of superficial origin, they may be derived from the weathering of garnet.

The following minerals occur very rarely: large biotite crystals, massive rose quartz (Pederneira), crystallized rose quartz (Laranjeira, Valdete), rosette-shaped amethyst (Sapo), gahnite (Faria), monazite (Jonas, Baixão), bismuth minerals (Palmeiras), geochronite (Limoeiro), sulphides and arsenides (Antônio Magalhães, Laranjeira), xenotime (Urubu) and zircon (Baixão). Magnetite and hematite are absent. The above deposits are only quoted as examples.

Due to repeated pulsations during the final crystallization of some pegmatites, mainly in those which are most albitized, some minerals became unstable in the new conditions and disappeared, being variously reabsorbed or replaced by other minerals. One example of this is that lepidolite (at Urubu or Jonas) or cookeite has replaced to a greater or less extent the rubellite or green tourmaline. In the same way, large tabular spodumenes may be altered to vividly coloured montmorillonite (Cruzeiro, Palmeiras).

Prospecting and mining

Direction and dip of both the pegmatite bodies and their wallrocks broadly vary from one deposit to another and cannot serve as prospecting criteria.

The window quartz crystals ('jacaré' of the garimpeiros) vary from a few centimetres to more than one metre long, and appear to be the most typical mineral of the tourmaline-bearing pegmatites. They are commonly coated with smaller quartz crystals. Window quartz is transparent, translucent, or may be milky, or rarely smoky; frequently it contains very large liquid inclusions.

In early 1994 giant pockets containing tens of tons of astonishingly perfect quartz crystals were discovered in the tourmaline bearing pegmatite of Morro Redondo, near Virgem da Lapa (Minas Gerais). Individual crystals were more than 300 kilograms in weight and up to 2 metres in length, and totally window-featured or sceptre-shaped when grown upon an older crystal. In the tourmaline-bearing pegmatites, window quartz is found rather than the 3-pyramids quartz crystals that are typical of the aquamarine deposits (Cassedanne and Alves, 1992–1994). The association of window quartz crystals with abundant muscovite (or lepidolite) and manganese oxides is a very valuable guide to the proximity of gem pockets of tourmaline (Barra da Salina, Cruzeiro deposits for instance).

It seems that a significant albitization stage is essential for the development and presence of gem tourmaline and a very pronounced zoning appears to be distinctive of the most important deposits (Cruzeiro, Barra da Salina, Jonas). This zoning is frequently asymmetrical, mostly in the horizontal pegmatite bodies where the gem quality tourmaline tends to occur below the quartz core. One explanation may be that a different distribution of the fluids results from differential upward migration due to different thermal gradients or gravity differentiation phenomena that is not obvious on a local scale in the vertical bodies. Uebel (1977) reported the same phenomenon in Norway. Frequently it may be noted that low dipping or horizontal pegmatite bodies have the greatest abundance of pockets (approximately one pocket per square metre in the Limoeiro pegmatite for example; Poço

Fig. 21. Pink and green tourmaline crystals close to the quartz core. Urubu pegmatite near Araçuaí.

d'Anta and Santa Rosa deposits are other good examples).

As a rule pockets are small (one to ten cubic decimetres in volume); those of one cubic metre or more are rare and found mainly in vertical pegmatites (Golconda, Jonas). The pocket shape is highly variable, commonly irregular, sometimes flat (Humaitá) or roughly ellipsoidal (Poço d'Anta). Locally there may be structural controls, mainly in subhorizontal or gently dipping pegmatites: e.g. in the famous Limoeiro pegmatite, pockets are concentrated in the vicinity of NS striking, steeply dipping fractures and below roof undulations due to small recumbent folds in the wallrock biotite schist. Elsewhere the very irregular distribution of pockets indicates that no geological hypothesis would be capable of predicting the sites of pockets and consequently where the tourmaline concentrations might be found. This fact, combined with a low economic (or industrial importance) explains why mining is almost always carried out by hand and is very primitive. In order to reach a pegmatite body the garimpeiros sink cross cuts through the wallrocks or, where possible, start directly from the outcrops. Then the adits are cut in the vicinity of the core of the pegmatite to search for pockets ('caldeirões') (Figure 21). The adits are tortuous, rising and descending, by means of steps and stairways which are very narrow and timbered in the crumbling zones. The altered and weathered pegmatite is cut with picks and hard pegmatite rock is blasted with the help of small pneumatic drills and compressors. When not piled in the chambers abandoned after mining, the waste is cleared by wheelbarrow. In some places the weathered or powdery tourmaline-bearing vein material is roughly screened and/or washed near the adit entrance (as in the Barra da Salina and São José da Batalha deposits for instance, Figures 22–24). As each garimpeiro cuts his own adit, the number of distinct dumps is

Fig. 22. Hauling with a hand winch from a pit in the kaolinized pegmatite at São José da Batalha mine.

Fig. 23. Screening and washing the kaolinized pegmatite at São José da Batalha mine.

impressive, even in a small pegmatite body. Exceptionally the overburden is stripped out with the help of a bulldozer (Barra da Salina).

Prospecting for deposits is empirical by digging out every white superficial spot (ant hill, armadillo hole, erosion gulch, etc.). If gem material is found, there is a temporary rush of garimpeiros to the new deposit. Mining of the pegmatites is by open pit or by means of adits. The weathered pegmatites where feldspars have been broken down by alteration are the easiest to work, and the gemstones are recovered simply by washing the hand-sorted ore. Fine gems also occur in the unweathered, hard pegmatites but there, outside the pockets, they are intergrown with quartz or feldspar. Extraction from this matrix commonly results in the breaking of the tourmaline crystals. The splendid specimens found in the gem pockets are sought after not only by lapidaries but also by mineral collectors.

Fig. 24. Blue tourmaline pieces recovered after washing the ore at São José da Batalha (see Figure 23).

The tourmaline crystals obtained from the workings vary greatly in colour, but generally green, blue or pink prevails. Achroite is rare (Urubu). Locally prisms showing chatoyancy are common (e.g. Olho de Gato, near Governador Valadares). One colour sometimes predominates in a deposit, e.g. blue (Pirineús), red (Ouro Fino) or green (Faria), but more frequently green/blue and red/pink are asso-

ciated (Cruzeiro, Santa Rosa, Barra da Salina). No prospecting guide exists to locate a particular colour, just as there is no simple explanation for colour genesis. However, from practical experience it appears that fine rubellite crystals are nearly always associated with Li-rich pegmatites (spodumene and/or lepidolite of type 5 above). According to Batista and Neto (1974) only 1 to 5 per cent of the extracted gem-quality tourmalines are of very good quality.

Spatial distribution and age of the pegmatites

In the geochemical evolution of the pegmatites, the transition from a dominant potassium phase to a more sodic one has been reported from many countries and it has been used as a basis for their classification (Fersman, 1931; Vlasov, 1952; Varlamoff, 1958; Smirnov, 1977, etc.). However, the establishment of a strict parallelism with the Brazilian deposits is not easy because criteria related to gems were not taken into account by the above authors. Nevertheless at a regional scale, the aforesaid geochemical evolution is shown in the eastern pegmatite province by a clear zonation: the tourmaline-bearing zone is surrounded in the east, north-east and south by the aquamarine-bearing zone. In turn, the aquamarine-bearing zone is bordered by a wide pegmatite belt, without gems and producing only muscovite, which extends south-west from the state boundary between Minas Gerais and Espirito Santo (Pecora *et al.*, 1949).

Beyond this zone and further to the south and south-west, pegmatites are only worked for feldspar (Menezes, 1982).

The intrusive granites with which gem bearing pegmatites are classically associated are either even grained (granodiorite, tonalite or other) or medium to coarse grained porphyritic varieties belonging to an active part of the Brazilian tectonic cycle between 650 and 450 m.y. (Correia Neves *et al.*, 1986). Pegmatites have been dated at 450 m.y. in the Conselheiro Pena region (Moura *et al.*, 1978) and at 490 m.y. in the neighbourhood of Araçuaí (Afgouni and Sá, 1977). They are always regarded as contemporaneous with, or in some instances post dating, the last stage of the Brazilian tectonic cycle. There is one report that zircon from a certain pegmatite gave an age of 350 m.y. (Pecora *et al.*, 1949). The Brazilian tourmaline-bearing pegmatites are all located in the Precambrian basement and are contemporaneous with those of East Africa, Madagascar and northern Baikal Province (Černý, 1982).

Major tourmaline deposits

Minas Gerais State contains the major deposits responsible for the bulk of Brazilian gem tourmaline output today and the tourmaline occurrences known in the states of São Paulo, Rio de Janeiro (Lavra do Esmério) and Espirito Santo have no economic importance. Omitting the small and worked-out pegmatites (Abreu, 1963; Ferraz, 1929; Franco, 1967; Araujo *et al.*, 1982), the following large deposits should be recorded (N.B. 'lavra' means mine, deposit or prospect).

In the middle of the Rio Doce Valley (see detailed map of area 1, Figure 25) east of Governador Valadares, in the Conselheiro Pena-Divino das Laranjeiras area, the main deposits are Itatiaia, Jonas, Urucum, Formiga and Pamaró. When necessary, alternative names are also given.

The Lavra to Itatiaia (Lajão or Cascalho) was discovered about 1930 and in the 1940s produced astonishing tourmalines (nicknamed 'papagaios' = parrots), exhibiting four to five colours along the *c*-axis and reaching up to 15 centimetres in length. The deposit is composed of vertical pegmatite veins running NS to NNE-SSW, a few metres thick, with some wider parts. Huge altered spodumene crystals and flat blue or pale green beryl prisms may also be present. The adits have now caved in, but small alluvial diggings persisted until a few years ago.

Fig. 25. Detailed map of the Area 1 in Figure 18.

The Lavra do Jonas became world-famous around Easter 1978, after the discovery of a pocket 2 metres wide and 2.5 metres high, coated with quartz, lepidolite, cleavelandite and K-feldspar crystals, and containing outstanding large rubellite prisms of exceptional transparency, some of which were 40 centimetres in diameter and one metre in length (Lallemant, 1978; Sullivan, 1978, Keller, 1979). 1800 kilograms of gem quality were produced of which 200 kilograms were raspberry to magenta red of fine quality. The pegmatite body extends NS for 70 metres in outcrop and 70 metres in height, reaching 11 metres in width; 23 pockets have been reported. The pockets contained green tourmaline, frequently producing cat's-eyes, rubellite, gem quality apatite, spessartine and microlite. The gems were extracted from irregular chambers, reached by cross cuts. Proctor (1985b) recorded the total tourmaline output as 2300 kilograms of gem material and 3600 kilograms of collectors' specimens.

The Lavra do Urucum (Lavrá do Tim) is famous mainly for its magnificent flat prisms of pink and salmon morganite (with many elbaite inclusions) and large kunzite crystals (Cassedanne, 1986). Almost black elbaite (Prescott and Nassau, 1978) and chatoyant tourmaline were also produced, and minor minerals include schorl, spessartine, stokesite and rare arsenates. The pegmatite body is lens-shaped, with an ESE-WNW strike and a high dip to the SW; it is locally 20 metres wide.

The Lavra da Formiga (Ferruginha, Fazenda Oswaldo Gonçalves) is a NS

Fig. 26. Highly transparent very pale green tourmaline from Pamaró mine. The sample is 28 mm long.

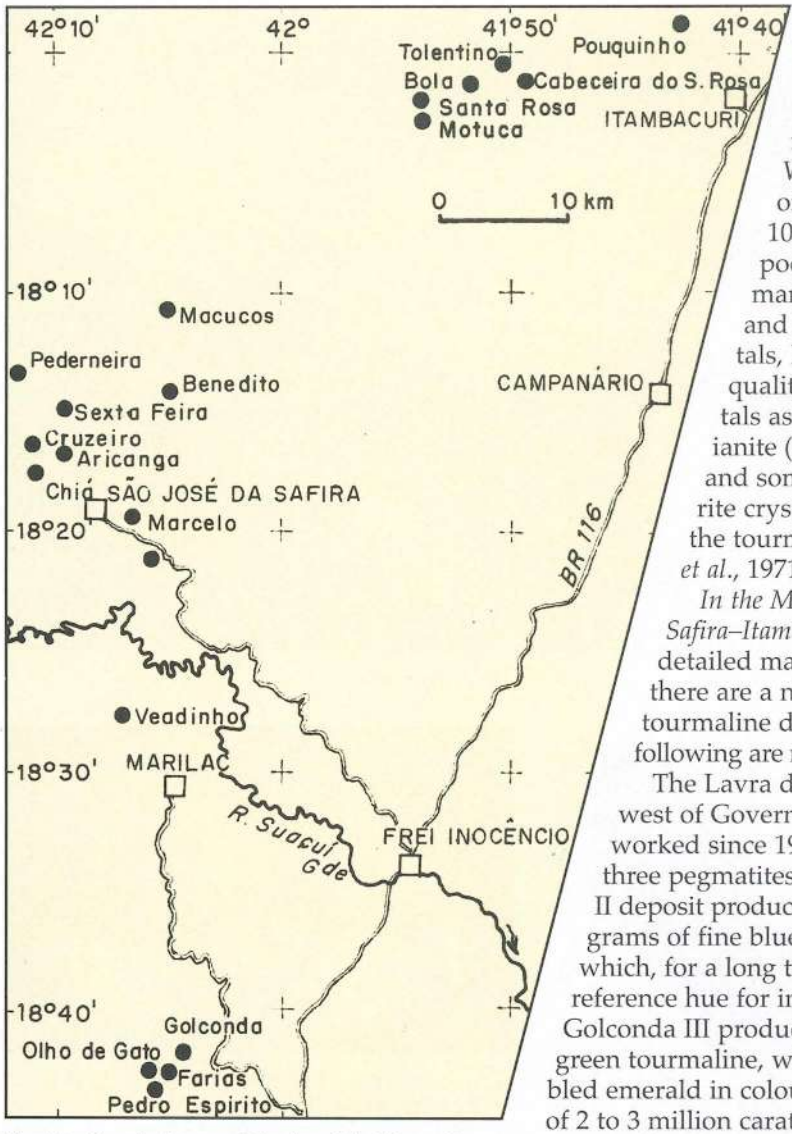

Fig. 27. Detailed map of the Area 2 in Figure 18.

pegmatite with a gentle westerly dip and many small undulations. About 1985 tons of blue, green, rose and bicoloured tourmaline crystals, some chatoyant, were produced. The finest crystal groups, up to one decimetre in length, were highly sought after by collectors and the remainder were cut and polished. After irradiation the pink specimens turned into a fine red hue.

The Lavra do Pamaró (Pamaroli, Morro do Cruzeiro) (Figure 26) is a pegmatite with an ESE-WNW strike and dip of 50–70° south. It is 10 metres wide and its pockets have yielded many gem quality green and rose tourmaline crystals, less commonly, gem quality amblygonite crystals associated with brazilianite (Cassedanne, 1983) and some very large eosphorite crystals associated with the tourmaline (Cassedanne *et al.*, 1971).

In the Marilac–São José da Safira–Itambacuri region (see detailed map of area 2, Figure 27) there are a number of famous tourmaline deposits of which the following are noteworthy (Figure 28). The Lavra da Golconda, northwest of Governador Valadares was worked since 1908 and comprises three pegmatites. In 1968 the Golconda II deposit produced more than 500 kilograms of fine blue tourmaline crystals which, for a long time, were used as the reference hue for indicolite. About 1962, Golconda III produced 900 kilograms of green tourmaline, which closely resembled emerald in colour, and a total output of 2 to 3 million carats after cutting was reported by Proctor (1985b). Because of the value of the deposits Golconda III and the nearby Pedro Espirito and Faria pegmatites (Figure 29) suffered several armed disturbances provoked by disputed ownership and mining rights. Well zoned, with huge altered spodumene laths, the Golconda III pegmatite is 150 metres long, and 20 to 25 metres wide along a NNE-SSW strike. It has a westerly dip and is presently worked underground, producing green tourmaline, much quartz and some

Fig. 28. The large Chiá mine. Photograph taken from the Cruzeiro mine road.

Fig. 29. Dark green gem quality tourmaline from the Farias mine near Governador Valadares. The sample is 105 mm long.

Fig. 30. Dark green tourmaline crystals up to 15 cm in length, surrounding kaolinized feldspar lump, near the quartz core of the pegmatite. Golconda mine near Governador Valadares.

hydroxylherderite crystals (Dunn *et al.*, 1979) associated with gem quality apatite (Figure 30).

The Lavra do Veadinho produced some hundreds of kilograms of green and pink tourmaline but is now abandoned, as is the Macuco deposit where only colluvium with an indistinct stone line was worked.

The Lavra do Cruzeiro was the first and for a long time the main Brazilian deposit

producing rubellite (with green elbaite). Discovered in about 1674 (Serra das Esmeraldas of Paes Leme) by early Brazilian explorers ('Bandeirantes') it was then forgotten, before starting as a mica producer during World War I and becoming a major producer during World War II. Gem mining started in 1950 and continues today. Three vertical or steep south-west-dipping pegmatite veins are known, with a strike of N20°W and exposed over some hundreds of metres. Their thickness varies from a few metres to more than 50 m. A detailed description of the deposit has been reported by Cassedanne *et al.* (1980). The wallrock is a whitish, thin bedded quartzite. The tourmalines occur in the Na-rich replacement bodies which generally are located in the vein widenings, either in pockets or in whitish lenses of alteration products. Schorl, weathered spodumene laths and lepidolite (sometimes with Fe-Mn hydroxides) surround the pockets and are used as prospecting guides. The tourmaline crystals are pale green or pale blue, blue, greenish-blue, emerald-green ('cromolite'), pink or ruby-red and rarely, colourless (Figure 31 and Cover Picture). Watermelon specimens, inclusion rich and terminated by a blue pinacoid, and green cat's-eye tourmalines are common. The crystals are frequently thickset and flattened, and up to 30 cm in length. They occur singly or as small divergent groups. Fine sets of specimens were brought out particularly in the years 1966, 1968, 1971, 1983–84 and 1993 with a weekly output of up to 200 kilograms of tourmaline of which 1 to 2 kilograms were of superior gem quality.

The Lavra da Pederneira, located NNW of the Cruzeiro mine, is worked underground, and has produced fine tourmaline crystals since 1985. The pegmatite is almost vertical with a SE-NW to ESE-WNW strike, is 20 metres thick and is well zoned. It has been almost completely albitized with a succession of quartz pods in the core (like a massive rosary) and many micaschist

Fig. 31. Fine gem quality rubellite crystal, 75 mm long, from the Cruzeiro mine.

xenoliths. Fine grained albite surrounds the tourmaline pockets and is a good prospecting guide. The tourmaline crystals, single or in groups, are green, grey blue, light pink with a dark termination or blue with a pale pink core and a red flat top. The most recently produced crystals were widely commented on (e.g. Koivula and Misiorowski, 1986). Also noteworthy was the abundance of milky-pink morganite and the occurrence of a few astonishing transparent dark red rhodochrosite crystals, probably formed in the final hydrothermal stages of the pegmatite crystallization.

The Lavra de Santa Rosa, discovered in about 1938 was worked first for mica and then abandoned. The first gem tourmalines appeared in 1967 when the mine was reopened. From 1968 to 1973 intense working produced several tons of gem quality tourmalines. Many multicoloured (zoned perpendicular or parallel to the *c*-axis)

Fig. 32. Bicolour tourmaline crystal, 82 mm long, from the Santa Rosa mine.

slightly divergent or bundle-shaped crystal groups from this deposit are at present proudly displayed in many world-famous museums. Some specimens are up to 45 cm long and weigh 20 kilograms. The crystals are blue, green (commonly with a pink flat top), pink or red (Figure 32). The watermelon crystals have a dark pink core surrounded by a turquoise blue or green rim (Pough, 1968; Behnke, 1986). The bulk of the output came from eluvium and the weathered upper part of the pegmatite. The pegmatite is 2 to 10 metres thick, hundreds of metres long with a gentle dip, and contains abundant pockets in common with other gently dipping pegmatites.

The Lavra do Ribeirão da Folha, far in the SSW of the Araçuaí region produced fine emerald green, a few blue tourmalines, and virtually no pink specimens. Hundreds of kilograms of gem quality tourmaline were produced from pockets in about 1982. At present the mine is abandoned. The pegmatite strikes N60°E with a low NW dip and is exposed for approximately 250 metres. It is locally more than 15 metres in width. Abundant lepidolite and muscovite, some bluish to pink flat beryl, amblygonite and bluish topaz are associated with the tourmaline. The wallrock is a biotite schist.

The Lavra do Areião worked the eluvium of a NS striking pegmatite, exposed for 400 metres. Most of the tourmaline appears black but displays a fine dark green after cutting and polishing. Some blue and pink crystals were also recovered. Having been abandoned for a long time the mine was recently reopened.

In the Araçuaí-Virgem da Lapa-Salinas region (see detailed map of area 3, Figure 33) numerous tourmaline bearing deposits occur in the Rio Jequitinhonha basin which includes the Rio Araçuaí and Salinas valleys. Fine green and blue, pink and red gem-quality tourmaline crystals are produced from a series of pegmatite bodies, almost all within mica schists. The pegmatites are mostly comparatively small in size, so their lucrative working is short. However, as the discoveries of new occurrences or of rich unworked parts of abandoned deposits keep occurring, a continuous but highly variable production is maintained (Cassedanne and Alves, 1994).

The Lavra de Poço d'Anta (Manoel Timóteo) belongs to a small pegmatite field in which the Taquaral hamlet is the centre. The mine worked various pegmatites with a NS strike and gentle dip to the west, in part superimposed, with many spurs or offshoots. More than 1000 kilograms of green and pink, with less common greenish-blue tourmalines were produced before 1982. The crystals, flat ended or with three-faced pyramidal terminations occur singly or in groups with parallel growth. There were virtually no collectors' specimens, the output essentially being destined for cutting. At present, the mine is abandoned.

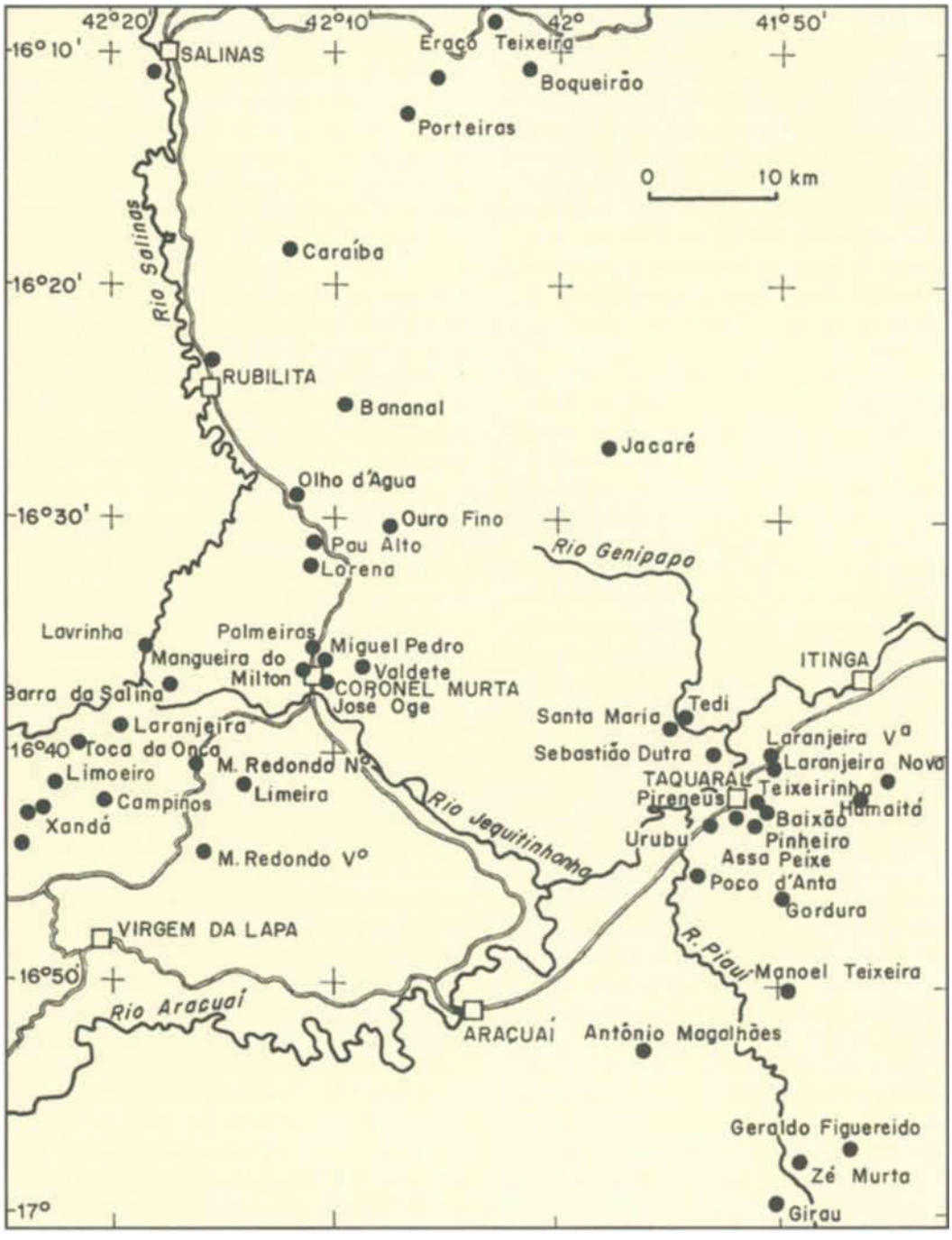

Fig. 33. Detailed map of the Area 3 in Figure 18.

The Lavra do Pirineú (Velha and Nova), in the past produced famous greenish-blue and green tourmaline crystals, reminiscent of those from the Golconda deposit. The pegmatite strikes NS with a dip of 60° and is one tenth of a metre thick. Eosphorite,

moraesite and amblygonite were associated with the tourmaline. A few years ago, on reopening the mine accompanied by stripping of the eluvium and part of the weathered outcrop, fine light blue indicolite was produced. Proctor (1985b) reported that the Pirineú's tourmalines are highly prized because they allow cutting perpendicular to the *c*-axis without appreciable change of hue; this enables production of larger cut stones than is possible from rough of equivalent size from other deposits.

The Lavra do Limoeiro, in the NNW of the Virgem da Lapa region belongs to another small pegmatite field, first mined for mica during World War II. It became famous worldwide during the 1970s with the production of outstanding green tourmalines up to one metre long and blue topaz crystals. After a rush in 1974–75, output declined until 1980, at which time the remaining eluvium and partly weathered pegmatite were stripped out. At present, the mine is abandoned and has caved in. The pegmatite strikes N30°E, with a gentle westward dip, is lens-shaped and was very rich in pockets. Its structure is identical to that previously reported for the Xandá deposit. Gem-quality fluorapatite, hydroxylherderite and fine transparent blue topaz crystals weighing up to 25 kilograms are associated with the tourmalines. Both at the rim and in the interior of the pockets, the tourmalines are commonly terminated by a pinacoid at one extremity and a trigonal pyramid at the other (Cassedanne and Lowell, 1982).

The mines Xandá, Toca da Onça (Souín, Lavra do Bruno) and Campinos (Manoel Mutuca) also produced fine blue and green gem tourmalines until they too were abandoned. The dark blue crystals turned sapphire-blue on heating.

The Lavra do Morro Redondo (Morro Redondo Novo or Laranjeira) reopened in 1990, and started production in 1991, which increased in 1993–94 to several tons of fine green, blue, pink, cat's-eye, bicoloured and tricoloured tourmalines. This huge output led to government intervention to resolve conflict between miners and landowners. The pegmatite strikes N30°E, dips 30°W locally and is up to 20 metres thick along an exposure of more than 350 metres. It is weathered in its upper part and is well zoned with a core of quartz masses shaped like a rosary (beaded), and zones of Na-rich feldspar with pockets lined with cleavelandite, tourmaline, quartz and much lepidolite. Window and sceptre quartz crystals are very abundant, and one particularly large pocket yielded more than 50 tons of quartz with outstanding transparent crystals more than one metre long and weighing 500 kilograms. The latest tourmaline being produced is brownish-pink and light green, with a small white strip between the two colours and small coloured crystals with a rich green termination (ICA, 1995).

The Lavra da Barra da Salina (Salinas, Vieirinho, Vieirão and Cata Rica), near the confluence of the Rios Salinas and Jequitinhonha, known as long ago as 1910, was worked by underground methods and hydraulicking until 1945. From 1973 long trenches and small open pits have been excavated using rippers, scrapers and bulldozers. Some trenches extend for up to 400 metres and are 20 metres deep. At present a series of highly weathered veins with a NNW-SSE strike and dip of 60 to 70° are being worked. They are up to 150 metres long and 6 to 8 metres thick and contain pockets with huge altered spodumene tabular crystals, window quartz, and columnar lepidolite associated with green, pink, bicoloured, tricoloured, and cat's-eye tourmaline crystals (Figure 34). Each pocket has yielded 20 to 25 kilograms of gem material of which approximately 0.1 per cent is of very good gem quality (Proctor, 1985a). The deposit of Salinas is well known for supplying large numbers of flat beryl crystals ranging from pale blue to pink (morganite) or colourless; some are also chatoyant.

Fig. 34. Spray of fan-like grey-green needle-like crystals of tourmaline from the Virgem da Lapa area. Sample is 140 mm long.

The Lavra do Ouro Fino (Chiquinho Freire) eluvial deposit with quartz fragments and limonitic pisolites was worked from 2 to 8 metres depth from 1979. In Spring 1981 approximately one ton of splendid cherry and ruby-red tourmalines were unearthed of which 50 kilograms were of astonishing colour and of the highest quality. Some pink, blue and green broken crystals were also present and the small size of these tourmaline fragments is characteristic of the deposit. The eluvium was sorted by sieving and washing in a nearby pond. After producing the finest Brazilian rubellites the mine was abandoned in about 1982.

Tourmaline deposits in the other states. In the State of Bahia a series of small tourmaline occurrences were explored, but none is of economic importance. At present almost all have been abandoned (Galvão *et al.*, 1975; Pedreira, 1976; Sampaio *et al.*, 1983 and 1985). The small Lagoa Grande (Fazenda do Osmar) deposit on the edge of the Vitória da Conquista high plain yields a sporadic output of green and blue tourmalines from eluvium covering a partly weathered pegmatite.

In the State of Paraíba, small occurrences have been known since World War II (Rolff, 1946); in particular the Alto Feio pegmatite (Johnson Jr., 1945) contains beryl, tantalite and much rose quartz associated with emerald-green tourmaline that fluoresces topaz-yellow (Cassedanne and Cassedanne, 1978a).

The Lavra de São José da Batalha (Figures 35 and 36, see also Figures 10, 22, 23, 24), an old tantalite-bearing prospect was reopened in 1985. Since August 1987 an astonishing output of 'fluorescent', 'neon', 'sapphire', bright emerald-green,

Fig. 35. A pit in a pegmatite, 60 cm thick, at the São José da Batalha mine.

Fig. 36. Partial view of the São José da Batalha mine. Each white dump consists of discarded rock from an adit.

mauve and violet tourmaline (Koivula and Kammerling, 1989) made the deposit rapidly famous. It is composed of four pegmatites which strike WNW-ESE and dip 60–85°N, a few decimetres to 3 metres wide and up to 75 metres high. The wall-rock is a white thin-bedded quartzite. The pegmatite is highly weathered and since hydrothermal leaching affected many tourmaline crystals, the gems almost always occur as angular fragments. Quartz, altered feldspar, lepidolite, muscovite and, less commonly, garnet are the only associated minerals. Gemstone production has totalled some hundreds of kilograms of which a small percentage is of the highest gem quality (Sauer in Cassedanne, 1996). Invariably the tourmalines of this deposit are characterized by a copper content of up to 2 per cent, associated with some bismuth and gold.

Occurrence in the states of Pernambuco and Rio Grande do Norte (Farias, 1977) are devoid of economic importance as are those in Ceará where the sporadic production is very small in comparison with that of Minas Gerais (Mendes, 1975; Limaverde, 1980).

In the central part of the state of Goiás, green, pink and bicoloured tourmalines are sporadically produced from some pegmatites, but always in small quantities (e.g. Lavra da Capivara Velha and Fazenda Cafezal-Cruzeiro). No large deposit is known at present (Lima Jr. *et al.*, 1984).

Detrital deposits of tourmaline

A series of physical and chemical surface phenomena under the general heading 'weathering' affect the primary deposits and lead to the formation of gem-bearing alluvium. Various types of deposits may be related to intermediate stages of this process, the formation of eluvium being the most important. For a detailed study of the Brazilian detrital deposits see Cassedanne and Roditi (1993). It is notable that, like chrysoberyl, tourmaline has been subjected to abnormal abrasion in the red

clay of the residual soil/regolith, resulting in more or less rounded fragments associated with lateritic pisolites. But only schorl survives the subsequent transportation and is deposited in alluvium (Cassedanne and Roditi, 1993). In contrast, the gem tourmaline which is almost always cracked, quickly disintegrates during transportation from the eluvium and only a very small portion of it reaches the alluvium. Schorl, however, commonly makes up an appreciable part of reworked alluvium.

Eluvium deposits

In the Oriental pegmatite province, the eluvium is commonly lateritic, and results from the more or less complete destruction of the underlying pegmatites. This medium preserves the gems, commonly as angular or subround fragments with fissures coated by ferriferous plastic reddish clay, or as the cores of small lateritic nodules. These eluvial deposits, which are also called 'Chapadas', and the high colluvial deposits are located upon the outliers of old peneplains or upon later piedmont slopes, always at some distance from the knick point of an inselberg. Locally, where slopes are gentle, eluvium passes imperceptibly to more steeply dipping tourmaline-bearing colluvium (e.g. at Macuco, Ferruginha, Acode a Chuva, Barra da Salina). Commonly no well-defined mineralized horizon occurs, and the gems are erratically present in a brown to reddish, sandy argillaceous bed several metres thick (Figure 37). Locally a thinner layer has been developed in the eluvium, where the gems are associated with abundant milky quartz fragments. This layer is incorrectly called 'gravel' by the garimpeiros. A pit section in the Lavrinha workings, in the neighbourhood of Barra da Salina (Figure 38), will illustrate this type of deposit. From the top to the bottom the sequence is:

- reddish soil with large pebbles: 1 metre;
- red ochreous sandy clay: 2.5 metres;
- locally hardened lateritic level: 0.3 metre;

Fig. 37. Typical landscape of a once rich eluvial deposit, now abandoned; Laranjeira mine (Araçuaí).

- 'gravel': 0 to 1 metre;
- bedrock made of argillaceous weathered schist.

'Gravel' is a lateritic soil with clay nodules containing some detrital gem tourmalines ('bolinhas') associated with abundant limonitic pisolites, quartz and a few schorl fragments.

The areal extent of the eluvium deposits may be several hectares (Ouro Fino, Santa Rosa) and they are extensively worked by means of irregular pits, small shafts of variable section and large irregular excavations which exceptionally may be 10 metres in depth. Their waste is typically brown to red, contrasting with the white to pale grey waste from pegmatite workings. Seen from afar the workings are an undulating scene of pits and dumps and resemble a bombed landscape. Sorting of the gems is generally carried out during the quarrying. However, where tourmalines occur in lateritic soil, the ore is crushed and washed in order to separate the gems (Lavrinha, Ouro Fino). Preliminary stripping of overburden with a bulldozer is rarely necessary. Prospecting for gems in eluvial deposits is hazardous because the gems are erratically distributed in unconsolidated sand and clay soils. No rich mineral-bearing horizon has ever been observed in eluvial deposits.

Alluvial deposits

Alluvial deposits typically consist of a mineralized gravel lying upon bedrock and overlain by fine-grained sediments; they are the same as those described for the chrysoberyl deposits by Cassedanne and Roditi (1993). No workings have been reported from lower areas of colluvium or terraces.

Alluvium specifically worked for tourmaline. At present the only small worked deposit is at Pouquinho, near Teófilo Otoni (Minas Gerais), in the vicinity of a large weathered pegmatite. A section through the alluvium comprises from top to bottom:

Fig. 38. The eluvial Lavrinha deposit near Barra da Salina.

- very sandy yellow clay with mud and organic matter-rich intercalations: 0.5 to 2 metres;
- gravel containing gem quality green tourmaline fragments: 0 to 50 cm;
- fine grained, slightly weathered granite bedrock, with pot holes.

Gem bearing alluvium with tourmaline as a by-product. In places tourmaline is a less important by-product of mining for other gems such as chrysoberyl or aquamarine (Cassedanne and Alves, 1991).

A pit section through old alluvium of the Córrego do Fogo chrysoberyl deposits near Malacacheta (Minas Gerais), will serve as a typical example. From top to bottom it consists of:

- yellow sandy colluvium overlying the alluvium: 1 metre;
- barren angular gravel: 60 cm;
- yellow argillaceous sand: 1.4 metre;
- black clay with grey lenses: 1.5 metre;
- mineral bearing gravel containing some green and pink tourmaline fragments associated with chrysoberyl: 40 cm;
- weathered schist bedrock.

The main areas of production are the chrysoberyl bearing gravels in northern Minas Gerais (Córrego do Fogo, Americana) and the adjacent aquamarine and/or chrysoberyl producing valleys of Rio Marambaia and Rio Santa Cruz (see location in Cassedanne and Roditi, 1993).

Alluvium working is commonly carried out by a small team of garimpeiros. Timbered square pits, a few metres in size are sunk down to bedrock, in a haphazard way. Water is evacuated by small pumps. In places part of the overburden is scraped off by bulldozer. Locally, working is done by using a 'dredge', a small horizontal gravel pump set upon a steel pontoon. The tourmaline is sorted by hand upon a coarse sieve, after washing to eliminate the clay, silt and sand which is then run to waste (Figure 39).

There are no reliable reports of possible reserves or future production of gem grade tourmaline from the detrital deposits. However, in alluvium, the tourmaline can be assessed very approximately as a few grams per cubic metre of gravel, but its quality and gemmological properties are variable and unpredictable.

Deposits not connected with pegmatites

There are only two important deposits in this category: the first is Brumado in the state of Bahia, West of Vitória da Conquista in the NNE of area 3 described above, and the second is Serra Branca in central Paraíba, WNW of the famous São José da Batalha deposit.

The Brumado or Serra das Éguas locality is one of the largest magnesite deposits in the world. It is famous particularly to mineralogists for its extraordinary specimens of

Fig. 39. Washing tourmaline-bearing alluvium at the Itatiaia mine (Conselheiro Pena).

twinned quartz, large magnesite crystals, dolomite, beryl, topaz, hematite, metazeunerite and novacekite along with others such as magnetite, tremolite and talc (Cassedanne and Cassedanne, 1978b). Although it has been known since 1884 it was only a few years ago that many very fine transparent tourmaline crystals belonging to the uvite species were found. There was a small production of emerald between 1913 and 1923, and extraction of the magnesite only began during the 1940s. Now there is a very large open pit more than 150 metres deep (the Pedra Preta deposit) and other minor excavations such as Pirajá and Gravatá.

In summary, the geology consists of Precambrian basement overlain by a metamorphosed sequence of dolomite in the lower part and quartzites in the upper part, both belonging to the Minas Series. The dolomite is more than 150 metres thick and was extensively converted to magnesite by replacement and fracture filling mechanisms. The sequence is tightly folded in a large synclinal structure striking about N20°E. This structure plunges south at a low angle and reverses at its southern extremity to dip north, so that the structure of the range, as a whole, is canoe-shaped. Thick talc veins are associated with large faults across the deposit. This talc is of excellent quality, being almost free of other minerals and in some places yielding a few large transparent crystals. Dark brown, reddish-brown, red, dark green and light green uvite crystals have been found both in the talc and in the surrounding magnesite (fresh and weathered) mainly in the Jatobá zone of the Pedra Preta open pit. Uvite occurs there as loose crystals scattered in a sandy and very ferrugineous, buff to violet soil or in red or white magnesite, and in clear talc in the unaltered ore. The uvite crystals are flattened and stubby, rarely reaching 5 cm in length, commonly in clusters of parallel prisms; they are commonly translucent to transparent and perched upon magnesite scalenohedrons or set in a matrix of thin platy white dolomite. The gem crystals are much sought after by mineral collectors (Moore, 1992 and 1994) and fine red gems of up to 10 ct have been cut. In the Pirajá zone, the uvite crystals are either small and flat or are partially enclosed by yellow topaz crystals.

Serra Branca deposit. Completely different in shape, colour and host rock from Brumado, tourmaline crystals from this locality have sporadically appeared on the specimens market, probably from collection at the site more than twenty years ago. Only during 1994 did proper mining begin. Serra Branca is in the Baixo dos Pereiras area NNW of Sousa town in Paraíba (Cassedanne, 1995). The deposit lies in a series of talc schist lenses which replace basic intrusions, roughly concordant in gneiss with a strike of N70°E and dip of 40–60°S. The lenses are some metres in width and a few hundreds of metres long, and are worked by open pit to a depth of 25 metres. The dark grey green, coarse or fine grained talc schists contain irregular flakes of quartz and feldspar, with molybdenite, apatite and rutile, and are stuffed, in no particular orientation, with tourmaline crystals. These are black and stubby, rarely elongated, and almost always doubly terminated. Generally they are 1 to 2 decimetres long and a few centimetres in diameter, but exceptionally may be up to 80 cm long and 20 cm in diameter. The faces are smooth, and the section is triangular, or more rarely flattened or hexagonal, with three predominant faces. The trigonal pyramid is the most common termination. Crystals occur singly or in groups, and are commonly brittle due to tectonic stress suffered by the host rock. Small orange rutile and transparent apatite crystals occur as inclusions in the tourmalines which belong to the dravite species. The deposit is worked only because the crystals belong to a rarer mineral species than elbaite (at least in Brazil) and have a very unusual habit; their opa-

city and unattractive colour rule them out for use as gems.

Conclusion

Although there is neither an official record nor a comprehensive account of past, recent or present total output of gem tourmaline, one can be confident that Brazil has abundant tourmaline reserves to be developed in the future.

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A spectral-luminescent technique for gemmology

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Abstract

The experimental results of investigation of the pulsed cathodoluminescence (PCL) of rubies, sapphires and topazes in the red range of the spectrum are presented. The results are useful for a variety of gemmological applications. The colour density dependence of a mineral upon the band width of its PCL spectrum is shown. Common minerals from different occurrences have been shown to have distinctive PCL spectra. It has also been shown that identical colours of topaz may result from different dopants or trace elements. It is concluded that the phenomenon of PCL can be used as a basis for a fast non-destructive identification in various gemmological applications.

Key words: pulsed cathodoluminescence, spectrum, ruby, sapphire, topaz

Introduction

Spectral luminescent techniques of material analysis are fast, versatile and informative. They are widely applied in various fields of human activity. However, their role is comparatively small in gemmology due to the peculiarities of the problems presented. Knowledge of the exact chemical composition of a gem is rather desirable but not so necessary that one must use the most advanced methods (such as atom-emission analysis). Such a method also requires partial destruction of the specimen which is undesirable for gems. Conventional non-destructive luminescent techniques used to obtain structural information of a material (luminescence of minerals) are far from being perfect and are applicable only to a limited number of 'luminescent' gems.

Some reports describing pulsed cathodoluminescence (PCL) excited by irradiation of minerals by high-current short-pulse beams of energetic electrons have appeared recently (Mesyats *et al.*, 1992; Mikhailov *et al.*, 1993; Solomonov *et al.*, 1993; Mesyats *et al.*, 1994). The PCL intensity is ten thousand times greater than the intensity of X-ray-luminescence or continuous cathodoluminescence and it can be excited in every mineral showing dielectric behaviour. Such gems may be considered as dielectrics containing dopant ions, i.e. all common gems should exhibit the property of pulsed cathodoluminescence. Besides, the PCL spectrum is characterized by high stability of its parameters: namely the wavelength, half-width, intensity and number of spectral bands and lines for each mineral species, and by their reasonable reproducibility. As a rule, the high PCL intensity generates a higher number of spectral bands and lines in a gem than continuous cathodoluminescence. That is why one can perform a more precise gem analysis by PCL. The general running time of PCL gem analysis takes only a few minutes because there is no need to perform preliminary treatment such as cooling or evacuation of specimens.

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This work presents the results of experiments on the PCL of rubies, sapphires and topazes, and demonstrates an application of the techniques in characterization of gems.

Apparatus

A detailed description of the experimental methods used in PCL investigations has been presented by Mesyats *et al.*, 1993. To excite pulsed cathodoluminescence a portable (600x300x200 mm, about 15 kg weight) electron accelerator of 'RADAN–220' type (Zagulov *et al.*, 1989) was used. An electron beam of $\approx 2.10^{-9}$s duration, ≈ 180 keV energy, and ≈ 100–200 A/cm^{-2}current density was input into a metal chamber, which protected the operator from X-rays. Within this chamber a test specimen was placed in the electron beam.

The emitted light was directed from the specimen to the inlet slit of the portable (150x75x75 mm) polychromator with a special diffraction grid (Skokov *et al.*, 1991). An optical spectral analyser, based on a 512-element CCD-array detector connected with a computer, was used to carry out the experiments. The detector can record simultaneously the spectral range of 300 nm in a time of ≥ 20 ms. The gems under test need neither chemical nor mechanical pre-treatment, nor extraction from their settings. All investigations were performed at room temperature in the air.

Results

Some tested gems in natural illumination are shown in Figure 1a and their pulsed cathodoluminescence is shown in Figure 1b. The spectral range 600–800 nm is the most informative for PCL of rubies and sapphires. This range displays both common and individual spectral characteristics of gems. The common feature of rubies and sapphires, as representatives of the same mineral species corundum, is a broad structured red band with a narrow double R-line due to Cr^{3+}(λ_{R1}= 694.3 nm, λ_{R2} = 692.9 nm, Figures 2 and 3). A general spectral feature of artificial rubies and sapphires is that they display about ten times greater intensity of luminescence than that shown by natural gems of the same colour.

Rubies

Eleven artificial and 36 natural specimens were investigated. Among the natural specimens 21 were from the occurrence Makar-Ruz' in the Rai-Iz mountain range (Urals, 66°52'N, 65°15'E), and six were from the Polozhikha occurrence (Urals, 57°22'N, 61°01'E). The rest of them were individual specimens from different occurrences. All the ruby specimens (Figure 2) are characterized by the dominant role of Cr R-lines located near the centre of a broad and comparatively weak red band. The structure and width of these broad red bands are distinctly different for different occurrences and production technologies, but are consistent for the specimens from the same locality or manufacture.

A considerable increase of R-lines intensity (6–10 times greater than intensity of any local maximum of the underlying red band) is a distinguishing feature of the spectra of the artificial specimens (Figure 2, curve 1). These rubies are characterized by a minimum of the broad red band width of $\Delta\lambda \approx 55$ nm. The structure of the local maxima is amplified in the short wave range.

The PCL spectra of the natural ruby specimens from the Polozhikha occurrence have much in common with the spectra of the artificial specimens investigated (Figure 2, curve 2). However, the R-lines intensities are only two to three times greater than the local maxima of the red band. Also, there are fewer distinctive maxima and the band width is up to 65 nm.

The rubies from Makar-Ruz' show additional structure in their spectra (Figure 2, curve 3). Apart from the R-lines and the red band there is a pronounced infrared band at λ max ≈ 770 nm.

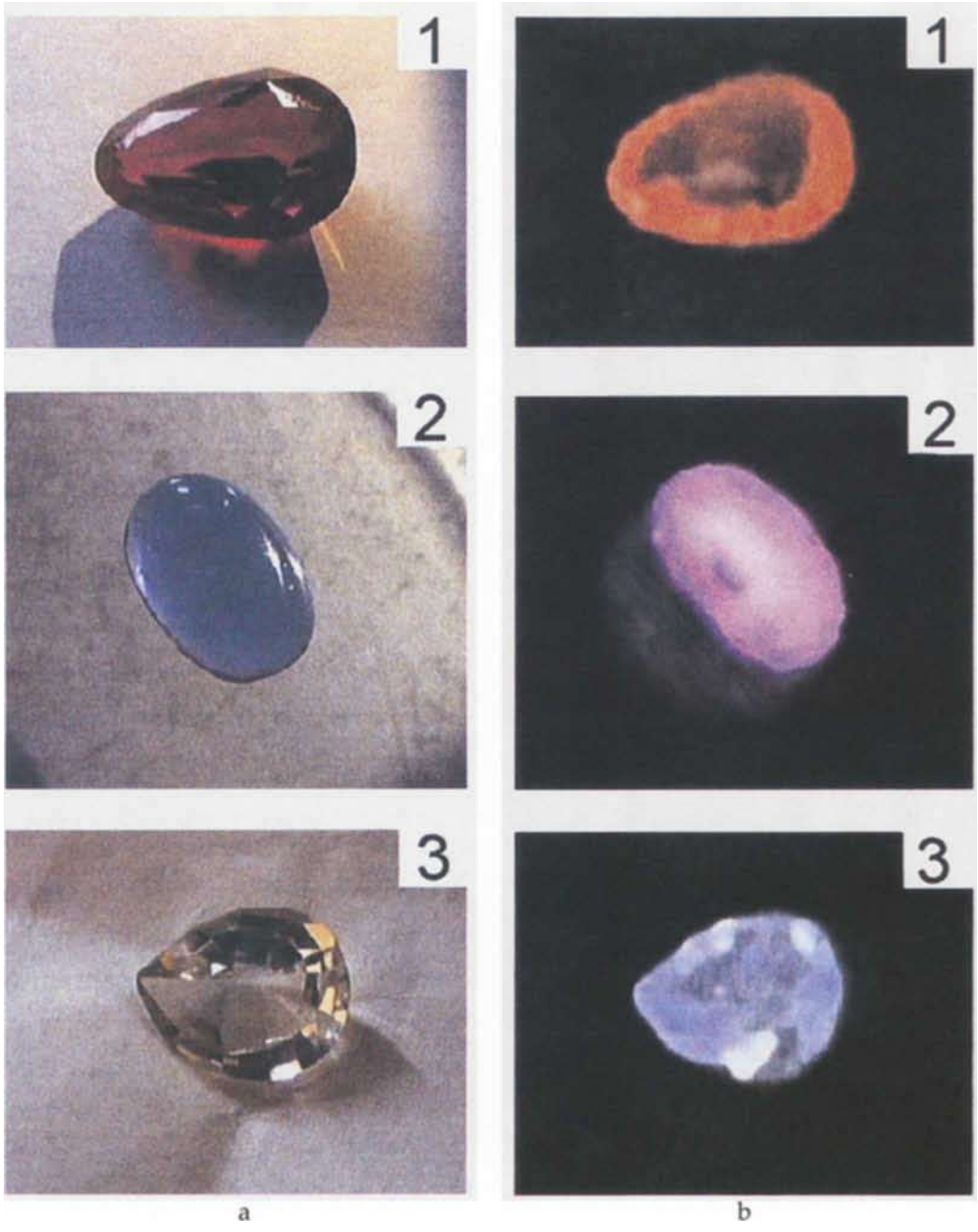

Fig. 1. Ruby (1), sapphire (2) and topaz (3) in (a) natural illumination and (b) displaying a pulsed cathodoluminescence

Sapphires

Specimens of different blue tints were investigated. The total number of specimens was 22, seven of which were artificial, five were from the Polozhikha occurrence (Urals), four were from Semiz-Bugu (Kazakhstan, 50°14'N, 75°00'E) and the rest were from other locations. The PCL inten-

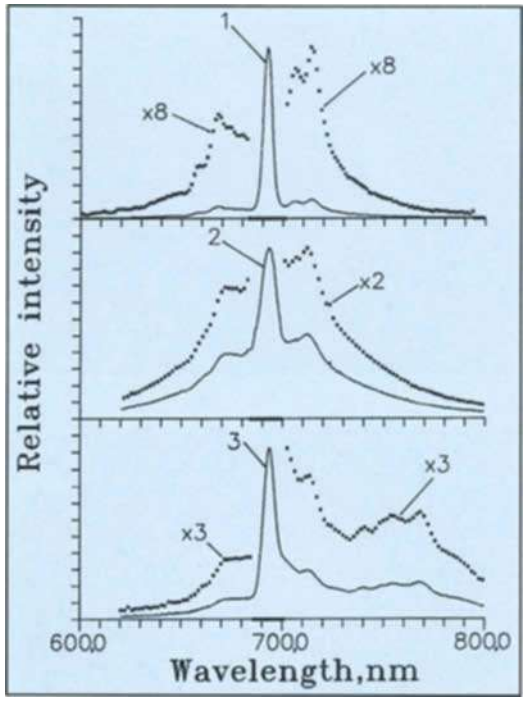

Fig. 2. Normalized PCL spectra of rubies: 1. artificial; 2. ruby from Polozhikha (Urals); 3. ruby from Makar-Ruz' (Urals)

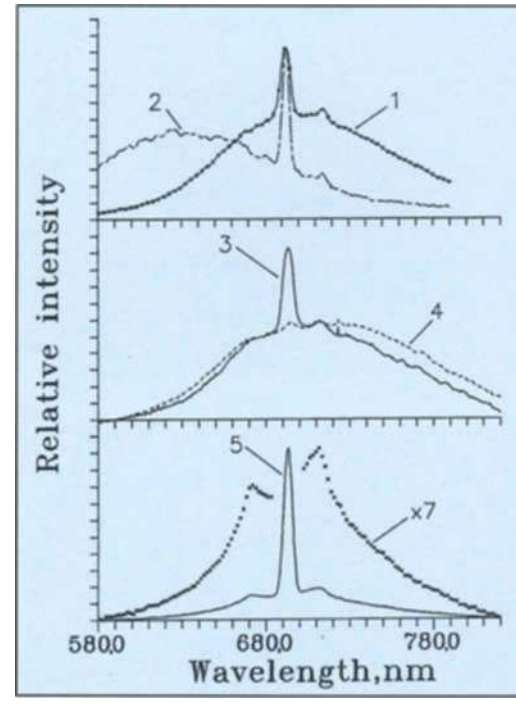

Fig. 3. Normalized PCL spectra of sapphires: curves 1 and 2, artificial; 3 and 4, sapphires from Polozhikha (Urals) (4 specimen with denser colour); 5, sapphires from Semiz-Bugu (Kazakhstan).

sity of most of the sapphires is lower than that for rubies. The main difference in the spectra of the two varieties is that the red band for sapphires is wider and less structured than in rubies. The dominant role of the R-lines of chromium (Figure 2) in rubies is not nearly so great in sapphires (Figure 3).

Most artificial specimens displayed spectra of the type shown in Figure 3, curve 1. For two specimens the spectra appeared to be of the type shown in Figure 3, curve 2 with a wide red-orange band at $\lambda \approx 625$nm. Among natural sapphires this kind of spectrum was observed only in specimens from the Kyshtym occurrence (Urals, 55°52'N, 60°33'E). For the remaining specimens the first type of spectrum is the one most commonly met. The curves 3 and 4 (Figure 3) for the specimens from the Polozhikha occurrence demonstrate this fact. While the blue colour density of tested sapphires increases, the relative intensity of the R-lines decreases and the red band becomes wider (Figure 3, curves 3, 4). For the sapphires of Semiz-Bugu the PCL spectrum (Figure 3, curve 5) is similar to that for rubies; it differs in having fewer local maxima and a wider red band ($\Delta\lambda \approx 75$ nm).

Topaz

Our investigations were performed on about one hundred specimens. Their PCL is characterized by intense wide bands with weak structure in the blue range. For yellow, pink, red and red-violet specimens the red range of the spectrum is most informative, while topaz of other colours generated no distinctive luminescence in these wavelengths.

The yellow topazes from the Emerald Mines of the Urals have a near-symmetrical band with $\lambda_{max} = 691$ nm, and width 60–70 nm. This symmetry is disturbed by

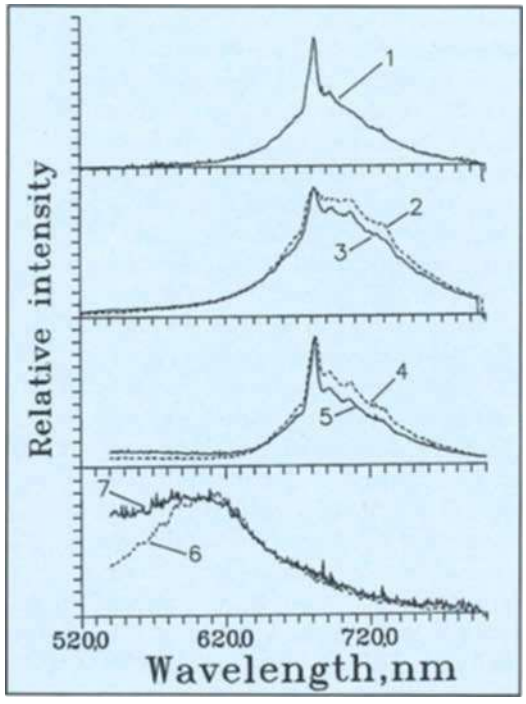

Fig. 4. Normalized PCL spectra of topaz : 1 yellow topaz from Emerald Mines (Urals); 2 and 3, pink-violet topaz from Kachkar' (Urals) (2 specimen is a denser violet); 4 and 5, from Chuksa (4 pink topaz, 5 yellow topaz); 6, pink-yellow topaz from Pakistan; 7, pink topaz from Volyn' (Ukraine)

the presence of a strong doublet R-line of Cr^{3+}(λ_{R1} = 682.0 nm—the stronger, and λ_{R2} = 677.1 nm—the weaker). In addition, there are three slight maxima in the band structure with λ = 691, 722 and 729 nm (Figure 4, curve 1).

The red band of luminescence is wider (95 nm) in the pink topazes with a violet tinge from Kachkanar (Urals, 58°45'N, 59°44'E) than it is for yellow topaz. The violet tint density increase is related to the expansion of that luminescence band (Figure 4, curves 2 and 3). The local maxima become more pronounced and more numerous due to the appearance of new maxima at λ = 663, 707, 740 nm. The relative intensities of R-lines decrease in this case.

For the Chuksa (Urals, 54°23'N,60°49'E) yellow-pink topazes (Figure 4, curves 4 and 5) the red band of luminescence is similar to the band shown in Figure 4, curve 1. The local maxima presented here at the same wavelength are more pronounced. Also, there is a considerable decrease of the R-lines intensity for the pink topazes as compared with that in the yellow ones and the red band width remains virtually constant.

In a number of pink, yellow and yellow-pink specimens from other localities the red band with the characteristic R-lines of chromium does not occur. However, a new red-orange band absent in the spectra of other specimens (λ_{max} = 605 nm, width = 90 nm) is present (Figure 4, curves 6 and 7). This band appears as single for Pakistan yellow-pink topazes (Figure 4, curve 6), while for the pink topazes of Volyn' (Ukraine, 50°53'N, 28°43'E) it is overlapped by another band on the short-wave side (Figure 4, curve 7).

After the analysis there were no mechanical defects and colour changes in any of the investigated specimens.

Discussion of the results

If the crystal lattice of these minerals were perfect and if there were no trace elements, one would be dealing with colourless and transparent crystals. Luminescence of such crystals could be studied in the context of optical transitions between the conduction band and the valence band in the UV and vacuum ultraviolet (VUV) ranges. In real crystals, lattice defects are always present as dopant ions and their complexes. These defects are, in essence, the centres of luminescence (LC) in the visible spectral range. Every LC has its characteristic bands and lines of luminescence whose wave length and width are dependent on the type of centre and its position in the crystal lattice. The intensity of a specific spectral band or line is determined both by the number of corresponding LCs contained in the mineral (the greater the number the higher the intensity) and by the concentration of centres of luminescence absorption (LCA). Some dopant ions such as iron may absorb

luminescence and in some situations luminescent centres may self-absorb; these are known as luminescence absorption centres (LCAs).

The most important dopant ion in ruby is Cr^{3+} which isomorphously replaces Al^{3+} (Taraschan, 1978; Marshall, 1988). In the absence of other dopant ions in the immediate vicinity of the individual Cr^{3+} ions the Cr narrow doublet R-line may be observed in the spectrum. It is important that the wavelength of this line is defined strictly. It is constant for each mineral species and it can be treated as an absolute indicator of minerals. For example, for corundum the wavelengths of R-lines are: λ = 694.3 and 692.9 nm; for topaz, λ = 682.0 and 677.1 nm; for spinel λ = 685.9 and 686.3 nm, and so on. The presence of these lines in the luminescence spectrum is uniquely indicative of the mineral species of a gem. Thus, the data obtained do not require further refining by any analytical methods. The presence of two ions of Cr^{3+} close together in the structure results in Cr-Cr pair formation, and gives rise to a luminescence band in the red spectral range with well-defined wavelengths of the local maxima (N-line of Cr (Taraschan, 1978)). If there are more ions of Cr^{3+} or ions of other elements in the vicinity, then complicated LCs are formed. They lead to luminescence as a widened red band that, generally, has different numbers and wavelengths of the local maxima. In addition, the dopant ions of other elements can produce their LCs emitting luminescence in other spectral ranges.

In most artificial rubies Cr^{3+} ions are the predominant dopant ions. The corresponding LCAs formed by other defects appear in a very minor way. This composition causes a very high PCL intensity of R-lines of Cr^{3+} and a comparatively low intensity of the red band due to Cr-Cr pairs. As the density of the red colour increases, i.e. the concentration of Cr^{3+} ions increases, the ratio of the intensity of R-lines and the red band changes, the latter becomes higher and the ratio falls. Such a phenomenon can be used to estimate the quality of specimens by their colour density.

Along with the Cr^{3+} ions other dopants should be present in natural rubies. The chemical nature and concentration of the dopants depends on the different geological and geochemical conditions in which the mineral formed. Such differences in composition will manifest themselves either through the distinctiveness of the red band structure (Figure 2, curve 2) or through other luminescence bands that may be typical for certain occurrences (Figure 2, curve 3). This seems to occur not only in rubies but also in other gems, at least as far as sapphires and topazes are concerned. If a spectral PCL data bank were available for gems from all occurrences, then it would be an easy matter to identify the occurrence for a specific specimen if its PCL spectrum characteristics were obtained.

There are two kinds of spectral PCL lines for artificial sapphires and this indicates that the blue colour of a sapphire can be due to at least two types of dopant ions. Specimens having the spectra of the type shown in Figure 3, curve 2 are very rare and such spectra have so far been found only in specimens from Kyshtym (Urals). It should be pointed out that the density of the colour blue in sapphires is reflected in the PCL spectrum by a width change of the red band and by the intensity of R-lines of Cr (Figure 3, curves 3 and 4). It makes the identification of the specimens more objective.

The investigation of the PCL spectra of topaz specimens shows that different dopants may cause similar colours (cf. sapphire described above). The violet-tinted pink colour can more or less unequivocally be assigned to the effect of the Cr^{3+} ions, while the yellow-pink colour seems to be a response either to Cr^{3+} ions and unidentified dopants or to such dopants emitting luminescence within the band at wavelength λ = 605 nm in the absence of

Cr^{3+} ions (Figure 4). The PCL spectra of topazes contain distinctive features related to their occurrences. As with the sapphires, this provides another technique for sorting specimens and perhaps for estimating the financial value of gems in a more objective way.

Conclusion

The investigation of the cathodoluminescence spectra of rubies, sapphires and topazes through the PCL-based technique (the PCL method) opens up considerable possibilities for obtaining fast and correct solutions to a wide range of gemmological problems.

These are:

1. the possibility of fast identification of a gem without invoking an additional investigative technique;
2. the possibility of fast determination of the origin of a gem (geographical or laboratory). With advanced computer and data-processing technology and with a quick-response PCL technique, the creation of a data bank of spectra becomes practically feasible;
3. the possibility of objective evaluation of the colour quality of a gem with identification of the dopants responsible for the colour;
4. the possibility of exact identification of artificial analogues of natural gems.

Further application of the PCL-method to various gemmological problems would undoubtedly lead to useful developments.

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Abstracts

Diamonds | Gems and Minerals | Instruments and Techniques | Synthetics and Simulants

Diamonds

Diamonds and their host rocks in the United States.
W.D. HAUSEL. *Mining Engineering*, **47**(8), 1995, pp 723–32.

More than 220 000 diamonds have been found in the US ranging in weight from microdiamonds to the largest authenticated diamond of 40.42 carats. Diamonds have been reported from several states in the US with the greatest concentrations coming from Colorado, Arkansas, California, Oregon, Georgia, Wyoming and Michigan. Many diamonds were mined from either kimberlite or lamproite, but in the case of the Appalachian and Pacific Coast diamonds, the source is unknown. W.D.H.

History of diamond sources in Africa: Part II.
A.J.A. JANSE. *Gems and Gemology*, **32**(1), 1996, pp 2–30, 14 illus. in colour, 5 tables.

In this second article the history of diamond exploration and mining in East and West Africa with detailed production figures are discussed. Theories on the geology and origin of the diamond are discussed and E.J. Dunn was the first to introduce the term *pipes* in print; later H.C. Lewis proposed the name kimberlite for the 'new' ultrabasic rock found in the pipes at Kimberley and recognized the volcanic nature of these pipes.

The central theme of modern theories is that diamonds were formed at depths of 150–200 km in the upper mantle as much as 3300 My ago. The presence of garnet and ilmenite in alluvial samples was a useful indication that diamonds might occur and from trace elements such as nickel in garnet it was possible to estimate the temperature of formation; when these corresponded to the temperature of the formation of diamond, the potential for diamond was correspondingly high.

The history of diamond production is given in detail and in the first thirty years (1871–1900) showed the emergence of De Beers as the dominant factor. The opening of the Premier mine in 1903 challenged the De Beers Syndicate but progressive buying of shares by the Barnato Brothers resulted in their control of the Premier Mine which then joined the quota system. World War I reduced demand for diamonds and production was curtailed. A glut of cut diamonds from Russia and a general recession in 1921/22 again resulted in a reduced output.

The emergence of the Oppenheimer Syndicate helped to stabilize the situation with Ernest Oppenheimer becoming the chairman of De Beers in 1929. A year later the Diamond Producers' Association was formed and prices were controlled through the depression of the 1930s. By 1932 De Beers had closed all their operating kimberlite mines. To cope with increased production from sources outside South and South West Africa the Syndicate was restructured in 1934. Buying was covered by the

ABSTRACTORS

R.K. Harrison	R.K.H.	R.A. Howie	R.A.H.	R.J. Peace	R.J.P.
W.D. Hausel	W.D.H.	M.O'Donoghue	M.O'D.	E. Stern	E.S.

For further information on many of the topics referred to consult *Mineralogical Abstracts* or *Industrial Diamond Review*.

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Diamond Corporation whilst sorting and selling became the concern of the new Central Selling Organisation (CSO); the first 'sight' was held in 1939. Diamond production today indicates that Botswana and South Africa are the largest producers by value on the African continent with Botswana the highest value producer in the world. R.J.P.

Gem News.

J.L. JOHNSON AND J.I. KOIVULA. *Gems & Gemology*, **32**(1), 1996, pp 52–62, 17 illus. in colour.

At the 1996 Tucson Show there were diamonds in matrix from both China and named localities in Russia. Synthetic diamonds from Russia were on sale by the Morion Company. Synthetic moissanite (silicon carbide SiC) is marketed as a diamond simulant with suitable orientation to minimize doubling of facets. R.J.P.

Gem Trade Lab.

R.C. KAMMERLING AND C.W. FRYER. *Gems & Gemology*, **31**(4), 1995, pp 266–73, 17 illus. in colour.

Energy dispersive X-ray fluorescence spectroscopy used to detect synthetic diamonds will detect iron and nickel which are used as catalysts in synthetic diamond formation even when flux inclusions cannot be identified. Even so the presence of iron and/or nickel is not proof of a synthetic origin. A heavily included black diamond with black inclusions in bands showed brown staining. The black inclusions were probably graphite and EDXRF revealed iron. Despite the detectable iron content the stone was not attracted to a powerful magnet (the iron and nickel found in synthetic diamonds is strongly magnetic).

A fracture-filled yellowish-orange cut-cornered rectangular modified brilliant showed feathers and blue and orange flash colours. EDXRF spectroscopy of the fill revealed lead and bromine and some thallium. R.J.P.

Gems and Minerals

Gemologie Aktuell.

H. BANK, U. HENN AND C.C. MILISENDA. *Gemmologie. Zeitschrift der Deutschen Gemmologischen Gesellschaft*, **45**(2), 1996, pp 43–6, 6 photographs in colour.

Orange spessartine garnets have been found in gneisses in Namibia; RI 1.800–1.801, SG 4.08–4.12. Distinct growth zoning and hollow tubes were observed with an immersion microscope. They are spessartine-rich garnets of the binary solid solution series pyrope-spessartine. Bright blue-green copper-bearing tourmalines have been found in Rio Grande do Norte in Brazil; they are similar to those from Paraíba and are sold as Paraíba-tourmalines. Porcelanite is a rock mined in the Czech Republic which can be manufactured into jewellery objects; it is a metamorphosed marly clay showing attractive sedimentary textures. Some lapis lazuli has come on the market showing attractive golden veins; these, however, proved to be cement with pyrite dust! Some synthetic hydrothermally grown blue sapphires from Novosibirsk are on the market, RI 1.760–1.762, 1.768–1.770; DR 0.008; SG 3.98–4.06. There are swirl-like growth marks and black bread-crumb like residues. Also from Russia are some synthetic chrysoberyls grown by the float-zone method and coloured by vanadium, RI 1.743–1.751; DR 0.008; SG 3.68. E.S.

Der Korallenachat von Halsbach bei Freiberg/Sachsen.

W. BECK. *Lapis*, **21**(6), 1996, pp 44–6, illus. in colour, 1 map.

Pink to brown banded agate is reported from the area of Halsbach, Freiberg, Saxony, Germany. The coral-like banded material has been fashioned. M.O'D.

Australian sun opal.

G. BROWN, S. STREET AND S. FAIRLEY. *South African Gemmologist*, **10**(1), 1996, pp 20–2, illus. in colour.

A golden-yellow oval brilliant weighing 1.94 ct was found to be opal. The material was reported to have occurred as a cavity filling in decomposing rhyolitic thunder-eggs from a basalt flow in the Mullenbimby area of north-eastern New South Wales. Minor flow features were detected inside the stone. M.O'D.

Le gîte de tourmaline de São José de Batalha (Paraíba-Brésil).

J. CASSEDANNE. *Revue de Gemmologie*, **127**, 1996, pp 6–11, 1 map.

Green and blue tourmaline of exceptional colour is reported from São José de Batalha, Paraíba, Brazil. Details of the occurrence in pegmatite and a history of its working for gem

material are given: the material is elbaite with the appropriate properties apart from the presence of Cu as a colouring agent. Notes on attempted simulants are given and there is a bibliography. M.O'D.

Shape, structure and colours of Polynesian pearls.

J.P. CUIF, Y. DAUPHIN, C. STOPPA AND S. BEECK. *The Australian Gemmologist*, **19**(5), 1996, pp 205–9, 9 illus. in black-and-white.

The shell structure of the *Pinctada margaritifera* and its development is discussed with some excellent microphotography. The cultured pearl is made by inserting a mother-of-pearl bead together with a piece of mantle tissue into a surgical incision made in the gonad of the oyster. After initial deposition of organic material, layers of prismatic calcite are deposited by epithelial cells of the 'outer layer' type whilst the more numerous 'inner layer' type deposits layers of aragonite nacre.

The black pigment in the outer layer of the oyster shell consists of a mixture of several organic compounds of relatively low molecular mass. Spectrophotometric examination suggested that three kinds of pigment molecules gave rise to the colour variations seen in Polynesian pearls. The hypothesis had some support from reflectance measurements which revealed variable mixtures of two molecular types. Reflectance spectroscopy was used to determine the statistical distribution of colour in pearl populations and hopefully would enable improved cultivation programmes to be devised. R.J.P.

Worldwide mineralogy: a sketch of an exposition.

A.A. EVSEEV. *World of Stones*, 9, 1996, pp 28–36.

The misleading title conceals an important list of specimens held at the newly established (1991) Moscow State Geological Exploration Academy. Entries are listed by continent, country and mine where known and many gem minerals are included. M.O'D.

Gem Trade Lab notes.

C.W. FRYER. *Gems & Gemology*, **32**(1), 1996, pp 44–51, 20 illus. in colour.

A grossular garnet-bearing rock resembled impregnated jadeite. Magnification showed the grossular standing out against the softer undercut white areas. The latter did not react to a hot point and X-ray diffraction analysis showed it to be a chlorite mineral. Bright brownish-orange metallic flakes present in mottled green and white beads of jadeite were shown to be elemental copper.

Several abalone pearls have been encountered shaped like shark's teeth. An X-radiograph revealed a large hollow centre; several new abalone pearl culturing farms are reported. A string of pearls had been partially coated to fill drill holes which did not pass near the centre (presumably for attachment to fabric). The pearls had then been re-drilled through the centre.

A transparent near-colourless emerald-cut stone had properties not significantly different from grossular garnet. EDXRF spectrometry and X-ray diffraction showed it to be periclase MgO. An imitation ruby necklace was shown to be dyed, quench-crackled quartz whilst a ruby doublet was shown to have two natural parts. A natural pink sapphire had unusual rounded facet junctions. A green synthetic sapphire revealed curved colour zones and EDXRF analysis indicated the presence of Co which was possibly the cause of the colour. R.J.P.

Spessartine aus Pakistan.

U. HENN. *Gemmologie. Zeitschrift der Deutschen Gemmologischen Gesellschaft*, **45**(2), 1996, pp 93–4, 2 photographs, bibl.

A new occurrence of orange- to cherry-red spessartine garnets was found in 1993 in Azad Kashmir in Pakistan; known under the trade name of 'Kashmirine', it is composed mainly of spessartine with some almandine and grossular. RI 1.798–1.802, SG 4.05–4.18. The clear crystals show only a few healing cracks with fluids; some crystals had inclusions which were analysed and shown to be potassium feldspar. E.S.

Durchsichtiger Obsidian (Marekanit) im Perlit von Superior, Arizona, U.S.A.

G. HOLZHEY. *Gemmologie. Zeitschrift der Deutschen Gemmologischen Gesellschaft*, 45(2), 1996, pp 83–9, 5 photographs, 2 diagrams, 1 table, bibl.

Obsidian is a nearly water-free glass which seldom occurs in a transparent form as those found in Superior, Arizona. The transparent, smoky coloured marekanite is rhyolitic in composition and has an RI of 1.480, SG 2.33. Anomalous birefringence is characteristic for rough stones only. The commonest microlites

within the marekanite consist of pyroxenes which mark the flow structure. E.S.

Sterndisthen und Disthen-Katzenaugen aus Indien.
J. HYRSL AND C.C. MILISENDA. *Gemmologie. Zeitschrift der Deutschen Gemmologischen Gesellschaft*, **45**(2), 1996, pp 91–2, bibl.

Dark blue kyanite cabochons weighing up to 10 ct from India came on the market recently. R.I. 1.71–1.72, SG 3.62–3.64. Some samples were chatoyant, some showed a four-rayed star, caused by parallel oriented hollow tubes. Chromium was the colouring agent. Included black crystals seemed to be ilmenite, some yellow-brown inclusions were thought to be biotite. E.S.

Gem Trade Lab notes.
R.C. KAMMERLING AND C.W.FRYER. *Gems & Gemology*, **31**(4), 1995, pp 266–73, 17 illus. in colour.

Impregnated black opal rough showing a play of colour gave two separate RI readings of 1.44 and 1.50, this latter high value being attributed to the impregnating substance. The SG of 1.82 was slightly lower than the lowest values obtained from Kyocera treated synthetic opal, and a faint orange fluorescence to short wave UV was consistent with Kyocera test samples. Magnification revealed a 'lizard skin' effect and a pronounced columnar structure. FTIR analysis showed several absorptions between 6000 and 4000 cm^{-1} which are not seen in natural opal and it was concluded that the specimen was impregnated synthetic opal.

A green and yellow bicoloured quartz, three rubies and a sapphire with chromium were described. A natural dark blue spinel showed a colour change from violetish-blue in fluorescent light to purple in incandescent light. R.J.P

Instruments and Techniques

New methods for photography through the microscope: application to gem materials.
K.A. KINNUNEN. *Geological Survey of Finland. Special Paper*, **20** (Current Research 1993–1994), 1995, pp 185–7.

New techniques are described for the photomicrography of macroscopic specimens in the natural state, including crystal faces and gold nuggets. An acetate peel is obtained from the cleaned surface of the specimen, and the peel is mounted and studied in transmitted light and photographed. Colour-filter shadowing is used to enhance the 3D aspects of the specimen. Examples are presented of the rhombohedral faces of amethyst crystals. The method has been applied to the identification of faked specimens and in criminological studies. R.A.H.

Application of Fourier transform infrared spectroscopy to silica diagenesis: the opal-A to opal-CT transformation.
S.B. RICE, H. FREUND, W.L. HUANG, J.A. CLOUSE AND C.M. ISAACS, *Journal of Sedimentary Research*, **A65**(4), 1995, pp 639–47.

Fourier transform IR spectroscopy is combined with XRD and TEM to experimental run products and natural opals from the Monterey formation and siliceous deposits in the W. Pacific. Using a ratio of two IR absorption intensities, the relative proportions of opal-A: opal-CT can be determined. Three stages in the opal-A to opal-CT reaction are: opal-A dissolution, opal-CT precipitation (with the end product marked by completion of opal-A dissolution), and opal-CT ordering during which tridymite stacking is eliminated in favour of cristobalite stacking. R.K.H.

Synthetics

Gem Trade Lab notes.
R.C. KAMMERLING AND C.W. FRYER. *Gems & Gemology*, **31**(4), 1995, pp 266–73, 17 illus. in colour.

A corundum in for test was near colourless and examination under short wave UV radiation revealed curved striae. However, on removing the stone after about three minutes it had changed to a brownish-yellow. Six hours exposure in a solar simulator removed most of the induced colour and a few minutes gentle heating over an alcohol lamp returned the stone to its original near-colourless condition. R.J.P.

Fabrication of hollow porous shells of calcium carbonate from self-organizing media.
D. WALSH AND S. MANN. *Nature*, **377**(6547), 1995, pp 320–3.

A method for synthesizing hollow porous shells of aragonite resembling the coccospheres of marine algae, is described. Thin cellular frameworks of mesoporous or macroporous aragonite can be formed from oil-water-surfactant microemulsions supersaturated with calcium bicarbonate. R.K.H.

BOOK REVIEWS

Roman jet in the Yorkshire museum.
L. ALLASON-JONES, 1996. The Yorkshire Museum, York. pp 55, illus. in colour, softcover. £4.50. ISBN 0 905807 17 0.

The Yorkshire Museum holds a collection of Roman jet artefacts retrieved since the nineteenth century and consisting largely of ornamental and some domestic specimens. This short and well-produced catalogue is arranged by specimen type beginning with pendants and concluding with unfinished items. Many of the pieces can be classed as jewellery: items are well-drawn or photographed, with entries giving specimen type, description, dimensions, details of the find and museum accession number.

Introductory chapters describe the Roman use of jet and its nature, how jet is worked and remarks on the particular uses of the specimens in the collection. A single page gives a chemical analysis of jet and there is a useful bibliography, from which Muller's *Jet (Butterworths Gem Books series)* is unaccountably absent. This is an excellent addition to the literature of jet and at the price should be available to a wide readership.

M.O'D.

Rock-forming minerals. Second edition. Vol. 5B. Non-silicates: sulphates, carbonates, phosphates, halides.
I.L.Y. CHANG, R.A. HOWIE, AND J. ZUSSMAN, 1996. Longman Group Ltd., Harlow. pp 383, hardcover. £115.00. ISBN 0 582 30093 2.

The stately progress of 'Deer, Howie and Zussman' continues after a lengthy pit stop of nearly ten years and with the addition of Professor Chang as senior author. We now await the volume dealing with oxides, hydroxides and sulphides.

All the good points of previous volumes are incorporated in this one: comprehensive lists of references, clear crystal drawings and phase diagrams and tables giving properties (for comparison purposes) of representatives of the minerals covered. The gap in publication means that references in the previous volumes are out of chronological balance with those in this one but it would be nearly impossible to keep up a steady rate of production and we should be satisfied with the data provided.

Readers of the *Journal* will find this volume worth consulting for the carbonates rhodochrosite, calcite, aragonite, malachite, azurite and smithsonite and for several less common species which are sometimes fashioned. Of the four rock-forming sulphates, baryte, celestine and gypsum have some ornamental significance: the apatite group needs no introduction and fluorite is a major member of the rock-forming halides.

To give an example of the type of information provided, the section describing fluorite gives a summary of the major optical and physical properties, a general overview of the mineral, details of crystal structure, chemistry, details of recent experimental work, a discussion of optical and physical properties which includes the cause of colour, distinguishing features in hand specimens and paragenesis. The list of references covers three closely-printed pages and concludes the section.

This type of reference work should not be considered 'above' the competence of gemmologists to understand but rather as a back-up to those more accessible sources of information which sometimes have to be consulted. The price rather limits accessibility to readers who are members of universities but we have left behind the days when reference books could be purchased by individuals and the smaller reference libraries.

M.O'D.

Opal, das edelste Feuer des Mineralreichs.
1996. CHRISTIAN WEISE VERLAG, MÜNCHEN. [*extraLapis* no 10]. pp 96, illus. in colour, softcover. DM 45.00. ISBN 3 921656 37 0.

The text contains pieces on many different aspects of opal while being arranged geographically, with sections covering Australia, Mexico, Brazil and Kirschweiler [the 'opal village' bordering Idar-Oberstein and celebrated for a concentration of opal dealers and cutters]. Before the text splits up into countries, introductory material includes notes on the nature and colouring of opal and an update on world localities. This is essential reading for all gemmologists.

M.O'D.

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THE 1997 GAGTL PHOTO COMPETITION

Collector's Gems

In the competition this year members are asked to submit pictures of exceptional or unusual gems which justify their place in a collection.

A gem's value in a collection may be in its rarity, its exceptional colour compared with most gems of its species, in its demonstration of particular features or perhaps in its historical associations. Send us your pictures of gems exceptional in some way for the 1997 Photographic Competition.

All entries will be judged for originality, beauty and gemmological interest.

The following prizes will be awarded:

First Prize: £100
Second Prize: £75
Third Prize: £50

Entry forms and details of the rules of entry will be circulated to all members.

OBITUARY

Mr John Francis Hodges, FGA (D.1953), Bradley, Wrexham, died on 11 June 1996.

GIFTS TO THE ASSOCIATION

The Association is most grateful to the following for their gifts for research and teaching purposes: Jamie Anderson-Slight, Horsham, Sussex, for an aquamarine fragment from the border of Zambia and Mozambique.

John Fyfield, Pinner, for a collection of specimens including dyed rubies, bone carvings, jade, an ivory bead necklet and an imitation shell cameo.

Dr A. Peretti and C.P. Smith, Switzerland, for cut sapphires from Vietnam.

Mr M. Sevdermish of Herzliya, Israel, for *The dealer's book of gems and diamonds* by M. Sevdermish and A. Mashiah, 1996, in two volumes. Gemology (A.M.) Publishers Ltd., Israel.

Mr Manfred Szykora, Munich, Germany, for a copy of *extraLapis No. 10: das edelste Feuer des Mineralreichs.*

MEMBERS' MEETINGS

London

On 5 June at the Gem Tutorial Centre, 27 Greville Street, London EC1N 8SU, David Minster of Pretoria, South Africa, gave a 3-D slide presentation of gemstones and minerals.

On 4 September at the Gem Tutorial Centre John Kessler gave an illustrated lecture entitled 'The importance of gems in Brazil's development'.

North West Branch

On 19 June at Church House, Hanover Street, Liverpool 1, David J. Lancaster from Christie's, South Kensington, gave a talk entitled 'Jewellery in the auction world and period jewellery'.

On 18 September at Church House, Deanna Brady gave a talk entitled 'Brush up your gemmology'

Scottish Branch

On 23 June a field trip was organized to the Campsies to collect jasper.

On 6 September at the British Geological Survey, Murchison House, West Mains Road, Edinburgh, Rosamond Clayton gave an illustrated talk on jade.

ANNUAL GENERAL MEETING

The Annual General Meeting of the GAGTL was held on 10 June 1996 at 27 Greville Street, London EC1N 8SU. Vivian Watson chaired the meeting and welcomed those present. The Annual Report and Accounts were approved and signed.

The Chairman announced that Eric Bruton had completed his two-year term as President and expressed the Association's gratitude for his

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FORTHCOMING MEETINGS

London

Unless otherwise stated, meetings will be held at the GAGTL Gem Tutorial Centre, 27 Greville Street (Saffron Hill entrance), London EC1N 8SU. Entry will be by ticket only at £3.50 for members (£5.00 for non-members) available from the GAGTL.

20 November	**The mystery of opal**	David Callaghan
4 December	**Burmese gems at the Natural History Museum**	Cally Hall
15 January	**Growth and identification of synthetic diamonds**	Chris Welbourn
12 February	**Sleepers—rediscovery and reattribution in the antique jewellery trade**	Geoffrey Munn

Midlands Branch

Monthly meetings will be held at the Discovery Centre, 77 Vyse Street, Birmingham 18. Further details available from Gwyn Green on 0121–445 5359.

29 November	**Jewellery for the world and his wife**	Shena Mason
7 December	**Annual Dinner**	
31 January 1997	**Bring and Buy and Quiz**	

North West Branch

Meetings will be held at Church House, Hanover Street, Liverpool 1. Further details from Joe Azzopardi on 01270 628251.

20 November	**Annual General Meeting**

Scottish Branch

13 November	**Lab Night.** Telford College, Crewe Toll, Edinburgh
12 February	**Lab Night.** Barmulloch College, Barmulloch Road, Glasgow

For further details of Scottish Branch meetings contact Ruth Cunningham on 0131–225 4105.

positive contribution during that period. To commemorate his Presidency, a new prize to be named the Bruton Medal would be awarded for the best set of answers submitted in the Gem Diamond Examinations.

The Council had recommended that Professor R.A. Howie be elected President for the 1996–1998 term (see p. 260) and the nomination was unanimously carried. Professor Howie's address is given below.

Terry Davidson and Noel Deeks were re-elected to the Council of Management.

It was announced that Patrick Daly and Gary Monnickendam had expressed the wish to retire from the Members' Council. John Greatwood and Jeffrey Monnickendam were elected and Peter Dwyer-Hickey, John Kessler, Laurence Music and Jamie Nelson re-elected to the Members' Council.

Following the Annual General Meeting, members enjoyed a Reunion and Bring and Buy sale. The winners of the 1996 Photographic Competition were announced and entries were displayed.

ADDRESS BY PROFESSOR R.A. HOWIE

I am very conscious of the honour that the Association is bestowing on me today, and I shall hope to fill the post of President as best I can.

On taking up such a position, one looks at the names of one's distinguished predecessors with awe. When I was invalided out of the Air Force in 1946 and went up to Cambridge, one of my lecturers in Physics was Sir Lawrence Bragg, an avuncular figure of great renown who later became your President. Through no fault of his, I soon switched to Mineralogy as my main subject, and soon afterwards joined the Mineralogical Society which has been my main Learned Society for over 45 years (indeed I've been on its Council for most of the last 38 years). There I came across Frank Claringbull, Sir Lawrence's successor, first as General Secretary and later as President and Managing Trustee. Eric Bruton I have not met, but his name is familiar and he and I share one vice: we both write books, though his have much more elegant titles, such as *Diamonds*. Who could resist dipping in to a book with that title. Many years ago I presented myself one freezing December morning at the door of one of the main diamond cutters in Amsterdam, asking to be shown around. I was both intrigued and appalled by the process of bruting whereby chunks of one diamond are knocked off by rotating it against another diamond. Yes, I know that this technique was developed more than 200 years ago and that the name had nothing to do with Eric, but I am sure nevertheless that he can knock spots of anyone!

Thank you for placing your confidence in me. I will try to repay your trust.

ISLAND OF GEMS

An exhibition on the gems and gem industry in Sri Lanka is to be held at the Commonwealth Institute, Kensington High Street, London W8 6NQ on 16 and 17 November 1996 from 9.30 a.m. to 4.30 p.m. Further details from Sri Lanka Gems, P.O. Box 1837, London N17 9BW (telephone/fax 0181 808 4746).

GEM DIAMOND EXAMINATION

In June 1996, 70 candidates sat the Gem Diamond Examination, 47 of whom qualified, including two with Distinction.

The names of the successful candidates are as follows:

Qualified with Distinction

Birrell, Andrew Tierney, Edinburgh.
Lake, Richard John, Gorey Village, Jersey, C.I.

Qualified

Abramian, Levon, London.
Baker, Kimberly Helen, Leicester.
Bowis, Mark Lister, London.
Burch, Clive R., Sunderland.
Buxani, Naina Mahesh, London.
Cadby, Sarah, London.
Carvalho, Roberta Melo de, Rio de Janeiro, Brazil.
Clarke, Norman V., Dunfermline.
Coker, Olive Admira, Freetown, Sierre Leone.
Daniel, Eliena, London.
Daniels, Razia, Chester.
Dinnis, Simon John, Swadlincote.
Dokken, Aarrynne Dennise Celeste, London.
Ezzedine, Marwan, London.
Guo, Lei, Wuhan, P.R. China.
Higgins, Sally Ann, Birmingham.
Hird, Shelly Rose, London.
Jackson, Lam, London.
Jones, Maureen, Coventry.
Jurvakainen, Risto, Helsinki, Finland.
Kathoon, Junaida, Singapore.
Lao Weng Hong, Scholastica Loretta, Macau, Hong Kong.
Liang-Chin, Wu, Birmingham.

GAGTL GEM TUTORIAL CENTRE

27 Greville Street (Saffron Hill entrance), London EC1N 8SU

5 and 6 November **Synthetics and Enhancements Today**
Are you aware of the various treated and synthetic materials that are likely to be masquerading amongst the stones you are buying and selling? Whether you are valuing, repairing or dealing, these two days of insights, tips and practical investigation will increase your knowledge of the market.
Price £223.25 (including sandwich lunches)

20 November **Review of Diploma Theory**
A day for Gemmology Diploma students to review their theory work and to prepare for the Diploma theory examinations. Find out about our tips on the consolidation and revision of facts, figures, principles, practical techniques and instruments.
Let us help you to review your examination technique with the help of past questions. This review would help students who intend to enter the Diploma examination in 1997.
Price £33.49 (including sandwich lunches)

27 November **Enquire Within : Ruby and Sapphire**
A day looking at all aspects of these gems – natural, treated, synthetic and imitation.
Price £111.63 (including sandwich lunch)

7 and 8 December **Weekend Diamond Grading Revision**
This intensive weekend course has been designed for all students about to take the Gem Diamond Diploma. This workshop will include a mock examination to help students gain familiarity and confidence with examination conditions.
Price £129.25

4 and 5 January 1997 **Two-Day Diploma Practical Workshop**
The long-established intensive practical course to help students prepare for the Diploma practical examination; also highly effective for those in the trade and elsewhere to brush up on technique. This is the course to help you practise the methods required to coax the best results from gem instruments. The course includes a half-length mock exam for you to mark yourself.
Price £160.39 (£111.04 for GAGTL registered students) – includes sandwich lunches

NOTE: All prices include VAT at 17.5%

Please ring the Education Office (0171-404 3334) for further information

Li, Zheng, Wuhan, P.R. China.
Lin, Songshan, Wuhan, P.R. China.
Lodge, Sara Anne-Marie, Nottingham.
Lord, Karen, Lutterworth.
McIntosh, Robert P., Edinburgh.
Metaxa, Ioulia, London.
Mistry, Janak Arvindbhai, Surat, India.
Mitchell, Beverly J., London.
Mitteregger, Unni, London.
Pepprell, Eija-Liisa, London.
Quinn, Samantha, Maidenhead.
Sotolongo, Sachiko Kashiba, London.
Sveen, Per Olav, Trondheim, Norway.
Turner, Caroline, London.
Vaja, Pravin, London.
White, Michele, Moseley, Birmingham.
Withington, Terry, London.
Xu, Feng, Wuhan, P.R. China.
Yang, Hui Hsien, Hong Kong.
Zhang, Weibo, Wuhan, P.R. China.
Zhang, Yindi, Wuhan, P.R. China.
Zhou, Li, Wuhan, P.R. China.

EXAMINATIONS IN GEMMOLOGY

In the June 1996 Examinations in Gemmology, 241 candidates sat the Preliminary Examination, 175 of whom qualified; 306 sat the Diploma Examination and 103 qualified, including three with Distinction.

The Tully Medal for the candidate who submits the best set of answers in the Diploma examination which, in the opinion of the Examiners, are of sufficiently high standard, was awarded to Miss Ding Qian, Shanghai, P.R. China.

The Anderson/Bank Prize for the best non-trade candidate of the year in the Diploma Examination was awarded to Mr Liu Xu, Wuhan, P.R. China.

The Diploma Trade Prize for the best candidate of the year who derives his/her main income from activities essentially connected with the jewellery trade was awarded to Miss Ding Qian, Shanghai, P.R. China.

The Anderson Medal for the best candidate of the year in the Preliminary examination was awarded to Miss Unni Mitteregger, London.

The Preliminary Trade Prize for the best candidate of the year who derives his/her main income from activities essentially connected with the jewellery trade was awarded to Miss Victoria Forbes, Portadown, Co. Armagh.

The names of the successful candidates are as follows:

Diploma

Qualified with distinction

Haria, Aarti Vipul, Nairobi, Kenya.
Mitteregger, Unni, London.
Sulan, Dai, Wuhan, P.R. China.

Qualified

Aarden-Kilger, Flavia, L.M., Haalderen, The Netherlands.
Achten, Louisa Wendelina Wilhelmina, Horst, The Netherlands.
Adams, Victoria, London.
Backstrom, Ingrid, Stockholm, Sweden.
Barnes, Patricia Ellen, Dunkirk, Md., USA.
Bonjer, Chantelle, M., Abbotsford, B.C., Canada.
Cameron, Iain, A., London.
Cao, Shumin, Wuhan, P.R. China.
Chan, Wai Keung, Hong Kong.
Cheung, Sau Ping Pamela, Hong Kong.
Cho Du-Ri, Taegu, Korea.
Choi, Kyeong Hye, Seoul, Korea.
Clark,Antony, Bolton.
Clarke, Sandra Davina, Wapping, London.
Clevers, Irene Laurina Rita, Utrecht, The Netherlands.
Curtis, Simon James, Torquay.
Damianidou, Tereza, Pireus, Greece.
Duguid, Angus Keith, Harare, Zimbabwe.
Effendy, Jusak, Hong Kong.
Forbes, Victoria E., Portadown, Co. Armagh.
Fujii, Noboru, Nara City, Nara Pref, Japan.
Fong Ka Chun, John, Hong Kong.
Getgood, Fiona Josephine, Hastings.
Harris, Annette Mia, Birmingham.
Hegi, Matthieu Manuel Marie, London.
Ho, Yan Yee Winne, Hong Kong.
Hopley, Katharine Bridget, Coventry.
Janssen, Maurice Janwillem, Schoonhoven, The Netherlands.
Kabiotis, George, Athens, Greece.
Karatzas, George, Athens, Greece.
Kasliwal, Ritika, Jaipur, India.
Kawczynski, Eva, Vancouver, B.C., Canada.
Kei, Oo Oo Tracy, Hong Kong.
Khairallah, Theresa, London.
Kitamon, Hideaki, Yamatokouriyam City, Nara Pref, Japan.
Kritikou, Eleni, Rhodes, Greece.
Kwok, Esther W.S., Vancouver, B.C., Canada.
Lai, Li, Wuhan, P.R. China.
Lam, Chiu Hung, Hong Kong.
Lee Ae Sook, Kyung Buk-Do, Korea.
Li, Anan, Wuhan, P.R. China.
Li, Li, Wuhan, P.R. China.
Li, Lung Hsing, Taipei, Taiwan, R.O. China.

Li, Qingnian, Wuhan, P.R. China.
Lindblom, Joachim, P.L., Turku, Finland.
Lindwall, Torbjorn, Lannavaara, Sweden.
Lixin, Yang, Wuhan, P.R. China.
Ly, Huong Dinh, Toronto, Ont., Canada.
Mackay, Colin Alexander, Edinburgh.
McKenzie, Wilma, South Surrey, B.C., Canada.
Modi, Shivani, New Delhi, India.
Mourtzanos, Stefanos M., London.
Ng, Emeralda, Toronto, Ont., Canada.
Ng, Shuk Hing Jonas, Kowloon, Hong Kong.
Pan, Jianqiang, Wuhan, P.R. China.
Pani, Tonu, Tartu, Estonia.
Pankaj, Nirmal Sethia, Mumbai, Bombay, India.
Parsons, Michael John, Bath.
Pepprell, Eija-Liisa, London.
Pham, Christina Tuyet Lieu Thi, Markham, Ont., Canada.
Pontynen, Raija, Helsinki, Finland.
Raghuwanshi, Prachi, Bombay, India.
Raphael, Menachem, Leeds.
Ren, Jiakai, Wuhan, P.R. China.
Rogers, Mark, Tauranga, New Zealand.
Ronkko, Veera Viktoria, London.
Sallinen, Virpi, Helsinki, Finland.
Schutt, Alan W., Bristol.
Seligman, Dominic, London.
Sequeira, Silvia W., Bombay, India.
Sharpe, Erica Jane, Wells, Somerset.
Shende, Vivekanand V., Mumbai, Bombay, India.
Snyman, Johanna E.W., Pretoria, Republic of South Africa.
Susan, V.E., Naarden, The Netherlands.
Tao, Hongwei, Wuhan, P.R. China.
Tao, Jinbo, Wuhan, P.R. China.
Thidar Htoo, Li Jin Hua, Yangon, Myanmar.
Tsang Wai Yi, Rita, London.
Van Dijk, Ennie, Schoonhoven, The Netherlands.
Vummidi, Sreeramakrirhna, Madras, India.
Wang, Congyou, Wuhan, P.R. China.
Wang, Dequan, Wuhan, P.R. China.
Wang, Fenglan, Wuhan, P.R. China.
Wang, Liqun, Guangzhou, P.R. China.
Whiting, Sarah, Crouch End, London.
Willis, Kathryn, Muswell Hill, London.
Wisawayodhin, Kitiya, London.
Wong, Mei Wai, May, Kowloon, Hong Kong.
Wu, Ming Hsun, Taipei, Taiwan, R.O. China.
Wu, Xiaobing, Wuhan, P.R. China.
Xie, Liming, Wuhan, P.R. China.
Xu, Xiaoxia, Wuhan, P.R. China.
Yoshikawa, Yoichi, Osaka, Japan.
Yoshimura, Shinya, Osaka, Japan.
Zhengyun, Bi. Wuhan, P.R. China.
Zhang, Xueli, Wuhan, P.R. China.
Zhang, Xueyun, Wuhan, P.R. China.
Zhang, Yanjun, Wuhan, P.R. China.
Zhu, Xionghua, Wuhan, P.R. China.
Zou, Tao, Wuhan, P.R. China.

Preliminary Examination

Qualified

Akashi, Kazuko, Kakogawa-city, Hyogo Pref, Japan.
Apergis, George, Athens, Greece.
Aukee, Sari, Vaasa, Finland.
Autar, Michael Suradj, Spijlienisse, The Netherlands.
Avery, Hilary Elizabeth, Bangor, N. Ireland.
Barsk, Christer, Lannavaara, Sweden.
Branch, Henry Christopher, Hampton.
Brittain, Roger Anthony, Norwich.
Brooks, Ian Edward Charles, Carshalton.
Budel, Annabelle N., London.
Cai, Bing, Guilin, P.R. China.
Cao, Huasong, Beijing, P.R. China.
Cao, Lianmin, Guilin, P.R. China.
Catlin, Elaine, Austin, Tex., USA.
Cauchi Savona, Louis, Brentwood.
Chan, Chi-Kian, Hong Kong.
Chang, Wai Chu, Josephine, Hong Kong.
Chang Yeun Hwa, Taegu, Korea.
Chen, Liang-Hsuan, Toronto, Ont., Canada.
Cheng, Jennifer, Hong Kong.
Cheng Kwai Tim, Hong Kong.
Cheung, Ping Kwan (Shadow), Hong Kong.
Chiang, Sheau-Yiun, Schoonhoven, The Netherlands.
Chih-Liang Lai, Taipei, Taiwan, R.O. China.
Choi Yun Hwa, Taegu, Korea.
Chu, Li-ji, Taipei, Taiwan, R.O. China.
Clarke, Sandra Davina, Wapping, London.
Coope, Simon David, Carlisle.
Cox, Michael Brian, Great Yarmouth.
Crabtree, Peter Flaherty, Harrogate.
Crutcher, Christie Barrett, Atlanta, Georgia, USA.
Deligianni, Christina, Athens, Greece.
Demner, Natascher, London.
Dongsheng, Li, Guilin, P.R. China.
Draper, Zoe Shaw, London.
Edwards, Heidi Louise, Burntwood.
Engstrom, Lena Elisabeth, Jarfalla, Sweden.
Fairhurst, James, Godalming.
Fan, Tai-ti, Taipei, Taiwan, R.O. China.
Goddard, Andrea Margaret, Weston, Sidmouth.
Griffin, Anthony Edgar, Godalming.
Guastoni, Alessandro, Milan, Italy.
Gao, Ms Honwei, Wuhan, P.R. China.

Haitsma, Maaike Cornelia, Schoonhoven, The Netherlands.
He, Xinping, Guilin, P.R. China.
Hill, John, St. Petersburg, Fla., USA.
Ho Shuk Fun, Mercedes, Hong Kong.
Hollander, B.M., Lopik, The Netherlands.
Hsu, Tien Mei, Yangon, Myanmar.
Hudson, Sally, Putney, London.
Hui, Mei Sum Virginia Ann, Hong Kong.
Iannicelli, Marco, London.
Inoue, Hideko, Maida Vale, London.
Ishijima, Juri, Nishinomiya City, Hyogo Pref, Japan.
Jiang, Chun Qing, Beijing, P.R. China.
Jiang, Ren-Yi, Shanghai, P.R. China.
John, Victoria Alexei, London.
Jones, Jesse Morgan, Auckland, New Zealand.
Jurvakainen, Risto, Helsinki, Finland.
Kadota, Yuka, Osaka, Japan.
Kaskara, Tatiana, Pimlico, London.
Kasliwal, Ritika, Jaipur, India.
Katagiri, Kumiko, Osaka, Japan.
Kim, Myung-Suk, London.
Kjendlie, Ole Richard, Larvik, Norway.
Konstantara, Aikaterini, Thessaloniki, Greece.
Kortelainen, Kimmo, Helsinki, Finland.
Ktistaki, Despina, Thessaloniki, Greece.
Kuang, Yonghong, Guilin, P.R. China.
Kuroda, Chikako, Hyougo, Japan.
Kyi, Aung, Yangon, Myanmar.
Lam, Ming Tak, Hong Kong.
Leadbitter, Elizabeth Victoria, Ruislip.
Lee, Ae Sook, Kyung Buk-Do, Korea.
Leung, Lai Tze Cheri, Kowloon, Hong Kong.
Leung, Wai Ming, Kowloon, Hong Kong.
Li, Kwai Ching, N.T., Hong Kong.
Liang-Chin, Wu, Tainan, Taiwan, R.O. China.
Liao, Yang, Guilin, P.R. China.
Lim, Seong Jim, Taegu, Korea.
Lin, Shwun-Jiun, Taipei, Taiwan, R.O. China.
Lin, Yauzhou, Guilin, P.R. China.
Lin, Yi Hwa, Yangon, Myanmar.
Liu, Ay Hwa, Taipei, Taiwan, R.O. China.
Liu, Ming, Guilin, P.R. China.
Liu, Olivia, Taipei, Taiwan, R.O. China.
Lodjak, Toivo, Keila, Estonia.
Ma, Qin, Beijing, P.R. China.
Makarainen, Paivi, Helsinki, Finland.
Makila, Kirsi Kaarina, Espoo, Finland.
Manolakos, Dimitrios, Athens, Greece.
Mao, Lingyun, Beijing, P.R. China.
McCarthy, Kieran, Crouch End, London.
Michelakou, Grigoria, Pireus, Greece.
Mitchell, Brenda Hilary, Cosham.
Miyamoto, Takuya, Himeji City, Hyogo Pref, Japan.
Miyamura, Kayoko, Otsu City, Shiga Pref, Japan.
Mol, Elisabeth Iefje, Bergambacht, The Netherlands.
Moore, Rown Duggan, Birmingham.
Muller, Hellen Ank Dorien, Wierden, The Netherlands.
Murata, Sanae, Yamatokouriyama City, Nara Pref, Japan.
Myint, Win, Yangon, Myanmar.
Nakazawa, Haruyo, London.
Nang Mo Kham, Yangon, Myanmar.
Nazos, Konstantinos, Athens, Greece.
Ng, Wai Ching, Hong Kong.
Ng, Yiu Hong, Hong Kong.
Nishiyama, Fumie, Suita City, Osaka, Japan.
Nuoraho, Piia Johanna, Espoo, Finland.
Nyan, Hlaing, Yangon, Myanmar.
Panagiotou, Panagiotis, Elassona, Greece.
Plitsi, Catherine, Larissa, Greece.
Ratcliffe, Matthew Patrick, Reading.
Riga, Olybia, Athens, Greece.
Rommens, Catharina Maria Christiana, Eindhoven, The Netherlands.
Sandar, Hlaing, Yangon, Myanmar.
Schweitzer, Wendy J., Guildford.
Scott, Trudi Yvonne, Skegness.
Seok, Jeong-Won, Taegu, Korea.
Sham, Raymond, Vancouver, BC, Canada.
Shao, Bing, Shanghai, P.R. China.
Shao, Zhen-Yu, Shanghai, P.R. China.
Shen, Yiming, Shanghai, P.R. China.
Shepherd, Guy B., London.
Shikazawa, Chiaki, Kofu City, Yamanahi Pref, Japan.
Sietsma, Talke, Amsterdam, The Netherlands.
Skliros, Athanasia, Athens, Greece.
Skogstrom, Helena, Jarvenpaa, Finland.
Speake, Malcolm Frank, Birmingham.
Sun, Yin Nei, Hong Kong.
Suzuki, Noriko, Ikoma City, Nara Pref, Japan.
Tang, Kin Fan, N.T., Hong Kong.
Tentikali, Nafsika, Thessalonika, Greece.
Thant, Myo, Yangon, Myanmar.
Thant, Tun min, Yangon, Myanmar.
Tin Lei Lei Aung, Yangon, Myanmar.
Tong, Wai Wan Vivian, Shatin, Hong Kong.
Tun (a) Gentle Yang, Tun, Yangon, Myanmar.
Tupper, Michael Ian, South Holmwood.
Umeda, Evelyn Y., Sacramento, Ca., USA.
Van Der Eng, Amber Valeska, Uitgeest, The Netherlands.
Van Der Graaff, M.A.L., H.I. Ambacht, The Netherlands.

Van Hoften, Johannes Hubertus Fransiscus, Gouda, The Netherlands.
van Kints, Matthias Cornelis Theodorus, Schiedam, The Netherlands.
van Zanten, Sander, Arnhem, The Netherlands.
Vernon, Penny Ann, High Wycombe.
Vincelj, Peter, Lannavaara, Sweden.
Wang, Chun Li, Beijing, P.R. China.
Wang, Chunsheng, Beijing, P.R. China.
Wang, Shu-Ying, Taipei, Taiwan, R.O. China.
Wang, Yilong, Guilin, P.R. China.
Wang, Zhong Hui, Beijing, P.R. China.
Wang, Shu-Hui, Taipei, R.O. China.
Wataya, Atsuto, Osaka, Japan.
White, Joanne Clare, Sheffield.
Williams, Lisa Jocelynne, Worcester.
Wong Eng Wai Eagle, N.T., Hong Kong.
Wong Poon, Wai Chun, Olivia, North Point, Hong Kong.
Woo Pui Wa, Hong Kong.
Wu, Sze Yin, Kowloon, Hong Kong.
Wunna, Yangon, Myanmar.
Xia, Songyao, Beijing, P.R. China.
Xie, Yujun, Guilin, P.R. China.
Xiong, Ying, Beijing, P.R. China.
Yan Yee Mei, Kowloon, Hong Kong.
Yang, Gang, Beijing, P.R. China.
Yang, Yuk-Ngor Sally, Hong Kong.
Yap Hui Ling, Penang, Malaysia.
Yau, Hau Yeung, Hong Kong.
Yumi Akieda, Tagarazuka City, Hyogo Pref, Japan.
Zhang, Sumei, Guilin, P.R. China.
Zhang, Wansong, Guilin, P.R. China.
Zhang, Xiao Dong, Beijing, P.R. China.
Zhu, Yong, Guilin, P.R. China.
Zini, Grazia, Ferrara, Italy.

MEETINGS OF THE COUNCIL OF MANAGEMENT

At a meeting of the Council of Management held on 12 June 1996 the business transacted included the election of the following:

Diamond Membership (DGA)

Li Zihui, Guangxi, China, 1996.
Yip Yick Hing, Brenda, Central, Hong Kong, 1996.

Fellowship (FGA)

Kennedy, Karen Fiona, Bracknell, 1995.
Sorrill, Rachel, Hammersmith, 1994.

Ordinary Membership

Andaluz Sanchez, Maria, London.
Armero, Julia, London.
Bambrick, Davina Jane, Graceville, Qld., Australia.
Coker, Olive Admira, London.
Cuschieri, Isaac, London.
Edwards, James, St. Albans.
Fujimura, Mika, Aichi, Japan.
Harvey, Kirsty Louise, Witney.
Scott, Anita, London.
Sharpe, Erica Jane, Wells.
Shiue, Ling-yu, Burnaby, BC, Canada.
Westlund, Dennis, Los, Sweden.

MEMBERSHIP '97

Members, Fellows and Diamond Members receive *The Journal of Gemmology* and the *Gem and Jewellery News* quarterly. Fellows (members who hold our Diploma in Gemmology) may use FGA after their name and Diamond Members (members who hold the Gem Diamond Diploma) the title DGA, and both may also apply for the use of the Coat of Arms on their stationery.

Laboratory Members receive an annual membership certificate for display, *The Journal of Gemmology* and *Gem and Jewellery News* quarterly, discounted testing and grading fees, and may apply for use of the Laboratory logo on their business stationery. Overseas members are assisted with the temporary importation of gemstones for grading or testing.

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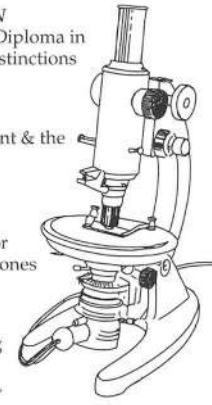

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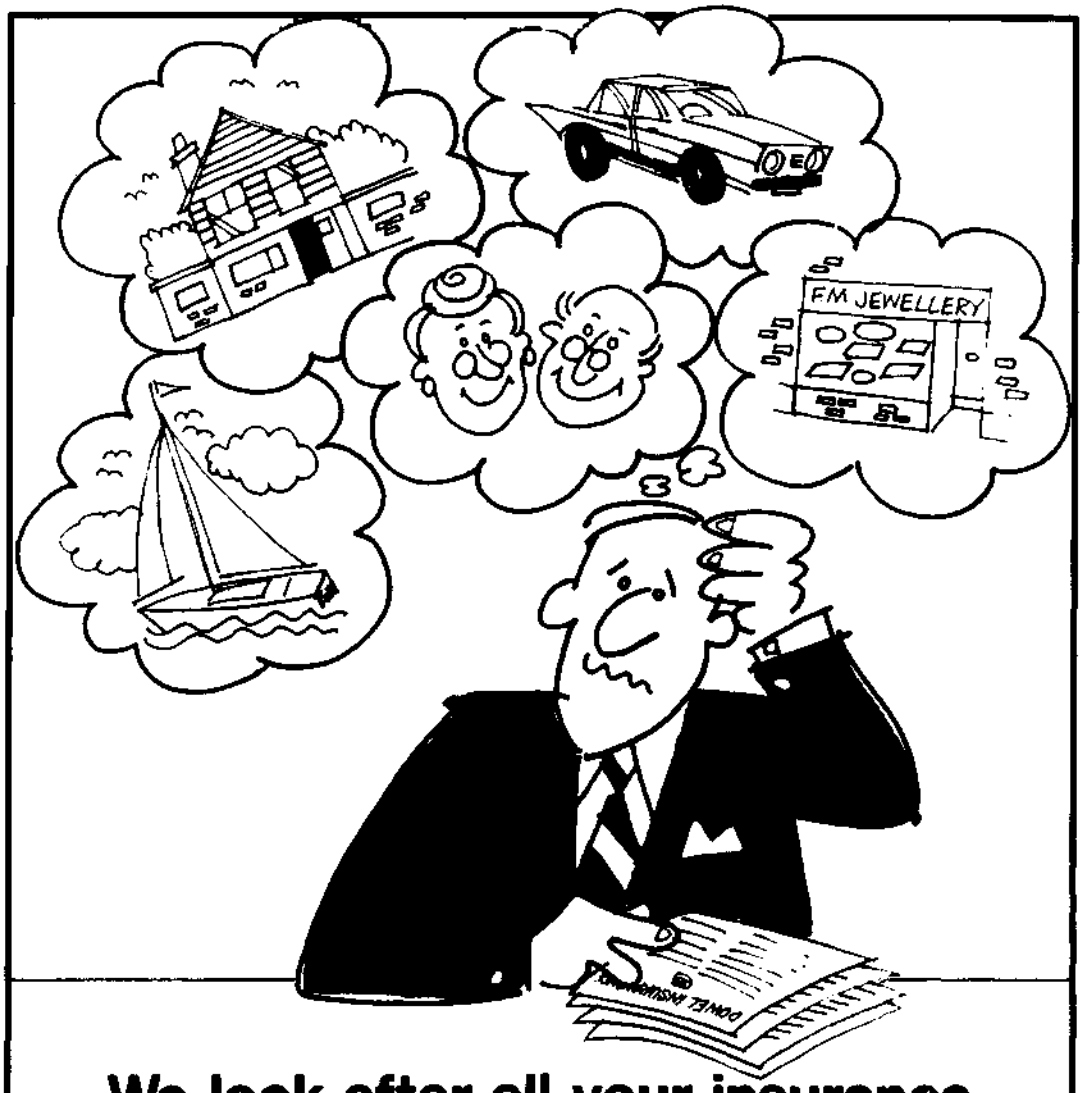

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The abstract, references, notes, captions and tables should be typed double spaced on separate sheets.

On matters of style and rendering, please consult *The Oxford dictionary for writers and editors* (Oxford University Press, 1981).

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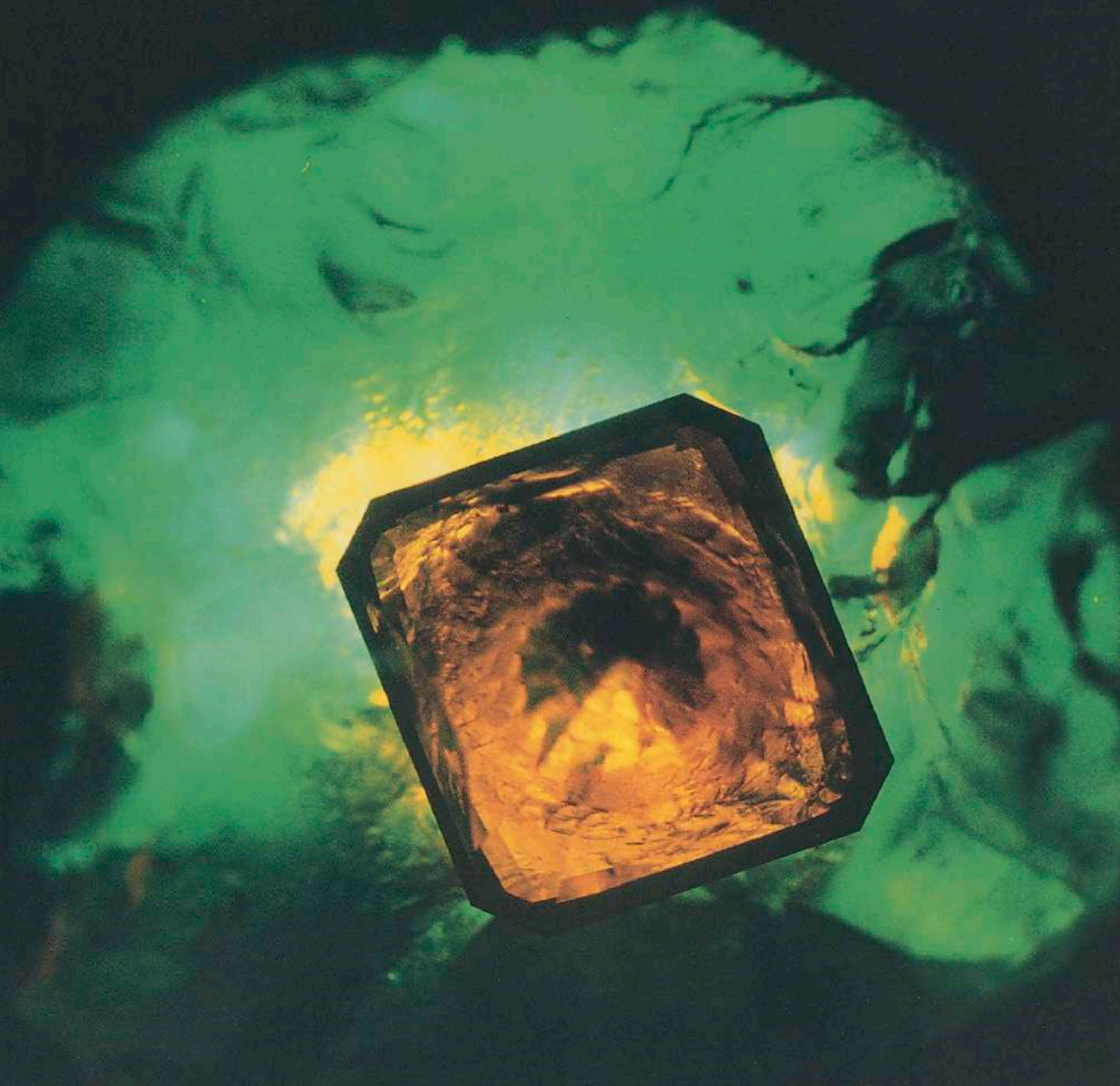

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A new colour-change effect

A. Halvorsen[1] and B.B. Jensen[2]

[1]*Norplan A/S 0612 Oslo*
[2]*Mineralogical Geological Museum, Oslo.*

ABSTRACT: Crystals of green chrome tourmaline from the Umba Valley (Tanzania) may show a wine-red colour when viewed in certain directions. This is neither pleochroism, nor a colour-change of alexandrite type. The change from green to red depends primarily on the path length of light through the stone and probably also on the content of Cr and V; in the samples tested the stones appear red when more than 15 mm thick. It is suggested that this new type of colour change be called the 'Usambara effect'.

Introduction

We have examined many pieces of green chromiferous tourmaline from the Daluni area in the Umba Valley of north-eastern Tanzania. Several showed a startling green to orange or red colour variation. Bank and Henn (1988) described green tourmaline from Tanzania that exhibited a green/red alexandrite effect and we thought at first that this was the same type of material. However, our studies indicate that since the red colour can be seen in any sufficiently thick portion of a crystal, irrespective of optical direction and only mildly modified by type of illumination, the colour change involves other factors.

The best demonstration of the effect is provided by two pieces which are both strong blue-green when examined separately, but which become red when superimposed, one upon the other, with no change in orientation or in the conditions of illumination.

Locality

The Umba Valley is one of the richest gemstone areas in East Africa producing ruby, sapphire, spinel, garnets, tourmaline, chrome diopside, zircon, scapolite, kornerupine and other gems. Some of these can have rare and unique colours which are not found elsewhere.

The rocks of the area are of medium to high metamorphic grade and belong to the Eastern Granulite Complex of the Precambrian Usagaran system. According to Dirlam *et al.* (1992), the metamorphic processes which have affected the granulites have caused a remobilization of chromophore elements such as chromium and vanadium, which have concentrated in several of the Umba gemstones and resulted in their unusual colours and optical phenomena. Colour-change tourmalines, sapphires and garnets with effects comparable to those seen in alexandrite have been described from this area (Bank and Henn, 1988; Dirlam *et al.*, 1992).

Figure 1 is a general view of the chrome-tourmaline locality from which the material was collected, with the Usambara mountains in the background.

Gemmology

Assuming a common thickness, different shades of green may indicate some chemical variation in the material available, so we examined several pieces in detail, mainly crystals and rough fragments but including some cut stones.

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Figure 1: *General view of the area, with the Usambara mountains in the background. The tourmaline locality is in the foreground of the picture.*

The following gemmological descriptions are based on two crystal fragments (T1 and T2), four pieces of rough (T3–6) and one faceted stone (T7). The weights are respectively T1 (7.735 g), T2 (4.721 g), T3 (1.788 g), T4 (2.161 g), T5 (4.026 g), T6 (5.840 g), T7 (0.719 g).

Specific gravity

The average specific gravity of the seven specimens, determined by hydrostatic weighing, is 3.06.

Crystal habit

Like other chromiferous tourmalines previously reported from this area, the crystals show pyramidal habits (Dirlam *et al.*, 1992). One good crystal (T1) is a fine bluish-green, about 1 cm thick and 2.5 cm in diameter, and carries three large pyramid faces, a small pedion and a fringe of thin prism faces *(Figure 2)*. The back of the crystal is a large irregular fracture surface.

Refractive index

The refractive indices determined on a crystal face of T2 and on a polished surface of T7 were consistent and are ω 1.644 and ε 1.622, with birefringence of 0.022. Uniaxial interference figures were observed in the samples under a polariscope.

Chemistry

Using the general formula for tourmaline of $XY_3Z_6B_3Si_6O_{27}(O,OH)_3(OH,F)$ various end members have previously been defined as follows:

	X	Y	Z	
Dravite	Na	Mg_3	Al_6	B_3.....
Liddicoatite	Ca	$(Li,Al)_3$	Al_6	B_3.....
Uvite	Ca	Mg_3	Al_5Mg	B_3.....

Table I gives the result of microprobe analyses of two samples of our material (T3 and T4) together with analyses from the work of Bank and Henn (1988) on the chromiferous tourmalines from Tanzania which show an alexandrite colour-change effect. Our analytical results are very similar to those of Bank and Henn.

A qualitative X-ray fluorescence spectrum from a sample supplied to S. Bergstøl at Norges Tekniske Høgskole indicates that vanadium content is significant, but only about a quarter of the chromium content, *i.e.*

***Figure** 2: A drawing of a tourmaline crystal showing pyramidal habit. In order of degree of development – trigonal pyramid, pedion, hexagonal prism and trigonal prism.*

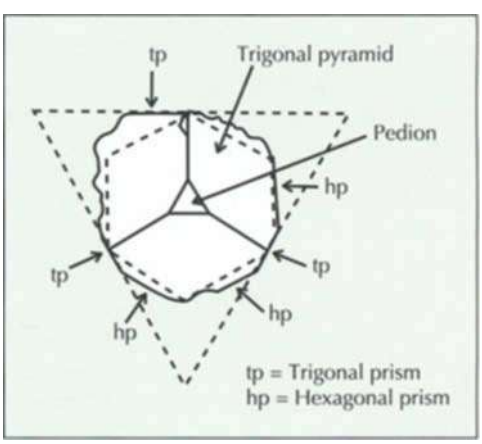

Table I: *Chemical analyses of East African tourmalines*

	1#	2#	3*	4*
SiO_2	37.84	37.51	35.29	34.87
TiO_2	.43	.36	.18	.48
Al_2O_3	32.49	32.71	33.57	31.73
MgO	11.30	10.58	11.13	11.40
CaO	1.87	1.89	1.95	2.63
Cr_2O_3	.34	.22	.36	.64
V_2O_3	(.05)	(.05)	.04	.06
Na_2O	1.76	1.66	1.53	1.39
FeO	.06	–	–	–
Total	86.14	84.98	84.05	83.20
Number of ions on the basis of 6 Si				
Si	6	6		
Ti	0.051	0.044		
Al	6.065	6.159		
Mg	2.666	2.52		
Ca	.317	.324		
Cr	.042	.029		
Na	.540	.515		
Fe	.008	–		

The analyses were performed by wavelength dispersive spectrometry using a CAMECA electron microprobe at the Mineralogical-Geological Museum in Oslo. Oxides, natural minerals and synthetics were used as standards. Each analysis represents the average of at least six single point analyses. Analytical precision (2sigma) is better than ±1% at concentrations >20wt.% oxide, ±2% in the range 10–20wt.%, ±5% in the range 2–10% and better than 10% in the range 0.5–2wt.%.

* Analysis of colour-change tourmaline from Bank and Henn (1988).

of the order of 0.08–0.05% V_2O_3. In most green tourmalines from Kenya and Tanzania vanadium is in excess of chromium (Schmetzer and Bank, 1979). This spectrum also indicates traces (10–100 ppm) of Zr, Sr and Zn.

Our analyses lack both boron and water, but since there is commonly little or no substitution of Al in the Si site of tourmaline, we are able to calculate a partial formula assuming six silicon atoms to be present. This gives reasonable stoichiometry in the X, Y and Z positions, always remembering that vanadium and possibly a number of other trace elements have not been allowed for in the calculations, and that there may also be vacancies in the X positions (Dietrich, 1985).

According to Bank and Henn (1988) their tourmaline lies about half-way in the isomorphous series dravite-uvite which involves a coupled substitution between the X and Z sites (Na, Al – Ca, Mg). In the present analyses the sodium/calcium ratios support the assumption of a significant uvite component, but the aluminium/magnesium concentrations are not consistent with a compensatory substitution of Mg for Al in the Z position. How then is the charge increase on the X position accommodated? Minor amounts of Li have been found in the Y position of some dravites and might be present here (partial solid solution with liddicoatite). Other types of charge balance, such as adjustment of the O^{2-}/OH^- ratio or the creation of vacancies in the X position are not uncommon in tourmalines (Foit and Rosenberg, 1977) and may be operative here. We would therefore prefer to consider this Umba valley tourmaline as a calcium-bearing dravite until we understand the exact nature of the substitutions.

Fluorescence

Under short-wave (254 nm) ultraviolet illumination all the specimens are mustard yellow. The same reaction was reported by Dunn for 'low-iron chrome-rich tourmaline' from an unknown locality (Dietrich, 1985).

Colour and colour variations

Colour

Viewed in transmitted light (using a Flexilux 30HL 'cold light' with fibre optics) the general colour observed is green in a variety of shades from golden green, via olive green to bluish-green. To some extent, these colour variations may be caused by an orientation effect as all the stones showed some change of colour when rotated over the light source and these were consistent with the well-known dichroism of green tourmaline where the darker colour is seen parallel to the *c*-axis. However, two of the stones (T1 and T5) showed bluish-green in some directions and wine-red in others. A green to orange colour change was seen in several other stones. It was noted that the stones only showed an orange or red colour when viewed through the thickest part of the crystal.

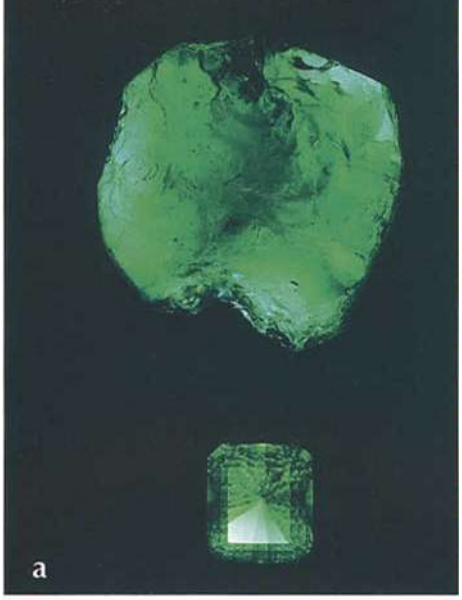

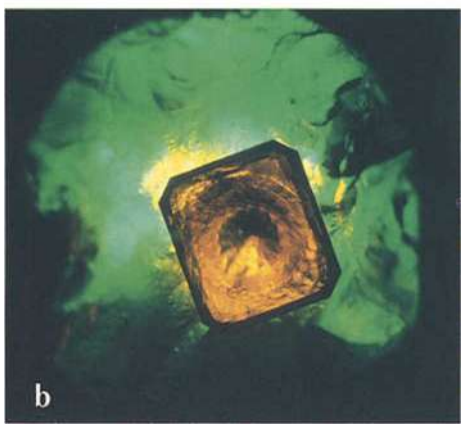

Figure 3: *(a) A crystal fragment (T1) and a cut stone (T7) both viewed looking down the c-axis. (b) The same two stones, superimposed without change in orientation, show a colour change to orange/red.*

Pleochroism

Because of the crystal habit, the red colour was at first seen only at right angles to the *c*-axis. It was therefore a natural next step to test the theory that this was a green/red dichroism. Under the dichroscope, using the same 'cold light' illumination, the large crystal (T1), was found to be pleochroic in two shades of red when viewed at right angles to the *c*-axis, but green when viewed in the direction of the *c*-axis *(Figure 3a)*. This evidence made the mineral trichroic, a feature only found in biaxial crystals. Whilst biaxial tourmalines are known (Dietrich, 1985), T1 gives a quite clear uniaxial interference figure and hence the colour variation is not due to pleochroism.

We then aligned and superimposed T1 and T7 that was also green when viewed along the *c*-axis. Looking along the c direction after superimposition *(Figure 3b)* there was a dramatic colour change which was further evidence against pleochroism and indicates that the decisive factor is path length within the crystal, irrespective of direction.

Influence of source of illumination

When a crystal is thick enough to show red, this colour is seen under both incandescent illumination and sunlight. The red colour is, however, absent under fluorescent lighting. The deepest wine-red is seen under strong illumination rich in the red end of the spectrum. It is best in torch light, being more orange-red than under 'cold light' fibre-optic illumination. One must therefore say that the effect is modified by the type of illumination, but not controlled by it.

Influence of pathlength

In a wedge-shaped sample the colour at the thin end is green; it passes to orange and then to red at the thicker end, but the transition is fairly abrupt. The red colour commonly appears when a bluish-green stone reaches a thickness of about 15–20 mm. However, red flashes are not uncommon in stones which are appreciably thinner than this. Presumably this is due to internal reflection, giving increased effective pathlength of light in the stone. Lighter-coloured stones may show no colour change even in thicknesses of 25 mm.

Cut stones are generally not thick enough to show red in transmitted light. A well proportioned stone of moderate size can, however, under strong illumination (incandescent or sunlight), show very strong red flashes, resulting in marked enhancement of an otherwise rather too dark green stone. The minimum size of cut stone in which red flashes have been observed is 3–4 mm in diameter.

The change from green to red does not occur at exactly the same thickness for all the

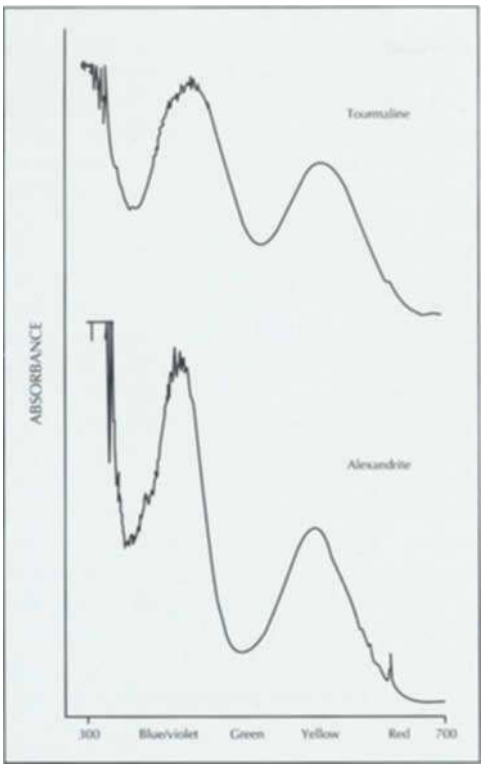

Figure 4: *Spectra over the range 300–700 nm, from Umba Valley tourmaline T3 and from alexandrite. Both have transmission windows in red and green. The spectrophotometer used was a Pye-Unicam PU8800/03 with a UV-visible range.*

examined crystals and, in addition to the path-length, small chemical variations may have some influence on the absorption and thus on the triggering of this optical effect. The general impression is that the change occurs at shorter pathlengths in dark bluish-green crystals than it does in paler stones.

Spectra

Spectroscope

When the visual impression is green, the stones show a typical chrome spectrum under the optical spectroscope, with heavy absorption in the yellow and blue/violet, transmission 'windows' in red and green and fine absorption lines in the red. When the visual impression is red the spectrum is unaltered except for a marked narrowing and weakening of the transmission in the green 'window'. This spectrum is clearly of the same general pattern as that which gives rise to the alexandrite effect.

In addition, all stones are strongly red under the Chelsea filter, but show no sign of red fluorescence under crossed filters.

Spectrophotometer

Figure 4 shows absorption spectra over the range 300 to 700 nm, made with a UV-VIS spectrophotometer on a small sample of tourmaline T3 and on a piece of alexandrite showing marked colour change. (The spectrometer beam intensity was unfortunately not strong enough to penetrate a thick tourmaline fragment in the direction showing red.)

The two spectra are broadly similar, showing absorption peaks in both traces at blue/violet and yellow, and transmission in green and red. However, there are differences: the transmission valley in the green region is almost as deep as the red valley in the alexandrite, but not in the tourmaline, the blue-violet peak in tourmaline is broader than that in alexandrite, and the absorption peaks in the red are stronger in alexandrite. (Clearly the differences should be confirmed and quantified with specially prepared samples.)

Conclusion

What is the explanation of this effect which, to the best of our knowledge, has not been observed previously in minerals?

Perception of colour in an object depends mainly on the nature of the illumination and the transmission properties of the material, but the response of the eye and brain to light stimulation are an important third factor. Poole (1964) in a study of colour change in chromium compounds spoke of the latter as the *psycho-physical effect*.

The human eye and brain, when presented with two very different transmission bands (colours), may ignore the weaker component. This can result in unexpected colour differences. For example, many chromium-bearing minerals transmit both red and green

wavelengths, but to varying degrees. It is then the mineral structure that determines which band is the stronger and thus determines the colour that we register (*e.g.* red in ruby and green in emerald).

In alexandrite the balance is so close that fairly minor differences in the nature of the illumination affect the relative intensity of the two transmitted bands sufficiently to trigger a dramatic change in our colour perception, which alters from green to red when the stone passes from daylight to incandescent light.

In tourmaline T3 the same two wavelength bands are transmitted, but the stone is most transparent to red light. The slight absorption of green is of no significance for thin stones, where the special sensitivity of the human eye to green light ensures that the sensation of green still predominates, but the intensity balance of the two transmitted bands changes significantly with thickness and this tips the colour perception to red once the light has travelled a given distance within the crystal. This change will, of course, only be triggered if the illumination has an adequate red component. A slow change in transmission properties is thus transformed by the eye and brain into a fairly abrupt and startling colour change. It should be possible, with detailed study, to quantify this effect in terms of differences in absorption factors for different wavelengths.

Both rays (ordinary and extraordinary) must be very similarly absorbed, since the colour-change occurs in all directions at about the same thickness and none of our samples showed green/red dichroism under the dichroscope. (However, we have seen one cut stone with an internal reflection from one of the facets where the ω- and ε-rays gave two partly separated images, one of which was red and the other orange.)

If the term 'alexandrite effect' is to be reserved for colour change produced solely by a change of illumination, then we need another name for this additional effect. Webster (1994) in discussing chromium as a source of colour, noted the existence of a colour change in solutions of chrome alum similar to the one we have observed in the chromiferous tourmalines and said, 'Strong solutions of the salt, seen in depth, appear purplish-red while more dilute solutions or thinner samples appear green'. He calls the effect 'dichromatism'. This word, by dictionary or lexicon definition, simply means 'two colours' and has been used in mineralogy in other contexts. For example, Balitsky and Balitskaya (1986) speak of the colour zonation seen in quartz crystals that are part amethyst and part citrine as 'dichromatism in quartz'. For this reason, and because the word dichromatism is uncomfortably close to dichroism, we suggest that another name is necessary. These stones are closely associated with the verdant Usambara region of Tanzania. We make the suggestion, therefore, that it should be given a locality name and called the 'Usambara effect'.

Acknowledgements

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Optical and X-ray topographic study of Verneuil-grown spinels

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ABSTRACT: A boule of synthetic colourless spinel, $1MgO \cdot 3.6Al_2O_3$, produced by the Verneuil fusion method has been investigated by optical microscopy and by X-ray transmission topography, Lang method. The X-ray topography shows that the sample is not monocrystalline but that it consists of domains, crystallographically disoriented with respect to each other. At the bottom of the boule there are large homogeneous areas, which pass upwards into large domains, each with the same crystallographic behaviour; towards the top of the boule the domains become very small. The relationships between the quality of the crystal and temperature variations are considered.

Keywords: spinel, crystal defects, X-ray topography, Verneuil method of growth

Introduction

It is known that the Verneuil process is successfully used by the industry to grow oxides with high melting point because it is a very simple, low-cost method which produces pure 'crystals' in open space and does not require crucibles. Nevertheless, the crystal quality of the produced materials is generally poor owing to the thermal stresses undergone by the sample during the growth process, when the first crystallized parts (on top of the rotating rod in the furnace) are moved downward and away from the hotter zone of the flame. Moreover, the sample may suffer further thermal shocks when it is cooled down[1–3]. In order to minimize the crystal damage (defects, polycrystallinity, anomalous birefringence, *etc.*) generated by the thermal gradients, which may even produce cracking of the sample, a variation of the Verneuil technique has been proposed, which allows the growth of larger crystals of better quality[1–2].

Furthermore, the growth of spinel by the Verneuil method produces synthetic spinels with a chemical composition different from the theoretical AB_2O_4, where A is a divalent (Mg^{2+}, Fe^{2+} ...) and B a trivalent (Al^{3+}, Fe^{3+}, Cr^{3+} ...) ion. In fact, synthetic magnesian spinel is normally grown from MgO and Al_2O_3 oxides, whose mutual solubilities depend on the growth temperature. This means that the synthetic crystals are richer in the more soluble oxide Al_2O_3. In consequence Al^{3+} ions also are located in positions normally ascribed to Mg^{2+} ions, and structural gaps (□) are generated following the scheme:

$$3Mg^{2+} \rightarrow 2Al^{3+} + \square$$

An increase of Al^{3+} in the chemical composition of the crystals generally reduces the cell parameters[4].

Thus, the Verneuil-grown spinels may be rich in structural defects, which can be observed under the optical microscope – with crossed nicols – as the so-called *tabby extinction*[5].

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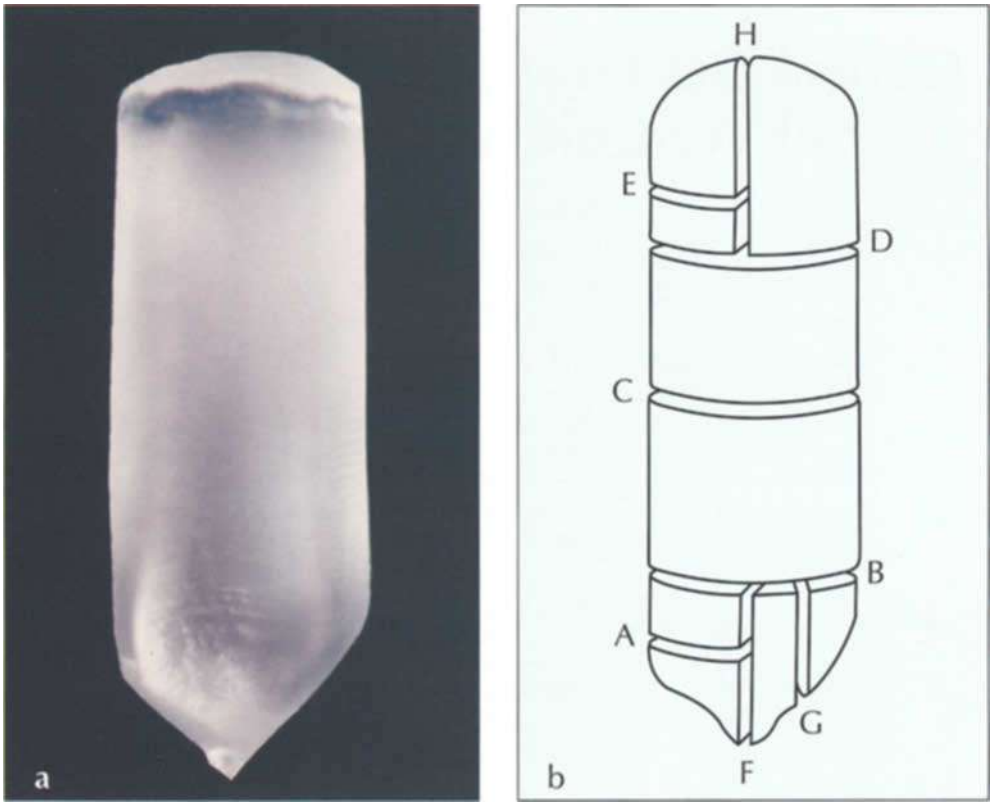

Figure 1: *(a) Boule of synthetic colourless spinel used in the present study. (b) Slices obtained from the boule and their positions. A, B, C, D and E are cut normal, and F, G and H parallel to the elongation axis.*

In order to analyse and correlate the optical and structural aspects of this phenomenon, a boule of colourless spinel *(Figures 1a and 1b)* with the composition of $1MgO \bullet 3.6Al_2O_3$, produced by the Verneuil method, has been investigated by optical microscopy and by X-ray transmission topography using the Lang method. This latter technique enables one to detect and locate the crystal defects[6–7].

Preparation of samples

The colourless spinel sample (*Figure 1a)* has been cut normal (*Figure 1b:* slices A, B, C, D, E) or parallel (*Figure 1b:* slices F, G, H) to the elongation axis of the boule. The thickness of the slices was ~1 mm.

The crystallographic plane parallel to each slice has been determined by using the X-ray powder method applied to a slice. Obviously, only if the slice is parallel or nearly parallel to a crystallographic plane will the Bragg condition giving a diffraction peak be satisfied. In our case, the slices A, B, C, D and E *(Figure 1b)* normal to the elongation axis are oriented almost parallel to (001), and the slices F, G and H nearly parallel to (110).

Subsequently, all the slices have been studied using a polarizing optical microscope and X-ray transmission topography using $MoK\alpha_1$ radiation.

Observations under the optical microscope

Spinel, $MgO \bullet Al_2O_3$, crystallizes in the cubic system (space group Fd3m) and optically it is expected to be isotropic. Nevertheless, the

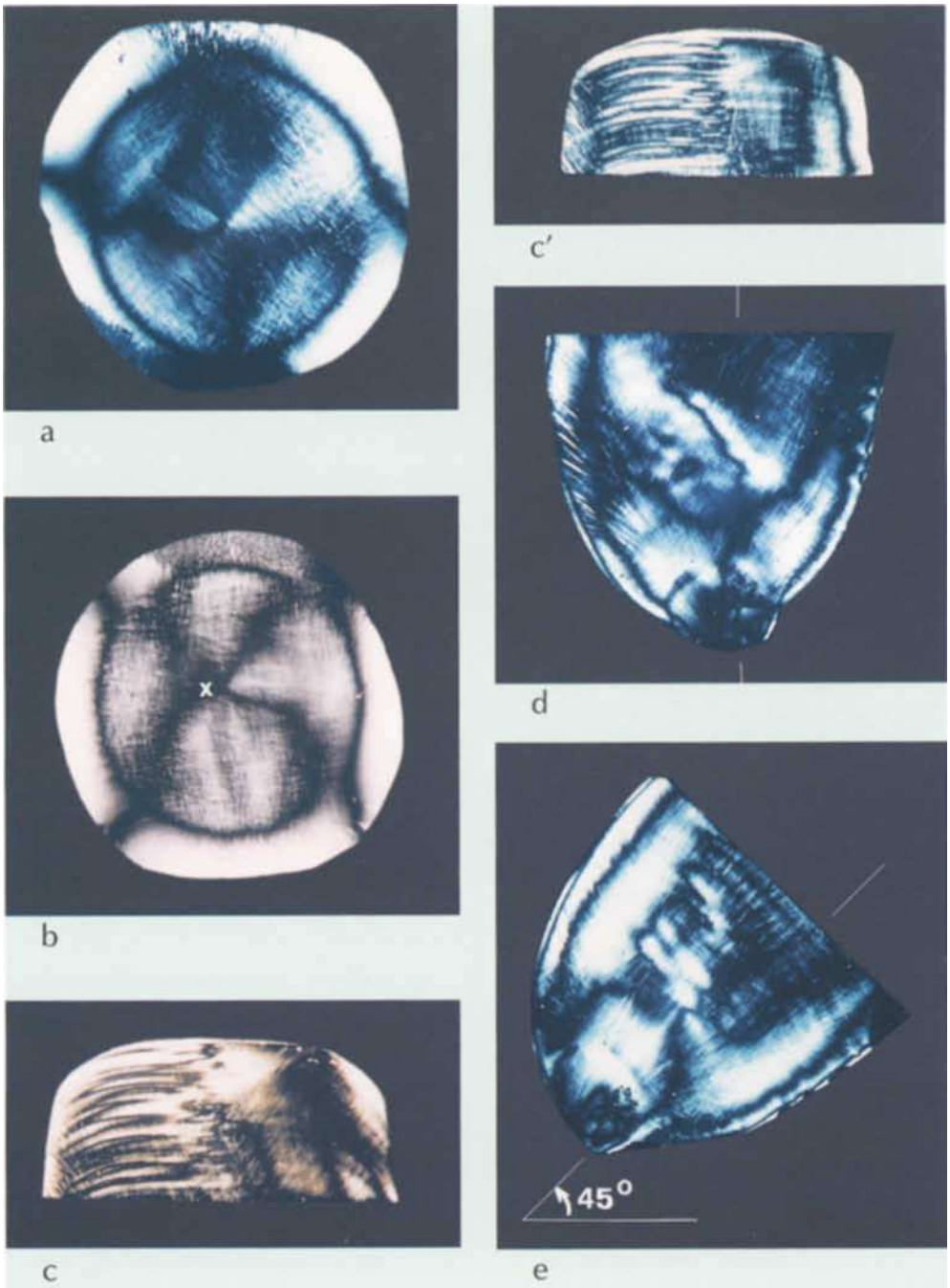

Figure 2: *(a) Slice B of Figure 1b, crossed nicols (2x). (b) Same as (a), but rotated through 45°. (c) Slice H of Figure 1b, crossed nicols (2x). (c′) Slice H (crossed nicols) after additional thinning (from 1.4 to 0.7 mm). The anomalous birefringence is still present. (d and e) Slice F of Figure 1b: crossed nicols, (e) has been rotated through 45° Magnification 2x.*

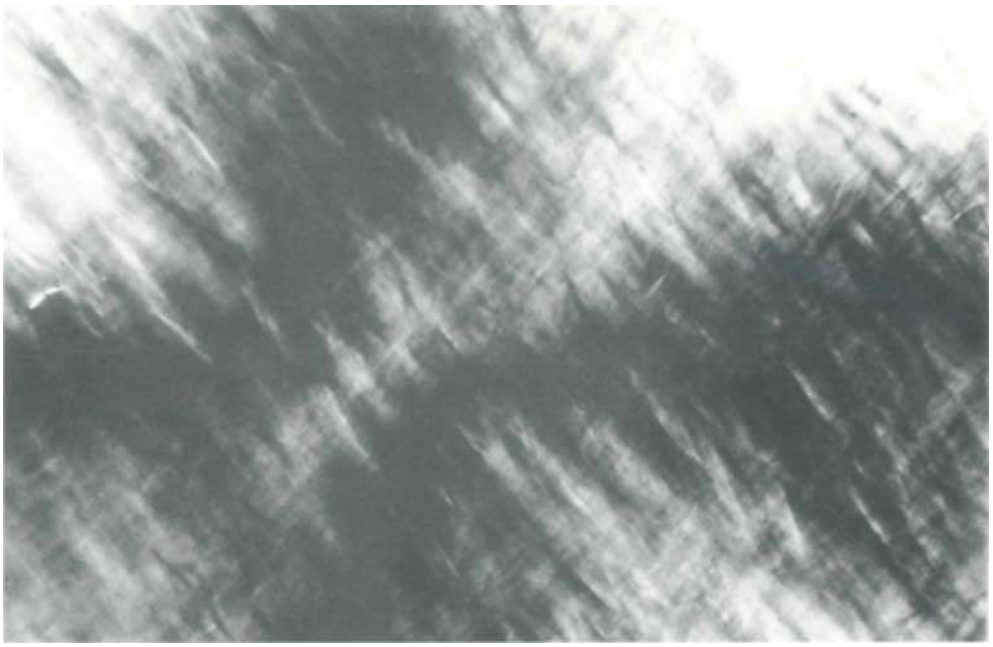

Figure 3: *Region marked by x on Figure 2b seen with the polarizing microscope, at a higher magnification (40x).*

Verneuil-grown spinels display structural defects, *i.e.* lattice distortions, responsible for an optical symmetry lower than the theoretical crystallographic one, resulting in an anomalous birefringence.

Figures 2a, b, c, d and e show the slices B, F and H of *Figure 1b* seen under crossed nicols. Note that *Figures 2a and b* refer to the same slice, B, observed in two positions making an angle of 45°, and showing a different distribution of brighter and darker zones. The same holds for *Figures 2d and e*, which refer to slice F. The sample is, as a whole, birefringent, but displays a configuration of zones with a more homogeneous behaviour, as can be seen in *Figures 2a and b*. The external part of the slice consists of two circular outer zones, *i.e.* an isotropic circular zone (black) and around it an external circular zone nearly completely light transmitting. The interior part of the slice shows four black distorted arms, intercalated with four brighter areas. Nevertheless, at higher magnification *(Figure 3)* the 'isotropic' zone marked by *x* in *Figure 2b* shows additional bright and dark areas. *Figures 2a, c and d* refer to slices cut from different parts of the boule and to sections cut with different orientation (*Figure 1b:* slices B, H and F respectively), that can be recognized by gemmologists when investigating cut synthetic spinels displaying similar images under crossed nicols.

Slice H has been reduced in thickness from 1.4 mm to 0.7 mm to obtain more insight into whether a thinning may lead to the expulsion of some internal stresses and make the slice optically more homogeneous. *Figure 2c'* shows that the optical behaviour (crossed nicols) is unchanged and we may therefore conclude that the internal stresses stored in the crystal during the growth process are not dispersed during the thinning operations.

X-ray topography

It is well known that a crystal lattice is seldom perfect; in fact any crystal is rich in defects such as dislocations and growth

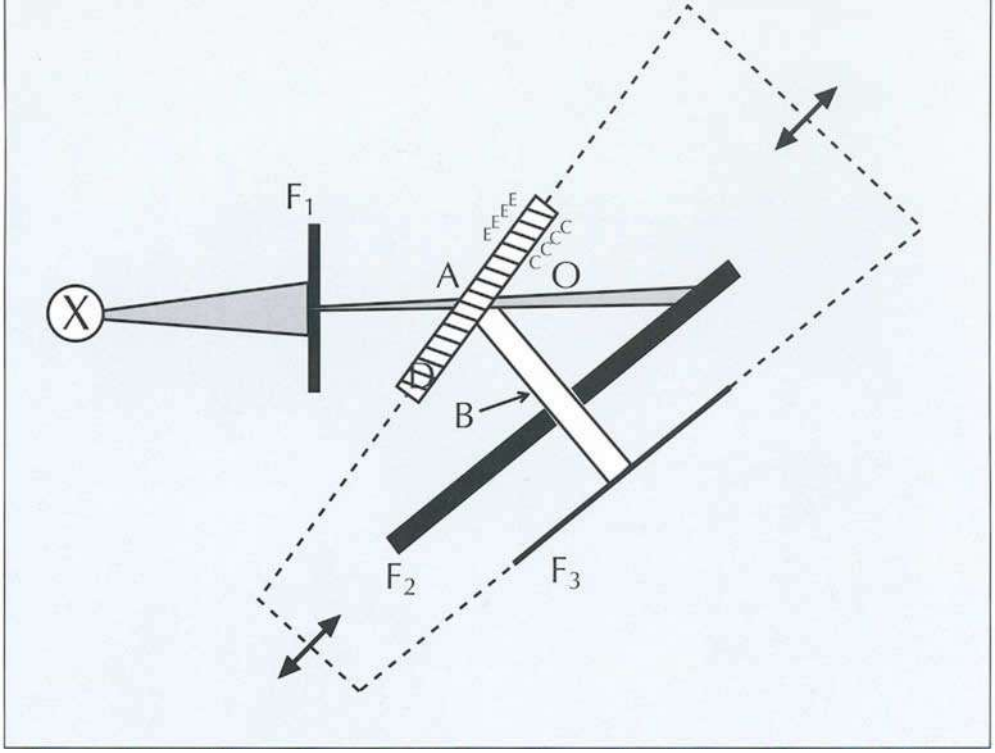

Figure 4: *Diagram of the topographic method after Lang. F_1 and F_2: slits; F_3: photographic plate; D: spinel slice; EC: diffracting planes; X: X-ray source; AB diffracted beam; AO direct beam; the double arrow indicates the movement back and forth of the crystal and the film in the X-ray beam.*

bands. X-ray transmission topography by the Lang method is an experimental technique which establishes the existence and positions of these types of defects[6–7]. The crystal sample (D in *Figure 4*) is oriented by the operator in front of a monochromatic X-ray beam, finely collimated by a slit (F_1) in such a way that a family of reticular crystal planes *hkl* (EC) with high diffraction intensity satisfies Bragg conditions[8]. In the crystal specimen, the beam generates wave fields, the direction of propagation is AB (diffracted beam) and AO (direct beam). The direct beam is absorbed by a lead plate (F_2) and the intensity of the diffracted beam is recorded on a photographic plate (F_3) placed behind the crystal. In a definite position of the sample with respect to the X-ray beam (*i.e.* where a family of reticular crystal planes *hkl* are in the Bragg position) only the perfect parts of the sample will satisfy the Bragg conditions; whereas the zones perturbed by lattice misorientations or by local imperfections, *e.g.* dislocations, change the intensity of the diffracted beam, then generate different contrasts on the photographic plate. The first type of contrast is called *orientation contrast*, the second one *extinction contrast*. Crystal and film, linked together, move slowly back and forth in front of the X-ray beam, maintaining always the Bragg orientation. Thus, the perfect parts and the defects of the sample are projected with different intensities on the photographic plate.

In the topographic study of our boule, the slices A, B, C, D and E are parallel to (001) planes and the relative topographs are made using 400 as diffracting planes; likewise F, G and H slices are studied using $(2\bar{2}0)$ topographs. 400 and $2\bar{2}0$ planes are chosen because they are reticular planes with high intensity of diffraction. *Figures 5a, b, c, d and e* show 400 topographs of, respectively, A, B, C, D and E slices normal to the elongation axis of the boule *(Figure 1b)* and *Figures 5f, g and h* show $2\bar{2}0$ topographs of respectively F, G and H slices, parallel to the elongation axis.

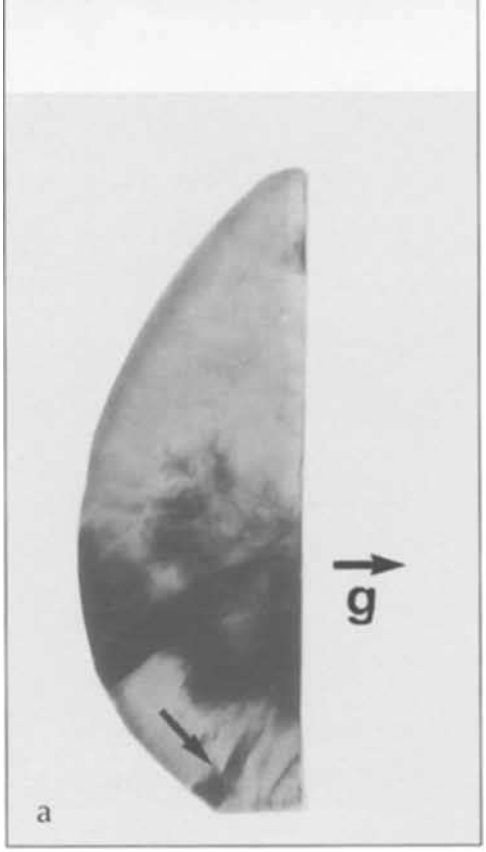

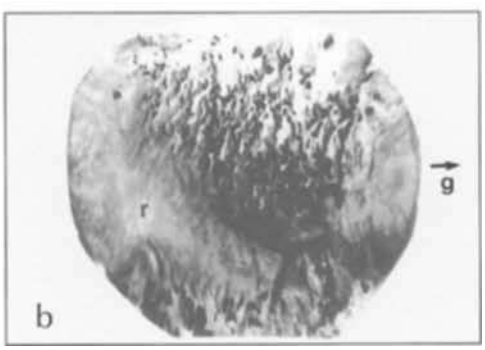

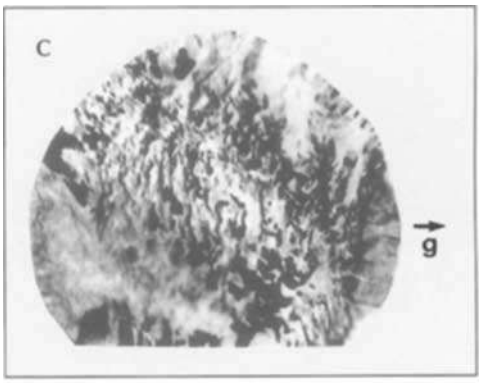

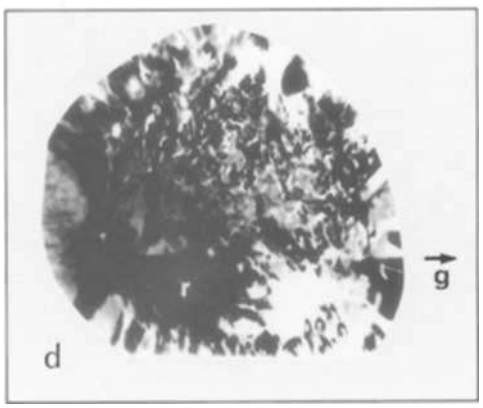

Figure 5: *Topographs with 400 as diffracting planes: (a) topograph of slice A of Figure 1b; (b) topograph of slice B; (c) topograph of slice C; (d) topograph of slice D; (e) topograph of slice E. Topographs with $2\bar{2}0$ diffracting planes: (f) topograph of slice F; (g) topograph of slice G; (h) topograph of slice H [for explanations see the text].* g *on all the topographs is the diffraction vector.*

All the topographs of *Figure 5* show black, grey and white areas. This means that in one slice, for a definite position of the slice with respect to the X-ray beam, certain parts of the crystal fulfil the Bragg requirements, while other parts deviate from the diffraction conditions to varying degrees (grey and white areas). When the operator moves the position of the slice with respect to X-ray beam, even a few tenths of a degree, different distributions of black and grey areas are the result *(Figure 6)*. In this case, other regions of the crystal display an optimal Bragg reflection. The topographs of *Figure 5* clearly show that the sample is not monocrystalline (if it were, the whole slice would be grey), but is made up of domains, which can be very small, the crystallographic orientation of which may differ by very small angles.

When comparing the topographs of *Figure 5*, the following differences are evident. Slice A *(Figure 5a)* shows two relatively large areas, one black and one grey, and only a limited region (arrow in *Figure 5a*) showing a group of small domains. In this part of the sample, which corresponds to the early growth stages, there are still just a few large

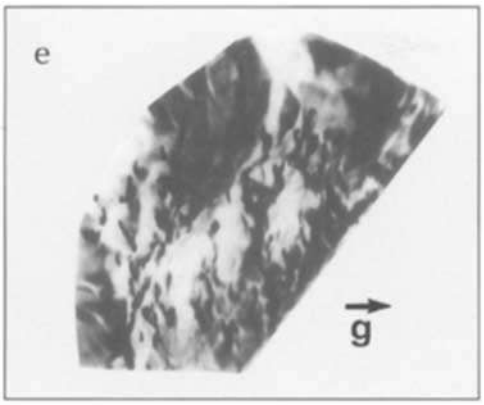

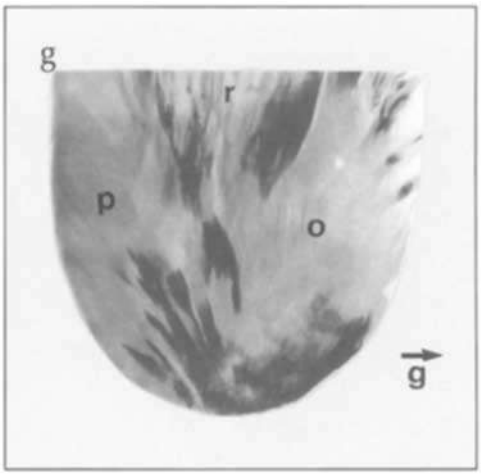

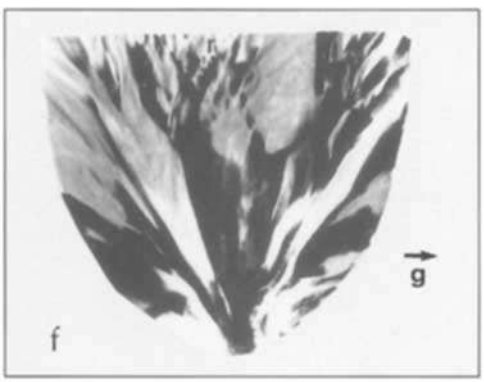

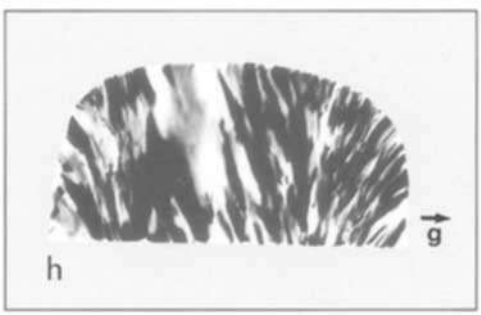

domains homogeneous from a crystallographic point of view. Moving from the bottom part of the boule towards the top (slices B, C, D and E, respectively the topographs of *Figure 5b, c, d and e*), the domains showing the same contrast in the topograph (zone r in *Figures 5b and d*) become progressively narrower, and the zones made up of smaller domains increase. This means that the quality of the sample becomes poorer from the base of the boule to the top *(Figure 5e)*.

The above considerations are confirmed by the topographs of the F, G and H slices, parallel to the elongation direction of the boule *(Figure 5f, g and h)*. In fact, the lower region *(Figure 5, f, g)* displays better quality in the external part *(Figure 5g)* where large areas showing the same contrast on the topograph (*Figure 5g*, zones o and p) can be observed. A trend to form microdomains (*Figure 5g*, zone r) is evident at the top of the slice (which corresponds to slice B, *Figure 5b*) and leads to a poorer crystal quality. The central part of the bottom of the boule *(Figure 5f)* appears more disturbed and, in the upper part (*Figure 5f*, zone r), the presence of small microdomains is apparent. G and F slices *(Figure 5g and f)* show fan-shaped contrasting patterns originating from the bottom of the boule. These images, characteristic for Verneuil-grown materials[2], indicate a migration of the deformations from the core to the periphery of the sample during the crystal growth process.

Finally, the poorest crystal quality at the top of the boule, as observed in topograph E *Figure 5e*, is confirmed by the $2\bar{2}0$ topograph of slice H *(Figure 5h)*. Here the contrasts, which all display a radial pattern of the stresses, are black or white, indicating a higher disorientation of the different domains.

Conclusion

The synthetic spinel studied in the present work shows an anomalous birefringence

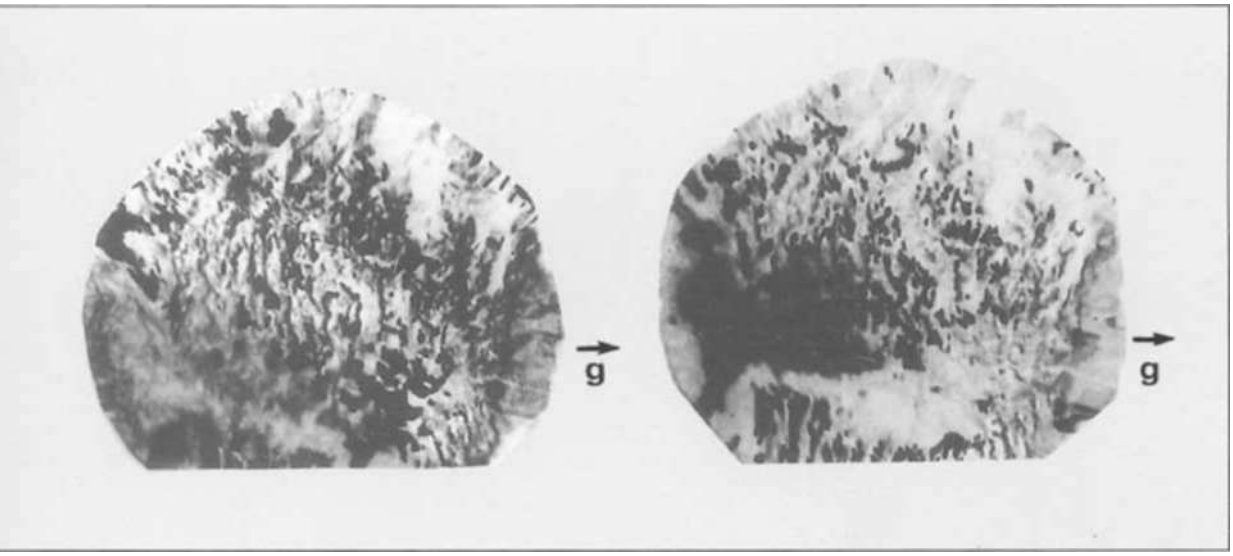

Figure 6: *Topographs of slice C of Figure 1b using the same diffracting planes 400 after the sample was tilted a few tenths of a degree with respect to the X-ray beam. Note the differences of distribution of the black and grey areas.*

when studied with a polarizing microscope. This birefringence, also known as *tabby extinction*, is the result of stresses built up during the growth process in the Verneuil furnace[1]. X-ray topographs of the sample do not reveal linear defects (edge or screw dislocations). Within the limits of the experimental method used, the sample shows a low density of dislocations. Nevertheless, the same topographs also demonstrate that the boule is not monocrystalline and that the quality of the crystal varies in different parts of the sample. In fact, the basal part of the boule consists of larger homogeneous areas of better crystalline quality. This could be due to the fact that it remains for a longer time in contact with the flame and is removed only slowly from the flame as the growth of the sample increases in height. Therefore, in the bottom part of the boule the temperature decreases slowly, allowing a more correct arrangement of the atoms in the crystal lattice and a relaxation of the stored stresses before the growth ends, when the temperature decreases at a more rapid rate. On the other hand, the median and the upper part of the sample have a shorter time to adapt to the decreasing temperatures before the growth ends, giving the top part of the crystal only a restricted opportunity for a proper arrangement. In fact, the topographs d, e and h *(Figure 5)* show an increase in the poly-crystallinity of the slices approaching the top of the boule. This part of the sample mainly consists of many small domains, which are crystallographically disoriented with respect to each other.

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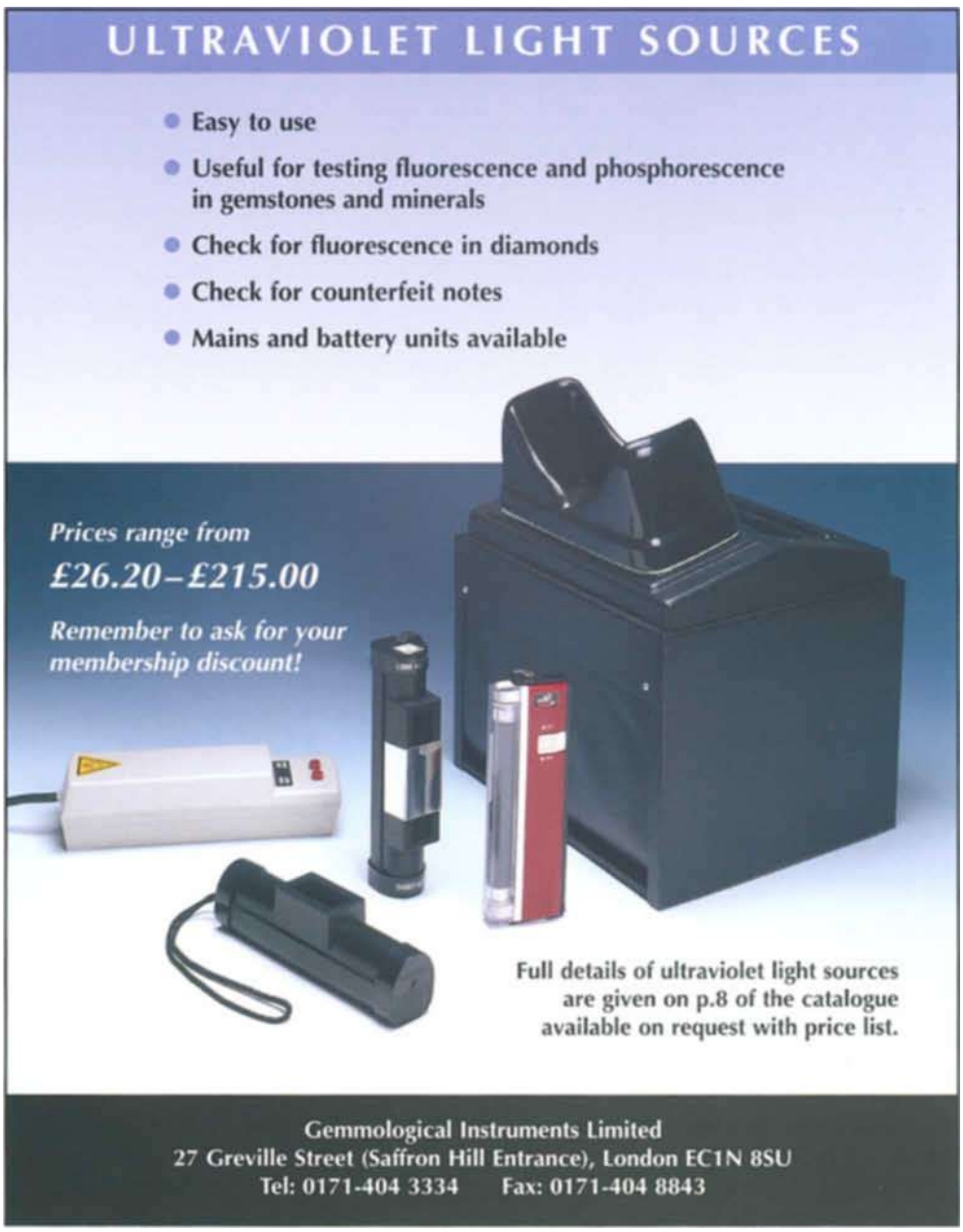

Characterization of alexandrite, emerald and phenakite from Franqueira (NW Spain)

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ABSTRACT: Structural, chemical, physical and microscopic characteristics of emerald, alexandrite and phenakite from Franqueira (Spain) are presented, and their gemmological possibilities are discussed. Comparison of data between Franqueira emeralds and Ural Mountains emeralds is emphasized, because both deposits contain the same associations of beryllium minerals and they are of similar genesis. The Ural Mountains deposit was until now the only one in Europe with these three rare beryllium minerals; it is now joined by the Franqueira deposit which is the only one of this type known in Spain.

Keywords: Emerald, alexandrite, phenakite, Franqueira (Spain), Tokovaja (Ural Mountains)

Introduction

The Franqueira deposit of beryl (emerald), chrysoberyl (alexandrite) and phenakite is the only one of its type known in Spain. A detailed geological description of this deposit was published by Martin-Izard *et al.* (1995).

The mineralization is located between the Braganza-Morais Portuguese complexes and the Ordenes complex in the Galicia-Tras Os Montes zone which is made up of two domains, the schistose and the granitic. The former is composed of metamorphic rocks and mafic-ultramafic overthrusting complexes of an ophiolitic nature. All of the rocks of this domain were affected by the Variscan Orogeny. The granitic domain includes peraluminous inhomogeneous synkinematic two-mica granitoids.

The Franqueira intrusive pegmatitic bodies, rich in fluids and volatile elements (Be, B, P, H_2O), are related to the above-mentioned granitic rocks. At the contact of pegmatite and dunite, a metasomatic zone has been developed. In the zones closest to the pegmatite, the dunitic rock is transformed entirely (chiefly due to the water, Si, Al and K from the pegmatite) into a rock mainly consisting of phlogopite, the Mg of which was provided by the dunite. In the zones furthest from the pegmatite, its influence is less and the dunite is transformed into an amphibolitic (tremolite) rock, in which the Mg is again provided by the dunite.

Beryl (emerald), chrysoberyl (alexandrite) and phenakite appear as accessory minerals beside tourmaline, garnet, apatite and zircon in a phlogopite rock, closest to the pegmatite, this being the only host rock containing beryllium minerals.

As described by Martin-Izard et al. (1995), the volatile element Be was distributed mostly in the zones closest to the pegmatite, favouring the development of beryl porphyroblasts

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Figure 1: *Cut stones from Franqueira; left, top to bottom, phenakite (0.33 ct), alexandrite (preform 3.39 ct and 0.34 ct) and right, emerald (2.53, 1.03 and 2.49 ct). Photo by Angel Ricardo.*

Figure 2: *Emerald (5 cm long) from Franqueira showing the typical prismatic habit. Photo by Angel Ricardo.*

among the phlogopite. The fact that emerald and alexandrite are the varieties of beryl and chrysoberyl present in the assemblage is due to their Cr content, which came from the dunite. Cr entered such crystals in the phlogopite rock but did not penetrate the pegmatite proper.

This deposit is similar to that at Tokovaja (Ural Mountains) studied by Fersman (1929) and summarized in part by Sinkankas (1981) and Sinkankas and Read (1986). Both deposits have produced the same mineral assemblage of beryl, chrysoberyl and phenakite, they occur in the same geological setting – a suture zone, and they are genetically similar. However, the Tokovaja deposit is very large and there are more than 60 species of accessory minerals, whereas the Franqueira deposit is only visible for 15–20 metres although it is probable that it is part of a larger deposit.

A detailed study of the structural, chemical, physical and microscopic properties of the beryllium minerals of the Franqueira deposit was performed in order to place on record its existence as a gemmological locality, before it is completely destroyed by mineral collectors.

On the basis of the resemblance between both deposits in relation to the association of beryllium minerals, the host rock and the genesis of mineralization, we have tried to compare the characteristics of the beryllium minerals from Franqueira with those from the Ural Mountains. However, there are very few data concerning emeralds from the latter locality (Gübelin, 1953; Lokhova *et al.*, 1977, Zhernakov, 1980; Granadchikova *et al.*, 1983, and Gromov *et al.*, 1990) and even less about alexandrite and phenakite; there is mention by Fersman (1929) of their visual appearance, chemical analyses which were published by Vlasov and Kutakova (1960), and more recently other authors have supplied some data *(see Table VI)*.

Materials and methods, experimental details

The present study is based on the examination of samples of emerald, alexandrite and

Table I: *Chemical composition of Franqueira emerald in a thin section*

Wt. %	Range of 17 analyses	Mean
SiO_2	65.61–68.25	67.05
TiO_2	0.00–0.06	0.01
Al_2O_3	14.99–17.58	16.74
Cr_2O_3	0.00–0.16	0.06
MgO	0.62–2.12	1.12
CaO	0.00–0.16	0.06
MnO	0.00–0.06	0.02
FeO	0.16–0.63	0.26
NiO	0.00–0.09	0.02
Na_2O	0.32–1.09	0.68
K_2O	0.00–0.24	0.03
Total		86.05
Atomic contents based on oxygen = 18 and beryllium = 3		
Si	5.940–6.105	5.998
Ti	0.000–0.004	0.001
Al	1.743–1.853	1.765
Cr	0.000–0.011	0.004
Mg	0.084–0.166	0.149
Ca	0.000–0.005	0.006
Mn	0.000–0.004	0.001
Fe	0.013–0.045	0.019
Ni	0.000–0.006	0.002
Na	0.056–0.136	0.118
K	0.000–0.025	0.003

NB. Detailed analyses may be obtained from the authors

phenakite crystals, faceted and cabochon-cut samples, and in thin section.

Fragments of single crystals of emerald (crystal A), alexandrite and phenakite for X-ray diffraction were mounted on the goniometric head of an ENRAF-NONIUS CAD4 automatic four-circle diffractometer equipped with graphite-monochromatized radiation MoKα (λ = 0.71069Å).

Electron microprobe analyses *(Tables I–IV)* were performed with a Cameca SX50 electron microprobe using an acceleration voltage of 15 kV and a beam current of 15 nA on several crystals of emerald, alexandrite and phenakite in a thin section, on a polished plane parallel to a hexagonal prism of an emerald crystal (A), on the bases of two cabochons (B and C) of emerald, on a polished section of a rough crystal (D) of emerald and on three polished fragments of alexandrite. For the calculation of oxide wt. % contents, the correction procedure described by Pouchou and Pichoir (1984) was applied.

The average lithium and beryllium contents of Franqueira emeralds were determined by inductively coupled plasma mass spectrometry (ICP-MS) using the decomposition procedure on a powdered sample (a mixture of several crystals with different shades of colour) in a closed teflon vessel heated by microwaves. The water content of a mixture of samples of beryl was determined by thermogravimetric analysis with a Mettler instrument on approximately 23 mg of powdered sample. Weight loss vs. Time (at a heating rate of 10°C/min) was plotted as a gradual continuous curve from 25 to 140°C, followed by another curve from 140 to 800°C, for a total weight loss of 2%.

Refractive indices were obtained from table facets of cut stones of emerald, alexandrite and phenakite *(Figure 1)*, on the polished surfaces of the crystals A and D and the cabochons (B and C). A gemmological refractometer was used, according to the method described by Hurlbut (1984). Specific gravities were determined hydrostatically from the same samples.

One infrared spectrum was recorded for a mixture of several crystal fragments of emeralds from Franqueira in the range of H_2O stretching modes (from 3200 to 3800 cm^{-1}) using a Perkin-Elmer 1710X spectrophotometer. After microscope examination, samples without major mineral inclusions were selected for spectroscopic examination. A disc was pressed from KBr with about 4 wt. % of sample powder.

Electron microprobe analyses were also made of phlogopite, quartz, pyrite and anthophyllite inclusions exposed at the surfaces of the fashioned emeralds, and of phlogopite inclusions in polished fragments of alexandrite.

Photomicrography was performed with a Zeiss microscope on the samples of *Figure 1* and on a cabochon cut emerald (B).

Properties of emerald

Emerald is the most abundant of the three Be minerals in the Franqueira deposit. The rough samples are light green to medium green and reveal a typical prismatic habit *(Figure 2)*, in sizes of up to 10 cm, with mica

Table II: Chemical analyses and gemmological properties of Franqueira emeralds

Sample	*Prismatic crystal A*	*Cabochon B*	*Cabochon C*	*Crystal D*	
Colour	*medium green*	*medium green*	*medium green*	*medium green*	
n_ω	1.582 (1)	1.582 (1)	1.582 (1)	–	
n_ε	1.576 (1)	1.576 (2)	1.575 (1)	–	
Δn	0.006 (1)	0.006 (1)	0.007 (1)	–	
SG	2.707	2.706	2.690	–	
Number of analyses	70	49	19	9	Mean 147
Wt. %					
SiO_2	66.247	65.713	65.964	65.610	65.99
TiO_2	0.005	0.006	0.004	0.004	0.01
Al_2O_3	15.157	15.596	15.584	14.999	15.35
V_2O_3	0.045	0.022	0.015	0.043	0.03
Cr_2O_3	0.111	0.042	0.051	0.101	0.08
MgO	2.154	1.613	1.764	2.121	1.92
CaO	0.086	0.079	0.115	0.163	0.09
MnO	0.014	0.022	0.016	0.014	0.02
FeO	0.506	0.589	0.548	0.634	0.55
NiO	0.015	0.015	0.016	0.014	0.02
Na_2O	1.417	0.931	1.036	1.094	1.19
K_2O	0.141	0.109	0.123	0.238	0.13
Total	85.898	84.737	85.236	85.035	85.38
Atomic contents based on O = 18 and Be = 3					
Si	5.934	5.893	5.902	5.882	5.913
Ti	0.000	0.000	0.000	0.000	0.000
Al	1.601	1.645	1.643	1.627	1.623
V	0.003	0.002	0.002	0.002	0.002
Cr	0.008	0.003	0.004	0.005	0.006
Mg	0.287	0.216	0.235	0.240	0.254
Ca	0.008	0.008	0.011	0.012	0.009
Mn	0.001	0.002	0.002	0.001	0.001
Fe	0.038	0.044	0.041	0.044	0.041
Ni	0.001	0.001	0.002	0.001	0.001
Na	0.246	0.162	0.180	0.170	0.205
K	0.016	0.013	0.014	0.018	0.015

crystals either bound to the prism faces or as inclusions. In places, emerald replaces chrysoberyl (alexandrite) and phenakite. Almost all the samples show uneven colour distribution and the majority are translucent.

The microprobe analyses were carried out at 164 analysis points several micrometres apart on several samples: 17 analysis points on 12 crystals of a thin section *(Table I)*; 70 analysis points on a prismatic section of the crystal A; 68 analysis points on the cabochons B and C, and 9 analysis points on the crystal D *(Table II)*.

Tables I and II report the average chemical compositions thus obtained. Cations were calculated on the basis of 18 oxygens, assuming Fe and Mn as Fe^{2+} and Mn^{2+}, assuming the number of Be atoms to be 3 as in the stoichiometric formula, and neglecting Li and H_2O contents.

The average Li_2O, BeO and H_2O contents determined by ICP–MS were 0.589, 13.71 and 2.00 wt. % respectively for a mixture of emeralds from Franqueira. On the basis of their total alkali content they can be defined as sodium-potassium beryls with low alkali content.

All components varied widely between different crystals. Whereas the variation of the Cr content did cause patchiness of colour, there is no evidence of colour zoning within the samples, even when observed with a microscope.

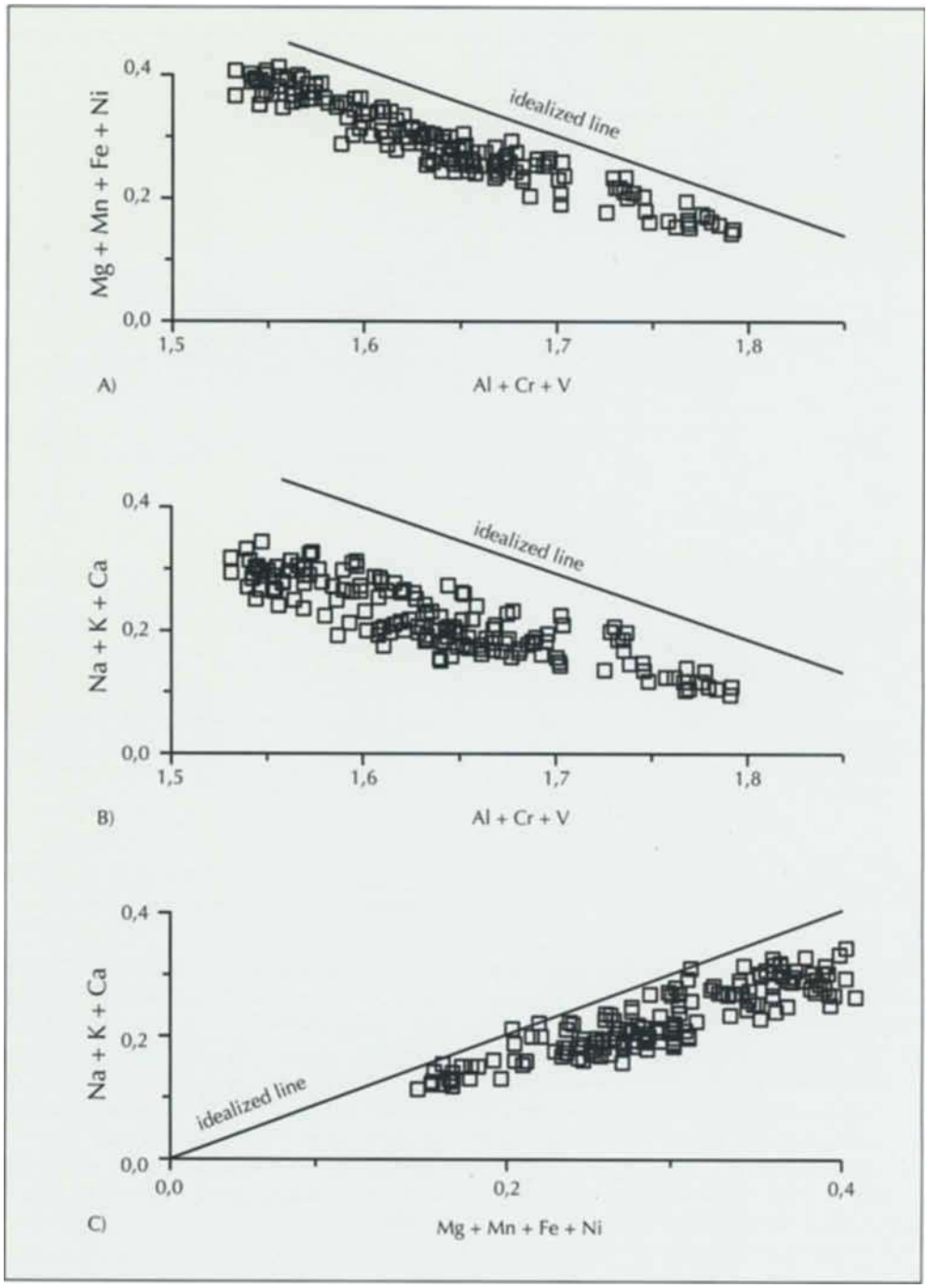

Figure 3: *(A) Plot of $Al^{3+} + Cr^{3+} + V^{3+}$ in octahedral sites versus Mg^{2+} in octahedral sites showing a negative correlation. (B) Plot of $Al^{3+} + Cr^{3+} + V^{3+}$ in octahedral sites versus $Na^{+} + K^{+}$ in channel sites showing a similar relationship to that of Figure 3A. (C) Plot of octahedral Mg^{2+} versus $Na^{+} + K^{+}$ in channel sites showing a positive correlation.*

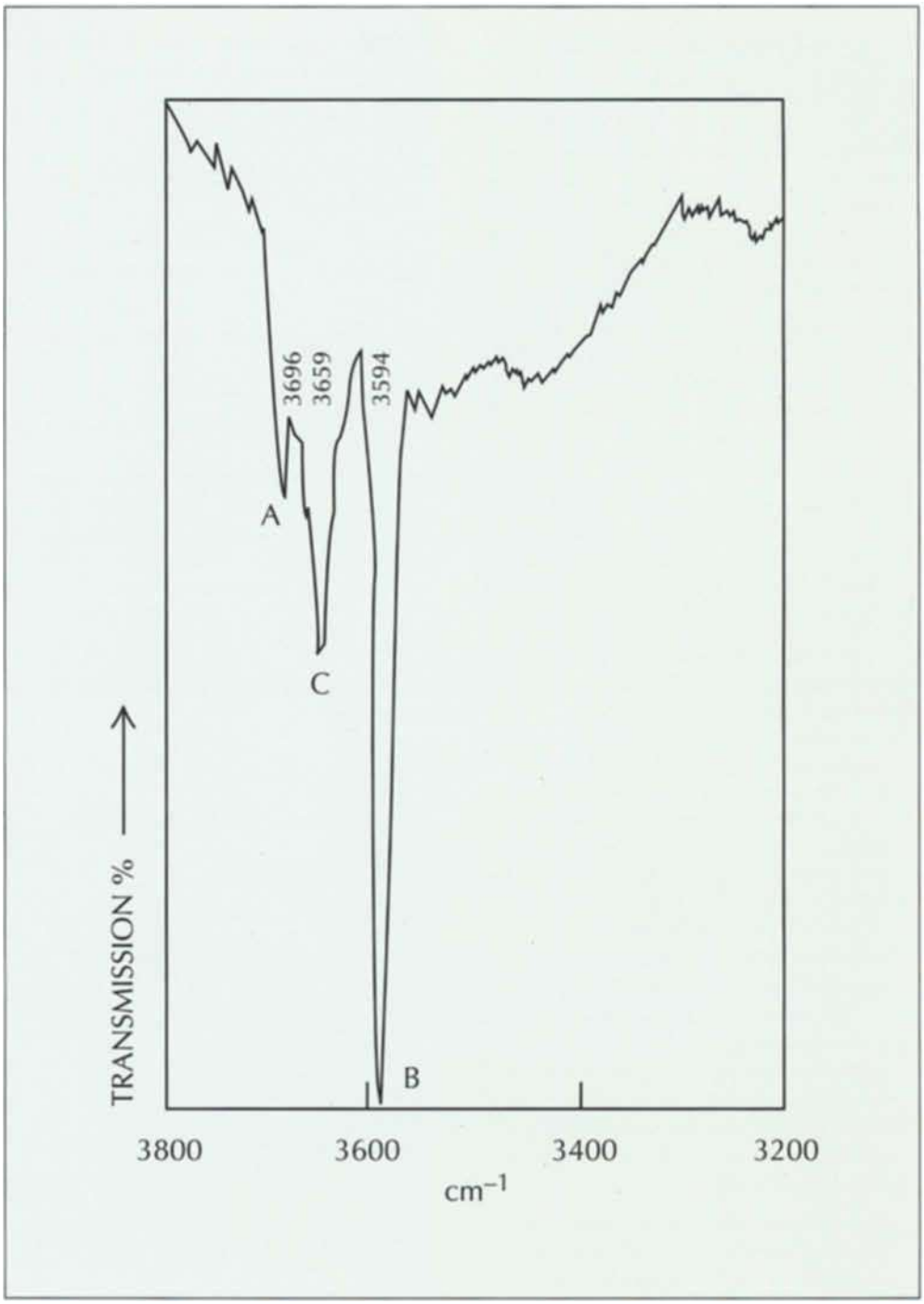

Figure 4: *The infrared spectrum of a mixture of emerald samples from Franqueira shows absorption bands of non-alkali-bonded (A) and alkali-bonded (B) and (C) water molecules. The intensity of absorption bands is B > C > A.*

Crystal chemistry of emerald

The channels of the beryl structure may contain alkalis, H_2O or CO_2 molecules and this relates to a complex substitutional pattern mainly affecting the tetrahedral Be and octahedral Al sites. The substitutional pattern used in this work is the generally accepted one of Aurisicchio *et al.* (1988):

1. *Octahedral substitution,* in which Al^{3+} in octahedral sites is replaced by trivalent transition metal ions or by divalent transition metals or magnesium, with alkali metal ions entering the channels for charge compensation.
2. *Tetrahedral substitution,* in which Be^{2+} in tetrahedral sites is replaced by divalent transition metal ions or possibly by Li^+, with alkali metal ions entering the channels for charge compensation.

The unit cell dimensions of beryls are correlated with their chemical composition and they are classified according to their *c*/a ratios as *octahedral beryls* with predominant octahedral substitution of Al^{3+}, as *tetrahedral beryls* with predominant tetrahedral substitution of Be^{2+} and as *normal beryls* with a limited octahedral and tetrahedral substitution of Al^{3+} and Be^{2+} (De Almeida Sampaio Filho *et al.*, 1973; Hawthorne and Cerný, 1977; Brown and Mills, 1986; Aurisicchio *et al.*, 1988; Sherriff *et al.*, 1991; Artioli *et al.*, 1993).

The microprobe analyses provide proof of the isomorphic replacement of Al in octahedral sites by correlation diagrams of trivalent octahedral cations versus magnesium or versus channel alkalis ($Na^+ + K^+$) and by correlation diagrams of magnesium versus channel alkalis.

These diagrams have been prepared for the above-mentioned 164 point analyses and are based on the following assumptions:

1. Si = 6 with Si in the tetrahedral site
2. Ti abundance is low and
3. V and Cr are trivalent and replace Al through the homovalent exchange:

$$R^{3+}_{(oct)} = R^{3+}_{(oct)}$$

So Al^{3+}, V^{3+} and Cr^{3+} only occur in the octahedral site.

4. Mg, Mn, Fe and Ni are all divalent and can only occur in the octahedral site as $R^{2+}_{(total)}$.
This involves the heterovalent exchange:

$$R^{3+}_{(replaced)(oct)} = R^{2+}_{(total)(oct)} + \textit{local charge deficit}$$

5. Na and K are monovalent and are large cations which can only enter the channel sites; divalent Ca^{2+} can also enter channel sites and its charge must be taken into account as follows:

$$R^{+}_{(total)(chan)} = (Na^+ + K^+ + 2Ca^{2+})$$

So, the overall charge balance is represented by:

$$R^{+}_{(total)(chan)} = R^{2+}_{(total)(oct)}$$

The substitution scheme is as follows:

1. in terms of quantities:

$$Al^{3+}_{(replaced)(oct)} + vacancy_{(replaced)(chan)} = (V^{3+} + Cr^{3+} + Mg^{2+} + Mn^{2+} + Fe^{2+} + Ni^{2+})_{(oct)} + (Na^+ + K^+ + Ca^{2+})_{(chan)}$$

2. in terms of charges:

$$charge\ deficiency_{(oct)} = (Mg^{2+} + Mn^{2+} + Fe^{2+} + Ni^{2+})_{(oct\ instead\ of\ R^{3+}oct)}$$

(i.e. one charge loss for each divalent cation)

$$= charge\ excess_{(chan)} = [Na^+ + K^+ + (2Ca^{2+})]_{(chan)}$$

Figure 3a shows a negative correlation between trivalent cations and divalent magnesium. *Figure 3b* shows a similar negative correlation. *Figure 3c* shows a positive correlation. The points lie below the ideal lines drawn in *Figures 3a, 3b and 3c*, and the reason for this is unknown; there are many unknown factors involved in this kind of crystal-chemistry and these include:

1. the possible replacements of some Si by Al and of some Be by Al have not been included in the above schemes;
2. the occupancy of octahedral sites by Li is unknown;
3. the structural position of Ti has been ignored;
4. $(OH)^-$ groups may be present rather than charge-balanced H_2O.

From these diagrams we can confirm that for Franqueira emeralds the following octahedral substitution scheme is valid:

$$(Al^{3+} + Cr^{3+} + V^{3+})_{(oct)} \rightarrow (Mg^{2+} + Mn^{2+} + Fe^{2+} + Ni^{2+})_{(oct)} + (Na^{+} + K^{+} + Ca^{2+})_{(chan)}$$

X-ray diffraction measurements of sample A indicated that the unit-cell dimensions were a_0 = 9.2483 (6) Å, c_0 = 9.1976 (8) Å, V = 681.28 Å^3; the number of reflections used in the refinement were 25. The *c*/a ratio of 0.9945 is that of emerald with predominant octahedral substitution and is thus compatible with the data presented in *Table II* and *Figure 3*. The structure refinement of this sample showed that Li was present in the channels; Li cannot enter the tetrahedral Si sites and most probably does not enter the tetrahedral Be sites but it might enter octahedral sites and upset the local charge balance.

Because the beryllium contents of emeralds could not be determined by electron microprobe analyses we cannot comment about possible tetrahedral isomorphic replacements (Shatskiy *et al.*, 1981; Schmetzer and Bernhardt, 1994).

The measurements of refractive index and specific gravity *(Table II)* are typical for medium alkali-bearing beryl (Cerný and Hawthorne, 1976).

The IR spectrum recorded *(Figure 4)* corresponds to the H_2O stretching modes (from 3200 to 3800 cm^{-1}) assigned to three different types of water molecules and/or hydroxyl groups (Wood and Nassau, 1967, 1968). Band A at 3696 cm^{-1} is assigned to *Type I* water molecules which are not bound to adjacent alkali ions. Bands B and C at 3594 and 3659 cm^{-1} are caused by *Type II* water molecules and hydroxyl groups, which are bound to alkali ions. Two other bands appear at 1580 and 1634 cm^{-1} due to deformation and are assigned to *Type I* and *Type II* water molecules, respectively. *Type I* water molecules have their 2-fold axis perpendicular to the 6-fold axis and the H–H direction parallel to the 6-fold axis, and the *Type II* water molecules are aligned with the molecular symmetry axis parallel to the 6-fold axis (Wood and Nassau, 1967).

The intensity of the absorption bands A, B and C is as follows: B > C > A. According to Schmetzer and Kiefert (1990), a correlation was found between increasing sodium contents from about 0.03 to 2.5 wt % Na_2O and increasing intensities of the B and C absorption bands and decreasing intensities of the A band. According to the classification of emeralds proposed by Schmetzer and Kiefert (1990) based on spectral features in the range of H_2O and OH stretching modes, the spectrum in the range from 3500 to 3800 cm^{-1} of the Franqueira emeralds indicates that they belong to *Group III;* these are medium to high alkali-bearing emeralds with distinct amounts of alkali-bonded *Type II* water molecules and lower amounts of non-alkali-bonded *Type I* water molecules. Consequently, the relations of the band intensities of bands A, B and C in the sample from Franqueira indicate that most of the H_2O is of *Type II*.

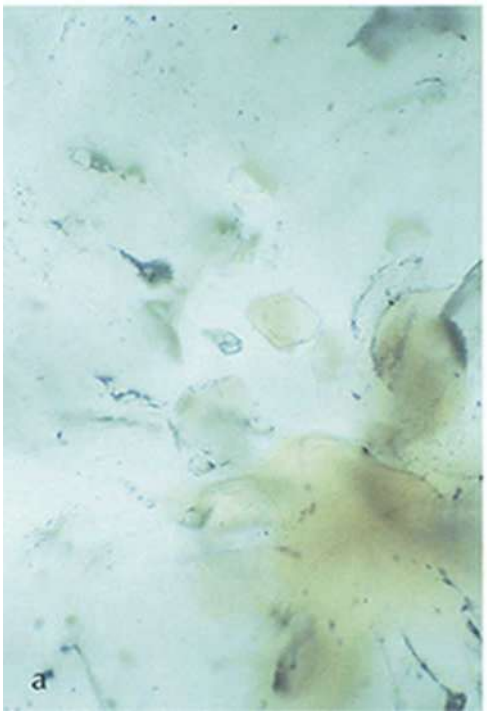

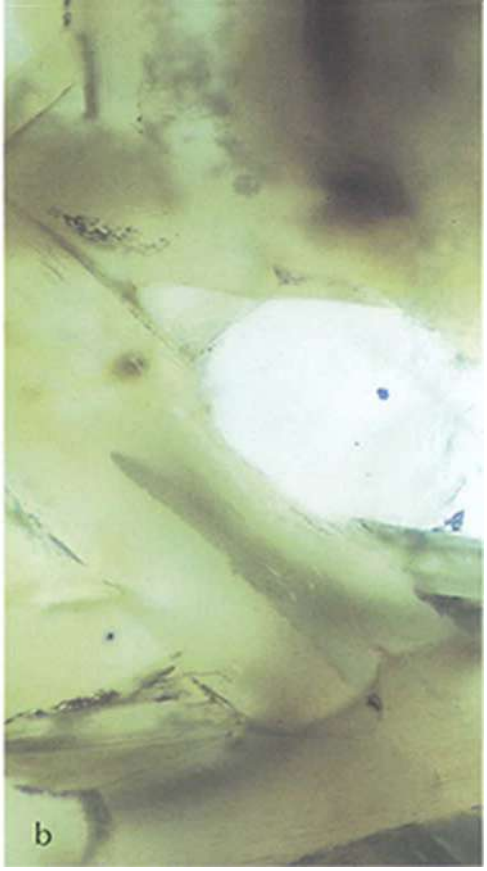

Figure 5: *(a) Isolated tabular crystal of phlogopite visible in an emerald from Franqueira (field dimensions 0.65 x 0.46 mm). (b) Cluster of brown phlogopite crystals in an emerald from Franqueira (field dimensions 0.65 x 0.34 mm).*

Inclusions in emerald

Under a transmission polarizing microscope abundant primary mineral and multiphase inclusions were seen in several cut stones, cabochons and some small emerald crystals in a thin section. Other inclusions related to fractures are pseudosecondary or secondary.

Mineral inclusions: Different forms of birefringent mineral inclusions are commonly present. Some are clustered or irregularly distributed elongated, tabular or rounded brown crystals *(Figure 5)*. Microprobe analyses indicate these to be iron-rich phlogopite with an average iron content of 8.32 wt. % FeO, which is similar to the FeO content (8.33 wt. %) of the phlogopite in the host rock. A curious effect, which consists of haloes free of multi-phase inclusions *(Figure 6)* around elongated brown crystals of phlogopite, was observed in distinct zones in a cabochon, viewed perpendicular to the *c*-axis. Phlogopite crystals are parallel to *c*-axis of the beryl host.

Other inclusions consist of quartz, pyrite, phenakite, beryl, ilmenite, alexandrite and another mineral which corresponds to anthophyllite according to electron microprobe analysis (SiO_2 62.90 wt. %, MgO 27.78 wt. %, FeO 5.76 wt. %, Al_2O_3 0.40 wt %), but they are not very common.

Multi-phase inclusions: Most multi-phase inclusions prove to be fillings in negative crystals *(Figure 7a)*, which are parallel to the *c*-axis, or filling fractures described as 'feathers'. Occasionally a section parallel to the *c*-axis shows typical prismatic faces, with dihexagonal dipyramids terminating in pinacoids *(Figure 7b)*, and some of them show a saw-like internal structure *(Figure 7c)*.

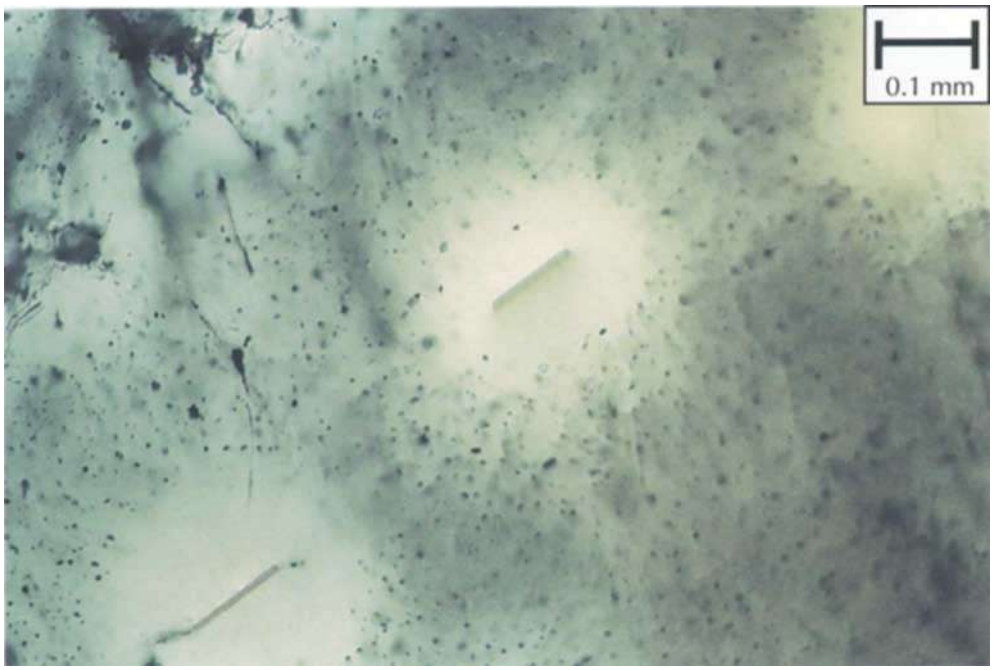

Figure 6: *Haloes free of multi-phase inclusions around elongated brown crystals of phlogopite in an emerald from Franqueira. The phlogopite crystals are oriented parallel to the c-axis of the emerald host.*

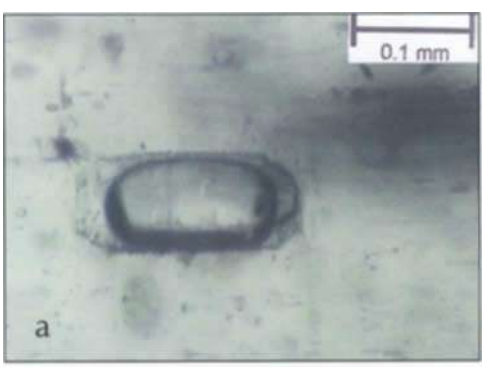

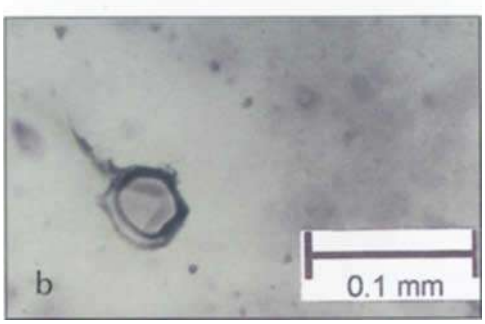

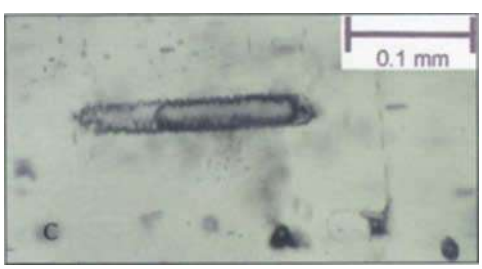

Figure 7: *(a) The commonest inclusions in emeralds from Franqueira are negative crystals containing liquid and gas, as shown in this view perpendicular to the c-axis in a cut stone. (b) Negative crystals in emeralds of Franqueira show the typical prismatic faces with dihexagonal dipyramids terminating in pinacoids, as shown in this view parallel to the c-axis in a cut stone. (c) Some negative crystals in emeralds from Franqueira show a saw-like internal structure. View perpendicular to the c-axis in a cut stone.*

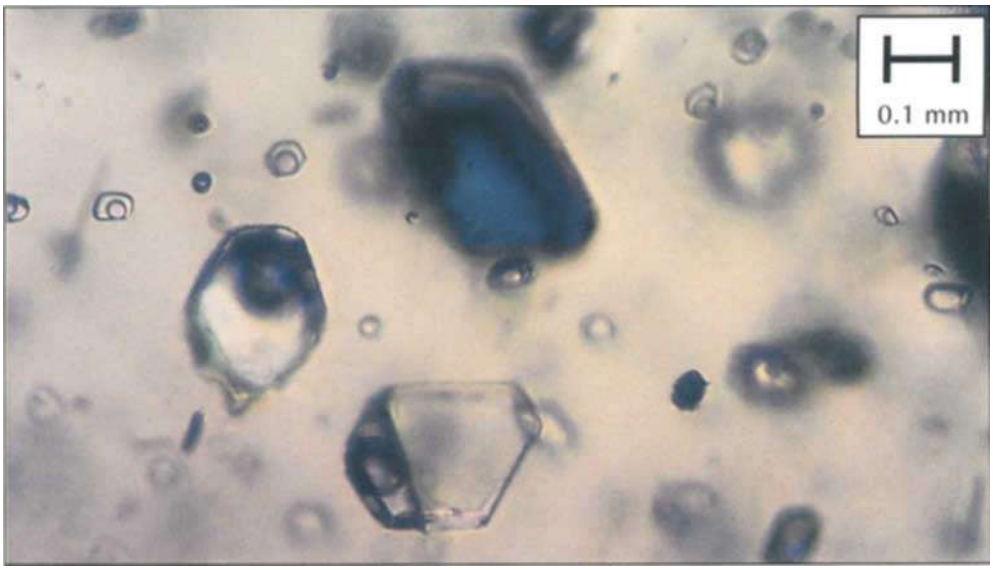

Microthermometry studies (Martín-Izard *et al.*, 1995) show three types of fluid fillings in these inclusions:

Type 1: Complex two-phase CH4 and aqueous inclusions (H_2O–NaCl–CH_4 and other volatiles). They are found in groups, isolated or in microfractures and mostly contain liquid H_2O and vapour CH_4. They are primary or pseudosecondary and are more common in the emeralds than in alexandrite or phenakite.

Type 2: Complex two-phase CO_2 and aqueous inclusions (H_2O–NaCl–CO_2 and other volatiles). These inclusions have the same distribution as type 1 but are less abundant, consisting mostly of liquid H_2O and vapour CO_2.

Type 3: Mixed salt two-phase aqueous inclusions (H_2O–NaCl and other salts). These contain liquid and vapour H_2O and are always secondary in character.

The inclusions of *type 1* frequently contain crystalline solids with hexagonal, prismatic or irregular habit; they are transparent and colourless and some are birefringent. They may be phlogopite, phenakite, emerald or possibly other minerals *(Figure 8)*.

Figure 8: *The two-phase liquid-gas inclusions in emeralds from Franqueira commonly contain birefringent crystals, which may be phlogopite, phenakite or emerald, as shown in this view of a thin section.*

Figure 9: *Twinned crystal (7 x 5.5 x 3 mm) of Franqueira alexandrite showing two of the three pleochroic colours, as viewed with polarized transmitted and oblique illumination.*

Table III: *Chemical composition of Franqueira alexandrite*

Sample	*Thin section*	*Polished surfaces of rough crystals*	*Inclusion in beryl*	
Wt. %	*Range*	*Range*		*Mean of 30 analyses*
SiO_2	0.000–0.029	0.033–0.780	0.06	0.13
TiO_2	0.008–0.128	0.107–0.638	0.06	0.24
Al_2O_3	79.626–80.997	70.298–77.341	74.44	76.00
V_2O_3	n.a.	0.017–0.100	0.03	0.05
Cr_2O_3	0.194–0.351	0.152–4.408	0.26	1.49
MgO	0.006–0.070	0.023–0.319	0.02	0.07
CaO	0.000–0.021	0.010–0.050	0.01	0.01
MnO	0.000–0.031	0.000–0.010	0.02	0.02
FeO	0.597–1.053	0.863–1.098	0.65	0.88
NiO	0.000–0.023	0.000–0.047	0.02	0.02
Na_2O	0.000–0.025	0.025–0.037	0.02	0.02
K_2O	0.000–0.020	0.004–0.091	0.00	0.01
Total	–	–	75.59	78.94

N.B. n.a. = not analysed

Properties of alexandrite

Alexandrite is less abundant than beryl and appears as three-member twins, in sizes up to 1 cm, in the phlogopite rock or as skeletal intergrowths within emerald. The crystals are cracked, the cracks being filled by phlogopite, and covered with flakes of phlogopite. The crystals show a pronounced colour change from purple-red under incandescent light to olive-green (or bluish-green, depending on observer) in daylight, and exhibit strong trichroism of blue-green, orange-yellow and red in daylight. In incandescent light the reds are stronger and greens weaker. In *Figure 9* two of the three colours of a twinned crystal are shown.

Figure 10: *Healing feathers consisting of two-phase inclusions in a cut alexandrite from Franqueira.*

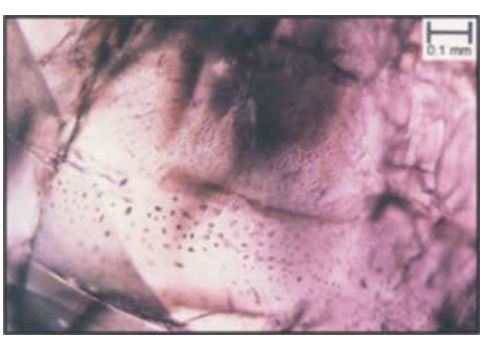

Franqueira alexandrite contains numerous phlogopite inclusions and it is difficult to obtain cut stones of good quality *(Figure 1)*.

The unit-cell dimensions are a_0 = 9.404 (4) Å, b_0 = 5.483 (2) Å, c_0 = 4.401 (8) Å, V = 226.9 (4) Å^3; the number of reflections used in the refinement was 25.

The chemical analyses were performed on several crystals in a thin section (*Table III* samples 1 to 5), on polished sections of three fragments (6, 7 and 8) and on one inclusion in emerald. The iron content ranges from 0.597 to 1.098 wt. % FeO and the Cr_2O_3 content was generally found to be between 0.152 and 0.351 wt. %, although one sample (crystal 8) contains over 4.4 wt. % Cr_2O_3.

The refractive indices obtained from the table facet of the cut stone are: n_α = 1.742, n_β = 1.746 and n_γ = 1.751, with a birefringence of 0.009. The measured specific gravity is 3.64.

The inclusions in alexandrite consist of phlogopite crystals with a composition similar to that of phlogopite in the host rock, and healed 'feathers' containing two-phase inclusions *(Figure 10)*.

Table IV: *Chemical composition of Franqueira phenakite in a thin section*

Wt. %	Range	Mean of 14 analyses
SiO_2	56.712–57.749	57.11
TiO_2	0.000–0.016	0.01
Al_2O_3	0.000–0.022	0.01
V_2O_3	0.000–0.013	0.01
Cr_2O_3	0.001–0.028	0.02
MgO	0.000–0.020	0.01
CaO	0.000–0.020	0.01
MnO	0.000–0.044	0.02
FeO	0.000–0.076	0.04
NiO	0.000–0.079	0.02
Na_2O	0.000–0.022	0.01
K_2O	0.000–0.015	0.01
Total	–	57.28

Figure 11: *Brown crystals of phlogopite and healed fractures in a cut phenakite from Franqueira.*

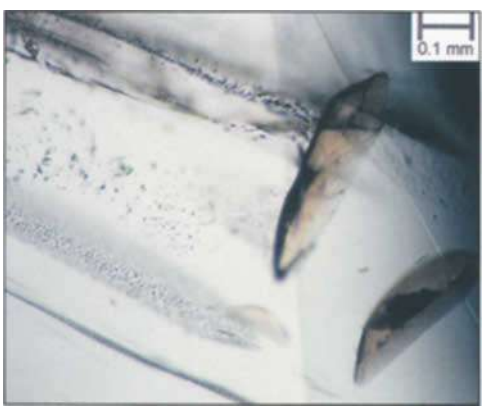

Figure 12: *The healed feathers in phenakite from Franqueira commonly contain two- or three-phase inclusions, liquid and vapour H_2O with NaCl dissolved in the aqueous medium.*

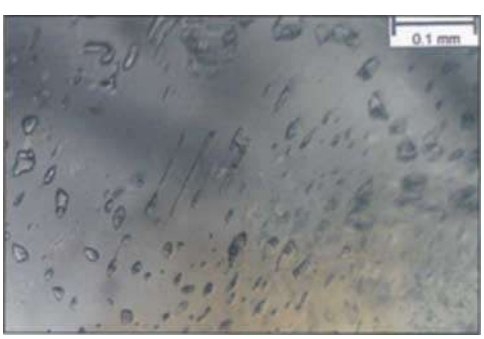

Properties of phenakite

At Franqueira phenakite is less abundant than emerald or alexandrite. It appears as angular or rounded grains, or sometimes as short subhedral and colourless prismatic crystals up to 3 cm long. Phenakite-apatite is a common association in the phlogopitic rock. In thin sections where chrysoberyl and phenakite are found together they may suffer partial replacement by emerald (Martín-Izard *et al.*, 1995). The phenakite is transparent and of cuttable quality *(Figure 1)*.

The unit-cell dimensions are a_0 = 12.472 (2) Å, c = 8.252 (2) Å, V = 1111.7 (3) Å^3; the number of reflections used in the refinement were 25. Chemical analyses carried out on several crystals in the same thin section are shown in *Table IV*.

The refractive indices measured on the table facet of the cut stone are: n_ω = 1.648 and n_ε = 1.664, with a birefringence of 0.016. The measured specific gravity is 2.959.

The crystals examined contain tabular or elongated brown crystals of phlogopite, partly healed fractures *(Figure 11)*, and some isolated two- or three-phase inclusions *(Figure 12)*.

The healed 'feathers' contain two-phase inclusions. These are generally pseudo-secondary or secondary and most consist of liquid and vapour H_2O with dissolved NaCl (from microthermometric data of Martín-Izard *et al.*, 1995).

Properties of Uralian samples compared with samples from Spain

As was mentioned in the introduction, the resemblance between the Franqueira and Tokovaja (Ural Mountains) deposits in terms of their assemblages of beryllium minerals, the host rock and the mineralization genesis, led us to compare the characteristics of emerald, alexandrite and phenakite from both deposits *(Tables V, VI and VII)*.

The properties of alexandrite and phenakite from each locality are practically identical but those of emerald show some differences which are now summarized:

1. The Franqueira emeralds are generally paler in colour than the Tokovaja emeralds because of their lower Cr content;

Table V: *Comparison between the properties of emerald from Franqueira (Spain) and Tokovaja (Ural Mountains)*

	Franqueira (Spain)	*Tokovaja (Ural Mountains)*
Occurrence	Metasomatic zone	Metasomatic zone
Emerald-bearing host rock	Phlogopite rock	Biotite[1] or phlogopite[2] rocks
Mineral assemblage	Phlogopite, phenakite, alexandrite, tourmaline, garnet, apatite, zircon	Phlogopite, fluorite, apatite, phenakite[1]
Visual appearance	Prismatic crystals, translucent and light green in colour with several tones of colour distributed unevenly	Prismatic crystals, transparent, most of them are dark green and show colour zoning
Chemical analyses	Cr_2O_3 wt. % = 0.04–0.11 V_2O_3 wt. % = 0.02–0.05 FeO wt. % = 0.51–0.63 $Na_2O + K_2O$ wt. % = 1.04–1.66	Cr_2O_3 wt. % = 0.02–0.50 V_2O_3 wt. % = 0.01–0.04 FeO wt. % = 0.16–0.57 $Na_2O + K_2O$ wt. % = 0.64–1.80[3]
Refractive indices	n_ω = 1.581–1.582 n_ε = 1.575–1.576 Δn = 0.006–0.007	n_ω = 1.581–1.590 n_ε = 1.575–1.582 Δn = 0.006–0.008[3,4]
Specific gravity	2.69–2.71	2.71–2.75[3]
Spectroscopic characteristics in the infrared (3500–3800 cm^{-1})	Intensity ratios of bands: B > C > A Typical of medium alkali-bearing emeralds	Intensity ratios of bands: B > A > C Typical of medium alkali-bearing emeralds
Mineral inclusions	Phlogopite (FeO wt. % ≅ 8) beryl, alexandrite, phenakite, pyrite, ilmenite, quartz, anthophyllite	Phlogopite (FeO wt. % ≅ 4) and biotite-phlogopite (FeO wt. % ≅ 7),[3] actinolite, tourmaline, biotite[5], rutile[2]
Fluid inclusions	Fluid fillings[6]: *Type 1:* Primary or pseudosecondary complex two-phase CH_4aqueous inclusions. These mainly show H_2O liquid and CH_4 vapour. They frequently also contain crystalline solids. *Type 2:* Complex two-phase CO_2 aqueous inclusions. These mainly consist of H_2O liquid and CO_2 vapour. *Type 3:* Secondary mixed salt two-phase aqueous inclusions. These show H_2O liquid and vapour.	Fluid fillings[7]: *Type 1:* Primary two-phase, aqueous solution and gas. *Type 2:* Primary and pseudosecondary three-phase aqueous solution, gas and liquid CO_2. *Type 3:* Primary and pseudosecondary three-phase aqueous solution, gas and a small halite crystal. *Type 4:* Pseudosecondary and secondary aqueous solution with a small gas component. *Type 5:* Extremely rare pseudosecondary inclusions consisting of small aqueous solution and/or gas phases with larger crystal inclusions.
Morphology of inclusions	Negative crystals // to the *c*-axis Healed 'feathers'	Thin channel-like structures // to the *c*-axis Thin and flat cavities Channel-like growth tubes // to the *c*-axis Healed 'feathers'[(3)]

[1]Fersmann (1929)
[2]Zhernakov (1980); Laskovenkov (1991)
[3]Schmetzer *et al.* (1991)
[4]Vlasov and Kutakova (1960)
[5]Gübelin and Koivula (1986)
[6]Martìn-Izard *et al.* (1995)
[7]Gromov *et al.* (1990)

Table VI: *Comparison between the properties of alexandrite from Franqueira (Spain) and Tokovaja (Ural Mountains)*

	Franqueira (Spain)	*Tokovaja (Ural Mountains)*	
Occurrence	Metasomatic zone	Metasomatic zone[1,2]	
Alexandrite-bearing host rock	Phlogopite rock	Phlogopite rock[1,2]	
Mineral assemblage	Phlogopite, beryl, phenakite, tourmaline, garnet, apatite, zircon	Phlogopite, phenakite, apatite, tourmaline, beryllium-margarite, fluorite and occasionally associated with beryl[1,2]	
Visual appearance	Euhedral or subhedral crystals composed of three twin units. Crystals are covered with flakes of phlogopite. Purplish-red (incandescent light) and green (in daylight). Green, orange and red trichroic colours.	Euhedral or subhedral crystals composed of three twin units. Crystals are covered with flakes of phlogopite and chlorite. Purplish-red (incandescent light) and bluish-green (in daylight). Green, orange and red trichroic colours[1,2]	
Chemical analyses	FeO wt. % = 0.60–1.10 Cr_2O_3 wt. % = 0.15–4.41 V_2O_3 wt. % = 0.02–0.10	FeO wt. % = 0.69–0.99 Cr_2O_3 wt. % = 0.18–1.45[3] V_2O_3 wt. % = 0.02–0.05	1.75 0.06[4] 0.03
Refractive indices	$n_\alpha = 1.742$ $n_\beta = 1.746$ $n_\gamma = 1.751$ $\Delta n = 0.009$	$n_\alpha = 1.749$ $n_\beta = 1.753$ $n_\gamma = 1.759$ $\Delta n = 0.010$[5]	
Specific gravity	3.64	3.644–3.663[6]	
Inclusions	Phlogopite crystals Healed 'feathers'	Healed 'feathers'	

[1]Vlasov and Kutakova (1960) [2]Fersman (1929)
[3]Ottemann *et al.* (1978) [4]Henn (1985)
[5]Webster (1983) [6]Vlasov (1964)

2. Most of the Franqueira samples show uneven colour distribution and the microprobe analyses revealed a large range of Cr content, but colour zoning, which is always present in the Tokovaja samples, has not been observed.
3. In all the Uralian emeralds examined by Schmetzer *et al.* (1991) a dominant octahedral substitution and a subordinate tetrahedral substitution were established, whereas in the Franqueira emeralds only an octahedral substitution has been established. Because the beryllium and lithium content of emeralds from both localities have not been determined in detail it is not possible to comment on possible tetrahedral isomorphic replacements.
4. The Uralian emeralds studied by Schmetzer *et al.* (1991) show a large range in their refractive indices, birefringence and specific gravity values which is probably due to the fact that the samples came from different mines in the Tokovaja area. The refractive indices, birefringence and specific gravity of the Franqueira samples agree perfectly with the values given by Vlasov and Kutakova (1960) for emeralds from the phlogopite zone in the Central Zone of the Tokovaja area.
5. In the Uralian emeralds Schmetzer *et al.* (1991) established the presence of both colourless Fe-poor phlogopites and more iron-rich brown crystals of the biotite-phlogopite series; the Franqueira emeralds contain only brown phlogopite with an Fe content comparable to that of the brown biotite-phlogopite of the Uralian emeralds.

Table VII: *Comparison between the properties of phenakite from Franqueira (Spain) and Tokovaja (Ural Mountains)*

	Franqueira (Spain)	*Tokovaja (Ural Mountains)*
Occurrence	Metasomatic zone	Metasomatic zone[1]
Phenakite-bearing host rock	Phlogopite rock	Phlogopite rock[1]
Mineral assemblage	Phlogopite, beryl, alexandrite, tourmaline, garnet, apatite, zircon	Phlogopite, phenakite, apatite, tourmaline, beryllium-margarite, fluorite and rarely associated with beryl[1]
Visual appearance	Annular or rounded and sometimes short subhedral prismatic crystals Transparent Colourless	Annular or rounded and sometimes sharp and short prismatic crystals with rhombohedral terminations. Crystals are transparent to translucent. White, colourless and pale yellow in colour.[2]
Chemical analyses	SiO_2 wt. % = 56.71–57.75 BeO wt. % = not analyzed In addition to the principal components, also contains small quantities of Al, Fe^{3+}, Fe^{2+}, Ca Mg, Na, K	SiO_2 wt. % =52.92 BeO wt. % = 45.82[2] In addition to the principal components, also contains small quantities of Al, Fe^{3+}, Fe^{2+}, Ca, Mg, Na, K
Refractive indices	$n_\omega = 1.648$ $n_\varepsilon = 1.664$ $\Delta n = 0.016$	$n_\omega = 1.654$ $n_\varepsilon = 1.670$ $\Delta n = 0.016$[1]
Specific gravity	2.959	2.93–3.00[1]
Inclusions	Phlogopite crystals Healed 'feathers'	

[1]Vlasov (1964)
[2]Vlasov and Kutakova (1960)

6. The intensity of the absorption bands in the IR spectrum (3200 to 3800 cm^{-1}) of the Franqueira emeralds is B > C > A, whereas in the Uralian ones it is B > A > C (Schmetzer *et al.*, 1991). In both cases the IR spectra are typical of medium alkali-bearing emeralds.

7. The morphologies of fluid inclusions in emeralds from each deposit differ in the following respects; the Uralian emeralds contain thin channel-like structures, thin and flat cavities, channel-like growth tubes and healed 'feathers', whereas the Franqueira emeralds contain only negative crystals and healed 'feathers'.

8. The following comparisons of inclusions described by Schmetzer *et al.* (1991) and those in Franqueira emeralds are proposed:

   type 1 of Uralian emeralds could correspond to *type 1* in Franqueira emeralds;

   types 1 and 2 of Uralian emeralds correspond to *type 2* in Franqueira emeralds;

   type 3 of Uralian emeralds have not been observed in the Franqueira emeralds;

   type 4 of Uralian emeralds correspond to some inclusions of *types 1 and 2* in Franqueira emeralds.

Finally, *type 5* of Uralian emeralds may correspond to some inclusions of *types 1, 2 and 3* of Franqueira emeralds.

Conclusions

The beryllium minerals from Franqueira and Tokovaja occur in Palaeozoic rocks trapped between acidic rocks (granites, pegmatites) and ultrabasic rocks (dunites) and gabbros.

The metasomatic rocks of the beryllium-bearing central metasomatic zone generally include phlogopite, which is commonly altered to chlorite, especially in Tokovaja.

The mechanism for the formation of the two deposits involves the emplacement of pegmatite and associated mobile elements (Be, B, P) into the basic rocks, with subsequent metasomatism and transformation of these rocks into phlogopitite, generally near to the pegmatite body. Gem mineral formation resulted when elements such as beryllium from the pegmatite and chromium from the basic rocks were brought together during the process of metasomatism.

In the Tokovaja area the metasomatic zone is more complex than at Franqueira, and it consists of serpentine, talc-serpentine, talc, talc-chlorite, talc-phlogopite, tremolitic rocks, amphibolites, amphibole-gneisses, quartzites and others. According to Fersman (1929) emeralds are found almost exclusively in biotite schists where the darkest and best-grade crystals were found; less commonly, emeralds appear in actinolite-talc or talc-schists, but biotite is present in quantity. Vlasov and Kutakova (1960) stated that the emeralds tend to occur in the phlogopite zone and at its contact with plagioclase bodies. It is rarer for the emeralds to be observed in the phlogopite-talc zones, although the emeralds found in this zone display an intense green colour. In a few places fine emerald crystals occur in actinolite lenses and phlogopite-tremolite zones.

Because both deposits are genetically similar the characteristics of their beryllium minerals are similar. Whereas in Tokovaja the metasomatic zone extends over a distance of more than 20 km, at Franqueira the zone is 3 m thick and crops out for only 15 m, although it may extend underground.

The limited extent of the Franqueira deposit probably explains the scarcity of different mineral species compared to their abundance (up to 80) in the Tokovaja area and this is probably the major difference between the two deposits. However, the chemical and physical properties and even the solid inclusions of the Tokovaja emeralds studied by Schmetzer *et al.* (1991) show differences from those of the emeralds at Franqueira; these differences can be attributed to the different geological sources tapped by the mines in the Tokovaja area.

With regard to the fluid inclusions the main differences are found in their morphology: the Tokovaja emeralds show thin channel-like structures, thin and flat cavities and channel-like growth tubes which are absent in the Franqueira samples; this may reflect different growth mechanisms of the emeralds or simply that the Franqueira deposit is smaller, with a smaller range of features displayed in its emeralds.

Acknowledgements

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Abstracts

Diamonds | Instruments and Techniques | Gems | Jewellery | Synthetics and Simulants

Diamonds

Trace elements in sulfide inclusions from Yakutian diamonds.

G.P. Bulanova, W.L. Griffin, C.G. Ryan, O.Ye. Shestakova and S.J. Barnes. *Contributions to Mineralogy and Petrology*, **124**, 1996, pp 111–25.

Sulphide inclusions in diamonds are possibly the best samples of mantle sulphides, giving clues to the distribution and abundance of chalcophile elements in the deep lithosphere. Trace element abundances from >50 sulphide inclusions in diamonds from Yakutia, Russia, were measured by proton microprobe. Peridotitic diamonds contain sulphide inclusions with Ni content 22–36%; in eclogitic diamonds the Ni content ranges 0–12% in the sulphide inclusions. Some specimens with no silicate or oxide inclusions had 11–18% Ni. Investigations of traces of other elements in sulphide inclusions are also given. M.O'D.

Microdiamond in high-grade metamorphic rocks of the Western Gneiss Region, Norway.

L.F. Dobrzhinetskaya, E.A. Eide, R.B. Larsen, B.A. Sturt, R.G. Trønnes, D.C. Smith, W.R. Taylor and T.V. Posukhova. *Geology*, **23**(7), 1995, pp 597–600.

Microdiamond grains were recovered from high-grade gneiss exposed in the Western Gneiss region, Norway. Raman and IR spectra indicate the presence of substitutional impurities of H and N in the diamonds. Primary fluid inclusions in garnet and quartz in the diamond-bearing rock demonstrate the evolution of metamorphic volatile fluids from reduced N_2–CO_2 composition during the peak phase of metamorphism to N_2–CH_4 ± H_2O bearing composition during the retrograde phase. Compatible geological, petrological and fluid composition data imply a metamorphic origin for the microdiamond. L.C.H.

Linear decorations defining edges of an internal octahedron within a natural diamond: observations and an explanation.

F.C. Frank, J.W. Harris, K. Kaneko and A.R. Lang. *Journal of Crystal Growth*, **143**, 1994, pp 46–57, 7 figs.

A 2.13 ct natural diamond, a slightly flattened octahedron with roughly-pitted surfaces, exhibits an internal framework of dense black 'lines' located a short distance below the present surface. Most of the lines lie closely parallel to <110> and connect up to delineate edges of an octahedron concentric with and slightly smaller than the present body. The lines are agglomerations of thin black discs (thickness too small to be measured in situ by optical microscopy), diameters ranging from 1 to 40 µm (but mainly in the 5 to 20 µm range), equally distributed on diamond {111}, and consistent with graphite. Special optical techniques were developed for examining this specimen and they provided control of relative visibility of internal versus superficial features. Optical micrographs taken in all eight <111> directions are discussed. Synchrotron X-ray topography detected the internal linear framework with good contrast, and helpfully displayed spatial relations between its segments. Findings from cathodoluminescence topography are described. An explanation proposes a sequence of pressure and temperature conditions and of resulting stresses between diamond and encasing solid matrix whereby graphitization was caused to occur locally along edges of an octahedron, which was subsequently enclosed by further diamond growth. Implications for the origin of the edge grooves frequently exhibited by diamond octahedra are suggested. (Author's abstract) F.C.F.

[Morphology of diamond crystals from kimberlites of Belomorye in relation to the history of their formation.] (Russian with English abstract).

V.K. Garanin and T.V. Posukhova. *Proceedings of the Russian Mineralogical Society*, **124**(2), 1995, pp 55–61.

Abstractors

P. Brown	P.Br.	L.C. Hsu	L.C.H.	R.E. Sampson	R.E.S.
F.C. Frank	F.C.F.	M. O'Donoghue	M.O'D.	E. Stern	E.S.
R.K. Harrison	R.K.H.	R.J. Peace	R.J.P.	I. Sunagawa	I.S.
R.A. Howie	R.A.H.	S.A.T. Redfern	S.A.T.R.	I. Vesselinov	I.V.

For further information on many of the topics referred to consult *Mineralogical Abstracts*.

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Two kinds of diamond microcrystals have been found in the Pioneer pipe, the normal octahedra and rhombododecahedra developed with intergrown faces, and skeletal box-zoned sectorial diamonds which grew by a normal (fibrous) mechanism. The conditions of the formation of these diamonds are discussed on the basis of crystallomorphological analysis and compared with experimental results. Numerous photomicrographs are presented. R.A.H.

Diamond and silicon carbide in impact melt rock from the Ries impact crater.

R.M. Hough, I. Gilmour, C.T. Pillinger, J.W. Arden, K.W.R. Gilkes, J. Yuan and H.J. Milledge. *Nature*, **378**(6552), 1995, pp 41–4.

Diamond/lonsdaleite plates and cubic diamond in association with SiC are reported from impact melts in this crater in S. Germany. These phases can be formed by chemical vapour deposition from the ejecta plume of an impact. Cubic diamond and SiC may be formed at any impact site from vaporized C-bearing rocks. Diamond and SiC occurrences may be criteria for identifying impact structures, as are also coesite, stishovite, planar deformation features in quartz and shatter cones. R.K.H.

Diamanten des Espinhaço Gebirges (Minas Gerais, Brasilien): Gemmologische und ökonomische Folgen geologischer Geschichte.

J. Karfunkel, M.L.S.C. Chaves, A. Hoppe and A. Banko. *Gemmologie. Zeitschrift der Deutschen Gemmologischen Gesellschaft*, **45**(3), 1996, pp 113–28, 10 photographs in colour, 4 in black-and-white, 1 map, 2 tables, 2 diagrams, bibl.

Once Minas Gerais was the world's main producer of diamonds, today it only produces 220 000 ct annually, half from the Espinhaço range of mountains. Within the Precambrian São Francisco Craton diamonds reached the upper crust through (kimberlite/lamproite?) pipes. After erosion the diamonds were probably transported to the mid-proterozoic Espinhaço rift lying to the east. The diamond-bearing conglomerates originated in fluvial and alluvial fan systems; today these rocks produce only 2 per cent of diamonds from the Espinhaço range. Uplift during Pliocene times was responsible for the physiographic features of the Serre do Espinhaço; and fanglomeratic deposits were formed. Erosion during the late Pleistocene formed a colluvium layer which for hundreds of years was explored as the main source of diamonds. Today the most important mining areas are the recent river systems. Although low-grade, the deposits are economically important because they comprise over 400 million cubic meters. The percentage of cuttable stones as opposed to industrial stones is in places 98 per cent as compared to 70–90 per cent in Precambrian conglomerates. E.S.

La grande table de diamant de Tavernier.

B. Morel. *Revue de Gemmologie*, **128**, 1996, pp 13–16, illus. in colour.

A diamond known as the Grande Table was described by Tavernier in *Six voyages*, published in 1676. Divided into two portions, one of which at least is now believed to form the Dariya-i-Nur diamond and the other the Nur ul-Ain diamond. M.O'D.

Are euhedral microdiamonds formed during ascent and decompression of kimberlite magma? Implications for use of microdiamonds in diamond grade estimation.

D.R.M. Pattison and A.A. Levinson. *Applied Geochemistry*, **10**(6), 1995, pp 725–38.

The relationship between euhedral microdiamonds and macrodiamonds is problematic. It is paradoxical that the former, by virtue of their smallness, should be more susceptible to resorption than the latter, whereas the opposite is commonly observed. Difficulties with published mechanisms for euhedral microdiamond formation and eruption are discussed. An alternative hypothesis is proposed, showing there is a significant decrease in the C-bearing volatile content of kimberlite magma as *P* decreases. During magma ascent this may result in a *P*-related transition from fluid-undersaturated conditions at which diamond is unstable to conditions at which diamond becomes stable/metastable as the magma reaches fluid saturation. In this scenario macro-diamond xenocrysts (of an early generation), entrained at asthenospheric or deep lithospheric depths, may partially or totally dissolve in the undersaturated magma upon disaggregation of their host rocks; upon ascent to shallow depths, and in appropriate oxidation conditions, the lowered capacity of the magma to dissolve C-bearing volatiles may result in euhedral microdiamond precipitation, probably just before final eruption. It is therefore suggested that the use of microdiamond abundances from small samples as a guide to economic microdiamond grade is problematic as an exploration strategy. R.E.S.

Petrology and diamonds.

B.H. Scott Smith. *Exploration & Mining Geology*, 4(2), 1995, pp 127–40.

Petrology and the necessary genetic terminology are essential if the origin and relationships of different rocks are to be understood, and have an important role in modern diamond exploration programmes. Groups 1 and 2 kimberlites and lamproites, the only known economic primary sources of diamond, have been shown to be petrogenetically distinct rock types. Although their magmas act only as transporting agents for diamond, there are important implications for the differences between these and other rock types. The uses of petrology in exploration are illustrated using examples from known kimberlites in Canada; lamproites and group 2 kimberlites are rare and have yet to be found in Canada. R.E.S.

Geology of the Sturgeon Lake 02 kimberlite block, Saskatchewan.

B.H. Scott Smith. *Exploration & Mining Geology*, 4(2), 1995, pp 141–51.

This diamondiferous body is the first documented glacially transported block of kimberlite. It is 50–240 m in size and up to 21 m thick. During glacial transport, it was juxtaposed between shale blocks, probably of Cretaceous age. It consists of a thinly laminated to thinly bedded

sequence of primary pyroclastic airfall coarse ash and lapilli tuffs which have probably undergone little or no reworking. More than one eruptive phase was involved in its formation. The kimberlite contains vesicular lapilli and may have formed by a style of subaerial eruption different from many other kimberlites. R.E.S

Gems

The genesis of emeralds and their host rocks from Swat, northwestern Pakistan: a stable-isotope investigation.

M. Arif, A.E. Fallick and C.J. Moon. *Mineralium Deposita, 31*, 1996, pp 255–68.

Emerald deposits in Swat, NE Pakistan, occur in talc-magnesite and quartz-magnetite assemblages which are investigated using stable isotope studies. Notes on the general geology of the area are given and extensive notes on the occurrence and distribution of emerald are provided. It is concluded that emerald formation in magnesites occurred at high temperatures and that emerald, quartz, fuchsite and tourmaline, compared to pegmatitic and other magmatic minerals from other places, show a strong enrichment in ^{18}O and are genetically related. M.O'D.

Gemmologie aktuell.

H. Bank, U. Henn and C.C. Milisenda. *Gemmologie. Zeitschrift der Deutschen Gemmologischen Gesellschaft*, **45**(3), 1996, pp 97–101, 6 photos in colour.

Beautiful pegmatitic gem crystals from Gilgit in Pakistan are being offered on the market as well as gem quality chrome diopside from Pakistan, exact occurrence unknown; these stones have a distinctive pleochroism, green, brownish-green and yellowish-green. Some red-purple almandine garnets have been found near Clarkston in Idaho, USA, RI 1.787–1.803, SG 4.10–4.15. Some bi-coloured quartzes from Bolivia have come on the market; these resemble the amethyst/rock crystal and smoky quartz/citrines varieties from Brazil. From Brazil also some multicolour fluorites with distinctly yellow, brown and green colour zones. From Mali came some yellowish-green to green grossular-andradite garnets. The occurrences near the villages of Kandia, Sangafe and Sibinndi produce non-transparent and therefore non-gem epidote, but some grossular garnets were found with long prismatic epidote crystals. Mali also produced some brownish almandine garnets and near Kayes some euhedral rock crystals with crystal faces on both sides with a lustre not dissimilar to that of 'Herkimer diamonds'. E.S.

Der Korallenachat von Halsbach bei Freiberg/Sachsen.

W. Beck. *Lapis*, **21**(6), 1996, pp 44–6, 1 map, illus. in colour.

Pink to brown banded agate is reported from the area of Halsbach, Freiberg, Saxony, Germany. The coral-like banded material has been fashioned. M.O'D.

Mineralien aus dem Bergell, den Màsino-, Codera- und Splügentälern.

F. Bedogné and E. Sciesa. *Lapis*, **21**(10), 1996, pp 15–26, 3 maps, illus. in colour.

Fine crystals of garnet and aquamarine are included in an extensive suite of minerals found in areas on the Swiss-Italian border. Eight distinctive mineralized regions are identified and their mineral species described. M.O'D.

Gems around Australia – Part 12.

H. Bracewell. *Australian Gemmologist*, **19**(6), 1996, pp 252–54, 7 illus. in colour.

In this continuing personal account, Yinnietharra and Mt. Phillip Stations in a remote part of Western Australia were visited. Yinnietharra provided some dravite tourmaline. Mining of the original deposit has stopped owing to the difficulty of extracting the tourmaline when the deposit ran in a gully between quartz and granite outcrops. Further north, the Mt. Phillip Station produced beautiful dark purple gem quality amethyst. R.J.P.

Charakterisierung von Saphiren mit Hilfe von Fluessigkeitseinschluessen.

B. Bruder. *Gemmologie. Zeitschrift der Deutschen Gemmologischen Gesellschaft*, **45**(2), 1996, pp 47–54, 6 photos, 1 graph, 2 diagrams, 1 table, bibl.

Fluid inclusions in sapphires from Burma, Kashmir, Sri Lanka, Madagascar and Rwanda have been studied with the help of microthermometry and the Raman-laser spectroscope. The fluid consists of pure CO_2; daughter crystals of diaspore suggest the former presence of water in the fluid phase. Four different types of inclusions were found on the basis of their morphology and density. Type one consisted of primary, euhedral, isometric negative crystals with high-density fluid; type two were secondary, short prismatic negative crystals in well preserved healed fissures, some also with high-density fluid. Types three and four are secondary inclusions in poorly healed cracks. Unequal densities of the primary fluid inclusions allow sapphires from Sri Lanka and Kashmir to be separated from those from the other studied locations. E.S.

Mon aventure vietnamienne.

M. Bruley. *Revue de Gemmologie*, **127**, 1996, pp 21–2.

The writer's journey to Vietnam in search of gemstones is further described and includes reports of dealers' methods. More is to come. M.O'D.

What's new in minerals?

M.P. Cooper *et al. Mineralogical Record*, **27**, 1996, pp 207–23, illus. in colour.

Among minerals and gemstones seen at a number of shows worldwide are transparent bright-yellow anglesite from Touissit, Morocco; blue-green elbaite crystals with rose-pink tips from Pederneira, Cruzeiro, Minas Gerais, Brazil; yellow transparent brazilianite from Linopolis, Minas Gerais; orange-yellow topaz from Zacatecas,

Mexico; colourless to pale blue topaz from the Hawthorne area, Mineral County, Nevada; green diopside from the Merelani Hills near Arusha, Tanzania; blue sapphire bipyramids from Galbkka, Vallivaya, Uva Province, Sri Lanka; ruby crystals of fine quality from the area of Jegdalek, Kabul Province, Afghanistan. M.O'D.

Estudio de los materials gemológicos del Tesoro de Guarrazar.

J.S. Cozar and C. Sapalski. *Boletin del Instituto Gemológico Espanol*, **37**, 1996, pp 5–18, illus. in colour.

The Guarrazar Treasure dates from the time of the Visigoths and is now housed in the Museo Arqueológico Nacional and in the Real Armería del Palacio Real. Gemstones in the artefacts are described and photographed. M.O'D.

Zoning of the Kremikovtsi marble onyx.

Z. Damyanov. *Comptes Rendus de l'Academie Bulgare des Sciences*, **48**(3), 1995, pp 33–6.

Calcite marble onyx occurs in the weathering crust of the Kremikovtski iron deposit near Sofia, Bulgaria. Four main factors have been responsible for its colour banding: (1) pigmentation by iron and manganese oxide-hydroxide particles, (2) refractivity variation due to rhythmic increase of Mg in calcite from nil up to 5 wt.% $MgCO_3$ in the individual bands, (3) porosity differences causing different refraction of the optical spectrum resulting in a variety of colour shades, and (4) textural alternation of spherulitic, grained and parallel rod-like aggregates which also affects the colour shades. Banded formation is explained by rhythmic auto-oscillations during calcite crystallization coupled with the tectonic-hydrogeological evolution of the area. I.V.

The Picos de Europa lead-zinc deposits, Spain.

B. Sainz de Baranda and G. Garcia Garcia. *Mineralogical Record*, **27**, 1996, pp 177–88.

The Picos de Europa range of mountains in northern Spain contain a number of lead-zinc deposits. Fine gem-quality specimens of sphalerite have been produced over the years, especially from the Aliva mines. The deposits are no longer worked, making the future supply of specimens uncertain. M.O'D.

Les camées double face sous la renaissance.

M. Duchamp. *Revue de Gemmologie*, **127** 1996, pp 13–16.

Short note on double-sided cameos with particular reference to six notable examples. M.O'D.

The structure of metamict zircon: a temperature-dependent EXAFS study.

F. Farges. *Physics & Chemistry of Minerals*, **20**(7), 1994, pp 504–14.

Two stages of thermal annealing within aperiodic zircon are identified between 293 and 1700 K. The first stage (≤600°C) shows a decrease of the *c*-cell parameter from 6.674 (at 300°C) to 6.610 (at 600°C) ± 0.005 Å. The average local environment around Zr (presence of ^{vii}Zr and *d*(Zr–Zr) ~ 3.3–3.6 Å) shows a weak, but significant increase of the Zr–Zr correlations located at 3.3–3.4 Å, undetectable by XRD. At $T \leq 700$°C (stage 2), the XRD-Bragg component arising from crystalline zircon increases in magnitude, whereas Zr–*K* EXAFS analysis indicates a progressive ^{vii}Zr → ^{viii}Zr transition, associated with a recovery of the crystalline zircon medium-range environment. For both techniques, the zircon structure is fully recovered at annealing $T \leq 900$°C. S.A.T.R.

Gem Trade Lab notes.

C.W. Fryer. *Gems & Gemology*, **32**(1), 1996, pp 44–51, 20 illus. in colour.

A grossular-garnet-bearing rock resembled impregnated jadeite. Magnification showed the grossular standing out against the softer undercut white areas. The latter did not react to a hot point but X-ray diffraction analysis showed it to be a chlorite mineral. Bright brownish-orange metallic flakes present in mottled green and white beads of jadeite were shown to be elemental copper. Several abalone pearls have been encountered shaped like sharks' teeth. An X-radiograph revealed a large hollow centre; several new abalone pearl culturing farms are reported. A string of pearls had been partially coated to fill drill holes which did not pass near the centre (presumably for attachment to fabric). The pearls had then been re-drilled through the centre.

A transparent near-colourless emerald-cut stone had properties not significantly different from grossular garnet. EDXRF spectrometry and X-ray diffraction showed it to be periclase MgO. R.J.P.

Pietre dure.

N.N. Germanova. *World of Stones*, **9**, 1996, pp 37–40.

The use of pietre dure in ornament is described with particular reference to Russian craftsmen and artefacts.

M.O'D.

Coal as a gemmological object.

S.V. Glushnev. *World of Stones*, **9**, 1996, pp 50–3.

Short account of the ornamental use of coal varieties with different names explained and a list of eleven references in Russian. M.O'D.

Corundum from basaltic terrains: a mineral inclusion approach to the enigma.

J. Guo, S.Y. O'Reilly and W.L. Griffin. *Contributions to Mineralogy & Petrology*, **122**(4), 1996, pp 368–86.

This paper investigates the origin of corundum (Al_2O_3) megacrysts that occur in many basaltic terrains, and which are considered to be eroded from basaltic rocks. Geochemical data for >80 primary mineral inclusions within corundum megacrysts are used to gain a new insight into the petrogenetic history of the corundum megacrysts from a wide spectrum of minerals present as

inclusions; the most common are Nb-Ta oxides, alkali feldspar, low-Ca plagioclase, and zircon. Rare inclusions include Fe,Cu-sulphide (low in Ni), Co-rich spinel, Th,Ce-rich phosphate and uraninite. The similar chemistry of some inclusion minerals from corundum occurring in widely separated areas suggests that the corundum megacrysts in basalts have a similar petrogenesis. Geochemical characteristics of the inclusions indicate a bimodal grouping, which is best explained by a mixing-hybridization process. The corundum megacrysts are not cogenetic with their basaltic hosts but are crustal fragments accidentally incorporated into the erupting magma. Interactions between a silicic component and an intruding carbonatitic or similar Si-poor magma were responsible for Al-oversaturation, resulting in locally distributed lenses of corundum-bearing rock of mixed paragenesis. Feldspar exsolution textures provide strong evidence that this hybridization occurred at mid-crustal levels. Subsequent volcanic eruptions brought the corundum-bearing rocks (later disintegrated in the magma) up to the Earth's surface. P.Br.

Über die Behandlung von Opalen.

U. Henn. *Gemmologie. Zeitschrift der Deutschen Gemmologischen Gesellschaft.* **45**(3), 1996, pp 129–33, 6 photos in colour, bibl.

Opals can be enhanced by using three basic treatment processes: (1) restoration, (2) artificial coloration and (3) impregnation. Lost water can be restored by water supply in vacuum. The porosity of some opals allows dyeing with colouring substances, especially matrix opals (in particular from Andamooka), hydrophane opals from Mexico and Brazil as well as oolitic opals, opalite sandstones and conglomerates. The most frequently used process is the sugar and acid method. Cracked opals can be treated with oils and resins to improve translucency and play of colour. According to CIBJO any dyed stones or stones treated with resin must be specifically declared. E.S.

Über 'Ammolith' einen irisierenden fossilen Schmuckstein aus Kanada.

U. Henn. *Gemmologie. Zeitschrift der Deutschen Gemmologischen Gesellschaft.* **43**(3), 1996, pp 138–40, 2 photos in colour, 1 table, bibl.

Ammolite is a fossilized ornamental material from Alberta, Canada, and is composed of thin iridescent shell fragments in a shale matrix. The material is also called 'korite' and shows iridescence of red, orange, golden yellow, green and deep blue colours. The cut ammolite is often sealed with resin; also doublets and triplets are known: in doublets the material is mounted on dark slate, in triplets this is covered with rock crystal or colourless synthetic spinel. E.S.

Transluzente Nepheline und Nephelin-Katzenaugen aus Norwegen.

U. Henn and H. Bank. *Gemmologie. Zeitschrift der Deutschen Gemmologischen Gesellschaft,* **43**(3), 1996, pp 134-5, bibl.

Nepheline is a sodium-potassium-aluminium silicate crystallizing in the hexagonal system, hardness 5½ to 6, colour varies from green and bluish-green to brown and dark red. It is found in Norway, Russia, Canada and the USA. In its massive form it is used as ornament and known commercially as elaelite. Gem quality translucent nepheline and nepheline cat's-eyes from south Norway have an RI of 1.531–1.539, DR 0.003–0.004; SG 2.58–2.60. The reddish-brown to bluish-green colour is caused by ferric iron. The cat's-eye effect is due to tiny needle-like inclusions parallel to the c-axis. E.S.

Edelsteine der Amphibol-Gruppe.

U. Henn and H. Bank. *Gemmologie. Zeitschrift der Deutschen Gemmologischen Gesellschaft.* **43**(3), 1996, pp 135–8, 1 table, bibl.

The authors survey gem materials found in the amphibole group, the most important being nephrite, but also the iridescent nuumite, tremolite and members of the tremolite-actinolite-ferroactinolite series, such as smaragdite and hornblende. E.S.

Agate Creek agate.

P. Howard. *Australian Gemmologist.* **19**(5), 1996, pp 215–20, 2 illus. in black-and-white, 16 in colour.

Agate Creek in North Queensland is noted for its attractively patterned agates which occur in and are weathered from amygdaloidal basalt of Carboniferous age. The occurrence of the agate deposit was first reported in 1900 and was realised to be large. Attempts to use heavy machinery for extraction after World War II caused animosity between the miners and rockhounds which resulted in legislation prohibiting the use of machinery. Excellent coloured photographs indicate the wide range and types of agate found. Red agates appear to predominate; the colour is due to iron but when other transition elements are also present a rainbow of colours can be exhibited. A somewhat chatoyant gold-flecked variety is the prized variety found in this location. Detailed maps are given. R.J.P.

Les sapphires de Montana [part 1].

R.W. Hughes and O. Galibert. *Revue de Gemmologie,* **128**, 1996, pp 4–6, illus. in colour.

Gives dates of significant events in the life of the Montana sapphire mines at Dry Cottonwood Creek, Yogo Gulch and Rock Creek. M.O'D.

Gem aragonite from the Czech Republic.

J. Hyrsl. *Canadian Gemmologist,* **17**, 1996, pp 76–7.

Description of gem-quality colourless, yellow, multi-coloured and green aragonite from Horenec near Bilina, northern Bohemia, Czech Republic. Aragonite occurs in monomineralic veins cutting hydrothermally altered Tertiary basalts and production dates back to the early nineteenth century. M.O'D.

Kazakhstan landscape chalcedony.

F.M. Ibragimov. *World of Stones,* **9**, 1996, p 24.

Examples of landscape agate found in Kazakhstan are briefly described. M.O'D.

Gem news.

M.L. Johnson and J.I. Koivula. *Gems & Gemology*, **32**(1), 1996, pp 52–62, 17 illus. in colour.

Colour-change garnet, virtually indistinguishable in colour from fine alexandrite, emphasized the need for thorough testing. Fine crystals and cut stones of heliodor from Tajikistan are described. A new material 'leopard opal' from Mexico is a black and white opal-bearing rock with good colour distribution. Namibian spessartine garnets are found in matrix with high manganese concentration. A large (36.05 ct) taaffeite crystal from Sri Lanka was shown at Tucson. A new source at Tunduru, Tanzania, appears to have large reserves of gem materials. An additional report from the 25th International Gemmological Conference included summaries of cathodoluminescence in diamonds and the extraction of Montana sapphires involving methylene iodide. R.J.P.

An examination of colour-change sapphires from Tanzania.

R.C. Kammerling, M.L. Johnson and Y. Liu. *Australian Gemmologist*, **19**(6), 1996, pp 255–8, 6 illus. in colour.

A new source of sapphires in the far south-west of Tanzania occurs in a wide range of colours including light pink, purple, dark red, blue and dark green. A small percentage show an alexandrite effect from a greyish-bluish-green in daylight conditions to a reddish-brown under incandescent light, reminiscent of the effect shown by vanadium-doped synthetic sapphires. Pleochroism was complicated by strong colour zoning. Refractive indices, double refraction and optic character were normal. All the stones were inert to the long- and short-wave ultraviolet radiation and showed red through the Chelsea filter. Absorption spectra combined features typical of ruby and pink sapphire along with iron-related lines at about 450, 460 and 470 nm. Chemical analysis using EDXRF detected traces of iron, chromium, titanium and vanadium although the colour-change could not be attributed to any one single element.

Colorimetric analysis of the colour-change showed that nine of the 11 stones had a type 1 colour change. In this class the hues in CIELAB colour space showed a hue angle change $\Delta H1$ from 26.9 to 115.8° between CIE illuminants D65 and A and therefore qualify as a true alexandrite effect. R.J.P.

Gem news.

R.C. Kammerling, J.I. Koivula and M.L. Johnson. *Gems & Gemology*, **31**(4), 1995, pp 274–88, 20 illus. in colour.

Papers given at the 25th International Gemmological Conference held in Thailand included the following topics.

Some Botswana diamonds contained hydrous fluid probably derived from a potassium-rich parent melt.

Unusual inclusions included a small insect trapped in the flower stamen of an extinct tree *Hymenaea protera* in amber from the Dominican Republic; blue-green inclusions of sapphirine in pebbles of iolite; tiny blue spinel octahedra in a swirled yellow background in a pale yellow hessonite from a new locality in Sri Lanka.

Green beryl and emerald from Central Nigeria were described.

A review of gem localities in China included diamonds, rubies, sapphires, emeralds and a long list of other gem species.

New gem deposits reported include a corundum deposit in Shan State, Myanmar, with mainly pink sapphires and a new find of emeralds in Tamil Nadu State, India.

A review of tektites with an origin from ejected residue of terrestrial rocks blasted by meteoric impact was given. Australian tektites are the youngest at 0.7 million years with North American tektites the oldest at 34.2 million years.

The polishing of the jadeite using bamboo on a lathe shaft and a jade market in Mandalay were described.

A report on pearls from freshwater oysters from Lac St. Jean, Quebec, showed that aragonite occurred as long slender crystals radiating from a point, although in the thin outer layer it was in the form of tabular crystals.

Rubies from the Barrington volcanic field, East Australia, are unusual as the parent rock contains ruby, sapphire, sapphirine and spinel.

In Laos gem-bearing lateritic soil was removed from vertical shafts and washed to reveal sapphires which ranged from a light to a dark blue and seemed of good quality.

Sapphires from a new source in southern Madagascar showed colour zoning and/or turbid areas and probably require heat treatment to become marketable.

Tanzanites and other zoisites from Merelani, Tanzania, were extensively examined. Brown and blue samples contained a V_2O_3/Cr_2O_3 ratio greater than two; this ratio was less than two in green zoisites. Light-blue crystals with elevated Ti content showed only a weak response to heat treatment despite their vanadium content. Violet zoisites owe their colour to V^{3+} and the presence of a little Cr_2O_3 results in a purer blue. The transition brown to blue is caused by the destruction of the 450 nm absorption band on heat treatment. R.J.P.

Dyed opalised sandstone and conglomerate – a new product from Andamooka.

J.L. Keeling and L.J. Townsend. *Australian Gemmologist*, **19**(5), 1996, pp 226–31, 4 illus. in black-and-white, 8 in colour.

This newly marketed product is a naturally occurring slightly porous silicified sandstone or sandy conglomerate in which the clay matrix and some quartz grains have been partially replaced by precious opal cement, and the whole is treated to darken the body colour and enhance the play of colours.

A characteristic of opal-cemented sandstone is that when viewed at right angles to bedding, opal colours often show as columns similar to those seen in some Gilson synthetic opal with stacks up to 10 mm high.

In the original treatment involving sugar solution followed by concentrated sulphuric acid, removal from the

sandstone of the last traces of acid was very difficult. Although the precise details are secret, the new treatment involves organic impregnation followed by conversion to carbon by heating under non-oxidising conditions to temperatures above 500°C; acid treatment hazards are avoided.

Opal-cemented sandstone and conglomerate are readily identified from other forms of opal by the presence of abundant sand-sized quartz grains (clasts). As the product does not readily take a polish it will usually be encountered in composite form as a quartz or glass-topped doublet or coated with clear polymer. R.J.P.

Southern African gem minerals: sugilite.

A. Kleyenstüber. *South African Gemmologist*, **10**(1), 1996, pp 23–30, illus. in colour.

Geological and mineralogical description of purple manganoan sugilite occurring in the Kalahari manganese field of South Africa. M.O'D.

Copper inclusions in gemstones.

J.I. Koivula. *South African Gemmologist*, **10**(1), 1996, pp 11–17, illus. in colour.

Summary of examples of native copper inclusions in gemstones. Copper is recorded as an inclusion in 13 different mineral species, some of gem significance. M.O'D.

Exkursion zu Mineralvorkommen des Urals.

B. Kühn. *Aufschluss*, **45**, 1996, pp 129–44, illus. in colour.

Details of an expedition through the Ural Mountains of Russia, including details of geology and mineralization. Several of the sites described contain gem-quality minerals: these include the Mursinka pegmatite producing a number of major species, the Sedelnikowo area, producing rhodonite, the Lipowskoje area with ruby deposits, the Tokowaja district with major emerald occurrences and including the Malyschewo and Krasnoarmeiski beryl finds. M.O'D.

Karneol und Chalcedon aus Thüringen.

C. Linde. *Lapis*, **21**(10), 1996, pp 38–41, 1 map, illus. in colour.

Fine ornamental chalcedony varieties, including carnelian and agate are described from the vicinity of Schöngleina, Thuringia, Germany. M.O'D.

Die Entdeckung der 'goldenen Calcite' in der Malmberget-Grube, Lappland, Schweden.

P. Lyckberg. *Mineralien Welt*, 7(3), 1996, pp 12–15.

Golden calcite with clear crystals attaining 6 cm in length is reported from the Malmberget mine, Lapland, Sweden. A report on the geology of the occurrence is given. M.O'D.

Luminescence of minerals and its application in geology.

V.V. Moroshkin. *World of Stones*, **9**, 1996, pp 4–7.

Examples of luminescence as a geological test are given: specimens illustrated include diamond crystals from China and Russia. M.O'D.

Blauquarze vom Calanda, Graubünden, Schweiz.

D. Mühlschlegel. *Lapis*, **21**(6), 1996, pp 42–3.

The blue colour in some quartz crystals reported from Calanda, Canton Grisons, Switzerland, arises from scattering by minute inclusions: facetable crystals have been found.

M.O'D.

Warrierite: a new black tourmaline from Western Australia.

J.G. Oliver and M. Thompson. *Australian Gemmologist*, **19**(5), 1996, pp 210–14, 4 illus. in black-and-white, 6 in colour.

A fine-grained massive black tourmaline marketed as warrierite formed within a major fault zone by metasomatic replacement of Archean volcanic rocks and was subsequently brecciated and intruded by white quartz veins. Warrierite contains both ferrous iron and magnesium and lies between dravite and schorl in the isomorphous tourmaline series. Due to its interlocking microscopic structure it has a toughness only slightly inferior to that of nephrite. Having a hardness of 7 to 7.5 on the Mohs' scale both the pure tourmaline, warrierite, and the mottled tourmaline-quartz rock are capable of displaying a superb polish. R.J.P.

Nouveaux gisements d'émeraude de l'inde méridionale.

J. Panjikar, K.T. Ramchandran and K. Balu. *Revue de Gemmologie*, **128**, 1996, pp 7–10.

Deposits of emerald are reported from sites near the villages of Idappadi and Konganapuram in the Sankari Taluka, Salem district, State of Tamil Nadu, India: geographical co-ordinates are given and specimens described. Mica is the most prominent mineral inclusion. M.O'D.

Neue Mineralienfunde aus den Pegmatiten der Insel Elba.

F. Pezzotta and P. Orlandi. *Lapis*, **21**(10), 1996, pp 27–35, 1 map.

A survey of the pegmatites of Elba has produced gem-quality and near-gem-quality crystals of tourmaline, morganite and spessartine. They are described with other minerals found on the island in recent years. M.O'D.

Mangatobangy. Amethyst-Zepter aus Madagaskar.

F. Pezzotta. *Lapis*, **21**(9), 1996, pp 32–5.

Fine large crystals of amethyst with sceptre shape are mined in the neighbourhood of Mangatobangy in the central mountainous region of Madagascar. Crystals up to 40 cm in length and weighing at least 20 kg are reported. M.O'D.

Russian demantoid, Czar of the garnet family.

W.R. Phillips and A. Talantsev. *Gems & Gemology*, **32**(2), 1996, pp 100–11, 2 tables, 15 illus. in colour, 15 in black-and-white.

Although demantoid was discovered in Russia in the mid-nineteenth century, mining was halted at the beginning of the Revolution. Today independent miners are recovering

notable quantities of stream-worn pebbles near Ekaterinburg in the Urals. Recovery of demantoid garnet has been erratic and it can be a by-product of platinum mining. Demantoid garnet is $Ca_3Fe_2[SiO_4]_3$ with minor chromium contributing the valued green colour. The colour varies from yellowish- or brownish-green to golden green and the rarest 'emerald' green with most stones being less than 1 ct. The unique 'horse-tail' inclusion generally referred to as hair-like byssolite has recently been identified as serpentine (chrysolite) usually diverging from a tiny source such as a small opaque crystal of a spinel-group mineral, probably chromite or magnesiochromite. R.J.P.

Notes sur le gisement d'émeraude de Mananjary (Madagascar).

N. Ranorosoa. *Revue de Gemmologie*, **127**, 1996, pp 4–5, 1 map.

Emerald with properties in the normal range and containing inclusions of plagioclase, quartz, pyrite, goethite/hematite, phlogopite in hexagonal or pseudo-hexagonal plates, allanite [undifferentiated] and baryte, is reported from the area of Mananjary in east Madagascar. Crystals also contain a variety of fluid and two- and three-phase inclusions: they are found in schists encased within gneiss cut by quartzites or pegmatites. M.O'D.

Sapphires from the Andranondambo region, Madagascar.

D. Schwarz, E.J. Petsch and E. Kanis. *Gems & Gemology*, **32**(2), 1996, pp 80–99, 26 illus. in colour, 2 tables.

Over the last three years, large amounts of gem-quality sapphires have come from this region of southern Madagascar. Found in metamorphic skarn-type deposits they show a broad range of gemmological and chemical properties similar to those of sapphires from Sri Lanka, Burma and even Kashmir. Most of the Andranondambo sapphires are heat-treated in Bangkok. Separation of the heat-treated and non-heat-treated sapphires is easy when so-called HT-bands (Heat Treatment) are present. These are greyish-white (rarely greyish-brown) fine- medium- or coarse-grained bands. Also after heat-treatment mineral inclusions become turbid, translucent or even opaque and stress fissures are formed round crystal inclusions and negative crystals often showing a mirror or frosted effect. In most non-heat-treated stones the most pronounced spectral absorption minimum is at around 490 nm (e-spectrum) but spectra may be complex and detailed work is necessary.

Separation of Andranondambo sapphires from synthetics from various manufacturers depends upon the chemistry (synthetics have little or no gallium) and on the internal features. R.J.P.

Agates of Armenia: the past and the present.

V.B. Seiranyan. *World of Stones*, **9**, 1996, pp 19–23.

A map gives the main locations for agates in Armenia and the geology of different deposits is discussed. A list of six references appears in the separate Russian version of the journal. M.O'D.

Farbiger Bernstein-die Minen der Dominikanischen Republik.

G. Steiner. *Lapis*, **21**(10), 1996, pp 43–6, 1 map.

General account of amber deposits and working in the Dominican Republic. M.O'D.

'Oregon sunstone' aus der Ponderosa mine-ein Labradorit mit vielen Gesichtern.

A. Stucki. *Mineralien Welt*, 7(5), 1996, pp 16–20.

Description of the local geology of the Ponderosa mine, Oregon, USA, and of the occurrence of deep red to orange transparent labradorite which has been faceted into gemstones. M.O'D.

Crystal growth in the mineral kingdom.

I. Sunagawa. *Journal of Crystal Growth*, **128**, 1993, pp 397–402, 2 figs.

The methodologies used to investigate the kinetic problems of mineral formation in Earth and Planetary solid materials are briefly summarized. These include deductive analysis of growth and post-growth histories of mineral crystals based on their characterization, dynamic crystallization experiments and in-situ observation methods at high temperatures. (Author's Abstract) I.S.

Comment s'est développé la taille brillant actuelle?

H. Tillander. *Revue de Gemmologie*, **127**, 1996, pp 17–20.

Notes with diagrams of the development of the brilliant cut. M.O'D.

The problem of jadeite jade in China.

C. Wang. *Friends of Jade Newsletter*, April/May 1996.

A brief summary of the occurrence of jade minerals in China with particular reference to the term *fei-ts'ui*, used with various meanings as far back as the Zhou dynasty. M.O'D.

Johann Georg Lenz and his Mustertafeln.

W.E. Wilson. *Mineralogical Record*, **27**, 1996, pp 191–5, illus. in colour.

The *Mustertafeln* was published in 1794 for only 26 patrons so copies are extremely scarce. The book contains 344 hand-painted examples of crystal specimens including many of quartz and is the first general illustrated field guide to minerals. M.O'D.

The status of pearl culture in Indonesia.

T. Winanto and K. Mintardjo. *Australian Gemmologist*, **19**(6), 1996, pp 245–9, 2 tables.

Indonesia is an emerging producer of bead nucleated saltwater cultured pearls commonly referred to as South Sea pearls. Marine pearl oysters are widely distributed in Indonesian waters but more abundant in the eastern areas. The potential area for development is approximately 5600 hectares. *Pinctada maxima* which produces the larger pearls is the most common oyster used.

The pearl culture techniques are described in detail producing both round pearls and blister pearls, the latter in oysters which are not suitable for bead insertion. Constraints in future expansion include limited seed supply and the necessity to improve the training of the people in the industry.

R.J.P.

The behavior of chromium ions in forsterite.

Y. Yamaguchi, K. Yamagishi and Y. Nobe. *Journal of Crystal Growth*, **128**, 1993, pp 996–1000, 4 figs, 3 tables.

Single crystals of Cr-doped forsterite were grown by the Czochralski and floating zone methods under varying growth atmospheres and Cr concentrations in the melt. Samples were also annealed under different oxygen partial pressures. The Cr absorption intensity was gradually saturated by increasing Cr concentrations or by changing oxygen partial pressure during growth. The results indicated that the tetravalent Cr ion is able to migrate between the Si and Mg sites in the forsterite structure. I.S.

[Composition, crystallostructural peculiarities and genesis of gem cordierite from the Eastern Pamirs.] (Russian with English abstract).

A.A. Zolotarev and M.S. Dufour. *Proceedings of the Russian Mineralogical Society*, **124**(2), 1995, pp 76–87.

Gem-grade cordierite occurs in the Sasyksky area of the Muzkolsky metamorphic complex. It is distinguished by a high degree of ordering (Δ0.233–0.247°) and low ferruginosity (8.5–16.0%), and was formed at the retrograde stage of amphibolite-facies metamorphism at 700–600°C and 340–470 MPa fluid *P*, with an intermediate fluid composition (X_{H_2O} 0.45–0.67). Chemical analyses and refractive indices are tabulated for eight cordierites, together with EPMA results and cell parameters for six cordierites. Calculated H_2O contents, X-ray diffraction patterns and IR spectra are also presented. R.A.H.

Antwerp gemmological update.

Antwerp Facets, **August 1996**, 1996, pp 43–63.

Brief coverage of risks and legal aspects of radioactive diamonds, of the first HRD-GGL Pearl Grading and Identification Seminar held in November 1995, of the present position of gemstones from Vietnam, and of diamond synthesis and identification. M.O'D.

Instruments and Techniques

A microscopic model for surface-induced diamond-to-graphite transitions.

A. de Vita, G. Galli, A. Canning and R. Car. *Nature*, **379**(6565), 1996, pp 523–6.

Results are presented of first-principles molecular dynamics simulations of a surface-induced diamond-to-graphite transition as a function of *T*, providing a microscopic model for graphitization processes. A well-defined diamond/graphite interface forms during the transition; the electronic properties of the atoms at this interface indicate that they are highly chemically active sites. A prediction of preferential hydrogenation sites at the coherent insertion of the (stable) graphitic phase into the (unstable) diamond phase substantiates the role of hydrogen in inhibiting graphite growth. R.K.H.

Kathodolumineszenz von Quarz-Grundlagen und Anwendung in den Geowissenschaften.

J. Götze. *Aufschluss*, **47**, 1996, pp 215–23.

Description of the effects shown under cathode rays by silica glass, quartz and chalcedony, with extensive bibliography. M.O'D.

Ein Renishaw Raman Mikroskop im gemmologischen Labor: Erste Erfahrungen bei der Anwendung.

H.A. Hänni, L. Kiefert, J.P. Chalain and I.C. Wilcock. *Gemmologie. Zeitschrift der Deutschen Gemmologischen Gesellschaft*, **45**(2), 1996, pp 55–70, 8 illus., 1 table, 8 graphs, bibl.

Various applications of the Raman spectroscope in a gemmological laboratory are shown and examples given. The major use of this system is the destruction-free identification of inclusions in gemstones and determination of organic fracture fillings in emeralds. Also quick and precise identification of a series of gemstones or of gems in jewellery as well as destruction-free analysis of archaeological samples are possible. Due to the high resolution of the instrument, several phases within a gemstone can be identified. E.S.

The Bailey light source.

T. Linton, R. Beattie and G. Brown. *Australian Gemmologist*, **19**(6), 1996, pp 250–1, 1 illus. in black-and-white, 1 table.

This light emitting diode (LED) light source uses Stanley high brightness 5000 series LEDs and produces a cool yellow light of constant colour and intensity. Power is provided by step-down transformer or a 9v dry cell battery which has a working life of about four hours.

The refractive indices determined using these LEDs and a sodium vapour lamp showed no significant differences. However, the luminance of the six LEDs was only 18 per cent of that of the sodium lamp at an equivalent distance. The six LEDs are mounted vertically in pairs in a plastic case giving a rectangular beam of light.

Brighter scale images are produced by light which is angled upwards into the refractometer portal. The Bailey light source which has essentially horizontal directed light should be angled for this better illumination. R.J.P.

Scotch tape and a magic box.

J. Nelson. *Diamond International*, November/December 1995, 1995, pp 47–54.

So far the easiest way to detect fracture-filled diamonds has been observation of the colour flashes produced by the filler. The flashes could be eliminated, however, by ensuring that the RI dispersion curve of the stone does not intersect the dispersion curve of the glass infill in the visible region. Producers could achieve the absence of flashes while allowing for a slightly enhanced stone/filler interface,

which would appear when they raised the intersection point from approximately 560 nm to 800 nm. While fairly elaborate LWUV methods might serve (and have been used) to observe different fluorescence strengths in Cape diamonds and, if present, in their fillers, a better means of detecting fillings is suggested.

A laboratory X-radiography unit has been devised for the purpose of filler detection. The unit, described in detail, is reported to be able to detect fillings even if no colour flash is seen and operates quickly and effectively over large quantities of specimens tested together, irrespective of individual stone size. The incorporation of a traversing stereoscopic microscope allows observation of fillings which are otherwise very hard to detect, particularly those whose planes lie at right angles to the incident beam direction. A depth enhancement of 6x has been obtained with the unit operating with 30KV X-rays: the contrast between a thin film of lead glass and the virtually X-ray transparent diamond host allows the smallest particle of glass to stand out. M.O'D.

Moderne Technologien im Farbedelstein-Bergbau. Teil 1.

K.C. Taupitz. *Gemmologie. Zeitschrift der Deutschen Gemmologischen Gesellschaft*, **45**(2), 1996, pp 71–82, 10 diagrams, 2 tables, bibl.

The author describes the most important types of gemstone occurrences such as veins, pegmatites, emerald deposits, amygdales-druses-geodes, stratabound as well as eluvial and alluvial secondary deposits. Open pit mining is economic to a depth of 30 to 40 metres, but where vertical veins are thin, only to about 10–15 metres.

Hydraulic excavators with tractor or trailer or articulated dump truck haulage were found to be more efficient than exclusive use of bulldozers, especially in deeper mines. The recovered ground should be treated in a washing or reduction plant in order to minimize losses. Diagrams illustrate safety angles in open pit mining. Profitability of the various methods are discussed. E.S.

Moderne Technologien im Farbedelstein-Bergbau: Teil 2.

K.C. Taupitz. *Gemmologie. Zeitschrift der Deutschen Gemmologischen Gesellschaft*, **45**(3), 1996, pp 103–12, 7 diagrams, bibl.

In mining coloured gemstones modern technology is taking over from the classical primitive artisan methods. This article discusses underground mining at more than 30 m depth, similar to those used in small gold mines; trackless diesel-driven equipment is also considered. Most gemstone ores should be treated in a washing or reduction plant in order to minimize losses. The article also discusses water, air, dust and lighting in the mine as well as the general infrastructure. E.S.

Jewellery

History of development of jewellery in the western world. Part 1.

J. Dykstra. *Canadian Gemmologist*, 17, 1996, pp 82–7.

First article in a series introducing jewellery designs, materials and techniques used in non-Oriental countries with descriptions based on items in the collections of the Royal Ontario Museum. The first part covers items to the end of the Classical era. M.O'D.

Synthetics and Simulants

Gemmologie Aktuell.

H. Bank, U. Henn and C.C. Milisenda. *Gemmologie. Zeitschrift der Deutschen Gemmologischen Gesellschaft*. **45**(3), 1996, pp 97–101, 6 photos. in colour.

Some alexandrites were offered on the market said to be from a new find in Brazil, but these were found to be Czochralski synthetic (Russian) with veil-like features induced by heat cracks to simulate a more natural appearance. Also from Russia synthetic phenakites produced by the flux method. At the German Gemmological Association conference 1996, two cut colourless synthetic diamonds from De Beers were shown, 0.48 ct and 0.60 ct. Results of laboratory examination of these stones will be published later. E.S.

Gem Trade Lab notes.

C.W. Fryer. *Gems & Gemology*, **32**(1), 1996, pp 44–51, 20 illus. in colour.

An imitation ruby necklace was shown to be dyed, quench-crackled quartz whilst a ruby doublet was shown to have two natural parts. A green synthetic sapphire revealed curved colour zones and EDXRF analysis showed Co^{3+} as the cause of the colour. R.J.P.

Face statistics on the dissolution forms of garnet crystals.

E. Hartmann and E. Beregi. *Journal of Crystal Growth*, **128**, 1993, pp 74–81, 9 figs., 2 tables.

Statistics based on 390 crystal faces appearing as dissolution forms of garnet crystals showed that octahedron and tetrahexahedron faces occurred most frequently as dissolution forms on single crystal garnet spheres. The dissolution forms were compared with growth forms of natural and synthetic garnets. I.S.

Growth and perfection of chromium-doped forsterite.

B. Hu, H. Zhu, P. Deng and P. Pan. *Journal of Crystal Growth*, **128**, 1993, pp 991–5, 4 figs., 1 table.

Large single crystal boules of Cr-doped forsterite were synthesized by the Czochralski method, and their defects were investigated. Three typical defects were observed. By adjusting growth parameters and choosing optimum composition of the charge, two of these defects could be reduced, and large crystal boules with good quality were obtained. I.S.

Gemological investigation of a new type of Russian hydrothermal synthetic emerald.

J.I. Koivula, R.C. Kammerling, D. DeGhionno, I. Reinitz, E. Fritsch and M.L. Johnson. *Gems & Gemology*, **32**(1), 1996, pp 32–9, 10 illus. in colour, 1 table.

A new type of Russian hydrothermal synthetic emerald produced by Tairus in Novosibirsk is being marketed in Bangkok. Examination of several faceted samples revealed that with the exception of certain characteristic inclusions, the basic gemmological properties are the same as those encountered in other hydrothermally-grown synthetic emeralds and some natural emeralds. When characteristic inclusions are absent distinctive spectral characteristics in both the mid- and near-infrared regions of the spectrum will serve to distinguish these synthetics from their natural counterparts.

In the near-infrared spectra two broad absorptions produced by the extraordinary ray centred at 1500 nm and 900 nm and one in the ordinary ray spectrum at about 1180 nm have not been reported in natural emeralds. Although the roiled, chevron-shaped growth zoning that is generally considered characteristic of Russian synthetic beryls was absent in the new product, tiny red-brown particles of an unidentified nature were found in all the faceted samples and have not been noted in other Russian hydrothermal products or natural emeralds. R.J.P.

Dendritic diamonds synthesized by simple hot-filament-assisted chemical vapor deposition.

M. Sakai, Y. Aoki, Y. Nakamuta and M. Ishii. *Journal of Crystal Growth*, **133**, 1993, pp 329–31, 2 figs.

By a simple method of hot-filament-assisted vapor deposition, dendritic single crystals of diamond, consisting of three square prisms elongated in the [100], [010] and [001] directions and one to four triangular pyramids elongated in <111>, were obtained. Twins and aggregates attached to dendritic individuals were also formed. Dendritic diamonds were formed under conditions of higher filament temperature and substrate temperature than those used for polyhedral diamond growth. I.S.

Growth method and growth-related properties of a new type of Russian hydrothermal synthetic emerald.

K. Schmetzer. *Gems & Gemology*, **32**(1), 1996, pp 40–3, 4 illus. in colour, 1 table.

A new type of Russian hydrothermal synthetic emerald is produced by seeded growth in steel autoclaves without noble-metal inserts; the seed slices have been cut parallel to a face of the second-order hexagonal dipyramid $s\{11\bar{2}1\}$. This orientation avoids the easily recognizable growth pattern seen in earlier Russian production. Characteristic growth planes of a different nature are present being parallel to *s* and forming a 45° angle with the optic axis.

With this seed orientation extremely fast growth can be obtained. The recognition of one dominant growth pattern parallel to *s* in an emerald of doubtful origin may indicate that it is synthetic but absorption spectroscopy and/or EDXRF should be used to confirm or disprove such a preliminary result. R.J.P.

Flux growth of pure and doped zircons.

A.K. Sinha, D.M. Wayne and R. Essex. *Journal of Crystal Growth*, **125**, 1992, pp 431–9, 8 figs, 2 tables.

Crystals up to 2 mm (relatively large for zircon) of pure and doped zircon were synthesized by a flux method. Morphological variation of zircon crystals was correlated with different growth conditions and dopant contents, and interpreted in terms of growth mechanisms associated with element substitutions in the zircon structure. I.S.

Combustion growth of large diamond crystals.

X.H. Wang, W. Zhu, J. von Windheim and J.T. Glass. *Journal of Crystal Growth*, **129**, 1993, pp 45–55, 8 figs.

Optically transparent, individual diamond crystals attaining mm size in diameter were successfully synthesized on Si substrate by oxygen-acetylene combustion flames at atmospheric pressure. The growth process involves three steps: (1) achievement of a suitable nucleation density by pretreating the Si substrate in an acetylene-rich flame (oxygen-to-acetylene ratio $R_f = 0.95$) for about 30 min at a downstream position (7–10 mm away from the tip of the flame inner cone); (2) growing crystals up to 200 µm in diameter in an annular area on the substrate at $R_f = 0.98$ and a substrate-to-tip of the flame inner core distance of 2 mm; (3) moving the preferred crystals from the annular region into either the central core region of the flame feather or near the edge of the flame feather for further growth up to mm diameters under carefully controlled conditions. The final step was necessary to avoid extensive secondary nucleation and structural defects. The key factor was to maintain the growth conditions at the growing surface constant throughout the process. The crystal surface could be effectively maintained at constant temperature by decreasing the total gas flow rate as growth continued. Both the crystal growth orientations and the amount of nitrogen impurity incorporated in the diamond were closely related to the crystal surface temperature. It is believed that the gas flow dynamics or the boundary layer thickness played an important role in the growth and morphological development of large diamond crystals. I.S.

LONDON DIAMOND REPORT

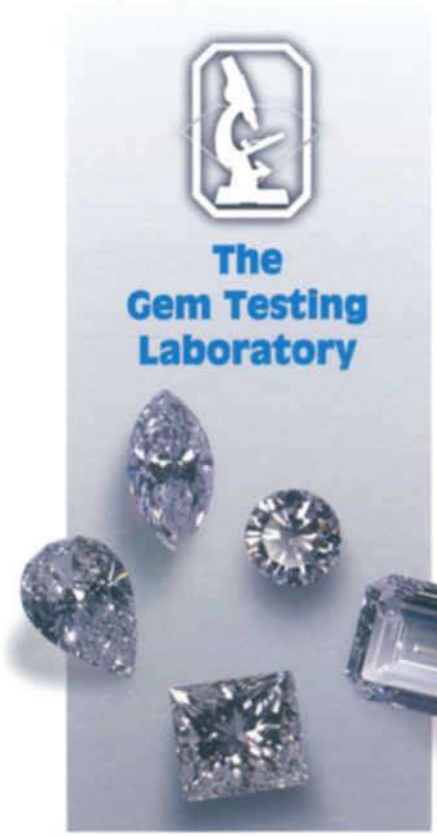

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BOOK REVIEWS

Caratteristiche interne delle gemme.

W. Andergassen, 1996. C. Bossi and C. Bossi, S.r.l., Via dei Pioppi n.6, 38033 Cavalese (Tn), Italy. Unpaged. Issued in parts with binder, illus. in colour. Price on application.

The first part of this work in progress contains coloured photographs of eighteen natural and synthetic gemstones, the majority being ruby and emerald, with topaz and biotite. Single pictures cover calcite, apatite, selenite [gypsum], kyanite, andalusite, peridot, natrolite and spodumene. Each page of eight photographs is accompanied by a facing page of description, with magnification and lighting conditions included. The quality is well up to the most exacting contemporary standard and the book should certainly be in the libraries of all working gemmologists. English and Spanish versions are promised.

M.O'D.

Mineralogy of Arizona. (Third edition)

J.W. Anthony, S.A. Williams, R.A. Bideaux and R.W. Grant, 1995. University of Arizona Press, Tucson. pp xvi, 508, illus. in colour, softcover. US$35.00. ISBN 0 8165 1555 7.

The first edition of this major mineralogy was published in 1977 and was followed by a second edition (in fact a revised reprinting) in 1982. Since that time the total of recorded Arizona mineral species has risen to 809, of which 76 were first discovered in the state. For each species the chemical composition, mode of occurrence and locations by county and mine are given.

For the gemmologist turquoise deposits must be of particular interest but Arizona also provides smithsonite, azurite, malachite, sphalerite, cuprite, chrysocolla and quartz varieties. Many of these provide such fine specimens that fashioning is out of the question. A 45-page bibliography and a comprehensive map section are given and in all respects the book is worthy of its subject.

M.O'D.

Opal, South Australia's gemstone. (Second edition)

L.C. Barnes, I.J. Townsend, R.S. Robertson and D.C. Scott, 1992. South Australia Department of Mines and Energy, Adelaide. pp 176, illus. in colour, softcover [Geological survey of South Australia. *Handbook* no 5]. £13.95. ISBN 0 7308 1709 1.

The second edition of this guide appears ten years after the first and during this period more work has taken place at the two main opal fields, Coober Pedy and Mintabie. All South Australian opal fields are described from the geologist's point of view and for this reason the book includes many geological maps and details of opal recovery. Interesting notes on claim establishment are included and the very useful bibliography has been updated. This is a book for the geologist rather than for the gemmologist but readers with a geological background will find a great deal of unique information.

M.O'D.

Minerals of South Africa.

B. Cairncross and R. Dixon, 1995. Geological Society of South Africa, PO Box 44283, Linden 2104, Johannesburg. pp xix, 290, illus. in colour, hardcover. Price on application. ISBN 0 620 19324 7.

Published to celebrate the centennial year of the Geological Society of South Africa, this book includes so much information on gem minerals that simply to turn to page 69, rhodochrosite crystals, or 53-quartz, or 162-map of the diamond field of Griqualand West, will compel gemmologists to consider buying the book. While there is the expected descriptive section covering South African minerals, this comes towards the end of the text and is preceded by chapters arranged under Archaean, Proterozoic and Phanerozoic periods: each of these sections is subdivided to give the geology and mineralization of major areas in South Africa. Maps and diagrams accompany a set of colour photographs of very high quality: the species descriptions give chemical composition, colours and localities, and there is an extensive bibliography, arranged alphabetically within geological periods. Gemmologists who are not geologists should not for that reason ignore this book which is likely to remain the standard work on South African minerals for some years.

M.O'D.

The gem merchant: how to be one, how to deal with one.

D.S. Epstein, 1996. Gem Business Publications, Murfreesboro, TN [PO Box 3145 Murfreesboro TN 37130]. pp 149, illus. in colour, softcover. US$18.00.

Despite the *doppelgänger*-ish suggestion of the title, the author has found it fun to be a gem dealer and others must have enjoyed dealing with this amiable and loquacious resident of Teofilo Otoni, Brazil. A welcome change from the serious tone of many gem books, this is a delightful account of the difficulties to be born in mind when setting up (or out) as a peripatetic gem dealer. There is a good deal of common sense (and, it must be said, a number of unimportant misprints) in the book and the stones shown in the final colour plate are badly out of focus: but, as the author might have said – for this price, what do you expect? I recommend all gemmologists to buy it – there have been few accounts of a gem dealer's life since the 1960s and the book is fun.

M.O'D.

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The Weardale mines.

R.A. Fairbairn, 1996. Northern Mine Research Society, Keighley. pp 151, illus. in black-and-white, softcover. [*British mining*. No. 56]. Covered by annual subscription to the Society. ISBN 0 901450 46 4.

Gemmologists with an interest in minerals will greatly welcome this monograph which describes the mining of lead and iron ores in the Weardale parishes of Stanhope and Wolsington in north-east England. With the ores came magnificently-coloured specimens of fluorite. Following the concise but lucid presentation of mining history the book describes mines and veins in detail, following a geographical arrangement, backed up by a reliable index. As anyone who has investigated old mines will know, names change bewilderingly! The information given is very detailed and in many cases veins and levels are shown in maps.

M.O'D.

Minerals of the Burra mine, South Australia.

B. Grguric, A. Pring and G. Drew, [1995]. Mines and Energy South Australia, Eastwood SA. (*Special publication* no. 11, Mines and Energy South Australia.) pp 32, illus. in colour, softcover. Price on application. ISBN 0 7308 0108 X.

The Burra mine is a source of high-grade ornamental-quality malachite which occurs with azurite. Specimens were known as long ago as 1877: some botryoidal pieces have a high natural polish and crystals up to 10 mm in length are also known. A list of mineral species found at the mine is given: a number of species are shown in colour and there is a short bibliography. This is a useful booklet for those interested in ornamental copper minerals.

M.O'D.

Minerale: Bestimmen nach äusseren Kennzeichen. 3 Auflage.

R. von Hochleitner, H. Philipsborn and K.L. Weiner, 1996. E. Schweizerbart'sche Verlagsbuchhandlung, Stuttgart. pp v, 390, illus. in colour, hardcover. DM 98.00. ISBN 3 510 65164 2.

This text is the third edition of *Tafeln zum Bestimmung der Minerale nach äusseren Kennzeichen*, a title which first appeared in 1866 under the authorship of Albin Weisbach of the Bergakademie Freiberg. The most recent edition was published in 1983. The text is simply and clearly laid out and represents a quick-reference guide to 487 mineral species, for which name, composition, crystal system, form and habit, physical and optical properties, mode of occurrence and location are given, the data occupying a whole opening section and concluding with notes on associated species. Brief introductory material includes notes on crystal morphology and notation and there is a short bibliography and a polyglot glossary. A section of high-standard colour photographs occupies the end of the book which is an excellent addition to the German tradition of well-produced mineral guides.

M.O'D.

Bulgari.

D. Mascetti and A. Triossi, 1996. Abbeville Press, New York. [488 Madison Avenue, New York, NY 10022]. pp 255, illus. in colour, hardcover. £57.00. ISBN 0 7892 0202 6.

The Italian jewellery firm of Bulgari has been prominent in Rome for virtually the whole of this century and is remarkable for its recognizable style of artefacts which are beautifully illustrated in this excellent book. This history of the firm is recounted with interesting notes on various personalities, including some celebrated customers, and the book will be essential reading for jewellery historians. Both jewellery and watches are included and the various threads in the development of the distinctive Bulgari style are examined. There is a short bibliography and the book displays the continuing excellence of modern jewellery history books.

M.O'D.

The pearl book: the definitive buying guide.

A.L. Matlins, 1996. GemStone Press, Woodstock VT. pp ix, 198, illus. in colour, softcover. US$19.00. ISBN 0 943763 15 0.

Though the author claims that there are many books on pearl, I have not seen an excess of good ones! This, though, could well be the one worth waiting for! As usual this author is eminently practical in her approach to a tricky subject and directs her advice to the potential pearl buyer. The text includes descriptions of some of the important pearls in history, biographies of some of the major figures in the pearl world and also a section in which leading jewellers and designers describe their feelings for and their use of pearls. Pearl price tables are also provided.

These novel sections are accompanied by plenty of bread-and-butter information which will help both buyer and student. Details of imitations and enhancements are given and identification tests described. I recommend the book, at so reasonable a price, to all gemmologists and students.

M.O'D.

Jewelry & gems: the buying guide.
(Third edition, revised)

A.L. Matlins and A.C. Bonanno, 1995. GemStone Press, Woodstock VT. pp xx, 262, illus. in colour, softcover. US$16.95. ISBN 0 943763 11 8.

This book can be recommended particularly for students for whom the standard gemmology textbooks lack trade coverage. The approach is well away from the airy advice given by other books attempting similar coverage: anecdotes are pointed and data accurate. Though it cannot be said too often, the book yet again encourages the trade to look more kindly on education and emphasizes the point by selected stories recounting loss of money and reputation when neither need to have been put at risk. The chapter on appraisals is timely and sensible and so are the remarks on investing in gemstones. At the price, all gemmologists should have the book.

M.O'D.

Agate, microstructure and possible origin.

T. Moxon, 1996. Terra Publications, Auckley, Doncaster. [Copies available from the author at 55 Common Lane, Auckley, Doncaster, DN9 3HX.] pp 106, illus. in black-and-white, softcover. £7.50 including post and packing. ISBN 0 9528512 0 2.

A description of the formation and structure of agate with a discussion on how its varied colours arise. Particular attention is paid to specimens from the United Kingdom and an overview is given of the various theories on agate formation proposed since the eighteenth century. An interesting book which will act as a springboard for further speculation.

M.O'D.

Minerals of New Mexico.

(Third edition, revised by Florence A. LaBruzza)

S.A. Northrop, 1996. University of New Mexico Press, Albuquerque. pp xiii, 346, hardcover. US$75.00. ISBN 0 8263 1662 X.

Revised from the previous edition published in 1959, the book lists and describes New Mexico mineral species in alphabetical order, this main section following introductory matter covering highlights of New Mexico mineralogy and mining with dates of notable finds. Following the descriptive section is a list of 172 districts, subdistricts and camps, some of which are referred to the following map section. Mineral species are then presented under alphabetical order of county and the book concludes with a bibliography and eight maps.

In the descriptive section chemical composition is given in words rather than symbols and this could easily lead to inadequate presentation of a mineral's true nature and to confusion. Crystal system and predominating colour are also given but nothing else, apart from accounts of discovery, where significant records exist and location details which are rather sketchy. The ornamental minerals of the state are well known and some details can be found, but there is disappointingly little information on many species and too many out-dated and discredited names are included, jamming up the text and making the jumbled information hard to sort through.

The book bears too many signs of the breathless style long associated with the enthusiastic amateur collector to be worthy of consideration as a serious state mineralogy: there are no colour photographs and the maps are unworthy of a tourist leaflet. We must hope that a fourth edition redresses the situation: the state's mineralogy is of considerable importance and deserves better than this.

M.O'D.

The regalia of the Russian empire.

I. Polynina and Rakhmanov, 1994. Red Square, Moscow. [23 Vorontsovskaya, Moscow, 109147.] pp 239, illus. in colour, hardcover. Approx. £90.00. ISBN 5 900743 04 2.

The senior author is head of the Diamond Fund Exhibition at the Moscow Kremlin and has previously co-authored *Russia's Diamond Treasury*. The present work is therefore of an expected high standard both of text and especially of illustration and can rank with the very best Russian productions of recent years.

The subject is the crown jewels and robes of the Russian state and is treated chronologically, with a number of reproductions from major MS and printed texts: a good deal of history is lucidly presented and there is an extensive bibliography consisting entirely of works in Russian: many can be consulted in major university libraries and it is a relief to find an information source which does not circulate the same few books which are well-known to all.

It is the colour plates, however, that catch the eye and which will sell the book. Most of them are full-page and the stones in some of the regalia show up clearly: I was pleased to renew acquaintances with several items from the Diamond Treasury which I remembered from a visit in less easy times. Since copies of Russian books often sell out quickly in western Europe readers are advised to buy one as soon as they can.

M.O'D.

Mysteries of ancient China: new discoveries from the early dynasties.

J. Rawson, 1996. British Museum Press, London. pp 303, illus. in colour, softcover. £25.00. ISBN 0 7141 1472 3.

Forming the catalogue of an exhibition held at the British Museum in 1996, the book covers a range of Chinese artefacts from discoveries made in recent years. The rate of discovery has greatly increased and it is not surprising that some jade artefacts have turned up along with bronzes, stoneware and textiles.

The exhibition and thus the catalogue is arranged chronologically so that the different materials have to be sought in more than one section. This is no disadvantage since turning through the pages reveals much interesting matter. Though there are not many specimens of jade (nephrite), the examples shown and described are especially fine. There are useful maps and an excellent bibliography.

M.O'D.

Photographing minerals, fossils and lapidary materials.

J.A. Scovil, 1996. Geoscience Press, Tucson, AZ. pp xv, 224, illus. in colour, hardcover. About £35.00. ISBN 0 945005 21 0.

This book fills an inexplicable gap in earth science literature and should be considered for purchase by any gemmologist with a camera. Scovil is a well-published photographer and the colour photographs are of exceptional quality even for today.

The text ranges from specimen choice, preparation and support (important for crystals and groups) through the advantages and disadvantages of different formats, choice of film, camera and lenses, lighting, meters, filters and paper. Microphotography and stereophotography sections precede notes on fluorescence photography. Final chapters deal with packing and transportation, slide presentations, gadgets and sources of supply. There is a glossary and an

excellent bibliography, including the valuable technical leaflets published by Kodak and others. Gemmologists will find so much information touching on gem testing that they should get the book, whether or not they are photographers.

M.O'D.

The dealer's book of gems and diamonds.

M. Sevdermish and A. Mashiah, 1996. Kal Printing House, Israel. pp xxiv, 1004, 2 vol., illus. in colour, hardcover, in slip case. £70.00. ISBN 965 90072 1 3.

It is some years since a comprehensive survey of gemstones was published in English and it hardly seemed possible that there would ever be a completely new book of this kind. Nonetheless, the authors have provided the gemstone and gemmology community with a major work, conveniently divided into two volumes, the second of which is devoted almost entirely to diamonds, which are thus separated from the discussions of other major gemstones in the first volume. This arrangement works quite well and apart from a small section in the second volume which deals with gemstone formation, properties, inclusions and testing – perhaps these would have made the first volume too long – the order seems perfectly logical. To test the arrangement I looked first at the diamond section to see if it did indeed stand alone without constant references to the first volume.

The second volume begins with diamond sources and mining and is sufficiently up-to-date for Chinese and Canadian deposits to be included. Next comes a description of diamond trade development, followed by a discussion of diamond crystallography and properties. This section contains all that the student should know and will also be useful to the diamond polisher and dealer. The rest of the volume covers synthetic diamond and diamond simulants, exhaustive sections on polishing and grading, with tables, notes on the history of diamond polishing and on diamond re-cutting appearing as appendices. Between the diamond section and the appendices comes the gemstone formation section already mentioned.

It is possible that readers of the second volume will need to turn to the first to find out the meaning of some of the instrument names and the significance of some of the tests used for diamond and its simulants but this is not a great disadvantage: the alternative would have been to explain everything as the text went along and would have made an unwieldy book.

The authors' enthusiasm clearly shows in the first volume where many old friends step on to the stage once more and very welcome they are: faceted painite still eludes us (there must be some) and if painite is in, what about taaffeite, smithsonite, tugtupite, willemite, zincite? They lurk in the index, tables and in the coloured pictures, however, and no book can or even should be fully comprehensive. But it does look as though rare stones beginning with T onwards have been banished! This is not a serious criticism. A silver star, however, for the authors' explanation of varying refractive index and other numerical values in the literature: such an explanation ought to be in all texts and notes but isn't. A gold star for the typography which is one of the best I have seen in any book on gemstones, making it exceptionally pleasing and comfortable to read. Some of the photographs, too, are quite first-class and many of them are the responsibility of the senior author. The book is successful and deserves wide circulation.

M.O'D.

A collector's guide to rock, mineral and fossil localities of Utah.

J.R. Wilson, 1995. Utah Geological Survey, Salt Lake City. [Utah Geological Survey. *Miscellaneous publication* 95–4.] pp vi, 148, illus. in colour, softcover. Price on application. ISBN 1 55791 336 8.

The name Utah will send gemmologists searching for remarks on red beryl and brown topaz locations and here they are in this lucid and interesting survey arranged in order of counties. While the coloured pictures lose by being set against a pinkish rocky background the text is simple, well-referenced and indexed. Directions to the locations are given, with the exception of the red beryl deposit in the Wah Wah Mountains, commercially important and in the news at the time of writing. The reviewer worked on this mine a few years ago and can testify that it would be hard to find – 80 miles from the mine office! The author does not fail to mention that many of the sherry-brown topaz crystals fade on exposure to bright sunlight.

M.O'D.

The Scottish pearl in its world context.

F. Woodward, 1994, Diehard, Edinburgh. pp iii, 165, softcover. £6.50. ISBN 0 946230 27 7.

This excellent book successfully combines up-to-date zoology, conchology, history, commerce and conservation with gemmology waiting in the wings. It is thus not a gemmological treatment of Scottish freshwater pearls, but rather an attempt to place them in their zoological context with accounts of their recovery over the years and of attempts to preserve their habitat. But there is plenty of useful information on a topic scarcely covered monographically during this century. Celebrated Scottish pearls are described and some of the best-known locations are mentioned. A welcome freshwater mussel recording scheme deserves public support and details are given, while the Universal Naiad Information Organization [UNIO] is now working on the establishment of an international network co-ordinating workers and projects on freshwater bivalves. With details of some monographs and papers scattered through the text a separate bibliography would have been welcome, but this is a very small blemish on an otherwise praiseworthy effort. Anyone with an interest in organic ornamental materials should buy the book which is very reasonably priced.

M.O'D.

Opal: the gem of the Never Never.

T.C. Wollaston, 1924. Thomas Murby & Co., London. pp 168, illus. in colour, softcover. Privately published in Australia and unpriced.

'By degrees [the black opal's] rare beauty has triumphed and it is the author's personal belief that fifty years hence the finest specimens of it may prove to be the

costliest gems on earth – he writes enthusiastically and also with abundant knowledge. His book is neither a scientific treatise nor a history of the opal industry: it is a mixture of both, combined with sketches of the human daring and endeavour that such a speculative job as opal-mining must have inevitably produced. Its unconventionality is one of its charms.'

This is part of a review published in *The Birmingham Post* in December 1924 and the original colour photographs have reproduced well in this smaller format reprint. Readers should watch for a wider distribution of this fascinating book.

M.O'D.

Cartier, splendeurs de la joallerie.

ANON, 1996. La Bibliothèque des Arts, Lausanne. pp 157, illus. in colour, softcover. £36.00. ISBN 2 88453 013 4.

An exhibition catalogue forming a review of work by the Paris firm of Cartier with major ornamental artefacts illustrated in colour and smaller items in black-and-white. A brief history of the firm is given: colour photographs are well up to the best quality obtaining today.

M.O'D.

Boucheron.

ANON, 1996. London. pp 44, illus. in colour, hardcover. £14.00.

An illustrated catalogue of items currently available from the London branch of Boucheron and featuring a collection of enamels as well as jewellery and watches. Colour reproduction is excellent.

M.O'D.

Catalogue of the Exhibition of Ch'ing Dynasty costume accessories.

National Palace Museum, Taipei, Taiwan, 1986. pp 352, illus. in colour, softcover. Price on application. ISBN 957 562 021 6.

Though ten years old, this beautifully-illustrated catalogue has just come to my attention and is worth noting for its notes on the exhibits (which include artefacts containing jade, organic substances and gemstones) which are described in English and in Chinese. In addition the catalogue describes the materials used in a very useful introduction presented both in English and Chinese. The colour reproduction of jade and gold, in particular, is exceptionally good.

M.O'D.

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Proceedings of the Gemmological Association and Gem Testing Laboratory of Great Britain and Notices

OBITUARY

Reginald Jewitt Peace, B.Sc., AIBMS, C.Chem., FGA, FRSC, died suddenly at home on 28 September 1996. Reg was born in Hull on 10 December 1927. He attended Hymers College and was a promising Rugby Union player for Withernsea 1st XV. After serving in the RAMC mainly on the Hospital Ship 'Somersetshire' in the Middle and Far East, he qualified as a chemist and later as a biochemist at the old Hull Royal Infirmary. He then spent ten years as a chemistry lecturer at the College of Technology, gaining the Fellowship of the Royal Institute of Chemistry before joining the staff of Beverley High School as Head of Chemistry, a post he held for 21 years.

Reg married Heather in 1955 and recently celebrated their 41st anniversary. He had two daughters, Elizabeth and Bridget, and five grandchildren, Siobhan, Nathan, Joel, James and Joseph. They gave him a great deal of happiness and a few more grey hairs!

An interest in gemstones saw him qualify as a gemmologist, becoming a Fellow of the Gemmological Association of Great Britain. Very soon after he put his teaching experience to good use and as a tutor in gemmology. Reg taught students from the four corners of the world, many of whom became personal friends. Reg also contributed materially to the educational development of the Association and latterly contributed a regular stream of abstracts for the *Journal*.

During his ten years of retirement he continued to develop a wide range of interests and became Captain of the Elderly Gentlemen's Golfing Society; his final match in Pocklington brought him back, appropriately enough, to the place of his childhood evacuation during the Second World War. His thirst for knowledge was unquenchable and his interest in computers became a consuming passion. He recently gained qualifications in computing and spent many happy hours surfing the internet!

Reg was a man of immense loyalty and integrity being thought of by many as one of life's true gentlemen. He tackled any task with enthusiasm and fervour and would not let anything beat him. His memory will live as an inspiration to us all, to learn from every experience, to use every second to advantage and to strive for perfection.

Compiled from contributions by Reg's family and friends.

Mr Graham D. Llewellyn, FGA (D.1948), Chislehurst, died on 28 September 1996.

GIFTS TO THE ASSOCIATION

The Association is most grateful to the following for their gifts for research and teaching purposes:

Mr Arlid Anderson, FGA, Oslo, Norway, for a cabochon-cut peridot 4.77 ct and an oval faceted peridot 2.15 ct from Sunmøre, Norway, and three emerald crystals from Byrud Farm, Lake Mjøsa, Norway.

Mr Michael Gray, Missoula, Montana, USA, for a sample of mica from pegmatite.

Judith Osmer, Los Angeles, California, USA, for a YGG crystal.

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Dr Xia Songyao, BG Gemmological Institute, Beijing, P.R. China, for seven crystals of beryl, variety emerald, from Yunnan, China.

Matthew Woods of Siegen, Germany, for a crystal and a cut stone of spessartine garnet from Kashmir.

NEWS OF FELLOWS

On 27 October 1996 **Michael O'Donoghue** gave a hands-on demonstration of Montana sapphires and their colour to the Gemmologisch Gilde Nederland; on 3 November he presented a paper on synthetic gemstones to the South-East branch of the Russell Society at Beckenham. Alan Hodgkinson gave a series of lectures in a number of locations throughout the USA during October and November 1996.

MEMBERS' MEETINGS

London

The Annual Conference on the theme 'Exceptional Gems' was held at the Scientific Society's Lecture Theatre, London W1, on 13 October 1996. A report was published in *Gem and Jewellery News*, December 1996.

On 20 November at the Gem Tutorial Centre, 27 Greville Street, London EC1N 8SU, David Callaghan gave an illustrated lecture entitled 'The mystery of opal'. His presentation included a live video camera recording of a revolving opal, emphasizing the ever-changing display of colours produced by these gems.

On 4 December at the Gem Tutorial Centre, Cally Hall gave a lecture entitled 'Burmese gems at the Natural History Museum'.

Midlands Branch

On 27 September 1996 at the Discovery Centre, 77 Vyse Street, Birmingham 18, John Henn spoke on 'Technological developments in the jewellery trade'.

On 25 October at the Discovery Centre, Richard Taylor gave a talk entitled 'Jewellery, gems and litigation'.

A practical training day was held at the New Cobden Hotel on 27 October.

On 29 November at the Discovery Centre, Shena Mason gave a talk entitled 'Jewellery for the world and his wife'.

North-West Branch

On 16 October at Church House, Hanover Street, Liverpool 1, Richard Digby gave an illustrated talk entitled 'Cameos, second-hand and antique jewellery'. A report was published in the December 1996 issue of *Gem and Jewellery News*.

Scottish Branch

On 17 October 1996 a Quiz Night and Bring and Buy was held at the Royal British Hotel, Princes Street, Edinburgh.

On 13 November a Lab Night was held at Telford College, Edinburgh.

PRESENTATION OF AWARDS

The Presentation of Awards gained in the 1996 examinations was held at Goldsmiths' Hall, Foster Lane, London EC2, on Monday, 11 November 1996. The President, Professor R.A. Howie, presided and congratulated the successful candidates. Among those present were award winners from as far away as Canada, China, Japan, Kenya and Taiwan, as well as Belgium, Finland, Greece and The Netherlands.

Professor Howie then related some of his early experiences in the world of gemmology: 'As one gets older and rises up the hierarchy of various organizations', he said, 'I have found that one gets increasing pleasure from being in a position to organize and facilitate rewards to one's colleagues for work often far beyond the normal call of duty: a pleasure quite distinct from any recognition of one's own work. When I first came to King's College, London, in 1962 as a Reader in Geology, having long been interested in gemstones as presenting a particularly attractive example of the problems arising in the identification of minerals, I was delighted to be invited along to

the old work rooms in Hatton Garden where Basil Anderson and Robert Webster demonstrated for me the techniques of distinguishing between natural and synthetic ruby by their growth rings and inclusions. Indeed, Robert Webster came along to one of my peripatetic gemstone lectures at Chelsea College and afterwards said he could fault me only in having the specific gravity of alexandrite slightly wrong – but as I was only using this as an example of yet another property which could distinguish between synthetic ruby with a touch of vanadium, masquerading as alexandrite, and the true alexandrite, the principle was still valid.

'However, Basil Anderson was a King's man, having graduated with a joint degree in Chemistry and Geology, and I was able therefore to propose him for a Fellowship of the College. This took the best part of a year to get through the appropriate committees, but one day I was tackled in the corridor by the College Secretary – Lord High everything at that time – who asked me if I knew that the Americans spelt gemmology with only one m. I assured him that I did indeed know that, but it was only later on that I realized that this was his coded way of telling me that due checks had been made with the GIA in California. The response must have been reassuring, and in due course Basil Anderson became a Fellow of King's, an honour of which I know he was particularly proud.'

Professor Howie introduced David Callaghan who presented the awards and his address is set out below. Following the presentation of awards gained in the Gemmology and Gem Diamond examinations, David Callaghan presented Professor Howie with an Honorary Fellowship in recognition of his work in the field of gemmology.

The new Bruton Medal was displayed at the reception preceding the presentation. The award is named in honour of the immediate

David Callaghan, Professor Howie, Evelyne Stern, Noel Deeks and Roger Harding at the Presentation of Awards.

Bruton Medal design winner Garry Barrett receiving his prize from Evelyne Stern.

past President, Eric Bruton, who is well known internationally for his work on diamonds, and is to be awarded to the candidate who submits the best set of answers of sufficiently high standard in the Gem Diamond Examination. A design competition was held in 1996 for the medal. The prize-winning entry was submitted by Garry Barrett of Chatham, and he was presented with the prize of £250 by Gem Diamond Examiner Evelyne Stern.

A vote of thanks was given to David Callaghan by Noel Deeks, who referred to the major contribution David had made to both the Gemmological Association and the Gem Testing Laboratory. Noel encouraged those present to continue their involvement with gemmology. 'It may well be', he said, 'that, like David, you may consider becoming seriously involved with the Association as tutors or later as examiners to help us spread the knowledge of gemmology and follow in the footsteps of the people who have helped you reach your goal today.

'Our courses are now taught in over forty countries and in the UK we are seeking people to start new branches of the Association, especially in East Anglia and the West Country. To make these things possible we require the help of enthusiastic, qualified people. So if you feel you can assist, please get in touch.'

In conclusion Professor Howie thanked the Goldsmiths' Company for allowing the GAGTL to hold the ceremony at the Hall.

ADDRESS BY DAVID CALLAGHAN

'I began my career in the jewellery trade as apprentice to Hancocks & Company in September 1955. At that time apprenticeships were still available to retail jewellers but these were phased out by the end of the 1950s and have not been replaced. So I first sat in this room in the summer of 1956 when I sat the Preliminary exam having completed my first year at Chelsea Polytechnic. Those of you who have some interest in the history – or perhaps the folk-lore – of the Gemmological Association will know that the Chelsea filter was named after this school, it having been 'invented' by B.W. Anderson in the 1930s. Incidentally, I am so old-fashioned as to still use it frequently as a preliminary diagnostic instrument.

'I digress – I first sat in this awe-inspiring room in 1956 and soon found myself staring at the ceiling because I soon realized how little I knew once I started on the question paper. By the way – I failed the exam. I was convinced that it was the examiners' age, lack of comprehension of my work and general debility that caused me to fail – and my conceit enabled me to try again and give the examiners another chance! I did pass the next time. The first lesson learned therefore was:

> Be as sure as you can to understand how little you know, and you will still have a mind open to learning. However, the trick is to make sure others do not find out how little you know!!

'I have been very fortunate over the many years in this trade, and my good fortune began early when I first went down the stairs to the old Gem Testing Laboratory in Hatton Garden, known then as the Diamond, Pearl and Precious Stone Laboratory of the London

Chamber of Commerce – the Lab, for short. The Director then was the great gemmologist B.W. Anderson, leading the team of C.J. Payne, Robert Webster and Alec Farn – now 80 years old and the last of what B.W. Anderson referred to as the phalanx of four.

'What were the problems facing the gem trade at that time? 1955 saw the first synthetic diamonds produced, and in the same year the revolutionary strontium titanate arrived. That year the Gem Lab tested 138,484 pearls! To give you some idea of how synthetics occupied our minds I have referred to the *Journal of Gemmology* for the decades from 1955–56 to date:

Volume 5 1955–56	6 entries
Volume 10 1966	4 entries
Volume 15 1976–77	23 entries
Volume 20 1986–87	A whole page from alexandrite to zircon.

'We now talk blithely of metallic and gallium inclusions in synthetics, diamond-topped doublets, and quantitative cathodoluminescence of ..... This is just of synthetics but that is not the only problem for the gemmologist today. In my opinion the problem of the synthetic pales into simplicity when compared with the 'treatment' of gemstones. This is said as if a doctor is curing a patient, or in similar terms that politicians refer to the continual problems in Ireland by the euphemism 'the troubles'. In my opinion the synthetic gemstone is an honest product of man's ingenuity, but what of the 'treated' gemstone? Consider just a few of these treatments:

- the oiling of emerald;
- the impregnation of emerald with plastic;
- the similar treatment to precious opal;
- pearls are bleached, dyed, stained and irradiated;
- diamonds are laser drilled and glass infilled; and
- sapphires and rubies are heated and glass infilled.

Does the trade in general mind? Let me warn you that much of the trade does not. It is 'accepted trade practice' and therefore an acceptable part of the business. I reject that utterly.

'Those of you now qualified are going to be subjected to enormous pressures in your career, pressures by those who have only a vested interest in the sale of their product. These sinister practices hide behind words such as 'enhancement' and 'induced colour'. The very use of the word synthetic is avoided wherever possible by the promoters of their product. I have looked at definitions of the words:

Synthetic – not natural – man made – not sincere – sham –

Enhance – to intensify – to rise in value.

'Now we are getting near the reason, are we not? The trade is fast becoming, or indeed may have already become, the victim of marketing. Let me define that 'technique' to you:

Marketing – the business techniques or process by which anything may be sold – note anything!!

'I have thought long and hard about these words and the glossing over of what is happening to the gemstone today. I wish to suggest to you a new definition of stones which have been tampered with – they are an *enticement.*

Entice – to tempt or persuade by arousing hopes or desires or by promising a reward – to lead astray.

'There you have it, Mr President, ladies and gentlemen – those last three words – to lead astray!!

'On top of all this the marketing agents all want to have Reports of Origin particularly when it adds to the price of a stone.

'Please note I say the price – I do not say the value. Other reports which give such information as 'No evidence of heat treatment was observed' or 'No evidence of staining was observed', become translated as *unheated* or *not stained.* In other words no treatment. That is not honest.

'And you, the new entrants to the trade, are going to be pushed further and further to provide pieces of paper which allow the Auction Rooms and uncaring trades the comfort of selling someone else's property with clean hands.

'When Basil Anderson first wrote his book *Gem Testing* in 1942 he spoke clearly about

the gemstones. He always spoke clearly and he wrote as he spoke. Please read his works – they may be 'old hat' now but they came from the heart, and from one who loved the trade and its history. He had no commercial slant to his words and neither should you. In his book *Gemstones for Everyman* his first chapter is entitled "What exactly is a gemstone?" and I will read the first paragraph.

> "The World is full of a vast variety of beautiful things, but most of them are ephemeral. The dewdrop and the daffodil, the rainbow and butterfly, last for a few moments or a few days and are gone; preserved only in memory or in lines written by a great poet. Precious stones, more than any other things which are lovely to the eye, endure, in terms of human measurement, eternally."

'I accept that man is ingenious, inventive and curious. That is fine and of course there is a place for the synthetic and the heated gemstone. But say so, unequivocally. Don't hide behind such words as Gilson, Chatham, Biwa, South Sea, etc. Say it for what it is – synthetic, freshwater cultured pearl, South Sea cultured pearl. In other words, it is not enough to mean what you say, you must say what you mean.

'In his last public lecture Basil Anderson closed with these words, the words of an unassuming man but a giant in his field:

> "Through all my life I reckon myself very, very lucky to have just by chance become a gemmologist. I've no particular skills or talents but great enthusiasm, and I've been able to use it to my limit, and I've made wonderful friends throughout the world in consequence."

'I say Amen to that and I truly wish that you will be able to say the same at the end of your career. Thank you for listening to me for so long.'

MEETINGS OF THE COUNCIL OF MANAGEMENT

At a meeting of the Council of Management held at 27 Greville Street, London EC1N 8SU, on 18 September 1996, the business transacted included the election of the following:

Diamond Membership (DGA)

Daniel, Eliena May Josephine, Brighton, 1996.
Ezzeddine, Marwan, Winchmore Hill, London, 1996.
Jurvakainen, Risto Kalervo, Helsinki, Finland, 1996.
Sveen, Per Olav, Heimdal, Norway, 1996.

Diamond Membership and Fellowship (FGA/DGA)

Kesheng, Chen, Guangxi, China, 1991/1995.

Fellowship (FGA)

Barnes, Patricia Ellen, Dunkirk, Md, USA, 1996.
Brangulis, Peters, Riga, Latvia, 1996.
Cameron, Iain Alexander, Wimbledon, London, 1996.
Chan, Wai Keung Addy, Hong Kong, 1996.
Cheung, Sau Ping Pamela, Kowloon, Hong Kong, 1996.
Clark, Antony, Bolton, 1996.
Curtis, Simon James, Paignton, 1996.
Getgood, Fiona Josephine, Hastings, 1996.
Harris, Annette Mia, Hanbury, 1996.
Janssen, Maurice Jan-Willem, Aruba, Dutch Caribbean, 1996.
Kenny, Sark, Kowloon, Hong Kong, 1995.
Kwok, Esther, W.S., Vancouver, B.C., Canada, 1996.
Lloyd-George, Kim, Los Angeles, Calif., USA, 1985.
McKenzie, Wilma Anne, S. Surrey, BC, Canada, 1996.
Naing, Aye Myo, Yangon, Myanmar, 1996.
North, Sara Elizabeth, York, 1991.
Parsons, Michael John, Bath, 1996.
Popov, Vladimir, Tallinn, Estonia, 1996.
Rege, Sonal, Pune, India, 1996.
Sallinen, Virpi Hannele, Helsinki, Finland, 1996.
Tsang, Wai Yi Rita, Hong Kong, 1996.
Whiting, Sarah Katherine, Crouch End, London, 1996.
Willis, Kathryn, Muswell Hill, London, 1996.
Yoshikawa, Yoichi, Osaka, Japan, 1996.

Forthcoming Meetings

London Branch

Meetings will be held at the GAGTL Gem Tutorial Centre, 2nd floor, 27 Greville Street (Saffron Hill entrance), London EC1N 8SU. Entry will be by ticket only at £3.50 for a member (£5.00 for a non-member) available from the GAGTL.

12 February
Sleepers – rediscovery and reattribution in the antique jewellery trade Geoffrey C. Munn

12 March
How will our Garden grow? Adrian Klein

16 April
Make paste! Imitating precious and semi-precious stones over 5000 years Ian Freestone

7 May
150 years of Cartier Terry Davidson

Midlands Branch

Monthly meetings will be held at the Discovery Centre, 77 Vyse Street, Birmingham 18. Further details from Gwyn Green on 0121 445 5359.

23 February
Gem Club – **Treated stones** Eric Emms

28 February
A gemmological journey from the Alps to Vesuvius E. Alan Jobbins

21 March
A talk on pearls

23 March
Gem Club – **Synthetic gemstones and their identification** Alan Hodgkinson

20 April
Gem Club – **Demonstration of diamond cutting techniques** David Proudlove

25 April
AGM followed by **Gems from the Law** John Bugg

18 May
Gem Club – **Diamond grading day** Gwyn Green

North-West Branch

For details of meetings contact Joe Azzopardi on 01270 628251.

19 February
Power and Gold. A talk and conducted tour at the Liverpool Museum

19 March
A talk by Brian Dunn of Garrard's

Scottish Branch

For details of Scottish Branch meetings contact Joanna Thomson on 01721 722936.

12 February
Lab Night Barmulloch College, Barmulloch Road, Glasgow

14 March
Valuations Euan Taylor

18–20 April
AGM. **Weekend Tutorial** in Peebles with Alan Hodgkinson and **Field Trip**

Ordinary Membership

Aladin, Naila, London.
Adeleye, Ernest, London.
Bang, Michael, East Grinstead.
Biberstein, Adrienne Francine, Kilchberg, Switzerland.
Christou, Angelos, Limassol, Cyprus.
Chung Luk-Mui, Ivy, Kowloon, Hong Kong.
Davies, Paul Brian, Great Missenden.
Deligianni, Christina, Athens, Greece.
Deutscher, Gilad, Kiryat-Ono, Israel.
Dewey, Paul, Netherfield.
Forward, Stephen, London.
Halday, Farzana, London.
Hashimoto, Hiroko, London.
Hill, Emma, Maida Vale, London.
Iqbal, Sameer, Gold Souq, Dubai.
John, Victoria Alexei, London.
Kaneko, Miki, St John's Wood, London.
Kerr-Patton, Cecilia, Hampstead, London.
Kim, Jung Shin, Hammersmith, London.
Lai, Ya Yu, Richmond.
Lam, Jill, Rochester.
Leal, Barbara, L., Cambridge.
Malik, Javaid, I., Lusaka, Zambia.
Muller, Hellen, A.D., Wierden, The Netherlands.
Munro, Camilla Morna, Holland Park, London.
Ng, Melloney, Bexleyheath.
Nunes, Clive Neville, London.
Pancratz, Mark, Weybridge.
Renard, Joelle, M., Ruislip.
Roobol, Michael John, Canterbury.
Seth, Rashni, Cobham.
Shah, Varsheet, Kingston.
Sham, Raymond, Vancouver, BC, Canada.
Speake, Malcolm Frank, Ladywood, Birmingham.
Thomas, Jessica Catrin, Glasgow.
Vassiliou, Marianna, Nicosia, Cyprus.
Verny-White, Catherine, Richmond.
Weldon, James, Dublin, Ireland.
Williams, Lisa Jocelynne, Worcester.
Wong Poon, Wai Chun Olivia, Hong Kong.
Yoshitake, Yumi, Cardiff.

Transfers – Fellowship to Fellowship and Diamond Membership (FGA/DGA)

Abramian, Levon, London, 1996.
Baker, Kimberly Helen, Mountsorrel, Loughborough, 1996.
Bowis, Mark Lister, Colliers Wood, London, 1996.
Buxani, Naina Mahesh, Kowloon, Hong Kong, 1996.
Cadby, Sarah, Highgate, London, 1996.
Clarke, Norman V., Dunfermline, 1996.
Daniels, Razia, Chester, 1996.
Dinnis, Simon John, Swadlincote, 1996.
Dokken, Aarrynne, D.C., Carshalton, 1996.
Kathoon, Junaida, Singapore, 1996.
Lake, Richard John, Gorey Village, Grouville, Jersey, 1996.
Lin, Sung-Shan, Taipei Hsien, Taiwan, 1996.
Lodge, Sara Anne-Marie, Lowdham, 1996.
Lord, Karen, Lutterworth, 1996.
McIntosh, Robert P., Penicuik, 1996.
Mitchell, Beverly J., Hendon Central, London, 1996.
Sotolongo, Sachiko Kashiba, London, 1996.
Turner, Caroline, Walberswick, 1996.
White, Michele, Moseley, Birmingham, 1996.
Withington, Terry, Aylesbury, 1996.

Transfers – Ordinary Membership to Fellowship and Diamond Membership (FGA/DGA)

Mitteregger, Unni, London, 1996.
Pepprell, Eija-Liisa, London, 1996.

Transfers – Ordinary Membership to Diamond Membership (DGA)

Burch, Clive, Cleadon near Sunderland, 1996.
Coker, Olive Admira, London, 1996.
Jones, Maureen, Allesley, Coventry, 1996.
Lam, Siu-Wing, Hong Kong, 1996.

Transfers – Ordinary Members to Fellowship (FGA)

Aarden-Kilger, Flavia, L.M., Haalderen, The Netherlands, 1996.
Achten, Louisa W.W., Horst, The Netherlands, 1996.
Adams, Victoria, London, 1996.
Forbes, Victoria E., Portadown, Co. Armagh, N. Ireland, 1996.
Fujii, Noboru, Nara City, Nara Pref, Japan, 1996.
Haria, Aarti Vipul, Nairobi, Kenya, 1996.

GAGTL Gem Tutorial Centre

5 February

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A day looking at all aspects of these gems – natural, treated, synthetic and imitation.
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19 March

Preliminary Workshop
A day of practical tuition for Preliminary students and those who need an introduction to instruments, stones and crystals. You can learn to use the 10x lens to maximum efficiency, to observe the effects and results from the main gem testing instruments and to understand important aspects of crystals in gemmology.
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Hegi, Matthieu Manuel Marie, Geneva, Switzerland, 1996.
Ho Yan Yee, Winnie, Hong Kong, 1996.
Hopley, Katharine Bridget, Coventry, 1996.
Khairallah, Theresa, London, 1996.
Kitamon, Hideaki, Yamatokouriyam City, Nara Pref, Japan, 1996.
Kritikou, Eleni, London, 1996.
Lam Chiu Hung, Kowloon, Hong Kong, 1996.

Transfer – Ordinary Members to Fellowship (FGA)

Li, Lung Hsing, Taichung, Taiwan, 1996.
Lindwall, Torbjorn, Lannavaara, Sweden, 1996.
Mackay, Colin Alexander, Edinburgh, 1996.
Mourtzanos, Stefanos M., Rethymno, Crete, 1996.
Raphael, Menachem, Alwoodley, Leeds, 1996.
Ren Jiakai, Wuhan, P.R. China, 1996.
Ronkko, Veera Viktoria, London, 1996.
Schutt, Alan W., Coombe Dingle, Bristol, 1996.
Sharpe, Erica Jane, Wells, 1996.
Susan-Roet, V.E., Naarden, The Netherlands, 1996.
Yoshimura, Shinya, Osaka-City, Osaka, Japan, 1996.

At a meeting of the Council of Management held at 27 Greville Street, London EC1N 8SU, on 23 October 1996 the business transacted included the election of the following:

Diamond Membership (DGA)

Lao, Weng Hong, Macau, Hong Kong, 1996.
Mistry, Janak, Nanpura, Surat, India, 1996.
Wu, Liang-Chin, Tianan, Taiwan, 1996.

Diamond Membership and Fellowship (FGA/DGA)

Birrell, Andrew Tierney, N'Maidens, 1992/1996.

Fellowship (FGA)

Bäckström, Ingrid, Frösön, Sweden, 1996.
Clevers, Irene Laurina Rita, Utrecht, The Netherlands, 1996.
Darmudas, Nathan, London, 1983.
Dinh Ly, Huong, Weston, Ont., Canada, 1996.
Lindblom, Joachim Peter Leander, Turku, Finland, 1996.
Pham, Christina Tuyet Lieu Thi, Markham, Ont., Canada, 1996.
Seligman, Dominic, London, 1996.
Verma, Hitesh, Jaipur, India, 1996.
Wu, Ming-Hsun, Taipei, Taiwan, ROC, 1996.

Ordinary Membership

Abaee, Soleman, London.
Boccard, Jean-Marie, Geneva, Switzerland.
Borg Olivier, Kathleen, London.
Chan, Chi-Kian, Hong Kong.
Curran, Rose, Bath.
Day, Rebecca, Whiston.
Kiaer, Elisabeth, London.
Leadbitter, Elizabeth Victoria, South Ruislip.
Mao, Lingyun, Beijing, PR China.
Panagiotou, Panagiotis, Corfu, Greece.
Rosenberg, David, London.
Samaraweera, Basil Jayanatha, Basingstoke.
Shah, Rohit, Nairobi, Kenya.
Shih, Shu-Chuan, Hampstead, London.
Van Zanten, Sander, Arnhem, The Netherlands.
Williams, Cynthia Clare, Uxbridge.
Yang, Yuk Ngor, Sally, Hong Kong.

Laboratory Membership

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Golden Dragon, Islamabad, Pakistan.

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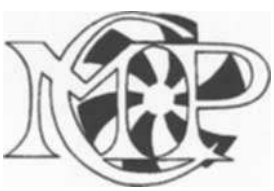

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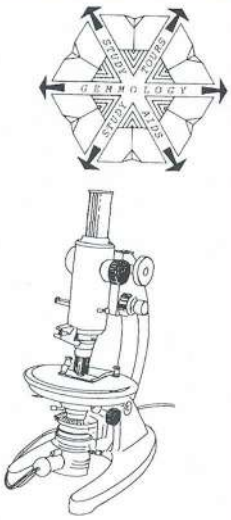

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Typescripts Two copies of all papers should be submitted on A4 paper (or USA equivalent) to the Editor. Typescripts should be double spaced with margins of at least 25 mm. They should be set out in the manner of recent issues of *The Journal* and in conformity with the information set out below. Papers may be of any length, but long papers of more than 10 000 words (unless capable of division into parts or of exceptional importance) are unlikely to be acceptable, whereas a short paper of 400–500 words may achieve early publication.

The abstract, references, notes, captions and tables should be typed double spaced on separate sheets.

On matters of style and rendering, please consult *The Oxford dictionary for writers and editors* (Oxford University Press, 1981).

Title page The title should be as brief as is consistent with clear indication of the content of the paper. It should be followed by the names (with initials) of the authors and by their addresses.

Abstract A short abstract of 50-100 words is required.

Key Words Up to six key words indicating the subject matter of the article should be supplied.

Headings In all headings only the first letter and proper names are capitalized.

A **This is a first level heading**

First level headings are in bold and are flush left on a separate line. The first text line following is flush left.

B *This is a second level heading*

Second level headings are in italics and are flush left on a separate line. The first text line following is flush left.

Illustrations Either transparencies or photographs of good quality can be submitted for both coloured and black-and-white illustrations. It is recommended that authors retain copies of all illustrations because of the risk of loss or damage either during the printing process or in transit.

Diagrams must be of a professional quality and prepared in dense black ink on a good quality surface. Original illustrations will not be returned unless specifically requested.

All illustrations (maps, diagrams and pictures) are numbered consecutively with Arabic numerals and labelled Figure 1, Figure 2, etc. All illustrations are referred to as 'Figures'.

Tables Must be typed double spaced, using few horizontal rules and no vertical rules. They are numbered consecutively with Roman numerals (Table IV, etc.). Titles should be concise, but as independently informative as possible. The approximate position of the Table in the text should be marked in the margin of the typescript.

Notes and References Authors may choose one of two systems:

(1) The Harvard system in which authors' names (no initials) and dates (and specific pages, only in the case of quotations) are given in the main body of the text, e.g. (Gübelin and Koivula, 1986, 29). References are listed alphabetically at the end of the paper under the heading References.

(2) The system in which superscript numbers are inserted in the text (e.g. ... to which Gübelin refers.[3]) and referred to in numerical order at the end of the paper under the heading Notes. Informational notes must be restricted to the minimum; usually the material can be incorporated in the text. If absolutely necessary both systems may be used.

References in both systems should be set out as follows, with *double spacing* for all lines.

Papers Hurwit, K., 1991. Gem Trade Lab notes. *Gems & Gemology*, **27**, 2, 110–11

Books Hughes, R.W., 1990. *Corundum*. Butterworth-Heinemann, London. p. 162

Abbreviations for titles of periodicals are those sanctioned by the *World List of scientific periodicals* 4th edn. The place of publication should always be given when books are referred to.

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Cover Picture

A crystal fragment of tourmaline (green) partly superimposed with a cut green tourmaline which results in a remarkable change of colour. (See 'A new colour-change effect' p.325)

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Volume 25 No. 6 April 1997

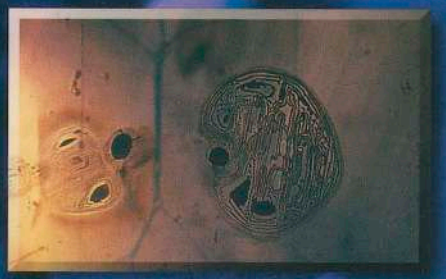

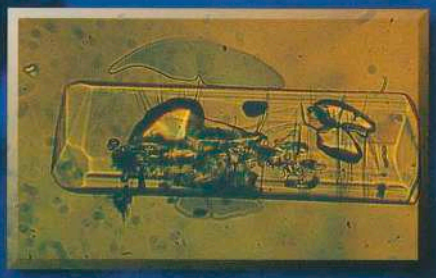

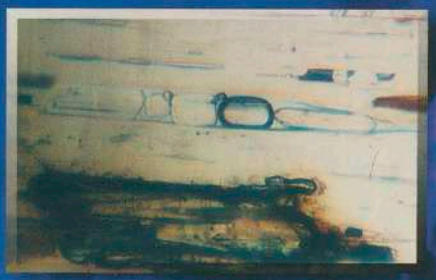

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The identity of reddish-brown inclusions in a new type of Russian hydrothermal synthetic emerald

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ABSTRACT: Transparent reddish-brown platelets in recently produced Russian hydrothermal synthetic emerald were determined as iron oxides with distinct contents of chromium, titanium and nickel.

A new type of Russian hydrothermal synthetic emerald was recently described by Koivula *et al.* (1996). The main difference between the growth methods previously used to grow emeralds (see Schmetzer, 1988) and the most recent type of Russian hydrothermal synthetic emerald is the orientation of the seed (Schmetzer, 1996); chemical and spectroscopic properties of both types of synthetic emerald were found to be more or less identical.

In addition to opaque hexagonal platelets, which were already known as inclusions in the older type of Russian hydrothermal synthetic emerald (Schmetzer, 1988; Sosso and Piacenza, 1995) and thought to be hematite, tiny reddish-brown platelets were mentioned as typical in the new synthetic emerald. These characteristic inclusions were present in all eight faceted samples which were examined by Koivula *et al.* (1996). The nature of these inclusions, however, remained undetermined (see also Scarratt, 1994).

One of the rough synthetic emerald crystals of the new type was found to contain transparent reddish-brown inclusions (Schmetzer, 1996). These were developed as thin, more or less irregularly shaped, somewhat corroded platelets *(Figure 1)*. This particular emerald sample was cut and polished in a direction to enable exposure at the surface of several of the reddish-brown inclusions. The examination of these platelets by electron microprobe revealed that they were iron oxides with distinct chromium, nickel and titanium contents and a small amount of manganese *(Figure 2)*. The thickness of the transparent reddish-brown platelets was found to be 2μm or less and, according to their morphology and colour, are also most probably hematite.

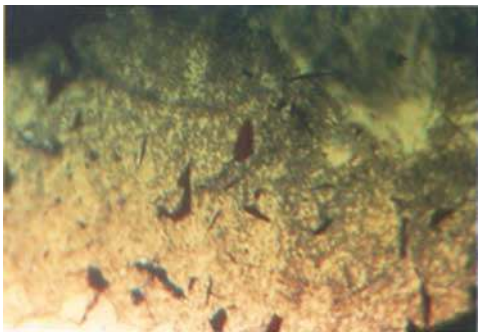

Figure 1: *Reddish-brown transparent platelets in Russian hydrothermal synthetic emerald. Immersion, 50x.*

The opaque hexagonal platelets in the older type of Russian hydrothermal synthetic emerald display a metallic lustre in reflected light and are composed of iron oxides with

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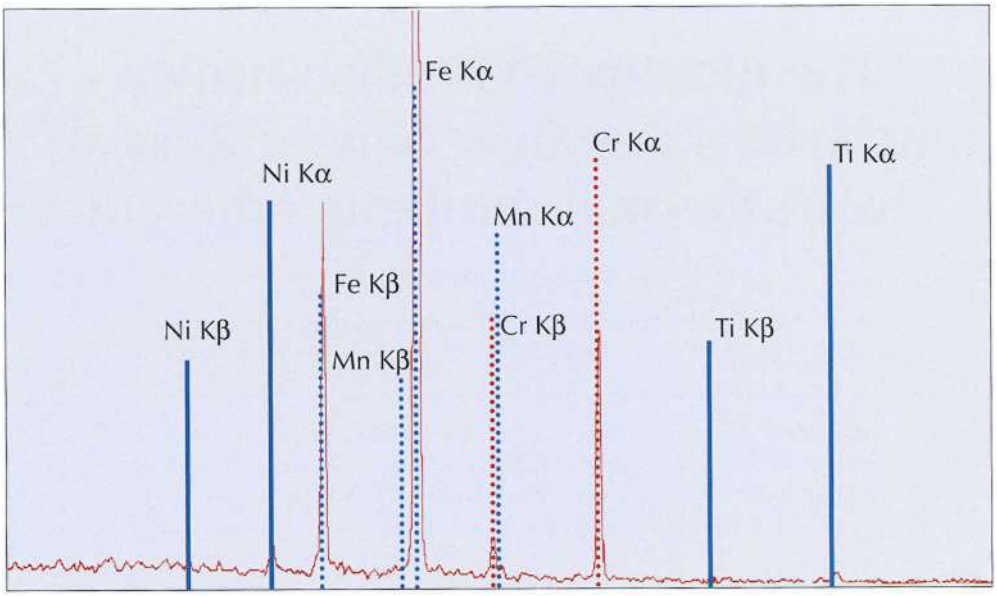

Figure 2: *Wavelength-dispersive spectrum typical of reddish-brown inclusions in Russian hydrothermal synthetic emerald, using LiF as diffracting crystal.*

distinct chromium and titanium contents (Sosso and Piacenza, 1995) or iron oxides with distinct amounts of chromium, titanium and nickel (Hänni, 1996). However, the thickness of the opaque hematite platelets is in the range of 10 to 20μm (Hänni, 1996).

Thus, since they are chemically similar, the only major difference found between the transparent reddish-brown and the opaque iron oxides lies in the thickness of the platelets. Their different appearance under the gemmological microscope is understandable in the light of this result: hematite platelets with a thickness of 2μm or less are transparent reddish-brown and platelets of 10 to 20μm in thickness appear opaque in transmitted light.

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A note on a new occurrence of vanadian grossular garnet from Madagascar

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ABSTRACT: A new occurrence of vanadian grossular garnet from Madagascar is described. Its composition is similar to grossulars from E. Africa and Pakistan and its bright green colour is attributed mainly to vanadium.

Vanadian grossular garnet of gem-quality (tsavorite) is known from East Africa (Kenya, Tanzania; Bridges, 1974) and, to a lesser extent, from Pakistan (Jackson, 1992). A new deposit was discovered at the end of 1991 in the Gogogogo area of south-western Madagascar, about 40 km north of Ampanihy *(Figure 1)* and is being mined by the Delorme Mining Company.

The Malagasy deposit lies in graphitic gneisses associated with marbles within the Precambrian granulitic Vohibory Group. The grossular occurs as porphyroblasts, sometimes idiomorphic, up to several centimetres across, usually fractured, and displays hues ranging from a pale yellowish-green to a dark green. It is surrounded by an assemblage including plagioclase (anorthite), diopside, quartz, graphite and sphene, minerals which may be partially or totally enclosed in the garnet along its borders. This assemblage is more or less replaced by serpentine in the most retrogressively metamorphosed gneiss samples.

Figure 1: *The Gogogogo tsavorite occurrence in Madagascar.*

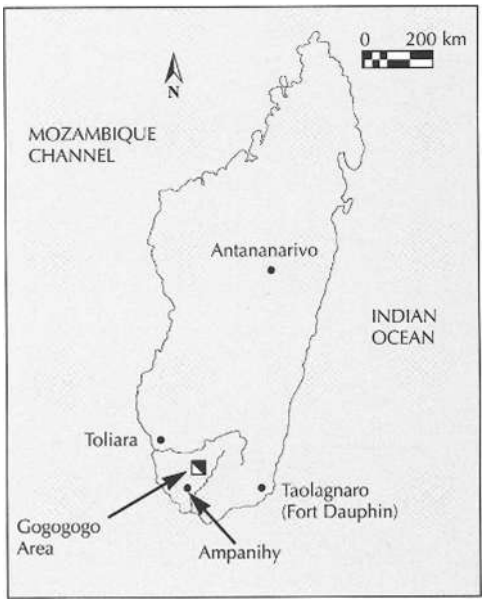

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Figure 2: *Tsavorite rough from Gogogogo, Madagascar; the largest piece is 28 mm long.*

Table I: *Composition of vanadian grossular garnet*

Location	*Madagascar (Gogogogo)*	*Kenya (Lualeni)*[1]	*Kenya (Lualeni)*	*Tanzania (Komolo)*	*Pakistan (Swat)*
RI	1.742	1.743	-	-	1.743
SG	3.62	3.61	-	-	3.64
Wt%	(a)	(b)	(c)	(d)	(e)
SiO_2	39.15	38.70	39.26	42.50	38.17
TiO_2	0.39	0.25	0.43	0.30	0.44
Al_2O_3	20.13	20.90	21.28	20.50	18.51
Cr_2O_3	*	0.19	**	0.12	0.00
V_2O_3	2.50	3.30	1.71	1.20	4.52
FeO	0.07	0.05	0.10†	0.10	0.05†
MnO	0.72	0.75	0.74	0.50	0.30
MgO	0.50	0.50	0.50	0.30	0.10
CaO	36.37	35.10	36.12	34.50	36.62
Total	99.83	99.74	100.14	100.02	98.71
Proportions of garnet group end members					
Grossular	0.91	0.90	0.93	0.95	0.91
Goldmanite	0.05	0.06	0.03	0.02	0.08
Uvarovite	0.01	0.00	0.00	0.00	0.00
Andradite	-	-	0.00	-	0.00
Almandine	0.00	0.00	-	0.00	-
Pyrope	0.02	0.02	0.02	0.01	0.00
Spessartine	0.01	0.02	0.02	0.01	0.01

*$Cr_2O_3 \approx 0.3$; **$Cr_2O_3 < 0.05$; †as Fe_2O_3
(a) Average of 6 analyses, (b) From Gübelin and Weibel (1975), (c) Average analysis from Key and Hill (1989), (d) From Muije *et al.* (1979), (e) Average analysis from Jackson (1992)
[1]Which has also occurred in the gemmological literature spelled Lualenyi

Some physical and chemical properties have been determined for a relatively dark green specimen of garnet 28 mm in length (largest piece in *Figure 2*). The results are given in *Table I* with comparable data from the literature. With a refractive index of 1.742 and a specific gravity of 3.62, the garnet examined has physical characteristics similar to those measured for specimens from Kenya, Tanzania (Gübelin and Weibel, 1975; Manson and Stockton, 1982) and Pakistan (Jackson, 1992).

Chemically also it is comparable to the green garnets from East Africa, in particular Kenyan, and Pakistani deposits. The main colouring agent is vanadium. In *Table I* we have not reported the Cr_2O_3 content of our sample because, with the overlap of VKβ on CrKα, it is difficult to determine Cr content accurately. Nevertheless, after correction the Cr_2O_3 concentration is estimated at 0.3%, and it is noteworthy that even with this value the chromium would have a significant effect on the green coloration of the grossular (Manson and Stockton, 1982).

Though still very limited, the first data reported in this note already show that many similarities exist between the tsavorite examined from Gogogogo and samples from the better known deposits of Kenya and Tanzania. This provides yet another geological link between the island of Madagascar and this portion of East Africa, and a fuller study of the green grossular garnets is in progress.

Acknowledgements

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A Raman microscope in the gemmological laboratory: first experiences of application

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ABSTRACT: Various applications of Raman spectroscopy in a gemmological laboratory are discussed with examples. The major advantage of this system over classical methods of gem testing is the non-destructive identification of inclusions in gemstones and the determination of organic fracture fillings in emeralds. Also, quick and precise identification of gemstones unmounted or in jewellery, as well as the non-destructive analysis of archaeological samples are possible. Due to the high resolution of the instrument, several phases in a gemstone can be identified. Limitations of the Raman microprobe are also listed.

Keywords: Raman spectroscopy, inclusions, gemstone identification, fissure fillings, archeometry

Introduction

The Raman effect was discovered by the Indian physicist Sir C.V. Raman at the beginning of this century. He observed that molecules which were hit by a monochromatic light beam scattered the light and produced spectra which were characteristic for different materials. Although Raman spectroscopy has so far not been widely known in the study of gemstones, it was introduced as an analytical tool for minerals a long time ago. Raman spectroscopy is also well established in other areas of application, such as physical chemistry, materials science, and superconductor and semiconductor physics.

Raman spectrometers have traditionally been large and very expensive instruments, but recent technical developments have revolutionized this technique. The traditional, rather insensitive instruments can be replaced by modern, compact, highly sensitive, easy-to-use and flexible instruments, more suited to the gemmological laboratory (see, for example, Williams *et al.*, 1994). A typical instrument consists of a classical microscope with either transmitted or reflected light, a low-power laser excitation source, the spectrometer for high resolution light analysis and an appropriate computer for data collection and analysis. The total system fits easily on a desk top *(Figure 1)*. For these reasons, Raman microscopes are gradually becoming more widespread in gemmological laboratories around the world, among them the University of Science and Technology in Nantes, AIGS Bangkok, and CISGEM Milan.

The Raman microscope presents the gemmologist with a unique combination of

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properties which make it a useful additional technique in tackling gemmological problems. These properties include a high spatial resolution, as low as one micrometre, allowing the highly accurate positioning of the microscope to study inclusions as small as one micrometre. With a high-power objective and spatial light filtering in the spectrometer, the system can be 'confocal', allowing the operator to construct profiles of layered compounds or inclusions inside gemstones, with minimal contribution from the main bulk species. In addition, the analysis is rapid, requires no sample preparation and, most importantly, is non-destructive.

The Raman microscope can thus provide spectra typical of the analysed materials. These spectra can be identified by comparison with known spectra, which means that a large set of reference spectra is an important condition for the successful use of the method.

The following references are generally recommended for understanding the method (McMillan and Hofmeister, 1988; McMillan, 1989); for its mineralogical (Griffin, 1987; Smith, 1987; Malézieux, 1990) and for its gemmological applications (Dhamelincourt and Schubnel, 1977; Delé-Dubois *et al.*, 1980; Delé-Dubois *et al.*, 1981; Delé-Dubois and Merlin, 1986; Pinet *et al.*, 1992; Schubnel, 1992; Lasnier, 1995) should be consulted.

Experimental and technical background

Most gemmologists are familiar with visible spectroscopy, i.e. from an incident broad band white light source, characteristic wavelengths or energies are absorbed by chromophore elements such as chromium in ruby. Fewer are familiar with emission spectroscopy and its application, for example, in X-ray fluorescence. Here the incident energy excites electrons in the substrate, which then decay back to the ground state, *emitting* distinct wavelengths of light, allowing the identification of chemical elements in the substrate (Stern and Hänni, 1982; Hänni, 1993).

The Raman effect is, in contrast, a scattering technique in which a monochromatic light source is used (usually a visible laser). Whilst most of the light is simply scattered and contains no useful information (the so-called Rayleigh or elastic scattering), a small amount, typically one photon in 10^6–10^8, is re-emitted having lost some energy. This shifted or Stokes radiation appears as lines in a spectrum characteristic for the substance under study. Most materials that the gemmologist or mineralogist will encounter have a typical Raman spectrum, serving as a 'fingerprint' for that type of material. The only major subset of materials that cannot be studied are metals and alloys. In addition, subtle changes within one material such as alterations in crystallinity and composition can often be detected.

Figure 1: *A Renishaw Raman microscope installed on a laboratory table at SSEF. The laser source is situated behind the spectrometer body.*

The Raman studies presented here were performed using a Renishaw Raman System 1000 equipped with a Peltier cooled CCD detector, together with a 25 mW air-cooled argon ion laser (Omnichrome) lasing at 514 nm *(Figure 1)*. The laser light was focused on to the sample and the scattering collected with an Olympus BH series microscope equipped with x10, x20 and x50 MSPlan objectives.

Using the 'extended scanning' facility, a complete spectrum from 100 up to 9000 cm^{-1} could be measured with a resolution of

Table I: Section of a Swiss Gemmological Institute search file for minerals with Raman peaks in order of the peak intensities. Line 101 shows the figures related to the mineral bustamite (peaks measured in cm^{-1})

	Colour	*Group*	*Mineral*	*1st Peak*	*2nd Peak*	*3rd Peak*	*4th Peak*	*5th Peak*	*Reference*	*Notes*
95			Brochantite	971.4	1074.5	594.3	480.7	386.5	SSEF	TSUMEB
96			Brookite	149.9					JNBM	USA p.222/514.5 nm 209.4s
97			Brookite	150.0	319.0				Schubnel	
98	Brownish-red		Brookite G	150.0	125.0	244.0	319.0	636.0	Maestrati	
99	Brownish-red		Brookite M	150.0	129.0	321.0	634.0		Maestrati	
100	Brownish-red		Brookite P	150.0	637.0	320.0	500.0	365.0	Maestrati	
101	Pinkish-brown		Bustamite	974.2	644.0	1036.5	315.1	405.4	SSEF	Franklin N.J. NMBS
102		Calcite	Calcite	1083.1	278.2	709.1	151.4	1433.1	JNBM	Mexico p.207/514.5 nm 19.9s
103		Calcite	Calcite	1084.0	279.0	709.0	152.0	1435.0	SSEF	Rough CH-Gonzen
104		Calcite	Calcite	1085.2	279.6				SSEF	3.05 ct

2 cm^{-1}. This allowed not just Raman measurements, but also simultaneous Raman and luminescence studies to be performed between 520 and 1000 nm. A standard PC computer with GRAMS/386™ software was used to collect and store the Raman spectra, as well as allowing data analysis, presentation and the ability to compare the collected data with reference spectra stored in a library in the memory.

Reference spectra

The identification of a mineral by Raman spectroscopy is a comparative method. Only in some rare cases is it possible to calculate and predict the peak positions of a given substance. Therefore the necessity of a collection or data base of reference spectra is extremely important. In the recent past some mineral data aimed at creating a comparison file have been published by the French scientists Maestrati (1989) Pinet *et al.* (1992), and Schubnel (1992). Renishaw is presently compiling a more comprehensive data base consisting of spectra supplied by the various users of their system. Meanwhile, the SSEF has developed its own preliminary data-base system with over 500 spectra from more than 200 different minerals using existing data and adding its own analyses. The reference samples analysed in the SSEF not only came mainly from the gemstone collection of one of the authors (HAH) but also from the Museum of Natural History in Basel (NMBS) and from other reliable collections. *Table I* shows an excerpt from the present SSEF search file. The spectra are not only in alphabetical order but also in order of the peaks, so that an unknown mineral can be identified by comparing the major peaks.

Examples of application

Solid inclusions in gemstones are an important indicator of the nature of a stone and may, additionally, be a characteristic feature of a particular origin. The identification of inclusions has been used frequently, among other methods, to determine the authenticity or origin of a stone. However, until recently the identification could in practical terms only be carried out when the inclusion reached the surface of the stone. Analysis of inclusions not reaching the surface is possible down to a depth of 5 mm, but best results are obtained when the inclusion is close to the surface of the stone. *Figure 2a* shows zircon clusters in a sapphire from Burma; *Figure 2b* shows the Raman spectrum of one of these inclusions, which was easily identified using the search file. An invaluable feature of Raman spectroscopy is that the analysis of solid inclusions can be carried out without damage to the gemstone.

The study of *fluid inclusions* in gemstones is of importance for the determination of the true identity of crystals. The phase transitions of fluids, i.e. the determination of the freezing and melting point of fluid inclusions, can be controlled under a microscope with a cooling/heating stage. This method, commonly applied with thin sections is called microthermometry. Peretti *et al.* (1990) have modelled the pressure oscillation during the formation of Kashmir sapphires using this method. Bruder (1995) has investigated fluid inclusions in sapphires and rubies from different origins. He found that primary and pseudo-secondary fluids in sapphires consist of pure CO_2. During his investigations on ruby samples, Bruder found characteristic differences among the compositions and densities of the fluids. He found indications that fluids in rubies from some marble deposits (e.g. in Pakistan and Afghanistan) contain impure CO_2, the admixture most probably being H_2S. Such a mixture gives a characteristic Raman peak at 2011 cm^{-1} and is of importance for the origin determination of unheated rubies. Dubessy *et al.* (1989) have developed a

Figure 2a: *Zircon clusters in a sapphire from Burma, magnification 50x.*

Figure 2b: *Raman spectrum of zircon in a sapphire from Burma. The major peaks from zircon are at 1011, 358 and 436 cm^{-1}. The peak at 414 cm^{-1} belongs to sapphire.*

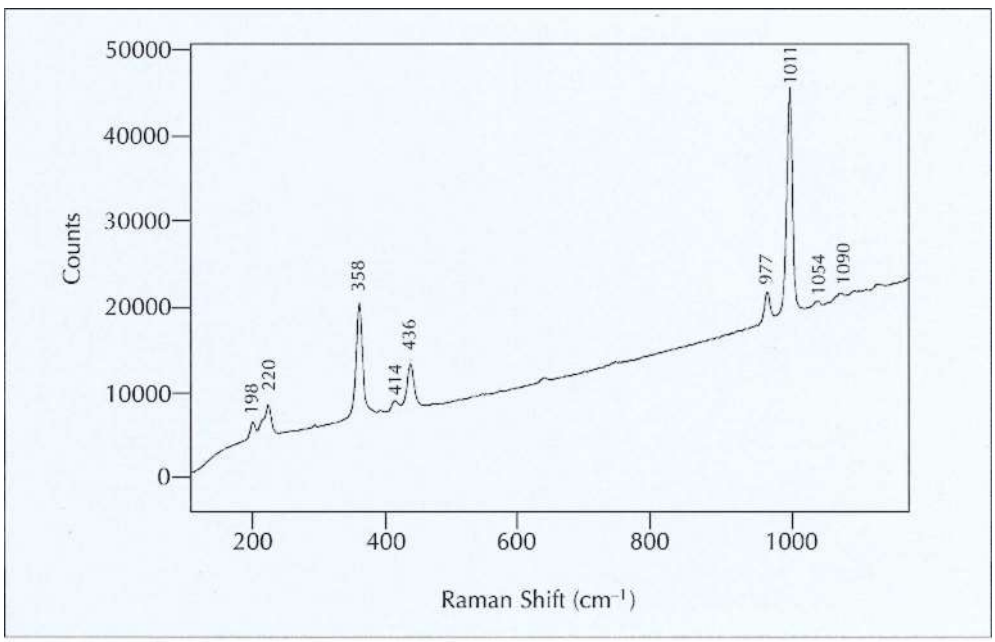

Figure 3a: *Three-phase inclusion in sapphire from Madagascar oriented parallel to the basal plane and showing liquid and gaseous CO_2 and diaspore needles. View parallel to the c-axis, magnification 50x.*

Figure 3b: *Raman spectrum showing the different phases of a three-phase inclusion in sapphire from Madagascar. The labelled peaks are assigned to corundum (top), diaspore (middle) and CO_2 (bottom).*

method of identification of mixed fluids using a program which quantitatively describes the composition of the fluids.

A *three-phase inclusion* in a sapphire from Andranondambo (south Madagascar) was an excellent candidate to evaluate the analytical possibilities with the Renishaw system (Kiefert *et al.*, 1996). *Figure 3a* shows a flat cavity in a tabular sapphire from Andranondambo. The microscope inspection revealed a gas bubble surrounded by a liquid phase containing bent fibrous crystals. The laser beam was directed on to these inclusions and the system produced the Raman spectra shown in *Figure 3b* which identifies corundum as the host, CO_2 and diaspore as inclusions.

The presence of carbon dioxide in fluids in corundum has been reported earlier (Koivula, 1980; Schmetzer and Medenbach, 1988; Bruder, 1995); its identification by Raman spectroscopy, however, is more straightforward than by microthermometry. The presence of a solid phase in CO_2 such as graphite or diaspore has been published in gemmological literature by Schmetzer and Medenbach (1988). Graphite was also identified by Raman spectroscopy in a three-phase inclusion in a sapphire from Sri Lanka.

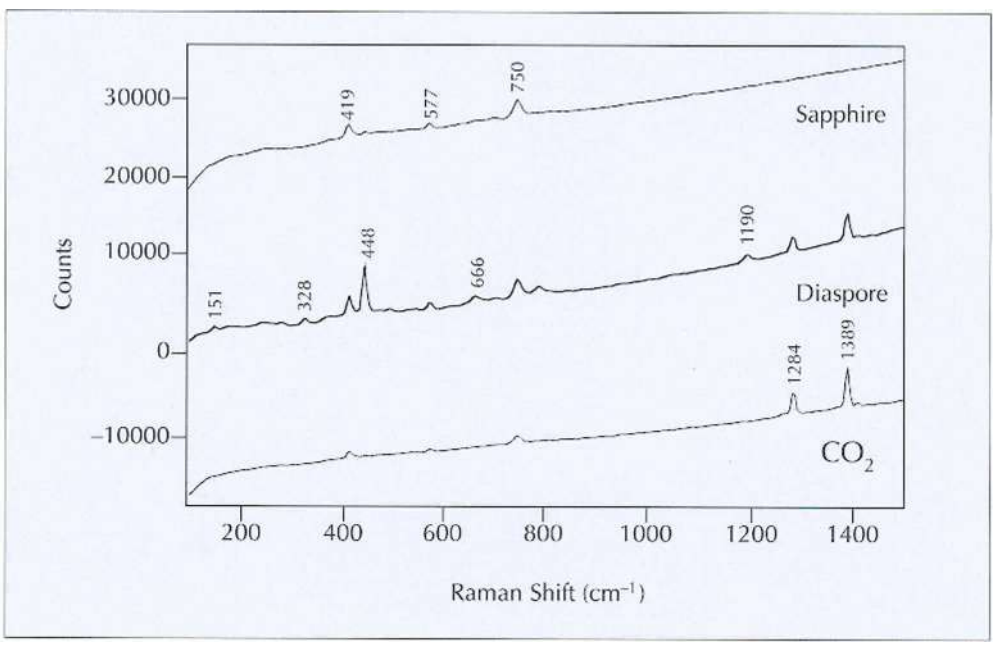

When produced by a flux technique synthetic stones may be identified by Raman spectroscopy by characteristic spectra from their included flux particles. A flux inclusion trapped in Chatham synthetic emerald produces its major Raman peaks at 221 and 570 cm^{-1}, while flux in a Douros synthetic ruby shows Raman peaks at 133, 824 and 850 cm^{-1}.

Organic fracture fillers in emerald frequently need to be identified for test reports. It is quite rare that an emerald is free of fractures and hence free of foreign material in fissures (Hänni, 1992). Organic substances such as oils and natural resins have been used for centuries as fissure fillers to enhance the clarity of emeralds. The organic substances have a refractive index close to that of emeralds and considerably reduce the reflection of fractures filled with air. The range of fillers encompasses numerous substances such as vegetable and mineral oils with volatile components, and more durable fillers like fats and resins (Hänni, 1992).

Nowadays, synthetic resins are used more frequently (Themelis, 1990) because they adhere more permanently to the stone than oils, and may not be released as easily due to their low solubility in detergents and solvents. However, the gem trade is sceptical about these synthetic resins for several reasons. One reason is that the use of artificial resins is relatively new and little is known about how they may alter with time.

The Raman microprobe enables a distinction between natural and artificial resins because of their different molecular structures. The Raman peaks for natural and artificial resin lie in two different parts of the spectrum, the first within the area between 2800 and 3100 cm^{-1}, a second area of characteristic but weaker peaks lies between 1200 and 1700 cm^{-1}. *Figure 4a* shows the Raman spectra of four different substances commonly used for filling fractures in emeralds. Peaks at 1250, 1606, 3008 and 3069 cm^{-1} are strong in artificial resins, but are absent or only very weak in natural resins and oils. Other differences lie within the intensities of certain peaks.

Figure 4a: *Raman spectra of organic substances commonly used to fill fractures in emeralds. The spectrum of the artificial resin, often referred to as 'opticon' in the trade, shows distinct differences from the other substances.*

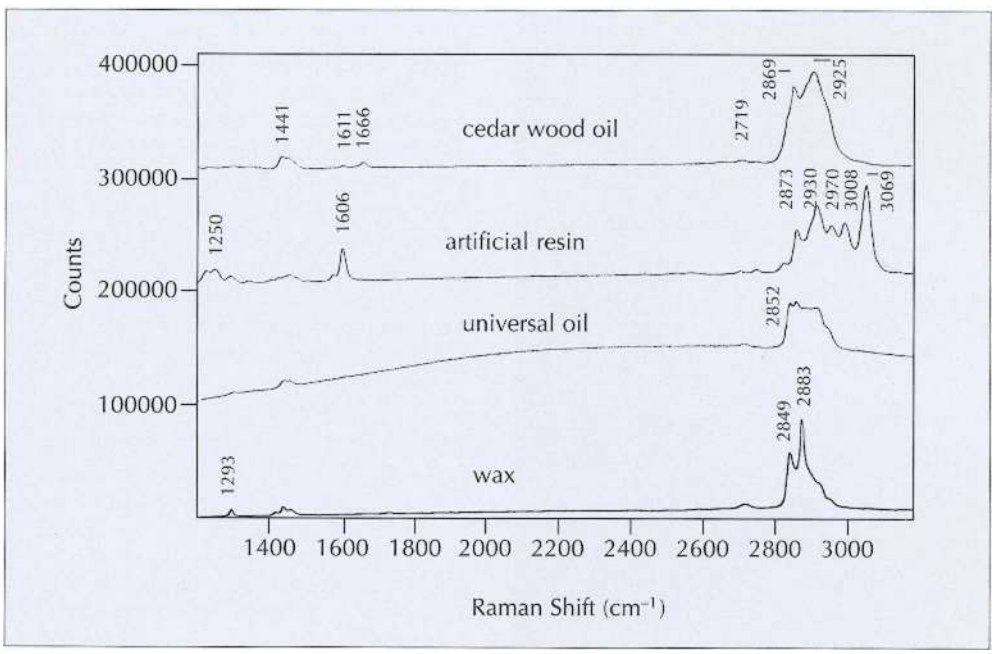

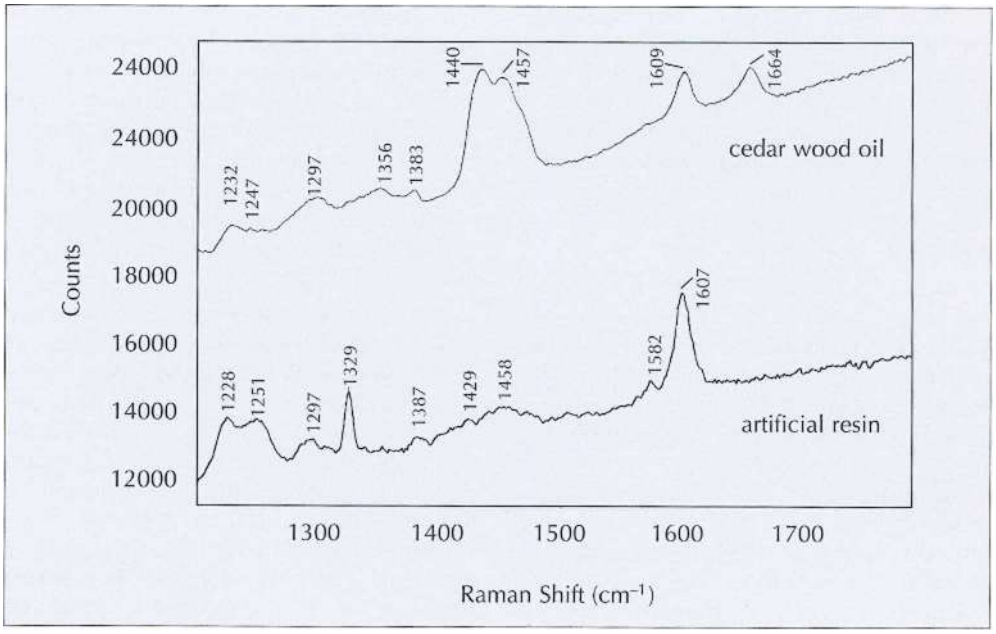

Figure 4b: *Raman spectra of two substances identified in fractures in emeralds.*

Figure 5a: *A watch with moving diamonds under a sapphire cover. By Raman microscopy it is possible to record the Raman line of diamond through the watch glass.*

After such resins have been introduced into emeralds, they may undergo alteration with time. Depending on the degree of alteration, the substance may display an increase in fluorescence which is superimposed on the Raman spectrum of fresh substances, especially in the 2800–3100 cm^{-1} area, so that the peaks in this area may hardly be visible. The 1200–1700 cm^{-1} area is less affected by this fluorescence, so that in some instances the peaks in this area are more useful for identification purposes. *Figure 4b* shows the Raman spectra of two fissure fillers detected in emeralds. The top spectrum shows a natural resin with strong 1440 and 1457 cm^{-1} peaks and an additional peak at 1664 cm^{-1} (*see also Figure 4a*). In comparison, the artificial resin has much higher peak intensities at 1251 cm^{-1} and 1607 cm^{-1}, but much lower intensities in the 1450 cm^{-1} area (*see also Figure 4a*). Hence, in this and in many other cases, the determination of the type of filler in an emerald fissure is possible.

The identification of diamond is most easily done with a thermal probe (thermotester) where direct contact between the instrument

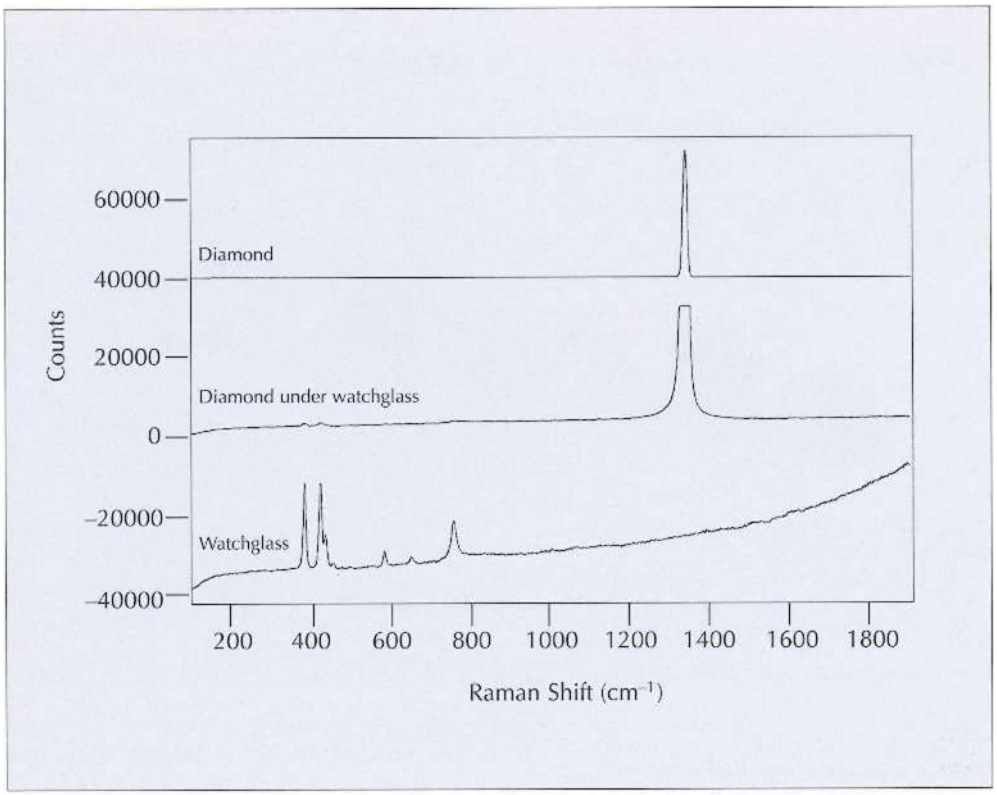

Figure 5b: *Raman spectrum of a diamond under a sapphire watch glass with the comparison spectra of pure diamond and the watch glass.*

and stone can be made. It would seem difficult if not impossible, however, to identify the nature of stones which look like diamond if they are set in a clock face under the watch-glass *(Figure 5a)*. With a Raman microscope it is sufficient to focus the laser beam down through the 'glass' and on the supposed diamonds. The resulting Raman spectrum recorded is a combined spectrum of the 'glass' material and the diamond. The sample diagram in *Figure 5b* shows the Raman characteristics of diamond with corundum (as 'glass cover').

A mixed lot of Burmese cut gemstones (kindly donated by Professor Dr E. Gübelin) was mounted table-up with Blu-Tack on a slide *(Figure 6a)*. The Raman spectra were subsequently recorded and the results compared with reference spectra at first selected as the most likely match. Where this did not lead to a satisfactory match of spectral pattern, i.e. identification, the 'strongest peak' table of our search file was taken as a reference. This way the stones could be identified within a very short time. *Figure 6b* shows spectra of seven identified gemstones. Identification by Raman spectroscopy can also be recommended for rough stones, especially when no characteristic visible absorption spectrum can be obtained or expected.

Identification of mounted gemstones set in jewellery may turn out to be difficult when the setting prevents direct contact of a stone with the refractometer. Pieces of jewellery with historical value, e.g. from museum collections, are in many cases adorned with gemstones. However, it is rather rare that such items have undergone gemmological investigations, mainly because until recently hardness testing was still a recognized gemmological technique

Figure 6a: *Seven Burmese stones fixed with Blu-tack on a glass slide and ready for the microscope sample stage. They are from left to right: peridot, diopside, spinel, amethyst, tourmaline, scapolite and datolite.*

Figure 6b: *Raman spectra of the seven Burmese gemstones.*

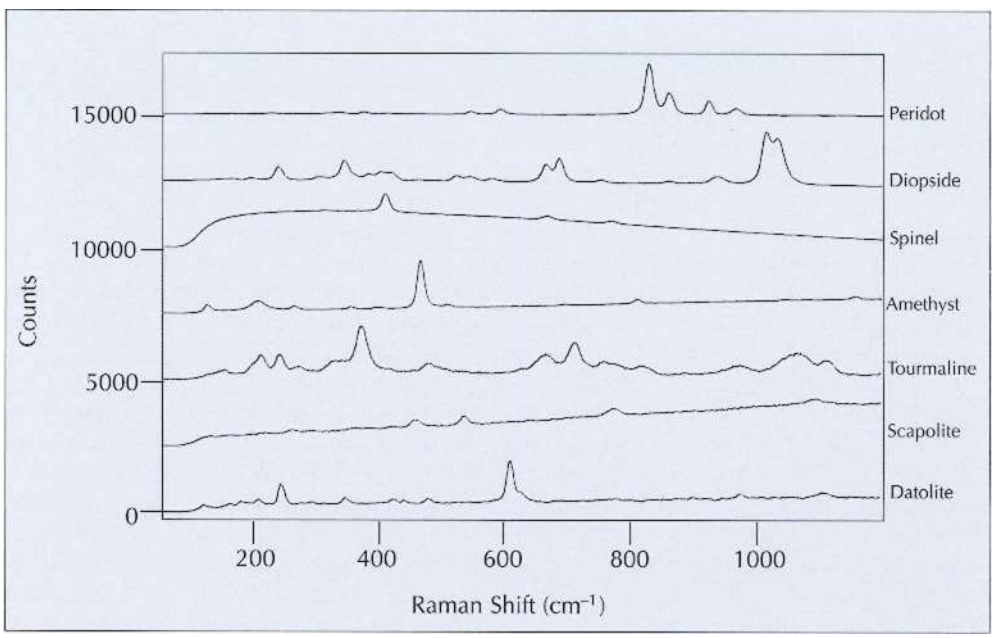

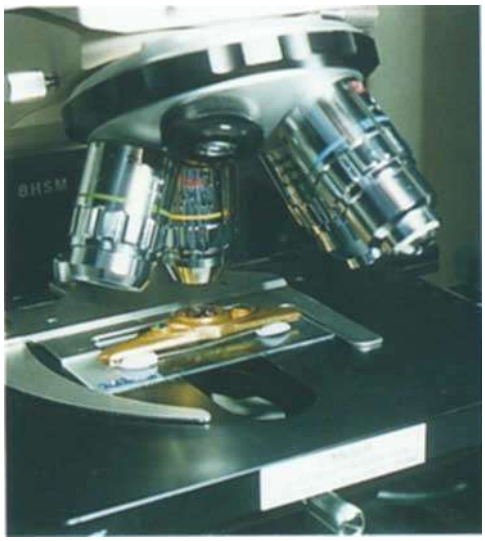

Figure 7: *A bar brooch with a red garnet being analysed on the microscope sample stage.*

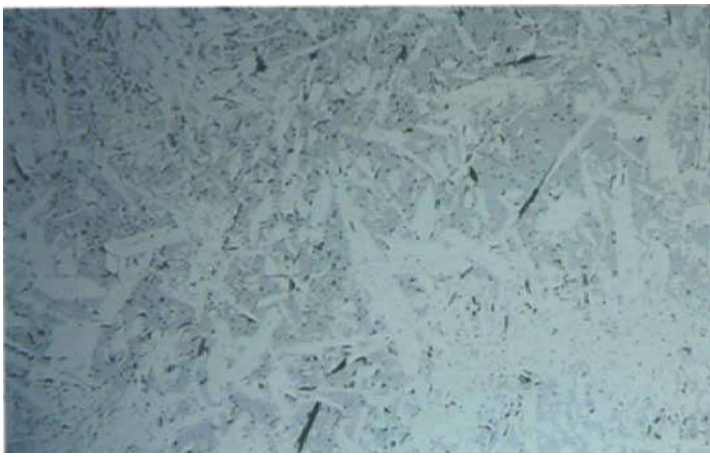

Figure 8a: *A dark violet jade cabochon revealed its complex nature under the Olympus BH microscope used in reflected light mode. The darker mineral groundmass was found to be albite feldspar, the lighter crystals are jadeite, magnification 50x.*

Figure 8b: *Raman spectra of jadeite and albite reference material compared with spectra obtained from the two phases in the violet cabochon.*

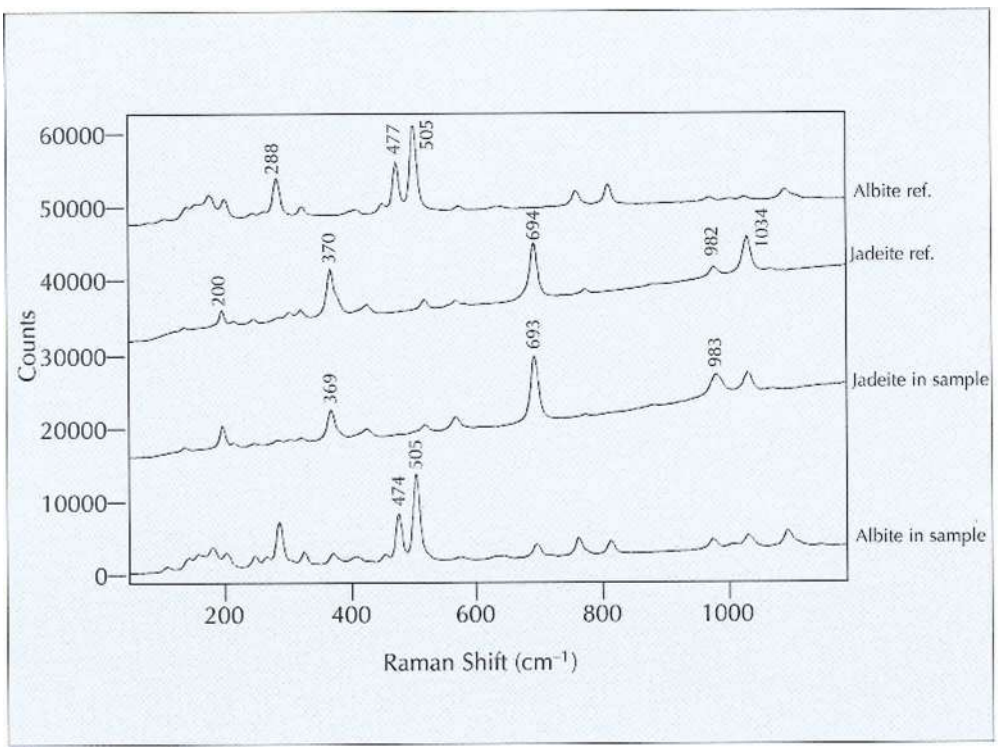

Figure 9: *This prehistoric small axe head (46 mm in length) gave Raman lines of tremolite-actinolite.*

by too many 'identifiers'. Raman spectroscopy now offers an entirely non-destructive means of identification which does not even require mechanical contact between the gem and the analytical tool. This opportunity will hopefully lead to more investigations of museum jewellery (Superchi, 1995).

The brooch shown in *Figure 7* contains a red stone which was easily identified as a garnet from its Raman spectrum, and the optical absorption spectrum confirmed the result.

A violet cabochon was purchased in Mae Sot (Thailand), a market-place for Burmese gemstones. The dark violet colour and the strange structure observed under the microscope first indicated an opaque artificial glass, but a reflected-light image indicated two phases in the material *(Figure 8a)*. Needle-like crystals were recognized and quickly identified as jadeite in a groundmass of lower lustre which was found to be plagioclase feldspar. The closest match in our data base of Raman spectra was found to be that of albite. The spectra of the two components of the gemstone are presented in *Figure 8b* together with the two related reference spectra of jadeite and albite.

Bustamite, a rare gem material, is difficult to identify safely with traditional gemmological means, especially when it has a composite polycrystalline nature and is cut as a cabochon. The values of SG (3.43) and RI (1.67 spot reading) are not conclusive. For the identification of this piece we were also considering the possibility of

Figure 10: *Three Raman spectra of an albite crystal, taken in three directions perpendicular to each other. The directional recording of spectra shows anisotropy with respect to the peak heights, but not the peak positions.*

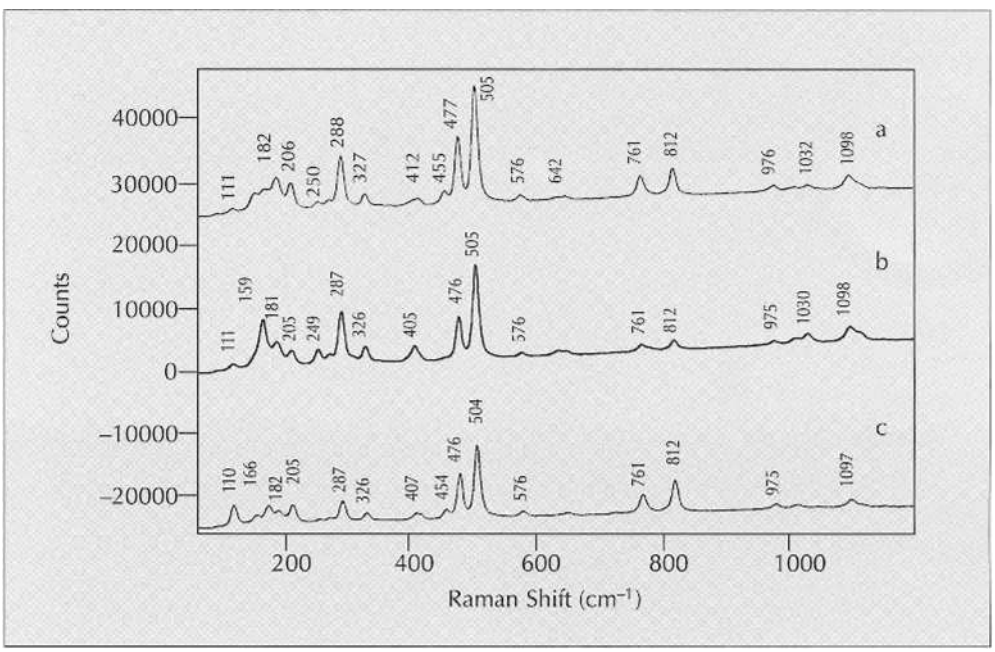

friedelite, another manganese silicate mineral. The Raman spectrum, however, when compared to a bustamite reference (collection of NMBS) allows instant identification. The bustamite reference file, with its major peaks, is shown in line 101 of *Table I*.

A prehistoric axe head (Figure 9) fashioned from an unknown fibrous whitish material was tested for the Laboratory of Prehistoric History of Basel University. Also, for archaeological material, a non-destructive identification technique is a requirement. The spectrum obtained was immediately recognized as a mineral of the amphibole group, the closest fit being with tremolite. In gemmological circles, massive tremolite-actinolite rock is often referred to as nephrite, and is a well known material used to make Stone Age tools. Nephrites are usually greenish due to their iron content (or portion of actinolite in solid solution), but the present sample has a composition close to the iron-free end of the series, i.e. tremolite.

Limitations

Although the cited literature and examples described above prove the importance and usefulness of Raman spectroscopy to gemmology and associated sciences, the method also has some limitations.

The only major subset of materials that do not yield usable Raman spectra are substances such as metals and alloys, characterized by a simple composition and a high symmetry.

Anisotropic minerals produce Raman spectra which can be very different depending on the relative orientation of the laser and the crystal lattice. Fortunately the wave-number position of the peaks is the same in the spectra obtained from every direction. It is only the relative intensity which may vary with the direction. Therefore, when using a data base for spectral comparison which is based on wavelengths of the strongest peaks, one must bear in mind that the sequence from strongest to weakest may change with orientation. An example of small directional differences among Raman spectra in the x-, y- and z-directions of an albite crystal is shown in *Figure 10*. Other minerals, such as phyllosilicates, may show significantly stronger directional differences in their spectra.

We have already remarked upon the general difficulties in getting useful Raman spectra from dense mineral aggregates such as turquoise, howlite, mother-of-pearl, etc. The spectra of such materials suffer from a high contribution of fluorescence radiation, although in some situations the fluorescence can be reduced by reducing the laser power and increasing the measuring time. This could result in a better peak/background ratio.

Although Raman microprobe investigations of gems are generally non-destructive, accidents may still happen with a small number of thermally unstable minerals (e.g. pyrargyrite, hydrated arsenates) or with some organic materials, so care should be exercised in deciding laser intensity and measuring time.

Fluorescent minerals such as ruby and spinel may produce a high amount of non-characteristic fluorescence radiation which might inhibit the analysis of an inclusion. Again, the reduction of the excitation and/or increase of scanning time may help to overcome the problem. In some situations where, for example, organic fillers in emeralds have to be identified, it is also possible to record peaks for an identification in spectral areas where the general fluorescence is small. Luminescence spectra may themselves provide analytical information where the Raman lines are swamped by fluorescence.

When equipped with a standard Olympus microscope the sample stage of the Renishaw Raman Microprobe can be lowered through approximately 15 cm. This free space between the objective and the sample's lower end is a limitation, although it will accommodate most gemstones. For larger pieces, such as a carving or a vase, the fitting of a special microscope objective which reflects the beam through 90° to the side of the microscope, often enables successful collection of data.

Conclusions

Raman spectroscopy offers a wide field of application in which mineralogical and

gemmological identifications play a major role. The fact that this spectral technique is usually non-destructive, is of inestimable value not only in gemmology but also in related sciences such as archaeology. Not only the host mineral but also inclusions can frequently be identified. An important application in gemmology for Raman spectroscopy is the detection of the nature of organic fracture fillings in emeralds. Raman spectroscopy can also aid the identification of gemstones set in jewellery when the usual gemmological identification methods such as determination of the density and refractive index or visible spectroscopy cannot be applied.

Acknowledgements

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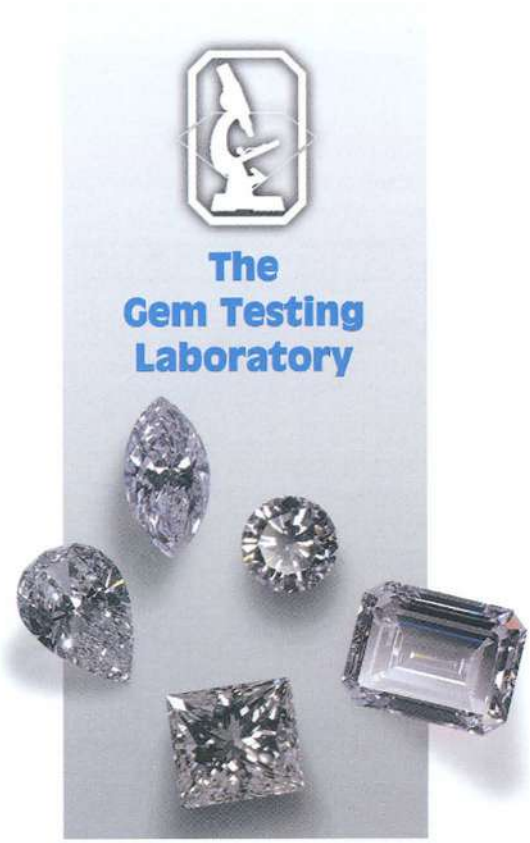

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A study of New Zealand Kauri copal

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ABSTRACT: New Zealand Kauri copal is well known and often appears on the market as a substitute for amber. It can be distinguished from amber by testing with alcohol. Some New Zealand fossil resins associated with coal deposits, however, are similar to non-succinite ambers and are indistinguishable using normal gemmological tests.

Keywords: New Zealand, Kauri, gum, copal, amber.

Introduction

In the early days of New Zealand's history, Kauri gum (as it is popularly known) was one of New Zealand's most important commercial export products *(Figure 1)*. Only ten years after the Colony was formalized by the signing of the Treaty of Waitangi in 1840, records show that 1000 tons were exported to Britain and North America for use in varnishes. Over the succeeding one hundred years, 1850 to 1950, some 450 000 imperial tons were recorded as being exported (McNeill, 1991, pp 18–45). Initially only the finest and most transparent grades were selected for export but in 1865 a 'new' floor covering was invented called linoleum, which led to a market for the poorer grades. Even in the 1980s fifty tons of Kauri gum were exported, mainly for high-quality varnishes for musical instruments. The origin of this gum is the Kauri pine (*Agathis australis,* family Araucariaceae), a conifer which lives for thousands of years. When damaged it may bleed gum or resin for long periods with some masses weighing over 250 kg, even after

Figure 1: *Location of the coal fields from which resin samples were obtained and the southern limit of the Kauri forest in New Zealand.*

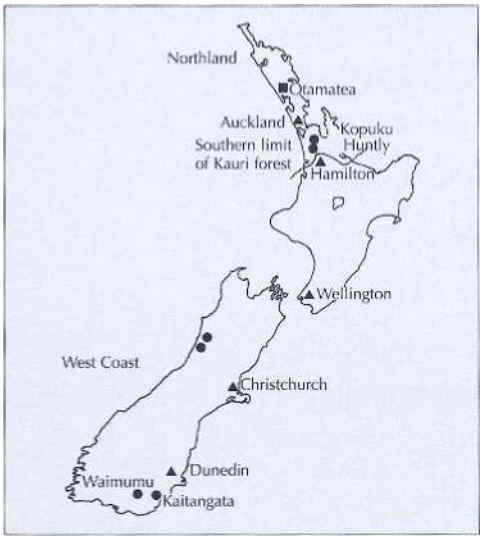

Figure 2: *The main building of the Otamatea Kauri Museum.*

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consolidation. Strictly speaking, these conifers exude *resins* as opposed to *gums*. True gums are hygroscopic substances which absorb water, like gum arabic, to form sticky gels; resins, on the other hand, repel water and gradually expel water droplets from their original constitution even when buried in swampy ground. In this respect it is more correctly referred to as Kauri copal.

Figure 3: *One of the specimen display cabinets in the museum.*

Fortunately, the history of Kauri copal in New Zealand has not been lost. The efforts of Merv Stirling, together with a devoted group of residents from the Otamahia and Matakohe area in the north, have resulted in an extensive museum, the Otamatea Kauri Museum at Matakohe *(Figure 2)*, devoted to the Kauri pine, the pioneer foresters, the timber and its resins.

This museum consists of five sections:

1. the timber, logs, machinery, the forestry aspects;
2. timber products, carvings, furniture, outsized planks and curios in wood;
3. the resin collection;
4. pioneer exhibits and photograph collection;
5. book and souvenir shop.

Figure 4: *A carved lighthouse, part of the museum collection. Carving 30 cm high.*

Figure 5: *A keepsake manufactured by using Kauri copal to embed two small shells and some maidenhair fern. 30 mm long.*

Figure 6: *Lock of golden 'hair' made by drawing heated copal into strands, subsequently plaited. Specimen 60 cm long.*

The large resin collection, mostly the result of private collectors' donations, is one of the most extensive collections of Kauri copal to be seen anywhere *(Figures 3, 4 and 5)*. It includes innumerable examples in the raw state, polished, compressed, carvings and models, moulded, with embedded curios and insects, drawn into locks of plaited hair *(Figure 6)* and dissolved in solvents as varnish.

The study

A study of Kauri copal was undertaken by members of the Gemmological Association of New Zealand to expand the knowledge published in traditional texts such as Webster (1994), Anderson (1990) and Fraquet (1987), and to establish a sound basis for the distinction of Kauri copal (or natural biological resins of recent origin) from true ambers.

The tests were generally based on:

- smell derived from rubbing or touching the specimen with a hot point;
- inclusions;
- physical properties, density and refractive index;
- shaving or cohesion characteristics when cut with a sharp tool;
- solubility in organic solvents;
- response to ultraviolet radiation.

When a gem or ornamental material is investigated, the quality of the results obtained depends on the quality and range of specimens submitted. The set of 25 specimens assembled for this study were contributed by Auckland members of the Gemmological Association of New Zealand's Study Group *(Figure 7)*. The aim was to study as wide a range of Kauri copal as possible, look for variations, tabulate them and then draw some conclusions. Since Kauri copal was traditionally exported as an industrial raw material the criteria were different from those that might be selected if other gems were being considered. The industrial market demanded that the premium grade had to be as near colourless as possible and to be completely soluble in solvents. The low desirability of specimens with high colour and low solubility led to a great deal of it being discarded until a use was found for it in linoleum. The Association felt that specimens retained from shipments

Figure 7: *A selection of the specimens used in the study.*

Figure 8a and b: *A pair of images of a visually similar variety of gnat, (a) in a Baltic amber bead and (b) in a fresh piece of Kauri copal. Specimens 1.5 mm long.*

overseas or carved by diggers on the field might not represent all aspects of the product. The methods of recovery also had a strong bearing on the product. As it was generally a low-value material (top quality yielding only 4 pence per pound in 1870 after scrubbing and dressing), recovery was limited to that from areas of relatively easy access. As these were predominantly the soft peat ground, swamps and bog areas, virtually all of the product was less than one million years old, which is very recent in geological terms. Some of the specimens in this study were derived from coal fields; their positions in the stratigraphic sequence helped to establish their ages and to ensure that the study included some local fossil resin specimens.

Appearance

The colour of the resins varied between colourless and the deepest red-brown. Diaphaneity ranged from a high degree of transparency to opaque. Some pieces were obviously relatively fresh with the typical translucency of a mist of included water droplets while others were quite obviously ancient, being attached to coal or lignite of Miocene age (10 to 25 million years old).

Fragrance and age

The composition of Kauri copal is, as with other natural organic resins, very complex and consists of a whole range of molecules with widely different boiling points (Fraquet, 1987, pp 150–1). A simplified differential thermal analysis performed on a fresh specimen indicated that one component started to boil off at 76°C with others vapourizing at various points up to 300°C when a significant residue remained (300°C was the limit of the test conditions). The most volatile components were not present in the older specimens. No great importance was attached to this procedure as a gemmological test because it is destructive. As expected, the older samples were found to have a much lower intensity of fragrance when rubbed on a soft cloth or the heel of the hand.

This loss of volatile components from the surface could also explain the development of fine cracks that commonly mar the surface of copal five to ten years after it has been polished (although this feature does depend on storage conditions). The volatilization causes a small loss of volume in the outer millimetre or so and, as the bulk of the specimen is unchanged, the brittle nature of the material leads to the opening of surface cracks. Minor cracking can be masked and inhibited to a large extent by replacing the loss of volatiles through rubbing the specimen with wheat germ oil, a high boiling point oil of similar refractive index which fills the cracks by partly dissolving a little of the sidewalls.

Inclusions

Most inclusions in the specimens were what one would expect to find in naturally exuded botanical resins, namely: bubbles of gas, air and water, various fragments of organic material, bark, branches, leaves and pollen. But it was the insects and their *disjecta membra* that provided the most interest.

None of the older specimens contained any recognizable fossils. Fossils were only found in the specimens of apparently recent origin but unfortunately it is an imprecise art to date a sample of copal from included insects. Many of our insect varieties have existed for millions of years. One piece of resin, prised from under the bark of a Kauri tree, was polished to reveal a gnat of identical appearance with one previously photographed by the author in a Baltic amber bead *(Figure 8a and b)*. The insect inclusions were essentially those of the forest and included juvenile wetas (a large native grasshopper *(Figure 9)*), spiders, mites, millipedes, native bees, gnats and cockroach egg-cases *(Figures 10–12)*.

Physical properties

Specific gravity

Various values for specific gravities of copal and amber between 1.03 and 1.11 have been given in the literature. A Hanneman SG balance was assembled to measure the Kauri copals and despite its simple appearance it was capable, with careful use, of very accurate results. Not all of the samples were suitable for physical tests of density or

Figure 9: *A juvenile cave weta trapped in recent Kauri copal. Specimen 6 mm long.*

Figure 11: *New Zealand native honey-bees trapped in Kauri copal. Specimens 20 mm long.*

Figure 10: *A Kauri tree leaf trapped in a recent specimen. 40 mm long.*

Figure 12: *Cockroach egg-cases trapped in Kauri copal. Specimens 3 mm long.*

refractive index due to their surface condition or porosity. For the solid non-porous samples our SG results ranged from 1.03 for the youngest specimen to 1.095 for one that was associated with a coal deposit which has been dated at 40 million years old. Three samples of Baltic amber which we tested gave specific gravities of 1.065 to 1.075. The samples could be assigned to two groups with the recent specimens having SGs of 1.03 to 1.055, while the ambers and mature samples ranged from 1.060 to 1.095.

Refractive index

Using a Rayner Dialdex refractometer all the refractive indices of the suitable samples coincided with the published figure of 1.540. There was no detectable variation even in the third decimal place.

Fluorescence

The response to ultraviolet radiation was consistent in some respects but variable in others. Using the GIA GEM LW and SWUV lamp it was found that the strength of fluorescence with exposure to LWUV was greater than to short wave, in every case. Under SWUV, the weathered and exposed surfaces were often more reactive than the body of the piece, usually exhibiting a yellow, mustard to brown fluorescence, and usually strong enough to mask completely the fluorescence colour of the body of the sample. Fresh breaks or polished areas had variable fluorescence ranging from no response through faint blues, medium blues to white. LWUV radiation caused similar but more intense responses. A proportion of the recent samples were inert to SWUV.

Table I. *New Zealand resins, including Kauri copal, and their properties*

Sample	Description	Source	Age	Specific Gravity (SG)	Refractive Index (RI)	Solubility in Ether	Solubility in Alcohol	Response in SWUV	Response in LWUV	Fragrance
1	Light honey	Northland	Recent		1.540	Slightly soluble	Soluble	Very-light blue	Light blue body	Very fragrant
2	Honey-coloured slight skin	Northland	Recent	1.04		Slightly soluble	Soluble	Inert	Mustard skin Slight blue body	Strong
3a	Honey coloured	Northland	Recent			Soluble	Soluble	Inert	Light blue	Strong
3b	Dark mottled	Northland	Recent	1.04	1.540	Soluble	Soluble	Inert	Light blue	Strong
4	Light honey opaque	Waimumu lignites	Mid-Miocene			Insoluble	Soluble	Inert	Whitish on skin	Moderate
6	Light brown opaque	Wederburn lignites	Late Miocene			Very slightly soluble surface	Soluble	Inert	White surface	Moderate
7	Honey coloured	Northland	Recent	1.055		Insoluble	Soluble	Inert	Inert	Very strong
8a	Light honey	Northland	Recent		1.540	Slightly soluble	Soluble	Inert	Mustard skin	Very strong
8b	Medium brown	Northland	Recent			Insoluble	Soluble	Inert	Light-blue body	Weak
9	Colourless	Northland	Recent	1.045	1.540	Soluble	Soluble	Very faint blue	Strong blue	Strong
10	Honey colour	Northland	Recent	1.048	1.540	Insoluble	Soluble	Slight mustard skin	Mustard skin	Moderate
11	Dark brown transparent	Kaitangata coals	Ancient	1.060	1.540	Insoluble	Insoluble	Very slight blue	Moderate blue	Slight tarry
12	Burnt surface	Northland	Recent			Soluble	Soluble	Light mustard skin	Mustard skin Blue body	Very strong
13	Dark honey, mottled	Northland	Recent			Soluble	Very soluble	Slight blue/grey	Light blue	Very strong
15	Medium brown transparent	Northland	Recent			Soluble	Soluble	Light blue	Mustard skin/blue body	Very strong
16	Light honey translucent	Auckland	Very recent	1.030	1.540	Soluble	Soluble	Very light blue	Light blue	Strong
17	Heterogeneous medium brown	Northland	Recent			Soluble	Soluble	Whitish with blue in dark areas		Moderate
18	Deep honey	Northland	Recent			Soluble	Soluble	Inert	Light blue	Strong
19	Light honey transparent	Baltic		1.078	1.540	Insoluble	Insoluble	Faint white	White on fresh breaks	Weak
20	Dark brown transparent	West Coast	Ancient	1.075	1.540	Insoluble	Insoluble	Light opaque brown skin	Brown opaque skin	Tarry
21	Honey translucent	Baltic		1.065	1.540	Insoluble	Insoluble	Light mustard skin	Mustard skin/white body	Slight
22	Honey translucent	Baltic		1.070		Insoluble	Insoluble	Opaque mustard	Strong mustard skin	Slight
23	Light honey transparent	Huntly West coal	40 m.y.	1.050	1.540	Insoluble	Insoluble	Very light blue	Medium ligh blue	Slight tarry
24	Light grey brown	Yallourn Victoria Australia	25 m.y.			Insoluble	Slightly soluble	Very light blue	Mustard skin, light blue body	Moderate, piney
25	Dark brown transparent	Kopuku coal	Ancient	1.095	1.540	Insoluble	Insoluble	Slight opaque brown skin	Opaque brown skin	Weak tarry

Solubility

All the specimens were tested for solubility in ether and in alcohol, and some were tested in acetone and in glacial acetic acid. The acetone test was later dropped as it gave unhelpful results.

Ether

Ether, a test liquid that has been extensively recommended in the gemmological literature (e.g. Webster, 1994, p. 575), had a variable effect on the samples. The procedure was to place some ether on the surface of the specimen by eye-dropper and allowed to remain for 30 seconds, the drop being replenished when necessary before the control time elapsed.

Three degrees of solubility were recorded:

Soluble where the sample became sticky and/or translucent,

Slightly soluble where only a slight dulling of the surface occurred,

Insoluble where there was no detectable effect.

Using ether, all of the known older specimens were insoluble but so were three of fourteen recent ones.

Alcohol

The test was carried out in a similar way using alcohol (methylated spirit) with extra drops added when necessary for 30 seconds of exposure. This solvent dissolved all of the recent copals, our three late Miocene specimens (10 to 25 million years old; sample nos 4, 6 and 24) but did not affect any of the three amber specimens, or the four that were associated with the mature coal deposits 40 million years old.

Glacial acetic acid

The glacial acetic acid proved to be an excellent testing reagent with its slow evaporation rate and strong solvent power but was discontinued for the following reasons:

1. the reagent has a pungent odour;
2. great care is needed in handling to avoid acid burns;
3. similar results could be obtained with two or three successive drops of alcohol.

Summary

On the basis of testing a range of copals and ambers it can be concluded that:

- recent copals had lower densities but the differences from older resins were not sufficient to be diagnostic;
- fluorescence in UV radiation is not a reliable guide to the nature of a resin as almost all of the specimens reacted to long wave, while eight of the recent specimens were inert to short-wave UV;
- of the solvents it is clear that ether is not satisfactory but alcohol (in the form of methylated spirits) was very reliable giving a clear differentiation between the recent and the true fossil resins. The fossil copal specimens nos 11, 20, 23 and 25 tested in this series, would not be distinguishable from most other varieties of amber on the market today. Using alcohol only the true ambers and the most mature of the copal specimens were insoluble. This reagent clearly can be used to separate all of the recent copals from the most mature ones, including those associated with the immature coals of mid-to-late Miocene age (and also one from Australia reputed to be of similar age). There is one further aspect.

Baltic amber is considered to be a succinite resin containing 3%–8% succinic acid (Fraquet, 1987). Most of the other ambers – that is from Southern Europe, the Dominican Republic, Burma and Borneo – have very low succinic acid contents and are usually referred to as non-succinite ambers. Chemically Kauri copal and the New Zealand fossil samples have low succinic acid content and are similar to ambers in the second category. With the exception of the Burmese variety, succinite ambers are generally rather tougher than non-succinite varieties when shaved with a jeweller's graver or sharp knife (Anderson, 1990, p. 332). Using standard gemmological tests, the toughness, hardness, density and solubility of the most mature specimens were indistinguishable from non-succinite ambers from other sources.

Conclusion

The traditional Kauri resin is young and is classified as a copal; it can be reliably distinguished from amber by testing its solubility with alcohol. However there are some examples of New Zealand fossil resins (ambers) that appear from time to time that are indistinguishable from other non-succinite ambers. These are usually associated with the coal deposits of the South Island, Kaitanga, Waimumu; the Huntly and Kopuku coal fields. Of these only the Huntly and Kopuku fields would be expected to be derived from the Kauri tree as this was the southern limit for the species. However, coal is mined by organizations with little interest in the small amounts of resin or gum associated with their product so it is highly unlikely that appreciable quantities of New Zealand amber would appear on the commercial market.

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Identification of B jade by diffuse reflectance infrared Fourier transform (DRIFT) spectroscopy

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ABSTRACT: Diffuse reflectance infrared Fourier transform (DRIFT) spectroscopy has been found to be a useful and non-destructive tool for providing evidence of bleached and wax- or polymer-impregnated jadeites (Grade B jade). Therefore, the natural and untreated jadeites and those which are wax-buffed (Grade A jade) can be reliably discriminated. The strong absorption peaks shown on the DRIFT spectra can be used to test for the presence of polymers and wax. Results of a systematic DRIFT study done on 10 jadeite samples show that some of them have been bleached and wax- or polymer-impregnated. The DRIFT results, which were backed by basic gemmological tests and X-ray photoelectron spectroscopy (XPS), were compared to similar studies by Fourier transform infrared (FTIR) transmission spectroscopy. In comparison, DRIFT spectroscopy has advantages limited to the testing of very thick (greater than 12 mm) jadeite samples and of relatively thin pieces of Grade A jadeite which may not be very transparent to infrared radiation. It also has an advantage for jadeite jewellery with completely closed mountings, which is rare.

Introduction

The international jade business appears to be suffering from a proliferation of treated stones that have appeared on the market since at least 1989 (Hurwit, 1989; Anon, 1991a and b). As the tampering of this translucent green gem, which is prized throughout Asia, is invisible to the naked eye and sometimes even under the optical microscope, more sophisticated detection methods are now required. Fritsch *et al.* (1992) had used infrared absorption (or transmission) spectroscopy to successfully identify bleached and polymer-impregnated jadeite. This technique is of limited use if the jadeite sample is more than 12 mm thick or if it is already a part of a piece of closed-setting jewellery. In the study carried out by Tay *et al.* (1993) using a scanning electron microscope (SEM), photomicrographs of bleached jadeites showed damaged crystal grain structure but failed to identify the chemical composition of the impurities found between grain boundaries. Possible identification of Grade B jadeites by studies of their structure and 'cracked' texture has been done by Ou Yang, 1993.

Although an energy dispersive X-ray fluorescence (EDXRF) spectrometer can be used to detect differences in the major constituents of jadeites, elements lighter than sodium that make up most polymers (carbon, hydrogen, oxygen and nitrogen) cannot be

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Table I: *Gemmological and spectroscopic data for natural and impregnated jadeite.*

Sample	Specific gravity (3.32)	Ultraviolet fluorescence	XPS C(1s)/Na(1s) ratio	Microscopic observations	Infrared absorption peaks (cm^{-1})	DRIFT absorption peaks (cm^{-1})
1	sink	none	6	Light green patches. Several brown spots. No fissures.	2920, 2852 (very weak)	2920, 2852 (very weak)
2	sink	none	12	Light, even green. No fissures. Some slight breaks.	2920, 2852 (very weak)	2920, 2852 (very weak)
3	sink	none	8	Very light green showing patches of white mineralization. No fissures.	2920, 2852 (weak)	2920, 2852 (weak)
4	sink	none	10	Very light green with white mineralization. Fine fissures.	2920, 2852 (very strong).	2920, 2852, 746 (very strong) 5792, 5676, 4337, 4260 (weak)
5	sink	none	15	Very light green with white mineralization. Fine fissures.	2920, 2852 (strong)	2920, 2852, 746 (strong) 5792, 5676, 4337, 4260 (weak)
6	sink	none	13	Light green with patches of white mineralization. Some fine fissures.	2920, 2852 (very strong)	2920, 2852, 746 (very strong) 5792, 5676, 4337, 4260 (weak)
7	float	chalky-blue (long wave)	43	Light green. Fine fissures and pit marks throughout surface.	3060, 2966, 2931, 2875 (very strong)	5985, 5800, 4685, 4620 (weak) 4324, 4170, 4054 (strong) 3100-2800 (very strong)
8	sink	none	30	Cabochon with green veins and patches. Fine fissures throughout surface.	3060, 2966, 2931, 2875 (strong)	5998, 4814, 4633 (weak) 4324, 4230, 4067 (strong) 3732, 3060, 2970-2850 (very strong)
9	sink	weak chalky-blue (long wave)	34	Light green cabochon with large pit marks. Fine fissures throughout surface.	3060, 2966, 2931, 2875 (strong)	5998, 4814, 4633 (weak) 4324, 4230, 4067 (strong) 3732, 3060, 2970-2850 (very strong)
10	float	chalky-blue (long wave)	40	Green cabochon. Dark green veins and patches, with pit marks. Fissures throughout surface.	3060, 2966, 2931, 2875 (very strong)	5985, 5800, 4685, 4620 (weak) 4324, 4054 (strong) 3100-2800 (very strong)

Wax buffed — Bleached wax impregnated — Polymer impregnated

Figure 1: *The photograph shows 3 samples of wax-buffed jadeite, numbered 1 to 3 (top row, from left to right), 3 samples of bleached wax-impregnated jadeite, numbered 4 to 6 (middle row, from left to right), 4 samples of bleached polymer-impregnated jadeite, numbered 7 to 10 (bottom row, from left to right).*

detected with most EDXRF instruments available to gemmologists (Fritsch, 1992). X-ray photoelectron spectroscopy (XPS), which can be used to detect the high carbon, oxygen and hydrogen content of polymers in jadeite, has been proven to be a reliable technique (Tan *et al.*, 1995). However, its use is severely restricted to research laboratories as the apparatus is expensive and elaborate expertise is required.

In our present investigation, diffuse reflectance infrared Fourier transform (DRIFT) spectroscopy was used for the first time to unambiguously and relatively inexpensively differentiate between Grade A (natural and untreated) and Grade B (bleached wax- or polymer-impregnated) jadeites, and between bleached wax-impregnated jadeite and natural jadeite with wax buffing.

Materials, tests and results

Ten samples of jadeite were used for this study, as shown in *Figure 1*. Three of them were wax-buffed (samples 1–3), another three were bleached wax-impregnated (samples 4–6) and the other four were bleached polymer-impregnated (samples 7–10). Preliminary studies were made on these samples using basic gemmological tests, X-ray photoelectron (XPS) and infrared transmission (FTIR) spectroscopies. The microscopic surface observations and results of preliminary tests are summarized in *Table I*. All the samples originated from Myanmar (Burma).

It can be seen from *Table I* that all of the natural wax-buffed jadeites were inert to ultraviolet irradiation. However, from *Table I*, only some, but not all, of the treated jadeites fluoresced under long-wave ultraviolet light. Also, not all the bleached wax-impregnated jadeites can be differentiated from the ones which are only wax-buffed by ultraviolet fluorescence. This is confirmed by the results of XPS and infrared transmission spectroscopic studies *(Table I)*. The samples were then placed in diiodomethane (specific gravity 3.32) and it can be seen that this test is not a good indication of whether

the samples are polymer impregnated or not. This is because only the samples which have a very high level of polymer impregnation float on diiodomethane, showing a specific gravity of less than 3.32 (since polymers have a specific gravity of less than 2.5).

The samples were further tested using a VG ESCALAB MkII X-ray photoelectron (XPS) spectrometer with an MgKα X-ray source (1253.6 eV photons) at a reduced power of 120 W (12 kV and 10 mA) (Tan, 1995). The carbon to sodium peaks ratio, C(1s)/Na(1s), was then found. The results *(Table I)*, when compared with those obtained by Tan *et al.* (1995), confirmed that samples 1–6 contained wax in varying quantities, as this ratio ranged from 6 to 15. Although, as stated in Tan *et al.* (1995), it is difficult to distinguish a wax-buffed jadeite from that which is wax-impregnated using the C(1s)/Na(1s) ratio, samples 7–10 were obviously polymer-impregnated with very high ratios of between 30 and 43.

In the infrared absorption (or transmission) technique, a Bomem DA3.002 Fourier transform infrared (FTIR) spectrophotometer (Tan *et al.*, 1995) was used to determine whether the samples were wax-buffed, wax-impregnated or polymer-impregnated. The resolution of the specrophotometer used was 4 cm^{-1}. For the samples which were only wax-buffed (samples 1–3), weak absorption peaks could be seen at 2920 and 2852 cm^{-1}, which indicate the presence of wax *(Table I)*. In samples 4–6, very strong absorption peaks at 2920 and 2852 cm^{-1} showed a significantly larger amount of wax, indicating that the jadeite had been wax-impregnated. The presence of several strong and distinct peaks in the 2800–3100 cm^{-1} range for samples 7–10 was due to the absorption of the specific functional groups of the polymer material, confirming that the samples were polymer-impregnated. For such samples, the most characteristic absorption peaks were at 3060, 2966, 2931 and 2875 cm^{-1}.

Diffuse reflectance infrared spectroscopy

The technique of diffuse reflectance spectroscopy is successfully and non-destructively used for surface analysis where more well known techniques are difficult to employ. Excellent spectra of coal (Fuller *et al.*, 1982), for instance, can be obtained by diffuse reflectance. Many substances in their natural state (surfaces of solids) exhibit diffuse reflection, i.e. incident light is scattered in all directions. The diffuse reflection spectra can show both absorbance and reflectance features due to contributions from transmission, internal and specular (mirror-like) reflectance components as well as scattering phenomena in the collected radiation (Wendlandt and Hecht, 1966; Kortüm, 1969).

For quantitative reasons, the diffuse reflectance spectra are generally expressed linearly (Kubelka and Munk, 1931) in the Kubelka-Munk function, $f(R_\infty)$:

$$f(R_\infty) = \frac{(1-R_\infty)^2}{2R_\infty} = \frac{k}{s} = \frac{(\ln 10)\,ac}{s}$$

where R_∞ is the reflectance of the sample at 'infinite' depth (i.e. up to 3 mm), relative to the reflectance of a non-absorbing reference (e.g. KBr); k is the absorbing coefficient, s is the scattering coefficient, a is the absorbance, and c is the sample concentration.

The high sensitivity (particularly to surfaces) and non-destructive sample preparation used for experiments are valuable characteristics of the DRIFT technique. The application of DRIFT to study polymer films and coatings is well established (Culler *et al.*, 1984; Sergides *et al.*, 1987). Furthermore, the application of reflectance infrared spectroscopy to gemmology in general has been reported in Fritsch and Stockton, 1981, and Martin *et al.*, 1989. However, the use of this technique to study the surface of jadeite has not yet been explored. All the 10 samples of jadeite were cleaned with highly volatile propanol before they were analysed to ensure that all the contaminants resulting from handling were removed fully. The DRIFT spectra were recorded using a Perkin-Elmer System 2000 FTIR spectrophotometer with a fast recovery deuterated triglycerine sulphate (FR-DTGS) detector. A Harrick Diffuse Reflectance Attachment (HDRA) with two hemispherical mirrors and four plane mirrors collected the diffuse reflectance spectra in the wavenumber

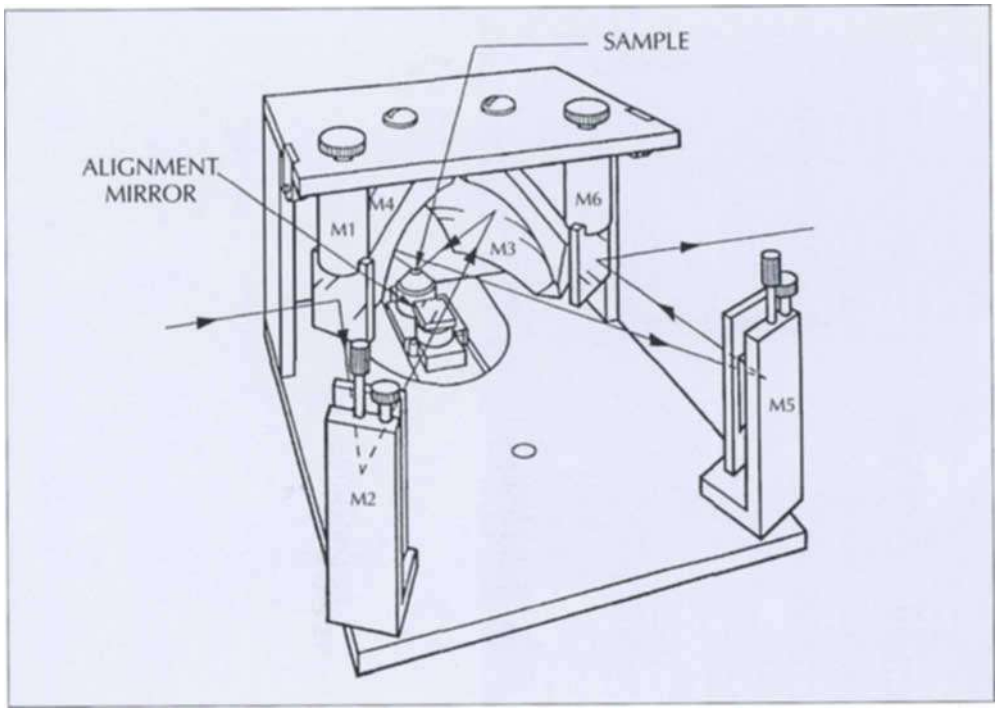

Figure 2: *Schematic drawing of Harrick Diffuse Reflectance Attachment (HDRA) (Harrick Scientific Corporation, 1994). M1, M2, M5, M6: Plane mirrors. M3, M4: Off-axis ellipsoidal mirrors.*

range of 350–6500 cm^{-1}. The schematic drawing of the HDRA, taken from Harrick Scientific Corporation, Document # DOC00008, 1994, is shown in *Figure 2.* The sample holder and the space below mirrors M3 and M4 *(Figure 2)* allowed the testing of jadeite samples up to a few cm thick. Potassium bromide (KBr) powder of less than 74 µm was used as the reference material. At least 100 scans of the sample and the reference material were taken to improve the signal-to-noise ratio of the spectra. The frequency precision of the absorption spectra was expected to be better than 0.5 cm^{-1}. Spectra on both sides of the jadeite sample were recorded to check for consistency of results.

Results and discussion

Figure 3(a) shows a typical infrared (FTIR) transmission spectrum of a natural sample of jadeite with only wax buffing (samples 1–3). Two very weak peaks occurring at 2920 and 2852 cm^{-1} indicate the presence of a small quantity of wax. A typical DRIFT spectrum of these natural samples is shown in *Figure 3(b).* The presence of a small amount of wax used in the wax buffing is similarly confirmed by two weak absorption peaks at 2920 and 2852 cm^{-1}. In contrast to the FTIR transmission spectrum, the DRIFT spectrum shows strong absorption from 1200 to 2200 cm^{-1}, a sharp absorption peak at 700 cm^{-1}, and a weak peak at 5200 cm^{-1}. The reasons for these differences are not yet known. Both DRIFT and FTIR transmission spectra show a typical absorption feature at around 3500 cm^{-1} due to water vapour. A series of lines at around 1600 cm^{-1} in *Figure 3(b)* were actually due to water vapour in the air. It must be added that both sides of each jadeite sample gave almost identical results.

The DRIFT spectrum of a sample of pure paraffin wax illustrated in *Figure 4(a)* shows strong and distinct peaks at 5792, 5676, 4337, 4260, 2920, 2852 and 746 cm^{-1}. *Figure 4(b)*

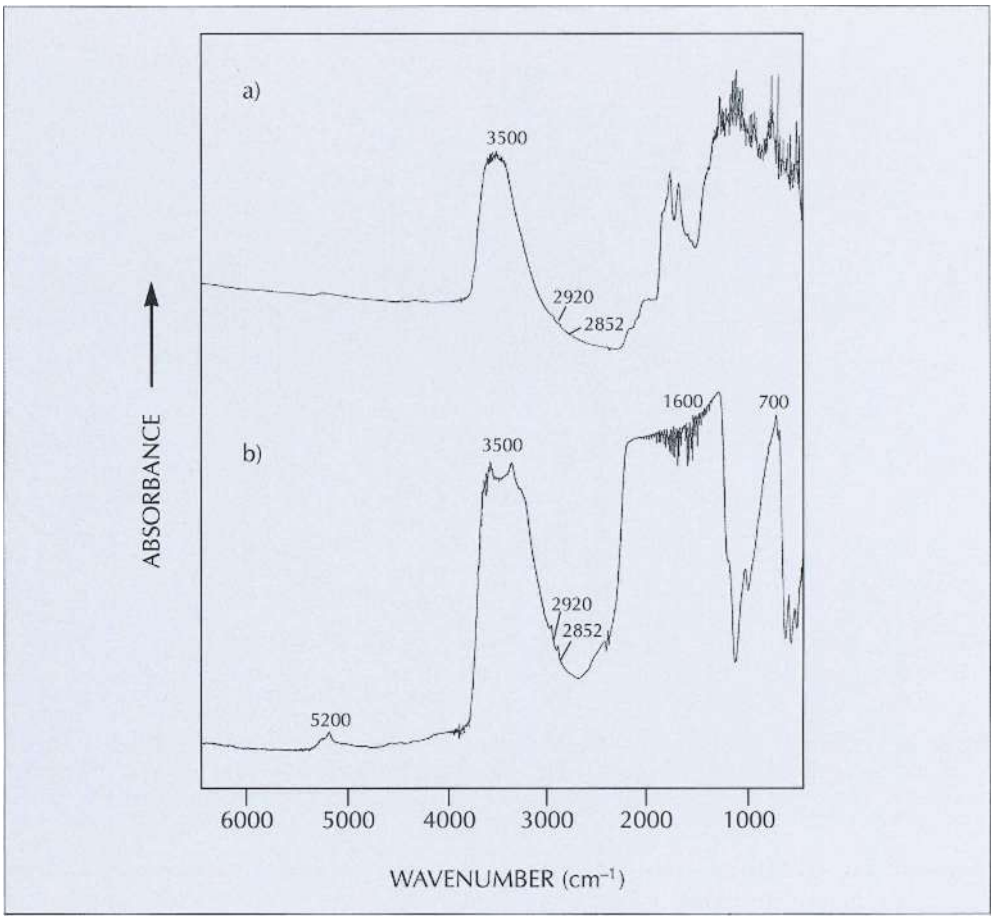

Figure 3: *(a) Infrared transmittance (FTIR) spectrum, and (b) Diffuse reflectance infrared (DRIFT) spectrum, of natural jadeite with wax-buffing (samples 1–3).*

shows a typical DRIFT spectrum of bleached wax-impregnated jadeites (samples 4–6). One can obviously note that these peaks are common to the two spectra. This confirms that wax is definitely present in large quantities in samples 4–6 as compared to the wax peaks in *Figure 3(b)*. The weaker absorption peaks at 5792, 5676, 4337 and 4260 cm^{-1} in the spectrum of paraffin wax, which are not obviously visible in the spectrum of the natural and untreated jadeites with wax buffing *(Figure 3(b))*, are visible in the spectra of the bleached wax-impregnated jadeites *(Figure 4(b))* due to the much higher content of wax. This makes it very easy for us to differentiate between jadeites with wax buffing and jadeites which are wax-impregnated by looking for the presence of significant absorption peaks at these wavenumbers in the DRIFT spectra. The absorption peaks at wavenumbers 2920, 2852 and 746 cm^{-1} are also much stronger in the spectra of the bleached wax-impregnated jadeites than the absorption peaks at these wavenumbers in the spectrum of the natural and untreated jadeites with wax buffing. The absorption peaks of wax in the DRIFT spectra are in good agreement with the infrared transmission spectra of Fritsch *et al.*, 1992.

Figure 5(a) shows the DRIFT spectrum of a polymer commonly used (Fritsch *et al.*, 1992) as a filler in jadeite treatment. The DRIFT spectrum of a highly bleached

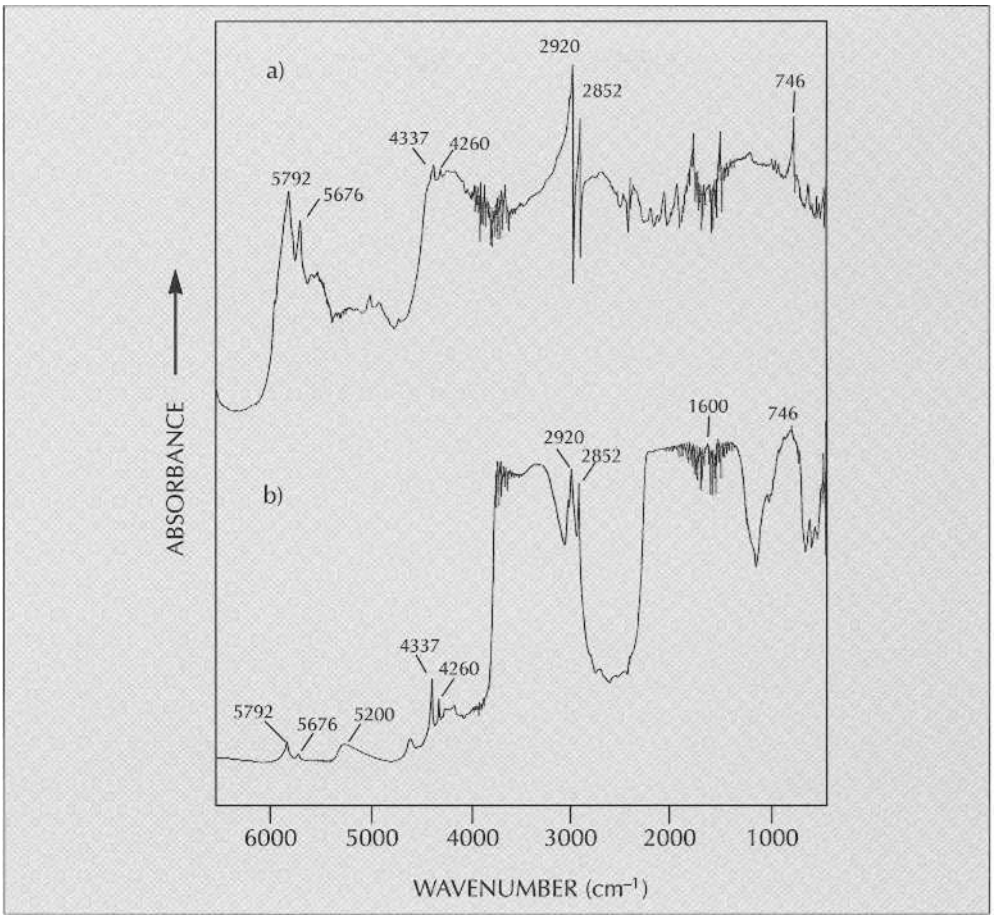

Figure 4: *Diffuse reflectance infrared (DRIFT) spectra of (a) pure paraffin wax, (b) bleached wax-impregnated jadeite (samples 4–6).*

polymer-impregnated jadeite (sample 7) is illustrated in *Figure 5(b)*. It can be observed that the frequency range below 4600 cm^{-1} in *Figure 5(a)* has been almost completely truncated as there is very high absorption of infrared radiation by the polymer below 4600 cm^{-1}. Therefore, studies can only be made on the part of the spectrum where the absorption is not saturated. However, results were still very satisfactory as absorption peaks at wavenumbers 5985, 5820, 5200 and 4685 cm^{-1} were common in both spectra. The strong absorption between 2800 and 3100 cm^{-1} and peaks at 5985, 5800, 4685, 4620, 4324, 4170 and 4054 cm^{-1} in *Figure 5(b)* indicate the significant presence of polymer on the surface of sample 7. None of these absorption peaks was found in the DRIFT spectra of natural and untreated or bleached wax-impregnated jadeite samples. In fact, the DRIFT spectrum in *Figure 5(b)* is in close agreement with that of *Figure 9(c)* of Fritsch *et al.*, 1992, confirming that the same type of polymer was used in the treatment. The strong features at frequencies above 4000 cm^{-1} of the DRIFT spectrum are found to be very useful determinants of the presence of the polymer used in the treatment. It must be noted that a semi-quantitative method to measure the concentration of polymer or wax in Grade B jadeite was reported in Fritsch, 1994.

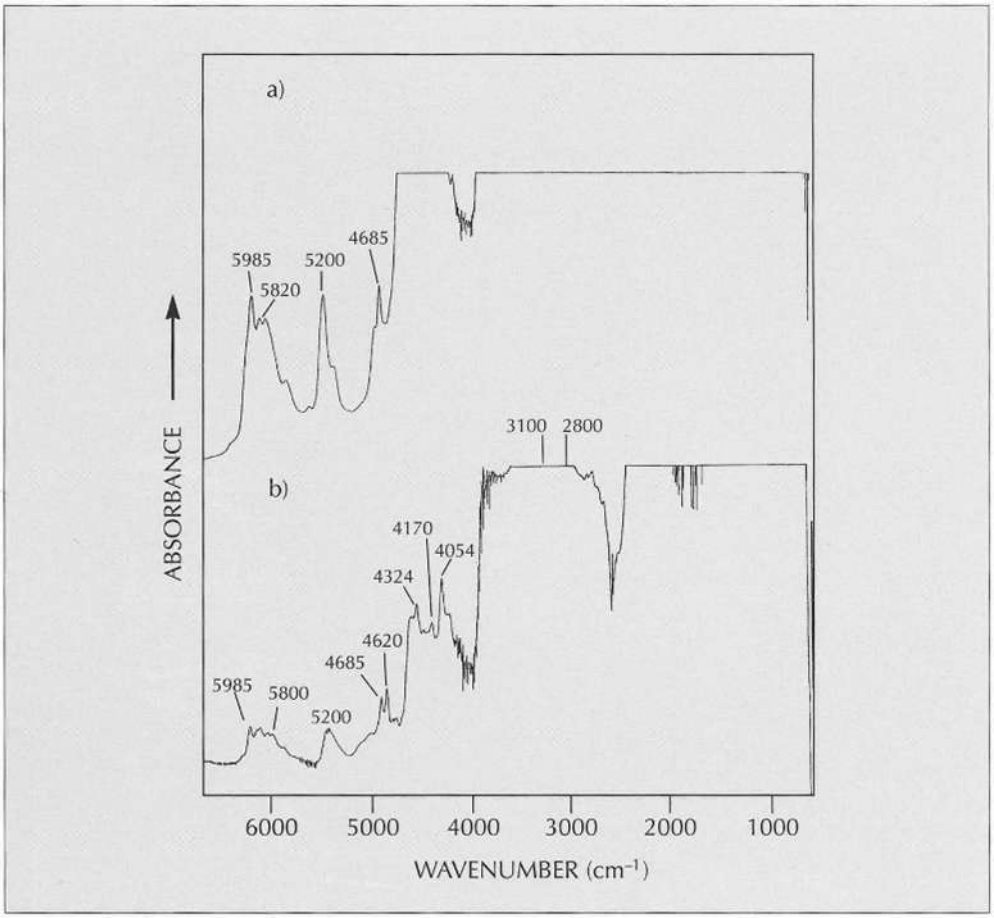

Figure 5: *Diffuse reflectance infrared (DRIFT) spectra of (a) a polymer, (b) highly bleached polymer-impregnated jadeite (sample 7).*

Figure 6 compares the DRIFT spectrum of a jadeite with a low level of polymer-impregnation (*Figure 6(a);* samples 8–9) and the DRIFT spectrum of a jadeite with a higher level of polymer impregnation (*Figure 6(b);* sample 10). The high absorption at 2800–3100 cm^{-1} in *Figure 6(b)* shows the high level of polymer impregnation compared to that of *Figure 6(a).* Although the strong absorption in the region 2800–3100 cm^{-1} clearly indicates the presence of polymer (Fritsch *et al.*, 1992; Tan *et al.*, 1995), the various peaks above 4000 cm^{-1} are in fact more useful indicators of the type of polymer present. The differing peak values above 4000 cm^{-1} in *Figures 5(a)* and *5(b)* show that the polymers were of different types, as polymers of the same type would show similar absorption peak values, e.g. *Figure 5(b)* and *Figure 6(b).*

The resemblance of *Figures 5(b)* and *6(b)* shows that the same type of polymer was used as a filler for impregnation. The stronger absorption peaks of the polymer may be compared with the weaker peaks of wax in *Figure 3(b);* their strength indicates that more polymer than wax was used in the filler. These spectra were in excellent agreement with that recorded using infrared absorption (or transmission) by Fritsch *et al.*, 1992). However, the stronger and more distinct peaks detected using DRIFT are an advantage in the

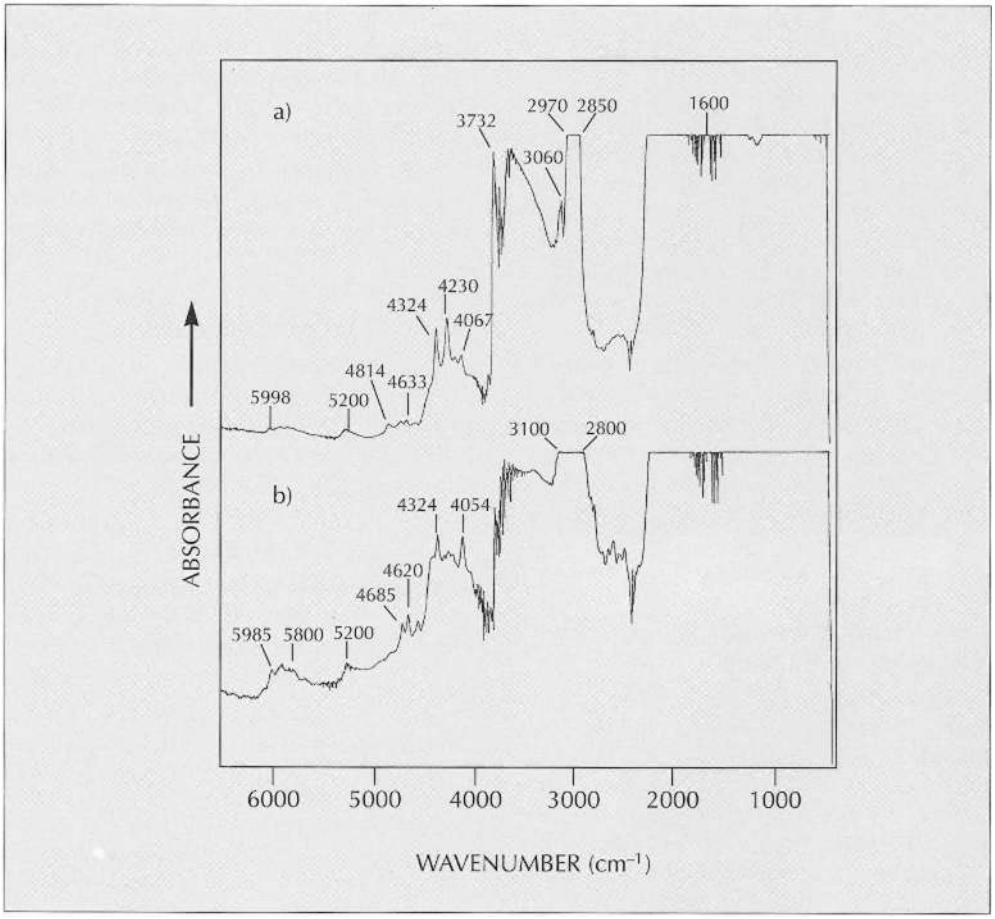

Figure 6: *Diffuse reflectance infrared (DRIFT) spectra of bleached polymer-impregnated jadeite with (a) low (samples 8–9), (b) high (sample 10), levels of impregnation.*

analysis. When one compares *Figure 6(a)* with *Figures 9(b)* and *9(d)* of Fritsch *et al.* (1992), one can see a startling resemblance in the spectra, indicating that the same type of polymer was used in the treatment of the jade. The useful absorption peaks *(Figure 6(a))* for identification of this polymer were at 5998, 4814, 4633, 4324, 4230, 4067, 3732 and 3060 cm^{-1} and at the 2970–2850 cm^{-1} region.

DRIFT spectra collected in our present study clearly demonstrate the high sensitivity of this technique in the wavenumber region studied, 350 to 6500 cm^{-1}. The various strong and distinct absorption features above 2800 cm^{-1} as shown in the *Figures* were useful indicators in differentiating a natural (wax-buffed) jadeite from one which is treated, and from one which is wax-impregnated from one which is polymer-impregnated. Almost identical results obtained for both sides of the jadeite samples demonstrated that the impregnation treatment was done for the whole jadeite surface. A study (Groves *et al.*, 1981) on the comparison of various Fourier transform infrared (FTIR) techniques for polymer films on metal surfaces shows that the sensitivity of the DRIFT technique gives it a clear advantage over other techniques for studying very thin films on substrates without sample preparation or destruction. This technique can be beneficially applied to the study of polymer in jadeite, as demonstrated in this work.

Conclusion

Basic gemmological tests like the measurement of specific gravity and the observation for fluorescence under ultraviolet light can only be used to indicate very high levels of polymer-impregnation, such as in jadeite samples 7 and 10. For low levels of polymer-impregnation, such as those in samples 8–9, or in samples which are wax-impregnated, as in samples 4–6, these tests fail to produce conclusive results.

Use of infrared absorption (or transmission) spectroscopy produces better results, but it is limited in that it cannot be used non-destructively in testing very thick pieces of jade (more than 12 mm thick) with completely closed mountings. Testing of the jade for polymer-impregnation by X-ray photoelectron spectroscopy is effective in determining wax- and polymer-impregnated jadeites, but this method requires expensive and sophisticated equipment which is rarely available.

DRIFT spectroscopy, in the study of jadeite treatment, however, is not hampered by these limitations. It is a relatively inexpensive and yet accurate way of differentiating natural and untreated jadeites from bleached wax- and polymer-impregnated jadeites. Also, since only the surface of the jadeite sample is tested, the thickness of the jade sample or whether it is part of a piece of jewellery is not of any consequence in the experiments using the Harrick Diffuse Reflectance Attachment (HDRA). In addition, the sensitivity of the DRIFT technique allows the reliable identification of the chemical composition of the surface coating of the jadeite sample.

A summary of the significant DRIFT spectroscopy absorption peaks for the 10 samples is given in *Table I*. From this, one can see that weak absorption peaks at wavenumbers 2920 and 2852 cm^{-1} show that the jadeite has been buffed with wax, but not impregnated with wax or polymer. The additional absorption peaks at 5792, 5676, 4337 and 4260 cm^{-1} and the much stronger absorption peaks at 2920 and 2852 cm^{-1} indicate that the bleached jadeite has been impregnated with wax. Furthermore, absorption peaks at wavenumbers 5998, 4814, 4633, 4324, 4230, 4067, 3732, 3060 and 2970–2850 cm^{-1} show that the sample has been polymer-impregnated. Another polymer-impregnated sample gives the peaks at 5985, 5800, 4685, 4620, 4324, 4054 and 3100–2800 cm^{-1}.

Thus, it has been demonstrated that DRIFT spectroscopy is a useful method of identifying bleached and wax- or polymer-impregnated jadeites.

Acknowledgements

The authors wish to acknowledge the kind provision of the jadeite samples by Fu Yau Yuan Jade Wholesale Company, Singapore. They thank H.Y. Chen for his assistance in the recording of the DRIFT spectra.

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The Stuart Jewel: a new acquisition for the National Museums of Scotland

Brian Jackson, FGA, DGA, and Susannah Honeyman, MA, M.Sc.

National Museums of Scotland, Chambers Street, Edinburgh, EH1 1JF

ABSTRACT: A rare seventeenth-century trembler-style hat ornament of rose design, set with rubies probably of Burmese origin, has been acquired by the National Museums of Scotland. Relevant historical information on the Stuart family background is included.

The Stuart Jewel

A rare seventeenth-century hat ornament, still in its original velvet-lined leather case, has been acquired from the family of the young woman who first owned it.

The gold, enamel and ruby-set rose is in the style known as a trembler; the flowerhead is joined to the stem by a spring, which allows it to 'tremble', as if nodding in the breeze *(Figure 1)*. An exotic green parrot perches on one of the leaves.

The 19 rubies, mounted with rubover settings, are all table cut with no pavilion facets and are probably of Burmese origin. The large central stone is approximately 8 x 9 mm and weighs about 2 ct *(Figure 2)*; small stones average about 0.25 ct each. Their colour is more 'rabbit's blood' than the classic 'pigeon blood' as there is a noticeable bluish cast giving the stones a very slight purplish hue. They have a treacly appearance and natural crystalline solid inclusions abound *(Figure 3)*. Collectively and characteristic of dolomitic marble host rock, these include dolomite, calcite, phlogopite, spinel and apatite. Adding to the turbid appearance and characteristic of Burmese origin are patches of tightly woven mats of silk (exsolved rutile). Afghanistan is the only other historic source of dolomitic marble ruby, but faceting quality material was rare and exsolved rutile needles

Figure 1: *The Stuart Jewel, a rose in gold and enamel set with rubies.*

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Figure 2: *Ruby, 8 x 9 mm, at the centre of the rose.*

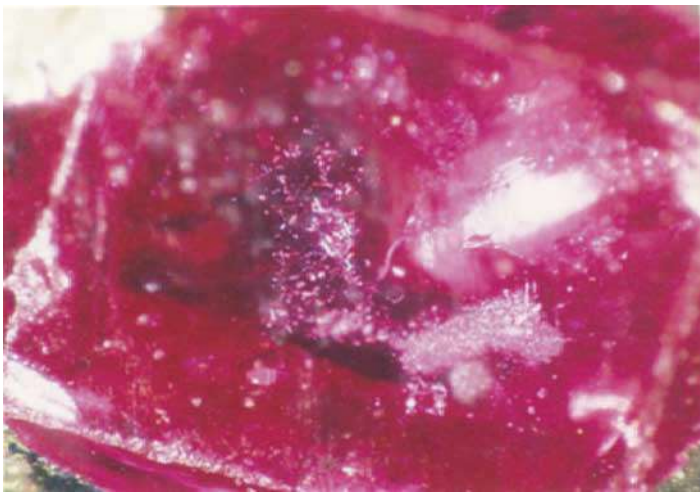

Figure 3: *Inclusions in the central ruby.*

have not been observed (Hughes, 1994). The rubies show a strong chromium spectrum (similar to rubies from other localities) and a strong red fluorescence under LWUV; less strong under SWUV.

This jewel, which is still in excellent condition, belonged to Elizabeth Stuart, a descendant of John Stuart of Ochiltree who accompanied Mary Queen of Scots to France in 1558 and served as colonel in the army of the King of France. James VI of Scotland acknowledged him as 'our blood brother'. His two sons, Hans and Anders, settled in Sweden as mercenary officers. Hans was raised to the Swedish nobility in acknowledgement of his background and rose first to command a regiment of Scots in the Swedish King's pay, then in 1609 to command all other foreign troops.

Their heirs followed in these military footsteps. Hans' grandson was the great General Carl Magnus Stuart (Berg and Langercrantz, 1962). Amongst his many European campaigns, he secured the duchy of Holstein against incursions by Danes in 1700 (Sinclair, 1923–4). In 1716 his daughter Elizabeth married General Otto Wilhelm Stael von Holstein. Perhaps it was he who presented her with this fine jewel. Attempts to locate any portraits of the period that depicted this or a similar jewel were unsuccessful and no information relating to the maker is currently available. Jewellery historians may find this a fascinating area for further research.

The National Museums of Scotland has one other example of this type of seventeenth-century trembler jewel – again an enamelled flower arrangement but set with a portrait of King Charles I; a second flower is surrounded with pale emeralds. Surviving seventeenth-century jewels with a Scottish connection are rare and the Stuart jewel will form part of the display in the new Museum of Scotland (opening in 1998) that deals with Scotland's European links.

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Abstracts

Diamonds | Jewellery | Gems and Minerals | Synthetics and Simulants

Diamonds

Subduction model for the origin of some diamonds in the Phanerozoic of eastern New South Wales.

G.M. Oakes, B.J. Barron and F.L. Sutherland. *Australian Journal of Earth Sciences*, **43**(3), 1996, pp 257–67.

Eastern New South Wales has produced >500 000 carats of alluvial diamonds, mostly from the Copeton-Bingara area. A local derivation is indicated by their distinct tribal character and lack of surface damage; their ^{13}C values and suite of mineral inclusions are unlike those in diamonds from conventional diamond-producing areas, and their Phanerozoic setting is >1000 km from the nearest craton. A subduction model is developed to explain the origin and geology of these diamonds; this model involves prolonged subduction of mature oceanic crust, resulting in the development of a low-*T* metamorphic window into the diamond stability field within the downgoing slab at half the depth required by conventional models. The diamonds are preserved at depth by termination of subduction, and brought to the surface by obduction or by entrainment in suitable magmas. The type of diamond formed depends on the original source rock. This model predicts that the New South Wales diamonds are young (Phanerozoic) and that their features, age, associated mineral and geographic distribution relates to the New South Wales tectonic provinces. The subduction diamond model extends the range of indicator minerals to include corundum and Na-bearing garnet, with a new series of carrier magmas (basanite, nephelinite, leucitite). R.A.H.

Diamonds in eclogitic xenoliths from the Udachnaya kimberlite pipe (Yakutia).

A.V. Bobrov, E.O. Bogacheva, V.K. Garanin and G.P Kudryavtseva. *World of Stones*, **11**, 1996, pp 51–3, illus. in colour.

Diamond and other minerals are described from eclogitic nodules in the Udachnaya pipe, Yakutia, Siberia. Out of 155 diamond-bearing nodules found in the Yakutia kimberlites, 130 are eclogites. Crystal forms are illustrated and described. M.O'D.

Chemische Gasphasenabscheidung von Diamant.

P.R. Buerki. *Gemmologie. Zeitschrift der Deutschen Gemmologischen Gesellschaft*, **45**, 1996, pp 159–74, 10 photos, 1 diagram, 1 table, bibl.

For 14 years, the techniques for depositing polycrystalline and single crystal chemical vapour deposition (CVD) diamond layers on various materials have existed, including use of a hot hydrocarbon/hydrogen plasma in vacuum. Much research has been undertaken and some products have appeared on the market. At present CVD on gem diamonds is not profitable, but this may change in connection with weight increase, improvement of proportions and cut, repair of damaged stones, production of coloured stones, and changes or improvement of existing colours. At present coatings of low quality can easily be recognized under the microscope; however, if the material is carefully chosen, the coating carefully applied and the stone carefully polished after deposition, treatment can be difficult to detect. This applies particularly to single crystal diamond layers where sophisticated techniques such as VIS or IR spectroscopy, or scanning electron microscopy are needed for detection. A table summarizes useful identification methods of CVD treated diamonds. E.S.

A new look at the olivine-lamproitic rocks of the Maddur-Narayanpet area, Mahbubnagar district, Andhra Pradesh, India.

N.V. Chalapathi Rao and V. Madhavan. *Journal of the Geological Society of India*, **47**(6), 1996, pp 649–64.

The olivine lamproitic/kimberlitic rocks of this area are re-examined in the light of new petrological and geochemical data. The Ti-poor phlogopites (TiO_2 < 3 wt.%), the presence of primary calcite and the composition of perovskites are comparable to those of kimberlites; kirschsteinite is reported for the first time from Indian kimberlites. Geochemically, these rocks are low in K_2O (< 3 wt.%), are Mg rich (MgO > 30 wt.%; *mg* 73–82) and have incompatible element enrichment levels similar to kimberlites. The *REE* abundances and their chondrite-normalized distribution patterns are remarkably different from those of the olivine lamproites of Western Australia. It is argued that these rocks

Abstractors

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For further information on many of the topics referred to, consult *Mineralogical Abstracts*.

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of the Mahbubnagar district are true kimberlites and are genetically related to each other, but differ from the kimberlite of the Chigicherla pipe 2 of the Anantpur district. R.A.H.

Magnesite-bearing inclusion assemblage in natural diamond.

A. WANG, J.D. PASTERIS, H.O.A. MEYER AND M.L. DELE-DUBOI. *Earth & Planetary Science Letters*, **141**(1–4), 1996, pp 293–306.

An inclusion in a diamond from the Finsch kimberlite pipe, South Africa, contains a euhedral rhombohedron-shaped crystal (~ 30 μm) coexisting with several idiomorphic olivine (Fo_{93}) grains (~ 80 μm); many tiny anatase particles (~ 2–5 μm) and microcrystallites of diamond (< 1 μm) and disordered graphite are attached to the surface of the magnesite grain. The occurrence of this syngenetic multi-phase inclusion assemblage in a natural diamond provides unambiguous evidence for the existence in the Earth's mantle of magnesite, which has been suggested to be a major carbon reservoir in most of the mantle. R.A.H.

De Beers natural versus synthetic diamond verification instruments.

C.M. WELBOURN, M. COOPER AND P.M. SPEAR. *Gems & Gemology*, **32**(3), 1996, pp 156–69, 14 illus. in colour.

With the advent of cuttable synthetic diamonds appearing on the market, especially from Russia, De Beers have developed two new instruments to distinguish synthetic diamonds from natural diamonds. Descriptions are given of how both the instruments operate together with the results of natural and synthetic diamonds tested.

DiamondSure is the cheaper of the two instruments and able to distinguish many stones rapidly either mounted or unmounted. Identification is based on the 415 nm absorption line, which is found only in natural diamonds, except for about 5 per cent of colourless stones, some fancy yellows, pinks and blues of type IIb.

DiamondView is for positive identification of all types of diamonds, based on their far-ultraviolet-excited fluorescence image. Synthetic diamonds show distinctive growth structures compared to natural diamonds which show octahedral or hummocky cuboid growth structures. DiamondView is more complex and less practical for testing large numbers of diamonds, and these two instruments need to be used together. So far they are not on the market but their practical use has been assessed by several gem-testing laboratories. J.J.

Gems and Minerals

Mineralogical Museum of Saint Petersburg University – 210 years.

G.F. ANASTASENKO AND V.G. KRIVOVICHEV. *World of Stones*, **11**, 1996, pp 26–35, illus. in colour.

Many gem species can be found in the collections of the Mineralogical Museum of St Petersburg University; their history is outlined together with some illustrations. Beryl and diamond crystals are especially prominent in the collections. M.O'D.

Gems from archaeological excavations at Rome (Crypta Balbi).

G.B. ANDREOZZI, G. GRAZIANI AND L. SAGUI. *Gemmologie. Zeitschrift der Deutschen Gemmologischen Gesellschaft*, **45**, 1996, pp 175–88, 8 photos, 3 tables, 2 graphs, bibl.

The Crypta Balbi together with the Pantheon and the Theatre of Marcellus is one of the most important buildings in the Campus Martius built by the Emperor Augustus and Agrippa. The monument was named after General Balbus who financed it and consists of a theatre and a porticoed area behind it: it is here that the excavations took place. Amongst the finds were gemstones and fragments of various quartz varieties (agate, carnelian, jasper, rock crystal), garnet, lapis lazuli, sapphire, emerald, coral, amber, nacre, various rock types and various glasses; some were beautifully engraved. The samples were analyzed by electron micro-probe, IR spectrophotometers and gas chromatography to seek their origins. The emerald was found to be from Djebel Zabarach, Egypt, a sapphire came from Sri Lanka and the amber from the Baltic. The materials were buried in the seventh century AD, while styles of the engravings point to a time between the end of the Republican age and the seventh century AD when they were made. E.S.

Tektites: their origins, properties and use.

C.E.S. ARPS. *Holland Gem Extra*, **2**(4), 1997, pp 2–3.

Review of the nature, types and occurrence of tektites worldwide with a summary of the three main theories on their origin. At the present time it seems most likely that tektites and impact glasses are ejected products of large meteorite impacts on earth. Notes on identification are also given. M.O'D.

The mineralogical collections of the Ural Geological Museum.

V.N. AVDONIN AND Y.A. POLENOV. *World of Stones*, **10**, 196, pp 46–53.

A number of gem-quality crystals are among the specimens in the collections of the Ural Geological Museum which forms part of the Ural Mining Institute in Ekaterinburg. Major items are described and a history of the enterprise given. M.O'D.

Sapphires from Laos and their inclusions.

G. BOSSHART. *Holland Gem Extra*, **2**(4), 1997, pp 4–5.

Gemstone placers of Ban Huai Sai in north-western Laos are producing blue sapphires associated with nearby Quaternary alkali basalt bodies and are usually dark blue. Notes on colour variations are given and on characteristic inclusions, which include frequently-occurring high zircon, U/Th members of the columbite and monazite series, albitic feldspar, rutile, graphite and possibly apatite: other as yet unidentified minerals also occur. Growth structures are prominent but rhombohedral glide planes are absent: negative crystals in basal orientation are surrounded by iridescent fluid rosettes similar to those observed in Thai rubies. A reported source of ruby in Laos is now known to be in a jungle area in the south of the country. M.O'D.

Peruvian opal.

G. Brown. *South African Gemmologist*, **10** (2/3), 1996, pp 16–18, illus. in colour.

A blue opal without play of colour and found at the Acari copper mine in Peru is believed to owe its colour to finely dispersed inclusions of Cu^{2+}. Properties are the same as those shown by other examples of common opal. M.O'D.

Rhodonite of the middle Urals. History and mineralogy.

A.I. Brusnitsyn and A.N. Serkov. *World of Stones*, **10**, 1996, pp 32–40.

Fine ornamental-quality rhodonite is found in the middle Urals of Russia. Details of the material and its occurrence are given with notes on the genesis of the rhodonite rocks. M.O'D.

Crocoite from the Berezovsk gold mines.

A.F. Bushmakin. *World of Stones*, **10**, 1996, pp 28–31.

Some crystals of crocoite recovered from the Berezovsk gold mines near Ekaterinburg, Russia, are of gem quality. Chrome green sphene of similar quality is also found in the area. M.O'D.

Les camées sur malachite.

M. Duchamp. *Revue de Gemmologie*, **129**, 1996, pp 6–9, illus. in colour.

Malachite is not immediately associated with cameo manufacture but this short paper describes several notable examples with details of size, subject and date. M.O'D.

The gem belt of the Urals: an interminable adventure.

E.F. Emlin. *World of Stones*, **10**, 1996, pp 8–22, 6 maps, bibl. in Russian-language section of the issue.

The name Gem Belt is used to denote an area reachable in a day from Ekaterinburg in the Urals. The geology of the area is briefly explained. Details and a chronology of gem mining exploits are given and several of the major gemstone-producing areas are described in some detail. Some celebrated deposits include mines of the Alabashka vein field (blue topaz and beryl), Izumrudnye Kopi (emerald, alexandrite, phenakite), the Lipovskoye mines (pink and polychromatic tourmalines), the Semininskaya mine (greenish-yellow beryl), Shaitanskii Perelivt (agates) and Kornilov Log (rock crystal). Detailed descriptions of emerald, chrysoberyl, alexandrite and phenakite are given. M.O'D.

Jewelry-quality chrome-diopside from the Inagli deposit.

V.G. Gadiyatov. *World of Stones*, **11**, 1996, pp 10–14, illus. in colour, 2 maps.

Probably the world's largest deposit of facet-quality bright green chrome diopside is found at Inagli, eastern Siberia. The geology of the area is described and properties of the diopsides given: colours include a deep emerald-green, grey to greenish-brown and yellowish to brownish-green. Cr content averages 0.5% for the dark green crystals and 0.18% for the light green ones. Trivalent iron is believed to be responsible for the yellow colour. Specimens are reported to be exceptionally transparent. M.O'D.

Fonctions symboliques du quartz dans les sociétés humaines.

E. Gonthier. *Revue de gemmologie*, **129**, 1996, pp 12–17, illus. in colour.

Quartz, especially rock crystal, has played a major part in ornament from the earliest recorded times: several pieces are illustrated and briefly described. M.O'D.

The Dactyliotheca of the Pope Leo XII.

G. Graziani. *Periodico de Minerali (Roma)*, **65**(1–2), 1996, pp 79–204.

A study has been made of a collection of gems and ornamental stones, including 388 items of different cut and shape, given by His Holiness Pope Leo XII to the Mineralogical Laboratory of Rome University 'La Sapienza' in 1824. Hallmarks on a ring and two collets allowed the period and place of manufacture to be put at 1792–1809 in Rome. Most of the specimens appear to consist of small, polished, rounded or octagonal plates of various varieties of silica, but the first section includes 32 jewels mostly set in rings; detailed descriptions of these are given in an appendix, where they are seen to range from topaz, opal, aquamarine, garnet (previously catalogued as zircon or 'ruby spinel'), yellow diamond and yellow sapphire. R.A.H.

Rubini e Zaffiri: inclusioni.

E.J. Gübelin. *Gemmologia Europa*, **V**, 1996, pp 106–36.

Illustrated survey of inclusions in rubies and sapphires with particular reference to specimens obtained from recently discovered and worked deposits. M.O'D.

Hydrogrossular aus Suedafrika – die sogenannte 'Transvaal Jade'.

U. Henn. *Gemmologie. Zeitschrift der Deutschen Gemmologischen Gesellschaft*, **45**, 1996, pp 189–97, 4 photos in colour, 3 photomicrographs, 3 tables, 2 graphs, bibl.

The so-called 'Transvaal Jade' is a translucent to opaque aggregate of hydrogrossular mined near Brits in the Transvaal. Colour is mostly intense green, but there are some pink specimens. Stringers of xenocrysts of pyroxenes, idocrase and chromite are common. Hydrogrossular is a solid solution of the binary series grossular $Ca_3Al_2(SiO_4)_3$ and tricalcium-aluminium-hexahydrate $Ca_3Al_2(OH)_{12}$ where the SiO_4 groups are partly replaced by OH. Water content ranges from 6.2 to 8.0% for the pink samples and 2.2 to 3.5% for the green. RI = 1.725–1.734, SG = 2.54–3.44 for the pink stones; the values for the green varieties are RI = 1.680–1.705, SG = 3.24–3.35. E.S.

Rubini: provenienze e caratteristiche.

E.A. Jobbins. *Gemmologia Europe*. **V**, 1996, pp 12–30.

A survey of some of the more recently-worked ruby deposits (Luc Yen and Khoan Thong in Vietnam, Lin Yaung

Chi and Yadana Kadaykadar in Myanmar and the Pailin area of Kampuchea). Some of the features distinguishing the rough crystals are described, with brief details of mining methods. M.O'D.

Paraíba tourmalines: distribution, mode of occurrence and geologic environment.

J. Karfunkel and R.R. Wegner. *Canadian Gemmologist*, **17**(4), 1996, pp 99–106.

Details are given of the occurrence of copper-bearing blue and green-blue tourmalines from the state of Paraíba, Brazil. Amethyst-violet or emerald green colours are attributed to Mn^{3+} and Mn^{2+}–Ti^{4+} charge-transfer, combined with Cu^{2+} absorptions. The local geology and the mode of occurrence of the tourmalines are described: constants are given in tabular form. Tourmalines of this type occur in two states, Paraíba and Rio Grande do Norte and have been found in at least five different localities. M.O'D.

The radiance of irradiated gemstones.

L.H. Luthiens. *Holland Gem Extra*, **2**(4), 1997, pp 6–11.

Details of the sources, use and results of high energy radiation on gemstones are given with particular reference to diamond and dark blue topaz. The safety of some of the procedures is also discussed. M.O'D.

Mineralientage München 1996.

P. Lyckberg. *Mineralien Welt*, **8**(1), 1997, pp 8–21.

Among specimens exhibited at the 1996 Mineralientage München were tanzanite from Merelani, Tanzania: epidote from Pakistan: citron-yellow tourmaline and intense blue aquamarine from western Nepal: transparent colourless hambergite crystals reaching 7.5 cm in length. From the Pamirs came rose-coloured spinel, orange clinohumite and violet scapolite as well as bicoloured tourmaline, and orange-brown and blue topaz. Corundum and spinel from Vietnam were on display and golden beryl from Orissa, India, crystals of which reached 8 cm in length. M.O'D.

Spektakuläre Quarzneufunde aus Zerrklüften des nepalesischen Himalaya.

G. Niedermayr. *Mineralien Welt*, **8**(1), 1997, pp 24–32, 2 maps.

Particularly large and developed examples of rock crystal have been recovered in the Himalaya of Nepal from alpine cleft-type deposits. The chief producing site is in the Northern Lake area of Dhading district. M.O'D.

Alkali basalts and associated volcaniclastic rocks as a source of sapphire in eastern Australia.

G.M. Oakes, L.M. Barron and S.R. Lishmund. *Australian Journal of Earth Sciences*, **43**(3), 1996, pp 289–98.

Clay-altered volcaniclastic rocks, products of the early explosive stages of Tertiary basaltic episodes, are widespread in the New England region and elsewhere in E. Australia, and are the major source of the alluvial corundum, sapphire and perhaps ruby in the area. Exceptional grades have been recorded during exploration and mining of volcaniclastic sequences in some New England localities, and these rocks therefore constitute prime exploration targets in their own right. Tertiary basaltic lavas are a relatively minor source of corundum and sapphire, although they may be locally significant in the development of derived alluvial orebodies. The contribution by volcaniclastic rocks to detrital accumulations of resistate minerals (e.g. sapphire, zircon and spinel) is strongly and positively disproportionate relative to the abundance of the volcaniclastic rocks themselves. The sapphire-rich provinces are characterized by volcaniclastic rocks that are significantly more fractionated than the surface basalt lavas. R.A.H.

Montana sapphires.

M. O'Donoghue. *Holland Gem Extra*, **2**(4), 1997, pp 3–4.

Summary of the two types of sapphire occurrence in the state of Montana, USA, with notes to accompany an exhibition of specimens from both localities.

[Author's abstract] M.O'D.

On the history of mineralogical studies in the Il'men nature reserve.

V.A. Popov. *World of Stones*, **10**, 1996, pp 42–5.

The Il'men area of the Russian Urals is celebrated for the number and quality of its mineral species. Notes on some of the geological and mineralogical studies carried out on the area are given. M.O'D.

Bernstein der Lausitz.

W. Sauer. *Aufschluss*, **48**, 1997, pp 43–51, illus. in colour.

Details of the occurrence and nature of amber from Lausitz, Saxony, Germany, are given with some notes on the mining history of the area. Some gem-quality material is found in deposits dating from the Tertiary and Quaternary eras. In 1990 approximately 1500 g of amber were found.

M.O'D.

Zaffiri: provenienze e caratteristiche.

K. Scarratt. *Gemmologia Europa*, **V**, 1996, pp 32–54.

Brief overview of the world's main sapphire-bearing areas with particular reference to those in Thailand and Vietnam. Notes on mining techniques are given. M.O'D.

Rubine e zaffiri: storia e leggende.

H-J. Schubnel. *Gemmologia Europa*, **V**, 1996, pp 56–74.

Notes on the occurrence of the corundum gems in pictures and artefacts. M.O'D.

Mineral inclusions in the rock crystal of the subpolar Urals.

L.S. Skobel. *World of Stones*, **10**, 1996, pp 23–7.

Minerals occurring as inclusions in rock crystal from the subpolar Urals, Russia, are listed and described in alphabetical order. M.O'D.

Gemstones in the pegmatites of the eastern Pamirs.

A.M. Skrigitil. *World of Stones*, **11**, 1996, pp 16–25, illus. in colour, 2 maps.

Tourmaline, topaz, scapolite, danburite, beryl, apatite, hambergite and moonstone are described from the eastern Pamirs. These species occur primarily in the pegmatites of the Rangkul' pegmatite field and it is reported that the gem-bearing pegmatites are spatially and genetically related to granites of the Shatput intrusive complex of Alpine age. Properties and varieties of the gem species are given. M.O'D.

Introduction to analyzing internal growth structures: identification of the negative d plane in natural ruby.

C.P. Smith. *Gems & Gemology*, **32**(3), 1996, pp 170–84, 20 illus. in colour, 3 tables.

In the first part of the paper the author introduces the topic of growth structures in stones and how they occur and explains their use in separating synthetic stones from natural stones. He identifies the crystal planes by centring accurately the optic axis, which is then positioned in a vertical or horizontal position and allows the angles of the growth planes to be measured.

The author recommends modifying the stone holder on the microscope so that maximum rotation may be facilitated for positioning the optic axis. Connecting growth planes may also be identified by using a specially designed eye-piece attached to the microscope oculars that acts as a mini-goniometer.

In the past it has been assumed that natural and synthetic corundum, especially flux grown synthetics, could be distinguished on the basis of the negative rhombohedral d $(01\bar{1}2)$ plane, as it had not been observed in natural rubies. The author has found that a small percentage (~1%) of natural corundum from both Vietnam and Myanmar may show the negative d plane. Although very unusual in natural stones, the negative d plane should only be used as a tool for identification in combination with other structural features. J.J.

Alkaline rocks and gemstones, Australia: a review and synthesis.

F.L. Sutherland. *Australian Journal of Earth Sciences*, **43**(3), 1996, pp 323–43.

Valuable gemstones that occur in Australian alkaline rocks include diamonds in lamproites and kimberlites, and sapphires, zircons and rubies in alkali basalts; one gem zircon prospect is carbonatite. In this review, the tectonic settings and origins of Australian gem-bearing alkaline rocks are discussed. There are marked contrasts between diamond and sapphire/zircon associations across the continent. Most western cratonic areas exhibit episodic, sparse, deep alkaline activity from the diamond zone (2000–20 m.y.), while in eastern fold belt areas prolific Mesozoic/Cainozoic basaltic volcanism carried up considerable sapphire and zircon (since 170 m.y.). Some South Australian Mesozoic kimberlitic diamond events (180–170 m.y.) represent ultra-deep material rising through the mantle transition zone. E. Australian diamonds are unusual and at present their origin is contentious. Several different models compete to explain sapphire-zircon formation in E. Australia, and range from eruptive plucking of metamorphosed subducted materials to crystallization from felsic melts or carbonatitic reactions. A unique ruby, sapphire, sapphirine, spinel assemblage from the Barrington basalt shield in New South Wales marks a separate ruby/pastel-coloured sapphire genesis. R.A.H.

Alpine Neuheiten aus dem Karakorum.

A. Weerth, *Lapis*, **22**(1), 1997, pp 13–22.

Fine and sometimes gem-quality crystals of sphene, amethyst, near-colourless to pale yellow and pale lilac apatite, green epidote, greenish calcite and axinite have recently been recovered in the Karakoram Mountains of Pakistan. Some of the calcite is coloured pale green by profuse byssolite inclusions while chlorite gives a similar effect to some of the sphene crystals. M.O'D.

Münchner Mineralientage 1996.

C. Weiss and S. Weiss. *Lapis*, **22**(1), 1997, pp 23–39.

Gem-quality materials on display at the 1996 Munich Mineral Show included fine tanzanite crystals from Merelani, Tanzania (where a crystal weighing 3210 ct has been found): rock crystal from the Urals: ruby crystals in phlogopite from Dhading, Nepal: amethyst crystals from Guerrero, Mexico: fluorite and sphalerite from Chen Zhou, Hunan Province, China: lilac spinel octahedra from south-east of Ratnapura, Sri Lanka. M.O'D.

Amber finds from Table Bay.

B.E.J.S. Werz, J.A. Lee-Thorp and D.E. Miller. *South African Gemmologist*, **10**(2/3), 1996, pp 39–44.

Amber specimens found in Table Bay, South Africa, are not thought to originate either from Europe or America. Specimens were recovered from the wreck of a ship voyaging from the Netherlands to the East Indies and it is possible that the amber came from Europe. Naturally-occurring amber is not recorded from South Africa. M.O'D.

Gemstones of the Timan-North Ural Province.

N.P. Yushkin. *World of Stones*, **10**, 1996, pp 3–7.

Gem species found in the geologically complex Timan-North Ural province of Russia include diamond in kimberlite pipes, silica gemstones, ruby, jadeite, nephrite, spinel, turquoise and a number of other materials. Particular attention is paid to the geology of the diamond deposits and to prospects for future developments in the recovery of many of the other species. M.O'D.

Jewellery

History of development of jewellery in the western world. Part 2.

J. Dykstra. *Canadian Gemmologist*, **17**(4), 1996, pp 112–17.

Covers mainly jewellery of the Byzantine empire and celtic work. M.O'D.

Synthetics and Simulants

Reconstructed rubies of South African origin?

G. Brown. *South African Gemmologist*, **10**(2/3), 1996, pp 32–5, illus. in colour.

Seven cabochons purporting to be reconstructed rubies were found to consist of red and colourless glassy fragments fused together into a solid mass, probably with a glassy matrix or binder. The fragments could be distinguished at 10x magnification. M.O'D.

Man-made substances simulating mainly massive type natural gem minerals.

I.C.C. Campbell. *South African Gemmologist*, **10**(2/3), 1996, pp 20–7, illus. in colour.

Ten specimens imitating turquoise, massive azur-malachite, coral, pink coral, malachite, massive rhodonite of light colour and coral-like colour, lapis lazuli, charoite and chrysoprase were tested and found to be sectile with a knife blade. From this and from other results presented in tabular form it was assumed that the materials were similar to very fine powders bonded with resin or other plastic M.O'D.

Structural analysis of flux grown emerald crystals.

J.-S. Lee, P.-L. Lee and S.-C. Yu. *Journal of the Geological Society of China [Taiwan]*, **38**(3), 1995, pp 273-85.

Crystals of synthetic emerald grown by a V_2O_5–PbO flux process had the composition SiO_2 66.31, BeO 13.70, Al_2O_3 19.42, Cr_2O_3 0.70, V_2O_5 0.04, = 100.17 giving the formula $Al_{2.05}Cr_{0.05}Be_{2.95}Si_{5.95}O_{18}$; their structure was refined to R 1.5% (*a* 9.203, *c* 9.172 Å, space group P6/*mcc*, D_{calc} 2.668 g/cm^3). The partial substitution of the excess octahedral cations (Al and Cr) for the tetrahedral Be and Si produced a highly distorted BeO_4 tetrahedron, confirmed by bond-angle variance and NMR spectrum. The substitution also involves the incorporation of minor V atoms as impurities in the channels of the beryl structure: difference Fourier analysis showed V to be located at (0,0,0.2091) and (0,0,0.2909). The centre of these two positions is (0,0,$^1/_4$) which is the 2a site for alkali cations in hydrous alkali-rich beryl. The doublet configuration for V in the synthetic emerald is attributable to the high-*T* growth effect of these crystals. R.A.H.

Rubini e zaffiri: trattamenti, sintesi e imitazioni.

M. O'Donoghue. *Gemmologia Europa*, **V**, 1996, pp 76–104.

Survey of the manufacture of the corundum gemstones and of growth methods with notes on the characterization of synthetics and imitations. An overview of work so far carried out on the treatments used to improve colour is given with particular reference to corundum from Montana. M.O'D.

Russian flux-grown synthetic alexandrite.

K. Schmetzer, A. Peretti, O. Medenbach, H.-J. Berhardt. *Gems & Gemology*, **32**(3), 1996, pp 186–201, 23 illus. in colour, 5 tables.

There is difficulty distinguishing natural and synthetic alexandrites, notably the flux-grown synthetics especially if there is a lack of diagnostic mineral inclusions. Synthetic alexandrites are manufactured commercially in the USA and Russia, the latter producing particularly good imitations.

A brief history of flux-grown alexandrites is given, describing the three main processes for the manufacture of alexandrites. A sample of 200 Russian flux-grown synthetic alexandrites, mostly rough, were tested. Most were cyclic twins having one irregular face and some were fully developed single crystals. The results of various tests are given in detail. The main diagnostic properties were identified as a result of examining these samples. Under the microscope it is sometimes possible to detect residual flux or platinum particles in the synthetics. Using an X-ray fluorescence analysis traces of germanium, molybdenum and/or bismuth could be detected in the synthetics, elements which are not found in natural stones. In natural alexandrites there are absorption bands in the 2500 to 3000 cm^{-1} range due to water and/or hydroxyls, which are absent in the flux synthetics. J.J.

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BOOK REVIEWS

Ammolite.

D. Barnson, 1996. Selkirk, Manitoba, Canada R1A 2B2 [Box 179]: The Author. pp [20], illus. in colour, softcover. US$19.95. ISBN 1 55056 421 8.

Very attractively produced guide to ornamental fossil ammonite with a play of colour. Specimens are found in Alberta, Canada, and are marketed under the name ammolite or korite. Details and properties of the material are given and a fine series of photographs illustrate the different types of colour pattern for which, as in opal, various names have been coined. Both solid and composite specimens are sold. Commercial production began in 1981 though the potential of the material had been recognized in the early 1970s. Korite Minerals Ltd is the world's largest producer of ammolite. Some details and illustration of recovery methods are given. The quality of the photographs is first-class: a Japanese version of the text is also available from the publishers under the ISBN 1 55056 420 X. M.O'D.

Beautiful Queensland gems.

H. Bracewell, 1996. Treasure Enterprises of Australia [PO Box 383], Archerfield, Queensland. pp 24, illus. in colour, softcover. AUS$15.00 incl. air mail postage. ISBN 1 86273 101 2.

This most attractive book in larger than A4 format is aimed to give the amateur gem hunter some idea of the gemstone wealth of Queensland. It is also intended to raise the imaginations of many who have never thought of looking for gems and minerals. In both purposes it succeeds admirably. Queensland produces a wide range of gem and ornamental mineral species, from sapphire and topaz to magnificent chrysoprase and, of course, opal. Examples of many species are well illustrated in colour and the brief text succinctly describes the history and present status of some of the more important mines. General information on mines and fossicking concludes a text which certainly ought to attract readers from far outside Australia. M.O'D.

Professional jewellery appraising.

Richard H. Cartier, 1996. Fischer Presses, 1228, Avenue Rousseau, Sillery, Quebec, Canada. pp 178, softcover. CDN$32.00. ISBN 2 921225 23 9.

Books on valuing are not new but most that are available in the UK have originated from the US, and unfortunately, despite a common language, they have not usually travelled well across the pond. Such books have made little impression on the average British jeweller/valuer, who probably still regards American practice to be alien and often indecipherable.

This book, by one of Canada's top gemmologist/appraisers, is a lucid and welcome addition to the literature available for valuers. The style, language and lay-out offers much of value on the theory, ethics and practice of valuing. And it should be remembered that valuing has become more professional in the UK than ever before. While standards here have undoubtedly improved over the last ten years, much more needs to be done before we can truly speak of the science of valuing.

Cartier takes the reader through discussions of the different types of value, including particular emphasis on the principle of fair market value – a concept well understood in North America and applied under specific guidelines, but not so well understood here, to taking in procedures, documentation and presentation, grading gemstones and on to some horror stories.

Along the way, Cartier speaks good common sense on a few issues that have generated an unnecessary amount of hot air in the UK in recent years.

The current debate on computers and which program is the best is an issue covered by a section of less than one page, with the conclusion that this be viewed by the individual as simply another (useful) tool to be made of what you will.

The chapter on diamond grading is fairly straightforward but I am pleased to see that Cartier nails the current fad for a so-called SI 3 grade. This deserves to be discarded.

As far as the chapter on coloured gems is concerned, there is a discussion on the various grading systems in existence, with input from Nelson on the basic science of colour with emphasis on hue, tone and saturation. Cartier favours a simple system of coloured gem grading based on a numerical range of 1–10, with a clarity grading structure analogous to that for diamonds. Such an easy to understand concept, which I strongly favour, lends itself to ready translation to a price guide, such as the Guide Pricing System, to which more UK valuers are likely to subscribe.

Other useful elements in the book include a guide to appropriate mark-ups, which, although I think should not be copied verbatim here, are none the less in sympathy with the principle of flexible and diminishing (as values increase) mark-ups that I constantly preach, tables of useful formulae, chain patterns, a bibliography and, for the masochists amongst us, some algebraic formulae that left me for dead!

Overall I would rate this book excellent, and at a very affordable price, I recommend it to UK valuers. Richard Cartier has produced a readable book full of useful knowledge and sound common sense. Get it on your bookshelf! B.R.D.

Tourmalines, minéralogie, gemmologie, gisements.

J. Cassedanne, J.M. Le Cléac'h, P. Lebrun, 1996. Paris. pp 87, illus. in colour, softcover. Price on application to the journal at 10 rue de Marignan, 75008 Paris. ISSN [of parent serial] 0335-6566 [*Minéraux et fossiles*. Hors série no 3].

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Most beautifully illustrated survey of the tourmaline group of minerals in which chemistry, mineralogy, nomenclature, tourmaline as a gemstone, mode of occurrence and prospecting methods, major deposits described by continent and a list of web sites from which further details can be obtained. A good deal of the text deals with Brazilian material and occurrences and each section has its own bibliography. The appearance of specimen details available only via a web site is timely and gemmologists should already be familiar with this unique source of information acquisition and publication. M.O'D.

Pearls, from myth to modern pearl culture.

David Doubilet, 1996. Schoeffel Pearl Culture, Stuttgart. pp 119, illus. in colour, hardcover in presentation sleeve. Price on application. ISBN 3 7701 3932 1.

The book is published to celebrate Schoeffel's 75th anniversary. It contains chapters on the history of pearls, taken from Kunz and Stevenson's *Book of the Pearl*, followed by photographic essays and a short text on some pearl-producing countries.

The colour photographs of both pearls and landscapes are superb, but the accompanying text is rather disappointing, being flowery in style and rather lacking in solid information. The chapters on the history of the pearl including the final pages describing the oyster and the growth of pearls, with clear diagrams, partly make up for this, but the pictures in the photo essay are so good that the book will surely be a hit with anyone interested in pearls or travel. M.C.P.

Glossary of mineral synonyms.

J. De Fourestier, 1994. Sanssouci Verlag, Montreal. pp 61, softcover, ring-bound.

Useful and easily-read guide to many (but not all – this would be impossible!) alternative names used at one time or another for minerals of established species status. Many of the names are attached to gem or ornamental species and when the second edition appears (scheduled for 1998 – the present one is said to be a draft) gemmologists and collectors will find it worth buying. As always, I have lingering doubts about some of the names cited in such books – many, I'm sure, never progressed beyond fanciful literature: this does not invalidate a worthy attempt to round them up, hopefully for the last time! M.O'D.

Ruby and sapphire.

R.W. Hughes, 1997. RWH Publishing, 4946 Clubhouse Circle, Boulder, CO 80301-3725. pp 511, illus. in colour, hardcover. £66.00. ISBN 0 9645097 6 8.

Covering the corundum gemstones, their nature, locations, properties, mode of occurrence and recovery methods, these and other sections accompanied by excellent and extensive bibliographies and by high-quality text diagrams and colour photographs, this major new book has to be on the bench as well as in the private library of serious gemmologists. For the amount of information presented the price is not excessive and my copy at least has survived quite a lot of student use, a good point to look for when the paper is heavy. Readers will find the personality of the author lurking in many places and like the garden robin he makes sure that you are aware of his presence. I found that an attractive feature of the book.

The corundum gems are a large subject to cover and there are many ways in which an author can approach it. The book opens with corundum in history, passes to chemistry and crystallography and thence to many areas which the gemmologist will find most useful. This part of the book includes a section on treatments with up-to-date information and illustrations. Synthetic corundum, composites and fashioning methods precede an interesting study of judging quality; while this aspect of gemstones has been made the subject of several useful small books, it is welcome here in this much larger text.

Preceding the area coverage is a review of corundum geology so that the reader does not come upon unfamiliar geological terms later on and have to search for their meaning. Then gem corundum-bearing areas are treated in alphabetical order of country. The book concludes with sections from Tagore's *Mani-Málá (A Treatise on gems)*, first published in 1879 and with notes on ruby and sapphire prices and how to estimate weight. There is an index in which most entries appear to be correct – I have checked only a sample. Major portions of the book are separated by sections of advertising, which are useful for addresses of dealers and which no doubt have helped with the costs of the book.

I found the book quite excellent and found no serious faults. The references are among some of the most comprehensive I have ever seen and the information is profuse and well arranged. Unexpected items such as a list of famous rubies with their descriptions, locations, weights and prices paid (where relevant), present location and references will save a lot of looking through sale catalogues (unaffordable for most private libraries), and other treasures make the book one of the most welcome additions to gemmological literature – improving all the time. All gemmologists should buy a copy. M.O'D.

Stones from heaven: ancient Chinese jade.

Los Angeles County Museum of Natural History, 1996. Los Angeles. pp 24, illus. in colour, softcover. Unpriced.

Short but very useful and well constructed guide to the materials, shapes and history of archaic Chinese jade, acting as a guide to an exhibition of the same name held in Los Angeles and Taipei. The guide selects artefacts from the exhibition to demonstrate major themes and uses; the student of jade could scarcely begin with a simpler or more attractive guide. M.O'D.

Pyrit und Markasit [by various authors].

1996. Christian Weise Verlag, Munich. pp 96, illus. in colour, softcover. DM 39.00. ISBN 3 921656 38 9 [*extraLapis* 11]

Among the papers devoted to a beautifully illustrated celebration of pyrite and marcasite is an examination of pyrite as an inclusion in a number of minerals, including gem species. Pyrite's crystal form and habit are described in other papers and conservation of the iron sulphide minerals, always difficult, is discussed. M.O'D.

Hoseki: Shouchu o kagaku suku. Shuyo hoseki no sekai. [Gems: science in a microcosm. The world of principal gemstones.]

JUNKO SHIDA, 1996. Zenkoku hoseigaku kyokai, Tokyo [National Gemmological Association] 1–24 Chuo-ku, Akashi-cho, Tokyo Bihokaikan, Tokyo T-104, Japan. pp 66, illus. in colour. 19,000 yen.

A superbly illustrated account of the types and significance of inclusions in the major gem species, their synthetic counterparts and treated forms. Notes on other phenomena are included and many photographs show specimen response to cathodoluminescence, to UV radiation and, in the case of treated corundum, to laser tomography. Dimensions of specimens are given in all photographs and, as always, very high magnification is not usually needed. Preliminary matter gives details of some of the photographic techniques used.

This is the only text I know in which the reader is able to detect some of the differences between hydrothermal and flux-grown emeralds and the features to be expected in gem-quality synthetic diamond. Treated stones are given a good deal of prominence.

The quality of the photographs and the general standard of production are the best I have seen in the literature so far, making other texts appear well-worn by comparison. Despite the whole of the text being in Japanese, captions contain at least one line of English so that the non-Japanese reader can be certain of the identity of the stones illustrated. Since the microscope is gradually displacing tests using undesirable chemicals, greater familiarity with the interior of gemstones is vital for the gemmologist. M.O'D.

Gold jewelry from Tibet and Nepal.

J.C. SINGER, 1996. Thames and Hudson, London. pp 142, illus. in colour, hardcover. £19.95. ISBN 0 500 97442 X.

Gold jewellery from this area of Asia has long held a particular fascination for the collector even though most inhabitants of the countries would have seen little of it. The hierarchical nature of Tibetan and Nepalese societies not only allowed a wide variety of jewellery to be made but also made it possible for the wearer's status to be established. Written records are scarce and not always easy to understand, making correct evaluation of artefacts of particular importance.

The book is especially well-illustrated with a set of 100 colour photographs in which the pieces are set against a black background. Preceding chapters deal with ornaments of faith, materials and master craftsmen, the iconography of Himalayan jewellery and the Himalayan amulet. The quickest run-through of the colour plates will show that, as expected, turquoise is by far the most used gemstone. Chapters are well-referenced and there is also a high-quality bibliography. Considering the poor quality of some of the books and articles on this particular area of Asian jewellery, this book represents the level of scholarship that should be aimed at – though there is much more work to do. M.O'D.

Derbyshire black marble.

J.M. TOMLINSON (with geological appendices by T.D. Ford), 1996. Peak District Mines Historical Society, Spec. Publ. No 4. pp 95. £9.95.

This work gives a beautifully illustrated account of the black marble from Ashford-in-the-Water, near Bakewell in Derbyshire, and the inlay work carried out in it, using such materials as Blue John, malachite, baryte and various coloured marbles. The Ashford marble is a very fine-grained, dark, bituminous limestone of Carboniferous age; this was mined from around 1750 until 1905. Such smaller items as brooches, pendants, paperweights and candlesticks, and the larger tabletops and urns, are now collectors' items. There are numerous colour plates and also black-and-white photographs of the workshops; in an appendix photographs are given of some of White Watson's geological tablets showing cross-sections of Derbyshire strata. R.A.H.

Wahroongai news.

Special commemorative issue ... 50th Anniversary, 1946–1996. 1996. East Brisbane: Gemmological Association of Australia, Queensland Division. pp 68 [forms vol. 30 no. 10 of *Wahroongai news*].

Interesting and informative account of the formation of the Queensland Division of the Gemmological Association of Australia, of which the first meeting took place on 29 October 1945. Details of the officials and activities are presented in a way which is an example of how archival material should be published – after it has been retained and subjected to scholarly appraisal. Similar associations should take note! M.O'D.

Opals.

F. WARD, 1996. Gem Book Publishers [7106 Saunders Court, Bethesda, MD 20817 USA]. pp 64, illus. in colour, soft-cover. US$9.95 plus $2.50 s & h. [Fred Ward Gem series.]

An accompanying letter sent to me gave details of how the book was produced and how easy production was compared to earlier volumes in the series. Today the whole text and illustrations fit easily on to a single CD and, apart from the final film made by the prepress house, this was all the material needing to be sent around. The book also contains more photographs than previous ones in the series, an increase of some 50 per cent. Readers might like to note that the drop capitals are each taken from a different opal!

The book itself is of course essential for all with the slightest interest in opal, and to the experienced gemmologist it is particularly valuable in the currency of much of the information provided. The text is divided into history and lore, black opal, boulder opal, light opal, crystals and fossils, Mexican opal, assembled opals, synthetics and simulants, buying and caring for opal and an explanation of the play of colour.

The main opal fields are described and commercial transactions introduced and illustrated – a welcome feature since many gemmologists have no idea of the difficulties, personalities and traditions involved – sometimes a long way from the 'pure' gemmology of the textbook. Also of great interest is the series of pictures illustrating the manufacture of a triplet. But the whole book is superb and another proof of how it is possible to cover a gem species in a single work. M.O'D.

Proceedings of the Gemmological Association and Gem Testing Laboratory of Great Britain and Notices

OBITUARIES

William Donald Goodger died on 20 November 1996 aged 81. He will be remembered as the Canadian who was instrumental in creating an independent gemmology course that was recognized by the Gemmological Association of Great Britain.

Don was born on 15 March 1915 in Woodstock, Ontario. He received his BA degree from the University of Western Ontario in London in 1937. He went to Emmanuel College at the University of Toronto and was ordained a minister of the United Church of Canada in 1940. During his career as a clergyman he saw a rock collection in the home of a colleague and that led to his second career as a lapidary and gemmologist.

Don completed the correspondence courses leading to his Diploma and FGA in 1972. The following year he helped to found the North York Faceting Guild. He also served on the executive of the Canadian Gemmological Association from 1973 until 1995. During his term as president of the CGA in 1976 the journal *The Canadian Gemmologist* was launched and Don was the managing editor until 1980. That year he retired from his United Church position and he became the Director of Education for the CGA. With time now on his hands he was able to supervise the completion of the Canadian Diploma course which began in 1982.

For many years Don's home was a centre of gemmology where he taught and was involved in gemmology business.

Don's dedication, enthusiasm and generosity will be sorely missed by those of us who knew and worked with him.

Jeannine Dykstra, FGA

Graham Llewellyn. Those in the jewellery trade who knew Graham Llewellyn will need no appreciation to be written of him, least of all by me. But there are many people who did not have the good fortune to meet Graham and I hope my words will bring this delightful man into their life for just an instant.

I do not recall when I first met Graham, but it was not long after I joined Hancocks in 1955. My late father knew him quite well and it was he who introduced me. The first impression gained was Graham's gracious manner – not in any way patronising – simply gracious. As my career progressed in the trade I met him more and more and, eventually, I became responsible for buying jewellery for Hancocks and often attended the auction sales. He was most supportive to me in many ways during my years as Chairman of the Gemmological Association and, all in all, was very kind to me.

Graham joined Sotheby's in 1953 as a jewellery specialist having begun his career in the jewellery department of Harrods. He qualified as an FGA obtaining his Diploma with Distinction in 1948. As a matter of interest another successful candidate that year, also with Distinction, was Robert Crowningshield of the USA. Graham became a Director in 1964 and it was he who set up the very first jewellery sale Sotheby's held in Switzerland. He was chief executive of Sotheby Parke Bernet from 1981 until 1983, a time of great

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strain for him personally. Since then he held many other senior appointments inside Sotheby's – but this is only a catalogue of his career and doesn't help you to 'know' Graham.

He was a tall man, slim enough to seem almost slender to those of us of a fuller figure, elegantly dressed, and his walk was almost languid. He was unflustered, unhurried, spreading an atmosphere of calm about him, but above all was his genuine politeness. He had a great sense of fun, his love of the English language led him to enjoy the most wicked of puns, and he had a warm comforting voice. As an auctioneer his style was admirable. He was very decisive, very clear, very observant and precise. In those days he had to know the names of all his regular buyers, not just the 'big' names, for the buyer's name was announced in the room as each lot was sold. It was a much more personal system than that of today where each bidder has a number and a paddle to wave about. Graham had no need of histrionics for he stamped his authority on the room from the very start of the auction. You wanted to buy from him, he had no need to persuade you. To me his gavel was more like the baton of an orchestral conductor, and he took all his sales at a great pace. I suppose attending one of his sales was more like going to the theatre, certainly not the circus!

Graham loved jewellery and particularly gemstones. In the days when he was chief executive and his time was taken up with the 'affairs of state' he was not as involved with jewellery as he had been. From time to time I would telephone him, eventually getting past the rampart of secretaries defending him from unwanted telephone calls, and tell him of a wonderful sapphire or emerald we had just bought suggesting he pop in on his way past Hancocks just to see it. Invariably he would do so just for the pleasure of seeing a beautiful gemstone.

The photograph kindly made available to me by 'Alex' Rhodes of Sotheby's shows Graham as many of us well remember him, smiling during one of his delightful chuckles. He is and will be sadly missed by all of us lucky enough to have known him; for his colleagues there must be a big void in their lives. Although he had retired from the mainstream of the business he was still

Graham Llewellyn

a great influence. I shall remember him in many ways and always for his kindness, but perhaps above all he represented the very best in manner and manners. He was the Englishman personified, admired, respected by all and, perhaps even better, very well liked – and if you think that is too weak a word spend a moment or two to look it up in the dictionary, you may be surprised!!

David Callaghan

GIFTS TO THE ASSOCIATION

The Association is most grateful to the following for their gifts for research and teaching purposes, and for contributions towards the gemstone loan collection being set up by the Education Department (see An Urgent Request below):

Mr George Barrell, Kimberley Diamond Ltd (UK EEC office), Windsor, for rough rubies from the John Saul Mine, Tanzania, and rough emeralds from Manyara, Tanzania.

Mr Santpal Singh Chawla, SS Agencies ROP, Bangkok, for 95 sapphires of various colours.

FORTHCOMING MEETINGS

25 April	**Midlands Branch** AGM followed by *Gems from the Law* by John Bugg, LLB, FGA DGA. The Jewellery Quarter Discovery Centre, 77 Vyse Street, Birmingham 18.
27 April	**Midlands Branch.** Gemmology Seminar for Preliminary students. To be held at 3 Denehurst Close, Barnt Green, near Birmingham.
4 May	**Midlands Branch.** Gemmology Seminar for Diploma students. To be held at 3 Denehurst Close, Barnt Green, near Birmingham.
7 May	**London.** Terry Davidson of Cartier Ltd will speak on *150 years of Cartier.* Gem Tutorial Centre, 27 Greville Street, London EC1N 8SU.
9 May	**Annual Trade Luncheon** to be held at the Langham Hilton Hotel, London W1. The guest speaker will be Mr Robin Buchanan-Dunlop, Clerk of the Worshipful Company of Goldsmiths.
18 May	**Midlands Branch.** Gem Club: A diamond grading day with Gwyn Green. 3 Denehurst Close, Barnt Green, near Birmingham.
21 May	**North West Branch.** Doug Garrod, the Education Executive at the GAGTL will give a talk entitled *The ins and outs of gemstones.* Church House, Hanover Street, Liverpool 1.
25 May	**Scottish Branch.** Lapidary Session. 12 noon at the National Museum workshop in Granton, Edinburgh.
18 June	**North West Branch.** Social evening and Bring and Buy. Church House, Hanover Street, Liverpool 1.
15 June	**Scottish Branch.** Field trip. Venue to be arranged.
30 June*	**London.** Annual General Meeting and Reunion of Members followed by a Bring and Buy Sale. Gem Tutorial Centre, 27 Greville Street, London EC1N 8SU.
9 July	**London.** Dr Robert Young will give a talk entitled *Exploring for diamond, emerald and alexandrite in Europe.* Gem Tutorial Centre, 27 Greville Street, London EC1N 8SU.

A date for your diary

GAGTL CONFERENCE
Collectors' Gems

The 1997 Annual Conference is to be held on Sunday 9 November at the Barbican Centre, Silk Street, London EC2Y 8DS. Full details will be announced in the July issue of the *Journal.*

For further information on the above events contact:

London:	Mary Burland on 0171 404 3334
Midlands Branch:	Gwyn Green on 0121 445 6359
North West Branch:	Joe Azzopardi on 01270 628251
Scottish Branch:	Joanna Thomson on 01721 722936

**Please note the change of date.*

Mrs Luella Dykhuis, Tucson, Arizona, for assorted stones including emerald, opal, quartz, Montana sapphires, spinel and topaz.

Mr Suresh Ellawala of Ellawala Exports, Colombo, for a contribution towards the stone loan collection.

Mr L.J. Fifield, FGA, Pinner, for three books: *Blue john cavers and blue john mine* by A.E. Ollerenshaw, *The history of blue john stone* by A.E. Ollerenshaw, R.J. Harrison and D. Harrison, and *Stump Cross caverns* by G. Gill.

Mr Dennis Price for garnet with inclusions.

Mr Wu Chao Ming, Taipei, Taiwan, for a cut diffusion-treated ruby.

AN URGENT REQUEST

Please will all members and their acquaintances search into the inner recesses of their 'bit-boxes' and around the darkest corners of desks and workbenches for those unwanted cabochons, doublets, beads, pastes, diamond and any other gem materials that they no longer need. Such gems may still have lots of life in them and if you send these to Ian Mercer at the Education office at the GAGTL they will all be acknowledged and put to work in our many and various student and trade tutorial stone sets and for the new loan collection. We have a great variety of requirements to help with training and demonstrations both in the UK and overseas and your help would be most welcome.

For instance, the Education office is now starting the process of setting up an extensive collection for loan of relevant gem materials especially for Correspondence Course gemmology Diploma students. Initially the collection will be available to UK students but it is hoped that this service will eventually extend overseas. We already provide stone sets for UK Allied Teaching Centres and these sets will be improved to help maintain the standard of practical tuition.

MEMBERS' MEETINGS

London

On 15 January at the Gem Tutorial Centre, 27 Greville Street, London EC1N 8SU, Christopher M. Welbourn, Principal Scientist at the De Beers DTC Research Centre, Maidenhead, gave an illustrated lecture entitled 'Growth and identification of synthetic diamonds'.

On 19 February at the Gem Tutorial Centre, Mr Geoffrey C. Munn, Managing Director of Wartski, gave a talk entitled 'Sleepers – rediscovery and reattribution in the antique jewellery trade'. As well as illustrating his lecture with a collection of fascinating slides, Geoffrey also displayed several of the pieces he had been discussing.

On 12 March at the Gem Tutorial Centre, Mr Adrian Klein of A. Freeman (Precious Stones) Ltd, and Judy Head of the Hatton Garden Association, gave a talk entitled 'How will our Garden grow?' Adrian looked at the chequered history of Hatton Garden and how it might cope with the demands of the new millennium, and Judy outlined the current initiatives to develop the area.

Midlands Branch

On 7 December 1996 the Annual Dinner of the Branch was held at Barnt Green.

On 31 January 1997 at the Discovery Centre, 77 Vyse Street, Birmingham 18, members enjoyed a Bring and Buy Sale and Quiz.

On 28 February at the Discovery Centre, Mr E. Alan Jobbins gave an illustrated talk entitled 'A gemmological journey from the Alps to Vesuvius'.

At Gem Clubs held at Barnt Green on 23 February and 23 March, Mr Eric Emms spoke on treated stones and Mr Alan Hodgkinson on synthetic gemstones and their identification.

North West Branch

On 19 February members of the Branch visited the Liverpool Museum to view the Power and Gold exhibition. A brief introductory talk was given by Ms Lynne Stumpe, the Exhibition Curator.

On 19 March at Church House, Hanover Street, Liverpool 1, Mr Brian Dunn gave a talk entitled 'Gemstones – a valuer's heaven or hell?'

Scottish Branch

A Lab Night was held on 12 February at Barmulloch College, Glasgow.

On 14 March at the Royal Bristol Hotel, Princes Street, Edinburgh, Mr Ewen Taylor gave a talk on valuation.

GEM DIAMOND EXAMINATIONS

In January 1997, 32 candidates sat the Gem Diamond Examination worldwide of whom 25 qualified, 4 with Distinction. The names of the successful candidates are listed below:

Qualified with Distinction

Kabiotis, George, Athens, Greece
Huali, Yao, Wuhan, P.R. China
Torrent, Denise, Geneva, Switzerland
Tsang Wai Yi, Rita, London

Qualified

Buxani, Reema Haresh, Hong Kong
Chen, Da, Wuhan, P.R. China
Chen, Shiyi, Wuhan, P.R. China
Chih-Chung Yuan, Joe, Wuhan, P.R. China
Chow, Chun Hung William, Hong Kong
Fowle, Michael J., Broughton, Stockbridge
Hun, Lai Chan, Macau
Kepel, Arthur Mvuta, London
Kenny, Sark, Hong Kong
Lawrence, George, Hove
Lemessiou, Maria A., Nicosia, Cyprus
Lodge, Tim, Muswell Hill, London
Mileris, Vladimir C., Bournemouth
Poon, Ka Vai, Hong Kong
Richardson, Cathryn, Silsden, Nr Keighley
Scott, Doreen M., Liverpool
Tse, Stephen Y.Y., Hong Kong
Tsui, Tommy Kin Wah, Hong Kong
Yuan, Jia, Wuhan, P.R. China
Zhang, Yanjun, Wuhan, P.R. China
Zhu, Miao, Wuhan, P.R. China

EXAMINATIONS IN GEMMOLOGY

In the Examinations in Gemmology held worldwide in January 1997 117 candidates sat the Preliminary Examination of whom 89 qualified. In the Diploma Examination 175 sat, of whom 73 qualified, one with Distinction. The names of the successful candidates are as follows:

Diploma

Qualified with Distinction

Li Liping, Wuhan, P.R. China

Qualified

Battiscombe, Brigid, London
Cai Bing, Guilin, P.R. China
Cao Huasong, Beijing, P.R. China
Chang, Morley Sheng-Hong, Seattle, Wash., USA
Chang Yeun Hwa, Taegu, Korea
Chen Liang-Hsuan, Toronto, Ont., Canada
Chen Yingli, Wuhan, P.R. China
Chen Yingying, Wuhan, P.R. China
Choi Su-Ok, Taegu, Korea
Chu Li-Ju, Taipei, Taiwan, R.O. China
Courage, Bruce Crandall, Mahwah, NJ, USA
Dai Fei, Wuhan, P.R. China
Davies, Paul B., Great Missenden
Dong Ping, Wuhan, P.R. China
Duncan, Kenneth Greg, Silver Spring, MD, USA
Dupuy, David John, London
Friedberg, Guy, London
Gao Hongwei, Wuhan, P.R. China
Guastoni, Alessandro, Milan, Italy
Guo Jize, Wuhan, P.R. China
He Xinping, Guilin, P.R. China
Hunter, Rachel Suzanne, Bath
Jackson, Stephen D., Perranporth
Jiang Renyi, Shanghai, P.R. China
Johnston, Dale, Dundonald, Co. Down
Kafetsis, Georgios, Athens, Greece
Kearton, Michael, Eastbourne
Kuang Yonghong, Guilin, P.R. China
Lamb, Maria Tegwen Hotung, Hong Kong
Lau Joyce Pao-Ching, Hong Kong
Lee Yow Hon, Tuen Mun, Hong Kong
Leung Yuen Fan, Hong Kong
Li Dongsheng, Guilin, P.R. China
Li Ki Wing, Kennedy Town, Hong Kong
Li Ruling, Xiang, P.R. China
Lim Seong Jin, Taegu, Korea
Lin Shwun-Jiun, Taipei, Taiwan, R.O. China
Liu Danyang, Wuhan, P.R. China
Liu Yang, Wuhan, P.R. China
McInnes, Catriona O., Edinburgh
McInnes, John L., Edinburgh
Made, Lollo Harriet Annika, Hong Kong
Mao Lingyun, Beijing, P.R. China
Marolla, Marianna, Athens, Greece
Nang Mo Kham, Yangon, Myanmar
Qi Wang, Wuhan, P.R. China
Qiao Li, Wuhan, P.R. China
Schellekens, Ben J., Capelle a/d Yssel, The Netherlands

Seok Jeong-Won, Taegu, Korea
Shao Bing, Shanghai, P.R. China
Shao Zhen-Yu, Shanghai, P.R. China
Starreveld, Francis M.M., Hilversum, The Netherlands
Thant, Tun Min, Yangon, Myanmar
Triantafillos, Spiridon, Athens, Greece
Tsang Shiu King, Kowloon, Hong Kong
Tun, Than, Yangon, Myanmar
Tun Tun, (a) Gant Tal Yang, Yangon, Myanmar
Uriben, Awr, Bellflower, CA, USA
Wang Chunsheng, Beijing, P.R. China
Wang Hsiao-Fei, Taipei, Taiwan, R.O. China
Wang Hongwei, Wuhan, P.R. China
Wang Hua, Wuhan, P.R. China
Wang Qi, Wuhan, P.R. China
Xi Bo, Wuhan, P.R. China
Xia Songyao, Beijing, P.R. China
Xiaoyan Ji, Wuhan, P.R. China
Yang, Eun Kyoung, Daejon, Korea
Yu Man, Wuhan, P.R. China
Yun Hwa Choi, Taegu, Korea
Yung Yung Chong Sylvia, Toronto, Ont., Canada
Zhang Sumei, Guilin, P.R. China
Zhu Yong, Guilin, P.R. China

Preliminary

Qualified

Al-Buflasa, Hanan Mubarak, Manama, Bahrain
Amor, Miranda, Taunton
Anastassopoulou, Angeliki A., London
Bappoo, Reenabai, London
Boccard, Jean-Marie, Geneva, Switzerland
Boddy, Carl S.R., Hong Kong
Brunstrom, Isabella Carin, Stockholm, Sweden
Chen, Hua, Beijing, P.R. China
Chen, Tao, Shanghai, P.R. China
Choi, Uk, Daejon, Korea
Choi, Su-ok, Taegu, Korea
Chong, Yuen-Kwan, Central, Hong Kong
Christou, Angelos G., Islington, London
Clements, Julia Helen, West Hampstead, London
Collins, John Raymond Frank, Swansea
Colombo, Fabrizio, Torino, Italy
Davidge, Elizabeth Anne, Pimlico, London
Davies, Maggie, Oxford
Deutscher, Gilad, London
Fukui, Osamu, Tokyo, Japan
Gevorkian, Vardan, Holmestrand, Norway
Gomez, Jorge E., London
Harding, Rachel Anne, Twickenham
Hill, Emma, Maida Vale, London
Hsieh, Juan Ku-Wei, Taipei, Taiwan, Rep. China
Infuehr, Nicole, London
Irtelli, Pierre Camille, Romford
Isacsson, Eva Johanna, Vilhelmira, Sweden
Jacquat, Stephane, Geneva, Switzerland
Kitazawa, Yoko, Tokyo, Japan
Komninos, Michael, Athens, Greece
Lai, Ho Yan, Kowloon, Hong Kong
Lam, Jill, Rochester
Lau, Bik Lin (Tolisa), Chai Wan, Hong Kong
Lee, Shui Chun, Hong Kong
Leung, Raymond Ying Kit, Aberdeen, Hong Kong
Li, Ling, Shanghai, P.R. China
Li, Wei, Shanghai, P.R. China
Lin, Chief, Kaohsiung, Taiwan, Rep. China
Lin, Zheng, Shanghai, P.R. China
Liu, Hui, Shanghai, P.R. China
Lodge, Tim, Muswell Hill, London
Luo, Xia Ying, Guilin, P.R. China
Ma, Huei Chi, Taipei, Taiwan, Rep. China
Maehara, Tamao, London
Marshall, Ralph Henry, Northwood
Millard, Simon Richard, Corsham
Mo, Yiming, Shanghai, P.R. China
Mutton, Valerie Jean, Langley
Naing, Myo, Yangon, Myanmar
Ng, Melloney Vanessa, Bexleyheath
Nuttall, Suzanne Kathleen, Hong Kong
Pan, Jie, Shanghai, P.R. China
Papadimitriou, Marianthi, Thessaloniki, Greece
Patel, Vishal Praful, Surat, India
Payne, Mark, Westbury-Sub-Mendip
Petersheim, Ragnar, Brumunddal, Norway
Portillo, Irma, Isle of Dogs, London
Qin, Hongyu, Guilin, P.R. China
Rackham, Christina J., Bentley, Nr Farnham
Renard, Joelle M., Ruislip
Sharma, Namita, Panchkula, India
Shen, Beiqi, Shanghai, P.R. China
Stratton, Claire Amanda, Clapham, London
Suh, Sung-Bong, Taegu, Korea
Tang, Tak Chuen, Yeun Long, Hong Kong
Taylor, Alison S.B., Chiswick, London
Teskeredzic, Senada, Sarajevo
Than, Tin Kyaw, Yangon, Myanmar
Tucker, Jonathan William, London
Van der Kuyp, Femke Mariken, Rotterdam, The Netherlands
Van der Vijgh, Caroline E., Diemen, The Netherlands
Vassiliou, Marianna, Nicosia, Cyprus
Vayrynen, Sanna Helena, Farnham
Verny-White, Catherine, Richmond
Wang, Chao, Guilin, P.R. China

GAGTL Gem Tutorial Centre

19 May

Pearl Course
A new course organized by the *Retail Jeweller* to help retailers distinguish between natural, cultured and imitation pearls and evaluate quality, as well as providing a guide to pricing. For further details call Lynda Bresgall at the RJ on 0171 417 2865.

20 May

Review of Diploma Theory
A day for Gemmology Diploma students to review their theory work and to prepare for the Diploma theory examinations. Advice on the consolidation and revision of facts, figures, principles, practical techniques and instruments. Let us help you to review your examination technique with the help of past questions. This review would help students who intend to enter the Diploma examination in June 1997.
Price £51.70; GAGTL students £37.00 (including sandwich lunch)

24 and 25 May or 31 May and 1 June

Two-Day Diploma Practical Workshop
The long-established intensive practical course to help students prepare for the Diploma practical examination; also highly effective for those in the trade and elsewhere to brush up on technique. This is the course to help you practise the methods required to coax the best results from gem instruments. The course includes a half-length mock exam for you to mark yourself.
Price £170.00 (£122.20 for GAGTL registered students) – includes sandwich lunches

28 May

Review of Preliminary Theory
A day for Gemmology Preliminary students to review their theory work and to prepare for the Preliminary examinations. Advice on the consolidation and revision of facts, figures and principles. Let us help you to review your examination technique with the help of past questions. This review would help students who intend to enter the Preliminary examination in June 1997.
Price £51.70; GAGTL students £37.00 (including sandwich lunch)

14 and 15 June

Weekend Diamond Grading Revision
This intensive weekend course has been designed for all students about to take the Gem Diamond Diploma. This workshop will include a mock examination to help students gain familiarity and confidence with examination conditions.
Price £141.00. Starts 10.00 a.m. Saturday.

3 July

The Natural History of Gems
Where, when and why do gems form? A different look at this planet's geology and dynamic nature.
Price £37.00 (including sandwich lunch)

5 and 6 July

FEEG Preparation for FGAs
A session to prepare Fellows for the new European examination in gemmology under the auspices of FEEG.

8 July

FEEG Examination

22 July

A day of Amber, Coral, Pearl and Ivory
A review of the variety and characteristics of these and other organic gems, the best way to identify them and their most common imitations.
Price £123.00 (including sandwich lunch)

Wang, Yi Fei, Guilin, P.R. China
Warrington, Jennifer Lucy, Auckland, New Zealand
Win, Sandar, Yangon, Myanmar
Wong, Yik Shih, Wimbledon, London
Xu, Lei, Shanghai, P.R. China
Xu, Zhiyi, Shanghai, P.R. China
Yang, Jung-In, Daejon, Korea
Ye, Lei, Guilin, P.R. China
Yumi, Yoshitake, London
Yu, Ping, Guilin, P.R. China
Zhou, Wei Ning, Guilin, P.R. China
Zhu, Ye, Shanghai, P.R. China
Zou, Hon Wah Coral, Kennedy Town, Hong Kong

MEETINGS OF THE COUNCIL OF MANAGEMENT

At a meeting of the Council of Management held at 27 Greville Street, London EC1N 8SU, on 11 December 1996 the business transacted included the election of the following:

Diamond Membership (DGA)

Crowder, Michael John, Maidenhead, 1996
Quinn, Samantha Jane, Maidenhead, 1996
Yang, Hui Hsien, Kwai Chung, Hong Kong, 1996
Bilby David, Cheam, 1963
Bonjer, Chantelle, Abbotsford, BC, Canada, 1996
Damianidou, Teresa, Piraeus, Greece, 1996
Fong, Ka Chun John, Hong Kong, 1996
Karatzas, George, Athens, Greece, 1996
Sethia, Pankaj, Mumbai, India, 1996
Snyman, Johanna, E.W., Silverton, Pretoria, Rep. of South Africa, 1996
Wisawayodhin, Kitiya, London, 1996
Xuefang, Lin, Zhunhai City, P.R. China, 1996

Ordinary Membership

Al-rushaid, Yasmeen Abdullah, London
Armati, Alexander Virgilio, Badgemore, Henley-on-Thames
Barsk, Christer, Pello, Sweden
Bashour, Hiyam, London
Boucher, Garry Mark, Leeds
Bruen, Niamh, Dublin
Bruggisser, Christine Edith, Winterthur, Switzerland
Crabtree, Peter F., Harrogate
Ioannou, Alkis, Nicosia, Cyprus
Ioannou, Yiannos C., Nicosia, Cyprus
Karpasitis, Marios A., Larnaca, Cyprus
McKeown, Nicola, Plymouth
McNair, Amelia Kate, Putney, London
Moroz, Inessa, Jerusalem, Israel
Nizam, Zahid Sarwar, Lusaka, Zambia
O'Neill, Gordon Francis, Thornton Hough, Wirral
Plant, Jenifer, Southgate, London
Rayner, David Paul, Gerrards Cross
Romer, Derek Michael, Kilmaley, Co. Clare, Ireland
Savage, Joan Adele, Warley
Tester, Garry Michael, Crowhurst
Tsiropoulos, Aris, Nicosia, Cyprus
Zetter Mag, Christa, Vienna, Austria

At a meeting of the Council of Management held at 27 Greville Street, London EC1N 8SU, on 12 February 1997 the business transacted included the election of the following:

Diamond Membership (DGA)

Li, Liping, Wuhan, P.R. China, 1996

Fellowship (FGA)

De Poli, Vesta, London, 1982
Guan, Zichuan, Shenyang, Liaoning, P.R. China, 1996
Li, Li, Wuhan, P.R. China, 1996
Mao Yanying, Zheijiang, P.R. China, 1996
Michallat, Mark, Tadcaster, 1991
Norström, Stig Erik, Skärholmen, Sweden, 1977
Pandya, Manoj Kumar, Mumbai, India, 1983
Wang, Fenglan, Tanghsan, P.R. China, 1996

Ordinary Membership

Bena, Thomas, Thornton Heath
Chookruvong, Kanjana, Rajtawee, Bangkok, Thailand
Clark, Darel James, Farnham
Fujii, Noriyuki, Higashi-Osaka City, Osaka, Japan
Fukai, Hiroshi, Osaka City, Osaka, Japan
Fukumitsu, Keiko, Kawanishi City, Hyogo Pref., Japan
Hashimasa, Mitsuyo, Kanazawa City, Ishikawa, Japan
Hikita, Yoshitsugu, Osaka City, Osaka, Japan
Hirai, Kayoko, Matsubara City, Hyogo Pref., Japan
Hirano, Tomoko, Sapporo City, Hokkaido, Japan
Honda, Minoru, Osaka City, Osaka, Japan
Hotta, Kimiko, Ikoma City, Nara Pref., Japan
Hudson, Sally, Putney, London
Iimuro, Yukiko, Chiba City, Chiba Pref., Japan
Ikeda, Naoko, Kofu City, Yamanashi Pref., Japan

Ishizaki, Kuniko, Tokyo, Japan
Kaneda, Yukari, Toyama City, Toyama Pref., Japan
Kataoka, Hideyuki, Kobe City, Hyogo Pref., Japan
Kawabata, Hiroyuki, Matsubara City, Osaka, Japan
Kepel, Arthur Mvuta, London
Kodera, Yukiko, Aichi, Japan
Koselja, Michal, Turnov, Czech Republic
Koshiba, Shoko, Sagamihara City, Kanagawa Pref., Japan
Lalaounis-Tsoukopoulou, Ionna, Athens, Greece
Leishman, Douglas Alan, Haute Nendaz, Switzerland
Matsumura, Yasunao, Kadoma City, Osaka, Japan
Maxey, Theresa Butterfield, Albuquerque, New Mexico, USA
Misaki, Yumi, Tokyo, Japan
Miwa, Yosuke, Tokyo, Japan
Montgomery Iii, Robert Lee, Glendale, CA, USA
Moore, Rowan Duggan, Stoke, Coventry
Murakoshi, Mitsuko, Nagareyama City, Chiba Pref., Japan
Oka, Chiayu, Mii Gun, Fukuoka Pref., Japan
Okumura, Ayako, Osaka City, Osaka, Japan
Orlicky, Zbynek, Praha, Czech Republic
Otsuka, Yoshimasa, Tokyo, Japan
Phillips, Andrew Hodson, Gorebridge
Pierce, Paul Richard, Mount Bryan, South Australia, Australia
Samejima, Mutsuko, Nara City, Nara Pref., Japan
Schulze, Julia Helen, London
Serjent, Philip Ronald, Riyadh, Saudi Arabia
Shibata, Masakazu, Toyonaka City, Osaka, Japan
Sonoda, Natsumi, Kobe City, Hyogo Pref., Japan
Stanley, Brendan, Mayfair, London
Tanaka, Sakura, Kobe City, Hyogo Pref., Japan
Tanaka, Chieko, Tokyo, Japan
Vaughan, Howard John, Widmer End, High Wycombe
Wachiruksasawakul, Suvilai, Bangruk, Bangkok, Thailand
Wijeyawardena, Tharanga Kanchana, Milton Keynes
Yamamoto, Kanae, Kobe City, Hyogo Pref., Japan
Yamashita, Rie, Fukuoka City, Fukuoka Pref., Japan
Yasuzawa, Yusuke, Osaka City, Osaka, Japan
Yoneda, Chie, Nishinomiya City, Hyogo Pref., Japan
Young, Robert, Ely
Young, Roger, Flitcham, King's Lynn

Laboratory Membership

Chic II, London EC1
Euro Pearls, London EC1
Robin Finnegan Jeweller, Darlington
Quy Design, Croxley Green

Coat of Arms and Laboratory Logo

Members of the GAGTL having gained their Diploma in Gemmology or the Gem Diamond Diploma (FGA or DGA) may apply for the use of the Coat of Arms on their stationery or within advertisements.
Laboratory members are invited to apply for use of the Laboratory logo.

It is a requirement of the GAGTL, in accordance with the by-laws, that written permission be granted by the Council of Management before use.

For further information please contact:
Jacqui Holness
Gemmological Association and Gem Testing Laboratory of Great Britain
◆ 27 Greville Street (Saffron Hill Entrance), London EC1N 8SU ◆
Telephone: 0171-404 3334 Fax: 0171-404 8843

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Advertising Manager
Gemmological Association and
Gem Testing Laboratory of Great Britain
27 Greville Street, London EC1N 8SU

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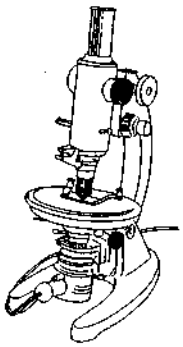

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The World 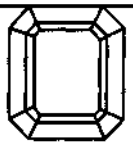 of Gemstones

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Typescripts Two copies of all papers should be submitted on A4 paper (or USA equivalent) to the Editor. Typescripts should be double spaced with margins of at least 25 mm. They should be set out in the manner of recent issues of *The Journal* and in conformity with the information set out below. Papers may be of any length, but long papers of more than 10 000 words (unless capable of division into parts or of exceptional importance) are unlikely to be acceptable, whereas a short paper of 400–500 words may achieve early publication.

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Headings In all headings only the first letter and proper names are capitalized.

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(1) The Harvard system in which authors' names (no initials) and dates (and specific pages, only in the case of quotations) are given in the main body of the text, e.g. (Gübelin and Koivula, 1986, 29). References are listed alphabetically at the end of the paper under the heading References.

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Books Hughes, R.W., 1990. *Corundum*. Butterworth-Heinemann, London. p. 162

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Cover Picture

Solid and liquid inclusions in sapphire (top), and multiphase inclusions in tourmaline (middle) and emerald (bottom) are highlighted on a background of violet flux-grown synthetic spinel. Identification of such inclusions is now possible with Raman spectroscopy (see pp. 394–406). Photographs of inclusions by Dr Hans Werner Schrader, FGA, and of the spinel by Petri Tuovinen, FGA.

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Sapphires from the Andranondambo mine in SE Madagascar: evidence for metasomatic skarn formation

by E.J. Gübelin[1] and A. Peretti[2]

[1]*Lucerne*
[2]*GRL Gemresearch Laboratory AG, Lucerne, Switzerland*

ABSTRACT: Mineral inclusions in gem quality sapphires from the new mining area in southern Malagasy (Andranondambo) include calcite, fluor-apatite, fluor-phlogopite, fluorite, baddeleyite, zirconolite, potassium-feldspar, anorthite, scapolite (meionite), thorianite (thorianite-uraninite solid solutions) and varieties of spinel, such as green Mg-Al-spinel, spinel-hercynite and spinel-hercynite-gahnite solid solutions. These minerals are typically found in various rocks in the mining area belonging to the so-called U-Th skarns (various types of calcsilicate marbles). Therefore, these skarns are considered to be the host rocks for sapphire formation.

Based on the different generations of primary fluid inclusions in the sapphires, various generations of solid inclusions and the absence of hibonite inclusions, it is concluded that the Andranondambo sapphires have formed during several different metasomatic events. The later blue sapphire generations have grown from CO_2-rich fluids of complex chemical composition with minor concentrations of fluorine, water and metals such as aluminium, titanium, iron, chromium and zinc as well as other elements (Mg, Si, Ca, Na, K, P, Zr, U, Th).

Introduction

Malagasy's (Madagascar) highly variable topography and her fascinating landscapes indicate that highly active tectonic powers have affected her geology, which as a result is very complex. This conjecture has been confirmed by the results of modern geological research and by the wealth of gemstones which has been found over the last hundred years. Indeed, Malagasy nowadays has become an important producer of a wide range of gemstones *(Figure 1)*, and the occurrences are undoubtedly comparable with those of Sri Lanka. Beryls of various colours (aquamarine, emerald, heliodor, morganite), corundums (ruby, sapphire), feldspars (amazonite, orthoclase and labradorite), garnets (almandine, rhodolite and spessartine), kunzite, quartz (macro and cryptocrystalline), tourmalines (e.g. liddicoatite) and also a large variety of rare gems such as kyanite, danburite, epidote, hambergite, kornerupine and titanite (sphene) are being excavated. Furthermore, hibonite (Ca, REE, Th)(Al, Ti, R^{2+})$_{12}O_{19}$ with Ti = Ti, Si; R^{2+} = Mg^{2+}, Fe^{2+}, Zn^{2+}; Al = Al^{3+}, Fe^{3+} and REE = Sm^{3+}, Nd^{3+}, Ce^{3+}, La^{3+} – a rare mineral

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Figure 1: *Map of Malagasy showing some of the most important gem deposits (from the World Map of Gem Deposits by E.J. Gübelin).*

Figure 3: *Gem collection at the Andranondambo mine by one of the authors (EG) in early 1996.*

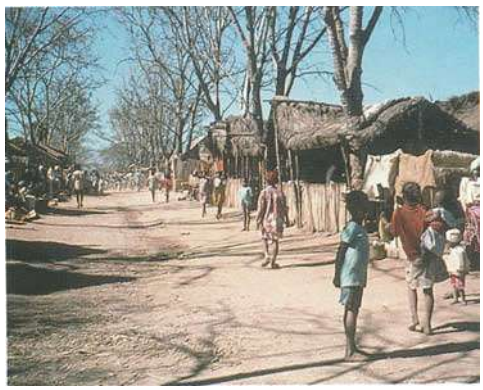

Figure 2: *Main thoroughfare of Andranondambo making a lively impression.*

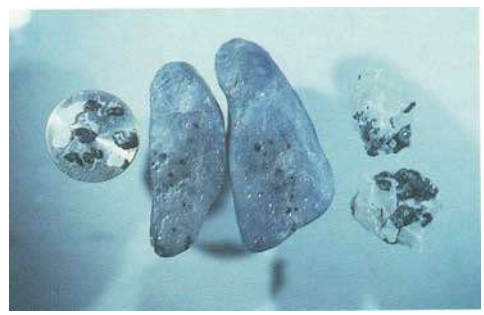

Figure 4: *Sapphire samples obtained from a source in Switzerland (Source C, see text) with eye visible inclusions. On the right, a rock fragment collected at the mines is shown. The section on the left demonstrates how the minerals were prepared for SEM-work.*

first found in meteorites – occurs at Andranondambo together with sapphires (for a chemical analyis of a hibonite from this locality, see Rakotondrazafy *et al.*, 1996). The classical expert in Malagasy mineralogy, Lacroix (1922), stated that corundum is commonly associated with metamorphic rocks. Gem quality corundum has, however, rarely been found up to now and the production was mainly limited to relatively small pieces of low quality. Chikayama (1989) referred to various deposits of cuttable corundum in the southern part of the island, while Koivula *et al.* (1992) were the first to mention a source of multicoloured sapphire south-west of Betroka.

The recently discovered new deposits of pale to saturated blue sapphire are situated in

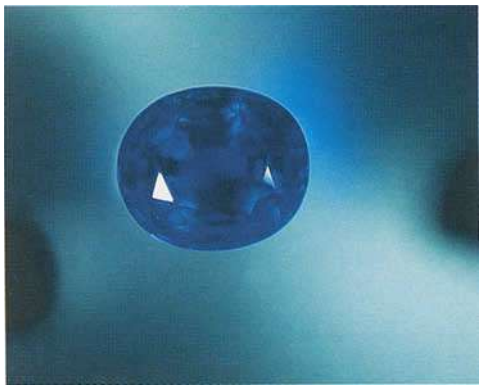

Figure 5a: *Superb royal blue sapphire of about 4 ct (not heat-treated) (Source D, Bangkok).*

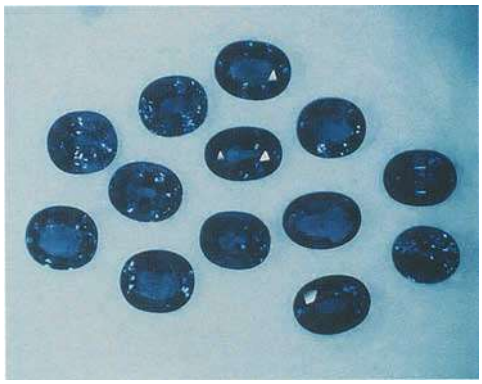

Figure 5b: *Faceted stones (about 1 ct) typical of sapphires after heat-treatment (Source D, Bangkok).*

the south-eastern part of Province Toliara, near the village of Andranondambo, approximately 100 km north-north-east of Fort Dauphin *(Figures 1 and 2)*. This source is probably the first large deposit of cuttable sapphire to be found on Malagasy. New mines have been reported by Johnson and Koivula, 1996, and at least three mining companies (a Swiss, a Thai and a joint venture enterprise) have been founded to excavate and market the sapphires.

Kiefert *et al.* (1996), Milisenda and Henn (1996) and Schwarz *et al.* (1996) have described the occurrence, genesis and gemmological properties of the sapphires. But although very characteristic properties of this new material have been established, considerable differences have arisen in the interpretation of the formation of the sapphires. According to Milisenda and Henn (1996), the sapphires were formed by high-grade granulite facies metamorphism of altered marbles and calcsilicate-gneisses. In contrast, Kiefert *et al.* (1996) relate the formation of the sapphires to pegmatites or pegmatite-like veins such as those of the Kashmir mining area (Peretti *et al.*, 1990). Schwarz *et al.* (1996) interpreted the genesis of the sapphires as the result of metasomatism. An in-depth petrographical study of the metamorphic and metasomatic events leading to the formation of hibonite has recently appeared (Rakotondrazafy *et al.*, 1996). This work provides excellent further data on the metasomatic events which occurred in the mining area and which led to the formation of hibonite and other minerals, including corundum, in skarns. The present paper provides further results of inclusion research relevant to the genesis of the sapphires. The material originates from the expedition of one of the authors (EG) to the gem mines in Madagascar including those of Andranondambo in early June 1996 (Source A) *(Figures 3 and 4)*. Further rough and faceted specimens and rocks containing sapphires were obtained from Dr D. Schwarz (Schwarz *et al.*, 1996) (Source B), rough material was obtained from a source in Switzerland (Source C, *Figure 4*), faceted samples were acquired in Bangkok, Thailand *(Figures 5a, b)* (Source D) and rocks containing sapphires were obtained through Dr K. Schmetzer (Source E, *Figure 7b*). The research material obtained from sources C and D offer a lesser degree of certainty about the veracity of their origin. However, the authors are confident that all the sapphires are from the new mining area (including the mines mentioned by Johnson and Koivula, 1996). The material was tested by different methods, including XRF-analysis for the chemical composition, SEM-EDS-analysis of solid inclusions and immersion microscopic examination for growth structures, and spectroscopic analysis. Based on comparison with published results (Milisenda and Henn, 1996; Kiefert *et al.*, 1996; Schwarz *et al.*, 1996)

some of the most typical characteristics have been summarized below. However, the present report concentrates mostly on analyses of the inclusions in the sapphires. Based on these data and the very detailed petrological framework of the mining area as presented by Rakotondrazafy *et al.* (1996), further conclusions are presented here about genetic aspects of the sapphire formation.

Geological petrographical and tectonic background

Malagasy is the world's fourth largest island. It extends over almost 600 000 km^2 (i.e. ten times the area of Sri Lanka). About 165 million years ago, it separated from Gondwanaland (which is known nowadays as the mainland of Africa) and drifted about 400 km east into the Indian Ocean where it came to a halt, while other subcontinents and continents, such as India and Australia respectively, continued their journey to their present positions. Within the framework of this paper, concentration is centred on the southern part of Malagasy, whose greater part consists of high-grade metamorphic rocks (Milisenda and Henn, 1996, p. 179). These are part of the Proterozoic crust and were metamorphosed to granulite grade during Pan-African times about 500–600 million years ago. These thermotectonic events affected vast parts of Africa, southern India and Sri Lanka (Kennedy, 1964; Kröner, 1980). In the context of Gondwanaland, the granulite of Malagasy formed the eastern part of the Mozambique belt which is interpreted as the result of a continent–continent collision that occurred about 600 million years ago.

According to Rakotondrazafy *et al.* (1996) the Andranondambo mine is situated in the metamorphic rocks of the Proterozoic Tranomaro group located in the south-east of the island. This group consists of varied granulite facies rocks of mainly sedimentary origin such as different gneisses (including pyroxene scapolite gneisses) and calcitic marbles. A schematic diagram of the minerals present in these rocks is shown in *Figure 6a*. Chemical and mineralogical alteration of these rocks by metasomatic infiltration of fluids produces different rocks generally termed skarns. The marbles and calcsilicate gneisses are altered to various skarns *(see Figures 6a and b)*, now mainly composed of impure calcitic marbles, diopside-pyroxenites with variable amounts of scapolite and spinel, pargasite amphibole-rich types and peraluminous rocks made up of plagioclase and/or scapolite with spinel, corundum, hibonite and phlogopite. According to the detailed petrographic framework of Rakotondrazafy *et al.* (1996), the rocks containing the corundum crystals, such as the anorthite-hibonite-spinel-corundum calcsilicates, occur as zones at the contacts

Figure 6a: *Ca–Al–(Fe + Mg) diagram showing minerals and rocks important in the skarns (after Rakotondrazafy et al., 1996).*

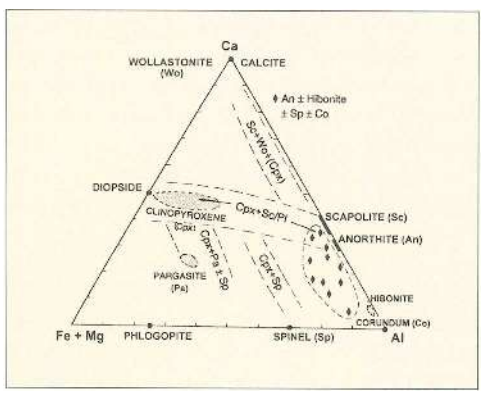

Figure 6b: *Section of scapolite diopside granulite rock collected at the mine (SEM – backscattered image). The dark area is native sulphur, lower centre is aluminous diopside with exsolution lamellae, and scapolite lies in the top left of the picture.*

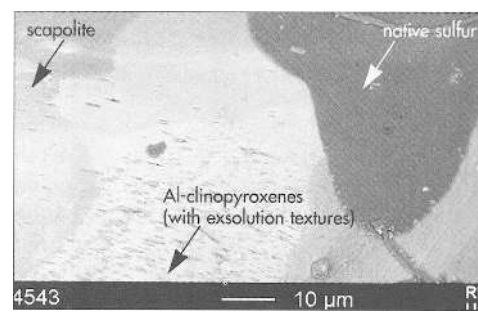

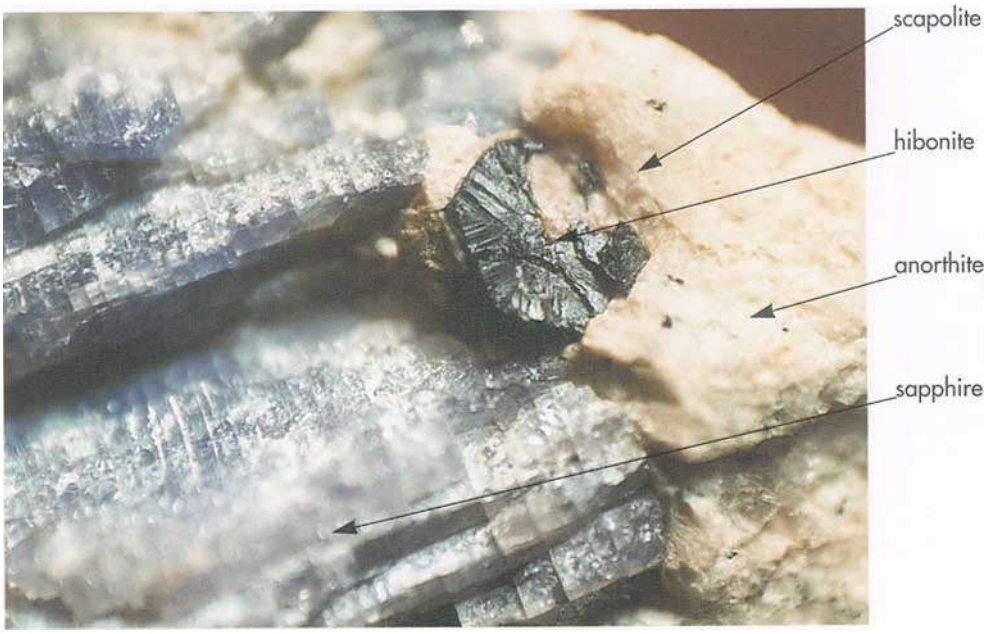

Figure 7a: *Madagascan sapphire (5 cm in diameter) from the Andranondambo mine in the host rock. The sapphire occurs in a skarn rock predominantly composed of anorthite on the right, minor Ca-rich, Cl-bearing scapolite (between anorthite and sapphire in the picture), hibonite (8 mm diameter) adjacent to local nests of calcite, isolated fine-grained local enrichments of spinel, isolated yellowish-green fluor-apatite crystals (up to 5 mm in size, see Figure 15), isolated fluor-phlogopite aggregates, poorly characterized pyroxene crystals and very small blackish crystals with radioactive haloes (most probably thorianite). SEM-EDX analysis of hibonite (see spectrum) gave a composition in weight percent of approx.: $Al_2O_3 = 72.6$, $MgO = 1.1$, $SiO_2 = 7.4$, $CaO = 6.6$, $TiO_2 = 4.1$, $ZnO = 1.2$, $Fe_2O_3 = 3.1$, $La_2O_3 = 1.6$, $Ce_2O_3 = 2.2$, $Nd_2O_3 = 0.1$, $ThO_2 = 0.2$ and minor concentrations of Cl and F. Sample from Dr D. Schwarz.*

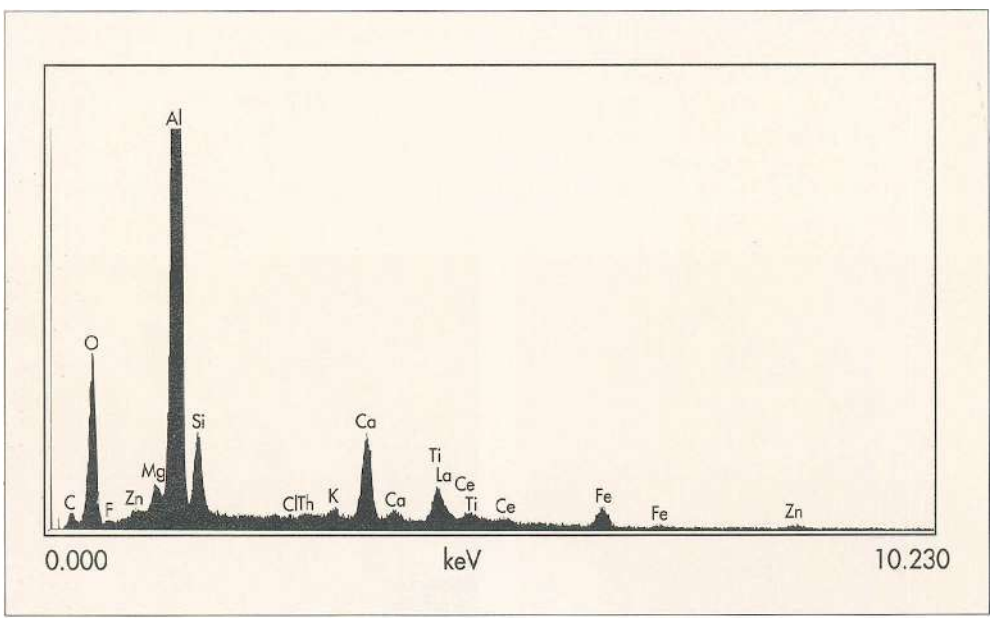

between marbles and intrusions of granite or charnockite, which is consistent with their metasomatic origin.

The different stages of metasomatism can be summarized as follows (Rakotondrazafy *et al.*, 1996):

Stage 1

Metasomatic transformation of the rocks due to CO_2-rich fluids at relatively high temperatures and medium pressures (850°C and 5 kilobar). Peraluminous and calcium-rich segregations made up of meionite, spinel and corundum are formed within titanite-bearing scapolite-clinopyroxene skarns. Concentrations of REE and Ti were low enough to preclude the crystallization of hibonite and since the quartz activity was below the zircon-baddeleyite-buffer, baddeleyite (ZrO_2) rather than zircon ($ZrSiO_4$) was formed during this phase. Typical, stable minerals are: aluminous diopside, carbonate, scapolite, titanite (sphene) or spinel, thorianite, corundum, baddeleyite.

Stage 2

Metasomatism of the rocks due to the infiltration of F-rich, Ti-rich, and REE-rich fluids at relatively lower temperatures and pressures (approx. 800°C and 3.5 kbar). Reaction of these fluids with corundum and spinel produced hibonite and there was breakdown of meionite into calcite plus anorthite. Quartz activity was below the zircon-baddeleyite-buffer and baddeleyite rather than zircon was formed. Newly formed thorianite (ThO_2) as well as fluor-phlogopite are also typical of this stage. Typical, stable minerals are: fluorine-rich pargasite, anorthite, calcite, thorianite, fluor-apatite, fluor-phlogopite, hibonite and baddeleyite. Later veins containing REE-rich calcites, zircon, titanite, diopside, scapolite and thorianite cut across these skarns.

Due to the unusual mineralogical compositions of the metasomatized rocks described above, their overall chemical compositions are characterized by low concentrations of SiO_2 and high concentrations of Al_2O_3 (Rakotondrazafy *et al.*, 1996). According to these authors, the chemistry is also characterized by a relatively high concentration of Zr, and Zr, Th and U are interpreted as typical, mobile elements in the metasomatism deduced for these skarns. Baddeleyite alone (without zircon) occurs in hibonite-bearing rocks. Metamict Ca–Zr–Ti oxides with variable amounts of Th, U and Nb, with compositions close to that of zirconolite [(Ca, Th, Ce) $Zr(Ti, Nb)_2O_7$] (Bayliss *et al.*, 1989) are also present in rocks containing hibonite. The coincidental occurrence of hibonite and sapphire in the mines at Andranondambo *(Figure 7a)* is confirmed by Kiefert *et al.* (1996), and Schwarz *et al.* (1996).

Figure 7b: *Sapphire-anorthite-phlogopite nodule from the Andranondambo mine. The sapphires are about 10 mm across, calcite is absent but 1 mm crystals of yellow–brown monazite are present plus one unidentified silicate (probably scapolite). SEM-EDX analysis indicates the monazite to be rich in U and Th. (Source E.)*

Figure 8a: *The miners work in narrow deep pits.*

Figure 8b: *Miner prospecting in a pit at the Andranondambo sapphire mine.*

Figure 8c: *Bucket to be filled with excavated material and hoisted to the surface on a rope.*

Mining operations

The mining area extends over a hilly region of approximately 2 to 3 km^2 and is squeezed like a wide trough between the mountains of ortho- and para-gneisses to the east and the old Precambrian granites and volcanic rocks to the west. The white skarns exposed at the mines and embedded in the green surroundings of hills and mountains afford a very beautiful sight. In the mining area, the sapphires are found in altered marbles and calcsilicates. At the visited localities, mining is accomplished by very simple means, in that narrow shafts are sunk into the snow-white and hard skarn to 20 and 30 metres depth; they are sunk in great numbers and close together so that only narrow walls are left. This creates a very dangerous landscape. The miners work in small groups using wedges, hammers, crowbars, shovels and buckets on ropes to hoist the loosened rock on to the surface. The calcareous rock is then hammered to ever smaller pieces *(Figures 8a, b and c)* to reveal any gems.

Production and distribution of sapphires from Andranondambo, Malagasy

When one of the authors (EG) visited the village in June 1996 and showed some interest in buying sapphires, he was soon surrounded by a large crowd of miners and village folk showing and offering sapphires, and the

Figure 9: *Sapphire from Andranondambo (Source A): beautifully developed blue colour phantom. 28x.*

Figure 10: *Sapphire from Andranondambo (Source A): a striking picture of the structure of the crystal faces which demonstrate a rhombohedral morphology. 40x.*

impression was gained that there were great quantities of gems in the hands of the natives. Most of the stones were small (between 0.5 and 2.0 ct) and of medium to low gem quality, yet good enough for gemmological research *(Figures 9 and 10)*. The occurrence of sapphire crystals at the Andranondambo mine is reported to be erratic and, considering the number of workers on the mine, the output appears to be limited at times. Gem traders are regularly present in the village and mostly acquire the day's spoil from the miners in the evening. The major proportion, estimated by some at 90%, of the production is shipped to Bangkok or Chantaburi for heat treatment and cutting *(Figures 5a and b)*. Dealers report a monthly average of 100 kg of rough, of gem or near-gem quality. The stones seem to be primarily marketed through Thailand. A large proportion of the crystals are less than 4 mm in size, but approximately 15% of the gem quality stones are reported to yield cut gems above 2 ct. To date, a number of 15–20 ct cut specimens have been seen in the trade, with exceptional stones which are even larger (Schwarz *et al.*, 1996). The largest piece of rough Madagascan sapphire, which was found in the first half of 1996 and later appeared in Bangkok, weighs 895 000 ct (17.9 kg), though this was not from Andranondambo.

Figure 11a: *Exsolved rutile needles as fine dust parallel to growth zones in unheated sapphire from Source B.*

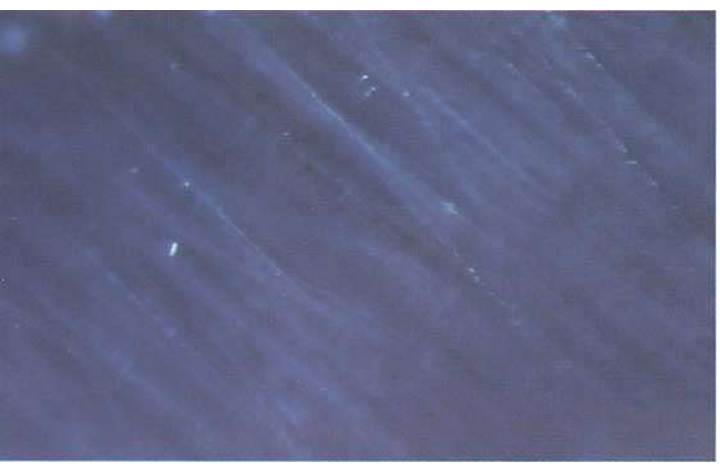

Madagascar sapphires at auction

During the regular examination of goods at the auctions of Christie's and Sotheby's in 1995 and 1996 by one of the authors (AP), a few lots were identified as Madagascar sapphires. Additional market studies were performed in Bangkok. The approximate prices for best qualities without visible colour zoning, without heat treatment, in different shapes of pleasing face-up appearance and not too heavily cut are listed below:

Sapphire weight	*Price*
more than 15 ct	above US $5000/ct
10–15 ct	US $3500–4500/ct
below 10 ct	US $1000–3000/ct
around 1 ct	around US $120 to 200/ct

These figures demonstrate that Malagasy sapphires have rightfully established themselves on the world market.

Growth structures and colour distribution

Growth structures have been extensively investigated by Kiefert *et al.* (1996), and Schwarz *et al.* (1996). The colour of the gems

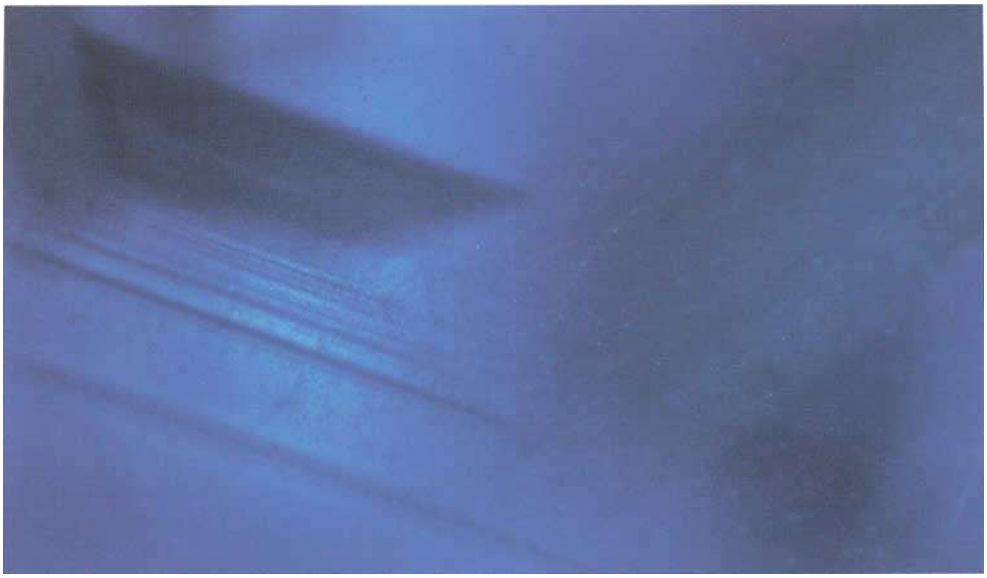

Figure 11b: *Phantom with milky growth structure parallel to basal pinacoid, in unheated faceted sapphire from Source D (typical for Andranondambo sapphires).*

varies from colourless to ordinary blue to fine royal blue *(Figure 5a)*. Some inky overtones may also be present. In most specimens the blue colour is not homogeneously distributed but rather forms blue phantoms or irregular blue patches and zones *(Figure 10)*. This patchy coloration may be evened out by heat treatment resulting in a more homogeneous coloration and improvement in the quality of the hue but colour zoning is commonly still present. Additional features include different types of streamers and 'clouds' as well as rutile needles *(Figure 11a)*. Such inclusions are also very often found in sapphires originating from Kashmir, Burma and Sri Lanka. Most conspicuous at first sight are the blue phantoms and colour zones (Sources A, B and D). The phantoms very often represent a precise replica of the crystal's habit at initial growth stages *(Figures 11b, 12)*. Especially it may be noted that the basal pinacoid is sometimes strongly emphasized by repeated striations parallel to it, inside the phantom. Apart from these, strongly coloured zones running parallel to dipyramids, the rhombohedron and the basal plane may also be observed *(Figure 9)*. Kiefert *et al.* (1996), and Schwarz *et al.* (1996) found that iron was the most common

Figure 12: *Sapphire, Andranondambo, Malagasy (Source A): a blue phantom containing a calcite fragment. 65x.*

Figure 13a: *Sapphire from Source A: negative crystals oriented parallel to the dipyramid n(22$\bar{4}$3) and yellow tablets of K-feldspar. 66x.*

Figure 13b: *Sapphire from Source A: negative dipyramids n(22$\bar{4}$3) aligned along the c-axis, and blue colour phantom. 40x.*

minor element (with 0.12 to 0.61 wt%), followed by Ti (with 0.01 to 0.10 wt%); Ga, V, Cr and Mn are also present in trace quantities (mainly between 0.01 and 0.04 wt%). Our data from representative samples are within these ranges. UV-VIS-NIR-investigations showed a high variability of absorption spectra, commonly assigned to variable contributions of Fe^{2+} and Ti^{4+} as well as Fe^{2+}–Fe^{3+} charge transfers. In conclusion, a wide range of chemical composition and absorption characteristics have been established for the Andranondambo sapphires which overlaps the ranges of observations recorded from a wide variety of other sapphires such as those from Myanmar (Burma), Sri Lanka and Kashmir.

Fluid inclusions

Occasionally, partially healed fractures with net-like patterns of the residual fluid inclusions have been observed. These, as well as the numerous negative crystals which are often aligned along crystal directions, appear to be mostly of monophase character when observed at room temperature, since no gas bubbles have been perceived *(Figures 13a, b)*. Detailed data on the chemical compositions of the fluids, predominantly CO_2, may be found in Bruder (1996), who also recorded occasional diaspore daughter minerals. The homogenization

Figure 13c: *P–T diagram with different isochores (after Rakotondrazafy et al., 1996) and reconstruction of the formation conditions (P,T) for different generations of sapphires and hibonite. Isochores (0.85 and 0.95) for two different generations of primary inclusions in sapphires are included on the basis of fluid densities published by Bruder (1996) (the two isochores constructed by inter- and extrapolation.) Range of A to B is estimated P–T range of sapphire formation (P = primary, S = secondary, Ps = pseudosecondary, Me = meionite).*

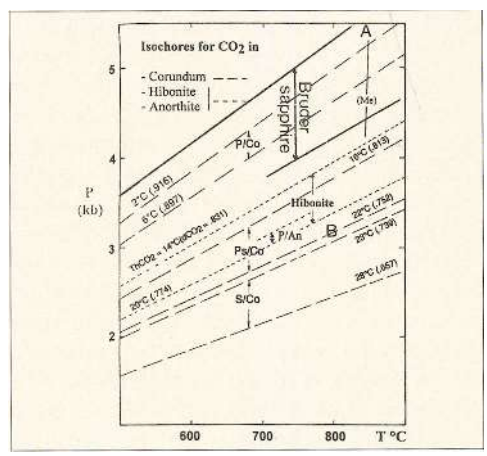

Table I: *Mineral inclusions in Madagascan sapphires (Andranondambo mine) from the literature and this work.*

Minerals found as inclusions in sapphire	*Milisenda and Henn, (1996)*	*Kiefert et al., (1996)*	*Schwarz et al., (1996)*	*This work*
Dolomite	x			
Calcite	x	x	x	x
Spinel	x?	x	x?	x
Hercynite-spinel s.s.				x
Hercynite-spinel-gahnite s.s.				x
Hedenbergite			x	
Mg-hornblende			x	
Feldspar (general)	x?		x	x
K-feldspar			x	x
Plagioclase (not specified)			x	
Anorthite				x
F-phlogopite				x
Phlogopite-annite			x	x
F-apatite				x
Apatite (not specified)	x	x	x	x
Ca-Na-silicates (scapolite?)			x	x
Thorianite-uraninite			x?	x
Baddeleyite				x
Zircon		x		
Zirconolite				x
Rutile	x?		x	
Diaspore (as daughter minerals in fluid inc.)	x?	x		
Clay minerals	x			
Fluorite				x

temperatures for primary inclusions range between 1°C and 19°C (Bruder, 1996), which is the reason that no bubbles are seen in the fluid inclusions above room temperature. Two different generations of primary inclusions were found by Bruder (1996) and additional fluid inclusion data on primary inclusions, pseudosecondary and secondary inclusions were reported by Rakotondrazafy *et al.* (1996). From these data different isochores have been prepared *(Figure 13c)*. It is evident that different generations of sapphires or corundum were formed in different conditions of pressure and temperature (*P* and *T*). Late sapphires grew most probably in similar *P/T* conditions as hibonite, but probably from different fluids, as will be discussed later.

Solid inclusions

The range of inclusions found during these investigations is shown in *Table I* next to those

Figure 14a: *Sapphire from Source A: two light calcite crystals beside botryoidal accumulation of F-phlogopite. 66x.*

Figure 14b: *Sapphire from Source A: calcite crystals; picture taken with polaroid filter. 66x.*

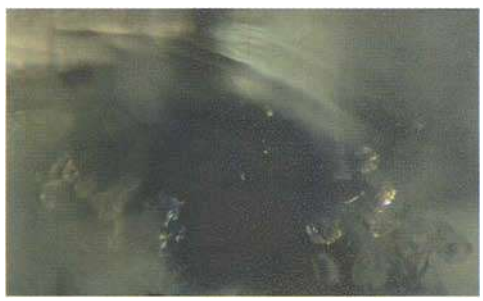

Figure 15a: *Sapphire from Source A: loose group of whitish inclusions comprising F-apatite, K-feldspars and calcites. 40x.*

Figure 15b: *Sapphire from Source A: group of more or less resorbed, colourless fluor-apatite crystals. 26x.*

found by other authors. In this investigation, inclusions were identified by a combination of optical and scanning electron microscope with energy dispersive system (SEM-EDX) analyses. Mineral inclusions are common and the most abundant in samples from source A – in order of their frequency – are colourless calcite as rhombohedral or rounded, resorbed crystals with many faces and twin planes *(Figures 14a, b);* hexagonal, more or less well shaped prisms of colourless apatite *(Figures 15a and b);* red-brown flakes of phlogopite *(Figure 16),* yellowish tablets of feldspar and black grains of 'thorianite-uraninite' with tension haloes. In contrast to source A, the most abundant mineral inclusion in the samples from source C is green spinel *(Figure 17).*

Below, new data about the properties of inclusions obtained by SEM-analyses will be discussed. Na-Ca-K-silicates, which could be scapolite or feldspars require XRD-analyses for identification. However, positive identification for meionite

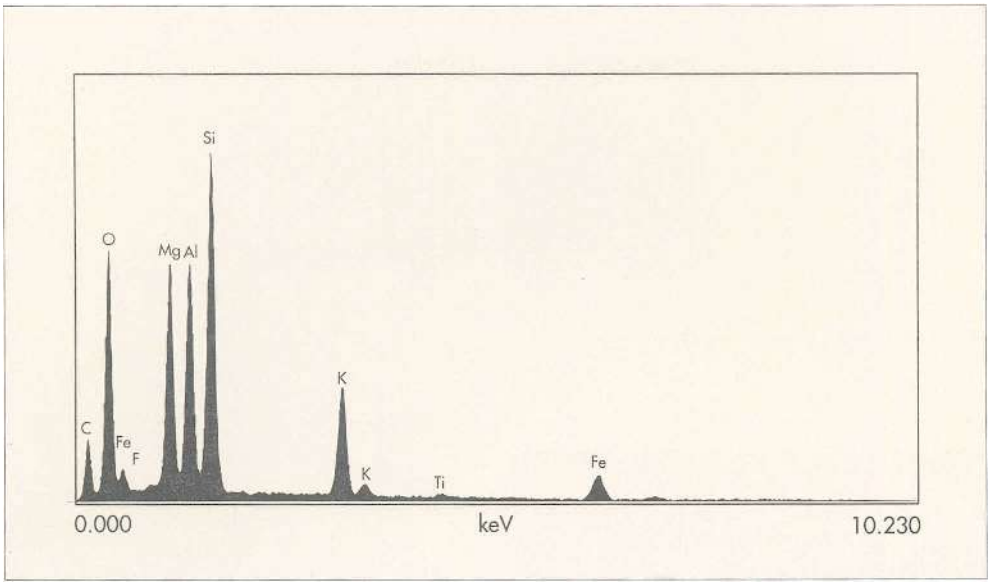

Figure 16: *Sapphire from Source A: botryoidal accumulation of F-phlogopite platelets accompanied by individual calcite crystals. 66x. An EDX spectrum indicates the major element peaks in the phlogopite.*

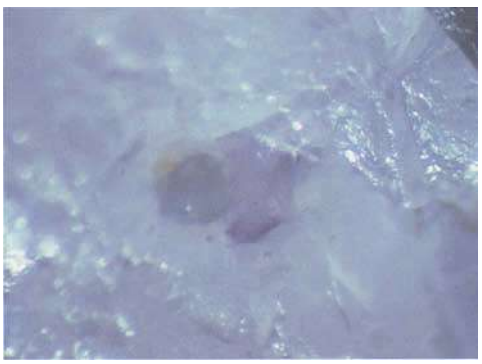

Figure 17: *Green spinel inclusion adjacent to lilac fluorite in a rough sapphire from Malagasy (Source C). Size of spinel is approx. 1 mm. Fluorite identification by SEM-EDX.*

inclusions is possible by combined SEM-analyses and acid testing (see *Figures 7 and 22*).

Baddeleyite (ZrO_2) from Source B

Baddeleyite inclusions were found with Mg–Al–spinel and Ca–Na–aluminosilicates (most probably scapolite and anorthite) in a rough sapphire *(Figure 18)* which had been heat-treated. Some silicate inclusions are transformed by heat treatment, but baddeleyite and Mg–Al–spinel are unchanged because of their very high melting points – above those of corundum.

Although baddeleyite has been discovered recently as an inclusion in a sapphire from a basaltic source, according to Guo *et al.* (1996), it was formed by alteration of zircon and is not considered to be a primary mineral inclusion.

Spinel group minerals from Sources A, B, and C

Spinel occurs in sapphires from each source. The chemical compositions range

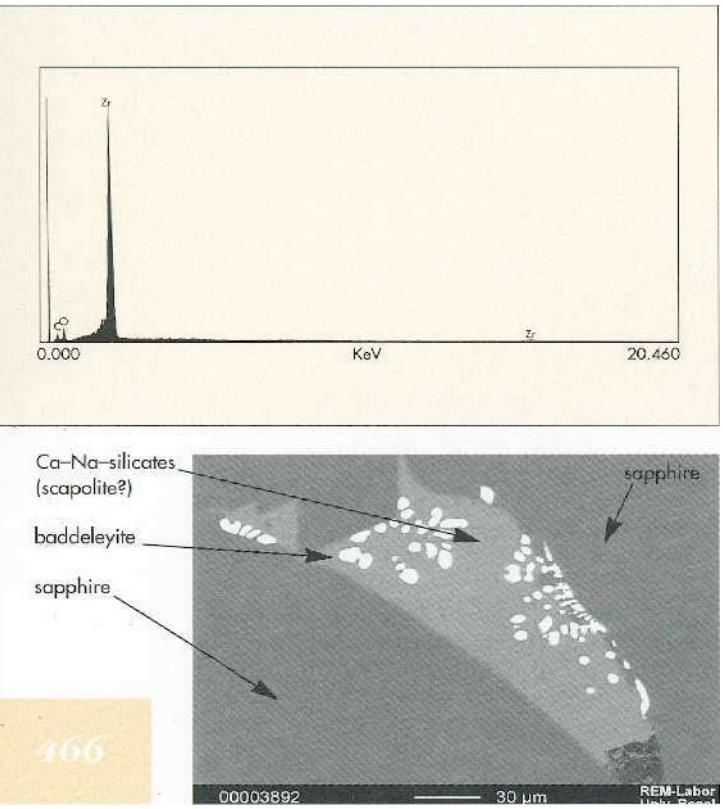

Figure 18: *Backscattered SEM image of baddeleyite inclusion (white) embedded in silicates (grey) in a matrix of a heat-treated rough sapphire (black) from Source A. Above is an SEM-EDX spectrum of baddeleyite (acceleration voltage 30 kV, carbon coated).*

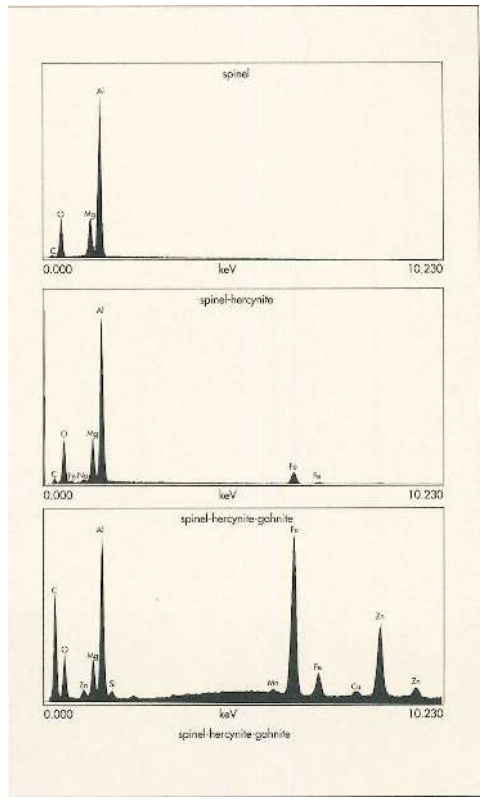

Figure 19: *A range of compositions of spinel group minerals which were found as inclusions in different rough sapphires (spinel, spinel-hercynite, spinel-hercynite-gahnite). SEM-EDX spectra from carbon-coated surfaces using an acceleration voltage of 20kV.*

from those of pure spinel ($MgAl_2O_4$) to green spinel with minor components of hercynite ($FeAl_2O_4$) and black spinel with a range of compositions in the gahnite ($ZnAl_2O_4$)–spinel–hercynite solid solution series *(Figure 19)*.

Thorianite (ThO_2) from Source C

This mineral was confirmed in sapphires only from Source C *(Figure 20)*. Its chemical composition is somewhat variable and results indicate that it lies in the thorianite-uraninite solid solution series in the region below 50 mol–% of the uraninite end-member. One example of a composition determined is: 65 wt% ThO_2, 30 wt% UO_2 and 3 wt% PbO with some traces of other elements.

Zirconolite [(Ca, Th, Ce)Zr(Ti, Nb)$_2$O$_7$] from Source C

'Zirconolite' was found as a minor constituent enclosed in the marginal part of a large rough sapphire from Source C *(Figure 21)*. It was intergrown with thorianite and surrounded by calcite and green spinel. These minerals were part of a minor piece of rock completely enclosed within the large pale-blue sapphire *(Figure 4)*. For details of the complex nomenclature and chemical composition of zirconolite, see Bayliss *et al.* (1989) and Williams and Gieré (1996). When comparing the chemical composition of Madagascan zirconolite included in sapphire to those published in the literature, the former show very

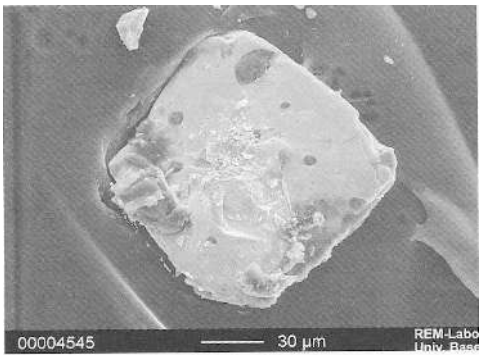

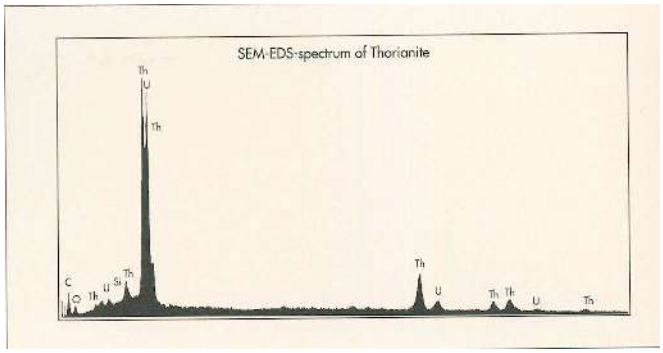

Figure 20: *Secondary electron SEM image of a separated thorianite-uraninite inclusion and its chemical composition (EDX spectrum, acceleration voltage 20kV, carbon coated). The sapphire host is from Source C.*

low Nb and rather high Th- and U-concentrations. They occur as inclusions associated with spinel, calcite and thorianite. Such associations occur in metasomatic skarn and other types of deposit (Purtscheller and Tessadri, 1985; Williams and Gieré, 1996), so this is consistent with the Madagascan assemblage also being of metasomatic skarn origin.

Fluorite (CaF_2) from Source C

Purplish fluorite inclusions were found in a rough sapphire from Source C. One of the fluorites was intergrown with spinel *(Figure 17)*. Fluorite inclusions have also been found in a ruby from the Mong Hsu mining area in Myanmar (Burma) (Peretti *et al.*, 1996) where they were formed in hydrothermal veins within dolomite marbles at lower temperature and pressure than the Andranondambo sapphires.

Fluor-apatite [$Ca_5(PO_4)_3(OH, F)$] from Source A

Minor concentrations of fluorine were found in a few of the apatites *(Figure 22)*.

Fluor-phlogopite [$KMg_3(Al, Fe)Si_3O_{10}(F, OH)_2$] from Sources A and B

Analyses indicate that with a small content of iron, the mica inclusions lie in the phlogopite-annite [$KFe_3(Al, Fe)Si_3O_{10}(F, OH)_2$] solid solution series. Traces of F and Ti were

Figure 21: *Backscattered SEM image of 'zirconolite' inclusion in sapphire from Source C. Its chemical composition is indicated by the EDX-spectrum obtained with an acceleration voltage of 20kV (carbon coated).*

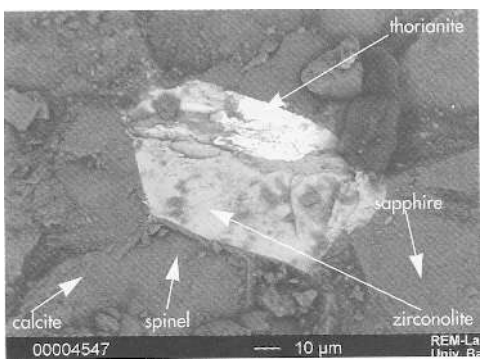

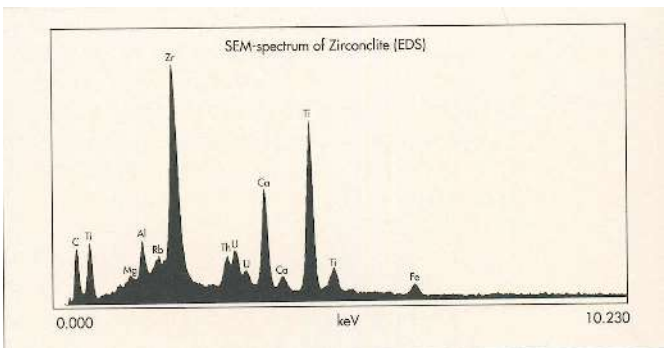

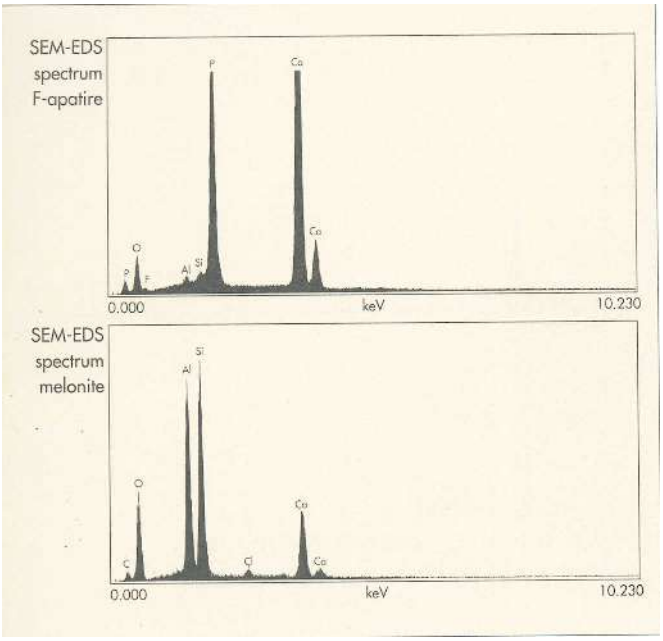

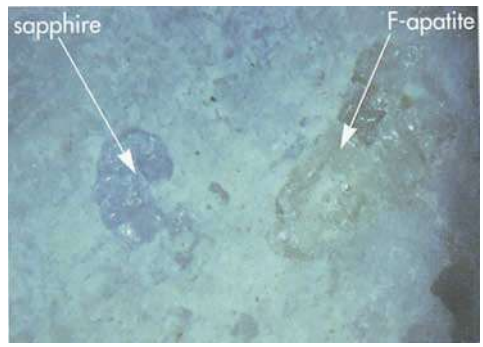

Figure 22: *Yellowish–green F-apatite next to a sapphire within a rock matrix consisting of anorthite and Cl-bearing meionite. EDX spectra of apatite and meionite are shown. Approximately the same F-contents were found in some apatite inclusions in the sapphires.*

also detected in the mica. Similar F-phlogopites were detected in a hand specimen from the Andranondambo mine *(Figures 7 and 16)*.

Calcite ($CaCO_3$) from Sources A, B and C

Calcite has been found in sapphires from each of the sources A, B and C. REE-elements above detection limits of 0.2–0.5 wt-% were not found during analysis.

Quartz from Source C

Although for chemical reasons one would not expect to find quartz inclusions in corundum, in one sapphire from Source C, a quartz inclusion was discovered alongside spinel. No other quartz inclusions have been seen in sapphires from Madagascan sources. It is worth noting that quartz inclusions have also been found in ruby from the mines of Luc Yen in Northern Vietnam (Delé-Dubois *et al.*, 1993), where the rubies occur in veins in marbles.

Summary

A review of the inclusions in sapphires from Madagascar (Andranondambo) which have been found to date is contained in *Table 1*. According to present knowledge, some have been found only in Madagascan (Andranondambo) sapphires, e.g. primary baddeleyite and zirconolite. On the other hand, some inclusions, which are often encountered in sapphires from other deposits, are uncommon in the Madagascan material examined in this study. This, for example, is the case with zircon. Although this mineral was described by Kiefert *et al.* (1996) as an inclusion in Madagascan (Andranondambo) sapphires, it is certainly extremely rare. It is much more common in the sapphires from other localities such as Kashmir, Sri Lanka and various basaltic deposits. Dolomite inclusions (except as listed in *Table 1*) were not found in this study, either in the mother rock or as inclusions in the sapphires. This demonstrates the distinctive genetic character of the skarn deposits at Andranondambo. Some inclusions, such as various types of Ca–Na–aluminosilicates, need further work to confirm their identities. In one sample, Ca-rich scapolite (meionite) could be identified by SEM-EDX analyses because of its high Cl-concentration and by its reaction to HCl *(Figures 7 and 22)*. Also, although hibonite occurs in some skarns *(Figure 7)*, it has not been reported as an inclusion in the Madagascan sapphires.

Conclusion

Mineral inclusions in the sapphires from the new mining area in southern Malagasy (Andranondambo) include carbonates (calcite), F-bearing minerals (F-apatite, F-phlogopite, fluorite), zirconium-bearing minerals (baddeleyite, zircon, zirconolite), Ti-bearing minerals (zirconolite, rutile, F-phlogopite), calcalkali silicate minerals (K-feldspar, plagioclase, scapolite), thorium and uranium phases (thorianite and zirconolite), hydrous minerals (Mg-hornblende, diaspore), phosphates (apatite) and various spinels in the system Mg–Al–Fe–Zn–O *(see Table I)*. This mineral association is typically found in rocks generally described as Th–U skarns. Therefore, these skarns are considered to be the most likely host rocks for sapphire formation which were produced by circulating fluids and mineral reactions within calcsilicate marbles.

Considering the different types of inclusions found in the sapphires and comparing them with the different generations of skarns (Rakotondrazafy *et al.*, 1996), the formation of sapphire can be more clearly defined. Mineral inclusions in sapphire can be related to at least two metasomatic events: the first event typically includes spinel and the second event is characterized by calcite, F-phlogopite and anorthite. Corundum (sapphire) therefore most probably formed during both phases of metasomatism. The published data on fluid inclusion analyses support this idea as different generations of CO_2-rich fluids are also present (see also Bruder, 1996). The variable formation conditions for the different corundum generations may be deduced from the data published by Bruder (1996) and Rakotondrazafy *et al.* (1996), ranging from approximately 850°C and 5 kbar (stage I) to lower temperatures and pressures of approximately 800°C and 3.5 kbar (stage II). The later metasomatic event is characterized by fluids rich in fluorine, titanium, and zirconium and mineral inclusions containing these elements (e.g. zirconolite and fluorite) are present in the sapphires.

Hibonite does not seem to have been formed with the first generation of sapphire but was formed during the later phase of the metasomatic event II from fluids rich in Ti, F, CO_2, and REE-elements. It has been demonstrated by Rakotondrazafy *et al.* (1996) that hibonite is formed from corundum by reaction with mineralizing fluids.

On the basis of this study of inclusions, metamorphic granulite facies metamorphism alone is not a likely model for the formation of the Andranondambo sapphires because at the time of formation of the sapphires, elements such as Th, U, K, Ca, Na, Mg, Al, Si, P, Fe, Mg, Zn, Zr as well as Cl, F and Ti must have been mobile. As suggested by Schwarz *et al.* (1996), sapphire formation seems to be best explained by metasomatic processes which are observed in the U–Th skarns within granulitic rocks (Rakotondrazafy *et al.*, 1996).

While most of the sapphires seem to have formed in a skarn environment, it is possible that other formation processes for sapphires may also have been active in other zones in the mines. Some indications of this are given by the presence of zircon as an inclusion (Kiefert *et al.*, 1996) and quartz (present work), which may have formed in later veins not equilibrated with the skarn rocks.

In conclusion, we have found no indication of formation of sapphires within a pegmatite-like vein environment as proposed by Kiefert *et al.* (1996), and the possible similarity between the Madagascan and Kashmir sapphires is now not thought to be significant. It is much more likely that the majority of Andranondambo sapphires were formed in a skarn environment.

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A unified system for classifying garnets

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ABSTRACT: Gem garnets are essentially solid solutions and compositions can be derived from refractive index data. Consequently, gemmological determinative tables can be greatly simplified by adopting a unified definition of a 'gem garnet species' as one containing 70 mole per cent or more of an end member. A simple new determinative table reflecting this concept is presented.

Garnet species classification

Although there will always be comments from mineralogists about nomenclature and the definition of a species, Stockton and Manson's (1985) paper put the matter on the line when they published their 'explicit gemmological definition' of species. It is now more than twelve years since publication of the 1985 definition and this author has yet to find any published disagreement with it. Silence gives consent (Goldsmith).

Whereas in the 1970s Webster dealt with five species of gem garnets, in 1985 Stockton and Manson introduced three more. In 1995, Johnson *et al.* added another. Simultaneously, a new generation of gemmologists has grown up familiar with that concept. Now it must be recognized that these 'new species' are a *fait accompli.*

Previously, it had been believed by many that expensive elemental analyses were required to enable one to usefully classify a garnet. Consequently, arbitrarily set dividing lines were established in the different classifications to separate the different fields or categories occupied by each garnet species. Stockton and Manson (1985), after analyzing over 200 specimens, continued to use this approach for their new species.

Now it is recognized that useful compositional data can be derived from refractive index values. 'A good estimate of a given stone's composition can be made by measuring its refractive index and interpolating between [end-members]' (Johnson *et al.,* 1995). Of course, spectral properties and/or colour are first used for deciding which series is appropriate. This aspect has been adequately covered in the two previous references.

Refractive index

The reason refractive index values are so useful is that, for practical purposes, most gem garnets can be considered as belonging to simple binary series. One great value of Stockton and Manson's study (1985) lies in its confirmation of this fact.

Defining limits of species

The problem to be dealt with in this paper is that of how one defines where an *end-member* species ends and a *mixed garnet species* begins. Granted, the initial decision is an arbitrary one. However, it is based on consistent proportions related to chemical

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composition, and its validity and utility should be readily apparent.

With any three-category series of a two-component system (i.e. end-member/mixture/end-member), two methods of dividing them come to mind: (a) divide the series into three equal parts of 33.33 per cent each; or (b) make the divisions at the 25 per cent and 75 per cent lines and have the mixture encompass the middle 50 per cent.

While the second alternative appears more attractive to this author, there is strong evidence that the trade, given the choice, prefers to deal with an 'end-member' over a 'mixture'. This is confirmed by the work of Stockton and Manson whose arbitrary boundaries reflect an acceptance of 70 mole per cent composition for their *end-member species*.

Therefore, it is proposed to 'draw the line' at 30 per cent and 70 per cent and adopt the following 'Rules':

1. if a garnet contains 70 per cent or more of the 'molecules' of one end-member, it shall be called that end-member;
2. if a garnet contains more than 30 per cent but less than 70 per cent of each of the 'molecules' of two different end-members, the names of the end-members will define the mixture.

Keeping with tradition, *mixed garnet species* will bear the following names: pyrope-almandine, pyrope-spessartine, almandine-spessartine and grossular-andradite. It is understood that the order of the names is an arbitrary one and does not necessarily reflect the ratio of the two components, as explained by Johnson *et al.* (1995).

Any three or more component garnets in which the end-member compositions are approximately equal shall be called by the three or more component name.

Benefits of unified system

Perhaps the greatest advantage for utilizing this unified approach is that it will, for the student, simplify the determinative tables for gem garnets. Given an unknown garnet, the investigator examines the colour, using the hand spectroscope if necessary, to determine the series to which it belongs. Then the refractive index is determined.

The following table defines the RI limits for the current *mixed garnet species* on the 70:30 basis:

Mixed garnet species	*Calculated refractive indices**
Pyrope-almandine	1.747–1.794
Pyrope-spessartine	1.740–1.780
Almandine-spessartine	1.816–1.824
Grossular-andradite	1.778–1.839

*see formula below

If the measured RI is below the limits of the mixture, the unknown is classified as the lower RI end-member. If the RI is higher, the unknown is classified as the higher RI end-member.

For example, both RI and end member composition data reported by Johnson *et al.* (1995) showed the lively greenish Mali garnets, which they classified as grossular-andradite, should be classified under this scheme as grossular. Their brown specimens, however, do cross the border into the grossular-andradite category.

Conversion of RI to composition or composition to RI can be done by means of the following formula using the appropriate end-member RI values:

End member garnets	*Refractive indices*
Pyrope	1.714
Almandine	1.830
Spessartine	1.800
Grossular	1.734
Andradite	1.887

Garnet refractive index = [0.01] {[(mole % of end-member A) (RI of end member A)] + (mole % of end-member B) (RI of end-member B)]}

If analytical results show the presence of more than two end-members, simply add additional terms. The total mole per cent should equal 100. Calculations can

frequently be approximated for small (<10%) components by combining pyrope with grossular and/or almandine with spessartine.

Conclusion

This approach will help to make gemmological terminology more straightforward by defining the criteria for differentiating an *end-member species* from a *mixed garnet species*.

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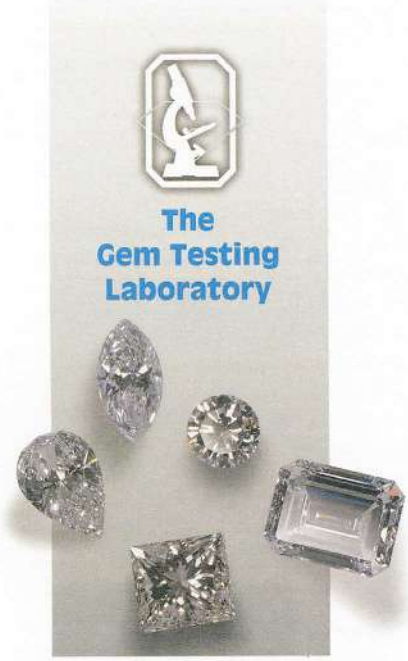

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Gems of Sri Lanka: a list of cat's-eyes and stars

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ABSTRACT: Twenty-eight cat's-eye and star gemstone varieties from Sri Lanka are listed. In addition to the usual chatoyancy and asterism, they show twenty-six different but related effects, from multi-chatoyancy and asterism to complex networks of optical reflections.

Keywords: gemstones, Sri Lanka, chatoyancy, asterism, optical effects.

Introduction

From ancient times, local cat's-eyes (mainly chrysoberyls) and star stones (mainly corundums) have been successfully traded in the global gem and jewellery market. Unfortunately, lesser-known gems of other mineral species have been largely ignored, reducing them to near redundancy. This article reports on virtually all the known Sri Lankan cat's-eyes and stars, with the purpose of making the reader aware of their existence, and of allowing the dissemination of information to establish a market share for these stones.

The many effects of chatoyancy and asterism of the gemstones in the following list only permits a brief description for each stone. For the same reason, although unusual phenomena are listed, the causes or mechanisms of some unusual patterns of chatoyancy and asterism have not been discussed.

Unusual features of chatoyancy and asterism

In additional to the more regular appearance of the effects of chatoyancy and asterism *(Figure 1a, d and e)*, certain species can display additional rays to their usual six-ray reflection pattern; for example, in corundum the total number of rays in the star is a multiple of six and as the total increases beyond 24 the star merges into a spot of light. Other examples are known from spinel and quartz *(see Figure 1i and j)*.

A second kind of unusual feature concerning reflections within a gemstone is the occurrence of more than one independent star, visible simultaneously only within narrow angles of observation (see corundum, *Figure 1p, q, r and s*). Each star is of generally similar pattern.

There are also cat's-eyes or stars with rays which appear to be split into two or three parallel segments; for example, in corundum, *Figure 1l and m*, and other examples are: quartz, moonstone, kornerupine or scapolite.

Networks of stars may occur throughout a stone and naturally the star configurations vary with the species. Numerous bands may occur within these stones along different directions and may intersect to create two kinds of networks, one with exclusively four-ray stars and the other with both four-ray and six-ray stars; for example, chrysoberyl, spinel, garnet, quartz, hypersthene and scapolite.

Finally, some varieties also display chatoyancy in transmitted light and these include moonstone, kornerupine and iolite.

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Table 1. *List of cat's-eye and star gemstones*

Species	Optical feature	Colour	Degree of abundance or rarity	Comments
Actinolite (amphibole group)	Cat's-eye	Dark greyish-brown, translucent to opaque	Rare	Strong chatoyancy
Almandine (garnet group)	Cat's-eye	Red, dark red, pink, brown colour shifts to red under tungsten light	Rarer than garnet stars	
	Four-ray star network	Deep wine red, orange red	Rare	Absorption lines attributable to almandine in the spectrum are stronger in deep red than in orange-red stones
	Four- and six-ray star networks[1]	Deep red, orange-red, brown colour shifts to reddish-brown under tungsten light, and may turn lemon-green under transmitted fluorescent light	Rare	One of the three bands in each six-ray star in the network is invariably weak. This is a characteristic feature
Apatite	Cat's-eye	Yellowish-green	Rare	
Aquamarine	Cat's-eye Six-ray star	Sea blue Sea blue	Rare Very rare	
Chrysoberyl	Cat's-eye	Yellow-green, honey-brown, green (including alexandrite), brown and black	Common	
	Four-ray star	Honey-brown, transparent to translucent; greenish-grey, opaque	Rare	Two bands of the star intersect at oblique angles
	Six-ray star	Pale yellow, translucent; greenish-grey, opaque	Very rare	Chrysoberyl is orthorhombic and a six-ray star may arise possibly from twinning (trilling) and appear hexagonal
	Four-ray star network	Yellow-green, honey-brown, lemon-yellow, green (alexandrite)	Rare	A common band is cut at right-angles and at regular intervals by a series of other bands
Corundum (including ruby and sapphire)	Narrow cat's-eye	Red (ruby), light blue, greyish-milky-white	Very rare	
	Broad cat's-eye	Light greenish-blue, light pink with a colour shift to medium pink in tungsten light	Rare	See six-ray star array below
	Six-ray star	Body colours – red, blue, pink, colourless, milky-grey, milky-white, yellow, orange, padparadscha, purple, lavender, green, black, blackish-copper-brown, other colours. With strong dichroism – blue-yellow, blue-yellowish green, other combinations. Parti-colours – red-blue, blue-pink, blue-yellow,	Common, greyish-blue is the commonest colour within the variety	There are three sets of parallel needle-like crystal inclusions (probably rutile) oriented at 60° to each other in the direction parallel to (0001) of the . corundum

Table 1. (Continued)

Species	Optical feature	Colour	Degree of abundance or rarity	Comments
		yellow-green, blue-yellow-green, other colour combinations. Colour change between daylight and tungsten incandescent light – blue to pink, green to red, purple to pink, brown to red, respectively		
	Twelve-ray star	Body colours – red, blue, yellow, milky-white, black, blackish-copper-brown. Parti-colours – blue-yellow-green, other colour combinations. Colour change between daylight and tungsten light – blue to pink, purple to pink, green to red, respectively	Varies with the colour. Blackish-copper is the commonest. Colour change green to red type is the rarest	Close examination of the twelve-ray star reveals an overlap of two six-ray stars, which are generally of two different colours, sizes and intensities
	Eighteen-ray star	Blackish-copper-brown	Rarer than twelve-ray stars	
	Twenty-four ray star	Blackish-copper-brown	Rarer than eighteen-ray stars	
	Six-ray chaotic star	Blue, light-blue, milky-blue, grey	Rarer than single six-ray stars	Parts of rays appear in discontinuous patches in such a way that collectively they show a six-ray star
	Six-ray star twins	Blue, metallic-copper-brown, milky-white	Rare	Two independent six-ray stars, often with more or less similar qualities, are seen side by side in the same polished face of the stone. The boundary between the two stars is jagged; when the stone is tilted under an overhead light source, both stars move, and always one star disappears or reappears progressively at this boundary. Generally, corresponding rays of the two stars are parallel to each other
	Twelve-ray star twins	Metallic-copper-brown	Extremely rare	Structural details are similar to those commented on in six-ray star twins
	Six-ray star triplets	Light-blue	Rare	Structural details are similar to those commented on in six-ray star twins
	Six-ray star array	Metallic blackish-copper-brown	Rare	This is a series of six-ray stars located

Table 1. (Continued)

Species	Optical feature	Colour	Degree of abundance or rarity	Comments
				close to each other with their centres forming a straight line. Where the stars are too close their identities are lost and they emerge as mere spots of light. Collectively they form a broad chatoyant band (see Broad cat's-eye above). Structural details are similar to those outlined for six-ray star twins above
	Twelve-ray star	Light blue	Very rare	This is the usual six-ray star, but each ray is split into two parallel segments
	Eighteen-ray star	Light blue	Rarer than twelve-ray star	This is the usual six-ray star, but each ray is split in to three parallel segments
	Eighteen-ray star	Pale greyish-green, translucent	Very rare	This is the usual six-ray star, but each ray is split into three segments which meet at the centre of the star
Diopside (pyroxene group)	Cat's-eye	Pale yellowish-green, brownish-brandy colour	Rare	There are characteristic spots of light on the chatoyant band apparently at regular intervals
	Four-ray star	Black-opaque, grass green -- semi-transparent	Black type is common, green is rare	Black type found in abundance in India
	Eight-ray star	Black-opaque	Very rare	
Ekanite	Four-ray star			This mineral may exhibit a weak asterism.
	Six-ray star			The stones are black in reflected light and grass green in transmitted light.
	Eight-ray star			These stones are rare. There are four sets of linear, red-brown inclusions in four orientations, and they intersect in three dimensions at 45° to each other
Enstatite (pyroxene group)	Cat's-eye	Colourless, brown or light green	Rare	
	Four-ray star Six-ray star Eight-ray star			
Epidote	Cat's-eye	Deep brown, translucent	Very rare	

Table 1. *(Continued)*

Species	Optical feature	Colour	Degree of abundance or rarity	Comments
Feldspar (alkali feldspar and plagioclase)	Four-ray star	Light-green, orange	Rare	
Hypersthene (pyroxene group)	Four- and six-ray network	Reddish-brown, translucent	Rare. The main source at Embilipitiya is now exhausted	The star configuration of the network is under study
Iolite (cordierite)	Cat's-eye	Greyish, translucent	Rare	Some stones exhibit strong chatoyancy under transmitted light also
	Four- and six-ray star network	Trichroic: deep purple-brownish yellow-yellow	Rare	Weak star net-work. The star configuration of the network is under investigation. Six-ray stars of the net-work are invariably oriented along the direction of the deep purple colour
Kornerupine	Cat's-eye	Black-opaque, honey-brown, yellow-green, greyish-brown. Stones other than black range from transparent to translucent	Rare	Rarely stones show a faint chromium absorption line in the red region of the spectrum
	Two-band cat's-eye	Honey-brown, translucent	Very rare	One chatoyant band is golden and the other is silver. Exhibits chatoyancy under transmitted light also
Monazite	Cat's-eye	Pinkish-brown with mottled appearance, translucent to opaque	Rare	Chatoyant band is of milky white colour
Moonstone (feldspar group)[2]	Two-band cat's-eye	Turbid white, semi-transparent	Rare	One band is golden and the other is silver. The two-band cat's-eye may be seen under transmitted light also
	Six-ray star	Turbid white, semi-transparent	Rare	This is the same two-band cat's-eye mentioned above, but the two bands are intersected at nearly 90° by a third silver band to form the star
	A star combination	Brownish-yellow, semi-transparent	Rare	Both eight- and four-ray stars mutually share a band. The same star combination is repeated on the other side of the stone *(Figure 2)*, but the positions of the two stars are changed along the common band. This common band and the two

Table 1. (Continued)

Species	Optical feature	Colour	Degree of abundance or rarity	Comments
				bands perpendicular to it are of silver colour, whereas the other two inclined bands are golden *(Figure 1u)*
Phenakite	Cat's-eye and four-ray star	Colourless with brownish tint	Rare	
Quartz	Cat's-eye	Colourless, reddish-brown, blackish-green, pale green	Rare	Large specimens over 100 carats have been reported
	Cat's-eye aggregate	Brownish with milky white, translucent	Rare	Several cat's-eyes differently oriented within the stone arise from many crystal individuals in an aggregate
	Four- and six-ray star network	Colourless, milky white, milky pink	Rare	
	Discontinuous four- and six-ray star network	Colourless, milky white, milky pink	Rare	Rays of each star may or may not link with other stars of the network, and therefore the network does not maintain a continuous order as in the type above
	Eighteen-ray star	Milky pink	Rare	
	Eighteen-ray star	Milky white	Very rare	This is an ordinary six-ray star, but each ray is split into three parallel segments
Rutile	Cat's-eye and four-ray star	Stones are greyish-black and nearly opaque, with high metallic lustre. Some are strawberry-red under transmitted light.	Cat's-eyes are rare. Stars are very rare	
Scapolite	Cat's-eye	Colourless-transparent, light yellow-transparent to translucent, black-opaque	Rare	
	Two-band cat's-eye	Greyish, transparent	Rare	Displays a two-band cat's-eye in transmitted light also
	Four- and six-ray star network	Black to grey, semi-transparent	Rare	
Scheelite	Cat's-eye and four-ray star	Turbid material. Colourless with yellowish or brownish tint, translucent.	Rare	
Sillimanite (gem variety known as fibrolite)	Cat's-eye	Colourless, greyish, reddish-brown, green	Rare	Very strong chatoyancy. Abundant supply of cat's-eye fibrolites from Orissa (India)
Sinhalite	Cat's-eye	Golden brown, transparent	Very rare	Silver chatoyant band caused by rutile needles *(Figure 3)*

Table 1. (Continued)

Species	Optical feature	Colour	Degree of abundance or rarity	Comments
Spinel	Cat's-eye	Light blue, pink-mauve, transparent; deep blue, translucent	Very rare	*(Figure 4)*
	Four- and six-ray star network	Blue, green, mauve, milky grey, transparent to translucent		Rare
	Twelve-ray star	Greyish-brown, translucent	Extremely rare	Observations were made on the single fine specimen recorded so far *(Figure 5)*
Taaffeite	Six-ray star	Brownish mauve	Very rare	Weak asterism
Topaz	Cat's-eye	Colourless with a tint of yellow, transparent	Rare	The cat's-eye effect is caused by long, parallel, blade-like, sillimanite inclusions along the length of the prismatic topaz crystal with a slight inclination of about 7° to the crystallo-graphic axis. There is an absorption band in the blue-green region of the spectrum of the stone
Tourmaline (Uvite)	Cat's-eye	Deep brown, brownish-green, transparent to translucent	Rare	Cat's-eye is caused by needle-like parallel inclusions oriented parallel to the c-axis of the host crystal
Zircon	Cat's-eye	Colourless, flame orange, green. Heat-treated: colourless, grey, brownish-yellow, and greenish-yellow	Rare. Production of cat's-eyes by heat treatment has affected rarity	Similar to diopside cat's-eye; there are characteristic spots of light on the chatoyant band at more or less regular intervals

[1]Colour change garnets found in Ethiliwawe, Theliulla, Wellawaya deposit (1995-1997) rarely produced stones with this star network. Dark blackish greyish green colour of these stones changes to purplish-red under tungsten light.

[2]In addition to these three effects, other kinds of chatoyancy and asterism are displayed by moonstone which are either:
Type A. an extension of the 'sheen effect', which naturally occurs along the same direction of sheen (the rays are silver, broad, diffused, and not well defined; the body colour of the stone is whitish, translucent; the stones are rare); or
Type B. occur along a direction at nearly 90° to the direction of the sheen effect (the rays are golden, very sharp, intense and well defined; the body colour of the stone is brownish-grey, with bluish sheen, and semi-transparent; the stones are rare)

Cat's-eye: Types A and B

Four-ray star: Types A and B

Six-ray star: Type B

Eight-ray star: Type B

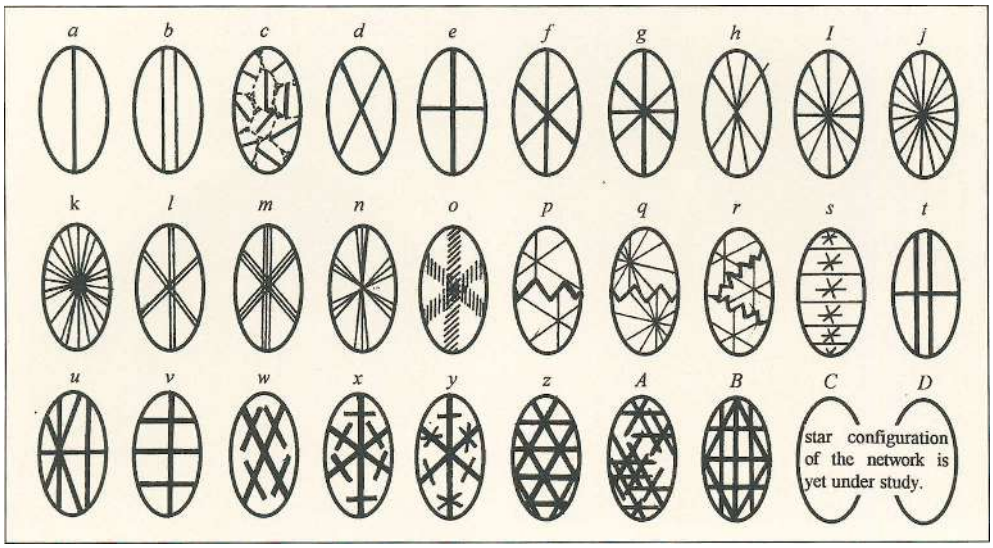

Figure 1: *A compilation of optical effects including chatoyancy and asterism observed in gemstones from Sri Lanka. Actinolite (amphibole group) a; almandine (garnet group) a, w, B; apatite a; aquamarine (variety of beryl) a, f; chrysoberyl a, d, f, v; corundum (including ruby and sapphire) a, f, i, j, k, l, m, n, o, p, q, r, s (Type A), s (Type B); diopside a, e, h; ekanite e ,f, g; enstatite (pyroxene group) a, e, f, h; enstatite, gem variety of hypersthene (pyroxene group) C; epidote a; feldspar (alkali feldspar and plagioclase) d; iolite (cordierite) a, D; kornerupine a, b; monazite a; moonstone (feldspar group) a (Type A), a (Type B), b, e (Type A), e (Type B), f, g, t, u; phenakite a, d; quartz a, c, j, m, z, A; rutile a, d; scapolite a, b, x; scheelite a, d; sillimanite (gem variety of fibrolite) a; sinhalite a; spinel a, i, y; taaffeite f; topaz a; tourmaline (uvite) a; zircon a.*

Figure 2: *Moonstone star combination.*

Figure 3: *Sinhalite cat's-eye. Only specimen recorded up to mid-1997.*

Figure 4: *Spinel cat's-eye.*

Figure 5: *Twelve-ray star spinel. Single fine specimen recorded so far.*

Concluding remarks

Patchy chatoyancy and asterism caused by parallel needle-like rutile inclusions have also been observed in Sri Lankan danburite, andalusite, sapphirine, vesuvianite and cassiterite. Therefore, it is likely that these gem species with well developed cat's-eye and star effects will be discovered in due course.

A recent study of topaz has revealed two sets of long, parallel, blade-like sillimanite crystal inclusions inclined at about 20° to each other. Consequently, it could be predicted that topaz with a four-ray star and a similar angle between the two bands may be found.

Fibrolites with very strong six-ray stars have been reported from Orissa, India *(Figure 6)*. Therefore, it is highly probable that similar stones may be found in Sri Lanka.

Chatoyancy and asterism are not mere accidental effects, they are ordered phenomena related to the crystallography of the host stone. Therefore, no natural amorphous material should show these effects with the possible exception of the metamict, ekanite and zircon. The occurrence of asterism in ekanite and the metamict zircons is the strongest evidence that the original materials were crystalline.

Figure 6: *Six-ray star fibrolite from Orissa, India.*

Acknowledgement

Many thanks to Mr T.G.N.R. Malinda for fine photographs.

The chronology of synthetic gemstones

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ABSTRACT: A detailed chronology of the various stages leading from initial experimental work to industrial production is presented for all of the gemstones that have been synthesized to date. Such information can be important for appraisal and authentication purposes.

Introduction

A chronology of synthetic gemstones is presented. Included are, for example, the first experimental growth of: emerald by J.J. Ebelmen (France, 1848); quartz by H. de Senarmont (France, 1851) and G. Spezia (Italy, 1898, *see Figure 1*); and ruby by E. Fremy and A.V.L.Verneuil (France, 1891, *see Figure 2*). Early commercial producers of ruby included the 'Geneva' product (Switzerland?, 1885; *see Figure 3*) and A.V.L. Verneuil and the Société Hellerite

Figure 1: *A natural quartz crystal, 25 mm long (above) and the same crystal after a five months' growth experiment (below) by G. Spezia in 1908 in Italy. Photo courtesy of E.A. Wood.*

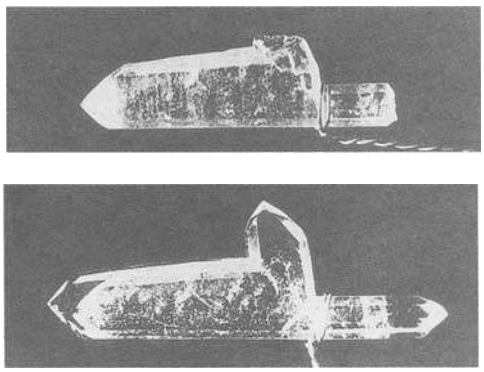

Figure 2: *An illustration from Fremy's 1891 hand-coloured book showing synthetic rubies in a crucible and experimental jewellery made from the product. The rubies grew only as small thin platelets up to 3 mm across and 0.33 carat in weight.*

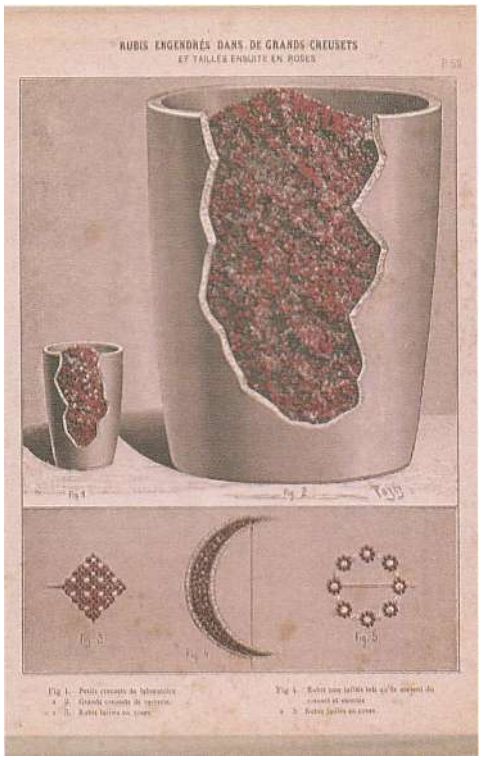

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Figure 3: *'Geneva' synthetic ruby produced about 1885 and sold as natural at that time. Photo copyright Kurt Nassau.*

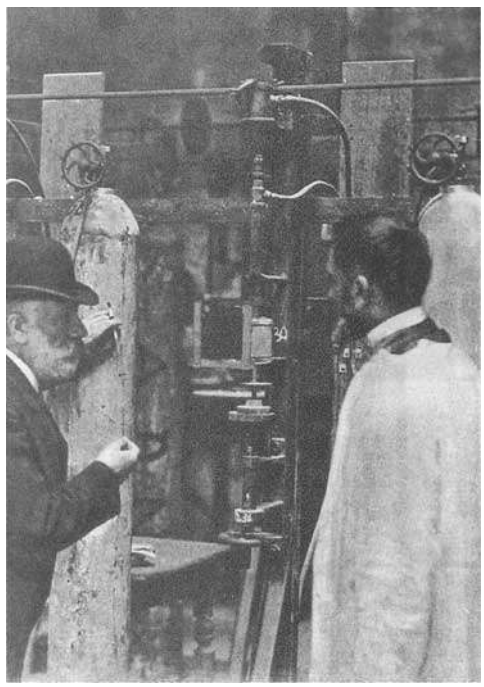

FABRICATION DU RUBIS SYNTHETIQUE
Devant le Chalumeau

Figure 4a: *Professor A.V.L. Verneuil, the discoverer of the flame fusion process (left) and Spec-Torski (right) in front of a Verneuil torch in the laboratory of the Société Hellerite in Paris, France, about 1910.*

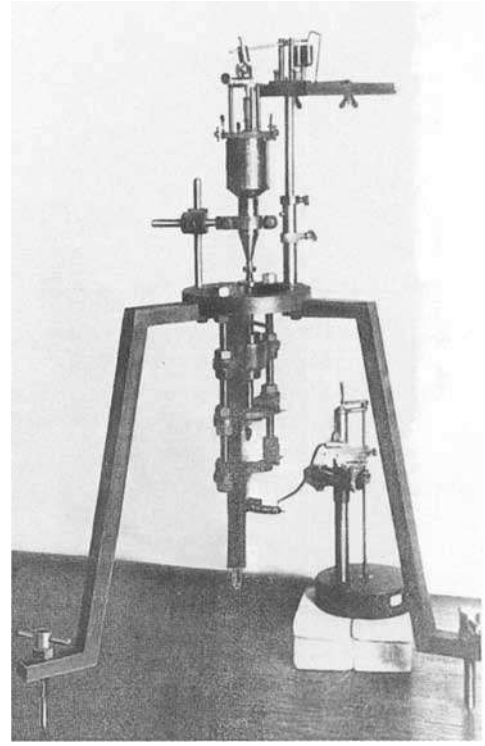

Figure 4b: *Verneuil's original flame fusion torch, about 1902, presently in the Museum of Art and Sciences, Paris.*

Figure 5a: *A rare photo of the De Beers synthetic diamond factory in the Rand, South Africa. Photo courtesy of De Beers.*

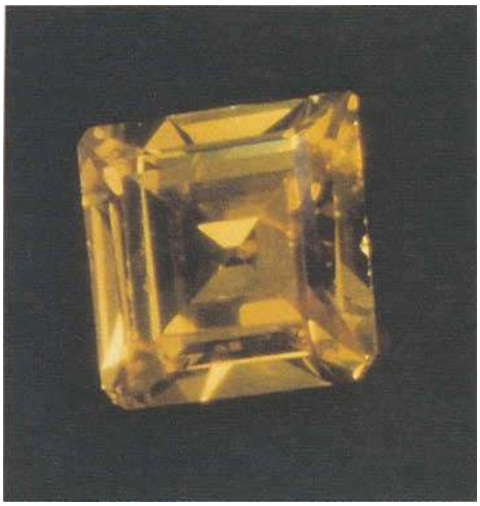

Figure 5b: *A yellow faceted De Beers synthetic diamond (0.24 ct), produced commercially for industrial use. Photo copyright Tino Hamid.*

Figure 6: *A synthetic moissanite, the most recent diamond substitute (1.68 ct, colour about G on the GIA diamond scale). Photo courtesy of C3 Inc. of Raleigh, NC, USA, which is introducing this material in 1997.*

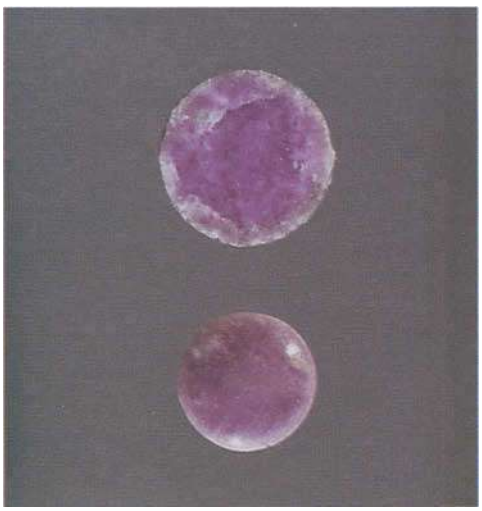

Figure 7a and b: *Synthetic jadeites produced on an experimental basis by the General Electric Co. in 1979. The largest disc is 12 mm diameter, 3 mm thick and weighs 2.46 ct. Photo copyright Kurt Nassau.*

(France, 1902, *see Figure 4*). The first commercial synthetic diamond production in size suitable for gemstone use was the yellow De Beers' material produced for semi-conductor use in 1985 *(see Figure 5a and b)*. The most recent product, entering the market only this year, is synthetic moissanite, the latest diamond substitute *(see Figure 6)*.

Discussion

The question is often asked: When was a certain synthetic gemstone material first produced? There may be several answers to this question depending on which stage of the process leading from discovery to full-scale production is required. When was the first experimental success of any size or quality?

Table 1: *The chronology of synthetic gemstones*

Year	*Synthetic material*	*Inventor/trade name/manufacturer/ country*	*Growth method*	*Reference*
Beryl, including emerald, aquamarine and red beryl				
Flux method:				
1848	Emerald (IS, NC)	JJ Ebelmen/France	FlS	N80, 128
1888	Emerald (IS, NC)	P Hautefeuille & H Perrey/France	FlS	N80, 129
1925	Emerald (IS, NC)	R Nacken/Germany	FlS	N80, 131
1934	Emerald (IS, NC)	H Espig/IG-Farben/Germany	FlS	N80, 129
1938	Emerald	CC Chatham/USA	FlS	N80, 141
1964	Emerald	Gilson/France	FlS	N80, 144
Hydrothermal and other methods:				
1960	Emerald (IS, NC); emerald over-growth (SP)	J Lechleitner/Austria	HyS	N80, 149; G81, 98
1964	Emerald (SP)	W Zerfass/Germany	HyS	N80, 130
1965	Emerald	EM Flanigen/Quintessa/Linde/USA	HyS	N80,150
1979	Watermelon beryl (SP)	Adachi Shin/Japan	?	G86, 55
1981	Aquamarine, pink and red beryl (SP)	Regency/Vacuum Ventures/USA	HyS	N90, 50; G81, 57
1988	Aquamarine, red and other colours (NC)	AS Lebedev/USSR	HyS	G88, 252; G90, 206
1994	Emerald, red beryl	Tairus/Russia and others	HyS	G96, 32
Corundum: ruby, blue sapphire and other colours				
Verneuil flame fusion, Czochralski pulling and other melt methods.				
1885	Ruby (SP) *(see Figure 3)*	'Geneva'/(Switzerland?)	FlF	N80, 42
1902	Ruby *(see Figure 4)*	AVL Verneuil/Société Hellerite/France	VeF	N80, 27
1903	Ruby (SP)	Hoquiam/USA	VeF	N80, 54
1907	Blue sapphire	Verneuil/Baikovsky/France	VeF	N80, 63, 66
1942	Ruby	L Merker/Linde/USA	VeF	N80, 69
1947	Star corundum	Linde/USA	VeF	N80, 69
1960	Ruby discs (SP)	Linde/USA	VeD	N80, 69
1965	Ruby	FR Charvat/Linde/USA	CzP	N80, 84
1971	Sapphire, colourless tubes, etc.	H LaBelle/Tyco/USA	CzE	N80, 87
1983	Ruby, etc. (NC)	Bijoreve/Seiko/Japan	FZo	G84, 60
1990	Pink Ti-sapphire	Union Carbide/USA and others	CzP	G95, 188, 214; G92, 66
Flux and vapour phase methods:				
1891	Ruby (IS, NC) *(see Figure 2)*	E Fremy and Verneuil/France	FlV	N80, 39
1958	Ruby	CC Chatham/USA	FlS	N80, 78; Pc
1958	Ruby (NC)	JP Remeika/AT&T Bell Labs/USA	FlS	N80, 78; Pc
1964	Ruby (IS,NC)	EAD White/England	VaR	N80, 91
1974	Blue sapphire	CC Chatham/USA	FlS	G82, 140; Pc
1980	Orange sapphire (padparadscha, SP)	CC Chatham/USA	FlS	G82, 140; Pc
1983	Ruby and sapphire; ruby overgrowth (NC)	J Lechleitner/Austria	FlS	N90, 53; J85, 557; G85, 35; J88, 95
Hydrothermal method:				
1958	Ruby (PQ, NC)	AT&T Bell Labs/USA	HyS	N80, 91; Pc
1965	Ruby (PQ, NC)	R Belt/Airtron/USA	HyS	N80, 91; G92, 278

Key

Growth methods:

CzE	CzP with edge-defined film-fed modification	HyI	HyS followed by irradiation
CzP	Czochralski pulling from the melt	HyS	Hydrothermal solution
Exp	Explosion reaction	SkS	Skull Solidification and equivalnt methods
FlF	Flame fusion, pre-Verneuil variant	SkH	SkS with yttrium oxide content higher than usual
FlS	Flux solution	SkI	SkS followed by irradiation
FlV	Flux-vapour complex system	SkL	SkS with yttrium oxide content lower than usual
FZo	Floating zone	VaR	Vapour phase reaction, atmospheric or low pressure
HPI	HPS followed by irradiation	VeD	VeF with disc modification
HPS	High pressure solution	VeF	Verneuil flame fusion
		VeT	VeF with tricone burner modification

***Table 1:** Continued*

Year	Synthetic material	Inventor/trade name/manufacturer/country	Growth method	Reference
Diamond, including film overgrowth and carbonado				
High pressure methods:				
1954	Diamond (IS)	T Hall/General Electric/USA	HPS	N80,174
1964	Carbonado	General Electric/USA	HPS	N80, 186
1970	Diamond: yellow, blue, colourless (NC)	RH Wentorf *et al.*/ General Electric/USA	HPS	N80, 186
1985	Diamond: yellow *(see Figure 5)*	De Beers/South Africa	HPS	N90, 58
1985	Diamond: yellow	Sumitomo/Japan	HPS	N90, 58
1993	Diamond: pink, red, purple (SP)	Many producers	HPI	G93, 38, 191; G94, 123; G96, 52, 128
1993	Diamond: blue, colourless (SP), yellow	Many producers	HPS	G93, 182; G95, 53; J95, 363
Other methods.				
1956	Diamond over-growth (IS, NC)	BV Derjaguin & BV Spitsyn/USSR	VaR	D93
1956	Diamond over-growth (IS, NC)	WG Eversole/USA	VaR	D93
1964	Diamond (IS, NC)	PS DeCarli and J Jamieson/USA	Exp	N80, 196
1966	Diamond (IS)	G.R. Cowan *et al.*/DuPont/USA	Exp	N80, 196
1991	Diamond over-growth, blue (NC) *(see Figure 9)*	A Phelps/USA	VaR	G91, 240
***Diamond imitation – Cubic Zirconia** (CZ is stabilized zirconia ZrO_2, usually with yttrium oxide Y_2O_3 added)*				
1969	CZ (NC)	Y Roulin *et al.*/France	SkS	G81, 9
1976	CZ	VV Osiko/USSR	SkS	G81, 9
1976	CZ	JF Wenckus/Ceres/USA	SkS	G81, 9
1978	CZ: many colours	JF Wenckus/Ceres/USA	SkS	G81, 9; J81, 602
1982	CZ: blue, green	C-Ox/Lebedev Institute/USSR	SkH	N90, 50
1983	CZ: opaque white (NC)	JF Wenckus/Ceres/USA	SkL	G91, 240
1983	CZ: opaque pink, white, black (NC)	?/Russia	SkL, SkI	G91, 240
Diamond – other imitations				
–	Spinel	See under Spinel below		
1948	Rutile	L Merker/National Lead/USA	VeT	N80, 211
1952	Strontium titanate	L Merker/National Lead/USA	VeT	N80, 214
1959	Yttrium garnets (IS, NC)	JW Nielsen and JP Remeika/ AT&T Bell Labs/USA	FlS	N80, 223
1968	Yttrium aluminium garnet	Many producers	CzP	N80, 224
1975	Gadolinium gallium garnet	Many producers	CzP	N80, 225
–	Cubic zirconia	See under Cubic Zirconia above		
–	Moissanite	See under Moissanite below		

Key

Production is (or was) for commercial gemstone use unless otherwise indicated:

IS	inadequate size for gemstone use
NC	not commercial, also in the sense that significant quantities are (or were) not seen in the USA trade
PQ	poor quality, not suitable for gemstone use
SP	small-scale production only.

References (source and year, page number)

D93	Davis, R.F. (Ed.), 1993. *Diamond thin films and coatings*. Noyes Publications, Park Ridge, NJ, USA
G– –	*Gems and Gemology*
J– –	*Journal of Gemmology*
N80	Nassau, K., 1980. *Gems made by man.* Chilton. Reprinted by Gemological Institute of America, Carlsbad, CA, and references given therein
N90	Nassau, K., 1990. Synthetic gem materials in the 1980s. *Gems and Gemology*, **26** (1) p. 50, and references given therein
Pc	Personal communication

***Table 1:** Continued*

Year	Synthetic material	Inventor/trade name/manufacturer/country	Growth	Reference
Alexandrite and chrysoberyl				
1973	Alexandrite	Creative Crystals/USA	FlS	N80, 246
1978	Alexandrite (NC)	Bijoreve/Seiko/Japan	FZo	G84, 60
1980	Alexandrite (SP)	Allied Chemical/USA	CzP	N90, 50
1983	Chrysoberyl cat's-eye (NC)	Sumitomo/Japan	FZo	G83, 186; J88,232
Forsterite and peridot				
1963	Forsterite (IS, PQ, NC)	TJ Shankland and K Hemmenway/USA	CzP	G94, 102
1971	Forsterite (NC)	CB Finch and GW Clark/USA	CzP	G94, 102
1991	Peridot (NC)	DR Hanson *et al.*/USA	FZo	G94, 102
1992	Forsterite *(see Figure 8)*	K Yamagachi/Mitsui Mining and Smelting, Japan	CzP	G94, 102
Jadeite				
1953	Jadeite (IS, NC)	L Coes/Norton/USA	MPS	N90, 50
1979	Jadeite (NC) *(see Figure 7)*	RC DeVries and JF Fleischer/General Electric/USA	MPS	N90, 50
Malachite				
1982	Malachite (NC)	VS Balitskii *et al.*/USSR	(HyS?)	N90, 50; G87, 152
Moissanite				
1970	Moissanite: yellow, brown, green, blue (IS, NC)	Many carborundum producers	VaR	Pc
1997	Moissanite *(see Figure 6)*	C3 Inc./USA	Sub	G96, 52; Pc
Opal				
1972	White opal	P Gilson/France	ChR	N80, 259; N90, 50
1974	Black opal	P Gilson, France	ChR	N80, 259; N90, 50
1975	Fire opal (NC)	P Gilson/France	ChR	N90, 50; J84, 43; G85, 110
Phenakite				
1988	Phenakite (IS, PQ, NC)	P Hautefeuille and H Perrey/France	FlS	N80, 129
1957	Phenakite (IS, PQ, NC)	CC Chatham/USA	FlS	Pc
1965	Phenakite (IS, PQ, NC)	A Ballman/AT&T Bell Labs/USA	FlS	Pc
1994	Phenakite (NC)	?/Russia	FlS	G94, 199
Quartz: including citrine, amethyst, smoky and rose quartz				
1851	Quartz (IS, NC)	H de Senarmont/France	HyS	N80, 100
1898	Quartz (NC) *(see Figure 1)*	G Spezia/Italy	HyS	N80, 100; J84, 240
1898	Quartz (NC)	R Nacken/Germany	HyS	N80, 101
1940	Quartz	AT&T Bell Labs/USA	HyS	N80, 102
1940	Quartz	Clevite/USA	HyS	N80, 102
1942	Smoky quartz (NC)	AT&T Bell Labs/USA and others	HyS	N80, 114
1958	Citrine (NC)	LI Tsinober/USSR	HyS	N90, 50
1959	Amethyst (NC)	LI Tsinober/USSR	Hyr	N90, 50
1974	Citrine	Many producers	HyS	N80, 116
1975	Amethyst	Many producers	HyI	N80, 117
1980	Amethyst/citrine (ametrine; NC)	K Nassau/AT&T Bell Labs/USA	HyI	G81, 37
1985	Rose quartz (NC)	M Hosaka *et al.*/Japan	HyS	N90, 50
Sodalite				
1973	Sodalite, colourless (NC)	R Belt/Airtron/USA	HyS	Pc
1991	Sodalite: blue, colourless (NC)	Liu/China	HyS	G92, 240
Spinel: colourless, blue, red, etc., including gahnite spinel				
1848	Spinel (IS, NC)	JJ Ebelmen, France	FlS	N80, 210, 247
1907	Spinel (NC)	L Paris/France	VeF	N80, 210, 247
1908	Spinel	AVL Verneuil/Societe Hellerite/France	VeF	N80, 210, 247
1960	Spinel and gahnite, various colours (NC)	EAD White et al./England	FlS	Pc
1960	Spinel and gahnite, various colours (NC)	JP Remeika et al./AT&T Bell Labs/USA	FlS	Pc
1989	Spinel: red, blue (SP)	Lebedev Institute/USSR	FlS	G93, 81

Key

Growth methods:

ChR	Chemical reaction in solution, then settling and compaction
CzP	Czochralski pulling from the melt
FlS	Flux solution
FZo	Floating zone
HyI	HyS followed by irradiation?
HyS	Hydrothermal solution
MPS	Medium pressure solidification
Sub	Sublimation in the vapour phase
VaR	Vapour phase reaction, atmospheric or low pressure
VeF	Verneuil flame fusion

Production is (or was) for commercial gemstone use unless otherwise indicated:

IS	inadequate size for gemstone use
NC	not commercial, also in the sense that significant quantities are (or were) not seen in the USA trade
PQ	poor quality, not suitable for gemstone use
SP	small-scale production only.

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N90	Nassau, K., 1990. Synthetic gem materials in the 1980s. *Gems and Gemology,* **26** (1) p. 50, and references given therein
Pc	Personal communication

When did the size and quality first reach the needs of the gemstone trade in experimental work? When was the first actual commercial production? When were there any significant changes in the process or in the product? And so on. Such information can be important for appraisal and authentication purposes, among others.

I have assembled in *Table 1* data for synthetic gemstones used at present in the gemstone trade. Included are diamond imitations as well as some synthetic materials that have been announced but have never arrived in the trade, such as synthetic malachite. Also included are some synthetic materials that have been produced only experimentally so far but that could conceivably appear in the trade at any time, such as synthetic jadeite first made in adequate size and quality in 1979 *(see Figure 7).* Enhanced synthetics are included only when different colours are produced by irradiation, as with synthetic amethyst, red diamond and smoky quartz.

Excluded from *Table 1* are enhanced or reconstructed natural gemstones, as well as imitations such as ceramic products (e.g. imitation coral, lapis lazuli and turquoise) and glasses (e.g. 'emerald glass', goldstone, opalescence and fibre-optic imitation cat's-eyes). Also excluded are the many man-made technological crystals which are faceted only for specialist collectors.

The years given usually can be only approximate for several reasons. Production may have been announced before a significant quantity of a product was actually available; it may have taken several years between the achievement and the publication of a description or the issuing of a patent; and so on. As always, patent disclosures generally cannot be relied upon for several reasons; the patent claim may not have been followed up, the range of compositions claimed is frequently much wider than can be achieved in reality, and some patents actually do not work!

In fact, not everything published even in the refereed literature can be accepted at face value. As one example, success at diamond synthesis is occasionally attributed to Scottish scientist J.B. Hannay about 1902, yet subsequent investigation of his products have completely negated his claim *(see Reference N80, 164 of Table 1).* Even more curious is the occasional attribution to the AT&T Bell Telephone Laboratories (where diamond synthesis was never investigated) in 1955 of the Hannay claim (possibly because of confusion with Dr N.B. Hannay, who worked at AT&T).

Early work is included only if it represented a significant advance in the state of the art or unusual circumstances. Only the first commercial manufacturer for any combination of process and product is given, again except

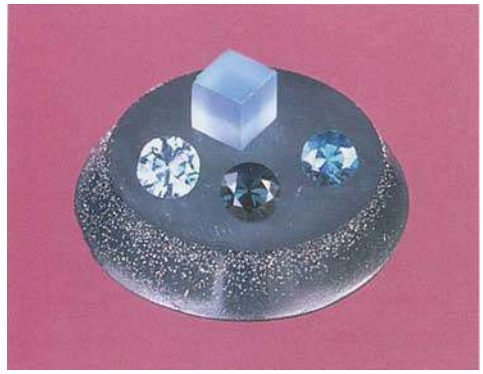

Figure 8: *Pure and chromium-doped synthetic forsterite grown by Mitsui Mining and Smelting Co., Japan, for laser use: a 27 mm diameter slice, a 50 mm cube and three faceted samples (1.18 ct, 1.07 ct and 0.83 ct). Photo by N. DelRe, courtesy of the GIA.*

Figure 9: *Originally near-colourless diamonds (0.33 ct, 1.15 ct and 0.36 ct) have been coated with a greyish-blue synthetic diamond film by A. Phelps at the University of Pennsylvania. Photo by R. Weldon, courtesy of GIA.*

for significant developments or unusual circumstances. Today most synthetic products have several to many manufacturers, with Japan and Russia particularly active.

In deciding whether a product is (or ever was) in commercial production, I have ignored publicity releases and always tried to determine when the material was actually seen in significant quantities in the gemstone trade and by gemmologists, e.g. in the Gem Trade Laboratories of the Gemological Institute of America.

Some of these synthetic materials are or were initially investigated and manufactured for uses other than those of the gemstones trade. Examples include colourless synthetic quartz used for oscillators and filters in communications and for lenses and windows for special optics; Czochralski-grown synthetic alexandrite and forsterite (peridot) used as the active material for some lasers; synthetic diamond for abrasive grit and for semiconductor heat sinks; and so on. A current example is the latest diamond simulant, the synthetic moissanite listed in *Table 1* (as shown in *Figure 6*), important for semiconductor, light-emitting diode and blue laser uses.

To avoid a long and awkward citation list, the limited references given in simplified form will lead the interested reader mostly to books or review articles where detailed descriptions and sources (or reference to further compilations of sources) may be found.

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LETTERS TO THE EDITOR

From Dr K. Nassau

Dear Sir,

A colour-change effect apparently never before reported in a gem or mineral has been described in chrome tourmaline from Umba Valley, Tanzania, by A. Halvorsen and B.B. Jensen (*J. Gemm.*, **25**(5), 1997, p. 325). The colour changed from green to red with an increase in thickness.

May I point out that this effect is well known in the field of organic dyes, in which field it is usually designated as 'dichroism'. The colour change is produced by an increase in the concentration of the dye, quite equivalent to an increase in the thickness of the tourmaline. An explanation is given on page 111 of my book *The physics and chemistry of color.*

A consideration of the mechanism involved makes one feel surprised that these effects have not been observed previously. Now that attention has been drawn to these effects, they will very likely be observed in other gem and mineral materials. So the question arises whether a name such as the 'Usambara effect' proposed by Halvorsen and Jensen is not tied too closely to the specific material they studied.

The simple designation 'dichroism' that already exists for these effects, however, conflicts with the orientation-dependent 'dichroism' of mineralogy and gemmology. Accordingly, I believe the simple and descriptive terms 'concentration dichroism' and 'thickness dichroism' would perhaps be more appropriate (and easier to remember as well!). One should note that the monumental *Oxford English Dictionary* does give both the orientation and concentration meanings under 'dichroism' and 'dichroic' on p. 327 in Vol. 3.

Yours, etc.
Kurt Nassau
Lebanon, New Jersey 08833, USA
25 January 1997

Reference

Nassau, K., 1983. *The physics and chemistry* of color. John Wiley & Sons Inc., New York.

From Asbjørn Halvorsen and Brenda Jensen

Dear Sir,

Reply to Dr Kurt Nassau

Dr Nassau raises three points to which we wish to reply:

1) *Lack of observations of colour change with thickness in the mineralogical literature.* We agree that it is surprising that such a colour change has not been reported in the mineralogical/gemmological literature earlier, but we conducted a careful search and failed to find any references. If we have missed something we would be glad to hear about it.

2) *Examples from solutions.* We did state in our paper that the same type of colour change was reported for solutions. Dr Nassau's example of organic dyes quotes only colour variation with concentration. If we had used it we would have had to explain the equivalence of concentration and thickness in modifying selective absorption patterns (with references to Beer's equation). Instead we quoted the Webster reference concerning chrome alum solutions, because the same chromophore was involved as in our tourmaline and because we could then refer to Webster's statement, that the effect is seen

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both with concentration and thickness change, without needing to make further explanation.

3) *Use of the term 'dichroism'*. We are aware of the disadvantages of introducing a locality name like 'Usambara effect', but we had problems in finding a suitable alternative 'scientific' term.

We considered 'dichroism' and Webster's 'dichromatism'. We must admit that we did not consult the *Oxford English Dictionary* in our search. We have, however, consulted many mineralogy and gemmology text books (American and English), *Glossary of geology, Concise Encyclopaedia of Science and Technology, Encyclopaedia of Mineralogy* and *Encyclopaedia Brittanica* and found only the pleochroic definition of dichroism in all of them. This would not, of course, prevent our introducing the term in another context if this were a logical extension of its use. However, 'dichroism' is synonymous with proof to a gemmologist that he is dealing with an optically anisotropic material; it seems therefore to us unnecessarily confusing to speak of 'thickness dichroism' in a case where the colour change can occur in any medium isotropic or anisotropic.

In a mineral, the point at which colour change occurs is determined by pathlength and chromophore concentration, possibly also modified by vibration direction, so 'thickness dichroism' (or pathlength colour change) does not tell the whole story, which was for us another reason for rejecting it in favour of the more neutral locality name.

Yours, etc.
A. Halvorsen and B. Jensen
Oslo, Norway

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Abstracts

Diamonds | Instruments and Techiques

Gems and Minerals | Synthetics and Simulants

Diamonds

The typical gemmological characteristics of Argyle diamonds.

J. Chapman, G. Brown and B. Sechos. *Australian Gemmologist*, **19**(8), pp 339–46, 1 illus. in black-and-white, 2 maps, 1 table, 13 illus. in colour, 5 graphs, bibl.

Western Australia's Argyle lamproite pipe is located at the headwaters of Smoke Creek in a small valley near the eastern end of the Matsu range. The pipe's annual yield of brown, yellowish brown, colourless and red to pink diamonds rose to almost 40 million carats in 1995. In their paper, the authors make a valuable contribution to the information available on the characteristics of Argyle's diamonds. In addition to the text, there is a table listing gemmological characteristics ranging from Type classification through N aggregation status to UV and X-ray fluorescence/phosphorescence, and inclusions. Other characteristics are illustrated in the thirteen colour figures, four transmission spectra of colourless, champagne, cape and pink diamonds, and a typical IR absorption spectrum of brown diamond. P.G.R.

Gem trade lab notes.

C.W. Fryer. *Gems & Gemology*, **32**(3), 1996, pp 204–12.

Nitrogen impurities in diamond can be the cause of yellow to brown colours, but the nitrogen need not be evenly distributed within the diamond crystal. Hydrogen impurities may also lead to an uneven distribution of grey or brown colours. A rough diamond with uneven colour was sawn into two pieces with the larger half yielding a fancy brownish yellow and the smaller half yielded a G colour. Both stones showed similar inclusions, but they had substantially different infrared spectra, due to variations in impurity concentrations.

A 3.40 ct heart shaped diamond, graded as a Fancy Intense Pinkish Orange & Internally Flawless was examined. Infrared spectroscopy revealed the stone to be type IIa, due to a lack of measurable nitrogen. The absorption pattern showed a broad band centred at 550 nm.

A suite of six treated-colour pink-to-purple diamonds showed some unusual properties. Out of the six stones, four were type Ib showing three sharp bands at 575, 595 and 637 nm. One had some additional type Ia component and the sixth stone appeared to have a type IaA spectrum with an H1b peak, a feature commonly seen in treated yellow diamonds. It was the first time such a spectrum had been seen in a treated pink diamond. Although this stone might have been mistaken for an untreated diamond, the 637 nm line is rarely seen and the 537 nm is never seen in natural stones. J.J.

Gem trade lab notes.

C.W. Fryer. *Gems & Gemology*, **32**(4), 1996, pp 277–281, 16 illus. in colour.

Colour often appears unevenly distributed in cut diamonds as a result of the cutting style, e.g. the tips of a marquise may concentrate colour. Also, occasionally diamonds may be colour zoned. It has now been found that cleavage may also influence the colour distribution within a diamond. J.J.

Identification of diamonds from cubic zirconia (CZ).

N.B. Jashnani and S. Chudawala. *Indian Gemmologist*, **6**(4), 1997, pp 5–10, illus. in colour.

Summary of the properties of CZ and diamond with a review of the simpler means of identification. M.O'D.

Gem news.

M.L. Johnson and J.I. Koivula. *Gems & Gemology*, **32**(3), 1996, pp 214–22.

A new cut of diamond is on the market called the 'Buddha Cut'. J.J.

Abstractors

A.F. Cooper	A.F.C.	R.A. Howie	R.A.H.	V. Jovic	V.J.	P.G. Read	P.G.R.
R.K. Harrison	R.K.H.	J. Johnson	J.J.	M. O'Donoghue	M.O'D.	R.E. Samson	R.E.S.

For further information on many of the topics referred to, consult *Mineralogical Abstracts*.

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Gem news.

M.L. Johnson and J.I. Koivula. *Gems & Gemology*, **32**(4), 1996, pp 282–292, 21 illus. in colour.

A summary of the types of diamond crystals is given from Kelsey Lake, Colorado. J.J.

Comments on the paper by G.M. Gonzaga *et al.* The origin of diamonds in western Minas Gerais, Brazil.

O.H. Leonardos, R.N. Thompson, R. Fleicher, S.A. Gibson, D.P. Svisero and R.K. Weska. *Mineralium Deposita*, **31**(4), 1996, pp 343–344.

A series of arguments was presented by Gonzaga *et al.* against a late Cretaceous kimberlitic diamond source in W Minas Gerais while giving geological evidence for glacial diamond transportation from a remote Precambrian source. It is considered that it failed on both counts. [Following abstract] R.E.S.

Reply to the comments by O.H. Leonardos *et al.*

G.M. Gonzaga, N.A. Teixeira and J.C. Gaspar. *Mineralium Deposita*, **31**(4), 1996, pp 345–347.

Although the comments [preceding abstract] do not stand up to critical analysis they provide the opportunity to continue the discussion. R.E.S.

Eclogitic inclusions in diamonds: evidence of complex mantle processes over time.

L.A. Taylor, G.A. Snyder, G. Crozaz, V.N. Sobolev, E.S. Yefimova and N.V. Sobolev. *Earth & Planetary Science Letters*, **142**(3–4), 1996, pp 535–551.

The first ion-probe trace element analyses of clinopyroxene-garnet pairs both included in diamonds and from the eclogite host xenoliths from the Udachnaya and Mir kimberlite pipes, Siberia, are reported. The most striking aspect of the chemical compositions of the diamond inclusions is the diversity of relationships with their eclogite hosts. Garnet and clinopyroxene inclusions in the diamonds from two Udachnaya samples have lower *mg*, lower Mg, higher Fe contents, and lower *REE* than those in the host eclogite; such variations are interpreted as due to metasomatism of the host eclogite after diamond formation. Clinopyroxene inclusions from the central (early) portions of Yakutian diamonds are lower in *mg* and Mg (by ≤ 25%) than those later inclusions at the rims of diamond. Diffusion rates in clinopyroxenes are much slower than in coexisting garnets, and therefore clinopyroxene may be the only useful mineral in determining the character of the ancient protoliths of these Yakutian eclogites. R.A.H.

Gems and Minerals

Die rubinminen im Ganesh Himal in Nepal.

A.M. Bassett. *Mineralien Welt*, **8**(3), 1997, pp 45–60, illus. in colour, 5 maps.

The geology and mineralogy of the Nepalese ruby deposits are discussed with notes on crystal morphology. Minerals accompanying corundum are listed and described. M.O'D.

Polished nephrite disc (refractive indices).

I. Campbell. *South African Gemmologist*, **11**(1), 1997, p 13, illus. in colour.

A dark-green nephrite disc gave RI 1.613–1.630 with an incomplete DR of 0.017 which figures compare with the published 1.62 usually obtainable. The disc was 38.90 mm in diameter and 4 mm thick. M.O'D.

L'huître aus lèvres noires, *pinctada margaritifera*. I. Dommages causés sur le bord des valves. Réconstruction-évaluartion des paramètres de croissance de la nacre coquillère.

J. Caseiro and J.-P. Gauthier. *Revue de Gemmologie*, **130**, 1997, pp 7–13.

First part of a study of black-lipped pearl-bearing oysters of *pinctada margaritifera*. Structure and growth are reviewed and the causes and effects of damage described. M.O'D.

Nephrite and metagabbro in the Haast Schist at Muddy Creek, northwest Otago, New Zealand.

A.F. Cooper. *Journal of Geology & Geophysics*, **38**(3), 1995, pp 323–332.

At Muddy Creek, NW Otago, a pod of gabbro, probably in a matrix of serpentinite, was tectonically emplaced into quartzofeldspathic sediments before the main metamorphism of the Haast schist. Metasomatic diffusion during pumpellyite-actinolite to greenschist-facies metamorphism produced talc-, tremolite-, chlorite- and muscovite-rich reaction zones at the margin of the pod. Subsequent shearing disrupted the metasomatic sequence and produced nephrite from the tremolite zone precursor. Relict magmatic hornblende and clinopyroxene from the metagabbro have compositions appropriate to a volcanic arc tectonic setting. In contrast, relict pyroxenes from four metabasaltic samples in the Greenstone mélange have compositions indicating generation of magmas in both ocean-floor and ocean-island environments. Ultramafic and mafic rocks at Muddy Creek and in the Greenstone mélange represent fragments of the ophiolitic basement to the Haast schist, the tectonic settings of which help constrain models for the evolution of the Rangitata orogen. A.F.C.

Les pierres gravées des portraits royaux. Un cas exceptionnel: Elisabeth I, reine d'Angleterre.

M. Duchamp. *Revue de gemmologie*, **130**, 1997, pp 3–6, illus. in colour.

Hardstone portraits of royalty are described with particular reference to representation of Queen Elizabeth I

of England. Illustrated examples are taken from various museums. M.O'D.

Gem trade lab notes.

C.W. Fryer. *Gems & Gemology*, **32**(3), 1996, pp 204–12.

A large carved white translucent aragonite set as a pendant had a similar appearance to nephrite and a comparable SG of 2.84. A large (38.91 ct) faceted, pear-shaped stone, of transparent yellowish green, was found to be herderite. A carved jadeite hairpin reportedly from the Qing dynasty (1644–1912) showed chromium lines in the absorption spectrum and a compact intergrowth pattern, different from the 'honeycomb' structure associated with bleached and impregnated jadeite. A ring made by Tiffany & Co. was set with old English brilliant cut diamonds and an oval faceted green quartz.

Two natural sapphires of treated blue colour showed some interesting results. The first stone had an incised design on the back and contained fluid-filled 'fingerprints' and unidentified crystals that were altered in ways consistent with heat treatment. The blue was caused by a dye, which was evident when the stone was immersed in methylene iodide. The second stone was a diffusion-treated natural sapphire, which had been quench crackled, making it more difficult to identify. J.J.

Gem trade lab notes.

C.W. Fryer. *Gems & Gemology*, **32**(4), 1996, pp 277–81, 16 illus. in colour.

A red statuette Buddha was found to be an assemblage of natural corundum chips and plastic. Under long-wave UV the statuette appeared splotchy orange red. It was thought the Buddha had been made in a mould. A Biron hydrothermal synthetic emerald showed an inclusion similar to pyrite. Under high magnification it was found to be platy as seen before in Biron synthetics. Also detected was a two-phase 'nail head' spicule typical of hydrothermal synthetics. An imitation star ruby was composed of three distinct layers: the top was synthetic ruby with gas bubbles and curved straie; then an opaque layer, highly reflective, composed of engraved foil giving rise to the asterism; the bottom layer was not identified, as the stone was mounted. J.J.

Ambre de roumanie.

V. Ghiurca. *Revue de Gemmologie*, **130**, 1997, pp 14–17, illus. in colour, 2 maps.

Short study of Romanian amber with notes on chemistry, geology and occurrence, varieties and characteristics. Amber is found in the Department of Buzâo in the south-east of the country. M.O'D.

The Illinois-Kentucky fluorite district.

A. Goldstein. *Mineralogical Record*, **28**(1), 1997, pp 3–49, illus. in colour, 7 maps.

Fluorite from the Illinois-Kentucky area is one of the best-known United States minerals and has been collected for many years (with many specimens labelled 'Cave-in-Rock', in fact a small area in a much larger district). While some crystals have been fashioned the majority are displayed for their size, attractive form and colours which include magnificent purple, blue and yellow. The last fluorite-producing mine in the area has now closed. The paper describes the mineralogy of the area (fine calcite and other crystals are also notable), giving details of the history and contents of the various mines and full mineralogical descriptions of the species found. There is an extensive bibliography. M.O'D.

Zircon inclusions in corundum megacrysts: I. Trace element geochemistry and clues to the origin of corundum megacrysts in alkali basalts.

J. Guo, S.Y. O'Reilly and W.L. Griffin. *Geochimica et Cosmochimica Acta*, **60**(13), 1996, pp 2347–2363.

The morphology and geochemistry of zircon inclusions are described with examples from E Australia (King's Plains, New South Wales; Lava Plains, Queensland), and from E China (Wenchang, Hainan; Changle, Shandong). EPMA are presented of zircons and their pseudomorphs (sillimanite, siliceous mullite, baddeleyite). Zircon inclusions are syngenetic with their corundum hosts and show similar crystal habit, morphology and trace element contents despite their wide geographical origin. A common mechanism of the formation of the inclusions in basalt is indicated, with the zircon crystallizing from a reduced, peralkaline environment of a highly evolved syenitic or granitic melt. R.K.H.

Ethiopia: a new source for precious opal.

D.B. Hoover, T.Z. Yohannes and D.S. Collins. *Australian Gemmologist*, **19**(7), 1996, pp 303–7, 10 illus. in colour.

One of the authors (T.Z. Yohannes) was given a broken nodule of volcanic rock containing a fine crystal base precious opal while visiting his homeland, Ethiopia, in 1993. From a description of the location where it had been found he was able to discover an extensive deposit of opal-filled lithophysae near the village of Mezezo in Shewa province. Common opal that fills the nodules comes in a wide variety of colours. Precious opal is estimated to be present in about one per cent of the nodules.

Government regulations have limited opal production to the gathering of representative samples for testing and evaluation pending detailed mapping of the deposit. Owners of the deposit were hoping to complete government requirements during the summer of 1996 and to begin formal production soon after. P.G.R.

Gem news.

M.L. Johnson and J.I. Koivula. *Gems & Gemology*, **32**(3), 1996, pp 214–22.

Natural green chrysoberyls lacking in colour change are now on the market, the first to be seen coloured by vanadium. Similar synthetic nonphenomenal chrysoberyls have been seen also coloured by vanadium. Two large faceted chrome diopsides from Inagly mine, Yakutsk, Siberia, north of Lake Baikal, were examined. This is not a new find and the stones could well have been mined some

thirty years ago. Spessartine garnets from Pakistan, marketed as 'Kashmirine', are from Azad Kashmir in the NE of the country. The first garnets were found in 1993 in several pegmatites in a migmatite complex. J.J.

Gem news.

M.L. Johnson and J.I. Koivula. *Gems & Gemology*, **32**(4), 1996, pp 282–92, 21 illus. in colour.

A new source of gem blue to purple chalcedony was discovered in 1994 in Mount Airy, Nevada. It is believed there are significant reserves still to be worked. Chatoyant emerald is reported to come from Coscuez mine in the Muzo region of Colombia. The vein containing the cat's-eye emerald was depleted within a month of being discovered. The new locality for colour-change garnets is Athiliwewa in the south of Sri Lanka, where the garnets are found in alluvial gravels. Details of the garnet properties are listed. J.J.

Some gemological challenges in identifying black opaque gem materials.

M.L. Johnson, S.F. McLure and D.G. DeGhionno. *Gems & Gemology*, **32**(4), 1996, pp 252–261, 9 illus. in colour, 1 table.

The authors list the main problems with identifying many black opaque gem materials. Much of the information is laid out in table form with a useful list of references for further research. Optical tests include visual observations, e.g. the types of fractures especially around the girdle or on the backs of cabochons, together with reflected light which can help to indicate aggregate material by the presence of grain boundaries, differences in relief or differences in reflectivity.

Specific examples are given illustrating some of the problems that may be encountered when testing aggregate materials or minerals that belong to solid solution series. Positive identification is usually obtainable by X-ray powder diffraction and EDXRF spectroscopy. As with other gem identification, all information available should be used before coming to a conclusion. J.J.

Chrysoberyl from Visakhapatnam and East Godavari districts, Andhra Pradesh.

C. Kasipathi. *Journal of the Geological Society of India*, **48**(4), 1996, pp 463–465.

Chrysoberyl is recorded from 13 tracts in the northern coastal areas of Andhra Pradesh, E. India. The chrysoberyl occurs as tabular, columnar or short prismatic crystals with distinct prismatic striations; the crystals range from 5 to 30 mm in length and 2 to 35 mm in width; (110) cleavage is distinct, with (001) and (100) poor. It is transparent to translucent, yellow-green to yellow in colour; H. 8.2–8.5 SG 3.72–3.80; weakly pleochroic in thin section. Chrysoberyl occurs in pockets in acidic pegmatites intrusive into khondalite, especially where the pegmatitic vein transects a mafic/ultramafic intrusion. R.A.H.

Richterite: a new gem material from South Africa.

A. Kleyenstüber and I. Campbell. *South African Gemmologist*, **11**(1), 1997, pp 10–12, illus. in colour.

A richterite with K-content is reported from the Kalahari manganese field of South Africa. A member of the amphibole group, richterite is a sodium calcium magnesium iron silicate hydroxide: the described specimen is blue with RI 1.620, 1.632: the published SG for richterite is 2.97–3.45 and the hardness 5–6. The material occurs in a carbonate-rich environment in association with manganese ores and is accompanied by sugilite, calcite, pectolite and quartz with a sugary consistency. Specimens up to a few kg in weight have been recovered from sporadic occurrences. M.O'D.

Emerald mineralization and metasomatism of amphibolite, Khaltaro granite pegmatite-hydrothermal vein system, Haramosh Mountains, northern Pakistan.

B.M. Laurs, J.H. Dilles and L.W. Snee. *Canadian Mineralogist*, **34**, 1996, pp 1253–1286, illus. in colour, 4 maps.

In the Nanga Parbat massif of northern Pakistan hydrothermal veins ranging from 0.1–1 m in thickness have been found to host emerald which is also found within granite pegmatites cutting amphibolite which itself forms a sill-like body within garnet-mica schist. Crystals of emerald, pale blue and colourless beryl have been found, Cr and Fe being the cause of the green coloration. Details of the mineralization process and of associated minerals are given. M.O'D.

Hydrogen and oxygen isotope ratios in chrysoprase and prasopal.

N. Miljević, Z. Maksimović, J. Pezdić, D. Cole and W.A. Van Hook. *Bulletin de l'Académie Serbe des Sciences et des Arts CVIII, Sciences naturelles*, **35**, 1994, pp 19–27.

Hydrogen and oxygen isotopic compositions of prasopal (Ni-bearing opal-CGT) and chrysoprase (Ni-bearing chalcedony) from the weathering profiles of ultramafic rocks from Glavica (southern Serbia) were determined. The δD and $\delta^{18}O$ values are in the vicinity of the kaolinite line, and nearly parallel to the world meteoric line, suggesting that meteoric waters were involved in their formation. A wide variation of Ni content (≤2.8%) in analyzed samples causes a scattering of $\delta^{18}O$ values between 23.7 and 20.3‰. Estimation of the ^{18}O fractionation factor between silica (quartz) and water used for the geothermometer leads to the conclusion that prasopal and chrysoprase have been formed at similar *T* and have been exposed to similar weathering conditions. V.J.

Business and industry review: gemstones.

M. O'Donoghue. *Britannica book of the year*, 1997, pp 164–5.

Summary of developments in the gemstone and diamond trade with notes on new varieties of garnet, gemstones from the former USSR, notes on enhancement,

on synthetic diamond production and its potential marketing arrangements. [Author's abstract] M.O'D.

Comparative study of corundum from various Indian occurrences – corundum from Jammu and Kashmir. Part 1.

J. Panjikar. *Indian gemmologist*, **6**(4), 1997, pp 36–47.

Corundum structure and properties are discussed before reference is made to corundum deposits in the Jammu and Kashmir areas of the northern part of the subcontinent. Gemmological properties are summarized: Kashmir sapphires have been examined with the electron microprobe and have been found to contain apatite, zircon and biotite. Tourmaline was found to be present when specimens were examined by X-ray power diffraction. Kashmir sapphires have also yielded inclusions of liquid and gaseous CO_2. M.O'D.

Fluid inclusion constraints on temperatures of petroleum migration from authigenic quartz in bitumen veins.

J. Parnell, P.F. Carey and B. Monson. *Chemical Geology*, **129**(3–4), 1996, pp 217–226.

Solid bitumens in fracture systems commonly contain microscopic crystals of authigenic quartz which were precipitated with the bitumen early in the paragenesis of the fracture fillings. The quartz contains primary fluid inclusions (aqueous and hydrocarbon) yielding homogenization *T* of mainly 95–130°C, indicating minimum *T* of entrapment during petroleum migration. Volumes of up to 50% entrained quartz, and a predominance of aqueous inclusions, suggest that the petroleum fluid had a substantial aqueous component. R.E.S.

What's new in minerals.

J. Polityka and M.P. Cooper. *Mineralogical record*, **28**(2), 1997, pp 131–139, illus. in colour.

Among the specimens seen at the Franklin, New Jersey, and Munich mineral shows were the Herkimer diamond variety of rock crystal, found at Fall Ridge, Little Falls, New York, where they occur in a weathered dolomite: non-gem ruby in a white massive quartz matrix, from Khit Ostrov island, northern Karelia, Russia: pink prisms of elbaite, up to 3 cm across, contained in a white albite matrix, from a new find at Paprock, Nuristan, Afghanistan: deep chestnut-red crystals of sphalerite ('ruby blende'), measuring approximately 1 cm and found in a matrix of small grey quartz crystals and colourless lenticular calcite: dark brown dravite crystals from Ganesh Himal, Dhading, Nepal: deep purple/green fluorite from Okaruso, Namibia: some milky lavender spinel crystals from Sri Lanka reached 8 cm on edge and one red spinel crystal from Myanmar was shown – this one an octahedron 1.2 cm on edge on a snow-white marble matrix. M.O'D.

Tasmania and Antarctica: a long association.

P.G. Quilty. *Australian Gemmologist*, **19**(9), 1997, pp 368–74, 7 diagrams, 3 illus. in black-and-white.

Tasmania and Antarctica were united as part of Gondwana from at least 600 million years ago until 55 million years ago when Australia separated and started moving northwards.

The author traces the movement of the landmass of Tasmania across eras of geological time and through climate zones, relating its present rock and soil composition to its long-term Antarctica partner. P.G.R.

The true story of White Cliffs.

G.R. Rowe. *Australian Gemmologist*, **19**(7), 1996, pp 296–300, 2 maps, 1 fig.

White Cliffs, Australia's first viable commercial opal field was discovered in the late 1880s. It was unique in that it represented the world's first seam opal deposit. Using abstracts from the literature, the author has documented the origins and problems associated with the mining of opal from this historic area in New South Wales. P.G.R.

Zoning in Sri Lankan zircons: chemically controlled?

M.S. Rupasinghe and A. Senaratne. *Australian Gemmologist*, **19**(7), 1996, pp 288–91, 1 illus. in black-and-white, 1 table, 5 graphs, bibl.

Zoned Sri Lankan zircon crystals of yellow and green colour were selected for electron microprobe analyses. Chemical data from at least three points in each crystal zone were obtained and some of the crystals were further studied under the scanning electron microscope. In each zircon crystal, a metamict zone was identified by the presence of high contents of trace elements including Th and U. In Sri Lankan zircons, iron migrates through pathways created by radiation damage. The clear coincidence of Fe peaks, and mid-points of zones, indicates a positive relationship between chemistry and zonation in these zircons. P.G.R.

Flammenachat aus Brasilen. Zur Entstehung ungewöhnlicher Chalcedon-Quarz-Geoden aus dem Paraná-Becken, Rio Grande do Sul, Brasilien.

R. Rykart. *Lapis*, **22**(5), 1997, pp 27–31, illus. in colour, 2 maps.

Agates with flame-like structure occur in the area of Paraná-Becken in the Soldedad region of Rio Grande do Sul, Brazil. Various examples are described and illustrated and there are notes on occurrence. M.O'D.

Kosmochlor from the Osayama ultramafic body in the Sangun metamorphic belt, southwest Japan.

S. Sakamoto and A. Takasu. *Journal of the Geological Society of Japan*, **102**(1), 1996, pp 49–52.

Kosmochlor occurs in actinolitic lenticular masses in serpentinized harzburgite; it is associated with uvarovite, Cr-bearing actinolite and minor chromite. EPMA results show that the pyroxenes contain Cr_2O_3 0–18.8 wt.%, Na_2O 0.3–7.9 wt.%; the uvarovite has Cr_2O_3 21.00 wt.% and the actinolite has Cr_2O_3 < 4.3 wt.%. The phase relations of this assemblage are tentatively discussed. R.A.H.

An update on Imperial Topaz from the Capao Mine, Minas Gerais, Brazil.

D.A. Sauer, A.S. Keller and S.F. McClure. *Gems & Gemology, 32*(4), 1996, pp 232–241, 15 illus. in colour.

The Ouro Preto Imperial Topaz district comprises two major active mining areas, Vermahao and Capao, the latter being the only completely mechanised, privately owned mine that also is currently in full production. The topaz is recovered from a single horizon of heavily weathered yellowish to dark-brown talc clay rock called 'brown terrain'. Details are given of the current mining operation and the recovery processes used.

All topaz from the Ouro Preto area is called Imperial Topaz and colours mined at the Capao mine range from yellows and oranges to pinks and reds, with the latter being the most sought after. Only 1%–2% of all the material recovered is of faceting quality. After heat treatment brownish-yellow and orange topaz may become peach to pink in colour. Most of the topaz is not suitable for heat treatment due to inclusions, especially liquid inclusions as these cause the stones to crack on heating.

It was found that the heat-treated stones showed a stronger fluorescence under short-wave UV than natural stones and this might prove to be an important diagnostic feature in the future but so far only a limited amount of stones have been tested. J.J.

Trapiche rubies.

K. Schmetzer, H.A. Hänni, H.-J. Bernhardt and D. Schwarz. *Gems & Gemology,* **32**(4), 1996, pp 242–50, 18 illus. in colour.

Trapiche rubies exhibit a fixed six-ray star effect, formed by six transparent ruby sections delineated by six non-transparent arms. The arms intersect at a small point in the centre of the crystal, or at an opaque yellow or black core. Most of the cores are tapered along the length of the crystal. The arms and boundaries of some of the cores are formed by a dense concentration of tubes, which under high magnification are found to be filled with a birefringent mineral, a liquid or a liquid and gas. The tubes are orientated perpendicular to the dominant dipyramidal faces ω {14 14 $\overline{28}$ 3}, which are inclined at 5° to the *c*-axis. By use of a Raman spectroscope and electron microprobe analysis the fillings were found to be calcite and dolomite. Excellent detailed coloured illustrations are included showing the various structures of the cores and arms. The authors thought the inclusions that gave rise to the core and the arms were primary structures. Myanmar, Vietnam and Mae Sai in N. Thailand are possible sources. Also discussed are the similarities and differences between trapiche emeralds and rubies, together with details of trapiche sapphires. J.J.

Achatführende Lithophysen aus dem Lierbachtal, Schwarzwald.

J. Schmidt. *Lapis,* **22**(5), 1997, pp 32–7, illus. in colour, 1 map.

Specimens of agate from the Lierbachtal in the German Schwarzwald show patterning attractive enough to make specimens worth collecting. Notes on their occurrence are given. M.O'D.

Mineralien aus dem Drammengranit, Norwegen.

M. Sendelbach. *Lapis,* **22**(4), 1997, pp 35–8, illus. in colour, 1 map.

Crystals of smoky quartz, light-blue topaz, colourless phenakite and blue-green beryl are described from the granites at Drammen in south-eastern Norway. M.O'D.

Amethyst aus den Colli Euganei, Monte Rusta, Fontanafredda, Padua/Italien.

S. Sovilla. *Mineralien Welt,* **8**(3), 1997, pp 36–8, illus. in colour, 4 maps.

Though insufficiently large for ornamental use, amethyst crystals found at Colli Euganei, Monte Rusta, Fontanafredda, in north-east Italy, are finely-coloured and well-shaped; they are likely to attract collectors of gem mineral crystals. M.O'D.

Gem quality rhodochrosite: 'the Inca rose'.

M. Sutherland. *South African Gemmologist,* **11**(1), 1997, pp 14–15.

Account of the testing and identification of a mounted rhodochrosite during which the real/apparent depth method was used to obtain RI. M.O'D.

Gem spinels from Tunduru, southern Tanzania.

A.E. Thomas. *South African Gemmologist,* **11**(1), 1997, pp 24–35, illus. in colour.

Spinels recovered from a parcel of alluvial gem mineral concentrate from the Tunduru area of southern Tanzania proved to make up over 60% of the species included. The area of origin and the spinels are described; specimens were found as rounded pebbles and presented various shades of blue, with some lilac and light-pink examples. A few stones gave a colour change. Some inclusions were identified as calcite and others as högbomite. A full table of testing results is given, with a list of references. M.O'D.

[REE-rare-metal pegmatites of Madagascar.] (Russian with English abstract).

V.V. Zhdanov. *Proceedings of the Russian Mineralogical Society,* **125**(3), 1996, pp 1–8.

The data from many years of study of the gem-bearing and other economically important pegmatites of Madagascar are summarized. The principal stages in the geological history of Madagascar are outlined and the composition and structural settings of these pegmatites are discussed. R.A.H.

Enstatite, cordierite, kornerupine and scapolite with unusual properties from Embilipitiya, Sri Lanka.

P.C. Zwaan. *Gems & Gemology,* **32**(4), 1996, pp 262–9, 10 illus. in colour, 2 tables.

Gem stones with unusual properties have been found in the vicinity of Embilipitiya, southern Sri Lanka, in alluvial deposits. Some of the stones are Mg rich, especially the pale to colourless enstatite, cordierite and kornerupine, other gemstones include scapolite, almandine garnets and spinels. The enstatites are colourless to deep brown, with the colourless stones exhibiting exceptionally low RIs ($n\alpha$ = 1.650 and $n\gamma$ = 1.658) and SG (as low as 3.194). All were found to have an absorption band at 506 nm, which is diagnostic. Cordierites were colourless to pale blue. The diagnostic strong pleochroism was not to be seen in the paler stones. Kornerupine was one of the more common gemstones found in the area and varied from yellow to green to brown with the SG generally increasing with increased colour intensity; all exhibited pleochroism. Scapolite was colourless to yellow and showed a strong yellow fluorescence under long-wave UV. J.J.

Instruments and Techiques

Measurement of refractive index by the apparent depth method.

D. Bennett. *Australian Gemmologist*, **19**(7), 1996, pp 292–4, 2 illus. in black-and-white, 5 tables.

Experiments were carried out to determine the practicability and accuracy of the direct method of refractive index measurement of a faceted gemstone. The average was taken of five measurements of the actual depth and apparent depth of a range of stones having a refractive index above 1.79. A binocular Siewa microscope at 40x magnification, a uniocular Shimadzu microscope at 50x magnification, and a vernier gauge were used for the measurements. Chips on the culet made it difficult to locate the absolute bottom of a stone when focusing through the table of the stone. It was also found that results were closer to accepted standards if the vernier gauge, rather than the microscope, was used to measure the actual height of the stone. The experiments proved that the method produced credible results which would assist gemmologists to identify faceted gemstones and other man-made materials having refractive indices beyond the range of the standard critical angle refractometer. P.G.R.

Gem news.

M.L. Johnson and J.I. Koivula. *Gems & Gemology*, **32**(4), 1996, pp 282–92, 21 illus. in colour.

International conference on Raman spectroscopy and geology. The merits of Raman spectroscopy are outlined, especially for identifying inclusions and the fillings in fractures in gem stones. The problems to date have been the setting up of a data base and with the variations of the Raman peak intensities, which depend on the crystallographic orientation of the stone. J.J.

Synthetics and Simulants

Gem trade lab notes.

C.W. Fryer. *Gems & Gemology*, **32**(3), 1996, pp 204–12.

Five imitation cubic zirconia shaped to look like diamond crystals, with diamond features such as triangular impressions, engraved parallel lines and frosted surfaces, were detected by the difference in 'heft', the SG of cubic zirconia being 5.80 compared to 3.52 for diamond. J.J.

EPR/ESR spectra of natural and synthetic opals.

D.R. Hutton, G.J. Troup and M. Young. *Australian Gemmologist*, **19**(9), 1997, pp 365–7, 4 graphs.

The late application of Electron Spin Resonance spectroscopy and Electron Paramagnetic Resonance spectroscopy to opal examination is explained by the authors as being due to the non-arrival of specimens of CSIRO's synthetic opal at the Physics Department, Monash University, in the mid-1960s. However, in retrospect, it is now thought that the sensitivity of the apparatus at that time would have been inadequate for research work into opal spectra.

Specimens of natural opal from various sources (Australian from Coober Pedy, Mintabie and Lightning Ridge, precious opal from Indonesia, Mexican fire opal and precious opal from Nevada, USA) and a sample of old production Gilson 'synthetic' opal were examined on a Varian E-12 9.1 GHz ESR spectrometer in the Physics Department of Monash University, and on an ESR spectrometer developed by members of that Department.

Observed differences between the spectra produced by the samples should allow discrimination between natural opals from Australia and those from other world-wide sources. Discrimination should also be possible between natural opals and 'synthetic' opal as represented by early production Gilson opal. P.G.R.

Gem news.

M.L. Johnson and J.I. Koivula. *Gems & Gemology*, **32**(3), 1996, pp 214–22.

Four chatham synthetic 'white' diamonds showed normal reaction of synthetic diamonds to UV, with the shortwave fluorescence being stronger than the longwave but no cross-shaped octagonal patterns were visible under UV. They were found to be type IIb and contained metallic inclusions which were magnetic.

Fibre-optic glass imitation of tiger's eye has been on the market since 1991 and marketed under the names of Catseyte, Cathaystone and Fiber Eye. It produces a sharp chatoyant band in white and brown. More recently yellow, pink, purple, black, blue and gun-metal grey reminiscent of hawk's-eye quartz, a bright green similar to some cat's-eye diopside are now coming from India. J.J.

Gem news.

M.L. Johnson and J.I. Koivula. *Gems & Gemology*, **32**(4), 1996, pp 282–292, 21 illus. in colour.

Imitations of ruby in a green-black-zoisite-matrix (imitation 'anyolite') have been moulded into plaques. The red grains were synthetic rubies, the yellow and colourless grains were not determined, and all were set in a polymer.

A grey metal pendant was thought to be a Tibetan Pendant consisting of meteorite iron. EDXRF spectroscopy found it to be a bronze or brass alloy.

Another tanzanite imitation consisted of a synthetic spinel triplet with a quartz centre. J.J.

Some tanzanite imitations.

L. Kiefert and S. Th. Schmidt. *Gems & Gemology*, **32**(4), 1996, pp 270–276, 11 illus. in colour, 2 tables.

The authors provide up-to-date identification criteria for some of the imitations of tanzanite that have recently appeared on the market. These are: doped heavy glass, trade name U.M. Tanzanic; YAG, trade name Purple Coranite; synthetic corundum, trade name Blue Coranite; and Ca phosphate glass. A table of the properties of tanzanite and the imitations is given. Most of the imitations are readily identifiable, as tanzanite is pleochroic, biaxial and inert under long- and short-wave UV. J.J.

Synthetic diamond: a challenge of the century.

J. Panjikar and K.T. Ramchandran. *Indian Gemmologist*, **6**(4), 1997, pp 11–16, illus. in colour.

An outline of some of the methods for the manufacture of synthetic diamonds is given with notes on the tests so far made available to gemmologists. M.O'D.

Identifying characteristics of hydrothermal synthetics.

B. Sechos. *Australian Gemmologist*, **19**(9), 1997, pp 383–8, 13 illus. in colour, 3 tables.

Dealing with those hydrothermally produced synthetic gems that are presently common on the Australian market, the author tabulates the identifying properties and illustrates the identifying features and inclusions in Biron and Russian synthetic emerald, and Russian synthetic ruby. While the hydrothermally grown Russian emeralds and rubies are quite readily identifiable, the Biron synthetic emerald presents more of a challenge. However, the gemmologist with a well equipped laboratory of standard gemmological instruments, including a good microscope, should have no difficulty in identifying any of these hydrothermal synthetics. P.G.R.

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BOOK REVIEWS

Gemme del Vicentino.

M. Boscardin and O.V. Tescari, 1996. Montecchio Maggiore: Museo Civico 'G. Zannato'. pp 114, illus. in colour, softcover. Price on application.

A number of mineral species with ornamental application have been found in the Vicenza area of north-eastern Italy. The present study describes the species in alphabetical order with notes on their occurrence and distinguishing features, together with their size and general appearance. Species selected for description are taken from the collections of the Museo Civico 'G. Zannato' at Montecchio Maggiore.

Gemmologists will be interested to know that while quartz in its various forms accounts for a high proportion of the specimens described, faceted examples of attractive orange-yellow-brown zircon and green peridot appear in the survey with cabochons of rhodonite and rhodochrosite. One faceted xonotlite is illustrated, here resembling white moonstone: this is a calcium silicate hydroxide with a hardness of 6.

Data are coherently assembled and there is an excellent bibliography. M.O'D.

Brazil

Companhia de Pesquisa de Recursos Minerais Principais depósitos minerais do Brasil. Vol. IV Parte A. Gemas e rochas ornamentais. Brazil, 1991. pp viii, 461, illus. in colour, softcover. No price given.

Published in association with the Departamento Nacional da Produção Mineral, the book forms one part of a survey of Brazil's major mineral deposits. This is the only current large-scale study of Brazilian gem occurrences written from the geological/mineralogical/mining standpoint and although English readers may have some slight difficulty with the Portuguese, this should not stand in the way of consulting the book where it can be found. The maps which seem to occur on almost every page are a vital source of information on their own. Each chapter has its own list of references, very many of them taken from the less easily obtained journals and forming a rich archive of information.

The first chapters deal with the definition of a gemstone, with nomenclature and classification and with the general 'gem province' of Brazil. The third chapter deals with the geology of Brazilian gemstone deposits and the book then continues with nine chapters (about 150 pages) on the geology, mineralogy and occurrence of diamond in Brazil. I cannot think of another such study apart from occasional papers. Emerald has three chapters (about 45 pages) and is followed by a survey of amethyst and agate in Rio Grande do Sul, Alto Bonito and Pau d'Arco (about 30 pages).

Similar coverage is given to topaz, aquamarine and opal, after which the book turns to a description of malachite, gemstones from pegmatite deposits and their properties, ornamental materials, granites and marbles from the state of Paraná and other states.

The book is in every way worthy of its subject and of one of the great gem-producing countries of the world. It has appeared quietly, as can be seen by this review written six years after publication. Interested readers should write to Departamento Nacional da Produção Mineral, SAN-Quadra 01-Bloco 'B', 70040 Brasília DF, Brazil. M.O'D.

Costume jewellery.

D.F. Cera, 1997. Antique Collectors' Club, 5 Church Street, Woodbridge. pp 256, illus. in colour, hardcover. £14.95. ISBN 1 85149 265 8.

For once there is a jewellery book of manageable size [20 x 12.5 cm] with high-quality illustrations! The text was first published by Arnoldo Mondadori Editore of Milan in 1995 and the English translation and captions read easily. The book is arranged chronologically, beginning with the Edwardian period and including the Arts & Crafts and Art Nouveau styles and continuing with Art Deco, the first costume jewels 1950-1959, the Hollywood years, the supremacy of Paris and the period from 1960 to 1969 when Italian costume jewellery held first place in fashion.

Illustrations are well chosen, the captions giving manufacturer, place and date, materials and techniques used, mark where relevant and provenance. Sizes are not given but this does not matter in most cases. Useful short biographies of major manufacturers and a glossary are given at the end of the book where there is also a very short bibliography. Small errors can be found in the glossary but they do not affect the general excellence of the book and its pleasing appearance. M.O'D.

Bernstein, Tränen der Gotter.

Michael Ganzelewski von Herausgegeben and Slotta Rainer, 1996. Katalog der Ausstellung des Deutschen Bergbau-Museums Bochum in Zusammenarbeit mit dem Ostpreussischen Landesmuseum Lüneburg und dem Siebenbürgischen Museum Gundelsheim. Deutsche Bergbau-Museum, Bochum. pp xiii, 585, illus. in colour, hardcover. Deutsche Bergbau-Museum, Am Bergbaumuseum 28, D-44791 Bochum, Germany. ISBN 3 921533 57 0. [Veröffentlichungen aus dem Deutschen Bergbau-Museum Bochum. Nr 64.] DM60.

This is the largest and most comprehensive study of amber to appear for many years and is published by the Bergbau-Museum with the co-operation of a number of German museums to accompany a loan exhibition shown during 1996. Any study by museum staff is expected to show a high level of scholarship and the book examines amber and its occurrence and recovery in such detail that it

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should remain the standard text for many years to come. At the outset I have to make the point that European amber is the main theme though deposits elsewhere are not omitted. The bibliographies that accompany each separate section reflect this very reasonable emphasis – European deposits and their working have been known for centuries and are well recorded.

The arrangement of the book is in major sections subdivided into smaller ones, some of which may be two or three pages only. To give an idea of the form, the first section is fully described as a model for the following sections. Though I have used the word chapter for convenience, there are no chapters and neither the major sections nor the smaller ones are numbered.

The first section opens with a short account of references to amber in Classical texts and especially to Ovid's *Metamorphoses* and to references in Lucian. The text then turns to the major task of introducing the finding and discovery of Baltic amber: a useful map shows the position of sea and land during the Eocene period. The formation and structure of amber are discussed with short notes on inclusions and notes on the wider use of the name amber. The next chapter surveys world deposits and includes maps.

Inclusions are dealt with in the next part which contains several photographs of the highest quality and which is followed by a short note on amber chemistry and origin. Methods of amber recovery are described next in a section covering contemporary resins as well as amber. By now we have covered over 60 of the 585 pages and completed the first major section.

The next major areas to be discussed are in Germany as understood today. Taken in order they are the south-eastern part of Lower Saxony (the area of Helmstedt), central Germany (Bitterfeld and its environs), Lausitz and Mecklenburg. Notes on amber finds in Jutland and south Sweden are also here.

Another major section now begins with reports on amber deposits and working in the former east Prussia. These are deposits well-known to all connoisseurs of amber and their history is minutely detailed with biographical notes on some of the major figures involved. Many mines are illustrated and the photographs show workings and techniques that I have not seen published before. Amber mining in Poland, the Ukraine, western Russia, the Alps, Romania, Italy and the Dominican Republic are also described in detail, completing another major section.

The book now deals with amber in history and in artefacts, taking a number of major works and examining them as well as describing the medicinal uses of amber. Imitations of amber are covered in this section.

The final section lists and describes the 437 items forming the exhibition. A double-page spread of 24 colour photographs of insect inclusions in amber, with the insects classified, is included in the exhibition.

The review can give only a glimpse of the very large amount of information contained in the book. The very large number of references include mostly papers in German or published in Germany: they are especially welcome as amber has not previously had a serious scholarly treatment on this scale and much published information has hitherto been very hard to trace. The production is excellent with good paper and clear printing: though the book is heavy it is bound in boards and seems firm. This is a major book in every way and needs to be in major libraries. M.O'D.

Otamatea Kauri and Pioneer Museum. [A guide to the Museum. Fifth printing]

Otamatea Kauri and Pioneer Museum Board, 1995. Matakohe, Northland, New Zealand. Unpaginated, 1 map. Price on application.

The Museum contains artefacts pertaining to the Kauri tree, source of the Kauri gum resin whose nature and processing are also described and illustrated. It is clear from the black-and-white photographs that the Museum should be visited by all with an interest in this type of material which is often not well understood by gemmologists. Matakohe is 142 km from Auckland and its position is shown on a useful map which also includes locations of forests and other notable places.

The literature of natural ornamental and workable resins is not large and gemmologists should try to obtain this excellent modern example. M.O'D.

Mani-málá, a treatise on gems.

TAGORE. RAJA SOURINDRO MOHUN, SIR ALSO KNOWN AS SAURÍNDRAMOHANA THÁKURA, 1996. Dr Nandkishor R. Barot, PO Box 47928, Nairobi. 2 vol., pp 1046, illus. in colour, hardcover. Price £120.00.

This welcome addition to the eastern lore and language of gemstones is published as a facsimile reprint of the now very rare Calcutta edition of 1879. Copies of the original often lack one or other of the parts which were usually bound together although the paper used was quite durable.

The purpose of the author was to bring together as a corpus some at least of the vast body of Indian reports, legends, stories, medical hints, accounts taken from the gemstone lore of other literatures including European ones, and notes on how gemstones were priced. Students needing to begin a search on any aspect of Indian gemstones must begin with this book: it provides a starting-point for many of the tales still current and repeated today from book to book and gives accounts of locations, however vague, for a number of important gem species.

The first volume comprises part 1 of the work and starts with an account of a mystical jewel with magical properties. This separate work, the *History of Syamantaka*, occupies 60 pages and tells of the Syamantaka, a gem of unstated species, which played a part in the activities of some of the deities of the Hindu pantheon. The author then turns to diamond after a brief note, with anecdotes, of other well-known species: he recounts in 95 pages how diamonds occur in different colours (including red) and how eight sources are known (all on the Indian sub-continent). While some of the properties are now known to be inaccurate (some stones are said to float on water), others are recognizable today. References are made to the diamond crystal rather than to fashioned stones. The chapter ends with a sudden jump to the nineteenth century and includes details of properties still used in gem testing and short accounts of named diamonds known by that time.

Ruby, which follows, is treated in the same way although no legend is transcribed. Sri Lankan stones are given pride of place: some rubies are compared to the interior of the half-blown red water lily while others are compared to cochineal. The best rubies are given the name *padmarága* and the author states that 'the authorities mention sixteen kinds of shade, four good and eight bad properties of rubies' – these are described. As with diamond, this account is then followed by an up-to-date description of rubies and their simulants and notes on famous specimens.

This way of ordering material is followed with the species cat's-eye [chrysoberyl is meant], pearl, zircon, coral, emerald, topaz, sapphire, chrysoberyl, garnet, carnelian, quartz and rock crystal. The first volume ends at this point.

The second volume, like the first giving English and the original text on opposing pages, deals with 'minor gems': these are aquamarine, chrysoprase, onyx, bloodstone, jade and tourmaline. After remarks on the genesis of gemstones and the division of diamonds into cast, particular properties of the major gem species are given – these are simple medicinal hints taken from Sanskrit rather than identification criteria. Sanskrit thoughts and legends pertaining to gemstones take up approximately the next 200 pages.

The remainder of the book is given to appendices in which a number of different topics are covered. They include details of some European regalia, further notes on the properties of gemstones, selling prices past and present, and notes on the Peacock Throne of Shah Jehan. This miscellaneous section is followed by gemstone descriptions taken from Arabic and Persian writers. Even now the book is not complete since the last hundred pages contain further descriptions and a most useful bibliography. A few black-and-white reproductions of various items of regalia and two coloured photographs (of a group of unnamed faceted stones and of the Imperial State Crown) bring the two volumes to an end.

We can see from this account that the book is an essential source for all kinds of information that would not have been brought together before its original publication. It is both informative and charming to read: the touch of the present editor is very light and serious students of gemstones should try to get a copy: the print run cannot be large and this is an opportunity to obtain one of the rarest and greatest gemmological texts. M.O'D.

The complete? polygon.

P. Taylor, 1997. Nattygrafix, 277 Cavendish St., Ipswich, IP3 8BQ. pp 60. Price on application.

This study will be of interest to readers specializing in crystal morphology and forms a part of an intended survey to be entitled *The complete? polyhedra*. The printing and layout are very well handled and though the text needs a good deal of concentration by the reader it is a useful and provocative essay. M.O'D.

Tiaras. One hundred tiaras: an evolution of style 1800-1990.

1997. Wartski, London. pp 38, illus. in colour. £5.00.

A short but informative and well illustrated catalogue raisonné of an exhibition of tiaras held at Wartski of London with descriptions, provenances and notes of present owners. The exhibition itself was very well arranged and lit. Studies of particular items of jewellery are not too common and readers should ensure that they obtain a copy. M.O'D.

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PHOTOGRAPHIC COMPETITION

The 1997 Photographic Competition on the theme 'Collectors' Gems' produced an interesting and varied selection of fascinating illustrations. After careful deliberation by the judges, the prizes have been awarded as follows:

First Prize

Patrick Daly, BSc, FGA, Windsor

***A hopper crystal of diamond* (see front cover)**

Second Prize

Robert J. Maurer, FGA, DGA, Redhill

A fish carved in fire opal

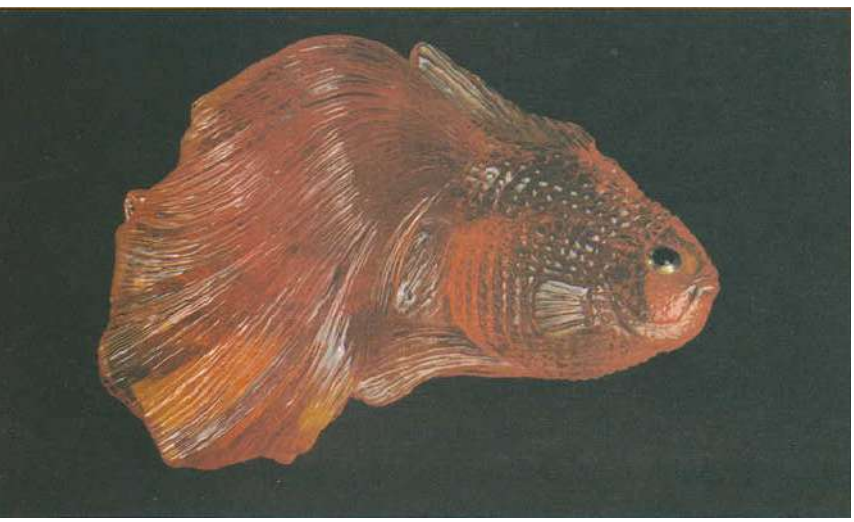

Third Prize

Victoria A. John, London

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We are pleased to announce that the prizes were sponsored by Quadrant Offset Ltd, and the GAGTL is most grateful to them for their generosity. The prizes were presented and the winning entries exhibited at the Reunion of Members held on 30 June.

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OBITUARY

Eunice Miles (Hon. FGA), Naples, Fla, USA, died 31 March 1997. A full obituary will be published in the October issue of the *Journal*.

GIFTS TO THE ASSOCIATION

The Association is most grateful to the following for their gifts for research and teaching purposes, and for contributions towards the gemstone loan collection being set up by the Education Department:

Tom Banker, Bangkok, Thailand, for 67 pieces of rough including amethyst, apatite (various colours), iolite, Mexican opal, topaz and tourmaline (various colours).

René Brus, Rijswyk, The Netherlands, for a copy of his new book *De Juwelen van het Huis Orange-Nassau*.

Eddie S.K. Fan, FGA, Kowloon, Hong, for 22 samples comprising treated jadeite, serpentine, saussurite and maw-sit-sit.

Mrs Ameena Kaleel, FGA, Mount Lavinia, Sri Lanka, for a collection of crystals including colour-change garnets, tourmaline and corundum and an unusual garnet crystal.

David Kent, FGA, a Vice-President of the GAGTL, for 193 small crystals and cut gemstones.

Çigdem Lüle, Ankara, Turkey, for crystals of diaspore from Milas, south of Izmir, Turkey, and *A catalogue of a collection of minerals of Turkey*.

Ms C.M. Ou Yang, Hong Kong, for an owl carved in hydrogrossular.

Michael Parsons, FGA., Bath, for 28 assorted stones.

Pierre Vuillet à Ciles, FGA, Villards d'Heria, France, for specimens of cut and rough garnet-topped doublets, slices of almandine garnet for GTDs, preformed soudé emerald, imitation emerald, 'roughs' of spinel/spinel soudé, glass and glass-coated samples, synthetic rubies, various cabochons and *L'industrie lapidaire* by G. Burdet.

Bernard Worth, FGA, Stow-on-the-Wold, for 192 stones including turquoise, opal, garnet, topaz and paste.

The Education Department would like to thank all those who responded to the request for gem materials for training and demonstration purposes, published in the April issue of the *Journal*.

NEWS OF FELLOWS

Michael O'Donoghue and **Tony French** gave a presentation on rare stones to the Wessex Branch of the National Association of Goldsmiths on Wednesday, 23 April 1997.

MEMBERS' MEETINGS

London

On 16 April at the Gem Tutorial Centre, 27 Greville Street, London EC1N 8SU, Ian Freestone gave an illustrated lecture entitled 'Make paste! Imitating precious and semi-precious stones over 5000 years'.

On 7 May at the Gem Tutorial Centre, Terry Davidson, FGA, gave an illustrated talk on '150 years of Cartier'.

The Annual General Meeting was held on Monday, 30 June, followed by the Reunion of Members and a Bring and Buy Sale. A full report will appear in the October issue of the Journal.

Midlands Branch

On 21 March at the Discovery Centre, 77 Vyse Street, Birmingham, Blane Price of the London Pearl Company gave a talk on pearls.

On 25 April at the Discovery Centre the Annual General Meeting of the Branch was held at which David Larcher was elected President, and Gwyn Green and Elizabeth Gosling were re-elected Chairman and Secretary respectively. The AGM was followed by a talk by John Bugg entitled 'Gems from the Law'.

At Gem Clubs held at Barnt Green on 20 April and 18 May, David Proudlove gave a demonstration of diamond-cutting techniques and Gwyn Green gave a practical session on diamond grading. Examination seminars for Preliminary and Diploma students were held on 27 April and 4 May.

North West Branch

On 21 May at Church House, Hanover Street, Liverpool 1, Doug Garrod gave an illustrated talk entitled 'The ins and outs of gemstones'.

On 18 June at Church House a social evening and Bring and Buy was held.

Scottish Branch

The Annual General Meeting and Conference of the Scottish Branch was held from 18 to 20 April in Peebles. At the AGM, Brian Jackson, Joanna

GAGTL CONFERENCE
Collectors' Gems

The 1997 Annual Conference is to be held on Sunday, 9 November, at the Barbican Centre, Silk Street, London EC2Y 8DS.

Gems are collected for a variety of reasons – perhaps for their rarity, or for an unusual feature compared with others of the species or for their historical associations. Our Conference will give an in-depth view of gems from important collections and speakers will include the following:

Gabriel (Gabi) S. Tolkowsky - Antwerp, Belgium	Forgotten terminologies
David Thomas - London	The Royal Jewels
Ludek Hubrt - Prague, Czech Republic	Crown Jewels of the Czech Kings
Monica Price - Oxford	An educational collection of gems
Lisbet Thoresen - Malibu, California, U.S.A.	Some thoughts on the origin and uses of gemstones in Classical Antiquity
Dr Eleni Vassilika - Cambridge	An historical setting: engraved gems in the Fitzwilliam Museum

As well as a full programme of lectures, delegates will be able to enjoy displays and demonstrations. Arrangements are being made for delegates to view museum collections in London on Monday, 10 November.

Full details of the Conference and an application form are enclosed with this issue of the *Journal*.

Thomson and Gillian O'Brien were re-elected Chairman, Secretary and Treasurer respectively. The Gordon Ness Trophy, for the student who achieves the highest marks in the Diploma Examination in Scotland, was awarded to Catriona McInnes of Edinburgh. A full report of the Conference was published in the June issue of *Gem and Jewellery News*.

A lapidary day was held on 1 June at the West Granton Research Centre, Edinburgh.

ANNUAL REPORT

The following is the report of the Council of Management of the Gemmological Association and Gem Testing Laboratory of Great Britain for 1996

The Gemmological Association and Gem Testing Laboratory of Great Britain (GAGTL) is a company limited by guarantee and is governed by the Council of Management. Professor R.A. Howie was elected President at the AGM in June and E.M. Bruton resumed his vice-presidency together with A.E. Farn, D.G. Kent and R.K. Mitchell. The company benefits greatly from the contributions of the Members' Council, the trade and education committees and meetings. Dr G. Harrison Jones continued as Chairman of the Board of Examiners and Miss C.M. Woodward was elected Vice-Chairman. C. Winter continued as Chairman of the Members' Council; G. Monnickendam retired at the AGM and J. Greatwood and J Monnickendam were elected to the Members' Council. D. Gann continued as Chairman of the Trade Liaison Committee.

It has been a good year for education, pearl testing and Gemmological Instruments Ltd which showed significant growth, but overall in GAGTL 1996 saw a slightly reduced turnover, with considerable investment in updating the education courses and reduced activity in diamond grading. At the Gem Tutorial Centre in Greville Street, the short course programme was expanded and an additional staff member was recruited to maintain this growth. Allied Teaching Centres (ATCs) were opened in four more cities in China during the year and more are under discussion. The second successful gemmological tour to Idar Oberstein took place in March and both this tour and other ventures are planned for 1997.

FORTHCOMING EVENTS

9, 10 and 11 August	**Scottish Branch.** Field trips.
17 September	**North West Branch.** Mrs Irene Knight will give a talk on jewellery, relating to her visit to Beijing, and Stanley Hill will speak on cloisonnè enamel work.
18 September	**Scottish Branch.** *A stone buyer abroad.* John Levy.
24 September	**London.** *Rock-forming minerals – the writing of a classic.* Professor R.A. Howie.
26 September	**Midlands Branch.** *Famous diamonds I have known.* Howard Vaughan.
13 October	**Scottish Branch.** *Gems – a valuer's heaven or hell?* Brian Dunn.
15 October	**London.** *From sparks to sparkle – a brief history of the use of marcasite/pyrites.* Lynne Bartlett.
15 October	**North West Branch.** A talk by Dr Jack Ogden.
25 and 26 October	**Midlands Branch.** Gemmology workshop.
31 October	**Midlands Branch.** *The sapphires of Scotland.* Brian Jackson.
9 November	**London.** Annual Conference – Collector's gems (full details given on p.506).
10 November	**London.** Visit to the Natural History Museum.
16 November	**Midlands Branch.** Practical gemmology training day.
20 November	**Scottish Branch.** *Scottish river pearls.* Fred Woodward.
28 November	**Midlands Branch.** *Opals.* David Callaghan.
3 December	**London.** *Fluid inclusions: solutions for mineral genesis and gem identification.* Andrew Rankin.
6 December	**Midlands Branch.** 45th Anniversary Dinner.

For further information on the above events contact:

London:	Mary Burland on 0171 404 3334
Midlands Branch:	Gwyn Green on 0121 445 5359
North West Branch:	Joe Azzopardi on 01270 628251
Scottish Branch:	Joanna Thomson on 01721 722936

GAGTL WEB SITE

For up-to-the-minute information on GAGTL events and workshops visit our web site on www.gagtl.ac.uk/gagtl

Students taking our examinations improved both their grades and their pass rate over 1995 performances. The Tully Medal was won by Miss Qian Ding of Shanghai, who also won the Diploma Trade Prize; the Anderson-Bank Prize was won by Mr Liu Xu of Wuhan; the Anderson Medal was awarded to Mrs Unni Mitteregger of London; and the Preliminary Trade Prize was won by Miss Victoria Forbes of London.

At the Presentation of Awards, again held at the Goldsmiths' Hall, David Callaghan handed over the diplomas and prizes to the successful students, and also presented a framed Honorary Diploma in Gemmology to Professor R.A. Howie. The new Bruton Medal, named in honour of the immediate past-president, Eric Bruton, was on display and will, in future, be awarded to students for excellence in the Gem Diamond Examination.

Over the past five years GAGTL has participated in developing the Federation of European Education in Gemmology (FEEG), and in August the Federation was legally registered in The Netherlands. Examinations for the Federation's European qualification in gemmology are planned for July in each of the Federation's member countries.

Laboratory staff continued to provide a highly professional service in gem identification and pearl testing. Although total coloured stone testing was slightly down on last year, issuing country of origin opinions and heat treatment opinions for ruby and sapphire continues to be in demand. Pearl testing in 1996 was higher and the benefits of the new X-ray machine installed in 1995 were apparent. In diamond grading, international advertising of the London Diamond Report continued and a new marketing initiative aimed at UK retailers commenced in the summer. Growth in requests for the London Report is steady and the marketing will be continued. CIBJO reports are also an important service offered by the laboratory and staff attended the annual CIBJO conference to participate in discussions on nomenclature and standards concerning diamonds, pearls and coloured stones. The laboratory was pleased to participate in the evaluation of the DiamondSure and DiamondView instruments developed by De Beers DTC Research Centre to distinguish synthetic diamonds from natural diamonds. In June, N.P.G. Sturman resigned from the GAGTL to take up a post with the Bahrain Government. The Council of Management would like to thank him for his contributions to the work of the laboratory – always of a high calibre – and wish him well in his future career.

This year the Trade Luncheon was held in June at the Langham Hilton Hotel and the guest of honour was Mr Naim Attallah, until recently Group Chief Executive of Aspreys. He addressed more than 60 members and guests with a very humorous and perceptive review of the industry today.

During the year staff from the Education section visited China, Hong Kong, Norway and the USA as well as a number of UK locations to give lectures, short courses and to liaise with the growing number of Allied Teaching Centres (ATCs). GAGTL had a stand with the UK group at the Basel Trade Fair, and laboratory staff exhibited at the Institute of Trading Standards Association Fair held in Bournemouth.

The theme of the annual conference held in October was 'Exceptional gems' and Professor Dr Hermann Bank presented the keynote lecture – a kaleidoscope of gem rarities from his exceptional resources in Idar-Oberstein. In sessions chaired by the President, Professor Howie, and by Vivian Watson, Howard Vaughan, Brian Jackson, Peter Zaltsman, Jonathan Condrup and Ben Gaskell presented a varied and fascinating programme of lectures to an audience of 150 from 14 countries.

The evening lecture programme for members in London was augmented by three overseas visitors – Grahame Brown from Australia, Shigeru Akamatsu from Japan and David Minster from South Africa. Several of the events were oversubscribed and accentuated the markedly higher attendances at all the members' lectures during the year. For members outside London, the Midlands Branch again provided a stimulating programme of lectures, club nights, courses and an annual dinner, and there were programmes of lectures and practical sessions at the North West and Scottish Branches – the latter mounting a field trip to hunt for agates.

The 1996 *Journal of Gemmology* issues contained 324 pages exceeding the totals of previous years and sufficient to clear much of the backlog of papers. A constant pressure is maintained to keep costs down, but even though production costs were reduced, mailing costs rose. The same is true for *Gem and Jewellery News*, our joint production with the Society of Jewellery Historians. During the year we welcomed Corinna Pike to the editorial board and she brings current first-hand experience of a top-class jeweller to coverage of a wide range of topics.

Response in the members' photographic competition with the theme 'Images in gems' was the best yet. The winner was S.J.A. Currie of New Zealand, and his rather abstract image of an owl on a branch together with a selection of other exceptional pictures were reproduced in the 1997 calendar, sent free to all members.

Gem Tutorial Centre
Autumn 1997

27 August — **A DAY TO STRING YOUR OWN BEADS**

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2 September — **SHADES OF GREEN**

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Price £99 + VAT (£116.33) – includes sandwich lunch.

17 September — **INTRODUCTION TO GEMSTONES**

A day to look into the beautiful world of gemstones. Hold the gems in your hands and discover the individual qualities and characteristics that make them so prized.

Price £44 + VAT (£51.70) – includes sandwich lunch.

1 October — **PRELIMINARY WORKSHOP**

A day of practical tuition for Preliminary students and anyone exploring the world of gemstones and crystals. You can learn to use the 10x lens at maximum efficiency, to observe the effects and results from the main gem testing instruments and to understand important aspects of crystals in gemmology.

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GAGTL student price £32 + VAT (£37.60)

14 October — **INTO THE BLUE**

An opportunity to see a variety of blue gemstones. Handle and examine sapphire, tanzanite, iolite, tourmaline, aquamarine, topaz and zircon, to name but a few. How do you tell them apart? How are they treated? Which man-made products look like them?

Price £99 + VAT (£116.33) – includes sandwich lunch.

28 October — **DIAMONDS TODAY**

An up-to-date review of all aspects of diamonds; rough and cut stones, and treated (laser-drilled and filled), synthetic and imitation materials.

Price £104 + VAT (£122.20) – includes sandwich lunch.

4 November — **REVIEW OF DIPLOMA THEORY**

A day for Gemmology Diploma students to review their theory work and to prepare for the Diploma theory examinations. Tips on the consolidation and revision of facts, figures, principles, practical techniques and instruments. Let us help you to review your examination technique with the help of past questions.

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4 and 5 November — **SYNTHETICS AND ENHANCEMENTS TODAY**

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11 November — **JADE – THE INSIDE STORY**

A panel of jade experts including Roger Keverne, Bob Frey and Rosamond Clayton will cover the history and carving, geology and make-up, simulants and factors affecting the price of jade.

Price £99 + VAT (£116.33) – includes sandwich lunch

Contact the Education Office on 0171 404 3334 for further information

In common with many other professional associations and learned societies it is a challenge to increase membership of the organization, and totals have varied by only 150 in the last six years. But 1996 did see an increase and the total is 3669. Efforts to gain more members and to retain those we have are bearing some fruit and we will continue the drive to expand the membership.

Gemmological Instruments Ltd can report a successful year in a very competitive market. Turnover rose by over 8 per cent, reflecting increases in both books and instruments. At the end of 1996, the London dichroscope, a low-cost dichroscope for trade and student use, was introduced, having been developed jointly by staff from the Education section and GI Ltd. This reflects the GI Ltd philosophy of supplying good value equipment for practical gemmological use.

In the demanding economic conditions, the Council of Management would like to thank all who have willingly supported and made effective the wide range of gemmological activities undertaken – including staff, those involved in developing and tutoring the courses, and those who have contributed their expertise through committee or personal contact. Their contributions have been crucial to the successes particularly of the education programme and of GI Ltd.

MEETINGS OF THE COUNCIL OF MANAGEMENT

At a meeting of the Council of Management held at 27 Greville Street, London EC1N 8SU, on 19 March 1997, the business transacted included the election of the following:

Diamond Membership (DGA)

Lawrence, George, Hove, Sussex. 1997

Tse Yiu Yu Stephen, Hong Kong. 1997

Fellowship and Diamond Membership (FGA/DGA)

Scott, Doreen M., Liverpool, Lancs. 1987/1997

Fellowship (FGA)

Ball Edwards, Chantal, Cheltenham, Glos. 1991
Dupuy, David John, London. 1997
Friedberg, Guy, London. 1997
Kasliwal, Ritika, Jaipur, India. 1996
Nang Mo Kham, Yangon, Myanmar. 1997
Zhang Xueyun, Jiansu, P.R. China. 1996

Ordinary Membership

Arsenikakis, Helena, Blackwood, SA, Australia
Bappoo, Reenabai, London
Breisach, Gabriela, Vienna, Austria
Brunstrom, Isabella, Stockholm, Sweden
Chong, Yuen Kwan, Kowloon, Hong Kong
Costola, Nicola, Grisignano di Zocco, Italy
Dennis, Damon Siegfried, Little Bytham, near Grantham, Lincs
Nyan Hlaing, Yangon, Myanmar
Sharples, James, Bolton, Lancs
Shen, Andy Hsi-Tien, Cambridge
Smith, Robert Jonathan, Birmingham, Warwicks
Stewart, Rosemary June, Sandwich, Kent
Wang Shu-Hui, Taipei, Taiwan, R.O.C.

Laboratory Membership

Russell Lane Antiques, 2–4 High Street, Warwick.

Transfers from Fellowship to Fellowship and Diamond Membership (FGA/DGA)

Chow Chun Hung William, Hong Kong. 1997
Fowle, Michael J., London. 1997
Richardson, Cathryn, Silsden, near Keighley, West Yorks. 1997
Torrent, Denise, Geneva, Switzerland. 1997
Tsang Wai Yi Rita, London. 1997

Transfer from Diamond Membership to Fellowship and Diamond Membership (FGA/DGA)

Liping Li, Wuhan, P.R. China. 1997

Transfers from Ordinary Membership to Diamond Membership (DGA)

Kenny, Sark, Hong Kong. 1997
Kepel, Arthur Mvuta, London. 1997
Lemessiou, Maria A., Nicosia, Cyprus. 1997
Lodge, Tim, London. 1997
Battiscombe, Brigid, London. 1997
Davies, Paul B., Great Missenden Bucks. 1997
Jackson, Stephen D., Perranporth, Cornwall. 1997
Johnston, Dale, Dundonald, Co. Down, N. Ireland. 1997
McInnes, Catriona O., Edinburgh. 1997
McInnes, John L., Edinburgh. 1997
Mao Lingyun, Beijing, P.R. China. 1997
Starreveld, Francis M. M., Hilversum, The Netherlands. 1997

At a meeting of the Council of Management held at 27 Greville Street, London EC1N 8SU on 17 April 1997 the business transacted included the election of the following:

Diamond Membership (DGA)

Buxani, Reena Haresh, Kowloon, Hong Kong. 1997
Zhang Yindi, Xia Men, Fujian, P.R. China. 1996

Fellowship (FGA)

Chang, Morley Seng-Hong, Taichung, Taiwan, R.O.C. 1997
Chong Sylvia Yung Yung, Thornhill, Ont., Canada. 1997
Courage, Bruce Crandall, Mahwah, NJ, U.S.A. 1997
Dougherty, William C., Alexandria, VA, U.S.A. 1982
Duncan, Kenneth Greg, Reston, VA, U.S.A. 1997
Hunter, Rachel Suzanne, Clapham, London. 1997
Kearton, Michael James, Eastbourne, East Sussex. 1997
LeungYuen Fan Janice, Hong Kong. 1997
Li Ki Wing Alison, Hong Kong. 1997
Li Qingnian, Xia Men, Fujian, P.R. China. 1996
Made, Lollo, Hong Kong. 1997
Pöntynen, Raija Kaarina, Helsinki, Finland. 1996
Qiu Zhili Zhongshan, Guangzhou, P.R. China.1996
Tang Deping,Fuzhou, Fujian, P.R. China. 1996
Triantafillos, Spiridon, Corfu, Greece. 1997
Tsang Shiu King, Kowloon, Hong Kong. 1997
Uriben, Awr, Bellflower, CA, U.S.A. 1997
Wang Hsiao-Fei, Taipei, Taiwan, R.O.C. 1997

Ordinary Membership

Adan, Abdikarim Abdi, Cardiff, Glamorgan
Aldred, Alison Jane, Wellington, New Zealand
Cheong-ly, Karine, London
Churchley, Chris M., Windsor Forest, Berks
Ebbs, Heather Alexandra, Winsley, Bradford-on-Avon, Wilts
Frediani, G., London
Fullwood, Garry, Bishops Wood, Stafford
Griffin, Donald John, London
Kitazawa, Yoko, Shibuya-ku, Tokyo, Japan
Lüle, Çigdem, Ankara, Turkey
Maehara, Tamao, London
Razvi, Ahsan, Pimlico, London

At a meeting of the Council of Management held at 27 Greville Street, London EC1N 8SU, on 14 May 1997, the business transacted included the election of the following

Fellowship (FGA)

Chen Liang-Hsuan, Toronto, Ont., Canada. 1997
Chu Li-Ju, Sanchung, Taipei, Taiwan, R.O.C. 1997
Hotung-Lamb, Mara Tegwen, Hong Kong 1997
Kafetsis, George, Athens, Greece. 1997
Lin Shwu-Jiun, San-Chorng City, Taipei, Taiwan, R.O.C. 1997
Marolla, Marianna, Athens, Greece. 1997
Ng, Shuk Hing Jonas, Kowloon, Hong Kong. 1996
Wijesuriya, Guthila, Nittambuwa, Sri Lanka. 1980

Ordinary Membership

Bhargan, Deepak Prakash, Bearwood, West Midlands
Dalaa, Zine Labidine, Oran, Algeria
De Reus, Leonardus Adrianus, Oisterwijk, The Netherlands
Hogg, Ronald, Crieff, Perthshire
Jones-Bateman, Peter, Cardiff
Kleiner, Peter Howard, London
Pagan, Sabine, Berne, Switzerland
Phillips, Andrew Thomas, Pulau Pinang, West Malaysia
Photiou, Maria, Berkeley, CA, USA
Slavin, Nathan, Cockfosters, Barnet, Herts
Thomas, Caan Marcus, Northwood, Middx

Transfer from Ordinary Membership to Fellowship (FGA)

Alessandro, Guastoni, Milan, Italy. 1997

Laboratory Membership

Lucie Campbell, Suite 203, 100 Hatton Garden, London EC1N 8NX
I.M.K. Ltd, 88-90 Hatton Garden, London EC1N 8DN

Corrigenda

On p. 318 above, second column, for 'Moore, Rown Duggan' read 'Moore, Rowan Duggan'
On p. 402 above, in the final line of the caption to Figure 6a and in the Raman spectra shown in Figure 6b, for 'datolite' read 'danburite'

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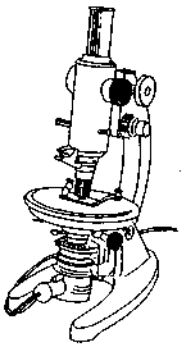

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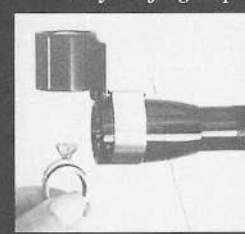

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The Editor is glad to consider original articles shedding new light on subjects of gemmological interest for publication in *The Journal*. Articles are not normally accepted which have already been published elsewhere in English, and an article is accepted only on the understanding that (1) full information as to any previous publication (whether in English or another language) has been given, (2) it is not under consideration for publication elsewhere and (3) it will not be published elsewhere without the consent of the Editor.

Typescripts Two copies of all papers should be submitted on A4 paper (or USA equivalent) to the Editor. Typescripts should be double spaced with margins of at least 25 mm. They should be set out in the manner of recent issues of *The Journal* and in conformity with the information set out below. Papers may be of any length, but long papers of more than 10 000 words (unless capable of division into parts or of exceptional importance) are unlikely to be acceptable, whereas a short paper of 400–500 words may achieve early publication.

The abstract, references, notes, captions and tables should be typed double spaced on separate sheets.

On matters of style and rendering, please consult *The Oxford dictionary for writers and editors* (Oxford University Press, 1981).

Title page The title should be as brief as is consistent with clear indication of the content of the paper. It should be followed by the names (with initials) of the authors and by their addresses.

Abstract A short abstract of 50-100 words is required.

Key Words Up to six key words indicating the subject matter of the article should be supplied.

Headings In all headings only the first letter and proper names are capitalized.

A **This is a first level heading**

First level headings are in bold and are flush left on a separate line. The first text line following is flush left.

B *This is a second level heading*

Second level headings are in italics and are flush left on a separate line. The first text line following is flush left.

Illustrations Either transparencies or photographs of good quality can be submitted for both coloured and black-and-white illustrations. It is recommended that authors retain copies of all illustrations because of the risk of loss or damage either during the printing process or in transit.

Diagrams must be of a professional quality and prepared in dense black ink on a good quality surface. Original illustrations will not be returned unless specifically requested.

All illustrations (maps, diagrams and pictures) are numbered consecutively with Arabic numerals and labelled Figure 1, Figure 2, etc. All illustrations are referred to as 'Figures'.

Tables Must be typed double spaced, using few horizontal rules and no vertical rules. They are numbered consecutively with Roman numerals (Table IV, etc.). Titles should be concise, but as independently informative as possible. The approximate position of the Table in the text should be marked in the margin of the typescript.

Notes and References Authors may choose one of two systems:

(1) The Harvard system in which authors' names (no initials) and dates (and specific pages, only in the case of quotations) are given in the main body of the text, e.g. (Gübelin and Koivula, 1986, 29). References are listed alphabetically at the end of the paper under the heading References.

(2) The system in which superscript numbers are inserted in the text (e.g. ... to which Gübelin refers.[3]) and referred to in numerical order at the end of the paper under the heading Notes. Informational notes must be restricted to the minimum; usually the material can be incorporated in the text. If absolutely necessary both systems may be used.

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Books Hughes, R.W., 1990. *Corundum*. Butterworth-Heinemann, London. p. 162

Abbreviations for titles of periodicals are those sanctioned by the *World List of scientific periodicals* 4th edn. The place of publication should always be given when books are referred to.

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Collector's gems
A hopper crystal of diamond. Photograph by Patrick Daly, B.Sc., FGA, Windsor
(see Photographic Competition pp. 504)

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Table 1: *The chronology of synthetic gemstones*

Year	*Synthetic material*	*Inventor/trade name/manufacturer/ country*	*Growth method*	*Reference*
Beryl, including emerald, aquamarine and red beryl				
Flux method:				
1848	Emerald (IS, NC)	JJ Ebelmen/France	FIS	N80, 128
1888	Emerald (IS, NC)	P Hautefeuille & H Perrey/France	FIS	N80, 129
1925	Emerald (IS, NC)	R Nacken/Germany	FIS	N80, 131
1934	Emerald (IS, NC)	H Espig/IG-Farben/Germany	FIS	N80, 129
1938	Emerald	CC Chatham/USA	FIS	N80, 141
1964	Emerald	Gilson/France	FIS	N80, 144
1964	Emerald (SP)	W Zerfass/Germany	FIS	N80, 130
Hydrothermal and other methods:				
1960	Emerald (IS, NC); emerald over-growth (SP)	J Lechleitner/Austria	HyS	N80, 149; G81, 98
1965	Emerald	EM Flanigen/Quintessa/Linde/USA	HyS	N80,150
1979	Watermelon beryl (SP)	Adachi Shin/Japan	?	G86, 55
1981	Aquamarine, pink and red beryl (SP)	Regency/Vacuum Ventures/USA	HyS	N90, 50; G81, 57
1988	Aquamarine, red and other colours (NC)	AS Lebedev/USSR	HyS	G88, 252; G90, 206
1994	Emerald, red beryl	Tairus/Russia and others	HyS	G96, 32
Corundum: ruby, blue sapphire and other colours				
Verneuil flame fusion, Czochralski pulling and other melt methods.				
1885	Ruby (SP) *(see Figure 3)*	'Geneva'/(Switzerland?)	FIF	N80, 42
1902	Ruby *(see Figure 4)*	AVL Verneuil/Société Hellerite/France	VeF	N80, 27
1903	Ruby (SP)	Hoquiam/USA	VeF	N80, 54
1907	Blue sapphire	Verneuil/Baikovsky/France	VeF	N80, 63, 66
1942	Ruby	L Merker/Linde/USA	VeF	N80, 69
1947	Star corundum	Linde/USA	VeF	N80, 69
1960	Ruby discs (SP)	Linde/USA	VeD	N80, 69
1965	Ruby	FR Charvat/Linde/USA	CzP	N80, 84
1971	Sapphire, colourless tubes, etc.	H LaBelle/Tyco/USA	CzE	N80, 87
1983	Ruby, etc. (NC)	Bijoreve/Seiko/Japan	FZo	G84, 60
1990	Pink Ti-sapphire	Union Carbide/USA and others	CzP	G95, 188, 214; G92, 66
Flux and vapour phase methods:				
1891	Ruby (IS, NC) *(see Figure 2)*	E Fremy and Verneuil/France	FIV	N80, 39
1958	Ruby	CC Chatham/USA	FIS	N80, 78; Pc
1958	Ruby (NC)	JP Remeika/AT&T Bell Labs/USA	FIS	N80, 78; Pc
1964	Ruby (IS,NC)	EAD White/England	VaR	N80, 91
1974	Blue sapphire	CC Chatham/USA	FIS	G82, 140; Pc
1980	Orange sapphire (padparadscha, SP)	CC Chatham/USA	FIS	G82, 140; Pc
1983	Ruby and sapphire; ruby overgrowth (NC)	J Lechleitner/Austria	FIS	N90, 53; J85, 557; G85, 35; J88, 95
Hydrothermal method:				
1958	Ruby (PQ, NC)	AT&T Bell Labs/USA	HyS	N80, 91; Pc
1965	Ruby (PQ, NC)	R Belt/Airtron/USA	HyS	N80, 91; G92, 278

Key

Growth methods:

CzE	CzP with edge-defined film-fed modification	HyI	HyS followed by irradiation
CzP	Czochralski pulling from the melt	HyS	Hydrothermal solution
Exp	Explosion reaction	SkS	Skull Solidification and equivalnt methods
FIF	Flame fusion, pre-Verneuil variant	SkH	SkS with yttrium oxide content higher than usual
FIS	Flux solution	SkI	SkS followed by irradiation
FIV	Flux-vapour complex system	SkL	SkS with yttrium oxide content lower than usual
FZo	Floating zone	VaR	Vapour phase reaction, atmospheric or low pressure
HPI	HPS followed by irradiation	VeD	VeF with disc modification
HPS	High pressure solution	VeF	Verneuil flame fusion
		VeT	VeF with tricone burner modification

Fool's gold?... The use of marcasite and pyrite from ancient times

Lynne Bartlett

London

ABSTRACT: This survey covers the early writings on the form, identification and occurrence of pyrite and marcasite. The origins of the confusion between the two species and their names are discussed. The material known today by the jewellery world as Marcasite and dismissed by many jewellery historians as merely a diamond imitation is, in fact, cut and polished iron pyrite. In order to differentiate clearly between the mineralogical marcasite and the cut and polished iron pyrite, a capital 'M' is used when referring to the latter. But, throughout its long history, pyrite was valued more for many other purposes. From antiquity and for many centuries iron pyrite was used by man as a convenient portable source of fire. This lead to the development of guns using the spark-producing properties of pyrite. Its value as a raw material for some chemical processes is shown.

Although little evidence remains of its early ornamental usage, there are examples from as far apart as S. America and Siberia. Since the early eighteenth century, Marcasite has been used in jewellery as an inexpensive alternative for the sparkle of diamonds. The cutting and polishing of the iron pyrite was initially done by hand but is now fully automated. The peak of the artistic use of Marcasite was in the 1930s where its soft steely sparkle compliments the beauty of other gems used in the design. This is best seen in the art deco styles of the company Theodore Fahrner. Subsequent decades did not produce such elegant pieces but Marcasite remains one of the options for the modern jeweller.

Introduction

My earliest recollection of Marcasite was as a young child in the early 1950s being fascinated by the glittering brooch and earrings worn by my mother when she dressed up to go out dancing with my father. It was only about ten years ago when I bought my first piece of thirties, silver-set, Marcasite jewellery from a market in Canterbury, that my interest was really kindled. By then I had become a gemmologist and amateur jeweller and I set out to discover more about the jewellery and the materials used. I was surprised and disappointed to find how little was written about the subject and resolved that I would try to find out more. The following account is the result of my researches so far and covers the uses of and thoughts about Marcasite/pyrites prior to the eighteenth century and the use of cut and polished stones for jewellery from the early part of the eighteenth century to the present.

What is Marcasite?

'Perhaps no other natural body has received so many names[1].' This is the

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Figure 1: *Group of pyrite crystals showing cube, pyritohedron and small octahedron (photograph by M. Hutchinson).*

challenge for anyone looking into the history of this widely spread mineral and has taken me along many diverse paths. Even the names by which the jewellery trade and the gemmologist know the material are confused. Marcasite is the jewellery trade name for iron pyrite when cut and polished. Pyrite is the cubic crystallization of iron disulphide (FeS_2). Mineralogical marcasite is the crystallization in the orthorhombic form of the same chemical compound. Orthorhombic marcasite will subsequently be spelled with a small 'm' and jewellers' Marcasite will have a capital 'M' to clarify meaning in the text. Although the cubic form is more stable, both decompose on prolonged subjection to heat, air and moisture. Both sulphides are found as opaque yellowish crystals with a metallic lustre but true marcasite has a more silvery appearance *(Figures 1 and 2).*

Figure 2: *Marcasite (photograph by M. Hutchinson).*

The confusion between the two species has existed for hundreds of years. The two names pyrite and marcasite were used interchangeably until the development of systematic crystallography in the early nineteenth century. It was only then that it became possible to distinguish between the minerals of similar appearance and identical chemical composition. Even after this the traditional names used in such old industries as mining continued to be used.

From the mid-sixteenth century, growing scientific interest resulted in an increasing number of books seeking to explain the natural world. Many took versions of ancient texts that had been passed down with a variable degree of accuracy but increasingly writers presented their own observations. The economic interest in mining and minerals ensured that all potential sources of metals were carefully examined.

Looking to the earliest writings on minerals, Boodt (1609)[2] refers to the writings of Galen on the subject of marcassites [*sic*]. Many types of metallic sulphides seem to have been covered by the term including both iron pyrites and chalcopyrite or copper sulphide[3]. The origin of the name is accepted by some writers as Persian, but there is also a view that the Persian word was probably adopted from a European language[4]. Chamber's Encyclopaedia of 1781 quotes Avicenna, who was writing in the early thirteenth century, as using the name 'marcasite nuhafi' but it is also stated that the Persians called it 'nagiar alruxenani' stone of light or brightness. The name pyrite is derived from the Greek, 'pyrites lithos' (stone which strikes fire)[5], which refers to its property of producing sparks when struck. Pliny mentions various stones which are interpreted as pyrites, the most likely being ...

'the kind of stone that contains a great quantity of fire. Stones known as 'live stones' are extremely heavy and are indispensable to reconnaissance parties preparing a camp-site.

When struck with a nail or other stone they give off a spark, and if this is caught on sulphur or else on dry fungi or leaves it produces a flame instantaneously.'[6]

Agricola[7] writing in 1546 notes that there are minerals which are intermediate between 'stones' and metals, a good example of which is pyrite 'which is called marchasite by the Moors'. Four kinds of mineral are described which are identified by colour; the true pyrite is 'silvery gold' and true marcasite, 'the colour of galena'. The others are probably chalcopyrite and arsenopyrite, being 'pure gold colour' and 'grey' respectively. He notes that only the hard pyrite can be struck to produce fire and also comments on the variable forms and location of the mineral.

Webster[8] gives a list of minerals said to be of affinity to metals; namely Cachimie, Marchasites, Pyritae and Firestones. All of these are said to be ... 'little known or regarded by miners as they can make no profit from them other than an indication of where metallic ores can be discovered.'

This opinion is confirmed by Woodward[9] in his description:

'A common Marcasite or Pyrite shall have the colour of gold most exactly and shine with all the Brightness of it and yet upon trial after all yield nothing of worth but vitriol and a little sulphur.'

He mentions the occurrence of pyrite nodules being washed out from chalky cliffs and found on beaches on the shores of Kent, Essex and Hampshire, among others.

Lovell[10] writing in 1661 in what is mainly a review of classical texts gives supposed healing properties for both pyrite and marcasite. As well as the fire-making properties of pyrite ('the best is that which is like brass') he notes that it 'purges away things hindering the eyesight', and 'it softens and discosseth hardnesses'. Marcasite is identified as being found in mines and used to produce salts with purgative properties.

The definitive text on pyrite, Pyritologia, was written in 1725 by Henckel[11], a former Chief Director of Mines at Freiberg in Saxony. He restricts the term to three types, namely yellowish or iron pyrite (also called sulphur pyrite), yellow or copper pyrite and white or arsenical pyrite. The latter is said to be unsuitable for smelting. Iron pyrite found in the mines at Freiberg and in the Harz Mountains was used for the production of vitriol and sulphur.

In spite of these clear distinctions and definitions, the name marcasite continued to be used widely by miners and mineralogists up to the end of the nineteenth century for all types of sulphides including those of bismuth and antimony. The development of systematic mineralogy led to more careful distinctions being made between the various species and in 1845 Haidinger gave the name of marcasite to the mineral previously known as white iron pyrite[12]. However by that stage the name of Marcasite for the cut and polished stones was so firmly established in the jewellery industry that it was maintained.

Form and occurrence

Iron pyrite crystallizes in the cubic system, the most symmetrical of the seven crystal systems into which all crystalline minerals are classified. It is often found as cubes or more rarely as octahedra *(Figure 1)*.

It does not exhibit the full symmetry of the system being typically found as pyritohedra, to which solid forms with twelve five-sided faces it gives its name.

Figure 3: *Pyrite inclusion in Colombian emerald (photograph courtesy of E.A. Jobbins).*

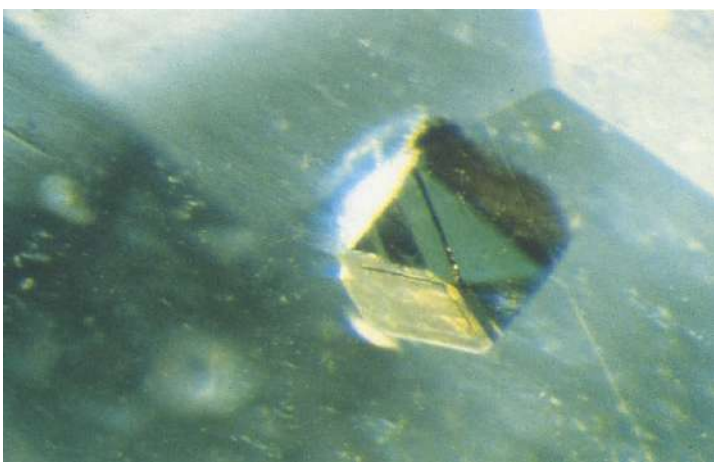

Figure 4: *Pyritized shells – some cut and polished on one side (photograph by M. Hutchinson).*

Figure 6: *Sand Dollar (photograph by M. Hutchinson).*

Figure 5: *Close-up of pyritized interior of shell (photograph by M. Hutchinson).*

Figure 7: *Pyrite nodules on slate (photograph courtesy of E.A. Jobbins).*

Even when found as well formed cubes, the faces of the cubes are often striated. Usually it is found as small cubes, pyritohedra or modified forms, often with the orthorhombic polymorph, marcasite, in irregular spherical nodules and veins in clay, slate and coal. It occurs abundantly in rocks of all ages from the oldest crystalline materials to the most recent alluvial deposits. Spangles and veins of pyrite are often found in lapis lazuli and sometimes very attractive microscopic crystals are found as inclusions in other gem materials such as emerald *(Figure 3)*.

Experiments[12] have established that when iron disulphide is crystallized from a neutral or an alkaline medium at high temperatures pyrite is produced, but from an acid medium at temperatures below 450°C marcasite crystallizes. In the Gault clays at Folkestone iron disulphide is in the form of pyrite nodules but in the limestone areas it is marcasite.

Both pyrite and marcasite are minerals that can replace the calcium carbonate in the shell of shellfish giving very attractive fossils[13]. Species, such as ammonites, buried in iron- and sulphur-rich mud can, over time, have part of the cell walls replaced by pyrite which is only evident when the fossil is broken *(Figures 4 and 5)*.

Other shapes such as 'sand dollars' which may resemble organic forms, are the product of the growing conditions of the pyrite crystals *(Figure 6)*.

Henckel[11] notes the occurrence of round pyrites washed down from the Swiss Alps and nodules the size of oranges and lemons from the island of Staritzo. These spectacular forms are illustrated in *Figure 7*.

Marcasite crystallizes in the less symmetrical orthorhombic system. Typical forms for marcasite are given more picturesque names such as 'cockscomb

pyrites' or 'spear pyrites' describing the typical twinned crystal shapes. Marcasite can be altered to iron pyrite.

The hardness of both species is 6 to 6.5 which means that pyrite can be carved using quartz sand as an abrasive but is hard enough to take a good polish. The specific gravity of iron pyrite is 4.95–5.10, slightly greater than that of marcasite, 4.85–4.90.

Iron pyrite is the most widespread sulphide in the world[12]. Nicholson[1] notes that 'pyritous minerals precede, accompany and follow veins of ores.' Pyrite is 'found in clays, chalk, marls, marbles, plasters, alabasters, slates, spars, quartz, granites, crystals' and 'also in pit-coals and other bituminous matters'. In view of such ubiquity, it is not worthwhile giving any location maps. Today where found in large deposits, such as in the copper mine at Rio Tinto in south-western Spain, it is still mined for the sulphur content. Pyrite crystals exposed to weathering can be altered to limonite, a hydrous iron oxide, and possibly further to hematite. Sometimes pyrite crystals are found with just a coating of limonite and other deposits are known where complete replacement has occurred, e.g. Hautes-Pyrenees in France. In a review of known ore deposits in 1896, Phillips[14] mentions that at Meggen in Germany operations commenced with surface mining of hematite but that these are underlain at depth by deposits of pyrite.

Exceptionally fine crystals of pyrite are found in Elba, Piedmont, various localities in Cornwall, St Gotthard in Switzerland, as well as in the former Czechoslovakia and many other locations in Europe. Well-formed crystals also occur in Peru, Bolivia, Chile, Brazil, Japan and Mexico. 'Sand dollars' are particularly known from Sparta in Illinois, USA, where they have formed in 'sedimentary rocks produced by compacted silt rich in carbonised plant material'[13]. Marcasite is much less common and, being relatively unstable, is easily altered. Good spear-shaped crystals can be found in the Pas de Calais and between Folkestone and Dover. The cockscomb form is found at Tavistock in Devon and Guanajuato in Mexico.

As well as iron and sulphur, iron pyrite can contain traces of other metals. Some localities contain sufficient gold or copper to make pyrite a worthwhile source of these metals. In his unpublished manuscript Halford-Watkins[15] conjectures that a large percentage of the world's free gold had its origin in pyrite that had subsequently decomposed releasing very fine particles of gold such as are found in alluvial deposits. Although it may be commercially feasible to process these 'auriferous' pyrites the amounts of gold they contain are very small. The bright brassy golden colour of pyrite has been known to cause confusion to the inexpert prospector and is also known as 'fool's gold'.

Early uses

Fire

Iron pyrite is arguably among the first minerals used by man. Caspall[16] estimates that the production of fire by striking pyrites with a flint edge was in use for around fourteen thousand years and was a method used in parallel with wood friction, depending on the local availability of materials. The sparks created were used to ignite a small pile of tinder such as dried fungus or grasses. Such fire-lighting kits comprising a nodule of pyrite, flint and tinder were found in a 'Beaker' burial site at Lambourn, Berkshire, and in three-thousand-year-old sites in Suffolk.

Irregular nodules of iron pyrite have been found in Anglo-Saxon graves[17] in Cambridgeshire, Suffolk, Hampshire, Sussex and Wiltshire. As, in some of these areas, pyrite nodules occur naturally in the surrounding soil, it was established in the course of the excavations that these were items deliberately placed in the graves and not accidentally included. In Burwell, Cambridgeshire, pyrite balls were found at the hips of a male skeleton. Meaney[17] concludes that these finds indicate a possible religious significance rather than any magical or amuletic properties. 'If pyrite was used to make fire as seems possible, it might simply have been buried as a prized possession.' Almost all of the finds have been with male skeletons and can be seen either as a valued personal possession or as a means of making light and heat in the next world. A notable

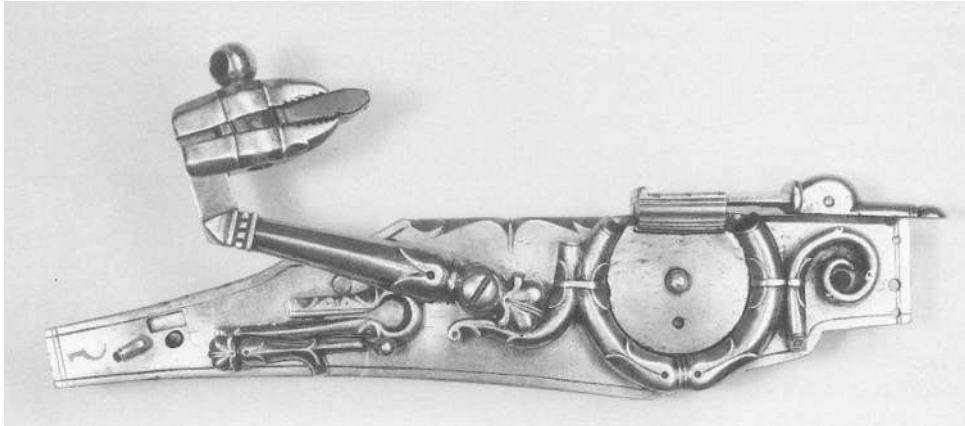

Figure 8: *Wheel-lock gun mechanism. Pyrite is held in a clamp, top left of the picture (photograph courtesy of Victoria and Albert Museum).*

exception to the predominantly male-related finds is a pyrite nodule found in Bronze Age Denmark, as part of a group of objects in a leather bag and thought to be the collection of a 'wise-woman'.

This combination of pyrite, flint and tinder continued in use throughout Europe as fire lighting apparatus until iron became readily available. Pyrite was then replaced by more conveniently-shaped iron strikers. The subsequent development of steel allowed the production of more durable strikers and resulted in a system, i.e. the tinder box, which was to last until the early years of the nineteenth century as the universal fire lighting system. Attempts to mechanize the earlier process resulted in the Monk's gun system in the late fifteenth century in which a piece of pyrite was held in steel jaws and forced against a roughened steel bar by the operation of a ring pull. A refinement of this system was the wheel-lock.

Firearms

The earliest records of wheel-lock mechanisms are those drawn by Leonardo da Vinci[18]. Several variations of the mechanism appear in drawings dated from the late fifteenth or early sixteenth century. A small piece of pyrite was forced by a spring against the serrated edge of a revolving steel wheel causing a shower of sparks which ignited the tinder.

Caspall[16] illustrates an elegant German sixteenth century example of such a tinder pistol which must have been owned by a wealthy man. Not only is the mechanism itself intricate and delicate but the decoration of the pistol is very elegant. Often the skills of gunsmiths, clockmakers and even blacksmiths were used to produce these luxuries for the very wealthy. Even much simpler examples would have been affordable only by the affluent middle classes.

The wheel-lock mechanism was more widely used for guns. Indeed another term for pyrite mentioned by Caire[19] is 'pierre de carabine' from its use by the Italians in early firearms. Apparently the material from Elba is particularly good for producing sparks (C. Cavey, personal communication).

The earliest dateable firearms using this mechanism are from the second quarter of the sixteenth century and it is now accepted that the Italians were the first to develop them[18]. The impact on society of these 'secret' weapons was on a par with the nuclear weapons of the twentieth century. These were the first guns that could be carried concealed and ready for immediate firing. Wheel-lock guns were produced in many countries in Europe for a further one hundred years *(Figure 8)*.

During this period older systems continued to be used and newer mechanisms were being

developed. The wheel-lock gun had superseded the match-lock system which relied on a slow-burning fuse and was in turn replaced by the simpler flint lock and other safer mechanisms. The delicate mechanism and the tendency of the pyrite to wear down quickly or break at inopportune moments made the wheel-lock a rather unreliable gun for warfare. A later gun development in Italy also used pyrite. This segment-lock, dating from the early seventeenth century, had some features in common with the wheel-lock, but operated with a steel striker instead of a wheel which scraped against the pyrite.

The rough cutting of the pyrite was probably not done by the gun-makers themselves. There would have therefore been a 'cottage' industry for the cutting of iron pyrite which would have needed to find alternative outlets when wheel-lock guns finally went out of production.

Chemicals

A major use for pyrite, described by Agricola[20], was to produce ferrous sulphate which was used, among other things, as a black dye. Its Roman name was *atramentum sutorium* (literally shoemakers blacking). In the thirteenth century this was given the name vitriol because of the glass-like transparency of the salts.

The production of vitriol from pyrite certainly dates back to pre-Christian times as a supplement to natural green vitriol called Melanteria[20] which was said to be mined in Cyprus. Vitriolus was the name given to the calcined pyrites and Agricola describes the process by which it was turned into vitriol. Vitriolus was left in heaps exposed to heat and rain for at least five months with regular turning before being covered and left for a further six to eight months. The weathered ore was stirred in a vat with water and the resultant pale green solution was run off. Solid salt was then obtained by evaporation. Writing in 1748 Hill[21] notes that vitriol is commonly called Copperas. In addition to its use as a black dye for hats and cloths, he mentions some varieties with other uses. A bluish-green vitriol (possibly a mixture of ferrous and copper sulphates) was used as a styptic and a white vitriol (lead or zinc sulphate) as a gentle and safe emetic.

The Copperas industry was a noted feature of Kent in the seventeenth century[22]. Pyrite nodules were collected by the local poor people on the beaches under the cliffs at Queenborough in Sheppey, Swalecliffe and Whitstable. At the end of the sixteenth century the stones were processed locally, but by the end of the seventeenth century the factories moved to places such as Deptford to be near the major market in London.

As well as vitriol, pyrite was also processed further to obtain sulphuric acid or 'oil of vitriol' and sulphur, and the latter use continues today.

Ornament

Undoubtedly such a bright, attractive and ubiquitous material has been known and used by man for ornament since prehistoric times. References have been made to pyrite found in various archaeological locations both in the old and new worlds. Pyrite beads[23] have been found in ancient Egypt, in Iron Age Iranian sites and in graves of the second and third centuries AD in Taxila in the Indus valley. The relative paucity of finds of such a widely occurring material must be because the conditions in some sites would cause chemical or physical break down and it would be unusual to find pyrite *in situ*. It is interesting to note that Sumerian Lapis jewellery has pyrite-shaped holes where the typical inclusions have decomposed (M. Hutchinson, personal communication).

Preserved in the frozen ground in a woman's grave at Pasyrak[24] in the eastern Altai was a pair of boots whose leather soles were decorated with colourful woollen embroidery and 42 pyrite crystals. The grave is dated to the six to fourth centuries BC. The pyrites are thought to have been obtained as a by-product from mining. A unique decorative use comes from the 'New World'. Pouget, the Parisian court jeweller, writing in 1762[25], calls Marcasite the 'pierre des Incas' because of its use as mirrors and from examples found in Inca tombs. So far it has not been possible to

Figure 9: *Aztec mirror depicting the God Quetzalcoatl (photograph collection musée de L'Homme, Paris).*

identify the source of his information, although one mirror survives[26] from the Mochica culture 100 BC–AD 600, in the National Anthropology and Archaeology Museum in Lima. This mirror consists of a carved wooden face with inlay of bone and shell on one side and an inlaid plaque of pyrite on the reverse. Other examples from Peru have not been traced and it is possible that Pouget was misled by some incorrect labelling when the Le Cabinet Royal d'Histoire Naturelle was opened to the public in Paris in 1745[27]. A splendid Mexican obsidian mirror, thought to be part of the treasure from Mexico sent by Cortes in 1522 to Charles V of Spain, captured by the pirate Jean Fleury of Honfleur and given to Francis I in return for safe anchorage in French ports, was labelled 'Miroir des Incas du Perou'. All sources so far discovered referring to Marcasite in later periods tend to quote Pouget but no mention is made of the Incas prior to his description. Indeed, in one of the most informative books about the Incas, Garcilaso de la Vega[28] notes, 'The mirrors used by the women of the blood royal were of highly polished silver, the ordinary ones of brass.'

Undoubtedly pyrite was known in South America. Barba[29] mentions 'margatita or perytis' mined by the Incas at Acoraymes and in the Potosi mines which are now in Bolivia.

There are several examples from Mexico of polished nodules of pyrite used either as mirrors or as eyeballs in decorated skulls. In the Musee de L'Homme in Paris there are three mirrors. The oldest is a simple cylindrical shape about 3 cm in diameter with one polished face and is dated AD 150–750 from Teotihuacan. The two other examples are approximately twice the diameter and date from the Aztec period (1325–1521) from Vallee de Mexico. One is a simple shape but the other is finely carved on one side *(Figure 9)*.

All have lateral drill holes so that they could have been worn suspended from the body in some way. Drawings of the carving were published by Kunz[30], who also refers to a carved head of iron pyrites with chalcedony eyes in the United States National Museum, Washington. In the collection at the British Museum[31] is a mask from the Mixtec-Aztec period 1400–1521: 'A human skull forms the base for this mask of Tezcatlipoca, 'Smoking Mirror', one of four powerful creator gods in the Aztec pantheon. His distinguishing emblem, an obsidian mirror, symbolizes his control over the hidden forces of creation and destruction. The mask is decorated with a mosaic of turquoise, lignite and shell; polished iron pyrites have been used to fashion the eyes.' *(Figure 10)*.

Figure 10: *Mexican mask with pyrite eyeballs (photograph courtesy of the British Museum).*

An example of pyrite carving seen in a middle eastern context is a Byzantine intaglio ring mentioned by Ogden[23]. This ring dates from the sixth to seventh century AD and has a monogram carved in the pyrite which was set in gold. The pyrite was partially decomposed. The ring was sold at auction in 1981–2 and its current whereabouts are not known. Lack of further evidence or examples may mean that suitable material for carving was not available, was not considered suitable or, more probably, smaller items were completely degraded after burial. Exactly when, where and why iron pyrite was first cut and faceted for use in jewellery is not recorded.

Marcasite jewellery in the eighteenth century

Until the early part of the eighteenth century there is relatively little evidence of the widespread decorative use of Marcasite. The earliest reference to Marcasite-set jewellery is by Pouget in 1762[25] but it had already been in production for some years. Its main attraction was as a simulant for diamond and it would not therefore have been introduced until the fashion for diamond-set jewels had become well established.

During the seventeenth century France had emerged as the centre of elegance and fashion, especially at the sumptuous court of Louis XIV. This pre-eminence was particularly true for jewellery[32] and French jewellery designs were disseminated throughout Europe. By the end of the century most of the diamond cuts now known had been established and diamond-set naturalistic styles predominated. The most widespread cut used for diamonds was the rose cut.

The discovery of diamonds in Brazil in the early decades of the eighteenth century ensured that, with an expanded supply, diamonds became the major stone used. They were generally set in silver and mounted in gold.

Around this time it became the fashion for social occasions to take place at night where diamond-set jewels sparkled beguilingly under the flickering candlelight[33]. Also at this period the growth in a more prosperous 'middle-class' created a demand for jewellery which imitated the precious jewels of the rich and the aristocracy. A flourishing business in such items developed and, such was the artistry and workmanship of the jewels produced, it became fashionable in its own right. The fineness of the settings and the elegance of the designs employed for the Marcasite pieces were equal to the best used for diamond-set jewels and show that it was not treated by the craftsmen of the time as an inferior material. Diamonds were also imitated by paste, i.e. glass, but the dark sparkle of the small rose-cut diamonds was best simulated by Marcasite. Being a reasonably hard stone iron pyrite takes a good polish as well as having a naturally high lustre. Both diamonds and glass, being transparent, were foiled to enhance the reflective properties of the stones. This involves the application of a fine reflective material to the back of the stones and is a skilled and expensive process. This extra cost was avoided by using Marcasite which is opaque.

The use of Marcasite as a diamond simulant was said to have first come into fashion during the reign of Louis XIV[34]. Little of the jewellery from the eighteenth century survives but there are more examples of that set with Marcasite than of the diamond-set pieces of the same period. The latter were liable to be refashioned as styles changed or sold in times of difficulty because of the intrinsic value of the stones.

The identification of makers of Marcasite set pieces from this period is not possible as there are usually no marks on the jewels. There are a few examples from the second half of the century in the Jewellery Gallery at the Victoria and Albert Museum[35] and from the Hull Grundy bequest to the British Museum *(Figure 11)*.

As with diamonds, Marcasites were mounted in silver and, as well as necklaces, brooches and earrings, were used for buttons, buckles and chatelaines. Marcasite is well suited to the rococo scrolls, bows and straps of the period. Pouget[25] tells us that this jewellery became fashionable in Switzerland when sumptuary laws forbade the wearing of diamonds. In fact it was only in Geneva in 1668 that such laws were enacted and at the

Figure 11: *Marcasite brooch-pendant 1790–1800 (photograph courtesy of the British Museum).*

time Geneva had not yet become a Canton of Switzerland. He also stresses the inexpensive nature of Marcasite set jewellery in comparison to that set with diamonds and implies that the period of economic retrenchment proposed in 1759 by M. de Silhouette, one of the finance ministers to Louis XV, encouraged the aristocracy to wear it. The fashion was also said to have been supported by the Comtesse Du Barry, the King's mistress[36]. Whether for patriotic, stylish or more practical reasons in times when 'highway robbery' was common, the fashion for Marcasite jewellery continued until the end of the century when the revolution in France changed the focus of the fashionable world. The lightness and elegance of the French pieces[37] are in contrast to the more showy nature of the Swiss jewels of the period[38].

Another diamond simulant produced at around the same period which may occasionally be confused with Marcasite is cut steel. Tiny studs of steel, originally from old nails, were cut and polished and set into jewellery and other trinkets. In England cut-steel became more fashionable than Marcasite and could be very costly. It was particularly favoured by men in the form of decorative sword hilts, buttons and shoe buckles. The two simulants can be identified by the settings. Marcasite was set in pavé settings with the metal mounting being used to hold the stones into place whereas cut-steel rosettes were riveted onto the mounts.

Marcasite jewellery in the nineteenth century

The exquisite workmanship of the eighteenth century could not be sustained as the demand for greater volume and less expensive pieces grew. Although it was still seen as a diamond substitute, the brilliant cut (now predominant for diamonds) gave an effect that could not be reproduced with marcasite and limited its use. Marcasite-set jewellery continued to be produced, but attempts to revive the original eighteenth century styles in the middle of the nineteenth century failed[39]. The settings were generally less well made and the jewellery was no longer seen as a fashionable alternative to gem-set pieces but cheap copies for those who could not afford the real thing. Some fine work was still done where Marcasites were used as surrounds for small enamels and miniature mosaics of the Tonbridge-ware type[32]. Nonetheless, Marcasite, having been established as one of the many stones available to the jeweller, continued to be used in a limited way, in a sense waiting for a change in fashion to improve its fortune.

One particular occurrence that was exploited by the local jewellery trade in this era was a thin encrustation of iron pyrite on shale found near Dublin[39]. Pieces of this material were cut and shaped and set in brooches that were sold by Cornelius Goggin in Dublin[40].

Cutting through the centuries

Caire[19] states that the cutting of Marcasite was carried out in the region of Geneva and that the stones were exported to many areas.

Only Portugal prohibited the import of Marcasite, which may have been due to a protectionist attempt to safeguard the diamond-cutting industry based on rough being imported from Brazil. Bauer[39] also quotes Geneva as the source of cut material but in addition mentions the Jura Alps in France. The relationship between these two areas, particularly in the field of lapidary work, goes back to the late fifteenth century[41].

The adoption of Calvinism in 1536 by Geneva resulted in refugees, who wished to retain their religious freedom, fleeing to the catholic areas of St. Claude in the Jura region of eastern France. Among the refugees were goldsmiths and jewellers skilled in the arts of gem-set work. In about the middle of the sixteenth century the new trade of watchmaking spread to Geneva and numerous lapidaries were employed in the manufacture of glasses, stones for the ornamentation of the cases and, after about 1700, in the cutting of rubies for the mechanisms. In 1673 strict religious laws forbidding the wearing of jewellery had a severe impact on the trade and further emigration occurred resulting in the emergence of Septmoncel in the Jura as a watchmaking area. The Jura was a poor farming region and there was a ready supply of outworkers who cut stones by hand in the long winter months to supplement their meagre income from the land.

Having thus been established, the lapidary business continued with fluctuating fortunes cutting whatever materials were required by the jewellers of Paris. This included Marcasites although, as the details of the various operations were considered to be trade secrets, it is not possible to identify particular cutters.

Iron pyrite is mostly cut into circular shapes with a flat back and six triangular facets on the front. This cut is similar to the standard rose cut for diamonds. Stones are produced with various diameters but most are quite small. Initially, as for all stones, this was done by hand but over time parts of the process were automated and production was moved into factories. In the early years of the twentieth century, the town of Turnov in Bohemia is mentioned[42] as an important centre for the cutting and polishing of both glass and Marcasite. The work was done by semi-automatic machines and the raw material came from South Tuscany in Italy. The complete history of one cutting factory in Turnov was related to me as follows. In 1899 a young man, having served in the Austro-Hungarian army, finished his engineering studies and established a cutting business in Turnov. The business must have flourished because by 1938 it employed approximately a thousand people. However, during the Second World War stone cutting ceased and although attempts were made to revive it in 1945 they were unsuccessful. In fact the 'young man', by then aged 70, escaped to Germany and followed his family to South America.

The company of Golay-Buchel based in Lausanne established the first fully automated cutting and polishing machine for Marcasite over fifty years ago and continues in the business today[43].

Not all pyrite is suitable for cutting; in particular the well-formed cubes are too brittle. Italy continued to be a major source of suitable material for cutting until it became uneconomic in the mid 1980s. Today the raw material comes from South America and most of the cutting of high quality stones is done in the Philippines using fully automated machinery. There is also some hand cutting in Thailand.

Marcasite jewellery in the twentieth century

To understand the success of the use of Marcasite in the manufacture of affordable and stylish jewellery in Europe in the 1920s and 1930s, it is necessary to discuss briefly the ideas and methods of one of the German jewellery industry's more innovative manufacturers, Theodor Fahrner, and the development of his company.

The firm of Theodor Fahrner of Pforzheim[44] was noted for the production and marketing of a range of stylish, artistic and relatively inexpensive jewellery at the turn of the century. In particular, Fahrner worked to improve the artistic quality of wholly or partly machine-made jewellery. He collaborated

with the artists of the Darmstadt Art Colony, such as Joseph M. Olbrich, to obtain designs for unusual jewellery that had a distinctive German character and individuality which broke free from the influence of France.

The Darmstadt Experiment was promoted by the Grand Duke Ludwig of Hesse to encourage collaboration between artists and manufacturers and promote the growth of local industry. The intention had been that there would be collaboration with the jewellery industry in Hesse but, whereas the jewellers of Hanau showed little interest in the project, Fahrner from Pforzheim was able to see the possibilities for modern jewellery and build on the contacts.

As an artist-manufacturer, Fahrner recognized the limitations of art nouveau designs for factory production but was determined to produce well designed, affordable jewellery. The modern styles worked well with the newer fashions which tended to simpler and more geometric lines. He recognized early the value of advertising and registered the TF monogram as a trade mark in 1901. In order to reach a wider, artistically aware, readership, he placed advertisements for the jewellery in a periodical about art and decoration *Deutsche Kunst und Dekoration* rather than in jewellery trade journals.

Fahrner died in 1919 after a long illness. The strong tradition of the marriage of artistic design with industrial manufacture that he had established provided a good base for Gustav Braendle who bought the business from Fahrner's widow. After war service, Gustav Braendle had returned to the family business in Esslingen but rather than just taking over the existing jewellery business, he saw greater potential for success in Pforzheim. He showed a flair for publicity comparable to that of Theodor Fahrner by advertising his ownership of Theodor Fahrner Nachfolge with a spoof telegram in the *Deutsche Goldschmiedezeitung* in 1920.

In the years after the First World War precious material such as gold and silver were in short supply. Companies that could use a minimum of these metals with other materials, including wood, to produce low- and medium-priced jewellery of artistic merit stood a better chance of survival than their more traditional competitors, many of whom were forced by the 1923 economic crisis to cease production. It is in this period that we first hear of the use by Braendle of Marcasite which had already been in use in the German jewellery industry since 1910.

Figure 12: *Maracasite, onyx and coral pendant with enamel ca. 1929 (photograph courtesy of Arnoldsche Verlagsanstalt GmbH, Stuttgart, Germany).*

From then onwards, through the 1920s and into the early 1930s, Marcasite became a regular design component for much of the company's production. The company designers, including Braendle himself, obviously appreciated the artistic properties of the material. They made full use of the particular steely glitter of the stone in combination with quartz, black onyx, red coral and other opaque decorative stones to

Figure 13: *Typical art deco silver, Marcasite and cornelian brooch, maker unknown (photograph by M. Hutchinson).*

Figure 14: *1950s Marcasite set brooch and earrings (photograph by M. Hutchinson).*

produce the art deco styles popular in this period *(Figures 12 and 13)*.

Other manufacturers, even some of the top French jewellery houses, also used Marcasite to produce art deco styles. Black and white combinations were particularly popular. In 1923 Vogue[45] reported, 'the mode has a passion for black and white jewelry, particularly when the black is onyx and the white is marcasite.'

The 'patriotic' styles of the late 'thirties, encouraged under the aegis of the Nazi regime, virtually eliminated the production of innovative and stylish jewellery in Germany, and Marcasite was once again out of fashion.

The styles of the 'forties and early 'fifties were characterized by exuberant and colourful jewels, which featured lavish amounts of gold (solid or plated) and multi-coloured stones. It was only during the mid- to late-'fifties when 'white' diamond jewellery returned to popularity that Marcasite was again used to imitate the sparkle of the more expensive stone *(Figure 14)*.

At this period there was a marked change in the materials used for manufacture in comparison with earlier years. Until this decade Marcasite had been set in silver mounts with grain or rub-over settings; pre-war apprentices were often given the job of setting Marcasites while training for the setting of diamonds. In the 'fifties the majority of mounts were made of base metals, often chromium or rhodium plated, and the stones were glued into place. One of the most popular themes was that of a bird or animal fashioned as a lapel brooch and sold at a very modest price. Although the artistic merit of these pieces was very variable, there was probably no woman or girl of the time who did not possess at least one Marcasite brooch. Unfortunately it is this unexceptional jewellery that many people think of when Marcasite is mentioned today.

The wider use of colourful plastics and the fashion revolutions of the 'sixties once again pushed Marcasite out of the mainstream.

The company of Butler and Wilson is credited[45] with the revival of silver, Marcasite-set jewellery in the 1980s. Sadly, there has been a tendency to produce pastiches of the styles of the 1930s rather than innovative designs. With the comparatively low labour costs, items of this kind are now mostly produced in Thailand *(Figure 15)*.

A more recent manifestation of the ornamental use of iron pyrite has been the appearance on the market of a range of beads mostly cut in China. These are most effectively used either as large beads, which show some of the crystal structure, or as 'spacers' to compliment other materials, enabling the designer to produce a wide range of attractive necklaces *(Figure 16)*.

It is also from China that an unusual combination of minerals has been exploited. Fine banded fluorite in various shades of green and violet with an encrustation of well crystallized iron pyrite has been discovered. This was cut by craftsmen in Germany into splendid bowls and demonstrates that such apparently unpromising material can, in the hands of skilled designers, be fashioned into exciting artefacts *(Figure 17)*.

Figure 15: *1980's ring set with Marcasite and lapis lazuli with pyrite inclusion (photograph by M. Hutchinson).*

Figure 16: *Pyrite beads (photograph by M. Hutchinson).*

Figure 17: *Bowl carved by Becker in Idar-Oberstein (photograph courtesy of M. Pout).*

Figure 18: *Winner of the 1995 Prix Golay Buchel – a competition for young Swiss jewellery designers to design a stopper for a perfume bottle with marcasites – by Manuela Bär (photography courtesy of Golay Buchel).*

A really modern use of Marcasite is seen in the winning entry for the competition held in Switzerland in 1995 for students to design a perfume flask incorporating Marcasites in the design *(Figure 18)*.

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A combined spectroscopic method for non-destructive gem identification

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ABSTRACT: The combined use of spectroscopic methods including Raman laser spectroscopy, mirror infrared reflection spectroscopy and diffuse reflection spectroscopy in ultraviolet, visible, and near infrared wavelengths can supply non-destructive and diagnostic information to identify gems. The items can be natural or synthetic gemstones, loose or mounted in jewellery, or in a rock matrix in various forms and dimensions.

Keywords: infrared, visible, ultraviolet reflection spectroscopy, Raman laser spectroscopy, non-destructive gem identification

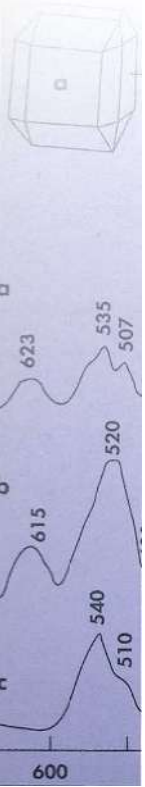

I. Introduction

Generally, identification of a gem can easily be made on the basis of optical and physical properties (Anderson, 1980; Bank, 1973; Smith, 1972). However, sometimes it is difficult or impossible to determine some physical properties of a gem mounted in jewellery with the use of standard gemmological equipment and in this case gem identification is made visually. Traditionally distinguishing synthetics from natural gems has been largely visual. The majority of well-known mineralogical techniques cannot be applied in gemmology because they are destructive (Gramaccioli, 1991). Also the full safety of some gems is not assured if their identification is attempted by single-crystal X-ray diffractometer (Bank, 1980; Pilati and Gramaccioli, 1988); there is a danger that a gem's colour may change under X-radiation. It is fundamental that gemmologists do not damage gems and jewellery in any way. That is why the requirement is to apply only non-destructive methods for gem identification. In the past, methods of infrared reflection spectroscopy have been described by Pfund (1945), Shimon (1951), Vierne and Brunel (1969, 1970, 1973), Brunel and Vierne (1970), Brunel *et al.* (1971), Tretyakova *et al.* (1987), Martin *et al.* (1989) and Gao Yan *et al.* (1995), and Raman laser spectroscopy by Griffith (1969), Nassau (1982) and Reshetnyak (1991).

Infrared reflection spectroscopy and Raman laser spectroscopy have been called methods of gem 'fingerprinting', and there are many optimistic declarations that each method may be used on its own to identify the majority of gems. In practice there can be problems with collection of spectra. Each method has serious technical limitations (usually not described in detail by authors). These limitations are connected with the chemical composition and crystal structure of a mineral, the dimension, form and surface characteristics of an item, and the mounting in jewellery or in matrix. Below, we propose that

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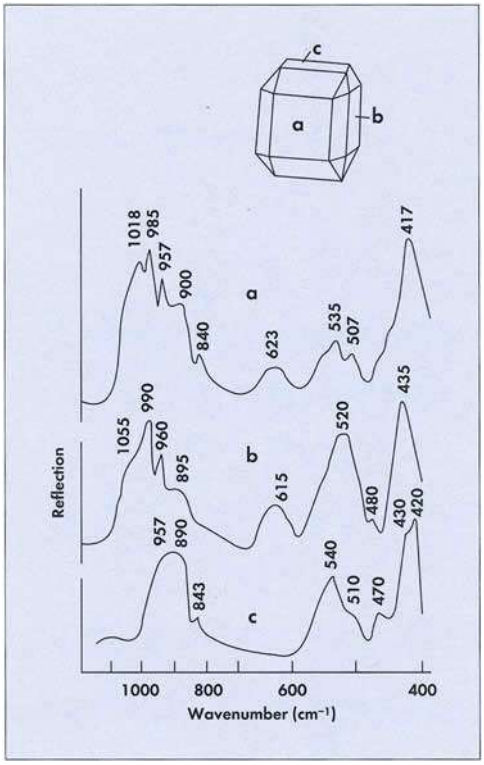

Figure 1: *The mirror reflection spectra in the medium infrared obtained from different orientation planes of an olivine crystal.*

the combined use of spectroscopic methods, including Raman laser spectroscopy, mirror reflection infrared spectroscopy and diffuse reflection spectroscopy in the ultraviolet/visible/near infrared (UV/VIS/NIR) range can provide non-destructive and diagnostic information for most gemmological objectives (Tretyakova and Reshetnyak, 1990; Tretyakova *et al.*, 1995; Tretyakova and Tretyakova, 1996).

II. The methods and their practical application

The methods are based on vibrational and electronic spectral analysis of a gem. The vibrational spectra obtained by IR mirror reflection spectroscopy and Raman laser spectroscopy are fundamental properties and can be used to identify a gem or mineral species. The number of spectrum lines, their frequencies, intensities and bandwidths in both the Raman spectrum and the spectrum of the medium infrared, are connected with the chemical composition and crystal structure of a mineral. Their patterns make them a reliable means of identification, in either the crystalline or the glassy state. The spectrum measurements using reflective spectroscopy and Raman scattering are simpler than in any other spectroscopic method. The gems do not require special preparation, or alteration of jewellery or matrix. To make it practical and efficient we must consider some limitations.

A. Infrared mirror reflection spectroscopy

1. If no active first order dipole vibration in the medium infrared is observed, identification of the sample by means of the mirror reflection spectrum appears to be impossible. Then the band scanning must be expanded with registration of fine lines of higher order which means increasing the time to record any diagnostic information.
2. It is well known that most crystals are anisotropic and the IR reflection spectrum depends upon crystal orientation (Shaffer and Matossi, 1930). Such differences in spectra cover a considerable range for many minerals, and the spectra from three planes labelled a, b and c in an olivine crystal are shown in *Figure 1*. It is important to keep this fact in mind to avoid making a diagnostic mistake. On the other hand, this limitation can also be viewed as an advantage; with a mirror IR reflection spectrum the crystal orientation can be determined! With such information the optimum orientation can be chosen for cutting a gem to show lustre, sheen and colour.
3. *Gem and jewellery dimensions:* In order to obtain an IR mirror reflection spectrum it is necessary to have a flat mirror face (no less than 2 mm^2) which may be a natural crystal face or a polished surface of a cut gem. If the gem face is less than 2 mm^2 or the gem has a curved or spherical surface (cabochon, bead), it is very difficult or

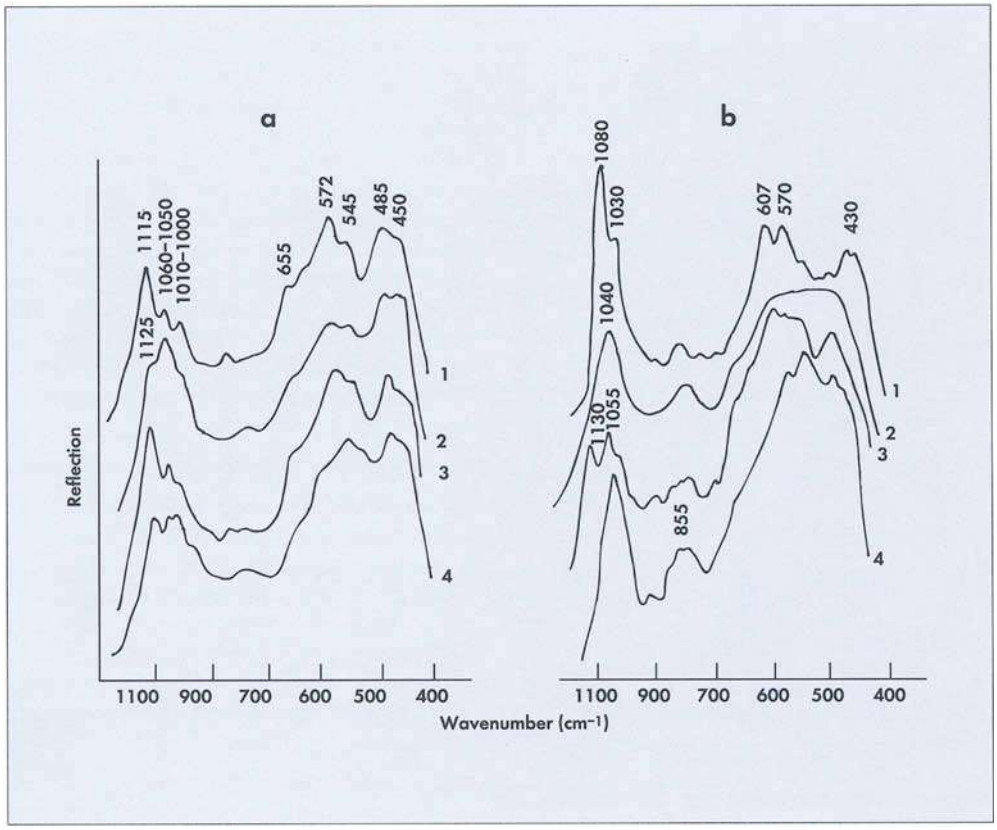

Figure 2: *The mirror reflection spectra in the medium infrared of turquoise: (a) natural: 1 blue, 2 light blue, 3 green, 4 green-yellow; (b) synthetic: 1–4 light blue*

impossible to obtain an IR mirror reflection spectrum. IR mirror reflection spectra are easy to record from loose gems and from gems mounted in small jewellery (for example a ring, earring, brooch, cuff-link, stud or a box). The limited size of the sample chamber in the IR equipment means that it is impossible to record IR reflection spectra from gems mounted in large items such as sceptres or crowns.

4. *Gem surface characteristics:* When dealing with non-ideal mirror surfaces one must recognize and differentiate mirror reflection lines from diffusion reflection lines in the infrared. When combined with or merging with mirror reflection lines the latter make gem spectra much more complicated. Ignoring this situation may lead to a serious mistake in identification.

B. Raman laser spectroscopy

Raman spectroscopy uses a focused laser beam (0.1 mm diameter) and spectra can be obtained from a wide range of stone sizes and forms. The spectrum can be measured from each free surface of the gemstone (mirror, rough or globular), whether mounted in jewellery or still in matrix. However, Raman laser spectroscopy is not so effective in the following cases:

1. When an object shows a strong luminescence background, especially under excitation in the blue-green region of the spectrum. Such materials include for example, some sulphurous aluminosilicates, amber, pearl and some synthetic emeralds. But it is true that this difficulty can be overcome to a considerable extent if an FTIR spectrometer is used and an

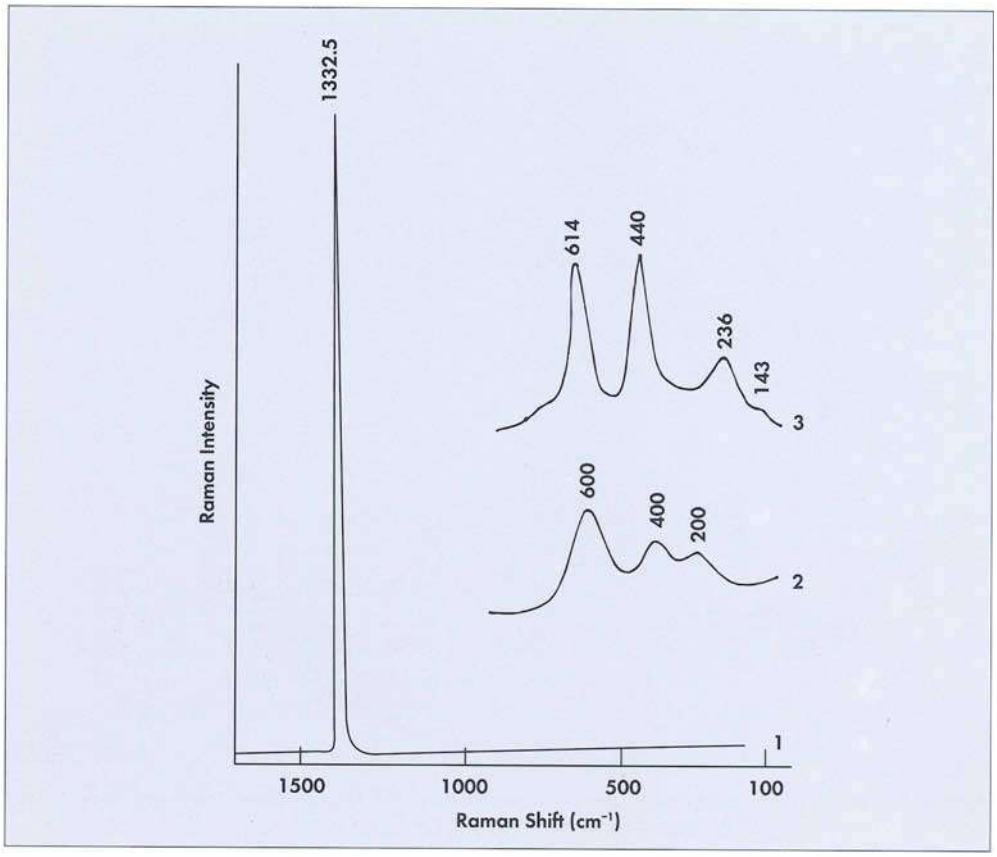

Figure 3: *Raman spectra of diamond (1) and two of its imitations; (2) phianite (zirconium oxide) and (3) rutile.*

excitation laser line of near infrared wavelength is selected.

2. One should be careful in the identification of gemstones containing rare-earth elements (for example apatite, fluorite, synthetic gemstones) as dopants which may cause colours. In this case the luminescence lines of rare-earth elements may be interpreted as Raman lines which could lead to a wrong identification. It is necessary to record Raman spectra from several excitation laser lines to correctly identify Raman lines.
3. It should also be noted that a few stones can be damaged by the laser. For example, some strongly absorbing gems such as malachite, azurite or turquoise, can be burnt by laser excitation in the blue-green region of the spectrum, and particular samples of synthetic auricalcite, natural blue sodalite or pink hackmanite can fade in laser radiation.
4. Minerals with amorphous or crypto-crystalline structures, such as opal or turquoise, produce low intensity Raman spectra that make identification difficult.
5. Low intensity Raman spectra are recorded from dark-colour (especially black) gemstones. Due to the strong absorption of both exciting and scattered light the Raman signal in such objects is found to be one to two orders of magnitude lower than in lighter-toned varieties of the same gems. Problems connected with the collection of Raman spectra from such objects are so difficult that it is more reasonable to use IR mirror reflection spectroscopy for identification.

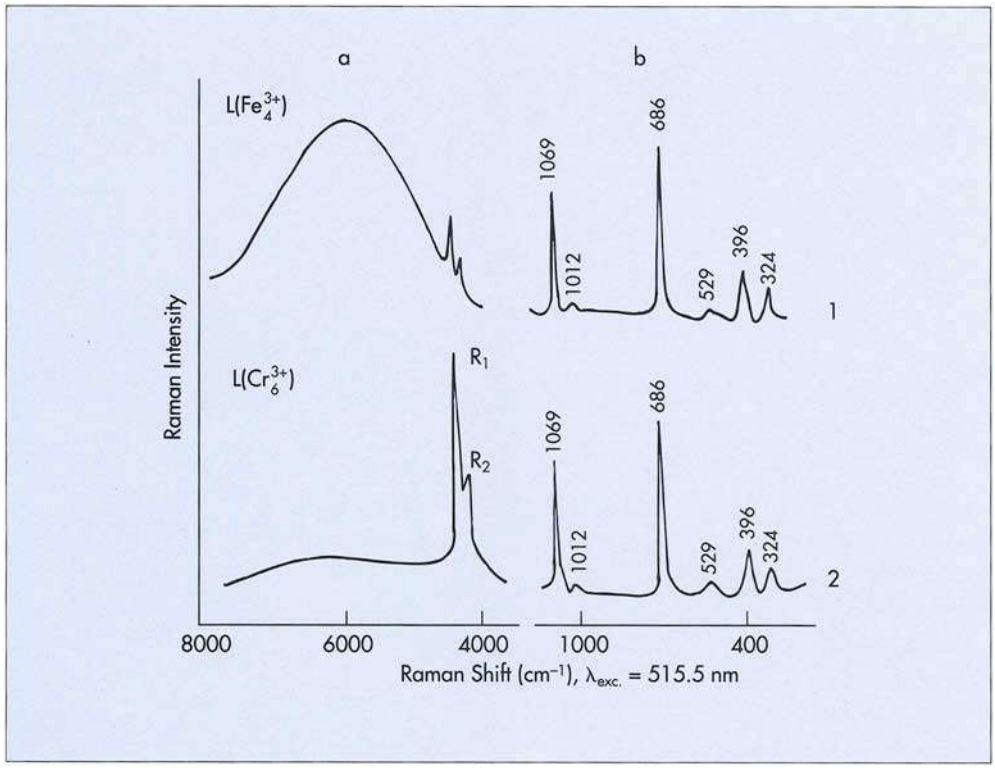

Figure 4: *Laser-excited spectra (a) luminescence lines, (b) Raman lines, of some beryl group minerals: 1 yellow beryl coloured by Fe^{3+}; 2 emerald coloured by Cr^{3+}.*

It should be noted that all the above-mentioned limitations can be reduced by longer counting times.

Obviously to obtain non-destructive diagnostic information for large gem items, it is reasonable to use both IR mirror reflection spectroscopy and Raman laser spectroscopy. Each method has its strengths and weaknesses. IR mirror reflection spectroscopy is preferable for gems with amorphous or cryptocrystalline structure, dark colour, mirror surfaces more than 2 mm^2, loose or mounted in small jewellery. Thus the IR reflection method is appropriate for turquoise identification *(Figure 2)*, since the Raman spectrum will not be very strong, and in addition a laser beam would spoil the gem.

It is better to use Raman spectroscopy for identification of cabochons, beads or gemstones with a badly polished surface and for gems smaller than 2 mm^2 or those mounted in large items of jewellery. For instance, Raman spectroscopy is very effective in identifying diamond which gives a non-distinctive IR reflection spectrum. The Raman spectrum of diamond is characterized by one intense line at 1332.5 cm^{-1} *(Figure 3)* which helps to distinguish diamond from its numerous imitations.

As mentioned above, a laser may excite in the crystal not only the Raman-shift but also luminescence. The use of the latter extends the diagnostic potential of laser spectroscopy. The Raman spectra of two varieties of one mineral – yellow and green – are shown in *Figure 4*. It is obvious that the Raman spectra are identical and allow easy identification of the mineral as beryl. But their luminescence spectra differ greatly. Analyses show that the colour of the first sample is caused mainly by Fe^{3+} ions and the colour of the second by Cr^{3+} ions. The second sample can be identified as

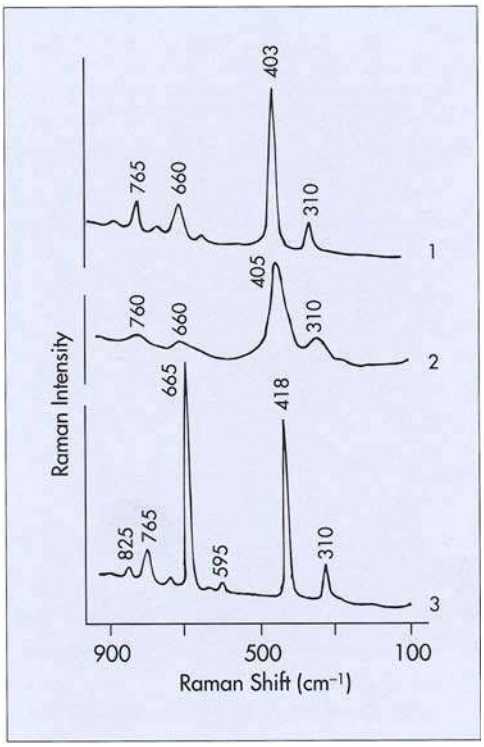

Figure 5: *Raman spectra of Mg–Al spinels: 1 natural; 2 and 3 synthetic.*

emerald. Therefore, the best laser diagnostics appear to be the simultaneous registration of two secondary glow components – the Raman and luminescence spectra. The crystal is easy to identify by means of the Raman spectrum, and data concerning the colour centres can be obtained from the luminescence spectrum.

III. Diffuse reflection spectroscopy in the UV/VIS/NIR range (200–2500 nm)

Absorption lines in the UV/VIS/NIR spectral range using diffuse reflection spectroscopy are caused by impurity or defect-impurity colour centres. These lines make it possible to diagnose some colour varieties of a mineral (for example ruby, emerald, pyrope). In general the spectra obtained in the UV/VIS/NIR range are used for colour studies and in some instances for origin determination of minerals (Platonov, 1976; Platonov *et al.*, 1984; Tarashchan, 1978). The diffuse reflection spectrum can be measured from a gem that is either loose or mounted in jewellery, provided it is larger than 2 mm^2; its shape and surface characteristics may vary as those found on natural crystals, cut gems, cabochons or beads.

IV. Origin determination for gemstones and a new approach to differentiating natural from synthetic gems by spectroscopic means

The problem of differentiating natural gems from their synthetic analogues requires an individual approach for each stone. The methods of Raman spectroscopy, IR mirror reflection spectroscopy or diffusion reflection spectroscopy in the UV/VIS/NIR range, either singly or in combination, are used. For example, it is simple to distinguish turquoise from its numerous imitations with IR mirror reflection spectroscopy *(Figure 2)* (Arnold and Poirot, 1975), natural spinel from its synthetic analogues with Raman spectroscopy *(Figure 5)*, and natural sapphire from its synthetic analogues with diffusion reflection spectroscopy in the visible range *(Figure 6)*. Ruby identification needs a combination of methods.

In studies of the Raman spectra of natural and synthetic zircons, the detailed spectral position of the line near 1008 cm^{-1} ($\Delta\nu$) has been plotted against its bandwidth at half height (γ) in *Figure 7*. A clear distinction between natural and synthetic zircons is demonstrated.

Using a combination of infrared, visible and ultraviolet reflection spectroscopy and Raman laser spectroscopy a range of colour-treated gems can be identified, including those coloured with chemical reagents (for example chalcedony and agate), thermally treated gems (such as corundum and zircon) and radioactively irradiated gems (for example, topaz, spodumene, citrine and amethyst). The fillings in glass-filled diamonds can also be determined.

V. Conclusion

Using a combination of spectroscopic methods, practically all gemmological objects can be identified (Reshetnyak and Tretyakova,

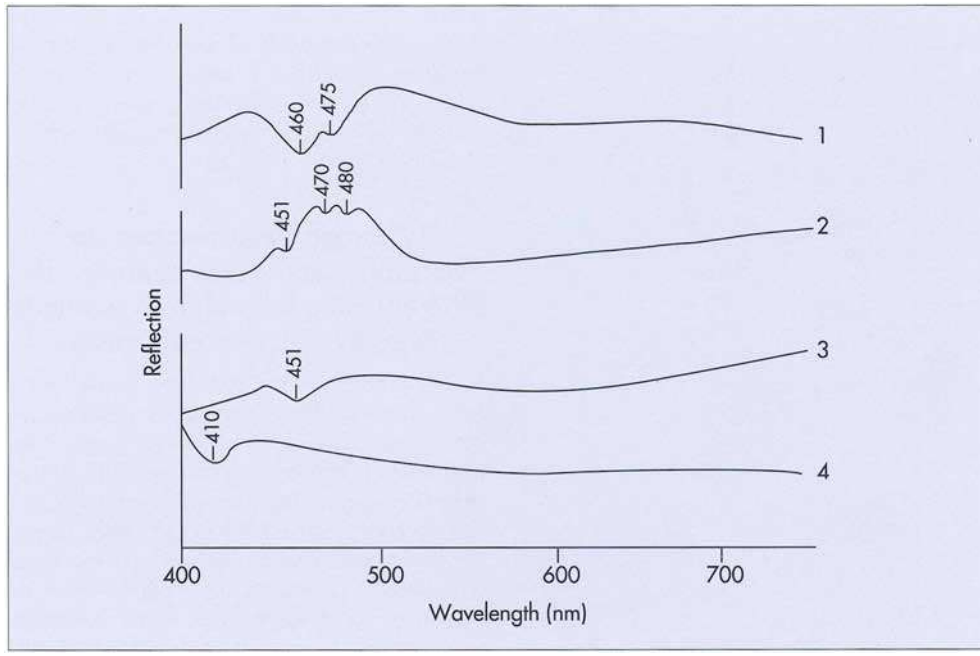

Figure 6: *Diffusion reflection spectra in the visible range of differently coloured natural and synthetic sapphires: 1–3 natural sapphires (1 green-blue, 2 violet, 3 blue); 4 synthetic blue sapphire.*

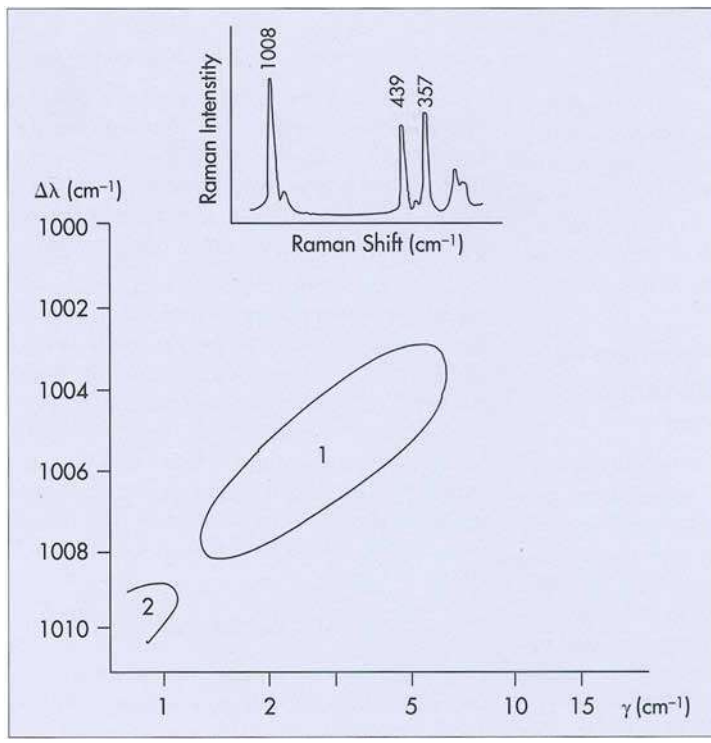

Figure 7:
The interdependence of the spectral position ($\Delta\nu$) and halfwidth (γ) of the Raman line vibration $\nu_2(B_{1g}) = 1008\ cm^{-1}$ in zircons of different genesis: 1 natural zircons, 2 synthetic zircons.

1994). With suitable safeguards, the methods are non-destructive and diagnostic, features which are very important during investigation of jewellery, museum exhibits, archaeological materials and antiques, because there is always a possibility that the original may be substituted by synthetics or simulants (Bank, 1973).

It is evident that the potential of these methods may be fully realized only when researchers have a comprehensive database of information on the Raman and reflection spectra for all gems (both natural and synthetic). For anisotropic crystals, the IR mirror reflection spectra of crystals in different orientations are needed also.

In support of these methods a database of IR mirror reflection and Raman spectra for 250 natural minerals and synthetic substances has been established; this is supplemented by diffuse reflection spectra in the UV/VIS/NIR range for colour varieties of these minerals.

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Inclusions in synthetic rubies and synthetic sapphires produced by hydrothermal methods (TAIRUS, Novosibirsk, Russia)

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ABSTRACT: Synthetic rubies and synthetic sapphires are produced by hydrothermal methods in Novosibirsk (Siberia, Russia) by TAIRUS, a joint venture of the Russian Academy of Sciences and Pinky Trading Company, Bangkok, Thailand. The rubies and sapphires are grown at high temperatures and pressures in steel autoclaves from complex carbonate- and chlorine-bearing aqueous solutions. The different colour varieties imitate Burmese and Thai rubies, Sri Lankan 'Padparadscha' colours (orange or pinkish-orange) and Thai and Australian sapphires. Diagnostic fluid (three-phase inclusions) and solid (copper) inclusions are present. A simple heating and freezing test is provided to enable the gemmologist to distinguish the three-phase inclusions in synthetic rubies from their counterparts in natural rubies.

Keywords: synthetic rubies, synthetic sapphires, hydrothermal, solid inclusions, fluid inclusions, formation conditions

INTRODUCTION

Commercial production of synthetic ruby includes flame-fusion, flux-grown processes and hydrothermal growth methods, e.g. see Schmetzer, 1986 or Hughes, 1997. The latter, which reached its commercial production stage very recently (Peretti and Smith, 1993a,b), is related to the political transformations of the former USSR and its opening to the international market.

Previously, research laboratories in the USA, Japan, Russia, China and France have reported their experimental research on the production of synthetic hydrothermal rubies, see Belt, 1967; Kutznetsov and Shternberg, 1967; Marais, 1969; Kutznetsov *et al.*, 1968; Nguyen Duc Chinh, 1972; Weirauch and Kung, 1973; but significant commercial productions from these laboratories have not been made known. One of the authors (AP) first became aware of the recent commercial production of hydrothermal rubies in Russia in 1991, due to personal communication from Russian scientists. Not later than February 1993, synthetic hydrothermal rubies began to

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appear as fine faceted materials; they were first seen on the market in Bangkok (Thailand) and were marketed by the Pinky Trading Company (Bangkok), which has a joint venture (TAIRUS) with the Russian Academy of Science (Siberian Branch, Novosibirsk). Through this joint venture synthetic materials are now produced in Novosibirsk (Russia) and marketed in Bangkok and elsewhere.

Fundamental research on the production of synthetic gemstones was earlier carried out by different research laboratories in Novosibirsk (see published reports: Institute of Geology and Geophysics, 1986 and the USSR Academy of Sciences, Siberian Division, Novosibirsk Science Centre, 1987 a,b). Several products developed at one or several of these research centres have become well known in the gem industry; these include synthetic flux alexandrites (Schmetzer *et al.*, 1996), synthetic flux spinel (Mühlmeister *et al.*, 1993), synthetic flux emeralds, synthetic hydrothermal beryls of different colours, synthetic hydrothermal emeralds (Schmetzer, 1996) and synthetic diamonds (Shigley *et al.*, 1993; *Gem News*, 1994).

The different institutes in Novosibirsk were visited by one of the authors (AP) in August 1994, following an invitation of the Russian Academy of Sciences (Siberian Branch) at the opening of a new TAIRUS production facility in Novosibirsk. During this visit, it was possible to study the production of hydrothermal rubies and sapphires in an older TAIRUS facility. It was also possible to discuss with the Russian scientists the research data presented earlier by Peretti and Smith (1993 a,b), fluid inclusion analyses from one of the authors (JM), and analyses of materials growing over the rubies (whitish crusts). All these early preliminary data were obtained from faceted materials acquired from the open market in Bangkok. More recent productions were purchased from the market in Bangkok in late 1996 (see also: Banker, 1996 and 1997).

Figure 1: *A set of faceted synthetic rubies produced by hydrothermal methods. From left to the right, different colour varieties are shown, including colours imitating Thai rubies (type 1 and type 2, Table I), Burmese rubies (type 3, 4 and 5) and Sri Lankan rubies (type 6 and 7). Sizes of rubies around 1 ct each, largest are 1.6 ct and smallest 0.2 ct. These products were created by TAIRUS (Novosibirsk, Russia) and purchased in Bangkok (Thailand).*

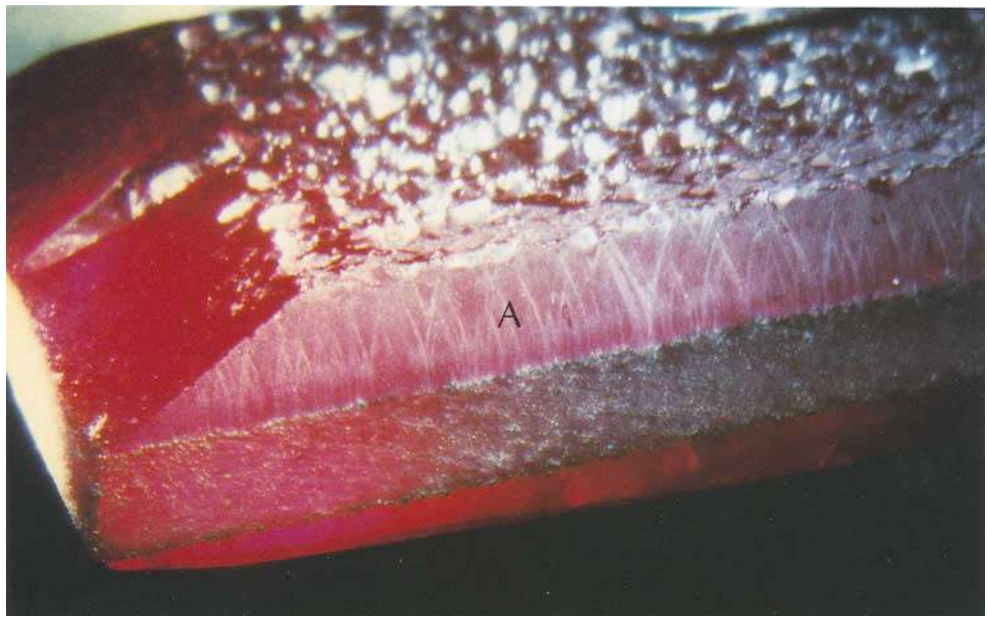

Figure 2: *Synthetic hydrothermal ruby of tabular habit. Note that the central portion of the rough synthetic ruby is covered with copper crystals and is produced by an earlier run (containing a very small colourless seed crystal, a slightly wedge-shaped plate which cannot be seen in this picture). A newly grown thick layer of synthetic ruby is overgrown. Note simultaneous growth in slightly different directions is created in the latest growth phase (see A). Thickness of the crystal is 5.5 mm.*

In a letter to the Editor of the *Journal of Gemmology* (Peretti and Smith, 1994), the distinction between synthetic rubies grown by flux and by hydrothermal methods was addressed. In this report, we concentrate on the inclusion properties of the hydrothermal synthetic rubies. A more detailed report on other gemmologically relevant properties, such as growth structures, chemical composition and the spectroscopic characteristics, will be presented in a successor to this paper (Peretti and Schmetzer, 1997, in prep.).

Materials

During 1993 and 1994, a series of rough and cut materials from different stages of corundum production were obtained through Pinky Trading Company in Bangkok. Prior to this, these kinds of rough materials were generally unavailable, but in February 1993 the authors were finally able to obtain three fragments of dark red rough, two containing very minor remnants of seed materials, and several faceted dark-red synthetic rubies.

In July 1993, two of the authors (AP and FM) obtained synthetic hydrothermal pink sapphires in Bangkok; they were marketed as the newest products with improved quality, particularly regarding the crystallinity of the materials, and weighed around 0.20 ct. Additionally, two rough fragments from production of synthetic hydrothermal dark-red rubies with whitish crusts and remnants of seed materials were acquired at that time.

The first complete crystals of synthetic hydrothermal dark red rubies with large variations in habit were studied at the Pinky Trading Company headquarters in Bangkok in 1994. Faceted synthetic rubies of various colours of approximately 1 ct (approximately 50 ct in total) were purchased in the second quarter of 1994 *(see Figure 1)*.

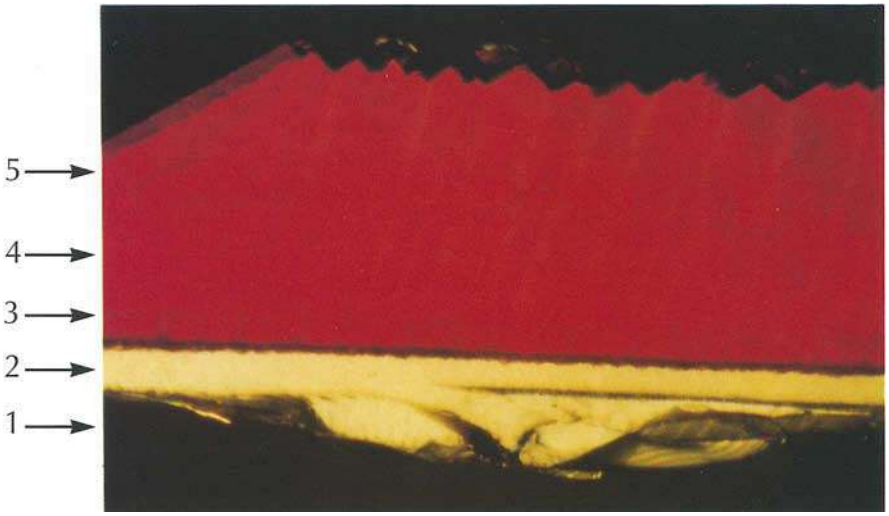

Figure 3: *Rough crystal with colourless seed and synthetic hydrothermal overgrowth. Note the irregular contact of the colourless seed with the synthetic ruby and the irregular ruby growth, the strong growth lines perpendicular to the seed crystal and the deposits of dust on the crystal on two different levels parallel to the seed crystal (phantoms of earlier growth stages). They are interpreted as indicating refilling of the autoclave and rerunning the experiments with the same crystals. In detail (from bottom to the top): the colourless seed crystal (1) is followed by synthetic white sapphire (2) and three synthetic ruby generations (3–5). Length of crystal section is 1 cm. Immersion, crossed polarizers.*

Figure 4: *A section through a rough crystal of a synthetic sapphire produced by hydrothermal methods (TAIRUS), cut perpendicular to the c-axis. The seed crystals are composed of Verneuil synthetic ruby overgrown by synthetic 'hydrothermal' white sapphire. Note the blackish irregular tubes that emerge in a direction perpendicular to the seed crystal within the synthetic sapphire portion of the rough crystal. Fluid inclusions are trapped in these tubes. Terminating crystal faces are prisms (11$\bar{2}$0). Diameter 1 cm. Transmitted light.*

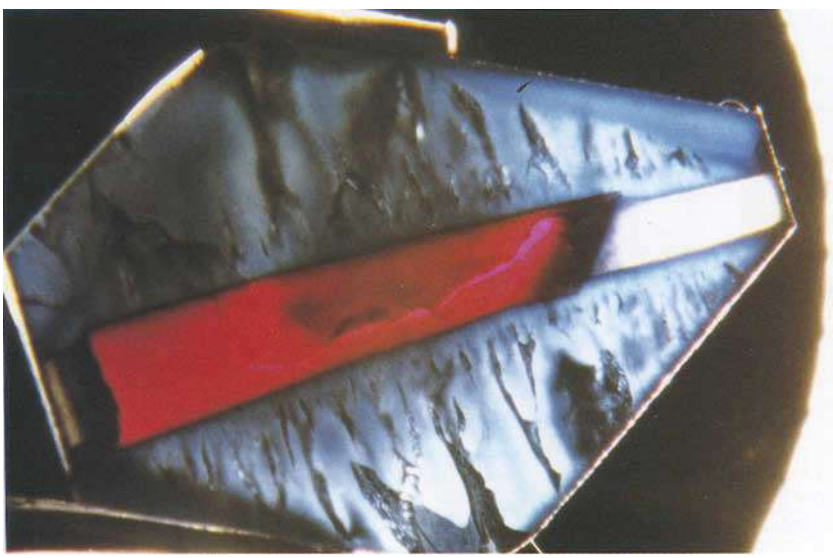

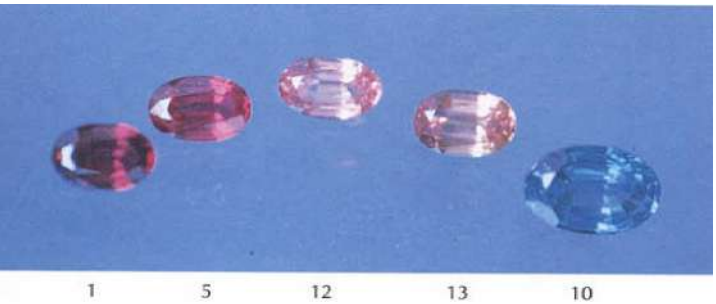

Figure 5: *Different types of synthetic rubies and sapphires produced by hydrothermal methods. From left to the right: approximately 1 ct each of dark-red and pinkish-red synthetic rubies (type 1 and 5, Table I), orangey-pink synthetic sapphire (imitating 'Padparadscha' colour) and orange synthetic sapphire (approximately 1 ct each, type 12 and 13, Table I) and a 2.65 ct large greenish-blue synthetic sapphire (type 10, Table I). TAIRUS products purchased in Bangkok.*

During our visit to the producing laboratory in Novosibirsk in August 1994, a range of complete synthetic hydrothermal crystals (mainly dark-red, *see Figures 2 and 3*) and synthetic hydrothermal sapphires were obtained for research purposes; these included first rough materials of synthetic hydrothermal dark blue sapphires *(Figure 4)* and synthetic pale-green sapphires produced by hydrothermal methods.

In December 1996 it was possible to purchase the newest production of various other hydrothermal synthetic corundums including rough orange synthetic sapphire (49.87 ct), faceted orange synthetic sapphire (1.18 ct), rough pinkish-orange synthetic sapphire (1.01 ct), and a newly manufactured intense greenish-blue sapphire (2.65 ct) *(Figure 5)*. Also, a large rough crystal of the intense greenish-blue sapphire was investigated in Bangkok.

Technical details of the production methods

A hydrothermal process for the production of synthetic corundum was patented by Bell Telephone Laboratories, US Patent 2,979,413; 1961 (see Ballmann *et al.*, 1961; Yaverbaum, 1980). This process may be summarized as follows.

A furnace and an autoclave *(Figure 6a)* consisting of a bomb tube without a liner or with one or two internal liners are used. The inner volume can be divided by a baffle into two chambers. The growing chamber contains seed crystals and the nutrition chamber contains solid nutrients, such as aluminium oxide, aluminium hydroxide or even crystalline corundum. Aqueous solutions with dissolved sodium carbonates are described as the most effective transporting media for dissolved alumina in the above literature. But other carbonates may be used as well *(Figure 6b)*.

The furnace produces the necessary heat and temperature gradients between the two chambers in order to create a convection current for the transportation of dissolved

Figure 6a: *The steel autoclave used for the production of the synthetic hydrothermal rubies in Novosibirsk (Siberia, Russia) in 1994. The weight of the autoclave is about 25 kg, the length is about 50 cm, the inner diameter is about 3–4 cm with slightly smaller estimated thickness of the steel walls. Inner liners of gold or platinum are fitted for production of Fe-free products, but their use is rare.*

alumina to the crystal seed located in the lower temperature chamber. Critical parameters for the growth of hydrothermal rubies include the nature of the mineralizer, the shape of the seed, the crystallographic orientation in the seed, the chemical composition of the aqueous solutions, the temperature gradients, the absolute maximum temperatures and the pressures reached in the autoclave. Such technical details as the permeability of the baffle and the volume of the autoclave filled by aqueous solutions (filling grade) must also be considered. The chemical composition of those parts exposed to the corrosive solutions is also critical. It may be necessary to cover the autoclave with precious metals such as silver, platinum or gold. Because the solutions will corrode iron, plating the interiors may be preferred if iron contamination of the growing crystals has to be minimized.

Recrystallization of pure aluminium oxide (corundum) under hydrothermal conditions is relatively easily carried out in solutions of alkali-metal-carbonates and bicarbonates (e.g. Na_2CO_3, K_2CO_3, Rb_2CO_3, $NaHCO_3$, $KHCO_3$). However, the formation of ruby, which also requires a solubility of chromic oxide in the same solutions, is much more difficult (see Kuznetsov and Shternberg, 1967). Ruby formation was, for example, successfully carried out in KCO_3- and $KHCO_3$- rich solutions by Kuznetsov and Shternberg (1967). Variations in the Cr_2O_3 concentrations were investigated by variations in other ingredients such as $KClO_3$, K_2SO_4, C_6H_6, and various hydroxides (Kuztnetsov *et al.*, 1968). Ballmann and Laudise (1963) have reported the production of rubies in aqueous solutions by adding sodium dichromate.

Table 1. *Characterization of different colour varieties of synthetic rubies and sapphires produced by hydrothermal methods on the basis of colour appearance, comparison with colours of natural rubies and UV-fluorescence. (Refractive indices as for other synthetic or natural equivalents.)*

Type	*Colour*	*Fluorescence under 365 nm radiation*	*Imitating*	*Remarks colouring trace elements**
1	very dark-red	weak red	Umba Valley (African) ruby	Cr very high, Fe high
2	dark red	medium red	Thai ruby	Cr high, Fe medium
3	intense red	strong red	Burmese ruby	Cr very high, Fe low
4	red	strong red	Burmese ruby	Cr high, Fe low
5	pinkish red to red	very strong red	Burmese ruby	Cr high, Fe free
6	purplish-pink	medium red	Sri Lankan purplish-pink-sapphire	Cr medium, Fe medium
7	pink	medium red	Sri Lankan pink sapphire	Cr low-medium, Fe medium
8	dark-blue	none	Thai or Australian sapphire	Fe very high, Ti low
9	pale greenish-blue	none	no equivalent	Ni low, Fe low
10	intense greenish-blue	none	no equivalent	Ni medium, Fe low
11	pale-green	none	no equivalent	V medium, Fe low
12	orangey-pink	medium-strong red	Sri Lankan 'Padparadscha' colours	Cr low, Fe low
13	light orange	medium red	Sri Lankan 'Padparadscha' colours	Cr very low to low, Fe low

N.B. 1. values in last column: low = 0.05–0.15, medium = 0.15–0.50, high = 0.5–1.0, very high = 1.00–2.00 oxide wt-%. 2. types 9 and 11 only seen as rough materials. 3. *for more details see Peretti and Schmetzer (in prep.)

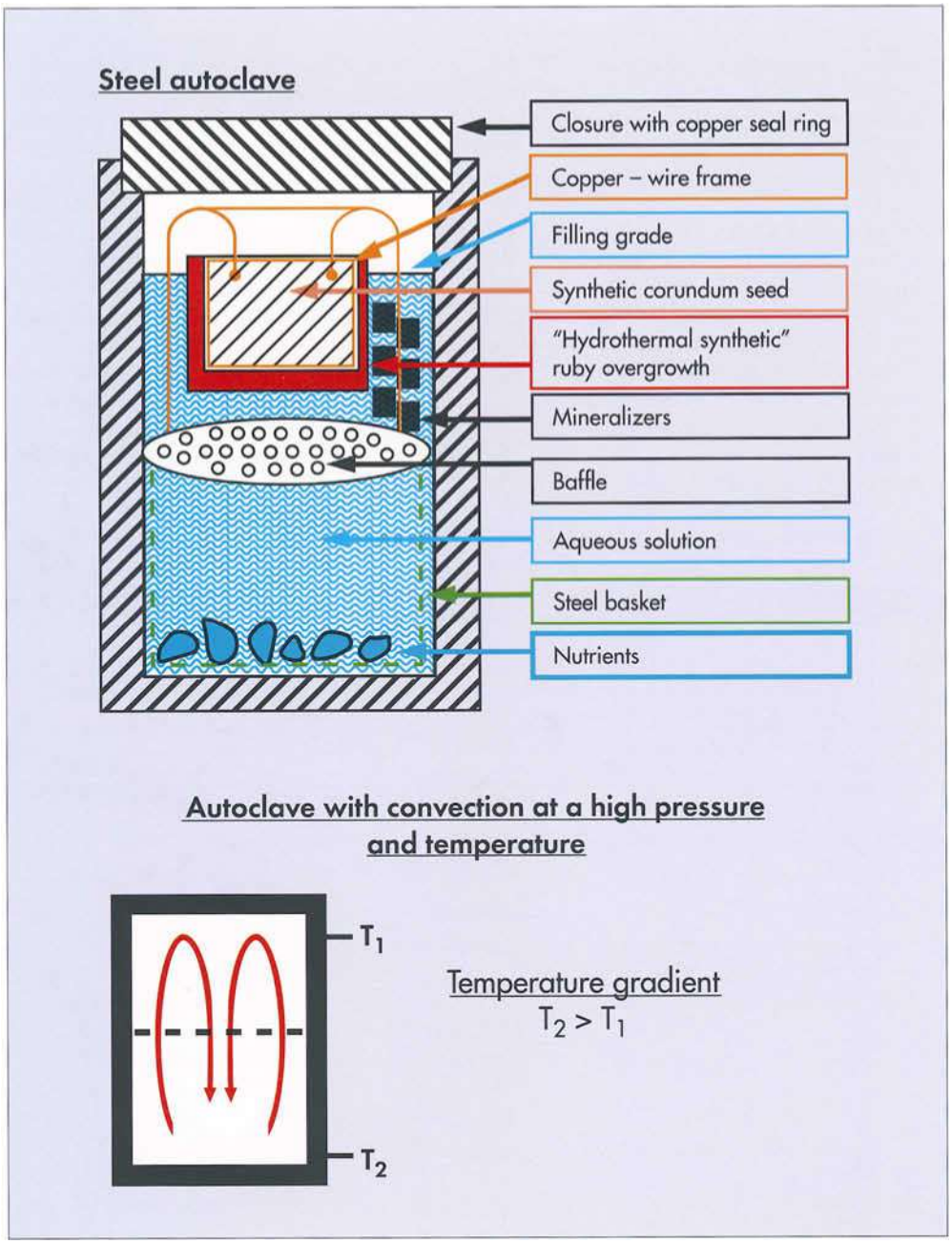

Figure 6b: *Simplified diagram of an autoclave used for producing hydrothermal synthetic ruby (after Ballmann* et al.*, 1961). Quantity of aqueous solution is indicated by the stippled area (filling grade). On heating, the solution will homogenize and fill the autoclave and above a certain temperature will produce internal pressure. Convection in the autoclave is produced by a temperature gradient. Mineralizers such as carbonates or chlorides are used to form metal complexes with Al and Cr-bearing nutrients and these can be transported to seed crystals in aqueous solutions. (Graphics by D. Mathys.)*

Visual appearance

The stones in this study possessed colours reminiscent of natural rubies from Thailand, Sri Lanka, Burma and Vietnam. The red hue of the synthetic rubies consisted of variable saturations, with tones ranging from medium to dark *(Figure 1, Table I)*. Orange and pinkish-orange synthetic sapphires imitate quite well the natural 'padparadscha' sapphires. The intense greenish-blue sapphires do not have natural colour equivalents *(Figure 5)*. Dark-blue colours are very similar to those natural counterparts which are found for example in Thailand, Australia or Vietnam (basaltic sources) (see also Bank *et al.*, 1996). The synthetic sapphires of weak greenish colours show a colour change to purplish-violet in tungsten light.

As described by Peretti and Smith (1993 a,b), some stones had a reduced transparency which had the effect of making the sharp facet edges of the pavilion appear diffuse when viewing the stones face-up. This effect was reduced in more recent productions which were characterized as 'Burmese-type colour' synthetic rubies or as 'Sri Lankan type colour' synthetic pink sapphires *(see Table I)*. No macroscopic colour zoning was present.

Inclusion analysis

A. Coatings on rough synthetic rubies and sapphires

Whitish crusts were found on different types of synthetic hydrothermal rubies and synthetic hydrothermal sapphires, mostly concentrated in indented naturals *(Figure 7)*. They were chemically analyzed by SEM-EDX using a Philips SEM 515 and a Jeol JSM6300F electron microscope at the University of Basel. The samples were coated with gold or carbon and the acceleration voltage mostly used was 20keV.

It was found that the whitish crusts have at least two different compositions:

1. *well crystallized materials* consistent with an Al-hydroxide and identified as boehmite *(see Figure 8a)* by X-ray determinations and
2. *irregular flakes or grains of amorphous appearance* and complex chemical compositions *(Figure 8b and Table IIa)*, (most probably *non-crystalline gel-like materials*). These irregular grains were formed on the top of the Al-hydroxides.

The chemical compositions of these minor amorphous or gel-like materials were determined by SEM-EDX-analysis and consisted of various combinations of the elements sodium (Na), calcium (Ca), potassium (K), carbon (C), oxygen (O), silicon (Si), barium (Ba), iron (Fe), copper (Cu), sulphur (S), chlorine (Cl), aluminium (Al) and phosphorus (P). Different particles of highly complex chemical compositions were found as overgrowths on different synthetic ruby generations *(Figures 8a, b and Table IIa)*.

These crusts are interpreted as depositions from oversaturated hydrothermal solutions, most probably formed at the end of the hydrothermal runs during cooling (*see Figures 8a, b*). Corundum is thermodynamically stable in alkaline aqueous solutions above 400°C rather than diaspore (see Ballmann and Laudise, 1963). During cooling, however, diaspore or boehmite can be formed and may

Figure 7: *Synthetic rough rubies of two different varieties as defined in Table I (type 5 on the left and type 2 on the right side). Both rubies are coated with whitish crusts, which are deposited at the end of the hydrothermal runs. The rough fragment on the left shows in addition relicts of copper-wires which are used for the mounting of the seeds in the autoclaves.*

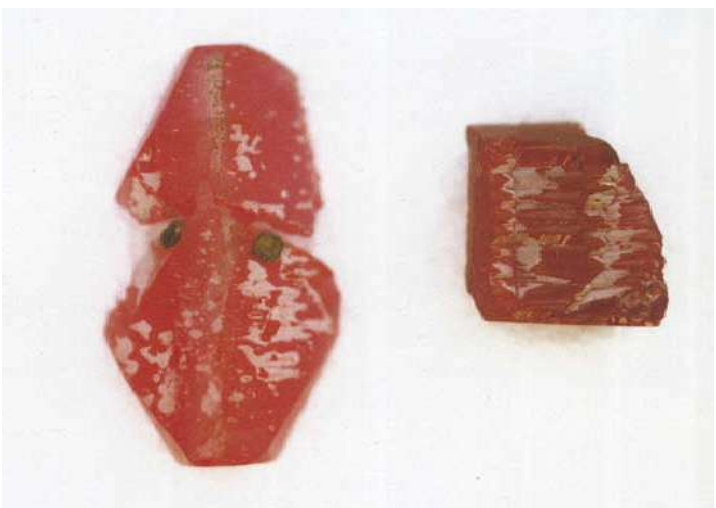

be precipitated on the surface of rough synthetic rubies and sapphires.

Based on the analyses of different generations and varieties of the synthetic materials by XRF-EDX as well as SEM-EDX *(Table IIa, b)*, it is concluded that different compounds were used during the production of hydrothermal ruby. The different chemical compounds may have been used (see Ballmann and Laudise, 1963; Kuznetsov and Shternberg, 1967; Kuznetsov *et al.*, 1968), for such purposes as:

- the joint transportation of aluminium and chromium in the solutions
- the production of different colour varieties
- optimizing the growth rates for commercial reasons
- optimizing the crystal habit

B. Solid inclusions in synthetic rough and faceted rubies

Different types of solid inclusions were found in rough as well as faceted materials

Figure 8: *SEM-images of the whitish crusts (synthetic hydrothermal ruby, types 2 and 12, Table I). Samples are gold-coated. The particles are mainly composed of boehmite with minor overgrowth of very poorly crystallized particles. Details: a) Well crystallized boehmite on the surface of a rough synthetic sapphire created by TAIRUS and a SEM-EDX-spectrum. b) Example of a Cu-chloride particle and poorly crystallized chloride-carbonate particles found in the crusts and their SEM-EDX spectra (see Table IIa).*

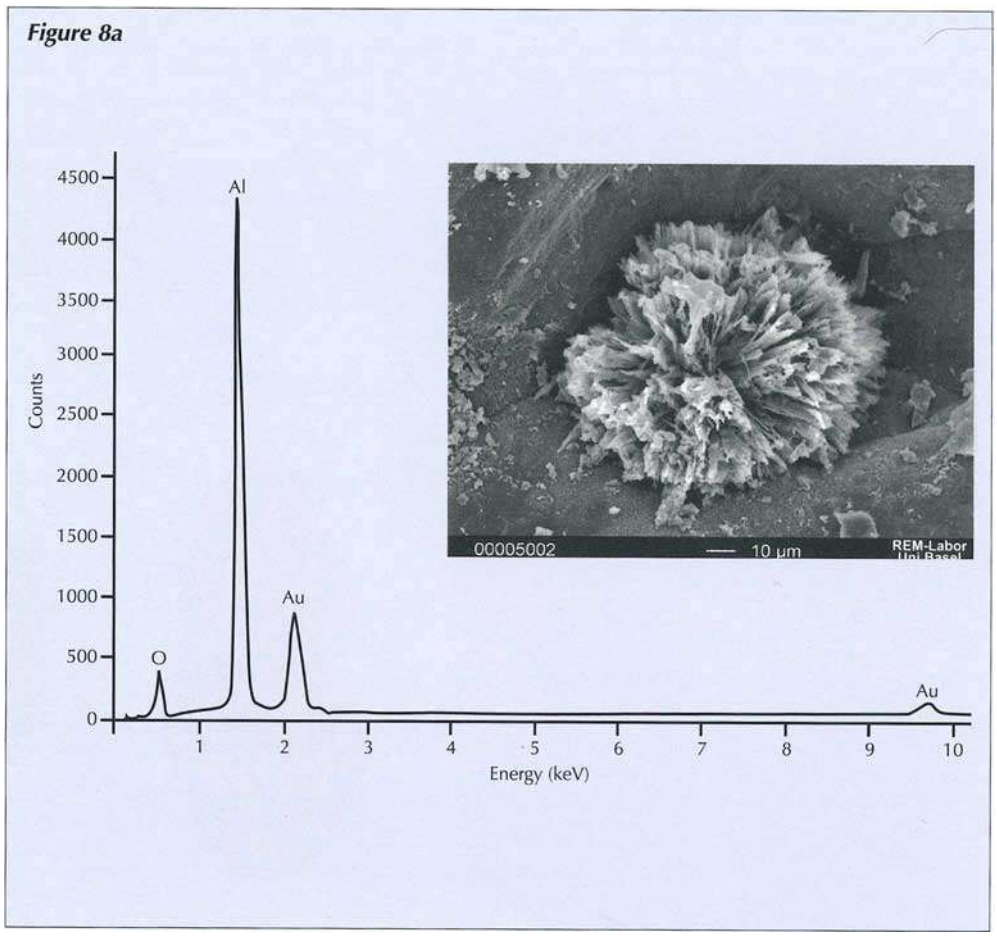

Figure 8b

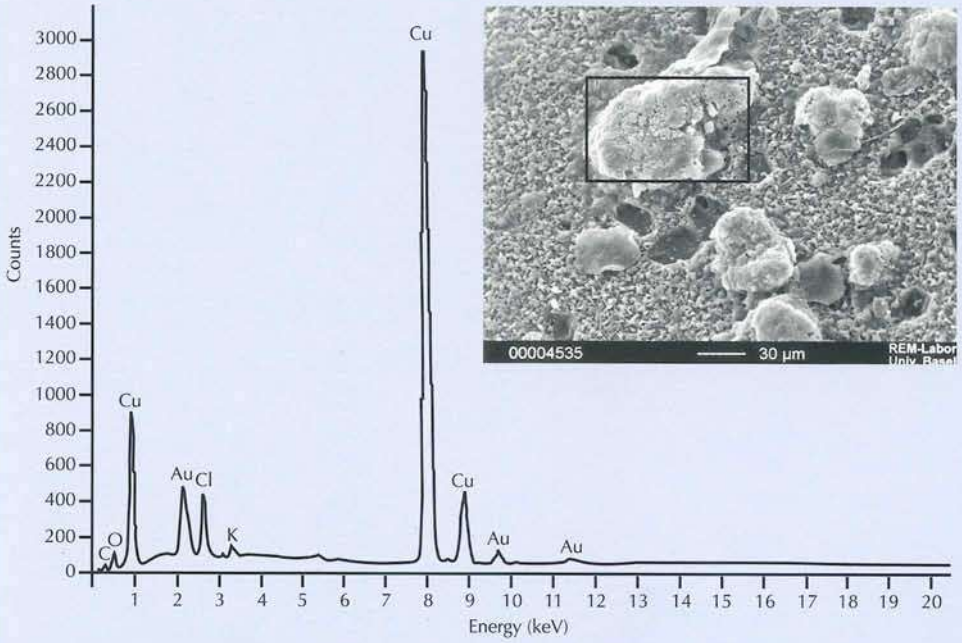
Counts
Energy (keV)
Cu
Cu
Au
Cl
K
O
C
Cu
Au
Au
00004535
30 µm
REM-Labor
Univ. Basel

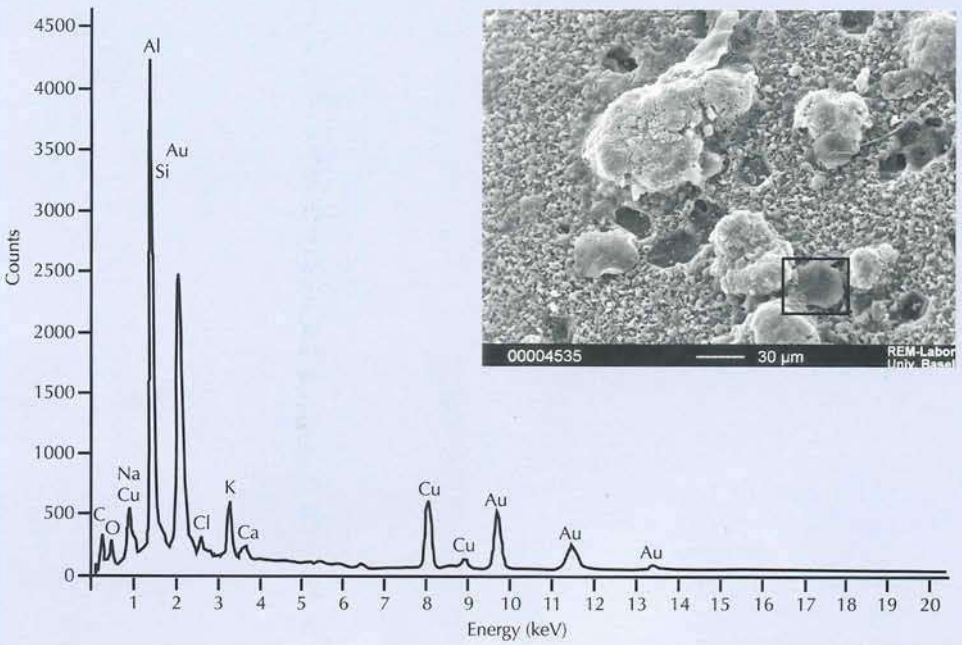
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Table IIa. *Chemical analyses of whitish crusts covering synthetic rough hydrothermal rubies (products of TAIRUS). Qualitative SEM-EDX analyses of isolated 'gel-like' particles found on the surface of various rough synthetic ruby and sapphire materials.*

Colour	Type	C	O	Al	Na	K	Ca	Cl	Mg	Ba	Si	S	Cu	Fe
Orangey-pink	13	x	x	x	x	x	x	x			x			
Pinkish-red	5	x	x	x	x	x		x		x	x		x	
(Figure 7 left)	5	x	x	x		x	x	x	x		x			
Red	2	x	x			x	x				x			x
(Figure 7 right)	2	x	x	x		x		x						x
Intense red	2	x	x	x	x	x	x					x		

Table IIb. *Semi-quantitative analyses of crusts by XRF-EDX using a Tracor Northern TN5000 system at the University of Basel (Prof. W. Stern). Carbonates, hydroxides, chlorides and other substances may contribute to the analyses.*

Sample (ct)	Colour	Type	K	Na	Ca	Si	Cl	S	P
53.56	orangey-pink	13	x	(x)	x		x		
37.47	red	2	x	x	(x)	x	x	x	x
1.15	red	2	x		x		x	x	
1.48	red	2	x		x	x	x		
1.31	red	2	x	(x)	x		x		
2.4	red	2	x	x	(x)		x		
1.52	red	2	x	x	(x)	x	x		
1.29	red	5	x	x	x		x		
5.35	red	2	x	(x)	(x)	x	x		

(x) = relatively minor concentrations

and characteristic opaque solid inclusions have been found in all the different colour varieties.

Irregularly shaped, highly reflecting opaque inclusions

Remnants of copper-wires, strongly corroded by the hydrothermal solutions, were found in rough ruby crystals *(Figures 7, 9 and 10)*. These fragments were of irregular shape and may be found as inclusions in faceted synthetic ruby (Peretti and Smith, 1993a,b). Some of the corroded fragments were composed entirely of copper (Cu), but others also had minor amounts of iodine (I) and sulphur (S) (Peretti and Smith, 1993 a). Copper chlorides were found as corrosion products on copper wires *(see Figures 8b and 9)*.

Figure 9: *Corroded copper wires are found as relicts in rough synthetic hydrothermal rubies (type 5, Table II). In addition to this diagnostic feature, characteristic whitish crusts are present. Corroded fragments of the copper wires are included in the synthetic ruby crystal near the copper wires (e.g. copper-chlorides). Diameter of copper wire is approximately 1.5 mm. Fibre optic illumination, reflected light.*

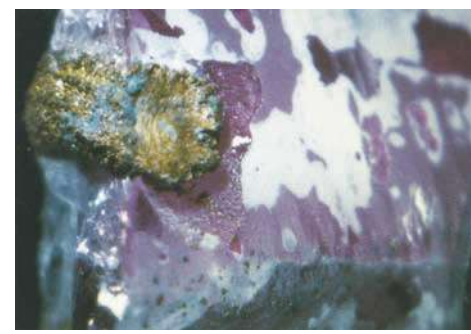

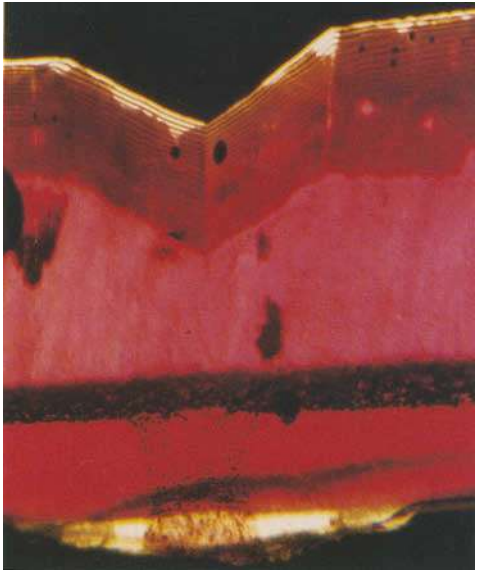

Figure 10: *Section through synthetic ruby rough with the following characteristics from bottom to top: synthetic white corundum seed, first generation of synthetic ruby with cloud of copper inclusions, second generation of synthetic ruby (cloud of copper inclusions discordantly cut off). Note that copper inclusions in the ruby are concentrated at the contact to the previously present copper-wires. The different colour concentrations of the synthetic ruby were most probably produced in different runs.*

Idiomorphic highly reflecting opaque inclusions

Another type of copper inclusion is composed of well shaped isometric crystals or hexagonal platelets consisting predominantly of copper (Cu) with minor amounts of iron (Fe), nickel (Ni), titanium (Ti) and chromium (Cr) (Peretti and Smith 1993a,b). Large amounts of copper crystals were found at the initial stage of the ruby growth at the seed contact *(Figures 2, 11, 12 and 13)*. Isolated single crystals with this type of copper inclusion or cloud can be found in the crystal during later growth phases.

Other solid inclusions

In addition to the various types of copper inclusions, whitish reflecting particles the size of pinpoints were found. They appear as clouds of isolated pinpoints or occur as linear series of pinpoints (especially in the pinkish synthetic products). Extremely small needles, as yet unidentified, have also been detected in these areas. Larger whitish particles are found in the intense greenish-blue synthetic sapphires.

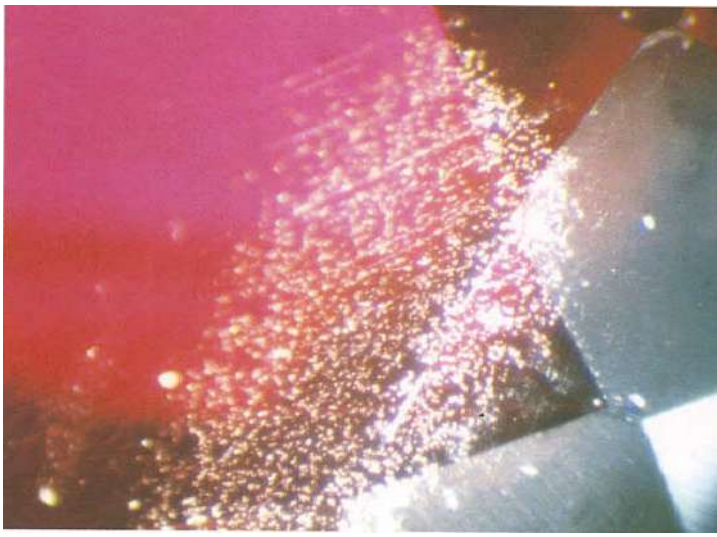

Figure 11: *Solid inclusions in a faceted synthetic hydrothermal ruby occurring as dense clouds. They occur as enrichments parallel to the original seed crystals. In this sample the seed has been cut off during faceting and only the copper enrichments close to the original seed crystal remain. Transmitted and reflected light. Fibre optic illumination. Magnification 75x.*

Figure 12: *Contact zone between a colourless synthetic sapphire seed and the overgrown synthetic hydrothermal ruby. Note the presence of opaque solid inclusions which are concentrated at the initial growth phase of the synthetic hydrothermal ruby close to the seed crystal. Magnification 120x. Transmitted light.*

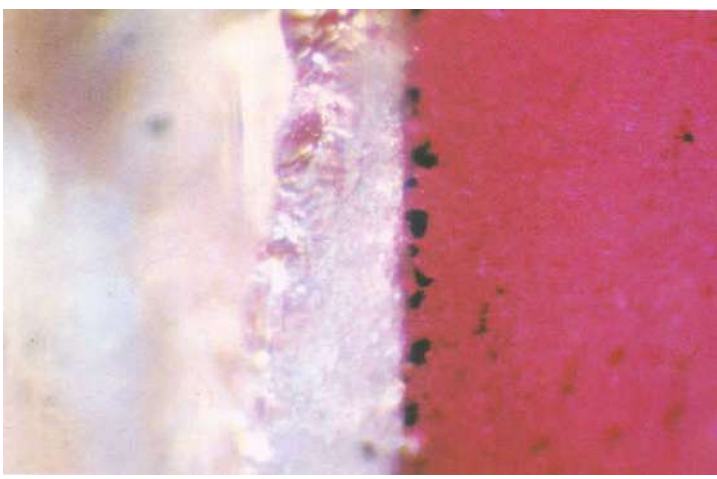

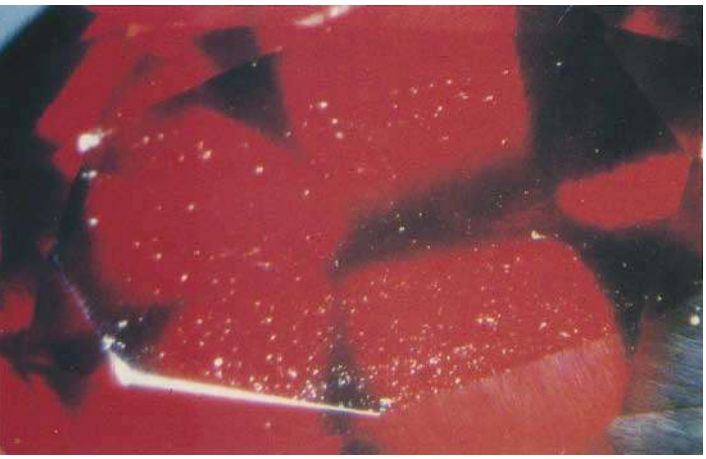

Figure 13: *Isolated copper inclusions in a synthetic hydrothermal ruby. Transmitted and reflected light. Classification of material as type 1 (Table I). Note also the diffuse facet edges as seen through the crown. This is due to irregular growth structures which are present in the rubies.*

Figure 14a: *Series of partially healed cracks in a rough ruby (polished thick section). Reflected and transmitted light, fibre optic illumination. Length of shown portion of the crystal is 5 mm (type 5, Table I).*

Figure 14b: *Partially healed crack extending into the colourless synthetic sapphire seed (polished thick section). Reflected and transmitted light, fibre optic illumination. Length of shown portion of the crystal is 3 mm (type 4, Table I).*

Figure 14c: *Fluid inclusion feather with trapped aqueous solutions in a faceted synthetic pink sapphire (type 7, Table I). In larger cavities, three-phase inclusions can be identified (see Figures 16 to 18). Note the irregular shape and the isolated occurrence of the single tubes and the similarity of the appearance of this type of fluid inclusion feathers with those found in natural rubies. Weight 0.22 ct, immersion, crossed polarizers, magnification 200 x.*

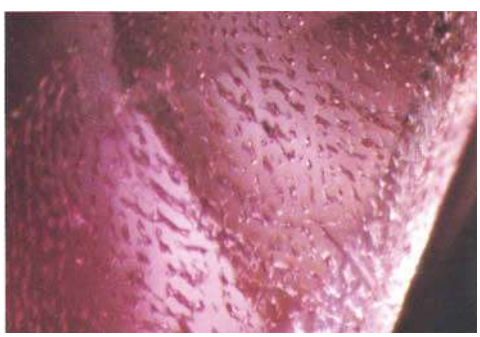

Figure 15: *Large negative tubes found in faceted synthetic 'hydrothermal' ruby (type 5, Table III). Note the irregular walls of the tubes. Weight of ruby is 0.95 ct, magnification 100 x, transmitted and reflected light, fibre optic illumination.*

Figure 16a: *Three-phase inclusion in a negative crystal of a faceted synthetic hydrothermal ruby of 0.95 ct (type 5, Table III). The three phases are composed of H_2O liquid, H_2O vapour and a solid crystal (most probably a calcium-carbonate). Transmitted light, fibre optic illumination, magnification 200 x.*

Interpretation

The origin of the copper inclusions lies in the dissolution and corrosion of copper materials used in the autoclave, such as seals and copper wires *(Figure 7)*. The contamination of copper crystals by Fe and Ti may originate from other ingredients in the solutions or from corrosion of the steel autoclave. This is confirmed by the presence of Fe-chloride particles on the surfaces of some rough synthetic rubies.

The whitish particles are interpreted as resulting from contamination from the mineralizers, such as alkali-carbonates or calcium-carbonates.

Figure 16b: *Three-phase inclusion of Figure 16a as seen in immersion with crossed polarizers. The solid phase is more clearly visible because it is birefringent.*

C. Fluid inclusions

In the early production of synthetic hydrothermal rubies, healed fracture systems resembling fingerprint inclusions were observed (Peretti and Smith, 1993a, b). Such fingerprint inclusions also occurred in later productions of different crystalline quality and colour *(Figures 14c and 15)*. Series of partially healed cracks occur in rough samples *(Figure 14a)* and some extend into the seed materials *(Figure 14b)*. This indicates that synthetic rubies were intentionally thermally shocked to produce fractures which were later repaired hydrothermally (see Koivula, 1983). In the pinkish-red to red synthetic hydrothermal rubies (Burmese-type imitations) more recently purchased (1994), however, relatively large three-phase inclusions were detected. These are composed of a liquid, a vapour and a solid daughter mineral *(Figures 16a, b)*. The three-phase inclusions are associated with the formation of large tube-like negative crystals *(Figures 4 and 15)*. Optical testing in

Table IIIa. *Phase transformations observed during the heating and freezing runs on two different samples A and B with different fluid populations (FP)*

Sample No.	Fluid Inclusion Population	Inclusion Type	Number of inclusions studied	V(%)	Temperature of first melting	Melting temperature of ice	T (melt, solid II)	T (hom)
A	1	I, II	10	10–12	–22	–5.9 –6.0; –5.8	44	346 345; 347
B	1	I, II	14	10–15	–22	–6.1; –6.2; –6.0	51; 50; 52	decrepitated
	2	I, II	16	10–15	–12	–5.2 –5.4; –5.0	50	363 359; 367
	3	I, II	7	10–15	–13	–5.4 –5.4; –5.3	36 36; 38	357 356; 358

Inclusion type — I: primary fluid inclusions; II: secondary fluid inclusions
V% — Volume % of the volatile part at room temperature
Melting temperature of ice (°C). — First number: mean value; second and third number: extreme values
T (melt, solid II) — Temperature of salt melting of solid II
T (hom) — Homogenization temperature of fluid inclusions (°C) to the liquid phase

Table IIIb. *The derivation of the chemical composition based on the observed phase transformations of ruby type 5 (Table I) on two different samples A and B.*

Sample No.	Fluid population	NaCl (wt%) a	KCl (wt%) b	$Na_2CO_3H_2O$ (wt%) c	$KHCO_3$ (wt%) d	$CaCO_3$ (wt%) e
A	1	9		32	32	3–6
B	1	9 equiv.		33	35	3–6
	2	0	8		34	3–6
	3	0	8		30	3–6

a NaCl is derived from T melt (ice) (at T eutectic of –22°C) as NaCl-equivalent after Potter *et al.* (1978)
b KCl is derived from T melt (ice) (at eutectic of –13 to –12°C) after Schäfer and Lax (1962)
c $Na_2CO_3 \cdot H_2O$ appears as yellow crystals after cooling. Its T (eutectic) is –2.1°C ($Na_2CO_3 \cdot H_2O$) lowering slightly the eutectic of NaCl from –20.8 to –22°C
d $KHCO_3$ appears as violet crystals within fluid inclusions after cooling down to –120°C. Its T (eutectic) of –5.43°C lowers slightly the T (eutectic) of KCl from –10.6°C to about –13°C
e Small anisotropic white solid crystals of 2–4 vol.%, which are insoluble at T of 400°C, are interpreted as $CaCO_3$ (density of 2.6–2.8 g/cm^3)
All data after Schäfer and Lax (1962) if not otherwise stated

immersion liquids under crossed polarizers showed that the daughter minerals are optically anisotropic *(Figure 16b)*, which is consistent with their identification as carbonates (see freezing/heating experiments).

In order to obtain further information on the chemical composition of the fluids and to further identify the solid daughter minerals within fluid inclusions, fluid inclusion analyses were carried out using a Chaixmeca freezing and heating stage mounted on a transmitted light microscope, designed to work in the range of –180°C to 600°C (Poty *et al.*, 1976). After freezing to –120°C, the inclusions were slowly heated at a constant rate of 1–2°C/min. Temperatures were calibrated with the triple points of distilled water (0.0°C) and various chemicals of high purity (hexane and pure CO_2-bearing fluid inclusions). Calibration at high temperatures was made with appropriate chemicals from the Merck Corporation. The uncertainty of the measurements was about ±0.1°C for –60 to

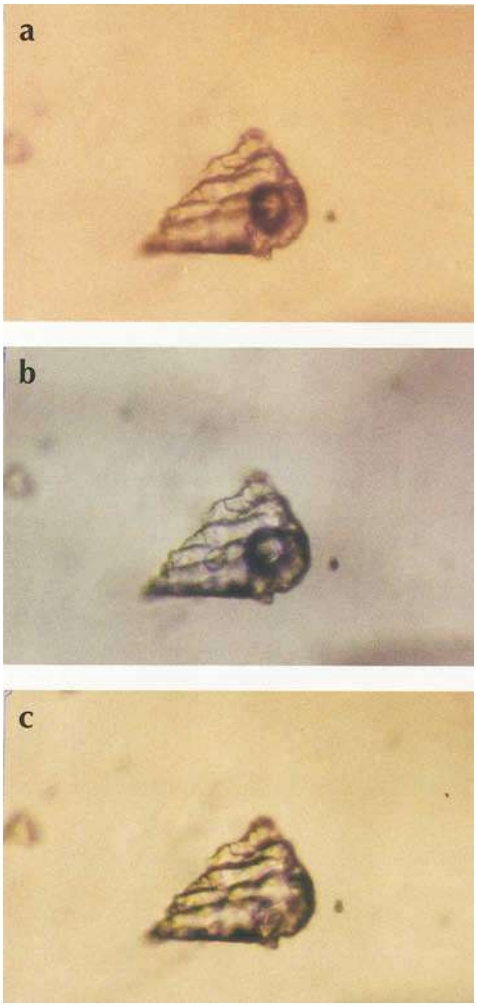

Figure 17: *Microphotograph of a three-phase inclusion at different temperatures. Inclusion found in a synthetic hydrothermal ruby of 0.64 ct (type 2, Table I). Transmitted light, picture length is 270 µm. Three temperatures are selected as examples (a–c). a) At –100°C. the inclusion at this temperature is composed of probably calcite, ice and H_2O vapour. The vapour bubble is deformed (compare with Figure 17b) due to the expansion of ice during freezing. b) At +30°C; at this temperature the inclusion is three-phase with solid phases (carbonates), a liquid phase (H_2O-rich) and a vapour phase (H_2O). c) At +350°C; the inclusion at this temperature is composed of a homogeneous liquid aqueous solution with a calcite daughter mineral (not visible here, see Figure 16b).*

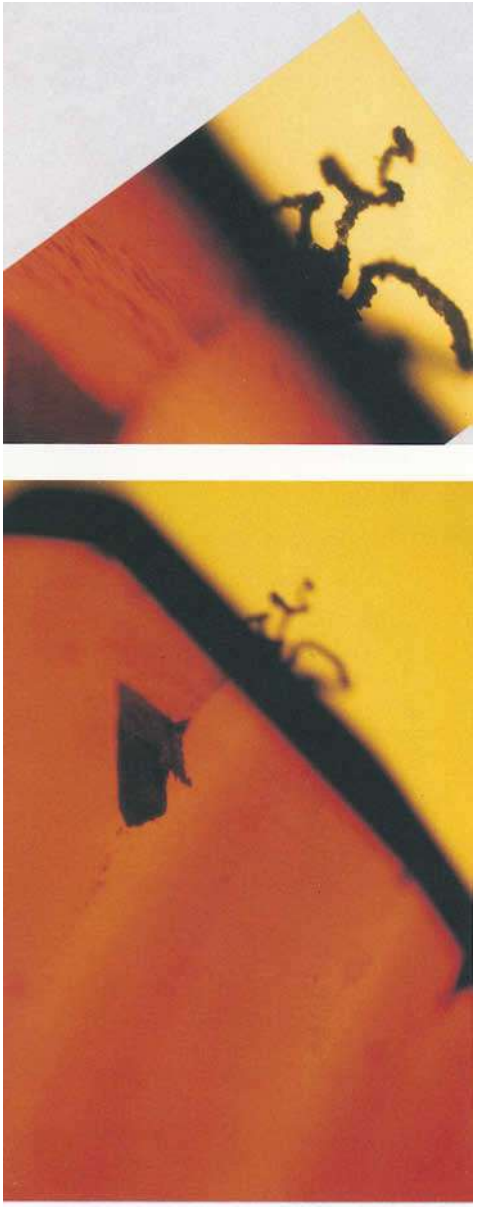

Figure 18a: *Thin section of a faceted synthetic ruby with fluid inclusion and after fluid inclusion analyses. The 'worm-like' solid materials on the surface of the ruby were formed from decrepitation of fluid inclusions during heating above 300°C, the escape of the fluids to the surface after decrepitation, the immediate drying of the aqueous solutions and the contemporaneous crystallization of the original dissolved materials.*

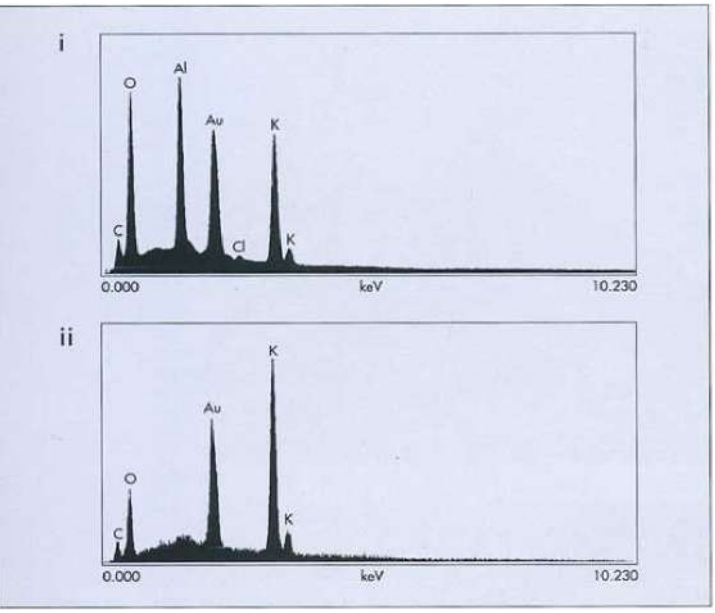

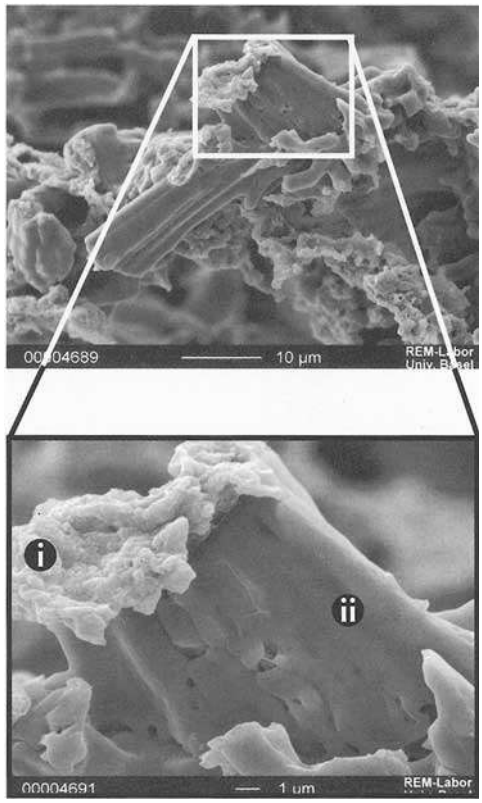

Figure 18b: *The chemical analyses (SEM-EDX, Au coating) in combination with fluid inclusion analyses showed that the worm-like aggregates formed after decrepitation are composed of: 1) about 90 per cent potassium bicarbonate ($KHCO_3$) and 2) about 10 per cent of potassium aluminium carbonate.*

40°C and ±1°C outside this range. Two faceted ruby samples were cut and polished to obtain parallel plates suitable for quantitative microthermometric investigations.

The results are given in *Table II*. In sample A *(Table III)*, only one fluid inclusion population was detected, whereas in sample B, three different inclusion populations could be recognized. The earliest inclusion population (1) in every ruby sample contains a NaCl-dominated fluid with 9 wt-% NaCl equivalents and 32 to 35 wt-% $NaCO_3 \cdot H_2O$ or $KHCO_3$. Fluid inclusion populations 2 and 3 of sample B are characterized by 9 wt-% KCl and 30 to 34 wt% $KHCO_3$. In addition fluid inclusions of every population contain 3 to 6 wt% of calcite as small daughter minerals. Complete microthermometric results are given in *Table III* and are discussed in detail below.

Example of a heating and freezing run and observed phase transformations in a synthetic ruby sample (Figures 17a–c and 18c)

1. At room temperature, a H_2O-vapour and a solid 'I' (daughter mineral) are present;
2. –120°C: ice, water-vapour and a second violet daughter mineral are present (see deformed gas bubble, *Figure 17a*);
3. –12°C: first melting of the ice;
4. –5,2 ± 0.2 °C: final melting of the ice; the two daughter minerals are still present *(Figure 17b)*;
5. +50°C: melting (i.e. dissolution) of the violet solid daughter minerals (solid 'II');
6. above 60°C: the multiphase inclusion, as seen at lower temperatures, has been transformed to a 3-phase inclusion (liquid and vapour of H_2O and solid 'I');

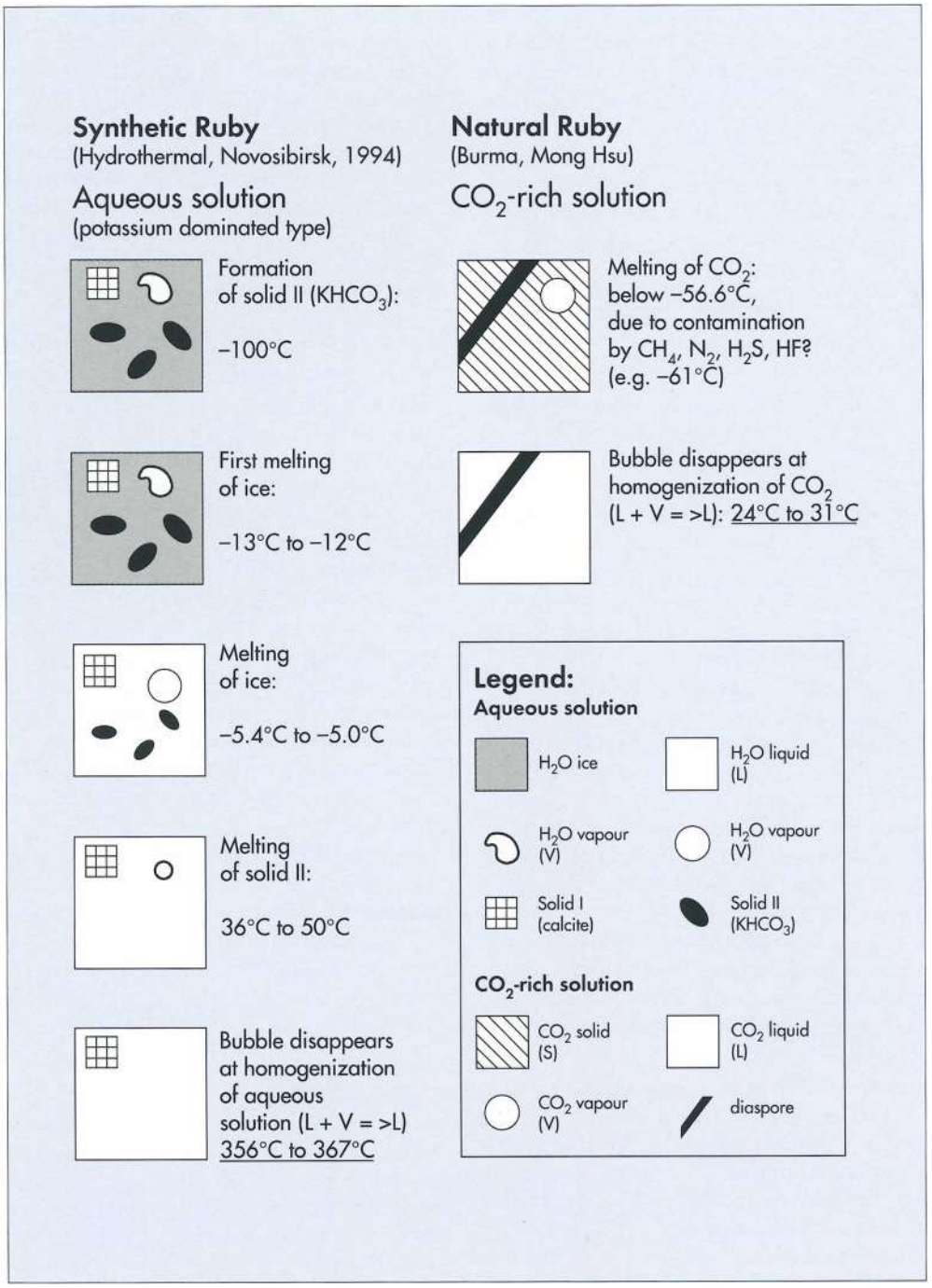

Figure 18c: *Comparison of phase transitions in fluid inclusions during heating and freezing experiments in two selected types of synthetic (left) and natural rubies (right). Solid II crystals were generated by cooling down to very low temperature liquid nitrogen. Note characteristic differences in the homogenization temperatures (bubble disappearance).*

7. +363 ± 4°C: homogenization of the vapour bubble with the aqueous phase (liquid + vapour = liquid), *Figure 17c;*
8. one fluid inclusion of one population decrepitated at this high temperature and the liquid was released through a small crack to the surface *(see Figure 18a);* solid 'II' crystallized during cooling on the surface of the ruby (SEM-EDX analyses *see Figure 18b*).

Phase transformations and reconstruction of chemical composition

Other types of phase transitions were found and are summarized in *Table III;* these indicated that different types of solid 'II' crystals could be created in the fluid inclusions during freezing. The chemical compositions of such solid 'II' crystals were reconstructed according to ideas described by Schäfer and Lax, 1962.

The fluid inclusion phase transition temperature measurements permit the following interpretations:

Where first melting of ice takes place between –12 and –13°C the fluids are interpreted as KCl-dominated (T eutectic of $KCl–H_2O$ = –10.7°C) and where the first melting takes place at –22°C the fluids are interpreted as NaCl- dominated (T eutectic of $H_2O–NaCl$ = –20.8°C). The amount of dissolved KCl and NaCl is 8 and 9 wt.% respectively *(Table III).*

Because of the presence also of such minerals as $Na_2CO_3 \cdot H_2O$ and $KHCO_3$ the first melting temperatures of $KCl–H_2O$ and $NaCl–H_2O$ are slightly lower than those of the pure binary systems.

The melting of the daughter minerals at 51 ± 1°C in the potassium dominated fluid indicates that they are $KHCO_3$, as its eutectic temperature lies above the observed eutectic temperature of –12 and –13°C at –5.43°C (Schäfer and Lax, 1962). K_2CO_3 is less likely as a possible daughter mineral 'II', as its eutectic temperature lies at –36°C, and there was no evidence of transition at this temperature.

The solid 'II' of a decrepitated fluid inclusion from population No. B2 *(Table III)* was analyzed by SEM-EDX-analysis and the results are consistent with our conclusion that the solid 'II' (daughter mineral) is $KHCO_3$. A mixture of a 90 vol.% potassium carbonate and of only approximately 10 vol.% K–Al–carbonate was found *(see Figure 18 b).* As the aqueous solutions in both fluid populations 1 of both crystals are sodium dominated, the chemical composition of daughter minerals 'II' is therefore interpreted as $Na_2CO_3 \cdot H_2O$ but $KHCO_3$ and a mixture of both cannot be excluded without direct chemical analyses (Table IIIb). Other hydrates of Na_2CO_3 are unlikely because the observed volume of solid 'II' at room temperature is much smaller than would be expected for such as $NaHCO_3$ (compare Rankin, 1975).

The solid 'I' crystals, which were present in fluid inclusions at room temperature and which were not grown by repeated heating and freezing experiments within the fluid inclusions, were not transformed during heating to over 400°C. They are anisotropic and are interpreted as $CaCO_3$, a conclusion supported by the traces of calcium found during XRF-analyses of the faceted rubies.

The heating runs showed that the fluid inclusions from all populations were homogenizing to the liquid phase (liquid + vapour = liquid) between 345° and 367°C, which proves that the liquid phase consists of aqueous solutions.

Combining the information from the heating/freezing runs with the analyses of the whitish crusts *(Table II),* it can be concluded that the concentrations of sodium and potassium varied in the mineralizers used in the different runs.

Interpretation of variations in chemical compositions of fluid inclusions

The importance of potassium carbonates, particularly of $KHCO_3$ in the hydrothermal growth of rubies, was described by Kutznetsov and Shternberg (1968). It is interesting to note that in such solutions the Cr_2O_3 concentrations in hydrothermal synthetic rubies can be controlled by variations in the formation conditions (*P,T*) above 700°C, as well as by $KClO_3$ concentrations and other ingredients (Kuznetsov *et al.*, 1968). Theoretically, variations in the formation

conditions (*P,T*) can be produced by variations in the salt-concentrations (see Roedder, 1984), by changing the filling grades *(see Figure 6b)* of the autoclave at room temperature, or by variations in the temperature at constant filling grades. The slightly different homogenization temperatures of the fluid inclusions may reflect slight variations in the filling grade.

Kutznetsov and Shternberg (1967) described the use of $KClO_3$ in the solutions for producing different colour varieties. They reported that $KClO_3$ is decomposed at high temperatures, evolving oxygen. The inferred presence of KCl in the fluid inclusions is therefore consistent with a possible use of $KClO_3$ in the production runs.

Fluid inclusions in synthetic and natural rubies and how to distinguish them

Comparing the fluid compositions of the hydrothermal synthetic rubies with those in natural rubies and natural sapphires (Schmetzer and Medenbach, 1988; Peretti *et al.*, 1990, 1995; Bruder, 1996), it is evident that they are very different *(Figure 18c)*. Natural fluid inclusions are often rich in CO_2. In contrast, fluid inclusions in the synthetic hydrothermal rubies contain aqueous (H_2O) solutions. Three-phase inclusions in natural rubies and sapphires are often composed of CO_2-liquid, CO_2-vapour and diaspore, with additional daughter minerals such as graphite and mica (Peretti *et al.*, 1990, 1995; Bruder, 1996). Daughter minerals in the H_2O-rich solutions of the synthetic rubies are carbonates. The CO_2-rich solutions (fluid inclusions in natural rubies) and H_2O-rich solutions (fluid inclusions in synthetic rubies produced by hydrothermal methods) can be distinguished by heating and freezing experiments between –10 and 31°C (Roedder, 1984). For example, two-, three- or multi-phase inclusions in natural rubies or sapphires will homogenize at temperatures below 31°C (Peretti *et al.*, 1995; Bruder, 1996). In contrast, vapour bubbles in the synthetic hydrothermal rubies are almost unchanged around these temperatures, and homogenization will occur at much higher temperatures, well above 300°C.

The following straightforward test is proposed for the gemmologist:

1. freeze a corundum down to –10°C (in a freezer) and inspect whether a gas bubble develops in the inclusion (Y/N);
2. heat the corundum with a lamp to approximately 40°C and simultaneously inspect the inclusion in the microscope; determine whether the gas bubble has disappeared (Y/N). (Caution: temperatures higher than 40°C will increase internal fluid pressures leading to potential gemstone damage).

If the answer is (Y,Y) this indicates that the corundum is natural ruby. This is true for more than 99 per cent of primary or early secondary fluid inclusions in natural corundum containing one CO_2-rich phase at temperatures above 31°C.

Conclusions

Synthetic hydrothermal rubies and sapphires are produced in Novosibirsk (Siberia, Russia) by TAIRUS, a Russian Academy of Sciences and Pinky Trading Company (Bangkok, Thailand) joint venture. Hydrothermal synthetic rubies of TAIRUS origin are grown at high temperatures and pressures in steel autoclaves from complex aqueous solutions under complex conditions. This is evident from the analyses of the fluid and solid inclusions, the composition of the synthetic materials and from the variability of the chemical composition of the whitish crusts which are found as overgrowths on the synthetic ruby and sapphire crystals.

Fluid inclusions found in natural sapphires and rubies differ significantly from those found in synthetics. The fluid inclusions in the synthetic materials are composed at room temperature of H_2O (liquid), H_2O (vapour) and carbonate solid daughter minerals (such as $CaCO_3$ and $KHCO_3$). The salt concentrations in trapped fluid inclusions contain between 8

and 9 wt.% of KCl and NaCl respectively. Carbonate concentrations were either almost pure $KHCO_3$ of approximately 30–35 wt.% or mixtures of $Na_2CO_3 \cdot H_2O$ and $KHCO_3$ in similar total concentrations. It is concluded that for the production of hydrothermal synthetic rubies and sapphires, complex chloride and calc-alkali-carbonate-bearing aqueous solutions were used. Such compositions are not present in the fluid inclusions of natural rubies and sapphires. The fluid inclusions found in the natural counterparts, including the heat-treated ones, are composed of CO_2-rich compositions with completely different reactions to heating and freezing. By studying these reactions, it is therefore possible to identify the new synthetics.

Further proof of identification is obtainable from the different types of solid inclusions in the synthetic rubies and sapphires, including various types of copper alloys, formed from items of apparatus. Such inclusions have not been found in the natural counterparts. Additional whitish pinpoints and streamers have been found in a few of the more recently produced synthetics. They are interpreted as remnants of the mineralizers, such as carbonates.

Regarding the hydrothermal process used for the production of the synthetic rubies and sapphires it is evident that the aqueous solutions were very complex, with chemical compounds of the system Al–Fe–Ti–Cu–Cr–Mg–Si–Na–Ca–K–Ba–C–O–H–Cl–I–S–P. The combined results of fluid inclusion analyses, SEM-EDX analyses and XRF-EDX-analyses indicate that different aqueous solutions were used for the production of different varieties and generations of synthetics (e.g. different Ca, Na, K, Si, Ba and Cl-bearing solutions for the production of intense red to pink or orangey-pink varieties). The solutions were also changed during the production of single rough crystals indicated by fluid inclusion analyses and analyses of the growth structures and colour zoning.

Acknowledgements

The authors are grateful to the following persons, companies and organizations: TAIRUS (Novosibirsk, Russia) and Pinky Trading Co. (Bangkok, Thailand), United Institute of Geology, Geophysics and Mineralogy of the Russian Academy of Sciences (Novosibirsk, Russia) and their managers, directors and research scientists; Mouawad Bangkok Co. (Bangkok, Thailand), Prof. W. Stern, Geochemical Laboratory, MPI, University of Basel (Switzerland), C.P. Smith, formerly Gübelin Gemmological Laboratory, Luzern (Switzerland), Dr K. Schmetzer, Petershausen (Germany), M. Düggelin and D. Mathys from the SEM Laboratory, University of Basel (Switzerland) and Linda Pfotenhauer (Editor Momentum) for editorial work.

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Letters

From William C.F. Butler

Sir,

Priority in diamond synthesis

Priority in science is usually given to the first to publish, and on this criterion Nassau was correct to attribute[1] the first successful synthesis of diamond by high pressure solution to GEC (USA) who announced their achievement by press release[2] on 15 February 1955. The formal scientific report[3] came five months later but revealed little, constrained by a US Government secrecy order; a full account of the resarch[4] appeared in 1959.

However, there now seems little doubt that the first indisputable high pressure synthesis was achieved on 15 February 1953 by ASEA (Allmänna Svenska Elekriska Aktiebolaget – now Asea Brown Boveri). The diamonds they produced in 1953 were investigated not only in their own laboratories but also in the Crystallographic Institution of the University of Stockholm. Publication[5] was delayed until 1955 when, coming after the similar announcement by GEC, the priority of the Swedish claim went almost unnoticed. A fuller account[6] of the ASEA work appeared in 1960, but it was not until 1962 that the inventor of their remarkable synthesis apparatus gave a detailed account[7] of its design and operation.

Lundblad has explained[8] that the reason ASEA did not immediately publish their results was that they believed they were the only people working on diamond synthesis. Bridgman had told them he knew of no American research and Sir Ernest Oppenheimer of De Beers had professed himself entirely uninterested in synthetic diamond. ASEA was planning in the first place to produce diamonds of a suitable size for cutting and polishing. The diamonds they produced in 1953 were less than 1 mm in size and seemed to them too small to warrant publicity.

In 1959 when I was collecting material for a paper on diamond synthesis, Dr Kistler, the then Dean of the College of Engineering at the University of Utah, but previously with the Norton Company, informed me[9] that, prior to the successful ASEA experiments, the Norton Laboratory had succeeded in synthesising diamond by the reaction between cubic silicon carbide and sodium carbonate at 45,000 atm. In a series of experiments some dozens of minute crystals of about 20 microns in diameter were produced. These were identified by specific gravity, refractive index, ability to scratch polished boron carbide and by micro-combustion analysis. Because of the very small size of the crystals no attempt was made to obtain X-ray patterns. Kistler said that diamond could also be made to grow on a natural seed by this process, the growths appearing as tiny pyramids on smooth surfaces. So far as I am aware, this work remains unpublished.

Diamond synthesis by vapour phase reaction at low or atmospheric pressure, which once seemed incredible, has been shown to be practicable. Perhaps therefore the time has come to re-examine the work of Von Bolton of Siemens and Halske. In 1911 he reported[10] that when wet town gas was bubbled though 14 per cent sodium amalgam at 100°C the hydrocarbons in the gas were dissociated by the mercury vapour and deposited in the form of diamond on seed crystals. The quantities involved were too small for analysis, but it was shown that the deposit was insoluble in hot mixed hydrofluoric and sulphuric acids and burnt completely in oxygen. The report was illustrated with photomicrographs of the seeds before the experiment and after four weeks treatment.

If this really was diamond deposition, it was almost certainly the first successful synthesis by any route.

Yours etc.
W.C.F. Butler
Hatfield, Herts
28 July 1997

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From Peter G. Read

Sir,

K. Nassau's excellent paper 'The chronology of synthetic gemstones' (*J. Gemm.*, **25**(7), 1997 pp 483–490) has filled an important gap in the gem literature and will form a very useful work of historical reference for both student and gemmologist.

However, for those who may be puzzled at the omission of the Swedish ASEA company in the diamond section of *Table I*, may I direct them to the following two references[1,2]. In the first of these Kurt Nassau (in 'A note on the history of diamond synthesis') states the ground rules for the claiming and verification of priorities in scientific achievements. In the second reference Erik G. Lundblad, Vice President of ASEA and former member of their diamond development team in 1953, responds (in a Letter to the Editor) with a brief report on the sequence of events which led to their commercial production of industrial quality synthetic diamond in the early 1960's.

Yours etc.
Peter Read
Bournemouth, Dorset
18 August 1997

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Abstracts

Diamonds | Synthetic and Simulants | Gems and Minerals | Techniques and Applications

Diamonds

Gem news from Tucson.

MARY L. JOHNSON AND JOHN I. KOIVULA. *Gems & Gemology*, **33**, 1997, pp 60–70, 27 coloured illustrations.

On show at Tucson were white diamonds, which are sometimes called opalescent due to the flashes of spectral colours caused by dispersion from the back facets. Five diamonds from the Kelsey lake Mine, Colorado, and a 'Star of David' twinned macle from South Africa were also on view. Diamond 'pearls' are formed from rough that has been ground into spherical shapes and then 'cooked' in sodium carbonate at 800°C to produce the pearly surface. J.J.

Gems and Minerals

Gemmologie Aktuell.

H. BANK, U. HENN AND C.C. MILISENDA. *Gemmologie. Zeitschrift der Deutschen Gemmologischen Gesellschaft*, **46**, 1997, pp 63–70.

Some mint-green chrysoberyls have been found in the Tunduru-Songea district of Tanzania which have the daylight colour of alexandrites but do not change colour in artificial light. A 10 ct specimen had RI 1.740–1.749, DR 0.009 with distinct zoning typically found in chrysoberyl as well as euhedral crystal inclusions. Sapphires as well as pyrope garnets from China were examined. A kunzite cat's-eye weighing 113.32 ct from Brazil is described as are phosgenites from Morocco. Schungite is a vitreous black material, essentially carbon with low water content; the specimens came from Schunga in Olenetz in Russia, have conchoidal fracture, hardness 3½, SG 1.84–1.98 together with faceted stones weighing 1.84 ct and 1.85 ct. From the Kola peninsula in Russia two faceted examples of brownish yellow vlasovite weighed 0.34 ct each, with SG 2.95, RI 1.608–1.627, DR 0.019. E.S.

Physicochemical structural characteristics of ambers from deposits in Poland.

F. CZECHOWSKI, B.R.T. SIMONEIT, M. SACHANBIŃSKI, J. CHOJCAN AND S. WOLOWIEC. *Applied Geochemistry*, **11**(6), 1996, pp 811–34.

The physical and chemical properties of eight samples of amber from various localities in Poland (Baltic Coast, Belchatów Tertiary brown coal and Jaroszów clay mine) have been investigated, using positron annihilation for chemical analysis, together with FTIR, ^{1}H and ^{13}C NMR, GC and GC-MS. The porosity of the ambers consists of narrow micropores with diameters of 0.8 ≈ 0.9 nm and a volume of 0.025 cm^3/g. The proportion of organic material extractable with 1:1 chloroform ≈ methanol ranges from 15 to 50% and correlates inversely with the average reflectance of polished amber surfaces (1.7 ≈ 0.2%). All these ambers belong to a common class of fossil resins, succinite (class Ia), irrespective of the sample location. An early enzymatically controlled (bacterial) process is suggested to have taken place during resin diagenesis from the biotic precursors. R.A.H.

Auf den Spuren Alexander von Humboldt im Ural.

F. DAMASCHUM. *Lapis*, **22**(7/8), 1997, pp 25–30, illus. in colour.

Alexander von Humboldt's 1829 journey through the Urals and Altai regions of Russia is followed with reference to the present state of some of the mines and mineral deposits his party encountered. Gem deposits of the Mursinka area are mentioned as some stones from that area were used in the Russian crown. Fine-quality malachite comes from Nishne Tagil, now the site of a large ironworks. M.O'D.

Gemmologie pratique.

Revue de gemmologie, **131**, 1997, pp 28–33.

A new section for this journal, including, in this issue, notes on the De Beers synthetic diamond: garnet with the alexandrite effect from Sri Lanka: the distinction between yellow chrysoberyl and yellow sapphire and a device to detect the magnetic properties of synthetic diamond. M.O'D.

Abstractors

R.A. Howie	R.A.H.	M. O'Donoghue	M.O'D.	I. Sunagawa	I.S.
J. Johnson	J.J.	E. Stern	E.S.		

For further information on many of the topics referred to, consult *Mineralogical Abstracts*.

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Jade – Verwechslungsmöglichkeiten, Imitationen und künstliche Eigenschaftveränderunge.

U. Henn and E.-M. Pintar. *Gemmologie. Zeitschrift der Deutschen Gemmologischen Gesellschaft*, **46**(2), 1997, pp 71–84, 4 photographs, 3 tables, 2 graphs, bibl.

The jade group consists of jadeite and nephrite, but a series of different materials are known as 'jade' in the international trade. This is incorrect and confusing. When examining sculptures which do not allow measurement of RIs and SGs, X-ray diffraction and infrared spectroscopy may be helpful. Furthermore, glass, doublets and triplets and most opaque green materials can be used to imitate jade. The appearance of jade can be enhanced by coating with paraffin or wax, or with artificial resins; it can also be dyed. Such treated material can be detected by infrared spectroscopy or under the microscope. The article includes an interesting table including hardness, SG and RI, naming pseudo-jades and their common misnomers, and another table listing additional jade substitutes and imitations.

E.S.

Sherryfarbener Topaz von der Thomas Range, Utah, USA.

G. Holzhey. *Gemmologie. Zeitschrift der Deutschen Gemmologische Gesellschaft*, **46**, 1997, pp 85–92, 5 photographs, 1 map, 2 tables, 2 graphs, 1 diagram, bibl.

Some famous occurrences of sherry-coloured topaz are located in the Thomas range in the west of Utah. The fluorine-rich gem crystals up to 3 cm long may fade in strong sunlight. RI 1.607–1.617, SG 3.56. Physical properties depend on ratio of fluorine to hydroxyl ions. There are quartz inclusions and secondary fluid inclusions.

E.S.

Gem grade diaspore: an account of its original discovery.

J.L. Liniger. *Canadian Gemmologist*, **18**, 1997, pp 50–1.

The first discovery of gem-quality diaspore is reported to have taken place in 1866 at a site close to the village of Unionville, Chester County, Pennsylvania, USA. Details of the occurrence, of the diaspore and of its subsequent mining are given.

M.O'D.

Synthetic and Simulants

Growth of high temperature β-quartz from supercritical aqueous fluids.

V.S. Balitsky, T.M. Bublikova, L.V. Balitskaya and A.G. Kalinichev. *Journal of Crystal Growth*, **162**, 1997, pp 142–6, 5 figs.

High temperature β-quartz crystals were grown on bar-like α-quartz seeds at temperatures from 580 to 900°C and pressures from 0.5 to 5 kbar under isothermal and thermal gradient conditions, using gas and hydrothermal high-pressure vessels, with internal volume of 10–12 ml and autoclaves of 20, 75 and 100 ml internal volumes. Pure water and NaOH, K_2CO_3, NH_4F, AlF_3, HF, Li_3PO_4 solutions, and nutrients similar to quartz bars and amorphous silica were used. Oxides of Fe, Al, P, Ti, Ge, etc, were added as impurities. It was found that only the faces $\{10\bar{1}0\}$ and $\{10\bar{1}1\}$ and higher-indexed $\{h0\bar{h}1\}$ faces were stable, and the growth rates of the former two faces were nearly the same, ~0.02 mm/day, giving rise to isometric dipyramidal or prismatic habits. At temperatures above 600°C noticeable growth was observed under the temperature gradient conditions even from fluids of rather low density, 0.05–0.15 g/cm^3. The intensity and direction of silica transfer substantially depended on temperature, temperature gradient, density and the alkalinity of the solutions, as well as on the fluoride ion concentration in acidic solutions. Impurity incorporation into the crystal was rather low, 0.001%, except for Ge. The results may provide useful information for understanding the origin of β-quartz crystals in miarolitic pegmatites and gas cavities of volcanic rocks.

I.S.

Gemological properties of near-colorless synthetic diamonds.

James E. Shigley, Thomas M. Moses, Ilene Reinitz, Shane Elen, Shane F. McClure and Emmanuel Fritsch. *Gems & Gemology*, **33**, 1997, pp 42–53.

Since 1984 the GIA have examined 51 near-colourless synthetic diamonds, both faceted and crystals, from various manufacturers, with the largest being 0.91 ct. The results have been presented in a very comprehensive tabular form. The main differences between natural and synthetic near-colourless diamonds can be summarized as follows. All the synthetic diamonds were found to be type IIa with a few showing a type IIB or type IaB component, whereas near colourless diamonds are usually type Ia. Also the type IIa diamonds do not show the 'Cape Lines' in the absorption spectra as would normally be seen in the natural type Ia diamonds. The De Beers DiamondView instrument uses growth variations for separating natural diamonds from synthetics and is particularly useful when testing small stones. The crystal morphology of the synthetics is cuboctahedral with growth having emanated from the seed location at the base of the crystal. Some of the crystals showed dendritic/striation patterns very unlike the abrasion/chemical etching to be bound on natural diamond crystals. Forty-one of the samples observed showed magnetism and many exhibited metallic inclusions, especially in the Russian grown synthetics. Most of the samples were inert to long-wave UV radiation; all except one diamond fluoresced yellow under short-wave UV radiation and some exhibited intense phosphorescence.

J.I.

BOOK REVIEWS

De juwelen van het Huis Oranje-Nassau.

R. Brus, 1996. Schuyt & Co., Haarlem. pp 168, illus. in colour, hardcover. Price on application. ISBN 90 6097 403 4.

The House of Orange-Nassau is the present ruling house of the Netherlands. A genealogy of the house is provided at the end of the book so that readers can see its descent from Jan, Graaf van Nassau-Vianden-Dietz (1455–1516). In passing it is worth mentioning that while this table is given in the customary tree form, entries at the relevant points are shown by large-font numerals, keys to which are provided on the two facing pages. This makes the table particularly easy to read. The book, neither large nor heavy, is attractively produced, with high-quality reproductions of jewellery, designs and persons.

The age, position and country of residence of the Orange-Nassau family make it likely that a variety of jewels and of diamonds in particular would become their property at some time. A chapter of the book is devoted to diamonds associated with the family: the diamonds include the 'Kleine Sancy' [little Sancy] for which 80,000 guilders were paid in 1642 and fine diamonds are contained in other pieces owned today. Diagrams of designs and pages from the ledgers of suppliers with connections to the royal house are reproduced, some from British sources. As the family was linked by marriage with the Stuarts (Frederick V married Elizabeth Stuart, Willem II married Mary Stuart, and Willem III married Mary Stuart II, becoming King of England in the 17th century) attention is paid to jewellery relating to the English connection.

Chapters describing a miscellany of gem materials follow, with photographs of the wearers, details of the pieces and some design reproductions. Wedding jewellery and pieces associated with other special occasions are described next: here, particular attention is paid to bridal tiaras. Interesting final chapters deal with jewellery manufacture and with the regalia of the Netherlands.

The book, dealing with an area of European royal jewellery not often covered by jewellery historians, is well constructed with close referencing to the royal and other archives and a useful bibliography in which many references to Dutch publications are given. A similar study for England would be welcome! M.O'D.

Chinese jades.

Scott, R.E. (ed), 1997. Percival David Foundation, School of Oriental and African Studies, University of London, London. pp 262, illus. in black-and-white, softcover. £25.00. ISBN 0 7286 0273 3. [*Colloques on art and archaeology in Asia*. No. 18.]

The series of *Colloques on Asian art and archaeology* began in 1970 and has set a high standard of scholarship which is maintained by the present volume, enriched as it is by many contributions from Chinese workers in the field of jade artefacts and history. I can assure potential readers and buyers that the book is excellently produced and illustrated and that the price represents very good (if not ridiculous) value. While aspects of jade testing are not included (they can be found in every textbook) some gemmologists and jewellery historians will find the book invaluable as a series of studies covering the role of jade in different Asian cultures, the nomenclature of artefacts and notes on major collectors and their collections.

Papers include a review of three origins of jade culture in ancient China, the use of jade in burial rituals, a chronology of Liangzhu jades, the function of the jade Bi and Cong (these regularly shaped objects, their names differently Romanized, have been the subject of speculation since well before my Chinese studies began in the 1960s): there are also papers on jade and stone epigraphy from the Shang and early Zhou periods, on a geoarchaeological study of Chinese archaic jade [while this paper does cover the mineralogy of jade artefacts, many gemmologists will have to brush up their mineralogy to get the best from it – but useful and relevant information is not too difficult to find]. The same paper notes many of the Chinese names used to denote the jade minerals, giving their characters too. A similar mineralogical theme pervades the following paper, on the alteration of *Yu* [one Chinese name for jade] artefacts. Here the reader is shown how most Yu artefacts were found to be manufactured from tremolite Yu or bowenite Yu (the latter mainly antigorite or serpentine). The alteration of the two types is shown in several ways on the objects: they may display calcification, changes in hardness or colour, whitening, recrystallization, secondary mineral coating or modification of reflectivity. Details of some of the tests are described.

Other papers include a review of jade carving in China from the tenth to the fourteenth centuries, a study of the re-use of ancient jades and the idea of *Gu Yu* [archaic jades] in texts of the Ming and Qing periods. A short biography of the jade collector Ferdinand Schiller and his collection [in Bristol City Museum and Art Gallery] precedes a note on the Sonnenschein collection in the Art Institute of Chicago.

While the papers are of great interest, their value is enhanced in almost all cases by comprehensive lists of references in which Chinese sources are widely cited. This compilation is an important addition to the literature of jade. M.O'D.

Gemstones of North America. Volume III.

J. Sinkankas, 1997. Geoscience Press, Tucson, AZ. [PO Box 42948, Tucson AZ 85733–2948, USA.] pp xvi, 526, 16 pages of colour plates, hardback. US$65.00. ISBN 0945005 22 9.

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First a short bibliographical account of the work as a whole. The gemstones of North America (including the United States, Canada, Greenland, Mexico and other central American countries) are described over the three-volume set, the two later volumes acting as supplements to the first rather than attempting coverage of entirely new and additional topics. The reader seeking details of spodumene, for example, will have to look in all three volumes and the latest information will be found in the third. The first volume was published by the D. Van Nostrand Company of Princeton, New Jersey, in 1959, and the second by the Van Nostrand Reinhold Company of New York in 1976. This volume also includes the first-rate and very comprehensive bibliography of 2661 entries. Jumping ahead, there are references for each gem species in the third volume: here the references are placed with the species and there is no general bibliography. The interested reader must obtain all three volumes to attempt a serious study of the subject.

Entries in the new volume are arranged in alphabetical order of species. Each species entry is divided into occurrences by state, which are not themselves arranged alphabetically. Without running species headings on the top of each page it is hard to know which gemstone is being discussed and unless the reader has some knowledge of the order in which the states are placed, the index will have to be consulted more than usual in a work when strict alphabetical principles are the rule. This is not a serious shortcoming and it is true that during a search (whose ultimate success is usually assured) the reader will come across a good deal of information which might otherwise have been missed and which will certainly come in useful one day.

This is my only criticism of a book whose arrival I have awaited for some years! Not only are we given the latest reported if not the present state of some of the classic mines (Yogo, Tourmaline Queen, the Rutherford pegmatites of Virginia) but when a locality is producing more or less as before, we are told as much. References bringing location reports up-to-date are given and quite a lot of references which have escaped the first two volumes find a place here. Species are also described with chemical composition, mode of occurrence, colours and other phenomena: important gemstones and sites have ownership and mining details, in some cases including recent prices paid for major specimens. Maps are also provided for a number of important sites: examples include the sapphire deposits of south-western Montana and the tourmaline mines at Mount Mica, Maine. A table at the end of the book lists the largest cut gemstones known from North American localities, giving species (more than one example for major species), colour, weight and locality (the largest cut blue benitoite cited weighs 15.42 ct and the largest orange willemite from Franklin, New Jersey, weighs 29.66 ct. There is also a well-constructed index and, preceding the text, sixteen pages of the highest quality colour photographs giving a variety of cut and rough stones, some set in jewellery. These are Van Pelt photographs and among the best available today.

This book, reasonably priced, is well worth getting and the publishers should make an effort to get all three volumes into press together (perhaps this is under way) so that readers can obtain the complete survey. In every sense this is a book to keep by the bed for constant delight as well as information. M.O'D.

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Proceedings of the Gemmological Association and Gem Testing Laboratory of Great Britain and Notices

OBITUARY

An appreciation of Eunice Miles by David Callaghan

Eunice Miles was unique – and that is no exaggeration. When Eunice joined GIA in 1953 she entered a trade which was very much a male preserve. I am sure New York was no different from London in this respect, but her work for GIA was primarily in the gem diamond world at that time. This within the trade was an exclusively male world and Eunice told me personally of the suspicion bordering on hostility she encountered at first. However, the powers of her personality soon prevailed and, in the end, many diamond merchants were leaving their stones at the GIA Lab. specifically for her attention.

Eunice was born in Connecticut and read Mineralogy at University. Before joining GIA in 1953 she had been the Assistant Curator at the American Museum of Natural History from 1942–1952. What a background of experience to bring with her to GIA. Some of her early work at GIA was the study of the coloration in diamond, and a number of articles appeared in the GIA journals of the period. This led her into the educational field of GIA and when I first met her some 20 years ago education had become her main task. She taught gemmology for many years and she always took a keen interest in the work and careers of her students. She was a great supporter of the FGA course and because of this became a good friend of the Gemmological Association.

This refers only to her career but doesn't help you to know her. What was she like as a person, what would be your first impression? That would depend on whether she was at work or 'off duty'. For me the first impression of her at work was one of complete pre-occupation, and therefore 'not to be disturbed'. I think this was a 'front' to remind her that her impish sense of humour was to be held in check and not let out to play! Eunice had a great sense of fun, enjoyed the use of the English language and particularly enjoyed the use of a pun. I did not work with her but I can well imagine her to have been very exacting for she set herself high standards and expected the same of others. She spoke quietly and quite slowly, but she was always a joy to listen to. All in all she made a lasting impression on you when you had broken through her 'defence' and got to know her.

Eunice was a great Anglophile and loved coming to London. In recognition of her work in the field of education in gemmology she was awarded the Honorary Fellowship of the Gemmological Association in 1984 and it was my privilege as Chairman to make the presentation to her. Eunice was very proud to receive this award and treasured it. She has left behind her many, many friends in the trade in the USA and, although she retired from GIA some time ago, kept in touch with many of them. I, for one, count myself fortunate to have known her and to be counted as a friend.

THE 1998 GAGTL PHOTO COMPETITION

Gems in fashion

What gem do you think typifies a particular period in history – Roman cameos, Renaissance jewellery, Victorian jet, Art Deco diamonds? What are the most sought after or fashionable gem varieties today?

Enter your pictures taken by yourself on this theme for the 1998 Photographic Competition. Three prizes of £100, £75 and £50 will be awarded for the most appropriate entries and we again plan to produce a calendar showing a range of entries. We are pleased to announce that the prizes are being sponsored by Quadrant Offset Ltd, Hertford, and the GAGTL is most grateful to them for their generosity.

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FORTHCOMING EVENTS

31 October	**Midlands Branch**. *The sapphires of Scotland.* Brian Jackson.
9 November	**London.** Annual Conference – Collector's gems.
10 November	**London.** Visit to the Natural History Museum.
16 November	**Midlands Branch.** Practical gemmology training day.
19 November	**North West Branch.** Annual General Meeting.
20 November	**Scottish Branch.** *Scottish river pearls.* Fred Woodward.
28 November	**Midlands Branch.** *Opals.* David Callaghan.
3 December	**London.** *Fluid inclusions: solutions for mineral genesis and gem identification.* Andrew Rankin.
6 December	**Midlands Branch.** 45th Anniversary Dinner.

1998

14 January	**London.** *Chinese snuff bottles: the use of stone in Chinese art.* Clare Lawrence.
30 January	**Midlands Branch.** Bring and Buy Sale; Practical Gemmology Quiz.

For further information on the above events contact:

London:	Mary Burland on 0171 404 3334
Midlands Branch:	Gwyn Green on 0121 445 5359
North West Branch:	Irene Knight on 0151 924 3103
Scottish Branch:	Joanna Thomson on 01721 722936

GAGTL WEB SITE

For up-to-the-minute information on GAGTL events and workshops visit our web site on www.gagtl.ac.uk/gagtl

NEWS OF FELLOWS

Michael O'Donoghue lectured on *The geology and gemstones of Pakistan* to the Ravensbourne Geological Society on 8 July 1997.

MEMBERS' MEETINGS

London

On 9 July at the Gem Tutorial Centre, 27 Greville Street, London EC1N 8SU, Dr Robert Young gave a talk entitled *Exploring for diamond, emerald and alexandrite in Europe.*

Midlands Branch

On 26 September at the Discovery Centre, 77 Vyse Street, Birmingham, Howard Vaughan gave an illustrated talk entitled *Diamonds I have known.*

Scottish Branch

Two field trips to localities in Scotland were held during the summer months. On 5 to 7 July trips were made to Glen Clova, Glen Esk and Mount Batock looking for hyaline and quartz, and on 9 to 11 August the venues were the Cairngorms and Lochan Na Lairige, sources of beryl and topaz.

GIFTS TO THE ASSOCIATION

The Association is most grateful to the following for their gifts for research and teaching purposes:

Mrs Mary Burland, Hoddesdon, Herts., for 60 various pieces including an opal, small diamonds and synthetic spinels.

Mr C.R. Cavey, FGA, Greenford, Middx., for 36 red spinel crystals.

Exclusive Merchandisers, Inc., Buffalo, New York, USA, for various pieces including natural and synthetic star corundum, peridot, quartz and opal.

Mr Ronald Ferrell, FGA, Downtown DeLand, Florida, USA, for 300 various pieces including diamond, emerald, garnet, iolite, apatite, turquoise, lapis, natural and imitation pearls, and synthetic materials.

Mr Lawrence J. Fifield, FGA, Pinner, Harrow, Middx., for 62 various pieces including jadeite, beryl, quartz, opal and pearls.

Mr A.G. Flewelling, FGA, Arthur, Ont., Canada, for a bag of rough corundum and zircon from Australia.

Mr John Fuhrbach, FGA, Amarillo, Texas, USA, for an exceptional collection of turquoise from the SW United States and for stones sold as imitations of this turquoise.

Robert James, Caribbean Gemological Institute, for two imitation tanzanites.

Harold Kipp of Exclusive Merchandisers Inc., Buffalo, New York, USA., for a bag containing various materials.

Miss Lucy Monje, FGA, Santa fe da Bogota, Colombia, for emerald on carbonaceous, pyritiferous shale from the Coscuez Mine in Colombia.

Mrs Margaret Pout, Worplesdon, Guildford, Surrey, for three hydrogrossular garnets.

Ami, Eitan and Yoram Siman-Tov of Siman-Tov Brothers, Gem Importers, New York, USA, for a tanzanite.

Mr Peter Truman of W. Truman Ltd., London, for a conch pearl.

G.F. Williams, London, for two coated topaz and one coated topaz subsequently heated.

On 18 September at the Royal British Hotel, Princes Street, Edinburgh, John Levy gave a talk entitled *A stone buyer abroad*.

ANNUAL GENERAL MEETING

The Annual General Meeting of the GAGTL was held on 30 June 1997 at 27 Greville Street, London EC1N 8SU. Terry Davidson chaired the meeting and welcomed those present. The annual Report and Accounts were approved and signed. Roger Harding and Vivian Watson were re-elected to the Council of Management.

It was announced that Keith Penton and Ian Roberts had expressed the wish to retire from the Members' Council. Peter Read, Richard Shepherd and Colin Winter were re-elected to the Members' Council. Messrs. Hazlems Fenton were re-appointed Auditors. Amendments to the By-laws were announced by the Secretary, Roger Harding, and accepted by the meeting.

Following the Annual General Meeting, the winners of the 1997 Photographic Competition were announced and presented with their prizes by the President, Professor Bob Howie. The members then enjoyed a Reunion and Bring and Buy Sale and a rolling display of selected entries in the Photographic Competition.

ISLAND OF GEMS

An exhibition of the gems of Sri Lanka is to be held at St. Albans Centre, 18 Brooke Street, London EC1S 7RD, on 19 and 20 December. Further details from Sri Lanka Gems, PO Box 1837, London N17 9BW (telephone/fax 0181 808 4746).

SUBSCRIPTION RATES 1998

The following are the subscription rates for the four categories of membership for 1998. Existing Ordinary Members, Fellows and Diamond Members will be entitled to a £5.00 discount for subscriptions paid before 31 January 1998.

	UK	*Europe*	*Overseas*
Ordinary Member *Fellow* *Diamond Member*	£55.00	£62.00	£70.00
Laboratory Member	£250.00 + VAT	£250.00	£250.00

GEM DIAMOND EXAMINATIONS

In June 1997, 76 candidates sat the Gem Diamond Examination worldwide of whom 49 qualified, 7 with Distinction. The Bruton Medal for the candidate who submitted the best set of answers in the Gem Diamond Examinations of 1997 which, in the opinion of the Examiners, are of sufficiently high standard, was awarded to Miss Rita Tsang Wai Yi, Hong Kong. The names of the successful candidates are listed below:

Qualified with Distinction

Cadby, John H.V., Trowbridge, Wilts.
Stather, Lorne Francis, Charlton, London
Ball Edwards, Chantal, Cheltenham, Glos.
Lingyun Mao, Beijing, PR China
Lin Hsin Pei, Wuhan, Hubei, PR China
Stead, Graham Scott, Tillsonburg, Ont., Canada
Jiang Renyi, Wuhan, Hubei, PR China

Qualified

Brooke-Webb, Susannah, London
Carlsson, Johanna A., London
Chu Kam Chiu, London
Churamani, Pooja, London
Cookson, Ian, Darnall, Sheffield, Yorks.
Dempster, Stuart, Shettleston, Glasgow, Scotland
Edwards, James, St. Albans, Herts.
Feeney, Eileen, Uddingston, Glasgow, Scotland
Feng Hsiu Yun, Wuhan, Hubei, PR China
Fielding, Geoffrey Ian, Tottington, Bury, Lancs.
Fitzmaurice, Karl, Dunboyne, Co. Meath, Ireland
Fu Ye, Beijing, PR China
Harris, Annette Mia, Hanbury, Worcs.
Heilpern, Helene, Epping, Essex
Hoare, G.M., Maynooth, Co. Kildare, Ireland
Hopley, Katharine Bridget, Coventry, West Midlands
Hsu, Robert, Wuhan, Hubei, PR China
Josyfon, Bruce Michael, Brighton, Sussex
Law Yiu Sing, Hong Kong
Li Ping, Beijing, PR China
Lo Shuk Lan, Hong Kong
MacDonald, Karen J., Dundonwell, Inverness, Scotland
Mak, Tsui Sim, Hong Kong
Martin, James, Leigh, Lancs.
Martin, Jennifer Frances, Acton, London
Michelson, Max J., London
Ocloo, Charles Seth, Eastcote, Middx.
Papadopoulos, A. Dimitrios, Athens, Greece
Pattni, Unnat Nagindas Gordhandas, Kingsbury, London
Randall, Gary Marshall, Kingston, Surrey
Shah, Jignesh Vinodbhai, Surat, India
Simpson, Peter Robert, Richmond, Surrey
Suchde, Aditya Ajit, Hendon, London
Thornton, Timothy John, Wimbledon, London
Tong Lai Ming, Kowloon, Hong Kong
Varey, Irena Maria, Ullesthorpe, Leics.
Verny White, Catherine, Fulham, London
Veryis, Anastassios, Athens, Greece
Wai Hung Raymond Law, Kowloon, Hong Kong
White, Robert, Kingsthorpe, Northants.
Wong, Yik Shih, Kuala Lumpur, Malaysia
Wu Ming Hsun, Wuhan, Hubei, PR China
Wu Tien Hsien, Wuhan, Hubei, PR China
Xia Songyao, Beijing, PR China
Yam Hang Ha, Hong Kong
Yan Yee Mei, Hong Kong
Yang Menghua, Wuhan, Hubei, PR China
Yip Shu Leung Christopher, Hong Kong
Yu Kam Chi, Hong Kong

EXAMINATIONS IN GEMMOLOGY

In the Examinations in Gemmology, held worldwide in June 1997, 201 candidates sat the Preliminary Examination of whom 134 qualified. In the Diploma Examination 248 sat, of whom 110 qualified, one with Distinction. The Tully Medal for the candidate who submits the best set of answers in the Diploma Examinations in 1997 which, in the opinion of the Examiners, are of sufficiently high standard, was awarded to Ms Li Liping, Wuhan, P.R. of China. Ms Li Liping was also awarded the Anderson Bank Prize for the best non-trade candidate of the year in the Diploma Examination.

The Diploma Trade Prize for the best candidate of the year who derives her main income from activities essentially connected with the jewellery trade was awarded to Ms Mary I. Garland, London, Ontario, Canada.

The Anderson Medal for the best candidate of the year in the Preliminary Examination was awarded to Miss Melloney Vanessa Ng, London.

The Preliminary Trade Prize for the best candidate for the year who derives his main income from activities essentially connected with the jewellery trade was awarded to Mr Simon Richard Millard, Corsham, Wiltshire. The names of the successful candidates are as follows:

Diploma

Qualified with Distinction

Yu Hailing, Wuhan, Hubei, PR China

Qualified

Arsenikakis, Helena, Blackwood, SA, Australia
Bae, Chai Soo, Seoul, Korea
Bappoo, Reenabai, Croydon, Surrey
Barsk, Christer, Pello, Sweden
Bienemann, Andre, Polsbroek, The Netherlands
Cao Weiyu, Wuhan, Hubei, PR China
Chang, Circle H., Toronto, Ont., Canada
Chaudhari, Ruchi, Bombay, India
Chen Qi, Shanghai, PR China
Chen Shiyi, Wuhan, Hubei, PR China
Chen Tao, Shanghai, PR China
Christou, Angelos G., Limassol, Cyprus
Cowley, Jacalyn G., Wimbledon, London
Davies, Maggie, Wareside, Herts.
Deligianni, Christina, Athens, Greece
Gilad, Deutscher, Kiryat, Ono, Israel
Dykhuis, Luella Woods, Tucson, Ariz., USA
Edwards, Heidi Louise, Burntwood, Staffs.
Endo, Masahiko, Osaka, Japan
Feng Hsiu Yun, Wuhan, Hubei, PR China
Forward, Stephen, London
Garland, Mary I., London, Ont., Canada
Glaser, N.V.K., Sonja, I., Galle, Sri Lanka
Hainschwang, Thomas N., Ruggell, Liechtenstein
Hazelius B., Wiveca, Lidingo, Sweden
Hill, Emma, Maida Vale, London
Hu Aiping, Wuhan, Hubei, PR China
Hu Shu, Wuhan, Hubei, PR China
Hutton, Katie, Twickenham, Middx.
Ikeda, Noriko, Takarazuka City, Hyogo, Japan
James, Robert C., Naples, Fla., USA
Jankowiak, Anna, Toronto, Ont., Canada
Jin Yingrui, Wuhan, Hubei, PR China
Juan, Ku-wei Hsieh, Taipei, Taiwan, Rep. of China
Karandikar, Surendra, Bombay, India
Kataoka, Noriko, Machida-City, Tokyo, Japan
Kazemi, Sima, Vancouver, BC., Canada
Kim, Amy, London, Ont., Canada
Kjendlie, Ole-Richard, Larvik, Norway
Kong Wei, Wuhan, Hubei, PR China
Konstantara, Aikaterini, Thessaloniki, Greece
Koshiba, Shoko, Sagamihara City, Kanagawa, Japan
Lam, Jill, Rochester, Kent
Lee, Dongjae, Masan, South Korea
Lei Lihong, Wuhan, Hubei, PR China
Leng Yanyan, Wuhan, Hubei, PR China
Li Ting, Wuhan, Hubei, PR China
Li Wei, Shanghai, PR China
Liao Yang, Guilin, PR China
Lindroos, Anna, Rauma, Finland
Liu Hui, Shanghai, PR China
Long Dan, Wuhan, Hubei, PR China
Lui, Alice, Richmond, BC, Canada
Lu Xiaomin, Wuhan, Hubei, PR China
Luo, Xia Ying, Guilin, PR China
Ma, Huei-Chi, Taipei, Taiwan, Rep. of China
McCabe, Marianne Carole, Guildford, Surrey
McCarthy, Keiran, M., London
Maehara, Tamao, Gunma, Japan
Makarainen, Paivi, Helsinki, Finland
Mo Yiming, Shanghai, PR China
Monje M., Lucy E., Santa fe da Bogota, Colombia
Moore, Rowan Duggan, Stoke, Coventry, Warwicks.
Ng Wai Ching, Hong Kong
Niemi, Markku, Lappeenranta, Finland
Nottbusch, Jurgen Uwe, Appel, Germany
Ohtsuka, Mayumi, Neyagawa City, Osaka, Japan
Pan Jie, Shanghai, PR China
Qin Hongyu, Guilin, PR China
Rees-Wardill, Tanya, Wallington, Surrey
Renard, Joelle M., Ruislip, Middx.
Rimmer, Ray Ian, Bootle, Merseyside
Rollings, Alexander, London
Roper, Bebs, Rokeby, Tasmania, Australia
Seki, Shoko, Osaka City, Osaka, Japan
Semenets, Elena, Vancouver, B.C., Canada
Shen Beiqi, Shanghai, PR China
Shih Shu-Chuan, Hampstead, London
Shu Yiqiang, Wuhan, Hubei, PR China
Skogstrom, Helena Anneli, Klaukkala, Finland
Soderstrom, Jenny, Lannavaara, Sweden
Stossel, Hilary Jeanne, Perth, WA, Australia
Sun Xingqun, Wuhan, Hubei, PR China
Suninmake, Virpi Kristina Annika, Helsinki, Finland
Suzuki, Noriko, Ikoma City, Nara, Japan
Tashiro, Hisami, Uji City, Japan
Teskeredzic, Senada, London
Than, Tin Kyaw, Yangon, Myanmar
Tsang Wai Wan, Kowloon, Hong Kong
van der Vijgh, Caroline E., Diemen, The Netherlands
Vernon, Penny, High Wycombe, Bucks
Verny White, Catherine, Fulham, London
Wang Yilong, Guilin, PR China
Wang Chien Ling, Taipei, Taiwan, Rep. of China
Wang Jianmin, Wuhan, Hubei, PR China
Wang Yi Fei, Guilin, PR China
White, Joanne Clare, Sheffield, S. Yorks
Wong, Yik Shih, Kuala Lumpur, Malaysia
Xia Jiancheng, Wuhan, Hubei, PR China
Xie Yujun, Guilin, PR China
Xu Lei, Shanghai, PR China
Xu Zhiyi, Shanghai, PR China
Yang, Jin Mo, Seoul, Korea
Yao Huali, Wuhan, Hubei, PR China
Yau Hau Yeung, NT, Hong Kong
Yogalingam, Nirupa, Kandy, Sri Lanka
Yu Ping, Guilin, PR China
Yuan Jia, Wuhan, Hubei, PR China
Yoshitake, Yumi, Oita, Japan
Zeng Shan, Wuhan, Hubei, PR China

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At a meeting of the Council of Management held at 27 Greville Street, London EC1N 8SU, on 25 June 1997, the business transacted included the election of the following:

Diamond Membership (DGA)

Scott, Michael, Harpenden, Herts. 1992

Fellowship (FGA)

Civitello, Odile, Montreal, Quebec, Canada. 1989
Gatward, Anna Bradly, Hitchin, Herts. 1966
Sharma, Maryada, Mumbai, India. 1983

Ordinary Membership

Boutle, David, London
Butcher, Elsbeth, Blandford Forum, Dorset
Carmona, Charles, Los Angeles, Calif., USA
Jayakody, Geetha Kamani, Saitama Ken, Japan
Johnson, Janet Mary, Friern Barnet, London
Kabangi, Antoine, London
McCabe, Marianne Carole, Guildford, Surrey
Nabukeera, Zamu Night, Forest Hill, London
Poole, Iain, Market Harborough, Leics.
Sillero-Arroyo, Andrés, Córdoba, Spain
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Mindry, Ernest Roy, Chesham, Buckinghamshire. 1980
Yang, Ruzeng, Zhenjiang, Jiangsu, PR China. 1996

Ordinary Membership

Bryan, Ian Robert, London
Collins, John Raymond Frank, Clydach, Swansea, Glamorgan
Curtis, Mark, Chemainus, BC, Canada
Edwards, Heidi, Burntwood, Staffordshire
Gascoigne-Pees, Carol Anne, Dorking, Surrey
Sayed, Mahta Bali Shah, Karachi, Pakistan
Sheppard, Gary Richard, Wellington, New Zealand
Siripaisarnpipat, Seitatip, Bangkok, Thailand
Srithai, Boontarika, London

CORRIGENDA

In the Contents list, back outside cover, Vol. 25(6), April 1997, third entry, the authors should read H.A. Hänni, L. Kiefert, J.-P. Chalain and I.C. Wilcock.

On p. 468 above, in the labels to Figure 22, for 'F-apatire' read 'F-apatite' and for 'melonite' read meionite'.

On p. 485 above, Figure 6, the moissanite should be colourless, not brownish-pink.

On p. 486 above, Table 1, Beryl; the entry for Emerald produced by Zerfass should have been included under the flux method rather than the hydrothermal method. A replacement page is enclosed with this issue of the *Journal*.

On p. 510 above, second column, under *Transfers from Ordinary Membership to Diamond Membership (DGA)*, the sub-heading *Transfers from Ordinary Membership to Fellowship (FGA)* was omitted and we apologize for any misunderstanding and embarrassment caused by the error. The section should read as follows:

Transfers from Ordinary Membership to Diamond Membership (DGA)

Kenny, Sark, Hong Kong. 1997
Kepel, Arthur Mvuta, London. 1997
Lemessiou, Maria A., Nicosia, Cyprus. 1997
Lodge, Tim, London. 1997

Transfers from Ordinary Membership to Fellowship (FGA)

Battiscombe, Brigid, London. 1997
Davies, Paul, B., Great Missenden, Bucks. 1997
Jackson, Stephen, D., Perranporth, Cornwall. 1997
Johnston, Dale, Dundonald, Co. Down, N. Ireland. 1997
McInnes, Catriona, O., Edinburgh. 1997
McInnes, John L., Edinburgh. 1997
Mao, Lingyun, Beijing, P.R. China. 1997
Starreveld, Francis M.M., Hilversum, The Netherlands. 1997

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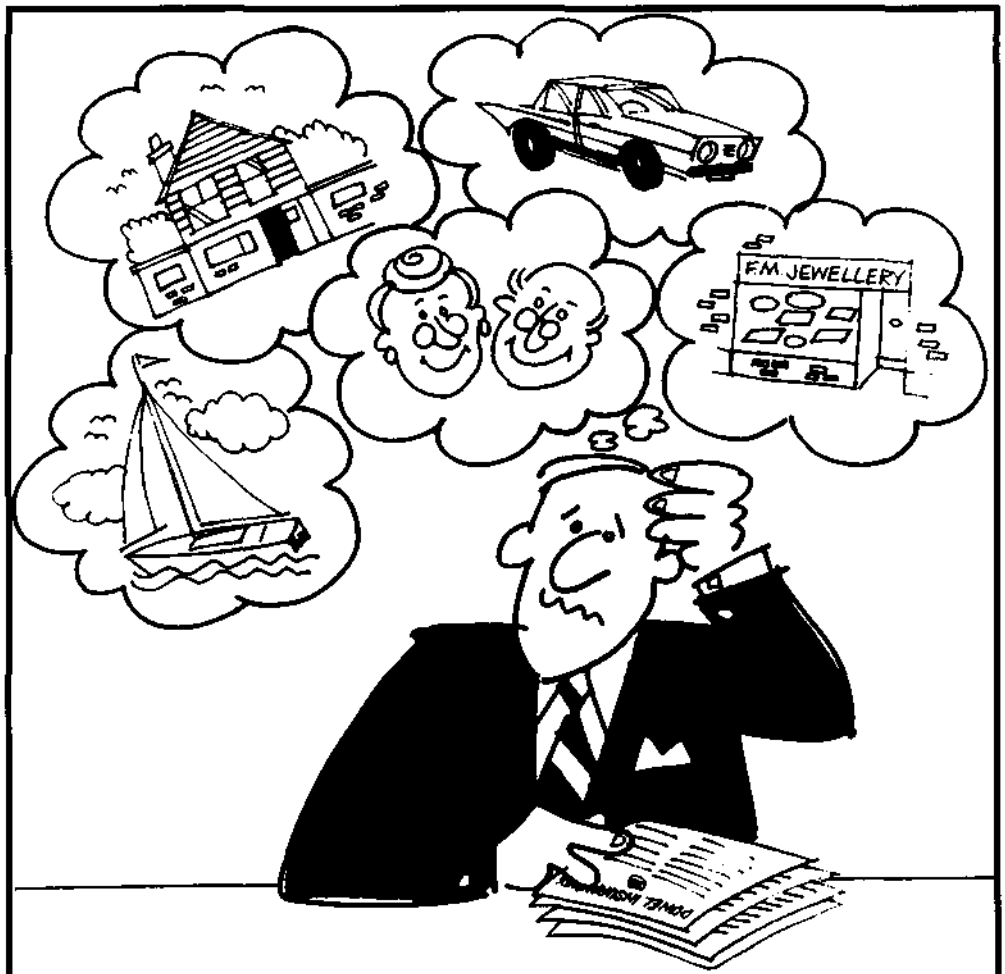

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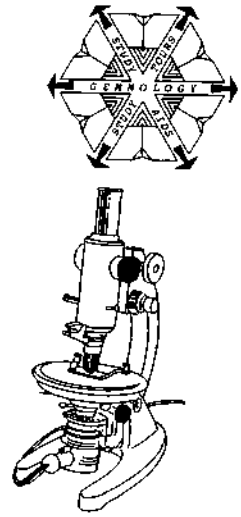

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Typescripts Two copies of all papers should be submitted on A4 paper (or USA equivalent) to the Editor. Typescripts should be double spaced with margins of at least 25 mm. They should be set out in the manner of recent issues of *The Journal* and in conformity with the information set out below. Papers may be of any length, but long papers of more than 10 000 words (unless capable of division into parts or of exceptional importance) are unlikely to be acceptable, whereas a short paper of 400–500 words may achieve early publication.

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Books Hughes, R.W., 1990. *Corundum*. Butterworth-Heinemann, London. p. 162

Abbreviations for titles of periodicals are those sanctioned by the *World List of scientific periodicals* 4th edn. The place of publication should always be given when books are referred to.

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From sparks to sparkle
Wheel-lock gun mechanism. Photograph courtesy of the Victoria and Albert Museum.

Marcasite brooch-pendant. Photograph courtesy of the British Museum. (See Fool's gold?... The use of marcasite and pyrite from ancient times. pp. 517–531.)

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Compiled by Robin W. Sanderson

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Turquoise from Hubei Province, China

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ABSTRACT: The turquoise deposit in Yunyang district, Hubei Province, China, is characterized by its large scale, complex and variable ore-body types and colour varieties, compared with similar bodies outside China. The copper and phosphorus in the deposit originate mainly from finely dispersed sulphides in layered carbonaceous-siliceous slates, and from colloidal apatites (collophane) that occur in an irregular and patchy distribution pattern. The host rocks favourable for the formation of the turquoise are relatively rich in silica, copper and phosphorus and relatively poor in potassium, calcium and magnesium. The ore occurs mainly in lenticular bodies compressed between the layers. The distinctive mineralization is controlled by lithology, structure and the effects of ground water movement. The colouring mechanism of the turquoise results from a combination of $[Cu(H_2O)_4]^{2+}$, Fe^{3+} and Fe^{2+} ions. The colouring ions and the existing form and content of H_2O limit directly the colour of the turquoise. The turquoise deposit can be considered as having been formed by a process of secondary leaching.

Keywords: turquoise, mineral deposit, secondary leaching

Introduction

Yunyang in Hubei Province, located in the eastern section of the Qinling fold zone at the intersection of Hubei, Henan and Shanxi provinces *(Figure 1)*, is well known not only for its high-quality turquoise but also for its excellent carving techniques and life-like handicrafts *(Figure 2)*.

The exceptionally long mining history of turquoise can be deduced from the 20 turquoise beads unearthed with Qijia cultural relics of late Neolithic Age, located in Yongjing County, Gansu Province, China. This indicates a mining history of about 3200–3800 years (Hao Yongwei *et al.*, 1982). At present, the holes for extraction of the turquoise ore are readily apparent *(Figure 3)*.

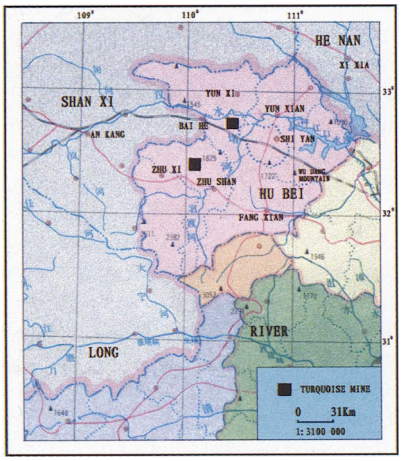

Figure 1: *Location map of the turquoise deposits in Hubei. Bai He is approximately 500 km NW of Wuhan.*

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Figure 2: *Turquoise carving 'A picture of Paradise' (32x48x27 cm). Photo: Yuan Jiaqi.*

Figure 3: *Ancient caves where turquoise was mined.*

Figure 4: *Turquoise deposits at Yungaisi, Yunxian County, Hubei.*

The complex metallogenic and geological conditions of the turquoise, the various morphologies of the ore body, the wide spatial distribution of the turquoise and its irregular occurrence in this district have attracted little attention from the Government for a long time. In 1980, a team from the Hubei Bureau of Geology and Mineral Resources carried out a reconnaissance geological survey of the turquoise deposit at 1:200,000 scale. In 1982, Zhang Huifen, Jiang Zechun, *et al.*, from the Guiyang Geochemistry Institute under the Academy Sinica made a detailed investigation into the turquoise mineralogy in this district and on the basis of this it was evident that more needed to be done.

For the past several years, the first-named author and his colleagues in the Gemmological Institute of the University of China (Wuhan) have climbed the Qinling

mountains, have investigated several tunnels which were still being actively mined and have explored several abandoned caves in order to trace the origin of the turquoise and to prospect for new occurrences *(Figure 4)*.

Stratigraphical and lithological features

The ore-bearing bed has been identified as the Lower Cambrian Shuigoukou Formation ($\in_1$sg), part of a regionally metamorphosed rock succession (Hao Yongwei *et al.*, 1982). Its lithology is composed mainly of carbonaceous-siliceous slates, carbonaceous clay and siliceous slates, banded thin-layer siliceous slates, carbonaceous mica quartz rocks, calcareous mica quartz-schists and carbonaceous clay marbles. The turquoise occurs mainly in the first three types of rocks. The carbonaceous-siliceous slates (the hosts of the turquoise ore bodies) have been universally silicified and recrystallized into massive slaty quartzite *(Figure 5)*. This rock is grey to black and characterized mainly by an intermediate-to-fine granular structure, and a dense and hard texture. The rock is composed of quartz (80–85%), carbonaceous material (10–15%), sericite (3–5%), and albite (<1%). The carbonaceous siliceous slates from the strongly mineralized segment of this district contain more of the patchy colloidal apatites (collophane). If this rock is sectioned and observed through the microscope, the features, typical of quartz, carbonaceous materials and sericite, can be observed *(Figure 6)*, together with colloidal structures and isotropic areas. Field observations show that the intensity of mineralization, ore body morphology and ore quality of this district are all controlled by the lithology *(Figure 7)*.

Figure 5: *Thin section of carbonaceous-siliceous slate, fine to medium grained, in crossed polars, x60.*

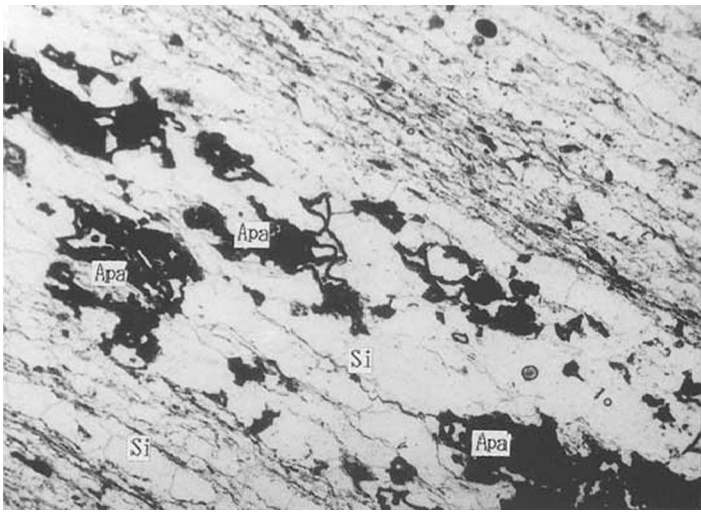

Figure 6: *Collophane (Apa) and quartz (Si) along a bedding plane in carbonaceous-siliceous slate, x60.*

Figure 7: *Mineralized intermediate to thickly bedded carbonaceous-siliceous slates. The marker indicates the mineralization.*

Table I: Chemical compositions of rocks associated with turquoise

Lithology	Number of analyses	Weight per cent oxide						Parts per million (ppm)							
		SiO_2	Al_2O_3	CaO	MgO	K_2O	P_2O_5	Cu	Pb	Zn	Mo	V	Ag	Ni	Mn
Carbonaceous-siliceous slate	32	90.92	2.26	0.21	0.38	0.51	0.43	747.23	25.41	177.45	196.25	1962.5	4.95	158.75	925
Carbonaceous muddy and siliceous slate	7	84.63	5.28	0.34	0.56	3.44	0.075	28.78	31.14	79.68	176.17	1420.6	7.26	47.41	866.67
Mica quartz schist	12	64.38	13.76	1.95	1.39	4.38	0.194	21.19	27.65	52.06	41.33	125.04	1.09	14.53	815.74
Calcareous mica quartz-schist	4	33.23	4.37	43.31	3.68	2.35	0.026	43.39	13.73	24.54	64.81	92.26	<0.3	13.65	540.16
Muddy marble	5	14.62	2.05	53.87	16.52	0.72	0.128	5.42	11.37	18.92	32.36	85.29	<0.3	9.44	672.01

Note: content of carbon not determined.

Geochemical features of the rocks containing the turquoise ore

The chemical compositions of 60 fresh unmineralized rock samples collected from different sections close to the turquoise deposit reveal that their petrochemical compositions differ greatly from those of the ore-bearing segment *(Table I)*. The contents of silica, copper and phosphorus in the ore-bearing carbonaceous-siliceous slates are much higher than those in the ore-free carbonaceous and siliceous slates and other rocks. Furthermore, the contents of copper and phosphorus are far higher than the regional geochemical background values (Cu: 80 ppm, P: 0.05%).

Figure 8: The relationship between the ratio of Al_2O_3 to SiO_2 in different rock types in the metamorphic rock system and its correlation with zones in the ore deposit (based on the chemical analysis of 60 rock samples).

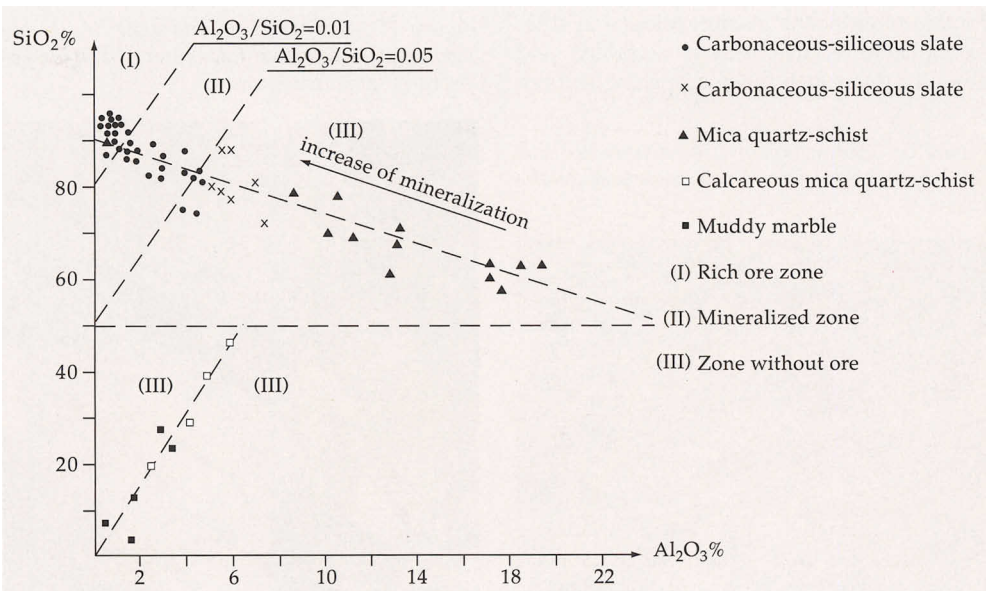

In order to further understand the state of occurrence of the copper and phosphorus in the ore-bearing rocks, eight samples were chosen from the varieties of rocks in the Shuigoukoy Formation in the Yungaisi profile ($\in_1$sg) and their constituents analyzed in detail. Results show that the copper occurs mainly in sulphides finely dispersed throughout the rock and that it constitutes only a very small percentage of the silicates. Phosphorus occurs mainly in the irregular patchy colloidal apatites (collophane).

Calculations of the ratio Al_2O_3/SiO_2 indicate that silicification is closely associated with the mineralization in this district *(Figure 8)*. That is, with the increase in mineralization, the Al_2O_3/SiO_2 ratio decreases; when the ratio of Al_2O_3/SiO_2 is <0.05%, it is favourable for metallogenesis.

Another marker in terms of the petrochemistry favourable for the formation of turquoise in this district is the relatively high concentration of SiO_2 compared with K_2O, CaO and MgO in the carbonaceous-siliceous slate, that is $(CaO+K_2O+MgO)/SiO_2<0.02\%$.

It is important to note that this district was subject to a series of geological processes including weathering, leaching and migration of metallogenic elements, which resulted in the formation of the turquoise deposit through local concentration and precipitation.

Geological features of the turquoise deposit

The turquoise deposits in Yunyang District occur at the southern edge of the eastern section of the Qinling fold zone and at the western edge of the Wudangshan terrain (Yu Gai Si Mine and La Ba Shan Mine). On the whole, the turquoise deposits follow the same direction as the major regional strikes and tectonic lines (Hao Yongwei *et al.*, 1982; Peng Yuanguo, 1989). In this region, secondary folds and fracture tectonics are well developed, but the tectonic patterns can be very complex. They have, however, created very favourable space conditions for the formation of the turquoise. Gem quality turquoise suitable for use in jewellery often occurs as lenticles and nodules in the compressed and fractured zones between the layers of complex fold structures and in tension joints. In this sense, the Yunyang region is distinctively characterized by tectonic control of the ore *(Figures 9 and 10)*.

Figure 9: *Turquoise in a compressed fractured zone between beds of slate.*

Most of the fracture zones in the Yunyang District are compressed between the strata of the intermediate- to thick-bedded

Figure 10: *Turquoise filling tension joints in slate.*

Figure 11: Nodular turquoise in the lenticles compressed between slate beds.

carbonaceous-siliceous slates. Generally speaking, the more the lenticles have been compressed between the strata, the more nodular the turquoise and the better its gem quality. In addition to turquoise, the lenticles are composed largely of loose clay, carbonaceous materials, limonite, silt, sand and protolithic breccia *(Figure 11)*.

Compared with turquoise deposits outside China (Fayaz and Forghani, 1975; Ivanova, V.P., 1974), the Yunyang turquoise deposits are larger and more complex in both

Figure 12: Nodular turquoise mined from a tunnel.

Figure 13: Detail of typical nodular turquoise.

Figure 14: Turquoise from a quartz vein.

shape and type. The colour varieties and excellent quality are among the best in the world. In Yunyang, also, there are more complex parageneses and a greater variety of associated minerals in the region.

The turquoise ore body is lenticular overall, but there are some secondary veins. Locally the accumulation of turquoise is nodular, massive or botryoidal *(Figures 12, 13 and 14)*.

The turquoise deposit is vertically zoned and at Yungaisi, for example *(Figure 15)*, at or near the ground surface 820–840 m above sea level the turquoise deposits are pale in colour, poor in quality, and of small volume and low hardness. But at the approximate ground water surface 720–800 m above sea level there are prolific ore zones with turquoise of the best quality and excellent colours. For instance, about 6000 kg has been mined from just one lenticular ore body, with some individual masses of turquoise as heavy as 100 kg. At depths lower than 700 m

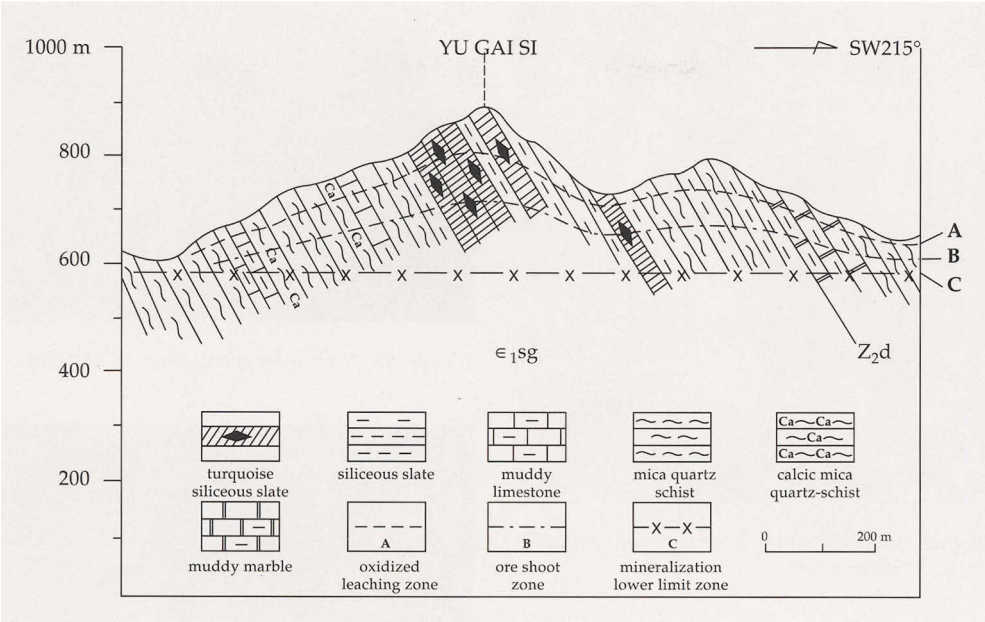

Figure 15: Schematic diagram of the turquoise range of occurrence.

above sea level, turquoise rarely occurs. But the quantity of massive allophanite markedly increases. Beneath 680 m above sea level, turquoise is virtually absent (these figures apply to the region whose water table elevation is about 800 m above sea level).

Gemstone and mineral features of the turquoise

Turquoise is a hydrous copper aluminium phosphate with a chemical composition of $CuAl_6(PO_4)_4 \cdot (OH)_8 \cdot 5H_2O$. Although the colour of turquoise is variable, its main chemical constituents Al_2O_3, P_2O_5 and H_2O, are relatively stable *(Table II)*.

Fresh turquoise, massive and opaque, displays a weak lustre described as waxy and a conchoidal fracture. Through the microscope the structure of turquoise can be seen to be cryptocrystalline to microcrystalline, and locally spherulitic *(Figures 16 and 17)*. In places, pisolitic and oolitic structures can be observed *(Figure 18)*. The refractive index of the turquoise ranges from 1.614 to 1.652, its hardness is between 5 and 5.4 and specific gravity lies between 2.56 and 2.78. Brown and black lines and irregular

Table II. *Chemical composition of turquoise from Yunyang, Hubei, China (in weight per cent oxides)*

Sample number	*Colour*	Al_2O_3	P_2O_5	Fe_2O_3	*FeO*	*CuO*	*CaO*	H_2O	*Total*
T-001	Blue	35.92	34.64	1.21	–	8.34	0.04	19.75	99.90
T-006	Pale-blue	36.12	33.40	1.14	–	7.52	0.02	20.64	98.84
T-019	Blue-green	35.57	34.15	2.70	0.03	7.17	–	20.32	99.94
T-022	Green	34.79	35.11	3.07	0.04	6.38	0.02	18.71	98.12
T-025	Yellow-green	34.06	34.89	6.58	0.08	6.23	–	18.73	100.57

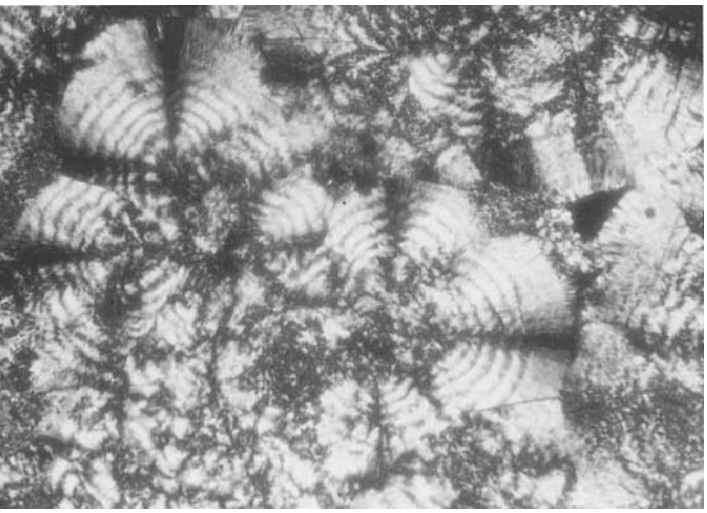

Figure 16: Spherulitic structure in turquoise, crossed polars, x100.

white veins in the turquoise are common features *(Figure 19)*; the black lines are attributed to carbonaceous material, and the brown to iron oxides or hydroxides.

Fourier transform infrared spectroscopy (using a Nicolet – 550) can be performed on KBr pressed discs containing the turquoise to determine its infrared absorption spectrum. One spectrum is shown in *Figure 20* where

Figure 17: Spherulitic structure of turquoise, crossed polars, x100.

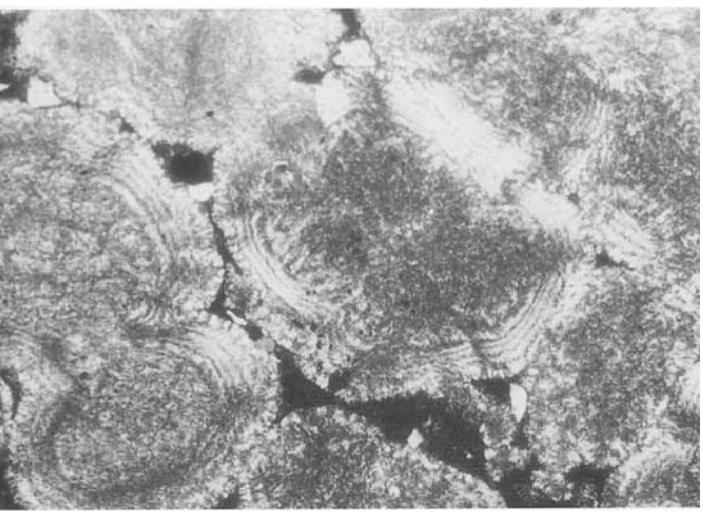

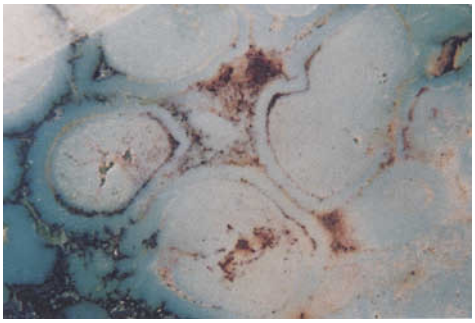

Figure 18: Turquoise displaying oolitic shapes, x20.

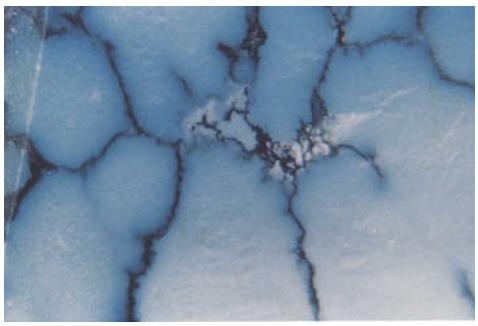

Figure 19: Irregular brown (iron) and black (carbon) lines with white vein striation crossing turquoise, x10.

the peaks are interpreted as resulting from the stretching and curving vibrations mainly from OH, H_2O and also from the $[PO_4]$ tetrahedron *(Table III)*.

In the present paper, the differential scanning calorimetry (DTA in DSC mode) technique is employed to determine the behaviour of turquoise powder with increase in temperature, with the turquoise samples and reference samples being subject to the same adjustable temperature conditions. The results are shown in *Figure 21*, in which the values on the ordinate represent Heat Flow (mW). The results show that the water (H_2O) in turquoise is driven off when heating through the temperature range from 350°C to 380°C, and the resulting endothermic effect is caused by the complete breakdown of the crystal lattice of the turquoise. Therefore, it is concluded that the water in turquoise occurs not only as crystalline water but also as

Table III. *Infrared absorption spectra of turquoise (peak positions in cm^{-1})*

Source	*Present paper (blue, 1996)*	*Zhang Huifen (blue, 1982)*	*H. Moenke (1962)*
Vibration type			
Stretching vibration of OH and H_2O	3508.70	3511	3508
	3465.97	3465	3463
	3448.20	3440	3446
	3289.15	3320	3295
	3088.23	3090	3090
Curving vibration of H_2O	1633.47	1625	1650
Stretching vibration of P–O(Υ_3)	1182.40	1184	1195
	1157.52	1160	1175
	1109.70	1105	1115
	1060.40	1050	1063
	1011.53	1010	1016
Stretching vibration of P–O(Υ_1)	902	890	905
Curving vibration of OH	835	837	838
	778	777	790
	723	717	
	698		
Curving of vibration of P–O(Υ_4)	648	645	615
	615	600	615
	588	585	596
	567	540	580
	502	475	480
	478	450	460
Curving vibration of P–O(Υ_2)	446		
	422	425	432
	410	405	411

Figure 20: *Infrared absorption spectrum of turquoise.*

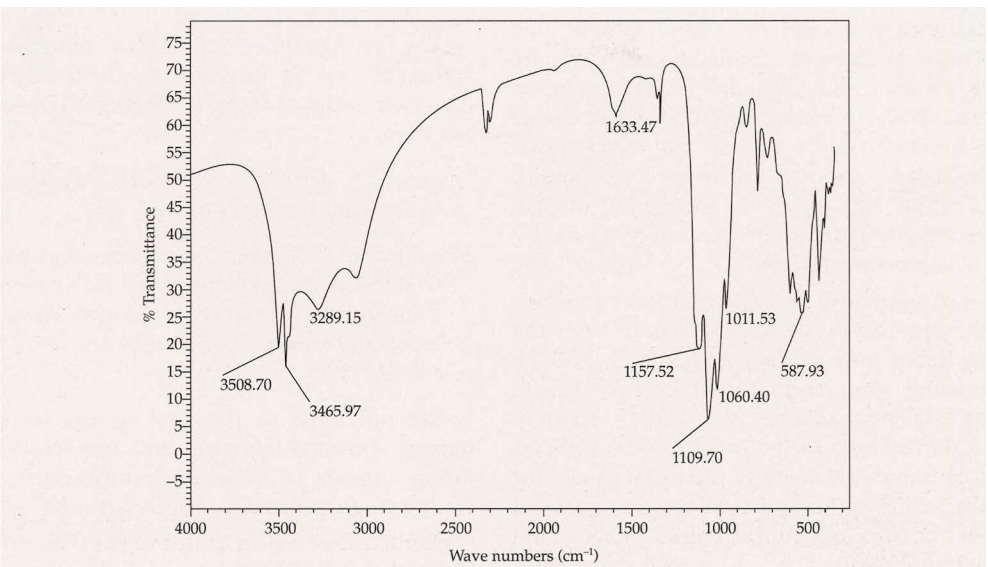

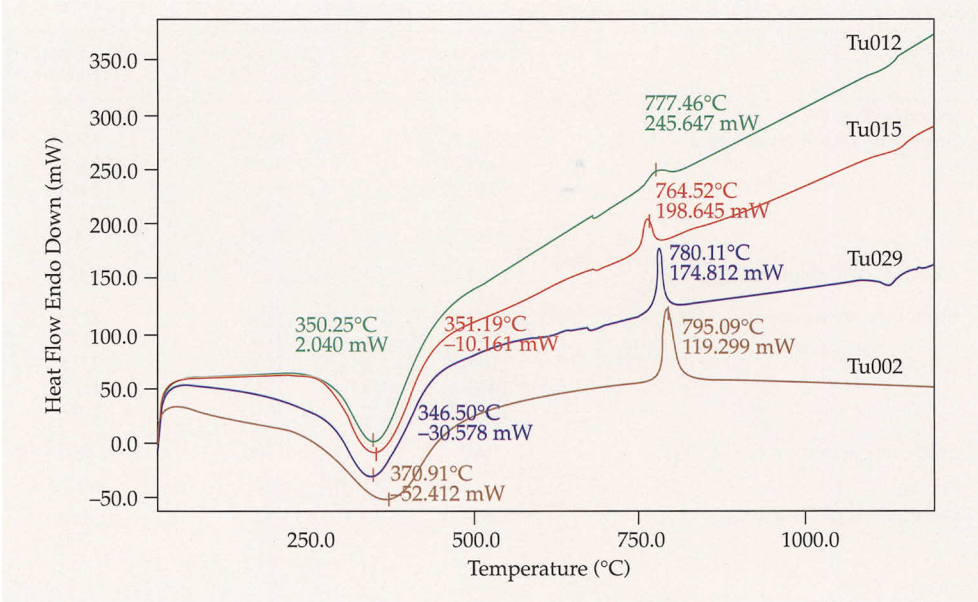

Figure 21: *Differential thermal analysis (DTA) in Differential Scanning Calorimetry (DSC) mode:spectra of turquoises of different colours. (Tu012 grey-yellow; Tu015 yellow-green; Tu029 blue-green; Tu002 blue).*

constitutional water, and the exothermic effect shown in the temperature range from 760°C to 800°C has resulted from recrystallization after expelling the constitutional water from the turquoise, resulting in a new heatphase transformation product. This phase is an aluminium phosphate whose structure is similar to those of cristobalite and tridymite (Khorassani and Abedini, 1976; Zhang Huifen *et al.*, 1982; Anderson, 1962) and whose colour is brown. In addition, it should be noted that turquoise samples differing in colour, hardness and degree of weathering display endothermic and exothermic effects at slightly different temperatures.

In summary, the colouring mechanism of the blue turquoise results mainly from the hydrated ions of copper $[Cu(H_2O)_4]^{2+}$. The existing form and content of H_2O in the turquoise structure plays an extremely important role in the quality of its brilliant colour and also is one of the major causes for the fading of turquoise. With an increase of Fe^{2+} or Fe^{3+} content, the colour of turquoise may vary from blue to blue-green to green.

Because the heat stability of the turquoise from this district is relatively poor, the gem should be well looked after and should be protected from too much exposure to the sun or to high temperatures. In this way the colour of the stone can be maintained.

The paragenetic and other minerals accompanying the turquoise can be divided into two major groups according to their origin:

1. quartz, sericite, colloidal apatites (collophane) and sulphides;
2. halloysite, allophane, variscite, evansite, woodhouseite, goethite, limonite, jarosite, chalcanthite, baryte, cuprocalcite, brochantite and azurite *(Figures 22, 23 and 24).*

The minerals in the first group were formed during diagenesis and the second group consists of minerals formed during weathering processes. Both groups of minerals are closely connected with the origin of the turquoise.

Figure 22: Evansite, an accompanying mineral of the turquoise.

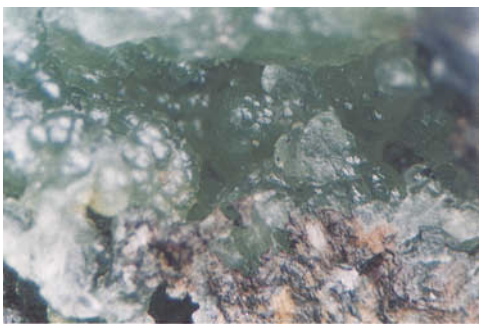

Figure 23: Variscite, associated with the turquoise deposit.

Summary

The Yunyang turquoise deposit is located at an intermediate latitude where humid and rainy seasons alternate with high temperatures and dry weather. This weather pattern is favourable for the weathering, leaching, migration, concentration and precipitation of metallogenic elements.

Weathering and erosion have affected the ancient land of Wudang for a long period of time, and a great number of metallogenic materials occur in this district. Their abundance in the ore-bearing rocks is tens of times the regional background levels. The copper and phosphorus occur mainly in finely dispersed sulphides in the carbonaceous-siliceous slates, and in the irregular patchy colloidal apatites (collophane).

The intensity of mineralization is controlled by lithology, structure and ground water level. The petrochemical indicators favourable for mineralization are high silica, copper and phosphorus and low CaO, K_2O and MgO; additionally, the ratio Al_2O_3/SiO_2 should be <0.05%, and $(CaO+K_2O+MgO)/SiO_2$<0.02%.

Figure 24: Brochantite, associated with the turquoise deposit.

The major ore shoot occurs in lenticular bodies compressed between the main rock strata. This ore-body morphology and the gem quality are both controlled by the scale of the fracture zone compressed between the strata. In space, the direction of the mineral occurrence is the same as that of the overall structural trend of the strata and faults.

The turquoise often occurs in massive nodules or as vein fillings. It contains concentric layered structures resembling specific spherulitic, oolitic or pisolitic bodies; such structures are characteristic of minerals formed by secondary leaching processes (Mitchell *et al.*, 1978). In vertical section, the turquoise deposit is markedly zoned as a result of ground water activity.

After comprehensive analysis of the geological features, the mineral compositions, the paragenetic mineral assemblage and structural features of the turquoise deposit, it is concluded that the turquoise in the Yunyang district was formed by secondary leaching processes.

There are strong indications that the turquoise resources of the Yunyang district have much potential and are of possible significant development in the future.

Acknowledgements

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Iridescence in plagioclase feldspars

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ABSTRACT: The play of colours shown by peristerite and some varieties of labradorite are an optical interference phenomenon caused by the occurrence of sets of plagioclase lamellae of two different compositions and thicknesses. It is now becoming clear that these lamellar intergrowths are restricted to and caused by two immiscibility regions in the compositional range of the plagioclase series. These cause distinct differences in the precise structure of the resulting plagioclases and the sharp boundaries of the lamellae.

Introduction

For at least two hundred years, mineralogists and gem lovers have marvelled at and enjoyed the strong iridescence shown by some labradorite, ever since the first specimens of this material were brought back from Paul Island, off the coast of Labrador, Canada, reputedly by Mr Wolfe, a missionary, around 1770 (Dana, 1982). But although numerous explanations have been advanced for this phenomenon, the first detailed scientific investigations were not reported until Lord Rayleigh's paper to the Royal Society in 1923 and that of Bøggild in 1924. Rayleigh (1923) made a detailed study of the optical scattering and calculated that the intergrowth texture giving rise to this scattering was ~6 µm across. Over the next two to three decades further work began to establish the existence of a layered structure, the iridescence in the visible range being an interference phenomenon (reminiscent of that seen in opal) due to the periodicity of the layered lamellar structures.

It was known from chemical analyses that no impurities or inclusions were responsible for this effect and that somehow plagioclase with more than one composition was present.

The advent of electron microscopy enabled the individual lamellae to be seen, e.g. Nissen *et al.* (1967), but it is only now that the crystal physicists, crystallographers and thermodynamicists have been able to provide a plausible scenario based on the plagioclase series as a whole.

It is believed that within the albite-anorthite series[1] there are at least three miscibility gaps due to structural transitions *(Figure 1)*. These were first mooted by Ribbe (1962) and their tentative boundaries outlined by McConnell (1974) and by Smith and Brown (1988), but the paper by Carpenter (1994) proposed an equilibrium phase diagram relating the three miscibility gaps to breaks in the ordering behaviour as a function of composition across the plagioclase series. It is unlikely to be a coincidence that iridescence is seen in the exact compositional ranges of these three gaps. These gaps have become known as the peristerite gap, the Bøggild gap and the Huttenlocher gap (Pe, Bø, Hu in *Figure 1*).

As mentioned above, the iridescence is an interference phenomenon and occurs because the lamellar intergrowths are on the same submicroscopic scale as the

1. For further details of feldspar nomenclature, etc., see, for example, Deer *et al.*, 1992.

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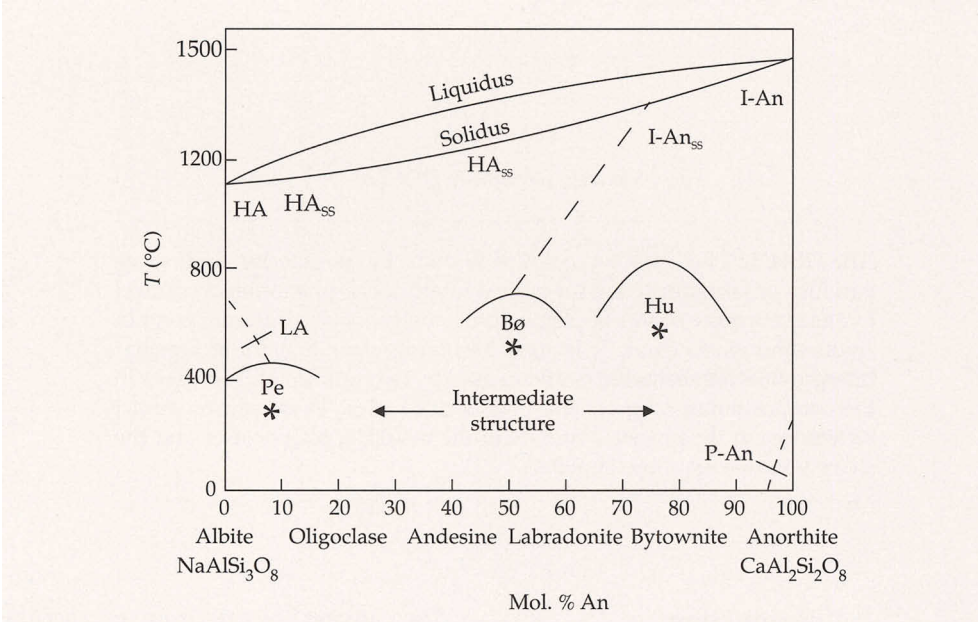

Figure 1: *Schematic illustration of variation in crystal structure across the plagioclase series. HA, high albite; I-An, body-centred anorthite; LA, low albite; P-An, primitive anorthite; ss (subscript) indicates solid solution; Pe, peristerite intergrowth; Bø, Bøggild intergrowth; Hu, Huttenlocher intergrowth (after Deer* et al.*, 1992). * Regions of 2-feldspar intergrowth.*

Figure 2: *Peristerite: sodic plagioclase showing 'delicate' interference colours.*

wavelength of visible light, i.e. a few hundred nanometres. In the plagioclase series there are two compositional ranges which may show iridescence, those representing a composition of the peristerite gap and the better known labradorescence in the Bøggild gap.

Peristerescence

Peristerescence is restricted to those plagioclases in the albite-oligoclase (An_1–An_{17}) range which show a play of colours (or schiller) reminiscent of those on the neck of a pigeon (Greek peristera). The name was given by Thomson (1843) for a specimen of iridescent albite in a granitic pegmatite from Perth, Ontario. Peristerite has since been described from Froland, Norway, and from many other localities in Ontario and the U.S.A. (Fleet & Ribbe, 1965) and Europe (Nissen *et al.*, 1967). The colours are generally more delicate than for labradorescence, often appearing on a white or buff-coloured plagioclase *(Figure 2)*. From

detailed work with the electron microscope and the electron microprobe, it has been shown that the colours are produced by alternating planar thick and thin lamellae of albite (An_0) and oligoclase (An_{25}), respectively. The sodic component is ordered low-temperature albite while the calcic component appears to be less well ordered oligoclase, the compositional difference being of the order of 20% An. The albite lamellae are always considerably thicker than the oligoclase lamellae, generally by 2:1; most simple lamellar peristerites have periodicities for a + b of 50–300 nm.

Figure 3: Labradorite: intermediate plagioclase showing strong interference colours.

Labradorescence

The second and more familiar type of plagioclase iridescence occurs in the andesine-labradorite (An_{45} – An_{60}) range and is known as *labradorescence*. After being originally found in orthopyroxene-plagioclase gabbro at Paul Island, it is now known to occur in the adjacent Nain gabbroic complex on the mainland of Labrador and in many Precambrian basic/ultrabasic igneous rocks worldwide. As in peristerite, labradorescence is an interference phenomenon due to reflected light waves from a multilayer assemblage of two periodically stacked lamellar structures. The colours displayed are in the blue, red and yellow parts of the spectrum, the overall effect being somewhat darker than for peristerite *(Figure 3)*. Nissen *et al.* (1967) carried out electron microprobe analyses of around 100 specimens and checked the presence of a submicroscopic layered structure by electron microscopy. They found that all the iridescent specimens contained an appreciable amount of the potassium feldspar (orthoclase $KAlSi_3O_8$) molecule (now generally put at ~2.5%) and that the wavelength of the average iridescence (colour) increased with the An content (blue $An_{48.5–52}$, green-yellow $An_{52–55.5}$, orange-red $An_{55–55.8}$). The lamellar periodicities for a + b are ~50–280 nm, but in labradorescence the difference in thicknesses of the two alternating lamellae is rather small, although the more An-rich set increases rapidly in thickness with increasing An content and the An-poor set decreases slowly. The differences in composition between the two sets of lamellae are ~12–15 mol. per cent An, typically from ~$An_{45–46}$ to $An_{58–60}$. Miúra *et al.* (1975) proposed a model with a schematic arrangement as shown in *Figure 4* for two compositional varieties of plagioclase, termed a and b. More recently, an investigation of Bøggild intergrowth in plagioclase from Ylämma, Finland, using high-resolution transmission electron microscopy demonstrated the occurrence of two phases of composition An_{60} and An_{47} for the thicker and thinner lamellae, respectively

Figure 4: Schematic representation of a model for lamellar structure in iridescent labradorite (after Miúra et al.*, 1975).*

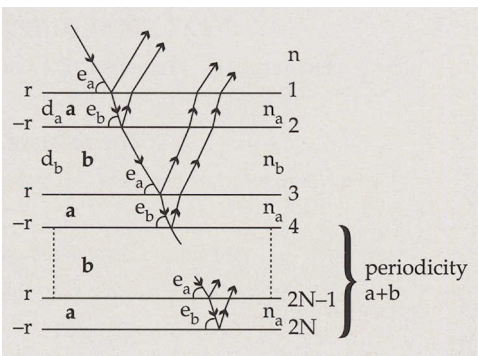

(Hoshi *et al.*, 1996), with a bulk composition of $An_{56.5}$; the matching of the crystal lattices across the exsolution lamellae was noted.

Huttenlocher intergrowth

The third of the miscibility gaps in the plagioclase series is in the calcic labradorite-bytownite range (~An_{67}–An_{90}). The lamellar structure in this region is called the Huttenlocher intergrowth and can be seen by electron microscopy. It is much coarser than intergrowths in the more sodic parts of the plagioclase series and so is unlikely to show any visible iridescence – indeed none has yet been discovered.

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Notes from the Gem and Pearl Testing Laboratory, Bahrain – 6

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ABSTRACT: Owing to amber's frequent use as prayer beads in the Middle East, we test quite a few pieces each month and these generally include some interesting or unusual examples. In these notes we will describe the surface enhancement, cavity filling, 'construction of and repair to' and chatoyancy observed in five amber prayer beads that were submitted for examination. The notes end with three items on pearls.

Surface-enhanced amber

Surface-enhanced amber is a topic we have discussed on more than one occasion in 'Notes from the Gem and Pearl Testing Laboratory of Bahrain' (Scarratt, 1992; Bubshait and Sturman, 1993). The reason for mentioning it again is that the colour difference between the surface area and the underlying 'body colour' of the 33 round beads, two disc-shaped spacers and one cylindrically-shaped terminating bead (the Arabic name for this bead is 'Shaahed') is exceptional. The row appeared semi-opaque to opaque, dark red to almost black when viewed under an ordinary desk lamp, and black in daylight. However, under a fibre-optic light source a translucent orange/red colour was observed, although it was still difficult to get a clear view of the interior as the light did not penetrate effectively even at full intensity. A saving grace for us was that the 'Shaahed bead' had been broken in two and this allowed the end of the fibre-optic light source to be placed right up against its 'interior surface'. It was evident that the pale yellow interior of this bead was markedly different from the dark orange/red marginal colour. With the customer's permission a small area around the fracture was tested with a thermal probe to see if more of the 'surface colour' could be removed to reveal the true underlying colour. This was carefully done to avoid spoiling the appearance of the bead's surface. Once removed (the material that was removed gave a typical resinous 'amber' odour) the colour difference was more noticeable *(Figure 1)*. Because it was difficult

Figure 1: *The obvious colour difference between the surface and interior of colour-enhanced amber.*

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Figure 2: The head section of the praying-mantis like insect.

Figure 3: Air bubbles trapped within the filler in amber (transmitted light).

to inspect the interior structure of the beads and find sufficient evidence for a natural or pressed structure, these beads were returned to the customer with only a verbal report. The customer was told that tests were inconclusive and further progress was only possible through removal of the coloured skin – either from a necklace bead or from material of the same type.

Filled amber beads

Although filled stones are often mentioned in gemmological literature, it is usually the more costly gemstones such as diamond, ruby and emerald that are involved. However, two sets of amber prayer beads examined recently, submitted by different customers at different times, revealed interesting fillings.

The first set consisted of beads that contained a number of good insect inclusions in mostly clear amber, including what appeared to be the head section of a praying-mantis-like specimen *(Figure 2)*. Unfortunately this inclusion was awkward to photograph. Most fillings were confined to small surface cavities, but two or three surface reaching fractures running through some beads were also filled. One characteristic of these particular fillings was that numerous air bubbles were found as inclusions within the filler *(Figure 3)*. In reflected light some of these bubbles were evident as 'blow-holes' on the surface (*Figure 4* transmitted and reflected light same feature).

Figure 4: The same subject as Figure 3 in reflected light. Note the 'blow holes'.

The second row comprising 33 prayer beads, weighed approximately 650 carats and did not contain insect inclusions. The beads were mostly transparent to translucent, clear to cloudy, yellow or yellow/orange and showed evidence of heat treatment. However, as it is not rare for amber to be heat treated these days, it was not this that interested us but a number of fillings. On the whole the beads were fine and unaffected, but the 'Shaahed' bead (see 'constructed Shaahed' below), two carved cylindrically-shaped spacers and one oval bead were each selectively filled. The material used to fill the 'Shaahed' looked

Figure 5: Large filled area in one of the oval amber beads.

Figure 6: An air bubble trapped in the adhesive used to repair a bead.

quite different from that used to fill the other three beads. In the 'Shaahed', one end of an unused drill-hole was filled with what appeared to be a transparent, possibly colourless or yellow adhesive, whilst the filler used on the other three beads took on a cloudy, translucent to opaque appearance, that could easily be mistaken for the frequently seen cloudy areas in some types of translucent to opaque amber. The cloudy filler was most apparent in the oval bead, where it had been used to fill a large surface-reaching cavity *(Figure 5)*, originally either a gas bubble or perhaps even the location of a pollen grain.

The fillers in both sets of prayer beads were first detected by optical examination. Secondly, exposure to ultraviolet light revealed a subtle difference in fluorescence that could easily have been overlooked, as the fluorescence of the larger amber beads masked the fluorescence of the filler. Finally, the thermal-probe provided confirmation of the presence of fillers in both sets of beads; each melted and gave wax-like odours. Although we could not identify the fillers, they were significantly different from amber.

Repaired and constructed 'Shaahed' beads

A Shaahed, the Arabic name given to the 'turned' cylindrical bead that commonly terminates a row of prayer beads *(Figure 7)*, is usually fashioned from the same material as the other beads in the row and also from a single piece of such material. There are also gold or silver 'Shaaheds' which are often more durable than amber. In many strings of beads we have examined, the 'Shaahed' has suffered breakage and then been repaired, with varying degrees of skill, using an adhesive. This problem is not surprising given the ratio of thickness to length of the 'Shaahed' and the sometimes rough handling that the prayer beads experience. The repaired area is usually very easy to detect, and commonly contains one or more bubbles in the adhesive *(Figures 6 and 7)*.

Figure 7: The constructed Shaahed. Note the translucency of the central section, compared to the pieces on either side. This bead was fashioned from three separate pieces of amber that had been bonded together with adhesive.

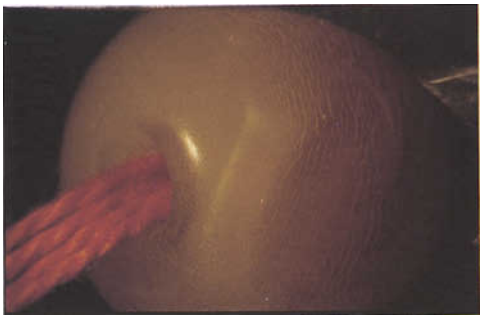

Figure 8: The chatoyant effect noted in one bead from a row of prayer beads.

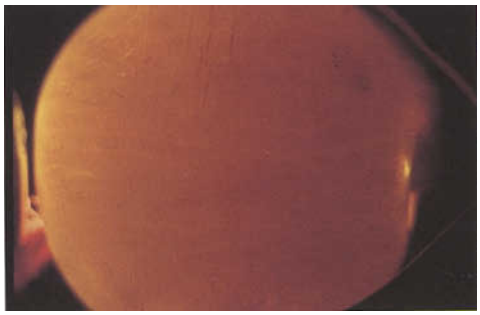

Figure 9: The 'banded' internal structure partly responsible for the chatoyancy seen in Figure 8.

Chatoyancy in amber

If students about to sit their gemmology examination were asked to name any chatoyant gemstone, they would probably suggest the names of the more likely stones such as chrysoberyl, quartz, tiger's-eye, apatite, tourmaline or scapolite. It would be doubtful if anyone would mention amber because it is not in the text books and until very recently we had not seen a convincing example. However, when we were carrying out a routine inspection of the beads in a row of prayer beads, we were surprised to find one bead that appeared to display a chatoyant effect near the drill-hole *(Figure 8)*.

Closer examination revealed that it was a chatoyant effect produced by finely banded streams of minute bubbles *(Figure 9)* combined with a series of 'chatter marks' in the same direction on the surface of the bead. The chatter marks seemed to enhance the rather weak chatoyant effect from the internal bubbles. As with obsidian, this is considered to be an accidental optical effect and not to be considered in the same way as chatoyant varieties of chrysoberyl or tourmaline whose optical effects are structurally controlled.

Figure 10: The 29.22 ct non-nacreous and nacreous, brown and white pearl.

Non-nacreous and nacreous pearl

Most of the pearls that gemmological laboratories around the world examine during their day-to-day routine are nacreous. Although these pearls are commercially more desirable, the majority of gemmologists and jewellers also know that there are certain non-nacreous pearls that are also very desirable, but much harder to find in good quality. These include pearls from various varieties of conch, namely queen conch [Strombus gigas], horse conch [Pleuroploca gigantea] and Melo volutes as well as pearls from other molluscs such as the giant clam (Tridacna gigas) and other lesser-known species. These species always produce non-nacreous pearls, unlike the nacreous pearl-producing species which can produce both kinds (Bubshait and Sturman, 1994, Hurwit, 1989, 1991).

A dark-brown pearl *(Figure 10)*, submitted for examination by Al-Majid Jewellery, showed this interesting phenomenon once again. The undrilled pearl, weighing 29.22 ct, and measuring approximately 18.21–18.34 x 14.51 mm, was found in the Arabian Gulf over forty years ago and has been in the possession of the Al-Majid family ever since. The button-shaped (bouton) pearl appears dark brown over most of its surface, but possesses a white circular area at its base. The whole of the brown area is non-nacreous, whilst the white area is nacreous. Since the pearl was undrilled, an adhesive was used to mount it into a ring for display at an exhibition in Bahrain. One of the Al-Majid brothers tried to recall from what species of oyster the pearl was found and although unsure (he was a young boy at the time), thought that it may have been from 'the same type of oyster that produces the usual (nacreous) pearls', i.e. Pinctada radiata. However, consultation with the Bahrain Centre for Studies & Research and another pearl merchant with a large stock of this type of pearl suggested that the oyster often, but not solely, responsible for producing this type of non-nacreous pearl (usually under 5–6 mm) is Pinctada margaritifera. Exactly which of these two species produced this particular pearl is unclear.

Gemmologically, this pearl was very interesting, because on first impression the white area on the base looked as if it could have been 'fixed' into position with an adhesive to fill a surface cavity. However, no features indicating a cavity of any description could be found with either a microscope or more importantly by using X-radiography. Close examination of the junction between the nacreous and non-nacreous 'junction' also revealed that, although a crack ran all the way around, a very small portion of the non-nacreous area was naturally intergrown with the nacreous area. One possible reason for development of a crack between the nacreous and non-nacreous areas, is that over time the climate together with natural ageing had produced natural shrinkage in one or both substances.

Figure 11: *Orange-red fluorescence displayed by the naturally coloured brown part of the brown and white pearl.*

The reaction of the pearl to ultra-violet light was additionally of great interest. *Figure 11* shows that the pearl fluoresced a strong orangey-red colour over the brown areas and a typical blue-white over the nacreous area at the base. This reaction fits in with those seen in other completely to partially coloured brown, black or grey pearls examined previously including the famous Hope Pearl (Kennedy *et al.*, 1994) and is generally considered to be proof that the colour is natural. The bright blue/white fluorescing areas in the cracks appeared to result from residual adhesive used to fix the pearl in the ring for display, described above. For interest, we contacted a number of natural pearl dealers in Manama (Bahrain's capital) and asked if we could browse through their stocks of brown/black pearls to try and find similar examples for comparison. After browsing through numerous lots of pearls, only a few were found to possess part-nacreous and part-non-nacreous sections, and their features were similar to those described for the large pearl discussed above. The varied fluorescence of three of these pearls can be seen in *Figure 12*.

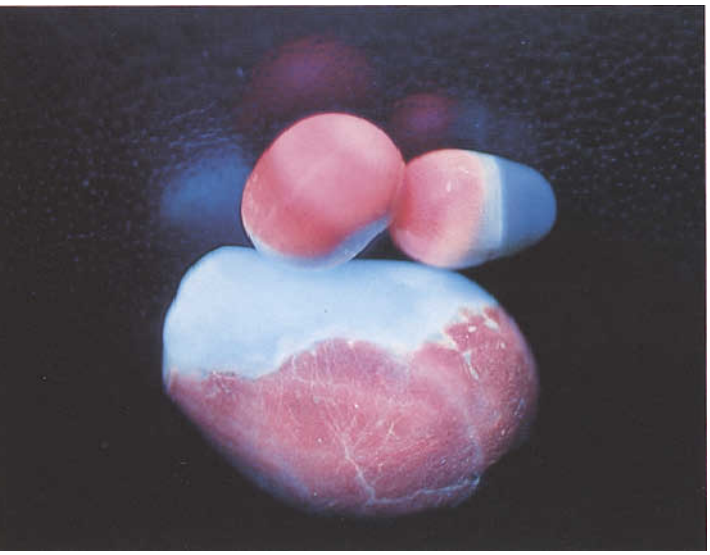

Figure 12: Three brown pearls showing red-orange fluorescence.

Figure 13: Radiograph showing the curious internal structure of the pearl purchased in Hong Kong (the opaque area around the pearl is due to lead).

Update on pearl-producing areas

In discussions with the Bandar Lengeh Fisheries Company (Iran) we have learned that most cultured or non-nucleated cultured pearls produced by Iran come from the islands of Khark (latitude 29°12′N, longitude 50°10′E) and Lavan (26°50′N, 53°15′E) or from along the Bandar Lengeh coasts. The small quantity of cultured and non-nucleated cultured pearls from these sources are usually supplied to the local jewellery trade. The pearl farm at Kish Island, reported by Anderson (Webster, 1983 p. 525) is apparently no longer operational.

In the laboratory, we see fairly large quantities of marine non-nucleated cultured pearls mixed with natural pearls. Up until our discussions with the Bandar Lengeh Fisheries Company, the thought that Iran could be the source of a majority of these was naturally in our minds. However, now our information is that most of the non-nucleated cultured pearls we see appear to originate from Japan as an accidental by-product of the traditional culturing process, i.e. 'keshi' or 'keshi-like' pearls. Large quantities of freshwater pearls from China and possibly Vietnam are also currently available throughout the Middle East and these are generally more prolific than the Japanese keshi pearls.

South Sea pearl

We were recently asked to determine the nature of a South Sea pearl pendant that had been purchased in Hong Kong (it was accompanied by a 'sales certificate'). We explained that the term 'South Sea pearl' usually refers to cultured pearls and the chances of it being natural were low. A radiograph *(Figure 13)* was obtained and proved surprising in that it did not show a shell bead nucleus as expected, but rather a cavity containing an inner 'solid body' that in turn had a small cavity. In normal circumstances, we would ask the customer to unset this particular pearl for further radiography, so that we could build up a three-dimensional image of the internal structure, in order to come to a positive result. Unfortunately, the customer was on a stop-over in Bahrain and had to board a flight the same day, so we had only a short time in which to examine it. Therefore, a

clear idea of the structure could not be determined. However, the internal and external appearance of the pearl suggested it was more likely to be of 'cultured' origin than natural and the price paid for it was consistent with this conclusion. How this pearl formed is unclear. If 'cultured', as expected, was its formation accidental or intentional? If the 'nucleus' was placed within an oyster on purpose to form the larger pearl, the correct nomenclature would be a cultured pearl; if, however, the 'nucleus' and resulting pearl were a result of accidental growth from a piece of mantle placed within an oyster, the term 'non-nucleated cultured pearl' would be more appropriate.'

Acknowledgements

The authors wish to thank Mr K. Scarratt for discussions on areas of the text during the compilation of these notes.

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Spinel and garnet star networks: an interesting asterism in gems from Sri Lanka

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ABSTRACT: Four-ray and six-ray star networks are reported in spinel and garnet from Sri Lanka. Details of their arrangement and orientations are discussed.

Keywords: networks, groups, loops, octahedral, rhombic dodecahedron

Introduction

Some Sri Lankan spinels and garnets exhibit star patterns comprising four-ray and six-ray stars combined in spectacular designs which will be described and referred to as *networks*. Complete networks can be seen in eggs cut from these stones *(Figures 1 and 2)*. While spinel can show only one network configuration consisting of four-ray and six-ray stars, garnet may display one consisting only of four-ray stars or another with both four-ray and six-ray stars.

Numerous long or short, slender and parallel crystal inclusions are responsible for the optical star effects and network formations. Several such inclusion groups (which may be simply called *groups*), orient themselves along several directions in the host crystal. In spinel they consist of either rutile (needle-like) *(Figure 3a)*, sillimanite (blade-like) *(Figure 3b)* or diffuse microscopic white granules which look milky and resemble a solution, whereas in garnet there are only rutile needles *(Figure 4)*.

Upon reflection of light from a group, a chatoyant band forms around it, in a plane at 90° to the length of inclusions, and develops an optical loop, in this paper described and referred to as a *loop*. Loops so generated from several groups are oriented in different directions and can intersect to form a web or a network. It is apparent that the star contents (ignoring the star type) of the 3 network configurations are determined by the efficiency of a loop which is defined by:

$$\textit{Loop efficiency} = \frac{\text{Number of stars in the network}}{\text{Number of loops in the network}}$$

Spinel

Four-ray and six-ray network (Figure 1).

A spinel octahedral crystal has six groups which orient parallel to the [110], [1$\bar{1}$0], [101], [10$\bar{1}$], [011] and [01$\bar{1}$] directions (i.e. at 90° to the virtual rhombic dodecahedral crystal faces). They generate six loops which intersect and form a network of eight six-ray stars and six four-ray stars. The former is located at the centre of every (111) face and the latter at every edge point where four crystal faces meet. The loop efficiency = 14/6 (i.e. each loop contributes to form $2^1/_3$ four-ray and six-ray stars).

Garnet

Four-ray network (Figure 2a).

A rhombic dodecahedral garnet crystal possesses four groups oriented parallel to the

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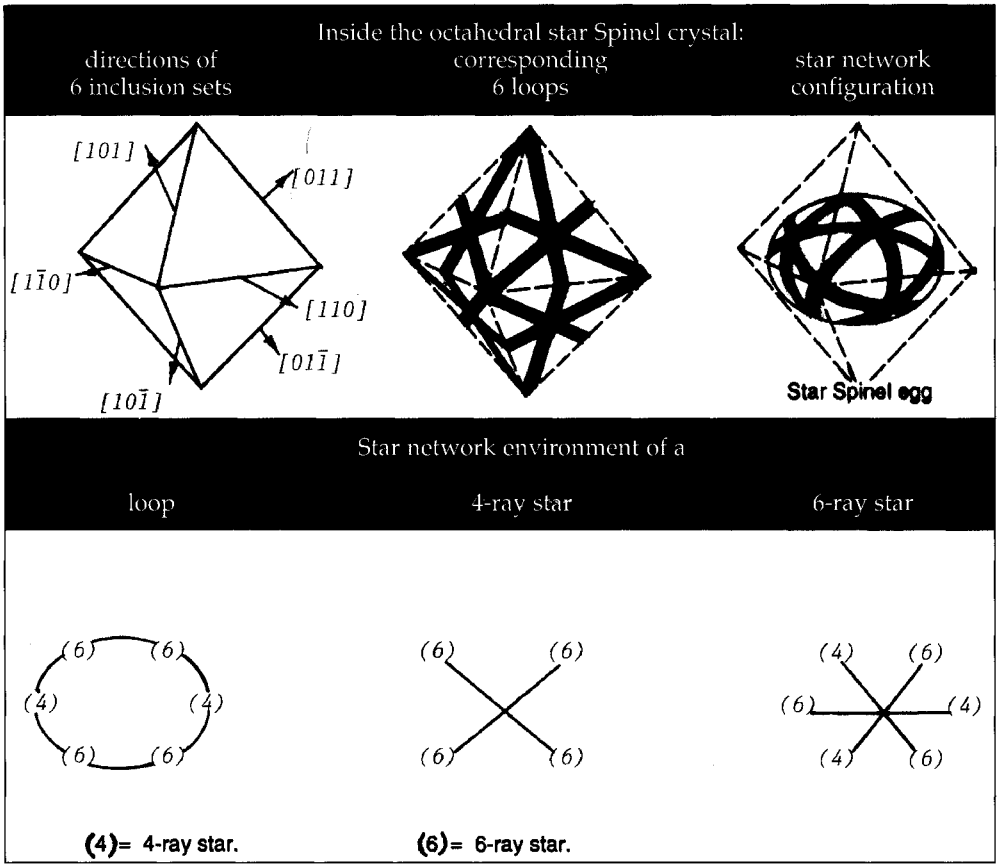

Figure 1: Details of spinel four-ray and six-ray star network.

[1$\bar{1}$1], [1$\bar{1}$1], [111] and [11$\bar{1}$] directions (i.e. at 90° to virtual octahedral crystal faces). These develop four loops, which intersect and create a network of twelve four-ray stars, at a rate of a star in the centre of every crystal face. The loop efficiency = 12/4 (=3), and, therefore, this kind of garnet network is more efficient than spinel loops but makes only four-ray stars.

Four-ray and six-ray network (Figure 2b).

A rhombic dodecahedral garnet crystal has 10 groups which fall into two classes of directions. One originates from a virtual octahedral crystal which coincides with the host crystal, with directions [110], [1$\bar{1}$0], [101], [10$\bar{1}$], [011] and [01$\bar{1}$] – as in the example of spinel above, and the other originates from the actual dodecahedral crystal with directions [111], [1$\bar{1}$1], [1$\bar{1}\bar{1}$] and [11$\bar{1}$]. Altogether they are responsible for 10 loops and thus could be labelled as six *octahedral loops* and four *rhombic dodecahedral loops*. Octahedral loops are invariably weak in intensity. Both kinds of loops may combine and create a network with thirty four-ray stars and twenty six-ray stars, making a total of 50 stars. The loop efficiency is 50/10 (=5) and although there are stars weak in intensity, these loops are the most efficient of the three networks discussed.

The correlation between octahedral and rhombic dodecahedral loops can be seen in the diagram given in *Figure 5*.

Box (b): A four-ray star results from an octahedral loop and a rhombic dodecahedral loop. There are 24 stars in total; each located on every corner where two dodecahedral

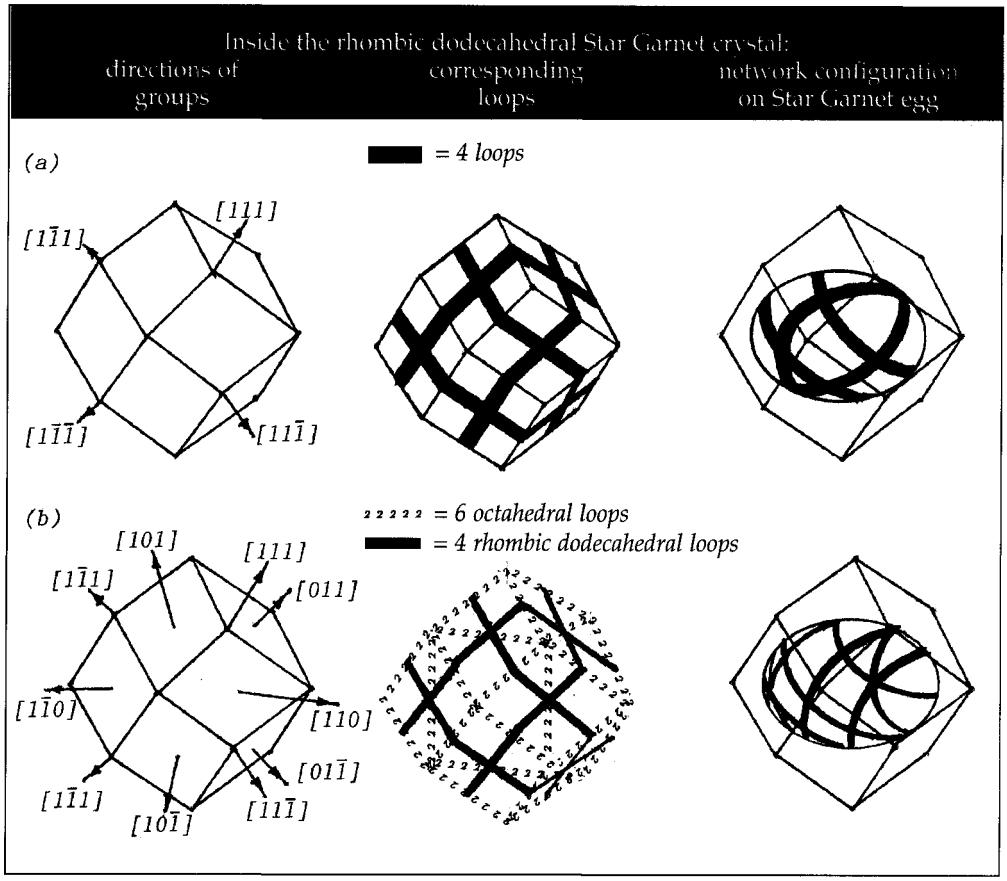

Figure 2: *Details of two garnet star networks.*

Figure 3(a): *Six-ray star isolated from the spinel star network.*

Figure 3(b): *Corresponding 'blade-like' sillimanite inclusion groups.*

Figure 4(a): Four-ray star isolated from the garnet four-ray star network.

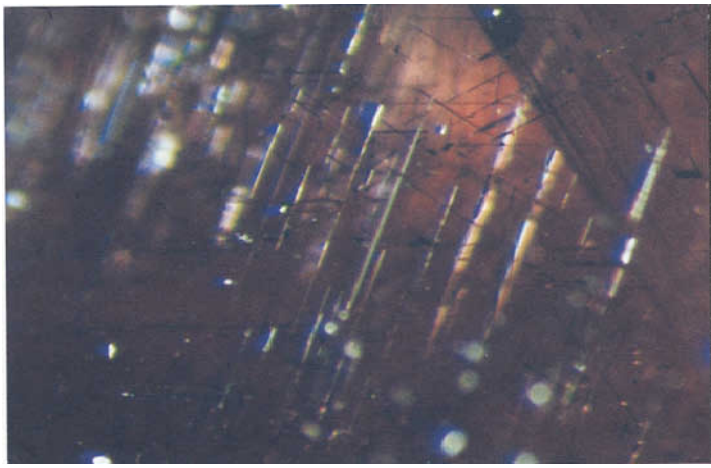

Figure 4(b): Corresponding 'needle-like' rutile inclusion groups.

Figure 5: Anatomy of garnet four-ray and six-ray star network.

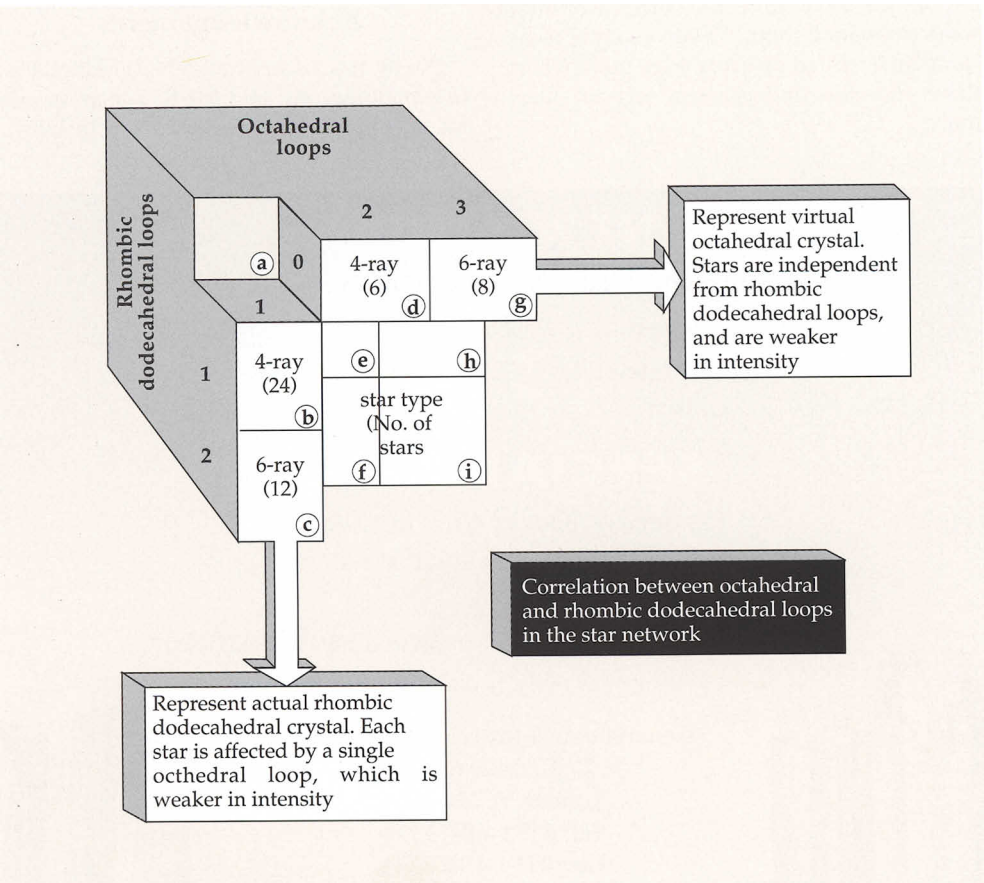

crystal faces meet. As the octahedral loop is weaker in intensity compared to the other rhombic dodecahedral loop of the four-ray star, rarely stones have been cut to isolate the stronger loop; the resulting stone may resemble a cat's-eye and thereby be potentially deceptive.

Box (c): A six-ray star results from an octahedral loop and two rhombic dodecahedral loops; again the weaker octahedral loop is immediately noticeable. There are 12 stars in total, each located at the centre of every rhombic dodecahedral crystal face.

Box (d): A four-ray star is formed solely by two weak octahedral loops. There are six stars in total and each is located on every edge point where four rhombic dodecahedral crystal faces meet.

Box (g): A six-ray star is the outcome of three weak octahedral loops. There are eight weak stars, each located on every edge point where three rhombic dodecahedral crystal faces meet.

Boxes (a),(e),(f),(h) and (i): These loop combinations are not valid for the network.

Boxes (b) and (c): Represent an actual rhombic dodecahedral crystal, where each star in the network is affected by a single octahedral loop.

Boxes (d) and (g): Represent an unaffected virtual octahedral crystal.

Conclusion

The directions of the inclusions and their contexts are the most important features in formation of the networks. First, they should be parallel with reference to each other to form a group and, secondly, several such groups orient themselves along specific directions related to the crystallographic orientation of the host stone.

Acknowledgements

Many thanks to Mr T.G.N.R. Malinda for fine photographs, and Mr R. Samaranayake for micro-photograph of garnet inclusions.

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Colour in topazes from rhyolite domes of the San Luis Potosi volcanic field, Mexico

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ABSTRACT: In the San Luis Potosi volcanic field (Mexico), both colourless and amber-coloured topazes (up to 4 cm) have crystallized in voids and fractures of the Cerro El Gato lava dome, near the village of Tepetate. They are well crystallized and the largest crystals are cut and marketed. In the neighbouring Cerro El Lobo lava dome, the topazes are very small (less than 5 mm) and slightly yellow tinted. Comparing these different crystals with respect to their growth environments in the field, habits, chemical compositions and EPR characteristics enable an explanation of the crystallization conditions and the amber colour to be given. The zonal distribution of the crystals in the deposits according to their colour can be used as a guide-line for prospecting.

Introduction

Topaz is an aluminium fluorosilicate, $Al_2SiO_4F_{2-x}(OH)_x$, that frequently occurs as accessory minerals in fluorine-rich rhyolites, pegmatites, greisens and hydrothermal veins. Deposits are known and mined in many places in the world (Hoover, 1992), such as in the Volyn region (Ukraine) and along the east side of the Ural Mountains, between Verkhoturye in the north and the Sanarka deposits, 400 km towards the south; along the eastern coast of Australia (Mount Surprise in Queensland is the largest topaz-producing area in Australia), in the western United States rhyolite belt (Thomas Range, Spor Mountain, Wah Wah Mountains in Utah, for example), in the Ouro Preto district and in the Jequitinhonha river basin (Minas Gerais State, Brazil), in Mexico on the eastern side of the Sierra Madre Occidental, from America in the Durango State to the north to Apulco (Hidalgo State) to the south. Clear and transparent crystals exist, but the most economically interesting ones (the gems) are usually yellow, brown, blue, pink or violet.

Most studies on topaz are focused on the crystallographic (Zemann *et al.*, 1979; Parise *et al.*, 1980), physical (Aines and Rossman, 1986; Londos *et al.*, 1992; Petrov, 1977; Ribbe and Gibbs, 1971), optical (Ribbe and Rosenberg, 1971), thermodynamic (Barton, 1982) and chemical (Akizuki *et al.*, 1979; Ribbe, 1982; Hervig *et al.*, 1987) properties with the purpose of identifying the colour origin (transition metals or colour centres)

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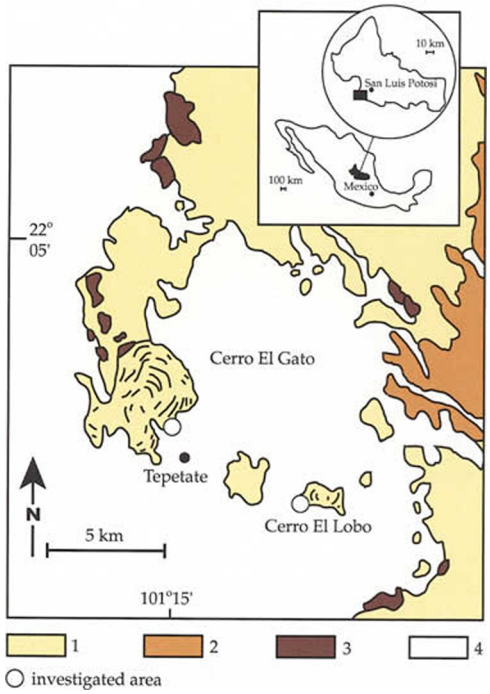

Figure 1: *Geological map and location of the Cerros El Gato and El Lobo (San Luis Potosi State, Mexico) (from Aguillon-Robles, 1994). 1 – San Miguelito rhyolite; 2 – Cantera ignimbrite; 3 – Panalillo rhyolite; 4 – Quaternary.*

and describing the morphological diversity. Topaz presents various crystal habits, well described by Goldschmidt (1913). Other papers deal with the petrogenesis of the topaz-bearing rhyolites (Christiansen *et al.*, 1985), the geological characteristics of the various topaz deposits (Hoover, 1992), origin (Olsen, 1971) and crystallization context (Foord *et al.*, 1988). But none of the papers combine the results of the laboratory analyses with the field studies to determine the growth conditions of the crystals.

It is the aim of this study to investigate the morphological properties (crystal habit and size) and the colour differences of some topazes from the San Luis Potosi volcanic field in Mexico, using both the field observations and the laboratory determinations of crystallography, chemical analyses by Inductively Coupled Plasma–Atomic Emission Spectrometry (ICP-AES) and Mass Spectrometry (ICP-MS), and Electron Paramagnetic Resonance (EPR) (Dewonck, 1996).

Features of Mexican topaz

Topaz-bearing rhyolites are common in Mexico. They correspond to an extensive Tertiary felsic volcanic belt which extends from central Mexico to western United States. In Mexico, the deposits related to rhyolite are located on the eastern side of the Sierra Madre Occidental, from Durango State (America and Cerro de los Renidios) to Hidalgo State (Apulco), but mainly in the central part of the belt in San Luis Potosi and Guanajuato States (Forshag and Fries, 1942; Menzies, 1995; Sinkankas, 1959, 1976). Crystals are usually rather small and a 10 ct gem would be considered large. However, in the Tepetate area (San Luis Potosi State) fine crystals may reach 15 cm in length and the largest flawless cut stone is reported as weighing 25 ct (Sinkankas, 1976). The topazes selected for investigation have been sampled from the Cerros El Gato and El Lobo, which are two rhyolitic domes of the San Luis Potosi volcanic field, near the village of Tepetate, 40 km southwest of San Luis Potosi city *(Figure 1)*. Only the topazes from the Cerro El Gato are worked. They are mainly marketed for mineral exhibition and sale. The largest or the best-crystallized stones are cut (M. Luna, Tepetate, pers. comm.).

Geological environment

The topaz-bearing San Miguelito rhyolite, with an age of 30±1.5 Ma (K–Ar method, Labarthe-Hernandez *et al.*, 1982) and 29.2±0.8 Ma (K–Ar on biotite, Aguillon-Robles *et al.*, 1994) is a silica-rich, meta-to peraluminous lava with a fluor content ranging from 0.1 to 0.35 wt%. Sn minerals (cassiterite) are always present in the lava dome, but are without economic value.

In the Cerro El Gato, the studied topaz-rich zones are located in the south-eastern border of the lava dome *(Figure 1)*, in a more or less anastomosed network of fractures and irregular and elongated voids (some 10

Figure 2a and b: *Topaz-bearing voids in rhyolites from the San Luis Potosi volcanic field. (a) (left) The anastomosed network of fractures and elongated cavities as exposed in the mined trenches of the Cerro El Gato deposits. This is considered as an open system for fluid circulation. Around the cavities the rhyolitic lava is greyish–white due to chemical leaching. (b) (right) The near spherical, closed and isolated cavities (up to 2 cm across) of the Cerro el Lobo lava (the largest cavity shown is 1.5 cm across).*

cm long), parallel to the lava flow *(Figure 2a)*. In the investigated zone, the lava flow is steeply dipping to near vertical, but topaz can also be observed in more or less horizontal lava flows. The colour of the topaz crystals (up to 4 cm) varies according to their location in the deposit. They are yellow to amber-coloured in the central part of the mineralized zone, whereas crystals towards the periphery are colourless, some with red to black inclusions of Fe-minerals. Hematite lamellae are also associated with these colourless topazes. Around the mineralized fractures, the initially grey rhyolite is paler in colour, resulting from chemical leaching. From the field observations, it can be concluded that these topazes have crystallized in an open system, where fluid circulated with possible renewal and chemical element enrichment.

The Cerro El Lobo *(Figure 1)* is a smaller lava dome, characterized by the presence of small (less than 20 mm) spherical-shaped, closed and isolated cavities, disseminated throughout the lava *(Figure 2b)*. As at Cerro El Gato, fluids have separated from the lava during rising and/or cooling, but in contrast to that locality the fluids at Cerro El Lobo did not coalesce and remained in the lava as isolated bubbles. However, very pale yellow topazes occur in these cavities, but do not exceed 5 mm in length. Their growth environment can be considered as a closed system.

Analytical procedures

Crystal habit

The various habits of the topaz crystals with their crystallographic parameters have been determined using a two-circle optical goniometer[1] for the millimetre-sized crystals and a self-collimating telescope for the centimetre-sized ones. The measurements of the angle between the normals to the crystal faces allow indexation of the crystallographically associated forms by their Miller indices. Four morphological groups can be thus distinguished. Using the Miller indices of all the listed pinacoids, prisms and bipyramids, the topaz crystal class (mmm) and their unit-cell parameters (a = 4.6499 Å, b = 8.7968 Å, c = 8.3909 Å) (Rosenberg, 1967), a theoretical crystal model has been drawn for each group *(Figure 3)* using the computer programme SHAPE and compared to the natural crystals.

Chemical characteristics

In order to characterize the factors that control the colour, 56 chemical elements

were analyzed in three crystals: an amber-coloured crystal and a colourless one from the Cerro El Gato and a slightly tinted one from the Cerro El Lobo. Eleven elements were analyzed by Inductively Coupled Plasma–Atomic Emission Spectrometry (ICP-AES)[2](Si, Al, Fe, Mn, Mg, Ca, Na, K, Ti, P, Sc), 43 by Inductively Coupled Plasma–Mass Spectrometry (ICP-MS)[3] (As, Ba, Be, Bi, Cd, Ce, Co, Cr, Cs, Cu, Dy, Er, Eu, Ga, Gd, Ge, Hf, Ho, In, La, Lu, Mo, Nb, Nd, Ni, Pb, Pr, Rb, Sb, Sm, Sn, Sr, Ta, Tb, Th, Tm, U, V, W, Y, Yb, Zn, Zr), Li by atomic absorption[4] and F by potentiometry[5]. Only the significant results are given in *Table I.*

EPR characteristics

Most minerals owe their colour either to the presence in their structure of transition metal and/or lanthanide elements as major or trace amounts, or to the presence of defects in their lattice (Dusausoy and Weil, 1994) formed by natural irradiation. Colour can be explained in a number of ways and these have been classified into four distinct groups: crystal field, molecular orbital, band theories or physical optic effects (Nassau, 1978). Pure topaz is a colourless mineral. Its colour can be due to the presence of trace amounts of a transition element and/or to hole/electron centres, which are colour centres and can be explained by crystal field theory. Most of these chemical defects are paramagnetic due to the presence of one or several unpaired electrons. Thus they can be identified by their electronic paramagnetic properties. Electron Paramagnetic Resonance (EPR) studies (Weil *et al.*, 1995) will provide data about the irradiation defects related to mineral colour. Although this analytical method is non-destructive if done on a single crystal, most EPR spectra are obtained from powder samples.

The crystal is placed inside the magnetic field B (Gauss) of the electromagnet which splits electron spin sublevels with an energy difference $g\beta B$ proportional to the value of the magnetic field (β is the Bohr magneton equal to $9.27314.10^{-21}$ erg G^{-1} and g is a non-dimensioned factor characteristic of the paramagnetic defect). For instance, in the case of one unpaired electron, there is a small but essential difference given by the Boltzmann distribution in the electronic spin

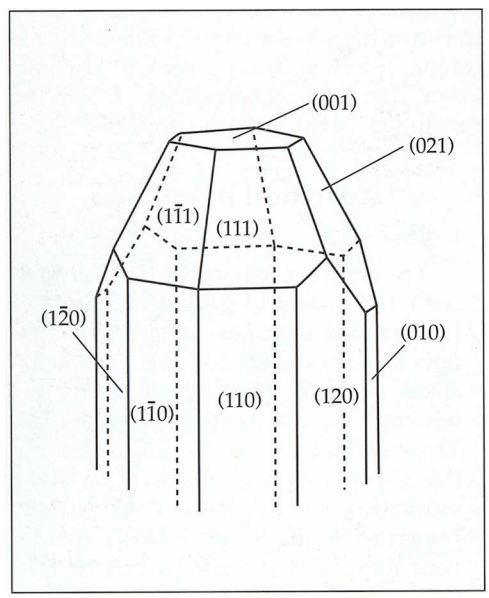

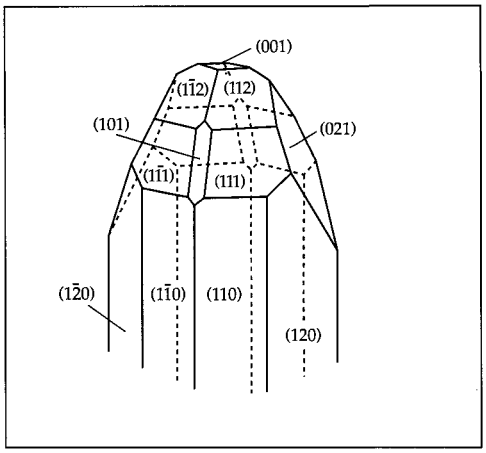

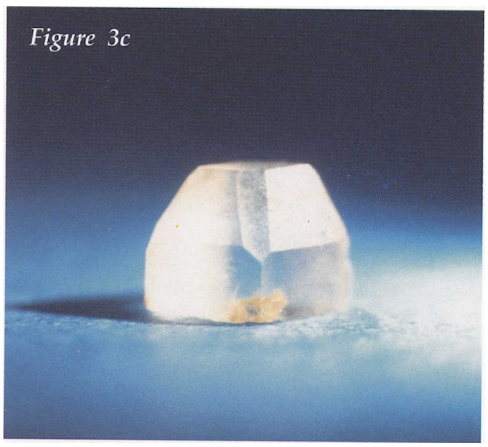

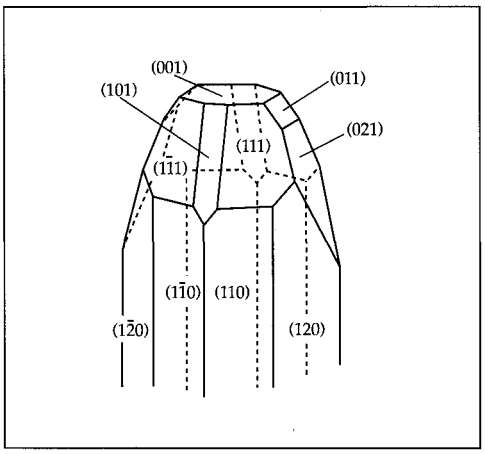

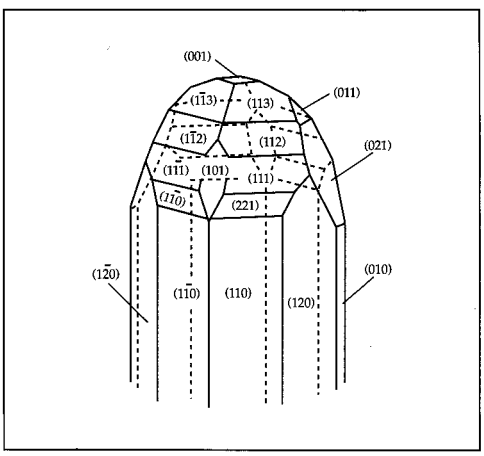

Figure 3: *Natural topaz crystals from the San Luis Potosi volcanic area and the theoretical habits of topaz crystals derived from computer calculations (produced by the computer programme SHAPE). The crystal morphology of the types is defined in Table I. a : type 1 (23 x 9 mm, 11.35 ct). b : type 2 (22 x 11 mm, 12.85 ct). c : type 3 (7 x 10 mm, 3.5 ct). d : type 4 (5.5 x 4 mm, 0.6 ct).*

Table I. Presence of the various forms in the four types of topaz crystals in the San Luis Potosi rhyolites.

locality		*Cerro El Gato*		*Cerro El Lobo*
type	*1*	*2*	*3*	*4*
colour	*amber and colourless*	*amber*	*colourless*	*yellow tinted*
size	*cm*	*cm*	*cm*	*mm*
crystal form				
{110}	+	+	+	+
{120}	+	+	+	+
{001}	+	+	+	+
{010}	+			+
{111}	+	+	+	+
{112}		+		+
{113}				+
{221}				+
{021}	+	+	+	+
{011}			+	+
{101}		+	+	+

populations of the ground and excited levels. A second magnetic field B_1 (frequency ν and energy hν, with h the Planck constant equal to $6.62554.10^{-27}$ erg.s) is used to stimulate transitions between adjacent energy levels. If the sample is placed in such a magnetic field B_1, applied perpendicularly to field B, inside a resonance cavity, it comes into resonance (r) when the magnetic field magnitude B or the frequency ν has been adjusted so that $h\nu r = g\beta B_r$.

In practice, adjusting ν is more difficult than varying B. An EPR spectrometer operates at constant frequency ν produced by a microwave source, i.e. an electron tube (Klystron) yielding a strictly monochromatic emission, but at variable magnetic field B produced by the electromagnet with two different configurations : X-band at ν=9.5 GHz ($9.5\ 10^9$ herz) with B from zero to 8,000 Gauss or Q-band at ν=35 GHz and B from zero to 20,000 Gauss.

In the simplest case, the resulting absorption curve shows a single line and the g factor defines the change in the position of the absorption line in the spectrum depending on the features particular to the state of the paramagnetic electron in the studied defect. But many nuclei of paramagnetic ions or ligands have a magnetic nuclear spin. In this case, if the electronic magnetic spin is in the neighbourhood of a nuclear magnetic spin, an interaction will produce an additonal weak splitting of the electron's spin levels. It will be expressed as new absorption lines in the EPR spectrum called hyperfine structure (HFS) if electronic and nuclear spins belong to the same atom, and called superhyperfine structure (SHFS) if the nuclear spin is located on the ligands surrounding the paramagnetic centre. SHFS is of prime importance in locating the electronic paramagnetic centre in the crystallographic structure. For instance, in topaz, the HSFS of the electron paramagnetic centre Fe^{3+} allows the conclusion that iron is linked to fluoride atoms with a nuclear spin. Thus iron substitutes for an aluminium atom to form an octahedron FeO_4F_2 and occupies a Wyckoff position 8d

of local symmetry point 1 in the space group Pbnm (n°62 International Tables for X-Ray Crystallography).

The EPR study was performed on the crystals that were chemically analysed; either single crystals (2 mm) or powders (60 mg) whose grain-size distribution is in the order of µm, using a Brucker spectrometer[6] operating at X-band between 0 and 4,000 Gauss at 95 K (liquid nitrogen temperature).

1 manufactured by N.V. nederlandsche Instrumenten compagnie, Venlo, Holland
2 JY70 type 2, manufactured by Jobin Yvon
3 model Elan 2000, manufactured by Perkin Elmer
4 model Perkin Elmer 4000
5 manufactured by Tacussel
6 manufactured by Brücker Spectrospin S.A., F-67160 Wissembourg

Results

Crystal habits

In the maximum symmetry of the orthohombic system, Miller indices {h00}, {0k0} and {001} describe pinacoids, {hk0}, {h0l} and {0kl} prisms and {hkl} bi-pyramids. Four morphological groups (types 1 to 4) are thus distinguished *(Figures 3a to 3d; Table I)*. The pinacoid {001} and a strongly developed prismatic system, which always consists of the {110} and {120} prisms, are observed in the four groups. The {010} pinacoid is not always present. The groups mainly differ from each other in the combination of pyramid forms. The crystal habits vary and are represented by 1 to 4 bi-pyramids and 1 to 3 prisms.

The morphology of type-1 topazes *(Figure 3a)* is the simplest and the pyramidal shape consists only of the combination of the {021} prism and the {111} bi-pyramid. The type-2 topaz crystals *(Figure 3b)* differ from those of type 1 by the addition of bi-pyramid {112} and prism {101} on the pyramidal termination. The type 3 habit *(Figure 3c)* is characterized by a combination of {111} bi-pyramid and {021} and {101} prisms. The type 4 morphology *(Figure 3d)* is the most complex with a combination of three prisms, {021}, {011} and {101}, and four bi-pyramids {221}, {111}, {112} and {113}.

The amber-coloured topazes from the Cerro El Gato are characterized by the presence of the type 1 and type 2 habits, whereas the colourless topazes, located in the border zone of the same mineralized structure, are of types 1 and 3. The type 4 morphology was only observed in small topaz crystals from Cerro El Lobo. The most complex habit thus appears to be characteristic of the smallest crystals, those which crystallized in a closed system.

Chemical characteristics

Major element contents have been determined only for two large crystals from the Cerro El Gato *(Table II)*. These topazes (average composition : SiO_2 = 33 wt%, Al_2O_3 = 57 wt%, F = 19 wt%) present a normal composition for topaz associated with rhyolites (Penfield and Minor, 1894). Compositional differences between the amber-coloured and the colourless crystals of the Cerro El Gato are very small.

The 44 trace elements mentioned above have been analyzed in the same crystals from Cerro El Gato and in a yellowish topaz from Cerro El Lobo. Only the significant element contents, i.e. those higher than the ICP-MS limits of detection, are given in *Table II*. For most of these trace elements, as for the major elements, there are no significant differences with respect to the crystal types.

However, some elements seem to be significant in each of the three crystals. The amber-coloured topazes are richer in volatile elements such as As and Sb, than the colourless ones. Conversely, the latter are richer in Li, Nb, Ta, Zr and in metallic elements, such as Cr, Ni and Zn. The small topaz crystals sampled in the vesicles of the

Table II. *Chemical composition of three representative topazes from the San Luis Potosi rhyolites*

Weight %	*Cerro El Gato*		*Cerro El Lobo*
	amber	*colourless*	*yellow tinted*
SiO_2	33.29	33.43	–
Al_2O_3	57.71	58.10	–
Fe_2O_{3t}	0.06	0.04	0.04
P_2O_5	0.06	0.07	–
LOI	1.28	1.30	–
F	18.77	19.10	–
	Cerro El Gato		*Cerro El Lobo*
μg/g	*amber*	*colourless*	*yellow tinted*
As	76.5	4.94	12.0
Ba	0.88	4.18	1.4
Be	tr	tr	1.12
Cr	0.97	3.26	0.89
Cu	1.04	0.94	3.5
Ga	7.68	9.34	13.6
Ge	23.8	21.8	21.2
Li	59	70	–
Nb	4.83	10.09	12.45
Ni	tr	3.39	2.26
Pb	1.01	1.1	1.27
Rb	2.4	1.63	1.13
Sb	0.29	0.03	0.22
Sr	0.18	0.19	tr
Ta	1.74	2.81	2.79
V	tr	0.05	0.47
W	1.97	2.34	0.91
Zn	1.52	2.84	5.96
Zr	1.78	5.32	4.37
numbers of ions on the basis of 24 (O, OH, F)			
Si	3.940}	3.926}	
Al	0.060} 4.00	0.074} 4.00	
Al	7.992}	7.971}	
Fe^{3+}	0.005} 8.00	0.004} 7.98	
P	0.006}	0.007}	
OH	1.011} 8.04	1.019} 8.12	
F	7.026}	7.095}	

Notes: The analytical results of various techniques have been combined in this table.
Total iron values listed as Fe_2O_{3t};
LOI means loss on ignition;
tr means trace;
– means not determined

Cerro El Lobo lava have an intermediate composition for both volatile and metallic elements; they also contain traces of Cu, Pb and Zn.

EPR characteristics

A number of investigations on coloured topaz have been performed in order to characterize the paramagnetic centres as potential causes of colour (Thyer *et al.*, 1967; Holuj and Quick, 1968; Barry and Holuj, 1973). Dickinson and Moore, 1967, connected colour and paramagnetic centres Fe^{3+}, V^{4+}, Cr^{3+} and six different colour centres corresponding to three electron-centres e^- (A, B, C) and to three hole-centres e^+ (X, Y, Z), which disappear with the colour by heating

to 500°C. Petrov (1993) gives a comparison of colour and paramagnetic centres between hydrothermal topazes (pink VO^{2+} and Ti^{3+}; orange Cr^{3+} and Mn^{2+}; yellow Fe^{3+}) and pneumatolytic topazes (colourless Fe^{3+} and AlO_4^{4-}; brown $SiO_4^{3-}/2^{27}Al$, $SiO_3^{3-}/^{27}Al$ and PO_4^{4-}; blue PO_3^{2-}).

In all three selected topazes, the Fe^{3+} spectrum consists of sets of SHFS mixed triplets (1400 to 1800 gauss) due to the coupling of the electron spin S of Fe^{3+} (S=5/2) and the nuclear spin l of each atom of ^{19}F (l=1/2, natural abundance 100%). The presence of one fluoride atom in the neighbourhood of Fe^{3+} induces 2l+1 resonance lines, i.e. a triplet in the EPR Fe^{3+} spectrum and the presence of n fluoride atoms induces 2nl+1 lines more or less mixed. The presence of Fe^{3+} in the colourless topaz indicates that this paramagnetic centre does not play any role in the colour of the investigated Mexican topazes. A very weak but broad band at 2500 Gauss can be possibly assigned to two PO_4^{3-} centres at two crystallographically nonequivalent positions.

The EPR-spectrum of the amber-coloured topaz *(Figure 4a)* exhibits several lines that are related to colour-centres (3200 to 3600 gauss). The first well-developed line (g = 2.01) is related to X hole-centre or to two $SiO_4^{3-}/2^{27}Al$ centres. The second (g = 1.88) is related to electron-centre A which vanishes with the colour by heating at 500°C. Two weak lines can be assigned to two B centres (g = 1.92 and 1.94). In contrast to that of the amber-coloured topaz the EPR-spectrum of the colourless topaz does not show additional lines that can be assigned to colour centres *(Figure 4b)*.

The slightly yellow tinted topaz *(Figure 4c)* presents, in addition to the Fe^{3+} centre, a broad band at 2850 Gauss observed on both powder and single crystal spectra, most probably due to magnetic micro-inclusions. The X-hole centre at g = 2.01 has produced the only well defined line in this spectrum. Thus the colour of the investigated topazes is clearly related to the presence of colour centres.

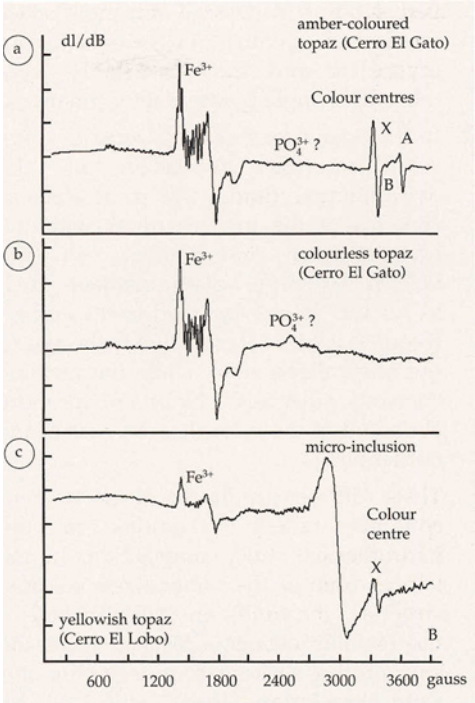

Figure 4: *EPR spectra obtained from powdered samples at T = 95 K, 9.45 Ghz (9.5 10^9 herz) with the magnetic field B ranging from 0 to 4000 gauss. The spectra correspond to the derivative of the intensity as a function of the magnetic field B. (a) amber–coloured topaz; (b) colourless topaz; (c) yellowish topaz*

Discussion and conclusion

1. The small topaz crystals from the Cerro El Lobo present the most complex habits (*Table I*, type 4), whereas the larger crystals from the Cerro El Gato are less complex (types 1, 2 and 3). Several factors can influence the crystallization of a mineral and thus its habit. From field observations it can be concluded that relationships exist between the size of the crystals, their habits and their crystallization environment. The vesicles where the type 4 topazes crystallized are small and considered as closed systems with low fluid abundance and no fluid renewal. Such conditions do not permit the development of large crystals. On the contrary, in an open system with fluid

percolation and renewal and more space (voids and fractures), larger crystals can crystallize and they invariably have relatively simple pyramidal terminations.

2. In the open system of the Cerro El Gato, with a free circulation of the hydrothermal fluids, the trace element contents of the topazes differ with the crystallization environment in the volcanic structure. Volatile elements, such as As and Sb, are enriched in the amber-coloured topazes crystallized in the axis of the mineralized zone, while the metallic elements, such as Cr, Ni or Zn, are more abundant in the colourless crystals of the border zone.

   These differences in the trace element contents reflect variations in the hydrothermal fluid composition. In the border zone of the mineralized volcanic structure, the fluids are still enriched in the metallic elements leached from the surrounding rocks during degassing and fluid circulation. Topaz will thus be enriched in these elements. Moreover, hematite lamellae are also observed in association with topaz in this zone. Consequent upon this, the fluids in the axis of the structure are impoverished in metallic elements but enriched in the most volatile elements, As and Sb.

   Crystallization in a closed system (Cerro El Lobo) results in topazes of intermediate composition with the presence of both metallic and volatile elements. This is due to the lack of opportunity for spatial fluid differentiation as in an open system.

3. Various studies indicate that the colour can be related to the ligand field effects in transition group metal impurities, and that elements such as Fe (Nassau and Prescott, 1975; Grigor'ev 1965), Ni (Deer *et al.*, 1982), Co (Deer *et al.*, 1982), Cr (Nassau and Prescott, 1975; Gübelin and Koivula, 1986) and Ti (Kievlenko, 1982) can be the cause of colour in gemstones. But in the investigated topazes of the San Luis Potosi area, these elements are either not present (Co, Ti), more abundant in the colourless crystals (Cr and Ni) than in amber-coloured ones, or present in all the crystals (Fe). This is in good agreement with the data of Dickinson and Moore (1967), who consider that Fe^{3+} plays no role as colouring agent, in contrast to previous studies (Lemmlein and Melankholin, 1951; Grum-Grzhimaylo, 1953).

4. The EPR studies clearly indicate that the colours of the crystals are caused by colour centres. According to Dickinson and Moore (1967), these colour centres are only stable below 500°C. We therefore may conclude that the colourless topaz crystallized first, in Ni–Cr–Zn-enriched fluids and at a temperature above 500°C, whereas the amber-coloured topaz crystallized most probably later, in volatile-enriched fluids at a lower temperature, below 500°C. The crystallization temperature of the small crystals, sampled in the vesicles of the Cerro El Lobo lava, could be around this temperature, since they contain only one colour centre. The crystallization temperature of the topaz is therefore an important parameter controlling the colour of the topaz in this area.

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Gemstones and ornamental stones from Bolivia: a review

Dr Jaroslav Hyršl[1] and Alfred Petrov[2]

1 Kolin, Czech Republic
2 Cochabamba, Bolivia

ABSTRACT: Gem, ornamental and collectors' stones from Bolivia are described. The most economically important are ametrine, amethyst, citrine, sodalite and stromatolite. Ametrine, amethyst and citrine come from the La Gaiba mine in eastern Santa Cruz department. The sodalite deposit of Cerro Sapo in Cochabamba department has been mined probably for almost three thousand years. Gem-quality beryl, cassiterite, phosphophyllite and vivianite are also briefly discussed.

Keywords: Bolivia, gemstones, ametrine, amethyst, sodalite, stromatolite

Introduction

Bolivia, in the centre of South America, is famous mainly for its vast deposits of silver and tin. It has been almost unknown until now as a source of gemstones. Only a few collectors of rare gems have known about the world's best cut cassiterites and phosphophyllites, but the situation has changed with the large production of ametrine in recent years; this has flourished in Bolivia's recent relatively stable political situation. Some relevant features of Bolivian gemstones and ornamental stones, including rare collector stones and several recent finds, are summarized below.

Figure 1: *Map of Bolivia showing main localities mentioned in the text.*

Apatite

Attractive transparent purple apatites were found in the 1940s in Llallagua and were described by Bandy (1944). More recently large apatite crystals have come from a magnetite-hematite vein cutting a dacite laccolith in Potosi department *(Figure 1)*. Crystals are up to 10 cm long, yellowish and opaque, and some have a transparent core. According to the X-ray analysis, both the core and crust are probably carbonate-hydroxylapatite. Stones faceted from this material are yellowish-white and

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Figure 2: Cassiterite from Viloco, weights 11.77, 2.31 and 1.09 ct (photo: P. Korbel).

Figure 3: Wood-tin cassiterite from Macha, length of largest cabochon 19 mm (photo: P. Korbel).

contain unusual needle-like inclusions. Their refractive indices are $n_o = 1.642$ and $n_e = 1.637$, specific gravity is 3.11–3.13. They have a pale orange luminescence in short-wave ultraviolet (SWUV).

Beryl

Very large opaque crystals of beryl have been known for a long time from pegmatites near Santa Rosa, San Ignacio de Velasco and San Ramon, east of Santa Cruz. Recently pieces with a transparent bluish core have been found and a few light aquamarines up to about 2 ct have been cut from crystals from the San Ramon area. Reports of alluvial 'aquamarine' crystals from streams draining the batholith north of La Paz city have not been confirmed.

In the eastern Santa Cruz department emerald occurs in veins of quartz and feldspar cutting shales. The crystals are up to 1 cm in length, are light green to a good emerald green, but are opaque and no cuttable material has yet been found.

Cassiterite

Cassiterite is one of the most important Bolivian minerals and the deposits are still a major source of tin. Probably the world's best cassiterite specimens come from the Viloco mine near Araca in La Paz department. Crystals from Viloco are up to 8 cm long and are often partially transparent, usually in a thin layer near the surface. The transparent part is usually yellow to brown but colourless cassiterites are also known *(Figure 2)*. Faceted cassiterites are usually less than 5 ct but there are rare stones up to 25 ct. Faceted cassiterites are extremely beautiful, but their brittleness and relative softness make them unsuitable for setting in rings.

A second type of cassiterite used in jewellery is the opaque colloidal variety called 'wood-tin', known mainly from the Condor-Iquina volcanic plateau of the Potosi department. It has a fine agate-like structure, sometimes with layers of opal or chalcedony and is usually brown, cream or yellow, more rarely black, red or pink. Cabochons cut from this material can be very attractive with a high lustre *(Figure 3)*.

Chalcedony

White to greenish or grey chalcedony with small blebs of native copper (in places oxidized to green malachite) is a very unusual ornamental stone. It was used for beads by pre-Columbian Indians and the source was rediscovered (Ahlfeld and Reyes, 1955) in the Turco Cu-deposit in northern Oruro department.

Another type of chalcedony was found by the authors in the vicinity of Capinota near

Figure 4: Rough chrome chalcedony from Chiquitania, length of largest piece 5 cm (photo: P. Korbel).

Cochabamba. Poorly consolidated Cretaceous sand and gypsum marl is cut by a large number of thin veins containing chalcedony which is usually milky but some bluish pieces resembling old chalcedony from Namibia were also found. Thicker veins usually have a centre filled with anhydrite.

Chrome chalcedony

Recently discovered in Bolivia, chrome chalcedony is called 'Chiquitanita' by local jewellers from its occurrence in the Chiquitania region in eastern Santa Cruz department. It occurs as small veins in a silicified laterite overlying Cr- and Ni-bearing ultrabasic intrusives. Some parts are coloured brown by Fe-oxides but the best material is translucent green and facetable *(Figure 4)*.

The refractive index of the chrome chalcedony is 1.530–1.550 with a birefringence up to 0.005 and SG of 2.56–2.57. It is a polycrystalline aggregate, which does not fluoresce in either short- or long-wave ultraviolet, but it is bright red under a Chelsea Colour Filter. The absorption spectrum shows an emerald-like pattern with two broad bands at 416 and 605 nm and a small peak at 684 nm, with a distinct minimum at 510 nm. Similar material was described under the trade name 'Mtorolite' from Mtoroshanga in Zimbabwe (see Phillips and Brown, 1989, and Webster, 1994). Dyed chalcedony (imitating chrysoprase) is brownish-red only under the Chelsea Filter and, when examined with a hand-held spectroscope, displays two absorption lines in the red part of the spectrum.

Some stones show a very fine agate-like structure and others contain a black 'net' of Fe-oxides. Most of the rough material is exported directly to Brazil and at the 1995 Munich mineral show the authors found cut chrome chalcedony described as 'apatite from Brazil', which could well have come originally from this source in Bolivia.

Danburite

Excellent doubly-terminated crystals occur in metamorphosed evaporites in the Alto Chapare region east of Cochabamba (Petrov, 1993). The danburite crystals are usually opaque, due to many dolomite inclusions, but some have been used in their natural shape to create unusual jewellery. Although crystals of up to 5 cm long have been found, their normal length is 1 to 3 cm. Several specimens of bluish danburite with parallel inclusions of a blue-grey amphibole, magnesioriebeckite, have been found and cabochon-cut specimens show a strong cat's-eye effect *(Figure 5)*.

Diamond

Diamonds have been reported from Permian glacial sediments of the Tequeje,

Figure 5: Cat's-eye danburite from Alto Chapare, cut stone 0.49 ct (photo: P. Korbel).

Figure 6: Phosphophyllite crystal about 15 cm long on matrix.

Suapi and other rivers in northern La Paz department by Ahlfeld and Reyes (1955) and Oppenheim (1943). They are colourless or pale yellow well-developed crystals generally weighing 0.10–0.35 ct, with some up to 1 ct. Two concessions were worked in the 1920s, but they proved to be uneconomic.

Kimberlites have been reported recently from the Ayopaya province north of Cochabamba, but information about diamonds is lacking.

Figure 7: Tri-colour ametrine from La Gaiba, 81.52 ct (photo: P. Korbel).

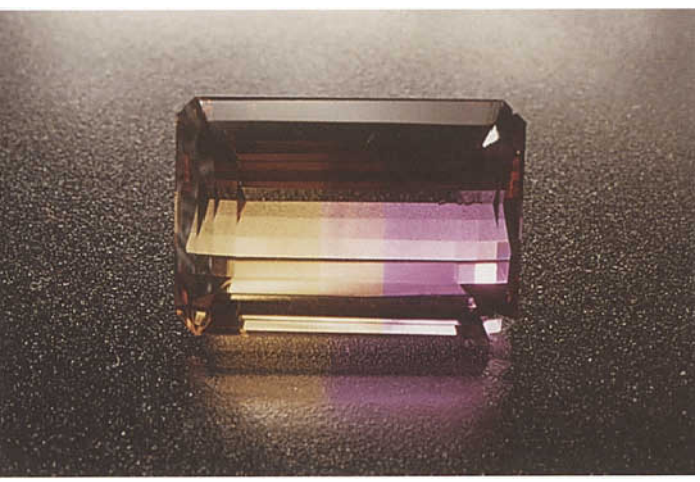

Fluorite

The Colquiri and Condeauqui fluorite occurrences north of Oruro have yielded many large pieces of transparent blue-green material.

Garnets

Dark almandines up to about 1 ct have been cut from small pebbles from alluvial deposits in Potosi department, but gem-quality garnets are rare in Bolivia.

Phosphophyllite

By far the world's best crystals of phosphophyllite were found in the 1950s and 1960s in the deepest levels, about 300 m

Figure 8: Ametrine slab with strong Brazil twinning, 39 x 22 mm (photo: P. Korbel).

Figure 9: Tri-colour quartz (purple–yellow–colourless) from La Gaiba, length 30 mm (photo: P. Korbel).

Figure 10: San Fermin amethyst mine (photo: J. Hyršl).

Figure 11: Amethyst specimens from San Fermin (photo: J. Hyršl).

underground, of the famous silver deposit of Cerro Rico de Potosi (Hyršl and Petrov, 1996). They have a unique blue-green colour, some are partially transparent and the biggest crystals are up to 15 cm long *(Figure 6)*. Only a few hundred crystals were found. Phosphophyllite is extremely difficult to facet due to its perfect cleavage, and of the limited number of faceted stones which do exist very few are over 10 ct (maximum 74 ct, Arem 1987). Consequently, they are in great demand by collectors.

Pyrargyrite

Several large faceted stones were cut from material from the very rich silver deposit at Colquechaca south-east of Oruro.

Quartz

Without doubt, ametrine (bi-colour amethyst-citrine quartz) is currently the most

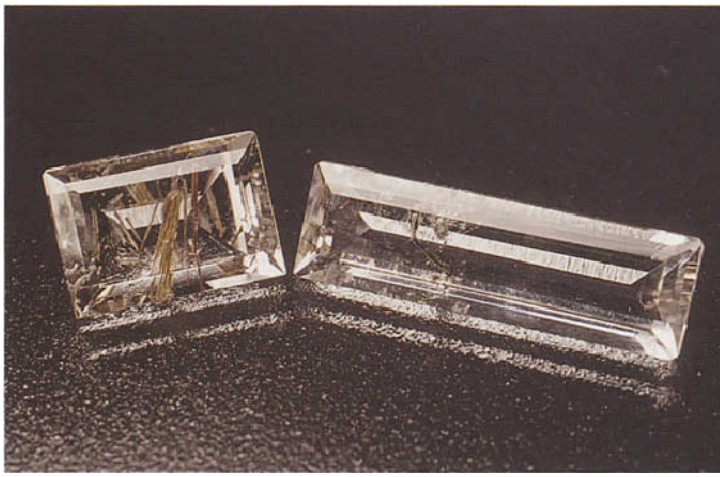

Figure 12: Quartz with dravite (4.20 ct) and arsenopyrite (5.69 ct) inclusions from Kami (photo: P. Korbel).

popular Bolivian gemstone (*Figures 7, 8 and 9*). Local jewellers call it 'Bolivianita'. The true locality was unknown for a long time, and some originally thought that it came from Brazil or that it was synthetic. Ametrine occurs at Anahi near La Gaiba in the far east of the Santa Cruz department in hydrothermal quartz veins which cut dolomites and limestones. The Anahi mine was described by Vasconcelos *et al.* (1994) and Collyer *et al.* (1994), but since then more ametrine deposits have been found in the La Gaiba area at the Mina Pobre, although quality and quantity do not match that from the Anahi mine. The mine at La Gaiba is probably also the world's only source of naturally coloured (unheated) citrine at the present time (Vasconcelos *et al.*, 1994).

Amethyst of very good quality is well known from the Anahi mine. Other amethyst occurrences from the La Gaiba area have yielded crystals up to 5 kg suitable for spheres or carving. Ahlfeld and Reyes (1955) described a huge hydrothermal amethyst vein 6 km long and 4 to 6 m wide near the town of Santa Ana in Santa Cruz department, but the amethyst here is of poor quality. Not far from Santa Ana, other vertical amethyst veins occur near the village of San Fermin. One vein is about 1 m wide and is accessed by a 33 m deep shaft

Figure 13: Sodalite boulder from Cerro Sapo, width 44 cm (photo: J. Hyršl).

Figure 14: Sodalite mining camp on Cerro Sapo (photo: J. Hyršl).

(July 1995, *Figure 10*). The vein has many cavities with crystals and the amethysts are strongly zoned, the tops of crystals being usually covered by milky quartz. Amethyst from the locality is rarely cuttable and is more useful for small carvings or tumbled stones *(Figure 11)*.

Quartz with unusual inclusions comes from several Bolivian localities and, when properly cut, can be an interesting material for jewellery. The most interesting inclusions are brown needles of dravite tourmaline and silvery metallic blebs of pyrrhotite, arsenopyrite and marcasite, all from the tungsten deposit of Kami near Cochabamba *(Figure 12)*.

Smoky quartz is rare in Bolivia, but a few large clean crystals up to about 50 cm long have come from recent diggings in the pegmatites of the Precambrian shield of Santa Cruz department.

Silicified limestone: An unusual fluorescent rock comes from Pajcha Pata, south of Cochabamba. It is a silicified dolomitic limestone from the Cretaceous Torotoro Formation. White carbonate grains have a net of dark chalcedony veinlets, wider veinlets are bluish and sometimes are filled by quartz microcrystals. Under short-wave UV, the carbonate fluoresces white and the chalcedony is green, while under long-wave UV the carbonate is yellowish and the chalcedony violet. The carbonate shows phosphorescence after exposure to either long- or short-wave UV.

Sapphire

Recently, several opaque to translucent blue sapphires have been found associated with almandine in alluvium in Potosi department. They reach only a few millimetres in size and few have been faceted. One 900 g translucent sapphire was found by Dr F. Ahlfeld in the gold placers of the Yungas de La Paz, but it too was of poor cutting quality.

Sodalite

Beads of blue sodalite have been found during archaeological research from almost all Andean cultural epochs including the oldest Mizque period (900–600 BC). The finds cover a very large area ranging from Ecuador to Argentina. Because a sodalite deposit was not known in the Andes, there were hypotheses about an origin outside South America. However, in 1923, the German geologist F. Ahlfeld found sodalite outcrops on Cerro Sapo (4200 m), Ayopaya province, Cochabamba department (Ahlfeld and Wegener, 1931). Nine old tunnels were found by Ahlfeld, the largest being 90 m long and 5 m high. Their ages range from pre-Incan to the latest period of mining in the eighteenth century by the Jesuits, who believed they were mining lapis lazuli.

The sodalite vein is about 3 km long (the productive part is much smaller) and from 1 to 5 m wide. In detail, the 'vein' is a unique type of carbonatite dyke, consisting mainly of pale green ankerite, white baryte, blue sodalite and

Figure 15: Stromatolite from Potosi; the edge of the cube is 8 cm (photo: J. Hyršl).

minor amounts of analcite, dawsonite, natrolite and sulphides *(Figure 13)*. It cuts both a nepheline syenite body and its surrounding hornfels and slate. The sodalite is an attractive blue and sometimes forms large slabs with a distinct zonal structure. Cabochons over 2 mm thick are opaque. One of the claims on the vein is currently exploited by an Italian company, which has a very well equipped mining camp on the slope of Cerro Sapo *(Figure 14)*. The content of ankerite causes brown patches in the sodalite and hinders outdoor ornamental uses.

More recently, a vein of sodalite up to 3 cm wide and of good quality was found near the town of Independencia. It lies about 20 km south of the Cerro Sapo occurrence and has the same strike.

Tourmaline

Green tourmaline occurs in the pegmatites of the Precambrian shield of eastern Santa Cruz department, but the cut stones are too dark to be attractive.

Vivianite

Good transparent crystals have been known for a long time from the tin deposits of Llallagua and Huanuni, but the best transparent crystals, some more than 20 cm in length, were found in the 1970s in Morococala, east of Oruro. Vivianite has a very distinct blue-green pleochroism. The excellent mica-like cleavage makes faceted stones extremely difficult to cut and therefore rare.

Other minerals and ornamental rocks

Chrysocolla and malachite are known from the vicinities of the Altiplano copper deposits, and there are minor occurrences of colourless topaz and adularescent feldspar in the alluvial 'wood tin' deposits of Macha in the Potosi department. Partially transparent siderite crystals up to 20 cm long have been discovered recently in Potosi.

Also from Potosi is an ornamental stromatolite called 'Pucalita' after its location in the Cretaceous Puca formation. It is an algal rock consisting mostly of calcite, dolomite and quartz with an overall hardness of about 4 and SG of 2.6. The stromatolite is yellow-brown to coffee-brown with distinct dark-brown or black layers and is cut and polished to display its wavy or concentric banding, the latter appearing as 'eyes' in appropriate specimens *(Figure 15)*.

A new red variety of stromatolite has been found in the Oruro department. Its colour is probably caused by hematite and its structure is the same as the yellow variety.

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Rock-forming minerals. [Second edition. Vol. 2B. *Single-chain silicates.*]

W.A. DEER, R.A. HOWIE AND J. ZUSSMAN, 1997. The Geological Society, London. pp x, 764, hardcover. £99.00 [£50 to Geological Society members]. ISBN 1 897799 77 2. Obtainable from the Society at Burlington House, Piccadilly, London W1V OJU [members] or [for members of the public] from Geological Society Publishing House, Unit 7, Brassmill Enterprise Centre, Brassmill Lane, Bath BA1 3JN.

While the progress of the second edition [of *DHZ* or *RFM*] would expect to produce a much larger body of information overall, this volume will probably be found to display a proportionately greater increase over its original form, first published in 1961. Mineralogists and geologists already know that the amphibole group has always posed problems of determination and nomenclature and continues to do so: advances in determinative techniques have, however, succeeded in setting out a base for some kind of permanent structure for the group, into which its individual members may fit more easily than before. At the time of reviewing the International Mineralogical Association is preparing to publish a review of amphibole group nomenclature.

Double-chain silicates are not all amphiboles, however, though the group takes up the bulk of the text. The interesting group of biopyriboles, the name coined in 1911 from pyroxene, amphibole and 'bio' to include the mica group, is surveyed for the first time in a major reference book.

The amphiboles are treated in four sections following a general introduction: Mg–Fe–Mn–Li amphiboles: calcic amphiboles (including tremolite and actinolite, the sections likely to be of most interest to the gemmologist): sodic-calcic amphiboles: sodic amphiboles. Then the biopyriboles are described and followed by the other double-chain silicates deerite and howieite, named after two of the book's authors.

Each section contains its own list of references and species are described structurally and chemically, with notes on experimental work, thermodynamic, optical and magnetic properties. Paragenesis completes the description of each mineral. As in previous volumes of both editions, lists show a number of representative examples, details being referred to the appropriate papers. The text contains well-drawn diagrams and the typeface is easy to read.

Naturally this is a text for reference and not for 'reading through' (although leafing through the text while on the track of one query throws up many other points which need noting for detailed examination later): gemmologists need to approach amphibole nomenclature with some care. Those who are also serious mineral collectors will do well to buy a copy – it is fortunate though of course inevitable that the complete work is being written and published quite slowly so that the sudden expense is not too irksome! While for Geological Society members the cost is very reasonable the list price seems fair, bearing in mind the work done over many years and so painstakingly assembled. M.O'D.

Cartier 1900–1939.

J. RUDOE, 1997. British Museum Press for the Trustees of The British Museum, London. pp 344, illus. in colour, hardcover. £50.00. ISBN 0 7141 0584 8.

The quickest glance into this beautiful book shows that it is an exhibition catalogue. In this case the exhibition is due (at the time of writing) to be held at the Metropolitan Museum of Art, New York, from 2 April to 3 August 1997, and at The British Museum from 3 October 1997 to 1 February 1998. While most of the text forms the catalogue, preliminary chapters describe the history of the firm of Cartier from its foundation by Louis-François Cartier in 1847 at 29 Rue Montorgeuil, Paris, and its division into three parts during the earlier part of the 20th century with separate enterprises in Paris, New York and London. The years from the establishment of the three businesses are described in the second chapter, which is followed by brief reminiscences of celebrated clients and by a review of production processes. Procedures and marks peculiar to each of the three branches are described. The three houses maintain their own archives which are fortunately available for jewellery historians: pages from stock books are reproduced.

The catalogue proper deals first with the gradual emergence of a distinctive style and then with the Russian style which began to appear from about 1906 with the production of hardstone flowers and which later developed into a wide variety of objects rivalling but not too closely resembling those produced by the firm of Fabergé whose London shop had closed in 1917, leading to a move of their clientele to Cartier. Gold and enamel fashion accessories, including cigarette and vanity cases as well as watches, are described in a chapter preceding a treatment of the Egyptian style which flourished from about 1910 to the 1930s: Persian, Indian, Chinese and Japanese styles of jewellery and accessories followed.

The catalogue continues with an account of Cartier's use of colour combinations (black materials with diamonds are especially characteristic), with diamond jewellery between the wars and with a review of design drawings. There is a glossary and a short bibliography.

Items are reproduced with full descriptions which include provenance, measurements, identification of materials, present whereabouts and publication where appropriate. With so attractive a guide we can only await the arrival of the exhibition itself with considerable anticipation. The price is by no means unreasonable for a book produced to so high a standard. M.O'D.

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Proceedings of the Gemmological Association and Gem Testing Laboratory of Great Britain and Notices

OBITUARY

Joseph Azzopardi, FGA (D. 1966), died on 19 September 1997 at his home in Nantwich, Cheshire, aged 72 years. Joe was born in Malta and attended St. Aloysius College until he was drafted into the British Army for the last two years of the Second World War.

On demobilization Joe joined the family business, The Sterling Jewellers (established as D. Azzopardi and Bros. in 1896) in Kingsway, Valletta. By 1971 he had become sole owner of the company and later opened a branch at the Phoenicia Hotel. Apart from retailing, he was closely involved with the design and manufacture of jewellery and with valuations.

By 1984 health problems led Joe to decide to sell the business and retire with his wife to England where his two children had settled.

Joe became an active member of the North West Branch of the GAGTL and served as both Secretary and Treasurer for six years. He was very much admired and respected by Branch members and is sadly missed. He was also a Registered Valuer with the National Association of Goldsmiths.

GIFTS TO THE ASSOCIATION

The Association is most grateful to the following for their gifts for research and teaching purposes:

Professor A. Chikayama, Japan, for a selection of I-pearls – imitation pearls made in Japan.

Luella Woods Dykhuis, Tucson, Arizona, USA, for a copy of the November 1978 issue of the *Lapidary Journal*, *Beautiful Queensland opals* by Lee Cram, eight pieces of quartz and also various packs of stones including emerald, sodalite, tourmaline, labradorite, fluorite and ruby.

Mr John R. Fuhrbach, FGA, Amarillo, Texas, USA, for specimens of cut and rough bytownite from New Mexico, USA, and for 45 items of rough and polished gems - a wide range of material from worldwide sources.

David Hargreaves, The Silurian Co. Ltd, Kingston-upon-Thames, for a rough ruby from Malawi.

High Pressure Diamond Optics, Inc., Tucson, Arizona, USA, for two 'busted' type IIa anvil diamonds.

Dr J. Kanis, Veitsrodt, Germany, for a selection of cut stones from South Africa, Zimbabwe, Zambia and Tanzania, including emerald, tourmaline, topaz, iolite, citrine and tsavorite.

Marcia Lanyon Ltd, London, for 357 various specimens including opal, garnet, ruby, sapphire (including a pinkish sapphire), peridot, topaz and spinel.

Mrs C.M. Ou Yang, Hong Kong, for five examples of B-jade, typical of material currently on the market.

Evelyn Ripley, Stockton, Cleveland, for 41 stones including ruby, spinel, quartz, jet, opal and turquoise.

Prashant R. Suchak of Suchak Mineral Resources Ltd, Arusha, Tanzania, for two tanzanite crystals.

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BEQUEST

We are pleased to announce that the GAGTL has recently benefited from a bequest made by Mrs Jeanne Maude Herbert Towers, daughter of the late Herbert Smith, CBE, MA, D.Sc., who was President of the Gemmological Association from 1942 to 1953.

Mrs Towers passed away on 16 December 1996 and in her will left the Association all her interest in the copyright of the book *Gemstones* written by her father in 1912 as the original set of course notes for the first gemmology course in the world. In addition she left the Association one half of the residuary estate; of which the Assent of copyright in *Gemstones* and a sum of £16 882 has already been received. An unquantified balance will follow at a later date.

At a recent meeting of the Council of Management it was decided to place the money from this bequest into the GAGTL Property Fund which, together with other monies received, will hopefully enable the organisation to acquire a building suitable to house all its activities and provide the standard of service rightfully expected by the membership.

To develop the GAGTL accommodation for teaching, research and gem-testing services is high on the Council's list of priorities and they would encourage members and well-wishers to consider remembering the GAGTL when planning their estates; whether it be in the form of gem materials, books, or a financial donation to either our research or building funds, these are always much appreciated.

MEMBERS' MEETINGS

London

On 24 September at the Gem Tutorial Centre, 27 Greville Street, London EC1N 8SU, Professor Robert A. Howie, President of the GAGTL, gave a talk entitled *Rock-forming Minerals – the writing of a classic.*

On 15 October at the Gem Tutorial Centre, Lynne Bartlett gave an illustrated lecture entitled *From sparks to sparkle – a brief history of the use of marcasite/pyrites.*

On 9 November at the Barbican Centre, London EC2, the GAGTL Annual Conference was held on the theme *Collectors' Gems.* This was followed on 10 November by a trip to the Natural History Museum, South Kensington. A full report of the Conference will be published in the *March issue of Gem and Jewellery News.*

On 3 December at the Gem Tutorial Centre, Professor Andrew Rankin of Kingston University gave a lecture entitled *Fluid inclusions: solutions for mineral genesis and gem identification.*

Midlands Branch

On 31 October at the Discovery Centre, 77 Vyse Street, Birmingham, Brian Jackson of the National Museums of Scotland gave an illustrated talk entitled *The sapphires of Scotland.*

On 16 November a Practical Gemmology Training Day was held.

On 28 November at the Discovery Centre, David Callaghan gave an illustrated talk on Opals.

On 6 December the Branch's 45th Anniversary Dinner was held at Barnt Green.

North West Branch

On 17 September at Church House, Hanover Street, Liverpool 1, Irene Knight gave a talk on jewellery, relating to her visit to Beijing, and Stanley Hill spoke on cloisonnè enamel work.

On 15 October at Church House, Dr Jack Ogden, Chief Executive of the NAG, gave a talk on matters concerning the jewellery trade.

On 19 November the Annual General Meeting of the Branch was held at which Irene Knight was re-elected Chairman, and Deanna Brady and Dr John Franks elected Secretary and Treasurer respectively.

Scottish Branch

On 20 October at the Royal British Hotel, Princes Street, Edinburgh, Brian Dunn gave a talk entitled *Gems – a valuer's heaven or hell?*

On 20 November at the Royal British Hotel Fred Woodward gave a talk entitled *Scottish River Pearls.*

PRESENTATION OF AWARDS

The Presentation of Awards gained in the 1997 examinations was held at Goldsmiths' Hall, Foster Lane, London EC2, on Monday, 10 November. The President, Professor R.A. Howie, presided and welcomed those present.

Professor Howie related a recent problem he had encountered: 'A research student from overseas, now studying in Britain a subject outside the earth sciences, wrote asking me to help a

FORTHCOMING EVENTS

1998

30 January	**Midlands Branch.** Bring and Buy Sale; Practical Gemmology Quiz.
18 February	**London.** Collecting gemstones in Scotland. Brian Jackson.
22 February	**Midlands Branch.** Gem Club – microscopy in all its aspects.
27 February	**Midlands Branch.** Chinese and Japanese pearls. Michael Houghton.
6–8 March	Field trip to Whitby
18 March	**London.** Fired with enthusiasm: the early history of enamel. Dr Jack Ogden.
22 March	**Midlands Branch.** Gem Club – Gemstones. Professor R.A. Howie
27 March	**Midlands Branch.** Dr Jack Ogden.
19 April	**Midlands Branch.** Gem Club – Bragging pieces; collectors' stones
19–25 April	Trip to Idar-Oberstein, Germany
22 April	**London.** Pearls – a fashion opportunity. Christianne Douglas
24 April	**Midlands Branch.** AGM followed by a mosaic of gemmological tessera
26 April	**Midlands Branch.** Diploma pre-examination seminar
3 May	**Midlands Branch.** Preliminary pre-examination seminar
13 May	**London.** The gemstone collections of the GAGTL
17 May	**Midlands Branch.** Gem Club – 'Black pearls' of Guyana, James Gosling, and The opals of Coober Pedy, Gwyn Green
29 June	**London.** Annual General Meeting followed by the Reunion of Members and a Bring and Buy Sale
8 July	**London.** The evolution of Georgian and Victorian jewellery. John Benjamin

For further information on the above events contact:

London:	Mary Burland on 0171 404 3334
Midlands Branch:	Gwyn Green on 0121 445 5359
North West Branch:	Irene Knight on 0151 924 3103
Scottish Branch:	Joanna Thomson on 01721 722936

GAGTL WEB SITE

For up-to-the-minute information on GAGTL events and workshops visit our web site on www.gagtl.ac.uk/gagtl

Dr Roger Harding, Professor Chen Zhonghui, Terry Davidson, Eric Bruton and (seated) Professor Robert Howie at the Presentation of Awards.

colleague in his home country who needed some crystal samples to be reliably identified. His colleague had already tried a National Museum in London and the X-ray Laboratory of a Midlands University but felt unhappy with the results. My name had been recommended as someone of scientific integrity whose opinion he could trust.

Preliminary Trade Prize winner, Simon Millard, receiving his prize from Professor Chen Zhonghui.

'Four specimens eventually arrived and a quick glance showed them to be virtually colourless crystal fragments, some 2 cm across, of calcite, fluorite and quartz (two) – but how to prove it to his satisfaction? Being retired and living in rural Derbyshire, I have no refractometer, spectroscope, X-ray facilities or even microscope – just a loupe and my wits! I have no hardness set as such, but hardness was the answer, and I was soon able to show that the calcite has perfect cleavage and was scratched by known fluorite; the fluorite had a very faint purplish colour, a good cleavage and was scratched by crystals of apatite and quartz and the two quartz pieces were readily scratched by topaz and ruby. I also noted that one quartz displayed growth trigons on one face: very proper for a trigonal mineral, but I wonder whether my overseas enquirer had growth trigons on diamond in his mind? I wrote out my report and have heard no more – but as the address on his notepaper was that of a National Mineral Exploration Programme, I did wonder as to his background!

'In an incident from earlier years, when I was responsible for assessing students for admission to the Geology Department at Kings College, a candidate bounced in and announced that he had a scheme he'd perfected for identifying minerals, did I want to hear it? I told him "No, but have a go at identifying this specimen," and I passed across a translucent octahedral crystal of diamond. "Fluorite," he said. I passed across a Mohs' hardness set and asked him to test it: he soon found that it scratched apatite, feldspar, quartz and topaz – at which point I stopped him, and said "Any comment?" "Hard fluorite!" was his astonishing reply! The moral of these two incidents is that (1) you should put your faith in someone of known integrity and (2) you must trust your results.

'But what is the relevance to tonight's occasion? Simply that you, the award winners, have indeed put your faith in the integrity of the Examiners appointed by the Gemmological Association, which is why you have come from all over the world to sit our examinations. Now put faith in their judgement and go forth with confidence to begin to develop your careers and to profit from your growing experience in the ever-increasing complexities of real gemmology.

'In January and June 1997, 1049 students entered the Preliminary, Diploma and Gem Diamond examinations. A total of 189 students passed the Diploma examination and they came from 21 countries, in all five continents. Here tonight we again have an international gathering

with successful candidates from as far away as Canada, Japan, Myanmar, Sri Lanka and the USA, as well as from Finland, Greece, The Netherlands and Sweden. Eighty-one students passed the Gem Diamond Examination and although this is not quite as widespread as the gemmology exam, there were successful candidates this year from China, Cyprus, Hong Kong and India.'

Professor Howie introduced Professor Chen Zhonghui from the China University of Geosciences in Wuhan who presented the awards. Professor Howie then called on Eric Bruton, immediate past President of the Association, to present the Bruton Medal to Miss Rita Tsang Wai Yi of Hong Kong, the first occasion on which this medal had been awarded.

Professor Chen delivered his address (see below) and a vote of thanks to Professor Chen was proposed by Terry Davidson who expressed the hope that the GAGTL and the China University of Geosciences would continue to work together into the twenty-first century.

In conclusion, Professor Howie thanked the Goldsmiths' Company for allowing the GAGTL to hold the ceremony at the Hall.

Eric Bruton presenting the Bruton Medal to Rita Tsang.

Address by Professor Chen Zhonghui

'I am very delighted to attend today's Presentation of Awards 1997. First of all, I would like to show my gratitude to the Gemmological Association of Great Britain which has kindly invited my wife, Professor Yan, and myself to pay this visit to your beautiful country. I am also honoured to present the Diplomas to those who have passed successfully the examinations this year. I would like to extend my warmest congratulations to the diligent students who have obtained the treasured Diplomas, especially to those who have obtained prizes this year.

'The Gemmological Institute, China University of Geosciences, started its co-operation with the Gemmological Association of Great Britain in 1988. Today is the tenth year of our friendly co-operation. In the spring of 1988, Alan Jobbins and Dr Jamie Nelson paid their first visit to our University at Wuhan, China. After the friendly negotiation, both parties worked together and eventually made an agreement that a new Allied Teaching Centre under the Gemmological Association of Great Britain be established in our University. This is the first ATC in the Chinese mainland, and also the first ATC in the Chinese language in the world. We will never forget Alan Jobbins, Dr Jamie Nelson and Ken Scarratt who offered us much help in the initial stages of our ATC. They once gave us this metaphor that the British teachers are like a wet towel; they expected our students to wring out this wet towel. Our students did not disappoint these British teachers! The sincere help from these British teachers has laid a solid foundation for the smooth development of our ATC since then. In 1993, a new Gem Diamond Course opened in our University with the help of Eric Emms. This is also the first in the Chinese mainland. Since the establishment of the ATC in our University, 155 students have obtained FGA Diplomas and 64 students have obtained DGA Diplomas, of whom 15 students have won the certificate with distinction, and five students have won prizes. The students in our ATC come from almost all the provinces, autonomous regions and municipalities in China. The graduates with FGA Diplomas have established the first gemmological testing laboratories in many different parts of China. In this sense, they have played an important role in the promotion of the gemmology and jewellery industry in China. The achievements of these graduates from our ATC have also made the FGA and DGA Diplomas by the Gemmological Association of Great Britain known all over China. The experience with the FGA and education in the Gemmological Institute of our University qualifies us to enrol the undergraduate students in gemmology at our University. In addition, the Gemmological Institute has already opened various short-term training programmes in gemmology and the gem diamond course. Around 2000 persons from the gem and jewellery

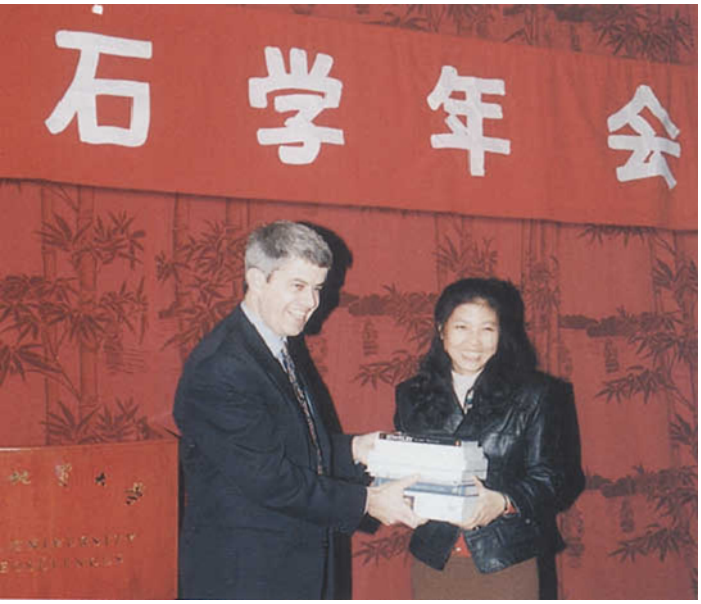

Stephen Kennedy presenting the Tully Prize to Ms Li Liping.

industry have been trained in these short-term programmes. Because of our persistent efforts and excellent achievements in gemmological education in China, the Gemmological Institute of our University has won the first prize in education at the provincial level, and the second prize in education at the national level in 1997. This has fully showed that what we have done has been positively acknowledged by the relevant authorities and by the public in China.

The first Allied Teaching Centre in the Chinese language in our university resulted in the present ten ATCs in the Chinese language in the Chinese mainland, Hong Kong and Taiwan, and this year also a new ATC in Singapore.

Looking back over the past ten years, we have enjoyed our friendly co-operation with the Gemmological Association of Great Britain. One major purpose of our present visit to your Association is to make a joint research with the Gemmological Association of Great Britain into the enhancement and development of our friendly co-operation with the Association and into the expansion of our field of co-operation. I am confident that more fruits will result from our sincere co-operation. I also sincerely hope that the Gemmological Association of Great Britain will make a greater development in the future.'

PRESENTATION IN WUHAN, CHINA

A presentation of gemmological awards, including those of the GAGTL, was held at the Gemmological Institute, China University of Geosciences, Wuhan, on 22 November 1997, during the Institute's Annual Conference. Stephen Kennedy of the GAGTL gave a lecture entitled 'Pearl Fishing and Pearl Identification' at the Conference and presented the Association's Diplomas and also the Tully Medal which had been awarded to Ms Li Liping of Wuhan.

FEEG EXAMINATION

REMINDER – FEEG application forms are available from Lorne Stather at the Gem Tutorial Centre, GAGTL. All applicants are reminded that they must already hold a gemmological Diploma from either GAGTL or one of the other member organizations. Candidates should note that there are no notes or other course materials available with this exam but that refresher courses could be arranged with sufficient notice.

Exam date – 7 July 1998

Final entry date – 31 May 1998

THE 26TH INTERNATIONAL GEMMOLOGICAL CONFERENCE (IGC)

The conference is biennial and was held in September-October 1997, at the Hunsruck Ferienpark Hambachtal, a conference and leisure centre outside Idar-Oberstein, Germany. It was attended by 44 delegates and 10 observers from 25 countries. The lectures listed below were delivered on 29 September to 2 October and covered a wide range of topics; a collection of abstracts of the talks was provided.

At the IGC business meeting held on 2 October, the place of the next meeting in 1999 was decided and Dr Panjikar of the Gemmological Institute of India, Bombay, will host the 27th IGC. Thanks were expressed to Professor Bank, his colleagues and family for a superbly organized meeting and programme of events.

On 3 October, the final day of the conference was spent on a field trip to the Eifel, north-west of Idar-Oberstein, to search for peridot, sanidine and hauyne in the lavas and tuffs – parts only 13 000 years old (some said they were still warm but that was just the autumn sunshine!).

R.R. Harding

Oral presentations (senior authors only listed)

Balitsky, V.S. The first commercial synthetic ametrine from Russia and its gemmological characteristics
Bosshart, G. Diamond inclusions in corundum
Brown, G. An opal nomenclature
Chikayama, A. The imitation pearl industry in Japan
Dereppe, J.M. Classification of emeralds by neural network analysis
Eliezri, I.Z. The isotopic composition of oxygen in emeralds as an indicator of origin
Forestier, F.H. Bactrian emeralds: myth or reality? Panjshir valley (Afghanistan)
Fritsch, E. The morphology of natural gem diamond: a status report
Fritsch, E. About a blue quartz from Madagascar (given on behalf of B. Lasnier)
Gao Yan. Research on Ti and Cr diffusion treated star sapphires
Gray, M. The benitoite gem mine: historical production and future potential
Graziani, G. The origin assessment of the Roman archaeological emerald
Gübelin, E.J. Gemstones of Switzerland
Hänni, H.A. Maw-sit-sit kosmochlor-jade: a metamorphic rock with a complex composition from Myanmar (Burma)
Harding, R.R. Collectors' stones
Hyrsl, J. Gemstones and ornamental stones of Bolivia
Joshi, V. Comparative study of Indian rubies *vis-à-vis* other rubies
Kane, R.E. Kashmir ruby – a preliminary report on the deposit at Nangimali, Azad Kashmir, Pakistan
Koivula, J.I. Reversible twinning in a unique synthetic material
Levinson, A.A. The Diamond Pipeline into the third millennium: part II. The role of the modern diamond cutting industry of India
Milisenda, C.C. The new Tunduru-Songea gem fields, southern Tanzania
Miyata, T. Relation between surface microtopographs and growth condition of quartz crystals
Ou Yang, C.M. Definition-nomenclature-classification of jade
Panjikar, J. New gem deposits from India
Pienaar, H.S. A fresh look at 'Kauri gum' from North Island, New Zealand
Poirot, J.P. Bezoar
Ponahlo, J. CL emission and photoexcitation spectrometry in gemmology
Saul, J.M. Libyan desert glass
Schmetzer, K. Characterization of Chinese hydrothermal synthetic emerald
Schwarz, D. The chemical properties of gem corundums from south-east Asia
Sevdermish, M. The Diamond Pipeline into the third millenium: part I. The restructured Diamond Pipeline: a multi-channel system and its effects on the retail diamond jewellery industry
Shida, J. Characteristics of cathodoluminescence for yellow diamonds of various types
Siripant, S. A gem colour communication system
Sobolev, N.V. Mineral inclusions in large crystals of Yakutian diamonds
Sunagawa, I. Growth-induced imperfections and inhomogeneities in single crystals
Superchi, M. Sapphire occurrences at Ambondromifehy, Antsiranana Province, North Madagascar
Sutherland, F.L. Remarkable similarities between gem corundum suites from Barrington, Australia, and Pailin, Cambodia, basalt fields
Tay, T.S. Amber identification using micro-Raman spectroscopy
Tillander, H. A critical analysis of rose cuts
Tombs, G.A. Distinction between natural and synthetic or imitation opal
Zoysa, E.G. Colour change garnet from Thelulla-Wellawaya, Sri Lanka
Zwaan, P.C. Cultured pearls from Indonesia

Poster presentations

Balitsky, V.S. High temperature pink quartz and other new synthetic coloured varieties of quartz
Graziani, G. Tomb n.2, Necropolis of Vallerano, Rome, Italy: study about the jewels
Joshi, V. Gemstone deposits of India
Kanis, J. Sandawana emerald mines, Zimbabwe
Shatsky, V. New hydrothermal synthetic sapphires, grown by TAIRUS Co. Ltd in Novosibirsk, Russia
Sutherland, F.L. Gem activities of the Australian Museum

GIA SYMPOSIUM : CALL FOR POSTERS

The Gemological Institute of America will host the 1999 International Gemological Symposium in San Diego, California on 21–24 June. More than 2000 people are expected to attend this pivotal event. The symposium programme – with the theme 'Meeting the Millennium' – will feature technical sessions and panel discussions on a variety of topics of vital interest to all members of the gem and jewellery industry. In addition, there will be an open Poster Session featuring original presentations on such topics as new gem materials, synthetic gem materials, treatments, gem identification and grading, instrumentation and techniques, gem localities, gem exploration, jewellery manufacturing, and jewellery design.

Contributions are being solicited for this Poster Session. To be considered for this important event (space is limited), please submit a preliminary abstract (no more than 250 words) to one of the Poster Session organizers by 1 October 1998. For further information on the Poster Session, contact Dr James Shigley at 760-603-4019 (Fax: 760-603-4021, E-mail: jshigley@gia.edu) or Ms Dona Dirlam at 760-603-4154 (Fax: 760-603-4256 or e-mail: ddirlam@gia.edu). For information on the Symposium, contact Carol Moffatt at 760-603-4406 (cmoffatt@gia.edu).

MEETINGS OF THE COUNCIL OF MANAGEMENT

At a meeting of the Council of Management held at 27 Greville Street, London EC1N 8SU, on 18 September 1997, the business transacted included the election of the following:

Diamond Membership (DGA)

Hun Lai Chan, Macau, Hong Kong. 1997
Josyfon, Bruce Michael, Hove, East Sussex. 1997
Law Wai Hung Raymond, Kowloon, Hong Kong. 1997
Simpson, Peter Robert, Richmond, Surrey. 1997
Yan Yee Mei, Kowloon, Hong Kong. 1997
Yip Shu Leung Christopher, Kowloon, Hong Kong. 1997
Yuan Joe Chih-Chung, Taipei, Taiwan, Rep. of China. 1997

Fellowship (FGA)

Cai Bing, Guilin, Guangxi, P.R. China. 1997
Chang, Circle Huen, North York, Ont., Canada. 1997
Garland, Mary I., London, Ont., Canada. 1997
Groom, Peter, Marlborough, Wilts. 1983
Hainschwang, Thomas Nikolai Alexander, Ruggell, Liechtenstein. 1997
Hazelius-Berglund, Wiveca, Lidingo, Sweden. 1997
He Xinping, Guilin, Guangxi, P.R. China. 1997
Kuang Yong Hong, Guilin, Guangxi, P.R. China. 1997
Li Dongsheng, Guiling, Guangxi, P.R. China. 1997
Ma Huei Chi, Taipei, Taiwan, Rep. of China. 1997
Ng Wai Ching, Hong Kong. 1997
Rimmer, Ray Ian, Bootle, Merseyside. 1997
Semenets, Elena, North Vancouver, BC, Canada. 1997
Teskeredzic, Senada, London. 1997
Tsang Wai Wan, Hong Kong. 1997
Yau Hau Yeung, N.T., Hong Kong. 1997
Zeng, Chunguang, Singapore. 1996
Zhang Sumei, Guilin, Guangxi, P.R. China. 1997
Zhu Yong, Guilin, Guangxi, P.R. China. 1997

Ordinary Membership

Astor, Flora, London
Barguirdjian, Ralph, London
Beaty, Julie Marie, London
Begley-Gray, Margaret Mary, Little Carlton, Newark, Notts.
Bhangu, Gurpaul, Ilford, Essex
Bhatia, Naresh, Richmond, Surrey
Burgoyne, Sheila, Totteridge, London
Chong Wai Ming, Orpington, Kent
Cooksey, Brian Derek, Bures St. Mary, Suffolk
Cortes, Carolina, London
de Botton, Caroline Coelho, London
Draper, Zoe Shaw, Upper Abbeywood, London
Dupuy, Harold A., Baton Rouge, La., USA
Freakley, Sharon Adele Maud, Bangkok, Thailand
Gandhi, Amar A.A., Stanmore, Middx.
Garrett, Frances S.J., Crawley, W. Sussex
Gray, Gisella, London
Grech, Carrieann, Richmond, Surrey
Greenfield, Dawn Melanie, Eynsford, Kent
Hunter, Pauline A., Caversfield, Oxon.
Kang, Bong Suk, London
Kellerson, Laurent P., London
Kemp, Margaret Anne, Backwell, N. Somerset
Konstandopoulou, Garoufallia, Athens, Greece
Lin, Chia Wei, London
Maung, Hla Wai, Singapore
Noyce, David, Bognor Regis, W. Sussex
O'Byrne, Rose-Marie, Bicester, Oxon.
Paphitis, Constantinos, Limassol, Cyprus
Patel, Nita, Newbury, Berks.
Paulsen, Sarah-Jean, Cutteslowe, Oxford
Riga, Olybia, Athens, Greece
Rollisson, Adelia, London

Saunders, Frank, Spennymoor, Co. Durham
Sethi, Barti, London
Shemirani, Payam, London
Strathnikova, Mariya, Stratford, London
Tulo, Karen Simone, Ludwigshafen, Germany
Tulsyan, Shalini, Karnataka, India
Valrani, Anju, London
Verhoeff, Dirk Jacobus, Leeuwarden, The Netherlands
Wood-Heath, David Lewis, near Meopham, Kent
Young, Geoffrey William, Surbiton, Surrey

Laboratory Membership

Arts & Antiques Ltd, London W1
Jethro Marles Trading Co., Newton Abbot, Devon, TQ12 5LD
The Southern Goldsmiths, Haywards Heath, Sussex, RH16 4LA
T.M. Sutton Ltd, London, SW1E 5LB

Transfers from Fellowship to FGA, DGA

Ball Edwards, Chantal, Cheltenham, Glos.
Brooke-Webb, Susannah, London
Cadby, John H.V., Trowbridge, Wilts.
Carlsson, Johanna A., London
Cookson, Ian, Darnall, Sheffield, Yorks
Dempster, Stuart, Shettleston, Glasgow, Scotland
Harris, Annette Mia, Hanbury, Worcs.
Heilpern, Helene, Epping, Essex
Hopley, Katharine Bridget, Coventry, West Midlands
Lin Hsin Pei, Wuhan, Hubei, P.R. China
Mao Lingyun, Beijing, P.R. China
Martin, Jennifer Frances, Acton, London
Papadopoulos, A. Dimitrios, Athens, Greece
Randall, Garry Marshall, Kingston, Surrey
Stather, Lorne Francis, Charlton, London
Stead, Graham Scott, Tillsonburg, Ont., Canada
Thornton, Timothy John, Wimbledon, London
Varey, Irena Maria, Ullesthorpe, Leics.
White, Robert, Kingsthorpe, Northants
Wu Ming Hsun, Wuhan, Hubei, P.R. China

Transfer from Ordinary Membership to DGA

Fielding, Geoffrey Ian, Tottington, Bury, Lancs.

Transfers from Ordinary Membership to FGA

Arsenikakis, Helena, Blackwood, SA, Australia
Bappoo, Reenabai, Croydon, Surrey
Barsk, Christer, Pello, Sweden
Bienemann, Andreas M., Polsbroek, The Netherlands
Christou, Angelos, Halkoutsa, Limassol, Cyprus
Deligianni, Christina, Athens, Greece
Deutscher, Gilad, Kiryat Ono, Israel
Dykhuis, Luella Woods, Tucson, Arizona, USA
Edwards, Heidi, Burntwood, Staffs
Endo, Masahiko, Osaka City, Osaka, Japan
Forward, Stephen, London
Glaser Nvk, Sonja I., Galle, Sri Lanka
Hill, Emma, Maida Vale, London
James, Robert C., Naples, Fla., USA
Kataoka, Noriko, Machida City, Tokyo, Japan
Koshiba, Shoko, Sagamihara City, Kanagawa Pref., Japan
Lam, Jill, Rochester, Kent
Lee, Dongjae, Happoku, Masan, S. Korea
Maehara, Tamao, Isesaki, Gunma, Japan
McCabe, Marianne C., Guildford, Surrey
Monje, Lucy, Santa Fe da Bogota, Colombia
Moore, Rowan Duggan, Stoke, Coventry, Warwicks.
Ohtsuka, Mayumi, Neyagawa City, Osaka, Japan
Renard-Richard, Joelle, Ruislip, Middx.
Seki, Shoko, Osaka City, Osaka, Japan
Shih, Shu-Chuan, Hampstead, London
Soderstrom, Jenny, Lannavaara, Sweden
Suzuki, Noriko, Ikoma City, Nara Pref., Japan
Tashiro, Hisami, Uji City, Japan
Vernon, Penny Ann, High Wycombe, Bucks
Wang Chien Ling, Taichung, Taiwan, Rep. of China
Yoshitake, Yumi, London

Transfers from Ordinary Membership to FGA, DGA

Feng Hsiu Yun, Wuhan, Hubei, P.R. China
Verney White, Catherine, Fulham, London
Wong, Yik Shih, Kuala Lumpur, Malaysia

Transfers from Diamond Membership to FGA, DGA

Nottbusch, Jurgen Uwe, Appel, Germany
Stossel, Hilary Jeanne, Perth, WA, Australia

At a meeting of the Council of Management held at 27 Greville Street, London EC1N 8SU, on 15 October 1997, the business transacted included the election of the following:

Diamond Membership (DGA)

MacDonald, Karen Jane, Dundonnell, Wester Ross, Scotland. 1997
Mak, Tsui Sim, Hong Kong. 1997

Fellowship (FGA)

Beentjes, Theodorus, Chichester, West Sussex. 1990
Cowley, Jacalyn Gloria, Wimbledon, London. 1997
Hsieh Juan Ku-Wei, Shin Juang City, Taipei, Taiwan, Rep. of China. 1997
Hutton, Katie, London. 1997
Kazemi, Sima, North Vancouver, BC, Canada. 1997
Konstantara, Aikaterini, Thessaloniki, Greece. 1997
Lindroos, Anna Karoliina, Pori, Finland. 1997
Lithiby, Jonathan Peter, Kingston-upon-Thames, Surrey. 1990
Lui, Alice Miu-Ling, Richmond, BC, Canada. 1997
Mäkäräinen, Päivi Helena, Helsinki, Finland. 1997
Niemi, Markku, Lappeenranta, Finland. 1997
Powell, Gergory J., Prestatyn, N. Wales. 1986
Suninmäki, Virpi Kristiina Annika, Helsinki, Finland. 1997
Tse Kwok Fung Matthew, Kowloon, Hong Kong. 1989
van der Vijgh, Caroline Elvira, Diemen, The Netherlands. 1997
Wells, Andrew, Caterham, Surrey. 1991
Yogalingam, Nirupa, Colombo, Sri Lanka. 1997
Zhao, Ying Ying, Nanning, Guangxi, P.R. China. 1997

Ordinary Membership

Arnold, Jane Elizabeth, London
Bernard, David Alfred William, Carshalton Beeches, Surrey
El Moussawi, Hamed, London
Fan, Po Chu Cynthia, Scarborough, Ont., Canada
Hodgson, Jane, Watford, Hertfordshire
Middlemiss, Ronald David, Norhill on Tweed, Northumberland
Mittal, Smita, Delhi, India
Olivares, Elka Marie, Gibraltar
Sujanani, Ramesh K., Ocho Rios, Jamaica, W.I.

Laboratory Membership

Dynasty Jewels Ltd, London EC1N 8LY

At a meeting of the Council of Management held at 27 Greville Street, London EC1N 8SU, on 19 November 1997, the business transacted included the election of the following:

Diamond Membership (DGA)

Hsu, Robert, Taipei, Taiwan, Rep. of China. 1997
Pattni, Unnat Nagin Gordhandas, Kingsbury, London. 1997

Fellowship (FGA)

Chen Tao, Shanghai, P.R. China. 1997
Davies, Maggie Willow, Wareside, Hertfordshire. 1997
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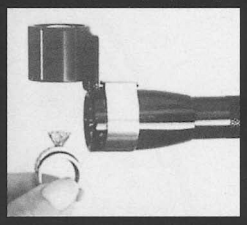

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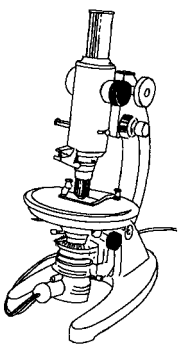

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A picture of Paradise
A turquoise carving photographed by Yuan Jiaqi
(See Turquoise from Hubei Province, China, p. 1)

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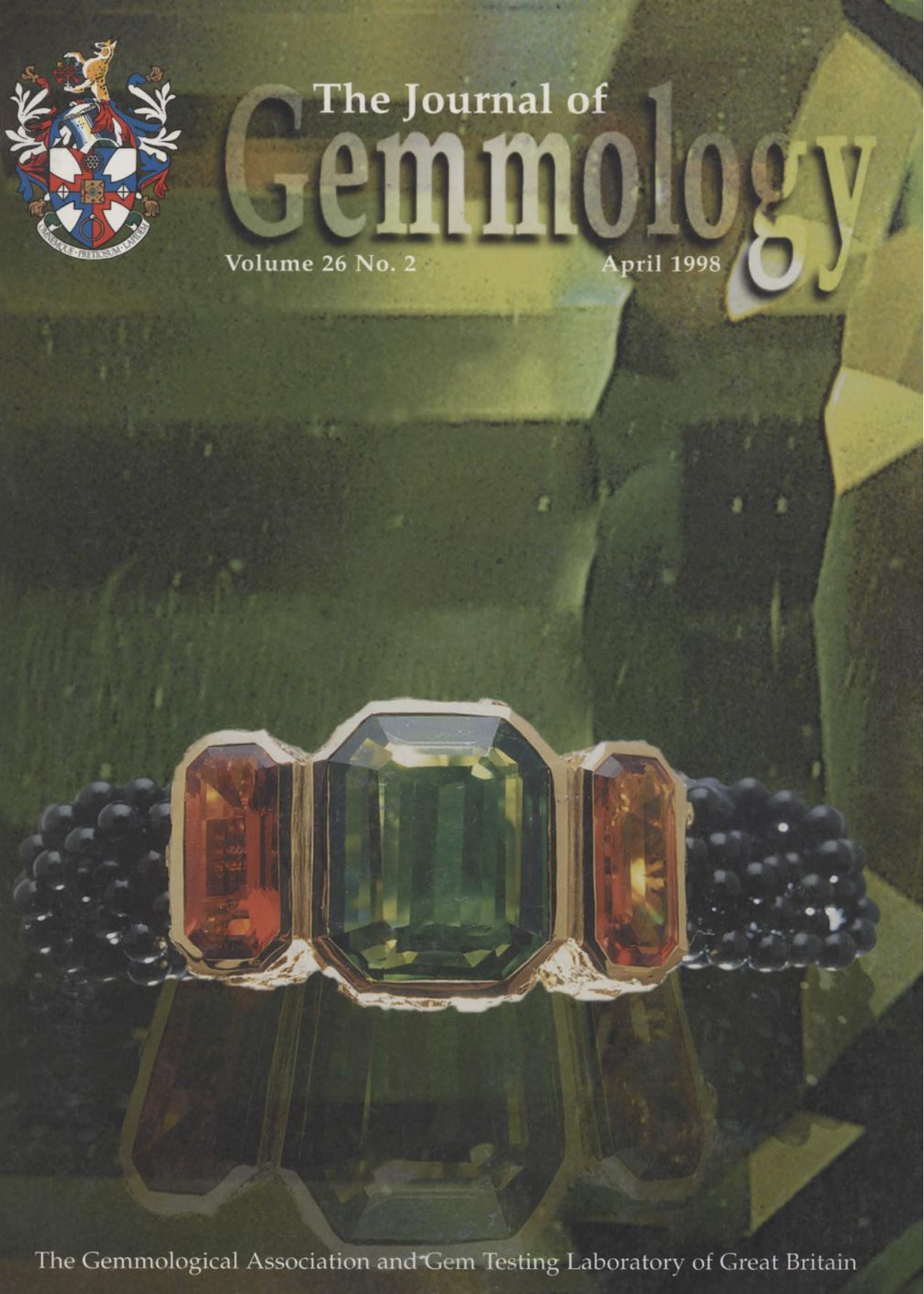

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Distinctive gem corundum suites from discrete basalt fields: a comparative study of Barrington, Australia, and West Pailin, Cambodia, gemfields

F.L. Sutherland[1], D. Schwarz[2], E.A. Jobbins[3], R.R. Coenraads[1] and G. Webb[1]

1. *Geodiversity Research Group, Australian Museum, Sydney, Australia*
2. *Gübelin Gemmological Laboratory, Lucerne, Switzerland*
3. *Caterham, Surrey, U.K.*

ABSTRACT: Barrington, Australia, and West Pailin, Cambodia, basalt fields yield remarkably similar 'metamorphic' corundums (including ruby) and 'basaltic' type blue corundums. These represent different underlying sources tapped by basaltic eruptions. The 'metamorphic' suites have high chromium/low gallium chemistry, with Ga_2O_3 contents <0.01 wt% and Cr_2O_3/Ga_2O_3 ratios above 3. The 'basaltic' suites show higher Ga_2O_3 (up to 0.04 wt%) and Cr_2O_3/Ga_2O_3 ratios below 1. The absorption spectra of blue 'metamorphic' sapphires are dominated by Fe^{3+} bands in the ultraviolet (375, 387 nm) and visible region (450, 460, 469 nm). A broad $Fe^{2+} - Ti^{4+}$ charge transfer band lies between 550–750 nm, without significant $Fe^{2+} - Fe^{3+}$ charge transfer absorption toward the near infrared that is typical of blue 'basaltic' sapphires. Most absorption spectra of 'metamorphic' corundums represent a combination of Fe/Ti/Cr-bands, with variable relative intensities.

Keywords: corundum, sapphire, ruby, sapphirine, absorption spectra, trace elements, basalt, Barrington (Australia), Pailin (Cambodia)

Introduction

East Australia and South East Asia exploit rich corundum deposits from their basalt fields, in significant mining, processing and cutting industries (Mumme, 1988; Hughes, 1990, 1997). East Australia produces sapphire and rare ruby (Coldham, 1985; Olliver and Townsend, 1990; Sutherland, 1991), while SE Asia produces both sapphire and ruby in abundance (Vichit, 1992). In this paper we describe corundum suites from two widely separated basalt fields, Barrington in East Australia and West Pailin in Cambodia, and show that they contain mixed ruby and sapphire suites of remarkable similarity.

Two distinctive gem corundum suites appear in eluvial and alluvial deposits from the Barrington basalt province in New South Wales, one typical of East Australian sapphire fields and the other associated with rubies (Sutherland and Coenraads, 1996). Besides typical Australian

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corroded blue-green-yellow zoned sapphires (Coenraads, 1992a, b; Sutherland, 1996; Guo *et al.*, 1996), the Barrington province also yields an abundant pastel-coloured sapphire-ruby suite (Sutherland *et al.*, 1993; Sutherland and Coenraads, 1996). Recognition of this last suite prompted a re-examination of ruby and sapphire collected from basalt fields around Pailin by E.A. Jobbins in 1974 (Berrangé and Jobbins, 1976; Jobbins and Berrangé, 1981).

Preliminary examination of West Pailin material showed its similarity to the Barrington suites, including sapphirine as an intergrowth in the ruby association (analysis by K. Williams). A more detailed investigation of samples collected by Jobbins was carried out by personnel from the Australian Museum and Gübelin Gemmological Laboratory, Switzerland. This work includes gemmological studies on

Figure 1: *Distribution of basaltic rocks (stippled areas) and main drainages, Barrington volcano province, 250 km north of Sydney, New South Wales. Corundum/zircon suites are marked by inclined crosses. The numbered sites are basalt age-dating sites, with the following ages, 1: 44–54 m.y., 1A: 54 m.y., 2: 37 m.y., 2A: 42 m.y., 3: 52–54 m.y., 4: 59 m.y., 5: 54 m.y. (based on Sutherland and Fanning, 1996). The main intrusive centre of Barrington volcano is marked by a triangle (1555 m above sea level) and the original extent of the volcano before dissection is marked by a dashed perimeter (600–800 m a.s.l.), after Pain, 1983.*

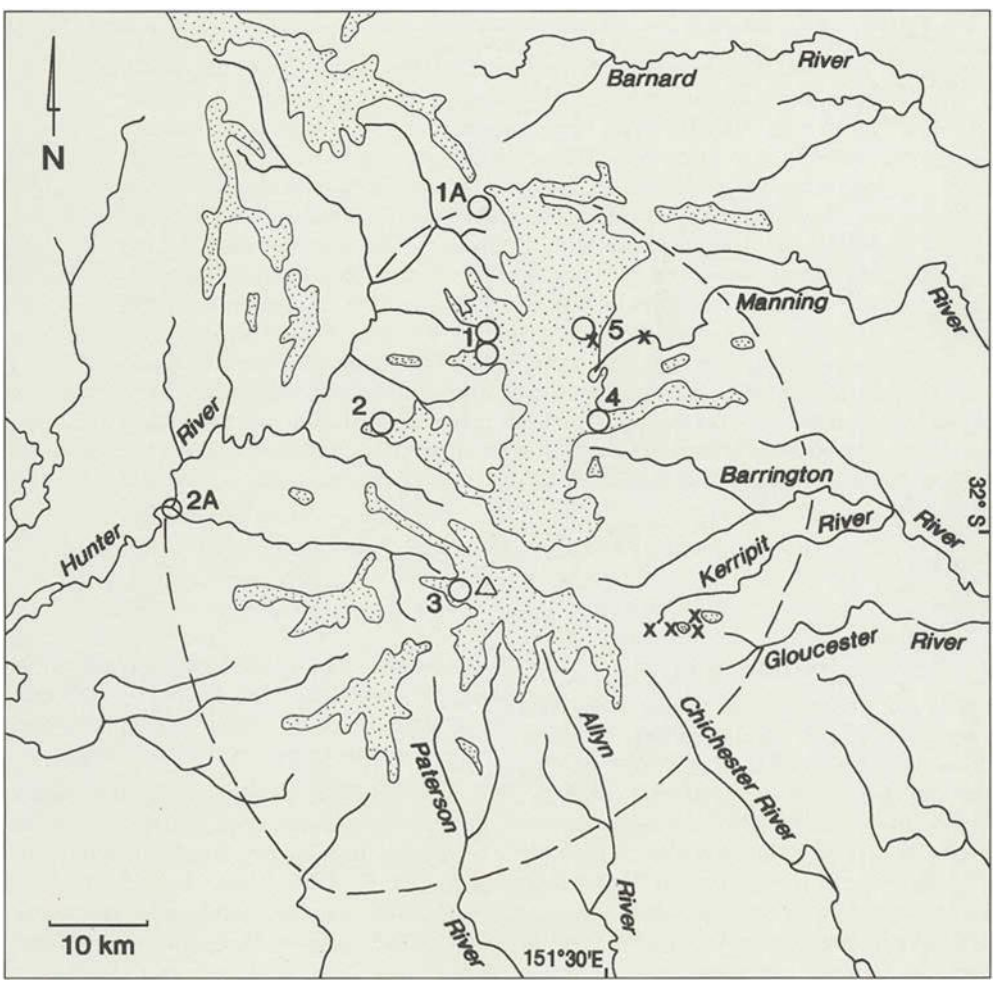

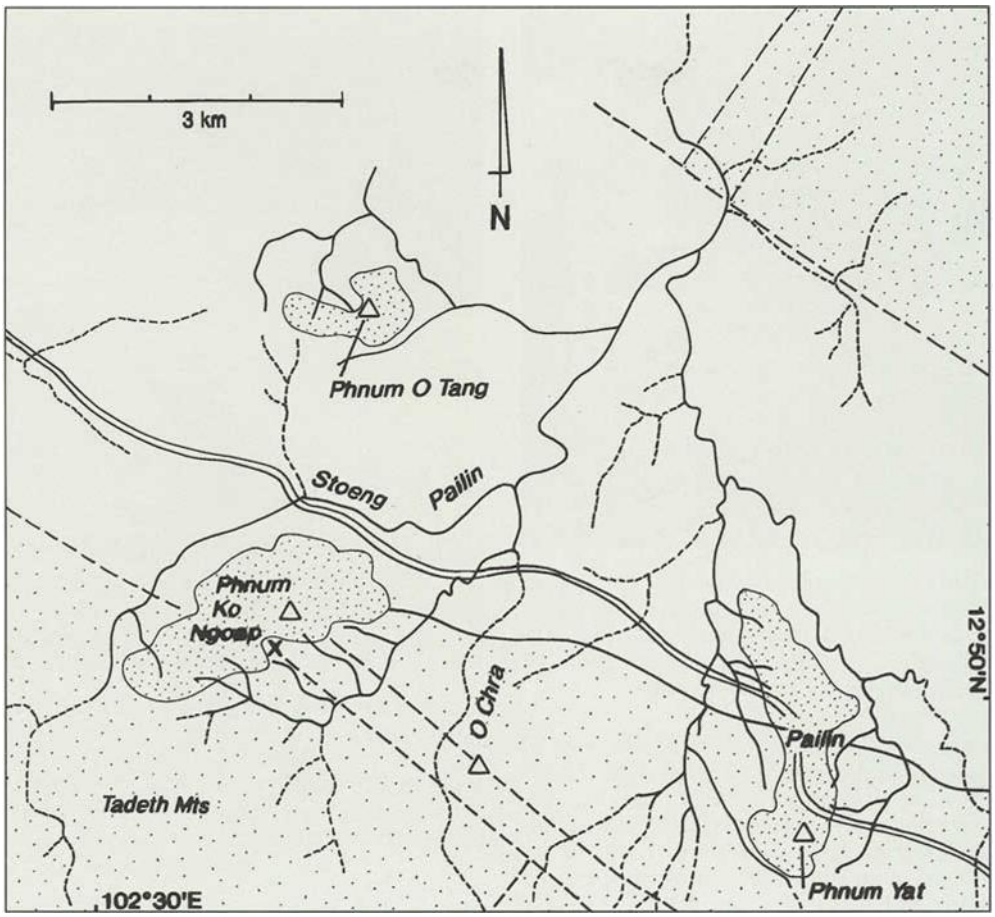

Figure 2: Distribution of basaltic rocks (denser stippled areas) and drainages, Pailin district, Cambodia. Gem-bearing drainage is shown as continuous lines, with gem-barren drainages shown as short dashed lines. Volcanic vents are indicated by triangles and the main basalt centres are Phnum Ko Ngoap, Phnum O Tang for dominant fancy coloured corundums, and Phnum Yat for dominant 'basaltic' blue corundums. The main drainages are the O Chra and Stoeng Pailin rivers and the road to Pailin is marked by a double line. The geological boundary between younger basement rocks (coarse stipple) and older crystalline basement (unmarked) is shown by a heavy line, and fault zones are marked by long dashes. Diagram modified from Berrangé and Jobbins, 1976, and Jobbins and Berrangé, 1981.

corundum from Barrington and West Pailin and comparative studies on sapphires from East Australia, from central Queensland (Anakie Fields) and New South Wales (New England Fields) and from East Pailin. Studies include photography and photomicrography (G. Webb, E.A. Jobbins), trace element and colour absorption spectral studies (EDXRF, UV-vis-NIR spectrometry; D. Schwarz), chemical analyses of inclusions and intergrowths in West Pailin corundums (CAMECA microprobe with WDS spectrometer; R.R. Coenraads, F.L. Sutherland) and comparisons of the corundum suites in discussion of their geological origins (F.L. Sutherland, D. Schwarz).

Geological settings

The Barrington corundums come from the eroded Barrington shield volcano in New South Wales within the Cainozoic

Figure 3: Working eluvial/alluvial gem gravels on the banks of a small stream about 0.4 km south-west of the Phnum Ko Ngoap vent. The analysed West Pailin specimens are from this locality. Photograph by E.A. Jobbins.

Figure 5: View looking south to the low hill (middle distance) forming the vent of the Phnum Ko Ngoap basalt body. Further south (in the background) are the jungle-clad Tadeth Mountains (largely greywacke sedimentary rocks). In the foreground are gem dealers on motorcycles, who collect and market the gem material from the miners. Photograph by E.A. Jobbins.

Figure 4: Washing gem gravel ('rai') at Phnum Ko Ngoap. Rubies, sapphires and garnets are recovered from impersistent lenses of sticky yellow-brown clays (green-grey when freshly exposed) which are difficult to break down. Photograph by E.A. Jobbins.

volcanic belt of eastern Australia (Pain, 1983; Johnson, 1989). This basaltic shield (*Figure 1*) was erupted through folded Palaeozoic basement and granite rocks, mostly between 50–60 million years (m.y.) ago, although episodic gem-bearing eruptions continued up to 5 m.y. ago (Sutherland *et al.*, 1993; Sutherland and Coenraads, 1996; Sutherland and Fanning, 1996). The shield is dominated by alkali basalts (O'Reilly and Zhang, 1995; Sutherland and Fanning, 1996). The oldest NE part sheds alluvial corundums that were studied from the Gummi area, which is drained by the upper Manning River. Associated zircons gave fission track ages of around 55 m.y. The youngest SE part provides near-source corundums that were studied from Gloucester Tops, in the headwaters of the Kerripit and Gloucester Rivers. Zircons with these corundums yield ages as young as 4–5 m.y.

The West Pailin material from the Pailin basalt field *(Figure 2)* came from the Phnum Ko Ngoap basalt body (E.A.J. collection station 29), from an eluvial/colluvial deposit on the basalt margin about 0.4 km south-west of the remnant vent *(Figures 3–5)*. The gem-bearing basalts around Pailin and adjacent eastern Thailand were erupted 1–4 Ma ago (Suttirat *et al.*, 1994; Davis and Barr, 1995). The West Pailin basalts yield corundum in which ruby is predominant over sapphire (about 70% ruby at Station 29), some pyrope-almandine garnet and little zircon. Phnum Ko Ngoap material is dominated by pale pink to red, light-blue, mauve and purple corundums. In contrast, at East Pailin sapphire predominates over ruby (about 95%) and zircon is a common accessory (Berrangé and Jobbins, 1976; Jobbins and Berrangé, 1981). Phnum Yat material is dominated by colourless to pale-blue to blue sapphires, many with colour zoning.

The western ruby-bearing basalts lie along a faulted older crystalline complex of metamorphosed granodiorite and diorite, amphibolitic gneisses and schists, whereas the eastern sapphire-bearing basalt intrudes younger rocks along a boundary between Devonian-Carboniferous metasedimentary and volcanic rocks and Triassic sedimentary beds *(Figure 2)*. These rocks lie within the Indo-China Terrane (microcontinental block), which extends west into Thailand (Bunopas and Vella, 1992). The West Pailin suites correlate with the Trat Thailand suites forming a 'ruby-rich' area. Further west basalts of south-eastern Thailand lie within the Shan-Thai block, which includes cratonic Precambrian gneiss (Bunopas and Vella, 1992), and show a significant sapphire component (see Hughes, 1990, *Figure 11.19*). They correlate more closely with the East Pailin sapphire fields.

Materials

Barrington suites

The Barrington corundums have been described in Sutherland *et al.*, 1993, Sutherland and Coenraads, 1996, and by Webb, 1997. The crystals and fragments show surface etchings *(Figure 6)* and a wide range of colours *(Figure 7)*. There are two distinct corundum suites, each with different trace-element patterns.

Figure 6: *Scanning Electron Microscope photomicrograph, showing corroded surface of a pink corundum grain from Gloucester Tops, Barrington volcano. Note the strong etching leaving a criss-cross ridge-like surface morphology. Photograph by G. Avern and B.J. Barron, X100.*

One suite contains ruby and sapphire ranging from colourless to pink, mauve, violet, blue, blue-green and purple with crystal forms which have been magmatically rounded with heavily etched

Figure 7: *Corundums from Gloucester Tops, Barrington volcano, showing surface corrosion features and range in colours. Photomicrograph by G. Webb, X15.*

Figure 8: Ruby series corundum crystal (mauve-pink) containing intergrowths of sapphirine (blue-green) and pleonaste spinel (dark opaque), from Gloucester Tops, Barrington volcano. Photomicrograph by G. Webb, X25.

Figure 10: Pale pink and ruby corundum crystals from Phnum Ko Ngoap suite, both showing prominent intergrowths of sapphirine (green). Photomicrograph by G. Webb, X20.

exteriors. Crystals range up to 6 mm across: chromian spinel, spinel and sapphirine occur as inclusions *(Figure 8)*, and crust-like spinel reaction rims are preserved on some grains. The other suite is typical of East Australian sapphires and is dominated by blue-green, euhedral, growth-zoned sapphire, often exhibiting corroded, broken-barrel habits. Crystals are generally larger than in the first suite and range up to 8 mm across.

Figure 9: Corundums from Phnum Ko Ngoap suite, West Pailin, showing surface corrosion features and range in colours. Note intergrowths of sapphire and spinel and fusion crusts on some corundums. Photomicrograph by G. Webb, X15.

West Pailin suites

These corundums *(Figures 9 and 10)* are very similar in characteristics to the Barrington suites and may also be considered in two groups of colours.

The first group of Phnum Ko Ngoap corundums range from 2 to 9.5 mm across and vary from pale pink to red, light blue, mauve and purple. Some show a colour change from red shades in incandescent light to blue shades in daylight. Pink and red corundums fluoresce red under long-wave ultraviolet, though less intensely than in equivalent Barrington stones. They are inert under short-wave ultraviolet. In habit, crystals are magmatically corroded and rounded. Mineral inclusions are present and negative crystals surrounded by decrepitation haloes are common, some with two-phase inclusions containing a gas bubble. Liquid-filled fractures often exhibit a thin-film effect and sometimes lie across twinning lamellae. Iron oxide/hydroxide staining is prevalent. Polysynthetic twinning is well developed and some twinning planes show tube-like, liquid-filled fractures, with associated mineralisations. Boehmite needles and crystallographically-controlled trellis patterns are present.

The second group of Phnum Ko Ngoap corundums contains a range from colourless to pale blue and many show colour zoning. Like Barrington blue crystals, they fall into two

different types. The larger type measures up to 8 mm in broken-barrel shaped crystals or as cross-sections along parting planes. Faces are often strongly magmatically corroded or slightly rounded. Among the inclusions, silk is present as oriented needles, as particles along hexagonal growth zones or radiating in bunches, like crystal axes, from a central hexagonal core; polysynthetic twinning lamellae are evident. The second group of smaller corundums are around 2–3 mm across, lighter in colour and more transparent. Crystals are magmatically rounded and etched, with no obvious colour zoning or silk.

Methods of analysis

Twenty-one Barrington corundums (CORBAR 1–21) and fourteen West Pailin (Phnum Ko Ngoap) corundums (CORCAM 1–14) were polished and analysed for trace elements and colour-absorption spectra. Twenty-nine Pailin corundums (Jobbins 1–5), showing inclusions, intergrowths or fusion crusts were selected on the basis of microscope study and polished for electron microprobe analyses. Of these, 12 were analysed for major element oxides and 9 were analysed for minor element oxides. The pastel-coloured sapphire-ruby suites are termed *fancy colours or 'metamorphic' type suites* and the blue-zoned corundums are termed *'basaltic' type suites* in the following descriptions (these two categories with inferred different origins are based on geochemical comparisons made in the Discussion section).

Chemical data

Chemical analyses were obtained by a semi-quantitative EDXRF method, using a Spectrace 5000 EDXRF system (Stern, 1984).

A total of 162 samples were tested comprising:

21 Barrington, 14 Cambodian and 9 corundums from West Pailin (E.A. Jobbins); 61 blue 'basaltic' sapphires (varying hue and colour intensity) from 'Pailin' (probably East Pailin mining area); 18 'basaltic' sapphires (blue, green, yellow-brown, parti-coloured; including a green and a blue star sapphire) from the Anakie Fields in Central Queensland (Tomahawk Creek, Willows, Rubyvale); 9 'basaltic' sapphires (blue, dark green-blue, yellow-brown) from Inverell (New England Fields, NSW); and 30 'basaltic' sapphires (blue, green, green-blue, yellow, parti-coloured) from Eastern Australian mining fields in Queensland and New South Wales, but without exact localities.

The elements considered useful in characterising the corundums are iron, titanium, chromium, gallium, and vanadium, and a quantitative classification scheme for these elements (as wt% oxides) has been established empirically:

	Low	*Medium*	*High*	*Detection limit*
Fe_2O_3	<0.5	0.5–1.0	>1.0	0.005
TiO_2	<0.01	0.01–0.03	>0.03	0.005
Ga_2O_3	<0.01	0.01–0.03	>0.03	0.005
Cr_2O_3	<0.01	0.01–0.05	>0.5	0.005
V_2O_3	<0.01	0.01–0.03	>0.03	0.005

Electron microprobe analyses of corundums and associated mineral phases were made using an automated CAMECA SX50 CAMEBAX electron-microprobe with an EDS attachment, in the Materials Science Faculty, University of New South Wales, Sydney. Operating conditions included an accelerating voltage of 15 kV, a sample current of 20 nA, PAPS software for processing raw counts and an ASTIMEX standard block.

Spectroscopic data

Ultraviolet-visible-near infrared (UV-vis-NIR, 280 to 880 nm) spectra were run on a Perkin Elmer Lambda 9 spectrophotometer at the Gübelin Laboratory. Although ordinary ray (o) and extraordinary ray (e) spectra were recorded where possible, the size and shape of most Barrington and Cambodian samples precluded registration of polarised spectra.

Table I: *Trace-element ranges in corundums from Australia.*

	Barrington corundum range					Typical Australian 'basaltic' sapphires
		'metamorphic'		'basaltic'	'basaltic' (Fe,Ti rich)	
Colour	blue	violet–blue	purple–red	blue	blue	blue, green, yellow, parti-coloured
Wt%						
TiO_2	0.02–0.05[1]	0.04–0.09	0.0–0.06	0–0.04	~0.1	0.0–0.5 (0.14)[2]
V_2O_5	<0.01	0.01–0.04	<0.01	<0.01	<0.005	<0.005
Cr_2O_3	0.01–0.04	0.05–0.02	0.1–0.4	0.005	<0.005	<0.005
Fe_2O_3	0.6–1.0	0.5–1.2	0.4–0.6	0.7–1.6	~2	0.7–1.8
Ga_2O_3	<0.01	<0.01	<0.01	0.02–0.04	~0.02	0.015–0.04
Samples						
CORBAR[3]	1,2,5,6	3,4,10,15, 16,17,18,20	7,8,9,19	11,13,14,21	12	57 (see text for explanation)
Spectral type[4]	'Fe(+Cr)'	'metamorphic' 'Cr+Fe'	'Cr(+Fe)'	'basaltic'	'basaltic'	'basaltic'

Notes:
1. Results obtained by EDXRF
2. Blue star-sapphire from Anakie, NSW
3. CORBAR symbolises corundums from Barrington
4. See text for details

Table II: *Trace-element range for West Pailin corundums ('metamorphic' type, 'basaltic' type, and Fe/Ti-rich 'basaltic' type), compared to 'basaltic' type sapphires from East Pailin.*

	West Pailin					East Pailin
		'metamorphic'		'basaltic'	Fe/Ti-rich 'basaltic' type	'basaltic'
Wt%	Blue	Violet-blue	Purple-red/red			
TiO_2	~0.1	0.04–0.08	0.01–0.05	0.01–0.02	0.01–0.02	<0.01
V_2O_5	~0.01	~0.01	<0.01	<0.005	<0.005	<0.01
Cr_2O_3	~0.04	0.1-0.2	0.1-0.7	<0.005	<0.005	<0.005*
Fe_2O_3	~1	0.7-1.0	0.4-0.9	0.3-1.1	~2	0.3–0.8
Ga_2O_3	<0.01	<0.01	<0.01	0.02-.03	~0.04	0.02–0.04
Samples						
CORCAM	2,4–10, 12,13,15			1,11,14	3	61 blue sapphires of different hues and colour intensities
Jobbins	3–2, 3–4 to 3–9			Jobbins 5	3–1	
Spectral type+	'metamorphic'			'basaltic'	'basaltic'	'basaltic'

+see text for details

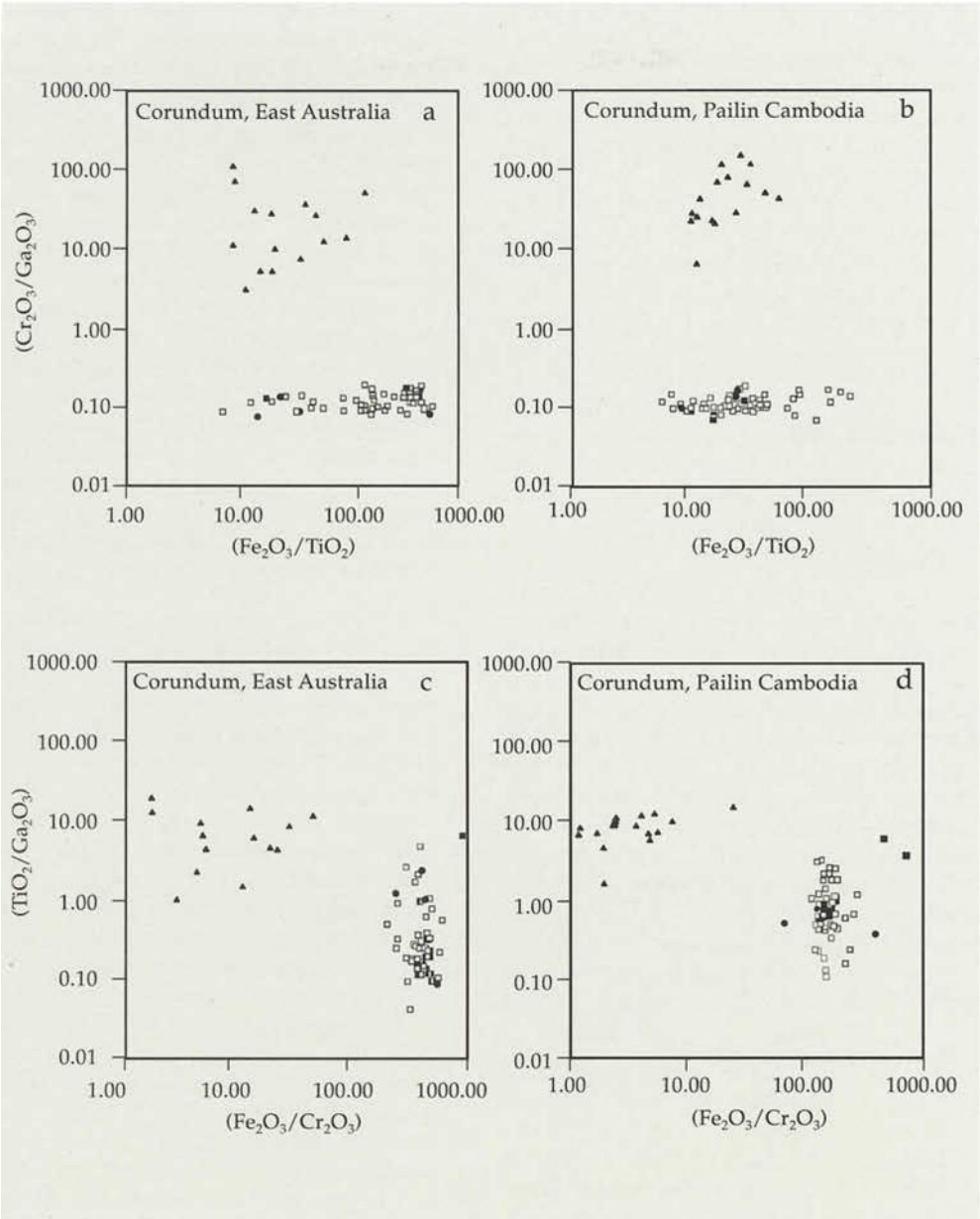

Figure 11: *Chemical variation diagrams showing wt% plots of trace-element contents of corundums from East Australia (Barrington and other gemfields, a and c, and from Pailin, Cambodia, b and d.*

(a) Cr_2O_3/Ga_2O_3 vs Fe_2O_3/TiO_2; Barrington 'metamorphic' type (▲); Barrington 'basaltic' type (●), East Australian 'basaltic' type (❑); Barrington high 'Fe, Ti type' (■).

(b) Cr_2O_3/Ga_2O_3 vs Fe_2O_3/TiO_2; West Pailin 'metamorphic' type (▲); West Pailin 'basaltic' type (●); West Pailin high 'Fe, Ti type' (■); East Pailin 'basaltic' type (❑).

(c) TiO_2/Ga_2O_3 vs Fe_2O_3/Cr_2O_3; Barrington and other East Australian corundums. Symbols as in Figure 11a.

(d) TiO_2/Ga_2O_3 vs Fe_2O_3/Cr_2O_3; West Pailin and East Pailin corundums. Symbols as in Figure 11b.

Results

Trace and minor element contents of corundums, that correlate with the absorption spectra, are summarised in *Table I* (Barrington 'metamorphic' type and 'basaltic' type compared to typical Australian 'basaltic' type sapphires from Queensland and New South Wales mining fields), *Table II* (West Pailin 'metamorphic' corundums compared to 'basaltic' type sapphires from East Pailin) and in *Figure 11a–d*. Major element values for corundums and co-existing minerals are summarised in *Tables IIIA and IIIB* and *Figure 12*. Selected UV-vis-NIR absorption spectra for East Australian and Pailin corundums are presented in *Figures 13–15*.

Corundum chemistry

Both Barrington and West Pailin corundums have comparable trace-element contents *(Figure 11)* and essentially fall into 2 distinct groups. The fancy coloured 'metamorphic' type suites are characterised by low Ga_2O_3 (<0.01 wt%) and by high Cr_2O_3/Ga_2O_3 ratios (mostly between 10 and 100). The 'basaltic' type sapphires show higher Ga_2O_3 (0.015–0.040 wt%) with Cr_2O_3/Ga_2O_3 always below 1. These two chemical groups correlate with two different patterns observed among the colour-absorption spectra, discussed below. Their chemistry in comparison to corundums from other areas provides the following results:

1. *Iron*

   The Fe- and Ti-concentrations of East Australian sapphires show some variation *(Table I)* with normally 0.4 and 1.8% Fe_2O_3, reaching up to about 2% Fe_2O_3 in a Fe/Ti-rich 'basaltic' type corundum from Barrington. Most 'metamorphic' Barrington corundums lie between 0.4 and 1.2% Fe_2O_3. The 'basaltic' corundums from the Anakie and New England fields range from 0.7 to 1.8% Fe_2O_3. The 'basaltic' corundums from the Pailin mining area show a smaller variation than in East Australian samples *(Table II)*. Over 90% of the 'basaltic' Pailin corundums occupy a narrow range between 0.3 and 0.7% Fe_2O_3. In 'metamorphic' Pailin corundums, however, values reach up to 1% Fe_2O_3. An Fe/Ti-rich 'basaltic' type sapphire from West Pailin contains about 2% Fe_2O_3.

   The Fe-content is a good 'separation criterion' for 'basaltic' corundums from East Australian and Pailin mining fields: most 'basaltic' Pailin corundums contain less than 0.5% Fe_2O_3. On the other hand, typical Fe-concentrations in 'basaltic' corundums from East Australia (Barrington, Inverell, Anakie) exceed 1% Fe_2O_3. Less than 10% of the 161 corundums examined here fall into the over-lapping 'corridor' between 0.6 and 1.0% Fe_2O_3. A separation of the 'metamorphic' corundums from East Australia and Pailin, using Fe, Ti concentrations, however, is not possible. As *Figure 11* shows, there is near complete overlap for these corundums.

2. *Titanium*

   Many East Australian 'basaltic' sapphires show only negligible Ti (<0.005% TiO_2). Some, however, may contain up to 0.05% TiO_2 (compare *Tables IA, B*), and the Fe, and Ti-rich 'basaltic' corundum from Barrington contains about 0.1% TiO_2. The highest Ti-content of 0.14% TiO_2 was found in a blue star sapphire from Anakie. The more usual 'basaltic' sapphires from Barrington fall into the concentration range of sapphires from Anakie and New England. Many 'metamorphic' Barrington corundums have Ti-contents over 0.04% TiO_2, with maximum values up to 0.09% TiO_2. The Ti-concentration in West Pailin 'metamorphic' corundums ranges from 0.01 to about 0.1% TiO_2, while four 'basaltic' sapphires from West Pailin contain only 0.01 to 0.02% TiO_2. The Fe- and Ti-rich type has 0.1-0.2% TiO_2. Many 'basaltic' sapphires from East Pailin are almost Ti-free, while maximum contents lie around 0.07% TiO_2 *(Table II)*.

3. *Gallium*

   Gallium in particular delineates two 'types' of corundum suites for East Australia and Pailin, with pronounced differences in their mineralogical/ chemical features.

'Basaltic' corundums have high Ga-contents (0.015 to 0.040% Ga_2O_3), whereas Ga concentrations for the 'metamorphic' corundums are low (<0.01% Ga_2O_3; compare *Tables I and II*).

4. *Chromium*

Chromium concentrations, like gallium, also differ in the basaltic and 'metamorphic' corundums.

The 'basaltic' corundums from East Australia analysed here are yellow, green, or blue, while those from Pailin are all blue with different hues and intensities. Gemmologically, they are considered as Fe- and Ti-coloured sapphires. The chromium contents of these sapphires are below the detection limit for the analytical method (about 0.005% Cr_2O_3). The 'metamorphic' East Australian and Pailin corundums show a quite distinctive range of colours: pink, red, mauve, violet, purple and blue, which can be considered in three groups as blue sapphires, fancy colour sapphires and rubies. Chromium is present in all 'metamorphic' Barrington and Pailin corundums, including blue or greenish-blue varieties, and contents range up 0.5% Cr_2O_3. Intensely coloured crystals may contain more; the highest analysed content of 0.75% Cr_2O_3 was found in a Pailin ruby. The highest Cr-content found in a Barrington ruby in this study was 0.4% Cr_2O_3, although 1.4 wt% Cr_2O_3 has been recorded previously (Sutherland *et al.*, 1993).

5. *Vanadium*

The vanadium contents in corundums from East Australia and Pailin generally lie below the detection limit of the EDXRF analytical method (about 0.005% V_2O_5), but rarely V_2O_5 may attain 0.01%. In the 'metamorphic' corundums, the range of content is wider and reaches 0.015% V_2O_5 for Pailin and 0.04% V_2O_5 for Barrington purple sapphires.

A more complete chemical characterisation of 'basaltic' and 'metamorphic' corundums from Pailin, Cambodia, and East Australia is based on the correlation diagrams shown in *Figure 11a, b*. These diagrams show the ratios (Cr_2O_3/Ga_2O_3) vs (Fe_2O_3/TiO_2) and are an excellent tool to distinguish two gem corundum suites in these basaltic fields. The metamorphic corundum field characterised by high Cr_2O_3/Ga_2O_3 ratios (mostly between 10 and 100) is clearly separate from the basaltic corundum field for which Cr_2O_3/Ga_2O_3 is always <1. The Fe/Ti-ratio is not diagnostic for separating these types, because of their practically identical width of variation.

The fields for the two 'metamorphic' suites from Pailin and Barrington are almost identical. For basaltic fields from East Australia and Pailin, the 'areas of highest density' are different: Pailin mostly has Fe_2O_3/TiO_2 ratios below 100 *(see Figure 11b)*, whereas East Australian ratios are mostly over 100 *(Figure 11a)*. This stems from 'typical' Fe-contents in Eastern Australian sapphires exceeding those for Pailin sapphires *(Table II)*.

The representative points for 'normal' basaltic corundums from Barrington and West Pailin all lie in the fields for sapphires from other East Australian (Anakie, New England) and East Pailin sapphire fields.

The TiO_2/Ga_2O_3 vs Fe_2O_3/Cr_2O_3 diagrams *(Figures 11c, d)* also clearly separate 'metamorphic' and 'basaltic' corundum suites. The Fe_2O_3/Cr_2O_3 ratio for metamorphic corundums from East Australian and Pailin mostly ranges between 1 and 10 (extending up to 50 for Barrington corundums). The ratios for 'basaltic' sapphires are much higher: mostly 100–200 for the blue sapphires from East Pailin, and 300–600 for the yellow, green, blue and parti-coloured sapphires from East Australia. Whereas typical TiO_2/Ga_2O_3 ratios for 'basaltic' sapphires from East Australia and Pailin are less than 1, for the vast majority of the members of the 'metamorphic' suite the ratio ranges from 1 to 10.

A few 'basaltic' sapphires from Barrington and West Pailin show unusually high Fe- and Ti-contents (2% Fe_2O_3 and 0.1–0.2% TiO_2), beyond the Fe_2O_3/Cr_2O_3 range of 'normal basaltic' corundums *(Figures 11c, d)*. It is uncertain whether these corundums represent another corundum-type, or are fragments of larger colour-zoned

Table IIIA: *Representative analyses of corundums and some primary inclusions from West Pailin.*

Mineral	*Corundum (pink)*	*Corundum (blue)*	*Pleonaste spinel*	*Sapphirine (11.13.5)*	*Fassaite pyroxene*	*Hercynite spinel*
Type	*'metamorphic'*	*'basaltic'*	*'metamorphic'*	*'metamorphic'*	*'metamorphic'*	*'basaltic'*
Wt%						
SiO_2	0.03	–	0.02	13.81	48.86	0.03
TiO_2	0.01	0.04	0.01	0.04	0.19	0.26
Al_2O_3	98.14	100.20	66.60	62.31	13.66	63.00
Cr_2O_3	0.20	–	0.73	0.47	0.11	0.29
NiO	0.00	0.03	0.09	0.41	0.12	0.07
FeO_{tot}	0.70	0.64	10.68	3.44	2.43	21.77
MnO	0.03	–	0.10	0.02	0.03	0.15
MgO	0.04	–	17.47	19.55	12.09	13.50
CaO	0.02	–	–	0.07	21.18	–
Na_2O	–	–	–	0.02	1.54	–
K_2O	–	0.02	0.01	–	–	–
Total	99.17	100.93	98.99	100.54	100.21	99.07
Samples	Job 1.1	Job 3.4	Job 4.3	Job 4.3	Job 3.3	Job 3.10

FeO_{tot} = total iron oxides expressed as FeO

Table IIIB: *Representative analyses of reaction, exsolution and alteration minerals in corundums from West Pailin.*

Oxide	*Reaction spinel 1*	*Reaction spinel 2*	*Reaction spinel 3*	*Exsolution spinel 4*	*Alteration Fe hydroxide*	*Alteration chlorite*
Wt%						
SiO_2	0.06	–	0.01	0.04	–	28.33
TiO_2	0.06	0.15	24.24	0.46	0.07	1.07
Al_2O_3	67.44	63.15	6.69	36.59	3.25	24.75
Cr_2O_3	0.18	–	0.05	0.30	0.04	0.44
NiO	0.23	–	0.13	0.08	0.05	0.02
FeO_{tot}	8.38	22.70	60.99	53.60	84.36	31.54
MnO	0.18	0.26	0.59	0.21	0.01	0.04
MgO	21.57	12.28	3.21	6.06	0.05	0.23
CaO	0.01	0.03	–	–	–	0.18
Na_2O	–	–	0.03	–	–	0.14
K_2O	–	–	–	–	0.02	0.14
Total	98.11	98.57	96.94	97.34	87.85	86.88
Samples	Job 2.5	Job 3.4	Job 3.4	Job 1.1	Job 1.1	Job 2.1

Spinel 1: Reaction rim on sapphirine. Spinel 2: Reaction rim on blue corundum.
Spinel 3: Reaction phase in spinel 2. Spinel 4: Exsolution lamellae in pleonaste.
– means below detection

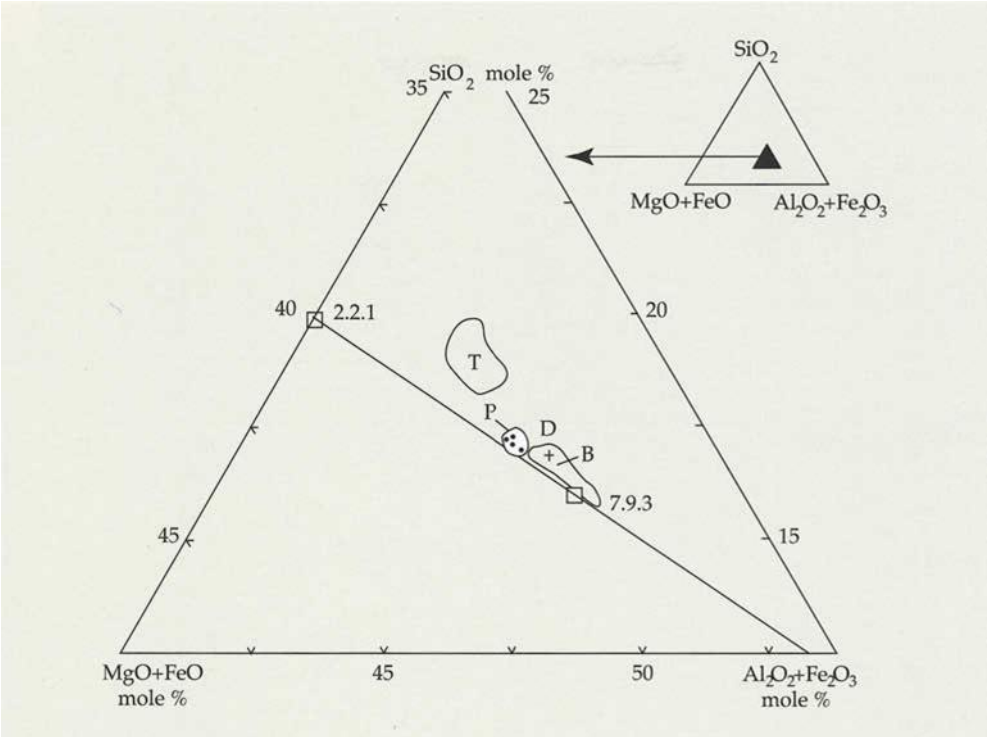

Figure 12: *Mole % MgO+FeO, Al_2O_3+Fe_2O_3, SiO_2 chemical variation diagram, showing relationship of Barrington (B) and West Pailin (P) corundum-hosted sapphirine compositions, in relation to the sapphirine composition reference line (including 2.2.1 and 7.9.3 member compositions). Thailand (Rubywell Mine) alluvial sapphirines (T) and NSW granulite-hosted sapphirine from lower crustal xenolith, Delegate (D) are plotted for comparison, based on diagram after Sutherland and Coenraads, 1996, Figure 4.*

crystals. Crystals with colour zoning and unusually high element concentrations related to certain zones have been found from other localities (Schwarz, in prep.).

Mineral inclusions and intergrowths

Despite their geographical separation, Barrington and West Pailin corundums include minerals of very similar compositions. Analyses of Pailin corundums and their primary inclusions *(Table IIIA)* are listed with those for alteration minerals *(Table IIIB)*. Primary sapphirine is near a $11(MgO + FeO) : 13(Al_2O_3 + Fe_2O_3) : 5SiO_2$ mole % composition and approaches the 7 : 9 : 3 composition of sapphirine inclusions in Barrington fancy coloured corundums *(Figure 12)*. West Pailin spinels (Sp 78 Hc 22) are slightly more Al-rich and Fe-poor than spinels from the Barrington field (*cf* Sp 68–73 Hc 26–29 Cm 0–3 in Sutherland and Coenraads, 1996). In the 'basaltic' type corundums, spinels are more Fe-rich, but West Pailin compositions are less so than at Barrington. They are spinel-hercynite (Sp 53 Hc 45 Usp 1 Mt 1; analysis in *Table IIIA*), rather than hercynite-magnetite (Hc 51–73, Mt 18–35, Mf 6–8 Usp 2–5) reported in Sutherland and Coenraads, 1996.

Absorption spectroscopy

The most important minor elements in corundums from East Australia and Pailin are Fe, Ti, Cr, Ga, and V and of these, Fe, Ti, and Cr are significant in colour-causing processes (the V-concentration is generally

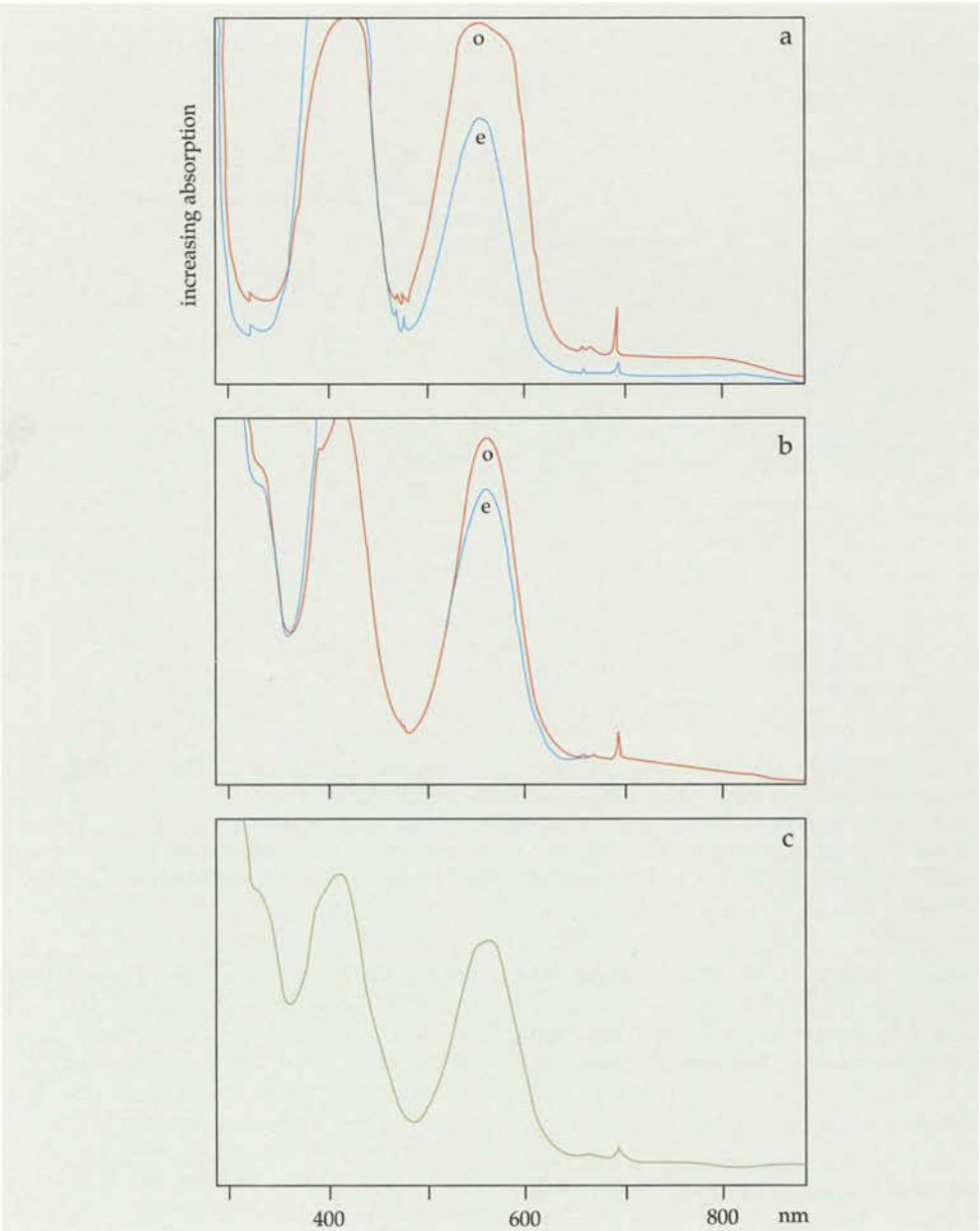

Figure 13: *Comparative colour absorption spectra related to Cr-bearing corundums.*
(a) Cr^{3+} absorption spectrum with intense bands around 400 and 550 nm in a metamorphic corundum (ruby) from Mogok, Burma. Such 'pure' Cr-spectra have not been observed in corundums from East Australian and Pailin basaltic gemfields.
(b) Representative absorption spectrum for ruby from basaltic fields, Thai-Cambodian border region. In addition to the two broad Cr^{3+} bands, a pronounced 'shoulder' in the UV region around 330 nm is present.
(c) The 'Thai ruby-type' absorption spectrum observed in 'metamorphic' type suites from Barrington and West Pailin basalts.

too low to act as colour agent). Chromium is the dominant chromophore in pink and red corundums (rubies). The 'pure' Cr-absorption spectrum shown in *Figure 13a* is characterised by two intense bands around 400 and 550 nm but such spectra are not observed in the red/pink corundums from Barrington and Pailin. Instead, they show a spectrum typical of rubies from the Thai/Cambodian border region *(Figure 13b)* with an absorption 'shoulder' around 330 nm that reflects relatively high Fe-contents (mostly about 0.3–0.7% Fe_2O_3; Schwarz, in prep.) and appears *(Figure 13c)* equally among Barrington and Pailin corundums.

Iron and titanium are the dominant colour-causing elements in blue sapphires. The absorption bands and characteristics in spectra of blue sapphires are related to the following mechanisms:

- sharp bands in the ultraviolet at 375 and 387 nm, due to dispersed Fe^{3+};
- sharp bands in the visible region at 450, 460 and 469 nm, due to dispersed Fe^{3+};
- broad bands with absorption maxima between 550 and 600 nm (ordinary ray spectrum) and between 680 and 750 nm (extraordinary ray spectrum), related to Fe^{2+}–Ti^{4+} intervalence charge-transfer processes (IVCT). Fe^{2+}–Ti^{4+} dominated spectra are typical for blue sapphires originating from Kashmir, Myanmar and Sri Lanka (cf. Schwarz *et al.*, 1996);
- an increasing absorption towards the near infrared (800–900 nm; *Figure 14a*), due to Fe^{2+}–Fe^{3+} charge transfer processes. Although this has been considered typical for sapphires from basaltic sources, the phenomenon is not entirely restricted to 'basaltic' sapphires as it also appears in sapphires from Andranondambo in Madagascar which originate from a skarn-type genetic environment (Schwarz *et al.*, 1996).

Absorption spectra dominated by Fe–Ti and Fe–Fe charge-transfer mechanisms typify blue sapphires from East Pailin *(Figure 14a)*. They also appear in the 'basaltic' *(Figure 14b)* suites in West Pailin and Barrington. Absorption spectra of green and yellow 'basaltic' sapphires from East Australia are compared in *Figures 14c and 14d*. The 'high Fe, Ti' 'basaltic' sapphires present absorption spectra marked by a relatively intense Fe^{2+}–Ti^{4+} absorption *(Figure 14e)*.

The absorption spectra of blue sapphires from the 'metamorphic' suites in West Pailin and Barrington are dominated by Fe^{3+} bands in the ultraviolet (375, 387 nm) and visible region (450, 460, 469 nm), and by a broad Fe^{2+}–Ti^{4+} charge-transfer between ca. 550 and 750 nm *(Figure 15a)*. There is no significant Fe^{2+}–Fe^{3+} charge-transfer absorption toward the near-infrared.

Practically all absorption spectra observed in the 'metamorphic' corundums from Barrington and West Pailin represent a combination of Fe, Ti and Cr bands with variations in the relative intensities of the absorption bands *(Figures 15b and 15c)*. Consequently, some 'blue' sapphires from the 'metamorphic' suites show considerable Cr components in their absorption spectra which can be seen in a hand-held spectroscope.

Discussion

Clearly, corundums from two distinct suites surfaced with basaltic eruptions at both Barrington and Pailin. Both exhibit surface features related to magmatic corrosion of former embedded crystal sites and the trigonal crystallographic structure (Coenraads, 1992b, and *Figure 6* of this study). Among these are 'needle-like' textures recently illustrated from sapphires at Cyangugu, Rwanda, Africa (Krzemnicki *et al.*, 1996). These authors attribute the needles to protection of the corundum by plagioclase crystals that crystallized from the coarse basalt host, but have since weathered away. Similar needle-like textures have been illustrated from corundums from other areas (Coenraads, 1992 b; Guo *et al.*, 1996) and have been interpreted as the results of differential corrosion of twinning planes. Thus, while large, flatter and squarer-ended ridges in Cyangugu sapphire may represent former

random sheaths of plagioclase, the ridge-like textures of Barrington and Pailin material are considered to largely stem from crystallographically controlled corrosion. Fused crusts on some corundums and composites suggest little alluvial transport from their source.

More than one generation of corundum is seen within the fancy coloured suite. Small hexagonal crystals of white or pale yellow corundum without significant trace-element contents are intergrown with or included in larger blue corundums containing Fe as the main trace element. Some features typical of Thai ruby suites such as decrepitation haloes (Gübelin and Koivula, 1986) appear in both Barrington and West Pailin rubies, illustrating that such features are not exclusive to Thai rubies.

Origin of the metamorphic corundum suite

Possible origins for Barrington corundums that favour metamorphic or metasomatic sources have been outlined by Sutherland and Coenraads, 1996. Crystallisation temperatures for Barrington corundum-sapphirine-spinel assemblages were estimated at around 780–940°C, with subsequent reaction with magmatic hosts taking place around 1000°C. West Pailin mineral analyses *(Table IIIA, B)* were subjected to the Mg–Fe exchange sapphirine-spinel thermometer calculations of Owen and Greenough, 1991, which were used in the Barrington study. This thermometer uses an increase in temperature dependence with the partitioning co-efficient Kd for Mg and Fe in the sapphirine (sa)/spinel (sp) pair. The formulation is T (°C) = [800 + (228 ln Kd)] – 273, where Kd = $(Xsp_{Fe}/Xsp_{Mg})/Xsa_{Fe}/Xsa_{Mg})$, with X representing the molar fractions of Fe and Mg in the minerals. Calculations based on a sapphirine-spinel pair (Job 4.3, *Table IIIA*) gave 772°C (Fe^{2+} calculation) and 943°C (Fe^{2+} and Fe^{3+} recalculation). This suggests comparable crystallisation temperatures for both Pailin and Barrington suites.

The trace-element and absorption characteristics of the fancy coloured corundums and co-existing minerals *(Figures 11, 12, 13 and 15)* are considered to characterise corundum assemblages produced by metamorphic recrystallization of aluminous material. Whether this metamorphism originated from contact metamorphism related to the basaltic magmas or from an earlier unrelated metamorphic event is not clear on present data.

Figure 14: *Representative absorption spectra of blue-green-yellow 'basaltic' type sapphires from East Pailin and East Australia.*
(a) Absorption spectrum of blue sapphire from East Pailin mining region, with absorption bands due to Fe^{2+}–Ti^{4+} and Fe^{2+}–Fe^{3+} charge transfer (o, ordinary ray; e, extraordinary ray).
(b) Typical absorption spectrum of blue 'basaltic' type sapphire from East Australia (New South Wales and Queensland mining areas). Blue absorption minimum (light transmission) only in the blue spectral region.

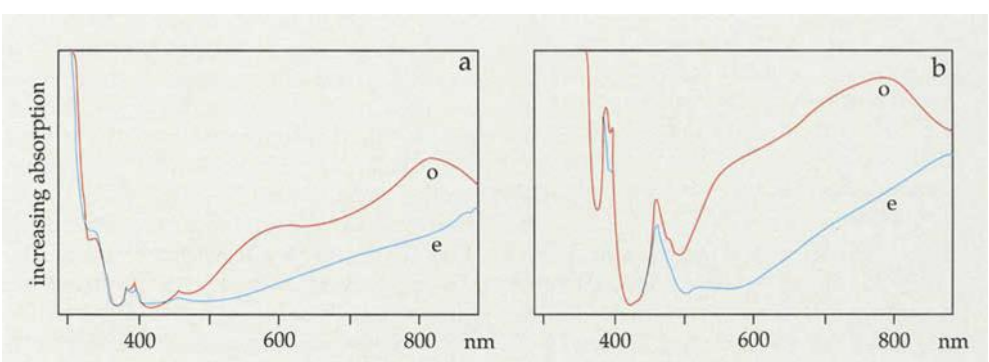

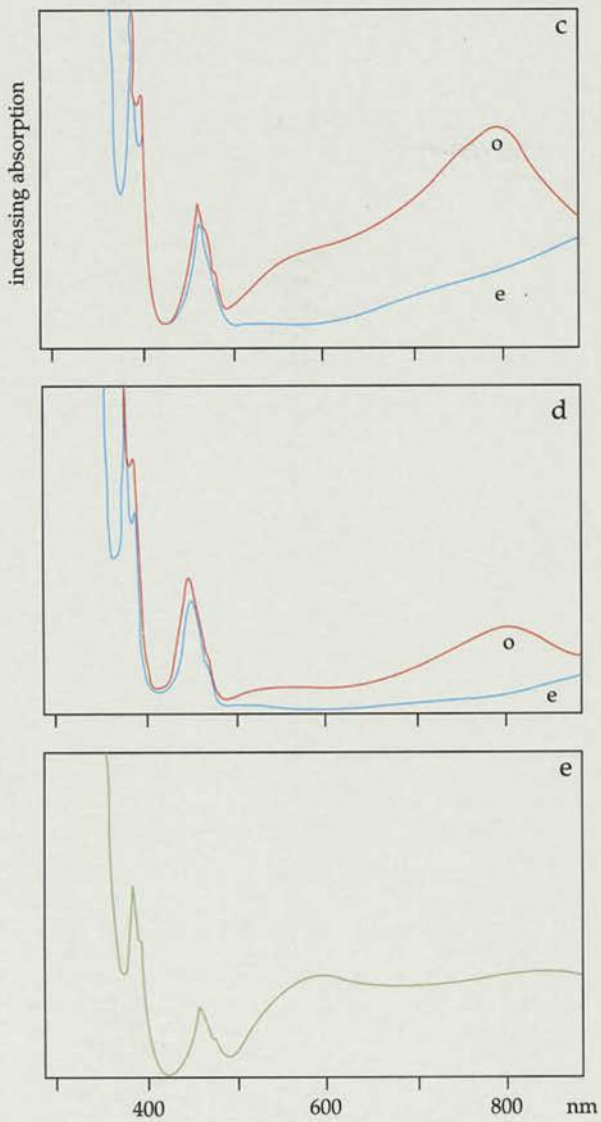

(c) Typical absorption spectrum of green 'basaltic' type sapphire from East Australia (New South Wales and Queensland mining areas). Two absorption minima in violet-blue region and blue-green region, resulting in (blue-) green body colours.

(d) Absorption spectrum of yellow 'basaltic' type sapphire from East Australia (New South Wales and Queensland mining areas). Yellow broad transmission over the whole green-yellow-orange spectral region.

(e) Absorption spectrum of blue 'basaltic' type sapphires with high Fe and Ti contents. The relatively strong absorption band in the 500 to 600 nm region is caused by Fe^{2+}–Ti^{4+} charge transfer.

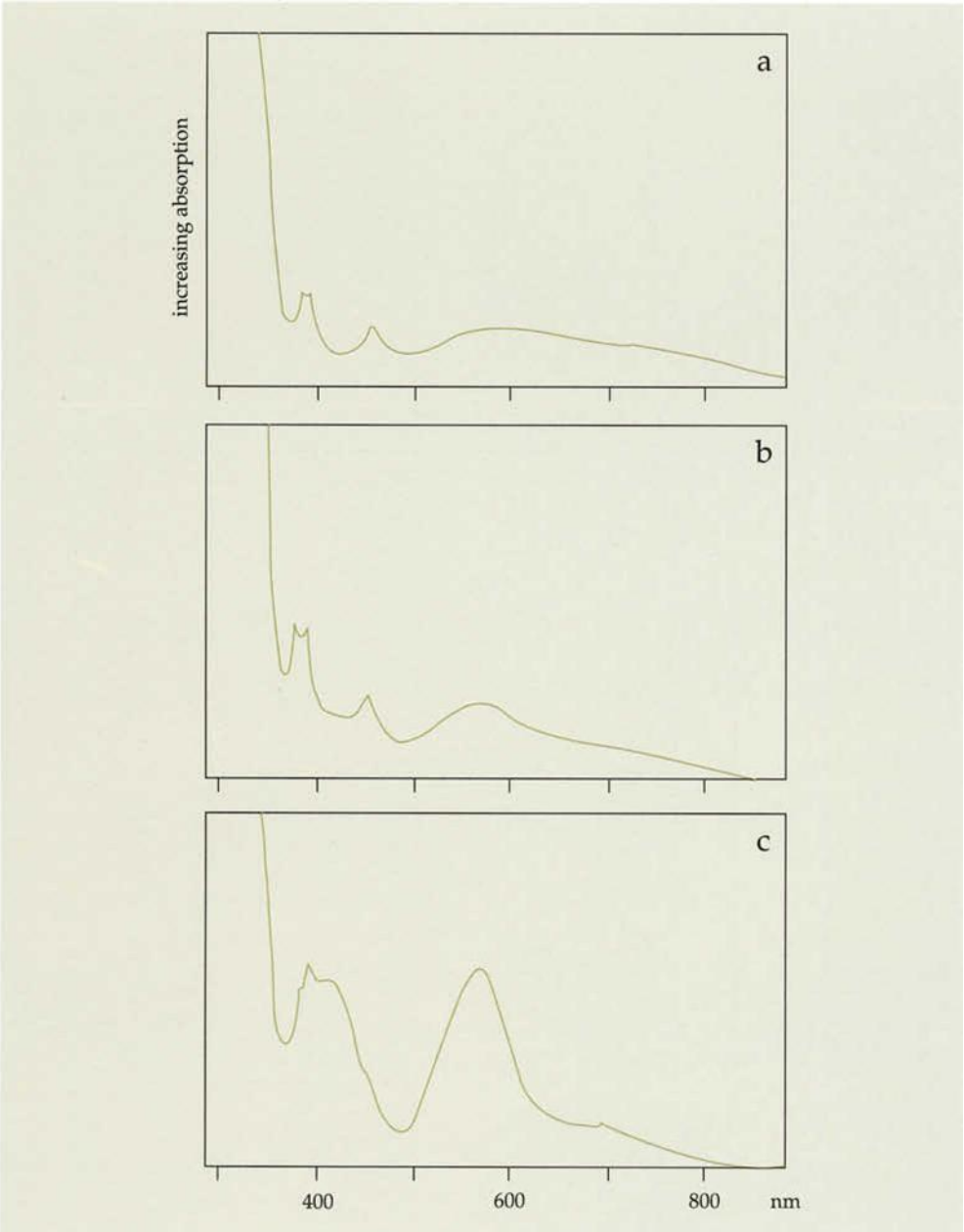

Figure 15: *Absorption spectra of 'metamorphic' type fancy colour corundums from Barrington and West Pailin corundum suites.*

(a) Blue sapphire, with dominating Fe^{3+} bands in the UV and visible region accompanied by the broad absorption band about 550 to 600 nm due to Fe^{2+}–Ti^{4+} charge transfer.

(b) Fancy colour corundum from 'metamorphic' type Barrington and West Pailin suites: typical spectrum showing strong Fe^{3+} and Fe^{2+}–Ti^{4+} charge transfer absorption bands with weak Cr^{3+} bands.

(c) Fancy colour corundum with dominant Cr^{3+} absorption spectrum combined with weak Fe^{3+} and Fe^{2+}–Ti^{4+} charge transfer bands.

Origin of the 'basaltic' corundums

Although subsidiary at Barrington and West Pailin, 'basaltic' corundums dominate suites elsewhere in East Australia and Pailin. The corundums range into higher Ga contents (up to 0.04 wt % Ga_2O_3) and lower Cr_2O_3/Ga_2O_3 (always <1) and their chemical ratios *(Tables I, II; Figure 11)* match values recorded for 'basaltic' corundums from South Vietnam (Smith *et al.*, 1995), China (Guo *et al.*, 1992), Madagascar (Schwarz *et al.*, 1996) and East Africa (Krzemnicki *et al.*, 1996). These 'basaltic' type corundums show Fe and Ti dominated absorption spectra *(Figure 14)* distinctly different from those of the fancy coloured corundums and contain a greater range of mineral inclusions, such as spinels, alkali and plagioclase feldspars, exotic Nb, Ta, U and Th oxides and Zr- or Th-rich silicates (Coenraads, 1992a; Guo *et al.*, 1996; Sutherland and Coenraads, 1996).

Work on the possible origin of these widespread 'basaltic' corundums has generated several models. Most involve plutonic crystallization from a melt, although widespread metamorphic recrystallization of Al-rich rock subducted below continental crust has also been advocated (Levinson and Cook, 1994). Several models use alkaline Si- and Al-rich melts, either evolved from basaltic magmas (Irving, 1986; Coenraads *et al.*, 1990; Coenraads, 1992a) or derived from melting of amphibolitised mantle (Sutherland, 1996). A more complex melt origin was proposed by Guo *et al.*, 1996, who claimed that mineral inclusions in the corundums reflect mixing of Si-rich and carbonatitic magmas under relatively low temperatures around 400°C at mid-crustal levels around 10–20 km in depth. Sutherland *et al.* (1998, in prep.), have questioned this model as a widespread means of generating 'basaltic' type gem corundum and favour melting of mantle source-rocks containing amphibole at depths of 35–40 km near the crust-mantle boundary; such melting could produce a final Si- and Al-rich rock with over 5 wt% corundum.

Regional distribution of corundum suites

Trace-element ranges for Barrington and West Pailin bimodal suites were compared with those from other East Australian and East Pailin gemfields *(Tables I and II)*. Similar bimodal suites also exist elsewhere, e.g. Tumbarumba in the Snowy River basalt field, East Australia (MacNevin and Holmes, 1980), between Chanthaburi and Trat, Thailand (Hughes, 1990) and possibly in Laos (Bosshart, 1995; D Schwarz, unpublished data). However, the situation appears more complicated than just basaltic tapping of two overlapping distinctive corundum suites.

Although many Thai sapphires carry mineral inclusions similar to Australian and Pailin suites (e.g. plagioclase, urano-pyrochlore; Gübelin and Koivula, 1986), Thai rubies carry mineral inclusions not seen in the Barrington and West Pailin fancy corundum suites (e.g. analcime, apatite, calcite, pyrope-almandine, plagioclase, olivine, diopside, biotite, rutile, pyrite and pyrrhotite, with only spinel being common to both groups). Similar species also appear in sapphires from Yogo Gulch (Montana, USA) and in corundums from metamorphic terrains (Burma, Sri Lanka and eastern Africa; Gübelin and Koivula, 1986). Thus, different metamorphic or pegmatitic sources and assemblages must exist under basaltic regions, and the corundum-sapphirine-spinel association is only one. The East Australian and Pailin corundum suites analysed here are clearly different to 'skarn' sapphires, such as those from Andranondambo, Madagascar, both in their trace-element ratios and inclusion content (Milisenda and Henn, 1996; Kiefert *et al.*, 1996; Schwarz *et al.*, 1996).

The West Pailin ruby source probably extends into Thailand, as sapphirine was recorded in Bo Rai ruby by Koivula and Fryer (1987) and inclusions are limited in mineral range (Keller, 1990). However, further east near Chanthaburi, Thai rubies show a greater range of mineral inclusions and may represent a different basement source within this complex tectonic region. Regional differences may also exist among 'basaltic' type corundums, as suggested by zircon inclusions. Zircons in Australian and Asian corundums (Guo *et al.*, 1996;

Sutherland *et al.*, 1998) are typically high in U and Th, but some are much less so. More detailed work on South East Asian corundum suites will help define corundum sources below these basaltic fields.

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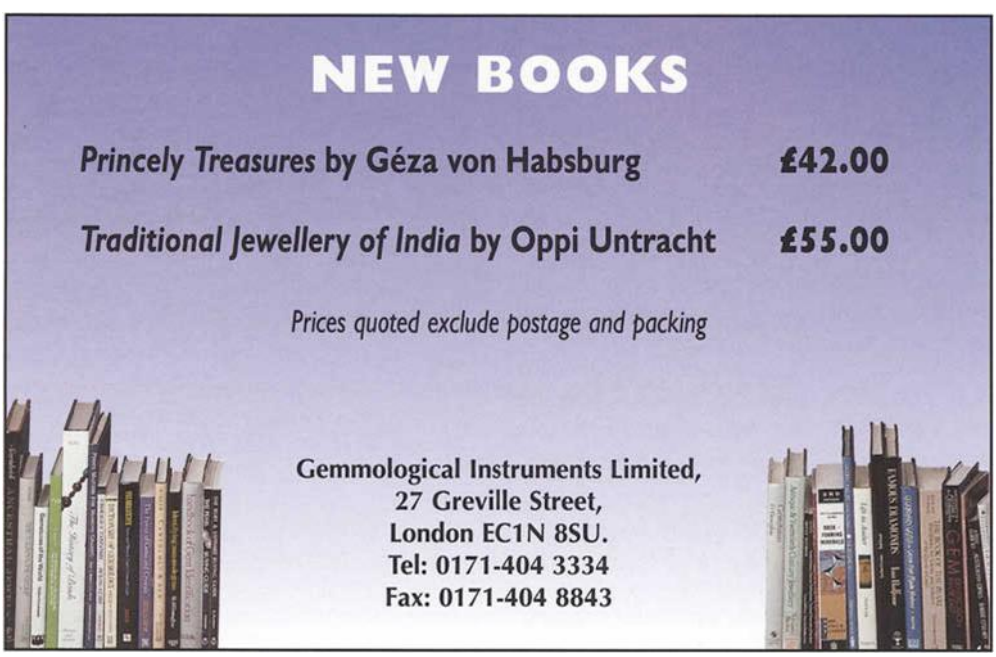

Peridot from the Black Rock Summit lava flow, Nye County, Nevada, USA

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ABSTRACT: An extinct volcano's alkaline basalt lava flow has fissures and tumuli filled with large phenocrysts of peridot and occurs near Black Rock Summit in east central Nevada, USA. The peridot was studied to determine chemical, optical and physical properties and the variations in these properties from peridot from other world occurrences. This little-known source provides peridot in varying shades of green to brown, similar to material found in a caldera known as Kilbourne Hole (Volcano), Dona Ana County, New Mexico, USA – some 1126 km distant. Several identified 'new' inclusions, not previously cited in the literature, are described. Though not mined commercially, the peridot is of interest due to its variation in colour from peridots of other world sources.

Introduction

Approximately 277 km north-north-east of Las Vegas, Nevada, lies a desert area of flatlands *(Figure 1)* sparsely dotted with *playa* lakes and mountain ranges and known as a 'pancake' desert. The northerly highway from Las Vegas passes by top-security military bases and desolate areas which historically represent the underground test area of over 800 nuclear weapons. Still farther north in a remote area will be found an extinct volcano, Lunar Crater, and black volcanic lava flows of Cenozoic age listed on US Geological Survey maps as the Black Rock Summit lava flow.

Figure 1: *View of the cinder cone and very dark lava field looking easterly with the cinder cone rising approximately 300 m from the desert floor. The lava field consists of jagged protrusions rising between 0.5 m and 10 m above the sandy desert.*

In the Black Rock Summit lava flow can be found one of the most diverse examples of peridot found in the world. The colour ranges from yellowish-brown through greenish-yellow into very dark 'muddy' shades of brown. With a history of peridot going back to 1500 BC, the study of peridot associated with volcanoes of high-alkali olivine basalt will continue to be a 'new discovery' event inasmuch as North America

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Figure 2: The western portion of the United States of America showing volcanic areas in the continental USA younger than five million years old (modified from Smith and Leudke, 1984).

provides unlimited numbers of recorded volcanoes from the Aleutian Islands into Alaska, Canada, and the continental United States. The Western United States *(Figure 2)* provides a lifetime of study for the gemmologist with its readily accessible areas for prospecting for this 'old' but currently little-respected gem.

In an effort to compare peridot from different areas of the world with regard to optical and physical data, as well as characteristic inclusions, the author has attempted to collect specimens of peridot from 'little-known' sources. Numerous trips were made over a five-year period to Black Rock Summit lava flow to collect specimens. As each new source is investigated a 'new' inclusion has been reported that is characteristic of the peridot of the area.

A basalt flow *(Figure 1)* on the west slope of the Pancake Range, near Black Rock Summit, Nye County, Nevada, is the youngest unit in an upper Cenozoic volcanic

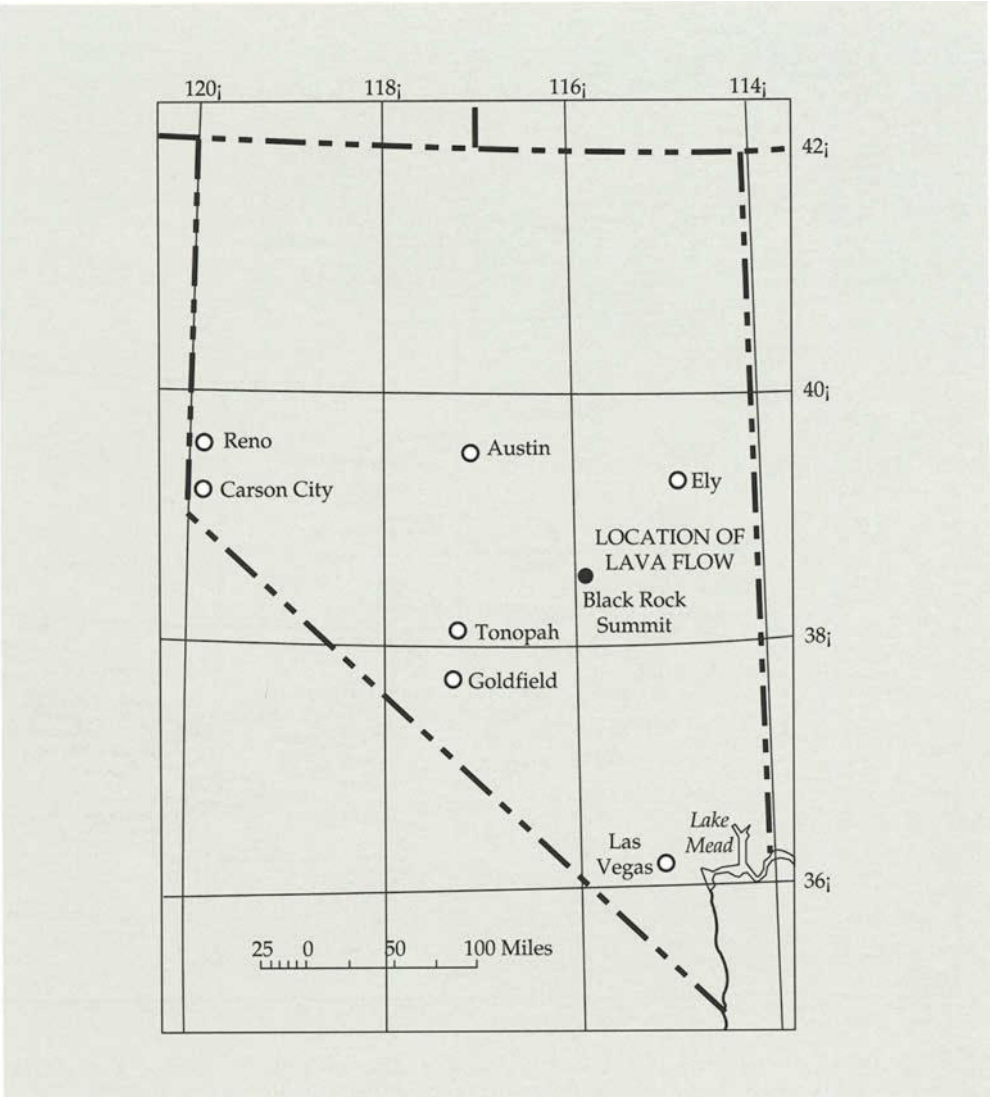

Figure 3: Index map of the State of Nevada, showing the location of Black Rock Summit lava flow (after Vitaliano and Harvey, 1965).

field composed mainly of cinder cones and ash deposits. The flow is black and vesicular to scoriaceous with the texture of the non-scoriaceous phase being porphyritic. Phenocrysts of olivine, pyroxene, and plagioclase are from 1 cm to 22 cm long.

Location and Access

The basalt flow is small covering an area approximately 8.0x4.8 km at 116°00′ west longitude and 38°29′ north latitude, and is accessible by Nevada State Highway Number 6 north-east from the city of Tonopah *(Figure 3)*. US Geological Survey topographic maps which cover the area are Black Rock Summit (number 38115-E8), the Wall (number 38115-D8), Lunar Crater (number 38116-D1), and Moores Station SE (number 38116-E1) which are 7.5 minute quadrangles (Map scale: 1:25000;

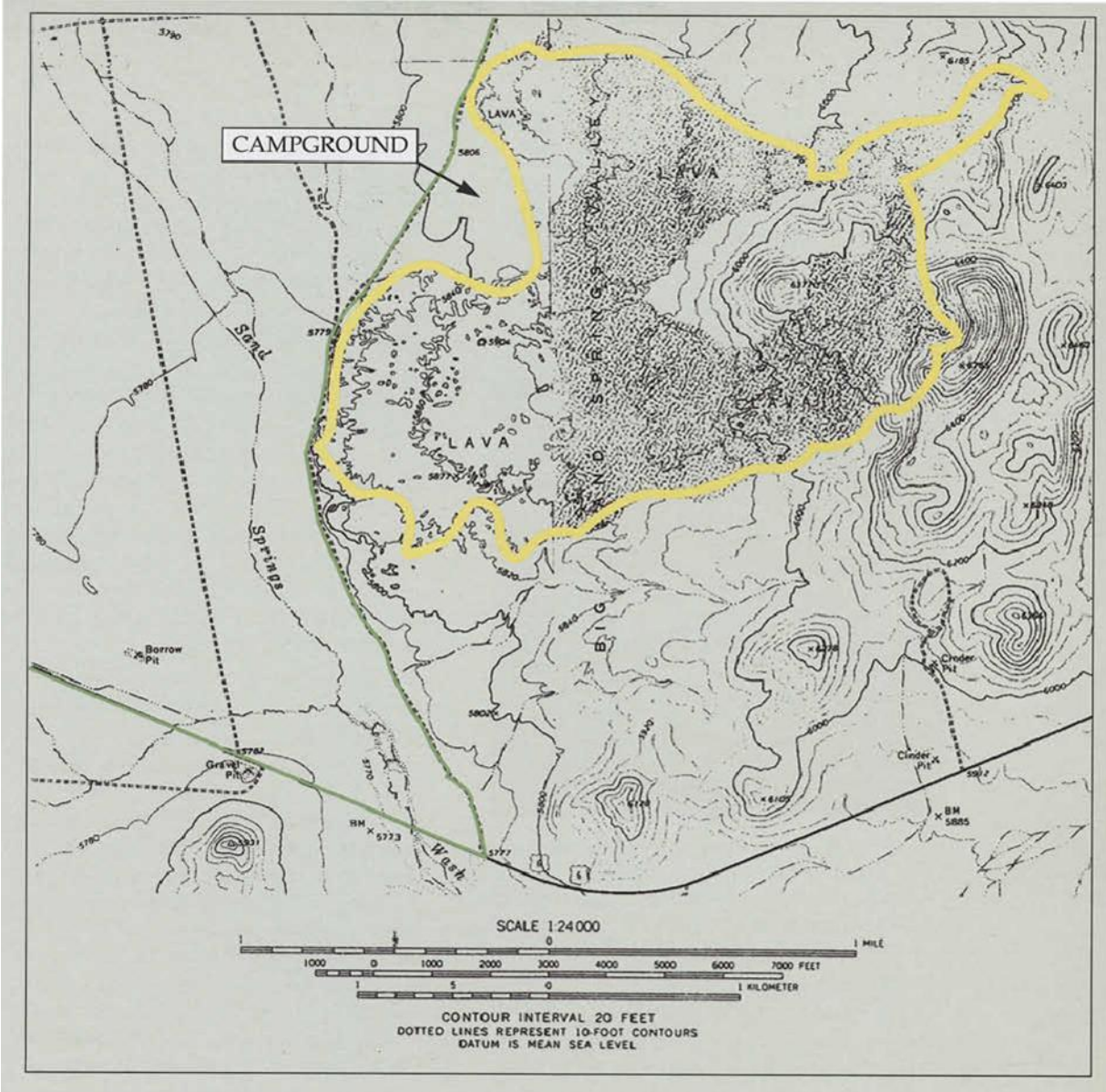

Figure 4: Outline showing access to the Black Rock Summit lava flow from Nevada State Highway Number 6 and the offroad to the encampment; based on US Geological Survey topographic maps. Due to the nature of the scattered lava pieces and the desert sand, it is highly recommended that only a four-wheel drive vehicle be used.

1"=2083 feet). A composite of these four maps is shown in *Figure 4*.

The altitude varies from 1761 m on the desert floor to 2062 m at the summit. The area surrounding the flow is sandy desert with short dried grass and no brush. Typical daytime temperatures in the summer are in the range of 35°C to 46°C with slight cooling desert winds in the late evenings; humidity is less than 5 per cent. Access is from the main highway; however, adequate supplies of food and especially water are mandatory as the temperature on the lava flow in July was measured at midday in excess of 63°C!

Geology and occurrence

A study of the petrology and mineralogy of the lava flow was made by Vitaliano and Harvey (1965). The following is taken from the introduction to their paper:

Figure 5: Centre of the lava field showing the infrequently found tumuli which contain the larger crystals of peridot. This particular tumulus yielded a single peridot specimen which weighed 614.60 ct!

'The lava issued from a breach in the southwest wall of a small cinder cone, one of several located on a N.20°E. trending fissure. About 90% of the lava issued from this crater; the remainder flowed from an orifice located near the northeastern extremity of the fissure. The vent of the crater is about 91 m in diameter and is now filled with solidified lava up to the level of the breach in the wall.'

Within the crater the surface of the lava *(Figure 5)* is infrequently dotted with jagged protuberances called 'tumuli' *(Figure 6)*. The name 'tumulus' was proposed by Daly (1914) (from the Latin 'a swelling-up'), following its application to certain prehistoric burial mounds). Daly recognized that tumuli are common in Hawaii and explained them as having been raised by 'the local hydrostatic pressure of still-fluid lava beneath the already chilled crust', a view with which the author concurs.

The following description of the lava is quoted from the paper by Vitaliano and Harvey (1965):

'Outside the crater it is dominantly a pahoehoe type of lava. Residual monolithic blocks of pyroclastic material, now scattered throughout the flow, may represent fragments from the breach in the crater wall. In the steep north-western wall of longitudinal depression in the lava three layers are exposed, each separated from the other by thin scoriaceous horizons. The thickness of this location exceeds 15 m but the base of the lava was not observed anywhere

Figure 6: 'Tumili', 'lava rises' or 'lava pits' as defined by Hawaii's Institute of Geophysics are more prolific near the edges of the lava flow than in the centre, rising from about 1.5 m to about 10 m and may be the result of pressure ridges.

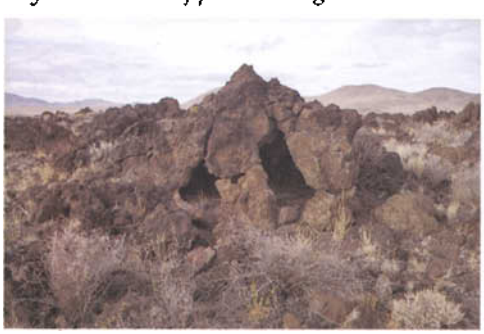

Figure 7: Variation in colour of the fragments collected from the tumuli debris; all pieces appear to be 'splintered' and 'spear-point-shaped' and these represent typical sizes of facetable quality: 7.03 ct (18.3 x 7.9 x 5.7 mm); 12.72 ct (26.7 x 11.1 x 10.1 mm); and 4.65 ct (19.6 x 6.7 x 6.9 mm). Photo by Maja DeMaggio.

> within the confines of the perimeter and consequently the thickness could not be determined.
>
> 'The rock is black, vesicular and porphyritic except where marked oxidation attending vesiculation has colored it red. Its most striking characteristic is the large crystals of olivine (peridot), pyroxene and plagioclase.'

Vesicular walls of lava are occasionally lined with hydrous iron oxide or with a buff-coloured material. Specimens of peridot larger than 2 x 2 cm are generally fractured into elongated 'spear-point-shaped' pieces *(Figure 7)*; those in the central portion of the lava flow are darker in colour and the lighter more 'yellowish' and more transparent material is found within the tumuli at the periphery of the lava flow. The interiors of the tumuli are lined with lava which weathered to release the peridot and colourless plagioclase feldspar and augite crystals; the fine powdery grey ash which has decomposed from the inner walls of the

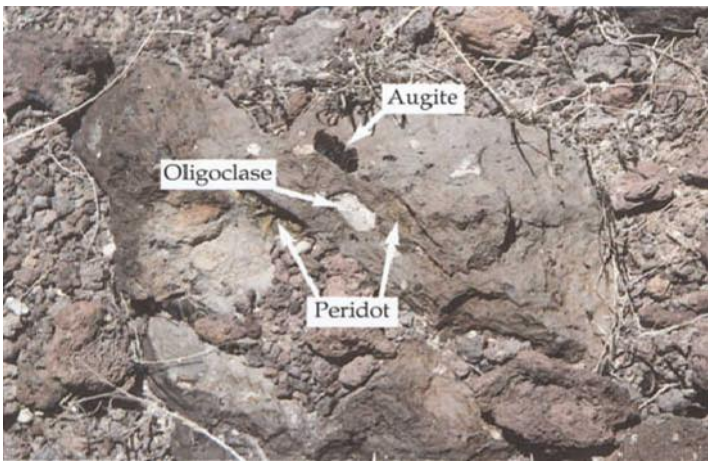

Figure 8: Typical specimen of the lava flow exhibiting single crystals of black augite, colourless (appears white) oligoclase feldspar and green peridot. Each crystal is approximately 5 x 2.5 x 2.5 cm.

tumuli and covers the floors is sifted to recover the gem material. Typical 'floor' lava flow material contains large individual crystals *(Figure 8)* of diopsidic augite, andesine and peridot (with 87% of the forsterite molecule) in proximity. Euhedral crystals of peridot are rare and their faces are highly etched or resorbed *(Figure 9)*.

Figure 9: A single crystal of peridot in lava. Single crystals are rare and this one has been partially rounded by chemical resorption. This faceting-quality peridot measures 22 x 11 x 9 mm.

Figure 10: The largest fissure observed in the lava flow measured 22.23 x 7.91 cm and was completely filled with peridot; the diameter of the coin is 17.9 mm.

Figure 11: This single crystal of peridot measured approximately 7 x 5 x 2 cm and the surface had been oxidized to iridescent colours resembling peacock feathers. Analogous coloration was experienced in the laboratory when heating unaltered material to 750°C for 10 hours.

The largest cavity observed in the lava flow *(Figure 10)* contained nothing but peridot and removal was only effected by use of a one-inch diamond core drill. Most of the peridot was highly fractured where the outer areas of the peridot met the lava.

Two of the larger tumuli contained large eroded and oxidized crystals of peridot *(Figures 11 and 12)* which exhibited iridescence on the weathered surface. These larger specimens could only be removed after many hours of pick and chisel drilling around each specimen.

Figure 12: Several hours of back-breaking work resulted in the removal of the largest peridot crystal found. Unfortunately it cleaved into three pieces but when reassembled it measured 70.0 x 43.0 x 26.0 mm and weighed 614.60 ct comprising three pieces weighing 140.00, 156.20 and 318.40 ct.

Materials and methods

Over 5200 ct of rough samples were removed and segregated by colour and clarity, and representative faceted gems were cut *(Figure 13)* which ranged in weight from 0.55 ct to 15.90 ct. Colours ranged from a

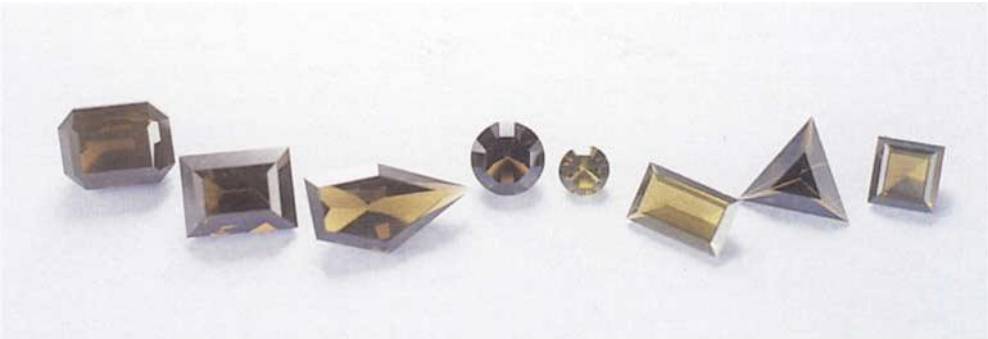

Figure 13: This group of cut stones (0.55 to 6.47 ct) is representative of the colour variation of peridot from the Black Rock Summit lava flow. Note the predominance of brown. Photo by Maja DiMaggio.

light greenish-yellow through olive-green into brownish-green and finally a dark brown. Gemmological properties were obtained from 30 samples representative of the colour range.

Refractive indices were determined with a Rayner Dialdex refractometer and GIA high-intensity sodium-vapour lamp. Refractive indices of grains taken at small intervals from edge to centre of large peridot crystals were determined by the immersion method. Pleochroism was determined with a GIA-GEM polariscope, Rayner and GIA calcite dichroscopes, and a modified Bausch & Lomb GIA Gemolite microscope. Specific gravities were measured hydrostatically using stabilized 1,2-dibromomethane (corrected for temperature) and an analytical balance with 0.1 mg sensitivity as well as the Berman balance. Ultraviolet testing was done with high-intensity (100 W), filtered, mercury-vapour lamps at typical short (253.7 nm) and long (366.0 nm) wavelengths.

Optical spectra were observed under darkroom conditions with two desk-top spectroscope units, one with a Beck prism spectroscope and the other with a GIA-GEM digital-readout, scanning, diffraction-grating spectroscope. Optical and infrared spectra were obtained from one of the larger (6.47 ct) faceted specimens using a Pye-Unicam 8800 UV-visible spectrophotometer and a Nicolet 60SX FTIR spectrometer.

Chemical analyses were obtained by electron microprobe and by proton-induced X-ray emission (PIXE) methods. PIXE is a non-destructive method which is similar in principle to energy-dispersive X-ray fluorescence (EDXRF). It employs an accelerator to drive a high-speed stream of protons toward the target sample, and each element in the sample responds by producing characteristic X-rays, which are detected and counted; within minutes of exposure, a computer produces both quantitative and qualitative data.

Description of the material

Peridot, a magnesium-iron silicate, is a member of the olivine group, an isomorphous series which ranges in composition from forsterite, Mg_2SiO_4 to fayalite, Fe_2SiO_4. The general formula is $(Mg, Fe)_2SiO_4$. Peridot lies close to the forsterite end of the series that has lower refractive indices and specific gravity than members of the fayalite end. Olivine is orthorhombic with two imperfect cleavages in the {010} and {100} crystal directions and a Mohs hardness of 6.5 to 7. Optically, it is biaxial with moderate to high birefringence.

Most of the material collected at Black Rock Summit lava flow, though large (30x14 mm), was weathered and eroded and quite difficult to remove from the matrix. Sectioned diamond-sawing of various specimens disclosed numerous fractures radiating from the surface of the peridot crystals resulting in limited flaw-free faceting material. Faceted specimens ranged in weight from 0.47 ct to 15.90 ct.

Table I: *Gemmological properties and chemical compositions of three representative samples of Black Rock Summit lava flow peridot.*

Properties and elements	*BRP#1*[a]	*BRP#2*[b]	*BRP#3*[c]
RI α	1.6595	1.658	1.656
β	1.6725	1.676	1.676
γ	1.6930	1.694	1.696
SG	n.d.	3.351	3.388
Wt.%			
SiO_2	40.55	40.05	37.90
Al_2O_3	1.62	0.08	n.d.
FeO	10.27	11.79	13.81
MgO	47.43	47.34	47.62
MnO	0.16	0.16	0.20
NiO	n.d.	0.28	0.27
CaO	n.d.	0.22	0.15
Cr_2O_3	n.d.	n.d.	0.034
ZnO	n.d.	n.d.	0.008
Total	100.03	99.92	99.992

[a]Chemical analysis performed by M. Coller, Department of Geology, Indiana University. (From Vitaliano and Harvey, 1965.)
[b]Electron microprobe analysis by David E. Lang, Harvard University.
[c]Analysis performed on the PIXE system of a General Ionex Corp. Tandetron accelerator with an intense proton beam of up to 3MeV, a Tracor lithium-drifted silicon X-ray detector; and a multichannel analyzer system.
n.d. not determined

None of the Black Rock Summit peridot exhibits asterism or chatoyancy although these optical phenomena have been reported in peridot from other localities.

Gemmological properties

The colours of Black Rock Summit peridot range from light yellowish-green to olive-green, brownish-green and dark-brown. In the normal process of crystallization of a magma, the first olivine to form is high in magnesium and as crystallization proceeds and temperatures slowly decrease, the mineral becomes progressively richer in iron. Therefore, in the large phenocrysts, one could expect a zoning with a magnesium-rich core and an iron-rich margin. Such a change in chemistry should be reflected in colour and refractive index, i.e. darker colour and higher indices at the margin than at the core. It was thus surprising to find only a slight variation in refractive indices and little, if any, correlation between refractive indices and colour in Black Rock Summit peridot. Observed refractive index ranges were: $\alpha = 1.656–1.660$, $\beta = 1.674–1.678$, and $\gamma = 1.694–1.699$, with a birefringence range of 0.033-0.038. Measurements of α, β and γ on 19 peridots ranging from very light to very dark colours gave means of 1.659, 1.676 and 1.695 respectively. This would indicate that there is little variation in the chemistry of the crystals from core to rim and that the chemical analyses given in *Table I* are representative of the bulk composition of the crystals.

Pleochroism is distinct, with colour combinations for the various colour categories of: light-greenish-yellow being 'light-yellow and light greenish-yellow'; olive-green being 'medium yellowish-green and medium orangy-green'; brownish-green being 'medium to dark yellowish-green and medium orangy-brown' and finally the dark brown being 'dark yellowish-brown and dark greenish-brown'. Specific gravities of 3.351 to 3.388 were obtained. All specimens remained inert to both long- and short-wave ultraviolet radiation.

Spectroscopy and chemical composition

Absorption bands were observed in all specimens at 453, 474 and 635 nm, the last being very weak. A moderately strong band centred at about 495 nm was also observed with the prism spectroscope, but the diffraction-grating unit resolved it into two bands at about 497 and 489 nm. Spectrophotometry of the 6.47 ct sample revealed these and additional weak bands as follows: 399, 403, 412, 421, 431, 435, 445 and 530 nm (*Figure 14*). As one might expect, all absorption bands were less apparent in the hand-held spectroscope in the paler stones. The spectral features have all been observed

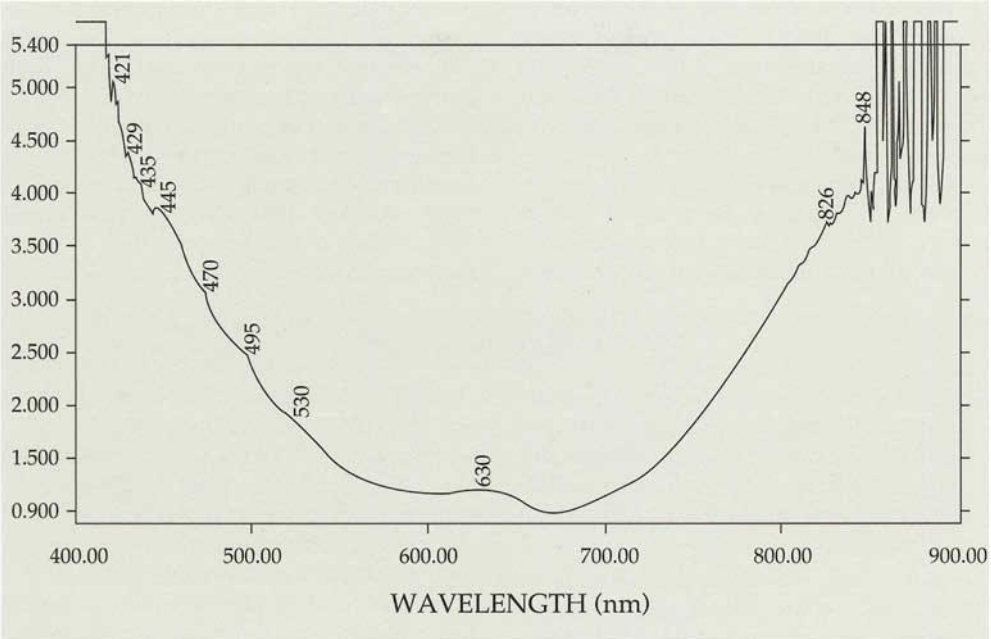

Figure 14: UV-visible spectrum of a representative sample of peridot from material found at Black Rock Summit lava flow – a 6.47 ct faceted stone (Figure 13, extreme left of picture) and recorded using a Pye-Unicam 8800 spectrophotometer.

previously in peridot from other localities, particularly those from Arizona (Farrell and Newnham, 1965; Burns, 1974; Koivula, 1981). Similarly coloured peridot from the Kilbourne Hole (Führbach, 1992) showed absorption bands at 452, 473 and 640 nm, the last being relatively weak. A moderately strong band seen at about 492 nm with the prism spectroscope was resolved by the diffraction-grating unit into bands at 497 and 489 nm.

The data obtained by electron microprobe analysis and PIXE analyses of three samples revealed compositions typical for peridot *(Table I)*. The Mg:Fe ratio for the Harvard analysis (omitting minor elements) is 87.9:12.1 from a formula: $(Mg_{88}Fe_{12})SiO_4$. The PIXE analysis gives a ratio of Mg:Fe of 86:14. The average of three analyses of comparable coloured material from Kilbourne Hole gives a ratio of Mg:Fe of 88.7:11.3.

The PIXE analysis gives the percentages of elements; it reports the metals but not oxygen. The analysis as reported has been recalculated to oxides and this in turn has been recalculated to 100 per cent. The new analyses from the microprobe and the PIXE agree well with the older analysis (Vitaliano and Harvey, 1965).

Yellowish-green peridot is a classic example of coloration by a transition metal ion, in this case Fe^{2+} (Farrell and Newnham, 1965), which produces a series of absorption bands visible in the spectroscope. Traces of chromium have been reported as contributing to the green colour (Arem, 1987), but no supporting data for this were found in Black Rock Summit peridot.

Spectrophotometry revealed essentially three components that, together, leave a transmission window centred around 550 nm, which corresponds to yellowish-green. The first of these is an absorption tail that absorbs much of the red and orange. This feature has been observed in peridots from other localities and is related to near-infrared absorptions that are attributed to Fe^{2+} (Burns, 1974).

The second component is the series of bands in the visible range, most of which have also been attributed to Fe^{2+} (Farrell and Newnham, 1965). The suggestion that some are related to Mn^{2+} (Gunawardene, 1985) was not substantiated.

The third spectral component is a general increase in absorption from about 550 nm toward the ultraviolet, which results in a brown colour. Studies on synthetic forsterite (Weeks *et al.*, 1974) and on other gem silicates and oxides (Fritsch and Rossman, 1987) indicate that this feature may arise from charge-transfer phenomena between oxygen and transition metal ions such as Fe^{3+} or Ti^{4+}. However, iron-rich olivine and the end member fayalite are often amber-coloured in thin section regardless of Ti content (Deer *et al.*, 1982, p 186), which suggests that Fe alone may be responsible.

Faceting procedure

Though peridot gives little or no trouble during preforming or cutting, it can be very unpredictable during polishing (Vargas and Vargas, 1989). Black Rock Summit peridot commonly has one direction in which polishing is quite difficult.

After trying numerous combinations of laps, polishing agents and lap speeds, the author recommends the following procedures for ease in faceting and polishing this and other peridot material: (1) preform on Crystalite® 100 Dot Disc, (2) facet on Crystalite® 260 Diamond Disc, (3) facet on RayTech® 1200 Nu-Bond Disc and (4) polish on Crystalite® Phenolic Lap with Crystalite® 14000 Mesh (1 micron) Diamond Spray @ 200 to 250 r.p.m. running the lap damp to nearly dry; moderate pressure. Care must be exercised on polishing with the phenolic lap as heat of friction develops rapidly and may cause the dopping cement to soften and the gem to shift!

When all else fails (as frequently happens with peridot) use a pure tin lap with half-micron (50 000 mesh) spray diamond.

Figure 15: Decrepitation haloes surrounding negative crystals; inclusion features descriptively known as 'lily pads' are rarely found in Black Rock Summit peridot. Photomicrograph by J. Koivula; 30x.

Microscopic features

Thorough examination of several thousand specimens taken from various areas, viz. tumuli from the central lava field, peripheral lava flow tumuli and material from the lava cone were examined with the microscope. From these some 10 types of inclusions were observed.

Lily Pads: although one expects to see inclusions of lily pads typical of peridot from other sources (Gübelin, 1974; Gübelin and Koivula, 1986), their near complete *absence* is characteristic of Black Rock Summit peridot. In fact, of more than 30 faceted specimens examined (0.55 ct to 15.90 ct) only one specimen contained an inclusion that could be described as lily pad *(Figure 15)*.

Geyser-Like: the most frequently noticed inclusion in the Black Rock Summit peridot consists of very fine geyser-like or fine hair-like patterns *(Figure 16)* which could not be resolved or defined at magnification up to 100x (Gübelin, pers. comm., 1991).

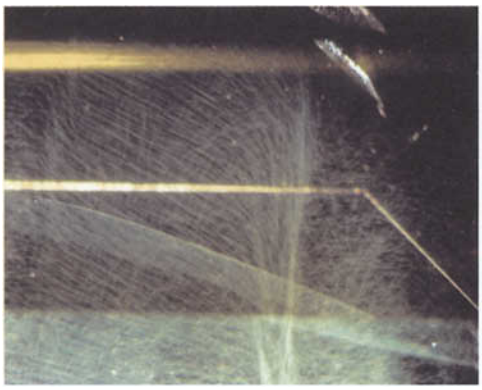

Figure 16: *Since these inclusions in Black Rock Summit peridot have not been seen in other worldwide sources the author has elected to describe the newly found inclusions as 'geyser-like' or 'fine hair-like' inclusions. Photomicrographs by J. Koivula; 30x.*

Milky: the second most encountered inclusion is an overall milky coloration which renders the apparently flawless material semi-transparent by transmitted light and hazy in appearance by reflected light.

Rosary-bead inclusions (Figure 17): straight and fine hair-like with tiny bright green chrome diopside crystals, partially resorbed.

PCB: one of the most intriguing new inclusions *(Figure 18)* was best described by Gübelin (pers. comm., 1990) as PCB (printed circuit board) in character. Its identity remains to be determined and of the thousands of specimens examined this inclusion was observed in but two specimens of very dark brown peridot. Dr Gübelin (pers. comm., 1991) described the inclusion(s) as '... tangle of regular thread-like inclusions ... difficult to interpret ...[possibly] the edges or borders of individual grains of a mosaic structure ...'

Smoke-like veils: the Black Rock Summit contains inclusions described as smoke-like

Figure 17: *Tiny chrome diopside inclusions, partially resorbed, exhibit the low relief and bright green colour typical of this mineral. Photomicrograph by J. Koivula; 50x.*

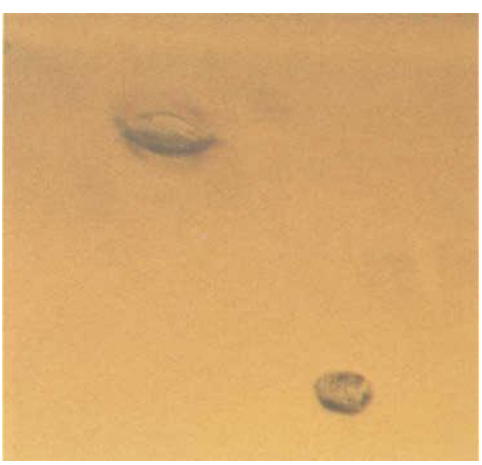

Figure 18: *This unusual inclusion was found in only two specimens examined from the Black Rock Summit peridot and has been best described by Dr Edward Gübelin as PCB (printed circuit board) in character. Photomicrograph by E. Gübelin; 60x.*

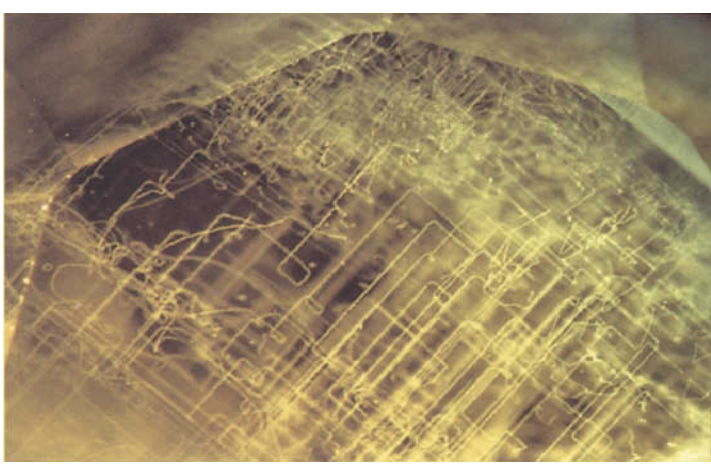

Figure 19: Patchy cross-hatched inclusions found in the Black Rock Summit peridot but not in peridot from other worldwide sources. This pattern could only be observed when the specimen was rotated 360° and examined by transmitted light, and is possibly the result of exsolution. Photomicrograph by J. Koivula; 35x.

Figure 21: Countless dark orangy-brown near-parallel flow lines in transmitted light, possibly the result of exsolution. Photomicrograph by J. Koivula; 50x.

Figure 20: Black metallic spheres in two peridots examined by dark-field illumination or transmitted light. When exposed by careful sectioning they reveal crystalline inclusions which were identified as pyrrhotite and pentlandite. Note the variation in colour between the two peridots. Photomicrograph by J. Koivula; 25x and 40x.

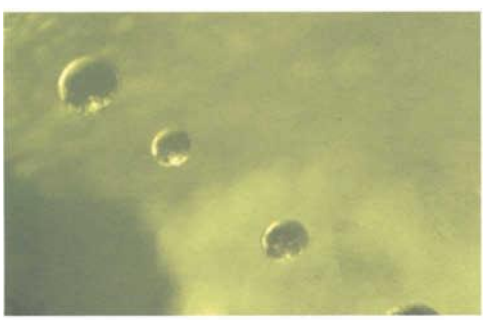

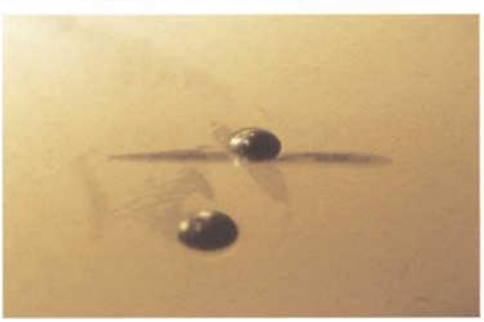

veils similar to those previously noted in peridots from Arizona and China (Koivula, 1981; Gübelin and Koivula, 1986; Koivula and Fryer, 1986; Führbach, 1992). They result from incomplete solid solution (Koivula, pers. comm., 1993) that develops as the peridot is brought to the Earth's surface and cools in the basalt; the process also causes dislocations which produce visible strain (Kohlstedt *et al.*, 1976). These veils appear as ghostly white streamers when viewed with darkfield illumination and appear hazy or milky in reflected light rendering the gem semi-transparent.

Patchy cross-hatched inclusions (Figure 19): observed by transmitted light at 10x magnification; these have not been observed in peridot from other sources.

Black metallic spheres: some black opaque spherical inclusions *(Figure 20)* are attracted to a magnet (Koivula, pers. comm., 1995) and

Figure 22: Dendritic crystals in fractures in darker brown specimens of Black Rock Summit peridot; this kind of inclusion is uncommon. Photomicrograph by J. Koivula; 15x.

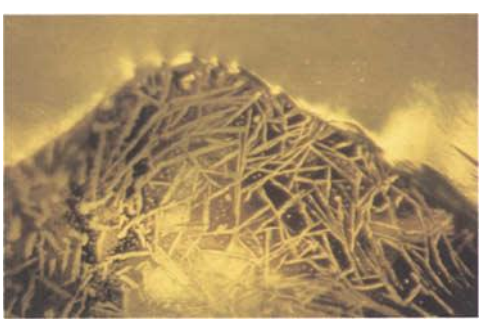

Table II: *Optical and physical properties of peridot from various world sources.*

Origin	*RI*			*Δ*	*OC*	*SG*	*Reference*
Antarctic	1.653	?	1.689	0.036	?	3.34–3.35	13
Arizona	1.653	1.669	1.690	0.037	B+/–	3.35	4
Arizona	1.652	1.671	1.689	0.037	B-	3.34	4
Arizona	1.652	1.668	1.689	0.037	B+	3.34	4
Arizona (light)	1.649	1.665	1.686	0.037	B+	3.28	10
Arizona (dark)	1.653	1.671	1.691	0.038	B+	3.38	10
Arizona	1.652	1.670	1.689	0.037	B+	3.33	9
Argentina*	1.650–1.656	1.670–1.675	1.688–1.691	0.035	B+/–	3.37–3.44	18
Australia	1.653	1.671	1.690	0.037	B+	3.39	7
Burma	1.654	1.671	1.689	0.036	B+	3.32	1
Burma	1.656	1.671	1.692	0.036	B+/–	3.35	6
China	1.653	1.670	1.689	0.036	B+	3.36	19
Ethiopia	No data available						20
Kentucky*	1.669	1.688	1.705	0.036	B–	3.47	18
Kenya (yellowish)	1.650	?	1.686	0.036	?	3.45	1
Kenya (brownish)	1.651	?	1.681	0.038	?	3.35	1
Kilbourne (yellowish)	1.659	1.674	1.693	0.034	B+/-	3.42	5
Kilbourne (greenish)	1.663	1.679	1.698	0.035	B+/-	3.43	5
Kilbourne (brownish)	1.669	1.684	1.705	0.035	B+/-	3.50	5
Nevada (Black Rock)							
(yellowish)	1.659	1.676	1.695	0.036	B+	3.37	14
(greenish)	1.659	1.676	1.695	0.037	B+	3.38	14
(brownish)	1.659	1.676	1.695	0.038	B+	3.39	14
New Mexico	1.652	1.671	1.688	0.036	B–	3.33	1
Mexico	1.652	1.671	1.688	0.036	B–	3.33	4
Mexico	1.652	1.668	1.685	0.033	B+	?	4
Norway (cabochon)	1.650		1.685	0.035	?	?	2
Pakistan	1.651	1.669	1.687	0.036	B+/–	3.35	15, 17
Sri Lanka	1.651	1.660	1.690	0.039	B+	3.36	7
Synthetic	1.65		1.68	0.03	B	3.30	16
Tanzania-Kenya (border)	1.650	1.658	1.684	0.034	B+	3.25	12
Unknown (cat's-eye)	No data available						11
Vietnam	1.650	1.666	1.688	0.038	B+	3.34	8
Zarbargad	1.652	1.668	1.690	0.035	B–	3.28	7

Notes:
OC Optical character.
B Biaxial positive or negative.
* Pallasitic meteorite peridot
1 Arem, 1987
2 Borg, 1980
3 Brown, Bracewell, 1983
4 Dunn, 1978
5 Führbach, 1992
6 Gübelin, 1975
7 Gunawardene, 1985
8 Koivula, 1993
9 Koivula, Fryer, 1987
10 Koivula, 1981
11 Kane, Koivula, 1987
12 Stockton, Manson, 1983
13 Wilson, Hendy, Taylor, 1974
14 Führbach, 1995
15 Larson, Thompson, 1994
16 Nassau, 1994
17 Thompson, 1994
18 Sinkankas, Koivula, Becker, 1992
19 Koivula, Fryer, 1986
20 Koivula, Kammerling and Fritsch, 1993

were found by X-ray diffraction to be pyrrhotite ($Fe_{1-x}S$) where x is between 0.0 and 0.2. Other similar-appearing spheres, but non-magnetic, were found to be pentlandite $(Fe, Ni)_9S_8$. Note the variation in colour between the two peridots photographed.

Paint-brush strokes: dark orangy-brown flow lines *(Figure 21)* seen in transmitted light appeared white in fibre-optic and dark-field illumination. Almost parallel arrangements, some consisting of only a few lines, others of several dozen, permeate the interior of many specimens, regardless of colour. They are possibly the result of exsolution.

Secondary inclusions in brown peridot are shown in *Figure* 22.

Conclusion

Black Rock Summit lava flow contains great fissures and cavities filled with peridot, and partially resorbed large peridot crystals within the alkali basalt – many exceeding 500 ct. Though of a darker hue than peridot from other world localities, the physical properties and chemical composition are consistent with those for peridot *(Table II)*. These peridots contain newly discovered inclusions which have not been reported in peridot from other world sources. Lily pad inclusions are rarely encountered in this material. While large specimens as well as cut gems are obtainable, the extent of the material available for commercial purposes has not yet been estimated.

Acknowledgements

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Rubies and pink sapphires from the Pamir Mountain Range in Tajikistan, former USSR

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ABSTRACT: A small number of gem-quality rubies and pink sapphires are being recovered from marble-type deposits in the Pamir mountains of the Republic of Tajikistan, southern portion of the former USSR. Presented in detail are the standard gemmological properties and internal features of a few samples from this remote locality. Some distinctive inclusion patterns were noted and a variety of mineral inclusions were identified. In addition, the spectral characteristics and chemical composition of the samples are provided.

Keywords: corundum, ruby, sapphire, Pamir mountains, Tajikistan, USSR, gemmological properties

Introduction

The Pamir mountain range traverses Tajikistan, along the southern region of the former Soviet Union, bordering Afghanistan and China. This mountain sequence is well known to professional and hobbyist mountain climbers for its beautiful and challenging topography. The mountains are relatively unknown, however, to most gemmologists around the world as a source of gemstones. The most recognized gems are the red spinels from along the eastern portion near the border with China (Koivula and Kammerling, 1989); however, these mountains also produce limited quantities of gem-quality clinohumite, tourmaline, topaz, danburite, scapolite, jeremejevite and corundum (Henn and Bank, 1990).

Rubies from the Pamir mountains were first described by Henn and Bank (1990) and Henn *et al.* (1990). Therein, these researchers described a marble-type deposit which was first discovered by a Soviet geologist in the early 1980s. Since their discovery, a limited supply of these rubies has entered the gemstone trade.

Turakuloma is the name of the ruby-producing region (I. Pojarevski and A. Trushin, 1997, pers. comm.) and is located about 6 km from the Chinese border and about 40 km NE of the town of Murgab (Henn and Bank, 1990; Henn *et al.*, 1990). Within this region several mines have been worked, the richest and best known being Snejnaya at an elevation of about 3500 m. The mines are typically worked from June until August – the weather conditions are too harsh during the rest of the year. In general about 30 people work each mine using picks and shovels, but at some, such as at Snejnaya, dynamite and a bulldozer are also used to recover the gems (I. Pojarevski and A Trushin, 1997, pers. comm.).

Samples, methods and equipment

This brief description of the rubies and pink sapphires from the Pamir mountains is

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Figure 1: Gem-quality rubies and pink sapphires from the Pamir mountains in Tajikistan. The samples range from 0.30 to 0.80 ct, with such qualities typically being found in sizes up to one and a half carats. Photographed by Nicole Surdez.

the result of an investigation of eight gemstones (ranging in weight from 0.30 ct to 1.48 ct), which were obtained from Ivan Pojarevski, president of Bulgaria Gems, Sofia, Bulgaria, and from other dealers specializing in gems from the Pamir region. The samples were purchased from miners working directly within the corundum deposits of the Pamir mountain range.

A binocular microscope combined with fibre-optic lighting techniques was used to examine internal and external characteristics. A Duplex II refractometer was used to measure the refractive indices, as well as determine the birefringence and optic character. Specific gravity determinations were made with a Mettler electronic balance equipped with the appropriate attachments for hydrostatic weight measurements. Long-wave (365 nm) and short-wave (254 nm) lamps were used to test the ultraviolet fluorescent reactions and a calcite dichroscope was used to observe the pleochroism.

Table I: *The gemmological properties of the rubies and pink sapphires from the Pamir Mountain Range, Republic of Tajikistan.*

Visual appearance	Highly transparent with richly saturated hues ranging from purplish-pink to purplish-red
Refractive index	Ne = 1.761–1.762 No = 1.770
Birefringence	0.008–0.009
Optic character	Uniaxial negative
Specific gravity	3.99–4.02
Pleochroism	Moderate to strong dichroism; Pinkish/reddish-orange to red-orange parallel to the c-axis Purple-pink to purple-red perpendicular to the c-axis
UV luminescence	Long-wave (365 nm): strong to very strong, slightly orangy- red to red Short-wave (254 nm): very weak to medium red
Visible absorption spectrum	General absorption up to approximately 450 nm; 468, 475 and 476 nm lines; broad band between approximately 530–580 nm; 659, 692 and 694 nm lines
Internal features	Very fine clouds, short rutile needles and pinpoint particles, faint to moderately distinct growth structures, occasionally faint colour zoning, twin lamellae, mineral or negative crystals with oriented equatorial thin films – singly or aligned in rows, various healed fracture patterns, 2- and 3-phase negative crystals, as well as crystalline inclusions of calcite, titanite, zircon, rutile and plagioclase feldspar

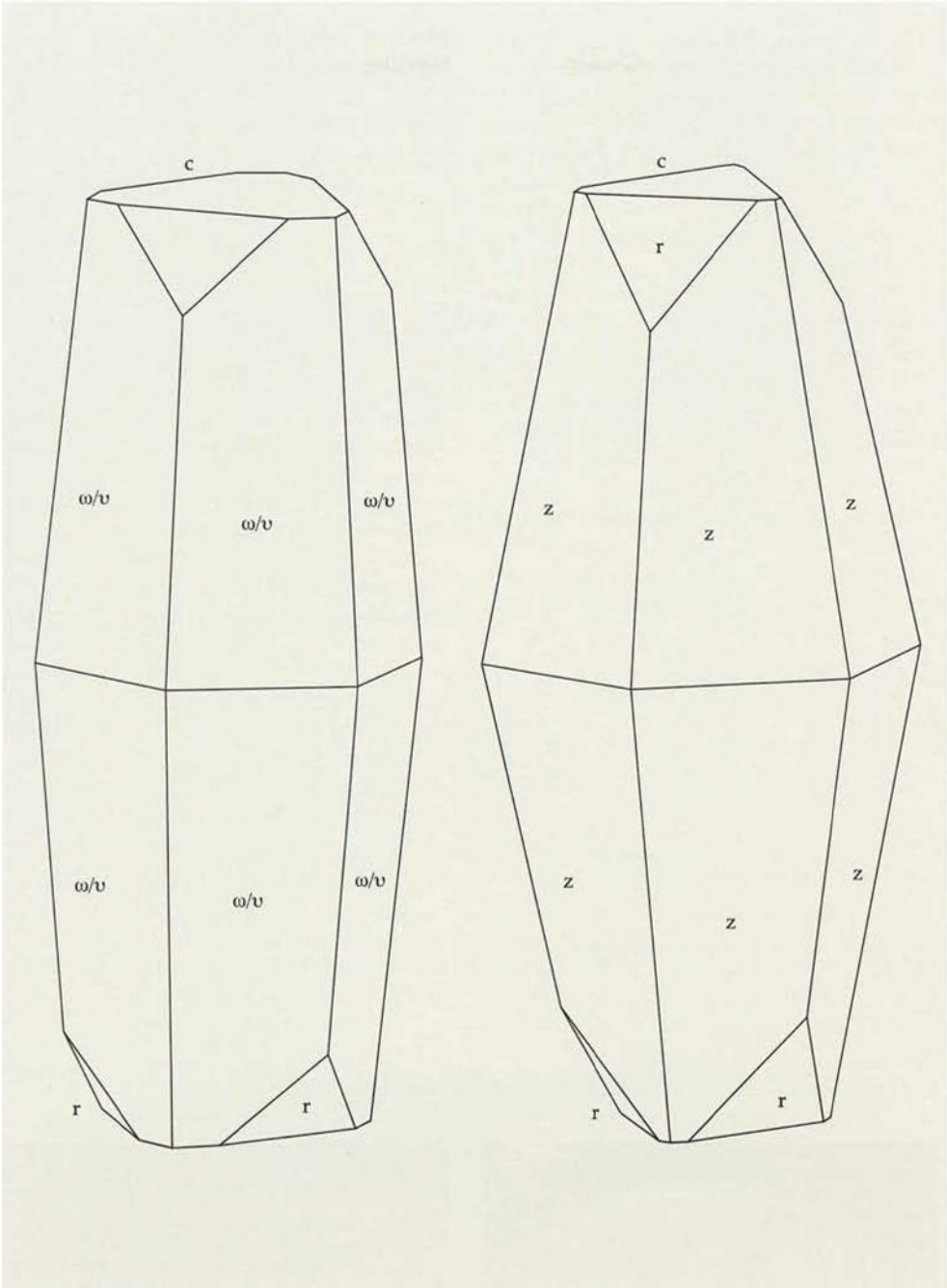

Figure 2: Two dipyramidal crystal habits were identified in rubies and pink sapphires originating from the Pamir Mountains: (a) habits composed of subordinate basal pinacoid c (0001) and positive rhombohedral r (10$\bar{1}$1) crystal faces and dominant ω (14 14 $\overline{28}$ 3) or ν (44$\bar{8}$1) crystal faces, and (b) Habits composed of subordinate basal pinacoid c (0001) and positive rhombohedral r (10$\bar{1}$1) crystal faces, with dominant dipyramidal z (22$\bar{4}$1) crystal faces.

The internal growth characteristics were classified using a specially designed stone-holder and immersion microscope incorporating the techniques described by Schmetzer (1985, 1986), Kiefert and Schmetzer (1991) and Smith (1996). The various mineral inclusions were identified using a scanning electron microscope equipped with an energy-dispersive X-ray fluorescence unit (SEM-EDS). Absorption spectra were taken with a standard desk-model spectroscope and a UV-Vis-NIR Perkin Elmer Lamda 9 spectrometer with a beam condenser and polarising filters in the region between 200 and 800 nm. Infrared spectra in the region between 400 and 7000 wavenumbers (cm^{-1}) were taken with a Pye-Unicam FTIR 9624 spectrometer using a diffuse reflectance unit. A semi-quantitative chemical analysis was performed with a Spectrace TN 5000 system energy-dispersive X-ray fluorescence spectrometer.

Visual appearance

The samples in this study are transparent and display richly saturated colours ranging from purplish-pink to purplish-red *(Figure 1)*.

Properties

Gemmological properties

The refractive indices, birefringence, optic character, specific gravity, UV fluorescence reaction and pleochroism are summarized in *Table I* and are consistent with rubies and pink sapphires in general (Liddicoat, 1989; Hurlbut and Kammerling, 1991; Webster, 1994; Hughes, 1996).

Internal growth structures, colour zoning and twinning

Faint to moderate linear and angular growth structures were observed parallel to the dipyramidal ω (14 14 $\overline{28}$ 3) or ν (44$\overline{8}$1) and positive rhombohedral r (10$\overline{1}$1) crystal faces. A dipyramidal crystal habit composed of subordinate c (0001) and r (10$\overline{1}$1), with dominant ω (14 14 $\overline{28}$ 3) or ν (44$\overline{8}$1) crystal faces, may therefore be considered as typical for the rubies and pink sapphires from the Pamir mountains. The author was also shown a small pink sapphire crystal, reportedly from the same locality in the Pamir mountains, which possessed a subordinate basal pinacoid c (0001) and positive rhombohedral r (10$\overline{1}$1), with dominant dipyramidal z (22$\overline{4}$1) crystal faces *(Figure 2)*. Although in general the Pamir samples are homogeneously coloured, one sample also displays a pale pink columnar zone bordered by darker pink sapphire with slightly irregular growth structures. Lamellar twin planes parallel to a single positive rhombohedral r (10$\overline{1}$1) plane were also observed *(Figure 3)*.

Inclusion features

Although the sampling of the rubies and pink sapphires from the Pamir mountains was small, they provided an interesting array of inclusions. Most commonly, these consisted

Figure 3: *Twin planes parallel to the positive rhombohedron r (10$\overline{1}$1) in a Pamir ruby. Fibre-optic illumination, 35x.*

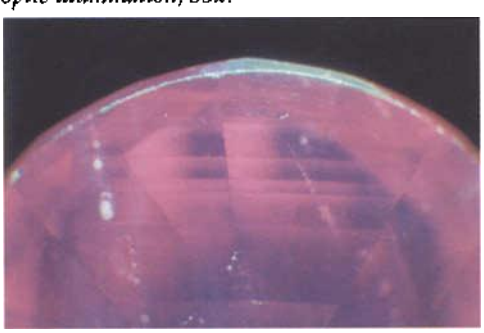

Figure 4: *Short rutile needles and pinpoint particles in a columnar pattern, distinctive of Pamir rubies. Fibre-optic illumination, 35x.*

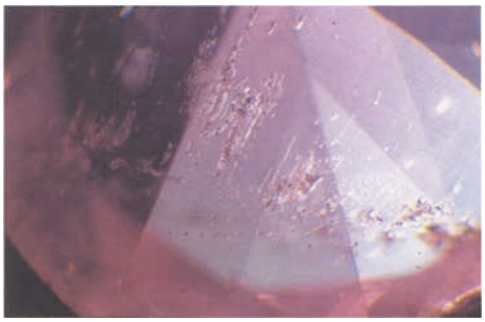

Figure 5: Calcite crystals, highly resorbed, in parallel rows form a distinctive inclusion pattern in the rubies and pink sapphires from Pamir. Fibre-optic illumination, 40x.

of very fine whitish to bluish-white clouds, where the individual pinpoint particles were not identifiable. In sufficient concentration, such clouds occasionally instilled a slightly hazy appearance. In addition, short very fine rutile needles and particles populated the samples, and in some stones formed a distinctive columnar pattern *(Figure 4)*.

A variety of larger crystalline inclusions were also identified. The most plentiful were distinctly rounded, irregular masses of transparent calcite. These consisted of highly resorbed platy crystals which were predominantly equidimensional to oblong in form and which were occasionally accompanied by thin films. Commonly the calcite crystals were present in distinctive, roughly parallel formations *(Figure 5)*. Pale yellow crystals of titanite (sphene) typically occurred as tiny rounded crystals, although larger more irregular forms were also identified. Small prismatic zircon crystals with a length-to-width ratio of approximately 3:1 occurred singly and one was identified intergrown with a larger irregular sphene crystal. Columnar crystals of rutile were either a vibrant orange or black, and oblong crystals of plagioclase feldspar were also identified *(Figure 6)*.

Another unusual inclusion feature consisted of aligned rows of small minerals or negative crystals, where each crystal was accompanied by an oriented equatorial thin film *(Figure 7)*. These inclusions also occurred singly. Various healed fracture patterns were

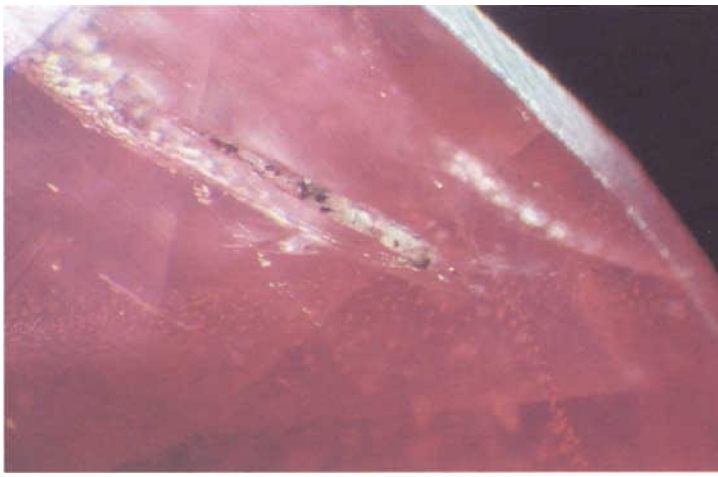

Figure 6: Oblong transparent, colourless crystals of plagioclase feldspar in a 0.80 ct purplish-pink sapphire from Pamir. Fibre-optic illumination, 48x.

noted and distinctive idiomorphic negative crystals often contained immiscible liquid and gas phases *(Figure 8)*.

Absorption spectra

The spectra of the rubies and pink sapphires from the Pamir mountains are dominated by Cr^{3+} absorption, with broad bands centred at approximately 405 and 550 nm, and weak to moderate sharp bands at approximately 468, 475, 476, 659, 692 and 694 nm. Such absorption characteristics are typical of rubies and pink sapphires in general (see e.g. Liddicoat, 1989; Hughes, 1996).

Figure 7: Aligned rows of small mineral or negative crystals, each being accompanied by an oriented thin film. Such inclusions also occurred singly. Fibre-optic illumination, 50x.

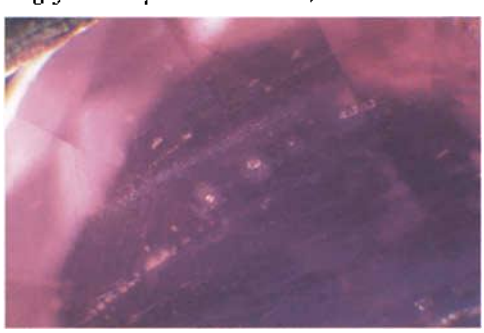

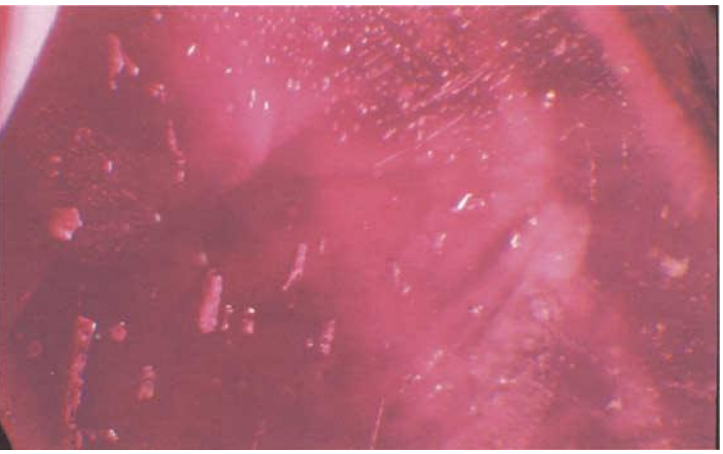

Figure 8: Idiomorphic negative crystals commonly contain immiscible liquid and gas phases. Fibre-optic illumination, 38x.

Table II: *Semi-quantitative chemical analyses of rubies and pink sapphires from the Pamir Mountain Range, Republic of Tajikistan.*

	Sample weight				
Wt% Oxide	0.30 ct	0.38 ct	0.44 ct	0.56 ct	0.80 ct
Al_2O_3	99.5	99.3	99.4	99.5	99.6
Cr_2O_3	0.224	0.516	0.498	0.286	0.185
TiO_2	0.156	0.047	0.017	0.091	0.068
Fe_2O_3	0.018	0.011	0.006	0.007	0.004
V_2O_5	0.024	0.015	0.025	0.025	0.016
Ga_2O_3	0.012	0.014	0.013	0.012	0.010

The infrared spectra are dominated by the AlO stretching frequencies typical for corundum, between approximately 300 and 1000 cm^{-1} (peak positions at approximately 760, 642, 602 and 405 cm^{-1}; Wefers and Bell, 1972). No absorption features were detected in the mid-infrared region (1900 to 4000 cm^{-1}), relating to foreign mineral phases or structural OH groups (see e.g. Volynets *et al.*, 1974; Moon and Phillips, 1994; Smith, 1995; Smith *et al.*, 1997).

Chemical analysis

Semi-quantitative chemical analyses of the five specimens shown in *Figure 1* revealed the presence of various minor to trace elements. Of these, Cr is the most significant minor element and is responsible for the pink to red hues of the gemstones. Ti is generally the next most abundant minor to trace element, followed by V, Fe and Ga. The contents of these oxides in five Pamir corundum samples are presented in *Table II*. In parts, Zr was also recorded in minute quantities and this is attributed to the presence of zircon inclusions.

Discussion

The Pamir mountains which extend along the southern perimeter of Tajikistan, in the former Soviet Union, are probably most well known to gemmologists because of their spinel deposits. Since their initial discovery in the early 1980s, rubies and pink sapphires have been recovered in small quantities and sold in the international gemstone market.

As a consequence of civil war, financial limitations and harsh climate, only the richest mine, Snejnaya, is currently worked. Although no details were obtainable as to the past or current production of these deposits, it can be assumed that any production is small and sporadic. It follows that the potential reserves are also unknown.

To date, fine gem-quality faceted gemstones are typically a carat and a half or less, while cabochon-quality gemstones are cut in sizes up to two or three carats. Low-quality ruby crystals may reach sizes of 5–7 kg. The largest known gem-quality faceted ruby from Pamir weighs nearly 3.5 ct (I. Pojarevski, 1997, pers. comm.). There are reports that fine gem-quality Pamir rubies or pink sapphires have been seen in sizes up to five carats, but these are unconfirmed.

The Pamir rubies and pink sapphires are most similar to stones from the Quy Chau deposits in central Vietnam. However, the combination of the parallel arrangements of calcite inclusions, the columnar concentrations of short rutile needles and particles, and the negative crystal inclusions, appear to be distinctive of rubies and pink sapphires from the Pamirs. The small mineral or negative crystals accompanied by oriented thin films are also distinctive and are quite different in

appearance to the doubly truncated negative crystals with equatorial thin films which characterize the rubies from magmatic sources, such as in Thailand and Cambodia.

In contrast, inclusion features frequently observed in rubies from other marble-type sources were not observed in the ruby and pink sapphire samples from the Pamirs. Such inclusion features include swirled growth structures, colour zoning and nest-like concentrations of rutile needles, typical of rubies from the Mogok stone-tract, or dense cross-hatch to flake-like inclusion patterns and distinctive growth structures indicative of Mong Hsu rubies, both from Myanmar (Burma), various stringer and cloud-like formations commonly seen in the rubies from northern Vietnam and Nepal, and the mineral inclusion assemblages typical of the rubies from east Africa.

Since gaining its independence from the former Soviet Union in September 1991, Tajikistan has suffered from regional conflicts, and this political factor, coupled with the difficulty of physical access to the region, has meant that the full gem potential of the Pamir region has yet to be fully exploited.

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Gemstone deposits of the former Soviet Union

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ABSTRACT: The most important gemstone deposits of the former Soviet Union are described. The deposits range from diamond and ruby to amber and pearl. Some genetic features of gemstones are reported.

Keywords: agate, aquamarine, diamond, gemstone, genetic mineralogy, gypsum, ruby, Soviet Union, topaz, tourmaline

Introduction

The famous Russian poet of the XIX century, Feodor Ivanovich Tiutchev writes in one of his poems:

'Nicht, was Ihr meint, ist die Natur
Nicht blind und geistlos von Gesicht
Freiheit und Liebe sind in ihr,
Nicht seellos ist sie, fühllos nicht ....'

'Nature is neither blind nor spiritless as you implied but includes freedom and love: nor is it without soul or feeling.' [Transl. M.O'D]

The territory of the former Soviet Union occupies one-sixth of the land mass of the Earth, including the larger portion of the European and nearly one-half of the Asian continents. The geological structure is very diverse and for this reason numerous types of gemstone deposits have been identified: only the largest and most interesting examples are dealt with in this paper.

Generally speaking, gem minerals are late to crystallize from the fluid phase in free space. The creation of cavities, dissolution, leaching and sometimes recrystallization follow original formation. In the paper we shall discuss three types of association, each of which hosts gem minerals.

1. Igneous (or magmatogene) associations

Diamond-bearing kimberlite

The former Soviet Union hosts large *in situ* diamond deposits with kimberlite pipes and accompanying placers accounting for one-fifth of world diamond production. More than 100 kimberlite pipes have been identified from Archaean-Proterozoic Siberian and Russian platforms. The age of the Siberian pipes ranges from early Paleozoic to Mesozoic and that of the north Russian pipes from Early Paleozoic to middle Carboniferous. The structure of the kimberlite breccia (autobrecciated foam-lava) pipes does not differ from similar structures in other countries. The north and centre of the Siberian platform house the richest pipes, which include the Mir [1], Aikhal [2], Udachnaya [3] and Internatsionalnaya [4], all in current operation. Mines which may be developed later include Yubileynaya [5], Zarnitsa [6] and Batuobinskaya [7]. In the north of the Russian platform are the Lomonosovskaya [8], Karpinskaya [9] and Pervomayskaya [10] pipes *(Figure 1)*.

Each of these deposits contains millions of carats of diamonds and no doubt many will be of high gemstone quality. There is a higher

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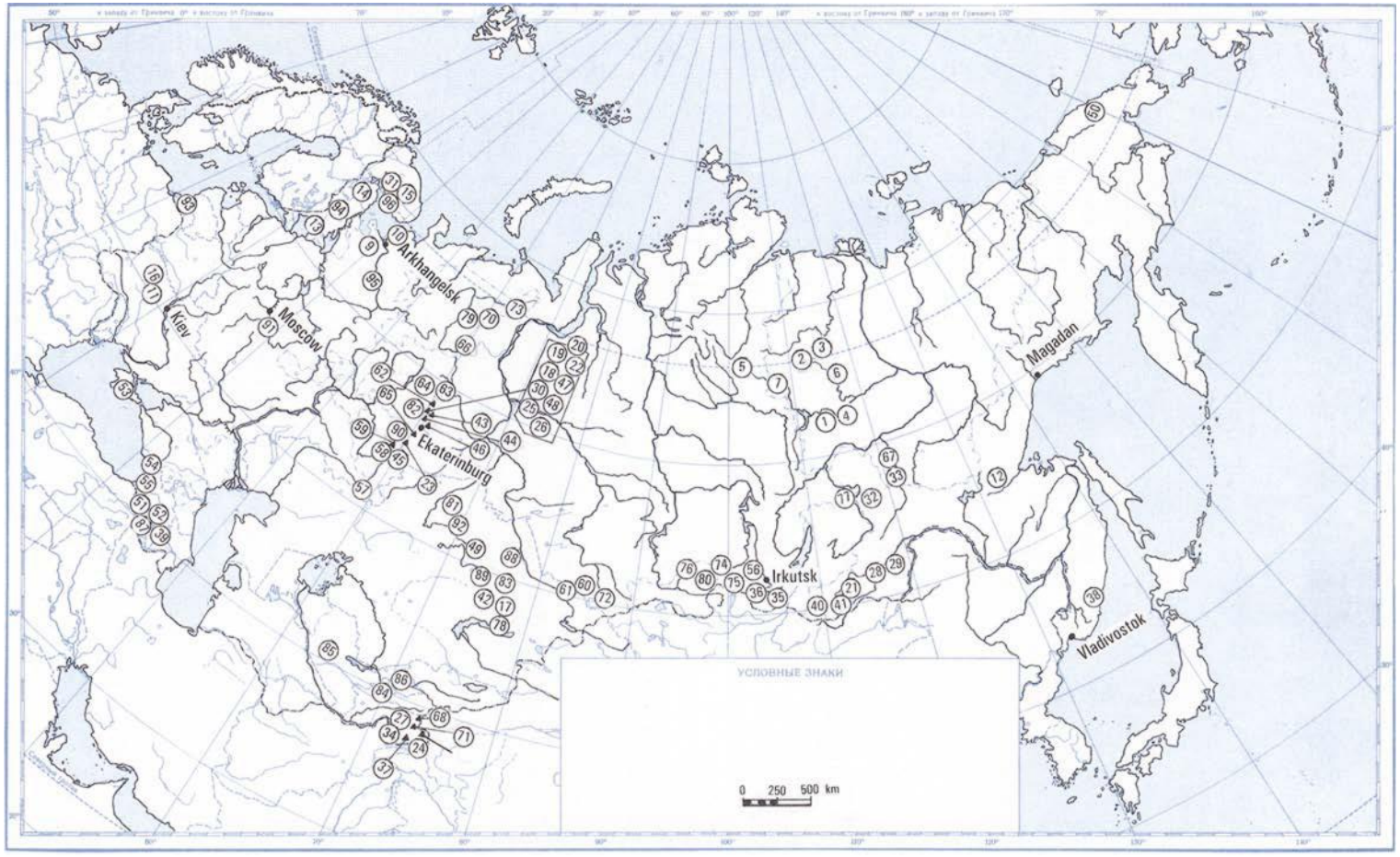

Figure 1: *Map of the precious and jewel stone deposits of the Former Soviet Union. Number corresponds to that of a deposit referred to in the text.*

gem diamond percentage in the pipes of northern Russia than in those of Siberia, which contain coarse and mainly medium-to-small-sized crystals. The Russian kimberlites produce mainly small and coarse diamond crystals. Siberian kimberlites have produced many crystals in the 50–100 ct weight range. The largest Russian gem-quality diamond weighs 342.5 ct and is a pale citron colour.

Diamonds from kimberlites in Russia and elsewhere are equivalent in size to characteristic mantle megacrysts from alkaline magmatic rocks such as ilmenite, pyrope, enstatite and clino-pyroxene.

Diamond crystals from Siberia are 90 per cent irregular or fragmentary with only 10 per cent showing regular polyhedral forms. The deepest Siberian kimberlites are pyrope-poor and are enriched in diamond which occurs as plane-faced octahedral and dodecahedral crystals. The shallower Siberian kimberlites are richer in pyrope and poorer in diamond which frequently show curve-faced dodecahedra and other antiskeletal forms.

Russian diamonds occur in a wide range of colours, most commonly colourless and less commonly yellow, green, smoky, brown, grey and black. Crystals with dense colours are comparatively rare. Earlier-formed plane-faced octahedra are most often colourless while later-formed crystals of cuboid habit, with rounded edges, have a yellowish colour of different intensity.

The interior features of Siberian diamonds include many blob-like and faceted inclusions of monosulphide solid solutions, mainly composed of troilite or pentlandite, of native iron and wüstite and intergrowths of sulphides, wüstite and iron: formerly these were believed to be graphite. This shows that the diamonds crystallized from the participation of locally-occurring metal (iron)-oxide-sulphide melts.

Kimberlite intrusions have cut sedimentary sequences and sills of dolerites. When limestone is the host rock it may house diamond crystals and pyrope grains at distances of up to 0.5 to 1 m from the pipe contact. At the Mir pipe, for example, fluid pressure on the solid phases in the kimberlite fluid-saturated foam-lava was so strong that the most durable individual crystals have been forcibly emplaced in the relatively soft country rock. In the Udachnaya pipe a collection of diamond-bearing eclogitic xenoliths up to 10 cm across has been sampled. Some of the xenoliths contain a lot of diamonds (up to a third in volume). The largest crystals range from 6 to 15 mm in size (*Figure 2*). Examination of these samples certainly supports the theory that diamond-bearing eclogite from the mantle is one of the main sources of diamond in kimberlite breccia.

While northern Russian kimberlites are pyrope-poor, Siberian kimberlites are pyrope-rich. Some Siberian pyrope crystals found in association with chrome diopside show an alexandrite effect with bluish-green colour in daylight and violet-red in artificial light. Rich diamond placers near to kimberlite pipes are found on the White Sea shelf.

Labradorite

Iridescent labradorite is found at the very large Golovinskoe deposit [11] located in the Volyn district which forms part of the western Ukrainian shield, itself

Figure 2: *Xenolith of a diamondiferous eclogite from the Udachnaya kimberlite pipe. Size of the diamond crystal is 6 mm. Photo by M.A. Bogomolov.*

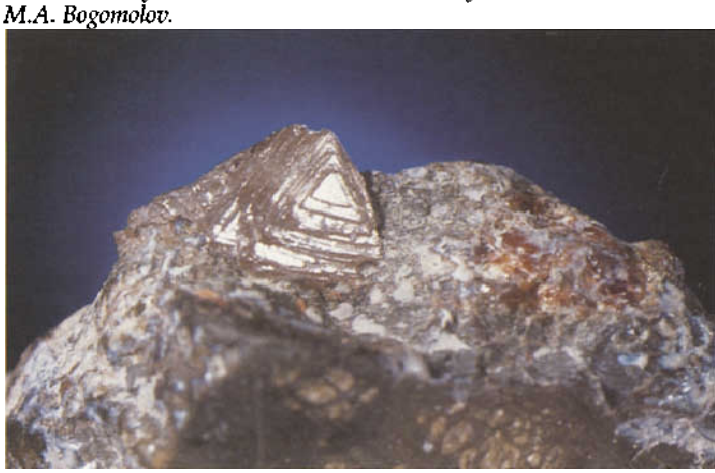

GLOSSARY OF SOME GEOLOGICAL TERMS USED IN THIS REVIEW

Anorthosite	Rock composed mainly of plagioclase feldspar
Boudin	Elongate rounded fragment of relatively strong and cohesive rock detached from a larger piece by flow of the more plastic rocks surrounding it; from the French 'boudin', a sausage
Breccia	Rock composed of angular fragments mixed with finer material
Facies	Group term for a range of rocks formed under a specified range of chemical, pressure, temperature or other physical conditions
Granitoid	Rock with granitic character but not necessarily a granite in the strict sense
Hydromica	Mineral with a structure like mica but altered to accommodate more OH groups or water molecules
Jadeitite	Petrologists' term for rock consisting largely of jadeite the mineral
Karst	Countryside formed on limestone which has suffered solution by groundwater to form caves and underground drainage
Leucogranite	Granite consisting mainly of light-coloured minerals
Meta	Abbreviation for metamorphosed
Metasomatism	Process of alteration by action on rocks of fluids from an external source
Metasomatite	Rock formed as a result of metasomatic processes
Miarolitic	Adjective used to describe granite with irregular cavities lined with well-terminated crystals of both the normal constituents of the rocks (quartz and feldspar) and some rarer accessory minerals
Protolith	Rock which is subsequently altered in some way – for example, by metamorphism or metasomatism
Septaria	Egg-shaped nodules up to 100 cm across characterized by radiating cracks that widen towards the centre and die out near the margin, crossed by cracks that are concentric with the margin
Supergene	Adjective describing processes involving water percolating downwards from the earth's surface; involves solution, reaction and deposition of minerals
Ultrabasite	Ultrabasic rock, one generally low in silica content, lower than basic rocks such as most basalts

forming part of a Proterozoic anorthosite and gabbro-norite pluton. Crystals may reach 20 x 12 x 3 cm and show black with dark blue, greenish- or yellowish-blue iridescence. Very thin ilmenite lamellae are responsible for the black body colour of the crystals. The Dzhugdzhurskoe deposit [12], also very large, is located within the Archean anorthosite in the east of the Aldan shield.

Granitic pegmatites

The deepest pegmatites are feldspar and muscovite-rich, occurring among high pressure metamorphic rocks (kyanite-bearing gneisses). The northern Karelian pegmatites may contain iridescent oligoclase and rose quartz while those from southern Karelia may contain gem-quality almandine. Translucent or semi-transparent peristerite-oligoclase

with an attractive light blue or yellowish light blue iridescence [known in Russia as belomorite] is found in the Chupa pegmatite [14] as blocks of up to 20 x 20 x 5 cm and also in small segregations in the contact gneiss. Some examples of water-transparent oligoclase with a strong, gentle blue schiller are particularly attractive.

Gem-quality amazonite has been found in a shallower granitic pegmatite containing rare metals at the Zapadnokeivskoe deposit [15], the largest in the former USSR. It is situated on Mount Ploskaya in the centre of the Kola Peninsula and consists of a series of thick, steeply-dipping pegmatite veins with a zoned structure. Bright bluish-green amazonite occurs in the feldspar zone of the pegmatite: crystals may reach more than 1 cubic metre in volume and show blades of snow-white albite forming exsolution patterns. Such crystals are not rare.

The shallowest miarolitic granite pegmatites of the Urals, Ukraine, Transbaikalia and Pamir contain quartz, beryl, topaz, tourmaline and gem-quality crystals of other species. Smoky quartz (morion) crystals are widespread in the cavities of Ukrainian and Uralian pegmatites. The Volynskoe pegmatite [16] in the Ukraine is a large example, related to the apical part of the late-Proterozoic Korosten leucogranite pluton: it contains cavities up to 250 cubic metres in volume and on occasion a shaft has had to be sunk in order to reach a single crystal of morion. The author was present at the recovery of such a crystal measuring 8 x 1 x 1 m, which rested near-horizontally on the druse of large orthoclase-perthite covering the cavity walls. Smoky quartz from Volyn shows colours ranging from a dense pitch-brown through brown with a lilac hue to yellow.

A light and completely transparent violet-rose amethyst found in blocks measuring up to 1.5 cubic metres occurs within a pegmatite nucleus in the Kent leucogranite pluton [17] of central Kazakhstan. This area also contains pegmatites in which light-blue fluorite of optical and gem quality has been found. The crystals may reach 350 kg in weight.

Figure 3: Verdelite crystals from a granitic pegmatite in the Pamirs. Long dimension of the image is 9 cm. Photo by M.A. Bogomolov.

Beryl – heliodor, aquamarine, morganite. Miarolitic pegmatites of the central Urals and in particular the Murzinskoe [18], Alabaschkoe [19] and Aduiskoe deposits [20] are celebrated for their crystals of heliodor which may show various shades of green and yellow and reach 27 cm in length. Heliodor of gem quality is found in every tenth cavity of the Volyn pegmatite in Ukraine and forms crystals up to 5300 g. Aquamarine is fairly widespread in the pegmatites of the central and south Urals, Altay, Transbaikalia and Pamir. Morganite [vorobyevite] is known in the Transbaikalia pegmatite (near the Urchugan river, close to the Russian-Mongolian border) [21] and at Schaytanka [22] in the central Urals.

Topaz [tyazheloves (heavyweight)] is found in miarolitic pegmatites of the Ilmen Mountains, south Urals [23] and the Murzin-Aduy belt in the central Urals. It also occurs in Transbaikalia and in the eastern Pamirs where notable crystals of light- and sky-blue are found. Blue, golden and pale-yellow topaz are found in the pegmatites of the middle Urals. Very fine yellow topaz can be found in the pegmatites of the Kukurt deposit, eastern Pamirs [24]. Every third cavity of the Volyn deposit (Ukraine) contains gem-quality topaz, specimens

Figure 4: Charoitites – tectonites with rounded inclusions of greenish ferrous orthoclase. Long dimension of image is 6 cm. Photo of author's sample by M.A. Bogomolov.

weighing up to 117 kg. These crystals are commonly zoned with the centre blue and the outside the colour of tea, the sectors having different densities. Associated with the topaz is colourless phenakite with crystals up to 4 cm long. The Volyn deposit also contains 'landscape' topaz and water-clear crystals measuring up to 20 x 10 x 15 cm with an intense brown outer zone 3 to 5 cm wide and a blue core. Snow-white skeletal cuneate fluorite crystal inclusions up to 2 cm long appear to float in the blue, the effect suggesting swans in flight against a blue sky.

Tourmaline – rubellite, verdelite, indicolite. Fine gem-quality tourmaline occurs in the miarolitic granite pegmatites of the central Urals, Transbaikalia and the Pamirs. The best-known deposits are Schaytanskoe, Sarapulskoe [25] and Lipovskoe [26] in the central Urals. These contain dense crimson crystals of elbaite-rubellite up to 14 cm long, known in Russia as siberite or red schorl. Polychrome crystals (black with crimson ends, crimson crystals with blue ends) are also common in these deposits.

Miarolitic granites of the southern Pamirs [27] contain fine coloured tourmalines including verdelite of elbaite-liddicoatite composition. Fine rubellite, verdelite, indicolite and polychrome tourmalines are distributed in the miarolitic pegmatites in the centre of Transbaikalia in the Borschovochny [28] and Malkhansky [29] ridges. Most crystals are 2–4 cm long though some specimens are reported to have reached 12 cm. An unusual colour of verdelite (elbaite-tsilaisite) *(Figure 3)* is ascribed to a Bi-content of 0.3 per cent.

Andalusite may crystallize instead of topaz when the availability of fluorine is low. Transparent pink and crimson andalusite in crystals up to 10 x 0.5 x 0.5 cm is recovered from the Yuzhakovskoe pegmatite [30] in the central Urals. Andalusite is associated with spessartine-almandine, schorl, muscovite and aquamarine. Hambergite occurs in the pegmatites of the Pamirs, middle Urals and Transbaikalia. Danburite in gem-quality crystals up to 12 x 2 x 2 cm can be found in pegmatites of the eastern Pamirs and Transbaikalia.

Syenite pegmatites

Sunstone as a sodic feldspar occurs in the pegmatites of the Ilmen and Vischenevy mountains of the Urals as well as in many other regions. It contains tiny inclusions of hematite, biotite and other coloured minerals as oriented lamellae which produce a characteristic sheen reminiscent of the sun at its rising or setting.

Sapphire. Dark-blue sapphire has been found in some syenite pegmatites of the central and south Urals and is plentiful in some areas. Grains of gem-quality sapphire have occurred in placers adjacent to the syenite-pegmatite.

Nepheline-syenite pegmatites

Eudialyte, a sodium calcium REE iron manganese zirconium silicate is sometimes used ornamentally. It has a fine dense lilac-red colour and occurs as separate segregations of up to 8 cm across in alkaline and peralkaline pegmatite and coarse-grained nepheline-syenite in the Khibinian massif, Kola Peninsula [31].

Post-magmatic high-temperature metasomatites of alkaline magmatites - fenites

Charoite rocks are found in a unique mineralization of the Sirenevy Kamen deposit [32], occurring in a halo around the Murun leucite-kalsilite pluton in north-eastern Transbaikalia. In this contact zone, fluids replaced the limestone and quartz sandstone. Charoite is a layered silicate with composition $(K_{Na,Sr,Ba})(Ca_{Na,Mn})_2[Si_4O_{10}](OH,F) \times H_2O$ and *en masse* forms the spectacular purple rock charoitite with pale green ferrous orthoclase and yellow tinaksite *(Figure 4)*.

Chrome diopside with a fine emerald-green colour has been called Siberian emerald. It forms separate segregations up to 50 cm in size and occurs in patches in coarse-grained orthoclase-phlogopite and amphibole-orthoclase-phlogopite metasomatites. These metasomatites occur within contact zones of alkaline syenite and Cr-bearing ultrabasite of the Inaglinsky massif [33] in the western Aldan shield.

Figure 5: *Lazurite-ferrous magnesium skarn at the contact between calciphyres and high alkali granitoids, Sludyanskoe deposit. Photo by author.*

Post-granitoid metasomatites-Mg skarn

Titanium-clinohumite is bright orange or reddish-orange. A variety enriched in Ti occurs in the zoned bodies of the deepest magnesium skarn in the Kukhi-lal deposit [34] within areas of calcic rocks recrystallized to assemblages of calcite, spinel, forsterite and other silicates (calciphyres). The size of the transparent pieces of clinohumite ranges up to 2 cm. Rose-coloured, red and lilac gem-quality spinel in the Kukhi-lal deposit is associated with titanium-clinohumite and chlorite within areas of recrystallized calciphyre. Octahedral and transparent but fractured spinel crystals may reach 7 cm in length, but those with faceting potential are in the range 5–9 mm.

Lazurite. This feldspathoid mineral is close to hauyne in composition and occurs in the deep magnesium-enriched alkaline skarn which is related to the horizons of dolomite marbles and associated high-pressure metamorphic rocks. These are the Sludyanskoye [35] and Malobystrinkskoe [36] deposits in the southern Baikal region. The Lyadzhvardarinskoe deposit [37] in the Pamirs is structurally similar to the celebrated Badakshanskoe deposit in north-east Afghanistan.

The Sludyanskoe deposit is composed of patches and lenses of diopside-lazurite, calcite-scapolite-lazurite, forsterite-lazurite, phlogopite-lazurite and azurite-scapolite rocks occurring along contacts of high-alkali granitoids and graphite-bearing marbles *(Figure 5)*. Lazurite crystals up to 5 cm in size are found in calciphyres. Lazurite-bearing rocks are considerably impregnated by pyrite and by grains of native sulphur. The composition of the Baikal lazurite is $Na_6Ca_2Al_6Si_6O_{24}[(SO_4)_{1.35}S_{0.45}(CO_3)_{0.15}Cl_{0.1}]$, and its colour is ascribed to S.

Post-granitoid metasomatites-calcic skarns

Hedenbergite-wollastonite skarn makes an excellent ornamental material, being composed of micro-, mezo- and macro-spherolites composed of regular bands of differing thickness. These are radial aggregates of bright-green manganous

hedenbergite and light-grey or pale-brown ferrous and manganous wollastonite which is predominant. This rock forms a deposit approximately 100 m long and approximately 10 m thick at the Tetiukhe mine [38] (Dalnegorsk) near Vladivostock in the Russian Far East.

Hessonite-andradite. One of the large skarn-magnetite deposits is at Daschkesan in Azerbaidzhan [39]. Distributed within the ore of massive garnet-magnetite are geodes encrusted by acicular epidote over which have grown large crystals of amethyst, carbonates, chalcopyrite and transparent yellowish-red and brownish-red andradite up to 2 cm across.

Post-granitoid metasomatites – zwitter and greisen

The high-temperature acidic (HF) metasomatites are *zwitter* (zinnwaldite and Li-Cs phlogopite-bearing) and *greisen* (muscovite-bearing). They may sometimes be accompanied by quartz veins and lenses with fine crystals of aquamarine, topaz and morion, among others.

In Russia *aquamarines* do not originate from pegmatites but from zwitter. Densely-coloured long prismatic crystals up to 30 cm are found at the Sherlovaya Gora deposit [40] in Transbaikalia. The colour is due to divalent Fe impurities which are stable in an acidic environment. Fine greenish-blue aquamarines are found in the Adunchilonskoe deposit [41] in Transbaikalia and in the quartz-pyrite-wolframite veins of the Akchatau deposits [42] in central Kazakhastan. Short prismatic crystals of blue topaz and large smoky quartz crystals with deep colour are often associated with aquamarine.

Processes of hydrofluoric metasomatism often occur outside the parent leucogranite pluton. When ultrabasite material containing chrome-magnetite (e.g. serpentinite, talc-carbonate rock) was infiltrated, zwitter-glimmerite containing Li-Cs phlogopite, fluorite, fluorapatite, emerald, chrysoberyl, phenakite and Be margarite were formed. The metasomatite is accompanied by oligoclase veins and lenses containing beryl, Cr-beryl and emerald. While Cr-beryl is unevenly coloured, containing residual chrome spinel and chrome-magnetite, emerald is coloured in crystal zones and contains inclusions of chrome spinel. Late metasomatic segregations contain the deepest-coloured transparent emeralds. The largest emerald deposits in the world are at Mariinskoe [43] and Sretenskoe [44] in the central Urals where they appear in elongate zones extending for approximately 25 km.

Emerald. It is possible that the 'Scythian emeralds' mentioned by Pliny the Elder are specimens from the Urals. These have a fine dense, clear green colour with Cr^{3+} as the main chromophore. Gem-quality crystals vary a good deal in size: production in 1977 reached 12 600 ct (1979 7 000 ct, 1982 12 900 ct, 1990 10 450 ct). In total, the mines have produced more than 2.5 million carats of faceted stones and approximately 50 tons of Cr-bearing beryl. Reserves are estimated at approximately 10 million carats.

Phenakite occurs with the emerald in glimmerite, oligoclase veins and cavities among them, with crystals reaching 20 cm in size. Intergrowths of phenakite weigh up to 6.5 kg. Transparent crystals are colourless, more rarely pink or wine-yellow. A water-clear and dark smoky phenakite crystal measuring 13 x 12 x 7 cm was found in 1991 at the Mariinskoe deposit.

Alexandrite, the chrysoberyl variety showing an emerald-green colour in daylight and reddish-violet in artificial light, was discovered at the emerald mines in the Urals and named for the famous Tsar Alexander II on the day of attaining his majority. The change of colour is considered to have a mystic association with the Tsar in that the green reflects his humanity and concern for the Russian peasantry while the red calls to mind his assassination. Russian alexandrite has been considered the best in the world and commonly forms penetration trillings of rhombo-pyramidal and short prismatic forms or aggregates of trillings. The largest of these measures 25 x 14 x 11 cm. Alexandrite mineralization is closely related to that of

emerald but the deposits are separate, the alexandrite being found in glimmerite and margarite-plagioclase veins in association with pink fluorite.

Quartz, pink topaz and euclase. Late minerals of the zwitter-greisen assemblages are generated by slightly acidic to neutral fluids, depleted in fluorine, in which Fe^{3+} is stable. The results are veins with quartz, pink topaz and euclase in the Kochkar district, southern Urals. Crystals of pink fluor-hydroxyl topaz may reach 5 cm in length and multi-coloured euclase 8 cm; most are found in placers.

Post-granodiorite metasomatites – beresite

Rock crystal and light-coloured smoky quartz are found in mid-temperature hydrothermal ankerite-quartz-sericite metasomatites (beresite) at the Beriozovskoe deposit [46] in the Urals.

Post-granitoid metasomatites – argillizites

Amethyst. Zones of low-temperature hydrothermal hydromicaceous and quartz-chlorite-kaolinite metasomatites (argillizites) hosted in granite, syenite and monzonite often contain quartz veins with amethyst druses. They occur in the central Urals, particularly at the Vatikha deposit [47] where a celebrated dark blood-red colour of amethyst is found together with lighter-coloured sceptre forms, at Aduy [48] and at Vischnevskoe [49] in Kazakhstan.

2. Metamorphic associations

Low-grade zeolite facies metamorphic rocks

Most of the agate deposits occur in volcanic rocks of a wide range of compositions. Most are basalts in which gas bubbles have been filled by agate (metamorphosed amygdaloidal basalts). No agate occurs, however, in the contemporaneous volcanic rocks. They occur only in the volcanic sequences affected by metamorphism during burial – in other words low-grade zeolite facies metamorphism (T = 130–220°C, P = 1–5 kb). Such metamorphosed rocks are widespread

Figure 6: *Brocaded jasper-like moss agates with goethite and hematite, western Georgia. Long dimension of image is 13 cm. Photo by M.A. Bogomolov of author's sample.*

along the edges of folded areas and in the lower parts of plate margins. Mineral assemblages of the zeolite facies in metavolcanic rocks are heulandite, stilbite, chabazite, chlorite, albite, quartz, chalcedony, amethyst, celadonite, montmorillonite, goethite and pyrite.

Agate is widespread among metavolcanic rocks in the north-east of European Russia, the mountains of the Crimea, Caucasus, southern Urals, central and eastern Kazakhstan, eastern Siberia, Chukotka and eastern Transbaikalia south of the Russian Far East. The best agates occur in Jurassic metavolcanic rocks in Georgia [50] and resemble brocaded jasper in their patterning *(Figure 6)*. Fine agates are found in mesozoic-paleogene metavolcanic rocks in Armenia at the Idzhevan [51] and Sarigiukh [52] deposits. The former deposit contains agate with amethyst and goethite coated with reddish heulandite *(Figure 7)*; the latter deposit contains mossy celadonite and goethite-bearing agate *(Figure 8)*. Agate mineralization in Siberia is often accompanied by fine zeolite druses with crystals of gem-quality prehnite and apophyllite. On passing to the laumontite-prehnite facies (220–300°C) agates are recrystallized and lose their soft lustre.

Figure 7: Agates with amethyst and goethite, with red rim of heulandite hosted in metavolcanic rocks, Idzhevan. Long dimension of image is 18 cm. Photo by M.A. Bogomolov of author's sample.

Figure 8: Carpet agates with goethite and celadonite, Sarygiukh. Long dimension of images is 19 cm. Photo by M.A. Bogomolov of author's sample.

Jet also occurs in lignite and soft coal deposits in low-grade zeolite metasedimentary bodies. Occurrences are at Beschuevskoe [53] in the Crimea, Tkvartchely [54], Tkibuli [55] and Akhaltsikhe [56] in western Georgia and Cheremkhovskoe near Baikal [57].

Prehnite-pumpellyite facies metamorphic rocks

If agate is characteristic for zeolite facies, the corresponding material for higher-temperature prehnite-pumpellyite facies (T = approximately 300°C, P = 2–6 kb) is jasper *(Figure 9)*. This is the fine-grained metarock with predominantly quartz composition. It is coloured by hematite, garnet, epidote, pumpellyite, actinolite, chlorite or manganese minerals. The many deposits of different kinds of jasper (cherty-metasedimentary, cherty debris, carbonaceous-cherty, volcanic-cherty rocks) and felsic volcanic rocks lie in the greenstone belts from the south Urals (Orsk [57], Kalkansk [58], Muldakaevskoe [59] and others) to the near-Polar region at the Altais (Kolyvan [60] and others). They are also found in central Asia and Kazakhstan.

Figure 9: Map of France composed of the different kinds of Ural jaspers. Product of the Ekaterinburg faceting factory. Late XIX century. Photo by author.

Prehnite-pumpellyite facies metamorphism is fluid-dominated, the main fluid being water vapour. Metarocks contain numerous fractures resulting from hydrofracturing. These fractures are filled by the constituent minerals of metarocks – quartz, prehnite, epidote, albite, chlorite and carbonates. Metamorphism affected not only sedimentary and volcanic sequences but also magmatic massifs. Prehnite-pumpellyite facies metagabbroids and meta-ultrabasic rocks contain a range of gem and ornamental minerals. They are related mainly to the rodingite association comprising grossular, andradite (including demantoid), vesuvianite, uvarovite, chrome titanite and jade as precious rodingite.

Grossular A recorded grossular deposit with greenish and yellowish-green crystals up to 8 cm in size lies in the Viluy river valley [61] of the eastern Siberian platform. Grossular and vesuvianite crystals are included in a fine-grained groundmass of hydrogrossular composition.

Demantoid is andradite or hydroandradite containing chromium and is associated with serpentine, asbestos, magnetite and residual chrome spinellids. It contains fine syngenetic actinolite fibres which give a golden tinge to the stones. Pavel Piotrovich Bazhov, a writer from the Urals, said that demantoid 'smells as sweet as Spring and sun'. Heavily serpentinized ultrabasites in the central Urals host a number of deposits, including Poldnevskoe [62] and Bobrovskoe [63]. The finest specimens are found in placers and one high-quality example weighing 76 ct appears to be unique.

Chrome garnets of the rodingite association, uvarovite and chrome-grossular from the Saranovskoe deposit [64] in the north-west of the central Urals have a fine colour. This deposit is a steeply dipping peridotite massif containing numerous chromitite beds and the massif itself is cross-cut by a series of gabbro-dolerite dykes. The massif was subsequently tectonized and affected by regional prehnite-pumpellyite facies metamorphism. Fractures caused by hydrofracturing in chrometite are filled by carbonates, uvarovite, chrome-chlorite, quartz and pumpellyite with chrome titanite, rutile, diaspore, anatase and millerite. The fracture surface in chromitite is often encrusted with druses of uvarovite crystals up to 6 mm in size. Uvarovite and chrome grossular are often associated with chrome-chlorite and acicular shuiskite *(Figure 10)*, a brown mineral of the pumpellyite group containing chromium.

Chrome titanite from the Saranovskoe deposit is a fine emerald-green to golden-green and occurs as transparent crystals up to 20 x 20 x 5 mm in size though most are less than 5 mm. Faceted chrome sphene is similar in colour to the finest demantoid.

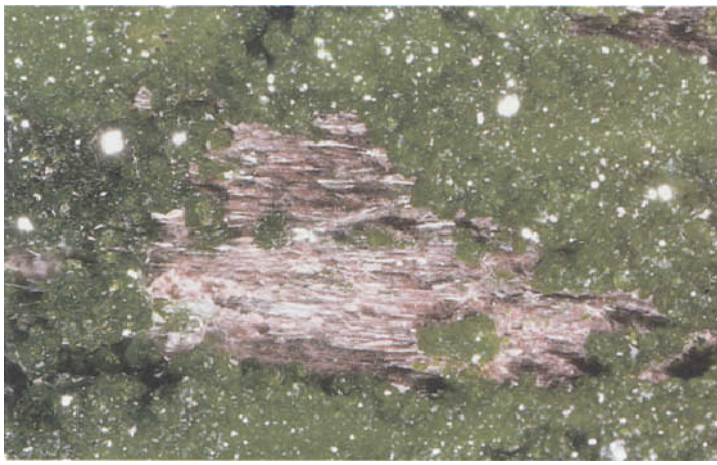

Figure 10: *Druse of emerald-green uvarovite crystals and acicular shuiskite (on metachromitite), Saranovskoe deposit. Long dimension of image is 3 cm. Photo by M.A. Bogomolov of author's sample.*

Metamorphic rocks of medium temperature and pressure

'Orlets', a rhodonite rock of very fine pink and crimson colour, is a celebrated Russian ornamental material. It is a manganous cherty-carbonaceous metamorphic rock in the greenschist facies. The finest material comes from the Malo-Sidelnikovskoe deposit [65]: other deposits are located not far from Ekaterinburg. 'Orlets' is composed of fine micrograined aggregates of rhodonite, rhodochrosite, tephroite (a Mn silicate of the olivine group), sonolite (a hydrated Mn silicate of the humite group), spessartine and quartz with supergene black Mn oxides located along fractures. Cobaltian rhodonite with an unusual lilac-violet colour has recently been discovered in the Polar Urals.

Rock crystal, amethyst and *citrine* as well as *axinite* and *titanite* as splendid crystals occur in the Alpine veins hosted in meta-morphic rocks of the Near-Polar Urals (the Khasavarka deposit – No. 66 and others).

Metamorphic rocks of high pressure

Ruby occurs only in the high-pressure metamorphic complexes within core parts of the Pamirs and Uralian folded areas, among

Figure 11: Table set with Urals malachite. Russian mosaic style typical of XIX century production. Ekaterinburg Museum of Applied Art. Photo by author.

Figure 12: The figure of the legendary 'Hostess of Copper (malachite) Mountain' produced from gypsum-selenite, 1975. Height of the figure is 130 cm. Ekaterinburg Museum of Applied Art. Photo by author.

meta-evaporites (most often a dolomite marble). A ruby-bearing belt in the eastern Pamirs is 200 km long and is the most interesting as a ruby producer. Deposits occur at Snezhnoe [67], Nadezhda [68] and Tura-Kuloma [69]. The semi-transparent prismatic ruby crystals reach 2300 g and 25 cm in length. Transparent deep-coloured areas are found in the apex and in the peripheral parts of the crystals and fine faceted stones up to 2 ct have been obtained. Ruby mineralization occurs within a sequence of coarse-grained dolomite, calcite and magnesite marbles containing intercalations of crystalline schist with scapolite. Ruby crystals occur in patches with carbonates, scapolite and fuchsite. At the Makar-Ruz deposit [70] in the Polar Urals rubies occur within small bodies of phlogopite plagioclasites hosted in meta-ultrabasites.

Experiments indicate that at a high CO_2 fugacity spinel breaks down according to the reaction $MgAl_2O_4 + CO_2 \rightarrow Al_2O_3 + MgCO_3$. The experiments show that at temperatures above 400°C aluminium oxide migrates within aqueous fluid – in other words, corundum formation is possible in the metamorphic process provided that the environment is fluid-saturated. Low activities of silica, potassium and sodium, and the presence of chromium, are necessary for ruby corundum formation. Such conditions are met in both meta-evaporites and meta-ultrabasites.

Scapolite. Gem-quality scapolite in yellow, light-lilac to lilac and deep-purple colours is widespread in cavities among scapolite and albite-scapolite veins hosted in meta-evaporite sequences of the eastern Pamirs near the town of Murgab. The largest deposit is the Kukurt [71] where scapolite-bearing stockworks are found. Gem-quality scapolite crystals weigh up to 150 g and some display asterism. Some places produced crystals of gem-quality weighing up to 20 kg. Compositionally it is marialite containing appreciable CO_3^{2-} and S^-.

Cordierite with deep-blue and blue-violet colours forms patches and metacrysts within metarocks of the Mountain Altaysm [72], East Pamirs and Transbaikalia. Transparent pieces may reach 4 x 3 x 3 cm in size.

Lazulite, a Mg–Al–Fe^{2+}–Fe^{3+} phosphate, is fairly widespread in metarocks of elevated pressure. The only Russian deposit of gem-quality lazulite is located near the Longotiegan river in the Polar Urals [73]. The lazulite patches in cavities in quartz veins measure up to 30 x 20 cm. Transparent fine blue and dark-blue crystals are found up to 2–4 mm, sometimes reaching 30 mm. Fine cabochons are fashioned from this hematite-included material.

Nephrite, green and white. White nephrite is a fine-grained tremolite with felted texture resulting from crystallization under high-pressure conditions, and with green nephrite, forms along the contacts between chromite-bearing serpentinized ultrabasites and gabbroids in most deposits. Variation of colour is due to differences in the amounts of Cr^{3+}, Fe^{2+} and Fe^{3+} in the tremolite. Deposits of green nephrite are at Ospinskoe [74], Bartogolskoe [75] and at other places in the eastern Sayans. Deposits also occur in the western Sayans at Kartashubinskoe [76], Polar Urals and Transbaikalia.

A rarer white to light citron-coloured nephrite comes from metasomatites at the contact zones between deep granitoids and dolomites. White nephrite may be translucent to depths of 2 cm. Deposits such as Buromskoe [77] and others occur in the Vitim river valley.

Metamorphic rocks of ultra-high pressures

Jadeite and chrome-jadeite. Lenticular bodies and boudins of jadeitite are found within Alpine basite-ultrabasite massifs in the zones of deep faults. Large deposits are at Itmurundy [78] in central Kazakhstan, Levokechpelskoe [79] in the Polar Urals and Kashkarskoe [80] in the western Sayans. Jadeitite is quite commonly present in the margins of enstatite or glaucophane rock where it is accompanied by albite- and quartz-bearing rocks. White and light-grey jadeitite is made up of almost pure jadeite. Gem-quality emerald-green chrome-bearing omphacite and ferri-omphacite (chloromelanite) are found as small areas in these rocks but occur more often as fine impregnations. The jadeitite is generally formed from a plagiogranitoid or leucogabbro containing chromite: at low-grade metamorphism such rocks are altered to albitite or analcite-bearing rock but at ultra-high pressure they are altered to jadeitite.

Figure 13: *Agates (carnelian and quartzite) hosted in silicified limestone, Golutvin. Long dimension of image is 9 cm. Photo of author's sample by M.A. Bogomolov.*

Diamond in the very large metamorphic deposit near Kokchetav [81], north Kazakhstan, occurs as small grains averaging approximately 30 µm in size (microdiamonds). Some crystals are cube-shaped. The diamonds are of Cambrian age and the host rocks early Proterozoic. Small but good-quality diamonds are concentrated in Cretaceous-Tertiary placers.

3. Supergene associations

Malachite. The ornamental material malachite is both the archetypal Urals stone and the favourite of the Russian people! *(Figure 11).* High-grade, silky-velvet, patterned malachite occurs in the residuum of the skarn magnetite-chalcopyrite deposits in the contact zone between limestone marble and syenite at the Vysokaya mountain in the Nizhny Tagil region; Mednorudnyanskoe [82] is a main producer among others. Limestone is heavily karsted and the size of the karst caves is in the region

of 140 x 100 x 30 m. The caves are completely or partially filled with ferruginated clays with malachite occurring as septaria, patches and impregnations, as massive nodules, stalactites and stalactitic aggregates. The size of some of the segregations in the Mednorudyanskoe deposit reaches an exceptional 450 t.

Dioptase, sometimes known as 'copper emerald', occurs in the residuum of copper ores at the Altyn Tiube deposit [83] in Kazakhstan. It is found as transparent crystals up to 2 cm long (though more often 3–7 mm) in limestone marble.

Turquoise. There are numerous deposits of turquoise in Tadzhkistan, including Biriuzakan [84], in Uzbekistan (Kyzylkumskoe [85] and Kalmakyrskoe [86]), Armenia (Tekhutskoe [87]) and in the Polar Urals. It is found in the residuum of phosphate-bearing sedimentary sequences, porphyry-copper and gold deposits. Recently a number of turquoise specimens were found at the Zhilandy deposit [88] near Ekibastuz, north-east Kazakhstan, where they occurred as nodules weighing exceptionally 1.5 kg though more commonly 3–20 g. The inner zone is light-blue zinc-rich turquoise with goyazite as an impurity while the outer zone is a deep-blue turquoise. It is penetrated by capillary veinlets of brown rancieite, a hydrated Ca Mn oxide.

Chrysoprase of fine quality forms patches and veinlets in birbirite, the name given to a weathering crust after carbonatized peridotite consisting of limonite, chalcedony and quartz at the Sarykoulboldy deposit [89] in Kazakhstan.

Gypsum. The selenite variety of gypsum forms as aggregates with long crystals of a warm pinkish-yellow. Selenite occurs as veins in the Permian gypsum and salt-bearing clay formations near the town of Kungur [90].

Flints. Concretions of flint measuring up to 150 x 150 x 30 cm (usually around 20 cm across) are widespread in the Carboniferous limestone of northern European Russia.

Agate. Fine coloured agates come from interbanded light-grey and milky chalcedonies, reddish-brown and gold-reddish-brown sard (carnelian) and bluish quartzites *(Figure 13)*. They occur as separate patches and metasomatic segregations of irregular form within Carboniferous silicified limestones locally overlain by Jurassic pyrite-bearing clays. Good examples are found at the Golutvin deposit [91] not far from Moscow. This rare type of agate may have formed with the participation of glacial water. Ornamental-quality agates measure up to 30–50 cm.

Fire opal has been found in the so-called pelikanite: this name has been given to kaolinized granitoids with leached quartz, as found at the Voznesenskoe deposit [92] in north Kazakhstan. Red, orange-red, yellowish-red and other opals form veinlets and patches, the size of absolutely transparent blocks being in the region of 10 x 10 x 4 cm. Vein-like segregations of semi-transparent opal have been found in the clay of recent dumps – it might have been possible to watch its formation! Semi-transparent opal adheres to the tongue; when it collects water it becomes completely transparent and as water is lost it resumes its translucency. This material is very suitable for polishing.

Amber. The largest deposit of amber in the world is at Palmnikenskoe [93]. Located near Kaliningrad-Keniksberg, it produces a bluish amber-bearing sandy clay of Paleogene age overlain by Miocene rocks rich in organic material and Quaternary moraine. This mine is the world's largest amber producer.

Freshwater pearl used to be bound in nearly all rivers of north European Russia and a large production was necessary to satisfy the demand for the ornamentation of dress and for icons. Two large centres of production were on the river Kem in Karelia [94] (the coat-of-arms of the town of Kem features a pearl coronet) and on the river Dvina [95] where very large pearls have been recovered. Currently the largest formations of freshwater pearls in the world can be found in the interior of the Kola peninsula.

Acknowledgements

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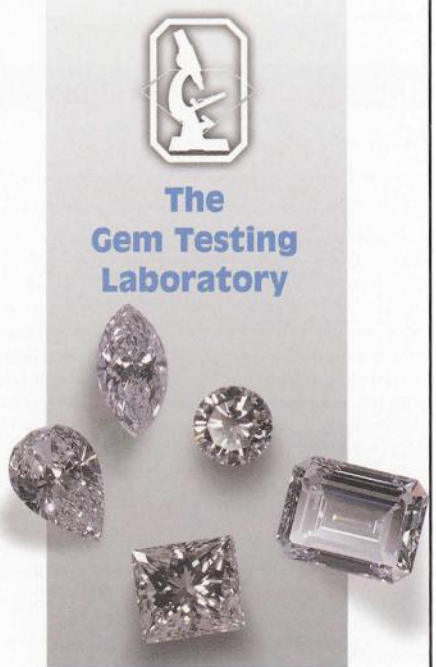

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Abstracts

Diamonds | Synthetics and Simulants

Gems and Minerals | Techniques and Applications

Diamonds

Modern diamond cutting and polishing.

A. Caspi. *Gems & Gemology*, 33(2), 1997, 102–20, 24 illus. in colour.

Since 1980 there has been a revolution in the cutting of diamonds, with great advances in the use of modern technology, especially in Israel, Belgium, South Africa and Russia. The manufacturing component of the final retail value is equal to only 2 per cent. The new advances made include a decision support system for marking diamonds, e.g. deciding where to cut a rough diamond, by using a Sarin Dia-Expert System. The rough diamond is shown on a computer screen identifying the best position to mark a stone for cleaving and sawing. Laser kerfing allows a greater precision in following the markers lines, with a narrower and shallower kerf being made; also many diamonds may be processed together. Laser mechanical sawing has given rise to greater accuracy and higher production rates. A bruting laser has also been developed and is mostly used for fancy cut diamonds. J.J.

Gem Trade Lab notes.

C.W. Fryer. *Gems & Gemology*, 33(2), 1997, 134–41, 19 illus. in colour.

A yellow heart-shaped diamond was found to have a distinct orange patch of colour, which was caused by a limonitic stain to a fracture. It should be possible to remove the stain by boiling in acid. A green and pink rough diamond showed properties of a natural pink diamond. The green colour arose from green radiation stains from natural radiation, which did not penetrate the body. Yellow to yellowish-green treated diamonds were found to have been treated possibly by a new method using very high temperatures (>1400°C). These diamonds showed a frosted burnt appearance on the facet junctions and a peak at 985 nm (not visible with a spectroscope) caused by the H2 centre, otherwise they exhibited many properties normally associated with natural diamonds. J.J.

Gem news.

M.L. Johnson and J.I. Koivula. *Gems & Gemology*, 33(2), 1997, 142–52, 23 illus. in colour.

A diamond set in a platinum filigree mount was found to be two diamonds placed one on top of another and held together by the claws. J.J.

Gems and Minerals

Zwei angeblich römische Gemmen aus Chalcedon bzw. Mis Sodalith aus dem ehemaligen Jugoslawien.

F. Brandstätter, W. Melchart and G. Niedermayr. *Gemmologie. Zeitschrift der Deutschen Gemmologischen Gesellschaft*, 46(2), 1997, 93–5, 2 photographs, 4 microphotographs, 1 table, bibl.

Two cameos of questionable Roman origin were found in the former Yugoslavia (Serbia). One was a chalcedony cameo from Sirmium found to be artificially coloured blue. Although the Romans had dark-blue to grey-blue gems, we have no examples of their colouring agates and chalcedonies blue. The second cameo was reported to come from Viminacium and was identified as transparent sodalite, similar to material discovered in 1973 in Namibia. The cameos themselves and the way they were produced closely resemble genuine Roman gems – the materials used, however, showed them to be fakes. E.S.

Broken Hill.

Australian Journal of Mineralogy, 3(1), special issue, 1997, 87 pp, illus. in colour.

A number of gem-quality species are found at Broken Hill, New South Wales. This is a thematic rather than a special issue of the journal since it is not outside the part numbering, and contains papers on some notable cabinets (fine gem-quality crystals from the Milton Lavers collection are illustrated) and on species recently obtained from the Kintore and Block 14 open cuts at the mine:

Abstractors

R.A. Howie	R.A.H.	M. O'Donoghue	M.O'D.	E. Stern	E.S.
J. Johnson	J.J.	P.G. Read	P.G.R.	I. Sunagawa	I.S.

For further information on many of the topics referred to, consult *Mineralogical Abstracts*.

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collectors of micromounts will be especially interested in the range of species found. Papers have their own lists of references. M.O'D.

Puiva: Gwindel und Axinit aus dem Polar-Ural.

J.V. BURLAKOV. *Lapis*, 22(7/8), 1997, 59–70, illus. in colour, 2 maps.

Fine crystals of ferroaxinite and of quartz with the so-called 'gwindel' habit are described, with other minerals, from the Puiva area of the Polar Urals of Russia. M.O'D.

Pridorozhnoje: Morionfunde im Polar-Ural.

J.V. BURLAKOV. *Lapis*, 22(7/8), 1997, 71–4, illus. in colour.

Fine crystals of morion (smoky quartz) are described from Pridorozhnoje in the Russian Polar Urals. Occurring in Alpine cleft-type deposits, crystals may reach up to 15 cm in length. Other minerals from the area are listed. M.O'D.

Die Smaragdgruben des Urals: Tokowaja-Malyshevo.

J.V. BURLAKOV, J.A. POLENOV, V.J. GERNAKOV AND A.V. SAMSONOV. *Lapis*, 22(7/8), 1997, 44–55, illus. in colour, 2 maps.

Superb crystals of emerald and alexandrite with a very marked colour-change are described from the Tokowaja-Malyshevo area of the Russian Urals. Specimens from the Fersman Mineralogical Museum, Moscow, are illustrated: the geology and the mineralization of the area are described, most emerald and alexandrite being recovered from mica schists. Yellow-green chrysoberyl is also found. Other minerals of interest to the gemmologist include euclase, topaz, phenakite, beryl and apatite. M.O'D.

Mines and minerals of Peru.

J.A. CROWLEY, R.H. CURRIER AND T. SZENICS. *Mineralogical Record*, 28(4), 1997, 7–98, illus. in colour.

Among the minerals of Peru, fine crystals of fluorite and rhodochrosite are most likely to interest the gemmologist. The different mining districts of Peru are described with geological and mine maps: details of the geology and mineralization are given in all cases and there is a useful bibliography. M.O'D.

GIA Gem Trade Lab notes.

C.W. FRYER (ed.). *Gems & Gemology*, 33(1), 1997, 54–9.

A red and yellow semi-translucent portrait of a Buddha proved to be 'hornbill ivory' from the helmeted hornbill. The most diagnostic feature of this organic material is the bright red border of the yellow helmet.

Three large baroque beads which were reported to have belonged to the Mogul emperor Alban Shah (1542–1605) were identified as spinel, sapphire and a green aquamarine. The hand drilling, the inscribing of the Mogul names and the colour of the aquamarine lent credence to their provenance.

A piece of rough and a cabochon-cut, greenish-yellow opal showed a chatoyant effect caused by linear inclusions.

A quartz cat's-eye effect was caused by large rutile needles: it was concluded that these stones should be known as cat's-eye rutilated quartz. J.J.

Gem Trade Lab notes.

C.W. FRYER. *Gems & Gemology*, 33(2), 1997, 134-41, 19 illus. in colour.

An unusual doublet composed of a fully faceted beryl over which a green plastic layer had been added to give an emerald colour and extra depth had a convincing appearance. Another unusual stone was a dark brown, oval cabochon feldspar, which exhibited a four-rayed star and two parallel bands of chatoyancy. A variegated banded brown, white and light-green bead necklace was composed of naturally-coloured jadeite; it was probably cut from the outside layer of a naturally stained jadeite boulder.A heat-treated blue sapphire showed all the diagnostic features together with a raised area on the culet, which was part of the original heat-treated surface. A small dark green stone was identified as a very rare mineral known as serendibite, with biaxial RIs of 1.697 and 1.704, a weak absorption line at 470 nm and no fluorescence. Unusually a dark brown zircon cabochon exhibited a play of colour showing flashes of green and red, similar to an opal. The cause of the colour was not determined. J.J.

Minerali in vetrina: alcune tormaline della collezione Giazotto [second part].

A. GIAZOTTO. *Rivista mineralogica italiana*, **16**, 1993, 93–101, illus. in colour.

Tourmaline crystals from pegmatites of the Gilgit area of Pakistan, from Madagascar, Nepal, Mozambique, California and Brazil are described and illustrated. M.O'D.

La cueillette des minéraux gemmes du massif du Mont-Blanc.

E. GONTHIER. *Revue de Gemmologie*, **131**, 1997, 21–4.

The geology and mineralization of the Mont Blanc massif are described with particular reference to the occurrence of gem-quality crystals: fine crystals of fluorite are especially notable. M.O'D.

Rubies and fancy coloured sapphires from Nepal.

E.J. GÜBELIN, A.M. BASSETT AND M.N. MANANDHAR. *Gems & Gemology*, 33(1), 1997, 24–41, 26 coloured illustrations, 2 tables.

Although Nepal is not a major source of gem-quality corundum, it does produce some unusual rubies and fancy coloured sapphires, together with a broad range of gemstones. The corundum is found as a primary deposit in the Dhading District in Nepal in isolated dolomite pods, which have been subjected to low-grade metamorphism. The exploration and mining of the gemstones have been sporadic due to the terrain and the harsh climate. Most stones are cut as cabochons with a very small percentage of higher gem quality faceted.

Much of the corundum is similar to that found in other marble type deposits, but there are some notable differences with inclusions comprising dense concentrations of very fine short rutile needles, rod-shaped apatite crystals, colourless margarite, anorthite feldspar and uvite tourmaline; distinct colour zoning is common and there are bicolour stones with red and violetish-blue zones in thick or wedge-shaped bands; also there are almost colourless halos surrounded by mineral inclusions.

Also found in Nepal are trapiche corundums with rays formed of phologopite, apatite, calcite and graphite which differ from those of other localities. J.J.

Gemmologische Kurzinformationen. Short gemmological notes.

U. Henn and C.C. Milisenda. Smaragde aus China [Emeralds from China]. *Gemmologie. Z. Dt. Gemmol. Ges.*, **46**(2), 109–12.

The emeralds come from Malipo, 300 km south of Kunming, near the Vietnamese border. The samples occur in mica schists with quartz and fluorite; they show long prismatic crystals up to 3 cm, mostly heavily included, translucent with an attractive green colour; dark needle-shaped tourmaline inclusions are visible to the naked eye. A few smaller crystals were transparent and of gem quality. RI 1.573–1.575 to 1.580–1.583, DR 0.007–0.008, SG 2.68–2.71. Apart from the tourmaline inclusions, fine cracks as well as distinct growth zoning were visible under the microscope.

U. Henn and H. Bank. Beryll-Katzenaugen und Sternberylle. Cat's-eye beryls and star beryls. *Gemmologie. Z. Dt. Gemmol. Ges.*, **46**(2), 113–17.

The cat's-eye effect is described in aquamarines, golden beryls, morganites, emeralds; this is caused by parallel needle-like inclusions, especially hollow tubes. Asterism is due to mineral inclusions or fluids oriented in layers parallel to the crystal base and is described as occurring in aquamarines and very rarely in emeralds. E.S.

Gem news from Tucson 1997.

M.L. Johnson and J.I. Koivula (Eds.). *Gems & Gemology*, **33**(1), 1997, 60–70, 27 coloured illustrations.

Gem-quality andradites were for sale from a new locality in Arizona, not far from the Stanley Butte locality, which has produced non-gem andradite for some years. All the andradites showed typical properties but no 'horsetail' inclusions were observed.

An unusual trapiche emerald from Colombia exhibited two central columns each with black spokes that extended through the length of the stone. Jet is now being quarried at Matagan near Lake Baikal, north of Irkutsk, some of the jet was just massive lumps of rough and some had been carved. Many cabochons of bicolour-labradorite were being marketed in different shapes and sizes, as were 'Rainbow' obsidian hearts. Botryoidal white opal from Milford, Utah, has been on the market for at least twenty years and is sometimes known as satin flash opal. Similar opal from Utah banded in translucent to transparent white is also now on the market.

Drusy iridescent pyrite from Russia. This new material is formed as crystals lining concretions and found in the bed of the River Volga in Russia. Quartz with 'rainbow' hematite inclusions comes from the Aldan Mountains in Yakutia. The inclusions are hexagonal to irregular, with the thinner inclusions appearing red, while the thicker inclusions appear black and opaque. Aventurescence in some rock crystal may arise from pyrite inclusions. To obtain the desired effect specific orientation of the inclusion plane just off parallel to the table facet is needed.

A very vivid orange natural sapphire from Tunduru region of Tanzania was being exhibited, but it was not known whether it had been heat treated. Also from the region were peridot, unusually coloured grossular and spinels. One very large tanzanite had a fluid inclusion with a movable gas bubble.

Fine gem tourmaline from the Neu Schwaben region, Namibia, is expected to come onto the market. The colours are mainly greens, blue and blue-green with only facet grade material to be marketed.

A green and black nephrite with magnetite inclusions from Victorville, California, has been electroplated with the gold adhering to the magnetite. J.J.

Gem news

M.L. Johnson and J.I. Koivula. *Gems & Gemology*, **33**(2), 1997, 142–52, 23 illus. in colour.

A mine near Patna, Bihar State, India, produces moonstones with a 'royal' blue sheen. Much of the good quality material is 1 ct or less. Properties of the stones are consistent with labradorite or bytownite (high calcium plagioclase). A brownish-purple stone was identified as very rare musgravite, a close relative of taaffeite. A new emerald filler has been developed and is reputed to have better properties than Opticon. The new filler consists of a resin and hardening agent and does not turn yellow with time. J.J.

Brasilianische Opale aus Pedro II.

J. Knigge and C.C. Milisenda. *Gemmologie. Zeitschrift der Deutschen Gemmologie Gesellschaft*, **46**(2), 1997, 99–105, 8 photos, bibl.

The Piaui State is the only place in Brazil where gem-quality opals have been mined in commercial quantities; although these opals are of high quality, the importance of these occurrences has decreased dramatically during the past few years as only very small quantities are now produced. The mines are located within a radius of 50 km of Pedro II which is about 200 km away from the capital, Teresina. Except for the Boi Morto mine all opals are recovered from secondary deposits. At Boi Morto the stones are found at a sandstone quartz-dolerite contact. In contrast to the Boi Morto opals the alluvial stones show no signs of cracking due to the relatively low water content. Most opals are translucent to semi-transparent and white to whitish; body colours include white, reddish, orangy, yellow, greenish and bluish. Some material has a very distinctive layer structure in its body colour and play-of-colour resembling synthetic opals, but with no lizard-skin effect. E.S.

Gem rhodochrosite from the Sweet Home Mine, Colorado.

K. Knox and B.K. Lees. *Gems & Gemology*, 33(2), 1997, 122–33, 15 illus. in colour, 1 table.

Some of the finest transparent vivid red rhodochrosite has been found in the Sweet Home Mine, in the Mosquito Range in Colorado. The mine is situated 11,600 ft above sea level and is only accessible two to three months a year. The geology of the area is Precambrian granite and gneiss, which were intruded 30 million years ago by a magma that formed a porphyry-molybdenum system. The veins are polymetallic (silver, lead, zinc and copper) and follow a NE trend with the rhodochrosite forming as a gangue mineral in pockets.

Mining was originally for silver but when it became unproductive mining switched to rhodochrosite in 1966. This was irregular until better geological mapping was used, and Ground Penetrating Radar (GPR) to locate the pockets. Also special tools and collecting techniques had to be developed to prevent damage to the stones. To date 90 per cent of the pockets have been found to be of little commercial value, but approximately a hundred 0.50 ct+ stones a year are cut. Due to its cleavage and softness it is a difficult stone to facet and has to be set with great care. Cutting is slow and has to be done by hand. As mining is problematical the future of the Sweet Home Mine is dependent on advances in methods used for geological exploration. J.J.

Geographie, Bergbau, Geologie und Lagerstätten des Urals.

P. Kolesar. *Lapis*, 22(7/8), 1997, 13–24, illus. in colour, 3 maps.

The Ural mountains extend over 2000 km in length and contain a number of major precious metal and gemstone deposits. The skarn deposits and pegmatites of Mursinka are described in some detail: this area produces aquamarine, heliodor, fine specimens of rock crystal and amethyst and is well known for museum quality examples of blue topaz. M.O'D.

New emerald deposits from Southern India.

J. Panjikar, K.T. Ramchandran and K. Balu. *Australian Gemmologist*, 19(10), 1997, 427–32, 1 illus. in black-and-white, 1 graph, 3 tables.

Early in 1995 emeralds were discovered on the inner walls of a well in the village of Sankari Taluka in Southern India's state of Tamil Nadu. This initial discovery led to further exploration which uncovered deposits in the Salem district of Tamil Nadu state. Investigation into the properties of the emeralds and their characteristic inclusions have revealed similarities between them and the emeralds from several locations in Madagascar. This suggests that the Sankari emeralds may have been emplaced into the ancient supercontinent of Gondwanaland before India separated from it and the nascent island of Madagascar some 20 million years ago. P.G.R.

Rubis et saphirs du Viêt-Nam.

J.-P. Poirot. *Revue de Gemmologie*, 131, 1997, 3–5, 1 map.

An overview of ruby and blue sapphire production in Vietnam with details of the specimens found. Notes on characteristic inclusions are given. M.O'D.

Das Geologische Museum von Jekaterinburg im Ural.

J.A. Polenov, J.V. Burlakov and V.N. Avdonin. *Lapis*, 22(7/8), 1997, 56–8, illus. in colour.

Some of the mineral specimens in the collections of the Geological Museum at Ekaterinburg (formerly Sverdlovsk) are described. One large rock crystal reaches 1.7 m in height and a number of type specimens, including uvarovite, are also held. M.O'D.

Colourless diopside and tremolite: two new 'end-member' gems from Canada.

G. Robinson and W. Wight. *Canadian Gemmologist*, 18, 1997, 45–9.

Diopside and tremolite are reported and described from rocks of the Grenville geological province, a belt of igneous and metamorphic rocks extending from south-eastern Ontario to northern Quebec. That part of the province known as the Central Metasedimentary Belt hosts a number of gem-quality minerals. Diopside of gem quality occurs at Lot 22, Range II, Cawood Township, Pontiac County, Quebec. Constants are given for the rare colourless material: white opaque material occurs more commonly. Colourless tremolite of gem quality is found on the Dancey Farm near Irondale, Snowdon Township, Haliburton County, Ontario: constants are given. Both minerals are near to end-member composition. M.O'D.

Neuer spektakulärer Amethystfund aus Südnorwegen.

F. Steinar Nordrum, A.O. Larsen, T. Bergstrøm and S. Larsen. *Mineralien Welt*, 8(4), 1997, 45–50, 1 map.

Large well-formed crystals of amethyst are reported from Holmestrand, south Norway. Many of the crystals show sceptre form: details of the mineralization of the area and other minerals are described. M.O'D.

Update on emeralds from the Sandawana Mines, Zimbabwe.

J.C. Zwaan, J. Kanis and E.J. Petsch. *Gems & Gemology*, 33(2), 1997, 80–100, 31 illus. in colour, 4 tables.

Since 1965 emeralds have been mined at Sandawana which is situated in the Mberengwa district in southern Zimbabwe. Emeralds are found along the southern limits of the archaean Zimbabwe craton, within the greenstone belt, which is composed of a series of intensely deformed metamorphic, mafic volcanic rocks and pegmatites. The emeralds occur near the pegmatites especially where they are in contact with the ultramafic rocks (komatiites).

Much of the emerald produced is small, less than 0.50 ct, and most is less than 0.25 ct. The emeralds are a vivid green and normally show an even colour distribution. Other typical characteristics are a high RI (n_e 1.584–1.587, n_ω 1.590–1.594) and a high SG (2.74–2.77). Most stones contain fibrous amphibole, both actinolite and cummingtonite. Fluid inclusions are not common and are usually present as partially healed fractures. The absorption spectra show broad bands around 430 nm, 610 nm (ordinary ray) and a sharp peak at 683 nm. Chemical analyses show these emeralds have a high Cr content (0.6–1.3 wt%) together with high MgO and Na_2O contents. The above characteristics and the constant properties of Sandawana emeralds are distinctive. J.J.

Synthetics and Simulants

Gemologie Aktuell.

H. Bank, U. Henn and C.C. Milisenda. *Gemmologie. Zeitschrift der Deutschen Gemmologischen Gesellschaft*, 46(2), 1997, 63–70.

Some tanzanite 'synthetics' on the market were found not be true synthetics but imitations; in particular, polysilicate which was rejected as real synthetic tanzanite. A transparent faceted red stone was found to be a natural corundum overgrown by synthetic ruby resulting in a small layer of dust-like mineral inclusions concentrated in a thin layer just underneath the rim. Recently an increasing number of hydrothermally produced synthetic alexandrites from Novosibirsk, Russia, have appeared on the market. Their most diagnostic features are distinct swirl-like growth inhomogeneities, sometimes visible under a 10x lens but obvious under a microscope. These synthetic alexandrites are produced in Novosibirsk. E.S.

The application and properties of Monocrystal.

P.R. de Heus. *Industrial Diamond Review*, 57(572), 1/97, 15–18, 4 diagrams, 2 photographs, bibl.

Unlike natural diamonds where slow crystal growth has concentrated the nitrogen atoms in flat layers (platelets), in a synthetic diamond the growth is rapid with the result that there are hardly any nitrogen crystals within the lattice; instead they are randomly distributed throughout the lattice, giving the Monocrystal its typical golden colour. These crystals display exceptional thermal conductivity and very low level of internal stress making them most suitable for industrial applications, which can vary from dressing of grinding wheels, machining of non-ferrous metals (such as aluminium disks for the computer industry), machining hard and soft contact lenses, to the milling of items of jewellery made of 22 ct gold. E.S.

Growth mechanism of flattened diamond crystals synthesized by chemical vapor deposition.

K. Hirabayashi and Y. Hirose. *Journal of Crystal Growth*, 142, 1994, 140–6.

Flattened diamond crystals were synthesized under high oxygen gas concentration and low substrate *T*. Preferential growth along side faces due to the presence of twin re-entrant corners, and the fact that a {111} face is oriented II the substrate surface due to texture growth in the early stage of nucleation, are responsible for the flattened morphology. SEM observations and Raman spectroscopic measurements indicated that the diamond crystals were of good crystallinity and high quality. I.S.

Gem news from Tucson 1997.

M.L. Johnson and J.I. Koivula. *Gems & Gemology*, 33(1), 1997, 60–70.

A green beryl had a cabochon Australian opal set within the culet area, giving rise to a curious effect to the beryl. When viewed face up, the play-of-colour from the opal appeared throughout the stone. Other such stones were on exhibition including amethyst, aquamarine and golden beryls. Gilson synthetic opal chips have been set in glass to form briolettes, hearts and spheres. J.J.

Structural analysis on flux grown emerald crystals.

J.-S. Lee, P.-L. Lee and S.-C. Yu. *Journal of the Geological Society of China [Taiwan]*, 38(3), 1995, 273–85.

Crystals of synthetic emerald grown by a V_2O_5-PbO flux had the composition SiO_2 66.31, BeO 13.70, Al_2O_3 19.42, Cr_2O_3 0.70, V_2O_5 0.04 = 100.17 giving the formula $Al_{2.04}Cr_{0.05}Be_{2.95}Si_{5.95}O_{18}$; their structure was refined to R 1.5% (*a* 9.203, *c* 9.172 Å, space group P6/*mcc*, $D_{calc.}$ 2.668 g/cm^3). The partial substitution of the excess octahedral cations (Al and Cr) for the tetrahedral Be and Si produced a highly distorted BeO_4 tetrahedron, confirmed by bond-angle variance and NMR spectrum. The substitution also involves the incorporation of minor V atoms as impurities in the channels of the beryl structure: difference Fourier analysis showed V to be located at (0,0,0.2901) and (0,0,0.2909). The centre of these two positions is (0,0,¼) which is the 2a site for alkali cations in hydrous alkali-rich beryl. The doublet configuration for V in the synthetic emerald is attributable to the high-*T* growth effect of these crystals. R.A.H.

Yttrium aluminium perovskite.

T. Linton. *Australian Gemmologist*, 19(10), 1997, 419–20, 3 illus. in colour.

Pink and orange faceted stones, marketed in the USA as yttrium aluminium perovskite or YAP, and manufactured in Russia by the crystal pulling process, were found to have properties of hardness, SG and RI, which did not match those of perovskite and are therefore a simulant of that mineral. The pink stones have a high refractive index of 1.85, and a dispersion near that of diamond. While these stones may superficially resemble pink Argyle diamond, their lower RI and striking rare earth absorption spectra should be sufficient to identify this new man-made product. P.G.R.

Diamants: la synthèse a une histoire.

D. SIRAKIAN. *Revue de Gemmologie*, **131**, 1997, 6–10.

Continuation of a history of diamond synthesis: the studies of Hannay, Moissan, Parsons and later workers are described. M.O'D.

A two-stage method for growing large single crystals of diamond with high quality.

WEI LI, H. KAGI AND M. WAKATSUKI. *Journal of Crystal Growth*, **160**, 1996, 78–86, 7 figs.

A novel method to grow high-quality large diamond crystals with a large net growth rate has been developed for diamond synthesis at high temperature and high pressure in metallic solution. The growing space is designed to have a recess at its lower temperature side, and the seed crystal is located at the bottom of the recess. When the recess is filled by the first-stage growth of diamond from the seed, its top surface serves as a large seed for the second-stage growth. If the size of the recess is selected appropriately, the perfection and quality of the second-stage are very high. The growth rate is small for the first-stage growth in the recess, but becomes larger for the second-stage growth. The diffusion field around a growth crystal is numerically simulated, satisfactorily explaining the growth nature.

I.S.

Two synthetic phenakites and their structure analysis.

S.-C. YU AND J.-S. LEE. *Journal of the Geological Society of China [Taiwan]*, **38**(4), 1995, 383–96.

Two flux-grown phenakites, one colourless and the other bluish-green, formed as minor accessories in an emerald growth experiment; both phenakites are close to the ideal composition of Be_2SiO_4 but the coloured one contains 0.3 wt% of V impurities. Both are trigonal, space group $R\bar{3}$; the colourless (bluish-green) crystals have *a* 12.466 (12.472), *c* 8.244 (8.253) Å; structural refinements gave final R factors of 1.81 (1.49)%. In the bluish-green phenakite two V atom positions are recognized; these are at interstitial positions rather than substituting for Be or Si. It is inferred that the green colour is due to the crystal field splitting of the d electron orbitals of the interstitial vanadium. R.A.H.

Techniques and Applications

Applications of geophysics in gemstone exploration.

F.A. COOK. *Gems & Gemology*, **33**(1), 1997, 4–23, 11 illus. in colour.

Geophysics has played a vital role in the exploration of minerals and hydrocarbons for many years, but this has not been the case for gemstones, where exploration techniques have remained relatively simple. The most common geophysical techniques include the use of gravity, magnetism, seismic reflection profiling, etc., but these are not always very useful for gemstone exploration as the resolution is not fine enough. More recently ground-penetrating radar (Georadar) has been used for the exploration of gemstones using radiowaves to measure the contrast in electroconductivity, producing images similar in appearance to seismic data. The main advantages are that Georadar can define subsurface features as small as 0.25 m, e.g. small pockets, and is particularly good for mapping shallow subsurface deposits; the data can also give three-dimensional images and is cheaper than most of the other methods.

The author explains the roll of plate tectonics with regard to rock types and therefore where various gemstones are most likely to be found. He also gives details of how and why all the geophysical methods are used; these are summarised in a table relating their usefulness for gemstones exploration and for the development of known ore bodies. J.J.

Réflexions sur des techniques lapidaires mogholes.

E. GONTHIER. *Revue de Gemmologie*, **131**, 1997, 25–7.

Lapidary work during the Mogul period is described and some details of settings are also given. M.O'D.

Short information about gemmological science and practice.

V.V. INDUTNY AND L.I. VISHNEVSKA. *Precious and Decorative Stones*, **1**(7), 1997, 7–14, illus. in colour, in Ukrainian.

Comments on the establishment and publication of the rights of jewellery manufacturers by the use of trade and other distinguishing marks on their products. Particular attention is paid to the amber recovered from the deposits of the state enterprise 'Ukrburshtin'. M.O'D.

A new view on the mechanism of diamond polishing.

F.M. VAN BOUWELEN, L.M. BROWN AND J.E. FIELD. *Industrial Diamond Review*, **57**(572), 1/97, 21–5, 4 illus. in black-and-white, 2 tables.

A concept is proposed for the development of a model to describe the highly anisotropic behaviour of diamond during frictional contact and polishing. The use of Scanning Probe Microscopy techniques have confirmed that after polishing in the hard octahedral {111} plane the diamond's surface shows that fracture and chipping mechanisms are involved in material removal. However, in the soft {100} cubic direction, a form of nano-grooving appears to take place which produces amorphous and graphitic debris (often referred to as 'black powder').

The removal of material while polishing in the soft direction may be caused by a mechanically induced degradation of diamond by bond bending. In the hard direction, the distortion of the crystal by bond bending is relatively small, and does not allow for a weakening of the structure. Further theoretical work is needed to study the realistic value of this concept. P.G.R.

BOOK REVIEWS

Discover opals.

S. ARACIC, 1996. The Author [P.O. Box 143, Lightning Ridge, NSW 2834, Australia]. pp 352, illus. in colour, hardcover. $A100.00. ISBN 0 959583 01 7.

Of course, an illustrated book on opal can hardly fail to be attractive and interesting. There have been many books on opal in the last few years, most of them published in Australia: as a general survey of Australian opal, its mining and geology, the present book (published as a limited edition of 1500 copies) is the best I have seen and should persist in availability (perhaps as a general rather than a limited print-run), finally establishing itself as an accepted classic along with the books of Wollaston and Murphy.

The text deals with the major fields of New South Wales, South Australia, Queensland and Western Australia and many of the individual mines in these states are described in some detail. But before the survey begins there is considerable coverage of surveying for likely deposits of opal, divining, pegging and working claims, processing of the recovered rough opal: there are also pen-portraits of celebrated miners and characters of the opal fields. The next 40 pages deal with opal as a mineral, its formation, the types of opal and the very large number of colour patterns recognized by miners and dealers. Some famous stones are illustrated and described and an attempt is made to equate opal types with their fields of origin. Matrix opal is described and a good account of treated opal matrix will be most interesting to readers in Europe and countries outside Australia, where this interesting, deceptive and beautiful material is less often encountered. Synthetic opal is also described along with the problem of cracking, opal pseudomorphous after fossils, the first discovery of opal, opal cutting and polishing, automatic cutting, selling value and investment. World markets and superstitions are covered in the last part of the general section before the area coverage begins.

Of the New South Wales opal fields, Lightning Ridge takes pride of place and about fifty pages are devoted to it. A map gives its location within the state and the coverage of the field would serve as an industrial and social history as well as a survey of the economics of opal mining and its effects. As it happens, colour photographs of most Lightning Ridge opal specimens are found chiefly in the preceding sections where exceptional opals are described. Nonetheless a very large coverage of the opals is here and a second and later maps give, in close detail and to scale, all the working deposits that can be said to be in the Lightning Ridge area. Useful diagrams show the strata in which opal can be found and there are many pictures of mines, of their dumps and of claim maps. Details of some famous cases concerning miners' rights are given so that as complete a Lightning Ridge history as possible is available to the reader who may find the smaller locally published histories hard to find.

Similar treatment, if less extensive, is given to White Cliffs, Tintenbar (once more the opal from this area is stated to be unstable though material with a jet-black body and play of colour is attractive), and to other smaller mines in New South Wales. Opal from other Australian states is described in a similar way so that there is little left unsaid. In South Australia, Coober Pedy and Andamooka take pride of place and there are extensive descriptions of Queensland boulder and nut opal. Perhaps less well known is the opal found in the gold-fields of Western Australia: quality is reported to be high and specimens have a black background but deposits were not being worked at the time of writing.

This is not only an authoritative study of Australian opal with an amazing amount of information but a book that can be read at any time with the greatest pleasure. I am not sure that the binding will stand up to very heavy usage and it would be churlish to expect a comprehensive list of references – this is not the aim of the author. In any case they appear in other studies and there is a book devoted to opal bibliography [De Boer, 1995]. Aracic's beautiful book deserves to stand with the greatest of opal studies if it is not that same study itself. M.O'D.

The F. John Barlow mineral collection.

F. JOHN BARLOW, 1996. Sanco Publishing [PO Box 177, Appleton WI 54912–0177], Appleton, Wisconsin. pp 408, illus. in colour, hardcover. US$208.68. ISBN 0 9653510 0 9.

The F. John Barlow mineral collection has been known for years, not only by mineralogists and collectors but also by many who have visited museums to which items have travelled from the collection to find their final home through the generosity of the collection's founder. It is one of the finest cabinets of minerals ever assembled and includes many gem minerals in their most beautiful crystal forms and colours: the aim has been to obtain the best specimens of their kind and no doubt frequent upgrading has taken place.

The first of the six main sections of the book opens with a short biography of John Barlow and then commences the mineral descriptions with the 'classics', this section being followed by fifty pages of gem crystal species: here, tourmaline has a section to itself, followed by a survey of beryl and the gem minerals to be found in pegmatites. Gemstones with other rare and important minerals complete this third section.

Part four describes a suite of native elements which include gold, platinum and gold and silver-bearing minerals. Part five covers minerals from especially notable locations, including Africa, Mexico, the major red

beryl site in the Wah Wah mountains of Utah and others. The collector gives an outline of his own philosophy of mineral collecting in a concluding chapter.

Once the descriptive part of the book is opened the reader finds magnificent colour pictures on each opening, with some pages accommodating two or even three photographs. All are accompanied by full details of the mineral depicted, notes on the size, mode of occurrence, chemical composition, world ranking where applicable and full crystal morphology. The photographs of gem minerals occupy quite a lot of the book and intending readers should save up to buy it — yes, it is expensive but worth every cent. I have seen no comparable book in thirty years' familiarity with the world's mineralogical literature. M.O'D.

Encyclopaedia of mineral names.

W.H. Blackburn and W.H. Dennen, 1997. Mineralogical Association of Canada, Ottawa. [Mineralogical Association of Canada, special publication no. 1.] pp 360, artwork in black-and-white, hardback. US$40.00. ISBN 0 921294 45 X.

Now that the number of valid mineral species approaches 3800 the appearance of an encyclopaedia is timely. Unlike previous attempts, all more or less good for their time, this one is not overloaded with discredited, trade and fanciful names but is confined only to species accredited by publication in standard mineralogical journals, some of the latest citations being published in 1997. Annual lists of additions are scheduled to be carried in the *Canadian mineralogist*, the first of these to appear in the August 1998 issue (vol. 36 part 4). In this way the monograph can enjoy a continuing usefulness until the number of additions makes a fresh single volume necessary.

Introductory matter introduces the reader to the derivation of words from their roots, which may lie in a variety of languages, not all of them European. A short history and summary of how minerals are named explains the various classifications of minerals used in the past: the Linnean system of groupings was for a time attempted for minerals but never got far because techniques of chemical analysis were insufficiently refined until quite recently.

The species are listed in alphabetical order with each entry carrying name, chemical composition, crystal system and space group – some of these characteristics are queried in the text when ambiguities or options exist. The etymology of the name is given next with transliterations from Arabic, Chinese, Greek, Japanese, Persian or Cyrillic. Species entries for persons (about 45% of those cited) carry brief biographical information and referrals to biographical notes published elsewhere. The source of the original study material is given, when known and when not already included in the etymology. References to major journals are given for all original species descriptions.

The book, with attractive artwork, is very easy on the eye and a careful read-through failed to show up any glaring omissions or inconsistencies. There is a short though useful bibliography and a list of journal abbreviations which is handier than it may seem at first: you can never find the precise title of a journal from abbreviations in papers! The authors and artist (Peter I. Russell) are to be congratulated on a fine and very reasonably priced work which will have considerable relevance for gemmologists.

M.O'D.

A brilliant history: jewels at Sotheby's.

1997. Sotheby's, London. Unpaginated, illus. in colour, softcover.

Presentation of the work of Sotheby's jewellery departments with notes of illustrations from major sales. Short biographies are given and a section on world record prices is arranged by gemstone. This is a beautifully produced celebration booklet which will become a collector's item. M.O'D.

Gold im Herzen Europa: Gewinnung, Bearbeitung, Verwendung. Aufsätze und Katalog.

1996. Bergbau-und Industriemuseum Ostbayern, Kümmersbruck. pp 294, illus. in colour, softcover. DM44 including postage and packing. ISBN 3 925690 33 6. (The Museum is at Schloss Theuern, Portnerstrasse 1, 92245 Kümmersbruck, Germany.)

Although the book includes a catalogue of an exhibition of gold and gold-mining artefacts in place at the Bergbau- und Industriemuseum Ostbayern during 1996, the catalogue itself occupies only a relatively small portion of the complete text, being placed at the back of the book, the remainder of which gives an authoritative account, current and historical, of gold and gold mining in Bavaria and in a few neighbouring areas. Since many gemmologists are also interested in precious metals, their recovery and application, the book should arouse considerable interest. A number of authors contribute chapters on the history of Bavarian gold deposits, on similar deposits in Bohemia, on gold in history and art, on Celtic money found in the Oberpfalz and considerably more. The catalogue describes and illustrates gold objects, mining implements and pages from books, with a high quality of reproduction overall (dimensions are given where appropriate). The chapters have their own lists of references which in some cases are extensive: black-and-white photographs scattered among the non-catalogue portion of the text illustrate the diverse uses of gold and some of the working methods of former times. M.O'D.

Mineralien Fundstellen in der Tchechischen und Slowakischen Republik.

P. Pauliš and R. Haake, 1997. Bode Verlag, Haltern. [Oerter Pütt 28, D-45721 Haltern, Germany.] pp 96, illus. in colour, softcover. DM22.80 (including post and packing). ISBN 3 925094 51 2.

Mineral locations in the Czech and Slovakian Republics are described. On maps of the two countries locations are marked, carrying numbers which refer to an accompanying list which then provides the reader with a page number. An odd arrangement but bearing language difficulties in mind one which works fairly well in so small a book. A more serious desideratum is the absence of a species index, so that the searcher for 'edelopal'

would have to know the local name for the deposit or (as I did) read right through the text in the hope of finding something.

Precious opal from the Dubnik deposit, now in Slovakia, is described on page 86: a brief sketch of the deposit is given with a brief description of its geology, mineralogy and history. This is the deposit sometimes shown as Cervenica on specimen labels and little work appears to be going on at present.

Many other important mineral sites are described and despite the small size and the lack of a species index, this is a welcome book and includes a good current bibliography.

M.O'D.

The bead jewellery book.

S. TOMALIN, 1997. David & Charles, Newton Abbot. pp 128, illus. in colour, hardcover. £16.99. ISBN 0 7153 0465 8.

With excellent photographs by Maggie Campbell Pedersen and at so reasonable a price this book would make a good present for almost anyone, let alone the many professional bead craft workers and the increasing number who make their own jewellery at home. The point made by the book is that you can in fact do this, and notes on materials and techniques accompany descriptions of classic jewellery forms. This reviewer, all of whose fingers are thumbs, might manage one or two of the very simplest designs but if greater skills were called for, this would be the first book to consult. It would be hard to beat. M.O'D.

The necklace from antiquity to the present.

A. TRIOSSI AND D. MASCETTI, 1997. Thames and Hudson, London. pp 224, illus. in colour, hardcover. £32.00. ISBN 0 599 01767 0.

The authors jointly have previously added lustre to the literature of jewellery history with *Earrings* (1990) and *Bulgari* (1996). Their account of the development, manufacture, style, use and significance of the necklace is a well-produced tribute to one of the oldest and most adaptable pieces of ornament. You can do anything you want with a necklace – make it yourself, give it any magical or medical properties that seem appropriate at any one time, put any stones you want into it, change them (with or without telling anyone) and upgrade them when more money is at hand. Necklaces are easily made to echo styles of dress and with no assistance from any other ornament, tell those who look at them when they were made and why a particular style was chosen.

To cover this great range of topics means that considerable selection has had to be exercised and the book succeeds in keeping a balance between ages, methods of manufacture, styles and gemstones. While the jewellery historian will welcome the conjunction of so many necklace examples, the gemmologist will also learn something about why particular stones are well-suited to this form of display: the general reader, coming across a book so reasonably priced, will dip into it and decide to buy it.

The material is arranged chronologically, thus placing the necklaces of antiquity first and present-day ones last. This survey is completed in five chapters, which are followed by a discussion of necklace types and clasps, a glossary and a bibliography. Working drawings accompany some of the photographs – they always add to the picture – and descriptions include provenance where appropriate as well as details of style, metal and gemstones. M.O'D.

Die Mineralien und Fundstellen von Schweden.

H.-J. WILKE, 1997. Christian Weise Verlag, München. pp 200, illus. in colour, hardcover. DM80.00 (including postage). ISBN 3 921656 41 9.

Though specimens of gem quality are absent from the mineralogy of Sweden, many gemmologists are mineral collectors too and for more than one reason this book deserves a note. Four chemical elements derive their names from Ytterby, near Stockholm, and the Långban area is one of the world's most productive of individual species. Furthermore, this is the only book I have seen in which the first pages of text link location with individual map sheets of the country's geological survey. This feature, together with a particularly extensive bibliography, provides an outstanding example of how such mineralogy should be arranged. The sites, arranged in four geographical sections, are fully described and each has its own sketch-map. Collectors of rare minerals will be particularly interested in this excellent survey in which many species are beautifully illustrated in colour.

M.O'D.

Zillertal.

Das Tal der Gründe und Kristalle, 1997. pp 100, illus. in colour, softcover. DM48.92 (including postage). ISBN 3 921656 40 0. [*extraLapis* no 12.]

The latest monographic supplement to the German journal *Lapis* (costed outside the journal subscription) deals with an area of considerable interest to gemmologists and mineral collectors. While the Zillertal in the Austrian Alps provides ornamental and sometimes gem-quality dark-red garnet which is often faceted, there are also fine sceptre crystals of rock crystal and amethyst, euhedral crystals of amethyst, citrine and smoky quartz, epidote, green grossular, orange hessonite, green diopside, green titanite (sphene), colourless moonstone and green tourmaline. Chapters deal with the major mines and collecting areas, their mineralogy and geology, with gold and with the finding of garnet and its ornamental use. There are attractive reproductions of early maps and panoramas and sections have their own lists of references, though these are short and there is no general bibliography. As always with this series, the printing, photography and general layout is beyond reproach. Readers are warned that at the time of writing five issues out of the first eleven are already out of print: reprinting may not always be an option and the second-hand market should be contacted before these magnificent surveys of species and areas become unavailable. So far emerald, rock crystal, fluorite, tourmaline, opal and garnet have been published, among others aimed at ore mineral collectors but not without significance to the gemmologist. M.O'D.

Proceedings of the Gemmological Association and Gem Testing Laboratory of Great Britain and Notices

OBITUARY

Mr John B. Taylor, FGA (D. 1979), Brisbane, Queensland, Australia, died on 22 June 1997.

Mr Philip G. Wyer, FGA, DGA (FGA 1964, DGA 1965), Edgbaston, Birmingham, died on 3 November 1997.

NEWS OF FELLOWS

At the invitation of Dr Frank Placido of the Physics Department, Paisley University, **Alan Hodgkinson** set up the *Hodgkinson method of visual optics* to demonstrate a series of hands-on experiments at a two-week open campus for secondary school pupils interested in working for a degree in physics. Demonstrations included the measurement of refraction, birefringence, dispersion and the use of a thermal probe and Hanneman Diamond Eye for the distinction of diamonds. Alan Hodgkinson has also been invited to lecture on *Visual optics* at Rhode Island University, New York State. The University has incorporated the Hodgkinson Method in its Physics Department gemmology course as standard syllabus for the last three years.

In addition to his involvement on the courses mentioned above, **Alan Hodgkinson** has had a very busy lecture programme including presentations to the National Trust for Scotland and the East Kilbride Historical Society in autumn 1997, to the American Gem Society at Anaheim, California, and, together with **Richard Hughes, E. Alan Jobbins, Stephen Kennedy** and **Colin Winter**, at the American Gemological Assocation Symposium held at the Tucson Gem Show.

Michael O'Donoghue, Lecturer in Gemmology at London Guildhall University since 1967, has been appointed Lecturer in charge of all gemmological work at the University.

Peter Read gave a talk on the identification of synthetic gem-quality diamonds and the new diamond simulant, synthetic moissanite, to the Wessex branch of the National Association of Goldsmiths on 28 January 1998. He concluded his talk with an illustrated review of his development work on the Brewster-angle meter. A prototype meter was then used by NAG members to identify a selection of gemstones.

GIFTS TO THE ASSOCIATION

The Association is most grateful to the following for their gifts for research and teaching purposes:

Argyle Diamonds, West Perth, WA, Australia, for the videos *The brilliant light of Australia* and *The diamond pipe line*.

Mr John R. Führbach, Amarillo, Texas, USA, for 8 cut peridots.

Miss Frances Garrett, Crawley, West Sussex, for a cellulose bracelet and a sphere of quartz.

Mrs Sonia Glaser, Galle, Sri Lanka, for 194 rough and cut stones.

Mr Robert Hsu, Taipei, Taiwan, for a financial donation.

Mr David Pratt, Bradford, West Yorkshire, for 7 pieces of ivory and 26 assorted cut stones.

L.M. Van Moppes & Son Ltd, London, for 50 boart diamonds.

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MEMBERS' MEETINGS

Trips and Tours

A field trip to Whitby, Yorkshire, was held over the weekend 6 to 8 March. As well as hunting for jet on the beaches, visits to a workshop and a local museum were arranged. A report of the trip will be published in the June issue of *Gem and Jewellery News*.

London

On 14 January 1998 at the Gem Tutorial Centre, 27 Greville Street, London EC1N 8SU, Clare Lawrence gave an illustrated talk entitled *Chinese snuff bottles: the use of stone in Chinese art*.

On 18 February at the Gem Tutorial Centre, Brian Jackson, Chairman of the Scottish Branch of the GAGTL, gave a talk on collecting gemstones in Scotland.

On 18 March at the Gem Tutorial Centre, Dr Jack Ogden, Chief Executive of the National Association of Goldsmiths and Secretary General of CIBJO, gave a talk entitled *Fired with enthusiasm: the early history of enamel*.

Midlands Branch

On 30 January 1998 at the Discovery Centre, 77 Vyse Street, Birmingham, a Bring and Buy Sale and Practical Gemmology Quiz were held.

On 27 February at the Discovery Centre, Michael Houghton of Phoenix Far East Pearls Ltd gave a talk on Chinese and Japanese pearls.

On 22 March, Professor R.A. Howie, President of the GAGTL, gave a lecture on gemstones, illustrated by slides and specimens.

On 27 March at the Discovery Centre a talk was given by Dr Jack Ogden.

North West Branch

On 18 March at Church House, Hanover Street, Liverpool 1, David J. Callaghan gave an illustrated talk entitled *The beauty of opal*.

Scottish Branch

On 25 January 1998, members joined the East of Scotland Jewellers Association at their Burns' Supper in the Witchery Restaurant, Secret Garden, Edinburgh.

On 22 February in the Geology Department of the National Museums of Scotland, Edinburgh, Clive Burch and John Harris ran a practical day entitled *Photographing gemstones and their inclusions*.

GEM DIAMOND EXAMINATIONS

In January 1998, 43 candidates sat the Gem Diamond Examination worldwide of whom 35 qualified, 5 with Distinction. The names of the successful candidates are listed below:

Qualified with Distinction

Ao Yan, Beijing, P.R. China
Hu Chin-Ching, Taipei, Taiwan, R.O. China
Li Jian, Beijing, P.R. China
Liu Ay Hwa, Taipei, Taiwan, R.O. China
Liu Jian, Beijing, P.R. China

Qualified

Balzan, Cortney G., San Francisco, Calif., USA
Chan Kwong Chi, Hong Kong
Chen Lili, Wuhan, Hubei, P.R. China
Gandhi, Amar A.A., Stanmore, Middlesex
Gao Bin, Wuhan, Hubei, P.R. China
Huang Yichun, Beijing, P.R. China
Huang Yizhi, Wuhan, Hubei, P.R. China
Iannicelli, Marco, Salerno, Italy
Kabangi, Nsapu, Leyton, London
Karim, Zapherali, Leicester
Kemp, Margaret A., Backwell, Somerset
Li Hongjun, Wuhan, Hubei, P.R. China
Li Li, Beijing, P.R. China
Li Li, Wuhan, Hubei, P.R. China
Lu Xin, Wuhan, Hubei, P.R. China
Lu Yung Ching, Taipei, Taiwan, R.O. China
Lüle, Çigdem, Ankara, Turkey
Marolla, Marianna, Athens, Greece
Mitchell, Susannah, Newton by Tattenhall, Cheshire
Panagopoulou, Anastasia, Athens, Greece
Qu Li, Beijing, P.R. China
Renard-Richard, Joelle M., Ruislip, Middlesex
Seligman, Dominic, Southfields, London
Slater, Richard M., Radstock, Bath, Avon
Sun Jingyu, Wuhan, Hubei, P.R. China
Tang Yun Hing, Frances, Hong Kong
Webster, Paul T., Greenford, Middlesex
Wong Ti Yin, Heather, Hong Kong
Yang Hong, Beijing, P.R. China
Zhu Ling, Wuhan, Hubei, P.R. China

FORTHCOMING EVENTS

22 April	**London.** Pearls – a Fashion Opportunity. Christianne Douglas.
24 April	**Midlands Branch.** AGM followed by A Mosaic of Gemmological Tessera.
26 April	**Midlands Branch.** Diploma pre-examination seminar.
3 May	**Midlands Branch.** Preliminary pre-examination seminar.
8–10 May	**Scottish Branch.** Annual Conference and AGM, Peebles. Speakers will include Gail Levine and Howard Rubin from America.
13 May	**London.** The Gemstone Collections of the GAGTL. Dr Roger Harding.
20 May	**North West Branch.** Time-bomb or fun? Brian Dunn.
29–31 May	**Gem trip to Scotland.** The weekend will include a field trip to the Campsie Fells, a visit to the National Museums of Scotland and a lecture on the gemstones of Scotland by Brian Jackson.
29 June	**London.** AGM (GAGTL members only) followed by the Reunion of Members and a Bring and Buy Sale.
8 July	**London.** The Evolution of Georgian and Victorian Jewellery. John Benjamin.
16 September	**North West Branch.** Gem collection with anecdotes. John Pyke, Snr.
3 October	**Trade Dinner.** To be held at the Café Royal, Regent Street, London. Guest speaker: Geoffrey C. Munn.
21 October	**North West Branch.** Silversmith of Williamsburg 1780. Martin Connard.
1 November	**Annual Conference.** Gems in Jewellery. To be held in the Barbican Centre, London.
18 November	**North West Branch.** Annual General Meeting.

For further information on the above events contact:

London and Trips:	Mary Burland on 0171 404 3334
Midlands Branch:	Gwyn Green on 0121 445 5359
North West Branch:	Deanna Brady on 0151 648 4266
Scottish Branch:	Joanna Thomson on 01721 722936

GAGTL WEB SITE

For up-to-the-minute information on GAGTL events and workshops visit our web site on www.gagtl.ac.uk/gagtl

EXAMINATIONS IN GEMMOLOGY

In the Examinations in Gemmology, held worldwide in January 1998, 127 candidates sat for the Preliminary Examination of whom 93 qualified. In the Diploma Examination 113 sat, of whom 53 qualfiied, three with Distinction. The names of the successful candidates are as follows:

Diploma

Qualified with Distinction

Liu Huai, Wuhan, Hubei, P.R. China
Park, Chan Won, Taegu, R.O. Korea
Zizi Zheng, Guilin, Guangxi, P.R. China

Qualified

Andaluz Sanchez, Maria, Peckham, London
Anderson, Elizabeth A., Peacehaven, East Sussex
Banks, Michelle, Leicester.
Boccard, Jean-Marie, Geneva, Switzerland
Britton, Andrea L., Woking, Surrey
Chan Sau King, New Territories, Hong Kong
Chen Xiatao, Wuhan, Hubei, P.R. China
Davidge, Elizabeth A., Pimlico, London
Draper, Zoe S., Upper Abbeywood, London
Han Lirong, Wuhan, Hubei, P.R. China
Ho Chuan-Hsiang, Taipei, Taiwan, R.O. China
Holt, Judith A., Darwen, Lancashire
Hsieh Pao Lien, Hong Kong
Htun Han, Yangon, Myanmar
Hu Chin-Ching, Taipei, Taiwan, R.O. China
Iannicelli, Marco, Salerno, Italy
Jacquat, Stephane, Geneva, Switzerland
Ji Tianxi, Shanghai, P.R. China
John, Victoria A., Agar Grove, London
Kiefert, Lore, Basel, Switzerland
Krzemnicki, Michael S., Basel, Switzerland
Liang Weizhang, Guangzhou, P.R. China
Lin, Chief R., Kaohsiung, Taiwan, R.O. China
Lin Yi Hwa, Yangon, Myanmar
Ling Li, Shanghai, P.R. China
Liu Yujun, Wuhan, Hubei, P.R. China
Lodge, Tim, Muswell Hill, London
Millard, Simon R., Corsham, Wiltshire
Mutton, Valerie, Langley, Buckinghamshire
Nazos, Konstantinos I., Athens, Greece
Oo, Thein Lwin, Yangon, Myanmar
Pancratz, Mark, Weybridge, Surrey
Park, Sung Ok, Taegu, R.O. Korea
Qiang Yin, Shanghai, P.R. China
Rommens, Catharina M.C., Eindhoven, The Netherlands
Rowntree, Josephine, Knaresborough, North Yorkshire
Sandar Win, Yangon, Myanmar
Song, Ruohan, Shanghai, P.R. China
Tinnyunt, Emma J., Kensal Green, London
Tong Tao, Guilin, Guangxi, P.R. China
Tupper, Michael I., South Holmwood, Surrey
Wang Chao, Guilin Guangxi, P.R. China
Wang Cun, Wuhan, Hubei, P.R. China
Wang Mingxun, Wuhan, Hubei, P.R. China
Wu Shizhou, Guilin, Guangxi, P.R. China
Xiang Xiaodan, Wuhan, Hubei, P.R. China
Xie Bing, Wuhan, Hubei, P.R. China
Zhang Caixia, Shanghai, P.R. China
Zhao Yanzeng, Guilin, Guangxi, P.R. China
Zheng Kaiwen, Wuhan, Hubei, P.R. China

Preliminary

Aster, Flora, London
Blatherwick, Clare, London
Brown, Vanessa, Sittingbourne, Kent
Browne, Dione, Battersea, London
Chan Kam Wai, Carolyn, Hong Kong
Chen Pai-Rong, Taipei, Taiwan, R.O. China
Cheong-Ly Karine, London
Cho, Chang-Bae, Taejon, R.O. Korea
Cropp, Alastair F.R., Lewes, East Sussex
Curran, Rose, Ealing, London
de Vries, Marius, South Kensington, London
Dun Yee Man, Stella, Chaiwan, Hong Kong
Eggerbratt, Pauline, Sundbyberg, Sweden
Fan Liying, Shanghai, P.R. China
Fris, Arnold, Goedereede, The Netherlands
Fujinara, Motoko, London
Fung Wai Man, Winnie, Shaukeiwan, Hong Kong
Garrett, Frances S.J., Crawley, West Sussex
Grech, Carrieann, Richmond, Surrey
Greenfield, Dawn M., Eynsford, Kent
Gudmundson, Inger M., Lannavaara, Sweden
Gwati, Martha, Harare, Zimbabwe
Han Xiao, Guilin, Guangxi, P.R. China
Harrison, Tarn J., Leamington Spa, Warwickshire
Henry-Stogdon, Sarah A., Sutton Common, Surrey
Hong, Angela Swee Leng, London
Hunter, Pauline A., Caversfield, Oxfordshire
Ikebe, Emi, London
Ip Kit Ling, New Territories, Hong Kong
Jain, Reena, Jaipur, India
Kang, Sung-Oong, Taegu, R.O. Korea
Kassas, Demetrios, Larissa, Greece
Kellerson, Laurent P., London
Kerkhof, Peter A.M., Eindhoven, The Netherlands
Koh, Hock Heng, Singapore
Konstandopoulou, Garoufallia, London
Lai Hoi Shan, Kowloon, Hong Kong
Lanz, Ernst, Veytaux, Switzerland

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SYNTHETICS AND ENHANCEMENTS TODAY

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STUDENT WORKSHOPS

Preliminary Theory Review	18 May
Three-day Preliminary Workshop	18-20 May
Diploma Theory Review	1 June
Four-day Diploma Workshop	1-4 June
Two-day Diploma Practical Workshop	6-7 June
Weekend Diamond Grading Revision	6-7 June

For further details contact the GAGTL Education Department

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Loe Shue Mon, Taipei, Taiwan, R.O. China
Long Chu, Guilin, Guangxi, P.R. China
Lüle, Çigdem, Ankara, Turkey
McFarlin, Michael, Amarillo, Texas, USA
Mafara, Ezekiel M., Harare, Zimbabwe
Martin, Edward, St. Ouen, Jersey, Channel Islands
Maung Aung Min, Yangon, Myanmar
Myo Thaw Lin, Yangon, Myanmar
Nang Latt Latt Htun, Yangon, Myanmar
Notaro, Tina M., Kandy, Sri Lanka
O'Byrne, Rose-Marie, Bicester, Oxfordshire
Okamoto, Chizuko, London
Ono, Shiho, London
Pang Chi Keung, Shatin, Hong Kong
Panoutsopoulou, Dolomidou G., Athens, Greece
Paphitis, Constantinos, Bayswater, London
Park, Chan Won, Taegu, R.O. Korea
Parker, Sarah J., East Dulwich, London
Patel, Nita, Newbury, Berkshire
Pavlou, Tasos, Nicosia, Cyprus
Pedersen, Gunnar, Lannavaara, Sweden
Qiang Yin, Shanghai, P.R. China
Rambukkange, Timothy P., Kandy, Sri Lanka
Roberts, Justin J., Wembley, Middlesex
Said, Mohammad Ali, Lannavaara, Sweden
Savla, Rajvee B., Bangalore, India
Schmocker, Karin, Fribourg, Switzerland
Shin, Hyun-Sook, Daejon, R.O. Korea
Smith, Peggy E.J., Rochester, Kent
Smith, Wayne M., Harrogate, Yorkshire
Soe Moe Naing, Yangon, Myanmar
Srithai, Boontarika, London
Su Cho Win, Yangon, Myanmar
Suda, Junko, London
Sun Pinghong, Shanghai, P.R. China
Sung, Jae-Bum, Daejon, R.O. Korea
Suwichakornpong, Sirima, Kensington, London
Tang Suk Yee, New Territories, Hong Kong
Tang Tiande, Wuhan, Hubei, P.R. China
Tharn Htite, Yangon, Myanmar
Thompson, Ian, Wood Green, London
To Man Fang, Hong Kong
Tsakanika, Christina, Athens, Greece
Tulo, Karen, London
Van Spaendonck, Anouk D., The Hague, The Netherlands
Vasilevskaya, Polina, San Francisco, Calif., USA
Wang Ming-chi, Taipei, Taiwan, R.O. China
Yin Sheng Shen, Shanghai, P.R. China
Zagana, Aphrodite, Athens, Greece
Zhou Wen Hao, Guilin, Guangxi, P.R. China

MEETINGS OF THE COUNCIL OF MANAGEMENT

At a meeting of the Council of Management held at 27 Greville Street, London EC1N 8SU, on 28 January 1998 the business transacted included the election of the following:

Diamond Membership and Fellowship (FGA/DGA)

Patel, Pankaj, Sudbury Hill, Middx. 1991,1992
Taylor, Roger, Birmingham, Warwicks. 1986, 1994

Fellowship (FGA)

Campbell, Robert Desmond, Wallington, Sutton, Surrey. 1995
Kan Wing Lok, Singapore. 1995
Karandikar, Surendra Narayan, Maharashtra, India. 1997
Kei, Oo Oo Tracy, Hong Kong. 1996
Lau Joyce Pao Ching, Hong Kong. 1997
Lee Yow Hon, Hong Kong. 1997
Pani, Tõnu, Tartu, Estonia. 1996
Pethiyagoda, Upali, Manama, Bahrain. 1978
Winiski, Ken, Vancouver, BC, Canada. 1995

Ordinary Membership

Asanuma, Yukiko, Kyoto City, Kyoto, Japan
Atarashi, Yoshie, Osaka City, Osaka, Japan
Blatherwick, Clare, London
Castoro, Loretta, New York, N.Y., USA
Finlay, Louden B., London
Gupta, Ashwani Kumar, Windsor, Berkshire
Hasegawa, Takako, Toyonaka City, Osaka, Japan
Hashiguchi, Naoko, Sendai City, Kagoshima Pref., Japan
Higashi, Moritomi, Yao City, Osaka, Japan
Higo, Chizuyo, Uda-gun, Nara Pref., Japan
Hoshino, Tomiko, Amagasaki City, Hyogo Pref., Japan
Ikeda, Yumi, Osaka City, Osaka, Japan
Inoue, Kazuko, Tokyo, Japan
Ishibashi, Shigeru, Kishiwada City, Osaka, Japan
Jinsenji, Osamu, Toda City, Saitama Pref., Japan
Kawahara, Miki, Enuma-gun, Ishikawa Pref., Japan
Kishikawa, Toshio, Osaka City, Osaka, Japan
Koukou, Katerina, Athens, Greece
Kubota, Mie, Higashi-Chikuma-gun, Nagano Pref., Japan
Lallerstedt, Anna, Barnes, London
Momosaki, Nobuko, Hirakata City, Osaka, Japan
Morris, David John, Stoke, Plymouth, Devon
Muratsu, Hirotoshi, Neyagawa City, Osaka, Japan
Nemoto, Kyoko, Kyou-Tanabe City, Kyoto, Japan
Nichol, Douglas, Wrexham, North Wales
Nilsson, Paul Graham, Auckland, New Zealand
Nishimura, Yoko, Nabari City, Mie Pref., Japan
Nishioka, Kimie, Osaka City, Osaka, Japan
Okamoto, Mayumi, Higashi-Osaka City, Osaka, Japan
Onohara, Miwa, Kobe City, Hyogo, Japan
Oya, Kenichi, Niigata City, Niigata Pref., Japan
Plant, Monika, Altrincham, Cheshire
Sakai, Junko, Otsu City, Shiga Pref., Japan
Sanui, Atsuko, Kawanishi City, Hyogo Pref., Japan
Smith, Christopher, Lucerne, Switzerland
Takayama, Rie, Kyoto City, Kyoto, Japan
Tanimura, Hiromi, Osaka City, Osaka, Japan
Taylor, Duncan Lawrence, Stowting, Near Ashford, Kent
Thoresen, Lisbet, Santa Monica, Calif., USA
Tsutsumi, Masao, Higashi-Hiroshima City, Hiroshima Pref., Japan
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On p.48 above, first column, second line, for 'Single-chain silicates' read 'Double-chain silicates'

On the back cover of Vol. 26 (1), under Contents, fifth item, for 'Colour in tapazes ...' read Colour in topazes ...'

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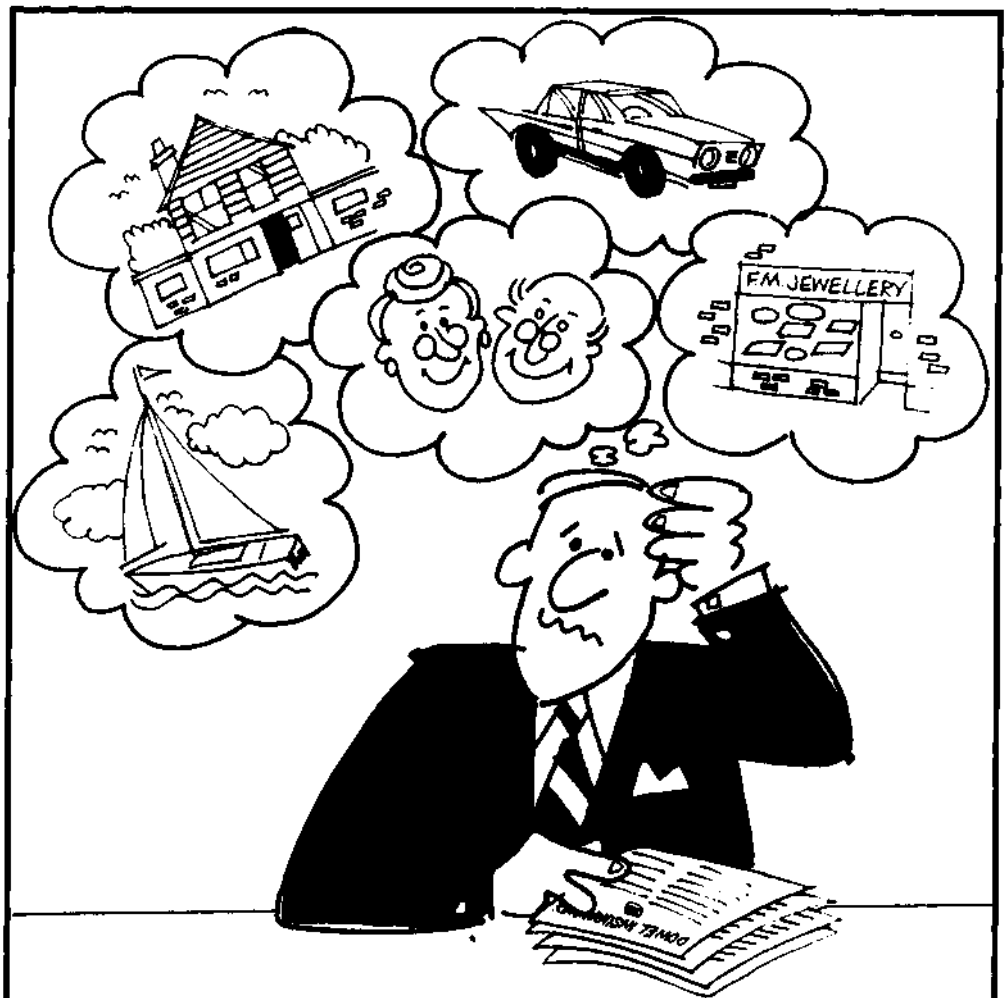

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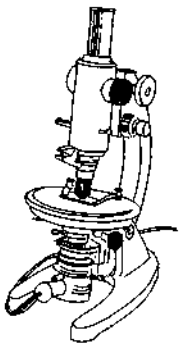

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Ladies' bracelet
A magnificent 105.57 ct peridot from Myanmar set with 35.45 ct and 35.74 ct citrines from Brazil, on ten strands of black nephrite beads (5.0–5.2 mm diameter) from Wyoming, USA. Bracelet the property of Georgia and Quentin Isaacs, Texas, USA. Photo courtesy of J.R. Führbach (see Peridot from Black Rock Summit lava flow, Nye County, Nevada, USA. p. 86)

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The colour of Igmerald: I.G. Farbenindustrie flux-grown synthetic emerald

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ABSTRACT: Seven samples of I.G. Farbenindustrie flux-grown synthetic emerald were examined. The synthetic emeralds were grown between 1929 and 1942 at Bitterfeld, Germany, in a lithium molybdate solvent. Gemmological, chemical and spectroscopic properties are given. The colour of the samples is caused by minor amounts of chromium and nickel and, thus, the secret ingredient mentioned by Espig (1960) is identified as a nickel-bearing compound.

Introduction

Historical background

The first emerald synthesis which produced facetable crystals above one centimetre in size was performed by I.G. Farbenindustrie (literally I.G. Dye Trust) at Bitterfeld, Germany. Facetable material had been grown since 1929 (Schiebold, 1935; Espig, 1960), but samples were released to the public only after the first announcement to the press in February 1935 (Anonymous, 1935). Gemmological descriptions of this synthetic emerald were published in the same year (Eppler, 1935; Jaeger and Espig, 1935; Anderson, 1935) and mineralogical investigations of the synthetic emerald crystals, e.g. by X-ray powder diffraction, were also performed (Schiebold, 1935; Espig, 1935; Anderson, 1935). Gemmological properties of these synthetic emeralds were examined later by various authors and their results were summarized and compared with the features of the first synthetic emeralds produced in the United States by Chatham in different articles in the '50s (e.g. Webster, 1952, 1955, 1958; Wiegand, 1952; Gübelin 1953; Eppler, 1958a,b). Regarding the growth technology used, there was only speculation until three more or less detailed papers of one of the inventors of the I.G. Farbenindustrie process were published (Espig, 1960, 1961, 1962). Before this information was available, the synthetic emeralds were considered as hydrothermally grown (Webster, 1955, 1958; Wilke 1956).

Growth technology

Espig reported that the first attempts to grow synthetic emeralds at Bitterfeld started in 1911 and that he was involved in these experiments from 1924. Crystal growth in the final stage of the technical development was performed in platinum crucibles with lithium molybdate as the solvent. A schematic drawing of the growth conditions *(Figure 1)* which followed closely the descriptions of Espig was published by Recker (1973). A nutrient of BeO and Al_2O_3 with lithium chromate as colour-causing dopant was placed at the bottom of a

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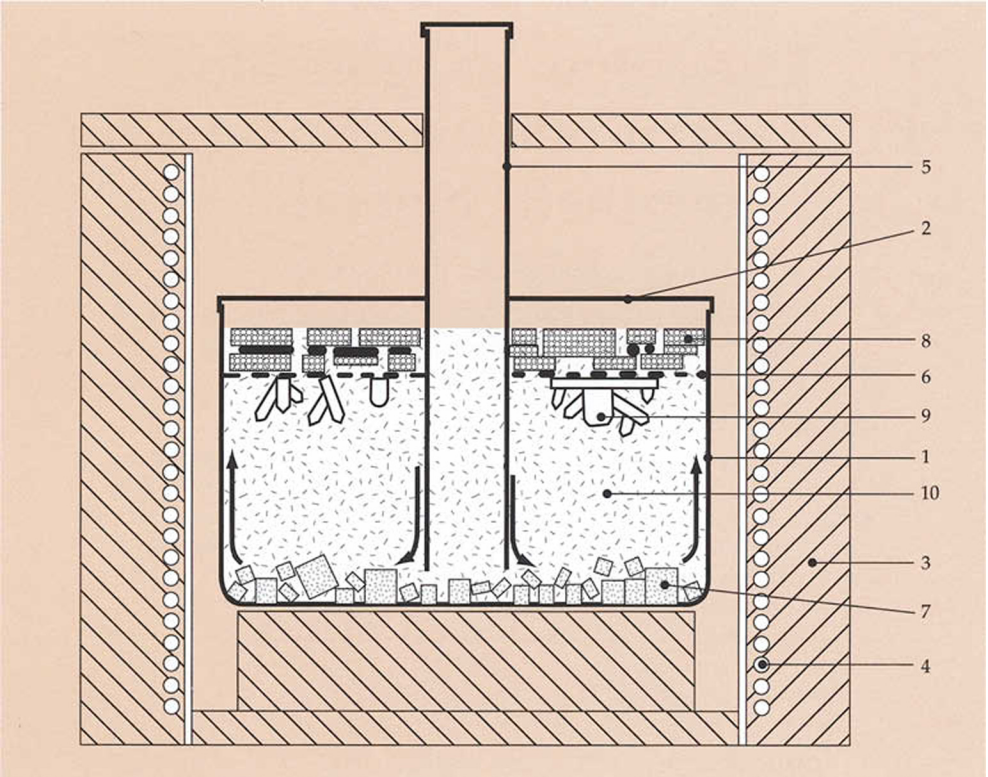

Figure 1: *Schematic diagram of the process applied to flux growth of synthetic emerald by I.G. Farbenindustrie at Bitterfeld, Germany, from 1929 to 1942; Key: 1 = platinum crucible, 2 = platinum lid, 3 = insulation, 4 = heating system, 5 = central platinum tube for the addition of material to the nutrient, 6 = baffle, 7 = nutrient, 8 = quartz plates, 9 = growing crystals, 10 = lithium molybdate solvent (adapted from Recker, 1973).*

platinum crucible. Subsequently, the crucible was filled with lithium molybdate and emerald seeds were positioned below a platinum baffle. Above this baffle, quartz plates of 8 to 10 mm in thickness were arranged. These quartz plates floated on top of the melt after heating the furnace to a constant temperature of about 800°C. This temperature was kept at a constant level over a growth period of 20 days, but new nutrient was added every second day by means of a central platinum tube to the material at the bottom of the crucible. After each growth period, the synthetic emerald crystals were examined and extremely impure layers of synthetic emerald material were removed. The largest crystals of prismatic habit which were obtained in about 18 growth periods during one year measured 2 or 3 cm in length (Espig, 1960, 1961, 1962). Faceted stones up to 1 ct in weight measuring 5 to 6 mm were cut from the rough.

Emeralds were produced at Bitterfeld from 1929 until 1942 in 12 furnaces (Espig, 1960), but due to the market situation for natural emeralds and the relatively high cost of crystal growth, there was no large-scale industrial production of synthetic emeralds at the I.G. Farbenindustrie (Anonymous, 1952; Wiegand, 1952). As a result, the synthetic emeralds were never sold commercially on the free market. The material was named Igmerald, standing for I.G. emerald, and was used for public relations purposes of the I.G. Farbenindustrie. In 1945, the complete platinum growth facilities were lost and production was not resumed after the war.

Colour of Igmerald

Although the basic technology of emerald production has been available to the public since 1960, a few sentences in the first of the three papers by Espig led to some speculation: 'Zwar steht in allen Lehrbüchern, daß Smaragd durch Chromoyxd gefärbt ist und in der Hauptsache trifft dies auch zu. Nachdem wir aber zum erstenmal große Kristalle erhielten, zeigte sich, daß Chrom allein ein kaltes bläuliches Grün gibt, und es waren Hunderte von Versuchen erforderlich, um diejenigen Stoffe ausfindig zu machen, die die Farbe zum warmen Grün einer Wiese im Frühling nuancierten.' ['It is mentioned in all textbooks that emerald is coloured by chromium oxide, and this is generally correct. But after we obtained large crystals for the first time, we recognized that chromium alone causes a cold bluish green. Hundreds of experiments were necessary to find those compounds, which shifted the colour to the warm green of a meadow in spring.']

Another flux growth process of synthetic emerald was performed in the '20s by Professor R. Nacken in Frankfurt, Germany, using a molybdenum- and vanadium-bearing flux. Crystals up to 5 mm in size were described by Nassau (1978) and the growth technique was elucidated using Nacken synthetic emeralds from private and public collections, because no publication is available from Nacken himself describing the growth process (see also Webster, 1955, 1958). Nacken synthetic emeralds were also regarded as hydrothermally-grown synthetic emeralds until the chemical composition of a trapped molybdenum- and vanadium-bearing residual flux was established and the absence of water was confirmed experimentally (Nassau, 1978).

Knowing of vanadium as a colour-causing trace element in natural emeralds from certain sources such as Colombia, Nassau mentioned a possible co-operation of I.G. Farbenindustrie with Nacken and a possible use of vanadium as a colour-causing dopant in the I.G. Farbenindustrie growth process of Igmerald. He suggested that the secret ingredient of Jaeger and Espig may have been vanadium (Nassau, 1976, 1978, 1980; Nassau and Nassau, 1980). This assumption was accepted by other scientists (see e.g. Elwell, 1979) and seems reasonable, because synthetic green 'emeralds' which were coloured by vanadium had already been mentioned in 1926 by Bernauer (in a paper dealing with trapiche emeralds from Colombia), although the growth method of these samples was not described. This information, however, was available to the scientists involved in the growth and examination of I.G. Farbenindustrie synthetic emeralds (see Schiebold, 1935).

Materials and methods

Seven Igmeralds (I.G. Farbenindustrie flux-grown synthetic emeralds) were available from the research collection of E. Gübelin, Lucerne, Switzerland *(Figure 2)*:

- one prismatic, slightly distorted crystal of 3.81 ct measuring 9.5 mm in length and between 6.0 and 6.8 mm in diameter;
- six faceted stones between 0.48 and 0.12 ct, all with an orientation of the table facet perpendicular to the *c*-axis.

All seven samples were tested by standard gemmological methods for optical properties, fluorescence, specific gravity and microscopic features. Inclusions were studied microscopically and identified by Raman spectroscopy with a Renishaw Raman Microscope. For a chemical characterization of the synthetic

Figure 2: *Rough and faceted I.G. Farbenindustrie synthetic emeralds (left) compared to two Chatham synthetic emeralds (right). The rough crystal is 9.5 mm long (photo by H.A. Hänni).*

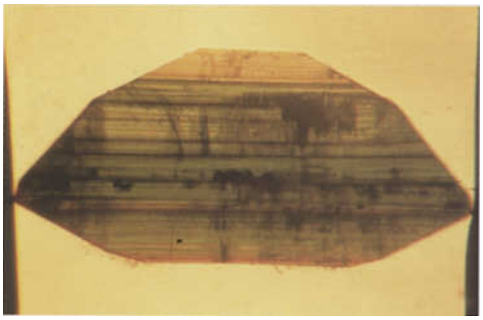

Figure 3: Growth and colour zoning parallel to the basal pinacoid in I.G. Farbenindustrie synthetic emerald. View perpendicular to the c-axis, immersion, 35x

emeralds, the rough crystal and the two larger faceted samples of 0.48 and 0.26 ct were submitted to energy-dispersive X-ray fluorescence analysis (EDXRF) using a Spectrace 5000 Tracor X-ray fluorescence spectrometer with a Tracor Northern Spectrace TX-6100 software system. Spectroscopic data in the visible and ultraviolet range for all seven samples were recorded with a Leitz-Unicam SP 800 spectrophotometer.

Results

Gemmological properties

Gemmological properties, e.g. refractive indices, specific gravity, and fluorescence data *(Table I)*, are comparable to the properties

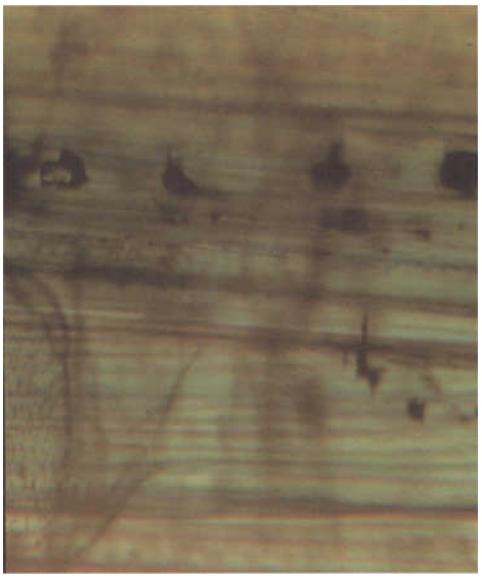

Figure 4: Growth and colour zoning approximately parallel to the basal pinacoid in I.G. Farbenindustrie synthetic emerald; some of the growth planes are not exactly parallel to each other. View perpendicular to the c-axis, immersion, 80x

of flux-grown synthetic emeralds of different producers, especially with those of synthetic emeralds which were grown in a solvent of lithium molybdate (see Flanigen *et al.*, 1967).

All samples revealed a characteristic growth zoning consisting of alternating

Table I: *Properties of chromium- and nickel-bearing synthetic emeralds*

	Chatham	*Igmerald*	*Gilson**
Colour	bluish-green	grass-green	yellowish-green
Pleochroism parallel c perpendicular c	blue-green yellowish-green	bluish-green yellow-green	intense green yellow-green
Refractive indices n_o n_e	1.564 1.560	1.563–1.566 1.559–1.561	1.563 1.559
Birefringence	0.004	0.004–0.005	0.004
Specific gravity	2.65	2.65–2.66	2.65
UV fluorescence long-wave short-wave	moderate red light red	moderate red light red	light yellowish light yellowish
Significant minor elements	Cr	Cr>Ni>>Fe	Cr≈Ni>(V,Fe,Cu)
Significant absorption bands	Cr	Cr>Ni	Cr≈Ni

* Schmetzer, 1989

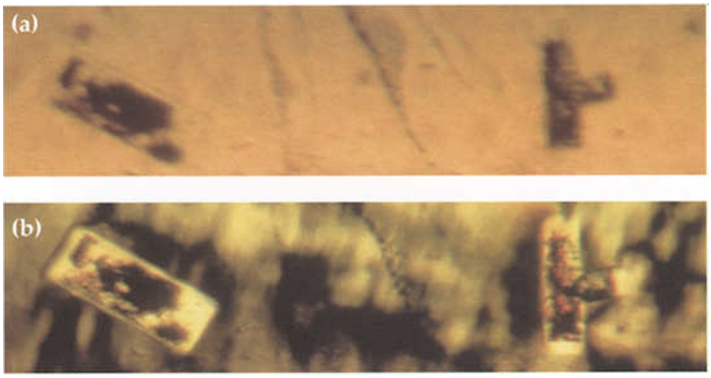

Figure 5: Inclusions of prismatic beryl crystals with orientations different from that of the host synthetic emerald; inclusions of opaque residues of the solvent have been trapped in the prismatic beryl. Immersion, (a) in plane-polarized light, 100x, and (b) in cross-polarized light, 100x.

green, yellowish-green and sometimes even greenish-yellow layers more or less parallel to the basal pinacoid *(Figure 3)*. Some of these growth boundaries were slightly inclined to each other, i.e. not all growth lines were exactly parallel, thus representing slightly uneven undulating planes within the beryl crystals *(Figure 4)*. The rough crystal showed also small areas with growth zoning parallel to the hexagonal prism faces $(10\bar{1}0)$ and $(11\bar{2}0)$, but these thin outer layers were completely removed by cutting in all six faceted samples.

Two types of birefringent crystals were present as inclusions: the first type consisted of prismatic, elongated crystals which contained numerous small opaque inclusions, most probably of residual flux. The refractive index of these prismatic crystals was close or identical to that of the host beryl and, thus, the single prisms were sometimes difficult to observe. Under crossed polarizers, however, these prisms always became visible due to their interference colours *(Figure 5)*. Consequently, these inclusions were identified as beryl with an orientation different from that of the host.

The second type of birefringent inclusions consisted of colourless crystals, mostly with somewhat rounded edges with refractive indices distinctly above that of the host. These inclusions were identified by micro Raman spectroscopy as phenakite, which is a common inclusion in flux-grown synthetic emeralds from different producers (Delé-Dubois *et al.*, 1986a, b).

Figure 6: Cellular pattern of residual flux in I.G. Farbenindustrie synthetic emerald. View parallel to the c-axis, immersion, 60x.

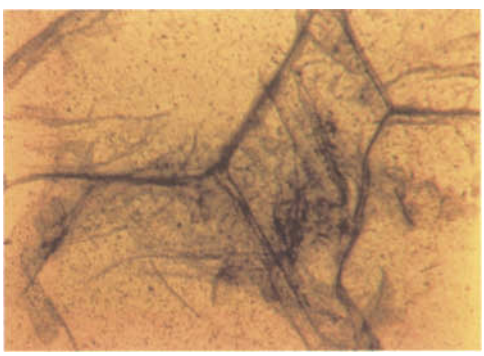

Figure 7: Residual flux trapped in I.G. Farbenindustrie synthetic emerald. Immersion, 60x.

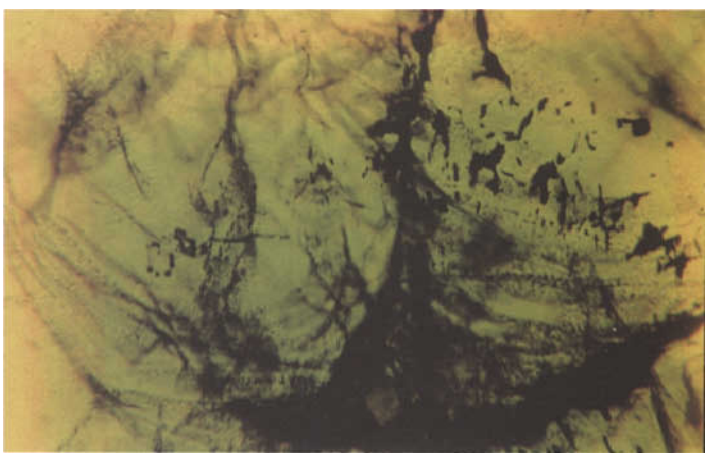

Residual flux was present in various forms in all seven I.G. Farbenindustrie synthetic emeralds examined. In views parallel to the *c*-axis, a cellular pattern of flux particles was sometimes visible *(Figure 6)*. In other directions of view, the wispy veils typical for flux-grown synthetic emeralds were commonly observed *(Figure 7)*.

Occasionally, residual flux was also found in channels parallel to the *c*-axis. Raman spectroscopy of the compounds trapped in channels parallel to *c* indicates that at least three solid phases are present. The spectra are consistent with the Raman spectra of different polymolybdate molecules in solutions (Johansson *et al.*, 1979; Murata and Ikeda, 1983) and with the spectrum of residual polymolybdate fluxes in different flux-grown emeralds (Delé-Dubois *et al.*, 1986a, b). In addition, the strongest Raman lines of orthorhombic molybdenum trioxide (Krasser, 1969; Py *et al.*, 1977; Delé-Dubois *et al.*, 1986a, b) were also observed.

Chemical and spectroscopic properties

The rough crystal and the two faceted samples which were examined by energy dispersive X-ray fluorescence revealed characteristic EDXRF spectra indicating the presence of molybdenum (from residual flux material), distinct amounts of chromium and nickel, and traces of iron *(Figure 8)*. In all samples tested the relative abundances were Cr > Ni >> Fe, but the characteristic emission lines of vanadium were not found.

Figure 8: *EDXRF spectrum of a faceted I.G. Farbenindustrie synthetic emerald showing distinct amounts of Cr and Ni (chromophores) and Mo (from the flux).*

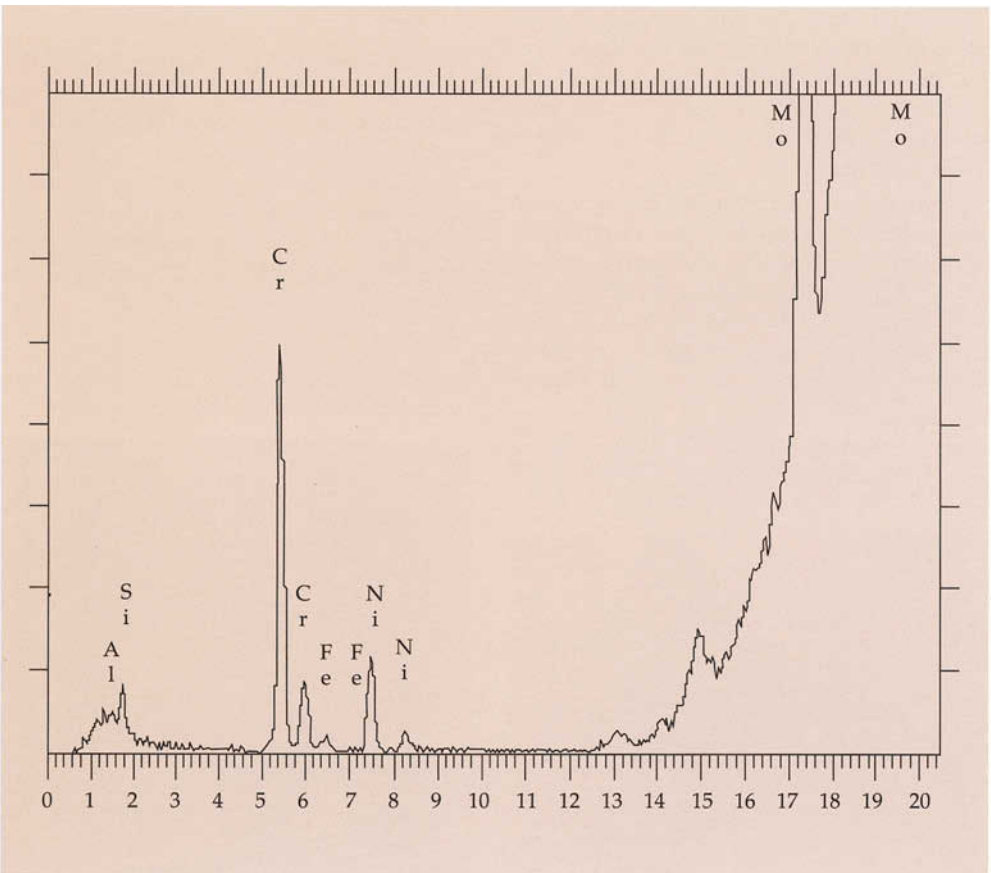

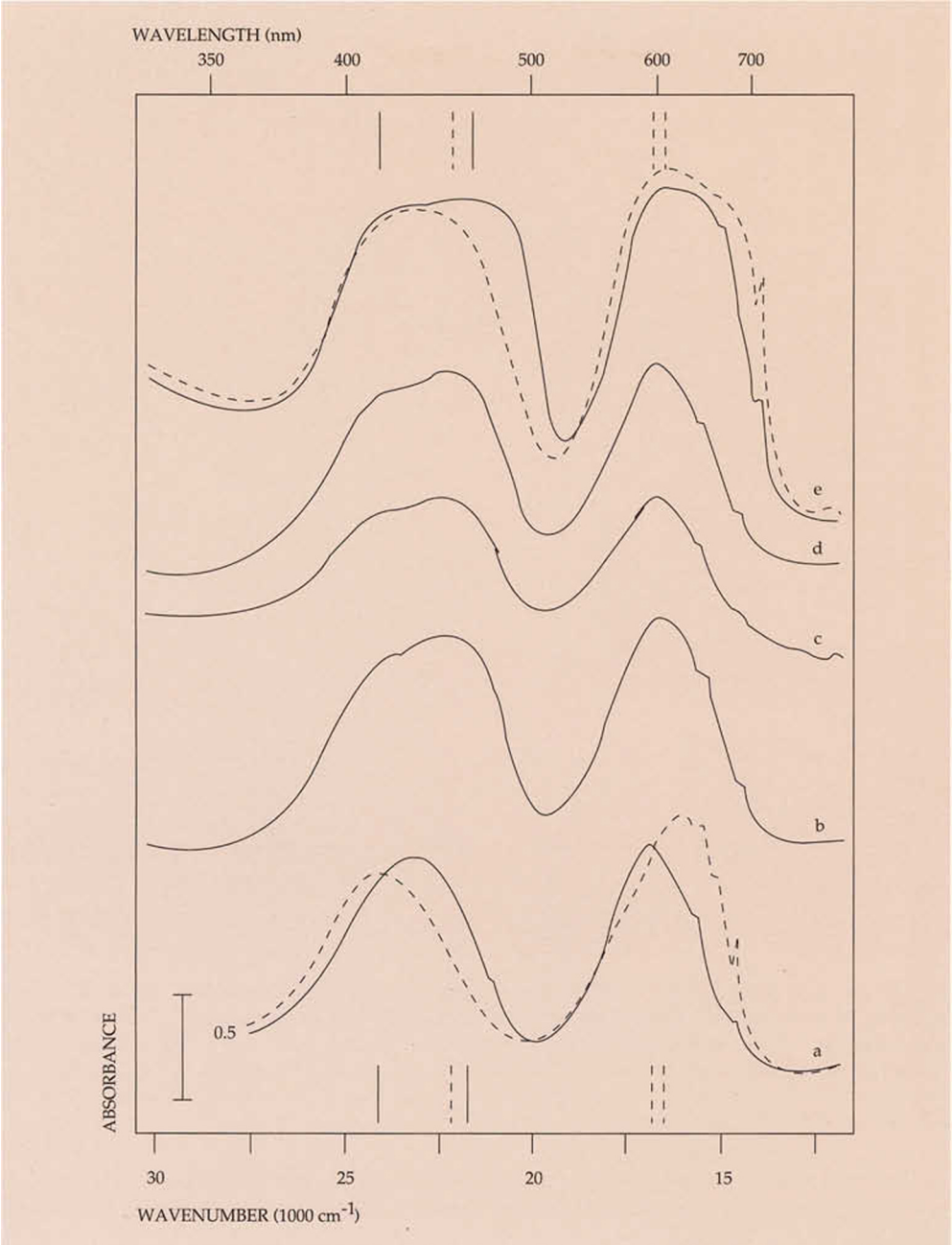

Figure 9: *Absorption spectra of chromium- and nickel-bearing synthetic emeralds: (a) chromium-bearing Chatham synthetic emerald, (b) to (e) chromium and nickel-bearing I.G. Farbenindustrie synthetic emeralds; spectra (b), (c), and (d) were recorded from faceted samples with direction of the beam parallel to the c-axis, the polarized spectra (a) and (e) were recorded from faceted or rough crystals with direction of the beam perpendicular to the c-axis; the positions of nickel absorption maxima are indicated by dashed and solid lines at the bottom and at the top of the drawing; solid lines represent a polarization perpendicular to the c-axis, dashed lines represent a polarization parallel to the c-axis.*

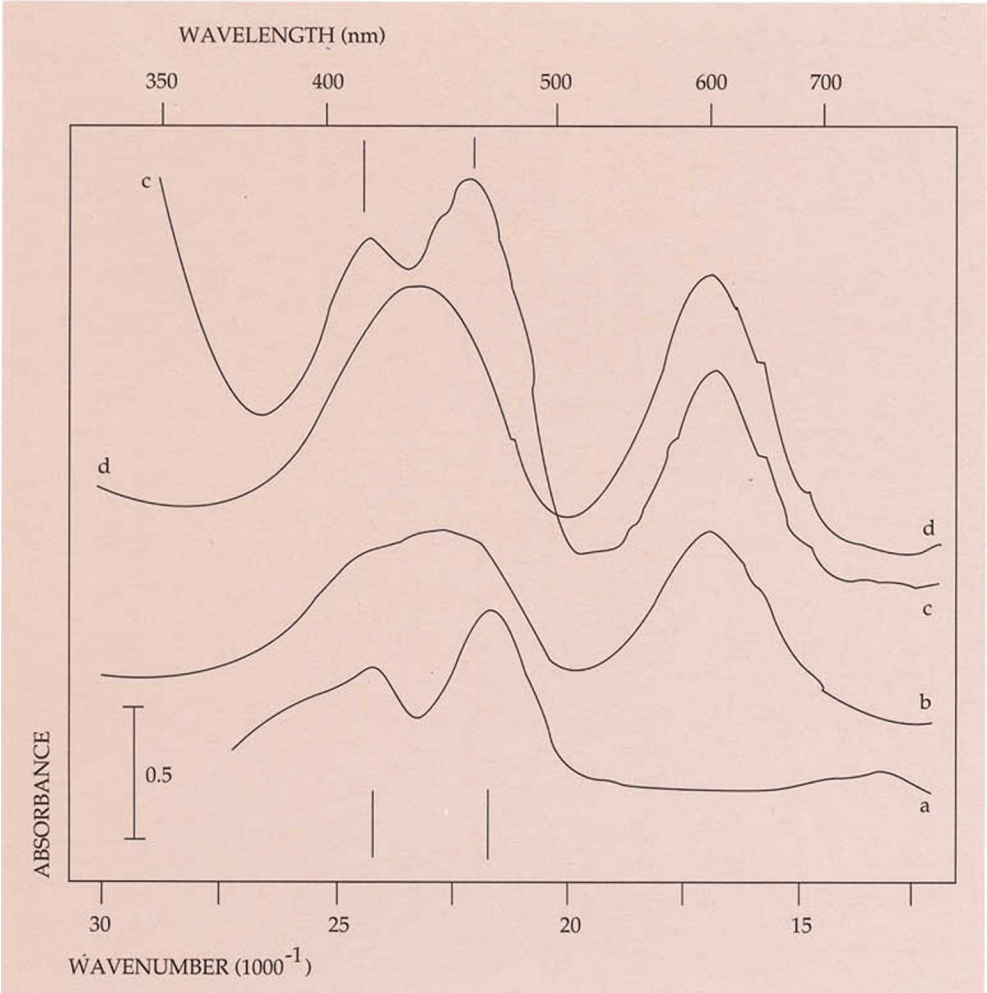

Figure 10: *Absorption spectra of chromium- and nickel-bearing synthetic emeralds and nickel-bearing synthetic beryl: (a) nickel-bearing Russian hydrothermally-grown synthetic beryl, (b) chromium and nickel-bearing I.G. Farbenindustrie synthetic emerald, (c) chromium and nickel-bearing Gilson synthetic emerald, (d) chromium-bearing Chatham synthetic emerald; the positions of nickel absorption maxima are indicated by solid lines at the bottom and at the top of the drawing; all spectra represent polarization perpendicular to the c-axis.*

Polarized absorption spectra of the rough crystal *(Figure 9e)* and non-polarized spectra of all six faceted samples *(Figure 9b to d)* where the incident beam was parallel to the *c*-axis, i.e. representing a spectrum with polarization perpendicular to *c*, consisted of the well-known absorption spectrum of chromium in beryl *(see Figure 9a)*, superimposed by a series of nickel absorption bands. In particular, the chromium spectrum perpendicular to *c* is superimposed by two absorption bands with maxima at 21 700 and 24 200 cm^{-1} *(Figure 10)* and the chromium spectrum parallel to *c* is superimposed by a doublet at 16 500 and 16 800 cm^{-1} and by an absorption band at 22 100 cm^{-1}. According to the examination of nickel-bearing hydrothermally-grown synthetic beryl and the assignments of the observed absorption bands to Ni^{2+} and Ni^{3+}

in the papers by Solntsev (1981a, b); Klyakhin *et al.*, (1981); and Lebedev *et al.*, (1986), the band at 22 100 cm^{-1} is caused by bivalent nickel and the remaining bands mentioned are due to trivalent nickel, both replacing Al^{3+} in octahedral sites of the beryl structure.

It is worth mentioning that the nickel doublet at 16 500 and 16 800 cm^{-1} had already been observed by Anderson (1935) in one of the first Igmeralds, and this was later confirmed for additional samples in the United States and Switzerland (Anonymous, 1937; Gübelin and Shipley, 1941). There was, however, no explanation for the additional absorption bands in the Igmerald spectrum at that time.

Discussion

Characteristic properties of I.G. Farbenindustrie synthetic emeralds

The most characteristic microscopic feature of Igmerald is the distinct growth and colour zoning parallel to the basal pinacoid. A rough calculation from the data given by Espig (1960, 1961, 1962) indicates a growth rate of about 0.06 to 0.09 mm per day. The growth layer obtained in a growth period of two days corresponds to the average thickness of growth layers in faceted samples, which were determined by microscopic examination. This is understandable according to the fact that the equilibrium between the different components of beryl in the solvent was abruptly changed every second day by the addition of new material to the nutrient at the bottom of the crucible. Obviously, there were different periods of growth and even dissolution (see Espig, 1962) within these growth cycles, and these caused somewhat uneven undulating surfaces on different parts of the growth layers.

The inclusions of small prismatic beryl crystals with a high concentration of trapped opaque flux material is also characteristic for Igmerald, but this feature was only observed in some of the samples. Inclusions of phenakite and various forms of trapped flux are common in flux-grown synthetic emeralds from various producers.

It is evident that the secret ingredient mentioned by Espig (1960) which was added to the nutrient for the flux growth of synthetic emeralds by I.G. Farbenindustrie at Bitterfeld was a nickel-bearing compound. From the present study, there is no evidence for the presence of vanadium in the flux or in the nutrient. Thus, our experimental data can offer no support to a possible link between Professor Nacken and the scientists who were involved at I.G. Farbenindustrie with the development of the growth process for synthetic emeralds. According to his 1962 paper, Espig was still assuming a hydrothermal technique for emerald growth by Nacken at that time. There was no reason to publish such a statement in 1962 in a description of most of the technical details of the emerald growth process by I.G. Farbenindustrie, if there really was co-operation in the '20s.

The authors are aware that nickel-free synthetic emeralds were also produced at Bitterfeld. Thus, for samples of doubtful origin or possibly mislabelled synthetic emeralds in gemstone collections, for which a distinct nickel content cannot be proven, the characteristic growth pattern and colour zoning and/or typical inclusions, e.g. prismatic beryl crystals with a high concentration of residual flux, may be appreciated as characteristic features.

It is interesting to note that the synthetic emeralds of Zerfass, which were produced at Idar-Oberstein from 1963 (Eppler, 1964) by one of Espig's former co-workers with knowledge of the I.G. Farbenindustrie process (Nassau, 1976, 1980), were coloured only by chromium and did not contain nickel. Based on investigations of several samples of Zerfass synthetic emeralds by the present authors using absorption spectroscopy and X-ray fluorescence analysis, the emeralds examined display a normal chromium absorption spectrum and contain among the minor elements only molybdenum (from the flux) and chromium.

Colour of nickel-bearing synthetic emeralds

In general, distinct amounts of nickel are present in addition to chromium, iron and

Figure 11: Chromium- and nickel-bearing I.G. Farbenindustrie synthetic emerald (left) and chromium-bearing Chatham synthetic emerald (right). The right-hand sample measures 9 x 7.3 mm (photo by H.A. Hänni)

copper in both types of Russian hydrothermally-grown synthetic emeralds which are produced commercially (Schmetzer, 1988, 1996; Koivula *et al.*, 1996). These crystals are grown in autoclaves without precious metal liners, a technique which was also proven for samples of Lechleitner hydrothermal fully synthetic emeralds (Schmetzer, 1990). These samples also contained distinct amounts of chromium, iron, nickel and copper as colour-causing trace elements. The colour of all these hydrothermally-grown synthetic emeralds is a complex function of the relative concentrations of all four transition metals.

Traces of 0.04 wt.% NiO were analyzed by Schrader (1983) in one sample of Inamori flux-grown synthetic emerald, but according to the high chromium content of this stone, an influence of nickel on the colour of this sample is unlikely.

Another nickel-to-chromium ratio was found in an extraordinary yellowish-green Gilson flux-grown synthetic emerald, which contained similar amounts of chromium and nickel (Schmetzer, 1989). Comparing the absorption spectrum of this sample with the spectra of the seven Igmeralds examined in this study, it becomes evident that the relative intensity of nickel absorption bands compared to the chromium spectrum is stronger in the Gilson sample than in the Igmerald spectra *(Figure 10)*. In terms of the colour and pleochroism of synthetic emeralds, increasing nickel content relative to chromium causes the pleochroic colour parallel to *c* to shift from blue-green to bluish green and green, i.e. the bluish component is reduced. The pleochroic colour perpendicular to *c* shifts slightly from yellowish-green to yellow-green, i.e. the yellow component of the green is slightly increased. In general, the overall colour shifts with increasing nickel content from bluish-green to grass-green and yellowish-green *(Figure 11, Table I)*.

These results are consistent with the data presented by Bukin *et al.* (1981), who found a complex relation between colour and the relative amounts of Ni^{2+}, Ni^{3+} and Cr^{3+} in individual samples. According to Bukin, a nickel content above 0.1 wt.% is able to change the colour of an emerald sample. With increasing amounts of nickel, a shift of colour is mainly observed parallel to *c*, and only a minor change is found perpendicular to *c*.

Obviously, the grass-green colour of chromium- and nickel-bearing synthetic emerald was more acceptable as a 'good' emerald colour in the '30s in Germany by the producers of Igmeralds than the more bluish-green of chromium-bearing, nickel-free emerald. As a consequence of the great efforts necessary to find the appropriate mixture of compounds in the nutrient which produced this 'good' emerald colour, this recipe was not disclosed in the papers of Espig (1960, 1961, 1962) and has been kept secret until now.

Acknowledgements

The authors are grateful to Professor E. Gübelin of Lucerne, Switzerland, for the loan of the seven samples of Igmerald (I.G. Farbenindustrie flux-grown synthetic emerald) used in the present study. Professor H.A. Hänni of SSEF, Basel, Switzerland, kindly reviewed the manuscript.

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A study of Korean precious serpentine

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ABSTRACT: A precious serpentine deposit was recently discovered in Booyo County, Republic of Korea, and is the first recorded occurrence in the country. It forms along both contacts of a garnet vein intruding the serpentinite. The precious serpentine is semi-transparent and deep green with an oily lustre. It is very tough and measures about 5 on Mohs' scale of hardness. Its SG and RI are 2.57~2.58 and N_D = 1.56, respectively. X-ray powder diffraction analysis indicates that the precious serpentine is antigorite. The major chemical components are SiO_2 (42.49%), MgO (39.08%), Fe_2O_3 (3.85%), and H_2O (11.87%). Important trace elements include Cr (2188 ppm), Ni (1110 ppm), and Co (58 ppm). An IR spectrum and DTA/TGA thermogram are discussed and black inclusions finely dispersed through the serpentine consist of magnetite.

Keywords: precious serpentine, Booyo, Korea, antigorite, serpentine

Introduction

A new gem-quality serpentine deposit was discovered in 1995 in the Booyo area, about 250 km south-west of Seoul, Korea *(Figure 1)*, and is being mined by the Booyo Nokok (meaning green jade) Mining Company. After the Booyo material has been fashioned as rings, beads, cabochons, pendants, earrings, etc. *(Figure 2)*, it is traded on the domestic market under the name 'Booyo precious serpentine'. The green-coloured Booyo precious serpentine has gained a high reputation in the country and is valued much more highly than the existing so-called 'Korea Jade' which is a greenish-yellow bowenite, reportedly produced from Haeju in North Korea *(Figure 1)*.

Occurrences

The geology of the precious serpentine deposit consists of Precambrian schist and granitic gneiss, Jurassic conglomerate

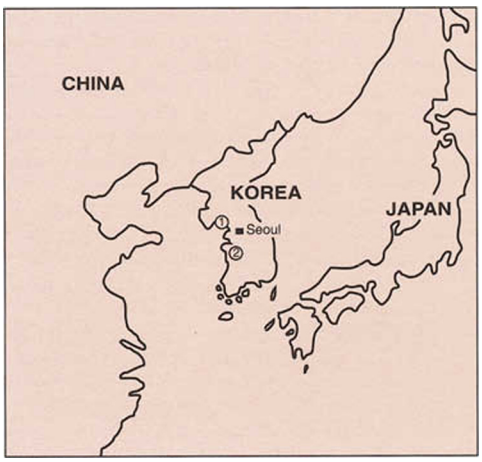

Figure 1: *Map of Korea showing two important gem-quality serpentine deposits, Haeju (1) and Booyo (2).*

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Figure 2: Precious serpentine from Booyo, Korea, fashioned as a ring, cabochon, pendant, button, and a string of beads with eye-visible black inclusions (magnetite). The semi-transparent nature of the serpentine is well demonstrated.

Figure 3: Geological map of the Booyo Nokok mine area, Korea.

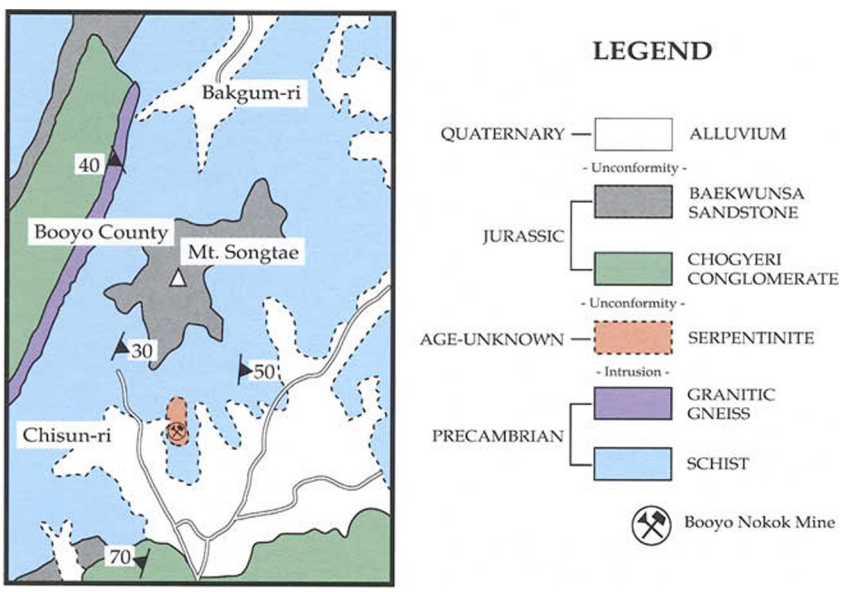

Figure 4: Non-precious serpentine extracted from the Booyo Nokok mine.

(Chogyeri Formation) and sandstone (Baekwunsa Formation), and serpentinite of unknown age *(Figure 3)*.

The precious serpentine lies in a body of serpentinite, a part of which is characterized by well-developed igneous layers that strike N18°W and dip 50°SW. Outcrop of the serpentinite at the surface is approximately 100 m long. A grossular garnet vein, 15 cm in average width at the surface and light brown in colour, has intruded the serpentinite, striking E–W and dipping 6°N. Precious serpentine has formed along both contacts and varies in thickness between 3 and 20 cm.

At present 2 adits are open at the mine. They are at 10 metres vertical interval and are about 80 m long, to follow the garnet vein. Extracted ore materials are dumped on the ground nearby *(Figure 4)*.

Gemmological properties

Colour, diaphaneity and lustre

The Booyo precious serpentine is deep green and colour distribution is quite uniform. The material is semi-transparent *(Figure 2)* and shows a resinous or waxy lustre. When heat-treated at 850°C for a few hours, its colour changes to orange-pink.

***Table I:** X-ray diffraction data of precious serpentine and antigorite.*

1		2					
d_o (Å)	I/I_0	d_o (Å)	I/I_0	h	k	l	
7.40	100	7.29	100	0	0	1	
		6.43	40		—		
		5.82	40	$\bar{6}$	1	0	
		5.15	40	3	1	1	
4.64	25	4.64	40	0	2	0	
		4.26	20	$\bar{4}$ 7	2 1	0 1	}
		3.99	5	9	0	1	
3.68	68	3.61	80	12	0	0	
2.757	69	2.794	20	11 3	2 3	1 1	}
		2.667	5	15 6	0 2	1 2	}
		2.596	20	12 7	0 3	2 1	}
2.530	49	2.525	100	16	0	1	
2.459	32	2.458	60	9	3	$\bar{1}$	
		2.429	20	17 2	0 0	$\bar{1}$ 3	}
		2.386	20	14	0	2	
		2.210	20	1 $\bar{1}$	4 4	1 1	}
2.113	32	2.172	60	8 9	3 0	$\bar{2}$ 1	}
		1.833	20	18 8	2 4	2 2	}
		1.812	20	15 1	1 5	3 1	}
		1.742	20	7 20	5 2	1 2	}
1.710	21	1.709	5	23 $\bar{9}$	2 5	1 1	}

1. Precious serpentine from Booyo Nokok mine
2. Antigorite, JCPDS 21-963.

Mineral composition and texture

X-ray powder diffraction analysis confirmed that the precious serpentine consists of antigorite *(Table I)*. Under the polarizing microscope, the precious

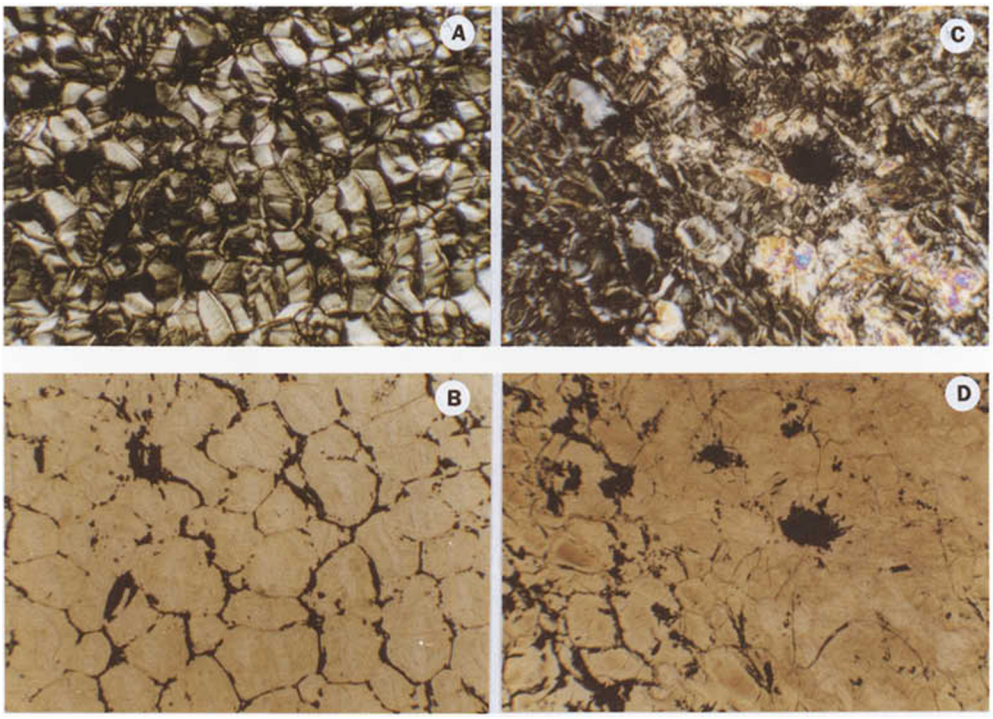

Figure 5: Photomicrographs showing textural variation between precious serpentine and ordinary serpentinite: a: Precious serpentine under crossed polars. Fibrous antigorite crystals are visible. 40 x. b: Precious serpentine under plane-polarized light. Original shapes of pre-existing minerals and interstitial magnetite grains are visible. 40 x. c: Serpentinite under crossed polars. Lath-shaped antigorite crystals occur with random orientation. 40 x. d: Serpentinite under plane-polarized light. Original shapes of pre-existing minerals are only just detectable.

serpentine can be seen to be composed of randomly oriented fibrous aggregates *(Figure 5a)*. The serpentine aggregates are bounded by rounded outlines that are clearly visible in plane-polarized light *(Figure 5b)*, indicating that the serpentine was formed by alteration of olivine and pyroxene. Olivine and pyroxene remnants are rare within the matrix of serpentine minerals. The fibrous nature of the serpentine changes significantly on passing to the opaque material of the main serpentinite in which blades, flakes and plates of antigorite crystals are predominant *(Figures 5c and 5d)*; the latter is similar to the 'interpenetrating texture' described by Wicks and Whittaker (1977). Therefore, it is believed that the diaphaneity of the serpentine aggregates is related to the development of the fibrous texture.

Refractive index

Owing to the aggregated nature of the microscopically small antigorite crystals, only a single reading of about 1.56 can be obtained on a standard gemmological refractometer. This value compares well with refractive indices for antigorite ($\alpha = 1.558 \sim 1.567$, $\beta = 1.566$, $\gamma = 1.562 \sim 1.574$). It is slightly higher than the RIs of the other two serpentine polymorphs, chrysotile (α 1.532 ~ 1.549, γ 1.545 ~ 1.556) and lizardite (α 1.538 ~ 1.554, γ 1.546 ~ 1.560).

Hardness and toughness

The hardness was measured at about 5 on Mohs' scale and, due to the felted nature of the crystal aggregates, it is very tough.

Table II: Chemical analyses of precious serpentine from Korea and serpentine minerals from other sources

Wt. %	1	2	3	4	5
SiO_2	42.49	43.1	43.60	38.04	39.45
Al_2O_3	1.30	1.3	1.03	0.86	1.07
Fe_2O_3	3.85	3.4	1.71	7.62	7.72
MgO	39.08	39.8	41.00	37.47	38.48
MnO	0.12		0.04	0.11	0.10
CaO	0.68		0.05	0.24	0.63
K_2O	0.06		0.03	0.01	0.02
Na_2O	n.d.		0.01	0.01	0.25
TiO_2	0.01		0.01	0.01	0.02
Cr_2O_3	*		0.02	n.d.	n.d.
NiO	*		0.16	n.d.	n.d.
P_2O_5	0.06		n.d.	0.01	0.11
LOI	11.87			n.d.	11.30
H_2O		11.97	12.26		
Total	99.52	99.57	99.92	84.38	99.15
ppb, in serpentine from Booyo Nokok mine, Korea					
Li	2717.50	Nb	12925.19	Tb	35.92
Be	321.10	Mo	2858.60	Dy	291.25
Sc	5409.16	Cd	n.d.	Ho	47.37
Cr	2188503.91	Te	2022.68	Er	135.69
Co	58426.31	Cs	1450.91	Tm	70.57
Ni	1110853.28	Ba	22816.11	Yb	254.40
Cu	5929.28	La	1941.50	Lu	n.d.
Zn	96669.14	Ce	4302.41	Hf	n.d.
Ga	2193.34	Pr	396.02	Ta	108501.11
Rb	19809.42	Nd	1242.18	Pb	4264.71
Sr	7097.00	Sm	450.36	Bi	675.74
Y	2897.50	Eu	26.83	Th	1894.58
Zr	8995.92	Gd	601.57	U	991.02

1. Precious serpentine (antigorite) from Booyo Nokok mine, Korea
2. Antigorite, JCPDS card 21–963
3. Antigorite, Venezuela (Hess *et al.*, 1952)
4. Lizardite from Ulsan serpentinite (Park and Lee, 1955)
5. Lizardite from Ulsan serpentinite (Choi *et al.*, 1990)

* see list of trace elements

n.d. not determined

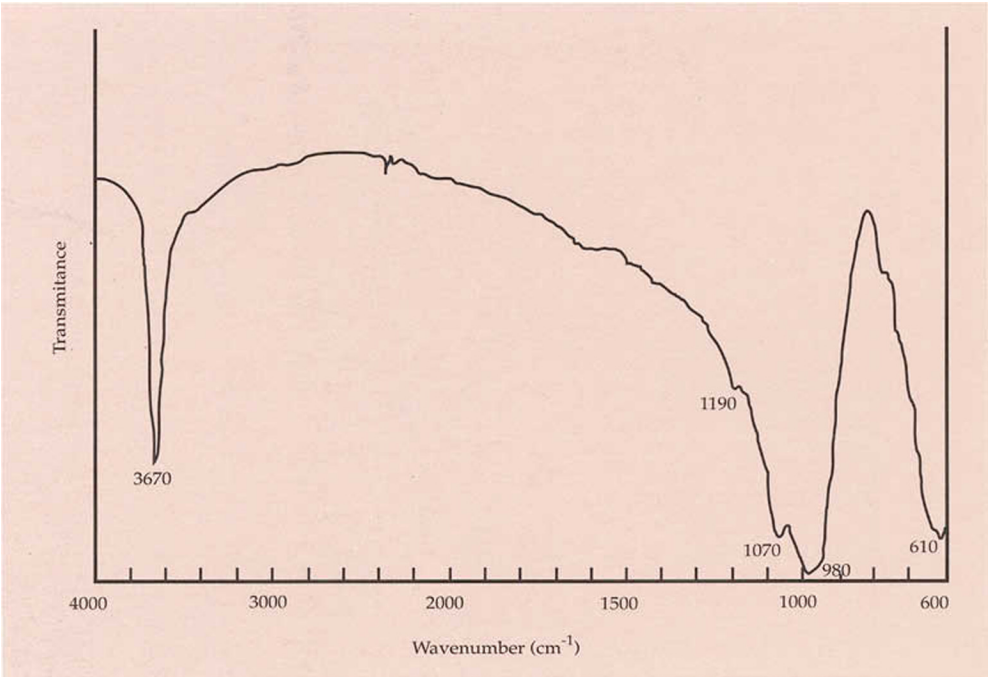

Figure 6: *Infrared absorption spectrum of the precious serpentine from Booyo, Korea.*

Specific gravity

The specific gravity of precious serpentine determined by the hydrostatic weighing technique ranges from 2.57 to 2.58. This value compares well with that of antigorite (2.58 ~ 2.59), but is higher than that of chrysotile (2.55) and lizardite (2.55 or lower) given by Deer *et al.* (1966). The specific gravity value of the Booyo precious serpentine, however, is considerably lower than the 2.617 reported for a bluish-green variety from South Island, New Zealand, by Webster (1994, p 370). The difference may be explained, in part, by different inclusions in the two materials but this needs further work.

Chemical composition

Chemical compositions of the precious serpentine were determined by X-ray fluorescence (XRF) and inductively coupled plasma mass spectrometry (ICP-MS) methods and are shown in *Table II.* Amounts of SiO_2 (42.49 wt. %) and MgO (39.08 wt. %) together with loss on ignition (LOI) (11.87 wt. %), probably water, compare well with the ideal chemical composition of serpentine, $Mg_3Si_2O_5(OH)_4$. The presence of other elements including Al and Fe is attributable to the elemental substitution of Al^{3+} for Si^{4+}, and Al^{3+}, Fe^{3+}, Fe^{2+}, and Ni for Mg^{2+} (Deer *et al.*, 1966). Amounts of SiO_2, MgO and Al_2O_3 of the Booyo material are surprisingly similar to those of antigorite from Griffin Range, New Zealand *(Table II, 2)*, and Caracas, Venezuela *(Table II, 3)*. The smaller amount of Fe in antigorite from Venezuela, when compared with that from Booyo and the Griffin Range, is consistent with a higher MgO content in the material. It is interesting to note that the amount of SiO_2 (38.04%, 39.45 wt. %) in lizardite from the Ulsan serpentinite, Korea *(Table II, 4–5)*, is significantly lower than antigorite from various sources. This deficiency may be compensated partly by its higher than normal Fe_2O_3 content.

The precious serpentine from Booyo is relatively rich in transition elements Cr (2188 ppm), Ni (1110 ppm) and Co

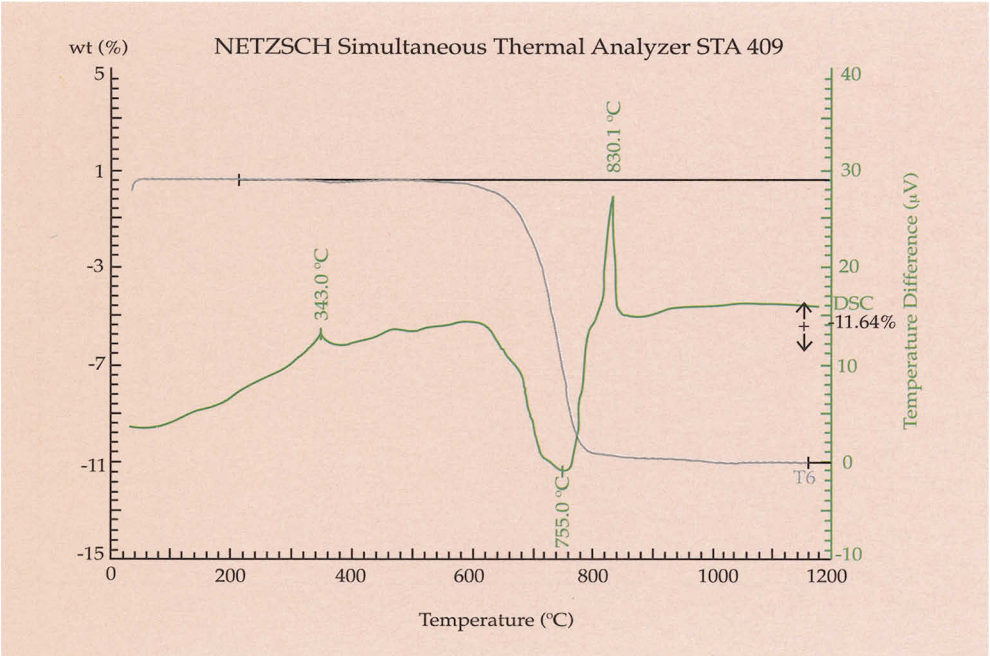

Figure 7: *Differential thermal analysis and thermogravimetric analysis (DTA/TGA) thermogram of the precious serpentine from Booyo, Korea*

(58 ppm) *(Table II)*. Such a large concentration of these elements suggests that the antigorite is an alteration product of ultramafic igneous rocks whose principal constituents were olivine and pyroxene.

Infrared spectrum

The infrared absorption spectrum *(Figure 6)* of the precious serpentine, recorded by a JASCO IRA-1 spectrophotometer, shows characteristic absorptions at 3670, 1190, 1070, 980, and 610 cm^{-1}. The strong peak at 3670 cm^{-1} is due to OH stretching, and those at 1190, 1070, and 980 cm^{-1} are due to SiO stretching. The 610 cm^{-1} band results from an OH bending vibration (Farmer, 1974); this is consistent with absorption between 600 and 660 cm^{-1} caused by hydroxyls in the serpentine minerals reported by Pampuch and Ptak (1970). The sharpness of OH absorptions at 3670 and 610 cm^{-1} may indicate that this precious serpentine (a trioctahedral 1:1 layered silicate) has a relatively ordered structure.

Fluorescence

The precious serpentine shows no luminescence under ultraviolet light.

Differential thermal analysis and thermogravimetric analysis (DTA/TGA)

Thermal analysis data recorded by a Netzsch simultaneous Thermal Analyser STA 409 *(Figure 7)*, show peaks at 343.0°C (exothermic), 755.0°C (endothermic), and 830.1°C (exothermic). The peak at 755.0°C (green line) corresponds to the decomposition of the mineral by expulsion of the structural water (Deer *et al.*, 1966). According to Smykatz-Kloss (1974) the decomposition temperature is influenced by the Fe-content in the structure, and can vary between 760 and 800°C for Fe-free serpentines and between 600 and 650°C for Fe-rich varieties. The strong exothermal peak at 830.1°C (green line) is related to the structural change of antigorite to olivine, which is supported by X-ray diffraction data of precious serpentines both before and after heat

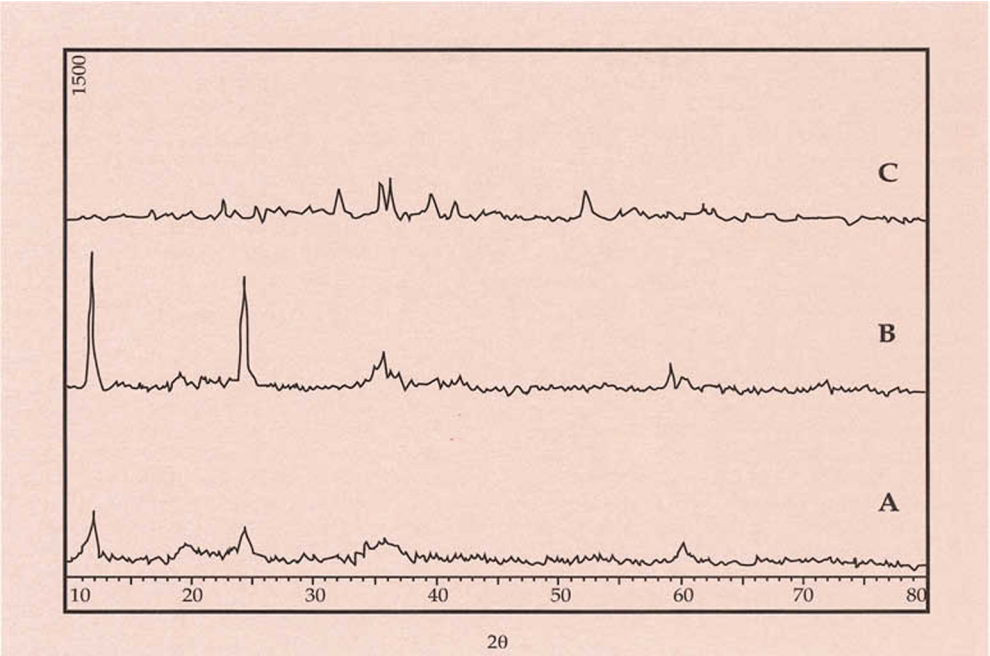

Figure 8: *X-ray diffraction data for the precious serpentine from Booyo, Korea. Antigorite structures of precious serpentine, A: untreated, B: after heat treatment at 600°C. C: Olivine structure is developed after heat treatment at 850°C.*

treatment at 850°C *(Figure 8)*. A total weight loss of water in association with this reaction is 11.64% (see red line and blue indicators in *Figure 7*); this corresponds very well with the chemical data (loss on ignition of 11.87 wt. %). The exothermic reaction at 343.0°C (green line) may possibly be caused by a polymorphic transformation of antigorite.

Inclusions

The precious serpentine from Booyo contains numerous fine black inclusions which are concentrated in the interstices of the former olivine or pyroxene grains *(Figure 5b)*. These opaque inclusions were identified as magnetite by X-ray diffraction using 114.6 mm Gandolfi X-ray camera. During the serpentinization process, much of the iron contained in the olivine and pyroxene may go to form magnetite because of the relatively low preference for iron in the serpentine structure (Wicks and Whittaker, 1977). Formation of magnetite can be represented by the following equation:

$$\underset{\text{olivine}}{(Fe,Mg)_2SiO_4} + \underset{\text{pyroxene}}{(Mg,Fe)SiO_3} + 2H_2O$$

$$\rightarrow \underset{\text{antigorite}}{(Mg_3Si_2O_5(OH)_4} + \underset{\text{magnetite}}{Fe_3O_4}$$

Conclusion

The Booyo precious serpentine is now being cut, polished and sold exclusively by the Nokokwon (meaning green jade garden) Company in Seoul.

Acknowledgements

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Distinction of taaffeite and musgravite

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ABSTRACT: Problems associated with the identification of taaffeite and musgravite are discussed. Due to an overlap of gemmological properties, time consuming mineralogical research techniques (quantitative chemical analysis, X-ray diffraction) are needed for a determination of both species. However, recently micro-Raman spectroscopy has been found to be useful as a quick non-destructive routine technique for identification of both species.

The structurally related Be-Mg-Al-oxides taaffeite, $BeMg_3Al_8O_{16}$, and musgravite, $BeMg_2Al_6O_{12}$, were originally regarded as polytypes of one single mineral. Chemical and structural examinations, however, proved the existence of two independent species with different chemical formulae, unit cell dimensions, space groups and crystal structures. In both minerals a certain amount of isomorphous replacement of Mg by Fe, Zn and Mn may be observed, thus leading to a more complex formula of $Be(Mg,Fe,Zn,Mn)_3Al_8O_{16}$ for taaffeite and to a formula of $Be(Mg,Fe,Zn)_2Al_6O_{12}$ for musgravite (Schmetzer, 1983, a,b; Nuber and Schmetzer, 1983).

For almost half a century since the discovery of the first taaffeite as a cut gemstone in 1945, faceted and rough taaffeites were known predominantly from Sri Lanka, a few rare samples were also mentioned from Myanmar (Kampf, 1991; Demartin *et al.*, 1993). In 1993, however, two faceted 'taaffeites' from Sri Lanka were identified as musgravites by means of X-ray single crystal diffraction (Demartin *et al.*, 1993) and, just recently, a third faceted musgravite was determined by X-ray powder diffraction (Johnson and Koivula, 1997). In this third stone, major amounts of zinc and iron were detected by qualitative EDXRF analysis.

Because the difference in BeO content between taaffeite and musgravite is only 1.56 wt. %, similar physical properties such as refractive indices and specific gravity are observed for both mineral species. In detail, a complete overlap has been found for the properties of the three faceted musgravites described so far (RI n_o 1.725–1.728, n_e 1.719–1.721, SG 3.62–3.69) and for high zinc- and iron-bearing faceted taaffeites from Sri Lanka (RI n_o 1.724–1.730, n_e 1.719–1.726, SG 3.61–3.71; Schmetzer and Bank, 1985; Ponahlo, 1993). Consequently, neither the determination of physical properties such as refractive indices and specific gravity in the range given above nor qualitative chemical analyses with the determination of zinc and iron in major amounts are useful in deciding whether taaffeite or musgravite is present.

Thus, an unequivocal distinction between taaffeite and musgravite has so far only been possible by quantitative chemical analysis or by X-ray diffraction (powder or single crystal techniques). These methods, however, are

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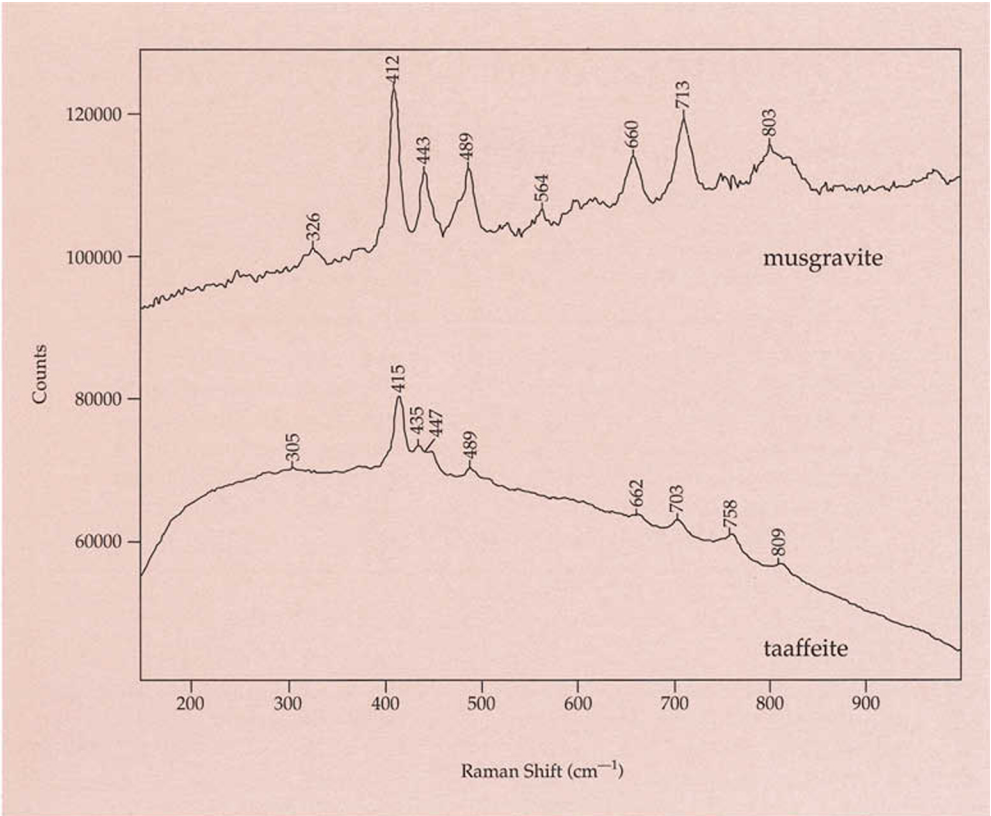

Figure 1: *Raman spectra of taaffeite, Sri Lanka, and musgravite, Antarctica.*

time-consuming research techniques and not routine methods in gemmology. In addition, for the preparation of an X-ray powder diffraction pattern, a small amount of substance has to be scraped from the girdle of a faceted stone, which is not always wanted or allowed by the owner of a sample to be identified.

With this background, the authors tested the applicability of micro-Raman spectroscopy for the distinction of musgravite and taaffeite. At the end of the '90s, an increasing number of Raman microscope facilities are available at the major gem-testing laboratories around the world and are used as routine instruments for various problems in gem testing (Hänni *et al.*, 1997). To evaluate possible determinations of taaffeite and musgravite by micro-Raman spectroscopy, six taaffeites (five faceted and one rough gem-quality) from Sri Lanka were examined. Small musgravite crystals were available from the Musgrave Ranges, Australia (type material) and from Casey Bay, Antarctica. For all samples quantitative chemical analyses were performed to identify them as taaffeites or musgravites and for most of them X-ray single crystal and/or powder diffraction data were also available. Raman spectra were recorded using a Renishaw Raman Microscope facility.

As a result, we observed a unique type of Raman spectrum for all taaffeites examined, as well as another Raman spectrum for the musgravites *(Figure 1)*. The six strongest Raman lines were recorded as 415, 435, 447, 703, 758 and 809 cm^{-1} for taaffeite and at 412, 443, 489, 660, 713 and 803 cm^{-1} for

musgravite; broad peaks for musgravite are schematically indicated by wavenumbers 564 and 803. It is notable that although there are small differences in peak intensities related to orientation of the specimen, the overall pattern of the spectrum (in terms of peak positions and peak shapes) of taaffeite is distinctly different from that of musgravite. Consequently, Raman spectroscopy is useful as a non-destructive routine technique for rapid distinction of taaffeite and musgravite.

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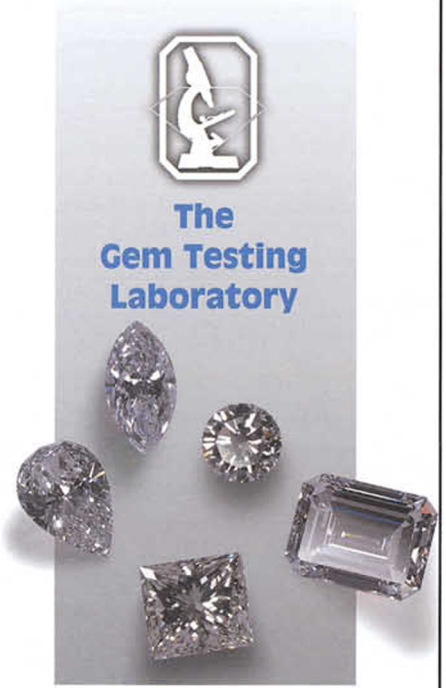

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Identification of polystyrene in impregnated jadeite

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ABSTRACT: Fourier transform infrared transmission and X-ray photoelectron spectroscopy have proven to be useful spectroscopic techniques used to detect the presence of wax and polymers in jadeites, thus enabling the discrimination between A and B jades. This paper reports the results of Fourier transform infrared transmission and X-ray photoelectron spectroscopic studies done on a sample of polymer-impregnated jadeite. The polymer used for the impregnation of this sample has been previously reported (e.g. Fritsch and McClure, 1993) to be present in impregnated jadeite. Using the above two spectroscopic techniques, this polymer has been identified as polystyrene.

Keywords: Fourier transform infrared spectroscopy, impregnation, jadeite, polymers, polystyrene, X-ray photoelectron spectroscopy

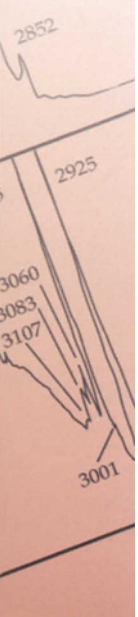

Introduction

Since at least 1989, the jade market in many parts of Asia has been infiltrated by many jade pieces which have been bleached then polymer-impregnated (Hurwit, 1989; Anon, 1991a and b). The gem is soaked in acid to take away the brown spots (iron oxides) present on the surface of the jadeite and these cracks and holes are then filled up with polymers. This ensures that the jadeite does not have visible flaws on its surface and enables it to fetch a higher price. It has been well established that the simple gemmological tests like measurement of refractive index, specific gravity and fluorescence under ultra-violet light cannot reliably detect impregnation (Fritsch *et al.*, 1992; Tan *et al.*, 1995; Quek and Tan, 1997). The impregnation is also not detectable under the optical microscope (Hurwit, 1989). Now, detection methods like Fourier transform infrared transmission spectroscopy (Fritsch and Stockton, 1987; Fritsch *et al.*, 1992), X-ray photoelectron spectroscopy (Tan *et al.*, 1995) and diffuse reflectance infrared Fourier transform spectroscopy (Quek and Tan, 1997), have been found useful in the detection of impregnated jadeite. Using a scanning electron microscope, evidence of damaged crystal structure was found in impregnated jadeites (Tay *et al.*, 1993) but this method cannot be used to determine the chemical composition of the substance of impregnation.

Though many detection methods have been used in jadeite testing, an exact identification of the polymers present in jadeite has not been carried out. The focus has been mainly on the identification and discrimination of A and B jade. In 1992, Fritsch *et al.* found that two polymers in impregnated jadeites had Fourier transform infrared transmission spectra very similar to an Opticon-like polymer and to a compound of the class of phthalates. In this study, we use similar methods to positively identify

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another polymer found in impregnated jadeites. Knowledge of the type of polymers used in jadeite impregnation is useful in many ways, and can be used in supplementing further gemmological studies on impregnated jadeites.

Methods and tests

A sample of jadeite which was shown earlier to be impregnated with polymer was used for this study. For the testing of the jadeite sample, a Bomem DA3.002 Fourier transform infrared transmission spectrophotometer (Tan *et al.*, 1995) was used. The resolution of the spectrophotometer used was 2 cm^{-1}. Spectra were taken of the jadeite sample only from 2000 to 5000 cm^{-1} as the infrared light used cannot pass through the sample beyond these frequencies.

The sample was further tested using a VG ESCALAB MkII X-ray photoelectron spectrometer using an MgK X-ray source (1253.6 eV photons) at a reduced power of 120 W (12 kV and 10 mA) (Tan *et al.*, 1995).

Results and discussion

As commonly known, infrared light is absorbed by different functional groups in organic compounds and, thus, each compound has a characteristic infrared spectrum. Comparison of infrared spectra can thus unambiguously identify a particular compound.

Figure 1a shows the Fourier transform infrared transmission spectrum of a piece of Grade A jade which has been only wax-buffed, something that is done very often by jewellers to improve the shine of the jade (Ehrman, 1958; Crowningshield, 1972). This does not affect the quality of the jade. Note that relative to the characteristic absorption of jadeite between 3800–3200 cm^{-1}, the peaks from the wax at 2920 cm^{-1} and 2852 cm^{-1} are much weaker, showing that the concentration of the wax is quite low.

Figure 1b, in comparison, shows the spectrum of the piece of bleached and polymer-impregnated jadeite examined in the present study. New absorption peaks are shown in comparison with *Figure 1a* at 4045 cm^{-1}, 3107 cm^{-1}, 3083 cm^{-1}, 3060 cm^{-1}, 3025 cm^{-1}, 3001 cm^{-1}, 2925 cm^{-1} and 2852 cm^{-1}. Fritsch and McClure (1993) also obtained a Fourier transform infrared transmission spectrum with identical peaks compared to *Figure 1b*, and both spectra match polystyrene's Fourier transform infrared transmission spectrum above 2000 cm^{-1} shown in *Figure 1c*.

Polystyrene is made of two main parts: an aliphatic component (CH_2) and an aromatic component (C_6H_5). The aromatic component comes from a single benzene ring occurring in every monomer unit. The monomer of polystyrene is styrene, named systematically as phenylethene. A clearer chemical formula is $[-CH_2{=}CH(C_6H_5)-]_n$, which indicates quite clearly the arrangement of atoms in polystyrene.

The two peaks at 2852 cm^{-1} and 2925 cm^{-1} correspond to the symmetric and asymmetric C–H stretches of the CH_2 group in polystyrene respectively. These strong peaks are superimposed on the wax absorption peaks if there is any wax present. The CH_2 is the aliphatic group in the polymer, and the two peaks correspond to the normal 2960–2850 cm^{-1} absorption frequency of aliphatic C–H bonds. Aromatic C–H bonds, however, reveal an absorption in a region of slightly higher wavenumber, between 3100 cm^{-1} and 3000 cm^{-1} and the absorption peaks at 3107 cm^{-1}, 3083 cm^{-1}, 3060 cm^{-1}, 3025 cm^{-1} and 3001 cm^{-1} in the polystyrene spectrum are attributed to this cause.

For further confirmation of the identity of the polymer, the X-ray photoelectron spectrum of the jadeite sample was collected at low and high resolutions. Many of the functional groups in organic compounds shift the value of the primary C 1s chemical shift from its standard position at 285.00 eV. This shift can be accurately measured and thus, the functional groups in the compound can be determined. In our study, the range of binding energies between 280 eV to 295 eV was scanned to show the C 1s chemical shift in the jadeite sample. This was also compared against standard spectra to confirm the identification of the polymer. It

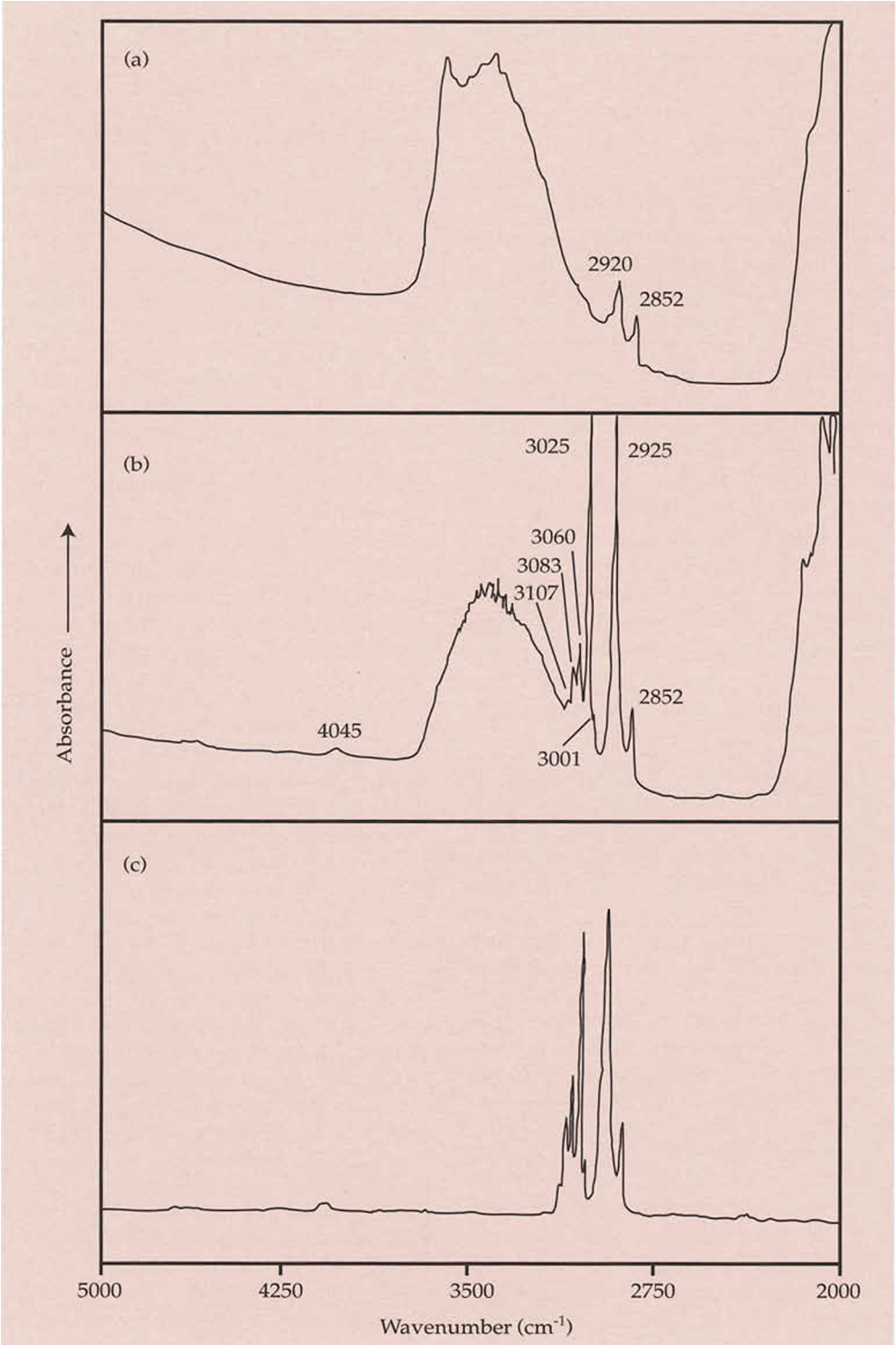
(a)
2920
2852
(b)
3025
2925
3060
3083
3107
2852
4045
3001
(c)
Absorbance
5000
4250
3500
2750
2000
Wavenumber (cm-1)

was found that the ratio of the C 1s peak to the Na 1s peak in the low-resolution spectrum is more than 40, a positive identification for polymer impregnation in jadeite reported in Tan *et al.* (1995).

Figure 2a shows the high-resolution X-ray photoelectron spectrum of the impregnated jadeite sample from 280 to 295 eV. There is an extremely intense peak at 285 eV composed of both aliphatic and aromatic carbons, which, because of their great similarity in eV values, are superimposed as one peak. The small peak at 287 eV corresponds to the C–O group. This peak is present because the jadeite samples were cleaned with highly volatile propanol (propyl alcohol) before spectra were collected, and some of the propanol is still present as an impurity. This peak is not seen in *Figure 2b*, which shows the high-resolution X-ray photoelectron spectrum of polystyrene. The peak due to the C–OH group in propanol is not seen on the infrared spectrum because the C–O group absorbs infrared light at wavenumber 1300–1000 cm^{-1} and the O–H bond absorbs infrared light at wavenumber 3550–3230 cm^{-1}. In these two regions jadeite absorbs infrared light very strongly, and thus, the C–OH peaks due to propanol are obscured.

However, the most distinguishing feature of the high-resolution X-ray photoelectron spectrum *(Figure 2a)* is the 'shake-up' feature between 292 and 295 eV. This is caused by the conjugation between the 2p orbitals of the carbon atoms in the phenyl group resulting in a π orbital being formed. The 'shake-up' is characteristic of aromatic and unsaturated systems, and this particular pattern of 'shake-up' is characteristic of polystyrene *(Figure 2b)* (Beamson and Briggs, 1992). This shows clearly that the polymer present on the jadeite surface is polystyrene.

Properties of polystyrene and polystyrene impregnated jadeite

The properties of polystyrene which make it suitable for jade impregnation are as follows: it is hard, cheap, readily available, has low moisture absorption, is easy to fabricate and has surface smoothness and clearness (Sprouse and Hansen, 1987). All these characteristics make it easy for impregnation to be carried out, yet make detection extremely difficult, especially when only small amounts of the polymer are used.

As mentioned before, polystyrene was reported as an unidentified polymer (Polymer 5) in Fritsch and McClure (1993). The jadeite samples at that time were reported to 'sweat' when tested with the Temperature Reaction Tester (TRT) and float in methylene iodide (specific gravity 3.32). This is consistent with the physical properties of polystyrene, which has a glass transition temperature of 100°C and is thus expected to cause the jadeite sample to 'sweat' easily. In addition, polystyrene's relative density of 1.047 would result in a significant decrease in the specific gravity of jadeite treated with polystyrene and cause it to float in methylene iodide.

Another important point to note is that polystyrene degrades under ultra-violet light and this could be the reason why some treated jadeites turn dark and have a greyish colour after some time, a feature reported by Fritsch *et al.* (1992).

Conclusion

In this paper, we have made use of two spectroscopic techniques to study a sample of bleached and impregnated jadeite and have identified the polymer used in the impregnation to be polystyrene; a substance that is cheap and commonly available, and yet has many characteristics which make it effective in jadeite impregnation. Further studies on the identification of polymers would be useful when looking for alternative methods of discrimination between Grade A and B jadeites.

Figure 1: *(a) Fourier transform infrared transmission spectrum of a sample of wax-buffed jadeite. (b) Fourier transform infrared transmission spectrum of the bleached and polymer-impregnated jadeite sample used for this study. (c) Fourier transform infrared transmission spectrum of polystyrene*

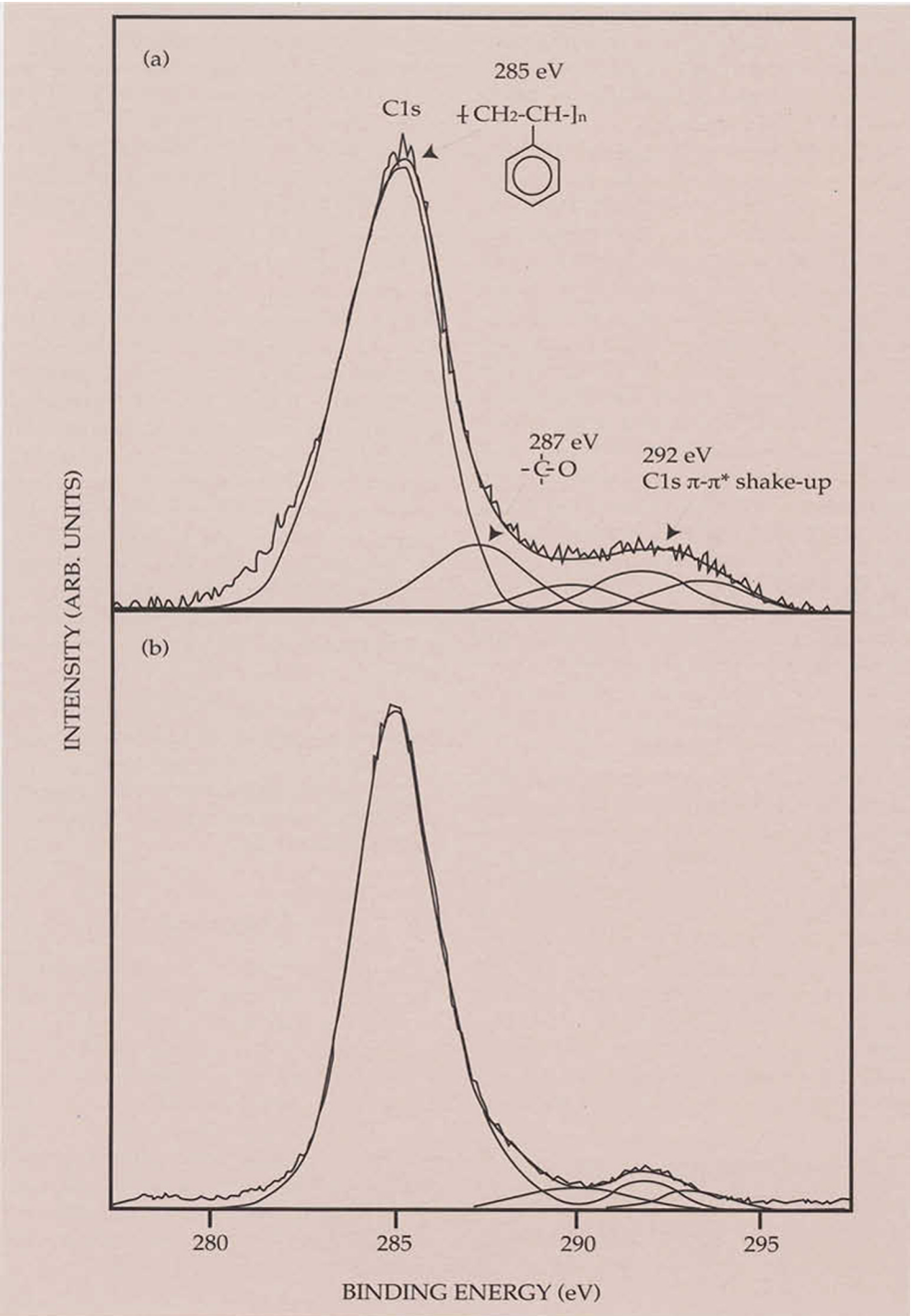

Figure 2: *(a) High-resolution X-ray photoelectron spectrum of the bleached and polymer-impregnated jadeite sample (from 280 to 295 eV). (b) High-resolution X-ray photoelectron spectrum of polystyrene.*

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Emeralds from Sandawana, Zimbabwe: the use of Raman microspectroscopy in identification of their solid inclusions

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ABSTRACT: For the first time, Raman microspectroscopy has been used as a tool to identify mineral inclusions in emeralds from Sandawana, Zimbabwe. Spectra of emerald, actinolite, cummingtonite, albite, apatite, calcite, Mn-Fe-bearing dolomite and quartz are presented and discussed. Correct characterisation and identification of solid inclusions in Sandawana emeralds could not be carried out by Raman microspectroscopy alone, but is effective in conjunction with chemical analysis by electron microprobe. By these means, inclusions of chromium-rich ilmenorutile have been identified; this variety has not been known and described before.

Keywords: Raman microspectroscopy, Sandawana, solid inclusions, chromian ilmenorutile

Introduction

Zimbabwe's Sandawana mines have been an important producer of emeralds for 40 years. The emerald deposits are located 65 km south of the village Mberengwa (or 68 km east of West Nicholson), in the Mweza greenstone belt. The mining lease and claim holdings cover a 21-km-long strip along the southern slope of the Mweza Hills, on which three mines, named Zeus, Aeres and Orpheus, are currently producing. The name 'Sandawana' refers to the entire mining area, and the emeralds mined there.

The Archaean Mweza greenstone belt consists of a series of intensely deformed and moderately metamorphosed ultramafic-to-mafic volcanic rocks and metasediments. It also contains numerous relatively small pegmatite bodies that intruded mostly the southern limb of the belt, during a main deformation event in the area, around 2.6 billion years ago. Emeralds occur near the pegmatites at the contact with (ultra)mafic lavas; they are concentrated in pockets at sites where the pegmatite is tightly folded and/or the rocks are sheared.

Mining at the largest mine (the Zeus mine) is done underground, with the ore processed in a standard washing/screening trommel plant. Since the Sandawana mines came under new ownership in 1993, consistent production of emeralds has been established. In addition to the small sizes for which Sandawana is best known, more polished stones up to 1.50 ct have been produced.

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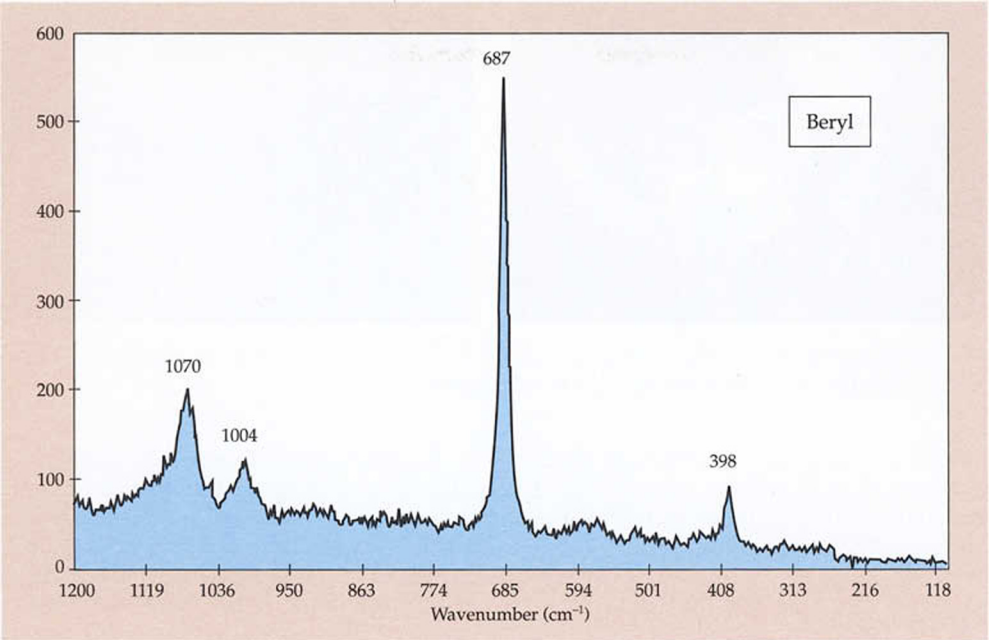

Figure 1: Raman spectrum of emerald with characteristic peaks at 1070 and 687 cm^{-1}.

Because of their relatively constant properties Sandawana emeralds can be readily separated from emeralds from other localities worldwide. They have high refractive indices and specific gravities, and chemically, they have very high chromium and sodium contents. Two amphiboles, actinolite and cummingtonite, are abundant inclusions; albite and apatite are common. Also found are remnants of fluid inclusions.

Soon after their discovery, characteristics of Sandawana emeralds were described by Gübelin (1958), while much later Böhmke (1982) described the paragenesis of the emerald and the geology of the Sandawana area. Anderson (1978) gave information on the occurrence and mineralogy of emeralds in Zimbabwe, with additional data on Sandawana emeralds. An update and overview of the geology, mining, physical properties and chemistry of emeralds from Sandawana, brief descriptions of the most common inclusions in them, and a comparison with properties of emeralds from other occurrences, are given in Zwaan *et al.* (1997). This paper gives more information on the solid inclusions (especially the rarer ones) and also aims to evaluate to what extent non-destructive identification of these inclusions could be carried out with the aid of a Raman microprobe.

Raman microspectroscopy in gemmology

The Raman technique and its instrumentation is thoroughly described in McMillan and Hofmeister (1988), McMillan (1989) and Williams *et al.* (1994). McMillan (1989) gives an overview of applications of Raman spectroscopy, which include applications in structural studies of silicate glasses and melts, study of dissolution mechanisms of volatiles (H_2O, CO_2, H_2) in aluminosilicate melts and glasses, study of the structure of aqueous fluids and liquids, study of geochemical fluids at high temperatures and high pressures, studies of phase-transitions in solids, and micro-Raman analysis of fluid inclusions which has been used successfully for qualitative *and*

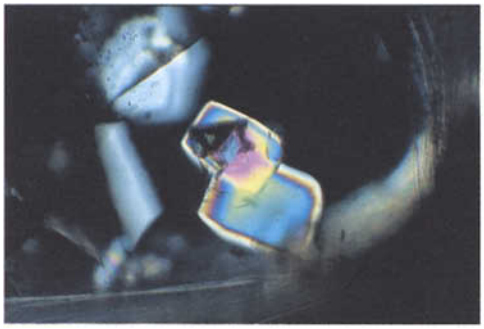

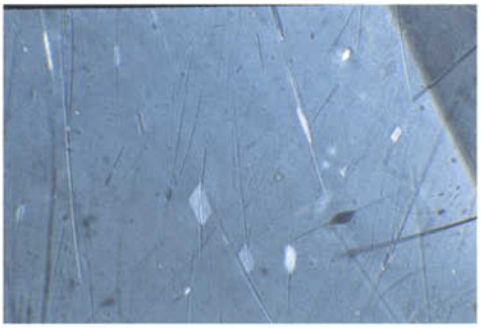

Figure 2a and b: *Emerald inclusions in emerald, in transmitted light between crossed polarising filters. Magnified 100x. Photomicrographs by J.C. Zwaan.*

quantitative analyses of molecular species, such as CO_2, CO, CH_4, N_2, H_2, O_2 and H_2S (e.g. Burke and Lustenhouwer, 1987; Van den Kerkhof, 1988; Burke, 1994).

Figure 3: *Actinolite (large long prismatic crystal) and cummingtonite (long prismatic crystal on the left, showing twinning) are common amphiboles in emeralds from Sandawana. Transmitted light, magnified 10x. Photomicrograph by J.C. Zwaan.*

Applications of Raman spectroscopy in identification of minerals and gems and solid inclusions in them are described by e.g. Dhamelincourt and Schubnel (1977), Delé-Dubois *et al.* (1980), Nassau (1981), Griffith (1987), Schubnel (1992), Pinet *et al.* (1992), Lasnier (1995) and Hänni *et al.* (1997). One of the earliest applications of Raman microspectroscopy to the identification of solid inclusions in emeralds was carried out by Rosasco and Roedder (1979). This paper presents another application, which shows advantages but also limitations of this technique.

Materials and methods

For this study, 68 emerald specimens were examined in detail, of which 36 were polished. Almost all the rough material was transparent and suitable for cutting. Inclusions were identified using a standard gemmological microscope (Super 60 Zoom Gemolite Mark VII), a polarisation microscope (Leica DMRP Research microscope) and a laser Raman microspectrometer (Dilor S.A. model Microdil-28®). Polished thin sections were prepared from 11 samples, and semi-quantitative and quantitative chemical analyses on the inclusions were carried out with EPMA (Electron Probe Micro Analysis, JEOL model JXA-8800M). Both Raman and EPMA analyses were performed at the Faculty of Earth Sciences, Vrije Universiteit Amsterdam.

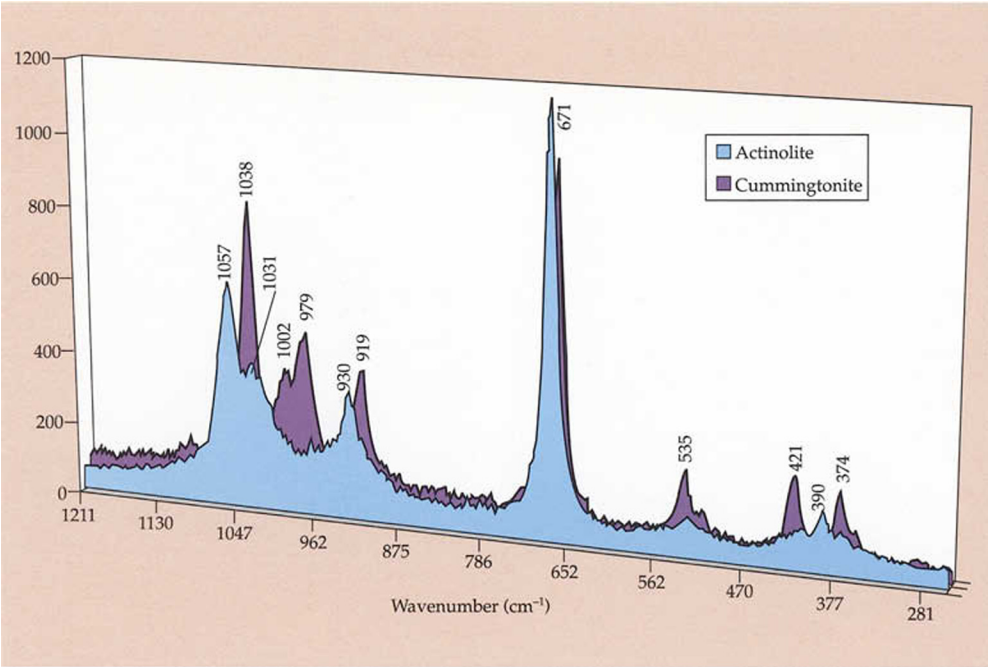

Figure 4a: *Raman spectra of actinolite and cummingtonite, both clinoamphiboles, which show a characteristic peak near 670 cm^{-1}.*

Results

Emerald

Emeralds from Sandawana show a Raman spectrum of beryl *(Figure 1)* with characteristic peaks at 1070 and 687 cm^{-1}. In addition to these peaks, Pinet *et al.* (1992) showed others at 1011, 526, 400 and 325. Our spectra showed only additional peaks near 1004 and 398 cm^{-1}. In some emeralds, emerald inclusions occur as crystals with a very low relief and a slightly different orientation, which can be viewed best between crossed polarising filters *(Figure 2)*. The inclusions and the host show the same Raman spectrum of beryl.

Amphiboles

The most common and well known inclusions in the emeralds from Sandawana are acicular amphibole crystals. In this study two amphiboles were identified, actinolite and cummingtonite *(Figure 3)*. Both minerals are equally abundant and occur as fibres as well as long-prismatic crystals.

Figure 4b: *Raman spectra of the OH stretching modes of actinolite and cummingtonite.*

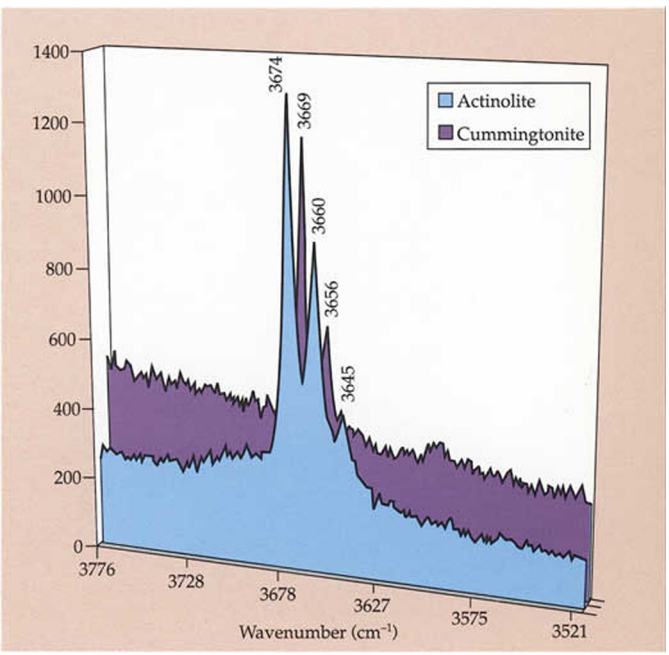

Table I. *Chemical analyses of the actinolite and cummingtonite crystals, of which Raman spectra are shown in Figure 4.*

Oxides (wt. %)	*Actinolite*		*Cumming-tonite*
SiO_2	54.1		56.4
TiO_2	0.05		–
Al_2O_3	2.91		0.45
Cr_2O_3	0.31		0.13
FeO	8.40		15.8
MnO	0.41		0.66
MgO	18.3		22.7
CaO	11.9		0.61
Na_2O	0.96		0.19
K_2O	0.06		-
H_2O*	2.01		2.11
F	0.13		-
Total	99.55		99.05
Cations based on 22 O and 2 (OH,F,Cl).	*Minimum Fe^{3+}*	*Maximum Fe^{3+}*	
Si	7.67	7.59	8.00
Al IV	0.33	0.41	0
T site	8.00	8.00	8.00
Al VI	0.16	0.08	0.07
Fe^{3+}	0	0.20	0
Ti	0.01	0.01	0
Cr	0.04	0.04	0.01
Mg	3.87	3.83	4.79
Fe^{2+}	0.94	0.79	0.12
M1, 2, 3 sites	5.00	5.00	5.00
Fe^{2+}	0.06	0	1.75
Mn	0.05	0	0.08
Ca	1.81	1.79	0.09
Na	0.08	0.21	0.05
M4 site	2.00	2.00	1.97
Na	0.19	0.06	0
K^+	0.01	0.01	0
A site	0.20	0.07	0
OH	1.90	1.90	2.00
F	0.10	0.10	0
Anion	2.00	2.00	2.00

- not detected
* calculated
All ferrous formulae for both amphiboles are permitted, for cation sums are not too high. Thus formula were calculated based on a minimum Fe^{3+} estimate = 0.000 (Compare Leake *et al.*, 1997). For an explanation of the actinolite formula based on a maximum Fe^{3+} estimate, see the text.

Table II. *Chemical analyses of two large albite ($NaAlSi_3O_8$) grains*. Albite is the only feldspar that has been identified in emeralds from Sandawana.*

Oxides (wt. %)	*ALB 1*	*ALB 2*
SiO_2	66.8	67.3
Al_2O_3	20.2	20.4
FeO	0.01	0.18
CaO	0.84	0.91
Na_2O	11.3	11.3
K_2O	0.04	0.03
Total	99.19	100.12
Cations based on 8 O.		
Si^{4+}	2.95	2.95
Al^{3+}	1.05	1.05
Fe^{2+}	0	0.01
Ca^{2+}	0.04	0.04
Na^+	0.97	0.96
K^+	0	0
Number of cations	5.01	5.01

*ALB 1 is feldspar I in *Figure 6*.

Cummingtonite may be distinguished from actinolite by its higher relief and lamellar twinning, which was seen under a microscope in transmitted and polarised light. However, both amphiboles are often intergrown and with a normal gemmological microscope it is in most cases not possible to

Figure 5a: *A large grain of feldspar (feldspar I in Figure 6) turned out to be albite. The lozenge-shaped crystal underneath it is identified as cummingtonite. Transmitted light, magnified 100x.*

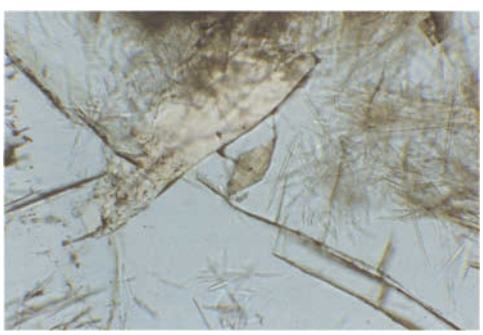

Figure 5b: Small idiomorphic albite crystals frequently occur in emeralds from Sandawana. The Raman spectrum of this crystal is shown in Figure 6 (feldspar II). Transmitted light, magnified 175x.

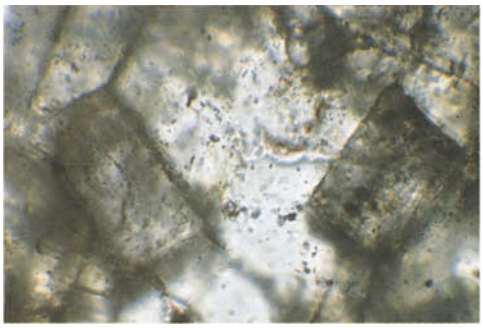

Figure 5c: Two slightly brownish to white crystals of albite, surrounded by minute inclusions, mostly also albite. The Raman spectrum of the crystal on the left is shown in Figure 6 (feldspar III). Transmitted light, magnified 175x. Photomicrographs by J.C. Zwaan.

make a distinction. Raman spectra of the two amphiboles are shown in *Figure 4a and b.*

Both actinolite and cummingtonite show a very strong peak at 671 cm^{-1}, which is characteristic for all clinoamphiboles (e.g. Pinet *et al.*, 1992). Various peaks are recorded near 1000 and 3650 cm^{-1}. The identities of actinolite and cummingtonite were confirmed by chemical analysis *(Table I).*

Feldspar

Feldspar is very common in emeralds from Sandawana and shows various morphologies. It may occur as large tabular fragments, as small idiomorphic to slightly rounded, colourless crystals or as whitish to slightly brownish crystals surrounded

Figure 6: Raman Spectra of feldspars with different morphology. The spectra show the same peaks, which all correspond to the spectrum of albite feldspar.

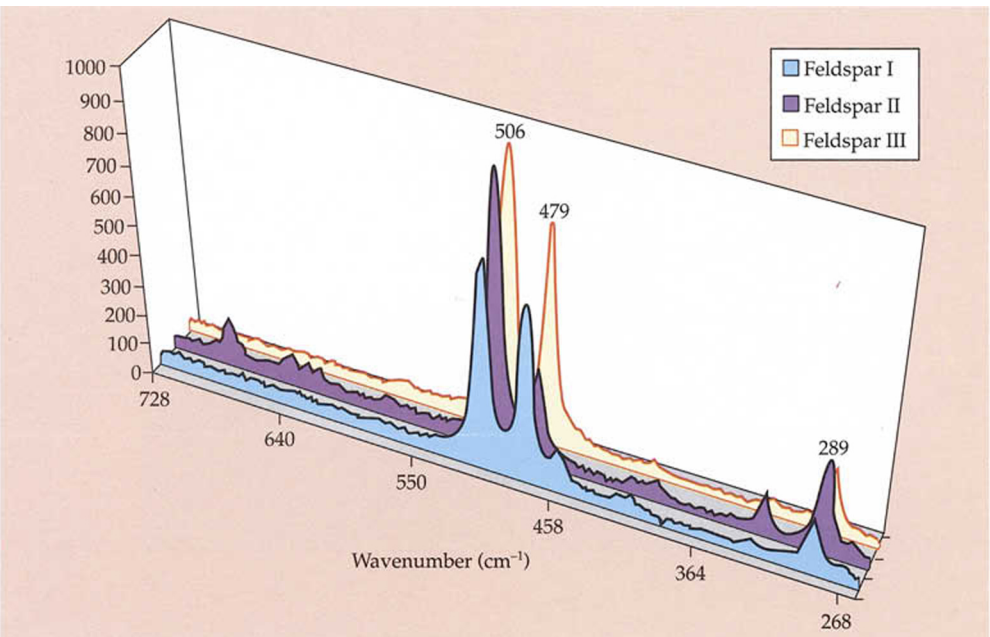

Figure 7: Idiomorphic apatite inclusion in Sandawana emerald; its Raman spectrum is shown in Figure 8. Transmitted and conoscopic light, magnified 175x. Photomicrograph J.C. Zwaan.

by minute inclusions *(Figure 5a, b and c)*. The Raman spectra of the three habits are shown in *Figure 6*.

The spectra of the feldspars with different habits are very similar. Although the intensity of the peaks may vary, due to different crystallographic orientations of the inclusions, they are all in the same positions. The most important peaks that were recorded are at 506, 479 and 289 cm^{-1}.

These similar spectra indicate that the various crystals represent just one particular kind of feldspar. Compared to the spectra of feldspars published by Pinet *et al.* (1992) and Hänni *et al.* (1997), our spectra corresponded mostly to the spectrum of albite, which was confirmed by chemical analyses as $Ab_{96}An_4$ *(Table II)*.

Figure 8: *Raman spectrum of apatite, with one diagnostic peak at 964 cm^{-1}, and an increasing background towards higher wavenumbers due to fluorescence.*

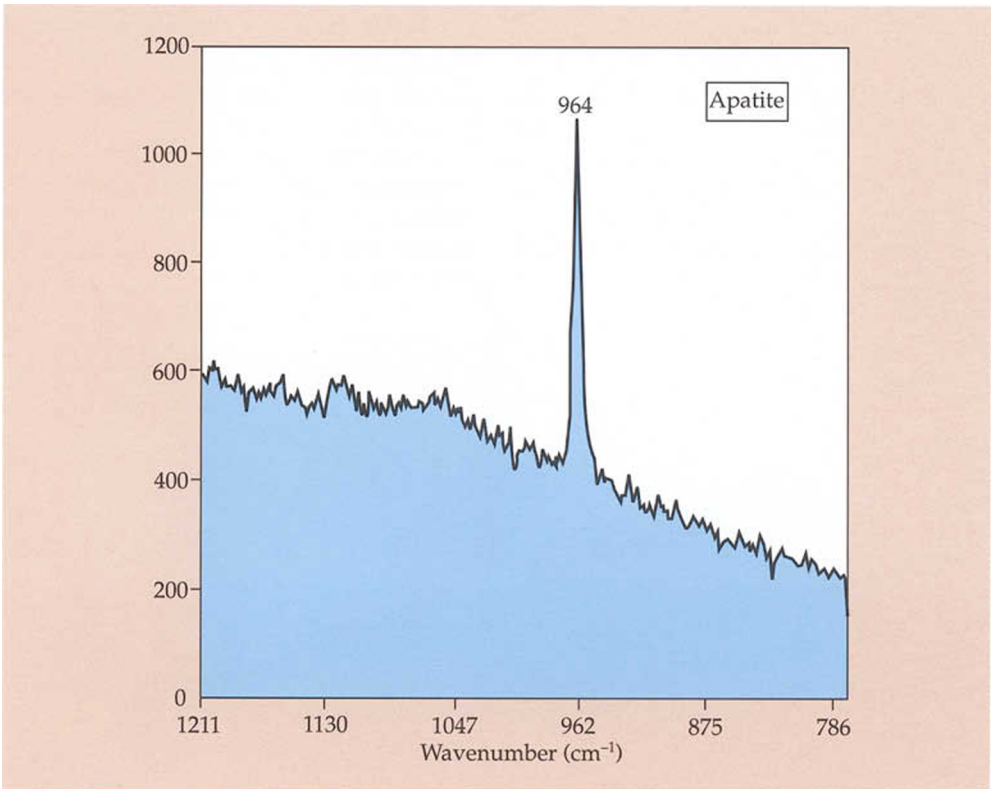

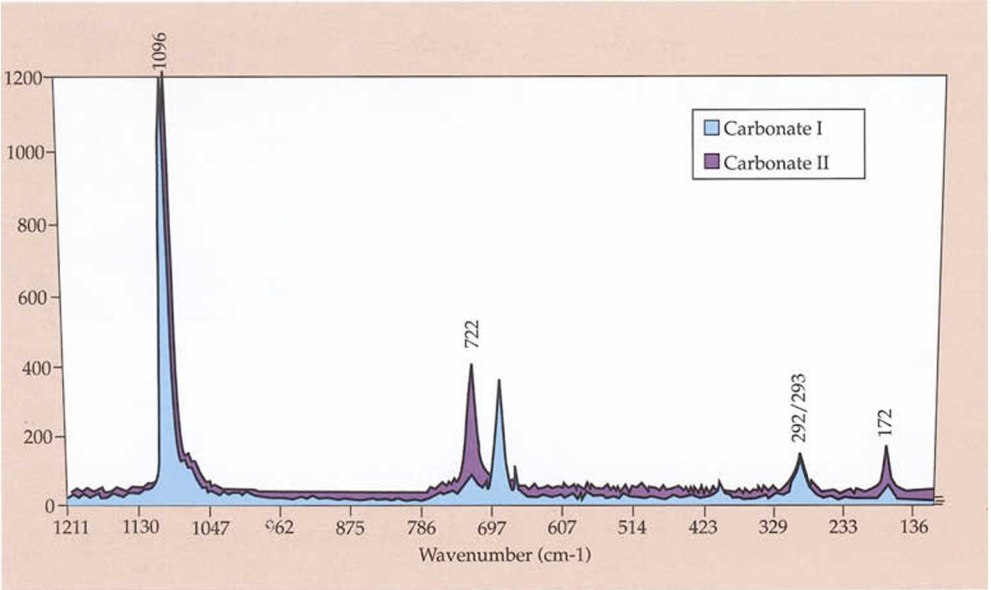

Figure 9: *Different grains of a common carbonate in Sandawana emeralds produced similar spectra. Chemical analysis of the carbonate shows it to be a dolomite. The peaks at 687 and 399 cm^{-1} are caused by emerald.*

Apatite

Like albite, apatite frequently occurs in emeralds from Sandawana, and also shows various morphologies. It occurs as transparent, often colourless idiomorphic crystals, either isolated or in clusters, and as rounded crystals with more irregular surfaces *(Figure 7)*. The apatite and albite crystals can appear very similar, although most apatite inclusions are very small. The Raman spectrum of apatite is characteristic with a peak at 964 cm^{-1} *(Figure 8)* and therefore provides a quick and reliable identification.

In fact, the Raman spectrum of apatite was so prominent (it caused abundant fluorescence), that it was not possible to analyse inclusions in apatite crystals, which occur in emerald-bearing amphibole schist at Sandawana.

Table III. *Published and previous recorded Raman spectra of carbonates*

Mineral	*Recorded peaks (cm^{-1})*				*Reference*
Dolomite	1097	725	299	176	a
	1099		300	175	b
Magnesite	1094	738	329		a
Ankerite	1091	720	284		c
Calcite	1085	711	283	156	a
	1086	712	280	153	b
Aragonite	1089	710	209	152	a
	1085	702	206	151	b

a) Burke, 1994.
b) Pinet *et al.*, 1992
c) reference sample Free University, Amsterdam (W. Lustenhouwer)

Table IV. Spot analyses of Carbonate I, a manganese-iron bearing dolomite.

Oxides (wt. %)	*1*	*2*
CaO	27.9	28.3
SrO	0.04	0.03
FeO	8.56	7.50
MnO	3.66	3.01
MgO	12.9	14.2
CO_2*	46.9	47.0
Total	99.96	100.04
Cations based on 6 O.		
Ca^{2+}	0.96	0.96
Sr^{2+}	0.00	0.00
Fe^{2+}	0.23	0.20
Mn^{2+}	0.10	0.08
Mg^{2+}	0.62	0.67
C^{6+}*	2.05	2.04
Number of cations	3.96	3.95

* C was not measured: CO_2 has been calculated at 100%.

Figure 10: *Mn–Fe dolomite is a common carbonate in emeralds from Sandawana, normally as very small and irregular grains, but also as larger elongated grains such as shown here. Between crossed polarising filters this grain shows high order interference colours characteristic for a carbonate. Magnified 100x. The Raman spectrum of this particular grain is shown in Figure 9 (carbonate I). Photomicrograph by J.C. Zwaan.*

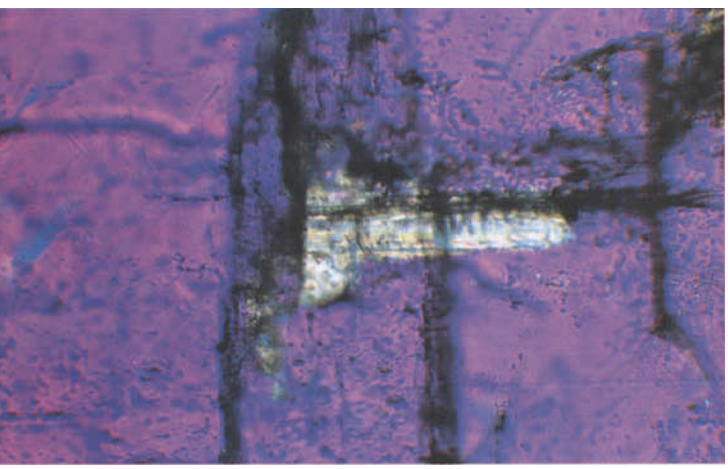

Figure 11: *Elongated and parallel quartz crystals occur in some emeralds from Sandawana. Magnified 100x, photomicrograph by J.C. Zwaan.*

Carbonates

Two carbonate minerals were identified: calcite and another carbonate which showed ambiguous Raman spectra. Calcite is present in very small grains, which showed characteristic Raman peaks at 1086 and 282 cm^{-1}. The spectra of two other carbonate grains, which show peaks at equal positions, are presented in *Figure 9*. Both carbonates show peaks at 1096, 722, 292–293, and 172 cm^{-1}.

Comparing these spectra with the published values *(Table III)*, they lie between the spectra of dolomite-$CaMg(CO_3)_2$ and ankerite-$CaFe(CO_3)_2$. Chemical analysis proved that the carbonates are Mn–Fe bearing dolomites *(Table IV)*.

Dolomites with similar chemical composition were regularly encountered in Sandawana emeralds, not only as small grains, like calcite, but also as larger, elongated grains *(Figure 10)*. Three dolomites which were chemically analysed contained on average 12.6 wt% MgO, 7.70 wt% FeO, and 3.35 wt% MnO.

Quartz

Quartz occurs in emeralds from Sandawana as small isolated and rounded grains, and as elongated and tube-like crystals with low relief, which are orientated parallel to the *c*-axis *(Figure 11)*. Because these grains are small and most are not close to the surface, it was not easy to get reliable Raman spectra; however, diagnostic peaks at 466 and 207 cm^{-1} were obtained from several grains.

Ilmenorutile

Opaque minerals are rare in Sandawana emeralds but black crystals with submetallic lustre up to 0.7 mm were present in one polished stone *(Figure 12)*. Reliable Raman spectra of these crystals cannot be obtained. Although Raman analysis is in principle non-destructive, the risk of instant oxidation is considerable when one tries to analyse opaque inclusions.

Chemical analysis proved these crystals to be a chromium-iron-niobium-tantalum-titanium oxide (ilmenorutile). From *Table V* (spot analyses 1–5) and *Figure 13* it can be seen that this grain shows a rather homogeneous composition with a very high chromium content. The whitish area at the upper side of the grain shows even higher Cr, but also higher Nb, Ta, Fe and lower Ti (analysis 6). Based on analyses 1–5 the average chemical formula could be written as:

$$(Ti_{0.805}Sn_{0.002}Nb_{0.062}Ta_{0.034}Cr_{0.081}Fe_{0.022})_{1.006}O_{2.00}.$$

For the whitish area in *Figure 13* the formula would be:

$$(Ti_{0.745}Sn_{0.002}Nb_{0.078}Ta_{0.051}Cr_{0.092}Fe_{0.040})\ S_{1.008}O_{2.00}.$$

The average atomic ratio Nb/Ta is 1.82 (whitish area: Nb/Ta = 1.53). Because the atomic ratio Nb/Ta > 1, this mineral may be called niobian rutile (preferred by Flinter, 1959 and Cerny *et al.*, 1964) or ilmenorutile (Siivola, 1970), a name which has been used since its discovery in 1854 (if Nb/Ta < 1 the name would be tantalian rutile or strüverite). Other phases that were identified in the analysed grain *(Figure 13)* are ilmenite and chromite; one grain of probable

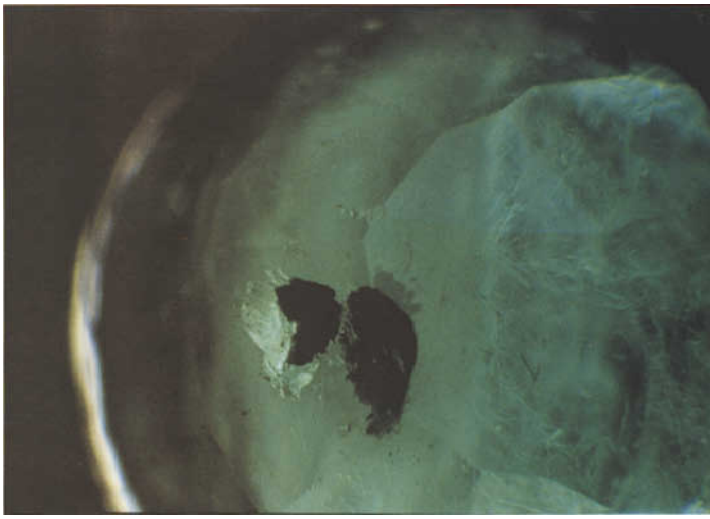

Figure 12: *Extremely rare crystals of Cr-ilmenorutile were found in a polished Sandawana emerald. Magnified 60x. Photomicrograph by J.C. Zwaan.*

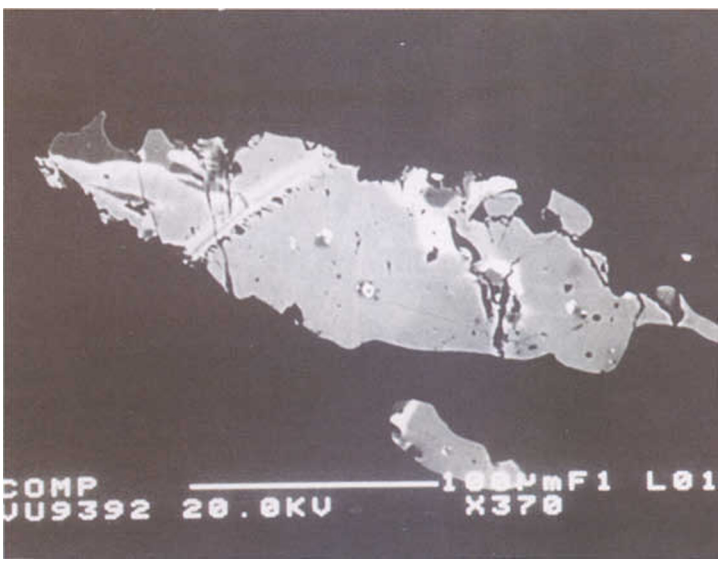

Figure 13: *Electron photomicrograph of a chromium rich ilmenorutile grain in Sandawana emerald. The whitish area at the upper side of the grain indicates a lower Ti concentration (and higher Cr, Nb, Ta and Fe concentrations). Other phases include ilmenite (the very dark grey part on the upper left side), chromite (the dark grey part next to it) and tantalite/columbite (the small white speck in the middle of the grain). Photomicrograph by W.J. Lustenhouwer.*

Table V. Spot chemical analyses of a chromium-rich ilmenorutile inclusion in emerald from Sandawana.

Oxides (wt.%)	*1*	*2*	*3*	*4*	*5*	*6*
TiO_2	72.1	71.7	70.3	70.1	70.7	63.7
SiO_2	0.07	0.07	0.07	0.08	0.07	0.09
SnO_2	0.38	0.42	0.45	0.45	0.32	0.34
Nb_2O_5	8.81	8.93	9.25	9.39	9.32	11.1
Ta_2O_5	8.23	7.79	8.41	8.15	8.67	12.1
Al_2O_3	0.05	0.04	0.05	0.05	0.05	0.06
Cr_2O_3	6.64	6.85	7.03	6.83	6.62	7.45
FeO	1.80	1.53	1.66	1.75	2.05	3.07
MnO	–	–	–	–	–	–
MgO	–	–	–	–	–	–
CaO	0.02	0.03	0.03	0.03	0.02	0.01
Total*	98.10	97.36	97.25	96.83	97.83	97.92
Cations based on 2 O						
Ti^{4+}	0.810	0.810	0.800	0.800	0.801	0.745
Si^{4+}	0.001	0.001	0.001	0.001	0.001	0.002
Sn^{4+}	0.002	0.003	0.003	0.003	0.002	0.002
Nb^{5+}	0.060	0.061	0.063	0.064	0.063	0.078
Ta^{5+}	0.033	0.032	0.035	0.034	0.036	0.051
Al^{3+}	0.001	0.001	0.001	0.001	0.001	0.001
Cr^{3+}	0.078	0.081	0.084	0.082	0.079	0.092
Fe^{2+}	0.023	0.019	0.021	0.022	0.026	0.040
Ca^{2+}	–	–	0.001	0.001	–	–
Number of cations	1.008	1.008	1.009	1.008	1.009	1.011

– not detected
* low totals are due to conductivity which was not optimal

tantalite/columbite is too small for microprobe analysis.

Discussion

The acicular amphibole crystals in the emeralds from Sandawana were previously described by various authors (e.g. Gübelin, 1958; Böhmke, 1982; Gübelin and Koivula, 1992) as tremolite needles or fibres. From results in our study, it became apparent that the amphiboles present are actinolite and cummingtonite but not tremolite.

The particular actinolite of which the Raman spectrum is shown, is magnesium-rich; the analysis *(Table I)* shows a $Mg/Mg + Fe^{2+}$ ratio = 0.79, which is slightly higher than the maximum ratio of 0.74, which was previously indicated (Zwaan *et al.*, 1997). The indicated ratio is based on a minimum ferric estimation. In order to define the range of possible formulae and possible names for this particular amphibole (as recommended by Leake *et al.*, 1997), the formula for the maximum ferric estimate has also been calculated *(Table I)*. From this

calculation the $Mg/Mg + Fe^{2+}$ ratio = 0.83, which is still consistent with naming the amphibole actinolite.

Unfortunately, very few Raman spectroscopic investigations of amphiboles have been reported (e.g. Wang *et al.*, 1988) and it should be noted that many amphiboles show strong fluorescence, which generally masks their Raman spectra. It is therefore difficult to obtain good Raman spectra and to interpret them correctly.

In *Figure 4a* the strong peak at 671 cm^{-1} is caused by the Si–O–Si bonds, but the peaks near 1000 cm^{-1} are difficult to interpret (Pinet *et al.*, 1992). The peaks near 3650 cm^{-1} *(Figure 4b)* are caused by the OH stretching vibrations. These spectra are used to study the cation distribution in amphiboles (Wang *et al.*, 1988). In this region, the recorded peaks of actinolite (3674, 3660 and 3645 cm^{-1}) and cummingtonite (3669 and 3653 cm^{-1}) closely correspond to the positions of the peaks, published by Wang *et al.* (1988). Some other peaks published by them were not recorded in this study, probably due to the variability of peak intensity with crystal orientation. Because the resolution of these spectra is not high enough, it is at present not possible (even with the use of the most sophisticated Raman spectrometers) to positively identify a particular clinoamphibole solely on the basis of positions of the peaks caused by OH (see also Wang *et al.*, 1988). Therefore chemical analysis on the surface of a sample is still needed to confirm the identity of a particular amphibole.

Considering the spectra of nearly pure albite, peaks were recorded at 506, 479 and 289 cm^{-1}. According to Pinet *et al.* (1992), albite should show peaks at 510, 482 and 294 cm^{-1}, while Hänni *et al.* (1997) reported peaks at 505, 477 and 288 cm^{-1} in this region.

Apatite shows a characteristic Raman spectrum, but may produce such fluorescence that identification of its inclusions by Raman spectrometry is not possible. Both apatite and albite have not been reported as inclusions in Sandawana emerald by previous authors, although Gübelin (1958) and Anderson (1978) mentioned the presence of 'decomposed feldspar' and Böhmke (1982) mentioned the presence of plagioclase feldspar and apatite in the ore-zone.

Mn–Fe bearing dolomite has not been reported before in Sandawana emerald. Raman spectra of this particular dolomite (peaks at 1096, 722, 292–293, and 172 cm^{-1}) are distinctly different from the previously published spectra of (normal?) dolomites (see *Table III*). These spectra may be difficult to distinguish from spectra of ankerite, another member of the dolomite group. A solid solution series exists between dolomite-$CaMg(CO_3)_2$, ankerite-$CaFe(CO_3)_2$ and kutnohorite-$CaMn(CO_3)_2$. Naturally occurring dolomite deviates somewhat from Ca:Mg = 1:1 with the Ca:Mg ratio ranging from 58:42 to 47.5:52.5 (Klein and Hurlbut, 1993). The Ca:Mg ratio of carbonate I *(Table IV)* varies between 60:40 and 59:41; which is very close to the ratios of dolomite. The slightly lower magnesium content is compensated by the presence of iron (ankerite component) and manganese (kutnohorite component). The chemical formula of the analysed Mn–Fe bearing dolomite in *Table IV* can be written as $Ca_{0.96}(Mg_{0.645}Fe_{0.215}Mn_{0.09})(C_{1.023}O_3)_2$.

The presence of ilmenorutile as a rare inclusion in Sandawana emerald was mentioned earlier by Böhmke (1982). While Mn-rich ilmenorutile is known from Uzumine, Japan (Kawai, 1960), a chromium-rich variety of ilmenorutile, such as encountered in our study, has not been reported before (see e.g. Cerny *et al.*, 1964; Siivola, 1970). Chromium is not present in ilmenorutile from other localities. Only in ilmenorutile from the type locality in the Ilmen mountains, Urals, Russia, chromium is possibly present in concentrations of <0.009% (Cerny *et al.*, 1964). While intergrowths of ilmenorutile with ilmenite and columbite are quite common (e.g. Sosedko, 1939; Ando and Nitta, 1941; Noll, 1949; Cerny *et al.*, 1964; Siivola, 1970), the association of ilmenorutile and chromite in Sandawana emerald is the first of its kind.

From this study it appears that in order to identify solid inclusions in gem material correctly, it is still generally necessary to get a (semi-)quantitative chemical analysis of the

inclusions, as support for the initial identification from Raman spectra, or simply as an alternative (e.g. in the case of phlogopite, which was identified in Sandawana emerald by optical microscopy and chemical analysis). In this context the restrictions of the Raman method, as mentioned by e.g. Van den Kerkhof (1988), are still valid: spectra of solids are not easy to interpret, Raman peak intensities are strongly dependent on the crystallographic orientation due to different polarisations of the light in different directions, which means that these intensities cannot be quantified; no direct quantitative information on the composition of the mineral can be obtained, some minerals are strongly fluorescent and some are not or are only weakly Raman active. Consequently, not only a huge database is needed, as indicated by Hänni *et al.* (1997), but also more theoretical understanding of the interaction of light and crystalline material (crystal lattice) is required to make the most of applying Raman microspectroscopy in identification of minerals.

Conclusion

Raman spectroscopy is a useful non-destructive technique to identify not only fluid but also solid inclusions in gemstones. An important advantage of this technique is that it enables us to not only identify inclusions at the surface but also underneath it. However, it also has its limitations. In this study, it appeared that amphiboles and carbonates are difficult to identify correctly, and that opaque minerals may be burnt, which means that in some cases the method might turn out to be destructive. Apatite may produce a fair amount of fluorescence, such that inclusions in it cannot be identified. It became apparent that Raman spectra of dolomites which contain some iron and manganese are distinctly different from the previously published spectra of dolomites. These spectra may be difficult to distinguish from spectra of ankerite, another member of the dolomite group.

Rare large opaque inclusions at the surface of a polished emerald could not be analysed by Raman but were identified with electron microprobe as chromian-ilmenorutile. This variety has never been reported before, and can thus be considered as extremely rare.

It is concluded that in order to identify solid inclusions in gem material correctly, in many cases it is still necessary to get a (semi-) quantitative chemical analysis of the inclusion, as a backup for the obtained Raman spectrum, or just as an alternative. In order to make the most of applying Raman Microspectroscopy in identification of minerals it is necessary to gain more theoretical understanding of the interaction of light and crystalline materials, and to build a reliable database.

Acknowledgements

We thank Willem J. Lustenhouwer for helping with the microprobe analyses. Facilities for Raman spectroscopy and electron microprobe analyses were provided by the Free University of Amsterdam and by NWO, the Netherlands Organisation for Scientific Research. Most of the gem material was kindly provided by Sandawana Mines (Pvt.) Ltd., Zimbabwe. Mr A.G. Bode, of Bodes & Bode, the Netherlands, and Dr J. Kanis, Germany, are thanked for loaning some of the polished material.

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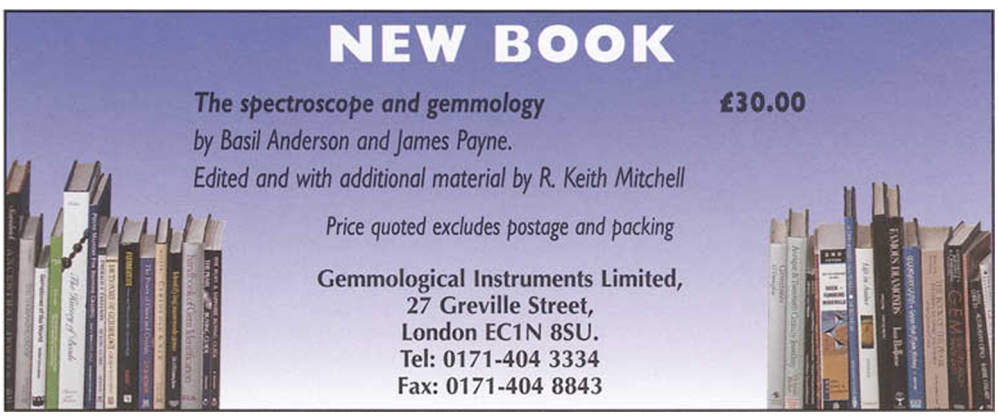

Abstracts

Diamonds | Instruments and Techniques | Gems and Minerals | Synthetics and Simulants

Diamonds

Pacific Coast diamonds – an unconventional source terrane.

W.D. HAUSEL. *Geology and ore deposits of the American Cordillera: Geological Society of Nevada symposium Proceedings, Reno/Sparks*, NV, **2**, 1996 925–34.

Several hundred diamonds have been found along the Pacific Coast of the United States in California, Oregon, Washington and Alaska, for which no known source rock has been identified. The Pacific Coast is an atypical terrain for diamonds and is not considered favourable for the emplacement of diamondiferous kimberlite or lamproite. The postulated source is an obducted ophiolite or alpine peridotite interpreted to have been tectonically emplaced during plate collision. Similar diamond occurrences have been identified at several other collision zones along plate margins in the world. Being derived from an organically-rich oceanic slab, such deposits could be extremely high grade, although relatively small. W.D.H.

The diamond deposits of Myanmar.

U.T. HLAING AND T.T. WIN. *Australian Gemmologist*, **19**(11), 1997, 445–7, 1 map, 4 tables.

The three diamond occurrences previously reported in the *Australian Gemmologist* (volume 17, p. 278) are now known as the Theindaw, Toungoo and Momiek deposits. The authors describe the occurrences of the three diamond deposits, their mineral associations and the general features of diamonds. P.G.R.

Gem news.

M.L. JOHNSON AND J.I. KOIVULA. *Gems & Gemology*, **33**(3), 1997, 220–30, 13 illus. in colour.

Assessments carried out on the lamproite pipe near Murfreesboro for its economic potential as a diamond mine proved the average diamond content to be 0.005 ct per ton of ore. This is not enough to support commercial mining so the pipe will remain as a tourist attraction. J.J.

First occurrence of strontian K-Cr loparite and Cr-chevkinite in diamonds.

M.G. KOPYLOVA, R.S. RICKARD, A. KLEYENSTUEBER, W.R. TAYLOR, J.J. GURNEY AND L.R.M. DANIELS. *Russian Geology and Geophysics*, **38**, 1997, 405–20. [Proceedings of the sixth International Kimberlite Conference, Vol. 2, Diamonds.]

Strontium-bearing K–Cr loparite and Cr-chevkinite, both Ti-bearing minerals, are identified as radioactive inclusions in diamonds from the River Ranch kimberlite pipe in the Limpopo Mobile Belt, SE Africa. Both minerals are partially replaced by secondary phases. The exotic titanates may indicate metasomatism genetically associated with kimberlite formation processes. M.O'D

Gem Trade Lab notes.

T.H. MOSES, I.M. REINITZ, AND S.F. MCCLURE. *Gems & Gemology*, **33**(3), 1997, 212–18, 15 illus. in colour.

A pair of black opaque cabochons (3.55 and 3.56 ct) were proved to be diamonds by a hardness test. It was the first time diamonds have been seen cut as cabochons. A rare fancy vivid faceted diamond was reported to be from South Africa. In the rough it appeared brown with only a hint of orange. It was a type IIa diamond. Recently fracture-filled diamonds have been seen when the flash colour effect was less pronounced due to reheating. A diamond had transparent droplets on the surface possibly caused by the subsequent reheating of the diamond after filling causing the filling to boil over. J.J.

Geothermometry and oxygen barometry of coexisting iron-titanium oxides of Majhgawan diamondiferous pipe, Madhya Pradesh.

A. MUKHERJEE, K.S. RAO, D. BANDYOPADHYAY, G. ROY AND A.K. CHATTERJEE. *Journal of the Geological Society of India*, **49**(1), 1997, 55–60.

Abstractors

R.K. Harrison	R.K.H.	J. Johnson	J.J.	P.G. Read	P.G.R.
W.D. Hausel	W.D.H.	B.E. Leake	B.E.L.	R.E. Samson	R.E.S.
R.A. Howie	R.A.H.	M. O'Donoghue	M.O'D.	E. Stern	E.S.
M.E. Hutchinson	M.E.H.	G. Raade	G.R.		

For further information on many of the topics referred to, consult *Mineralogical Abstracts*

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Geothermometry of the coexisting magnetite-ilmenite pair from this diamondiferous pipe indicates a T of 1150°C. The values of fo_2, T and P fall in the equilibria field defined by iron-wüstite and wüstite-magnetite, indicating depth of sampling of ~155 km and P 46 kbar. The Majhgwan pipe is the only diamond-producing primary source in India and has an annual capacity of 29 000 ct. R.A.H.

Petrology and geochemistry of kimberlite pipe 11 of Chigicherla area, Anantapur district, Andhra Pradesh, south India.

D.S.N. Murthy, A.M. Dayal, R. Natarajan, V. Balram and P.K. Govil. *Journal of the Geological Society of India*, **49**(2), 1997, 123–32.

This kimberlite pipe contains two generations of olivine with phlogopite, spinel, perovskite and melilite. A comparative study with other kimberlite pipes in the area indicates that Zr–Hf, Nb–Ta and Th–U have a high degree of correlation; the ratios of Ba/Nb (< 10), Zr/Hf (~ 50) and Nb/Zr (> 0.5) are similar to those of group-I kimberlites). The chondrite-normalized *REE* pattern of pipe 11 is similar to that of other kimberlites and shows enrichment of *LREE*. The incompatible trace elements indicate similarity with OIB or other types of alkaline intraplate volcanic rocks. The major element chemistry and Ce/Yb and La/Yb ratios suggest that the formation of kimberlite was due to a low degree of partial melting of an ultrabasic source along with an earlier subducted oceanic lithosphere. R.A.H.

Fifty years of the Diamond Research Laboratory.

C. Owers. *Industrial Diamond Review*, **57**(575), 1997, 109–11, 9 illus.

The author traces the history of De Beers Diamond Research Laboratory from the laying of its foundation stone by Sir Earnest Oppenheimer in March 1947 to its 50th anniversary celebrations attended by the outgoing Chairman of De Beers, Julian Ogilvie Thompson and his successor Nicky Oppenheimer.

During its first half century of operation, the laboratory, through its mineral processing division, developed technology for the mining, extraction and sorting of diamond using surface characteristics, X-rays, colour and thermal properties. Although diamond for industrial use was initially limited to grit produced from the crushing and processing of boart, when the synthesis of diamond was achieved in the '50s, the laboratory, through its synthesis division, was also in the forefront of that research. Although its actual formal success in diamond synthesis followed the scientific breakthroughs by ASEA in Sweden and GE in the USA, it became one of the leaders in the development of a range of natural and synthetic abrasive products. P.G.R.

Trace element analyses of fluid-bearing diamonds from Jwaneng, Botswana.

M. Schrauder, C. Koeberl and O. Navon. *Geochimica et Cosmochimica Acta*, **60**(23), 1996, 4711–24.

Trace element analyses using INAA are reported for 13 fibrous diamonds previously examined by EPMA and Fourier-transform IR spectroscopy. Concentrations of incompatible elements (K, Na, Br, Rb, Sr, Zr, Cs, Ba, Hf, Ta, Th, U and the *LREE*) are higher in the water- and carbonate-rich fluids in microinclusions than are those of primitive mantle, mantle-derived melts or melt inclusions in low-P peridotites. Cr, Co and Ni are similar in abundance to those of primitive mantle. Minerals in equilibrium with the fluids must have already been enriched in K, Ti and many incompatible elements, and the fluids were not derived by partial melting of common peridotites or eclogites. The major and trace element compositions of the trapped fluids in fibrous diamonds confirm that at P compatible with those of the diamond stability field, carbonatitic and hydrous fluids can be efficient carriers of incompatible elements, and such fluids are common in the mantle. R.K.H.

Geology of the Sturgeon Lake 01 kimberlite block, Saskatchewan.

B.H. Scott Smith, J.P. Letendre and H.R. Robison. *Exploration & Mining Geology*, **5**(3), 1996, 251–61.

This kimberlite, found by heavy mineral sampling and shown to be diamondiferous but not economic, was the first to be discovered in Saskatchewan. The body, a 98 m.y.-old glacially-transported megablock, occurs within glacial sediments overlying Cretaceous bedrock shale. Marine shale of a similar age occurs adjacent to the kimberlite and appears to represent a separate glacial block. The kimberlite is typical of Group 1, containing two generations of olivine, macrocrysts of ilmenite, garnet, spinel and mica together with groundmass mica, spinel, perovskite, apatite, carbonate and serpentine. R.E.S.

The origins of Yakutian eclogite xenoliths.

G.A. Snyder, L.A. Taylor, G. Crozaz, A.N. Halliday, B.L. Beard, V.N. Sobolev and N.V. Sobolev. *Journal of Petrology*, **38**(1), 1997, 85–113.

Major, trace and *REE* mineral chemistry of clinopyroxenes and garnets (pyrope, grossular, almandine), C isotopes in diamonds, Rb–Sr, Sm–Nd, Re–Os and O isotopes have been determined on ultrapure minerals and rocks from eclogites in the Udachnaya, Mir and Obnazhennaya kimberlite pipes in Yakutia, Russia. The results show that the eclogites were formed in a variety of ways, both within the mantle and from oceanic crustal residues. The Udachnaya eclogites lack chemical zoning in the minerals have unradiogenic Sr and lack O, S and C isotope variation relative to the mantle. They, and most of the Obnazhennaya samples, correspond with the Group A eclogites from elsewhere (probably true mantle cumulates), have not been re-cycled, and were derived from typical depleted mantle except for a few samples derived from either enriched, or very depleted, mantle. The Mir eclogites are more typical of other eclogites worldwide and have convincing evidence of a recycled oceanic crustal affinity. B.E.L.

Kinetics of Ib to IaA nitrogen aggregation in diamond.

W.R. TAYLOR, D. CANIL AND H.J. MILLEDGE. *Geochimica et Cosmochimica Acta*, **60**(23), 1996, 4725–33.

High-*P* and high-*T* experiments with aggregation state determination by IR microspectrometry are used to re-evaluate Ib → IaA aggregation kinetics and the sector dependency of the aggregation state. Diamonds with N_2 impurities as singly-substituted C centres (Ib) are rare because Ib N_2 atoms aggregate to form A centres (type IaA) during 500–3000 m.y. upper mantle residence times. The results show that cube sectors have an activation energy Ib → IaA conversion (E_a) = 6.0 ± 0.2 eV compared to E_a = 4.4 ± 0.3 eV for the octahedral sectors. Sector dependency is ascribed to different mechanisms of N_2 migration. Application to Kokchetav microdiamonds indicates that their aggregation state is consistent with peak *T* of 950°C and a burial to exhumation of ~17 m.y. Yellow diamond cubes and diamond 'coat' from Yakutia with ~20% Ib grew ≤ 7 m.y. before kimberlite eruption for mantle *T* ≥ 950°C, but did not grow directly from the transporting kimberlite magma. R.K.H.

Gems and Minerals

A donation of Archbishop Nil to St Petersburg University.

G.F. ANASTASENKO. *World of Stones*, **12**, 1997, 24–7, illus. in colour.

Some gem mineral crystals are included in the gift made in 1874 by Archbishop Nil of Yaroslavl' and Rostov [secular name Nikolai Fedorovich Isakovich] to the University of St Petersburg. Many specimens are from Russian deposits. M.O'D.

500 Jahre Edelsteinregion Idar-Oberstein (1497–1997).

H. BANK. *Gemmologie (Zeitschrift der Deutschen Gemmologischen Gesellschaft)*, **46**, 1997, 129–52, 10 photographs, 2 maps, 1 table, bibl.

Although apparently the Romans had mined agates in Idar-Oberstein, there is no written evidence before the year 1497. From then on there are numerous mentions in various documents (the article reproduces one mention of chalcedony and rock crystal in 1606). The industry was fairly small (in 1825 200 cutters and 70 miners were working) till some emigrants went to Brazil and found similar material there and started to export these agates back to Idar. The industry grew, so that during the period between 1890 and 1930 there were up to 2328 lapidaries working including 325 engravers. Before the Second World War up to two thousand goldsmiths were employed. Apart from Germany, the industry delivered goods to France, England, Russia, USA and the orient. Many cheaper articles were sold to the African and Arab countries and Freemasons were supplied. Cameos were fashionable in the late nineteenth century and this art was brought to perfection. E.S.

Alexandrite chrysoberyl from Dowerin, Western Australia: revisited.

A. BEVAN AND P. DOWNES. *Australian Gemmologist*, **19**(11), 1997, 460–3, 1 illus. in black-and-white, 5 illus. in colour.

In the form of a preliminary report, the authors describe the geology and mineralogy of the Dowerin deposit, an area in Western Australia where small crystals of gem-quality chrysoberyl (including a few showing the characteristic alexandrite colour change) were first discovered in 1930. These workings have recently been reopened and small cut stones have been produced from the alexandrite rough. P.G.R.

A miscellany of organics

G. BROWN. *Australian Gemmologist*, **19**(12), 1997, 503–6, 16 illus. in colour.

Identifying features are given of some of the rarer organics that have appeared in the author's laboratory reports over the last decade. Among these are kukui nuts, imitation ox-blood coral, apple coral and imitation black pearls. P.G.R.

Two zincian rarities.

M. BURFORD. *Canadian Gemmologist*, **18**, 1997, 108–10.

Taaffeite and gahnospinel [the latter not a distinct species but a specimen with composition on the series between spinel and gahnite] are described with a table of properties and notes on occurrence and inclusions. Some constants (for both materials) are slightly outside figures usually cited. M.O'D.

Kingsbridge: an early quarrying district on Manhattan Island.

L.H. CONKLIN. *Mineralogical Record*, **28**, 1997, 457–73, illus. in colour, 1 map.

Attractive and apparently gem-quality crystals of dark red rutile and yellow-brown uvite, with well-crystallized diopside, pyrite and other minerals are described from the long built-over Kingsbridge marble quarry in the north of Manhattan Island, New York City. M.O'D.

Characteristics of violet jade from Turkey.

M.A. DIGENNARO, C. TROSSARELLI AND C. RINAUDO. *Gemmologie (Zeitschrift der Deutschen Gemmologischen Gesellschaft)*, **46**, 1997, 169–74, 6 photographs, 1 table, 1 graph, bibl.

Violet jade from Turkey has an RI of 1.65–1.66, SG 3.10, and an inert reaction to UV. The samples are composed of jadeite, quartz, feldspar, muscovite, pyrite, Mn and Fe oxides. Various concentrations of some of these minerals are responsible for varying colours of violet. Jadeite is the preponderant mineral and the rock should be defined as impure jade. E.S.

A mineralogical and structural study of red corundum, $Al_{1.98}Cr_{.02}O_3$, from Froland, Norway.

B. ESTIFANOS, K. STÅHL, P.-G. ANDRÉASSON, G. BYLUND AND L. JOHANSSON. *Norsk Geologisk Tidsskrift*, **77**(2), 1997, 119–22.

The crystal structure of red corundum, $Al_{1.98}Cr_{0.02}O_3$, from Froland has been refined from X-ray powder diffraction data by Rietveld analysis. Space group *a* 4.7597 (4), *c* 13.0013(9) Å. The substituting Cr-atoms do not take the site of Al-atoms, they depart 1.04 Å in the direction of the vacant octahedral interstices. A SEM (EDS) study revealed microphases of diaspore; one of the reasons for gem quality being lost. The reaction $Al_2O_3 + H_2O \rightleftharpoons 2AlO(OH)$ occurred in the late stage of the metamorphic history of the Froland region. G.R.

Raman spectra of various types of tourmaline.

B. GASHAROVA, B. MIHAILOVA AND L. KONSTANTINOV. *European Journal of Mineralogy*, **9**(5), 1997, 935–40.

From an investigation of 25 tourmalines in the spectral range 150–1550 cm^{-1}, classified chemically into three main groups buergerite-schorl, elbaite-type and dravite-buergerite-uvite, it was found that they can be similarly classified on the basis of their Raman spectra. R.A.H.

Les saphirs du nord de Madagascar.

E. GONTHIER. *Revue de gemmologie*, **132**, 1997, 14–17. illus. in colour.

Description of blue sapphires found in the northern part of the Malagasy Republic with notes on local geology and usages of the people in whose territory the sapphires occur. M.O'D

Origin and formation of agate-bearing spherulites: the Thuringian Forest, Germany.

G. HOLZHEY. *Australian Gemmologist*, **19**(11), 1997, 452–9, 24 illus. in colour, 1 map.

In the Thuringian Forest of Central Germany agate occurs in many locations, mostly as spherules within rhyolites that form a low volcanic mountain chain covered by the forest. These agate-bearing spherulites were formed epigenetically by silica-mineralizations which occurred in two distinct phases to produce hollow spherulites and wall-banded and horizontally layered agate plus macrocrystalline quartz. P.G.R.

Gem news.

M.L. JOHNSON AND J.I. KOIVULA. *Gems & Gemology*, **33**(3), 1997, 220–30, 13 illus. in colour.

Prospecting for beryl in Saudi Arabia found epidote and not emerald in the Hadiyah area. Between Riyadh and the Red Sea some gem-quality aquamarine was found. Radioactive cat's-eye chrysoberyls have been sold in Bangkok. More fine Russian demantoid garnet is on the market, reportedly from the Nizhniy Tagil area. Namibia is also producing commercial quantities of demantoid garnets. A large yellow cabochon and two other pieces from the Kuruman District in South Africa were found to represent the ettringite group of minerals and were probably sturmanite. Brownish-yellow and greenish-yellow bicoloured grossular garnet has been found in Mali; the RI varies according to which colour zone is being tested. A piece of opal rough had inclusions in the form of thin tubes which did not affect the play of colour and were therefore thought to be older than the aggregation of opal spheres. 'Pink geuda' sapphires are being sold in Vietnam. Most are opaque and cloudy with a pronounced milkiness, but it was found that with heat treatment some of the stones were improved enough to be cut into low-quality cabochons. J.J.

Multicoloured bismuth-bearing tourmalines from Lundazi, Zambia.

M.L. JOHNSON, C.Y. WENTZELL AND S. ELEN. *Gems & Gemology*, **33**(3), 1997, 204–11, 7 illus. in colour, 2 tables.

These multicoloured tourmalines have an unusually high content of bismuth and recently have been mined in the Kalungabeda area of the Lundazi district. Colours include pink, orange, green and yellowish-green with cut stones containing two or more colours. They occur in alluvial gravels associated with granitic pegmatites, which were intruded into gneiss and schist basement of the Mozambique Belt. Much of the rough is susceptible to cracking during sawing, so to keep the multicoloured appearance it was noted that the green rind must be retained as it imparts a physical stability to the stone. The most distinctive features of these tourmalines are growth bands, straight, wavy or angular. Unexpectedly the inclusions show no signs of bismuth minerals. EDXRF showed the highest concentration of bismuth to be in the pink centres and the lowest in the green rims, with one pink stone containing 0.49 wt% Bi_2O_3. J.J.

Neuer Rauchquarzfund aus dem Pendeli bei Athan, Griechenland.

H. KIRCHNER AND E. KOFLER. *Mineralien Welt*, **8**(6), 1997, 59–60, illus. in colour, 2 maps.

Fine crystals of gem-quality smoky quartz are reported from Pendeli, near Athens, Greece, where they occur in the Penteli marble. M.O'D.

Emerald mineralization and metasomatism of amphibolite, Khaltaro granitic pegmatite-hydrothermal vein system, Haramosh Mountains, northern Pakistan.

B.M. LAURS, J.H. DILLES AND L.W. SNEE. *Canadian Mineralogist*, **34**(6), 1996, 1253–1286.

Emerald mineralization occurs in 0.1–1 m thick hydrothermal veins and Tertiary pegmatites cutting amphibolite in the Nanga Parbat-Haramosh massif, N Pakistan. The emerald in quartz and tourmaline-albite veins, and more rarely in pegmatite; the Cr_2O_3 and Fe_2O_3 contents, respectively, of the emeralds decrease systematically from emerald (>0.20, 0.54–0.89 wt.%), to pale blue beryl (≤ 0.07, 0.10–0.63 wt.%). EPMA results are reported for tourmaline, biotite, muscovite and beryl, together with major and trace element analyses of the amphibolite and leugranites.

Oxygen isotope analyses of igneous and hydrothermal minerals indicate that a single fluid of magmatic origin with $\delta^{18}OH_2O$ 8‰ produced the pegmatite-vein system and hydrothermal alteration at 550–400°C. The introduction of HF-rich magmatic-hydrothermal fluids into the amphibolite caused hydrogen ion metasomatism, releasing Cr and Fe into the pegmatite-vein system. R.A.H.

Benitoite from the New Idria District, San Benito County, California.

B.M. LAURS, W.R. ROHTERT AND M. GRAY. *Gems & Gemology*, **33**(3), 1997, 166–87, 29 illus. in colour, 2 tables.

Benitoite ($BaTiSi_3O_9$) is only produced in commercial quantities from the Benitoite Gem Mine in the San Benito County; it was first discovered in 1907. These strongly dichroic stones are typically violet-blue; rare stones are pink or colourless. Orange stones have been produced by heat treatment. Benitoite is found exclusively in blueschist bodies within serpentine and thought to have originated when Ba and Ti were released by the alteration of blueschist in the presence of Mg- and Ca-rich fluids generated by regional metamorphism. Gem-quality benitoite is found in veins and usually coated in natrolite. The crystals are normally triangular with dominant π $(01\bar{1}1)$ faces being frosted and the m faces being smooth. Colour zoning is common with colourless cores and blue rims. Non-gem-quality benitoite has abundant fibrous inclusions. Sizes range up to 2–3 ct. Details of the history, mining and production are given together with details of the various local claims. J.J.

Neues Vorkommen von Demantoid in Namibia.

TH. LIND, U. HENN, A. HENN AND H. BANK. *Gemmologie (Zeitschrift der Deutschen Gemmologischen Gesellschaft)*, **46**, 1997, 153–60, 6 photographs, 3 tables, 2 graphs, bibl.

The demantoid occurrences in Namibia are in the central part of the Damara-Orogen, a flat land surrounded by mountains consisting of intrusive rocks. Some demantoids have been picked up from the ground and sieved, others cut out of the rockface. The RI cannot be read on a standard refractometer, SG 3.81–3.85. Chemical analyses show the andradite to be pure with a low content of Cr_2O_3 (0.02–0.13%). Absorption spectra show bands of Fe^{3+} and Cr^{3+}. Distinct growth zoning is visible under magnification in addition to as yet unidentified ore-like inclusions. No chrysotile inclusions have been found. E.S.

Minerali e pietre figurate della discarica di Candeli (Firenze).

R. MELI. *Rivista Mineralogica Italiana*, **22**, 1997, 369–76, illus. in colour, 1 map.

Fine landscape-like patterning occurs on some limestones found on railway tunnelling spoil dumps in the Candeli district, Firenze, Italy. Patterning arises from the presence of Fe and Mn hydroxides. M.O'D.

Gem Trade Lab notes.

T.H. MOSES, I.M. REINITZ, AND S.F. MCCLURE. *Gems & Gemology*, **33**(3), 1997, 212–18, 15 illus. in colour.

A faceted semi-transparent green stone with a sharp 'cat's-eye' was identified as an emerald. A polymer impregnated jadeite carving showed some interesting features, with near-colourless areas of exceptional transparency surrounding isolated green grains of jadeite. The infrared spectrum showed polymer peaks so strongly that the typical jadeite spectrum was dwarfed. A jadeite carved urn had the appearance of nephrite as the colour distribution showed a typical cloudy effect.

Two faceted purple beads showed typical quartz properties as well as a peak in the infrared absorption at 2900 cm^{-1} similar to that seen in polymer impregnated materials. It was assumed that the beads had been quench-cracked and dyed, but the cracks made it impossible to determine whether they were synthetic or natural. Topaz fashioned to look like diamond rough were identified as topaz especially with occurrence of tourmaline and chlorite inclusions. Trigons had been carved and were raised above the surface and not depressed. J.J.

Die 'opal pineapples' von White Cliffs in New South Wales.

G. NIEDERMAYR AND G.M. PEARSON. *Mineralien Welt*, **8**(4), 1997, 51–5, and 8(5), 1997, 1997, 48–53.

Assemblages of precious opal taking a pineapple shape are described from the White Cliffs opal field, New South Wales, Australia. The relationship between opal, glauberite, gaylussite and ikaite is discussed. M.O'D.

Le saphir 'padparadscha'.

F. NOTARI. *Revue de Gemmologie*, **132**, 1997, 24–7, illus. in colour.

Chemical composition and spectra of a large number of orange-pink sapphires is presented to show what may or may not be the padparadscha variety. A Cr content of between 0.04 to 0.8% is needed to produce the colour as well as the presence of undefined colour centres. Sri Lanka is the only known producer. M.O'D.

Jadeite – K-feldspar rocks and jadeites from northwest Turkey.

A.I. OKAY. *Mineralogical Magazine*, **61**(6), 1997, 835–43.

Blueschist-facies rocks with jadeite-K-feldspar-lawsonite paragenesis occur as exotic blocks in Miocene debris flows in the Bektablar region of NW Turkey. The jadeite-feldspar rocks are very fine-grained and retain a relict porphyritic volcanic texture; nepheline microphenocrysts are pseudomorphed by jadeite and K-feldspar, and relict magmatic aegirine has rims of jadeite. In some rocks jadeite amounts to > 60% of the rock; EPMA results show the jadeite, K-feldspar and lawsonite to have essentially pure end-member compositions. *P–T* estimates for these rocks are 8 ± 2 kbar, 300 ± 50°C. The preserved volcanic texture, relict aegirine and bulk rock composition indicate that these rocks represent metamorphosed phonolites; it is considered that jadeite – K-feldspar is a stable mineral pair in blueschist-facies *P–T* conditions. R.A.H.

New chrysoberyl deposits from India.

J. PANJIKAR AND K.T. RAMCHANDRAN. *Indian Gemmologist*, **7**(1/2), 1997, 3–7, illus. in colour.

Chrysoberyl of gem quality from the states of Madhya Pradesh, Orissa and Andhra Pradesh originates from very similar geological environments. in Madhya Pradesh alexandrite is reported from Latapara and Matrapara in Raipur district where it occurs in pegmatites intruding granite. In Orissa pale yellow to green chrysoberyl, sometimes chatoyant, occurs in pegmatites at Jerapani, Surjapalli and Dakalguda: alexandrite is found at Ranchipura where it occurs in the contact zone between pegmatite and peridotite. Green tourmaline, yellow chrysoberyl, green beryl and garnet are found in association. In Andhra Pradesh large chrysoberyl deposits occur in the Narsipatnam area of Vishakhapatnam region which forms part of the Eastern Ghat Supergroup.

The Orissa alexandrite occurred as small brownish-green crystals with a moderate colour change while chatoyant material was a bright yellow with attractive sheen. Andhra Pradesh alexandrite occurred as pale to dark green crystals, some with a pronounced colour change while chatoyant material was a pale yellow with a whitish sheen. Alexandrite from Madhya Pradesh was a dark green with a strong colour change while the yellow chrysoberyl had a slight greenish tinge. Sillimanite, quartz, mica and rutile have been generally observed as inclusions while flattened apatite crystals are found only in the material from Andhra Pradesh. M.O'D.

Tugtupit-kamień ozdobny końca XX wieku.

T. SOBCZAK AND N. SOBCZAK. *Mineralogia Polonica*, **27**, 1996, 99-103.

Review of the occurrence, mineralogy and recovery of tugtupite which was first reported in 1960. A table gives the chief properties of tugtupite together with those of the similar-appearing species stichtite, sogdianite, sugilite, jadeite and eudialyte. M.O'D.

Gemmological features of rubies and sapphires from the Barrington volcano, Eastern Australia.

G. WEBB. *Australian Gemmologist*, **19**(11), 1997, 471–5, 13 illus. in colour, 1 map, 1 table.

Although Australia is an important source of sapphires, ruby remains a rare gemstone among the country's corundum deposits. However, among the few ruby occurrences, the best gem-quality stones originate from alluvial deposits derived from the Barrington volcano in New South Wales. Ruby and pink sapphire can form 50 per cent of the weight of sampled gem corundum concentrate in this area. Two distinct suites of sapphire accompany the rubies, one of which relates to the ruby, while the other is typical of eastern Australian sapphires. Gemmological features of these rubies and sapphires are described by the author. P.G.R.

Gemstone occurrences in British Columbia.

B.S. WILSON. *Canadian Gemmologist*, **18**, 1997, 74–83.

Descriptive list of the gem species found in British Columbia with notes on the volcanic rocks, high-grade metamorphic rocks, felsic plutonic rocks with associated granite pegmatites, and skarns, all of which provide hosts to gemstone mineralization. M.O'D.

Canadian tourmaline: a new discovery.

B.S. WILSON. *Canadian Gemmologist*, **18**, 1997, 107.

Gem-quality tourmaline, mostly pink and brownish-pink and identified as elbaite, is reported from miarolitic cavities at the Stargazer claims near O'Grady Lake in the Mackenzie Mountains, Northwest Territories of Canada. M.O'D.

Instruments and Techniques

Fourier transform-Raman spectroscopy of ivory: a non-destructive technique.

H.G.M. EDWARDS, D.W. FARWELL, J.M. HOLDER AND E.E. LAWSON. *Studies in Conservation*, **43**, 1998, 9–16, 10 figures.

This paper presents the results of a comprehensive, non-destructive, Fourier transform-Raman spectroscopic study of elephant ivory, bone and tooth. Samples tested ranged from museum specimens to modern tusks. The principles of FT-Raman spectroscopy are described and the characteristic vibrational features identified which distinguish elephant ivory from tooth and bone. Another important result is the ability of this technique to characterize ivory from the woolly mammoth, African and Asian elephants, which may help in attributing ivories to different species. The use of a remote-sensing Raman probe on inlay is also described. M.E.H.

The Gem Kit.

T. LINTON, S. SULTMAN AND J. PETERS. *Australian Gemmologist*, **19**(11), 1997, 448–51, 3 illus. in black-and-white.

The portable gem testing kit described is a product of NM Australia Pty Ltd, and is contained in a black leatherette carrying case the size of a small laptop computer. The kit contains the basic gem testing instruments (refractometer, spectroscope, polariscope, dichroscope, Chelsea filter, triplet loupe, tweezers and light sources, together with a Leveridge gauge and accessories) and is available in three versions depending on the mix of instruments purchased. P.G.R.

A new technique for detecting synthetic yellow sapphire.

T. LINTON. *Australian Gemmologist*, **19**(12), 1997, 509–11, 3 illus. in colour.

The problems experienced by gemmologists and valuers when confronted with a large yellow sapphire that does not contain obvious inclusions can be overcome by using a test procedure developed for identifying flame-fusion synthetic yellow sapphire. The technique described used a Nelson M17 Gemstone Cooling Unit which is filled with liquid nitrogen to rapidly cool the sapphire under test. The gem is then irradiated with UV. If the sapphire is a flame-fusion yellow corundum coloured by nickel and

chromium this produces a fluorescent line at 693.5 nm (not visible at room temperature) in the gem's visible absorption spectrum. In addition to this spectroscopic analysis, details are given of other UV fluorescent tests which can also be applied. P.G.R.

Meiji Technico model GF-252 refractometer-polariscope.

T. LINTON, S. SULTMAN AND G. PETERS. *Australian Gemmologist*, **19**(12), 1997, 513–14, 2 illus. in colour.

Two of the most often used gemmological instruments, the refractometer and the polariscope, have been combined together in the same case in the Meiji Technico unit checked by the GAA Instrument Evaluation Committee. The internal light source for both the refractometer and the polariscope is a low wattage filament lamp which provides yellow-rich illumination suitable for the refractometer's yellow interference filter. A control at the side of the instrument's case enables the interference filter to be moved out of the refractometer's light path so that an external white light or sodium light can be used as alternative sources of illumination. P.G.R.

Synthetics and Simulants

Gem news.

M.L. JOHNSON AND J.I. KOIVULA. *Gems & Gemology*, **33**(2), 1997, 142–52, 23 illus. in colour.

At the 1996 Diamond Conference in Tours, France, one of the topics discussed was the use of diamond thin films and their industrial uses. Also discussed was the high pressure/high temperature synthetic mono crystals manufactured in Japan. Some have coloured centres caused by cobalt used as a solvent during growth; these are yellow stones types Ib and IaA, and showed cobalt-related fluorescence. They are also grown with phosphorus for electronic appliances. Thin films of synthetic diamond have been used in jewellery; they are transparent and can appear grey due to the light scattering from the tiny diamond crystals.

On examination in methylene iodide of a piece of rough and two faceted stones of vanadium-bearing Russian synthetic green chrysoberyl, showed strong bands of curved zoning. A cat's-eye effect was obtained from a Russian hydrothermal synthetic emerald when the stone was cut as a cabochon and the original rough base was retained. Imitation Zambian emerald crystals have been sold to the unwary. They are composed of fragments of quartz crystal glued together with green epoxy resin and another type was a quartz crystal coated in a bluish-green plastic. All have matrix that covers up the glue and the plastic coating. A quench-cracked synthetic ruby had an extensive fracture system that made it difficult to observe the fine Verneuil banding. Flux grown red spinels from Russia have been found to contain dendritic inclusions only seen before in the synthetic blue spinels. J.J.

Gem news.

M.L. JOHNSON AND J.I. KOIVULA. *Gems & Gemology*, **33**(3), 1997, 220–30, 13 illus. in colour.

Three native-cut purple sapphires supposedly from a new locality in Afghanistan were found to be synthetic. Since 1995 new colours of GGG have become available in various shades of pink, blue, red, lilac, etc. All are easily identifiable, but the blue GGG had a much lower SG than normal as it contained calcium and zirconium. J.J.

Tairus hydrothermal synthetic sapphires doped with nickel and chromium.

V.G. THOMAS, R.I. MASHKOVTSEV, S.Z. SMIRNOV AND V.S. MALTSEV. *Gems & Gemology*, **33**(3), 1997, 188–202, 17 illus. in colour, 4 tables.

Hydrothermally grown synthetic sapphires have been produced for the last forty years, but until recently the manufacture of blue hydrothermal synthetic sapphires has been unsuccessful due to the uneven colour distribution within the stones. The researchers of the Tairus joint venture have developed the technology to overcome this problem, by using nickel (Ni^{2+}) as a dopant and this has resulted in 'sky' blue synthetic sapphires. This technique has also produced different coloured synthetic sapphires by varying the concentrations of (Ni^{2+}) (Ni^{3+}) and chromium (Cr^{3+}), together with varying the controls on the oxidation-reduction environment. The authors give detailed descriptions of the growing techniques together with the materials and methods used. Synthetic sapphire grown from a hydrothermal solution resembles more closely the natural counterparts than would corundum grown by flux or melt growth techniques. There are diagnostic features such as swirl-like patterns (common); a red reaction to UV radiation of the greenish-blue synthetic sapphires due to Cr; crystalline copper inclusions; and five small peaks between 2500 and 2000 cm^{-1} in the infrared spectrum. The Ni-doped synthetic greenish-blue sapphire absorption spectrum includes three intense bands at 377, 599 and 970 nm and two weak bands at 435 and 556 nm. J.J.

Synthetisch 'Phantomquarze', 'Herkimer' und bestrahlte 'Rauchquarz'.

S. WEISS. *Lapis*, **22**(11), 1997, 38–49, illus. in colour.

Among specimens seen at a recent Germany mineral fair were synthetic phantom quartz and Herkimer-type crystals, as well as synthetic 'rough' quartz. M.O'D.

Hydrothermal growth of diamond in metal-C-H_2O systems.

X.Z. ZHAO, R. ROY, K.A. CHERIAN AND A. BADZIAN. *Nature*, **385**(6616), 1997, 513–15.

From spectroscopic XRD and microscopy, evidence suggests that aggregates (tens of mm in size) of diamond crystals can be grown in a hydrothermal environment from a mixture of C, H_2O and metal (usually pure Ni). New diamonds are distinguished from the diamond seeds added to nucleate the new growths. The diamonds were grown using 3 wt.% powdered Ni (99.7% pure) with 95 wt.% glassy C, 2 wt.% diamond seeds (0.25 mm) and H_2O 50–100 wt.% of the glassy C, all sealed in gold tubes in conventional Roy-Tuttle bombs. R.K.H.

Book Reviews

The nature of diamonds.

G.E. HARLOW (ED.), 1997. Cambridge University PRESS, Cambridge. pp x, 278. Hardback £55.00, ISBN 0 521 62083X; paperback £19.95, 0 521 62935 7.

In this comprehensive, large-format book, published in association with the American Museum of Natural History, a dozen or more experts on the geology, mineralogy, gemmology and social-economic aspects of diamonds cover every facet of this mineral.

After an introductory chapter, the nature of colour in diamonds is discussed (E. Fritsch), and this is followed by a chapter on the origin of diamonds and the involvement of relatively cool harzburgite keels at the base of the thickest, oldest parts of the Earth's crust (M.B. Kirkley), later subduction of basaltic oceanic crust resulting in some portions of it adhering to the bases of the continental keels and recrystallizing there as eclogite. The basaltic crust contained carbon (some of organic origin) and recrystallized as diamond; heating or fluid infiltration of this continental keel caused kimberlite to form, which under the right conditions ascended rapidly to the Earth's surface.

After a brief chapter (Harlow, Shatsky and Sobolev) outlining the collision and return of ultra-high-pressure terrains, permitting formation and preservation of diamonds in the continental crust, there is a detailed chronological and geographical account of the discovery of diamond sources (Levinson). This chapter presents many fascinating insights into diamond production, firstly in India which was the sole source until around 1730, when diamonds were found in Brazil; then from around 1870 to the present day, with South Africa, Namibia, Botswana and some ten other African countries, followed by the Russian kimberlite sources mainly in Siberia (mining started in 1957), the Australian development in the lamproite of the Argyle mine (from 1979), China, and currently the active exploration in the Lac de Gras region of the North West Territories of Canada. This account is accompanied by numerous production statistics, but it is not always easy to compare production in terms of weight of carats produced with the value of diamonds mined, there being wide variations in the proportions of gem-quality diamonds in the different deposits: thus in 1995 the Argyle mine produced about 38% of the world's diamonds on a weight basis, but only about 6% on a value basis.

Sandwiched in the middle of the book is a chapter on the world's great diamonds, but here unfortunately two colour plates have been transposed relative to their legends, making the Koh-i-Noor appear in the Imperial State Crown! This is followed by various chapters outlining the history of diamonds as gemstones, their place as regal ornaments through the centuries, their value in English literature, diamond jewellery in Russia, Hollywood and the rest of the world, and into the twentieth century.

The final three chapters deal with the processing of diamonds from the Earth to fashioned objects (Harlow), diamonds as gemstones (Shigley and Moses) and the synthesis of diamonds and their applications in modern technology (Collins). The production figures are interesting, being 100 tons per year (500 million carats) of which 80% is represented by the production of synthetic diamond grit for industrial use; mined natural diamonds amount to 100 million carats per year of which 25 million are used in the gem trade.

Altogether, this is a fascinating book, covering almost all aspects of diamonds from the aesthetic to their possible use in supercomputers, and from their discovery in the frozen wastes of Siberia to their synthesis by chemical-vapour deposition. The presentation is excellent, with many clear diagrams and sketch-maps. Almost my only regret (apart from the mis-labelling of plates mentioned above) is that surprisingly there is no mention, either in the chapter on famous diamonds or in those concerned with colour in diamonds, of the wonderful Williamson 54.50 ct pink diamond (23.60 ct after cutting) presented to H.M. Queen Elizabeth II to celebrate her Coronation. R.A.H.

Gemstone buying guide.

R. NEWMAN, 1998. International Jewelry Publications, Los Angeles. pp 148, illus. in colour. Softcover US$19.95. ISBN 0 929975 25 1.

With colour on almost every opening few could resist this book whether or not they were in the gemstone and jewellery trade or were gemmologists. Here the reader is given all the information needed to show the customer what a stone is, interesting facts about particular species and advice on cleaning and conservation. Some properties have to be given but they are introduced before the stones are described. Since this is not a gem testing book but an introduction to appraising gemstones, we are shown how to evaluate cuts, styles, colour, inclusions - all with a view to establishing a specimen within an acceptable order of value, as far as this is possible. Treatments, phenomenal stones and synthetic stones are also described.

The book should be on the counter or by the bedside (or both). Beautifully produced with fresh photographs of a high standard, it could be sold to the customer along with their gemstone or jewellery purchase. Students can learn a lot from it and it would make an excellent introduction to a gemmology course, for which an imaginative stimulus of this kind is a pre-requisite. M.O'D.

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Proceedings of the Gemmological Association and Gem Testing Laboratory of Great Britain and Notices

PHOTOGRAPHIC COMPETITION

The 1998 Photographic Competition on the theme 'Gems in Fashion' produced an interesting selection of photographs illustrating gem-set jewellery typical of many periods. After careful deliberation by the judges, the prizes have been awarded as follows:

We are pleased to announce that the prizes were sponsored by Quadrant Offset Ltd, and the GAGTL is most grateful to them for their generosity. The prizes were presented and the winning entries exhibited at the Reunion of Members held on Monday 29 June.

First Prize

Bob Maurer, FGA, DGA, London
Coral Buddha brooch by Stephen Webster
(see front cover)

Second Prize

Petri Tuovinen, FGA, Finland
Ear ornament of faceted opal from Lightning Ridge set in 14 carat yellow and white gold. Opal cut by Marita Lempinen, ornament designed and set by Petri Tuovinen

Third Prize

John S. Harris, FGA, Cumbria
Cameo of peridot set in gold enamel with pearls, 19th century.

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GIFTS TO THE ASSOCIATION

The Association is most grateful to the following for their gifts for research and teaching purposes:

Mrs Susan M. Anderson, Perth, WA, Australia, for 33 parcels of various mineral specimens including small opal pieces and an opal in matrix.

Mr Dennis M.C. Chen, Taipei, Taiwan, for 14 pieces of coral of different colours and three books, *A Chinese treasure - the coral of Lucoral Museum*, *Wish gems* and *The rockhounds*.

Mr John R. Führbach, Amarillo, Texas, USA, for samples of the current production from Zambia of garnet (almandine) and amethyst; four specimens of oligoclase feldspar (three rough and one cut); a collection of peridot and related minerals of various colours from the Kilbourne Hole, New Mexico, USA.

Dr U. Henn and Dr C. Milisenda, Deutsche Gemmologische Ausbildugszentrum, Idar-Oberstein, Germany, for two pieces of dianite (potassium richterite, albite and augite).

Mr John Kessler, London, for emeralds (10.42 ct) from a new and as yet undisclosed source in Brazil.

Mr Kamel Kothari, Jaipur, India, for four emeralds, six rough sapphires and 17 rough rubies.

Mr Jan Sluis, Rotterdam, The Netherlands, for 132 stones including beryl, moonstone, quartz, topaz, turquoise and synthetic sapphire.

Thomson (Gems) Ltd., London, for 176 onyx cabochons that had faded.

Mrs J. M. Ward, FGAA, West Perth, WA, Australia, for the book *The Lure of the pearl* by B. Aquilina and W. Reed, presented by the authors through Joyce Ward.

OBITUARY

Mrs Tuija Nurminen, FGA (D.1985), Helsinki, Finland, died on 24 January 1998.

MEMBERS' MEETINGS

Trips and Tours

The fourth GAGTL trip to Idar-Oberstein, Germany, was held from 19 to 25 April. The group enjoyed tours of museums, workshops, showrooms and a mine, as well as a visit to the German Gemmological Association. A full report was published in the June issue of *Gem and Jewellery News*.

A trip to Scotland was held during the weekend of 29 to 31 May. The event included a tour of the mineral and gem galleries at the National Museums of Scotland, Edinburgh, followed by a lecture by Brian Jackson on the gemstones of Scotland, and a field trip to the Campsie Fells where attractive jasper and quartz was found. A report will be published in the September issue of *Gem and Jewellery News*.

London

On 22 April 1998 at the Gem Tutorial Centre, 27 Greville Street, London EC1N 8SU, Christianne Douglas gave a talk entitled *Pearls – a fashion opportunity*.

On 13 May at the Gem Tutorial Centre Dr Roger Harding exhibited and described some of the rare and interesting specimens contained in the gem and mineral collections donated to the Association over the years.

The Annual General Meeting was held on Monday 29 June, followed by the Reunion of Members and a Bring and Buy Sale. A full report will appear in the October issue of the *Journal*.

Midlands Branch

On 19 April the subject for the Gem Club was *Bragging pieces – collectors' stones*. The day gave members an insight into gemmology in practice; keen observations, few instruments and a fount of knowledge.

On 24 April at the Discovery Centre, 77 Vyse Street, Birmingham, the Annual General Meeting

FORTHCOMING EVENTS

16 September	**North West Branch.** Gem collection with anecdotes. John Pyke Snr.
3 October	**Trade Dinner.** To be held at the Café Royal, Regent Street, London. Guest speaker: Geoffrey C. Munn.
21 October	**North West Branch.** Silversmith of Williamsburg 1780. Martin Connard.
1 November	**Annual Conference.** Gems in Jewellery. To be held at the Barbican Centre, London. A full programme of lectures, demonstrations and displays is being planned and full details will be published in the September issue of *Gem and Jewellery News*.
2 November	**Tours of jewellery and gemstone galleries at two London museums.**
18 November	**North West Branch.** Annual General Meeting.

For further information on the above events contact:

London and Trips:	Mary Burland on 0171 404 3334
Midlands Branch:	Gwyn Green on 0121 445 5359
North West Branch:	Deanna Brady on 0151 648 4266
Scottish Branch:	Joanna Thomson on 01721 722936

GAGTL WEB SITE

For up-to-the-minute information on GAGTL events and workshops visit our web site on www.gagtl.ac.uk/gagtl

of the Branch was held at which David Larcher, Gwyn Green, Elizabeth Gosling and Stephen Alabaster were re-elected President, Chairman, Secretary and Treasurer respectively. A President's jewel had been commissioned during the year and was presented to the President. The AGM was followed by *A mosaic of gemmological tessera.*

Pre-examination seminars for Diploma and Preliminary students were held on 26 April and 3 May respectively.

North West Branch

On 20 May at Church House, Hanover Street, Liverpool 1, Brian Dunn of Garrard's, London, gave a talk entitled *Time-bomb or fun?* which included advice on how to avoid 'time bombs' when valuing watches.

Scottish Branch

On 29 March a visit to the Creetown Gem Rock Museum was arranged.

The Annual General Meeting and Conference of the Scottish Branch was held at Peebles from 8 to 10 May. At the AGM Alan Hodgkinson, Brian Jackson and Gillian O'Brien were re-elected President, Chairman and Treasurer respectively, and Catriona McInnes was elected Secretary. A report of the Conference will appear in the September issue of *Gem and Jewellery News*.

On 7 June a trip was arranged to Ruby Bay to collect the garnets of the area known as 'Elie Bay rubies'.

ANNUAL REPORT

The following is the report of the Council of Management of the Gemmological Association and Gem Testing Laboratory of Great Britain for 1997.

The Gemmological Association and Gem Testing Laboratory of Great Britain (GAGTL) is a company limited by guarantee and is governed by the Council of Management. The President, Professor R.A. Howie, and the Vice Presidents E. Bruton, A.E. Farn, D.G. Kent and R.K. Mitchell,

continued in office and the company also benefits greatly from the contributions of the Members' Council, the Trade Liaison Committee and the Board of Examiners. Dr G. Harrison Jones continued as chairman of the Board of Examiners, and Dr M. Newton was appointed to strengthen the diamond examination team. C. Winter continued to chair the Members' Council; K. Penton and I. Roberts retired from the Council and thanks are due to them for their contributions over the past four and seven years respectively. D. Gann completed his two-year term as chairman of the Trade Liaison Committee and T.M.J. Davidson was elected to the position with J. Monnickendam elected Vice-Chairman.

Overall, the GAGTL can report a financially better year in 1997 than 1996. Careful monitoring of expenditure, introduction of new courses and some hard earned orders in Gemmological Instruments Ltd, have contributed to a gratifying increase in turnover and reserves. In the laboratory, continued investment in promotion of the London Diamond Report is running parallel with a 28 per cent increase in revenue for diamond grading. This contrasts with a less financially rewarding position for coloured stones and pearls and efforts to improve this situation are in hand.

The nine-month diploma in gemmology course continues to thrive with a full complement having started in September. A new four-month Gem Diamond Diploma course started in October with 18 students and the classes in the expanded evening programme are nearly full. New correspondence course tutorials have started successfully drawing students from overseas as well as the UK to practise observation and instrumental measurements on gems and improve their examination technique. Both education and laboratory staff are involved in practical tuition in daytime and evening classes.

The exam entries in 1997 were 16 per cent down on the 1996 figure, at first sight disappointing but over 20 years such figures have fluctuated markedly and there were signs of a recovery for the 1998 examinations. The Tully Medal for 1997 was awarded to Ms Li Liping of Wuhan, Peoples Republic of China, who also received the Anderson-Bank Prize. The Diploma Trade Prize went to Ms M.I. Garland of London, Ontario, Canada, the Anderson Medal for the best candidate in the Preliminary Examination was awarded to Miss M.V. Ng of London, and the Preliminary Trade Prize went to Mr S.R. Millard of Corsham, Wiltshire.

At the Presentation of Awards held in Goldsmiths' Hall the guest of honour was Professor Chen Zhonghui of Wuhan University, accompanied by his wife, Professor Yan Weixuan. Professor Chen presented the diplomas and prizes to successful candidates from nine countries and then handed over to Eric Bruton to make the first presentation of the Bruton Medal, struck in his honour. The medal was awarded to Ms R. Tsang of Hong Kon for excellence in diamond studies.

Further improvements to the Preliminary course notes were completed in May and translations have been made into Chinese and Swedish. Development continued of Diploma supplements prior to production of a new Diploma course and practical manual. New Allied Teaching Centres (ATCs) have started in Singapore and Taipei and whilst gemmology taught at some UK colleges has declined, other centres are active.

A full programme of tutorials, practical workshops and update courses was conducted at the Gem Tutorial Centre and there were more enquiries for personal tuition and instruction than previously. Travelling tutorials were held in Chicago, USA, Sweden, and at cities in the UK, including the Earls Court International Jewellery Show.

The spring tour to Idar-Oberstein has now become an annual feature – again very successful – and in September 12 participants ventured even further afield to Kenya and Tanzania for a fourteen-day conducted tour of gem sites.

The Federation for European Education in Gemmology (FEEG) examinations were held for the first time in Britain at the Gem Tutorial Centre; the candidates that passed are now entitled to call themselves European Gemmologist (EG).

The new GAGTL website was established in May and by the end of the year had been visited more than 30 000 times (www.gagtl.ac.uk/gagtl).

Laboratory staff continued to provide a very professional service in diamond grading and in gem and pearl identification. The number of London Diamond Reports increased in 1997 compared with 1996, and CIBJO Diamonds Reports continued to make up about 20 per cent of grading activity. In coloured stones, the pattern of work was broadly similar to that of 1996, with increases in coloured diamonds and treated rubies and a decrease in emeralds reported on. Pearl testing was down compared with 1996 but there are an increasing number of pearls whose natural or cultured origin is difficult to determine. Work with trading standards organizations was continued both in the laboratory and in the high street. Two visits were made to different regions to

tour areas with a concentration of jewellers and survey the descriptions of their displayed goods. Where incorrect or insufficient labels were encountered, discussions were held with the jeweller to improve the information available to the public.

The Trade Luncheon was again a success at the Langham Hilton Hotel, where members and guests were addressed by Mr R. Buchanan-Dunlop, CBE, Clerk of the Worshipful Company of Goldsmiths.

Overall, membership increased to 3673 – small decreases in direct subscribers and laboratory members were countered by encouraging recruitment of ordinary members and laboratory members. At our branches in Birmingham, Liverpool and Edinburgh, and in our London centre, varied programmes of seminars, lectures, update courses and field trips covered a wide range of topics. Sadly a stalwart of the North West Branch, Joe Azzopardi, died in 1997 and we miss his enthusiasm. The members again provided a wide range of entries on the theme *Collectors' Gems* for the 1997 Photographic Competition. The winners' names and their entries were published in the Journal of Gemmology and additional images were selected for the 1998 calendar – again designed by Rod Coleman of Quadrant Offset Ltd.

The Annual Conference was held for the first time at the Barbican Centre in London. The theme was *Collectors' Gems* and the speakers were Ludek Hubrt (Prague), Monica Price (Oxford), David Thomas (London), Lisbet Thoresen (Los Angeles), Gabi Tolkowsky (Antwerp) and Eleni Vassilika (Cambridge). Each presented their individual views of important aspects of collections or collectors' stones to an audience of over 120 from 18 different countries. Some delegates combined their visit with attendance at a symposium on Cartier organized jointly by the Society of Jewellery Historians and the British Museum held the previous day.

Midway through the year, Council was very pleasantly surprised by news of a bequest from Mrs Jeanne Maud Herbert Towers, daughter of G.F. Herbert-Smith, a past President of the Association. It was decided to use this money to inaugurate a property fund with the ultimate aim of buying a building. Council would also like to thank all those benefactors of gems, instruments, books and documents for their generosity, enthusiasm and support for the aims and well-being of the GAGTL. Donations have come in from all over the world and checking and curation for entry on a database is going ahead. Details of the books in the GAGTL library have now been entered on a database and Council would like to thank M.J. O'Donoghue who has brought all his skill and experience to carrying out this task.

During the year, sixteen papers were published in the *Journal of Gemmology*, with such topics as colour change effects, Raman microscopy, New Zealand copal resin, marcasite, and a history of synthetic gems. Totals of 191 abstracts and 48 book reviews were produced and Council would particularly like to thank the Assistant and Associate editors for their generous help in maintaining the high standards of the *Journal*. The design of the Journal has been actively developed while costs of production have been kept steady.

Four issues of *Gem and Jewellery News* were published during the year - the first highlighting the new equipment developed by De Beers to counter any difficulties caused by synthetic diamonds. The GAGTL's new website was outlined in the June issue. Meanwhile discussions about a new design were under way and Volume 7 No. 1 published before Christmas was the first issue with the fresh image.

Gemmological Instruments Ltd is a wholly owned subsidiary of the GAGTL. In 1997 sales of instruments, books and students' stones all increased over 1996 levels and the turnover was enhanced by two particularly large orders. The new dichroscope for students launched in 1996 is selling well. Its design is similar to that of the Chelsea Colour Filter (CCF) and marks the continuing commitment to develop and supply practical affordable gem testing instruments. The good results in GI Ltd are a result of staff commitment and professionalism and it is a pleasure to report that now the company is a significant contributor to GAGTL finances.

The GAGTL was represented at the CIBJO conference in Las Vegas and on the committee examining nomenclature for a revised *Blue Book* of standard terms and policy statements. The Association was also represented at the biennial International Gemmological Conference held in Idar-Oberstein, Germany.

The Council of Management would like to thank all the staff, the Committee and Council members, and the helpers in the education and collections spheres who have worked so hard to make the gemmology scene interesting and successful.

MEETINGS OF THE COUNCIL OF MANAGEMENT

At a meeting of the Council of Management held at 27 Greville Street, London EC1N 8SU, on 25 March 1998 the business transacted included the election of the following:

GEM TUTORIAL CENTRE

27 Greville Street, London EC1N 8SU

A Colourful Day

16 September

A rainbow of opportunity - Why and how do we see colour in gemstones?

A day spent looking at the uses and importance of colour in gems.

This is the ideal workshop for both students and enthusiasts.

Price £42.55 + VAT (£50.00) – includes a sandwich lunch

Diamonds Today

7 October

A valuable and concentrated look at all aspects of diamonds: rough and cut stones, treated (laser drilled and filled), synthetic and imitation materials.

Price £104 + VAT (£122.20) – includes a sandwich lunch

Everyday Life – Treatments and Synthetics

28 October

This one-day course will look at the synthetic, imitation and treated materials encountered in the jewellery trade today. The course will concentrate on emerald, ruby, sapphire and diamond, emphasizing observation techniques.

Price £80 + VAT (£94.00) – includes a sandwich lunch

Student Workshops

Preliminary Workshop	21 October
Preliminary Theory Review	9 November
Three-day Preliminary Workshop	9 to 11 November
Diploma Theory Review	23 November
Four-day Diploma Workshop	23 to 26 November
Weekend Diamond Grading Revision	12 and 13 December
Two-day Diploma Practical Workshop	9 and 10 January 1999

For further details contact the GAGTL Education Department

Tel: +44 (0)171 404 3334 Fax: +44 (0)171 404 8843

Diamond Membership (DGA)

Balzan, Cortney G., Fairfax, Calif., USA. 1998

Tang Yun Hing, Frances, New Territories, Hong Kong. 1998

Wong Ti Yin, Heather, Hong Kong. 1998

Diamond Membership and Fellowship (FGA/DGA)

Allardyce, Tony, Birchington, Kent. 1970/1971

Hepburn, John Alexander, Orpington, Kent. 1986/1987

Fellowship (FGA)

Anderson, Elizabeth A., Peacehaven, East Sussex. 1998
Liao Yang, Guilin, Guangxi, P.R. China. 1997
Luo Xia Ying, Guilin, Guangxi, P.R. China. 1997
Millard, Simon R., Corsham, Wiltshire. 1998
Qin Hong Yu, Guangxi, P.R. China. 1997
Rowntree, Josephine, Knaresborough, North Yorkshire. 1998
Tinnyunt, Emma J., Kensal Green, London. 1998
Tupper, Michael I., South Holmwood, Surrey. 1998
Wang Yi Fei, Guilin, Guangxi, P.R. China. 1997
Wang Yi Long, Guilin, Guangxi, P.R. China. 1997
Xie Yu Jun, Guilin, Guangxi, P.R. China. 1997
Yu Pink, Guilin, Guangxi, P.R. China. 1997
Zhang Wansong, Guilin, Guangxi, P.R. China. 1997
Zhou Wei Ning, Guilin, Guangxi, P.R. China. 1997

Ordinary Membership

El Attar, Waleed, Cairo, Egypt
Feroldi, Luca, Milan, Italy
Kinnaird, Judith, Anstruther, Fife
Rohrbach, Tanya, Dorchester, Dorset

Transfer from Diamond Membership to FGA, DGA

Lodge, Tim, Muswell Hill, London

Transfers from Fellowship to FGA, DGA

Lu Yung Ching, Taipei, Taiwan, R.O.China. 1998
Marolla, Marianna, Athens, Greece. 1998
Mitchell, Susannah, Newton by Tattenhall, Cheshire. 1998
Renard-Richard, Joelle M., Ruislip, Middlesex. 1998
Seligman, Dominic, Southfields, London. 1998
Slater, Richard M., Radstock, Bath, Avon. 1998

Transfers from Ordinary Membership to FGA, DGA

Iannicelli, Marco, Salerno, Italy. 1998
Andaluz I. Sanchez, Maria, Peckham, London. 1998
Boccard, Jean-Marie, Geneva, Switzerland. 1998
Britton, Andrea L., Woking, Surrey. 1998
Draper, Zoe S., Upper Abbeywood, London. 1998
Holt, Judith A., Darwen, Lancs. 1998
John, Victoria A., Agar Grove, London. 1998
Lin Chief R., Kaohsiung, Taiwan, R.O. China. 1998
Pancratz, Mark, Weybridge, Surrey. 1998

Transfers from Ordinary Membership to DGA

Gandhi, Amar A.A., Stanmore, Middlesex. 1998
Kemp, Margaret A., Backwell, Somerset. 1998
Lüle, Çigdem, Ankara, Turkey. 1998
Webster, Paul T., Greenford, Middlesex. 1998

Laboratory Membership

Trafalgar Jewellers, Newcastle upon Tyne, NE1 5AN
Voorhuis & Brown, Rijswijk, The Netherlands

At a meeting of the Council of Management held at 27 Greville Street, London EC1N 8SU, on 30 April 1998 the business transacted included the election of the following:

Diamond Membership and Fellowship (FGA/DGA)

Hu Chin-Ching, Taiwan, R.O.China. 1998/1998

Fellowship (FGA)

Gini, Aspasia, Athens, Greece. 1990
Hsieh Evelyn Pao Lien, Shatin, NT, Hong Kong. 1998
Jacquat, Stéphane, Geneva, Switzerland. 1998
Kiefert, Lore, Basel, Switzerland. 1998
Krzemnicki, Michael Stanislaus, Basel, Switzerland. 1998
Marsh, Leona Claire, Harare, Zimbabwe. 1992
Nazos, Konstantinos, Athens, Greece. 1998
Tin Hlaing, Taunggyi, Myanmar. 1998
Tong Tao, Guilin, Guangxi, P.R. China. 1998
Wang Chao, Ning Bo, Zhe Jiang, P.R. China. 1998
White, Joanne Clare, North Sheffield, South Yorkshire. 1997
Wu Shi Zhou, Guilin, Guangxi, P.R. China. 1998
Zhao Yan Zeng, Guilin, Guangxi, P.R. China. 1998
Zheng Zi Zi, Guilin, Guangxi, P.R. China. 1998

Ordinary Membership

Borg, David, Paola, Malta
Carver, Elizabeth Mitchell, Arundel, West Sussex
Henry-Stogdon, Sarah Anita, Sutton, Surrey
Ohhara, Reiko, Ashiya City, Hyogo, Japan
Sison-Jones, Maria, London
Stimler, Harvey Jacob, Mill Hill, London
Zylberman, Nicolas, Saint Maur des Fossés, France

Laboratory Membership

Pearmain's Jewellers, Worthing, Sussex.

GIA SYMPOSIUM: CALL FOR POSTERS

The Gemological Institute of America will host the 1999 International Gemological Symposium in San Diego, California, on 21-24 June. As well as technical sessions and panel discussions on the theme 'Meeting the Millennium' there will be an open Poster Session featuring original presentations (details of which were published in the *Journal of Gemmology*, 1998, **26** (1), 56).

To be considered for this event please submit a preliminary abstract (no more than 250 words) to one of the Poster Session organizers by *1 October 1998*. For further information on the Poster Session contact Dr James Shigley at 760-603-4019 (Fax 760-603-4021, e-mail jshigley@gia.edu) or Ms Dona Dirlam at 760-603-4154 (fax 760-603-4256 or e-mail ddirlam@gia.edu). For information on the Symposium, contact Carol Moffatt at 760-603-4406, e-mail cmoffatt@gia.edu).

The Journal of Gemmology

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Back issues

Back issues of the Journal may be purchased as follows*:

Vol. 25 and 26– £10.00 per issue
Up to and including Vol. 24 – £4.00 per issue.

Members of the GAGTL are eligible for a 10% discount.

A proforma invoice including postage and packing will be issued on receipt of orders.

*Subject to availability

For details of issues in print and an order form contact:
Mary Burland at the GAGTL
Tel: 0171 404 3334 Fax: 0171 404 8843
e-mail: gagtl@btinternet.com

ISLAND OF GEMS

The exhibition on gems and the gem industry of Sri Lanka is to be held for the third successive year from 29 to 31 October 1998 at Leigh Place, Baldwin's Garden, London EC1N 7AB. This exhibition is organized by D.H. Ariyaratna, FGA, DGA, FGS. The main objective of the exhibition is to give a wider publicity to Sri Lanka's gem industry in Europe. All visitors are given a chance to examine some typical Sri Lankan gemstones using many gem testing instruments, and there will be a section to give particular help to gemmology students and collectors. Visitors will receive either a souvenir brochure or a Sri Lankan gemstone on arrival. For further details contact D.H. Ariyaratna, c/o Sri Lankan Gems, P.O. Box 1837, Tottenham, London N17 9BW. Telephone/ fax: 0181 808 4746.

CORRIGENDUM

On p.93 above, second paragraph, for '1,2-dibromomethane' read '1,2-dibromoethane [$C_2H_4Br_2$]

Idar Oberstein 1999

The 5th GAGTL tour to the gem centre of Germany

Sunday 11 April to Saturday 19 April 1999

Visits to museums, mines, workshops, showrooms and much more!
Full details will be circulated with the September issue of *Gem and Jewellery News.*

For further information and a booking form contact Sarah Kimber at the GAGTL on 0171 405 3351
e-mail gagtl@btinternet.com

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- *DEALERS IN GEMSTONES/DIAMONDS & CRYSTALS*

We buy & sell cut and rough gemstones and diamonds, particularly for the F.G.A. syllabus, and have many rare or unusual specimens. Gemstones & Diamonds also available for commercial purposes.

- *SUPPLIERS OF GEMMOLOGICAL INSTRUMENTS*

We offer a comprehensive range of gem-testing instruments, including inexpensive Petrological & Stereo-zoom Microscopes, Refractometers, Hand Lenses, Pocket U/V Lights, S.G. Liquids, the world famous OPL Spectroscope, and many other items including Books & Study Aids.

For further details of these and our other activities, please contact –
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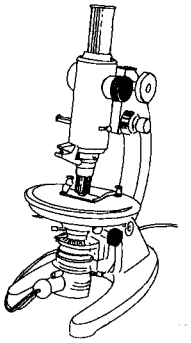

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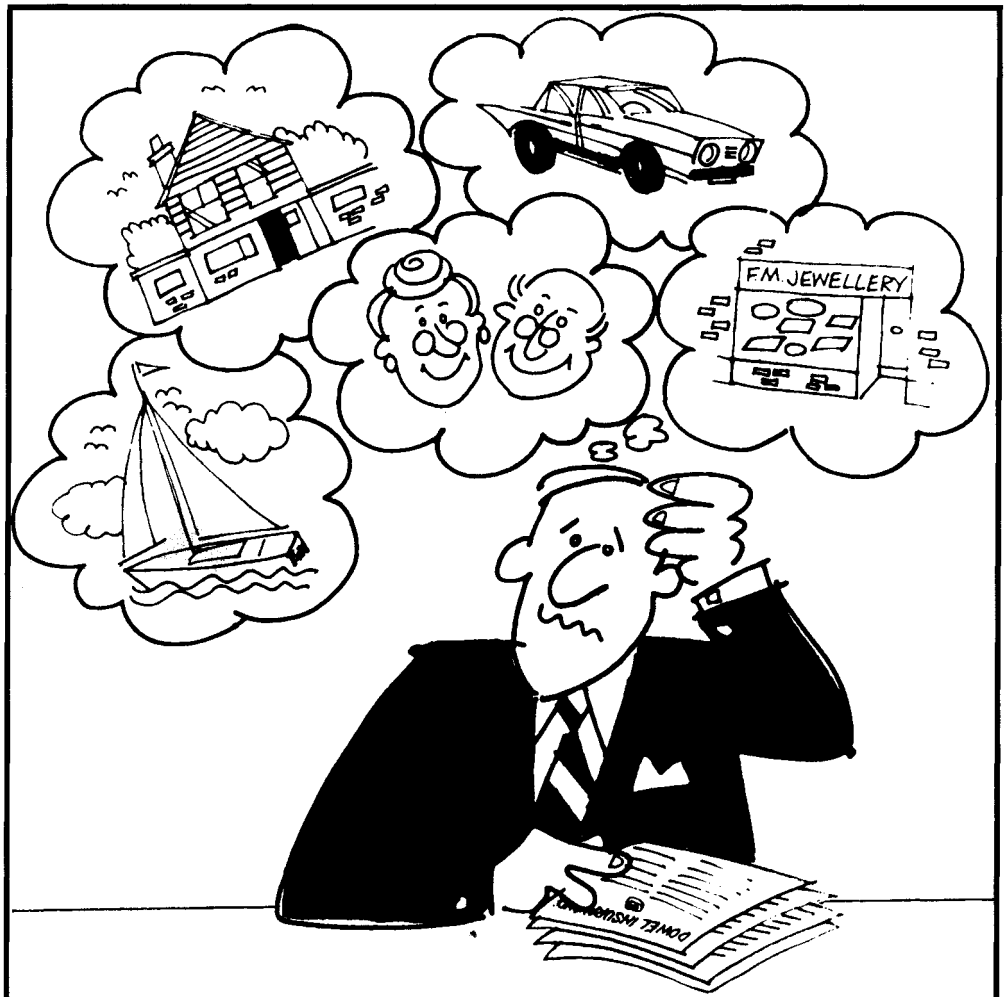

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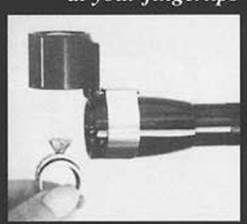

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Gems in Fashion
Coral Buddha brooch by Stephen Webster. Photograph by Bob Maurer, FGA, DGA, London
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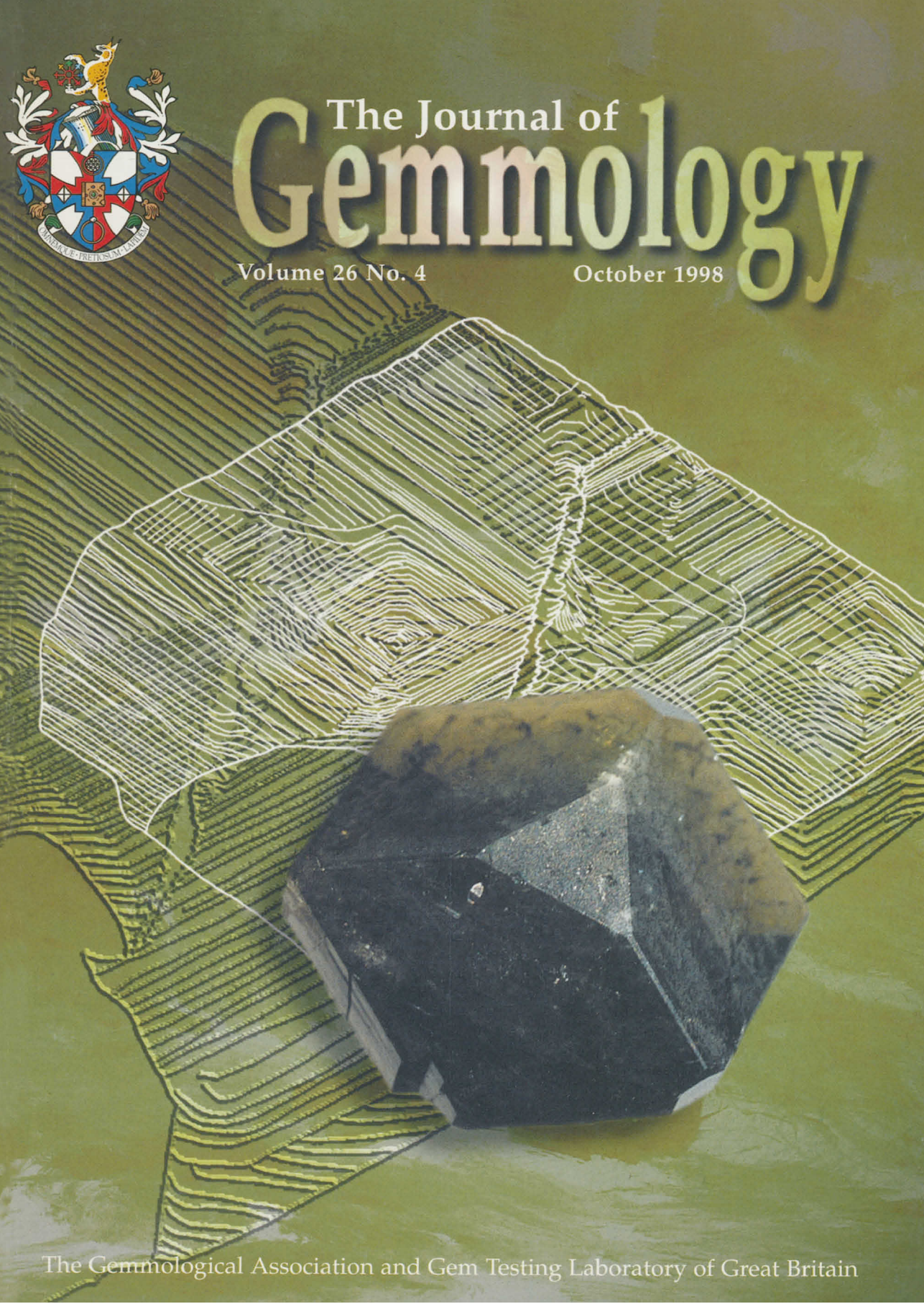

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Blue euclase from Zimbabwe – a review

Susan Stocklmayer (née Anderson), FGS, FGA

Philip Antrobus Ltd., London

ABSTRACT: Blue euclase from Mwame, Hurungwe District, Zimbabwe, which was first collected in the late 1970s has recently been available for study. This paper presents information on mineral inclusions for the first time and the complex surface morphology of the crystals is shown in a series of photomicrographs.

Keywords: euclase, inclusions, pegmatite, Zimbabwe

Introduction

Euclase, a rare beryllium mineral ($BeAlSiO_4$ (OH)), occurs worldwide as a late-stage hydrothermal mineral often associated with beryl and other beryllium minerals in a variety of host rocks, usually quartz veins, granitic pegmatites or greisens.

Although euclase can occur as a primary mineral, more usually it is secondary in origin formed by replacement of other beryllium minerals.

First recorded from Brazil in 1785 (Dana, 1892; Bastos, 1969), euclase has been found more recently from sources in Colombia, Russia, Tanzania and Zimbabwe; spectacular crystals have been described from all these localities. Of less importance gemmologically, occurrences with small crystals or non-transparent types of euclase have been recorded from New Zealand, USA (Sharp, 1961), Europe, Guyana, Sri Lanka (Deen, 1984), Kashmir, Mozambique, Uganda and Namibia.

Euclase occurs in a range of colours including pale green, pale to medium blue, medium greenish blue, pale yellow and colourless; the gemmological interest in the crystals from Zimbabwe is for the deep azure colour.

Euclase in Africa

Tanzania

Spencer (1934) first described euclase from Africa. Spectacular crystals were found with quartz in pegmatite at Lukangasi Mica Claims, 8 km south of Mikese Station, Morogoro District. The largest of these crystals measuring 72 x 38 x 35 mm (*b* axis direction) is in the collection of the Natural History Museum, London. It is described as being white and cloudy but bluish green and transparent on the face parallel to *b*. Other crystals were sold in the 1930s to collections in the USA (Pough, 1991; *see also* Dirlam *et al.*, 1992; McKie, 1955).

Mozambique

A reference to the occurrence of euclase from Muiane pegmatite, Alto Ligonha District, was made by von Knorring *et al.* (1964). This pegmatite was mined for microlite and tantalite and was an important source of gem beryl, producing both aquamarine and pink beryl; it was also noted for giant crystals of microcline. Two crystals, apparently similar in morphology to the Zimbabwean euclase were described, one was used for analysis, and the other reportedly weighed about 20 gm. No

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Figure 1: Partial euclase sheath on beryl crystal. Photo: E.A. Jobbins

information was given about the accompanying minerals or the paragenesis of the euclase.

Namibia

A report by Beyer (1980) described colourless to slightly yellow crystals up to 5 mm long from Spitzkopje. The euclase grew freely on microcline together with quartz, green feldspar, fluorite, and the other beryllium minerals, herderite and bertrandite. Beyer inferred that the euclase formed after a first generation of beryl but was older than the tabular crystals of bertrandite. The associated euclase and herderite showed no signs of etching or dissolution and euclase was not considered to be the source of beryllium for a younger generation of beryl (aquamarine) which also occurred in the pegmatite.

Figure 2: Group of euclase crystals, each about 10 mm across. Photo: E.A. Jobbins

Uganda

In a report by von Knorring (1962) on the mineralogy of pegmatites in Uganda, euclase was recorded in the Namapherere tin mine, Ankole. Beryl is a common minor constituent in all the pegmatites mined in south-west Uganda and at Kihandu mine, an unusual form of beryl with acute bipyramidal form has been pseudomorphed by muscovite and albite together with crystals of clear flaky bertrandite. No further information was found on this locality.

Zimbabwe

Euclase has been found in several of the pegmatites mined for mica since the 1920s and for beryl since the 1950s in the Mwame area 19 km NNE of Karoi, in northern Zimbabwe *(Figures 1, 2, 3 and 4)*. These occurrences are described in more detail in this paper.

Euclase in Zimbabwe

History

Euclase was first recorded in Zimbabwe in 1952, from a location 16 km east of Mwame (Geological Survey, 1952) and again (Wiles, 1961) where it is mentioned in a review of the economic minerals of the Mwame Mica Fields, Hurungwe District. Mwame was formerly known as Miami, Urungwe District, Rhodesia or Southern Rhodesia; most references cited give the earlier names, which are used in this paper where relevant. Euclase is one of a group of rare beryllium minerals that had been found in pegmatites in this area; hurlbutite and herderite occur in the Grand Slam Beryl mine, phenakite in an unnamed beryl working and chrysoberyl in the Renda mine. No bertrandite

has been recorded. Only chrysoberyl and euclase have been exploited commercially.

The crystal aggregates and faceted gems of blue euclase described in 1978 (Gübelin) 1980 (Anderson) and in this paper, came from the Last Hope claims located on Haslemere and Momba Estates 13 km NNE of the town of Karoi. Recent information unsupported by geological reports refers to the production of some euclase specimens from the MWM claims, Haslemere and Momba Estates and from Trim, Mukwichi District. Both localities are within the general Mwame area. Samples of euclase at the Geological Museum, Harare, are recorded from the Eurythmic and Lion Hill claims, situated N and NNW of Mwame; the euclase from Last Hope claims, however, remains the most significant source for the blue variety.

Euclase specimens displayed in mineral collections at the Natural History Museum, London, and the National Museum of Scotland in Edinburgh, originate from the Last Hope claims.

Geology

The country rocks are sillimanite gneisses and sillimanite garnet schists; formed by high-grade metamorphism of former argillaceous sediments of the mid-Precambrian Piriwiri supergroup. There have been several metamorphic episodes, the most significant phase being the Palaeozoic to Proterozoic (400–650 Ma) event referred to as Miami metamorphism (Stagman, 1978).

Pegmatites are of two main groups representing distinct episodes in the metamorphic history of the area. An 'older' group, secretionary in type and unzoned, are composed principally of plagioclase, quartz and some tourmaline and belong to a phase of sodic metasomatism; these are of no economic importance. The 'younger' group include the economic pegmatites and belong to a later potassic phase of metasomatism considered to be part of the Miami metamorphic event.

These pegmatites contain abundant microcline and may also have mica, beryl and other gem species. They are clearly associated with late kinematic intrusive granite plugs termed the Miami Granites. Radiometric data gave K-Ar ages of 520 and 530 Ma on muscovite from the Catkin and Esquire pegmatites (Wiles, 1961) and K–Ar and Rb–Sr ages of 480 ± 20 Ma and 500 ± 20 Ma on biotite from the Miami Granites (Clifford *et al.*, 1967).

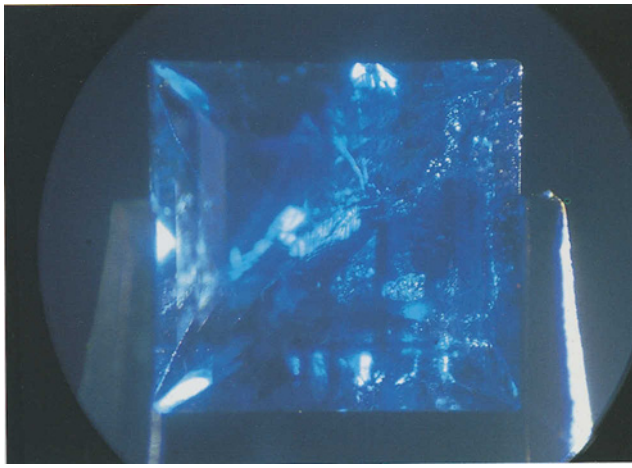

Figure 3: *Faceted euclase, 4 mm across. Photo: S.M. Stocklmayer*

Figure 4: *Faceted euclase of Figure 3 immersed to show the colour distribution. Photo: S.M. Stocklmayer*

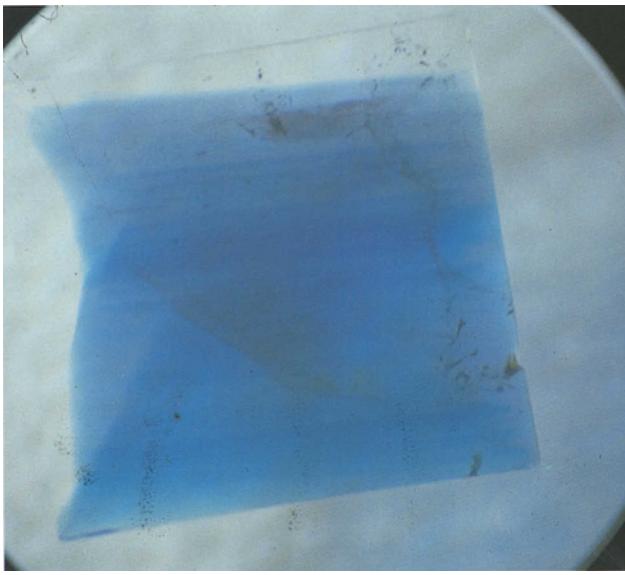

The nature of the mineral content of these pegmatites is complex with source material not only derived from the granites but, in the case of the mica-bearing type, from assimilated country rock. The close association of the economic mica-bearing pegmatites and the nature of the enveloping country rocks demonstrates the metamorphic control. This was noticed by early prospectors and miners who called the country rocks 'kindly' schists which were host to 'mellow' mica-bearing pegmatites. In them, mica often formed large blocks perpendicular to the strike of the pegmatite in the contact and border zones.

Not only are pegmatites composite in derivation but also may contain simple or complex mineral zones. Late pneumatolytic activity, resulting in kaolinization of the feldspars, is considered to have provided a suitable environment for the crystallization of tourmaline, beryl and other species such as the blue topaz (St Ann's claims) and for recrystallization and replacement of pre-existing beryl by secondary euclase. The mineralogical sequence of replacement was described in a preliminary report (Anderson, 1980).

Figure 5: Euclase crystal with mica 'booklet' projecting from base and showing 'hour glass' colour distribution. Photo: S.M. Stocklmayer

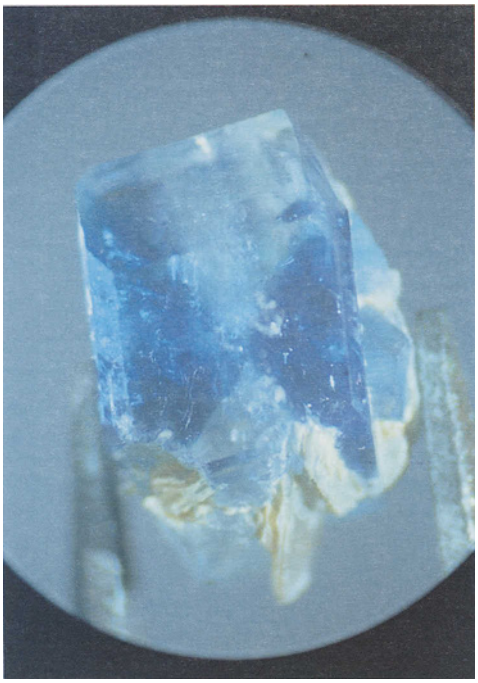

The Last Hope pegmatite, located 8 km SW of Mwame, was first pegged for mining mica sometime soon after 1920. The pegmatite intruded along a normal fault, discordant to the foliation of the host gneiss, and displaced a barren tourmaline pegmatite. Late faulting and movement related to the nearby intrusive Miami Granite produced bent beryl crystals and buckled mica in some local pegmatites and faulting is demonstrable in some of the larger euclase crystals. Small-scale fissuring of euclase crystals has resulted in fractures, later filled with fine-grained mica and iron-stained clay.

During its productive life, the mine was exploited for mica on five levels, the fifth level at 85 m below surface; the longest drive was on the third level and had total length of 347 m. The width of the pegmatite ranged from 1.5 to 4 m. Mining ended in 1959 with a total production of cut mica of 225 tonnes. Only a small amount of beryl, 0.44 tonnes, was declared in 1953 but this may have originated from nearby claims. This production of beryl included blue and yellow varieties; there was no gemstone industry at the time and all production was classed as commercial.

The section of pegmatite from which euclase was collected is a few metres west of one of the old mine shafts. The pegmatite is approximately 2.5 m wide, strikes parallel with the country rocks but dips more steeply. It is simply zoned with marginal areas containing 'fish tail' mica developed perpendicular to the strike of the pegmatite, together with anhedral quartz, iron-stained kaolin and tourmaline. Beryl crystals were located in the core in a matrix of iron-stained kaolin, muscovite and quartz; this zone was also penetrated by 'blows' of quartz. Euclase occurs with the beryl as well as in association with quartz (Fey, 1978).

The euclase samples were extracted loose from soil and overburden by digging, hand-sorting and washing the rubble. Single, doubly terminated crystals and crystal

aggregates were released from the reddish clay soil by washing, while other crystals were loosened from the vugs of massive samples. The excavation was small and covered only a few metres and mining stopped when barren quartz was exposed. The pit was refilled and never reopened. Before these claims were officially pegged and worked, illegal mining at the site accounted for the appearance of samples in 1977 and early 1978.

Crystal morphology

The Last Hope euclase occurs in two distinct habits; in crystal aggregates and massive. Massive euclase is intimately associated with beryl and progressive replacement of beryl by euclase can be demonstrated in a series of petrographic sections *(Figure 1)*.

Euclase in bladed, flattened and blocky habits may be present on the surface of beryl crystals as a sheath. In other samples replacement of beryl has been complete and perfect pseudomorphs have resulted, preserving hexagonal prismatic form; one of these measures 115 mm across. The outer surface of the pseudomorph may also be coated with massive white translucent quartz and white mica *(Figure 5)* and may be cavernous with vugs lined with euclase crystals. Some massive euclase has small straight gashes in the surfaces; these penetrate to a depth of several mm and it seems likely that they were occupied by mica booklets. Feldspar occurs on the surface of some samples but is not common.

The crystals of euclase of this massive type each cover several cm and can be seen surrounding and traversing areas of relict beryl. The remnant beryl has ragged borders and is penetrated by numerous veinlets of euclase in optical continuity, providing clear evidence for progressive replacement of the beryl. These large anhedral euclase crystals commonly contain inclusions of small quartz crystals, perfectly hexagonal prismatic in form and random in distribution, producing a sieve texture. No strain patterns were evident in the enclosing euclase. Mica inclusions are rare, and confined to the veins traversing the beryl or between crystals of euclase.

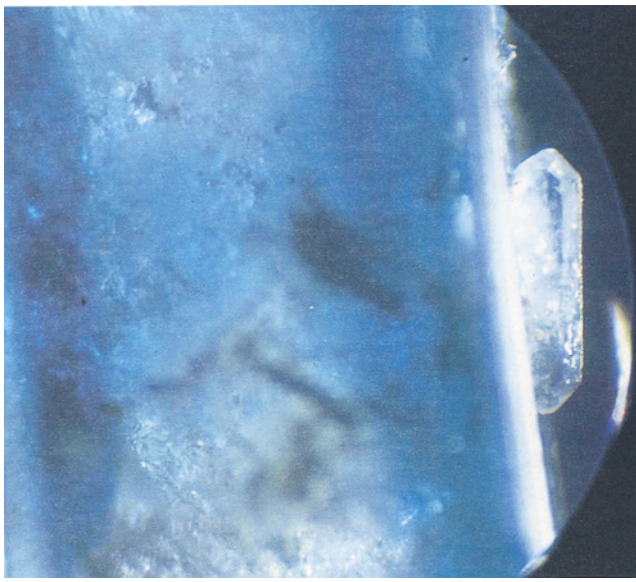

Figure 6: *Euclase crystal with a euhedral quartz crystal on its surface. Photo: S.M. Stocklmayer*

The blue colour of euclase is evident in thin section under plane polarised light (PPL) and pleochroism is distinct from blue to colourless. The blueness occurs in small patches with no apparent pattern to its distribution.

The beautiful specimen crystals of euclase occur commonly as groups of well-formed terminated prisms, patchily transparent and blue with colourless zones. Some of the crystals appear cloudy, with surfaces encrusted with quartz *(Figure 6)*. The development of euclase seems to be partly concurrent but generally later than the quartz; quartz crystals may have an encrustation of euclase and similarly crystals of euclase contain quartz euhedra which comprise the most common mineral inclusion.

The largest well-formed euclase crystal in the group of specimens studied measured 74 mm x 42 mm x 47 mm (*b*-axis); however, this is exceptional and most of the terminated crystals are less than 10 mm in their largest dimension. The deep-blue colour that appeared patchy in thin section may display a coherent pattern in certain

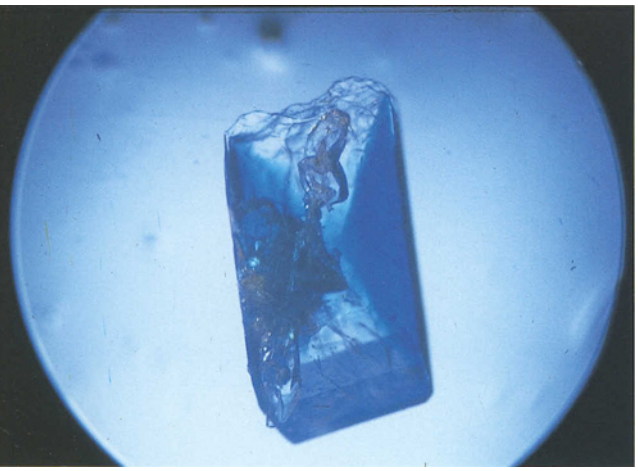

Figure 7: 'Hour glass' colour distribution or zonation in a euclase crystal. Photo: S.M. Stocklmayer

zones of the crystals. The most intense blue is seen as a series of vertical planes, parallel to the a-faces (100) perpendicular to the b-face (010) and diminishing in length towards the crystal centre. Viewed from the direction of the b-face this produces a distinct 'hour glass' colour distribution *(Figures 5 and 7)*. Viewed from the direction of the a-faces a chevron pattern of intense blue is often seen at the crystal apices more or less parallel to the (011/021) prisms (clinodomes).

Figure 8: Complex surface morphology of a zone between the a *and* c *axes of a euclase crystal. The view is taken looking down a and shows the terracing. Photo: R. Huddlestone*

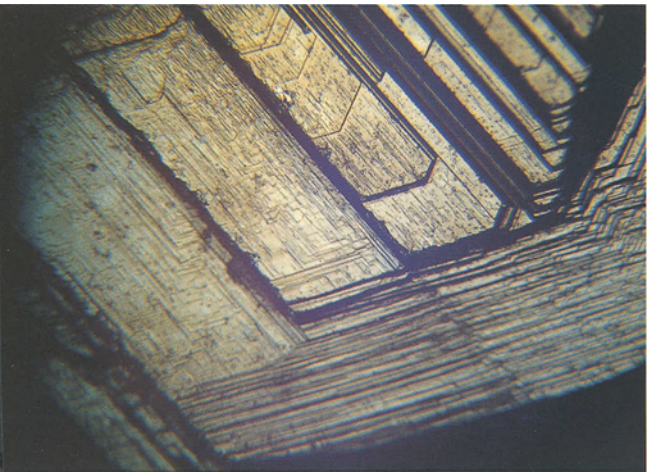

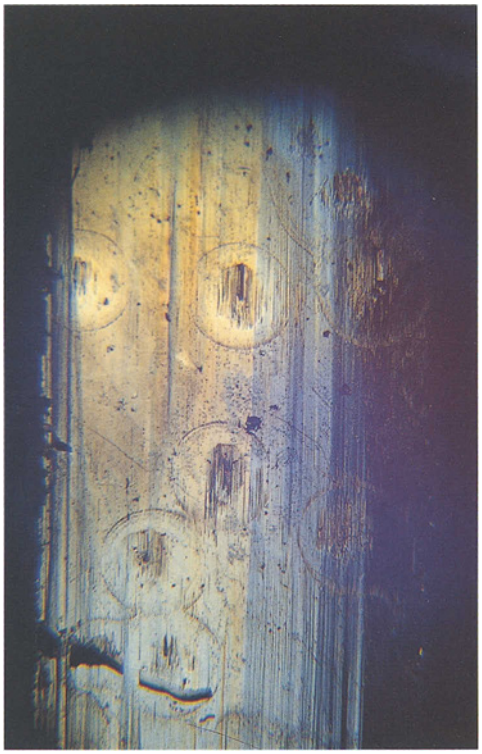

Figure 9: Circular depressions on a (100) face of euclase. Photo: R. Huddlestone

Euclase crystals are monoclinic prismatic in habit, almost equant, slightly flattened parallel to (100) with perfect cleavage (010). Crystals comprise broad pinacoids (100) and (010) and prisms (011) and (021); the latter are usually featureless and unmarked. In contrast the c-zone intergrowths between vertical prisms (hk0) and pinacoids (010) are commonly striated *(Figure 8)*, and in the complex zone between the *a* and *c* crystallographic axes (hkl, h0l) terracing is common. An unusual feature comprising a series of circles with micropit centres was found on the (100) face of one euclase crystal *(Figure 9)*. The circular features may be the result of solution activity.

Terracing has been described in equivalent zones in euclase crystals from

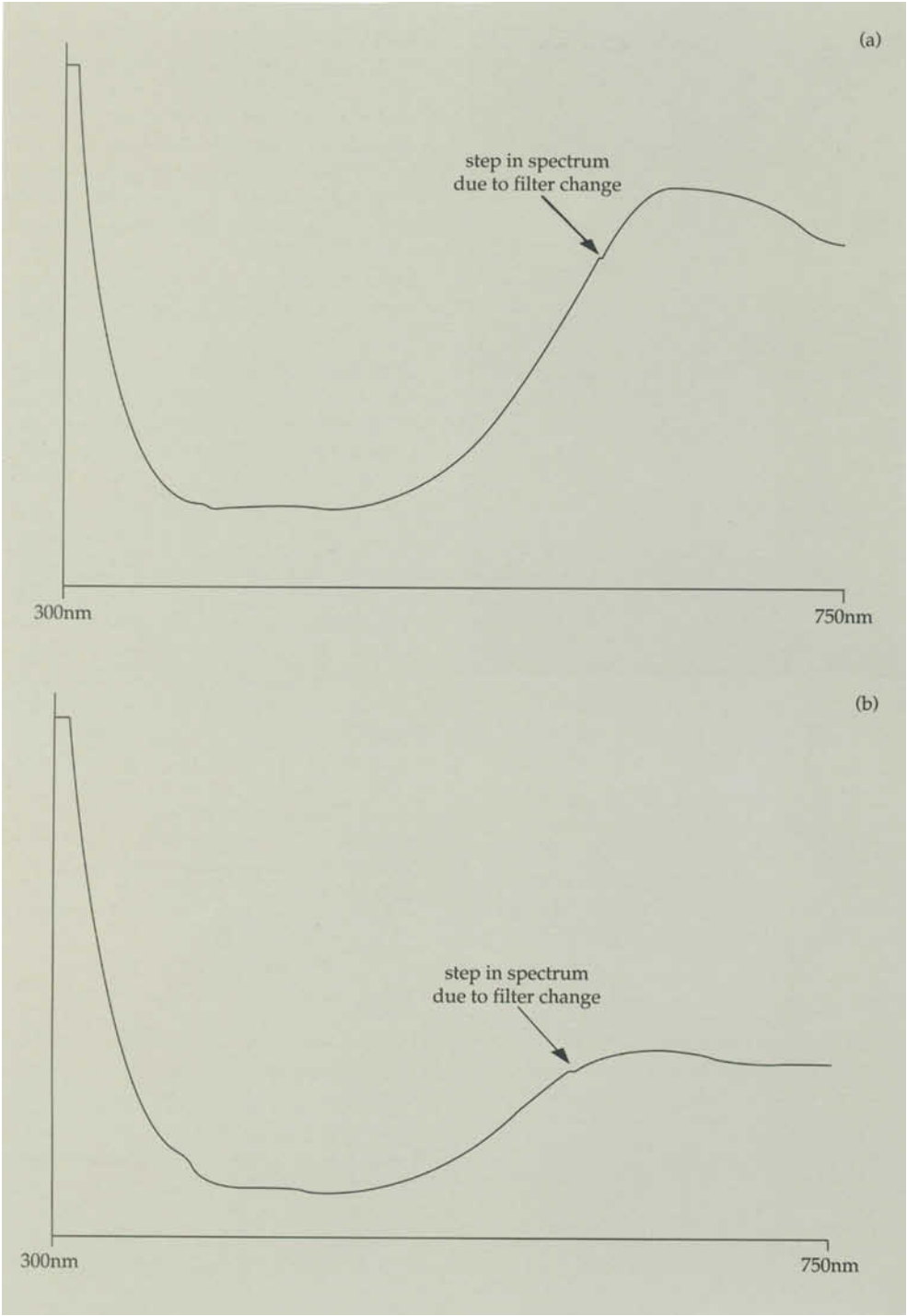

Figure 10: *Absorption spectra (a) parallel and (b) perpendicular to the c-axis of a euclase crystal from the Last Hope mine.*

Figure 11: Slender euhedral quartz crystal inclusions in euclase. Photo: S.M. Stocklmayer

Brazil (Graziani and Guidi, 1980). The terraces have developed parallel to the junctions (hkl)–(hk0) and (hkl)–(100) and contain rows of discrete mineral inclusions. Micro pits are also a feature in the (hk0) faces of some of these Brazilian crystals.

Optical features and chemistry

Euclase crystals are monoclinic, normal class and holohedral, with an axial ratio a:b:c of 0.84:1:1.55. Refractive indices measured on a faceted stone were α – 1.652, β – 1.656, γ – 1.672, all ± 0.001 (Na) with a birefringence of 0.020 which values are within the range recorded by Gübelin (1978). Trichroism is distinct from deep blue, to pale blue to colourless.

Specific gravity was measured in the range 3.06–3.13 (Gübelin, 1978), 3.075 (Anderson, 1980) but the crystals lack mineral homogeneity.

Analysis of euclase from the Last Hope claims using a MAC 5 - SA5 electron microprobe indicates that the blue zones contain 0.06% Fe as FeO; titanium was detected in only one blue zone near detection levels at 0.02% TiO_2 (Mattson and Rossman, 1987). These authors also inferred from a study of the beta-polarized spectrum that the colour can be attributed to charge transfer $Fe^{2+} - Fe^{3+}$ and $Fe^{2+} - Ti^{4+}$ transitions. A 670 nm spectral absorption band was assigned specifically to $Fe^{2+} - Fe^{3+}$ charge transfer.

Gübelin (1978) reported that colourless parts of the crystals contain 0.06% FeO and dark-blue parts contain 0.12% FeO and concluded that trivalent iron is the cause of the blue colour.

No absorption bands were visible in the hand-held optical spectroscope, the spectrum showing transparency in the 450 nm region. *Figure 10* shows the results of a spectrophotometer scan on euclase from the Last Hope. The crystal was positioned first to transmit the light parallel to the *c*-axis and secondly in a position at right-angles to show the results produced by a combination of vibration directions. The broad transmission transparency in the blue region attains a maximum in the range 380–460 nm with a gradual increase in absorption in the red with a maximum in the range 650–670 nm.

Inclusions in euclase

Worldwide sources

There is little published information about inclusions in euclase.

In euclase from Santa do Encoberto, Minas Gerais, Brazil (Graziani and Guidi, 1980), black inclusions of hematite were noted along terraces of the crystal surfaces. Hematite and 'rounded' zircon grains are described as inclusions formed before the euclase, and subhedral opalite and rutile needles are considered as syngenetic. These inclusions were identified using an electron microprobe, as their small size precluded identification by optical means.

Photomicrographs of three-phase inclusions in euclase from Colombia have recently been reported (Duroc-Danner, 1996), and their appearance is reminiscent of inclusions in emeralds from the same country.

From various descriptions of occurrences of euclase worldwide, several pegmatite minerals are described in association with euclase, e.g. fluorite, muscovite, quartz, albite in Norway (Strand, 1953). However, none are reported to occur as mineral inclusions. These reports are of a geological nature where the study of inclusions was not carried out.

Zimbabwe

Gübelin (1978) examined a suite of faceted Zimbabwean euclase and described healed fissures with no particular orientation or distribution and epigenetic 'dry' fissures showing colour iridescence, but noted no mineral inclusions. Photographs of Zimbabwean euclase by Hochleitner (1989) showed crystal faces studded with quartz. The writer noted that only the colourless parts of the crystals are clear and that the blue zones contain liquids that make them cloudy and opaque. All crystals, including those of the finest quality, show colour zonation and this feature together with perfect cleavage (010) are potential problems in faceting the gem. When correctly orientated the faceted gem can appear a uniform blue, but oil immersion reveals the patchiness of the blue colour. Two-phase inclusions are common, but show no preferred distribution. Although terracing is a common feature of the external faces of the crystals, no feature equivalent to axial tubes common in beryl was seen.

Mineral inclusions

The range of mineral inclusions reflects the genetic mineral association of quartz, mica and euclase found in the surrounding rocks.

Quartz

Quartz is the most common inclusion *(Figure 11)*. Clear and glassy crystals, usually doubly terminated, occur clustered on the surfaces of euclase crystals as well as entirely enclosed within as a syngenetic generation of inclusions. These inclusions may form aggregations so dense that the host crystal appears cloudy. In a few crystals they also occur alone or in small groups. No crystallographic control of their distribution is apparent either macroscopically or microscopically.

Mica

The occurrence of white mica commonly encrusting the surfaces of the beryl pseudomorphs has already been discussed. Books of white mica are found on the surfaces of or partly enclosed by euclase crystals. In some crystals, laths of a dark coloured mica were found. Fine-grained white mica and clay minerals occur in fractures and negative crystals but further work is needed to identify the precise species.

Opaque minerals

Three kinds of opaque minerals have been seen as rare inclusions in euclase. Two occur as euhedral-subhedral equant grains, one type with yellow brassy metallic lustre, likely to be pyrite, the other with a grey-silver metallic lustre. In one crystal, dark mica foliae are associated with these grains. Grains of similar appearance were seen in some of the larger quartz crystals that are intergrown with euclase.

The third kind of opaque inclusion consists of groups of dark granules which appear red-brown in reflected light.

Discussion

The intimate association of euclase and quartz is constant and interesting. Their synchronous crystallization indicates that the conditions necessary for their formation are very similar and that some small fluctuations may determine which phase is developed; quartz occurs both as syngenetic inclusions in euclase and as surface encrustations. That the two minerals are physically compatible is shown optically by the lack of strain and stress-induced fissures around the quartz

within the euclase crystals. The surface encrustations are similar to the quartz–epidote–magnetite mineral 'dust' adhering to aquamarine described by Eppler (1963) who suggests temperature fluctuations as the likely cause for the vari-crystal shower.

Mining ceased at the Last Hope claims at the end of 1978. It is likely that further occurrences of euclase will be discovered but prospecting requires careful search by mineral collectors rather than commercial miners.

Acknowledgments

Grateful thanks are extended to Ralph Rea of Zimbabwe, former owner and miner of the Last Hope claims, for the samples loaned for this investigation; Stephen Kennedy at the GAGTL for the spectra of euclase; Alan Jobbins for photographs and Roy Huddlestone for the photographs of crystal surfaces; and finally to Vernon Stocklmayer and Ian Kirkpatrick, former colleagues of the Geological Survey, Zimbabwe, for valuable advice and editorial assistance given in the preparation of this report.

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Further aspects of the history of rose-cut diamonds

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ABSTRACT: The development of rose-cut diamonds in centres such as Antwerp and Amsterdam is discussed. Suggestions for a realistic terminology are made.

Introduction

In the recent treatise on historical diamond cuts (Tillander, 1995), I corrected early, long-lived, misunderstandings regarding the development of the brilliant cut, but did not pay the same attention to the obviously parallel situation with reference to the rose cut. Consequently I spent the summer of 1997 reading everything I could possibly find on this cut.

My prime disclosure is that the rose cut cannot have been developed from surviving primitive hexagons by gradually adding facets. In the Dutch encyclopedia on diamonds of 1908 (Leviticus and Polak, 1908) I found the clear statement that both the hexagonal and square rose cuts had been experimental only and turned out to have been abortive. Consequently neither could have served as a starting point. Max Bauer, writing in 1896 and 1909, and Karl Schlossmacher initially in 1932 in the sequence named 'Edelsteinkunde', were the ones who established the concepts about rose cuts. Ever since, they have been uncritically repeated. It is therefore high time to correct early misunderstandings.

Development of the rose cut

Since the early fifteenth century, beginning in Bruges, the Flemish cutters have been unequalled creators of a great variety of new diamond cuts. Consequently it is likely that they will also have hit on the idea of stepping cleavages and other suitable rough, a trick which, since the mid-sixteenth century, they had successfully performed on crystals not thick enough for perfect table cuts. This stepping was found to disperse light entering from above and consequently to increase the light effects, but also, by trial and error, they went on to create the ideal facetings and proportions.

We may never be able to find out when the prototypes were created, including their original outline and height proportions, if these events coincided with the catastrophic and destructive invasions by the Spaniards. In addition, the following depression forced many cutters to re-establish in Amsterdam and records are often lost in such movements. In these circumstances, serial production of this new cut would have been postponed. This was consequently the beginning of diamond cutting in Amsterdam, but we do not know which of the two competitors will have been in the position to market the full range of rose cuts in large quantities, if not both.

In any case we find that from 1625 rose cuts had already been available for some time. They were, however, simply described as faceted diamonds (faucets by some) and named as rose cuts only by the end of the seventeenth century. This was the reason

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Some notes on Thomas Cletscher 1598–1668

Cletscher was Crown Jeweller to Prince Frederik Hendrik in the Hague, a specialist in gem setting and a financier. In 1625 he began to reproduce diamond cuts in jewellery, which in various ways passed through his hands. For some undisclosed reason he concentrated on the 'new-fangled' rose cuts. Although he omitted mentioning the provenance of the diamonds, Cletscher's collection of drawings fortunately turned out to be the prime and priceless source of reliable information on cuts from 1625 onwards. On his fifty drawings of jewellery with roses he depicts a wide range of roses (sometimes classified into seven types on the basis of facet pattern), every conceivable outline and a great variety of applications, many fairly soon abandoned.

Most pages of Cletscher's notebook have gone astray, but those surviving in the Museum of Boymans-van Beuningen in Rotterdam, suffice as a source of information about early rose-cut jewellery. More details on jewellery of the period can be found in the book *Juwelen en Mensen* by M.H. Gans published in 1961.

why they had only occasionally been mentioned in this period as 'a rose fashioned out of one crystal'. As late as 1673 such a cut was described as 'an oblong, thin diamond with large facets and a flat bottom'. Any earlier documentation of rose cuts has not yet been found. Those rose cuts present in earlier jewellery, such as on the Fellowship Pendant in the Grünes Gewölbe (see Tillander, 1995, p. 54) are now found to be later replacements of some insignificant stones (such replacement was a regular habit also in the Schatzkammer in Munich). At some (so far unknown) stage, rose cutting was obviously introduced also in Amsterdam, but the cutters appear not to have been competitive enough with the Antwerp cutters. When the river Schelde was closed in 1648 Antwerp was forced to rely exclusively on Amsterdam for deliveries of rough. In order to put a stop to Antwerp's supremacy the Amsterdam dealers offered only rejection qualities such as coloured, flawed and hard-to-master goods. The victims of this treatment did not, however, give up. On the contrary, the situation was excellently mastered. First of all the height of the rose had to be substantially lowered, foils were adopted for reducing the effects of off-coloured rough, and finally inclusions were disguised by switching some facet ridges. Contrary to what has been alleged, they retained the full number of facets, except on stones too small to accommodate them. The cutters in Amsterdam simply concentrated on higher quality and larger sizes with near to ideal proportions, but nevertheless continued to produce some stones with irregular outlines. These circumstances prevailed at least until 1668 when there was a generally chaotic market situation and Holland reduced its diamond trade to a minimum. At that time Antwerp would then most likely have found some kind of access to the developing London market for rough of any quality.

The terms Antwerp and Amsterdam as applied to rose cuts were, even though incorrectly defined, relevant, but only for a relatively short period. In practice they differed mainly in that the former were considerably shallower, being described as spread roses. Recently, on a two-day visit to Moscow, I was shown their entire collection of thousands of roses, mostly spread. Not one of them had less than the standard number of facets, obviously with the exception of the exceedingly small ones. On reflection, this is not really surprising because it would take more time to leave open spaces than to apply regular facets all the way round.

The rose cuts were originally based on cleaved dodecahedral crystals. The two halves of the cleaved crystal formed the initial point of departure for the cutter. They resemble consequently the shape of a

flat-bottomed triangular cupola. Quite obviously this called for a pattern of faceting with threefold symmetry. It also explains the variety of regular and irregular outlines which, for weight-saving reasons, followed the outlines of the rough.

With the introduction of brilliant cuts, roses gradually lost their popularity and most of the large ones were refashioned into brilliants. Small roses were mostly used as complementary stones surrounding central brilliant cuts and coloured gems. By the nineteenth century they were already out of date, but occasionally rehabilitated for specific purposes. In Fabergé jewellery about 1900, costly gems were totally excluded and, on visiting the Green Vaults in Dresden, Carl Fabergé will no doubt have been influenced by the specific charm of minor roses, set in succession, and decided to try this arrangement out on his Easter eggs. On Fabergé's platinum and gold egg of 1914 the cost price paid for the extraordinary number of 1782 roses was only 75 kopeks each. Even so, this amounted to only 5 per cent of the total cost of material used in its manufacture. The size of the stones is generally below 1 mm, but there are three larger irregular lozenges on the outsize crown each with six more or less rectangular facets round their bases.

Summary of rose cuts

Rose cuts may be considered in three main categories:

1. *Gothic roses*

   Flat-bottomed diamonds with a great variety of facet shapes, mostly trihedral, created in the early fifteenth century and still popular throughout the sixteenth (see also Tillander, 1995, pp 45–52);

2. *Renaissance roses or rosettes*

   Combination of from 4 to 16 pavé-set and pavilion-based diamonds marketed as complete settings which may easily be fixed on any suitable piece of jewellery (see also Tillander, 1995, pp 87–98);

3. *Baroque roses or simply rose cuts or roses*

   Flat-bottomed, stepped diamonds with triangular facets in threefold symmetry, a crown with six facets coordinating with the outline of the stone and, in principle, 18 facets at the base (see also Tillander, 1995, pp 45, 52 and 54–63).

Conclusion

The ultimate reason for this paper is, however, to influence the gemmological institutions the world over in their use of suitable terminology when referring to rose-cut diamonds, to refrain from unhelpful or even incorrect statements such as 'originating in India', 'double roses' or 'rounds only'.

There is also no sense any longer in naming roses Antwerp or Holland roses, since at times both centres delivered whatever type their customers were looking for. It is far clearer and more understandable to describe a rose as high or spread.

In future, gemmologists should be able to correctly name most historic cuts and give full exposure and value to their interest as collectors' items.

I finally suggest that both gemmologists and historians refrain from using the trade vernacular 'polished'. In most other languages polishing stands for 'the final touch on the scaife'. Several authors have already replaced 'polished' with 'fashioned' or 'faceted'. Neither of these latter terms can be misunderstood.

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Kyanite in diamond identified by Raman analysis

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ABSTRACT: This paper describes the identification of kyanite and garnet as inclusions in a round brilliant-cut diamond. Kyanite is a very rare inclusion in diamond, and this is the first time Raman analysis has been used to make such an identification. It is an effective analytical technique and both the host diamond and inclusions remain undamaged.

Introduction

In 1994, during the routine examination of a 0.65 ct round brilliant-cut diamond to determine its clarity grade, gemmologist Gary Roskin of Los Angeles, California, noticed what appeared to be a small blue crystal inclusion just under the table facet near the edge of the diamond's crown. Since this was the first blue mineral inclusion in a diamond that he had seen, he contacted one of the authors (JIK) and, with the permission of the owner, submitted the gem for further examination.

Under magnification it was noted that the diamond actually contained three blue crystals ranging in size from 0.15 to 0.42 mm in largest dimension. The diamond also contained several transparent colourless crystals and an orange crystal measuring 0.3 mm in length. While the two smallest blue crystals were very pale in colour, the largest one showed a rather intense blue when viewed at a slight angle to the plane of the table, through the edge of the crown *(Figure 1)*.

Polarized light microscopy revealed that the blue crystals were doubly refractive, as were the colourless crystal inclusions. But no signs of double refraction were observed in the orange crystal. The pleochroism of the largest blue crystal was weak, showing blue and violet. Previous descriptions in the literature (Prinz *et al.*, 1975; Meyer and Tsai, 1976) indicated that this inclusion might be kyanite, which is a very rare inclusion in diamond. It was also thought that the isotropic orange crystal was a garnet and, if both these interpretations proved to be correct, it is likely that the diamond came from an eclogite.

By coincidence, N. Sobolev from Novosibirsk, Russia, was visiting the GIA and was able to examine the stone. He also concluded that in all probability the blue crystals were kyanite and that the orange

Figure 1: *This 0.42 mm blue inclusion in diamond was identified as kyanite by laser Raman microspectrometry.*

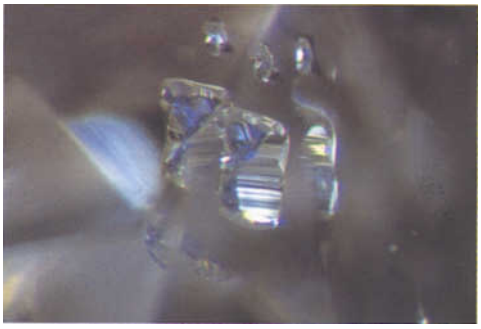

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crystal was an eclogitic garnet. He based this conclusion on his observations of similar-appearing kyanites he had examined from xenoliths of eclogite and grospydite (a rock composed of *gros*sular *py*roxene and *di*sthene – or kyanite). Sobolev also stated that this diamond was a significant stone because of its inclusions and suggested that the diamond be purchased for destructive analysis, to determine if the blue inclusions were in fact kyanite. Such analysis procedure would require burning the diamond away in oxygen, or some other destructive technique, to free the mineral inclusions so that they could then be identified.

A price was settled on and the stone was purchased from the pawn shop that owned it in Kenmore, New York. However, since a very strong case for rarity had been made, it was decided that the stone would not be destroyed but would be held intact until the technology needed to identify the inclusions non-destructively became available at the GIA. With the recent acquisition of a Renishaw Raman Imaging Microscope System the non-destructive identification of the inclusions in this diamond has now become possible.

Experimental

In preparation for laser Raman micro-spectrometry with the Renishaw system, the diamond was first cleaned in acetone and then carefully examined under magnification. This was done to determine which of the blue inclusions was closest to the surface, and which orientation of the stone would be the most advantageous for the analysis. It is an advantage to direct the laser as near perpendicular to a facet as possible so that its traverse through the host gem to the inclusion is as short as possible.

As it was relatively near the surface (less than 1 mm) and it presented a large blue-coloured target area through the edge of the crown, the largest blue inclusion was chosen for Raman analysis. The diamond was placed in a special mount on a glass microscope slide with the chosen target area of the diamond in parallel alignment with the plane of the glass slide. This allowed the inclusion to be focused with minimum risk to the surface of the 50x objective lens of the Leica targeting microscope.

Using the continuous scan feature, the Raman system was set up for 10 complete scans of the inclusion. The 514 nanometre argon ion laser was used to obtain the Raman spectrum shown in *Figure 2*. The search programme was then employed using the Raman software in conjunction with the Renishaw digital spectral library. The computer selected a spectral match for kyanite.

As a back-up to this result, to ensure the integrity of the identification, a cabochon of kyanite was also analysed with the Raman system using the same laser strength and the same number of scans. Once again the computer match from the Renishaw digital spectral library was for kyanite. The resulting spectrum obtained from the cabochon is shown in *Figure 3*. The strengths of the major peaks for kyanite vary slightly due to the host's matrix effect in the case of the inclusion, and the difference in optical and crystallo-graphic orientation between the cabochon and the inclusion. However, all the major kyanite peaks are present, and their positions are identical, proving that the largest blue inclusion in this diamond is kyanite.

To complement the genetic picture of this diamond, the orange isotropic crystal *(Figure 4)* was also examined with the laser Raman microspectrometer. The result of this analysis confirmed what was already suspected, that this inclusion was a garnet, and its orange colour is a strong indication that the host diamond is eclogitic rather than from a peridotite (where the associated garnets are chrome pyrope and pale to deeply coloured red to purplish-red).

Conclusion

Kyanite is the high-temperature, high-pressure member of the trimorphous mineral group of kyanite, andalusite and sillimanite. It is known to occur in diamondiferous eclogites and on this basis it is not surprising to find kyanite as an inclusion in diamond.

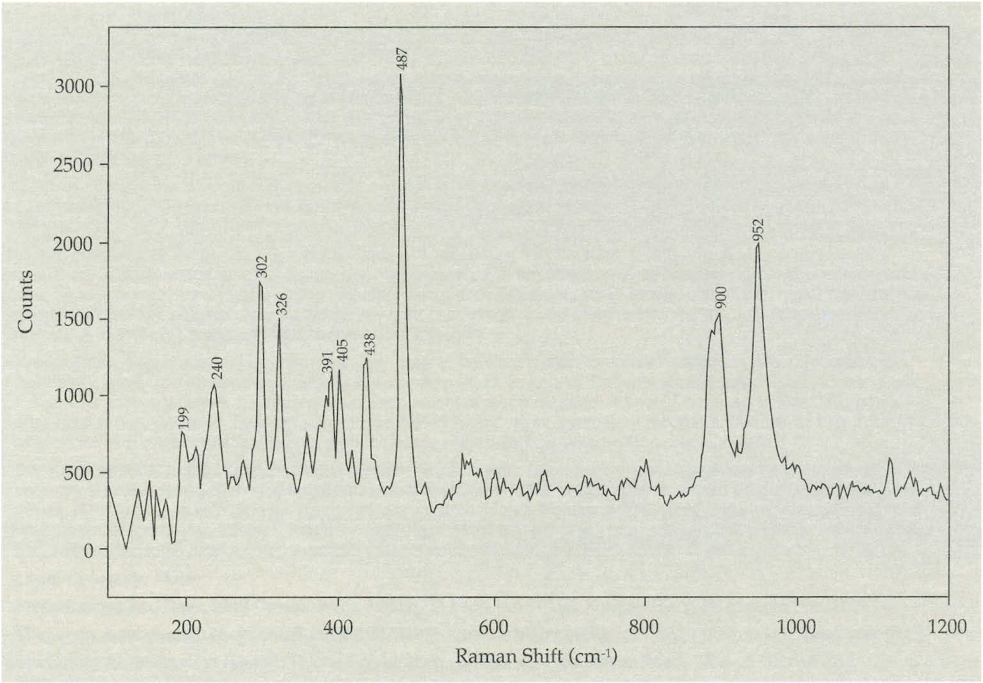

Figure 2: *The Raman spectrum obtained from the kyanite inclusion shown in Figure 1.*

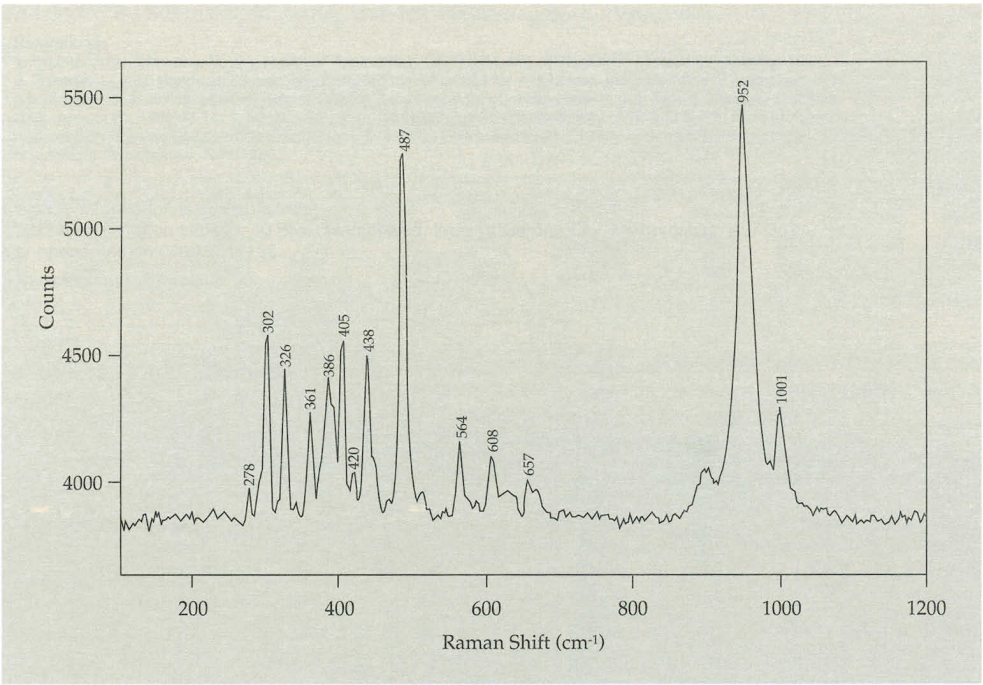

Figure 3. *Raman spectrum from a kyanite cabochon used as a reference standard.*

But kyanite in diamond is apparently very rare. This rarity may be partly illusory and due at least in part to the fact that the smaller the inclusion of kyanite in diamond, the lighter it is in colour, to the point that the smallest appear colourless. This fact is well demonstrated by the inclusions in the diamond described in this paper. This size-to-colour dependence would make smaller kyanite inclusions very difficult to recognize. Since most mineral inclusions in diamonds are quite small, some kyanite inclusions have probably been overlooked because they are so small and lack a distinctive colour.

The authors were able to find only two previous reports of such an occurrence. The first description is provided by Prinz *et al.* (1975) who reported a crystal of about 1 mm in size exposed on the surface of a cut stone from an unknown locality. According to Meyer and Tsai (1976) this identification '... must be viewed with caution,' however, because 'Unfortunately, the identification by Prinz *et al.* was of the kyanite on a cut surface of a diamond'. In the second description, Harris and Gurney (1979) reported finding a kyanite inclusion in a diamond from the Premier Mine.

This paper also shows that it is possible, in certain instances, to identify mineral inclusions in a diamond without burning, cutting, grinding or breaking the host to expose an inclusion at the surface, which has been a necessary practice in research for many years. Raman analysis, however, is by no means the complete answer to inclusion investigation. If inclusions are too deep in their host then they cannot be identified in this manner. Laser Raman microspectrometry also does not give details of chemistry comparable with those from an electron-microprobe, and it cannot provide precise structural information like that provided by X-ray diffraction. However, it does leave the host intact to be re-examined and enjoyed at any time in the future.

Figure 4. *Reflected three times, and measuring only 0.12 mm, this orange garnet is in the same diamond as the kyanite.*

Acknowledgements

The authors extend their thanks to Gary Roskin for calling our attention to this unusual diamond. This study would not have been possible without the generous support of Mike Scott of Los Altos, California, for his donation of the Renishaw Raman Imaging Microscope System.

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Tourmaline: morphological and compositional variations during the growth history of uvite single crystals

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ABSTRACT: Surface microtopographs of crystal faces, internal textures and associated compositional variations have been investigated on single crystals of uvite from Brumado, Bahia, Brazil. From the surface microtopographic observations of major faces, it is demonstrated that the uvite crystals grew by the spiral growth mechanism, and the growth rate in the positive direction was about twice as high as in the negative direction. Based on the investigations of internal textures including growth sectors, sector boundaries and growth banding, the morphological and compositional evolution during the whole growth history was analysed, and four stages where morphological changes took place were distinguished. In the first stage, crystals were bounded principally by r and r′{10$\bar{1}$1}, but in the second stage [010], [110] and [100] sections (probably corresponding to either r and r′ or r and m, m′ {10$\bar{1}$0}) appeared, which was associated with an increase of Mg contents. The appearance and development of a{11$\bar{2}$0} faces at the third and fourth stages were associated with a decrease of the uvite component. At the earlier stages of growth, the uvite component was high, and the dravite component increased in the later stages, reflecting compositional changes of the fluid formed by the action of granitic fluids on the original carbonate rocks. There was no partial dissolution at any period during the growth history nor was there any excessive increase of the driving force at the latest stage, and the whole growth proceeded and terminated rather gently.

Keywords: compositional variation, growth history, growth mechanism, morphological evolution, single crystal, tourmaline, uvite

Introduction

Tourmaline is a mineral which typically shows morphological, compositional and colour changes during its growth history. In sections cut perpendicular or parallel to the elongation of a prismatic crystal of elbaite of pegmatitic origin, such changes are typically seen in the form of sector or colour zoning and growth banding. Beautiful examples may be seen in the monograph by Benesch (1990).

Tourmaline is also a representative polar, hemimorphic crystal. It shows different development of faces in positive and

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negative directions of the *c*-axis. Usually one end is terminated by trigonal pyramidal faces, whereas the other end is characterized by a basal face. One may often find a group of tourmaline crystals all pointing in the positive direction or all in the negative direction, but only rarely does one find a group with the two directions coexisting. In previous works on polarity of tourmaline crystals, somewhat controversial observations have been reported; some papers reported that the growth rates were higher in the positive direction, whereas other papers reported the higher growth rates for the negative direction (Dietrich, 1985). It is known that surface microtopographs of crystal faces can tell much about growth mechanism and the difference of growth rates in different directions (Sunagawa, 1988b), but such investigations on tourmaline have not been reported so far.

Tourmaline crystals typically showing morphological, compositional and colour changes in a single crystal, such as elbaite crystals of pegmatitic origin, usually have an elongated prismatic habit bounded by heavily striated vicinal prism faces, and the terminal faces are often corroded. These make elbaite crystals unsuitable for detailed observations of their as-grown features. Crystals formed in pegmatitic environments have usually been subject to repeated partial dissolution and re-growth processes during their growth histories. The evidence for such processes has been found in various pegmatitic minerals, e.g. beryl, topaz and quartz (see, for example, Sunagawa, 1982, 1984a, 1988a; Scandal, 1996), and pegmatitic tourmaline is no exception. It is probably due to this fact that the growth mechanism and process, as well as morphological and compositional changes of tourmaline crystals through their growth histories, have so far not been investigated in detail.

Uvite is the Ca end member of the dravite $[(NaMg_2Al_6B_3Si_6O_{27}(OH,F)_4]$ – uvite $[CaMg_3(Al_5,Mg)B_3Si_6O_{27}(OH,F)_4]$ series (Dunn, 1977). Dravite and uvite form a continuous solid solution through the coupled substitution $Na^+ + Al^{3+} \leftrightarrow Ca^{2+} + Mg^{2+}$, although the pure end member uvite has not yet been reported. The composition is expressed in mole ratio of uvite and dravite end members. Although there is a report that Fe can be a component of this series, the name uvite is, in this paper, applied to those compositions with Ca > Na, since no Fe was detected in the samples.

Uvite crystals typically exhibit a flat rhombohedral (equant) to short prismatic habit terminated in both positive and negative faces. They show similar internal textures to those observed in elbaite. Uvite typically occurs in carbonate rocks contact metasomatized by an intrusion of acidic (granitic) magma (Dietrich, 1985) where the crystals often occur as isolated single crystals, not in a group. Such crystals are suitable for detailed investigations of their surface microtopographs and internal textures. In this paper, we report the results of investigations on the external morphology, surface microtopography of crystal faces, morphological and compositional evolution during the growth history of uvite single crystals from Brumado, Bahia, Brazil, purchased from a mineral dealer in Belo Horizonte. Altogether 15 crystals were investigated.

We intended to analyse how and by what mechanism the uvite crystals grew and how morphological and compositional evolution took place in the contact metasomatic environment. The methodology and results of the present analyses may be applicable, in essence, to the features commonly observed in other elbaite crystals of pegmatitic origin.

Crystal morphology and polarity

The uvite crystals are brownish-green in colour in transmitted light. They occur as doubly terminated and isolated single crystals with a flat rhombohedral (equant) to short prismatic habit bounded by well developed positive and negative trigonal pyramidal faces, $r\{10\bar{1}1\}$ and $r'\{01\bar{1}\bar{1}\}$, second-order prism faces $a\{11\bar{2}0\}$, and a basal face, $c'\{000\bar{1}\}$. Much smaller $m\{10\bar{1}0\}$ and $m'\{01\bar{1}0\}$, $o'\{02\bar{2}\bar{1}\}$, $e'\{01\bar{1}\bar{2}\}$, and $t'\{21\bar{3}\bar{1}\}$ faces are also associated *(Figure 1a)*. The well developed crystal faces are macroscopically

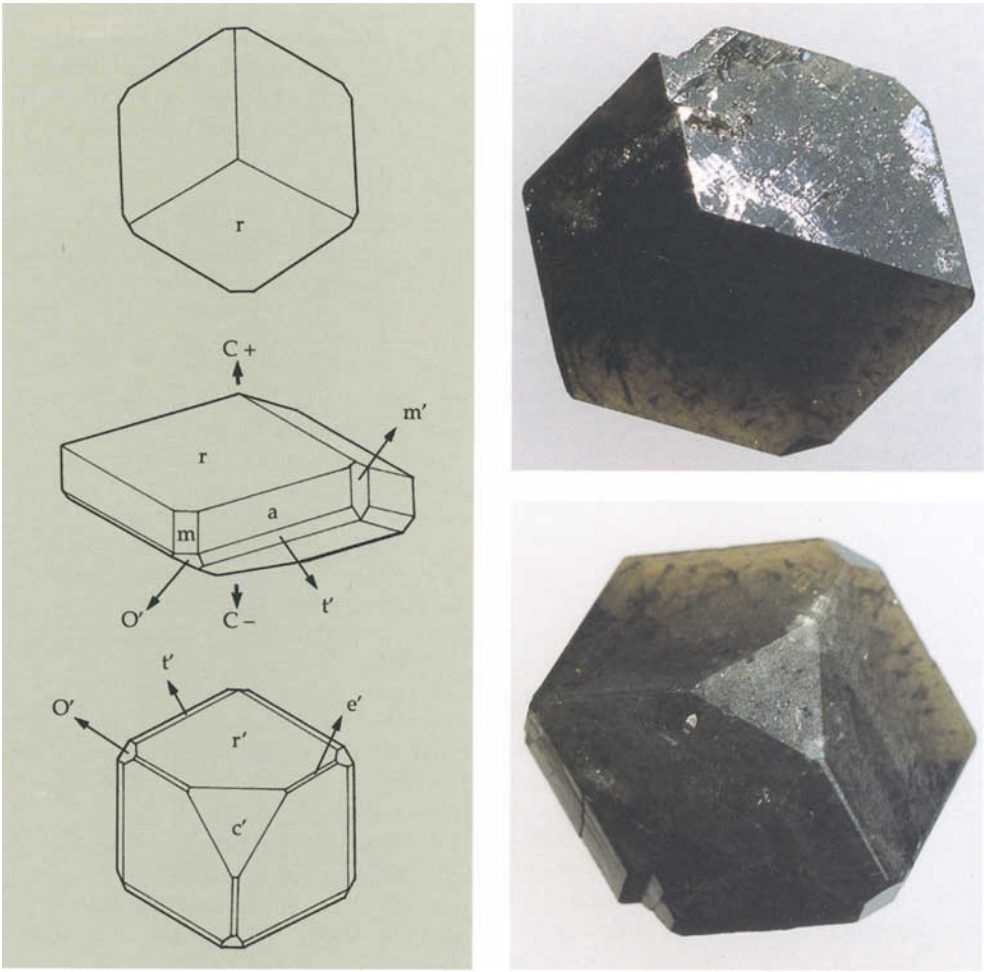

Figure 1: (a) Crystal figures. Orthogonal projection of positive (top) and negative (bottom) terminations, and (centre) clinographic projection. (b) Close-up photographs of positive (top) and negative (bottom) terminations of a crystal.

flat or striated, but microscopically show growth step patterns resembling the contour lines on a geographical map.

The polarity of the crystal was identified by Kundt's method (1883). Three r{10$\bar{1}$1} faces appear on the positive termination, whereas on the negative termination c′{000$\bar{1}$} and three r′{01$\bar{1}\bar{1}$} faces appear. The prism zone consists of six well-developed, flat a{11$\bar{2}$0} faces and six much smaller m and m′{10$\bar{1}$0} faces. *Figure 1* shows the crystal figure and close-up photographs of a uvite crystal showing positive and negative terminations.

Tiny rhombohedral magnesite crystals are the only paragenetic mineral, suggesting a contact metasomatic origin of the specimens.

Surface microtopography

The surface microtopographs of all faces were observed by the differential interference microscope (DIM), which can reveal growth steps with step heights of the order of nanometers (Sunagawa, 1988b). The surfaces were coated with silver under vacuum to secure high reflectivity so that steps of one nanometre height could be observed.

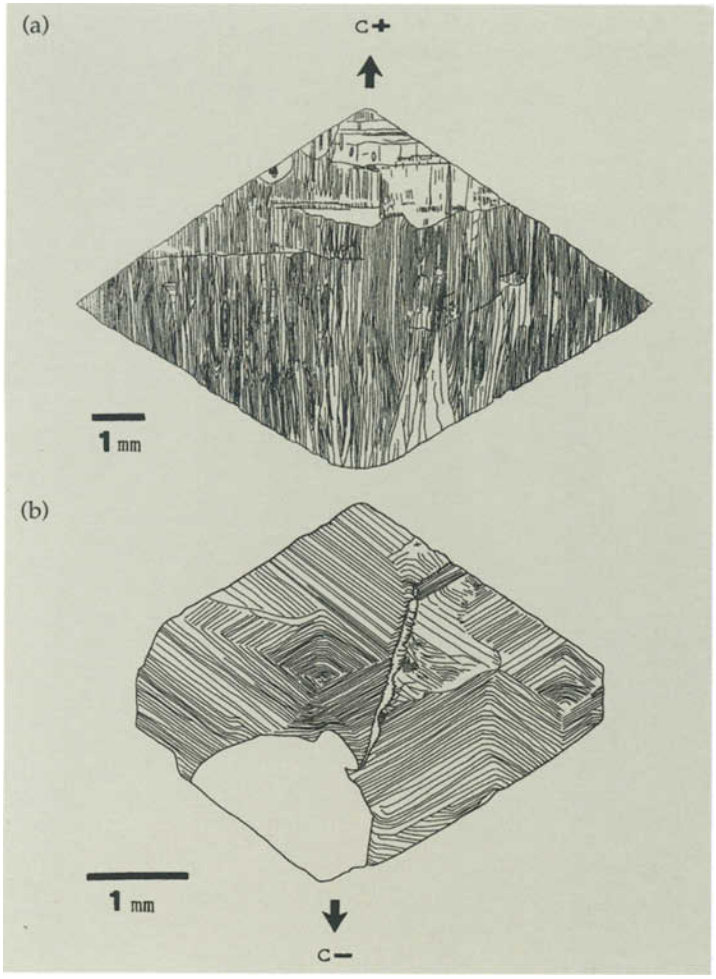

Figure 2: *Surface microtopographs of positive (a) and negative (b) trigonal pyramidal faces, r and r′; sketches prepared based on microscopic observations at low magnification.*

Trigonal pyramidal faces, r{10$\bar{1}$1} and r′{01$\bar{1}\bar{1}$}

Positive and negative trigonal pyramidal, r and r′, faces exhibit markedly different surface microtopographs, as can be seen in *Figure 2*. Although positive trigonal pyramidal r faces appear macroscopically as striated faces, they are microscopically featured by the development of growth hillocks having a very elongated spindle form with an aspect ratio larger than 10, whereas negative faces have a smaller number of growth hillocks with rhombic form concordant with the edges of the face. All of these features are as-grown features, and dissolution features, such as etch pits, were not observed.

Growth hillocks on positive r faces are elongated parallel to the shorter diagonal of the face, i.e. [211], which is the reason for the macroscopic appearance of striations. Under high magnification, they can be seen to be elongated growth hillocks, with plateau tops. On such plateau tops, a number of extremely thin circular growth steps are discernible, aligning in the direction perpendicular to the elongation of the growth hillock, i.e. in the [010] zone. Some of the circular growth steps show spiral patterns with a half or a couple of turns. This is seen in a high-magnification DIM photograph, *Figure 3a*, and the corresponding sketch, *Figure 3b*, where circular steps are indicated by arrows. Although the

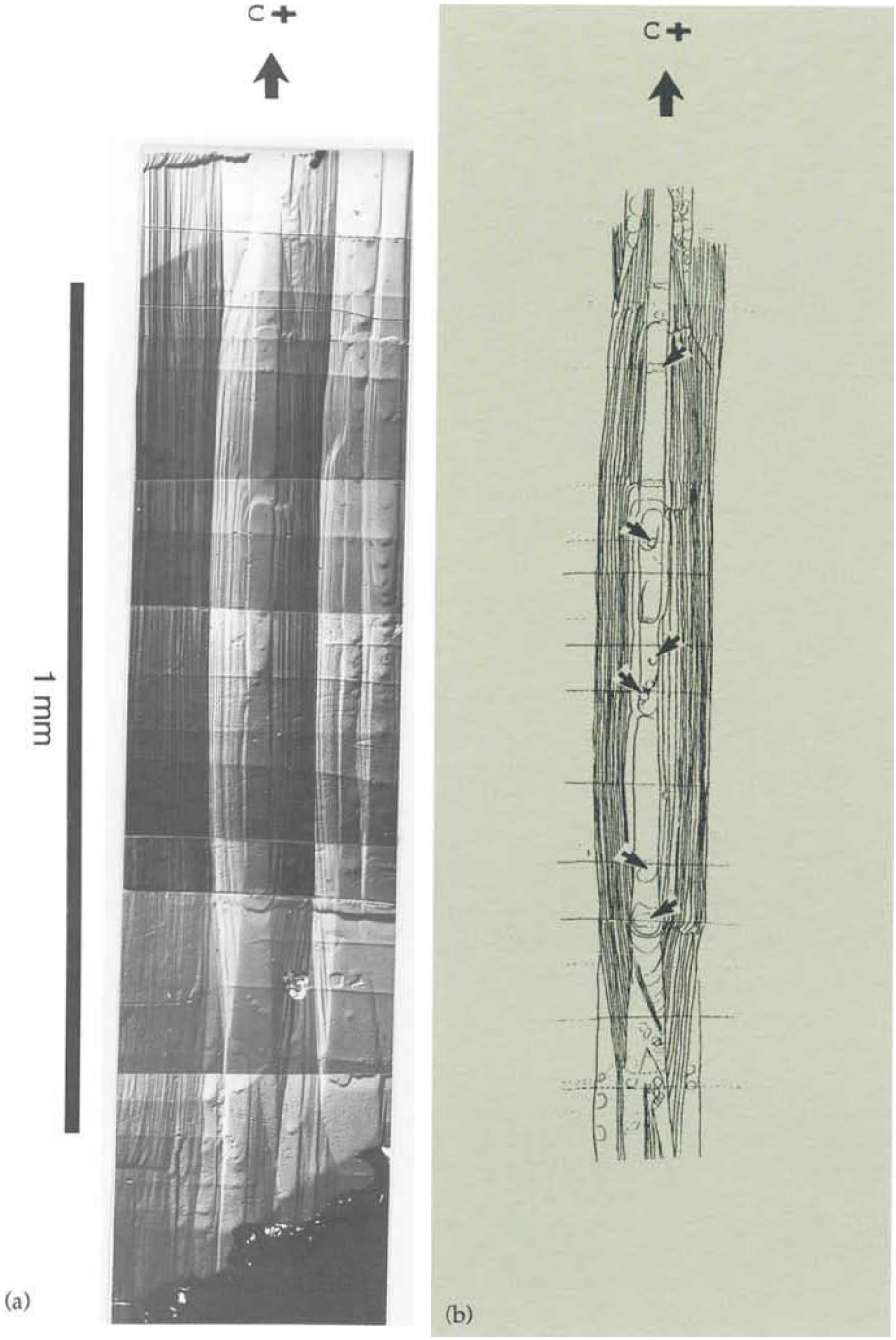

Figure 3: *(a) High-magnification photomicrograph taken on a differential interference microscope (DIM) showing growth hillocks on a positive trigonal pyramidal r face, and (b) the corresponding sketch. Small arrows indicate elemental circular growth steps. Straight lines are faint cracks running perpendicular to the elongation of growth hillocks.*

height of the circular growth steps could not be measured directly, it is safe to assume that they are elemental steps with the height of the $d\{10\bar{1}1\}$ lattice spacing, judging from the visibility under DIM (Sunagawa, 1988b).

On the side slopes of elongated hillocks, growth steps are seen with an average step separation of 2.6 µm, whereas the average step separation in the elongation is 11.3 µm. It follows from these observations that the positive trigonal pyramidal r faces grew most probably by the spiral growth mechanism, and that elemental growth spirals took a circular form, rather than polygonal or elongated spindle forms at their centres. The elongated spindle form of the growth hillocks develops through interaction and merging of circular growth spirals.

In contrast to the above, on the negative trigonal pyramidal r′ faces, rhombic growth hillocks are seen. The hillocks show plateau tops, with two sides which are steeper toward the direction of negative polar axis and two gentler sloping sides in the positive direction. Even on the steeper side, the average step separation is more than 5 µm, more than twice that on the positive trigonal pyramidal r faces. It was not possible to confirm the presence of elemental growth spirals on the plateau top, but it is reasonable to assume that the growth hillocks are spiral hillocks from their morphologies.

Circular or rounded morphology of growth steps on positive trigonal pyramidal r faces in contrast to the rhombic morphology on negative trigonal pyramidal r′ faces, and twice the average step separation on r′ compared with r can be taken as an indication that the growth rate in the positive direction was more than twice that in the negative direction.

Prism faces, a{11$\bar{2}$0} and m and m′ {10$\bar{1}$0}

The second-order prism faces a{11$\bar{2}$0} develop as much larger faces than the first-order prism faces m and m′{10$\bar{1}$0} *(Figure 1)*. On the a{11$\bar{2}$0} faces, rectangular growth hillocks are seen, whereas the m and m′ faces show either simple striations or undulating surfaces with no step pattern. Rectangular growth hillocks on the a{11$\bar{2}$0} faces are

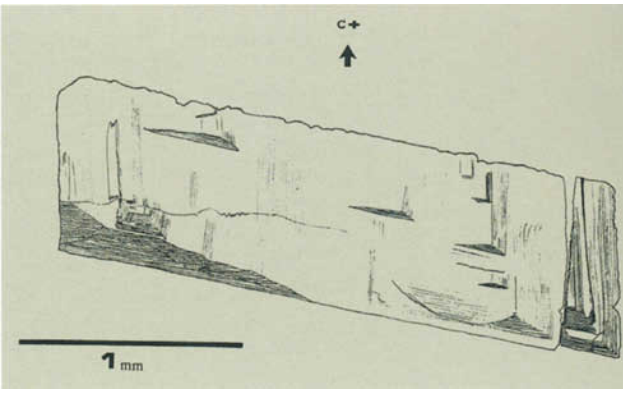

Figure 4: *A sketch of growth hillocks on an a(11$\bar{2}$0) face.*

concordant with the outline of the face *(Figure 4)*; they exhibit gentler sloping sides towards the positive direction and steeper ones in the direction of the negative axis which is towards the edge with the neighbouring m or m′ face *(see Figure 4)*.

Basal face, c′{000$\bar{1}$} and minor faces

The basal face is an undulating face with many polygonal cavities resulting from detachment of magnesite crystals, and does not show any step patterns. Other minor faces, o′{02$\bar{2}\bar{1}$}, e′{01$\bar{1}\bar{2}$}, t′{21$\bar{3}\bar{1}$} are rough, showing no step patterns.

Internal textures

Method of observation

Sections perpendicular to and parallel to the c-axis of a crystal were prepared to observe internal textures under a polarizing microscope, and to investigate variations in chemical compositions using an electron probe micro analyser (EPMA). Both point analyses (at 7 points) and line scans along six lines were made on the two sections.

Section perpendicular to the c-axis

More than 40 photomicrographs were taken to prepare a mosaic photograph to visualize the internal textures. Each photograph was taken at a slightly rotated position from the extinction to reveal the

Table I: EPMA point analyses of a uvite crystal together with gemmological data.

Stage	*1*	*2*			*3*		*4*		
Point	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*
wt %									
SiO_2	37.45	37.63	37.39	37.71	37.45	37.28	37.93	36.01	36.17
TiO_2	0.57	0.53	0.60	0.52	0.64	0.48	0.52	0.55	0.66
Al_2O_3	29.54	28.61	28.84	28.80	28.45	28.49	30.29	26.36	28.87
Cr_2O_3	0.08	0.06	0.07	0.06	0.04	0.03	0.08	—	—
FeO	0.06	0.02	0.02	0.02	0.07	0.05	0.01	0.49	1.65
MnO	0.00	0.03	0.00	0.01	0.00	0.01	0.00	—	—
MgO	13.36	14.00	13.76	13.49	13.84	13.52	13.16	14.90	12.23
NiO	0.01	0.00	0.00	0.05	0.02	0.00	0.00	—	—
CaO	4.15	4.53	4.23	3.79	4.10	3.62	2.65	5.09	2.81
Na_2O	0.66	0.53	0.63	0.74	0.67	0.76	1.18	0.35	1.26
K_2O	0.02	0.03	0.01	0.00	0.00	0.00	0.02	—	—
Total	85.90	85.97	85.55	85.19	85.28	84.24	85.84	83.75	83.65
Uvite %	78	82	79	74	77	73	56	91	50

NB: Corresponding growth stages 1 to 4 are shown. Positions of analytical points are shown in *Figure 5*.
8 and 9 show maximum and minimum data of uvite component in Dunn (1977).
Contents of B, F, OH were not determined.

RI: 1.610–1.628
SG: average 3.04
Fluorescence: inert
Chelsea colour filter: red
Magnification: magnesite inclusions, liquid film

Birefringence: 0.018
Pleochroism: dichroic (strong) green, yellowish-green
Spectroscope: Cr lines are difficult to discern

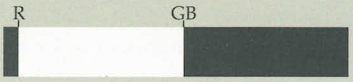

internal texture most clearly. This procedure was necessary because optical properties, including extinction angles, vary from point to point even in a single crystal. This phenomenon in tourmaline crystals was reported as early as in the last century (Madelung, 1883), and more recently investigated by Foord and Mills (1978). Such variations in optical properties within a single crystal have been attributed to crystal growth processes, which itself is an interesting problem for further investigation. The problem has been treated in terms of 'vicinal sectoriality' by Chernov (1984), or 'intrasectorial zoning' by, for example, Scandal (1996), but we shall not deal with this problem in the present paper.

Since the internal textures revealed on the mosaic photograph are too faint to be reproduced, only the corresponding sketch of the observed internal texture is presented in *Figure 5*. Boundaries of growth sectors (a sector formed by the growth of a particular face) and their changes during the growth history, as well as growth banding in some sectors are discernible under the microscope. From the observed pattern, there are three distinct features relating to the growth process of the uvite crystal.

First, there is no peripheral mantle portion with fibrous texture. Such mantles are common in pegmatitic tourmalines and their fibrous texture has been attributed to a rapid increase of driving force with a

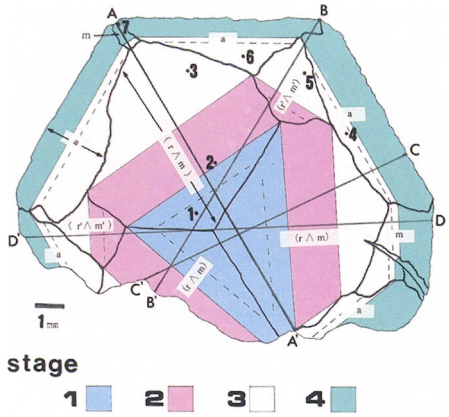

Figure 5: Internal textures (growth sectors, sector boundaries, directions of growth banding and growth stages) seen in a section perpendicular to the c-axis. Growth stages are shown by different colours, growth banding by dotted lines, and other boundaries by solid lines. Numbers correspond to analytical points in Table I. *A–A′, B–B′, C–C′ and D–D′ are line scans. Arrowed solid lines indicate ranges of respective growth sectors, a, r + m, r′ + m′.*

consequent increase in growth rate and associated morphological changes at the final stage of crystallization (Sunagawa, 1984a,b, 1988a); this is a feature also commonly observed in the phenocrysts of volcanic rocks and in coated diamonds. Lack of a fibrous mantle in the uvite crystals is an indication that crystal growth proceeded rather gently from beginning to end of their growth history, keeping the polyhedral morphology. This indicates that there was no abrupt change in the growth parameters at the latest stage, which might have induced a drastic change of morphology from polyhedral to dendritic.

Secondly, no rounded discontinuous boundaries which intersect growth sectors were seen. This indicates that there were no periods of intermittent partial dissolution during the growth process of the uvite crystals.

Thirdly, from the sequence of changes in growth sector boundaries and growth banding, the following four stages have been distinguished. The morphological evolution during the growth history of the uvite crystals may also be correlated with changes in their compositions.

1. The earliest stage 1, i.e. the central portion of the crystal, is characterized by a triangular outline bound by [010], [110] and [100] directions. In this stage, the most developed faces were positive and negative triangular pyramidal r and r′ faces, and the habit was rhombohedral. Whether or not m and m′{10$\bar{1}$0} faces were present cannot be concluded from this section only, but certainly no a{1120} faces were present.
2. The second stage takes a hexagonal outline, bounded by [010], [110], [100], [100], [010] and [110] directions. It is not certain whether the six sectors corresponding to positive r and negative r′ trigonal pyramidal growth sectors alone, or whether they are associated with the growth sectors of m and m′{10$\bar{1}$0} faces.
3. The third stage takes a 12-sided outline, characterized by the development of a{11$\bar{2}$0} faces.
4. In the final stage 4, narrow growth sectors corresponding to smaller m and m′{10$\bar{1}$0} faces appear, in addition to the a{11$\bar{2}$0} growth sectors.

Compositional variation

Table I gives the results of point analyses in the cross-section, together with corresponding growth stages, reference chemical data and gemmological data. The contents of the major oxides, SiO_2, Al_2O_3, MgO, CaO and Na_2O, and uvite mole % are given. It can be seen in *Table I* that Ca and Mg show concordant variation, whereas Al and Na show reverse variation with Ca and Mg, indicating coupled substitution. *Figure 5* shows the analysis points and where the EPMA line scans (A–A′, B–B′, C–C′, D–D′) were carried out.

Figure 6 shows relative variation in contents of Mg, Ca and Na along each scan compared with the centre. From these variations, changes in uvite mole ratios have been calculated. From *Table I* and *Figures 5* and *6*, we note the following:

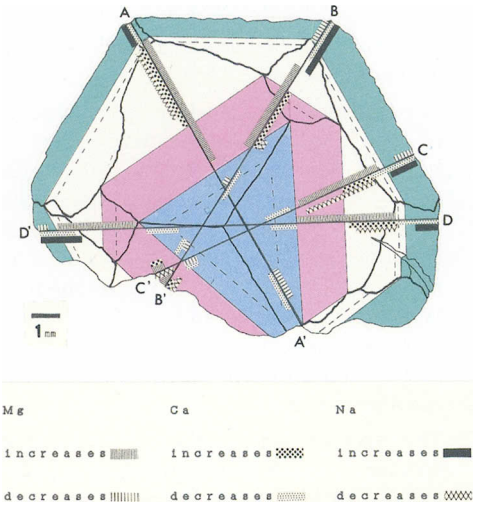

Figure 6: Compositional changes based on the results of EPMA line scans. Relative changes in the contents of Mg, Ca and Na are shown, taking the respective contents at the centre as standard. Boundaries of growth sectors and stages are also indicated.

1. At the boundary of the triangular outline of stage 1, there are slight decreases of less than 1% in Mg and Ca contents, i.e. the uvite component decreased temporarily.
2. In the second stage, an increase of Mg content (less than 1 wt% MgO) occurs simultaneously with the appearance of [100], [010] and [110] directions (corresponding to the growth sectors of r and r′, or r + m and r′ + m′). In these growth sectors, an increase of Ca and a decrease of Na, both being less than 1 wt% of the oxides, occur simultaneously with the increase of Mg. There is a general increase of the uvite component at this stage.
3. In the third stage, Mg and Ca start to decrease and Na increases only in the a{11$\bar{2}$0} growth sectors, and this coincides with the appearance of this face. Meanwhile Mg continues to increase in the growth sectors corresponding to [010], [110] and [100], where an increase of Mg had already been noted in the second stage. In other words, the appearance of the a{11$\bar{2}$0} growth sectors is closely related to a decrease in uvite and an increase in the dravite component.
4. In the fourth and final stage, the CaO content decreases by almost 2 wt%, and the Na_2O content increases by about 0.5 wt% (almost doubling), i.e. the uvite component sharply decreases in all growth sectors in the fourth stage.

In the sections parallel to the *c*-axis distinct growth sectors are not easily discernible under a polarizing microscope, and only faint features may be visible. However, from the results of EPMA analyses, the following compositional variations were established:

1. Compositional variation similar to that noted at the boundary between the second and third stages in the cross-section is present along the whole periphery of the crystal, with a constant width of less than ca. one-fifth of that of the prism. Mg and Ca contents decrease towards the periphery whereas the Na content increases, i.e. the uvite component decreases and the dravite increases both perpendicular and parallel to the *c*-axis, at the onset of the third stage, where a{11$\bar{2}$0} faces started to develop.
2. The width of prismatic growth sectors is much narrower than those of trigonal pyramidal growth sectors, and limited to the peripheral portion, about one-fifth of the prism.
3. Judging from the compositional variation and the form of the growth sectors, the initial point of uvite growth is situated at about one-third of the length along the prism and closer to the negative end.

In *Figure 7a* and *b*, growth sector boundaries, growth stages and variations in uvite component are summarized and schematically illustrated, in sections perpendicular and parallel to the *c*-axis, respectively.

Discussion

Salient points revealed in this study are:

1. Uvite contents of the tourmaline changed from $Uv_{78} - Uv_{82} - Uv_{74} - Uv_{56}$ from the initial stage to the latest stage of growth of the single crystals.

2. Morphology of the crystals changed from flat rhombohedral (or equant) bounded principally by r{10$\bar{1}$1} and r′{01$\bar{1}\bar{1}$} faces to short prismatic bounded by r{10$\bar{1}$1}, r′{01$\bar{1}\bar{1}$}, c′{000$\bar{1}$} and a{11$\bar{2}$0} faces during the growth history. Four stages were distinguished in the morphological evolution.
3. The appearance and development of a{11$\bar{2}$0} faces at the third stage are related to an increase of the dravite component. However, morphological changes in other stages are not directly or clearly related to compositional changes.
4. The major portion of the uvite prism was formed by growth on positive and negative trigonal pyramidal faces, r and r′. Growth on the prism faces contributed to the volume of a uvite crystal by less than one-fifth in terms of the width of a prism.
5. The growth rate along the *c*-axis in the positive direction was about twice as high as in the negative direction.
6. The spiral growth mechanism operated most probably on both positive and negative trigonal pyramidal faces, r and r′, and also on second-order prism a faces, but probably did not on the c′{000$\bar{1}$}, m, m′{10$\bar{1}$0} and other faces.

Based on the above summary, we will now analyse how uvite crystals grew and what were the causes for morphological evolution.

The chemical formulae of dravite and uvite are $NaMg_3Al_6B_3Si_6O_{27}(OH,F)_4$ and $CaMg_3(Al_5,Mg)B_3Si_6O_{27}(OH,F)_4$, respectively, forming a continuous solid solution between the two end members (Deer *et al.*, 1966). Among the major components in these formulae, Ca and Mg are clearly derived from the original carbonate rocks, whereas Na, Al, B, Si, OH, F are considered to come from acidic magma. The observed changes in uvite–dravite components during the growth history of uvite crystals suggests that the crystals were formed at the beginning from a fluid enriched in the compositions derived from the original rocks. However, towards the later stages of crystallization, Mg and Ca diminished, whereas the dravite component derived from the acidic magma was enriched. In other words, the components

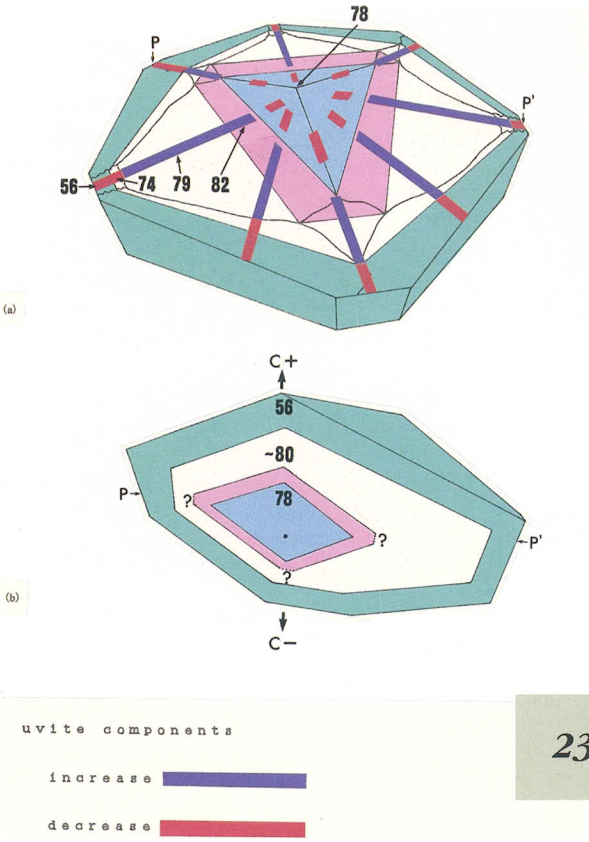

Figure 7: Schematic diagrams showing changes in uvite components in mole % and morphological evolution and growth stages in sections perpendicular (a) and parallel (b) to the c-axis. Numbers in (a) indicate uvite mole %. Trends of increase and decrease of uvite components are distinguished by different colour lines. The dot in (b) indicates the initial point of growth. Both (a) and (b) are perspective projections.

from the original rocks were consumed at the earlier stages, and those from the acidic magma became gradually enriched. This is reasonable, considering the reaction taking place between the original carbonate rocks and acidic magma.

The formation of uvite crystals from a fluid phase, not by solid-state reaction, is supported by their well-formed idiomorphic morphology, an indication of freely developed crystals. The fact that uvite crystals occur in isolation, not in a radiating

group, indicates that the nucleation rate was low. This implies that the nucleation took place under a relatively small driving force. Uvite growth proceeded throughout its history under such a condition, and neither partial dissolution during the growth process nor a rapid increase of the driving force at the latest stage took place. Nucleation and growth proceeded and finished in a gentle growth environment. Spiral growth is the most likely growth mechanism under such conditions (Sunagawa, 1984a). The undulating surface features of other faces imply that they appeared temporarily through the agencies of mechanisms other than spiral growth or two-dimensional nucleation growth. These features appear on faces by an adhesive-type growth mechanism on rough interfaces or by selective impurity absorption (see, for example, Sunagawa, 1988a).

During the morphological evolution from stages 1 to 4, the appearance and dominant development of second-order prism faces a{11$\bar{2}$0} at the onset of stage 3 are clearly related to compositional change from a uvite-rich to a more dravite-rich composition. The change in morphology occurring at the onset of stage 3 was very distinct; up to that point, the major habit-controlling faces were r{10$\bar{1}$1}, r′{01$\bar{1}\bar{1}$} and c′{000$\bar{1}$}, and possibly narrow m and m′{10$\bar{1}$0} faces, with a{11$\bar{2}$0} faces being entirely absent. The initial morphology probably represents the morphology of crystals of uvite composition, whereas the appearance of a{11$\bar{2}$0} faces is attributed to an increase of dravite component.

It has been proven in the present study that the growth rate in the positive direction along the *c*-axis is twice as high as in the negative direction. Why there is a higher growth rate in the positive direction should be related to the structural characteristics of the tourmaline crystal and this is a subject of re-investigation and future study.

Summary

1. The uvite crystals were formed and grew freely in a fluid phase derived from the reaction between carbonate rocks and acidic or granitic magma. They nucleated and grew under a small driving force condition. The uvite component in the fluid was relatively enriched in the early stages of growth, but decreased in favour of dravite in the later stages.
2. Initially, uvite crystals were bounded principally by positive and negative trigonal pyramidal faces r and r′, but later when the uvite component diminished, second-order prism faces a started to develop.
3. Uvite crystals grew by the spiral growth mechanism on positive and negative trigonal pyramidal r and r′, and second-order prism faces, a.
4. Growth was twice as rapid in the positive *c*-axis direction as in the negative direction, a feature which is reflected in the differences of step separation and morphology of growth steps.
5. The driving force changed rather monotonously during the whole process of growth. There was no abrupt change in the growth conditions, such as to cause partial dissolution during the growth process or rapid increase of the driving force at the final stage.

Acknowledgements

We acknowledge the help of Professor E. Horikoshi, O. Ujike and Dr S. Ohtou of Toyama University for using the facilities and discussions about EPMA analyses. Thanks are also due to Professor T. Miyata of our Institute for the discussions.

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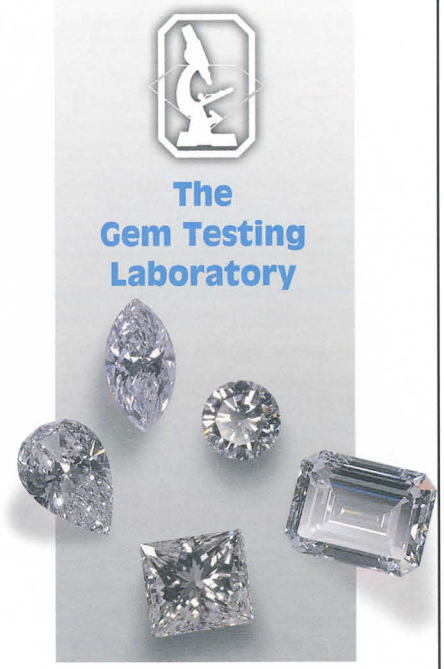

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Maxixe-type colour centre in natural colourless beryl from Orissa, India: an ESR and OA investigation

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ABSTRACT: A change in colour of colourless beryls to green to greenish-yellow on irradiation is reported for the first time from Indian samples. On heating to 300°C, the colour of the irradiated beryl changes from greenish-yellow to yellow and finally to colourless at 500°C. On the basis of Electron Spin Resonance (ESR) and Optical Absorption (OA) studies, the cause of colour is deciphered to be due to the formation of a defect centre similar to the Maxixe type, and radiation-induced oxidation of Fe^{2+} present at the octahedral Al^{3+} site with associated ultra-violet charge transfer (UVCT) tail. The former gives rise to blue and the latter to yellow colours in beryl. A combination of the above two results in a greenish-yellow colour. A new weak additional ESR line at 1500 gauss is reported for the first time after irradiation of a beryl crystal; the line gradually disappears on heating to 300°C.

Keywords: beryl, colour centre, electron spin resonance, gemstones, India, optical absorption

Introduction

Gem enhancement is a field of high potential wherein less attractive gemstones are transformed to more desirable stones by various methods such as chemical treatment, irradiation and heating; e.g. rendering an attractive blue hue to a colourless topaz crystal by irradiation, and removal of patches of silk in ruby by intense heating. An exhaustive review of such techniques is discussed by Nassau (1994). In the present paper the authors have documented colour enhancement

Technique Abbreviations

EPMA	Electron Probe Micro Analysis
EPR	Electron Paramagnetic Resonance
ESR	Electron Spin Resonance
IVCT	Intervalence Charge Transfer
NIR	Near InfraRed
OA	Optical Absorption
RT	Room Temperature
UVCT	Ultraviolet Charge Transfer

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Experimental details

Colourless beryl samples from the Badmal mines of Orissa were irradiated using a Cavity Resonator type Linear Electron Beam Accelerator (model No. ILU6) at the Isotope Division, BARC, Mumbai, India. An energy of 1.7 MeV was used and the beam current was maintained at 2 mA with the samples kept on a water-cooled aluminium target. The samples were also subjected to gamma-ray radiation using a ^{60}Co source.

On the bases of external morphology and a conoscopic interference figure, the samples were cut parallel (H||c) and perpendicular (H⊥c) to the *c*-axis and had dimensions of about 1.5 x 1.5 x 10 mm for ESR measurements. ESR measurements were carried out on a Varian E-112 E-line century series X-band ESR spectrometer which utilizes 100 KHz field modulation. Tetra Cyno Nitro Ethylene (TCNE, g = 2.00277) was used as a standard for g-factor measurements. A Varian variable temperature accessory was used to carry out experiments at different temperatures.

Polarized OAs were measured at variable temperatures over 300–2500 nm (25000–4000 cm^{-1}) range with a Schimadzu UV 3101PC scanning spectrophotometer. Colourless beryl crystals cut along the *ac* plane were doubly polished to a crystal thickness of 1.0 mm. Polarized sheets (HN 22) were used to obtain polarized spectra. Heat treatments in air at temperatures up to 500°C were carried out using an electric furnace, with samples kept in a nickel crucible. Analyses of colourless beryl samples were carried out by WDS EPMA using an SX–50 Microprobe. Operating conditions were 15 kV accelerating voltage, 20 nA beam current and 10 s counting time; the results are given in *Table I*.

Table I: *EPMA of colourless beryls*

Wt. %	*1*	*2*
SiO_2	65.698	64.240
Al_2O_3	17.740	17.442
FeO	0.545	0.744
MnO	0.025	0.012
Cr_2O_3	0.027	0.031
V_2O_3	0.032	0.012
TiO_2	0.034	—
NiO	0.022	0.016
CoO	0.056	0.056
MgO	0.093	0.281
CaO	0.020	0.041
K_2O	0.019	0.031
Na_2O	0.206	0.275
F	0.216	0.057
Total	84.733	83.238

1. When irradiated, colour changed to greenish-yellow.
2. When irradiated, colour changed to yellow-orange.
NB: Total iron reported as FeO; BeO and H_2O not determined.

experiments conducted on colourless beryls from Badmal mines of Orissa state, India, using a radiation technique.

Beryl is a typical cyclosilicate mineral with the chemical formula $Be_3Al_2Si_6O_{18}$. It has a honeycomb-like hexagonal crystal structure belonging to the space group P6/mcc. The Si_6O_{18} sixfold rings of SiO_4 tetrahedra lie one above the other along the C_6 axis and form intercommunicating channels *(Figure 1a)*. The channels are joined laterally by Al^{3+} and Be^{2+} ions *(Figure 1b)*. The aluminium and beryllium ions are located in distorted octahedral and tetrahedral sites respectively, whereas the SiO_4 tetrahedron is nearly undistorted. The diameter of the channels varies between 2.8 Å in the plane of Si_6O_{18} rings and 5.1 Å between neighbouring rings and they are capable of accommodating a number of elements (e.g. Na, K, Rb, Cs and Fe) and molecules (e.g. CO_2 and H_2O). Two types of water molecules have been recorded in beryl occupying two distinct positions in

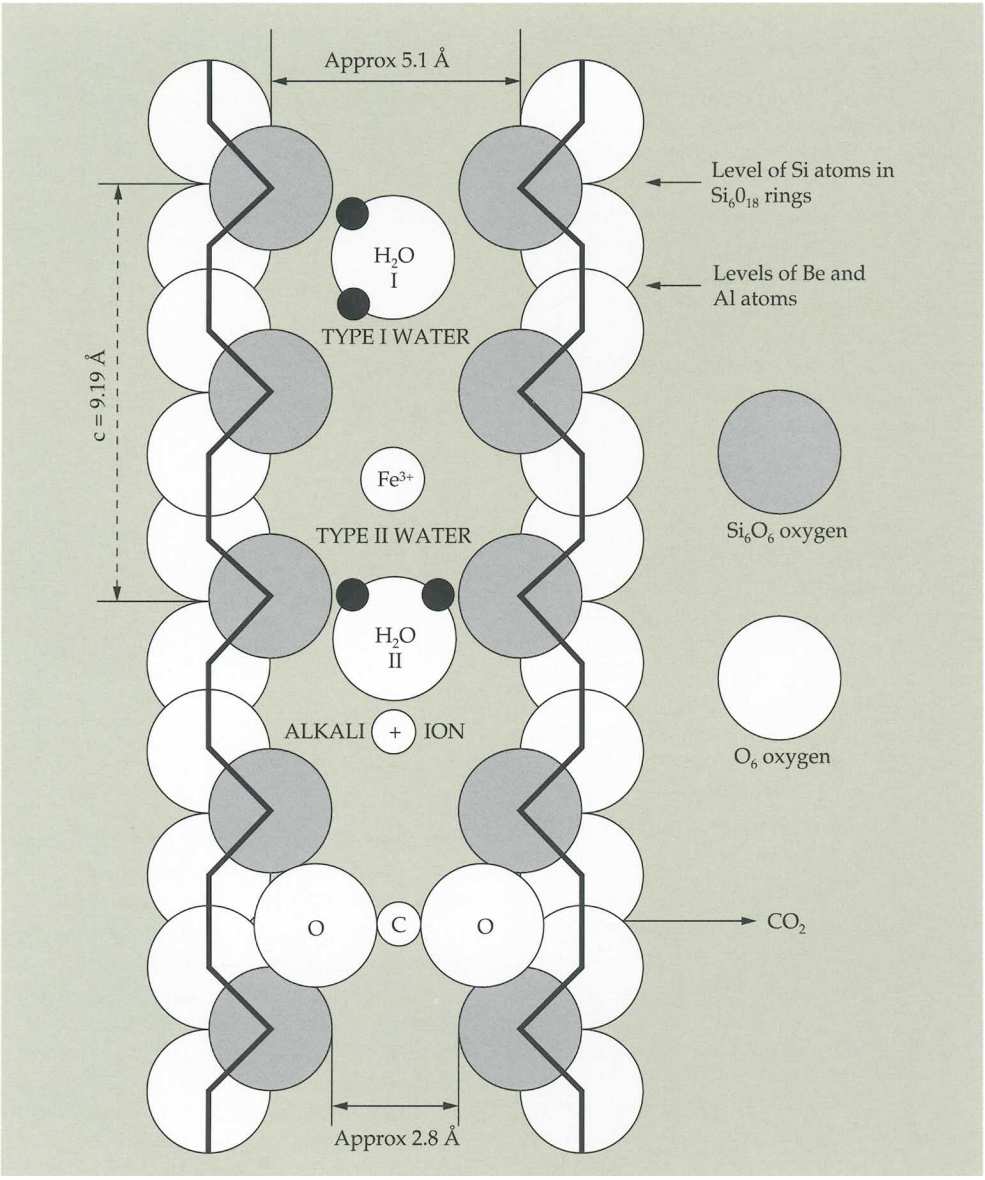

Figure 1a: Schematic drawing parallel to c-axis showing the Fe^{3+} ion in a channel site in the beryl structure (modified after Wood and Nassau, 1968).

the channel site (Wood and Nassau, 1967); the presence of such water molecules has also been noticed in the Orissan beryls (Mathew *et al.*, 1997).

High energy radiations are capable of changing the colour of several minerals and of inducing a variety of radiation damage centres which include trapped electrons and oxidized and reduced cations and anions. It has been found that on irradiation, colourless beryl from various localities turns to (i) pale brown (Mukerjee, 1951); (ii) blue (NO_3^- and CO_3^{2-} impurity bearing variety: Nassau *et al.*, 1976); and (iii)

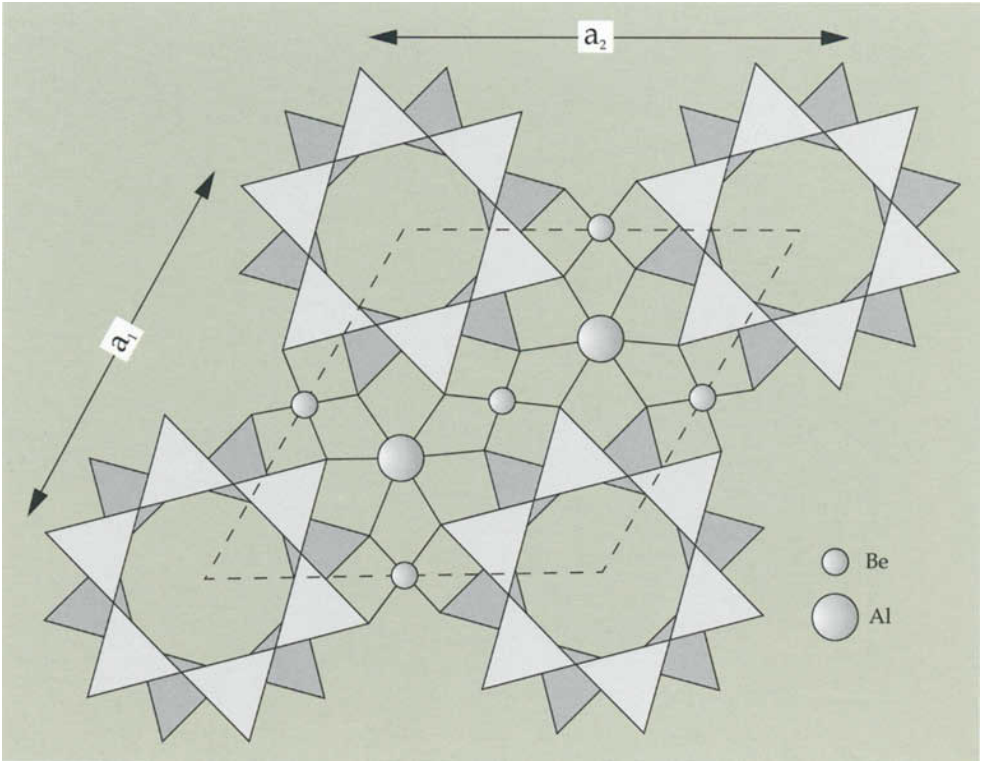

Figure 1b: *Structure of beryl projected on plane perpendicular to c-axis.*

yellow-orange (Nassau *et al.*, 1976; Sinkankas and Read, 1985). Nassau *et al.* (1976) observed that if the original beryl is yellow or green, then a green or blue-green colour results from generation of a Maxixe colour centre. According to a few authors (Wood and Nassau, 1968; Blak *et al.*, 1982) Fe^{2+} in a channel site is more powerful in causing a blue colour than in the substitutional Be and Al site, where it fails to induce any effect on colour. They attributed yellow in beryl to Fe^{3+} in a substitutional site, whereas its presence in the structural channel has no effect on colour. However, according to Goldman *et al.* (1978), the blue colour is due to IVCT and yellow is due to UVCT arising from Fe^{3+} in a channel site. When both Fe^{2+} and Fe^{3+} ions are present, the resultant colour depends on the proportion of each, thus explaining the 'gamut of hues' that may be observed from blue to various shades of blue-green, yellow-green and yellow (Sinkankas and Read, 1985). Thus, the colour of iron-containing beryls depends on the distribution of iron in the channel, octahedral Al site, tetrahedral Be site and interstitial positions and upon the character of their interactions. From the above references it is evident that several researchers have proposed different views to explain the cause of colour in beryl. In the present study, it is shown that on irradiation some colourless beryl (goshenite) samples have turned to green to greenish-yellow and some to yellow-orange *(Table I)*. The green colour fades on heating to 300°C, leaving yellow, and finally becomes colourless on further heating to 500°C. The yellow-orange beryl also turns colourless at 500°C. In this study, we report the results of the investigation on colourless beryl using the techniques of ESR and OA.

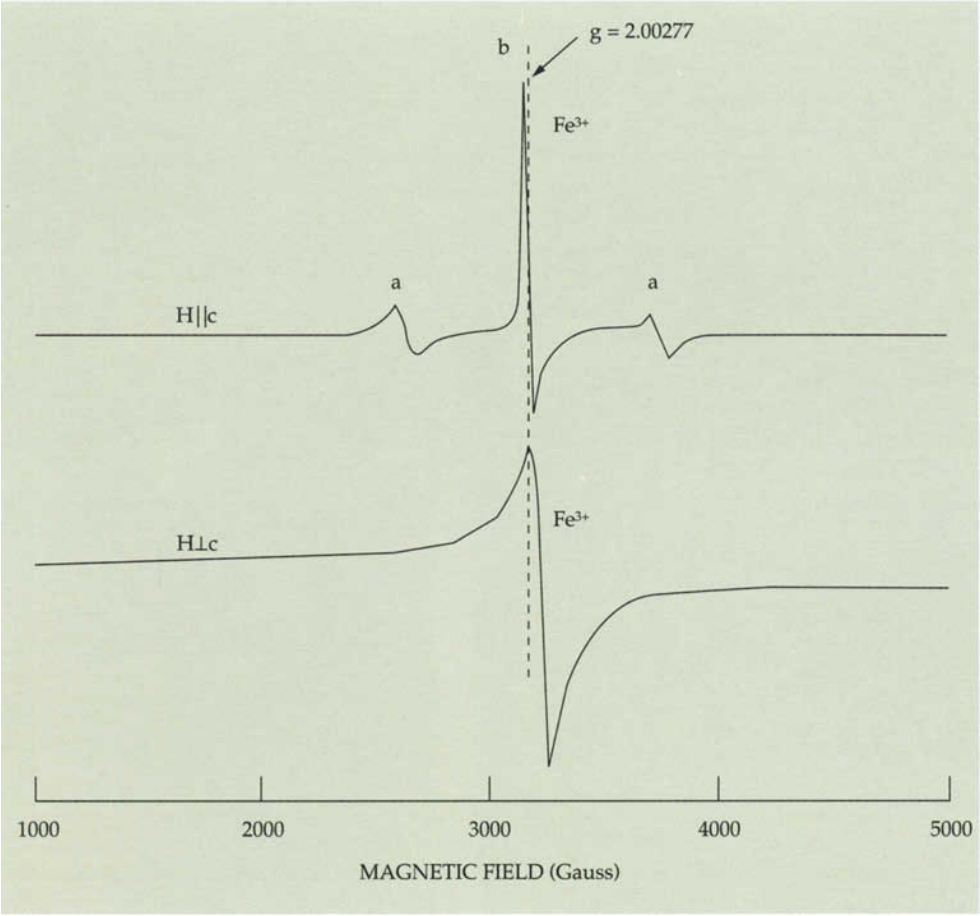

Figure 2: ESR spectra of colourless beryl (before irradiation) for two magnetic field directions (H||c and H⊥c) in the 3200 G region. The g = 2.00277 line shown in the figure is the marker (TCNE).

Results and discussion

Electron Spin Resonance (ESR) studies on unirradiated beryl

ESR, also referred to as EPR, is a spectroscopic technique based upon resonant absorption of microwaves by paramagnetic substances tuned by an external magnetic field. It is a powerful technique in detecting colour centres which are responsible for colour in minerals. The first detailed ESR studies on beryls were carried out by Davir and Low (1960), in which they proposed that Fe^{3+} ions occupy octahedral Al^{3+} sites and also indicated their probability in tetrahedral sites.

The ESR spectrum of unirradiated colourless beryl presently under study is shown in *Figure 2* for the two field directions (H||*c* and H⊥*c*). Similar spectra were reported by Davir and Low (1960) and Blak *et al.* (1982). The spectrum consists of a large asymmetrical single line (labelled 'b') near the free electron resonance attributed to Fe^{3+} in the channel site (g = 1.996 for H parallel and g = 1.998 for H perpendicular to the crystallographic *c*-axis). The observed g-value for the Fe^{3+} ion (strong line) is close to the free electron value of 2.00233. The Fe^{3+} in the channel is surrounded by 24 oxygen atoms. The distance between Fe^{3+} and an oxygen atom is 3.4 Å in the SiO_6 plane and 4.1 Å in the plane

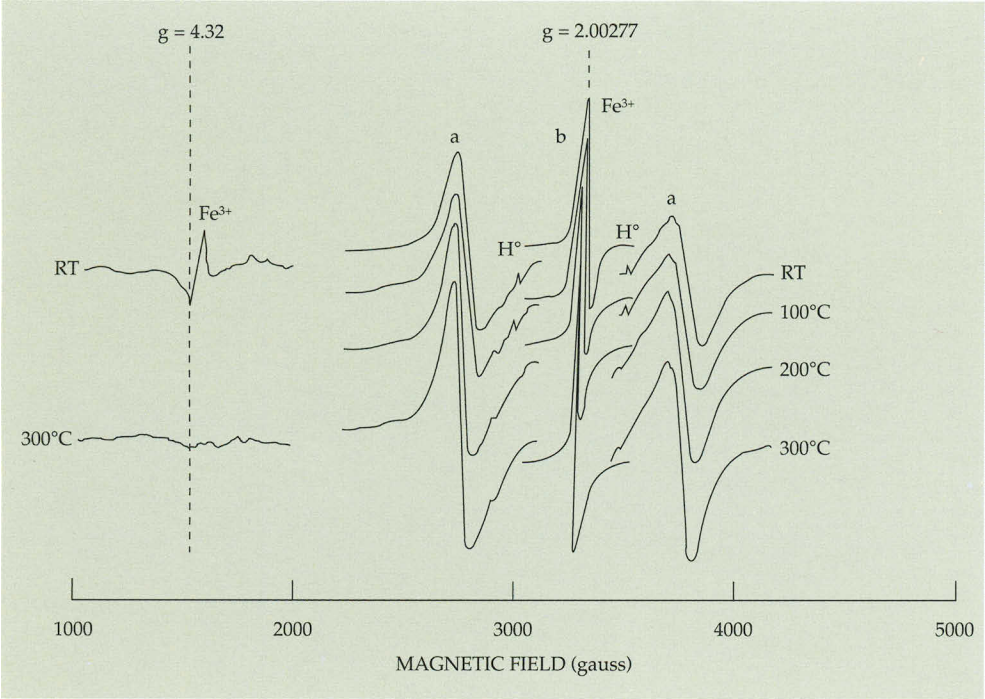

Figure 3a: *Variable temperature ESR spectra of colourless beryl (after irradiation) for the magnetic field parallel (H||c) to the crystallographic c-axis depicting the presence of new line at 1500 G.*

of O_6 (Blak *et al.*, 1983) and these distances are too large to allow the occurrence of any significant crystal field splitting in the ESR spectra and consequently in ESR absorption. Therefore, Fe^{3+} with a 'g' value close to 2.00233 behaves almost as a free ion; thus it probably occupies a site in the structural channel (Blak *et al.*, 1983). Additional weak lines (labelled 'a') are observed on either side of the strong line. These weak lines are possibly due to the small presence of Fe^{3+} substituting in the octahedral Al^{3+} site as suggested by Davir and Low (1960).

ESR studies on irradiated beryl

The colourless beryl samples from Orissa as explained above turned to greenish-yellow and some to yellow-orange after irradiation in the electron beam, whereas gamma radiation did not produce any colour change. *Figures 3a and 3b* show the ESR spectra of irradiated beryl for the magnetic field along the *c*-axis and for a random orientation in the plane perpendicular to the *c*-axis respectively. In addition to the main Fe^{3+} peak at 3200 gauss, an additional line is observed in the low field region around 1500 G. Although such lines were reported by Blak *et al.* (1982) in natural green beryl, they are observed here for the first time in natural beryl crystals after irradiation. The g-factors in the vicinity of 4.3 in many minerals (e.g. feldspars and mica) have been attributed to high spin Fe^{3+} in a low symmetry environment of rhombic distorted site (Castner *et al.*, 1960; Abragam and Bleany, 1970; Calas, 1988). Therefore it is likely that in the beryl sample under study, the Fe^{3+} ion occupies a distorted rhombic site. This indicates that the above Fe^{3+} ion was initially in the form of Fe^{2+} in the unirradiated sample and on subsequent irradiation it was oxidized/ionized to Fe^{3+}.

The low-intensity line observed around 1500 gauss in the ESR spectrum *(Figures 3a*

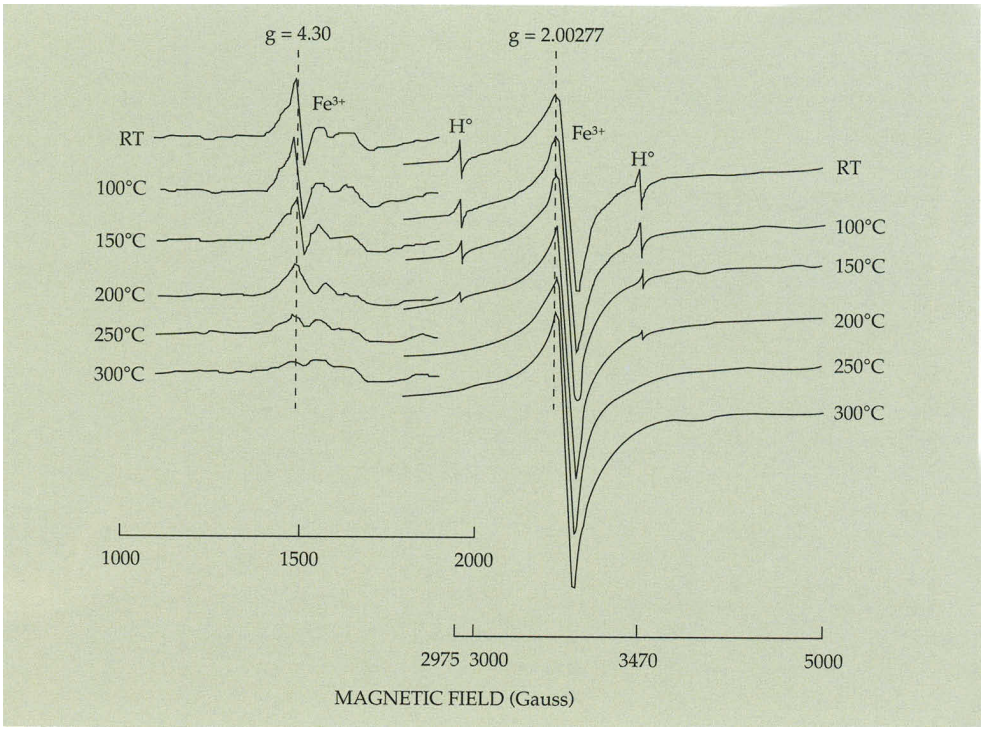

Figure 3b: *Variable temperature ESR spectra of colourless beryl (after irradiation) for the magnetic field perpendicular (H⊥c) to the crystallographic* c*-axis.*

and 3b) is tentatively assigned here to the Fe^{3+} ion formed by oxidation of Fe^{2+} at the Be^{2+} tetrahedral site. As the Fe^{2+} ion is characterized by a short spin relaxation time, it was not possible to observe the ESR lines attributable to Fe^{2+} in the present ESR investigation at room temperature.

The ESR lines around the g-factor of 4.3 *(Figures 3a and 3b)* due to the Fe^{3+} ion show a gradual decrease in intensity on heating, which points to a reduction of Fe^{3+} to Fe^{2+}. The Fe^{3+} line disappears around 300°C and is accompanied by a change in colour of irradiated beryl from greenish-yellow to yellow. This observation apparently indicates a possible correlation of Fe^{3+} at the tetrahedral site to the coloration in irradiated beryl. However, it is important to mention here that the disappearance of the above Fe^{3+} ESR signal around 300°C is also observed in irradiated yellow-orange beryl; but there is no significant change in the yellow-orange hue. The yellow and yellow-orange colours are found to disappear around 500°C in both beryls irradiated to greenish-yellow and yellow-orange respectively.

A 'g' value of 4.3 is not expected from an Fe^{3+} ion situated at the channel site, since here the ion behaves almost as a free electron (g = 2.00233). Its possible substitution at an octahedral site is also doubtful, as it is clearly seen in the ESR spectrum that the 4.3 signal of Fe^{3+} disappears at 300°C and yet the sample retains its yellow colour. It is well documented by many authors (e.g. Wood and Nassau, 1968) that yellow in beryl is due to the presence of Fe^{3+} at an octahedral site. Further it is known that the bond distances for Be–O and Si–O are 1.657 and 1.608 Å respectively and the typical Fe–O bond distance is 1.980 Å (Hazen *et al.*, 1986; Shannon and Prewitt, 1969). It is therefore likely that Fe^{2+}, although characterized by large ionic radius, substitutes in small

quantities at the fourfold coordinated beryllium site, while most Fe^{2+} ions prefer the octahedral Al^{3+} site and the channel site. According to Samoilovich *et al.* (1971), on thermal excitation (heating) of the electron, the capture cross-section is greater for the $[Fe^{3+}]_{tetr}$ than for the $[Fe^{3+}]_{oct}$ ion. In the present study, step annealing experiments show that $[Fe^{3+}]_{tetr}$ is first reduced to $[Fe^{2+}]_{tetr}$ below 300°C *(Figures 3a and 3b)*. On the other hand, $[Fe^{3+}]_{oct}$ is found to reduce to $[Fe^{2+}]_{oct}$ at higher temperatures. These findings are in accordance with the expectations of Samoilovich *et al.* (1971). It was found that the greenish-yellow colour as well as ESR signals could be restored after repeated irradiation.

ESR spectral studies also revealed that, on irradiation with an electron beam, beryl produces atomic hydrogen (H^0) represented by two weak satellites at 2970 and 3470 gauss *(Figures 3a and 3b)*. The atomic hydrogen occupies the channel site and appears to be formed by irradiation-induced splitting of the hydroxyl group (Koryagin *et al.*, 1966). In the present study it was observed that H^0 becomes unstable above 200°C. Similar weak H^0 satellite peaks are also observed in samples irradiated by gamma rays, and these also disappeared above 200°C.

ESR experiments were also carried out on greenish beryl at low temperatures (77 K) to observe the presence of colour centres in the beryl lattice, but failed to reveal the possible presence of the ESR lines attributable to colour centres due to strong overlap from the Fe^{3+} signal around the free electron resonance region. Nevertheless, the presence of such colour centres has been deduced from OA spectroscopy as explained in the next section.

Optical Absorption (OA) studies

In general three types of processes generally contribute to OA spectra in minerals (Rossman, 1988):

1. crystal field;
2. charge transfer (UVCT and IVCT);
3. absorption edge.

OA studies of irradiated coloured beryl were carried out at various temperatures. The absorption spectra of irradiated greenish-yellow beryl taken at RT are shown in *Figures 4a and 5*. UVCT is due to electron transfer from anion to cation, i.e. transfer of electron from O^{2-} ligands to a central (Fe^{3+}) metal ion (Rossman, 1988) and the absorption this causes below 390 nm extends into the visible region. These transitions occur in the ultraviolet region and produce absorption 2 to 3 orders of magnitude higher than the ordinary crystal field transition (Marfunin, 1979). The tail of the absorption band extends into the visible region due to an increase in concentration of Fe^{3+}, which in turn resulted from ionization of Fe^{2+} as seen in *Figures 4a and 5*. The strongest absorption is in the violet and the tail extends into the green.

The visible region of the optical spectrum in the irradiated greenish-yellow beryl is characterized, in the ordinary ray only (o-ray or $\perp c$), by sharp absorptions at 644 and 688 nm *(Figure 4b)*. Such a sharp absorption pattern is not seen in the beryl irradiated to yellow-orange. The sharp absorption feature observed above is similar to the optical spectrum of Maxixe-type beryl observed by Nassau *et al.* (1976) who attributed this absorbance to colour centre formation and concluded that this was the cause of blue colour in Maxixe-type blue beryls from Brazil. Later workers (Edgar and Vance, 1977; Andersson, 1979) with the help of ESR studies, inferred this centre to be the CO_3^- radical in Maxixe-type beryl and NO_3 in Maxixe beryl. These radicals are derived from CO_3^{2-} and NO_3^- respectively residing in the structural channel sites of beryl crystals. On irradiation, these ions lose an electron and become CO_3^- and NO_3 radicals. This results in generation of a hole centre in Maxixe-type beryls. Nassau *et al.* (1976) defined Maxixe beryls as those natural deep blue beryls formed by natural radiation in which the impurity precursor is NO_3^-, whereas Maxixe-type beryls are those deep blue-green beryls produced by artificial irradiation having the impurity precursor as CO_3^{2-}. Edgar and Vance (1977) considered also the presence of HCO_3^- precursors to be

Figure 4a: *Absorption spectra (UV–VIS–NIR) of irradiated greenish-yellow beryl showing the Fe^{2+} peak in channel site polarized along o-ray. Crystal thickness = 1.0 mm. Solid line RT, dashed line 300°C and dotted line 500°C.*

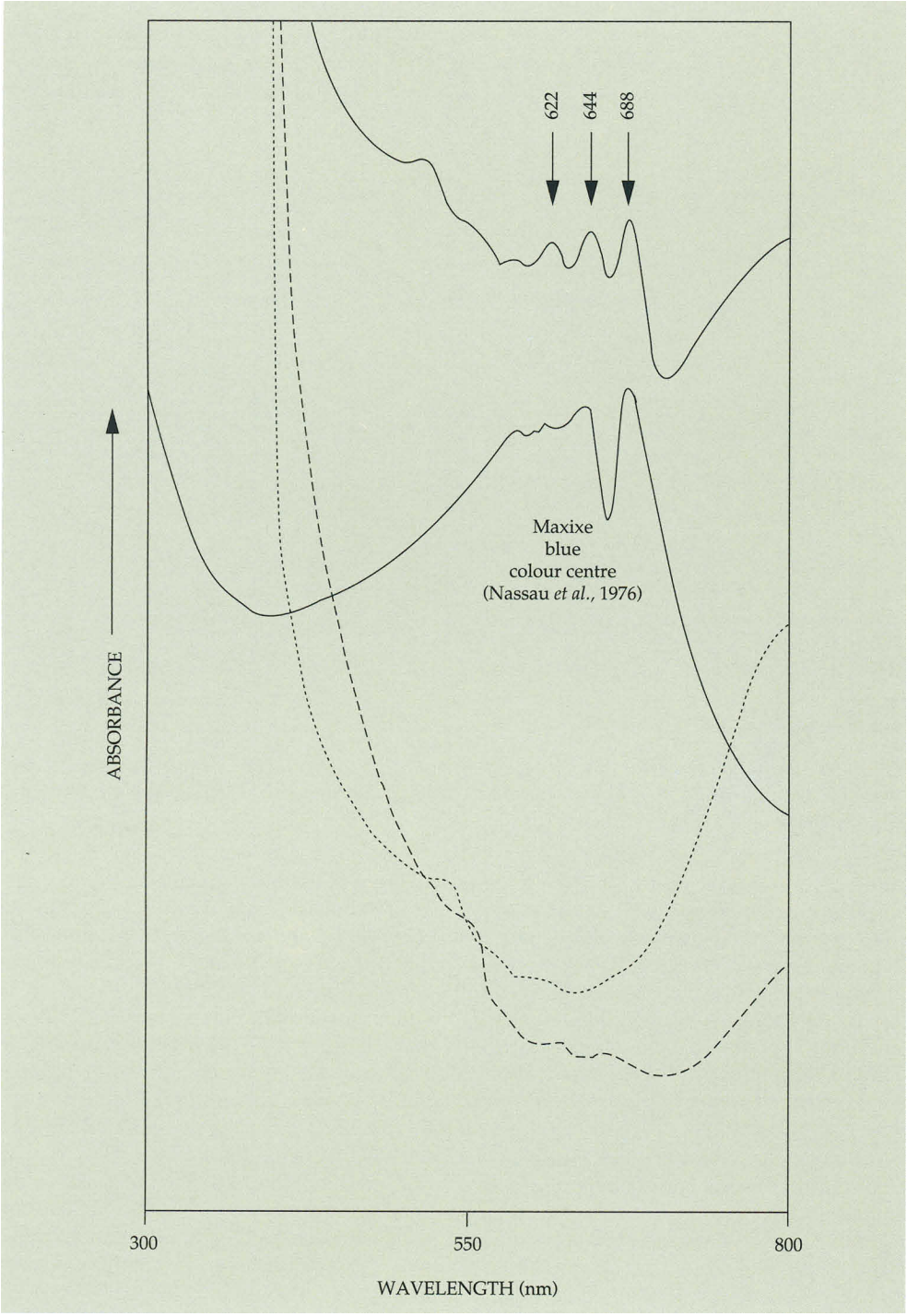

Figure 4b: *Absorption spectra (UV–VIS) of irradiated greenish-yellow beryl polarized along o-ray showing the presence of Maxixe-type colour centre. Solid line RT, dashed line 300°C and dotted line 500°C.*

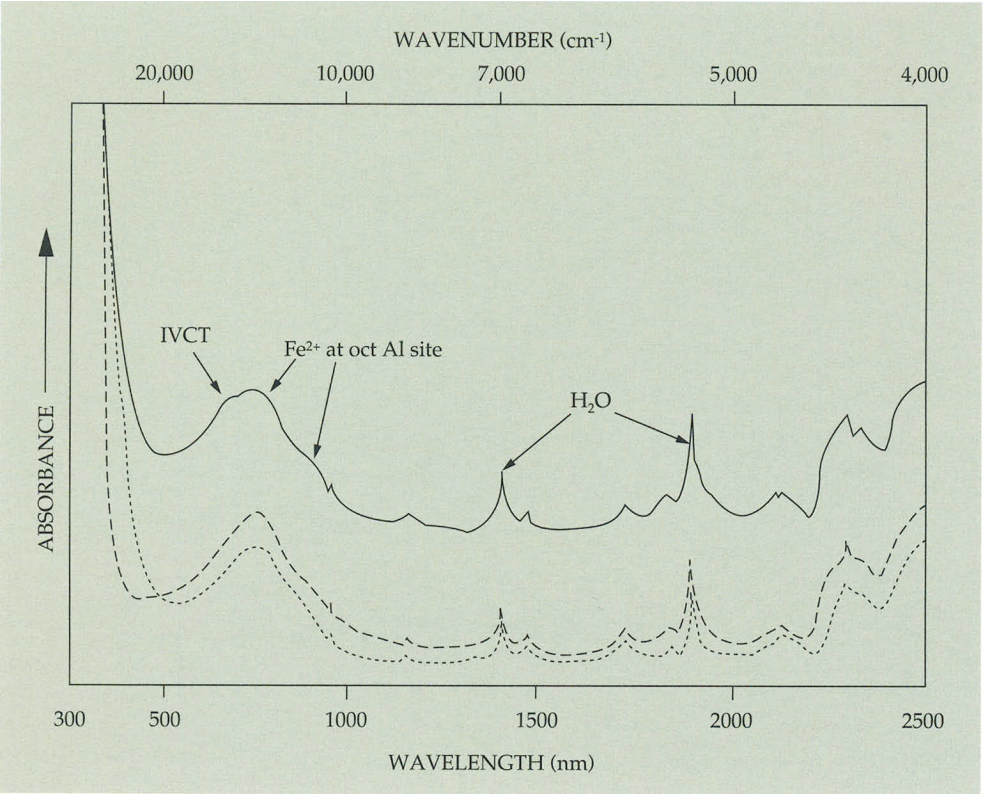

Figure 5: *Absorption spectra (UV–VIS–NIR) of irradiated greenish-yellow beryl showing the Fe^{2+} peak in octahedral Al site along e-ray. Crystal thickness = 1.0 mm. Solid line RT, dotted line 300°C and dashed line 500°C.*

more reasonable than CO_3^{2-} due to the formation of a neutral hydrogen atom (H^0) after irradiation. In the present study, as explained earlier, the formation of atomic hydrogen is seen both in the case of electron beam and gamma-ray irradiation. However, no colour is produced from gamma-ray irradiation and this indicates that atomic hydrogen produced from irradiation comes solely from H_2O.

The existence of two distinct types of Fe^{2+} in colourless Orissan beryl is indicated by the optical spectra *(Figures 4a and 5)*. Wood and Nassau (1968) recognized three absorption bands in the NIR region and attributed them to Fe^{2+}. A band near 810 nm polarized $\perp c$ (perpendicular to the crystallographic *c*-axis) was assigned to Fe^{2+} in the Al^{3+} site. On the other hand, a set of bands near 810 nm and 1000 nm polarized $\|c$ (parallel to the crystallographic *c*-axis) was attributed to Fe^{2+} in the channel site and the band centred at 620 nm ($\|c$) was attributed to Fe^{2+} in a different site. Samoilovich *et al.* (1971) and Parkin *et al.* (1977) agreed with the assignments of Wood and Nassau (1968). However, according to Price *et al.* (1976), bands at 810 and 1000 nm ($\|c$) arose from Fe^{2+} in the Al^{3+} site and the 810 nm band ($\perp c$) possibly indicated Fe^{2+} at a tetrahedral site. Goldman *et al.* (1978) attributed 820 nm and 970 nm peaks in the spectrum polarized to Fe^{2+} in the Al^{3+} site and assigned 820 nm ($\perp c$) and 2100 nm ($\|c$) peaks to Fe^{2+} in a channel site. They ascribed a broad absorption feature seen from 1700 nm to 2500 nm also to iron in a channel site. Thus there is no universally agreed point of view regarding the interpretation of OA spectra of

beryl. Panjikar (1995) also carried out extensive work on Orissan beryls and indicated the possible presence of Fe^{2+} bands from octahedral as well as tetrahedral sites.

In the present study, strong absorption due to the crystal field transition of Fe^{2+} at 820 nm *(Figure 4a)* polarized along the ordinary ray ($\perp c$) is assigned to Fe^{2+} in the channel site. Since the octahedral Al site is distorted, the Fe^{2+} absorption band is expected to be in pairs rather than a single band due either to distortion of the polyhedron or to the dynamic Jahn-Teller effect (Goldman *et al.*, 1978; Burns, 1970). This absorption pair feature is seen at 760 and 920 nm polarized along the extra-ordinary ray ($\|c$) *(Figure 5)*. It is attributed to the spin allowed crystal field transition of Fe^{2+} ($^5T_2 \rightarrow {}^5E$, ^5D), assigned to arise from Fe^{2+} in the octahedral site. This is further supported by the barycentre energy of 12,150 cm^{-1}, which indicates that the Fe^{2+} is situated in a site of 1.94 Å average metal oxygen distance (Faye, 1972). This agrees favourably with the 1.90 Å distance determined for the octahedral Al site in beryl by Gibbs *et al.* (1968). Although the presence of Fe^{3+} at the tetrahedral site cannot be deduced with any confidence from the OA spectrum, an absorption close to 684 nm (e-ray) is present as a shoulder after irradiation *(Figure 5)*. This can be attributed to IVCT between Fe^{2+} and Fe^{3+}, the Fe^{2+} at an octahedral or channel site and the Fe^{3+} at a tetrahedral site.

Heating experiments (in air)

As described earlier, after heating the irradiated beryl to 300°C, the greenish-yellow beryl turned yellow and no significant change in hue of yellow-orange beryl was observed. On further heating to 500°C both greenish-yellow and yellow-orange beryl become colourless. The following changes in the optical spectrum were seen after heating the beryl crystals to 300°C *(Figures 4a and 5)*:

1. sharp absorption peaks at 644 and 688 nm, which are polarized only along the ordinary ray, disappeared;
2. the intensity of the 820 nm band (o-ray) decreased;
3. the intensities of the 760 and 920 nm bands (e-ray) decreased; and
4. the absorption band at 684 nm (e-ray) disappeared.

On further heating to 500°C, it was observed that:

5. the intensity of the 820 nm band (o-ray) increased;
6. the intensities of the 760 and 920 nm bands (e-ray) increased; and
7. the UVCT tail receded to shorter wave-lengths and became steeper.

The first observation indicates that the sharp absorption features at 644 and 688 nm have thermal decay characteristics, which are similar to the observation of Serway (1967) on irradiated calcite. In irradiated calcite, the 650 nm band shows thermal decay behaviour similar to that of the ESR signal attributed to the CO_3^- molecular ion. Identical decay characteristics of a narrow absorption band were also observed by Nassau *et al.* (1976) in Maxixe-type blue and green beryls as shown in *Figure 4b*. It appears that a defect centre, similar to Maxixe type, probably results in the blue coloration in irradiated Indian colourless beryl. On heating to 300°C, the defect centre decays and the crystal becomes yellow.

The second and third observations indicate that the amount of Fe^{2+} ions residing in the channel as well as in the octahedral site decrease. These changes are due to the fact that, on annealing, the Fe^{2+} ions in both channel and octahedral sites are converted into Fe^{3+} ions. This explains the decrease in the 820 nm (o-ray), 760 and 920 nm (e-ray) bands. The above observation indicates that on irradiation there is partial reduction of Fe^{3+} to Fe^{2+}. A similar feature was also observed by Goldman *et al.* (1978) in a natural yellow beryl which, on irradiation and subsequent heating to 500°C, showed recovery of the Fe^{2+} ion in the channel as well as in the octahedral sites. The complete disappearance of IVCT at 684 nm in the fourth observation is in accordance with the

disappearance of the Fe^{3+} ESR line at 1500 gauss at 300°C. Thus, in addition to the blue coloration due to a Maxixe centre, the IVCT band at 684 nm possibly also contributes to the blue colour after irradiation of colourless beryl. However, in the yellow-orange beryl the g-value of 4.3 in the ESR spectrum is seen only as a small hump, unlike sharp peaks in irradiated green beryl. This indicates that the Fe^{2+} is present only in very small concentration at the tetrahedral site in yellow-orange beryl, which does not favour appreciable charge transfer to be observed in the optical spectra. The fifth observation indicates that the amount of Fe^{2+} ions has increased. This suggests that the Fe^{3+} ions residing in the channel are reduced to Fe^{2+} by the thermal release of electrons. The sixth observation indicates that on heating above 300°C, the Fe^{2+} ion (760 and 920 nm, e-ray) increases in concentration at octahedral Al sites due to partial reduction of the Fe^{3+} ion to Fe^{2+}. The fifth and sixth observations are accompanied by the seventh observation. This is consistent with the decrease in Fe^{3+} concentration accompanied by a recession of the $Fe^{3+}-O^{2-}$ charge transfer band towards the ultraviolet region. These changes are accompanied by a change in colour of the sample from yellow to colourless. It is observed that the major portion of increase in intensity of the 820 nm band (o-ray) and the 760 and 920 nm bands (e-ray) manifests mainly above 300°C, and the UVCT tail recession also starts above 300°C. Therefore it would not be appropriate to correlate the yellow colour formed after irradiation to the UVCT tail arising from Fe^{3+} in the channel site.

Conclusion

From the present ESR and OA study of irradiated coloured beryls it appears that the coloration with electron-beam irradiation of colourless beryl to green to greenish-yellow and decoloration of the blue component and yellow with heating is due to the following:

1. formation of a defect centre and possible IVCT giving rise to the blue colour;
2. radiation-induced oxidation of Fe^{2+} and the associated UVCT tail, which results in a yellow colour.

The combination of these two colours results in a greenish-yellow hue in the beryl crystal. In the yellow-orange irradiated beryl, the above defect centre does not form due to the absence of suitable precursors except for the oxidation of Fe^{2+} at the Al site and the associated UVCT tail which results in a yellow colour.

On heating, the defect centre and IVCT decays at 300°C, resulting in disappearance of the blue colour. On subsequent heating to higher temperature, there is formation of some Fe^{2+} and an associated retreat of the UVCT tail to shorter wavelengths. This results in colourless beryl at 500°C. Although the Fe^{3+} line at 1500 gauss attributed to the tetrahedral site is tentative, its appearance after irradiation and disappearance after heating clearly demonstrates the oxidation and reduction phenomena. It is quite possible that various shades of green and yellowish-orange beryl may have formed in nature from colourless beryl due to natural irradiation during the course of geological time and subsequent heating of the host body might have resulted in the development of various shades of green. The differential behaviour of colourless beryl to irradiation from the same locality calls for further studies on the genesis of beryl crystals in relation to their crystal chemistry.

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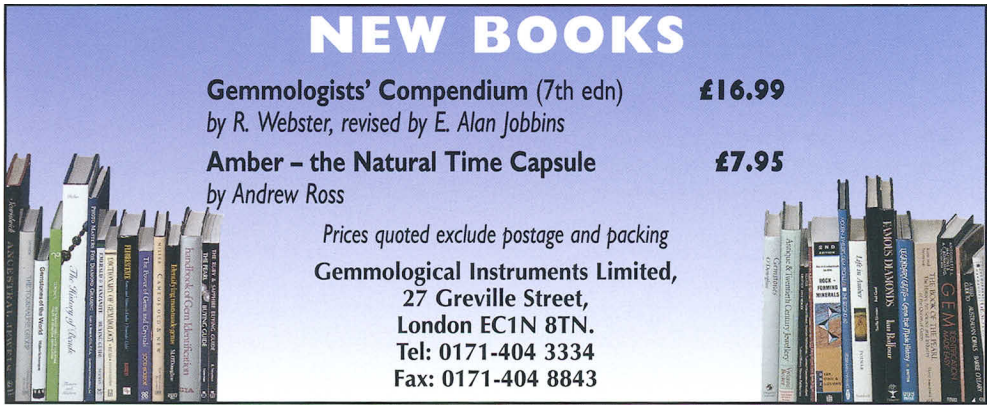

The chemical signature of emeralds from the Campos Verdes-Santa Terezinha Mining District, Goiás, Brazil

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ABSTRACT: Emerald crystals from the Campos Verdes mining district have been analysed by inductively coupled plasma mass spectrometry (ICP-MS), Fourier transform infrared spectroscopy and Mössbauer spectroscopy. These gems contain measurable amounts of Fe^{2+}, Fe^{3+}, Cr, V, Sc, Ni and Zn; large-ion lithophile element (LILE, Ba, Sr, Rb, Pb) and high field strength element (HFSE, Zr, Y, Ti) contents are near or below the limit of detection. This chemical signature reflects the metasomatic reactions between the mineralizing fluids and the ultrabasic host-rocks of this gem deposit.

Keywords: Brazil, emerald, chemistry, infrared spectroscopy, Mössbauer spectroscopy

Introduction

The Santa Terezinha de Goiás–Campos Verdes region, herein termed the Campos Verdes mining district, located about 400 km northwest of the capital Brasília, Brazil, is one of the most important Brazilian emerald production areas (Giuliani *et al.*, 1990). Mining started on the surface and at shallow depths on a small scale in the early 1980s. Currently, as the underground mines reach depths of more than 100 m and have required heavy investment, extraction is mostly performed by three large companies.

Emerald is a variety of beryl ($Be_3Al_2Si_6O_{18}$), characterized by different shades of green (Bosshart, 1991). Beryl is a cyclosilicate in which the arrangement of Si_6O_{18} rings contains channels parallel to the *c*-axis, which can accommodate alkalis and molecules (such as H_2O and CO_2), retained in the structure during crystallization (Aines and Rossman, 1984; Wood and Nassau, 1968).

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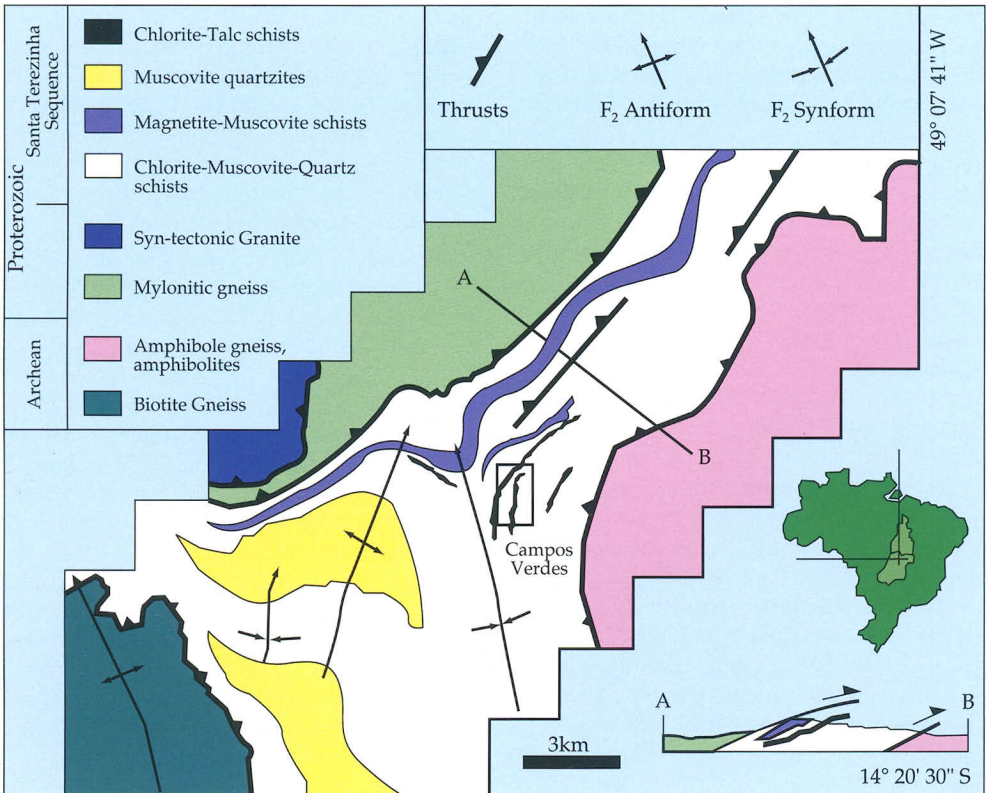

Figure 1: *Simplified geological map of the Campos Verdes Mining District, Goiás. The rectangle represents the area occupied by the town of Campos Verdes, built right above the orebodies. AB is the line for the simplified geological cross-section.*

More recent metallogenic studies have demonstrated the importance of these channels, as they provide clues for the geochemical composition of fluids entrapped therein (Fallick and Barros, 1987).

Since 1996, the Campos Verdes mining district has been the focus of intense geochemical research for gemmological objectives. This paper reports the results of the compositional determination of the emerald crystals by inductively coupled plasma mass spectrometry, Mössbauer spectroscopy and infrared spectroscopy, and the data provide diagnostic information.

Geological setting

The Campos Verdes mining district lies within a relatively narrow, NNE-SSW

Figure 2: *Carbonate vein sample showing an emerald crystal from Campos Verdes. The length of the crystal is about 25 mm.*

trending belt of the Santa Terezinha volcano-sedimentary sequence which has been deposited on biotite and amphibole gneisses of probable Archean age (Ribeiro Filho, 1981; Souza and Leão Neto, 1984). This volcano-sedimentary belt consists of talc schist, chlorite-muscovite-quartz schist, magnetite-muscovite schist, muscovite quartzite and emerald-bearing biotite schist and chlorite-carbonate-talc schist *(Figure 1)*. The emerald crystals are recovered mainly from carbonate veins *(Figure 2)* in chlorite-carbonate-talc schist and biotite schist. All these rocks underwent ductile-brittle deformation and shearing in a number of episodes under greenschist facies metamorphism.

Most of the gem mineralizations coincide with the main phases of regional metamorphism and only small quantities of gems are found in the late-stage brittle fractures that crosscut all the ductile structures in the area (D'el-Rey Silva and Giuliani, 1988; Barros Neto and D'el-Rey Silva, 1995). Recently, Ribeiro-Althoff *et al.* (1996) argued that the ages of the mineralizations are close to 522 ± 1 Ma, based on K-Ar and ^{40}Ar–^{39}Ar ages of phlogopites formed with the emerald crystals. These chronological data are consistent with the Brasiliano Orogeny, which involved reworking of older continental crust.

The polyphase structural evolution of the Campos Verdes mining district produced 1–10 m scale sheath folds with axes broadly parallel to the long axes of the deformed pyrite, feldspar and quartz, which plunge around 15° towards 350°. As a result, the orebodies consist largely of cigar-shaped bodies of carbonate-talc schists enclosed in the core of the sheath folds. On a regional scale it is part of a synformal structure. The strong structural control of the orebody demonstrates that the shear zones channelled the emerald-forming fluids.

According to Barros and Kinnaird (1987a) the emerald-forming fluids at Campos Verdes were aqueous solutions saturated with NaCl which also contained minor quantities of CO_2 and CH_4. KCl, $CaCl_2$ and $MgCl_2$ salts were also identified in these fluid inclusions. The origin of the emerald-forming fluids was investigated by Fallick and Barros (1987) through stable isotope analyses. Their results indicated a clear distinction between the H_2O contained in the structural channels ($\delta D = -39 \pm 5‰$), the H_2O present in other parts of the emerald structure ($\delta D = -50 \pm 10‰$) and the H_2O in the fluid inclusions ($\delta D = -156 \pm -62‰$). These results suggest that the emerald-forming fluids were derived either from a magmatic source or from the metamorphism of ultrabasic rocks.

Gemmological properties

The emeralds of the Campos Verdes mining district appear mainly as euhedral crystals which combine a first-order hexagonal prism $(10\bar{1}0)$ with a basal pinacoid (0001). The size of these crystals is extremely variable, reaching up to 27 mm in length.

Figure 3: Back-scattered electron images illustrating (a) parallel intergrowth and (b) growth striae on emerald crystal faces.

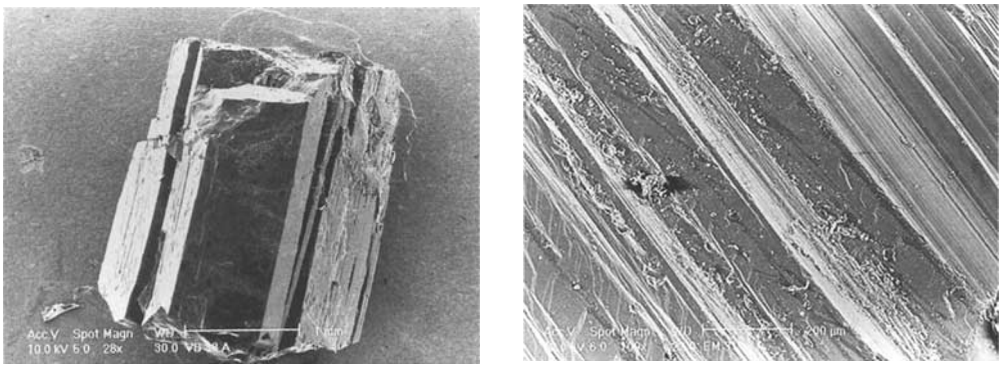

Figure 4: *Photomicrographs of emerald crystals with sharply defined colour zones. (a) Colourless core surrounded by a green outer zone. (b) Green core enveloped by colourless outer zone.*

Short prismatic crystals, parallel intergrown *(Figure 3a)*, and radiating and irregular crystal groups are common. All crystals show a strong parting perpendicular to the *c*-axis and striae parallel to this crystallographic axis *(Figure 3b)*. Rarely, the crystals contain gradational colour zoning parallel to the basal pinacoid (0001), passing from green to colourless. Concentric zoning is also observed, which comprises a colourless core enveloped by a green outer zone *(Figure 4a)* or the opposite – a green core and a colourless outer zone *(Figure 4b)*.

The densities obtained from transparent emeralds varied between 2.713 and 2.793 g/cm^{-3}, whereas those crystals with abundant solid inclusions showed values up to 2.8 g/cm^{-3}. Under the gemmological microscope, the emerald crystals in this study were seen to contain one or more inclusions of the following: talc, phlogopite/biotite, carbonate, pyrite, beryl and quartz. Magnesite and dolomite *(Figure 5)* were identified by X-ray diffraction and not only occur as inclusions but also fill emerald fractures. Inclusions of

Figure 5: *Scanning electron image of dolomite crystals filling a fracture in emerald, and an X-ray diffractogram of the dolomite shown.*

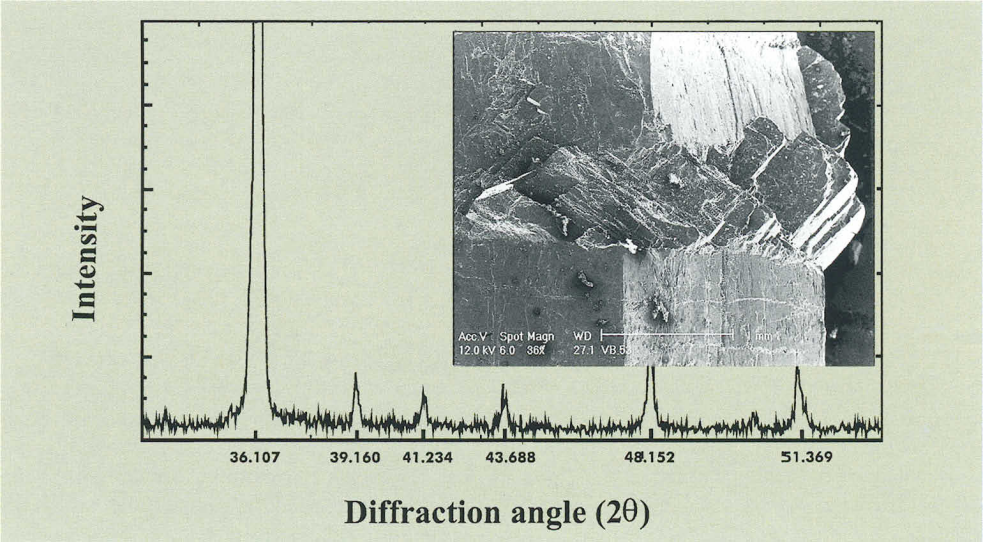

Analytical procedures

Refractive indices of emerald crystals were measured with a Schneider refractometer on polished surfaces of emerald crystals, and the crystal density was determined in distilled water at room temperature using a hydrostatic balance.

Emerald crystals apparently free of inclusions were washed with a dilute solution of HCl at 130°C, for 90 minutes, in order to remove carbonate from the fractures. The minerals were analysed by X-ray diffraction, after that only samples free of solid inclusions were selected for analysis by inductively coupled plasma mass spectrometry (ICP-MS), Fourier transform infrared spectroscopy (FTIR) and Mössbauer spectroscopy (MS).

The X-ray diffraction analyses were carried out using a Siemens diffractometer equipped with CoKa tube, operating at 30 kV and 30 mA, in the 2–80° 2θ range. The angles of diffraction spacings were measured with a precision of 0.026° 2θ. Quartz powder was used as internal standard.

Emerald crystals without colour zoning were analysed by ICP-MS. The contents of SiO_2, TiO_2, Al_2O_3, MnO, MgO, CaO, Na_2O, K_2O, P_2O_5, Cr_2O_3, BeO, V_2O_5, Cs_2O, Sc_2O_3, Rb_2O and LOI were determined by fusion; FeO/Fe_2O_3 contents were measured by titration. The other elements (Ba, Sr, Y, Zr, Li, Cu, Pb, Zn, Ag, Ni, Cd and Bi) were analysed by total digestion.

The CO_2 content was determined on an automated LECO CS-344 carbon sulphur analyser. A weighed sample was mixed with iron chips and a tungsten accelerator, and was then burned in an oxygen atmosphere at 1370°C. The moisture and dust were removed and the CO_2 gas and SO_2 gas were measured by a solid-state infrared detector. CO_2 was determined by taking a second sample in a ceramic crucible and adding 25% HCl dropwise until no reaction was observed. The sample was dried on a hotplate at low temperature and C was redetermined on the dried residue. The difference was calculated as CO_2.

The Mössbauer analyses were performed using absorbers prepared with appropriate amounts of ground (320 mesh) material in order to satisfy the ideal absorber thickness approximation (Long *et al.*, 1983). Each sample, ground in an agate mortar, was mildly compacted in a Plexiglas holder. The spectra were obtained at room temperature (RT) using a constant acceleration electromechanical drive system with a multichannel analyzer for collecting and storing the data.

The volatile substances in the powder of the emerald crystals were identified using a Galaxy series 3000 Fourier transform infrared spectrophotometer, operating at room temperature, with a precision of 4 cm^{-1}. These analyses were done on powder pellets consisting of emerald and KBr in the ratio 1:100, according to the technique described by Russell (1974).

feldspar, ankerite, garnet, baryte, apatite, chromite, picotite, actinolite/tremolite, glass, rutile, hematite, limonite, ilmenite and magnetite have already been reported by Bank and Petsch, 1982; Barros and Kinnaird, 1987b; Borelli, 1986; Cassedanne and Sauer, 1984; Fillmann, 1987; Giuliani and Weisbrod, 1988; Hänni and Kerez, 1983; Lind *et al.*, 1986; Mendes and Svisero, 1988.

The RI measurements supplied relatively constant averages with n_o = 1.590 to 1.593 and n_e = 1.580 to 1.587, while the birefringence ranged from 0.005 to 0.012. The dichroism is distinct and the colours are green //*c* and yellowish-green ⊥*c*. These emerald samples showed a reddish glow when viewed under the Göttinger colour filter, but they are inert under the Chelsea filter and to long- and short-wave ultraviolet light.

Table I: Compositions of emeralds from Campos Verdes obtained by inductively coupled plasma mass spectrometry (ICP-MS)

Sample	*VB-1000*	*VB-3000*	*VB-4000*	*VB-5000*	*VB-6000*
colour	*medium-green*	*medium-green*	*medium-green*	*medium-green*	*medium-green*
wt. %					
SiO_2	59.22	63.42	63.82	60.44	63.50
Al_2O_3	12.68	12.42	13.58	12.74	13.02
Fe_2O_3	1.52	1.77	1.21	1.67	1.54
FeO	0.62	0.25	0.26	0.25	<0.1
MnO	0.01	<0.02	<0.02	<0.02	<0.02
MgO	6.26	4.52	3.56	5.06	4.10
CaO	1.10	0.24	<0.02	1.38	0.18
Na_2O	2.32	2.36	2.34	2.32	2.36
K_2O	0.06	0.10	0.06	0.04	0.08
TiO_2	<0.01	<0.02	<0.02	<0.02	<0.02
P_2O_5	<0.02	<0.02	<0.02	<0.02	0.06
Cr_2O_3	0.36	0.44	0.46	0.44	0.36
BeO	10.95	10.66	11.14	10.78	10.78
V_2O_5	0.07	0.08	0.06	0.06	0.06
Cs_2O	0.10	0.10	0.10	0.10	0.10
Sc_2O_3	0.20	0.22	0.18	0.20	0.18
Rb_2O	<0.01	<0.02	<0.02	<0.02	<0.02
LOI	4.52	3.32	2.92	4.62	3.18
Total	99.99	99.90	99.69	100.10	99.50
wt. %					
CO_2	2.27	0.54	0.08	2.24	0.34
ppm					
Ba	1	<2	<2	<2	<2
Sr	32	10	<2	38	6
Y	<1	<2	<2	<2	<2
Zr	<1	4	<2	4	<2
Li	30	24	38	28	28
Cu	2	2	5	3	2
Pb	<5	<5	<5	<5	<5
Zn	7	4	8	7	2
Ag	<0.4	<0.4	<0.4	<0.4	<0.4
Ni	97	44	40	44	37
Cd	<0.5	<0.5	<0.5	<0.5	<0.5
Bi	<5	<5	<5	<5	<5

Chemical signature

The composition of Campos Verdes emerald is summarized in *Table I*. The ICP-MS results of emerald samples indicate a relatively constant Be content of 10.6 to 11.2 wt.% BeO and variable quantities 11.96 to 13.58 wt.% of Al_2O_3. These results are consistent with previous works (Fillmann, 1987; Schwarz, 1990). In all samples there is fair correlation between Ca + Mg and the CO_2 contents *(Table I)*, which suggests that the analyses were contaminated with carbonate inclusions. Therefore, the values for Ca and Mg are not considered in relation to the emerald structure.

In all emerald samples analysed *(Table I)*, the elements Fe, Cr, Ni, Zn, Sc and V were all present in detectable quantities. The large-ion lithophile elements (LILE, Ba, Sr, Rb and Pb) and the high field strength elements (HFSE, Zr, Y and Ti) occur in amounts near or below the detection limits. The presence of the Cr–Ni–Zn association and the low contents of LILE and HFSE suggest the contribution of an ultrabasic component during the interaction between fluids and rocks.

However, we have not recognized any systematic correlation between the intensity of the green colour and Cr^{3+} or V^{3+} quantities.

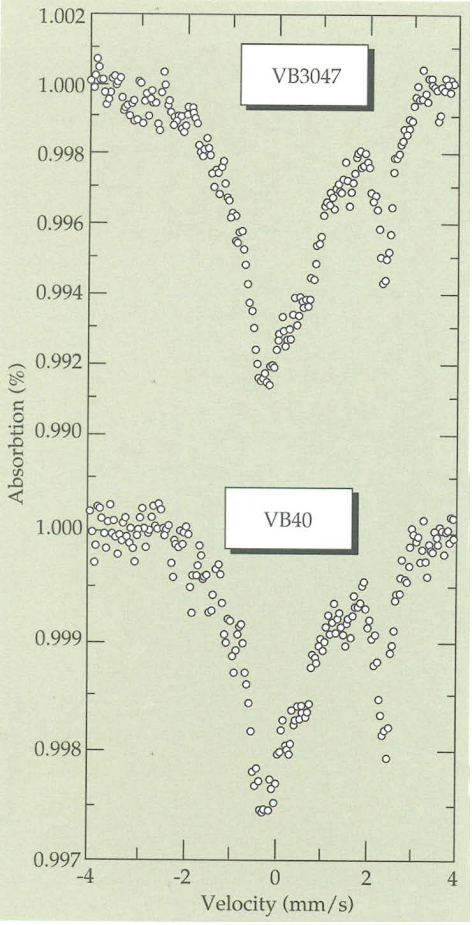

The valence state of iron in the Campos Verdes emerald samples VB40 and VB3047 was investigated by Mössbauer spectroscopy. The spectra obtained are very complex *(Figure 6)* and resemble quite closely that obtained by Parkin *et al.* (1977) for a blue beryl sample. Although it was not possible to fit the Campos Verdes emerald spectra, they indicate proportions of $Fe^{3+} > Fe^{2+}$, consistent with results in *Table I.* Thus, according to ligand field theory it is reasonable to expect that the variety of hues observed in the Campos Verdes emerald samples is in part due to the presence of Fe^{3+} in these gems. In addition, the values of the birefringence (Δ up to 0.012) and the failure of the emeralds to respond to both short- and long-wavelength ultraviolet light probably can also be attributed to the Fe content of these gems, such as has already been suggested by Gübelin (1989) for Pakistan emerald crystals.

Alkali metals were detected in all Campos Verdes emerald crystals, which show $Na^{+} > Cs^{+} > Li^{+}$ *(Table I).* The average Li content is 29.6 ppm, which probably is

Figure 6: *Mössbauer spectra for emerald samples at room temperature.*

Figure 7: *Diagram of* Al^{3+} versus $(Fe^{3+} + Cr^{3+})$ *values, expressed in atomic proportions, in emerald from Campos Verdes.*

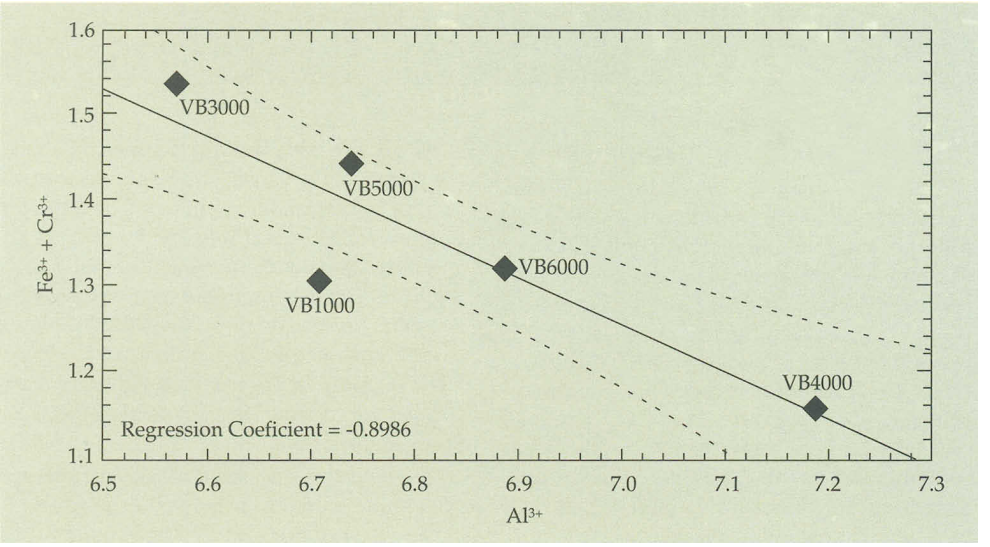

Table II: Comparison of H_2O contents in Campos Verdes emeralds with those reported by Aurissichio et al. *(1988) and Cheilletz (1993) in emeralds from other deposits..*

Locality	*Sample number*	*H_2O (wt.%)*	*Reference*
Mingora, Pakistan	4	2.20	
Habachtal, Austria	23	2.60	
Carnaíba, Brazil	9	2.30	Aurisicchio *et al.*, 1988
Muzo, Colombia	10	2.40	
Ural Mountains, USSR	26	2.30	
Carnaíba, Brazil	CATV	2.42	Cheilletz *et al.*, 1993
	VB-1000	2.25	
	VB-3000	2.78	
Campos Verdes, Brazil	VB-4000	2.84	This study
	VB-5000	2.38	
	VB-6000	2.84	

related to the Be-deficiency according to the Be ↔ Li isomorphous replacement (Aurisicchio *et al.*, 1988; Hawthorne and Cerny, 1977). The Al-deficiency is compensated by (Fe^{3+} + Cr^{3+}) as indicated by the negative linear correlation between these elements *(Figure 7)*. Any charge deficiency due to such substitutions is normally compensated by introduction of Na^+ and Cs^+ into channel sites (Aurisicchio *et al.*, 1994; Hawthorne and Cerny, 1977).

The total volatile content of the Campos Verdes gems ranges from 2.92 to 4.62 wt.%, while the CO_2 content varies between 0.08 and 2.27 wt.% *(Table I)*. The abundance of H_2O may be estimated by subtraction of the CO_2 from the LOI content. Thus, the total H_2O contents of Campos Verdes emerald crystals vary between 2.25 and 2.84 wt.%. These values are similar to H_2O contents of emerald crystals from other schist deposits *(Table II)*. For example, Aurisicchio *et al.*

***Figure 8:** Fourier transform infrared (FTIR) spectrum from 400 to 1200 cm^{-1} for emerald VB5000 from Campos Verdes.*

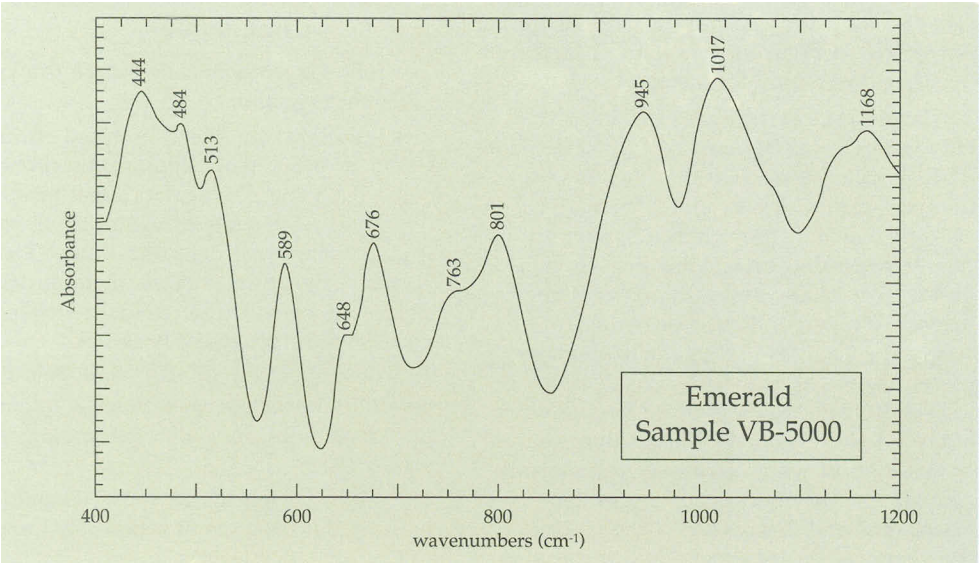

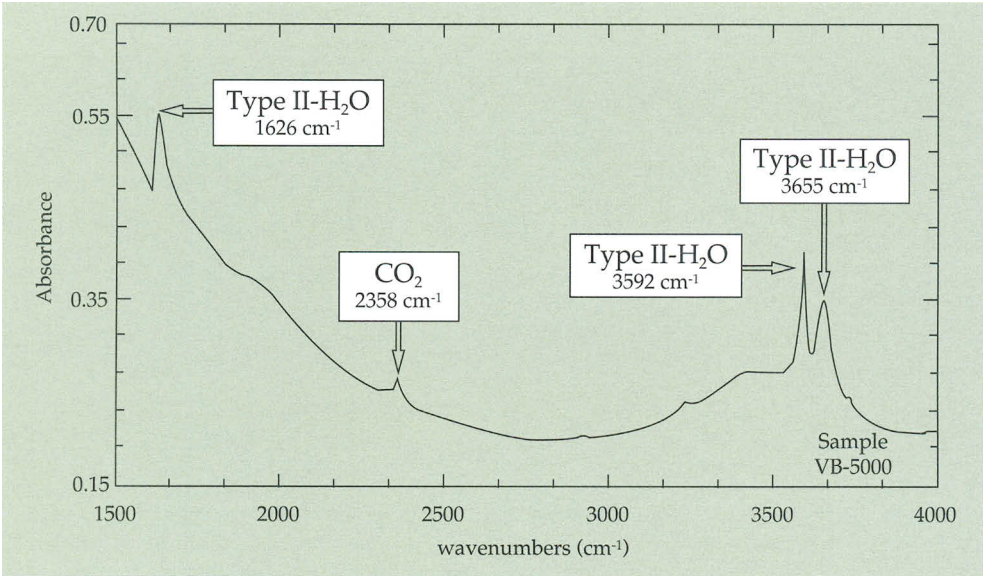

Figure 9: *Infrared spectrum from 1500–4000 cm^{-1} showing CO_2 and type II H_2O peaks in emerald from Campos Verdes.*

(1988) reported similar H_2O quantities in emeralds from Habachtal (Austria), Carnaíba (Brazil), and Mingora (Pakistan).

Infrared spectroscopy analyses were done on 18 emerald powder samples, in order to identify volatile substances in these gems. The various spectra obtained are very similar in the 400–1200 cm^{-1} interval *(Figure 8)*, except for the vibration intensities. According to Plyusina (1964) the bands in this range are typical for the beryl structure.

The presence of molecular species, such as H_2O and CO_2, can be easily recognized in the FTIR spectra *(Figure 9)* of the emeralds from Campos Verdes. Wood and Nassau (1968) classified water molecules as type-I or type-II, depending on whether the symmetry vector of H_2O molecule is oriented, respectively, perpendicular or parallel to the *c*-axis. The Campos Verdes emerald samples present bands at 1625–1627, 3591–3592 and 3655–3658 cm^{-1}, which indicate the presence of type-II H_2O *(Figure 9)*. The predominance of this kind of water is related to the alkali content in the beryls as suggested by Hawthorne and Cerny (1977). The spectra of the Campos Verdes emerald samples also show a peak at 2353 cm^{-1}, which is typically caused by CO_2 molecules either in the channel sites or in fluid inclusions (Wood and Nassau, 1968). The water peaks are of higher intensity than the CO_2 peak, which is consistent with the relative contents found by analysis *(Table I)*.

Conclusions

The following conclusions can be drawn from the investigation:

1. The emerald samples analysed from Campos Verdes show significant contents of Fe, Cr, V, Ni, Zn, Sc and alkali metals (Na $\gg$ Cs > Li), while LILE and HFSE are near or below the detection limits. This chemical signature suggests metasomatic exchanges between the emerald-forming fluids and the ultrabasic host rocks.
2. The emeralds contain Fe^{3+} and Fe^{2+} in quantities sufficient to influence colour, refractive index and other gemmological properties.
3. The infrared spectra of these emeralds indicate the presence of type-II H_2O and CO_2.

Acknowledgements

The authors wish to thank Dr Onildo J. Marini for research support and the Mineração Peneri, Mineração Verobi and Mineração Itaobi for access and logistical assistance during field work, and Ms Silvia M. Barreto for her help with the English translation. This research was financed by PADCT/FINEP-DNPM nº65.94.0158. FTIR analyses were carried out at Instituto de Química, Universidade Federal do Rio Grande do Sul (UFRGS) and ICP analyses at Actab-Activation Laboratories Ltd., Ontario, Canada. Special thanks are due to Dr D. Schwarz for a critical reading of the manuscript.

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An interdisciplinary approach to identifying solid inclusions in corundum: thorite in a 'Sri Lanka' sapphire

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ABSTRACT: A blue sapphire of commercial provenance examined using a transmitted-light microscope revealed at least two different types of inclusions. One was considered to be an idiomorphic spinel with an appreciable content of Cr^{3+}, and the second, a metamict zircon. A more complete characterization by EDS microanalysis and gamma-spectrometry led to identification of the latter inclusion as thorite ($ThSiO_4$). This report emphasizes the desirability of using completely independent techniques when dealing with complex identification problems.

Keywords: gamma-spectrometry, sapphire, Sri Lanka, solid inclusions, spinel, thorite

Introduction

Reports have been published recently (Ajò *et al.*, 1996a; Carbonin *et al.*, 1998) on the application of photoluminescence (PL) spectroscopy to gemmological problems. The PL technique was successfully employed by some of us, in addition to the more usual methods, in the investigation of minerals and of their synthetic analogues. These studies are of interest in different fields, among which are gemmology, laser material production (Barba *et al.*, 1997) and works of art (Ajò *et al.*, 1996b).

A comprehensive discussion concerning our studies of corundum and related materials is presently in preparation. However, we think it is useful at this stage to briefly demonstrate the value of a multi-disciplinary approach to chemical, structural and morphological features of corundum.

Results and discussion

A 'classic' blue sapphire was one in a series of samples kindly provided by Mr Silvano Bettella (Settore Orafo, Confederazione Nazionale Artigianato (C.N.A.), Padova), whose experience (in the absence of reliable information about its provenance) induced us to ascribe it to the 'Sri Lanka' type.

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Observation by means of transmitted-light microscopy revealed at least two different types of inclusions.

The first kind of solid inclusion *(Figure 1)* is associated with 'fingerprints' and its red colour and habit led us to think it was an idiomorphic spinel octahedron, reported as a typical feature of Sri Lanka sapphires by Gübelin and Koivula (1992) and Webster (1994).

Since a red spinel should have an appreciable concentration of Cr^{3+}, we recorded a photoluminescence (PL) spectrum of this material using a He–Ne (λ = 632.8 nm, 25 mW) laser. Most sapphires, blue or even colourless (Ajò *et al.*, 1996a; Carbonin *et al.*, 1998), and spinels investigated so far contain enough chromium to give rise to a PL spectrum.

The He–Ne excited PL spectrum exhibited the well-known Cr^{3+} (Ajò *et al.*, 1996a) emission from the host sapphire but it was much weaker and noisier than those of materials previously studied by He–Ne (Ajò *et al.*, 1996a; Carbonin *et al.*, 1998). Therefore, in order to confirm the assignment we resorted to a much more intense Ar (λ = 488.0 nm, 1.5 W) source *(Figure 2)*.

Figure 1: *Idiomorphic octahedral inclusion in transmitted light (50x).*

On examination through a microscope, the second solid inclusion *(Figure 3)* showed the typical habit and tension-halos and

Figure 2: *Ar-excited PL spectrum of the sapphire.*

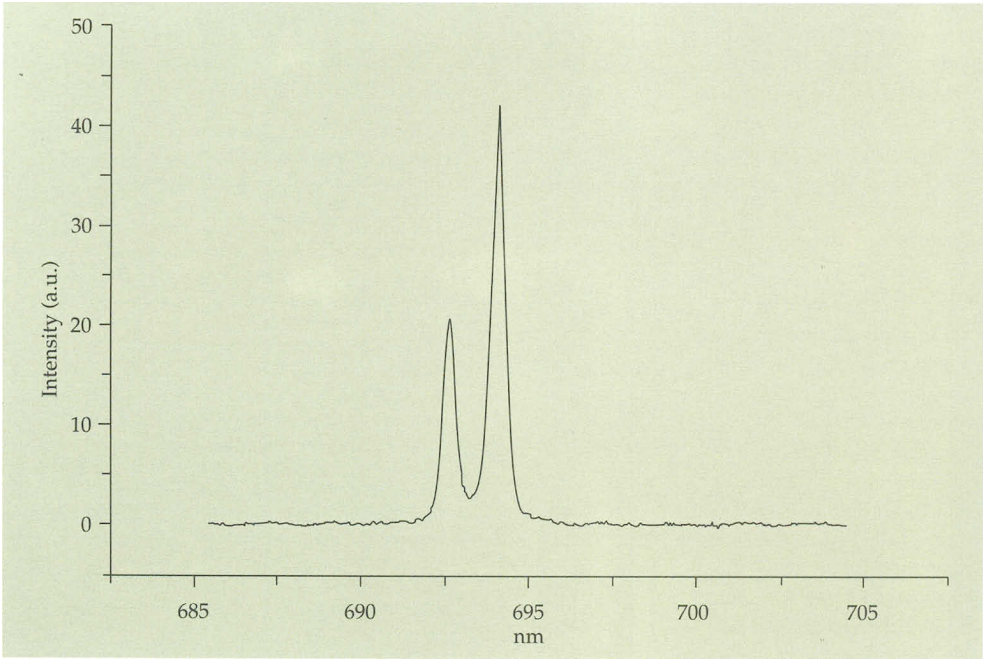

Figure 3: Thorite inclusion about 45 μm long, resembling zircon, transmitted light (100x).

fissures of a metamict zircon grain (Gübelin and Koivula, 1992; Webster, 1994). This inclusion appeared close to the surface of the host crystal, and during preparation of the sapphire for electron probe microanalysis, it was thought worthwhile to determine the nature of this inclusion by polishing the sapphire until the level of the inclusion was reached and then analysing it.

Surprisingly, once the electron beam was focused on the extremely small polished area, no characteristic Zr radiation was detected by means of the energy dispersive system (EDS). Instead, together with the already expected silicon Kα, various wavelengths were present that could be ascribed to thorium: among these the most intense were $M_{\alpha 1}$, $M_{\alpha 2}$ (2.996, 2.986 keV) and M_{β} (3.145 keV). No other major peaks were present and the possibility that the mineral was thorite ($ThSiO_4$) is supported by the habit which is very similar to that of zircon.

Due to the extremely small size of the crystal under investigation, we thought further support for our identification using a different technique was necessary. So, using gamma-spectrometry with a low-background configuration n-type intrinsic germanium detector equipped with an epoxy window, the presence of natural ^{232}Th in the sample was definitively confirmed. The identification was possible through the gamma emission of daughters ^{212}Pb and ^{208}Tl at 238.6 keV (44.7% probability) and 583.1 keV(84.2%), respectively.

Conclusions

The above results indicate the value of using completely independent techniques – in the present case related to electronic (valence and core) and nuclear energy levels – when dealing with complex identification problems. In particular, we have shown that some caution is needed when an inclusion is attributed to zircon on the basis only of optical and morphological properties.

Finally, our findings concerning solid inclusions indicate the possibility of considering another mineral species in determining the provenance of a sapphire.

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The authors gratefully thank Dr A. Speghini (Ist. Policattedra Facoltà di Scienze, University, Verona) for recording the Ar-excited PL spectrum, and Dr C. Brogiato and Mr L. Tauro (Dipart. Mineralogia e Petrologia, University, Padova) for pictures and for carefully polishing the sapphire, respectively.

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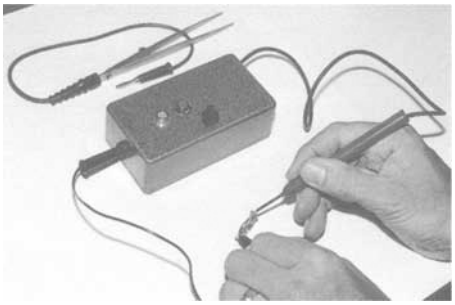

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Diamonds

Gem news – the 26th International Gemmological Conference.

M.L. Johnson and J.I. Koivula. *Gems & Gemology*, **33**(4), 1997, 298–310, 15 illus. in colour.

Cathodoluminescence could be used to help determine the diamond type with a possible classification of mixed types given. Diamond and graphite inclusions have been found in sapphires from Ban Huai Sai, Laos. Major mineral inclusions in large Yakutian diamonds were found to be sulphides, olivine and chromite, with the proportions varying from mine to mine. Three growth morphologies are found in natural diamonds; octahedral being the most common and forming the majority of gem material, cuboid of which only a portion forms gem material and fibrous which never yields gem-quality diamonds. J.J.

Mineral inclusions in diamonds from the River Ranch kimberlite, Zimbabwe.

M.G. Kopylova, J.J. Gurney and L.R.M. Daniels. *Contributions to mineralogy and petrology*, **129**, 1997, 366–84.

Mineral inclusions in diamonds from the River Ranch kimberlite pipe in Zimbabwe are almost entirely composed of phases of harzburgitic paragenesis (olivine (Fo92), orthopyroxene (En93)), G10 garnets and chromites. The pipe is situated in the Late Archean Limpopo Mobile Belt (LMB). Inclusion studies are used to assist the assignment of the tectonothermal age of the LMB and strengthen the theory that an ancient thick mantle root existed beneath the Belt about 530–540 million years ago. M.O'D.

[Diamonds in suevites of the Sudbury impact structure, Canada.] (Russian with English abstract)

V.L. Masaitis, G.I. Shafranovsky, R.A.F. Grieve, W.V. Peredery, E.L. Balmasov and I.G. Fedorova. *Proceedings of the Russian Mineralogical Society*, **26**(4), 1997, 1–6.

The treatment of samples of suevite from Black Onaping, Sudbury, Ontario, has revealed the presence of diamonds. Their morphology, optical properties, X-ray data and e.p.r. spectra show the surface and polycrystalline state of the cubic phase and prove the impact origin of the diamonds. Three forms of carbonaceous material, including shocked and single-crystal graphite, were found together with diamonds, having probably originated by the transformation of graphite in the target rocks. R.A.H.

A contribution to understanding the effect of blue fluorescence on the appearance of diamonds.

T.H. Moses, I.M. Reinitz, M.L. Johnson, J.M. King and J.E. Shigley. *Gems & Gemology*, **33**(4), 1997, 244–59, 9 illus. in colour, 3 tables.

Over the last few decades diamond dealers thought that fluorescence in diamonds had a negative effect on the overall appearance of the stone. Under concentrated LW ultraviolet radiation some diamonds fluoresce blue and this should be used as an identifying feature rather than a grading factor by gem testing laboratories. The GIA GTL investigated the effect of blue fluorescence on colourless to faint yellow diamonds when viewed from various positions under different lighting conditions. Four sets of six stones were chosen, which were similar in all respects (clarity, size, etc.) except fluorescence. The observers ranged from diamond dealers to people outside the trade. Only the experienced observers found any difference and their responses varied, but a correlation was found between viewing position and fluorescence. Strong blue fluorescing diamonds were thought to have a better colour appearance when viewed from the table down. Otherwise no relationship between fluorescence and transparency was found. These results show that it is best to judge each diamond on its own visual merits. J.J.

Gem Trade Lab notes.

T.H. Moses, I.M. Reinitz and S.F. McClure. *Gems & Gemology*, **33**(4), 1997, 292–6, 7 illus. in colour.

Diamonds can crack spontaneously without any apparent cause, but this could be linked to high amounts

Abstractors

R.K. Harrison	R.K.H.	J. Johnson	J.J.	P.G. Read	P.G.R.
R.A. Howie	R.A.H.	M. O'Donoghue	M.O'D.	E. Stern	E.S.
		G. Raade	G.R.	P.J. Treloar	P.J.T.

For further information on many of the topics referred to, consult *Mineralogical Abstracts*

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of strain within the stone. A square cut diamond of saturated pink colour with abundant fractures was examined and after fracture filling procedure the colour appearance was much enhanced, although the clarity was not significantly improved. J.J.

Radiation-induced diamond crystallization: origin of carbonados and its implications on meteorite nano-diamonds.

M. OZIMA AND M. TATSUMOTO. *Geochimica et Cosmochimica Acta*, **61**(2), 1997, 369–76.

Analyses are presented of 10 carbonados from Central Africa, for U–Th–Pb elements and isotopes, and of Y,Th–derived noble gases. On the basis of the U–Th–Pb systematics a model is proposed for the origin of carbonados in which radiation-induced diamond crystallization is involved. This mechanism may be relevant to the origin of nanodiamonds in primitive meteorites. A minimum age of 2600 m.y. and a maximum age of 3800 m.y. are assigned to the radiogenic Pb by assuming instant production or integrated production from radioactive decay of U. The radiogenic Pb in the carbonados was implanted from its surroundings due to the a-recoil of radiogenic Pb. Excess radiogenic Pb and fission Xe, Kr and ^{4}He in carbonados suggests that energetic particles emitted by U and Th changed carbonaceous precursor material to diamond, the crystallization age of microdiamonds in carbonados being 2600–3800 m.y. R.K.H.

The Premier mine, Pretoria, South Africa.

R. SANCROFT-BAKER. *Christie's Jewellery Review 1997*, 1998, 14–15, illus. in colour.

Short account of a visit paid to the Premier diamond mine, Pretoria, South Africa. Details of the local geology and of the recovery of diamonds are given. M.O'D.

Mineral inclusions in diamonds from the Sputnik kimberlite pipe, Yakutia.

N.V. SOBOLEV, F.V. KAMINSKY, W.L. GRIFFIN, E.S. YEFIMOVA, T.T. WIN, C.G. RYAN AND A.I. BOTKUNOV. *Lithos*, **39**(3–4), 1997, 135–57.

The Sputnik kimberlite pipe is a small satellite of the larger Mir pipe in central Yakutia (Sakha), Russia. Study of 38 large diamonds (0.7–4.9 ct) showed that nine contain inclusions of the eclogitic paragenesis, while the remainder contain inclusions of the peridotitic paragenesis, or of uncertain paragenesis. The peridotitic inclusion suite comprises olivine, enstatite, Cr-diopside, chromite, Cr-pyrope (both lherzolitic and harzburgitic), ilmenite, Ni-rich sulphide and a Ti–Cr–Fe–Mg–Sr–K phase of the lindsleyite-mathiasite series. The eclogitic inclusion suite comprises omphacite, garnet, Ni-poor sulphide, high-Ti phlogopite and rutile. G.R.

Syngenetic inclusions in diamond from the Birim field (Ghana) – a deep peridotitic profile with a history of depletion and re-enrichment.

T. STACHEL AND J.W. HARRIS. *Contributions to Mineralogy and Petrology*, **127**(4), 1997, 336–52.

The physical properties (size, shape, colour, deformation, inclusion assemblage, N content, % B, type, δ^{13}C, δ^{15}N) of diamonds from placer deposits of the Akwatia mine, southern Ghana, are tabulated and the inclusion abundance is reported for 693 inclusion-bearing diamonds. In comparison with a worldwide database for 1100 diamond inclusions, the Akwatia inclusions have olivines with lower Mg/Fe ratios and extremely high Ni contents. Geothermometry shows the Akwataian inclusions to be 140–190°C hotter than the peridotitic average (1050°C), and since garnet-orthopyroxene equilibria (1100°C/50 kbar to 1370°C/67 kbar) indicate a typical shield geotherm (40–42 mW/m^2), these elevated temperatures imply an origin for the Akwatia diamonds unusually deep for a peridotitic suite. It is considered that the inclusions in these diamonds represent the most complete cross-section through peridotitic subcontinental lithospheric upper mantle so far observed, down to a maximum depth of 200–240 km. R.A.H.

Diamanten aus China.

G. STEINER. *Lapis*, **22**(11), 1997, 13–17, 1 map in colour.

The presence of diamond in the territory composing present-day China has been known as long ago as the fourth century. Several Chinese authorities are cited in support of this view. Today at least 14 major sites have been identified and three major platforms accommodate both peridotite and lamproite-housed diamond deposits. Today about one million carats of diamond are recovered annually and details of the occurrence and working of the Chang-ma kimberlite pipe are given. This area is already responsible for notable crystals. M.O'D.

Metamorphic evolution of diamond-bearing and associated rocks from the Kokchetav Massif, northern Kazakhstan.

R. ZHANG, J.G. LIOU, R.G. COLEMAN, N.V. SOBOLEV AND V.S. SHATSKY. *Journal of Metamorphic Geology*, **15**(4), 1997, 479–96.

Representative diamond-bearing gneisses and dolomitic marble, eclogite and Ti-clinohumite-bearing garnet peridotite from Kumdu Kol and whiteschist from Kulet were studied. Diamond-bearing gneisses contain variable assemblages including Grt + Bt + Qtz ± Pl ± Kfs ± Zo ± Chl ± Tur ± Cal and minor Ap, Rt and Zrn; abundant inclusions of diamond, graphite + chlorite (or calcite), phengite, clinopyroxene, K-feldspar, biotite, rutile, titanite, calcite and zircon occur in garnet. Diamond-bearing dolomitic marbles consist of Dol + Di ± Grt + Phl; inclusions of diamond, dolomite ± graphite, biotite and clinopyroxene were identified in garnet. Other ultrahigh-pressure (UHP) indicators include Na-bearing garnet (≤ 0.14 wt.% Na_2O) with omphacite Cpx in eclogite, occurrence of high-K diopside (≤ 1.56 wt.% K_2O) and phlogopite in diamond-bearing dolomitic marble, and Cr-bearing kyanite in whiteschist. P.J.T.

Neue Smaragdfunde aus Chile, Südamerika.

A.G. Banko, F. Brandstätter, G. Niedermayr and J. Karfunkel. *Gemmologie (Zeitschrift der Deutschen Gemmologischen Gesellschaft)*, **46**, 1997, 213–24. 16 photographs, 3 graphs, 4 tables, bibl.

One new occurrence of emeralds is high in the Andes, east of a town called Ovalle in Chile, near the Argentinian border; and another report indicates that emeralds have been found in the Atacama desert between the coast and the Andes. Up to now there have been very few Chilean emeralds on the market. The emeralds have proto- and syngenetic one-, two- and multi-phase mineral inclusions. There is strong zonal coloration, emphasized under crossed nicols. The inclusions consist largely of actinolite, dolomite, pyrrhotite, rutile, with also some bismuth, sulphides, silicates, oxides and phosphates (determined by spectroscopy, electron microprobe and an analytical scanning microscope). The Chilean emeralds are mineralogically and gemmologically very similar to the metamorphic emeralds from the Habachtal. E.S.

Radiation damage in zircons.

R. Biagini, I. Memmi and F. Olmi. *Neues Jahrbuch für Mineralogie Abhandlungen*, **6**, 1997, 257-70.

The uranium and thorium content of zircon affects the degree of metamictization observed. U and Th contents of samples tested ranged from 57–2890 ppm and 27–420 ppm respectively. Density decreased in parallel with U and Th content and a range 4.80 > 4.10 g/cm^3 was measured. Changes in X-ray powder diffraction were also noticed. During annealing these patterns gave different results as did IR spectra. After heating at 950°C, X-ray diffraction patterns became sharp and showed a nearly complete structural recovery which was, however, seen to be incomplete when compared to fully crystalline examples. M.O'D.

Dossier central [on pearls].

J. Caseiro, J.-P. Gauthier, J. Taburiaux, G. Grospiron, C. Levi-Plé and P. Verhoeven. *Revue de gemmologie*, **133**, 1998, 10–22, illus. in colour.

A collection of short papers dealing with: pearls from Tahiti; *pinctada margaritifera;* trends and developments in the world of the pearl; the possibility of grading pearls; pearl restoration; freshwater pearls. M.O'D.

Rubies, sapphires and emeralds – quality and origin.

A.I. Castro. *Christie's Jewellery Review 1997*, 1998, 26-8, illus. in colour.

Properties, values and outstanding features of the major gemstones are briefly described, the piece accompanied by illustrations selected from items recently sold by Christie's. M.O'D

Aussergewöhnlicher Quarzfund im Valle Bedretto, Tessin.

D. Donati, R. Guerra, N. Oppizzi and P. Oppizzi. *Lapis*, **23**(2), 1998, 31–5, illus. in colour.

Extraordinarily large crystals of smoky quartz have been found near the Valleggia glacier in the Valle Bedretto, Ticino, Switzerland. The largest crystal so far found measures 92 cm in length, 45 cm in thickness, weighing 150 kg. Fluid inclusions are visible in some specimens. Temperature of formation is believed to be 300° to 450°C with a pressure of between 2 and 3.5 kbar. M.O'D.

XRD and IR spectroscopic investigations of some chrysoprases.

A. Gawel, S. Olkiewicz and W. Zabinski. *Mineralogia Polonica*, **28**, 1997, 43–50.

Chalcedony content of some chrysoprase from different localities was examined by XRD and IR spectroscopy. Samples showed a wide range of silica crystallinity. Specimens with a low degree of silica crystallinity generally have higher Ni content and an intense green colour. Some of these samples also gave XRD reflections of the microcrystalline silica phase moganite as well as a broad reflection d_{hkl} ~ 10 Å whose origin is still unestablished. In none of the specimens examined were reflections of NiO (bunsenite) present. M.O'D.

Les gisements d'émeraude du Brésil: genèse et typologie.

G. Giuliani, A. Cheilletz, J.-L. Zimmermann, A.M. Ribeiro-Althoff, C. France-Lanord and G. Feraud. *Chronique de la recherche minière*, **526**, 1997, 17–61, illus. in colour, 9 maps.

The pre-Cambrian mineralization of the Brazilian emerald deposits is discussed. Main locations are in the states of Bahia (Carnaíba and Socotó), Minas Gerais (Mina Belmont, Capoeirana) and Goiás (Santa Terezinha). The deposits are always located in Lower Proterozoic volcano-sedimentary sequences with intercalations of mafic to ultramafic rocks. Mineralization is associated either with pegmatites intruding mafic to ultramafic rocks (Socotó, Carnaíba, Belmont, Capoeirana) or are linked to ductile shear zones affecting formation of mafic or ultramafic rocks. The origins of both types of deposit are described and considerable detail on the quality of the emeralds and their inclusions is provided. M.O'D.

La foitite delle pegmatiti di S. Piero in Campo, Isola d'Elba.

A. Guastoni and F. Pezzotta. *Rivista mineralogica italiana*, **21**, 1997, 251–5, illus. in colour.

Foitite, a newly-reported end-member of the tourmaline group, is found in the S. Piero di Campo pegmatites on the Isle of Elba, Italy. It occurs as fibrous crystals, and details of some of the gem-quality elbaite crystals are also given. M.O'D.

Über die Bildung von Perlmutter und Perlen.

H.A. Hänni. *Gemmologie (Zeitschrift der Deutschen Gemmologischen Gesellschaft)*, **46**, 1997, 183–96, 7 photographs, 3 diagrams, bibl.

The author reviews various papers dealing with nacre and pearls and compares these notes to his own observations. Nacre and pearls are formed in the same way, the outer mantle epithelium first producing the periostracum, then columnar and finally tabular calcium carbonate (nacre). The same sequence produces natural pearls from the centre to the rim of the pearl. The transplantation of an epithelium graft to an organ in the shell means that a 'microchip' brings the knowledge of nacre forming to a part of the animal with no tradition of pearl forming and the graft grows into an entire pearl sac. The article ends with a short survey of the properties of natural, cultured and imitation pearls. E.S.

Quartz-Mineralisationen in Rhyolithkugeln nahe des Seebachsfelsens südwestlich Friedrichroda, Thüringer Wald.

G. Holzhey. *Gemmologie (Zeitschrift der Deutschen Gemmologischen Gesellschaft)*, **46**, 1997, 197–212, 16 photographs, 2 maps, 1 table, bibl.

Globular rhyolites (spherulites) contain in central star-shaped cavities epigenetic jasper-like minerals, agates and macrocrystalline quartzes such as rock crystal and amethyst as well as calcite and fluorite. The agates, including the dominant horizontal granular type agate are characterized by differences in genetic attributes. Layers of granular type are followed by layers of increasingly crystalline grained structure, followed by layers showing macrocrystalline quartz. E.S.

Some new unusual cat's-eyes.

J. Hyrsl. *Canadian Gemmologist*, **18**, 1997, 105–6, illus. in black-and-white.

Some rare chatoyant gem materials recently reported include yellow baryte from the Czech Republic, brazilianite, dark blue translucent kyanite from India, red to dark red Tasmanian crocoite, bluish danburite from Alto Chapare area of Bolivia and from Madagascar, light brown enstatite from Tanzania, rhodochrosite from a new locality in Kazakhstan and opaque, brownish-black rutile from Sri Lanka. M.O'D.

Darwin-Glas: ein schleifwürdiger, grüner Tektit.

Sr.-A. Jacobs. *Gemmologie (Zeitschrift der Deutschen Gemmologischen Gesellschaft)*, **46**(1), 1997, 7–12.

Tektites of gem quality have been recovered from the area of Mount Darwin, Tasmania, and have been found to be compositionally similar to moldavites from Bohemia. They arise from an impact event and are mostly pale to dark green with a few greenish-brown and black specimens. The RI range is 1.470–1.482 and SG is 2.26. Swirl marks and gas bubbles are found as inclusions. M.O'D.

Gem news – the 26th International Gemmological Conference.

M.L. Johnson and J.I. Koivula. *Gems & Gemology*, **33**(4), 1997, 298–310, 15 illus. in colour.

The Renishaw Micro-Raman spectroscopy system with a near infrared system has helped to separate amber from its various imitations. Kauri gem from New Zealand may be labelled amber if older than Middle Tertiary otherwise younger material should be called copal. Fluorescence zoning in amber is associated with fauna inclusions and is diagnostic for natural amber. Three new chrysoberyl deposits were discovered in 1996 near the east coast of India, although separated by hundreds of kilometres they were probably formed at the same geological time. Bactrian emeralds are now thought to have come from Bactria (Northern Afghanistan) on the basis of new deposits of emeralds found in the Panjshir valley. The country of origin of emeralds, especially Colombian emeralds, may be determined by the isotopic composition of oxygen of the various rock types and the emeralds found in association with these rocks. Emeralds used by the ancient Romans were probably mined in Upper Egypt.

Blue quartz from Madagascar was found to contain many species of inclusion; lazulite inclusions were significant and imparted the overall blue colour to the quartz. Ornamental and gem stones from Bolivia are discussed with regard to their location, size and economics. Good quality cultured pearls from Indonesia are produced from blister pearls grown in the mollusc *Pinctada maxima;* recently resin has been used as the bead nuclei in some pearls so that they resemble artificial pearls with a low SG and a deceptive sheen caused by a thin nacreous layer. Several new sapphire deposits have been found in Madagascar especially in the north. The Tunduru-Songea gem field in southern Tanzania produces many different varieties of gemstone such as corundum, spinel, garnet, quartz, beryl, tourmaline, kyanite, diamond, etc. J.J.

Pearl identification.

S.J. Kennedy. *Australian Gemmologist*, **20**(1), 1998, 2–19, 48 black-and-white illustrations and 1 in colour, 1 graph.

Commencing with the description of a new X-ray unit, designed as a replacement for the original unit in the Gem Testing Laboratory's London premises, this review of pearl identification covers their mode of formation and the various techniques employed to test both individual pearls and pearl necklaces. The use of X-ray techniques to test pearls is discussed as well as the visual features which allow pearls to be categorized. 'Keshi cultured pearls', natural blister pearls, imitation pearls and the treatment of pearls are also covered. The differentiation of natural pearls from non-nucleated cultured pearls is considered to be the biggest challenge facing the pearl tester. P.G.R.

Pearls and pearl oysters in the Gulf of California, Mexico.

D. McLaurin, E. Arizmendi, S. Farell and M. Nava. *Australian Gemmologist*, **19**(12), 1997, 497–501, 6 illus. in colour, 1 map.

For more than four centuries until overfishing caused their demise, pearl fisheries in the Gulf of California were the main source of natural coloured pearls. Now a pilot-scale commercial venture has been set up by I.T.E.S.M.-Perlas de Guaymas for culturing the native pearl oysters *Pteria sterna* and *Pinctada mazatlanica*, and their pearls. The pearl farm is located at Bacochibampo Bay, Guaymas, Sonora, Mexico, and uses the suspended culture system and the Mexican grafting technology developed by I.T.E.S.M. Around 150,000 pearl oysters were cultured from both the above species, and in 1997 produced 30,000 mabe pearls and some round pearls. P.G.R.

What's new in minerals.

T. MOORE. *Mineralogical Record*, **28**, 1997, 505-8 illus. in colour.

Gem-quality yellow prisms of the rare mineral sturmanite are reported from the Springfield, Massachusetts Mineral Show, 1997. Other species of interest and of gem quality include sea-green fluorite octahedra from the Wise mine, Westmoreland, New Hampshire (once more being worked for specimens), orange transparent baryte from the Rosh Pinah mine in southern Namibia and crystals of pale brown transparent axinite from Khapalu, Ghanche District, Baltistan, Pakistan. M.O'D.

Gem Trade Lab notes.

T.H. MOSES, I.M. REINITZ, AND S.F. MCCLURE. *Gems & Gemology*, **33**(4), 1997, 292–6, 7 illus. in colour.

A green aquamarine showed an unusual absorption band at 537 nm in addition to the bands at 427 and 456 nm, this line is typical of untreated aquamarines and is found in yellow and colourless beryls. A violetish-blue cushion-shaped stone thought to be tanzanite was found to be beryl and it was strongly pleochroic with six sharp closely spaced lines between 575 and 690 nm. The colour in these stones is not stable and liable to fade. Using a Raman spectrometer and EDXRF a large dark red cabochon was found to be a pyrope-almandine garnet and not highly refractive glass. J.J.

Chrysoprase from Warrawanda, Western Australia.

T. NAGASE, M. AKIZUKI, M. ONODA AND M. SATO. *Neues Jahrbuch für Mineralogie, Monatshefte*, 1997(7), 289–300.

A study of chrysoprase from the boundary between granite and serpentinite in the Warrawanda district, 80 km SW of Newman, Western Australia, is reported using EM, TEM, FTIR and EPMA techniques. Inclusions of a cotton-like aggregate of kerolite were found as extremely fine-grained crystals; the kerolite contains ~ 10 wt.% NiO, the NiO content increasing with the degree of silicification of the surrounding serpentinite. It is inferred that this Ni-bearing kerolite is the cause of the apple-green colour of the chrysoprase. R.A.H.

Gems from the collection of Princess Dashkov.

O. YA NEVEROV. *World of Stones*, **12**, 1997, 39–41, illus. in colour.

Engraved gems form part of the collection of Princess Catherine Dashkov, whose *Memoirs* were published in 1859. Some outstanding specimens are illustrated with a brief biography. The Princess played a conspicuous part in the Revolution of 1762. M.O'D.

Titanite und seine Einschlüsse.

G. NIEDERMAYR. *Mineralien Welt*, **9**(1), 1998, 15-16, illus. in colour.

Titanite (sphene) has been found to contain a number of fluid inclusion patterns which are described and illustrated from specimens originating from Austria and Brazil. M.O'D.

Business review: gemstones.

M. O'DONOGHUE. *Britannica Book of the Year 98*, 1998, 164.

Reviews new gem species and varieties, stones returning to the market after long periods of absence, developments in gemstone commerce and the saleroom with details of particularly important prices paid. Reports on the use of child labour in the Indian diamond trade are noted and the economic financial situation in some Asian countries is reviewed as it affects gemstone prices.

(Author's abstract) M.O'D.

Le contrôle des perles à partir de 1929 au Laboratoire Gemmologique Français (du laboratoire syndical au laboratoire CCIP).

J.-P. POIROT AND E. GONTHIER. *Revue de gemmologie*, **133**, 1998, 26–7, illus. in colour.

History of the part played by the Laboratoire Gemmologique Français in pearl testing since 1929 with details of some of the instruments and tests used.

M.O'D.

Turkis aus Thüringen und Sachsen.

H. RIEDEL, G. HOLZHEY, S. PESTEL AND S. WEISS. *Lapis*, **23**(2), 1998, 42–4, illus. in colour, 1 map.

Turquoise of ornamental quality is reported from Weckersdorf, Thuringia, Germany, where it occurs in a siliceous schist with iron hydroxides and translucent crystals of yellow baryte. Turquoise is also described from Chrieschwitz near Plauen in the Vogtland area of Saxony. Some of this material may also be of fashioning quality.

M.O'D.

Green vanadium-bearing titanite from Chibougamau, Quebec, Canada.

G. ROBINSON AND W. WIGHT. *Gemmologie (Zeitschrift der Deutschen Gemmologischen Gesellschaft)*, **46**, 1997, 225–8, 1 photograph, 2 tables, bibl.

Gem-quality emerald-green titanite (sphene) has been found at the Lemoine vanadium mine near Chibougama, Quebec, where it occurs in alpine-type hydro thermal veins in magnetite and gabbro. RI 1.90–1.99, SG 3.519. Because chromium is present only in trace amounts, vanadium seems to be the principal chromophore; vanadium causing emerald-green colour in titanite has not previously been reported. E.S.

Historie, Geologie und Mineralogie der Quarz-Kristalle von Herkimer, New York.

R.H. Russ. *Mineralien Welt*, **8**(6), 1997, 61–71, illus. in colour, 2 maps.

Rock crystal quartz from the Herkimer 'diamond' mine in the Upper Cambrian at Middleville, north-west of Albany, New York, is famous for its perfection of form. Crystals took their varietal name from Nicholas Herkimer (1728–1777), from a family of German origin. They occur at different levels in the mine and may show phantom effects or sceptre forms. Some specimens of particular clarity have traditionally been called Herkimer diamonds. M.O'D.

Bitterfelder Bernstein: der Schatz aus der 'Goitsche'.

S. Schellhorn. *Lapis*, **23**(3), 1998, 35–7, Illus. in colour.

Short history of the amber finds, estimated at approximately 22 million years old, in the Bitterfeld region of central Germany. The actual amber-producing area, known locally as Goitsche, contains brown-coal recovery sites, some flooded, which have been illegally raided for amber specimens. Some insect inclusions have been reported. M.O'D.

Die Tucson Show 1998.

J. Scovil and B. Lees. *Lapis*, **23**(4), 1998, 35–8, illus. in colour.

Among gem-quality minerals appearing at the 1998 Tucson Show were fine crystals of amazonite from Tree Root Pocket, Pike's Peak, Colorado, USA, where it occurs in a pegmatite with smoky quartz. Fine blue aquamarine crystals from the Thuong Xian district, Hoa Province, Vietnam, were also on display. M.O'D.

A new era for opal nomenclature.

A. Smallwood. *Australian Gemmologist*, **19**(12), 1997, 486–96, 26 illus. in colour.

A new opal nomenclature, formulated by the GAA Opal Nomenclature Sub-committee, is designed for use throughout the gemstone and jewellery industry, not only in Australia but internationally.

Under the category 'Types of natural opal', three forms of natural opal are listed which apart from being cut and polished are otherwise untreated. These types include opal having a substantially homogeneous chemical composition, boulder opal and matrix opal.

The next category, 'Varieties of natural opal', describes the gem's body tone (i.e. its face-up relative darkness or lightness, ignoring play-of-colour) and its transparency. Body tones N1 to N4 are used for black opal, N5 and N6 for dark opal, and N7 to N9 for light opal. An opal with a distinctly coloured body has a hue notation appended to its body tone classification. Transparency codes A, B and C are used to cover all forms of diaphaneity ranging from transparent to opaque.

Although not associated with the descriptive classifications for natural opals, the nomenclature also discusses opal treatments, composite natural opal, synthetic opal and imitation opal. P.G.R.

What's new in minerals.

[Various authors.] *Mineralogical Record*, **28**(5), 1997, 409–17, illus. in colour.

Among gem minerals displayed at recent shows were large green Chinese fluorites from the Zianghualin mine, Hunan, and large rutile crystals from the classic site at Graves Mountain, Georgia, USA. The Chinese fluorites are reported from more than one show in the United States. Tanzanite crystals are still on the market; one fine specimen was nearly 3 cm long. The area of Xu Bao Diang, Piugwu, Sichuan, China, is known for fine specimens of cassiterite. It is associated with crystals of colourless beryl to make attractive groups. Crystals of ruby on calcite matrix, some with a fine raspberry-red colour, and measuring up to 5 cm, have been found at the Luc Yen ruby mine in Vietnam and featured in the Paris show. Fine reddish crystals of grossular from Sierra de las Cruces, Coahuila, Mexico, measured up to 2.8 cm and beautiful crystals of amethyst and smoky quartz up to 12.7 cm were shown from the Phillis Ann claim, Lake George, Colorado. The same locality produces twins of purple fluorite. M.O'D.

What's new in minerals.

[Various authors.] *Mineralogical Record*, **29**, 1998, 125–41, illus. in colour.

Different correspondents describe mineral specimens seen at a number of gem and mineral shows during 1997 all in the United States except for the München Mineralientage. Among the specimens of gem quality are amazonite and smoky quartz from the classic locality at Pike's Peak, Colorado, pink fluorite octahedra from the Chamonix area of the French Alps, yellow-brown sphene crystals from Alchuri, Baltistan, Pakistan, emerald crystals from the Brumado mine, Bahia, Brazil, and from the Medina mine, Minas Gerais, Brazil.

The feature also describes the newly-opened mineral hall at the National Museum of Natural History, Smithsonian Institution, Washington DC, USA. M.O'D.

Synthetics and Simulants

Gem news – the 26th International Gemmological Conference.

M.L. Johnson and J.I. Koivula. *Gems & Gemology*, **33**(4), 1997, 298–310, 15 illus. in colour.

(Further summaries of papers given at the 26th IGC cover a range of topics.) 80% of imitation pearls manufactured in Japan use plastic bead centres, while other imitation pearls have shell or white alabaster glass for the central bead. Growth induced imperfections and inhomogeneities in crystals are important especially in the identification of synthetic material. Recent research into synthetic quartz grown in sodium hydroxide solutions shows variations in morphology with an increase in temperature. Three pieces of a transparent purplish-pink material were found to be neodymium penta-phosphate (NdP_5O_{14}).

Titanium and chromium diffusion-induced star sapphires can be identified by characteristic colour zoning, absorption spectra together with a red halo on the surface and a high relief red outline when immersed in methylene iodide. J.J.

Lab notes.

T. MOSES, I. REINITZ AND S.F. MCCLURE. *Gems & Gemology*, **33**(4), 1997, 292–6, 7 illus. in colour.

A pair of sunglasses made for Elton John had lenses made from synthetic sapphire. J.J.

Synthetic moissanite: a new diamond substitute.

K. NASSAU, S.F. MCCLURE, S. ELEN AND J.E. SHIGLEY. *Gems & Gemology*, **33**(4), 1997, 260–75, 19 illus. in colour and 2 tables.

A new diamond substitute is synthetic moissanite, a silicon carbide (SiC), and has only recently been manufactured as a near colourless material. The GIA examined 23 samples of near colourless to light yellow, green and grey stones, but all appeared colourless when viewed face up. Although there is no simple test to identify moissanite conclusively, there are many tests that will prove it is not diamond. Moissanite is slightly less brilliant than diamond, shows more dispersion and is doubly refractive with a birefringence of 0.043, which is most readily seen when viewed through the girdle as all the stones examined were cut with their *c*-axis perpendicular to the table facet. Moissanite shows none of the strain fractures and inclusions associated with diamonds, but instead there are white line inclusions parallel to the *c*-axis. Moissanite has an SG of 3.20–3.24 (diamond 3.52) and a hardness of 9¼. Problems do occur when a thermal probe is used as diamond and moissanite have overlapping thermal inertial ranges and further tests must be used to separate these stones. J.J.

Characterization of Chinese hydrothermal synthetic emerald.

K. SCHMETZER, L. KIEFERT, H.-J. BERNHARDT AND Z. BEILI. *Gems & Gemology*, **33**(4), 1997, 276–91, 20 illus. in colour and 3 tables.

In 1993 hydrothermal synthetic emeralds made by Professor Zeng Jiliang, China, became commercially available. These emeralds were grown in an alkali-free chlorine-bearing solution at much higher pressures than normally associated with synthetic emeralds. The authors examined 11 stones and tested them by standard gemmological methods. Diagnostic microscopic features were observed in the stone which included natural or synthetic beryl seeds together with characteristic growth zoning, usually associated with colour zoning, parallel to the seed. The zoning formed at an angle of between 20° and 40° to the *c*-axis of the synthetic emerald and as no crystal faces in natural emerald are found within this range it is an important diagnostic feature. Spicules orientated parallel to the *c*-axis were commonly associated with tiny crystals of chrysoberyl or occasionally beryl. Also typical were needle-like inclusions which were found orientated almost perpendicular to the seed on dominant growth faces. EDXRF analysis and infrared spectroscopy showed chlorine to be a diagnostic element giving rise to a series of absorption bands in the 2500–3100 cm^{-1} region, which are not seen in natural emeralds. The stones examined did not show any detectable iron, but this is similar to certain natural emeralds. Also it was found that the RI and SG values of the synthetic stones overlapped those of low alkali natural emeralds. J.J.

Techniques and Instruments

The Hodgkinson method, a.k.a. the eye and prism method: some further adaptions.

D.B. HOOVER. *Australian Gemmologist*, **20**(1), 1998, 20–33, 5 diagrams, 4 graphs, 3 tables.

The Hodgkinson method, which uses only the human eye and a distant light source, permits the identification of many gemstones by enabling their refractive indices, absorption spectra, dispersion and birefringence-to-dispersion ratio to be estimated. The fundamentals of this method are reviewed, an alternative technique for estimating refractive index explained, and the method of quantifying the birefringence-to-dispersion ratio for identification purposes described. P.G.R.

Kristalle und Licht.

O. MEDENBACH, P.W. MIRWALD AND P. KUBATH. *Mineralien Welt*, **9**(2), 1998, 17–32, Illus. in colour.

Despite the title, the article illustrates and describes a number of optical instruments used for mineral identification. Microscopes, producers of polarized light, goniometers, universal stages and instruments for obtaining refractive index are presented with brief biographical notes of pioneers in mineralogical instrumentation. M.O'D.

BOOK REVIEWS

Famous diamonds. [Third edition]

I. BALFOUR, 1997. Christie's, London. pp 320, 150 colour and 70 black-and-white illustrations. Hardback and DW £65.00. ISBN 0 903432 56 X.

Although this is the third edition of *Famous diamonds*, it is on an altogether more lavish scale than its predecessors. It has a slightly larger format, is on better quality paper, and much new information has been added on important stones, including stones auctioned up to 1997.

The book starts with a most informative general introduction to diamonds, detailing their history, sources, mining, trade cutting and use. The mention of their properties of brilliance and fire is unfortunately so brief as to be, perhaps, unhelpful to those not already familiar with these properties.

There are then 76 separate chapters dealing alphabetically with individual major stones, most in impressive detail including descriptions of the stones themselves, their history and often details of associated and similar material. Some of these chapters, particularly that on the Hope, have been significantly expanded from the previous edition. These are followed by a chapter devoted, again alphabetically, to describing more briefly a further 40 'notable' stones.

In many cases, due to their value, the ownership of such stones is extremely closely guarded, and it is very difficult to acquire accurate knowledge about them. Ian Balfour, who spent many years in the diamond business, has been granted unprecedented access to many of these stones and their associated archival material. He has gathered together in this book a vast amount of information on major diamonds that is simply not available elsewhere. A table is included towards the end of the book listing the 89 diamonds of over 100 carats known up to 1997. Diamonds are not easy to photograph well, and the producers of this book are to be congratulated on the generally fine illustrations throughout.

There is a section of three pages on fancy coloured diamonds and the causes of their colour. This has been written by Eric Emms, FGA, DGA, who has handled a difficult subject very well in such a small space.

A column is included on the carat weight and the confusion that can occur from the difference between various old carats and the modern metric carat (0.2 gram). It is unfortunate that, as an example of such confusion, the Koh-i-Noor is used. The previously much quoted weight of the Koh-i-Noor (after re-cutting in 1852) as 108.93 ct, rather than the recently authenticated weight of 105.60 metric ct, seems, in fact, to have arisen from faulty research by authors rather than from any confusion over the unit of weight (108.93 metric carats converts to $106\frac{1}{16}$. old English carats). This incorrect weight is reported in several nineteenth-century books including Davenport's English regalia of 1897. It seems then to have been copied by many later authorities. However, both Dieulafait in 1871 and Professor Church in 1882 give a weight of 102 $^{3}/_{4}$ ct. This converts to 105.53 metric carats, extremely close to the actual weight.

An absolutely fascinating appendix is included which reproduces, over five pages, Asscher's step-by-step diary of their cutting of the Cullinan between February and October 1908.

There is a useful bibliography of two pages with some interesting items, although it should really be headed 'A selected bibliography' because the literature on diamonds is now immense. It is satisfying to find that the book ends with a good index, the lack of which has ruined many an otherwise good publication. This is, perhaps, the place to plead with publishers to revert to the old custom of binding in a bookmark (or even two). This greatly facilitates looking up items that have more than one reference in indexes.

This is a most desirable book, full of useful and fascinating information, beautifully produced at a price which, by current standards, is quite reasonable. It should have wide appeal to both jewellery and other historians, as well as to a large spread of general readers. N.B.I.

Identifying gems and precious stones

C. HALL, 1997. Apple Press, London. pp 80, illustrated in colour, hardcover. £5.99. ISBN 0 85076 426 3.

Reprint of an excellent short guide first published in 1993 by Quintet Publishing Ltd. The major gem species are described with notes on properties neatly set out diagrammatically and in colour. M.O'D.

Collecting and classifying coloured diamonds: an illustrated history of the Aurora collection.

S.C. HOFER, 1998. Ashland Press Inc., New York, USA (distributed in the UK by CRU Publishing Ltd., London). pp xxi, 742, illus. in colour. Hardcover ISBN 0 9659410 1 9. £197.00.

This very large and heavy book is a celebration of the 260 polished coloured diamond specimens at present on display at the American Museum of Natural History, New York. The collection is catalogued, described and illustrated at the beginning of the book, which continues with an account of the world of coloured diamonds, including a lengthy examination of the cause and perception of colour. Chapters deal with the collecting of coloured diamonds, natural supply and human demand and the conception of rarity, buying and selling, colour perception and colour grading, how face-up colour can be defined, coloured diamond classification and the terminologies used. Appendices include a cut and colour compendium, a glossary and a bibliography.

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The book is beautifully produced and there is no doubt that serious collectors will want to buy it, whether or not they also collect coloured diamonds. The standard of photography is state-of-the-art and the hundreds of illustrations gain a great deal by being kept small. Mounted stones are so often chosen to illustrate books on gemstones that the reader cannot see very much of individual diamonds and when coloured diamonds are featured it is much better to group loose polished examples together, sometimes with several everyday coloured objects for comparison and this is what has been done here. Opening the pages, with the text embraced by very wide margins, the carefully-placed photographs, many by Nick Hale and Tino Hammid, lead the eye naturally through the print. In many pages the text is also broken up by quotations, printed in light red, taken from a variety of sources, which amplify or give a fresh imaginative dimension to the topic under discussion.

So as a production the book scores very highly. As a treatise on coloured diamonds it first provides a *catalogue raisonné* to the Aurora collection which, maintained for a long time without addition, was greatly enhanced in recent years by additional specimens provided by Alan Bronstein, who, with the author, visualized a major book on coloured diamonds. Each of the stones in the collection is fully described and each one illustrated to show one of the widest colour ranges of diamond kept as a single collection. The formation of a collection of coloured diamonds is described with particular reference to the Aurora collection and how some of the stones were acquired. Chapters on rarity, buying and selling and colour perception lead very easily to the second major theme of the book, the singular importance of colour and how to describe it. During examination of these topics, the current colour theories are discussed with well-drawn diagrams and applied, with explanations of colour grading, to diamonds. All through the text the specimens illustrated are given their provenance where it has been ascertained and one feature of the book is the noting of important coloured diamonds that have passed through the major salerooms. I have long advocated the collection of saleroom catalogues which are not usually indexed in the ways gemmologists would want!

The glossary and bibliography are well up to present-day standard with many citations of significant papers. Interesting sidelights on diamond, colour, buying and selling abound through the book which is a delight in every way: expensive but well worth it. M.O'D.

The Jewellery of Roman Britain: celtic and classical traditions.

C. JOHNS, 1996. UCL Press, London. pp xvii, 246, illus in black-and-white and in colour. Hardback £36.00. ISBN 1 85728 566 2.

The author states in her introduction that this is the first general survey devoted to the jewellery worn in Roman Britain and that this country, distant from the centres of empire on the Continent, had received less consideration than others when ornament was discussed. The book takes 'jewellery' as any item of personal adornment, whatever it was made of and equates the English noun *jewellery* to the German *Schmuck*.

After a survey of what jewellery means in the context of Roman Britain, the book considers some of the evidence with an examination of hoards and of the general archaeological context. The two cultures, Celtic and Graeco-Roman (i.e. native and imported) brought together distinct types of ornament and the designs, metals and workmanship of the two areas make up most of the following text.

Material is considered under the headings finger-rings, gemstones and other settings, necklaces and bracelets, earrings and hair-ornaments and brooches. The last chapter describes how Roman jewellery was manufactured and there is an afterword in which the author asks for jewellery and other ancient artefacts to be considered in context rather than in isolation and for more care to be exercised by the metal digger. The archaeology of jewellery (and mineral collecting) is not the only area in which a certain type of tedious amateur wastes the time of scholars and many fail to see that persistence with the private possession of particular artefacts may cause the progress of identification to be slowed down.

An appendix gives details of the Backworth treasure (Tyne and Wear), the Snettisham hoard, the Thetford treasure and the Hoxne treasure. Notes relating to the chapters follow this section and there is an excellent bibliography. M.O'D.

Gem identification made easy. Second edition.

A. L. MATLINS AND A. C. BONNANO, 1997. Gemstone Press, Woodstock, VT. pp xxii, 322, illustrated in colour, hardcover. US $34.95. ISBN 0 943763 16 9.

Well-conceived and constructed gem testing manual in which the reader can quite easily find clues to the nature of most gem specimens. Written from the standpoint of the retail jeweller, the text begins with describing the equipment needed by the beginner, without going too deeply into the principles behind their operation. Instead the authors concentrate upon evaluating the results obtained: a central colour section illustrates synthetic and treated gemstones with excellent clear photographs. Since the publication of the first edition in 1989 developments in these areas have been so extensive that the text has been re-written. The bulk of the text is written around the major gem testing instruments and there are useful chapters on less common instruments and on the handling by the retail jeweller of antique and estate jewellery. Appendices include lists of useful addresses and a short bibliography. Used in conjunction with other texts this would make a good addition to a gemmological library and for the beginner it is a worthwhile first book. M.O'D.

Synthetic, imitation and treated gemstones.

M. O'DONOGHUE, 1997. Butterworth Heinemann, Oxford. pp x, 203. Illus. in black-and-white with 10 pages of colour plates. Softcover £35.00. ISBN 07506 3173 2.

Filling an important gap in gemstone literature, this book by the well-known author, lecturer and gemmologist encompasses three related subjects of synthetic, imitation and treated gems in a manner suitable for both the student gemmologist with perhaps little knowledge of gem testing techniques, and the professional.

Following a brief preface and introduction, the plan of the book is outlined (a glossary is mentioned here but appears to have been omitted in production!) and suggestions for further reading are listed. The book proper then gets underway with a chapter giving an account of the basic ground rules and methods for the commercial growth of synthetic gemstone crystals. This is followed by a chapter on gem testing which describes the basic identification techniques and equipment. The next chapter, 'The major natural gemstones', describes the most important identifying features of diamond, corundum, spinel, beryl, quartz, opal, alexandrite and topaz in order that these can be compared with their synthetic, imitation and treated versions in the body of the book.

Each subsequent chapter takes one of these gem species and describes the tell-tale features which will enable the reader to distinguish the real from the man-made or imitation, or the untreated from the treated. One chapter deals with the organic gems, and the penultimate chapter includes other materials such as lapis lazuli, turquoise, the synthetic garnets and cubic zirconia. The final chapter covers glass, ceramics, plastics, composites and experimental materials. Many of the features described are illustrated by black-and-white sketches and in the book's 40 colour plates (although the latter would have benefited from being printed larger at three-to-the-page.

Perhaps the most valuable section in each of the gem chapters is the 'Reports of interesting and unusual examples from the literature'. Here, the author has gathered together a valuable hoard of information from articles, laboratory reports, gem shows and his own gem observations to give the reader faced with a puzzling specimen the chance to find matching features among the more unusual gems described.

As a practical guide to ways of avoiding the pitfalls of misidentification, the book is a must for the jeweller, the valuer and the gemmologist. P.G.R.

Topas: das prachtvolle Mineral, der lebhafte Edelstein.

1997, *extraLapis* no. 13 (not covered by Lapis subscription). Christian Weise Verlag, Munich. pp 95, illus. in colour. Softcover DM 34.80. ISBN 3 921656 42 7 (series ISSN 0945-8492).

Numbers 1 to 6 of *extraLapis* are already out of print and readers who are unfamiliar with this out-of-series set of thematic monographs should try hard to obtain as complete a set as possible before second-hand prices become unreasonably high. Since the series deals in the main with gem-quality minerals and precious metals (totalling nine out of the thirteen) it is clear that this forms a major information resource for the study of gemstones.

Each issue that I have received seems even more excitingly produced than its predecessors: topaz is not the easiest gemstone for frequent reproduction since there is less colour variation than in some of the other species. None the less the publishers have faithfully shown the colour from yellow through to brown with amazing accuracy and as I particularly admire these colours I found the whole production the best illustrated guide to topaz that I have yet seen.

As in previous issues of *extraLapis* the work of the different authors does not fall easily into separate papers: rather, they combine their work in a long undifferentiated survey of the species. Thus we begin with topaz in antiquity, its chemical, physical and optical properties and its distribution. The main topaz-producing areas are then described, this task taking up most of the remainder of the text. Considerable attention is given to topaz from Schneckenstein, Saxony, and from the Russian Urals, with crystal drawing reproductions from Goldschmidt's *Atlas der Krystallformen* and from other authorities. Topaz mining in Brazil and Pakistan as well as at other sites is also described, with a continuous series of very fine photographs. There is no general bibliography but this is not too serious a loss. This is altogether a beautiful production and German printing has lost none of its skill. M.O'D.

Gemmologists' compendium. [Seventh edition.]

R. Webster, revised by E.A. Jobbins, 1998. NAG Press, London. pp 240, illus. in colour. Hardcover £16.99. ISBN 0 7198 0291 1.

First published as a now rare and collectable small-format edition in 1938, this old friend has undergone further revision necessitating a new edition rather than a reprint. In general appearance alone this is welcome since the typeface is much more pleasant to read. The colour photographs are chiefly the work of the reviser and are first-class. As always there is ever more material to choose from and the reviser has unerringly selected a number of topics for consideration outwith the glossary which comprises most of the text. These topics include methods of gemstone manufacture and treatment, colour grading scale for diamond and an update on the hazards likely to be encountered in gem testing outside a laboratory. The short bibliography, too, has been updated and contains no dross (in fact it serves very well as an introduction to the subject).

Naturally everyone will find some favourite topic omitted (several mentioned in the photograph captions are not in the glossary) and brush aside some strays from the past (not very many and not worth worrying about). For general lucidity the descriptive sections would be hard to beat and the junction between original author and reviser, apart from obvious chronological differences, is imperceptible. My only criticism is that moissanite is out of sequence (but easily spotted) in the glossary and that there are a few unimportant typos. In my copy at least, the cover picture is quite noticeably out of focus, one large specimen showing as a glaring white and upsetting the otherwise fine balance. The caption to the cover might be misread by a beginner not realizing that all specimens depicted are opals. The price is unbelievably low for today! The reviser (and the author, from some unimaginable shore) should be proud. M.O'D.

Proceedings of the Gemmological Association and Gem Testing Laboratory of Great Britain and Notices

OBITUARY

Professor Harold Schnieden, FGA (D.1967), Bramhall, Stockport, Greater Manchester, died in January 1998.

MEMBERS' MEETINGS

London

On 8 July 1998 at the Gem Tutorial Centre, 27 Greville Street, London EC1N 8TN, John Benjamin gave a talk entitled *The evolution of Georgian and Victorian jewellery.*

On 26 August at the Gem Tutorial Centre Shyamala Fernandes of the Gem Testing Laboratory, Jaipur, India, gave a lecture entitled *Gemstones of India: variety, quality, availability*. The talk was illustrated by slides and a collection of gemstones from India was displayed.

Midlands Branch

On 25 September 1998 an introductory social evening was held to explore the new Branch meeting venue in the Earth Sciences Building of Birmingham University. A guided tour of the Lapworth Museum was also held during the evening.

North West Branch

On 16 September 1998 at Church House, Hanover Street, Liverpool 1, John Pyke Snr gave a talk entitled *Gem collection with anecdotes.*

Scottish Branch

A field trip to Glenbuchat, Pitscurrie Quarry and the Pass of Ballater in Aberdeenshire was held from 25 to 27 July 1998.

On 25 September at the Royal British Hotel, Princes Street, Edinburgh, Alan Hodgkinson gave a talk entitled *What's new in gemmology, gems, simulants and synthetics.*

NEWS OF FELLOWS

Congratulations to Martin Donoghue, Newlands, Glasgow, who gained top marks in the annual competition of the UK Facet Cutters' Guild. This is the first time that the competition has been won by a gemmologist.

ANNUAL GENERAL MEETING

The Annual General Meeting of the GAGTL was held on 29 June 1998 at 27 Greville Street, London EC1N 8TN. Noel Deeks chaired the meeting and welcomed those present. The Annual Report and Accounts were approved and signed.

Professor R.A. Howie was re-elected President for the period 1998-2000. Christopher R. Cavey and Ian Thomson were re-elected to the Council of Management.

Tony Allnutt, Robert G. Fuller and Brian Jackson were re-elected and Sally A. Everitt, Amanda G. Good and Peter J. Wates elected to the Members' Council. Messrs. Hazlems Fenton were re-appointed Auditors.

In response to comments from members, further details of the figures in the accounts were provided, the desirability of improving access to the library was discussed, and the possibility aired of the laboratory extending certification of fancy coloured diamonds. In answer to an opinion from the floor that membership of the Council of Management and the Members' Council could do with some new faces, the Chairman said nominations would be welcome.

Following the Annual General Meeting, a Reunion of Members and Bring and Buy Sale were

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GIFTS TO THE ASSOCIATION

The Association is most grateful to the following for their gifts for research and teaching purposes:

The American Institute of Diamond Cutting, Deerfield Beach, Florida, USA, for *Rough diamonds: internal and external features* by Nizam Peters.

Mr Ismail Hussein Duale, London, for a blue beryl crystal.

Mrs Shyamala Fernandes, Gem Testing Laboratory, Jaipur, India, for the Silver Jubilee book of the Jaipur Gem Testing Laboratory, a geological map of India, a picture made from various powdered gem materials, and cut gems and gem crystals from India including ruby, fluorite, feldspar, chrysoberyl, beryl, apatite, garnet and sillimanite.

Mrs Sonja Glaser NVK, Galle, Sri Lanka, for 12 stones including sapphire, aquamarine, tourmaline and kornerupine.

Mrs Gwyn Green, Barnt Green, Birmingham, for a collection comprising ruby, sapphire, emerald, shell cameos, pastes, garnet-topped doublets, quartz, opal, cultured pearls and pearl simulants, and many other materials, amounting to well over a thousand specimens.

Professor Robert A. Howie, President of the GAGTL, for *Exploring Minerals and Crystals* by R.I. Gait and *Rocks, Minerals and Gemstones* by I.O. Evans.

Mrs Brenda Hunt, London, for two pieces of opal.

Mrs Ameena Kaleel, Mount Lavinia, Sri Lanka, for eight pyrite crystals

Mrs Janice Kalischer, Finchley, London, for many interesting pieces including imitation coral and ivory bangles, star rubies, citrines and dress jewellery.

Mr Peter H.A. Nancarrow, West Horsley, Surrey, for two pieces of turquoise from Gunheath Pit, St Austell, Cornwall.

Mr Daniel Piat, Paris, France, for *L'émeraude*, D. Giard (Editor), Assoc. Francaise de Gemmologie, Paris, 1998.

Mr Samuel F. Redknap, Twickenham, Middlesex, for a microscope, a refractometer, books and journals.

Miss Elisabeth Strack, Gemmologisches Institut Hamburg, Germany, for a copy of *Antiker Schmuck*.

E.A. Thomson Gems, London, for two specimens of coated topaz.

held, at which the winners of the 1998 Photographic Competition were announced and entries displayed.

GEM DIAMOND EXAMINATIONS

In June 1998, 97 candidates sat the Gem Diamond Examination, 71 of whom qualified, including seven with Distinction. The names of the successful candidates are listed below:

Qualified with Distinction

Bell-Burrow, Briony, London
Goddard, Valerie J., Alford, Surrey
Kearton, Michael J., Eastbourne, East Sussex
Makri, Hariklia, Thessaloniki, Greece
Sharpe, Erica J., Wells, Somerset
Vernon, Penny, High Wycombe, Buckinghamshire
Zhaoyang Wu, Wuhan, Hubei, P.R. China

Qualified

Ali, Shaukat, Karachi, Pakistan
Anastassiou, Evangelia, Athens, Greece
Anderson-Slight, Jamie, Horsham, West Sussex
Arnold, Jane E., London
Ashton, David, London
Au, Leslie Pak Hong, Kowloon, Hong Kong
Begley-Gray, Margaret, Little Carlton, Nottinghamshire
Bo Zhong, Wuhan, Hubei, P.R. China
Britton, Andrea L., Woking, Surrey
Brohi, Nosheen, Wanstead, London
Carter, Kevin J., Dagenham, Essex

Chan Yuk Yee, May, Kowloon, Hong Kong
Clancy, Jo, London
Cowley, Jacalyn G., Wimbledon, London
Damiao, Lourenco, Streatham, London
Dan Long, Wuhan, Hubei, P.R. China
De Souza, Suzanne P., Walton on Thames, Surrey
de Vries, Marius, London
Deer, Georgina, Manchester
Deligianni, Christina, Athens, Greece
Edwards, Heidi L., Burntwood, Staffordshire
Flynn, Matthew, Amersham, Buckinghamshire
Forward, Stephen, London
Franks, Ivor S., London
Garrett, Frances S.J., West Worthing, West Sussex
Gillary, Adam J., Woodley, Reading, Berkshire
Hill, Emma, Maida Vale, London
Howard, Christine, Sevenoaks, Kent
Hussain, Arshid, Birmingham, Warwickshire
Irwin, Edward, Limerick, Ireland
Kimber, Sarah J., Weybridge, Surrey
Kleiser, Alwen M., Anglesey, North Wales
Kong Jie, Beijing, P.R. China
Leung Andy Wing-Lok, Kowloon, Hong Kong
Ling Yu, Wuhan, Hubei, P.R. China
Liu Decai, Beijing, P.R. China
Liu Feng, Beijing, P.R. China
Ma Si Ji, Beijing, P.R. China
Michael, Marios, Limassol, Cyprus
Moore, Rowan D., Stoke, Coventry, Warwickshire
Okutu, Yula, London
Ouxiang Zhang, Beijing, P.R. China
Owen, Charryn P., Rudheath, Cheshire
Papadopoulos, Desiree, Wimbledon, London
Paphitis, Constantinos, Limassol, Cyprus
Pasmooy, Pauline B., London
Patel, Purnima, Kintbury, Berkshire
Perks, Helen E., Kinver, Staffordshire
Pinter, Max, London
Raphael, Menachem, Alwoodley, Leeds, West Yorkshire
Reilly, Clare, Sutton Coldfield
Reineke, Antony M., Chelsea, London
Rennes, Michael, London
Shi Yan, Beijing, P.R. China
Shun Yam Yau, Kowloon, Hong Kong
Smith, Colin, Teddington
Tete, Nair C., Waltham Cross, Hertfordshire
Uhlin, Christophe, Leytonstone, London
Vassiliou, Marianna, London
Wealthall-Morrison, Maxine, Cold Ash, Berkshire
White, Joannne C., Sheffield, South Yorkshire
Willis, Keith T.J., Romford, Essex
Wong King Suen, Kowloon, Hong Kong
Yoshitake, Yumi, Golders Green, London

INTERNATIONAL GEMMOLOGICAL CONFERENCE – '99

The 27th IGC will be hosted in India by the Forum of Indian Gemmologists for Scientific Studies, a non-profit organization established by qualified gemmologists in India.

IGC – '99 will be held in Goa from 27 September to 2 October 1999 and will be accompanied by pre- and post-conference excursions.

The Forum of Indian Gemmologists has set up an organizing committee to make the necessary arrangements chaired by Mr K.T. Ramchandran, with Dr (Mrs) Jayshree Panjikar as the Executive Secretary. Attendance at IGC is strictly by invitation and enquiries should be directed to the Forum at 29 Gurukul Chambers, 187–189 Mumbadevi Road, Bombay 400 002, India. Tel: +91 342 0039.

EXAMINATIONS IN GEMMOLOGY

In the Examinations in Gemmology held worldwide in June 1998, 190 candidates sat the Preliminary Examination of whom 113 qualified. In the Diploma Examination 234 candidates sat of whom 96 qualified, including two with Distinction. The Tully Medal for the candidate who submits the best set of answers in the Diploma Examinations in 1998 which, in the opinion of the Examiners, are of sufficiently high standard, was awarded to Mr Laurent Kellerson of London. Mr Kellerson was also awarded the Anderson Bank Prize for the best non-trade candidate of the year in the Diploma Examination.

The Diploma Prize for the best candidate of the year who derives her main income from activities essentially connected with the jewellery trade was awarded to Miss Tina Notaro of Madison, Wisconsin, USA.

The Anderson Medal for the best candidate of the year in the Preliminary Examination was awarded to Miss Long Chu of Guilin, P.R. China.

The Preliminary Trade Prize for the best candidate of the year who derives her main income from activities essentially connected with the jewellery trade was awarded to Miss Linda Rythen of Stockholm, Sweden.

FORTHCOMING EVENTS

1 November	**Annual Conference.** Gems in Jewellery. To be held at the Barbican Centre, London. Current issues concerning gems and jewellery presented by a distinguished gathering of experts.
2 November	**Tours of jewellery and gemstone galleries at two London museums.**
4 November	**London.** F.F.H. Moissan, polytypes and synthetic moissanite. Kurt Nassau.
12 November	**Scottish Branch**. Moissanite, a new diamond simulant. Kurt Nassau.
18 November	**North West Branch.** Annual General Meeting.
27 November	**Midlands Branch**. Gemmological journeys in Brazil. E. Alan Jobbins.
5 December	**Midlands Branch 46th Annual Dinner.**
1999	
13 January	**London.** Insects in amber. Andrew Ross.
29 January	**Midlands Branch.** Bring and Buy followed by Quiz.
26 February	**Midlands Branch.** Cameo and gemstones carvings. David Callaghan
11 March	**London.** Some current problems in diamond research. Dr H. Judith Milledge.
26 March	**Midlands Branch.** Jewels in the hand. James Gosling

For further information on the above events contact:

London:	Mary Burland on 0171 404 3334
Midlands Branch:	Gwyn Green on 0121 445 5359
North West Branch:	Deanna Brady on 0151 648 4266
Scottish Branch:	Catriona McInnes on 0131 667 2199

GAGTL WEB SITE

For up-to-the-minute information on GAGTL events and workshops visit our web site on www.gagtl.ac.uk/gagtl

The names of the successful candidates are as follows:

Diploma

Qualified with Distinction

Kellerson, Laurent P., London
Notaro, Tina M., Madison, Wisconsin, USA

Qualified

Amor, Miranda, Taunton, Somerset
Astor, Flora, London
Avery, Hilary E., Bangor, Co. Down, N. Ireland
Bin Gao, Wuhan, Hubei, P.R. China
Boels, Vigdis, Ieper, Belgium
Burgoyne, Sheila, Totteridge, London
Castoro, Loretta C., New York, USA
Cho Ka Wah, Hong Kong
Combee, Mireille M., Capelle aan den Yssel, The Netherlands
Cooksey, Brian, Bures St. Mary, Suffolk
Dalsplass, Line M., Oslo, Norway
French, Thomas, Woking, Surrey
Fujii, Noriyuki, Higashi, Osaka, Japan
Fujiwara, Motoko, London
Gudmundson, Inger, Lit, Lannavaara, Sweden

Haitsma, Maaike C., Schoonhoven, The Netherlands
Han Xiao, Guilin, Guangxi, P.R. China
Harding, Rachel A., Twickenham, Middlesex
Haris, Mohamed Thowfeek Mohamed, Maggona, Sri Lanka
Hodgson, Jane E., Watford, Herfordshire
Hong, Angela, London
Hsiao Chin-Kang, Taipei, Taiwan, R.O. China
Ikebe Emi, London
Ikeda, Yumi, Osaka City, Osaka, Japan
Inoue, Kazuko, Tokyo, Japan
Jacky Lee Chun Man, Hong Kong
Jain, Reena, Jaipur, India
Jing Zhang, Wuhan, Hubei, P.R. China
Jones, Jesse, Auckland, New Zealand
Jung-In Yang, Taegu, R.O. Korea
Kim Mi Young, Taegu, R.O. Korea
Konstandopoulou, Garoufallia, Athens, Greece
Kuroda, Chikako, Kawanishi City, Hyogo Pref, Japan
Lam Lai Chun, Kowloon, Hong Kong
Lanz, Ernst, Veytaux, Switzerland
Lee Yin Wa, Kowloon, Hong Kong
Lempinen, Marita, Lahti, Finland
Liying Fan, Shanghai, P.R. China
Long Chu, Guilin, Guangxi, P.R. China
Lule, Cigdem, Ankara, Turkey
Maddison, Steven, Benfleet, Essex
Makri, Hariklia, Thessaloniki, Greece
Marshall, Andrew P., Gravesend, Kent
Miwa, Yosuke, Tokyo, Japan
Miyamoto, Takuya, Himeji City, Hyogo Pref, Japan
Miyamura, Kayoko, Otsu city, Shiga Pref, Japan
Morgan, Jacqueline, London
Murakoshi, Mitsuko, Nagareyama City, Chiba Pref, Japan
Muratsu, Hirotoshi, Neyagawa, Osaka, Japan
Nakazawa, Haruyo, London
Ning Zhang, Wuhan, Hubei, P.R. China
Nishimura, Yoko, Nabari City, Mie Pref, Japan
Nunn-Weinberg, Danielle, Toronto, Ontario, Canada
O'Byrne, Rose-Marie, Bicester, Oxon
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Chan, Sau King, Hong Kong. 1998
Dirlam, Dona Mary, Carlsbad, California, USA. 1982
Ho, Chuan-Hsiang Taipei, Taiwan, R.O. China. 1998
Htun, Han, Yankin, Yangon, Myanmar. 1998

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Leaver, Shirley, Edgeley, Stockport, Cheshire
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Oparaeche, Charles, Brixton, London
Porter, Alan Redvers, Capel, Dorking, Surrey
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Said, Mohammad Ali, Gothenburg, Sweden
Speer, Teresa Ann, Mountsorrel, Leicestershire

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Damiao, Lourenco G., Streatham, London. 1998
Hussain, Arshid, Birmingham, Warwickshire. 1998
Irwin, Edward, Limerick, Ireland. 1998
Leung, Wing Lok, Kowloon, Hong Kong. 1998
Pasmooy, Pauline B., London. 1998
Reineke, Antony M., Chelsea, London. 1998
Willis, Keith, Romford, Essex. 1998

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Herold, Richard A.J., Bordon, Hampshire. 1985/86

Fellowship (FGA)

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Chung, Stephen, Leeds, Yorkshire.1986
Combee, Mireille M., Capelle a/d Yssel, The Netherlands. 1998
Fujiwara, Motoko, Nagoya City, Aichi, Japan. 1998
Haitsma, Maaike C., Gouda, The Netherlands. 1998
Haris, Mohamed Thowfeek Mohamed, Colombo, Sri Lanka. 1998
Hong, Angela S.L., London. 1998
Jones, Jesse, Auckland, New Zealand. 1998
Lanz, Ernst, Veytaux, Switzerland. 1998
Lempinen, Marita, Lahti, Finland. 1998
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The World 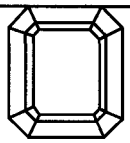 of Gemstones

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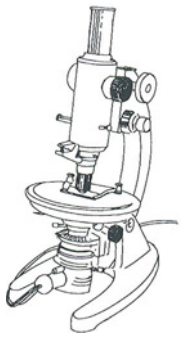

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Cover Picture

Tourmaline crystal showing prominent basal and pyramidal faces resting on sketches of the growth step patterns of a pyramidal face. (see the paper on tourmaline by Takahashi and Sunagawa, pp 226–37)

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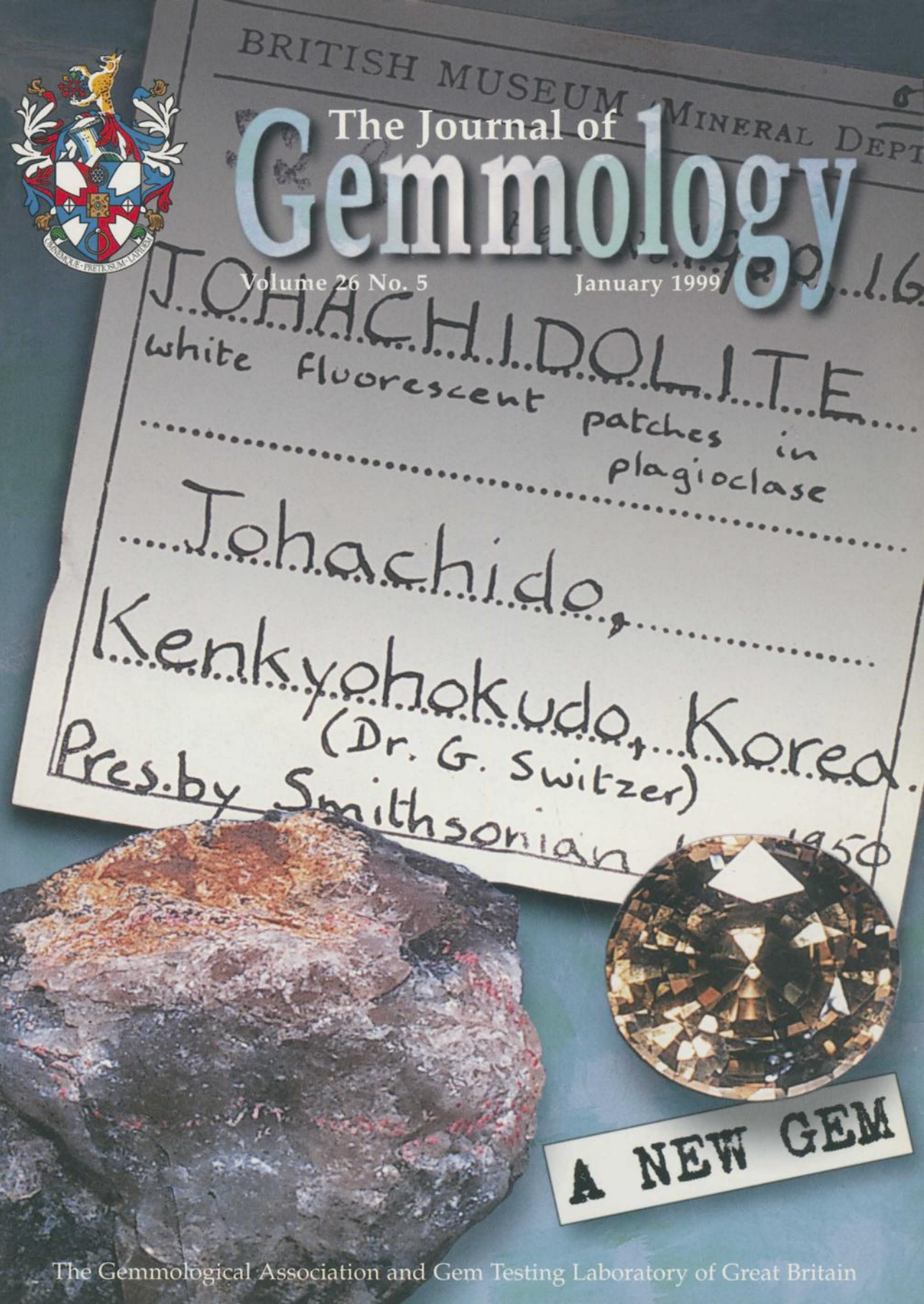

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Element mapping of trapiche rubies

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ABSTRACT: Chemical zoning in trapiche rubies was examined by X-ray microfluorescence analysis and by electron microprobe analysis. Two-dimensional element maps indicate a chemical variability of Al, Si, Ca, Ti, Cr and Fe within the samples. This chemical variation is mainly due to primary growth zoning as well as due to carbonate and in places silicate inclusions in orientated channels of the host rubies. Secondary iron staining caused by intense weathering of the samples is also observed.

Keywords: electron probe, element map, ruby, trapiche, X-ray micro-fluorescence

Introduction

Trapiche rubies from south-east Asia with a fixed six-rayed star, similar in effect to trapiche emeralds from Colombia, were recently described by Schmetzer *et al.* (1996a). Information available at present indicates that the trapiche rubies come from Myanmar and Vietnam. They consist of six transparent-to-translucent ruby sectors separated by the yellow- or white-appearing arms of a six-rayed star. In some crystals, the six arms (which, unlike typical asteriated gems, are fixed - that is, they do not move when the stone or light source is moved) intersect at one small point, forming six triangular ruby sectors. In many specimens, however, the arms extend outward from a hexagonal central core, producing six trapezohedral ruby areas. The cores are usually opaque yellow or black, but transparent red central areas are also present occasionally.

In the yellow or white arms of the star and in the boundary zones between the core and the six trapezohedral ruby sectors, a massive concentration of tube-like inclusions is observed. These inclusions are orientated perpendicular to morphologically dominant dipyramidal crystal faces; they contain liquid, two-phase (liquid/gas) and solid fillings identified as magnesium-bearing calcite and dolomite by a combination of electron microprobe analysis and micro-Raman spectroscopy. In black or yellow cores, tube-like structures with identical fillings also run parallel to the *c*-axis, i.e. perpendicular to basal faces of the trapiche rubies.

Because tube-like structures that extend into the gem-quality ruby sectors are almost colourless, and the calcite and dolomite inclusions are iron-free, it was concluded that the yellow colour of the arms and some cores must be due to intense weathering and secondary iron staining of the cavities and tubes. This interpretation was supported by

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Table I. Chemical zoning of trapiche rubies

	Sample description	Zoning in	Mg	Al	Si	Ca	Ti	V	Cr	Fe
A	Six-rayed star with sharp yellowish-white arms intersecting at one small point	Triangular ruby sectors							z	
		Yellowish-white arms		—	+	++			–	+
B	Six-rayed star with sharp yellow arms intersecting at one small point	Triangular ruby sectors							z	
		Yellow arms		–		++				++
C	Six-rayed star with sharp yellow arms, black core	Trapezoidal ruby sectors								
		Black core		–	+	+++	+	*	–	++
		Yellow arms		–	+	++	+	*		+++
D	Six-rayed star with yellow arms that widen toward the edge, black core	Trapezoidal ruby sectors								
		Black core		—	+	++	+	*		+++
		Yellow arms		—	+	++	+	*		+++
E	Six-rayed star with zoned, sharp yellowish-white (inner part) to yellow (outer part) arms, black core	Trapezoidal ruby sectors							z	
		Black core		–		++			–	+
		Yellowish-white to yellow arms		–		++				+ or ++ (z)
F	Six-rayed star with thin yellow arms without distinct, continuous boundaries to the host, small red core	Trapezoidal ruby sectors							z	
		Red core							+	
		Yellow arms		–		+				+

– smaller concentration than in the six trigonal or trapezohedral ruby sectors
— much smaller concentration than in the six trigonal or trapezohedral ruby sectors
+ higher concentration than in the six trigonal or trapezohedral ruby sectors
++ much higher concentration than in the six trigonal or trapezohedral ruby sectors
+++ very much higher concentration than in the six trigonal or trapezohedral ruby sectors
z zoning from centre to rim
* not observable in small concentrations due to an overlap of VK_α with TiK_β

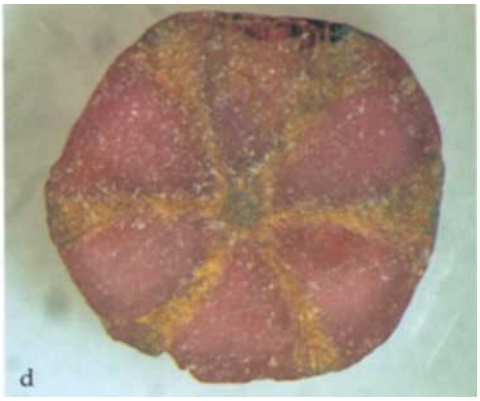

Figure 1a to f: *Hexagonal cross-sections of six trapiche rubies, samples A to F; the arms of the fixed six-rayed stars intersect in a small central point (a,b) or extend outward from the corners of a hexagonal black (c,d,e) or red (f) core. The arms of the stars are yellowish-white (a), yellow (b,c,d,f) or zoned yellowish-white in an inner part and yellow in an outer part of the sample (e). Sizes of the samples are 4.8 mm (a), 3.3 mm (b), 3.2 mm (c), 4.1 mm (d), 4.2 mm (e), and 4.5 mm × 5.0 mm (f).*

X-ray fluorescence analyses of selected trapiche ruby areas with or without a part of a yellow arm.

Two methods were applied to determine the chemical properties of trapiche rubies by Schmetzer *et al.* (1996a) providing analytical data that represent different-size areas within a sample. X-ray fluorescence analysis reveals an average composition of that part of the ruby in an area exposed to the X-ray beam that can be measured in the range of square millimetres. The electron microprobe, on the other hand, is able to analyse much smaller areas with diameters down to about one micrometre.

The chemical variability of a mineralogical sample is, in general, detectable by electron microprobe using two conventional techniques. Preparing X-ray scanning images for selected elements, the intensities of single spots within an image of the area covered by the electron beam are approximately proportional to the concentration of the respective elements. A typical example for trapiche rubies, which was given in the previous paper, showed the distribution of calcium and magnesium in calcite and dolomite as fillings of single orientated tube-like structures and covered an area of approximately 100 x 100 μm (0.1 x 0.1 mm). According to the experimental conditions of the instrument, this technique – which is performed with a fixed, non-moving sample – is limited to the examination of sectors which cover a maximum area of about 200 x 200 μm (0.2 x 0.2 mm).

Another technique for the evaluation of chemical variability of a sample by electron microprobe is performed with a moving stage, i.e. a moving sample and a fixed electron beam, in order to prepare various scans across the surface of the sample. A typical traverse across a ruby crystal or another gemstone to show its chemical variability consists of about 30 to 120 point analyses within a scan length in the mm range (see Peretti *et al.*, 1995; Schmetzer *et al.*, 1996b). Using this particular technique, information about chemical zoning along single traverses across a sample is obtainable.

The application of the two conventional methods described, however, is unable to provide two-dimensional information about element concentrations and chemical variability in minerals, which is of great interest in trapiche rubies.

The present paper describes two different techniques for the determination of two-dimensional element maps in trapiche rubies, which have been only rarely applied to the characterization of gem materials. Using trapiche rubies as an example, the techniques described are able to fill the gap between conventional X-ray fluorescence analysis and conventional electron microprobe techniques.

Materials

For the present study six slices of trapiche rubies were cut in a direction perpendicular to the c-axis of the corundum crystals. The samples were selected in order to cover the variability of structural features in trapiche rubies (see *Table I*). In detail, samples were selected with six-rayed stars intersecting at one small point (*Figure 1a, b*) as well as trapiche rubies with black (*Figure 1c, d, e*) or red (*Figure 1f*) cores. Parts of the samples revealed sharp yellowish-white (*Figure 1a*) or yellow (*Figure 1b, c*) arms, and one sample showed a colour zoning within the six sharp arms of the star with yellowish-white central parts and stronger yellow outer parts (*Figure 1e*). In one sample, the six yellow arms of the star widen toward the rim of the crystal (*Figure 1d*), and in one trapiche ruby, only thin yellow arms without continuous boundaries to the six trapezohedral ruby sectors were observed (*Figure 1f*).

Results

X-ray microfluorescence (XRMF) analysis

Chemical zoning was observed in all six samples of trapiche rubies examined with the OMICRON XRMF system. Different element concentrations were found for Al, Ca and Fe in all samples as well as for Si, Ti and Cr in parts of the samples. No chemical inhomogeneities were proven for Mg and V with the experimental conditions applied (*Table I*).

Methods

Data collection procedures

A well-known technique to display two-dimensional element distributions of sample areas is to scan the electron beam of an electron microprobe (or of a scanning electron microscope) and to collect the signals for image development using a wavelength dispersive spectrometer (WDS), which has been set to the position of the required characteristic X-radiation. Another possibility is to use the signals of a selected range of channels of an energy dispersive spectrometer (EDS) representing the requested radiation. The signals are displayed in real time on a screen which is synchronized with the scanning system of the microprobe. In modern systems, these signals may be stored and accumulated in order to display the complete image. In the latter case the signals of more than one element can be acquired simultaneously. Limiting factors are the number of WDS facilities available on the microprobe or the maximum number of energy regions allowed by the EDS software.

Using WDS systems, the analysed sample, the diffracting crystal and the detector must be on one circle (*Figure 2a*). According to these optical and geometrical conditions, only small areas of a sample can be examined with a fixed sample stage. Because it is not possible to scan an X-ray beam, X-ray fluorescence techniques cannot be used for this kind of imaging procedure.

In order to overcome the problems mentioned, a different kind of image generation can be applied. For these techniques the electron beam or a strongly collimated beam of primary X-rays of a microfluorescence system remains fixed at one position and the sample with its sample stage is moved in two orthogonal directions under the fixed beam covering the sample area of interest. In these

Figure 2a: *Schematic drawing of the experimental conditions in the electron microprobe for element mapping of larger areas showing the incident electron beam, the moving sample stage, the fixed diffracting crystal and the X-ray detector; the diffracting crystal and the detector form a wavelength dispersive spectrometer (WDS).*

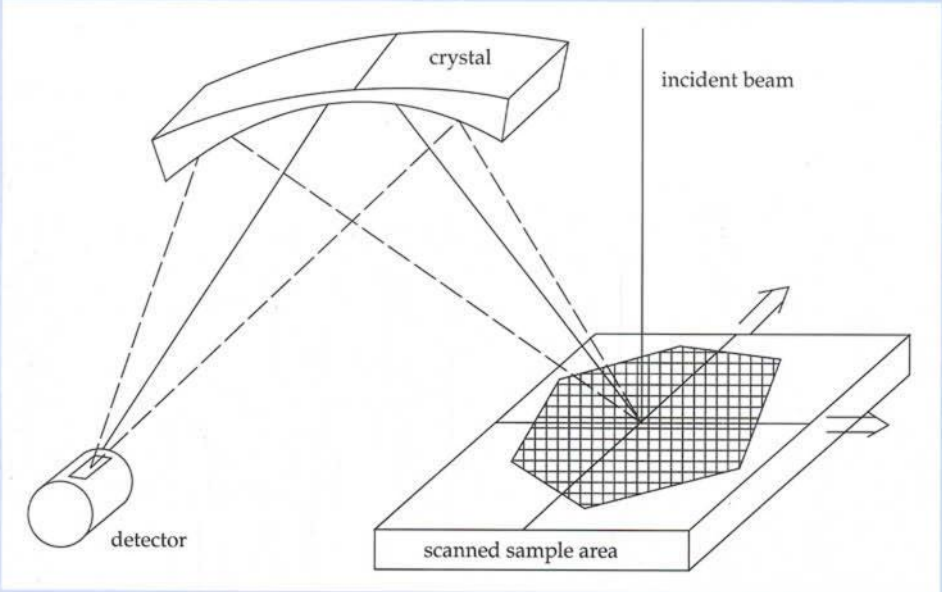

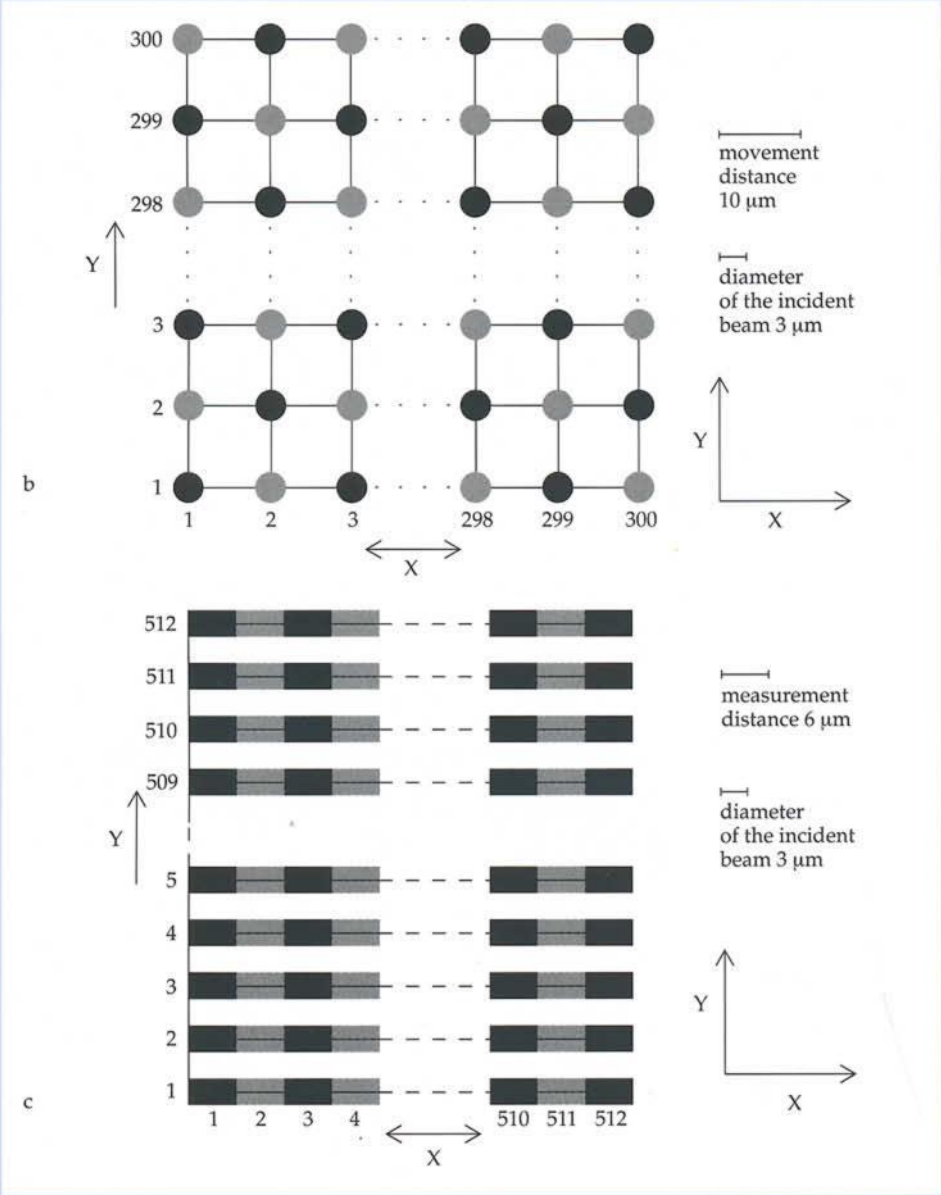

Figure 2b, c: *Data collection for element mapping by XRMF and EMPA in a step-by-step (b) or continuous raster mode (c); the analytical details of Figure 2b represent the data collection for a trapiche ruby by electron microprobe with a step-by-step measuring distance of about 10 µm and a beam diameter of approximately 3 µm; the analytical details of Figure 2c represent data collection for a trapiche ruby by electron microprobe in a continuous raster mode with a beam diameter of approximately 3 µm and a line length of about 6 µm; analysed areas are hatched, arrows indicate the direction of the moving stage. For element mapping by XRMF analysis an X-ray beam with a diameter of 70 µm was used in a continuous raster mode, i.e. overlapping areas within the sample were measured several times.*

systems, in addition to the elements to be analysed and the sample area, the user has also to select the desired resolution, i.e. the number of data points on the analysed sample area which form a regular, rectangular grid on the sample surface. Each point of such a grid represents one pixel in the later X-ray image. Furthermore, the counting time for each measuring point has to be selected. Two slightly different data collection procedures are possible:

(a) In a non-continuous analysis mode (*Figure 2b*) the sample is moved to a point of the rectangular grid and then the counting time is started. The measured intensity signal of the fluorescence radiation represents the element concentration of the currently excited sample volume which mainly depends on the beam diameter. On completion of the selected counting time, the measuring procedure is stopped and the sample is moved to the next point of the grid. This is a step-by-step procedure.

(b) In a continuous analysis mode (*Figure 2c*) along the movement of the sample between two grid points, the intensity of the specified characteristic X-radiation is continuously measured by the detector. The resulting intensities represent the average element concentrations of the excited sample volume between the two points of the rectangular grid. The position of the data point in the pixel-by-pixel image is set to the middle between the two adjacent points of the grid in the direction of movement.

In both modes the counting results of each point for each element are stored. Subsequent to the complete measuring procedure of the selected sample area, using special computer software the intensities of each element are linked to a colour or to a grey scale. Each data point is classified and plotted on a screen according to a corresponding colour with respect to its original position on the sample surface. Thus, an enlarged image of the sample is produced representing the element composition of one element in the sample. The images can be treated mathematically, e.g. intensity relations between two elements may be computed and depicted. The element distribution can be stored and printed depending on the capabilities of the computer programme in use.

Element mapping using X-ray microfluorescence analysis (XRMF)

Element mapping by XRMF was developed in the mid-'eighties by several working groups in Japan and in the United States (Kobayashi *et al.*, 1985; Nichols and Ryon, 1986; Wherry and Cross, 1986). A commercially available analysis system was designed by Kevex Instruments and marketed with the trade name OMICRON. The OMICRON system and similar facilities were applied for element mapping of metals, alloys, rocks and minerals, but also for organic matter, e.g. leaves, tissues and bones (Boehme, 1987; Nichols *et al.*, 1987; Cross and Wherry, 1988; Wherry and Cross, 1988; Carpenter *et al.*, 1989; Carpenter and Taylor, 1991; Kobayashi *et al.*, 1991; Cross *et al.*, 1992; Rindby *et al.*, 1992; Voglis *et al.*, 1993; Carpenter *et al.*, 1995a,b). XRMF was compared by Pozsgai (1991) with similar techniques, e.g. X-ray fluorescence in the electron microscope or X-ray fluorescence excited by synchrotron radiation.

For the preparation of element images of trapiche rubies, a conventional OMICRON system (*Figure 3*) was used. The data collection and handling of this analytical facility was briefly described by Nichols *et al.* (1987) and a schematic drawing of the OMICRON analysis system is given by Cross and Wherry (1988).

In the analytical facility available for the present study, the diameter of the primary X-ray beam could be varied between 50 and 2000 μm. However, the best spatial

Figure 3: The OMICRON XRMF analysis system consisting of the basic measurement unit (right) colour TV sample display (centre) and computer-based data processor (left).

resolution and intensity versus background conditions were obtained in vacuum with a collimator diameter of 70 μm. The examination of the six trapiche ruby samples of about 3 to 5 mm in size was performed in a continuous raster mode (see *Figure 2c*) with 250 analytical data collection steps along both X and Y directions of the sample stage. Consequently, a single X-ray image of one sample contains information from 62 500 single grid points. With a beam diameter of 70 μm, each grid point represents an area of ruby and a possible range of inclusions in that area. The energy dispersive X-ray fluorescence spectra obtained during the continuous movement were collected with a Si (Li) detector. The required measuring time was about two to three hours. As the data collection was repeated up to four times for each ruby sample, the examination of one trapiche ruby was carried out over 8 to 12 hours. The collected data were processed by image-forming software to complex two-dimensional element images consisting of 62 500 pixels each. Element maps were prepared for eight elements, namely Mg, Al, Si, Ca, Ti, V, Cr and Fe (the OMICRON system allows the simultaneous acquisition of up to 25 element maps from one set of analytical data).

Element mapping using electron microprobe analysis (EMPA)

The data acquisition procedure by electron microprobe is similar to that of XRMF. As WDS facilities (see *Figure 2a*) have much better wavelength resolution than EDS systems and better peak-to-background ratios, WDS images are much clearer than EDS images. Thus, data collection by WDS systems is preferred for element mapping by electron microprobe. According to the number of WDS facilities available in the analytical system of a microprobe (up to five spectrometers in modern instruments), the number of elements which can be mapped simultaneously is limited to five. For mapping of additional elements, the run is repeated with new spectrometer settings. From experience it was found that expressive images should consist of at least 30 000 pixels representing single points in the rectangular grid. This corresponds to about 12 hours of acquisition time with, for example, one second counting time for each analytical point (plus processing time, plus time for moving the sample stage if data collection in a non-continuous raster mode is applied). Consequently, this technique is time consuming and requires an extremely stable microprobe system (Bernhardt *et al.*, 1995).

For the evaluation of this technique to gemmological problems element maps were performed for one trapiche ruby (sample C, *Figure 1c*) in both analytical modes mentioned above, i.e. in non-continuous and continuous raster modes.

A first run was done with a CAMECA Camebax electron microprobe for three elements, Al, Ca and Fe. Data were collected step by step along a rectangular grid with point distances of 10 μm during an analysis time of 1 second at each of the 90 000 analysis points (see *Figure 2b*). For this measurement, an analysis time of 35 hours was needed.

A second run was performed with a CAMECA Camebax SX50 electron

microprobe facility for Al, Si, Ca and Fe. Using the four wavelength dispersive spectrometers of the microprobe, data were collected in continuous raster mode along a scan line of approximately 6 μm for 512 lengths along the X and for 512 lengths along the Y direction of the sample (*Figure 2c*). Consequently, the element images consist of 262 144 pixels each. Data collection was performed during a period of 0.2 seconds along each measuring distance of about 6 μm, and approximately 15 hours were needed for the complete measurement procedure for mapping of the four elements mentioned.

For image formation, special data handling and image-forming software written by one of the authors (H.-J.B.) was applied.

Characterization of inclusions

The examination of the six trapiche rubies by X-ray microfluorescence analysis revealed extraordinarily high concentrations of Si, Ti and Fe in the six arms of the samples C and D. For the characterization of inclusions in the orientated channels of these two trapiche rubies (in addition to the previously identified calcite and dolomite fillings), several channels in both samples were analysed by electron microprobe using conventional energy dispersive and wavelength dispersive systems of a CAMECA Camebax SX50 electron microprobe.

The image processing software of the analytical system generates element images of the samples, in which a colour code is used for varying concentrations between different analysis points. Variable element concentrations are displayed pixel by pixel in the X-ray image in the sequence (from low to high concentrations) violet → blue → green → yellow → red and examples of Ca and Fe are shown in *Figure 4a, b*.

Element distribution maps of samples A, B and D are presented in *Figures 5 to 7*. In all samples, we observed a distinctly smaller aluminium concentration in the yellow or yellowish-white arms of the stars as well as in the black cores of samples C, D and E compared to the aluminium concentration of the six triangular or trapezohedral ruby sectors. This was also observed for chromium in the yellowish-white arms of sample A (*Figure 5*) and in the black cores of samples C and E. The red core of sample F, on the other hand, revealed a higher chromium concentration than the six trapezohedral ruby sectors of the sample. In four trapiche rubies, a distinct chromium zoning within the six triangular (samples A and B; *Figure 6*) or the six trapezohedral ruby sectors (samples E and F) was also observed.

Figure 4a, b: *Element maps of Ca (left) and Fe (right) for trapiche ruby, sample C, obtained by XRMF analysis. Different element concentrations are displayed pixel by pixel in the XRMF map; increasing concentrations are colour coded in the sequence violet → blue → green → yellow → red.*

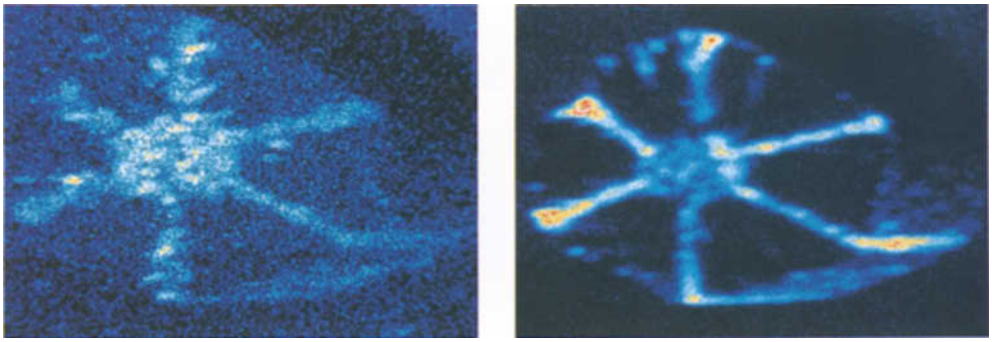

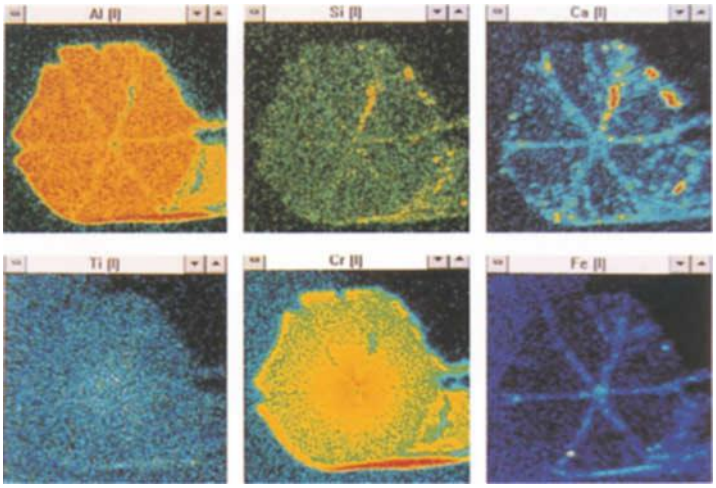

Figure 5: *Element distribution maps for trapiche ruby, sample A, obtained by XRMF analysis; the six yellowish-white arms of the sample intersect at one small central point.*

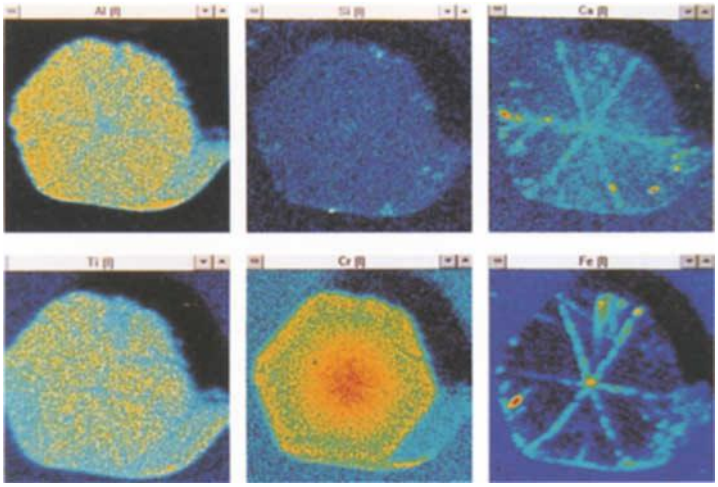

Figure 6: *Element distribution maps for trapiche ruby, sample B, obtained by XRMF analysis; the six yellow arms of the sample intersect at one small central point.*

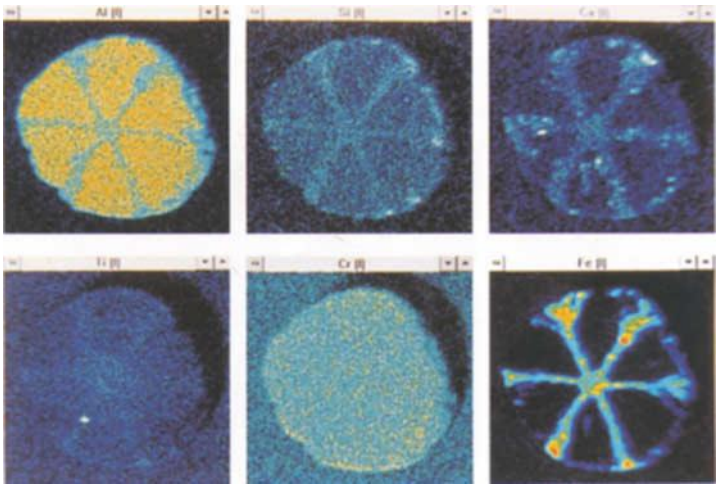

Figure 7: *Element distribution maps for trapiche ruby, sample D, obtained by XRMF analysis; the six broad yellow arms of the sample extend outward from a hexagonal black core.*

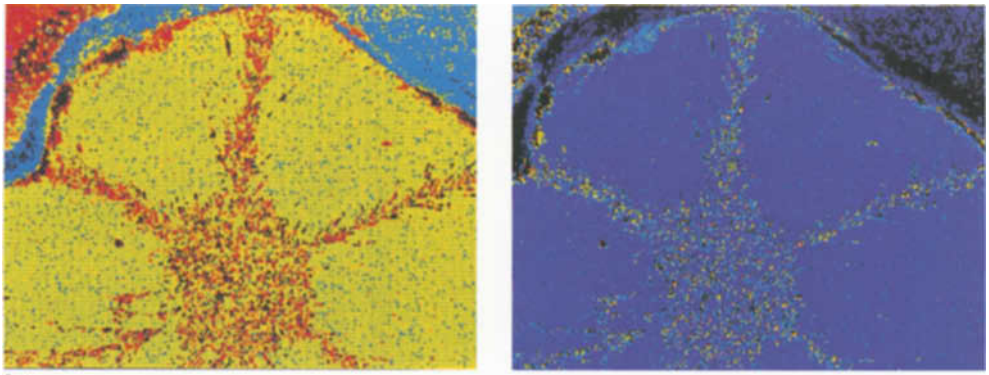

8a

Figure 8: *Element maps of Al, Si, Ca and Fe for trapiche ruby, sample C, obtained by EMPA. Different element concentrations are displayed pixel by pixel in the XRMF map; increasing concentrations are colour coded in the sequence violet → blue → green → yellow → red; (a) two element maps for Ca are given, which were obtained from data collected in a step-by-step measuring mode, different colour codes are applied for image forming according to the counting rates measured at each analysis point; (b) four element maps for Al, Si, Ca and Fe were obtained from a continuous raster mode.*

8b

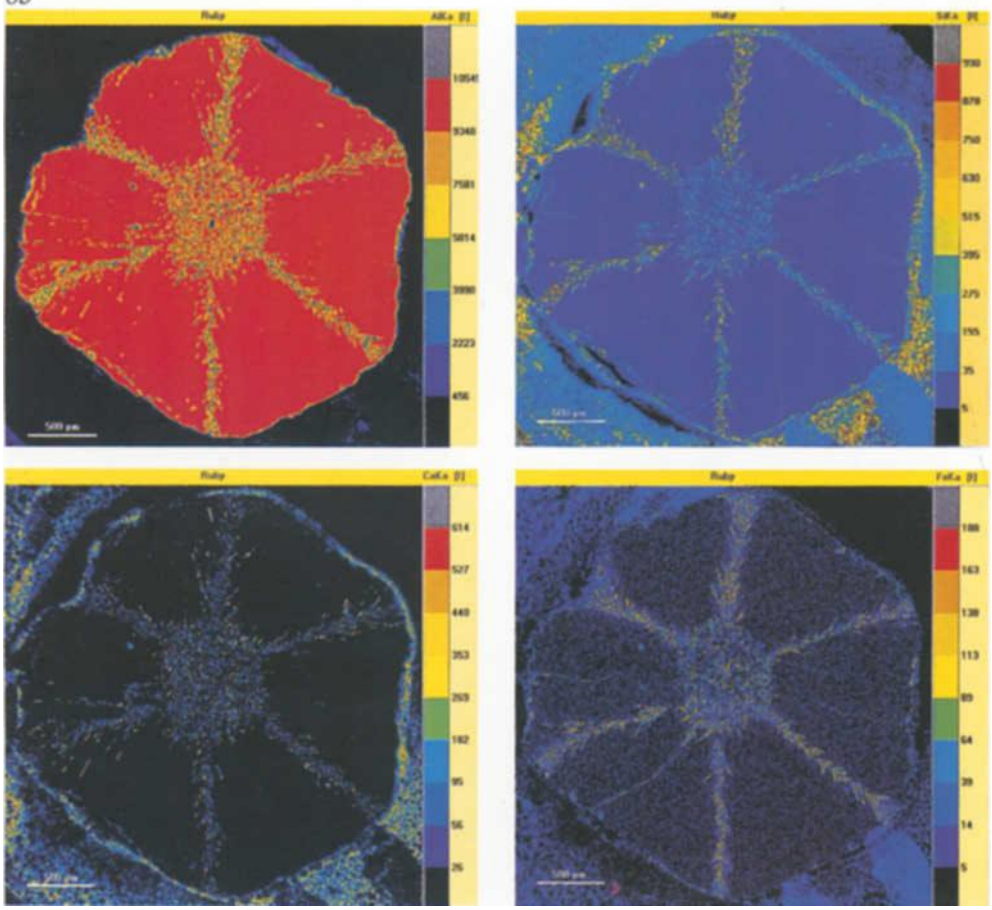

Various calcium concentrations due to inclusions of calcite and dolomite (see Schmetzer *et al.*, 1996a) were found in the yellowish-white or yellow arms of all six samples and in the black cores of samples C, D and E. Any variation of magnesium concentration caused by the dolomite inclusions, on the other hand, was not resolved with the measuring conditions used. This result is consistent with decreasing sensitivity of the instrument towards lighter elements.

Iron was also observed in various concentrations in the arms of the six-rayed stars as well as in black cores. In general, yellowish-white arms (sample A, *Figure 5*) or yellowish-white inner parts of zoned arms (sample E) revealed smaller iron concentrations than the yellow outer parts of zoned arms (sample E) or completely yellow arms (samples B, C and D, *Figures 6 and 7*). No iron was found in the six triangular or trapezohedral ruby sectors of all six samples or in the red core of sample F.

A somewhat unexpected result was the observation of distinct concentrations of silicon in the yellowish-white arms of sample A (*Figure 5*) and of silicon and titanium in the yellow arms and black cores of samples C and D (*Figure 7*).

Electron microprobe analysis (EMPA)

The mapping of Al, Si, Ca and Fe in sample C by electron microprobe (*Figures 8a,b*) confirms the analytical results obtained by XRMF. According to the smaller diameter of the electron beam of the microprobe, a somewhat higher resolution is obtained for these element maps (compare *Figure 1c* and *Figures 4a,b*). In both analysis procedures applied, i.e. in a step-by-step (*Figure 8a*) and in a continuous raster mode (*Figure 8b*), no significant differences between the element images were observed. Iron contents were observed in the core and in the six arms of the star as well as in different small irregular fissures.

Characterization of inclusions

XRMF of trapiche rubies C and D revealed extraordinarily high concentrations of Si, Ti and Fe in the yellow arms and in the black cores of the samples. Semi-quantitative and quantitative chemical examination of several inclusions within these zones were performed by single-point analyses using the energy dispersive and wavelength dispersive analytical systems of the microprobe. These analyses of solid inclusions in orientated channels proved the presence of K–Al- and Fe–Al-silicates with or without titanium contents in addition to the previously identified calcite and dolomite fillings (see also Schmetzer *et al.*, 1996a). Quantitative chemical analyses, however, gave extremely variable results and proved compositions of the silicates in the channels to be inhomogeneous. From these results, it is concluded that the channels contain several extremely fine-grained silicate minerals.

Discussion

Chemical zoning in trapiche rubies has been proved by element mapping using XRMF and EMPA techniques. Three overlapping effects were observed in the samples (*Table I*):

(a) Chromium zoning within trigonal or trapezohedral ruby sectors (samples A, B, E and F) or between a red core and six trapezohedral ruby sectors (sample F) is due to growth zoning which is not related to inclusions in orientated channels.

(b) Calcite, dolomite and K–Al–Fe–Ti-silicate inclusions in the yellowish-white to yellow arms of all samples and in the black cores of samples C, D and E, cause aluminium and chromium deficiencies and variable concentrations of Si, Ca, Ti and Fe in these areas.

(c) A third mechanism contributing to the chemical inhomogeneity of trapiche rubies is caused by iron staining of primary tube-like cavities and secondary irregular fissures due to intense weathering of most samples. A distinct zoning with intensely weathered yellow arms in the outer parts and less weathered yellowish-white arms in the inner part of sample E (*Figure 1e*) is correlated with higher iron contents in the more weathered parts (*Table I*).

In summary, element mapping of trapiche rubies reveals a characteristic primary growth zoning, the presence of carbonate and some silicate mineral inclusions in orientated channels, and secondary weathering and iron-staining of the samples.

Conclusions

Element mapping by XRMF or EMPA is an extremely useful tool to understand various effects of chemical zoning within gem materials. Possible applications of element mapping to gemmological testing problems are the distinction of natural and synthetic gem materials due to variable chemical growth zoning as well as providing proof of diffusion treatments as recently demonstrated by Zhang *et al.* (1997).

Different diameters of incident X-ray or electron beams (70 or 3–4 μm respectively) were applied to excite characteristic X-ray fluorescence radiation in the samples and these give different spatial resolutions.

XRMF facilities include image-producing software packages which are nowadays routinely available (e.g. the OMICRON system by Kevex Instruments). The more time-consuming element mapping by electron microprobe requires extremely stable instrumental conditions and specially developed image-processing software applied to the data collection.

Acknowledgement

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Identification of B jade by FTIR spectrometer with near-IR fibre-optic probe accessory

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ABSTRACT: A FTIR spectrometer with a near-IR fibre-optic probe accessory has been found to be a useful and non-destructive tool for identification of bleached and polymer-impregnated jadeites (so-called B jade).

This method has the advantage of application to the testing of not only very thick or mounted stones, but also very large samples such as bracelets, which are difficult to test with other IR techniques. The important features of the technique are use of the fibre-optic probe and measurement of the near-IR frequency range. Therefore, clear near-IR absorption spectra from 7400 cm^{-1} to 4000 cm^{-1} could be obtained. The absorptions are caused mainly by the combination of stretching and bending vibrations and the harmonics of stretching vibration of C–H bonds.

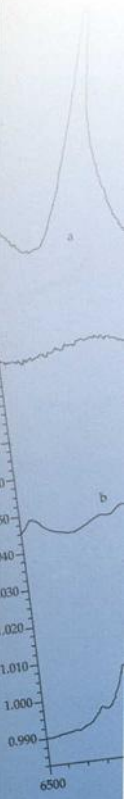

Introduction

FTIR spectrometers have been successfully used to identify B jade for many years. The first report was by Hurwit (1989) when little was known about this kind of jade treatment and its detection. The methods developed to include the widely used FTIR transmission technique (Fritsch *et al.*, 1992), and the more recent DRIFT technique (Quek *et al.*, 1997). Although thick or mounted samples can be tested using the DRIFT method it cannot be used for testing very large samples.

The basic principle of the FTIR transmission and DRIFT techniques to identify B jade is to study and compare two groups of absorption peaks, one from 3200 cm^{-1} to 2800 cm^{-1}, caused mainly by the stretching vibration of C–H bonds in the treatment material and another centred at 3500 cm^{-1}, caused by the stretching vibration of O–H bonds in the host jade. In some specimens it is very hard to differentiate the two groups of peaks. For example, if a sample is too thick then a general absorption band from 3600–2800 cm^{-1} may form. When this occurs, the absorption peaks in the near-IR frequency range can be measured to determine the nature of the jade.

Because of the low near-IR energy distribution of normally used FTIR instruments and the low molecular absorption coefficients of C-H bonds in the near-IR frequency range, it can be hard to get good signal-to-noise ratio spectra of B jade in the near IR-range. This problem can be resolved by use of a near-IR fibre-optic technique.

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Figure 1: The near-IR fibre-optic probe accessory connected to the FTIR spectrometer.

Principle and experiment

Polymers show absorption peaks at about 4300 cm^{-1}, caused by the combination of C–H stretching and C–H bending vibrations and at about 5900 cm^{-1} caused by the first-grade multiple frequency vibration of C–H stretching.

In jade, except for absorption at 5230 cm^{-1} caused by water molecules in alteration of the pure jadeite, there are no other clear absorptions in the near-IR frequency range, thus the polymer absorptions in B jade in the near-IR range are clear and not affected by any jadeite absorption.

For measurement a Nicolet Magna-750 FTIR spectrometer and a 'sabIR' fibre-optic probe accessory were used for the first time. The accessory consists of integrated optics, fibre-optic cable, sampling probe, detector and probe mount. One end of the fibre-optic cable is connected with the stainless-steel probe and the other end is connected with the FTIR spectrometer by a special detector (*Figure 1*). White light (quartz-halogen) and a KBr beam-splitter were used. The wavenumber range scanned was from 6500 to 4200 cm^{-1} with a resolution of 8 cm^{-1}; the scan number was 10.

A sample is exposed to near-IR radiation via the fibre optic and mainly diffuse reflectance light from the aggregate sample is collected. Thus, a diffuse reflectance spectrum can be obtained with the accessory; for the principle of diffuse reflectance, see Quek *et al.* (1997).

Except for cleaning the surface of a sample with a clean cloth, no sample preparation is necessary. The sample can be either placed on the probe mount (*Figure 2*), or touched directly with the probe by hand (*Figure 3*).

More than 50 pieces of A and B jade that had been tested by normal gemmological methods and by an FTIR transmission spectrometer were studied with the accessory. For conclusive results, a rough specimen of A jade was cut into two pieces by the authors (samples 1 and 2), and sample 2 was bleached and polymer-impregnated by a jade wholesale corporation.

Results and Discussion

Figure 4 (a,b) shows typical near IR spectra of two natural jadeites (samples 3

Figure 2: The sample can be tested by placing it on the mount of the fibre-optic probe.

Figure 3: A large sample can be tested by bringing the probe adjacent to the sample by hand.

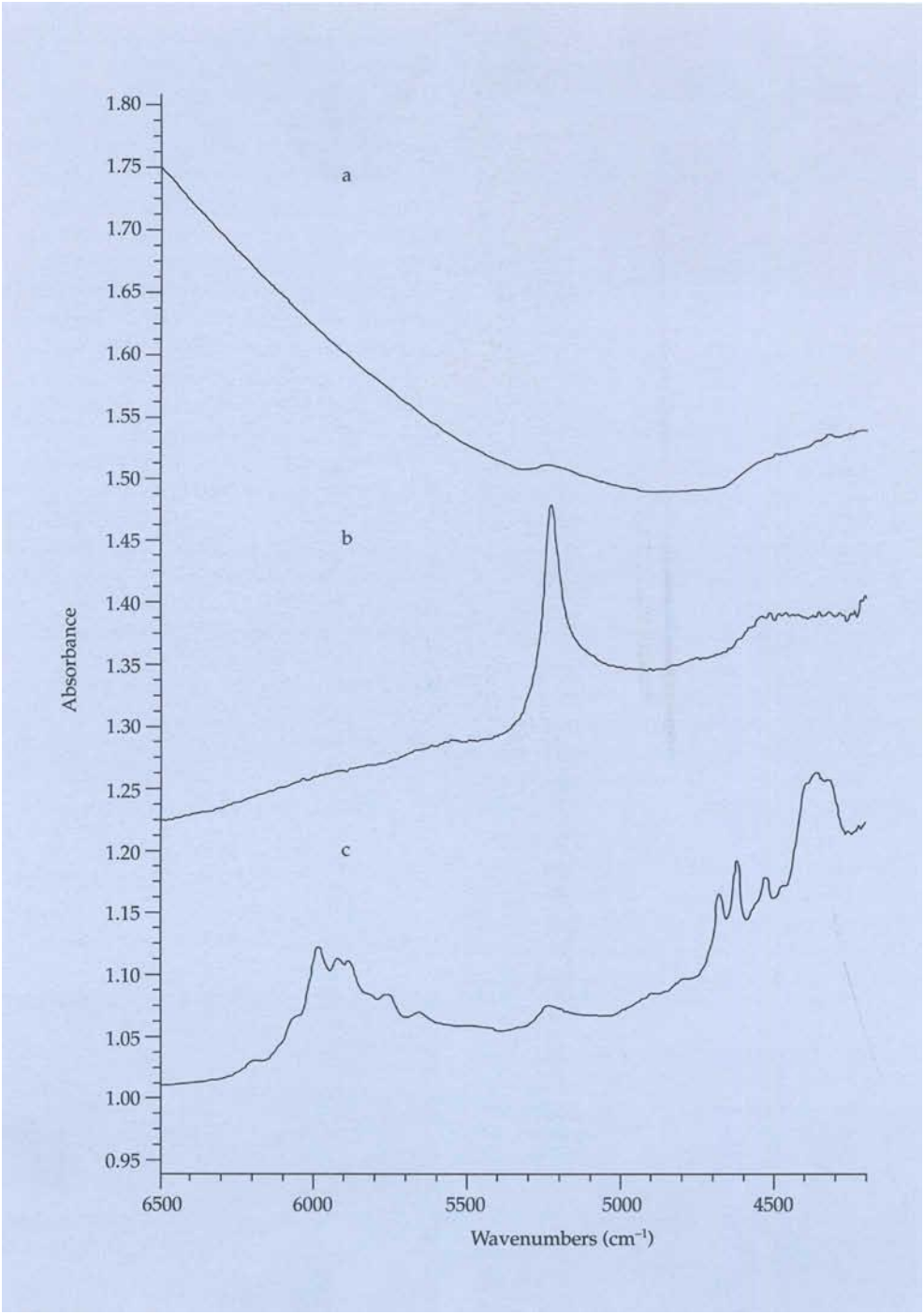

Figure 4: *Near-IR spectrum of (a) a high-quality, near-transparent, green natural jadeite (sample 3), (b) a poor-quality, opaque, green natural jadeite (sample 4), (c) a bleached and polymer-impregnated jadeite, tested using a 'sabIR' accessory.*

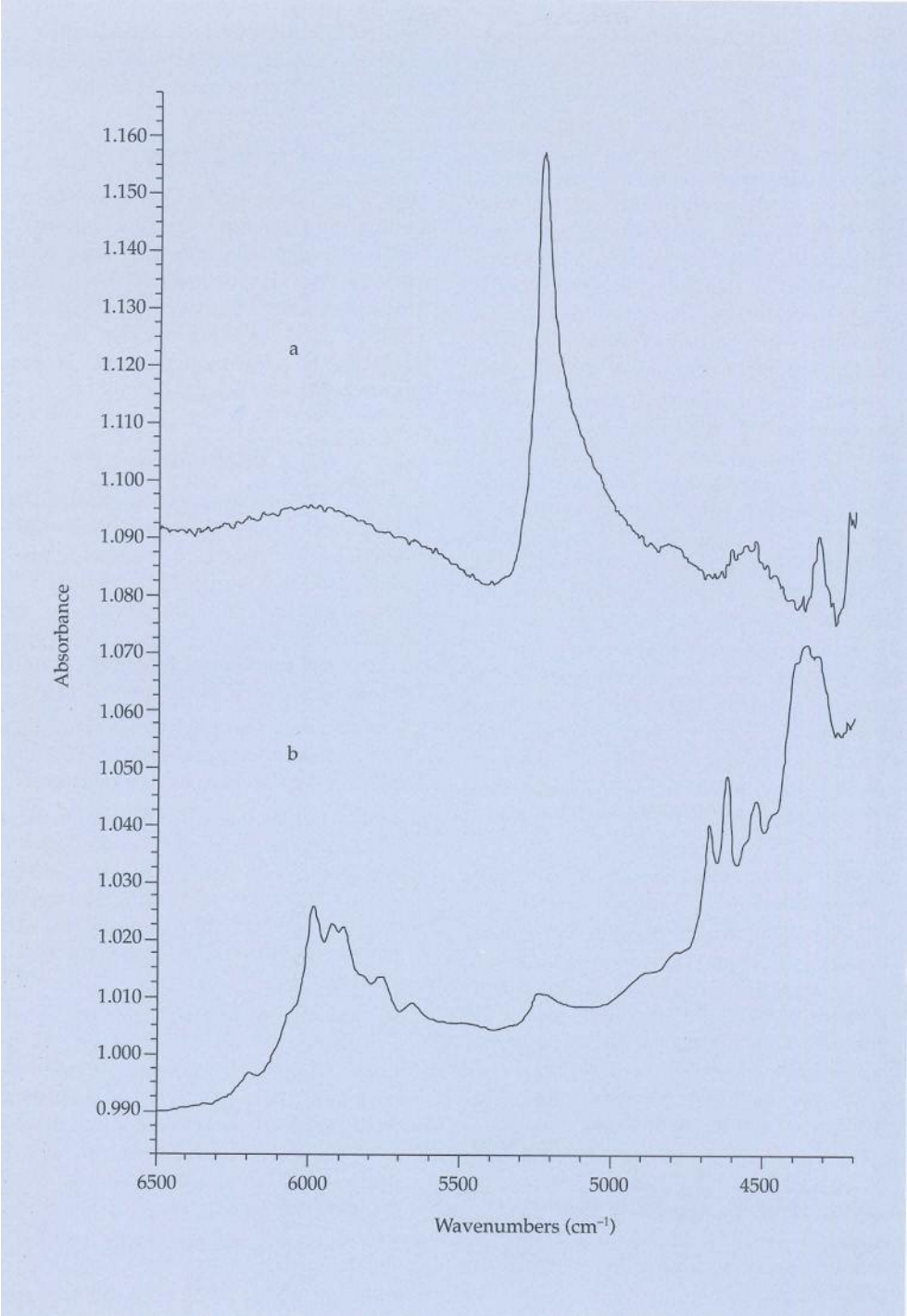

Figure 5: *Near-IR spectrum of (a) A jade before being bleached and polymer impregnated (sample 1), (b) B jade made from the material of sample 1 (sample 2), tested using a 'sabIR' accessory.*

and 4). Sample 3 is a high-quality, near-transparent, natural green jadeite. Sample 4 is a poor-quality, opaque, natural green jadeite.

It can be seen that the absorption peak occurring at 5230 cm^{-1} is the characteristic mark of natural jadeite, but the relative intensities of the absorption peak may vary significantly from specimen to specimen. Generally the better the quality of a jadeite, the lower relative intensity. So the relative intensity of the peak my be used as an indicator of the content of impurities in the jadeite, especially minerals that contain water.

Figure 4 (c) shows a typical near-IR spectrum of a bleached and polymer impregnated jadeite. The representative absorptions include four groups of peaks. The first group mainly contains peaks at 5985, 5922, 5885 and 5700 cm^{-1}, the second at 5230 cm^{-1}, the third at 4680, 4622 and 4530 cm^{-1} and the fourth at 4370, 4342 and 4324 cm^{-1}.

The first group of peaks near 6000 cm^{-1} are believed to be mainly related to the absorption caused by the C–H stretching vibration, the fourth group of peaks near 4300 cm^{-1} to the absorption of both stretching and bending vibrations of C–H. The cause(s) of the other two groups of peaks have not yet been explained.

Figure 5 (a,b) shows the spectra of sample 1 and sample 2.

It is evident that the relative intensity of the peak at 5230 cm^{-1} is lower after bleaching and polymer-impregnating treatment. It proves directly that impurities (especially minerals containing water) can be destroyed by bleaching. Although the absorption peak at 5230 cm^{-1} occurs in the two samples, the causes of formation are different.

The spectrum of jadeite which has been wax buffed is almost the same as that of the natural jadeite, the authors believe that the content of wax in such jadeite is too low to produce significant absorption peaks in the near-IR range.

The near-IR spectra of bleached and wax-impregnated jadeites have not yet been studied, but the authors believe that the spectrum of wax-impregnated jadeite could be characteristic and that identification of wax-impregnated jadeite could be as easy as that of polymer-impregnated jadeite.

Limitation

If a specimen of A jade is very thin and mounted in jewellery with glue, the near-IR radiation could penetrate the sample and reach the organic glue layer. Consequently a spectrum resembling that of B jade could be obtained and be misleading. In such instances, the measurements must be done carefully with this possibility in mind.

Conclusions

A near-IR fibre-optic accessory fitted to an IR spectrometer offers an effective and easy method for testing jade in various kinds of jewellery, and is particularly applicable to large samples. The sensitivity of the technique is good, and clear and characteristic spectra can be easily obtained. The following conclusions can be drawn:

1. Except for an absorption at 5230 cm^{-1}, there are no absorption peaks between 6500 cm^{-1} and 5000 cm^{-1} shown by natural jadeites.
2. The relative intensity of the peak at 5230 cm^{-1} can be used as an indicator of the quality of a natural jadeite specimen when compared with standard laboratory specimens. The better the quality of the jadeite, the lower the intensity of the 5230 cm^{-1} peak.
3. In jadeites examined after bleaching treatment, the relative intensity of the peak at 5230 cm^{-1} was smaller than before treatment, so a relatively high peak at 5230 cm^{-1} can be an indicator that the jade is A jade. This conclusion can also be applied to FTIR spectra obtained using a transmission technique.
4. The existence of absorption peaks at wavenumbers 5985, 5922, 5885, 5230, 4680, 4622, 4530, 4370, 4342 and 4324 cm^{-1} indicates that the jade being tested has been bleached and polymer impregnated. Ten scans of a sample are usually

sufficient to obtain a good spectrum, so the technique is very suitable for rapid testing of large batches of jewellery containing jade.

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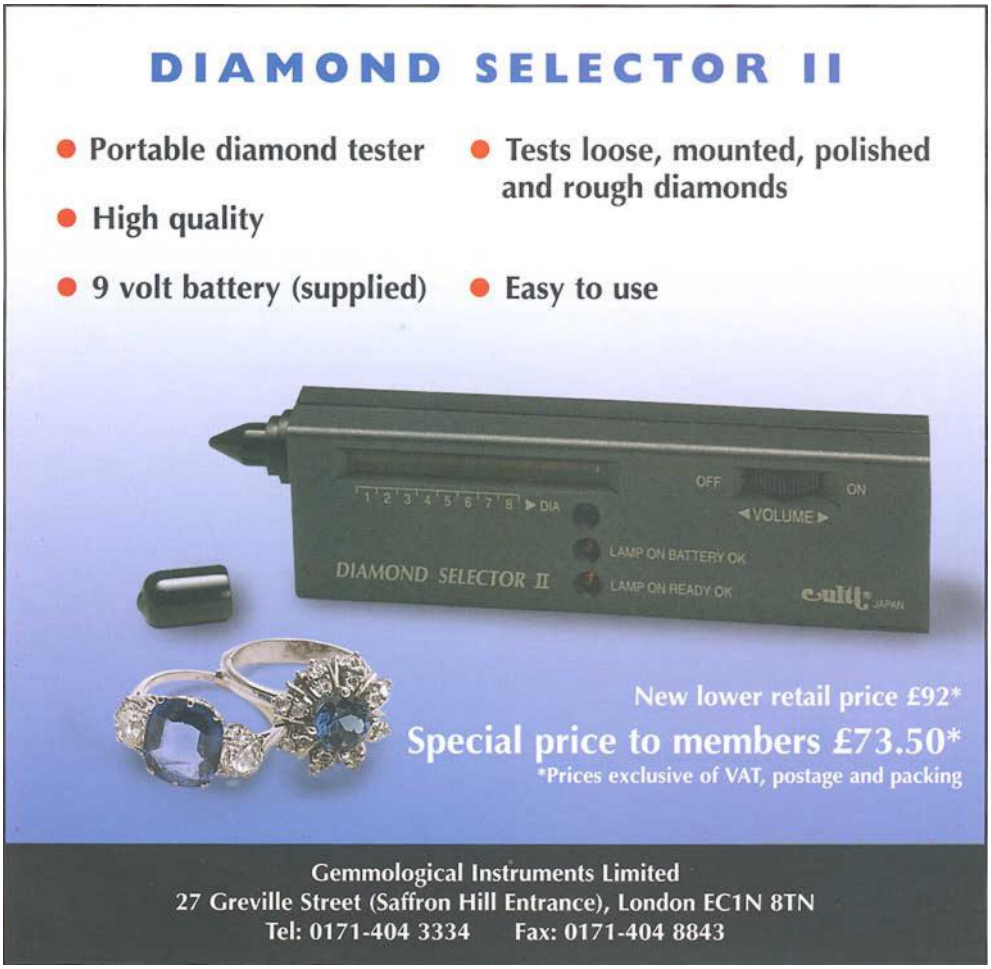

Natrolite from the Bela ophiolite, Pakistan

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ABSTRACT: The zeolite mineral natrolite was found as fracture filling in a slightly boudinaged dolerite dyke in serpentinized harzburgite WSW of Hazarganji, Khuzdar District, SW Pakistan. The mineral occurs as acicular, bundle-shaped aggregates up to 35 cm long and as prismatic milky-white or transparent idiomorphic crystals up to 12 cm long. Unusually large collectors' stones of up to 20.62 ct have been cut from this locality. The shape of idiomorphic crystals and mineral chemistry indicate a structurally highly (Si,Al)-ordered natrolite and this is consistent with the low temperature assemblage of associated minerals.

Keywords: Bela ophiolite, natrolite, Pakistan, rodingite, zeolite

Introduction

Natrolite (ideally $Na_2Al_2Si_3O_{10}.2H_2O$) is an orthorhombic zeolite mineral which is structurally closely related to mesolite ($Na_2Ca_2Al_2Si_3O_{10}.8H_2O$) and scolecite ($CaAl_2Si_3O_{10}.3H_2O$). The name derives from the Greek natron = soda and lithos = stone. Orthorhombic (pseudo-tetragonal) natrolite was first described by Klaproth (1803). The hardness is 5–5.5 on Mohs' scale, and its specific gravity is 2.20–2.25. Natrolite is biaxial positive and refractive indices are $\alpha = 1.473–1.480$, $\beta = 1.476–1.486$ and $\gamma = 1.485–1.496$ (Anthony *et al.*, 1990). The structure of the mineral was solved by Pauling (1930) and Taylor *et al.* (1933), and recently refined by Artioli *et al.* (1984). The basic structure of natrolite is an aluminosilicate framework composed of (Si, Al) tetrahedra. Each oxygen is shared between two tetrahedra and the negative charge is balanced mainly by Na situated in the cavities between; H_2O molecules also occupy the cavities. The structure of the natrolite-group zeolites contains a fundamental chain-like unit of edge-shared tetrahedra oriented parallel to the *c*-axis (*Figure 1*). This is the reason for the fibrous morphology common for this mineral group. Although natrolite is structurally related to mesolite and scolecite, it shows only limited solid solution with less than 0.5 Ca per unit cell present in natrolite. Other elements which may be present in small amounts are magnesium and potassium. Small impurities, order-disorder effects, and different hydration stages lead to the structurally, optically and chemically slightly different minerals of the natrolite group called gonnardite, tetranatrolite, ranite and paranatrolite (Chao, 1980; Chan and Chao, 1980; Mazzi *et al.*, 1986; Nawaz, 1988; Krogh Andersen *et al.*, 1969, 1990; Alberti *et al.*, 1995).

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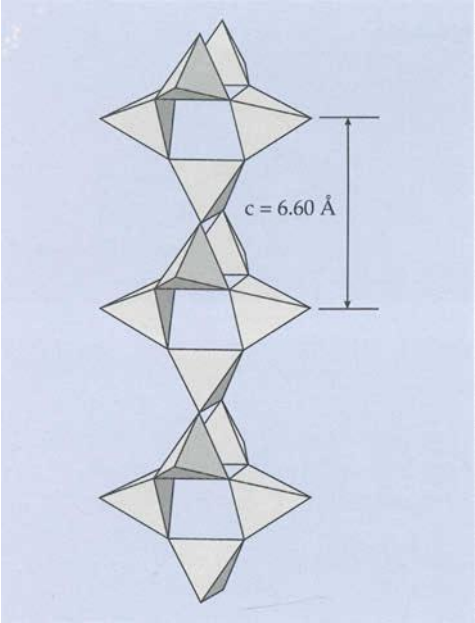

Figure 1: Basic chain-like orientation of Si, Al-tetrahedra in natrolite structure, which explains its preferred fibrous growth.

Natrolite occurrences are characteristically associated with basaltic rocks, alkaline intrusions, basic rocks in serpentinites and salt-lake environments (alkaline brines). In basaltic rocks well-developed crystals form in vugs (e.g. Hegau, Germany; Faeroe Islands; Auvergne; Bohemia) or in association with hydrothermal alteration (e.g. seafloor metamorphism). Natrolite associated with alkaline intrusions is, for example, described from Kola, USSR; Ilimaussaq, Greenland; San Benito County, California; the Langesundsfjord in Norway, and the Kimberley diamond mines in South Africa. Natrolite associated with basic rocks in serpentinites is reported from the Borus Mountains (Judin, 1963) and from the Johnston asbestos mine in Quebec, Canada (Poitevin, 1938). Natrolite formation in association with alkaline saline brines is reported from Tanzania, and from salt lakes in the USA (Hay, 1966).

Gem-quality natrolite is known from Bound Brook, New Jersey (Dunn, 1976) and Mont Saint-Hilaire, Quebec (Wight, 1996).

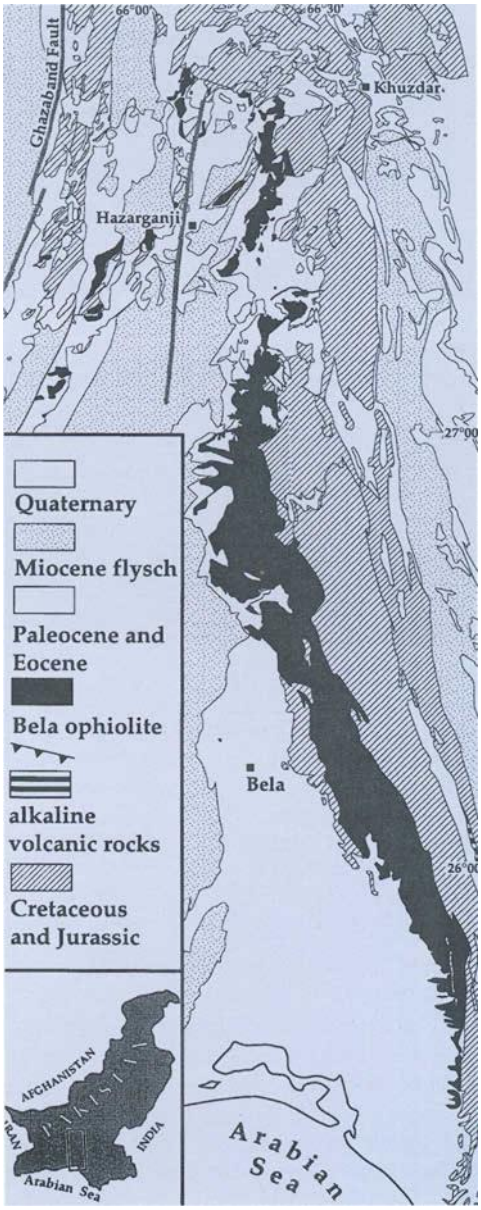

Figure 2: Overview map of the Bela ophiolite and surrounding Mesozoic and Tertiary rocks. The map is based on Jones (1960).

Regional geology

The natrolites of this study are from dolerite dykes, metasomatized towards rodingite, in serpentinite of the Bela ophiolite, Pakistan (*Figure* 2). The Bela

Figure 3: (a) Typical outcrop of serpentinized harzburgite of the Bela ophiolite (Hazarganji area) containing white-weathering folded and boudinaged dolerite dykes.
(b) Long prismatic, bundle-shaped aggregate of natrolite associated with prismatic white natrolite; size of specimen ca. *30 cm.*
(c) Long prismatic, idiomorphic gem-quality natrolite crystals, up to 12 cm in length, showing the morphology drawn in Figure 4.
(d) Cut and faceted natrolites from the Bela ophiolite. Back: left, modified scissors cut, 13.48 ct; centre, round brilliant-cut, 2.53 ct; right, modified scissors cut, 20.62 ct. Front: left, octagonal cut, 11.26 ct; right, rectangular cut, 5.08 ct. All stones are clean. Photo B. Schmied.

ophiolite is a fragment of ocean floor and forms part of the western ophiolite belt of Pakistan which was obducted onto the edge of the Indian continental plate during Palaeocene-Eocene times (Allemann, 1979; Mahmood *et al.*, 1995). The specimens were collected from a nearly monomineralic crack filling, up to 10 cm across, in a several metre thick dolerite dyke WSW of Hazarganji (*Figure 3a*). Only calcite (< 2 vol.%) was associated with the natrolite in the crack. Most of the natrolite occurs in the form of milky-white long prismatic radiating crystals (*Figure 3b*) filling the cracks but a few cavities contained freely-grown white to transparent crystals (*Figure 3c*) which allowed a study of their morphology. The two thickest pure crystals were used for faceting and the results are displayed in *Figure 3d*.

Nearby, boudinaged dolerite dykes metasomatized towards rodingite and weathering white, contain small (< 1 mm) andradite (demantoid) and green vesuvianite crystals as coatings on fissures. Fibrous xonotlite, $Ca_6(Si_6O_{17})(OH)_2$, the hydrous low-temperature mineral related to wollastonite, also forms cross-fibre fracture fillings.

Mineralogy

The natrolite from the Bela ophiolite forms medium to long prismatic and fibrous radiating crystals which are morphologically simple, with dominant {110} prism and {111} pyramid, and smaller {100} prism and {101} pyramid forms (*Figure 4*). A few crystals have twinning on {110}. The samples are

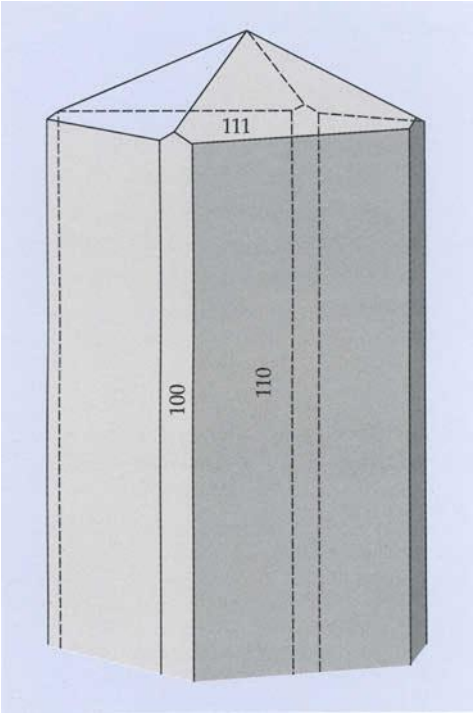

Figure 4: Morphology of natrolite from the Bela ophiolite. The {110} form may be absent; a second pyramidal form {311} was observed in some twinned crystals.

colourless and show no fluorescence in long- or short-wave ultraviolet light, although fluorescence has been described for samples from other localities (e.g. Laurent, 1941; Anthony *et al.*, 1990). Three different white and transparent natrolite crystals were analysed by powder X-ray diffraction, and the mineral was identified as natrolite.

A mean of four microprobe analyses of a gem-quality natrolite from the Bela ophiolite is listed in *Table I*. Data were collected with an enlarged beam diameter, and corrected online for H_2O absorption, assuming $2H_2O$ per formula unit. The chemical composition is close to endmember natrolite.

Gemmological characteristics

The refractive indices for the Bela material have been determined on a gemmological refractometer as $\alpha = 1.480$, and $\gamma = 1.485$. This gives a birefringence of 0.005 which is low and probably reflects the high Na and unusually low Ca, K and Mg contents. Spindle stage measurements yielded a $2\,V_z$ angle of $63.362 \pm 0.492°$. The natrolite gem material is free of inclusions and neither zoning nor luminescence were observed under the cathode luminescence microscope.

Table I. *Electron microprobe analysis of Bela natrolite*

Wt. %		*Cations on basis of 10 oxygens*	
SiO_2	46.55	Si	2.983
TiO_2	0.08	Ti	0.001
Al_2O_3	26.74	Al	2.019
FeO	0.04	Fe	–
MnO	0.05	Mn	–
Cr_2O_3	0.07	Cr	–
MgO	0.07	Mg	–
CaO	0.00	Ca	–
Na_2O	16.34	Na	2.030
K_2O	0.06	K	–
Total	90.00	Total	7.033

Note: Mean of four analyses. H_2O was not determined and the total is low; absorption due to H_2O was taken into account in calculating the oxide percentages.
Microprobe analyses were performed on a Cameca SX-50 microprobe at Bern University by E. Gnos. Beam conditions were 15 kV and 10 nA, with a defocused beam size of approximately 30 microns. Natural and synthetic minerals were used as standards.

Formation conditions

The development of natrolite in cracks is related to post-obduction ophiolite deformation and to hydrothermal activity along faults (Sarwar, 1992; Bannert *et al.*, 1992). These caused deformation and serpentinization of the peridotites, and fracturing, boudinage and metasomatism towards rodingite of doleritic dykes. The faults are parallel to the large Chaman, Ornach-Nal, and Ghazaband fault systems (*Figure 2*) which are the result of extrusion of the Afghanistan continental blocks due to the Himalayan collision (e.g. Tapponnier *et al.*, 1981).

Heating experiments by Van Reeuwijk (1972) showed that natrolite dehydrates and transforms to metanatrolite at 285°C under atmospheric pressure. On the other hand, natrolite can grow under atmospheric conditions in saline lake basins. In natural hydrothermal assemblages fibrous zeolites generally occur in the highest temperature zone (Alberti *et al.*, 1995). Thus, comparison with similar occurrences and the presence of andradite garnet, vesuvianite and xonotlite suggest that formation of the Bela natrolites took place at 150–285°C. The proposed low-temperature hydrothermal origin of the natrolites is also consistent with a strongly ordered natrolite structure (Alberti *et al.*, 1995) which is indicated by its Si/Al ratio of *ca.* 1.5.

Conclusion

Natrolite is probably not an unusual mineral in Pakistan and can be expected in vugs in alkaline lavas or in hydrothermal veins associated with alkaline intrusions, as well as in alkaline lake deposits. The development of large idiomorphic gem-quality crystals at this locality is unusual and the occurrence is interesting for mineral collectors, but it is not of economic importance.

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Heat treatment of milky sapphires from the Mogok stone tract, Myanmar

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ABSTRACT: Heating experiments on Myanmar geuda sapphires indicate that the most beautiful blue stones are obtained by heating to temperatures about 1600°C.

Keywords: geuda, heat treatment, Myanmar, sapphire

There are numerous reports in the literature about heat treatment of geuda stones from Sri Lanka (e.g. Nassau, 1984; Ediriweera and Perera, 1989; Hughes, 1990; Hurlbut and Kammerling, 1991; Webster, 1994) and they are well known among gemmologists, but reports of heat treatment of geuda-like sapphires from the Mogok stone tract, Myanmar, are still scarce. Geuda-like sapphires from the Mogok stone tract generally appear milky or contain abundant silk, in a range of pale colours including waxy-white to colourless, yellowish, bluish, etc. (Themelis, 1992). Heat-treatment experiments of Upper Myanmar stones carried out under reducing atmospheres in the past have shown that

(i) translucent to opaque white/milky/bluish sapphires characterized by a dull blue appearance turned to lighter blue, opaque or translucent, suitable for cabochons (1800°C, 60 minutes),

(ii) translucent to semi-translucent, white to pale bluish sapphires characterized by a dull appearance turned medium to light bright beautiful blue, very transparent, suitable for faceting (1750°C, 30 minutes), and

(iii) some transparent to semi-translucent waxy whitish or colourless sapphires with intense silk turned into light to medium blue, suitable for faceting (1800°C, 120 minutes) (Themelis, 1992).

The authors recently had a chance to examine geuda-like sapphires from the Mogok stone tract and the opportunity to treat some of these stones (*Figure 1, A–D*). The stones were heated from room temperature using a supertherm high-temperature furnace model HT 08/17 in an oxidizing atmosphere and under atmospheric pressure in all experiments.

Heating started with a rise of 10°C per minute up to 1200°C. The temperature was held at 1200°C for two hours and then the furnace was cooled to room temperature over a period of eight to ten hours. The results were surprising: the milky sapphires turned to transparent or translucent colourless stones with the exception of a very light blue milky sapphire with zonal structure (*Figure 1D*), which turned white.

Next, the temperature was raised to 1300°C, also starting from room temperature with a rise of 10°C per minute and held for two hours, but the results were the same as

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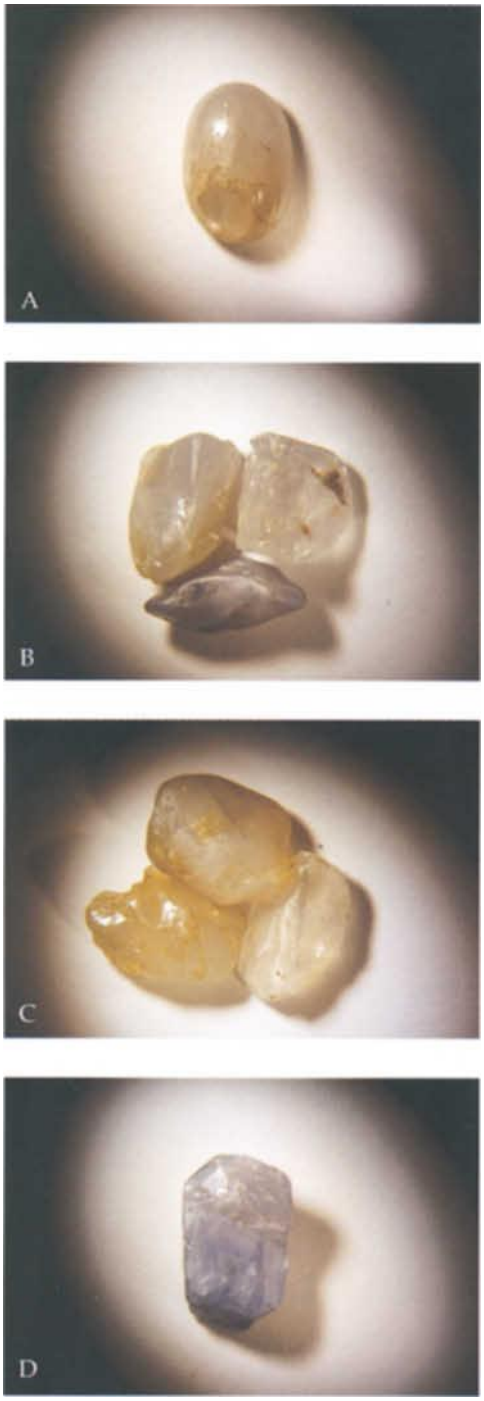

Figure 1 A–D: Geuda-like, milky sapphires from the Mogok stone tract before heat treatment.

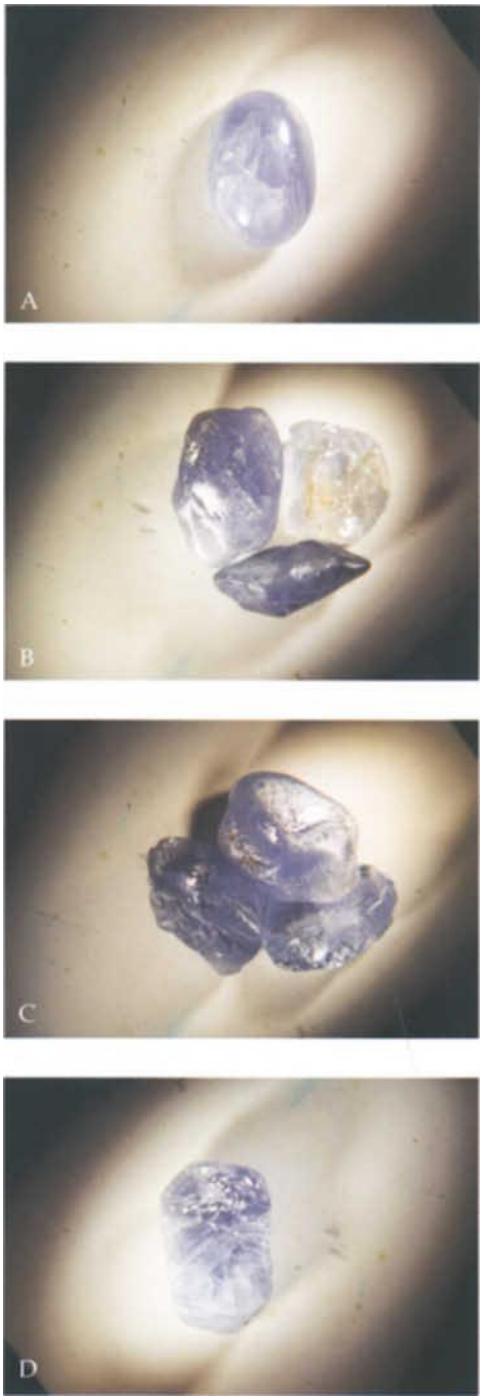

Figure 2 A–D: Medium blue to beautiful blue sapphires from the Mogok stone tract after heat treatment at 1600°C.

those obtained at 1200°C. Repetition of the experiment to a temperature of 1400°C caused no further dramatic changes in the sapphires.

At a temperature of 1500°C, the heating period was much longer than for the treatments described above, and this caused the colour of some milky sapphires to change to medium blue. The light-blue milky sapphire which had turned to white at 1200°C also changed to blue at 1500°C. When the temperature was raised to 1600°C and the heating period further extended, the colour dramatically changed from medium blue to a beautiful blue as shown in *Figure 2 A–D*. When the temperature was increased to 1700°C and the period of heating increased over that used at 1600°C, the beautiful blue sapphire turned to medium blue.

On the basis of these preliminary results on a small sample of geuda-like sapphires from Myanmar it would seem that the best results are obtained when the temperature range does not exceed 1600°C in an oxidizing atmosphere (cf. results obtained by Themelis, 1992). Further experimental details are available from the senior author.

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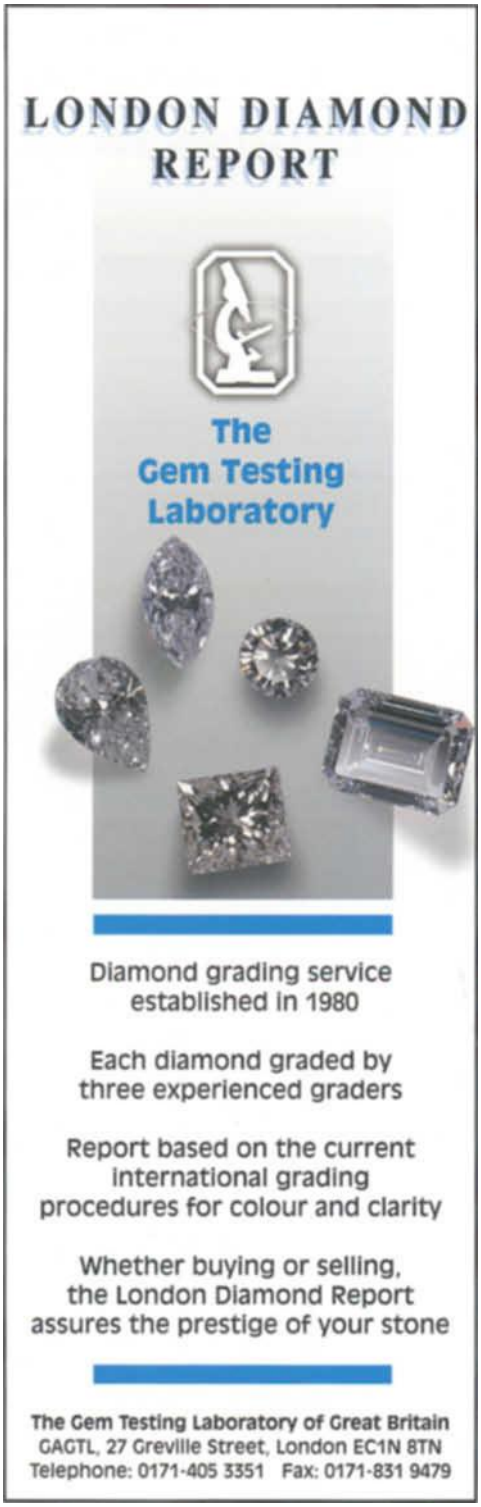

Laser-induced luminescence of emeralds from different sources

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ABSTRACT: Preliminary spectroscopic analysis in the red range of the spectrum between 674 and 679 nm using the new laser-induced (time-resolved) photoluminescence (LPL) technique, has been carried out on six natural emeralds from Afghanistan, Brazil, Colombia, Nigeria, Russia and Zambia, and one hydrothermally grown synthetic emerald. Emeralds from different sources have distinctive luminescent spectra and the usefulness of the results is evaluated. Although the luminescence spectra of emeralds from Afghanistan, Russia and Zambia are similar to that of the synthetic emerald, they show an additional 'bulge' towards the longer wavelength. The artificial emerald displays about three times greater intensity of luminescence than that shown by the natural emeralds.

Keywords: emerald, laser, photoluminescence, spectrum

Introduction

A selection of emeralds from six gem-mining regions in Afghanistan (Panjshir), Brazil (Carnaiba), Colombia (Muzo), Nigeria (Jos), Russia (Malishevo), and Zambia (Kitwe), and one synthetic hydrothermally grown emerald were chemically analysed with the electron microprobe (Moroz and Eliezri, 1998). The emeralds are chemically not homogeneous for the most part and display colour zoning that correlates directly with variations in chromium content. Emerald occurrences in Afghanistan, Brazil, Russia and Zambia belong to 'schist-type' deposits (Beus and Mineev, 1974; Kiyevlenko *et al.*, 1974; Moroz, 1978; Sliwa and Nguluwe, 1984; Schwarz, 1991; Moroz, 1996). They are located in regions where acidic magmas have penetrated country rocks in the vicinity of basic and ultrabasic rocks, and formed phlogopite-bearing bodies of rock related to distinctive greisens which contain actinolite or tremolite and variable quantities of talc, chlorite, quartz, albite, chromite, ilmenite, magnetite, apatite, tourmaline, fluorite and so on (Moroz, 1978; 1996). Some of these minerals were identified as inclusions in our samples of emeralds from these deposits (Moroz, 1997). In contrast to the emeralds from the 'schist-type' deposits, which have relatively high magnesium and sodium contents, the Colombian and Nigerian emeralds are low in magnesium and sodium. This suggests that the rocks in the vicinity

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Apparatus

The principle characteristics of the luminescence equipment are as follows (*Figure 1*):

Pulsed UV radiation (337 nm) from a nitrogen laser beam of 20 µsec pulse duration focused on the test specimen is used to excite photoluminescence. The emitted light is directed from the specimen to the inlet slit of the monochromator. The luminescence spectra of the emerald samples were recorded in the Laboratoire de Physico-Chimie des Materiaux Luminescents, Lyon Université Claude Bernard, using an Instaspec V detector which combines the advantages of a new intensified CCD camera and an optical microscope. This detector, triggered by the laser, provides quick time-resolved spectra acquisition at a nanometre scale as well as selective separation of overlapping emission spectra from 200 nm up to 900 nm. An optical spectral analyser, based on the detector connected with a PC with INSTASPEC software, was used to produce the luminescence spectra. The method is non-destructive. All investigations were performed at room temperature in the air. The general data collection time is less than 20 µsec.

Figure 1: *Schematic presentation of the time-resolved photoluminescence equipment.*

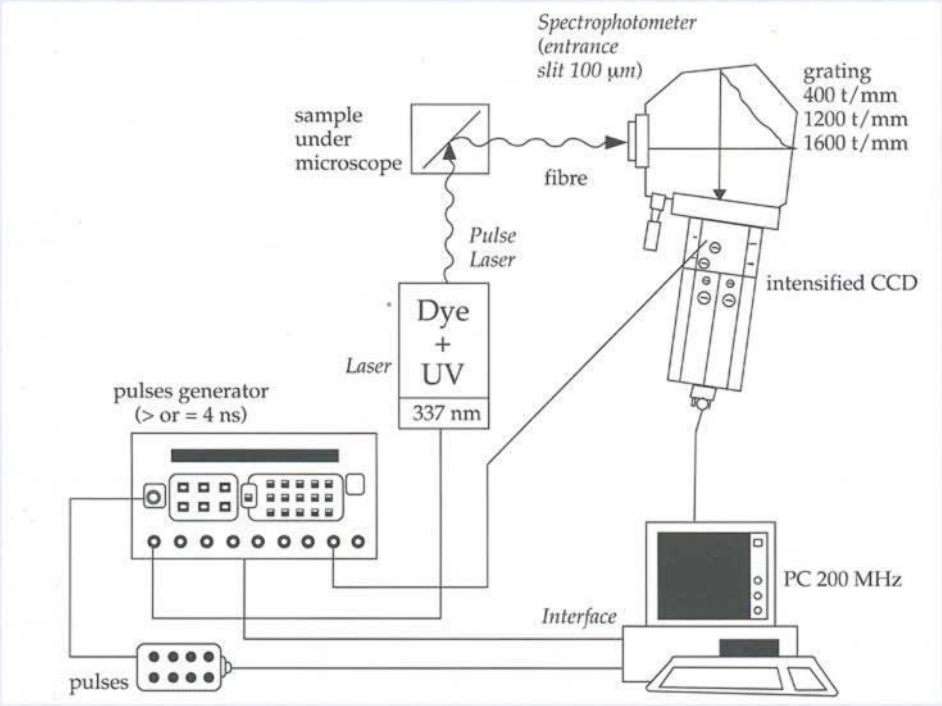

Table I. *Ranges of composition of emeralds from different sources*

Country Deposit	*Afghanistan Panjshir*	*Russia Malishevo*	*Zambia Kitwe*	*Brazil Carnaiba*	*Colombia Muzo*	*Nigeria Jos*	*Synthetic Hydrothermal*
No. of samples	3	2	3	2	2	3	3
No. of analyses	25	16	15	15	14	17	8
Wt%							
SiO_2	62.09–66.60	61.51–64.40	58.92–65.72	62.21–63.04	62.02–66.50	63.40–67.15	62.93–65.30
Al_2O_3	14.45–17.09	16.89–17.59	13.63–15.26	15.01–16.03	16.79–18.02	17.84–19.15	17.23-18.10
FeO	0.21–1.16	b.d.–0.52	0.47–0.97	0.52–0.85	b.d.–0.25	0.09–0.73	b.d.–0.30
MgO	0.95–1.89	0.60–1.29	1.84–2.34	1.51–2.26	0.7–0.76	b.d.–0.08	0.19–0.46
Na_2O	0.01–1.61	0.62–1.16	0.96–1.65	0.68–1.38	b.d.–0.65	0.10–0.67	0.01–0.58
Cr_2O_3	b.d.–0.16	b.d.–0.30	0.23–0.53	0.02–0.09	b.d.–0.29	b.d.–0.19	0.20–0.88

Note. Compositions were determined by electron probe microanalysis. BeO and H_2O were not measured. Contents of Ca, K, Ti, Mn, V, Cu, Ni, Co, Zn, Cs and S range from below detection to minor amounts less than 0.5% of oxide. b.d. = below detection level.

emerald, but vanadium also may contribute. Some samples from Colombia, Nigeria and Brazil (Carnaiba) have low chromium values, and some may contain up to 0.3% V_2O_3 (*Table I*).

The seven samples were studied by luminescence spectroscopy using a laser-induced (time-resolved) photoluminescence (LPL) technique. Conventional techniques currently used to obtain luminescence spectra of minerals are far from being perfect and are applicable only to a limited number of 'luminescent' gems. Emerald is usually considered a 'non-luminescent' gem (Smith, 1972; Samsonov and Turingue, 1984), but the luminescence intensity generated by the laser is significantly larger than the luminescence excited by conventional light sources and the LPL technique can be applied effectively in most minerals, especially those containing dopant ions. This technique is also attractive as it is non-destructive. In this contribution the preliminary results of the LPL technique carried out on a selected number of the chemically analysed emeralds are discussed and a possible application of the technique to characterize these gemstones is evaluated.

Results

The spectral range 675–679 nm is the most informative for analysing luminescence of the emeralds. The common spectrum of emeralds is a broad band in the 'red' part at 675 to 677 nm due to Cr^{3+}.

The emerald spectra (*Figure 2*) of the six samples of natural emerald and one synthetic hydrothermal emerald are characterized by the dominant role of Cr appearing at room temperature as a broad red band. The emeralds from Afghanistan, Russia and Zambia, which belong to 'schist-type' deposits, show an additional 'bulge' structure in the curves (*Figure 2*, curves 1–3). Apart from the broad red band there is a band at λ max ≈ 678 nm in these samples.

The artificial emerald displays about three times greater intensity of luminescence than that shown by each of the natural emeralds (*Figure 2*, curve 7). The luminescent spectra of the natural emerald specimens from Afghanistan, Russia and Zambia are similar in form if not intensity to the spectrum of the synthetic emerald.

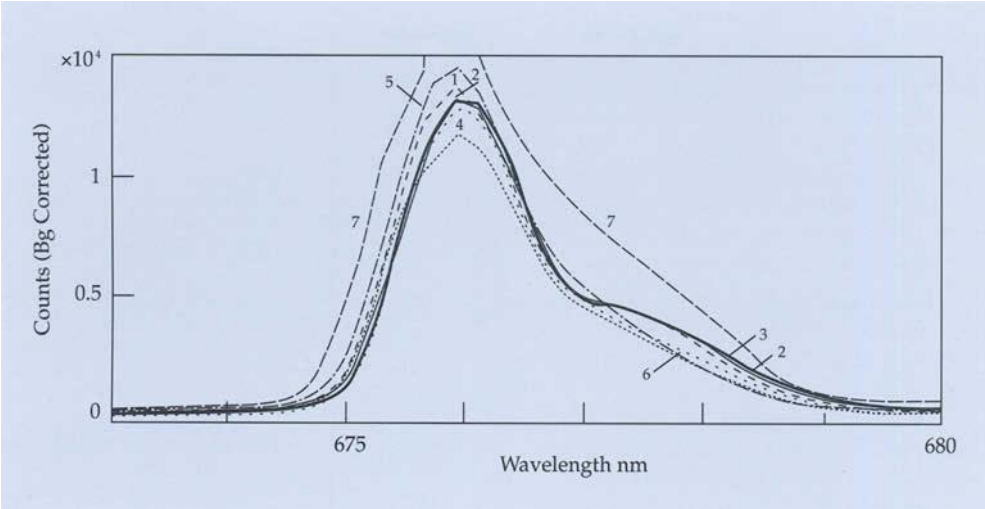

Figure 2: LPL spectra of seven emeralds (the crystallographic c-axis is oriented parallel to the laser beam) from the following sources: 1 Afghanistan; 2 Russia; 3 Zambia; 4 Brazil; 5 Colombia; 6 Nigeria; 7 synthetic hydrothermal emerald.

Discussion

The crystal structures of most minerals have defects which are usually present as dislocations or as 'dopant ions' and are, in essence, the luminescence centres (LC) in the visible spectral range. Every centre has its characteristic luminescence bands and lines (Ginzburg, 1985). The intensity of a specific spectral band or line is determined both by the number of centres contained in the mineral and by the concentration of luminescence absorption centres (LCA). Some dopant ions such as Fe^{2+} and Cu^{2+} may completely absorb or quench luminescence.

The most important dopant ion in emerald is Cr^{3+} in octahedral Al^{3+} sites (Wood and Nassau, 1968; Taraschan, 1978; Moroz *et al.*, in press). It is important that the wavelength of the major Cr-line in the red part of the spectrum is calibrated precisely. Along with the Cr^{3+} ions in natural emeralds, the presence of other dopants depends on their chemical nature and on their concentration in the geological and geochemical conditions of mineral formation. Differences in the chemical composition of emerald will show themselves either through the distinctiveness of the red band structure (*Figure 2*) or through other luminescence bands that may be typical for certain occurrences (Mesyats *et al.*, 1992). The stones from Afghanistan and Zambia contain appreciable iron concentrations (*Table I*). According to Platonov *et al.* (1984, p. 60), the colouring of emeralds may be influenced not only by iron, but also by other dopant ions, including 'non-chromophores' – for instance magnesium because they may change the proportions of the chromian polyhedrons in the beryl structure and shift the chromium bands towards longer wavelengths. We report elsewhere (Moroz and Eliezri, 1998) on heightened concentrations of magnesium in emerald samples from Zambia (to 2.34 wt%), Afghanistan (up to 1.73 wt%) and Russia (up to 1.3 wt%); which give rise to 'red shifts' of the Cr^{3+} absorption band in these samples (Moroz *et al.*, in press). Correspondingly, an additional 'bulge' structure appears as a long wavelength shoulder at λ max ≈ 678 nm in the luminescence spectra of the same samples reported here (*Figure 2*, curves 1–3). Such an influence on Cr^{3+} spectral bands position in emeralds may also be exerted by other impurities such as manganese, zinc and titanium when they enter octahedral positions in the emerald structure.

Conclusion

The luminescent spectra of emeralds from different sources are presented. The spectra of emeralds from Afghanistan, Russia and Zambia, which belong to 'schist-type' deposits, are less intense than the spectrum of the synthetic hydrothermally grown emerald and show an additional 'bulge' structure in the luminescence curves.

The investigation of luminescence spectra of emeralds through the laser-induced luminescence (LPL) technique opens up possibilities for obtaining fast and reliable solutions to a range of gemmological problems including gem identification, indication of the source of a gem, and characterization of synthetic gemstones.

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Obsidian from Chile with unusual inclusions

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ABSTRACT: A new type of transparent slightly yellowish obsidian from northern Chile is described and its chemical composition is given. The obsidian has a refractive index of 1.540 and a specific gravity of 2.36; it contains three types of distinct well-crystallized inclusions – hexagonal very strongly pleochroic columnar crystals thought to be indialite (high-temperature polymorph of cordierite), elongated striated rods of sillimanite and tiny parallelepipeds of probable feldspar.

Keywords: Chile, inclusions, indialite, obsidian, sillimanite

Introduction

Transparent natural glasses, with the composition of obsidian, are known from many places throughout the world but, unless they are of attractive colour and appearance, are not very interesting for the gemmologist or for the trade. The new material from northern Chile is a nice exception especially due to its wonderful interior with a variety of inclusions.

Description

Three cut stones between 7.13 and 12.90 ct and three rough pieces between 5 and 8 g were bought in Brazil in 1997 and 1998 respectively by the first author and they reputedly came from the Atacama desert in northern Chile (see *Figure 1*). The locality is probably correct, because similar obsidian comes from a nearby region in Peru and has been called 'macusanite' after the regional name (see later). Very little obsidian was found and only a few pieces were transparent enough to be cut according to the owner. One faceted obsidian is completely transparent and two are slightly milky, their colour being slightly yellowish. The refractive index of 1.540 is at the higher limit for natural obsidians, and the specific gravity is 2.36. All three pieces of rough show fine dark layers, rarely curved, indicating fluidal structure. Their surfaces are dull, probably as a result of wind erosion. All stones stay bright during rotation in the polariscope due to the abundant anisotropic inclusions; obsidian itself is isotropic. The chemical

Figure 1: *Faceted obsidians, 17 mm and 14 mm long. Photograph by J. Hyrsl.*

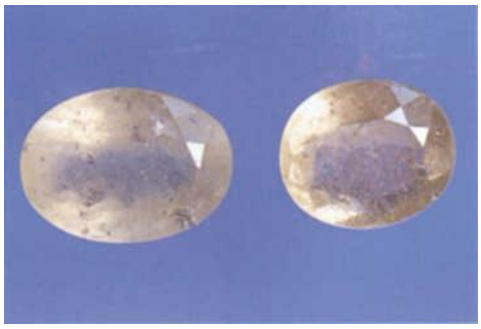

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Table I. Chemical composition of obsidian from Chile compared with macusanite from Peru, marekanite from Arizona and an indialite inclusion from Chile.

Wt.%	1. Obsidian, Chile	2. Macusanite, Peru	3. Marekanite, USA	4. Indialite inclusion
SiO_2	74.20	77.98	74.64	47.87
TiO_2	0.09	–	0.12	–
Al_2O_3	14.26	13.16	12.48	32.39
CaO	0.33	0.54	2.25	0.05
FeO	0.46	1.34	0.82	7.83
MgO	0.08	–	0.44	7.51
MnO	0.27	–	0.06	1.53
Na_2O	3.82	–	2.46	0.36
K_2O	4.48	6.98	5.66	–
P_2O_5	–	–	0.24	–
SO_3^-	–	–	0.58	–
Cl^-	–	–	0.25	–
Total	97.99	100.00	100.00	97.54
RI	1.540	1.489	1.480	
SG	2.36	2.36	2.33	

NB: Total iron is given as FeO; – means below detection; macusanite analysis from Henn, 1995; marekanite analysis from Holzhey, 1996; obsidian and indialite compositions from microprobe analyses by I. Vavrin.

composition of the Chilean obsidian was studied using an EDX microprobe fitted with a LINK-eXL system. The results are given in *Table I* together with the chemical compositions of two recently described obsidians, marekanite from Arizona (Holzhey, 1996) and 'macusanite' from Peru (Henn, 1995). The analysis shows high silica and alkali contents and confirms an origin connected with rhyolitic volcanism.

Inclusions

All three cut stones contain easily visible inclusions which diminish their transparency (see *Figure 2*). The most striking inclusions are blue columnar hexagonal crystals with very strong pleochroism, deep bluish-violet along *c*-axes and colourless perpendicular to the elongation. They show only two crystallographic forms, the hexagonal prism and basal pinacoid, and the longest crystals reach 1 mm. They show high relief with pale interference colours even in plane polarised light.

The second type of inclusion consists of colourless long rods striated parallel to the *c*-axes. The rarest inclusions are tiny colourless parallelepipeds with monoclinic or triclinic symmetry. All three types of inclusions are anisotropic, have a higher refractive index than obsidian (measured by a Becke line) and show a straight extinction in cross polars.

The blue columnar inclusions were initially interpreted as cordierite from their shape and pleochroism, and this was confirmed by a microprobe analysis which indicated a compositional formula of $(Mg_{1.17} Fe_{0.68} Mn_{0.14} Na_{0.07} Ca_{0.01})_{2.07} (Al_{3.98} Si_{5.00})O_{18}$. Cordierite is very rare as an inclusion, having been reported by Gübelin and Koivula (1992) only as an inclusion in beryl. In this Chilean

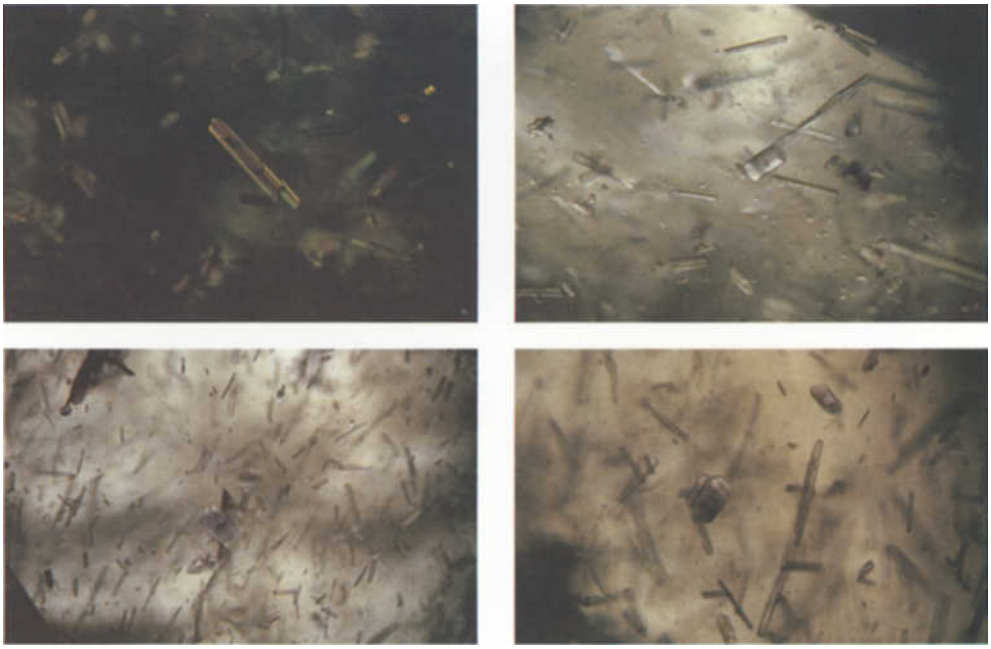

Figure 2: Inclusions in the faceted obsidians (in crossed polarized light). Photographs by J. Hyrsl.

obsidian the inclusions are probably not orthorhombic cordierite, but its high-temperature hexagonal polymorph, indialite. Distinction between these polymorphs would only be possible by X-ray methods.

Although the long rod-like inclusions are very similar to andalusite inclusions in Peruvian obsidian (macusanite) described by Gübelin and Koivula (1992) and Henn (1995), who analysed them chemically, they have been identified as sillimanite by laser Raman methods (Koivula, pers.comm.). Some rods were found to be broken, signifying crystallization in a plastic medium rather than formation from recrystallization of the solid obsidian. Sillimanite is a high-temperature polymorph of Al_2SiO_5 which is consistent with presence of indialite postulated above. The crystal shape of the third kind of inclusion corresponds with feldspar, and tiny feldspars are mentioned as common inclusions in many obsidians (Bouska *et al.*, 1994). Due to its RI of more than 1.54, sanidine and albite can be excluded as possibilities, but it could be a basic plagioclase.

Acknowledgements

We would like to thank Dr I. Vavrin at the Czech Geological Survey, Prague, for microprobe analysis, and J.I. Koivula at the GIA, Carlsbad, U.S.A., for identification of inclusions in the obsidian.

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Johachidolite – a new gem

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ABSTRACT: A pale yellow mixed-cut gemstone of 14.02 ct has been identified as the rare borate, johachidolite ($CaAlB_3O_7$) and is the first recorded gem of this species. Its gemmological properties are described and are broadly consistent with the data published for the original mineral from Korea except that the birefringence of the gem (0.007) is smaller and its fluorescent properties may differ. The Raman spectrum of johachidolite is presented.

Keywords: borate, johachidolite, new gem variety, Raman spectrum

Introduction

On the advice of C.R. Cavey, the owner of a pale yellow cut gemstone came to the GAGTL in Spring 1998 to have the stone identified (*Figure 1*). The results from RI and SG measurements and from spectrum, fluorescence and filter examination were inconclusive and an electron probe microanalysis (EPMA) at the Natural History Museum was suggested.

The analysis at the Museum indicated the presence of Ca and Al but significantly the total was low, which suggested the presence of an element or elements of low atomic number (less than sodium). The most promising line of enquiry was then investigation by X-ray diffraction and since this meant scraping a minute amount of powder from the girdle of the stone, permission had to be obtained from the owner. This was duly granted; an X-ray powder diffraction pattern was then obtained and this proved to be a clear and convincing match with the standard pattern of the rare borate mineral, johachidolite (Powder Diffraction File number 29-280).

Figure 1: *Johachidolite, 14.02 ct. Photograph by F. Greenaway.*

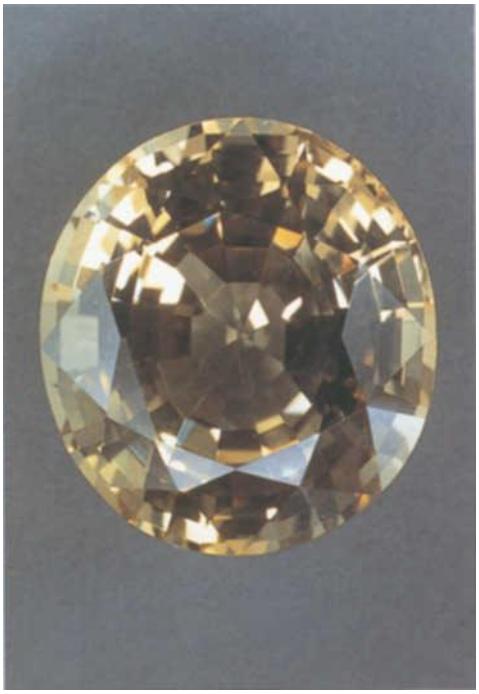

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Johachidolite – the mineral

Johachidolite was first described by Iwase and Saito (1942) from the type locality in the Johachido District, Kisshu County, Kankyo Hodu Prefecture, North Korea (*Figure 2*). Moore and Araki (1972) solved the structure of a crystal (in the National Museum of Natural History, Washington) from the same locality and this led them to assign a formula of $CaAlB_3O_7$ to johachidolite, i.e. without the components H, F and Na of the original formula of Iwase and Saito (1942) which Moore and Araki (1972) attributed to impurities. Aristarain and Erd (1977) reviewed the history of investigation into johachidolite, further refined the data on its crystallographic properties and, with the approval of the IMA Commission on New Minerals and Mineral Names, confirmed its composition as $CaAlB_3O_7$. Until now, the only reported occurrence of johachidolite is in North Korea where it is found in nepheline veins cutting metamorphosed limestone. In specimen 105479 in the National Museum of Natural History (Washington), johachidolite is associated with scapolite, diopside, albite and phlogopite (in addition to nepheline) as equant anhedral grains up to 1 mm across. It is colourless and transparent or whitish and semi-transparent; under short-wave ultraviolet radiation it shows pale-blue fluorescence and weak phosphorescence.

The rock specimen shown in *Figure 2* was presented to the British Museum (Natural History) by Dr G. Switzer of the Smithsonian Institution, Washington, and is presumably comparable with the material originally examined. Recent electron microprobe work on this specimen has confirmed the presence of a vein of small grains of johachidolite in a matrix of feldspathoid, plagioclase feldspar and other minerals.

Properties of gem-quality johachidolite

The gem johachidolite has a modified brilliant-cut crown and a step-cut pavilion, measuring approximately 15.83 mm (long diameter) by 14.36 mm (short diameter) by 8.99 mm (depth), and weighing 14.02 ct. It is pale yellow with no detectable pleochroism and displays strong whitish-blue fluorescence under long-wave ultraviolet, weak blue fluorescence under short wave, and no phosphorescence. Under the Chelsea Colour Filter it appears yellowish-green.

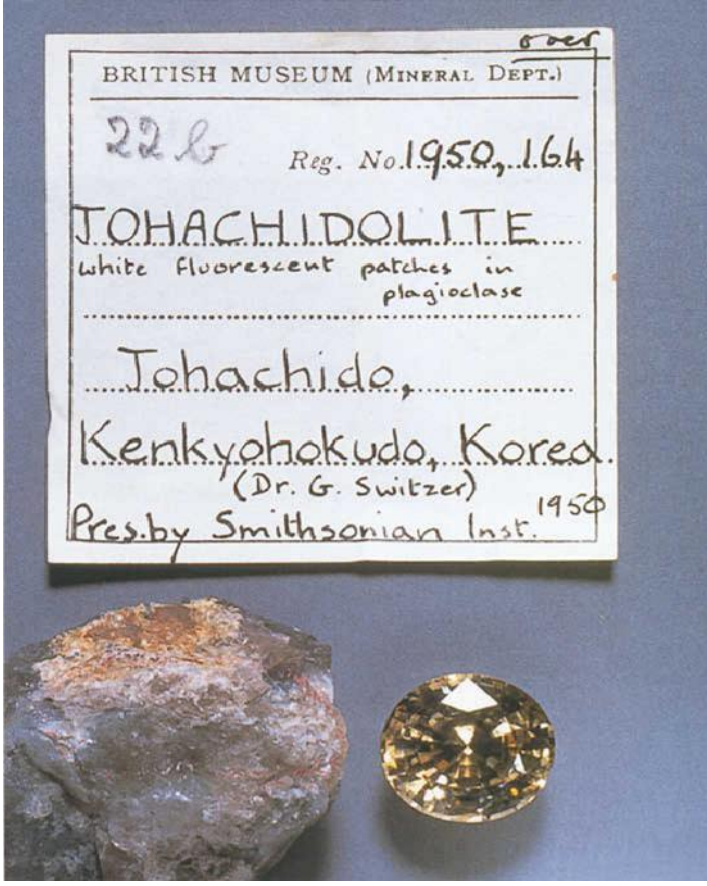

Figure 2: Johachidolite occurs as tiny grains in a small vein crossing the centre of the specimen which was presented to the Natural History Museum by Dr G. Switzer of the Smithsonian Institution in 1950. Details of the specimen are on the museum label and the gem johachidolite is shown for comparison. Photograph by F. Greenaway.

Refractive index readings taken from the table facet on Rayner Dialdex and Kruss refractometers give the following results: α 1.717, β 1.720 γ 1.724, giving a birefringence of 0.007. Specific gravity measurements were carried out using the hydrostatic method in demineralized water and yielded a mean SG of 3.45.

Examination of the stone through a hand-held spectroscope revealed no

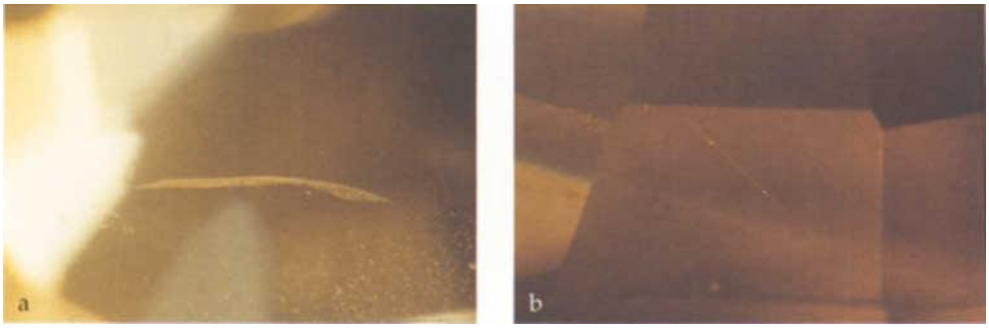

Figure 3: *(a) One of two curved planes showing dense pattern of tubular cavities, just beneath the table facet.*
(b) Needle inclusion angled into the stone from a pavilion facet, with reflecting crystals or discs along the length (about 2 mm). Photographs by R.R. Harding.

distinctive absorption or fluorescence bands; a UV-visible spectrum of the johachidolite from the Pye Unicam PU8800 spectrophotometer showed complete absorption at wavelengths shorter than 350 nm, a shoulder at 380 nm and transmission with no significant absorption bands up to 750 nm.

Under 10x magnification, two feathers are visible just under the table (see *Figure 3a*) and two needles occur deep in the pavilion. Under the higher magnifications of a microscope, more needles are visible and some are accompanied by a tiny disc or tabular crystal at a high angle to the needle (*Figure 3b*).

Some properties of johachidolite reported by Aristarain and Erd (1977) are compared with results obtained from the gem in *Table I*. Two differences worth noting are the birefringence values and the possible differences in behaviour under ultraviolet radiation. The measured birefringence of the gem johachidolite is half that reported by both Iwase and Saito (1942) and Aristarain and Erd (1977). In the paper by Aristarain and Erd (1977) it is not clear if the mineral they tested fluoresced under long-wave ultraviolet; the gem johachidolite is strongly fluorescent under long-wave ultraviolet, shows weak

		1	2
Refractive indices	α	1.712	1.717
	β	1.717	1.720
	γ	1.726	1.724
Birefringence		0.014	0.007
Optic sign		positive	positive
Specific gravity		3.37 (meas.)	3.45
		3.43 (calc.)	
Colour		colourless	pale yellow
Fluorescence:	LWUV	not reported	strong whitish-blue
	SWUV	pale blue	weak blue
Phosphorescence		weak	none

1. from Aristarain and Erd (1977)
2. this work

Table I. *Properties of johachidolite derived from 1, the mineral from North Korea, and 2, the gem*

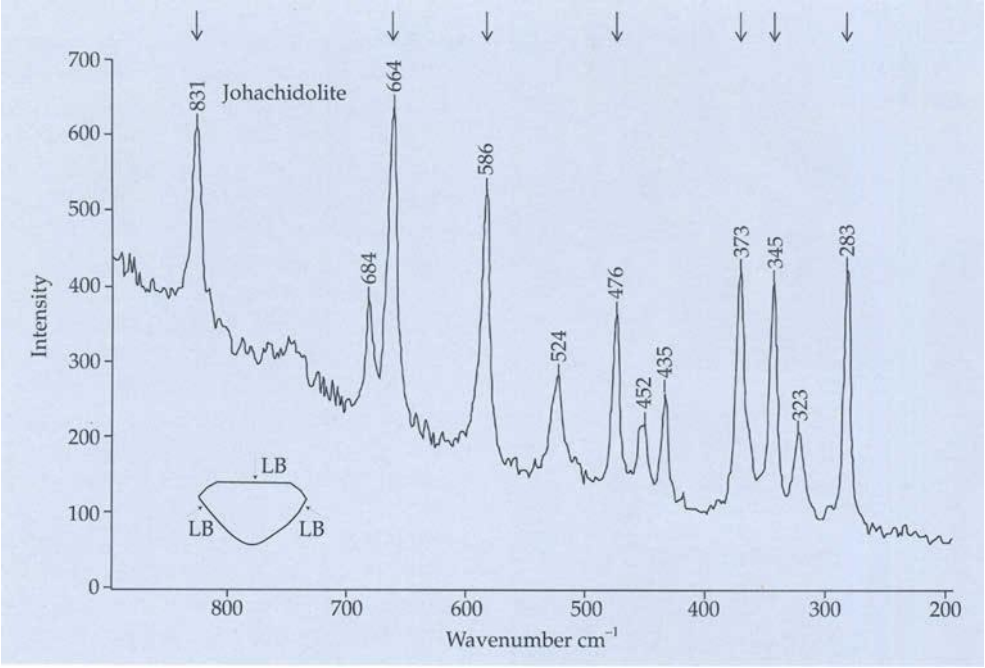

Figure 4: ***Raman spectrum of johachidolite; table facet*** *perpendicular to the laser beam. Sketch of stone shows three directions of laser beam (LB) used to obtain spectra. The spectra from all three directions contained the seven peaks arrowed.*

fluorescence in SWUV (in agreement with that of the mineral), and shows no phosphorescence – unlike the mineral.

Raman spectra were obtained using a Renishaw micro-Raman 1000 system coupled to an Ar ion laser (514 nm) and a petrological microscope. The system was operated in confocal mode with the laser beam focused about 50 μm below the surface of the stone and operated at full power (20 mW). Scanning times of 60 seconds were used for each of three spectra obtained from different orientations of the crystal. Characteristic Raman shifts in wavenumbers (cm^{-1}) are shown in *Figure 4*.

The spectrum with the most peaks was obtained with the laser beam perpendicular to the table facet. Spectra obtained from pavilion facets near the girdle at each end of the stone contained fewer peaks, but all spectra contained the seven peaks arrowed in *Figure 4*, i.e. at 831, 664, 586, 476, 373, 345 and 283 cm^{-1}, all ± 2 cm^{-1}.

Discussion

The appearance of a 14 ct cut gemstone of a species only known in nature as colourless transparent grains less than 1 mm across was a considerable surprise, and immediately led to questions about its origin; in particular initially as to whether it was natural or synthetic.

The stone was bought in Myanmar as a natural gem but the species is so rare that the possibility that it had been introduced into the gem trade after having been grown in a laboratory had to be investigated. Natural and synthetic substances containing boron were recently described in an encyclopaedic volume edited by Grew and Anovitz and published by the Mineralogical Society of America (1996). In this volume, Werding and Schreyer (1996) set out to present existing data on experimental studies of borosilicates and selected borates and made no reference to johachidolite, presumably reflecting the absence of any significant work. Anovitz and Hemingway (1996) also presented a

Figure 5: Johachidolite (centre right, 14.02 ct) with two sinhalites (centre left, brown, 9.84 ct; and top right, yellow, 6.25 ct) and two danburites (bottom right, table cut, 18.85 ct; and top left, round, 13.10 ct). The danburites are from Mogok, Myanmar, and the sinhalites are probably from Sri Lanka. Photograph by F. Greenaway.

summary (in their Table 6) listing references to known experimental data for minerals containing boron, and although johachidolite is in the list, the adjacent column for references to any experimental work on johachidolite is blank.

Crystal growing activities are extensive and varied in the former USSR, Thailand, the P.R. of China and other countries. So searches were made for references to johachidolite and to CaAl borates in the indexes of the *Journal of Crystal Growth* and of *Chemical Abstracts* from 1990–97. These also proved fruitless, and provisionally one must conclude that CaAl borate is either of little interest to the materials researchers or, if it is of interest, the results are not being published. Anyway, no source for synthetic johachidolite was indicated.

If the stone is of natural origin and possible sources are being considered, it might be useful to compare it with other borates. Gem-quality examples of natural borates include hambergite [$Be_2(OH, F)BO_3$], rhodizite [$(K, Cs)Al_4Be_4(B, Be)_{12}O_{28}$] and jeremejevite [$Al_6B_5O_{15}(OH, F)_3$], but the best known is sinhalite [$MgAlBO_4$] (see *Figure 5*).

Sinhalite of gem quality comes largely if not exclusively from Sri Lanka, but one crystal (rough) was found in Burma and brought to London by A.C.D. Pain (Payne, 1958). Non-gem-quality sinhalite has been found in both Warren County, New York (Schaller and Hildebrand, 1955), and Handeni District, Tanzania (Bowden *et al.*, 1969); both occurrences are in metamorphosed limestones, geological contexts very similar to that described for johachidolite. The occurrence of the borosilicates tourmaline, kornerupine and danburite in or near the Mogok gem gravels (*Figure 5*) together with the admittedly rare occurrence of sinhalite suggests that other borates may also be present at Mogok. In this context, painite, the most famous rare mineral of all from Burma, has a small content of boron in an essentially aluminate structure. This area therefore could be a possible source of natural gem johachidolite.

In a historical context, the present investigation into johachidolite has many similarities with the discovery of a borate, already cut as a gem, some fifty years ago when collaboration between Anderson and Payne of the Gem Testing Laboratory and Claringbull and Hey of the Natural History Museum led to the recognition and description of the new mineral sinhalite (Claringbull and Hey, 1952).

Conclusion

This is the first reported occurrence of gem-quality johachidolite. No evidence of any sources of synthetic CaAl borates could be found in current literature and the stone is probably natural, with a possible source in the Mogok area of Myanmar.

Acknowledgements

We would like to thank F. Greenaway for photographs of the gems and Museum specimen, and J. Spratt for the electron microprobe analyses. A.I. Castro, S.J. Kennedy and T. Lodge at the GAGTL Gem Testing Laboratory are thanked for their work on the gem, and M.J. O'Donoghue and Dr Chen Changkang (Clarendon Laboratory, Oxford) provided useful advice in searching the literature. Finally we would like to thank the owner of the stone for permission to examine it in detail.

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Abstracts

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Diamonds

Gem news.

M.L. Johnson and J.I. Koivula. *Gems & Gemology*, **34**(1), 1998, 50–62, 23 coloured illus.

Diamond crystals in various shapes from Russia and China were on display at the 1998 Tucson Trade Fair. J.J.

Zur Vulkanologie von diamantführenden Kimberlit- und Lamproit-Diatremen.

V. Lorenz. *Gemmologie (Zeitschrift der Deutschen Gemmologischen Gesellschaft)*, **47**(1), 1998, 5–30, 11 photographs, 2 diagrams, bibl.

The vulcanology of diamondiferous kimberlite and lamproite diatremes and dykes is considered in the light of a detailed model of phreatomagmatic formation of maar-diatreme volcanoes. Maars and the underlying diatremes form when magma rises in dykes and contacts groundwater resulting in thermohydraulic explosions. The magma with the surrounding country rocks is fragmented, the groundwater vaporized and then, because of the expansion of the steam, the fragmented materials are ejected at the surface and cause the collapse of the surrounding rocks; at the earth's surface it forms a collapse crater, a maar. The article explains the hydrogeological conditions necessary for the formation of kimberlite and lamproite diatremes. E.S.

The rise to prominence of the modern diamond cutting industry in India.

M. Sevdermish, A.R. Miciak and A.A. Levinson. *Gems & Gemology*, **34**(1), 1998, 4–23, 15 illus. in colour and 2 tables.

Over the last thirty to forty years India has become one of the major centres for the cutting of diamonds, and is the sixth most important diamond market in the world. India specializes in cutting low quality small diamonds often less than 7 points and these are mostly exported to foreign jewellery manufacturers; 70 per cent by weight and 35 per cent (wholesale) value of diamonds in the world are cut there. From the late sixties the market has expanded by 82 fold by polished weight and 249 fold by polished (wholesale) value. This expansion has been due to the exploitation of the large diamond deposits in Russia, Botswana and Australia, especially the Argyle mine in Western Australia, which produces large quantities of small low quality material. In the future India will have difficulties maintaining its position as the largest supplier of polished stones in the world due to the diminishing availability of small stones. There are no new major mines in an advanced stage of development that could produce the volume of gem rough needed to replace the Argyle mine when it becomes exhausted within the next six years. The implications for India are of unemployment but this might be alleviated by the cutting and polishing of synthetic diamonds. J.J.

Diamond prospecting in Finland – a review.

M. Tyni. In *Mineral Deposits*, ed. H. Papunen (Balkema, Rotterdam), 1997, 789–91.

To date, 24 kimberlites and related deposits have been discovered in Finland, of which 16 are diamondiferous. R.A.H.

[Examination on colouring of diamonds by proton beam irradiation.]

(Japanese with English abstract.)

I. Umeda and K. Iida. *Journal of the Gemmological Society of Japan*, **21**, 1996, 15–19.

A 2.378 ct colourless diamond was first irradiated by high energy electron beam using a linear accelerator, which produced homogeneous green colour, and subsequently annealed. The stone became homogeneously yellow, which was then irradiated by 18 MeV proton beam using a cyclotron to the culet through a ϕ 3 mm metallic collimeter. The stone became bi-colour; surrounding the culet is green, the table and the girdle are yellow. The stone exhibits an umbrella mark around the culet, whereas green diamonds produced by irradiation by high energy electron beam do not show such a mark. I.S.

Abstractors

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J. Johnson	J.J.	E. Stern	E.S.		

For further information on many of the topics referred to, consult *Mineralogical Abstracts*

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Gems and Minerals

Iridescent andradite garnet from the Sierra Madre Mountains, Sonora, Mexico.

M.A. BADAR AND M. AKIZUKI. *Neues Jahrbuch für Mineralogie Monatschefte*, **12**, 1998, 529–39.

Iridescence in andradite from the Sierra Madre Mountains, Sonora, Mexico, was examined by optical microscopy, electron microprobe analysis, back-scattered electron image and single-crystal X-ray diffraction. The iridescence is caused by cyclically stratified growth lamellae in the {211} and {110} sectors with chemical content And_{79}–And_{94}. A marked contrast between adjacent lamellae arises from differing refractive indices and gives a source of iridescence. The garnet was found to contain isotropic and anisotropic (triclinic) zones. M.O'D.

A corundum-quartz assemblage in altered volcanic rocks, Bond Range, Tasmania.

R.S. BOTTRILL. *Mineralogical Magazine*, 62(3), 1998, 325–32.

This unusual assemblage occurs in a hydrothermally altered Cambrian quartz porphyry; the quartz and corundum are in mutual contact, in association with andalusite, pyrophyllite, diaspore, etc. This metastable assemblage apparently resulted from advanced argillic alteration at moderate *T* and *P*, followed by rapid depressurization accompanying boiling of hydrothermal granite-derived fluids. This corundum appears to be unrelated to the sapphires found in placer deposits in Tasmania. R.A.H.

A re-examination of the turquoise group: the mineral aheylite, planerite (redefined), turquoise and coeruleolactite.

E.E. FOORD AND J.E. TAGGART, JR. *Mineralogical Magazine*, **62**(1), 1998, 91–111.

The turquoise group has the general formula $A_{0-1}B_6(PO_4)_{4-x}(PO_3OH)_x(OH)_8 \bullet 4H_2O$, where $x = 0$–2, and has six members: planerite, turquoise, faustite, aheylite, chalcosiderite and an unnamed Fe^{2+}–Fe^{3+} analogue. The existence of 'coeruleolactite' is doubtful; planerite is revalidated as a species characterized by a dominant *A*-site vacancy; aheylite is established as a new member of the group characterized by having Fe^{2+} dominant in the *A*-site. Chemical analyses of 15 pure samples of microcrystalline planerite, turquoise and aheylite show that ≤ two of the (PO_4) groups are protonated (PO_3OH) in planerite; complete solid solution exists between planerite and turquoise. Most samples of 'turquoise' are cation-deficient or are planerite. There are four molecules of water. Planerite, ideally $\square Al_6(PO_4)_2(PO_3OH)_2(OH)_8 \bullet 4H_2O$, is white, pale blue or pale green, and occurs as mamillary botryoidal crusts as much as several mm thick; it may also occur massive, microcrystalline, typically with crystals 2–4 µm, lustre chalky to earthy, H 5, D 2.68 g/cm^3, mean RI ~ 1.60. Aheylite, ideally $Fe^{2+}Al_6(PO_4)_4(OH)_8 \bullet 4H_2O$, is pale blue or green, and occurs as isolated crystals and hemispherical aggregate of crystals that average 3 µm in maximum dimension; porcellanous-subvitreous lustre, mean RI ~ 1.63, biaxial (+), D 2.84 g/cm^3. R.A.H.

Feueropal von Opal Butte, Oregon, USA.

G. HOLZHEY. *Gemmologie (Zeitschrift der Deutschen Gemmologischen Gesellschaft)*, **46**, 1997, 161–8, 10 photographs, 3 tables, 1 graph, bibl.

This occurrence has been known as Peter's Butte in the Blue Mountains north east of Oregon since 1889, but has only been worked intensively since 1986. The specimens occur within concretion-like spherical masses, which carry fillings of fire and other opals. The fire opal is an arrangement of silica spheres of different diameter up to 250 nm with a high calcium content. RI 1.431, SG 2.05. Some inclusions seem to be of organic (vegetable?) matter. E.S.

[Study on the mechanism of formation of 'circle pearls' – an approach from the nacreous. structure.] (Japanese with English abstract.)

E. ITO. *Journal of the Gemmological Society of Japan*, **21**, 1996, 33–44.

Pearls showing circumferential ditches or depressions are called circle pearls, and are often encountered among cultured black pearls. Optical and SEM observations were made on the internal structures of the nacreous layer of circle pearls of various types, as well as flat pearls formed on flat shape nucleus, twin pearls formed on two nuclei. Sectional colour distribution, stage of initiation of circles, deviation of circles from symmetry, the degree of continuation of aragonite layers, thickness and number of aragonite layers at depressed and elevated portions, comparison of nacreous structures between twin and flat pearls, and circle twin and flat pearls were investigated. Two possible mechanisms are proposed for the origin of circle pearls; one assumes wrinkles formed on pearl sac due to illness of mother pearls or external stress, and the other assumes rotation of the nucleus in the pearl sac. I.S.

Gem news.

M.L. JOHNSON AND J.I. KOIVULA. *Gems & Gemology*, **34**(1), 1998, 50–62, 23 illus. in colour.

Chiastolite spheres from China were on offer at the 1998 Tucson Trade Fair. Coral with a blue sheen and horn like appearance has been found in the ocean of Alaska at depths of 300 m or more. A faceted corundum, reportedly from Vietnam, gave rise to a nomenclature problem as it was ruby one end and blue sapphire at the other end. Samples of emerald from a new deposit in Tocantins State, Brazil, were darker than most Colombian emeralds and showed evidence of clarity enhancement. Yellowish to reddish-orange spessartine garnets from northern Madagascar are of a large size and unusual cuts. A new deposit from Northern Madagascar is producing yellowish-brown sphenes, with some crystals up to 29 ct, much of the material possibly contains chromium and is red when viewed through a Chelsea filter. Spinel from the Luc Yen area in Vietnam is now available and is mined as a bi-product of ruby mining. Parti-coloured faceted liddicoatite tourmaline from Madagascar has limited use in jewellery as they tend to have a muddy appearance in the finished stone. Transparent and uniform coloured green tourmalines from Namibia were on show. J.J.

Diopside inclusions in Arizona pyrope identified by Raman analysis.

J.I. KOIVULA. *Gemmologie (Zeitschrift der Deutschen Gemmologischen Gesellschaft)*, 47(1), 1998, 39–44, 4 photographs, 2 graphs, bibl.

The author describes the identification of bright green diopside inclusions in pyrope garnets from Arizona by means of Raman laser microspectrometry. The Raman spectrum of a completely enclosed inclusion was compared to some obtained from surface-exposed inclusions in both pyrope and diamonds; the latter were previously identified by X-ray powder diffraction and served as a chrome diopside standard. E.S.

Die dicken Brunner aus St Egidien.

W. LEONHARDT. *Mineralien Welt*, 8(5), 1997, 28–31, 2 maps.

Fine ornamental agates are described from St Egidien, Saxony, Germany. Details of the occurrence are given. M.O'D.

Dendritenachat: 'kristalline Pflanzenwelt'.

W. LERGIER. *Lapis*, 22(11), 1997, 25–8, illus. in colour.

Illustrations and discussion of notable examples, mostly from Minas Gerais, Brazil, of dendritic agate. M.O'D.

Teaching gemology at the undergraduate university level.

A.A. LEVINSON. *Mineralogical Association of Canada Newsletter*, 57, 4–12, 1998.

University courses in gemmology held at the undergraduate level are thought to benefit both gemmology students and geology/mineralogy students who are able to share the classes. Canadian experience in more than one institution is outlined. M.O'D.

Vergleichende Untersuchungen an Rhodolithen verschiedener Provenienz.

TH. LIND, U. HENN AND C.C. MILISENDA. *Gemmologie (Zeitschrift der Deutschen Gemmologischen Gesellschaft)*, 47(1), 1998, 53–9, 4 photographs, 2 graphs, 2 tables, bibl.

The examined rhodolites came from Tanzania, Orissa (India), Sri Lanka, Malawi, Brazil and Madagascar and could be subdivided into three types on the basis of their visible absorption spectra. Type 1 was found only seldom, with the exception of the find in Siali in Orissa; most rhodolite belonged to type 2 (landaban); type 3 came mainly from Tanzania. All types have typical mineral inclusions such as zircon, apatite and rutile. The origin of the stones could not be determined by microscopic examination. E.S.

Texture and structure of opal-CT and opal-C in volcanic rocks.

T. MAGASE AND M. AKIZUKI. *Canadian Mineralogist*, 35(4), 1997, 947–58.

For opal in volcanic rocks from the Hosaka and Akase opal mines in Japan, textures of opal-CT are optically classified into anisotropic columnar and isotropic massive (opal-CT_M) types; both textures consist of thin and platy crystals showing two wide {101} faces of low cristobalite. Images from HRTEM show that the cristobalite structure is the fundamental component of volcanic-type opal-CT, and that many stacking faults occur at random in the structure. Columns are produced by parallel growth of platy crystals; opal-CT_M and lepispheres consist of criss-crossing aggregates of blades; each blade consists of ~ parallel aggregates of platy crystals. The variation of d_{101} values with textural and structural changes of the opal-CT was measured by an XRD powder method; with decreasing d_{101}, highly ordered cristobalite domains develop surrounding the domains of disordered cristobalite. This considerable difference in degree of order of stacking between the two types of domain implies changes in the growth process of the crystal. R.A.H.

Gem Trade Lab notes.

T. MOSES, I. REINITZ AND S.F. MCCLURE. *Gems & Gemology*, 34(1), 1998, 44–9, 12 illus. in colour.

Colombian emeralds with three-phase inclusions were found with a solid inclusion of triangular shape and not cubic; this is possibly due to space restrictions during formation. The triangular platinum inclusions seen in synthetic emeralds should not be confused with natural inclusions. A large greenish-blue fibrous rough and a cabochon of the same colour were found to be hemimorphite, the first time this material had been seen at the GIA Lab since 1971. A Raman Imaging Microscope System was used to identify some small crystal inclusions, which reached the surface of a green cabochon jadeite, as zircon. A cabochon-cut yellow cat's-eye was found to be opal with the chatoyancy caused by fine and coarse needles, possibly pseudomorphous after goethite. Two reddish-brown scapolites from Tanzania both exhibited chatoyancy and one also had six additional weaker rays. A rare bluish-green oval brilliant-cut topaz was found to be natural, the stone had marked colour zoning and displayed no radioactivity. Spherical blue clouds surrounding dark blue crystal inclusions were seen in sapphires that have been heat-treated to a temperature approaching the melting point of sapphires. J.J.

The color of minerals.

N.V. PUTIVTSEVA AND E.V. PRYAKHINA. *World of Stones*, 12, 1997, 34–7, illus. in colour.

Drawing from exhibits forming part of an exhibition held at the Mineralogical Museum of the Moscow State Geological Prospecting Academy, notes on mineral coloration are summarized with a number of examples, some of ornamental species. M.O'D.

Grosser Rauchquarzfund am Piz Giuf, Bündner Oberland.

V. SIALM-BOSSARD. *Lapis*, 23(1), 1998, 42–5, illus. in colour.

Exceptional crystals of smoky quartz have been recovered in a cavity at about 2800 m on Piz Giuf in the

Bündner Oberland of eastern Switzerland. Specimens up to 1.2 m have been found as crystal groups and some of the finest examples are displayed at the Museum 'La Truaisch', CH-7188 Sedrun. M.O'D.

La géologie des gisements de saphirs.

C. SIMONET. *Revue de gemmologie*, **132**, 1997, 21–3.

A short study of sapphire occurrence submitted for the Diploma of the Université de Gemmologie, Nantes, France. Sedimentary, volcanic and metamorphic types of deposit are considered. M.O'D.

Imperfections and inhomogeneities in single crystals as a basis to distinguish natural from synthetic gemstones.

I. SUNAGAWA. *Gemmologie (Zeitschrift der Deutschen Gemmologischen Gesellschaft)*, **47**(1), 1998, 45–52, 3 diagrams, bibl.

The author discusses physical imperfections and chemical inhomogeneities in single crystal gemstones. They are a record of growth and post-growth history of the stone and show the differences between natural and synthetic stones as well as differences in origin. Thus they serve as diagnostic features. Methods of application of these features are briefly explained. E.S.

Tessiner Rauchquarze: die grössten Kristalle vom Cavagnoli-Gletscher.

S. WEISS. *Lapis*, **23**(2), 1998, 36–7, illus. in colour.

Very fine large crystals of smoky quartz are reported from the Cavagnoli glacier, Ticino, Switzerland. The largest crystal found measures 60 x 75 cm in thickness and length, weighing 114 kg. M.O'D.

Cultured pearls from Indonesia.

P.C. ZWAAN. *Gemmologie (Zeitschrift der Deutschen Gemmologischen Gesellschaft)*, **47**(1), 1998, 31–8, 8photographs, 2 maps, 2 tables, bibl.

Cultured pearls from different localities in Indonesia, produced by *Pinctada maxima*, were examined. Dobo pearls come from the Aru Islands; there is, however, now a pearling project by an Australian company near Kupang in West Timor; this is supposed to reach a maximum capacity by the year 2000 of 200–400 thousand pearls. Dobo pearls are silvery white and have a nacre thickness of 1.0 to 2.0 mm, they are rarely round, often egg- or pear-shaped. Lambok Mabe pearls have a hemi-spherical nucleus consisting of artificial resin; the nacre has a thickness of 0.4–1.1 mm. Kuta pearls are blister pearls with a nucleus of artificial resin plus a plug of an echinoid; they are round, button-shaped and resemble imitation pearls because of their sheen. It is not known where these are grown. E.S.

Synthetics and Simulants

Russian synthetic pink quartz.

V.S. BALITSKY, I.B. MAKHINA, V.I. PRYGOV, A.A. MAR'IN, A.G. EMEL'CHENKO, E. FRITSCH, S.F. MCCLURE, LU TAIJING, D. DEGHIONNO, J.I. KOIVULA AND J.E. SHIGLEY. *Gems & Gemology*, **34**(1), 1998, 34–43, 16 illus. in colour.

The first reported production of transparent synthetic pink quartz was in 1992 manufactured by Russian laboratories, and the first material was commercially available in 1994. It is currently produced near Moscow under the name of 'Flamingo quartz'. The synthetic material is grown in a solution containing ammonium fluoride (NH_4F) and silica at temperatures between 220°C and 350°C. The pink colour is produced by subsequent irradiation and heating together with a concentration of phosporus in the fluoride solution. Although natural massive rose quartz is relatively common, natural transparent single crystal pink quartz is very uncommon and only found in Madagascar and Brazil. The authors, both from Russia and the GIA, examined synthetic material and natural quartz from Brazil. Although they found many similarities between the stones, advanced testing techniques helped to distinguish the natural quartz from the synthetic. In synthetic material the colour banding was found to be always parallel to the basal faces and often uneven, while in the natural stones the banding was oblique to the axis with feathery edges, which was not seen in the synthetic stones. All synthetic material lacked twinning. The infrared absorption spectrum of the synthetic quartz contained a diagnostic band at 3420 cm^{-1} and weak bands at 3500 and 3650 cm^{-1}. J.J.

Gem news.

M.L. JOHNSON AND J.I. KOIVULA. *Gems & Gemology*, **34**(1), 1998, 50–62, 23 illus. in colour.

A new synthetic amethyst from China has been grown on dome-shaped seed crystals. They were all deep purple and showed natural quartz faces, but FTIR spectroscopy showed a peak at 3545 cm^{-1} in the infrared spectrum, which confirmed they were synthetic. Glass cabochons and beads to imitate agate are now being made. A brown and nearly opaque faceted synthetic moissanite originated from a new source in Russia, which is producing material using a vapour deposition technique. Synthetic bi-coloured amethyst and citrine, which resembles ametrine from Bolivia is now being manufactured in Russia. J.J.

Gem Trade Lab notes.

T. MOSES, I. REINITZ AND S.F. MCCLURE. *Gems & Gemology*, **34**(1), 1998, 44–9, 12 illus. in colour.

Repolished heat-treated rubies have been seen recently with surface pits that have been partially repolished and showed semi-circular grooves. When viewed under magnification an orangey-pink cabochon was found to be an assemblage of a plastic top and an aragonite base. J.J.

BOOK REVIEWS

Recovery and refining of precious metals. [Third edition]

C. W. Ammen, 1997. Chapman and Hall, New York. pp xi, 441, softcover. £37.00. ISBN 0 412 72060 4.

The first edition has become known as the 'Precious metal bible' and anyone connected with the manufacture, testing or evaluation of jewellery should read this text which approximates to a metal testing manual with copious explanations of how the testing results are obtained. The book opens with a very useful section on general chemistry before proceeding to the chemistry of the precious (and other) metals. Recovery and refining methods are described at considerable length, and the whole text is presented lucidly in such a way that the reader can assimilate a good deal of serious metallurgy and at the same time find out how to regard the precious metals that may turn up needing to be tested. Appendices give a list of the naturally-occurring chemical elements with their atomic weights and numbers, a list of some of the metallic salts and their contents and one of the best glossaries I have seen for some time.

While intended for a wide readership, students beginning a course in metallurgy in particular will find many uses for the book and the price is very reasonable for so comprehensive a coverage of the field. M.O'D.

Handbook of mineralogy. Vol III: halides, hydroxides, oxides.

J.W. Anthony, R.A. Bideaux, K.W. Bladh and M.C. Nichols, 1997. Mineral Data Publishing, Tucson. pp ix, 628 Hardcover. Price on application. ISBN 0 9622097 2 4.

Three down and two to go! I refer of course to the progress of this magnificent series which gives single page coverage to each validated mineral species and which has been exceptionally well-received by the mineralogical community. The first volume covered elements, sulphides, sulphosalts and some less important classes and the second, in two volumes gave (at last!) an up-to-date survey of the silicates. The remaining two volumes are scheduled to cover arsenates, phosphates, uranates and vanadates (one volume) and borates, carbonates, sulphates and small groups which have not been dealt with already.

Gemmologists will find the present volume interesting for the information given on oxides alone. A complete set of the *Handbook* should last a long time even though new species are arriving at the rate of around one a week. M.O'D.

Führer durch das Deutsche Edelsteinmuseum.

H. Bank, 1996. The Museum, Idar-Oberstein, Germany. pp 128, illustrated in colour, softcover. Price on application.

Beautifully produced and illustrated guide to the 'new' [i.e., relocated] Deutsche Edelsteinmuseum at Idar-Oberstein. Much of the text and illustrative matter is close to that used for a description of the museum published in *Der Aufschluss* fairly recently and an advertisement for the publishers of Aufschluss appears on the back cover. However, an insert gives a plan of the new building and arrangement of its exhibits and this is dated 1996.

After a history of the museum and of the gemstone industry in the Idar-Oberstein area, the book goes on to describe the nature and testing of gem specimens before covering the major species in chemical order, the customary arrangement for a cabinet of minerals. Both major and uncommon species are introduced and a great many are illustrated by top class colour photographs. Organic and man-made materials are reviewed before accounts of gemstone fashioning, naming and use. There is a very short bibliography, a table of synthetic materials and growers with the date of their first appearance and a table of recently discovered gem species and varieties. An index concludes the book. M.O'D.

Gem minerals of Victoria.

W. D. Birch and D. A. Henry, 1997. (Mineralogical Society of Victoria: Special Publication No. 4), Melbourne. pp 121. A$29.95 (plus A$14.00 economy air post). ISBN 0 959 4573 3 X.

Although the State of Victoria is not the richest in Australia for gemstones, nevertheless it contains a considerable range of collectable gems. The aim of this well-illustrated book is not to be a locality guidebook (though each of the more important localities for each species is listed and discussed), but rather to provide assistance with the identification of the gem minerals.

After an introductory chapter outlining the discovery of gem deposits, those such as diamonds, sapphires, zircons and olivine which are typically associated with basic volcanic rocks are described. Small diamonds have been found in alluvial deposits, most being discovered by accident during treatment of wash dirt for gold and tin recovery; no commercial deposits have been found and the primary source of the diamonds remains unknown. Sapphires are of widespread occurrence as waterworn crystals in present-day streams and older gravels; blue is the dominant colour, but purple, yellow and brown varieties are found. Pale rubies also occur but are rarer and smaller than sapphires. Rounded grains of reddish brown to near colourless zicon are also found in stream gravels at numerous localities. The primary sources of the sapphires and zircons are thought to be basalts and volcani-sedimentary rocks. Olivines and anorthoclase occur in xenoliths and megacrysts in lava flows of the Newer Volcanics in the W of the state; scoria cones have yielded olivine fashioned to give peridot < 8 mm in size.

In the areas of granitic rocks and pegmatites, tourmaline is common but mainly as schorl; elbaite is extremely rare. Topaz has been found *in situ* in granites at only a few localities, but waterworn colourless to blue fragments are widespread in alluvial deposits. In Victoria, the garnet species almandine, spessartine, pyrope, grossular and andradite have been found, mainly in stream gravels, but few have been large or transparent enough to facet. Quartz is the most common gem mineral, with the varieties rock crystal, amethyst, smoky quartz and citrine all recorded; agate, chalcedony, jasper and common opal also occur.

The book is extremely well illustrated, both by numerous sketch maps showing most of the localities mentioned in the text and by an abundance of excellent colour photographs of rough and faceted stones for each of the principal localities. It ends with a list of some 180 references, a localities index and a glossary, together with tabulated mineral data for Victorian occurrences, and clearly fulfils the author's intentions of providing a book to assist with the identification of many of the gem minerals through the use of colour photographs. R.A.H.

Gemme del Vicentino.

M. Boscardin and O. V. Tescari, 1996. Montecchio Maggiore, Vicenza, Italy (Museo Civico 'G. Zannato'). pp 114.

Descriptions (often accompanied by colour photographs) are given of gem materials which occur in the Vicenza area of NE Italy. These range from alabaster to amber, aragonite/calcite, beryl, brucite, celestine, feldspars, garnet, hematite, ilmenite, obsidian, rhodochrosite, rhodonite, serpentine, silica minerals (agate, amethyst, carnelian, chalcedony, jasper, quartz, rose quartz) and zeolites (analcite, mordenite and natrolite). Johannsenite occurs with rhodonite at Mte Civillina, and has been fashioned into cabochons. Olivine (peridot) is well represented in the area around Salcedo and cut stones of 0.36–3.68 ct are reported. Xonotlite is found at the contact between a monzonite and dolomitic limestone near Molini di Laghi and yields translucent cut stones (including a 12.19 ct oval showing the characteristic pinkish white appearance of this mineral). Gemmy golden brown zircons occur in stream gravels and have yielded cut stones up to 4.11 ct. R.A.H.

Calcit: das formenreichste Mineral der Erde.

1998. Christian Weise Verlag, München. pp 96, illustrated in colour, softcover. ISBN 3 921656 44 3.

With the greatest number of recorded forms, calcite is a worthy subject for the latest number of the beautifully-produced and informative *extraLapis* series. While gemmologists will particularly welcome the exposition of the use of calcite in obtaining interference figures and of its varied fluorescent effects, mineralogists and collectors will find equal pleasure in the details of classic occurrences. M.O'D.

The Amber book.

A. Dahlström and L. Brost, 1996. Geoscience Press, Tucson AZ. pp 134, illustrated in colour, hardcover. US$27.00. ISBN 0 945005 23 7.

A translation of *Stenen som flyter och brinner*, first published in 1995 by Norsteds Forlag Stockholm, the book is pleasingly produced and is intended as an uncomplicated guide to amber, its composition, mode of occurence, lore and use with particular emphasis on material from the Baltic area. Photographs in colour are found in almost every opening and maps are provided for major amber-producing areas: the maps are, however, insufficiently detailed for serious use. A 35-item bibliography leads the reader to further sources of information: I was surprised by the omission of Fraquet (1987) and by the inclusion of the poor book by Hunger (1977) to which an incorrect publication date is ascribed. As a stimulus to readers with an interest in amber, with good illustrations and at a reasonable price the book is worth buying. M.O'D.

Gemstones of Brazil: geology and occurrences.

P.J.V. Delaney, 1996. Revista Escola de Minas, Ouro Preto. pp 125, illustrated in colour, softcover. US$5.00. ISBN 85 86112 02 X.

The apparently impossible does happen sometimes! A geological survey of the major gem-fields of Brazil, with notes for those wishing to visit some of the locations, an excellent bibliography, maps of the deposits and all at a very modest price. This is one of the most useful books I have seen for a long time and it is particularly welcome for its geological basis.

The text opens with a short history, followed by a description, of the diamond deposits of Brazil. Eleven major deposits are shown on a sketch-map and all are described. Short notes on modes of occurrence are given: these include presently-held theories on how the deposits formed. Notes on present-day status and workings are provided where appropriate. The beryl minerals are treated in the same way, with notes on early discoveries and on the currently-worked deposits at Carnaíba and Socoto (Bahia), Itabira and Capoeirana (Minas Gerais), Santa Terezinha de Goias, Pirenópolis and Porangatu (Goiás), Tauá, (Ceará). Aquamarine deposits are described under southeastern pegmatite province and northeastern pegmatite province and there are brief notes on other Brazilian beryl deposits. Chrysoberyl, topaz, tourmaline, opal and quartz are dealt with in similar fashion while brazilianite, amazonite, andalusite, kunzite and garnet are described in a section on other gemstones.

Briefer details on other species are given in the first of three appendices: species name, location and state are the only facts provided: ruby and sapphire can be found in this list, together wih peridot, green spodumene, spinel, zircon and others. The second appendix gives suggestions on how to organize field trips to Brazilian gem deposits and the 10-page bibliography follows a glossary in the third appendix.

The book is lucidly written and a pleasure to read. I should welcome similar treatment for other major gem-producing countries. M.O'D.

Franklin and Sterling Hill, New Jersey: the world's most magnificent mineral deposits.

P.J. Dunn, 1995. Franklin-Ogdensburg Mineralogical Society, Franklin NJ. pp 978, illustrated in black-and-white, paper cover. £150.00.

Since the area of Franklin, New Jersey, has attracted so many mineral collectors who also have an interest in gem species, this highly individual presentation deserves as much publicity outside the United States as it can get. First of all, the absence of any colour is not a disadvantage since the black-and-white reproductions are of excellent quality (and in any case the cost of colour used on so large a scale would have been prohibitive). Secondly, opening the first section to find a bibliography heading the text would perhaps surprise and disconcert some readers: I felt that this was the place to put it and since it covers 63 pages (approximately 3000 entries) the scale of the whole undertaking is apparent at once.

This area does merit a survey of this size and quality: mining operations carried out by the New Jersey Zinc Company and many other bodies are fully described and a most useful chronology can be found at the end of the first part. Collectors and many gemmologists will know that the area has produced something like 10 per cent of all validated mineral species and that 69 of them were first described from this locality (this is a record). Something like 10 per cent of the species are found nowhere else. While some specimens can be fashioned in one way or another, by far the most presentable ones fluoresce and it is this property which places Franklin very high on the list of sites from which ornamental minerals can be recovered.

Everything is here and the whole work is a model which I hope will be followed by others: this author's dedication is universally known and admired and we must hope for echoes from other writers about other major sites, including some gemstone-producing ones.

M.O'D.

The world of opals.

A. W. Eckert, 1997. John Wiley & Sons, Inc., New York and Chichester. pp xiv, 448. £60.00. ISBN 0 471 13397 3.

This is the first comprehensive book on opals for over thirty years and claims to give a complete guide to the science and history of this gem material. After a definition of exactly what constitutes an opal, the author provides a new look at opal formation, and this is followed by chapters describing opalized fossils and pseudomorphs, the mythology of opals (the 'bad luck' popular image being blamed on the one of Sir Walter Scott's *Waverly Novels 'Anne of Geierstein'*), famous and otherwise noteworthy opals, types of opals, the World's major opal occurrences, and a glossary of opal-related terms; there is also an extensive bibliography and an index.

The chapter on the mode of formation of opals is based largely on the thesis that most of what has been taught about opals has been based on theories now proven, in part at least, to be incorrect. The author's style is distinctly idiosyncratic, and it is difficult to unravel the use of such terms as atom migration [metasomatism?] and the definition of an electrolyte as 'a liquid carrying a chemical that generates an electrical pathway through anything'. The work of Sanders and Darragh in 1965 using electron microscopy to demonstrate that precious opal consists of aligned lepispheres and voids giving rise to a three-dimensional diffraction grating is acknowledged, but we are told that the refutation of part of if not all of the other theories on the basic formation of opal must take place because of experiments carried out by a man from Lightning Ridge, New South Wales, who has succeeded in growing opals from 'opal dirt' in a liquid in glass jars in an incredibly short time (a few days to six months, followed by the secret electrolyte being siphoned off through a small hole in the container's cover, allowing air contact to dry the stone). These opals are said to be indistinguishable by sight from natural opal, but have not yet been scientifically analysed; a lot of work has been done, but the experimenter quite reasonably wants to publish the results himself. We are thus left with various statements, but a lot of the author's work reminds one of a current British advertising campaign on the lines of '... I don't know the answer but I know a man who does'. Nevertheless, the evidence of fossil pseudomorphs leads one to the conclusion that opalization does not neccessarily require a geological time-scale in which to operate.

Putting aside these reservations, this book does succeed in giving an overall account of the occurrence of opals, not only in Australia, the United States and Mexico, but also in British Columbia, Honduras, Austria, the Czech Republic, Slovakia and Hungary. The descriptions of opal deposits in Opal Butte, Oregon, and the Virgin Valley area of Humboldt County, Nevada, are described in detail , and in the section on noteworthy opals details are given of the Roebling opal (2560 ct) and the Bonanza opal (25 586 ct) both from Virgin Valley. Opal being what it is, many of the black-and-white photographs in the text are uninspiring, but 22 colour plates demonstrate the amazing variability in play of colour to be seen in opals even from the same mine. A book that manages to be both provoking and informative, while we await the promised definitive work on the geology and chemistry of opal by the 'man who does'.

R.A.H.

Jean-Pierre Bertrand de Lom (1799-1878), prospecteur-minéralogiste vellave, et son oeuvre gemmologique.

F. H. Forestier, 1995. Cahiers du Haute-Loire. pp 66 illustrated in black-and-white, softcover. FF80.00.

Jean-Pierre Bertrand de Lom (1799–1878) was occupied with geological and mineralogical studies for most of his life, as a child obtaining specimens of sapphires and zircons occurring in the vicinity of Espaly, the town of his birth. This small book sheds light on the activities of a pioneer French mineralogist with an interest in ornamental minerals. By 1840 Bertrand de Lom (the second element of the surname arriving through marriage) was contributing to mineralogical reports, including items on garnets and corundum from Haute-Loire and on both jade minerals. The area of Riou-Pezouillou, in Haute-Loire, was extensively described, with its gem minerals, in a paper published in 1844, subsequent years up to 1878 producing more studies of this and other areas. The book is a very well-constructed study of the way in which different hands contributed to French determinative general and gemmological mineralogy through most of the last century: there are many useful footnotes and references

while all Bertrand de Lom's papers are fully abstracted. There are also notes on the disposition of his property after his death. M.O'D.

Dana's new mineralogy: the system of mineralogy of J.D. Dana and E.S. Dana. [8th edition, entirely rewritten and greatly enlarged]

R.V. Gaines, H. C. W. Skinner, E. E. Foord, B. Mason and A. Rosenzweig, 1997. John Wiley & Sons Inc., New York. pp xlv, 1819, hardcover. £191.00. ISBN 0 471 19310 0.

For mineralogists this has to be the most important new publication of the last few years. Even a continuation of Dana 7th edition [D7] had rapidly been lost to sight and the last complete edition of the *System* was published late in the last century. For those new to taxonomic mineralogy, the *System*, first privately published in 1837, was the first large-scale attempt in English to classify mineral species using data provided from earlier workers and leaving behind medical and magical properties as a basis for systematization. The second edition followed in 1844 and the third in 1850. Today's reader of these (very rare) early editions (and gemmology students) would find the Berzelian (chemical) notation used hard to understand and today's formulae are much simpler in this respect as strange symbols have been banished!

Following the sixth edition serious attempts were being made to establish a seventh as far back as 1915 but no volume appeared until 1944 when the first volume was published. A second volume and a third (on silica alone) followed but by then it was 1960 and the number of new species, established by many new laboratory techniques was outstripping the production capacity of editors and publishers.

Thus the concept of a single-volume eighth edition, this time with five co-authors was a bold one but it has succeeded brilliantly: even though many crystal drawings, references and locality information have not found a place this time, such data can easily be obtained from journals and thus via the Internet. The authors tell us that even during the years of compilation the number of species to be covered nearly doubled.

Prefatory material is short though there is a useful index of the symbols used for the main bibliographic sources. The main text is arranged in chemical order (and includes a number of anthropogenic and synthetic minerals). A hierarchical numbering system (updating that used in the incomplete seventh edition) is useful and the profuse and complex silicate species are here classified according to a structural-chemical system developed by two of the co-authors. Name, chemical formula, isostructural substitutions, vacancies or voids in structures, name derivations, groups, dimorphs and polymorphs, synonyms, varieties and polytypes are all indicated. The notation used to describe crystals is explained and referred to the authorities from which it was derived: a useful section on crystallographic principles [adopted from this work] explains the use of systems, classes, Miller indices and zone symbols, forms and space groups, choice of settings [i.e. assignment of unit cell edges to the axes a, b and c], twinning and epitaxy. The choice and arrangement of physical and optical property data is also explained , followed by notes on phase relationships and occurrences. Finally the structure used for locality citation is explained: the exclamation mark (!) is used to indicate specimens of exceptional museum quality – this reminds me of the nineteenth and early twentieth-century British county floras, when the same symbol indicated that the author had found the specimen described!

Having read the prefatory matter the reader is already expecting a highly compressed text and this is what is presented. I found it, together with an excellently-chosen typeface and good-quality [acid-free] paper, particularly pleasing to read. I noted one or two small misprints and no doubt there are others but several samples chosen to identify small errors were amazingly free from them (there seems to be slight confusion between occurrence of the Yogo and Missouri River sapphire deposits – this is perhaps undue compression of the text) – but the book is intended only to lead to more detailed descriptions elsewhere and small omissions and errors are too trivial to mention. Species described up to the end of 1995 are included - at the time the review was written there were approximately 3,700 validated species.

This is a magnificent effort: the price is high but it is worth every cent of it. M.O'D.

Geological Survey and Mines Bureau of Sri Lanka.

Colombo, 1997

The seven sheets under review are 8 10 11 13 14 16 and 17 and while 16, covering the Colombo-Ratnapura area, will be of the highest interest, gemstones feature on some of the other sheets. Each sheet carries identical notes on the geology of Sri Lanka as a whole and then gives a useful summary of the local conditions and the economic minerals found. Sheet 8 (Anuradhapura-Polonnaruwa) includes major apatite deposits: sheet 10 covers the coastal region of Battulu Oya-Kurunegala: sheet 11 (Dambulla-Pallegama) includes the major Elahera gem field: sheet 13 covers Kochchikade-Attanagalla: sheet 14 (Kandy-Hanguranketa) includes gem deposits hosting spinel, sapphirine and ornamental feldspar minerals among others: sheet 17 (Nuwara Eliya-Haputale) also includes major gem deposits (Ratnapura, Pelmadulla and Balangoda in particular). It is very rare for maps to be available from gem-producing countries and these beautifully-produced examples are greatly welcomed. M.O'D.

Dana's minerals and how to study them (after Edward Salisbury Dana). [Fourth edition]

C. S. Hurlbut and W. E. Sharp Jr, 1998. John Wiley & Sons, Inc., New York. pp v, 328, illustrated in colour, softcover. £32.50. ISBN 0 471 15677 9.

The bibliographic history of this small simple manual is almost as interesting as its contents! The first edition was published nearly 100 years ago and the edition preceding the current one is about 50 years old. It is pleasing to see an old friend received with what is admittedly the same general form. The book is directed

mainly at the amateur and the collector but there is enough solid material for the gemmologist who will be able to view some areas of the subject in a different light. Some of the old sections, including the use of the blowpipe (not so easy as it sounds!) have been retained but more up-to-date techniques of mineral testing are here too, together with a new chapter on mineral genesis. About 150 of the major species are described and there is a pleasant central colour section. M.O'D.

Cultured Pearls: the first hundred years.

A. MÜLLER, 1997. Golay Buchel Group. pp 142, illustrated in colour, hardcover. US$60.00. ISBN 4 9900624 1 8.

This well presented and richly illustrated book starts with a brief description of pearls in history then continues in some depth on the story of the cultured pearl, how it came about and who was instrumental in its development over the past one hundred years. The latter part of the book describes today's cultured pearls.

It is not a definitive work and the gemmologist could wish for much more detail, but that can be found elsewhere. The author himself states in the foreword that he has targeted a wide audience and tried to fill a specific gap in the literature on cultured pearls. He writes factually, but his love of the subject is very obvious, and the result is an interesting and pleasing book which would be a good addition to any collection. M.C-P.

Crystallization. [Third edition]

J. W. MULLIN, 1997. Butterworth Heinemann, Oxford. Softcover. £35.00. ISBN 0 7506 3759 5.

The softcover issue of the third edition of Mullin appears just at a time when many of the standard crystallization and crystal growth texts are about due for update. While the emphasis has always been on industrial crystallization, there is much for the mineralogist and the gemmologist to work upon and the earlier chapters give a valuable introduction to the crystalline state, viewed from a position which may be unfamiliar to earth science-based students.

It would be hard to over-praise the lucidity of much of the material. The section on solutions and melts will help the reader to understand something of the processes which take place on a larger scale in the Earth and the same can be said for the exposition of phase equilibria, nucleation and crystal growth. There is a 32-page bibliography with the emphasis on industrial crystallization and while much of the treatment of the subject is inevitably mathematical the general level is such that the careful reader with an interest in gem crystal growth will find the book well worth buying. M.O'D.

Color for science, art and technology.

K. NASSAU, 1998. Elsevier, Amsterdam. pp xvii, 491 Illustrated in colour, hardcover. US$132.00. ISBN 0 444 89846 8.

Making the point that there is still much more to be learnt about colour, its production, uses, measurement and perception, the authors combine to produce a broad coverage of colour science with many features of interest to the gemmologist. Such readers will at once turn to the editor's own chapter (there are three) dealing with the fifteen causes of colour: the text is understandably based on the editor's monograph *The Physics and chemistry of colour* (Wiley, 1983). In case this book is now hard to obtain, readers will find the present one worth obtaining for this chapter alone, since the colour of gem materials is discussed there along with a good deal of background information on colour causes.

This coverage apart, the editor has also contributed chapters on fundamentals of colour science: on a double-blind test for biological and therapeutic effects of colour and on colour preservation, this section being of special interest to the curator and archivist. Other chapters of the book deal with colour vision and measurement, colour in anthropology and folklore, in plants, animals and man, with the therapeutic effects of light and with colour imaging and photography.

Though a substantial book, no section of it can hope to serve as an exhaustive treatment of its subject. For this reason the possible readership must have been hard to define and in such a case the publisher must ensure the most authoritative standards from contributors. This has certainly been achieved in those chapters on which this reviewer has some knowledge and a reading of the remainder of the text suggests that a uniformly high standard prevails. The rather small number of colour illustrations, placed together at the back this time, achieves a fair standard but with some loss of definition in the Nassau pictures, in my copy at least. This is a very small matter when set against the excellence and interest of the text and the careful citations. M.O'D.

A Fossicker's guide to gemstones in Australia.

N. PERRY AND R. PERRY, 1997. Reed Books, Kew, Victoria. pp viii, 160, illustrated in colour, softcover. £16.50. ISBN 0 7301 000 8.

Updated edition of a book first published in 1982 under the title *A prospector's guide to gemstones*, this guide intended for the amateur gem collector in Australia describes the basic techniques of fossicking [mine dump searching], the evaluation of and collecting possibilities of alluvial deposits, gemstone recognition in the field, details of Australian gem materials and an all-states summary of gemstone locations. These introductory sections precede a detailed state-by-state survey of the major gem deposits: there is a glossary and a short list of references. The book is clearly written and well illustrated with both black-and-white and coloured photographs: legal notes are given and sketch maps are plentiful and certainly needed. All Australian gem hunters will welcome this accurate and handy guide. M.O'D.

The National Gem Collection, Smithsonian Institution.

J. E. POST, 1997. Smithsonian Institution in association with Harry N. Adams, Inc, New York, Washington DC. pp 144, landscape format, hardcover (softcover available), illustrated in colour. £29.00. ISBN 0 8109 3690 9.

After a short introduction in which the nature of gemstones and minerals, fashioning, colour and the history of the collection are introduced, the book introduces historical jewels; not only the Hope diamond but also the Napoleon diamond necklace, the Marie-Antionette earrings and the Spanish Inquisition necklace, with the Portugese Diamond and the Hooker emerald (75.47 ct and set together with diamonds).

Diamond, corundum and beryl have the next chapter to themselves, the following section dealing with quartz, topaz, garnet, tourmaline, peridot, zircon, spinel, chrysoberyl, spodumene and tanzanite. Phenomenal gemstones (star stones and cat's-eyes) have their own chapter: the ornamental species jade, lapis lazuli, turquoise and malachite are treated individually. Appendices cover rare and unusual gemstones, birthstones, a glossary of fashioning terms, hardness values for the more important species, diamond grading and a list of some of the more important specimens in the collection. This list appears in previous guides but it has of course been updated. Entries, alphabetically arranged, give weight, source, donor (where important) and museum accession number.

Quality of the photographs is all-important in this kind of book and for the very reasonable price the quality is good, though variable, Particularly attractive are the pictures of kunzite (in which pleochroic colours are shown), peridot, topaz, variously-coloured sapphires and the red phosphorescence of the Hope diamond. The collection is well-served by this excellent guide. M.O'D.

A field guide to rocks and minerals. [5th edition]

F. H. POUGH, 1996. Houghton Mifflin Company, Boston. pp xv, 396, illustrated in colour, softcover. £10.99. ISBN 0 395 72777 4.

According to the preface this excellent guide was first published 46 years ago but while it has always been one of the best field guides and long familiar to all serious collectors, this edition is worth particular mention on account of the fresh colour photographs supplied by Jeffrey Scovil. They are grouped together in a single section at the centre of the book and are of very high quality. Otherwise the text is similar in arrangement to past editions and so is the genial and sometimes combative style. M.O'D.

Antiker Schmuck vom Klassizismus bis zur Moderne.

E. STRACK, 1998. Rühle-Diebener Verlag, Stuttgart. pp 112, illustrated in colour, softcover. DM42.89 including postage and packaging. ISSN 0175-565-X.

The 118 coloured photographs of jewellery very pleasingly illustrate a short survey of European jewellery from 1789 to Art Deco and modern styles. A good deal of gemmological information appears within a text devoted in the main to jewellery for German speakers. Incidentally the book has no ISBN number as it is not available through bookshops; it can be obtained only from the publisher who has been allocated an ISSN number. M.O'D.

The Theodore Horovitz Library.

[Catalogue of a sale held at Christie's Geneva] 1997. pp 46, illustrated in colour, softcover.

Theodore Horovitz, born in Romania, eventually became one of Geneva's best known jewellers. During his life he collected a number of fine and rare books on jewellery and gemstones summarized in the catalogue descriptions and supported with several excellent illustrations. M.O'D.

Jadeite.

LEE YING HO, 1996. Asiapac, Singapore. pp 126, illustrated in colour, softcover. £17.95. ISBN 981 3029 87 0.

Short but beautifully illustrated survey of jadeite and jadeite jewellery first published in 1991, the Chinese text now translated and accompanied by illustrations taken largely from Sotheby's jadeite sales. Notes on buying jadeite, on it's simulants and treatments are particularly useful but other sections, dealing with jadeite carving and styles of ornament are also valuable. I can strongly recommend this book to all classes of reader. M.O'D.

BOOK SHELF – NEW EDITIONS

Pearl Buying Guide (3rd edition) edited by Renee Newman (softback) £11.95
Amber – the Natural Time Capsule by Andrew Ross (softback) £7.95
Art Nouveau Jewelry by Vivienne Becker (softback) £18.95
The Art of Perfume – discovering and collecting perfume bottles by Christie Mayer Lefkowith (softback) £18.95

Revised editions of the following Fred Ward books (softback) are now available at **£9.95** each; Rubies and Sapphires – Diamonds – Pearls

Prices quoted exclude postage and packing

Gemmological Instruments Limited,
27 Greville Street,
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Tel: 0171-404 3334
Fax: 0171-404 8843

Proceedings of the Gemmological Association and Gem Testing Laboratory of Great Britain and Notices

NEWS OF FELLOWS

We are very pleased to report that our President, Professor R.A. Howie, has recently been awarded the Distinguished Public Service Award for 1999 by the Mineralogical Society of America. This is one of their three highest awards, and is for Professor Howie's services to mineralogy – particularly his enormous contribution to *Mineralogical Abstracts*.

Michael O'Donoghue gave a paper on *Synthetic gemstones at the end of the twentieth century* to the Gemmological Association of Hong Kong on 21 September 1998 and the same paper to the Shanghai Gem and Jade Association on 30 September.

1960s brooch with gem garnets by David Thomas. Photograph by Bob Maurer, FGA DGA, London.

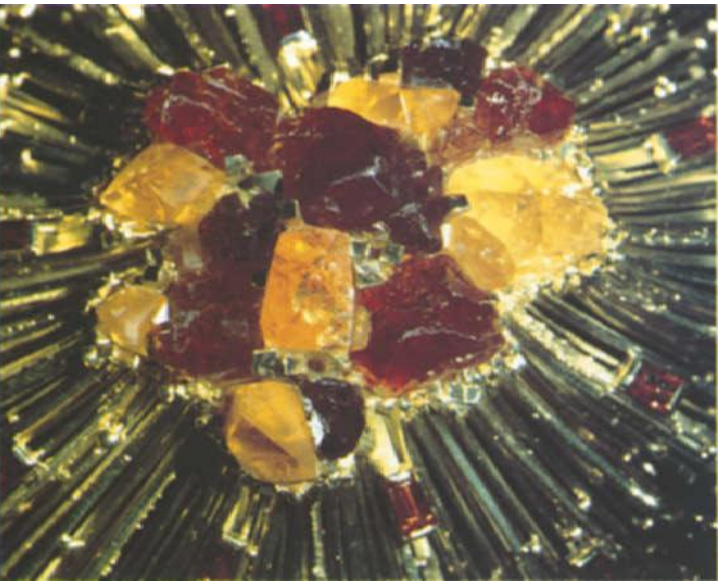

OBITUARY

Alan Bridgewood (D.1988), Bramhope, Leeds, West Yorkshire, died suddenly on 10 May 1998.

1999 CALENDAR

The brooch illustrated for January and February in the GAGTL 1999 calendar (see below left) was by David Thomas and not Stephen Webster. We apologize for the error and any embarrassment caused.

MEMBERS' MEETINGS

London

On 9 October 1998 at the Gem Tutorial Centre, 27 Greville Street, London EC1N 8TN, Kreg Skully from Virginia Beach, USA, gave a talk on *Contemporary Gem Art in America*. Kreg creates crafted carvings of stone enclosing gold-bezelled opal freeforms, and he spoke about his own work and that of other contemporary gem artists in North America.

On 1 November at the Barbican Centre, London EC2, the GAGTL Conference was held on the theme *Gems in Jewellery*. This was followed on Monday 2 November by visits to the Victoria and Albert and the Natural History Museums, South Kensington. A full report of the Conference was published in the December issue of *Gem and Jewellery News*.

On 4 November at Imperial College, South Kensington, Dr Kurt Nassau gave a lecture entitled *F.F.H. Moissan, Polytypes and Synthetic moissanite*. Samples of the new diamond simulant were available for examination.

Midlands Branch

On 30 October 1998 at the Earth Sciences Building, University of Birmingham, Edgbaston, Clive Burch gave an illustrated talk on *The amazing*

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GIFTS TO THE ASSOCIATION

The Association is most grateful to the following for their gifts for research and teaching purposes:

Richard Burton for an apatite (aqua blue) from Mogok, Myanmar.

Daniel Dower, London, for a smoky quartz and 32 pieces of amber.

Luella Dykhuis, Tucson, Arizona, USA, for a various gem materials including quartz, calcite, peridot and bone.

Arthur Flewelling, Arthur Ontario, Canada, for a collection of quartz crystals from Herkimer, New York.

John R. Führbach, Amarillo, Texas, U.S.A., for a specimen of smithsonite, a superb Herkimer quartz crystal with interesting inclusions, a halite from a little-known source in Mexico and a topaz from the new mine in Colorado.

Elizabeth Gage, London, for 50 specimens including tanzanite, quartz, fire opal, tourmaline and glass.

Sonja Glaser, Galle, Sri Lanka, for 15 cut specimens including aquamarine, natural and synthetic spinels and hessonite garnets.

Marcia Lanyon, London, for a CD-writer for the new CD-ROM archiving and production system.

Jean Smith (the late Robert Webster's daughter), West Wimbledon, London, for *Gemme* (in Italian) by Robert Webster.

Yasukazu Suwa, Tokyo, Japan, for *Gemstones quality and value* volumes 1 and 2, with English translations.

Paul Thurlby, Birmingham Institute of Art and Design, for a large collection of coloured glass.

Wilma van der Giessen, Voorburg, The Netherlands, for a Gilson mosaic opal triplet.

Pierre Vuillet, Villards d'Héria, France, for nine specimens of emerald replacing fossil snails.

Robert Wood, Stamford, Lincolnshire, for a quantity of mineral specimens, a selection of rough beryls, and cut stones including garnet, ruby, sapphire, synthetic spinel and fire opal.

Yumi Yoshitake, London, for a report on Japanese cultured pearl with samples of oyster shell and cultured pearls of various qualities.

and informative world of gemstone inclusions. The accent was on geological signatures of inclusions and the data available indicating formation and provenance of the gem inclusions observed.

On 27 November at the Earth Sciences Building Alan Jobbins gave a talk on his *Gemmological journeys in Brazil*, covering the pegmatite gems of Minas Gerais and the opals and diamonds of Piauí.

On 5 December the 46th Annual Dinner was held.

North West Branch

On 21 October 1998 at Church House, Hanover Street, Liverpool 1, Martin Connard gave a presentation entitled *Silversmith of Williamsburg 1780*.

On 18 November at Church House the Branch AGM was held at which Irene Knight, Deanna Brady and Dr John Franks were re-elected Chairman, Secretary and Treasurer respectively.

Scottish Branch

On 12 October 1998 at the British Geological Survey, Murchison House, West Mains Road, Edinburgh, David Lancaster gave a talk entitled *Pointers for valuation*.

On 11 November at the British Geological Survey Dr Kurt Nassau gave a talk entitled *Gemstones: science, synthesis, beauty, deception*.

PRESENTATION OF AWARDS

The Presentation of Awards gained in the 1998 examinations was held at Goldsmiths' Hall, Foster Lane, London EC2, on Monday 2 November. The President, Professor R.A. Howie, presided and welcomed those present. He announced that in January and June 1998 a total of 972 students entered the Preliminary, Diploma and Gem Diamond Examinations. A total of 149 students passed the Diploma examination and they came

from 18 countries. 106 students passed the Gem Diamond examination and there were successful candidates this year from nine countries.

'Here tonight,' continued Professor Howie, 'we have successful candidates from the U.K. and Europe as well as those from Canada, Japan, New Zealand, Sri Lanka and the U.S.A.'

Professor Howie recalled that at previous Presentation ceremonies he had talked about hardness and its importance to mineralogists and gemmologists. 'Tonight', he said, 'I want to spend a few moments talking about carborundum. Having been brought up on a farm, I became acquainted with all manner of devices used for sharpening scythe blades, and the blades or "knives" of mowing machines and harvesting machines. Such sharpening stones, or whetstones, ranged from sandstone to fine-grained metamorphic rocks or hornstones, but these were mostly supplanted by bonded carborundum. Carborundum was first manufactured in 1893 and was so named because it was originally believed to be a compound of carbon and aluminium. It is commonly bluish grey when bonded, but material produced as slag from electric furnaces has bright blue to greenish colours with a very high lustre. Indeed if one talks to museum curators, they will tell you that one of the most frequent "unknowns" brought in by the general public for identification is coarse-grained lustrous carborundum.

Diploma Trade Prize winner Tina Notaro from Madison, U.S.A., receiving her prize.

Tully Medal and Anderson Bank Prize winner Laurent Kellerson from London, receiving his awards from Robin Buchanan-Dunlop.

'It was found later that carborundum was in fact a compound of carbon and silicon, SiC, and as such material had been described in 1904 from the Canyon Diablo meteorite in Arizona, the mineral SiC was named moissanite after the Frenchman who first described it. It is, however, extremely rare, and is not represented in most museum collections. Indeed in the decade around 1960, many scientific papers were produced arguing that the identification of the occasional grains may have been correct but that in fact they represented contamination from grinding materials used to prepare the thin sections for microscopic examination. The 1997 edition of *Dana's New Mineralogy*, the mineralogist's bible, for example observes that moissanite was "originally described from the Canyon Diablo meteorite, but is probably a contaminant". However, moissanite is now accepted as a very rare natural mineral species found in some meteorites and in kimberlites and as even as inclusions in diamonds. But it is still extremely rare, occurring in amounts of around 0.001 per cent in rocks that are themselves rare.

'With the brilliant lustre and bright colours shown by carborundum, I must confess that for some years I have been expecting a new synthetic

gem to be produced from silicon carbide – however, I was thinking in terms of an attractive, lustrous, greenish-blue or blue stone to simulate some of the corundum family of gems. But this new material currently called synthetic moissanite is virtually colourless and water-clear, with hardness 9¼ and high dispersion. Its manufacturers (C3 Inc.) claim that it is not meant to simulate diamond, but merely to offer a reasonably cheap stone for incorporation into jewellery at an attractive price. We shall see. Certainly the "synthetic" part of the name must never be dropped but must be used for each and every mention of this material. However, the gem trade has got used to the term CZ as a shorthand name for cubic zirconia (to distinguish this material from natural zirconia, baddeleyite, which is monoclinic). So why not call this material simply SiC – or even C3 as opposed to CZ. I will leave you to think on these things!

'You may not have yet seen this newest "fashionable" stone but, as trained gemmologists, you should find that your training in observation with a lens and in the measurement of specific gravity leaves you amply equipped to deal with it; it is doubly refractive and floats in methylene iodide (as I still call it; perhaps diodomethane or just CH_2I_2 to you). Your training in fundamentals will stand you in good stead and hopefully will provide you with the means to deal with whatever the trade comes up with in the future – and even to make new discoveries.'

Professor Howie then introduced Robin Buchanan-Dunlop, Clerk of the Worshipful Company of Goldsmiths, who presented the awards. Mr Buchanan-Dunlop delivered his address (see below) and a vote of thanks was given by Vivian Watson.

Professor Howie concluded the proceedings by thanking the Goldsmiths' Company for kindly permitting the GAGTL to hold the ceremony at the Hall.

Robin Buchanan-Dunlop's address

'I am delighted to be here tonight to present these awards, but I do so with a little trepidation, because although I am lucky enough to work surrounded by gold and silver and jewels, I know very little about gemmology. A little knowledge is a dangerous thing, and I learnt sometime ago that it is even more dangerous to display one's ignorance in the company of experts. So if you are expecting a learned dissertation on heat treatment or radiation or analysis by proton-induced X-ray emission – I am afraid you are going to be disappointed! Instead I want to talk briefly about the history and romance of precious stones. Part of the fascination of precious stones is not just that they are beautiful, rare and expensive, but behind them lies an age-old history of myth, love, hate and intrigue. If you are exploring the history of precious stones as jewels, then it is possible with a little imagination to reach out and touch that history.

Preliminary Trade Prize winner Linda Rythen from Stockholm, Sweden, receiving her award.

'Let us start with my grandfather (well, one has to start somewhere). He fought in the Boer War and First World War, which is of little consequence. But he was born in 1876. You may find nothing remarkable about that date. But if I were to tell you that that was the year in which Alexander Bell submitted a patent for a telephone; that it was the year in which the Otto engine, the first practical internal combustion engine in general use, was introduced; that it was the year in which electric light started to be used as a public utility; then you might change your mind. The motor car and the airplane had still to be invented, not to mention the silicon chip, but arguably it was the dawn of modern civilization as we are accustomed to it today.

'Forty-one years before he was born you could have been sitting here for the grand dinner to celebrate the opening of Goldsmiths' Hall in 1835.

Robin Buchanan-Dunlop speaking at Goldsmiths' Hall

The room would have been lit by candlelight, but from the four chandeliers only because the central chandelier was a later addition, being one of the first gas chandeliers in the country. The colour scheme would have been in the chaste colours of white and cream and buff picked out in gold. The colours you see today were a late Victorian concoction. There would have been no royal portraits. Queen Victoria had yet to ascend the throne, and she did not meet Prince Albert for the first time until the following year in 1836. Queen Adelaide in the centre was certainly William IV's consort at the time, but she had yet to present her portrait to the Company. And up here at the top table giving a speech, instead of me, you would have seen the Duke of Wellington, a great national hero from the Battle of Waterloo exactly twenty years earlier.

'This was the third Hall on this site. When the first Hall which was acquired shortly after the Goldsmiths' Company received its first charter in 1327, England was in the grip of the 100 Years War with France, and the Black Death had yet to sweep away a third of the population.

'One hundred years earlier in 1227, that great warlord Genghis Khan who drove his armies across Asia to the gates of Vienna died. By now you may be wondering where I am taking you. Have patience! We are now at the limit of so-called modern history, so let us leap back 1500 years to the Sinai Desert where the children of Israel having escaped from Egypt are journeying to the Promised Land. And you will recall that God commanded Moses to build a tabernacle, and there was to be a High Priest, Aaron, and he was to have a breastplate of beaten gold, and set into that breastplate in mountings of gold were to be four rows of precious stones: the first row: a sardius, a topaz and a carbuncle; second row: an emerald, a sapphire and a diamond; third row: a ligure, an agate and an amethyst; fourth row: a beryl, an onyx and a jasper. They present an interesting mixture on what the early recorders of history regarded as important precious stones.

'Come forward again in time just over 1500 years and we have the first record of the Koh-i-Noor Diamond, the Mountain of Light, which was acquired in 1304 by the Sultan Ala-ed-din. Eventually it was to be presented to Queen Victoria and displayed in the Great Exhibition of 1851.

'The fascination of precious stones has provided many an author with inspiration. It was believed at one time to have been the eye of an idol in a temple in an island in Mysore. This may have given Wilkie Collins the idea for his book *The Moonstone,* published in 1868 which is widely regarded as the first detective story. If you are a fan of James Bond you will remember Ian Fleming's *Diamonds are Forever,* now immortalized by De Beers' famous slogan.

'The romance of the past is still with us today, but so is ignorance, deception and greed. And just as we here at Goldsmiths' Hall believe that hallmarking protects both the consumer and the honest trader, so knowledge and expertise in gemmology has never been more important in our trade.

'The part which the Gemmological Association and Gem Testing Laboratory of Great Britain plays in making this happen is significant, not only in our domestic trade but as tonight's awards have demonstrated throughout the international avenues as well. When I visited the Gem Testing Laboratory the other day I was told that 60 per cent of the students came from overseas, and that is a remarkable figure.

'Finally, I should like to congratulate the awards winners once again. I hope whatever you do next and wherever it is, you will enjoy being an important part of this great jewellery trade. Someone once said that there are four essential

FORTHCOMING EVENTS

29 January	**Midlands Branch.** Bring and Buy followed by Quiz.
21 February	**Scottish Branch.** Gemstone photography course. Clive Burch and John Harris
26 February	**Midlands Branch.** Cameos and gemstones carvings. David Callaghan
11 March	**London.** Some current problems in diamond research. Dr H. Judith Milledge.
17 March	**Scottish Branch.** Diamonds from the crust to the core. Dr Jeff Harris
17 March	**North West Branch.** Exotic diamonds. Keith Mason
26 March	**Midlands Branch.** Jewels in the hand. James Gosling
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Cover Picture

Johachidolite in a rock specimen from the original locality in Korea shown next to a cut stone of 14.02 ct recently acquired in Myanmar (see 'Johachidolite – a new gem', pp. 324–9)

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The Gemmological Association and Gem Testing Laboratory of Great Britain

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Heat-treated Be–Mg–Al oxide (originally musgravite or taaffeite)

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ABSTRACT: A heat-treated rough gem mineral from Sri Lanka was examined by gemmological and mineralogical methods. The sample consists of lamellar intergrown taaffeite and beryllium-bearing spinel. Comparing the observed phases and textural patterns with the results of synthesis experiments by Kawakami *et al.* (1986), the formation of the observed phases and their texture may be explained.

Keywords: heat treatment, musgravite, taaffeite, spinel, Sri Lanka

Introduction

This paper describes the gemmological and mineralogical examination of a rough gem mineral from Sri Lanka. It is shown how a gem mineral determination, which was thought at first to be a normal and simple routine procedure, can become quite complicated and time consuming. It is also shown which determinative steps can be necessary to come to a final and conclusive result.

Experimental results

The sample was first observed in the course of examination of a lot of water-worn rough corundum crystals, originating from Sri Lanka, which had been submitted to commercial heat treatment at about 1650°C by a gem dealer in order to improve the colour of the stones. Within this lot, a somewhat milky-white slightly bluish-to-mauve stone did not show any of the common microscopic features of heat-treated corundum and, thus, a window was polished at the surface of the rough stone for the determination of refractive indices of the birefringent sample.

Figure 1: *Faceted sample of 0.50 ct which was determined as heat-treated Be–Mg–Al oxide (originally musgravite or taaffeite), now consisting of intergrown taaffeite and Be–Mg–Al-spinel. Size of the stone approx. 4.2 x 5.8 mm. Photo by Maha DeMaggio.*

Values of 1.717 to 1.721 indicated that the specimen was either taaffeite, $BeMg_3Al_8O_{16}$, or musgravite, $BeMg_2Al_6O_{12}$. Taaffeite is located at the binary join chrysoberyl $BeAl_2O_4$-spinel $MgAl_2O_4$ at 75% of the spinel end member, whereas musgravite contains

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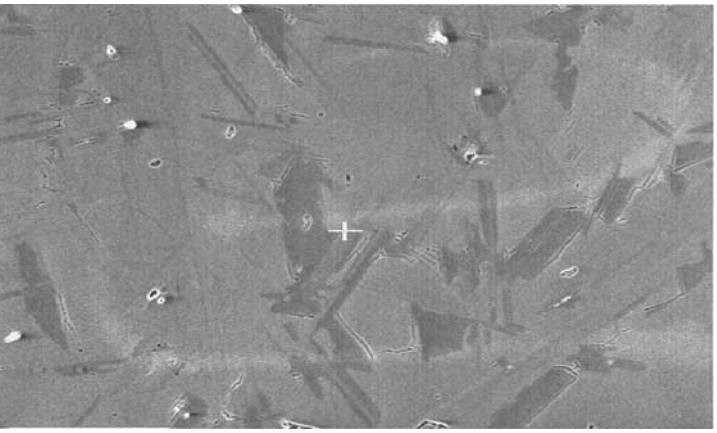

Figure 2: Back-scattered electron (BSE) image revealing lamellar intergrown spinel (dark) and taaffeite (lighter) areas. The width of the photograph represents 0.47 mm.

66.7% of the spinel molecule. Both minerals are only rarely found in lots of faceted stones from Sri Lanka, and similarly only a few rough taaffeite crystals of gem quality are known from this country (Schmetzer, 1983a; Kampf, 1991; Demartin *et al.*, 1993).

Figure 3: Thin section revealing intergrown blue and orange lamellae (representing birefringent taaffeite) and purple areas (representing isotropic spinel and birefringent taaffeite in extinction position). Crossed polarisers with a gypsum plate inserted in the microscope; the width of the microphotograph represents 0.45 mm.

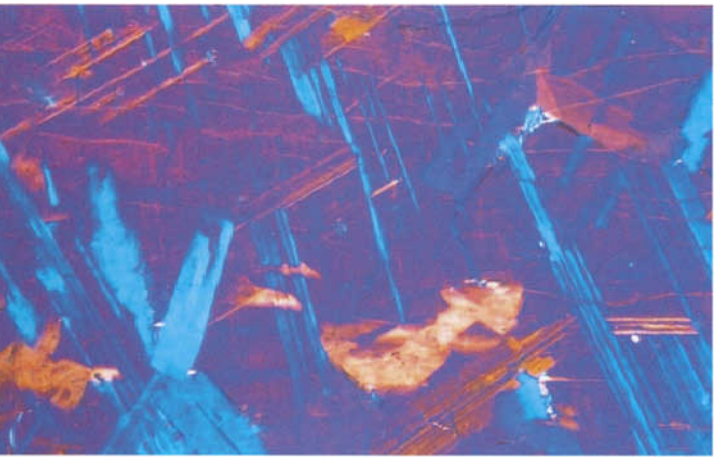

Problems associated with the distinction of faceted taaffeites and musgravites were recently discussed by Kiefert and Schmetzer (1998). Due to an overlap of gemmological properties, e.g. refractive indices or specific gravity, the distinction of these two minerals needs additional data from, for example, quantitative chemical analysis or X-ray diffraction. Consequently, after cutting two faceted stones of 0.69 and 0.50 ct from the rough sample, one of which is shown in *Figure 1*, small residual fragments of the rough were used for subsequent mineralogical examination.

X-ray powder diffraction analysis was first performed by the Debye-Scherrer technique, but no complete match was found with standard films of taaffeite and musgravite. Subsequently, a Guinier camera was used, which reveals a better resolution of diffraction lines; in addition, this permits three exposures simultaneously, i.e. the examination of the powder pattern of an unknown sample together with two external standards. Consequently, the unknown sample from Sri Lanka was examined together with external standards of an analysed taaffeite from Sri Lanka and an analysed musgravite from Antarctica. As a result, the powder pattern of the unknown sample from Sri Lanka was found to consist of the complete pattern of taaffeite with a number of additional lines which matched the pattern of magnesium–aluminium spinel. The strongest lines of musgravite were not found.

In order to obtain chemical data from the sample, two of the residual fragments mentioned above were polished and submitted to electron microprobe analysis. Although no clear differences between single phases were observable in reflected light, a back-scattered electron (BSE) image (*Figure 2*), performed with the BSE system of the microprobe, revealed a fine lamellar pattern of two intimately intergrown phases. A similar texture was also observed in thin section with crossed polarizers (*Figure 3*).

Quantitative chemical data were obtained from 10 single analysis points for each of the

two phases. They indicate a first oxide phase whose composition is almost identical with the theoretical formula of taaffeite and a second oxide with somewhat larger BeO contents and a different Mg:Al ratio. In detail, the average composition of the taaffeite was calculated as $Be_{1.0}Mg_{2.97}Fe_{0.05}Al_{7.98}O_{16}$ (assuming one BeO per formula unit and total iron calculated as FeO), which is almost identical to the ideal formula of taaffeite, $BeMg_3Al_8O_{16}$ (Schmetzer, 1983b; Nuber and Schmetzer, 1983).

Calculating the second phase to 2.0 Al atoms per formula unit (according to the determination of spinel by X-ray powder diffraction), and assuming the difference of divalent cations to be due to beryllium, which cannot be analysed directly by electron microprobe, the formula of the average composition of the 10 microprobe analyses was calculated to be $Be_{0.35}Fe_{0.01}Mg_{0.64}Al_2O_4$ (again assuming total iron as FeO and summing the divalent cations to 1.0). This composition indicates a beryllium-bearing spinel with 65% of the pure magnesium–aluminium end member within the chrysoberyl–spinel join.

In summary, all the evidence indicates that the sample consists of two lamellar intergrown phases: taaffeite and beryllium-bearing spinel.

Discussion

Considering the experimental examinations of the binary system chrysoberyl $BeAl_2O_4$–spinel $MgAl_2O_4$, published by Kawakami *et al.* (1986), the observations described above become understandable. In 1986 taaffeite and musgravite were still regarded as polytypes with an identical chemical composition (the difference in BeO content is only 1.56 wt.%) and, consequently, the phase diagram is somewhat simplified. The general results presented by Kawakami *et al.*, however, are extremely useful in understanding the analytical results obtained from the sample from Sri Lanka.

According to Kawakami *et al.* (1986), both taaffeite and musgravite are incongruently melting compounds. Above an inversion temperature, which is not specified exactly, only a spinel phase and a melt exist. At high temperatures, spinel and chrysoberyl form a solid solution series. This high-temperature compound, i.e. the beryllium-bearing spinel, exsolves taaffeite and/or musgravite lamellae with decrease of temperature.

These phase relationships in the chrysoberyl–spinel system were investigated using the floating-zone technique for crystal growth starting from sintered rods formed from $BeAl_2O_4$ and $MgAl_2O_4$ powders. One experiment was performed with a rod having a starting composition of 37.5% chrysoberyl and 62.5% Mg–Al-spinel. In this run, Kawakami *et al.* (1986) obtained a sample consisting of fine lamellar intergrown taaffeite, musgravite and spinel. These phases were identified by X-ray powder diffraction, but no analytical data, e.g. by electron microprobe, were given and the transition temperatures and extent of intermediate phases still need to be established. It is evident, however, that with a starting composition of 62.5% Mg–Al-spinel and a synthetic end product of taaffeite (which contains a formula percentage of 75% Mg–Al-spinel) and musgravite (which contains a formula percentage of 66.7% Mg–Al-spinel), the resulting intermediate spinel is also a beryllium-bearing phase.

Consequently, the optical pattern of lamellar intergrown phases and the crystalline compounds obtained in the laboratory experiment of Kawakami *et al.* (1986) are consistent with our results. Most probably, during heat treatment of a natural Be–Mg–Al-oxide crystal (musgravite or intergrown musgravite and taaffeite), a beryllium-bearing spinel phase was formed at elevated temperatures. In the course of the cooling process, this high-temperature spinel phase exsolved taaffeite lamellae, but did not transform completely to taaffeite or musgravite. No evidence for the formation of melt was seen at the surface of the rough specimen.

Conclusion

The sample from Sri Lanka was found to be a heat-treated Be–Mg–Al-oxide crystal, most probably musgravite or intergrown musgravite and taaffeite, which now (after heat treatment) consists of intergrown taaffeite and spinel lamellae.

Acknowledgement

The authors are grateful to Professor I. Sunagawa of Tokyo, Japan, for the translation of the relevant literature in Japanese.

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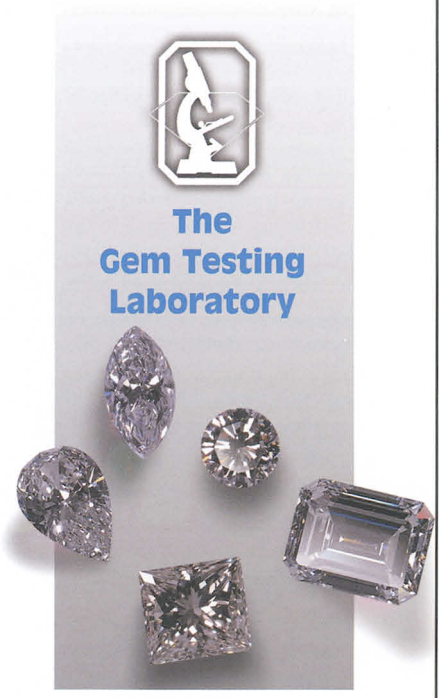

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Mineral inclusions in emeralds from different sources

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ABSTRACT: Mineral inclusions in emeralds from eleven gem-mining regions and a hydrothermally grown synthetic emerald were chemically analysed with the electron microprobe JEOL JXA-8600. Emerald occurrences in Australia, Brazil, Mozambique, Russia, Tanzania (Lake Manyara) and Zambia belong to 'schist type' deposits. The inclusions comprise micas, talc, pyrophyllite, chlorite, wollastonite, chromite, calcite, dolomite, Fe-oxide, apatite, quartz, pyrite, fluorite and plagioclase. The geological settings for Colombian, Nigerian and Sumbawanga (Tanzania) deposits resulted in related assemblages of solid inclusions in these emeralds (for example, chlorine-rich Al-glauconite, sphalerite, titanium-rich mica, anhydrite and beryllium minerals).

Keywords: electron microprobe, emerald, mineral inclusions

Introduction

Emerald is the most important gemstone of the beryl group (Gübelin, 1974; Sinkankas, 1981; Smith, 1972; Samsonov *et al.*, 1984) and the commercial value of emeralds is affected by many factors, not only by their colour and clarity, but also by their provenance. For the gemmologist the identification of inclusions in gems is of the utmost importance both for their authentification and for the determination of their geological origin (Dele-Dubois and Schubnel, 1987).

A selection of emerald crystals, cut stones and their associated mineral inclusions, from eleven gem-mining regions in Afghanistan, Australia, Brazil, Colombia, Mozambique, Nigeria, Russia, Tanzania, and Zambia, and Biron synthetic emerald were studied using an optical microscope, chemically analysed with an electron microprobe JEOL model JXA-8600 and photographed. This work presents the results of studies of the solid inclusions in these emeralds. Some of the same samples were also studied by a laser Raman microspectrometer DILOR XV (Moroz *et al.*, in press). The study was undertaken to compare the mineral inclusions, characterize distinctions between them and to establish a data base which will enable distinction of emeralds originating from different sources. The electron microprobe technique allows nondestructive chemical analysis of discrete spots across a single crystal, but it has some disadvantages:

(1) with our equipment we cannot measure elements lighter than Na (atomic number 11), so we could not obtain data for Be, a major constituent of berylliium minerals; Li, B, F and water, which can be present in quantities up to several wt%;

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Table I: *Mineral inclusions in emeralds from different deposits.*

Country	*Colombia*	*Nigeria*	*Tanzania*		*Brazil*		*Afghanistan*	*Russia*	*Zambia*		*Australia*	*Mozambique*	*Synthetic*
Locality or deposit	*Muzo*	*Jos*	*Manyara*	*Sumbawanga*	*Carnaiba*	*Santa Terezinha*	*Panjshir*	*Malishevo*	*Kitwe (blue-green)*	*Kitwe (green)*	*Pool*	*Santa Maria*	
No. of samples	2	4	2	2	1	2	3	2	2	3	2	1	2
Fe oxide		●			●			●					●
Fe-Cr oxide							●			●		●	
Fe-Cr-Ni-oxide	●												
Fe-Mn oxide									●				
Sphalerite	●												
Phlogopite			●			●		●	●	●	●	●	
Muscovite					●								
Ti-rich mica				●									
Talc	●		●			●				●			
Chlorite					●								
Pyrophyllite								●					
Glauconite		●	●						●	●			
Illite				●									
Illite-smectite					●								
Margarite								●					
Wollastonite					●								
Apatite										●			
Chromite						●							
Aragonite						●							
Dolomite						●							
Fluorite		●										●	
Anhydrite				●									
Baryte								●					
Pyrite						●							
Albite	●	●	●										●
Quartz	●	●			●					●		●	●
Beryl	●	●					●						
Bertrandite				●		●							
Euclase		●	●	●		●							
Phenakite				●									

NB: The following identifications are unconfirmed: tetrahedrite and tourmaline in Jos emerald, helvine in Sumbawanga, calcite in Panjshir and gypsum in Kitwe emerald.

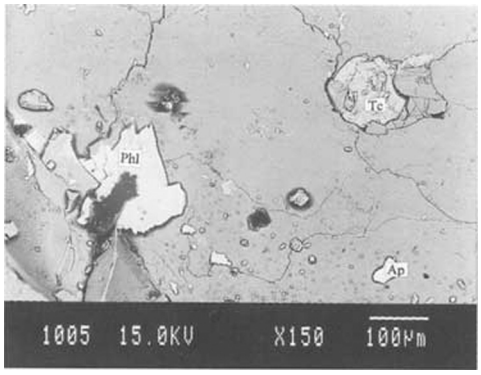

Figure 1: *Inclusions of phlogopite (Phl), talc (Tc) and apatite (Ap) in emerald from Zambia. Image from scanning electron microscope (backscattered electrons)*

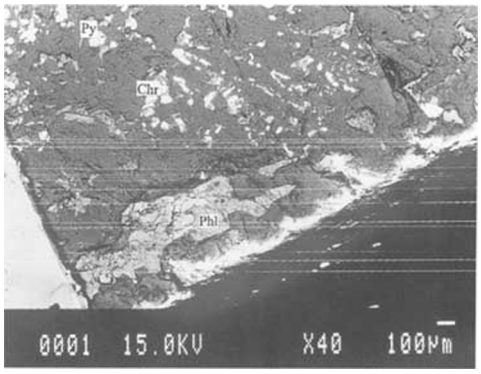

Figure 4: *Inclusions of phlogopite (Phl), aluminochromite (Chr) and pyrite (Py) in emerald from Brazil (Santa Teresinha).*

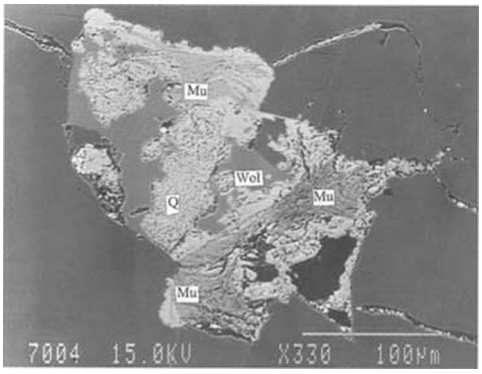

Figure 2: *Wollastonite (Wol), quartz (Q) and muscovite (Mu) aggregate in emerald from Brazil (Carnaìba).*

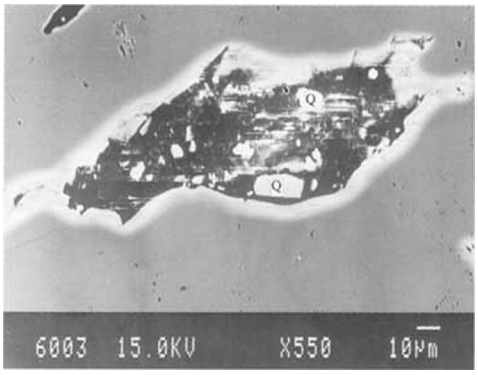

Figure 5: *Quartz (Q) in fluid inclusion in synthetic emerald.*

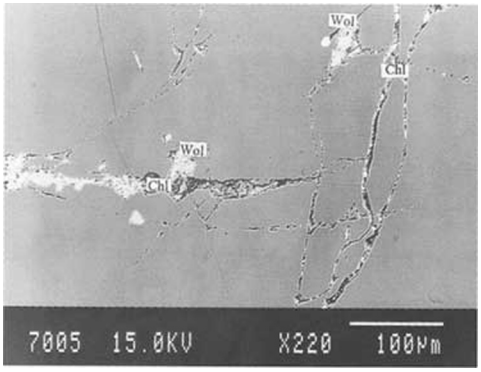

Figure 3: *Chlorite (Chl) and wollastonite (Wol) in flaws in emerald from Brazil (Carnaìba).*

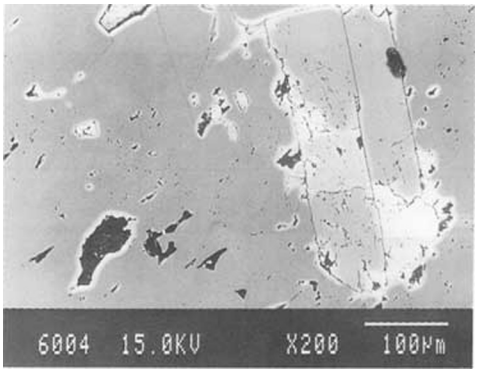

Figure 6: *Albite crystal inclusion in synthetic emerald.*

***Table II:** Crystallochemical formulae of mineral inclusions in emeralds from different deposits (summary of microprobe study)*

Phlogopite		
1	Brazil, Santa Terezinha	$(K_{0.79}Na_{0.002})_{0.792}(Mg_{2.51}Fe_{0.23}Al_{0.36}Cr_{0.02}V_{0.001})_{3.12}[(Si_{3.38}Al_{0.62})_{4.00}O_{10}][OH,F]_2$
2	Tanzania, Lake Manyara	$K_{0.993}(Mg_{2.33}Fe_{0.54}Al_{0.01}Ti_{0.03}Ni_{0.04}Cr_{0.001})_{2.95}[(Si_{2.83}Al_{1.17})_4O_{10}[OH,F,S_{0.045}]_2$
3	Tanzania, Lake Manyara	$(K_{0.71}Na_{0.03}Ca_{0.12}Ce + La_{0.05}Cs_{0.005})_{0.92}(Mg_{2.15}Fe_{0.40}Al_{0.28}Ti_{0.02}Ni_{0.04}Mn_{0.02}Cr_{0.003})_{2.85}$ $[(Si_{2.94}Al_{1.06})_4O_{10}][OH,F,S_{0.05}]_2$
4	Russia, Malishevo	$(K_{0.84}Na_{0.06}Ca_{0.01}Ce + La_{0.04}Cs_{0.01})_{0.96}(Mg_{1.97}Fe_{0.48}Al_{0.29}Ti_{0.03}Mn_{0.03}Cr_{0.01}Cu_{0.01}Co_{0.01})_{2.82}$ $[(Si_{3.06}Al_{0.93})_4O_{10}][OH,F,S_{0.01}]_2$
5	Zambia, Kitwe (in green emerald)	$(K_{0.87}Na_{0.04}Ca_{0.01})_{0.92}(Mg_{2.33}Fe_{0.36}Al_{0.21}Cr_{0.01})_{2.91}[(Si_{3.10}Al_{0.90})_4O_{10}][OH,F]_2$
6	Zambia, Kitwe (in bluish-green emerald)	$(K_{0.67}Na_{0.10}Cs_{0.005})_{0.78}(Mg_{1.29}Fe_{0.77}Al_{0.56}Zn_{0.04}Mn_{0.02}Cu_{0.02}Ti_{0.01}V_{0.004})_{2.71}$ $[(Si_{3.36}Al_{0.64})_4O_{10}][OH,F]_2$
7	Australia, Pool	$(K_{0.73}Na_{0.06}Cs_{0.01})_{0.80}(Mg_{1.40}Fe_{0.54}Al_{0.56}Ti_{0.03}Zn_{0.02}Sn_{0.02}Cr_{0.02})_{2.60}$ $[(Si_{3.44}Al_{0.56})_4O_{10}][OH,F,S_{0.01}]_2$
8	Mozambique, Santa Maria	$(K_{0.41}Na_{0.25}Ca_{0.05})_{0.71}(Al_{0.50}Mg_{1.57}Fe_{0.32}Ti_{0.005}Mn_{0.03}Cr_{0.005})_{2.43}$ $[(Si_{2.82}Al_{0.66}P_{0.52})_4O_{10}][OH,F]_2$
Muscovite		
9	Brazil, Carnaiba	$(K_{0.92}Na_{0.01}Ca_{0.01})_{0.94}(Al_{1.33}Fe_{0.35}Mg_{0.33}Cr_{0.01})_{2.05}[(Si_{3.38}Al_{0.62})_4O_{10}][OH,F]_2$
Titanium-rich mica		
10	Tanzania, Sumbawanga	$(K_{0.65}Na_{0.08}Ca_{0.02})_{0.75}(Ti_{1.00}Al_{0.81}Fe_{0.06}Mg_{0.02}V_{0.03}Cr_{0.002})_{1.92}[(Si_{2.54}Al_{1.46})_4O_{10}][OH]_2$
Margarite		
11	Russia, Malishevo	$(Ca_{0.93}Na_{0.06})_{0.99}Al_2[(Si_{1.79}Al_{1.37}Be_{0.84})_4O_{10}][OH,F]_2$
Mixed-layer illite-smectite		
12	Brazil, Carnaiba	$(K_{0.34}Na_{0.01}Ca_{0.22})_{0.57}(Al_{1.70}Mg_{0.29}Fe_{0.04}Cr_{0.01})_{2.04}[Si_{3.36}Al_{0.64}O_{10}][OH]_2.nH_2O$
Illite		
13	Tanzania, Sumbawanga	$(K_{0.34}Na_{0.019}Ca_{0.02})_{0.38}(Al_{1.86}Mg_{0.10}Fe_{0.046}Mn_{0.01}Cr_{0.02})_{2.04}[(Si_{3.61}Al_{0.39})_4O_{10}][OH]_2.nH_2O$
Al-glauconite		
14	Nigeria, Jos	$(K_{0.42}Na_{0.12}Ca_{0.065}Cs_{0.002})_{0.61}(Al_{1.17}Fe_{0.64}Mg_{0.31}Ti_{0.054}Zn_{0.02}Cr_{0.005})_{2.20}$ $[(Si_{3.5}Al_{0.5})_4O_{10}][OH,Cl,S_{0.05}]_2.nH_2O$
Al-celadonite		
15	Zambia, Kitwe	$(K_{0.28}Na_{0.14}Cs_{0.01})_{0.43}(Al_{1.14}Mg_{0.80}Fe_{0.24}Cr_{0.02}Pb_{0.02}Sn_{0.02}Ni_{0.01}Ti_{0.01})_{2.27}$ $[(Si_{3.97}Al_{0.03})_4O_{10}](OH]_2.nH_2O$
Talc		
16	Brazil, Santa Terezinha	$(Mg_{2.94}Fe_{0.12}Cr_{0.002}Ni_{0.02}Mn_{0.005})_{3.09}[Si_{3.95}O_{10}][OH]_2$
17	Tanzania, Lake Manyara	$(Mg_{3.09}Fe_{0.08})_{3.17}[Si_{3.92}O_{10}][OH]_2$
18	Zambia, Kitwe	$(Mg_{2.49}Fe_{0.34}Al_{0.17}Cr_{0.002}Ca_{0.02}Na_{0.01}K_{0.01})_{2.99}[(Si_{3.92}Al_{0.08})_4O_{10}][OH]_2$
19	Colombia, Muzo	$(Mg_{2.31}Fe_{0.08}Al_{0.17})_{2.56}[Si_{4.16}O_{10}][OH,S_{0.01}]_2$
Pyrophyllite		
20	Russia, Malishevo	$(K_{0.19}Na_{0.11}Cs_{0.001})_{0.30}(Al_{1.31}Mg_{0.53}Fe_{0.18}Cu_{0.01}Cr_{0.01})_{2.04}[Si_{4.07}O_{10}][OH]_2$
Chlorite		
21	Brazil, Carnaiba	$(Mg_{4.47}Fe^{2+}_{0.50}Ca_{0.02}Na_{0.01})_{5.00}(Al_{0.68}Fe^{3+}_{0.46}Cr_{0.004})_{1.14}[Si_{3.01}Al_{0.99}O_{10}][OH]_8$
Wollastonite		
22	Brazil, Carnaiba	$(Ca_{0.86}Mg_{0.09}Fe_{0.03}Ni_{0.006}Cr_{0.001}Na_{0.01}K_{0.005})_{1.00}[(Si_{1.04}Al_{0.02})_{1.06}O_3]$
Aluminochromite		
23	Brazil, Santa Terezinha	$(Fe_{0.96}Mg_{0.04})(Cr_{1.33}Al_{0.43}Fe_{0.25}V_{0.01})_{2.02}O_4$
Euclase		
24	Tanzania, Lake Manyara	$Be_{1.02}(Al_{0.89}Ti_{0.01}Mg_{0.01}Fe_{0.13})_{1.04}[(Si_{0.93}Be_{0.07})_{1.00}O_4][OH]$

(2) different oxidation states of elements such as iron and vanadium cannot be determined; and

(3) the technique allows chemical analyses only at the surface of a grain.

Nevertheless, the microprobe is being used more frequently in the study of single emerald samples and their solid inclusions; see, for example, Gübelin, 1982; Graziani *et al.*, 1983; Cassedanne and Sauer, 1984; Eidt and Schwarz, 1986; Ringsrud, 1986; Dele-Dubois and Schubnel, 1987; Miyata *et al.*, 1987; Schmetzer *et al.*, 1991; Schwarz *et al.*, 1996 and Moroz, 1997.

Materials and apparatus

The samples in this study were provided by Israel's Emerald Cutters Association. This article presents the results of testing a selection of emerald crystals and faceted emeralds from eleven gem-mining regions ranging from 0.3 (Afghanistan) to 4.39 ct (Brazil, Carnaiba), and Biron synthetic emerald. The samples represent a wide range of colours between bluish-green and yellowish-green. The rough crystals are predominantly euhedral prismatic. Some of the rough and the polished samples have eye-visible colour zoning, with sporadic colourless zones, typically parallel to the prism faces. The diaphaneity of the samples ranged from transparent to translucent, depending on the nature and number of inclusions present. Weak-to-prominent growth structures are present in most of the samples. Most common (especially in Nigerian specimens) were strongly developed straight and angular sequences of prism, basal-pinacoid and pyramid planes.

Mineral inclusions in 28 samples were chemically characterized by use of the electron microprobe JEOL model JXA-8600 Superprobe at the Institute of Earth Sciences, The Hebrew University of Jerusalem. The instrument was equipped with four wavelength-dispersive spectrometers which were used to analyse Mg, Na, Cr and V; the other element contents were measured using an energy-dispersive spectrometer, which displays the entire spectrum (atomic number eleven and above) produced by the spot that was exposed to the beam. The microprobe was operated using 15 kV acceleration voltage with a beam current of 10 nA. The Tracor-Northern Computerized automation system was used to collect and store data, as well as allowing data analysis and presentation. Standards consisted of natural minerals and synthetic materials. We refer the reader to Goldstein *et al.* (1981) for a thorough review of the instrumentation, theory and applications of the technique.

Results and Discussion

The inclusions identified are listed in *Table I* and a selection is shown in *Figures 1–6*. The means of 10–15 microprobe analyses for each species of inclusion for each locality are presented in *Table II* as calculated formulae. The detection limits for elements analysed by microprobe are generally in the range up to two thousand parts per million. Total iron is reported as FeO; vanadium can also occur in multiple valence states but is reported as V_2O_3. It has been possible to identify some beryllium minerals, using calculations based on stoichiometry.

Emerald occurrences in Australia, Brazil, Mozambique, Russia, Tanzania (Lake Manyara) and Zambia belong to so-called 'schist-type' deposits, similar in many respects to those described by Fersman (1925) as emerald-bearing biotite schists in the Ural Mountains; that is, they are located in regions where acidic magmas have penetrated country rocks in the vicinity of basic and ultrabasic rocks. In these situations the beryllium is believed to be derived from acidic intrusions and the chromium appears to have originated from the country rocks (Beus and Mineev, 1974; Kiyevlenko *et al.*, 1974; Moroz, 1978; Sliwa and Nguluwe, 1984; Schwarz and Eidt, 1989; Schwarz, 1991; Laurs *et al.*, 1996; Moroz and Eliezri, 1998). Such emeralds usually occur in phlogopite-biotite rocks which also contain actinolite or tremolite and variable quantities of talc, chlorite, quartz, albite, chromite, ilmenite, magnetite, apatite and fluorite (Moroz, 1978;

1979; 1983; 1996). Some of these minerals occur as inclusions in the emeralds studied and vary in size, with the largest up to 1mm. Usually there is no visible crystallographic orientation of the mineral inclusion distribution within the emerald host crystals. Only the minerals trapped on crystal faces (for example, aragonite, dolomite, or the bertrandite and euclase aggregate on the prism and pinacoid of emerald from Santa Terezinha) during a period of growth interruption show a spatial distribution related to the emerald crystallography. Some of the inclusions are identifiable optically, but many are not and these have been identified by electron probe and Raman microanalyses. The results of the study allow us to distinguish different compositions of the same mineral species in emeralds from different deposits (see the compositions in *Table II*).

Phlogopite is the most common mineral inclusion in these emeralds (*Table I; Figures 1 and 4*), but its composition varies (*Table II, 1–8*). Formulae calculated on a basis of 11 oxygens typically have total numbers of octahedral cations less than the ideal 3.0. The Mg:Fe ratios in phlogopite inclusions in emeralds from Brazil (Santa Terezinha, *Figure 4*), Zambia (*Figure 1*), Tanzania (Manyara), Mozambique and Russia lie in the range 4.1–10.9 with the highest ratio in phlogopite from Santa Terezinha. This ratio in phlogopite inclusions in emeralds from Australia is 2.6 and in bluish-green emerald from Zambia is 1.7. The values of this ratio in phlogopite correlate with relative concentrations of these elements in the host emeralds from these deposits and reflect country rock compositions.

In addition to chromium (0.001–0.02 atoms per three octahedral sites) and titanium (0.03 atoms), several other substitutions are recorded in small amounts for the octahedral sites of phlogopites. The analyses show a few hundredths of an atom of Mn per three octahedral sites in Mozambiquean, Russian, Tanzanian (Manyara) and Zambian phlogopites and there is a coexisting phase of Mn-rich oxide in a Zambian bluish-green emerald (*Table I*). Copper is present in Russian and Zambian phlogopite, nickel in Tanzanian, cobalt in Russian, vanadium in Brazilian and Zambian (from bluish-green emerald) and tin in Australian phlogopite inclusions (*Table II*). Cesium is found in Russian, Australian and Tanzanian phlogopite; the higher values being in phlogopite from the first two deposits. Phlogopite inclusions of tabular habit in emerald from Mozambique (*Table II*, N 8) usually contain appreciable phosphorus concentrations (to 0.52 atoms per four tetrahedral sites). Sulphur occurs in amounts of 0.01–0.05 of an atom in the mica inclusions from Tanzanian, Australian and Russian samples, with the highest value in phlogopite from the first deposit.

Conclusions

Mineral inclusions in emeralds from eleven gem-mining regions were chemically characterized by use of the electron microprobe JEOL JXA-8600.

The emeralds from the Australia, Brazil, Mozambique, Russia, Tanzania (Lake Manyara) and Zambia localities belong to 'schist-type' deposits, and they may contain micas, margarite, aluminiferous glauconite, celadonite, mixed-layer illite-smectite, talc, pyrophyllite, chlorite, wollastonite, aluminochromite, aragonite, calcite, dolomite, Fe-oxides, apatite, quartz, pyrite, anhydrite, fluorite, plagioclase, beryl, euclase and bertrandite. The results of the study allow us to distinguish different compositions of the same mineral species in emeralds from different deposits – for example, mica.

The geological settings for Colombian, Nigerian and Sumbawanga (Tanzania) deposits result in related sets of solid inclusions consisting of chlorine-rich Al-glauconite, essentially a copper–antimony sulfide and tourmaline in Nigerian emerald; sphalerite in Colombian emerald; and titanium-rich mica, illite, anhydrite, helvine, euclase, phenakite and bertrandite in emerald from Sumbawanga.

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Chrome chalcedony – a review

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ABSTRACT: Three chrome chalcedonies from different sources are described. Stones from recent finds in Zimbabwe and Bolivia have refractive indices of 1.530–1.550, rarely with a birefringence up to 0.005. Roman intaglios have refractive indices about 1.540. All have a bright-red reaction under a Chelsea colour filter and show chromium spectra in a hand spectroscope. The intaglios show in addition complete absorption in the blue part of spectrum, caused probably by higher iron contents. Properties of artificially dyed Cr-chalcedony are given for comparison.

Keywords: Bolivia, chrome chalcedony, Roman intaglios, Zimbabwe

Introduction

Cryptocrystalline quartz, chalcedony, has many varieties of which the green chrysoprase, known from several localities, is the most valuable. The oldest known commercial chrysoprase deposit was near Szklary in today's Poland, where the first written report dates from 1425 (Natkaniec-Nowak *et al.*, 1989); the deposit was rediscovered in 1740. Much younger finds are from the Ural Mountains, California and Oregon at the end of the nineteenth century. The most important recent chrysoprase deposits were discovered in the 1960s in Queensland, Australia (Krosch, 1990), in Western Australia, in the states of Goias and Minas Gerais in Brazil and in Sarykulboldy, Kazakhstan (Samsonov and Turingue, 1984).

There is no doubt that chrysoprase is coloured by Ni, which can be contained in amounts up to 5.08% NiO (Barsanov and Jakovleva, 1981). Although the form of Ni is not established beyond doubt, most probably it is bonded in hydrated Ni-silicates (see Webster, 1994) or in tiny particles of the mineral bunsenite, NiO (Barsanov and Jakovleva, 1981). Green opal very similar to chrysoprase is known from Szklary and from Dodoma in Tanzania, where it contains about 1.1% Ni (Schmetzer *et al.*, 1976). Opal can be distinguished by means of its lower refractive index.

Occurrences of chrome chalcedony

Green chalcedony with a high Cr-content was found at first in about 1955 near Mtoroshanga in today's Zimbabwe and called mtorolite (*Figure 1*). Its best

Figure 1: *Mtorolite, Zimbabwe, the larger piece is 17 x 9 cm.*

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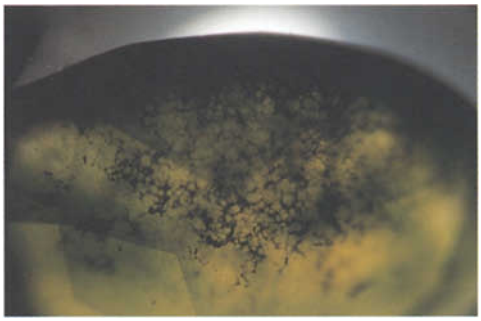

Figure 2: Chrome chalcedony Bolivia, black net of Fe-oxides (?).

Figure 3: Chrome chalcedony Bolivia, yellow-brown Fe-oxides.

descriptions were written by Phillips and Brown (1989) and Campbell (1955). It comes from the Great Dyke, a huge 500 km long dyke of ultrabasic rock. Mtorolite occurs in a deposit 1.7 km long striking N–S, and is often accompanied by white chalcedony. The best cuttable material came from a small shaft where chrome chalcedony formed three layers with a width of 6–25 mm. The best qualities have already been mined out and at present only low-grade pale green or mottled mtorolite is recovered occasionally as a by-product during the mining of serpentinite for carvings (A. Loke, pers.comm, 1996).

A new occurrence of Cr-chalcedony was found recently in eastern Bolivia (Hyrsl and Petrov, 1998). It is called 'chiquitanite' by local jewellers, from the Chiquitania region of eastern Santa Cruz Department. The chrome chalcedony has a pleasant apple- to dark-green colour and is opaque to translucent (*Figures 2 and 3*). Some stones show a very fine agate-like structure (Figure 4) or a brown 'net' of Fe-oxides. Some parts are coloured more generally brownish by Fe-oxides. The best quality material is facetable and compares favourably with mtorolite. Most of the rough material is exported directly to Brazil and the author found cut chrome chalcedony at the 1995 Munich mineral show described as 'a new find of apatite from Brazil'.

Figure 4: Chrome chalcedony Bolivia, very fine agate-like layers.

Figure 5: Chrome chalcedony Mercury intaglio (coll. W.Mican), 16.9 x 12.5 x 6.8 mm.

Figure 6: Two intaglios (chrome chalcedony and carnelian) in a necklace from the Museum of Decorative Art, Prague.

A third occurrence of chrome chalcedony is mentioned in the 10th edition of Anderson's *Gem Testing* (1990), revised by E.A. Jobbins. He described Roman cameos and intaglios made from Cr-chalcedony which appeared red under a Chelsea colour filter. Unfortunately, there is no more published information about it. There is one similar intaglio in a private collection of Professor W. Mican in Vienna (*Figure 5*). The gem has dimensions 16.9 x 12.5 x 6.8 mm and weighs 1.820 g. It is apple-green with an uneven colour. Several white spots can be seen inside and a small quantity of brown matrix occurs near the girdle. The gem is an intaglio with the head of the Roman god Mercury and is polished on the other side. Its age is not certain and it could be either Roman or a younger copy.

Another two small light and dark green chrome chalcedony intaglios form part of a necklace in the collection of the Museum of Decorative Arts in Prague, Czech Republic (*Figure 6*). The necklace is probably from the beginning of the nineteenth century, but the Cr-chalcedony intaglios could be much older, because they are more scratched than the others made of carnelian. Two small Cr-chalcedony intaglios were also studied in Prague from a Romanesque reliquary of St Maurus dating from the beginning of the thirteenth century. According to Ondrejova (pers.comm.), both intaglios probably date from the second century AD. They are olive green and emerald green respectively, with n = 1.540, no birefringence, and a specific gravity of 2.58. They show no luminescence in UV, both are red under a Chelsea filter and show Cr-spectra in a hand spectroscope (the emerald green intaglio shows a much sharper line in the red than

***Table I:** Gemmological properties of Cr-chalcedonies from different sources*

	Zimbabwe	*Bolivia*	*Intaglio*	*Dyed chalcedony*
Colour	dark green	dark green	dark green	dark green
Diaphaneity	translucent	translucent	translucent	translucent
Hardness	7	7	7	7
RI	1.540	1.530–1.550	1.540	1.532–1.540
Birefringence	0–0.005	0–0.006	–	0–0.005
SG	2.56–2.60	2.56–2.57	2.56	2.56–2.58
UV luminescence:				
LWUV	yellowish	yellowish	very light yellowish	inert
SWUV	pale yellowish in light parts	inert	inert	inert
Chelsea colour filter	Bright red	Bright red	Bright red	Weak brownish-red

Table II: Chemical composition of analysed chalcedonies from Bolivia and Zimbabwe, and artificially coloured chalcedony.

Wt.%	Cr chalcedony – Bolivia		Cr chalcedony – Zimbabwe		Artificially coloured chalcedony	Detection limits
	Dark	Light	Dark	Light		
SiO_2	95.90	96.00	93.56	94.38	98.92	0.10
TiO_2	0.09	–	–	–	–	0.07
Al_2O_3	0.09	0.13	0.29	0.18	0.16	0.08
Cr_2O_3	0.36	0.51	0.45	0.21	0.28	0.10
MgO	0.11	0.15	0.30	0.16	–	0.06
MnO	–	–	0.08	–	–	0.08
TOTAL	96.55	96.79	94.68	94.93	99.36	

NB: CaO (0.10 wt.%), FeO (0.10 wt.%), NiO (0.30 wt.%), K_2O (0.05 wt.%) and Na_2O (0.30 wt.%) were sought but below their respective detection limits.

the olive green stone) with complete absorption in the blue part of the spectrum, very similar to the Mercury intaglio which is described later.

Many ancient gems made from Cr-chalcedony are housed in the Cabinet des Medailles in the Bibliotheque Nationale in Paris. Their colours range from emerald-green with a red response under the Chelsea colour filter to light yellowish-green with a pink colour under the Chelsea filter. Their quality ranges from clean translucent to greyish opaque with brown or red networks or spots of Fe-oxides. According to Broustet (pers.comm.), they are mostly from the first to the third century AD, and some could be older. Considering their number (a few dozen) and very different qualities they could come from different parts of the same deposit or from many deposits.

Green chalcedony coloured artificially has usually been dyed by chromium salts. Fortunately, it is easy to distinguish from natural stones by its different reactions under a Chelsea filter and in a hand spectroscope. It also has a typical structure, because grey chalcedony must be cut perpendicular to its fibres to facilitate better permeability for the dye (Webster, 1994). The chemical analysis (*Table II*) shows also that it has a lower content of water than natural chrome chalcedonies.

Gemmological properties

The four materials mentioned above were studied at the same time, including both high- and low-grade chrome chalcedony from Bolivia and Zimbabwe, and their gemmological properties are listed in *Table I*, chemical analyses are reported in *Table II*.

All the chrome chalcedonies are polycrystalline aggregates and they remain light during rotation in a polariscope. Their refractive indices lie between 1.530–1.550 (mostly 1.540) and a few of them exhibit a slight birefringence, caused by its semi-colloidal structure. The most useful property in distinguishing the chrome chalcedonies is their colour under the Chelsea filter. Both natural rough samples and the cut and polished intaglios are bright red under the Chelsea filter, while the artificially coloured Cr-chalcedony is only brownish-red and chrysoprase is nearly inert. The second useful test is to examine them by means of a hand spectroscope. Natural chrome chalcedonies show an emerald-like spectrum with a sharp line (at 684 nm) in the red and an absorption of the yellow and violet parts of the spectrum. The Mercury-gem and the intaglios show, in addition, complete absorption in the blue part of the spectrum, which may well be caused by higher iron contents. The spectrum of artificial Cr-chalcedony typically shows two diffuse lines

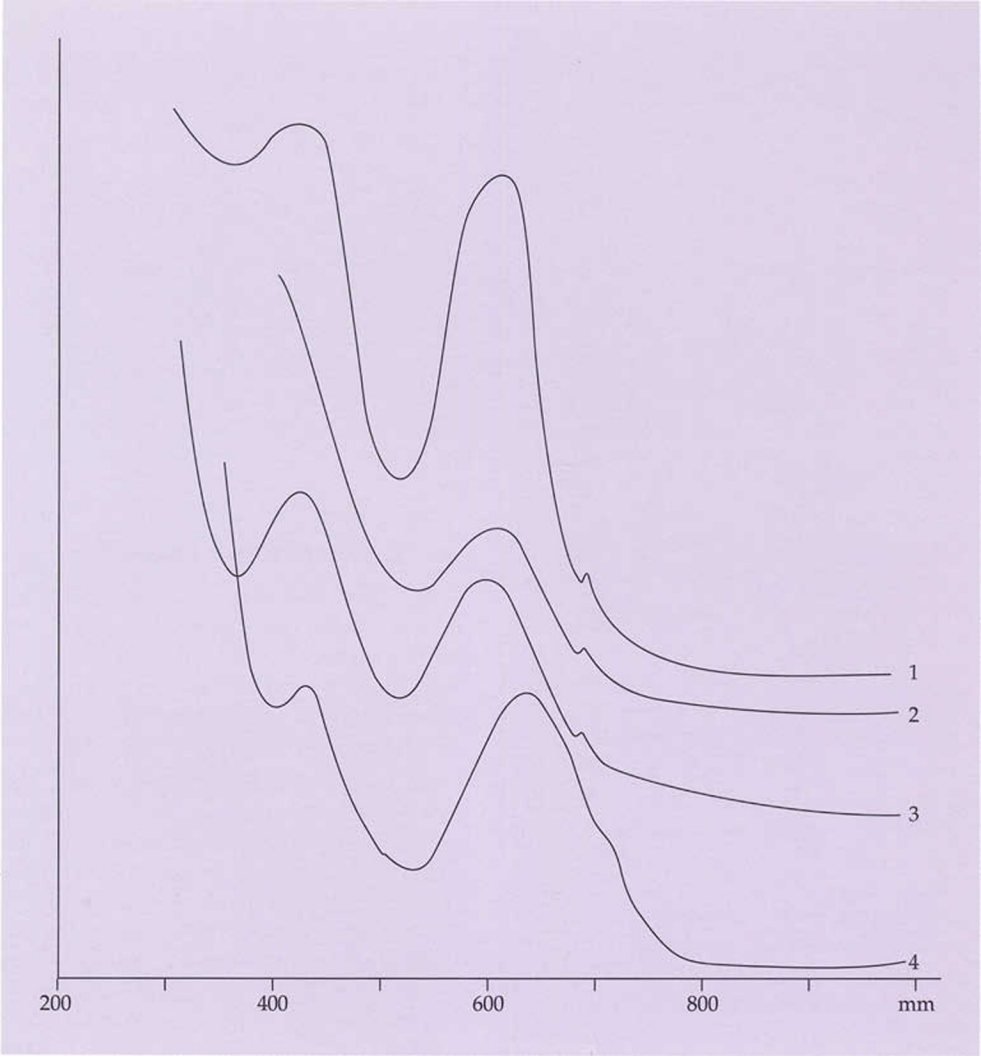

Figure 7: UV-VIS spectral curves of Cr-chalcedony from: 1) Bolivia, 2) Mercury intaglio, 3) Zimbabwe, and of dyed chalcedony 4).

in the red. The curves from the UV-VIS spectrophotometer are shown in *Figure 7*. Surprisingly, artificial Cr-chalcedony is more easily recognised by hand spectroscope, because the two lines in the red show only as weak shoulders on the spectrophotometer trace.

Yellowish fluorescence in SWUV was observed on pale parts of a mtorolite vein, and opal could be present (see *Table I*). Dark mtorolite has much weaker fluorescence than the light variety. Chrysoprase does not usually fluoresce, but Kammerling *et al.* (1990) described greenish-blue fluorescence of chrysoprase from Goias, Brazil. It was stronger in LW than in SWUV.

An attempt to identify the cause of colour was made during a microprobe study. Chromium content in a single specimen ranged from less than 0.10% to 0.95%. Unfortunately in a scanning electron microscope, the back-scattered electron

images of the material look homogenous and it means that possible particles of a Cr-mineral are smaller than 100 nm. In some analyses, the Cr content has a positive correlation with contents of Mg and Al, but the results were not statistically significant.

Conclusions

To determine the origin of chrysoprase and chrome chalcedony is an interesting geochemical task. Both originate from Ni–Cr-rich ultrabasic rocks, where Ni is usually bound in olivine and Cr in spinels such as chromite and in pyroxenes such as chrome diopside. Olivine is the most unstable mineral in the ultrabasic rocks (i.e. it weathers first) whereas spinels are almost insoluble. This means that when the olivine weathers first, the SiO_2 is leached out together with Ni and precipitates nearby in fractures to form chrysoprase. Too much circulating water can cause complete leaching of SiO_2 and then no chrysoprase can form. Chrome chalcedony occurs probably after stronger weathering where pyroxenes have been dissolved too, thereby releasing their component Fe, Mg, Cr and Si to recombine under new conditions.

The original locality of the chrome chalcedony used for gems by the Romans is not known and could be very difficult to find. There is no evidence that the Bolivian material was available before recent times. However, the Romans were trading with the East African coast and probably could have obtained material from Zimbabwe, but mtorolite looks completely different from the chrome chalcedony used for Roman intaglios. There must have been another locality which has probably been mined out and forgotten. Two clues could help locate this unknown deposit: one is the relatively rich occurrence of Cr-chalcedony intaglios in the first to third century AD. Their quality fluctuates over a wide range. Older ones are very rare and their dating might even be incorrect. Several examples of Cr-chalcedony intaglios in younger decorative objects may well be a reflection of the very common re-use of antique stones throughout history. For example, the St Maurus reliquary dates from approximately the year 1200 and contains 66 carved gems, most of which are Roman intaglios. There are also possibilities that there was more than one period of mining at the original locality, and that there were later finds of similar stones elsewhere.

The second clue is the origin of Cr-chalcedony in strongly weathered ultrabasic rocks. In the ancient world, the most important accessible areas with such rocks occur in Turkey, Albania and the former Yugoslavia. Recently, Bank *et al.* (1997) described a cuttable green opal from Kutahya in Turkey. It has an RI between 1.438 and 1.442, SG 2.03–2.06 and, according to its spectrum, its colour is caused by trivalent chromium. The occurrence of Cr-chalcedony would be logical in the same region and it might be rediscovered by chance in the future.

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A colorimetric study of the alexandrite effect in gemstones

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ABSTRACT: The variation in colour hue (the alexandrite effect) for gemstones that change colour under pairs of light sources can be measured by the difference in their calculated CIELAB hue-angle. Depending upon the measured hue-angle and the light sources used, gemstones that exhibit this phenomenon can be grouped into several categories. Colour measurement can provide support for visual observation to help the gemmologist determine if a gemstone displays this behaviour.

Keywords: alexandrite effect, colour, colour appearance, colour change, colour measurement

Introduction

Gemstones that change colour under different light sources are quite valuable and are much sought after in the jewellery trade. On identification reports issued by gem-testing organizations such as the GIA Gem Trade Laboratory, whether or not a gemstone exhibits a colour change can be an important explanatory comment. This phenomenon has been reported in some chrysoberyl (the important variety alexandrite), sapphire, spinel, pyrope-spessartine garnet, zircon, tourmaline and diaspore, to name several of the better-known examples (see, e.g. Schmetzer and Gübelin,

Figure 1: *Three natural alexandrites as seen under two light sources – (a) a fluorescent daylight simulator and (b) an incandescent light. The three gemstones are, from the left, a 1.29 ct stone from Russia, and two stones from the Hematita mine in Brazil (1.06 and 1.32 ct). Photograph by Tino Hammid, copyright GIA.*

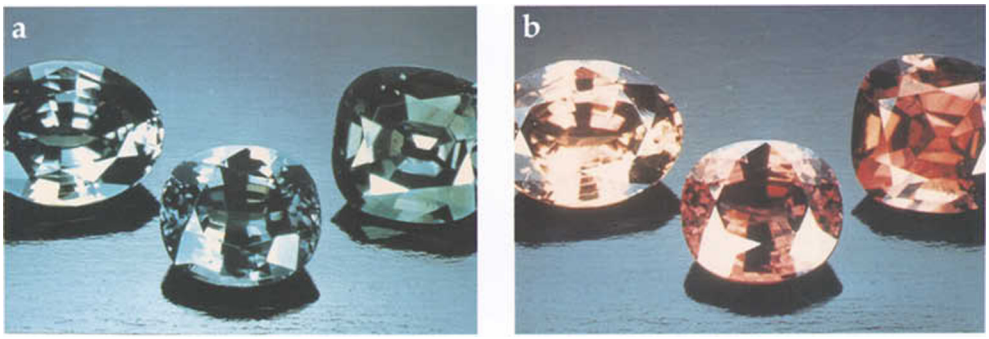

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1980a; Scarratt, 1980). It is described as a difference in the colour hue of the gemstone, and not a change in either its colour saturation or colour lightness. Quite pronounced colour changes are known (such as the violet-red to bluish-green change in alexandrite; see *Figure 1*). However, when the colour-hue change is less pronounced, it may be difficult to determine by visual observation whether a gemstone is actually changing colour.

Colour in gemstones is the colour appearance that a person sees. Within the past decade, however, both visual colour comparison instruments, and colour measurement instruments such as colorimeters, spectrophotometers, and imaging spectrophotometers have been introduced into the jewellery trade as an aid for gemstone colour determination (Nelson, 1986; Allaman, 1995). Measuring the colour of a three-dimensional, transparent, faceted gemstone presents challenges in comparison to working with flat, parallel-sided coloured samples. By measuring the interaction of light with a gemstone, the instruments calculate a location of the gem's colour in colour space (which location must then be translated into a word description of the colour to be of practical use in the jewellery trade). However, the question that is often unanswered or unclear when using these measurement instruments is the relation between the colour appearance we see, and the colour appearance of the gemstone that is being measured by the instrument. This is because the colour of a gemstone is due not just to its bodycolour, but also to optical effects due to its size, faceted shape, and other factors. In the table-up orientation, a faceted gemstone exhibits a pattern of colour appearances, and both the human observer viewing the gemstone, and the instrument measuring light coming from the gemstone, may not be 'seeing' the same colour appearance. To date, none of these instruments has yet attained widespread use in the jewellery trade. Nelson (1986) summarized many of the objections in the jewellery trade that have hindered the widespread acceptance of gemstone colour grading systems, and the use of colour comparison and measurement instruments.

The purpose of this article is to report on the results of a colour measurement study of gemstones that change colour under three CIE standard illuminants (theoretical light sources), which represent different types of actual light sources commonly used in the jewellery trade. The goals of this study are:

(1) to further investigate if the calculated colour appearance of a gemstone, obtained by instrumental measurement, can be related to its colour appearance determined by visual observation, as has been suggested by the results of other gemmological studies;

(2) to calculate by colour measurement the colour appearance changes of gemstones under several different pairs of standard illuminants; and

(3) to determine if instrumental colour measurement can assist the gemmologist to decide if a gemstone is changing colour, when the visual appearance of the colour hue change is uncertain.

Background

Colour is one of the most important aspects that make up the beauty of a gemstone. It is a significant contributor to a gemstone's value. Describing this colour in word terms that are widely understood and accepted in the jewellery trade is vital for both effective communication among jewellers and consumers, sustaining integrity in the jewellery trade, and helping to increase gemstone commerce. However, this remains a challenge for jewellers and gemmologists because of:

(1) the difficulty that can occur of describing the colour seen in a gemstone in word terms;

(2) variations in colour description terminology that are used in the trade;

(3) the absence of practical colour-reference standards for visual comparison purposes that effectively simulate the wide range of colours seen in gemstones;

(4) differences in the lighting and viewing conditions under which gemstones and their colour are observed; and

(5) the lack of accepted boundaries in colour space for the ranges of colours of important gemstones (such as the boundary between red ruby and pink sapphire).

Colour is best described in words by means of three attributes – hue (what we normally think of as the colour, such as blue or green), saturation (the depth of the colour, described in terms ranging from, for example, faint to vivid), and lightness (from light to dark). Observation of gemstone colour should be done using controlled lighting and viewing conditions for the most consistent results (the gender, age, colour vision, and physiological state of the observer are also important). Visual colour perception is a complicated phenomenon, but a gemstone's colour appearance arises from a combination of the illumination characteristics of the light source (the actual lamp or bulb), the lighting and viewing conditions used, the light absorbing and transmitting properties of the gemstone itself, and the light detection characteristics of the eye. One example of a procedure for observing and describing colour in gemstones can be found in the article on coloured diamonds by King *et al.* (1994). The scientific basis for observing colour in objects has been standardized and published by the Commission Internationale de L'Éclairage (CIE), an international organization of researchers in the areas of colour science, human vision, and lighting (see CIE, 1986). Descriptions of colour observation and measurement can also be found in standard textbooks such as Billmeyer and Saltzman (1981), Wyszecki and Stiles (1982), Nassau (1983), and Kuehni (1997).

For most gemstone species, a given specimen appears nearly the same colour when seen under different light sources. This results from the extraordinary ability of the human vision system to adapt chromatically over a short time to the changing lighting conditions when viewing an object. Chromatic adaptation means that our eyes adjust when observing an object under different light sources, so that the object's colour often appears nearly constant as the lighting changes (such as an apple that appears red under daylight, incandescent light, and fluorescent light). A good discussion of both vision experiments and the constancy of colour appearance of objects is presented in the article by Land (1959).

Despite colour constancy and the chromatic adaptation of our vision system, some objects do appear to change colour to a certain degree when viewed under different light sources, although we are not normally aware of this change. Colour change in materials seems to have been known at least since the Middle Ages, when Leonardo da Vinci is believed to have first investigated it. This phenomenon has been investigated in some detail by scientists studying colour and colour vision (Ives, 1912; Helson, 1938; Helson and Jeffers, 1940; Judd, 1940; Helson *et al.*, 1952).

Reports on colour-change gemstones are widespread in the gemmological literature (see e.g. Jobbins *et al.*, 1975; Schmetzer and Gübelin, 1980a,b; Scarratt, 1980; Bosshart *et al.*, 1982; Duroc-Danner, 1987; Bank and Henn, 1988, Dharmaratne, 1993; Federman, 1995). For the most part, these articles describe the gem material, and give an explanation of the features in the absorption spectrum that contribute to the colour-change behaviour. Because of its prominent colour change between daylight and incandescent light, the alexandrite variety of chrysoberyl gave its name to the 'alexandrite effect' (White *et al.*, 1967). Although some gemmologists restrict this name only to gems that change from green (or yellowish- to bluish-green) in daylight to red or purplish-red in incandescent light, in the trade this name is often applied to gemstones that change between any two colour hues. At the GIA Gem Trade Laboratory (GIA-GTL), a gemstone that exhibits different hues under different light sources is described as showing a 'colour change' when this behaviour is not typical of all samples of that gem varieties (S. McClure, pers.comm., 1998). Certain purple gemstones, such as amethyst, always display different hues under different light sources; these gemstones are described at GIA-GTL as showing a 'colour shift'.

Some results have also been published on the instrumental measurement of gemstones that exhibit the alexandrite effect. Different gemmological researchers have used several methods to calculate colour information based upon these instrumental measurements.

Schmetzer and Gübelin (1980a) used the difference in calculated dominant wavelength of a colour in the CIE 1931 (x,y) chromaticity diagram to represent the colour change in gem materials when going from daylight to incandescent light. In our opinion, there are several problems with this approach. First, the CIE 1931 (x,y) chromaticity diagram is not a uniform colour space, which means that equal distances between pairs of chromaticity coordinates do not represent equal differences in visual colour perception. Secondly, the change in dominant wavelength does not correspond uniformly to the colour-hue change that a person would see in an object. Finally, their method does not take into account the chromatic adaptation of the human vision system.

Table I: *Colour-change materials examined during this study*

Sample. no.	*Material*	*Observed colour hue*			*Calculated hue-angle*			*Hue-angle change*		
		Incand.	*Daylight*	*Fluor.*	*A*	*D65*	*F7*	*A-D65*	*D65-F7*	*A-F7*
Type 1 colour-change										
1422	Alexandrite, synthetic	P	G	yG	304	200	196	104	4	108
2316	Alexandrite, synthetic	P	G	G	24	136	134	112	2	110
2310	Diaspore	oY	gY	GY	30	82	88	52	6	58
2311	Diaspore	oR	yG	yG	8	138	140	130	2	132
730	Fluorite	V	gB	gB	269	217	213	52	4	56
2467	Garnet	P	gB	gB	292	245	240	47	5	52
2534	Garnet	rO	yO	yO	21	69	87	48	18	66
1369	Sapphire	gY	gY	yG	264	214	228	50	14	36
1326	Sapphire, synthetic	rP	V	P	319	281	267	38	14	52
2161	Spinel, synthetic	yG	G	bG	27	82	91	55	9	64
4644	Sapphire	yG	pV	P	299	273	278	26	5	21
4645	Sapphire, synthetic	pV	V	P	319	284	275	35	9	44
4646	Tourmaline	yG	G	G	84	114	119	30	5	35
Type 2 colour-change										
1327	Glass, synthetic	pR	pR	rO	31	29	64	2	35	33
1366	Glass, synthetic	oR	oY	O	37	36	65	1	29	28
Type 3 colour-change										
1421	Sapphire, synthetic	rP	vP	P+G	316	245	213	71	32	103
Type 4 colour-change										
1116	Garnet	rP	oR	Y	359	14	30	15	16	31
1119	Garnet	oY	oY	G	51	69	76	18	7	25

Codes for colour hues: P – purple, pV – purplish-violet, V – violet, gB – greenish-blue, bG – bluish-green, G – green, yG – yellowish-green, GY – green-yellow, gY – greenish-yellow, oY – orangy-yellow, yO – yellowish-orange, rO – reddish-orange, oR – orangy-red, pR – purplish-red, rP – reddish-purple, vP – purple with a hint of violet

Boguth (1990) used a microscope and a multichannel spectrometer to record transmittance colours for an amethyst and an alexandrite, and then employed a method developed by Yonemura to calculate the colour change. This method does take into consideration chromatic adaptation, but the overall approach taken by Boguth still uses the dominant wavelength change to represent the colour change.

Liu *et al.* (1994) used calculated coordinates in the uniform CIELAB colour space to depict the behaviour of colour-change gemstones in terms of differences in their hue-angle and the extent of their colour change. They grouped the studied gemstones into several categories depending upon the pair of light sources used. In the CIELAB colour space, equal measured hue-angle differences approximately represent equal visual-perception hue changes (and take into account chromatic adaptation). The present article summarizes results from this study, presents some additional data, and addresses the three questions mentioned in the introduction. The alexandrite effect is described as a non-colour constancy phenomenon. It is also suggested that the combination of the response of the visual system to the incoming light from the gemstone under the different light sources, and the chromatic adaptation of the human visual system under different light sources, are the cause of the alexandrite effect.

Materials and methods

During this study, a variety of gemstones were re-examined (including natural and synthetic samples) that exhibited colour hue changes ranging from obvious to subtle. *Table I* lists 18 gemstones that are the subject of this article.

Visual observations of the colours of these samples were made independently by the authors both outdoors in daylight in southern California, as well as indoors using incandescent (tungsten filament) and fluorescence (daylight simulator) light sources using a MacBeth Judge II light booth. When outdoors, daylight strikes both the crown and pavilion facets of the gemstone from a number of angles, is reflected within the gemstone, and then it exits. Our observations were made by holding the sample at arm's length (about 60 cm) and looking straight down on the table and crown facets, to judge a colour hue that would be best representative of the overall face-up colour appearance. For the incandescent and fluorescent light sources, observations were made in the light booth that had a neutral grey interior, with the light source directly above the sample at a distance of about 30 cm, and the observer looking at a 45 degree angle from the vertical, and at a distance of about 30 to 45 cm from the gemstone. Again, the representative colour hue was judged from the face-up orientation of the gemstone. In cases where there was a disagreement between observers about a sample's colour hue, the gemstone was examined by both observers together to reach an agreement about the face-up colour appearance and the

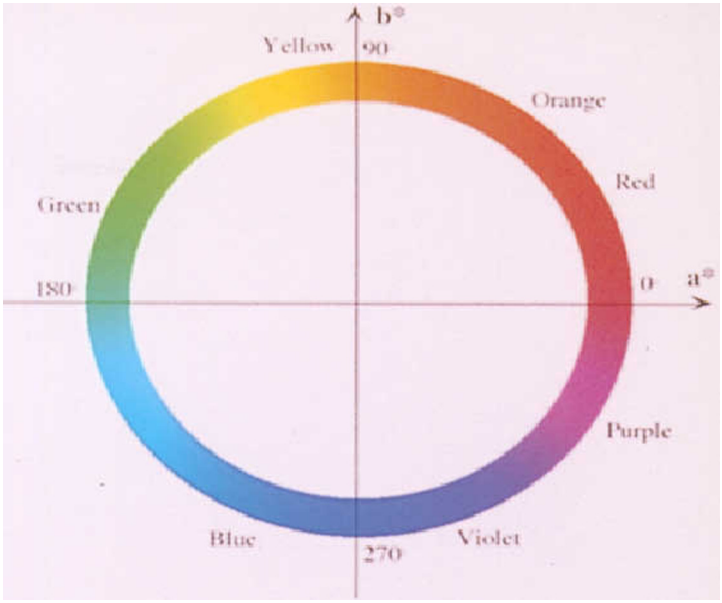

Figure 2: *In the CIELAB colour space, colour hues are arranged around a circle, and their locations can be indicated by the hue-angle (a value up to 360 degrees). These hue-angles can be calculated from the CIELAB coordinates a* and b*, which in turn can be obtained from the measured spectral data. The position a* represents a 0 degree (or 360 degree) hue-angle, and values of the hue-angle increase in a counter-clockwise direction, as shown here.*

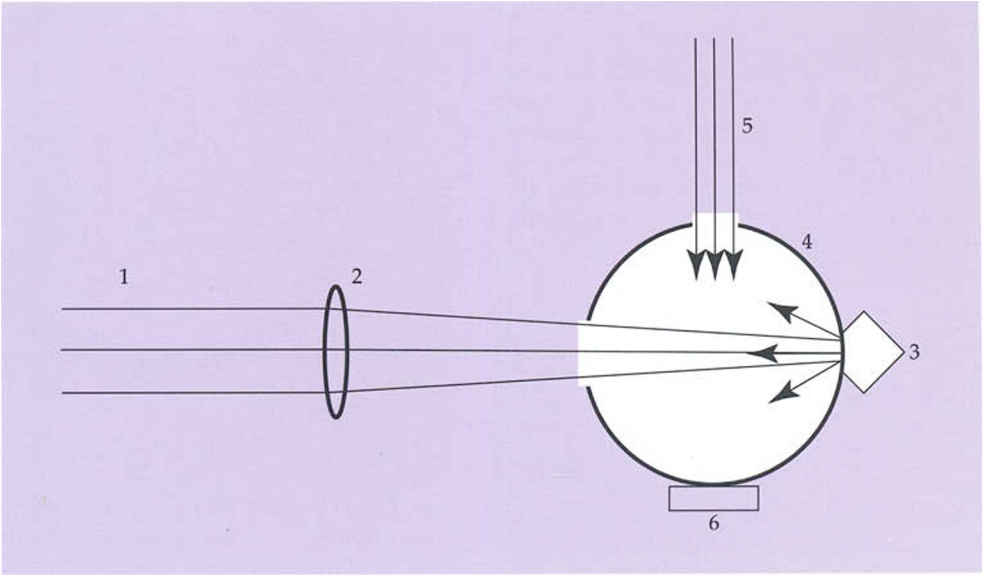

Figure 3: The optical arrangement for measurement of gemstone colour using an integrating sphere mounted in the Hitachi U-4001 spectrophotometer. Numbers refer to: (1) the incident light beam, (2) focusing lens, (3) sample position, with light striking perpendicular to the polished table facet, (4) integrating sphere, (5) reference light beam, and a (6) white reference tile. The measurement resolution is 1 nm. Light striking perpendicular to the table facet is internally reflected within the gemstone; the portion of this light that exits through the table (but not through the crown facets) is captured by the integrating sphere.

hue term(s) to describe this colour. No colour-reference standards were used for visual comparison to our samples. Their colours were described with simple hue terms (such as blue, greenish-yellow, etc.). For the 18 samples, colour-hue changes were seen between one or more pairs of these three light sources, but not necessarily between each pair of sources. A colour change can sometimes be difficult to observe in a gemstone because of its faceted shape, the saturation or lightness of the colour, or the lighting and viewing conditions used.

In the CIELAB colour space, the colour hues are arranged in a circle, and their locations are indicated by an angle (up to 360 degrees), known as the hue-angle (*Figure 2*). Colour measurement data on the hue-angle were calculated from reflectance spectra recorded with an Hitachi U-4001 UV-VIS-NIR spectrophotometer for most of the samples. The wavelength range for these spectra was 300 to 830 nm; a bandwidth of 1 nm and a scan speed of 300 nm per minute were used. *Figure 3* shows the optical arrangement of the measurement experiment. Unpolarized incident light was focused on crown facets of the sample (primarily the table facet) by means of a lens (75 mm focal length); no incident light entered through the pavilion facets. The size of the incident light beam was smaller than the size of the table facet. An integrating sphere mounted within the sample chamber of the spectrophotometer permitted the capturing of most of the light coming from the crown facets of the sample.

Spectra were recorded with the gemstone in the reflectance position (as shown in *Figure 3*), which corresponds closely to how one visually observes a polished coloured gemstone in a face-up orientation. To achieve the closest relation between the observed and the measured colour for a sample, the light source, the gemstone sample, and the 'observer' (either the eye or the instrument

detector) were arranged in nearly the same relative positions with respect to one another (although differences existed between how the light struck the sample outdoors and within the spectrophotometer). In the reflectance position, we attempted to capture light that had been transmitted and reflected through the sample. Light specularly reflected from the surface of the table facet left the integrating sphere through the open port, and was not included in calculating the recorded spectra. Thus, our measurement geometry differed slightly from our observation geometry, principally in terms of how the incident light illuminated the sample.

Using the measured reflectance spectral values recorded every 1 nm across the 400–700 nm range, the CIELAB values L*, a*, and b* were calculated. These numbers were then used to calculate the hue-angle (h) of the sample's overall colour appearance by means of a version of the SpectraCalc™ software programme (Galactic Inc.) that was modified by us. The hue-angle (h) is calculated by the following equation:

$$h = \text{arctangent}\ (b^*/a^*)$$

The absolute hue-angle difference (Δh) between two colour hues for the same sample under light sources 1 and 2 is:

$$\Delta h = |h_1 - h_2|$$

This software programme can calculate coordinates of a measured colour:

(1) in several colour spaces (including CIELAB);

(2) using various CIE standard illuminants; and

(3) a 2-degree or a 10-degree standard colorimetric observer (which is a graph of the spectrum of the colour-matching curves of an average group of human observers with normal colour vision, using a 2-degree or a larger 10-degree angular field of view). Because of the small diameters of our samples, the hue-angle calculations reported here were made with a 2-degree standard observer.

In contrast to light sources, which are daylight or actual lamps with measurable spectral power distributions (SPDs), illuminants are not actual lamps, but are mathematically defined SPDs that are routinely used in colour-science calculations. In this study, three CIE standard illuminants were employed to represent the three light sources we used to observed the colour changes in our samples. The SPDs of the three illuminants are shown in *Figure 4*. By calculating the hue-angle of the colour hue of a sample using each of these three illuminants, hue-angle differences between pairs of illuminants could be derived. These calculated differences in hue-angle would then be an indication of the possible extent of a colour change, if any, that could be observed in the sample under the corresponding pair of light sources.

Illuminant A represents light emitted by a 'blackbody' radiator at an absolute colour temperature of 2856 Kelvin (corresponding to an incandescent (tungsten filament) light source). The D illuminants represent one of the several phases of natural daylight, each with a particular correlated colour temperature (such as D65 or D75). Illuminant D65, representing average daylight with a correlated colour temperature of 6504 Kelvin, was used here. The CIE has not recommended an actual light source (a lamp) that corresponds to any of the D illuminants.

Fluorescent daylight simulators are widely used in the jewellery trade for observing the colour of gemstones indoors; they are often the only light source (other than daylight) that is available for gemstone display purposes. As shown in *Figure 4*, although they are commonly referred to as 'daylight simulators', these fluorescent lamps have very different spectral power distributions in comparison to the SPD of natural daylight. The CIE has recommended twelve different F illuminants to represent a variety of typical fluorescent lamps. Illuminant F7, with a correlated colour temperature of 6500 Kelvin and a colour rendering index of 90 (a measure on a scale from 0 to 100 of the accuracy of a light source to correctly render the colour of Munsell

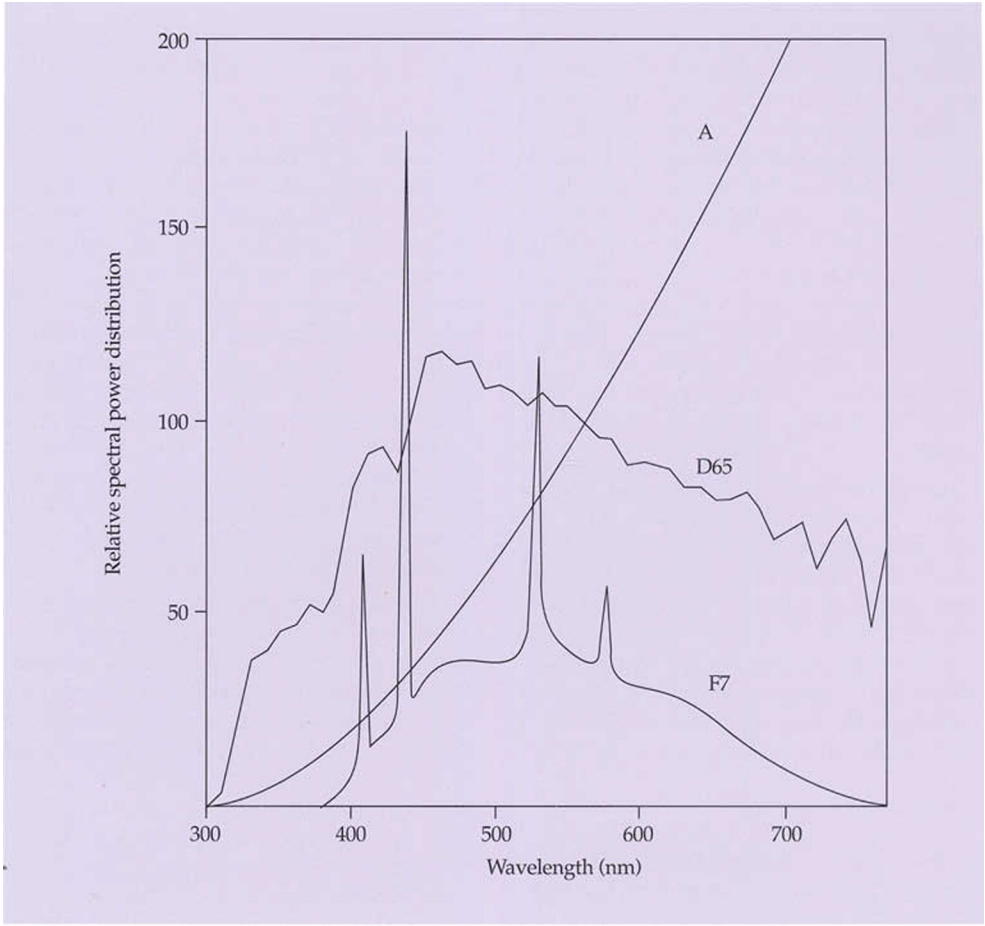

Figure 4: *Comparison of the spectral power distributions (SPDs) of the three CIE standard illuminants used for the colour calculations in this study. An SPD shows the relative portion of energy emitted at each wavelength segment across the electromagnetic spectrum by an illuminant or a light source. The SPD of an actual light source differs from that of the corresponding illuminant; furthermore, the SPD of the former can vary over time as a lamp ages. The SPD of illuminant D65 is very close to that of natural daylight. Illuminants A and F7 are explained in the text.*

samples), was chosen for this study since it is close to the type of fluorescent lamps used by jewellers and gemmologists.

Results

Table I lists the 18 samples included in this study, their colour hue as observed under incandescent and fluorescent lamps and in daylight, and the calculated hue-angles obtained from reflectance spectra for the three corresponding CIE standard illuminants. Comparison of the observed colour hues and the calculated hue-angle values indicates that there is general agreement between our colour observations and the measured data obtained with the spectrophotometer for the 18 samples.

For a given light source, the colour hues of our samples covered a wide range, as did their hue-angles for the corresponding standard illuminants. By comparing the hue-angles of a given sample obtained for different illuminants, the values of the hue-angle difference range up to almost

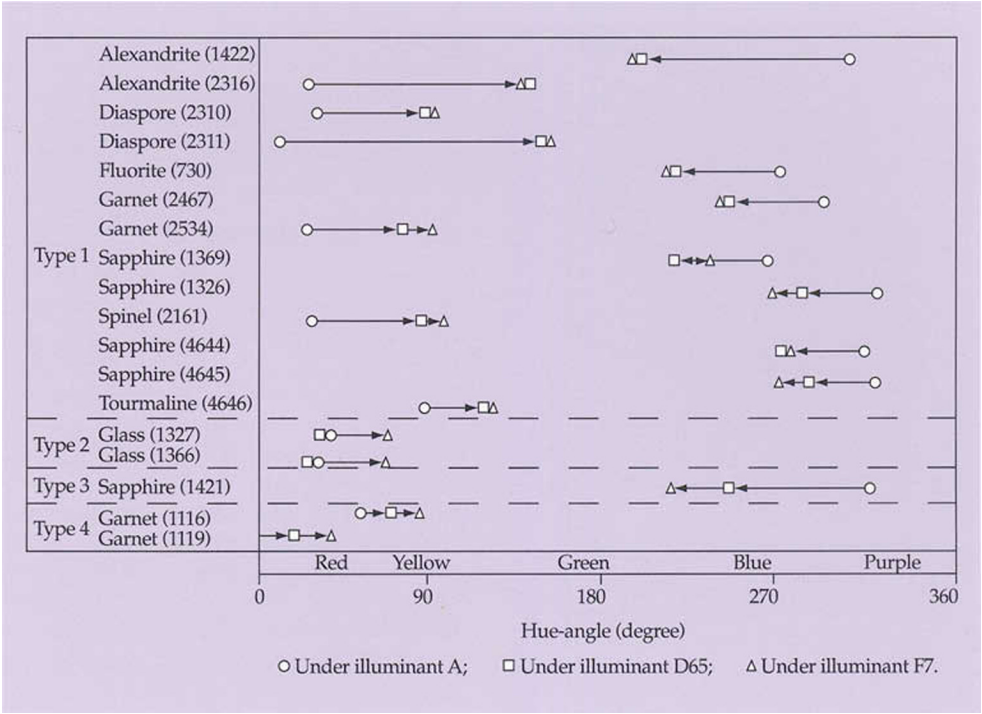

Figure 5: The hue circle depicted as a linear graph to show the direction and extent of colour change as calculated from hue-angle differences for the samples included in this study. For each sample, the measured hue-angles for illuminants A, D65 and F7 are indicated by a circle, a square, and a triangle symbol, respectively. When changing from illuminant A to D65 and F7, the direction of the hue-angle change for each sample is toward the 180 degree value. In general, this corresponds to a gemstone that is more 'red' or 'purple' in incandescent light, and more 'yellow', 'green' or 'blue' in daylight or fluorescent light.

180 degrees (the greatest possible difference). Since in most cases the hue-angles appear to correlate tolerably well with the observed colour hues in our samples, we suggest that the magnitude of the difference in the hue-angle can be used as indication of the extent of colour change that the samples will exhibit between the corresponding light sources.

The data in *Table I* illustrate observations made previously by others that the calculated hue angles of the samples always move in a *direction* toward the 180 degree value (toward a green hue) when the illuminant changed from A to D65 or F7 (corresponding to a change from incandescent to daylight or fluorescent light), as illustrated in *Figure 5*. However, the extent of the hue-angle change, and its location on the hue circle, varied from one sample to the next, as shown in this same figure.

As a test of our colour measurement methodology, we carried out ten repeated colour reflectance measurements of the same sample of a synthetic glass (#2088; a round-brilliant cut weighing 2.55 ct, and measuring 9.3 x 9.3 x 5.6 mm) to check the precision of our results. As shown in *Table II*, the standard deviations in the hue-angle changes for each of the three pairs of illuminants are each less than 4 degrees. These small values indicate that our measurements for this sample are reproducible to establish the colour hue and the hue-angle, since such small variations in hue-angle could not be recognized visually by a person relying on their memory to remember a colour (see Burnham and Clark,

Table II: Precision of hue-angle measurements.

Test	Hue-angle change		
	A and D65	*D65 and F7*	*A and F7*
1	7.7	63.7	56.0
2	6.5	69.3	62.9
3	6.9	70.7	63.8
4	4.8	61.8	57.0
5	4.1	65.1	61.1
6	5.2	67.2	62.0
7	8.1	70.3	62.2
8	8.8	72.1	63.3
9	6.2	63.8	57.5
10	4.7	63.2	58.5
Mean	6.3	66.7	60.4
Standard Deviation	1.6	3.7	2.9

Calculated differences in hue-angle (measured in degrees in CIELAB colour space) between pairs of illuminants A, D65 and F7, for a colour-change glass (#2088). The hue-angle changes were obtained by ten separate measurements of the reflectance spectra of this glass. Between measurements, the Hitachi spectrophotometer was recalibrated, and the glass sample was repositioned in the instrument.

1960). However, with similar experiments with polished gemstones of smaller diameter (4 mm or less), we found less repeatability with the colour measurements. We attribute this to the difficulty in positioning smaller samples in exactly the same position each time in the spectrophotometer.

While measurement of a sample's colour hue by this method seems promising, we could not correlate the observed colour changes in our samples seen under different light sources to changes in either their saturation or lightness calculated from reflectance spectral data. Based upon our experiments to date, the method discussed here seems best suited for gemstones or other samples that possess relatively saturated colours (with a chroma value of 5 or more in the CIELAB colour space). Samples that exhibit very pale, desaturated colours have hues located near the origin (i.e. the central 'white point') in colour space. While the calculated hue-angle changes of these materials can be artificially very large, these values are meaningless in such instances since any change in their very pale colour would not be perceptible to the eye.

Discussion

Since the CIELAB colour space is a uniform colour-order system, equal differences in hue-angle correspond to equal differences in observed colour hue. Therefore, the hue-angle change in the CIELAB colour space can be used to quantitatively characterize the change in a sample's colour hue for pairs of the three CIE standard illuminants and the corresponding light sources we selected. Use of the instrumental method described here can help support visual observations and the verbal description of a colour-change in gemstones.

One goal of this study was to establish an objective (observer independent) means for determining if a particular gemstone actually changes colour when viewed under different light sources. Based upon a published study of the colour appearance change of opaque Munsell colour chips under different light sources (Helson *et al.*, 1952) and our own experiments with coloured gemstones, we previously selected a 20 degree hue-angle change as our criterion for determining whether a sample would display an observable colour change between a pair of light sources (Liu *et al.*, 1994). If the hue-angle change for a sample between any pair of the three CIE standard illuminants (A, D65, and F7) was equal to or greater than 20 degrees, and the colour saturation of the sample was suitably high (a perceptible saturation of chroma level 5 or higher), we would expect to see a colour change in the sample when viewing it under one and then the other of the corresponding pair of light sources. By subtracting pairs of hue-angle values for the samples listed in *Table I*, it can be seen that all of these samples exhibited a calculated hue-angle change of 20 degrees or more for at least one pair of the three CIE standard illuminants (and in almost all cases,

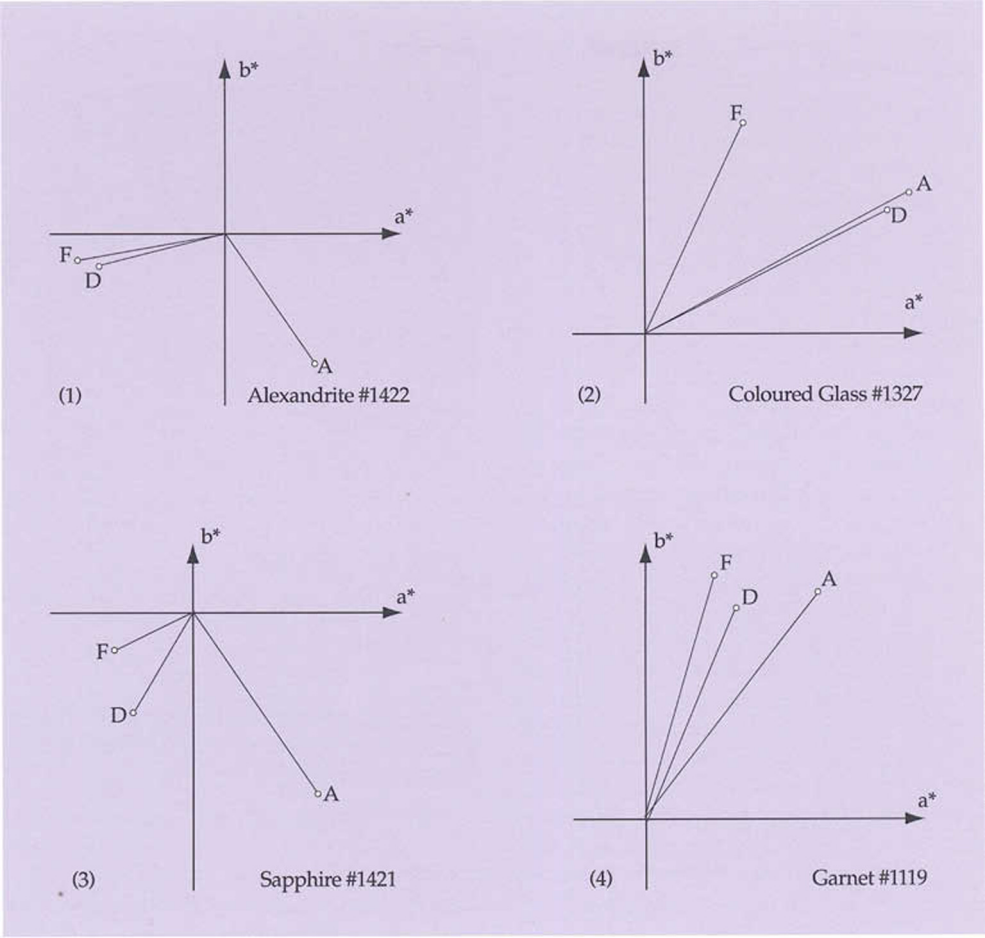

Figure 6: *Hue-angle changes of specific samples, depicted on the a* b* plane of the CIELAB colour space (refer again to Figure 2), for four types of colour change. In each of these sketches, the point marked 'A' represents the hue-angle of the sample for illuminant A, the point marked 'D' is for illuminant D65, and the point marked 'F' is for illuminant F7. The colours of these samples under the different light sources, and the extent of their colour change between pairs of light sources, can be predicted from these sketches. The distance of the point from the origin of the diagram also provides an indication of the saturation of the colour of the particular sample that is represented by the point. These sketches provide a means of illustrating the difference between the types of colour-change behaviour.*

we could see a hue change in the sample between the corresponding light sources). It can also be seen from this table that the hue-angle changes vary up to almost 180 degrees (the maximum value), with a larger hue-angle difference representing a more pronounced change in colour hue. Finally, a sample may exhibit a hue-angle change of 20 degrees or more for one pair of CIE standard illuminants, but not for another pair (i.e. the sample would be expected to change colour between one pair of light sources, but not between another pair).

It should be emphasized that we do not consider the 20 degree hue-angle value as a final or absolute criterion of a colour-hue change in a gemstone. It is an indicator value of the extent of a hue-angle change, above which a colour change could be observed in the samples we examined. If a criterion

describing a more obvious colour change is preferred, a 30 degree hue-angle change could be used.

The observation and measurement of colour-change gemstones led Liu *et al.* (1994) to define four categories or types of colour change, based upon the 20 degree hue-angle change criterion and the three CIE standard illuminants listed above. Both illuminants A and D65 can each be considered as approximating a thermal radiator in the visible region of the spectrum. The difference in their SPDs is mainly due to their colour temperature difference (see again *Figure 4*). Illuminants D65 and F7 have the same colour temperature, but different SPDs. Compared to illuminant A, illuminant F7 has both a higher colour temperature and a spectrum that contains sharp emission lines. Therefore, if the hue-angle change between illuminants A and F7 is smaller than 20 degrees, theoretically there is little possibility that the hue-angle changes between A and D65, and between D65 and F7, could be larger than 20 degrees. For this reason, Liu *et al.* (1994) suggested that the hue-angle change for colour-change gemstones should always be greater than 20 degrees for the illuminant pair (A–F7). The criteria for these four categories are summarized in *Table III*. The four types can be described as follows:

Type 1. This category represents the traditional 'alexandrite effect' recognized by gemmologists; it is also the type of colour change found most commonly among our study samples (see *Table I*). It represents a situation of a sample's colour change between illuminants that differ in their SPD and in their colour temperature. Perhaps not surprisingly, this type 1 colour change can be quite pronounced, with colour hues on almost opposite sides of the hue circle (with hue-angle changes approaching 180 degrees).

Type 2. This type of colour change was found in three samples of faceted glass. In this situation, similar colours are seen in the sample under either daylight or incandescent light sources, but a different colour occurs under a fluorescent light source. In this category, the extent of the colour change is more moderate, with hue-angle changes from 40 to 90 degrees for the samples measured so far.

Table III: *The types of colour change for CIE illuminants A, D65 and F7 for conditions where at least one hue-angle change is greater than 20 degrees.*

Type	*Hue-angle changes for each pair of illuminants*		
	A and D65	*D65 and F7*	*A and F7*
Type 1	> 20	< 20	>20
Type 2	< 20	> 20	>20
Type 3	> 20	> 20	>20
Type 4	< 20	< 20	>20
Type 5	< 20	> 20	<20
Type 6	> 20	> 20	<20
Type 7	> 20	< 20	<20

The types of colour change can be defined as to whether the calculated difference in hue-angle (as measured in the CIELAB colour space) is greater or less than 20 degrees for pairs of illuminants A, D65 and F7 as shown here.
Type 5, type 6 and type 7 categories have not yet been encountered based upon hue-angles calculated from reflectance spectra measurements.

Type 3. Samples belonging to this category will exhibit a colour change between any pair of the three illuminants, but the extent of the hue change will be moderate. So far only one synthetic sapphire has been found to display this type of colour change.

Type 4. This type of colour change occurs only between fluorescent and incandescent light sources that have a suitably large colour temperature difference. At best, the extent of the colour change in this category is very weak, with hue-angle changes of only 20 to 30 degrees.

As additional colour-change samples are investigated, we expect to find further representatives of these categories of colour-change behaviour. The diagrams in *Figure 6* illustrate the hue-angle changes or samples that fall into these colour-change categories. *Figure 7* presents three colour-corrected photographs of representative gemstones from this study that are examples of the four colour-change types mentioned above. These

Figure 7: *Four representative gem samples are shown under three light sources to illustrate their different colour-change behaviour. Clockwise from the top, the four gem samples are coloured glass, alexandrite, sapphire and garnet. They range in weight from 2–10 ct. The three light sources are (a) incandescent light, (b) natural daylight, and (c) fluorescent light. The three photographs have been colour-corrected using a computer and the Photoshop™ software program to show the correct colours under the different light sources. Original photos by Tino Hammid, copyright Tino Hammid and GIA.*

photographs illustrate how different colour changes in gemstones can occur between different light sources.

Conclusion

In this study, we have explored the use of a spectrophotometer for colour measurement to investigate the colour-change behaviour of some gemstones and other materials. Many descriptions of such gemstones have been published, which often give explanations of the spectral causes of this phenomenon. Other gemmological researchers have preceded us in exploring the use of colorimeters and spectrophotometers for gemstone colour measurement, and some of their results have been published. While we cannot claim that our use of a spectrophotometer for gemstone colour measurement is either new or original, we do claim that:

(1) the geometry of colour measurement should approximate as closely as possible the geometry of observing colour in gemstones (as attempted here), if the results of the two methods are to be comparable;

(2) the reflectance measurement geometry gives results that are more consistent with the observation of face-up colour in faceted gemstones, especially for the colour hue (but not necessarily for the colour saturation or colour lightness); and

(3) how colour measurement data are graphically depicted in colour space is important in understanding the relationship between the results of colour measurement and colour observation.

We have shown how the use of the CIE-LAB uniform colour space to depict hue-angle relationships can be used to develop a minimum hue-angle difference (20 degrees) criterion for samples that would be expected to display a colour-hue change perceptible to the eye. By tabulating hue-angle values for gem materials with three CIE standard illuminants that correspond to the daylight, incandescent, and fluorescent

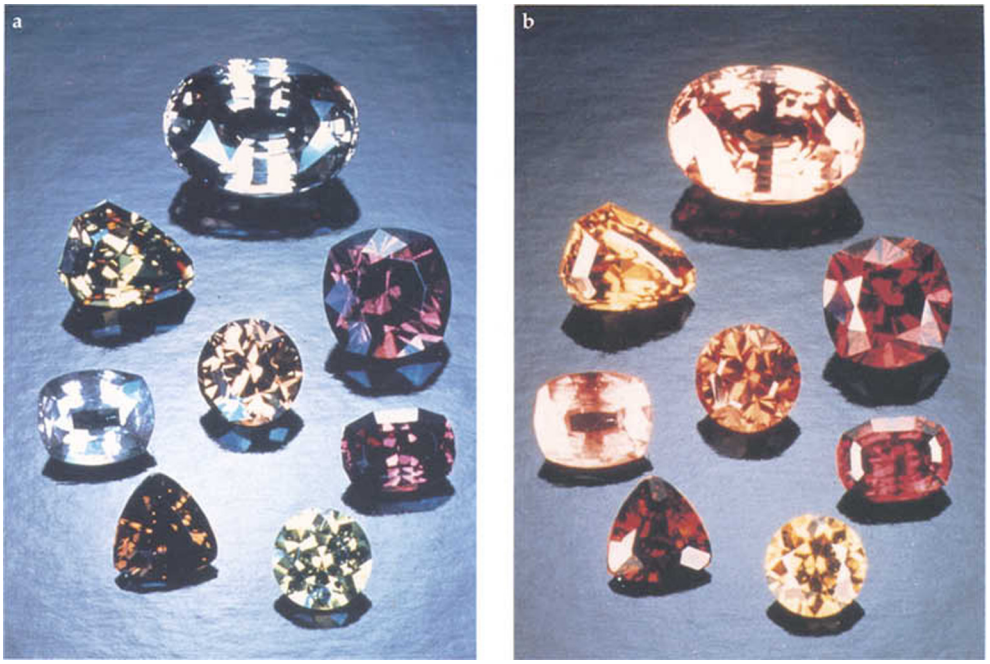

Figure 8: A group of eight colour-change garnets (0.74 to 5.32 ct) seen under (a) a fluorescent daylight simulator and (b) an incandescent light (right). Photo by Tino Hammid, copyright GIA.

light sources used in the jewellery trade, we demonstrate that the traditional 'alexandrite effect' is more complicated than previously recognized by gemmologists. Gem samples may not display a change of colour under one pair of light sources, but may display a change between another pair of light sources when their hue-angle difference is greater than 20 degrees. Examples of gemstones are given of the different types of colour-change behaviour, along with criteria that could be used to assign the colour-change behaviour of other gem materials to one of these types. The most practical benefit of this study is to illustrate how colour reflectance measurement data can assist the gemmologist who, when examining a gemstone and thinking it may change colour under different light sources and not wanting to solely rely on his or her colour memory, wishes to have some independent confirmation that the gemstone is actually displaying a colour change, which could increase its market value. Gemstones exhibiting an attractive alexandrite effect, such as the group of garnets shown in *Figure 8*, will always be in demand in the jewellery industry.

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The authors thank the following individuals for supplying colour-change gemstones or useful information for this study: G. Cankur of Miami Beach, Florida; D. Clary of Los Angeles, California; Dr. E. Gübelin of Lucerne, Switzerland; T. Hammid of Los Angeles, California; A. Hodgkinson of Glasgow, Scotland; the late R. C. Kammerling of the GIA Gem Trade Laboratory, Santa Monica, California; S-P. Kanaan of Paris, France; the late D. Knapp; and Dr G.R. Rossman of the California Institute of Technology, Pasadena, California. S. McClure, manager of gem identification in the GIA Gem Trade Laboratory, Carlsbad, California, provided comments on the practices of describing colour-change gemstones. An earlier version of this article benefited from comments by Dr George Rossman and Dr Karl Schmetzer.

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Colour hue change of a gem tourmaline from the Umba Valley, Tanzania

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ABSTRACT: The hue of a tourmaline from the Umba Valley, Tanzania, changes from green to red with increases in path length of light through the material. This hue change phenomenon, called the 'Usambara effect', is different from any colour-change effect previously described in gemstones. Colorimetric methods have been used to analyze this tourmaline. Results of this study suggest that the Usambara effect is a complex phenomenon including effects of both path length and the colour change observed under different light sources (the alexandrite effect).

Keywords: Alexandrite effect, colour, colour change, light, tourmaline, Usambara effect

Introduction

Halvorsen and Jensen (1997) described a reportedly new colour-change effect, which they called the Usambara effect, in gem tourmaline from the Umba Valley, Tanzania. These tourmaline samples are strong yellow- to blue-green when viewed separately in transmitted light, but when two are superimposed over one another, their combined colour becomes red with no change in sample orientation or type of illumination. These authors attributed this effect to a change in the path length of light through the material.

In this study, we re-examined samples of this gem tourmaline, and have analyzed their colour-change behaviour using colorimetric methods as described in Liu *et al.* (1994). Although Halvorsen and Jensen (1997) concluded that the Usambara effect is due to changes in path length, they stated that the observed colours could be mildly modified by the type of illumination, which is the well-known alexandrite effect. We present here a more complete explanation using colorimetric calculations of both effects in this material, and demonstrate how the alexandrite effect predominates over a certain range of sample thicknesses, while the Usambara effect becomes more pronounced as the sample thickness increases beyond this range. According to K. Nassau (pers.comm., 1998), this gem tourmaline provides an interesting example of how several different causes can give rise, either separately or in combination, to colour changes in a gem or mineral.

Materials

Several rough tourmaline crystal fragments from the Umba Valley were examined (*Table I*). Sample #4140 weighs 13.21 ct, has parallel polished surfaces which

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Table I: The properties of the three gem tourmaline samples.

Sample #	Weight (ct)	Colour[1]	Thickness[2]	Shape
4140	13.21	Green	6.25	Parallel Surfaces
4427	16.14	Green	6.79	Rough
4428	48.16	Yellowish-green	11.68	Rough

Note: 1. Transmittance colour over a daylight simulator.
2. Maximum thickness in mm.

were specially prepared for this study, and is approximately 6.25 mm thick. The gemmological properties, colours, and spectra of the sample are the same as the samples described by Halvorsen and Jensen (1997). *Figure 1* shows two tourmaline samples viewed by transmitted light over a daylight simulator. Sample #4427 weighs 16.14 ct, and with a maximum thickness about 6.79 mm, its colour appears green. Sample #4428 weighs 48.16 ct, has a maximum thickness about 11.68 mm, and its transmittance colour appears yellowish-green. When sample #4427 is placed on the top of sample # 4428 to increase the total path length, their combined transmittance colour changes to dark red (see *Figure 2*). *Figure 3* shows the spectral transmittance curve of tourmaline sample #4140, which was obtained using a Hitachi U-4001 spectrophotometer with an integrating sphere. A wavelength range from 300 nm to 830 nm was scanned with a wavelength interval of 1 nm. Colorimetric data were obtained using the Spectracalc software from Galactic Industries Corporation.

Figure 1: *Transmittance colours of tourmaline sample #4427 on the left and tourmaline sample #4428 on the right. Photograph by Yan Liu.*

Figure 2: *A dark red total transmittance colour is observed when tourmaline sample #4427 is placed on the top of sample #4428. Photograph by Yan Liu.*

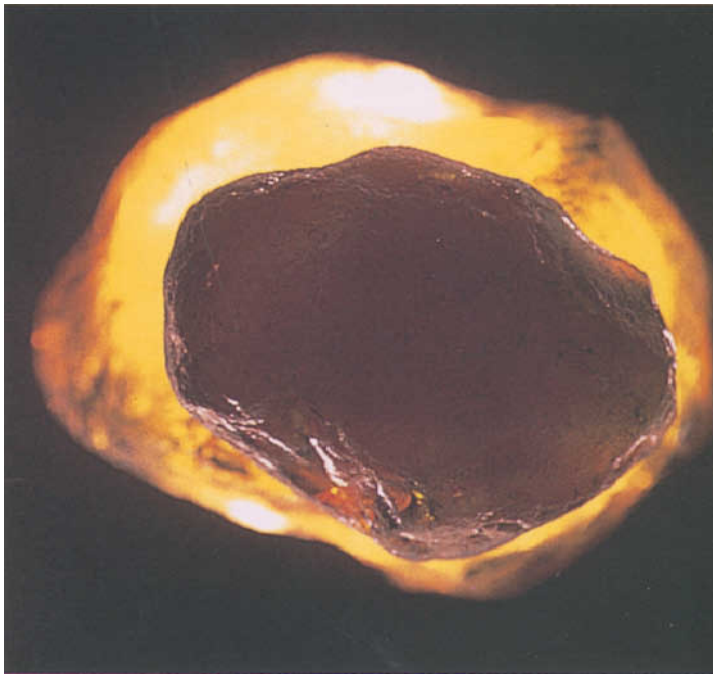

Results

Transmittance Calculations

The intensity of transmitted light can be calculated by Bouguer's law:

$$I(\lambda) = I_0(\lambda)\, p(\lambda)\, e^{-\alpha(\lambda)t} \qquad (1)$$

where λ is the wavelength, $I(\lambda)$ is the intensity of the transmitted light, $I_0(\lambda)$ is

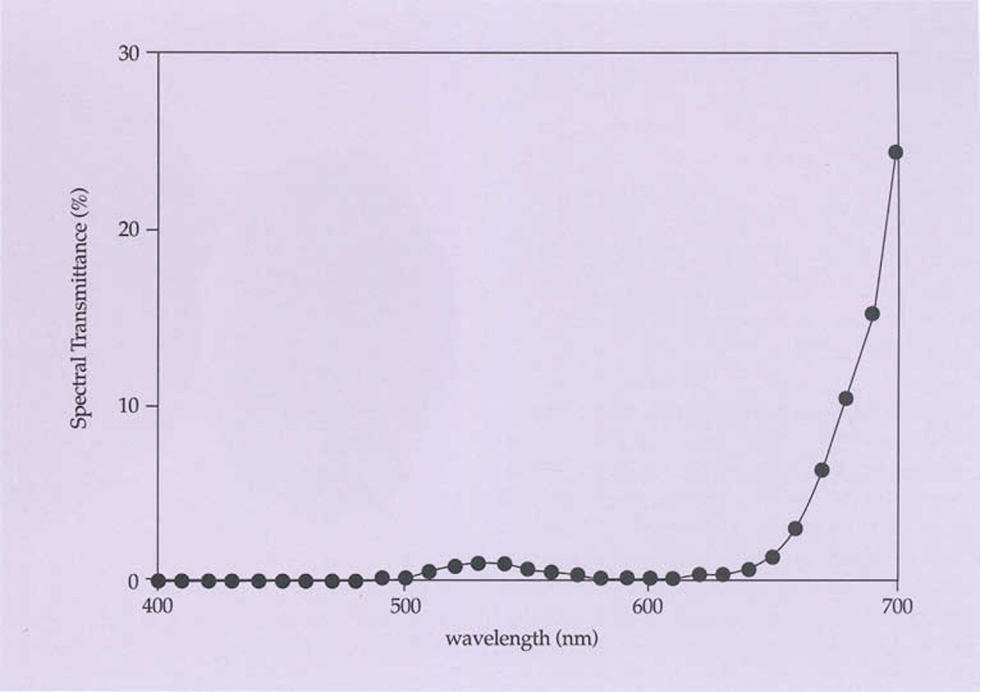

Figure 3: *The measured spectral transmittance curve of tourmaline sample #4140. A weak transmittance band is centred at about 540 nm, and a strong band is located above 650 nm.*

intensity of the incident light, $p(\lambda)$ is reflection factor which takes into account the light loss due to multiple reflections at the parallel surfaces of the specimen (Liu *et al.*, 1991), $\alpha(\lambda)$ is the absorption coefficient of the material, and t is the sample thickness. The measured refractive indices of this tourmaline as reported by Halvorsen and Jensen (1997) are 1.644 and 1.622. Since the dispersion of the tourmaline is relatively small, we used a value of 1.63 as an approximate refractive index in the visible range to calculate the surface reflection factor [calculated by the equation $p = 2n/(n^2 + 1)$], which is about 0.89. The absorption coefficient varies with wavelength. The transmittance $T(\lambda)$ varies exponentially with $\alpha(\lambda)$ multiplied by sample thickness according to the formula:

$$T(\lambda) = 0.89e^{-\alpha(\lambda)t} \qquad (2)$$

If the transmittance is measured for various wavelengths at one known thickness (in this case, the 6.25 mm-thick sample #4140, with results plotted in *Figure 3*), then the absorption coefficient of this tourmaline can be calculated using equation (2) in the form:

$$\alpha(\lambda) = \frac{1n\,(T/0.89)}{6.25\ mm^{-1}} \qquad (3)$$

For the purpose of this study, we wanted to understand the effect of increasing path length on the colour change of this tourmaline, and since only a limited amount of actual gem tourmaline was available from the deposit in the Umba Valley, we used the colorimetric method to calculate colour coordinates for this tourmaline as if it existed in polished pieces of several different thicknesses.

Since the absorption coefficient is a constant for each wavelength, Beer's equation can then be used to calculate the transmittance $T(\lambda)$ for any number of thicknesses of this tourmaline material, as

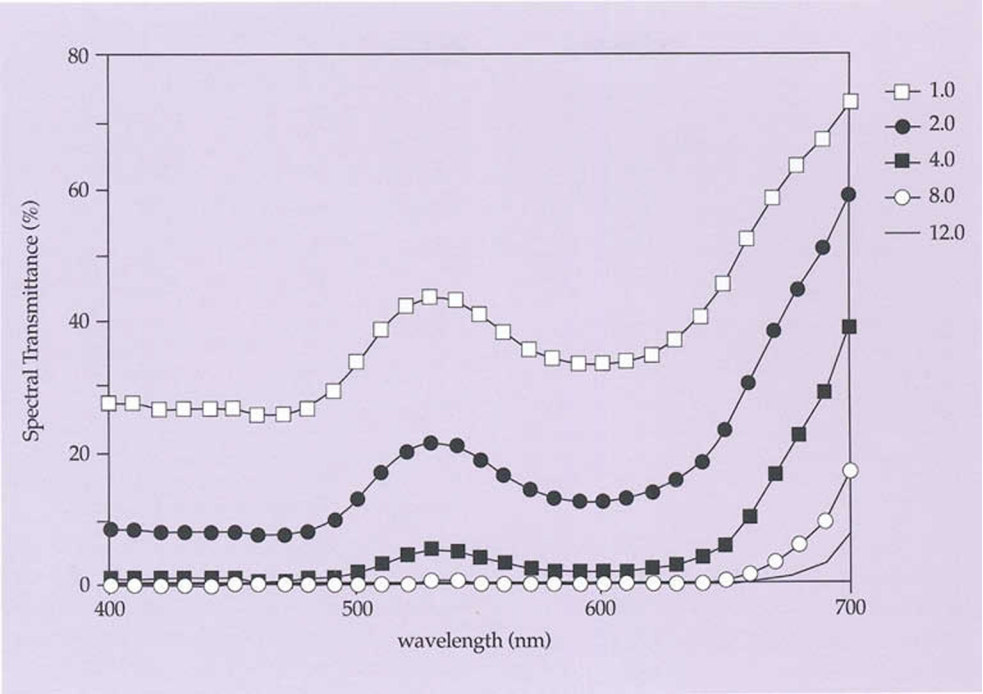

Figure 4: *The calculated spectral transmittance curves of tourmaline sample #4140, if it could be fashioned into pieces of different thicknesses ranging from 1.0 up to 12.0 mm.*

shown by the curves in *Figure 4* (for 1.0, 2.0, 4.0, 8.0 and 12.0 mm-thick samples). This figure shows that there are two transmittance bands in the visible range, one centred at 540 nm (a middle wavelength band referred to here as the 540 nm band), and the other in the region above 650 nm (a long wavelength band). Since the spectral transmittance of the band centred at 540 nm is reduced much faster than that of the long wavelength band due to Beer's law with increasing sample thickness (or path length), only the long wavelength band is left when the thickness of the tourmaline is over 10 mm.

Colorimetric Calculations

The CIELAB colour space is the most used uniform colour space for representing colour appearance, and equal colour differences approximately represent equal visual colour perception differences. The calculation of L*, a*, and b* is based on the opponent colour vision model and chromatic adaptation:

$$L^* = 116\,(Y/Y_n)^{1/3} - 16$$

$$a^* = 500\,[(X/X_n)^{1/3} - (Y/Y_n)^{1/3}] \qquad (4)$$

$$b^* = 200\,[(Y/Y_n)^{1/3} - (Z/Z_n)^{1/3}]$$

where X, Y, and Z are the CIE tristimulus values of the coloured object calculated from data measured by a colorimeter or spectrophotometer, and X_n, Y_n, and Z_n are the similar values obtained for a standard white object (CIE, 1986). In CIELAB colour space, L* represents lightness; +a* represents 'redness', −a* is 'greenness'; +b* is 'yellowness', and −b* is 'blueness'. The CIELAB colour space includes the von Kries type chromatic adaptation X/X_n, Y/Y_n, and Z/Z_n (CIE, 1986). In the CIELAB colour space, the hue-angle is used to represent the hue of a colour. The hue-angle is given by:

$$h = \arctan\,(b^*/a^*) \qquad (5)$$

Table II: Calculated CIELAB data of tourmaline sample #4140, if it were fashioned into pieces of different sample thicknesses.

t (mm)	L*	a*	b*	C	h (degrees)
1.0	67.77	−8.92	14.69	17.19	121.3
2.0	47.24	−12.18	21.27	24.51	119.8
4.0	20.66	−10.47	22.42	24.75	115.0
6.0	5.97	−3.88	8.85	9.66	113.7
8.0	1.38	0.14	2.19	2.20	86.3
10.0	0.37	0.60	0.60	0.85	45.3
12.0	0.12	0.44	0.20	0.48	24.3

Note: t is the thickness, C is the saturation, and h the is hue-angle. Standard D65 illuminant. Maximum chroma is about 24.75 at the thickness of 4.0 mm.

Table III: Hue angle (h) and hue-angle change (Δh) (in degrees) data of tourmaline sample #4140, if it were fashioned into pieces of different sample thicknesses, using CIE standard illuminants D65 and A.

t(mm)	h(D65)	h(A)	Δh
1.0	121.3	102.6	18.7
2.0	119.8	100.5	19.3
4.0	115.0	92.5	22.5
6.0	113.7	70.5	43.2
8.0	86.3	42.2	44.1
10.0	45.3	26.0	19.3
12.0	24.3	19.3	5.0

Note: t is thickness, h(D65) is the hue-angle under illuminant D65, h(A) is the hue-angle under illuminant A, and Δh is the hue-angle change between illuminants D65 and A.

The hue-angle has been used to explain the alexandrite effect (Liu *et al.*, 1994).

Table II shows calculated CIELAB data of the tourmaline sample #4140 using the CIE standard D65 illuminant, which represents average daylight, at different thicknesses. *Figure 5* illustrates the colour trace of the tourmaline sample with changes in the thickness under the D65 illuminant. The hue-angles and hue-angle changes under CIE standard illuminants A and D65 are tabulated in *Table III*. *Figure 6* shows the hue-angle change of the sample with changes in the thickness.

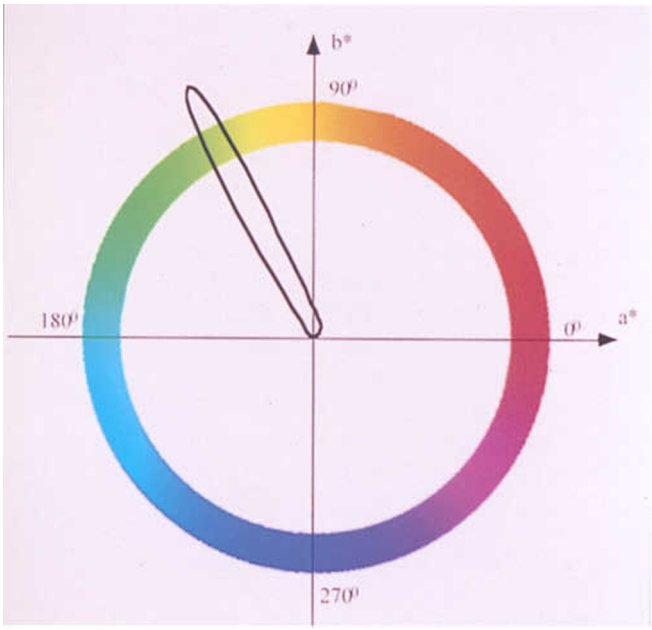

Discussion

This study briefly mentions several important topics relevant to the colour of gemstones:

1. colorimetric calculations,
2. colour change with the change in sample thickness,
3. the alexandrite effect, and
4. colour visual perception.

A discussion involving all four topics is necessary to understand the colour effects observed in this gem tourmaline.

***Figure 5:** The hue circle and the colour trace of the tourmaline sample #4140 in the CIELAB colour space (plotted according to the hue-angle and saturation values in Table II). Increases in saturation occur with greater distances from the origin. The colour trace moves clockwise from zero saturation for the thickness of 0 mm, to a maximum in saturation of about 25.0 and a hue-angle of about 117.5 degrees for thickness of 3.0, to saturation of 0.85 and hue-angle of 45.3 degrees for thickness of 10.0 mm. When the relative thickness becomes infinite or very thick, the saturation again becomes zero (the sample becomes black).*

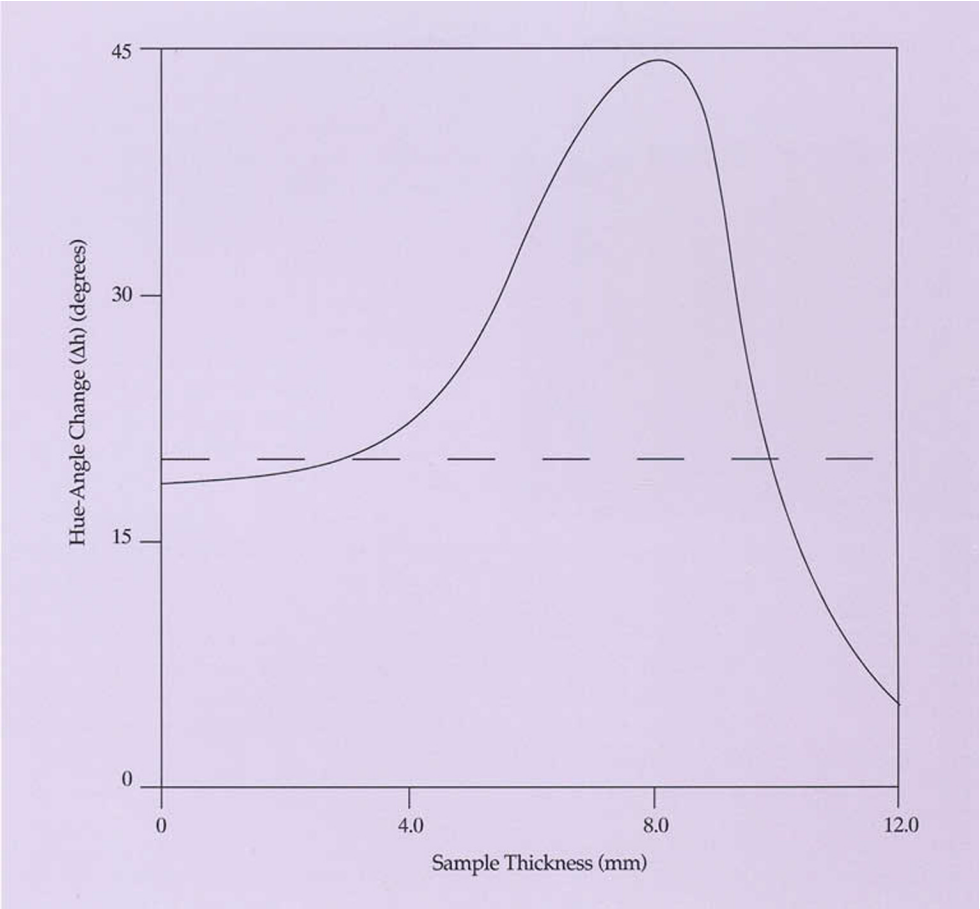

Figure 6: *The hue-angle change of the tourmaline sample between CIE illuminants D65 and A with changes in sample thickness. The dashed line is the 20 degree line. According to a convention proposed by Liu* et al. *(1994), the tourmaline shows an 'alexandrite effect' when the hue-angle change is greater than 20 degrees (for a sample thickness from 3.5 to 9.9 mm when the hue-angle change is above this line).*

Colorimetric calculation

The hue of a gemstone can be accurately represented by the hue-angle in the CIELAB colour space. As such, the calculated hue-angle can be used to investigate colour-change effect in materials (Liu *et al.*, 1994, and previous paper in this issue). From *Table II*, we know that the hue-angle of the tourmaline under D65 illumination decreases as the sample thickness increases. The hue-angle is 121.3 degrees with a thickness of 1.0 mm, and it decreases to 115.0 degrees with the thickness of 4.0 mm. Hue-angles between 121.3 degrees and 115.0 degrees represent the colour range with a yellowish-green hue (again see *Figure 5*). When the thickness increases to 8.0 mm, the hue-angle is 86.3 degrees, which represents yellow. The hue-angle is 45.3 degrees when the thickness is 10.0 mm (an orangy-red hue), and when the thickness is 12.0 mm, the hue-angle is about 24.3 degrees, representing red.

The colour change caused by a light-path change

All coloured materials change colour with changes in thickness or colourant concentration, and most of them also change

Figure 7: A hue change with colourant concentration or thickness change can be seen in many dyes, such as this commercially available yellow food colour. Its hue changes from yellow, to orange, and to red with increasing colourant concentration. Photograph by Maha DeMaggio.

hue (Nassau, 1983, 1997; Kuehni, 1997, 111–4). A chrome alum solution appears green in a thinner sample, and purplish-red in a thicker sample, which has been referred to dichromatism (Webster, 1994, p. 678). This phenomenon is similar to the colour change of the gem tourmaline described by Halvorsen and Jensen. *Figure 7* shows the colour change of a common type of food dye (for colouring Easter eggs) with a change in its colourant concentration. For a low concentration, the solution appears yellow. With an increase in concentration, the colour changes from yellow to orange, and then to red. This illustrates a colour-hue change with an increase in colourant concentration (Nassau, 1983). The hue and saturation changes of dye solutions with changes in concentration are usually represented by their *colourant traces*, which are the curves in a CIE colour space connecting the chromatic coordinates of the colourants at different concentrations. For materials other than colourants, similar curves called *colour traces* are used to represent hue and saturation changes with changes in the path length of light through them (Kuehni, 1997, 111–4).

The 'Usambara effect' is typical of the colour change caused by a change in sample thickness or concentration. With increase in the sample thickness of this tourmaline, the 540 nm band becomes smaller and smaller compared to the intensity of the long wavelength band (again see *Figure 5*). The tourmaline, therefore, appears increasingly red the thicker the sample. When the thickness is greater than 10.0 mm, only the long wavelength band is transmitted. The stone appears red as long as the light source has a red component, regardless of the kinds of light sources used. If the light source has no red component, this tourmaline will appear black when its thickness is more than 10.0 mm.

The colour trace curve in *Figure 5* is similar to that of some dyes that change hue and saturation with changes in concentration or thickness (Kuehni, 1997, 111–4). The saturation of the colour of the tourmaline first increases with increases in thickness until it reaches a maximum at about 4.0 mm; then the saturation decreases with increases in thickness.

The alexandrite effect

With increase in the thickness, the hue-angle difference between CIE illuminants D65 and A also changes. According to the 20 degree hue-angle change criterion suggested by Liu *et al.* (1994), the alexandrite effect between CIE illuminants D65 and A is shown by this tourmaline in sample thicknesses between 3.5 and 9.9 mm (again see *Figure 6*), with a maximum alexandrite effect when its thickness is about 8.5 mm.

Human colour perception

Webster (1994, 673, Fig. 31–2) mistakenly referred to the V(λ) function as the 'curve showing the colour response of the normal human eye'. Historically, he and many others incorrectly used it to explain some colour phenomena, such as the alexandrite effect. In fact, the sensitivities of the photoreceptors of the eye depend upon the chromatic adaptation under a particular light source.

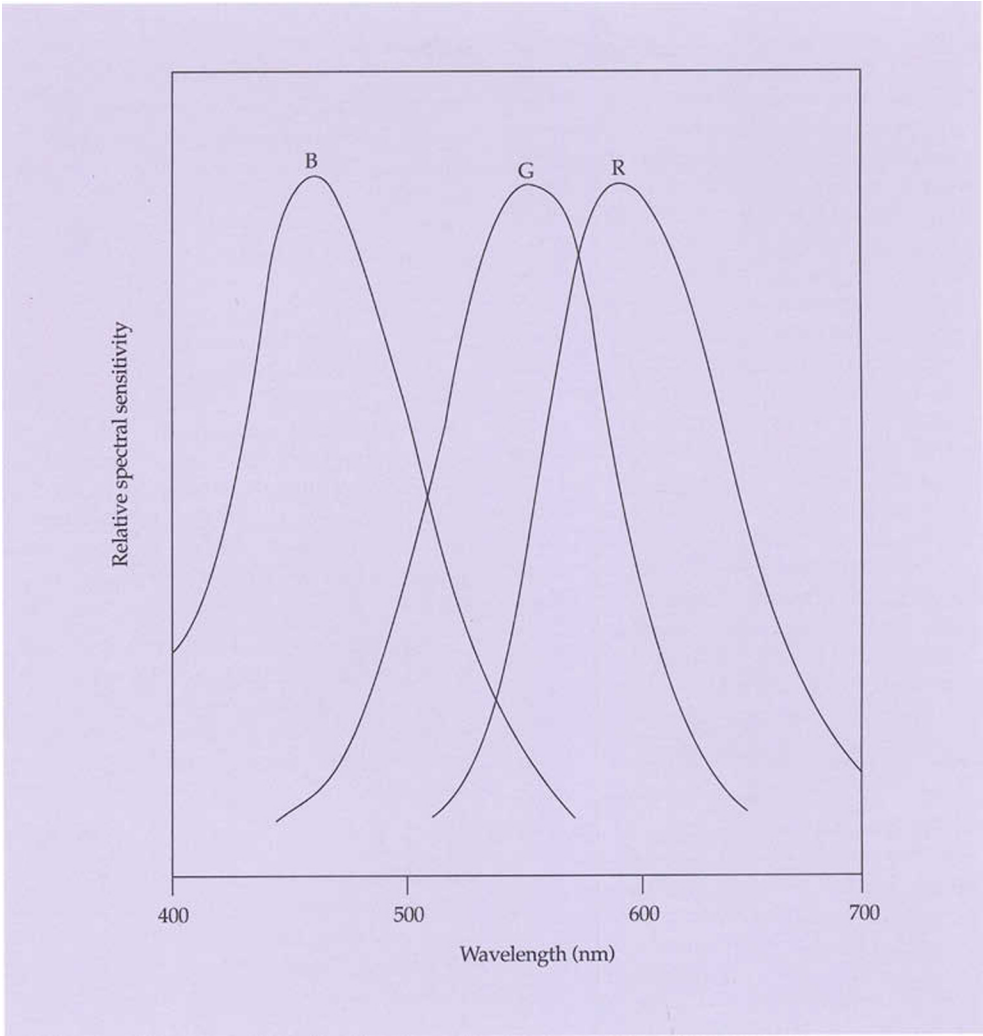

Figure 8: *The normalized spectral sensitivities of the red (R), green (G), and blue (B) cone photoreceptors for human colour vision.*

The human eye has three types of cone photoreceptors (red, green and blue) for colour vision (see *Figure 8*). The sensitivities of the three types of cone photoreceptors depend on adaptation of the eyes to the visual surroundings (Liu, 1996). When the three types of cone photoreceptors receive light from a gemstone, they produce three types of visual signals (R, G, B). These signals are processed though the visual path, and sent to the brain where colour sensations are experienced.

The R, G, and B visual signals can be represented by the CIE tristimulus values X, Y, and Z, which are calculated by the equations

$$X = \int T(\lambda) S(\lambda) \bar{x}(\lambda) d\lambda$$

$$Y = \int T(\lambda) S(\lambda) \bar{y}(\lambda) d\lambda$$

$$Z = \int T(\lambda) S(\lambda) \bar{z}(\lambda) d\lambda \qquad (6)$$

where $T(\lambda)$ is the spectral transmittance, $S(\lambda)$ is the relative spectral power distribution of the light source, and $\bar{x}(\lambda)$, $\bar{y}(\lambda)$ and $\bar{z}(\lambda)$ are the CIE colour-matching functions which correspond to the spectral sensitivities of the cone photoreceptors. The visual signals we experience depend on the integrated effects of the spectral power distribution of the light source, the spectral transmittance of the sample, and the spectral sensitivities of the cone photoreceptors. Therefore, colour perception is determined by four factors: chromaticity adaptation, the spectral sensitivities of the cone photoreceptors, the spectral power distribution of the light source, and the spectral transmittance of the material being observed. A colour phenomenon cannot be explained by relying only on one or two of these factors. This is why, using the two spectral transmittance bands in the spectra of certain gemstones, and the change in spectral power distribution of the light sources, fails fully to explain the cause of the alexandrite effect.

Colour change in this tourmaline

One can explain the colour change of this tourmaline with its thickness change by using the three R, G, and B visual signals, or equally, by the CIE tristimulus values. When the thickness of this sample is very thin (for example, 1.0 mm), the calculated tristimulus values are $X = 33.2$, $Y = 37.7$, and $Z = 29.7$. Since $Y > X$ and $Y > Z$, the green signal Y is dominant, therefore, the sample appears green. When the thickness is medium, $X = 0.15$, $Y = 0.15$, and $Z = 0.01$, therefore, $X = Y$ and Z can be ignored.

Since the red signal X and the green signal Y are equal, the tourmaline appears yellow. When the thickness reaches, for example, 12 mm, $X = 0.023$, $Y = 0.013$, and $Z = 0.000$, we have $X > Y$, and $Z = 0$. The red signal is thus dominant, and the stone appears red.

Using a sample thickness of 8.0 mm and under CIE D65 illuminant, the calculated a* and b* values are: a* = 0.14, and b* = 2.19. Its hue-angle is about 86.3 degrees. Therefore, a 8.0 mm thick tourmaline under daylight appears a slightly orangy-yellow. When it is under an incandescent light, the hue-angle is about 44.1 degrees, thus the tourmaline appears an orangy-red (again see *Figure 5*).

The lightness sensation of the human visual system depends on the spectral luminous efficiency function $V(\lambda)$ (see *Figure 9*), which was established for photometry (Wyszecki and Stiles, 1982). This function refers to the relative effectiveness of radiant power to stimulate lightness sensation. The luminous efficiency in the short wavelength region is very low, but with an increase in wavelength, the efficiency increases, reaching a maximum at 555 nm, before decreasing with further increase in wavelength. In the long wavelength region, the efficiency again becomes very low. For example, it takes about 90 times the amount of light at 430 nm to produce the same sense of lightness in the human brain as it takes at 555 nm.

Although the $V(\lambda)$ function is not related to the colour change phenomenon in the tourmaline, it can explain a change in lightness. With an increase in thickness of this tourmaline, the transmittance decreases, and so does the lightness. The lightness L* changes from 100 for 0 mm thickness to 67.77 for 1.0 mm, to 47.24 for 2.0 mm, to 20.66 for 4.0 mm, and to 5.97 for 6.0 mm, and so on (see again *Table II*). The change of the 540 nm band contributes much more than the long wavelength band in the lightness change when the stone is relatively thin, due to both the higher luminous efficiency and faster decrease of transmittance of the 540 nm band compared to that of the long wavelength band.

Different causes that can produce a colour change

To put the colour-change phenomenon described here into perspective, K. Nassau (pers.comm., 1998) suggests that there are four possible causes of this behaviour in gems and minerals. These four causes can be active one or more at a time, and all four appear to play a role in producing the coloration of the tourmalines discussed here. The four causes are:

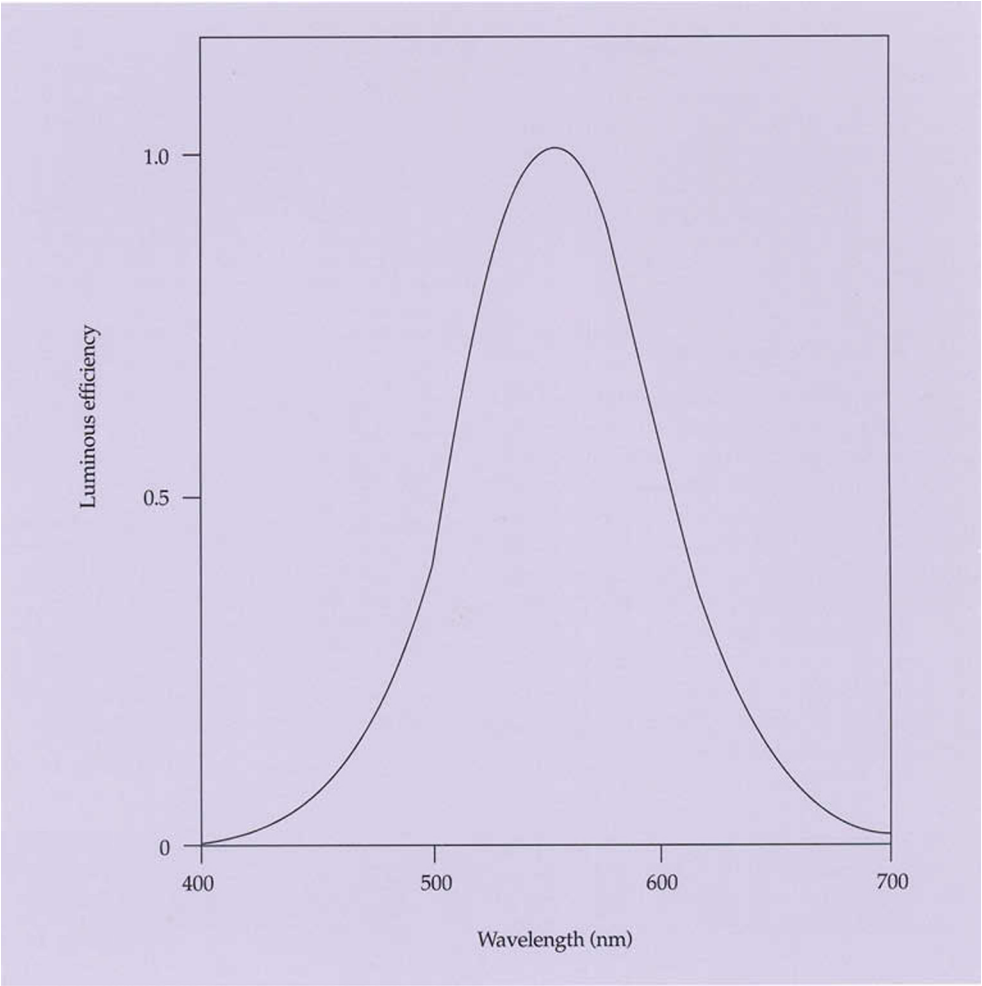

Figure 9: *The spectral luminous efficiency function V(λ), which was established for photometry. This function refers to the relative effectiveness of radiant power to stimulate a sensation of lightness.*

(A) Pleochroism, which can be seen in anisotropic materials (referred to as dichroism in a uniaxial material, or trichroism in a biaxial material) where the colour varies either with differences in crystallographic orientation of the material, or with polarization observing in one orientation (such as with a dichroscope).

(B) Alexandrite effect, where a material (in one orientation) changes colour when viewed under different light sources, depending upon the light sources used, the spectrum of the material, and the chromatic adaptation of the human visual system.

(C) Colour zoning, due to spatial differences in chemical composition in the material, or to differences in concentration of a particular chemical element, that are seen along one orientation.

All three of these causes are described in mineralogy and gemmology texts.

(D) Usambara effect, where the material changes colour hue due to increasing path length of light through the sample in one orientation.

It is clear from the data reported by Halvorsen and Jensen (1997) and the results described here that the colours of this tourmaline can be attributed to causes B and D (see again *Figure 4*). This Usambara type of colour change itself is difficult to recognize, since it is not often possible to compare the colours of two faceted samples of a suitable gem material that vary significantly in thickness.

Conclusion

The Usambara colour-change effect reported in tourmaline from the Umba Valley, Tanzania, is a complex effect involving two types of colour change: one caused by the 'alexandrite effect' within a certain sample thickness range, and another caused by a change in thickness with consequent lengthening of the light path. The hue changes with differences in the tourmaline sample thickness are caused by spectral transmittance changes. Although the hue change of this tourmaline with thickness is very large, this kind of hue change can happen in any coloured material, particularly in dye solutions with a change of colourant concentration. When the thickness of the tourmaline reaches about 10 mm, only a long wavelength band is transmitted; therefore, the tourmaline appears red under any standard light sources. This material shows the alexandrite effect in samples ranging between about 3.5 and 9.9 mm in thickness. The colour change caused by the change in thickness is light-source independent, but the alexandrite effect shown in a certain thickness range depends upon the light sources used. This effect can be quantified with colorimetric calculations, and the results correspond to the visual colour appearances of the tourmaline in different thicknesses and under different light sources.

Acknowledgments

The authors would like to thank Dr Mary Johnson, manager of research and identification of GIA Gem Trade Laboratory, for her helpful discussions and comments and providing the yellow food dye for the colour-change photo. Earlier versions of this article benefited from the comments of Dr Kurt Nassau and other reviewers.

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Abstracts

Diamonds | Instruments and Techniques | Gems and Minerals | Synthetics and Simulants

Diamonds

Touring the diamond factories of Amsterdam.

A. BARNARD. *Australian Gemmologist*, **20**(3), 1998, 98–101, 1 illus. in black-and-white, 1 map.

A report on the tours and facilities offered by seven diamond-polishing operations in the main metropolitan area of Amsterdam (their locations are indicated on the accompanying map). These cutting factories comprise The Amsterdam Diamond Centre (the primary focus here is the retailing of diamonds to the tourist; cutting demonstrations are not conducted continuously, although the centre is open seven days a week), Coster diamonds (guided tours are available five times a day with explanations in several languages), Gassan diamonds (tours of the showrooms are given by a multi-lingual staff, and cutting demonstrations are sometimes offered), Van Moppes Diamonds (tours of the cutting workshops are available; the historic aspect of polishing equipment and techniques is a speciality), Stoeltie Diamonds (tours are conducted regularly in many languages; although the factory is small and may become crowded at times, private tours can be pre-arranged before or after the regular opening hours), Lazare Diamonds (demonstrations of all cutting equipment in use at the other factories, plus the simulation of the cleaving process which these days is seldom used in practice), Singel Diamonds (a small, more intimate operation suitable for those who dislike large tours; a range of diamond-cutting equipment can be seen and staff are willing to demonstrate it. A selection of diamonds is also on view in the display cases.) Admission is free to all tours, and diamonds are available for sale at most cutting factories as well as at diamond wholesalers which are located mainly on the Rokin (the main street in the centre of Amsterdam) or in the surrounding streets. P.G.R.

Testing problems at grass roots level. Fancy coloured diamonds.

I. C. C. CAMPBELL. *South African gemmologist*, **11**(2), 1997, 19–31, illus. in colour.

Review of testing methods for fancy coloured diamonds with special reference to pink stones. M.O'D.

Steine der Erde: Neue permanente mineralogisch-geologisch Ausstellungen im Naturhistorischen Museum Bern.

B. HOFMANN AND U. MENKVELD-GFELLER. *Aufschluss*, **11**, 1998, 329–44.

Diamond crystals and other gem minerals are included in the new display of earth sciences at the Natural History Museum in Bern, Switzerland. M.O'D.

Gem news.

M.L. JOHNSON AND J.I. KOIVULA (EDS). *Gems & Gemology*, **34**(2), 1998, 134–45, 23 coloured illus.

Recent exploration in Alberta, Canada, has discoverd more than 20 kimberlite pipes, many of which contain diamonds. The largest diamond so far weighs 1.31 ct. Anticipated diamond production in the Northwest Territories, Canada, is estimated at 4.2 mct, making Canada the sixth largest diamond producer (by volume) in the world. J.J.

GIA Gem Trade Lab Notes.

T. MOSES, I. REINITZ AND S.F. MCCLURE (EDS). *Gems & Gemology*, **34**(2), 127–33, 14 coloured illus.

A 5.75 ct brownish purple-pink marquise brilliant diamond was found to be a coated diamond, with the speckled surface colour readily visible under the microscope. When assessing the colour of coloured diamonds, it is best to do so from the face-up position. A diamond recently submitted had a face-up colour of fancy yellow brown, but the body colour was orange. J.J.

Treated blue diamond.

B. SECHOS. *Australian Gemmologist*, **20**(3), 1998, 124, 2 illus. in colour.

The radiation-induced colour of a trilliant-cut 3.78 carat greenish-blue diamond was confirmed by the

Abstractors

R.A. Howie	R.A.H.	M. O'Donoghue	M.O'D.	P.G. Read	P.G.R.
J. Johnson	J.J.	E. Stern	E.S.		

For further information on many of the topics referred to, consult *Mineralogical Abstracts*

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diamond's lack of electrical conductivity. The presence of fracture filling was discovered when the stone exhibited the typical purplish 'flash effect' while being examined with a loupe. P.G.R.

CVD diamond: a new engineering material for thermal, dielectric and optical applications.

R.S. SUSSMANN, J.R. BRANDON, S.E. COE, C.S.J. PICKLES, C.G. SWEENEY, A. WASENCZUK, C.J.H WORT AND C.N. DODGE. *Industrial Diamond Review*, **58**, 1998, 69–77, 5 photographs, 15 graphs, 4 tables, bibl.

Recent advances in the technology and application of diamond synthesised by chemical vapour deposition (CVD) are presented. The properties of large area CVD diamond plates of different grades are synthesised for a range of different applications. These plates can be made up to 160 mm (6.3 in) across and can have a thickness of 2.0 mm; they can also be grown in hemispherical domes up to 70 mm. The strength seems to be lower than that of a single crystal diamond, but considerably higher than other alternatives. The optical properties are as good as those of a best-quality single crystal type IIa. The values for thermal conductivity are similar to those of a single crystal type IIa. E.S.

Gems and Minerals

Mineralien aus dem Westschweizer Jura.

P.J. ANDERMATT AND N. MEISSER. *Lapis*, **24**(2), 1999, 13–21 1 map.

Collectable and perhaps facetable crystals of calcite, celestine are among the minerals found in the Jura area of Western Switzerland. M. O'D.

Gemmologie Aktuell.

H. BANK, U. HENN AND C.C MILISENDA. *Gemmologie, Z. Dt. Gemmol. Ges.*, **47**(3), 1998, 121–28.

Items include garnet cat's-eye from Sri Lanka, star moonstone from India and blue quartz from Madagascar which owes its colour to lazulite inclusions the material is translucent and can be cut into blue cabochons. The Russians are growing bicoloured quartzes esp. amethyst and citrine coloured stones known as ametrines. Synthetic zincite is also being manufactured, red in colour, with a hardness of 4.5–5. Some quartz-feldspar doublets have been found on the market, as have imitations of malachite-azurite; the latter seem to be 'reconstructed', with an SG 3.36 which is lower than the natural material. E.S.

Achat, Karneol und Jaspis aus dem Pechstein von Ebersbach in Sachsen.

W. BECK AND U. THONFELD. *Lapis*, **24**(2), 1999, 35–8.

Ornamental silicas in the form of agate, jasper and carnelian are described from the Ebersbach area of North-West Saxony, Germany, where they occur in volcanic rocks. Moss agate, yellow and amethyst single crystals have also been found. M .O'D.

Gems around Australia – Part 14.

H. BRACEWELL. *Australian Gemmologist*, **20**(3), 1998, 108–11, 8 illus. in colour, 1 map.

The author describes a visit made some years ago to the Aga Khan emerald mine and its associated workings at Poona in Western Australia. The history of the mine and the stories behind its name and that of the Solomon open pit were related to the author by Ralph Bellairs, the mine's caretaker. Bellairs had a mining lease at the site, and called it 'Emerald Pool'. It was this mine that supplied the low quality emerald that the Biron Corporation used as source material to grow its hydrothermal synthetic 'Pool' emerald. P.G.R.

An ?Australian synthetic opal.

G. BROWN. *Australian Gemmologist*, **20**(3), 1998, 112–3, 8 illus. in colour.

A 26 x 15 x 5 mm free-form pendant-mounted translucent black opal was found to have a quite distinctive purplish-brown hue. The opal displayed no evidence of either dark potch or inclusions of pink sandstone that usually characterize Lightning Ridge black opal, and further gemmological inspection revealed the columnar colour structure and 'lizard skin' surface appearance seen in Gilson man-made opal. Subsequent inquiries indicated the possibility that the opal was manufactured in South Australia, and the author warns of the existence of this very effective look-alike in the Australian market. P.G.R.

Topaz, aquamarine and other beryls from Klein Spitzkoppe, Namibia.

B. CAIRNCROSS, I.C. CAMPBELL AND J.M. HUIZENGA. *Gems and Gemology*, **34**(2), 1998, 114–25, 19 illus. in colour and 2 tables.

Topaz has been found at Klein Spitzkoppe for over a hundred years, together with beryls and other gem stones. Gem-quality topaz and beryl are found in cavities in the pegmatites that intrude the Klein Spitzkoppe alkali granite, which is Jurassic/Cretaceous in age, or found in alluvium. The major mining is for granite for building purposes while local workers collect the gems. The topaz is typically 0.5 ct to 5 ct, usually colourless (silver topaz) and also pale blue or yellow, but tends to lose its colour if exposed to sunlight. The RI values are relatively low (1.610–1.620), more typically associated with topaz found in rhyolite deposits. The SG values are slightly higher than would be expected and this is thought to be due to a high fluorine content, with a maximum amount of 20.3 wt %. The beryl occurs in various colours and specimens of yellow beryl up to 12 cm long have been recovered. J.J.

Mineralsammeln in Kalifornia.

G. FÄRBER. *Lapis*, **24**(2), 1999, 25–33, 1 map.

Benitoite is described and illustrated among the notable California minerals in a general survey of the state's mineralogy. M.O'D.

Gemmologische Kurzinformationen.

Gemmologie, Z. Dt. Gemmol. Ges., **47**(3), 1998, 167–73.

P.G.R. Dharmaratne reports on some greenish-brown stones from Sri Lanka. The article includes a photograph of a number of similar-looking stones found in parcels in Sri Lanka and the various properties from glass to sapphire, chrysoberyl and zircon are listed in a table. In the parcel described the stones were found to be chrysoberyls.

G. Holzhey describes and illustrates some colourless danburite from Dalnegorsk in Russia.

C.C. Milisenda describes a special exhibition, in the German Gem Museum in Idar, of objects on loan from the Green Vaults in Dresden, mainly objects (bowls, etc.) in serpentine, jasper, marble, alabaster, and rock crystal, made from about 1600 to the first half of the 18th century. E.S.

Elfenbein: Vom Aussehen bis zur Identifizierung.

V.M.F. Hammer. *Gemmologie, Z. Dt. Gemmol. Ges.*, **47**(3), 1998, 129–46, 14 photographs, 1 X-ray diffraction graph, bibl.

Throughout the ages, teeth, bones, antlers and horns of animals have been used as jewellery. Ivory is the most valuable of these materials and it is therefore important to identify it correctly. Often in the past this was only possible by destroying the object. The author discusses the range of materials classified as ivory and describes their characteristics: African and Indian elephant teeth, also those from the mammoth (fossil ivory). Sometimes there are malformations caused by faulty growth, those from the mammoth being known as elephant pearls. Then there is ivory from hippos, walrus, whale esp. narwhal. Not known as ivory, the teeth of other animals have also been used, such as bear, stag, wild boar and wart hog. There is also 'vegetable ivory', a substance produced by a South American 'phytelephas' palm. The beak of the helmeted hornbill is another source of non-ivory ivory. Other substances used to imitate ivory include bones, antlers and horns. Physical properties and various possibilities of identification are given. E.S.

Raman investigations on two historical objects from Basel Cathedral: the Reliquary Cross and Dorothy Monstrance.

H. A. Hänni, B. Schubiger, L. Kiefert and S. Häberli. *Gems & Gemology*, **34**(2), 1998, 102–13, 15 illus. in colour.

Two fifteenth-century objects, the Reliquary Cross and the Dorothy Monstrance, were examined by the Swiss Gemmological Institute to identify the gems. This was done using a Raman spectroscope and an optical microscope. It was surprising to find in such important works of art that many of the stones were imitations composed of glass and doublets. The doublets were made of glass or quartz with the cement layer coloured. Closed back settings made it difficult to identify the pavilion material. Natural stones included amethyst, citrine, colourless quartz, turquoise, peridot, sapphire, red garnet and pink spinel. Inclusions in the spinel and sapphire suggested a Sri Lankan origin with the turquoise and peridot possibly originating from the Near East. Also identified were engraved carnelian and agate and these were thought to be Greek or Roman in age. J.J.

Achate: zur Diskussion über die Genese, die Farben sowie über seltene Achatqualitäten.

H. Harder. *Aufschluss*, 49, 1998, 325–44.

The origin, form and structure of the chalcedonies are discussed with notes on fashioning and on notable chalcedony artefacts. Reasons for the coloration of natural material are given and numerous types are illustrated. M.O'D.

Bestrahlte Edelsteine – Grundlagen, Erkennung, Normenklatur.

U. Henn. *Gemmologie, Zeitschr.d.deutsch. Gemmol. Ges*, **47**(3), 1998, 153–66, 8 photographs, 3 tables, bibl.

In 1997 the appearance of radioactive chrysoberyl cat's-eyes stimulated discussion about colour enhancement of gemstones by ionizing radiation. More irradiated gemstones have been found on the south-eastern Asian markets. The author summarizes the background of gemstone irradiation, esp. radioactivity, international units and legal release levels as well as methods of detection and measurement. A distinct part of the article deals with the natural radioactivity of gemstones, the formation of colour centres by ionizing radiation, the artificial irradiation for colour enhancement, identification and nomenclature. In some stones such as orange-coloured corundum or dark-blue beryl the colour tends to fade very quickly. In smoky quartz and red tourmaline causes of the natural colours are identical to the causes of colour in irradiated stones, so it is very difficult to distinguish between naturally and artificially irradiated stones. E.S.

Gem news.

M.L. Johnson and J.I. Koivula (Eds). *Gems & Gemology*, **34**(2), 1998, 134–45, 23 coloured illus.

As no one governs the use of descriptive terms in gemmology, this can lead to problems; the situation with the flame agates, where both the colour and the pattern are important, is described and the names should be applied appropriately. The Benitoite Gem mine in San Benito County, California, has been placed under a 14-month option for evaluation by AZCO Mining Inc, which extends until February 1999, at which time AZCO may elect to purchase the mine. At the 1998 Tucson show, a large aquamarine from Farafangana in Southern Madagascar was exhibited and appeared not to have been heated treated. Light greyish-green six-sided 'trapiche' emeralds from near Mananjary, Madagascar ,were also on show. Pyrope spessartine garnets from Sri Lanka exhibited a colour change from greyish greenish-blue in daylight to either dark greyish-violet or purple in incandescent light. Also on show were yellow, orange and

orangy-brown cat's-eye opal from Kasulu, Tanzania. A new locality yielding rubies has been found in the Polar Urals in Siberia but the gem potential of the deposit is not yet known. Star and trapiche blue sapphires have been found in a new alluvial deposit in north-east Madagascar. J.J.

Der Baltische Bernstein.

F. KAUFFUNGEN. *Aufschluss*, **11**, 1998, 348–58.

Describes with black-and-white and coloured photographs some of the characteristic inclusions in Baltic amber. A brief account of amber mining is given. M.O'D.

Amazonite in Sri Lankan topaz.

J.I. KOIVULA AND S. ELEN. *Australian Gemmologist*, **20**(3), 1998, 106–7, 2 illus. in colour, 1 graph.

Using Raman microspectroscopy, a blue-green crystal inclusion 0.5 mm beneath the surface of a 3.88 ct near-colourless rectangular step-cut Sri Lankan topaz was identified as amazonite. This appears to be the first time a blue-green microcline feldspar has been identified in topaz or in any other transparent material. P.G.R.

Mineralien aus dem Dronning Maud Land, Antarkis.

G. MARKL AND H. STEEN. *Lapis*, **24**(1), 1999, 13–19.

Aquamarine of apparent gem quality, red garnet, topaz, scapolite and topaz are reported from Dronning Maud Land, Antarctica. M. O' D.

GIA Gem Trade Lab notes.

T. MOSES, I. REINITZ AND S.F. MCCLURE (EDS). *Gems and Gemology*, **34**(2), 1998, 127–33, 14 coloured illus.

A 10.45 ct orange-red cabochon-cut stone, which was full of needle-shaped inclusions, was identified as calcite; the inclusions were thought to be chalcotrichite. A parcel of rubies included one stone that was identified as a diffusion-treated corundum, but whether the original stone was natural or synthetic was undeterminable. A 8.64 ct brownish orangy-red stone from Tunduru, Tanzania, was found to be sapphirine. This is the largest sapphirine reported to date and the first reported sapphirine from Tunduru. J.J.

Separating natural and synthetic rubies on the basis of trace-element chemistry.

S. MUHLMEISTER, E. FRITSCH, J.E. SHIGLEY, B. DEVOUARD AND B. M. LAURS. *Gems & Gemology*, **34**(2), 1998, 80–101, 12 coloured illus. and 5 tables.

With the use of an EDXRF spectrometer, the authors found that synthetic rubies contain relatively few trace elements, with the presence of Mo, La, Ni, Pt, Pb and Bi being distinctive to synthetic stones. No single trace element proves that a stone is of natural origin, but an assemblage can help distinguish stones, with concentrations of Ti, V, Fe, and Ca being important, natural rubies usually contain higher quantities of these elements than synthetic stones. Although these results can separate synthetic from natural rubies, the information should be used with caution and combined with traditional methods of gem testing. Rubies from different geological origins can also be distinguished. Rubies from basalt type deposits typically contain little V but moderate to high amounts of Fe, whereas the opposite trends are seen in rubies from marble-hosted deposits, and metasomatic deposits give rise to rubies with a wide variety of trace elements. The information is summarised in very accessible diagrams and useful tables. J.J.

Die Formenwelt der Japaner Zwillinge.

G. PASCHER. *Lapis*, **23**(12), 1998, 13–30.

Japan-law twins in rock crystal, citrine and amethyst are eagerly sought by gem crystal collectors. The paper illustrates a number of examples from different localities. M.O'D.

Investigation of the intracrystalline Cr^{3+} distribution in natural and synthetic alexandrites.

H. RAGER, A. KHIRI-BAKHSHANDEH AND K. SCHMETZER. *N. Jb. Miner, Mh.*, 1998, 545–57.

Electron paramagnetic resonance measurements were carried out on three synthetic and five natural alexandrites to ascertain Cr^{3+} distribution over octahedrally co-ordinated Al_I and Al_{II} sites. In all samples Cr^{3+} substitutes the larger Al_{II} sites and a small fraction the smaller Al_I sites. Distribution ratio for the chromium over the Al_{II} and Al_I sites is approximately 3:1 and is very similar for low Cr doping levels of pulled alexandrites. A ratio of approximately 2:1 is found in flux-grown alexandrite. Fe and other additional dopants do not cause a redistribution of Cr over the Al sites in the tested samples.

The Cr^{3+} percentage at Al_{II} sites increases in natural alexandrites. The intensity of the colour change correlates with the total Cr content of a sample. No influence on the colour change by Cr at the Al_I sites was observed. M.O'D.

On the identification of amber and its imitations using Raman spectroscopy – preliminary results.

T.S. TAY, Z.X. SHEN AND S.L. YEE. *Australian Gemmologist*, **20**(3), 1998, 114–23, 7 illus. in colour, 9 illus. in black-and-white, 5 tables, 3 graphs.

A selection of 173 specimens of amber were examined by conventional gemmological methods, and then by Raman spectroscopy. Compared to the conventional methods, Raman spectroscopy is a fast, accurate and non-destructive technique for the routine testing of amber and its imitations. The strong red and yellow fluorescence that is generated in amber when using a laser operating in the visible range is effectively eliminated by using a near-infrared laser. Preliminary results indicate that Raman spectroscopy can be used to differentiate amber from its imitations (including copal resin) and to identify those imitations. P.G.R.

Composite gems.

A. THOMAS. *South African Gemmologist*, **11**(2), 1997, 4–13, illus. in colour.

Illustrated descriptive list of composite ornamental materials, also including cultured and Mabe pearls, false cameos, faked gem rough with matrix, coated and filled stones. M.O'D.

Granate aus der Umgebung von Sao Valéria, Tocantins, Brasilien.

R. WEGNER, A. RAMOS DE BRITO, J. KARFUNKEL, U. HENN AND TH. LIND. *Gemmologie, Z. Dt. Gemmol. Ges.*, **47**(3), 1998, 14–52, 7 photographs, 2 tables, 1 graph, bibl.

The garnets are found at Fazenda Balisto, in the Municipio Peixi about 12 miles WSW of Sao Valeria, and are of an unusual amethyst colour, RI 1.792 to 1.798, SG 4.08 to 4.11. Small cut stones possess sufficient transparency and may be called rhodolite garnet because of their blue-violet colour. E.S.

Cat's-eye black opal.

M.S. WHITE. *Australian Gemmologist*, **20**(3), 1998, 126, 2 illus. in colour.

A rare cat's-eye black opal from Lightning Ridge was cut as a semi-translucent brownish-black free-form double cabochon weighing 1.27 ct. What appear under the microscope as 'fibres' (as yet unidentified) which produce the chatoyant effect run at a 40 degree angle to the long axis of the eye. Expert opinion suggests that this is a true cat's-eye phenomenon generated by the internal structure of silica spheres and should not be confused with Brazilian cat's-eye material in which the chatoyant effect is caused by asbestos inclusions. P.G.R.

Instruments and Techniques

The Hodgkinson method, a.k.a. The Hodgkinson method: Clarifying the record.

W.W. HANNEMAN. *The Australian Gemmologist*, **20**(3), 1998, 103–4.

In response to an article by Hoover, 'The Hodgkinson Method, a.k.a. The eye and prism method: some further adaptations' which appeared in the *Australian Gemmologist*, **20**(1), the author defends his coining of the term the 'Hodgkinson method' for what is more commonly known as 'Visual optics'. He reasons that this non-instrumental confirmation of the identity of a gem was not simply a rediscovery of a method first proposed by Crowningshield and Ellison as claimed by Hoover, but is the result of Hodgkinson's personal experimental observations and the assimilation of well-known observable phenomena. Hanneman's article is preceded by a letter to the editor on the same subject and followed by a 'reply' from Hoover. The arguments put forward by Hanneman and Hoover in their respective letters and articles on this subject appear to be both philosophical and gemmological. The philosophical argument is about whether Hodgkinson is the originator of the method and should have his name associated with it as proposed by Hanneman. The gemmological argument revolves around the question of Hodgkinson's 'Visual optics' being a tool of *confirmative* gemmology as claimed by Hanneman, or a tool of *determinative* gemmology as inferred by Hoover, whose suggested additions to the method simply reinforce this determinative aspect. P.G.R.

Synthetics and Simulants

The 'Biron' synthetic emerald. An update.

G. BROWN. *South African gemmologist*, **11**(2), 1997, 53–64.

Describes the Biron hydrothermally-grown emerald with notes on means of identification. Inclusion-free material will need chemical analysis or IR Spectroscopy for certain determination. M.O'D.

Gem news.

M.L. JOHNSON AND J.I. KOIVULA (EDS). *Gems & Gemology*, 34(2), 1998, 134–45, 23 coloured illus.

A jadeite boulder appeared complete with its alteration crust and a few polished windows, but when sawn it was found that the windows were thin slices of better coloured green jadeite that had been placed in a fabricated crust. Topaz of pink, orange and red colours had been treated by a sputter-coating process, but the coating was found not to be permanent and was easily scratched. Bluish topaz had been coated with a cobalt-rich material, which could only be scratched with a point of hardness 8 on Mohs' scale. J.J.

Review of synthetic rubies over the years.

A. KLEYENSTÜBER. *South African Gemmologist*, **11**(2), 1997, 38–39, 65–73.

Review of the growth and determination of the main types of synthetic ruby manufactured during the present century. M.O'D.

GIA Gem Trade Lab notes.

T. MOSES, I. REINITZ AND S.F. MCCLURE (EDS). *Gems & Gemology*, **34**(2), 1998, 127–33, 14 coloured illus.

Nine loose undrilled pearls, together with some beads used in their culturing, were submitted for identification. The beads were dolomite and had been fashioned in South Korea and the pearls had been cultured in Japan. A strand of fairly large black pearls, with a metallic appearance, were found to be cultured pearls that had been dyed, possibly with silver nitrate solution. Six triangular brilliants were thought to be natural green obsidian from Tunduru, Tanzania, but with the aid of FTIR spectroscopy the stones were found to be manufactured glass. A purple cabochon thought to be sugilite, was a dyed quartz aggregate with the colour concentrated around and between the aggregate grains. J.J.

Specious or precious.

J.E.W. SNYMAN. *South African Gemmologist*, **11**(2), 1997, 40–52, illus. in colour.

Review of hydrothermal and natural emeralds and the means of distinguishing between them. M.O'D.

BOOK REVIEWS

The Crown Jewels: the History of the Coronation Regalia in the Jewel House of the Tower of London.

C. Blair, S. Bury, A. Grimwade, R.R. Harding, E.A. Jobbins, D. King, R.W. Lightbown and K. Scarratt, 1998. Volume I: The History (pp xxiv + 812) and Volume II: The catalogue. The Stationery Office, London, pp xxiv + 630. ISBN 0 11 701359 5. Royal Quarto: quarter bound in leather; edition limited to 650 copies. £1000.00.

These two sumptuously produced volumes, with text and photographs printed on substantial, silk-surfaced paper, record the results of research into the history of the English Coronation and the associated regalia in greater detail than has ever before been possible.

Volume I is concerned entirely with the origins and history of the Coronation ceremony, but it is in Volume II that detailed examination of the Crown Jewels is documented, revealing many discoveries and new insights about the history of the gemstones. Each item has been newly photographed and the team of three gemmologists have taken the opportunity to examine the jewels with sophisticated gemmological techniques. This review will be concerned therefore only with volume II (although the complete set was loaned for the purpose of review).

The catalogue illustrates and describes the regalia, not only the numerous crowns, orbs and sceptres, but also the various swords, plate and textiles. Each chapter begins with a brief 'abstract' giving the size and general appearance of the item, before a general description of the history of the various formats and vicissitudes (as when the plan by the adventurer Thomas Blood in 1671 to steal the Crown Jewels was frustrated, but not before he had battered the arches of the crown with a mallet the better to be concealed beneath his cloak: repair to Crown and Orb £145). The description of each major item is concluded with a 'Gemmological commentary', and it is here that we get a listing of the size and weight of all the major gemstones, including details of their surface imperfections, chips, minor scratches and any visible inclusions.

The Imperial State Crown in brief has 2668 diamonds, 17 sapphires, 11 emeralds and 269 pearls, but interest lies mainly in its larger individual gemstones. The so-called Black Prince's Ruby may have been in the Crown Jewels since around 1367 and for many centuries was described more correctly as a balas ruby. It is actually a large polished crystal (~ 170 ct) of red spinel with three vestigial octahedral faces and was pierced in the Middle Ages for use as a pendant; at the top it supports a small ruby, and on the back of its mounting is a small plaque recording the recent history of the crown. The Stuart sapphire (~ 104 ct) at the rear of the crown (replaced at the front by the Cullinan II diamond) is a fine blue, cut with an oval brilliant crown and step-cut pavilion; at least one of the seven visible crystal inclusions appears to be zircon. The octagonal rose-cut St Edward's sapphire set in the cross is a fine velvety blue (e 1.760, w 1.768); scratches on the crown facets appear to be the result of testing the hardness of the stone, a rather basic form of gem testing, now generally avoided. The large cushion-shaped brilliant on the front of the Crown is the second largest stone (317.40 ct) cut from the Cullinan diamond; it has a maximum diameter of 45.4 mm, is free from internal reflections and its colour-grade in the basket setting compares with a D master stone.

The Cullinan I diamond (530.20 ct), formerly known as the Star of Africa I, is a pear-shaped brilliant mounted in the head of the Sceptre with Cross, and is the largest cut colourless diamond in the world; it weighs 530.20 ct when free from its setting. The rough Cullinan diamond (3025 ct) discovered in the Premier mine, South Africa, was purchased by the Transvaal Government and presented to the reigning monarch, King Edward VII (the package was escorted on board ship to England by armed guards; this, however, was a dummy operation, the diamond being sent by ordinary mail. Both packages arrived safely). The Cullinan was handed over to the firm of Asscher in Amsterdam for cutting and was successfully cleaved into two main pieces weighing 2029.9 and 1068.1 ct. We learn that, contrary to popular legend, the cleaver Joseph Asscher did not faint afterwards; he is reported to have said later that 'No Asscher would faint over an operation on a diamond. He's much more likely to open a bottle of champagne.' The faceting and polishing of the gems cut from the rough Cullinan took three polishers, working 14 hours a day, eight months to complete. There are many other gems in the Sceptre (332 diamonds, 31 rubies, 15 emeralds, 7 sapphires, 6 spinels and an amethyst); the positions of all of these are indicated and it is remarked that although most of the rubies are of a fine purplish-red colour they are accompanied by two spinels in positions where rubies might be expected, and that some or all of the spinels may have been used in the belief that they were rubies. The amethyst 'sphere' (~ 32.8 mm diameter) is composed of two joined hemispheres to form part of the 'monde' at the head of the sceptre; pleochroism is noticeable.

The Crown of Queen Elizabeth the Queen Mother contains some 2800, mainly cushion-shaped, diamonds, but the main feature is the Koh-i-nûr (Mountain of Light) cushion-shaped brilliant. When this stone (186 ct) was ceded to Queen Victoria following the annexation of the Punjab in 1849, its Indian cut was considered to be poor, and it was recut in 1852 to 105.6 ct. It is classified as a type II diamond, and though by modern standards the cut is far from perfect in that the large culet is parallel with the

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table facet giving the impression of a black hole in the centre of the stone, it is nevertheless described as still being full of 'life'.

There are many other crowns and parts of the regalia described in detail in this outstanding work. Mention must be made of the Sovereign's Orb, for example, which is in gold, set with jewels in enamel settings. In the meticulous detail recorded in the gemmological commentary we learn that the jewels comprise of 365 diamonds, 9 emeralds, 9 sapphires, 13 rubies, one amethyst and one glass! Two or three centuries ago, it was common to hire diamonds and other jewels for use in Coronation ceremonies. Thus, at the Coronation of George II in 1727, diamonds valued at £12,000 were hired for £480 and set in St Edward's Crown and three sceptres. Nowadays the opposite situation applies: the Stuart sapphire originally on the front band of the Imperial State Crown was moved to the back in 1909 to accommodate the Cullinan II diamond in its place, and the 'spare' sapphire previously at the back is now free from the regalia and is displayed in the Martin Tower, Tower of London.

One of the many delights of this work lies in the numerous colour photographs of the regalia, many of the close-up views of the individual stones having been produced by the team of gemmologists, including Alan Jobbins, Ken Scarratt and Roger Harding, and also Frank Greenaway, the photographer from the Natural History Museum. The price of these two magnificent volumes may prevent one from dashing out to buy a set, but this work records for posterity far more details of the gemstones in the regalia than have hitherto been available. We should each try to ensure that it is available for consultation in a nearby university or regional library.

R.A.H.

Jewellery – English/Chinese, Chinese/English dictionary.

CHEN ZHONGHUI, YAN WEI XUAN, C.M. OU YANG, AND WU SHUN TIAN. 1998. China University of Geosciences Publishing House, Beijing, P.R. China. pp 310, hardcover. HK $120. ISBN 7 5625 1323 6.

Amazingly useful and comprehensive dictionary found especially useful by this reviewer who (a long time ago) studied the language. Some entries are unexpected but most of those you really want appear to be there. M.O'D.

I gemmologi del mondo raccontano le gemme dal mare Gemmologia Europa VI

CISGEM, 20123 Milano, Italy. (1998) pp 267, Illustrated in colour, softcover. Price on application.

A welcome addition to the literature of maritime ornamental products, this now biennial volume contains papers on pearls and corals from Asia (K. Scarratt), pearls and corals from Australia (G. Brown), gems from African waters (H. Pienaar), formation and composition of gems from the sea-pearls from American waters (C. Hedegaard), gems from British waters (R.R. Harding), gems from French waters (J.P. Poirot), gems from Italian waters (M. Superchi), gems from Italian waters – magic and preciousness in coral manufacturers (C. Ascione), sapphires from Andranondambo, Malagasy (E. Gübelin). Papers are presented in both Italian and English and bibliographies relating to each paper are placed together at the end of the book. There is a good provision of maps and useful short biographies of the authors. The standard of the papers is very high and continues this authoritative and impressive series. M.O'D.

Pearl buying guide. [Third edition]

R. NEWMAN, 1998. International Jewelry Publications, Los Angeles. pp 156, illus. in colour, softcover. US $19.95. ISBN 0 929975 27 8.

At the end of the main text of this most attractive book are quizzes arranged in order of the chapters to which they refer. A quick glance through the questions convinced me that while I knew that most black pearls were not very round, that most black pearls were in fact a dark shade of grey and that 'AAA' quality as applied to pearls has no particular significance, every seller being able to apply any designation desired, most of the remainder of the questions required immediate recourse to the text. This shows how much the book is needed ! This third edition is even better produced than its two predecessors and the text is arranged in a now familiar order, with an introduction showing just why pearls are desirable. Though not really an organic ornamental materials student, this is the book I shall consult on any pearl topic whatsoever. M.O'D.

Saltbush rainbow: the early days at White Cliffs.

G. ROWE, 1998. The author, White Cliffs. pp vi, 57, softcover, Available from Mrs D. Hoffman, Kerara Road, White Cliffs, New South Wales 2836, Australia. $A9.50. ISBN 0 95919 280 8.

In a re-issue with additional photographs of a book first published in 1983, the story of the White Cliffs opal fields of New South Wales is entertainingly told with a wealth of maps and anecdotes. Opal from the area is recorded from at least 1884 though it is not known who made the first discoveries. As well as mining stories, details of community development are recounted, the whole picture being typical of 19th century Australian mining areas. There is a useful bibliography: readers interested in opal history should be keeping a look-out for books such as this as they may have short print-runs.

M.O'D.

Emeralds around the world.

J. R. SAUER, 1992. The author, Rio de Janeiro. pp 160, illus. in colour, hardcover. Price on application.

Well-compiled survey of the world's major emerald deposits with illustrations depicting all kinds of mining scenes as well as examples of cut and rough emeralds from the sources described. A good deal of the information has not appeared in monograph form before. The author promises books on diamonds and ruby.

M.O'D.

Proceedings of the Gemmological Association and Gem Testing Laboratory of Great Britain and Notices

OBITUARY

An appreciation of Miss 'Lena' Willis by David Callaghan

The death of Miss 'Lena' Willis at the age of 99 is the final chapter in the life of a remarkable lady, one who was unique, and one with whom I had the privilege of working for 15 years. From the moment I joined Hancocks in London's West End in 1955, as one of the NAG apprentices, she took me under her wing and gave me the opportunity to learn from her any and all aspects of the jewellery trade, a trade which had become her life.

Miss 'Lena' Willis, taken in 1960 by Vivienne.

Born on 7 December 1899, 'Lena', as she was known to most people, was the eldest daughter in a family of six, having three brothers and two sisters. The family lived in Leigh-on-Sea, Essex, and she lived in that area all her life. Her father held the view that she, as the eldest daughter, should not go out to work but stay and help run the home. She defied her father by going to work as a secretary. Her first job was at a local timber merchant but she found it 'lonely, surrounded by nothing but planks of wood'. She left that job and went to work as secretary to 'Jimmy' Wixley, a local jeweller, and here she really found her niche in life. Mr Wixley was an entrepreneur, a dealer in gems and almost any object sold by the retail jeweller in a county town. He had a love for gem opal and this he passed on to Miss Willis. She really took to the trade and Mr Wixley soon recognized her interest and encouraged her to train further. The Gemmological Diploma of the NAG – to become the FGA in 1931 – was still in its infancy and she had to take the course by correspondence. She qualified in 1930, only the tenth woman to do so. She soon became indispensable to Mr Wixley and when he opened another shop in Westcliff-on-Sea she was appointed manager.

In the 1930s, Hancocks, in common with many small firms, was finding the going very tough and by 1935 was in some difficulty. The company needed a fresh impetus and Mr Wixley was introduced to the then two partners, and so began his 25 years of service until his death in 1959 at the age of 82. At the beginning of World War II his Westcliff-on-Sea business was closed down and the stock transferred to Wigan and Miss Willis went with him to work there. This was not to last long and Mr Wixley returned to Hancocks during the war service of the other partners. Miss Willis joined the Ministry of Supply and her task was to supervise the collection of iron railings and other

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such metal objects from all over East Anglia and the Home Counties during the Government's drive for scrap metal. She began this work in 1941 but in 1942 she answered a carefully worded advertisement in *The Times*. This led to a successful interview on 27 August 1944 with a Lt. Col. O'Hea. He was based in Denham, at Sir Oswald Mosley's home that had been requisitioned at the beginning of the war. Miss Willis transferred there under the direct written order of the Prime Minister, Winston Churchill. It was known as War Station 14 and was, in fact, an arm of MI6. She worked there for the rest of the war.

In 1945 she returned to Hancocks to work alongside her 'old chief' Mr Wixley, and in 1950 she was appointed a Director. Thus she was unique in the history of the firm – the first woman to be appointed a Director and no other woman in the West End jewellery trade had ever reached such a level of responsibility. Why was this so unusual?

The jewellery trade was male dominated and, of all firms in the West End, Hancocks was amongst the most male chauvinistic. Such was the male dominance in the trade that even her own name became masculinized (if there is such a word!). When she first worked for Mr Wixley she would have been referred to as Miss Willis. However, as time progressed and she became indispensable to him, it became appropriate to recognize this. It was not the done thing in those days to refer to someone by their first name, so she became known as 'William'. In turn this was shortened to 'Bill'. This made her an equal, of course, as she now had a man's name! I had always thought it perverse that such a ladylike person should have to suffer this indignity, but recently I realized she took it as a compliment, albeit a very backhanded one!

What was she like as a person? Diminutive in stature, as well as in nickname, 'Lena' Willis was attractive, very ladylike in her manner and dress, generous in every sense of the word, and a sound businesswoman. She was a very fine judge of colour in a gemstone, and had a love of the two 'miracles' of the gem world – pearls and opals. She was a wonderful teacher, and very interested in and encouraging to the young. Without her, Hancocks would not have been the force in the jewellery trade that they became after World War II, and I was the the main beneficiary of her time and knowledge. She gave me every opportunity to stand on my own feet and I felt always that I was working with her and not for her. She retired in 1970 when she had no reason to, other than to give me the opportunity she felt confident I could use. In the portrait taken in 1960 by Vivienne she is shown wearing both pearls and opals. The photograph is not one that flatters her, it shows her as she was and how she appeared every day in business. She is wearing a cultured pearl necklace of carefully graded and matched pearls. The brooch is a basket of flowers and was her favourite. She designed it herself, and the 'basket' is a single piece of precious black opal. The flowers comprised many small pieces of very bright opal, ruby, sapphire, pearl and turquoise – all carefully blended to give a realistic picture.

You will realize that she was retired for very nearly 30 years, during which time she kept herself very active. However, a younger sister with whom she shared a house became very ill. Lena nursed her daily for nearly four years until her death. This took a toll on her own health and she suffered a stroke at the age of 94. This affected her mobility but she recovered well and lived very happily in a rest home for her remaining years. It was only in the last 12 months that her health failed her.

There are now very few people left in the London trade who worked with her either as a buyer or supplier, but her name lives on in those of us lucky enough to have known her. Her love of gemstones and of the trade she passed on to me. Now in my own retirement I look back over 42 very happy and fulfilling years in the trade. My life has been enriched by the generosity, enthusiasm and grace of a unique lady, and I am very fortunate to have worked alongside her.

***

Mr R.K. Bennett, FGA, DGA (D.1978), Winchcombe, died in August 1998.

Mr Matthew S. Potter (D.1980), San Jose, Calif., U.S.A., died on 13 November 1998.

Mr Robert A. Pudner (D.1963), Childwall, Liverpool, died suddenly on 5 March 1999.

Mr Samuel F. Redknap (D.1947 with Distinction), Twickenham, Middlesex, died in January 1999.

NEWS OF FELLOWS

Congratulations to Dr Roger M. Key, FGA, Keyworth, Nottinghamshire, who was awarded an MBE in the 1999 New Year's Honours list. The award was made in connection with his work for the Botswana Geological Survey.

MEMBERS' MEETINGS

London

On 13 January 1999 at the Gem Tutorial Centre, 27 Greville Street, London EC1N 8TN, Andrew Ross, Curator of Fossil Arthropods in the

GIFTS TO THE ASSOCIATION

The Association is most grateful to the following for their gifts for research and teaching purposes:

The Bahrain Promotions and Marketing Board for a copy of the book *Treasures of Bahrain*.

Richard Burton for an 11.93 ct aquamarine.

Luella Woods Dykhuis, FGA, DGA, Tucson, Arizona, U.S.A., for various specimens including agate, coral, ruby in sillimanite, horn and shell, and *The Gem Kingdom* by Paul E. Desautels and *Brazil, Paradise of Gems* by Jules Roger Sauer.

Eddie S.K. Fan of Chui Wah Jewellers, Kowloon, Hong Kong, for two pieces of dyed jadeite.

Alec Farn, FGA, Seaford, East Sussex, for a zircon in memory of Hubert Mornard who died in January 1999 (see *Gem and Jewellery News* 1999, 8 (2), 28).

Sonja Glaser, FGA, Galle, Sri Lanka, for samples of blue apatite, sapphire, spinel and garnet.

Alfred H. Gunn, Dover, Kent, for a set of brass scales.

Janice Kalischer, Finchley, London, for a plastic imitation cameo set in a brooch.

Li Liping, FGA, DGA, China University of Geosciences, Wuhan, P.R. China, for a carved bone flower.

Mrs C.M.Ou Yang, Hong Kong Institute of Gemmology, for a boxed collection of jadeite containing 15 pieces.

Philip Seager, FGA, Didcot, Oxfordshire, for a quantity of back issues of *The Journal of Gemmology*.

E.A. Thomson (Gems) Ltd., London, for 21 garnets, and five packets containing blue and green glass.

Professor Yan Weixuan, FGA, DGA, China University of Geosciences, Wuhan, P.R. China, for a bowenite carving, a row of non-nucleated freshwater pearls, and a corozo nut and carving.

Linda Zhou, Tongji University, Shanghai, P.R. China, for a 'Duschan jade' bangle.

Department of Palaeontology at the Natural History Museum, South Kensington, gave an illustrated lecture on insects in amber.

On 11 March 1999 at the Gem Tutorial Centre, Dr H. Judith Milledge, Emeritus Reader in Crystallography at UCL, gave a lecture entitled *Some current problems in diamond research.*

Midlands Branch

On 29 January 1999 at the Earth Sciences Building, University of Birmingham, Edgbaston, a Bring and Buy evening was held, followed by a quiz.

On 26 February 1999 at the Earth Sciences Building, David Callaghan gave a lecture entitled *Cameos and gemstone carvings.*

On 26 March 1999 at the Earth Sciences Building, James Gosling gave a talk on the fascinating world of miniatures and the beautiful jewelled settings used for their display.

North West Branch

On 17 March 1999 at Church House, Hanover Street, Liverpool 1, Keith Mason gave a lecture entitled *Exotic diamonds.*

Scottish Branch

A Members' Night and Bring and Buy were held on 20 January 1999 at the British Geological Survey, Murchison House, West Mains Road, Edinburgh. A series of short talks was given by members, including one by Alan Hodgkinson on how to identify synthetic moissanite in a parcel of diamonds.

On 17 March 1999 Dr Jeff Harris gave a talk entitled *Diamonds from the crust to the core.*

FORTHCOMING EVENTS

30 April	**Midlands Branch.** ID challenge and AGM
30 April to 2 May	**Scottish Branch.** Annual Conference and AGM. Guest speaker Dr W.W. Hanneman
6 May	**London.** A guide to affordable gemmology. Dr W.Wm. Hanneman
14 May	**London.** Shining examples – the teaching potential of a gemmologist's jewel box. Cecilia Pople
19 May	**North West.** Pearls – romance and fact. Rosamond Clayton
23 May	**Midlands Branch.** Gem Club – Jet. Peggy Hayden
26 June	**Midlands Branch.** Summer supper
28 June	**London.** Annual General Meeting, Reunion of Members and Bring and Buy Sale
14 July	**London.** Demantoid garnet and other new gems and minerals from Namibia. Professor Peter R. Simpson
15 September	**North West Branch.** Photographing gems and their inclusions. John Harris
20 October	**North West Branch.** Window to beauty. Piero Di Bela
31 October	**Annual Conference – New Developments in the Gem World.** Keynote speaker: James Shigley, Director of Research at the GIA, Carlsbad. To be held at the Barbican Centre, London
17 November	**North West Branch.** Annual General Meeting

For further information on the above events contact:

London:	Mary Burland on 0171 404 3334
Midlands Branch:	Gwyn Green on 0121 445 5359
North West Branch:	Deanna Brady on 0151 648 4266
Scottish Branch:	Catriona McInnes on 0131 667 2199

GAGTL WEB SITE

For up-to-the-minute information on GAGTL events visit our web site on www.gagtl.ac.uk/gagtl

GEM DIAMOND EXAMINATIONS

In January 1999, 55 candidates sat the Gem Diamond Examination, 40 of whom qualified, including three with Distinction. The names of the successful candidates are listed below:

Qualified with Distinction

Chen Chuyiao, Beijing, P.R. China
Chik Wing Sheung, Kowloon, Hong Kong
Zhang Ning, Wuhan, Hubei, P.R. China

Qualified

Ashby-Crane, Robert J., Bratton Fleming, Barnstaple, Devon
Briginshaw, Richard C., Hampstead, London
Cheung Shiu Cheong, Randy, Kowloon, Hong Kong
Deng Xiuquan, Beijing, P.R. China
Dennis, Roger A., Elstree, Hertfordshire
Doucet, Francois L.G., Brockley, London
Dykhuis, Luella Woods, Tucson, Ariz., U.S.A.
Fan Hidy Kit-Ha, Kowloon, Hong Kong
Galdeano, Nerea L., London
Han Xu, Beijing, P.R. China
Hu Yunhua, Beijing, P.R. China
Hunter, Pauline A., Caversfield, Oxfordshire
Kendall, David, Addiscombe, Surrey
Mak Kin Yeung, Kenny, Hong Kong
Konda, Muana Mputu, London
Lee, Martin, South Croydon, Surrey
Li Ki Wing, Alison, Kowloon, Hong Kong
Li Wei, Beijing, P.R. China

Lin Ling, Wuhan, Hubei, P.R. China
Maslik, Magdalena M., Fulham, London
Ng Kwok Wai, Kowloon, Hong Kong
Oldershaw, Cally J. E., Leavesden Green, Hertfordshire
Osband, Peter M., London
Patel, Nita, Newbury, Berkshire
Perez Dorao, Carlos, Golders Green, London
Poon Mei Han, Kowloon, Hong Kong
Qiu Mingjun, Wuhan, Hubei, P.R. China
Qiu Yanping, Wuhan, Hubei, P.R. China
Schatzle-Parisod, Arlette, Basel, Switzerland
Sethi, Barti, London
Sinclair, Gary, London
Sun Haipeng, Wuhan, Hubei, P.R. China
Warshow, Nancy, Nairobi, Kenya
Xie Shirong, Wuhan, Hubei, P.R.China
Yan Yushuang, Beijing, P.R. China
Yang Yong, Wuhan, Hubei, P.R. China
Zhang Jing, Wuhan, Hubei, P.R. China

EXAMINATIONS IN GEMMOLOGY

In the Examinations in Gemmology held worldwide in January 1999, 129 candidates sat the Preliminary Examination of whom 95 qualified. In the Diploma Examination 130 candidates sat of whom 67 qualified.

Diploma

Qualified

Aho, Jouko, Oulu, Finland
Amarasinghe, Ashan S., Rajagiriya, Sri Lanka
Arentsen, Ernst W., Wapse, The Netherlands
Bagri, Abhishek I., Mumbai, India
Bai Chenguang, Guilin, Guangxi, P.R. China
Blampied, Julie K., Trinity, Jersey
Blatherwick, Clare, Hampstead, London
Brown, Vanessa, Sittingbourne, Kent
Chan So Ying, Hong Kong
Chang Kung Jung, Taipei, Taiwan, R.O. China
Chen Shu-Chuan, Taipei, Taiwan, R.O. China
Choi Sun Young Chun, Seoul, Korea
Curran, Rose, Ealing, London
Deljanin, Branko, New York City, New York, U.S.A.
Ding He, Guilin, Guangxi, P.R. China
Edery, Gabrielle J., London
Elen, Shane, Oceanside, Calif., U.S.A.
Finlay, Louden B., London
Garrett, Frances, Sutton, Surrey
Gong Dong, Wuhan, P.R. China
Grech, Carrieann, London
Greenfield, Dawn M., Eynsford, Kent
Grostate, Stephen E., Ashtead, Surrey
Ho Cheuk Fung, Kowloon, Hong Kong
Hsu Feng, Taipei, Taiwan, R.O. China
Hunter, Pauline A., Caversfield, Oxfordshire
Ip Kit Ling, Kowloon, Hong Kong
Ji Yan, Shanghai, P.R. China
Keating, Elaine, Hackney, London
Kilian, Angela M.C., Leidschendam, The Netherlands
Koh Hock Heng, Singapore
Kwon Sung Hae Yoon, Yangon, Myanmar
Lei Wei Hong, Singapore
Li Rutian, Guilin, Guangxi, P.R. China
Lin Ling, Guilin, Guangxi, P.R. China
Lixia Xu, Wuhan, Hubei, P.R. China
Lu Ning, Shanghai, P.R. China
Mafara, Ezekiel M., Harare, Zimbabwe
Mingjun Qiu, Wuhan, Hubei, P.R. China
Mossuto Mori, Maria E., Yangon, Myanmar
Muller, Hellen A.D., Wierden, The Netherlands
Oshida, Reiko, Singapore
Owen, Charryn P., Northwich, Cheshire
Panagiotou, Panagiotis, Corfu, Greece
Pang Chi Keung, Maurice, Shatin, Hong Kong
Park Sang Rok, Sangju-Gun, R.O. Korea
Pavlou, Marios G., Megaro Chianteclair, Nicosia
Ping Su, Wuhan, Hubei, P.R. China
Qiu Jian, Guilin, Guangxi, P.R. China
Rambukkange, Timothy P., Kandy, Sri Lanka
Rusch, Louise V., Hatfield, Hertfordshire
Schmocker, Karin, Neuchatel, Switzerland
Sethi, Barti, London
Shuqiang Feng, Wuhan, Hubei, P.R. China
Siyu Geng, Wuhan, Hubei, P.R. China
Su Cho Win, Yangon, Myanmar
Swe Zin Aye, Yangon, Myanmar
Tanaka, Rika, Yangon, Myanmar
Tang Suk Yee, Shawn, Hong Kong
Townsend, Rachel E., Kingsland near Leominster, Herefordshire
Tulo, Karen, Ludwigshafen, Germany
Walker, Zoë, Pelsall, Walsall, West Midlands
Xin Lu, Wuhan, Hubei, P.R. China
Yanhan Zou, Wuhan, Hubei, P.R. China
Yuling Li, Wuhan, Hubei, P.R. China
Yun Dong, Guilin, Guangxi, P.R. China
Zhou Wen Hao, Guilin, Guangxi, P.R. China

Preliminary

Qualified

Ancemot, Alexandre, Tooting, London
Andries, Stephanie S., Kensington, London
Antenen, Didier R., Lausanne, Switzerland
Arbon, Kathryn J., Wimbourne, Dorset
Arrowsmith, Jodie, Oxhey, Hertfordshire

Bagri, Abhishek I., Mumbai, India
Beekhuis, Alexander F., Oegstgeest, The Netherlands
Bell-Burrow, Briony, London
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Sethi, Barti, London. 1999

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Briginshaw, Richard C., Hampstead, London. 1999
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Li Ki Wing, Alison, Kowloon, Hong Kong. 1999
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Patel, Nita, Newbury, Berkshire. 1999
Warshow, Nancy, Nairobi, Kenya. 1999

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Kilian, Angela M.C., Leidschendam, The Netherlands. 1999
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The World 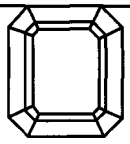 of Gemstones

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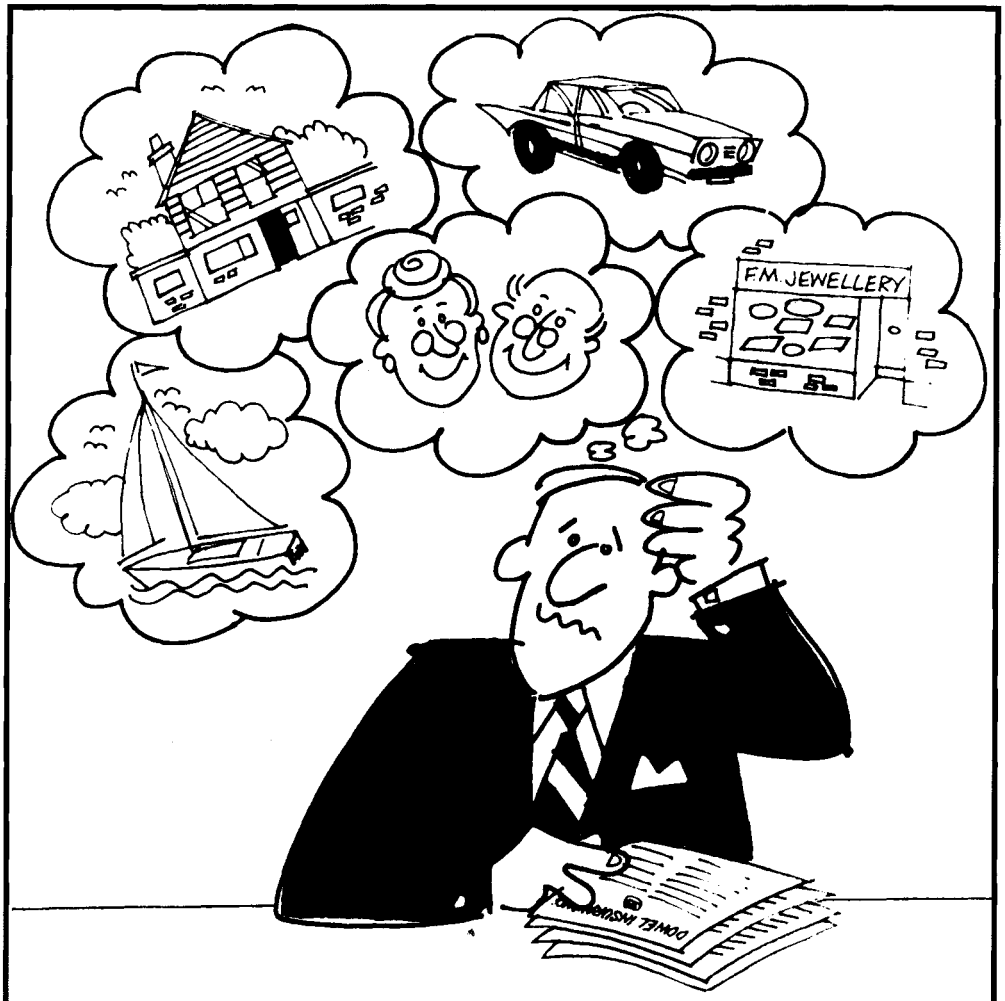

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A sapphire shown under three different light sources to illustrate the colour-change (clockwise from top: fluorescent light, natural daylight and incandescent light). See 'A colorimetric study of the alexandrite effect in gemstones'. pp 371–85.

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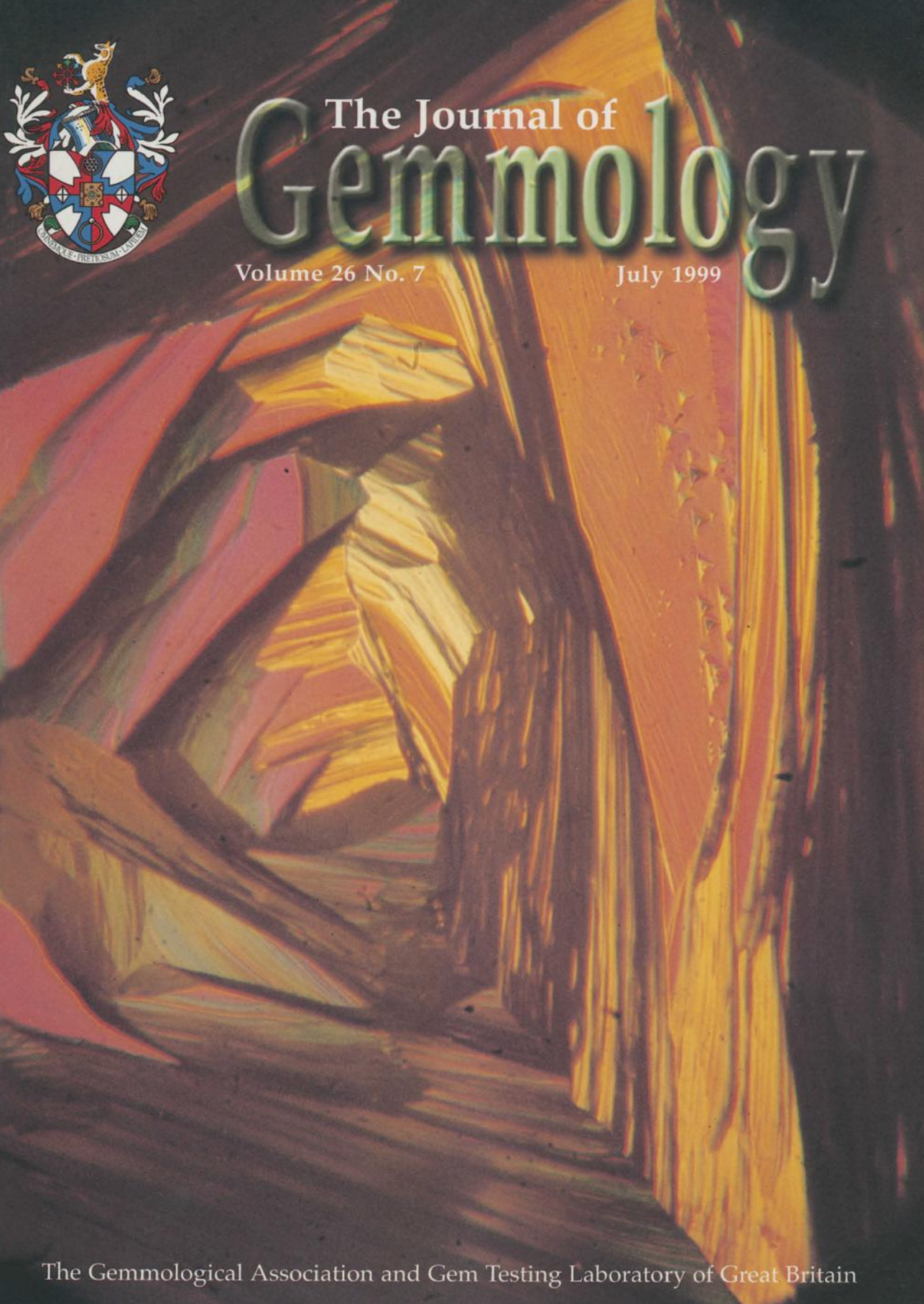

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Review of recent studies on black jadeite jade

C.M. Ou Yang[1] and Li Hansheng[2]

1. *Hong Kong Institute of Gemology, Hong Kong*
2. *Institute of Geology, CAGS, Beijing, P.R. China*

ABSTRACT: Black jadeite jade, appearing on the Hong Kong market as bangles, beads and pendants, consists mainly of jadeite with small amounts of omphacitic pyroxene and accessory minerals. The colour of the jade is attributed to minute inclusions, largely of amorphous carbon with some metallic oxides and sulphides. In places the colour is patchy and the jade is colloquially known as black-skin-chicken jadeite.

Keywords: black-skin-chicken jadeite, electron microprobe analysis, inclusions, jade, petrography

Introduction

The term jade encompasses tough, compact fine-grained aggregates of minerals from two isomorphous series. Nephrite jades consist mainly of amphiboles (actinolite series) and pyroxene jades consist mainly of pyroxenes in the series jadeite-aegirine-diopside-kosmochlor. Burmese jadeite consists mainly of the sodium pyroxene jadeite with variable quantities of kosmochlor, omphacite, amphiboles (actinolite, tremolite or glaucophane) and albite feldspar (Deer *et al.*, 1978; Ou Yang, 1984, 1985, 1993a,b).

The colour of Burmese jade ranges from white (colourless) to bluish-violet, pinkish to dark purple, pale to dark and bright green, and yellow to brown and red – the latter caused by weathering and iron staining. Currently the term 'black jade' may include

Figure 1a,b: *Black jadeite jade bangles.*

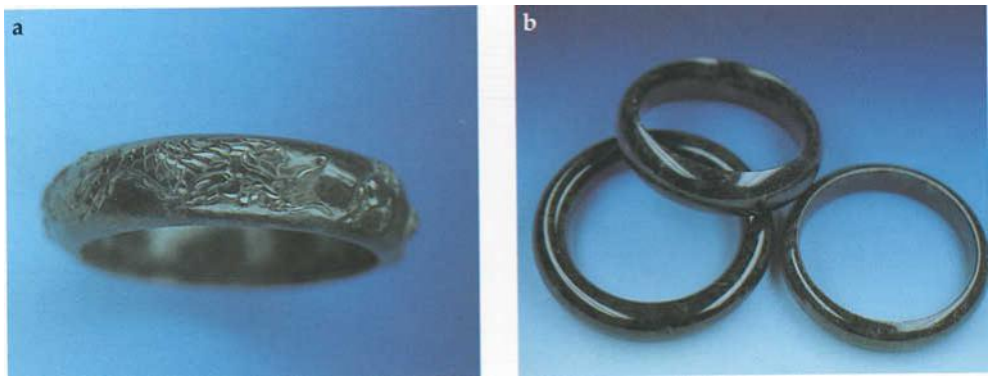

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Figure 2: Black jadeite jade pendant.

different types of pyroxene jades and is potentially confusing for the trade. This account describes a particular kind of black jade available recently on the Hong Kong market.

Black jade

The 'black jadeite' on the Hong Kong jade market is overall a greyish-black rather than pure black. It is similar in colour to that of black-skinned chickens – hence the colloquial term black-skin-chicken jadeite. Although not common on the market, it does appear in bangles, strung beads, carved pieces, and pendants (*Figures 1 and 2*). Some pieces of rough black jadeite of this type have been found in Myanmar by one author (C.M.O.Y.) and it appeared at the Myanma Jadeite Auction market in 1996 (*see Figure 3a,b*). Hitherto the black jadeite has not been popular and little is known about it, so six samples were selected for microscopic examination, X-ray diffraction studies, electron microprobe and chemical analysis, and laser Raman analysis to determine its composition and the cause of the colour.

Gemmological characteristics of black jadeite jade

Black jadeite jade is a compact fine- to coarse-grained aggregate of crystals in an interlocking granular texture. The blackness is uneven, varying between grey and jet black in patches, with the lighter parts showing a tinge of green. In general, the finer the grain size, the darker the colour. The jade is opaque (fine grained) to translucent (coarser grained) with a vitreous lustre except in a few areas where it tends towards an oily lustre; fresh and well-polished

Figure 3a,b: Rough black jadeite jade.

Figure 4: *Polished surface of black jadeite jade bangle.*

surfaces have a vitreous lustre. On polished surfaces, a black vein-like pattern is commonly visible (*Figure 4*), and in the more coarsely grained varieties the faces and cleavages of the constituent grains can give rise to star-like flashes in reflected light – termed 'jadeite flower' or 'fly wing flash'. Such features are not shown by black nephrite jade. On Mohs' scale the black jadeite jade is about 7, close to or slightly harder than agate. Using hydrostatic methods the SG of black jadeite ranges from 3.325–3.333, and its RI range on a Rayner refractometer is 1.653–1.665. It is inert under ultraviolet radiation, both long and short wave.

Black jadeite jade is very compact and generally free from cracks, being therefore very suitable for the manufacture of bangles. It is generally considered to be less valuable than green jadeite but is believed to bring physical protection and happiness. Black jade has been used for jewellery in Hong Kong and Taiwan.

Mineral composition of black jadeite jade

Under the microscope the black jadeite jade is seen to consist of an interlocking mosaic of granular and short prismatic jadeite crystals (*Figure 5*) in a heteroblastic texture. Grain size varies greatly with some porphyroblasts reaching 1.4 x 3.5 mm in size (*Figure 6*). In general, however, the grain size lies between 0.14 x 1.28 mm and 0.70 x 1.40 mm. The pyroxene cleavages

Figure 5: *Granular interlocking texture of jadeite crystals; crossed nicols; field of view about 6 mm across.*

intersect at 87° and the extinction angle to the *c*-axis is 38°, although many grains show wavy extinction and some have zones of crushing or cataclasis.

Microscope, X-ray diffraction, electron microprobe and laser Raman microprobe analyses indicate that black jadeite jade is essentially monomineralic, consisting of 95% jadeite and about 5% accessory minerals and black pigments. However, the jadeite is not

Figure 6: *Porphyroblastic texture in black jadeite; crossed nicols; field of view about 6 mm across.*

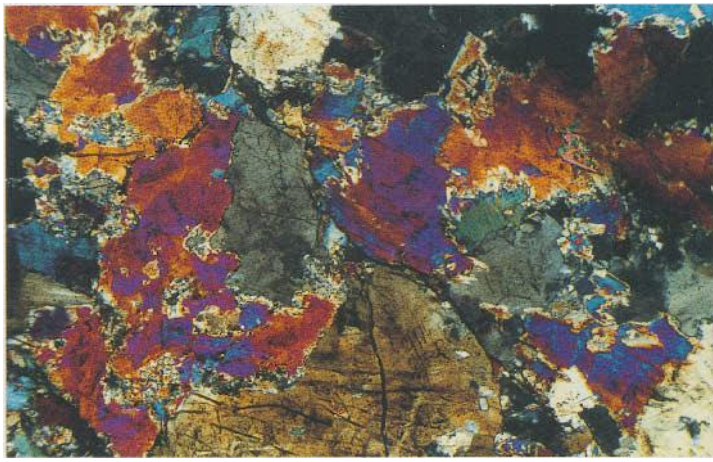

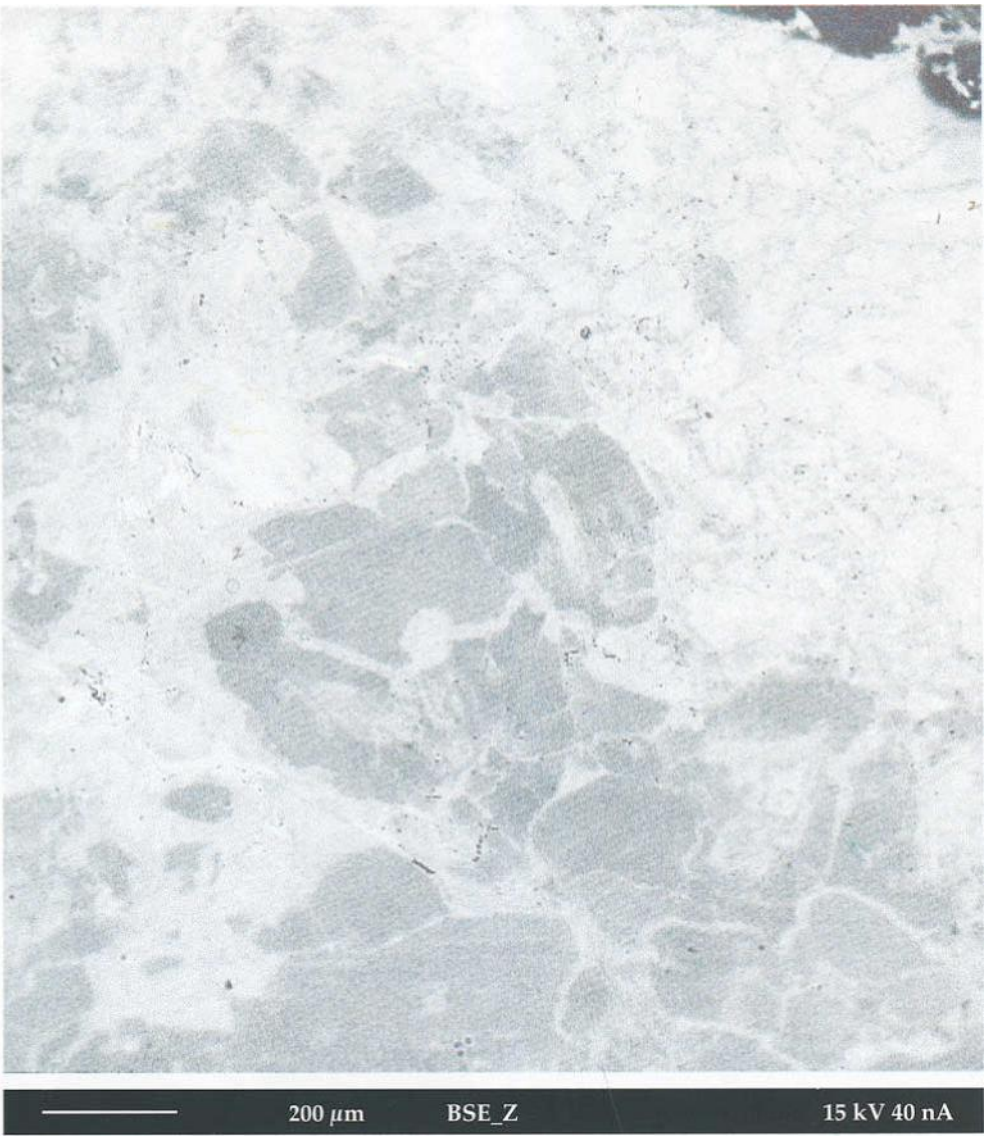

Figure 7: Black jadeite jade analysed by electron microprobe.

all pure Na Al silicate; the crystals are zoned and away from the cores the compositions grade into the jadeite-omphacite-diopside pyroxene series; the electron microprobe analyses indicate compositional zoning whereby Ca and Mg contents increase from core to margin of the grains at the expense of Na and Al (see *Table I* and *Figure 7*). In mineral terms the grains range from pure jadeite (J in Table I) to omphacitic jadeite (OJ) to jadeitic omphacite (JO). Accessory minerals in the black jadeite consist of apatite, zircon, magnetite, pyrite, titanite and opaque dust-like materials (pigments).

The major element composition of black jadeite jade

As shown in *Table I*, the whole-rock composition of black jadeite jade is close to

Table 1: Composition of black jadeite.

Wt. %	Analysis of rock 1	Electron microprobe analyses of jadeite grains								
		Sample 21			Sample 28			Sample 35		
		Core 3	Zone 2	Rim 1	Core 3	Zone 2	Rim 1	Core 3	Zone 2	Rim 1
SiO_2	57.81	58.989	58.248	57.474	59.446	59.476	57.214	58.656	58.099	56.498
TiO_2	0.02	0	0.034	0.082	0	0	0.125	0	0.046	0.046
Al_2O_3	19.90	22.647	18.194	13.929	25.205	23.425	13.092	22.606	20.320	13.107
Fe_2O_3	1.10	1.678	1.598	2.464	0.033	0.579	1.912	0.550	2.128	2.830
FeO	0.35	0	0	0	0	0.381	0	0.361	0	0
MgO	2.81	1.595	4.655	7.330	0.046	0.894	8.558	1.514	2.825	8.264
CaO	4.02	2.323	6.418	10.261	0.104	1.254	11.931	2.364	4.267	11.557
MnO	0.04	0.058	0.060	0.046	0.031	0.044	0.117	0.041	0.123	0.130
NiO	n.d	0	0	0.017	0	0	0.007	0	0	0
ZnO	n.d.	0.021	0.004	0.016	0	0	0.075	0.021	0.021	0.052
Na_2O	12.39	14.043	11.503	9.274	15.281	14.554	8.364	13.803	12.803	8.415
K_2O	<0.02	0.017	0.003	0.029	0	0.003	0.018	0	0.009	0.006
Ce_2O_3	n.d	0.016	0	0	0	0.010	0	0.023	0.017	0.020
Nb_2O_3	n.d.	0.014	0	0	0	0.004	0.004	0	0.015	0
SO_3	0.01	0.003	0.006	0.019	0.009	0	0.016	0.010	0.014	0.013
CO_2	0.04									
H_2O	0.05									
F	0.03									
Total	98.55	101.404	100.723	100.941	100.155	101.005	101.433	99.949	100.687	100.938
Classification		J	OJ	JO	J	OJ	JO	J	OJ	JO

Notes: Rock analysis (1) by the National Research Center of Geoanalyses of China, 1997.
Electron microprobe analyses by Institute of Geology, Academia Sinica, 1995, 1996.
J = jadeite; OJ = omphacitic jadeite; JO = jadeitic omphacite.
Analysis 21.2 contains 0.02% Cr_2O_3; 28.1 contains 0.03% ZrO_2. CO_2, H_2O and F were not determined for the jadeite grains.

that of relatively pure jadeite, suggesting that both the black and the greyer varieties are near monomineralic. The small differences in composition are due to the presence of accessory minerals and inhomogeneities in the jadeite. From relatively pure jadeite cores the Na and Al contents of the jadeite grains decrease towards the rims, with corresponding increases in Ca and Mg towards omphacite and diopside compositions. The chemical basis of the nomenclature is as follows: jadeite contains $Na/(Na + Ca) > 0.8$; omphacite contains $Na/(Na + Ca)$ of 0.8~0.2; and diopside has $Na/(Na + Ca) < 0.2$; also, according to Wang Pu *et al.* (1984), omphacite has $Al/(Al + Fe^3) > 0.5$. Microprobe analyses indicate that in the black jadeite jade, the jadeite grains contain 20.3 to 25.2% Al_2O_3 and 11.5 to 15.3% Na_2O, with $CaO < 4.3\%$ and $Mg < 2.9\%$, while the

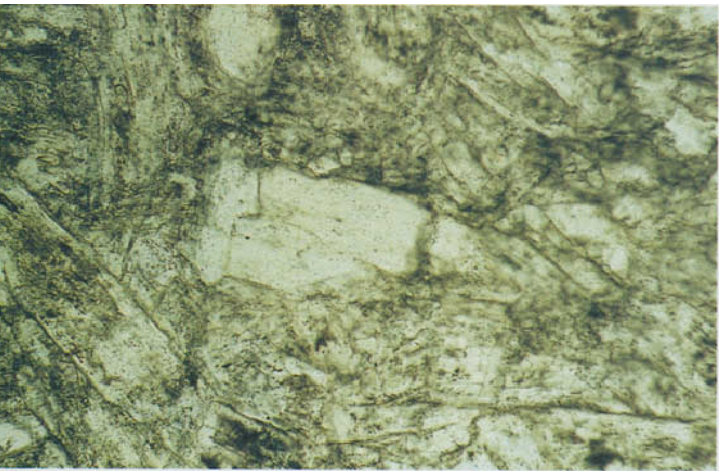

Figure 8: Jadeite grains with black dust-like inclusions along cleavages, cracks and grain boundaries. Plane polarised light; field of view about 6 mm across.

omphacitic jadeite and jadeitic omphacite (OJ and JO respectively in *Table I*) contain lower Na and Al and higher Ca and Mg in proportion.

The colour of black jadeite jade

On polished surfaces of the jadeite, black or dark opaque dust-like materials may be observed as dispersed grains, tiny pellets or patches, or fine networks. Under a high, resolution microscope, thin sections of the jadeite also reveal particular patterns of the microgranular or dust-like inclusions. Five such patterns can be distinguished:

1. Brown inclusions may be on particular crystal faces of the jadeite grains or dispersed at random (*Figure 8*); they consist mainly of CO_2 and organic hydrocarbons and relate to deep-seated fluid inclusions. The shapes of single inclusions are slightly irregular, while some are vermicular, but a group of associated inclusions tends to be arranged in an orderly way in the direction of a particular crystal surface.
2. Opaque or dark dust-like grains are distributed regularly along compositional zones of jadeite grains; these are primary inclusions.
3. Regular distribution of opaque or dark grains along one or more sets of cleavage planes; this may create a schiller effect and be due to segregation of the granules during formation of the jadeite crystals (*Figure 9*).
4. Opaque dust-like grains and pellets occur as discontinuous strings or as veinlets along microcracks at angles to the jadeite cleavages (*Figure 10*).
5. Dust-like grains, pellets, patches or veinlets of opaque material occur in the interstices between jadeite grains or along microcracks across mineral aggregates (*Figure 11*).

Figure 9: Cleavage planes in jadeite with black dust-like inclusions; crossed nicols; field of view about 2 mm across.

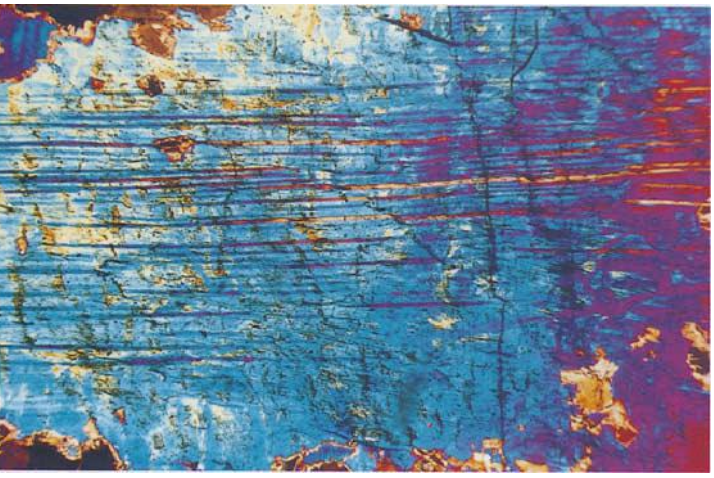

Figure 10: Jadeite grains with black dust-like inclusions along microcracks at angles to the cleavage. Plane polarised light; field of view about 6 mm across.

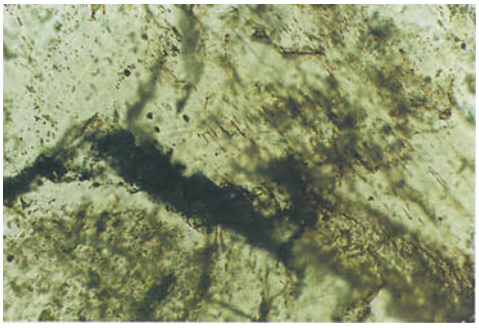

Figure 11: Black pigment concentrated along grain boundaries. Plane polarised light; field of view about 6 mm across.

The dust-like and opaque microgranular material is abundant and widely dispersed, and is the reason why the jade is grey or black.

On polished surfaces of black jadeite, the intensity of blackness may vary and this is due to the amount and distribution of pigmentary material. Where the fine-grained opaque materials are thinly dispersed throughout jadeite jade of average grain size, the rock may appear greyish-black, but where perhaps the pigmentary materials have reacted to stress and fluids in the rocks and migrated to form more concentrated patches and veinlets the jade will be very black. Where the jadeite is very coarse, and perhaps originally light green, similar stress and fluids may cause the opaque grains to gather in the interstices between jadeite grains and form a greyish-green mottled rock with reticular black veinlets.

Inclusions

High-resolution microscopy indicates that there are some colourless and transparent two-phase (gas + liquid) and three-phase (gas + liquid + mineral) inclusions associated with opaque and dark-coloured solid inclusions of the first three categories outlined in the previous section. In reflected light, at high power, metallic reflections from the solid inclusions can be seen; these were probably formed syngenetically with the host jadeite (*Figure 12*). Electron microprobe analyses indicate that the solid inclusions consist of magnetite, pyrite, amorphous carbon, leucoxene and organic salts of iron. Laser Raman microprobe analyses carried out by the Xian Institute of Geology and Mineral Resources, Chinese Academy of Geological Sciences (1996), indicate that the multiphase inclusions contain a range of substances including water, CO_2, alkanes, alkenes, aromatic hydrocarbons and resins.

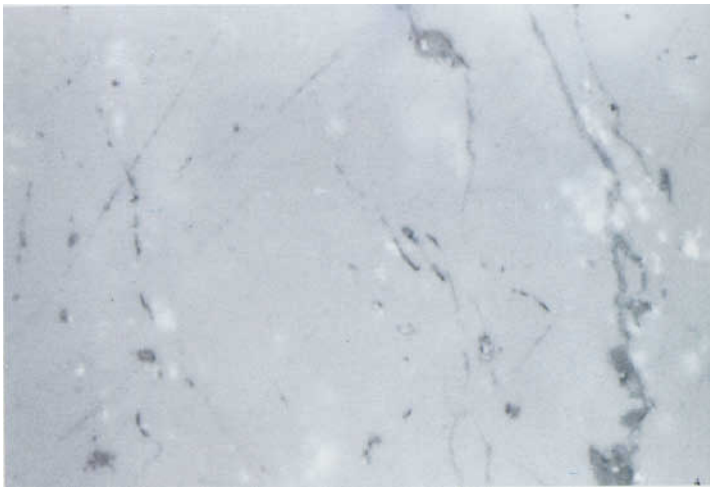

Figure 12: Metallic reflections from inclusions in jadeite, x 1600.

Some inclusions are protogenetic, originating from magma source regions, some syngenetic, forming at the time of the jadeite host crystals, and some are epigenetic, formed under hydrothermal conditions or by segregation under pressure and stress on the jadeite which in turn caused migration of inorganic and organic materials along cleavages to grain boundaries (*Figures 8, 10 and 11*).

Summary

Black jadeite jade consists of more than 95% jadeite or omphacitic jadeite, coloured black by the presence of minute inclusions evenly or unevenly dispersed throughout. The inclusions comprise metallic oxides and sulphides, amorphous carbon, organic salts, water, CO_2 and a range of hydrocarbons. Some inclusions are protogenetic or syngenetic but others are epigenetic and have concentrated in patches to give a blotchy appearance to the jade.

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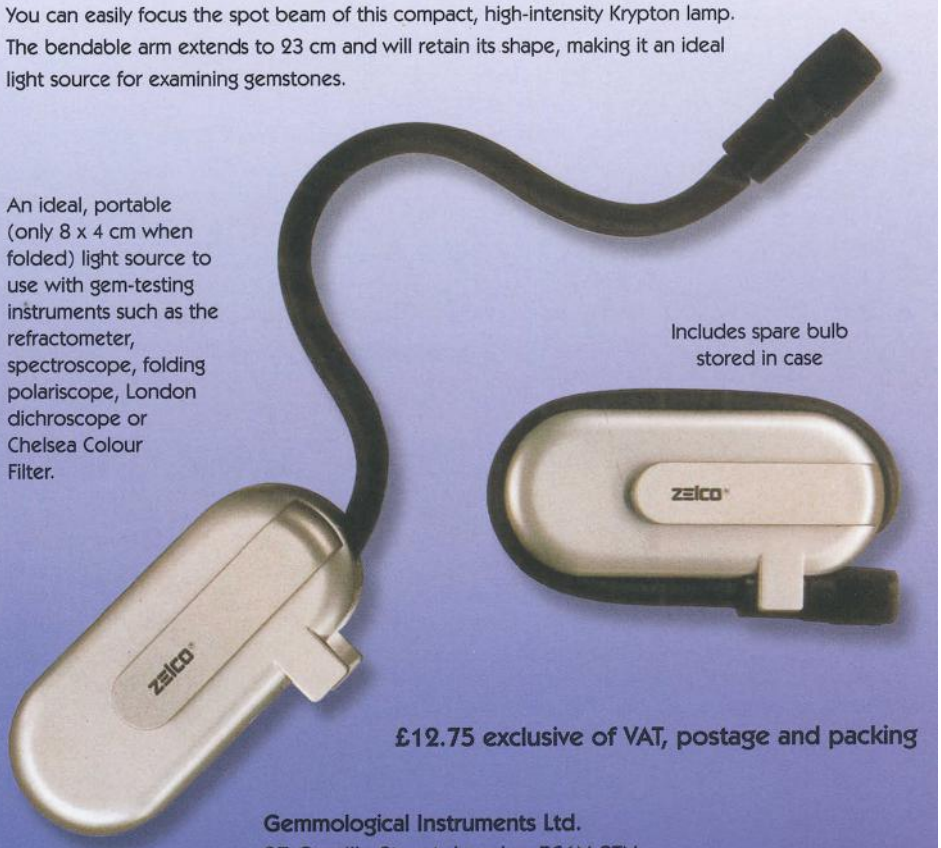

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Moissanite: a new synthetic gemstone material

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ABSTRACT: Synthetic moissanite (silicon carbide, SiC) is a new synthetic gemstone material developed and marketed by C3 Inc. of the USA. It provides a new gemstone that can also serve as a diamond substitute with properties overall closer to those of diamond than any other substitute: refractive indices 2.648 and 2.691, dispersion 0.104, birefringence 0.043, hardness 9 1/4, specific gravity 3.22. Diagnostic to the trained gemmologist are the birefringence, inclusions and surface appearance.

Keywords: diamond simulant, Moissan, synthetic moissanite, silicon carbide

Introduction

This report describes the background for, and characteristics of, synthetic moissanite (silicon carbide, SiC), a new gemstone material that can also serve as the most convincing diamond substitute to date (see *Figure 1*). A summary of gemmological data and identification techniques is given, but for more detailed spectroscopic and XRF information on moissanite see Nassau *et al.*, 1997. While moissanite does exist in nature, both terrestrially and in meteorites as discussed below, it has not been found in pieces large enough to be faceted.

As always happens with the introduction of any new synthetic, there is considerable concern in the jewellery trade. Particularly problematic are properties so close to those of diamond that synthetic moissanite passes as 'diamond' under test by thermal probe instruments, by the read-through effect and by several other tests.

It is now 23 years since cubic zirconia (CZ) was first seen in the trade as a diamond

Figure 1: *Twelve near-colourless synthetic moissanites; the largest is 6.37 ct, 12.5 mm, and would be classified as M, SI1 in the GIA diamond grading system. Photo by Robert Weldon.*

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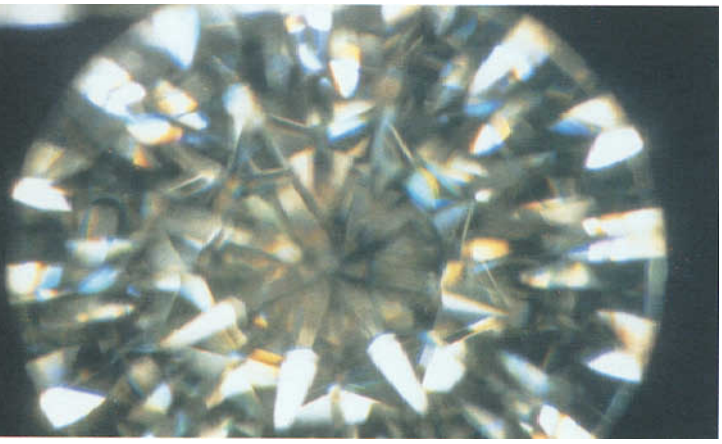

Figure 2: Viewed squarely through the table, doubling is seen in reflections of the table and crown facets, but not in the culet region (here somewhat out of focus) because the view is down the optic axis. Photo by Shane Elen, courtesy of the GIA.

imitation in 1976 (Nassau, 1980). This is probably the longest unchallenged reign of any synthetic diamond substitute and it was difficult to foresee what material might serve in an improved role – other than synthetic diamond itself.

All previous synthetic diamond imitations have significant deficiencies. As examples, synthetic spinel, colourless sapphire and yttrium aluminium garnet (YAG) are much less brilliant; synthetic rutile and strontium titanate (ST) are much too soft; gadolinium gallium garnet (GGG) and CZ have very high specific gravities, and the last of these is somewhat brittle. By contrast, the synthetic moissanite here described has (using average values):

- a refractive index higher than that of diamond (2.67 vs. 2.42);
- a significantly higher dispersion (0.104 vs. 0.044), but not as excessive as the 0.190 of ST;
- a specific gravity near that of diamond (3.22 vs. 3.52);
- a hardness of 9¼, second as a gemstone material only to the 10 of diamond; and
- it is even tougher than diamond because the pronounced octahedral {111} cleavage of diamond is absent or weak, although there may be a relatively weak {0001} cleavage.

A drawback of synthetic moissanite as an imitation of diamond is the presence of a significant birefringence of 0.043, but less than the 0.059 of zircon or the large 0.330 of synthetic rutile, both once used as diamond imitations. However, this effect is minimized because currently all stones are faceted with the optic axis perpendicular to the table facet. As a result, doubling of facets is absent when looking squarely into the top of a stone at the culet region; doubling is only seen when focusing deeper at reflections in the pavilion facets (see *Figure 2*) or when looking into a stone at an angle, say, through the girdle.

Two US patents (Hunter and Verbiest, 1998) have recently been granted to C3 Inc., giving this firm the exclusive right to market synthetic moissanite as a gemstone material in the USA. Patent applications are also under way in other countries. Their tester to identify synthetic moissanite is also patented. In mid-1998, C3 Inc. began shipping faceted stones to a limited number of retailers in the USA and to exclusive distributors internationally; 18,000 ct were shipped in 1998 and 14,000 ct in the first quarter of 1999.

The background of moissanite

The growth of single crystals of silicon carbide, SiC, mineral name moissanite, has been under investigation for more than a century for three ends:

1. as a very hard abrasive, second only to the hardness of diamond;
2. for its potential as a promising technological semiconductor material; and
3. as a possible gemstone material and diamond substitute with properties closer to those of diamond than any other known material.

The potential promise of synthetic moissanite has been described several times in the gemmological and related literatures (Gill, 1978). Enthusiastic optimism reigned, frequently with claims that colourless material was available (e.g. De Ment, 1948, 1949; Mitchell, 1962; McCawley, 1981), but Nassau (1980) outlined the situation thus:

Ferdinand Frederick Henri Moissan

Ferdinand Frederick Henri Moissan, *Figure A1* (taken from Harrow, 1920), did not normally use his first two names. He was born in Paris, France, on 28 September 1852. His father was a chemist. The young Henri was so good at science that his science teacher gave him supplementary private lessons. Because of the family's limited means, at first he had to work as a pharmacist's assistant but in time managed to return to school and received the doctorate degree in chemistry at the age of 27.

While lecturing at the Ecole Superieur de Pharmacie, he began his own research into inorganic chemistry, a subject much neglected at that time. He was the first to isolate the element fluorine from one of its compounds in 1884, a process that had been unsuccessfully attempted by many eminent chemists. There were ample rewards for this achievement, among them a full professorship, election to the French Academie des Sciences and, the ultimate recognition of all, the Nobel prize for chemistry in 1906.

Figure A1: Ferdinand Frederick Henri Moissan (Harrow, 1920), the discoverer of elemental fluorine (Nobel Prize for chemistry, 1906), the carbon-arc furnace, and moissanite in the Canyon Diablo (Arizona) meteorite.

Among the many reactions of fluorine that Moissan studied were high temperature ones with carbon. This had two consequences: he developed his famous electric-arc furnace which could reach 4000°C and he became interested in diamond, carbides and meteorites. He thought (Moissan, 1920), erroneously, that he had prepared synthetic diamond (see also Nassau, 1980).

In one of his experiments Moissan dissolved a 53 kg specimen of the Canyon Diablo (Arizona) meteorite in a succession of strong acids and identified in the residue tiny crystals of silicon carbide (Moissan, 1904). The mineral name moissanite was given to this material in Moissan's honour by Kunz:

> 'As this is the first instance in which this compound has been proved to occur in nature, and therefore, as a mineral, is entitled to a distinct mineralogical name, it would seem that the name of Professor Moissan himself should be associated with it. I would, therefore, propose for it the name of Moissanite, as a slight recognition of his many services to chemistry, and especially of his researches on the artificial carbides and his study of the constituents of meteorites, and the reproduction of similar substances by means of the electric furnace.' (Kunz, 1905)

According to Harrow, Moissan's lectures at the Sorbonne were crowded:

> 'The charm of his personality and his evident joy in exposition gave keen pleasure to his auditors. He will live long in the memories of all who were privileged to know him, as a man full of human kindness, of tact, and of true love of the subject which he adorned by his life and work.' (Harrow, 1920)

Moissan died in 1907 from appendicitis (in an era before antibiotics) at the age of 55.

Table I: Some simple polytypes of moissanite[i]

Ramsdell designation	Stacking sequence repeat unit	Space group	Optical constants[ii] n_o	n_e	Birefr.	Disp.
β –SiC (β–silicon carbide) cubic[iii]						
3C	ABC	$F\bar{4}3m$	2.652	–	0	0.112
α –SiC (α–silicon carbide) hexagonal						
2*H*	AB	$C6_3mc$	2.633	2.707	0.074	0.106
4*H*	ABCB	$C6_3mc$	2.659	2.712	0.053	0.122
6*H*	ABCACB	$C6_3mc$	2.648	2.691	0.043	0.104
8*H*	ABCABACB	$C6_3mc$	–	–	–	–
10*H* etc.	ABCBACABCB	$P\bar{3}ml$	–	–	–	–
α –SiC (α–silicon carbide) rhombohedral						
15*R* etc.	ABCBACABACBCACB	$R\bar{3}ml$	2.650	2.697	0.047	0.108

i. The most common polytype of moissanite in synthetic abrasive material is 6*H*; 15*R* is the second and 4*H* the third most common polytype. The topic of this report is the synthetic moissanite 6*H*.

ii. n_o and n_e are the ordinary and extraordinary refractive indices at 589 nm; birefringence (Birefr.) is n_e–n_o; dispersion (Disp.) is n_o (431 nm) – n_o (687 nm). Values were calculated from the precision equations given by Von Muench (1982) and Harris (1995).

iii. There is only one cubic polytype; it has an inherent deep-yellow colour.

> 'Despite many decades of intense effort by scientists using a variety of different approaches, it has not yet been possible to control either the color, or even the crystal growth itself precisely enough to make single crystals suitable for either technological or gemological use.' (op. cit. p.253)

Only recently has the controlled growth of synthetic moissanite actually been achieved (Davis *et al.*, 1990; Carter *et al.*, 1998) so that material that is colourless to the naked eye is finally available for gemmological use.

Early work on silicon carbide (it has also sometimes been called carbon silicide) was summarized by Mellor (1929). Edward G. Acheson (1893) appears to have been the first to recognize its hardness and potential as an abrasive. He prepared it accidentally while trying to grow diamond by passing an electric arc between carbon electrodes through a mixture of carbon and molten clay, an aluminium silicate. He named the substance 'carborundum', later to become a trade name, because at first he thought it to be a compound of carbon and corundum (alumina, Al_2O_3) and/or because of its hardness being intermediate between those of diamond and of corundum. Subsequently, he obtained a better yield by using a mixture of carbon and sand. This came to be known as the 'Acheson process' and is still used today for the manufacture of silicon carbide for abrasive and other uses.

At about the same time, the Nobel prize-winning chemist Henri Moissan discovered natural silicon carbide in the Canyon Diablo meteorite (see Ferdinand Frederick Henri Moissan, p.427) and the mineral name 'moissanite' was given to this material in Moissan's honour by Kunz (1905).

The technological importance of silicon carbide is shown by a series of international conferences starting in 1959 (O'Connor and Smiltens, 1960), but it was not until the sixth conference in 1996 that there were:

> '... epoch-making results in the history of the subject ... For SiC these included ... a sublimation method for crystal growth ...' (Nakashima *et al.*, 1996).

The structure and preparation of moissanite

Considerable confusion resulted when early investigators found a variety of different structures for moissanite, including those having cubic (*C*), hexagonal (*H*) and rhombohedral (*R*) symmetries. This complexity is explained by the existence of *polytypes*, variations in the crystal structure that can depend on growth conditions. Such polytypes can occur in any materials which consist of the stacking of hexagonal layers as described in Polytypism and moissanite (p.430). More than 150 polytypes are known for silicon carbide, all of which are properly designated 'moissanite'.

The synthetic material here described is the moissanite-6*H* form of α-silicon carbide or SiC:6*H* (see *Table I*). The only other moissanite polytype that can be grown in large crystals is the 4*H* form (Nakashima *et al.*, 1996). The cubic 3C polytype, β-silicon carbide, might be interesting if it could be grown in bulk; however, its inherent deep-yellow colour (von Muench, 1982) would prevent its use as a diamond imitation, but not as a unique synthetic gemstone.

In the Acheson process for industrial production of moissanite (Divakar *et al.*, 1993; Verma and Krishna, 1966; Smoak *et al.*, 1978; Von Muench, 1982, 1984), carbon in the form of petroleum coke or anthracite coal is mixed with sand and a little sawdust and salt. An electric current is passed through a central graphite rod surrounded by the mixture to heat it internally to a maximum temperature of 2700°C, producing the simple reaction:

$$SiO_2 + 3C \rightarrow SiC + 2CO$$

Clusters of single crystals occasionally occur in sizes up to 1 cm across and a few millimetres in thickness, ranging from black to green to tan, as in *Figure 3*, sometimes with an iridescent coating.

For high-purity moissanite powders, volatile substances such as silicon tetrachloride, organic silicones, and gases such as methane have been reacted or decomposed by using a plasma or other heat source; moissanite fibres have been made by decomposing fibres of organosilicon polymers (Divakar *et al.*, 1993).

Single crystal growth of moissanite

Several techniques for growing crystals of synthetic moissanite have been studied for many decades (O'Connor and Smiltens, 1960; Verma and Krishna, 1966; Divakar *et al.*, 1993; Wilke, 1988; Von Muench, 1984). Of these only a seeded sublimation process, derived from the 'Lely' approach, has proved viable for the controlled growth of large single crystal boules of moissanite (Davis *et al.*, 1990; Nakashima *et al.*, 1996).

Melt processes cannot be used to grow moissanite crystals because decomposition of the starting materials begins at 2830°C, well before melting can occur. Flux processes

Figure 3: *Synthetic moissanite produced by the Acheson process for abrasives use: (a) a typical black crystal cluster; (b) faceted yellow and green stones, the largest is 0.52 ct. Photos by K. Nassau.*

Polytypism and moissanite

When hexagonal layers of atoms are stacked on top of each other, there are various stacking sequences that can occur. The term 'polytypism' is used for the occurrence in a substance of several crystal structures when all have the same chemical composition but have different layering sequences in the stacking direction (Verma and Krishna, 1966).

While not common, polytypes occur in several minerals. The best-known example of polytypes are the zinc sulphides: sphalerite (also blende or zinc blende, cubic) and wurtzite (several hexagonal and trigonal forms); all have the composition ZnS. The element carbon occurs in two polytypes: the cubic form diamond and the hexagonal form lonsdaleite (graphite and chaoite are not polytypes but only polymorphs).

Consider the hexagonal double layer of SiC in *Figure B1*, where each solid circle marked *A* represents a silicon atom with a carbon atom exactly below it. Let a second double layer be placed on top of the double layer *A*, occupying the positions *B* as shown with dashed circles. A third double layer can now be added in two different ways.

First consider the third double layer occupying positions exactly above the first double layer A as at (a) in *Figure B2*. This stacking, when repeated, can be described as ABABAB... Close examination of the resulting structure shows that this is hexagonal, designated *H*; since the repeat unit consists of *two* double layers, one way of designating this structure is 2*H* in the Ramsdell notation (Verma and Krishna, 1966).

Figure B1: *The stacking of hexagonal layers.*

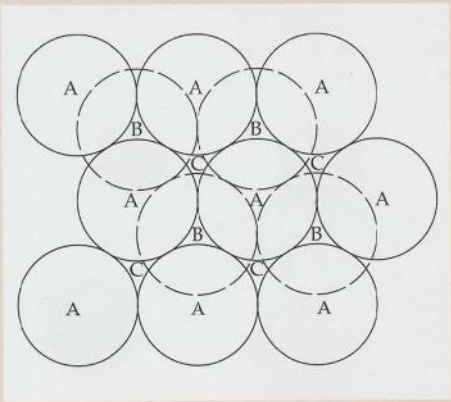

However, if the third double layer instead occupies the positions *C* in *Figure B1*, the repeated stacking can then be described as ABCABC... Although not evident from *Figure B2* at (b), examination of an actual model shows that this structure is cubic *C*; since the repeat unit consists of *three* double layers, this structure is usually designated 3*C*.

Yet two more stacking sequences are shown at (c) and (d) in *Figure B2*, corresponding to ABCB... and ABCACB... Both of these are hexagonal, with four double layer repeat units designated 4*H*, and six double layer repeat units designated 6*H*, respectively. Moissanite-6*H* is the most common form in the synthetic abrasive material and is the form that is the subject of this report. 4*H* and 6*H* are the only polytypes of moissanite that can be grown as large crystals at present. Some additional simple hexagonal polytypes are included in *Table I*. The simplest rhombohedral structure of moissanite is 15*R*, with a repeat unit as given in *Table I*.

At temperatures below about 2000°C the stable form of moissanite appears to be 3*C* or β-silicon carbide, the only cubic form, given in *Table I*. At higher temperatures, crystals of any of the more than 150 polytypes of α-silicon carbide, either hexagonal or rhombohedral, may occur, often mixed with each other and with the cubic form (Verma and Krishna, 1966; Davis *et al.*, 1990). Interlayers of polytypes within a crystal as well as other defects can occur when crystal growth is not under good control.

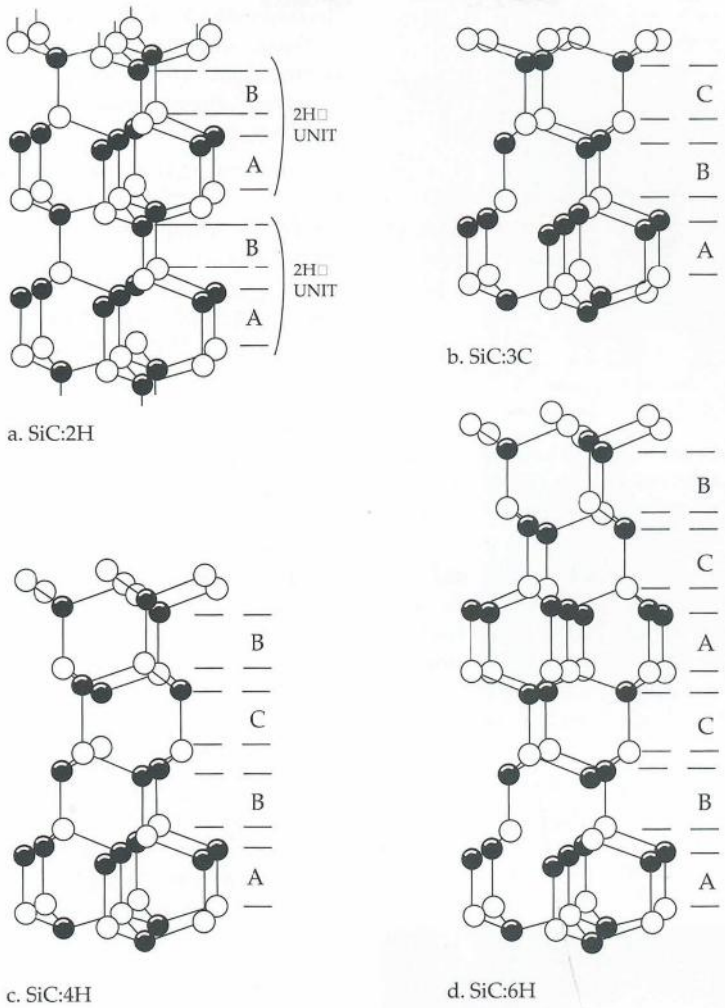

Figure B2: *The structures of the hexagonal 2H, 4H, and 6H forms of α-silicon carbide and of the cubic 3C β-silicon carbide.*

In all forms of moissanite each Si is surrounded by four C and each C by four Si atoms; all Si-C bond lengths are equal at about 1.90 Å. In all hexagonal and rhombohedral structures the stacking direction is the *c*-axis which is also the optic axis; in the cubic form the stacking direction is the body diagonal [111]. All SiC polytypes have hexagonal (or equivalent hexagonal) unit cells with dimensions very close to a = 3.08 Å and c = 2.52*n* Å, where *n* is the number of double layers in the repeat unit. Hence the specific gravities, optical and most other properties are very similar. Space groups and some optical properties of several moissanite polytypes are given in *Table I.*

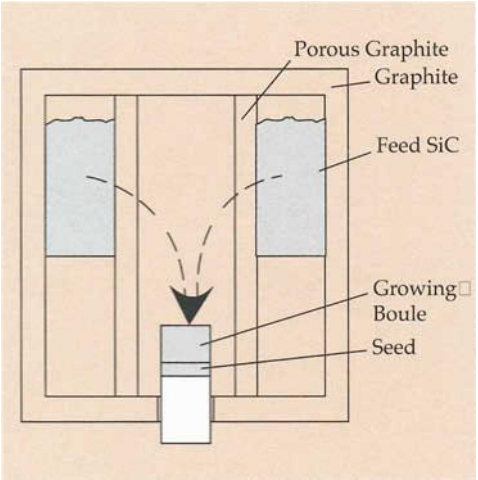

Figure 4: *The growth configuration described in the Davis, Carter and Hunter (1990) patent for the controlled growth of single crystal moissanite.*

have, however, produced results and tiny crystals of the cubic β-silicon carbide have been grown at about 1700°C from solutions of carbon in molten silicon, and from SiC solutions in molten nickel, chromium and various metal alloys. Vapour transport at

Figure 5: *The triangular pit on the surface of this 71.4 gram part of a synthetic moissanite boule resembles the trigons commonly seen on diamond crystals. The pit has sides of 6 mm and a depth of less than 0.25 mm. Photo by K. Nassau.*

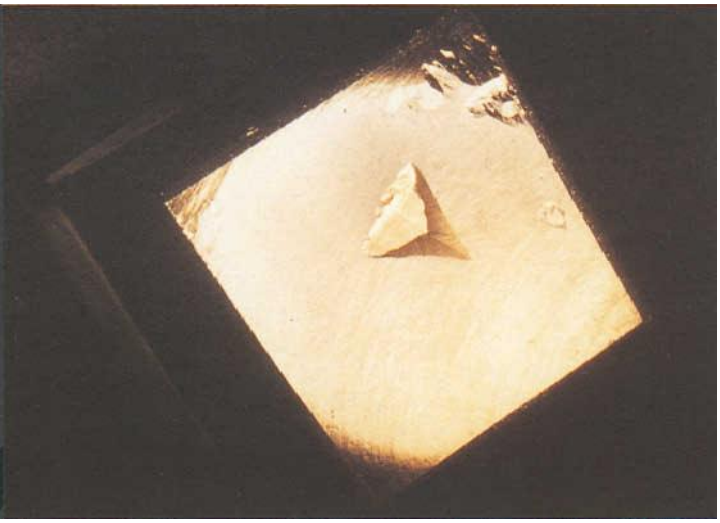

1800°C has been used to obtain thin films. In gaseous cracking, also called pyrolytic decomposition or the 'van Arkel' process, various volatile Si- and C-containing compounds are passed over a heated tungsten wire, and moissanite is deposited as small crystals.

The Lely process uses sublimation, where the silicon carbide is vaporized and then condenses without ever passing through the liquid state. In his original work, Lely (1955) used a cylinder made of lumps of SiC containing a hollow cavity. This was heated in a sealed graphite crucible to 2500°C when crystals grew inside the cavity. Many modifications have been tried to control purity and polytypes, particularly the use of a thin porous graphite tube to line the cavity, as well as carefully controlled atmospheres and temperature gradients. The lining tube controls the rate of sublimation, with crystals growing on its inside. The work of Tairov and co-workers in Russia (e.g. Tairov and Tsvetkov, 1981) provided significant advances.

The final break-through to provide a greater control of the Lely process came with the patent of Davis *et al.* (1990), where growth occurs on a seed crystal. One configuration described in this patent is shown in simplified form in *Figure 4*. As indicated by the arrows, SiC vapour from the feed powder passes through the porous graphite tube to feed the growing crystal boule.

Growth factors discussed in this patent include the following typical conditions:

- feed temperature 2300°C;
- growing crystal 100°C cooler than the feed region;
- seed crystal orientation slightly off axis and prepared by a detailed cleaning process;
- seed crystal and feed powder both the same polytype;
- feed powder having controlled grain size that is constant throughout the growth;
- heat derived from a resistance-heated graphite sleeve;
- atmosphere initially vacuum, then low pressure of argon.

Other factors mentioned include seed rotation, the use of ultrasonic vibration for feeding, and the adjustment of the growing crystal position during the growth process. Because of proprietary considerations, details of the actual growth process have not been released. The Davis *et al.* (1990) patent reports the growth of a 12 mm diameter 6 mm thick moissanite–6*H* crystal during a six-hour growth period. Some boule surfaces show triangular pits resembling the trigons seen on diamonds (*Figure 5*).

Nakashima *et al.* (1996) report various aspects of moissanite growth and applications to the electronics industry and Tsvetkov *et al.* (1996) mention 50 mm diameter boules produced in 1994. To place this size in perspective, if uniformly clear this would permit the manufacture of a 50 mm diameter faceted brilliant-cut synthetic moissanite of height about 28 mm and weight about 380 ct. The equivalent weight of a diamond of equal size would be 420 ct. One can reasonably assume that even larger boules must be possible by now.

A technique for obtaining near-colourless synthetic moissanite by compensating impurities is described in a patent by Carter *et al.* (1998).

Gemmological characteristics of synthetic moissanite

Examination of 23 faceted 'near-colourless' stones, ranging from 0.09 to 1.12 ct, and several pieces of rough ranging up to 71.4 gm, were described in detail by Nassau *et al.* (1997). More than one thousand loose stones were also briefly examined, including a 4.92 ct round brilliant-cut (11.9 mm diameter) of approximate colour grade N on the GIA scale, a 17.31 ct medium green round brilliant-cut (17.5 mm), and over 100 preform cubes. Also examined were 21 pieces of jewellery containing a total of 50 stones, including the 14-carat gold ring shown in *Figure 6*, where the stones had been mounted in wax and then cast in place.

An outline of gemmological characteristics, updated from Nassau *et al.*, 1997, with references, is here presented with those of diamond given in square brackets.

Figure 6: *A 14 ct gold ring containing two rows of faceted pale green synthetic moissanites that were mounted in wax and then cast in place. Ring courtesy of C3 Inc., photo by Maha DeMaggio, courtesy of GIA.*

Visual characteristics

To the unaided eye: No visible inclusions; lustre subadamantine [diamond: adamantine]; effective brilliance similar to that of average diamond; read-through effect none [none]; pavilion flash colours orange and blue [same].

Colours on the GIA diamond colour-grading scale range from I to V, with greyish, greenish, yellowish or brownish hues; because many of these hues are not present in diamond reference stones, it is sometimes difficult to decide on a unique equivalent diamond colour grade [which is also the case for those rare diamonds having such hues].

The colours of synthetic moissanites under ordinary illumination, especially when set in jewellery, usually appear to be better than those indicated by their diamond grades. This difference has two origins: the first is particularly noted in greyish stones, which lack the expected yellow of the Cape series; the second derives from the higher dispersion of synthetic moissanite, the fire

Figure 7: The most common inclusions in synthetic moissanite are thin white needles, generally parallel to the optic axis. Photo by Gary Roskin.

Figure 9: In diamond the polishing orientation must be repeatedly changed for successive facets because of its directional hardness; synthetic moissanite can be polished in a relatively consistent direction as is shown by the polishing lines on the facets of this stone, magnified 32x. Photo by Shane F. McClure, courtesy of GIA.

from which appears to create a 'whiter' impression.

Under magnification: Facet doubling not seen when looking perpendicularly through the table at the culet, but noticeable when looking in this manner at secondary reflections in the pavilion facets as seen in *Figure 2* or when looking into the stone at an angle [absent]; white sub-parallel needles and fine reflective stringers near-perpendicular to the table facet as in *Figures 7 and 8*, pinpoint inclusions, sometimes arranged in clouds; facet junctions may be rounded; polishing lines all in one direction as in *Figure 9* [variable]; occasional small surface cavities or 'whitish' pits; girdle frosted, polished or striated, but no bearding.

Figure 8: In a few synthetic moissanites offsetting bends occur in the needles. Photo by Gary Roskin.

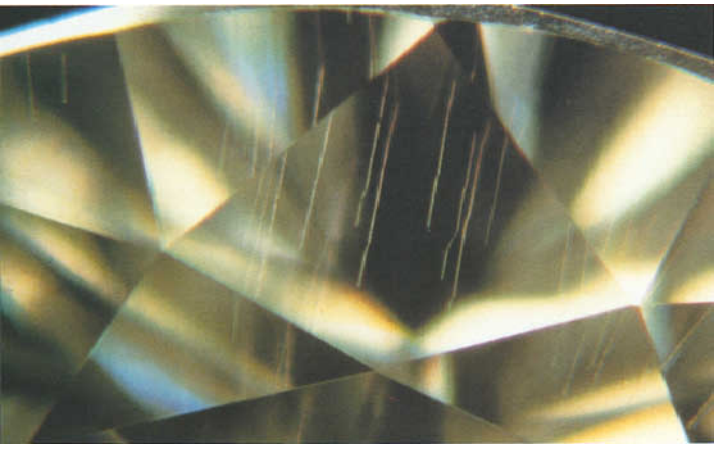

Optical refractive properties

Refractive indices 2.648 and 2.691 [2.417]; reflectometers give a reading above that for diamond: doubly refractive, uniaxial positive [singly refractive, isotropic]; birefringence moderate, 0.043 [none]; dispersion strong 0.104 [moderate, 0.044]; polariscope examination negative through the table, doubly refracting in other directions [negative]; relief in SG 3.32 liquid high [high].

Examined through a hand-held spectroscope, synthetic moissanite shows no absorption lines but there is a cut-off below about 425 nm[1], which could be confused with the diamond 'Cape' line at 415 nm;

1. The 4*H* form of moissanite, the only other polytype that can be grown in large crystals at present, has properties very close to those of the 6*H* form here described (see also *Table 1*), except that the spectrum transmission cut-off is below 400 nm

infrared, ultraviolet and Raman spectra are characteristic and different from those of diamond; fluorescence in short-wave and long-wave UV is inert (usually) to moderate orange, uniform if present [variable]; X-ray luminescence inert (usually) to moderate yellow [variable]; X-ray transparency medium opaque [transparent].

Chemical, mechanical, thermal and other characteristics

Composition SiC [C]; no other impurities detectable down to 0.001%; SG 3.22 ± 0.02 [3.52], therefore floats in methylene iodide (SG 3.32) [sinks]; precision density 3.224 g/cm^{-3}, hence a faceted stone weighs about 9% less than a diamond of equal size; hardness 9 1/4 [10]; Knoop hardness 2954 kg/mm^2 [8000 kg/mm^2]; toughness excellent [good to excellent]; twinning absent [twinning present]; no strong cleavage but a weak basal (0001) cleavage [prominent octahedral cleavage]; previously reported prominent cleavages in moissanite (O'Connor and Smiltens, 1960) were probably partings due to polytype mixtures, a type of twinning.

The stability of synthetic moissanite is better than diamond – in air to 1700°C, in vacuum to 2000°C, to most chemicals to well over 1000°C, except in contact with fluorine, chlorine, molten alkalis, and some molten metals (Divakar *et al.*, 1993); excellent resistance to in-situ soldering of broken prongs and all usual jewellery procedures such as setting, repairing and cleaning, including casting in place in gold jewellery as in *Figure 6*.

Thermal conductivity 2.3 to 4.9 W/cm.K (Harris, 1995) or 0.55 to 1.7 cal/cm.°C.sec [7 to 20 and 1.6 to 4.8, respectively], hence equally 'cold' as diamond; thermal inertia 0.3 to 0.63 cal/cm^2. °C. sec$^{1/2}$ [0.8 to 1.4], hence all thermal inertia ('thermal conductivity') testers currently in use give a 'diamond' reaction; heat capacity 28.5 J/mol.K (Verma and Krishna, 1966) or 0.170 cal/g. °C.

Moissanite is a semiconductor material just like diamond, hence only very low levels of impurities [same]; electrical conductivity variable [variable]; has been made in both highly conducting and insulating forms; conductivity (and colour) affected by the presence of very low levels (a few ppm) of donor nitrogen impurity (which also gives yellow to green to black colours when present at higher concentrations) [same], and of acceptor aluminium purity (which also gives a blue colour at higher concentrations) (Biederman, 1965; Verma and Krishna, 1966; Nakashima *et al.*, 1996) [the boron acceptor in diamond also causes it to be blue]; 'surface tension', wetting or 'diamond pen' test same as diamond (Nassau and Schonhorn, 1977).

The C3 Inc. Tester Model 590

The Colorless Moissanite/Diamond Tester Model 590 (*Figure 10*) was developed and is marketed by C3 Inc. to specifically distinguish between SiC and diamond after a thermal tester has given a positive 'diamond' indication. It determines relative transparency in the near-ultraviolet, a region where near-colourless diamond is transparent and synthetic moissanite absorbs. A polished facet of the stone being tested is placed in contact with the probe while the stone is illuminated at an angle by

Figure 10: *The Colorless Moissanite/Diamond Tester Model 590 is marketed by C3 Inc. for the purpose of rapidly distinguishing synthetic moissanite from diamond after a stone has been identified as 'diamond' on a thermal probe. Photo by Maha DeMaggio, courtesy of GIA.*

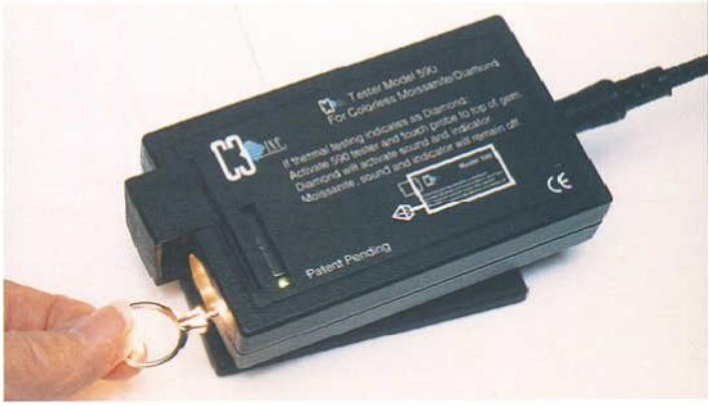

a small high-intensity halogen lamp. A light and buzzer indicate that diamond is being tested; absence of a reaction indicates moissanite. While not intended for use on other materials, many near-colourless gem materials also transmit in the near ultraviolet. Extensive testing with many moissanite specimens and with diamonds between D and X on the GIA colour scale showed a correct reaction in each instance. However, a correct indication may not be obtained from diamonds with abundant inclusions where barely any light manages to emerge from the stone. Tests with diamond/moissanite doublets made by cementing a thin diamond over synthetic moissanite also gave a 'moissanite' reaction.

Distinguishing synthetic moissanite from diamond

To a trained gemmologist, to distinguish SiC from diamond should present no problems. Under a loupe, the double refraction as seen when focusing deep within a stone (*Figure 2*) is diagnostic. It must be emphasized that visual examination looking squarely down at the table can be misleading, since all synthetic moissanites currently marketed are faceted with the optic axis perpendicular to the table.

As *Figures 7* and *8* show, the presence of sub-parallel needles and stringers near perpendicular to the table facet are strong indications of moissanite. Synthetic moissanite may also show uni-directional polishing lines (*Figure 9*) and rounded facet junctions.

Indicative but not necessarily conclusive results can be obtained from the spectroscope (but see the footnote comment on p.434 for the *4H* form of moissanite), fluorescence and electrical conductivity, all of which can be variable. Reflectometers can give positive identification, but great care must be taken, since these may give variable responses with doublets and with dirty or poorly polished surfaces.

M. Kellam at C3 Inc. (pers. comm.) reports that during ongoing research on synthetic moissanite a process has been discovered that can lower the apparent refractive index to the point where a reflectance meter gives a 'diamond' reading. The change in refractive index is a surface effect and it is permanent. Accordingly it is not safe to rely on a reflectometer to distinguish synthetic moissanite from diamond. Removal of a thin surface layer will, of course, restore the intrinsic refractive index. The surface layer consists of silica (silicon dioxide) formed when synthetic moissanite is heated at high temperature in air or oxygen.

A thermal tester will give a positive 'diamond' response for both diamond and moissanite, distinguishing these two materials from all other gemstones; the C3 Inc. Tester Model 590 described above can then be used to further identify the diamond or moissanite. For loose stones, the measurement of specific gravity can provide a convenient method of distinction; moissanites float but diamonds sink in methylene iodide; note that care and adequate ventilation are required with this toxic material. Both the near-ultraviolet and X-ray opacities could also be used as distinguishing criteria.

Summary

Synthetic moissanite is an interesting new gemstone material. At present it can be grown in green, yellow, blue and near-colourless forms, the last of these providing a believable diamond substitute that is closer in appearance and heft to diamond than any other gemstone material.

Compared to diamond, it has more dispersion, similar brilliance, a higher RI, a slightly lower SG, is closer in hardness to diamond than any other gemstone material known to man, but does have a significant birefringence.

The structure in diamond is based on a tetrahedral network of carbon atoms in an overall cubic structure. In moissanite the network is also tetrahedral, but with every other carbon atom replaced by a silicon atom. Just as carbon can exist in two

polytypes, cubic diamond and hexagonal lonsdaleite, so silicon carbide can exist in cubic, hexagonal and rhombohedral polytypes, all traditionally designated moissanite, see *Table I*.

Only two moissanite polytypes, both hexagonal, can be grown at present in large crystals, the moissanite-6*H* here described in detail, and the moissanite-4*H* mentioned above. Because the prominent octahedral (111) cleavage of diamond is not present in synthetic moissanite, this material is tougher than diamond. It is also more resistant to high temperatures and gold jewellery can be cast with stones in place (*Figure 5*).

A positive distinction from diamond is most conveniently obtained in one of three ways:

a. for the trained gemmologist, by examination under magnification primarily for birefringence (*Figure 2*) and inclusions (*Figures 7* and *8*), secondarily for girdle, facet edges and polishing marks (*Figure 9*);

b. by the use of a thermal tester followed by the C3 Inc. Tester Model 590 (*Figure 10*); or

c. for loose stones by flotation in methylene iodide.

While there have already been a number of misidentifications based on blind reliance on thermal testers, knowledge of the characteristics of this new synthetic material should readily prevent such occurrences.

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The Indian diamond-cutting industry: an assessment of the number of cutters and the size distribution of their production

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ABSTRACT: The number of diamond cutters in India during the 1990s has been estimated in published reports to be in the range of 600,000 – 800,000. Based on the number of diamonds polished annually in India, and the rate at which these stones are likely to be manufactured, we estimate that about 400,000 cutters working full time, mostly in modern factories, could produce the approximately 750 million diamonds currently polished annually in India. The high estimates for the number of cutters given in the literature include perhaps as many as 600,000 part-time workers in the cottage industry sector, some of whom only cut an average of one stone per day; there are only about 200,000 full-time diamond cutters.

Based on the amount (weight) of diamonds polished in India in the mid-1990s and their estimated average size (2.5 pt, or 0.025 ct), a hypothetical size distribution for diamonds is suggested. We calculate that approximately 80 per cent of the polished diamonds by weight, and 96 per cent by total number, are less than 10 pt (0.10 ct). Polished diamonds 3 pt (0.03 ct) and less constitute about 42 per cent by weight and 65 per cent (i.e. about 500 million) by total number of the stones polished in India.

Keywords: diamond, diamond cutting, India

Introduction

The modern diamond-cutting industry of India started very slowly in the late 1950s. In 1966 about 230,000 ct of polished diamonds, representing about 6 per cent of the world's production of polished by weight and 2 per cent by wholesale value, were exported and since then production has increased rapidly. In 1996, the most recent year for which data are available, 18.88 million carats (mct) of polished diamonds were exported from India representing about 70 per cent of the world's polished diamonds by weight and about 35 per cent by value. The Indian fiscal year, on which all statistical data are based, runs from April to March and is

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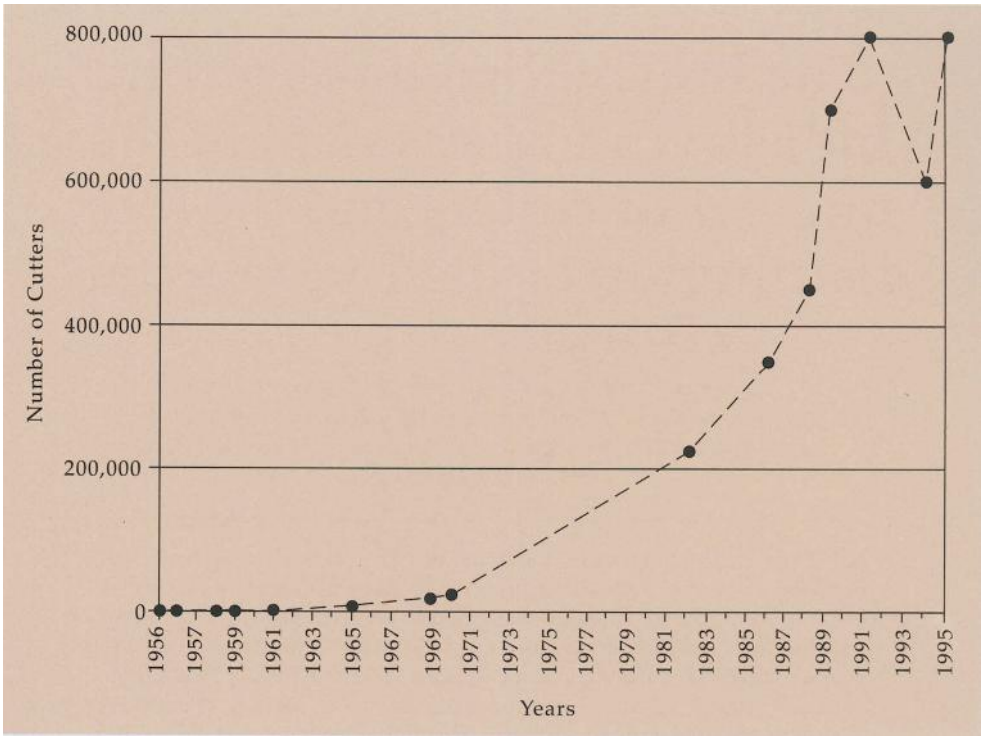

Figure 1: *The dramatic increase in the purported number of diamond cutters in India (1955–1995) is illustrated by this graph of data from the literature.*

officially reported as, for example, 1996–97. However, for this paper we use the first year only, e.g. 1996, for simplicity and also because other data, e.g. the number of diamond cutters, are reported on a calendar-year basis. It is assumed that all diamonds polished in India are exported, as is required by law.

In general, stones polished in India are very small averaging about 0.025 ct or 2.5 pt or 40 stones per carat (spc). Thus, in 1996 we estimate that India produced about 755 million polished diamonds (18.88 mct x 40 spc) (see Sevdermish *et al.*, 1998, for a history of the development of the modern diamond-cutting industry in India and historical details of its polished production). Other estimates of the number of stones polished in India are similar. For example, Anonymous (1997) stated that worldwide about 850 million polished diamonds are set into jewellery annually, of which 11 out of 12, i.e. 779 million, are cut in India.

The vast number of small polished diamonds produced in India requires an equally vast number of diamond cutters. So, are the estimates of how many diamond cutters there are in India true? We use the term 'cutter' to include all those directly involved in the physical aspects of manufacturing polished diamonds, i.e. cleavers, bruters and polishers who we assume act as a 'team'. In the diamond market as a whole it is also of interest to know the size distribution of the diamonds polished in India.

Estimates in the literature of the number of diamond cutters in India

Table 1 contains a compilation from the literature of the purported number of diamond cutters in India (estimates are available for 16 years only); however, there is

Table I: Purported number of diamond cutters in India (from literature sources) and the average number of carats polished annually by each cutter (calculated)

1 Year	2 Number of cutters	3 Reference	4 Polished diamonds exported annually (mct)[1]	5 Average weight of diamonds polished annually per cutter (carats)[2]
1955	800	Leeper (1957)	not known	–
1956	1500	Moyar (1959)	not known	–
1957	1250	Moyar (1959)		
		(average of 1200–1300)	not known	–
1958	1200	Moyar (1960)	not known	–
1959	2000	Moyar (1960)	not known	–
1961	2500	Moyar and Buxant (1963)	not known	–
1965	8000	Szenberg (1973)	not known	–
1969	20,000	Stuyck (1969)	0.48	24
1970	25,000	Kinsbergen (1970)	0.53	21
1982	225,000	Rothschild (1982)	4.66	21
1986	350,000	Anonymous (1986)	7.52	21
1988	450,000	Johnson *et al.* (1989)		
		(average of 400,000–500,000)	11.03	25
1989	700,000	Liddicoat and Boyajian (1990)	10.11	14
1991	800,000	Sharma (1992)	8.72	11
1994	600,000	Jhaveri (1994)	15.98	27
1995	800,000	Pandya (1997)	19.21	24

1. See Sevdermish *et al.*, 1998
2. Average calculated by dividing Column 4 by Column 2.

no distinction between those working in modern factories (generally full time) and those working in the cottage industry sector (generally part time). The data are plotted in *Figure 1* and graphically show the amazing 1000–fold increase in the number of cutters in 36 years from 800 in 1955 to a peak of 800,000 in 1991. Since then there has been a decrease to 600,000 cutters in 1994 but then another rise to an estimated 800,000 in 1995; these changes approximately reflect market conditions, specifically, the quantities of diamonds polished in India that were sold in world markets annually (Sevdermish *et al.*, 1998). Thus, if we accept the data in *Table I*, in 1995 about one out of every 1125 people in India cut diamonds as a source of income (assuming a population of 900 million). It is unlikely, however, that all – or even most – of these people were cutting full-time.

Calculations necessary to determine the number of cutters in India

Purported productivity of Indian cutters

By dividing the annual polished diamond exports (by weight) from India (*Table I*, column 4) by the reported number of cutters (*Table I*, column 2), the average number of carats polished annually per cutter is

Table II: Reported productivity of Indian diamond cutters in the mid-1990s compared with expected productivity based on the authors' assumptions (see text for details).

	Reported	Expected	Ratio (Expected/ reported)
Number of carats polished annually per cutter	23	48	2.1
Number of stones polished annually per cutter	920	1920	2.1
Number of stones polished per day per cutter	4	8	2.0
Number of points polished per day per cutter	10	20	2.0

obtained (*Table I*, column 5). Eliminating the two extremely low values of 11 and 14 (again see *Table I*, column 5), all remaining values from 1969–1995 are within the relatively narrow range of 21–27, with an average of approximately 23 ct per year per cutter. (Even if the two low values are included, the average is 21 ct per year, a value that does not significantly affect the following discussion.)

If we accept that each cutter in India produces 23 ct of polished diamonds each year, and we accept that India's polished diamond exports average 40 stones per carat (i.e. they are 2.5 pt stones; see above), then the average cutter in India produces 920 stones (23 ct x 40 stones) per year. Further, assuming that an Indian cutter works 240 days per year, then the average diamond cutter in India cuts a mere four (actually 3.8) stones per day (920 stones ÷ 240 days) which is equal to 10 pt (4 stones x 2.5 pt) of polished diamonds per day. (Full-time workers in India typically work 5.5 to 6 days a week, 44–48 hours per week and take 10 weeks of leave annually; about 6 weeks for Diwali and about a month in May/June. Part-timers also take about two additional months at harvest time.)

Estimated productivity of Indian cutters

When the above information is considered in the light of the production of cutters in other parts of the world, especially those in modern factories, we encounter an enigma. For example, in Israel when diamond cutters polished 5 pt stones they produced an average of 10 stones (50 pt of polished) per day (although stones of this small size are rarely cut in Israel today). Based on the senior author's experience, a full-time, experienced worker in a modern factory in India could cut an average of eight 2.5 pt stones (20 pt of polished) a day (the lower number, i.e. 20 pt vs 50 pt polished per day for cutting stones of different but comparable sizes, i.e. 2.5 pt and 5 pt, reflects a lesser degree of automation in India compared to Israel). From this it follows that: (a) an experienced, full-time diamond cutter in India could cut, on average, 1920 2.5 pt stones per year (240 days x 8 stones per day), equivalent to 48 ct (1920 stones ÷ 40 stones per ct) of polished diamonds per year.

Our estimate of the number of diamond cutters in India

Table II contains a summary of the reported vs. expected productivity of Indian diamond cutters in the mid-1990s based on the assumptions we have made, e.g. cut stones average 2.5 pt. Most importantly, if the Indian diamond-cutting industry did employ 800,000 experienced and full-time workers, expected productivity should be about 2.1 times (ratio: expected/reported) greater than it actually is.

Further, it follows that if each of the purported 800,000 workers in India in 1995 (*Table I*) were experienced and full time, then India should have produced 1536 million 2.5 pt stones (800,000 cutters x 1920 stones per year). Again assuming 40 stones per carat, this would be the equivalent to 38.4 mct annually – about two times greater than the maximum ever produced in any one

***Table III:** Hypothetical distribution of diamond cutters in India in 1996 by employment category designation and the contribution of each category to the total number of diamonds polished.*

Employment category designation	*1* *Number of diamond cutters*	*2* *Number of diamonds cut per day per cutter (estimated; this paper)*	*3* *Number of diamonds cut per year per cutter (col. 2 x 240)*[1]	*4* *Number of diamonds cut annually by all workers (col. 1 x col. 3)*
A. Full time (in modern factories)	200,000	8	1920	384,000,000
B. Cottage industry predominantly	200,000	5	1200	240,000,000
C. Part-time workers in cottage industry and factories	200,000	2	480	96,000,000
D. Auxiliary workers	200,000	1	240	48,000,000
Total	800,000			768,000,000

1. Assuming 240 working days per year

year (19.21 mct in 1995; *Table I*, column 4). Working from another direction, we would also say that if all the cutters in India worked full time (240 days per year), each producing 8 stones per day (or 48 ct per year), then 'only' 400,000 cutters in India would have been needed to cut all the polished stones produced in 1995 (19.21 million ct/yr divided by 48 ct/yr/cutter).

Clearly, the purported number of diamond cutters must include a vast number of people who work only part time if the total number of workers in 1995 is assumed to be 800,000. They range from farmers, who do not cut diamonds during the growing seasons, to children who only cut diamonds when not in school. Older studies reported that children made up 10–15 per cent of the workforce (Anonymous, 1989), but a 1995 survey showed that child labour (below the age of 14 years) constituted only 0.4 per cent in the 'organized sector' (i.e. factories) of the workforce and 3.4 per cent in the 'unorganized sector' (i.e. cottage industry) (Pandya, 1997); further improvements toward the total eradication of child labour is a goal of the Government of India.

Employment for occasional workers also depends on market conditions. For example, in 1991 when polished-diamond production in India was very low (only 8.72 mct; see *Table I*), occasional workers were probably not employed to any significant extent even if they were available for work. (The low production of polished diamonds in 1991, coupled with the apparent employment of 800,000 cutters when there was undoubtedly significant unemployment, is the reason for the average of only 11 ct/yr/cutter that year.)

Supportive of our concept that there are fewer cutters than stated in the literature is the fact that in mid-1990, when there were a purported 800,000 cutters, there were only about 135,000 scaifes in use in India (Curtis, 1991) which are too few to enable 800,000 cutters to work full time. More likely, at that time about half these scaifes were in modern lapidaries where two cutters typically use the same scaife (a total of 135,000 cutters) and the other half were engaged in the cottage-industry sector where typically three (rarely four) cutters use the same scaife (a total of 202,500 cutters).

A hypothetical scenario illustrating the number of full-time and various categories of part-time workers in India, and their productivity, is given in *Table III*. The categories are based on the average number of polished diamonds, i.e. 1, 2, 5 and 8, that we suggest Indian diamond cutters produce daily over the year. Based on data from 1996 in which about 755 million diamonds averaging 2.5 pt were cut in India, and which data we believe are representative of the

Table IV: Hypothetical distribution by size (weight) of 18.88 million carats of diamonds polished in India in 1996.

1 Size categories (weight)	2 Weight range	3 Number of carats of polished	4 Percentage of polished stones by weight (from col. 3)	5 Average number of polished stones per carat; 1 ÷ by col. 2)	6 Number of polished stones (col. 3 x col. 5)	7 Percentage of polished stones produced (from col. 6)
A	> 0.5	500,000	2.6	2	1,000,000	0.1
B	0.2–0.5	1,000,000	5.3	5	5,000,000	0.7
C	0.1–0.2	2,500,000	13.2	10	25,000,000	3.3
D	0.03–0.1	7,000,000	37.0	33	231,000,000	30.6
E	< 0.03	7,900,000	41.8	62.5	493,750,000	65.3
Total:		18,900,000			755,750,000	

Indian diamond industry at least since 1995, there are probably about 200,000 full-time cutters in well organized lapidaries, some using modern equipment, who produce about half of India's polished diamonds (*Table III*, column 4). The vast majority of the remaining 600,000 or so workers do not work full time, and certainly not in modern factories; some probably average no more than one stone per day working at home with relatively simple equipment in the cottage-industry environment. Thus, we conclude that there might be 800,000 people in India involved to some extent in cutting diamonds; however, only about 25 per cent of them are involved full time.

Size distribution of diamonds polished in India

To this point we have emphasized for purposes of calculation that the average size of diamonds polished in India is 2.5 pt (40 spc) and now it is appropriate to consider the size distribution of Indian polished diamonds in greater detail. Although most of India's production is very small in size, in recent years perhaps 20 per cent by weight of the stones have been over 10 pt. Further, in the period 1991–1996 about 1 mct of polished diamonds from India weighing over 0.50 ct were imported into the United States (see Sevdermish *et al.*, 1998, for further details).

Taking these facts into account it is possible to estimate the size distribution of the stones (range of sizes) of the Indian production. We use data for 1996 in which 18.88 mct of polished diamonds were produced which represents about 755 million stones averaging 2.5 pt (18.88 mct x 40 spc = 755.2 million). The hypothetical size distribution is presented in *Table IV* where the polished diamonds are placed in five size categories.

The data in *Table IV* show that the vast majority of the stones polished in India are under 10 pt (categories D and E); these total 78.8 per cent by weight, and 95.9 per cent by number, of all polished diamonds. Further inspection of the tabulation above shows that: (a) although the largest stones above 0.50 ct (category A) constitute 2.6 per cent of the total production by weight, they make up only 0.1 per cent of the total number of polished stones; and, similarly, (b) although the largest three categories (A, B, C; 0.1 ct and above) constitute 21.1 per cent of the total production by weight, they make up only 4.1 per cent of the total number of polished stones.

Discussion and conclusions

There can be few industries in the world for which reliable statistics are as elusive as the diamond business. Because the diamond market is secretive and there is a reluctance

on the part of all segments to disclose detailed information on their activities, researchers are forced to make do with what is available in the open literature that originates from such sources as Government bodies and trade journals. In addition, this study has been hampered by the difficulty in obtaining accurate data from the cottage industry sector which is characterized by poor record keeping. Thus, the use of estimates and extrapolations is normal to discern concepts, trends and other objectives. We have found it necessary to resort to such techniques, including developing certain hypothetical models. Nevertheless, we feel that the hypotheses upon which we base our discussions and manipulations are realistic, particularly since they permit us to arrive at logical conclusions that are internally consistent and also are in agreement with conventional wisdom in the industry.

The diamond-cutting industry in India currently produces about 750 million polished diamonds annually. Calculations based on a hypothetical size distribution show that about 96 per cent of these diamonds weigh less than 10 pt; about 65 per cent of these diamonds, consisting of about 500 million stones, are about 3 pt or less. To cut and polish this huge number of stones, there are about 200,000 full-time workers, mostly in modern factories who polish half the stones. Another 600,000 workers are part time, some of them produce no more than one stone per day.

In recent years, and especially starting in 1998, India has seen a considerable change in the nature and the size of polished diamonds produced there. Until 1997 one could safely assume that the average cut stone was about 2.5 pt, or 40 spc, and of poor quality. However, today the average size of the diamonds cut in India is certainly larger, and the quality is improving. This is not due to the fact that India has stopped cutting low quality gems of 1–3 pt, rather it is because in recent years many more larger, better quality stones are cut in India than ever before. Many stones, larger than 50 pt and up to 2 ct, cut in India now are available on the world market. This trend becomes clear when we compare the official cut-diamond import data for the U.S.A. in 1996 and 1997. In 1996, 259,000 ct over 50 pt were imported into the U.S.A. from India which represented 3.5 per cent of the total U.S.A. imports from India. In 1997 this increased to 375,000 ct which represented a 45 per cent increase in this size category and 4.6 per cent of the total Indian polished-diamond imports to the U.S.A. (United States Geological Survey, 1998, table 7). Although figures are not yet available for 1998, we are confident that the statistics will show that the amount of larger (> 50 pt) Indian cut diamonds, and the ratio of larger gems to smaller gems cut in India, imported into the U.S.A. will have increased even more. The effect of these changes on the local Indian cutting industry will be significant in two main areas: first, the cutting of larger stones will require more highly trained personnel and, secondly, there will be an increase in the number of well-equipped modern facilities required for expensive stones and not available in the cottage-industry sector.

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Druses of synthetic alexandrite and synthetic phenakite from Russia

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ABSTRACT: Two druses of synthetic alexandrite and phenakite crystals were reportedly grown in Novosibirsk, Russia. Both minerals contain inclusions typical of flux growth, and their origin in a silicate melt rich in Be, Al and Cr is discussed.

Keywords: synthetic alexandrite, synthetic phenakite

Introduction

Growing synthetic stones from a flux is a common practice nowadays and the method is used particularly to produce rubies, sapphires, emeralds, alexandrites and spinels. Normally, crystals are grown singly or in monomineralic druses. Exceptions to these conditions are very rare and when a different mineral starts growing on the seed it indicates that some unpredicted changes have taken place in the growing process.

Some years ago, the senior author first saw an example of this phenomenon, a specimen consisting of two olive-green YAG crystals (each about 1 cm long), with a flat dark-red ruby crystal about 3 cm long which was covered by younger pink ruby pseudo-octahedrons. Apparently, this unique specimen had been grown accidentally in the Bell Laboratories (Art Grant, pers. comm.).

Figure 1: *Synthetic alexandrite and phenakite, 15 x 13 mm (photo: J. Hyrsl).*

Figure 2: *Synthetic alexandrite and phenakite, 11 x 9 mm, transmitted light (photo: I. Quintens).*

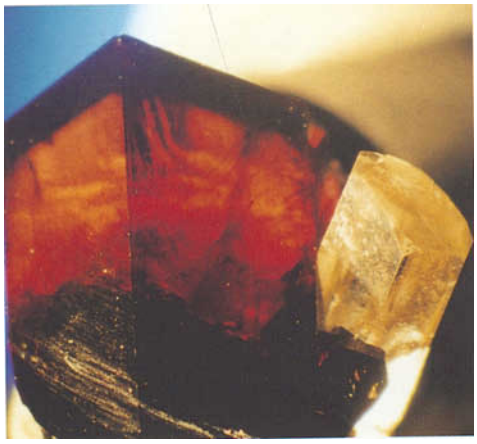

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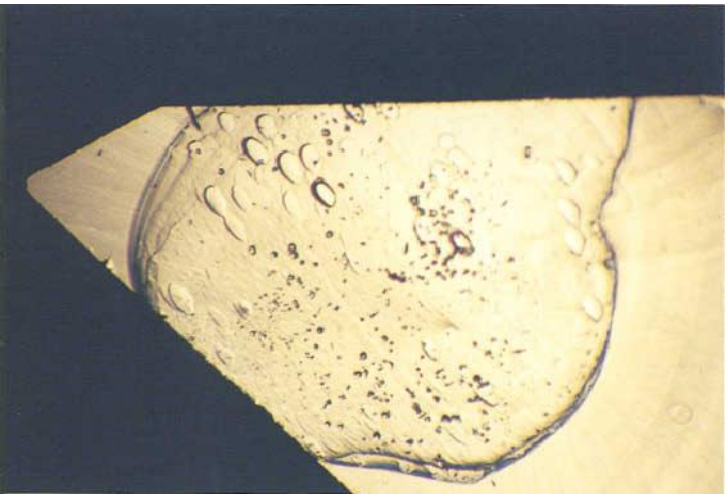

Figure 3: Rounded growth patterns on synthetic alexandrite, x35, oblique light (photo: I. Quintens).

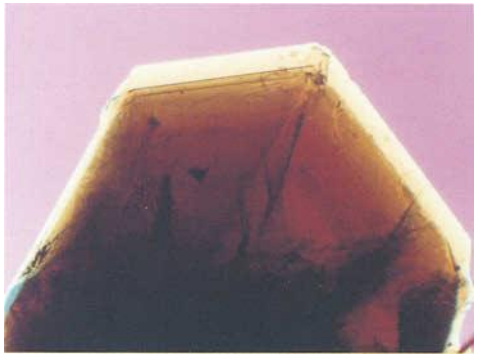

Figure 5: Near colourless outer zone and flux veils in synthetic alexandrite, x15, transmitted light (photo: I. Quintens).

Alexandrite and phenakite

Two interesting specimens were obtained recently from a Russian dealer and reportedly come from Novosibirsk. These consist of almost black crystals of alexandrite up to 12 x 9 x 9 mm supporting yellowish phenakite crystals up to about 5 x 2 x 2 mm (*Figures 1 and 2*). Crystal faces of the alexandrite show rounded growth patterns, indicating a synthetic origin (*Figure 3*) and are irregularly developed trillings. The typical colour-change of the alexandrite can be seen only at the edges of the crystals and under strong illumination. The saturated colour also makes it very difficult to observe inclusions. Nevertheless, with strong transmitted light, some typical internal characteristics can be detected. Trigonal or distorted blackish inclusions with submetallic lustre (?hematite) reach the surfaces of some crystals (*Figure 4*), and flux veils are abundant; growth features and colour zoning are less common (*Figure 5*) and mostly confined to the outer rim. Refractive indices were measured on flat crystal faces

Figure 4: Black triangular crystal of ?hematite in synthetic alexandrite, x63, oblique light (photo: I. Quintens).

Figure 6: Hexagonal ?platinum crystals in a synthetic phenakite crystal, x30, transmitted light (photo: J. Hyrsl).

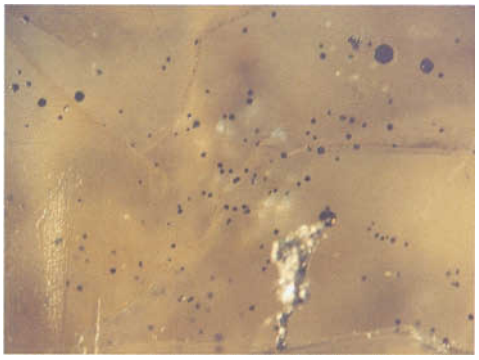

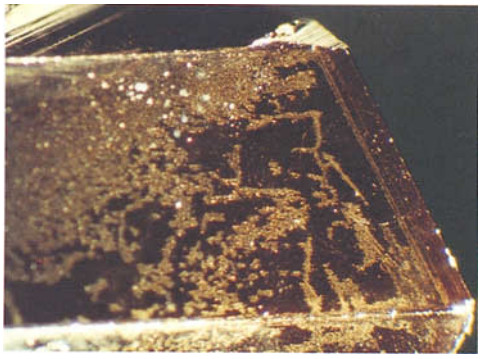

Figure 7: Flux particles near the surface of a synthetic phenakite crystal, x16, oblique light (photo: I. Quintens).

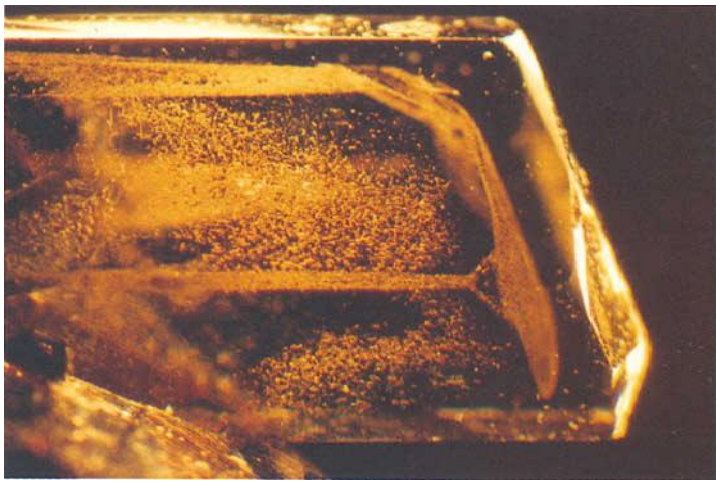

Figure 8: Flux in a form resembling a phantom crystal in synthetic phenakite, x25, darkfield (photo: I. Quintens).

and yielded values between 1.750 and 1.758, with a birefringence of 0.008. No fluorescence in UV was observed, possibly indicating the presence of iron.

Phenakite forms simple hexagonal prisms terminated by several irregular low rhombohedron faces. It is yellowish and transparent. Three similar single synthetic phenakite crystals from Novosibirsk were also available for study; they are only slightly yellowish and are up to 13 mm long. Their refractive indices are o = 1.659 and e = 1.673 with a birefringence of 0.014, and their specific gravity was found to be 2.97–2.99. No fluorescence was seen under an ultraviolet lamp. Under a microscope they show fine curved veils of brown and yellow flux, much coarser black remnants of a ?flux with a strong metallic lustre in reflected light and flat, almost round crystals of ?platinum in groups near the surface (*Figure 6*). Dust-like flux following crystal faces can in rare instances form phantom-like patterns (*Figures 7 and 8*). Blue-green crystals of flux-grown synthetic phenakite from Russia were described by Koivula *et al.* (1994).

Conclusion

The association of these two synthetic species is somewhat surprising. Phenakite (Be_2SiO_4), as a by-product of synthesis of beryl in a silica-rich medium, is a very common inclusion in synthetic beryl ($Be_3Al_2Si_3O_8$). On the other hand, chrysoberyl variety alexandrite ($BeAl_2O_4$ + Cr), being an oxide, is generally grown in silica-poor conditions. Nevertheless, the described specimens must have grown in a mixture where elements Be, Al, Cr and Si were all present in sufficient amounts to develop both alexandrite and phenakite.

Reference

Koivula, J.I., Kammerling, R.C., and Fritsch, E. (Eds.), 1994. Gem news. *Gems & Gemology*, **30**, 199–200

Abstracts

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Diamonds

Rb–Sr ages on kimberlites from the Lac de Gras area, Northwest Territories, Canada.

R.A. Armstrong and R.O. Moore. *South African Journal of Geology*, **101**(2), 1998, 155–8.

Rb-Sr dating of two kimberlites, from the Lac de Gras area within the Slave craton in the Northwest Territories, shows they are of Eocene age. Leached phlogopite and whole-rock isochrons give Rb–Sr ages of 47.5 ± 1.6 and 52.1 ± 1.0 m.y., confirming palaeontological evidence from fossils in mudstones preserved as xenoliths within the kimberlites. J.F.

Has science overthrown the King of Gems?

A. Bernard. *Australian Gemmologist*, **20**(4), 1998, 138–40, 1 illus. in black-and-white.

A brief review of the history of diamond synthesis which contrasts the attributes and appeal of natural diamond with its synthetic counterpart and, in terms of hardness, with the new superhard material carbon nitride. P.G.R.

Subduction-related diamonds? – The evidence for a mantle-derived origin from coupled $\delta^{13}C$–$\delta^{15}N$ determinations.

P. Cartigny, J.W. Harris, D. Phillips, M. Girard and M. Javoy. *Chemical Geology*, **147**(1–2), 1998, 147–59.

Coupled determinations of $\delta^{13}C$–$\delta^{15}N$, for more than 150 diamonds of known paragenesis, originating from different localities, argue against a direct formation from subducted biogenic carbon, and confirm the isotopic disequilibrium of nitrogen between the internal (mantle) and external (atmosphere + crust) reservoirs of the Earth, thus supporting the heterogeneous accretion model of the Earth inferred from earlier fibrous diamond studies. Non fibrous diamonds have recorded the evolution of the nitrogen isotopic mantle composition, from a $\delta^{15}N$ value < –25‰ to the present value of ~ –5‰, caused by recycling of nitrogen on a large scale during the early history of the Earth. J.F.

Diamond in jewellery manufacture.

D. Hayes. *Industrial Diamond Review*, **58**, 1998, 26–7, 6 photographs.

The article describes an operation in which precision, single-crystal diamond tooling is used as standard in the manufacture of gold, silver and copper jewellery in Korea. E.S.

Gemmologische Kurzinformationen. Ein neuer Typ farbbehandelter Diamanten. (A new type of colour treated diamonds.) [German with English abstract.]

U. Henn and C.C. Milisenda. *Gemmologie – Z. Dt. Gemmol. Ges.*, **48**(1), 1999, 43–5, 2 illus. in colour, 1 graph, bibl.

The yellow-greenish stones were enhanced to brown 'fancy' coloured diamonds using the Russian 'BARS' system at high temperatures and high pressure. The absorption spectrum is different from that produced by natural as well as irradiated stones. They fluoresce green, partly along growth lines. Under the microscope one can see strong graining, fine cracks and cleavages under the table and around the girdle, as well as visible burn marks. E.S.

Mineral inclusions in diamonds from the River Ranch kimberlite, Zimbabwe.

M.G. Kopylova, J.J. Gurney and L.R.M. Daniels. *Contributions to Mineralogy & Petrology*, **129**(4), 1997, 366–84.

More than 99% of the small diamonds from the River Ranch kimberlite contain minerals of harzburgitic paragenesis: olivine, orthopyroxene, chromite and garnet,

Abstractors

A.A. Finch	A.A.F.	R.A. Howie	R.A.H.	W.E. Sharp	W.E.S.
J. Flinders	J.F.	M. O'Donoghue	M.O'D.	E. Stern	E.S.
R.K. Harrison	R.K.H.	P.G. Read	P.G.R.	I. Sunagawa	I.S.
C.L. Hayward	C.L.H.	G.W. Robinson	G.W.R.	I. Vesselinov	I.V.

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with rare ferropericlase, amphibolite, pyrrhotite, pentlandite, strontian K–Cr loparite, rhönite, Cr-chevkinite and perovskite. Their compositions have been determined by EPMA. Most inclusions were equilibrated at 1080–1320°C and 47–62 bar with fo_2 between IW and WM buffers; the *P–T* profile beneath the Limpopo mobile belt is consistent with an ancient heat flow of 42 mW/m^2. R.A.H.

Emplacement and reworking of Cretaceous, diamond-bearing, crater facies kimberlite of central Saskatchewan, Canada.

D.A. Leckie, B.A. Kjarsgaard, J. Block, D. McIntyre, D. McNeil, L. Stasiuk and L. Heaman. *Geological Society of America Bulletin*, **109**(8), 1997, 1000–20.

Detailed stratigraphical descriptions are given of a core through four facies of subaerial kimberlitic volcanism. The deposit is noted for the preservation of a pyroclastic kimberlitic facies with 5–25 μm diamonds. Detailed petrographical descriptions, XRD and chemical analyses are given for 18 samples. U-Pb dates on perovskites in a kimberlite lapillistone give an age of 101.1 m.y. which is consistent with the sedimentary setting. W.E.S.

Graphite pseudomorphs after diamond? A carbon isotope and spectroscopic study of graphite cuboids from the Maksyutov Complex, south Ural Mountains, Russia.

M.L. Leech and W.G. Ernst. *Geochimica et Cosmochimica Acta*, **62**(12), 1998, 2143–54.

Cuboid graphite aggregates (< 5 mm long mainly, but up to 13 x 10 mm) composed of flakes (4–100 μm) occur in mica schist near Karayanova. Carbon isotope analyses indicate that it is biogenic C. Spectroscopy, including TEM imaging, XRD and laser Raman microspectroscopy, shows that the graphite is well crystallized with only minor dislocation defects. IR spectroscopy shows no relict organic compounds. Comparison of thin sections through the cuboid aggregates and SEM imagery of Maksyutov graphite aggregates with diamond pseudomorphs from the Beni Bousera peridotite (N Morocco) shows many similarities. Although the results are inconclusive, the evidence suggests that the present graphite pseudomorphs are after diamond. R.K.H.

Simple identification and quantification of microdiamonds in rock thin-sections.

H.-J. Massonne, H.-J. Bernhardt, D. Dettmar, E. Kessler, O. Medenbach and T. Westphal. *European Journal of Mineralogy*, **10**(3), 1998, 497–504.

A method is described for the preparation of polished thin-sections which allows the rapid and quantitative detection of microdiamonds in high-*P* metamorphic rocks by distinctive pattern of striations on the polished surface of the thin-section. Diamonds as small as 1 μm are revealed by a striation pattern as soon as they emerge on the surface during the polishing procedure, but this pattern disappears almost immediately after extraction of the microdiamond that caused it. Results are presented for samples from diamondiferous gneiss and marble from the Lake Kumdy-Kol region of the Kokchetav Massif, N Kazakhstan. The examination of > 600 polished thin-sections of igneous and metamorphic rocks without a high-*P* origin showed striation patterns in < 1% of them;. here, the striations could conceivably be due to outside contamination. M.O'D.

Evaluation of diamond potential from the composition of peridotitic chromian diopside.

P. Nimis. *European Journal of Mineralogy*, **10**(3), 1998, 505–19.

Chemical variations known in synthetic and natural, high-*P* chromian diopsides have been used to evaluate the potential use of mantle-derived clinopyroxene as a diamond-indicator mineral in kimberlite and lamproite exploration. A two-step model is proposed that involves 1) identification of clinopyroxenes from garnet peridotite and 2) discrimination of those equilibrated within the diamond stability field. The first step is achieved via a Cr_2O_3 *vs* Al_2O_3 classification diagram together with a consideration of Al_2O_3 *vs* MgO relations. The exclusion of all other clinopyroxenes allows simple chemical parameters to be used as *P–T* indicators. The Ca in clinopyroxene is negatively correlated with *T* and the Al content is negatively correlated with *P*. A Ca *vs* Al plot can be used to identify clinopyroxenes that last equilibrated within the stability field of diamond with an 'accuracy' of 89%. R.A.H.

Of diamonds, dinosaurs and diastrophism: 150 million years of landscape evolution in southern Africa.

T.C. Partridge. *South African Journal of Geology*, **101**(3), 1998, 167–84.

In this Alex du Toit Memorial Lecture, the tectonic and geomorphological evolution of southern Africa during the post-Gondwana period is reviewed. Basic to an understanding of post-rifting events are: 1) the high elevation which much of Africa possessed prior to rifting, 2) the erosion of 1–3 km from its surface during the Cretaceous and 3) the role of Neogene uplift in re-establishing high elevations, particularly within the E half of the subcontinent. The configuration of the Upper Cretaceous river system is fundamental to an understanding of the present distribution of alluvial diamonds and of gems transported to the sea via these rivers. R.A.H.

Diamond precipitation and mantle metasomatism – evidence from the trace element chemistry of silicate inclusions in diamonds from Akwatia, Ghana.

T. Stachel and J.W. Harris. *Contributions to Mineralogy & Petrology*, **129**(2–3), 1997, 143–54.

Trace element concentrations in garnet, olivine, orthopyroxene and clinopyroxene included in diamonds from Akwatia were determined by SIMS. Incompatible trace elements are hosted in garnet and clinopyroxene, except for Sr which is equally distributed between orthopyroxene and garnet in harzburgitic diamonds. The separation between lherzolitic and harzburgitic paragenesis is also seen in the Ti and Sr contents in both

olivine and garnet. Chondrite-normalized *REE* patterns of lherzolitic garnets are enriched (10–20 times chondritic) in *HREE* (La_N/Yb_N 0.02–0.06) while harzburgitic garnets have sinusoidal REE_N patterns with the highest values for Ce and Nd (2–8 times chondritic). The *REE* patterns for calculated melt compositions fall into the compositional fields for kimberlitic-lamproitic and carbonatitic melts. The much more strongly fractionated *REE* patterns calculated from harzburgitic garnets, and low Ti, Y, Zr and Hf, differ significantly from known alkaline and carbonatitic melts and require a different agent. Equilibration *T* for harzburgitic inclusions are generally below the C–H–O solidus of their paragenesis, those of lherzolitic inclusions are above; crystallization of harzburgitic diamonds from CO_2-bearing melts or fluids may thus be excluded. Diamond precipitation by oxidation of CH_4-rich fluids with highly fractionated trace element patterns is therefore favoured. R.A.H.

Rare and unusual mineral inclusions in diamonds from Mwadui, Tanzania.

T. Stachel, J.W. Harris and G.P. Brey. *Contributions to Mineralogy & Petrology*, **132**(1), 1998, 34–47.

Syngenetic diamond inclusions of diamond from the Mwadui kimberlite indicate sampling of an unusually fertile section of lithospheric mantle beneath the central African craton, as shown by a very high ratio (1:2) of lherzolitic to harzburgitic inclusions and low Mg/Fe ratios in olivine and orthopyroxene. Disequilibrium between garnet-olivine and garnet-orthopyroxene pairs suggests successive iron enrichment during diamond formation, e.g. giving harzburgitic garnet and lherzolitic olivine in the same diamond. Two diamonds, one with eclogitic garnets with moderate pyroxene solid solution, and the other with a single ferro-periclase inclusion, suggest the contribution of a small sub-lithospheric component. The discovery of the association Fe-FeO-Fe_3O_4 in one single diamond indicates diamond formation over a range of fo_2 conditions, possibly along redox fronts. Steep compositional gradients may also be reflected by the joint occurrence of harzburgitic garnet and a SiO_2-phase in the same diamond; alternatively, the SiO_2-phase may be due to extreme carbonation of the peridotitic source. Other unusual occurrences are the exsolution of a silicate phase from magnetite inclusions (i.e. primary solution of γ-olivine) and an ilmenite inclusion with an eskolaite (Cr_2O_3) component of 14.5 mol.%, the latter together with harzburgitic paragenesis silicate inclusions. R.A.H.

Gems and Minerals

(Gem corundums and zircons from the Primorye placers.) [Russian with English abstract.]

S.A. Ananyev, T.A. Ananyeva, V.K. Garanin and G.P. Kudryavtseva. *Proc. Russian Mineralogical Society*, **127**(4), 1998, 120–4.

Descriptions are given of sapphire and hyacinth, and their associated chromespinel, magnetite and enstatite, in heavy mineral concentrates ultimately derived from alkali basalts. Transparent blue, blue-green, green and occasional multicoloured sapphires are represented by rolled crystals 2–5 to 30 mm in size; silky and star-shaped stones may also be found. Chemical analyses and optical absorption spectra show that the colouring is related to the presence of Fe (FeO 0.72–1.75 wt. %) and Ti (TiO_2 0.02–0.20 wt. %). Inclusions of hercynite and ferrocolumbite have been noted in some of these corundums. Hyacinths are represented by strongly rolled crystals from 1–3 to 25 mm in size; they are transparent orange, orange-yellow or brown-red in colour; on heating, they become completely colourless. The chemical compositions of these zircons correspond with the rare variety naegite, with Ta_2O_5 4.59–6.14, Nb_2O_5 3.22–3.59 and ThO_2 3.98–4.09 wt. %. R.A.H.

The Idar-Oberstein gemstone industry's 500th anniversary – a brief history.

H. Bank. *Australian Gemmologist*, **20**(4), 1998, 141–4, 5 illus. in colour, 1 map, 1 table.

This brief history traces the five-hundred year evolution of Idar-Oberstein's gem cutting industry which, although developed around the agate occurrences of the Nahe-Saar region of Germany, now polishes gem material from all the major occurrences around the world. P.G.R.

Gemmologie Aktuell (Gemmological news).

H. Bank, U. Henn and C.C. Milisenda. *Gemmologie, Z. Dt. Gemmol. Ges.*, **47**(4), 1998, 179–82, 4 photographs.

Tourmalines showing a wide range of colours, particularly green, red, pink and bi-coloured now come from Nigeria, although the exact location is not known. The crystals are prismatic, RI 1.622–1.640, DR 0.018, SG 3.06, often trigonal growth zones are visible, and there are round birefringent mineral inclusions. A brownish-black rutile cat's-eye, 0.51 ct, SG 4.30, was found in Sri Lanka. The name 'erenite' found in the trade is a term for a pale green synthetic spinel, usually found in cheap jewellery. A new opal occurrence has been reported in Lambina Station in South Australia, about 260 km north of Coober Pedy. More than 4000 requests for claims have been submitted after a 100 kg piece with beautiful opal veins was found in June 1998, value said to be about £18,000. E.S.

Gemmologie Aktuell (Gemmological news).

H. Bank, U. Henn and C.C. Milisenda. *Gemmologie, Z. Dt. Gemmol. Ges.*, **48**(1), 1999, 1–8, 10 photographs in colour.

New gem occurrences have been discovered in Madagascar; these include corundums of various colours, chrysoberyls and garnets; some pink corundums were examined: they are coloured by chromium and their inclusions are very similar to those corundums found in the Tunduru-Songea area of Tanzania; it seems likely that both areas belonged to a single sedimentation field before the break-up of Gondwana. Beautiful bluish-green tourmalines have been found on a farm called 'Neu-Schwaben' in Namibia. Stones from this locality have been known in Idar-Oberstein since 1925, but only in the last two years have

larger quantities reached the market; RI 1.621–1.640, DR 0.019, SG 3.07. There are also short notes on some green-yellow opal cat's-eyes from Sri Lanka; also from Sri Lanka some minerals thought to be rutile, but identified as monazite, a cerium-lanthanum-thorium-phosphate. A rose-quartz cat's-eye from Brazil is described, as is also a parcel of faceted green iridescent sapphires from Australia. Other items described include a tourmaline with artificial fracture filling and a tourmaline-plastic doublet. E.S.

'Lombardische Diamanten' aus Selvino bei Bergamo/Italien.

M. BENZ. *Lapis*, **24**(3), 1999, 23–5.

Doubly-terminated rock crystal specimens are described from Selvino, near Bergamo, Italy. The resemblance to the American Herkimer diamonds is noted. M.O'D.

Chinas Nordosten: Saphirgruben und eine der besten Diamantminen der Welt.

P. BOSSE. *Mineralien Welt*, **9**(6), 1998, 68–72, illus. in colour.

Brief survey of sapphire and diamond production in the north-east of China, with special reference to the provinces of Liaoning and Shandong. M O'D

A miscellany of organics – Part 2.

G. BROWN. *Australian Gemmologist*, **20**(5), 1999, 193–7, 1 illus. in black-and-white, 16 colour illus., 1 graph.

A further compilation of unusual biological materials which describes and illustrates a composite blister pearl, a 'jet' necklace, a shell cameo whose colour had been degraded by the use of a cleaning agent containing bleach, tiger's claw jewellery and a carved tagua nut. The author concludes with a warning against the use of ultrasonic cleaners for pearls, and news of a new imitation amber being manufactured in southeast Asia in which (non-struggling) insects are embedded in yellowish brown polystyrene. P.G.R.

Rare gem minerals from Brazil – Part 1: Euclase and phenakite.

M.L.S.C. CHAVES, J. KAARFUNKEL AND D.B. HOOVER. *Australian Gemmologist*, **20**(2), 1998, 80–6, 5 illus. in colour, 1 map.

The authors give a brief historical review of the discovery in Brazil of the rare beryllium-bearing gem minerals euclase and phenakite. Euclase was first discovered over 200 years ago near Ouro Preto in the State of Minas Gerais, and phenakite was discovered 80 years ago at Rio Piracicaba in the same State. The eight principal occurrences of euclase and the three principal occurrences of phenakite are described, and the minerals' optical and physical properties summarised. Their locations are indicated on a map showing the States of Minas Gerais, Espirito Santo, Bahia and Rio Grande do Norte. Due to their scarcity cut examples of these minerals are much sought after by gemmologists and gemstone collectors. P.G.R.

Die Amethyste aus dem Bieligertal, Wallis.

D. CHESEAUX. *Schweizer Strahler*, **11**, 1999, 384–7.

Amethyst, sometimes of gem quality, is described from the Bieligertal area of Canton Valais, Switzerland. Well-formed single crystals and crystal groups are found, some specimens reaching up to 30 cm in length. The faceted stone illustrated shows some signs of colour zoning. M.O'D.

New opal carving factory at Khao Yai, Thailand.

R.R. COENRAADS AND P.E. ELMER. *Australian Gemmologist*, **20**(5), 1999, 198–201, 8 black-and-white illus., 7 illus. in colour.

Opened in 1997, the Pacific East Trading Company's boulder opal cutting factory and showroom is located some two hours drive northeast of Bangkok at a popular tourist destination near Khao Yai. Local carving expertise and the large Asian market for carved material are the reasons for setting up the factory which is capable of handling the large quantities of Australian boulder opal shipped in from numerous mines in Queensland. P.G.R.

Axinite vom Piz Vallatscha (GR).

U. EGGENBERGER. *Schweizer Strahler*, **11**, 1998, 229–32, illus. in colour.

Axinite of gem quality is reported from Piz Vallatscha in the Lukmanier region of Canot Graubünden, Switzerland. The crystals were found at around 2900 m and are the characteristic brown-violet colour for this mineral. The axinite-containing fissure also produced adularia, violet apatite, pericline, epidote and some smoky quartz. Though axinite is found at many locations in the Val Cristallina granodiorite to the east of the Gotthard massif, the present find has produced exceptional specimens. M.O'D.

Comparative study of Indian rubies vis-a-vis other rubies.

S. FERNANDES, V. JOSHI AND S. SARMA. *Indian Gemmologist*, **7**(3/4), 1998, 29–32.

Mean SG of Indian rubies was 3.93, the lowest value of 3.75 being shown by some specimens from Orissa while some material from Karnataka gave 4.13. Tables of inclusions are given in which Indian rubies are compared with those from the Morogoro area of Tanzania, from Mogok, Vietnam and Kenya. Properties of rubies from the various Indian deposits are also given. M.O'D.

Pink topaz from the Thomas range, Juab County, Utah.

E.E. FOORD, W. CHIRNSIDE, F.E. LICHTE AND P.H. BRIGGS. *Mineralogical Record*, **26**(1), 1995, 57–60.

The colour of pink topaz crystals from lithophysal cavities in rhyolite from the Thomas Range, Utah, is thought to be due to $Mn^{3+} \pm Fe^{3+}$ substitution for Al^{3+}. LA–ICP–MS analysis shows Mn is concentrated in the pink-red colour zones (MnO 0.65, Fe_2O_3 0.35 wt. %). Cr, V, Co or other possible chromophores were not detected. G.W.R.

La détection du jade B.

E. Fritsch. *Revue de gemmologie*, **136**, 1999, 14–18.

Summarizes methods of detecting B-jade by IR absorption spectroscopy which proves the presence of impregnating material which is not found in untreated A-jade. IR spectroscopy is advocated for use in laboratories in which jade samples may need to be tested. M.O'D.

Sur la piste de la ligne verte: un voyage vers les mines de jade du Myanmar.

O. Galibert and R.W. Hughes. *Revue de gemmologie*, **136**, 1999, 19–25.

Description of a visit by the authors to the jade mining areas of Myanmar with an account of the recovery and selling of the rough material. M.O'D.

XRD and IR spectroscopic investigations of some chrysoprases.

A. Gawel, S. Olkiewicz and W. Zabinski. *Mineralogia Polonica*, **28**(1), 1997, 43–51.

The crystallinity of chalcedonic quartz in several samples of chrysoprase from various localities was determined. Samples with a low crystallinity index have, in general, higher Ni contents and intense green colour. In the XRD patterns of some chrysoprases with low crystallinity, diffraction lines due to the microcrystalline silica phase, moganite, were noted, as well as a broad reflection at $d \sim 10$ Å. No reflections due to bunsenite (NiO) were seen, even in samples with NiO ≥ 1.71 wt. %. R.A.H.

Le jade-jadeite du Guatemala: archéologique d'une rédécouverte.

F. Gendron. *Revue de gemmologie*, **136**, 1999, 36–42.

History of the use of jadeite in Guatemala in which seven types are identified and distinguished. Present-day recovery and use are described. M.O'D.

Ambra in Provincia di Ragusa.

G. Giardina. *Rivista Mineralogica Italiana*, **22**(2), 1998, 50.

Amber specimens from Ragusa province, Italy, are shown to contain insect inclusions. The main occurrence is on the coast of Pozzallo where amber is thrown up by the sea. Most pieces contain some red and when fashioned show a characteristic amber colour with red overtones. Some specimens have reached 2–3 cm in diameter. M.O'D.

Hildegard von Bingen De Lapidibus. Welsche Steine beschrieb Hildegard tatsächlich?

M. Glas. *Lapis*, **23**(6), 1998, 46–52, illus. in colour.

An attempt is made to identify stones described in Hildegard von Bingen's *De Lapidibus* (1098) with their modern equivalents. M.O'D.

Réflexion sur l'esthétique des objects de jade traditionnels chinois avant le XVIIIéme siécle.

E. Gonthier. *Revue de Gemmologie*, **136**, 1999, 31–5.

Thoughts on the use of jade by the Chinese for ornamental purposes before the 18th century. M.O'D.

Manganese minerals from the southern New England district.

M.P. Goodwin. *Australian Journal of Mineralogy*, **4**, 1998, 101–7.

Rhodonite of ornamental quality is described from the southern part of the New England district of New South Wales, Australia. Fine quality specimens have been found at the Black and White mine at Danglemah. M.O'D.

Alexandrite, emerald, ruby, sapphire and topaz in a biotite-phlogopite fels from Poona, Cue District, Western Australia.

G. Grundmann and G. Morteani. *Australian Gemmologist*, **20**(4), 159–67, 6 illus. in colour, 5 black-and-white illus., 1 map.

During 1994, corundum (ruby and colourless to blue sapphire), chrysoberyl (green alexandrite – the first discovery of alexandrite-bearing rocks in Australia), colourless topaz, beryl (light green emerald), pink fluorite, margarite, muscovite and quartz were discovered at Poona in Murchison Province, Western Australia. The report includes the history of mining in the area and details of the mineralization of the deposits. Although very little material suitable for faceting has been found to date, it is hoped that ongoing exploration will result in more and better quality gem material being discovered. P.G.R

Cloudiness in zircons – a chemical and morphological study.

L.N. Gupta, G. Meier and W. Johannes. *Journal of the Geological Society of India*, **51**(4), 1998, 475–84.

A study of zircons from migmatites in the Turku area, Finland, using EPMA and IR techniques, showed that cloudy areas in these zircons contain additional Fe_2O_3, CaO, MgO, Al_2O_3 and water over values for the clear areas. IR spectroscopic analysis showed that the clouded parts have both molecular H_2O and OH molecule in similar proportions; the total H_2O in these clouded parts is ~ 8 wt. %. A direct relationship exists between water + secondary components and the cloudiness of the zircons. It is suggested that the Fe_2O_3, CaO, MgO and Al_2O_3 dissolved in water got incorporated into the crystal structure of the zircon, replacing ZrO_2 and SiO_2 simultaneously. R.A.H.

Tiefgrüner Lazulith.

V.M.F. Hammer. *Lapis*, **24**(5), 33–4, 1999, 1 map in colour.

Transparent crystals of dark-green lazulite are reported from the Skardu district, Northern Areas of Pakistan. The specimens are sharply pyramidal and range up to 5 cm in length. M.O'D.

'Transvaal-jade' aus Südafrika.

R. Hochleitner and M. Vogt. *Lapis*, **23**(10), 1998, 36–8, illus. in colour.

Various colours of hydrogrossular garnet to which the undesirable name 'Transvaal jade' has long been in use for the green variety are described from the Rustenberg area of South Africa where they occur near the Buffelfontein

and Turffontein farms, the area forming part of the Bushveld complex. Chromium is held to be responsible for most of the green coloration and manganese for the pink. M.O'D.

Scottish gem lab news.

A. HODGKINSON. *Australian Gemmologist*, **20**(4), 1998, 154–8, 15 illus. in colour, 1 table.

The author reports on three new gem materials seen during the 1998 Tucson Show and gives recommendations on methods of identification. With synthetic moissanite, a table indicates the main identification features of large DR, high RI and some electrical conductivity. The author's visual optics method can also be used to distinguish synthetic moissanite from diamond, and is particularly useful for identifying the second new material, bluish-green cobalt-diffused topaz which produces a negative reading on a refractometer and a CZ type reading on a reflectance meter. The third new material described is a red synthetic diamond which can be identified by floating it on a raft and checking its attraction to a small rare earth magnet. P.G.R.

Achate aus Sachsen und Thüringen – Ein Überblick zu ihren Vorkommen in Gängen und Vulkaniten.

G. HOLZHEY. *Gemmologie, Z. Dt. Gemmol. Ges.*, **47**(4), 1998, 199–224, 25 photographs, 4 diagrams, 3 maps, extensive bibl. 1 table.

The author describes in detail what types of agates are found in Saxony and Thuringia in their geological and geographical contexts. The agate-bearing spherulites from Wiederau are mentioned – these are shown in the green Vaults in Dresden. Beautiful colours and cracks are characteristic features of both vein agates and agates in rhyolitic spherulites found at the foot of the Ore Mountains. Amygdaloidal agates occur in the andesitic volcanic rocks both in Saxony and in the Harz mountains in Thuringia. Other occurrences with agate which contain spherulites from the Thuringian Forest are located within marginal facies of volcanic domes and lava flows. Because of the fine cracks in many of these agates, usually only small cabochons can be cut from them. E.S.

Alaskan jade.

P. HOWARD. *Australian Gemmologist*, **20**(4), 1998, 149–53, 8 illus., in colour, 1 map.

First discovered by Eskimos who used it for ornamentation as well as for tipping weapons and tools, gem-quality nephrite, known commercially as Alaskan jade, is mined from several deposits in north-west Alaska's Baird or Jade mountains. Although early explorers of the region such as Captain James Cook were aware of its use by the Eskimos, the precise location of the Alaskan 'greenstone' source remained a mystery to Europeans for many years until it was finally discovered in the Kobuk area of Alaska in 1885. Today gem-quality nephrite jade is mined and stockpiled during the three months of Alaskan summer from June to September before being hauled out on sledges during the first freeze of the on-coming winter. P.G.R.

Foreign affairs – fracture healing/filling of Mong Hsu ruby.

R.W. HUGHES AND O. GALIBERT. *Australian Gemmologist*, **20**(2), 1998, 70–4, 12 illus. in colour, 1 map.

Although not of the same quality as Mogok rubies, the stones from the Mong Hsu deposit in Myanmar's Shan State have recently dominated the world's ruby trade in sizes below 3 carats. 99% of rubies traded today in Chanthaburi, Thailand, are from Mong Hsu. The stones have a strong purplish colour and contain dense clouds of silk, both of these features being improved by heat treatment to produce stones having a rich clear red colour. However the stones are also heavily fractured and these flaws are filled and 'healed' in Thailand by heating the stones in a flux containing borax and other chemicals. This latter treatment has created problems as it is generally accepted by Bangkok dealers/gemmologists, but rejected by those outside the country. P.G.R.

Eine neue gemmologische Untersuchung der Sankt Wenzelskrone in Prag. (A new gemmological study of the St. Wenceslas crown in Prague.) [German with English abstract.]

J. HYRSL AND P. NEUMANOVA. *Gemmologie – Z. Dt. Gemmol. Ges.*, **48**(1), 1999, 29–36, 12 illus. in colour, bibl.

The crown was ordered by Charles IV and made between 1346 and 1387. In the front there is one sapphire, one rubellite, five spinels and one pearl. On the right one spinel, six sapphires, one aquamarine and one pearl; the back has two sapphires, 14 spinels and one pearl, the left one spinel, seven sapphires and one pearl. Four spinels are on the metal closure. The two bows on top have 25 emeralds, 15 rubies, four spinels and 16 pearls; the cross on top contains a cross-shaped sapphire cameo, two sapphires and one spinel. Many stones, especially the sapphires, are of exceptional quality, seven of them weighing more than 100 ct. They are probably from Sri Lanka as are the spinels; some stones come from Afghanistan. The rubies are either from Sri Lanka or Burma. The origin of the emeralds is unknown. Most stones are irregularly shaped, just polished, and some have primitive facets. E.S.

A theoretical study of the absorption spectra of Pb^{+} and Pb^{3+} in the K^{+} site of microcline: applications to the colour of amazonite.

A. JULG. *Physics & Chemistry of Minerals*, **25**(3), 1998, 229–33.

The blue-green colour of amazonite has been assigned by various authors to Pb^{+} ($6s^26p$) and/or Pb^{3+} (6s) in the K^{+} site of microcline. Owing to the complex which forms between the Pb^{3+} ion and the lone pairs of the O atoms surrounding it, the peripheral electron of Pb^{3+} passes onto the 6p level, which results in great similarity between the spectra of Pb^{+} and Pb^{3+} in amazonite (the transition energies are increased). In the isolated state, however, the spectra are completely different. A model for the crystal field around the K^{+} is developed. Under the effect of the crystal field, the transition $^2P_{1/2} \rightarrow 2P_{3/2}$ (6p) is split into

two double transitions. Only the lower transition falls in the visible domain (1.6–1.8 eV for Pb^{+}) – the second in the UV. The green colour arises from the Pb^{+} ion, whereas the blue is attributed to Pb^{3+}. A.A.F.

Bernstein an den Küsten und im Binnenland der norddeutschen Tiefebene.

K. KRAUSE. *Aufschluss*, **49**, 1998, 205–12, illus. in colour.

Amber of near-ornamental quality is described from the north German Baltic coast and adjoining lowlands. Details of transportation and formation are given with notes on the history of amber recovery in the area. M.O'D.

Neue Amazonitfunde aus Colorado.

B.K. LEES. *Mineralien Welt*, **9**(4), 1998, 33–48, illus. in colour, 5 maps.

Fine gem-quality crystals of amazonite have been found at the classic Lake George location in Pike National Forest, Colorado, U.S.A., the area forming part of the Pikes Peak batholith. Well-crystallized amazonite specimens reach up to 12 cm in length. Details of the location, recovery methods and specimen descriptions are given. Large clear crystals of smoky quartz occur in association with the amazonite. M.O'D.

(Comparative study on the colour of natural emerald, synthetic emerald and green beryl.) [Chinese with English abstract.]

LI YALI. *Journal of Gems and Gemmology*, **1**(1), 1999, 50–3.

EPMA results and transmission spectra in the visible range are presented for five specimens, and their colour indices are calculated. The concentrations of the trace elements Cr and V are diagnostic, each giving a characteristic colour index. R.A.H.

New occurrence of demantoid in Namibia.

TH. LIND, U. HENN AND H. BANK. *Australian Gemmologist*, **20**(2), 1998, 75–9, 6 illus. in colour 2 graphs, 3 tables.

The new demantoid occurrence in Namibia is located in a large steppe-like plain in the central part of the Damara Orogen. These andradite garnets display similar compositions and spectroscopic features as low-chromium demantoids from the Ural mountains of Russia. The differences in patterns of internal inclusions in stones from both sources reflect the differing genesis of both occurrences. Chrysotile (asbestos) fibres, typical of demantoids from the Ural mountains, have not been found in the Namibian material. P.G.R.

Origin of sapphires from the Jizerska Louka alluvial deposit in north Bohemia, Czech Republic, Europe.

P. MALIKOVA. *Australian Gemmologist*, **20**(5), 1999, 202–6, 1 black-and-white illus., 6 illus. in colour, 1 map.

A study of the optical features, inclusions and surface patterns of Jizerska Louka sapphires reveal that these characteristics are very similar to those found in and on sapphires from Thai and Australian alluvial deposits, and suggest an origin in a basaltic vent breccia. P.G.R.

The mineralogy, geology and occurrence of topaz.

M.A. MENZIES. *Mineralogical Record*, **26**(1), 1995, 5–53.

Various tectonic settings and geological environments hosting topaz are reviewed. Worldwide occurrences of topaz in rhyolites, granitic pegmatites and hydrothermal deposits including greisens, skarns and veins, are discussed in detail, and their parageneses summarized. (OH) substitution for F is related to decreasing *T*, and results in a progression from orthorhombic volcanic topaz to predominantly triclinic hydrothermal topaz. G.W.R.

Demantoid aus Eritrea. [German with English abstract.]

C.C. MILISENDA AND J. HUNZIKER. *Gemmologie – Z. Dt. Gemmol. Ges.*, **48**(1), 1999, 37–42, 4 illus. in colour, 1 graph, 1 table, 2 maps, bibl.

The demantoid garnets from Eritrea have been known for about 50 years, but were unknown to the public. They are found in sandy gravel near Asmera. Of eight faceted stones and a parcel of rough (altogether nearly 240 ct) one faceted stone and a few pieces of rough were found to be peridot. The remainder were found to be demantoid garnet of SG 3.80 to 3.88 and above the RI limit of a standard refractometer. The absorption spectra show typical bands of trivalent iron, and chromium. Horse-tail chrysolite inclusions, similar to those found in Russian demantoids, were observed. The occurrence of demantoid garnets together with peridots suggests that they had primarily been formed in serpentinized peridotites. E.S.

Edelsteine aus Sambia – Teil 1: Smaragd. (Gemstones from Zambia – part 1: emerald.) [German with English abstract.]

C.C. MILISENDA, V. MALANGO AND K.C. TAUPITZ. *Gemmologie – Z. Dt. Gemmol. Ges.*, **48**(1), 1999, 9–28, 8 illus. in colour, 3 graphs, 2 tables, 6 maps, bibl.

The article describes the geological and geographic location of the Kagem Kafubu gemstone mines and the examination of their production. The Kagem is at present the largest mine within the Kafubu emerald field in the Ndola Rural District. The licensed mining area is about 40 square km and includes many open pit mines, such a FwayaFwaya, Chama, etc. The emeralds occur as porphyroblasts in biotite-phlogopite rocks and were formed during the late stages of the Pan-African event (approx. 500–450 million years ago). Kagem was privatized in 1998 and it is hoped that it will produce very fine emeralds. The stones are sorted into five categories, according to colour and clarity. RI 1.581–1.597, DR 0.008, SG 2.69–2.77. Mica platelets form the most characteristic inclusions; rod-like inclusions were shown to be amphiboles. Fluid inclusions are oriented square to rectangular negative crystals filled with a liquid and there were also some gaseous inclusions. E.S.

Contemporary identification to [sic] green jadeite. [In French and English.]

D. Mok. *Revue de gemmologie*, **136**, 1999, 11–13.

Present-day methods of treating green jadeite are summarized. Particular care needs to be taken with B and B + C jade. M.O'D.

What's new in minerals.

T. Moore et al. *Mineralogical Record*, **29**, 1998, 209–21, illus. in colour.

An overview of the Tucson show of 1998 describes a number of interesting gem specimens, in particular a 43 cm plate of benitoite crystals on matrix: smaller benitoite specimens were also on sale. Among other gem materials were azurite from the Hanover #42 mine, Fierro, New Mexico, yellow baryte from the Barrick Meikle mine, Carlin, Elko County, Nevada, pale yellow amblygonite from a number of different locations, pale to deep green Mali garnet and demantoid (lacking crocidolite inclusions) from the Namgar mine, Usakos, Namibia. More transparent green zoisite was on show as well as red spessartine from the Gilgit area of Pakistan. M.O'D.

What's new in minerals.

T. Moore. *Mineralogical Record*, **30**, 1999, 211–40.

Gem-quality green andradite has been found at the Yellow Cat mine, New Idria District, San Benito County, California, and shown at the 1999 Tucson Show. Other gem-quality materials at this show were: green diopside crystals up to 8 cm long from Chamachu, Baltistan, Pakistan, and rhodochrosite (some found with silver) from Uchucchacua, Peru: crystals and faceted tourmaline from Keffi, Nigeria (crystals predominantly red but showing some other colours): gemmy yellow rhodizite from Antsogombato, Madagascar: red spinel from Pain Pyit, East Mogok, Myanmar: gem-quality forsterite from Sappat, Pakistan: spessartine of fine quality from an as-yet unnamed location in Yunnan Province, China. Finally a deep turquoise-blue euclase crystal measuring 12 cm from Colombia. M.O'D.

Emerald chemistry from different deposits – an electron micropobe study.

I.I. Moroz and I.Z. Eliezri. *Australian Gemmologist*, **20**(2), 1998, 64–9, 3 illus. in colour, 1 table.

Twenty-nine emerald samples were analysed chemically using a JEOL JXA-8600 electron microprobe at the Institute of Earth Sciences of the Hebrew University of Jerusalem. The samples consisted of a selection of rough and faceted emeralds from occurrences in Australia, Brazil, Colombia, Mozambique, Nigeria, Russia Tanzania and Zambia, and included three hydrothermally grown synthetic emeralds. Emeralds from schist-type deposits (Australia, Brazil, Mozambique, Russia, Tanzania and Zambia) were characterized by high concentrations of MgO, FeO and Na_2O, while Colombian and Nigerian emeralds had low concentrations of MgO and Na_2O. The synthetic emeralds had the smallest amount of Na_2O. P.G.R.

The IMA Commission on New Minerals and Mineral Names: procedures and guidelines on mineral nomenclature.

E.H. Nickel and J.D. Grice. *Mineralogical Record*, **30**, 1999, 163–76.

Describes the work of the Commission and how minerals are finally named and published. A list of nomenclature changes from 1987 to 1998 is appended. M.O'D.

How to make an appraisal of jadeite.

C.M. Ou Yang. *Australian Gemmologist*, **20**(5), 1999, 188–92, 10 illus. in colour, 2 tables.

Because of the difficulties in appraising jadeite, the author (one of Hong Kong's acknowledged experts in this field) proposes the use of the four Cs (colour, clarity, cutting, cracks), the two Ts (transparency, texture) and one V (volume) in the valuation of this material. Guidelines and colour illustrations are included for the assessment of colour, clarity, cutting, cracks, transparency and texture. P.G.R.

(Mineral component of jadeite jade.) [Chinese with English abstract.]

C.M. Ou Yang. *Journal of Gems and Gemmology*, **1**, 1999, 18–25, illus in colour.

Three types of minerals can be determined as jadeite jade: they are metamorphic crystalloblastic minerals, primary and secondary minerals. These were studied with the polarizing and electron microscopes and details are given. M.O'D.

Quarz und Fluorit von Selvino und Zogno, Lombardiche Kalkalpen/Oberitalien.

F. Pezzotta. *Lapis*, **24**(3), 1999, 13–22, 1 map.

Gem-quality crystals of quartz and fluorite are described from Selvino and Zogno respectively in the Lombardy Alps of Italy. The quartz crystals are compared with those from Herkimer, New York, U.S.A., and the fluorite occurs in a number of different colours, reaching large sizes. M.O'D.

Grosse Sphenkristalle aus dem Kötschachtal bei Badgestein (A).

W. Pfeffer. *Lapis*, **24**(5), 11–14, 1999.

Fine well-formed crystals of sphene up to several cm in length are reported from Kötschachtal near Badgestein, Austria. Some crystals display a characteristic roundness. Rock crystal with black inclusions of chlorite and short prismatic crystals of phenakite have also been found in the area. M.O'D.

Chrysoberyl from Azklary – a new occurrence in Poland.

A. Pieczka and B. Golebiowska. *Mineralogia Polonica*, **28**(1), 1997, 31–3.

Chrysoberyl occurs in a granitic pegmatite in contact with serpentinites of the Szklary massif, Lower Silesia, as fine, 6–8 mm long, idiomorphic, single or twinned individuals, translucent to transparent in hand specimen, with a greenish or yellow-green colour. The XRD and IR spectra are reported; the chrysoberyl has *a* 5.4800, *b* 9.4147, *c* 4.4289 Å, space group *Pbnm*. R.A.H.

Purple-red colour of quartz caused by piemontite inclusions.

A.N. Platonov, M. Sachanbinski, A. Szuszkiewicz and V.S. Sedenko. *Gemmologie, Z. Dt. Gemmol. Ges.*, **47**(4), 1998, 193–8, 3 photographs, 4 diagrams, 2 tables, bibl.

The article describes a new variety of purple-red quartz from the North Caucasus. Lens-shaped pieces of quartz with piemontite from distinctive veins up to 15 cm thick; where they become thin, the quartz is of purple to cherry-red colour. The material was investigated by microprobe and optical absorption spectra were obtained. E.S.

(Mechanism for kosmochlor symplectite and compositional variation zoning in jadeite jade.) [Chinese with English abstract.]

Qi Lijian, Zheng Shu and Pei Jingcheng. *Journal of Gems and Gemmology*, **1**, 1999, 13–17, illus in colour.

A study on the petrography and geochemistry of kosmochlor in jadeite is reported, together with the EPMA results. The kosmochlor mainly occurs as a symplectite substituting or surrounding chromite; part of the kosmochlor next to jadeite has been metasomatized by chromite, resulting in a three-layer symplectitic zoning of kosmochlor + calcic kosmochlor + uvarovite. The chemical zoning reveals the multiple stages and complexity of the unbalanced metasomatic reaction. The coupling of diffusive bimetasomatism with flow-percolating metasomatism between the mineral grains is the main reason for the formation of kosmochlor symplectite and the compositional zoning. R.A.H.

(Testing of copal resin and amber.) [Chinese with English abstract.]

Qiu Zhili, Chen Binghui and Zhang Yuguang. *Journal of Gems and Gemmology*, **1**, 1999, 35–9, illus in colour.

New Zealand Kauri copal and amber are compared. Alcohol and infrared spectroscopy are used in identification but care needs to be taken when fluorescence, SG, RI and inclusions are tested. M.O'D.

Zwei Wege zur Bildung von Augenachaten.

R. Rykart. *Schweizer Strahler*, **11**, 1999, 476–80.

'Eye' agate may have been formed either from a silica gel or from different pre-existing minerals. Examples of agate from a number of world localities are considered in the light of both theories. M.O'D.

Smaragde, das 'Grüner Feuer' aus Kolombien.

F. Schindler. *Lapis*, **23**(10), 1998, 13–18, illus. in colour.

Up-to-date review of emerald production in Colombia with emphasis on the Muzo group of mines and their specimens. Crystal aggregates, a rare form of emerald occurrence, have been found with calcite at the Coscuez mine, Muzo. M.O'D.

Rote, rosafarbene und zweifarbige Turmaline aus einem neuen Vorkommen in Nigeria.

K. Schmetzer. *Lapis*, **23**(11), 1998, 25–6.

Crystals of gem-quality tourmaline from Nigeria are described. Diagrams of the crystals are given. Red and multi-coloured crystals of characteristic form are found near the town of Ogbomosho in the Benin area of the country. M.O'D.

Aus farblos wird Blau: synthetische Saphire und ihre Diffusions-behandlung.

K. Schmetzer. *Lapis*, **24**(5), 1999, 39–40.

Short account of the methods by which pale sapphires may be turned blue by diffusion of colouring agents into the surface. US patent 3, 897,529 (1975) is cited and examples quoted were Verneuil-grown sapphires. M.O'D.

Les jades de la Chine ancienne.

S. Soubra. *Revue de gemmologie*, **136**, 1999, 27–30.

Description of the use of nephrite in China during the Neolithic period (around 6000–1700BC) and the Han Dynasty (206BC–AD220). M.O'D

Lavra da Sapo-derzeit fündigate Turmalin-Mine in Minas Gerais, Brasilien.

G. Steger. *Lapis*, **24**(3), 1999, 26–8.

Fine gem-quality tourmaline is described from Sapo, near Goiabera in the Brazilian state of Minas Gerais where crystals up to 14 cm long have been found in pegmatites. Zoned and water-melon varieties are reported though the majority are a fine bluish or green colour. M.O'D.

A new phase of natural feldspar, An_xOr_{100-x}, x ≈ 50.

T. Takagi and T. Hoshi. *Proceedings of the Japan Academy*, **71B**, 1995, 72–4.

A new phase, An_xOr_{100-x} was found as inclusions in labradorite from Ylämaa, Finland, during the course of study by TEM. The chemical composition of this labradorite was determined by X-ray microprobe analysis as $Ab_{40}An_{56}Or_4$. A thin-section parallel to the b^*–c^* plane of this labradorite was subjected to observations under the TEM equipped with an analytical system. A TEM micrograph obtained showed two kinds of exsolution lamellae, A and B and an inclusion, where the compositions of A and B were determined as $Ab_{43}An_{57}$ and $Ab_{53}An_{47}$, respectively, by TEM analysis. K was confirmed to be localized in the inclusion, and it was also discovered that the inclusion contains Ca but is free from Na. The composition of the inclusion derived by TEM analysis can be expressed as An_xOr_{100-x}, a phase of natural

feldspar not having been reported up to the present. The value of x in the above formula is tentatively estimated to be close to 50. [Authors' abstract] I.S.

Les épidotes du Mont-Chemin (VS).

B. VEIGEL. *Schweizer Strahler*, **11**, 1999, 446–8.

Epidote crystals of gem quality are reported from Mont-Chemin, Valais, Switzerland, where they occur in a quartz matrix. The colour of the crystals depicted is a yellowish- to brownish-green and some crystals up to 3.2 cm in length have been found. M.O'D.

Gemstones of New England.

G.B. WEBB AND F.L. SUTHERLAND. *Australian Journal of Mineralogy*, **4**, 1998, 115–22.

Notes on the occurrence of diamond, sapphire, peridot, topaz, zircon, garnet, rhodonite, nephrite, fluorite and feldspar group minerals are given for the New England area of New South Wales, Australia. The New England area includes the sapphire mines at Inverell: diamonds are found at Copeton and emerald in the Emmaville and Torrington areas. Some geology and mining history is given. M.O'D.

Faszination Vesuvian.

P. WELTI. *Schweizer Strahler*, **11**, 1999, 437–46.

Vesuvianite crystals from areas of Switzerland are described. The area of Saas-Fee in the Swiss Valais, which is 1800 m above sea level, provides particularly attractive specimens. Clinochlore, diopside and hessonite have been found as accessory minerals, and crystals up to 3 cm in length are illustrated. Some are of facetable quality. M.O'D.

(Research on texture and structure type of Hetian jade in Xingjiang.) [Chinese with English abstract.]

WU RUIHUA, LI WENWEN AND AO YAN. *Journal of Gems and Gemmology*, **1**, 1999, 7–2, illus in colour.

Discusses the structure of Hetian jade, a material found in Xingjiang. Specimens illustrated show blastic textures, some being felt-like cryptocrystalline, some radiated and others microflaking or wispy. M.O'D.

(Study on clinopyroxene minerals of jadeite jade.) [Chinese with English abstract.]

ZOU TIANREN, YU XIAOJIN, XIA FENGRONG AND CHEN WEISHI. *Journal of Gems and Gemmology*, **1**, 1999, 24–32.

While jadeite jade is mainly $NaAlSi_2O_6$ (occurring as mineral aggregates) other clinopyroxene minerals in jadeite include chromian jadeite, diopsidic jadeite, ureyitic jadeite, omphacite, ureyitic omphacite, diopsidic ureyite, jadeitic ureyite, ureyite, diopside, jadeitic clinoenstatite, diopsidic clinoenstatite, aegirine-augite and aegirine. A jade specimen composed mainly of other clinopyroxene minerals should carry the name of the mineral as a qualifying noun before the noun jade, thus aegirine-jade and so on. M.O'D.

Instruments and Techniques

History of the development of the crystallographic goniometer.

U. BURCHARD. *Mineralogical Record*, **29**, 1998, 517–83.

The goniometer was devised to measure the interfacial angles on crystals. Beginning with a simple instrument which could be laid directly on to the specimen, the goniometer developed into a complicated piece of apparatus which has sometimes been used by gemmologists. By the beginning of the twentieth century large (and beautifully-constructed) three-circle goniometers were being made, especially by the Berlin firm of Fuess: English and French firms were prominent in the first half of the preceding century. M.O'D.

The cutting edge.

Goldsmiths' Review 1997/98, 1998, 40–3, illus in colour.

Short account of the history of lapidary work in Hatton Garden where, now as in past years, a small number of firms deal with the high-quality cutting of fine gemstone rough. Lapidaries are concerned to find suitable trainees to take up apprenticeships. Details of the stages of polishing coloured gemstones are given. M.O'D.

Raman spectra of silicate garnets.

B.A. KOLESOV AND C.A. GEIGER. *Physics & Chemistry of Minerals*, **25**(2), 1998, 142–51.

The single-crystal polarized Raman spectra of four natural silicate garnets with compositions close to end-members almandine, grossular, andradite and uvarovite, along with synthetic spessartine and pyrope, were measured along with powder spectra of synthetic pyrope-grossular and almandine-spessartine solid solutions. Mode assignments were made based on a comparison of the different end-member garnet spectra and, in the case of pyrope, based on measurements made on additional crystals synthesized with ^{26}Mg. A general order of mode frequencies, i.e. $R(SiO_4) > T$ (metal cation) $> T(SiO_4)$, is observed which should also hold for most orthosilicates. The main factors controlling the changes in mode frequencies as a function of composition are intracrystalline P (i.e. O–O repulsion) for the internal SiO_4-vibrational modes and kinematic coupling of vibrations for the external modes. Low frequency vibrations of the X-site cations reflect their weak bonding and dynamic disorder in the large dodecahedral site, especially in the case of pyrope. Two mode behaviour is observed for X-site cation vibrations along the pyrope-spessartine binary, but not along the almandine-spessartine join. A.A.F.

GemScan II.

T. LINTON, R. PEMBERTON, A. CUMMING, B. SWEENEY AND N. MASSON. GAA Instrument Evaluation Committee report. *Australian Gemmologist*, **20**(5), 1999, 182–5, illus in black-and-white.

Marketed by GemScan International, the GemScan II is a reflectance meter fitted with both an instrument mounted test pad and a remote test probe. Readout is on a three and a half digit LCD panel. Test results indicate good repeatability of readings from a range of natural and synthetic sapphires (*abstractor's comment:* although the majority of synthetic sapphires tested on the instrument gave a lower reading than natural sapphires, this is due to the poorer polish of machine cut synthetics). While warning of the pitfalls associated with the inexperienced use of reflectance meters, the Evaluation Committee considers that the GemScan II will work efficiently once the operating principles and test constraints are understood. P.G.R.

Expanded scale Eickhorst refractometer.

T. LINTON, S. SULTMAN AND J. PETERS. *Australian Gemmologist*, **20**(4), 1998, 145–8, 3 illus., in black and-white, 1 table.

Tested by the GAA's Instrument Evaluation Committee, the Eickhorst SR/XS refractometer was reported to be of robust construction and was therefore particularly suitable as a replacement for the Division's teaching instruments. Its expanded scale compared favourably to those of other refractometers, including the Topcon, and this particular feature enabled easy estimation of RIs to the third decimal place. Compared to the price of other refractometers, the Eickhorst SR/XS was also considered to be good value for money. P.G.R.

Tieftemperaturspektroskopie von farbigen Diamanten mit neuartiger Kühlzelle.

M. LUHN AND L. ACKERMANN. *Gemmologie, Z. Dt. Gemmol. Ges.*, **47**(4), 1998, 225–30, 2 photographs, 5 diagrams, bibl.

The authors have developed a new cryostat for spectroscopic measurements of coloured diamonds at low temperatures. Because of the simple geometric arrangement of the light path, maximum intensity of light through diamond is obtained. The result is a very accurate spectrum where the absorption lines relevant for the separation of naturally coloured diamonds from irradiated diamonds are clearly visible. E.S.

Neue Entwicklungen der CVD-Diamant-synthese für den Schmucksektor.

E.M. WINTER AND J. GÄBLER. *Gemmologie, Z. Dt. Gemmol. Ges.*, **47**(4), 1998, 183–92, 6 photographs, 2 diagrams, bibl.

The article deals with two new developments of Winter in conjunction with the Fraunhofer Institute for Thin Films and Surface Engineering. The first is the CVD diamond generated with microprisms at the rear, allowing larger brilliant dimensions than the conventional brilliant cut natural diamond. The surfaces of the microprisms appear as sparkling reflections. The large number of total reflections generates the splitting-up of the light beam. The second development is a motif diamond, in which individual images are created on the gem diamond by means of lithography and are aimed at producing personalised jewellery.

The motif appears as a bright picture on the darker diamond background. This technique can be applied on natural diamonds which are not suitable to be cut as brilliants but are cut into slices, or the technique can be used with CVD diamond layers. The CVD can be applied as a silky black layer to give a good contrast background for the bright motif. The CVD method can extend diamond faces to several centimetres, which could be applied to rings, medals and amulets. Suggested applications include commemorative coins, brooches or medals, and special anniversary and birthstone jewellery. E.S.

Synthetics and Simulants

Melting of corundum using conventional and two-phase molecular dynamic simulation method.

A.B. BELONOSHKO. *Physics & Chemistry of Minerals*, **25**(2), 1998, 138–41.

The melting curve of corundum is calculated using two approaches: the first is conventional and the second by two-phase molecular dynamics (MD) both utilizing the same pairwise interatomic potential previously developed. The melting curve obtained by the 2-phase simulation is in agreement with experimental data up to 25 GPa. A comparison of melting curves obtained by a 2-phase simulation and a conventional MD in NPT ensemble conventional MD. The inaccuracy of the conventional method increases with increasing *P*, and in the case of corundum, changes from about 300 K at 1 bar to 1000 K at 1 Mbar. A.A.F.

'Faux et usage de faux': les falsifications de minéraux. Part 1.

M. BORZYKOWSKI. *Schweizer Strahler*, **11**, 1998, 242–55. illus in colour.

Introduces natural minerals with their synthetic counterparts, outlining the ornamental, research and industrial uses of artificial mineral products. A number of gemstone simulants are described and illustrated. M.O'D.

'Faux et usage de faux': les falsifications de minéraux. Part 2.

M. BORZYKOWSKI. *Schweizer Strahler*, 11, 1998, 294–301. illus in colour.

Second and concluding part of a short review of mineral fakes, synthetic and imitation gemstones. Extensive bibliography. M.O'D.

'Pseudosinhalite', a new hydrous MgAl borate: synthesis, phase characterization, crystal structure, and *PT*-stability.

P. DANIELS, S. KROSSE, G. WERDING AND W. SCHREYER. *Contributions to Mineralogy & Petrology*, **128**(3), 1997, 261–71.

'Pseudosinhalite' is a new, provisionally-named phase produced during hydrothermal experiments at 4–40 kbar, and ~ 650–900°C. Stability at higher *T* increases with increasing *P*. 'Pseudosinhalite' forms monoclinic crystals, elongated along *b*, with *a* 7.455, *b* 4.330, *c* 9.825 Å, β 110.68(1)°, *V* 296.7(1)Å^3; space group $P2_1/c$. The structure is based on hexagonal close packing of oxygens with tetrahedral B and octahedral Mg and Al. Boron fully occupies all tetrahedral sites. *M*1 sites are occupied only by Al, while *M*2 and *M*3 contain both Al and Mg in the proportion 0.17:0.83 and 0.95:0.05 respectively. The ideal formula is $Mg_4Al_6B_4O_{18}(OH)_2$. No OH-stretching bands are observed in IR spectra, possibly because of the strong hydrogen-bonding which results from H location at a split position between two O atoms which are only 2.55 Å apart. The experimental *P–T* conditions of 'pseudosinhalite' formation and the mineral's chemistry indicate that this mineral may in theory form naturally. If so, the properties of 'pseudosinhalite' are sufficiently similar to those of sinhalite that the two minerals might be mistaken. [It has since been recognized in rocks from the Tayozhnoye deposit, Siberia.] C.L.H.

Gemmologische Kurzinformationen. Synthetische Feueropale mit Farbenspiel von Kyocera, Japan. (Synthetic fire opals with play-of-colour from Kyocera, Japan.) [German with English abstract.]

U. Henn and C.C. Milisenda. *Gemmologie – Z. Dt. Gemmol. Ges.*, **48**(1), 45–8, 1999, 2 illus. in colour, 1 graph, bibl.

These synthetic opals have the usual characteristics, like lizard-skin effect and columnar structure. RI 1.459–1.460, SG 1.87–1.91. Sharp absorption peak of an artificial resin was seen in the infrared spectrum. The colours are mainly yellow-orange with some stones having a yellow-green colour flash, some showing a definite red play-of-colour. E.S.

Hydrothermal growth of man-made corundum crystals.

M. Maleev. *Review of the Bulgarian Geological Society*, **57**(2), 1996, 57–60.

Growth runs were carried out in 150 ml unlined steel autoclaves at crystallization *T* of ~ 500°C and *P* 140–170 MPa. The systems consisted of 1 M and 1.5 M $NaHCO_3$ and $KHCO_3$ aqueous solutions as solvents, melt-grown corundum, electrocorundum, corundum ceramics and metal Al as nutrients, and platelets of melt-grown corundum cut parallel to $(10\bar{1}1)$ as seeds. The solubilities of the nutrients in the different solvents have been studied to optimize the growth conditions. The crystals grew at rates of 5–10 g per week and always produced well defined morphologies. The rates of growth forms have been found to decrease in the order $\{10\bar{1}1\} > \{22\bar{4}3\} > \{11\bar{2}0\} > \{0001\}$, and in 30 days all crystals reached a final growth morphology of $\{0001\}$ and $\{11\bar{2}0\}$ only. The study also reports data on the surface morphologies of growth forms and on colour effects due to iron and copper impurities. I.V.

(FTIR features of Guilin hydrothermally-grown synthetic emerald and its significance.) [Chinese with English abstract.]

Shi Guohua. *Journal of Gems and Gemmology*, **1**, 1999, 40–4, illus in colour.

The nature of the colour and the form of water molecules in Guilin synthetic emerald were investigated by electron microprobe and IR spectra. The results show that the Guilin synthetic emerald is characterized by low contents of alkalis and Fe (and Cl); both I-type and II-type water is present. The colour should be attributed to the separation of the ^4F spectrum term and the spectrum resulting from electrons jumping between the different energy levels. Nail-like inclusions are typical. FTIR spectra can be applied to the identification of all types of emerald. R.A.H.

(Identified characteristics of Guilin hydrothermally-grown synthetic ruby.) [Chinese with English abstract.]

Yuan Xingqiang, Kuang Yonghong and Di Jingru. *Journal of Gems and Gemmology*, 1, 1999, 47–9, illus in colour.

Guilin hydrothermally-grown ruby shows an orange-red colour, no absorption in the blue-green part of the spectrum, a colourless seed and crumb-like inclusions. The extraordinary ray has the stronger (yellow) colour, the ordinary ray being a weaker orange-red. M.O'D.

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BOOK REVIEWS

Understanding jewellery (revised edition)

D. Bennett and D. Mascetti, 1994. Antiques Collectors' Club, Woodbridge. pp 425, illus. in colour, hardcover. ISBN 1 85149 205 4. £39.95.

Though the reproduction of some of the photographs (in my copy, at least) leaves something to be desired, this easy-to-read survey of the history of jewellery has been updated to take into account developments in techniques and styles over the period 1960–1980 which has a 40-page chapter to itself. Simple gem testing is described over the first 40 pages: thenceforward the text is arranged chronologically, beginning with the late eighteenth century to 1820. Many readers will find particular interest and information in the tables of approximate auction values (of many of the items depicted in the main text), occupying six pages, and there is a short but useful bibliography. For so comprehensive a survey this book accomplishes its task well and is very good value for the price. M.O'D.

Science and technology of diamond

G. S. Bhatnagar (Ed.), 1999. Mineral Club of India, New Delhi, and Cambridge International Science Publishing, Cambridge. pp 181, illus. in colour, hardcover. ISBN 1 898326487. £55.00.

A multi-author book with chapters on: The diamond connection (D. Lal), discussing age and depth of formation: Biogene indicators of kimberlities and lamproites (P. O. Alexander): Relevance of stream sediment sampling in kimberlite exploration (T.R.K. Chetti *et al*): Gemmology of diamond (M. O'Donoghue): Synthetic gem diamonds and their gemmological identification (J.R Shigley and E. Fritsch): Diamond synthesis (the late B.K. Agarwala): The ultrahard abrasives industry (M.P. Jennings): Science of diamond in protohistoric India (G.S. Bhatnagar and S.R.N. Murthy). There is an excellent bibliography with 253 entries all of papers of significance and including some which would be quite hard to track down otherwise, and eight pages of colour photographs, several indicating distinguishing features of synthetic gem diamond. The book is a useful and pleasingly-written mixture of current topics with some history. It has taken some time to appear: I remember writing my chapter while at the National Physical Laboratory of India in New Delhi quite early in this decade.

Compared with some recent multi-author diamond books, this is on a smaller scale but the contents are easily assimilated and relevant to many branches of gemmological and geological study. M.O'D.

The complete handbook for gemstone weight estimation

C. I. Carmona, 1998. Gemania Publishing, Los Angeles. pp xiv, 434, softcover. ISBN 0 9666370 0 3. US$ 59.95.

In suggesting a reliable method for finding out the weight of mounted gemstones the book places the major gemstones into eight groups on the basis of their specific gravity. Having identified the stone, its SG is noted and its measurements are taken. Style of cutting affects the final result which is calculated by multiplying length by width by depth by SG by a weight correction factor which is designed to take into account various non-standard features of cutting such as a very large table. Without a considerable number of tests the reader takes a certain amount on trust but the idea seems sound and the presentation is very clear, with diagrams illustrating sizes and cutting styles. For a book whose text consists mainly of columns of figures the chosen type-face has succeeded in allowing the user to work at speed with minimum eyestrain and wide readership can be predicted. M.O'D.

(Emerald.) [In Chinese]

Chang Wang Shi Ying and Chang Si Fen, 1996. Kenny Jewellery, Taipei, Taiwan. pp 95, illus. in colour, hardcover. ISBN 957 97172 4 9. Price on application.

A survey of emerald from different localities is illustrated by excellent photographs of emerald-set jewellery. Some characteristic inclusions are also shown. A very attractive book undoubtedly intended for the firm's customers but well worth buying in any case if you are collecting books on emerald. M.O'D.

Shells

C. Claasen, 1998. Cambridge Manuals in archaeology. Cambridge University Press, Cambridge. pp xiv, 266 Illus. in black-and-white, softcover, ISBN 0 521 57582 3. Price on application.

Though tangential to gemmological studies however widely interpreted, learning something of the nature of shells is important, especially when as in this case they are treated from the point of view of the archaeologist. In fact there is quite a lot here about the biology of freshwater and marine molluscs (and about the people who collected them) and also about pearls. There is a first-class bibliography as one would expect from this publisher. M.O'D.

A journey with colour: a history of Queensland opal 1869–1979

L. Cram, 1998. The Author, PO Box 2, Lightning Ridge, New South Wales 2834, Australia. pp 368, illus. in colour, hardcover. ISBN 0 9585414 O X. A$ 178 (including postage and packing to the UK: about £115.00).

Australian opal books are always very pleasing to the eye but this one is up to now the most magnificent of all. In conversation with the author it was established that the

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book is in fact intended to form the first volume of a complete history and review of Australian opal in general (and also of opal from other places in the world) – this is why the otherwise mysterious 'volume one' appears on the spine but nowhere else. I make this point on behalf of Len Cram so that readers will not imagine that the final work will deal only with Queensland opal. It is expected that the succeeding volumes will be quite a lot larger than the present one, so that there is a good deal to look forward to!

Queensland opal has taken a leading role over the last few years: the state, once associated only with boulder opal (sometimes superb, sometimes found only as streaks in a dark ironstone), now produces what is probably the finest material in the world. The text (with magnificent photographs on every opening) deals with the history of the earliest discoveries of Australian opal (in South Australia) and then proceeds to examine all the major Queensland deposits. Miners, methods of working, local geological conditions, celebrated stones and opal commerce are all described. A map and a useful glossary can be found at the end of the main text. This is one of the most beautiful books on any gemstone that I have yet seen: while opal is almost always spectacular in some way, it is hard to imagine how the quality of the photographs here could be improved. The book is by no means expensive for the riches it contains: the print run is only 1600 so try to buy it if you can. M.O'D.

L'émeraude

[Monographic issue of] *Revue de gemmologie*, 134/135, 1998. (pp 192), illus. in colour. ISSN (for the series) 0398 9011. This issue comes under the annual subscription of FF250 (Europe, 1 year).

This multi-author issue is devoted entirely to emerald in both its natural and synthetic forms, giving the physical and optical properties of specimens from all major sources and for the different man-made varieties. Inclusions are well-photographed and reproduced, the illustrations showing the differences between emeralds from the different places of origin. Both students and experienced gemmologists will find this a useful book to keep on the bench or counter. Monographs on emerald in so convenient a size are not plentiful and the customer could well be interested in the photographs, especially if they can be related to actual items in stock. There is room for similar works on the other major gem species. M.O'D.

Die Staatliche Bernstein-Manufacktur Königsberg, 1926–1945

U. Erichson and L. Tomczyk, 1998. Ribnitz-Damgarten: Deutschen Bernsteinmuseum (Im Kloster 1 - 2, D-18311). pp 153, illus. in colour, landscape format. ISBN 3 00 002986 9. DM49.00.

Not-to-be-missed, beautifully-illustrated history of the Königsberg amber factory during its most productive years. Many of the pieces shown are items of jewellery or other ornaments and the methods used to fashion the amber are clearly described with contemporary black-and-white photographs. There is a useful bibliography and reproductions of some price lists and advertisements. M.O'D.

Falize; a dynasty of jewellers

1999. Wartski, London (14 Grafton Street, London W1X 4DE) pp 36, illus. in colour, softcover. £5.00.

Attractively produced catalogue of a loan exhibition held at and by Wartski for the benefit of Befrienders International, this short study of a number of items by Falize describes and illustrates some of the work of one of the major jewellery designers and makers of the late nineteenth/early twentieth century. Many of the items have been featured in a major study of Falize by Katherine Purcell (Thames & Hudson, London, 1999). M.O'D.

Das Ei. Kostbare Ostereier aus Edelstein

S. Frazier, A. Frazier, D. Jerusalem, B. R. Starke, and M. Wild, 1999. Stiftung Deutsches Edelsteinmuseum Idar-Oberstein. pp 71, illus. in colour, hardcover. ISBN 3 932515 13 7. Price on application.

A small book, as beautifully produced as the hardstone Easter eggs described and illustrated between its covers. The exhibition of which the depicted examples form a part celebrates 25 years of the Deutsche Edelsteinmuseum, catalogues of whose contents have appeared in the journal *Aufschluss* and separately. Not only are the eggs described but methods of making them, with some history, form the first part of the book. Views of the Museum itself encourage visitors. M.O'D.

Gem Testing Laboratory Silver Jubilee 1972–1997

The Gem Testing Laboratory, Jaipur, India. 1997. pp 80, illus. in colour, softcover. Price on application.

Gem testing history is not often found in the literature so this is a very useful survey of how work has been carried out at the centre of the Indian gemstone trade. Short biographies are especially welcome and there are some notes on topics of the moment, particular gemstone enhancement. M.O'D.

Gold in Bayern: Vorkommen am Westrand der B^hmischen Masse

Forms 102 of *Geologica Bavarica*, 1997. pp 424, Illustrated in colour, softcover, ISSN for the series 0016-755X.

For the gemmologist who also collects gold specimens this study of the gold-bearing areas of the Western end of the Bohemian massif will be indispensable. Chapters cover all types of occurrences as well as the history of gold mining in the region. M.O'D.

Guide to affordable gemology

W. W. Hanneman, 1998. Poulsbo (PO Box 942, Poulsbo, WA 98372). pp xii, 172, softcover ISBN 0 9669063 0 6. US$25.00.

Eminently readable and amusing too in many places: this reviewer suspects that 'combative' would be another aim of this polymath and fascinating author who enjoys setting up imaginary scenarios travelling through which he can quixotically defeat or, better, irritate a series of cardboard enemies who, if they existed, would almost certainly be on his side!

This is not a book for the beginner but most certainly one for the teacher whose methods and ideas need constant refreshment. I found it a genuinely excellent conspectus of a number of simple and trusted techniques lucidly described with a leavening of gentle malice with which, if I am honest, echoes many thoughts which have at some time passed through my mind. The book begins with a survey of instruments and long accepted testing methods (with extensive comment on Alan Hodgkinson's rediscovery and careful development of the once-abandoned visual optics technique) and follows with an evaluation of various textbooks, specimens and tests: maybe he errs in not realizing that there are some quite good books around and in dismissing (or appearing to dismiss) some of the work done by the perhaps dull organisations whose staff look wonderingly up from their old textbooks and the instruments of academic determinative mineralogy as Comet Hanneman-Hodgkinson traverses the skies above!

Whatever your experience of gem testing, the book can add to it so buy it and see where you can take issue with the author. Perhaps not too often? But a note to the beginner – 'affordable' does not mean 'elementary' so students, take care while you read! M.O'D.

Mineralogical studies of archaic jades

HSIEN HO TSIEN (Ed.), 1996. **Special issue** (no 32 of 1996) of *Acta Geologica Taiwanica*. pp 199 Illustrated in colour, softcover. Series ISSN 0065-1265. Price on application.

Presented as a set of essays in honour of Professor Li-Ping Tan, this important study should be required reading for all with an interest in the jade minerals and the artefacts fashioned from them. Essays include discussions of Raman spectroscopy as applied to the jades, sources of jade materials, methods of working with crystal growth and whitening of archaic tremolite *yu*. Each chapter has its own list of references and there is a short glossary. M.O'D.

Chaumet, Paris: two centuries of fine jewellery

R. HUREL AND D. SCARISBRICK, 1998. Musées de la Ville de Paris, Paris. (pp 173), illus. in colour, hardcover. ISBN 2 87900 390 3. £28.00.

The history and artefacts of the Parisian jeweller Chaumet are described in this catalogue of an exhibition held at the Musée Carnavalet, Paris, from 25 March–28 June 1998. Items are well illustrated and described, the catalogue entries giving details of personages, materials, dimensions and provenance. A short history of the firm opens the text and there is a useful bibliography. M.O'D.

(Natural bleach jadeite identification.) [In Chinese]

J.W. HWANG, 1995. GGL, Taipei, Taiwan. pp 216, illus. in colour, hardcover, ISBN 957 99831 19. (Obtainable through World Trade and Technical Publications Co. Ltd, Room 1423, Star House, 3 Salisbury Road TST, Kowloon, Hong Kong.) Hong Kong $2760.00.

Yes, this is an expensive book but there is nothing else in monograph form on the bleaching of jadeite and even though the text is in Chinese, as always the photographs and their captions are so good that the reader can tell what is being discussed. This time the photographs are magnificent rather than good and despite the price, libraries in the West at least ought to make an effort to buy so important a treatment of this vital subject. I assume that gem collectors and laboratories in China already have it.

The text opens with several pages of photographs showing jade pebbles and boulders, including a number of shots of material on sale at the 1990 Myanmar gem auctions. This is interesting for a number of reasons, not least because you can see the different colours revealed by the saw cutting of the boulders and also the price paid for particular lots. I have never met this feature before. Details and illustrations of the treatments follow and the remainder of the book covers testing for the various materials used in colour alteration – again, this section is profusely illustrated. There are at least four and usually 10 photographs to be seen on each opening, making an average of five pictures on each separate page. At least try to get a look at this and at other China-produced books. M.O'D.

Kristallmuseum Riedenburg im Altmühltal, München

Lapis [Christian Weise Verlag], 1998. pp. 96, illus. in colour, softcover. DM 16.00.

This guide to one of Germany's most interesting mineral museums forms the first issue of a new series from this excellent publisher. The aim is to supplement the journal *Lapis* (founded in 1976 and which also has the monographic series *extraLapis*) by adding guides to notable museums. Riedenburg is north-east of Munich and south-east of Nuremburg and the museum contains many items of gemmological and ornamental interest. Notes on gemstones in general, including notable diamonds, accompany the guide. M.O'D.

(Gemstone inclusions identification.) [In Chinese]

LAI TAI-AN, 1995. Gemological institute of Lai Tai-An (PO Box 53-1142), Taipei, Taiwan. pp ix, 342, illus. in colour, hardcover in slip case. ISBN 957 99439 0 7. US$115.00.

Yes, there is enough English in the captions to be able to work out what is being shown in the magnificent series of inclusion photographs in this large and beautiful book, in which no opening has less than 4 pictures and sometimes up to ten. Beginning with instructions on how best to look for significant inclusions, the text goes on to review the major gem species, both natural and synthetic: treated and enhanced specimens are also discussed. The standard is at least as high as in other books on inclusions and in many instances excels them. M.O'D.

(Gem jade identification and buying guide.) [In Chinese]

LIAO ZONG TING AND BIAN QING, 1997. Shanghai Illustrated Magazine Publishing House, Shanghai, P.R. China. pp 123, illus. in colour, softcover. ISBN 7 80530 286 3. Price approximately £10.00.

With all the colour at the front, this is a very neat and concise guide to the jade family of minerals in their fashioned form, so it is especially useful for gemmology students who are in fact using them during their courses. A few text diagrams complete the survey. M.O'D.

Fleischer's glossary of mineral species (8th edn)

J. A. MANDARINO, 1999. The Mineralogical Record, Tucson. (pp vi, 226), softcover, ring-bound. Approx. £13.50 in UK.

The small but significant change in title of this very popular book comes through the recent death of Michael Fleischer, its begetter, at the age of 90. The *Glossary* has long been the bible of mineral species collectors and is worth serious consideration by gemmologists for its up-to-date information on species, their composition, group membership, crystal system and most topical reference in English. In this edition, now in the charge of the former junior author, colour has been omitted (since it may vary significantly with location) as have non-validated species: the 'compositions in words' are also omitted this time for the sake of saving space.

For the rest we have the now familiar alphabetical arrangement, retaining the squares preceding each entry and intended to be marked off by the fortunate collector who secures an example. The main text is followed by the section describing mineral groups and their constituent species (whose compositions are repeated): since there have been major revisions of the amphiboles and zeolites the opportunity has been taken to incorporate the new information gained. The *Glossary*, first published in 1971, appears once more as a welcome survey of mineral species with emphasis on relationships. For today the price is amazingly reasonable and the production as good as ever. M.O' D.

Jewellery making in Birmingham, 1750–1995

S. MASON, 1998. Phillimore, Chichester. pp xi, 211, illus. in colour, hardcover. ISBN 0 86077 079 7. £25.00.

The visitor to Birmingham today will find a rail (and tramway) station named 'Jewellery Quarter'. Alighting, the surrounding scene, though clearly one of contraction, is still devoted almost entirely to the jewellery trade which at last has a worthy history of its own. While Birmingham is correctly regarded as the centre of what in any other form of manufacture would be called mass-production, there has been no lack of innovative techniques or designs since jewellery-making began in the eighteenth century. By 1773 Birmingham had its own Assay Office and the trade employed a high proportion of the city's workforce. In 1887 the jewellers had their own trade association and a training school, established in 1890 and well in evidence today.

In this fairly short book the origins of the Birmingham jewellery manufacturing trade are discussed with considerable comment on how designs, machinery and skills developed. The author has been able to draw quite a lot of material from local records and this shows in the excellent bibliography and text references, both sections placed together at the end of the book. The text is well illustrated with both black-and-white and colour photographs, of a good standard: I can recommend it highly and also a visit to the jewellery quarter, where a really first-rate museum is open daily. The museum is in fact a jewellery-making factory, preserved in its original state after the owners decided, virtually overnight, to retire, leaving the workers, correspondence, gold stocks and work in progress just as they were. M.O'D.

Jewelry from the Pearl Museum, Vol. 1

K. MATSUZUKI, 1998. Mikimoto Pearl Island Co. Ltd, Mie, Japan. pp 47, illus. in colour, hardcover. £13.00.

The first in a series of volumes describing and illustrating artefacts in the Pearl Museum is concerned with sash clips from the Meiji, Taisho and Saisho periods as well as with sash clips and hilt ornaments in general. All exhibits in the Pearl Museum are set with pearls: each of the 50 or so items is described with dimensions and notes on the metals and stones used. In many cases small insets show designer's drawings. Though a small book it is beautifully produced and other volumes in the series are eagerly awaited. M.O'D.

El maravilloso mundo del la esmeralda Colombiana (The remarkable world of the Colombian emerald.) [In Spanish and English]

R. MONCADA AND T. QUINN, 1995. Photo World Press-Editores, Santafé de Bogota. pp 131, illus. in colour, hardcover. ISBN 958 95780 0 4. Price on application.

A vocabulary of words and phrases concludes this excellent and well-illustrated book on the Colombian emerald, its nature, mining and marketing. 'Voiadora' is working a mine 'on the sneak' while 'cuerda' is a collection of fighting cocks belonging to an individual. While this might seem rather distant from gemstones it shows that the authors have found and reproduced the spirit and life of everyday Colombian emerald working which of course is well described throughout the remainder of the book. Words for emerald qualities and for miners' agreements are also given while tables identify the different working shafts of the Chivor, Muzo, Quipama and Coscuez mines. Many mining scenes are graphically and dramatically shown by a series of fascinating pictures and the gemmologist will need this book as an addition to any serious library. M.O'D.

Museés royaux d'Art et d'Histoire [Belgium]. Quand la pierre se fait précieuse...

The Museum, Brussels, 1995. pp 134, illus. in colour, softcover. £15.00.

Catalogue of an exhibition at the Brussels and Tervuren museums of art, the book acts as a quite useful and well-illustrated introduction to gemstones and jewellery and shows a large number of rough and fashioned stones (in rather small dimensions), later turning to the history of jewellery which is also pleasingly illustrated. M.O'D.

Kristalle aus den Schweizer Alpen

E. OFFERMANN, 1999. Christian Weise Verlag, München. pp 66, illus. in colour, softcover. ISBN 3 921656 47 8. Price on application.

A pocket-sized book worth noting for the number of gemmologists who are also crystal-specimen collectors and also for the unique combining of high-quality photographs with computer-produced diagrams, generated with the software Shape 4.2 with Canvas 3.5.4 for the graphics. A most attractive production which shows developments and translation of forms in a very simple way, the book should be of interest as much for its production as for the fine specimens presented. M.O'D.

(Jadeite observation.) [In Chinese]

C. M. Ou Yang, 1995. World Library Ltd, Hong Kong. pp 191, colour, hardcover. ISBN 962 257 584 6. HK $198.00.

A survey of jadeite from the geological and mineralogical standpoints as well as from that of the gemmologist and connoisseur, this book is a good starting point for the Chinese reader who wishes to learn, fairly quickly, about jadeite. The text begins with jadeite occurrences (shown on maps) and continues with notes on structure before proceeding to the series of pictures depicting finished jewellery set with the finest qualities of the material. Production is excellent, as seems to be the case with many Far Eastern books on jade. M.O'D.

(Jadeite ABC.) [In Chinese]

C.M. Ou Yang, 1997. Cosmos Books, Hong Kong. pp 192, illus. in colour, hardcover, ISBN 062 950 214 3. HK $238.00.

Exhaustive study of jadeite from recovery and fashioning to testing, enhancement, imitation and sale. The illustrations are first-class, especially of jadeite in the rough, not often seen in much larger books. The excellence of the illustrations greatly diminishes the inevitable textual difficulties which could be experienced by non-Chinese readers. M.O'D.

(Jadeite selection and buying.) [In Chinese]

C. M. Ou Yang, 1998. World Library Ltd, Hong Kong. pp 185, illus. in colour, hardcover. ISBN 962 950 379 4. HK $190.00.

Beautiful pictures of set jadeite enliven this most useful buyer's guide which seeks to point out the beauty of the material rather than to give notes on treatment and testing. As such the book succeeds admirably and will be welcome to all readers, whether or not they can read Chinese. M.O'D.

Rough diamonds. Internal and external features

N. Peters, 1997. American Institute of Diamond Cutting, Inc., Deerfield Beach, Florida (PO Box 4067) 33442-4067, USA. pp 46. Illus. in colour. Hardcover. Price on application.

A series of 86 excellent colour photographs illustrates diamond crystals, indicating external and internal features which may affect initial sorting and subsequent fashioning. The polishing process and some finished stones are also illustrated and the whole book is a first-rate introduction to the subject, whether the reader is a polishing beginner or a student of gemmology. A larger treatment of the subject is promised by the author and publishers and if the same standard is maintained it will be worth waiting for. M.O'D.

Rough diamonds. A practical guide

N. Peters, 1998. American Institute of Diamond Cutting, Inc., Fort Lauderdale. pp 172. Illus. in colour. Hardcover ISBN 0 9665854 1 0. £55.00.

The author has previously produced *Rough diamonds: internal and external features* and this larger text also considers diamond crystals and how their nature influences their final polished state. The first chapter gives an overview of the rough diamond market: this is followed by a discussion of the structure of rough diamonds and how to obtain optimum weight from a finished specimen. Surface and internal features, colour in the rough state and details of manufacturing each has its own chapter and the final section details the valuation of rough diamonds.

A great deal of the material in the book would be difficult to find elsewhere and the majority of the photographs give good views of the specimens they illustrate. Although a few of the black-and-white pictures are slightly out of focus, the student of diamond should have this book available for reference. M.O'D.

Handbook of industrial diamonds and diamond films

M.A. Prelas, G. Popovici and L.K. Bigelow, 1998. Marcel Dekker Inc., New York. pp xii, 1214. Illus. in black-and-white. Hardcover ISBN 08247 9994 1. £140.00.

While aimed in the first instance at readers interested in the use of diamond as an engineering and research material, this large book brings together all extant and on-going research into the physical and optical properties of natural and synthetic diamond. A team of 45 writers has compiled a guide to all the properties of diamond (including a section by Collins giving up-to-date ideas on band theory): pages 232–343 attribute defect-induced vibrational bands, one- and two-phonon Raman bands and optical bands to their causes. For gem diamond specialists this section allows finding the particular band (e.g. 415.2 nm [as cited]) and finding out the exact cause (this band has a 25-line paragraph devoted to it) and treatment of similar length, with diagrams where appropriate, is given to other well-known optical absorption bands (together with bands in the ultraviolet and infrared regions). Altogether more than 100 vibrational and over 400 electronic optically active centres have been identified in diamond in the spectral range from 20 to 0.17 μm (i.e. from the middle IR to the vacuum UV region).

While this section will certainly interest the scientific gemmologist most, much of the information elsewhere in the book will also be useful. Pages 481 to 526 deal with natural diamond, its locations, formation (in kimberlites and lamproites), distribution, exploration, mining and processing, mineralogy and geochemistry, classifications, fashioning and marketing. In the absence of a similar in-depth study in English this summary chapter gives one of the best sets of current references.

The book also contains individual chapters on thermal properties and characterization methods and includes a very large section on the chemical vapour deposition of diamond thin-films. This opens with the theory of CVD and follows with sections on the modelling and diagnostics of plasma reactors and on methods of CVD growth. Similar exhaustive treatment is given to the structural modification of diamond (nucleation and epitaxy, ion implantation of diamonds and diamond films, and processing). This section deserves careful study since any kind of alteration of diamond has considerable significance for many areas of materials science.

The last sections describe many of the applications of industrial diamonds (as abrasives, in computers and in other fields) and conclude with a discussion on diamond economics and commercialization. This is a large and expensive book but potential readers should ensure that their university library obtains a copy. M.O'D.

Catalogue of Mineralientage München 1998

ROT AND LEBENDIG, 1998. Mineralientage München, Oberhaching. pp 288, illus, in colour, softcover, DM50.00.

This year's theme of the Munich Mineral Show was red minerals and gemstones and this beautifully-illustrated catalogue includes a number of short papers certain to be interesting to gemmologists. My eye was particularly caught by a description of trapiche ruby as well as a survey of the role played by chromium in the coloration of minerals and gemstones. A short photographic essay showing interference figures, a return to Mogok and a review of rhodochrosite from the Sweet Home mine, Colorado, U.S.A., are among other articles accompanying the show guide, the main purpose of the catalogue. M.O'D.

Geology of East Africa

T. SCHLÜTER, 1997. Gebrüder Borntrager, Berlin. pp xii, 484. ISBN 3 443 11027 4. [*Beiträge zur regionalen Geologie der Erde*. Bd 27] DM 196.00.

The series has already included studies of the gem-producing areas of Myanmar and Pakistan, each with considerable mention of gem minerals and their occurrence, so that a similar comprehensive coverage of the geology of East Africa is particularly welcome since there are fewer detailed studies outside the Survey reports (where they exist) of the original colonies. The book sets out to give an account of the regional geology and stratigraphic history of East Africa: the countries included are Kenya, Tanzania and Uganda, but surrounding regions with similar geology are frequently mentioned.

The text is arranged in geochronological order by country, stratigraphy, petrology and mineralization, and students with an interest in the gemstones of the region will find the best account in the section (2.84) dealing with the neoproterozoic of the Mozambique belt in Kenya, Tanzania and Uganda. Here we have treatments of gemstone mineralization which include the desilication of granite pegmatites or gneisses by ultramafic rocks leading to the formation of ruby, sapphire, spinel, emerald, alexandrite and tourmaline: medium- to high-grade metamorphism of closely associated crystalline limestones and graphic gneisses giving tsavolite, tanzanite and rarer collectors' species: classic emplacement of Li- and Be-rich pegmatites providing the well-known granite pegmatite gem minerals tourmaline, beryl, quartz, phenakite and euclase: hydrothermal alteration of serpentinite and other ultramafic bodies giving peridot, and the lower-temperature establishment of chrysoprase, rhodonite and prase-opal.

There is an excellent bibliography and subject, fossil and locality indexes. The book is a worthy companion to others in this distinguished series and the price is not unreasonable for a work of this quality. M.O'D.

Gemstones of the world (revised and expanded edition)

W. SCHUMANN, 1997. NAG Press, London. pp 271, illus. in colour. Hardcover ISBN 0 7198 0271 7, £18.50.

This well-known text is popular with students and has now been edited to get rid of some really awful mistakes which were included in some at least of the earlier editions. The pictures are as good as ever: for students the main drawback is what C.S. Lewis, one of my professors long ago, calls 'the boundless assurance of the pure textbook' so that what you are told has to be compared with serious textbooks, which, in fairness, this has never claimed to be. It is very pleasant to look at and most of the information is more or less correct. Read with care. M.O'D.

Pearls and pearl oysters of the world. [In English and Japanese]

S. SHIRAI, 1994. Marine Planning Co., Nagano, Japan. pp 108 Illustrated in colour, hardcover, ISBN 4 9900287 1 6. Price on application.

Illustrations with dimensions and descriptions of 275 species of mollusc of which 24 marine examples are pearl-bearing, 238 freshwater pearl-bearing and 13 other pearl-bearing species. While the majority of examples are arranged by continent the major marine pearl molluscs are arranged under the Pacific, Atlantic and Indian oceans. Both Latin and English names are given with commonly-used synonyms where applicable. Endangered species are flagged and museum specimens indicated. The standard of photography is state-of-the art and the book is a very welcome addition to the still rather sparse pearl literature. M.O'D.

Mineralienlexikon der Schweiz

H.A. STALDER, A. WAGNER, S. GRAESER AND P. STUKER, 1998. Verlag Wepf & Co., Basel, Switzerland. pp 579, illus. in colour, hardcover. ISBN 3 85977 200 7. SFr 178.00.

As a highly mineralized country Switzerland is naturally of great interest to the mineral collector and gemmologist. The present book is a worthy successor to the earlier surveys of Parker in 1954 and Parker (with some of the present writers) in 1973. A further general study by Weibel *et al.* was published in 1990.

The book opens with mineral descriptions in alphabetical order, the entries giving chemical composition, details of crystallization and other properties, together with notes on major Swiss occurrences. This large section is followed by descriptions of the major types of mineral occurrence, details of meteoritic and organic materials and a 21-page bibliography. The book concludes with an index and with coloured maps illustrating geology and some of the major mineral occurrences. This is essential reading for all interested in Swiss minerals and is well-produced and reasonably priced. Gem mineral collectors will be especially eager to read about Swiss occurrences of fluorite, sphene and the various types of quartz. M.O'D.

Standards and applications for diamond report, gemstone report, test report. [English language edition]

SSEF Swiss Gemmological Institute, 1998. Basel, Switzerland. pp 118, Illustrated in colour, Softcover, US $65.00.

Very well-illustrated guide to standards employed in testing gemstones by the Swiss Gemmological Institute and a model of its kind. A large number of coloured photographs accompany specimen certificates and explanations of the grading systems used. The book will be especially valuable for the study of inclusions and of colour-enhanced specimens. M.O'D.

Limpiar la tierra: guerra y poder entre esmeraldos

URIBE ALARCÓN, M.V., 1992. CINEP, Bogotá. pp 150, illus. in black-and-white, softcover. ISBN 958 644 016 8. Price on application.

Official and unofficial emerald miners, the Colombian government, political parties and the Roman Catholic Church have traditionally striven for power in the east of Boyaca state since the discovery of emerald there. The book describes many elements of social conflict arising from the power struggle and also gives a good deal of detail, including maps, of the emerald-producing districts of Colombia and how the stones are recovered. Violence has been especially severe from the 1960s and the area is still unsafe. A useful bibliography includes a good deal of unpublished material. M.O'D.

(Pearl Science.) [In Chinese]

XIE YUKAN, 1995. South China Sea Institute of Oceanology, Guangzhou, P.R. China. pp 313, 11 colour plates, hardcover, Price on application. ISBN 7 5027 4090 2.

A serious and comprehensive study of pearl and pearl fishing with the emphasis on the biology of the various pearl-bearing molluscs, this book will be required reading for Chinese students of the pearl and for marine biologists working in this particular field. The structure of the molluscs is drawn in great detail and here, as elsewhere, the reader longs for a translation into a Western language. Even so, there are useful points to be found and the index is in English – sadly the extensive bibliography remains in Chinese and no doubt conceals many treasures of information! Reproduction is somewhat faint in places but on the whole the book is well produced. M.O'D.

(Jadeite identification pictorial book.) [In Chinese]

ZHENG YONG ZHEN, 1984. Bao Hong Jewellery Company, Taipei, Taiwan. pp 392, illus. in colour, hardcover. ISBN 957 97114 2 9. Price approximately £115.00.

Compared to the earlier work by the same author, this one, though as magnificently illustrated, deals more with the day-to-day identification of all types of jadeite, going as far as to provide the spectra of some of the materials used as fillings. All that the reader could want appears to be here and it is hard not to believe that this author's production will not set the standard for many studies to come. M.O'D.

(Gem jade.) [In Chinese]

ZHENG YONG ZHEN, 1986. Bao Hong Jewellery Co., Taipei, Taiwan. pp 325, illus. in colour, hardcover. ISBN 957 97074 4 8. Price approximately £115.00.

Beautifully illustrated survey of gem-quality jade with an emphasis on jadeite as most current Chinese studies for publication show. The first section describes and illustrates the recovery of jadeite and gives the reader an excellent view of the material in its rough pebble and boulder forms. The following sections describe qualities, testing and treatment, with a sudden appearance right at the end of the book of a number of other gem species in faceted form. For readers who are connoisseurs of jade this is yet another unmissable item for their personal libraries. M.O'D.

Proceedings of the Gemmological Association and Gem Testing Laboratory of Great Britain and Notices

PHOTOGRAPHIC COMPETITION

The 1999 Photographic Competition on the theme 'Gems of the Century' produced a fascinating selection of photographs illustrating gems that were considered of special significance in the twentieth century.

First Prize

Roy Huddlestone, London

Etched cave diamondscape (see front cover)

Second prize

Bob Maurer, FGA, DGA, London

Detail from a large specimen of labradorite

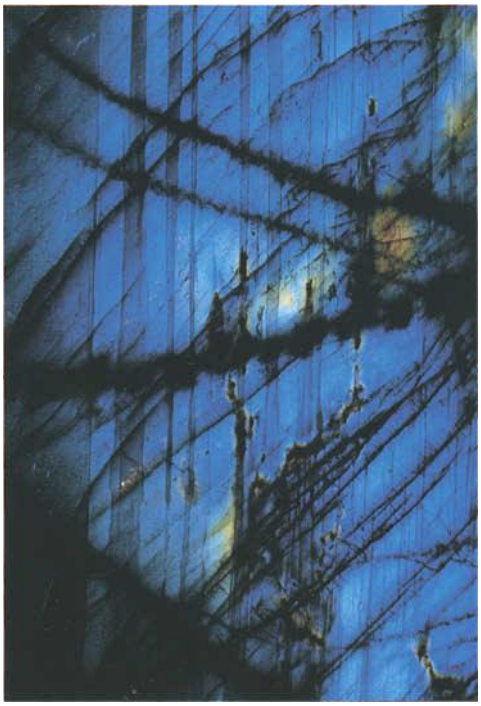

Third Prize

Spencer J.A. Currie, FGA, Auckland, NZ

Leaf opal

We are pleased to announce that the prizes were sponsored by Quadrant Offset Ltd, and the GAGTL is most grateful to them for their generosity. The prizes were presented and the winning entries exhibited at the Reunion of Members held on 28 June.

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AWARDS

The Council of Management has recently made the following awards:

Professor Dr. H. Bank of Idar-Oberstein, Germany, has been awarded Honorary Life Membership of the Association in recognition of his services to gemmology on the international scene, and particularly for his support for education both at the GAGTL and in Europe.

Professor Chen Zhonghui of Wuhan, P.R. China, has been awarded an Honorary Fellowship of the Association for his extensive and devoted services to the establishment and development of modern gemmology in China.

NEWS OF FELLOWS

Congratulations to David J. Callaghan, Kenton, on his recent election as President of the National Association of Goldsmiths.

MEMBERS' MEETINGS

London

On 6 May 1999 at the Gem Tutorial Centre, 27 Greville Street, London EC1N 8TN, Dr W. W. Hanneman gave a lecture entitled *A guide to affordable gemmology.*

On 14 May at the Gem Tutorial Centre, Cecilia Pople gave an illustrated talk entitled *Shining examples – the teaching potential of a gemmologist's jewel box.*

The Annual General Meeting was held on Monday 28 June, followed by the Reunion of Members and a Bring-and-Buy Sale. A full report will appear in the October issue of the *Journal.*

Midlands Branch

On 30 April 1999 at the Earth Sciences Building, University of Birmingham, Edgbaston, the Annual General Meeting was held at which David Larcher, Gwyn Green, Elizabeth Gosling and Stephen Alabaster were re-elected as President, Chairman, Hon. Secretary and Hon. Treasurer respectively. The AGM was followed by an ID Challenge.

On 23 May at Barnt Green, Peggy Hayden led a Gem Club session on jet.

On 26 June a Summer Supper was held at Barnt Green.

North West Branch

On 19 May 1999 at Church House, Hanover Street, Liverpool 1, Rosamond Clayton gave a talk on *Pearls – romance and fact.*

Scottish Branch

The Annual General Meeting and Conference of the Scottish Branch was held at Perth from 30 April to 2 May. At the AGM, Alan Hodgkinson, Brian Jackson, Catriona McInnes and Gillian O'Brien were re-elected as President, Chairman, Secretary and Treasurer respectively. A report of the Conference was published in the June issue of *Gem and Jewellery News.*

ANNUAL REPORT

The following is the report of the Council of Management of the Gemmological Association and Gem Testing Laboratory of Great Britain for 1998.

The Gemmological Association and Gem Testing Laboratory of Great Britain (GAGTL) is a company limited by guarantee and is governed by the Council of Management. The President, Professor R.A. Howie, was re-elected at the Annual General Meeting in June, and the Vice-Presidents, E. Bruton, A.E. Farn, D.G. Kent and R.K. Mitchell, continued in office. M.J. O'Donoghue joined the Council of Management in September. The company also benefits from the contributions of the Trade Liaison Committee, the Board of Examiners and the Members' Council. Dr G. Harrison Jones continued as Chairman of the Board of Examiners, and J. Greatwood was appointed to strengthen the gemmology examination team.

At the AGM in June, S.A. Everitt, A.G. Good and P.J. Wates were elected to the Members' Council, which continued to be chaired by C. Winter. The Chairman and Vice-Chairman of the Trade Liaison Committee were T.M.J. Davidson and J. Monnickendam respectively.

We were greatly saddened by the death of Howard Vaughan of De Beers, who had been a major contributor to the Trade Liaison Committee and was a very sincere friend to the GAGTL in so many ways. The committee welcomed the continued attendance of D.J. Callaghan in his role as a Jewellery Consultant.

At the Gem Tutorial Centre in Greville Street, the Gemmology and Diamond courses have been well subscribed with a good mix of students

GIFTS TO THE ASSOCIATION

The Association is most grateful to the following for their gifts for research and teaching purposes:

Gerhard Becker, Idar-Oberstein, Germany, for rough specimens of benitoite, rhodolite, axinite, scapolite, amblygonite, phenakite, demantoid garnet, sphene and red tourmaline from Nigeria.

Daniel Dower, London, for a selection of specimens including natural and artificial lapis lazuli, elephant ivory, marble, rough and fashioned chalcedony, and a large bag of amber pieces.

Sonja I. Glaser N.V.K., Galle, Sri Lanka, for packets of various materials including hessonite and colour-change garnet, opal, cultured pearl, coral and turquoise.

Beverly Mitchell of the Signet Group plc, London, for 40 bags of fashioned gem materials including chalcedony, quartz, opal, garnet, moonstone, sapphire, emerald, ruby and zircon.

Susanna van Rose, B.Sc., Northwood, Middlesex, for olivine nodules from Raumer Kulm.

Dr N. P. Wijayananda of the Geological Survey and Mines Bureau, Colombo, Sri Lanka, for a Geological Map of Central and Western Sri Lanka together with *Geology in South Asia II*.

coming from both inside and outside the gem trade. The number of Allied Teaching Centres (ATCs) continues to grow with new additions in Montreal, Canada, and the Caribbean, and the commencement of the Gem Diamond course at Tongji University, Shanghai.

There has been continued investment in developing aspects of the Preliminary and Diploma Gemmology courses and plans are well in hand to update the Gem Diamond Diploma course. The new stone library service launched in September for UK-based home study students working towards their Gemmology Diploma has proved very popular. Enhanced visual aids for tutors and students are also being developed with a new system for scanning and archiving photographs and illustrations for CDs. More visual aids are also being produced for the GAGTL website, which is now receiving an average of 20,000 visits per week.

A wide range of short courses and tutorials were offered in 1998 and in addition to the regular programmes in Greville Street, tutorials were presented in Norway, Finland and in Washington DC, USA. We extend our very sincere thanks to the many people who have kindly made donations to the stone and mineral library; these items are crucial to providing a comprehensive service to our students.

In 1998 the Tully Medal and the Anderson-Bank Prize were awarded to Laurent Kellerson of London. The Diploma Trade Prize was awarded to Tina Notaro of Madison, Wisconsin, USA. The Anderson Medal for the best candidate of the year in the Preliminary Examination went to Long Chu of Guilin, P R of China, and the Preliminary Trade Prize was awarded to Linda Rythen of Stockholm, Sweden. As no student excelled in the year's Diamond Examination the Bruton Medal was not awarded.

Once again the Presentation of Awards was held in Goldsmiths' Hall. The guest of honour was Mr R. Buchanan-Dunlop, CBE, Clerk of the Worshipful Company of Goldsmiths, who presented the diplomas and prizes to the successful students.

In January 1998 the Gemmological Association hosted the second General Assembly of the Federation of European Education in Gemmology (FEEG), attended by representatives of gemmological schools from six European countries. The FEEG examinations were again held in London.

The annual Spring tour to Idar Oberstein, Germany, was very successful and later in the year there were field visits to Whitby and Edinburgh in search of jet and agates. In addition a trip was arranged to visit the diamond workshops in Antwerp.

The Laboratory continued to issue both London and CIBJO diamond reports, origin of colour reports for coloured diamonds, identification and treatment reports for coloured stones and pearl reports. One interesting 14.02 ct pale-yellow stone proved to be a new gem variety; after a joint investigation with the Natural History Museum, it was identified as the rare borate mineral, johachidolite.

FORTHCOMING EVENTS

5 August	**Scottish Branch.** An apatite for faceting. Art Grant
15 September	**North West Branch.** Photographing gems and their inclusions. John Harris
26 September	**Midlands Branch.** Play group – a practical gemmology session
20 October	**North West Branch.** Window to beauty. Piero Di Bela

Annual Conference

New Developments in the Gem World

Sunday 31 October 1999 – Barbican Centre, London

Keynote speaker: James Shigley
Director of Research at the GIA, Carlsbad
The challenges of gem identification at the close of the twentieth century

Campbell Bridges, Nairobi, Kenya
New African gemstones and their acceptance in the market place

Jack Ogden – Secretary General of CIBJO and
Chief Executive of the National Association of Goldsmiths
Colourful language or a treatment in store: retailing in a gem minefield

Forum

Delegates will have the opportunity explore the views of the speakers on the impact of new gems, new treatments and new synthetics on the producers, manufacturers and retailers in the gem trade.

Full details and application forms available from the GAGTL on 020 7404 3334

1 November	Visits to the School of Geological Sciences, Kingston University, and to De Beers
17 November	North West Branch. Annual General Meeting

For further information on the above events contact:

London:	Mary Burland on 020 7404 3334
Midlands Branch:	Gwyn Green on 0121 445 5359
North West Branch:	Deanna Brady on 0151 648 4266
Scottish Branch:	Catriona McInnes on 0131 667 2199

GAGTL WEB SITE

For up-to-the-minute information on GAGTL events visit our web site on www.gagtl.ac.uk/gagtl

The annual trade function organized by the GAGTL in 1998 was a formal dinner held at the Café Royal, London, where members and guests were addressed by Geoffrey Munn, the Managing Director of Wartski.

The GAGTL was represented at the annual CIBJO conference in Vicenza, Italy, and members of staff have taken an active part in the CIBJO working group which is revising the rules and nomenclature in the gemstone *Blue Book*. The

GEM TUTORIAL CENTRE

27 Greville Street (Saffron Hill entrance), London EC1N 8TN

15 September — **Preliminary Workshop**
A day of practical tuition for anyone who needs a start with instruments, stones and crystals. Learn to use the 10x lens at maximum efficiency and observe the effects and results from the main gem testing instruments.
Price £44 + VAT (£51.70) – includes a sandwich lunch
GAGTL student price £32 + VAT (£37.60)

6 October — **Pearls Today**
The pearl industry has seen enormous changes this century. This one-day course will give you the opportunity to handle a variety of natural, cultured and imitation pearls found in the marketplace today. Ann Margollis will explain the commercial aspects of the pearl industry; laboratory techniques for pearl identification will also be discussed.
Price £80 + VAT (£94.00) – includes a sandwich lunch

20 October — **Diamonds Today**
A valuable and concentrated look at all aspects of diamonds: rough and cut stones, treated (laser drilled and filled), synthetic and imitation materials.
Price £104 + VAT (£122.20) – includes a sandwich lunch

26 and 27 October — **Synthetics and Enhancements Today**
Are *you* aware of the various treated and synthetic materials that are likely to be masquerading amongst the stones you are buying and selling? Whether you are valuing, repairing or dealing, can you afford to miss these two days of investigation?
Price £198 + VAT (£232.65) – includes sandwich lunches

2 November — **The "Ins and Outs" of Amber**
A rare opportunity to immerse yourself in the fascinating world of amber. Join Andrew Ross of the Natural History Museum and Maggie Campbell-Pedersen in a day devoted to looking at a variety of natural, treated and imitation materials and study the huge variety of flora and fauna inclusions found in amber.
Price £104 + VAT (£122.20) – includes a sandwich lunch

For further details contact the GAGTL Education Department
Tel: +44 020 7404 3334 — e-mail: gagtl@btinternet.com
Fax: +44 020 7404 8843 — web: www.gagtl.ac.uk/gagtl

GAGTL had a major presence in the Gemstone Forum area of the International Jewellery Fair at Earls Court in September. The daily GAGTL seminars at the Fair on current issues in the gem trade attracted good audiences.

Ian Mercer visited Taiwan in March 1998 to meet ATC personnel and further the cause of gemmology, and also to set up a new examination centre.

The GAGTL took a stand at the Las Vegas Jewellery Fair in June for the second year running, where Alan Clark and Doug Garrod successfully promoted Gemmological Instruments Ltd and Educational Services. At the Hong Kong Fair in September, Michael O'Donoghue, Brenda Hunt and Lorne Stather promoted the services of the GAGTL. Michael O'Donoghue and Brenda Hunt repeated this promotion later in Shanghai.

At home, the branches in Birmingham, the North West and Scotland, continued with a wide variety of lectures, seminars, updates on courses and field trips, to interest a broad range of members. One of the subjects well covered in 1998 was the new synthetic moissanite and included lectures by Dr Kurt Nassau in London and Edinburgh. Other topics in the London lecture series included an

account of gems from India (Mrs S. Fernandes), contemporary gem art in America (Kreg Scully), the early history of enamel (Dr J. Ogden), Chinese snuff bottles (Clare Lawrence), pearls (Christianne Douglas) and Georgian and Victorian jewellery (John Benjamin).

The theme of the 1998 Photographic Competition was *Gems in Fashion*, the winner being Bob Maurer of London. We are most grateful to Quadrant Offset Ltd, who design and print both the calendar and the *Journal of Gemmology*, for sponsoring the prizes. A selection of the entries was made to grace the 1999 calendar, which is circulated free of charge to all members.

The Annual Conference was again held at the Barbican Centre in London, the theme being *Gems in Jewellery*. The speakers were Derek Palmer (De Beers), John Carter (Cellini, Cambridge), Stephen Kennedy (GAGTL Laboratory), Michael Smookler (Vice-President of the London Diamond Bourse and Club) and Chris Welbourn (De Beers Research Department, Maidenhead). A forum chaired by Harry Levy and made up of Ana Castro, Rosamond Clayton, David Davis and Adrian Klein completed the day. The participants at this conference came from no less than thirteen different countries.

The Journal of Gemmology published 22 papers in 1998, with topics ranging from turquoise in China, and rubies in Australia and Cambodia, to emeralds in Zimbabwe. A total of 135 abstracts and 22 book reviews were also included and the Council express their sincere thanks to the Assistant and Associate Editors for all their expert help, comment and advice during the year.

Gem and Jewellery News published jointly with the Society of Jewellery Historians, again contained a wide range of stimulating comment on such issues as synthetic moissanite, radioactive gems, the new exhibition at the Natural History Museum and a recent judgement about an alleged alexandrite.

Gemmological Instruments Ltd is a wholly owned subsidiary of the GAGTL. An additional member of staff was recruited during the year to help consolidate and develop activities so that the range of goods and services may be improved to meet the current demand. The new Megger Tester to identify synthetic moissanite was introduced in 1998 and an improved version of the recently developed Brewster Angle Meter will be available for sale in 1999.

The overall financial picture for the GAGTL in 1998 was not exciting and resulted in a small deficit, mainly due to the financial crisis in several Far Eastern countries where we have been particularly active in recent years. Whilst the turnover in Gemmological Instruments Ltd was down on the previous year for the same reason, the final result was a small profit. The Council of Management has every confidence that the organization is in a strong position to take advantage of any opportunities that arise as the financial position improves globally.

The Council of Management extends their thanks to all the staff for the effort and dedication they have contributed during the year. Also, a special thank you is due to the committees and individual members for their contributions, especially of time, and the many companies and individuals who have generously donated gems and other gemmological items that have been much appreciated and put to very good use.

MEETINGS OF THE COUNCIL OF MANAGEMENT

At a meeting of the Council of Management held at 27 Greville Street, London EC1N 8TN, on 21 April 1999, the business transacted included the election of the following:

Fellowship (FGA)

Aho, Jouko, Oulu, Finland. 1999
Blampied, Julie K., St Helier, Jersey, CI. 1999
Chang Kung Jung, Taipei, Taiwan, R.O.China. 1999
Chen Shu-Chuan, Kaohsiung, Taiwan, R.O.China. 1999
Deljanin, Branko, New York, NY, U.S.A. 1999
Edery, Gabrielle J., Hither Green, London. 1999
Goynshor, Frederick Jay, Northbrook, Ill., U.S.A. 1974
Hsu Feng, Taipei, Taiwan, R.O. China. 1999
Koh Hock Heng, Singapore. 1999
Mafara, Ezekiel M., Harare, Zimbabwe. 1999
Oshida, Reiko, Singapore. 1999
Tanaka, Rika, Beijing, P.R. China. 1999
Yoon Sung Hae Kwon, Yangon, Myanmar. 1999

Diamond Membership (DGA)

Cheung Shiu Cheong, Randy, Kowloon, Hong Kong. 1999
Chik Wing Sheung, Hong Kong. 1999
Mak Kin Yeung, Kenny, Fanling, N.T., Hong Kong. 1999

Ordinary Membership

Gregory, Pauline A., Westgate-in-Weardale, Co. Durham
Jacobs, Stephan-Andreas, Trier, Germany
Lai Chih-Liang, Taipei, Taiwan, R.O. China

San-San Chen, Taipei, Taiwan, R.O. China
Travlos, Gary, Ely, Cambridgeshire
Wills, Elle, London
Young, Margaret R., Bearsden, Glasgow

Transfers

Diamond Membership to Fellowship and Diamond Membership (FGA DGA)

Garrett, Frances S.J., Sutton, Surrey. 1999

Ordinary Membership to Fellowship (FGA)

Grech, Carrieann, London, 1999
Panagiotis, Panagiotou, Corfu, Greece. 1999

At a meeting of the Council of Management held at 27 Greville Street, London EC1N 8TN, on 19 May 1999, it was unanimously agreed that Professor Chen Zhonghui of Wuhan, P.R. China, should be awarded an Honorary Fellowship in recognition of his services to the development of gemmology in the People's Republic of China. It was also agreed that Professor Dr Hermann Bank of Idar-Oberstein, Germany, be awarded an Honorary Life Membership in recognition of his services to gemmology on the international scene, and particularly for his support for education at GAGTL and in Europe.

The business transacted included the election of the following:

Diamond Membership (DGA)

Ng Kwok Wai, N.T., Hong Kong. 1999
Poon Mei Han, Maggie, Hong Kong. 1999

Fellowship (FGA)

Amarasinghe, Ashan S., Rajagiriya, Sri Lanka. 1999
Banks, Michelle, Leicester. 1998
Chan So Ying, Hong Kong. 1999
Ho Cheuk Fung, Hong Kong. 1998
Ip Kit Ling, Kowloon, Hong Kong. 1999
Kwok Siu Chung, Central, Hong Kong. 1983
Ning Lu, Shanghai, P.R. China. 1999
Pang Chi Keung, Maurice, Hong Kong. 1999
Pavlou, Marios G., Larnaca, Cyprus. 1999
Schmocker, Karin, Brooklyn, NY, USA. 1999
Stąhl, Elone, Malmo. Sweden. 1993
Tang Suk Yee, Hong Kong. 1999

Ordinary Membership

Chitondo, Martin C., London
Crowhurst, Michael M., Ramsgate, Kent
Edge, Donald, London
Goracci, Giulia, London
Gordon, Carole, Kew, Richmond, Surrey
Halvorsen, Asbj¯rn, Son, Norway
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CORRIGENDUM

In *The Journal of Gemmology*, 1999, **26**(6), p. 409, first column, the following name should have been added to the list of those who qualified in the Preliminary Examination in Gemmology held in January 1999: Bastos, Ana Pestana, Lisbon, Portugal.

The Editor apologizes for the omission.

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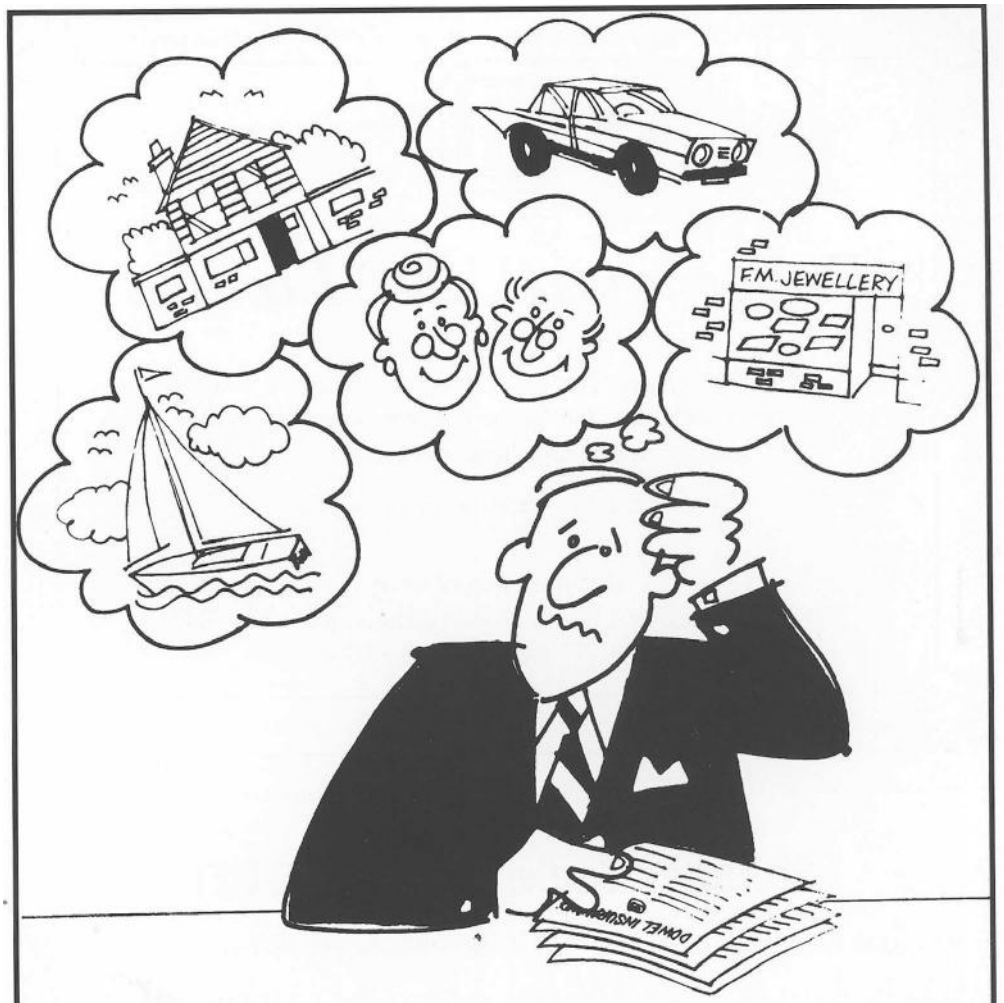

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Gems of the Century
Etched cave diamondscape. Photograph by Roy Huddlestone. (First Prize in Photographic Competition, see p.470)

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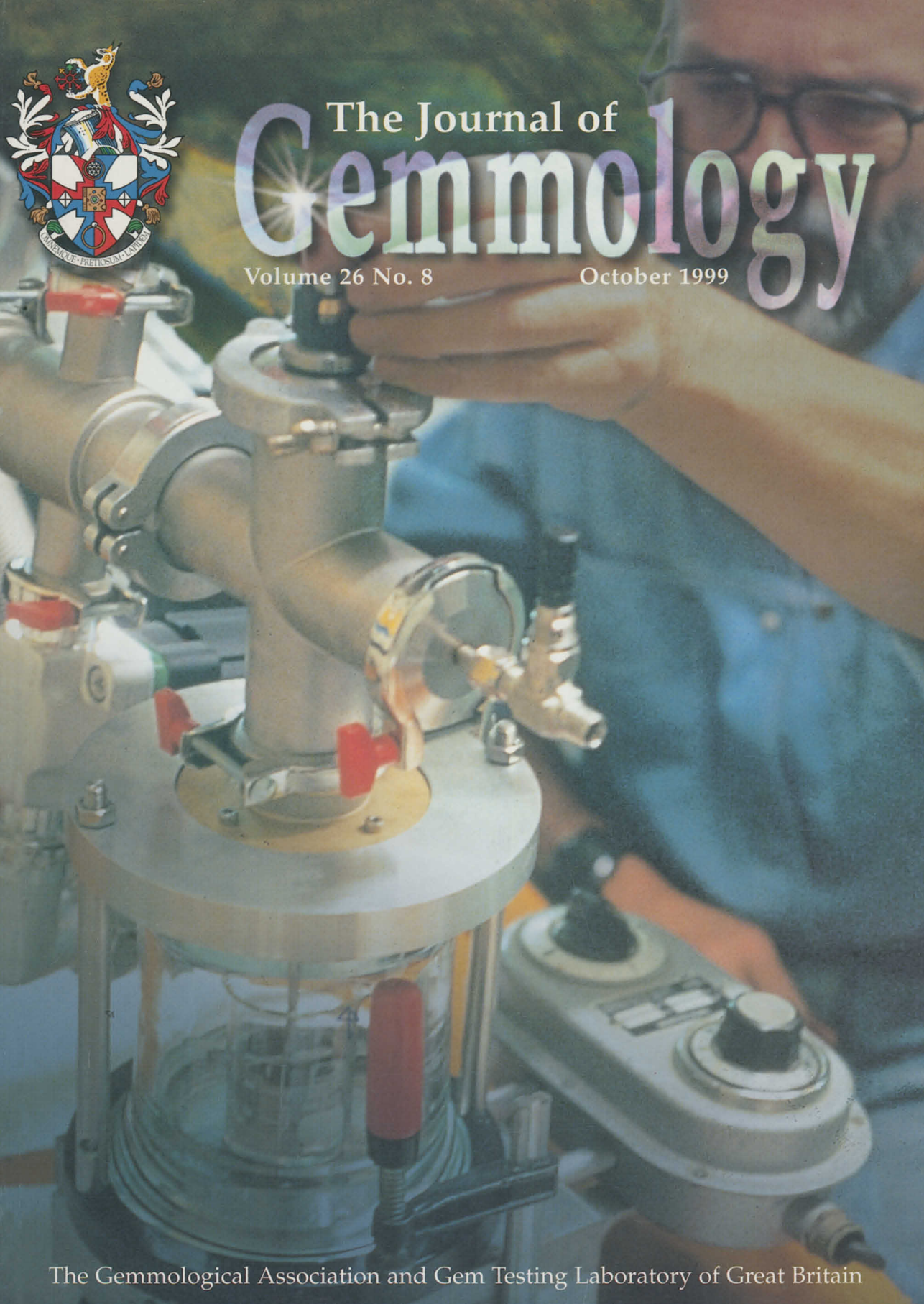

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Synthetic red beryl from Russia

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ABSTRACT: The present study is a result of an examination of synthetic red beryls recently produced in Russia. The standard gemmological properties correspond to the known range for synthetic beryls of Russian production. Chemical analyses showed distinct cobalt contents in addition to iron and manganese. Divalent cobalt dominates the absorption spectra and is responsible for the red colour. The low Na_2O concentrations are typical for synthetic beryls produced hydrothermally. An overall low alkali content can also be concluded from the IR spectra which showed a predominance of H_2O-type I, i.e. water molecules not bound to alkali ions. Inhomogeneous growth structure formed a typical inclusion pattern.

Keywords: synthetic red beryl, hydrothermal growth, Russian production, physico-chemical properties, internal characteristics

Introduction

Commercial quantities of synthetic emeralds have been available since the 1930s and it was in the 1960s when large amounts of that material entered the trade. Although it is well known that in Japan and particularly in Russia various other synthetic beryl varieties had been produced, these specimens did not gain commercial importance, firstly because natural beryls are present in quite large amounts and in very good qualities, and secondly, except for synthetic emeralds, the price differences between synthetic beryls and their natural counterparts is too low.

During the development of the growth of synthetic emeralds a number of colouring agents have been used for research purposes which have resulted in a number of synthetic beryl varieties.

Emel'yanova *et al.* (1965) first mentioned synthetic beryls which were doped with vanadium, manganese, cobalt and nickel. A few samples of synthetic pink beryls were first observed in the trade in 1981 (Bank & Becker, 1981). In the same year Dillon (1981) mentioned synthetic pink to reddish beryls produced by Regency Created Emeralds Co. in the USA. Since 1979 various synthetic beryls including green, reddish, pale blue, pink and violet varieties have been produced in Japan by Adachi New Industrial Ltd. of Osaka (Chikayama and Miyata, 1987; Scarratt, 1987; Chikayama, 1992) which are known under the trade name 'ANICS'. These specimens have been produced by chemical vapour deposition, i.e. crystallization from a vapour phase. As a speciality this Japanese company also produced bicoloured, 'watermelon' type synthetic beryls which consist of a synthetic pinkish beryl core and a synthetic emerald overgrowth (Koivula and Misiorowski, 1986).

Both Solntsev *et al.* (1978) and Ilyin *et al.* (1980) reported on synthetic beryl varieties

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Table I: Gemmological properties of synthetic beryl

Synthetic beryl source and colour	Refractive index n_e	n_o	Δn	Specific gravity	Fluorescence UVL (long wave)	UVS (short wave)
ANICS (Japan)						
reddish	1.563	1.566	0.003	2.66	weak red-violet	dull red
violet	1.563	1.567	0.004	2.65	red-violet	strong violet
pale blue	1.566	1.571	0.005	2.67	milky green-blue	violet
'watermelon'	1.562	1.566	0.004	2.64	core: red rim: violet	core: inert rim: violet
Biron (Australia)						
pinkish	1.571	1.578	0.007	2.69	orange-pink	
Novosibirsk (Russia)						
pinkish	1.570	1.576	0.006	2.67	weak violet	
orangy-red	1.574	1.580	0.006	2.69		
blue (Cu)	1.570	1.576	0.006	2.69	violet	
blue (Fe)	1.571	1.579	0.008	2.68		
	1.575	1.583	0.008	2.69*		
green (V)	1.570	1.578	0.008	2.69		
Russia, this study						
red	1.570–72	1.578–80	0.008	2.63–65	inert	inert

* data after Schmetzer (1989). All other data obtained by the authors.

including cobalt-bearing synthetic red beryls manufactured in Novosibirsk, Russia. Various facetable synthetic beryls produced in Russia were mentioned by Koivula and Kammerling (1988) and include purple (coloured by chromium and manganese), pinkish (manganese), blue (copper) and orangy-red (cobalt) varieties. The production technique is analogous to that used to grow hydrothermal synthetic emeralds in Novosibirsk. However, the resulting crystals were only a few centimetres long and relatively flat so that only small stones could be cut. The synthetic crystals weighed between 11 and 25 ct. In contrast the same producer grew synthetic emeralds that weighed on average between 50 and 100 ct, sometimes even more. Blue synthetic aquamarines from Russia coloured by iron like the natural specimens were described by Schmetzer (1990). In addition, other synthetic beryl varieties of Russian production were briefly mentioned by Koivula and Kammerling (1991) and Koivula *et al.* (1992).

Pinkish synthetic beryls are also produced in Australia by Biron International Ltd., which are well known as a major producer of hydrothermally grown synthetic emeralds. The synthetic rough is coloured by trivalent titanium and allows the faceting of stones with a weight up to 20 ct (Brown, 1993). Overall, the occurrence of faceted non-green synthetic beryls is rare.

Recently, the German Gemmological Association received from one of its fellows both rough and cut synthetic red beryls which were produced in Russia. The faceted round stones measure 6.5 x 5 mm and weigh between 0.98 and 1.08 ct (*Figure 1*). The colour is reminiscent of the natural red beryls from Utah, USA (see Henn and Becker, 1995).

The physico-chemical properties and the microscopic characteristics of the samples investigated are given below.

Standard gemmological properties

The refractive indices, maximum birefringences and specific gravity are given in *Table I* and the measured values were: $n_e = 1.570 - 1.572$, $n_o = 1.578 - 1.580$ with $\Delta_n = 0.008$ and SG = 2.63 – 2.65. Except for SG, these data are within the known range for hydrothermally grown synthetic beryls from Russia which are also shown in *Table I* for comparison, along with data obtained on a number of synthetic beryls produced in Japan and Australia. The recent red beryls show strong pleochroism with cinnamon-brown and violet colours and they are inert to both long- and short-wave UV radiation.

Figure 1: *Two faceted synthetic red beryls produced in Russia each weighing approximately 1 ct.*

Spectroscopic analysis

The UV/VIS absorption spectrum is plotted in *Figure 2*, and the absorption maxima and their assignments are given in *Table II*. The spectrum of the ordinary ray (o) is characterized by absorption maxima in the green and blue and that of the extraordinary ray (e) by absorption in the yellow-green and blue. The broad absorption in the green and yellow-green part of the polarized spectra is responsible for the red colour of the samples.

Figure 2: *Polarized absorption spectra of a representative sample of synthetic red beryl of Russian production.*

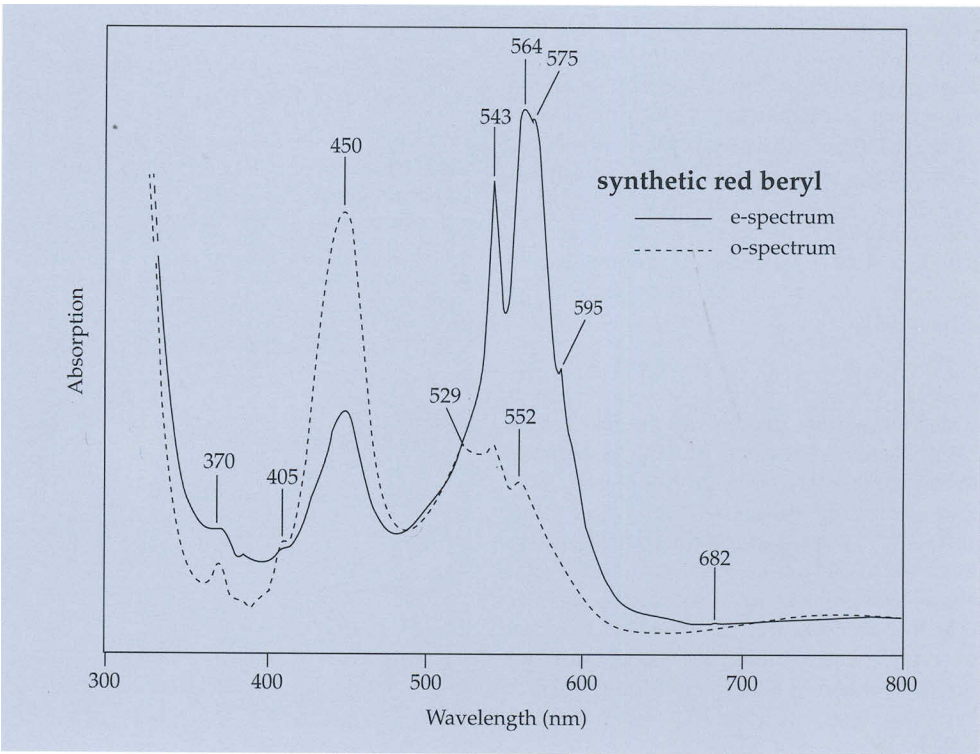

Table II: UV/VIS absorption maxima and assignments

Absorption maxima (nm)	(cm^{-1})	Assignment	Polarization o = ordinary ray e = extraordinary ray
370	27000	Fe^{3+}	e < o
405	24700	Fe^{3+}	e ≈ o
450	22200	Co^{2+}, Co^{3+}	e < o
529	18900	Co^{2+}	o
543	18400	Co^{2+}	e > o
552	18100	Co^{2+}	o
564	17700	Co^{2+}	e
575	17400	Co^{2+}	e
595	16800	Co^{2+}	e
682	14600	Cr^{3+}	e

In both cases this absorption is a combination of several maxima. In the o-spectrum the maxima occur at 552, 543 and 529 nm and are caused by Co^{2+} (Solntsev *et al.*, 1978; Ilyin *et al.*, 1980; Platonov, pers. comm., 1999). This trace element also produces the absorption maxima at 595, 575, 564 and 543 nm in the e-spectrum. The non-pleochroic broad absorption in the blue with a maximum at 450 nm is also attributed to Co^{2+} and possibly Co^{3+} (Platonov, pers. comm., 1999). Two additional absorption maxima at 370 and 405 nm in the ultraviolet and violet part of the spectrum are caused by trivalent iron. A weak chromium (Cr^{3+}) absorption line at 682 nm is visible in the e-spectrum.

The IR spectrum is consistent with the general pattern found in low alkali hydrothermally grown synthetic beryls (Schmetzer and Kiefert, 1990). The samples tested showed H_2O-vibrations between 3500 and 4000 cm^{-1} and between 5000 and 5600 cm^{-1}. The most distinct maxima are those at 3694 and 3592 cm^{-1}, with the absorption band at 3694 cm^{-1} being stronger than that at 3592 cm^{-1}. The former is assigned to type-I water molecules which are not bound to adjacent alkali ions and the weaker band is caused by type-II water molecules which are bound to alkali ions.

Chemical analysis

The chemical composition of a representative sample was obtained by electron microprobe analysis and is given in *Table III*. Aluminium and silicon oxides form the major components. Beryllium oxide cannot be measured with the electron microprobe. The analyses revealed iron, cobalt and manganese as the most significant trace constituents and this is consistent with conclusions drawn from the absorption spectra. The low Na_2O-content of 0.06 wt.% and even lower K_2O content confirm the conclusion drawn from the IR-spectrum that the synthetic red beryl is a low alkali type.

Microscopic features

Under an immersion microscope the faceted samples showed a step-like growth structure. A distinct inhomogeneous growth in the form of irregularly changing subgrain boundaries is visible almost perpendicular to the step-like growth (*Figures 3 to 5*). These growth characteristics are also typically found in Russian hydrothermally grown synthetic emeralds (cf. Henn *et al.*, 1988; Schmetzer, 1988). Planar and veil-like feathers consisting of liquid and two-phase inclusions form

Table III: Electron microprobe analysis of a Russian synthetic red beryl

wt.%	Range (7 analyses)	mean
SiO_2	65.55–66.77	66.08
TiO_2	0.03–0.08	0.05
Al_2O_3	16.75–17.38	16.96
Cr_2O_3	0.00–0.03	0.02
FeO	1.45–1.73	1.62
MnO	0.15–0.21	0.18
CoO	0.17–0.47	0.31
MgO	0.02–0.05	0.03
Na_2O	0.00–0.14	0.06
K_2O	0.00–0.03	0.01
Total		85.32

NB: BeO and H_2O not determined

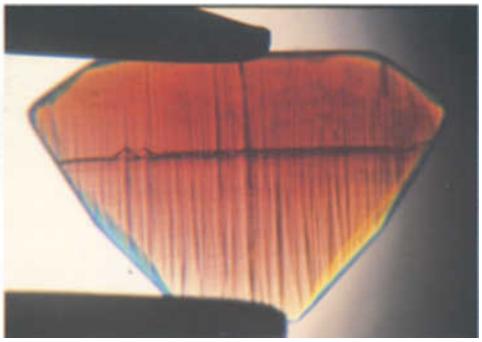

Figure 3: Faceted synthetic red beryl. Step-like growth structure parallel to the table and inhomogeneous growth almost perpendicular to the table. Immersion, magnified 6x.

inclusion patterns also typical of such emeralds, and black platelets (*Figure 6*) may well be hematite (cf. Schmetzer, 1990).

Conclusions

The standard gemmological properties and the microscopic characteristics of synthetic red beryls of recent Russian production correspond to the known properties for hydrothermally grown synthetic beryls manufactured in Russia. The absorption spectra of the synthetic red beryl showed that the colour is caused by divalent cobalt. Based on the IR-spectra the samples can be classified as hydrothermally grown low alkali-type synthetic beryls. The spectroscopic characteristics are confirmed by chemical analyses which show significant amounts of cobalt and manganese oxides and low sodium concentrations.

As with synthetic emeralds hydrothermally grown in Russia, inhomogeneous growth patterns in synthetic red beryls are diagnostic in distinguishing them from natural red beryls.

Figure 4: Subgrain boundaries, variably oriented in detail, almost perpendicular to the step-like growth structure. Immersion, magnified 30x.

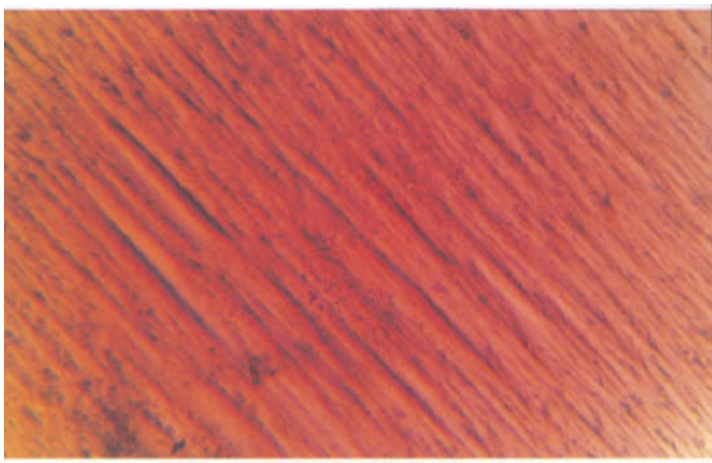

Figure 5: A distinct inhomogeneous growth in the form of irregularly oriented subgrain boundaries is one of the most diagnostic identification features of Russian synthetic red beryls. Immersion, magnified 40x.

Figure 6: Feathers with liquid and two-phase inclusions and hexagonal black platelets also form a typical inclusion pattern. Immersion, magnified 30x.

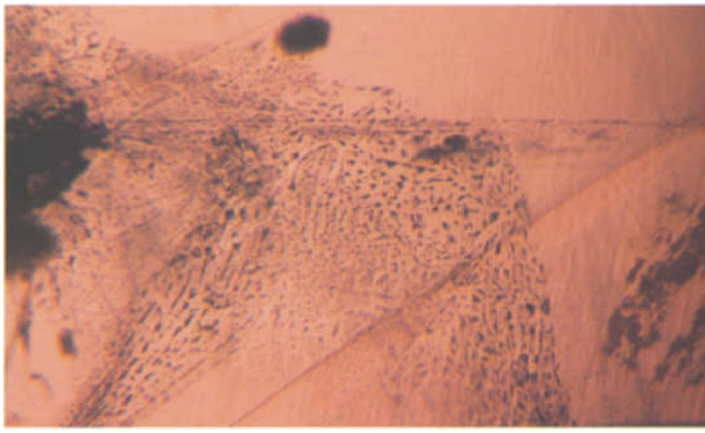

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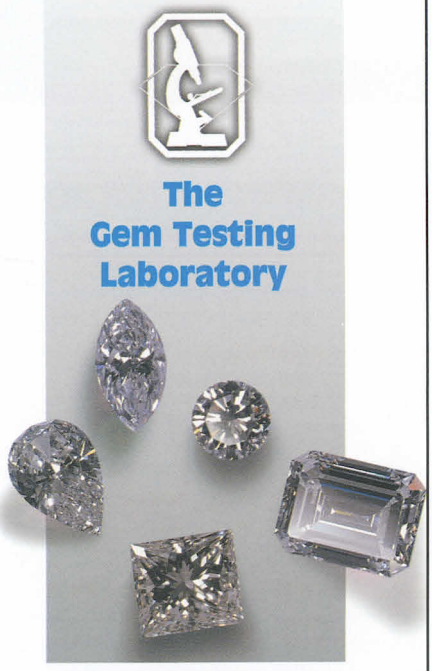

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Multicomponent inclusions in Nacken synthetic emeralds

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ABSTRACT: Multicomponent inclusions in Nacken synthetic emeralds were examined by a combination of microscopy, electron microprobe analysis and micro-Raman spectroscopy. The tiny crystals at the widest ends of nailhead spicules are most probably beryl. Various forms of cavities contain single component and multicomponent fillings, which were determined as a solidified melt consisting of the ingredients of beryl and residues of a molybdenum- and vanadium-bearing flux. The residual slightly inhomogeneous melt trapped in elongated cavities is partly unmixed and contains polymerized and non-polymerized molybdates as well as Si–O–Si networks and isolated SiO_4 tetrahedra. Similar inclusions in Chatham synthetic emeralds are also characterized.

Keywords: Chatham, crystal growth, electron microprobe analyses, multi-component inclusions, Nacken, nailhead spicules, Raman spectra, synthetic emerald

Introduction

Nacken synthetic emeralds were grown in the 1920s by Professor R. Nacken of Frankfurt, Germany, and were regarded as hydrothermally grown synthetic emeralds for almost half a century (Van Praagh, 1946, 1947; Webster, 1955, 1958; Eppler, 1958; Espig, 1962; Landais, 1971; see also Schmetzer and Kiefert, 1998). This view was also confirmed by the examination with modern analytical techniques such as infrared spectroscopy which revealed the presence of characteristic water absorption bands of hydrothermally-grown synthetic emeralds (Landais, 1971). A detailed study by Nassau (1976, 1978, 1980), however, showed that two different types of Nacken synthetic emeralds were grown, both by the flux method. The first type of crystal contained irregularly shaped seeds of natural, colourless beryl, and the second type was grown without natural seeds.

The examination of both types of Nacken synthetic emerald by Nassau (1976, 1978, 1980) revealed the presence of water absorption bands in the spectra of the first type samples, which are caused by the water content of the natural beryl seed. In contrast, infrared spectra of samples of the second type of Nacken synthetic emeralds showed an absorption spectrum without any water related absorption bands, which is typical for flux-grown synthetic emeralds. These results are also useful to understand the earlier examinations by Landais (1971) using infrared spectroscopy, who, most probably, investigated samples of the first type with a natural beryl seed (Landais, 1998).

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Chemical investigations by Nassau (1978, 1980) proved that the flux used by Nacken was a molybdenum- and vanadium-bearing compound, most probably a lithium-containing oxide of a general formula MoO_3–V_2O_5–Li_2O, whose exact composition is still unknown. The X-ray fluorescence spectrum of characteristic inclusions was examined in the scanning electron microscope (SEM-EDXRF). With this technique, however, the presence of light elements such as lithium and beryllium cannot be determined. The experimental conditions applied by Nassau (1978, 1980) allowed the examination of the material trapped within various cavities alone, i.e. the X-ray fluorescence spectra represented only substances trapped in cavities without any contributions of the synthetic emerald host to the X-ray fluorescence patterns obtained (Nassau, 1998).

Two types of patterns were described consisting of the characteristic X-ray lines of (a) an Al–Si–V–Mo-bearing compound and (b) an Al–Si–V–Cr–Mo-bearing compound.

These results indicate that the material trapped within the cavities consists of a mixture of the components of beryl (BeO, Al_2O_3, SiO_2) with different percentages of chromium and of components of the flux (most probably MoO_3, V_2O_5, Li_2O). The material in the cavities was assumed to be in the vitreous state (Nassau, 1978, 1980, 1998).

Occasionally, inclusions that form elongated spicules with a tiny crystal at their widest ends are present in Nacken synthetic emeralds. These tiny crystals were described as phenakite by Nassau (1978), which is not consistent with the description of Eppler (1958), who assumed tiny beryl crystals being present as nailheads in Nacken synthetic emeralds. Both determinations, however, were based on visual appearance only and not on direct analytical measurements.

Tiny crystals at the base of nailhead spicules are common in hydrothermal synthetic emeralds, but may also form in flux-grown synthetic emerald when growth is started on a seed plate inclined at an angle to the *c*-axis (Flanigen *et al.*, 1967). In hydrothermal synthetic emeralds, these tiny crystals at the widest ends of elongated spicules were regarded exclusively as phenakite crystals for a long time. It was proven by micro-Raman spectroscopy, however, that not only phenakite but beryl and chrysoberyl crystals could also be present at the ends of elongated spicules in hydrothermal synthetic emerald from different producers (Schmetzer *et al.*, 1997). Continuing the study of nailhead spicules in synthetic emeralds, the authors have tried to determine experimentally the identity of the nailhead crystals present in these typical inclusions of Nacken synthetic emeralds and

Figure 1a,b: *Nacken synthetic emerald crystals with natural seeds (a) and without natural seeds (b). The largest crystals of both types measure about 5.5 x 4 mm (photos: M. Glas).*

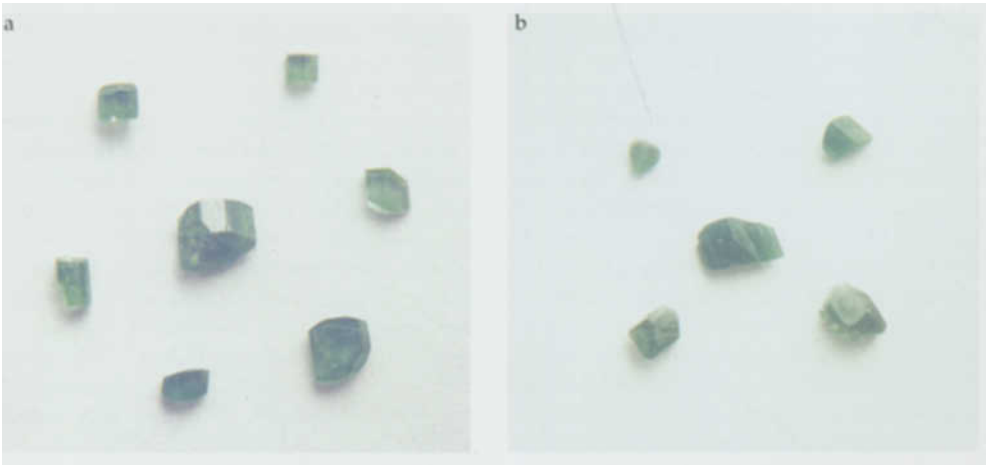

to evaluate the discrepancy between the papers of Eppler (1958) and Nassau (1978). In addition, the identification of various substances present in the cavities of Nacken synthetic emeralds has been attempted.

Materials and methods

The present study is based on the examination of 14 individual samples (*Figures 1a, b*) ranging from 5.5 to 2 mm in size. The synthetic emeralds originated from the following collections: E. Gübelin, Lucerne, Switzerland (5); F.H. Pough, Reno, Nevada, USA (8); M. Schaeffer, Detmold, Germany (1).

For assessing the study of Eppler (1958), Nacken synthetic emeralds of the Gübelin collection have been available. The papers of Nassau (1976, 1978, 1980) were based on samples of the Pough collection and on synthetic emeralds from the British Museum (Natural History), London. The present authors tried to obtain the Nacken synthetic emeralds kept in the British Museum for comparison, but these samples were not made available.

For the examination of chemical properties of the substances trapped in elongated spicules and/or channels parallel to the *c*-axis, one sample without a microscopically visible colourless seed was sawn into two parts along the *c*-axis and subsequently polished down step by step. In some of these steps several elongated cavities were carefully opened and the inclusions exposed to the surface were examined by electron microprobe.

To determine the compositions of nailhead crystals at the widest ends of elongated spicules as well as individual components or phases trapped in different cavities of Nacken synthetic emeralds, numerous inclusions in both types of samples (with and without colourless seeds) were examained by micro-Raman spectroscopy. This technique, which is useful for the determination of inclusions in natural and synthetic emeralds (Schmetzer *et al.*, 1997; Schmetzer and Kiefert, 1998; Zwaan and Burke, 1998), is also a very sensitive tool for determining the substances present in artificially filled fissures of natural emeralds (Hänni *et al.*, 1997). Micro-Raman spectroscopy has been used by Delé-Dubois *et al.* (1986) as well as Delé-Dubois and Poirot (1989) for the determination of residual substances in synthetic emeralds. In these papers, the materials trapped in various cavities of flux-grown synthetic emeralds were determined as polymolybdates and molybdenum oxides.

Figure 2: *Prismatic crystal of Nacken synthetic emerald which contains a colourless, natural irregularly-shaped seed; the c-axis runs vertically, melt filled channels and spicules are oriented parallel to c. Immersion, length of crystal 2 mm.*

Microscopic properties

The microscopic examination confirmed the results of Nassau (1976, 1978, 1980), who classified the 19 synthetic emeralds available for his study into two groups with and without natural seeds.

In our 14 samples, colourless, natural irregularly shaped seeds were observed in eight synthetic emeralds (*Figures 2 and 3*). In two of these crystals, thin, flat cavities oriented on planes parallel to the basal pinacoid were observed (*Figure 3*). These

Figure 3: Prismatic crystal of Nacken synthetic emerald which contains a colourless, natural irregularly shaped seed; the c-axis runs vertically, melt filled channels and spicules are oriented parallel to c, flat cavities with primary liquid and two-phase inclusions are oriented perpendicular to c. Immersion, length of crystal. 3.4 mm.

cavities contain primary liquid and/or two-phase inclusions, which is a typical microscopic feature for natural beryl or natural emerald from certain localities, e.g. Russian Uralian emeralds (see Schmetzer *et al.*, 1991).

In the remaining six of our Nacken samples, no colourless irregularly shaped seeds were observable by microscopic examination. One larger synthetic emerald crystal of this group was examined by infrared spectroscopy, which showed the absence of water-related absorption bands. Again, these results are consistent with the findings described by Nassau (1978, 1980).

All Nacken synthetic emeralds revealed numerous channels or spicules oriented parallel to the *c*-axis (*Figures 2 and 3*), which are more or less opaque in transmitted light (*Figure 4a*). Nailhead spicules, i.e. elongated spicules with tiny crystals at their widest ends, are common in samples with colourless seeds, but rare in the second group of synthetic emeralds without colourless natural seeds. The tiny birefringent crystals have a refractive index close to that of the host synthetic emerald, so they can be difficult to observe without crossed polarizers (*Figure 4a, b*). In samples with colourless seeds, most of these tiny birefringent crystals were in direct contact with the irregularly shaped surface of the seed. The narrower ends of the spicules always pointed in the direction of growth parallel to the *c*-axis of the synthetic emerald crystals. Occasionally, nailhead spicules were seen on two opposite surfaces of the seed with their tips pointing in opposite directions up and down along the *c*-axis (*Figure 5*).

The material trapped in the channels and spicules appeared inhomogeneous under the microscope. In addition to a shrinking bubble, which was frequently oberved, several yellow, yellowish or whitish, transparent or translucent substances were

***Figure 4a, b:** Nailhead spicules in Nacken synthetic emerald: the tiny beryl crystals at the wider ends of the spicules display a low relief in plane polarized light (a), the birefringent crystals are clearly visible with crossed polarizers (b; right), Immersion 100x.*

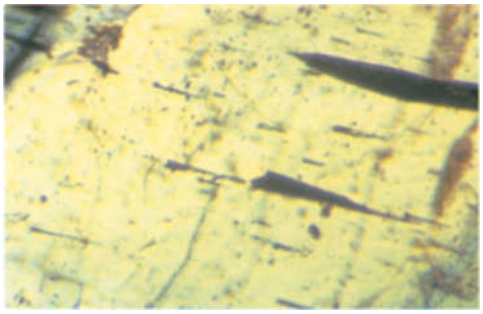

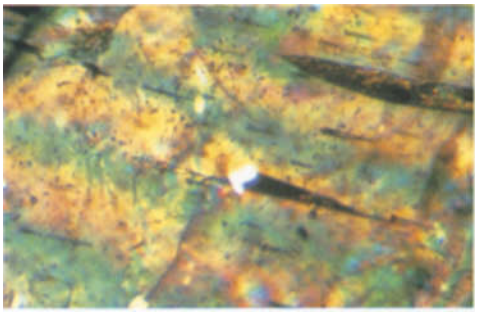

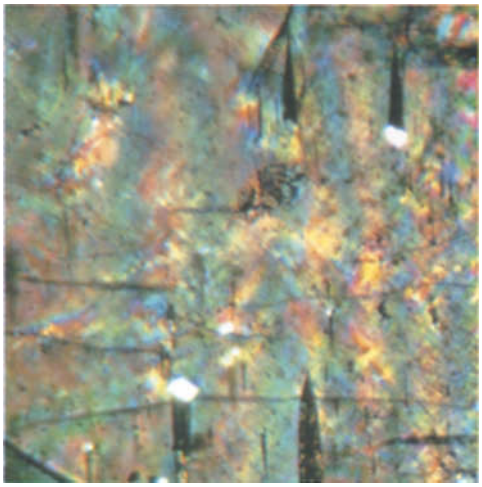

Figure 5: *Nailhead spicules in Nacken synthetic emerald: the c-axis runs vertically, the narrower ends of the spicules point towards the directions of growth up and down along the c-axis, the tiny beryl crystals at the wider ends of the spicules are in direct contact with two irregularly-shaped surfaces of a colourless beryl seed in the centre of the crystal. Immersion, crossed polarizers. 60x.*

often present (*Figures 6, 7 and 8*). Only in a few cases did a single cavity appear to be homogeneously filled with one single phase or component.

Determination of birefringent crystals at the widest ends of cone-shaped spicules

Numerous nailheads at the widest ends of elongated spicules (*Figures 4, 5 and 6*) in different samples were examined by micro-Raman spectroscopy. In all cases, we obtained Raman spectra of beryl only; no spectra indicating phenakite were recorded. The authors have identified nailhead spicules in hydrothermal synthetic emeralds from various producers (Schmetzer *et al.*, 1997) and have used the same experimental conditions in the present investigation; they are confident that if the spicules had been anything other than beryl they would have been detected by the Raman microprobe. Consequently, the birefringent crystals at the ends of cone-shaped spicules are most

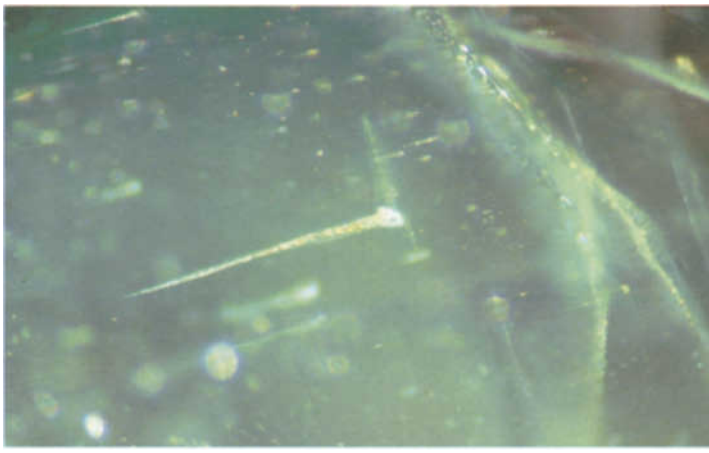

Figure 6: *Nailhead spicule with multicomponent filling in Nacken synthetic emerald. 100x.*

Figure 7: *Elongated spicule with multicomponent filling in Nacken synthetic emerald. 100x.*

Figure 8: *Elongated channel parallel to the c-axis with multicomponent filling and shrinking bubble. Renishaw Raman microscope. 200x.*

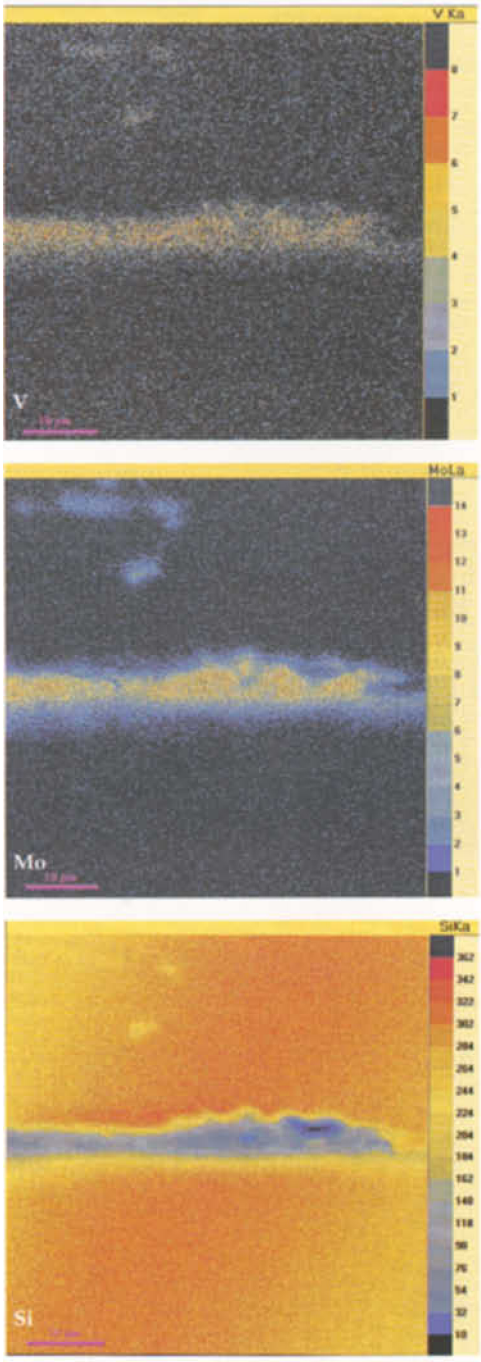

Figure 9a, b, c: *Element distribution maps obtained by electron microprobe analysis showing a slightly inhomogeneous distribution of Si, Mo and V as components of residual melt trapped in a channel parallel to the c-axis.*

probably tiny beryl crystals whose orientation is different from that of the host synthetic emerald.

Examination of multicomponent inclusions in elongated cavities

Microprobe analyses showed that the substances trapped in various cavities (*Figures 6, 7 and 8*) revealed the characteristic X-ray lines of Al, Si, V, Cr and Mo. Consequently, these cavities contain the ingredients of emerald (Al, Si, Cr) and residual quantities of the flux (Mo, V). Furthermore, neither sodium nor potassium was found in the cavities. These chemical data are consistent with the analytical results of Nassau (1978, 1980).

Although element distribution maps for some cavities (*Figure 9a, b and c*) revealed various inhomogeneities, no different phases or distinct phase boundaries between different chemical compounds were seen. No individual areas which consisted only of clearly resolved silicates without components of the flux (molybdenum and vanadium) or which consisted of only molybdenum and/or vanadium without any silicon were observed.

In Nacken synthetic emeralds, several basic types of Raman spectra were obtained from the material trapped in various cavities. No differences were observed relating specifically to sample type. For individual areas of different cavities, similar spectra were observed in some cases, but varying types of spectra were commonly obtained from different areas within one single cavity.

The most simple and frequently measured spectrum consisted of a single Raman line at about 956 cm^{-1} with a shoulder at about 871 cm^{-1} (*Figure 10a*). Other parts of the inclusions gave more complex spectra containing two additional lines at 830 cm^{-1} and in the 425 to 435 cm^{-1} range (*Figure 10b*) and in most cases, a line at about 714 cm^{-1} was also present (*Figure 10c, d and e*). Less commonly, two lines at 894 cm^{-1} and in the 313 to 320 cm^{-1} range were observed.

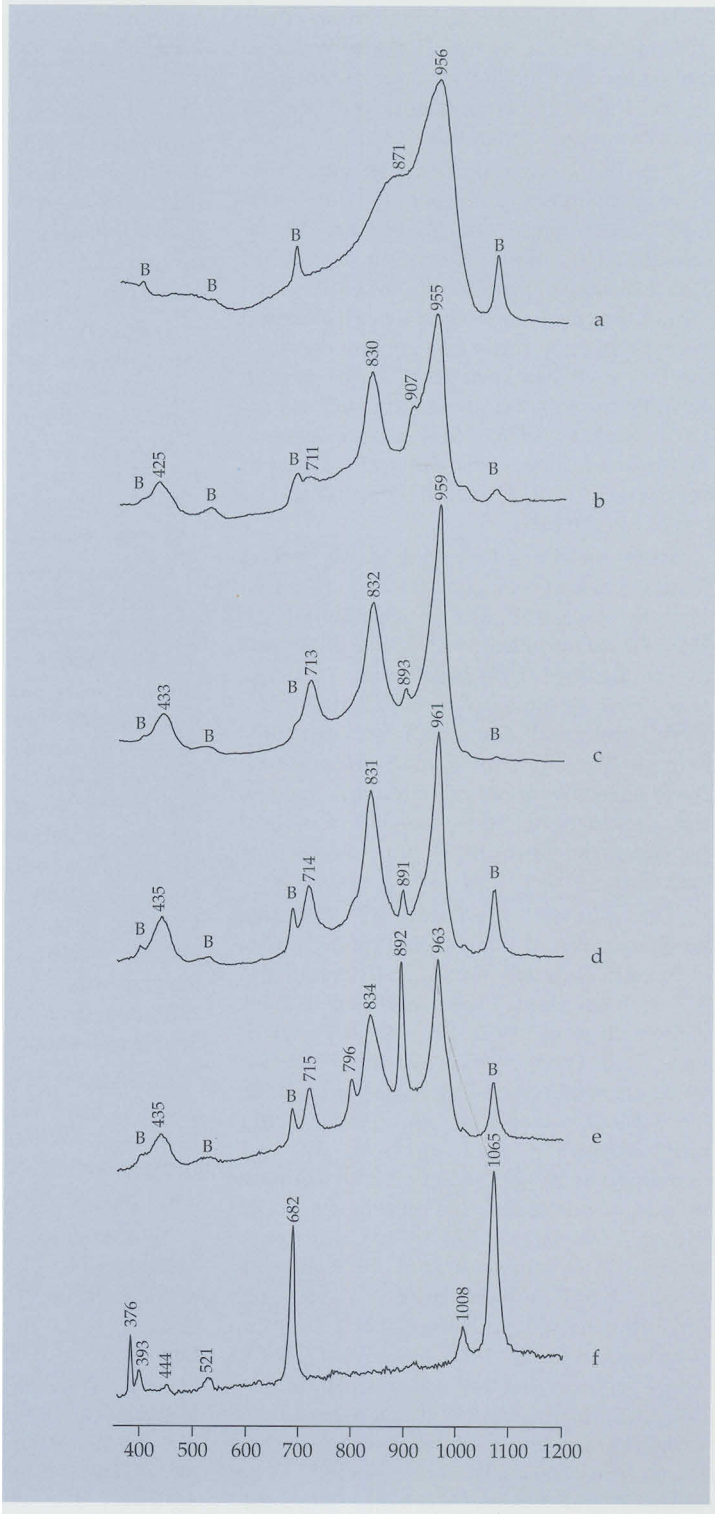

Figure 10: *Typical Raman spectra obtained from multicomponent inclusions in spicules or channels parallel to the c-axis of Nacken synthetic emerald crystals; the inclusions consist of residues of a molybdenum- and vanadium-bearing flux and the ingredients of beryl; in spectra 10a to 10e the positions of Raman lines of the host beryl are indicated by B: 10f is a Raman spectrum of the beryl host alone.*

The variation in Raman lines, their possible overlaps and their relative intensities, indicate that the spectra represent several individual components in cavities in Nacken synthetic emeralds.

For the assignment of Raman lines measured, major amounts of MoO_3 and minor percentages of V_2O_5 have to be considered as components of the flux. It has also to be taken into account that Li_2O, which cannot be measured directly by electron microprobe, could also be a component of the flux as it has been used in the past in solvents for emerald growth (Flanigen *et al.*, 1967; Nassau, 1976; Nassau and Nassau, 1980). In addition, the main components of beryl, i.e. SiO_2, Al_2O_3 and BeO could also be present in the melt.

MoO_3 is characterized by two strong Raman lines at 996 and 826 cm^{-1} (Krasser, 1969; Py *et al.*, 1977; Mohan and Ravikumar, 1984; Hirata and Zhu, 1992) and V_2O_5 reveals two strong lines at 994 and 701 cm^{-1} (Sanchez *et al.*, 1982; Abello *et al.*, 1983; Clauws *et al.*, 1985; Hirata and Zhu, 1992). Consequently, because the dominant Raman lines of both oxide phases were not present in our spectra, the presence of both molybdenum and vanadium in the form of pure oxides was excluded.

The Raman spectrum of the free molybdate ion in aqueous solution consists of three lines at 897 (strong), 837 (weak) and 317 cm^{-1} (medium) (Busey and Keller, 1964; Weinstock *et al.*, 1973; Schwab *et al.*, 1985; Pope and West, 1995). A similar Raman spectrum was reported for a melt of Li_2MoO_4 in K_2MoO_4 (Cape *et al.*, 1976). After polymerization, the spectrum of the heptamolybdate ion ($Mo_7O_{24}^{6-}$) in solution reveals a dominant Raman line at about 940 cm^{-1} (Aveston *et al.*, 1964; Griffith and Lesniak, 1969; Johansson *et al.*, 1979; Schwab *et al.*, 1985), which shifts to 960 cm^{-1} according to the pH-value of the solution (Murtaa and Ikeda, 1983; Ozeki *et al.*, 1987). The spectrum of the octomolybdate ion ($Mo_8O_{26}^{4-}$) in solution is characterized by a strong Raman line at about 960 to 970 cm^{-1}, in solids several lines were observed in the 920 to 970 cm^{-1} range (Aveston *et al.*, 1964; Griffith and Lesniak, 1969; Johansson *et al.*, 1979; Murata and Ikeda, 1983; Ozeki *et al.*, 1987).

In lithium borate molybdate glasses, the strongest Mo-related Raman line is observed at 940 cm^{-1} with a shoulder at about 880 cm^{-1} (Maaß *et al.*, 1993). In lithium phosphate molybdate glasses similar Raman lines were observed at about 940 cm^{-1} with a shoulder at 880 cm^{-1} (Chowdari *et al.*, 1993).

For crystalline lithium molybdates, especially for Li_2MoO_4, no Raman spectrum is available to the present authors from literature data. Only infrared spectra are reported for Li_2MoO_4 (Clark and Doyle, 1966; Spoliti *et al.*, 1981; Kurilenko *et al.*, 1988; Badilescu *et al.*, 1993), for $Li_2Mo_2O_7$ (Goel and Mehrotra, 1985) and for Li_2MoO_3 (Badilescu *et al.*, 1993).

To evaluate a possible presence of lithium molybdate in cavities of Nacken synthetic emeralds, we examined the Raman spectrum of Li_2MoO_4, a compound which is commercially available from ALFA (a Johnson Matthey company), Catalog-No. 48115. The substance was checked by X-ray powder diffraction and revealed a powder diagram consistent with rhombohedral lithium molybdate, Li_2MoO_4 (JCPDS file No. 12-0763) with some weak additional lines. The Raman spectrum of crystalline Li_2MoO_4 consisted of a dominant line at 904 cm^{-1} with some weaker additional Raman lines. Consequently, the presence of rhombohedral Li_2MoO_4 in the cavities of Nacken synthetic emeralds can be excluded.

In addition, it is worth mentioning that no Raman lines of lithium vanadate (see Feigelson *et al.*, 1972; Ghorai and Bhattacharya, 1995; Tang *et al.*, 1995; Zhang and Frech, 1997) were observed.

Silicate glasses that contain large amounts of BeO and Al_2O_3 and especially glasses with a composition close to that of beryl are known (e.g. Riebling and Duke, 1967; Dmitriev and Khan, 1971), but Raman spectra are lacking. Raman spectra of glasses in the silica-alumina system, however, reveal one dominant Raman line at about 430 cm^{-1} (McMillan and Piriou, 1982; Poe *et al.*, 1992), which is also observed in vitreous silica

Chatham flux grown synthetic emeralds

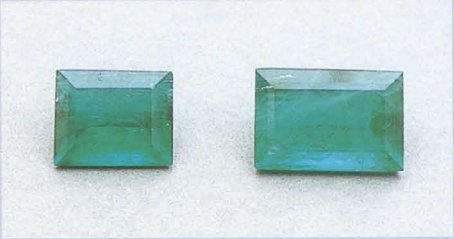

Figure 11: Two faceted Chatham synthetic emeralds; sizes of the samples 9.1 x 7.3 mm and 11.4 x 7.7 mm (photo: H.A. Hänni).

During the examination of nailhead spicules in hydrothermal synthetic emeralds (Schmetzer *et al.*, 1997) and Nacken synthetic emeralds (this article), similar inclusions in two Chatham flux grown synthetic emeralds were also observed. These two faceted stones of 3.31 and 2.08 ct (*Figure 11*) from the Gübelin research collection are remarkable because they contain tiny crystals at the ends of elongate spicules without any contact to a special seed plate or to an irregularly shaped core.

In both synthetic emeralds, the microscopic examination in an immersion liquid revealed a pattern consisting of two distinct growth sectors which are related to the basal pinacoid and to a prism face (*Figure 12*). Numerous nailhead spicules were found as inclusions only in those growth sectors related to the basal pinacoid. The multicomponent inclusions consist of a birefringent tiny crystal at the widest ends of the elongate cone-shaped spicules, and colourless or yellowish, transparent or translucent substances within the cones; the spicules are oriented parallel to the *c*-axis (*Figure 13*).

The examination of numerous birefringent crystals at the widest ends of the spicules by micro-Raman spectroscopy consistently indicated that they were phenakite. The spectra of the material trapped within the cones (*Figure 14*) consisted of several sharp Raman lines with the most intense and dominant lines

Figure 12: Growth pattern of Chatham synthetic emerald consisting of growth sectors related to the basal pinacoid (right) and to a prism face (left); nailhead spicules occur in the basal growth sector. The c-axis runs vertically, immersion, 50x.

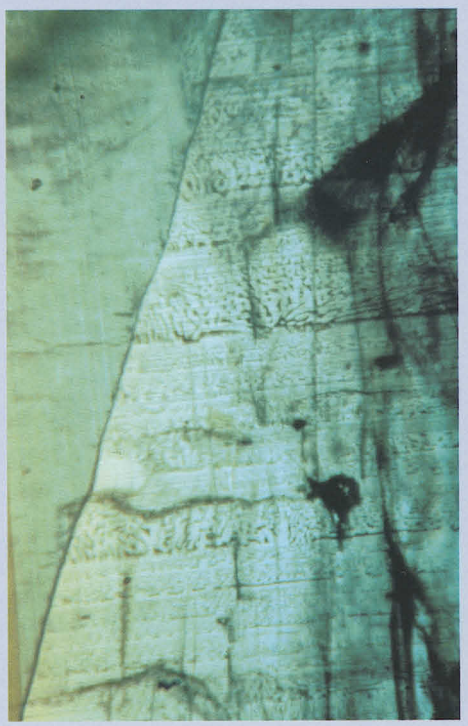

Figure 13: Nailhead spicule with multi-component filling in Chatham synthetic emerald. 50x.

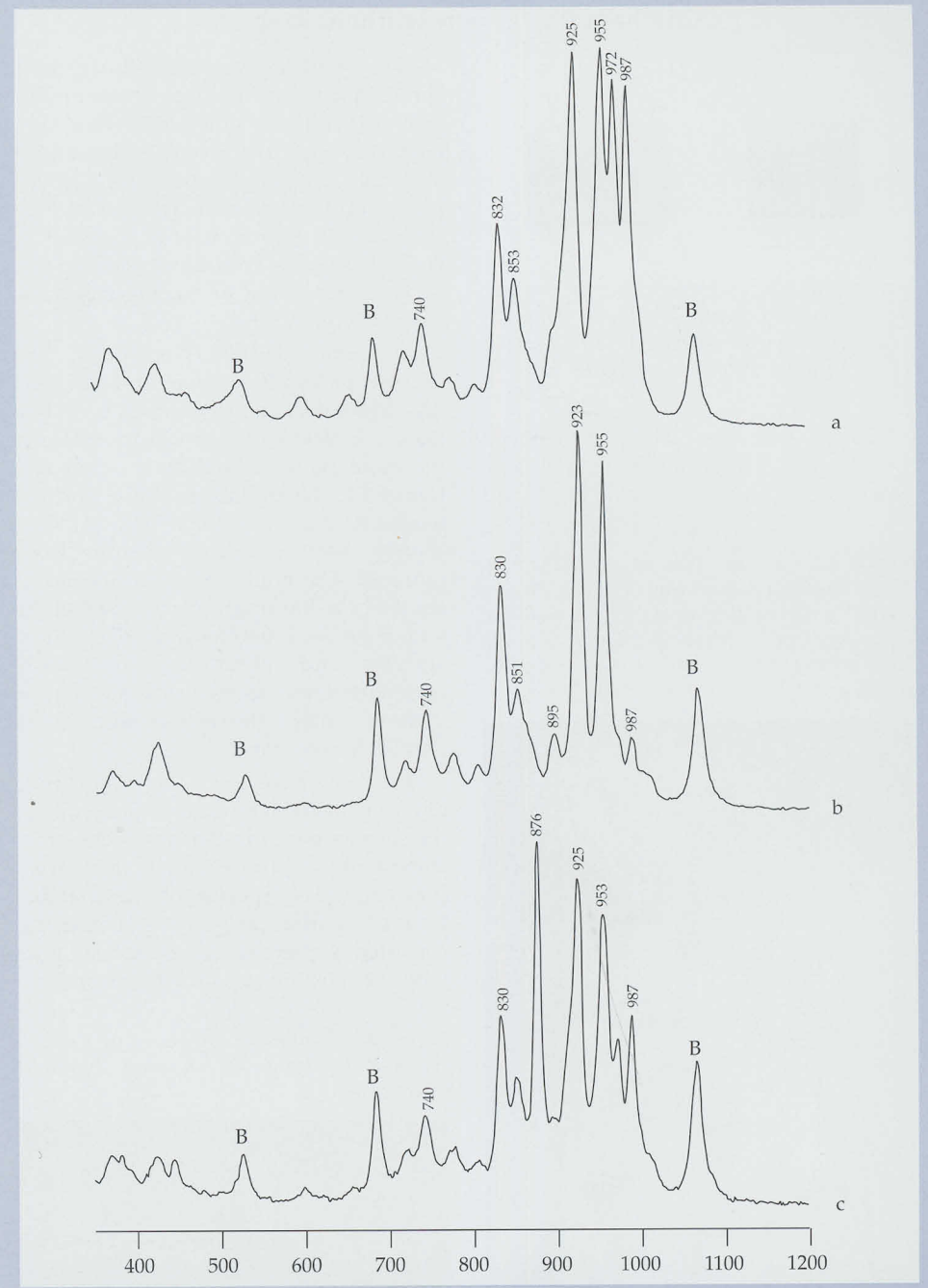

Figure 14: *Typical Raman spectra obtained from multiphase inclusions in spicules parallel to the* c*-axis of Chatham synthetic emerald crystals; the inclusions comprise residues of a molybdenum-bearing flux and components of beryl; the position of Raman lines of the host beryl is indicated by B, spectrum c shows the dominant Raman line of a phenakite nailhead at 876 cm^{-1}.*

always in the 900 to 1000 cm^{-1} range. In particular, four Raman lines at 925, 957, 972 and 989 cm^{-1} were frequently found in our spectra. Raman lines in the 430 and 830 cm^{-1} range were also present. Due to variable intensities of these dominant lines, probably different substances are trapped in the cone-shaped spicules of the two Chatham synthetic emeralds but some variation could be due to differences in orientation. This confirms conclusions drawn from microscopic examination (*Figure 13*). In both samples, the presence of molybdenum as a residual ingredient of the flux was proven by X-ray fluorescence (EDXRF).

At present, we are unable to present a complete and detailed interpretation of all Raman lines observed. However, comparing our measured Raman lines with literature data (Aveston *et al.*, 1964; Griffith and Lesniak, 1969; Johansson *et al.*, 1979; Kasprzak *et al.*, 1982; Murata and Ikeda, 1983, Schwab *et al.*, 1985; Ozeki *et al.*, 1987), we may conclude that several polymolybdates are present, especially the octomolybdate ion ($Mo_8O_{26}^{4-}$). In addition, the bands in the 830 and 430 cm^{-1} range are assigned to a polymerized network of SiO_4 tetrahedra and to isolated SiO_4 tetrahedra with non-bridging oxygen atoms.

(McMillan *et al.*, 1982; Xu *et al.*, 1989; Poe *et al.*, 1992). This strong Raman line is assigned to a three dimensional, polymerized Si–O–Si network or to six-membered Si–O–Si rings (McMillan *et al.*, 1982; Matson *et al.*, 1983; Xu *et al.*, 1989).

Raman spectra of Li_2O–SiO_2 and Li_2O–Al_2O_3–SiO_2 glasses have been examined by various authors. Glasses with lower Li_2O contents reveal strong Raman lines in the 490, 570, 950 and 1100 cm^{-1} ranges (Sharma and Simons, 1981; Matson *et al.*, 1983; Xu *et al.*, 1989; Fukumi *et al.*, 1990; Mysen, 1990; Mysen and Frantz, 1992); these were not observed in our spectra. Crystalline spodumene has two strong lines at 707 and 356 cm^{-1} (Sharma and Simons, 1981; Dowty, 1987), the 356 cm^{-1} line was not observed in our spectra. In Li_2O–SiO_2 glasses with higher Li_2O contents, however, a strong Raman line at 830 cm^{-1} is characteristic and is assigned to isolated SiO_4^{4-} tetrahedra (Iwamoto *et al.*, 1987; Tatsumisago *et al.*, 1987; Umesaki *et al.*, 1988). In these glasses, the SiO_4 tetrahedra contain non-bridging oxygen atoms. This assignment is confirmed by White and Minser (1984) for sodium silicate glasses.

Raman spectra of amorphous BeO show a strong line at 683 cm^{-1} and one weaker line at 723 cm^{-1} (Walrafen and Samanta, 1979). These two lines were also obtained from crystalline BeO, bromellite (Loh, 1968; Hofmeister *et al.*, 1987). Because the 683 cm^{-1} line is absent from some of our spectra showing a distinct 714 cm^{-1} line (see e.g. *Figure 10c*), an assignment of this line to BeO is rather uncertain.

According to the above data, a possible assignment of our Raman spectra obtained from trapped residual melt in Nacken synthetic emerald is as follows (see again *Figures 10a to f*):

component A, line at 956 cm^{-1} with a shoulder at about 871 cm^{-1} – polymerized polymolybdate, especially heptamolybdate;

component B, lines at 894 and about 317 cm^{-1} – non-polymerized molybdate;

component C, line at 430 cm^{-1} – polymerized Si–O–Si network or ring;

component D, line at 830 cm^{-1} – non-polymerized SiO_4 tetrahedra;

component E, line at 714 cm^{-1} – unknown component of the solidified (Li–Be)–Al–Si–V–Cr–Mo melt.

Most probably, the vanadium content of the residual melt is incorporated in components A to E, as has been already described for various hexamolybdates or molybdovanadophosphates (Kasprzak *et al.*, 1982; Buckley and Clark, 1985).

Consequently, the residual melt trapped in cavities of Nacken synthetic emerald consists of several components, the main

ones of which were identified as polymerized and non-polymerized molybdates, Si–O–Si networks and isolated SiO_4 tetrahedra. All components of the solidified melt are in the vitreous state and no crystalline phases have so far been identified. It is interesting to note that similar (Li–V–Mo) – (Be–Al–Si–Cr) – glasses were prepared as intermediate substances for the growth of synthetic emeralds (Kasuga, 1985 a, b, c, d, e). The variation of Raman spectra obtained from different parts of a single inclusion indicates that the melt trapped within such channels and spicules has partly unmixed during the cooling process. Similar observations,. i.e. phase separations in beryl glasses, have also been described by Riebling and Duke (1967).

At present, we are unable to assign the Raman line at 714 cm^{-1} to a specific crystalline or amorphous (vitreous) compound. Additional research is needed, and synthesis experiments should be performed to prepare specific compounds with known chemical compositions until one is found with this feature.

Conclusion

Nailhead spicules in Nacken synthetic emeralds consist of cone-shaped cavities with tiny crystals, most probably beryl, at the widest end and are partially filled with multicomponent inclusions. These inclusions derive from residual melt and consist of vanadium-bearing polymerized poly-molybdate and non-polymerized molybdate from vanadium- and molybdenum-bearing fluxes. Additional components of the solidified melt are isolated SiO_4 groups and polymerized aluminous silicates. It has been shown by optical, chemical and spectroscopic means that various cavities in Nacken synthetic emeralds contain single or multicomponent, partly inhomogeneous vitreous fillings. The fillings have partly unmixed during the final stage of emerald growth and subsequent cooling.

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Identification of filler substances in emeralds by infrared and Raman spectroscopy

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ABSTRACT: For many centuries, fissures in emeralds have been filled with oils and other natural substances to enhance their clarity. For approximately 15 years, the substances used also comprise various artificial resins, mainly epoxy resins. The various substances have different stability, but none of the treatments is permanent. Oils are the most volatile of the fissure filling media used, but the stone can easily be cleaned and refilled. Artificial resins, on the other hand, are much more durable, but they also decompose with time and are then hard to remove. Because of this, some traders require an identification of these substances which can be performed by infrared and/or Raman spectroscopy.
The first step in fissure filler identification is visual observation by the microscope and under long-wave UV-light to estimate the presence or absence of a filler and its position in the stone. Then the filler is identified with one or both of the above-mentioned methods. At the SSEF laboratory, which pioneered the techniques in a complementary way, infrared spectroscopy is used as a macro method and Raman spectroscopy as a micro method. Once a spectrum is obtained with either method, it is compared to the extensive data bank of either infrared or Raman spectra of the pure filler substances. The present paper summarizes common emerald fillers and describes in detail their identification with infrared and Raman spectroscopy.

Keywords: emerald, fissure fillers, infrared, oil, Raman, resin, spectroscopy

Introduction

Most varieties of beryl (aquamarine, yellow beryl, morganite) are generally quite clear and do not contain important inclusions. The clarity of emerald, in contrast, is usually affected by the presence of healed or open fissures. While aquamarines have grown with little interference in pegmatite dykes and pneumatolytic druses, most emeralds were formed in metamorphic rocks and underwent a more agitated geological history. Shearing forces and fluid action due to metamorphic processes led to mineral transitions and any rigid and large gem mineral crystals were prone to crack or break under the pressure with consequent

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Table I: Selection of filters analysed at SSEF.

Category	*Trade name*
oil	Universal Oil (paraffin oil); Johnson's Baby oil; 'MAZOLA' pure corn oil; olive oil; Clove oil nat 80–82%; Roth AG; cedar wood oil, Merck; 17196 H.E.Daniel, chinese cedar wood oil; MC153263 H.E. Daniel, 100% nat.cedar wood oil; CE108 Spectrum Quality Products cedar wood oil; 21695 H.E. Daniel 100% nat. Virginian cedar wood oil; 23292 H.E. Daniel 100% nat. cedar wood oil; Merck Cedarwood oil for microscopy; Panreac purified cedar oil; Cedro oil, Colombia; BPC FIG 34 cedarwood oil thick micro
coloured oil	green Joban oil, India
oil/wax	paraffin wax; wax from F.Hakimian, N.Y.; sperm whale oil (hardened)
Canada balsam	hardened; for microscopy; 100% natural, ref M; synthetic, ref Go
artificial resin	Opticon (epoxy resin); Palm oil, Palma (epoxy resin); Permasafe (bisphenole A); 77–309.RM (bisphenole A); Caldofix Struers; Epoxy 330; Scandiplex A 911F; LV 15 (UV-hardening resin)
silicon	'Silicon DC4' silicon fat; Luster's PCJ Nutrientsheen 3 silicon oil

formation of fissures. Should physical and chemical conditions still be favourable to crystal growth after the main destructive event, healing of damaged crystals may take place together with continued growth. If breakage and fissure formation in the gem crystals occurred at a much later period, e.g. during the blasting of the parent rock, the defects stay unhealed and artificial fissure treatment then becomes a commercially attractive step for the miner or stone dealer.

The clarity of an emerald is reduced by the presence of inclusions – guest crystals, internal cavities or negative crystals, healing fissures, structural features and by open fissures. The latter are especially visible in Colombian emeralds because most are otherwise relatively inclusion-free. In emeralds from other countries (e.g. Brazil, Russia, Zambia, Zimbabwe-Sandawana, Afghanistan and India) crystalline inclusions are more frequent, but fissures are still present (see e.g. Gübelin and Koivula, 1986; Epstein, 1989; Kazmi and Snee, 1989; Laskovenko and Zhernakov, 1995; Zimmermann *et al.*, 1997).

To improve the clarity of emerald open fissures may be disguised by impregnating the stones with some more or less permanent colourless substances. Although coloured oils and resins are also used to fill emeralds, we do not focus on these substances in this publication. Effective fillers have refractive properties close to those of emerald. Such substances comprise oils (natural or synthetic), resins (natural or with a natural resin base), glues or artificial resins *(Table I)*. Fissure treatments have been carried out for years – see Ringsrud (1983), Nassau (1984), Hänni (1988), Hurwit, (1989), Themelis (1990), Kane (1990), Kammerling *et al.* (1991), Bosshart (1991a), Shida (1991) and Koivula *et al.* (1994).

The identification of the nature of filler substances in emeralds started to become an issue when artificial resins, commonly epoxy resins, were used as fissure filling substances. When the treatment was performed on rough stones it masked the real appearance of the emerald and inhibited reliable estimation of their true quality. Furthermore, the durability of the new substances was questioned when decomposition of the originally 'invisible' filler was reported in some stones by Kammerling *et al.* (1991) and Federman (1998). The fillers had turned white and totally spoiled the stone it was originally supposed to have improved. Therefore an increasing number of people involved with emeralds wanted to identify epoxy-treated stones, knowing from articles in the gemmological literature that such an

identification is possible (e.g. Hänni, 1992; Kammerling *et al.*, 1995; Kiefert and Hänni, 1996; Chalain *et al.*, 1998; Johnson *et al.*, 1998).

The present paper is an attempt to guide laboratories in identification of fissure fillings in emerald, if required. Appropriate optical and spectroscopic properties of emerald filler substances are described. Based on gemmological needs and the results of early analyses of one of the authors (WW), the substances are divided into three major groups, namely oil, Canada balsam, and artificial resin (see *Table I*). Under these headings, methods for the detection and identification of enhancements in emeralds are described in detail. The following two steps are necessary to obtain reliable results: observation by optical means and identification with analytical instruments.

Fissure treatments

Open fissures of emeralds are filled with substances (air, for example) with a refractive index significantly different from that of emerald. Light entering the emerald, even at high angles of incidence to the fracture, is reflected off the surface of the fracture and it behaves as if it were a mirror. When these fractures are filled with substances with a refractive index close to that of the emerald the light can pass through the fractures with almost no reflection. This cancels out the mirror effect and the visibility of the fracture is greatly reduced.

In Colombia, Brazil, and the majority of the other emerald producing countries, treatments of emerald fissures are first carried out on the rough material. If cutting intersects unfilled fissures, further treatment may take place. Fissure fillers usually are heated to reduce their viscosity. The substances are then introduced into emerald fissures using various vacuum or pressure techniques (*Figure 1*). A number of emerald dealers call this technique 'oiling' (Ringsrud, 1983) regardless of the kind of substance used. This causes confusion among inexperienced buyers who think the treatment of emeralds is performed with oil only.

Figure 1: *Vacuum chamber on heating stage. This system is in use at the Institute of Earth Sciences of Basel University for hardening porous rocks to make them workable. For emerald treatment, the cleaned stones are evacuated above the filler, and then lowered into the substance. Normal pressure is admitted when the liquid has penetrated into all open fissures and fractures. © SSEF Swiss Gemmological Institute.*

In the past, the fact that treatments of gemstones have not been communicated or declared has caused considerable damage to the confidence of consumers. Sales figures appear to have gone down directly due to law cases concerning filled emeralds which were reported by the media. Nowadays most trade associations expect dealers to disclose the product that has been used for enhancement. But such disclosures are not always made, and with many older stones it is not clear to the owner whether such stones have been

treated. The situation is further complicated by possible multiple treatment with different substances at different trade levels.

The various colourless oils, either natural or synthetic, appear to be well accepted among the trade. Artificial resins, however, which have been used for emerald treatment for about 15 years, are accepted by fewer in the trade. The reasons for this difference in acceptance may be the following.

Oils are mobile to viscous, simple to introduce into fissures, but also prone to escape if in contact with liquid detergent. The fissures are comparatively easy to clean out, and stones are readily re-oiled. The improvement in appearance due to oil is less than with resins since the refractive indices of oils are lower (Chalain *et al.*, 1998). To many jewellers the fact that a customer may recognize the real state of an emerald when the oil drains or dries out may lead him to favour resinous substances.

Artificial resins are more viscous and may possess a solidifying character, which the oils do not have. Fresh artificial resins with higher refractive indices give a better enhancement to a stone. They adhere well in the fissures, but are difficult to dissolve and replace should they have changed their appearance or decomposed.

It is also worth noting that the stability of the treatments with organic substances is difficult to define and depends on the time and temperature specified. When an announcement appears in the trade press that a well known filling product should at the same time be 'permanent' and also 'removable' it casts doubt on its stability. Compared to the durability of an emerald, which can be worn for many centuries without damage, none of the treatments should be considered as stable.

Green fillers are also applied to enhance not only the clarity but also the colour of emerald using green Joban oil, green Opticon etc. This treatment, mainly practised in India, is easily visible under magnification. Emeralds treated in this way must be called 'treated emeralds' according to CIBJO rules (CIBJO, 1991, 1997). This type of treatment is, however, not considered in this article.

Colourless substances in emerald fractures are more difficult to detect than coloured substances. Some substances have a refractive index so close to that of the emerald that when observed with the unaided eye, the fracture disappears almost completely.

Spectroscopic properties of pure filler substances

The organic substances used to fill emeralds either alone or mixed, are commercially available. Therefore, their properties are well known and Fourier transform infrared (FTIR) and Raman spectra are readily available (e.g. Hummel, 1990).

All available organic substances at the SSEF Swiss Gemmological Institute which could be used to fill emerald have had their infrared spectra recorded and the major characteristic peaks related to the chemical bonds (*Figure 2*, see Hummel, 1990). Since 1991, 42 possible filler substances have been characterized at SSEF with FTIR spectroscopy and stored in a reference library for comparison. These include various oils and waxes, among them various natural and synthetic cedarwood oils and Canada balsams, clove oil, olive oil and paraffin oil as well as various epoxy resins such as Opticon, Palma (Palm Oil) and Permasafe which was available in a polymerised state. Initially, use of the term 'Palm Oil' was confusing for those in the trade, until the substance proved to be an epoxy resin made by Shell and marketed under the name 'Epon 828'. The analysed products were supplied by a number of customers, emerald treaters and chemical companies. The technical or trade names of a selection of these substances are listed in *Table I*.

The Raman spectra of the most important filler substances have also been recorded since 1995 at SSEF and stored in a reference library. The spectral area lying between 1200 and

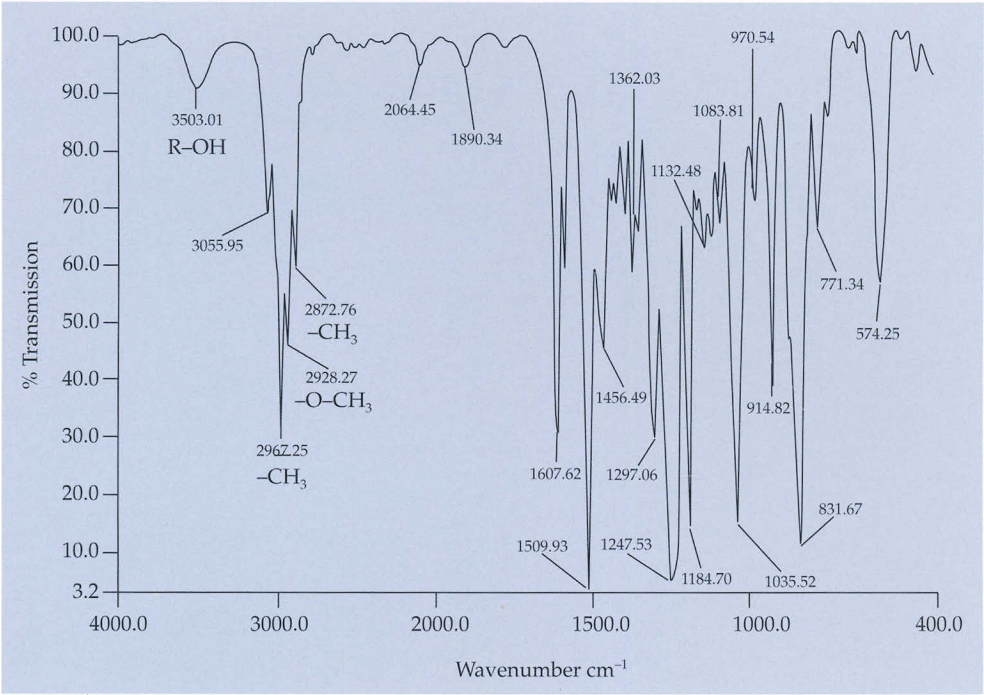

Figure 2: *Infrared spectrum of Epon 828, showing the chemical bonds related to the various peaks.* *© SSEF Swiss Gemmological Institute.*

3200 cm^{-1} contains the characteristic Raman peaks for the kind of organic substances used for fissure fillers without interference from the Raman peaks of emerald (see below).

According to their spectroscopic properties, which are closely related to their physical properties, the fillers can be divided into three groups: oils, Canada balsam, and artificial resins (see *Table I*). While we could not establish any reliable difference between the spectra of natural and synthetic oils or Canada balsams, distinct differences were observed between the spectra of oils or Canada balsams on the one hand and artificial resins on the other (see below).

FTIR spectra of pure substances

After having verified the identity of the substances in the characteristic spectrum region below 2000 cm^{-1}, we concentrated on the peaks in the 2800–3100 cm^{-1} range which do not suffer interference from emerald absorption.

A comparison of FTIR spectra of oils and artificial resins shows that the general distributions of their absorption peaks are very similar between 2800 and 3000 cm^{-1}. This is not surprising since the peaks in this part of the spectrum are due to C–H vibration bonds which are present in both organic substances. An experienced spectroscopist may, however, note that the relative absorption heights of the peaks at 2870 and 2854 cm^{-1} may differ in oils and artificial resins (*Figure 3a,b*). This difference can be interpreted as giving an indication of one or the other substance, but should not be considered as strictly characteristic, as can be seen in the spectrum of cedar wood oil (*Figure 3c,d*).

In contrast, it appears that none of the analysed oils (natural or synthetic) show significant absorption above 3000 cm^{-1}, while all artificial resins show clear and typical absorption (*Figure 3a–d*). Therefore, the peaks between 3000 and 3100 cm^{-1} are important in distinguishing oils from

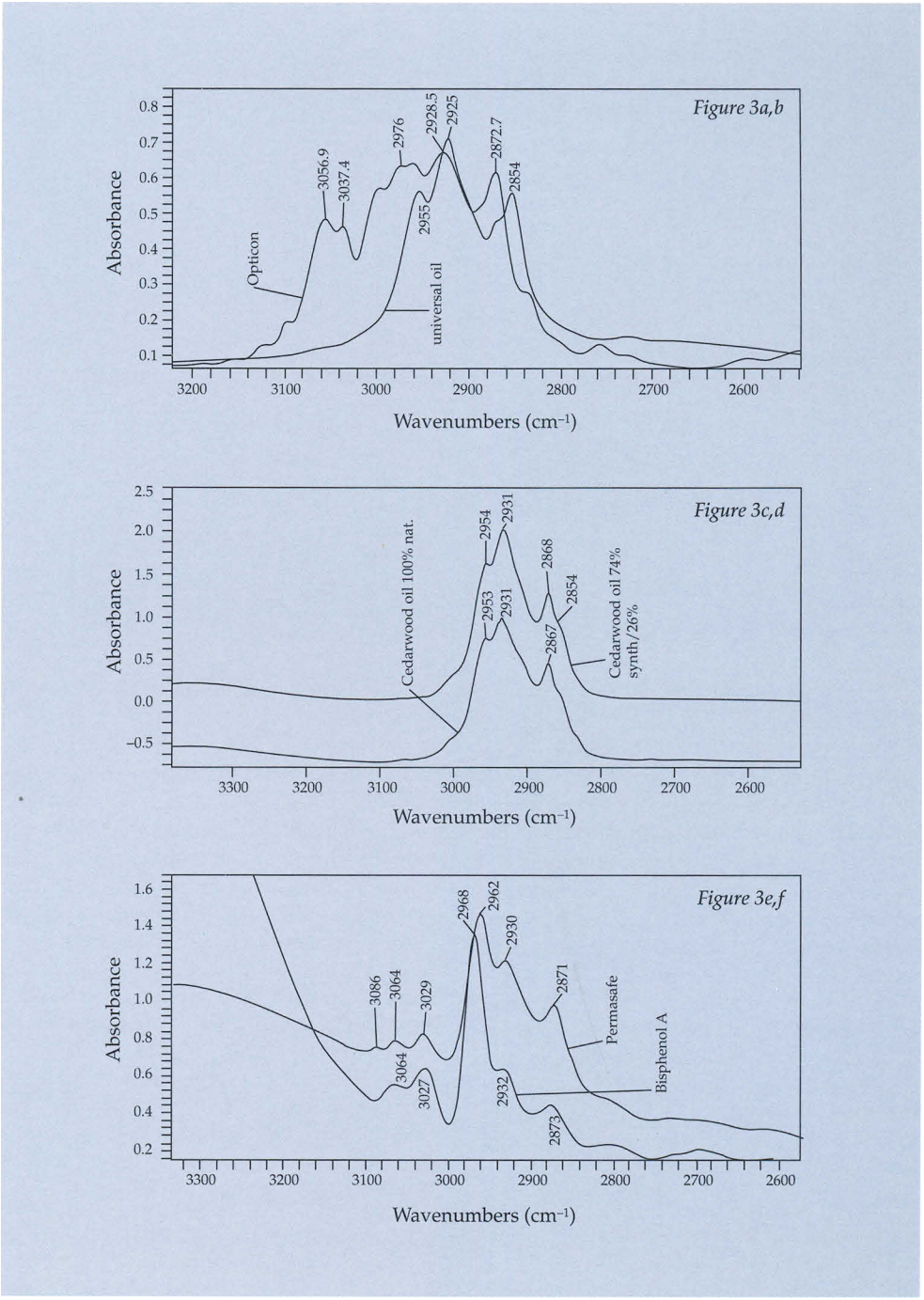

Figure 3: *FTIR spectra of: (a) universal oil; (b) artificial resin (Opticon) showing that the absorption features of the 2854 and 2870 peaks are different in intensity and that absorption features are very different in the 3000–3050 cm^{-1} area; (c) and (d) cedarwood oil; (e) Permasafe; (f) bisphenole A. © SSEF Swiss Gemmological Institute.*

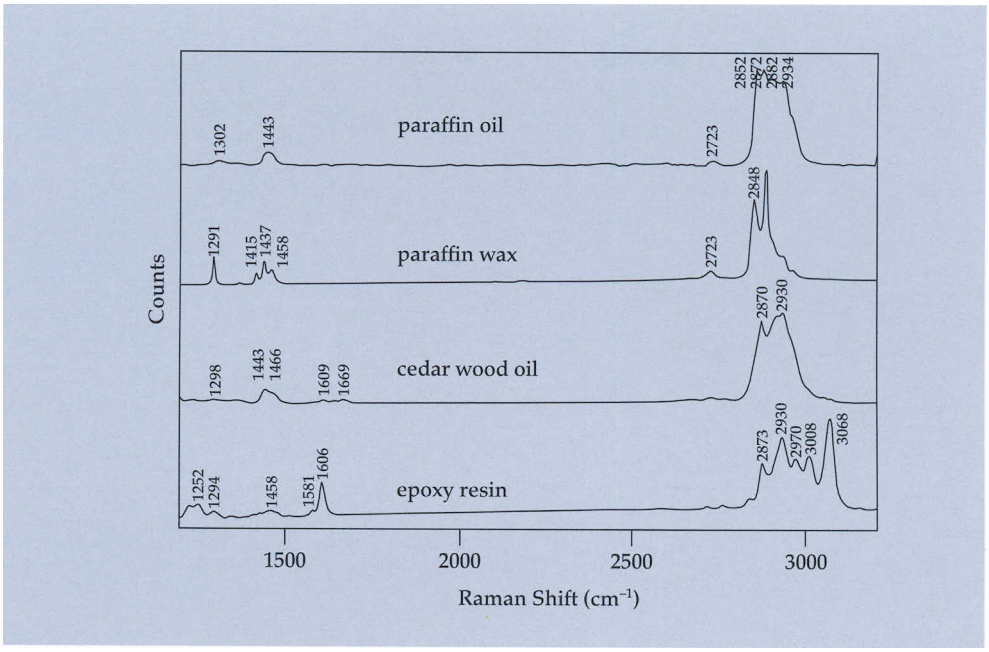

Figure 4: *Part of the SSEF reference collection of Raman spectra of emerald fillers. The four spectra contain peaks at different wavenumbers and an identification of products is possible by comparison. © SSEF Swiss Gemmological Institute.*

Figure 5: *Raman spectra of various cedar wood oils: (a) natural cedar wood oil; (b) synthetic cedar wood oil; (c) 74% synthetic cedar wood oil. © SSEF Swiss Gemmological Institute.*

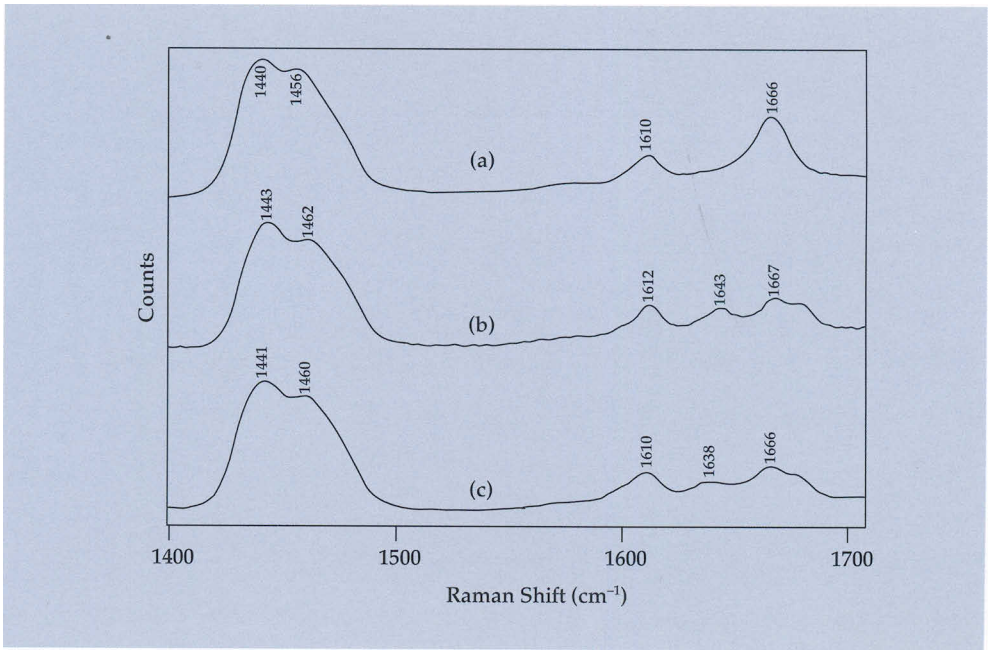

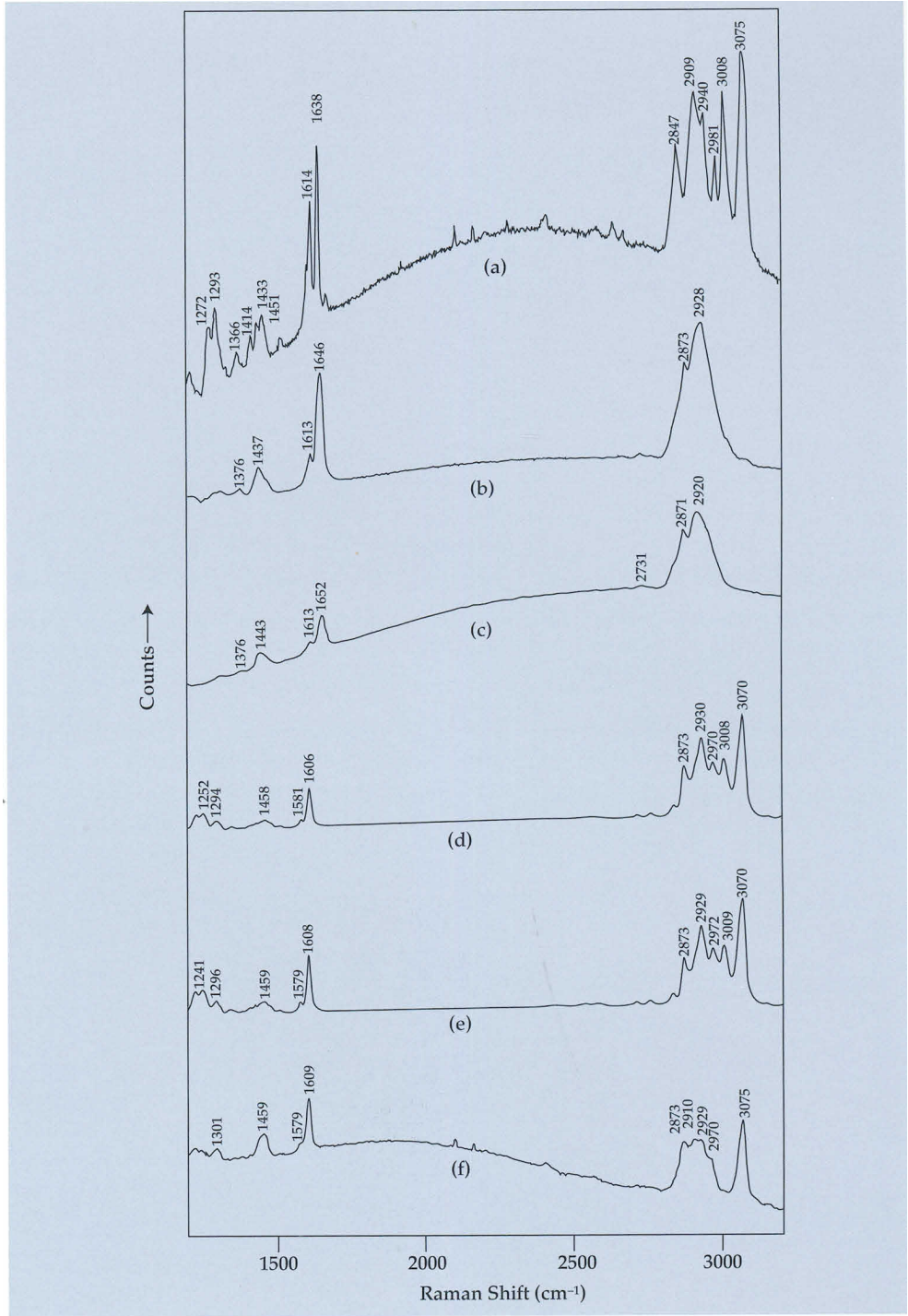

Figure 6: *Raman spectra of (a) clove oil; (b) natural Canada balsam; (c) synthetic Canada balsam; (d) Opticon; (e) Palm oil; (f) Permasafe. (d), (e) and (f) are epoxy resins. © SSEF Swiss Gemmological Institute.*

artificial resins. Some other, less frequently used substances such as Canada balsam or clove oil have other characteristic FTIR spectra which differ from the spectra of oils and artificial resins. A newer artificial resin which is marketed under the name 'Permasafe' has a spectrum very much like the other epoxy resins (*Figure 3e,f*, see also Fritsch *et al.*, 1999) and is also a member of the Bisphenole A family.

Raman spectra of pure substances

In Raman spectroscopy, just as in FTIR spectroscopy, oils and resins show different peaks depending on their chemical composition. Of all the oils identified a distinction can be made between two different types: one type includes oils such as mineral and paraffin oil (*Figure 4*); the other type consists of cedar wood oil (*Figure 4*), which can be natural or produced synthetically. The various cedar wood oils tested in the laboratory show some variation in peak intensity probably due to ageing and oxidation. Their major peaks in the lower region of wavenumbers at 1441 cm^{-1}, 1445 cm^{-1} and 1666 cm^{-1} occur in all tested samples (*Figure 5*). There is a third oil, which may have been used in the past to fill emerald and that is clove oil, but it is identifiable by its strong smell. However, its Raman spectrum differs considerably from the spectra of the other oils (*Figure 6a*), and may be confused with artificial resin if its smell has been undetected and the peak measurements not carefully made (see *Figure 6d,e,f*).

In contrast to FTIR spectroscopy, the Raman spectra of paraffin wax and paraffin oil show similar peak positions, but the peaks of paraffin wax are sharper due to the fact that the molecules in hardened substances are less mobile. Thus, the more liquid substances appear to have a broadening effect on Raman peaks (*Figure 6a*).

One organic substance which is used to fill emerald fissures is Canada balsam which may occur as a natural resin but may also be produced synthetically. The properties of natural and synthetic Canada balsam are alike (*Figure 6b,c*) and just as natural and synthetic cedar wood oil properties are similar, Canada balsam and the oils used to fill emerald have similar chemical properties. They are unable to polymerise, so do not harden as much as epoxy resins and are generally easier to remove from the stone if they start decomposing.

The various epoxy resins marketed under the names Opticon, Palma, Epon 828, have identical spectra with major peaks distinguishing them from the other substances mentioned above (*Figure 6d,e,f*). Permasafe differs slightly from the above-mentioned epoxy resins (*Figure 6f*, see also *Figure 3e,f*).

The spectra presented in *Figures 4 to 6* show that a distinction can be made between oils, Canada balsam, and artificial resins. Other materials such as hardeners for epoxy resin or various polishing materials (diamond powder, chromium oxide) have also been tested and show distinct peak positions.

Storage of the obtained spectra in a reference library file is advisable, so that the spectra of fillers found in emeralds can easily be compared. It is also of advantage to examine the whole possible spectral range of the substance, but to save the detailed spectra only in the range critical for detecting fissure fillings in emerald.

Identification of fissure fillers in emeralds

The aim of this section is to give a detailed description of the methods used at SSEF to identify fissure fillers. In order to enable gemmologists to reproduce these methods, this section is written in the style of a manual describing various steps in identification of fillers, pointing out any difficulties.

The analysis of fissure filling in emerald previously treated with known substances by one of the authors (HH) was carried out with FTIR as well as Raman spectroscopy on several stones and proved that the methods produced spectra comparable with the pure

Instrumentation

For successful identification of fissure fillers in emeralds, thorough analysis with a gemmological microscope, observation under UV light, and identification with FTIR and/or Raman spectroscopy are essential.

At the SSEF laboratory, microscopic observation is performed with a gemmological microscope by Bausch & Lomb, allowing magnification up to 70x. The UV source used is a long-wave (365 nm) UV lamp which is part of the Dialite lamp supplied by System Eickhorst.

The Fourier Transform infrared spectrometer used at the SSEF is a Philips PU9800 instrument with Nicolet software OMNIC. An additional software package from Nicolet which contains a number of IR data collections including Hummel (Polymer), Organics by Raman, Sigma Biological Sample Library, Crime Lab Sample Library, and Aldrich Sample Library allows the direct comparison of a measured spectrum with stored data and its identification.

A Renishaw 1000 Raman system equipped with a CCD Peltier detector and an argon ion laser (514 nm) with a power of 25 mW was used for filler identification. The objective lenses on the microscope are Olympus BH lenses with x5, x10, x20 and x50 magnification. Raman analysis with this system can be performed in two modes. The first is a mode in which data points are collected over a selected range of wavenumbers for a certain time; the range can be chosen by specifying a centre wavelength, and then the system automatically collects data several hundred wave numbers to each side. The second mode, the extended mode, collects data successively over the pre-chosen area. This type of analysis makes it possible to cover any scan range from 100 to 9000 cm^{-1} with a resolution of 2 cm^{-1} (Ostertag, 1996; Hänni *et al.*, 1997). Up to 1999, spectra were collected using Renishaw software, and then translated into the software package GRAMS/386. Since 1999, with the aid of an upgrade of both the Renishaw and the GRAMS software, spectra are directly recorded in GRAMS.

substances. During the last five years, successful identifications have been obtained on more than 500 stones from customers of the laboratory.

Observation

Observation of fissures with the microscope; for the observation of an emerald treatment, a 10x loupe is not always sufficient, while a detailed study with the microscope generally allows the detection of a filler substance in the emerald. It also gives information about the extent of treatment and one may also form an opinion about the nature of the filler. Fractures filled with foreign, artificially-introduced substances commonly appear different from those occupied by natural fluids. Fissures which contain natural fluids (notably aqueous brine) are often oriented parallel to one of the crystal faces, and commonly consist of more than one phase (liquid, vapour or solid).

Trapped individual gas bubbles or extended 'lakes' of air are a reliable indicator for the presence of an artificial filler. Frequently, dendritic to lobular structures can be observed, showing the distribution between the (liquid) filler and a gas phase; the oils or resins have refractive indices close to that of emerald. As a function of the thickness of the fissure, an effect due to the dispersion of light may be observed which resembles the 'flash effect' observed in fissure filled diamonds (Nelson, 1993).

While oil may create an orangy flash effect, flashes which change their colour in different light positions appear to be due only to artificial resins (*Figure 7;* Kammerling

et al., 1995). Depending on the orientation of the fibre optic light, the flashes may be orange, violet, or blue, the blue colour being mainly visible when observed almost along the fissure plane. However, multicolour flashes are not always present in fissures treated with artificial resin, and single colour orange flashes are frequently observed.

When fissures are not filled completely, dendritic patterns and worm-like structures may be observed, sometimes with trapped air bubbles (*Figure 8*). The nature of these structures gives an indication of the viscosity of the filler but cannot be used for identification.

On drying, the fillers may become opaque and then the treated fissures are readily visible (*Figure 9*). This is generally the point when identification of the filler becomes a factor of significance for buyers of emeralds.

Before any instrumental analysis is performed, it is important to use the microscope to locate the most easily accessible fillers. The necessary lighting includes reflected light, dark field and/or fibre optic illumination. The latter allows a strong and precise lighting, but, more importantly, easier and more flexible observation in different directions. Holding the emerald with tweezers prevents the surface of the stone becoming greasy from handling and allows light to enter the stone more easily.

Figure 7: *Colour flashes from an epoxy resin treated fissure in an emerald. The resin has a refractive power close to that of emerald and the colours are due to a dispersion effect. © SSEF Swiss Gemmological Institute.*

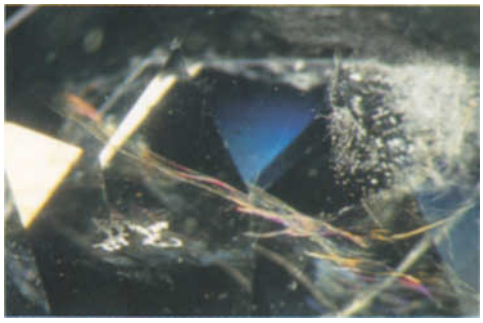

Figure 8: *Trapped air bubbles and dendritic pattern in an epoxy resin-treated emerald. © SSEF Swiss Gemmological Institute.*

Observation of emerald fissures under UV light: The use of long-wave UV light (365 nm) is a convenient tool to observe fissure fillings in emeralds. The stone is placed on top of the UV light source and may be inert or show a reddish colour depending on the amount of Cr and Fe in the stone; but a different fluorescence colour may show in the fissures and can indicate the extent of the treatment by virtue of the spread and number of fluorescing fissure planes (*Figure 10*).

Figure 9: *Decomposed oil on a fissure plane of an emerald. For various reasons it is possible that filling media dry out or may decompose. Heat, solvents, or ultraviolet radiation may contribute to disintegration and lead to a whitish appearance which may be easily visible. © SSEF Swiss Gemmological Institute.*

Figure 10: Observation under long wave UV radiation (365 nm) can be an effective method for judging the amount of treatment and for finding the best positions to obtain spectra for filler identification. © SSEF Swiss Gemmological Institute.

Like many organic substances, the majority of substances used to treat fractures in emeralds (oils, balsam, resins) show fluorescence under UV light. In contrast, most natural fluids are inert, although hydrocarbons have been observed and described in Colombian emeralds (Bosshart, 1991b), and it cannot be excluded that they may exhibit a similar fluorescence. Again, artificially filled fissures may not always show fluorescence, especially if the amount is small and the filler fluoresces weakly. Thus, although UV fluorescence may give important information, it should not be considered as a diagnostic test for identification.

Generally speaking, oils show a yellowish fluorescence while many artificial resins that react to UV light show a bluish-white fluorescence. Although not a complete identification tool, this fluorescence allows evaluation of the position and the quantity of filler in the treated fissure (*Figure 10*). When the fissures are readily visible, it is possible to classify the extent of the treatment. At the International Coloured Stone Association (ICA) meeting in Tucson, 1998, the consensus was to use three categories to classify the extent: minor, moderate and significant (SSEF Standard and Applications, 1998). It is emphasized that these grades do not replace a judgement by the dealer who has to evaluate the general quality of the stones. For example, if a small single treated fissure is situated at the centre of the table of an emerald, its extent may be classified as minor. But after the substance decomposes, the visibility of the fracture may have a significant impact on the overall appearance of the stone.

The observation of emerald fissures under UV light combined with microscopic observation, allow location of treated fissures in stones and is an important step in preparation for point analysis with the Raman microprobe or with infrared spectroscopy (see below).

Thus observation of emerald fissures with a microscope and UV light enables the gemmologist to conclude if a foreign substance is present or not, and although some features of emerald fillers such as a certain dendritic pattern or a certain UV fluorescence may give an indication of the type of substance present in the emerald, positive identification of the substance can only be carried out by FTIR or Raman spectroscopy.

Identification by spectroscopic analysis

The identification of individual substances is restricted to laboratory techniques. The first analyses of these substances at SSEF Swiss Gemmological Institute were carried out in 1991 using infrared spectroscopy (*see Figure 11*), and in 1995 SSEF acquired a Raman spectrometer. Since then both FTIR and Raman spectra have been obtained routinely to analyse fissure fillings in emeralds.

It is important to note that the interpretation of spectra obtained with both techniques relies strongly on comparison with known reference spectra stored in a database. Thorough analyses to characterize the chemical nature of the substances were carried out in 1993 by one of the authors (WW) and led to a decision at SSEF to group the substances into three distinct groups; oil,

Canada balsam, and artificial resin. Any further distinction (such as that between the different types of oils) is too time consuming and difficult to obtain with the spectroscopic means usually present in a gemmological laboratory to be economically justifiable.

Methods of FTIR analysis: Infrared spectroscopy is one of the most efficient analytical techniques to characterize organic materials. IR spectroscopy is a vibrational spectroscopy, which measures the energies of vibrating molecules in the infrared spectral area. For over fifty years, organic compounds have been studied and their structures explained on the basis of IR spectra. IR spectra are considered as characteristic 'fingerprints' for given compounds. Large catalogues and collections of spectra are available to enable identification and comparison when unknown materials are investigated (Hummel, 1990; Moenke, 1962; Sadtler, 1973).

At SSEF, FTIR spectroscopy is performed in two modes: one is direct transmission, where the analysing beam is transmitted through the sample; the other is measurement in reflection-absorption mode using diffuse reflectance equipment where the analysing beam is directed onto the sample placed on a flat mirror and covered by a hemispherical mirror. Thus the beam is focused through the sample by the mirrors before being collected by the detector. Tests have also been performed in a third mode, with a 5x beam condenser (KBr lens), but the signal obtained with the diffuse reflectance accessory was stronger and the method quicker.

Although the majority of samples are best analysed by the diffuse reflectance method, there are samples in which it is necessary to analyse fissure fillings by *direct transmission*, either because they are too large to fit into the sample chamber for diffuse reflection (more than 40 ct), or because they are mounted in jewellery. To perform analysis by direct transmission, a baseline has to be recorded by measuring the infrared beam in the empty sample chamber. After this, the stone, mounted onto a sample holder, is placed into the beam making sure that it does not contact any masking or plastic. In order to obtain good results with FTIR absorption analysis, either a significant amount of filler substance must be in the stone or the infrared beam must be focused through a fracture which has been located previously (e.g., with UV fluorescence). There are several difficulties using the direct transmission method, the main ones being:

Figure 11: *FTIR spectra from 1991 of untreated emerald (red), of Opticon epoxy resin (blue), and of an Opticon treated emerald (green). Within the transmission area of emerald between 3500 cm^{-1} and 2400 cm^{-1}; the major absorption of the artificial resin is clearly visible. © SSEF Swiss Gemmological Institute.*

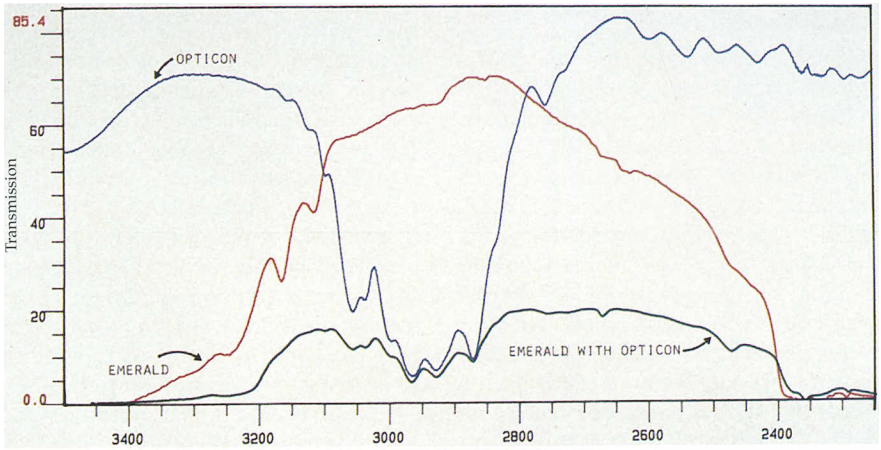

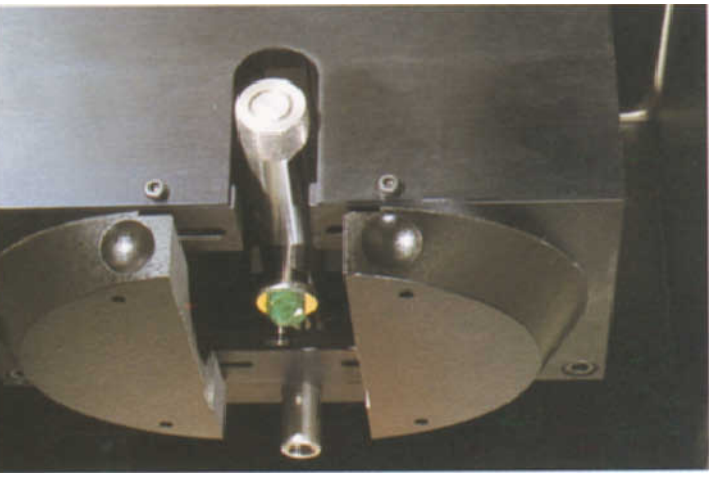

Figure 12: Diffuse reflectance accessory used at the SSEF fitted to the Philips (PU9800) FTIR spectrometer. In contrast to the micro-method of analysis with Raman spectrometry, this type of FTIR analysis is a macro-method giving an average result. © SSEF Swiss Gemmological Institute.

- intersecting at least one larger fissure to give a sufficiently strong filler signal;
- selecting an orientation of the stone so that the emerging beam reaches the detector;
- obtaining a transmitted beam of sufficient energy.

It can take a long time to adjust a stone to produce a measurable signal, and since the path of the beam through the stone cannot be exactly monitored, it could well pass beside a treated fracture. The results therefore must be critically assessed.

In *absorption-reflection analysis* the diffuse reflectance accessory tool of FTIR spectrometry (*Figure 12*) has the advantage that the beam can interact with a large volume of the stone. The equipment consists of a flat mirror on which the stone is placed. A baseline spectrum is recorded for the ambient condition in the sample chamber and then the sample is placed into the path of the beam and covered with a hollow mirror which reflects the refracted beam back onto the stone. In this way we are dealing with a macro-method that accumulates analytical information from various fissures in different parts of the stone. Contrary to the analysis of a directly transmitted beam, it is not crucial to look for a special path through the stone (i.e., the beam does not have to be focused on a fracture as precisely as with the direct beam method). The orientation of the stone is, however, important, because the absorption bands of OH-vibrations are close to the spectral area of analysis and cause structural effects which interfere with absorptions of C–H-vibrations of the substance to be analysed (*Figure 13*).

Generally, better results are obtained when the beam interacts with a larger sample, but if the sample is too big, a rather large loss of energy of the reflected beam may occur. If a filler substance located using the microscope cannot be identified with this equipment it is necessary to apply a more localised analysis with micro-FTIR or Raman micro-spectroscopy.

FTIR spectra of fissure fillers in emeralds: Untreated emerald from any natural source shows total absorption below 2400 cm^{-1} and above 3400 cm^{-1} with a transmission window between 2800 and 3100 cm^{-1} (*Figure 11*). The spectra are, however, influenced by the crystal orientation of the emerald (*Figure 13*). Therefore, tests have been carried out to define the best orientation for recording spectra of treated emerald. A more detailed description of the influence of emerald orientation on FTIR spectra will be given in a later article (Chalain *et al.*, in preparation).

As shown with pure substances, the FTIR spectra of emerald fillers present two characteristic areas which can be used for identification. The best absorption region for organic substances such as C–H groups and cyclic aromatic substances is between 1700 and 1600 cm^{-1}. However, the emerald spectrum shows complete absorption in this region and cannot be investigated. The second characteristic region for filler substances lies between 2800 and 3100 cm^{-1}, in which emerald shows an absorption minimum. Therefore, this region is suitable for analysis. When an FTIR analysis is performed on a treated emerald, a combination of the absorption spectrum of the filler substance and the emerald spectrum is obtained (*Figure 11*).

Emeralds treated by one of the authors (HH) with known substances showed that none of the emeralds treated with oil possess any absorption between 3000 and 3100 cm^{-1} (*Figure 14a*), while all emeralds treated with various artificial resins do show characteristic absorption features in this region (*Figures 11,14b,c*). Emerald treated with Canada balsam has yet another typical feature which makes it distinguishable from emeralds treated with other substances. Based on these results, FTIR spectroscopy enables distinction between emeralds treated with oil, with artificial resin, or with Canada balsam. The study was continued by including various treated emeralds with newer substances, which were sent to the laboratory for scientific analysis. Two emeralds were sent to the SSEF laboratory by A. Groom, who promotes emerald treatment with his substance called 'Gematrat'. Unfortunately the pure substance was not supplied. The FTIR spectra of the analysed stones show features similar to those of epoxy resins, so that the substance can be classified in the group of artificial resins (*Figure 14b*). Five emeralds donated by R. Giraldo of Colombia, had been treated with 'Permasafe' and a comparison of the spectrum with the solidified substance shows good agreement with epoxy resin (*Figure 14c*). Due to its spectroscopic features, Permasafe is also classified as artificial resin.

When performing FTIR spectroscopy, care has to be taken that no pollutants adhere to the emerald. When the whole stone is analysed by FTIR spectroscopy, such pollutants may disguise a relatively pure stone and may lead to misinterpretation. Among potential pollution sources are the grease from fingers when handling the stone without tweezers, refractometer fluid when the refractive index has been performed before FTIR analysis, or detergent from the water with which the specific gravity of an emerald has been determined. To avoid such effects, care must be taken to clean the emerald thoroughly prior to analysis, preferably with alcohol or acetone.

Raman micro spectrometry: The Raman spectrometer is equipped with a microscope for selecting the analytical area and targeting the beam to the selected spot. The advantage of this instrument is the ability to focus inside a sample to several millimetres depth. In this way, gemstone inclusions as small as 2 µm can be investigated (see e.g., Dhamelincourt and Schubnel, 1977; Delé-Dubois *et al.*, 1980; Hänni *et al.*, 1997; Koivula and Elen, 1998), and this makes it convenient to focus into the

Figure 13: *FTIR spectra of ε and ω vibrations of emerald show distinct variations in absorbance of OH-bonds within the 'transmission window' between 3200 cm^{-1} and 2600 cm^{-1}. © SSEF Swiss Gemmological Institute.*

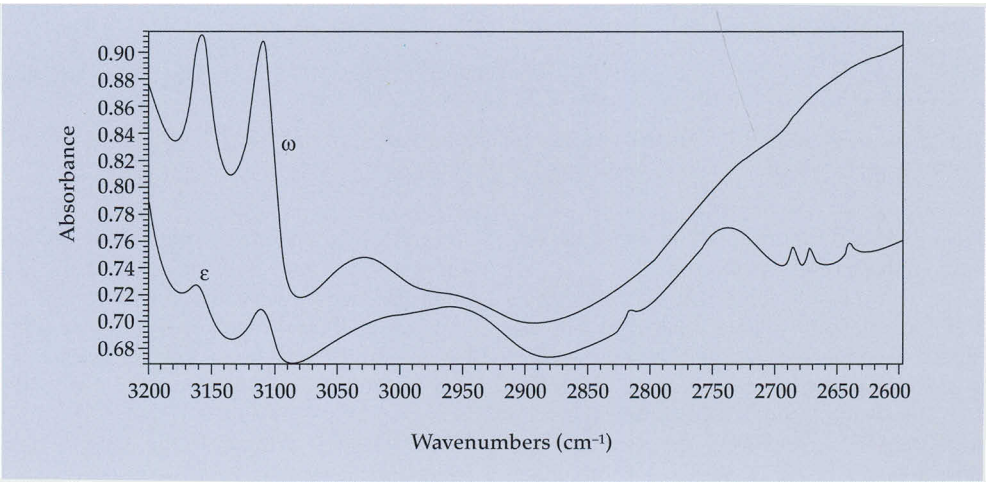

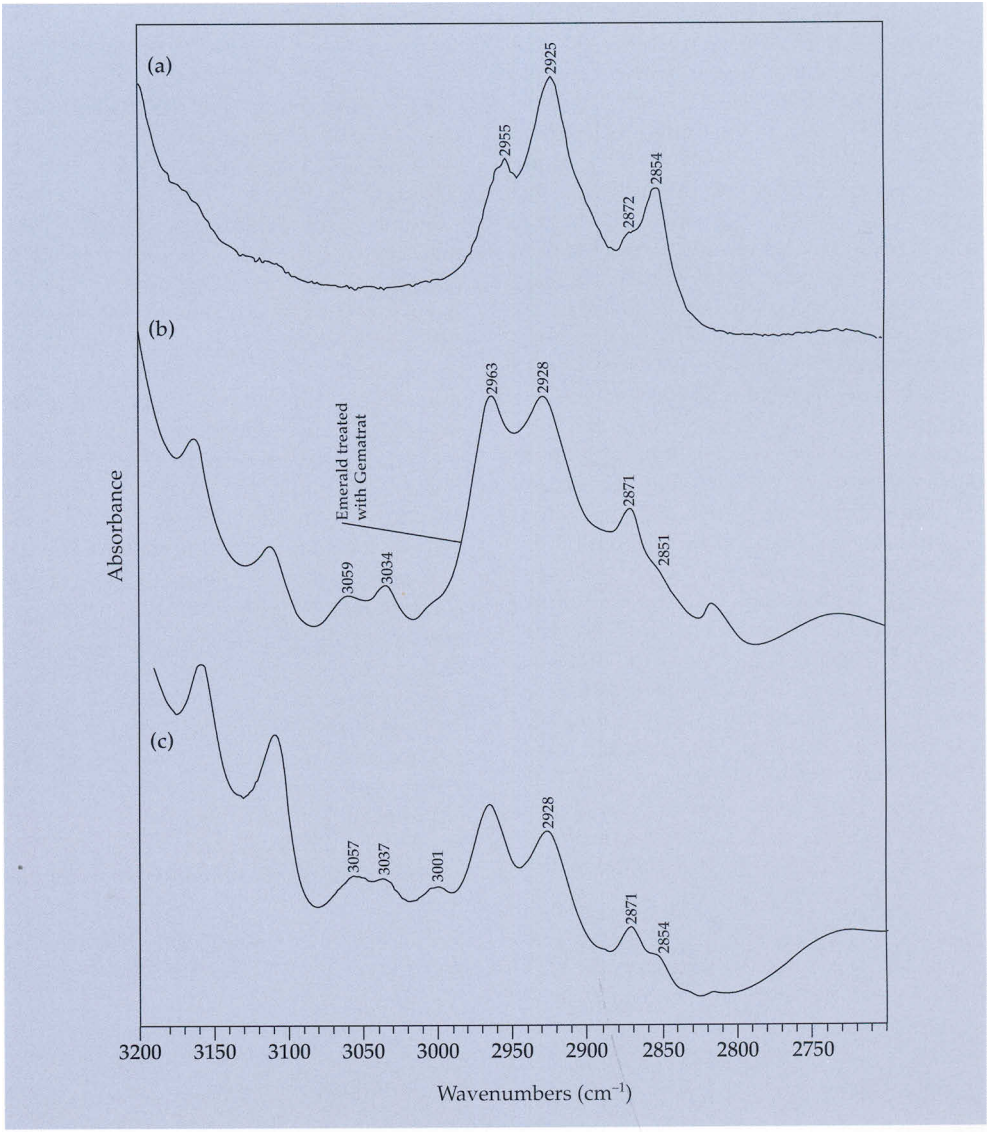

Figure 14: *FTIR spectra: (a) emerald treated with oil; (b) emerald treated with 'Gematrat'; (c) emerald treated with 'Permasafe'. © SSEF Swiss Gemmological Institute.*

fissure of a fracture-filled emerald where spot analysis can be performed.

In comparison with diffuse reflectance FTIR spectroscopy where a large part of the stone is analysed, Raman spectroscopic analysis is applied to a small spot, which has to be chosen first using a microscope. It is very important to perfectly focus the beam onto the area to be analysed. Even then a result is not always obtained and very often several different areas have to be analysed. This may make the method very time consuming.

Fissure fillers have two characteristic regions in their Raman spectra which do not interfere with the emerald peaks: 1200–1700 cm^{-1} (*Figure 15*) and 2800–3100 cm^{-1}. Although the second area generally displays more intense peaks than the

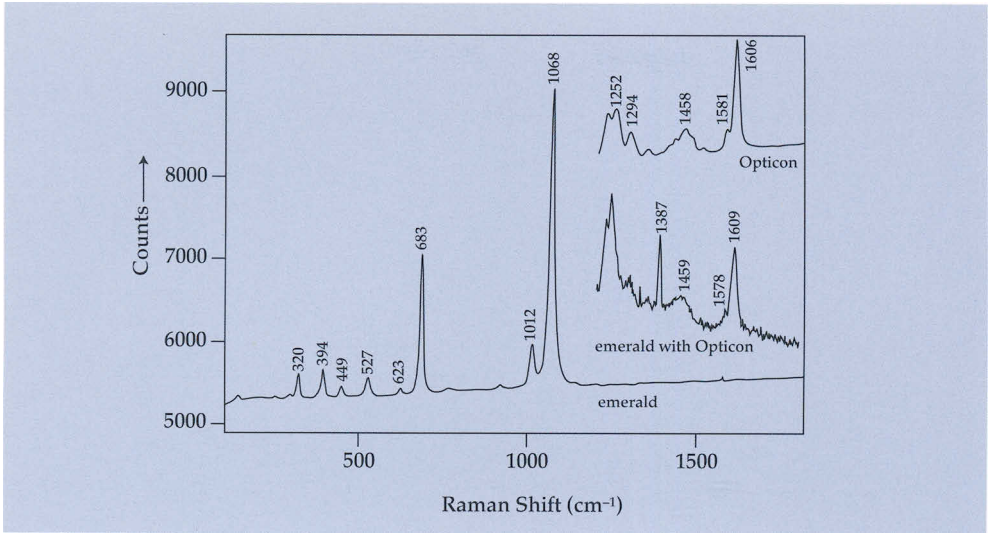

Figure 15: *Raman spectra of Opticon epoxy resin (top), of emerald without treatment (bottom), and of an Opticon-treated emerald (middle). The valuable peaks are in the 1200 to 1800 cm^{-1} area where the vibrations of organic fillers are visible. © SSEF Swiss Gemmological Institute.*

first, it may be masked by a strong Raman fluorescence of the emerald due to the wavelength of the selected laser source. Therefore the first range from 1200 to 1700 cm^{-1} is used routinely for filler identifications by Raman spectroscopy at SSEF (Hänni *et al.* 1996; Kiefert and Hänni, 1996).

The fact that this analysis can be carried out using a finely focused beam on a small area (*Figure 16;* Ostertag, 1996) makes it a much more precise method than non-focused FTIR spectrometry. Therefore, where a treatment is visible with microscopic methods or where FTIR analyses are insufficient for a positive identification, the Raman microprobe often supplies a positive response.

Raman spectra of fissure fillers in emeralds: as mentioned above, the Raman spectrum of emerald itself shows a number of distinct peaks between 100 and 1100 cm^{-1} (*Figure 15*), which are constant for emeralds from many different source areas. Due to the chromium content of an emerald in combination with the selected wavelength of the laser source, the background of the spectrum starts to rise at approximately 2500 cm^{-1} and increases towards higher numbers. This may mask some of the peaks of the filler substances between 2700 and 3100 cm^{-1}. Therefore, when doing Raman analysis on emerald fillers more attention should be given to the spectral area between 1200 and 1800 cm^{-1} where interference with the emerald spectrum is minimized and good spectra of fissure fillers are obtained.

Figure 16: *The laser beam of a Raman spectrometer focused in the middle of a transparent crystal. At the focus the excited volume is a few cubic microns. Photo by Thomas Ostertag.*

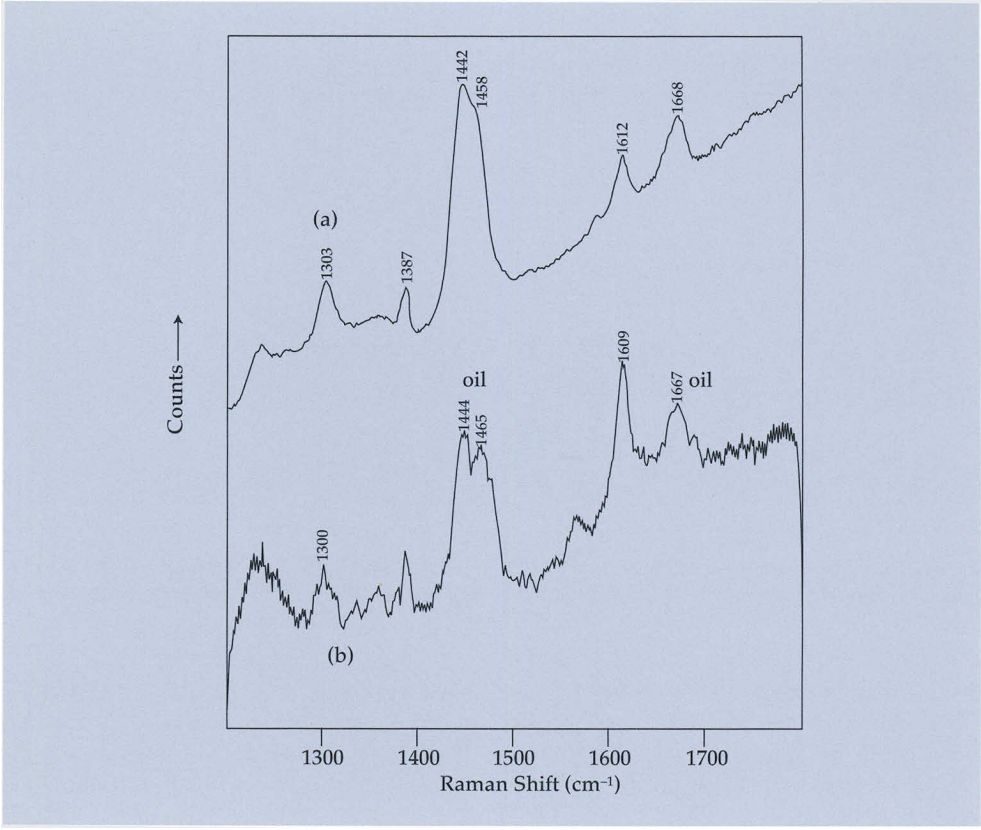

Figure 17: *Raman spectra: (a) emerald fissure with cedar wood oil; (b) emerald fissure with a mixture of cedarwood oil (1440–65 and 1667 cm^{-1}) and artificial resin (1609 cm^{-1}). The peak at 1387 cm^{-1} indicates emerald. © SSEF Swiss Gemmological Institute.*

Figure 15 shows the Raman spectrum of an emerald and the spectrum of a typical epoxy resin, in this case 'Opticon'. When an epoxy resin is encountered in an emerald fissure, the spectrum may vary from a strong signal to a very weak outline of the major peak which, however, is always visible to a certain degree. In contrast, emeralds filled with cedar wood oil show a different spectrum (*Figure 17a*).

Mixtures of various substances are generally also identifiable. Raman spectra of the more recent 'Gematrat' from the United States showed that it possesses spectroscopic properties consistent with a mixture of artificial resin and oil. Multiple fillers which may be the result of incomplete cleaning and refilling with another substance could also show similar mixed substance spectra (*Figure 17b*).

As in FTIR spectroscopy, care must be taken about any pollution from such sources as dop stick glue.

Discussion and conclusions

Experience in day-to-day laboratory routine shows that over the past few years identification of fissure fillers in emeralds has been receiving more and more attention in the trade due to new substances being introduced as fillers. The properties of these new substances such as ageing behaviour and removability are generally not well known and those in the trade are concerned about the reversibility of a filling process when the new filler substances are applied.

The identification of fissure fillers presents a challenge for gemmologists in laboratories, who, up to now have mostly specialised in inorganic chemistry and mineralogy. They have to become familiar with organic chemistry, as the commonly used fillers are organic substances. Therefore, identification of filler substances mainly relies on the comparison of spectra obtained by FTIR or Raman methods from an emerald with those of known substances.

As has been frequently observed in the use of mineralogical techniques the experience of the laboratory shows that FTIR and Raman analyses are complementary. On the one hand, certain substances which cannot be identified with FTIR spectroscopy can easily be identified with Raman spectroscopy. On the other hand there are certain substances which are difficult to identify with Raman spectroscopy but are readily identifiable with FTIR. Oil in emerald fissures, for example, shows a spectrum which is difficult to interpret when the same is analysed with an argon ion laser, but gives good results with FTIR spectroscopy. Which one of the two spectroscopic methods is applied first depends on the position of the fissures and the quantity of substance in the emerald.

The identification techniques are complementary to microscopic observations and results obtained by UV light viewing. For an experienced observer, these two latter methods can be used as an indication of a fissure treatment and an estimation of the quantity of filler(s) present.

Using spectral methods for identification, the analyses of filler substances in emeralds may sometimes be difficult to interpret because:

- there may be variations in infrared absorptions of the emerald due to anisotropy, as a function of its orientation;
- more than one filler substance may be present in the interior of the stone which presents a mixed spectrum;
- the fissures may be filled with artificial resins other than epoxy resins (*Table I*) and may not have aromatic bondings. Continuous research is necessary to keep in contact with developments.

Synthetic or artificial?

To some people in the trade it makes a big difference if a filler substance is natural or synthetic. They think that a synthetic product is worse and less acceptable. As a matter of fact, synthetic substances (by definition of the term) are analogues to their naturally occurring counterparts. Synthetic cedar wood oil or synthetic Canada balsam for example have basically the same properties as the natural ones. They possess chemical compositions and structures that cause the same optical effects and removability from the stone. Therefore, in the context of emerald treatment it is unimportant to differentiate whether a given substance is in its natural state or duplicated by a synthesis. The characteristics as fillers are the same.

In contrast to this, artificial substances do not have a natural counterpart and are newly designed substances with new properties. Epoxy resins possess chemical structures that were invented and designed by chemists and material scientists. Some of the properties are welcome as emerald enhancers, others are not. The ability to form long molecular chains and to polymerise makes them more durable in some respects, but also difficult to remove once applied. Usually epoxy resins have a refractive index closer to emerald than oils. This makes it hard for the jeweller and goldsmith to evaluate the extent and position of the treatment, and damage may occur during setting. The difference should therefore not be made between natural and synthetic, but between natural and synthetic on one side and artificial on the other.

Recent laboratory experience at SSEF indicates that about 5 per cent of emeralds examined contain fillers which cannot be positively identified. These are generally stones in which the filler has decomposed and become opaque, perhaps losing its original homogeneous chemical characteristics.

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Beryl crystals from pegmatites: morphology and mechanism of crystal growth

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ABSTRACT: Surface microtopographs of {0001}, {10$\bar{1}$0} and {11$\bar{2}$1} faces, growth sectors and growth banding, distribution of inclusions and growth dislocation, and the associated strain fields in single crystals of beryl from four pegmatite localities have been investigated by means of optical microscopy, X-ray topography and etching methods. Based on the observations, the processes of incipient crystal growth, growth fluctuations and partial dissolution of beryl in a pegmatitic environment could be analysed. Single crystals of beryl record clearly multiple changes and fluctuations in growth parameters and directional flow of nutrients during formation of the pegmatites. Entrapment of solid and liquid inclusions, generation of dislocations, and morphological changes have occurred in association with these changes and fluctuations. It has been confirmed that beryl crystals grew by the spiral growth mechanism with elemental step heights on {0001} and probably on {10$\bar{1}$0} faces throughout their growth histories, whereas {11$\bar{2}$1} faces only appeared as transitional faces during recovery after periods of partial dissolution.

Keywords: beryl, crystal growth, pegmatite, X-ray topography

Introduction

Pegmatites are major sources of coloured gemstones such as beryl (aquamarine, heliodor, goshenite, etc.), tourmaline, topaz, spodumene (kunzite, hiddenite) and chrysoberyl (cat's-eye). Crystallization of these minerals in pegmatites takes place in supercritical vapour phase conditions or in high temperature hydrothermal solutions which occupy voids in a solidifying magma. In such voids, crystals can grow freely, with little interference from the growth of co-existing crystals. Large, well-developed, transparent and near-perfect crystals can be formed and these are suitable for cutting.

Pegmatite formation represents the latest stage of magmatism, when volatile components such as H_2O, CO_2, Cl_2, F_2 and large cations such as the rare earth elements (REE) and radioactive elements, which cannot find suitable sites in the structures of the rock-forming minerals, are concentrated. Although various magmatic series may develop pegmatites as a result of differential crystallization, those producing gem-quality crystals are principally granitic pegmatites.

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Although we know broadly the formation conditions of pegmatites, we do not yet have sufficient knowledge about how the crystals grew or about the nature of changes or fluctuations in growth parameters. To clarify such a problem, the best way is to investigate the constituent minerals and particularly the surface microtopography of their crystal faces, their morphology, and their physical imperfections and chemical inhomogeneities. The external morphology of crystals provides information on growth conditions. The surface microtopographs of crystal faces reflect the growth processes and any partial dissolution processes. The internal morphology of crystals is the record of growth or partial dissolution processes, growth rate anisotropy among different crystallographic orientations, and growth rate fluctuations in one growth sector, or among crystallographically equivalent orientations. The spatial distribution of dislocations and inclusions may be correlated with events that took place during the growth process of the crystal. For successful investigations of this kind, single crystals of high perfection and homogeneity are required to reveal delicate changes in these features.

Despite severe post-growth histories, diamonds are a good example of a mineral species whose growth features have survived and have been investigated to explain growth histories; this knowledge also enables natural and synthetic diamond to be distinguished (Sunagawa, 1995). Therefore, this type of investigation forms an important basis not only for earth sciences but also for gemmology.

The stability field of beryl is the widest among eight Be-containing minerals (behoite, bertrandite, beryl, beryllite, bromellite, chrysoberyl, euclase and phenakite) of 18 minerals belonging to the $BeO–Al_2O_3–SiO_2–H_2O$ (BASH) system (Barton, 1986), and ranges from about 320° to 680°C in pressures up to 10 kbar.

Single crystals of beryl from pegmatites have been investigated using X-ray topography by such investigators as Scandale *et al.* (1979, 1990, 1993), Graziani *et al.* (1981, 1990), and Yoshimura *et al.* (1985). Scandale (1996) has recently reviewed these results, and analysed the growth histories and the relation between optical anomalies and element partitioning during growth. Observations on morphology, growth and etch figures on crystal faces and inclusions have been summarized by Sinkankas (1981).

The purposes of the present study are:

1. to correlate the imperfections and inhomogeneities in single crystals of beryl revealed by polarization microscopy, with those revealed by X-ray topography and etching methods;
2. to analyse the growth mechanism from surface microtopography and spatial distribution of dislocations;
3. to trace the morphological evolution during growth history; and
4. to interpret these results and deduce the growth history of each crystal.

The present study is principally focused on crystal growth phenomena and subtle physical imperfections.

Samples and procedures

We have investigated 19 single crystals of beryl obtained from pegmatites in Australia, Brazil and China. Eleven single crystals from Heffernan's mine, Torrington, New South Wales, Australia, five from Araçuaí and two from unknown localities in Minas Gerais, Brazil, and one from China have been investigated (*Table 1*). Crystals are hexagonal prismatic, bounded by basal {0001} and first order prism $\{10\bar{1}0\}$ faces, with some showing second order dipyramidal $\{11\bar{2}1\}$ faces. Some crystals have smooth as-grown surfaces (i.e. they retain growth features), but others have heavily etched surfaces.

The surface microtopographs of {0001}, $\{10\bar{1}0\}$ and $\{11\bar{2}1\}$ faces were observed using reflected light in an optical microscope, a reflection type phase contrast microscope (PCM) and a differential interference contrast microscope (DICM). The surfaces were coated in silver under vacuum to secure high reflectivity, and on such surfaces PCM and DICM microscopy can reveal steps with

Table 1: Some details of the beryl crystals investigated

Locality	*Sample numbers*	*Size*	*Colour*	*Morphology*
Australia:				
Heffernan's mine, Torrington, NSW	1–11	<1 cm – 2 cm	transparent yellowish pale green	hexagonal prism c, m faces present
Minas Gerais, Brazil:				
Araçuaí	12–16	3 cm – 4 cm	transparent pale green	hexagonal prism c, m, s faces present
Unknown	17	1.5 x 5 cm	transparent pale green	hexagonal prism c, m, s faces present corroded
Unknown	18	2 x 2.5 cm	translucent	c, m faces present
China:				
Unknown	19	1 x 7 cm	transparent	hexagonal prism c, m, s faces present corroded

heights of the order of one nanometre (Sunagawa and Bennema, 1982). Both spiral growth steps and etch figures were observed, depending on faces and samples.

Solid and two-phase inclusions, growth banding and growth sectors were investigated under a polarizing microscope by immersion in n-methylaniline solution, with RI 1.5702.

Dislocations were visualized by X-ray topography using the Lang method (Lang, 1978), as well as by chemical etching in HF at 150°C for three hours. X-ray topographs were taken both in prismatic and sectional directions. For the former direction, the natural prism faces of the crystals were used but for the latter direction, sections 2 mm thick were cut perpendicular to the *c*-axis, followed by polishing and weak chemical etching by HF. Dislocations, growth sectors, growth banding, inclusions, and boundaries indicating abrupt growth changes were clearly discernible on X-ray topographs.

Observations

Surface microtopographs

Surface microtopographs of crystal faces (*Figures 1, 2 and 3*) represent the final states of the faces, which may be either as-grown surfaces or weakly dissolved (etched) surfaces, or a combination of both.

Figure 1 is a low magnification reflection photomicrograph of a {0001} face of a representative beryl crystal from Heffernan's mine, and *Figures 2a, b* and *c* are DICM photographs at high magnification of a {0001} face of a crystal obtained in Teofilo Otoni. In *Figure 1*, spiral step patterns originating from a group or an alignment of screw dislocations and, in *Figure 2*, growth spirals originating from isolated dislocations are clearly visible. Spiral steps in *Figure 1* are bunched thick steps and those in *Figure 2* are elemental steps. They are visible, because the steps are decorated by impurities. The height

Figure 1: *Low magnification reflection photomicrograph showing composite growth spirals on (0001) face. Sample No. 6, Heffernan's mine, Torrington, NSW, Australia. Bar 1 mm.*

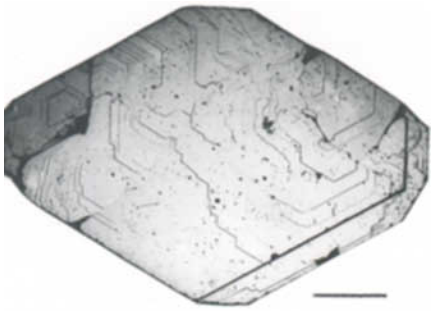

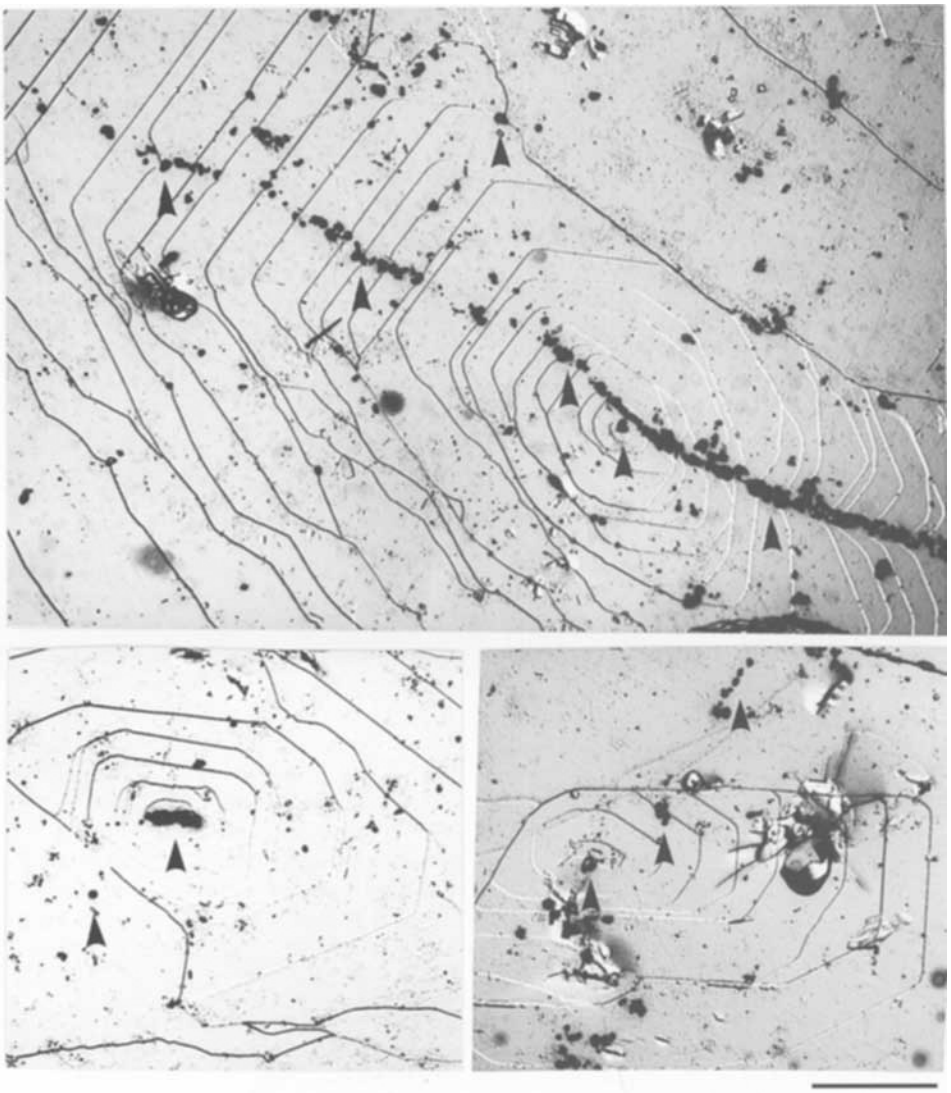

Figure 2a, b and c: *Differential interference contrast microscope (DICM) photographs showing elemental growth spirals on a {0001} face. Arrows indicate typical etch pits at dislocation outcrops. Sample No. 18, Minas Gerais, Brazil. Bar 500 µm.*

of the elemental spiral steps in *Figure 2* has been calculated to be equal to $d_{(0001)}$, i.e. 0.92 nm, whereas that of the bunched steps in *Figure 1* is much higher.

The observed spiral step patterns are essentially hexagonal, following the symmetry of the basal face, although a slight modification is present at the central turns where they show a circular form (*Figure 2*). Step separations between the successive turns of elemental spirals are in the order of 10–200 µm. The average ratio of step separations vs. step height in elemental spirals is 10^{4-6}, topographically comparable with a profile of 10000 to 1000000 metres flat terrace and a cliff of 1 metre.

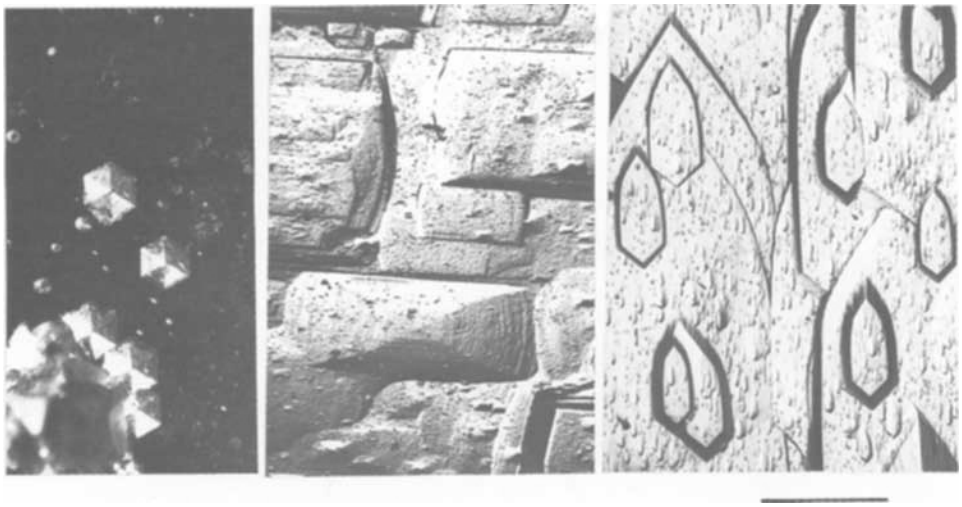

Figure 3: *(a) Deep etch pits on a {0001} face. (b) Rectangular etch figures on a {10$\bar{1}$0} face. (c) Etch pits on a {11$\bar{2}$1} face. All on sample No. 17, Minas Gerais, Brazil. Bar 200 μm.*

The {0001} faces of some samples from Araçuaí, Minas Gerais, and China show corroded surfaces, with a large number of point bottomed hexagonal or circular etch pits about 1 mm across (*Figure 3a*). They occur either isolated or in clusters and growth features are entirely absent from such surfaces. However, on the {0001} surfaces which show spiral growth steps, small etch pits are also visible at the centres of elemental growth spirals (e.g. *Figure 2a, b*), in an alignment (*Figure 2a*), as well as independently (*Figure 2a, c*). Furthermore the advancement of elemental spiral steps is disturbed, either kinked or retarded, along the alignment of these etch pits (*Figure 2a*). All these minute pits are etch pits formed at the outcrops of dislocations on the {0001} surface. Some are edge dislocations, but there should also be some screw or mixed dislocations which did not play an active role as spiral growth centres and only appear as etch pits.

The {10$\bar{1}$0} faces of beryl crystals from Heffernan's mine are characterized by elongated hillocks parallel to the *c*-axis, whereas those from Minas Gerais have hillocks of rectangular form elongated perpendicular to the *c*-axis, with curved shorter edges (*Figure 3b*). The rectangular patterns usually show a summit at the centre and discernible steps on the sloped side faces, suggesting the presence of spiral growth hillocks on the original as-grown surfaces, before they received etching. The {10$\bar{1}$0} faces of most of the samples show weakly or heavily etched surfaces and do not retain any original as-grown surfaces. Thus, elemental growth spirals were not observable on these present surfaces but they must be present on the original as-grown surfaces.

The {11$\bar{2}$1} faces of crystals from Minas Gerais and China are characterized by heavily developed etch pits only (*Figure 3c*) whose symmetry follows strictly that of the face. Step patterns indicative of growth steps were not observed on these faces.

Internal features

Section perpendicular to the c-axis

A section cut perpendicular to the *c*-axis of a crystal (No. 12) from Araçuaí is shown in *Figure 4* as an X-ray topograph (a), an optical photomicrograph under crossed polarizers before (b) and after etching (c).

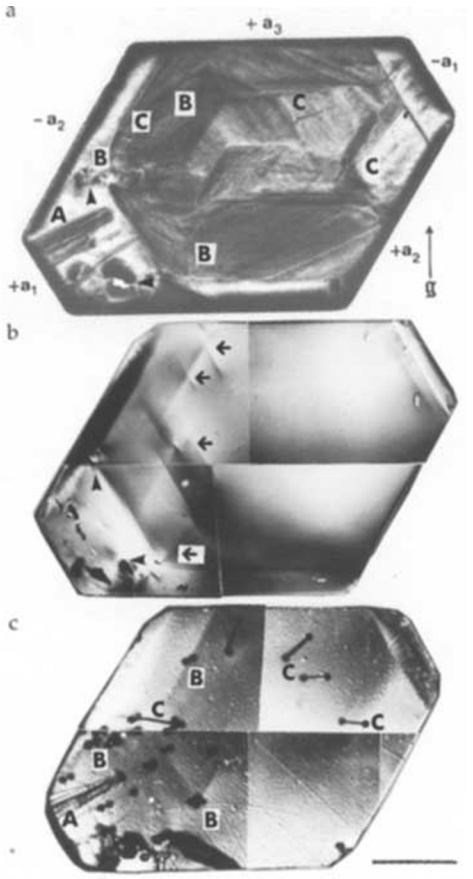

Figure 4: *(a) X-ray topograph; (b) photomicrograph under crossed polarizers before etching of a section cut perpendicular to the c-axis of a crystal (No. 12) from Araçuaí, Minas Gerais, Brazil; (c) same section as (b) after etching. Dislocations parallel (A), perpendicular (B) and inclined (C) to {0001}, and the associated anomalous birefringence (open arrows in b) are indicated. Solid inclusions are indicated by closed arrows. Bar 1 mm.*

Comparing *Figures 4a* and *c*, dislocations parallel, perpendicular and inclined to the section can be clearly distinguished. On the X-ray topograph (*Figure 4a*) and the etched section (*Figure 4c*) dislocations parallel to the section appear as sheaf-like groups of lines, indicated by A. Dislocations perpendicular to the section appear as rounded hexagonal dots indicated by B. On the etched section, they can be seen much more clearly than on the X-ray topograph. The rounded hexagonal dots are etch pits formed at dislocation outcrops. Dislocations inclined to the section appear as short lines connecting two rounded hexagonal dots, as indicated by C. These are dislocation tunnels formed by preferential etching along dislocation lines. Due to the strain fields around dislocations, hexagonal etch pits formed at the outcrops of such dislocations are to some degree rounded, and the associated etch tunnels along the dislocation lines are narrower. Dislocations (B) perpendicular to the section show distinct anomalous birefringence, clearly visible under crossed polarizers (*Figure 4b*, open arrows). Dislocations inclined and parallel to the section do not give distinct anomalous birefringence images. The latter two types of dislocations also appear less clearly on the X-ray topograph (*Figure 4a*). From the thickness of the section it can be deduced that dislocations indicated by C have an inclination of about 30° to the *c*-axis.

Figure 4b shows the distribution of inclusions, which are also visible on the X-ray topograph (*Figure 4a* closed arrowheads). It should be noted that dislocations running perpendicular to the section (parallel to the *c*-axis) are generated from these inclusions.

In *Figure 4a*, an X-ray topograph reveals internal textures more clearly than photographs of unetched (*Figure 4b*) and etched (*Figure 4c*) sections. Three distinct stages (two boundaries) can be seen on *Figure 4a*; the central superimposed double rhombic outlines, surrounded by a slightly rounded hexagonal outline and further by a malformed hexagonal outline. We distinguish three stages – 1, 2 and 3 – during the growth process of this particular crystal.

From the internal textures shown in *Figure 4a*, it is apparent that the widths of the successive stages in crystallographically equivalent directions, i.e. the growth rates, are not the same. The growth rates in the $+a_1$ direction both between stages 1 and 2, and 2 and 3, are about three times higher than in

the $-a_1$ direction. The growth rates in the $+a_2$ direction between stages 1 and 2 are nearly equal to that in the $-a_2$ direction, but decrease to a third of the growth rate in the $-a_2$ direction between stages 2 and 3. There are similar changes in the a_3 direction. The observed variation of growth rates among crystallographically equivalent directions demonstrates that during the period from stage 1 to 2, there was no severe anisotropy involved in the growth environment, except a weak directional flow along the a_1 direction. However, during the period between stages 2 and 3, the presence of a strong directional flow of solutions along the a_1 direction has to be assumed.

A higher growth rate in the $+a_1$ and $-a_2$ directions compared with the $-a_1$, $+a_2$ and a_3 directions should be related firstly to some extent to dislocations parallel to the section which were generated from inclusions at the boundary between stages 2 and 3, and secondly, but to a lesser extent, to dislocations perpendicular to the section which were generated from inclusions trapped at a rounded corner between stages 2 and 3. Entrapment of inclusions should be related to the change in conditions which resulted in the appearance of this boundary, and the dislocations from these inclusions should have accelerated the growth rate in this direction.

By correlating *Figure 4b* with *4a* and *4c*, an anomalous birefringence due to strain fields associated with dislocations is apparent when a section perpendicular to the optic axis is viewed under crossed polarizers. Beryl crystals often exhibit marked optical anomalies under crossed polarizers (*Figure 5*). The present observations have demonstrated that dislocations are one of the main causes of optical anomalies observed in beryl crystals.

Figure 5: *An example of commonly observed optical anomalies, most of which are associated with dislocations. Section perpendicular to* c*-axis. Crossed polarizers. Sample No. 8, Heffernan's mine, Australia. Bar 1 mm.*

Observations parallel to the c*-axis*

Optical observations were carried out in immersion liquid under crossed polarizers and X-ray topographs were taken parallel to the *c*-axis of uncut prismatic crystals. Since the thicknesses of the crystals are more than a few mm, the quality of the X-ray topographs is poorer than those from the 2 mm section cut perpendicular to the *c*-axis; yet important information was still obtainable.

In *Figures 6a* (a mosaic photograph of images of internal textures under crossed polarizers) and *6b* (a line drawing of *6a*), the internal textures are most clearly shown in the optical photograph. Also in *Figure 6* the following features can be seen:

1. elongated tube-like inclusions parallel to the *c*-axis, and another type of inclusion concentrated parallel to the {0001} face near the termination of the crystal (F in *Figure 6b*);
2. growth zoning, both strong and faint, parallel to {0001}, $\{10\bar{1}0\}$, $\{11\bar{2}1\}$ and associated higher order index faces;
3. six growth stages as indicated by labels A to F in *Figure 6b*, where growth zones parallel to {0001} are truncated by rounded boundaries. Starting from the rounded boundaries, growth banding is initially parallel to rounded higher index faces and then to $\{11\bar{2}1\}$ faces, which eventually disappear, and the crystal becomes bounded again only by {0001} and $\{10\bar{1}0\}$;

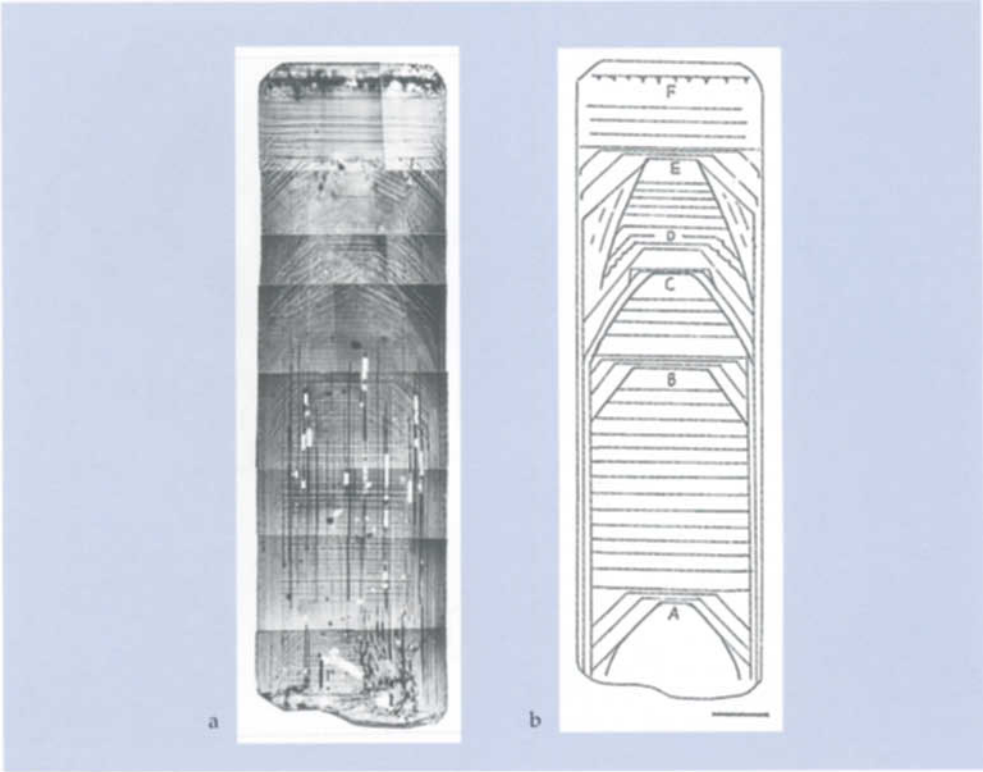

Figure 6: *(a) Mosaic photomicrograph under crossed polarizers and (b) sketch of section in (a) showing the internal texture. Labels A to F in (b) indicate the positions where partial dissolution (A to E) and bubbling (F) took place. Sample No. 10, Heffernan's mine, Australia. Bar 1 mm.*

4. the {0001} growth sector occupies five-sixths of the whole prism in the section, whereas the $\{10\bar{1}0\}$ growth sectors amount to only one-sixth throughout the growth process.

An X-ray topograph of the crystal in *Figure 6* indicated the presence of strain fields. To investigate these strain fields in more detail, another X-ray topograph of another sample from the same locality was taken (*Figure 7*).

Figure 7 clearly shows contrast images parallel and perpendicular to the *c*-axis. A series of bundles of linear contrast images originate from two lines parallel to $\{10\bar{1}0\}$ and nearly perpendicular to the prism surface (indicated by arrows). Their origins are related to faint lines (contrast images) parallel to the *c*-axis in the central zone of the prism.

Figures 8a, b and *c* show higher magnification photographs of tube-like inclusions parallel to the *c*-axis under crossed polarizers. Growth banding, solid and two-phase inclusions, and associated strain fields are discernible. *Figure 8a* clearly shows that the elongated tube-like two-phase inclusions originate from near-platy solid inclusions, either on their own or in clusters. The solid inclusions are, in many cases, inclined to the tube-like inclusions and are located not on the {0001} surface, but on surfaces which are curved or inclined to {0001}. On the basis of their distribution, the starting points of the tube inclusions appear to be closely related to the start of the growth period marked by rounded boundaries, i.e. immediately after the cessation of partial dissolution.

The tube-like inclusions are variable in shape, some with simply tapering tips and

others with tips showing crystallographic forms, although all have an aspect ratio (length/breadth) of more than 5. The presence of linear strain fields extending along lines defined by the tubes are visible in *Figure 8c*, indicating that a dislocation is generated from the tip. This is most probably the origin of dislocations running parallel to the c-axis, shown in *Figure 4c*. Negative growth banding is also present (*Figure 8c*). Negative growth banding is due to crystallization of the solution enclosed in the tube-like inclusion, i.e. it constitutes part of the process of formation of a negative crystal.

Both solid and liquid inclusions densely distributed on a plane near and parallel to the {0001} surface (*Figure 6a*) have different properties from the tube-like two-phase inclusions described above. Their distributions in plan and section are shown in *Figures 9a* and *b* respectively. Two-phase inclusions are concentrated below the solid inclusions directly below the plane. The relations between solid and two-phase inclusions are just the reverse of those shown by the first type of inclusions (*Figure 8a*). The two types of inclusions thus cannot have the same origin.

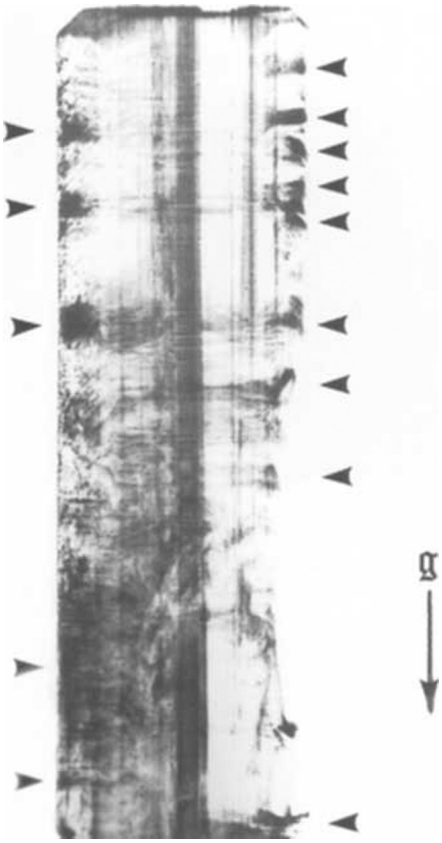

Figure 7: *X-ray topograph of a crystal from Heffernan's mine, Australia. Arrows indicate positions of dislocation bundles perpendicular to the c-axis, 'g' indicates the direction of diffraction plane. Bar 1 mm.*

Discussion

Growth history

At least six stages where partial dissolution took place were distinguished in crystal No. 12 from Heffernan's mine. Similar multiple periods of partial dissolution and re-growth have been observed in beryl crystals from many other localities. We may safely assume that such events took place generally during the formation of many pegmatites. Growth → partial dissolution → re-growth events and morphology changes in association with these events have been encountered in other pegmatitic minerals such as topaz (Isogami and Sunagawa 1975), quartz and tourmaline.

The assumption that pegmatite formation took place under conditions of an open system is confirmed by the fact that directional flow of nutrient solutions during the formation of beryl crystals has been indicated by the growth features in many crystals investigated (*Figure 4*). Similar observations have been reported by Scandale *et al.* (1979, 1990, 1993), and Graziani *et al.* (1981, 1990). In general there is little evidence for directional flow at the early stages of growth, but at the later stages of beryl formation the growth rates on the sides facing the flow of solution were twice as high as on those on the 'lee' side. The increased flow rate resulted in the entrapment of solid inclusions on the interface, which in turn generated dislocations, resulting in further acceleration of the growth rates of the crystal faces facing the flow.

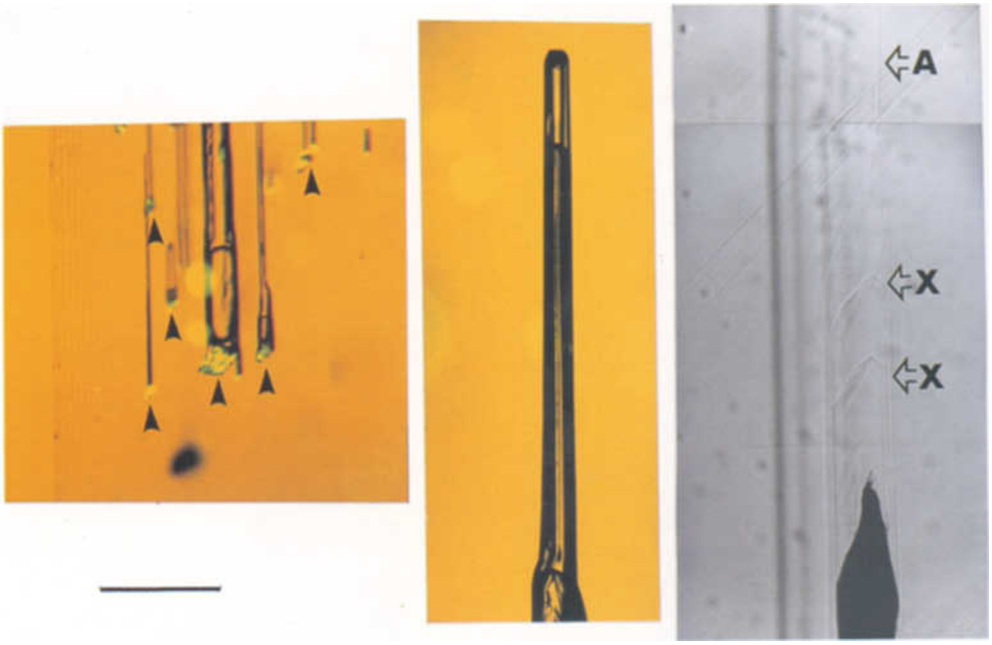

Figure 8: (a) Photomicrograph of tube-like two-phase inclusions formed adjacent to solid inclusions (indicated by arrows). (b) Negative crystal. (c) Strain field (arrow A) around a dislocation generated from a misfit in the incorporation of the inclusion and negative growth banding (arrows X). Growth banding is also present. Sample No. 10, Heffernan's mine, Australia. Bar 500 μm.

Based on observations of growth banding in sample No. 10 (*Figure 6*), the morphological evolution of the beryl crystal can be traced, and the morphological importance of the different faces can be evaluated.

At the earliest stage, the crystal developed a hexagonal tabular habit with an aspect ratio (i.e. a ratio of length ∥ c versus width ⊥ c) less than 0.2, and bounded by {0001} and $\{10\bar{1}0\}$ faces only. As growth proceeded the aspect ratio increased, and at the final stage the crystal habit became hexagonal prismatic, with a ratio up to 3. The width of the hexagonal prism did not change much and about five-sixths of the width of the prism was already realized during the earliest stage. This implies that the normal growth rate of $\{10\bar{1}0\}$ is much smaller than that of {0001}. The average ratio of normal growth rates, {0001}: $\{10\bar{1}0\}$, is about 2 : 1, measured from the widths of concurrently formed growth bands.

Partial dissolution has taken place preferentially and severely at the edges and corners between {0001} and $\{10\bar{1}0\}$ faces, resulting in rounded rough hexagonal pyramidal surfaces, with higher $\{hk\bar{i}l\}$ indices than $\{11\bar{2}1\}$. After a period of partial dissolution, regrowth starts and $\{11\bar{2}1\}$ faces start to appear on the partially dissolved rounded surfaces, but eventually completely disappear. The crystal habit changes to a simple hexagonal prism, bounded by {0001} and $\{10\bar{1}0\}$ faces only, when the growth conditions are stabilized. The ratio of growth rates of the faces $\{11\bar{2}1\}$ and {0001} are around 3.3 to 4.3, and ratio of growth rates of $\{11\bar{2}1\}$ to $\{10\bar{1}0\}$ around 5 to 6.

From the above analysis, it can be concluded that:

1. only {0001} and $\{10\bar{1}0\}$ faces are stable and persistent faces in beryl crystals in pegmatitic environments;
2. $\{11\bar{2}1\}$ faces are transient faces which can appear only when certain changes (in the present case, partial dissolution) occur in the growth parameters and which may

disappear when the conditions are stable again; and

3. the order of morphological importance is $\{10\bar{1}0\} > \{0001\} >> \{11\bar{2}1\} >> \{hk\bar{i}l\}$.

Dislocations and inclusions

Two types of inclusions were distinguished: firstly, tube-like two-phase inclusions elongated parallel to the *c*-axis which originate from solid inclusions are common (*Figure 8a*); the second type is shown in *Figure 6a*, where a group of inclusions parallel to {0001} near the termination of a prismatic crystal characteristically show an origin from two-phase inclusions and are capped by solid inclusions.

Most solid inclusions which generate the tube-like inclusions are probably micas distributed principally on partially dissolved beryl faces with their crystal axes inclined to the elongation of the two-phase inclusions. The two-phase inclusions were formed 'behind' the solid inclusion, relative to the direction of crystal growth, where mother liquid was trapped in tubes and normal growth could not proceed. Two-phases appeared in the tube through later cooling and when temperatures had dropped sufficiently. When an inclusion of mother liquid was incorporated, it generated dislocations by mismatch of lattice planes. The dislocations propagate generally along the same direction as the inclusion, parallel to the *c*-axis. The outcrops of these dislocations on the growing {0001} surface acted as growth centres, producing growth spirals. Within the occluded mother liquid, some further growth on the inclusion walls took place, and this resulted in so-called negative crystals (*Figures 8b* and *c*).

The second type of inclusion comprises two-phase inclusions situated beneath the solid inclusions relative to the crystal top (*Figure 9b*). This is the reverse of the relation between solid and liquid inclusions of the first type and may be explained in the following way. If it is assumed that gas bubbles stick on a growing {0001} surface, crystal growth will be retarded underneath, and the bubbles will be surrounded as growth proceeds. This results in the formation of inclusions of the second type, and indicates that gas bubbles were present at this latest stage of beryl formation.

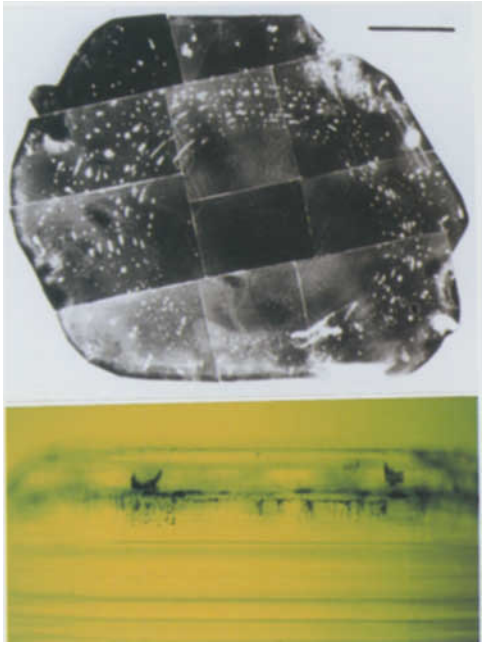

Figure 9: *Cluster of inclusions parallel to (0001), close to the termination of the crystal. Sample No. 10, Heffernan's mine, Australia. (a) Plan view; spiral growth steps on the surface are visible. (b) View perpendicular to {0001} with tube inclusions and growth banding visible. Bar 500 μm.*

In *Figure 4c*, bundles of dislocations parallel to {0001} are visible, i.e. perpendicular to the *c*-axis, and they originate from solid inclusions present along the boundary of two growth stages. In *Figures 6* and *7*, it is obvious that dislocations of this type were generated repeatedly during the whole growth history of the crystal. They originated from a few specific prismatic crystal faces (growth stages), and while some were inherited from earlier dislocations, others were newly generated. There is no doubt that these dislocations acted as sources for growth spirals on $\{10\bar{1}0\}$ faces.

Crystal growth mechanism

Spiral growth on {0001} and probably on $\{10\bar{1}0\}$ faces with spiral layers of elemental height, i.e. equal to $d_{(0001)}$ or $d_{(10\bar{1}0)}$ have been confirmed. Both $d_{(0001)}$ and $d_{(10\bar{1}0)}$ are about 0.92 nm, nearly equal. But the normal growth rate of {0001} is nearly twice as high as that of $\{10\bar{1}0\}$. To explain this difference, it must be assumed either that the density of dislocation outcrops is twice as high on {0001} as on $\{10\bar{1}0\}$ or that the elemental height of spiral steps is a half of $d_{(10\bar{1}0)}$ on $\{10\bar{1}0\}$ faces and equal to $d_{(0001)}$ on {0001} faces. Since there is no significant difference in the density of dislocation outcrops on X-ray topographs (e.g. see *Figures 4a* and *c*, or 7), it is reasonable to assume that the difference in step heights of elemental layers is the probable reason for the growth rate difference between the two faces.

The observed elemental growth spirals on the {0001} face are essentially hexagonal, following the symmetry of the face. The step separation normalized by step heights was 10^{4-6}. Although elemental growth spirals were not confirmed on $\{10\bar{1}0\}$ faces in this study because they received natural etching, two types of elongated rectangular patterns are present on these faces. One pattern consists of growth hillocks elongated parallel to the *c*-axis, and the other is a rectangular form with curved steps on the shorter sides parallel to the *c*-axis and straight steps perpendicular to the *c*-axis on the longer sides.

Rectangular growth spirals elongated perpendicular to the *c*-axis, and rhombic growth spirals with the shorter diagonal parallel to the *c*-axis have been reported on $\{10\bar{1}0\}$ faces of beryl and emerald by several workers (Griffin, 1950; Sunagawa, 1964). The first evidence to prove the spiral growth theory (Frank, 1949) was indeed observed on $\{10\bar{1}0\}$ faces of beryl, which exhibited rectangular patterns elongated perpendicular to the *c*-axis, in a form of horseshoe due to co-operation of right-hand and left-hand growth spirals (Griffin, 1950).

The morphology of growth spirals is controlled by the growth parameters. Growth spirals take a circular form when spiral steps are rough, consisting almost entirely of a succession of kinks. They take a polygonal form, with the straight sides in crystallographic directions consistent with the symmetry of the face, when the steps are smooth (low kink density). Thus, in terms of the growth parameters, circular spirals appear when a crystal grows in either higher temperature or higher driving force (supersaturation) conditions.

The step separation between the successive spiral arms is related to the radius of the critical two-dimensional nucleus, which itself is determined by the step free energy and the driving force. This means that for a smaller driving force, i.e. when supersaturation is low, a wider step separation is expected. These relations were theoretically analysed and the ideas were confirmed by observations (see Sunagawa and Bennema, 1982).

Sunagawa (1978) showed that the step separation versus step height ratios are in the order of 10^{4-6} for crystals grown from a vapour phase, and 10^{2-3} for crystals grown from an aqueous solution. The values obtained in this study of 10^{4-6} suggest that the beryls grew from a fluid with a low concentration of nutrients, close to a vapour phase. Hexagonal and rectangular morphologies of observed growth spirals on {0001} and $\{10\bar{1}0\}$ faces respectively, imply that the growth temperature was too low to stimulate many kinks and was therefore below the roughening temperature of the respective faces. From both results, a dilute phase for the formation of the pegmatite can be deduced.

Etching effects after the cessation of growth

Etch pits of various sizes were observed on the crystal surfaces. Small etch pits with hexagonal form appear at the outcrops of dislocations. On the surfaces of {0001}, $\{10\bar{1}0\}$ and $\{11\bar{2}1\}$ faces, much larger and deeper etch pits were formed after the cessation of beryl growth, but the degrees of etching on different crystals differ both within and between localities. Some crystals are not etched, preserving their as-grown surfaces, whereas others are heavily etched and some crystals have been reduced to rounded or irregular forms full of hollows.

Conclusion

From the examination of beryl crystals from four regions by means of polarization microscopy, X-ray topography and etching methods, the following issues have been clarified.

1. The crystallization of hexagonal prismatic beryl crystals in pegmatitic environments is characterized by multiple periods of growth and partial dissolution.
2. The growth rate of $\{10\bar{1}0\}$ is about half that of $\{0001\}$, and about a sixth that of $\{11\bar{2}1\}$. $\{10\bar{1}0\}$ and $\{0001\}$ are stable faces, whereas $\{11\bar{2}1\}$ is a transient face appearing only when growth conditions change.
3. Solid inclusions, principally micas, precipitated on partially dissolved surfaces and were the basis of tube-like two-phase inclusions. These in turn generated dislocations which acted as centres of growth spirals. A second type of two-phase inclusion results from adhesion of gas bubbles in the mother liquid on to the crystal surfaces.
4. The mechanism of spiral growth operated on $\{0001\}$ and $\{10\bar{1}0\}$ faces.
5. Beryl formation in pegmatites probably took place in very dilute liquids, close to vapour phase conditions.
6. After the cessation of growth, some crystals were etched to various degrees with formation of etch pits, whereas other crystals preserved their as-grown surfaces.

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Investigation of the 'haggis rock' from the Scottish Borders

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ABSTRACT: The nature and origin of the peculiar spotted rudite known as 'haggis rock' from the Peebles area of Scotland has long been shrouded in controversy. A re-examination of the rock fragment assemblage indicates that the principal pebble constituents include clayrock, quartz, chert and igneous rocks and that the amount of each varies appreciably even within a single hand specimen. The unusual composition and structure of the rock are attributed to mixing of two independent clast populations; a rounded pebble population resedimented from a shallow water, tidal environment and a matrix population of finer grained material with deep-water affinities associated with oceanic turbidity currents. The 'haggis rock' beds are affected by faulting and appear lensoid in shape. They range up to 5 m thick and are traceable discontinuously for at least 60 km. The 'haggis rock' is amenable to processing using conventional lapidary equipment to produce ornamental pieces but the variations in hardness among the diverse pebbles and between the pebbles and matrix need careful polishing to produce good surfaces.

Keywords: haggis rock, rudite, Scotland

Introduction

The term 'haggis rock' has been used to denote an unusual rudaceous (pebbly) rock that, although dark green coloured, contains sharply contrasting, uniform sized, subrounded to subangular clasts of various colours (*Figure 1*). The striking similarity with Scotland's national culinary dish and ease of working of the rock have resulted in its desultory use in ornaments and costume jewellery. 'Haggis rock' has not been promoted as an ornamental stone and surprisingly has been overlooked by the local tourist industry for the souvenir trade.

Elsewhere in the world, the mining of ornamental rocks has undergone spectacular development during the last 20 years with considerable improvement in both productive processes and the machinery used. Accordingly, a renewed interest in the development potential of 'haggis rock' appears apposite.

The best known occurrences of the rock are restricted to a relatively narrow belt of country in the vicinity of Peebles in the Scottish Borders region of Great Britain (*Figure 2*).

Geological setting

Throughout the Southern Uplands of Scotland, Lower Palaeozoic turbidite sequences predominate. Turbidite is a sedimentary rock inferred to have been deposited from a turbidity flow or

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bottom-flowing current laden with suspended sediment. Such a current would be relatively dense and would move swiftly under the influence of gravity down a subaqueous slope and spread over the seabed or the bottom of a lake. Turbidity currents are known to exist at the present day and are believed to have produced the submarine canyons notching the continental slope. They appear to originate in various ways such as by storm waves, tsunamis, earthquake-induced sliding, tectonic movement, over-supply of sediment, and heavily charged rivers in spate. Turbidites are characterised by graded bedding, poor to moderate sorting and well developed sedimentary structures.

The turbidite strata in the Southern Uplands are generally steeply inclined with a consistent northeast-southwest regional strike. They are cut by a series of major northeast-southwest trending strike-parallel faults.

Figure 1: *Samples of the 'haggis rock' illustrating its characteristic texture.*

The principal outcrops of 'haggis rock' lie within thin to thick bedded, sandy and silty turbidite strata which underlie the northern part of the Southern Uplands. The 'haggis rock' forms discontinuous lenses within the Marchburn Formation, a sub-unit of the Leadhill Group of mid-Ordovician age and adjacent to the Southern Upland Fault (SUF) (*Figure 2*). Possible correlatives of the 'haggis

Figure 2: *Sketch map showing location of the 'haggis rock' outcrops. After Ritchie and Eckford (1936).*

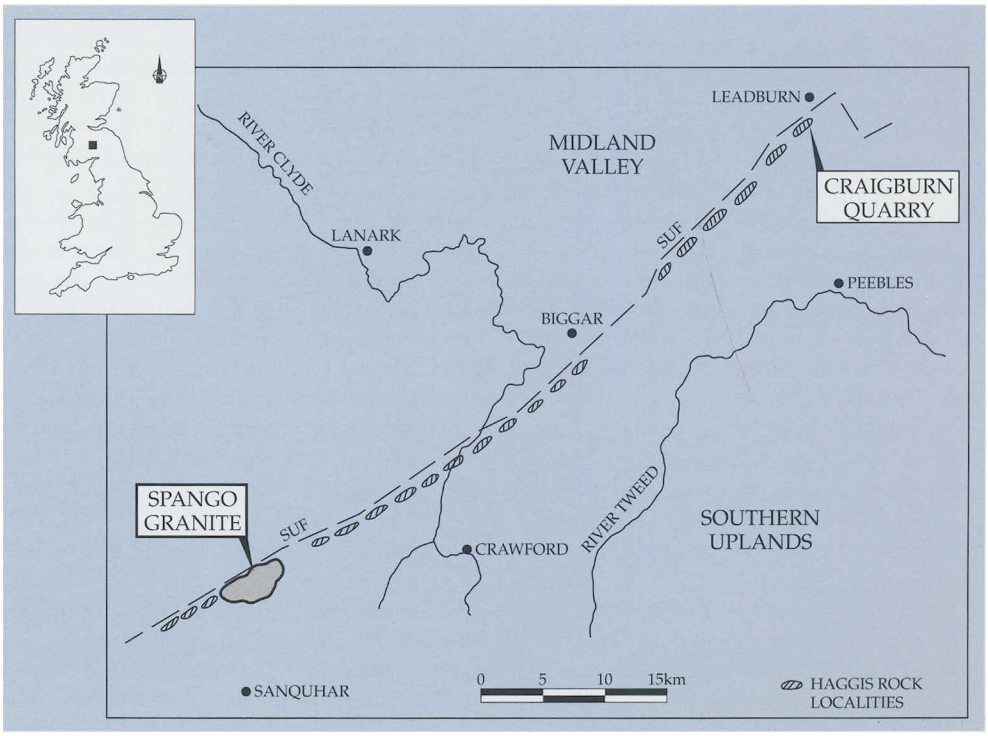

rock' have been recognized by Kelling (1961) in the Portpatrick Formation of southwestern Scotland.

The 'haggis rock' can be most readily examined in the disused Craigburn quarry situated alongside the A703 Edinburgh-Peebles Road, 1.5 km south of Leadburn crossroads (Stone, 1992). National Grid Reference NT 237544 applies. Here, the beds strike northeast and dip at moderate to steep angles northwestwards. Fault-bounded outcrops of 'haggis rock' are observationally accessible at the northeastern end of the quarry.

Historical background

The term 'haggis rock' is acknowledged to be of considerable antiquity having been applied to the rock in olden days by quarrymen. Indeed mention is made of the rock in the explanatory notes of a geological map sheet published in 1871 where the name is stated to be of local origin. Other early accounts of the 'haggis rock' are given by Peach and Horne (1899) who provided hand specimen descriptions and Ritchie and Eckford (1936) who carried out petrographic examination of samples collected from several localities along the outcrop belt. Ritchie & Eckford (*op cit*) matched approximately 80% of the rock-fragment assemblage with older rocks cropping out nearby and concluded that a large part of the material composing the 'haggis rock' is of local derivation. They also considered the narrow grain size distribution and subrounded shape of the pea-sized clasts indicative of sedimentation in a quiet, shallow, inshore, marine environment affected by tidal scour processes.

In marked contrast, the strata associated with the 'haggis rock' are turbidite (greywacke and mudstone) beds that are widely described as accumulations associated with pelagic, open-ocean and deep water environments of deposition (*e.g.* Leggett, 1987, and references therein). In this deep-water setting, the 'haggis rock' apparently represents a deposit of coarse-grained turbidite, perhaps the product of a single turbidity flow instigated by a regional tectonic event during Ordovician time.

Thus two very different settings have been proposed for the depositional environment of the 'haggis rock' and some uncertainty remains. From this brief review of the literature it is evident that the origin of the 'haggis rock' remains a matter of controversy. Conceivably, the 'haggis rock' comprises two independent clastic populations. First, fine grained turbidite material similar to that composing the neighbouring strata and secondly, the pebbly material that originated in a shallow water environment but was subsequently transported from this provenance by turbidity currents and recycled into the deeper waters of the basin of accumulation. This postulated origin accords with the distinctive bimodal grainsize distribution exhibited by the 'haggis rock'. These two clastic populations combine to give a rock which classifies as either a pebbly turbidite or fine conglomerate.

Composition

The most striking feature of 'haggis rock' is the mosaic of colour displayed by the various pebble constituents. Lithologies are listed in *Table I* together with colours quoted with numerical designations based on the Munsell system of colour identification (Rock-Colour Chart Committee, 1963). Munsell colours were determined on polished specimens.

The rock-fragment assemblage of the 'haggis rock' consists predominantly of clayrocks with green, grey and black shales and brown mudstone. White quartz and grey and black chert are subdominant. Igneous rock-fragments constitute a diverse group and the relative abundance of each clast type varies appreciably even within a single hand specimen. The igneous clast types include red jasper, purple volcanic rock, pink felsite and granite and dark green gabbro, dolerite, andesite and spilite.

The matrix material consists of sand, silt and clay sized particles. Following sedimentation and burial, regional metamorphism partially transformed the finer grained detrital matrix material causing minor mineralogical reconstitution. The principal metamorphic mineral is chlorite.

Table I: Composition and colour of the pebble clasts in the 'haggis rock'.

Rank No.	Lithologies	Colour	Colour designation (Munsell)
1	Clayrock	Pale brown	5YR 5/2
		Light brown	5YR 5/6
		Light brown	5YR 6/4
		Moderate brown	5YR 4/4
		Moderate brown	5YR 3/4
		Brownish black	5YR 2/1
		Dark greenish grey	5GY 4/1
2	Quartz	White	N9
		Very light grey	N8
3	Chert	Black	N1
		Medium grey	N5
4	Igneous rocks	Medium light grey	N6
		Moderate red	5R 5/4
		Moderate red	5R4/6
		Greyish red	10R 4/2
		Moderate yellowish brown	10YR 5/4
		Dark yellowish brown	10YR 4/2
		Greyish orange	10YR 7/4
		Greyish green	5G 5/2
		Dark greenish grey	5GY 4/1

Physical features

The 'haggis rock' beds range up to 5 m thick and are traceable discontinuously for at least 60 km along the line of strike. They are generally affected by faulting and so outcrops appear lensoid in shape.

Certain samples of 'haggis rock' display a poorly developed foliation associated with the main phase of regional metamorphism and folding. Other structural features include faults, joints, minor fractures, tension cracks, discordant veins and open cavities. In the near surface zone, weathering has affected these tectonic dislocations and rock defects and they commonly feature localised discolouration and a susceptibility to disintegration. Weathered and fresh rock range from moderately weak to weak and strong to very strong respectively.

The known deposits of 'haggis rock' either crop out or are concealed beneath thin overburden and can therefore be worked by opencast methods. Borehole exploration would indicate the subsurface extent and quality of specific 'haggis rock' deposits and provide geotechnical information for quarry design purposes.

Processing

Selected material can be processed satisfactorily using conventional slabbing, trimming, tumbling and polishing equipment.

The textural features and variable grain composition affect the polishing characteristics. The softer matrix material tends to undercut producing an uneven polish. To a much lesser extent, variations in hardness and toughness of the pebble clasts

Figure 3: 'Haggis rock' ornaments.

also cause irregularities on polished surfaces. Nonetheless, a variety of items have been successfully produced including pendants, paperweights, bookends and costume jewellery pieces (*Figure 3*).

Conclusions

'Haggis rock' formed in a sedimentary environment. It is an unusual pebbly turbidite or fine conglomerate that crops out prominently in the Peebles district of the Scottish Borders. It appears associated with the turbidite strata within the Marchburn Formation which is of Ordovician age.

The 'haggis rock' is characterized by a bimodal grainsize distribution and a mosaic of colour displayed by the pebble constituents. It is suggested that these pebbles were recycled from a shallower water, tidal environment and subsequently combined with finer grained detrital material during turbidite sedimentation in a deep-water ocean basin.

These features confer a visual likeness to Scotland's national culinary dish and prompt considerable interest in the material as an ornamental stone.

The quantity of 'haggis rock' available for extraction appears substantial. It occurs as concordant, lenticular bodies that range up to 5 m thick and which are traceable discontinuously for at least 60 km.

A range of ornaments and jewellery including paperweights, bookends, pendants and brooches can be produced using conventional lapidary equipment. Surprisingly, no recent commercial endeavour has been undertaken to exploit the 'haggis rock' for the ornamental stone market. Further exploration appears warranted to assess the potential for commercial development.

Acknowledgements

Thanks are extended to Miss Angela Hughes for preparing the figures.

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A new Brewster-angle meter for gem identification

R.R. Harding,[1] P.G. Read[2] and N.W. Deeks[1]

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2. Bournemouth, Dorset

ABSTRACT: A portable, battery-operated meter for determining the Brewster angles of faceted gemstones using polarised laser light is described. The Brewster angle range covered is 54–72°, approximately equivalent to a refractive index range of 1.4–3.1. Birefringence of more than 0.01 can also be measured, and all measurements can be made without the need for contact fluid.

Keywords: Brewster angle, gemstone, laser source, refractive index

Introduction

Brewster's Law states that when an incident monochromatic ray meets the flat surface of an optically denser medium, and the reflected ray from this surface is at 90 degrees to the associated refracted ray in that medium, only those rays polarised in the plane of that surface will be reflected (this is why vertically polarised sun glasses reduce the glare from horizontal reflecting surfaces such as the sea). At the Brewster-angle A in *Figure 1*, the RI of the denser medium is equal to tan A.

The first recorded attempt to use the angle of polarization to measure the RI of a

Figure 1: *Where the reflected and refracted rays are at 90°, angle A is the Brewster angle and the reflected ray is polarised parallel to the reflecting surface.*

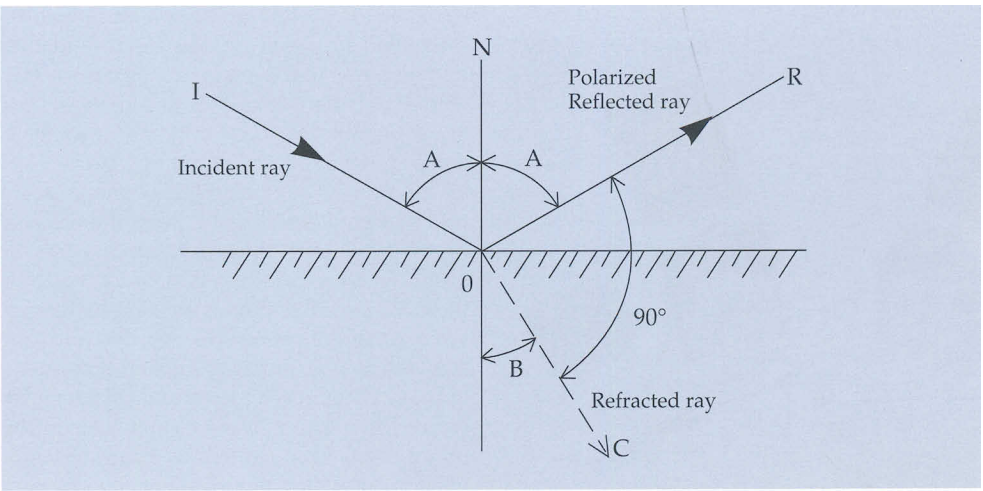

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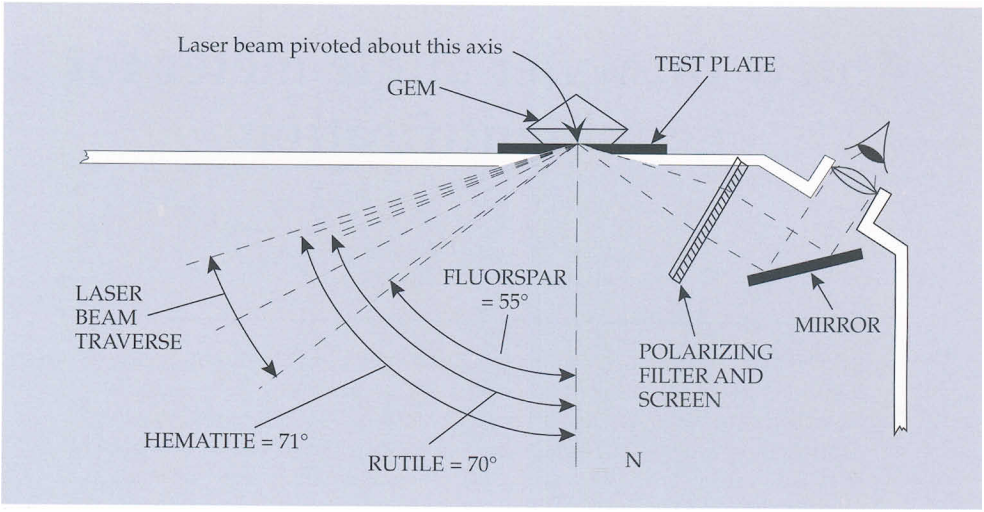

Figure 2: *Schematic diagram showing how a Brewster angle can be measured to identify a gemstone. The reflected ray from the laser beam is passed through a vertically polarised filter and imaged on a translucent screen. At the Brewster angle the reflected light falling on the screen drops to a minimum.*

gemstone was made by B.W. Anderson[1] in 1941 while testing the newly introduced Polaroid polarizing sheet. The method he used involved the construction of a pantograph type mechanism in which one arm was used to rotate a beam of incident light about the surface of a gem while the second arm duplicated this angular movement. An eyepiece, fitted with a sample of the new filter, which was set for vertical polarisation against the horizontally-viewed plane of the gem's surface, was attached to the second arm. This allowed the viewer to follow the movement of the reflected ray as the incident ray was rotated. At the Brewster-angle of the gem the eyepiece filter reduced the intensity of the now horizontally polarized reflected ray to a minimum.

Figure 3: *Two views of the GAGTL Brewster-angle meter. The operate button on the test plate cover is used to switch on the laser.*

However, the mechanical complication of a pantograph can be avoided by passing the reflected ray through a polarizing filter orientated for vertical polarization and then imaging the result on a translucent screen (*Figure 2*)[2]. Between 1979 and 1994 several experimental Brewster-angle refractometers were developed[3,4,5,6] ranging from fully electronic versions using helium neon lasers, photo-electric detection of the null point, and direct RI readout (in the recession of the late 80s these were considered to be too costly to be commercially viable) to simpler optical screen-imaging versions using miniature solid state lasers. It is this latter method that is used in the GAGTL instrument (*Figure 3*) which, for reasons that will become clearer later in this report, has been called a 'Brewster-angle meter' rather than refractometer.

The Brewster-angle meter

The GAGTL Brewster-angle meter uses a solid state laser with a wavelength in the red of 670 nm as the light source. It would have been in many ways desirable to use a low-cost laser having an output at the sodium wavelength of 589.3 nm but one is not yet available. However, using a 670 nm laser does have the advantage of separating the high-dispersion strontium titanate from the lower-dispersion diamond (both having almost identical refractive indices at 589.3 nm).

The laser is mounted in a carriage which is pivoted in an arc around a test aperture by means of a control knob calibrated in Brewster angles from 54 to 72 degrees. The reflected ray from a gemstone placed over the test aperture is passed through a vertically polarized filter and imaged on a translucent screen.

Using the eye as a very sensitive detector to low levels of light intensity, the angle of the laser beam is adjusted until the image of the reflected light falls to a point of minimum brightness. This occurs at the Brewster-angle for that gemstone where the now horizontally-polarized reflected ray is reduced to a minimum by the vertically-polarized filter. This angle is read from the calibrated laser control knob and the gemstone identified from a set of tables.

The reason that the instrument has been designated a meter rather than a refractometer is to avoid confusion with the currently well known refractive indices derived from measurements based on the 589.3 nm wavelength. If Brewster angles obtained at 670 nm were used to derive equivalent refractive indices at 589.3 nm, values of dispersion for each individual gem would have to be assumed. Such assumptions would introduce an element of uncertainty which may be quite significant for gems whose dispersions were not well known and so the simpler procedure of recording the angle was adopted.

Because the reflectivity of a gemstone is related to its refractive index, this can make it difficult to detect the exact angle of minimum brightness for high RI gems. To control image brightness, a polarising filter is inserted behind the eyepiece lens. The eyepiece can then be used as an intensity control and rotated until there is just enough light to detect the minimum intensity Brewster-angle. Normal focusing of the image is by push-pull adjustment.

Identification of gems

The refractive index range covered by the meter is 1.40 to 3.1. Brewster angles can be measured to an accuracy of 0.2° at the lower end of its range and to an accuracy of 0.4° at the top end. Double refraction can be measured by rotating the stone in 30 degree increments on the test platform, but becomes increasingly difficult to detect for values around and below 0.2° (equivalent to birefringence of 0.01). If not detectable by the meter, the presence or absence of double refraction can be verified by using a polariscope. The method is particularly relevant in identifying gems of high RI and a selection, in ascending order of Brewster angle, is given in *Table I*. The range of angles

Table I: *Brewster angles of a selection of gems.*

Brewster angle	*Gem*
55.0-55.3	*Fire opal*
57.0, 57.1	Quartz
58.2, 58.5	Tourmaline
59.5-59.8	Spinel (natural)
60.3, 60.4	Sapphire, ruby
60.6-61.4	Zircon (low)
60.8-61.0	Spessartine garnet
61.2	YAG
61.8	Demantoid garnet
61.4, 63.0	Titanite (sphene)
62.0, 63.0	Zircon (high)
62.3, 62.4	Scheelite
62.9	GGG
64.8-65.1	CZ (colourless)
65.6, 66.2	Lithium niobate
66.5-66.9	Strontium titanate
67.4	Diamond
69.0, 69.3	Synthetic moissanite
68.2, 70.2	Synthetic rutile

N.B.: Readings from birefringent stones separated by a comma; a dash indicates a range of readings possible from an isotropic stone because of compositional variation.

given for some gems reflects both theoretical (birefringence) variation and that found from practical measurement.

Compared to the standard refractometer, the Brewster-angle meter has the advantage of providing a wide measurement range without the need for a contact fluid. Compared to the reflectance meter, it is less sensitive to the surface condition of the gem, a less than perfect polish simply diminishing the sharpness of the minimum brightness setting of the laser angle rather than giving a misleading low reading. However, a clean grease-free gemstone test surface will, with most gemstones, produce an improved image of the reflected beam in which the precise Brewster-angle is indicated by a dark horizontal band bisecting the viewed image.

If one wishes to obtain the RI of a gem at 589.3 nm from its Brewster angle at 670 nm, this can be estimated if one assumes that the gem's dispersion varies in a linear way with wavelength. The RI can be obtained using the following formula:

$$\text{RI at 589.3 nm} = \text{Tan } A_G + \frac{670.0 - 589.3}{686.7 - 430.8} \times D_G$$

$$= \text{Tan } A_G + 0.3154 \times D_G$$

where A_G = Brewster angle of gem; D_G = dispersion of gem as measured between the wavelengths 686.7 and 430.8 nm.

Safety features

The instrument is powered by two standard AA batteries. For safety, and to give maximum battery life, the laser can only be switched on (by means of a push button) when the test platform cover is in position. The laser used in this instrument is a Class IIIa device (rated at 5 mW) and, like pen-type laser pointers, its beam can be harmful to the eyes if viewed directly. When in use, the meter's laser beam is reflected by the surface of the gemstone under test and imaged via a polarising filter onto a translucent screen. It is this diffused and much weaker image of the gemstone surface, and not the direct laser beam, which is viewed, via a mirror, through the instrument's eyepiece.

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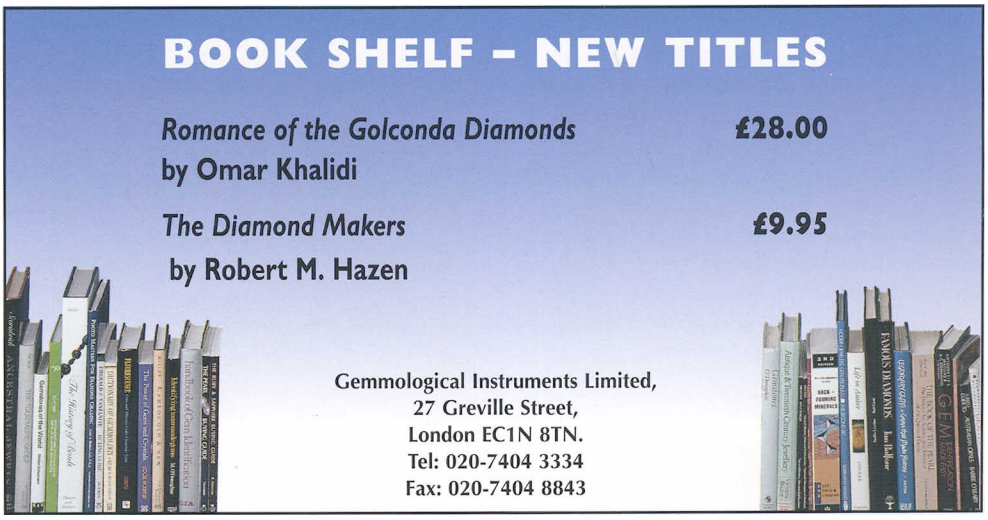

Abstracts

Diamonds

Gems and Minerals

Diamonds

He, Ar and C isotopes in coated and polycrystalline diamonds.

R. Burgess, L.H. Johnson, D.P. Mattey, J.W. Harris and G. Turner. *Chemical Geology*, **146**(3–4), 1998, pp 205–17.

Helium, Ar and C isotopic measurements were carried out on different qualities of industrial grade and polycrystalline diamonds from Africa and Brazil, including coated and cloudy diamonds, which contain abundant volatile-rich micro-inclusions, and framesites and carbonados, which consist of aggregates of micron-sized diamond crystals interspersed with mineral inclusions. In order to selectively release the primary trapped He, the diamonds were analysed using an *in vacuo* crushing technique. The He data were combined with Ar, K and U data, obtained from $^{40}Ar-^{39}Ar$ stepped-heating studies of irradiated fractions of the diamonds, and bulk C isotope data obtained from crushed residues. Results indicate that coated and cloudy diamonds best preserve a mantle signature, with $^{3}He/^{4}He$ values of 1–7 Ra and $\delta^{13}C$ of –5 to –6 ‰. Coated diamonds have high He and Ar concentration of $10^{-6} - 10^{-5}$ cm^3/g. Framesites have $^{3}He/^{4}He$ values 0.1–3 Ra and bimodal $\delta^{13}C$, with modes at –6 and –20 ‰. Carbonados have the lowest $\delta^{13}C$ values ≤ -25 ‰ and $^{3}He/^{4}He$ of < 0.1 Ra. U and K concentrations increase progressively from coats to framesites to carbonados. Whilst it is tempting to attribute low C, low $\delta^{13}C$ and high U to the influence of subducted crustal material, it is likely that implantation of ^{4}He by U- and Th-rich minerals adjacent to the micro-diamonds is also a possible cause of low He isotope ratios. J.F.

Twinning in natural diamond. II. Interpenetrant cubes.

W.G. Machado, M. Moore and A. Yacoot. *Journal of Applied Crystallography*, **31**, 1998, pp 777–82.

Single crystals of natural diamond which exhibit an approximately cubic morphology are known to have grown either: (a) by non-faceted cuboid growth or (b) by fibrous growth branching in a multiplicity of (111) columns, to give a mean surface orientation of {100}. Interpenetrant twins of diamond are uncommon; when they occur they are usually coloured and appear (by X-ray topography) to have been formed by fibrous growth on a twin origin, with the 14 growth sectors adequately filled by fibres, without the necessity of branching. R.A.H.

Behandlung natürlicher Diamanten zur Reduzierung der Gelb-oder Braunsättigung.

K. Schmetzer. *Goldschmiede Zeitung*, **97**(5), 1999, pp 47–8.

An announcement by the firm of Lazare Kaplan International of a stated new process of improving the colour of natural diamond has agitated the trade. The statement by LKI announces an irreversible process of decreasing yellow and brown tones in natural stones. The method of treatment was developed by the General Electric Company and according to the statement made by LKI was undetectable. More than one hundred stones treated by this method have been passed by workers without the artificially induced colour being noticed. The treated stones have come specifically from the Antwerp firm of Pegasus Overseas Limited. Pegasus OL alone is selling the treated stones. Despite this limited outlet the arrival on the market of these stones is not merely a rumour and it is serious when diamonds pass freely into the market with certification.

The available technical literature has had to be searched and in particular the literature of patents, to see whether previously published reports bear on the question in any way. Two reports describing the reduction of yellow colouration in diamond have so far been found, one involving a high-pressure/high temperature method, the other involving irradiation/high pressure/high temperature. M.O'D.

A noble gas study of cubic diamonds from Zaire: constraints on their mantle source.

N. Wada and J.I. Matsuda. *Geochimica et Cosmochimica Acta*, **62**(13), 1998, pp 2335–45.

Analyses are presented of 16 diamond samples for their isotopic compositions and concentrations of He, Ne, Ar and Xe. The results show slight but significant

Abstractors

J. Flinders	J.F.	R.A. Howie	R.A.H.	P.G. Read	P.G.R.
R.K. Harrison	R.K.H.	M. O'Donoghue	M.O'D.	G.W. Robinson	G.W.R.

For further information on many of the topics referred to, consult *Mineralogical Abstracts*

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differences from the noble gases and their isotopes in MORB, which are discussed. A nucleogenic origin for excess ^{21}Ne in the diamonds relative to MORB is consistent with their lower $^{3}He/^{4}He$ ratios. Positively correlated excesses of ^{129}Xe and $^{131-136}Xe$ of ≤ 10 % relative to atmospheric Xe ratios, are attributed to the decay of extinct ^{129}I and spontaneous fission of extinct ^{244}Pu and/or extinct ^{238}U, respectively. From the $^{3}He/^{4}He$ ratios and $^{40}Ar/^{36}Ar$ ratios, it is suggested that the cubic diamonds crystallized in a fluid which separated from a mantle source previously enriched in incompatible elements. R.K.H.

Formation of diamond with mineral inclusions of 'mixed' eclogite and peridotite paragenesis.

W. WANG. *Earth & Planetary Science Letters*, **106**(3–4), 1998, pp 831–43.

Two diamonds which contain both ultramafic and eclogitic mineral inclusions in the same diamond hosts were studied. Diamond L32 contains seven Fe-rich garnets, four omphacites and one olivine inclusion, whilst diamond S32 contains four olivine, one sanidine and one coesite inclusion. Both garnet and omphacite inclusions have a basaltic bulk composition, similar to those from other localities. All the garnet and omphacite inclusions in diamond L32 have positive Eu anomalies (Eu/Eu* 1.64–1.79). These observations imply that mantle eclogite is the metamorphic product of subducted ancient oceanic crust. Olivine inclusions from both diamonds have *mg* values (91–92) lower than normal olivine inclusions in diamonds from the same kimberlite pipe (92–95). A suggested model for formation of diamonds with mixed mineral inclusions invokes ascending diamond-bearing eclogite (recycled oceanic crust) entrained in mantle plumes, undergoing extensive partial melting, whereas the ambient peridotite matrix remains subsolidus in the diamond stable field. This provides a mechanism for transporting diamond from an eclogitic to an ultramafic host. Subsequent regrowth of diamond captures mineral inclusions of different lithological suites. Partial melts of basaltic sources interact with the surrounding peridotite, producing lower *mg* values of the coexisting olivine inclusions in the studied diamonds. Diamonds with 'mixed' mineral inclusions demonstrate that plume activity occurred in Archaean cratons. J.F.

Twinning in natural diamond. I. Contact twins.

A. YACOOT, M. MOORE AND W.G. MACHADO. *Journal of Applied Crystallography*, **31**, 1998, pp 767–76.

Growth histories of contact twins of natural diamonds have been elucidated by non-destructive techniques of X-ray topography, using both conventional and synchrotron sources. The common 'triangular' contact twin (macle) results from {111} faceted growth from a central nucleation site, sometimes marked by an inclusion. If this period of growth is followed by one of dissolution, then the twinned rhombic dodecahedron may result; the dissolution shape of a twinned octahedron is the same as the twin of the dissolution shape of the octahedron. A peritropic twin consists of two macles fortuitously joined on their common (111) facets in only approximate twin orientation. In all these variants, the composition 'plane' may be far from planar, resulting from intergrowth of one twin component into the other. R.A.H.

Gems and Minerals

Australian Chinese writing stone.

A. BEVAN, P. DOWNES AND J. BEVAN. *Australian Gemmologist*, **20**(5), pp 178–81, illus. 3 black-and- white, 1 map.

This appraisal of a decorative porphyritic basaltic rock from the Pilbara region of Western Australia details its geological occurrence and its mineralogy, petrology and physical characteristics. Also known as Chinese writing stone (some groups and sprays of lath-like crystals look like characters in Chinese writing), and, in Australia, as 'chook's foot rock' (the laths resembling chicken's feet), this material is an attractive carving rock which could be fashioned into a variety of items. P.G.R.

[Mineralogy of rhodonite deposits of the Middle Urals.] (Russian with English abstract)

A.I. BRUSNITSYN. *Proceedings of the Russian Mineralogical Society*, **127**(3), 1998, pp 1–11.

Mineralogical details are presented for the minerals of the rhodonite deposits at Malosedelnikovskoye, Kurganovskoye and Borodulinskoye, all of which are worked out of decorative material. Analyses are tabulated for rhodonite, pyroxmangite, tephroite and spessartine, and a list of 30 other associated species is presented. R.A.H.

Occurrence and distribution of 'moganite' in agate/chalcedony: a combined micro-Raman, Rietveld, and cathodoluminescence study.

J. GÖTZE, L. NASDALA, R. KLEEBERG AND M. WENZEL. *Contributions to Mineralogy & Petrology*, **133**(1–2), 1998, pp 96–105.

Raman, XRD (using Rietveld refinement), and CL techniques were used to measure the content and spatial distribution of the silica polymorph moganite, considered to represent periodic Brazil-law twinning of α-quartz at the unit-cell scale, in agate/chalcedony samples of different origin. Homogeneous standard samples, which included the nearly α-quartz-free moganite type material from Gran Canaria, were analysed by XRD and Raman spectroscopy to compare results from these techniques, and provide a calibration curve for the Raman results. However, because different length scales were analysed by each technique, the 'moganite content' in microcrystalline SiO_2 samples measured by Raman spectroscopy (short range order) was considerably higher than when measured by XRD (long-range order). The low XRD values result from the presence of moganite nanocrystals, nano-range moganite lamellae and single Brazil-law twin-planes, that are detected by vibrational spectroscopy but too small to be detected by XRD. High-resolution Raman analysis can measure moganite content, and its spatial variation in microcrystalline silica samples, with a lateral resolution in

the μm-range. Variations in the moganite-to-quartz ratio are revealed by varying intensity ratios of the main symmetric stretching-bending vibrations (A_1 modes) of α-quartz (465 cm^{-1}) and moganite (502 cm^{-1}), respectively. Traces of Raman microprobe analyses ⊥ the rhythmic zoning of agates showed that the moganite-to-quartz ratio is often not uniform; exhibiting a cyclic pattern that correlates with the observed CL pattern (colour and intensity). Variations of C1 and Raman data between single bands in agates suggest alternating formation of fine-grained, highly defective chalcedony intergrown with moganite, and coarse-grained low-defect quartz. Multiple zones indicate dynamic internal growth during self-organizational crystallization from silica-rich fluids. J.F.

Neolithic jadeitite axe from Sobotište (western Slovakia).

D. HOVORKA, Z. FARKAŠ AND J. SPIŠIAK. *Geologica Carpathica*, **49**(4), 1998, pp 301–4.

Numerous archaeological artefacts suggest the presence of a Neolithic population in the area between the villages of Kunov-Sobotište-Podbranc, W Slovakia. Early linear pottery of the Baden culture, together with polished stone artefacts, constrain the time period as early Neolithic to middle Aeneolithic. Among the polished stone artefacts one, an axe, is unique for its use of jadeitite. EPMA of the axe (Na_2O 9.86–14.91 wt. %) as well as results of detailed studies from N Italy and the W Alps, showed the rock had a complicated geological history. Since the use of jadeitite as a raw material has not been previously recorded for finds from either the E Alps, Bohemian Massif or W Carpathians, it is inferred that the finished product was imported from a distant area, such as NW Italy. J.F.

Mineralien aus der Reisseckgruppe (Kärnten).

G. KANDUTSCH. *Lapis*, **23**(6), 1998, pp 27–45, illus. in colour.

Gem-quality crystals of aquamarine, scheelite, smoky quartz and amethyst are found in the Reisseck group of mountains of the Hohe Tauern, Carinthia, Austria. Examples are described and illustrated. M.O'D.

Il ghiaccaio di Argentìere.

G. MONISTIER. *Rivista mineralogica italiana*, **22**(2), 1998, pp 30–7.

Exceptional and gem-quality crystals of smoky quartz with some fine pink fluorite and reddish-brown sphene, occur in the area of the Argentiere glacier, Chamonix, France. Specimens can be found in the mineral shows held at Chamonix. M.O'D.

The Rozná pegmatite field, western Moravia (Czech Republic).

D. NEMEC. *Chemie der Erde: Geochemistry*, **58**(3), 1998, pp 233–46.

Further investigation of the area surrounding the late Variscan Li-bearing pegmatite dyke, on the Hradisko hill at Rozná, has revealed a coarse-grained muscovite-pegmatite dyke swarm, with the same geochemistry as the main dyke, and which together represent a pegmatite field. Li mineralization is confined to the quartz zone, and mostly consists of lepidolite of variable composition. A sky-blue, low-Fe, low-Mn elbaite is typical of the Rozná pegmatite field. Hydrozircon, cassiterite, monazite, goyazite and eosphorite (the last two from alteration of amblygonite-montebrasite) were examined in detail; EPMA results are given. J.F.

Blue quartz from the Antequera-Olvera ophite, Málaga, Spain.

J.C. ROMERO SILVA. *Mineralogical Record*, **27**(2), 1996, pp 99–103.

Crystals of blue quartz occur as fracture fillings and in vugs in altered ophite in gypsum near Antequera, Malaga, Spain. The colour is due to inclusions of the rare mineral aerinite. Laser ablation MS show a high iron content for the aerinite. G.W.R.

Rubine und verschiedenfarbige Saphire aus Ilakaka, Madagascar.

K. SCHMETZER. *Lapis*, **24**(6), 1999, pp 46–7.

Gem-quality ruby and variously-coloured sapphires are reported from Ilakaka, Madagascar, in an area close to the Isalo National Park. Crystals ranging between 0.5 and 2 ct occur as rubies or as sapphires coloured blue-violet, violet, reddish-violet, yellow or orange. Twinning lamellae have been observed as inclusions. Details of the absorption spectra are given. M.O'D.

Die wundervollen Achate von Ojo Laguna, Chihuahua, Mexiko.

J. ZENZ. *Mineralien Welt*, **10**(4), 1999, pp 58–63.

Exceptional and highly-coloured specimens of agate are described from Ojo Laguna, Chihuahua, Mexico. The location borders Highway no 45 and is about 230 km from the Texan city of El Paso. M.O'D.

BOOK REVIEWS

The Koh-i-Noor diamond

I. AMINI, 1994. Roli Books, New Delhi. pp 257, softcover. £6.95. ISBN 81 7436 003 4.

Very readable mixture of legend and fact with the Koh-i-Noor diamond as a theme. M.O'D.

Chanel joaillerie

F. BAUDOT, 1998. Editions Assouline, Paris. pp 78, illus. in colour. Price on application.

Short history of the life of Gabrielle 'Coco' Chanel and of her innovative jewellery designs. Very well illustrated. M.O'D.

Diamonds

M. DUNDEK, 1999. Noble Gems International, London. pp 31, £7.00. ISBN 0 9535371 0 2.

Short but well-produced coverage of the production, grading and valuation of gem diamonds aimed at the student or trade beginner. Quite a lot of information is included and there are some good photographs, including one showing a laser-inscribed brilliant. Well worth the very reasonable price. M.O'D.

The optical papers of Sir Isaac Newton. Vol 1. The optical lectures, 1670–1672

I. NEWTON AND A. E. SHAPIRO (Ed.), 1984. University Press, Cambridge. pp xix, 627, hardcover. £135.00. ISBN 0 521 25248 2.

Though this book was published some time ago it is so relevant to our studies that I make no apology for bringing it to readers' notice. The original high price is down to £30.00 (in Cambridge bookshops, at least, in mid-1999) so anyone who wishes to read about the multitude of experiments conducted by Newton on the nature and production of colour, with accompanying commentary of high scholarship, should be able to secure a copy. The book presents the text of two versions of the *Optical lectures* with accompanying diagrams: the original Latin is translated and there are many illuminating notes. Cambridge University Library is the major centre of Newton scholarship and most of his MSS are housed there. M.O'D.

Royal Insignia: British and foreign orders of chivalry from the Royal Collection

S. PATTERSON, 1996. The Royal Collection, Windsor. pp 208, illus. in colour, softcover. £14.95.

The Royal Collection contains a wide variety of artefacts, not least among which are many classes of material of interest to the jewellery historian. Badges of British and foreign orders of knighthood and their equivalents have been exchanged between royal families for several generations and the collection, housed in the Royal Library at Windsor Castle, has not been widely publicized in the past. Fortunately escaping the fire of 1992, the insignia are beautifully illustrated in the most reasonably priced book: catalogue descriptions are authoritative and both notes and bibliography match the text in quality. The book usefully complements the recent great survey of the crown jewels and readers should try to get a copy as soon as possible, since there seem to be few about. M.O'D.

Falize: A dynasty of jewellers

K. PURCELL, 1999. Thames and Hudson, London. pp 320, illus. in colour, hardcover. £55.00. ISBN 0 500 01911 8.

As the author is a director of a leading London firm which specializes in antique jewellery, 18th century gold boxes and in Fabergé items, she is almost uniquely fitted for the task of describing the history and products of the firm of Falize which began life in 1840 and continued in business until 1936. An interesting brief note on the last years of the firm is provided by Robert Falize, who well remembers the last members of the three generations of the family to work in the jewellery trade. The products of the firm attracted crowned heads and many other celebrated people at the turn of the century and the Paris shop must have been beautiful to see in those days.

The book begins with family biographies: the author has looked very carefully into them, the impetus given by a chance noting of a Falize gravestone near Fontainebleu in 1988. The works and designs of each generation are given together with their biographies and this conjunction works very well. Another most interesting section deals with sources of inspiration – the artefacts produced varied greatly in design but with all showing prodigies of ornament which make them recognizable to the connoisseur of today. Materials and techniques are described in another chapter and the book concludes with notes on writings, lectures and travels undertaken by the Falizes and with comprehensive notes to the text and bibliography.

As always, books by this publisher are excellently illustrated and we find the same high standard with this one. The small but elegant exhibition shown with the launch of the book showed the public the beauties of this particular style of jewellery and the present author has further helped to ensure the immortality of this most interesting firm. M.O'D.

Perlen & Perlmutter

J. SCHLÜTER AND C. RÄTSCH, 1999. Hamburg [Friedensallee 7–9, D-22765, Hamburg], pp 175, illus. in colour, hardcover. DM 19.80. ISBN 3 89234 832 4.

Forming a very attractive small book on pearl and mother-of-pearl, this study describes the formation and

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use of the two materials from the earliest times, the text being supplemented by well-chosen illustrations depicting the use of pearl in art as well as in ornament. Together with the historical survey are notes on the testing of pearls: gemmology students will need more than these notes provide but German readers could not do much better if they need an introduction to this beautiful material as a starter for their studies. An English version would be welcome. M.O'D.

Science in the micro-cosmos: gemstones

J. SHIDA, Gemmological Association of all Japan, Tokyo. pp 520, illus. in colour, hardcover, in slip case. £122.00 approx.

Described on the dust-jacket as 'volume 2', this superbly illustrated book in fact is the author's second book on gemstones, the first one dealing with inclusions. The majority of the photographs in the present book are of inclusions too, but there are some illustrations of gemstones in various fashioned states. Despite possible language difficulties it is easy for the experienced gemmologist to work out what is being shown by the photographs and for the keen photographer details of the cameras and films used are noted at the end of the book which also carries a short bibliography. Readers in the west should try to keep up with Far Eastern gem and mineral book publishing as the standard is so high. The paper used here is heavy so handle the book with respect for the binding. M.O'D.

The arts of the Sikh kingdoms

S. STRONG, 1999. V & A Publications, London. pp 256, illus. in colour, softcover. £19.95 ISBN 1 85177 262 6.

A catalogue of an exhibition held at the Victoria and Albert Museum, London, during the Summer of 1999, this celebration of the 300th anniversary of the formation of the sacred Sikh brotherhood describes a variety of artefacts, some of which are set with magnificent examples of rough fashioned gemstones. Surely pride of place among these is taken by the Timur ruby (a rough red spinel) set on a necklace of gold, diamonds and spinels and lent by Her Majesty The Queen: nevertheless other examples rival it, especially another royal loan, the belt of Maharaja Sher Singh. This was made in Lahore around 1840 and is set with 19 large faceted emeralds, some of which are carved. It is possible that all or at least some of the emeralds were fashioned from the same crystal which may have come from the Urals or from the general area of Afghanistan. The book describes these items not only in captions to the excellent photographs but also in the catalogue at the end of the main text.

While a relatively small section of the whole book is devoted to gem-set pieces, the reader should carefully study the whole of the text to gain some idea of why such items were made and for whom. The development of the Sikh religion is very important for the study of civilizations in general and the decorative arts play a significant part in it. Many of the items shown come from British collections and so can be pursued after the exhibition has closed. The whole work is a study in the best traditions of national museum scholarship with many references to major sources and with a leavening of informed conjecture. M.O'D.

Gemstones: quality and value (2nd edn.)

Y. SUWA, 1999. Sekai Bunka Publishing Inc, Tokyo. pp 143, Illus. in colour, hardcover. £120.00 approx. ISBN 4 418 99902 7

The previous edition of this book appeared in Japanese with a separate supplement in English. There are two main sections: the first deals with 24 classic gemstones: in each case a 'beauty grade' is allocated and different shades of colour (or general appearance in the case of opal) are shown on a grid as photographs of fashioned stones. Details, including properties, variations and producing locations of the stones are given as well as an overall guide to values. Photographs by the well-known team of Harold and Erica Van Pelt make for a most beautiful first part and the second, dealing with the mining, fashioning and manufacturing of gem-set jewellery, is equally attractive and full of useful information which is not too easy to find quickly elsewhere. There is a short bibliography and a glossary. I strongly recommend this book which will be particularly appropriate on the counter. M.O'D.

Türkis: der Edelstein mit der Farbe des Himmels

extraLapis no 16, 1999. Christian Weise Verlag, Munich. pp 96, illus. in colour, softcover. DM 38.92. ISBN 3 921656 48 6 (series ISSN 0945 8492).

Turquoise is one of the most difficult of gemstones to illustrate adequately. So many specimens have a somewhat pale and unfeatured blue while the darker and finer examples are usually set in ways which demand the best of the photographer's ingenuity. I was keenly anticipating the appearance of this number of the beautiful *extraLapis* series so that I could experience turquoise at its best. The publishers have not disappointed (they never do!) and this study, cast like the others into a single chapterless sequence by a number of authors, will be found immediately essential to the many gemmologists and others who handle this fairly common gemstone.

The text introduces turquoise and how it occurs and then proceeds to list and briefly describe major world sources, the south-western United States, China, Persia/Iran, Sinai and Cornwall being singled out for particular attention. Handling and pricing, followed by a bibliography, complete an excellent and very reasonable priced book. *ExtraLapis* issues are even now becoming hard to find and readers should buy them as soon as they appear. M.O'D.

Proceedings of the Gemmological Association and Gem Testing Laboratory of Great Britain and Notices

MEMBERS' MEETINGS

London

On 14 July 1999 at the Gem Tutorial Centre, 27 Greville Street, London EC1N 8TN, Professor Peter R. Simpson gave a talk entitled *Demantoid garnet and other new gems and minerals from Namibia.*

On 22 September 1999 at the Gem Tutorial Centre, Ian Mercer illustrated gemmological activities in China, Hong Kong and Idar-Oberstein.

Midlands Branch

On 4 July 1999 the first of a series of practical 'Play Groups' was held at Barnt Green. The session included an enquiry into the properties and spectrum characteristics of all colours of gem garnets, including new garnets from Tanzania and colour-change varieties.

On 24 September 1999 at the Earth Sciences Building, University of Birmingham, Edgbaston, a three-fold presentation was given. Gwyn Green lead a discussion on the findings of the first Play Group session. Doug Morgan and Denis Price spoke on various facets of gem cutting.

A second Play Group was held on 26 September.

North West Branch

On 15 September at Church House, Hanover Street, Liverpool 1, John Harris gave a talk entitled *Photographing gems and their inclusions.*

Scottish Branch

A field trip was held on 4 and 5 July to Aberdeenshire, a source of tourmaline and other minerals.

On 5 August in Edinburgh, Art Grant gave a talk entitled *An apatite for faceting.*

ANNUAL GENERAL MEETING

The Annual General Meeting of the GAGTL was held on Monday 28 June 1999 at 27 Greville Street, London EC1N 8TN. Ian Thomson chaired the meeting and welcomed those present. The Annual Report and Accounts were approved and signed.

Ian Mercer, Jeffrey Monnickendam, Michael O'Donoghue and Evelyne Stern were elected, and Terry Davidson and Noel Deeks re-elected to the Council of Management. It was reported that Christopher Cavey had resigned from the Council in January 1999.

Peter Dwyer-Hickey, John Greatwood, Laurence Music, Dr Jamie Nelson and Peter Read were re-elected to the Members' Council. John Kessler and Jeffrey Monnickendam did not seek re-election to the Members' Council, and it was reported that Robert Fuller had resigned from the Council in February 1999. Hazlems Fenton were re-appointed Auditors.

The comment was made from the floor that despite repeated requests, the accounts did not contain any more detail than in previous years. Discussion followed and it was agreed that the Council of Management would consider providing additional information in the 2000 figures.

Responding to a question from the floor, Noel Deeks reported that the website had proved very popular and was attracting approximately 20,000 hits a month.

Following the Annual General Meeting, a Reunion of Members and Bring and Buy Sale were held, at which the winners of the 1999 Photographic Competition were announced and entries displayed.

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GIFTS TO THE ASSOCIATION

The Association is most grateful to the following for their gifts for research and teaching purposes:

Daniel Dower of Dower & Hall, London, for four salt crystals from the Salt Lake, Tunisia.

Alex Farn, Vice President of the GAGTL, for a photograph of a 'Bombay Bunch' strung with silver wire tassels (published in *Gem & Jewellery News*, September 1999) and an envelope containing many of the silver wire tassels; two freak sectioned cultured pearsl; an X-ray of a cultured pearl necklet with interesting nuclei; the name plate from an early endoscope in mother-of-pearl; an X-ray of a single line diamond bracelet showing that the diamonds are transparent to X-rays; and an X-ray of two sections of natural pearls joined together and mounted in a ring with the join hidden by the mount.

Luc Genot, Brussels, Belgium, for his diploma thesis *Les pierres de lune bleues de Meethi-yagoda.*

Martin Guptill, California, for six pieces of sunstone, two in matrix, three rough pieces and a faceted sample.

Holts of London for 211 crystals and gem materials comprising a wide range of teaching specimens.

Beverly Mitchell of the Signet Group, London for 40 bags of various fashioned gem materials including chalcedony, quartz, opal, garnet, moonstone, sapphire, emerald, ruby and zircon.

NEWS OF FELLOWS

Michael O'Donoghue arranged an exhibition *Gemstones of the 20th century* for the London Guildhall University Summer Show in June 1999. Specimens of species discovered from 1900–1999 were shown as well as examples of established gemstones found in new locations. He also gave a talk on synthetic and treated gemstones to the staff of Chanel Joaillerie, London, on 5 July 1999.

On 8 September 1999 Tony French and Michael O'Donoghue conducted a one-day course for the Wessex Branch of the National Association of Goldsmiths at Wimborne, Dorset. Gemmological techniques were explained and rehearsed, with some emphasis on synthetic and treated specimens.

GEM DIAMOND EXAMINATIONS

In June 1999, 90 candidates sat the Gem Diamond Examination, 65 of whom qualified, including two with Distinction. The Bruton Medal was not awarded on this occasion. The names of the successful candidates are listed below:

Qualified with Distinction:

Cunningham, DeeDee C., Toronto, Ont., Canada
Dong Cheng Yu, Beijing, P.R. China

Qualified

Arrowsmith-Katada, Jodie, Lower Plenty, Victoria, Australia
Barbarovich, Peter M., North Crawley, Buckinghamshire
Beattie, Rosamund C., Chiswick, London
Bhatia, Umesh K., Faridabad, Haryana, India
Bin Luo, Wuhan, Hubei, P.R. China
Burgoyne, Sheila, Totteridge, London
Chan Lai Lai Lily, Hong Kong
Chen Geng, Beijing, P.R. China
Chongjie Pan, Wuhan, Hubei, P.R. China
Cooksey, Brian D., Bures St. Mary, Suffolk
Cubbins, Graham, Blackpool, Lancashire
Dai Ru, Beijing, P.R. China
Edery, Gabrielle J., Hither Green, London
Englezos, Antonios, Lescos, Geece
Farrell, Terry, Cambridge
Finlay, Louden B., London
Furze, Cindy, Cheshunt, Hertfordshire
Ge Wang, Wuhan, Hubei, P.R. China
Hardiman, Julie, Eastleigh, Hampshire
Hering, Peter, Cambridge
Hodgson, Jane E., Watford, Hertfordshire
Huaxia Lin, Wuhan, Hubei, P.R. China
Hui Zhang, Wuhan, Hubei, P.R. China
Iconomou, Politimi, Kallithea, Athens, Greece
Kalha, Mahmoud A.M., Linstock, Carlisle
Kam Siu Tong John, Hong Kong
Konstandopoulou, Garoufallia, Athens, Greece
Koukou, Katerina, Athens, Greece
Kwok Emily Yee-Man, Hong Kong
Lam, Jill, Rochester, Kent
Lan Wang, Wuhan, Hubei, P.R. China
Liang Cai, Wuhan, Hubei, P.R. China
Liu Kai Lin, Beijing, P.R. China

Ma Guoqiang, Beijing, P.R. China
Ma Zhen, Beijing, P.R. China
Marshall, Andrew P., Gravesend, Kent
McCabe, Marianne C., London
McCarthy, Kieran, London
Mi Zhou, Wuhan, Hubei, P.R. China
Murase, Yuka, Chiba, Japan
Nakazawa, Haruyo, London
Ngala, Dabou K., Forest Gate, London
Parnell, Alexander J., Brighton, Sussex
Polette, Anne-Sophie, London
Qu Shang, Beijing, P.R. China
Saunders, Ian, Worksop, Nottinghamshire
Selant, Sabbir, Manchester
Shah, Varsheet, Kingston-upon-Thames, Surrey
Shan, Kuang, Wuhan, Hubei, P.R. China
Siyu Geng, Wuhan, Hubei, P.R. China
Smits, Cyntha, Alphen aan den Rijn, The Netherlands
Thackrah, Merle, Great Horkesley, Essex
Tupper, Michael I., South Holmwood, Surrey
Walls, Karen, New Malden, Surrey
Wenhong, Tian, Wuhan, Hubei, P.R. China
Woolland, Natalie K.A., Seaton, Devon
Worters, Fleur, Sevenoaks, Kent
Yan Zhang, Wuhan, Hubei, P.R. China
Yee Loo Andrew Shun, Hong Kong
Yu Chaofan, Beijing, P.R. China
Zhang Cheng, Beijing, P.R. China
Zhang Chufen, Guangzhou, P.R. China
Zhao Jun, Wuhan, Hubei, P.R. China

EXAMINATIONS IN GEMMOLOGY

In the Examinations in Gemmology held worldwide in June 1999, 206 candidates sat the Preliminary Examination of whom 156 qualified. In the Diploma Examination 231 sat of whom 116 qualified, including four with Distinction.

The **Anderson Bank Prize** for the best non-trade candidate of the year in the Diploma Examination was awarded to Jie Yang of Wuhan, Hubei, P.R. China.

The **Diploma Trade Prize** for the best candidate of the year who derives her main income from activities essentially connected with the jewellery trade was awarded to Miss Yurika Tachibana of Tokyo, Japan.

The **Anderson Medal** for the best candidate of the year in the Preliminary Examination was awarded to Miss Liu Jie Wen, Guilin, Guangxi, P.R. China.

The **Preliminary Trade Prize** for the best candidate of the year who derives her main income from activities essentially connected with the jewellery trade was awarded to Miss Yan Wei of Shanghai, P.R. China.

The Tully Medal was not awarded on this occasion.

The names of the successful candidates are as follows:

Diploma

Qualified with Distinction

Chan Wai Mang Eva, Montreal, Quebec, Canada
Jie Yang, Wuhan, Hubei, P.R. China
Tachibana, Yurika, Tokyo, Japan
Yan Wei, Shanghai, P.R. China

Qualifed

Adcock, Graham D., Lutterworth Leicestershire
Arrowsmith-Katada, Jodie, Lower Plenty, Victoria, Australia
Aung, Tin Lei Lei, Yangon, Myanmar
Bell-Burrow, Briony, London
Camroux-Oliver, Jessica, Edinburgh
Cheng Mu-Sen, Taipei, Taiwan, R.O. China
Chun Min-Jun, Seoul, Korea
Clouder, Carol, Southampton, Hampshire
Daniel, Eliena, London
Dapergolas, Stavroula, Toronto, Ontario, Canada
de Vries, Marius L., London
Dines, Rachel S., London
Domercq, Sandrine, London
Dower, Dan, London
Englezos, Antonios, Lescos, Greece
Flynn, Matthew, Amersham, Buckinghamshire
Freakley, Sharon A.M., Bangkok, Thailand
Fris, Arnold, Goedereede, The Netherlands
Fujiwara, Yuka, Kobe Hyogo, Japan
Galdeano, Nerea, Basauri-Bizkaia, Spain
Haden, Claire L., Birmingham, West Midlands
Haiyu Wen, Wuhan, Hubei, P.R. China
Harrison, Tarn J., Leamington Spa, Warwickshire
Hengyi Zheng, Wuhan, Hubei, P.R. China
Hill, Stephen E., Rickmansworth, Hertfordshire
Hsu Hui May, Taipei, Taiwan, R.O. China
Hu Yiqing, Shenzhen, P.R. China
Huaxia Lin, Wuhan, Hubei, P.R. China
Isacsson, Johanna, Stockholm, Sweden
Jamal-Jetha, Nimet, Dollard des Ormeaux, Quebec, Canada
Jingshi Wu, Wuhan, Hubei, P.R. China
Jinsenji, Osamu, Saitama Pref., Japan
Kamil, Ruzwain, Colombo, Sri Lanka
Kataoka, Satomi, Osaka, Japan
Kerger, Michele L., Sutton Coldfield, West Midlands
Keung Lam Ho, Hong Kong

Koukou, Katerina, Athens, Greece
Lam King Nam, Hong Kong
Lan Jiang, Wuhan, Hubei, P.R. China
Lee, Seung-Jun, Taegu, Korea
Lee, Martin, South Croydon, Surrey
Lewinsohn, Lisa, Sharpthorne, Sussex
Li Yat Choi Johnson, Hong Kong
Liang-Chin Wu, Taipei, Taiwan, R.O. China
Lin Chung-Jung, Taipei, Taiwan, R.O. China
Lin Wanxia, Guilin, P.R. China
Liu Jie Wen, Guilin, P.R. China
Liu Kaixin, Shenzen, P.R. China
Lopez Perez, Jose M., Valencia, Spain
Lu Jeng-Ven, Taipei, Taiwan, R.O. China
McFarlin, Patrick M., Amarillo, Texas, U.S.A.
McKeown, Nicola, Plymouth, Devon
Morton, Heather D., Vancouver, BC, Canada
Murase, Yuka, Chiba, Japan
Osborne-Shaw, Lisa, London
Oya, Kenichi, Niigata City, Niigata Pref., Japan
Parikh, Purnima, Vancouver, BC, Canada
Perez-Dorao, Carlos, Bilbao-Bizkaia, Spain
Petropoulos, Andreas, Athens, Greece
Qin Bin, Guilin, P.R. China
Raniga, Dhanesh G., Vancouver, BC, Canada
Rythen, Carolina, Stockholm, Sweden
Sakai, Junko, Otsu City, Shiga Pref., Japan
Saminpanya, Seriwat, Singapore
San-San Chen, Taipei, Taiwan, R.O. China
Schepers, Reinhold M., Limbricht, The Netherlands
Scholtes, Wanda, Schagk, The Netherlands
Shah, Monica, Manchester
Shahdadpuri, Neeta D., Hong Kong
Sherman, Gregory E., New York, NY, U.S.A.
Sietsma, Talke, Breda, The Netherlands
Smith, Peggy E.J., Rochester, Kent
Soe Moe Naing, Yangon, Myanmar
Sopers, Margarita B.M., Den Haag, The Netherlands

FORTHCOMING EVENTS

31 October	**London.** Annual Conference: *New Developments in the Gem World.* The Barbican Centre, London
3 November	**Scottish Branch.** *New gemstones from East Africa.* Campbell Bridges
17 November	**North West Branch.** AGM followed by talks on diamonds and simulants
26 November	**Midlands Branch.** *The Crown Jewels.* Alan Jobbins
4 December	**Midlands Branch.** 47th Annual Dinner
8 December	**London.** *Jewellery and silverware today.* Chris Walton
28 January	**Midlands Branch.** Bring and Buy followed by a quiz
30 January	**Midlands Branch.** Gem Play Group
15 February	**London.** *Some sites of precious minerals in England.* Dr R.F. Symes
25 February	**Midlands Branch.** *Gem trails from the Orient to Germany.* Ian Mercer
27 February	**Midlands Branch.** Gem Play Group
15 March	**London.** *Chalcedony – 21st century girl's best friend.* Stephen Webster
31 March	**Midlands Branch.** *All that glisters is not gold.* Dr Rob Ixer

For further information on the above events contact:

London:	Mary Burland on 020 7404 3334
Midlands Branch:	Gwyn Green on 0121 445 5359
North West Branch:	Deanna Brady on 0151 648 4266
Scottish Branch:	Catriona McInnes on 0131 667 2199

GAGTL WEB SITE

For up-to-the-minute information on GAGTL events visit our web site on www.gagtl.ac.uk/gagtl

Speake, Malcolm F., Birmingham, West Midlands
Stewart, Michelle, Stourport-on-Severn, Worcestershire
Susitha, Pothmulla, Kankanamge, Colombo, Sri Lanka
Tamaki, Yosuke, Sakurai City, Nara Pref., Japan
Tanaka, Nariko, Tokyo, Japan
Tang Yu-Lung, Taipei, Taiwan, R.O. China
Tang Tak Chuen, Hong Kong
Tezapsidou, Eleni K., Thessaloniki, Greece
Thomas, Allyson R., Harborne, West Midlands
Tianyang Zhang, Wuhan, Hubei, P.R. China
Tsutsumi, Masao, Higashi-Hiroshima City, Hiroshima Pref., Japan
van der Have, Ciska A., Amsterdam, The Netherlands
Van Spaendonck, Anouk D., Oegstgeest, The Netherlands
Vanderburgh, Amy E., Nobleton, Ontario, Canada
Vidoni, Tanya M., Toronto, Ontario, Canada
Wang Yan-Ping, Shanghai, P.R. China
Wang Dongmei, Shanghai, P.R. China
Wangchun Liao, Wuhan, Hubei, P.R. China
Ward-Jones, Ann, London
Warren, C., Donald, Weston, Ontario, Canada
Warrington, Jennifer L., Auckland, New Zealand
Waterfall, Mary C., Ely, Cambridgeshire
Wen Jiang, Wuhan, Hubei, P.R. China
Westbury, Vikki L.H., Woking, Surrey
Wheeler, Nick, Sudbury, Suffolk
Xiaoling Huang, Wuhan, Hubei, P.R. China
Xinping Li, Wuhan, Hubei, P.R. China
Xueqian Cheng, Wuhan, Hubei, P.R. China
Yang Hui-Ning, Taipei, Taiwan, R.O. China
Yi Zhou, Wuhan, Hubei, P.R. China
Yili You, Wuhan, Hubei, P.R. China
Zaw, Thiha, Yangon, Myanmar
Zhang Chunyan, Shanghai, P.R. China
Zhou Weiqi, Shantou, P.R. China
Zhu Jian-Qing, Shanghai, P.R. China
Zhuang Yilin, Shantou, P.R. China
Zimmermann, Bettina E., Zunzgen, Switzerland
Zin Win Mon, Yangon, Myanmar

Preliminary Examination

Qualified

Abdulrazzaq, Anwar A.H., Myharraq, Bahrain
Ahari, Roshanak, Tehran, Iran
Al-Alawi, Abeer S.T., Manama, Bahrain
Alcenius, Jim, Espoo, Finland
Ascot, Leon, Urdorf, Switzerland
Bakker, Jeroen, Apeldoorn, The Netherlands
Balzan, Cortney, Fairfax, Calif., U.S.A.
Bashore, Kerri A., Hayes End, Middlesex
Basile, Appadoure, London
Bass, Adrienne K., Preston, Lancashire
Bergmann, Eleanor, London
Blairs, Lawrence I.J., Llanrwst, Conwy, North Wales
Blomquist, Eva, Jonkoping, Sweden
Boardman, Adrian, Warrington, Cheshire
Bonac, Lia, Stechford, West Midlands
Bonnet, Christian, La Chaux-de-Fonds, Switzerland
Brown, Mary J., Mayangone Township, Myanmar
Burton, Mark Greig, London
Chan Ying Fong Bianca, Hong Kong
Chan, Rebecca, Hong Kong
Chan Wai Mang Eva, Montreal, Quebec, Canada
Chang Keng Ti, Taichung, Taiwan, R.O. China
Checkley, Emma, Hockley, West Midlands
Chen Hsi Hung, Taichung, Taiwan, R.O. China
Cheng Sze Man, Hong Kong
Cheng Kin-Nor Anne, Hong Kong
Cheng Po Lam, Hong Kong
Cheung Lai Yee Joey, Hong Kong
Choksi, Shivang R., Gujarat, India
Chow Suet Lai, Hong Kong
Chung Ju Ching, Taichung, Taiwan, R.O. China
Cubbins, Graham, Blackpool, Lancashire
Delpachitra, Samadara, Kandy, Sri Lanka
Deng, Luyang, Shanghai, P.R. China
Diyaljee, Dalida I., Berbice, Guyana
Dowling, Siobhan L., London
Dunn-Lwin, Simon B., London
Dupuy, Harold A., Los Angeles, Calif., U.S.A.
Eensaar, Karin, Tallinn, Estonia
Fu Sheng, Shanghai, P.R. China
Fujita, Takashi, Osaka City, Osaka, Japan
Galdeano, Nerea, Basauri-Bizkaia, Spain
Gravier, Denis M., St. Jean le Vieux, France
Gray, Christopher, Glasgow
Gschwend, Heinz, Rorschach, Switzerland
Gunston, Rosa M., London
Haddow, Jane E., Hockley, West Midlands
Hagen, Bente, Oslo, Norway
Haider, Hamayou Yousafzai, Islamabad, Pakistan
Hashimoto, Megumi, Kyoto City, Kyoto, Japan
Hirano, Kiyomi, Kawanishi City, Hyogo Pref., Japan
Ho Wing Hung, Anthony, Hong Kong
Ho, Anna, Hong Kong
Ho See Wai, Celia, Hong Kong
Ho Siu Kei, Paulie, Hong Kong
Ho Sau Wa, Hong Kong
Ho Sau Lan, Hong Kong
Ho Wing Cheung, Hong Kong
Hoksbergen, Edward C., Schoonhoven, The Netherlands
Holgate, Martin R., Doncaster, Yorks
Holt, Jason B.A., London
Htay Than Than, Yangon, Myanmar
Hui Po Lung, Hong Kong
Hung Tin Man, Hong Kong
Hynes, Lola A., London

GEM TUTORIAL CENTRE

27 Greville Street (Saffron Hill entrance), London EC1N 8TN

26 and 27 October — **Synthetics and Enhancements Today**

Are *you* aware of the various treated and synthetic materials that are likely to be masquerading amongst the stones you are buying and selling? Whether you are valuing, repairing or dealing, can you afford to miss these two days of investigation?

Price £198 + VAT (£232.65) – includes sandwich lunches

2 November — **The 'Ins and Outs' of Amber**

A rare opportunity to immerse yourself in the fascinating world of amber. Join Andrew Ross of the Natural History Museum and Maggie Campbell-Pedersen in a day devoted to looking at a variety of natural, treated and imitation materials and study the huge variety of flora and fauna inclusions found in amber.

Price £104 + VAT (£122.20) – includes a sandwich lunch

Student Workshops 2000

Weekend Diamond Grading Revision	8–9 January
Two-Day Diploma Practical Workshop	8–9 January
Three-Day Preliminary Workshop	2–4 May
Four-Day Diploma Workshop	22–25 May

For further details contact the GAGTL Education Department

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Fax: +44 020 7404 8843 web: www.gagtl.ac.uk/gagtl

Jamal-Jethra, Nimet, Dollard des Ormeaux, Quebec, Canada
Julkunen, Maarit, Savukoski, Sweden
Kassotakis, Dimitris, Xaidari, Greece
Kauppinen, Minna K., Varkaus, Finland
Kause, Nora M., Tampere, Finland
Khan, Mariyam Z., London
Klingspor, Pontus A., Oslo, Norway
Knight, Jennifer J., Selby, N. Yorks
Kong Bei, Guilin, P.R. China
Kumagai, Hiromi, Sendai City, Miyogi Pref., Japan
Ladak, Nelina, London
Lam Chi Hing, Hong Kong
Lam Chuk Yi, Winnie, Hong Kong
Langton, Ronnie, Blackpool, Lancashire
Lauttanen, Tero T., Helsinki, Finland
Lee Ching, Hong Kong
Leung Kin On, Hong Kong
Leung Shun Lok, Hong Kong
Leverington, Michael C., Bexhill-on-Sea, Sussex
Lichtsteiner, Patrick, Ormalingen, Switzerland
Lin Yeong Leh, Taipei, Taiwan, R.O. China
Liu Jie Wen, Guilin, Guangxi, P.R. China
Liu Jun, Shanghai, P.R. China
Liu Kwok Kwan, Hong Kong
Lo Chau Heung, Hong Kong
Loxton, Sam C., London
McAuley, Mary, Harmondsworth, Middlesex
Matos, Maria, Ericeira, Portugal
Maulave, Xavier R.L., Yangon, Myanmar
Min Zin, Yangon, Myanmar
Mitch, Alexandra, Atlanta, Georgia, U.S.A.
Momosaki, Nobuko, Hirikata City, Osaka, Japan
Morris, Julie, Tadcaster, N. Yorks
Murai, Shinobu, Minamikawachi Gun, Osaka, Japan
Nakazaki, Tomoko, Higashikurume City, Tokyo, Japan
Nassar, Shareen, Nairobi, Kenya
Ndirangu, Joseph K., Hong Kong
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Letter to the Editor
From Susan Stocklmayer, FGA

Dear Sir

Chrome chalcedony

It is generally recognized that the first modern discovery of chrome chalcedony was from Zimbabwe (Rhodesia). As a former mineralogist for the Geological Survey of Zimbabwe, I read with interest the recent article by Dr Jaroslav Hyrsl in the April 1999 volume of the *Journal*. However, it was disappointing to note that Dr Hyrsl, in quoting the date of the discovery as 1955, has propagated an error first introduced in 1989 by Philips and Brown (*Australian Gemmologist*, **17**, 205–7).

To set the record straight the discovery of chrome chalcedony ('mtorolite'), as reported in three articles published in the *Chamber of Mines Journal* of Rhodesia in 1967, is attributed to a Mr M.J. Maclean in 1965. One of these articles written by C.C. Smith (former Curator of Geology, Bulawayo Museum) also contains comments by Dr Gübelin and provides a full gemmological description of the material including spectrographic analyses.

Whilst it may be difficult to access original articles published in somewhat obscure journals, I could supply copies of the three mentioned for anyone interested.

Yours etc.
Susan M. Stocklmayer
Lesmurdie, Perth, WA 6076, Australia

Lam, Jill, Rochester, Kent
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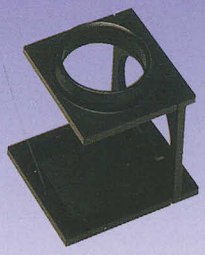

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Cover Picture

Vacuum and heating equipment used to harden porous rocks and to fill fractures in emeralds (see 'Identification of filler substances in emeralds by infrared and Raman spectroscopy' pp.501–520)

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Compiled by Robin W. Sanderson

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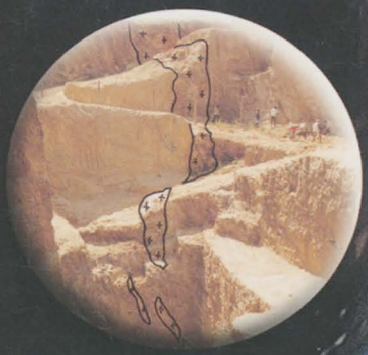

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Characterization of a group of experimental Russian hydrothermal synthetic sapphires

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ABSTRACT: Various types of experimental samples of Russian hydrothermally-grown synthetic sapphires are characterized according to causes of colour and microscopic features of diagnostic value. Two types of samples represent the synthetic counterparts of natural basaltic bluish-violet and yellow sapphires. Other synthetic sapphires are coloured by traces of cobalt, manganese and vanadium.

Keywords: absorption spectra, hydrothermal, Russia, synthetic sapphire, XRF analysis

Introduction

Hydrothermal synthetic ruby of Russian production appeared on the market in 1993 (Peretti and Smith, 1993, 1994) and yellow, orange, bluish-green and blue synthetic sapphires have been described more recently (Peretti *et al.*, 1997; Thomas *et al.*, 1997). Most samples examined in these papers were coloured by chromium and/or nickel, but Russian scientists also tried to grow the direct counterparts of natural blue sapphire doped with iron and titanium (Thomas *et al.*, 1997). One sample of this type was briefly described by Peretti *et al.* (1997) and a vanadium-bearing sample was also mentioned.

The present study is based on the examination of what appear to be research samples from Russian production. In the course of examination of 83 samples produced either at the United Institute of Geology, Geophysics and Mineralogy, Novosibirsk, Russia, or at the hydrothermal growth facilities of Tairus Co., Novosibirsk, Russia, 71 belonged to the group of commercially produced colours, which contain chromium and/or nickel as the predominant colour-causing trace elements (Schmetzer and Peretti, 1999).

In the absorption spectra of this group of 71 samples, no bands attributable to Fe^{3+} were observed although traces of iron were found by EDXRF and, consequently, the influence of iron on their colour is not significant. In the hydrothermal synthetic rubies and pink sapphires energy dispersive X-ray fluorescence analyses revealed the presence of various amounts of chromium. In yellow, green, blue-green and blue samples, only traces of nickel were present as colour-causing trace elements, whereas blue-violet to violet and orange to reddish-orange synthetic sapphires contained traces of both chromium and nickel.

Three synthetic sapphires with significant iron contents in addition to chromium and nickel were also described by Schmetzer and Peretti (1999). These samples were either bluish-violet or changed colour from bluish-green in daylight to reddish-violet in incandescent light. Two samples of the group

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of 83 mentioned above are colourless synthetic sapphires.

According to visual colour observation, absorption spectroscopy and trace element analysis, the remaining seven hydrothermal synthetic sapphires do not belong to the series coloured by chromium, nickel, chromium and nickel, or by chromium, nickel and iron. Although not widely distributed in the trade, these more or less experimental samples could appear at any time in the future on the free market. Therefore these samples are described briefly in the present paper.

Although a complete and detailed determination of properties of the different types of synthetic sapphires is impossible with the limited number of rough and faceted samples available, some important diagnostic features can be summarized.

Materials and methods

The seven synthetic sapphires to be described in this study are listed in *Table I.* Two samples were acquired between 1993 and 1996 by one of the authors (AP) during various stays in Bangkok and Novosibirsk (see Peretti *et al.*, 1997). Four samples were found in a collection submitted by C.P. Smith of Lucerne, Switzerland. This collection contained rough and faceted synthetic rubies and sapphires obtained from 1993 to 1998 in Novosibirsk and Bangkok. One faceted sample from the research collection of the GIA at Carlsbad, California, originated directly from Tairus Co., Novosibirsk.

All samples were grown on tabular seeds. One complete crystal and two pieces with external crystal faces that had been sawn from rough crystals were available. Three samples were plates sawn perpendicular to tabular seeds and polished subsequently on both sides. One faceted bluish-violet synthetic sapphire was also examined.

In order to characterize the samples according to causes of colour and trace element contents, all sapphires were spectroscopically examined in the visible and

Table I: *Russian hydrothermal synthetic sapphires, samples and properties*

Type of sapphire	*Cause of colour*	*Pleochroism* // *c*	*Pleochroism* ⊥ *c*	*Samples (number of samples) [orientation of seed]*	*nat: natural counterpart imit: imitating*
bluish-violet	Fe^{3+}, Fe^{2+}/Ti^{4+}, Fe^{2+}/Fe^{3+}	light greenish-blue	intense bluish-violet	plate (1) [b], faceted (1)	nat: basaltic type bluish-violet sapphire
yellow	Fe^{3+}, minor Cr^{3+}	light yellow	yellow	crystal (1) [b]	nat: basaltic type yellow sapphire
green	Co^{2+}, Co^{3+}	yellowish-green	bluish-green	plate (1) [-r]	imit: green sapphire
reddish-orange	Mn^{3+}	yellowish-orange	purplish-red	rough piece (1) [40° to c]	imit: padparadscha
colour-change d: greyish-green i: reddish-violet	V^{3+}	d: yellowish-green i: light reddish-violet	d: greyish-violet i: intense reddish-violet	rough piece (1) plate (1) [both 40° to c]	nat: colour-change vanadium-bearing sapphire

d: daylight; i: incandescent light
[b]: seed parallel to a prism $\{10\bar{1}0\}$
[–r]: seed parallel to a negative rhombohedron $\{01\bar{1}1\}$
crystal: complete crystal grown on a tabular seed
rough piece: rough piece sawn from a crystal grown on a tabular seed
plate: thin plate sawn perpendicular to a tabular seed and polished on both sides
faceted: faceted gemstone

ultraviolet range by means of a Leitz Unicam SP 800 UV-VIS spectrophotometer. Trace element analysis was performed by X-ray fluorescence (EDXRF) using a Tracor Northern TN 5000 system.

Results

The seven hydrothermal synthetic sapphires were classified into five types according to colour and causes of colour as indicated by absorption spectroscopy and EDXRF trace element analysis (see *Table I*). These are (a) counterparts of basaltic type bluish-violet, (b) counterparts of basaltic type yellow, (c) green cobalt-doped, (d) reddish-orange manganese-doped, and (e) vanadium-doped colour-change sapphires.

In each of the six rough samples at least part of a tabular seed plate was present. Thus, it was possible to determine the orientation of seed used for crystal growth. Two samples were grown on seeds parallel to a hexagonal prism b $\{10\bar{1}0\}$ and one sample was grown on a seed parallel to a negative rhombohedron -r $\{01\bar{1}1\}$. These two orientations are the standard cuts of seed plates used in Russia for commercial production of synthetic rubies and sapphires in the chromium- and/or nickel-bearing series (Schmetzer and Peretti, 1999). Three samples were grown with an inclination of the seed plate at 40° to the *c*-axis.

Microscopic examination revealed the presence in most of the samples of solid, liquid and multiphase inclusions comparable to those described in detail by Peretti *et al.*

Figure 1: *Plate of hydrothermal synthetic bluish-violet sapphire cut perpendicular to the c-axis (the thickness of the plate is approximately 1.2 mm); the seed consists of colourless sapphire and synthetic ruby and is oriented parallel to a prism b $\{10\bar{1}0\}$. The synthetic blue sapphire reveals six a $\{11\bar{2}0\}$ prism faces and has an absorption spectrum comparable to the spectrum of basaltic type natural sapphires coloured by iron and titanium. Size of the sample about 14.4 x 11.8 mm.*

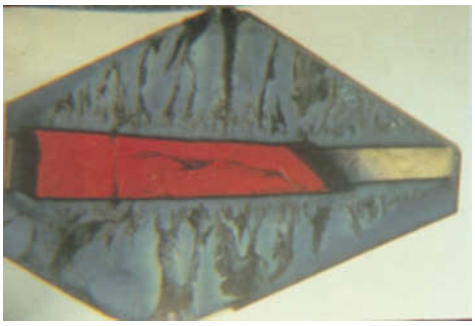

Figure 2: *Absorption spectra of bluish-violet and yellow synthetic sapphires and their natural counterparts. Bluish-violet sapphires reveal absorption bands of Fe^{3+}, Fe^{2+}/Ti^{4+} and Fe^{2+}/Fe^{3+}; (a) Russian synthetic sapphire, (b, c) natural sapphires from Pailin, Cambodia. Yellow sapphires reveal strong absorption bands of Fe^{3+} and weak bands of Cr^{3+}; (d) Russian synthetic sapphire (e, f) natural sapphires from Thailand.*

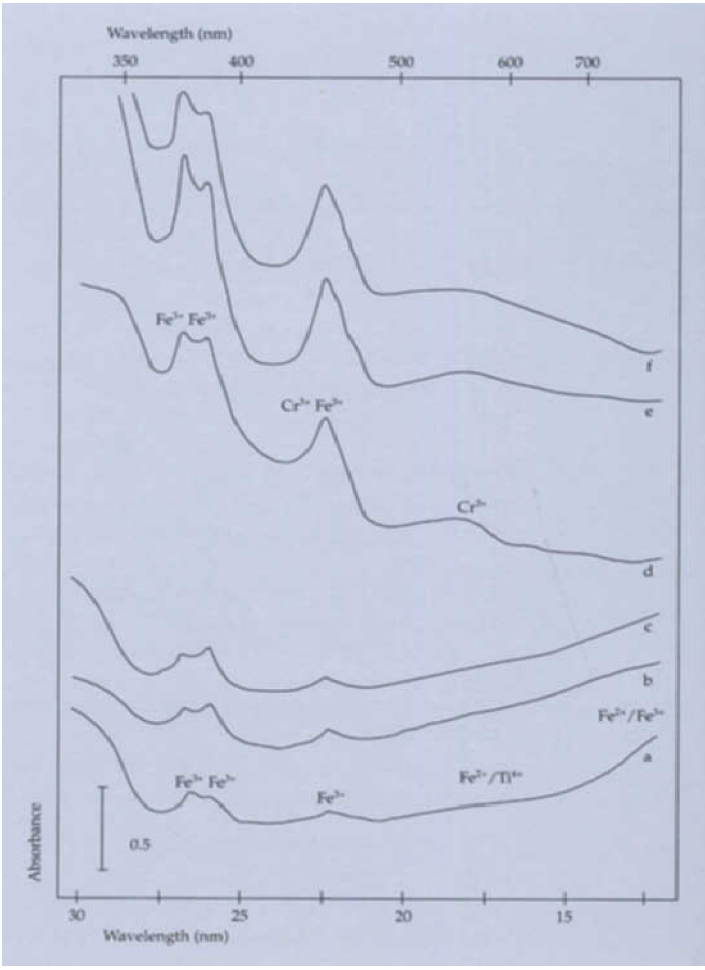

Figure 3: *Boundaries of variable orientation between subindividuals and colour zoning in synthetic bluish-violet sapphire; large cavities with multiphase fillings appear opaque in this orientation of the sample. Immersion, magnified 30x.*

(1997). Preliminary heating and freezing experiments on multiphase inclusions revealed that they contained aqueous solutions and other phases which did not homogenize at temperatures below 40°C.

A *bluish-violet synthetic sapphire* was grown with a seed parallel to a prism face b (*Figure 1*). From absorption spectroscopy and trace element analysis it is evident that the colour and absorption spectra (*Figure 2*) of this type of synthetic sapphire is consistent with that of natural, basaltic type bluish-violet sapphire (Schmetzer and Bank, 1980, 1981; Schmetzer, 1987; Kiefert and Schmetzer, 1987). Consequently, the pleochroism of this synthetic sapphire is identical to that seen in natural basaltic type sapphires. The closest match of the absorption spectrum to natural sapphires in the authors' collection is with those of some basaltic sapphires from Pailin, Cambodia, which show only weak Fe^{2+}/Ti^{4+} charge transfer absorption bands (*Figure 2*).

Both synthetic samples available contain large multiphase inclusions (*Figure 1*), the exact composition and phase analysis of which is not yet known in detail. The growth patterns are different from those of sapphire samples of the chromium-nickel series (Schmetzer and Peretti, 1999). No parallel or near-parallel striations representing subindividuals of similar diameters were found. In contrast, irregular variable boundaries between different growth zones were observed, which in general represent growth areas of varying colour intensity. In immersion, a somewhat fibrous internal texture is seen, which results from the irregularly varying growth areas (*Figure 3*). This growth pattern resembles the chevron or angular growth features seen in hydrothermal synthetic emeralds (see e.g. Schmetzer, 1988).

A rough crystal plate of yellow synthetic sapphire (*Figure 4*) revealed an absorption spectrum consisting mainly of Fe^{3+} absorption bands with weak Cr^{3+} bands (see references cited above). The spectrum of this sample is similar to that seen in some natural yellow sapphires from basaltic sources, which normally consists of intense Fe^{3+} absorption bands. In some samples from

Figure 4: *Crystal of hydrothermal yellow synthetic sapphire grown on a seed parallel to a prism b {10$\bar{1}$0}; the absorption spectrum of the synthetic yellow sapphire is comparable to the spectrum of basaltic type natural sapphires coloured predominantly by iron. Size of sample about 35 x 10 mm; photo by M. Glas.*

Thailand, an additional weak Cr^{3+} absorption band can also be present (*Figure 2*). Samples with similar colours and absorption spectra are also known from Umba, Tanzania. The roughness of the crystal plate on both faces parallel to the seed plate prevented a detailed microscopic examination of internal growth features and inclusions.

The absorption spectrum of a plate of *green synthetic sapphire* (*Figure 5*) consists of absorption bands attributed to Co^{2+} and Co^{3+} (*Figure 6*) following McClure, 1962; Müller and Günthard, 1966; Hush and Hobbs, 1968. This interpretation is also consistent with the chemical composition of the sample. The microscopic examination of this green synthetic sapphire grown on a seed with an orientation parallel to *-r* revealed a series of parallel striations inclined to the seed and numerous healing feathers (*Figure 7*). This

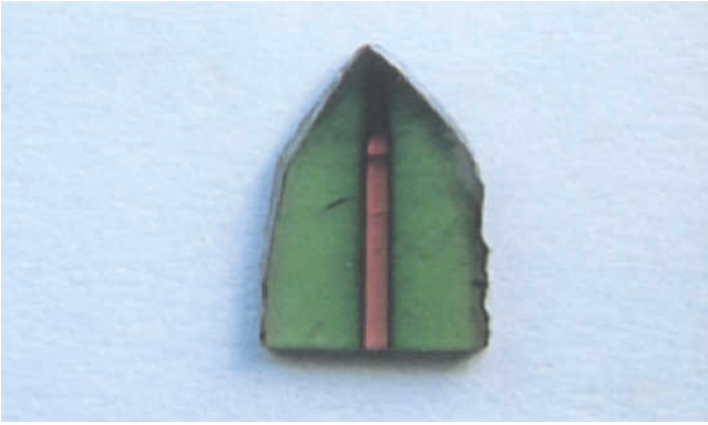

Figure 5: *Plate of hydrothermal synthetic green sapphire grown on a seed parallel to a negative rhombohedron –r {01$\bar{1}$1}; the absorption spectrum of the synthetic green sapphire reveals absorption bands of bi- and trivalent cobalt. Size of sample about 12 x 8 mm; photo by M. Glas.*

Figure 6: *Absorption spectra of manganese-, vanadium- and cobalt-bearing synthetic sapphires; (a) reddish-orange sapphire coloured by Mn^{3+}, (b) greyish-green synthetic sapphire coloured by V^{3+}, (c) green synthetic sapphire coloured by Co^{2+} and Co^{3+}.*

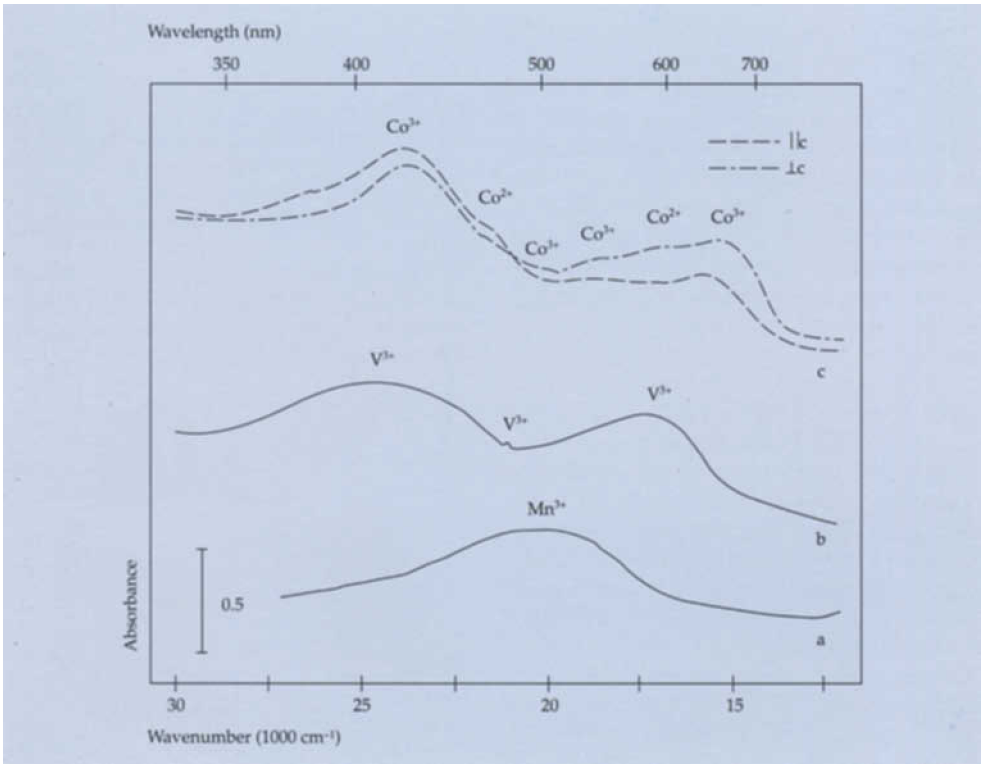

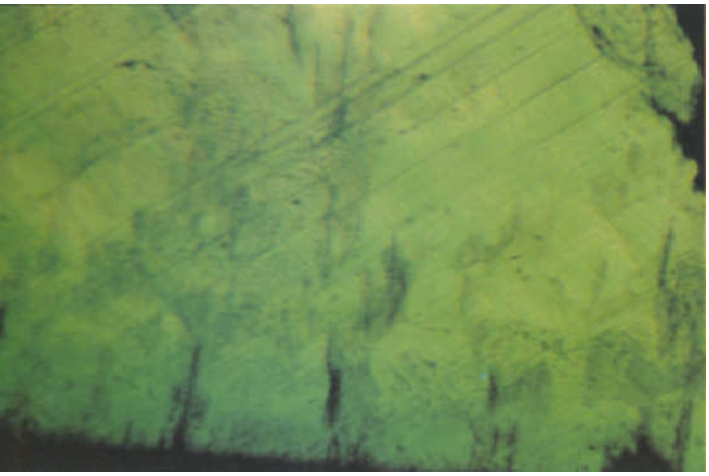

Figure 7: Cobalt-bearing green synthetic sapphire with colourless seed; parallel striations are observed inclined to the seed, numerous small healing feathers are also seen. Immersion, magnified 50x.

kind of colour or absorption spectrum has not been found in natural sapphire.

Three samples, a *reddish-orange synthetic sapphire* (*Figure 8a*) and two *colour change greyish-green synthetic sapphires* (*Figure 8b and c*) were grown on seeds inclined at about 40° to the *c*-axis. All three samples grown with this particular seed orientation revealed intense colour zoning parallel to the seed which decreased in colour intensity outwards away from the seed. The absorption spectrum of the reddish-orange sample (*Figure 6*) consisted of a broad absorption band which was assigned to Mn^{3+} in corundum (McClure, 1962; Hush and Hobbs, 1968). Each absorption spectrum of the two greyish-green samples (*Figure 6*) consists of two dominant absorption bands attributed to V^{3+} (McClure, 1962; Schmetzer and Bank, 1981). Verneuil-grown colour-change synthetic sapphire doped by vanadium is widely known to gemmologists as colour-change synthetic sapphire. In contrast, vanadium-bearing, colour-change natural sapphire is extremely rare. A faceted sample of this type originating from Burma (Myanmar) was first mentioned by Hänni (1983).

A second type of *colour-change bluish-green synthetic sapphire* was found to be a heavily iron-doped member of the chromium-nickel series and was described by Schmetzer and Peretti (1999).

Conclusion

Different types of not yet commercially produced, more or less experimental, hydrothermally grown synthetic sapphires of Russian production were examined. Some of the samples represent synthetic counterparts of natural bluish-violet and natural yellow sapphires from basaltic environments. No natural equivalents of green synthetic sapphire coloured by cobalt and reddish-orange synthetic sapphire coloured by manganese are known. The vanadium-doped, colour-change synthetic sapphire does have a natural equivalent, but it is extremely rare.

The seven synthetic sapphires contain solid, liquid and multiphase inclusions, as well as characteristic growth features and, together with their absorption spectra, these properties are sufficient to identify the materials as synthetic products.

Figure 8: (a) Piece of a crystal of synthetic reddish-orange sapphire coloured by trivalent manganese. Size of sample about 18 x 16 mm. (b) Plate with seed visible and (c) piece of a crystal of colour-change synthetic sapphire; the absorption spectra of the samples, which are greyish-green in daylight and reddish-violet in incandescent light, consist of absorption maxima indicating trivalent vanadium. Incandescent light, the piece of a crystal is about 23 x 16 mm. Photo by M. Glas.

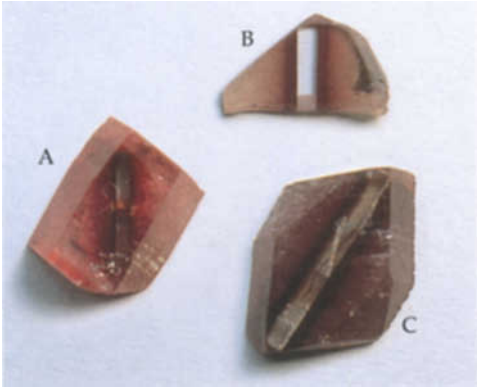

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Note added in proof

In a poster presented at the International Gemological Symposium, San Diego, California, U.S.A., from 21 to 24 June 1999, a new type of hydrothermally-grown synthetic sapphire was described (see Abstract by Smirnov *et al.*, 1999). It was stated that the dark blue or violetish-blue samples were submitted to heat-treatment subsequent to hydrothermal crystal growth in order to produce a bright blue coloration. An absorption spectrum presented in the poster revealed a dominant Fe^{2+}/Ti^{4+} charge transfer absorption band but no Fe^{2+}/Fe^{3+} absorption. Consequently, this new type of hydrothermal synthetic sapphire reveals spectroscopic properties comparable to those of metamorphic type natural blue sapphires, e.g. from Kashmir, Sri Lanka or Myanmar.

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A very convincing forgery

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ABSTRACT: Cubic zirconia (CZ), is one of the most serious diamond impostors today. It is rare that a well-made ring in silver is encountered set with very well selected cut and polished cubic zirconias, in a deliberate attempt to fool the connoisseurs. One such is described.

Keywords: cubic zirconia, diamond simulant

Introduction

Recently the author received for examination, spectral analysis and origin of colour determination, what seemed to be a cushion-shaped fancy light yellow diamond circled by 16 brilliant-cut diamonds (*Figure 1*). They were mounted in either white gold or platinum, and doubt arose because the hallmark on the ring was unfamiliar to the author (*Figure 2*).

The cushion-shaped light yellow transparent gemstone, which was set with four pairs of claws, was measured with a Leveridge gauge and was 13.38 x 13.15 mm at the girdle with a depth of 7.95 mm. The weight estimate was approximately 12 ct. No characteristic inclusions were observed under the microscope, but it was noticed that the girdle was faceted (*Figure 3*). It was decided to unset the light yellow stone to obtain its exact weight, measurements and complete gemmological properties, which are described below.

Gemmological properties

The loose stone proved to be a cushion-shaped mixed-cut, with a brilliant-cut crown and modified Barion-cut pavilion. The measurements obtained with a Mitutoyo micrometer were 13.21 x 13.14 mm girdle

Figure 1: *Enlarged view of the ring received for examination. (The yellow cushion-shaped stone is much more lively than the colour plate shows.)*

Figure 2: *The unidentified hallmark stamped on the exterior of the ring. Notice also the hammered surface of the ring in order to give it an older appearance.*

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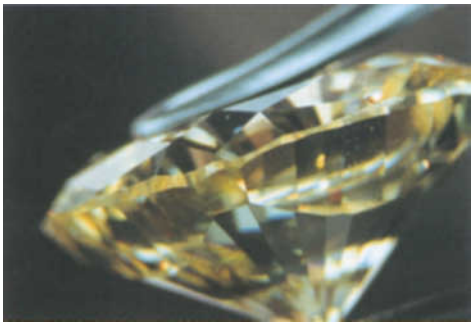

Figure 3: The faceted girdle observed on the 18.11 ct light yellow cushion-shaped cubic zirconia.

diameters and a depth of 7.85 mm. The weight on a Mettler PL 300C carat scale was 18.11 ct. At this stage it was evident from the difference between actual and calculated weights that the stone was not a diamond, but the testing procedure was continued.

Under a Bausch & Lomb Mark V Gemolite binocular microscope using dark field illumination and overhead lighting as appropriate, neither polishing lines nor internal inclusions could be found, but blue and orange flashes as a result of dispersion could be seen on many facets as the stone was rocked (*Figure 4*).

Refractive index (RI) determinations were carried out using a Rayner Dialdex refractometer and monochromatic sodium light. The indices obtained from the table facet proved to be above the limit of the refractive liquid of 1.81.

The thermal conductivity was tested with the Ceres Diamondprobe and proved to be very weak.

Ultraviolet fluorescence was examined with a Multispec combined LW/SW unit and the stone fluoresced a moderate apricot under SW, and a strong yellow under LW.

The specific gravity (SG) was obtained by hydrostatic weighing in distilled water using a Mettler PL 300C carat scale, and was found to have a value of 5.99.

The absorption spectrum was observed through the pavilion, in daylight conditions, with a Beck spectroscope, and revealed strong absorption between 400 and 410 nm, sharp lines at 412, 415, 418 and 424 nm, a strong line at 490 nm, and diffused lines at 660 and 680 nm.

Conclusion

These properties do not correspond with those of diamond but are consistent with the published values for cubic zirconia (Nassau, 1980; Webster, 1994). It is of interest to note that all 16 colourless brilliant-cut stones set in the ring fluoresced a strong dark yellow under LW when examined in the Multispec LW/SW ultraviolet unit. This again is not characteristic of gem-quality diamonds which, under the same conditions, would be expected to show a range of responses, usually weak to strong blue. Only very rarely (less than 0.2%) is a yellow fluorescence in LW observed in gem-quality fluorescent diamonds. Again the thermal conductivities proved very weak, which confirms that these stones are not diamond. The metal of the ring was also tested and proved to be neither white gold nor platinum, but 970‰ silver.

Discussion

It seems evident that this ring was made to deliberately deceive, for the following reasons:

Figure 4: Blue and orange flashes observed on many facets of the pavilion, as the stone was rocked under the microscope (dark-field illumination).

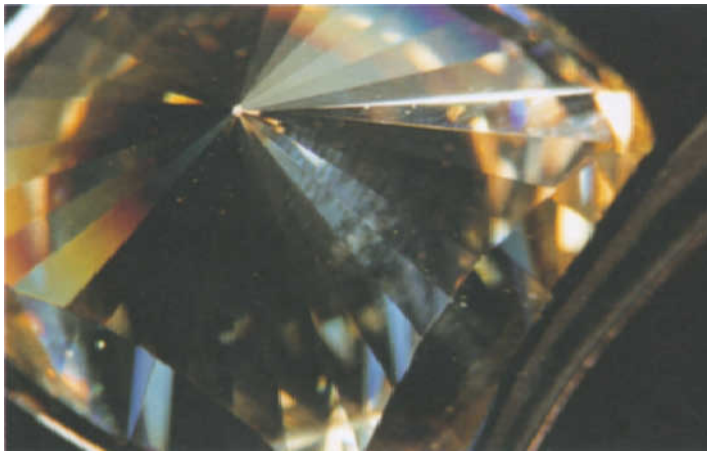

Figure 5: Maker's mark inscribed on the inside of the ring.

- The very convincing mount is of a good workmanship in silver, but with an unidentified hallmark on the outside of the ring (the way some countries have their jewellery stamped), and a mark of the jeweller on the inside of the ring (*Figure 5*).
- The ring, which was voluntarily aged on the outside (hammered), as if it had belonged to a private lady who had worn it over a long period of time (*Figure 2*).
- The classical design of a main stone circled by a row of small brilliant-cut stones.
- The choice of a light colour for the main stone, but strong enough to be attractive and warrant a fancy light grade which, for most professionals dealing with fancy coloured diamonds, evokes a natural colour, and could therefore fool them to take the risk of buying it for such. Had the stone been deep or intense yellow, the same potential buyer would suspect some possible treatment and certainly have the colour origin tested before making an offer for the stone.
- The cutting style, with a cushion-shape brilliant crown and modified Barion-cut pavilion, intensifies the face-up colour appearance.
- The facets are exceptionally well cut and polished; no polishing lines were observed under the microscope.
- A faceted girdle is often observed in diamonds with a slightly thick to thick girdle; here the facets avoid leaving a bruted or plain polished girdle which could betray the cubic zirconia.

It must be said that yellow cubic zirconia, like the stone tested here, has a much more convincing similarity to diamond than the more common colourless variety. This light yellow cushion-shaped stone bears a close visual resemblance to a natural diamond and required appropriate examination and tests to reveal its true identity.

Potential buyers of such goods should be warned that apparent bargains obtainable in the street away from a legitimate supplier, or without a receipt from a reliable source, can often lead to this kind of costly deception.

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Geology of the Yellow Mine (Taita-Taveta District, Kenya) and other yellow tourmaline deposits in East Africa

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ABSTRACT: Tourmaline is a common gemstone in Kenya and Tanzania but little information is available on the geology of its deposits. The geology of a major yellow (savannah) and bicolour tourmaline deposit, the Yellow Mine in the Mangare area (southern Kenya) is described. Mg-tourmaline (dravite-uvite series) of yellow and green colour occurs in a pegmatite which has undergone several stages of deformation, metasomatism and metamorphism. For comparison, several other yellow tourmaline deposits from southern Kenya and Tanzania are also briefly described. Yellow tourmaline deposits may be linked to gneisses and anatectic pegmatites, or to the result of the interaction of such pegmatites with different lithologies such as ultrabasic rocks or marbles. An example of coexistence of dravitic and elbaitic tourmaline in a pegmatite from the John Saul Mine (southern Kenya) is also given. New mineralogical and gemmological data on east African tourmalines are also provided. Tourmaline showing a yellow core and a green rim are common in different kinds of geological environments in east Africa; this indicates the existence of a major, wide scale genetic mechanism for such crystals.

Keywords: East Africa, Kenya, tourmaline

Introduction

Tourmaline is a fairly common gemstone in the Mozambique Metamorphic Belt, particularly in the area stretching from the Taita Hills in southern Kenya to the Umba River Valley in Tanzania (Keller, 1992). In concentrates from eluvial and alluvial deposits, it is common in black, brown, yellow, orange or green hues, coming usually from gneisses where it is an accessory mineral, or from anatectic pegmatites in the gneisses. Often, crystals are green to brown with a sharp green/brown-orange dichroism. These tourmalines are usually solid solutions between dravite and schorl (Na Mg – Na Fe series) or dravite and uvite (Na Mg – Ca Mg series).

Chrome tourmaline (blue-green) is gathered in many deposits as a by-product of ruby mining, both minerals being commonly associated, as for example at the John Saul Ruby Mine, in the Mangare Area of southern Kenya (Key and Ochieng, 1991). A major chrome tourmaline deposit is located next to

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the Landenai Mountain in Tanzania, and other deposits have been mentioned along the Umba River valley (Keller, 1992). Chrome tourmalines are typically solid solutions between dravite and uvite and are Fe-poor, and Cr-rich (Cr_2O_3 = 0.2 to 1 wt %, see *Table IV*). Halvorsen and Jensen (1997) have described green chromiferous and vanadiferous tourmalines from the Umba Area displaying a new colour change effect. These stones show a red hue through sections thicker than 15 mm. Such stones are also present at the John Saul Ruby Mine in metasomatised gneisses next to ultrabasic rocks. Barot *et al.* (1995) also described green cat's-eye tourmalines from southern Kenya. Green colour change tourmaline from the Lelatema area in Tanzania has been described by Bank and Henn (1988). According to Schmetzer and Bank (1979) and Schmetzer *et al.* (1979), vanadium-bearing tourmaline is also common in Tanzania (Landenai, Gerevi near Umba) and southern Kenya (Kwale district). I have observed dark green vanadian tourmaline crystals as poikiloblasts in graphite gneisses of the Lemshuko (Komolo) tsavorite deposit.

Red dravite has been reported next to quartzite outcrops in the Narok District of Kenya (Dunn *et al.*, 1977; Keller, 1992). In southern Kenya, there are no pocket-bearing pegmatites and elbaitic tourmalines are very rare. An example of red elbaitic tourmaline from the Mangare area is described below. In Tanzania, green and red elbaites originate from the pegmatites of the Morogoro area (Keller, 1992).

Yellow, golden and savannah tourmalines from southern Kenya have been mentioned and described several times (e.g. Schmetzer and Bank, 1979; Hänni *et al.*, 1981; Gem News, 1996), but until now no data have been published about the geology of their deposits, which can be complex with many variations. Stones of similar appearance may have a very different geological and geographical origin. The names of golden tourmaline and savannah tourmaline have sometimes been confused (e.g. Gem News, 1996), especially as both colour varieties can occur together in one deposit. However, these appellations, as they are used in east Africa, have very specific meanings and are respectively used for a bright, slightly orange, yellow tourmaline, and a sharply dichroic yellow-green tourmaline comparable with colours of the African savannah.

The aim of this paper is to describe the geology of a major savannah and green tourmaline deposit in southern Kenya, the 'Yellow Mine'. For comparison, the geology of other yellow tourmaline mineralisations in Kenya and Tanzania are also described. New mineralogical and gemmological data on east African tourmalines are also given. Field trips to the sites that are described here took place during 1996 and 1997, as part of the author's work for Rockland Kenya Ltd.

Instrumentation

Minerals were analysed by means of electron microprobe at the Microprobe Service of the University of Paris-Jussieu (analysis number beginning with 97) and at the Microprobe Service of the IFREMER, Brest, France (analysis number begining with 98). Appropriate standards were used for calibration. Bulk rock analyses were performed at the CRPG of Nancy (France). Major elements were analysed by ICP-AES and trace elements by ICP-MS. F, C1, B, and Li were measured by titration. Absorption spectra were produced with a Unicam UV 4–100 Spectrometer. Standard gemmological instrumentation was used for optical measurements on gemstones.

The Yellow Mine

History and exploitation

The Yellow Mine is located about 4 km south of the John Saul Mine, near the Mangare Swamp, next to the eastern boundary of the Tsavo West National Park, and to the confluence of the Bura and Mwatate rivers (*Figure 1*). It processes material from the deposits mentioned in Gem News (1996) as 'Kasigau Mine' and 'Mangare Area'. Kasigau is an inselberg mountain about 15 km northwest of the Mangare Swamp.

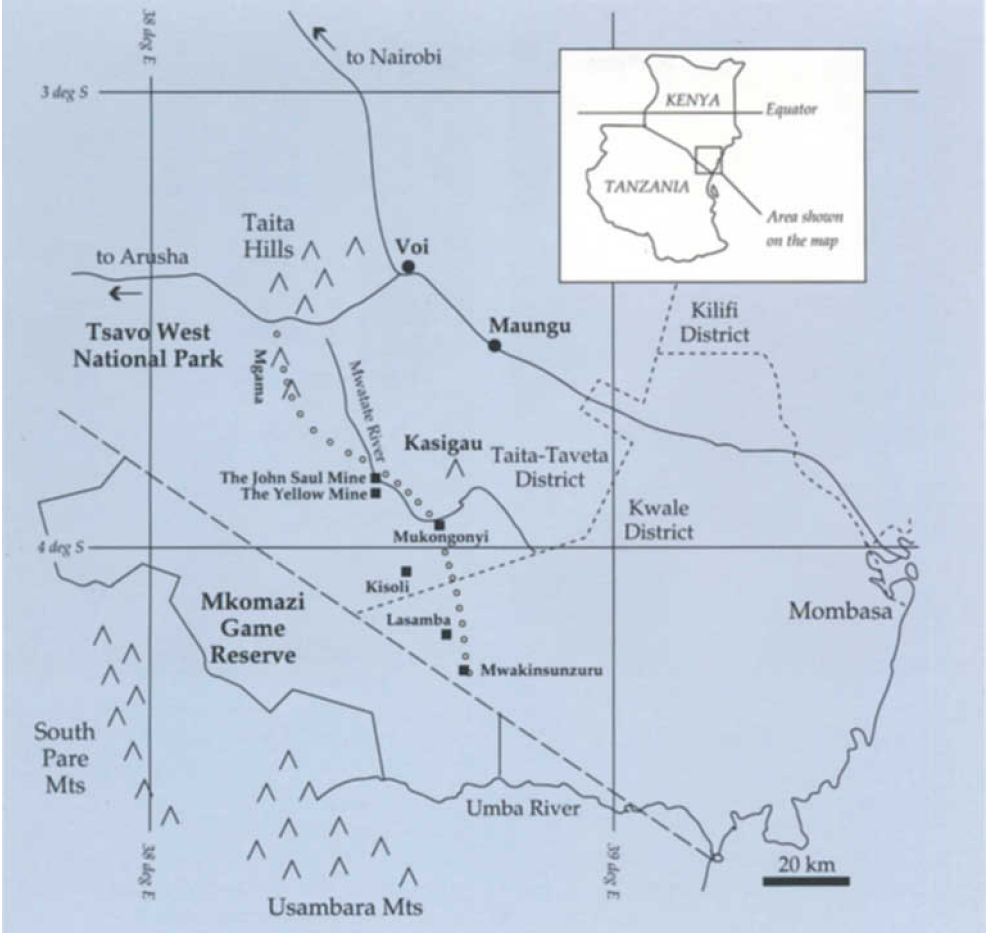

Figure 1: *Map of southern Kenya showing most of the places mentioned in the text. The line of small open circles represents the tsavorite belt along which most green garnet deposits of southern Kenya are located.*

Discovered in the eighties, the deposit was exploited at the beginning of the nineties by the company Rockland Kenya Ltd., which also runs the John Saul Ruby Mine. During that period, the tourmaline was followed to a depth of about 25 metres. After a few years of inactivity, the mine restarted and now produces 'savannah' (*Figure* 2), golden, and bicolour (green and yellow) tourmaline.

The tourmaline-bearing vein appears as a planar zone following the contact between a kidney shaped ultrabasic body and its

Figure 2: *Faceted savannah tourmalines from the Yellow Mine. Weights range from 4.8 to 6.2 ct.*

Figure 3: Pegmatite vein indicated by crosses in the pit at the Yellow Mine.

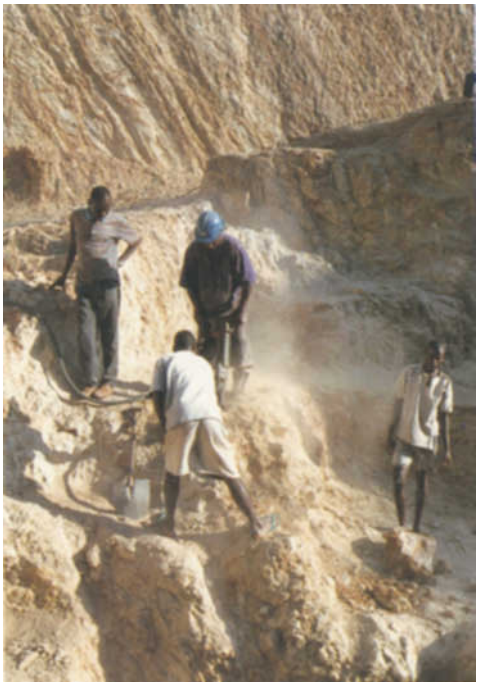

Figure 4: Working on the pegmatite vein at the Yellow Mine using jack hammers; no explosives are used.

graphite gneiss host rock and consists of pegmatite boudins more or less mineralized in tourmaline, kyanite, apatite and graphite.

Extraction is done by open cast pitting, following the vein from the surface (*Figure 3*). The ultrabasic rock is sufficiently homogeneous and coherent to allow high, steep walls in the mine with little risk of collapse. Two-metre-high steps are cut in order to allow access with ladders, and evacuation of the mine waste. Digging is done using jack hammers (*Figure 4*). The barren rock is removed by hand or by mechanized means and dumped outside the mine. A dozen workers are involved in these operations, and work is done under the surveillance of guards and of a security officer to avoid theft of stones.

When tourmaline crystals are encountered, they are carefully extracted using chisels and hammers. The material coming from the disintegration of the rock (sand, gravel) is then sieved in order to recover any smaller crystal fragments from the vein. Rough tourmaline is then cobbed and sorted, with a recovery percentage of marketable material of about 30%.

Regional geology

The Yellow Mine is situated on a major geological structure called the Mozambique Metamorphic Belt, which extends in east Africa along the Tanzanian craton, and which results from Neoproterozoic collision of the Tanzanian craton to the west and an eastern 'Kibaran' plate (Key and Ochieng, 1991). Many east African gemstone deposits are associated with this structure (Malisa and Muhongo 1990; Key and Ochieng, 1991). On a more detailed scale, the deposit is associated with an ultrabasic body contained in the graphite gneisses of the Kurase Group (defined by Saggerson, 1962), a series of mostly metasedimentary rocks metamorphosed to amphibolite or granulite facies (Arneth and Schidlowski, 1985). These

metasediments include graphite gneisses, biotite garnet gneisses, quartzites and marbles. They are associated with metavolcanic rocks and the whole assemblage is thought to represent metamorphosed shelf sediments and volcanic rocks (Key and Ochieng, 1991). Tsavorite mineralizations of southern Kenya are typically associated with rocks of these series (Pohl and Niedermayr, 1979; Key and Ochieng, 1991).

Another important characteristic of these series is the presence of scattered ultrabasic bodies consisting of talc, enstatite, magnesite, and other magnesian silicates, rich in Mg and poor in Si, Al and Fe (see *Table 1*). They are also rich in Co, Cr and Ni, which shows that they have an igneous origin (Horkel *et al.*, 1979), compared to metasedimentary ultrabasic rocks (rocks derived from sedimentary rocks such as dolomites) which are devoid of these elements (Faust *et al.*, 1956). The origin of these rocks is not clear, but the fact that they underwent, like their host rocks, several phases of metamorphism and deformation shows that their emplacement happened during an early stage of the evolution of the Mozambique Metamorphic Belt (Prochaska and Pohl, 1984). The ultrabasic bodies of the Mangare area have been described as sheets tectonically interleaved with the metasediments by Key and Ochieng (1991), who consider them as parts of an ophiolitic complex. They range from metres to kilometres in length, and are often associated with gemstone mineralization, the best known being the John Saul Ruby Mine (Pohl and Horkel, 1980; Key and Ochieng, 1991), the Umba sapphire mine in Tanzania (Solesbury, 1996), and the sapphire deposits of southern Madagascar (Kiefert *et al.*, 1996). The crystallization of corundum is due to complex metasomatic desilicification phenomena linked to the silica-deficient character of the ultrabasic rocks. These rocks can also be related to some kinds of rhodolite deposits, such as Kisoli, about 20 km south of the Yellow Mine, or to tsavorite deposits (see below).

Table 1: *Composition of three ultrabasic rock samples from the Mangare area, Kenya.*

Sample No.	*RT001*	*RT002*	*RT003*
wt. %			
SiO_2	51.30	38.28	15.04
Al_2O_3	0.40	0.34	0.67
Fe_2O_3	5.49	4.21	3.33
MgO	24.27	16.95	19.75
CaO	0.32	12.98	22.00
Na_2O	0.13	0.09	0.09
K_2O	0.06	0.03	0.02
L.O.I.	17.65	26.75	38.72
Total	99.62	99.63	99.62
ppm			
Co	72.9	68	34.4
Cr	2231	1298	1468
Cu	63	31.1	31.1
Ni	1605	947	876
U	4.56	2.77	1.56
V	87.5	44.2	34.4

N.B.: L.O.I. (loss on ignition) represents water and carbon dioxide content of the rock. High L.O.I. can be translated in terms of high carbonate content (dolomite and magnesite). Note high Cr and Ni, and low alkalis and alumina.

Geology of the deposit

The ultrabasic body at the Yellow Mine is about 100 m long and 50 m wide, and is elongated parallel to the regional foliation, which in this area trends 340 degrees (see *Figure 5*). It mainly consists of enstatite, talc, Mg amphibole and magnesite. Talc is clearly an alteration product which grows along the cleavage directions in enstatite crystals. This assemblage is cut by chlorite veinlets which contain pockets of chlorite with scattered granules of spinel rimmed by phlogopite. The spinel is red-orange, but its small size makes it of no value as a gemstone. These vein minerals have developed by metasomatic reactions between the ultrabasic rock and invading pegmatitic fluids. Opaque pink corundum mineralizations in the form of epidote, plagioclase, phlogopite, and corundum veins are also present. They also have a metasomatic origin, are broadly comparable to plumasites (cf. Lawson, 1904) and reflect the importance of metasomatism in the genesis of many gem deposits in southern Kenya.

The ultrabasic body is associated with a series of graphite, muscovite and sillimanite gneisses which are locally mobilised and

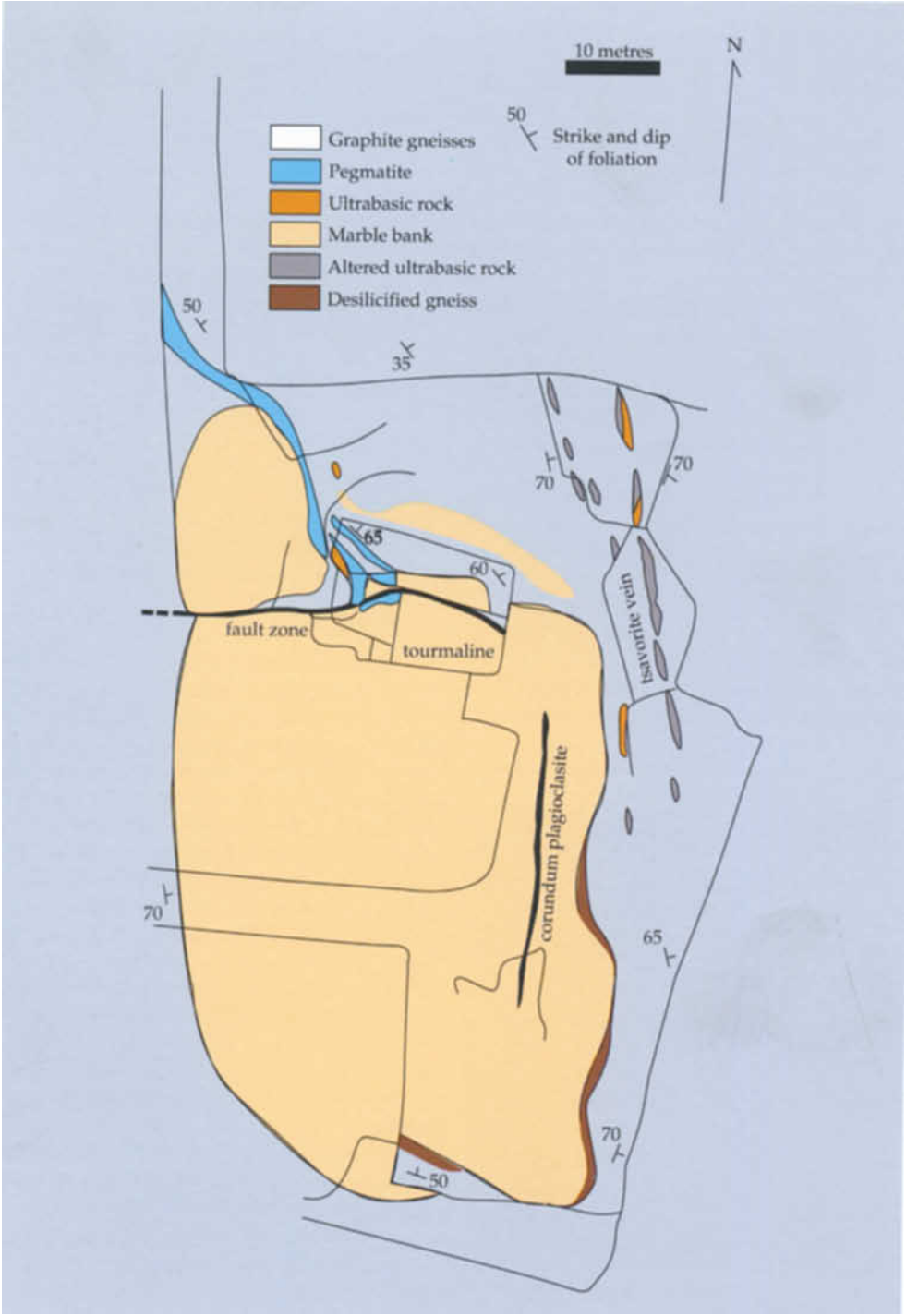

Figure 5: *Geological map of the Yellow Mine. Note the close association of corundum, green garnet and tourmaline mineralizations; and the boudinage of the tourmaline-bearing pegmatite near the fault zone.*

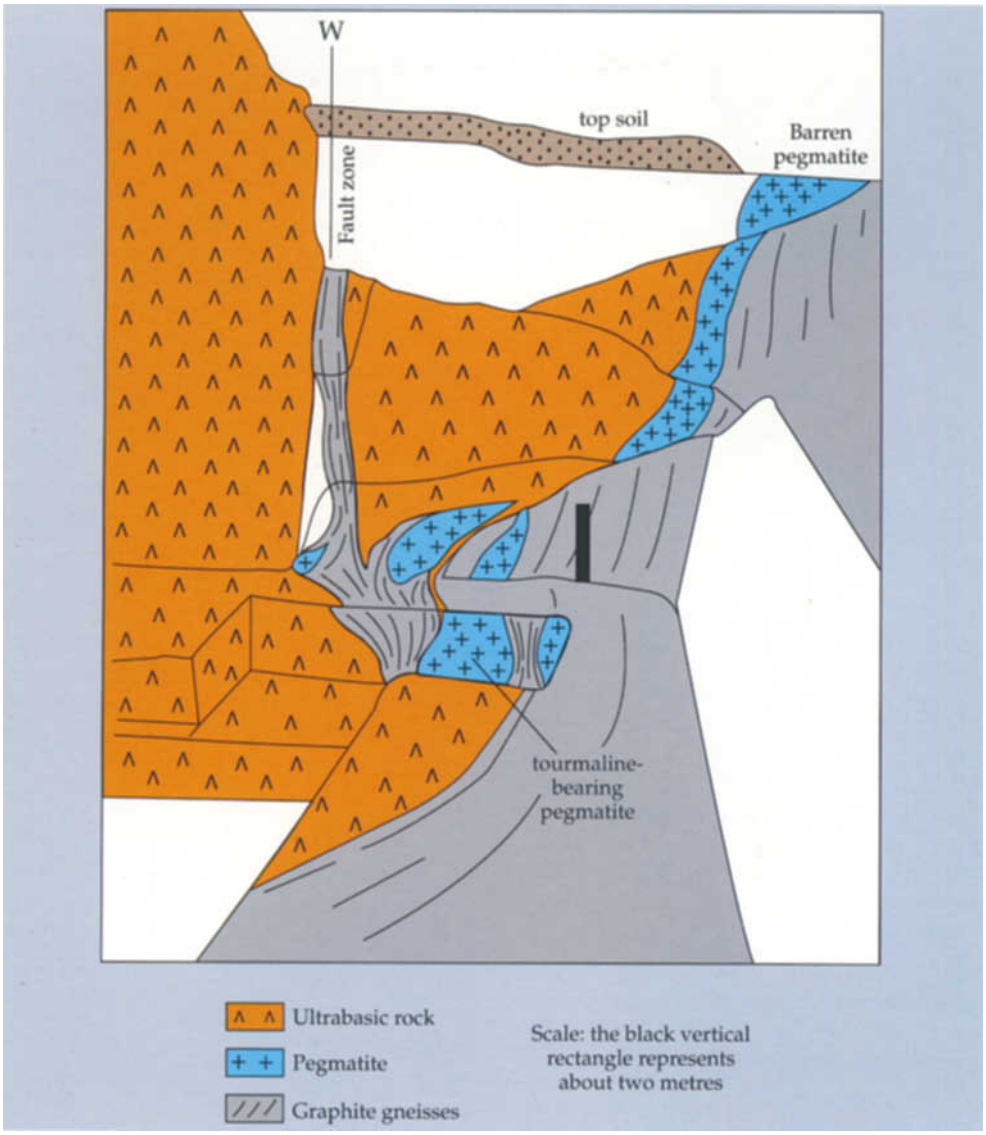

Figure 6: Sketch of the tourmaline mineralization at the Yellow Mine. The pegmatite follows the contact between the ultrabasic body (to the left) and the graphite gneisses (to the right) and enters into the fault zone where the mineralization is more pronounced.

injected with concordant anatectic pegmatite dykes. Except at one point, the contact between the ultrabasic body and its host rock is parallel to the foliation of the gneisses. These gneisses have undergone intense deformation marked by boudinage and the formation of isoclinal folds. Ultrabasic boudins on a scale of metres are also visible in the eastern part of the mine where the rock is more or less altered, and Mg–Al amphibole, Mg mica, corundum and spinel bear witness to the penetration of Si, K and Al fluids into the ultrabasic boudins.

Tsavorite is also present along the lines of ultrabasic boudins. Its Cr_2O_3 content varies from 0.1 to 0.3 wt % and V_2O_3 varies from 0.6

Figure 7: *Closer view of the pegmatite vein with the ultrabasic rock on the left. T: tourmaline; A: apatite.*

to 2.2 wt %, and these elements are responsible for its blue-green colour. Cr probably comes from the ultrabasic rocks and V from the graphitic gneisses. The tsavorite crystals are surrounded by a partially kelyphitic rim of purple tanzanite formed in response to decreasing pressure and temperature conditions. Dark green vanadian tourmaline has also been observed as an accessory mineral in the graphite gneisses.

In its northern part, the ultrabasic body is cut by a fault zone two to four metres wide, consisting of gneiss lumps and anatectic pegmatites (*Figure 6*). The muscovite in these gneisses is a deep green chromiferous variety (fuchsite).

The tourmaline mineralization is partly inside this fault zone (*Figures 3 and 6*) and follows a more or less boudinaged anatectic pegmatite rooted in sillimanite gneisses.

The basic mineral assemblage of the pegmatite is plagioclase, muscovite and quartz. The plagioclase is oligoclase (*Table II*), and is partly altered to fine-grained micaceous material. Graphite and apatite are common accessory minerals, graphite appearing as rounded flakes up to 10 mm across, while apatite forms vivid blue hexagonal prisms up to 10 mm long (*Figure 7*), regrettably not of gem quality. In some places, the pegmatite is stained with small patches of green copper minerals. At the contact with the ultrabasic rock, the pegmatite has a thin phlogopite blackwall (a reaction wall between a dyke and its host rock) and away from the wall, tourmaline increases, quartz decreases or disappears and centimetre-size blades of light blue (chromiferous) kyanite have been developed (*Table II*). When in contact with plagioclase, kyanite has transformed into a white or pale green mica, but in contact with quartz no reaction is visible. Fibrous sillimanite is also present both in the pegmatite and as inclusions in the zoned tourmalines, which indicates that it appeared earlier than the kyanite. Part of this sillimanite, like the kyanite, has transformed into mica.

The chemical composition of the pegmatite is given in *Table III*. Because of the difficulty of getting a representative sample of the rock owing to the mineralogical variability and grain size, three samples were selected. RT011 and RT012 represent the mica and tourmaline facies with more or less

Table II: *Chemical composition of plagioclase and kyanite from the tourmaline-bearing pegmatite of the Yellow Mine.*

wt. %	*Plagioclase Y91/Y94*	*Kyanite Y92/Y93*
SiO_2	62.17	37.20
TiO_2	0.01	0.01
Al_2O_3	23.23	63.00
FeO	0.01	0.02
MnO	0.02	0.01
MgO	0.02	0.02
CaO	4.86	0.01
Na_2O	8.57	0.01
K_2O	0.15	0.01
Cr_2O_3	0.01	0.09
V_2O_3	0.00	0.00
NiO	0.00	0.00
P_2O_5	0.01	0.01
F	0.02	0.01
Total	99.08	100.40
Ab %	75.50	
An %	23.70	
Or %	0.80	

N.B.: Y91/Y94 mean of 2 analyses; Y92/Y93 mean of 2 analyses.

Table III: Chemical composition of pegmatites from Mangare and Madagascar

	Yellow Mine tourmaline pegmatite			*Mangare area*	*Madagascar*
	RT011	*RT012*	*RT013*	*RT009/10*	
wt. %					
SiO_2	74.52	74.96	80.38	73.84	70.22
TiO_2	0.17	0.06	0.02	0.06	n.d.
Al_2O_3	15.44	13.86	16.93	14.89	17.20
Fe_2O_3	0.11	0.03	0.04	0.04	1.76
MnO	tr	tr	tr	tr	0.28
MgO	1.13	0.56	0.07	0.27	tr
CaO	1.42	0.57	0.21	1.50	1.36
Na_2O	1.92	1.55	0.66	2.90	4.45
K_2O	3.27	7.11	0.67	5.56	2.85
Li_2O	n.d.	0.001	0.002	0.004	1.49
P_2O_5	0.13	0.25	0.06	0.05	2.85
F	n.d.	0.010	0.002	0.026	0.11
L.O.I.	1.67	0.72	0.84	0.72	n.d.
Total	99.78	99.67	99.88	99.83	102.57
ppm					
As	1.43	1.87	0.49	0.16	n.d.
B	n.d.	0.13	0.001	0.004	0.18
Be	2.73	0.62	0.70	7.09	n.d.
Co	39.2	46.4	47.9	45.0	n.d.
Cr	21.6	1.93	8.06	2.27	n.d.
Cu	1.5	1.3	1.3	4.25	n.d.
Ni	10.4	1.76	8.59	23.2	n.d.
Pb	14.2	25.3	4.97	19.2	n.d.
U	14.84	7.93	0.22	5.07	n.d.
V	35.3	7.46	25.4	16.3	n.d.

N.B.: RT009/10 is mean analysis of Main Pit anatectic pegmatite; Madagascar data from Shigley and Kampf, 1984. In the Mangare analyses, Li and F are not included in the totals.
n.d. means not determined; tr means trace; L.O.I. means loss on ignition.

quartz, and RT013 represents the kyanite facies without quartz. For comparison two analyses of anatectic pegmatites with light green tourmaline from the Mangare area (more precisely, the John Saul Mine) are also given. An analysis of a gem-bearing pegmatite from Madagascar is reproduced from Shigley and Kampf (1984).

The very different compositions of the Yellow Mine pegmatite and the Madagascar pegmatite indicate that the Yellow Mine pegmatite is not a typical Na–Li tourmaline-bearing pegmatite. The geochemical similarity between the Mangare area anatectic pegmatites and the Yellow Mine pegmatite could indicate a possible genetic link between them. The high Co, Cr, and Ni contents are unusual for pegmatites and at both localities are due to the proximity of ultrabasic rocks.

Characteristics of the tourmalines

Three types of tourmaline appear in the pegmatite vein:

- *Type 1:* Yellow or green granules (typically about 10 mm across), euthedral or not, associated with feldspar, quartz, fuchsite and kyanite.
- *Type 2:* Euhedral prisms of various size (one to ten centimetres in length and width) showing a yellow core surrounded by a green rim, associated with feldspar, quartz, fuchsite and in some places kyanite. The green rim tourmalines have a blue-green/yellow-green dichroism. This zoning is visible only on macroscopic samples, and cannot be observed in thin sections (*Figure 8*).
- *Type 3:* Euthedral crystals of savannah tourmaline, honey coloured in outcrop;

Figure 8: Sample of tourmaline showing zoning with a yellow core and a thin green rim.

up to several kg in weight; associated with oligoclase but not with quartz (*Figure 9*). Inclusions of apatite, sulphides, graphite, plagioclase, quartz and sillimanite occur in all types, and macroscopic vivid blue apatite inclusions are common in type 3 crystals.

Figure 9: Sample of savannah tourmaline without any colour zoning.

The different kinds of tourmaline crystals are all transparent but may be more or less fractured and included. Gem quality pieces reach 4 to 5 g in weight. Cut stones are very bright and usually display sharp pleochroism.

Yellow tourmaline from the Yellow Mine showed the following optical characteristics:

- RI : ε = 1.622–1.624 and ω = 1.643–1.646 ($\omega - \varepsilon$ = 0.020–0.023) (dichroism yellow/pale green)
- RI : ε = 1.623 and ω = 1.644 $\omega - \varepsilon$ = 0.021) (dichroism yellow/pale yellow)

Analyses of savannah and green tourmalines from the Yellow Mine are given in *Table IV*. These analyses are similar to those reported by Hänni *et al.*, (1981) for tourmalines of the Voi-Taveta area, which strongly suggests that those tourmalines actually came either from the Yellow Mine or from a similar type of deposit.

Mineralogically, these tourmalines are solid solutions between dravite and uvite with a ratio of 78:22 to 90:10. They contain no significant amounts of Fe, V or Mn. The yellow crystals contain small amounts of Ti (see analysis) and no Cr. The green rims contain traces of Cr_2O_3 (0.27 to 0.59 wt %) and lower amounts of Ti. We could not detect any Fe in the green rims (cf. Hänni *et al.*, 1981). The colour zoning is not correlated with any other chemical feature in the tourmalines (*Figure 10*). The dravite:uvite ratio in tourmalines from many sources remains constant from the yellow core to the green rim. Henry and Guidotti (1985) have shown that the chemical composition of tourmaline is strongly linked to the host rock. According to these authors, dravite is characteristic of meta-ultramafic rocks, and dravite-uvite solutions are characteristic of meta-carbonates.

The green rim of the tourmaline probably owes its colour to Cr. Its absorption spectrum shows two wide absorption bands at 437 and 596 nm, and a small peak at 681 nm (*Figure 11*). The yellow core of this tourmaline shows a rather flat spectrum with a wide absorption band centred at 435 nm. (cf. Hänni *et al.*, (1981), who considered that the 440 nm absorption band that they observed in yellow tourmaline is due to Ti).

Table IV: *Composition of tourmaline from southern Kenya.*

locality	*Yellow Mine*			*John Saul Mine*				*Mukongonyi*	*Voi-Taveta*
colour	*yellow (savannah)*	*green*	*light green*	*blue green*	*yellow green*	*yellow pink*	*red*	*yellow brown*	*yellow*
source	*pegmatite*	*pegmatite*	*pegmatite*	*plagioclasite & eluvial*	*eluvial*	*pegmatite*	*pegmatite*	*eluvial*	
no. of analyses	*mean of 3*	*mean of 2*	*mean of 2*	*mean of 3*	*mean of 2*		*mean of 2*	*mean of 2*	*mean of 2*
wt. %									
SiO_2	38.23	37.61	37.44	36.91	37.14	36.83	33.89	38.07	36.54
TiO_2	0.57	0.53	0.06	0.72	n.d.	n.d.	0.20	0.47	0.68
Al_2O_3	35.96	35.50	31.75	34.35	35.41	34.83	48.34	34.11	35.02
FeO	0.02	0.00	0.03	0.02	0.07	0.92	0.01	0.17	0.00
MnO	0.02	0.00	0.00	0.02	0.36	0.02	0.31	0.03	0.00
MgO	9.54	9.64	12.41	9.57	9.25	8.95	0.01	10.57	9.28
CaO	0.65	0.92	3.14	1.24	0.64	0.90	0.62	1.88	1.09
Na_2O	2.15	1.98	1.06	2.01	2.32	1.98	1.58	1.70	2.04
K_2O	0.06	0.04	0.01	0.09	0.05	0.08	0.01	0.08	0.07
Cr_2O_3	0.01	0.43	0.07	0.23	0.06	0.09	0.00	0.06	0.00
V_2O_3	0.02	0.03	0.00	0.02	0.14	0.01	0.00	0.01	0.00
F	0.01	n.d.	0.17	n.d.	n.d.	n.d.	0.00	0.00	n.d.
Total	87.24	86.68	86.14	85.18	85.44	84.61	84.97	87.15	84.72

N.B.: Amounts of B and H_2O not determined. n.d. means not determined. F not included in totals. Voi-Taveta analysis taken from Hänni *et al.*, 1981.

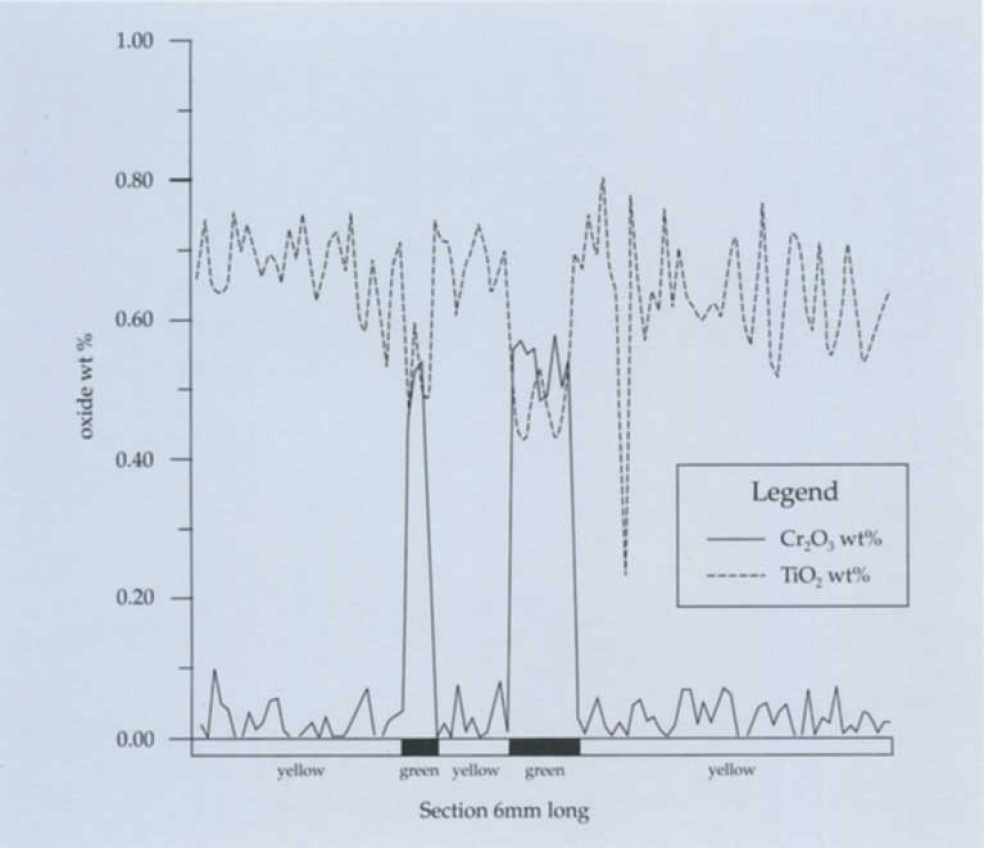

Figure 10: *Cr_2O_3 and TiO_2 contents in a section, approximately 6 mm long, containing type 2 tourmaline crystals from the Yellow Mine. The alternate yellow and green bands are due to the juxtaposition of several crystals and not to multiple zoning. Transition from yellow to green is obviously linked to a decrease of TiO_2 and a sharp increase in Cr_2O_3.*

Origin of the mineralization

The presence of three different types of tourmaline and the presence of zoned crystals, indicate that the mineralization developed during more than one phase of magmatic and metasomatic crystallization. However, no geode type pockets occur in the pegmatite and, although the tourmalines are mostly euhedral, they are always included in a mass of feldspar and/or quartz. Under the microscope, they appear as poikiloblasts. The pegmatite itself does not show any mineralogical zoning, except the presence of a few sulphide-bearing quartz cores.

No granitic batholith is present within 100 km of the Yellow Mine and this type of pegmatite clearly has an origin totally different from that of the usual gem bearing Na–Li pegmatites, such as those described by Shigley and Kampf (1984), London (1986), and Cassedanne and Roditi (1996).

The following phases, that may not be clearly distinct in time, are proposed for the formation of the vein itself:

1. Formation of a fault zone cutting part of the ultrabasic body.
2. Injection of a local anatectic pegmatite along the contact of the ultrabasic body and its host rock and partly along the fault zone, under *P–T* conditions of the sillimanite stability field.

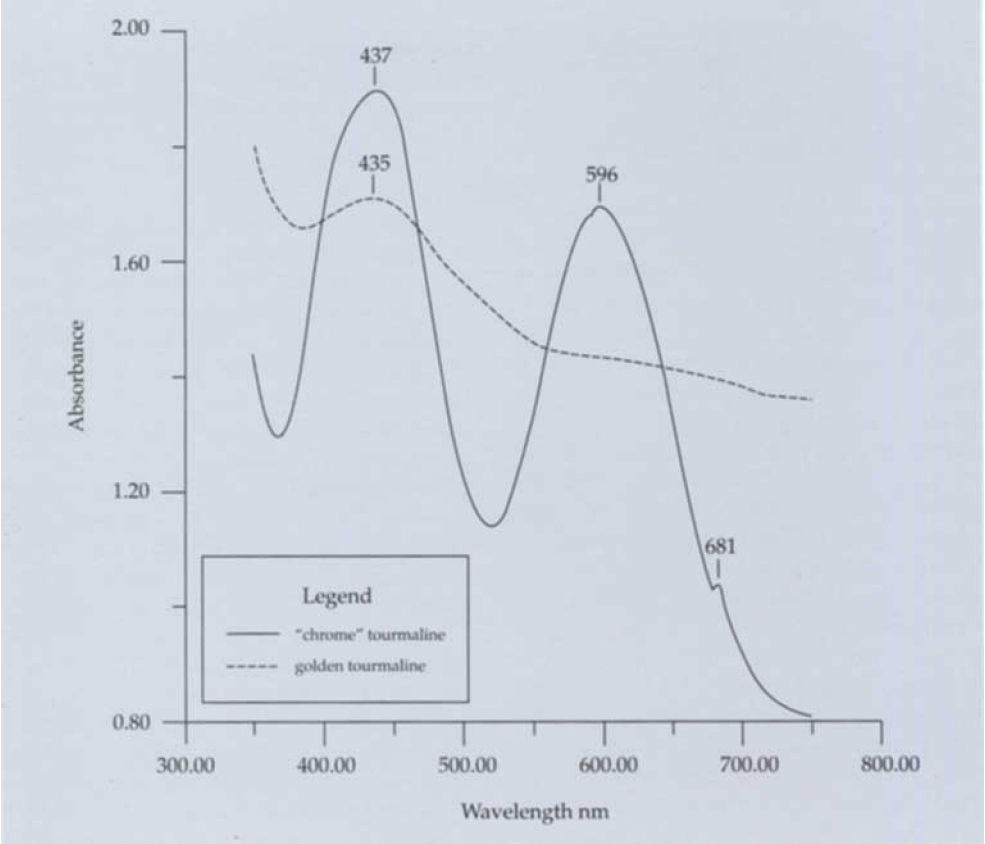

Figure 11: Absorption spectra of the green and yellow zones of a type 2 tourmaline from the Yellow Mine. The light beam was orientated approximately parallel to the c-axis of the crystals along the respective zones to obtain the spectra.

3. Deformation inside the fault zone, boudinage of the pegmatite. Kyanite formation may have taken place before or after this phase.
4. Metamorphic transformation of sillimanite and kyanite (+plagioclase) into mica.

Tourmalines of type 1 and 2 are related and probably crystallized together in the following way:

- Crystallization of yellow cores.
- Crystallization of green rims around some of the yellow cores, and of new green cores.

It is likely that type 3 tourmalines crystallized at the same time as the yellow cores of types 1 and 2 tourmalines. Sillimanite inclusions in the yellow cores of type 2 tourmalines show that they crystallised in the stability conditions of sillimanite, whilst the occurrence of the three chromian minerals kyanite, fuchsite and tourmaline, and the common association of kyanite and green tourmalines at outcrop, suggest that kyanite formation is contemporaneous with crystallization of the green tourmalines.

The B-bearing fluids originate in the host gneisses and, as they contain Mg and Cr, are likely to be equilibrated with the ultrabasic rocks. After Rosing and Rose (1993), Cr-bearing minerals such as Cr kyanite and fuchsite indicate that fluids from ultramafic rocks were significant.

Graphitic metasediments of the Mangare area may be an alternative source of Cr for the fluids. The absence of Fe in the tourmalines can be explained by the low iron content of the host rocks (metasediments and ultrabasic rocks), and by the reducing environment (presence of graphite) which causes iron to be fixed in sulphide phases.

The colour zoning of the tourmaline crystals may have appeared during one or several phases of metasomatic crystallization. However, the absence of multiple zonation points rather to one phase. The zoning itself may be due to a change of the chemical composition of the fluid. For example, Ti zoning in Mong Hsu rubies (Myanmar) is controlled by the F content of the fluid which itself depends on the crystallisation of fluorite (Peretti *et al.*, 1996). The zoning of the Yellow Mine tourmalines may well be due to a change of the partition coefficient between Cr and Ti, and the fluid, following perhaps a change in the thermodynamic conditions. This last hypothesis is supported by the fact that for types 1 and 2 tourmalines, yellow cores seem to have crystallized together with sillimanite, while green rims and green crystals probably formed together with kyanite, i.e. in different pressure and temperature conditions.

Other yellow tourmaline deposits

Minor yellow tourmaline deposits are abundant in southern Kenya (Mgama Mindi, Kambanga, Kuranze in Taita-Taveta and Kwale districts) and, for comparison, a few are described below.

The geology of the John Saul Mine tourmaline deposit resembles in appearance that of the Yellow Mine, but striking differences also exist. Other deposits of different origin may be linked to simple magmatic crystallization in anatectic pegmatites, or to interactions between marbles and pegmatites, or fluids of pegmatitic affinities. Such deposits were observed in southern Kenya and Tanzania in the area South of Arusha (Lelatema).

The John Saul Mine tourmaline deposit

This deposit is located a few hundred metres north of the famous ruby deposit. It is a pegmatite vein along an ultrabasic body 200 m long and 10 to 20 m wide. The deposit has not yet been developed, and is visible only in a small exploration trench. The pegmatite vein itself is almost one km long and probably originates in a major E–W shear zone cutting the metasediments at the Bura River. However, the vein seems to be mineralised only in the vicinity of the ultrabasic body. The rock is quartzo-feldspathic and has no mica. It is generally fine grained and is in places more aplitic than pegmatitic, with small patches of yellow tourmaline and blue apatite; at one point it becomes coarser and richer in tourmaline. There, the feldspar crystals reach 20 cm across and the pegmatite yields graphite, blue apatite, green, yellow, and red tourmaline. The rock may locally form quartz-bearing tourmalinites. All three colours can be present in one hand sample. No mineral zoning is visible within the pegmatite, and no other Li-bearing mineral has been observed. Tourmaline crystals do not seem to be zoned and they probably crystallized together with the pegmatite. This, added to the presence of red tourmaline, makes this deposit substantially different from that of the Yellow Mine. However, the small size of the outcrops may hide more complex features of the vein.

The yellow tourmaline from this deposit cannot be termed savannah because of the lack of the green hue. It has a yellow/pale yellow or yellow/pinkish yellow dichroism that makes it different from the stones of Yellow Mine. The resultant colour is more orange and may be termed 'golden'. Mineralogically these stones are also dravite-uvite solid solutions with a ratio of 80:20 (*Table IV*, yellow pink analysis), and they are richer in Fe (FeO = 0.92 wt %) than the Yellow Mine stones.

Gem-quality samples of red tourmaline have not yet been found, but may be present at depth. The red tourmaline crystals that were sampled are rendered opaque by

alteration minerals in the fractures. Chemical analysis (*Table IV*) showed that they are elbaite (82%)-liddicoatite (18%) solid solutions. The presence of Mn (MnO = 0.29 to 0.32 wt %) shows that small amounts of the Li–Mn end member tsilaisite are present. Gem tsilaisite was described by Schmetzer and Bank (1984), who commented that only small amounts of Mn in elbaitic tourmalines leads to pink or red colours.

Optically, these red tourmalines have refractive indices higher than those of the dravitic yellow tourmalines ($\varepsilon = 1.637$ and $\omega = 1.656$, $\omega - \varepsilon = 0.019$). They show a red/orange pink dichroism.

Deer *et al.* (1962) and Henry and Guidotti (1985) state that there is an immiscibility gap in the elbaite-dravite series, an idea which is clearly supported here by the presence of two completely different tourmalines in the same pegmatite vein. Dunn *et al.* (1977) also showed that there is no solid solution between uvite and liddicoatite, the respective Ca bearing equivalents of dravite and elbaite. In their study of the crystal chemistry of tourmaline, Foit and Rosenberg (1979) showed that there is no chemical or crystallographic reason for the lack of solid solution between dravite and elbaite observed in natural samples. They proposed that extreme fractionation between Mg and Li during petrogenesis, as well as fractionation due to the different field strengths of these cations, is responsible for this apparent lack of intermediate members. For these authors, this is an example of modification which does not involve a change of the chemical environment .

At the John Saul Mine, field observations indicate that both types of tourmaline (dravitic and elbaitic) crystallized together (i.e. more or less simultaneously) during the cooling of the pegmatite. This would imply that the *P–T*, and chemical crystallization conditions of the two tourmalines are very close.

Anatectic pegmatites of southern Kenya

Blue-green, green, yellow and orange tourmalines have been observed as accessory minerals in anatectic pegmatoids in gneisses of the Kurase series. This kind of mineralization, not economically important because of the scarcity of crystals in the rock, is nevertheless an important source of tourmaline for eluvial and alluvial deposits. Such deposits are present, for example, at Mukongonyi, Kisoli, Lasamba and Mwakisunzuru. In some deposits chrome dravite is associated with kornerupine. The composition of tourmaline samples from Mukongonyi are given in *Table IV.* These tourmalines are of a brownish yellow colour and are richer in uvite than those from Yellow Mine, with a dravite:uvite ratio of 62:38. They are also richer in Cr ($Cr_2O_3 = 0.05$ to 0.07 wt %). Refractive indices of $\omega = 1.648$ and $\varepsilon = 1.628$ ($\omega - \varepsilon = 0.020$) have been measured. The dichroism is brownish-yellow/pale green. In the concentrates, they are found together with ruby, kyanite, tsavorite, and blue green, bottle green and brown tourmaline.

Metasomatised marbles at Kisoli

Tourmalines with a yellow core and a green rim have been recovered during the eighties from the sides of Kisoli Hill, in the southern part of the Taita-Taveta District of Kenya. The tourmalines occur in micaceous veinlets cutting across graphite-bearing marbles and as crystals scattered in the marble next to the veinlets. Locally, the veinlets have been reworked in faults and

Figure 12: *Tourmaline mines in the marbles of Lengasti, Tanzania.*

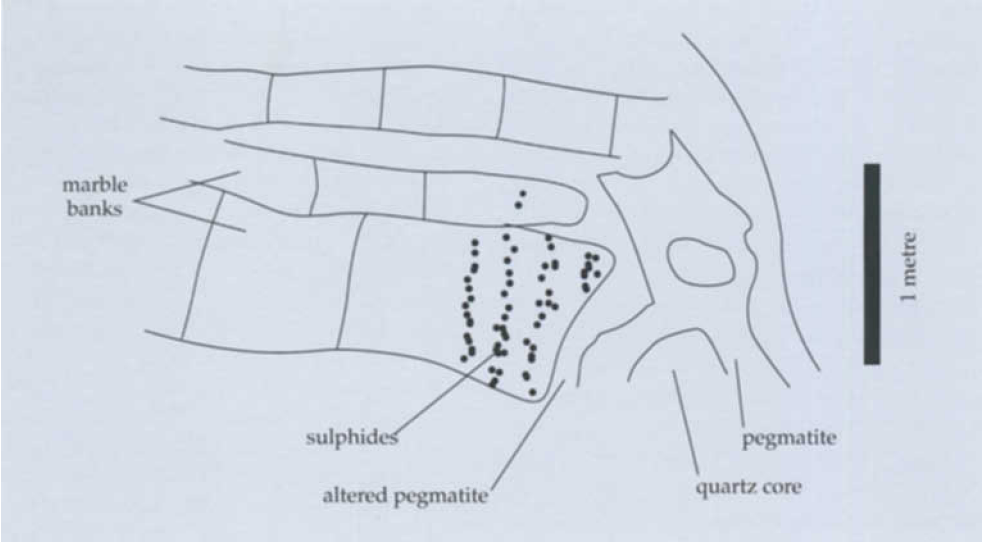

Figure 13: *Geological sketch of a tourmaline-bearing pegmatite in a marble environment at Lengasti, Tanzania.*

joints filled with a carbonate cement. The mineralization then appears as a tourmaline breccia, from a centimetre to a decimetre thick.

This kind of mineralization is similar to the chrome tourmaline mineralization described by Jan *et al.* (1972) from Swat in western Pakistan, except that at Swat, the chromium is provided by a nearby serpentinite, while at Kisoli no ultrabasic rock is directly associated with the deposit. The traces of chromium in the green rims of the Kisoli tourmalines are thought to have come from the graphitic metasediments.

Marble-pegmatite interactions at Lengasti

The Lengasti tourmaline deposit in Tanzania is located in the northern part of the Lelatema Hills, on a group of marble ridges hosted in graphite, sillimanite and muscovite gneisses. These gneisses contain concentrations of tsavorite and rhodolite.

The tourmaline mineralizations are associated with a set of pegmatitic veins and veinlets which cut at right angles across sub-horizontal marble banks. Both lithologies (the marble and the pegmatite) have the same structural direction and it is likely that the marbles are at this place folded into an anticlinal structure and that the pegmatites were emplaced in its axial plane thus cutting the top of the structure. The mineralized area extends over several hundreds of metres, and has been followed by Tanzanian prospectors and miners who use explosives to enable the digging of small pits a few metres deep in the marbles (*Figure 12*).

On the outcrop, one can observe altered feldspathic masses (the pegmatite veins) cutting through the marbles (*Figure 13*). Tourmaline occurs in nests in the central part of the pegmatite, together with masses of transparent granular quartz. Here again, no geodes have been observed. Tourmaline crystals are zoned with a yellow core and a green rim (*Figure 14*). At the contact of the pegmatite, the marble displays a coarser structure than in the main mass: the carbonate crystals are more transparent and there are patches of lime yellow sulphur. Sulphide enriched zones in the marble form bands parallel to and a few decimetres away from the contact with the pegmatite (*Figure 13*).

The occurrence of sulphides and graphite associated with the mineralization indicates that the pegmatites could have originated by anatexis of graphite gneisses underlying the marbles.

Conclusions

Studies of the Yellow Mine tourmaline deposit, and of some other east African yellow tourmaline deposits, show that yellow (savannah and golden) and bicolour tourmalines of east Africa can have very different geological origins. However, all the mineralizations are more or less directly associated with anatectic mobilization of the metasediments of the Kurase Series in Kenya and their equivalent in Tanzania.

Most of these tourmalines are dravite-uvite compounds in which dravite is dominant. Their particular chemistry is due to the association of the mineralizations with Mg-rich ultrabasic rocks and with metasediments where Fe is low or fixed in sulphides due to the reducing environment established by the presence of graphite.

The low Fe content of the tourmalines described above and of other green tourmalines whose analyses are also given in *Table IV* (analyses of John Saul Mine stones), is important for gemmology in that gem quality stones tend to have little Fe and higher contents of Fe (and Ti) tend to opacify tourmalines (Michailidis *et al.*, 1996).

The survey of many Kenyan and Tanzanian deposits has shown that the yellow core/green rim zoning in tourmaline has a regional value, whatever the geology. Similar zoning has also been observed in other minerals; for example, some (but not all) rubies of the Mangare area display zoning with a pink silky core (more Ti, less Cr) and a bright red rim devoid of rutile silk (more Cr, less Ti). This suggests that some of the gemstones in the Kurase Series were formed in one major phase of crystallization. For the tourmalines, it is proposed that the zoning may be linked to a change in metamorphic conditions in the whole Kurase Series, leading to dramatic modifications in the partition coefficients of Cr and Ti between metasomatic fluids and the host rocks.

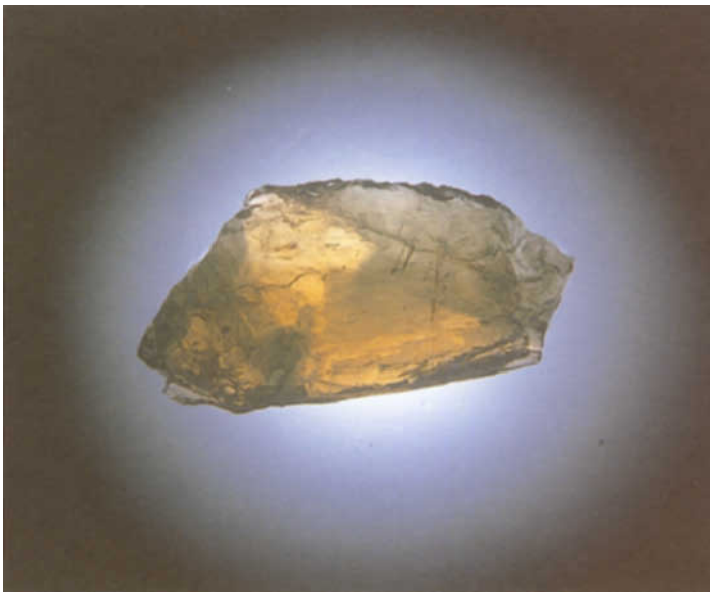

Figure 14: *Yellow and green zoning in a tourmaline from Lengasti, Tanzania.*

On the Al–Fe–Mg diagrams of Henry and Guidotti (1985), tourmalines of southern Kenya lie in the field of ultramafic rocks and of Al-saturated metapelites and metapsammites, which is consistent with field observations (see *Figure 15*). Most of the samples fall in field 7, except elbaites from the John Saul Mine which fall in field 1. It is interesting that two very different tourmalines from the same rock the Mg-tourmaline and the Al-tourmaline from the pegmatite vein of the John Saul Mine, fall in two different fields (respectively 7 and 1), but nevertheless this pegmatite remains consistent with the definition of these two fields: it is a Li bearing pegmatite hosted in an ultrabasic rock.

Another example of the close proximity of dravite and elbaitic tourmalines has been described recently by Novak *et al.* (1999) in an elbaite subtype pegmatite in the Czech Republic.

Through these examples, the geology of tourmaline deposits (and more generally gemstone deposits) in east Africa has been shown to be complex and many studies are still to be done, both in detail and regionally.

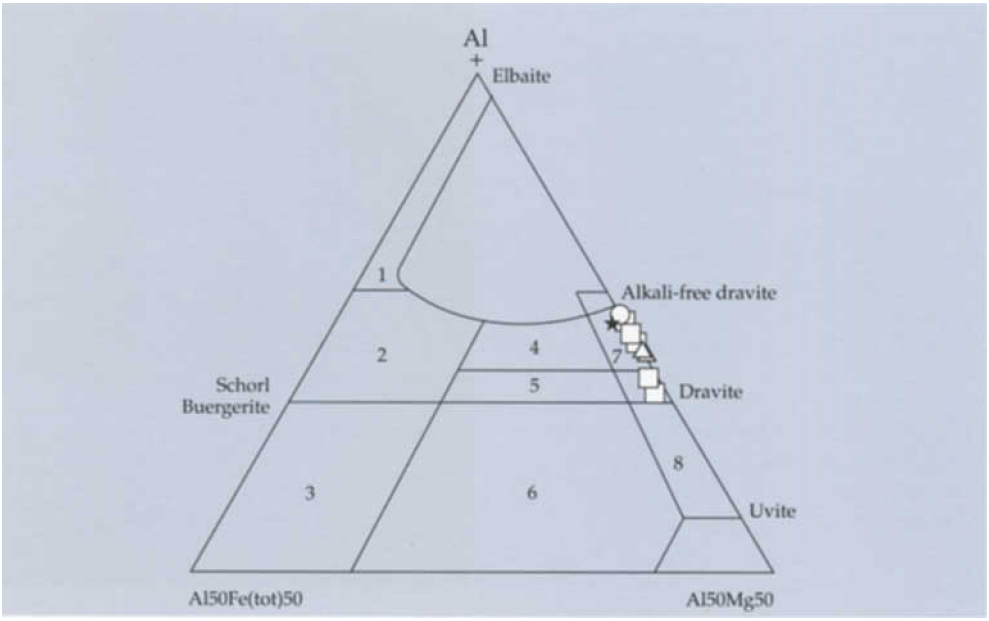

Figure 15: *Ternary diagram taken from Henry and Guidotti (1985), where Al, Fe, and Mg are molecular proportions, and the symbols represent tourmalines from southern Kenya as follows: cross: Al-tourmaline from the John Saul Mine; star: yellow Mg-tourmaline from the John Saul Mine; circle: Mg-tourmaline from the Yellow Mine; square: green tourmaline from the ruby deposit of the John Saul Mine; triangle: brownish-yellow tourmaline from Mukongonyi.*
The fields are:
1 Li-rich granitoid pegmatites and aplites;
2 Li-poor granitoid and their associated pegmatites and aplites;
3 Fe^{3+}-quartz tourmaline rocks (hydrothermally altered granites);
4 Metapelites and metapsammites coexisting with an Al-saturated phase;
5 Metapelites and metapsammites not coexisting with an Al-saturated phase;
6 Fe^{3+}-rich quartz-tourmaline rocks, calc-silicate rocks, and metapelites;
7 Low-Ca ultramafics and Cr, V-rich metasediments;
8 Metacarbonates and meta-pyroxenites.
Fields 4 and 5 overlap with field 7.

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Identification of synthetic spinels by means of photoluminescence spectroscopy

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ABSTRACT: Blue synthetic spinels resembling sapphires in an old brooch were identified using photoluminescence spectroscopy.

Keywords: photoluminescence, spinel, synthetic

Introduction

The main advantage of photoluminescence (PL) spectroscopy in identifying materials of gemmological interest is that it is totally non-destructive and the only requirement for the sample is that it is clean. Most chemical methods require more elaborate preparation.

In this spectroscopy the most relevant feature of rubies and of most sapphires (Carbonin *et al.*, 1998) is the luminescence band centred at $\lambda_{Cr} = 694$ nm which is related to the position of Cr^{3+} in the crystal structure. However, there are many imitations of ruby and sapphire, and this paper describes a brooch with blue stones which were identified as spinels (*Figure 1*).

Experimental

The apparatus developed at Istituto di Chimica e Tecnologie Inorganiche e dei Materiali Avanzati (ICTIMA) includes a versatile sample-holder designed for the investigation of samples of any shape (even irregular) and a large range of sizes (from a few hundredths of a millimetre to several centimetres). Rough materials such as sapphire in its host rock (Carbonin *et al.*, 1998) and finished objects can be studied.

The PL spectra presented here were obtained from equipment containing a frequency doubled Nd continuous wave laser ($\lambda = 532$ nm) (CASIX), a grating spectrometer (640-HR, Jobin Yvon) with a reciprocal dispersion of 2.4 nm/mm, and a

Figure 1: *Brooch containing a central blue gem (A) and several smaller ones (A').*

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germanium detector (EO817L, North Coast) cooled by liquid nitrogen. Spectra are compared with those on a database of standard spectra obtained from known stones.

Results and discussion

The central blue gem (A) (oval cut, 14 x 11 mm) of an old brooch (*Figure 1*) exhibited a PL λ_{Cr} value of 691.5 nm, significantly lower than that of sapphires (*Figure 2*). This observation, together with the value (1.73) of the single refractive index, led us to identify this gem as a synthetic spinel (Webster, 1994).

The PL spectrum of Cr^{3+} in natural spinel is complex but the relevant component for comparison with the above spectra is a peak at 686 nm, distinctly different from those of synthetic spinel and sapphire.

The position in the brooch of the twelve smaller gems (A') that encircle A prevented the application of some gemmological techniques (including measurement of the refractive index), but the PL spectra are comparable with that of the central stone and indicate that these gems also are synthetic spinel.

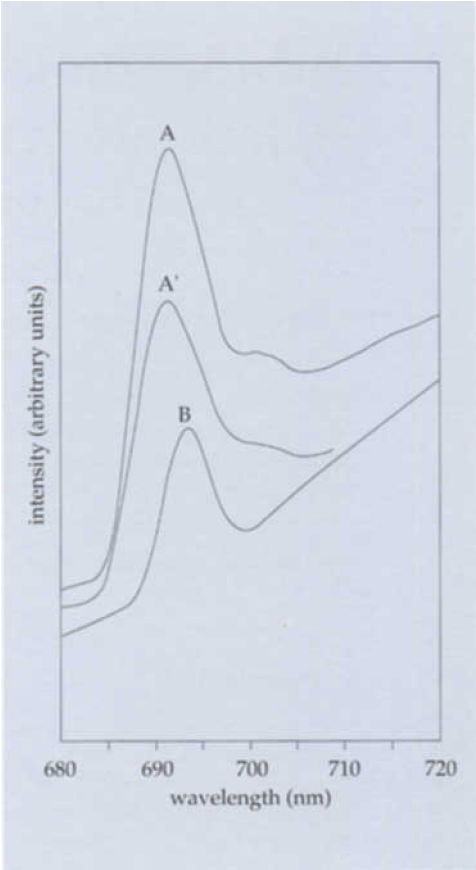

Figure 2: *PL spectra of central synthetic spinel A, surrounding synthetic spinels (typical example A'), and blue sapphire B.*

Conclusions

The use of PL spectroscopy, in the present case by means of the 'tracing' Cr^{+3} ion, whose behaviour is sensitive to its crystal environment, is particularly appropriate for the investigation of mounted gems or jewels of unusual shape or size.

Acknowledgements

We are much indebted to Mrs Brunella Fabro for the loan of the brooch, and thank Dr Claudio Brogiato [Dept. Mineralogia e Petrologia, University of Padova] for the picture.

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An independent gemmological examination of six De Beers synthetic diamonds

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ABSTRACT: A study has been made of six De Beers synthetic diamonds – one yellow, two brown, one blue and two 'colourless' stones. Published information about synthetic diamonds already exists, but independent investigations can justifiably add to existing knowledge.

Keywords: fluorescence, spectra, synthetic diamond

Introduction

Substantial and meaningful data on synthetic diamonds have already been published and a selection of papers is given in references (1–11). The object of this particular study is to either independently confirm that which has, in part, already been reported, or to describe possible significant variations of phenomena already observed, which may be of additional benefit to other gemmologists. As much supportive information as possible is always beneficial for identification work of any kind. Although one can criticize duplication of data, this author believes it can strengthen a case already put, perhaps from a different viewpoint.

At the present time there appears to be relatively few synthetic diamonds on the market, but there are strong indications that other interests, such as Chatham Created Gems and Sumitomo, may wish to market stones. The author has recently identified two Sumitomo synthetic diamonds that were set in gold earrings and belong to a member of the general public. Chatham has, for some time now, made it clear that marketing will go ahead as soon as production yields suitable synthetic diamonds. In any case, the stones are still expensive to produce, particularly the 'white' range. It is in fact the latter group that is important in this context.

Major advances have been made in the knowledge of, and the means of differentiating between, natural and synthetic stones, particularly in the past few years. The Gemological Institute of America has published much useful and practical knowledge in *Gems & Gemology*[2–9], and De Beers, through their Research Centre, has developed the DiamondSure[1] and DiamondView[1]. Enough data now exist to identify the stones with confidence and it could be said that the principal laboratories are in a position to successfully handle a substantially increased volume of synthetics should this occur. As so often happens with many synthetics, while producers show good intentions with accompanying documentation of the true identity of their stones, further along the trading chain – even among the public – such documents are often discarded and the products unscrupulously sold as natural.

Associated education is priceless in terms of establishing a solid foundation. Student gemmologists should be taught the

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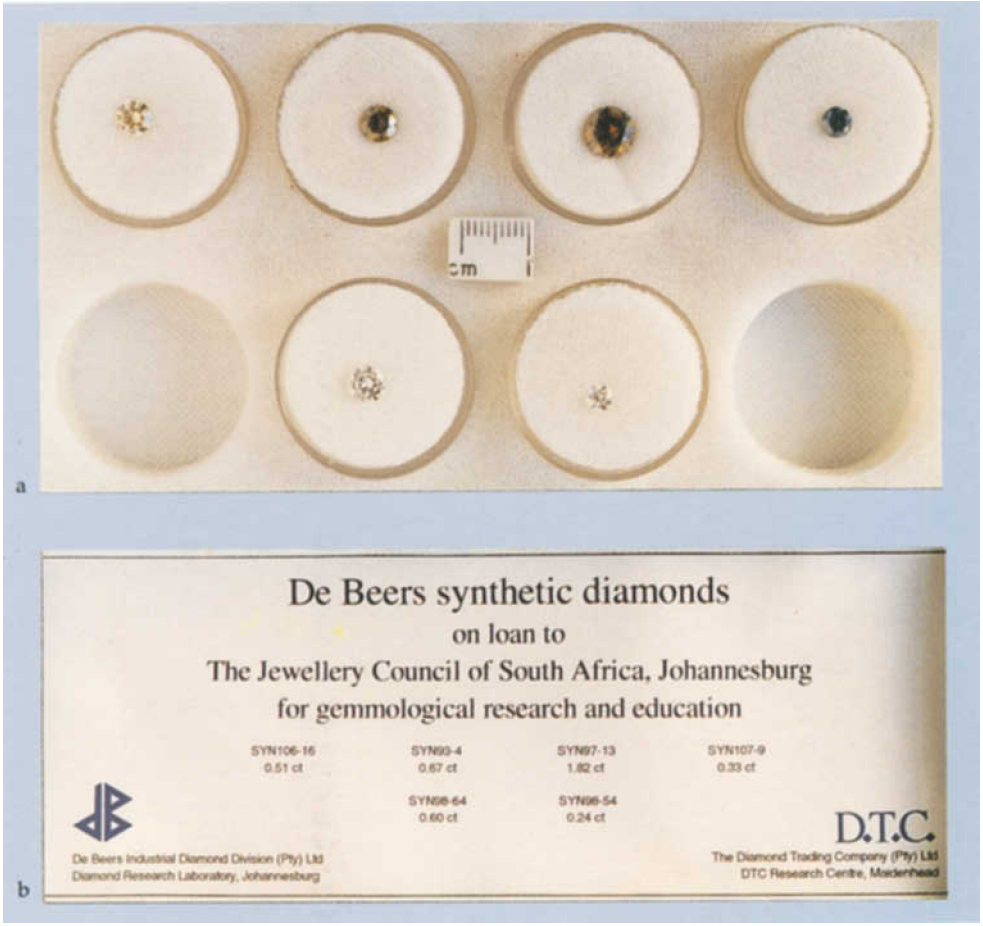

Figure 1a and b: *(a) The six synthetic diamonds examined (actual size) and (b) details in the same order.*

fundamentals of synthesis in more detail – particularly in the context of gem-quality diamonds which until recently were deemed as being 'safe' because of high costs and limited production.

The De Beers synthetic diamonds

The details of six synthetic diamonds examined in this study are illustrated in *Figures 1a* and *1b*.

In *Figure 1a*, the upper row consists of (left to right): yellow, two brown, blue; and the lower row contains two white (colourless) stones. *Figure 1b* shows details in the same order – the De Beers reference numbers can be seen to be 106–16 (0.51 ct), 93–4 (0.67 ct), 97–13 (1.82 ct), 107–9 (0.33 ct), 98–64 (0.60 ct) and 98–54 (0.24 ct) in the above order. All are prefixed by 'SYN' and are modern round brilliant cuts.

Description of colour

Colour descriptions used here are based on rules laid down by the International Diamond Council (IDC) representing the World Federation of Diamond Bourses and the International Diamond Manufacturers Association. The two 'colourless' stones are shown with the GIA equivalent grades (H to I, probably a low H), the HRD colour grade being 'white'. The other four

***Table I:** Weight, colour and luminescence of six De Beers synthetic diamonds.*

Reference Number	*SYN 106-16*	*SYN 93-4*	*SYN 97-13*	*SYN 107-9*	*SYN 98-64*	*SYN 98-54*
Weight (ct) actual:	*0.510*	*0.677*	*1.822*	*0.338*	*0.604*	*0.240*
estimated:	*0.52*	*0.66*	*1.78*	*0.33*	*0.60*	*0.23*
Colour	*yellow*	*brown*	*brown*	*intense blue*	*HRD: White*	*HRD:White*
Appearance	*fancy*	*fancy*	*fancy*	*fancy*	*GIA: H-I* [i]	*GIA: H-I*[i]
UV Luminescence (fluorescence)						
Raytech L5-7 LW	none	none	none	none	none	none
SW	none	mod-weak yellowish-green X-type pattern	weak yellowish-green X-type pattern	strong yellowish-green obvious X-type pattern	strong yellowish-green X-type pattern	strong yellowish-green X-type pattern but not as obvious as SYN 98–64
Chromato-Vue LW	Extremely weak yellowish-green	Extremely weak yellowish-green	Extremely weak yellowish-green	None	Weak yellowish-green	Weak yellowish-green
SW	None	None	None	Moderately strong yellowish-green	Not tested	Not tested
SB.2000SW[ii]	Slight, non-descriptive. X-pattern	Strong yellowish-green. X-pattern	Fairly strong yellow-green. X-pattern but not well defined	Strong yellowish-greenish. Dark X-pattern	Strong yellowish-green with a dark X-pattern	Fairly strong yellow-green. Ill-defined X-pattern
De Beers DiamondView [iii]	Growth sectors: blue and slightly greenish-blue	Growth sectors: brownish yellow and green	Growth sectors: brownish yellow, brown and green	Growth sectors: blue and slightly greenish blue	Growth sectors: blue and very slightly greenish-blue	Growth sectors: Blue and very slightly greenish-blue
Phosphorescence	None	None	None	Strong and persistent (extinction of SWUV). None after LWUV	Strong and persistent (extinction of SWUV). None after LWUV	Strong and persistent (extinction of SWUV). None after LWUV

i. It is not normal to give split grades. A 'very low' H is probably closer.
ii. This SW source is considerably more sensitive than other standard SW sources.
iii. This SW source provides wavelengths shorter than standard sources, i.e. <230 nm as opposed to 253.7 nm.

Equipment used

1. To examine inclusions: Wild Heerbrugg M4 binocular stereoscopic microscope with magnification 6–160x. Also a Leica MZ12 binocular stereoscopic microscope with zoom magnification 8–320x (the upper magnification when using 32x oculars). Photomicrographs were taken under the M4 using an adapted Nikon FE.2 35 mm camera and periscope type optical photo-tube designed for the microscope under reference. Introlux 5000, 150 watt, variable brightness, constant colour temperature (5000 K) fibre optics illumination was used in all cases.
2. De Beers DiamondSure[1] (which referred all stones for further tests).
3. De Beers DiamondView[1] which yielded the images showing internal structures of the stones and other comparisons against natural diamonds.
4. The Adamas Advantage SAS2000 Spectrophotometer Analysis System: a dual channel system, dedicated to gemstone analysis and, in particular, diamonds. Specifications: PC based, with fibre optic coupling, 380–850 nm wavelength range (normalized to 400–850 nm), ~ 0.3 nm or better wavelength quantization; ~ 1.5 nm or better optical resolution. It is comparatively fast, very compact, and the software is upgraded regularly.
5. To assess magnetism: 50 x 10 x 5 mm bar magnet, a relatively powerful little magnet capable of attracting and holding a 750 g (maximum) steel weight positioned 90° to its base, and 1250 g (maximum) at 90° to its 10 mm wide face at one end.
6. Electrical conductivity: Gem Instruments 0–150 AC volts conductivity tester.
7. Specific gravity: determined hydrostatically in softened H_2O, drops of domestic liquid detergent were added to remove surface tension. Mettler H.800 C balance. Weights estimated from the GIA formula based on dimensions for round brilliants are also given for comparison – see the summary *Table I.*
8. Fluorescence: dark conditions. Four instruments used:
   (a) Raytech LS-7 LW and SWUV (diamonds placed 20 cm from source).
   (b) Ultra-Violet Products Inc., CHROMATO-VUE. Cabinet Model CC-20. LW and SWUV (stones approximtely 20 cm from source).
   (c) SuperBright 2000SW. SWUV (large u-shaped quartz tube). Very sensitive, giving a much better response than other standard SWUV. The stones were placed approximately 20 cm from the source.
   (d) De Beers DiamondView[1] (DV), the fluorescent results of which were photographed from the instrument's monitor using the camera mentioned above.

All stones were tested by the De Beers DiamondSure[1], not passed as natural and referred for further tests.

stones have had their face-up (table-up) colour appearances described according to procedures used for natural fancy-coloured stones. (Strictly speaking, in the trade the terminology 'fancy' does not apply to either synthesized or treated natural stones.)

The spectra and fluorescence patterns of the synthetic diamonds and some natural diamonds

The following description consists of annotated illustrations and a summary in tabular form. The spectra obtained from the

six stones using an Adamas Advantage SAS2000 PC based spectrophotometer, are as shown in *Figures* 2 and 3. Although most gemmologists are used to viewing absorption spectra, transmittance spectra also contain the same essential information necessary to differentiate between natural and synthetic diamonds, the results of which, in certain cases, can be diagnostic.

The DiamondView shows with spectacular clarity the visual differences between natural and synthetic diamonds and examples are shown in *Figures* 4 and 5.

The advantages and limitations of spectra

Spectral features when examined in isolation, are not always diagnostic of natural or synthetic diamonds, but are extremely useful when aided by back-up tests. There are diagnostic differences between the De Beers colourless stones and Type Ia Cape Series with the exception of a natural diamond of colour D on the GIA scale. The latter transmittance spectrum can be ambiguous and is open to misinterpretation without supporting data such as ultraviolet fluorescence and phosphorescence tests. A microscopic examination alone can be used to identify the stone as being diamond, even if internally clean. A diamond has characteristically sharply defined facet edges and can even be distinguished from the latest simulant, moissanite (SiC), in this way.

Similarly, back-up tests can also be done to determine the differences between a colourless synthetic (Type IIa) and a colourless natural stone. The former has been found to be, within itself, selectively electrically conductive. This is due to the nickel catalyst, essentially used to date, to

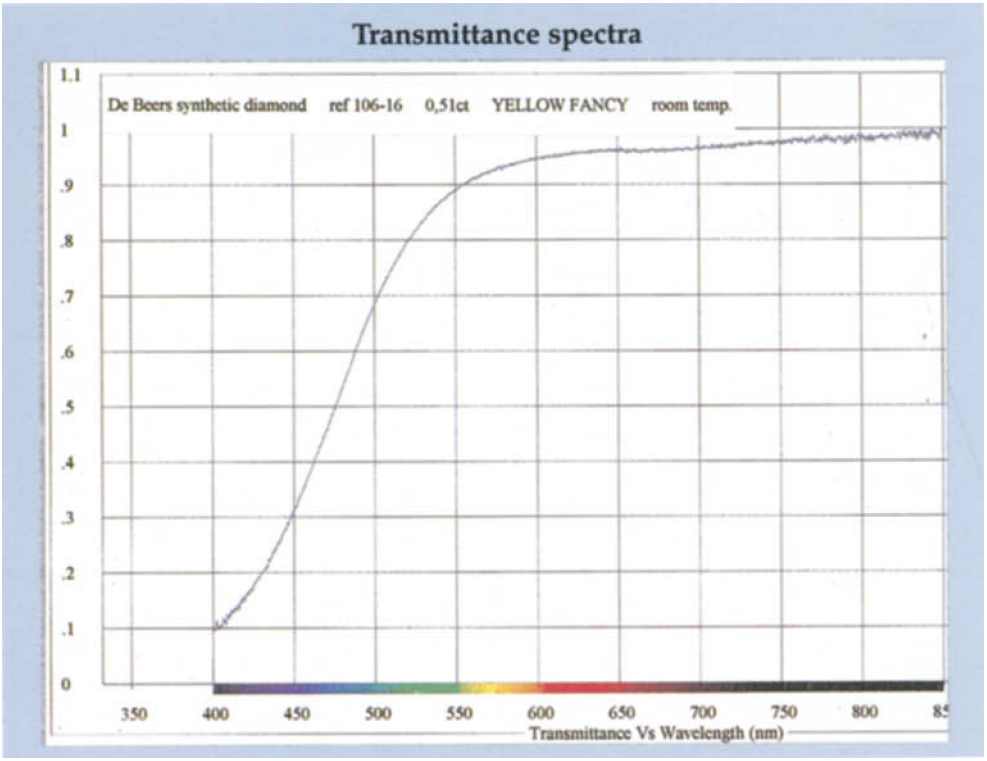

Figure 2a: *Fancy yellow synthetic diamond. Spectrum differs from a Cape series spectrum (see Figure 3c), although some natural yellow diamonds do exhibit this type of absorption.*

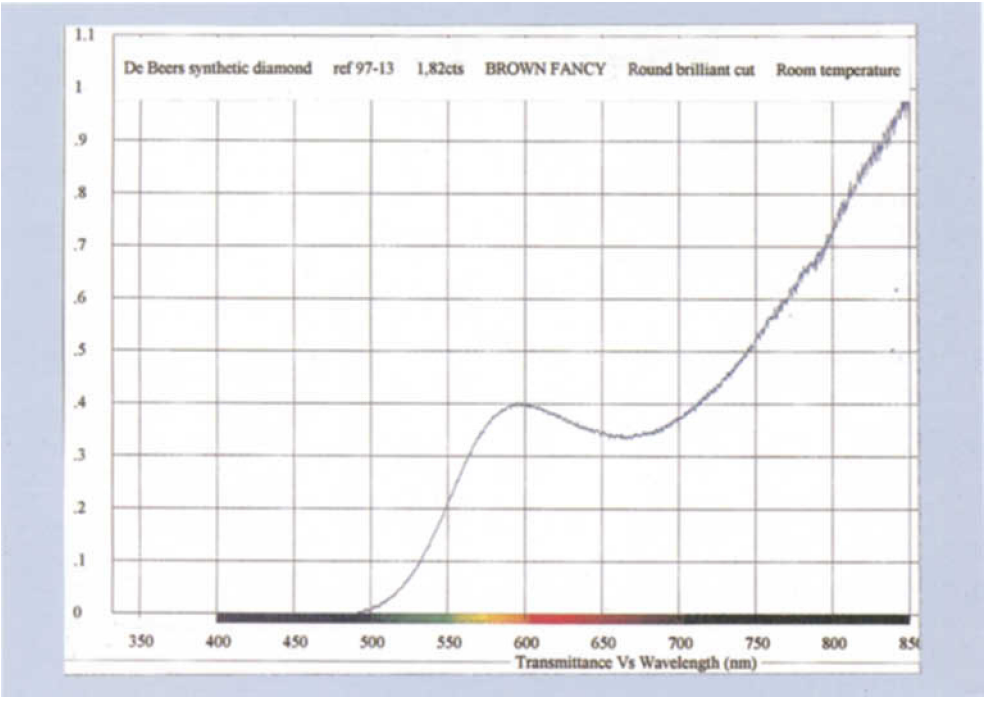

Figures 2b and c: *Fancy brown synthetic diamonds. Spectra show absorption below 490 nm and 475 nm respectively; similar to some natural brown diamonds.*

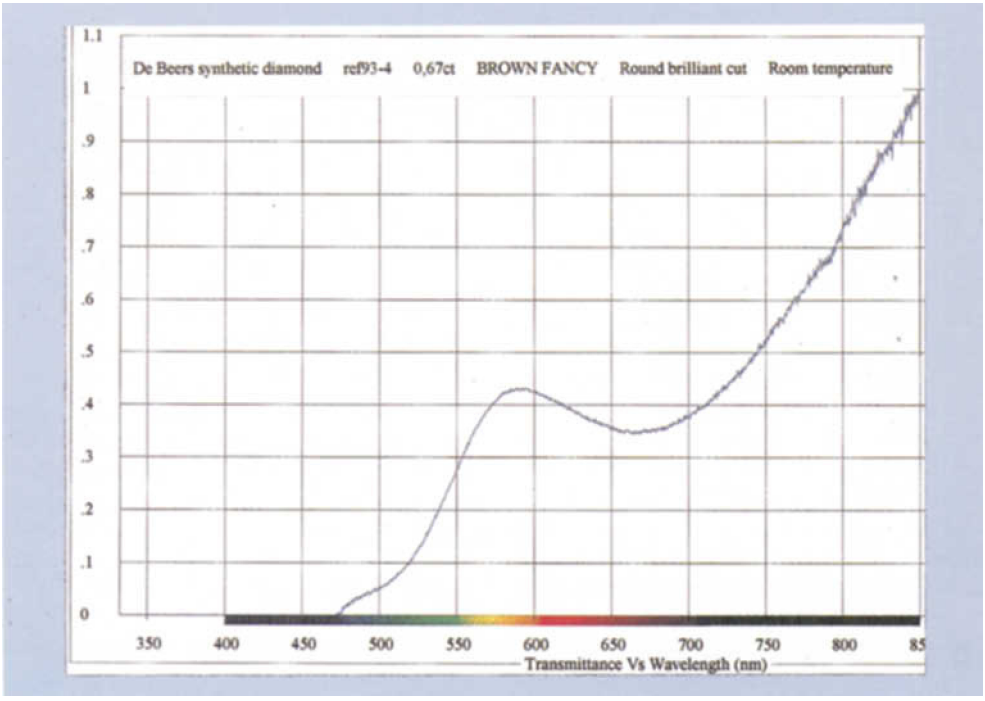

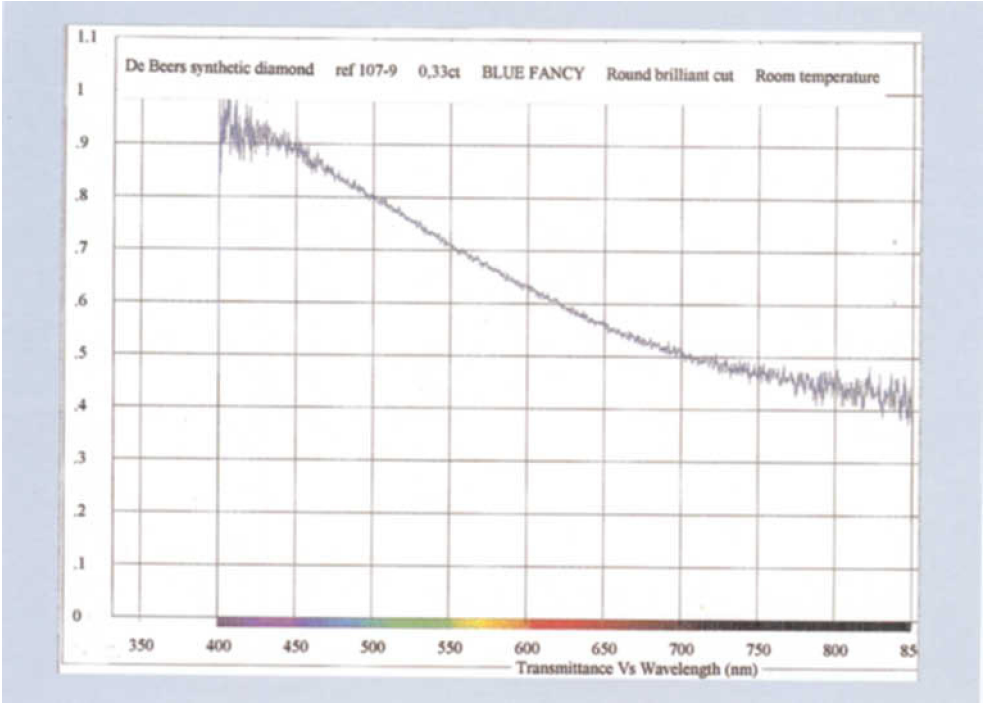

Figure 2d: *Fancy blue synthetic diamond. Spectrum is similar to that of natural blue diamond. This stone is highly phosphorescent (after exposure to SWUV).*

produce the colourless synthetic stones. Its natural counterpart is not electrically conductive. A new portable hand-held instrument that shows this electrical property in Type IIa colourless synthetic diamonds very successfully is the Moissketeer SD-2000 manufactured in the USA. It was primarily designed to detect synthetic moissanite – a spin-off being the results obtained from colourless synthetic diamonds (both from De Beers and from other sources).

Standard fluorescence tests are usefully employed to differentiate between brown synthetic and natural stones. The x-configuration seen is easily differentiated from natural stones which do not show it.

The spectra of blue natural and synthetic diamonds are similar and again there are clear differences between the phosphorescence of each. The De Beers synthetic has very strong and persistent phosphorescence with the characteristic x-configuration fluorescence pattern. The natural has not.

Every instrument has its strong points and limitations. The SAS2000 spectrophotometer is no exception to this rule, but its strength lies in its ability to accurately differentiate between treated (irradiated/annealed) fancy colours and natural ones, with very few exceptions.

General discussion on techniques and related educational topics

There are a number of ways to differentiate between natural and synthetic diamonds, namely: by using a dedicated spectrophotometer such as the SAS2000; by microscopic examination and additional supportive gemmological tests; or by using the De Beers DiamondView. The last of these is the surest, quickest method if the equipment were available. Alternatively, a combination of the first method, specifically using the SAS2000 and conventional gemmological means is viable. This depends

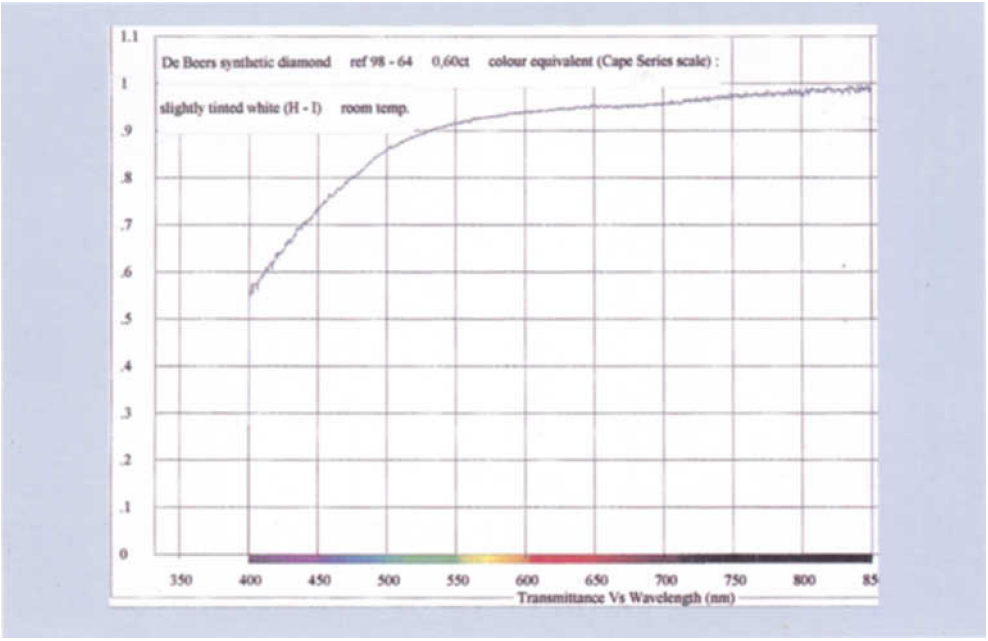

Figures 3a and b: *Colourless synthetic diamonds*

These spectra lack absorption features typical of Cape Series diamonds, specifically, due to the absence of the N3 centre (responsible for absorption at 415 nm). The synthetic diamonds are strongly and persistently phosphorescent after irradiation by short-wave UV, the effect lasting 10 seconds or more. White natural stones only very rarely have this property, and then only relatively slightly. There appears to be pronounced absorption below approximately 575 nm showing a smooth increase without any peaks.

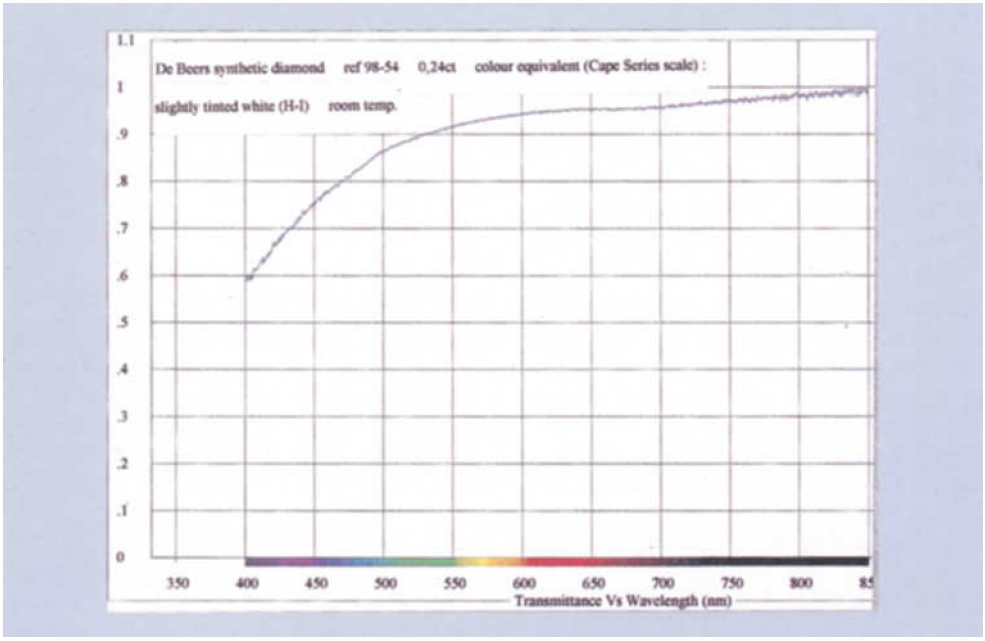

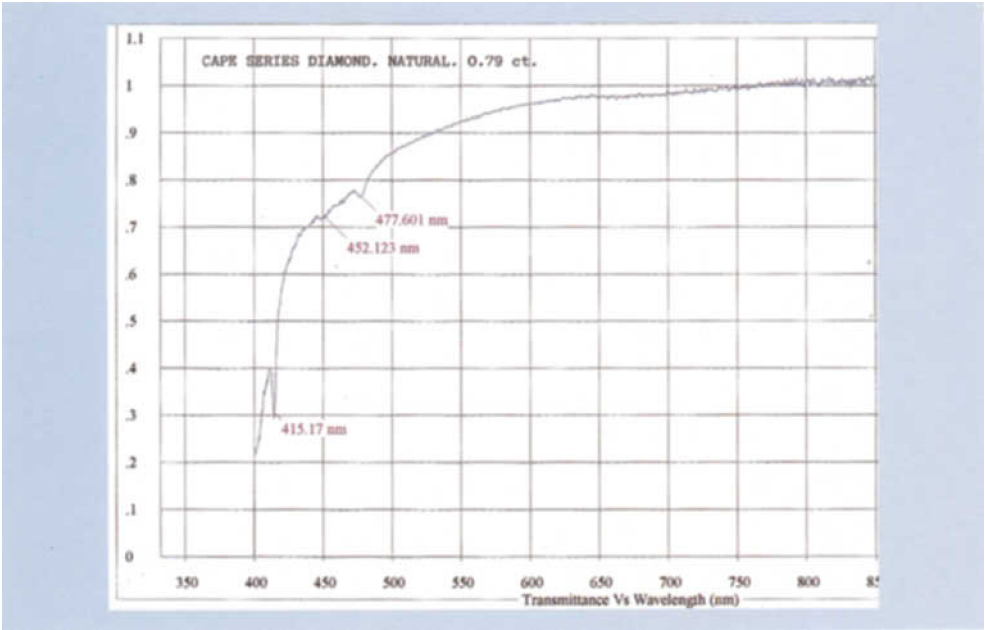

Figure 3c: *Transmittance spectrum of a Cape Series natural diamond showing the peaks that distinguish it from the synthetic diamond spectra.*

on circumstances (i.e. the extent of inclusions, etc.), although the latter can be slow because of the often painstaking supportive back-up tests required. One can also use cathodoluminescence techniques, but specialized equipment is required. Standard long- and short-wave ultraviolet radiation sources can also provide useful supporting information. However, the emphasis here is on what is now becoming more accepted – the increasing use of dedicated scientific equipment to do the job.

There will *always* be the standard gemmological approach which will continue to be used by the majority of gemmologists to provide a basic framework of information. In any case, training and acquisition of experience is necessary along these lines in the first instance – basics, like any scientific subject, must be known and understood first before other building blocks of knowledge can be added. Only then can the advanced and dedicated high-tech equipment be used with advantage.

Inclusions

Details of inclusions in the synthetic diamonds are summarized in *Table II*. There appear to be subtle variations in the inclusions depending on the source of manufacture. It would be potentially useful if a greater in-depth comparative study of inclusions could be made and published in a concise way. For example, Sumitomo synthetic diamonds have some individual characteristics which have already been published[4].

The DiamondView images

The images presented here as groups clearly highlight the visual differences between the De Beers synthetic diamonds and some natural diamonds. Comments are given in the captions.

White (colourless) stones

It is evident that good quality white synthetic diamonds *can* be grown and the larger of the two examined here would create

Table II *Inclusions and some physical properties of six De Beers synthetic diamonds.*

Reference Number	*SYN 106–16*	*SYN 93–4*	*SYN 97–13*	*SYN 107–9*	*SYN 98–64*	*SYN 98–54*
Figure	4(a)	4(b)		4(c)	4(d)	
Inclusions	Round and rod-shaped inclusions	Cloud of pin-prick sized particles, and some larger irregular ones. Zone type graining.	Fine particles in clouds – small rounded shapes. 'Mosquito larva' shaped inclusion under table. Graining visible through pavillion.	Flux in irregular shapes. Fracture iridescence recorded in photomicrograph.	Small flux globule only. In VS range of clarity grade.	Flux inclusion and associated cleavage. Irregular flux rods and rounded shapes. In VS range of clarity grade.
Electrical conductivity	None	None	None	Present	None*	None*
Magnetic attraction (stones resting on glass)	Magnet approx. 1.00 mm from stone when moved. Stone was not lifted	No reaction	No reaction	Magnet approx. 10 mm from stone when moved. At a distance of 5 mm, stone lifted to magnet.	No reaction	No reaction
SG (Hydrostatic)	3.517	3.526	3.517	3.521	3.516	3.529

NB: (i) The mean SG of the six stones is 3.518.

* (ii) The Moissketeer SD-2000, not available at the time of these tests, has since detected electrical conductivity selectively in both of the two 'colourless' stones. This is due to the nickel catalyst essentially used in the production of colourless synthetic diamonds.

Figure 4: *DiamondView images of synthetic diamonds.*

Figure 4a: *De Beers yellow synthetic diamond 0.51 ct (106–16).*
In this case the seed is evident at the centre of the image through the table facet. Compare the very different internal structure to that of the 5 ct natural yellow-brown diamond also shown for comparative purposes (see Figure 5a).

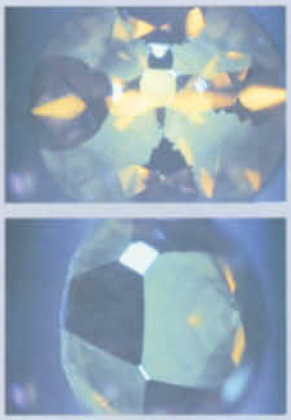

Figure 4b: *De Beers brown synthetic diamond 0.67 ct (93–4).*
The seed is clearly evident at the centre of the image through the table facet. The other view is at an oblique angle to the pavilion. The structure of this stone is quite different from that of the 5 ct natural one. The characteristic growth sectors of the two brown stones and the yellow synthetic listed above all show a common pattern. 97–13 shows similar images.

Figure 4c: *De Beers blue synthetic diamond 0.33 ct (107–9).*
The fluorescence is basically blue, some of the growth sectors showing as a paler blue in a characteristic pattern. The last image shows the very strong and persistent phosphorescence.

Figure 4d: *De Beers white synthetic diamond, 0.60 ct (98–64).*
The characteristic internal structure of the synthetic origin of this stone is clearly evident. The last image records the strong and persistent phosphorescence. Stone 98–54 (0.24 ct) is similar.

Figure 5: *Typical growth phenomena in a selection of five natural diamonds*

Figure 5a: *Yellowish-brown, 5 ct.*

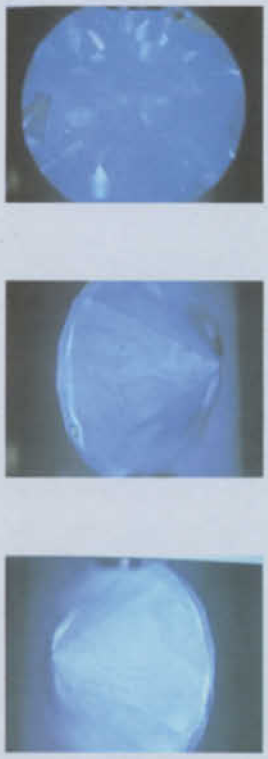

Figure 5b: *Greenish-brown, 1.15 ct.*

Figure 5c: *Brown tinted 13.78 ct.*

Figure 5d: *White 5.27 ct.*

Figure 5e: *White 3.36 ct.*

much consternation in the retail jewellery trade if it entered the supply pipeline. The small inclusion under the table has a very natural appearance and could quite easily be missed for what it really is – metal flux. If stones with similar characteristics come into the trade in any numbers it would certainly underline the need for routine testing using high-tech means.

Technology does not stand still – neither must defensive education. Much more is now being done in this context than ever before, but we cannot afford to be complacent.

Acknowledgement

The writer wishes to acknowledge the courtesy of the following for the loan stones:

The Jewellery Council of South Africa, through the Director of the Diamond Grading Laboratory, Leslie (Les) Milner; De Beers, through the Diamond Trading Company (Pty) Ltd. (DTC Research Centre), Maidenhead, England. The stones were made available for scientific, gemmological research and educational purposes only as De Beers have a policy of not selling synthetic diamonds for marketing purposes.

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Abstracts

Diamonds | Instruments and Techniques | Gems and Minerals | Synthetics and Simulants

Diamonds

New CVD Diamond products.

J.L. Collins. IDR, **59**, 212–13, 3 photographs, 1 table.

Collins describes a number of new chemical vapour deposition (CVD) diamond products in a range by De Beers Industrial Division during the last six months; these include not only cutting, dressing and truing materials, but also diafilms which can be used in the optical and precision industries, and radiofrequency and high power semi-conducting devices. Seven different types of CVD diamond products are listed. E.S.

Ekati – Canada's first commercial diamond mine (an editorial review).

Australian Gemmologist, **20**(7), 1999, 293–7, 4 coloured illus., 2 maps.

The Ekati mine in Canada's Northwest Territories was officially opened on 14 October 1998. It comprises five kimberlite pipes that are located in the Lac de Gras area 300 km northeast of Yellowknife. Initial production started from the Panda pit, 277,770 ct being produced in the first three months of its operation. It is anticipated that beyond the year 2000 the Ekati mine will be producing 4% by weight and 6% by value of the world's diamonds. P.G.R.

Gem news.

M.L. Johnson and J.I. Koivula. *Gems & Gemology*, **34**(3), 1998, 218–30, 23 coloured illus.

At the International Mineralogical Meeting held in Canada the main feature was on diamonds. Under discussion were the advances in UV-visible-infrared spectroscopy, X-ray topography and the genesis of diamond, especially gem material. Diamonds have been found in two additional small pipes in the Ekati Project area at Lac de Gras in Canada. J.J.

Gem news.

M.L. Johnson and J.I. Koivula. *Gems & Gemology*, **34**(4), 1998, 290-302, 23 coloured illus.

A detailed report is given on the diamond production that has commenced at Canada's Ekati Mine in the North West Territories. At the *Financial Times* Diamond Conference held in Antwerp, De Beers said that they continue to restrict sights for stability in rough diamond prices although there are economic problems bedevilling manufacturers due to over capacity and financial liquidity. J.J.

Characterizing natural-color Type IIB blue diamonds.

J.M. King, T.M. Moses, J.E. Shigley, C.M. Welbourn, S.C. Lawson and M. Cooper. *Gems & Gemology*, **34**(4), 1998, 246–68, 20 coloured illus. and 3 tables.

Of all diamonds, blue diamonds are some of the rarest and some of the most expensive. The colour differences of blue diamonds are subtle and difficult to appreciate. The GIA have studied over 400 predominantly blue IIb diamonds. It was found that the degree of difference in the appearance within each fancy grade is much narrower for fancy blue diamonds than for yellow diamonds. There is a limited saturation zone, which leads to subtle differences between the fancy terms. They have a higher degree of clarity than other fancy diamonds, but tend to exhibit graining and colour zoning. Phosphorescence is never seen under long-wave UV but they react to short-wave UV and the deeper coloured stones give rise to the more persistent phosphorescence. Also it was found that the stronger and/or darker blue stones tended to have a higher electrical conductivity. The colouring agent is boron. This paper hopes to provide a better understanding of the narrow colour range in which type IIb diamonds occur and the colour appearances associated with their various 'fancy' grades. J.J.

L'exploitation diamantifère en République Centre-Africaine.

B. Lancet. *Revue de gemmologie*, **137**, 1999, 24–8, 1999.

Survey of the history and present state of diamond mining in the Central African Republic. M.O'D.

Abstractors

J. Johnson	J.J.	M. O'Donoghue	M.O'D.	E. Stern	E.S.
		P.G. Read	P.G.R.		

For further information on many of the topics referred to, consult *Mineralogical Abstracts*

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Gem Trade Lab notes.

T. Moses, I. Reinitz and S.F. McClure. *Gems & Gemology*, **34**(3), 1998, 212–17, 13 coloured illus.

With the use of a laser Raman microscope inclusions in two diamonds were identified; the green elongate crystals were olivine and the purplish-red crystals were pyrope. J.J.

Gem Trade Lab notes.

T. Moses, I. Reinitz and S.F. McClure. *Gems & Gemology*, **34**(4), 1998, 284–9, 11 coloured illus.

By use of laser Raman microspectrometry, a black inclusion in a marquise diamond was identified as a mixture of graphite and chromite. Internal trigons all orientated in the same direction and apparently aligned along an octahedral plane were seen in an oval brilliant-cut diamond. J.J.

Modeling the appearance of the round brilliant-cut diamond: an analysis of brilliance.

T. Scott Hemphill, I.M. Reinitz, M.L. Johnson and J.E. Shigley. *Gems & Gemology*, **34**(3), 1998, 158–83, 16 illus. in colour and 4 tables.

This paper presents a three dimensional mathematical model of round brilliant-cut symmetrical, colourless diamonds that interprets and describes the interaction of light with diamonds. The aim of the model was to explore how brilliance, fire and scintillation depend on the varying proportions of a faceted diamond. The report is based on the effect of brilliance, which is considered to be the main factor in the appearance of a diamond and is quantified on weighted light return (WLR). WLR is the weighted sum of the amount of light returned through the crown of the diamond to all positions of observation above the girdle. Computer graphics simulation techniques have been used to develop the model together with years of research on how to express mathematically the interaction of light with diamonds. As brilliance is just one aspect of a faceted diamond more research is being done on models for scintillation and fire. J.J.

Fingerprinting of two diamonds cut from the same rough.

I. Sunagawa, T. Yasuda and H. Fukushima. *Gems & Gemology*, **34**(4), 1998, 270–80, 13 illus.

Three diamonds were examined as two of the stones were reportedly from the same rough. X-ray topography and cathodoluminescence (CL) tomography were used and showed conclusively that two of the diamonds came from the same rough. They exhibited the same dislocation densities and a good correlation in the morphology and position of the dislocation bundles. Also discernible were two distinctly different growth histories, which were revealed from the original crystals. One diamond originated from a crystal which had grown by spiral growth mechanisms on octahedral faces in near equilibrium conditions, and the other two diamonds originated from a crystal that showed growth of octahedral or dodecahedral forms on a cuboid seed in two different environments. Fingerprinting of any diamond is possible as each natural single crystal experiences its own unique growth and post-growth history, which is recorded in its internal imperfections and inhomogeneities. Although the future demand for fingerprinting diamonds is unknown, these techniques could also be used for distinguishing natural from synthetic gem diamonds. J.J

Gems and Minerals

Occurrences of minerals in Himachal Pradesh.

D. Bagai. *Indian Gemmologist*, **8**(1/2), 1999, 30–1.

A short general survey of Himachal Pradesh State in India has not yet uncovered gemstone deposits of importance although reports of blue sapphires of gem quality in the rocks of Kullu district have not been followed up. M.O'D.

Amethyst aus Brasilien.

R. Balzer. *Lapis*, **24**(10), 1999, 13–18, 1 map.

Describes some of the amethyst deposits in the Brazilian state of Rio Grande do Sul. Basaltic deposits of amethyst frequently occur in unusually-shaped geodes. M.O'D.

Gemmological news.

H. Bank, U. Henn and C.C. Milisenda. *Gemmologie. Z. Dt. Gemmol. Ges.*, **48**(2), 1999, 61–4, 4 photographs.

Madagascar continues to provide new gem materials, including fancy coloured sapphires, variously coloured spinels and many others. Especially mentioned are colour-changing garnets (bluish-green in daylight to reddish-violet in artificial light) RI 1.760–1.763, SG 3.76–3.87. Some spessartine garnets from Nigeria range from yellowish-orange to dark orange, RI 1.801–1.803, SG 4.18–4.22. Also from Nigeria some red tourmalines found near Ibadan. Some dark blue labradorite feldspar beads from India offered in Tucson were found to be dyed and other shiny black beads offered turned out to be onyx coated with plastic. E.S.

Geozoological prospecting for gold and gems.

D.M. Colchester. *Australian Gemmologist*, **20**(6), 1999, 218–21.

Plants and many animals disturb the soil fabric by detaching, transporting and redepositing soil material. This bioturbation activity of animals in mineral prospecting may be termed geozoological in contrast to geobotanical which employs the growth and trace element chemistry of plants as an aid to prospecting. The bioturbation activities of rabbits and ants have been used successfully in kimberlite prospecting in Botswana and South Australia. In alluvial gravel deposits in northern New South Wales, meat ants occasionally expose grains of sapphire, zircon, topaz and even diamond on the bare surface of their nests. In ancient times the processing of material thrown up by 'ants' was used by miners to

extract gold. However, in the accounts of classical writers, these ants were described as smaller than dogs but bigger than foxes! Allowing for changes in the word usage over the millennia, these 'ants' were most likely medium-sized burrowing vertebrates. P.G.R.

Identification of some colourless gemstones from Sri Lanka.

P.G.R. DHARMARATNE. *Gemmologie. Z. Dt. Gemmol. Ges.* **48**(2), 1999, 105–9, 1 photograph, 2 tables, bibl.

In a parcel of colourless rough gemstones weighing over 1000 ct, 17 different mineral varieties could be identified. The bulk of the stones were shown to be sapphire, quartz and topaz, but there were also orthoclase, cordierite, scapolite, beryl, tourmaline, danburite, euclase, fibrolite (sillimanite) and zircon. Of special interest was the identification of gemstones such as chrysoberyl, sinhalite, forsterite and spinel which rarely occur colourless. E.S.

L'origine de la couleur dans les gemmes. 1er partie.

E. FRITSCH AND G.R. ROSSMAN. *Revue de gemmologie,* **137**, 1999, 17–23, illus. in colour.

First part of a descriptive paper on the origin of colour in gemstones. Notes on the role played by chromophores are given together with examples of absorption spectra and the influence of structure on colour. M.O'D.

The fluid inclusions in the gem-quality lazulite from the Banderinha formation (Diamantina, Minas Gerais, Brazil).

I. GATTER AND G. MORTEANI. *Gemmologie. Z. Dt. Gemmol. Ges.,* **48**(2), 1999, 65–76, 3 photographs, 2 tables, 4 diagrams, bibl..

At the Fazienda Rapadura near Diamantina a second and hitherto unknown site of gem-quality lazulite crystals was found in quartz-kyanite-hematite veins in the metaquartzites of the Middle Proterozoic Banderinha formation. The oldest generation of fluid inclusions were found to be rich in CO_2, the youngest rich in H_2O. The different quartz generations only showed hydrous fluid inclusions. It is difficult to determine the time of vein formation; they may have formed during the Espinhaço tectonothermal event. E.S.

Neu: grüner Pargasit aus Pakistan.

V.M.F HAMMER, F. BRANDSTÄTTER AND C.L. LENGAUER. *Lapis,* **24**(10), 1999, 41.

Green transparent pargasite of probable gem quality is briefly reported from the Nagar area of the Hunza valley, Gilgit Province, in the Northern Area of Pakistan. The colour is said to be between the green of peridot and that of diopside: the chemical composition was given as $Na_{0.9}Ca_{2.7}Mg_{3.7}Al_{1.0}[(OH)_2](Si_{6.3}Al_{1.7})O_{22}$. M.O'D.

Sur la formation de nacre et de perles.

H.A. HÄNNI. *Revue de Gemmologie,* **137**, 1999, 30–5, Illus. in colour.

Paper bringing together from current literature the state of present-day knowledge on nacre and pearl formation since both nacre and pearl show a similar structure. General cultured and keshi pearl structure are considered as well as natural examples. M.O'D.

Gemmological short notes.

U. HENN. *Gemmologie. Z. Dt. Gemmol. Ges.,* **48**(2), 1999, 111–16, bibl.

Emerald-green grossular garnets near Bekily in Southern Madagascar were found in 1998. RI 1.741–1.746, SG 3.58–3.62. The absorption spectrum shows two broad bands in the red and violet. Under the microscope apatite crystals and some other tiny inclusions were observed. Gem-quality peridot has been found near the village of Damaping in the Huebei province, China, since 1979. The mining is concentrated on tertiary basalt flows which contain peridot crystals in nodule-like cavities. The quality is similar to that found in San Carlos, Arizona. RI 1.652–1.688 to 1.654–1.690. DR 0.034–0.036. SG 3.34–3.36. There are fingerprint-like healing cracks, lily-pad inclusions and fine growth inhomogeneities. E.S.

Burmite – Burmese amber.

U.T. HLAING. *Australian Gemmologist,* **20**(6), 1999, 250–3, 5 illus. in colour, 1 map, 1 table.

A review of the history, geology and gemmological properties (including patterns of inclusions) of Burmese (Myanmar) amber mined from a deposit near Maingkwan in the Hukawang Valley of Myanmar's Kachin state. P.G.R.

Mong Hsu ruby revisited – some further data.

U.T. HLAING. *Australian Gemmologist,* **20**(7), 1999, 289–92, illus. in black-and-white and colour, 3 tables.

Since the publication of two previous reports by U.T. Hlaing in the Australian Gemmologist (Mong Hsu ruby update, **18**(5), 157–60, and New extension of Mong Hsu ruby deposits, **19**(2), 51) further spectrographic and HIAF proton microprobe analysis of selected rubies from the deposits has revealed the presence of sapphire. With the recovery of two blue corundum crystals it is hoped that a commercial deposit of sapphire will soon be discovered. P.G.R.

Sodalite from Bolivia.

J. HYRSL AND A. PETROV. *Canadian Gemmologist,* **20**(2), 1999, 54–6.

Specimens of blue sodalite are reported from Cerro Sapo (Toad Mountain) in the Ayopaya region, near the town of Independencia (formerly Palca), Bolivia. Though the deposit has been known for at least 80 years, renewed prospecting work in the early 1990s has produced more sodalite, most of which has been used for indoor decorative work. Sodalite also occurs in a vein at Cerro San Cristobal and good quality material at another site approximately 20 km south of Cerro Sapo. M.O'D.

Gem news.

M.L. JOHNSON AND J.I. KOIVULA. *Gems & Gemology,* **34**(3), 1998, 218–30, 23 coloured illus.

Amethyst is being mined again from the Four Pearls mine in Maricopa County near Phoenix, much of the material is 0.5–2 ct with very limited quantities of 2–6 ct stones being mined. Recently seen were four yellowish-green to brownish faceted andradite garnets from the Yemen, all showing typical andradite properties. Danburite has recently been found at the Little Three mine near Ramona, California. Three orange to brown stones from Mali were found to be gem-quality grossular and not grossular-andradite, illustrating the complex classification problems of garnets. Three faceted colour-change pyrope-spessartine garnets were recently examined and described as light greenish-yellow in daylight and intense pink to red in incandescent light, but their exact locality in Madagascar is unknown. Hackmanite, the UV-sensitive luminescent colour-change variety of sulphur-rich sodalite, has recently been discovered at the Dattawa Mine in Mogok, Myanmar. Striped bicolour labradorite from Ylamaa, Finland, was found to have two sets of stripes in different orientations caused by twinning and exsolution. Lapis lazuli is being marketed from the Blue Winkle mine, southwest of Denver, with the best material occurring in veinlets within the host rock. Trapiche rubies have reportedly come from secondary deposits, some eluvial in the Yen Bai Province, Vietnam: some stones showed slightly lower SGs than normal due to mica and other secondary minerals. A new deposit of blue sapphire is being mined in the Chelyabinsk region of the Urals and crystals are found embedded in a tough metamorphic matrix. A worn green pebble purchased in Myanmar from a jade dealer was a mixture of two sodic amphiboles, magnesioarfvedsonite and glaucophane with minor quantities of chamosite and jadeite; this rock has possibly formed as a result of high pressure and low temperature metamorphism of gabbro or basalt. A new variety of tourmaline has been named rossmanite $(LiAl_2)Al_6(Si_6O_{18})(BO_3)_3(OH)_4$, an alkali deficient pale pink tourmaline, found in granitic pegmatite in the Czech Republic, Canada and Sweden; it can only be distinguished from elbaite by quantitative chemistry. J.J.

Gem news.

M.L. Johnson and J.I. Koivula. *Gems & Gemology*, **34**(4), 1998, 290–302, 23 coloured illus.

At the Coloured Stone Presentation at the International Mineralogical Association meeting, presentations included talks on the coloration of tourmaline, garnet and coloured quartz being due to transition metal ions, colour can also be induced by natural irradiation especially yellow to brown colours in silicate minerals; models for the origin of corundum; the use of Raman spectra of emeralds to differentiate emerald localities, plus many more papers. Chalcedony containing abundant tiny dark spherical aggregates of goethite have come from Madagascar. A colourless transparent oval faceted stone (1.48 ct) posed a challenge for identification; properties were typical for plagioclase feldspar, but when analyzed by a laser Raman microspectrometer it indicated it was cordierite (iolite). On further examination of low quality sapphires from Day Cotton Gulch, Montana, unusually pyrrhotite and clinozoisite were found as inclusions together with microscopic grains of gold found in the cavities and cracks in some of the sapphires. Unusually, translucent yellowish-green beads reportedly from Afghanistan were antigorite, a serpentine mineral. Colourless topaz contained channels that had been subsequently filled with yellowish-brown limonite that had been deposited later by ground waters. Tourmalines are now being produced in Nigeria from a locality near Ogbomosho near the Benin border, most are purplish-red to pink or nearly colourless. J.J.

Barite Inclusions in Fluorite

J.I. Koivula and S. Elen. *Gems & Gemology*, **34**(4), 1998, 281–3, 3 coloured illus.

Fibrous white hemisperical aggregates of baryte were identified as inclusions in fluorite from Illinois. One baryte inclusion appeared purple in incandescent light and blue in fluorescent light. This pseudo colour change was imparted to the white inclusion by reflection from the fluorite host, which showed the actual colour change. J.J.

Pearls and pearl oysters in the Gulf of California, Mexico – an update.

D. McLaurin, E. Arizmendi, S. Farell and M. Nava. *Australian Gemmologist*, **20**(6), 1999, 239–45, 10 illus. in colour, 1 map, 1 table.

The Mexican pearl farm, which in 1996 was the first to be established on the American continent, is based near the coastal town of Guaymas in the northern State of Sonora. This update on a 1997 paper (*Australian Gemmologist*, **19**(12), 497–502) by the same authors includes news that production of whole pearls (round, baroque, keshi) has increased, and that the Gulf of California mabe pearls have successfully made their debut in international markets. The production target for 1999 is a harvest of 1300 whole cultured pearls, rising to 3000 for the year 2000. P.G.R.

Die Edelsteine Sri Lankas: Vorkommen und Genese.

C.C. Milisenda and U. Henn. *Gemmologie. Z. Dt. Gemmol. Ges.*, **48**(2), 1999, 85–96. 7 photographs, 2 geological maps, 2 tables, bibl.

This study of the gemstone occurrences and their formation is mainly based on the results of a study carried out by a German-Sri Lankan Consortium within a programme for the study of the lower continental crust established by the Deutsche Forschungsgemeinschaft (German research co-operative). The genesis of the stones is strongly associated with metasedimentary rocks of the Highland Complex. This goes back to the main thermo-tectonic evolution during the Pan-African event, known to have affected large parts of Africa. Recent investigations suggest that the high grade rocks of Sri Lanka once formed part of the East African Mozambique belt, which is regarded as having resulted from the collision of East Gondwana (India-Antarctica-Australia) and West Gondwana (Africa-South America) some 600 Ma ago. A table gives a comprehensive survey of the Sri Lankan gemstones and where they are found. E.S.

Gem Trade Lab notes.

T. Moses, I. Reinitz, and S.F. McClure. *Gems & Gemology*, **34**(3), 1998, 212–17, 13 coloured illus.

A dark green chrysoberyl coloured by vanadium rather than chromium came from the Tunduru region of Tanzania. A ruby cabochon showed an unusual phenomenon of a double star, two six-ray stars slightly offset, which was caused by a difference in the orientation of the rutile silk across the pervasive twin planes. Synthetic and natural rock crystal can be difficult to distinguish, which was the case with a large colourless rock crystal sphere (9.6 cm in diameter), only by using darkfield illumination were tiny rods of tourmaline visible (63x). J.J.

Gem Trade Lab notes.

T. Moses, I. Reinitz and S.F. McClure, *Gems & Gemology*, **34**(4), 1998, 284–89, 11 coloured illus.

A light greenish-blue beryl and three blue beryls were found to be maxixe beryls; the latter three beryls were placed in a solar simulator and after four hours the colour had started to fade. Symmetrical oval drop shaped light pink concretions were shown to be natural carbonate by X-ray and reportedly originate from an oyster found along the Pacific Coast of North America. An unusual red spinel from Mogok not only exhibited colour zoning but two different RIs of 1.732 and 1.718; on immersion it was revealed that the spinel had a dark core and a paler surround and it was the darker core that gave the higher reading, together with a higher content of chromium and vanadium. J.J.

Comparative study of corundum from various Indian occurrences: corundum from Karnataka.

J. Panjikar. *Indian Gemmologist*, **8**(1/2), 1999, 3–7, illus. in colour.

Ruby from Karnataka occurs as well-formed crystals with orthoclase and shows pinkish-red to red colour with diaphaneity ranging from semi-transparent to translucent. Rutile is the most prominent solid inclusion and is found in a range of sizes from very small needles up to 1 mm: the crystals show perfect tetragonal cross-section. Feathers and veils of liquid are also found and both growth and twin planes are reported, the latter containing boehmite needles. Some biotite and possibly chromite have been found. Absorption spectroscopy shows the presence of both iron and chromium. M.O'D.

The effect of the gamma-irradiation dose combined with heat on the colour enhancement of colourless quartz.

M.V.B. Pinheiro, K. Krambrock, J. Karfunkel and J.B. da Silva. *Australian Gemmologist*, **20**(7), 1999, 285–8, 4 coloured illus., 1 table.

Using a combination of gamma irradiation and thermal treatment, colours ranging from pale yellow, yellow, greenish-yellow, olive-green, greenish-orange, orange and reddish-brown were produced from colourless quartz. The irradiation treatments used a conventional cobalt-60 gamma cell at room temperature. The final colour was obtained by heating batches of irradiated quartz at atmospheric pressure in an alumina crucible, the temperature being raised in steps by 5 degree C per minute intervals to 250 degrees C. All nineteen colourless quartz specimens used in the experiment originated from Minas Gerais, Brazil. P.G.R.

Characterisation of recent and fossil ivory.

V. Rolandi. *Australian Gemmologist*, **20**(7), 1999, 266–76, 3 coloured illus., 14 illus. in black-and-white.

Although some physical properties are common to all types of ivory, sometimes the appearance of its surface under magnification is diagnostic. However, elephant and 'fossil' mammoth ivory are similar texturally and require more sophisticated test techniques for their identification. Although Fourier Transform Infrared and Raman spectroscopy may be useful for discriminating recent from fossil ivory, biochemical tests indicate that differences in the amino acid content of their collagen can positively separate these look-alike ivories. P.G.R

White Cliffs: Australia's first commercial opal field – a century of history.

G. Rowe. *Australian Gemmologist*, **20**(6), 1999, 230–1, 1 black-and-white illus.

In 1899 White Cliffs opal field became the world's largest producer of precious opal. During the last hundred years White Cliffs has been a magnet for geologists, palaeontologists, government officials and hopeful fortune-hunters. The intense summer heat drove the first miners underground. By 1900 most other residents followed suit. Today, around 220 residents occupy 40 above-ground dwellings and 130 dugouts on Smith's Hill, Turkey's Hill and the southern outskirts of the main field. White Cliffs History Group, and White Cliffs Opal Fields Tourist Association have applied for Federation funding for 1999-2000, and plan to convert two town blocks into a tree-lined picnic area for the use of visitors. P.G.R.

Vogelschnäbel und Sterne.

K. Schäfer. *Lapis*, **24**(10), 1999, 19–26.

Describes quartz twins found in the area of Idar-Oberstein, Germany. Many show a star-like form while others are said to resemble the beak of a bird. M.O'D.

Ruby and variously coloured sapphires from Ilakaka, Madagascar.

K. Schmetzer. *Australian Gemmologist*, **20**(7), 1999, 282–4, 5 coloured illus.

The appearance, absorption spectra and microscopic features of faceted non-heat-treated rubies and pink, blue-violet, violet, purple and orange sapphires from a recently discovered secondary deposit at Ilakaka, Madagascar, closely resemble those corundums from Umba, northern Tanzania, which have been known in the trade for more than 30 years. P.G.R.

Amethystfund in den Hohen Tauern.

R. SCHOLZE. *Lapis*, **24**(9), 1999, 43–5, illus. in colour.

Large amethyst crystals of good colour are reported from Rauris in the Hohe Tauern area of Austria. Some show sceptre habits. M.O'D.

The nomenclature of gemstones. With special reference to the garnet and tourmaline mineral groups.

E.L. STEVENS. *Australian Gemmologist*, **20**(7), 1999, 277–9, 4 tables.

Gemmological nomenclature sometimes confuses the mineral species name with either its group or variety name. There is also frequently a contradiction by gemmologists about the naming of certain species and varieties of gem minerals, although the rules of nomenclature for minerals should apply equally to the gemstone subset. Tables list the mineral species names for the garnet, tourmaline and olivine groups of minerals, and illustrate the fact that there is no such mineral as 'garnet', 'tourmaline' or 'olivine'. Although an overnight change of gemstone nomenclature (e.g. from tourmaline to elbaite) would be too much of a shock at the retail end of the jewellery world, an effort to increase the gemmological student's awareness of mineralogy and its nomenclature rules would be a good starting point. P.G.R

Explosion of interest in Canadian gemstones.

W. WIGHT. *Canadian Gemmologist*, **20**(2), 1999, 45–53.

Precious opal, diamond, emerald, blue sapphire and ruby have been found at various sites in Canada. While work on evaluating the products, some of which have so far been recovered in very small sizes only, is still going on, it is likely that Canada will play a larger part in gemstone production than it has done so far. Details of the specimens and locations are given. M.O'D.

Instruments and Techniques

Estimating weights of mounted coloured stones.

C.I. CARMONA. *Gems & Gemology*, **34**(3), 1998, 202–11, 13 coloured illus.

The author has updated formulas for estimating the weights of mounted coloured stones. These formulas have been derived from the measurements of weights of thousands of German cut calibrated amethysts and citrines. As the face-up outlines of faceted stones vary from one classic shape to another, the shape factors in their weight estimation formulas change accordingly. Both precise face-up measurements and profile observations are critical to the accurate estimation of the weight of a mounted coloured stone. The results have been published in *The Complete Handbook for Gemstone Estimation*. It includes the estimation of weights of twenty-four common shapes of coloured stones and 48 formulas for stones with unusual shapes. Also, it has a section dealing with diamonds and pearls. The updated formulas presented by the author are meant to set a new standard for weight estimation. It is claimed this method reduces the margin of error from 15 – 10% to 5% and less. J.J.

Synthetischer Moissanit und Diamant: Sichere Unterscheidung mit Hilfe des reflektometers.

J.P. CHALAIN AND M.S. KRZEMNICKI. *Gemmologie. Z. Dt. Gemmol. Ges.*, **48**(2), 1999, 77–84, 4 photographs, 1 table, bibl.

The thermal conductivity of synthetic moissanite is similar to that of diamond and the two cannot be told apart by using a thermotester. However, the reflectance power for synthetic moissanite is higher (0.19–0.20, 116–119) than that of diamond (0.17, 100). The authors suggest a two-step routine for jewellers; first the use of a thermotester to separate moissanite and diamond from other imitations, then a reflectometer to distinguish moissanite from diamond. The authors do add that moissanite has a slightly greyish colour and strong double refraction. (Abstractor's note: the double refraction alone is a complete give-away.) E.S.

Tester Model 590 for colourless moissanite/ diamond – an instrument evaluation.

V.M.F. HAMMER AND J. STEPHAN. *Australian Gemmologist*, **20**(7), 1999, 298–302, 2 black-and-white illus.

The tester, manufactured by C3 Inc. of North Carolina U.S.A., uses a halogen lamp to check the absorption characteristic of diamond and synthetic moissanite in the blue and near visible UV end of their spectra. Synthetic moissanite exhibits an intense absorption from around 425 nm down to the UV region, while colourless diamonds transmit well down into the UV range. Light from the instrument's halogen light source is reflected from the table facet of the stone under test. If this reflected light contains wavelengths from the blue end of the visible spectrum to the near UV region, a buzzer and a green warning light are activated to indicate that the stone is a diamond. Absorption of this range of wavelengths by the test stone will not activate the buzzer/lamp and will indicate that the stone is a moissanite. The evaluation report includes some result errors due to the colour grade of the diamonds tested. Further test reservations are made by the Instrument Evaluation Committee of the Gemmological Association of Australia whose comments form an addendum to the main paper. P.G.R.

L_H – an 'old' gemmological property.

W.W. HANNEMAN. *Australian Gemmologist*, **20**(6), 1999, 236–8.

The author refers back to his 1978 paper 'The role of reflectivity in gemmology' which appeared in the *Journal of Gemmology* (**16**(2), 109–20) and which introduced his concept of a scale of lustre using L_H (Lustre-Hanneman) values. Although the L_H concept has never been universally adopted by gemmologists, the author criticizes other writers for quoting reflectance meter readings in terms of RI values rather than L_H values (in which YAG, GGG, strontium titanate and diamond are

used as reference standards, and are given the L_H values 1, 2, 3, 4). Reference is made to two topaz treatments which produce misleading high readings on a reflectance meter, and negative readings on a refractometer. The reason for this is that both instruments are making surface rather than bulk measurements. However, the use of Hodgkinson's visual optics method, or the Hanneman-Hodgkinson refractometer, both of which examine the bulk properties of a gem, reveal readings characteristic of topaz when applied to this treated material. P.G.R.

Gemstones in a new light.

A. HODGKINSON. *Australian Gemmologist*, **20**(6), 1999, 246–9, 12 illus. in colour.

Methods suitable for the rapid screening of large numbers of diamonds to detect the presence of synthetic moissanites are described. This method uses the Nelson Pavilion Facet Fingerprinter technique, but by using inexpensive items such as a plastic immersion cell and a pen torch this technique can become available to a wide range of users. Another identifying technique for synthetic moissanite involves heating suspect stones on the hot plate of an electric cooker. With the cooker set to medium heat, synthetic moissanites (unlike diamonds) turn bright yellow when they reach this temperature. Alternatively, this reversible colour change can be produced by the heat from a 250 watt electric lamp bulb or by placing the flame of a match 15 mm beneath a suspect stone. P.G.R.

Gem news.

M. L. JOHNSON AND J. I. KOIVULA, *Gems & Gemology*, **34**(3), 1998, 218–30, 23 coloured illus.

New methods will be used in the future for the exploitation of Colombian emerald deposits, with side-scan radar promising to be the most versatile for mapping the emerald district. J.J.

Refractometers and the pin-hole disc.

T. LINTON. *Australian Gemmologist*, **20**(6), 1999, 227–9, 4 black-and white illus.

Although a paper by G.S. Walker titled 'A new spot reading technique for the refractometer' appeared in the *Australian Gemmologist* (1987, **16**, 253–6), this was concerned with improving the accuracy and ease of using the 'spot' or 'distant vision' method of measuring the refractive index of cabochons. In the current paper, the author has extended the use of the pin-hole disc to improving the weak shadow edge image produced by small and poorly polished gem facets. With the low light level produced by such an image, the eye's iris dilates, but if the shadow edge is viewed through a pin-hole disc, this increases the depth of focus and reduces the exposed area of the eye's lens, thus reducing any optical errors likely to occur at the perimeter of the lens. P.G.R.

Evaluation of a teaching aid for 'Visual Optics'.

T. LINTON. *Australian Gemmologist*, **20**(6), 1999, 232–5, 6 colour, 1 black-and-white illus.

D. Hoover's lecture aid for demonstrating the major features of Hodgkinson's Visual Optics consists of half a ping-pong ball, a glass microscope slide, and an inexpensive hand-held laser pointer. The gem used in the demonstration is mounted table facet upwards under the glass slide, and the half ping-pong ball cemented centrally over the table side of the stone on the slide. The laser pointer is then used to illuminate the stone's pavilion. The primary refracted rays, used to identify gems by the 'visual optics' method, appear as red spots on the surface of the ping-pong ball. A warning is given of the dangers of directing the laser beam directly into the eyes (*a laser pointer must not be used for examining the gemstones using the conventional Hodgkinson technique of visual optics*). P.G.R.

Cathodoluminescence du jade.

J. PONAHLO. *Revue de gemmologie*, **137**, 1999, 10–6, illus. in colour.

Cathodoluminescence (CL) provides a non-destructive method of distinguishing natural jadeite from maw-sit-sit and chloromelantite, treated and non-treated materials. Descriptive examples of CL spectra for the various substances are given. M.O'D.

Synthetics and Simulants

Gemmological miscellany.

G. BROWN. *Australian Gemmologist*, **20**(6), 1999, 223–6, 11 illus. in colour.

Short laboratory reports with illustrations describe the identifying features of Chinese synthetic amethyst, two unusual composite stones, a colourless faceted glass, synthetic moissanite, imitation sapphire rough, and blue-dyed lapis. P.G.R.

Synthetische rote Berylle aus Russland.

U. HENN AND C.C. MILISENDA. *Gemmologie. Z. Dt. Gemmol. Ges.*, **48**(2), 1999, 97–104. 5 photographs, 3 tables, 1 graph, bibl.

Constants of the recently obtained synthetic red beryls correspond to those of the known range for hydrothermally grown beryls from Russia, i.e. RI 1.570–1.580, DR 0.008, SG 2.63–2.65. The spectrum is characterized by maxima in the green and blue, and yellow-green and blue respectively. There is a strong pleochroism (cinnamon brown and violet) and there is no fluorescence under UV. The colour of the stones is similar to that of the natural red beryls from Utah. The examined samples were 6.5 x 5.00 mm in size and weighed between 0.98 and 1.08 ct. E.S.

Gem news.

M.L. JOHNSON AND J.I. KOIVULA, *Gems & Gemology*, **34**(3), 1998, 218–30, 23 coloured illus.

Two brownish-red radioactive rubies with bubble-filled inclusions from Indonesia were received by the AGTA for examination and it was thought that these

stones had been treated by irradiation. An unusual material, gallium phosphide has been faceted; it resembled a dark orange diamond but has a hardness of 5–6 and gave off a very pungent (phosphorous) odour when cut. J.J.

Gem news.

M.L. Johnson and J.I. Koivula, *Gems & Gemology*, **34**(4), 1998, 290–302, 23 coloured illus.

Problems arise in testing polymer impregnated materials, e.g. turquoise, jade and especially opal; some treated opals were ignited and burnt very readily and lost up to 16–27% of their weight. When exposed to gamma irradiation, inclusions in topaz of colourless halite (NaCl), sylvite (KCl) and villiaumite (NaF) became yellow, lilac and brown respectively. Great quantities of diffusion-treated synthetic sapphires are appearing on the market in Bangkok, but when immersed all showed uneven coloration from one facet to another. J.J.

Lab notes.

T. Moses, I. Reinitz and S. McClure. *Gems & Gemology*, **34** (3), 1998, 212–17, 13 coloured illus.

When viewed from the back, the sections of a green and black oval cabochon imitation trapiche emerald were misaligned and under magnification a plastic coating was seen. An orangey-yellow diamond known to have some type Ib component was irradiated with low energy electrons and the colour changed to a reddish-purple, with a strong concentration of colour in the culet. Diamonds sent to be graded have been found to be synthetic moissanite; they were readily distinguished by their specific gravity and polish lines that smoothly crossed the facet junctions but doubling of the pavilion facets was not visible. China is now the dominant producer of tissue nucleated cultured pearls and recently a necklace examined was composed of pearls up to 15 mm in both white and pink shades. J.J.

Gem Trade Lab notes.

T. Moses, I. Reinitz and S.F. McClure, *Gems & Gemology*, **34**(4), 1998, 284–9, 11 colured illus.

Two diamonds with a brown body colour with concentrated colour zones of green and blue were examined, one was found to be irradiated and the colour origin of the other was undeterminable. An interesting synthetic diamond exhibited a colour change from greenish-yellow in daylight to an orange hue in incandescent light. A strand of light grey faceted pearls that had been faceted were cultured pearls. J.J.

Cultured abalone blister pearls from New Zealand.

C.Y. Wentzell. *Gems & Gemology*, **34**(3), 1998, 184–200, 18 coloured illus.

Since 1995 the Empress Abalone Company in South Island, New Zealand, has successfully produced cultured blister pearls with vibrant bright colours and a rainbow like iridescence that are unique to New Zealand's *Haliotis iris* abalone. Details of the biology and gathering techniques of the abalone are given. The author explains how the cultured blister pearls are cut from the shell, filled with a blue polymer, backed with mother-of-pearl and finally buffed into a high lustre. The thickness of the conchiolin is important to the face up appearance of the 'mabes'. If the conchiolin layer is thin or absent, then the blue polymer layer affects the colour of the nacre, whereas the presence of a thick layer of conchiolin optimizes the naturally vivid colours and iridescence. None of the stones examined revealed any evidence of surface treatment. Size, colour, lustre and surface blemishes control the price of these abalone 'mabes'. Research is in progress to decrease the mortality rate and increase production rates, together with commercial production of whole free-formed beads and tissue-nucleated cultured abalone pearls. J.J.

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BOOK REVIEWS

Jewellery: Two in one manual.

M. Coles, 1999. Apple Press, London. pp. 128, illus. in colour, hardcover, ring-bound. ISBN 1 84092 197 8. £12.99.

Ingenious guide to simple jewellery making, most of the text being divided horizontally to form what are in effect two books whose pages can be turned independently, the upper section illustrating step-by-step projects and the lower one the basic techniques needed. This approach is very handy, provided always that the upper and lower pages line up. There are useful tables and a glossary at the back of the book: the standard of illustration is high and beginners could work from the text and pictures combined. M.O'D.

The Ekati diamond mine.

BHP Diamonds Inc., Yellowknife, NWT, Canada, 1998. pp. 58, illus. in colour, softcover, landscape format. Unpriced.

As recently as 1985 minerals associated with possible diamond occurrence were detected in the Lac de Gras area of Canada's Northwest territories. The Ekati mine is the first diamond mine to be established in Canada and is expected to produce 3.5 to 4.5 million carats of rough industrial and gem-quality diamonds a year. This would represent about 4% of current global production by weight and about 6% by value. This beautifully-produced and illustrated account of the Ekati mine shows all areas of diamond production from (possible) formation and transport through recovery, sorting and sale. Copies of this kind of book go out of print quickly and anyone with an interest in diamond mining (or in the minerals of Canada) should try to get one. M.O'D

Hallmark. A history of the London Assay Office.

J.S. Forbes, 1999. Unicorn Press in conjunction with the Goldsmiths' Company, London. pp. 367, illus. in black-and-white and in colour. Hardcover ISBN 0 906290 26 0. £35 + £3 post and packing.

At the time of publication, it was still uncertain what effect possible new European legislation would have on the continued use and legal force of hallmarking in constituent countries and especially in the UK where hallmarking has been in use since the king's mark of the fourteenth century. John Forbes, Assay Master from 1953 to 1983, is uniquely fitted to write the history of hallmarking and his concentration in particular upon the work of the London Assay Office in the capital of a major trading country serves to make this book a notable monograph on a special area of economic history as well as a study of the practice of hallmarking itself.

The Goldsmiths' Company is fortunate to have been able to preserve its records, especially minute books and archives: the author has been able to draw freely on them and to illustrate not only the excellent supervision which was exercised over the gold and silver trades but also the ingenious efforts made by some to profit by evading the rules. The links between the company and the Royal Mint are emphasized and a description given of the Trial of the Pyx, still conducted annually.

The book is arranged chronologically with special notes on a number of important topics: they include Britannia Silver, Plate Duty, the Hallmarking Act of 1973 (taking effect in 1975) and London hallmarks for silver. The historical commentary is continuously accompanied by notes on the different techniques used by assayers over the years and there is a useful glossary and a bibliography. Colour plates illustrate some significant artefacts and documents.

This is a book for anyone concerned with the jewellery or precious metal trades: it is very easy to read, very economically priced and a worthy climax to the distinguished career of its author. M.O'D.

Les pierres de lune bleues de Meethiyagoda, Sri Lanka. [A thesis.]

L. Genot, 1998. Université de Nantes UFR des sciences et des techniques, Nantes. pp. 105. Illus. in colour, softcover, unpriced.

This study of blue moonstones from Meethiyagoda, Sri Lanka, forms a thesis submitted to the Université de Gemmologie of the University of Nantes. Theses on topics of gemmological interest appear from time to time but are not often published in printed form and this example is welcome as something of a rarity of information production. It is much more welcome of course, for the light which it throws upon a beautiful gemstone. The author begins with geological and mineralogical studies of the Meethiyagoda area in the south-west of Sri Lanka and bravely discusses the place of the blue moonstone in the feldspar group of minerals. Details of the moonstone's recovery from alluvial deposits are given and, with other sections of the study, are illustrated by colour photographs taken during the author's time in Sri Lanka. Tests used to examine the moonstones are described: they include Raman spectroscopy as well as the usual gemmological tests.

Colours, fashioning and values are briefly described, and the author concludes with a useful bibliography, a vocabulary, notes on the use of moonstone in jewellery and in literature, a description of the electron microscope and its workings, and of the alteration of feldspar minerals. This is a useful study and one which would stand a wider exposure by a commercial publisher. M.O'D.

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Edelsteine: Symbole der Schönheit und der Macht.

E. GÜBELIN AND F-X. ERNI, 1999. Verlag Hans Schoner GmbH., Königsbach-Stein, Germany. pp. 240, illus. in colour. Hardcover ISBN 3 923765 30 4. DM 73.84.

Despite the title, this beautifully-illustrated history of the use of gemstones would also serve as a vehicle for gemmological study since considerable detail is given on many of the species described and because it is so well illustrated. So we find notes not only on cutting and polishing but also in some cases on those properties able to be tested gemmologically: major groups have appended notes sufficient for tests to be made on unknown specimens and if the eye of the reader jumps over the notes to the next photograph this is only to be expected! However, the stimulus given to the imagination by such a book will impel many readers who may come across the book accidentally to study further in the world of gemstones.

The table of contents shows that the text follows a well-tried and virtually inevitable path via formation, occurrence, the major species, symbolism and medical properties to the internal world of stones, stones for the collector and man-made products. There is a useful bibliography and an English edition is promised.

Readers familiar with gemstone literature over the past 30 years will expect new photographs: here they are, many by the renowned team of Harold and Erica Van Pelt whose work is, as always, first-class. But many pictures are by the first author and by others: all reach the same high standard. Take no notice of imagined language difficulties and buy this beautiful book. M.O'D.

The diamond makers.

R.M. HAZEN, 1999. Cambridge Univ. Press, Cambridge. xiv, 244 pp. Paperback ISBN 0 521 65474 2. £9.95.

This book spans centuries of ground-breaking science, bitter rivalry, outright fraud and self-delusion, and is centred around the brilliant but often controversial pioneers of high-pressure research. It represents a new and heavily revised edition of *The New Alchemists* (1994), and is presented as a blend of dramatic personal stories and scientific advances (and failures) in the quest to create synthetic diamonds. After a brief account of the natural occurrences of diamond, details are presented of the early work by Hannay, Moissan, Crookes, Hershey and Sir Charles Parsons, and the founding of modern high-pressure research by P.W. Bridgman, before turning to the first true synthesis of diamond by ASEA in Sweden 1953 followed by the General Electric Company in the U.S.A. in 1955.

One of the delights of this book is its inclusion of many photographs of the experimenters and their apparatus. We are given insights into the belt apparatus, the tetrahedral-anvil press and the cubic-anvil press with its six carbide anvils arranged in three opposed pairs to give a cube-shaped sample chamber.

A whole chapter is devoted to the crystal syntheses carried out by Loring Coes, a chemist working for the Norton Company. Rather than tackle diamond synthesis directly, Coes crept up on the conditions necessary for its formation by first producing more than forty silicates never before synthesized, such as pyrope, staurolite, kyanite, topaz, zircon, etc. These were produced not from the pure oxides of the conventional logic but from mixing such ingredients as, for pyrope, $Mg(NO_3)_2$, $Al(OH)_3$ and SiC and reacting them in a slightly open capsule allowing the volatile components to escape leaving tiny but perfect crystals of garnet. The results were not initially published, but after the synthesis of a new dense form of crystalline silica, now coesite, a short note appeared on this together with a remark that 'the synthesis of several naturally occurring minerals' was to be reported in a subsequent paper. This led to a meeting in December 1953, at the Norton Co., at which Coes demonstrated his methods and results to Messrs. Birch, Boyd, Hurlbut, MacDonald, Robertson, Roy, Thompson, Van Valkenburg and Yoder. Coes never did succeed in making diamonds, but these nine scientists left in amazement and on return to their respective laboratories developed research techniques which continue to be of lasting importance to the earth sciences.

In further chapters are the six-year legal battle between De Beers and General Electric in which the former challenged the originality and accuracy of description of the latter's discovery, the production of diamonds via explosive processes, and their successful synthesis from chemical vapour deposition. A final chapter details the invention and development of the diamond-anvil cell, with an interesting history of Van Valkenburg and Weir having an abundant supply of natural gem diamonds confiscated by the U.S. Customs and offered to scientists at the National Bureau of Standards.

This is an eminently readable book, full of fascinating, often first-hand, accounts of the trials and tribulations of high-pressure research workers in academic, commercial and government laboratories. The price should encourage a wide readership. R.A.H.

Visual optics II: diamond and gem identification without instruments: the Hodgkinson method.

A. HODGKINSON, 1999. Gemworld International Inc. Northbrook, Illinois, U.S.A. pp. 77. illus. in colour, softcover, ring-bound. ISBN 0 964 17334 4. US$29.95

The advent of synthetic moissanite stimulated author and publishers (by their own account) to revise *Visual optics* and useful information on this latest diamond imitation is provided. Like the previous edition, this one is attractively produced and readers will want to try the tests out for themselves. Apart from hints on catching moissanite out, of equal interest are the descriptions of several uses of Nelson's Fingerprinter, devised in 1984, which records, among other things, the optical behaviour of every pavilion facet of a specimen. 'Try this one at home' can safely be said of all the tests described (but at least read up on general gem testing first, so that the full benefit of visual optics can be obtained).

While the book is easy to read, the lack of an index does hinder the reader and a glossary too is a desideratum. I wonder whether an A4 format would frame each section better? Some personal names are mis-spelt and this reviewer at least tires of obtrusive and rather fulsome praise directed at gemmological worthies who don't need

it: the author could now completely abandon his stance of the one against the many since his methods have long been recognized and he can be well satisfied with what he has accomplished to the benefit of all. M.O'D.

Romance of the Golconda diamonds.

O. KHALIDI, 1999. Mapin Publishing Pvt. Ltd., Ahmedabad, India. pp. 127, illus. in colour, hardcover ISBN 1 890206 10 5 and 81 85822 57 3. £28.00.

Accounts of the Golconda mines are hard to come by and this one is well-produced and illustrated. After a short account of diamond in general and of the legends associated with the stone the author describes the Golconda mines and some of the famous diamonds which they have produced, presenting them in a useful and convenient table. The account is written in a pleasing, informal style and various larger-than-life personalities are introduced. According to the author no mining is carried out in the Golconda area today (though the situation may have changed by now). Most of the remainder of the book is anecdotal: many of the stories, some involving important jewellery sales and pieces, are new (to the reviewer, at least). There is a useful annotated bibliography. Few books would make more acceptable presents than this one, which would interest a very wide potential readership. M.O'D.

Cameos old and new. 2nd edn.

A.M. MILLER. 1998. GemStone Press, Woodstock VT. pp. x, 270, illus. in colour, softcover. ISBN 0 943763 17 7. £18.00.

Though described as a second edition there is no reference to a first, and the entries in the bibliography are no more up-to-date than 1989. The second imprint is that of the UK distributors Robert Hale and it may be that the putative first edition may have been the American one. None the less this is a very important book on a major subject and is well worth buying. Beginning with a history of the glyptic arts the author goes on to describe some at least of the most popular subjects portrayed by the cameo, giving short accounts of some of the most persisting legends. The technique of cameo manufacture is then addressed and succeeding chapters deal with distinguishing old and new cameos, modifications and imitations, and all the details needed for building up a collection: major world collections are described and market prices are discussed. The cameo has never lost its popularity and some fine examples are still available from time to time on the market. This lucid and concise study will be widely read and deserves to be. There is a satisfactory bibliography, illustrations are good and the price very reasonable. M.O'D.

Ruby, sapphire and emerald buying guide.

R. NEWMAN, 2000. International Jewelry Publications, Los Angeles. pp. 164, illustrated in colour, softcover. ISBN 0 929975 28 6. £11.95.

The best-produced book on gemstones I have yet seen in this price range (how is it done?). This is the book for anyone who buys, sells or studies gemstones and also for the casual reader who notices the cover which reproduces three gem-set rings: such a reader may begin a life-long friendship with gemstones and for an author to have achieved this is a rare prize. This style of book (and similar ones by the same author) is the only one I know which introduces actual trade conditions and successfully combines a good deal of gemmology with them. Especially good are remarks on the influence of local lighting conditions – hardly ever mentioned elsewhere but profoundly affecting display and sales: colour taste and preference are considered too and the purpose and effect of different cutting styles. As well as all this are the details any gemmologist would want. Last of all, the pictures are very good, and no internet reproductions have achieved this quality so far. Buy it, read it and keep it. M.O'D

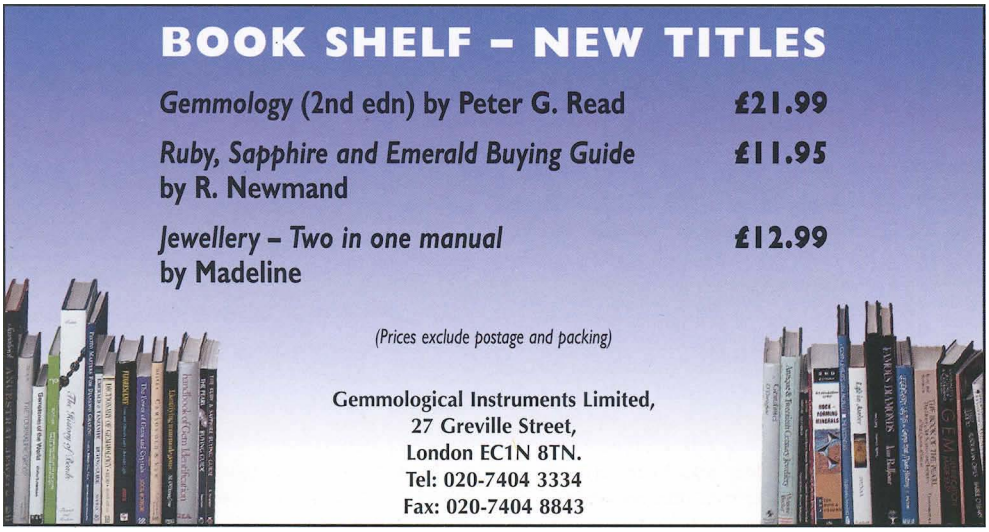

Proceedings of the Gemmological Association and Gem Testing Laboratory of Great Britain and Notices

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OBITUARY

Michael B. Aburrow FGA (D.1983), Poole, Dorset, died in September 1999.

Mark S. Milton (D.1967), Liverpool, died suddenly on 19 August 1999.

MEMBERS' MEETINGS
1999 Annual Conference

The 1999 GAGTL Conference on the theme *New Developments in the Gem World* was held on Sunday 31 October at the Barbican Conference Centre. A full report was published in the December 1999 issue of *Gem & Jewellery News.*

London

On 12 October 1999 at Imperial College, South Kensington, Michael Marks, Production Manager for Elizabeth Gage, gave a talk entitled *Jewellery production problems and what to look out for.* A report of the talk was published in the December issue of *Gem & Jewellery News.*

DONATIONS

The appeal for donations to enable the Association to meet the challenges of the 21st century has brought a good response, and the Council of Management would like to thank all those members who have contributed.

A list of those who have responded to the appeal will be published in the April issue of *The Journal.*

On 8 December at Imperial College, Chris Walton of the Goldsmiths' Company gave a talk on *Jewellery and silverware today.*

Midlands Branch

On 29 October 1999 at the Earth Sciences Building, University of Birmingham, Edgbaston, Professor Dr H.A. Hänni of the SSEF Swiss Gemmological Institute, Basel, gave a presentation of his considerable expertise in the recognition and identification of treatments, particularly of diamonds, corundum and emerald.

On 26 November at the Earth Sciences Building, Alan Jobbins gave an illustrated talk on the Crown Jewels.

On 4 December the 47th Annual Branch Dinner was held at Barnt Green.

North West Branch

On 20 October 1999 at Church House, Hanover Street, Liverpool 1, Piero Di Bela gave a talk entitled *Window to Beauty.*

On 17 November at Church House the Branch AGM was held at which Irene Knight, Deanna Brady and Dr John Franks were re-elected Chairman, Secretary and Treasurer respectively.

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GIFTS TO THE ASSOCIATION

The Association is most grateful to the following for their gifts for research and teaching purposes:

Campbell Bridges, Nairobi, Kenya, for the loan of a drop-shaped faceted tsavorite weighing 4.54 ct.

Mr R. Burton for a scapolite from Mogok.

Spencer Currie, Auckland, New Zealand, for a Paua shell.

Luella Dykhuis, Tucson, Arizona, U.S.A., for over a hundred specimens including peridot, fluorite, opal (including 20 pieces of fire opal), garnet, emerald, quartz (one piece with tourmaline inclusions), citrine, topaz, unfashioned cubic zirconia and fashioned bone.

Feng Hsiu Yun, China Formosa Gem. Lab, Taichung, Taiwan, for a display specimen of fossil orthoceras.

Amanda Good, Thomson Gems Ltd., London, for three pieces of tourmaline and three pieces of garnet.

Britt Inger Hansson, Kil, Norway, for two pieces of kyanite rock.

Marcia Lanyon Ltd., London, for two chrome tourmalines and a garnet-topped doublet.

Mrs C.M. Ou Yang, Hong Kong Institute of Gemmology, for jadeite from Kazakh, Russia.

Wilma van der Giessen, Voorburg, The Netherlands, for two zircons, a ruby and a dyed ruby.

Louis Yick-Sun Lo, Hong Kong, for diamond in kimberlite from China.

This was followed by an informal session on diamonds and simulants.

Scottish Branch

On 4 October 1999 at the British Geological Survey, Murchison House, Edinburgh, John Wheeler gave a presentation on Australian opal, including a video on black opal from Lightning Ridge. Samples of top-quality black opal, boulder opal and white opal were displayed.

On 13 October at the British Geological Survey Michael Gray gave a talk entitled *Extraordinary gemstones. Benitoite: diamond and sapphire in one stone.*

On 3 November at the National Museums of Scotland, Chambers Street, Edinburgh, Campbell Bridges gave a talk on the new gemstones from East Africa.

PRESENTATION OF AWARDS

The Presentation of Awards gained in the 1999 Examinations was held at Goldsmiths' Hall, Foster Lane, London EC2, on Monday 1 November. The President, Professor R.A. Howie, presided and welcomed those present, particularly students who had travelled from as far away as China, Hong Kong, Japan, Kenya, Sri Lanka, Thailand and the U.S.A. He announced that in January and June 1999 a total of 1001 students entered the Gemmology Preliminary and Diploma, and the Gem Diamond Examinations. A total of 183 students qualified in the Diploma examination and they came from 21 countries in all five continents. 105 students passed the Gem Diamond Examination and there were successful candidates from seven countries.

'Getting your Diploma in Gemmology', continued Professor Howie, 'is rather similar to taking your driving test: it allows you to go forward in the knowledge that you have been taught special skills. But I always remember the words of my driving test examiner: "Right, you've passed the test safely, but now the real learning begins and will continue all your life!" And so it is with gemmology – you have learnt all the procedures employed in examining and assessing a gemstone, but now you will have to continue to integrate and expand that knowledge and to develop that sixth sense that enables a gemmologist to feel that everything is not quite as it should be, and to continue testing and examining the stone until the uncertainty is quelled.

'Reverting again to the comparison with driving, my own view is that the most important factor in driving safely on the roads is to drive with "intelligent anticipation"; to expect the unexpected. I well remember that while my wife was learning to drive, I was driving in the narrow winding lanes in Cornwall with high banks and hedges on each side, and had just enunciated the principle that one should always drive expecting a steam-roller around the next corner: this time there

Miss Liu Jiewen, Guilin, China, receiving the Anderson medal.

was! We squeezed by, but on arrival at my destination, the Camborne School of Mines, the car park attendant seemed to be looking hard at the offside front of my old Morris and eventually enquired why I had got half a hedge wrapped round the end of the bumper!

'And so it is with gemmology. Expect your steam-roller, whether it be a moissanite or blue cobalt-doped synthetic forsterite showing strong pleochroism and convincingly masquerading as tanzanite, or indeed some new trickery of which there assuredly will be plenty. Be prepared to examine all its properties in detail as well as its overall appearance. But be ready to be surprised and delighted by yet further new gem mineral varieties in nature: some years ago no one would have dreamt of a blue zoisite – or indeed a gem johachidolite.

'To quote from Michael O'Donoghue's book *Synthetic, imitation and treated gemstones*, gemmologists, jewellers and gemstone collectors now have to accept that nothing is what it seems – or as Shakespeare has it in Macbeth "...and nothing is but what is not!" Take care and good luck in your future careers.'

Professor Howie introduced Mr E. Alan Jobbins, past Editor of the *Journal of Gemmology* and Chairman of the Board of Examiners, who presented the awards. Alan Jobbins delivered his address (see below) and a vote of thanks was given by Michael O'Donoghue.

Professor Howie concluded the proceedings by thanking the Goldsmiths' Company for kindly permitting the GAGTL to hold the ceremony at the Hall.

Address by E. Alan Jobbins

'You have passed your FGA Diploma, you have a great deal of theoretical knowledge and some practical experience – you have (as does a newly qualified doctor) a licence to practise. How are you to approach or continue in your future career? May I give you some useful tips. Which facts of the syllabus do you particularly need to remember; let us go back to Basil Anderson who often spoke of the three legs of the tripod of gem testing – the microscope, the spectroscope and the refractometer – they all depend on making use of light as does revealing the beauty of the gemstones themselves. By now all of you should be carrying your 10x lens (your low power microscope) in your pocket and this alone could usually help to distinguish diamond from the new simulant synthetic moissanite. Your pocket spectroscope will help with many coloured stones and your pen torch will provide the light. The refractometer will require operation on a bench or table and it is not that portable. Let us return to *light*, not only will it help to identify stones, but it will also help you to display and sell them. Good lighting in a shop or exhibition is is essential, and if your employer is not providing it you should use persuasion to get it improved.

'Another important topic I want to discuss is the making and taking of opportunities. Hopefully, by now you will have some idea of the career you hope you will be able to carve out for yourself. You will need to keep up with the latest developments and opportunities; you will need to read trade magazines (such as the *Retail Jeweller*) for adverts for new jobs (opportunities) and be prepared to apply for them; and gemmological journals such as *The Journal of Gemmology* to keep up-to-date with the latest gemmological developments.

'Shortly I will mention some of the opportunities that I have been able to take, but first I would like to tell you of the *great* opportunity taken by our President, Professor Howie, (way back in the '60s). He took over the editorship and developed *Mineralogical Abstracts*, which is now consulted in every country of the world by gemmologists, mineralogists, geologists and others for short abstracts of scientific papers published worldwide – it was a great opportunity taken and subsequently recognized as a colossal international achievement.

'I come now to an opportunity which has ultimately resulted in Chinese students gaining three of the four prizes awarded this year. The story started in 1981 when I visited Hong Kong en route to the International Gemmological

Conference in Tokyo. In Hong Kong I met Mrs Ou Yang who ran the Hong Kong Gem Laboratory and is a leading expert in jadeite jade. She had been teaching at Beijing University and many members of the staff there had moved to Wuhan during the revolution in China where they joined the China University of Geosciences – the powerful geological training university. In 1988 Dr Jamie Nelson and I, through the good offices of Mrs Ou Yang, were invited to go to Wuhan to give a series of gemmological lectures. We went via Hong Kong and spent 24 hours on a train to get to Wuhan – quite an interesting experience! We lectured and ran laboratory tutorials from 8 am to after midnight each day for a week – they were the keenest students we had ever met. I returned in 1989 with Ken Scarratt, who was then Director of the Gem Testing Laboratory in London and is now Director of the American Gem Trade Association laboratory in New York. The opportunities we took up then have resulted in the Association having many allied teaching centres in China, and the FGA being a coveted qualification in China as well as other Chinese-speaking countries.

'I could go on with opportunities taken – they took me to Burma, Sri Lanka, India, Brazil and many other places during my 35 years at the Geological Survey and Museum. I didn't *have* to go on these overseas assignments – I took the opportunity.

'In 1982 the stocks of the small volume describing the English Regalia were running out and I was asked if I would be prepared to carry out a gemmological study of all the stones in the Regalia. I readily agreed. In late 1985 I was told that the examination would take place in February 1986 during the annual cleaning of the Regalia in the Tower of London. I was able to co-opt Dr Roger Harding and Ken Scarratt to assist me since I thought I had some idea of the magnitude of the task – little did I realize that we would examine 22,599 gemstones before we finished our work in February 1989. The major two-volume treatise *The Crown Jewels* was eventually published in 1998 – there were seven authors encompassing a wide range of subjects. An opportunity which none of us would have missed and is unlikely to be repeated.

'Nowadays permanent jobs are almost the exception and most of you will need to move – maybe to similar jobs in the jewellery industry. However, even if you leave gemmology for another profession, it will never leave you. Your power of observation and appreciation of beauty will stay with you. Seek out your opportunities, consider them carefully, and take the promising ones.

(From the left) Dr Roger Harding, Alan Jobbins, Professor Bob Howie and Michael O'Donoghue at the Presentation of Awards ceremony.

'Let me finish with the words of Francis Bacon, the statesman and philosopher. "A wise man will make more opportunities than he finds."

'Good luck to you all in your future careers.'

MEMBERSHIP

The following have been elected to membership during October and November 1999:

Fellowship (FGA)

Carvey, Robyn, Charleston, SC, U.S.A. 1983
Clouder, Carol J., Southampton, Hampshire. 1999
Hill, Stephen E., Rickmansworth, Hertfordshire. 1999
Isacsson, Johanna, Stockholm, Sweden. 1999
Lam Ho Keung, Hong Kong. 1999
Lam King Nam, Hong Kong. 1999
Li Yat Choi Johnson, Hong Kong. 1999
Li Yuling, Zibo, Shandong, P.R. China. 1999
McKeown, Nicola, Landrake, Cornwall. 1999
Morton, Heather D., Vancouver, BC, Canada. 1999
Osborne-Shaw, Lisa M., London. 1999
Parikh, Purnima, Vancouver, BC, Canada. 1999
Petropoulos, Andreas, Athens, Greece. 1999
Raniga, Dhanesh G., Burnaby, B.C., Canada. 1999
Schepers, Reinhold M., Limbricht, The Netherlands. 1999
Scholtes, Wanda, Schaijk, The Netherlands. 1999
Sietsma, Talke, Breda, The Netherlands. 1999

FORTHCOMING EVENTS

28 January	**Midlands Branch.** Bring and Buy followed by a quiz
30 January	**Midlands Branch.** Gem Play Group
15 February	**London.** *Some sites of precious minerals in England.* ***Dr R.F. Symes***
16 February	**North West Branch.** *Ages and variety of amber.* ***Wendy Simkiss***
21 February	**Scottish Branch.** *The lore of gemstones.* ***Brian Jackson***
25 February	**Midlands Branch.** *Gem trails from the Orient to Germany.* ***Ian Mercer***
27 February	**Midlands Branch.** Gem Play Group
15 March	**London.** *Chalcedony – 21st century girl's best friend.* ***Stephen Webster***
15 March	**North West Branch.** *Moissanite.* ***Alan Hodgkinson***
31 March	**Midlands Branch.** *All that glisters is not gold.* ***Dr Rob Ixer***
7 April	**London.** *Visit to Kingston University*
19 April	**London.** *The colour of diamond and how it can be changed.* ***Prof. Alan Collins***
27 April	**London.** *Visit to De Beers*
28 April	**Midlands Branch.** ***Martyn Pugh*** *– Silversmith: designer and manufacturer*
30 April	**Midlands Branch.** Gem Play Group
28 April to 1 May	**Scottish Branch Conference, Perth.** *Keynote speaker:* ***Ken Scarratt***
10-12 May	**London – Kingston.** User school in Raman analysis for gemmologists
18 May*	**London.** *The Rose – nature's jewel as a decorative emblem.* ***Corinna Pike***
21 May	**Midlands Branch.** ***Memory Stather:*** *Sources of inspiration and samples of her work.* ***Doug Morgan:*** *Gem cutting explained and demonstrated.*
14 June	**London.** *Visit to Treasures of the 20th Century exhibition at Goldsmiths' Hall*
24 June	**Midlands Branch.** Summer supper
26 June	**London.** AGM, Reunion of Members, and Bring and Buy Sale
12 July	**London.** *Faceting revolution.* ***Roger Young***
30 July	**Midlands Branch.** Gem Play Group
27 August	**Midlands Branch.** Gem Play Group

** Note change of date for this event.*

For further information on the above events contact:

London:	Mary Burland on 020 7404 3334
Midlands Branch:	Gwyn Green on 0121 445 5359
North West Branch:	Deanna Brady on 0151 648 4266
Scottish Branch:	Catriona McInnes on 0131 667 2199

GAGTL WEB SITE

For up-to-the-minute information on GAGTL events visit our web site on www.gagtl.ac.uk/gagtl

Sopers, Margarita B.M., Den Haag, The Netherlands. 1999
Susitha, Pothmulla K., Colombo, Sri Lanka. 1999
Tang Tak Chuen, Hong Kong. 1999
van der Have, Ciska A., Amsterdam, The Netherlands. 1999
Vidoni, Tanya M., Toronto, Ontario, Canada. 1999
Wunna, Kyaw, Yangon, Myanmar. 1995
Xu Lizhen, San Francisco, Calif., U.S.A. 1998
Yang Hui Ning, Taichung, Taiwan, R.O.C. 1999

Diamond Membership (DGA)

Ao Yan, Beijing, P.R. China. 1998
Barbarovich, Peter M., North Crawley, Buckinghamshire. 1999
Chan Lai Lai Lily, Hong Kong. 1999
Chen Hui Lan, Shenzhen, P.R. China. 1995
Deng Xiuquan, Beijing, P.R. China. 1999
Griffin, Anthony Edgar, Haslemere, Surrey. 1994
Huang Yichun, Guangdong, P.R. China. 1998
Iconomou, Politimi, Athens, Greece. 1999
Kong Jie, Beijing, P.R. China. 1998
Li Li, Beijing, P.R. China. 1998
Li Wei, Beijing, P.R. China. 1999
Liu Feng, Beijing, P.R. China. 1998
Ma Si Ji, Beijing, P.R. China. 1998
Ngala, Dadou K., London. 1999
Parnell, Alexander J., Hove, E. Sussex. 1999
Shi Yan, Beijing, P.R. China. 1998

Ordinary Membership

Abeid, Ahmed, Southall, Middlesex
Brunt, Emily F., Fivemiletown, Co. Tyrone
Chan Hin Tung, Tony, Hong Kong
Checkley, Emma L., Warley, Birmingham
Christianos, Melina Z., Notting Hill, London
Cosmelli, Diana F., London
Damalis, George H., Winchmore Hill, London
Donovan, Matthew J.R., Berkhamstead, Hertfordshire
Fung Wai Chu, Edwina, Hong Kong
García Oliver, Eugenia M., London
Hunter, Thomas S., Southport, Lancashire
Killingback, Harold, Brooke, Oakham, Leicestershire
Reid, Rosa Maria, London
Sansford, Martin, Ayr
Stone, Roger W., Parwich, Derbyshire
van Doren, Jean-Paul, London
Walton, Ralph N., Hermanus, Cape, South Africa

Laboratory Membership

Chris Chaplin, St. Martin, Guernsey, CI.

CORRIGENDUM

In *J. Gemm.*, 1999, **26**(8), p. 550, second column, Diploma Examination results 'Kamil, Ruzwain' should read 'Kamil, Ruzwan'. We apologize for the error.

COAT OF ARMS

Fellows and Diamond Members

Members of the GAGTL having gained their Diploma in Gemmology or the Gem Diamond Diploma (FGA or DGA) may apply for the use of the Coat of Arms on their stationery or within advertisements.

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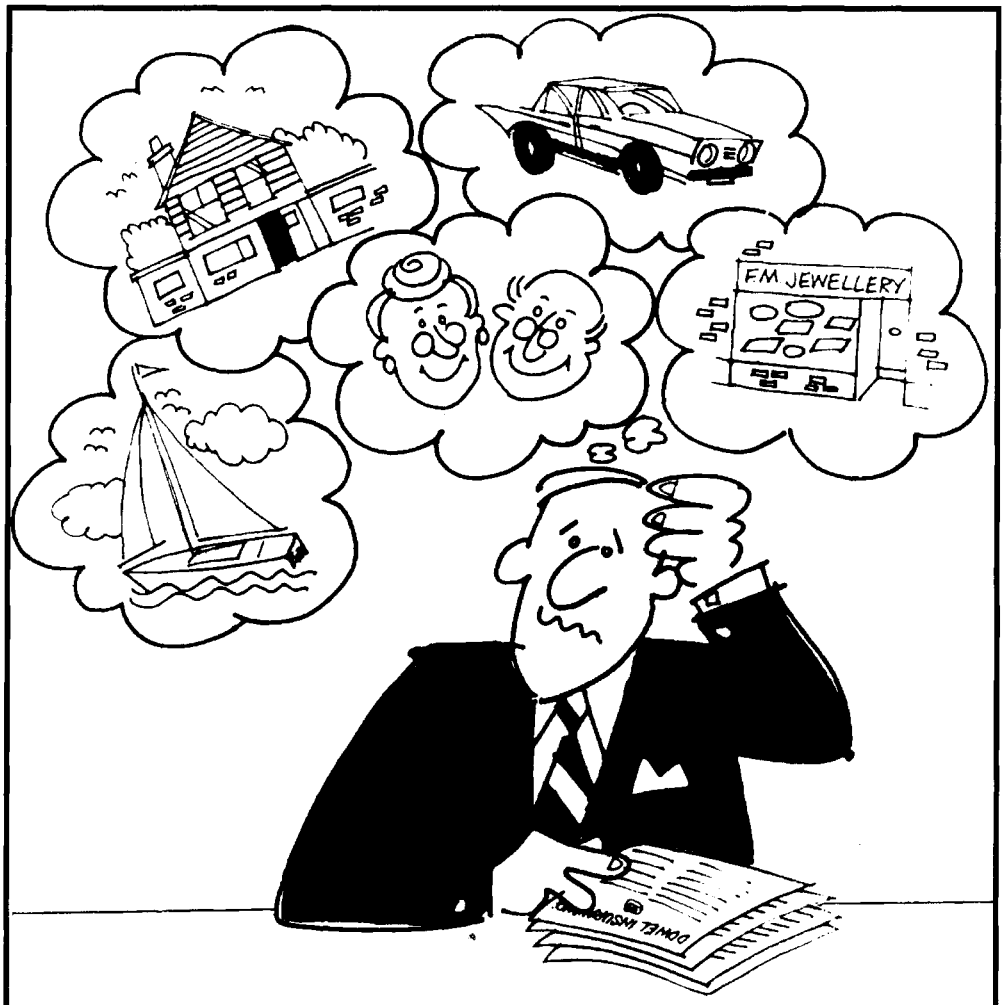

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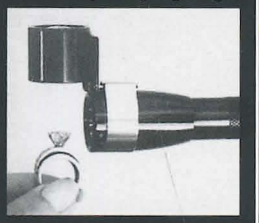

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Cover Picture

From the depths of the Earth or the depths of the laboratory. Images of synthetic sapphire, tourmaline mining and synthetic diamond – see inside

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The Journal of Gemmology

Volume 27 No. 2 April 2000

Sri Lankan gem deposits

GE POL diamonds

Maw-sit-sit

Lab notes

Emerald classification

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Occurrences of two new types of gem deposits in the Okkampitiya gem field, Sri Lanka

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ABSTRACT: Two new types of gem deposits have been discovered recently in the Okkampitiya gem field which is situated in south-eastern Sri Lanka. These are (1) the gem-bearing sediments enclosed within (paleo) karstic potholes and channels in marble, and (2) a primary hessonite deposit in a calc-silicate rock. Dissolution of marble by meteoric waters, particularly along joints and fractures, and perhaps subsidence and collapse may have formed the potholes and channels. Subsequently these karstic features may have trapped the alluvial sediments. The physical and chemical properties of the hessonites are similar to pure grossular garnet. It is suggested that the hessonite-bearing calc-silicate rock was formed during the granulite grade metamorphism of marl, rich in grossular-forming components.

Keywords: alluvial deposit, hessonite, karstic potholes and channels, marble, primary deposit

Introduction

Sri Lanka, well known for its wide variety of fine quality gemstones, is, with a land area of 65,500 km^2, the largest producer of gemstones per square kilometre in the world (Gunaratne and Dissanayake, 1995). In recent years, Sri Lanka has been producing large amounts of heat-treatable geuda (a poor quality corundum which could be enhanced by heat treatment). According to Gunaratne and Dissanayake (1995), about 35-40% of the corundum mined in Sri Lanka, belongs to this category. Almost all gemstones from deposits, locally known as 'illam'. They occur as thin, discontinuous layers, in the palaeo and present-day stream beds, and gemstones are also derived from residual or eluvial deposits located on hill slopes (Dahanayake, 1980). Several primary gem mineral occurrences have been reported (e.g. moonstone), but most contribute little to the gem wealth of Sri Lanka. In this paper two new types of gem deposits from the Okkampitiya gem field are described. These are (1) gem deposits enclosed in (palaeo) karstic potholes and channels in marble, and (2) an occurrence of a primary hessonite

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Geological setting

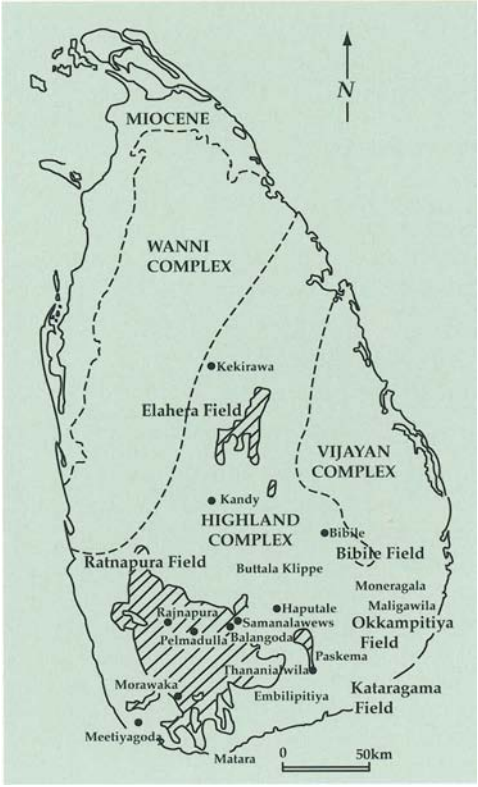

Figure 1: *Sketchmap indicating the three Proterozoic crustal units (Cooray, 1994) and the major gem fields of Sri Lanka (Gunaratne and Dissanayake, 1995).*

Sri Lanka is underlain mainly by Proterozoic high-grade rocks which make-up about 90% of the exposed area. The rest of the area consists of Miocene formations, Quaternary deposits and minor unmetamorphosed igneous rocks including late pegmatites.

The basement rocks have been subdivided into three main units; viz. Highland Complex (HC), Wanni Complex (WC) and Vijayan Complex (VC) (Cooray, 1994) (*Figure 1*). The central, granulite grade HC is a dominantly metasedimentary belt, comprising metasedimentary rocks such as marble, calc-silicate rock, quartzite, pelitic gneiss, khondalite (a garnet-sillimanite schistose rock) and metamorphic rocks of igneous parentage, particularly charnockitic gneisses and orthogneisses. The metasedimentary rocks and certain late unmetamorphosed pegmatites are the major source rocks of the Sri Lankan gemstones despite limited evidence of occurrence of primary gem minerals in them. The possibility should be borne in mind that many gem-rich rocks of the above Complex/es within the original Gondwana may have weathered, eroded away and disappeared in the geological past (cf. Hapuarachchi, 1991). Metasedimentary rocks and pegmatites containing primary gem minerals have been found in several localities (e.g. corundum at Tannahena near Kandy, Haldumulla near Haputale and Kolone near Embilipitiya, moonstone at Meetiyagoda and Balangoda, amethyst at Kekirawa and beryl at Lunugamvehera near Tanamalwila (Gunaratne and Dissanayake, 1995). The HC essentially hosts all the major gem fields of Sri Lanka; viz. the Ratnapura field, the Elahera field, the Bibile field, the Kataragama field and the Okkampitiya field (see *Figure 1*). The Ratnapura field includes the famous gem-producing areas near Ratnapura, Pelmadulla, Embilipitiya and Morawaka. Both the WC and the VC units, which consist mainly of granulite to upper amphibolite grade metamorphic rocks derived from igneous rocks, are practically devoid of gems.

Geological studies have shown that the combined HC-WC unit was overthrust on to the VC, and isolated remnants of the HC rocks occur as 'klippes' or 'outliers'within the VC area. The Buttala 'klippe', which is found near the HC-VC boundary within the VC, is one such occurrence (Kröner *et al.*, 1991) (see *Figure 1*). The Okkampitiya gem field is situated within the Buttala klippe. The area is underlain by marble, pelitic gneisses, quartzite, migmatite, basic granulite and minor pegmatites and calc-silicate rocks, and these rocks are bounded by Vijayan granitic gneisses to the east. Marble is a dominant lithology within the Okkampitiya region. The marble is composed mainly of calcite and dolomite, other minerals present in minor amounts

include, forsterite, diopside, phlogopite, and accessory spinel and apatite. The spinel shows a well-developed octahedral habit occasionally up to 10 mm across and it is often of gem-quality. Forsterite in the marble is usually partly altered. Occasionally, the top of the marble is weathered to a beige to buff-coloured saprolite zone, composed of microcrystalline carbonate material and coarse calcite fragments. The marble shows cavernous features in places which are linked to short joints and fractures (<10 m). The gem deposits described below provide further evidence of karstification in the marble. Elsewhere in Sri Lanka, karstic features in marble have caused serious engineering geology problems including massive leakage in the Samanalawewa Reservoir (Gunatilake, 1995).

Geomorphology

The climate of the Okkampitiya is relatively dry and cool (Somasekaram *et al.*, 1997, p.17). The most prominent morphological feature of the Okkampitiya-Maligawila area is an erosional remnant which occurs in the form of a 'turtle back' hill. The rest of the area is generally flat and gently undulating, with a prominent N-S trending ridge (Nilgala-Buttala ridge) to the west and the Karthalhina mountains to the north-east. The tributaries of Kumbukan Oya drain the area. The geomorphological setting of the Okkampitiya area and the surroundings provide ideal conditions for the formation of placer gem deposits. The tributaries of Kumbukan Oya drain the upper areas in the north and then they enter the broad, flat and gently undulating Okkampitiya area in the south and south-east.

Gem deposits in (palaeo) karstic potholes and channels

The main gemstones occurring in the Okkampitiya gem field include geuda-type corundums, sapphires (blue, yellow and colourless), garnets including hessonite, spinel, tourmaline and zircon, in order of decreasing abundance. Additionally, gem ekanite (a radioactive calcium-thorium silicate) is also found in the area (see Arps, 1989). In contrast to the other gem fields, in

Figure 2: *A schematic E-W cross section of the area indicating occurrences of karstic potholes, blind shafts and channels. The enlargements are schematic representations of sedimentary infills in karstic potholes located on the gentle slope (A), on the flood plain (C) and on a bifurcating channel (B).*

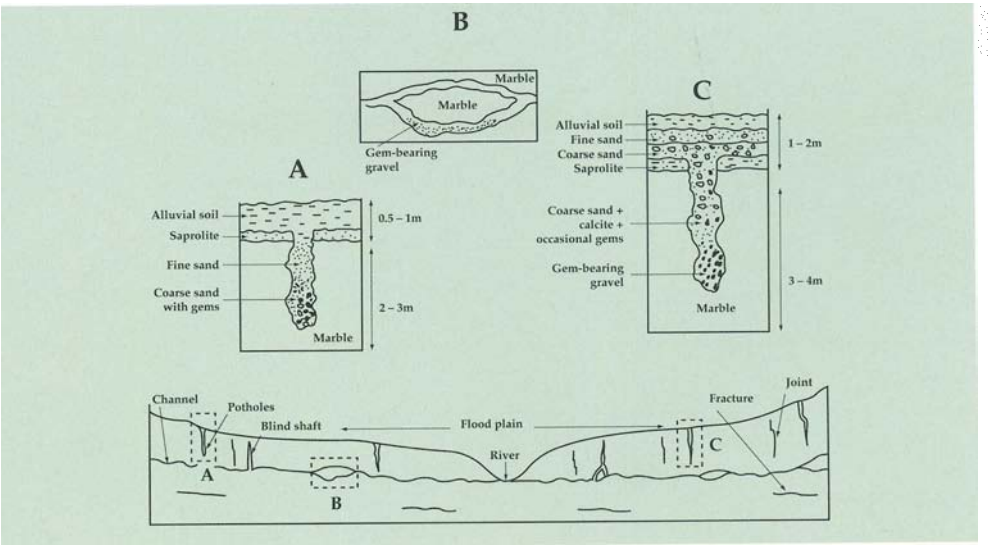

Figure 3: A mined karstic channel in the marble.

the Okkampitiya gem field many of the gem-bearing sediments are enclosed within karstic potholes and channels in the marble (*Figure 2*). The sizes of these potholes range from a few decimetres (on the gentle slopes) up to a few metres (on the flood plains) while the depth ranges up to 3 – 4 m (see *Figures 2* and *3*). Our present data on the subsurface geology is insufficient to comment on the nature of karstic channels, but some may have been sinuous and interconnected (see *Figures 2* and *4*). Dissolution of marble by meteoric waters, particularly along joints and fractures, and perhaps subsidence and collapse would have formed the karstic potholes and channels. Perhaps the palaeo-karstic process may have played a dominant role in the development of the present alluvial flood plains, and in this respect the gem-bearing sediments have calcite and dolomite as the major constituents besides quartz (*Figure 5*).

The dominant gems in the deposits located in the flood plains are geuda-type corundums and sapphires. Their abundance decreases in sites located on the gentle

Figure 4: *Complicated gem mining in a karstic channel in marble.*

slopes, where spinel and tourmaline are more prominent. The corundums invariably show worn crystal faces or rounded surfaces and the quartz pebbles, which are also present occasionally in the gem sediments, have well rounded shapes. These features either indicate long distance of transport before deposition in the potholes and the channel beds, or they represent reworked older sedimentary deposits. Another factor to consider is that karst hydrology can be complicated due to the presence of constrictions along the channel; these can cause reverse flow, resulting in to and fro movements of the sediments (see Jennings, 1971, pp. 92-5). Additionally, swirling of sediments in the potholes could also have contributed the observed rounded features. The rough stratification of the sediments possibly suggests that the karstic plains may have been flooded with gem-bearing sediments (see *Figure* 2). Primary occurrences of corundum in the Okkampitiya area have been observed (Weerawarunakula, 1998, personal communication), but the worn crystal faces of corundums indicate distant provenance further north, possibly from the Bibile region. In contrast to the effects of strong mechanical abrasion shown by corundum, spinel and tourmaline show sharp crystal edges on the spinels and striations remaining on the tourmalines, which are evidence of local provenance. As noted earlier, gem-quality spinel occurs in the host marble, and the local pegmatites may have been the source of the tourmaline. In addition to

Figure 5: *Gem-bearing sediment from a karstic pothole. Note abundant calcite/ dolomite grains.*

Figure 6: *Gem mining activities in a shallow gem pit.*

Figure 7: Gem-bearing sediments being sieved to remove the fine-grained fraction. This method is adopted when water is scarce in the dry season.

alluvial deposits, gemstones are also recovered from residual soils (Chandrajith *et al.*, 1998) (*Figure 6*). Karstic marble terrains clearly provide important 'sedimentation traps' for gem-bearing deposits. Small pockets of gemstone-rich deposits, found elsewhere on the island and sometimes referred to as 'gedi illam', may have been formed in a similar manner either in marble or related lithologies. The richness of these (small) deposits may be due to the fact that the relatively heavy gemstones have been prevented from further transportation or dispersal, while the (very) fine grained and lighter particles originally comprising much of the sediments have been washed away.

Gem mining and exploration

The gem mining methods practised in the Okkampitiya gem field differ considerably from the methods carried out in other gem fields of Sri Lanka. This is mainly because the gem-bearing sediments occur at shallow depths of 2-6 m, and many of the deposits are enclosed in karstic potholes and channels. Gem mining activities usually begin in the dry season. An iron rod referred to as 'illam kuru', is sometimes used to locate the potholes or even the normal placer deposits, but many deposits are located accidentally. The gem miners also use the surface characteristics of the 'heavy' minerals in the sediments and their abundance as a guide to identify mining sites.

Once a pothole or channel is located, the top soil layer is scraped off and the sand and gravel layers are removed until the gem-bearing layers are found, usually at the bottom. If the hole is not large enough to accommodate a person, additional space is obtained by widening the wall of the pothole or channel either by using explosives or by drilling. The gem-bearing sediment is collected and piled nearby, and later on the 'illam' are washed, panned and examined for gemstones in the presence of the gem 'mudalali' (usually one who finances the gem mining). The groundwater in the cavity or a nearby water source is used for washing the sediments.

The 'illam' in those potholes located on the gentle slopes are usually dry and contain considerable amounts of fine-grained material, which is removed by sieving (*Figure 7*). Water required for panning and sorting may not be available at such a site, and in these instances the sieved sediment is packed in sacks and taken to the nearest water source.

Primary hessonite deposit

Sri Lanka is the world's main producer of hessonite, a yellowish-brown to red grossular garnet (Cipriani and Borrelli, 1986; Gunaratne and Dissanayake, 1995). Hessonite is recovered from many places in the island but specifically from Ratnapura, Pelmadulla, Okkampitiya and Kataragama (Arps, 1989). However, except for a weathered deposit at Kamburpitiya in Matara (Gunaratne and Dissanayake, 1995) a primary occurrence of hessonite had not been reported until recently. In 1997 gem miners discovered primary hessonite in a calc-silicate rock near Maligawila, and this was briefly reported by Kalubandara and Mathavan (1998) and Chandrajith *et al.*

(1998). This small deposit is now completely exhausted, except for the nongem-quality remains. According to the miners, the inner parts of the deposit yielded the best quality hessonites.

Hessonite from this deposit is characteristically massive (*Figure 8*) and shows colour ranging from pale orange to reddish-brown to red. It exhibits good lustre but the transparency is moderate to poor in the studied samples. The geochemical, physical and optical properties of the studied 'low quality' samples, as well as the data reported by Arps (1989) of the hessonites from Paskema (Kataragama field) and Okkampitiya, are shown in *Table I*. The hessonites are very close to pure grossular in composition, similar to the Paskema hessonites. A thin section study confirmed

Figure 8: *Massive primary hessonite in a scapolite-rich part of a calc-silicate rock sample.*

Table I: *Chemical and physical properties of hessonites from Maligawila compared with those from Paskema (Arps, 1989).*

Wt%	Maligawila			Paskema		
	1 Probe	2 Probe	3 Probe	89.1 XRF	G9 Probe	G6 Probe
SiO_2	38.66	38.30	39.23	38.08	39.57	39.49
TiO_2	0.19	0.19	0.01	<0.02	0.02	0.24
Al_2O_3	19.79	19.13	20.29	22.05	22.06	22.40
Cr_2O_3	0.02	0.03	–	–	–	–
Fe_2O_3	5.38	6.56	4.67	1.71	1.19	0.69
FeO				–	0.13	0.75
MnO	0.47	0.60	0.34	0.32	0.19	0.20
MgO	0.07	0.05	0.09	<0.01	0.02	0.02
CaO	34.80	32.87	35.25	36.53	36.66	36.25
Na_2O	0.02	0.06	0.09	<0.02	–	–
K_2O	0.35	0.15	–	<0.02	–	–
P_2O_5	–	–	–	0.28	–	–
F	0.35	0.15	0.18	–	–	–
Cl	0.02	0.04	0.04	–	–	–
Total	100.12	98.13	100.19	98.99	99.84	100.04
End-member composition						
Gross.	94.4	98.1	98.8	94.4	96.5	95.9
Pyr.	0.3	0.2	0.4	0.0	0.1	0.1
Spess.	1.1	1.5	0.8	0.7	0.4	0.4
Andr.	0.0	0.0	0.0	4.6	1.7	2.0
Uvarov.	0.1	0.1	0.0	0.0	0.0	0.0
Alman.	0.0	0.0	0.0	0.2	1.3	1.6
RI.	–	–	1.74	1.732	1.731	1.735
SG.	3.622	3.637	–	3.598	3.622	3.616

NB: Maligawila hessonite compositions were determined by microprobe and SG was determined on crushed grains using a specific gravity bottle.

the presence of calcite and scapolite as inclusions in the hessonites, and this contrasts with Arps' (1989) study which indicated the occurrence of apatite as inclusions in all the samples. The contact rock of the hessonite deposit was not exposed in the field due to intense weathering and soil cover. The nearest outcrop, which occurs about 25 m away, is a migmatitic hornblende-biotite gneiss and this rock contains decimetre scale calc-silicate rock layers. In the hessonite-bearing calc-silicate rock samples, garnet is the predominant mineral and is accompanied by scapolite, diopside, wollastonite, calcite and quartz. These minerals show polygonal granoblastic texture, which indicates that this assemblage was formed by metamorphism of marl, a mixture of clay and calcareous sediment, under granulite facies conditions. The marl may have been rich in grossular-forming components to produce a hessonite-rich deposit. Garnet occurs in two forms; large to porphyroblastic grains, and small coronas or rims interstitial between other minerals in the rock. The rim garnets postdate the porphyroblasts and may have formed following granulite facies metamorphism.

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Identification of GE POL diamonds: a second step

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ABSTRACT: An identification method for GE POL treated diamonds in two steps is proposed. First, as almost all GE POL diamonds are type IIa, near colourless type IIa diamonds are separated from other diamonds of similar colour using the SSEF Type IIa Diamond Spotter. Second, a Raman spectrum of these IIa stones is obtained using the 514 nm laser line of a Raman spectrometer. If a luminescence pattern at 3760 cm^{-1} is observed, this proves the presence of a small number of N-V centres in the stones. This is believed to be characteristic of the material used for the GE process, as all studied GE POL diamonds exhibit this emission. Hence, a near-colourless type IIa diamond showing a N-V centre emission is likely to be a GE POL treated diamond. Further samples are necessary to confirm this preliminary criterion.

Keywords: GE POL, HPHT diamond treatment, type IIa, N-V centres (637 nm), luminescence, Raman spectrum

Introduction

General Electric (GE) currently treats certain brownish diamonds to make them more colourless, up to D colour. GE applies this high pressure and high temperature process on essentially type IIa diamonds, which are rare on the diamond market (approximately 1%, only) (Anthony and Casey, in Moses, 1999).

Since April 1999, these treated diamonds have been marketed by Pegasus Overseas Limited (POL) in Antwerp, a subsidiary of a sight holder based in New York City, Lazare Kaplan International (LKI). These stones are known in the trade as Pegasus diamonds, GE POL diamonds and more recently as Monarch™ diamonds (Schmetzer, 1999). LKI markets them at the same price as their untreated counterparts because the treatment is claimed to be undetectable and remain so in the future. While GIA discloses on reports that these diamonds have been only 'processed', CIBJO laboratories disclose 'treated diamonds' in accordance with a CIBJO directive dated May 1999.

GE POL has been subsequently inscribed on the girdle of these diamonds to make them easily identifiable. But unfortunately, GIA has recognised a few GE POL diamonds that were resubmitted for certificates after a repolish of the 'GE POL' inscription. Until now, no gemmological criterion has been proposed to identify this treatment with certainty, thus it is an ongoing challenge for all gemmologists.

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A first article from our team described observations under magnification of two GE POL diamonds, as well as some fluorescence bands triggered by the laser of the Raman spectrometer; one of these bands has been attributed to the presence of N-V centres (Chalain *et al.*, 1999). This article demonstrates how this emission may be used for identification of GE POL diamonds. It also describes the SSEF Type IIa Diamond Spotter, a new simple device for a quick identification of all type IIa diamonds and type IaB, an even rarer type.

Type IIa diamond samples

As the vast majority of GE POL diamonds are type IIa, it is important for the trade to be able to separate these near-colourless diamonds, potentially GE POL treated, from those of other types. Laboratories do this on the basis of infrared absorption; however, most jewellers do not have an infrared spectrometer. In addition, the original definition of type I and type II diamonds is based also on transparency to shortwave ultraviolet radiation (SWUV; Robertson *et al.*, 1934). When putting a diamond on top

Method of study

The aim of the current study is to present, compare and discuss the spectra obtained on a Raman spectrometer of these fifteen diamonds. For each diamond of the three groups, the following tests were performed, besides classical gemmological observations (which are not discussed further here, as they did not prove diagnostic in all cases):

- FTIR spectrum to verify that the diamond is indeed type IIa by the infrared spectrum pattern as well as the ultraviolet;
- Raman spectra were obtained at room temperature.

The Renishaw 1000 Raman spectrometer used is equipped with a Peltier-cooled CCD detector and ionised argon laser, with a green ray at 514 nm (Hänni *et al.*, 1997). It is calibrated with the 1332 cm^{-1} diamond peak of a reference diamond prior to each analysis. For better consistency of the results each diamond is set under the laser beam of the Raman microprobe by the same operator who always follows the same procedure. The table of the diamond is rubbed on a clean and dry white sheet of paper to ensure that no grease is present. The diamond is then placed on a glass support and held up by two small pieces of Blutack^R placed between the glass and the pavilion of the diamond. The Blutack^R is set as far back as possible from the area of interest, because it might induce a non negligible fluorescence. Then, the laser beam is focused on the table using a x20 magnification lens (Olympus: MS Plan 20; 0.46), the beam being perpendicular to the table of the stone. Finally, both sample and Raman microprobe are wrapped in an opaque black fabric to avoid any interference from external lighting. The particular experimental instrument set up parameters are saved in a computer file and loaded before each analysis, so that experimental conditions are always identical. This experimental procedure uses a 25 mW laser power, in the Renishaw 'extended and continuous mode', as well as the 'Gain and Cosmic Ray elimination mode'. Five scans are averaged in the range 100 cm^{-1} to 6500 cm^{-1}. This procedure takes approximately 25 minutes per stone.

Raman spectra were obtained at room temperature on two diamonds in various zones, to ensure that the whole stone is sample tested in a comprehensive way.

of the SSEF Type IIa Diamond Spotter (*Figure 1*), and illuminating it with SWUV, type IIa stones will transmit the radiation, exciting a green fluorescent screen placed underneath the stones. If the screen remains inert, the stone is not type IIa. This is a quick and easy way of recognising type IIa stones without infrared absorption.

Since October 1999, ten diamonds of type IIa, both colourless and brownish, have been recognised by staff of the SSEF laboratory thanks to several diamond dealers who kindly sent them to SSEF for one day. The identification of IIa diamonds is done with the SSEF Type IIa Diamond Spotter. They were further divided into two groups. Group 1 is composed of seven untreated colourless diamonds, all D colour (see *Table I*). Group 2 consists of three untreated diamonds of a brown to brownish hue (see *Table II*). Group 3 is composed of the GE POL diamonds that were submitted to SSEF for research (see *Table III*).

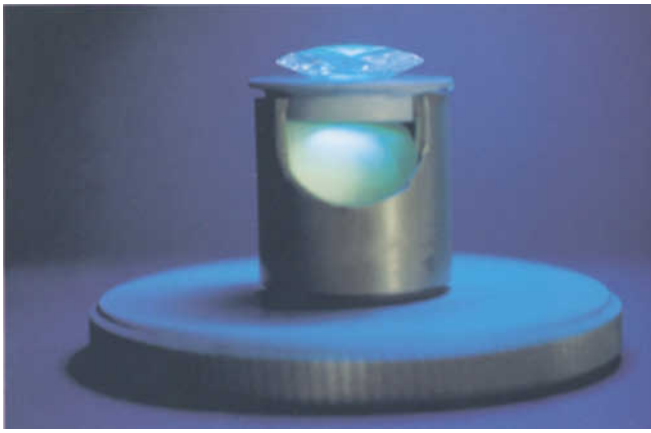

Figure 1: *The SSEF Type IIa Diamond Spotter.*

Results

All the spectra obtained showed of course the first order (1332 cm^{-1}) and second order (2000 to 2665 cm^{-1} approximately) Raman spectrum of diamond. Additional weak

Table I: *Group 1: Untreated near-colourless type IIa diamonds*

Reference	*Weight (ct)*	*Shape & Cut*	*Colour*	*N-V centre (3760 cm^{-1}/637 nm*	*Other noticeable bands (cm^{-1})*
ma048	0.468	marquise, modified brilliant	D	no	3076
ma354	3.54	marquise, modified brilliant	D	no	3073
ma202	2.02	marquise, modified brilliant	D	no	none
pea175	1.751	pear-shaped, modified brilliant	D	no	5966
pea180	1.808	pear-shaped, modified brilliant	D	no	none
pea202	2.028	pear-shaped, modified brilliant	D	no	none
ma161	1.613	marquise, modified brilliant	D	no	none

Table II: *Group 2: Untreated brownish to brown type IIa diamonds*

Reference	*Weight (ct)*	*Shape & Cut*	*Colour*	*N-V centre (3760 cm^{-1}/637 nm*	*Other noticeable bands (cm^{-1})*
RD465	4.650	round, rose cut	L(brown)	yes	4276
ma354	5.838	marquise, modified brilliant	M-Q (brown)	yes	794
					4284
					2065
rou903b2	9.03	rough, flat	faint brown	yes	5960

Table III: Group 3: GE POL type IIa diamonds

Reference	*Weight (ct)*	*Shape & Cut*	*Colour*	*N-V centre (3760 cm^{-1}/637 nm*	*Other noticeable bands (cm^{-1})*
GE POL001	0.75	round, brilliant	E	yes	none
GE POL002	0.56	marquise, modified brilliant	F	yes	794 2073
GE POL003	0.79	pear-shaped, modified brilliant	E	yes	794
GE POL004	0.94	oval, modified brilliant	D	yes	none
GE POL005	0.72	round, brilliant	F	yes	786

signals, interpreted as luminescence on the basis of their already known energy position and associated vibronic structure, are also of interest.

Untreated colourless diamonds

The seven untreated colourless diamonds of Group 1 were confirmed to be type IIa by infrared spectroscopy. None of these diamonds shows the fluorescence of an N-V centre in the Raman spectrum. The corresponding spectra are presented in *Figure 2* and some of their properties are summarised in *Table I*.

Untreated brown to brownish diamonds

Infrared spectrometry confirmed that the three untreated brown diamonds of Group 2 are indeed type IIa. The colour of these three stones ranges from L on the GIA colour grading scale to faint brown. Their Raman spectra reveal the presence of a peak at 3760 cm^{-1} (*Figure 3*). The laser emits at 19435 cm^{-1} (514 nm); the apparent Raman shift therefore corresponds to an emission at 19435 - 3760 = 15675 cm^{-1} (637 nm). This is the position of the characteristic line of the N-V centre, therefore this defect is present in each of the three stones.

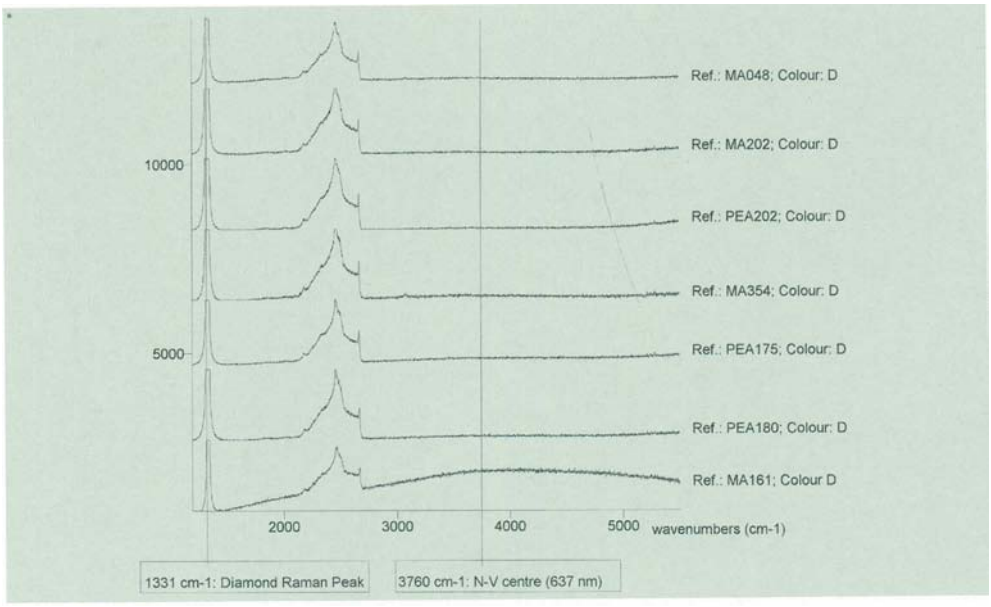

Figure 2: *Raman spectra of seven type IIa near-colourless diamonds. No emission is observed at 3760 cm^{-1}*

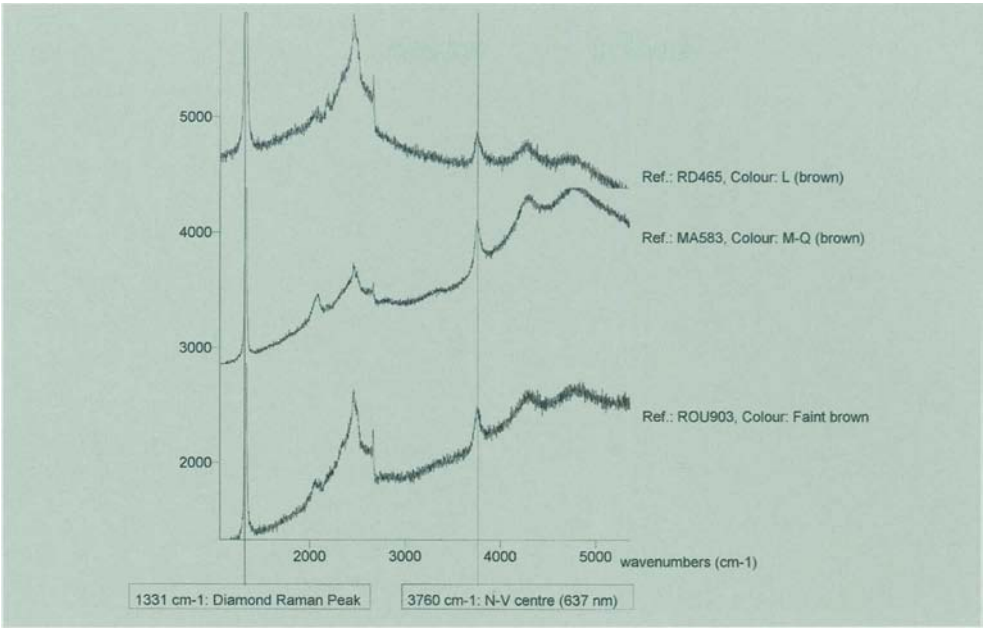

Figure 3: *Raman spectra of three brown type IIa diamonds. They all show an emission at 3760 cm^{-1}, due to the N-V centre.*

The weak band observed around 2060 cm^{-1} corresponds to an emission at 17375 cm^{-1} (575.5 nm) which is a known companion line to the 637 nm peak (Collins, 1982). The properties of these stones are summarised in *Table II*.

Treated GE POL diamonds

As reported from GIA, 99% of 858 GE POL diamonds are type IIa (Moses *et al.*, 1999). The five GE POL diamonds analysed at SSEF are also type IIa as confirmed by infrared spectrometry, and their colours range from D to F. Their Raman spectra also show emissions indicating the presence of N-V centres (*Figure 4*). Their properties are summarized in *Table III*. Note that they are arranged by colour and that the darker the colour, the stronger the 3760 cm^{-1} fluorescence band.

Synthesis of results and discussion

All seven untreated near-colourless diamonds of type IIa show no N-V luminescence. On the other hand, both GE POL and brown diamonds of type IIa all show N-V emission. This luminescence is also found in a rare category of type IIa pink diamonds ('Golconda type', Fritsch, 1998). The original colour of now near-colourless GE POL diamonds has been stated as brown (Rapaport, 1999). Thus, the presence of N-V centres in GE POL diamonds might be a characteristic of the original brown diamonds, prior to treatment. We assume that the treatment removes the brown colour but not the N-V centres. In other words, the presence of N-V centres in GE POL diamonds is not in agreement with the fact that they are near-colourless, because untreated near-colourless diamonds of type IIa have no N-V centres.

The criterion proposed here is based on a small number of samples, perhaps not statistically representative. The reason for this is twofold. First, type IIa diamonds are rare (1% approximately). Second, the work is at a preliminary stage.

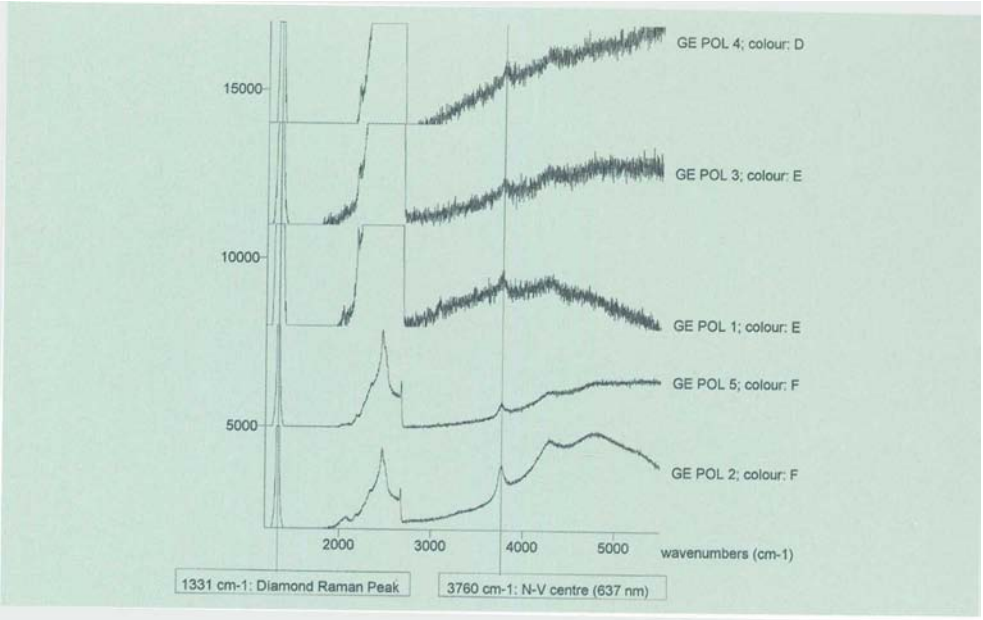

Figure 4: *Raman spectra of five GE POL diamonds, all exhibiting emissions at 3760 cm^{-1}, due to the N-V centre.*

SSEF will continue to study a selection of type IIa untreated diamonds, both colourless and brown, and endeavour to obtain more GE POL diamonds for comparison.

Conclusion

Five GE POL diamonds and ten untreated diamonds, all type IIa, have been studied. We have shown here that the presence of N-V centres might not be consistent with the fact that GE POL diamonds are colourless. Hence, the presence of a small number of N-V centres, luminescing under the excitation of the 514 nm line of a Raman spectrometer, might indicate that a colourless type IIa diamond has been treated by the GE process. However, because of the scarcity of type IIa untreated and treated diamonds, this identification criterion based on fluorescence spectroscopy must only be considered as a promising hypothesis. But we believe that, if confirmed, this method could be of considerable benefit for the diamond trade.

Acknowledgements

The authors are grateful to the gemmological laboratories and diamond dealers for supplying the samples for this study.

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Notes from the Laboratory

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ABSTRACT: The topics discussed are: the use of cathodoluminescent spectroscopy in testing alexandrites; definitions of jet within gemmology; detection and safety considerations of blue irradiated topaz; false reporting of synthetic emeralds; unusual descriptions and trading standard laws; and considerations of phenakite, tanzanite and a scheelite-powellite mineral.

Alexandrite chrysoberyls

The inclusions in two alexandrite chrysoberyls, which were submitted for testing at different times, were not considered typical enough to satisfy us as to their natural origin. We decided to seek corroborating evidence from cathodoluminescence (CL) spectroscopy. On both occasions the stones were sent to Dr Johann Ponahlo at the Natural History Museum in Vienna.

The first alexandrite, weighing 2.36 ct, was found to behave differently under CL to many other natural alexandrites, most of which tend to have relatively low CL. This is evident in *Figure 1* where the spectrophotometric curves of low intensity can be taken as being representative of most natural alexandrites. The green curves in increasing CL intensity are an alexandrite from the Hematita mine in Brazil (AL-HEMA1), an alexandrite from the old Tokowaja mine in the Ural Mountains (AL-U/K9456) and a Sri Lankan alexandrite (AL-SRI/G74N).

In comparison, synthetic alexandrites (melt or flux melt) have a much higher relative CL intensity (see the black curve ALY-KC in *Figure 1*). In 1993 Dr Ponahlo had

Equipment

The equipment used is a cold cathode apparatus Luminoscope[R] produced in the USA. It is mounted on the table stand of a standard polarising microscope with an attached micro-spectrophotometer. The cold cathode apparatus consists of a large compartment that houses the sample and electron gun that can produce an electron beam of up to 16.5 kV at a vacuum of less than 100 mTorr using a carrier gas (helium or air). The luminescing sample can be observed at magnifications up to 125x. Macro- or microphotos may be taken or CL spectra run at increments of 0.5 to 10 nm.

The whole unit is a computer-assisted assemblage manufactured by Zeiss, enabling the operator to produce not only cathodoluminescence, but also emission or absorption spectra between 380 nm and 950 nm (my thanks to Dr Ponahlo for this information).

The use of cathodoluminescence in coloured gemstone identification has already been described elsewhere (Ponahlo *et al.*, 1986; Ponahlo, 1988, 1989, 1993).

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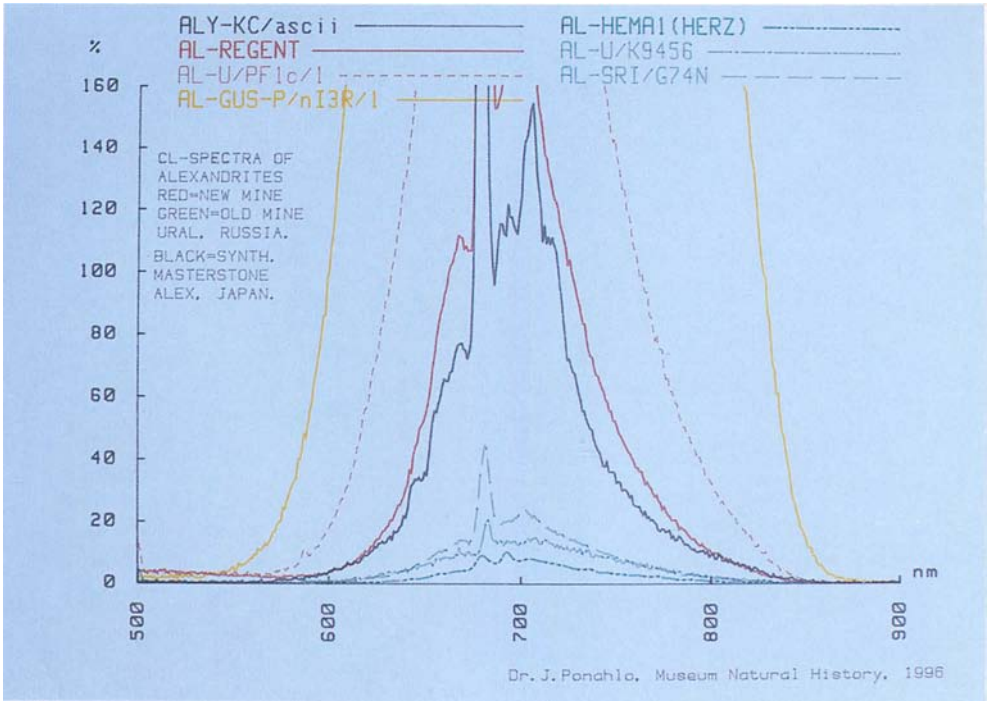

Figure 1: *Cathodoluminescence spectrophotometric curves for natural alexandrites:*
1. *Dash-double dotted green curve – Hematita mine, Brazil;*
2. *Dash-dotted green curve – Sri Lanka;*
3. *Long dashed green curve – old Tokowaja mine, Russia;*
4. *Short dashed red curve and yellow curve – Malisheva mine, Russia;*
5. *Solid red curve – the stone sent to Vienna;*
6. *The black curve is a synthetic alexandrite masterstone for comparison.*

become aware of some natural alexandrites, which were characterised by exceptionally high CL intensities. The dotted red curve (AL-U/PF) is the CL spectrum for a cut natural alexandrite of more than one carat, the yellow curve (AL-GUS) relates to a polished crystal of alexandrite taken from a crystal group. The relative CL intensity of this polished crystal is some 20x greater than that of the synthetic alexandrite masterstone (black curve). Dr Ponahlo believes that these alexandrites are from a mine 80 km south-east of Jekaterinburg (Sverdlovsk), which is reportedly called 'Malisheva'. In Dr Ponahlo's opinion the CL of our 2.36 ct alexandrite was similar to that of alexandrites from 'Malisheva' (AL-REGENT solid red curve). This provided us with the confirmation we sought, enabling a report to be issued stating its natural origin. The second alexandrite, subsequently sent to Vienna proved to have the lower CL intensity typical for alexandrites from other natural sources.

A while ago we were asked for a quick verbal assessment on an alexandrite. The client could allow us time only to study the inclusions, which consisted of tapering exsolved zoning patterns reminiscent of those seen in hydrothermally synthesised emerald (*Figure 2*). Subsequent enquiries to colleagues in the trade and in other laboratories were inconclusive about whether or not alexandrite was being synthesised hydrothermally. We know chrysoberyl has been grown hydrothermally, but has any alexandrite been grown by this

method and found its way onto the market or been grown commercially? Because we were not permitted to carry out further work on this stone, its origin will have to remain a mystery. A.I.C./S.J.K.

Jet?

In most gemmological teaching the identification of jet is presented as being relatively straightforward. This tends to be based on the material from two or three localities, but more detailed work has shown that even from these sources jet can show differences in properties (Weller and Wert, 1994). Coal is categorised in various interconnecting ways (Carpenter, 1988). The rank or maturity of the coal is related to the temperatures to which it has been subjected and the geological time involved. The rank increases from lignite, to sub-bituminous, through bituminous coal to anthracite. In coal petrology, the organic components are referred to as macerals and reflect their origins. Examples are vitrinite (chemically reactive - wood and allied tissue), liptinite (waxy and fatty parts of plants, e.g. spores, resin and cuticle) and inertinite (chemically inert charcoal-like material). As the rank of a coal increases (coalification) the liptinites are the first to react, losing volatiles and becoming indistinguishable under the microscope from each other and from vitrinite. Further heating, and increase of rank, leads to the loss of all botanical structure from the vitrinite, until finally in an anthracite the coal may appear almost totally homogeneous with perhaps only a few inertinite fragments visible. A low rank coal contains some 40% of volatile constituents (e.g. hydrogen), which decrease to around 4% in an anthracite.

In geological terms, jet is a form of vitrinite derived from homogeneous logs of wood washed from the land into water, usually the sea. When they become waterlogged they sink into the mud on the sea floor. If the mud is anoxic it will contain the remains of marine algae and plankton which are decaying and generating hydrocarbons (oil). The oil soaks into the wood and reduces its brittleness, producing the more resilient jet rather than the vitrinite that it would normally have become without the oil impregnation.

Figure 2: Growth zoning present in an alexandrite of questionable origin.

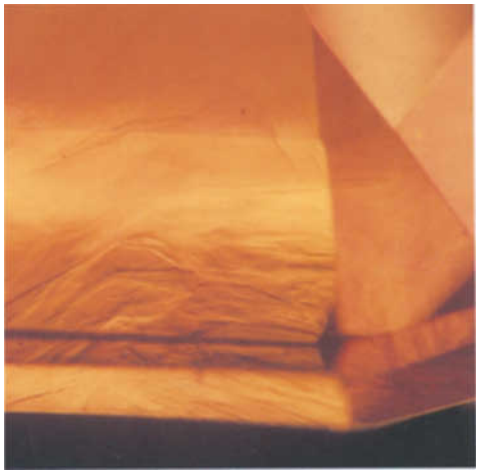

In gemmology we probably need to be more pragmatic in accepting jet as being coal of sub-bituminous to bituminous rank, with enough impregnated hydrocarbons to make the black material compact, carvable and durable. Coal that is to be considered as jet also needs to be free of mineral impurities (i.e. high grade) to reduce the chance of any fragmentation of the material. Therefore low ranked lignite, high ranked anthracite and low grade coal should be rejected as being too fragile and/or brittle to be considered gemmologically as jet.

A black bead necklace submitted to us proved to be an example of one of the above reject categories. Three features stopped us calling the material jet. There was an iridescent bloom to the black colour, the material would not burn with a hot point and the material deposited a black streak on unglazed white ceramic when a bead was drawn over it (the streak test). In itself this last feature should not be taken as ruling out

the material as being jet, but in association with the other two aforementioned properties it quite rightly created suspicions in our minds.

Staff in the Mineralogy Department at the Natural History Museum kindly liaised with us by running X-ray powder diffraction and electron microprobe analyses, and these indicated that no mineral content was present. A section of a bead was also burned in a test tube: it burned virtually to completion leaving only a small white residue but gave off no smell of coal. By a process of elimination it was considered to be a high ranked coal or anthracite.

We decided to seek the assistance of Dr J.M. Jones, a coal petrologist and jet specialist, recently retired from the Fossil Fuel Department of Newcastle University, in order to obtain a positive identification. A fragment of our material was embedded in resin and polished down to produce a flat surface to carry out a reflectance test, which is commonly used in industry to identify different kinds of coal. The reflectance under oil immersion was 4% (you can measure in air or oil) which, being over 2.5%, accords with what is expected for anthracite (Stach, 1982). Jet has a reflectance of around 0.2%; the reflectance of vitrinite in coal rises with increasing rank from about 0.4% in lignite to over 2.5% in anthracites, and reaches 15% in graphite. Dr. Jones confirmed the anthracite determination by his microscopic examination, which showed only inertinite fragments in a structureless matrix. This structureless matrix is all that remains of the liptinite and vitrinite macerals. The result of anthracite was given to the client. A.I.C/S.J.K.

Irradiation and topaz

The irradiation of gemstones has come under scrutiny within Europe due to Council Directive 96/29/Euratom of 13 May 1996 (396L0029), which under article 6.5 states;

'Member states shall permit neither the deliberate addition of radioactive substances in the production of foodstuffs, toys, personal ornaments and cosmetics nor the import or export of such goods.'

The directive is due to be adopted into national legislation of member states by 13 May 2000. France is in the process of implementing a rather draconian interpretation of the law by forbidding the import and marketing of known irradiated gemstones. In the U.K. the Department of Trade and Industry (DTI) have commissioned a report from the independent National Radiological Protection Board (NRPB). The NRPB has submitted a report to the DTI after liaising with the trade and carrying out some sample testing of gems within the trade, using a geiger counter. A response from the DTI is expected in the next few months.

There have been two occasions when we have used the services of NRPB in relation to irradiated topaz for the identification of radionuclides by gamma ray spectroscopy (Ashbaugh III, 1992). The issue with the first topaz was that the owner wanted to ensure that the stone was safe to wear when mounted in a ring. It is a fair assumption that all commercially available blue topaz is the result of the irradiation and annealment of colourless topaz (Nassau, 1994). On testing the 23.31 ct stone NRPB detected the presence of two radionuclides, tantalum 182 (^{182}Ta) and manganese 54 (^{54}Mn), which were reported as being known to be the result of artificial irradiation. This provided us with the evidence to state categorically that the stone was treated topaz, and that the colour had been artificially produced by heat and/or irradiation. The activity levels of the two radionuclides were low enough for the NRPB to assure our member's customer that these levels did not represent a radiological hazard to anyone wearing the gemstone. It is important that these assurances come from such authorised professionals.

On the second occasion three stones, weighing 4.38 ct, 14.66 ct and 21.63 ct, were sent to NRPB as samples from 135,000 ct of blue topaz, which were presented in parcels

Figure 3: *An emerald-cut steely blue topaz in the lower left of the picture was found to be radioactive, registering 20 counts per second on a geiger counter. On its right is a green beryl and the three large stones above are topaz.*

of identical colour, all in a suitcase! In this case no evidence of artificial irradiation was found by NRPB, but it was pointed out to the customer that the activity levels of the radionuclides will diminish below the detection level of the analytical equipment if the period since irradiation is long enough. In view of this the concluding sentence of our report stated that, in our experience, the fact that as the topaz were presented in perfectly matched colours it was still fair to assume, for commercial purposes, that they had been artificially irradiated.

I learnt some months later that this concluding sentence had been deleted on a copy of the report. Any reader of an abbreviated report would be left in some doubt as to the colour origin of the stones. It is important to stress that wherever possible original reports should be consulted - beware of photocopies!

Topaz was also involved when we had a visit from some Russians, who were seeking verbal assessments of the stones in their possession. In addition to three large topaz and a green beryl, they had an emerald-cut steely blue topaz (*Figure 3*). The colour prompted us to check the stone on a geiger counter – it produced some 20 counts per second. Without the time to analyse it further, we suggested that they adhere to the regulations for transporting radioactive substances and obtain a detailed report on the activity before selling the stone.

A.I.C./S.J.K.

Trading standards and terminology

In the U.K. there are no trading standard laws relating specifically to the use of gem materials. The jewellery trade is governed by the Trade Descriptions Act of 1968 which, in conjunction with the International Jewellery Confederation's (CIBJO) Gemstone Book guidelines, has provided the means to prosecute false trade descriptions through the courts when it is ajudged to be necessary.

Contacts with our local government trading standards authorities have provided us with invaluable feedback from the jewellery trade across the country. In the last few years I have accompanied trading standards officers on gem surveys of their local jewellery outlets – mainly retail shops but also antique and collectors' markets.

There is nothing particularly unusual in the mistakes that are encountered, which reflect the varying standards that occur the

world over with regard to gem descriptions. Some of the situations encountered have been:

- A low quality ruby cabochon described as an 'unusual faux ruby'. The retailer was unsure of the stone's origin so he decided to play safe by using the French word for false, which is very commonly used to replace 'imitation'. His caution was admirable.
- A peridot described on a label as 'zercon' because the retailer did not know how to spell peridot! He had not checked zircon either!
- An artificial glass sphere sold as a quartz crystal ball. The 'new age' retailer who sold it argued with the trading standards officer that since the sphere was made with silica his description should be allowed. He was firmly informed of the essential difference between a natural mineral and a man made product.
- Aquamarine has been synthesised by the hydrothermal method, but the description of 'synthetic aquamarine' is often misapplied to aquamarine simulants such as artificial glass, synthetic spinel and treated blue topaz.
- A chrome diopside was described as a 'Russian emerald'. The trader concerned received a conditional discharge from a magistrate's court but had to meet the costs.
- A lot of stained green quartzite is being sold as jade. Recently a trader received substantial fines for each of three items being misdescribed in this way. S.J.K.

Synthetic emeralds and reports

Three green stones, weighing 9.70 ct, 10.28 ct, and 13.01 ct, were quickly ascertained to be hydrothermal synthetic emeralds. The stones were accompanied with reports claiming that they were natural (*Figure 4*), and it was the address of the Gemmological European Institute, given as Sinkansas Street, Swanscombe, U.K., which intrigued us. There is a Swanscombe in the county of Kent, but Sinkansas Street does not exist there or anywhere else in the UK according to the UK Royal Mail.

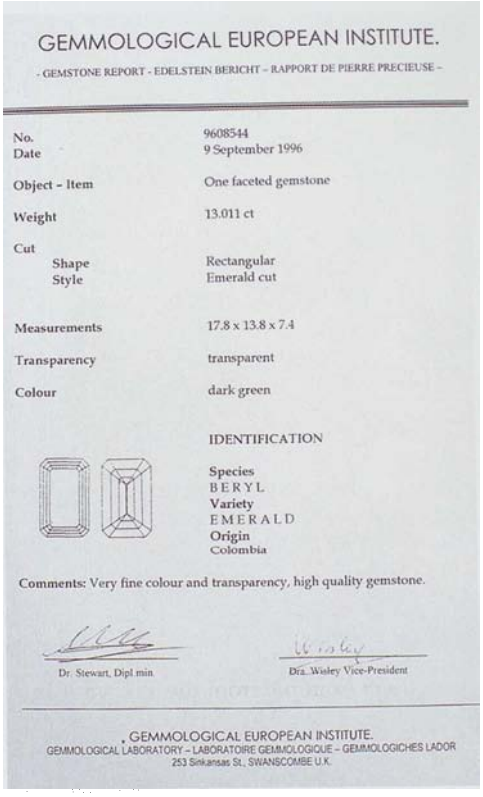

GEMMOLOGICAL EUROPEAN INSTITUTE.

- GEMSTONE REPORT - EDELSTEIN BERICHT – RAPPORT DE PIERRE PRECIEUSE –

No.	9608544
Date	9 September 1996
Object - Item	One faceted gemstone
Weight	13.011 ct
Cut	
Shape	Rectangular
Style	Emerald cut
Measurements	17.8 x 13.8 x 7.4
Transparency	transparent
Colour	dark green

IDENTIFICATION

Species
BERYL
Variety
EMERALD
Origin
Colombia

Comments: Very fine colour and transparency, high quality gemstone.

Dr. Stewart, Dipl min

Dra. Wisley Vice-President

GEMMOLOGICAL EUROPEAN INSTITUTE.
GEMMOLOGICAL LABORATORY – LABORATOIRE GEMMOLOGIQUE – GEMMOLOGICHES LADOR
253 Sinkansas St., SWANSCOMBE U.K.

Figure 4: *A photocopy of a report, which represents a synthetic hydrothermal emerald weighing 13.01 ct as being natural. The address of the Laboratory could not be found.*

Therefore in this case the origin of the stones was easy enough to determine, but that of the laboratory must remain a mystery.

A.I.C./S.J.K.

Phenakite

Most phenakite is grey or colourless but occasionally it is found in rather beautiful pastel shades. Two coloured phenakites were recently sent to the GAGTL by J. Houran of Springfield, Illinois, USA, and he supplied the following comments:

'Phenakite (Be_2SiO_4) is from the Greek word meaning 'deceiver', in allusion to the

mineral's similarity to quartz. Though considered a rare mineral, faceted gems are common among collectors of unusual stones and can be quite large.' 'The ample hardness (7.5 – 8) and imperfect cleavage make phenakite suitable for wear, but the typical lack of colour, vitreous lustre, and low dispersion (0.015) limit its appeal as a commercial gem. Still, the species may be seen in designer jewellery, as the use of rare and unusual gemstones is becoming increasingly popular with artists and the general public.'

'Subtle shades of pink and yellow are occasionally noted in phenakite. The 2.14 ct gem pictured in *Figure 5* is from Mt. Antero, Colorado, and was faceted by John Rhoads (D. & J. Rare Gems, Salida, Colorado). The stone has a yellowish cast that reportedly was much more saturated but faded after cutting, a phenomenon also observed in rose quartz and kunzite. Also pictured in *Figure 5* is a 7.18 ct example from the Takavara Mine in the Ural Mountains of Russia, showing a deep peach colour. The gem was cut by Mark Kaufman (Kaufman Enterprises, San Diego, California). The colour and intensity appear stable and are rare for the species. Kaufman reports that he has seen only forty to fifty comparable gems, and that the deep colour is found only near the centre of the crystal. Consequently, a large crystal is needed to yield stones of any size. This gem was cut from a crystal weighing approximately 120 ct and shaped like a ball about 37.5 mm in diameter.' R.R.H.

Figure 5: *On the left a 7.18 ct peach-yellow phenakite from the Ural Mountains, Russia; on the right a 2.14 ct light pink phenakite from Mt. Antero, Colorado.*

African exploration

From time to time, gem prospectors or gem merchants bring minerals to us for identification because some exceptional feature or quality has excited their interest. In regions of the world that are still relatively unexplored, this is of particular interest to us because there are realistic chances of discovering something new. In this context two highly coloured materials were recently submitted for examination from Tanzania by J.M. Saul.

The first is a rich purple pebble 8 mm across, which was suspected of being, and later proved to be, a zoisite, variety tanzanite. This is not the first occurrence of tanzanite from Tunduru, but confirmation of its identity will stimulate the search for more.

The second specimen is a rich yellow-green, like that of some sphenes, but it was identified as a mineral of the scheelite-powellite ($CaWO_4$ - $CaMoO_4$) solid solution series. Both minerals were confirmed by X-ray diffraction methods at the Natural History Museum by John G. Francis. As far as we know the scheelite-powellite has not been cut, but its hardness of about 5 and its intense colour make it a candidate for cutting as a collectors' stone. R.R.H.

Acknowledgements

We would like to thank Dr Johann Ponahlo for his advice and for sharing his expertise with us; Dr John M. Jones for checking the information given on coal and jet petrology, as well as examining the jet for us; and Cally Oldershaw, John Francis, John Spratt and Gary Jones at The Natural History Museum for their expert help with the various specimens.

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The mineralogical composition of *maw-sit-sit* from Myanmar

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ABSTRACT: *Maw-sit-sit* has been present on the world market for a few decades and its mineralogical composition and genesis are still not well known. The mineralogical composition of a sample of *maw-sit-sit* consists of albite, chromian-eckermannite, kosmochlor, chromite and natrolite in decreasing order of abundance, and its gemmology, microstructure, and mineral chemistry are discussed.

Keywords: *maw-sit-sit*, mineralogy, mineral chemistry, X-ray diffraction

Introduction

Maw-sit-sit is the name of a village close to Tawmaw (Myanmar) and is the source of a distinctive green rock first reported by Gübelin (1965). The gem quality material is generally described as green with black and white spots and streaks and is inhomogeneous. The mineralogical composition is not, however, well defined, and different authors have reported a range of constituents. Gübelin (1965) described the *Maw-sit-sit* as a rock mainly composed of albite and Cr-jadeite; Manson (1979) identified natrolite and kosmochlor (then known as ureyite), as the main constituents. More recently, Hänni and Meyer (1997) found chromite, kosmochlor, Cr-amphibole as the main, well developed minerals; and zeolites, chlorite, albite and serpentine in minor quantities, commonly

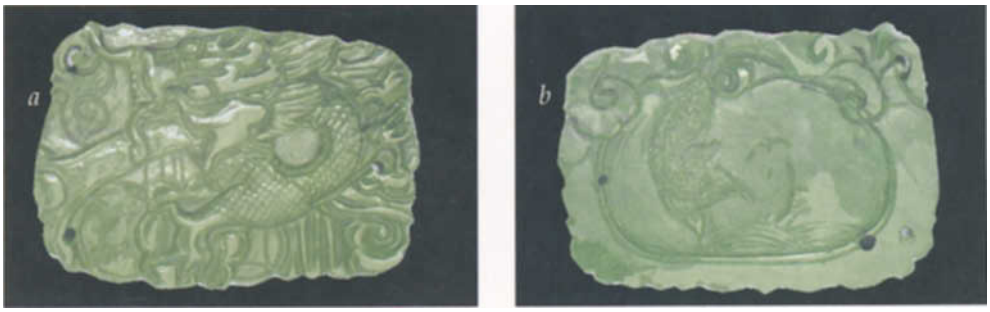

Figure 1: *(a) Front view of sample of Maw-sit-sit; length 45 mm. (b) Rear view of the same sample.*

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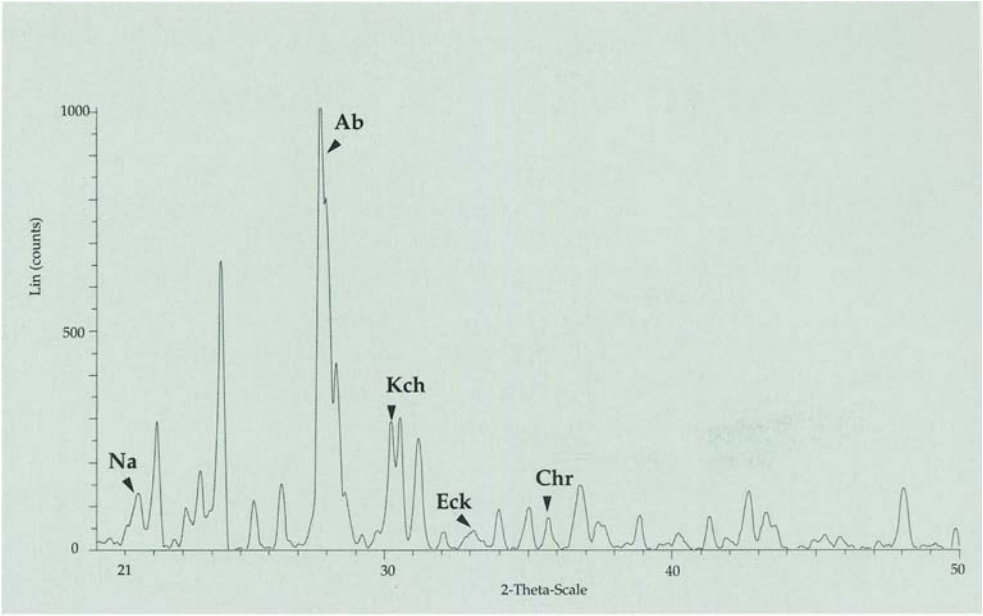

Figure 2: *X-ray powder spectrum obtained directly from the surface of the sample. Ab, albite; Kch, kosmochlor; Chr, chromite; Eck, chromian-eckermannite; Na, natrolite. The peaks of albite are the most intense, indicating prevalence of this phase in the sample.*

intergrown on a fine scale (symplectitic texture). In this paper we describe a mineralogical study performed on a sample from Myanmar, and weighing 62.5 g, measuring 45 × 33 × 4.5 mm, and represented in *Figures 1a* and *1b*.

Gemmology

The specific gravity determined by hydrostatic balance is 2.7. The average refractive index by distant vision is 1.54. The rock is inert under the Chelsea colour filter, and spectroscope examination reveals strong absorption from the red to yellow, and strong absorption from 470 nm, increasing to total absorption at the violet end of the spectrum.

X-ray analysis

X-ray determinations were carried out directly on the surface of the sample. A Siemens D5000 diffractometer equipped with *Göbel Mirrors* was used with Cu Kα radiation. The mirrors are a new device and consist of a graded mutilayered crystal bent to a parabolic shape. Its function is to transform the primary divergent X-ray beam into a single, intense, brilliant, parallel and collimated beam regardless of the distance from the source. The parallel beam allows qualitative analysis to be carried out directly on the irregular surface of a sample without any need to take a powder sample (Chiari *et al.*, 1996; Chiari *et al.*, 1998). The X-ray results are shown in *Figure 2* and may be summarised as follows:

- The sample consists mostly of albite $NaAlSi_3O_8$, which gave the most intense diffraction peaks in the spectrum (the formulae reported in the text describe the simplified chemical formulae for the analysed mineralogical phases);
- *Kosmochlor* (formerly known as ureyite) $NaCrSi_2O_6$ is the second most abundant mineral;
- The other components are: *chromite* $FeCr_2O_4$, *natrolite* $Na_2Al_2Si_3O_{10}{\cdot}2H_2O$,

and *chromian-eckermannite* $(Na,Ca)_3(Mg,Fe,Al,Cr)_5Si_8O_{22}(OH,F)_2$.

Spectra were recorded from several different parts of the sample, but no significant differences in mineral content or abundance were detected.

Optical microscopy and mineral chemistry

Under the optical microscope the sample appears inhomogeneous as shown in *Figure 3*, and relicts of chromite, often surrounded by kosmochlor *Figure 4* are contained in a fine-grained matrix mainly consisting of albite, chromian-eckermannite and natrolite closely intergrown in a symplectitic texture. Chemical analyses of the areas showing different optical contrasts were carried out using a Cambridge SEM-EDS microprobe. Operating conditions were 15 kV acceleration voltage, beam current 50 nA and 50 s counting time. Natural and synthetic minerals were used as standards. A ZAF correction procedure was performed on-line. Back scattered electron images showing the different brightness responses of the different minerals and their textural relations are shown in *Figures 5* and *6*, and representative chemical analysis of the detected minerals are presented in *Table I*.

Albite (Ab)

Albite is the major constituent of the sample and can be observed either in extended areas (Ab in *Figure 5*) or as symplectitic aggregates intergrown with eckermannite and/or kosmochlor (Ab+Eck+Kch in *Figure 5*). As demonstrated by *Table I*, albite is nearly pure with a small content of Cr, substituting for Al, up to 1.1 wt% in parts.

Kosmochlor (Kch)

All the analyses performed on the pyroxene relicts display a high amount of Cr (up to 31.52 wt%), substituting for Al, and can be classified as kosmochlor. In all the analysed grains, the amount of Cr decreases towards the rim of the kosmochlor crystals (*Figure 6*) or away from the chromite relicts (see *Figure 4* and Chr in *Figure 5*). The content of other pyroxene end-members is negligible.

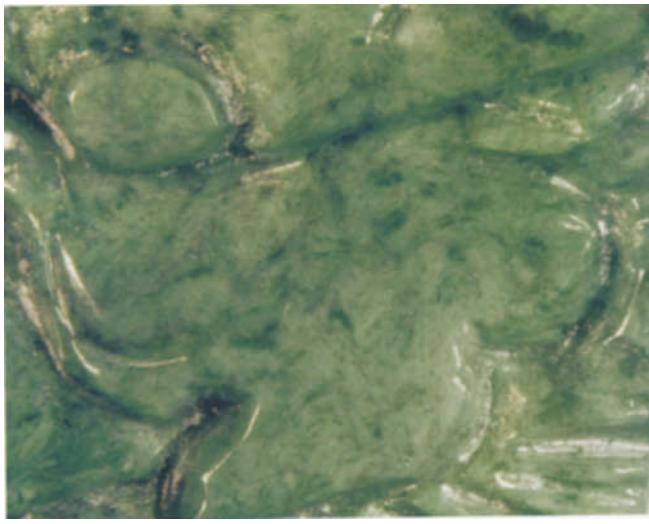

Figure 3: *Detail of the front of the sample showing its mottled appearance (the mineral association in the middle of the picture is 1 mm long).*

Chromian-eckermannite (Eck)

The analysed amphiboles show a high content of Cr (up to 6.62 wt%) replacing

Figure 4: *Detail of the back of the sample showing, as confirmed by EDS analyses, a relict grain of chromite (dark/metallic) surrounded by a deep green kosmochlor rim and an albite-rich matrix (the mineral association Chr+Kch is 1 mm long).*

Table I: *Representative microprobe analyses of* maw-sit-sit *minerals: albite (Ab), kosmochlor (Kch), chromite (Chr), and chromian-eckermannite (Eck).*

Sample	*Ab 20*	*Ab 26*	*Kch 13*	*Kch 3*	*Chr 1*	*Chr 17*	*Eck 30*	*Eck 31*
SiO_2	67.25	68.45	57.02	53.22	0.41	0.44	57.57	58.02
TiO_2	–	–	–	–	0.06	–	0.07	–
Cr_2O_3	1.11	–	5.42	31.52	56.55	56.33	6.41	6.62
Al_2O_3	18.65	19.25	19.86	1.61	5.72	6.00	3.06	1.58
Fe_2O_3	–	–	–	–	9.07	8.85	–	–
FeO	–	–	1.29	–	20.59	20.86	3.52	3.67
MnO	–	–	–	–	2.24	2.84	0.17	-
MgO	–	–	–	-	1.82	2.32	16.48	16.89
NiO	–	–	–	–	–	–	–	0.37
CaO	–	–	–	–	–	–	0.41	0.11
Na_2O	11.94	12.05	15.03	14.09	–	–	11.02	11.38
K_2O	–	–	–	–	–	0.05	0.19	0.23
H_2O	–	–	–	–	–	–	2.17	2.14
Total	98.95	99.75	98.62	100.44	96.46	97.69	101.07	101.01
Si	2.9829	2.9987	1.9981	1.9917	0.0147	0.0156	7.9662	8.0534
Ti	–	–	–	–	0.0016	–	0.0073	–
Cr	0.0389	–	0.1502	0.9326	1.5988	1.5774	0.7013	0.7265
Al	0.9749	0.9939	0.8202	0.0710	0.2411	0.2505	0.4990	0.2585
Fe^{3+}		–	–	–	0.2440	0.2360	–	–
Fe^{2+}	–	–	0.0378	–	0.6158	0.6180	0.4073	0.4260
Mn	–	–	–	–	0.0678	0.0852	0.0199	–
Mg	–	–	–	–	0.0970	0.1225	3.3990	3.4943
Ni	–	–	–	–	–	–	–	0.0413
Ca	–	–	–	–	0.0027	–	0.0608	0.0164
Na	1.0268	1.0234	1.0211	1.0223	0.1165	0.0927	2.9565	3.0626
K	–	–	–	–	–	0.0023	0.0335	0.0407

Structural formulae are calculated on the basis of: 5 cations and 8 oxygens for albite, 4 cations and 6 oxygens for kosmochlor, 3 cations and 4 oxygens for chromite, 23 oxygens and 13 cations + K + Na + Ca for chromian-eckermannite.

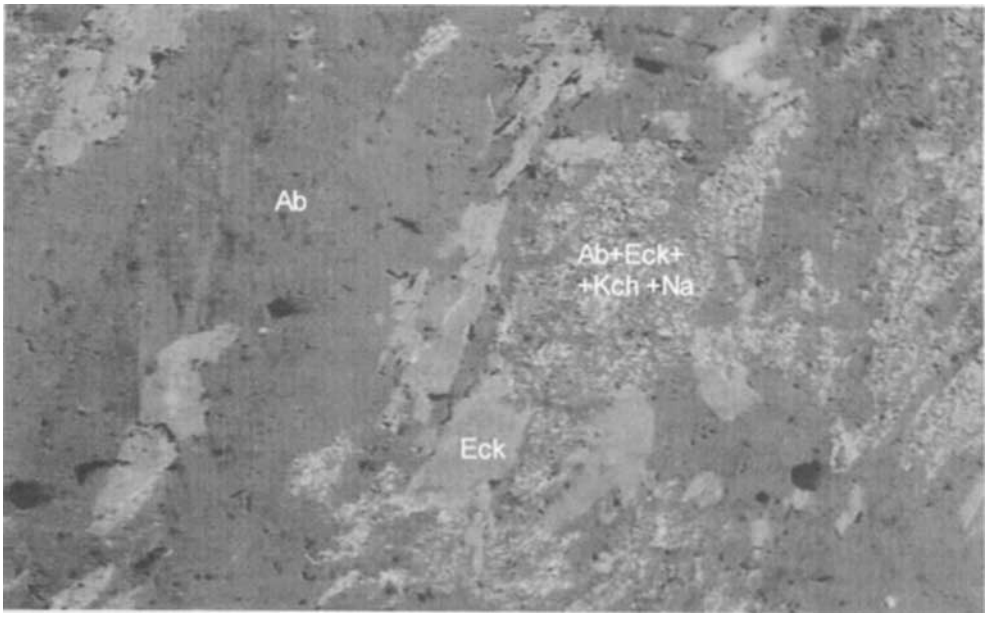

Figure 5: *Electron photomicrograph showing large regions made up of albite (Ab), finer grains of chromian-eckermannite and symplectitic association of albite + chromian-eckermannite + kosmochlor + natrolite (Na).*

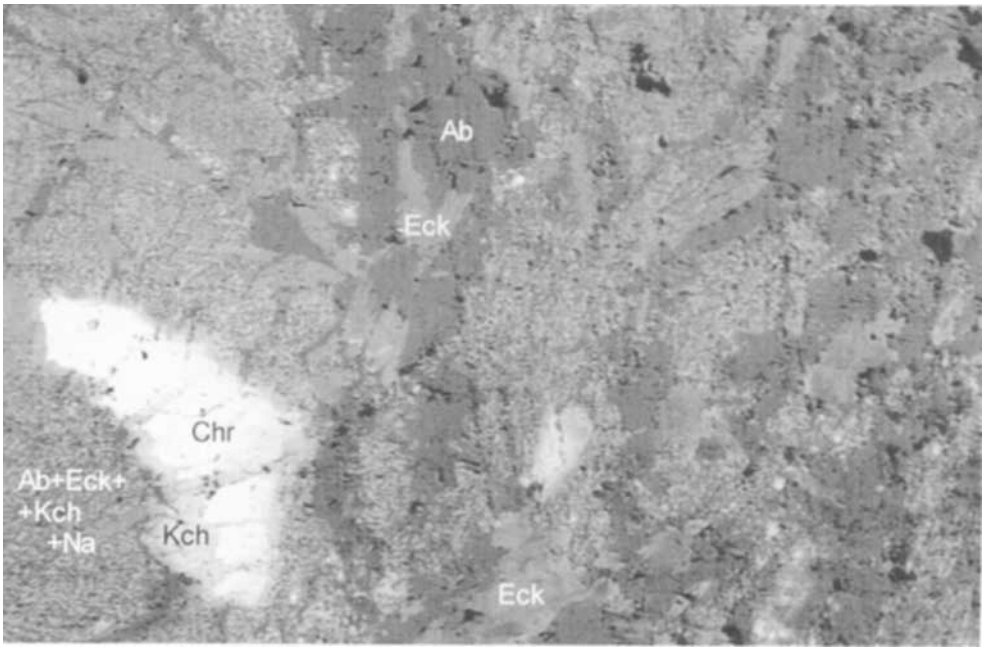

Figure 6: *Back scattered electron photomicrograph showing a relict grain of chromite (Chr, c. 1 mm long) rimmed by kosmochlor (Kch), large crystals of chromian-eckermannite and symplectitic intergrowths of albite + chromian-eckermannite + kosmochlor + natrolite.*

Al and are classified as chromian-eckermannite (after Leake *et al.*, 1997). They are coarse grained crystals or intergrown with albite and kosmochlor as symplectites (see *Figures* 5 and 6).

Chromite (Chr)

The black minerals visible under the optical microscope (*Figure* 4) have spinel compositions, showing a prevalence of chromite (62-66%) over Mg-chromite (10-12%), see *Figure* 6. Minor contributions of other end-members of the spinel group have been identified in all the analysed relicts.

Discussion

The sample of maw-sit-sit shows a brilliant green colour as a whole, but with higher magnification veinlets, spots or streaks of different colours (mainly white and sometimes black) can be observed. X-ray analysis performed directly on the surface confirmed the presence of different mineralogical phases and these were confirmed by EDS analysis, except for natrolite which is too fine-grained. Chromium was detected in all minerals except for natrolite and the relatively high amounts account for the green colour of the rock. On the basis of microstructural relationships between the different rock forming minerals seen by optical microscope and electron microscope, we suggest that the different mineralogical associations reported by various authors are due to the fact that maw-sit-sit is a rock resulting from metamorphism of a heterogeneous parent rock mass. This is consistent with the heterogeneity of jadeite-rich, albite-rich, and amphibole-bearing rocks exposed in the field and described by Gübelin (1965) and Soe-Win (1968). Also the metamorphic processes can generate different mineral assemblages in neighbouring rock volumes, so different rocks can be generated from the same overall deposit.

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Classification of emeralds by artificial neural networks

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ABSTRACT: Artificial neural networks (ANN) are structures which are built up from elements that behave like biological neurons. They are used for prediction purposes and for the classification of data into categories. ANN data processing has been applied to the geological origin determination of emeralds. Microprobe data for the elements Si, Al, Mg, Na, Fe, Cr, V, Mn, Ca, K, and Ti of more than 450 emeralds originating from different geological environments have been considered. The sample material has been classified into five categories. Details about the occurrences hosting the different types of emeralds are given by Schwarz and Giuliani (2000).

Emeralds belonging to Category 1 originate from deposits related to granitic pegmatite intrusions and hydrothermal veins in mafic-ultramafic rocks (e.g. Ndola Rural District/Zambia, Sandawana-Machingwe mining area/Zimbabwe, Carnaíba-Socotó and Belmont mine-Capoeirana/Brazil, Ural Mountains/Russia). Emeralds of Category 2 originate from deposits related to tectonism (thrusts, shear-zones, faults) in mafic-ultramafic rocks (Santa Terezinha and Itaberaí, Goiás State/Brazil). Category 3 comprises emeralds from the Swat Valley in Pakistan (talc-carbonate-mica schists) and the Panjsher Valley in Afghanistan (quartz-ankerite-pyrite veins). These deposits are related to oceanic suture zones. The Colombian emeralds representing Category 4 are related to thrusts and faults in sedimentary 'black shale' rocks. Category 5 comprises the emerald mineralisations of the Kaduna-Plateau States in central Nigeria. These are of the so-called 'granite cupola-type'.

ANN data processing makes it possible to separate quickly and reliably Colombian emeralds (Category 4) from non-Colombian emeralds (bad scores 2.6%). A supervised classification into Categories 1, 2, 3 and 5 gave very good results: bad scores 1% and 0% respectively for Categories 1 and 5; for Category 2 acceptable results (bad scores 7%); but for Category 3 scores are rather poor (bad scores 12.5%). The lower 'classification quality' for Category 3 becomes understandable when considering the fact that emeralds from the Swat Valley are found in a (Fe+Mg)-rich environment (talc-carbonate-mica schists), whereas their Afghani counterparts originate from quartz-ankerite-pyrite veins.

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Introduction

The origin of a gemstone is an important parameter for its characterisation. Origin determination of gemstones is based, in principal, on the interpretation of data sets obtained through the examination of mineralogical properties. The most important factors used for this procedure are:

(a) internal characteristics (solid inclusions, fluid inclusions, growth structures, etc.);

(b) chemical data (element concentrations and concentration ranges, correlation diagrams, trace element profiles, isotope ratios);

(c) physical data (specific gravity, refractive indices, double refraction);

(d) spectrometric data (UV-vis-NIR spectra; NIR/MIR spectra; Raman).

All these properties depend directly or indirectly on the specific geological and geochemical conditions of the genetic environment during the formation of a gemstone.

Gemstones of one variety are complex solids with similar properties. Of necessity, the analysis of their properties has to be multivariate. To detect the relationship between the totality of the samples and the variables related to them, in an efficient manner, it is necessary to process large quantities of data simultaneously, and not one or two at a time. Modern statistical analytical methods may be used to make a valuable contribution to the origin determination of gemstones. In this paper, the use of artificial neural networks has been applied, for the first time to the best of our knowledge, to the origin determination of emeralds.

Artificial Neural Networks

Artificial Neural Networks (ANN) provide a powerful tool for data processing. In contrast to traditional statistics, the main goal of ANN is not to analyse and to understand series of data, but to use them for prediction and classification purposes. As the name implies, ANN are artificial structures, which are built up from elements that behave like biological neurons, and which are able to successfully emulate the low level mechanisms of the brain.

Historical aspects

A biological neuron is basically composed of a nucleus which has two types of extensions: the dendrites and the axon. The many dendrites receive signals from other neurons or from any kind of sensors. These signals are processed in the cell body and transmitted to other neurons or organs by the axon which branches into several collaterals. The axon or collateral ends in synapses. The signals, essentially electrical in nature, are transmitted from synapses to dendrites by means of a chemical substance called a neurotransmitter. The synapses also modulate the signal flowing through them. The amount of change is called the synaptic strength. The first artificial neuron was produced by the neurophysiologist Warren McCulloch and the logician Walter Pits, but computer technology at that time was too limited to allow much progress. Following an initial period of enthusiasm, the field had to survive a period of disrepute and re-emerged during the late 1970s and early 1980s, boosted by computer developments. Significant progress has been made since then, and ANN are now applied in many different fields, such as industrial process control, data validation, sales forecasting, marketing and interpretation of biomedical data. Today, research is rapidly advancing the field on many fronts, and applications to increasingly complex problems are emerging.

Emeralds: geological environments and mineralogical characteristics

The classification of emeralds performed in this study, by using ANN, is based on microprobe data of more than 450 emeralds collected during several research projects undertaken by one of the authors (Schwarz, 1990 a,b; 1991 a,b; 1992 a,b). These samples

ANN Modes

An artificial neuron is a device with many inputs and one output. The neuron has two modes of operation: the training mode and the using mode. In the training mode, the neuron is trained to fire or generate an output signal, according to a firing rule. The firing rule is an important concept in neural networks and accounts for their flexibility. It is the way to calculate the response of the neuron for any input pattern. In the using mode, the input pattern is presented and the firing rule is used to determine the amplitude of the response.

In an artificial neuron (*Figure 1*), the individual input signals s_i, weighted by a coefficient corresponding to the synaptic strength in the biological world, w_i, are added.

$$\Sigma = w_1 \cdot s_1 + w_2 \cdot s_2 + \Sigma$$

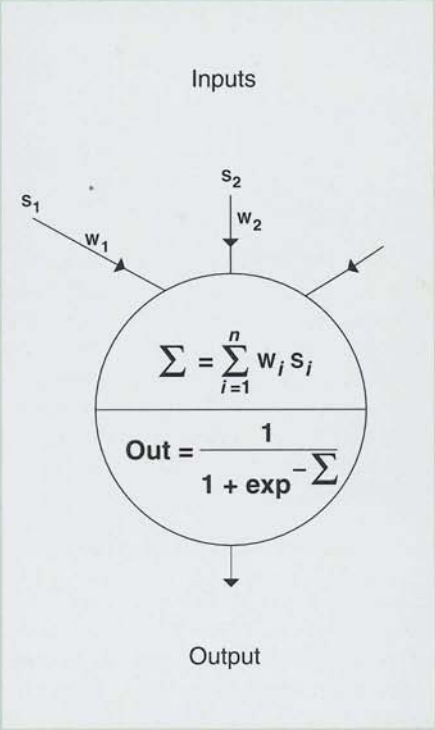

Figure 1: *Artificial neurons (see text for explanations)*

The output signal is obtained by processing Σ with a transfer function. For linear units, the output activity is proportional to the total weighted output. For threshold units, the output is set at one out of two levels, depending on whether S is higher or lower than some threshold value. For sigmoid units, the transfer function is the so-called S or sigmoid function.

$$S = 1 / [1 + \exp - (\alpha \Sigma + \delta)]$$

Sigmoid units bear a greater resemblance to biological neurons than do linear and threshold units, but all three must be considered as rough approximations. Of most importance is the fact that the non-linear relationship between input and output signals, represented by the sigmoid transfer function, also represents a non-linear relationship between properties. This is a task which can only be carried out with great difficulties by other methods. Moreover, α and δ are two parameters that can be used to influence the function of a neuron.

Artificial neurons are assembled in networks. Many kinds of networking strategies have been investigated, the most common being the layered model (*Figure 2*). In a layered model, the neurons are divided into groups or layers. The neurons of the same layer are not interconnected, but are only linked to the neurons in the layer above and below. The first layer is a layer of input units, not considered as neurons as they do not perform any arithmetic operations. They represent the raw information or data to be fed into the network. The input layer is connected to one or more hidden layers of neurons. The activity of each hidden unit is determined by the signal received from the input units, the weight of the connections between input and the hidden units, and the characteristics of the transfer function. The efficiency of the network as a whole is given by the output

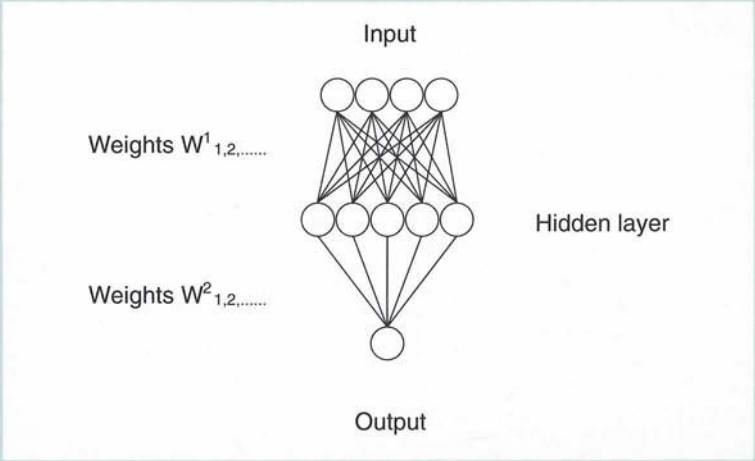

Figure 2: Layered network strategy model (see text for explanations)

layer. The activity of the output unit depends on the activity of the units in the last hidden layer, and also on the weighting coefficients between the units of the hidden layer and those of the output layer.

ANN also contain some form of 'learning rules' which modify the weights of the connection according to the input patterns they are presented with. Initial values of the weights are random values between -0.1 and +0.1. The unsupervised training or learning is based only upon local information. The network self-organizes the input data and detects their collective properties. In the supervised learning, input data are presented and the output is compared with the desired output. The error is used to modify the weight of the connections in order to bring the output close to the desired value. This process is usually performed by using an algorithm known as backpropagation of errors. Because of the non-linearities of the network, convergence is slow and the learning phase is usually a time-consuming process. The training set may have to be presented several tens or even hundreds of thousands of times.

When the network has been trained, it can be tested on data which are not included in the training set. ANN are often used for classification of data into categories; they are especially useful when the link between data and categories is not clear, and when many factors (properties) should be taken into account simultaneously.

originate from a wide range of geological environments in which gem-quality emeralds have grown. The relationship between the different genetic environments, and mineralogical characteristics of the emeralds originating from them, are discussed in detail by Schwarz *et al.* (in prep). A comprehensive review of emerald deposits is given by Schwarz and Giuliani (2000). Two basic types of emerald deposits can be distinguished: type I is related to granitic intrusions, and type II to tectonic events.

The mineralogical properties of an emerald will always reflect the specific conditions of the geological environment in

which it has grown. Characteristics like chemical composition (especially the presence of minor and trace elements, the basis of 'chemical fingerprinting'; cf Schwarz and Stern, 2000), spectrometric data, optical values, and internal features, depend directly or indirectly, on the physical and chemical conditions predominant during emerald formation. Factors like the nature of the host rock, as well as composition, pressure and temperature of the solutions involved in the emerald crystallization, will control the appearance of the above-mentioned characteristics.

The emerald sample material used for this study has been classified into five categories 1 to 5. The specific characteristics of the deposits hosting these emeralds are discussed by Schwarz and Giuliani (2000) and can be typified as follows:

Category 1

This category comprises deposits related to granitic pegmatite intrusions and hydrothermal veins in mafic-ultramafic rocks (e.g. Miku-Kafubu in the Ndola Rural District of Northern Zambia; Mweza Range in Zimbabwe; Mananjary region in Madagascar; Ural Mountains/Russia; Itabira-Nova Era region in Minas Gerais/Brazil; Carnaíba-Socotó mining field in Bahia/Brazil).

The emerald mineralizations are located in the immediate vicinity or within the exocontact zones of pegmatite-bearing granitic intrusions. Emerald is generally found in black phlogopite schists, e.g. containing black Mg-rich biotite + greyish talc ± phlogopite ± quartz/albite/muscovite/fluorite veins. Emerald formation is the result of the reaction of fluids which circulate in pre-existing rocks (e.g pegmatite- or granite-related fluids in mafic-ultramafic rocks, like serpentinite, amphibolite, etc.). Micas of the biotite/phlogopite series are the dominant mineral inclusions in most emeralds of Category 1. Tremolite/actinolite inclusions can be present in amounts comparable to mica, or they can even become the most frequent mineral inclusions. Other

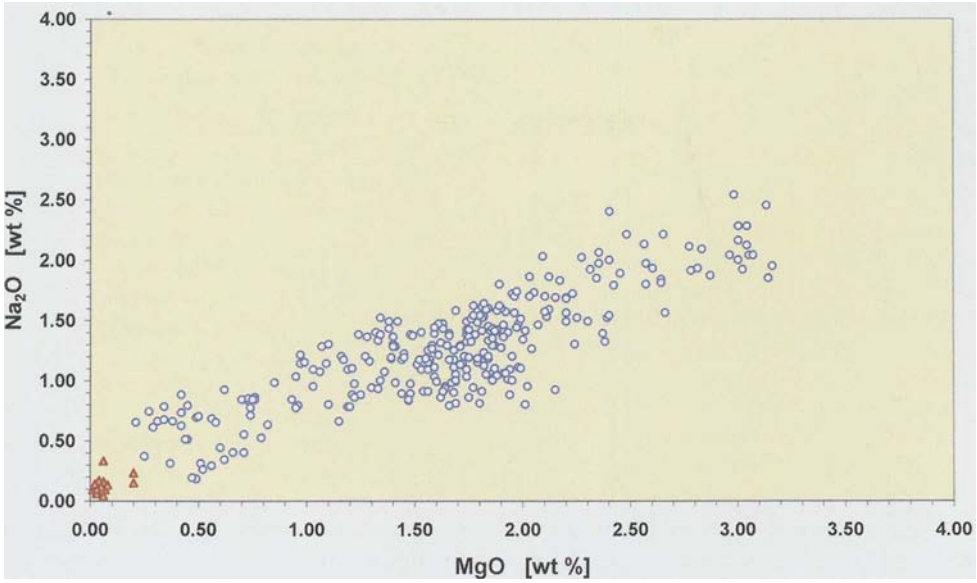

Figure 3: *Na_2O-MgO correlation diagram for Categories 1 ○, e.g. most African and Brazilian deposits, and 5 ▲, Nigeria (see text for explanations).*

minerals which may be present are muscovite (margarite), chlorite, talc, spinels, feldspars, quartz, tourmaline, sulphides, carbonates, rutile and apatite. Two types of fissures occur frequently in emeralds of this category: healed fissures with a large variety of cavity fillings (mostly two-phase inclusions of the liquid-gas 'lg'-type), and unhealed fissures. Emeralds belonging to Category 1 exhibit the widest range of optical data (refractive indices and birefringence). The highest values (n_o = 1.60, n_o - n_e = 0.008 - 0.010) have been measured in African emeralds from Zambia and Zimbabwe. The e- and o-absorption spectra of Category 1 emeralds are Cr-spectra with a dominant Fe absorption band in the 700-900 nm range. Chromium is the dominant chromophore element of Category 1 emeralds. Vanadium is of no importance as a chromophore in emeralds of this category. A typical feature of this category is the large variation in iron, magnesium, and sodium contents (compare *Figure 3*).

Category 2

Emerald occurrences of Category 2 are related to tectonism (thrusts, shear-zones, and faults) in mafic to ultramafic rocks. The host rocks of the emerald mineralisations belong to volcano-sedimentary series.

- *Santa Terezinha de Goiás (Campos Verdes Mine), Goiás, Brazil*

  The infiltration of hydrothermal fluids is controlled by tectonic structures such as thrusts and shear zones. Pegmatite veins are absent and the mineralization is stratiform. Emeralds are disseminated in phlogopites and phlogopitized carbonate-talc schists (Gusmão Costa, 1986; Biondi, 1990; Giuliani *et al.*, 1990 a). Talc-schists provide the main sites for thrusting and the formation of sheath folds. Emerald-rich zones are commonly found in the core of sheath folds and along the foliation.

- *Itaberaí, Goiás, Brazil*

  Emeralds are mainly found in metasomatic zones, together with biotite/phlogopite, and in talc-bearing schists. Less important as emerald host rocks are chlorite-talc schists, quartz veins, or altered feldspar veins (Barros *et al.*, 1990).

The most common inclusion minerals in emeralds from Category 2 are biotite/phlogopite, talc, tremolite/actinolite, titanite, pyrite, pyrrhotite, chalcopyrite, pentlandite, quartz, rutile, calcite, dolomite and apatite (Schwarz, 1990 a).

Emeralds from the Santa Terezinha mining area have high RIs with n_o up to 1.60 and n_o-n_e up to 0.010. The data for emeralds from the Itaberaí-deposit are slightly lower: n_o up to 1.59 and n_o-n_e = 0.008 - 0.009.

A quite unusual absorption spectrum is shown by the emeralds originating from the Santa Terezinha deposit: it is a combination of a Cr-Fe absorption spectrum with an intense band in the 780-820 nm range (e-spectrum). Emeralds from Category 2 originate from occurrences where the mineralisations are stratabound and not related to veins. They are distinguished by high contents of magnesium and sodium, with only small variation (compare *Figure 4*).

Category 3

Emerald occurrences of Category 3 are also related to tectonic events. They are encountered in oceanic suture zones.

- *Swat, Mingora, Gujarkili and Barang, Pakistan*

  The ophiolitic melange which contains the emerald mineralizations, is composed mainly of altered ultramafic rocks. Emerald occurs within hydrothermally altered serpentinites, which show some or all of the following metasomatic zones (Dilles *et al.*, 1994): an outer zone composed of talc + magnesite ± chlorite ± micas; an intermediate zone consisting of talc + magnesite with dolomite veins; an inner zone with dolomite + magnesite + talc schists and quartz ± dolomite ± tourmaline ± fuchsite veins. Emerald is disseminated throughout the inner and intermediate zones in or next to veins.

  Sulphide minerals (pyrite, pyrrhotite, molybdenite, pentlandite and

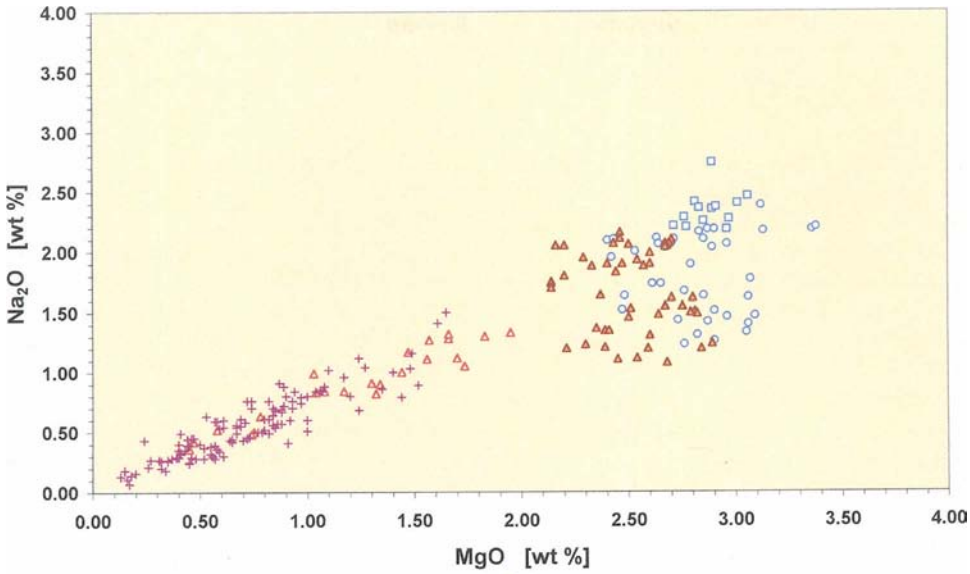

Figure 4: *Na_2-MgO correlation diagram for Categories:*
Category 2 Santa Terezinha/GO ○ and Itaberaì/GO □
Category 3 Mingora/Swat, Pakistan ▲ and Panjsher Valley, Afghanistan △
Cateogry 4 Cordillera Oriental, Colombia + (see text for explanations).

gersdorffite) are quite common in emeralds from the Swat region in Pakistan. The primary cavities show rectangular to jagged outlines or they have elongated tube-like forms. Emeralds from the Swat region are characterized by high values for the optical data (n_o up to 1.60 and n_o - n_e up to 0.010). Their absorption spectra are characterized by the combination of Cr-V-Fe-bands. Magnesium and sodium contents of the Pakistani emeralds from the Swat-region are always high, the variation range of these elements is small (*Figure 4*).

- *Panjsher Valley, Afghanistan*

Emeralds occur along shear zones which cut Palaeozoic metasedimentary rocks (limestones and slates) in veins containing quartz, ankerite and pyrite. Hydrothermal alteration is evident by strong silicification, albitization, carbonatization, and phlogopitization of the host rocks. Typical mineral inclusions are different carbonates (especially dolomite, less frequent are calcite and magnesite). Afghani emeralds from the Panjsher Valley may show elongated cavities with a multi-phase filling (i.e. several s-phases). The Panjsher-emeralds show optical data, which fall into the medium-range (n_o around 1.585 and n_o-n_e = 0.007). Their absorption spectra can be practically free of Fe-bands, or they may show a weak Fe^{2+} and/or Fe^{3+} absorption. The Panjsher emeralds show a large concentration range for magnesium and sodium (*Figure 4*).

Category 4

Deposits hosting emeralds of Category 4 are related to thrusts and faults in sedimentary rocks with high contents of organic matter (the so-called 'black shales').

- *Cordillera Oriental, Colombia*

Emerald mineralisations are found in two areas of Early Cretaceous black-shale series: (a) Eastern emerald zone Gachala, Chivor, and Macanal; and (b) Western

emerald zone Coscuez, Muzo, and La Palma-Yacopi. There is a lack of any igneous activity in the genesis of these deposits (Giuliani *et al.*, 1990 b, 1992; Ottaway, 1991; Cheilletz *et al.*, 1994; Ottaway *et al.*, 1994; Cheilletz and Giuliani, 1996). The favoured genetic model involves the interaction, at about 300°C, of basinal fluids with evaporites and organic matter contained within black shales. Fluids in emeralds are derived from the dissolution of primary halite (Banks *et al.*, 1995), and the source of beryllium is local (Kozlowski *et al.*, 1998; Giuliani *et al.*, 1990 b; Ottaway *et al.*, 1994).

The most frequent inclusion minerals are carbonates (mostly calcite/dolomite), quartz, albite and pyrite, together with opaque black particles of carbonaceous shale from the host rock. An inclusion mineral with a locality-specific character is Ca (Ce, La) carbonate parisite.

The Colombian emeralds are well-known for their classic 'slg'-three-phase inclusions with a cubic s-phase (halite). Other phase-combinations, as well as fluid inclusions with organic substances, have been described also. Pronounced growth phenomena are common in Colombian emeralds: growth bands, colour- and inclusion-zoning, growth inhomogeneities with a treacle-like appearance. The Colombian emeralds from the Cordillera Oriental are characterized by low to medium constants for the optical data ($n_o < 1.585$, n_o-$n_e < 0.007$). Typical absorption features of Colombian emeralds are Cr-V spectra, which may show varying Cr/V-intensity ratios. The chemical fingerprints of the Colombian emeralds are characterised by practically equal concentration ranges for the colouring elements chromium and vanadium. Besides this, the Colombian emeralds show lower values for Fe, Mg and Na than those observed in most emeralds from mafic-ultramafic rocks (*Figure* 4).

Category 5

Category 5 comprises the emerald mineralizations of the Kaduna-Plateau states in central Nigeria. They are the so-called 'granite cupola-type'.

Emerald mineralizations are associated with granitic pegmatites of two periods of magmatism (Schwarz *et al.*, 1996): the Panafrican orogeny (600-450 Ma) and the Mesozoic orogeny (190-144 Ma) with the intrusion of alkaline granites belonging to ring complexes which contain important Sn-Nb-Ta-Zn mineralizations (Kinnaird, 1984). In the older pegmatites, emerald is associated with aquamarine, beryl and tourmaline. In the younger granites, emerald is found with quartz, blue topaz and beryl (aquamarine) in pegmatitic pods with biotite and alkaline-feldspar granites. The pods are found in the roof zone of the intrusions and in the margins of the granite cupolas. They are not affected by metasomatism, and emerald formed during late magmatic and early hydrothermal stages. Emeralds from the Kaduna-Plateau states show a rather 'exotic' inclusion mineral association: Fe-Li-rich mica (probably annite-siderophyllite) + albite + K-feldspar + tourmaline + beryl/emerald + quartz + ilmenite + monazite + fluorite + ralstonite + boldyrevite (Schwarz *et al.*, 1996). Fluid inclusions are frequent and present a large variation of phase-combinations (including 'slg'-three-phase inclusions, which show an appearance that is practically identical to that known from the 'classic' Colombian fluid inclusions). Most emeralds from central Nigeria display distinct growth phenomena (growth-bands and -planes; colour-zoning). The Nigerian emeralds distinguish themselves by the lowest optical data observed in emeralds: $n_o < 1.576$, n_o-n_e normally 0.005-0.006. The absorption spectra of the Nigerian emeralds are considered a 'mixed type' consisting of the combination of Cr-Fe emerald spectra with Fe^{2+}-Fe^{3+} aquamarine spectra.

The most striking chemical features of the Nigerian emeralds are extremely low sodium and magnesium contents (compare *Figure* 3).

Materials and methods

The first attempt to classify emeralds according to their geological environments, using ANN is exclusively based on chemical data (contents of minor and trace elements;

Schwarz, 1990; 1991 a,b; 1992 a,b). In the future, it is certainly of interest to include additional data obtained by microscopic and spectrometric techniques. Factors like specific gravity, isotope ratios, nature and aspect of inclusions, or even subjective impressions of the observer (colour, beauty, etc.) could be taken into consideration. A larger volume of data will improve the accuracy of the prediction. Emerald, as a variety of the beryl group, has the general chemical formula $Be_3Al_2Si_6O_{18}$. The oxide concentrations that correspond to this 'ideal' composition are SiO_2 67.07 wt%, Al_2O_3 18.97 wt%, and BeO 13.96 wt%. It has been known for a long time, however, that only in rare cases natural beryls come close to this standard composition. In general, they show

Table I: *Emerald samples used for ANN processing.*

Continent	*Country*	*Category*	*Code*	*Mine/Area*	*No. of samples*
Africa:	Zambia	1	SAM	(1) Miku-Kafubu	21
	Mozambique	1	MOC	(2) Alto Ligonha	12
	South Africa	1	COB	(3) Cobra Mine	14
	Nigeria	5	NIG	(4) Kaduna/Plateau	13
	Madagascar	1	MAD	(5) Mananjary	16
Asia:	Russia	1	URA	(6) Urals	25
	Afghanistan	3	AFG	(7) Panjsher	31
	Pakistan	3	PAK	(8) Mingora-Swat	41
South America:	Brazil	2	STA	(9) Santa Terezinha	29
		1	CAR	(10) Carnaiba	30
		1	SOC	(11) Socotó	39
		1	ITA	(12) Itabira (Belmont)	39
		1	CAP	(13) Itabira (Capoeirana)	16
		2	IAI	(14) Itaberaí	13
	Colombia	4	YAC	(15) Yacopi	11
		4	CHI	(16) Chivor	17
		4	GAC	(17) Gachalá	8
		4	MUZ	(18) Muzo	20
		4	COS	(19) Coscuez	7
		4	'COL'	(20) 'Cordillera Oriental'	56

Table II

Type	*Training*	*Validation*	*Total*
Non-Colombian NC	2/230 (0.9%)	5/109 (4.6%)	7/339 (2.1%)
Colombian (Category 4)	2/79 (2.5%)	3/40 (7.5%)	5/119 (4.2%)
Total	4/309 (1.3%)	8/149 (5.4%)	12/458 (2.6%)

distinct deviations (a well-known behaviour observed in many minerals). These discrepancies go back to the fact that major components may be substituted by extraneous elements of similar ionic radius (that do not appear in the chemical formula). In the case of emerald, these 'extraneous' elements are mainly magnesium, sodium and, of course, the colouring agents chromium, vanadium and iron. Therefore, the discussion of the chemical characteristics of the beryl variety emerald can be restricted, initially, to these five elements. But in view of geochemical/genetic considerations, it is certainly of interest to include trace elements such as Mn, Ca, K, Ti and Sc.

The microprobe analyses were carried out using an ARL-SEMQ instrument, with wavelength dispersive (WD) spectrometers and an energy dispersive system (EDS, TN2000). The beam diameter was 2 microns, accelerating voltage was 15 kV and specimen current 30 mA. Standards used for the analyses comprised synthetic oxides and some simple silicate minerals. Lighter elements, such as Be or Li, cannot be analysed with the microprobe and were not taken into consideration. Chemical compositions are expressed as wt% of the oxides of Si, Al, Mg, Na, Fe, Cr, V, Mn, Ca, K and Ti. For this study we examined 458 natural emeralds from very different origins chosen to represent the most important commercial sources. Country of origin, mining areas and the number of samples analysed for each mine, as well as reference/category numbers and codes for the mines, are given in *Table I*. Several mines/areas in the original data bank, containing less than 10 samples (e.g. Sandawana/Zimbabwe) were discarded, as training a system with less than 10 samples from the same mining area is considered as non-valid.

Results

In a first exploratory step, an ANN composed of 11 data inputs (corresponding to the chemical components expressed as oxide percent), 20 neurons in the hidden layer and 20 neurons in the output layer (the 20 different mines/areas reported in *Table I*) was used in the unsupervised mode. Approximately two-thirds of the data of each mine/area were used for training the network, and one third for validation of the training. It becomes immediately evident that most Colombian samples (Category 4) were correctly classified in their category and very few non-Colombian samples (NC) were classified in the Colombian category. This suggests that Colombian emeralds would be quickly and successfully separated from non-Colombian emeralds, and the full set of data was presented to ANN of the type 11-20-2 in the supervised mode in order to check the possibility of separation between Colombian and non-Colombian emeralds. The value of the neurons of the output layer makes the decision 'Colombian or non-Colombian origin'. Again, about two-thirds of the samples (332) were used for training and about one third (160) were used for the validation of the network. Several trials were

Table III

Category	*Mine/Area*	*Training*	*Validation*	*Total*
1	1, 2, 3, 5, 6, 10, 11, 12, 13	1/144 (1%)	1/68 (1%)	2/212 (1%)
2	9, 14	1/30 (3%)	2/12 (17%)	3/42 (7%)
3	7, 8	7/47 (15%)	2/25 (8%)	9/72 (12.5%)
5	4	0/9 (0%)	0/4 (0%)	0/13 (0%)
Total:		9/230 (4%)	5/109 (5%)	12/468 (3%)

used in order to find the best training systems. Up to 30.000 epochs (or iterations) were used to train the system. Results are given in *Table II* in terms of bad scores (= misclassifications). Only four out of the 309 samples were not correctly classified in the training step, and eight out of 149 samples were not correctly classified in the validation process. These results show that, after training, the network can be used with a reasonably good degree of confidence to separate Colombian and non-Colombian emeralds.

In a further step, those non-Colombian mines/areas containing at least ten samples were used as input of another ANN, in order to attempt a supervised classification into four categories, based on the first ANN study and on geological-mineralogical criteria. These categories 1, 2, 3, 5 are defined in *Table III*. The ANN used in this step was of the type 11-10-4, where the four neurons in the output layer represent the four categories. Up to 30.000 epochs were used in training the system on a total of 230 samples. Validation was tested on the remaining 109 samples. *Table III* presents the results expressed, as usual, in terms of bad scores.

Discussion

Classification for samples belonging to Categories 1 and 5 in *Table III* is very good with bad scores 1% and 0% respectively. As mentioned above, Category 1 contains emerald deposits which are related to granitic pegmatite intrusions and hyrothermal veins in mafic-ultramafic rocks. The geological environment is very similar for most of these deposits (e.g. the nature of the emerald host-rocks or the nature of the emerald-forming fluids). Consequently, emeralds originating from these deposits show properties which, in most cases, are very similar to each other. It is difficult, and in many cases not possible, to separate emeralds coming from some of these occurrences (e.g. emeralds from Madagascar and Zambia). On the other hand, however, ANN has shown that the separation of Category 1 emeralds from representatives of the other categories is very good.

Category 5 emeralds originate from a unique geological environment in the Nigerian Kaduna-Plateau states ('granite cupola-type'). This results in the appearance of a locality-specific combination of mineralogical properties which distinguishes them from emeralds of all other deposits (see also Schwarz *et al.*, 1996.)

The ANN classification for samples of Category 2 is acceptable (bad scores 7%). Category 2 emeralds considered in the ANN-procedure of this study originate from the Santa Terezinha mining field and from the Itaberaí deposit, both located in the Brazilian Goias state. They are related to tectonism: thrusts, shear-zones, faults in mafic-ultramafic rocks. Santa Terezinha and Itaberaí emeralds show combined high sodium and magnesium concentrations. The Na-contents in Itaberaí emeralds are among the highest observed in emeralds from any source.

In contrast to the former categories, the allocation for samples belonging to Category 3 is rather poor (bad scores 12.5%). Considering, however, the geological background of the representatives in this category, this behaviour becomes perfectly understandable. The members of Category 3 (Swat Valley in Pakistan and Panjsher Valley in Afghanistan) are both found in oceanic suture zones. However, their mineralogical properties (especially their chemical compositions) show some significant differences. The Pakistani emeralds from the Swat region always have high values for magnesium and sodium, the variation range for these elements is only small. On the other hand, the Panjsher emeralds show large concentration ranges for magnesium and sodium. The different chemical features for emeralds from these two deposits becomes quite evident in the correlation diagram shown in *Figure 4*. Emeralds from the Swat Valley are found in a (Fe+Mg)-rich environment (talc-carbonate-mica schists). They show distinctly higher foreign element contents and higher optical data than their Afghani counterparts, which originate from

quartz-ankerite-pyrite veins. As can be expected, all this results in a 'classification quality' for the Category 3 which is distinctly lower than that found for the categories 1, 2 and 5.

Conclusions

Artificial neuron networks (ANN) using only chemical data appear to be a rather effective tool for determining the origin of emeralds. It is well-known that the geological environment of a mineral will be reflected by its chemical characteristics, especially by the minor and trace element contents. Many classification studies based on bi- or tri-dimensional correlations have been reported in the literature. The main advantage of the ANN technique is that the entire element signature is taken in a single operation. Another major advantage of the ANN technique is, in contrast to other previously reported techniques, the non-linear behaviour of the method. A major disadvantage is that ANN are 'black boxes', as there is currently no simple way of interpreting the set of weights in the trained systems. This indicates that ANN could be very dangerous. At the present stage of development, ANN should never be used exclusively, but should be used in conjunction with traditional methods. Use of ANN should be considered as a useful supplement to standard gemmological techniques.

The accuracy of ANN could be greatly improved by taking into account more of the same and of different kinds of data, collected by other techniques, such as: refractive indices/birefringence, spectrometric data, inclusion types, and isotope ratios. Research in these directions will continue on other series including larger numbers of samples and more data per sample. Other methods, known as 'data mining' will also be used to reveal any relationships between sets of samples.

Acknowledgements

We would like to thank Mr George Bosshart of Gübelin Gem Lab for reviewing the paper and for constructive discussion.

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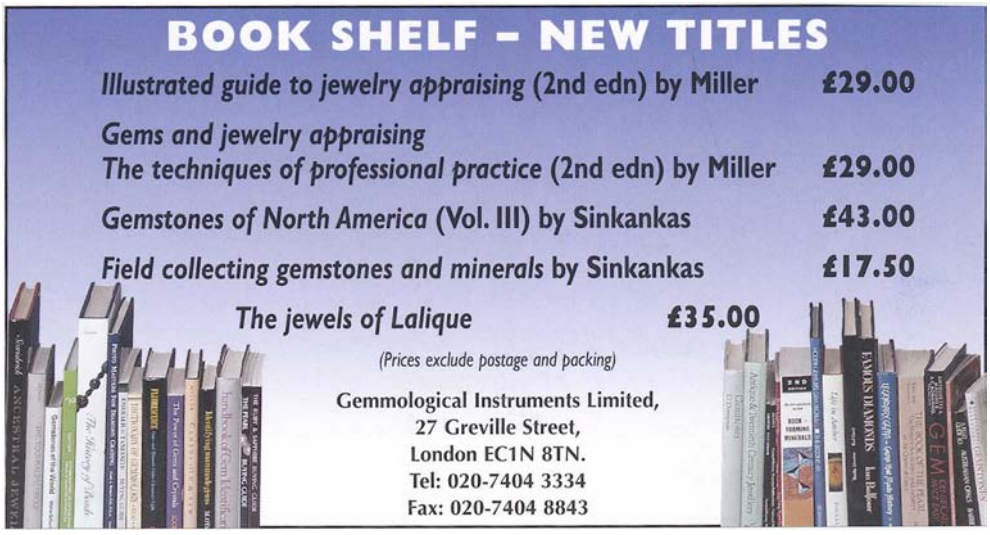

Abstracts

Diamonds | Instruments and Techniques | Gems and Minerals | Synthetics and Simulants

Diamonds

Gemmologie Aktuell.

H. BANK, U. HENN AND C.C. MILISENDA. *Gemmologie – Z. Dt. Gemmol. Ges.*, **48**(4), 1999, 185-90.

A 3.07 ct so-called chameleon diamond was submitted for investigation. The stone temporarily became yellow when heated, but returned to its original colour when removed from the heat (an alcohol flame) and exposed to light. Strong orange-yellow fluorescence and phosphorescence.

A 2.41 ct green irradiated diamond was examined and showed a radioactivity approximately twenty times above environmental radiation levels. Stones like these are unsafe to be worn. The radioactivity can be removed by repolishing or acid treatment. E.S.

Magnetic properties of polycrystalline diamonds.

D.W. COLLINSON. *Earth and Planetary Science Letters*, **161**(1-4), 1998, 179-88.

The remanent magnetism and bulk magnetic properties of two types of polycrystalline diamonds, those occurring with gem-grade diamonds in kimberlite pipes in S Africa, and carbonados in placer deposits in Brazil and the Central African Republic, were investigated. Both types possess measurable remanent magnetization, that of kimberlite diamonds being greater than that of carbonados, and stability tests show the presence of primary and secondary components. Magnetite is the dominant carrier of NRM in the kimberlite diamonds, but very small magnetic mineral content in the carbonados makes carrier identification difficult, possible contributors being tetrataenite, native Fe and cohenite. Anomalous acquisition of isothermal remanence occurs in some carbonados, saturation being unachievable in applied fields > 1 T. The ratio of saturation remanence to initial NRM is anomalously low in some of the kimberlite diamonds, and the possibility of magnetic contamination is investigated. J.F.

Diamonds from Wellington, NSW: insights into the origin of eastern Australian diamonds.

R.M. DAVIS, S.Y. O'REILLY AND W.L. GRIFFIN. *Mineralogical Magazine*, **63**(4), 1999, pp 447-71.

Diamonds (~0.17 ct) from alluvial deposits near Wellington, New South Wales, have been characterized on the basis of their morphology, mineral inclusions, $d^{13}C$ values, N content and aggregation state, and internal structure. The diamonds are of two types. The larger group (group A) is indistinguishable from diamonds found worldwide from kimberlitic and lamproitic host rocks. This group is inferred to have formed in a peridotitic mantle source in Precambrian subcratonic lithosphere. The second group (group B) has unique internal structures which show evidence of growth in a stress field, non-planar facets, unusually heavy $\delta^{13}C$ values, and contains Ca-rich eclogitic inclusions. This group is inferred to have formed in a subducting slab. Diamonds of both groups have external features (corrosion structures and polish) indicating transport to the surface by lamproitic-like magmas. The diamonds show evidence of long residence at the Earth's surface and significant reworking, they are not accompanied by typical diamond indicator minerals. R.A.H.

Microstructural observations of polycrystalline diamond: a contribution to the carbonado conundrum.

S. DE, P.J. HEANEY, R.B. HARGRAVES, E.P. VICENZI AND P.T. TAYLOR. *Earth and Planetary Science Letters*, **164**(3-4), 1998, 421-33.

A microstructural analysis of systematic defects and inclusions in carbonados from Brazil and the Central African Republic (CAR) is reported. TEM shows pervasive defect lamellae, in both CAR and Brazilian carbonados, that are distinct from planar defects observed in synthetic polycrystalline diamond (PCD). EDS analyses of included minerals imply the presence of metallic Fe, Ti and Si, and SiC and Fe-Cr alloys within the diamond matrix: inclusions of the phosphates florencite-goyazite and rhabdophane are also recorded. Results show a close

Abstractors

J. Flinders	J.F.	M. O'Donoghue	M.O'D.	I. Sunagawa	I.S.
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R.A. Howie	R.A.H.	E. Stern	E.S.		

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genetic relationship between Brazilian and Central African carbonados, suggesting formation within a united landmass during the late Archaean, although the data do not preclude formation by meteorite impact. J.F.

Evidence of fluid inclusions in metamorphic microdiamonds from the Kokchetav massif, northern Kazakhstan.

K. De Corte, P. Cartigny, V.S. Shatsky, N.V. Sobolev and M. Javoy. *Geochimica et Cosmochimica Acta.* **62**(23-4), 1998, 3765-73.

Three fundamentally different models for the formation of micro-diamonds discovered *in situ* in ultra-high pressure metamorphic rocks (UHPM) are briefly discussed, and assessed by further Fourier transform IR spectroscopy which provides information on all the volatile and substutional impurities, particularly N_2. All diamonds have high N_2 contents (4488 ± 20% at. ppm) and are of Ib-Ia A type; the N_2 data are consistent with diamond formation over a narrow *T* range. The presence of H_2O and carbonate inclusions in the diamonds from garnet clinopyroxenites suggests formation from a C-O-H-bearing fluid. The micro-diamonds are compared to alluvial diamonds from the northern part of the Kokchetav massif; these do not contain carbonate inclusions, show less or no H_2O absorption and have higher N_2 contents than the diamonds from the clinopyroxenites and probably derive from a different host rock. The new study supports a metamorphic origin for the micro UHPM rocks of this massif. R.K.H.

Types, abundances and distribution of kimberlite indicator minerals in alluvial sediments, Wawa-Kinniwabi Lake area, northeastern Ontario: implications for the presence of diamond-bearing kimberlite.

T.F. Morris, D. Crabtree, R.P. Sage and S.A. Averill. *Journal of Geochemical Exploration,* **63**(3), 1998, 217-35.

In response to the discovery of diamonds within modern alluvium in the glaciated area of Wawa, the Ontario Geological Survey carried out a regional programme of surficial mapping and alluvial sediment sampling to assess the potential of the area for diamond-bearing kimberlite. Five kimberlite-derived indicator minerals were recovered, and the compositions of three were evaluated resulting in identification of G10 Cr-pyrope garnet, inclusion field chromite and Mg-ilmenite. The distribution of indicator minerals was examined in relation to the glacial and bedrock geology. Glacial dispersal for non-kimberlitic marker units is restricted (commonly <200 m), and many kimberlite indicator minerals were recovered from samples collected close to cross-cutting faults, and from a strong trend in the bedrock associated with the Kapuskasing structural zone. The results of this survey have provided several potential exploration targets for diamond-bearing kimberlite. J.F.

Compositional study of spinels from Wajrakarur pipe-10 (Anumpalle), Anathapur district and its significance in diamond prospectivity.

A. Mukherjee, K.S. Rao, E.V.S.S.K. Babu and G. Roy. *Journal of the Geological Society of India,* **52**(6), 1998, 677-82.

Spinels from the recently-discovered Wajrakarur pipe-10, Southern India, were analysed, and Q-cluster analysis based on Cr_2O_3, Al_2O_3, TiO_2 and MgO contents indicates the presence of S1, S3, S4, S5 and S10 groups. S1 group spinels are considered to be cogenetic with diamond; they are stable in the mantle within the *P-T* regime under which diamonds are known to form experimentally. A plot of Cr/(Cr + Al) *vs* Fe/(Fe + Mg) shows that some spinels are from the field of diamond inclusion chromites. This study suggests that the Anumpalle pipe is probably diamondiferous. J.F.

A petrographic and $^{40}Ar/^{39}Ar$ geochronological study of the Voorspoed kimberlite, South Africa: implications for the origin of group II kimberlite magmatism.

D. Phillips, K.J. Machin, G.B. Kiviets, L.F. Fourie, M.A. Roberts and E.M.W. Skinner. *South African Journal of Geology,* **101**(4), 1998, 299-306.

The Voorspoed kimberlite pipe, one of a cluster of 11 kimberlite and related rock intrusives north of Kroonstad, comprises tuffisitic kimberlite breccia and is associated with several hypabyssal sills and dykes. Recent drilling has identified two types of tuffisitic kimberlite breccia and seven varieties of hypabyssal-facies kimberlite. The Voorspoed kimberlite lies between the ~ 120 m.y. Barkly West and ~ 145 m.y. Swartruggens kimberlites. An accurate determination of intrusion age is crucial to evaluation of the group II age progression across southern Africa and models of the origin of group II magmatism. $^{40}Ar/^{39}Ar$ laser probe analyses on six individual groundmass phlogopite grains from an hypabyssal kimberlite autolith all yielded reproducible plateau ages with a mean of 131.8 ± 1.7 m.y. Intra- and inter-grain reproducibility of the data indicates that this age is a reliable estimate for the time of pipe emplacement, and also agrees with recent data from the nearby Lace and Besterskraal kimberlites. These results confirm the regular NE age progression of group II kimberlites across the Kaapvaal craton. Previously models invoking hotspot tracks, subduction of ocean crust, and rafting of the subcontinent over an oceanic lithosphere megalith have been suggested to account for the distribution of group II kimberlites. An alternative model, involving extensional tectonics related to disaggregation of Gondwanaland, is considered here. J.F.

The significance of eclogite and Cr-poor megacryst garnets in diamond exploration.

D.J. Schulze. *Exploration & Mining Geology.* **6**(4), 1997, 349-66.

Whilst eclogite is an important source of diamond in the upper mantle, it is more localised than peridotite, and

using eclogitic minerals in kimberlite and diamond exploration is also more problematic than using the well-known peridotite-derived indicator minerals Cr-pyrope and magnesio-chromite. Problems occur with colour similarities of orange garnets from eclogites, Cr-poor megacryst suite garnets (especially increased Na_2O contents), and low abundance of eclogite garnet xenocrysts in most kimberlites. Varieties of orange garnets in exploration samples can be distinguished by their FeO contents, crustal origin having > 22 wt.%, mantle origin having less. Na_2O-bearing garnets from the Cr-poor megacryst suite have higher TiO_2 contents than Na_2O-bearing garnets from diamondiferous eclogites. However, low abundance of eclogite garnet xenocrysts in kimberlites worldwide may dictate that use of eclogite garnets in diamond exploration is restricted to advanced stages of kimberlite exploration and evaluation of kimberlite diamond potential. Cr-pyropes, Mg-ilmenites and Cr-rich chromites are more useful than eclogitic garnets in most stages of diamond exploration. If orange garnet xenocrysts are sought in a kimberlite exploration programme, those from the Cr-poor megacryst suite will be more useful than eclogite-derived garnets because of their typically greater abundance, although they carry no information of the diamond potential of the host kimberlite. New EPMA results are tabulated for 393 Cr-poor garnet megacrysts. J.F.

Gems and Minerals

Gemmologie Aktuell.

H. Bank, U. Henn and C.C. Milisenda. *Gemmologie – Z. Dt. Gemmol. Ges.*, **48**(3), 1999, 121-7, 12 photographs.

Amongst specimens discussed are a high clarity, olive-green peridot from Eritrea; red tourmaline from Luc Yen, Vietnam, a locality well-known for its corundum deposits; treated stones include dyed rubies, very often to be found amongst cracked specimens which are then sealed with glass and dyed at the same time, some diffusion-treated sapphires where the colour is to be found near the surface; rock crystal clusters as well as faceted rock crystal stones are coloured with a thin layer, producing a rainbow effect. E.S.

Gemmologie Aktuell.

H. Bank, U. Henn and C.C. Milisenda. *Gemmologie – Z. Dt. Gemmol. Ges.*, **48**(4), 1999, 185-90.

Notes include star sapphires from Australia; also from Australia an opal with two-phase inclusions. From Sri Lanka some low radioactive green zircons. E.S.

The Zapot pegmatite, Mineral County.

E.E. Foord, A.E. Soregaroli and H.M. Gordon. *Mineralogical Record*, **30**, 1999, 277-92.

The Zapot pegmatite is located in the Gillis Range, north-east of Hawthorne, Nevada, USA. Narrow veins and dikes make up the bulk of pegmatites and some amazonite, smoky quartz and topaz of fashioning-size are described and illustrated together with other species found in the area. M. O'D.

Characterisation of emeralds from the Delbegetey deposit, Kazakhstan.

E.V. Gavrilenko and B. Calvo Pérez. *MDSTAN*, 1999, 1097-1100.

A study of the properties and composition of 12 samples of emeralds and green beryls from the Delbegetey deposit is reported and comparisons are made with emeralds from elsewhere in the world and with synthetic emeralds. The Delbegetey emeralds have a strong bluish green hue, with ε 1.558–1.562, ω 1.566–1.570; *D* 2.65 g/cm^3; *a* 9.218, *c* 9.201 Å, *V*677.1 Å^3. Averaged EPMA values for 11 emeralds are tabulated; Cr_2O_3 ranges 0.02–1.23 and V_2O_3 0.01–0.19 wt.%; Na, Mg and Fe are low. Primary fluid inclusions have unusual liquid: vapour ratios of 50:50 to 90:10. A.H.

Behandlung von Edelsteinen und ihrer Farbe.

T. Häger. *Aufschluss*, **50**, 349-52, 1999, illus. in colour.

Defines the essential nature of a gemstone with particular reference to colour, including artificial coloration. M.O'D.

Ruby from Tunduru-Songea, East Africa – some basic observations.

G. Hamid, S.M.B. Kelly and G. Brown. *Australian Gemmologist*, **20**(8), 1999, 326-30, 16 illus. in colour, 1 map.

The authors describe some preliminary observations, including gemmological properties and morphological features, made on representative specimens of ruby from the river gravels of the Tunduru-Songea area of Southern Tanzania. Most, but not all, of these 'hot' pink, purplish-red and red corundums marketed in Bangkok appear to have been heat treated to improve their colour and clarity. P.G.R.

Gemmologische Kurzinformationen.

U. Henn. *Gemmologie – Z. Dt. Gemmol. Ges.*, **48**(3), 1999, 165-8, 3 photographs, 1 diagram, bibl.

A Colombian trapiche emerald was identified as treated. The relatively broad dark area between the six emerald sectors surrounding the hexagonal emerald core consisted of a fine-grained substance with a resin as a stabilizer. E.S.

Saphire aus einem neuen Vorkommen im Südwesten von Madagaskar.

U. Henn, C.C. Milisenda and J. Henn. *Gemmologie – Z. Dt. Gemmol. Ges.*, **48**(4), 1999, 201-10, 1 map, 10 photographs, 2 graphs, bibl.

The new occurrences were discovered in 1998. The secondary deposits extend from the south of the Isalo National Park near Ranohira to the town of Sakaraha further west. The mines produce pink, blue, violet, yellow, orange, green, brownish and colourless corundum, spinel,

chrysoberyl (including cat's-eyes and alexandrite), aquamarine, tourmaline, zircon, topaz and garnet. Commercially the most important are the blue and pink sapphires, which are sold as rough to Sri Lankan and Thai dealers, and then thermally enhanced to improve colour and clarity. The gemmological properties of the fancy sapphires are similar to those found in the Umba Valley and Tunduru in Tanzania, whereas the blue sapphires are reminiscent of Sri Lankan sapphires. The properties and geological environment are so similar to the alluvial deposits of Sri Lanka and Tanzania that it suggests the idea that they were formed in a single land mass before the break up of Gondwana. E.S.

Die Edelsteinvorkommen Madagaskars.

U. Henn, C.C. Milisenda and E. Petsch. *Gemmologie – Z. Dt. Gemmol. Ges.*, **48**(4), 1999, 191-200, 2 maps, 4 photographs, 2 tables, bibl.

The article describes the large variety of gemstones found in Madagascar and their occurrences, especially beryls (particularly emeralds and aquamarines), tourmalines, quartzes, garnets, feldspars and recently also sapphires. The sapphires are mainly blue or a very fine pink. E.S.

Prevalence and origin of birefringence in 48 garnets from the pyrope-amandine-grossularite-spessartine quaternary.

A.M. Hofmeister, R.B. Schaal, K.R. Campbell, S.L. Berry and T.J. Fagan. *American Mineralogist*, **83**(11–12 Part 1), 1998, 1293-1301.

Weak and undulatory birefringence is ubiquitous throughout a large suite of pyralspites (i.e. garnet solid solutions within the Py-Al-Sp ternary) and quaternary garnets. Birefringence (δ) correlates poorly with the diameter of the garnet crystals, but positively, albeit weakly, with Ca^{2+} coexisting with Mg^{2+}. Overall the undulatory nature of the birefringence suggests that most optical anomalies in quaternary garnets originate through residual strain. P.M.W.

A personal critique of 'Modeling the appearance of the round brilliant cut diamond: An analysis of brilliance', Gems & Gemology, vol. 34, Fall 1998, pp 158-83.

G. Holloway. *Australian Gemmologist*, **20**(8), 1999, 331-5, 338-9, 3 illus.

The computer analysis study of the brilliant cut diamond by T.S. Hemphill *et al.*, which appeared in the Fall 1998 issue of *Gems & Gemology* focused on brilliance as the main factor of diamond appearance. However, the GIA authors concluded that the study should be extended to encompass 'fire' and scintillation (and probably symmetry deviations and colour) as 'any cut grading assessment devised in the absence of this broader picture is premature'.

The critique presents a possible solution, discovered by the author a decade ago, which he believes is supported by data provided in the GIA study. This solution includes a 2:1 relationship between the ideal crown and pavilion angles, in contrast to the GIA 2.5:1 relationship, and a suggestion that assumptions concerning 'leakage' and lighting could be challenged. The critique has been presented to the authors of the GIA paper, and is aimed at provoking collaboration for establishing a standard for cut. Readers are invited to participate in an open website discussion at **diamond-cut.com.au.** P.G.R.

Die Entstehung der Farben in Achaten.

G. Lenz. *Aufschluss*, **50**, 343-8, 1999, illus. in colour.

Discusses the formation and coloration of agate with reference to the mechanisms by which colour arises. M.O'D.

Schatzkammer Alpen: Alpine Edelsteine (1).

W. Lergier and S. Weiss. *Lapis*, **24**(12), 13-20, 1999, illus. in colour, 2 maps.

Locations and types of deposit are given for versuvianite, cordierite and ruby from the European Alps. Most specimens are translucent to opaque. Details and illustrations of gem-set jewellery are given. M.O'D.

Brothers corundum: sapphires in Sri Lanka.

M.M.M. Mahroof. *Australian Gemmologist*, **20**(8), 1999, 321-5.

A history of gemstone mining, cutting and trading in Sri Lanka with particular reference to the sapphire variety of corundum and the treatment of geuda material. P.G.R.

Les septarias de la région d'Orpierre, Hautes-Alpes (F), décadence de leurs minéraux.

R. Martin. *Schweizer Strahler*, **11**, 1999, 509-25. In French and German, illus. in colour.

Fine examples of quartz septarian nodules are reported and described from the Orpierre region of Hautes-Alpes, France. Details of their formation and of the morphology of some individually-occurring crystals are given. M.O'D.

Spessartine aus Nigeria.

C.C. Milisenda and J. Zang. *Gemmologie – Z. Dt. Gemmol. Ges.*, **48**(4), 1999, 223-6, 4 photographs, diagram, table, bibl.

The spessartine garnets are reported to come from an area near Iseyin, north-west of Ibadan in Western Nigeria and resemble the Mandarin garnets from Namibia. Most specimens were rounded crystal fragments, but occasionally there were well-developed crystals up to a diameter of 2 cm. RI 1.801 to 1.803; SG 4.18–4.23. E.S.

The visible absorption spectroscopy of emeralds from different deposits.

I.I. Moroz, M.L. Roth and V.B. Deich. *Australian Gemmologist*, **20**(8), 1999, 315-20, illus, 3 graphs, 1 table.

Rough and faceted emeralds from eleven gem mining areas were studied in the visible absorption region using Perkin Elmer Lambda 15 and Bausch & Lomb Spectronic 2000 spectrophotometers. Emeralds included in the study came from deposits in Afghanistan, Australia, Brazil, Colombia, Nigeria, Mozambique, Russia, Tanzania and Zambia. The absorption spectra of many of the emeralds exhibited a 'mixed type' absorption pattern that was related to an emerald component (Cr^{3+} and/or V^{3+}) and an aquamarine component (Fe^{2+} and Fe^{2+}/Fe^{3+}). However, the relative intensities of chromium and iron bands differed for emeralds from different deposits. When emeralds from the same mining region were examined their optical spectra were found to be identical. As a result of this research it has been possible to classify the emeralds studied into three groups based on the relative intensity or absence of the 810 nm band, and to show that visible absorption spectroscopy is a valuable tool for characterizing emerald and for allowing emeralds from differing sources to be identified. P.G.R.

Business and industry review: gemstones.

M. O'Donoghue. *Britannica book of the year 1999*, **168**, 1999.

A decline in world gemstone trading was due largely to the downturn in Far Eastern economies with resulting lowered consumer spending. By 1998 the downward trend, though not yet reversed, was flattening out: more than one kind of confused situation in Russia seemed likely to affect the German gemstone trade. Strict controls were imposed on gem mining in Tanzania where the Tunduru deposit had been producing fine blue and fancy-coloured sapphires as well as pink and orange spinel and some alexandrite, colour-change garnet and mint-green chrysoberyl. Fine blue tourmaline coloured by copper was found in the Brazilian state Rio Grande do Norte and Madagascar was beginning to re-assert its importance as a source of fine blue sapphire. Synthetic moissanite was a diamond simulant perhaps likely to cause difficulties in the diamond trade. The major salerooms world-wide reported good results, the Hong Kong jadeite sales being especially successful. M.O'D.

Selvino e Zogno: quarzo e fluorite.

F. Pezzotta. *Rivista Mineralogica Italiana*, **23**, 1999, 146-56.

Describes large ornamental-quality crystals of quartz and fluorite found between the valleys of Seriana and Brembana, Bergamo Province, Italy. Fluorite may occur as interpenetrating green or purple twins while rock crystal in sceptre form is reported. M.O'D.

Tränen aus Glas.

C. Pinter. *Lapis*, **24**(12), 21-8, 1999, illus. in colour.

Types of natural glass, including tektites, are described from different locations world-wide. M.O'D.

Der Achat- und Amethystbergbau in der Region Medio Alto Uruguai in Rio Grande do Sul, Brasilien: Eine geologische und technische Betrachtung.

M. Priester. *Gemmologie – Z. Dt. Gemmol. Ges.*, **48**(4), 1999, 211-22, 9 photographs, 1 diagram, bibl.

The mining of agate and amethyst in the State of Rio Grande do Sul is the most important non-agricultural income generator of this region. The article discusses the legal situation of the informal artisanal mining as well as the geological setting and conditions of the geode-bearing basalt layers. These geodes are filled with amethysts, agates, chalcedony, calcites and zeolites. Mostly they are exploited in a semi-mechanised small scale underground operation, using black powder blasting. Raw material production is about 3000 to 3500 tons per year which are exported all over the world after some preparation as collectors' specimens, cutting and polishing as decorative pieces and also as raw material for gem cutting. E.S.

Investigations about the structure of freshwater cultured pearls.

C. Rinaudo, M.A. Digennaro, R. Navone and C. Chatrian. *Gemmologie – Z. Dt. Gemmol. Ges.*, **48**(3), 1999, 147-56, 10 photographs, 1 diagram, 3 graphs, bibl.

Tissue-nucleated freshwater cultured pearls were investigated using various methods: RI, SG, UV, loss on ignition, optical microscopy, SEM EDS and X-ray diffraction powder analysis both on ground material and directly on the surface of half-cut pearls. Only aragonite was detected growing as concentric orientated crystals. The pearls seem to have been formed by the development of a succession of subspherical shells, each separated by a growth discontinuity. E.S.

Tanzanit.

T. Sobczak and N. Sobczak. *Mineralogia Polonica*, **29**, 1998, 121-26.

A review of the occurrence, recovery and testing of the tanzanite variety of zoisite, with a table showing the properties of those gem materials with which confusion may arise. M.O'D.

Fluid inclusion characteristics of sapphires from Thailand.

B. Srithai and A.H. Rankin. *MDSTAN*, 1999, 107-11.

Three main types of fluid inclusion occur in Bo Ploi sapphires: (1) vapour rich CO_2 with $D \leq 0.86$ g/cm^3, (2) multiphase inclusions with several daughter minerals, hypersaline brine and a CO_2-rich vapour phase, and (3) (silicate?)-melt inclusions with immobile vapour bubbles in an isotropic/weakly anisotropic phase of low relief. The bubbles move when heated to > 800°C. These results suggest magmatic sources for these sapphires. R.A.H.

Kamienie szlachetne i ozdobne czech.

J. STANEK. *Minerlogia Polonica*, **29**, 1998, 113-20.

A short review, with some historical notes, of the occurrence of gem and ornamental materials in the former Czechoslovakia M.O'D.

Schleifwürdiger Shomiokit-(Y) von Lovozero, Halbinsel Kola, Rußland.

J. STEFAN AND V.M.F. HAMMER. *Gemmologie – Z. Dt. Gemmol. Ges.*, **48**(3), 1999, 141-6, 3 photographs, 1 graph, 2 tables, bibl.

This is a report of a faceted transparent, rose-coloured shomiokite (Y) weighing 0.61 ct, measuring 7.75 x 5.39 x 3.34 mm. SG 2.64; RI 1.530 – 1.539 with a DR of 0.009. These values are slightly higher than those reported for non-gem-quality samples. E.S.

Models of corundum origin from alkali basaltic terrains: a reappraisal.

F.L. SUTHERLAND, P.W.O. HOSKIN, C.M. FANNING AND R.R. COENRAADS. *Contributions to Mineralogy & Petrology*, **133**(4), 1998, 356-72.

Corundums from basalt fields, particularly in Australia and Asia, include a dominant blue-green-yellow zoned 'magmatic' suite (BGY) and subsidiary vari-coloured 'metamorphic' suites. BGY corundums have distinct trace-element contents (≤ 0.04 wt.% Ga_2O_3, and Cr/Ga and Ti/Ga values < 1). Primary inclusion minerals are typically feldspars, zircon and Nb-Ta oxides, hercynite-magnetite, gahnospinel, rutile-ilmenite solid solution, calcic plagioclase, Ni-rich pyrrhotite, thorite and low-Si Fe-rich glass. Magnetite exsolution, feldspar compositions and fluid inclusion homogenization suggest that some corundums crystallize at 685-900°C. Overlap of inclusion Nb-Ta oxide compositions with new data from Nb-Y-F-enriched granitic pegmatites implies a silicate melt origin for the corundums. The MELTS programme was used on the amphibole pyroxenite xenolith chemistry of basalts to test the feasibility of crystallizing corundum from low-volume initial melting of amphibole-bearing mantle assemblages. Corundum appears in the calculations at 720-880°C and 0.7-1.1 GPa, with residual feldspathic assemblages matching mineral compositions found in corundums and related xenoliths. A model that generates melts from amphibole-bearing lithospheric mantle during magmatic plume activity is proposed for BGY corundum formation. J.F.

Chatoyant tremolite (nephrite).

G.A. TOMBS. *Australian Gemmologist*, **20**(8), 1999, 340, 5 illus. in colour.

Examination by the author of a mid-green to dark green-grey high-doomed cabochon (submitted by S. Jenkinson and R. Bauer) yielded a 'spot' RI of 1.60, an SG of 3.00 (measured by Jenkinson) and an estimated hardness of $5^1/_2$ - 6. LWUV produced a patchy bluish through green to yellow fluorescence, but the stone was inert under SWUV. These properties were consistent with tremolite, and the stone's chatoyancy was caused by a flow-like structure of channels. P.G.R.

Gemstones of New England.

G.B. WEBB AND F.L. SUTHERLAND. *Australian Journal of Mineralogy*, **4**(2), 1998, 115-21.

Brief details are given of the occurrence of diamond, sapphire, beryl, topaz, garnet, zircon, feldspar, rhondonite, nephrite, peridot and fluorite from this area of NE New South Wales. More than 500 000 ct of diamonds have been produced. Two distinct categories of diamond are recognized: yellow, rounded crystals with a high, uniform nitrogen content, and white internally complex crystals with low, variable nitrogen content. Most of the diamonds have been substantially resorbed; under cathodoluminescence, one shows octahedral growth zones on a resorbed surface. Fine blue sapphires are produced with medium to dark hue, but greenish-blue, yellow and green varieties are also found; colour zoning down the *c* axis is a prominent feature. Beryl with emerald zones perpendicular to *c* giving alternating 'stripes' is illustrated. White and more rarely blue topaz occur in alluvium derived from the granitic rocks of the area. Zircons with a yellow, brown and pink range of colours are shed from basalts and are often obtained in sapphire workings. R.A.H.

The new Mineral and Gem Gallery at the British Museum.

J.S. WHITE. *Mineralogical Record*, **30**, 1999, 373-77.

Continuing the occasional series of *Gallery reviews* former Smithsonian Institution curator John White describes the new mineral and gemstone display gallery at London's Natural History Museum. Commenting that the terms mineral and gem are hard to find anywhere in the Museum (though occurring once in the publicity material), he goes on to show that the dimensions of the cases and the lighting militate against adequate viewing of the admittedly excellent specimens, many of which have become mis-labelled since first being set up and which are also capriciously lit, some being well outside the range of nearest spotlight and thus not lit at all. A flashlight has become an essential tool for viewing. The new displays are contrasted, considerably to their disadvantage, with the adjoining Mineral Gallery, lit by daylight, in which all specimens can be seen perfectly well and where labelling is perfectly satisfactory. M.O'D.

The colour of stones.

M. WILSON. *Transactions of the Oriental Ceramic Society*. **62**, 27-37, 1999, illus. in colour.

Describes the usage of and names given to hardstones, exclusive of the jades, used in Chinese artefacts. Rock crystal, amethyst, smoky quartz and rose quartz names are described with explanations of the Chinese characters used. M.O'D.

Martin Zinn III.

W.E. WILSON. *Mineralogical Record*, **30**, 1999, 311-16.

Short biography of the noted American collector and gem/mineral show organizer Martin Zinn III, including notes on and illustrations of important gem-quality specimens from his collection. M.O'D.

Lavra Berilo Branco: the original 'Sapucaia' rose quartz occurrence, Minas Gerais, Brazil.

W.E. WILSON. *Mineralogical Record*, **30**, 1999, 361-5. 1 map.

The first discovery of crystallized rose quartz was made in 1950-60 from the pegmatite of the Lavra Berilo Blanco [white beryl mine], Minas Gerais, close to the town of Sapucaia do Norte, from which the occurrence has been named. There has been confusion over the name Sapucaia because it has previously been used for a deposit of rare phosphates, only a few km away to the south, during the 1940s. Some of the rose quartz crystals have been considered important enough to have been named. The Berilo Blanco pegmatite forms part of the Lower Precambrian Paraiba Group: the Sao Tome mica schist complex was intruded about 600 ma. ago by a granitic batholith, with a late stage formation of many pegmatite veins in the area of Conselheiro Pena. M.O'D.

Instruments and Techniques

X-ray and spectral characterization of defects in garnets.

A. LUPEI, C. STOICESCU AND V. LUPEI. *Journal of Crystal Growth*, **177**, 1997, 207-10, 1 fig.

X-ray and optical spectroscopy of high temperature (HT) grown YAG and GGG revealed low intensity {222} X-ray reflections, forbidden in the cubic garnet Ia3d space group, with equivalent intensities for the four [111] directions. Structural arguments in connection with optical spectroscopy data on various ions (Nd^{3+}, Tm^{3+}, Pr^{3+}) allow one to assign these reflections (absent in flux grown crystals) to local reduction of symmetry introduced by nonstoichiometric random occupancy of octahedral sites by Y^{3+} or Gd^{3+} ions in HT garnets. I.S.

Kristalle und Polarisationsfarben.

O. MEDENBACH. *Aufschluss*, **50**, 357-64, 1999, illus. in colour.

The use of polarized light in mineral identification is discussed with reference to the various ways in which experiments can conveniently be conducted. M.O'D.

Modern mineral identification techniques. 1. WDS and EDS.

T. NIKISCHER. *Mineralogical Record*, **30**, 1999, 297-300.

Describes wavelength-dispersive spectroscopy (WDS) and energy-dispersive spectroscopy (EDS) with short explanations of their roles in mineral specimen identification. M.O'D.

Synthetics and Simulants

Gemmologie Aktuell.

H. BANK, U. HENN AND C.C. MILISENDA. *Gemmologie – Z. Dt. Gemmol. Ges.*, **48**(3), 1999, 121-7, 12 photographs.

Treated quartz is used as an imitation of jade; small pieces of opal are mixed with a resin and sold as matrix opal, cabochons or eggs; synthetic spinel is used as an imitation of tanzanite and some rounded sapphire crystals from Sri Lanka turned out to be synthetic. E.S.

Gemmologie Aktuell.

H. BANK, U. HENN AND C.C. MILISENDA. *Gemmologie – Z. Dt. Gemmol. Ges.*, **48**(4), 1999, 185-90.

Notes include a Knischka synthetic ruby and some natural/synthetic sapphire doublets, the crown being the natural stone. E.S.

Energie aus farbigen Kristallen: oxidische Laserkristalle-Herstellung, Bearbeitung, Anwendungen.

K. DUPRÉ. *Aufschluss*, **50**, 365-70, 1999, illus. in colour.

The synthetic garnets are examined as part of a general discussion of the growth and coloration of crystals suitable for laser use. M.O'D.

Verneuil synthetic corundums with induced fingerprints.

J. FREE, I. FREE, G. BROWN AND T. LINTON. *Australian Gemmologist*, **20**(8), 1999, 342-7, 11 illus. (10 in colour).

Quench-cracked Verneuil synthetic ruby and blue sapphire (a by-product of the routine heat treatment of corundums in Chanthaburi, Thailand) are produced by first heating the boules and then plunging them into water to induce fractures. These fractures are then heat-treated in a colourless flux. The resulting flux-healed quench-cracked stones contain 'fingerprints' and 'feathers' similar to those found in their Burmese and Sri Lankan natural counterparts. A study of 6 faceted rubies and 10 faceted blue sapphires showed that they could be discriminated from their natural counterparts by their curved striae/colour banding, checker-board pattern of solid flux filled surface-reaching induced fractures and their increased transparency to SWUV. P.G.R.

Zur Verwendung künstlicher Gläser als Schmuckmaterial: Schwarzes und blaues Glas mit ungewöhnlichen Einschlüssen.

V.M.F. HAMMER, J. STEFAN AND F. BRANDSTÄTTER. *Gemmologie – Z. Dt. Gemmol. Ges.*, **48**(3), 1999, 157-62, 5 photographs, 2 graphs, table, bibl.

Black beads from a necklace from Asia were shown to be glass with dendritic intergrown fluorite. A new gemstone from Namibia was identified as blue glass with tridymite inclusions. E.S.

Gemmologische Kurzinformationen.

U. HENN. *Gemmologie – Z. Dt. Gemmol. Ges.*, **48**(3), 1999, 163-5, 3 photographs.

The author describes a faceted hydrothermally grown aquamarine weighing 0.85 ct. SG 2.71; RI 1.572–1.580, DR 0.008. Using an immersion-type microscope distinct inhomogeneous growth patterns are visible which are typically found in hydrothermally-grown synthetic beryls including emeralds. E.S.

Gemmologische Kurzinformationen.

U. HENN. *Gemmologie – Z. Dt. Gemmol. Ges.*, **48**(4), 1999, 232-6, 3 photographs, table, bibl.

A faceted, orange fresnoite was examined, weighing 6.11 ct. RI 1.765-1.775, DR 0.010; SG 4.45. Gas bubbles were observed.

A synthetic forsterite has recently been offered as tanzanite. RI 1.635-1.670, birefringence 0.035; SG 3.26. The blue colour is caused by divalent cobalt. Strong pleochroism with violet, blue and purple. Tiny gas bubbles and doubling of facet edges were observed. E.S.

Gemmologische Kurzinformationen.

U. HENN AND C.C. MILISENDA. *Gemmologie – Z. Dt. Gemmol. Ges.*, **48**(4), 1999, 227-31, 4 photographs, 2 diagrams, bibl.

The short note describes the GE-POL (General Electric/Pegasus Overseas Ltd.) treated diamonds. They are originally brown or brownish type IIa diamonds where colour is removed by a high pressure/high temperature treatment. This modification cannot be identified by present gem testing techniques. GE laser inscribes the girdle surface with 'GE-POL'. A specimen stone of 0.72 ct was graded as G, VS1. E.S.

Gamma-ray diffractometry investigation of dislocation density in massive quartz crystals.

I.I. KALASHNIKOVA, V.S. NAUMOV, A.I. KURBAKOV, A.E. SOKOLOV AND S.S. PASHKOV. *Journal of Crystal Growth*, **177**, 1997, 57-60, 1 table.

Gamma-ray diffractometry, using intense monochromatic gamma-ray radiation from a ^{198}Au source activated by nuclear reactor neutrons, was applied to investigate dislocation density in AT-cut plates of synthetic quartz crystals. The beam cross section was 0.1 x 10 mm^2 with angular divergence of 9 angular seconds. Statistical dynamic diffraction theory was used to calculate dislocation density. Data obtained by this method were compared with those obtained by X-ray topography and etch channel method, giving good agreement. I.S.

Synthetische Quarzkristalle – Kristalleigenschaften, hydrothermale Züchtung und gemmologische Unterscheidung von natürlichen Quarzkristallen.

A. LANDMANN. *Gemmologie – Z. Dt. Gemmol. Ges.*, **48**(3), 1999, 129-40, 7 photographs, 7 diagrams, 3 graphs, bibl.

The proportions of a synthetic quartz crystal differ significantly from those of a natural quartz crystal and can be influenced by varying the growing parameters. This applies also to fluid inclusions in synthetic quartz. Synthetic quartz crystals are grown mainly for the electronic and optical industries, but some synthetic rock crystal, amethyst, citrine and smoky quartz is found on the jewellery market. These can be identified using low temperature infrared spectroscopy. The author describes the large autoclaves used in the production in Russia and China, and his study is based on the synthetic quartz crystals produced by these methods. E.S.

Synthetic andalusite crystals: morphology and growth features.

G.T. OSTAPENKO, V.N. KVASNITSA, L.P. TIMOSHKOVA, N.P. SEMENKO AND B.A. DOROGOVIN. *Journal of Crystal Growth*, **186**, 1998, 420-6.

Using a method by Ostapenko andalusite crystals attaining 1 mm were synthesized under hydrothermal conditions in complex water solutions. Smaller crystals (0.05-0.1 mm) were obtained in pure water. The growth rate of {001} is the highest at 0.04-0.08 mm/day, that of {110} is the slowest at 0.01-0.02 mm/day. The surface microtopographic observations indicated that adhesive type growth mechanism operated for the {001} and the layer-by-layer mechanism for {110}, and apparently for {001} and {101}. I.S.

Crystalline perfection of high purity synthetic diamond crystal.

H. SUMIYA, N. TODA, Y. NISHIBAYASHI AND S. SATOH. *Journal of Crystal Growth*, **178**, 1997, 485-94, 12 figs.

By means of double-crystal X-ray rocking curve measurement, polarization microscopy, topography and Raman spectroscopy, crystalline quality of high purity synthetic diamond crystals (type IIa) with impurities < 0.1 ppm grown by a temperature gradient method under high *P* and high *T* have been investigated. The diamond crystals contain fewer crystal defects, less internal strain and less variation in defects than those of natural diamond or synthetic type Ib diamond. The crystals however contain some line and some plane defects. It is suggested that these highly perfect crystals can be used as seeds to grow diamond crystals of high perfection. I.S.

Growth of diamond on silicon tips.

G. YUAN, Y. JIN, C. JIN, B. ZHANG, H. SONG, Y. NING, T. ZHOU, H. JIANG, S. LI, Y. TIAN AND C. GU. *Journal of Crystal Growth*. **186**, 1998, 382-5.

Diamonds with (111) orientation were preferentially grown on the top of silicon-tip arrays by microwave-plasma chemical vapour deposition. The observed preferential growth can be explained as an effect of chemisorption on the surface. I.S.

BOOK REVIEWS

Ancient Chinese jades (Part 1)

Zacke Auctions Vienna, 1999. pp 207, illus. in colour. Price (for this part) US$26.00

Chapters describing the authentication of early Chinese jades accompany this first part (of a projected three) of a sale catalogue in which 90 items are presented and very well illustrated. The services of a research laboratory (Aventis Research & Technologies, Hoechst, Germany) were called into play and X-ray fluorescence analysis (XRF) played the main part in determining whether or not a particular artefact had been naturally weathered. Atomic absorption spectroscopy (AAS) and electron spectroscopy (ESCA) were also used. The laboratory provides a very interesting presentation of the stages of investigation undertaken: analysis of tool marks and traces of workmanship are given as well as details of how possible weathering is established. This is a sale catalogue with a difference and readers should try to obtain a copy while it is still current. M.O'D.

Lure of the pearl: pearl culture in Australia

B. Aquilina and W. Reed. Kimbooks Pty Lt, Broome, Western Australia, 1998. pp 135, illus. in colour, softcover. ISBN 1 876332 00 X. Price on application.

Excellent and beautifully-produced guide to the culture of pearls in Australia. The culture methods are clearly described and there are a number of clear diagrams and attractive photographs. M.O'D

Catalogue of the Beck Collection of beads in the Cambridge University Museum of Archaeology and Anthropology. 1 Europe

Bead Study Trust, Cambridge. 1997. pp 160: two microfiche in rear pocket, softcover. £16.00 from the Trust at 29 Elliscombe Road, London SE7 7PF.

With a (free) corrected and expanded version of the Beck Collection catalogue available shortly and the second part (on Middle Eastern beads) promised for 2001, readers may feel that the present stop-gap work is unsatisfactory in some way. This is not the case since work on the now historic (*circa* 1945) collection has really only just begun and it was important to get records set out and available to scholars as soon as possible. I recommend anyone with an interest in this type of artefact to buy this very reasonably-priced book and make arrangements to see the collection (after making and keeping an appointment at Cambridge – the museum is Downing Street, Cambridge CB2 3DZ). While the materials may not interest gemmologists quite so much as the history and significance of the beads, there is much to be learnt by consulting this further addition to the renaissance in bead studies. M.O'D.

The drowning dream [A tale]

P. Burke. Fremantle Arts Centre Press, South Fremantle, Western Australia. 1998. pp 264, softcover. ISBN 1 863682 14 7. A$17.50 (includes air postage).

The background of pearling in the Indian and Pacific oceans makes this rousing adventure story of considerable value to readers with an interest in pearls. M.O'D.

Gold in the counties of Cornwall and Devon

S. Camm. Cornish Hillside Publications, St Austell: 1999. pp 116, illus. in colour, softcover. ISBN 0 9519419 7 6, £9.99.

This is an excellent small book for the mineral collector and has been reprinted with minor corrections from a first edition published in 1995. British minerals do not often make the monograph market: this book is well-written by an experienced consultant geologist who has worked for many years in this particular field and has an excellent list of references as well as some good colour photographs illustrating notable specimens. Details of these, their places of occurrence and of mining fill the lucid text. Readers with an interest in the subject should get the book quickly since the print-run may be small. M.O'D.

Memoir of localities of minerals of economic importance and metalliferous mines in Ireland

G.A.J. Cole. The Mining Heritage Society of Ireland Dublin, 1998. Softcover, illus. in black-and-white. ISBN 0 9534538 0 4. Price around £10.

Since publication of the second edition of 'Cole' in 1956 (the first edition came out in 1922 and is virtually unobtainable) this rare survey of an important source of minerals has long been in need of an update (and of finding at all). Ireland has a rich mineralogy and some specimens, notably of sphalerite, are of very high ornamental and even gem quality. The recent cessation of operations at Silvermines and probably elsewhere in the quite recent past makes careful recording even more urgent. A section of pictures of some famous mines has been added to the original text, thus making this, as stated on the verso of the title-page, a third edition: a short history of the book and of Cole himself opens the text, whose main section is arranged first by mineral and then by mine. Very important locality information is given, with copious reference to records which may now have been lost. The Mining Heritage Society of Ireland deserves every possible support in their work of preservation and recording. This reviewer, whose forbears included a least one celebrated Irish man of letters, welcomes a long-awaited survey of his ancestral minerals! M.O'D.

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Beautiful opals: Australia's national gem. Special 2000 commemorative edition

L. CRAM. The Author, Lightning Ridge, 1999. pp 80, illus. in colour, softcover. ISBN 0 9585414 2 6. $A30.00.

Very beautiful guide to the major Australian opal fields and to the best of their products, the book consists in the main of Len Cram's justly celebrated photographs which must have given an enormous boost to opal collecting and buying. Notes are given on some of the major locations and personal anecdotes give considerable insight into mining conditions and opal trading. M.O'D.

Minerals of Colorado

E.B. ECKEL. Updated by R.R. Cobban, D.S. Collins, E.E. Foord, D.E. Kile, P.J. Modreski, J.A. Murphy. Fulcrum Publishing, 1997. pp x, 665, illus. in colour, hardcover. ISBN 1 55591 365 2. Price around £100.

This very large book does justice to one of the most important mineralized areas of the Earth. Sponsored by the Colorado Chapter of the Friends of Mineralogy and by the Denver Museum of Natural History, the book updates Eckel's *Minerals of Colorado*, published as *Bulletin* 1114 of the United States Geological Survey in 1961. Since publication of that work, 329 new mineral species have been recorded from the State of Colorado and of course there have also been fresh localities found for species already described. Early chapters present the growth of mineralogical knowledge in Colorado, a list of selected mineral locations and a section of maps in black-and-white; then comes the main part of the text covering species arranged in alphabetical order. Each entry gives name, chemical composition, crystal system, group membership where relevant, location by county and district, details of occurrences and significant references in the literature. The clear and well-spaced printing is one reason why the book is so large but readers will welcome it, I am sure.

Nothing in the way of colour illustrations occurs until page 326 when a section of colour photographs is found. Quality and clarity are excellent: size and ownership of specimens are given as well as location. There are 118 colour photographs and the remainder of the pictures, up to 145, feature SEM depictions, also of high quality. After this section the alphabetical listing, with addendum, is complete by page 546, at which point it is followed by previously unpublished chemical analyses of some Colorado minerals.

A magnificent bibliography from pages 557-665 completes the book. Readers will be aware that Colorado produces a number of gem-quality minerals and they can be found in the text. The cost is by no means unreasonable and I suspect that the excellent Friends of Mineralogy have helped a great deal here. M.O'D.

Derbyshire Blue John

T.D. FORD. Landmark Publishing Ltd, Ashbourne, 2000. pp 111, illustrated in colour, softcover. ISBN 1 873775 19 9. £5.95.

The ornamental minerals of Derbyshire have not been specially well served by the writers of monographs since the nineteenth century: Trevor Ford, sometime Associate Dean of Science at the University of Leicester, a leading centre for geology and mineralogy, has redressed the balance by this really excellent book which is illustrated in colour throughout and which gives a new meaning to 'value for money'. After an opening chapter in which fluorite is introduced the book continues with descriptions of caverns and mines in which the mineral can be found and with geological accounts of the Derbyshire locations in the Peak District and at Treak Cliff in particular. Blue John mineralogy and Blue John-bearing veins are described.

Recovery of the Blue John has rarely been the subject of published papers and the account here is fully detailed with graphic illustrations. Blue John simulants, fashioning and examples of the use of material in Roman and later times, the work of Matthew Boulton, who used a great deal of Blue John in ornaments and its various uses up to the present time occupy much of the remainder of the text, which also includes details of the different patterns of Blue John which can sometimes show which veins it comes from. There is a survey of places where specimens may be seen and a useful bibliography. I cannot speak too highly of this book. M.O'D.

Gemstones

Grange Books, Rochester, 1998. pp 64, illustrated in colour, hardcover. ISBN 1 84013 136 5. £4.95.

The text is a compilation of material from three other books and while refreshingly cheap, does not quite come off in the sense that some of the photographs let it down: presumably they are copies of copies which themselves may not have been of the best quality. Whatever the reason, some are badly out-of-focus. Each page is devoted to a single species: a laudable idea but the accompanying text is larded with unexplained adjectives which will pass by the readers concentrating attention on the pictures but which will stop the same readers in their tracks as soon as they want to find out more. This is the age-old problem with this kind of book. As always such texts should be submitted to a competent scientific authority before being let loose on the market. M.O'D.

L'émeraude. The emerald. Connaissances actuelles et prospectives

D. GIARD (Ed.). Association française de gemmologie, Paris, 1998. pp 229, illus. in colour, softcover, price on application.

A very attractively produced and well-illustrated update on a number of emerald localities and their products, with extensive notes and individual papers on synthetic emerald. Most papers, each written by different authors under the general editorship of Didier Giard, have their own list of references and there is a more general bibliography, covering publications of the 1990's only, at the end of the book. Papers have English abstracts, some of them extended.

The survey comes at an opportune time with the arrival on the world gem markets of emeralds from Madagascar, Afghanistan and Pakistan, among other places, and the papers act as a general and welcome update of Sinkankas (1981) *Emerald and other beryls* with its coverage of earlier and less commercially prominent localities. Readers should have both on their shelves.

Many of the papers show mining districts not often depicted elsewhere and a study of early work on synthetic emeralds includes photographs of specimens grown by Hautefeuille in 1888 - the first time I have seen pictures of this material in colour. A paper on the hydrothermal growth of emerald in China also includes interesting photographs of autoclaves in action and of the inclusions visible in the product.

There are treasures everywhere: this is an essential book for the gemmologist, for those likely to be searching for emerald in the field and for the student of crystal growth. The editor, authors and publishers can be proud.

M.O'D.

The glass beads of Anglo-Saxon England, *c.* AD 400-700

M. Guido, 1999. The Boydell Press, Woodbridge, Suffolk, for the Society of Antiquaries of London. pp (xi) 361, illus. in colour. Hardcover. ISBN 0 85115 718 1. (Reports of the Research Committee of the Society of Antiquaries of London. no. 56. ISSN 0953-7163.) £50.

Edited and with two chapters by Martin Welch and subtitled *A preliminary visual classification of the more definitive and diagnostic types,* this study of Anglo-Saxon beads is based on examination of all the glass beads recovered from known British sites and is the first-ever national survey of the subject. Guido realised that research on glass beads would not only enlarge our knowledge of the development of this kind of artefact but also throw additional light on the post-Roman and early Saxon periods in Britain. The main text begins with a descriptive analysis of the beads by type, mainly their colour, and continues with schedules which are preceded by a topographical index placing sites of recovery in alphabetical place-name order, both describing and showing what the particular finds were and the present locations of the artefacts. The schedules themselves are arranged by type of bead, following the characteristics set out in the descriptive analysis in the first part of the text.

A section of eight colour plates presents beads grouped by colour and shows how attractive they can be. Finally an extensive and authoritative bibliography brings the reader up-to-date with work in this field: many items described could be hard to find were it not for their inclusion here.

The very reasonable price of the book reflects the considerable help made available from a number of sources, notably The British Academy. Production has not been skimped and my only very slight anxiety over sustained use is the thinness of the paper (acid-free, though). While jewellery historians in particular will be grateful for this book, it will also be very useful to those historians who depend upon artefacts like these to amplify their knowledge of social history and local economics.

M.O'D.

Classicism to neo-classicism: essays dedicated to Gertrud Seidmann

M. Henig and D. Plantzos (Eds). Archeopress, Oxford, 1999. pp iv, 232 illus. in black-and-white, softcover. ISBN 1 84171 009 1. (*BAR International Series* 793). £32.40.

Several papers in this festschrift dedicated to the distinguished Oxford antiquary and authority on the glyptic arts deal with set gemstones of the classical and post-classical taste in European ornamental artefacts during the succeeding centuries. Of particular interest are the accounts of gem collections now lost or dispersed. Chapters cover a wide range of topics and have their own useful lists of references: a bibliography of Seidmann's own works is included.

Readers with an inclination towards the use of the gemstones in earlier times should consult the published list of *BAR* (*British Archeological Reports*) available from Oxford.

M.O'D.

Madagaskar: das Paradies der Mineralien und Edelsteine

Christian Weise Verlag, München, 1999. pp 96, illustrated in colour, softcover. ISBN 3 921656 50 8. *extraLapis* no 17. DM34.80.

With this monographic multi-author treatment in the now accepted *extraLapis* form, the minerals and gemstones of Madagascar take another step towards regaining the international recognition and admiration that they have lacked since the 1950's and previous years when specimens used to come in profusion to Europe via the Compagnie Générale de Madagascar. When Alfred Lacroix published *Minéralogie de Madagascar* (Paris, 1922) mineralogists became familiar with some of the world's richest pegmatites and they are reviewed here with some splendid illustrations of rose quartz, beryl, tourmaline and many other gem-quality species. As always every page is a delight both to read and to the eye: I should have liked a bibliography (and a copy of Lacroix!) but I have to warn readers that issues of *extraLapis* are becoming scarce quite shortly after publication so get this one as soon as possible.

M.O'D.

Famous jewelry collectors

S. Papi and A. Rhodes, 1999. Thames & Hudson, London. pp. 208, illus in colour, hardcover. ISBN 0 500 01960 6. £29.95.

This well-produced and attractive book takes the reader into the jewellery collections of some of the most celebrated figures of the expiring century. Useful short biographies as well as details of the pieces depicted accompany the photographs and details of sales are given in appropriate cases. There is a short bibliography.

Collectors chosen for inclusion include royalty, stars of the concert room, cinema and theatre: details of some major gemstones can also be found in the text which will

interest equally the gemmologist, the jewellery historian and the recorder of 20th century social life in Europe and the United States. The standard of the photographs is high and the price very reasonable. The book would make an ideal Christmas or birthday present. M.O'D.

Portrait der Edelsteinmetropole Idar-Oberstein

This small booklet was published on the occasion of the 1999 Intergem exhibition. It is an illustrated account of 500 years of the local gemstone industry. In the 15th century the first local agates were worked using local water power. The development of the lapidary, stone cutting and carving, and jewellery industries is briefly described. E.S.

Gemmology

P.G. Read, 1999. Butterworth-Heinemann, London. pp 326, illus. in black-and-white and in colour. £21.99.

The second edition of this most excellent text-book is very much a repeat of the first edition with various additions to bring it up to date.

Well-written and quite explicit, it covers the subject admirably. A few minor spelling errors were detected (e.g. taafeite for taaffeite, aparite for apatite, managanese for manganese) due almost certainly to careless typesetting. Moissanite, the latest diamond simulant, is dealt with briefly but adequately in the main text, but does not appear in appendix D nor in the index. Mr Read's Brewster-angle meter is described in some detail and has advantages over the normal refractometer in that no contact fluid is needed and hence there is no limit to its range.

The author still uses the term metamerism for the colour change in alexandrite. My Chambers' dictionary defines the word as 'a particular form of isomerism in which different groups are attached to the same central atom'. I think it is wrongly applied to alexandrite.

Appendix C now contains a number of rare gem species which do not appear in the current Gemmological Association Syllabus for Examinations. So much the better for these rare stones do exist.

Perhaps the most amazing fact is that this edition is far cheaper then the first one (which did appear later in paper-back). This has been achieved by using a limp cover, a slightly smaller type-face and by drastically reducing the size of most of the profuse illustrations. This reduction is in no way detrimental to their interpretation however.

Colour illustrations of jewellery are very good and two pages of coloured diffraction-grating spectra are welcome. Altogether the book is eminently readable and should be regarded as a very reasonably priced text-book deserving a place in any student's library. R.K.M.

Black opal fossils from Lightning Ridge: treasures from the Rainbow billabong

E. Smith. Kangaroo Press (imprint of Simon & Schuster), 1999. East Roseville, NSW. pp 112, illus. in colour, hardcover. ISBN 0 86417 909 X. A$39.95.

There seems to be no end to the succession of beautiful opal books from Australia. This one describes and illustrates fossils in which black opal with play-of-colour is found replacing plant, shell or skeletal material. The text opens with a brief description of how the fossils of Australia came about and what types there are. The author then gives an account of mining experiences in the Lightning Ridge area and how she began to collect fossils. This section is followed by an introduction to the ways in which opal can form and to the various types of opal pseudomorphs after fossils: this section includes a useful evolution and time chart. The next section deals with opal replacements of different types of material, beginning with plants and going on to include primitive animals and again begins with an introduction to the appropriate commoner fossils. The book closes with a useful glossary and a bibliography.

The reader will want above all to know how good the photographs are and whether or not they arouse a desire to see (if not collect) them. The pictures are uniformly good and the display of colours is exceptionally fine, with the specimens in most cases shown against a black background: sizes are given, too! Some locations are depicted, giving an idea of the prevailing geology. The book's simple text is designed to accompany a fine set of pictures rather than to provide a palaeontological or gemmological study: it succeeds admirably. Credit is also due to the excellent series of marginal diagrams showing 'how the fossils once were'. M.O'D.

Von Ammoniten und Zwillingen (catalogue of the 1999 München Mineralientage)

Oberhaching, Germany, 1999. pp 287, illus. in colour, softcover. Price on application.

The catalogue of the annual München Mineralientage is always a beautiful production. In 1999 the theme of the show was fossils, with special attention given to ammonites, and to twinned crystals which are described and discussed by several authors on pages 29-111, this large section thus forming a serious study of twinning, with many high-class photographs and diagrams. Sources of especially fine examples are identified: some of the crystals highlighted are of gem and ornamental quality (chrysoberyl, quartz). The different types of twinning are clearly shown both in diagrams and photographs. Readers should try to obtain these catalogues: with a different theme each year and the wealth of directory and advertising information it is hard to see why more gemmologists do not possess them. M.O'D.

Proceedings of the Gemmological Association and Gem Testing Laboratory of Great Britain and Notices

OBITUARY

Howard Blackmore (D.1957 with Distinction), Caterham, Surrey, died on 24 November 1999. An obituary was published in the March issue of *Gem and Jewellery News*.

Syed Jafer Ali (D.1979), South Norwood, London, died recently. We are most grateful to his widow for the donation of his collection of gemmological books and instruments.

Helge R. Westgaard (D.1995), Kragero, Norway, died in 1999.

MEMBERS' MEETINGS

London

On 15 February 2000 at Imperial College, South Kensington, Dr R.F. Symes gave a talk on *Some sites of precious minerals in England.*

On 15 March at Imperial College, Stephen Webster gave a talk entitled *Chalcedony – 21st century girl's best friend.*

Midlands Branch

On 28 January 2000 at the Earth Sciences Building, University of Birmingham, Edgbaston, a Bring and Buy Sale and a Quiz were held.

On 25 February at the Earth Sciences Building, Ian Mercer gave a talk entitled *Gem trails from the Orient to Germany.*

Gem Playgroups were held at Barnt Green on 30 January and 27 February.

North West Branch

On 16 February 2000 at Church House, Hanover Street, Liverpool 1, Wendy Simkiss gave a talk entitled *Amber – different varieties and ages from around the world.*

On 15 March at Church House, Alan Hodgkinson gave a talk and demonstration on the identification of synthetic moissanite.

Scottish Branch

On 1 March 2000 at the British Geological Survey, Murchison House, Edinburgh, Drew Burrell gave a talk entitled *The diamond pipeline.*

NEWS OF FELLOWS

Alan Hodgkinson has been honoured by the Accredited Gemologists Association in the USA with the Antonio C. Bonanno Award for Excellence in Gemology.

The winner of the award was announced at the AGA Gala Dinner and Awards Ceremony in Tucson, Arizona, during the international gem show. The citation on the sculpted bronze relief reads: 'Awarded by the Accredited Gemologists Association to Alan Hodgkinson, February 3rd, 2000. For your invaluable contribution to the detection of synthetic emerald, and for the development of simple instrumentation and identification techniques known as *Visual Optics.*'

Michael O'Donoghue gave a six-lecture lunch-time course at the Bishopsgate Institute, London, in January and February 2000. The subject was *The classic gemstones.*

Cally Oldershaw is leaving the Natural History Museum where she has worked for almost 13 years and has been the Museum Gemmologist for the last ten years. She will be taking on the job of Researcher and Parliamentary Liaison Officer for the Geological Society, which is based in Burlington House, Piccadilly. Cally will not be leaving gemmology, but will continue as a Scientific Associate at the Museum, a freelance author, editor and consultant for the earth sciences, and as an examiner with the GAGTL.

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DONATIONS

The Council of Management are most grateful to the following for responding to the appeal for donations to enable the Association to meet the challenges of the 21st century. A list of those who have responded to the appeal follows:

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A.H.G. Armstrong, Bridge of Allan, Stirling
Kathryn L. Bonanno, New York, U.S.A.
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In the Examinations in Gemmology held worldwide in January 2000, 119 candidates sat the Preliminary Examination of whom 92 qualified. In the Diploma Examination, 100 candidates sat of whom 53 qualified.

Diploma

Qualified with Distinction
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Joyner, Louise, London
Shin, Mina, Seoul, Korea

Qualified
Al-Buflasa, Hanan Mubarak, Isa Town, Bahrain
Ancemot, Alex, Nantes, France
Antenen, Didier, Lausanne, Switzerland
Balzan, Cortney G., Fairfax, California, U.S.A.
Bawa, Mohammed S.R.M., Harrow, Middlesex
Bin Luo, Wuhan, Hubei, P.R. China
Bolissian, Inge Sahr, London
Brown, Mary J., Yangon, Myanmar
Chambers, Sara, Cardiff
Chaohui Lu, Wuhan, Hubei, P.R. China
Cheong Ly Karine, London
Chiu Mei-Hsiu, Taipei, Taiwan, R.O. China
Chongjie Pan, Wuhan, Hubei, P.R. China
Criado Friesch, Romina, Madrid, Spain
Dickson, Rebecca, London
Dwane, Christine, Montreal, Quebec, Canada
Ellis, Nigel, Lune River, Tasmania, Australia
Fu Sheng, Sushou, P.R. China
Geung Wan Yin, Hong Kong
Hicks, Suzanne C., Yardley, West Midlands
Hsu Miao Chu, Taipei, Taiwan, R.O. China
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Kong Bei, Guilin, Guangxi, P.R. China
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Lan Wang, Wuhan, Hubei, P.R. China
Liying Lu, Wuhan, Hubei, P.R. China
Poon Wai Kong, Singapore
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Shiwei Yu, Hong Kong
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Thompson, Ian, Wood Green, London
van Dam, Anita, Maasland, The Netherlands
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Xinyuan Li, Wuhan, Hubei, P.R. China
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Zini, Grazia, Ferrara, Italy

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Bruce-Lockhart, Simon, London
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Chao Chung Hsiao, Taipei, Taiwan, R.O. China
Chen Peijia, Guilin, Guangxi, P.R. China
Chen Jijuan, Guilin, Guanxi, P.R. China

GIFTS TO THE ASSOCIATION

The Association is most grateful to the following for their gifts for research and teaching purposes:

Tayyo Adolphus, Mintabie, South Australia, for 4 pieces of opal within matrix.

Maggie Campbell Pedersen, London, for a blue jade and 6 resin beads with insects.

European Gemmological Laboratory, New York, U.S.A., for a chamber for the production of synthetic diamond.

Vesta de Poli, South Kensington, London, for 355 specimens for teaching.

Peter Dwyer-Hickey, South Croydon, Surrey, for 21 specimens including diamond with burnt polish, sapphire, topaz, quartz, ivory and a garnet-topped-doublet set in a brooch.

John R. Fuhrbach, Amarillo, Texas, U.S.A., for a collection of crystals, stones, slabs and rough, including rough heat-treated quartz from Zambia, emerald and amethyst from Brazil, bytonite from Texas, calcite from Colorado, rhodochrosite, a piece of deer antler and some small faceted stones.

Rod Griffin, Yowah, SWQ, Australia, for a piece of korite stone.

Marie-Irene Hicter, Grenoble, France, for a synthetic opal cabochon.

R. Holt & Co. Ltd., London, for a brown enstatite crystal weighing 38.15 ct.

Marcus McCallum, London, for a jadeite doublet.

Mrs C.M. Ou Yang, Hong Kong Institute of Gemmology, Hong Kong, for a jadeite butterfly from a Russian mine.

Wilma van der Giessen for a doubly terminating quartz crystal and packets of topaz and emerald crystals.

Susanna van Rose, Northwood, Middlesex. for a piece of talc from Luzenac, French Pyrenees.

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FORTHCOMING EVENTS

28 April	**Midlands Branch.** ***Gwyn Green*** *– Treated gemstones*
28 April to 1 May	**Scottish Branch Millennium Conference, Perth.** *Keynote speaker:* ***Ken Scarratt***
4 May	**London.** *Famous diamonds and conceptual jewels.* ***John Nels Hatleberg,*** *New York, U.S.A.*
10-12 May	**London –** Kingston. User school in Raman analysis for gemmologists
18 May	**London.** *The Rose – nature's jewel as a decorative emblem.* ***Corinna Pike***
21 May	**Midlands Branch.** ***Memory Stather:*** *Sources of inspiration and samples of her work.*
	Gem identification with a 10 × lens.
5 June	**The Millennium Trade Dinner**. *Guest speaker:* ***Gary Ralfe,*** *Managing Director of De Beers.* Goldsmiths' Hall, London. Fully booked.
14 June	**London**. Visit to Treasures of the 20th Century exhibition
21 June	**North West Branch**. *Pocket sculptures – gemstone carving?* ***Memory Stather***
24 June	**Midlands Branch.** Summer supper
26 June	**London.** AGM, Reunion of Members, and Bring and Buy Sale
12 July	**London.** *Faceting revolution.* ***Roger Young***
30 July	**Midlands Branch.** Gem Play Group
27 August	**Midlands Branch.** Gem Play Group
20 September	**North West Branch.** *History of English watches from verge to lever.* ***Peter McIvor***
18 October	**North West Branch**. *Minerals and gems at the Great Exhibition of 1851.* ***David Lancaster***
29 October	**London.** Annual Conference
	Keynote speaker: ***Professor Al Levinson,*** *Calgary, Alberta, Canada*
30 October	**London.** Presentation of Awards
15 November	**North West Branch.** *AGM* followed by *Gem collection and anecdotes.* ***John Pyke Snr.***

For further information on the above events contact:

London:	Mary Burland on 020 7404 3334
Midlands Branch:	Gwyn Green on 0121 445 5359
North West Branch:	Deanna Brady on 0151 648 4266
Scottish Branch:	Catriona McInnes on 0131 667 2199

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Letter to the Editor

From Ian C.C. Campbell

De Beers synthetic diamonds

I refer to my recent article relating to six De Beers synthetic diamonds (*J.Gemm.*, 2000 **27**(1), 32-44). Access to information, new to me since having written that article, has caused me to amend my view relevant to the assumed nickel content in the two *near-colourless* De Beers synthetic diamonds reported on.

I have since been informed, on good authority, that there is not a presence of nickel in either of those stones – and that if there was, it would produce a green hue, not the colourless or near-colourless appearance seen in them. I am unaware of what metal catalyst was actually used by De Beers – this is understandably a sensitive issue – but based my assumption at the time on other reports of nickel catalysts being used which were allied to the selective electrical conductivity reported to be seen in different productions of colourless to near-colourless synthetic diamonds.

Boron is responsible for the blue colour in natural type IIb diamonds, which are semi-conductors of electricity as a result of it. I (and no doubt others) have also detected electrical conductivity in natural, *apparently near-colourless,* diamonds that contain *minute* traces of boron – insufficient to cause any noticeable blue colouring, but sufficient to produce electrical semi-conductors. One is thus forced to ask the question to what extent boron plays in the growth of these synthetic diamonds insofar as producing colourless to near-colourless stones? Current information appears to indicate colourless to near-colourless synthetic diamonds with electrical properties as being classified as type IIa. Obviously a more in-depth study is required in this context – which, unfortunately, I am unable to do in the context of these particular stones.

I do therefore apologize, as a result of the information received, for the apparent incorrect message I was unwittingly giving to the readers of this report, relevant to the nickel aspect. I will in fact be grateful for any additional information in this context from any researcher who will be willing to enlarge on what I have said above.

Ian C.C. Campbell
Independent Coloured Stones Laboratory
Randburg, Republic of South Africa

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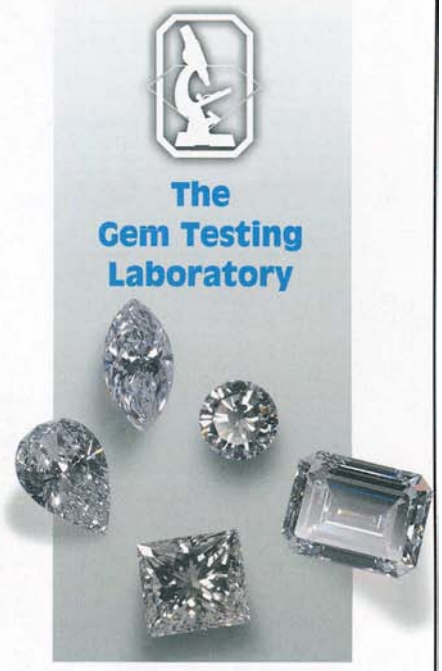

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The Editor is glad to consider original articles shedding new light on subjects of gemmological interest for publication in *The Journal*. Articles are not normally accepted which have already been published elsewhere in English, and an article is accepted only on the understanding that (1) full information as to any previous publication (whether in English or another language) has been given, (2) it is not under consideration for publication elsewhere and (3) it will not be published elsewhere without the consent of the Editor.

Typescripts Two copies of all papers should be submitted on A4 paper (or USA equivalent) to the Editor. Typescripts should be double spaced with margins of at least 25 mm. They should be set out in the manner of recent issues of *The Journal* and in conformity with the information set out below. Papers may be of any length, but long papers of more than 10 000 words (unless capable of division into parts or of exceptional importance) are unlikely to be acceptable, whereas a short paper of 400–500 words may achieve early publication.

The abstract, references, notes, captions and tables should be typed double spaced on separate sheets.

On matters of style and rendering, please consult *The Oxford dictionary for writers and editors* (Oxford University Press, 1981).

Title page The title should be as brief as is consistent with clear indication of the content of the paper. It should be followed by the names (with initials) of the authors and by their addresses.

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Key Words Up to six key words indicating the subject matter of the article should be supplied.

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Papers Hurwit, K., 1991. Gem Trade Lab notes. *Gems & Gemology*, **27**, 2, 110–11

Books Hughes, R.W., 1990. *Corundum*. Butterworth-Heinemann, London. p. 162

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The Journal of Gemmology

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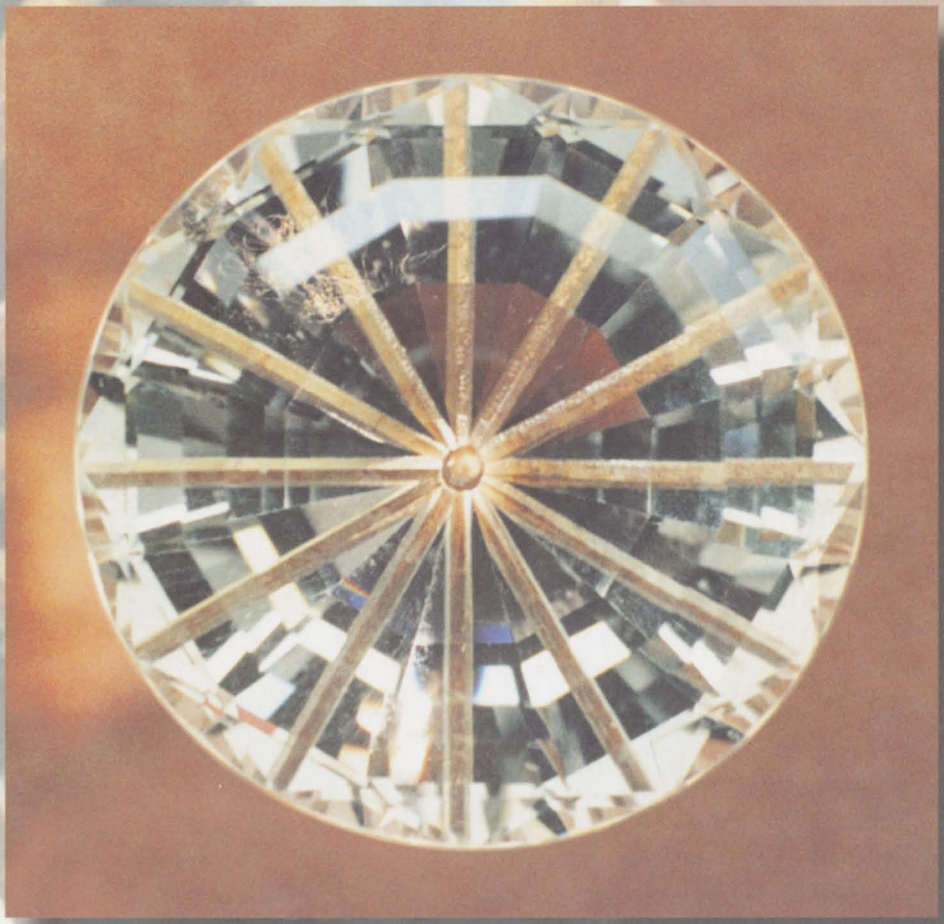

Spessartine garnets in Nigeria

Gems of Somaliland

The Hanneman Refractometer

The cause of colour of alexandrites

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A new find of spessartine garnets in Nigeria

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ABSTRACT: The physico-chemical and microscopic features of spessartine garnets from a new occurrence in Nigeria are presented. Chemical analyses show that these garnets have a very high spessartine component of 89-95% with varying small amounts of pyrope and almandine. Variation of the almandine component between 1% and 6% is responsible for a variation of colours between yellow, golden yellow and brown-orange. Absorption spectra of the yellow and golden yellow specimens (type a spectra) are very similar to those of spessartine from Kunene (Namibia), while those of brown-orange colour (type b spectra) are similar to those from Ramona (USA). The main inclusions in the Nigerian spessartines are healed cracks representing thin liquid-filled cavities or fingerprint-type feathers.

Keywords: spessartine garnet, Nigeria, physico-chemical properties, internal characteristics

Introduction

Spessartine garnets of gem quality are relatively rare compared to other species of the garnet solid solution series. Both quantity and quality of the material from different sources such as Ramona County, California, Macon County, Virginia, Minas Gerais, Brazil, Madagascar, Sri Lanka and Kenya, have been very erratic, and therefore spessartine garnets have been a collector's gemstone rather than a stone suitable for jewellery industry purposes.

This whole picture changed, when in 1992 an occurrence of spessartine garnet was discovered on the northern edge of Namibia, near the border with Angola (Lind *et al.*, 1993, 1994).

The material from this occurrence is of a fine, bright orange colour which is easily distinguished from all hitherto known spessartine garnets. These gem garnets were first designed as 'Kunene spessartine' after the boundary river between Namibia and Angola, but became widely known in the jewellery industry under the trade name 'mandarin garnet'.

Figure 1: *Cut spessartine garnet of 2.68 ct from a new occurrence in Nigeria.*

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Production from this source has been continuous, and has made spessartine garnets popular among gem dealers and jewellers. Unfortunately, sizes of cut stones generally are small, and faceted gems of more than 1 ct are already relatively rare. For sizes of 2-3 cts and up, a regular supply cannot be maintained, even at high prices.

Recently, a new source of gem quality garnets of fine yellow-orange colour was discovered in Nigeria, West Africa (Bank *et al.*, 1999). The material from this new occurrence complements the range of sizes available for fine orange spessartine garnets, as sizes of 2-3 ct and more can now be supplied to jewellers (*Figure 1*).

Refractive index and specific gravity

Refractive indices of 20 specimens were measured using a Rayner refractometer and fluid with an RI of 1.81 and the results varied between 1.801 and 1.803. Specific gravities measured using the hydrostatic method varied between 4.15 and 4.22.

Table I compares values of measured gemmological data for spessartine garnets from Nigeria with values for spessartine garnets from other occurrences described in the literature.

Table I: *RI values and SG values for gem quality spessartine garnets from Nigeria compared with published work.*

Locality	*n*	*SG*
Nigeria[6]	1.801-1.803	4.15-4.22
Rutherford Mine, Virginia[1]	1.802(3)	-
Taita Hills, Kenya[2]	1.795-1.809	-
Minas Gerais, Brazil[3]	1.803-1.805	4.15
Ramona, Calif.[4]	>1.81	4.17
Kunene, Namibia[5]	1.801-1.803	4.15-4.22

1. Sinkankas and Ried, 1966
2. Medenbach *et al.*, 1978
3. Bank *et al.*, 1970
4. Tisdall, 1962
5. Lind *et al.*, 1993, 1994
6. this work

Composition

Garnets are a group of minerals with extended isomorphous solid solution between its end members. Although solid solution of five and more components is common, usually 80% of the crystal is built up of only two or three main constituents, and all garnets can be broadly subdivided into the two solid solution series *ugrandite* (with end members uvarovite, grossularite and andradite) and *pyralspite* (with end members pyrope, almandine and spessartine).

Pyralspite garnets with spessartine being the main component are called spessartine in

Table II: *Microprobe analyses of spessartine garnets from Nigeria.*

	ligr324	*ligr325*	*ligr326*	*ligr327*
Wt%				
MgO	0.67	0.99	0.96	0.85
FeO	0.62	2.77	1.44	2.44
CaO	0.27	0.09	0.19	0.35
MnO	40.38	37.67	39.36	37.76
Al_2O_3	21.21	21.40	21.36	21.48
Fe_2O_3	0.00	0.00	0.00	0.00
V_2O_3	0.00	0.00	0.00	0.00
Cr_2O_3	0.07	0.03	0.05	0.02
TiO_2	0.07	0.01	0.08	0.09
SiO_2	36.68	37.04	36.55	37.02
Total	99.97	100.00	99.99	100.01
Mol%				
Pyrope	2.8	4.1	3.9	3.5
Almandine	1.4	6.5	3.3	5.7
Spessartine	95.0	89.1	92.1	89.7
Grossular	0.6	0.2	0.4	1.0
Uvarovite	0.2	0.1	0.2	0.1

the trade. Gem-quality spessartine garnets are usually members of two mainly binary solid-solution series:

1. spessartine-almandine series (pyrope and grossular < 10%);
2. spessartine-pyrope series (almandine and grossular < 15%);

(see Sinkankas and Ried, 1966, Bank *et al.*, 1970, Jobbins *et al.*, 1977, Medenbach *et al.*, 1978, and Lind *et al.*, 1993, 1994).

Compositions of spessartines from the new occurrence in Nigeria are shown in *Table II.*

Figure 2 shows the position of investigated samples from the new occurrence within the composition triangle of pyralspite garnets, together with analyses of garnets from pyrope-spessartine solid solution series from the literature and unpublished data of Lind (1999, in prep.)

As can be seen from this diagram, the garnets from the new occurrence in Nigeria have very high spessartine contents of 89-95%, with varying small contents of both pyrope and almandine.

Figure 3 shows typical visible absorption spectra of specimens with low almandine content (a) and high almandine content (b). Spessartines of spectra type (a) show yellow-golden colour, while type (b) spectra are typical for stones of more brownish-yellow colours.

Type (a) spectra are dominated by spin forbidden bands of $Mn^{2+[8]}$. Type (a) spectra are very similar to those of Kunene material (Lind *et al.*, 1993, 1994), although extremely weak $Fe^{2+[8]}$ bands can also be identified.

Type (b) spectra show bands of $Mn^{2+[8]}$ and $Fe^{2+[8]}$, which are superimposed on a strong charge transfer band system, which causes continuously increasing absorption from the red part of the spectrum towards the ultraviolet region, and which is the reason for the brownish-yellow colour of these spessartines. Type (b) spectra resemble those of material from Ramona.

Positions of absorption bands are given in *Table III.*

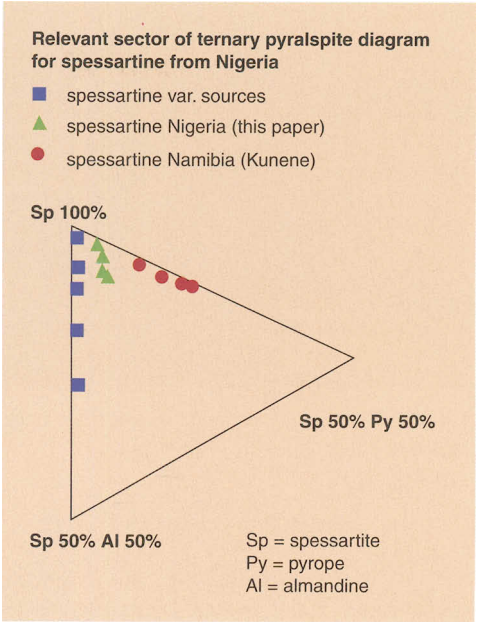

Figure 2: *Relevant part of ternary pyralspite diagram for spessartine garnets from different sources and from the new find in Nigeria.*

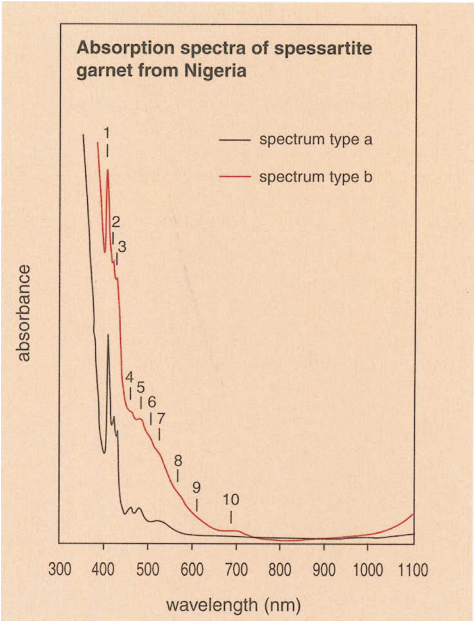

Figure 3: *Absorption spectra of spessartine garnet from Nigeria. Numbers refer to bands listed in Table III.*

Figure 4: *Healed cracks in spessartine from Nigeria.*

Figure 5: *Tabby extinction visible under crossed polarizing filters.*

Internal features

The main inclusions in the Nigerian spessartine garnets are healing-cracks representing thin liquid-filled cavities or fingerprint-type feathers *(Figure 4)*. A distinct tabby extinction is visible under crossed polarizing filters *(Figure 5)*. The tiny black inclusions and hollow-tubes which are typically present in Namibian spessartines have not been found.

Table III*: Absorption bands (nm) in spessartine from Nigeria (this work) compared with those in Namibian stones (Lind et al., 1993, 1994)*

Band	*Spessartine Nigeria [nm]*	*Spessartine Namibia [nm]*	*Assignment*
1	406	408	Mn^{2+}
2	420	420	Mn^{2+}
3	428	430	Mn^{2+}
4	457	457	Mn^{2+}
5	480	483	Mn^{2+}
6	503	n.f.	Fe^{2+}
7	524	527	Mn^{2+}, Fe^{2+}
8	566	n.f.	Fe^{2+}
9	566	n.f.	Fe^{2+}
10	607	n.f.	Fe^{2+}
11	686	n.f.	Fe^{2+}

Conclusion

Chemical analyses and absorption spectra show that the spessartine garnets from the new occurrence in Nigeria fall between the binary series spessartine-almandine and spessartine-pyrope. Variation of the almandine component between 1% and 6% is responsible for the variation of colour between yellow, golden-yellow and brown-orange with the latter containing the higher almandine component.

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Imperial topaz from Ouro Preto, Brazil: chemical character and thermal behaviour

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ABSTRACT: Imperial topaz from two mining fields near Ouro Preto have been investigated by thermal analysis and X-ray diffraction. It was found that no changes in the composition occurred on heating up to 1000°C, but the colour changed from reddish-brown to colourless. A first loss of mass, ascribed to the release of OH groups occurs at about 1200°C, and a second loss occurs at 1320°C at which mullite was formed.

Keywords: Imperial topaz, thermal stability

Introduction

The mineral topaz is a fluorine aluminium silicate, with chemical formula $Al_2SiO_4[(OH)_{1-x}F_x]_2$, where the hydroxyl group can replace fluorine up to ~ 30 mol% (Barton, 1982). A fully hydrated topaz has been recently synthesized at high temperatures and pressures (Wunder *et al.*, 1993).

There are two major types of geological occurrences of topaz producing precious stones: (a) pegmatite, and (b) hydrothermal veins in carbonate rocks. In the first case, the topazes are associated with minerals such as quartz, feldspar, muscovite and cassiterite. The colours of these topazes are pale blue, pale green, colourless or, rarely, pale yellow. The topazes from pegmatites are known as common topaz or simply topaz, are common in weights more than 1 kg and may attain 100 kg. As there are many occurrences of this mineral in the world, it is considered a common gem.

In the second case, topaz from hydrothermal veins can be associated with quartz, dolomite, and sometimes, in smaller amounts, muscovite, hematite, euclase, and rutile. Topaz from hydrothermal veins can be found in a broad range of colours including orange-yellow, brownish-orange, orange-pink, violet, and, rarely, as green or colourless. Except for the green and colourless topaz, these variations are called imperial topaz. The crystals of imperial topaz usually weigh less than 200 g, and, only very rarely have these crystals been found with a weight exceeding 1 kg.

In fact, imperial topaz is rare, and, today, mining of this mineral is taking place only in two localities in the world. One is Chundao Hill, in Pakistan, and the other is near the historic town of Ouro Preto, Minas Gerais, Brazil.

The two most important mining sites of imperial topaz in Ouro Preto are Capão, and Vermelhão. These mines and the characteristics of their imperial topaz varieties have been described elsewhere (Olsen, 1971; D'Elboux and Ferreira, 1975; Cassedanne and Sauer, 1987; Menzies, 1995; Sauer *et al.*, 1996).

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The typical colours of imperial topaz from the Ouro Preto area range from yellow-orange to reddish-brown. Some of the reddish-brown crystals can be heat treated to pink, which is appreciated in the gem market. The heat treatment of imperial topazes from Ouro Preto has been performed at a few mines (Sauer *et al.*, 1996), and has also been a subject of scientific research (Sabioni *et al.*, 1997). This work was performed in this context, and deals with the study of the chemical and thermal behaviour of imperial topaz during heating. The chemical composition and structure changes are investigated, and a chemical formula for the Capão topaz is calculated.

Materials and methods

Topaz samples

This work was performed using two samples from the Capão Mine (samples C1 and C2) and two samples from the Vermelhão Mine (V1 and V2). The two samples from each mine were orangy-yellow and brownish-red as shown in *Figure 1* for the samples C1 and C2.

The refractive indices of these imperial topazes lie in the ranges α, 1.629, ß 1.632 and γ1.637, and the specific gravity is about 3.54.

Figure 1: *Orangy-yellow and brownish-red imperial topazes from the Ouro Preto region (samples C1 and C2). Actual size. (Photo by A. Liccardo.)*

Chemical and thermal characterization

Typical values for transition metal elements found in these topaz varieties are shown in *Table I*, and the most significant variation is related to the chromium content. Chromium is a chromophore and its amount increases from the orangy-yellow topazes to the brownish-red varieties. The elements V and Ni are also chromophores and may play some role in the topaz colour.

Fourier-transform infrared spectra (FTIR) were collected in a Nicolet spectrophotometer in order to characterize the presence of hydroxyl groups in both natural and thermally treated samples. The pellets were prepared by grinding about 1 mg of the sample with 100 mg of KBr.

The water content of the topaz was determined by titration using the Karl-Fischer method after heating at 1200°C. The principle of this method is described elsewhere (Skoog *et al.*, 1992).

Powder X-ray diffraction patterns (XRD) were taken to check the effect of the thermal treatment on the topaz structure, and for the determination of the fluorine content. The diffractograms were collected by using a Rigaku Geigerflex diffractometer with Cu Kα radiation and a graphite monochromator. The scans were done in the range of 15° - 70° (2θ) at a speed of 1° min^{-1}. For the quantification of fluorine the method proposed by Ribbe and Rosenberg (1971) was used. This method is based on the shift of the (021) topaz diffraction line, which was shown to be proportional to the fluorine content. For these experiments, sodium chloride was mixed with the samples and the scans were done in the rate of 26° - 33°C at a speed of 0.25° min^{-1}. Peak positions were determined by fitting the numerical profiles with a Pearson VII function.

Simultaneous thermogravimetric analysis (TGA) and differential thermal analysis (DTA) were performed in a Du Pont SDT2960 module. The temperature ranged from 25°C to 1380°C, using a constant flow of nitrogen or synthetic air (100 ml/min) and a heating rate of 10°C/min. All runs were

Table I: Contents of transition metal elements (ppm) and fluorine (%) in imperial topazes

Sample	*Colour*	*Fe*	*Mn*	*Cr*	*V*	*Ni*	*Co*	*F*
C1	Orangy-yellow	2150	<10	280	116	22	<5	18.0
C2	Brownish-red	3100	<10	660	114	12	<5	16.2
V1	Orangy-yellow	5000	46	160	60	15	<5	17.1
V2	Brownish-red	4400	40	380	56	10	<5	15.1

performed with powders as well as with crystals about 3 mm in size.

Results and discussion

Chemical characteristics

The fluorine contents were first determined using the specific ion electrode method at a commercial laboratory, but the results were much lower than those predicted by the chemical formula of topaz. The reason is assumed to be associated with the method of preparation of the samples for this type of analysis. Therefore an alternative method based on X-ray diffraction was used to estimate the fluorine contents. According to the method, proposed by Ribbe and Rosenberg (1971), the fluorine content in topaz is given by:

$$(\%\ F) = 155.6 - 35.7\ \Delta_{021},$$

where $\Delta_{021} = 2\theta_{NaCl\ 200} - 2\theta_{topaz\ 021}$ and is measured in degrees.

The results obtained for the fluorine contents in the topaz samples C1, C2, V1 and V2 are listed in *Table I*. The total error, considering an uncertainty of about 0.05° in Δ_{021}, is about 1%.

The water contents of samples C1 and C2, were determined using the Karl-Fischer method and gave results of 1.73% and 1.84%

Figure 2: Thermogravimetric curves of topaz samples from Capão and Vermelhão mines.

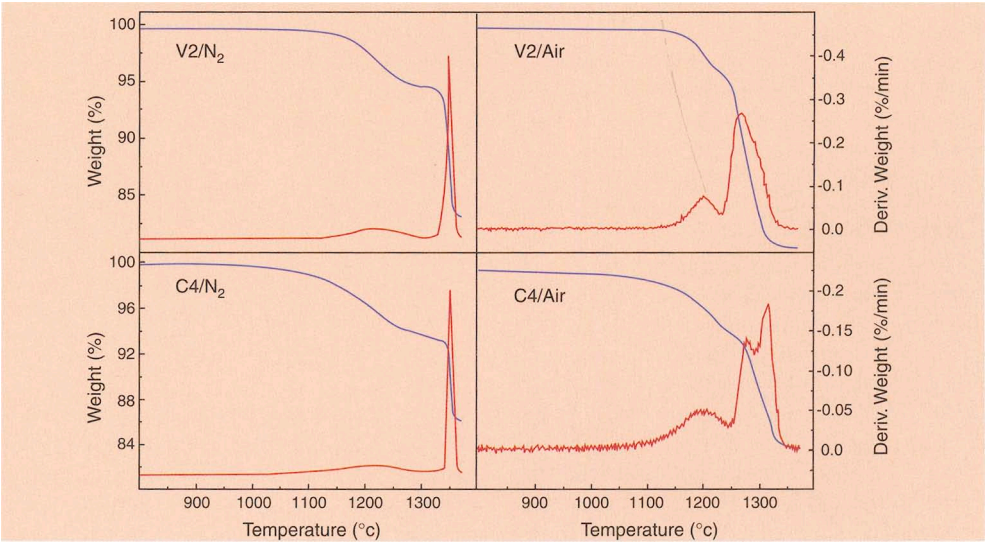

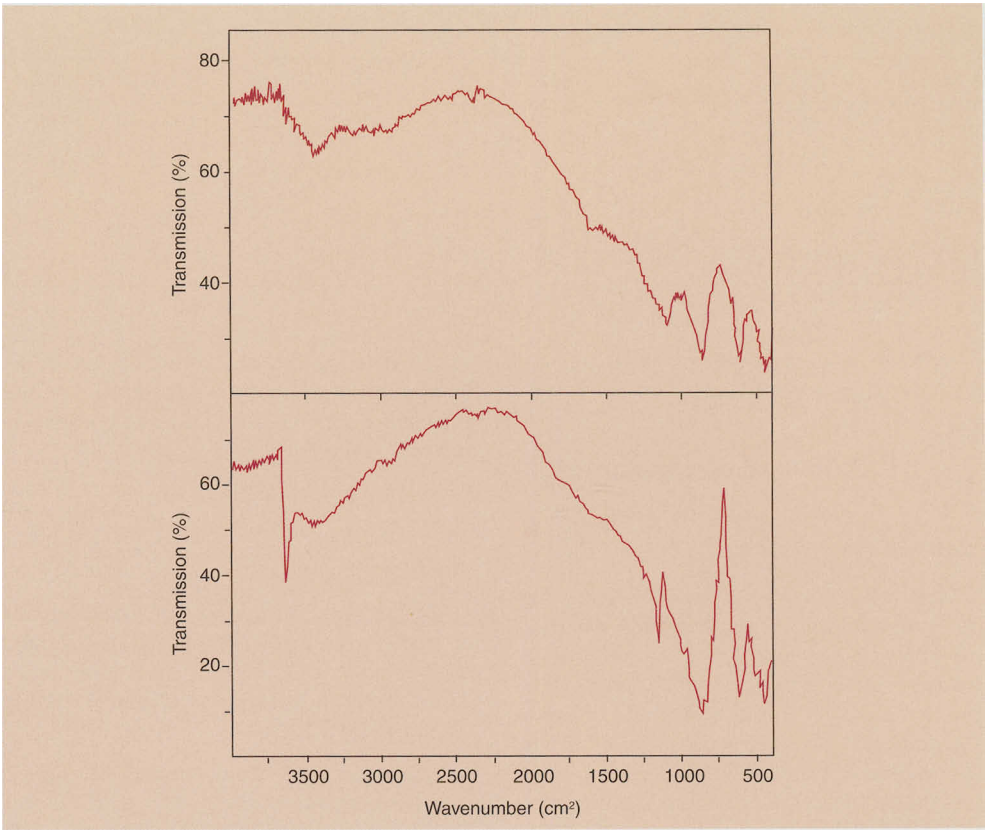

Figure 3: *Infrared spectra of sample V2 before (bottom) and after thermal treatment at 1230°C (top).*

respectively. Using the above results for the F and H_2O contents in the samples from Capão Mine, it was possible to deduce the value x~0.80 in the chemical formula $Al_2SiO_4[F_x(OH)_{1-x}]_2$. This result is similar to the value of 0.75 reported by Barton (1982) for a topaz sample from Ouro Preto.

Thermal characteristics

Typical thermogravimetric curves of samples from Vermelhão (V) and Capão (C) in different atmospheres are shown in *Figure 2*. A common feature for all samples is the thermal stability up to temperatures of 1000°C. All samples show an endothermic loss of mass of about 5% in the vicinity of 1200°C, and a second endothermic loss ranging from 8% to 15% at temperatures about 1320°C.

The atmosphere used in the experiments plays an important role in the overall shape of the thermogravimetric curves, but the loss of mass is generally not so affected. In some samples the high temperature peak clearly splits in two depending on the atmosphere used. All these results show that the interpretation of these curves is not straightforward, and only a general proposition can be made at this stage: the low temperature peak is due to the loss of OH groups, probably as water, or as $Si(OH)_4$, whereas the other one is due to the loss of fluorine.

Further evidence that the first loss of mass at about 1200°C is due to the release of OH groups was found from the following experiment: the TGA was repeated for sample V2, but the run was interrupted at

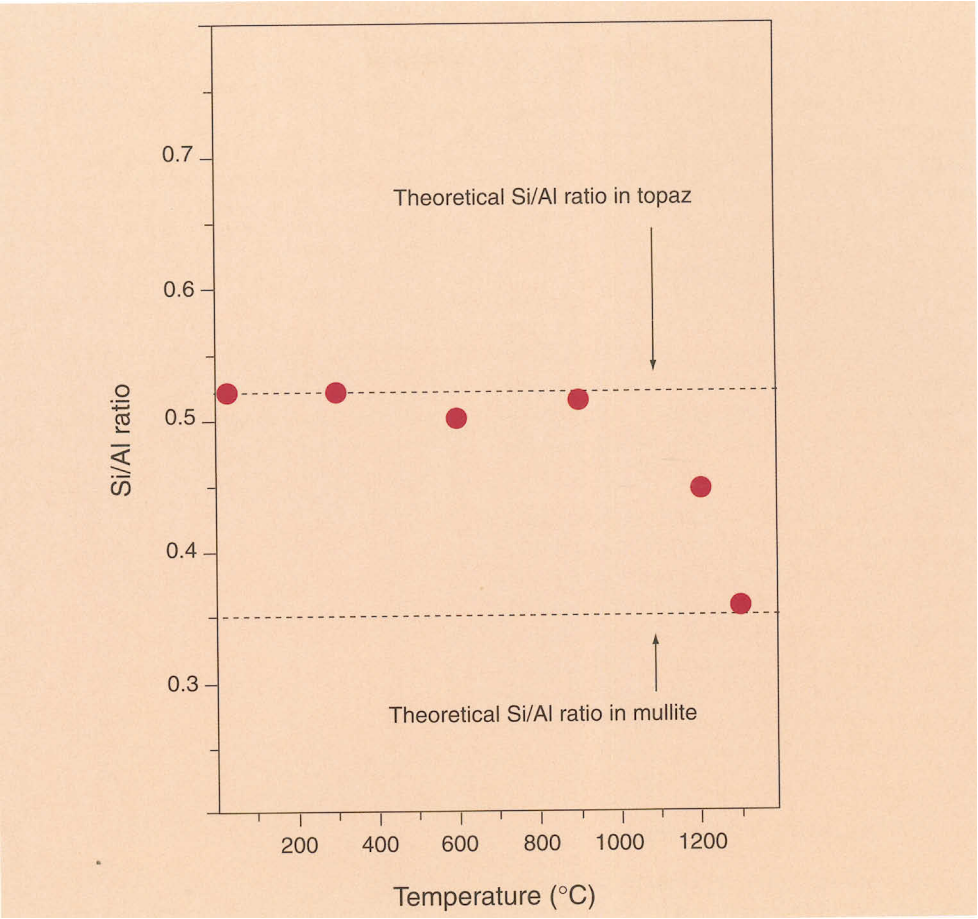

Figure 4: *Effect of the thermal treatment on the Si/Al ratio of sample CI.*

1230°C (air atmosphere). The infrared spectra of both the original and heated sample were collected, and are displayed in *Figure 3*. The sharp peaks at 3460 cm^{-1} and 1166 cm^{-1} are attributed to the stretching and bending modes of OH groups (Shinoda and Aikawa, 1997), and these peaks are clearly reduced in the heated sample. However, the loss of about 5% of mass is not in agreement with the value determined from both the Karl-Fischer method (H_2O) and XRD (fluorine), and therefore it is likely that more than one reaction is taking place at this temperature.

From the above discussion it is seen that the mechanism for the thermal decomposition of topaz in not yet clear. The product obtained after heating the sample at 1380°C was identified by XRD as mullite ($Al_6Si_2O_{13}$), which means that silicon has been released from the topaz structure, perhaps as SiF_4.

This assumption is corroborated by *Figure 4*, where the Si/Al ratio for identical topaz samples from Capão mine was plotted after heating from room temperature to 1380°C, during one hour, in an air atmosphere. It is seen that the Si/Al ratio approaches that of mullite as the annealing temperature increases, in good agreement with the results obtained by XRD.

Concerning the colour changes of the

topaz samples during the thermal analysis, it was found that up to 300°C no change in the reddish-brown or orangy-yellow topaz occurs. However, at 600°C a pink colour developed, which disappeared after further heating at 900°C. At higher temperatures a white and opaque material was formed.

Conclusions

Imperial topazes from Ouro Preto have been chemically and thermally characterized. From determination of F and OH contents, a representative formula of $Al_2SiO_4[F_{0.8}(OH)_{0.2}]_2$ was calculated for the Capão topazes.

Thermogravimetric studies indicate that heating of topaz up to 1000°C apparently causes no change in the composition, but the colour changes from reddish-brown or orange-yellow to colourless. A first loss of mass, ascribed to the release of OH groups occurs at about 1200°C, and a second loss occurs at 1320°C. At this temperature, mullite is the only crystalline phase present.

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Somaliland – a potential gem producer in the Mozambique Belt

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ABSTRACT: Gem-quality minerals such as emerald, ruby, sapphire, aquamarine, garnet and amethyst have been found recently in Somaliland. The majority of the gemstones are derived from pegmatitic host rocks, which are related to late granite intrusions in the Mozambique orogenic belt. The pegmatites occur in an east-west zone through the centre of Somaliland. Where pegmatites cross-cut biotite and amphibole schists, emeralds may occur, whereas when pegmatites cross-cut migmatites and granite gneisses, aquamarines are more common. Not all the gemstones described have been collected from production sites, and minerals such as rubies, sapphires, opal and pyrope or almandine garnet are likely to have originated from a range of different rock types. Most gemstones are being extracted from solid unweathered rock and recovery methods are unsophisticated.

The importance of gems in the Mozambique orogenic belt has previously been noted within Kenya, Tanzania, Sri Lanka, India and Madagascar. The recognition of the extension of the Mozambique belt into Somaliland is therefore of considerable interest as it means there is potential for the production of a wide-range of gemstones, and this remains to be fully assessed.

Keywords: amethyst, aquamarine, emerald, extraction, garnet, geology, Gondwana, Mozambique Belt, opal, pegmatites, sapphire, Somaliland, titanite, vesuvianite, zircon

Introduction

The discovery of gemstones in Somaliland and their subsequent recovery only began in 1990. It is surprising, considering the widespread distribution and range of gemstones, that they were not noted previously during the excellent field mapping undertaken by the Geological Survey Department during colonial rule. Sustainable development of natural resources is being investigated and the gemmological potential of Somaliland may provide an important income generation in this country where many will earn only $10 per month. This article presents more detailed information than appeared in a preliminary note introducing Somaliland as a new gem source. (Kinnaird, 1999). It is based on mineral samples shown and donated by various mining groups and is not necessarily representative of the types

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of material, or the quality of stones available. It also emphasizes that the majority are derived from pegmatite host rocks.

Location and access

Somaliland lies in the Horn of Africa. It is a hot country with a varied scenery ranging from upland plateaux to forested mountainous regions and a hot coastal plain fringed by white sands. On independence in 1960, the British protectorate joined with the Italian protectorate to form the new State of Somalia, but civil war between the two factions soon followed. Despite the declaration of independence in 1991 and the restoration of NW Somalia as Somaliland, there have been local disputes and occasional upsurges in clan-related violence. Generally however, it is now quite safe to visit most gem-bearing areas, although their remote location, coupled with local suspicion, means that an arranged guide from the appropriate area is essential, and permission from the Ministry of Water and Minerals should also be sought. Access into any area is by four-wheeled drive vehicle, which can be hired in the capital Hargeisa. Hire includes a driver who can act as an interpreter. Roads have suffered badly during the war, and few bridges remain intact, which requires deviations through stream valleys. Only the main roads from Hargeisa to Berbera, Hargeisa to Borama and Hargeisa to Sheik are in relatively good condition, the remainder are dirt roads of poor quality. To reach the emerald-bearing localities to the north of Bawn, for example, requires a ten-hour return journey by road from Borama. Also, individual localities may be a long walk or climb from access tracks as the gem localities are often in mountainous terrain. The difficulty of access means that the miners must camp away from their home village.

Variety of gemstones

During a visit to Somaliland, a number of minerals were shown to one author (JAK) by collectors and traders in Hargeisa, Borama, Berbera and Sheik. These vary from common low-value minerals like garnet and amethyst and rarer mineral species, to minerals such as emerald, ruby, sapphire and aquamarine *(Table I)*, which contain a proportion of gem-quality material that has definite potential for the overseas market.

***Table I**: Minerals from Somali pegmatites, or in the collections of miners and traders.*

Silicate	*Non-silicate*
beryl: aquamarine	apatite
emerald	cassiterite
diopside	chalcopyrite
epidote	chrysoberyl
garnet: pyrope	corundum: ruby
almandine	sapphire
grossular	hematite
hornblende	pyrite
opal	rutile
quartz varieties (including amethyst and rock crystal)	spinels ('pleonaste')
titanite	
topaz	
tourmaline	
zircon	

Other mineral varieties like phenakite, alexandrite and heliodor were reported though were not seen, and it is unwise to place too much reliance on local gem identification as most producers or traders are only just beginning to learn to identify the minerals. Occurrences reported as 'tanzanite', either turned out to be purple fluorite or lilac vesuvianite. Similarly, a supposed emerald from a gem-producing area was found to be quartz coloured green by secondary copper minerals. Green epidote and diopside are frequently confused as tourmaline or peridot. Unfortunately, there is also a widespread belief among the inhabitants that there is an abundance of diamonds in the country. This is based on the mis-identification of quartz by certain traders using gem-testing equipment incorrectly. The abundant small quartz crystals common in small cavities in rocks are called 'sugar-diamonds' by these traders.

Geology and occurrence

The geological history spans a long period of time even by geological standards. The oldest rocks are more than 1800 Ma (Kröner *et al.*, 1989), whilst basaltic flows have erupted in the last 30 Ma with the opening of the Gulf of Aden. It is possible that rare rhyolite horizons within these basalts may be the source of opals which are being mined in NW Somaliland. The extensive Mesozoic and Cenozoic sedimentary succession deposited in the last 200 million years does not contain gem minerals.

The crystalline basement of Somaliland crops out at the surface in a discontinuous belt about 600 km long and 30 km wide, running parallel to the Gulf of Aden and covering an area of around 30,000 km^2 *(Figure 1)*. It comprises an older Precambrian crust in the west, which has been through several geological events, and a simpler Pan-African terrain in the eastern sector which has evolved in one geological period from around 700-500 Ma. Altogether, the basement consists of five metasedimentary sequences interrupted by two different phases of igneous activity *(Table II)*. Single zircon age dates on samples from the Hargeisa-Sheik-Burao area give very precise ages for these rocks (Kröner and Sassi, 1996).

The Palaeoproterozoic Qabri Bahar Complex was originally dominantly sedimentary sandstones and mudstones. These were metamorphosed and deformed several times. In contrast, the overlying Mora Complex (Gebile, Borama and Mora Series)

Figure 1: *Geological map of part of the northwestern Somaliland, showing the older rocks of the Qabri Bahar and Mora Complexes, and the Neoproterozoic rocks of the Mozambique orogenic belt, with important pegmatite localities. The younger rocks shown in yellow are Jurassic, Cretaceous and Tertiary sandstones, siltstones, limestones, evaporites and Tertiary to Quaternary basalts.*

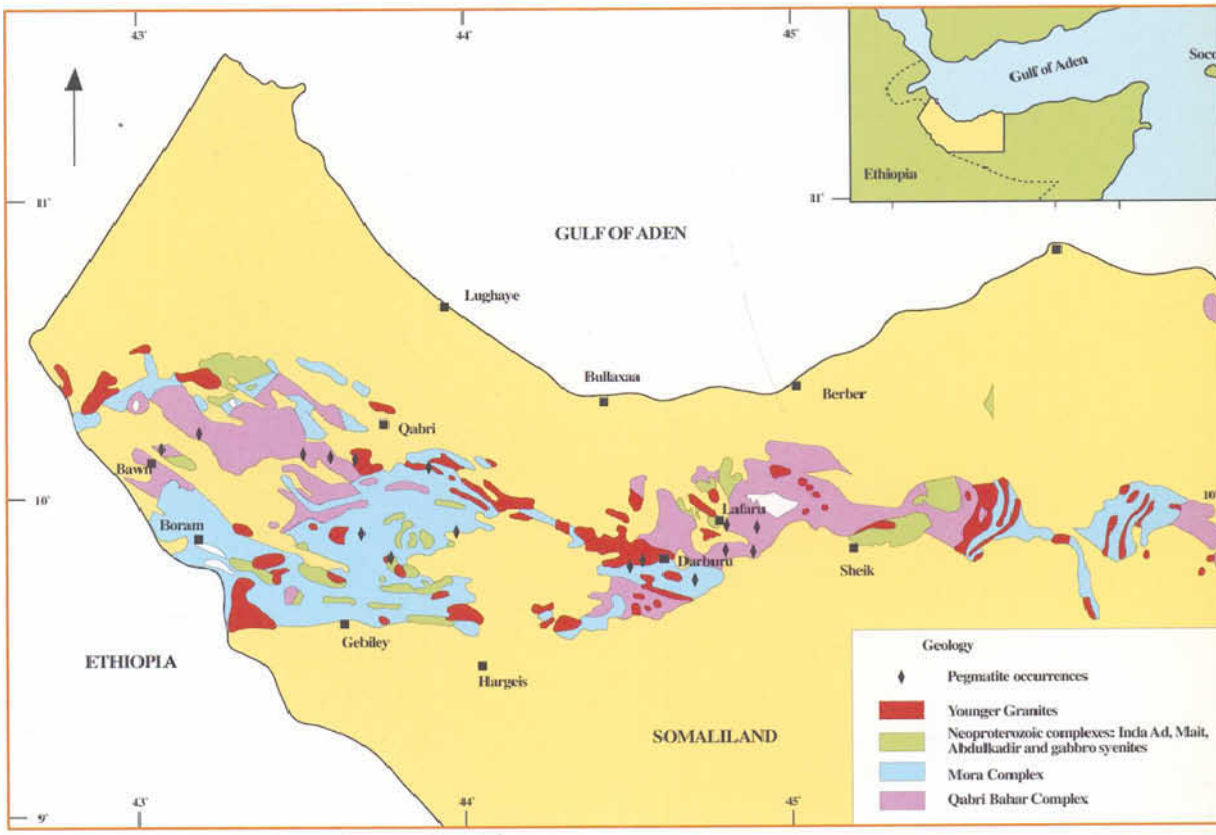

Table II: *The subdivisions of the Somaliland Basement.*

Chronometric subdivision	*Complex*	*Age*	*Lithologies*
Cambrian	Younger granite complexes	500 – 550 Ma (S)	Unfoliated subalkaline to alkaline granites with aplites and pegmatites; massive to foliated calc-alkaline granites.
Cambrian	Inda Ad Complex	500 – 550 Ma (S)	Low to very low grade metasedimentary turbiditic sequence of conglomerates, sandstones, silts and mudstones. The sequence has been interpreted as molasse sediments derived from erosion of a volcanic arc in Saudi Arabia (Abbate *et al.*, 1985).
Neoproterozoic	Mait Complex	640- Ma (S)	Pillow to massive basalts and associated deposits, muds and sands and occasional carbonate units which have been metamorphosed to greenschist facies to form a greenstone belt.
Neoproterozoic	Abdulkadir Complex	640 ± 67 Ma (S) 772 ± 40 Ma (S)	Volcano-sedimentary sequence with greenschist facies pelites and acid and basic volcanics which were deposited unconformably on the older Mora Complex (Warden and Daniels, 1983). Most of the contacts appear to be faulted.
Neoproterozoic	Gabbro-syenite	~700 Ma (F) 778 – 814 ± 7 Ma (K&S)	Deformation and low-grade metamorphism. Granitoid magmatism 720 Ma (K&S) to 697 Ma (Sassi *et al.*, 1989). Gabbros, diorites and syenites (778 – 814 ± 7) emplaced at a relatively high crustal level during crustal extension (Abdalla *et al.*, 1996) early minor alkaline granites at 842 ± 4 Ma (K&S).
Mesoproterozoic	Mora Series	1400 Ma	Dominantly marbles with metaquartzites and pelite intercalations.
?Mesoproterozoic	Borama-Ubali Pelitic Series (F)		Pelites with intercalated amphibolites.
?Mesoproterozoic	Gebile Psammitic Series (F)		Dominantly psammites with minor amphibolites, schists and marbles (Warden & Horkel, 1984).
Palaeoproterozoic	Qabri Bahar Complex	1710 Ma-1822 ± 5 Ma (K&S) migmatised at ~ 840 Ma	Medium to high grade, polymetamorphic basement of migmatites, gneisses, paragneisses, granite gneisses, amphibolites and rare calc-silicate rocks. Relics of granulite facies remain within a dominant amphibolite facies metamorphism retrograded to greenschist facies.

N.B. The terminology used is that of the Geological map of Somalia (1994), Frizzo (1993) (F in table), Warden and Horkel (1984). Age data from Sassi *et al.* (1989) (S in table) and Kröner and Sassi (1996) (K&S in table). The ages are not necessarily the complete time span of the series shown, but give ages of samples dated from the sequence. Chronometric subdivisions are from the International Commission on Stratigraphy (Plumb, 1991).

is dominated by carbonates with some sandstones and mudstones, which do not appear to have undergone the same multiphase deformation events. Field evidence suggests that the Mora Complex is in tectonic contact with the Quabri Bahar and the migmatites separating these two complexes are interpreted as a high strain zone. The Mora and Qabri Bahar Complexes were intruded by gabbro-syenite bodies (Daniels *et al.*, 1965) about 700 Ma ago (Ferrara *et al.*, 1987; Kröner and Sassi, 1996).

A second phase of plutonism affected the whole Precambrian basement in the period 550-500 Ma with the intrusion of two granitic series: an older, sometimes foliated series affected by a late orogenic deformation and a younger post-orogenic group which has associated aplitic and acid pegmatite intrusions (*Table II*). These pegmatite intrusions (very coarse-grained igneous rocks) are widespread (*Figure 1*) and are the main source-rocks of the gemstones found in Somaliland.

Pegmatites occur in two sectors in an east-west zone (*Figure 1*). In the western sector, which is approximately 30 km wide by about 100 km long, and extending from Bawn to northwest of Hargeisa, pegmatites cross-cut biotite and amphibole schists of the Mora Complex. The eastern sector lies between Hargeisa and Berbera, and is approximately 30 km wide and 50 km long (*Figure 1*). These pegmatites cross-cut migmatites, granitoids and paragneisses of the Qabri Bahar complex. Elsewhere scattered pegmatites occur, e.g. in the highest part of the Sheik pass south of Berbera, numerous pegmatites cross-cut the basement and comprise quartz, microcline and muscovite, with neither ores nor gem minerals.

The pegmatites occur in swarms, with individual bodies typically between 1 and 3 m wide and 100-200 m long, although the largest may exceed 1 km in length. Generally, they have a dyke-like form, dipping 70° to vertical, typically oriented NW-SE, NE-SW and N-S, sub parallel to the main faults. Irregular masses and pegmatitic sheets also occur but are less common than dykes.

Although most of the gemstones are recovered from the pegmatites, rubies and sapphires probably also occur in basalt flows in the Molis area, 50 km north of Hargeisa, although it proved logistically impossible to visit the locality. The opals, by analogy with the Ethiopian occurrences may come from rhyolite horizons within young volcanic rocks.

Pegmatite petrology

The majority of the pegmatites have a simple mineralogy comprising quartz and microcline with minor accessory muscovite, but some of the pegmatites are more complex and are clearly zoned. In the Hargeisa and Borama district these zoned bodies have an inner core of white quartz, which is typically several metres wide and up to 100 m long, surrounded by coarse-grained quartz, K-feldspar, albite and muscovite sometimes with accessory beryl and columbite, or garnet or zircon. There may be an outer zone of feldspar intergrown with wedge shaped quartz. Although the core widens at depth, beryl disappears. In some pegmatites the quartz core is transparent rock crystal which has potential for its piezo-electric nature, and

Figure 2: *Gem-bearing pegmatites can be seen on the hillside near Heiwena as thin white cross-cutting bands. Eastern Daarburuq-Larfarug pegmatite area.*

Figure 3: Working in an aquamarine-bearing pegmatite near Heinwena with an iron bar, the only tool available at the site apart from a pick-axe.

in the period 1977-78, at one locality, 200 tonnes of pure quartz were extracted from a trench 5-6 m deep. In other pegmatites, coarse crystalline amethyst may occur in vugs in the central core, associated with smoky quartz.

Clearly, the pegmatites are of more than one type. For example, in the Aliheley area north of Bawn, there are two types exposed, one of which is very white, quartz-poor, saccharoidal feldspathic pegmatite with emerald and aquamarine, while the other is pink, coarser-textured, more quartz-rich with accessory coarse zircon and garnet.

Figure 4: View across an emerald site at Aliheley, north of Bawn. This was the only site visited with a compressor and a range of equipment.

Recovery of the gem-quality minerals

Most gemstones in Somaliland are being extracted from solid unweathered rock, often with primitive tools such as pry bars made from car axles (*Figure 3*). Extraction is all the more difficult because the pegmatites are very hard and have not undergone the process of albitisation like the gem-bearing pegmatites in Nigeria for example, which has rendered the feldspar soft and crumbly. Explosives are hardly available, and only in one locality of more than 30 visited, was a compressor being used (*Figure 4*). Extraction is extremely hard work, and as money is so very limited, even protective gloves are too expensive to buy. The open pits are typically less than 5 m deep and recovery is by simple hammering and hand-picking of the crystals, many of which are damaged in the process. Any production estimates of the gemstone varieties would at present be very speculative.

Description of minerals and gemstones from Somaliland

Beryl

Beryl occurs as euhedral crystals up to 1 m long and 30 cm across. It appears that wherever milky white quartz occurs in large masses, beryl is also present. Only small parts of many beryl crystals are transparent, but some are zoned with a blue core and

Figure 5: Emeralds being extracted at Aliheley. Stringers of pegmatite facies form fingers into the friable black biotite-schist. The majority of emeralds occur within the schists close to the contact with the pegmatite band or the pegmatitic fingers.

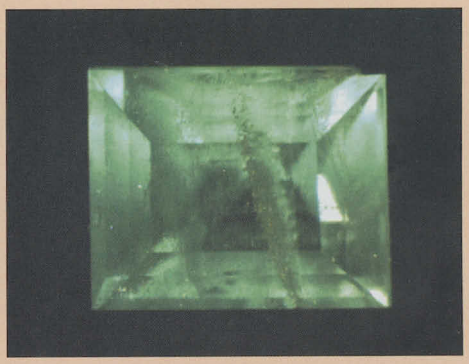

Emeralds from Aliheley

Figure 6 (above): *Mid-green emerald partly covered with flecks of phlogopite.*

Figure 7 (above right): *A cut emerald weighing 0.15 ct showing two-phase growth disturbance swathes.*

Figure 8 (right): *Rounded phlogophite inclusions in emerald.*

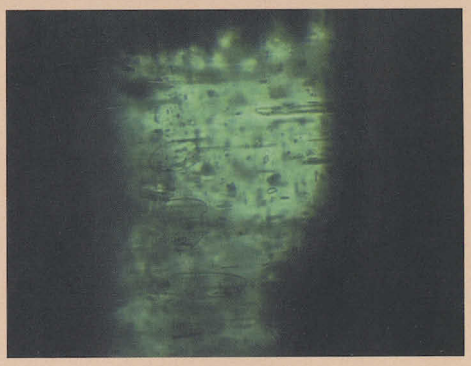

white rim. Green varieties occur on the margin of the pegmatites, while blue beryl occurs in the quartz core.

Emeralds have been encountered in pegmatites in both the western pegmatite sector, and in the eastern Lafarug sector. However, emeralds are much more abundant in the west where pegmatites cut biotite and amphibole schists of the Mora Complex than in eastern Daarburug-Lafarug pegmatite belt, where the pegmatites cross-cut the Qabri Bahar complex. The chromophores (chromium, and more rarely vanadium), that are responsible for the coloration of emerald are of low concentration in pegmatitic fluids, and these colouring agents are more likely to have been derived from the mafic-ultramafic basement, so it is where the pegmatites cut biotite-rich schists of the Mora Complex that the emerald localities are more common. In the Aliheley area northwest of Bawn, near the Djibouti road, where there are two types of pegmatites; the emeralds appear to be associated with the later, whitish pegmatites. Stringers of this pegmatite facies form fingers into the friable black biotite-rich schist *(Figure 5)* where the emerald crystals often have a thin coating of phlogophite *(Figure 6)*. The emeralds are a mid-green colour *(Figure 7)* and lack the depth of colour and clarity of the finest Colombian emeralds. Typically, the colour distribution is irregular; e.g. a 17 mm diameter emerald crystal from Bawn has a pale yellow beryl core and a 3 mm rim of emerald. Stones are flawed with natural cracks and inclusions, and a 0.15 ct cut stone contained two phase growth disturbance zones *(Figure 7)* and thin platy crystals of phlogopite *(Figure 8)*. This stone had refractive indices of 1.568 - 1.574, a bi-refringence of 0.006, and a specific gravity of 2.76. In contrast to the zoned crystal which was inert, this stone showed red under the Chelsea colour filter signifying a greater chromium content.

Aquamarine is more abundant than emerald. Commonly it occurs as perfectly-shaped hexagonal crystals in the milky quartz core of pegmatite particularly in the Heinweina area to the east of Larfarug where crystals in excess of 8 cm have been recorded. The hardness of the quartz makes it difficult to extract the aquamarine without damage and furthermore, the aquamarines are characterized by numerous cracks across the crystal. These cracks are a natural characteristic of the aquamarines and have nothing to do with the rough mining methods, but nevertheless, they affect the potential size of any cut stones. Irregular colour distribution is also a natural characteristic of the stones, caused by the variation in iron content throughout the crystal. The colours of the crystals examined range from medium blue to pale pastel hues (*Figure 9*). A 0.18 ct cut stone, for example, still retains a good but pale tone (*Figure 10*); it has RIs of 1.572 and 1.579, birefringence of 0.007 and an SG of 2.69.

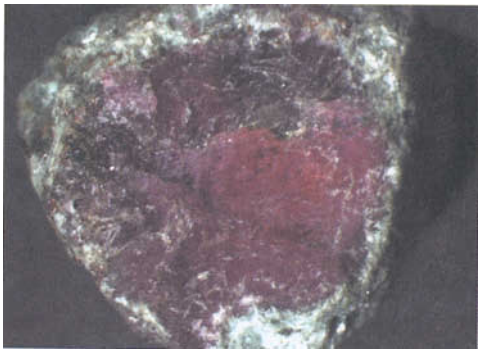

Figure 11: *Translucent ruby crystal, 1 cm in diameter, surrounded by fuchsite, a chrome-bearing muscovite.*

Corundum

Sapphires are generally dark green and translucent rather than transparent because of the large number of inclusions. Although most of the sapphire in Somaliland is not particularly transparent or deep blue, some of the material should be tested with heat to determine whether a deep blue colour enhancement can be obtained. Bluish corundum, has been observed in a quartz-poor, muscovite-rich pegmatite west of Hargeisa on the Gebily road. Many of the crystal fragments however, which were shown by traders in Hargeisa, showed residual truncated hexagonal pyramidal faces and smooth resorption features characteristic of corundum from alkali basalts rather than from pegmatites.

Ruby: some Somaliland ruby is of good quality although both ruby and sapphire seem less abundant than emerald and aquamarine. The rubies are typically colour banded with natural cracks and inclusions, and are often surrounded by a rim of dark amphibole or a bright green rim, presumed to be zoisite. This is very similar to the ruby in chromiferous zoisite amphibolites known from the Matabatu Mountains near Longido in Tanzania (Keller, 1992). In Tanzania, ruby-bearing amphibolites are intimately

associated with serpentine and the latter rock type may act as indicator for similar ruby deposits in Somaliland. Another similar ruby specimen was found to be coated with the green chromium muscovite fuchsite, and associated with tiny grains of red rutile (*Figure 11*).

Garnets

Garnets are very abundant in Somaliland. A range of crystal sizes, colours and clarities has been seen in the collections of various traders. Crystals often show a perfect dodecahedral form (*Figure 12*), and these may be more valuable sold as mineral specimens than as potential gemstones. Colours range from light orange, through pink, cherry red and dark red, to purple and almost black. Garnet compositions were determined by electron probe microanalysis (EPMA), and the data in *Table III* of three average compositions from 41 analyses illustrate their compositional range. In *Table III*, GI is the average of 14 analyses of a deep orange-red stone which is a grossular (*Figure 13*); G2 (average of 18 analyses), is a pyrope of a deep red colour characteristic of this variety (*Figure 14*); whilst G3 (average of 9 analyses), is a scarlet red stone compositionally intermediate between pyrope and almandine (*Figure 15*). Specimens G2 and G3 showed iron

Figure 12: *Rough grossular garnet and fragment of dodecahedron, 5-6 mm in diameter.*

Figure 13 (below): *Orange-red grossular garnet (sample G1), 1.15 ct.*

Figure 14 (right, top): *Deep red pyrope garnet (sample G2) 0.77 ct.*

Figure 15 (right, bottom): *Bright red pyrope almandine garnet (sample G3), 1.01 ct.*

Figure 16: *A cluster of parallel tubular, partially liquid-filled inclusions in sample G1.*

absorption spectra characteristic of almandine; the intensity of the spectrum increasing with increasing iron content.

Elongate tubular inclusions that are partially filled with liquid are confined to one orientation (*Figure 16*), while exsolved rutile or boehmite are oriented parallel to the dodecahedral faces.

Green garnets have also been reported and tiny green glassy garnets were observed in the field in a calc-silicate body to the NE of Hargeisa. These occurred as bright green crystals, up to 4 mm across, in a variegated matrix of diopside and calcite; they have been identified by X-ray diffraction analysis as grossular.

This grossular is similar to the tsavorite garnets from Kenya which suggests that there is gem potential for this garnet if larger pieces exist.

The wide-range of garnet compositions indicates that they are not all from pegmatitic rocks. Pyrope may have been derived from ultramafic intrusions, or high-grade metamorphic basement rocks, whilst some of the almandine may also have been derived from amphibolite-grade metamorphic terrain.

Table III: *Composition of Somaliland garnets.*

	G1	*G2*	*G3*
SiO_2	38.78	41.79	40.19
TiO_2	0.71	0.06	0.03
Al_2O_3	19.97	23.28	22.56
Cr_2O_3	0.01	0.09	0.04
Fe_2O_3	3.42	0.35	0.32
FeO	1.21	9.54	20.07
MnO	0.12	0.27	0.54
MgO	0.12	17.95	12.68
CaO	35.49	6.30	3.80
Total	99.82	99.63	100.22
Formula based on 24 Oxygens			
Si^{4+}	5.92	6.00	5.99
Ti^{4+}	0.08	0.01	0.00
Al^{3+}	3.59	3.94	3.97
Cr^{3+}	0.00	0.01	0.01
Fe^{3+}	0.39	0.04	0.04
Fe^{2+}	0.15	1.15	2.50
Mn^{2+}	0.02	0.03	0.07
Mg^{2+}	0.03	0.85	2.82
Ca^{2+}	5.81	0.97	0.61
Sum: cations	16.00	15.99	16.00
End member proportions			
Pyrope	0.44	64.16	47.01
Almandine	2.57	19.13	41.74
Spessartine	0.27	0.54	1.13
Andradite	9.86	0.92	0.90
Uvarovite	0.01	0.27	0.13
Grossular	86.85	14.98	9.08

N.B. G1 is the mean of 14 analyses, G2 of 18 analyses and G3 of 9 analyses. Microprobe analyses were carried out by Dr P. Hill of the Department of Geology, University of Edinburgh.

Opal

Examples of both common opal and precious opal have been seen in Hargeisa. The opal nodules range from 1-5 cm in diameter - like golf-balls, and vary from white to yellow, orange or red fire opal. Although the opals were not seen *in situ*, they are known to originate from a locality which lies between Borama and the coast. The opals display a small amount of play of colours (*Figure 17*) and would make fine cabochon gems. However, some of this

Figure 17 (above): Two opals, 25 mm and 42 mm across. The orange piece shows a little green fire in the top left.

Figure 18 (right): Opal nodule, 6 mm across, with crust.

material which was cobbed for cutting, developed fractures within a short time.

The Somali opals bear a remarkable similarity to opal from Shewa Province in Ethiopia, some 300 km to the west (Johnson *et al.*, 1996) which range in colour from near colourless or white, to yellow, orange, grey or brown and are typically 10 cm in diameter. Both Ethiopian and Somali opals are nodular with a 1-5 mm crust (*Figure 18*). Qualitative EDXRF on Somali samples showed the presence of calcium, iron, strontium, zirconium, potassium, niobium and sulphur as trace elements. These data are almost identical to the trace elements reported from the Ethiopian material (Johnson *et al.*, 1996) and suggest a related paragenesis.

The Ethiopian opals occur as nodules in acid volcanic rocks in a layer of welded tuff (approaching obsidian in character) about 3 m thick, between sub-horizontal rhyolite layers. The volcanic pile is 300-400 m thick and believed to be of Miocene age (8-27 Ma). Similar Miocene volcanic rocks occur in Somaliland west of Cabdulqaadir near the border with Djibouti (Abbate *et al.*, 1993). Within extensive basalt flows there are rare intercalated rhyolites, but whether these are

the source of the Somali opals is not known. A full review of the stability and durability of the opal will be required before serious development can be initiated on proven reserves but nevertheless, the Somali material is likely to drift onto the market as a result of small scale mining.

Amethyst

Amethyst occurs in the quartz core of numerous pegmatites. Often it is somewhat banded in colour, or the deep purple coloration is patchy. In general, the mineral is rather pale and of low value as a gemstone, although it would make excellent beads. However, intensely purple amethyst of exceptionally fine quality has been shown, and was said to come from the Molis area just north of Hargeisa.

Chrome diopside

Chrome diopside occurs in fragments which may exceed 3 cm. Larger masses tend to be bottle green to greenish black. Smaller fragments are transparent and may be a lovely emerald green colour. This is known from other localities in East Africa as well, although the African deposits are until now quite small compared to those in Russia which is the major source.

Epidote

Epidote occurs as dark green or brown crystals in a number of localities. They are always confused for tourmaline. The identification of one transparent brown crystal as epidote was confirmed by FTIR.

Figure 19: *Four titanite fragments, the largest crystal is 9 mm across.*

Figure 20: *Vesuvianite with colour-banding.*

Spinel

Spinel occurs quite widely. Deep wine-red spinels, often mistaken for garnet or ruby by the locals, seem moderately abundant although not all will have come from the pegmatites. A bag of small sapphire crystals contained a few black spinel and augite fragments. On examination by EDXRF and FTIR the spinels proved to be 'pleonaste' with an SG of 3.82.

Titanite

Four yellowish-green crystals up to 10 mm were reported to have come from a pegmatite; these had good clarity and were thick enough to cut stones 3-5 mm in depth (*Figure 19*).

Topaz

Large colourless transparent crystals of topaz up to 10 cm in length have been shown by several traders although they were not observed *in situ* by the authors.

Tourmaline

Although tourmaline has been described as an accessory in pegmatites in old Survey reports, it did not appear in the collections shown, nor was it observed in any of the pegmatites visited in the field. Epidote or chrome diopside were always identified as tourmaline by the locals.

Vesuvianite

Vesuvianite occurs as abundant aggregates of coarse grey-purple to greenish-

yellow elongate crystals in the same calcareous body which hosts the green grossular garnet. The vesuvianite crystals are mainly translucent although parts of the crystals are transparent and of gem quality. The largest single crystal examined was 40 x 15 mm and showed strong colour zoning in apple green and pale lavender (*Figure 20*). Parti-coloured gem-quality material could be particularly desirable, but the group that work this deposit are completely unaware of the potential of this mineral.

Zircon

Zircon appears to be quite widespread in occurrence in Somaliland. It varies from colourless to pale orange brown to deep red.

The development of the Mozambique orogenic belt

The deformation of Proterozoic rocks in Somaliland between 800 and 500 Ma ago, was part of a wider sequence of tectono-thermal events which has also been recognised on other continents. In relatively simple terms, rifting of a large continental mass (Rodinia) 900-850 Ma ago led to the formation of the 'Mozambique Ocean' (Abdelsalam and Stern, 1996) which then began to close again around 800 Ma. Crustal shortening led to NNW-trending continental folding on a regional scale which was linked to a high temperature metamorphic event (amphibolite to granulite facies), during the collision of West Gondwana (Africa and South America) and East Gondwana (India, Antarctica etc.) to form what is now known as the *Mozambique orogenic belt* (*Figure 21*). This belt forms the suture zone along which the final amalgamation of various continental fragments took place as a result of subduction of the 'Mozambique Ocean' floor. The timing of the tectono-thermal event varies. In the northern part of the belt in Somaliland, the event has been dated around 800 Ma (Dal Piaz *et al.*, 1987), with similar dates of 808 ± 6 provided by Stern (1994), and 828 ± 170 by Abbate *et al.* (1985). In Tanzania zircon age dates for the event are

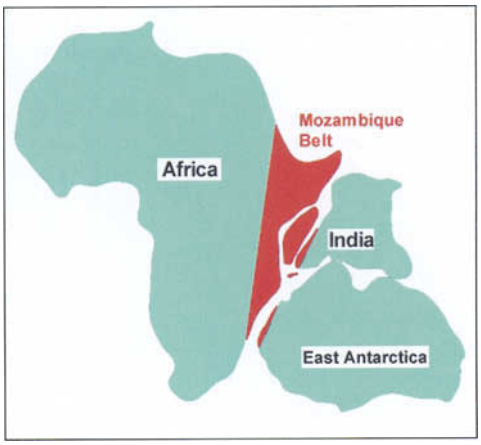

Figure 21: *Extension of the Mozambique orogenic belt from Mozambique through Tanzania and Kenya and extending into Somaliland. Note how the reconstruction includes Madagascar, part of India, Sri Lanka and East Antarctica within the Mozambique belt. Reconstruction based on Dalziel (1991) and Shackleton (1996).*

somewhat younger (720 and 640 Ma; Kröner *et al.*, 1997), whilst the culmination of metamorphism in Mozambique has been dated as 615 Ma and in Malawi at 550-575 Ma (Kröner *et al.*, 1997).

The belt averages between 250 and 325 km in width and extends from Mozambique and Tanzania, northwards to Ethiopia, Somaliland and into Saudi Arabia. It also includes rocks within Madagascar (Malisa and Muhongo, 1990), Eastern Antarctica (Dalziel, 1991; Shackleton, 1996), India (Choudhary *et al.*, 1992) and Sri Lanka (Harris *et al.*, 1996).

Although igneous activity has occurred in the Mozambique belt, both during periods of extension and compression, it is the emplacement of late stage granites, intruded after continental collision which are important for the genesis of gem-bearing pegmatites in eastern Africa. The most intense period of potassic granite intrusions occurred between 585 and 540 Ma (Küster and Harms, 1998), largely coinciding with the peak of temperature metamorphism in Madagascar and with regression to lower

temperature amphibolite facies in north-eastern Africa (Somaliland and Sudan). According to Küster and Harms (1998), the high temperature metamorphism and late-stage granitic magmatism are probably both related to post-collisional lithosperic thinning, magmatic underplating and crustal relaxation. However, the emplacement of potassic granites continued until 470 Ma and implies several magmatic episodes associated with different phases of post-orogenic crustal uplift after collision. Rb-Sr and K-Ar cooling ages for micas from granites in southern India (Soman *et al.*, 1982, Unnikrishnan-Warrier *et al.*, 1995) and Sri Lanka (Burton and O'Nions, 1990) which vary between 490 and 450 suggest that post-collisional uplift and cooling occurred much earlier in the northwest of the orogenic belt.

Comparison with other African gem occurrences within the Mozambique belt

Keller (1992), defined four categories of gem deposits within the Mozambique Belt in Kenya and Tanzania, according to their paragenesis:

1. Desilicification of granitic pegmatites or gneisses by ultramafic rocks resulting in the formation of ruby, sapphire, spinel, emerald, alexandrite and tourmaline.
2. Medium- to high-grade metamorphism of carbonates closely associated with graphite gneisses that provide the chemistry for the formation of tsavorite garnet, tanzanite and other gemstones.
3. Emplacement of lithium and beryllium-rich granite pegmatites with tourmalines, beryl, quartz, phenakite and euclase.
4. Hydrothermal alteration of serpentinites and other ultramafic rocks resulting in the formation of peridot, chrysoprase, prase-opal and rhodonite at much lower temperatures.

The first three of Keller's categories have definite equivalents in Somaliland. The majority of the emerald/aquamarine-bearing pegmatites in Somaliland would correlate with category 3 of Keller (1992), although no lithium-bearing minerals have been noted so far. The granitic pegmatites intruded into ultramafic rocks of the Bawn area would equate with category 1 of Keller (1992). These emerald-bearing pegmatites cut exceptionally biotite-rich rocks, which are interpreted to be ultramafic in origin. Limestones to the north of Bawn and NW of Hargeisa, which have undergone medium to high grade metamorphism, have a paragenesis similar to category 2 of Keller (1992). Although, no 'tsavorite' garnets, have been located, tiny crystals of green grossular have been identified from a thin calc-silicate horizon NE of Hargeisa. Purple vesuvianite, green diopside, scapolite and other minerals have also been identified in the same area so there is potential for 'tanzanite' and similar minerals. As yet no equivalents of Keller's category 4 are known, although the Abdul Qadr Complex has been identified as an ophiolite fragment (Berhe, 1990) and so typical source rocks for category 4 occurrences do exist within the area.

Conclusions

The gem deposits of the Mozambique belt in Kenya and Tanzania have been well documented by Keller (1992). Malisa and Muhongo (1990) have noted the extent of the Mozambique belt in eastern Gondwana and highlight the gem occurrences within Sri Lanka, India and Madagascar. The recognition of the extension of the Mozambique belt into Somaliland is therefore of considerable interest as it means that there is a potential for the production of a wide range of gemstones. This has important implications for the Somaliland economy, although the Somali producers need external help to maximize the potential. They need help to recognize the importance of geological factors, such as controls on emerald formation, to identify minerals using simple physical tests and to appreciate the value of different gem minerals. In particular, they need support with the marketing of gemstones as this will help to provide the funding they need to buy equipment to develop their prospects.

Acknowledgements

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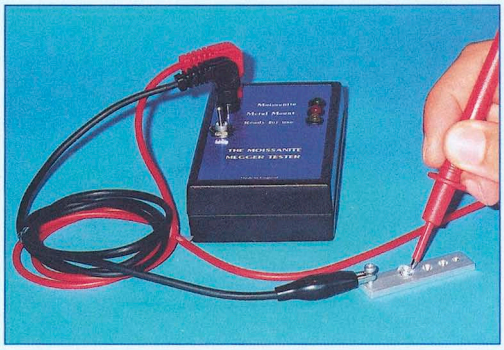

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The Hanneman Refractometer

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ABSTRACT: The description of a very simple and very inexpensive refractometer of unlimited range for faceted stones is described. This instrument and the Hanneman specific gravity balance provide the basic tools for the student wishing to master gemstone identification.

Introduction

The two most useful physical properties for gemstone identification are specific gravity and refractive index. It is imperative that every gemmological student fully understands these principles and the means by which they can be determined.

For many years, the measurement of specific gravity was hampered by the lack of an inexpensive balance having the required sensitivity to handle small gems. Additionally, there were mathematical calculations involved. These problems were solved by the development of the Hanneman Balance (Anderson, 1980; Hanneman, 1998, pp. 50-64).

Refractive index measurements are frequently performed by rote by students using a critical angle refractometer which has an upper range limit of 1.81. An alternative, the inexpensive Hanneman-Hodgkinson refractometer (Hodgkinson, 1995, pp. 25-32; Hanneman, 1998, pp. 70-83), presented the student with a visual demonstration of the optical properties of transparent gemstones. This included the determination of refractive index, birefringence and dispersion. It also extended the RI range to about 2.37.

The basic principles of this technique were first expounded in a discussion of a pinhole refractometer (Hanneman, 1982). This present paper describes a logical extension of that concept which has culminated in a new unlimited range refractometer. Surprisingly, it can be constructed by any student at a cost of only a few pennies. Because of the educational features offered by this instrument, the author believes a treatment of the concept should be incorporated into the basic programme of every gemmological student.

Background

While visiting Alan Hodgkinson in May 1999, I witnessed a demonstration of a modified version of Dr Jamie Nelson's Pavilion Facet Fingerprinter (Hodgkinson, 1999). This incorporated a liquid immersion cell and was used to demonstrate the high refractive index and dispersion of synthetic moissanite.

I immediately recognized that this was essentially a pinhole refractometer. The immersion liquid allowed for an effective reduction of the refractive index of the test zone so that the 2.37 limit for round brilliant-cut gems which was imposed by air could be raised considerably and cover all gemstones.

The limit can be raised by a value equal to the difference between the refractive index of the liquid and that of air (n_D=1.000). Use of water n_D=1.333 could raise the limit by 0.333 to a value of 2.70, or use of baby oil (n_D=1.465) could raise the limit to above 2.8. Use of methylene iodide (n_D=1.74) could raise the limit above 3.00.

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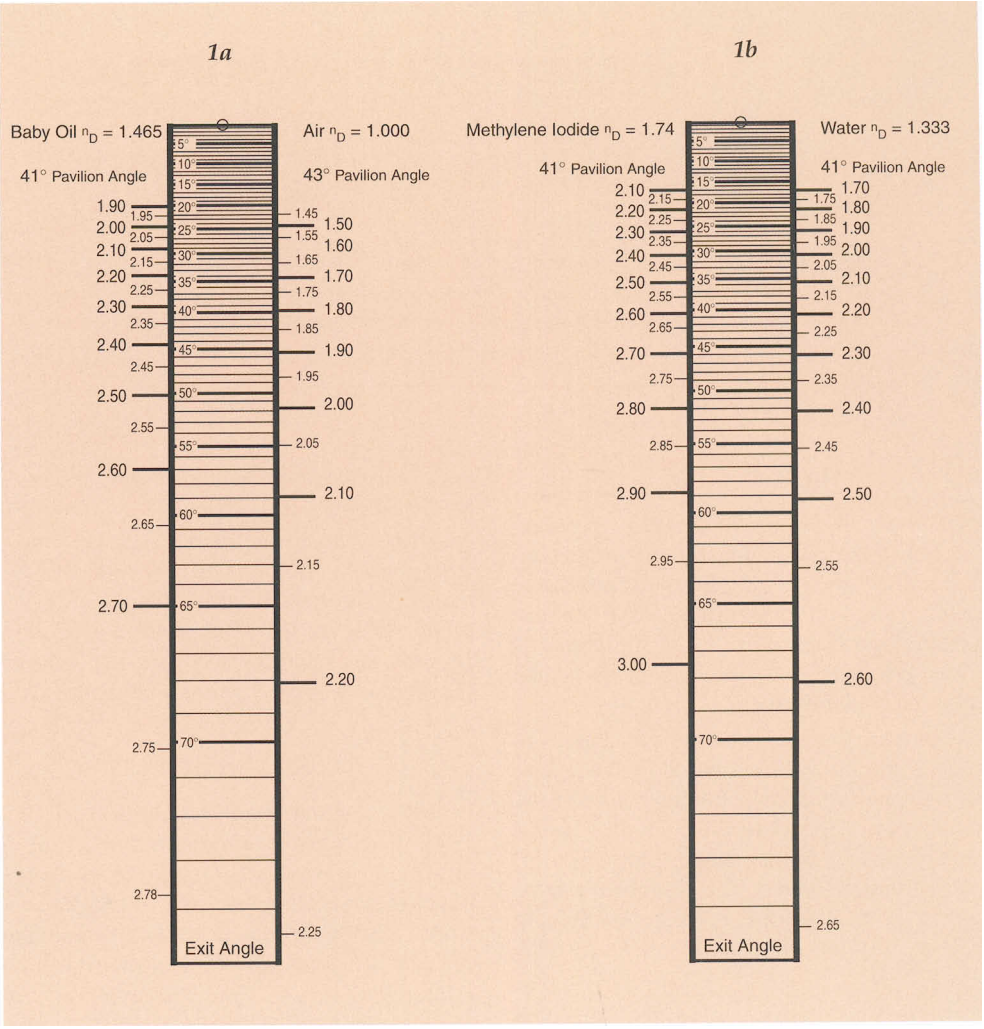

Figure 1: *Hanneman Refractometer scales* ***(a)*** *for baby oil and air for specified pavilion angles* ***and (b)*** *for methylene iodide and water for a 41° pavilion angle.*

Using the Hanneman Refractometer Conversion Tables which had been calculated from the equation in Hanneman (1982) to relate exit angle to refractive index, the refractometer scales shown in *Figures 1(a)* and *(b)* were constructed. A schematic diagram of the refractometer is shown in *Figure 2* and an example in *Figure 3*. The scales can be enlarged to any size for the purpose of improving accuracy or readability. It is important that the height of the stone above the scale exactly matches the distance between the origin and the 45 degree line on the scale.

The refractive index (n_D) is determined from the position of the yellow region of the spectral image. A monochromatic filter can be employed if desired. Birefringence is determined as the difference in refractive index value (n_D) of the two images exhibited by doubly refractive gems.

It should be noted that the scales are calibrated in terms of index of refraction (n)

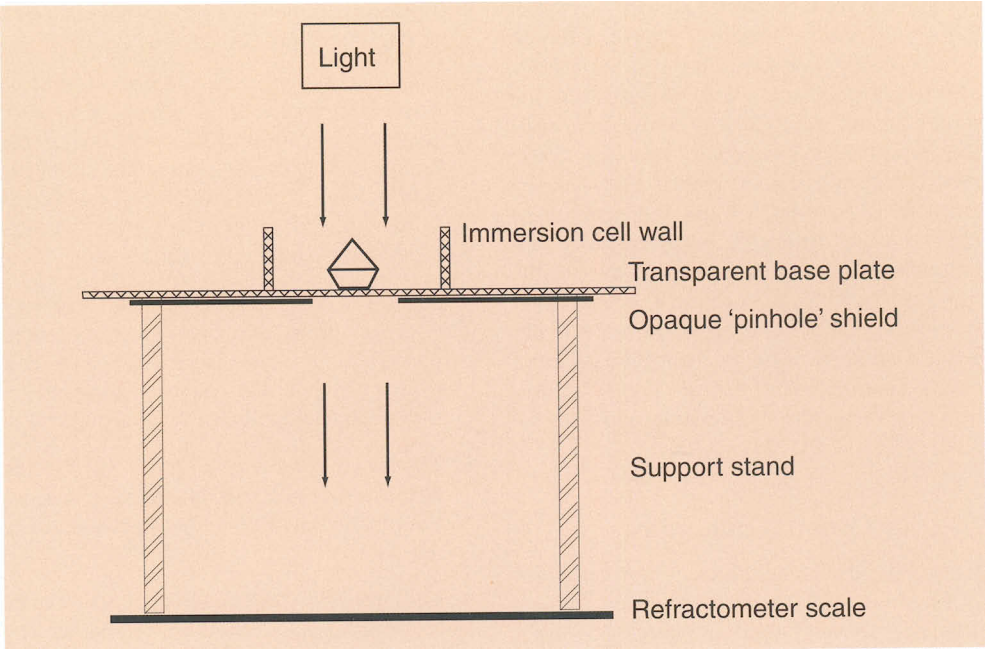

Figure 2: *Cross section diagram of Hanneman Refractometer at scale origin.*

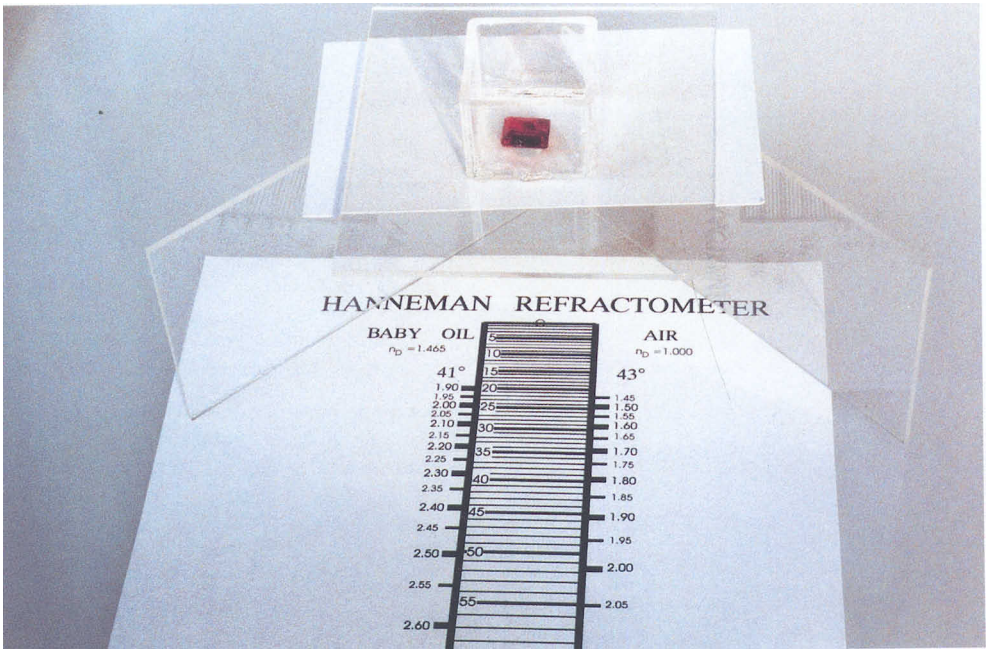

Figure 3: *Hanneman Refractometer stone holder and scale. Exit angle measurements are converted to values of 'n' by means of the Hanneman Refractometer Conversion Tables according to the pavilion angle of the sample.*

and not refractive index (n_D), as in the case of the critical angle refractometer. Consequently, one can determine the index of refraction for any colour of light that one might desire. This allows one to determine the gemmologist's value of dispersion. To do this, determine the difference between the extreme values (n) for the red and violet which can be observed. Then, multiply that value by 0.71. The extremes of the visible spectrum which are measured here extend from 760 to 397 nm (Fraunhofer lines A to H), while dispersion is defined over the range of B to G, i.e. from 687 to 431 nm. The 0.71 factor is derived from the relationship (687 - 381) / (760 - 397) = 256 / 363 = 0.705.

Construction notes

1. Any light source will do. A bare bulb and filament will produce sharper images than a frosted bulb or fibre-optic light pipe. A penlight torch is perfectly adequate.
2. Depending on the intensity of the light source, it may be necessary to shield the refractometer scale from extraneous light. A darkened room is ideal.
3. For general purposes, the hole should be large enough to allow a ring of light to form a halo around the shadow of the gem which is centered over the O on the origin line. A piece of white cardboard with a hole punched in its centre serves as a perfectly adequate opaque plate.
4. A sheet of polarizing material can be placed over the gem and rotated in order to observe or measure birefringence. A lens from a pair of broken polarizing sunglasses is perfectly adequate for this purpose.
5. The transparent plate and the walls of the liquid container can be fabricated from the plastic cover of a 'compact recording disc'.
6. The support for the transparent plate can be constructed from anything available. The only important feature is that its height must be such that the bottom of the gem (top of the plate) is exactly the height above the scale as the distance between the origin and the 45 degree line on the scale.

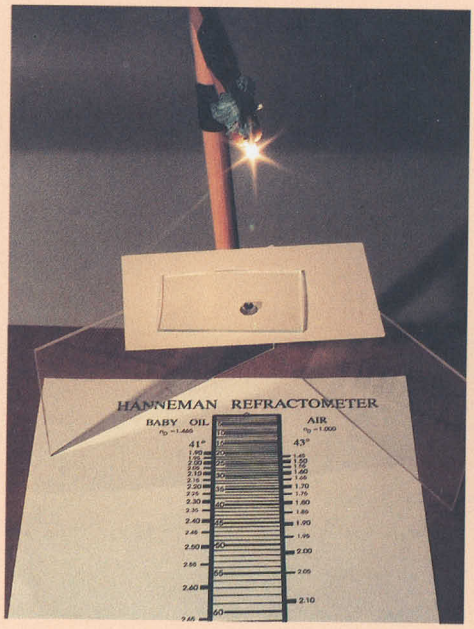

Figure 4a: Hanneman Refractometer set up to examine a round brilliant-cut CZ in air (no immersion liquid). Illuminated by a SIC (Standard Image Candle of 1 candle-power).

Figure 4b: Appearance of refracted images of CZ in a darkened room with the SIC light shielded. Photographic limitations prevent the long blue and violet portions of the spectrum from appearing. They are readily visible by eye.

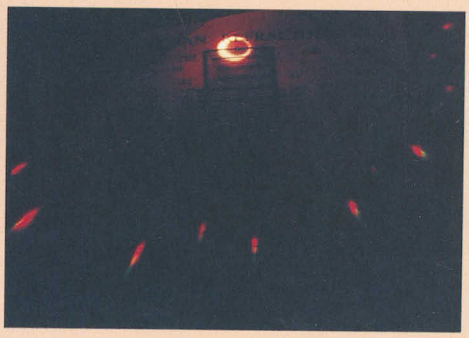

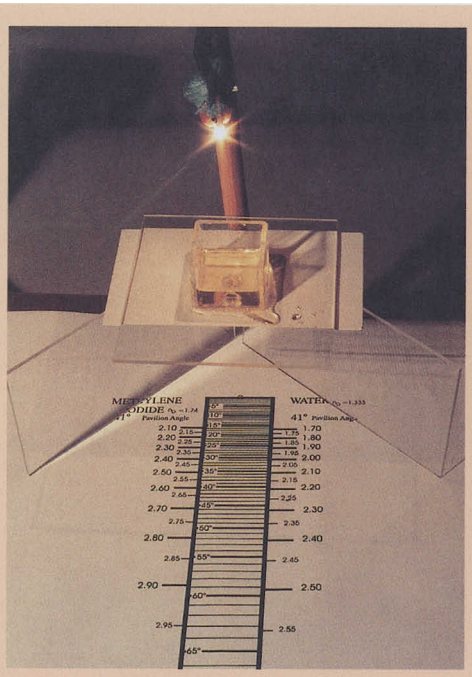

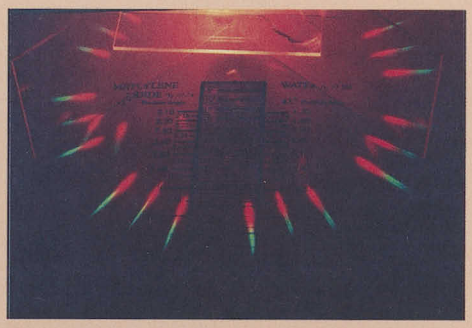

Figure 5a: *Hanneman Refractometer set up to examine a round brilliant-cut synthetic rutile immersed in methylene iodide. Illuminated by a SIC (Standard Image Candle of 1 candle power).*

Figure 5b: *Appearance of refracted images from synthetic rutile in a darkened room with the SIC light shielded. Note the extreme dispersion exhibited by the synthetic rutile. Each image consists of two overlapping images which must be separated by means of the polarizing filter in order to measure the dispersion.*

Figure 5c: *Appearance of refracted images from a diamond in a darkened room with the SIC light shielded. Photographic limitations prevent the long blue and violet portions of the spectrum from appearing. They are readily visible by eye.*

Operation notes

1. Set up the refractometer as shown in *Figures* 2 and 3. While it is obvious that the most precise and accurate results can only be obtained by carefully aligning and rigidly securing all the component parts and the light source, results adequate for most confirmatory purposes and for teaching demonstrations can be obtained by merely assembling the components and using a hand-held penlight (torch).

2. Place a round brilliant cut-gem on the transparent plate and adjust the plate, the light, and the opaque plate with the pinhole, so that the light shines directly down onto the gem, through the hole, and produces a small bright halo around the shadow of the gem which is centered over the O on the origin line of the scale (*Figure 4a*). A symmetrical circle or circles of spectral images should appear concentric to the O (*Figure 4b*). If a different shaped gem is used, the images will correspond to the design of its pavilion facets. The arrangement and results from synthetic rutile and diamond are shown in *Figure* 5.

3. Adjust the gem so that the image you wish to examine falls along an imaginary centre line of the scale.

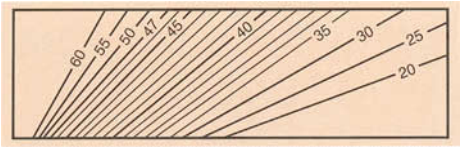

Figure 6: *Protractor for estimating crown and pavilion angles.*

4. Read the scale. Almost all faceted gems have at least one set of pavilions facets cut at angles between 41 and 43 degrees. For general purposes, two calibrations have been provided. The one on the right of *Figure 1a* is for use with no liquid and assumes a 43 degree pavilion angle. This is a common angle used for lower refractive index gems. The scale on the left requires immersion in baby oil and assumes a pavilion angle of 41 degrees which is common for round brilliant cuts of higher refractive index gems. Higher index gems can be immersed in di-iodomethane (methylene iodide) and measured on the scale in *Figure 1b*.

5. The most accurate results can be obtained by (i) accurately measuring the angle of the facet producing the image by means of a protractor like that shown in *Figure 6*, (ii) using an enlarged scale for a more precise reading of the exit angle, and (iii) converting the measured exit angle to the refractive index using the Hanneman Refractometer Conversion Tables. However, none of these refinements are necessary to impart the basic principles to a student.

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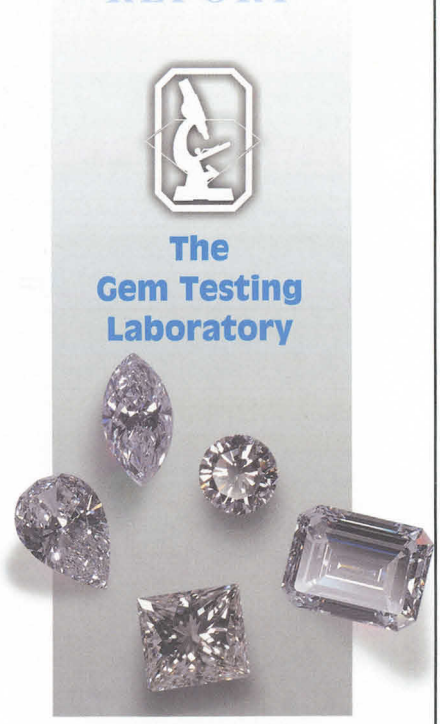

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The cause of colour of the blue alexandrites from Malacacheta, Minas Gerais, Brazil

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ABSTRACT: A rare and very attractive variety of chrysoberyl, a blue alexandrite from Malacacheta, Minas Gerais (Brazil), commercially called 'peacock-blue' alexandrite, was investigated by electron paramagnetic resonance (EPR), optical absorption, photoluminescence and X-ray photoelectron spectroscopy (XPS). The peacock-blue alexandrite is known for its strong pleochroism ranging from blue to green or greenish-yellow, as well as its strong colour-changing effect showing blue or greenish-blue in daylight and reddish-purple in incandescent light. The results show that the rare bluish colours of the peacock-blue alexandrite are related to a critical balance between Fe^{3+} and Cr^{3+} substituting for Al^{3+} in the sites with mirror symmetry, while the concentration of Cr^{3+} in the sites with inversion symmetry is negligible.

Introduction

Most gemstones owe their colours to transition metal ions dispersed in the crystalline matrix. Such ions give rise to, in the presence of a strong ligand field, absorption bands in the visible spectral range. A classical example is the Cr^{3+} impurity in an octahedron formed by six oxygen atoms that, depending on the strength of the ligand field, causes both the deep red colour of ruby (Al_2O_3) and the vivid grass-green of emerald ($Be_3Al_2Si_6O_{18}$) (Nassau, 1983).

When the octahedral ligand field is intermediate in strength between that in ruby and that in emerald, a very interesting phenomenon occurs. That is the case of the very rare and highly prized alexandrite. This gemstone can have both the green colour of emerald and the red colour of ruby depending on the illumination conditions (daylight or incandescent light, respectively). Alexandrite is a variety of chrysoberyl, a beryllium aluminate gem mineral structurally isomorphous with the olivine family and with an ideal chemical composition $BeAl_2O_4$ (Bragg and Brown, 1926). Unlike the more common iron-bearing yellow chrysoberyl, alexandrite also contains Cr^{3+} that substitutes for $A1^{3+}$ (*Figure 1*).

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Figure 1: *Chrysoberyl crystals from Malacacheta photographed in incandescent light.*

The colour-changing effect, or the 'alexandrite-effect' (White *et al.*, 1967) as it is referred to nowadays, is attributed to two broad absorption bands belonging to Cr^{3+} substituting Al^{3+}. Their maxima are at approximately 400 nm (violet-blue) and 600 nm (yellow-orange) with a transmission window in between (White *et al.*, 1967, Farrell and Newnham, 1965). According to Poole (Poole, 1964), the alexandrite-like colour changes, which appear in various chromium-bearing compounds, occur due to the much higher spectral response of the human eye and brain to the green and yellow colours that fall near the 600 nm absorption band (Nassau, 1983). In green-rich natural light, the crystal is vivid green, while in the red-rich incandescent light the alexandrite shows a red colour with a violet hue. The same absorption bands, together with the orthorhombic symmetry of the crystal structure, render alexandrite strongly pleochroic (Farrell and Newnham, 1965). This pleochroism is also observed as a change in the colour, but only when looking at the crystal with light propagating along different orientations. Another important optical fingerprint of alexandrite is its characteristic emission spectrum. The Cr^{3+} in alexandrite, as in ruby and emerald, is responsible for an intense red fluorescence, with two sharp lines (called R_{1m} and R_{2m}) near 1.83 eV (or 679 nm) (Walling *et al.*, 1995).

Although the origin of natural alexandrite is still a controversial subject, it is accepted by many that alexandrite is formed when solutions rich in beryllium, originating from granites, percolate through ultramafic rocks (which are the source of chromium) and crystallise in a medium saturated by aluminium (Martin-Izard *et al.*, 1995).

For more than 20 years, alexandrite from Malacacheta has been recovered from alluvial deposits located along four streams named Córrego do Fogo, Ribeirão Setubinha, Ribeirão Santana and Ribeirão Soturno (Guimarães and Grossi Sad, 1977, Proctor, 1988, Basílio, 1999). Nowadays very few alexandrites of gem quality are found. The size of the crystals ranges from 1 mm up to 1 cm.

The main purpose of this paper is to present an optical and a structural characterization of this alexandrite from Malacacheta, with the focus on the peacock-blue variety. Electron microprobe, electron paramagnetic resonance (EPR), X-ray photoelectron spectroscopy (XPS), optical absorption and emission methods were used to provide reliable information on the colour and its correlation with the impurity-related point defects present in the material.

Structural details

$BeAl_2O_4$ is an orthorhombic crystal with space group D_{2h}^{16} (p_{nma}) (Bragg and Brown, 1926). The unit cell has the following lattice parameters: a = 9.404 Å, b = 5.476 Å and c = 4.472 Å, and is composed of four $BeAl_2O_4$ molecules (Swanson *et al.*, 1960). The oxygen atoms are arranged in an approximately hexagonal close-packed array perpendicular to the c axis. The aluminium cations (Al^{3+}) occupy half of the interstitial octahedral sites, while the beryllium (Be^{2+}) ions are found in one eighth of interstitial tetrahedral sites. Both the octahedral and the tetrahedral sites are distorted in shape.

A refinement of the chrysoberyl structure showed that the eight distorted octahedral sites occupied by Al cations in the unit cell can have two distinct symmetries (Farrell

Glossary

X-ray photo-electron spectroscopy (XPS): A non-destructive technique generally used for chemical analysis of surfaces. In a vacuum chamber, the sample is irradiated by X-rays and the energy of the emitted electrons is measured. It is the opposite of the electron microprobe technique in which a sample is irradiated with electrons and the characteristic X-rays of each element are collected. With XPS, it is possible e.g. to obtain the relative concentrations of the chemical elements present at the surface.

Electron paramagnetic resonance (EPR): Used for chemical identification, site symmetry and valence states of point defects and impurities. In general, the samples are placed into a microwave resonance cavity. The resonance lines are detected with a fixed microwave frequency perpendicular to a variable static magnetic field. The sensitivity for paramagnetic impurities in solid state samples is from ppb to ppm.

Crystal field: The inhomogeneous electrical field of the neighbourhood ions of an impurity is called the crystal field. The crystal field around Cr^{3+} differs in intensity in different structures, e.g. in ruby, emerald or alexandrite structures. It can also have different symmetries due to the coordination number, resulting in different colours.

Crystal field transitions: Are transitions that involve redistribution of electrons in the partially filled 3d shells of transition metal impurities embedded in a crystal field. The crystal field transitions are optical transitions between ground and excited states. They result from the splitting of the 3d energy level of the free ion, induced by the crystal field. Normally these transitions are related to absorption bands in the visible spectrum and are the cause of colour.

Site symmetry: The site symmetry, which is directly associated with the coordination number, has a strong influence on the colour of some gems due to the symmetry of the crystal field. For example, in beryl, iron can enter either in an interstitial position in structural channels, or substitute for Al ions. In the substitutional site, Fe^{2+} produces a blue colour while in the interstitial site it causes no colour.

et al., 1963). The first four sites lie on a mirror plane (C_S) with only one Be^{2+} neighbour, while the other four have inversion symmetry (C_I), due to the symmetrical location of two neighbouring Be^{2+} ions. These sites differ not only in symmetry but also in volume, with the C_S site being larger than the C_I sites. While the C_S sites have an average nearest-neighbour distance (Al-O) of about 1.934 Å, the same distance for the C_I sites is only 1.890 Å (Farrell *et al.*, 1963). This volume difference strongly determines the distribution of substitutional Cr^{3+} between the two types of sites. For lower chromium and iron concentrations, the larger C_S sites are preferentially occupied. As the concentration of Cr increases, the C_I sites can also be occupied (Newnham *et al.*, 1964). In synthetic alexandrite, the relative site occupancy of the mirror-symmetry (C_S) sites is well known to be between 60 and 74% for the highest Cr concentrations (Newnham *et al.*, 1964). For lower chromium contents, EPR experiments yield more accurate data concerning site occupancy than X-ray powder diffraction data. In synthetic laser-quality alexandrite crystals with chromium contents ranging from 0.1% up to 0.3%, the relative site occupancy of the mirror sites has been estimated as 78% ± 3% (Forbes, 1983). There are basically two transition ion impurities in alexandrite and chrysoberyl, Fe^{3+} and Cr^{3+} that substitute for the Al^{3+}. With electronic spins S = 5/2 and S = 3/2 respectively, those impurities are paramagnetic, being thus detectable by means of electron paramagnetic resonance (EPR). While the substitutional C_S sites are magnetically equivalent in pairs, the four inversion sites (C_I) are magnetically inequivalent (Forbes, 1983). The EPR parameters for Cr^{3+} and Fe^{3+} on the C_S sites were first determined by Barry and Troup in 1969 and 1970. Later, the Cr^{3+} EPR

Experimental details

The microprobe analysis had the following operational conditions: 15 kV accelerating voltage, 20 mA current and 10 s counting time. The results in *Table I* are givenin per cent of weight. The spectrometer used for the chemical analyses was a Cameca model Camebax 5X-50. The analytical standards were Ian Steele and the lower limit of detection of 0.01 per cent of weight, with errors of the same order. It is important to note that the BeO level was not directly measured with the microprobe, being estimated from the stoichiometric concentrations of other oxides. The Be contents were confirmed with X-ray photo-electron spectroscopy (XPS). For the optical characterization, optical absorption and photoluminescence were used. The optical absorption spectra were collected with a Hitachi U-3510 spectrophotometer. The photoluminescence was measured with a Dilor Micro-Raman spectrometer with the green line of an Ar-ion laser (514.5 nm) as excitation. The EPR study was done with a conventional EPR spectrometer working at the X-Band (9 - 10 GHz). X-ray photoelectron spectroscopy (XPS) spectra were recorded by a VG-escalab 2201-XL spectrometer using Al Kα excitation (hυ = 1486.6 eV) operating at 10 mA and 15 kV. The vacuum during data acquisition was always near 10^{-9} torr. The analyser was operated at a constant pass energy of 40 eV and in 'small area mode' (~ 0.2 mm^2), in order to focus on different sample positions. When necessary, the gemstone was bombarded with Ar ions to eliminate surface contamination. Most experiments were made at room temperature.

parameters were refined for both the mirror and the inversion sites and the relative site occupancy was defined (Forbes, 1983).

Results and discussion

The peacock-blue alexandrite samples selected for this investigation were the rough crystals with highest purity and transparency, and with both the most intense and homogeneous pleochroism and alexandrite effect (*Figure 1*). The results of the electron probe microanalysis (WDS-EPMA) for two of the samples are shown in *Table I*.

From the group a single crystal was carefully chosen as the most representative sample. It was cut in the shape of a parallelepiped with dimensions of about 4 x 2.5 x 2 mm and faces oriented along the rhombic axes *a*, *b* and *c*.

Unpolarized optical absorption spectra were measured at 300 K for light propagating along the *a* and *b* axis as shown in *Figure 2*. Three strong bands at 570 nm (Cr1 or Y-band), 410 nm (Cr2 or U-band) and 300 nm (Cr3) are caused by Cr^{3+} in an octahedral site *(Table II)*. These three bands belong to the spin-allowed crystal field transitions of the Cr^{3+} ion, i.e. $^4A_2 \rightarrow {}^4T_2(F)$, $^4A_2 \rightarrow {}^4T_1(P)$ respectively (Farrell and Newnham, 1965). Phonon structure can also be barely seen at 300 K as sharp and less intense peaks at 620

Table I: *Electron probe microanalyses of two representative rough samples of the blue alexandrite from Malacacheta.*

Wt.%	*No.1*	*No.2*
Al_2O_3	80.55	80.90
BeO	17.91	17.61
Na_2O	0.01	0.01
MgO	0.02	<0.01
SiO_2	<0.01	0.02
K_2O	<0.01	<0.01
CaO	<0.01	<0.01
TiO_2	0.29	0.33
Cr_2O_3	0.65	0.59
MnO	0.02	0.02
FeO	0.53	0.51
Total	99.98	99.99

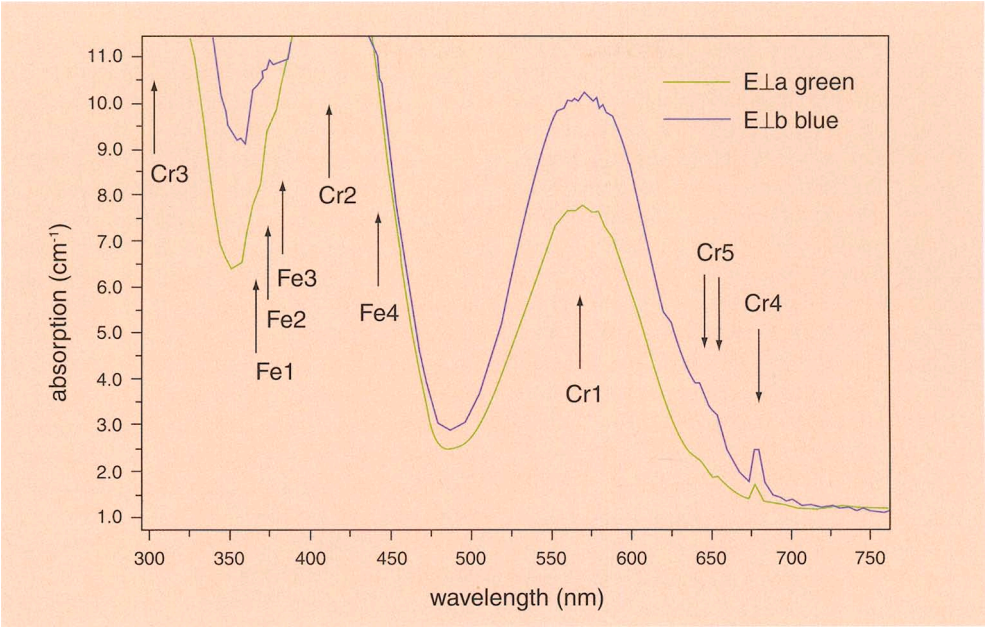

Figure 2: *Unpolarized optical absorption spectra of the peacock-blue alexandrite measured at room temperature for light propogating along the crystal axis a and b with the marked positions in Table II.*

nm (Cr4) and 640 nm (Cr5). Other weak absorption peaks at 679 nm belong to the spin-forbidden transitions of Cr^{3+}, i.e. $^4A_2 \rightarrow {}^2E$ (Cr6), $^4A_2 \rightarrow {}^2T_1$ and $^4A_2 \rightarrow {}^2T_2$ (not marked).

As in most natural alexandrites, Fe^{3+} substituting for Al^{3+} was also detected in the blue alexandrites from Malacacheta. Four iron-related weak absorption lines were observed at 368 nm (Fe1), 378 nm (Fe2), 385 nm (Fe3) and 440 nm (Fe4), as marked in *Figure 2*. All four lines are due to spin-forbidden transitions from the ^6A ground state to the $^4A_1(G)$, $^4E(G)$, $^4T_2(D)$ and $^4E(D)$ excited states, respectively. Without Cr^{3+}, these four Fe^{3+} related lines in the violet and blue spectral range result in the yellow colour of chrysoberyl (Farrell and Newnham, 1965). The origin of the absorption transitions and their average positions are summarised in *Table II*. For samples with high Fe^{3+} content, the transmission window between the Fe and the Cr related absorption bands at about 480 nm shifts toward the green, resulting in a green alexandrite without blue hues.

Table II: *Average positions and origin of the absorption bands of the peacock-blue alexandrite.*

Absorption band	*Position (nm)*	*Transition*
Cr1 (Y-band)	570	$^4A_2 \rightarrow {}^4T_2$ (F)
Cr2 (U-band)	410	$^4A_2 \rightarrow {}^4T_1$ (F)
Cr3	300	$^4A_2 \rightarrow {}^4T_2$ (F)
Cr4	620	phonon structure of Cr1
Cr5	640	phonon structure of Cr1
Cr6 (R_{1m} and R_{2m} lines)	~679	$^4A_2 \rightarrow {}^2E$
Fe1	368	$^6A \rightarrow {}^4A_1$ (G)
Fe2	378	$^6A \rightarrow {}^4E$ (G)
Fe3	385	$^6A \rightarrow {}^4T_2$ (D)
Fe4	440	$^6A \rightarrow {}^4E$ (D)

The visually observed colours of the peacock-blue alexandrite, for natural light propagating with polarization perpendicular to the a and b axes are green and blue, respectively. Even though the transmission for the blue wavelengths is slightly higher for E ⊥ *a* (i.e. less absorption), as can be seen in the spectrum of *Figure 2*, the strength of the absorption bands between 550 nm and 600 nm is greater by far for E ⊥ *b*. Since the human eye is more sensitive to green-yellow (Nassau, 1983), the final result is green for E ⊥ *a* and blue for E ⊥ *b*, which is consistent with recent results obtained for certain synthetic alexandrite grown from a melt of stoichiometric composition by the Czochralski method (Liu *et al.*, 1995).

Figure 3 shows the photoluminescence spectrum of the same peacock-blue alexandrite sample measured at room temperature. The line observed in the absorption spectrum at about 679 nm (Cr6) (*Figure 1*) is in fact a doublet (678.5 nm and 680.3 nm at 300 K) that was better resolved in the photoluminescence spectrum (along with the phonon vibronic structure). This doublet, known as the R_{1m} and R_{2m} lines appears to be due to the deviation from octahedral symmetry of the Cr^{3+} ion on the mirror-symmetry sites, which lifts the degeneracy of the 2E level into two states A′ and A″ (Walling *et al.*, 1979; Hori et al., 1989). The inversion sites do not contribute to the photoluminescence spectrum.

The EPR spectrum for the magnetic field (B) approximately parallel to the crystal axis b measured at 300 K and a microwave frequency of 9.45 GHz is shown in *Figure 4*. In the spectrum, the two lines from Cr^{3+} in the mirror symmetry sites (C_S) can clearly be seen at about 1364 Gauss and 7845 Gauss. They belong to the Zeeman transitions -3/2 → 3/2 and -1/2 → 1/2, respectively, as observed in synthetic alexandrite (Forbes, 1983). The other EPR lines belong to Fe^{3+} in the mirror site (Barry and Troup, 1970).

In the peacock-blue alexandrite it was very difficult to detect the EPR lines from Cr^{3+} in the inversion sites (C_I). From the (C_I) four lines expected at 1638 Gauss, 1872 Gauss, 5704 Gauss and 9003 Gauss for B ∥ *b* (Forbes 1983), we could only detect a broad and weak line at 5700 Gauss. While the 9003 Gauss line was outside the range of our magnetic field, the other low-field lines were masked by the stronger Fe^{3+} lines and the low-field Cr^{3+} (C_S) line. The EPR line of the inversion site can, in principle, be associated with the very weak and broad line at about 5700 Gauss shown in *Figure 4*. This line, together with other weak and broad lines at lower fields could, however, belong to other defects like, for example, Cr-pairs. Assuming that the line observed at 5700 Gauss belongs in fact to the - 1/2 → +1/2 transition from the Cr^{3+} (C_I) (Forbes, 1983), we could roughly estimate its intensity ratio to be about 1/12 with respect to the - 1/2 → +1/2 line of Cr^{3+} (C_S) at 7845 Gauss. This value is slightly smaller than the ratio of ~ 1/10 one can estimate from the synthetic alexandrite EPR spectrum (Forbes, 1983). For synthetic alexandrites, a relative site occupancy of 78 ± 3% was found (Forbes, 1983). By comparing the intensity ratios of the two lines estimated for the peacock-blue alexandrite with the ratio obtained for the synthetic alexandrite, and scaling them with site occupancy, we conclude that the relative site occupancy for substitutional Cr^{3+} should be higher than 90% on C_S sites. This is also consistent with the strong luminescence of Cr^{3+} in the C_S sites (R_{1m} and R_{2m}), since the luminescence-active site is the C_S site.

Another aspect of the EPR spectrum that is important to mention is the large halfwidth of the EPR lines, that for most lines either from Cr^{3+} and Fe^{3+} exceeds 50 Gauss, and that in some cases even reaches 100 Gauss. For synthetic alexandrites it stays in the range between 10 and 30 Gauss (Forbes, 1983). This difference in the EPR linewidth of transition ion impurities in natural and synthetic alexandrites occurs mainly due to the disorder of the lattice that is expected to be higher for a natural crystal than for its synthetic counterpart.

The XPS spectrum of the same alexandrite sample studied by EPR is shown in *Figure 5*. From relative peak areas and sensitivity

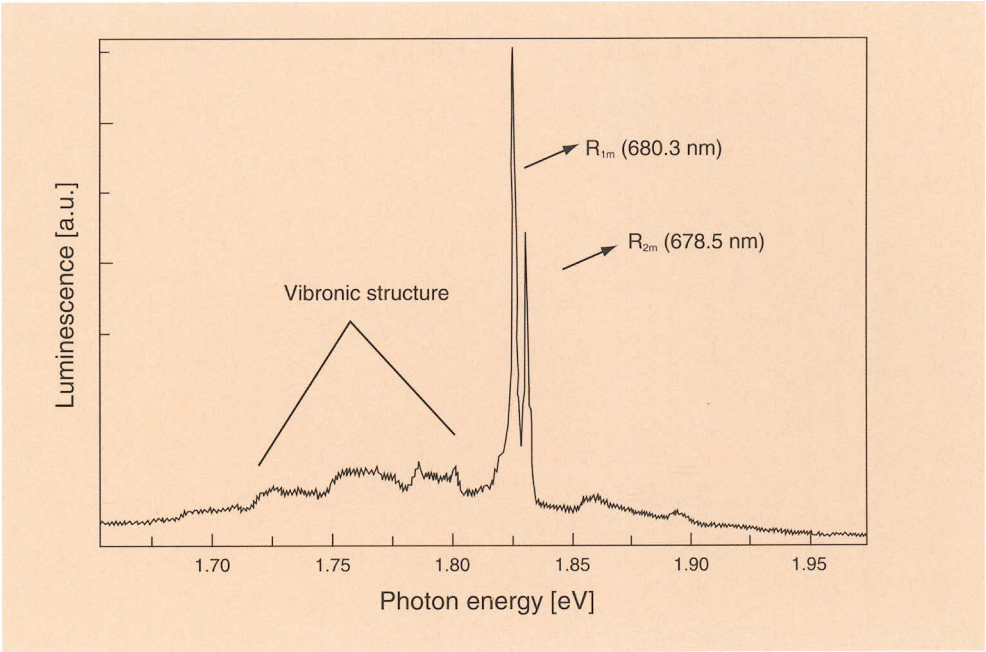

Figure 3: *Photoluminescence spectrum measured at room temperature with the green line (514.5 nm) of an Ar-ion laser as excitation.*

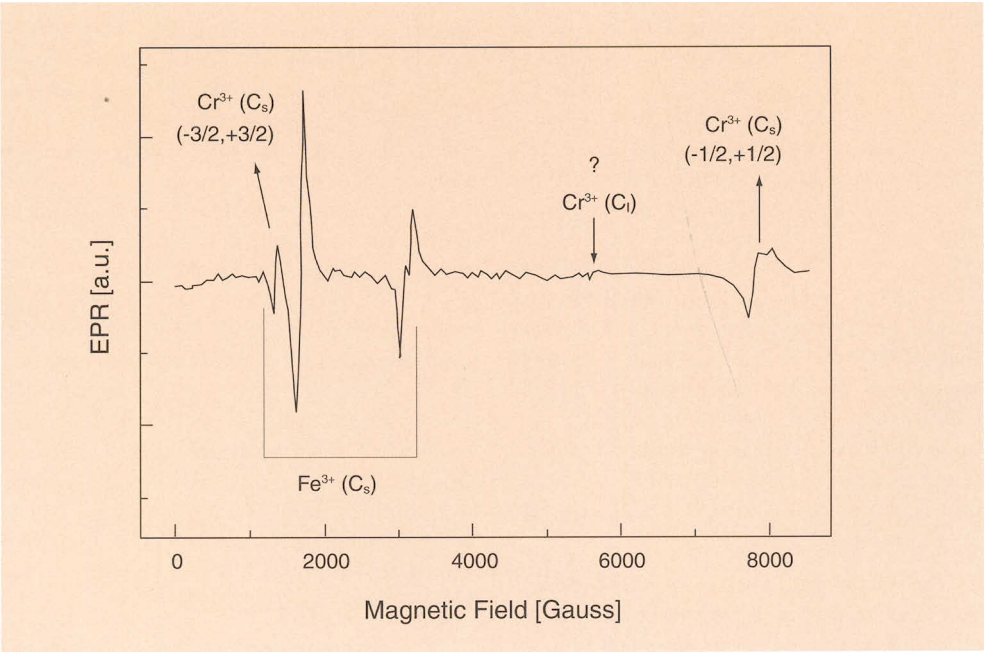

Figure 4: *EPR spectrum measured at room temperature and with microwave frequency of 9.45 GHz and for B ‖ b.*

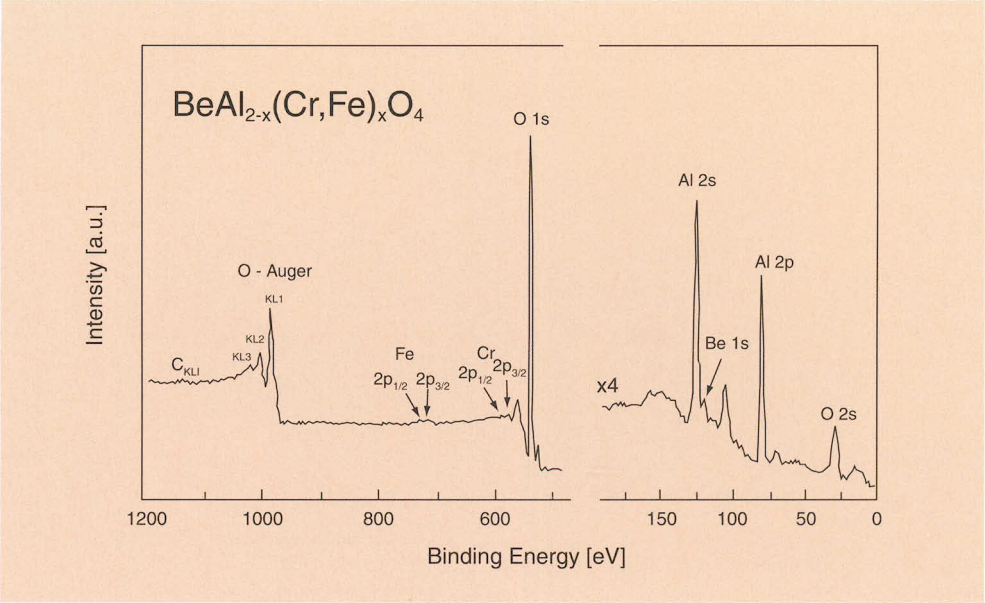

Figure 5: *XPS spectrum of the peacock-blue alexandrite measured with Al Kα radiation in the binding energy ranges of 1200-500 eV, as collected (left side), and 200-0 eV, multiplied by 4 (right side).*

factors of the photo-emission lines, the molar fractional content in the alexandrite formula $BeAl_{2-x}$ (Cr, Fe)$_x$ O_4 was calculated, where $x = x_{Fe} + x_{Cr}$. Spectra were collected at different sample positions and the results averaged Al/O = 0.51 ± 0.06, and Al/Be = 1.87 ± 0.22, which gives 2 - x = 1.96 ± 0.23. From the $2p_{1/2}$, $2p_{3/2}$ of the Fe and Cr and the O-1s transitions $x = x_{Fe} \pm x_{Cr} = 0.022 \pm 0.015$. The Cr/Fe molar ratio x Cr/x Fe was calculated as 0.8 ± 0.4, consistent with the WDS-EPMA analysis. From the EPR and optical absorption experiments, it is clear that the Cr^{3+} and Fe^{3+} are the main cations in the peacock-blue alexandrite which affect the colour of this gemstone. EPR and photoluminescence results showed that Cr^{3+} occupies preferentially the mirror sites, i.e. more than 90% with respect to the inversion sites.

The pleochroic colours of the peacock-blue alexandrite, and the strong alexandrite effect of a change from greenish-blue in daylight to reddish-purple under incandescent light, are consequences of a specific balance in the concentrations of Cr^{3+} and Fe^{3+} substituting for Al^{3+} in the C^S sites in an otherwise colourless chrysoberyl crystal. While it is known that the iron-related absorption bands, in the absence of Cr, gives the typical yellow colour of the chrysoberyl, for samples with Fe and Cr, green or blue-green alexandrite is expected depending on the relative concentrations of Fe and Cr. For samples with high Fe content, the Fe-related broad absorption bands in the blue are intense and, as a result, the transmission window shifts slightly from 480 nm (blue-green) to the green 500 nm. *Figure 6* shows clearly that by changing the concentration ratio of Fe^{3+} and Cr^{3+}, the overlap of the two absorption bands and therefore the position of the absorption minimum at about 500 nm is influenced. As a consequence, the amount of transmitted blue wavelengths will depend heavily on the balance between Cr^{3+} and Fe^{3+}.

XPS enables determination of the specific range in the Cr/Fe molar ratio which gives the most attractive colours and the best

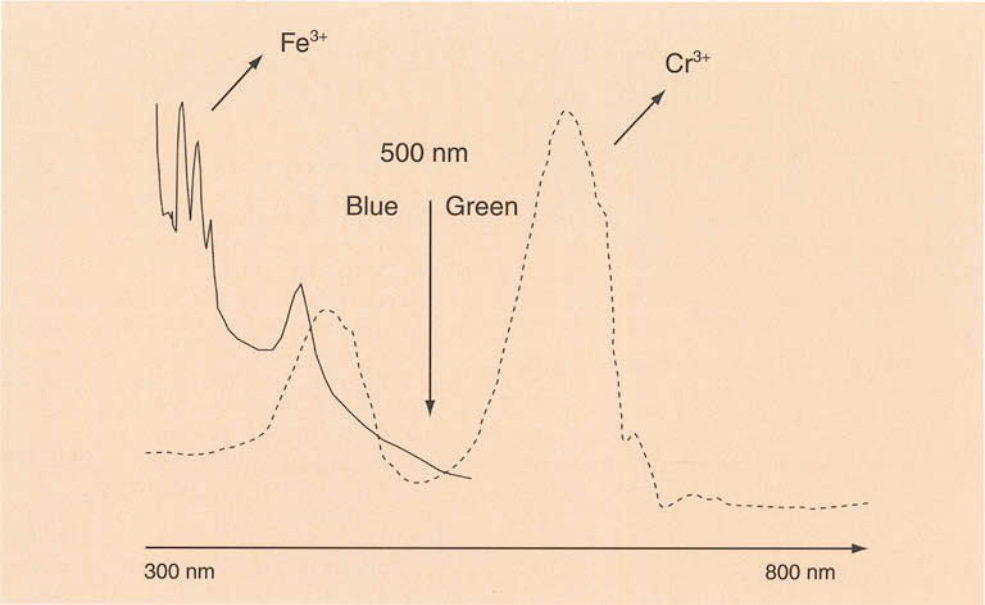

Figure 6: *The shape of the absorption bands of Cr^{3+} in synthetic alexandrite and of Fe^{3+} in chrysoberyl (after Farrell and Newnham, 1965). Both spectra were measured for light polarized along b.*

colour change in the peacock-blue alexandrite. The result was $0.4 < x_{Cr}/x_{Fe} < 1.2$. Finally, this model is also consistent with the existence of green alexandrites without blue tints because of the higher iron and/or lower chromium content, compared to the peacock-blue alexandrite. The results are consistent with the WDS-EPMA analysis. However, it is interesting to note the relatively high titanium content (*Table I*). Whether or not optical transitions belonging to charge transfer Fe^{2+} - Ti^{4+}, well known in so many oxygen-based minerals, influence the optical absorption spectrum has not yet been resolved.

Conclusions

The origin of colour of the peacock-blue variety of alexandrite from Malacacheta (Minas Gerais, Brazil) is explained by the presence of Fe^{3+} and Cr^{3+} substituting for Al^{3+} in the mirror sites. For intermediate Fe/Cr ratios ($0.4 < x_{Cr}/x_{Fe} < 1.2$), and with both Fe^{3+} and Cr^{3+} in the mirror sites, the minimum in the absorption spectrum lies at about 480 nm, giving rise to the blue tones of this variety of alexandrite. For higher Fe and intermediate Cr contents, the minimum in the spectrum shifts to the green ($\lambda > 500$ nm), and the alexandrite loses the bluish colours when viewed along *b*. For very low Cr concentrations, absorption is strong in the violet-blue region and the chrysoberyl cannot be considered to be alexandrite because it becomes yellow, losing its strong pleochroism in the green range and the 'alexandrite-effect'.

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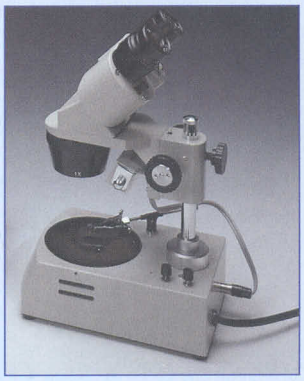

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Abstracts

Diamonds

Synthetics and Simulants

Gems and Minerals

Diamonds

Diamonds in volcaniclastic komatiite from French Guiana.

R. CAPDEVILA, N. ARNDT, J. LETENDRE and J-F. SAUVAGE. *Nature*, **399**(6735), 1999, pp 456-8.

Analyses are presented of diamondiferous volcaniclastic komatiites from the Dachine deposit in the 2210 ± 900 m.y. old greenstone belt of the Guiana Shield, French Guiana. The ultramafic host of the deposit is ≥ 5 km x ≤ 1000 m wide. Bulk samples contain < 1-77 (mainly) microdiamonds/kg rock. Larger diamonds (>1 mm) (≤ 4 carats/m^3 rock) occur in poorly sorted alluvium overlying mineralised bedrock. Cubo-octahedral diamonds and low $\delta^{13}C$ ratios (-23 to 27‰) indicate eclogitic sources. Nine analyses are listed of komatiites for major and trace elements. The diamonds are probably xenocrysts sampled at depths of > 150 km and transferred rapidly to the surface. Primary, anhydrous komatiite magma formed by deep melting, penetrated hydrated lithosphere beneath the Dachine island arc, accumulated H_2O and diamonds and was propelled to the surface. R.K.H.

Layered mantle lithosphere in the Lac de Gras area, Slave Craton: composition, structure and origin.

W.L. GRIFFIN, B.J. DOYLE, C.G. RYAN, N.J. PEARSON, S.Y. O'REILLY, R. DAVIES, K. KIVI, E. VAN ACHTERBERGH AND L.M. NATAPOV. *Journal of Petrology*, **40**(5), 1999, pp 705-27.

Garnet and chromite concentrates and lherzolite, harzburgite, dunite, websterite and eclogite xenoliths from 21 Cretaceous-Tertiary kimberlite intrusions have been used to map the Archaean lithosphere mantle beneath the central Slave Province, Canada. Ni (for garnet) and Zn (for chromite) - derived *T* enable estimates of the depth of crystallization and show a sharp discontinuity in mantle composition at 900°C. The lithospheric mantle < 145 km is extremely depleted in LILE and HFSE compared to other known Archaean mantle. It has a higher harzburgite/lherzolite ratio and may have a higher olivine/orthoproxene ratio. It is an ancient oceanic or sub-arc mantle. The deep mantle (145-200 km) is similar to the Kaapvaal lithosphere sampled by Group I kimberlites but the harzburgite/lherzolite ratio decreases with depth. Eclogites come from this deeper layer which contains abundant diamonds, was derived from the lower mantle (ferropericlase-perovskite inclusions) and is a fossil plume head. Some representative partial major and trace element analyses of garnets are given. B.E.L.

Changes and new developments in Africa.

J.J. GURNEY. *Gems & Gemology*, **35**(3), 1999, 34-6.

Africa currently produces 51.8 million carats of rough diamonds annually (46% of the world total by weight, or 72% by value). It is forecast that African diamond production will increase to > 60 million ct/yr in the foreseeable future. It is reasonable to expect further discoveries in the Kalahari craton and in Mauretania. R.A.H.

Diamonds from Australia.

A.J.A. JANSE. *Gems & Gemology*, **35**(3), 1999, 37-9.

The Argyle lamproite pipe has been mined since 1985 and produces mainly small brown diamonds of irregular shape; only 5% are of gem quality, but now ~ 40% of the non-gem Argyle diamonds are cut economically in India into inexpensive low-quality stones. The only other producing diamond mine is Merlin, in the Northern Territory, which came into production in 1999; it draws from 4-7 small kimberlite pipes and produces diamonds of very good quality.

Created Diamonds'; avariety of colours are being produced as well as near-colourless material. It is noted with some amusement that synthetic moissanite is more expensive than synthetic diamond. R.A.H.

Gem news.

M.L. JOHNSON, J.I. KOIVULA, S.F. MCCLURE AND D. DEGHIONNO (eds). *Gems & Gemology*, **35**(2), 1999, 142-55.

Abstractors

J. Flinders	J.F.	B.E. Leake.	B.E.L	A.H. Rankin	A.H.R.
R.K. Harrison	R.K.H.	P.B. Leavens	P.B.L.	I. Sunagawa	I.S.
R.A. Howie	R.A.H.	M. O'Donoghue	M.O'D.		

For further information on many of the topics referred to, consult *Mineralogical Abstracts*

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The first diamonds from Merlin project in the North Territory, Australia, included a 14.76 ct 'white' octahedron from the Scaramore pipe. R.A.H.

Genesis of diamonds in the lower mantle.

L. Liu. *Contributions to Mineralogy and Petrology*, **134**(2-3), 1999, 170-3.

The occurrence of the ('forbidden') assemblage ferropericlase + enstatite as inclusions in diamonds implies formation and that of their host diamonds in the lower mantle. Magnesite is probably the only stable carbonate at > ~ 220 km depth. The reaction boundary for magnesite decarbonation has a positive dT/dP slope at lower P which becomes negative at higher P if no other phase intervenes, and probably intersects the geotherm at ~ 900 - 1100 km, below which magnesite decomposes into assemblages periclase + diamond + O. Hence, the most likely inclusion to form in diamond in the lower mantle is ferropericlase, the occurrence of only this type of inclusion in diamonds from Sao Luiz, Brazil, substantiating this view. J.F.

Observations of GE-processed diamonds: a photographic record.

T.M. Moses, J.E. Shigley, S.F. McClure, J.I. Koivula and M. Van Daele. *Gems & Gemology*, **35**(3), 1999, 14-22.

Natural high-purity diamonds are being processed at high T and high P by the General Electric Co. to improve their colour, i.e. to make them more nearly colourless. Agreement has been reached with Pegasus Overseas Ltd (POL) and GE to inscribe the girdle surface of all their processed stones with the letters POL. The GIA has now established a database of information after examining 858 GE POL diamonds; 99% of them are type IIa. Most of the stones examined were 1-2 ct generally cut in one of several 'fancy' shapes. Photographs are presented showing some of the unusual internal features such as graining and 'partially healed' cleavages; they often show a slightly hazy appearance. Examples are reported of stones in which the GE POL inscription has been partially or completely removed, but the database built up on these stones allowed their detection. R.A.H.

Canadian diamond production: a Government perspective.

D. Paget. *Gems & Gemology*, **35**(3), 1999, 40-42.

The main cluster of economically viable diamond-bearing kimberlite pipes occur in the Lac de Gras area in the Slave Province of the Northwest Territories. Here the Ekati mine has a resource of 66 million tonnes at 1.07 ct/t, with an average value of US$100 per carat. Other diamond projects in the evaluation stage include that at Jericho in Nunavat [a new territory in the East Arctic, on the east side of Hudson Bay, formally created in 1999]. R.A.H.

Russian diamond sources.

N.V. Sobolev. *Gems & Gemology*, **35**(3), 1999, 43.

More than 800 kimberlite bodies have so far been identified in the Siberian craton of the Republic of Sakha (formerly Yakutia) and produce ~ 98% of all diamonds mined in Russia, the remaining 2% being recovered from placers in the Ural Mts. Within Saakha, 10% of the production is from the Anabar placers on the Ebelyakh River; several pipes in the Muna field are being prepared for mining. The Arkhangelsk diamondiferous province in the East European craton has several high-grade kimberlite pipes, of which the Lomonossov may be the first to be developed. R.A.H.

Gems and Minerals

Il 'demantoide' della Val Maleno

F. Bedognè, E. Sciesa and P. Vignola. *Rivista mineralogica italiana*. **23**, 208-17, 1999, illus. in colour.

Yellow-green andradite is found in the Val Malenco area of northern Italy. The name demantoid has frequently been used for this material and some small crystals do achieve a deep emerald-green. Crystals occur in serpentinites as rhombic dodecahedra with faces modified by trapezohedra: the composition of a number of specimens is given in tabular form. The finest green crystals appear to be limited to the two areas Campo Francisca and Alpa Acquanegra M.O'D.

[The quantitative appraisal of the green of jadeite.] (Chinese with English abstract)

Y. Chan, F. Pan and J. Ren. Kuangwu Yanshi (*Bulletin of Mineralogy, Petrology and Geochemistry*), **18**(4), 1999, 412-15.

A new standard is proposed for the naming and classification of the green colour of natural jadeite, based on photometry. Green jadeite is classed as one of six 'species' pure green, very slightly yellowish-green, very slightly bluish-green, slightly bluish-green, yellowish-green and bluish-green. The colour is evaluated according to saturation and brightness, these two indices then being united to establish the new standard. R.A.H.

[Mineralogical characteristics of chatoyant quartz in Luodian County, Guizhou.]

(Chinese with English abstract)

M. Deng. Kuangwu Yanshi (*Bulletin of Mineralogy, Petrology and Geochemistry*), **18**(4), 1999, 416-7.

The Luodian chatoyant quartz may have originated in quartz veins in blue asbestos; it is brown-green, light green and bluish-green in colour. It contains parallel fibres of tremolite. In bright sunshine or under a tungsten light it reflects a dazzling slit of light from the interior of the stone. R.A.H.

The separation of natural from synthetic colourless sapphire.

S. Elen and E. Fritsch. *Gems & Gemology*, **35**(1), 1999, 30-41.

Increasing amounts of colourless sapphire, promoted mainly as diamond substitutes but also as natural gemstones, have been seen in the gem market during the past decade. Natural colourless sapphires can be distinguished from their synthetic counterparts by their

trace-element composition and short-wave UV transparency. EDXRF shows higher Fe, Ti, Ca and Ga in natural sapphires; these impurities cause a reduction in the SWUV transparency that can be detected by UV-visible spectrophotometry, i.e. a total absorption in the UV region below 280-300 nm, which is not seen in synthetic stones. A SWUV transparency tester that can rapidly identify parcels of colourless sapphires is described.

R.A.H.

The identification of Zachery-treated turquoise.

E. Fritsch, S.F. McClure, M. Ostrooumov, Y., Andres, T. Moses, J.I. Koivula and R.C. Kammerling. *Gems & Gemology*, **35**(1), 1999, 4-16.

Over the last ten years, millions of carats of turquoise have been enhanced by a proprietary process called the Zachery treatment. This process effectively improves a stone's ability to take a good polish and may or may not improve the colour. It also decreases the material's porosity limiting its tendency to absorb discolouring agents such as skin oils. Examination shows that the process does not alter the gemmological properties of the turquoise; it does not involve impregnation with a polymer. Most Zachery-treated turquoise can be identified only through chemical analysis (most efficiently by EDXRF or EPMA techniques) as it contains significantly more K than its untreated counterpart.

R.A.H.

Guatemala jadeites and albites were formed by deuterium-rich serpentinizing fluids deep within a subduction zone.

C.A. Johnson and G.E. Harlow. *Geology*, **27**(7), 1999, pp 629-32.

Jadeites and albitites from the Motagua Valley, Gutemala, are high-*P*-low-*T* metasomatic rocks that occur as tectonic inclusions in a serpentinite-matrix mélange. Metasomatism was driven by a fluid with a $\delta^{18}OH_2O$ value of 6‰ and a δDH_2O value that is high in comparison with metamorphic fluids at the other high-*P*-low-*T* localities of similar grade. It is inferred that the fluid was originally sea-water that was entrained during subduction either as mineral-bound H_2O, or as free pore waters. The fluid drove serpentinization reactions in ultramafic rocks, possibly leading to deuterium enrichment of H_2O, prior to forming the jadeites and albitites at a depth of 29 ± 11 km. There are isotopic and fluid-inclusion similarities to rodingites, which are Ca-rich metasomatites found at other serpentinite localities. The results suggest that the serpentinization process, whether it occurs within subduction zones or on the flanks of oceanic spreading ridges, may produce residual fluids that are H_2O rich, have 1-8 wt.% eq. NaCl, and have high, perhaps sea-water-like δD values. P.B.L.

On the identification of various emerald filling substances.

M.L. Johnson, S. Elen and S. Muhlmeister. *Gems & Gemology*, **35**(2), 1999, 82-107.

Criteria for distinguishing emerald filling materials have been investigated, 39 fillers being divided into six substance categories ~ three 'presumed natural' (essential oils, including cedar wood oil, other oils and waxes) and three 'artificial resin' (epoxy and other prepolymers, including UV-setting adhesive, and polymers). Regardless of their composition, fillers with RI > 1.54 show flash effects in emeralds. On the basis of Raman and IR spectroscopy, the fillers can be separated into five spectral groups A-E. Most, but not all, commonly used artificial resins have spectra distinct from that of cedar wood oil. However, the detection of one substance in a fissure does not imply that all others are absent. R.A.H.

Gem news.

M.L. Johnson and J.I. Koivula (eds). *Gems & Gemology*, **35**(1), 1999, 47-60.

Items described include a 2 cm prism of Colombian emerald with a large moveable gas bubble and a twelve-rayed star quartz from Sri Lanka (sillimanite being responsible for the asterism). R.A.H.

Gem news.

M.L. Johnson, J.I. Koivula, S.F. McClure and D. DeGhionno (eds). *Gems & Gemology*, **35**(2), 1999, 142-55.

A new source for tsavorite is recorded ~ 15 km from Ruangwa in Lindi Province, Tanzania. R.A.H.

[The colorimetry and chromaticity study of Xinjiang Hetian jade.] (Chinese with English abstract)

W. Li and R. Wu. Kuangwu Yanshi (*Bulletin of Mineralogy, Petrology and Geochemistry*), **19**(4), 1999, 418-22.

Analysis of the visible spectrum of Hetian jade indicates that the green colour is due to the total iron content. The absorption peak at 450 nm is produced by the *d~d* transition of Fe^{3+}, and the broad, weak bands at 640 nm can be attributed to the $Fe^{2+} \rightarrow Fe^{3+}$ charge transfer. The colour indices of Hetian jade are calculated from the reflectivit and transmission ratio; this jade has low saturation and low brightness. EPMA results and cell parameters are given for tremolite in the Hetian jade.

R.A.H.

Exotic origin of the ruby deposits of the Mangari area in SE Kenya.

A. Mercier, P. Debat and J.H. Saul. *Ore Geology Reviews*, **14**, 1999, 83-104

The Mangari gem-quality ruby deposits occur as lenses and veins associated with ultrabasic bodies of the Proterozoic Mozambique belt. Representative chemical compositions are presented for the following minerals associated with corundum (ruby): sapphirine, chlorite, spinel, zoisite and plagioclase. Data are also presented for the following minerals from the sillimanite gneiss, country rocks: biotite, garnet at plagioclase. The *P-T* conditions for the gneisses, based on mineral thermobarometric methods, are within the ranges 5.4 to

6.7 kbar and 605 to 670°C. Comparable *P-T* estimates for corundum-bearing rocks are within the ranges, 8 to 10.5 kbar and 700 to 750°C. The Mangari deposits are fragments of a deeper crust brought up to their present-day level by ultrabasic bodies during emplacement as thrust sheets. It is suggested that the rubies were formed under granulite conditions but were tectonically emplaced into country rocks of lower metamorphic grade and *P-T* conditions. A.H.R.

Gem Trade Lab notes.

T. Moses, I. Reinitz and S.F. McClure (eds). *Gems & Gemology*, **35**(1), 1999, 42-6.

Items noted include green faceted ovals purporting to be chinese peridotite which were found to be glass, and a cat's-eye taaffeite in which the chatoyancy was due to the presence of parallel reflective planar inclusions with striations. R.A.H.

Achat in Osterreich.

G. Niedermayr. *Mineralien Welt*, **10**(6), 1999, 52-6.

Fine ornamental-quality specimens of agate are found at several locations in Austria. A number of formations are described, notably the Bohemian Massif where the agate is found in serpentinites. Agate is also found in volcanic rocks. M.O.D.

Sapphire and garnet from Kalalani, Tanga Province, Tanzania.

A.V. Seifert and J. Hyrsl. *Gems & Gemology*, **35**(2), 1999, 108-20.

Reddish-orange gem-quality sapphire, pyrope-almandine and tsavorite occur in desilicated pegmatites cutting serpentinite massifs surrounded by amphibolite-facies rocks in the Kalani area (~ 3 km S of the Umba area). Gemmologically, the sapphires are virtually identical to those from Umba, but the garnets are different. The dark red to brownish-red pyrope-almandine from Kalalani is distinct from the pink-purple rhodolite found at Umba, and tsavorite is not known from the Umba area. Optical and physical properties are reported together with EPMA values for pyrope-almandine. R.A.H.

Texture formation and element partitioning in trapiche ruby.

I. Sunagawa, H.-J. Bernhardt and K. Schmetzer. *Journal of Crystal Growth*. **206**, 1999, 322-30, 5 figs., 1 table.

Based on textural and compositional investigations on ruby single crystals which show textures with six arms and six growth sectors (trapiche ruby from Mong Hsu, Myanmar), the mode of formation of the unique texture has been determined, and the element partitioning was related to the growth mechanism. The arms and the branches were formed earlier by dendritic growth on rough interfaces, and the growth sectors by lateral growth on smooth interfaces. The arm and branch portions consist of plural mineral phases but show a low and almost uniform Cr content in corundum throughout the extension, whereas the growth sectors consist of a single ruby phase and show Cr zoning parallel to the growth surfaces. Element partitioning in the earlier dendritic growth is governed by thermodynamic parameters, whereas that of the latter layer-by-layer growth by kinetics. The present size of trapiche ruby crystals was attained in a very short duration, i.e. that required to complete the skeleton by dendritic growth. I.S.

[The identification of a filled ruby.] (Chinese with English abstract)

H. Wan. Kuangwu Yanshi (*Bulletin of Mineralogy, Petrology and Geochemistry*), **18**(4), 1999, 410-11.

An EPMA examination of a secondary inclusion in a faceted ruby showed that its main component is a silica glass. R.A.H.

[The enhancement and treatment of pearl's colour.] (Chinese with English abstract)

J. Wang, J. Liang and M. Peng. Kuangwu Yanshi (*Bulletin of Mineralogy, Petrology and Geochemistry*), **18**(4), 1999, 407-9.

It is argued that since the colour of neither natural nor cultured pearl can meet people's demands, the colour needs enhancing. After being bleached, dyed and irradiated the colour of pearls is more satisfactory. R.A.H.

The colour of stones.

M. Wilson. *Transactions of the Oriental Ceramic Society*. **62**, 27-37, 1999, illus. in colour.

Describes the usage of and names given to hardstones, exclusive of the jades, used in Chinese artefacts. Rock crystal, amethyst, smoky quartz and rose quartz names are described with explanations of the Chinese characters used. M.O.D.

[Discussion on character of the rough jadeite crust.] (Chinese with English abstract)

E. Zhang, X. Yin and M. Peng. Kwangwu Yanshi (*Bulletin of Mineralogy, Petrology and Geochemistry*), **18**(4), 1999, 400-2.

The natural rough jadeite crust can be distinguished from man-made crust by EPMA, XRD and IR techniques. Chemical analyses (9) and IR spectra of three different depth zones in the sample are presented. R.A.H.

[Rossmanite, olenite, elbaite and the 50% rule as a basis for distinguishing between mineral species in Li-Al tourmalines.] (Russian with English abstract)

A.A. Zolotarev and A.G. Bulakh. *Proceedings of the Russian Mineralogical Society*, **128**(2), 1999, 32-8.

New structural formulae for liddicoatite, rossmanite and olenite have been calculated using a uniform approach. The compositions of the Li-Al tourmalines are plotted on vector diagrams; on these the composition of

rossmanite plots in the olenite field, and there seems no difference between properties and XRD data for rossmanite and olenite. This work indicates that, for the Li-Al tourmalines, new mineral species cannot be distinguished only on the basis of atomic occupancy at a particular structural site; all interdependent substitutions for atoms in the various structural positions must be considered. R.A.H.

Synthetics and Simulants

Russian synthetic ametrine.

V.S. Balitsky, T. Lu, G.R. Rossman, I.B. Makhina, A.A. Mar'in, J.E. Shigley, S. Elen and B.A. Dorogovin. *Gems & Gemology*, **35**(2), 1999, 122-34.

Gem-quality synthetic ametrine has been produced commercially in Russia by hydrothermal growth in alkaline solutions. The faceted material mostly resembles the Bolivian natural ametrine, but colour zoning and twinning are distinctive in the synthetic stones. XRF showed higher K, Mn, Fe and Zn than in natural ametrine. IR spectra of the synthetic citrine portions showed more intense absorption in the 3700-2500 cm^{-1} range and the synthetic amethyst zones showed a weak diagnostic peak at 3543 cm^{-1}. R.A.H.

Controlled crystallization of emerald from the flux melt .

S.N Barilo, G.L. Bychkov, L.A. Kurnevich, N.I. Leonuk, V.P. Mikhailov, S.V. Shiryaev, V.T. Koyava and T.V. Smirnova. *Journal of crystal growth*, **198/199**, 1999, 716-22, 3 figs., 3 tables.

Gem-quality emerald single crystals, with small dichroism, uniform distribution of colour throughout, and weighing as much as 150 ct, were synthesized from flux melt, using seed plates cut parallel to $(10\bar{1}0)$ and $(11\bar{2}0)$. The optimal concentration ratio of the solute near the crystallization front was maintained through adequate stirring by a platinum crystal holder rotated at a rate of 30 rpm and seed positioning. Laser experiments and threshold measurements were made to examine the emerald quality. Lasing was achieved at an absorbed pump energy threshold of less than 0.6 mJ. I.S.

Diamond formation during reduction of oxide and silicate-carbon systems at high *P-T* conditions.

A.I. Chepurov, I.I. Fedorov, V.M. Sonin, D.G. Bagryantsev and N. Yu. Osorgin. *European Journal of Mineralogy*, **11**(2), 1999, 355-62.

Diamonds have been synthesized in fayalite + graphite and magnetite + graphite mixtures by partial reduction of the samples with hydrogen and metallic titanium at 1300-1400°C and 45-55 kbar. Hydrogen provided local reduction of the samples with separation of metallic iron, which catalysed the transformation of graphite into diamond. Iron reacted with other elements and was not found in the free state in the experimental products. These experiments can be regarded as a simplified model for the formation of some types of natural diamond during the interaction of reduced fluids with carbon-bearing mantle rocks. R.A.H.

[Study on inclusion in synthetic diamond.]

(Chinese with English abstract)

B. Lin, H. Wan and M. Peng. Kuangwu Yanshi (*Bulletin of Mineralogy, Petrology and Geochemistry*), **18**(4), 1999, 308-9.

An inclusion in a synthetic diamond was shown by EPMA and XRD to be 'melnikovite' (greigite, $A^{2+}\ B_2^{3+}\ S_4$). It is suggested that the growth conditions in a specific oxidation-reduction environment allowing the coexistence of Fe^{2+} and Fe^{3+}. R.A.H.

Gem Trade Lab notes.

T. Moses, I. Reinitz and S.F. McClure (eds). *Gems & Gemology*, **35**(2), 1999, 136-41.

Items noted include a 19.64 ct faceted orange-brown bastnäsite, a 0.29 ct black synthetic diamond, and cobalt-doped synthetic forsterite whose strong pleochroism makes it a convincing tanzanite imitation. R.A.H.

Some diagnostic features of Russian hydrothermal synthetic rubies and sapphires.

K. Schmetzer and A. Peretti. *Gems & Gemology*, **35**(1), 1999, 17-28.

Most Russian hydrothermal synthetic rubies, and pink, orange, green, blue and violet sapphires (coloured by Cr and/or Ni), reveal diagnostic zigzag or mosaic-like growth structures associated with colour zoning. After proper orientation, these internal patterns are easily recognized using a standard gemmological microscope in conjunction with immersion or fibre-optic illumination; pleochroism is also useful for separating Cr-free blue-to-green synthetic sapphires from their natural counterparts, but this requires the determination of orientation of the optic axis in a faceted sample. Samples coloured by a combination of Cr, Ni and Fe are also described. R.A.H.

Epitaxial diamond growth on sapphire in an oxidizing environment.

M. Yoshimoto, K. Yoshida, H. Maruta, Y. Hishitani, H. Koinuma, S. Nishio, M. Kakihana and T. Tachibana. *Nature*, **399**(6734), 1999, 340-2.

The nucleation and growth of diamond by vapour deposition in a hydrogen-free, pure-O_2 environment to form hetero-epitaxially aligned crystallites on single-crystal synthetic (0001) sapphire wafers, are reported. The growth of the diamond occurs where the oxidative etching of C must compete with its formation. By choosing a *T*-range that results in preferential oxidation of graphite to that of diamond, accumulation of the latter occurs. Diamond crystals grew at ~ 600°C under O_2 *P* of 0.1-0.2 torr. An SEM photograph shows diamond crystals on the sapphire substrate. R.K.H

BOOK REVIEWS

The diamond formula

A.S. BARNARD, 2000. Butterworth Heinemann, Oxford. pp x, 166. Illus. in black-and-white. Softcover. ISBN 0 7506 4244 0. £24.99.

Useful and brisk round-up of the present position in the synthesis of gem-quality diamond with the first chapters giving an account of how the different processes developed. Some of the early pioneers are introduced and a large section of the text is devoted to developments in gemmological testing. For all sections references are made to a list at the end of the book and a number of photographs show persons and apparatus of diamond synthesis history. A good deal of useful information is given on De Beers synthetic industrial diamond and a chapter discusses the possible use of chemical vapour deposition (CVD). Details of gemmological laboratory testing are well-written and easy to read.

In compiling such a book the author accepts that most of the text should be 'stop press', so fast is the development of gem diamond synthesis! Details of the high pressure/high temperature altered diamonds and the story of GE POL must wait for the next edition of an excellent, readable and affordable book which is very suitable for diamond course students as well as the general reader. M.O'D.

Glossary of obsolete mineral names

P. BAYLISS, 2000. The Mineralogical Record, Tucson. pp viii, 235 + extra leaves for additional notes. Hardcover. ISBN 0 930259 04 1. US$32.00 plus $3 postage and packing.

With two columns per page and a small though legible typeface, this book is a companion to *Fleischer's glossary of mineral species* (Mandarino, eighth and latest edition 1999) and to *Hey's mineral index* (Clark, 1993). It is also something of a successor to the now rare *Dictionary of the names of minerals* (Chester, 1896) and *A catalogue of minerals and synonyms* (Egleston, 1892). The present work aims at the inclusion of all names used for mineral substances throughout history, which are not now considered valid or current [author's preface]. Varietal names of the gem minerals (e.g. ruby, sapphire) are not included. Further details on group, supergroup, subgroup, family, superfamily and subfamily are defined by Smith *et al.* in *Advances in X-ray analysis* **41** (1998) and notes on structural formulae can be found in Smith *et al. American Mineralogist*, **83**(126), 1998.

The entries in this book are brief, consisting of name, present equivalent, if any, source and author of information, thus Alumina hydrate = diaspore, Egleston 8 (1892): taprobanite = red Cr-rich taaffeite-*8H*, *American Mineralogist*, **69** (215), 1984. I have noted a few typos but on the whole the entries have been carefully transcribed. I have not attempted to check the Linnean-style names proposed for minerals in the earlier editions of Dana's *System of mineralogy* but on a read-through some of them have shown up; cuprum lazureum (azurite), oculus mundi (opal) are examples. Many names appearing unfamiliar at first sight are later seen to consist of non-English forms and on the whole the author has traversed this minefield successfully. Gemmologists with an interest in minerals should buy this very reasonably-priced book. M.O'D.

Minerals of Broken Hill

W.D. BIRCH (Ed.), 1999. Broken Hill City Council, Broken Hill. pp xii, 289. ISBN 0 9599486 9 4. Price on application.

This is the second large, full coloured survey on the minerals of Broken Hill to appear in the last 17 years: in 1982 Australian Mining and Smelting Ltd published a good quality survey under the same title. Considerable work has taken place on the site since that time and all serious mineral collectors will want to be able to consult a copy of the present book, if not to buy it. The text begins with a geological and historical survey of the area, including a close study of the main ore-body, and then continues with the main descriptive section in which mineral species are arranged alphabetically. The text includes notes on species no longer validated: this type of information is always necessary and should never be discarded even when the species is discredited. Future workers may have lost sight of type specimens, thus making work cited in earlier reports uncertain so it is well worth knowing why a particular theory is advanced. References are given to significant papers where the occurrence of a particular species is especially noteworthy.

The descriptive section is followed by a complete list of recognized minerals from the Broken Hill deposit, by a first-class bibliography of 25 pages and by a glossary. The editor and publishers are to be congratulated for producing so fine a book: the photographs are for the most part of outstanding quality though I found the odd one slightly (but only slightly) out of focus. Several of the species could have been taken as having ornamental potential and more would make collectors' gemstones. M.O'D.

Symmetrielehre der Kristallographie

R. BORCHARDT AND S. TUROWSKI, 1999. Oldenbourg Verlag, München. pp viii, 108, pl 32, softcover. ISBN 3 486 24648 8. DM 63.00.

Clear and useful guide to mineral crystals with 32 cut-out models of the simpler examples, the book is unusual as it is arranged in descending orders of symmetry, the text relating specifically to the models at the end but also providing crystallographic descriptions and examples of mineral species whose crystals take, or can take, the particular forms depicted. M.O'D.

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The Desmond Sacco collection: focus on southern Africa

B. CAIRNCROSS, 2000. The author, Marshalltown, Johannesburg. pp 408, illus. in colour. Hardcover. ISBN 0 620 24340 6. Price on application.

This magnificent book catalogues a part of the Desmond Sacco mineral collection, covering southern Africa. Though many of the specimens depicted would have gemstone potential, faceted stones, though forming part of the complete collection, are specifically excluded from the book. The countries covered apart from South Africa, are Zimbabwe, Mozambique, Namibia and the Democratic Republic of the Congo. Introductory material gives a brief biography of Desmond Sacco and the development, housing and growth of the collection. Sacco trained as a field geologist and the various positions he has held have greatly assisted both the collection and the public awareness of the beauty and importance of fine African minerals. Perhaps the greatest highlight in a fascinating career was Sacco's discovery of rhodochrosite at his own company's mine, N'Chwaning 1 in the south African Kalahari manganese field. This material is, of course, well-known to gemmologists.

Tributes to the collection and its founder follow and many of the displays are illustrated before the section on Namibia begins: as with the other countries covered the text opens with a map before examining the major mineral deposits in detail. The mineral photographs are so arranged that there are never more than six in a single opening and may occupy a whole page: dimensions of the specimens are given and, even better, each location has its own bibliography. From the gemmological point of view some of the finest specimens in the Namibian section are translucent yellow smithsonite (from Berg Aukas), amethyst (Brandberg), blue and yellow-green tourmaline (the Karibib-Usakos pegmatites), topaz (Klein Spitzkoppe), cerussite and nambulite (the Kombat mine), fluorite (Okorusu), cuprite (Onganja) and yellow transparent mimetite (Tsumeb - naturally the location with the most species). From South Africa are the rhodochrosites from the Kalahari and prismatic purple sugilite (Wessels mine): gold deposits and diamond crystals are not included. From Mozambique are manganotantalites and very large topaz crystals from the Alto Ligonha pegmatites, transparent yellow-green beryl and red tourmaline from Nampula. Gemmy specimens from Zimbabwe include a fine heliodor from the Green Walking Stick mine, Miami, gemmy aquamarine from Karoi and both ruby and blue sapphire crystals from the south of the country. Cuprite and cobaltian calcite crystals feature in the Democratic Republic of the Congo.

Reading through the book the reader will come across several examples of minerals large and clear enough to facet ~ but this would really be vandalism! Here are some of them, none the less: orange sturmanite, colourless thaumasite and bright yellow ettringite (N'Chwaning), wulfenite and orange cadmium-rich smithsonite (Tsumeb). The book is not cheap but try to see a copy somehow, somewhere! M.O'D.

Gemme: dati per l'identificazione

P. DE STEFANO, R. MARCON AND S. MORABITO, 1993. Finpreziosi Italia s.r.l., Milan, for the Istituto Gemmologico Italiano. pp xii, 99. Absorption spectra in colour. Softcover, ring-bound. ISBN 88 86279 00. price on application.

Large-format (34 × 24 cm) tabular guide to the major gemstones arranged by colour. All major constants are given and consolidated individual tables of refractive index and specific gravity are provided at the end of the main text. There is a short though useful bibliography and an index. Presentation is very clear and the whole production reflects credit on the compilers and publishers. M.O'D.

Gems: a lively guide for the casual collector

D.J. DENNIS Jr, 1999. Harry N. Abrams Inc., New York. pp 192, illus. in colour. Hardcover. ISBN 0 8109 4126 0. £18.95.

This is a book like many other general enthusiastic introductions in that it does not aim to be gemmologically accurate, nor is it. This would only be of concern to the pedant, perhaps, as the book is quite attractive, with small colour photographs of gemstones placed in the text margins in place of larger ones in a separate central section, a commoner practice today. This may not be the happiest way of introducing gemstones when details of the text are a little vague on occasion. The reader new to the subject needs more illustrations - some of stones set in jewellery would be welcome - but on the whole the book succeeds quite well in its stated aims. There is some pleasing eccentricity which surfaces most prominently in the section on the care of jewellery: it is suggested that toothpaste is not an ideal cleaning medium - this instantly brings to my mind one way in which a piece of jewellery (never loose stones of course) might in ignorance of the book's strictures be cleaned in haste before a dinner party, with alarming consequences. It would be better not to dwell on this! M.O'D.

Einkaufsführer 1999

Sudwestdeutsche Verlagsanstalt, Mannheim, 1999. pp 748. ISBN 3 87804 276 0. Softcover, DM79 + DM17.50 post and packing.

Latest edition of an established guide to the watch, jewellery, precious stone and silver goods industries of Germany, this well-produced directory is invaluable with anyone wishing to get in touch with gemstone dealers and others who in many cases have included most attractive advertisements of their products. Entries are classified and cross-referenced. M.O'D.

Boron: mineralogy, petrology and geochemistry

E.S. Grew and L.M. Anovitz, 1996. Mineralogical Society of America, Washington. pp xx, 862, softcover. ISBN 0 939950 41 3 (series ISSN 0275 0279) (*Reviews in Mineralogy*. **33**). Price on application.

Gemmologists as well as mineralogists and geologists will find a great deal of useful information in this large multi-author study of the role of boron in the earth sciences. From page 503 to page 623 attention is focused on tourmaline group minerals and this will be of particular interest to the student of the gem minerals and their geochemistry but there is also much to say about all boron-bearing species. Comprehensive bibliographies accompany all sections. M.O'D.

Naming gem garnets

W.W. Hanneman, 2000. The author, Poulsbo, WA, U.S.A. pp xii, 103. Includes colour charts. Ring-bound, softcover. ISBN 0 9669063 1 4. US$20.00.

Passing on a warning from the author that the print run will be short, try to get this excellent overview of garnet nomenclature before too long.

There has always been a problem over 'what to call the garnets?'. Hanneman gives a useful conspectus of previous work on garnet nomenclature and adds, to summarized papers by various authors, copies of letters to the editors of gemmological journals in which he comments upon the papers. Hanneman feels that some at least of the nomenclature schemes postulated by mineralogists are unhelpful and that some of the names (which may have arisen through trade sources) are both of equal validity through assumption and also help to promote the wider acceptance of the newer gem species and varieties among the general public. The use of such names would in no way detract from mineralogical precision since quite different ends are sought by gemmologist and mineralogist. Perhaps one analogy might be with coats-of-arms, some of which are so ancient that no documents record their granting: none the less they are accepted just because everyone has long recognized them. This is in fact what seems to be happening: if it is, a certain common sense would seem to be operating. Probably the two sides might never agree but why should they need to?

In pointing out the steps by which garnet classification and nomenclature have reached their present state, Hanneman has performed a useful service and the book deserves a wide readership. In his journey quite a number of other topics arise, all throwing light upon his main thesis: in addition he includes colour charts and tables listing properties taken from a number of different sources. A note describing the operation of the Hanneman Garnet Refractometer is included (it will measure refractive indices up to 1.90). Like all the author's instruments and this book, it works well and the cost is minimal. M.O'D.

Rubies (diamonds, emeralds, sapphires) are a girl's best friend

Sue Heady with gemmological introduction by Michael O'Donoghue, 1999. Grange Books plc, Rochester. Series of four books, each with 96 pages, illus. in colour. Hardcover. ISBN 1 84013 259 0: 1 84013 258 2: 1 84013 261 2: 1 84013 260 4. £3.99 each.

Attractive tall-format presentations of four major gemstones set in major items of jewellery which have featured in Christie's sales catalogues of the past few years. A short gemmological introduction to each species is provided by the present reviewer. For the most part the jewels have reproduced well: the descriptive text is selected from the sales catalogue entries and the whole series, let alone each book, is amazingly cheap for what you get and would make a starter gift for anyone developing an interest in jewellery and gemstones. The dust covers are particularly attractive when seen in combination with the tall format. Each book is available separately. M.O'D.

Gems and gem industry of India

R.V. Karanth, 2000. Geological Society of India, Bangalore. pp ix, 405. Illus. in colour. [*Memoirs of the Geological Society of India*, **45**.] Hardcover. ISBN 81 85867 41 0. US$75.00.

Despite history, India remains the sleeping giant of Asiatic gemstone production. Rumours abound of specimens of the highest quality turning up but there seems never to have been a consistent supply. This reviewer has spoken to a number of gem miners who have worked in India who bear out these possibilities. India has a varied geology which is well described in this standard text. The preface correctly remarks that there has been no book on Indian gemstones since the publication of Iyer's *Indian precious stones* (1946) [and this book has many weaknesses] so the appearance of this one is timely to say the least.

The reader may be surprised to find that the first 188 pages comprise in fact a treatise on gemmology with no particular reference to India. Details of specifically Indian stones and conditions begin almost apologetically during the section on diamond which appears as the first of the isotropic minerals (the descriptive text is arranged as isotropic, uniaxial and biaxial). While the descriptions of the materials are what the reader would expect, the real treasure (in that the details have never appeared in monograph form before) is the comparative wealth of locality information, much of which is referred to coordinates. It is here that we find some indication of the potential gem wealth of the country. Entries also describe the significant geology and mineralogy of the major deposits with some notes on mining practices; some historical references are also given and extracts from correspondence giving up-to-date information occur here and there. There are also notes on simulants in the appropriate places.

The descriptive section and the book close with a fairly extensive bibliography and a set of identification tables. While three maps are provided they are too small in scale to be much more than a rough guide to the whereabouts of the major sites. There could well have been more and better maps and their absence detracts from the general usefulness of the book. While thoroughly

appreciating the difficulties that would be encountered if a long-term study of current deposits was undertaken it might have been better to have gone all-out for that, rather than trying to make a gemmological textbook out of at least one third of the text. Nevertheless, the book is of real value, but when I think what it could have been ...! M.O'D.

The MicroWorld of Diamonds

JOHN I. KOIVULA, 2000. Gemworld International Inc., Northbrook, Ill., U.S.A. pp xxiii, 157, Illus. in colour. Hardcover. ISBN 0 964 17335 2. US$95.00.

The author (an internationally acclaimed gemstone inclusion photographer and researcher) hopes that this book will open 'a doorway providing an introductory look at the colourful, fascinating and highly educational microworld of nature's diamonds, and the microclues to diamond enhancement, synthesis and simulation.' It goes much deeper and could well serve as a reference text and laboratory manual for all gemmologists whether they be tiros or experienced researchers.

There are twelve chapters of varying length and importance. The first four describe the Virtues; the famous 4 C's; the tabulation of properties; and diamond notes ~ a mini textbook of general information. In Chapter 5 on inclusion identification the author suggests that his Level One may be seen as observing and mentally analysing; it requires considerable experience and is time consuming. Level Two as identifying with instruments, which may be highly sophisticated and expensive and Level Three as providing a complete chemical and structural analysis for serious research papers; it is seldom performed in most gemmological laboratories. Chapter 6 on microscopy describes all the standard techniques as well as many innovative procedures which the author himself has developed over the years. In Chapter 7 the micro-surfaces on nature's diamonds are explained as being largely due to etching and dissolution and are dealt with under the headings of surface graining, knots and naats, nuances of polishing, burn marks, radiation stains and etched dislocations and channels. The next 34 pages of text (Chapter 8) with over a hundred colour photographs are probably a very appropriate illustration of the author's real passion ~ inclusions in gemstones and in diamonds in particular. He explains how these inclusions tell us about their host's place of origin and its journey through the earth and how they are our only real window through the crust and into the mantle. Chapter 9 explains how evidence of the enhancement of natural diamonds can be detected by the study of micro-surfaces and interiors. In contrast Chapter 10 details the micro-features of gem-quality synthetic diamonds, whilst Chapter 11 describes the corresponding features of the various diamond simulants. In his short Chapter 12 the author concludes that from what he can determine this work is the largest single published compilation of photomicrographs on the subject of diamonds; he also comments that 'the book is as much a work of natural art as it is of natural science' (the reviewer agrees).

There are over 400 superb colour photographs and each is explained with a detailed and lucid caption. The whole text is very user-friendly for the beginner, but there is also much 'meat' for the specialist, who will find the excellent bibliographies at the end of each chapter particularly useful. The standard of production is commendably high. At US$95 the book is not cheap, but its cost could easily be retrieved by any jeweller or gemmologist who avoids an expensive mistake with an enhanced diamond or synthetic moissanite as a result of studying this admirable and artistic work. E.A.J.

De wondere Wereld van de Edelsteen

R.C. LITJENS, 1998. Vakschool voor Edelsmeden en Fijne Techniek, Schoonhoven, The Netherlands. pp 153, hardcover. Dfl 49.50.

Attractively produced gemmological textbook for students with no colour pictures but quite good ones in black-and-white. The text follows an acceptable pattern, placing theory and instrumentation before discussing the gem species. Diagrams and photographs (I have not seen them before and a very interesting one of emerald mining in Zimbabwe caught my eye) are often arrestingly placed in the margins of the text and the various tables and notes on nomenclature seem to be accurate. There is a shortish bibliography whose entries for the most part refer to respectable literature. Altogether this would make a good introductory text for Dutch speaking students. M.O.D.

Miller's jewellery antiques checklist

Miller's, London, 1997. pp 192, illus. in colour. Hardcover. ISBN 1 85732 816 7. £9.99.

A pocket-sized guide in which all objects are shown in colour, this attractive book aims at helping first-time customers in the antique jewellery market. After an introduction in which the commoner gemstones are described, together with notes on stone measurement and the care of jewellery, the text is arranged by type of object: thus brooches, bracelets, cameos, mourning jewellery and stickpins all have their individual though small sections. In each section the descriptions are roughly chronological. There is a short bibliography and an equally short list of major designers and manufacturers. Read with care, this makes a good introduction to jewellery studies. M.O.D.

Pietre pretioase fine ornamentale, perle

A. MIRCEA-DRAGOMIR AND K. HEINZ, 1997. Editura Ipunct Bucuresti. pp 146. Softcover. IISBN 973 99265 0 9. Price on application.

Pleasantly produced and well-illustrated guide to gemstones and pearls with general notes on a wide range of species, identification tables and a bibliography in which entries are arranged chronologically. The book is claimed to be the first professional book on gemstones to be published in Romania: readers with a classical background will find little language difficulty. A second edition might well incorporate colour photographs and a little more information on European and other localities but this book is a good start. M.O'D.

The triumph of love: jewellery 1530-1930

G.C. MUNN, 1993. Thames & Hudson, London. pp 104, illus. in colour. Hardcover. ISBN 0 500 23661 5. £18.95.

A beautifully-produced book in which the jewellery of romance, courtship, liaisons, marriage and fidelity are celebrated, as these qualities (or some of them) were celebrated in their time, which in the context of the book takes the reader to the middle of the 20th century. The arrangement of the text is chronological: there is a bibliography and the history of many of the artefacts described is noted, as are the biographies of many of the designers and owners. This is a book of scholarship lightly worn and of great charm. M.O'D.

Gold and platinum jewelry buying guide

R. NEWMAN, 2000. International Jewelry Publications, Los Angeles. pp 156, illus. in colour. Softcover. ISBN 0 929975 29 4. US$19.95.

Many gemmologists will be concerned professionally or more loosely with the use of gold and platinum in jewellery. This reviewer, with an interest in some aspects of gold and other precious metals, found the book set at exactly the right standard for both professional sales staff and for those who come across gold and precious metals less often, with chapters on terminology, manufacturing methods, mounting and setting techniques and their evaluations, chains (and how cheap or fake ones frequently kink), determination of fineness and of fakes, colours, coin jewellery and bullion coins, valuations and care of jewellery. As always the text is very easy to read and the pictures succeed very well, considering that most gold artefacts are of similar colour. There is a useful bibliography and the price is amazingly low, as always with this publisher. Both publisher and author must be highly commended once more. M.O'D.

Gold in der Schweiz 2 Auflage

P. PFANDER AND V. JANS, 1999. Ott Verlag, Thun. pp188, illus. in colour, hardcover. ISBN 3 7225 6300 3. DM43.80.

Revised edition of a guide to Swiss gold localities first published in 1996, this survey will be of considerable interest to those gemmologists with an interest in minerals and in gold itself. Types of occurrence, mineralogy and geology are generally described and the main body of the text, in which locations are given, is arranged on a geographical basis. Details of the different occurrences and illustrations of some notable specimens and mines go to make up an invaluable guide, in which up-to-date references are also given. Most sites are indicated on maps in the text and the quality of the illustrations is excellent. M.O'D.

The simpler? polyhedra. Part 3

P. TAYLOR, 1999. Nattygrafix, Ipswich. pp 79, softcover ISBN 0 9516701. £6.00.

The third part of this interesting presentation of possible answers to the question 'What constitutes a uniform polyhedron?' deals with those polyhedra which are essentially assemblies of polygons, similar to tilings of the plane but with fewer or lesser valued polygons at each vertex. M.O'D.

Von Ammoniten und Zwillingen (catalogue of the 1999 München Mineralientage)

Oberhaching, Germany, 1999. pp 287, illus. in colour, softcover. Price on application.

The catalogue of the annual München Mineralientage is always a beautiful production. In 1999 the theme of the show was fossils, with special attention given to ammonites, and to twinned crystals which are described and discussed by several authors on pages 29-111, this large section thus forming a serious study of twinning, with many high-class photographs and diagrams. Sources of especially fine examples are identified: some of the crystals highlighted are of gem and ornamental quality (chrysoberyl, quartz). The different types of twinning are clearly shown both in diagrams and photographs. Readers should try to obtain these catalogues: with a different theme each year and the wealth of directory and advertising information it is hard to see why more gemmologists do not possess them. M.O'D

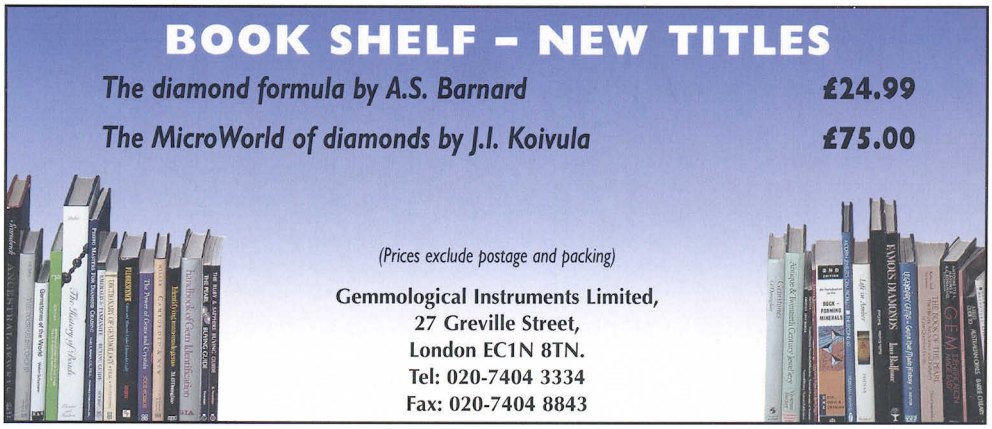

Proceedings of the Gemmological Association and Gem Testing Laboratory of Great Britain and Notices

Photographic Competition

The 2000 Photographic Competition on the theme ***The Light Fantastic: optical effects in gems*** drew a record number of entries of a very high standard.

First Prize

Dennis Durham, Kingston upon Hull

Rock crystal (15.86 ct) depicting twelve reflections of a single hexagonal crystal now transformed to secondary minerals (illustrated on front cover).

Second Prize

Anthony de Goutiere, Victoria, BC, Canada

Trigons on diamond crystal

Third Prize

Victoria James, Orem, Utah, USA.

Opal

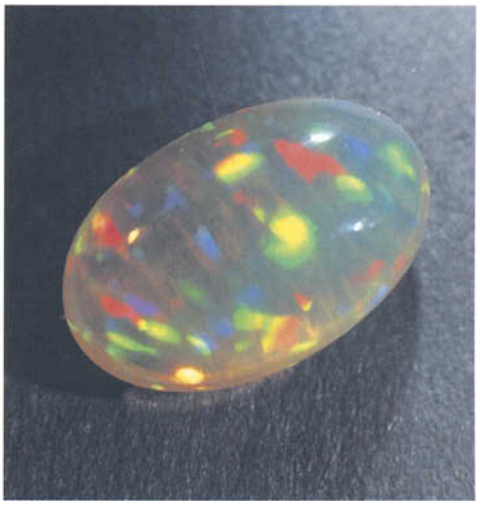

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OBITUARY

Dean Stirling Mark Field

Members of the Canadian Gemmological Association were saddened recently to learn of the sudden death of the founder of the CGA, Dean S.M. Field (D.1955). Dean was born in Cape D'Or, Nova Scotia, on 1 June 1917 and died in Toronto on 7 May 2000.

His interest in gemstones began at an early age when a local jeweller and watchmaker befriended him and gave him a small phial of stones consisting of a seed pearl, a small diamond, an emerald, a ruby, a sapphire and several other small gemstones. Later Dean and his mentor hunted for zeolites, amethyst crystals and agate pebbles which he sold to tourists.

Like many young men of his age Dean suffered as a result of the stock market crash in 1929 and a university degree was denied him. He moved back and forth between home and Montreal, Toronto and Vancouver seeking work wherever he could find it. A breakthrough for him came with the publication in 1941 of Robert Webster's *Practical Gemmology*. He read the whole book in not much more than one night and then went back to study it in detail. In 1947 he began his studies toward a Fellowship Diploma. As a result of continuing work with National Security Dean was not able to complete his studies until 1955. Had he been able to complete his theory and practical examinations the same year he would have passed with distinction.

Dean had begun to work in 1947 for the Toronto Gem Lab and when he completed his studies he prepared a series of twenty semi-formal lectures on gems and gemmology which he offered to 32 students from the Toronto area. The disadvantage of these private lectures was that his students did not have recognized documents of achievement so he began negotiations to coach the established course of the Gemmological Association of Great Britain. In 1958 Dean founded the Canadian Gemmological Association to, in his words, 'foster the friendship and camaraderie that was built up during the years of study and discovery' (see *The Canadian Gemmologist*, **10**(1), 8-12). Dean served as president from 1958 to 1960 and again from 1980 to 1981.

Later Dean Field became the official gemmologist and gem buyer for the T. Eaton Company, a major Canadian department store featuring outlets from coast to coast as well as a mail order service. With his formidable knowledge, his wealth of anecdotes, his wonderful sense of humour and his enthusiasm, Dean was a welcome speaker at many of the CGA meetings which he continued to attend as recently as April of this year. In recent months he had begun a compilation to mark the discovery of deposits of gem diamonds in the North West Territories of Canada which he had predicted in an article he wrote for *The Canadian Mining Journal* in July of 1950.

Dean Field, Founder of the Canadian Gemmological Association, at the CGA Gem conference, Toronto, in October 1993. Photo: Willow Wight.

Dean was able to bridge the generation gap and was a mentor to many of us in his later years. All at the CGA had hoped that he would be here to celebrate the 50th anniversary of the association that he founded.

* * *

Hugh B. Crawford (D.1978), Castle Douglas, Kirkcudbrightshire, died in January 2000.

Dr William G. Cross (D.1965), Christchurch, Dorset, died on 16 January 2000 after a long illness.

GIFTS TO THE ASSOCIATION

The Association is most grateful to the following for their gifts for research and teaching purposes:

Arild Andersson, Oslo, Norway, for a 2.73 ct faceted oval peridot and two thulite cabochons, all from Norway.

Mrs Afzal Fatima Ali, South Norwood, for a collection of books and instruments presented in memory of her late husband, Syed Jafer Ali Abedi.

Professor Hermann Bank, Idar Oberstein, Germany, for 9 quartz soudés and 14 synthetic spinels imitating moonstone.

Friedrich August Becker, Idar Oberstein, Germany, for three tourmaline pieces each with one facet, cut during the GAGTL trip to Idar Oberstein, and ten posters.

K.C. Subhash Chandra of the Geological Society of India, Gavipuram, Bangalore, for Gems and gem industries in India by R.V. Karanth.

John R. Führbach, Amarillo, Texas, U.S.A., for two pieces of tumbled Brazilian amethyst and a faceted stone.

Eiko Ito for a blue-grey cultured pearl, a flower of cultured pearls, a packet of ground coffee containing ground-up cultured pearl and an article on 'Circle pearls' by Eiko.

Dr George Harrison Jones, Burnham, Buckinghamshire, for two blue chalcedony cabochons.

Ronald F. King, Maidenhead, Berkshire, for a box of miscellaneous stones and a set of slides.

Charles McShane for a stained quartzite.

Keith Palmer, Sphinx & Femina Ltd, Chiswick, London, for seven bead bracelets ~ imitation turquoise, hematite, calcite, tiger's-eye and three quartzite, two of which are stained.

Stephane Salerno, Edmonton, Alberta, Canada, for a 3.35 ct chatoyant agrellite cabochon.

Pierre Vuillet a Ciles, Villards d'Heria, France, for a 2.95 ct langasite, a yellow-green synthetic stone.

MEMBERS' MEETINGS

London

On 7 April a visit was arranged to the School of Geological Sciences, Kingston University. As well as learning about the current research on fluid inclusions in minerals from Professor Andy Rankin and his team, the group visited the the School's new laboratories which house equipment such as the Raman and electron microprobes.

On 19 April at the GAGTL Gem Tutorial Centre, Professor Alan Collins gave a lecture entitled *The colour of diamond and how it can be changed*.

On 27 April members visited De Beers, where they were given a talk on the diamond trade today and were able to view the displays in the Diamond Information Office.

On 4 May at the GAGTL Gem Tutorial Centre John Nels Hatleberg, visiting the UK from New York, gave a talk on the replicas of famous diamonds that he produced and also his conceptual jewels. Samples of his work had been displayed in a temporary exhibition at the Natural History Museum, South Kensington.

On 18 May at the GAGTL Gem Tutorial Centre Corinna Pike gave an illustrated talk entitled *The Rose - nature's jewel as a decorative emblem*.

On 14 June a visit was arranged to the *Treasures of the 20th Century*, the Millennium Exhibition at Goldsmiths' Hall.

Midlands Branch

On 31 March at the Earth Sciences Building, University of Birmingham, Edgbaston, Dr Rob Ixer gave a talk entitled *All that glitters is not gold*.

On 28 April at the Earth Sciences Building, silversmith Martyn Pugh gave a review of 20 years in the art of design and manufacture of jewellery, official pieces and objets d'art. The talk was followed by the Branch Annual General Meeting at which David Larcher, Gwyn Green, Elizabeth Gosling and Stephen Alabaster were re-elected President, Chairman, Hon. Secretary and Hon. Treasurer respectively.

On 21 May at the Earth Sciences Building, jewellery designer Memory Stather talked about her choice of materials, sources of inspiration and displayed samples of her work.

FORTHCOMING EVENTS

13 September	**London.** *From geology to jewellery - the platinum millennium.* ***Dr Judith Kinnaird***
20 September	**North West Branch.** *History of English watches from verge to lever.* ***Peter McIvor***
29 September	**Midlands Branch.** *Gemmology and Gem Testing Quiz*
18 October	**North West Branch.** *Minerals and gems at the Great Exhibition of 1851.* ***David Lancaster***
27 October	**Midlands Branch.** *The works of Peter Carl Fabergé.* ***Stephen Dale***

GAGTL ANNUAL CONFERENCE

Sunday 29 October - Barbican Conference Centre, London

Keynote speaker: Professor Al Levinson, Calgary, Alberta, Canada
Diamonds in Canada - geology to gemmology

Paul Spear, DTC Research Centre, Maidenhead
Synthetic and treated diamonds

Dr Judith Kinnaird, University of Witwatersrand, South Africa
The sparkle in Somaliland

Robert Fawcett, The Cultured Pearl Company Ltd.
South Sea cultured pearls - their place in the market

Harry Levy, President of the CIBJO Diamond Commission
What's in a name?

CONFERENCE VISITS
27 October: **De Beers**
30 October: **The Gilbert Collection at Somerset House**

Full details and application forms available from the GAGTL on 020 7404 3334

30 October	*Presentation of Awards*
15 November	**North West Branch.** *AGM* followed by *Gem collection and anecdotes.* ***John Pyke Snr***
23 November	**London.** *Amber - has the bubble burst?* ***Helen Fraquet***
24 November	**Midlands Branch.** *The minerals of Pakistan.* ***Michael O'Donoghue***
2 December	**Midlands Branch.** *Annual Branch Dinner*

For further information on the above events contact:

London:	Mary Burland on 020 7404 3334
Midlands Branch:	Gwyn Green on 0121 445 5359
North West Branch:	Deanna Brady on 0151 648 4266
Scottish Branch:	Catriona McInnes on 0131 667 2199

North West Branch

On 21 June at Church House, Hanover Street, Liverpool 1, Memory Stather gave a talk entitled *Pocket sculptures - gemstone carving?*

Scottish Branch

On 27 March at the British Geological Survey, Edinburgh, Brian Jackson gave a talk entitled *The lore of gemstones.*

The Annual Conference of the Scottish Branch was held in Perth from 28 April to 1 May. A report was published in the June 2000 issue of *Gem and Jewellery News.*

MILLENNIUM TRADE DINNER

To celebrate the 75th anniversary of the founding of the Laboratory and to renew confidence and optimism in the jewellery trade at the start of the millennium, the GAGTL joined with the London Diamond Bourse and Club to hold a dinner at Goldsmiths' Hall in the City of London. The guest speaker was Gary Ralfe, Managing Director globally of De Beers.

Freddy Hager, President of the LDBC, welcomed those present and GAGTL Trade Liaison Committee Chairman, Jeffrey Monnickendam, introduced Gary Ralfe. The vote of thanks was given by Terry Davidson, immediate past Chairman of the Trade Liaison Committee. The event was generously sponsored by Malca-Amit (U.K.) Ltd.

A full report of the Dinner and Gary Ralfe's speech was published in the June 2000 issue of *Gem and Jewellery News.*

ANNUAL REPORT

The following is the report of the Council of Management of the Gemmological Association and Gem Testing Laboratory of Great Britain for 1999.

The Gemmological Association and Gem Testing Laboratory of Great Britain (GAGTL) is a company limited by guarantee and is governed by the Council of Management. The president, Professor R.A. Howie, and the Vice Presidents E. Bruton, A.E. Farn, D.G. Kent and R.K. Mitchell continued in office. C.R Cavey resigned from the Council of Management in January; J. Monnickendam and E. Stern joined the Council in April and I.F Mercer in June.

Dr G. Harrison Jones retired from the Board of Examiners and Miss C.M. Woodward was elected Chairman. The GAGTL is indebted to Dr Jones for his guidance and wisdom in examination matters for more than 24 years. At the AGM in June,

Millennium Trade Dinner held at Goldsmiths' Hall in the City of London. Centre, Gary Ralfe, Managing Director globally of De Beers, with Jeffrey Monnickendam, Chairman of the GAGTL Trade Liaison Committee and his wife (left) and Freddy Hager, President of the London Diamond Bourse and Club with his wife (right).

R.G. Fuller resigned from the Members' Council and J. Kessler and J. Monnickendam did not seek re-election; the Council continued to be chaired by C. Winter. J. Monnickendam was elected Chairman of the Trade Liaison Committee and the new Vice-chairman is J. Kessler.

At the Gem Tutorial Centre in Greville Street, the Gemmology and Gem Diamond courses were well subscribed with a good mix of students coming from home and overseas. Correspondence courses (or distance learning) have been made very much more effective with establishment of a gemstone library, regular gem practical tuition or refresher courses, and seminars on examination technique. New sections have been added to the Gemmology Diploma course to improve guidance and productive homework, and a new supplement with information on the latest treatments was added at the end of the year.

Gem Diamond course students now have the option of training in the evenings over eight months, training for one day a week over four months, or by correspondence. New options are being prepared for 2001.

New Allied Teaching Centres (ATCs) have been established in Montreal, the Caribbean, Singapore and Taiwan, and numbers of students overseas taking our courses now exceed those in the UK.

Comprehensive training in gems for the jewellery trade is available through a growing number of focused short courses and custom-made tutorials. Topics range from pearls to jade, synthetics, enhancements and diamond.

In addition to the Gem Tutorial Centre courses held in London, the education team has run courses in other major cities in the UK and in Finland, Ireland, Norway, Sweden and the USA (Chicago and Washington). In association with De Beers D. Garrod ran a series of tutorials entitled 'Diamond or not' to inform trade personnel on how to detect synthetic moissanite.

Practical handbooks have been written for nearly all of these courses, and one of them, the Gem observation guide, has been developed and produced for sale. Plans are in hand to develop other handbooks in a similar way.

Through study at the ATCs, students can train to take diplomas in gemmology or gem diamond. The Preliminary gemmology examination has recently been augmented with a practical element, and the Diploma can now be taken in nine languages in addition to English: Chinese, Dutch, Finnish, Greek, Japanese, Korean, Norwegian, Spanish and Swedish.

For all examinations, pass rates were better this year than for several recent years although no student quite reached the levels required for the Tully and Bruton medals. In the Diploma in Gemmology examinations, the Anderson-Bank prize was awarded to Miss Jie Yang of Wuhan, P.R of China, and the Diploma Trade prize was awarded to Miss Yurika Tachibana of Tokyo, Japan. The Anderson Medal for the best candidate of the year in the Preliminary examination went to Miss Liu Jiewen of Guilin, P.R of China, and the Preliminary Trade prize was awarded to Miss Yan Wei of Shanghai, P.R of China.

Once again, the Presentation of Awards was held at Goldsmiths' Hall; the President presided and the prizes and diplomas were presented by the Guest of Honour, Mr E. Alan Jobbins.

The laboratory continued to issue both London and CIBJO Diamond reports, origin of colour reports for coloured diamonds, identification and treatment reports for coloured stones and pearl reports. Growing numbers of treated gems and non-nucleated cultured pearls in the gem trade have meant that the balance of work in the laboratory has changed to respond. Staff have participated in developing guidelines for the best nomenclature in the CIBJO standard books, and S.J Kennedy represented GAGTL at the annual conference in Bern, Switzerland.

GAGTL again exhibited at the International Jewellery Fair at Earl's Court in September, and daily seminars run by D. Garrod and L. Stather attracted full houses. GAGTL also exhibited at the Las Vegas Jewellery Fair in June (M. Burland and D. Garrod), and at the Hong Kong Fair in September where B. Hunt, L. Stather and A.J. Clark promoted education, instruments and membership to Far Eastern visitors. I.F. Mercer visited Hong Kong, Wuhan and Shanghai in March to coordinate Allied Teaching Centre (ATC) activities, and in November R.R. Harding visited Wuhan to present an Honorary Fellowship to Professor Chen and to present a prize and diplomas to students successful in GAGTL exams. Diplomas were also presented to successful students in Hong Kong at the Annual Dinner of the Hong Kong Gemmological Association on 11 November.

In the UK, the GAGTL branches in Birmingham, the North West and Scotland continued with a variety of lectures, seminars and field trips.

The theme of the 1999 Members' Photographic Competition was 'Gems of the Century', the

winner being R. Huddlestone of London. We are most grateful to Quadrant Offset Limited, who design and print both the calendar and the Journal of Gemmology, for sponsoring the prizes. A selection of entries was made for the 2000 calendar which is circulated free to members.

The Annual Conference was held at the Barbican Centre in London on the theme 'New developments in the gem world'. The keynote speaker was Dr James Shigley of the GIA who spoke on diamond identification. New African gemstones were comprehensively discussed by Campbell Bridges of Bridges Exploration Ltd., and a thought-provoking perspective on the retail gem trade was provided by Dr Jack Ogden, Chief Executive of the NAG and Secretary General of CIBJO. Over 130 participants from twelve different countries attended the lectures and demonstrations where synthetic moissanite, a GE POL treated diamond and the new Brewster Angle Meter could be examined.

In the *Journal of Gemmology* 22 papers were published in 1999 with topics ranging from trapiche rubies to colour changes in alexandrite and tourmaline, and from black jadeite to the diamond industry in India. A total of 171 abstracts and 81 book reviews were also published and the Council express their sincere thanks to the Assistant and Associate Editors for their invaluable help and advice during the year.

Gem and Jewellery News is published jointly with the *Society of Jewellery Historians* and in 1999 contained a wide range of comment on such topics as synthetic and treated diamonds, the new eternal cut diamond, Society lectures, the International Gemmological Conference in India, and Millennium marketing. The contributions of editors C. Johns, H. Levy, M. O'Donoghue and C. Pike are very much appreciated.

Gemmological Instruments is a wholly-owned subsidiary of GAGTL and in the last few years has pursued a policy of introducing a range of equipment which is simple, robust and effective. Developed over many years by P.G. Read, and latterly with the collaboration of N.W. Deeks, the Brewster Angle Meter was introduced to members at the Annual Conference. Work continues on refining the Megger tester for synthetic moissanite identification.

Whilst the GAGTL managed a slightly increased turnover in 1999, it finished the year with a deficit of £116,000, which is very disappointing for all concerned when one considers the hard work put in by the staff in an endeavour to achieve a better result. A large proportion of our business is now outside the UK and the strong pound has made it difficult to achieve realistic margins and remain competitive. However, a number of new projects have been formulated during the year, which should improve our prospects in 2000. Measures have since been taken to reduce costs.

Gemmological Instruments Ltd. achieved an increase in turnover, but only returned a small surplus on the year. During the year work proceeded with the development of some new and improved instruments, which should boost trade in 2000 as they become available.

During the year Miss J. Holness and Miss V. Adams resigned and Miss L. Halton and Miss E. Rolph joined the staff. Miss M. Keating joined under a European Union scheme and Miss Y. Yoshitake assists with various educational activities. To all staff, the Council of Management extend their thanks for the effort and dedication demonstrated in the success of many activities. The Council also pays tribute to the work of the committees and appreciates the expertise voluntarily offered in advising the GAGTL on its future course of action. Lastly the Council would like to thank all those individuals who have donated gems, books, instruments and other gemmological items; these are much appreciated and actively used in many of our courses.

The Council of Management, May 2000

1950 - 2000
CONGRATULATIONS
to the Norwegian Gemmological Association
on their 50th Anniversary

GEM DIAMOND EXAMINATIONS

In the Gem Diamond Examinations held in January 2000, 45 candidates sat the examination and 40 qualified, 5 with Distinction. The names of the successful candidates are listed below:

Qualified with Distinction
Rose, Neil R., Wetherby, North Yorkshire
Keating, Michelle, London
Li Peng He, Beijing, P.R. China
Lv Jie, Beijing, P.R. China
Song Huagiang, Beijing, P.R. China

Qualified
Chawla, Upkaran Singh, Wimbledon, London
Chen Shu-Chen, Kaohsiung, Taiwan, R.O. China
Chen Shu-Chuan, Taipei, Taiwan, R.O. China
Comar, Ankush, Bushey, Hertfordshire
Domercq, Sandrine, London
Du Juan, Beijing, P.R. China
Du Min, Beijing, P.R. China
Fengmei Lu, Wuhan, Hubei, P.R. China
Garbis, Nikolaos, Argostoli, Kefalonia, Greece
Gordon, Carole A.M., Richmond, Surrey
Guan Da Wei, Beijing, P.R. China
Hengyi Zheng, Wuhan, Hubei, P.R. China
Hsu Miao Chu Taipei, Taiwan, R.O. China
Jang, Yunsil, Staines, Middlesex
Kamil, Ruzwan, Colombo, Sri Lanka
Katada, Mitsuru, Ivanhoe, Victoria, Australia
Katz, Joslynne, F., Johannesburg, South Africa
King, Kumi, London
Kote, Satomi, London
Langton, R., Marton, Lancashire
Lei Shi, Wuhan, Hubei, P.R. China
Li Lung Hsing Jerry, Taipei, Taiwan, R.O. China
Lin Yeong Leh, Taipei, Taiwan, R.O. China
Linjun Fu, Wuhan, Hubei, P.R. China
Nanda Sareen, Shaunali, London
Qi Chen, Wuhan, Hubei, P.R. China
Wang Cheng-An, Puli Town, Nan-tu County, Taiwan, R.O. China
Wu Rong, Beijing, P.R. China
Wu Sung-Mao, Taichung, Taiwan, R.O. China
Xie Hao, Wuhan, Hubei, P.R. China
Xunxiao Qian, Wuhan, Hubei, P.R. China
Yang Hui-Ning, Taipei, Taiwan, R.O. China
Yihua Wu, Wuhan, Hubei, P.R. China
Yuanfeng He, Wuhan, Hubei, P.R. China
Zhu Ming, Beijing, P.R. China

MEMBERSHIP

The following have been elected to membership during March, April and May 2000:

Fellowship and Diamond Membership (FGA DGA)

Walton, Brian, Oldham, Lancashire, 1972/1973

Fellowship (FGA)

Bawa, Mohammed Shah Riza, Harrow, Middlesex. 2000
Brown, Mary J., Yangon, Myanmar. 2000
Criado Friesch, Romina, Madrid, Spain. 2000
Dickson, Rebecca B., London. 2000
Dwane, Christine, Montreal, Quebec, Canada. 2000
Ehlenbach, Richard J., Carlisle, Massachusetts, U.S.A. 1984
Ellis, Nigel, Tasmania, Australia. 2000
Fukushima, Hideaki, Chiba City, Japan. 1991
Geung Wan Yin, Hong Kong. 2000
Jiang Wen, Jing Zhou, Hubei, P.R. China. 1999
Johnson, James P., Friern Barnet, London. 2000
Koers, Jessica M., Amsterdam, The Netherlands. 2000
Poon Wai Kong, Singapore. 2000
Rambukkange, Timothy P., Kandy, Sri Lanka. 1999
Sedore, John D., Richmond, British Columbia, Canada. 2000

Diamond Membership (DGA)

Chawla, Upkaran S., Wimbledon, London. 2000
Chen Li Li, Ashfield, Sydney, New South Wales, Australia. 1998
Nanda Sareen, Shaunali, London. 2000
Wang Cheng An, Nan-tou County, Taiwan, R.O. China. 2000
Wu Sung-mao, Taichung, Taiwan, R.O. China. 2000
Yu Kam Chi, Hong Kong. 1997

Ordinary Membership

Anderson, James I., Southampton, Hampshire
Apostolatos, Panos, Patras, Greece
Beattie, Alan P., Glenageary, Co. Dublin, Ireland
Black, Valerie, London
Boillat, Pierre-Yves, Geneva, Switzerland
Bond, Eileen, Braughing, Hertfordshire
Cedeno, Leonor, Sutton, Surrey
Cheng, Helen S.F., St John's Wood, London
Di Fonzo, Antonio, Ridgmont, Bedfordshire
Feely, Martin, Galway, Ireland
Fenton, Sarah, Battersea, London
Gammon, Linda, Cowes, Isle of Wight
Gravier, Denis M., Hauterive, France
Irwin, Cyan, Dublin, Ireland
Maher, John K., Celbridge, Co. Kildare, Ireland
Mathews, Fiona, Amersham, Buckinghamshire
Meaden, Phillip A., Pakefield, Suffolk
Mitchell, Deborah J., Goffs Oak, Hertfordshire

Mulligan, Ardythe, Dundee, Ohio, U.S.A.
Ram, Satyen, Richmond, Surrey
Smith, Susanna M., London
Tse, Jerry, Ilford, Essex
Whelan, Craig, Liverpool

Laboratory Membership

Elka SA, Athens, Greece

TRANSFERS

Fellowship (FGA) to Fellowship and Diamond Membership (FGA DGA)

Chen Shu-Chuan, Taipei, Taiwan, R.O. China. 2000
Domercq, Sandrine, London. 2000
Kamil, Ruzwan, Colombo, Sri Lanka. 2000
Rose, Neil, R., Wetherby, North Yorkshire. 2000
Yang Hui-Ning, Taipei, Taiwan, R.O. China. 2000

Diamond Membership (DGA) to Fellowship and Diamond Membership (FGA DGA)

Balzan, Cortney G., Fairfax, California, U.S.A. 2000
Ma Si Ji, Beijing, P.R. China. 2000
Simpson, Peter R., Richmond, Surrey. 2000

Ordinary Membership to Fellowship (FGA)

Ancemot, Alexandre, Nantes, France. 2000
Chambers, Sara L., Cardiff. 2000
Cheong-Ly Karine, London. 2000
Johnson, Janet M., Friern Barnet, London. 2000
Joyner, Louise, London. 2000
Pratt, Jonathan J., Guildford, Surrey. 2000
Sharples, James, Bolton, Lancs. 2000
Zini, Grazia, Ferrara, Italy. 2000

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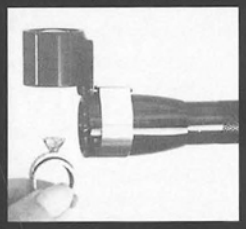

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Guide to the preparation of typescripts for publication in *The Journal of Gemmology*

The Editor is glad to consider original articles shedding new light on subjects of gemmological interest for publication in *The Journal*. Articles are not normally accepted which have already been published elsewhere in English, and an article is accepted only on the understanding that (1) full information as to any previous publication (whether in English or another language) has been given, (2) it is not under consideration for publication elsewhere and (3) it will not be published elsewhere without the consent of the Editor.

Typescripts Two copies of all papers should be submitted on A4 paper (or USA equivalent) to the Editor. Typescripts should be double spaced with margins of at least 25 mm. They should be set out in the manner of recent issues of *The Journal* and in conformity with the information set out below. Papers may be of any length, but long papers of more than 10 000 words (unless capable of division into parts or of exceptional importance) are unlikely to be acceptable, whereas a short paper of 400–500 words may achieve early publication.

The abstract, references, notes, captions and tables should be typed double spaced on separate sheets.

On matters of style and rendering, please consult *The Oxford dictionary for writers and editors* (Oxford University Press, 1981).

Title page The title should be as brief as is consistent with clear indication of the content of the paper. It should be followed by the names (with initials) of the authors and by their addresses.

Abstract A short abstract of 50-100 words is required.

Key Words Up to six key words indicating the subject matter of the article should be supplied.

Headings In all headings only the first letter and proper names are capitalized.

A **This is a first level heading**

First level headings are in bold and are flush left on a separate line. The first text line following is flush left.

B *This is a second level heading*

Second level headings are in italics and are flush left on a separate line. The first text line following is flush left.

Illustrations Either transparencies or photographs of good quality can be submitted for both coloured and black-and-white illustrations. It is recommended that authors retain copies of all illustrations because of the risk of loss or damage either during the printing process or in transit.

Diagrams must be of a professional quality and prepared in dense black ink on a good quality surface. Original illustrations will not be returned unless specifically requested.

All illustrations (maps, diagrams and pictures) are numbered consecutively with Arabic numerals and labelled Figure 1, Figure 2, etc. All illustrations are referred to as 'Figures'.

Tables Must be typed double spaced, using few horizontal rules and no vertical rules. They are numbered consecutively with Roman numerals (Table IV, etc.). Titles should be concise, but as independently informative as possible. The approximate position of the Table in the text should be marked in the margin of the typescript.

Notes and References Authors may choose one of two systems:

(1) The Harvard system in which authors' names (no initials) and dates (and specific pages, only in the case of quotations) are given in the main body of the text, e.g. (Gübelin and Koivula, 1986, 29). References are listed alphabetically at the end of the paper under the heading References.

(2) The system in which superscript numbers are inserted in the text (e.g. ... to which Gübelin refers.[3]) and referred to in numerical order at the end of the paper under the heading Notes. Informational notes must be restricted to the minimum; usually the material can be incorporated in the text. If absolutely necessary both systems may be used.

References in both systems should be set out as follows, with *double spacing* for all lines.

Papers Hurwit, K., 1991. Gem Trade Lab notes. *Gems & Gemology*, **27**, 2, 110–11

Books Hughes, R.W., 1990. *Corundum*. Butterworth-Heinemann, London. p. 162

Abbreviations for titles of periodicals are those sanctioned by the *World List of scientific periodicals* 4th edn. The place of publication should always be given when books are referred to.

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Cover Picture

Rock crystal (15.86 ct) depicting twelve reflections of a single hexagonal crystal now transformed to secondary minerals.

Photograph by Dennis Durham

(First Prize in Photographic Competition, see p.181)

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The Journal of Gemmology

Volume 27 No. 4 October 2000

Nephrite Jade

Treated Diamonds

Diamond Brilliance

Spinels from Madagascar

Brewster Angle

The Gemmological Association and Gem Testing Laboratory of Great Britain

Gemmological Association and Gem Testing Laboratory of Great Britain

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Two contrasting nephrite jade types

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ABSTRACT: Two principal types of nephrite jade orebody are now recognized: (1) ortho-nephrite jade bodies associated with serpentinized ultrabasic igneous rocks and exemplified by those of the Canadian Cordillera, British Columbia; and (2) para-nephrite jade bodies associated with metasedimentary strata and exemplified by those of Eyre Peninsula, South Australia. Major-element geochemistry of nephrite jades from the two contrasting geological environments have much in common. However, trace-element geochemical signatures show marked dissimilarity with ortho-nephrites distinguished by high levels of the basic elements Cr, Co and Ni, and para-nephrites characterized by relatively subdued trace-element abundances. Whereas ortho-nephrite jade forms in folded orogenic belts and bears a mantle signature, para-nephrite jade may appear in a variety of tectonic settings but carries a crustal signature. The role of tectonic setting is important but subordinate to that of the composition of the source region in determining the typology of nephrite jades.

Keywords: Australia, Canada, nephrite jade, ortho-nephrite, para-nephrite

Introduction

Nephrite jade is a microfibrous, interfelted variety of tremolitite. Over the past 25 years much literature dealing with the characteristics and occurrences of nephrite jade in various geological settings has appeared, interest being fostered not only because these rocks represent one of the world's most highly prized ornamental gemstones, but also by the fact that major deposits of relatively recent discovery have changed the traditional pattern of international trade. Indeed, at the present time, world production of raw nephrite jade appears to be dominated by Canada and Australia (Olliver and Townsend, 1993; Ward, 1987).

Nephrite jade studies in recent years have focused on individual occurrences. From straightforward descriptions of producing and newly-discovered deposits, geologists have turned increasingly to discussion regarding their genesis and unifying characteristics. The concept has evolved that two principal, distinctive and contrasting rock associations exist; those nephrite deposits associated with serpentinized ultrabasic igneous rocks, and secondly, those formed within metamorphosed sedimentary strata.

At the present time, however, a variety of names is applied to the nephrite jades from the two rock associations. Leaming (1978) introduced the terms *metasomatic nephrite*

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(serpentine type) and *metamorphic nephrite (non-serpentine type)* to denote the two geological suites. More recently, Wang (1996) adopted the terms *serpentine-type* and *carbonate-type* and Sekerina *et al.* (1996) referred to them as *aposerpentinite nephrite* and *apomarble nephrite*. The latter terms were subsequently refined by Sekerin *et al.* (1996) to *apohyperbasite nephrite* and *apocarbonate nephrite* respectively.

Despite the diversity in nomenclature already in circulation, possibly *ortho-nephrite* and *para-nephrite* are more acceptable geological terms to denote the two types, a proposal which gains much support from the fact that nephrite jade is a variety of tremolitite which in turn is a form of amphibolite and the terms ortho-amphibolite and para-amphibolite are already entrenched in the geological literature to make precisely the distinction that is sought in this instance (e.g. Leake, 1964). The prefix *ortho-* indicates that the rock was derived from an igneous rock such as peridotite, whereas *para-* siginifies derivation from sedimentary material such as dolomitic shale.

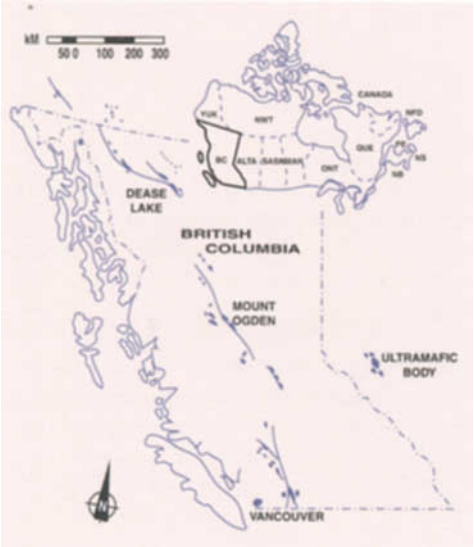

Figure 1: *Orientation map of British Columbia, Canada.*

Collectors of jade, as well as workers on archaeological jade, frequently wish to determine the orginal source of specimens and have expressed considerable interest in the use of trace-element signatures as a discrimination tool. The concepts appear generally accepted that the composition of nephrite jades reflect their source regions and that the abundance of certain trace-elements in nephrite jades provides a 'fingerprint' that enables the source to be inferred. However, the extent to which these concepts apply remains uncertain. Elucidation awaits sufficient and adequate data.

The objectives of this paper are to demonstrate the relations between geologic setting and nephrite jade typology, compare trace-element concentrations for samples from exemplars of the two principal types and attempt to establish criteria for initial characterization of geological sources. The nephrite jade deposits selected are from British Columbia, Canada, and Eyre Peninsula, South Australia. They are Mesozoic ortho-nephrite and Precambrian para-nephrite jades respectively.

Ortho-nephrite jade of British Columbia, Canada

Numerous ortho-nephrite jade occurrences are recorded along a narrow median belt of the Canadian Cordillera through British Columbia (*Figure 1*). The belt is characterized by serpentinized alpine-type ultramafic rocks and major faults (Fraser, 1972; Leaming 1978) and is traceable southwards into the USA and northwards through the Yukon into Alaska.

Two principal areas of ortho-nephrite jade production are Mount Ogden in the Omineca Mountain Range and Dease Lake area in the rugged Cassiar Mountains in the north-central region of the province. At both localities, lenses and pods of ortho-nephrite jade have formed either within serpentinite masses or, more commonly, within the contact zone between serpentinite and the country rock.

The ortho-nephrite jade bodies are typically small, lenticular, fault-bounded and although variable in structure, generally appear to be concordant with neighbouring rock formations (*Figure 2*). Size ranges up to 100 m long by 10 m wide though most bodies are much smaller. The host ultramafic igneous rocks are mostly peridotite, dunite and pyroxenite. They vary from minor intrusions to major batholiths and whereas the former are almost invariably completely serpentinized, the latter are usually at least partially altered. The predominant sedimentary country rocks are chert, quartzite and argillite of the Cache Creek Group of Permo-Carboniferous age. Typically, the contact alteration zone ranges up to 30 m wide and includes talc schist, tectonic blocks of Cache Creek Group sediments, sheared serpentinite and fine-grained leucocratic rock (rodingite) as well as ortho-nephrite jade bodies.

The ortho-nephrite jade ranges from greyish-yellow-green (5GY 7/2) through olive-green (10GY 2/1) to dusky yellowish-green (10GY 4/2), but is predominantly dusky yellowish-green (10GY 3/2). Accessory minerals, seldom present in appreciable amounts, include picotite, uvarovite, chlorite, talc and pyrite.

As well as those of Canada, ortho-nephrite jade deposits have also been described from South Island, New Zealand (Beck, 1970; Finlayson, 1909; Turner, 1935), the Lake Baikal area, Russia (Kolesnik, 1970; Sekerin *et al.*, 1996), the Tian Mountains, Western China (Wang, 1996), California, USA (Coleman, 1967), the Fengtien and Nanao areas, Taiwan (Tan *et al.*, 1978; Yui *et al.*, 1987), the Great Serpentine Belt of New South Wales, Australia (Hockley *et al.*, 1978) and the Jordonow district, Poland (Heflik, 1968).

Para-nephrite jade of South Australia

Para-nephrite jade occurs within the Precambrian crystalline basement on the eastern margin of the Australian Precambrian Shield, in the Minbrie Ranges near Cowell on Eyre Peninsula, South Australia (Nichol, 1977). The 120 individual outcrops, which extend over an area 6 km by 2 km are hosted exclusively by a

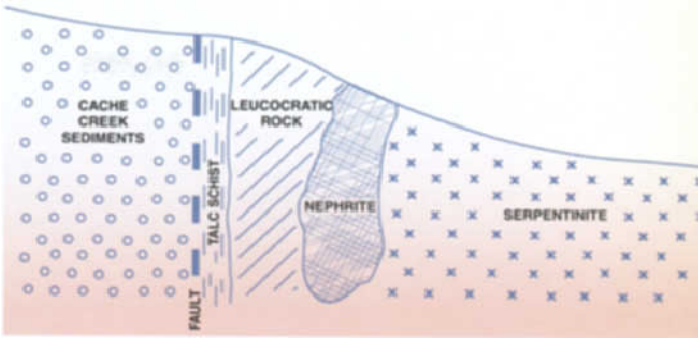

Figure 2: *Diagrammatic cross section of nephrite jade orebody at the 'main showing' on Mount Ogden. After Leaming (1978).*

Nephrite jade samples tested

British Columbia, Canada:

BC1: Yellowish-green (10GY 5/4). Mount Ogden

BC2: Predominantly dark yellowish-green (10GY 4/4) and dusky green (5G 3/2) with minor speckles of moderate green (5G 5/6). Mount Ogden

BC3: Dark yellowish-green (10GY 4/4) with minor crystals of pyrite. Dease Lake

BC4: Moderate yellowish-green (10GY 6/4) and dark yellowish-green (10GY 4/4). Dease Lake

Cowell, Eyre Peninsula, South Australia:

SA1: Dusky yellow green (5GY 5/2) and dusky yellowish-green (10GY 3/2)

SA2: Dusky green (5G 3/2)

SA3: Black (N1) and greenish-black (5G 2/1)

NB: Numerical designations of colours are based on the Munsell system of colour identification (Rock-Colour Chart Committee, 1980).

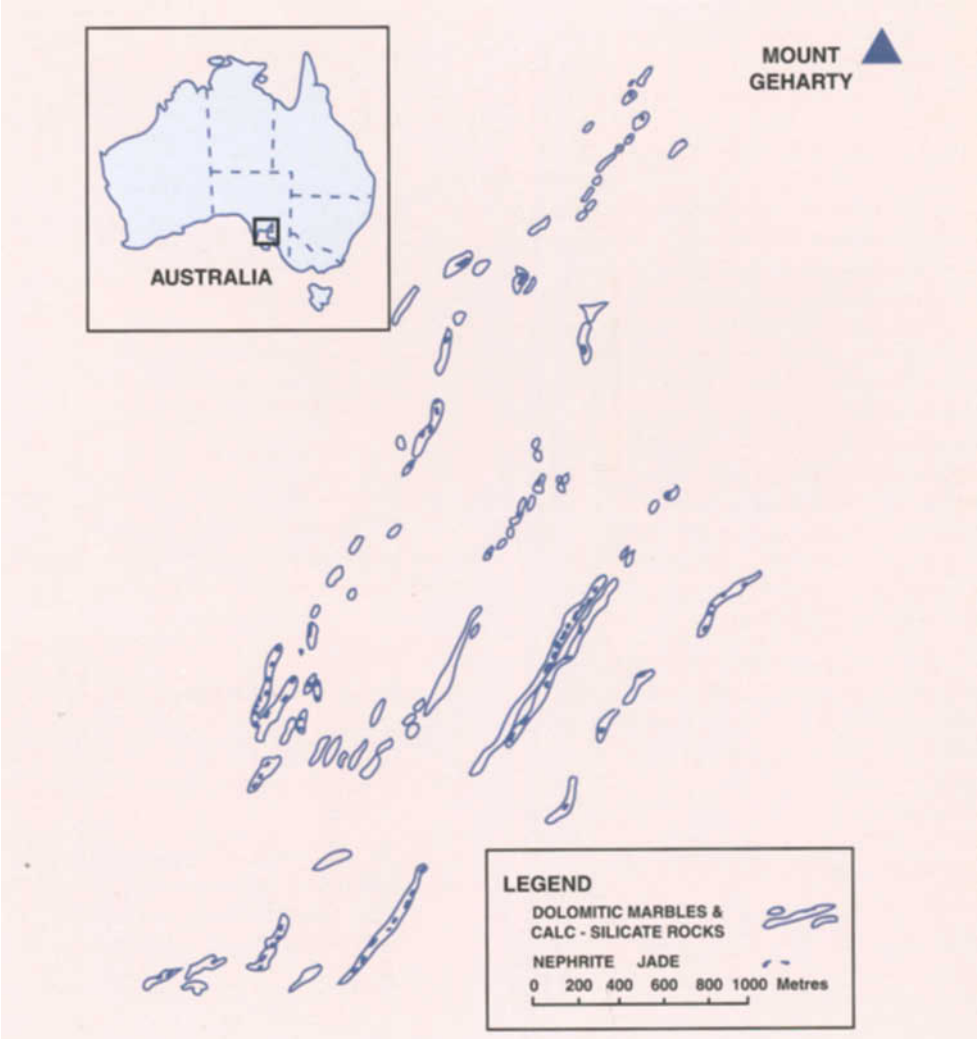

Figure 3: *Geological map of Cowell Nephrite Jade Providence, South Australia.*

metamorphosed dolomarble and calc-silicate rock assemblage. The country rocks are metasedimentary schists, quartzites and quartzo-feldspathic gneisses within which the dolomarble and calc-silicate rock assemblages forms a prominent stratigraphic horizon. This index horizon is traceable along the limbs of a series of tight isoclinal antiforms and synforms (*Figure 3*).

The para-nephrite jade occurs in irregular lenticular and pod-shaped, mainly concordant bodies that range in size up to 65 m long by 3 m wide. They lie within, between and alongside the dolomarble, tremolitite and other calc-silicate rocks with which they are intimately associated. Almost invariably, the para-nephrite jade bodies have developed where the host rocks display locally more intense deformation and tectonic disruption. Contacts between nephrite and calc-silicate or carbonate rocks are usually sharp but may be transitional

Figure 4: Suite of samples, from left to right, ortho-nephrite jade from Canada (BC1, 2, 3 and 4) and para-nephrite jade from Australia (SA1, 2 and 3).

where the adjacent calc-silicate rock is tremolitite or talc-chlorite schist.

Colours range from greyish-yellow-green (5GY 7/2), through moderate yellowish-green (10GY 6/4) and dusky green (5G 3/2) to black (N1). Colour variations reflect total iron content; pale tones correspond to low iron content (1-2%) whereas black (N1) para-nephrite jade contains up to 8% total iron (Nichol, 1975). Texture is microcrystalline. Associated mineral inclusions are uncommon but include epidote, tremolite and pyrite.

As well as those of South Australia, para-nephrite jade deposits have also been described from the Chuncheon area, Korea (Kim, 1995), the Kunlun Mountains, Western China (Wang, 1996), the Lake Baikal area, Russia (Sekerin *et al.*, 1996; Sekerina *et al.*, 1996), and Wyoming, USA (Sherer, 1969).

Modes of origin

The petrogenesis of nephrite jade is considered to be a two-stage process. First, the mineralogical transformation to a tremolitite end-product either by alteration of serpentinite by hydrous fluids from adjacent rocks with the addition of calcium and silica, and the following reaction applies:

$$\underset{\text{serpentine}}{5Mg_3[Si_2O_5](OH)_4} + \underset{\text{silica}}{14SiO_2} + 6CaO$$

$$= \underset{\text{tremolite}}{3Ca_2Mg_5Si_8O_{22}(OH)_2} + 7H_2O$$

or by reconstitution of impure sedimentary dolomite according to the following equation:

$$\underset{\text{dolomite}}{5CaMg(CO_3)_2} + \underset{\text{quartz}}{8SiO_2} + H_2O$$

$$= \underset{\text{tremolite}}{Ca_2Mg_5Si_8O_{22}(OH)_2} + \underset{\text{calcite}}{3CaCO_3} + 7CO_2$$

Table I: *Chemical analyses of ortho-nephrite jade from Canada (BC) and para-nephrite jade from Australia (SA).*

Sample No.	*BC1*	*BC2*	*BC3*	*BC4*	*SA1*	*SA2*	*SA3*
Analysis (Wt.%)							
SiO_2	56.23	56.37	54.68	55.15	57.44	58.82	56.09
TiO_2	0.12	0.11	0.15	0.10	0.04	0.07	0.11
Al_2O_3	1.74	1.81	1.93	1.89	0.70	1.38	0.83
Fe_2O_3	3.61	3.74	5.77	4.39	1.42	1.75	7.78
MnO	0.09	0.10	0.22	0.19	0.05	0.12	0.07
MgO	21.38	21.44	20.92	21.17	23.26	22.06	20.19
CaO	12.88	12.91	12.23	12.38	13.77	11.24	12.32
Na_2O	0.10	0.11	0.05	0.06	0.08	0.19	0.07
K_2O	0.06	0.06	0.03	0.02	0.09	0.11	0.15
P_2O_5	0.08	0.06	0.11	0.07	0.07	0.14	0.06
Loss on ignition	3.47	3.53	3.61	3.95	1.98	3.52	1.87
Total	99.76	100.24	99.70	99.37	98.90	99.40	99.54
Trace elements (ppm)							
As	20	20	20	20	10	10	10
Ba	20	20	20	20	20	20	20
Co	80	90	60	50	10	20	25
Cr	4000	5000	9000	7000	20	20	20
Cu	10	15	15	10	50	50	100
Nb	10	10	10	10	10	10	10
Ni	1100	1300	900	800	50	50	100
Pb	20	30	20	20	5	5	5
Sr	15	15	15	15	10	20	10
V	100	200	200	150	10	10	20
Zn	60	70	60	40	50	50	100

Analyses by Geochem Group Ltd, Chester, UK

These two reactions by which tremolitite develops are generally considered to represent metasomatism and metamorphism respectively, but to assign a particular deposit to one or other such process may prove difficult. The reasons are that the paths taken by metasomatism and metamorphism are frequently not too dissimilar and, moreover, the influence of various other factors operating within the environment in which the reactions take place are almost invariably poorly understood.

The second step comprises wholesale recrystallization whereby relatively coarse-

grained tremolitite is converted to fine-grained, felted nephrite. This tectonic modification is essentially mechanical. It consists of dynamic (shock) metamorphism and involves a sudden release in confining pressures within tremolitite bodies that are saturated with water under high partial pressure. The change in earth pressure conditions possibly coincides with some local tectonic event.

Geochemistry

Laboratory testing was carried out on selected samples collected from *in situ* rock outcrops and believed to be typical of the average quality of nephrite jade from each locality in Canada and Australia (*Figure 4*). Seven XRF/ICP analyses of whole rock samples for up to 21 main elements are presented in *Table I*. Sample descriptions are detailed in the box on p.196 and include colours quoted with numerical designation based on the Munsell system of colour identification (Rock-Colour Chart Committee, 1980).

The virtually monomineralic nature of nephrite jade restricts the compositional variation of the gross rock geochemistry. The whole rock chemical analyses approach that of the theoretical pure composition of tremolite, SiO_2, 59.17%; CaO, 13.80%; MgO, 24.81%; H_2O, 2.22%. Departures from this ideal composition reflect the presence of accessory mineral constituents as well as variations due to atomic substitutions normally occurring in tremolite. Accordingly, the fields of composition derived from the major-elements appear similar whether the nephrites had formed by the alteration of basic igneous rocks or by the metamorphism of dolomitic sedimentary rocks.

On the other hand, trace-element characteristics reflect greater geochemical diversity. Whereas the overall trace-element concentration of arsenic (As), barium (Ba), niobium (Nb), strontium (Sr) and zinc (Zn) have a fairly narrow range, those of copper (Cu), lead (Pb) and vanadium (V) fall within wider bands of variation. However, the values for cobalt (Co), chromium (Cr) and nickel (Ni) provide the strongest geochemical contrasts between the two types of nephrite jade, with the principal geochemical distinction being the Cr content. The ortho-nephrites typically contain around 5000 ppm Cr (equivalent to 0.72% Cr_2O_3) and show exceptionally high levels over para-nephrites that typically contain only 20-30 ppm Cr. Such a wide difference in absolute concentrations of Cr appears to provide the most useful means of distinction between the two types. These preliminary conclusions concerning the importance of chromium generally accord with the observations of other workers (e.g. Flint *et al.*, 1985; Kovalenko *et al.*, 1985; Tan *et al.*, 1978; Wang, 1996). However, they should be confirmed by testing other para- and ortho-nephrite jade deposits.

Conclusions

Nephrite jade may be subdivided into two types: ortho-nephrite jade that is associated with serpentinized ultrabasic igneous rocks and para-nephrite jade that is associated with metasedimentary strata. Exemplars for each type are the deposits of the Canadian Cordillera, British Columbia and those of the Cowell district on Eyre Peninsula, South Australia respectively.

Although host rock associations are quite different, the two types of nephrite jade appear similar in mineralogy, texture and gross geochemical composition. Also, many of the tectonic features present are similar in both cases. They are frequently affected by multiple phases of folding or dismembered by faulting to form fault-enclosed bodies. Contacts between orebodies and country rock are frequently sharp, zoning appears absent and form is irregular but subparallel to the regional trend. There is every indication that formation of the bodies was not a passive development but rather involved active tectonism and favoured localized sites of relatively intense deformation.

Trace-element analysis provides a useful tool for discriminating the two types of nephrite jade. The principal geochemical distinction is chromium content. Typically, ortho-nephrites have Cr contents around 5000 ppm and at least 100 times greater than those found in para-nephrites. However, this preliminary conclusion concerning the importance of chromium should be tested on para- and ortho-nephrite jade deposits from other parts of the world.

To apply the knowledge, future workers should be advised that the Cr criterion is valid for XRF average analysis but not necessarily for 1 μm points determined by EPMA.

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Investigation of seven diamonds, HPHT treated by NovaDiamond

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ABSTRACT: An investigation of seven type Ia diamonds, treated at high pressure and temperature (HPHT) by NovaDiamond. UV-VIS-NIR and FTIR spectroscopies reveals some typical characteristics of HPHT-treated diamonds.

Keywords: HPHT treatment, diamond, spectroscopy

Introduction

Modern technology is increasing its impact on the diamond sector. Methods for changing the colour, and consequently the value, of diamonds are becoming more and more advanced (a review of such methods is given in reference 1). Specifically, High Pressure and High Temperature (HPHT) treatment of diamond is growing more important. As technology and knowledge are spreading, this technique is becoming more refined and accessible.

The aim of HPHT treatments is to change defects in the crystal lattice under the influence of elevated temperature and pressure. At these temperatures, defects can become mobile and can aggregate, thereby changing the colour of the diamond; other defects may dissociate, again leading to colour changes. The parameters used in these treatments can be similar to the pressure and temperature (1200°C-1300°C) of the environment where diamonds grow in nature. However in order to reduce the long aggregation time, higher temperatures (1400°C -2000°C or higher) and pressures (up to 70 000 atm) are used during HPHT treatments. The detection of these treatments is a major problem for diamond grading laboratories all over the world.

Press releases of the American company NovaDiamond state that the original brownish colour of type Ia diamonds is changed to yellowish-green by HPHT treatment, without using irradiation.

In the following section, a short introduction is given on the influence of HPHT treatment on defects and defect formation in diamond, to provide the background for the work on the treated diamonds.

Defects in diamonds

Defects in diamonds (e.g. substitutional nitrogen) are kept in position by the carbon atoms. Because of the high tenacity of carbon atom binding, a large energy barrier reduces the mobility of the defects. During HPHT treatments, the thermal energy allows the defects to overcome that energy barrier and diffuse through the diamond crystal lattice. Although pressure has a negative influence on defect mobility, and therefore on the 'reaction' rate of defect aggregation, it is necessary to keep the diamond stable at the

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Instruments

UV-VIS-NIR optical absorption measurements were performed with a CCD diode array spectrophotometer equipped with a Princeton Instruments ST-121 temperature controller, cooling the diode array down to - 30°C, and a monochromator with a 300 grooves/mm grating. The diamond is placed in a sample holder and illuminated with the full spectrum of a halogen light bulb. The transmitted light from the diamond is then guided to the spectrophotometer unit by a quartz fibre optic. Therefore the fluorescence of the diamond is also included in the measured spectrum. This should be taken into account when analysing the spectrum. FTIR measurements were performed using a Bio-Rad FTS-40 spectrophotometer, equipped with an intergrating mirror accessory. This arrangement makes it possible to measure spectra of polished diamonds. Short wave UV topographic observations were made using a DiamondView instrument on loan from De Beers. Due to differences in growth parameters each diamond has a unique fluorescence pattern, which can be recorded by a camera. Observations with crossed polarization filters were made with the aid of an HRD gemmological microscope (magnification ranging from 10x up to 40x). Cooling to liquid nitrogen temperature (-196°C) was not performed as the diamonds were heavily strained and it was feared that the crystals could be damaged.

high temperatures applied (i.e. to prevent diamond turning into graphite).

The presence of other defects, however, can have a positive effect on the reaction rate: vacancies[2] (empty positions or sites in the diamond lattice) and interstitials[3,4] (atoms located between two lattice sites of the diamond crystal) can enhance the aggregation of single substitutional nitrogen (C defect) to groups of 2 N-atoms (A defects) or 4 N-atoms, surrounding a vacancy (B defect). In natural untreated type Ia diamonds the combination of all three A, B and C defects together in substantial amounts has not been found.

The results of high energy irradiation of diamonds can be observed in the UV-VIS spectrum. Depending on irradiation dose and diamond type, ND1 (393 nm) [5-12] or GR1 (741 nm)[13-18] centres appear. When a type Ia diamond is irradiated and heated to temperatures of about 300°C, the 594 nm line appears[19-21]. When heating these diamonds at higher temperatures in vacuo to 1100°C, the 595 nm line disappears[20-24], and H_1b (4940 cm^{-1}) and H_1c (5170 cm^{-1}) lines can be seen in the infrared spectrum. The H_1b and H_1c lines are believed to be an aggregate of the 594 nm defect and the A centre and B centre respectively[21-24]. The precise nature of the 594 nm defect is still unclear. When heating the irradiated diamond to 800°C aggregates of defect centres emerge: in type Ib diamonds, nitrogen-vacancy aggregates form (called N-V centres), and when these centres capture an electron from an electron donor, the 637 nm line appears[25-28]. A possible electron donor can be a C centre (ionisation energy of 1.7 eV) or an A centre (ionisation energy of 4 eV). When the N-V centre does not capture an electron, a line at 575 nm is detected[29]. In type Ia diamonds, other defects involving a vacancy appear: when an A centre captures a vacancy, an H3 (503 nm line) defect is formed [29-31], and when a B centre (4 nitrogen atoms surrounding a vacancy) captures a vacancy, an H4 (496 nm) line appears[32-33].

During HPHT treatment defects can not only aggregate, but aggregates themselves can also dissociate: for example platelets (large scale defects) can be destroyed by the HPHT treatment[34]. Experiments performed by Brozel *et al.*[34], Kiflawi *et al.*[35] and Collins *et al.*[36] indicate that at 1960°C (or higher) and a stabilizing pressure of more than 8.5 GPa C centres can be generated by dissociating other nitrogen aggregates, such as the A centre. In these experiments no reduction of A centre absorption was detected, probably

Figure 1: The seven HPHT treated diamonds studied in this paper.

because only a small concentration of C centres was produced. Other defects capable of generating vacancies and interstitials under these extreme circumstances are dislocation planes[36] and large atoms such as Ni or Co in synthetic diamond[37–38].

When A centres are dissociated at the elevated temperatures used in the HPHT treatment, C centres can diffuse through the diamond lattice. It is also possible that when platelets dissociate, some C centres are released by the platelets. The presence of nitrogen in platelets is however still a point of discussion. C centres act as electron donors, changing H3 to H2 (986 nm line). This explains why the H2 centre is considered to be a fingerprint of HPHT treatment.

Sample details

All treated samples are type Ia and yellowish-green to green in colour (*Figure 1*). In the following paragraphs the diamonds will be referred to as numbers 1 to 7. In *Figure 1* from left to right, it is seen that diamond 1 is triangular (0.68 ct), diamond 2 is triangular (0.69 ct), diamond 3 is a radiant cut (0.93 ct), diamond 4 is a round brilliant cut (0.79 ct), diamond 5 is oval (0.86 ct), diamond 6 is pear-shaped (0.73 ct) and diamond 7 is a radiant cut (0.45 ct). In some diamond samples, black cracks can be seen around inclusions.

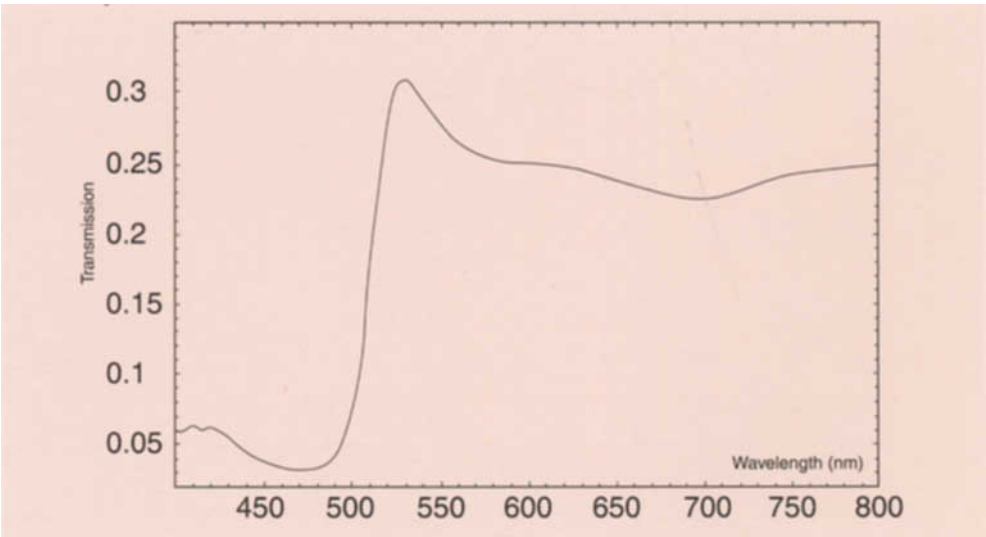

Figure 2: UV-VIS-NIR spectrum of a HPHT treated diamond at room temperature. Strong H3 fluorescence is observed with a maximum around 529 nm.

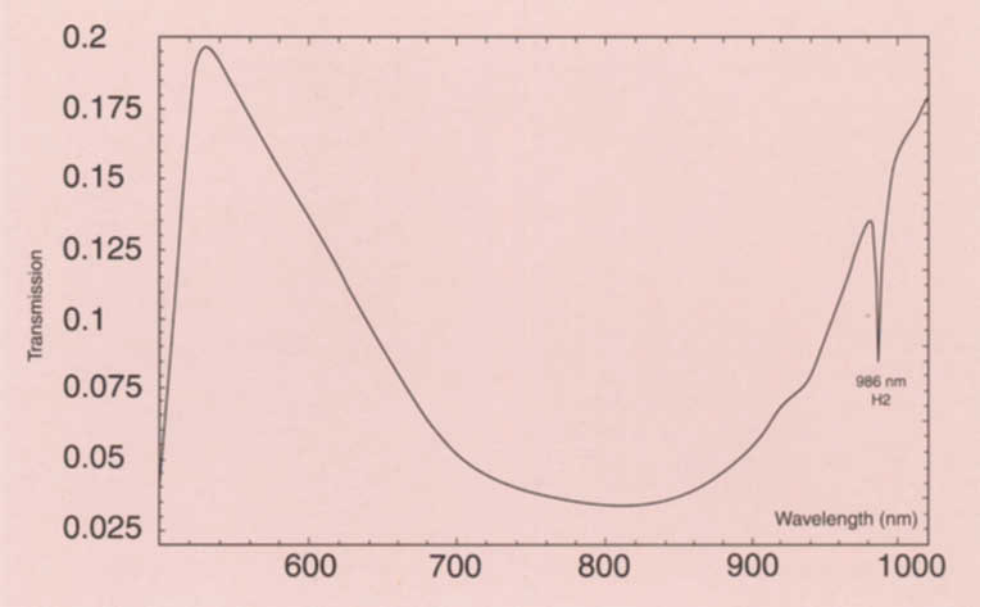

Figure 3: *NIR spectrum of a diamond with strong H2 absorption, measured at room temperature. The presence of the strong H2 side band induces a more intense green colour in the diamond.*

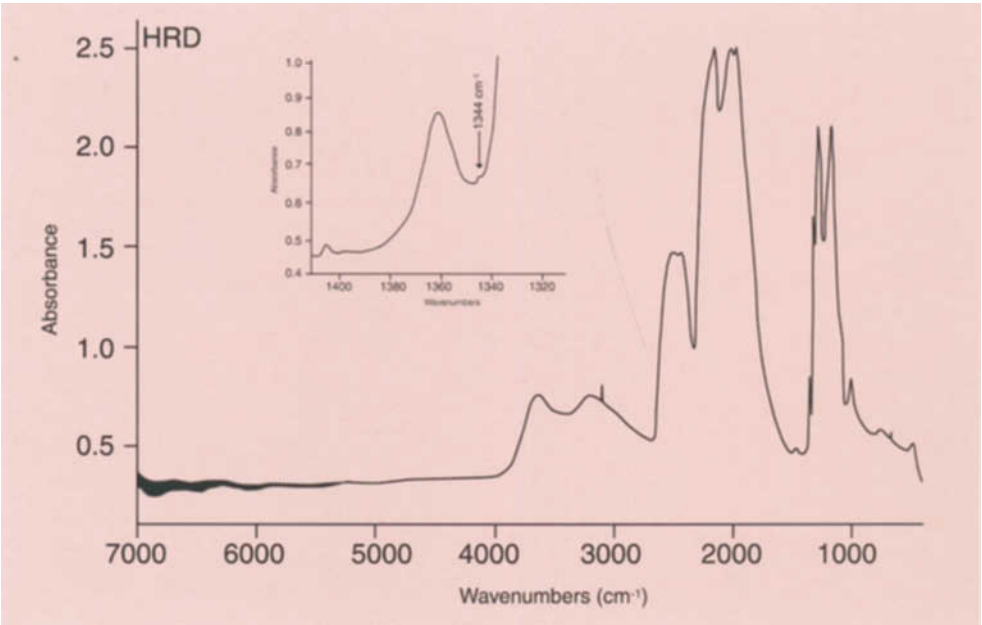

Figure 4: *Room temperature FTIR spectrum for one of the HPHT treated diamonds. The inset shows a small C centre absorption peak at 1344 cm^{-1}.*

Because the samples have been polished in commercial shapes no estimates of the path lengths of transmitted light could be made, so analytical conclusions which can be drawn from the spectra are restricted to some extent.

Results

UV-VIS-NIR spectroscopy

A general trend observed in the UV-VIS spectrum of the treated diamonds is a very strong green H3 fluorescence with a maximum at 529 nm (*Figure 2*) also seen when illuminating the diamonds with a long wave UV lamp. This causes the colour of the diamonds to be yellowish-green to green. NIR measurements show that the diamonds have a strong to very strong H2 absorption (*Figure 3*). The strong to very strong absorption sideband of the H2 centre extends to the visible region, causing a more pronounced green colour of the diamond: the maximum of the transmitted light shifts towards the 500 to 600 nm (green to yellow) region.

FTIR spectroscopy

All diamonds show considerable absorption due to A centres and B centres. A relatively weak platelet absorption peak is observed in the spectrum. High resolution measurements (resolution 1 cm^{-1}) show that some of the treated diamonds exhibit a small C centre absorption peak at 1344 cm^{-1} (*Figure 4*). No absorption due to the so-called amber centre is detectable.

Short wave UV topographic fluorescence observations

Short wave UV topographic fluorescence observations show that green H3 fluorescence correlates with the strain patterns seen during observations of the diamond through a microscope with crossed polarization filters (*Figure 5*). In some diamond samples these can be seen in unpolarized light with a microscope.

Discussion

All diamond samples clearly show a strong H3 fluorescence and strong to very strong H2 absorption. Samples 1, 2 and 7 contain C centres detectable with high resolution FTIR measurements. This combination of A, B, C and H2 centres is characteristic of HPHT treatment in natural type Ia diamonds.

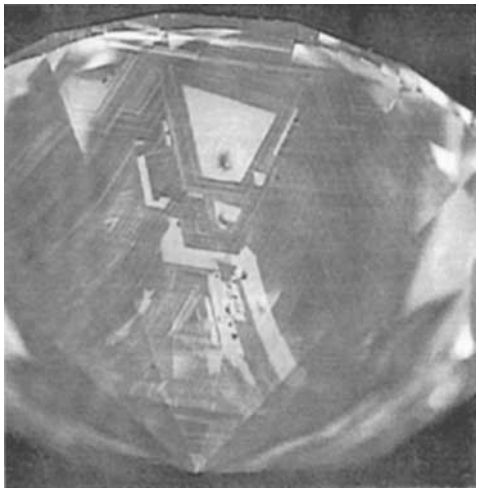

Figure 5: *A short wave UV topographic image of sample 4. The greenish H3 fluorescence pattern is consistent with the graining pattern observed with a microscope and crossed polarization filters.*

For comparison, a brownish Type Ia octahedral diamond from Argyle (which belongs to HRD) was cut in two parts: one part was kept as reference (0.35 ct; sample 8), the other part was HPHT treated (0.17 ct; sample 9). *Figure 6* shows the two diamond samples. HPHT parameters were: 1900±70°C and 7 GPa and these conditions were applied for 10 hours. *Figures 7a* and *7b* show the UV-VIS-NIR spectra of the treated and untreated diamond, recorded at liquid nitrogen

Figure 6: *The untreated part of an Argyle octahedral diamond (sample 8, right) and the HPHT treated part (sample 9, left).*

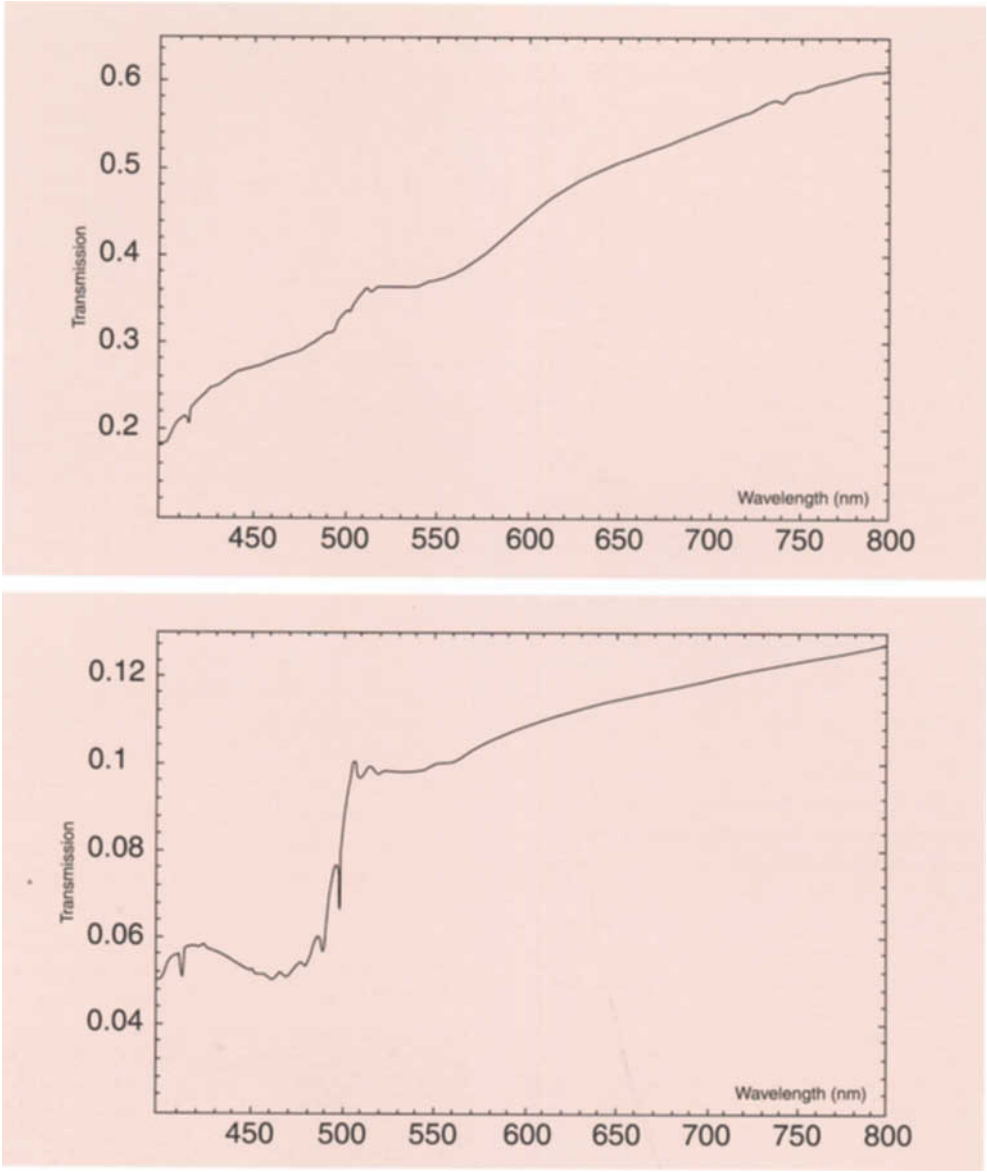

Figure 7: *UV-VIS-NIR spectra of the untreated (7a, top) and the treated (7b, below) diamond samples 8 and 9 at liquid nitrogen temperature.*

temperature. The untreated sample has a weak GR1 absorption peak, consistent with observations in reference 39. This is attributed to natural radiation damage which is located in the outer layer of the rough diamond. However, the concentration of vacancies is not large enough to cause the strong increase of H3 defects seen in the treated diamond sample. As the samples were not irradiated before HPHT treatment, the source of vacancies must be another defect. Possible vacancy sources could be lattice distortions, releasing vacancies under HPHT conditions. The broad absorption band centred around 550 nm has weakened after treatment. The NIR spectrum of the

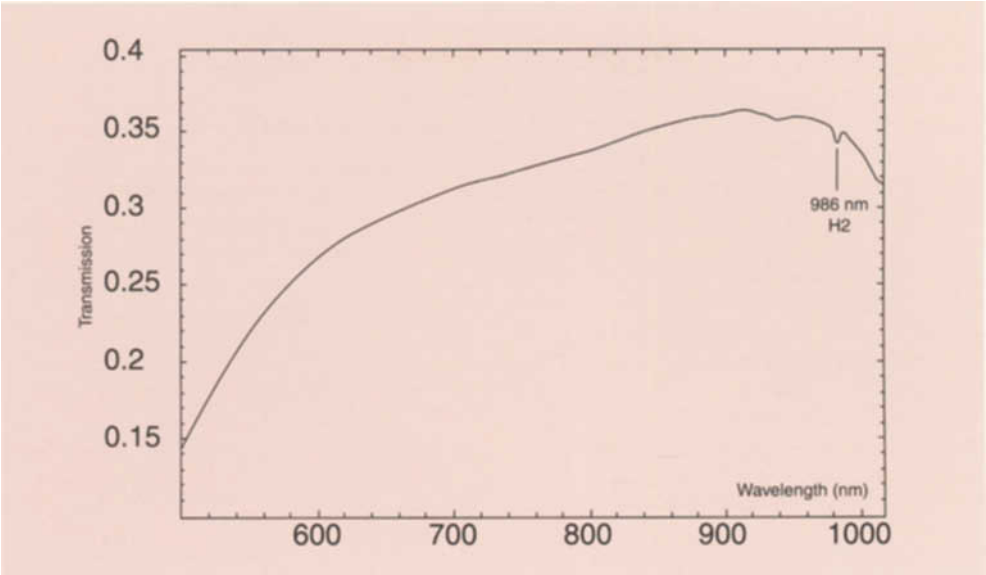

Figure 8: *NIR spectrum at room temperature of an untreated natural type Ib diamond with fairly strong H2 absorption.*

untreated sample does not show H2 absorption, but that of the treated sample does show a fairly strong H2 absorption. Neither the treated nor the untreated diamond samples show a detectable C centre concentration in FTIR measurements. Short wave UV topographs show that untreated sample 8 displays a uniform blue N3 fluorescence, and the treated sample 9 displays a green H3 fluorescence, correlating with growth history features of the diamond sample.

Sample 10 is a rough untreated natural type Ib diamond with a fairly strong H2 absorption (*Figure 8*). Low temperature measurements show very weak $[N\text{-}V]^-$ absorption at 637 nm. No H3 centres were detected by absorption spectroscopy, but were detected by fluorescence spectroscopy and short wave UV topographs (*Figure 9*).

Nearly all H3 centres are converted into H2 centres due to the presence of the relatively high concentration of nitrogen donors (the C-centres). Again, we must state that no analytical conclusions can be made from the spectra due to the impossibility of determining the path length of the transmitted light.

Conclusion

HPHT treated sample 9 shows a strong H3 absorption but a weak H2 absorption, compared with the NovaDiamond treated samples. The fact that H3 and H2 defects can be detected in natural untreated diamonds, like sample 10, indicates that the presence of

Figure 9: *Short wave UV topographic observation of sample 10. The H3 absorption is localized near dislocation planes.*

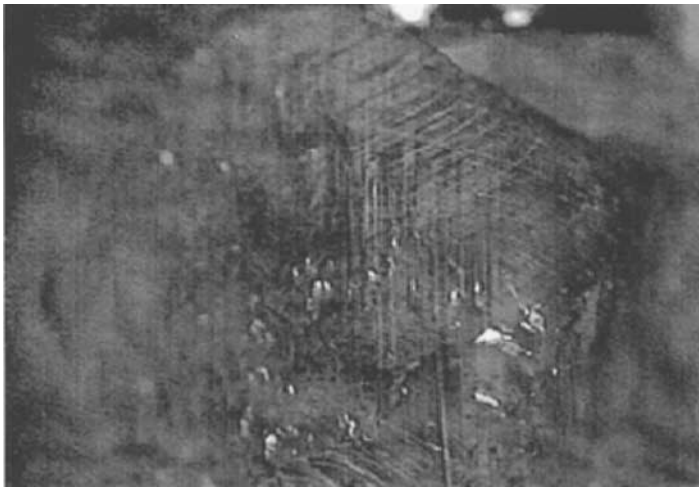

the H2 defect cannot be used as absolute proof of HPHT treatment. The strong to very strong H3 fluorescence/absorption and H2 absorption, however, is a very strong indication of HPHT treatment. The simultaneous presence of A, B and C centres in the IR spectrum and H2 absorption in the NIR spectrum is a definite sign of HPHT treatment. The same can be said of the presence of a combination of A, B and H2 centres with other C centre related defects, like the neutral or the negatively charged N-V centre (absorption at 575 nm and 637 nm respectively). Together with strong H3 absorption/fluorescence and H2 absorption, these are a definite sign of HPHT treatment.

Acknowledgements

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Diamond brilliance: theories, measurement and judgement

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ABSTRACT: The observation of brilliance in a diamond involves a complex interaction of the viewer, the illumination environment, and the manner in which light is processed by a diamond. In order to measure the brilliance of a diamond, a computer simulation of this interaction must model all three of these aspects. The success of any theoretical measure of brilliance is how well it agrees with human judgement.

A study and analysis is reported that contrasts the recent GIA 'analysis of brilliance' findings with the teaching of the GIA Diamond Course and the experience and theories of Tolkowsky and others in the diamond and gem trades. Three-dimensional computer modelling and diamond photography are used to gain a greater understanding of brilliance and arrive at suggestions for improving its measurement.

Keywords: brilliance, computer model, diamond

Introduction

The Gemological Institute of America (GIA) and the American Gem Society (AGS) both have common roots in their founder Robert Shipley. For over half a century both have taught the concept of an 'Ideal' round brilliant cut diamond. The GIA attributed the mathematical computations of the best angles and proportions for what they termed the American 'Ideal' or the Tolkowsky cut diamond to Marcel Tolkowsky and his 1919 book *Diamond Design*. In his book, Tolkowsky stated that "the most vivid fire and the greatest brilliancy" is obtained with pavilion main angles of 40.75°, crown main angles of 34.5° and a table size of 53%.

GIA students have been taught: "Most cutters and other experts agree that even a two-degree deviation from Tolkowsky's theoretical pavilion angle will result in a less attractive diamond. An increase of two degrees in pavilion angle will result in a noticeable darkening of the stone and an obvious loss of brilliance ... a decrease of only two degrees in pavilion angle ... usually shows a reflection of the girdle in the table and is called a 'fish-eye' ... [and] also gives the stone a very 'glassy' appearance" (Diamond Grading Course, 1979, Assignment 21).

In their latest revised course on diamond grading, the GIA adheres even more strictly to Tolkowsky's angles, e.g.: "Today most cutters and other diamond experts agree that varying more than one degree from a pavilion angle of about 41° reduces a diamond's optical efficiency, and thus its beauty ... A crown angle close to 34.5° is the best compromise between optical theory and economic reality" (GIA Diamond Grading Course, 1993, Assignment 6, p.16, 17).

The AGS uses a 0-10 grading system for diamond cuts that is based upon the 'Ideal'.

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For discussion purposes, we will use their definition of 'Ideal', which is AGS 0. This AGS 0 grade requires fairly close adherence to Tolkowsky's pavilion and crown angles, but allows his 53% table to range from 52.5% to as large as 57.5%.

Recently, Hemphill *et al.* (1998) reported ongoing research at GIA that has come to some conclusions that mark a significant break with the GIA Diamond Course teaching. The authors use a measure of brilliance known as Weighted Light Return (WLR), which they say "captures the essence of brilliance" (op. cit. p.182). If brilliance were the only factor determining the beauty of a diamond, the GIA believes their measure has captured this essence of beauty. They qualify this by saying that remaining to be analysed for a full understanding of diamond beauty are "fire and scintillation, and probably symmetry deviations and color". They also state that "... the relationship between brilliance and the three primary proportion parameters (crown angle, pavilion angle, and table size) is complex, and that there are a number of proportion combinations that yield high WLR values" (op. cit. p.182) and "The results of this study suggest that there are many combinations of proportions with equal or higher WLR than 'Ideal' cuts" (op. cit. p.158).

Boyajian (1998) concluded that, "Although it is not the GIA's role to discredit the concept of an 'Ideal' cut, on the basis of our research to date we cannot recommend its use in modern times."

Is this GIA brilliance study cause for abandoning the Tolkowsky or American 'Ideal'? To answer this question, we have focused, as did the GIA study, on this single aspect of diamond beauty referred to as brilliance.

Brilliance is defined in the *GIA Diamond Dictionary* (Gaal 1977, p.29) as "the intensity of the internal and external reflections of white light to the eye from a diamond or other gem in the face-up position". The face-up position is the normal viewing position of a diamond with the viewer looking from a position that is approximately perpendicular to the gem's table.

Has the GIA captured the essence of brilliance in this single WLR measure? We will see that, in order to be useful, a measurement of brilliance such as WLR must agree with human judgement.

What are the necessary features that a computer model needs in order to measure brilliance in a way that is consistent with human judgement of brilliance? Since observation of brilliance in a diamond involves an interaction of the way in which light is processed by the diamond, the diamond's illumination, and the act of viewing by the observer, all three aspects of this interaction should be essential parts of a computer model of brilliance.

In particular, when brilliance only is being measured, as in the GIA study, a simulated illumination is needed that captures the properties of the typical lighting environments in which brilliance is normally judged. If the goal were a more complete computer analysis of diamond beauty, an illumination environment that enhances fire and sparkle as well as brilliance would be needed.

Jewellers know that it is important to display diamonds with illumination that best brings out a diamond's brilliance, fire and sparkle. Because point sources of light bring out a diamond's fire and sparkle as well as brilliance, most diamond-selling areas in jewellery stores have many bright spotlights to illuminate the diamond jewellery. Diamonds displayed in flat, diffuse, fluorescent illumination found in typical office environments may exhibit brilliance but display less fire and sparkle.

Let us now examine the three main features of the computer model of diamond brilliance described by Hemphill *et al.* (1998).

1. The diamond

The GIA took great care to create a computer model of the way in which light is

processed in a diamond that is more complete than any before it. Included are three-dimensional effects, a wavelength-dependent refractive index, and the accounting of secondary rays and light polarization. They state that their model differs from its predecessors in that it is three-dimensional and "uses the most detailed existing data on the properties of a colorless diamond" (Hemphill *et al.* 1998, p.182). It would be difficult to improve on this representation of how light is processed by a diamond.

It is necessary to point out that the modelling concerns a colourless, flawless round brilliant-cut diamond with mathematically perfect symmetry. Hemphill *et al.* (1998, p.161) put this in context by saying, "Real diamonds will inevitably differ from the model conditions because of inclusions, symmetry deviations, and the like." Differences such as symmetry faults and inclusions could also be modelled, but are not addressed in this study. There are varying opinions as to the point at which these imperfections have an impact on diamond brilliance.

2. The illumination

A "diffuse hemisphere of even, white light" was selected "to best average the many different ambient light conditions in which diamonds are seen and worn, ... such as a common consumer experience of seeing a diamond worn outdoors or in a well lit room" (Hemphill *et al.*, 1998, p.167). This 'hemisphere' illumination provides even lighting from above the girdle but no lighting from below. Visualize the diamond in the centre of a white evenly-illuminated hemisphere mounted in a setting that blocks the light from entering below the girdle.

A computer-generated image of a diamond reveals the effect of this illumination environment (see *Figure 2a*, excerpt from Figure 2 of Hemphill *et al.*, 1998).

***Figure 1**: Actual 'Ideal' cut photograph from Figure 1, lower left, of Hemphill* et al.*, 1998.*

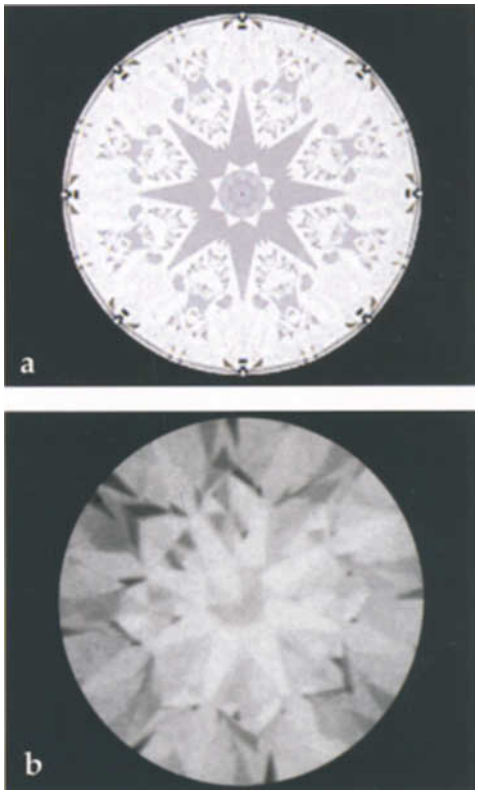

***Figure 2**: (a) Virtual image of 'Ideal' cut, and (b) photo of 'Ideal' cut in hemisphere lighting. Both from Hemphill* et al.*, 1998, Figure 2.*

Unlike the diamond photograph shown in *Figure 1*, the images obtained using hemisphere lighting look fairly evenly white except for some minor darker areas where the diamond is reflecting and refracting light from below the girdle where there is no light source.

To obtain a photograph that looked similar to the computer generated image of *Figure 2a*, Hemphill *et al.* (1998) photographed the diamond "in diffuse white light using a hemispherical reflector" and noted "diffuse illumination reduces the overall contrast" (see *Figure 2b*).

The images in *Figures 1, 2a* and *2b* show that hemisphere lighting may not give a realistic presentation of the diamond brilliance observed in typical viewing circumstances. The reason for this is that most points on the diamond's crown are refracting and reflecting the same even light from above the plane of the girdle causing all these points to be bright. Consequently, differently proportioned diamonds under hemisphere lighting show smaller differences in brilliance than are seen by an observer in typical lighting environments. The study results of Hemphill *et al.* (1998) indicate that with 'hemisphere illumination' the WLR of known high-brilliance diamonds and those of average brilliance varies from .285 to .275, or about 4%.

When diamonds are judged for brilliance in typical viewing circumstances, the viewer's head and body interfere with the illumination that would otherwise be coming from behind the viewer. Diamond proportions that respond poorly under these circumstances are perceived to have low brilliance. Because the 'hemisphere' illumination does not incorporate this viewer interference, in some important instances these same diamond proportions may have high WLR.

In sections 5 and 6, evidence will be presented to show that greater consistency between the GIA WLR brilliance measure and human observation of brilliance can be obtained by taking explicit account of the interference in illumination resulting from the physical presence of the viewer.

3. The viewer's perception of brilliance

In the Hemphill *et al.* (1998) study the brightness of 65,536 pixels (tiny areas) across the surface of the diamond image is evaluated. This requires up to 65,000,000,000 light rays traced from their hemisphere lighting source through the virtual diamond. This is similar in concept to the approach taken by most investigators from Tolkowsky in 1919 through to the present. Most of the reported research has concerned itself with whether light coming into a diamond's crown from all angles above the girdle (as in hemisphere illumination) is reflected and refracted back through the crown or is lost out of the pavilion. This approach does not concern itself with the impact of the physical presence of the viewer on the illumination environment, or whether the light returned through the crown is seen in the important face-up position by the 'normal' observer.

In the normal face-up observation of a diamond, the viewer sees the portion of light that exits the diamond at approximately 90° to the table. In answer to the question "Should a mathematical definition of brilliance represent one viewing geometry – that is a 'snapshot' – or an average over many viewing situations?", Hemphill *et al.* (1998) chose the average instead of the 'snapshot', as have previous researchers, but with an important difference. Their measure sums the light rays returned through the crown, multiplied by "the square of the cosine function". Recognizing the importance of the face-up viewing position they "wanted the contribution from rays that emerged straight up to be much greater" (op. cit., p.168). Their weighting function emphasizes the face-up, 'normal' observer condition by giving light rays near 90° the greatest weight. They note: this "averaged observer condition ... takes into account the likeliest ways in which a diamond dealer or consumer looks at the stone" (op. cit. p.182).

If the weight given to light rays near 90° were increased to the limit relative to other angles of observation, it would lead to a 'snapshot' of a diamond in the face-up position. Let us consider the suitability of a measure of brilliance using this 'snapshot'. Evaluating the 'snapshot' of brilliance in the face-up, 'normal' position has three important advantages over averaging:

(i) The single value of WLR obtained by an averaging of viewing angles has lost the detailed knowledge of the relative brilliance occurring at any particular angle of observation such as the most important face-up position. 'Snapshots' can individually measure brilliance at each viewing angle.

(ii) By analysing the face-up 'snapshot' of a diamond for brilliance, a large economy of computation is realized. Analysing this one 'snapshot' greatly simplifies the search for the most brilliant diamond proportion parameters.

(iii) There are aspects to the perception of brilliance that go beyond the amount of light returned from the crown of a diamond. Such aspects may be observed and measured from a 'snapshot'. A large amount of intensity variation or contrast between light and dark areas across the surface of a diamond gives it an aspect of brilliance that has been described as 'snappy', 'dramatic', 'hard' or 'sharp' (Bruton, 1978, p.227). This aspect is the opposite of the brilliance description of 'watery' and 'glassy' used in the GIA Course and the *Diamond Dictionary* (Gaal, 1977) to describe a 'fish eye' diamond, which has a weak appearance due to the lack of contrast as well as lower light return. This contrast aspect of brilliance has properties similar to the contrast variation from bright to dark that occurs with diamond movement called sparkle or scintillation. We will call this aspect 'surface sparkle' to distinguish it from the sparkle that occurs with movement.

Additional aspects to the perception of brilliance are the size and number of these contrasting light and dark areas and how evenly they are distributed over the surface of a diamond. A diamond exhibiting very efficient light return but having little contrast in intensity from facet to facet over the diamond surface is perceived to be 'glassy' or lacking 'snap'. By analysing a 'snapshot' of a diamond, more can be learned about these aspects of brilliance that are lost in a single measure that averages many viewing positions.

Because diamonds are evaluated for beauty in the face-up viewing position, this 'normal' viewing angle is of paramount importance. The principal concern in deciding to use this 'normal' snapshot for brilliance, instead of averaging viewing angles, is whether a diamond will retain its

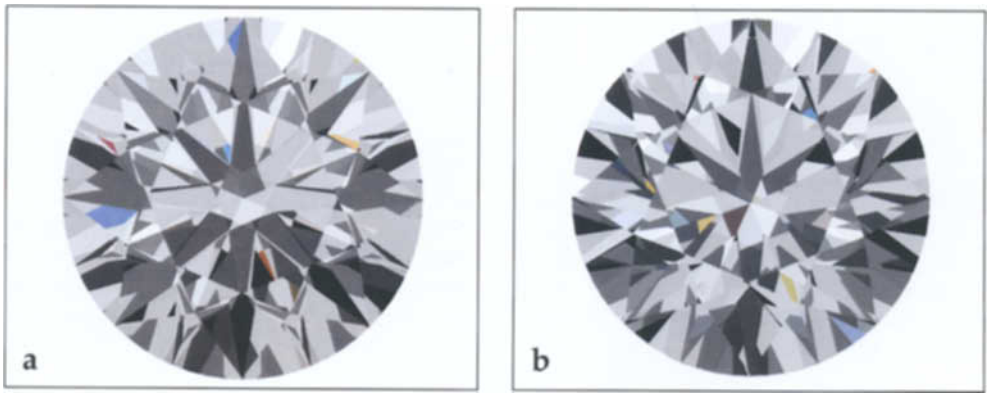

Figure 3: *'Ideal' cut diamond (a) face-up view, and (b) tilted 10°.*

brilliance when it is tilted slightly from the perpendicular. To answer this concern, diamond proportions with the highest face-up brilliance should be evaluated at other viewing angles. Our experience has shown that diamonds with near 'Ideal' proportion parameters maintain superior brilliance when viewed at angles off the perpendicular. Brilliance is essentially undiminished through 15° of tilt, only slightly at 25° and slightly more at 45°. Owing to its relatively high refractive index (RI), maintaining brilliance when tilted is one of the properties that distinguishes diamonds from white gemstones that have lower RI. The tendency of diamond imitations such as YAG, GGG, white topaz or spinel to lose brilliance when tilted can be used to separate them from diamonds.

Let us look at two views of an 'Ideal' cut diamond, one face-up and the other tilted 10° (*Figures 3a* and *3b*). These were generated with the Russian DiamCalc software (OctoNus Software http://www.gemology.ru/octonus). They illustrate that the brilliance of the 'Ideal' cut is retained at angles off the perpendicular.

We will see later through the use of ray tracing diagrams, such as those in *Figures 5a* and *5b* of section 5 of a 'nail head' diamond, that certain paths of light from the illumination source back to the viewer remain basically unchanged in spite of normal amounts of diamond tilt.

Both examples illustrate that we are on safe ground by evaluating the face-up 'snapshot' of diamond brilliance.

4. Understanding brilliance in diamonds

It is clear from sections 2 and 3 that more can be learned about diamond brilliance if the analysis is done in a lighting environment that accounts for the viewer interference. The important viewing angle is the face up, 'normal' viewing position.

To study this single important viewing geometry, the 'normal snapshot', we only have to consider those light rays that emerge from the diamond's crown directly to our eyes along a path approximately perpendicular to the diamond's table. (The following discussion extends to any 'snapshot'.)

Each pixel or tiny area of a diamond can be thought of as refracting and reflecting light to our eyes from some angle and position in the space around the diamond. This is a good first order approximation. (That position varies slightly with the colour and polarization of the light ray, and there are additional secondary positions.)

Let us follow the path of light in reverse from the eye, along the perpendicular into the diamond through that tiny area in order to determine where it emerges. Because light follows the same path moving in either direction, that point of emergence and direction is the primary path along which light would have to enter the diamond in order to be seen in that pixel by the 'normal' viewer.

If that path of light emerges from the diamond below the girdle where there is no light, as in *Figure 4a*, no light will be seen in that pixel's area. (Notice that a weaker, secondary path of light reflection also exits below the girdle.) If the light path emerges in a direction above the girdle, as in *Figure 4b*, that pixel will be bright if light exists in that direction, as it is bound to under hemisphere lighting. However, as will be seen in the 'nail head' diamonds of *Figures 5a, 5b, 8c* and *9b*, if the viewer's head and body block some of the light, as they would in close-up examination of the diamond, the pixels reflecting light from the direction of the viewer will also be dark.

Because of multiple reflections and transmissions of each of these rays, there are other secondary paths from which light can reach the eye from any particular pixel (note *Figure 4a* for example). Strickland and Long's

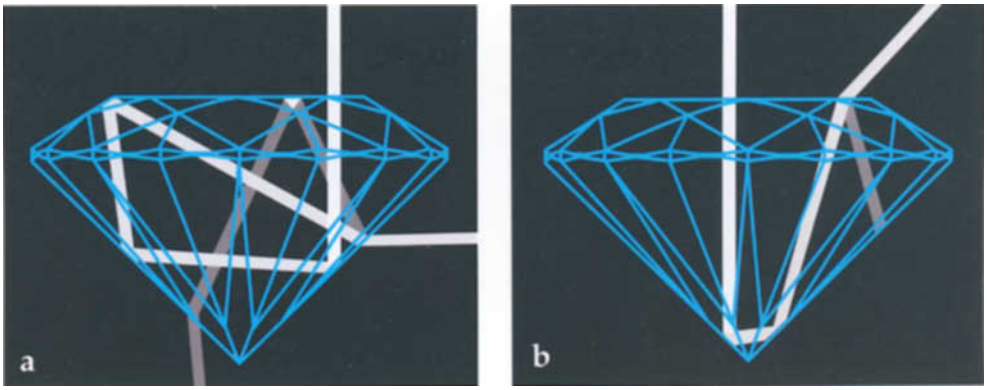

***Figure 4**: (a) This point on the diamond's table will be dark because little or no light enters below the girdle. (b) This point on the diamond will be bright if there is light in the direction of this ray.*

(pers. comm., 1999 and 2000) measure of brilliance defines the sum of all these contributions as the brilliance for that pixel, and summing across all the pixel areas gives the total brilliance of a diamond for the 'normal' viewing position.

When evaluating diamond proportion parameters for brilliance, it is important to consider where light rays would have to originate in order to reach the viewer's eyes. Diamond proportion parameters that cause most of the tiny pixel areas to refract and reflect light from directions where illumination exists will result in a brilliant diamond. The next two sections will contain examples of diamonds that exhibit inferior brilliance owing to areas on the diamond that refract and reflect light to the observer from directions where little light exists.

The methodology is to determine where each pixel or point on a diamond gets its light for each set of diamond proportions, and then to choose combinations of pavilion and crown angles that reflect the least light from the direction of the observer or from below the gemstone's girdle, where there is little or no source of illumination. This concept was first advanced by Harding (1975) and has had a significant impact on the determination of optimum angles for cutting gemstones. Glen and Martha Vargas published a portion of the work in chart form in *Faceting For Amateurs* (1977). However, Harding's concepts appear to have been largely overlooked, or not understood, by those in the diamond and jewellery industry concerned with optimum angles for cutting diamonds.

Harding's work did not have all the answers, but he showed that good brilliance depends on avoiding combinations of crown and pavilion angles that reflect light to the viewer from his/her direction, as well as from below the gemstone's girdle. Instead of searching for ideal angles, Harding eliminated combinations of crown and pavilion angles that were clearly not ideal from this perspective. This process of elimination is a useful tool in narrowing the search for the possible range of ideal diamond proportions.

The computer faceting design software of Strickland, such as Gemcad, Gemray, Gemframe and Gemflick, can be used to simulate and measure diamond brilliance and explore these concepts. Strickland employs three-dimensional gemstone modelling with several illumination environments. His work and the work of others such as Long and Steele have taken faceting design to new levels of technological sophistication. In the present study, programs and work done by a group in Russia associated with Moscow State University have also been employed. This parallel effort in Russia has culminated in the

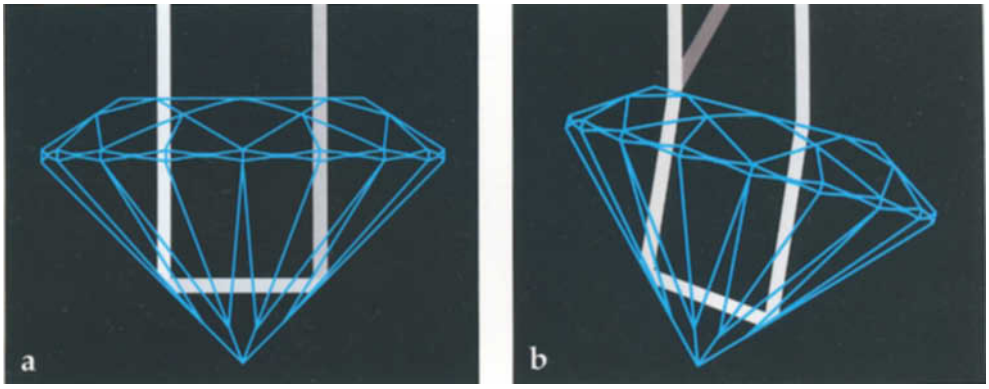

Figure 5: *'Nail head' diamond with pavilion angle of 45° (a) upright and (b) tilted 15°.*

computer aided, diamond cut design software called DiamCalc and the MSU Diamond Cut Study. Led by Sergey Sivovolenko, OctoNus Software, Yurii Shelementiev, Gemology Center of MSU, and Anton Vasiliev, this Russian effort grew from work by Vasiliev that expanded on Harding's original work. The diamond cutting community could with advantage consider all these contributions and ideas in the quest for the proportions of the most beautiful round brilliant-cut diamonds.

5. The classic case of the 'nail head' diamond

Perhaps the best case to illustrate the need for incorporating the effect of the viewer's physical presence on brilliance is a diamond with pavilion main facets between 43° and 45°. This is known as the 'nail head' diamond owing to its dark appearance under the table relative to areas outside the table. Assignment 8 of the GIA Diamond Grading Course (1993), states: "If the pavilion is very deep, much of the light is leaking out. Then the table reflection and star facets look almost black, and the stone is called a 'nail head'."

Pavilion main facets of 45° exactly mirror light from above through the table in those main facets sending light straight back towards its source. A viewer of such a diamond could observe a mirror image of him/herself in those pavilion main facets. Furthermore, the head obscures any illumination from behind, causing those main facets to darken under the table. The pavilion girdle facets, which are cut between 1° and 2° steeper than the mains, also darken under the table giving the whole table area a darkness relative to areas outside the table.

Figures 5a and *5b*, generated by the Russian computer software, illustrate light passage in a 'nail head' diamond with a pavilion angle of 45°. 'Nail head' diamonds reflect light from the direction of the viewer's head even when the diamond is tilted. Compare these to the diamond in *Figure 4b*, which has an 'Ideal' pavilion angle, causing light to reflect from an angle safely away from the viewer's head.

Much course and textbook literature attributes the undesirable 'nail head' appearance to light leakage out of the pavilion. Primary and secondary leakage (leakage at the first and second points of internal reflection) occurs to a greater extent in gemstones with lower refractive indices such as quartz, beryl or the plastic used in the GIA GEM Instruments' Proportion Comparator demonstration tool. Compare the *Figure 6a* photograph of the demonstration tool (courtesy of the Gemological Institute of America) and *Figure 6b* derived from the Russian computer software. They are similar and illustrate the secondary, pavilion light leakage that occurs

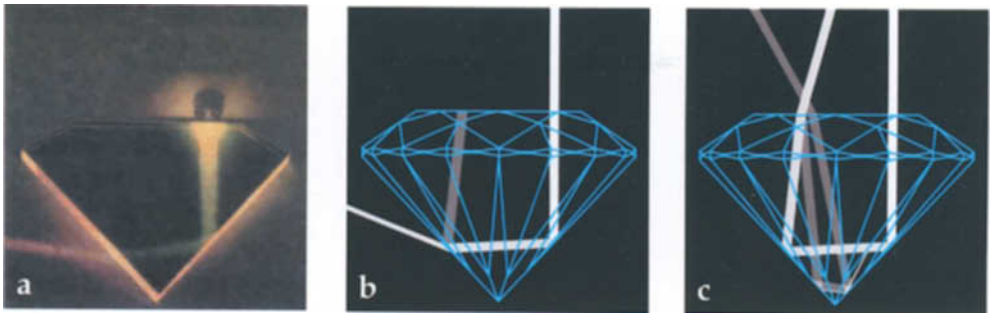

Figure 6: *(a) Demonstration tool showing pavilion light leakage in a 'nail head' diamond (see text); (b) Path of light in plastic with a lower RI; (c) Path of light in diamond, (RI 2.42).*

with steep pavilion angles in the plastic demonstration tool.

In diamond with its relatively high refractive index, the pavilion angle would have to approach 52.5° before this type of leakage became apparent in the pavilion mains in the table in the face-up viewing position. The 'nail head' appearance is evident in diamonds with pavilion angles between 43° and 45°. Thus, as we see in *Figures 5a, 5b* and *6c*, the dark 'nail head' appearance is due not to loss of light through the pavilion, as was commonly believed and taught. Rather, it is due to a steeper than 'Ideal' pavilion that is reflecting light to the 'normal' observer from the area of his head rather than from an unobscured source of illumination.

A computer model of the 'nail head' diamond will not show the darkening caused by the observer's head if the illumination model does not take into account the way light is blocked by the physical presence of the observer. To support this, note that Hemphill *et al.* (1998, p.171) state:

"*Pavilion Angle.* This is often cited by diamond manufacturers as the parameter that matters most in terms of brilliance ... Images of virtual diamonds with low, optimal, and high pavilion angles (again, see Figure 5) are consistent with the appearances that we would expect for actual diamonds with these pavilion angles ('fish-eye', normal, and 'nail head')."

When we look at these virtual images in *Figure 7*, the 'nail head' example on the right does not appear consistent with the appearance of 'nail head' diamonds. Instead of being dark under the table, the virtual image shown is extremely bright in the

Figure 7: *From GIA study Figure 5 (Hemphill* et al.*, 1998).*

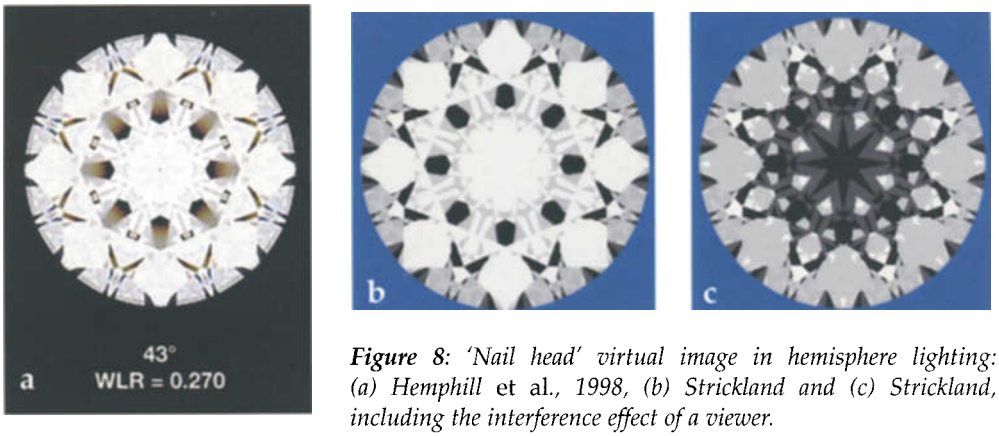

***Figure 8**: 'Nail head' virtual image in hemisphere lighting: (a) Hemphill* et al.*, 1998, (b) Strickland and (c) Strickland, including the interference effect of a viewer.*

centre two-thirds of the table. Compare the virtual image of the 'nail head' diamond in *Figure 8a*, reproduced from Hemphill *et al.* (op. cit.) with the virtual image of the same 'nail head' diamond in *Figure 8b* that has been generated by a new version of Strickland's Gemray computer software and uses hemisphere lighting similar to that described by Hemphill *et al.* (op. cit.).

Though Strickland's model uses only one RI and averages the ray polarization, the *Figure 8a* and *8b* images depict a similar bright centre that is unlike the appearance of a 'nail head' diamond. By introducing the effect of the viewer blocking some of the light from above, a new virtual image is generated (*Figure 8c*). This looks darker under the table and is much more like the familiar appearance of a 'nail head' diamond. Also the light return falls off more as expected when compared to the 'Ideal'. In hemisphere lighting, Hemphill *et al.* (1998) found only a 0.282 to 0.270 = 4.25% drop-off in WLR between an 'Ideal' cut and this 'nail head' diamond. The truly dark 'nailhead' appearance is more apparent in diamonds with a pavilion depth of 48% to 50%, which corresponds to pavilion main angles of 44° to 45°. The 'nail head' discussed and pictured here, with 43° pavilion, is only beginning to darken under the table. It took a large amount of light blockage, simulating close-up inspection, to produce *Figure 8c*.

To further demonstrate the importance of the type of illumination, we created a photographic set-up using three actual diamonds: a close to 'Ideal' cut and two 'nail heads'. Two lighting environments were used. The first approximates hemisphere lighting with diffuse illumination in a 180° hemispherical arc above the diamond's girdle plane. The second also approximates hemisphere lighting but with light blocked in an area above these diamonds to simulate the close-up viewing situation. In both cases, the three diamonds were photographed simultaneously. Interchanging them produced essentially no change in appearance, verifying that, for comparative purposes, each was illuminated in the same manner. (In both cases the diffuse illumination was not as even as in the computer model due to use of two diffused fibre optic light sources.)

In the diffuse hemisphere lighting photograph (*Figure 9a*), all three diamonds have similar even brilliance. There is slightly more brilliance in the near 'Ideal' cut due to some dark areas in the outer table region of the 'nail head' diamonds. However, the two 'nail heads' are very bright in the middle portion of their tables, just as in *Figures 8a* and *8b*. Contrast this with the dramatic darkening of the whole table and star facet areas of both 'nail head' diamonds in *Figure 9b*. This appearance is consistent with Strickland's virtual image of the 'nail head' diamond in *Figure 8c*, because it has accounted for the viewer blocking light directly over the diamond in the 'normal' viewing position.

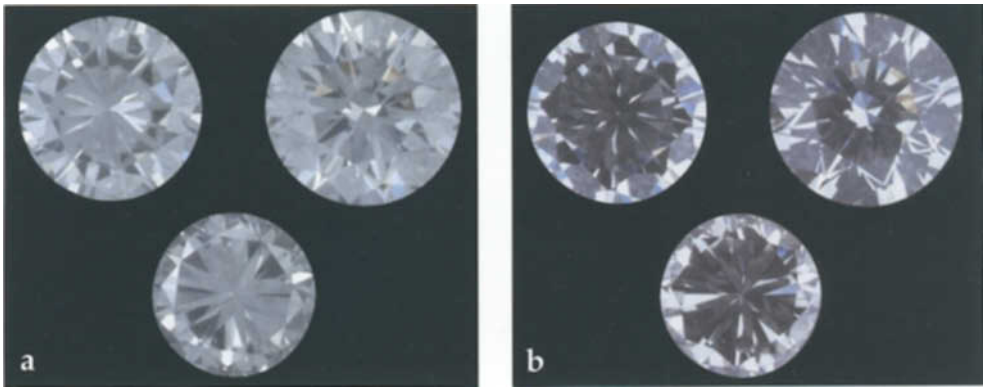

Figure 9: *'Nail heads' vs. near 'Ideal' cut diamonds (a) in hemisphere lighting created by diffusing two fibre optic light sources, and (b) in hemisphere lighting partially blocked as in close-up inspection.*

Table I: *Proportions of diamonds in Figures 9a and 9b.*

Position	*Diamond*	*Weight (ct)*	*Colour*	*Table Size (%)*	*Crown Angle (°)*	*Pavilon Angle (°)*
Top left	'Nail head' 1	0.58	H	69	30.0	42.6
Top right	Near 'Ideal'	0.74	G	56	36.0	40.9
Bottom	'Nail head' 2	0.49	I	74	37.6	43.7

This is photographic evidence that the typical 'nail head' appearance in a diamond with deep pavilion angles is not seen in hemisphere lighting. It is observable in lighting environments where little or no light is available in the area above the diamond such as occurs in the case of close-up inspection by the 'normal' viewer.

The following demonstration was inspired by a jeweller's deduction that if his head were truly causing the darkness, rather than light leakage being the cause, looking close up at a 'nail head' diamond with a red bag over his head should turn the diamond's table to red instead of it simply looking dark. Employing the Russian DiamCalc software, the Hemphill *et al.* (1998) example of a 'nail head' diamond has been illuminated with blue hemisphere lighting above the girdle. Instead of having no light below the girdle plane, we have added a lower hemisphere of green illumination. The effect of the jeweller's head, covered with the red bag,

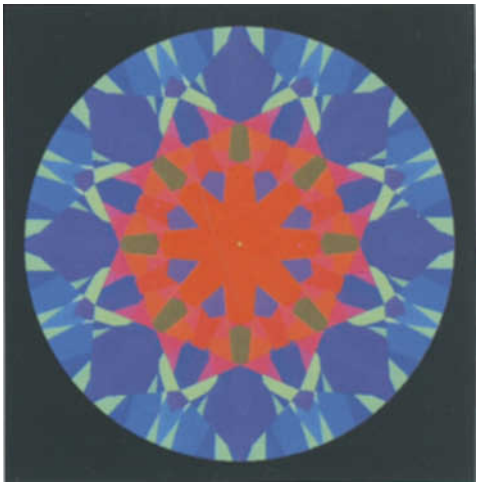

Figure 10: *GIA's 'nail head' example in the reflection source detector.*

has been simulated by a circle of red illumination over the diamond. The pattern of colours seen in the computer simulation of the face-up appearance of the 'nail head' illuminated in this manner shows from where each point on the diamond's surface is reflecting its light.

A green table would verify the occurrence of light leakage from the pavilion, because the green illumination would follow the reverse path to the 'normal' observer through the area which was leaking and turn it green. A red table would verify that the viewer's head interference is the cause of the 'nail head' diamond appearance. Areas of blue would have neither of these problems.

As the jeweller with the red bag on his head learned, the table shows red rather than green (see *Figure 10*) providing further support for the cause of table darkening in a 'nail head' diamond. Outside the diamond's table there are green spots indicating light leakage in those regions of the diamond. The blue spots within the table show small regions that do not have either the problem of light leakage or viewer interference. In a 'nail head' cut with very good symmetry one would predict that these small spots within the table should be bright. If we refer again to the actual photograph of the 'nail head' diamond in the upper left of *Figure 9b*, those bright points, which this demonstration predicts, are apparent. The predictive ability of this reflection source detector adds verification of its utility.

6. The case of shallow crown main angles

While examining many diamonds in various lighting environments, it has been noticed that diamonds with shallow crown angles below 33° are darker and less brilliant than an 'Ideal' cut when viewed close-up. This observation seems to conflict with GIA Gem Trade Lab Reports concerning crown angles.

In their diamond grading reports, the GIA Gem Trade Lab adds the comment, "crown angles less than 30 degrees" when appropriate. The Laboratory allows a 4.5° variation below Tolkowsky's 34.5° before this critical comment is included. The comment, "crown angles greater than 35 degrees" is added if they exceed 36° (pers. comm., 'Gem Trade Lab', June 1999). This only allows 1.5° of variation above the 'Ideal' and implies that as little as 0.5° upward variation above 34.5° is detrimental. To avoid these critical comments, diamond cutters and dealers must maintain the diamond's crown angle between 30° and 36°. This sends the message that relative to Tolkowsky's 34.5° 'Ideal' crown angle, shallower crown angles are more acceptable than steeper ones.

Hemphill *et al.* (1998) reinforce the idea that shallow crown angles are better in relation to a diamond's brilliance. Their study reported: "In general, WLR increases as crown angle decreases. ... These results suggest that, at the reference proportions, a diamond with a 23° crown angle is brighter than a stone with any other crown angle greater than 10°. ... Ironically, the highest WLR values are obtained for a round brilliant with no crown at all" (p.170).

These results run contrary to the present analysis of close-up viewing of diamonds with shallow crown angles between 28° and 32° compared to those between 33° and 36°. Diamonds with shallow crown angles appear darker and less brilliant when viewed close-up. Diamonds with as little as a 2.5° lower crown angle look less brilliant than those with crown angles of 34.5°. The same variation in the opposite direction does not appear to produce this loss in brilliance compared to the 'Ideal'.

Watermeyer (1982) made the following observation when viewing a diamond's mains:

"When the crown is cut on 30° the area outside the table reflection becomes a darker grey. At 29° the diamond appears blackish in colour with only the table reflection remaining white."

In this paraphrase of his words, Watermeyer was referring to a diamond

Figure 11: 'Ideal' vs. slightly shallow crown angle diamonds.

(a) Hemisphere lighting created by diffusing two fibre optic light sources.

(b) Hemisphere lighting with two 'hot spots'.

(c) Hemisphere lighting partially blocked as in close-up inspection.

***Table II**: Proportions of diamonds in Figures 11a, 11b and 11c.*

Position	*Diamond*	*Weight (ct)*	*Colour*	*Table Size (%)*	*Crown Angle (°)*	*Pavilion Angle (°)*	*Pavilion Depth (%)*	*Girdle*
Top	AGS 0 'Ideal'	0.47	E	54	35.3	41.2	43.8	thin
Bottom	Near 'Ideal'	0.46	G	56	32.6	41.0	43.5	thin

"when in full eight sides" (before the 40 star and girdle facets are cut). We will see that his observations still apply to a completed diamond in the pavilion main facet areas of the diamond.

To demonstrate this, two diamonds in the 'normal' viewing position under three different lighting conditions were photographed. The diamonds are a close match in most respects, except for crown angle (see *Table II*). This presents a valuable opportunity to document how variations in the crown angle alone affect the brilliance in differing lighting environments. The top diamond meets AGS 0 tolerances for 'Ideal', while the bottom diamond has an 'Ideal' pavilion angle and table size, but has a lower 32.6° crown angle.

The first lighting environment approximates hemisphere lighting, having diffuse illumination in a 180° hemispherical arc above the diamond's girdle. In this lighting both diamonds appear to the eye and the camera lens to be similar in brilliance (see *Figure 11a*).

The second lighting environment (*Figure 11b*) has more the flavour of jewellery store lighting. In addition to hemisphere lighting, it contains two 'hot spots'. Like jewellery store spotlights, these improve dispersion or

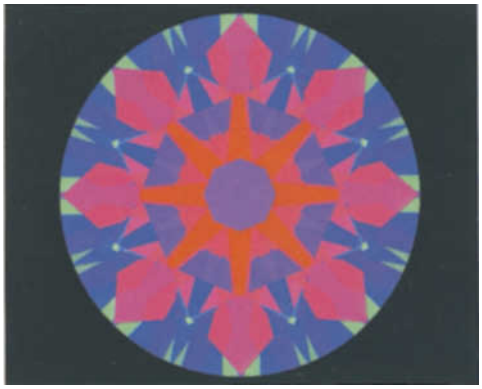

***Figure 12**: Reflection source detection of simulation of bottom diamond in Figure 11c with 32.6° crown angle.*

fire in the diamond. In this lighting, both diamonds appear to the eye to be equally brilliant, although the photography makes the 'Ideal' cut (top) look slightly better. Both diamonds exhibit similar dispersion.

The third lighting environment approximates hemisphere lighting but with little light in an area directly above to simulate a close-up viewing situation (*Figure 11c*). There is now a dramatic decrease in brilliance in the diamond with a shallower crown angle compared to the 'Ideal'. The bottom diamond's eight main facets have gone dark everywhere except for the central bright circular area, which is the table reflection. This is the area where light, which has entered the table, reflects to the 'normal' viewer. The pattern of darkness in the main facet areas is just as observed by Watermeyer (1982) when he described the appearance of diamonds with crown mains cut on 30° and below.

This is photographic documentation that when viewed close-up in real lighting environments, shallow crown angles produce less brilliance than Tolkowsky's 34.5°, just as diamond cutters such as Watermeyer and others have observed. Photography or computer modelling can only capture this fact using an illumination environment where little or no light is available directly above the diamond to simulate the circumstances of close-up inspection.

The red head reflection source detection can be employed to further document the cause of the darkening of the eight mains in the diamond with shallower than 'Ideal' crown angles. As observed in *Figure 12*, the red areas show that the close-up viewer's head interference is the cause of the darkening in the main facet areas outside the table reflection. The blue table reflection correctly predicts that the diamond will remain bright in that inner circle as it does in the diamond of *Figure 11c* (bottom) with a halo of darkness surrounding it.

As the viewer looks at an 'Ideal' cut diamond, from closer distances, there is a point where it too will darken in the main areas. As the crown angle is decreased, the point at which the viewer's interference causes the mains to darken occurs at farther viewing distances.

Darkening of the mains due to the blocking of light from above the diamond is also illustrated with devices such as the Firescope®. This diamond viewing instrument was developed in Japan in 1977 to demonstrate diamond brilliance. This device reveals the well-known, eight-rayed arrows pattern which characterizes the Eightstar® and subsequent 'hearts and arrows' type diamond cuts. *Figure 13* (courtesy of Eightstar® Diamond Co.) shows a photograph of the Firescope® view of the arrow pattern in an 'Ideal' cut diamond. In place of the red head of the model is the darkness due to the Firescope's® viewing lens. Instead of green illumination from below, the Firescope® has white light, and red illumination exists in place of the blue computer illumination. Besides colour, the main causes of the differences in the pattern of these images are the diamonds' proportion parameters and the proximity of the viewer interference.

This comparison illustrates a similarity in properties between the reflection source detector and the Firescope®. The Firescope® may be used to analyse light reflection in

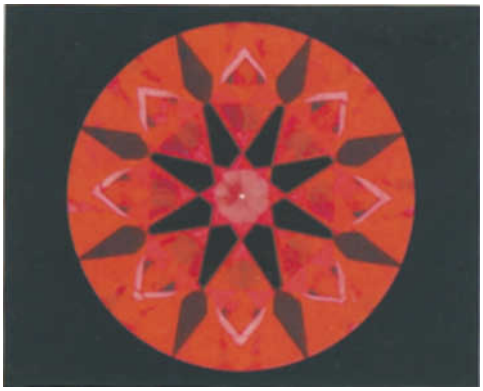

Figure 13: Firescope® image of 'Ideal' cut diamond with 34.5° crown angle (courtesy of Eightstar® Diamond Co.)

diamonds in a fashion similar to the reflection source detector. Extensions of this hardware device for more detailed analysis of diamond light return was the idea of gemmologist A. Gilbertson in 1996, who is using multi-coloured lighting devices to study the efficiency of light return in diamonds and other gemstones (pers. comm.).

7. The wisdom of Marcel Tolkowsky

Can the optimum range of pavilion, crown and table proportions be worked out with a simpler model than the complete 3D model? Can a 2D model such as Tolkowsky's establish the range of ideal combinations of crown, pavilion and table proportions, or was his analysis inadequate because it was only two-dimensional?

To begin answering these questions, compare the diamond model images published by Tolkowsky in 1919 with those appearing in recent times (see *Figures 14a, b* and *15a, b*).

There are three principal differences reflecting the changes in 'Ideal' diamond cutting from Tolkowsky's time until today. First, Tolkowsky did not consider girdle thickness but assumed a knife-edge girdle. Secondly, his table is 53%, which is smaller than is normally cut today. Thirdly, the pavilion (or lower) girdle facets extend only 50% of the way to the culet of Tolkowsky's drawing from 1919, while they extend at least 75% down the pavilions of diamonds cut today.

It is important to understand that the three parameters (pavilion main facet angle, crown main facet angle and table percentage) were all that Tolkowsky was attempting to optimize for brilliance. Other proportion parameters such as total depth percentage are a result of the choice of these three and the choice of a reasonable girdle thickness. Tolkowsky knew, as do most gemstone cutters, that the interaction of the pavilion angle, crown angle and to a lesser extent the table percentage has the greatest influence on brilliance. The other proportions, such as the lower-girdle facet angles (which are cut between 1° and 2° steeper than the pavilion main angle), are chosen relative to these three parameters.

Thus, obtaining optimum brilliance and beauty in a round brilliant-cut diamond simplified to finding the best combination(s) of these three most important cutting parameters. This is what Tolkowsky endeavoured to accomplish. Because his model was two-dimensional, he only considered a cross-section or plane through the diamond perpendicular to the pavilion mains and crown mains, so only rays of light travelling in that plane were studied. This covers a more significant portion of the diamond than one might imagine. Because the round brilliant-cut has four-fold, mirror image symmetry, that cross-section repeats in eight positions around the diamond. In *Figure 11c*, for example, the eight dark main facet areas in the bottom diamond are where Tolkowsky's analysis would apply, since his two-dimensional model plane was a slice through the mains and table.

Tolkowsky is credited with revolutionizing diamond cutting with publication of his book *Diamond Design* in 1919, and his crown and pavilion angles are

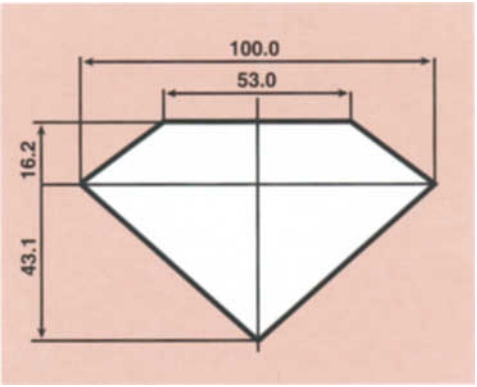

Figure 14a: Tolkowsky's drawings from Diamond Design *(1919).*

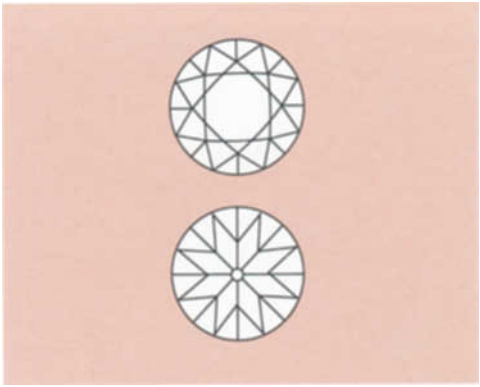

Figure 14b: Tolkowsky's drawing of the round brilliant-cut top and bottom views from Diamond Design *(1919).*

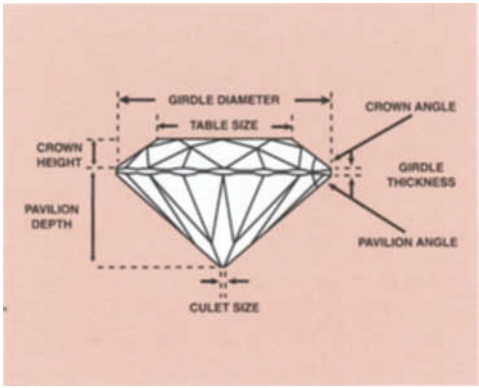

Figure 15a: Profile diagram of a modern round brilliant.

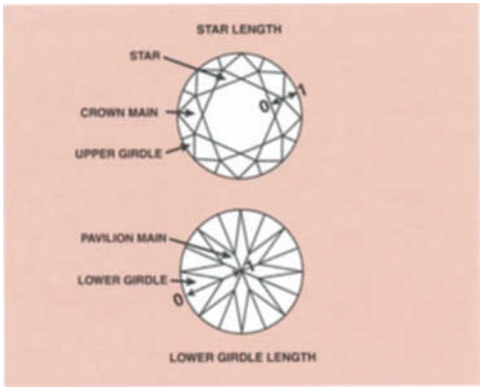

Figure 15b: Top and bottom diagrams of modern brilliant.

still considered 'Ideal' today. Both are indications of the validity of his conclusions relating to those two angles. Tolkowsky (1919) says:

"The gradual shrinking-in of the corners of an old-cut brilliant necessitated a less thickly-cut stone with a consequent increasing fire and life, until a point of maximum brilliancy was reached. This is the present-day brilliant", and he goes on to say, in a footnote, "Some American writers claim that this change from the thick cut to that of maximum brilliancy was made by an American cutter, Henry D. Morse."

Then he says: "In the next chapters the best proportions for a brilliant will be calculated without reference to the shape of a rough diamond and it will be seen how startlingly near the calculated values the modern well-cut brilliant is polished."

While many credit Tolkowsky with the development of the 'Ideal' cut diamond, we see from his own words that diamond cutters such as Henry D. Morse had been cutting maximum brilliance diamonds (as defined by Tolkowsky) for years before he wrote his book. We also see that Tolkowsky placed great importance on ensuring that his results

agreed with what the best cutters of diamonds had been practising for years before his book. When his mathematical analysis verified these proportions he declared the following in his Mathematics Chapter:

"In the course of his connection with the diamond-cutting industry the author has controlled and assisted in the control of the manufacture of some million pounds' worth of diamonds, which were all cut regardless of loss of weight, the only aim being to obtain the liveliest fire and the greatest brilliancy. The most brilliant larger stones were measured and their measures noted. It is interesting to note how remarkably close these measures, which are based upon empirical amelioration [improvement] and rule-of-thumb correction, come to the calculated values."

Tolkowsky's words indicate that he was acutely aware and in awe of the diamond cutters' skill in developing the proportions that had been in use for many years to produce optimum brilliance and dispersion. Because his mathematics confirmed these proportions he concluded: "We may thus say that in the present-day well-cut brilliant, perfection is practically reached; the high-class brilliant is cut as near the theoretical values as is possible in practice, and gives a magnificent brilliancy to the diamond."

The last words in his book are: "It seems likely that the brilliant will be supreme for, at any rate, a long time yet."

Although there have been changes such as increases in table size and girdle thickness and lengthening of the lower girdle facets, his basic findings concerning the best pavilion and crown angles have held up for eighty years.

Conclusions

The GIA is making a concerted effort with its computer modelling to explore the extent to which the proportion parameters may be varied and still retain or exceed the beauty of the current 'Ideal'. Hemphill *et al.* (1998) state that their study results "do not support the idea that all deviations from a narrow range of crown angles and table sizes should be given a lower grade".

The study, computer modelling and diamond photography presented above demonstrate that, with an illumination that accounts for interference from the 'normal' viewer, the possible range of deviations from 'Ideal' proportions can be narrowed. In summary:

(i) A measure of brilliance must agree with human judgement. Observations of the effects of diamond proportions on brilliance by diamond cutters from Tolkowsky to Watermeyer, and observations by people in the diamond trade and consumers provide the litmus test for conclusions drawn from computer modelling of brilliance in diamonds.

(ii) An illumination that takes into account the observer's physical presence is necessary to reveal the loss in brilliance in the 'nail head' and diamonds with shallow crown angles.

(iii) Diamond cutters and the GIA Diamond Course are correct in their adherence to close to a 41° pavilion angle as the single most important proportion. The present work shows that the 43° to 45° pavilion angles lower brilliance under close-up inspection by a greater amount than hemisphere lighting revealed. (There are further reasons why the pavilion angle should have a smaller tolerance than 2° around 41° that may be demonstrated in a continuation.)

(iv) With the pavilion angle held close to 41°, crown angles below Tolkowsky's 34.5° yield decreasing brilliance under close-up observation in spite of the fact that they show increasing WLR in hemisphere illumination. With a

***Figure 16**: Parker's cut with a 55.9% table, 25.5° crown angle, and 40.9° pavilion angle.*

***Figure 17**: 'Ideal' cut resulting from increasing the Parker's cut crown angle by 9°.*

pavilion angle near 41°, shallow crown angles are not a direction to go in search of greater brilliance.

(v) When a diamond is graded for cut, crown and pavilion angles are the important proportions that should be measured along with table size, rather than total depth or even crown height and pavilion depth percentages. As gemstone cutters know, these angles most directly affect the gemstone brilliance. Many diamonds that possess an 'Ideal' total depth have thin crown heights and shallow crown angles with a deep pavilion depth to compensate. This yields an 'Ideal' depth even though the brilliance and beauty of the diamond is negatively affected owing to the faults discussed in section 5 and section 6. Also, a greater than 'Ideal' pavilion angle, producing a deep pavilion, can be made to measure within AGS tolerance of the 'Ideal' pavilion depth by cutting a medium culet facet.

(vi) The illumination of the diamond has as much influence on the measure of brilliance as the diamond's proportions do. In *Figures 1* and *2b*, the differing illumination environments have caused the diamond in *2b* to have greater light return, but the diamond in *Figure 1* would normally be judged to be more brilliant because of the 'surface sparkle' or 'snappy' contrast between its facet reflections. Although both of these diamonds are 'Ideal' cut, the illumination has made them appear dissimilar. Illuminating a diamond from enough different angles can cause even the most poorly proportioned diamonds to have high light return. By employing typical rather than averaged illumination environments, and by including consideration of the physical presence of the viewer, a measure of brilliance can better separate diamonds of 'Ideal' proportions from those of poor proportion.

(vii) Computer modelling programs, such as those of Hemphill *et al.* (1998), Strickland (1992, 1993) and Sivovolenko *et al.*(2000), are effective tools for exploring diamond brilliance. For a final illustration supporting this the Parker's cut is examined. This was the diamond that Hemphill *et al.* (1998, p.178) calculated to have "the highest WLR (0.297)". The diamond images of *Figures 16* and *17* were generated with the Russian DiamCalc software using a representation of jewellery store lighting, which included the effect of a close-up viewer. Parker's cut appears in *Figure 16*. By increasing the crown angle by 9°, the Parker's cut becomes the AGS

0 'Ideal' pictured in *Figure 17*. Visual comparison of these leave little doubt as to which is more brilliant in this lighting environment.

These images support the idea that aspects of brilliance including the amount of light return and 'surface sparkle' can be effectively studied with computer modelling using a face-up 'snapshot' generated using illumination representative of normal viewing conditions.

Acknowledgements

Thank you to Bruce Harding, William Day, Robert Strickland, Martin Haske and Donald Dietz for many hours of intense discussion, peer review, ideas and suggestions gratefully received which contributed greatly to this work. Thank you to Sergey Sivovolenko and Anton Vasiliev for personal communication of their work and all at Octonus for custom modifications to their software product enabling the fine computer imaging.

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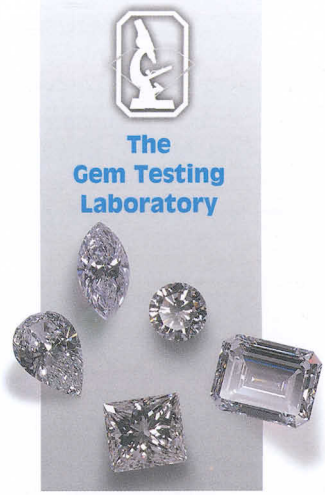

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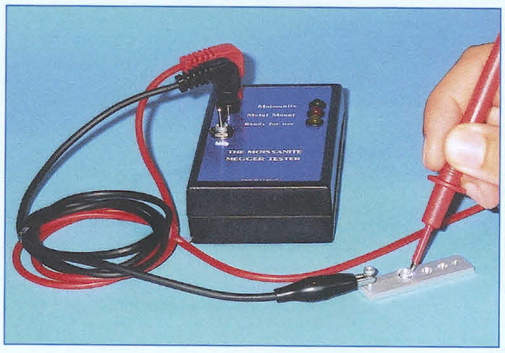

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Oriented inclusions in spinels from Madagascar

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ABSTRACT: Orientated inclusions in bluish-grey gem spinels from Madagascar were determined by a combination of qualitative and quantitative electron microprobe analysis with laser Raman microspectroscopy as enstatite, $MgSiO_3$. A possible origin of the spinels from the sapphire and spinel-bearing deposits of Andranondambo and Ilakaka, southern Madagascar, is briefly discussed.

Introduction

Oriented needle-like inclusions in cubic host minerals are responsible for the six-rayed and/or four-rayed stars in asteriated spinels and garnets (see e.g. Kumaratilake, 1998). This inclusion pattern is frequently observed in spinels and especially in garnets from different localities. Lamellar inclusions in cubic gem minerals, on the other hand, are quite rare. As an example, the determination of högbomite lamellae that are oriented parallel to octahedral {111} faces of Tanzanian spinels has been described by Schmetzer and Berger (1992).

In Madagascar, large quantities of gem-quality spinels are now recovered from the gem gravels around Ilakaka (Hänni, 1999; Schmetzer, 1999, 2000), but spinel was also mentioned from the skarn-related sapphire deposit of Andranondambo in southern Madagascar (Kiefert *et al.*, 1996; Gübelin and Peretti, 1997).

Gemmology of the spinels

The lamellar and needle-like inclusions in gem-quality spinels to be described in this paper were observed in a parcel of six light bluish-grey faceted samples ranging from 0.15 to 0.50 ct. The owner of this parcel indicated that these spinels originate from an unknown locality in southern Madagascar and were faceted in their country of origin. He also indicated that this parcel had been purchased about four years ago on a local gemstone market.

Gemmological properties of the samples are normal for natural gem spinels, and the absorption spectra in the visible and ultraviolet range are typical for spinels containing iron.

Several sets of lamellar inclusions were observed by microscopic examination in three of the samples. In one specific orientation of the hosts, an equilateral triangular network of three sets of birefringent lamellae was observed (*Figure 1*).

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Inclusions in spinel from Madagascar

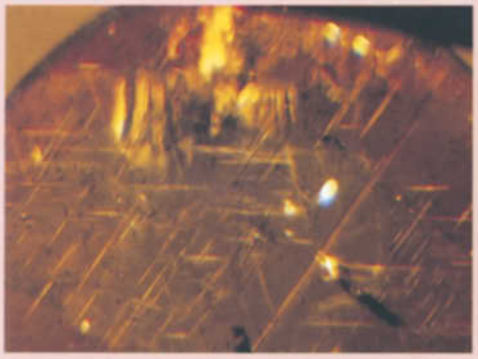

Figure 1: Three sets of birefringent lamellae that form an equilateral triangular pattern are observed in a view parallel to one of the three-fold axes of the host. Immersion, crossed polarizers, magnified 80x. Photomicrograph by K. Schmetzer.

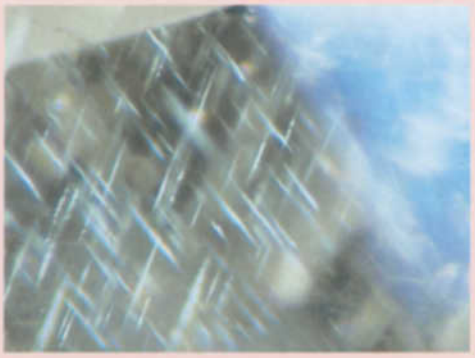

Figure 2: Two sets of birefringent lamellae that are inclined to each other are observed in a view parallel to one of the three-fold axes of the host. Dark field, fibre optic illumination, magnified 65x. Photomicrograph by E. Gübelin.

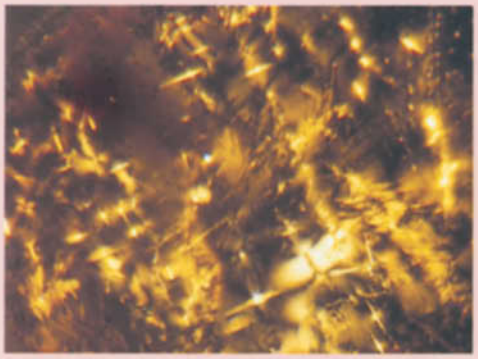

Figure 3: Birefringent crystals with various shapes are oriented parallel to specific planes within the host. Immersion, crossed polarizers, magnified 70x. Photomicrograph by K. Schmetzer.

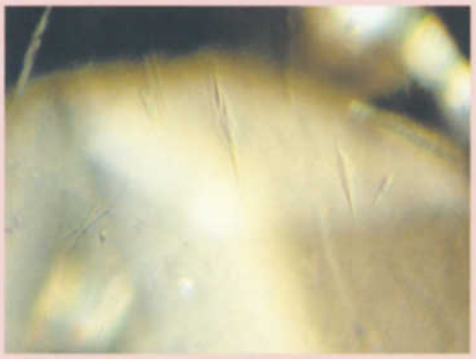

Figure 4: Oriented lozenge-shaped or needle-like crystals, some with a distinct jagged outline. Dark field, fibre optic illumination, magnified 100x. Photomicrograph by E. Gübelin.

Occasionally, lamellae that are inclined about 60° to each other were observed only in two of these three orientations (*Figure 2*). In another direction of view, two sets of lamellae were found that formed a rectangular inclusion network. These microscopic observations indicate that the lamellae are oriented parallel to the dodecahedral {110} faces of the host spinels. The observation of a triangular pattern of three or two sets of parallel lamellae that are inclined to each other is consistent with a view of the samples parallel to one of the three-fold <111> axes, and the observation of a rectangular pattern of two sets of parallel lamellae is consistent with a view parallel to one of the four-fold <100> axes of the cubic spinels.

The remaining three samples showed an inclusion pattern, which can be described as 'incomplete lamellae'. Again, inclusions are oriented parallel to distinct planes. Some of these inclusions are small fragments of a

lamella with irregular or jagged boundaries, others were developed as lozenge-shaped or needle-like crystals, but with all elongated axes of the birefringent inclusions orientated parallel to specific crystallographic directions within the spinel hosts (*Figures 3 and 4*).

Three of the six samples mentioned (designated A, B and C) revealing a dense pattern of lamellar to needle-like inclusions were selected for further examination. For the determination of inclusions in these three spinel host crystals, electron microprobe analysis and laser Raman microspectroscopy were applied. We tried to analyse inclusions that were exposed on the tables of the spinels, sometimes after having repolished these faces to avoid contamination in small cavities. One of the samples (spinel B) was cut into slices and after repolishing the surfaces, the inclusions exposed were examined by both techniques. All procedures were rather time consuming, and because the inclusions are close to 1 µm across - the diameter of the electron or laser beams - it was extremely difficult to find inclusions that gave conclusive results.

By microprobe analysis of samples A and C we were unable to separate the signals of the inclusions from the characteristic Mg-Al X-ray pattern of the host spinel. For all inclusions of this type examined, we only observed one additional characteristic X-ray line of Si (together with the lines of Mg and Al). This result indicates that the inclusions are magnesium-, aluminium- or magnesium-aluminium-silicates.

On slices of sample B we observed some 'larger' inclusions with thicknesses up to 5 µm, which allowed us to perform quantitative microprobe analysis of the crystals. We found that these birefringent minerals were magnesium silicates with smaller percentages of iron and aluminium (*Table I*). The quantitative data indicate that the inclusions are enstatites $MgSiO_3$.

These results were confirmed by Raman analysis. In all samples, a strong fluorescence of the host spinels interfered with the Raman spectra of the inclusions.

Table I: Chemical properties of enstatite inclusions in spinel

Wt%	*Crystal 1*	*Crystal 2*
	Mean of 4 anals.	*Mean of 2 anals.*
SiO_2	58.30	58.56
Al_2O_3	2.54	2.61
MgO	38.11	38.34
FeO	1.26	1.22
CaO	0.06	0.08
Total	100.27	100.81
	Cations based on 6 oxygens	
Mg	1.904	1.905
Fe	0.035	0.034
Ca	0.002	0.003
Al	0.100	0.103
Si	1.954	1.953
Total	3.997	3.997

Nevertheless, we obtained Raman lines typical for enstatite from several inclusions of samples B and C.

In summary, we were able to perform qualitative chemical analysis of inclusions of samples A and C and we even obtained quantitative chemical data of two crystals in sample B. Significant Raman spectra were measured for inclusions in samples B and C. All data indicate that the orientated inclusions in the spinel were enstatite.

The literature was searched for data relating to the co-existence of spinel and enstatite but none were found which described an exsolution of enstatite in spinel or an oriented intergrowth of both minerals. Determination of the mode of origin of the enstatite lamellae must await further experimental data.

Source of the spinels

Spinel occurs within the rocks of the sapphire- and spinel-bearing skarn area of southern Madagascar, but enstatite was not

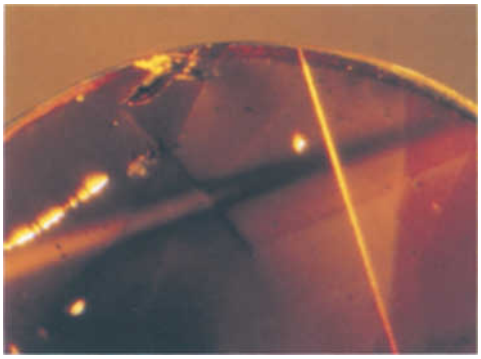

Figure 5: *Lamella in purple spinel from Ilakaka, Madagascar, consisting of polycrystalline rutile. Immersion, crossed polarizers, magnified 50x. Photomicrograph by K. Schmetzer.*

reported from these mineral assemblages (Rakotondrazafy *et al.*, 1996; Kiefert *et al.*, 1996; Schwarz *et al.*, 1996; Gübelin and Peretti, 1997; see also Pezzotta, 1999).

The spinel samples examined were purchased at least two years before the new Ilakaka deposit in southern Madagascar was discovered and intensely exploited. In about 120 blue, bluish-green, violet, purple or pink spinels from Ilakaka recently examined by one of the authors (see Schmetzer, 2000), only one rough sample with a lamellar inclusion was found. After faceting of this dark purple spinel, the lamella was exposed on the surface of one smaller facet (*Figure 5*) determined by the Raman technique to be rutile. A careful microscopic examination showed that the lamella consists of numerous small rutile crystals.

Consequently, there is no indication that the spinels with various forms of enstatite inclusions might come either from the Andranondambo or from the Ilakaka area in southern Madagascar and the exact location of the samples remains unclear.

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Critical angle vs. deviation angle vs. Brewster angle

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ABSTRACT: The limitations inherent in each of the three convenient approaches to refractive index determination available to the gemmologist at the end of the twentieth century are described. A light-ray diagram for each approach centres upon the vibration direction(s) that are tested. It is shown that the refractometer can be used to measure all vibration directions but the required contact liquid sets a limit of usability; the deviation angle approach is free of contact liquid limitations but vibration directions that are tested are somewhat reduced; the Brewster-angle approach is also free of contact liquid limitations but vibration directions that are tested are much reduced.

Keywords: Brewster angle, critical angle, deviation angle, refractive index, vibration direction

Introduction

As this century and millennium draws to a close, we must admire the clever ingenuity, indeed the genius of those who developed the non-destructive tools and methods we use to identify gems. The greatest respect we can show our gemmology pioneers is to use their tools and methods with a clear understanding of how they work to interpret unusual or exceptional results sensibly, and not treat instruments as 'black boxes' giving magical results. With the introduction of the Brewster-angle meter[1] there are now three distinct approaches convenient to the gemmologist for determination of refractive index. In the order of their introduction they use the following optical properties: the critical angle, using the refractometer; the deviation angle, as used in visual optics (also known as the Hodgkinson technique); and Brewster's angle utilised with the new Brewster-angle meter.

Ray diagrams are particularly helpful if it is considered that the propagation direction (ray direction) is *where* the light interacts with the medium, while the electric vector (vibration direction) controls *how* the light interacts with the medium. In the following diagrams the vibration directions shown inside each tested stone indicate vibration direction(s) in the medium that can yield a reading using the testing approach under discussion.

The refractometer

The refractometer is undoubtedly the most important of the tools available to the practising gemmologist. For a well polished gem having an RI within the limits of the unit one can determine RI, birefringence, optical character, and optic sign from

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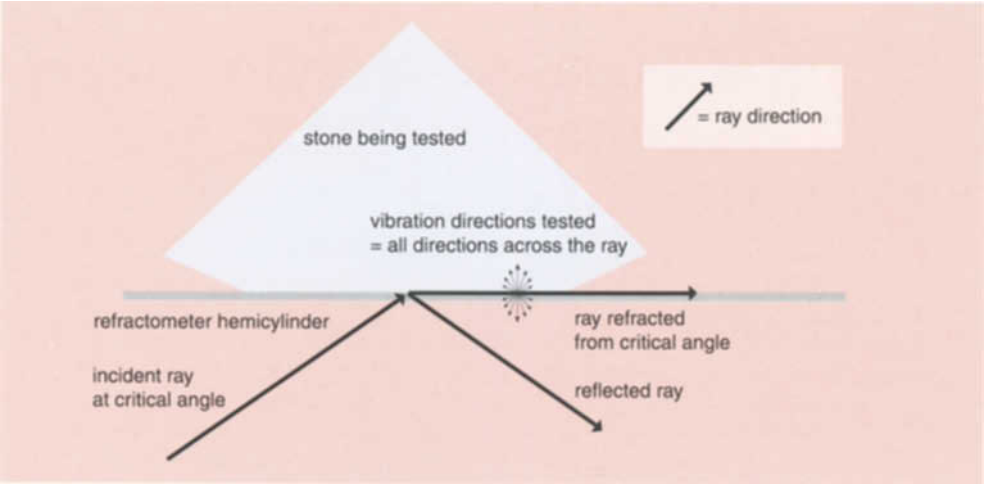

Figure 1: *Different propagation directions can be tested by horizontally rotating the stone on the test facet, therefore, all possible vibration directions can be tested.*

measurements on a single facet. There have been suggestions that for some special cases it may be necessary to check readings on a second or even a third facet, but it has been known for more than half a century that these special cases can be resolved using a polarising filter over the eyepiece[2] without going to another facet, a particularly helpful technique since the facet chosen for refractometer testing is usually the largest, most accessible and well polished facet on the stone.

The greatest advantage of the refractometer is that within equipment limits, every vibration direction within the medium can be tested on a single facet. The position of the stone on the window of the instrument and horizontal rotation through various orientations allow the minimum and maximum RI for each direction along the surface to be observed (*Figure 1*).

The effective limit of standard gemmological refractometers is the refractive index of the fluid which provides optical contact between the instrument and the specimen. Stones with RI over 1.79 (1.81 with the older more toxic fluid) will yield a 'negative' (i.e. over-the-limit) result with no specific values indicated for the RI.

Visual optics

Visual optics is an experimentally developed technique of testing a faceted stone by observing a light through it[3,4]. It can give a very quick approximation of refractive index and birefringence /dispersion ratio with no instruments or aids whatever and, with a facet-angle measuring template and a sheet of paper marked in degrees[5], can yield reproducible two-decimal place refractive indices. The technique is best understood by comparison to the light ray deviation method[6] even though it does not require the elaborate apparatus of the minimum deviation method so lucidly explained by Webster. One of the limits of deviation angle methods arises when total internal reflection takes place, which means that the stone's RI cannot be obtained if the angle between the two faces is more than twice the critical angle of the medium[7]. This problem is virtually eliminated when immersion fluids are used, as in Nelson's Pavilion Facet Fingerprinter or the Hanneman Refractometer[8]. Another limit of the deviation angle methods is that only one propagation direction can be tested through each pair of test facets, although there is no limit to the vibration directions being tested across the direction of travel (*Figure 2*).

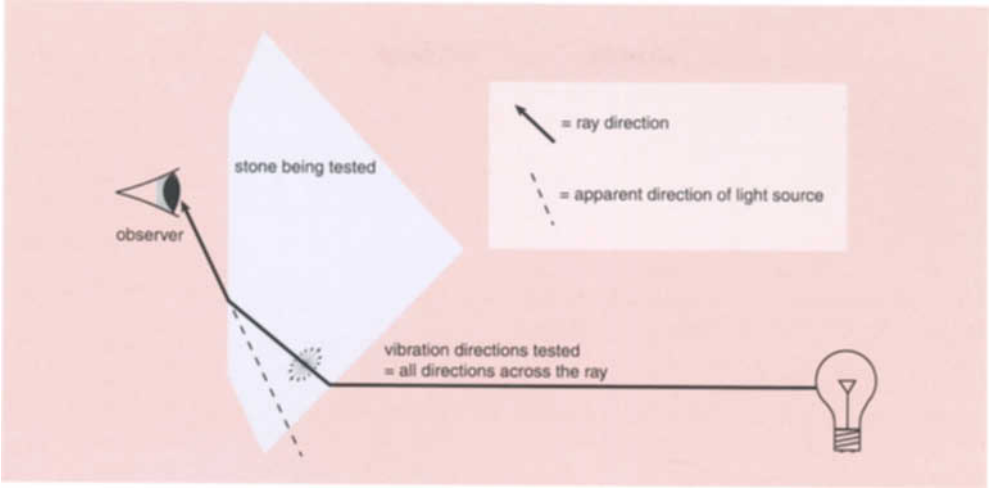

Figure 2: *Visual optics: different propagation directions can be tested by looking through the table at light coming through different pavilion facets, therefore many different vibration directions can be tested.*

The number of transmission directions that can be tested on a faceted stone, typically at least eight and often more, can yield RI readings for many different vibration directions. The minimum and the maximum RIs for all vibration directions between those parallel to the table and those 90° to the directions of travel through the stone (in the plane perpendicular to the table) can be observed. How close the observed birefringence comes to the full birefringence of the stone under examination depends upon how close the principle vibration direction of the highest or lowest RI comes to being perpendicular to the table of the stone.

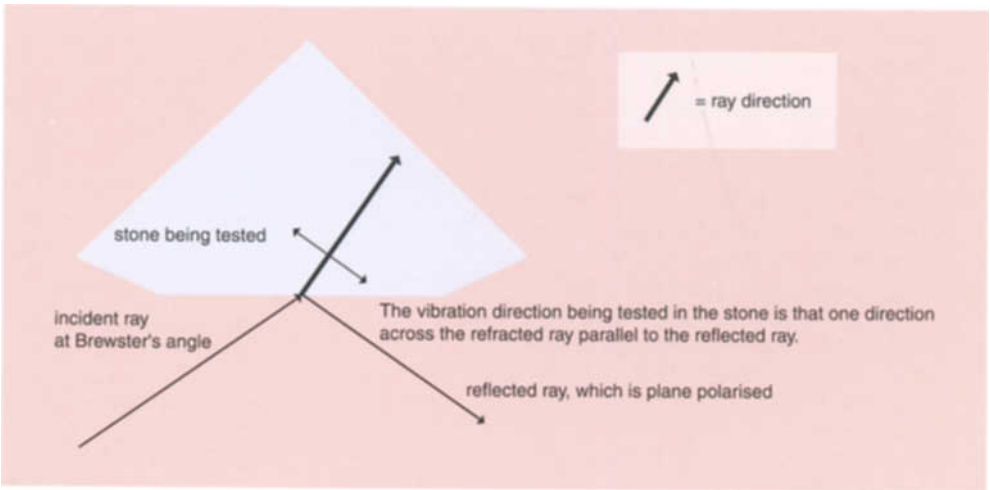

Figure 3: *Different propagation directions can be tested by horizontally rotating the stone on the test facet so all the vibration directions that can be tested will form an elliptical cone shape at the critical angle(s).*

Brewster-angle meter

The new Brewster-angle unit actually can measure refractive index (refractive index is simply the tangent of the Brewster angle) but, because the laser light source it uses provides monochromatic red light of 670 nm wavelength rather than monochromatic yellow light at 589 nm, the developers wisely decided to calibrate in angles rather than refractive indices to save confusing this new red wavelength standard with the traditional yellow wavelength standard. Some early discussions about the concept of a Brewster angle refractometer suggested that it could be a particularly powerful tool which, without the limits imposed by a contact fluid, would render the critical angle refractometer entirely obsolete. The difficulties in living up to this expectation seem to be more than simply problems of technical development.

The limits for the Brewster angle approach to refractive index measurement, aside from those imposed by the level of precision engineered into the measuring unit, are that the only vibration directions that can be tested are those actually at the Brewster angle for the facet being tested. Although some birefringence may be measured, it is somewhat unlikely that the full birefringence will be seen because of the very limited number of vibration directions that can be tested (*Figure 3*).

As pointed out by Webster[9], at the Brewster angle the plane polarized reflected ray must be at 90° to the refracted ray, so it is the refracted ray which establishes the Brewster angle (the polarized reflected ray must follow Snell's law of reflection). The vibration direction tested using the Brewster angle is therefore the vibration direction of the polarized component of the refracted ray.

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Abstracts

Diamonds | Synthetics and Simulants | Gems and Minerals | Instruments and Techniques

Diamonds

Détection des diamants GE POL: une première étape. (Detection of GE POL diamonds: a first stage.)

J.-P. Chalain, E. Fritsch and H.A. Hänni. *Revue de gemmologie*, 138/139, 1999, 24-33. Illus. in colour. (French and English versions)

Type IIa diamonds with the colour grade E and F have the letters GE POL lasered on the girdle. They show apparently colourless crossed strain patterns under polarized light and crystalline inclusions are surrounded by expansion islands reminiscent of similar effects in high-temperature treated corundum. Raman spectroscopy has showed several fluorescence bands, one at 637 nm indicating the presence of N-V centres. A detection instrument, the SSEF IIa Diamond Spotter, works in conjunction with a SWUV source. M.O'D.

Nature, origin and age of diamonds: a state-of-the-art report.

V. Ferrini and G. Sassano. *Periodico di Mineralogia*, **68**(2), 1999, 109-26.

Solid inclusions in diamonds are as small as 150-200 µm and show that diamonds invariably are derived from peridotitic and eclogitic rocks. The kimberlite and lamproite hosts to diamonds are more recent and not necessarily linked with the origin of the diamonds, merely acting as their transport to the surface. Diamonds associated with peridotitic rocks are ~ 3300 m.y. old, whereas those associated with eclogitic rocks range in age from 1600 to 1000 m.y. Isotopic studies have shown that diamonds originating in peridotitic rocks appear to have been generated in fairly homogeneous zones of the mantle, whereas those from eclogitic rocks have apparently been generated from crustal plates transported at depth by subduction phenomena related to continental drift. Kimberlite and lamproitic rocks are only diamondiferous if, prior to ascent, they intersected those sectors of the mantle where peridotitic or eclogitic diamond-bearing rocks originate. It is possible for some diamondiferous diatremes to contain diamonds of different ages. R.A.H.

Spectroscopic evidence of GE POL HPHT-treated natural type IIa diamonds.

D. Fisher and R.A. Spits. *Gems & Gemology*, **36**(1), 2000, 42-9.

Results from spectroscopic analyses of GE POL high-*P*–high-*T* annealed nominally Type IIa diamonds are presented and compared with results for untreated diamonds of similar appearance and type. Absorption spectroscopy reveals that any yellow coloration in such HPHT-treated diamonds is due to low concentrations of single nitrogen, not observed in untreated Type IIa diamonds. Laser-excited photoluminescence spectroscopy reveals the presence of nitrogen-vacancy centres in most, but not all, HPHT-treated stones. When these centres are present, the ratio of the 575:637 nm luminescence intensities offers a potential means of separating the HPHT-treated from untreated Type IIa diamonds. R.A.H.

Crown angle estimation for diamond using a 'tilt test'.

G. Holloway. *Australian Gemmologist*, **20**(9), 2000, 374-5, 4 illus. in black-and-white.

The crown angle of a brilliant-cut diamond can be estimated by viewing the image of its culet through one of the kite facets as the diamond is tilted about its vertical axis [this should be horizontal axis - ed.] A brilliant with a shallow crown will require a considerable tilt before the image of the culet becomes visible. Brilliants with an 'ideal' crown angle require less tilt before the culet becomes visible. However, the size of the table should be taken into account. If the table is large, the angle of tilt will be more than if the table is small. P.G.R.

Raman barometry of diamond formation.

E.S. Izraeli, J.W. Harris and O. Navon. *Earth & Planetary Science Letters*, **173**(3), 1999, 351-60.

Diamond and source region *P-T* conditions are commonly estimated using chemical equilibria between coexisting mineral inclusions. Here, another type of geobarometer, based on determination of the internal *P* in olivine inclusions and the stresses in the surrounding diamond, is presented. Using Raman spectroscopy, *P* of 0.13–0.65 GPa were measured inside olivine inclusions in

Abstractors

J. Flinders	J.F.	R.A. Howie	R.A.H.	P.G. Read	P.G.R.
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For further information on many of the topics referred to, consult *Mineralogical Abstracts*

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three diamonds from the Udachnaya mine, Siberia. Stresses in the diamond surrounding the inclusions indicated similar P (0.11–0.41 GPa). N_2 contents and aggregation state in two of the diamonds gave mantle residence T of ~ 1200°C. Using this T and the bulk moduli and thermal expansion of olivine and diamond, gives a calculated source P (0.4–5.2 GPa. The general dependence of the source P (P_0 GPa) on source T (T_0°C) and measured internal P in the inclusion (P_i) is given by: $P_0 = (3.259 \times 10^{-4} P_i + 3.285 \times 10^{-3}) T_0 + 0.9246 P_i + 0.319$. Raman barometry in combination with IR determination of the mantle residence T of the diamond allows estimation of the P at source using non-destructive examination of a single inclusion within a single diamond. J.F.

New Ca-silicate inclusions in diamonds - tracers from the lower mantle.

W. Joswig, T. Stachel, J.W. Harris, W.H. Baur and G.P. Brey. *Earth & Planetary Science Letters*, **173**(1-2), 1999, 1-6.

Diamonds from the Kankan district of Guinea, which commonly contain ultra-high P majoritic garnet and ferropericlase mineral inclusions, similar to those from São Luiz in Brazil, also contain inclusions of Ca silicates. One diamond contained walstromite-structured $CaSiO_3$, and three others the mineral assemblage $CaSi_2O_5$ (titanite-structured) with larnite (β-Ca_2SiO_4). The first two phases have not before been identified in natural occurrences. The phase diagram for mantle $CaSiO_3$ indicates that primary $CaSiO_3$-perovskite underwent successive retrograde phase transformations. Development of equilibrium textures implies slow exhumation. Ca-silicates are possibly important carriers of Sr, P and K, and hence contain part of the inventory of radioactive elements in the transition zone and the lower mantle. Coesite (formerly stishovite) in two of the diamonds containing Ca-silicates indicates they belong to an 'eclogitic' suite, whereas ferropericlase together with $CaSiO_3$ and $MgSiO_3$ in the third diamond may imply a 'peridotitic' environment. J.F.

The Merlin diamond mining project. Part 1: an introduction.

An editorial review. *Australian Gemmologist*, **20**(9), 2000, 382-5, 2 colour illus., 1 map.

Ashton Mining's Merlin diamond mining project in the Northern Territory consists of twelve kimberlite pipes named after the Arthurian legends Merlin, Bedevere, Ector, Excalibur, Gareth, Gawain, Kay, Launfal, Palomides, Sacramore, Tristram and Ywain, which are located some 600 km south-east of Darwin. Early in 1999 commercial mining operations commenced and the first sale of diamonds from the Merlin Project was completed in Antwerp in May of that year. Forecast production for the first year of operation is approximately 200,000 carats from the treatment of 550,000 tonnes of ore, rising to 300,000 carats from 700,000 tonnes of ore for the second year. P.G.R.

Gem Trade Lab notes.

T. Moses, I. Reinitz and S.F. McClure (eds). *Gems & Gemology*, **36**(1), 2000, 60-65.

Notes are given on greenish-yellow 'chameleon' diamonds with blue-to-violet 'transmission' luminescence, and light blue synthetic brilliant-cut diamonds. R.A.H.

Diamonds and accompanying minerals from the Arkhangelsk kimberlite, Russia.

T.V. Possoukhova, G.P. Kudryavtseva and V.K. Garanin. *Mineral Deposits: Processes to Processing*, 1999, 667-70.

A study of > 200 diamond crystals, as well as garnets, spinels, ilmenites, pyroxenes and olivines, from three kimberlite fields in the Arkhangelsk diamondiferous province is reported. The characteristics of the diamonds and their accompanying minerals change from one field to another, according to the depth of formation of the parent kimberlite melts. R.A.H.

Gems and Minerals

Rare Australian gemstones - stichtite.

R.S. Bottrill and G. Brown. *Australian Gemmologist*, **20**(9), 2000, 391-3, 2 colour illus., 1 map.

A summary of the history of discovery, occurrences, associated minerals and gemmological properties of this rare Australian stone. Stichtite was first found on Stichtite Hill, about 500 m east of the Adelaide Proprietary mine, Dundas, Tasmania. This deposit is currently being mined for stichtite for lapidary purposes. P.G.R.

Gems around Australia: Part 15.

H. Bracewell. *Australian Gemmologist*, **20**(9), 2000, 378-81, 9 colour illus., 1 map.

This final part of a fossicking survey of Australian gem sources describes locations and gem materials in the south west of the country. Included are soapstones from Bridgetown, microcline feldspar, petalite, beryl, columbite and lepidolite mica from the Londonderry quarries, pink tourmaline from Ravensthorpe and Catlin Creek, and moss opal from near Norseman. P.G.R.

A new deposit of smoky quartz crystals from the Torrington area.

H. Bracewell. *Australian Gemmologist*, **20**(9), 2000, 388-90, 5 colour illus., 1 map.

More than 8000 prismatic smoky quartz crystals with lengths which ranged from 1 to 30 cm were recovered from a small collapsed clay-filled vugh at Silent Grove north of Torrington in the New England district of New South Wales. P.G.R.

La liste de Mogok.

M. Bruley. *Revue de gemmologie*, 138/139, 1999, 62-6.

Account of a journey to Mogok and of the working of the ruby mines. M.O'D.

Mise à jour sur la détermination des substances de remplissage dans les émeraudes.

J.-P. Chalain. *Revue de gemmologie*, 138/139, 1999, 18-21. Illus. in colour.

Oil, Canada balsam and artificial resins used as

fillings in emerald are reviewed. An artificial ageing test showed that artificial resins turn yellow from colourless. Clove oil can be distinguished from artificial resins and C-H chemical bonds present in some of the inclusions in natural emerald can be detected by infrared spectrometry. Spectra from emerald fillers can be affected by the presence of refractometer fluid and by liquid soap.

M.O'D.

Lapis lazuli from the Coquimbo Region, Chile.

R.R. Coenraads and C. Canut de Bon. *Gems & Gemology*, **36**(1), 2000, 28-41.

Lapis lazuli has been mined since 1905 in the Coquimbo Region of central Chile, near the border with Argentina. It occurs in contact metamorphosed limestone later metasomatized with the introduction of sulphur, the deposit consisting of blue lazurite with wollastonite, diopside, calcite, haüyne and pyrite. The Chilean material varies in quality and tends to be more spotted or less pure than Afghan material. The mines are at a height of 3500 m and produce some 150 tonnes annually. R.A.H.

Découvertes récentes sur l'opale.

E. Fritsch, B. Rondeau, M. Ostrooumov, B. Lasnier, A.-M. Marie, A. Barrault, J. Wey, J. Connoué and S. Lefrant. *Revue de gemmologie*, 138/139, 1999, 34-40.

A number of opals from new localities are described with respect to their microstructure and coloration. These include mauve opal from Androy in the south of Madagascar; blue-green opal from Acrari, Arequipa, Peru; blue opal from Var, France; pink opal from Montana, U.S.A., Quincy, Cher, France, and Mapimi, Mexico; and yellow opal from Saint-Nectaire, Puy-de-Dôme, France.

M.O'D.

Historique des gisements d'émeraude et identification des émeraudes anciennes (part 1).

G. Giuliani, M. Chaussidon, H.-J. Schubnel, D.H. Piat, C. Rollion-Bard, C. France-Lanord, D. Giard, D. de Narvaez and B. Rondeau. *Revue de gemmologie*, 138/139, 1999, 22-3.

First part of a review of emerald locations known in classical and later times. M.O'D.

In defense of gemmologists: a different view on nomenclature.

W.W. Hanneman. *Australian Gemmologist*, **20**(9), 2000, 370-3.

In responding to E.L. Steven's article 'The nomenclature of gemstones with special reference to the garnet and tourmaline group' (*Australian Gemmologist*, **20**(7), 1999, 277-9), the author defends the gemmologists' trade-orientated naming of traditional gem varieties and criticises the stricter method imposed by the mineralogists' nomenclature committee. P.G.R.

Les grenats gemmes.

H.A. Hänni. *Revue de gemmologie*, 138/139, 1999, 50-4.

Review of the gem garnets with discussion of their atomic structure, properties and colour. M.O'D.

Classification of the minerals of the tourmaline group.

F.C. Hawthorne and D.J. Henry. *European Journal of Mineralogy*, **11**(2), 1999, 201-15.

A systematic classification of the tourmaline-group minerals, general formula $XY_3Z_6O_{18}(BO_3)_3V_3W$, is proposed, based on chemical composition and ordering at the different crystallographic sites of tourmaline structure. There are currently 13 accepted tourmaline species, each of which is defined. A feature that extends the number of possible end-members is the anion occupancy of the *W* site (dominated by OH^-, F^- or O^{2-}) and the *V* site (dominated by OH^- or, more rarely, O^{2-}), thus giving hydroxy-, fluor- or oxy-end-members; the presence of dominant O^{2-} at the *W* site commonly requires local cation-ordering at the *Y* and *Z* sites. The tourmaline group minerals can be classed into three principal groups based on the dominant species at the *X* site: alkali tourmalines (Na), calcic tourmalines (Ca) and *X*-site-vacant tourmalines (□). These groups are further divided, firstly on the occupancy of the *W* site, then by the (actual or inferred) occupancy of the *V* site, followed by the (actual or inferred) occupancy of the *Y* site, and finally by the (actual or inferred) occupancy of the *Z* site. Several examples are used to illustrate the application of this procedure. R.A.H.

Burmese jade: the inscrutable gem.

R.W. Hughes, O. Galibert, G. Bosshart, F. Ward, T. Oo, M. Smith, Tay Thye Sun and G.E. Harlow. *Gems & Gemology*, **36**(1), 2000, 2-26.

Jade (primarily nephrite) has been prized in China for thousands of years, but the finest jade - jadeite - has been part of Chinese culture only since the late 18th century, when the mines in north-central Myanmar were opened. The authors were the first Western gemmologists to visit the remote jadeite mining area in the Hpakan/Tawmaw region and provide graphic descriptions of tens of thousands of miners working the river boulders, Uru conglomerate and *in situ* deposits, where jadeite dykes intrude serpentinized peridotite. Colour, clarity, transparency and texture are the key considerations in evaluating fine jadeite. The finest Imperial jadeite is a rich 'emerald' green colour and is highly translucent to semi-transparent with a good lustre. R.A.H.

Gem news.

M.L. Johnson, J.I. Koivula, S.F. McClure and D. DeGhionno (eds). *Gems & Gemology*, **36**(1), 2000, 66-78.

In a report on the Tucson 2000 show, descriptions are given of cabochons of 'Siberian blue nephrite' (also called 'Dianite' in Russia); EPMA showed this to be a submicroscopic mixture of quartz, tremolite and the blue amphibole potassian magnesio-arfvedsonite, nearly all the Fe is in the ferric state and the blue colour is attributed to Fe^{2+}–Fe^{3+} charge transfer. New commercial emerald deposits are reported from La Pita and Polveros, Colombia, and examples are shown of faceted ruby from Chimwadzulu Hill, in S. Malawi, and of a cabochon of tugtupite from Greenland. R.A.H.

Les grenats du Millénaire.

T. LIND. *Revue de gemmologie*, 138/139, 1999, 45-9. Illus. in colour.

Update of the garnet gemstones with notes on recent discoveries. M.O'D.

Ruby mineralization in southwest Madagascar.

A. MERCIER, M. RAKOTONDRAZAFY and B. RAVOLOMIANDRINARIVO. *Gondwana Research*, **2**(3), 1999, 433-8.

The primary ruby deposits in the Ejeda-Fotadrevo area in SW Madagascar are closely associated with basic/ultrabasic complexes within the high-grade metamorphic terrain of the Precambrian Vohibory unit. Ruby is recovered from amphibolite and anorthosite veins within these complexes. Petrographical data and *P-T* estimates indicate that the ruby-bearing rocks crystallized under granulite-facies conditions of 750–850°C and 9-11.5 kbar. These Malagasy ruby deposits present many similarities with those of East Africa, particularly Tanzania, indicating a similar geological context and suggesting that ruby formation in both these areas resulted from the same mineralizing event when Madagascar was still adjacent to East Africa in the Gondwanaland assembly at the end of the Proterozoic. R.A.H.

L'état actuel de la commercialisation des émeraudes.

J.-C. MICHELOU. *Revue de gemmologie*, 138/139, 1999, 10-14. Illus. in colour.

Overview of the colour enhancement of emerald by various methods and of the disclosure vocabulary proposed to and by the gemstone trade. M.O'D.

Gem Trade Lab notes.

T. MOSES, I. REINITZ AND S.F. MCCLURE (eds). *Gems & Gemology*, **36**(1), 2000, 60-65.

Notes are given on a 0.79 ct dark blue emerald-cut dumortierite from Sri Lanka, and a 12 cm statuette of pink hydrogrossular (*n* 1.71). R.A.H.

A propos de l'opale australienne.

F. PAYETTE. *Revue de gemmologie*, 138/139, 1999, 67-71. Illus. in colour.

Description of some Australian opal locations with notes on geology and mining. M.O'D.

La tourmaline.

E. PETSCH. *Revue de gemmologie*, 138/139, 1999, 41-4. Illus. in colour.

General survey of tourmaline with particular reference to Brazilian and Namibian deposits. M.O'D.

Purple to purplish-red chromium-bearing taaffeites.

K. SCHMETZER, L. KIEFERT AND H.-J. BERNHARDT. *Gems & Gemology*, **36**(1), 2000, 50-9.

Gemmological, chemical and spectroscopic properties are provided for eight purple to purplish-red Cr- and Fe-bearing taaffeites all believed to be from Sri Lanka, together with two greyish-violet Fe-bearing but Cr-free samples. These extremely rare purple taaffeites have $Cr_2O_3 \leq 0.33$, Fe_2O_3 2.59 and ZnO 2.24 wt. %. Other features include apatite and zircon inclusions, and healed fractures consisting of negative crystals with multiphase fillings that contain magnesite. R.A.H.

Fluid inclusion characteristics of sapphires from Thailand.

B. SRITHAI and A.H. RANKIN. *Mineral Deposits: Processes to Processing*, 1999, 107-11.

Three main types of fluid inclusion occur in Bo Ploi sapphires: (1) vapour-rich CO_2 with $D \leq 0.86$ g/cm^3, (2) multiphase inclusions with several daughter minerals, hypersaline brine and a CO_2-rich vapour phase, and (3) (silicate ?)-melt inclusions with immobile vapour bubbles in an isotropic/weakly anisotropic phase of low relief. The bubbles move when heated to > 800°C. These results suggest magmatic sources for these sapphires. R.A.H.

Instruments and Techniques

Raman spectroscopic study of 15 gem minerals.

E. HUANG. *Journal of the Geological Society of China (Taiwan)*, **42**(2), 1999, 301-18.

The Raman active modes of each of 15 gem minerals have been collected in the low-wavenumber (150–1500 cm^{-1}) and high-wavenumber (2800–3800 cm^{-1}) regions. Typical Raman spectra are presented for beryl, chrysoberyl, corundum, diamond, grossular, jadeite, kyanite, nephrite, olivine, quartz, spinel, tourmaline, zircon and tanzanite. A flow chart is suggested to assist in the verification of these minerals from their characteristic Raman modes. M.O'D.

A warning: beware of 1.815 refractometer contact fluid.

T. LINTON. *Australian Gemmologist*, **20**(9), 2000, 373.

A warning is given that a refractometer contact fluid, which is claimed to have an RI of 1.815 and which has become available via the internet from an obscure source, is in fact toxic and potentially dangerous. The viscous and very dark liquid has an odour similar to that of acetic acid, and severely etches the surface of standard glass refractometer prisms after only a few minutes' contact. Inhalation of fumes from the fluid rapidly causes headaches and nausea. It is surmised that the liquid could possibly be a solution of sulphur in arsenic tribromide, and gemmologists are advised not to use any unbranded and unlabelled refractometer contact fluids that display these characteristics. P.G.R.

D-limonene: a useful immersion liquid for gemmology.

T. LINTON. *Australian Gemmologist*, **20**(9), 2000, 386-7, 3 colour illus.

Historically, immersion liquids used by gemmologists to estimate refractive indices and reduce surface reflections have included a range of colourless to near colourless liquids of known RI. Over recent years, the search for a new chemically stable and relatively non-toxic liquid for immersion purposes has indicated that d-limonene, a synthetic citrus fruit oil, may be suitable. D-limonene (or 4-isopropenyl-1-methylcyclohexene) is a clear slightly oily pale yellowish liquid with an SG of 0.838-0.843 and an RI of 1.47. It is virtually insoluble in water, but readily soluble in common organic solvents including methyl alcohol (methylated spirits). It is recommended that d-limonene is employed where user sensitivity or the potential toxic-carcinogenic qualities of commonly used immersion liquids prevent their safe application in gem testing. P.G.R.

Diamond Proover II

T. LINTON, A. CUMMING AND K. HUNTER. (GAA Instrument Evaluation Report.) *Australian Gemmologist*, **20**(9), 2000, 367-9, 1 illus. in black-and-white.

The new Diamond Proover II tested by the GAA's Instrument Evaluation Committee uses both thermal conductance and reflectance techniques to discriminate between diamond and its simulants (including synthetic moissanite). When the built-in thermal conductance probe is in use, the appropriate display 'Diamond/Moissanite, Cubic zirconia' or 'Others' will appear (if the probe touches the metal of a mounted stone, 'Metal' will be displayed). In its reflectance mode, the test unit is programmed to display either a limited range of appropriate diamond simulant names, or 'Others' to cover stones outside this range. However, a warning is given in the Committee's report that the Diamond Proover may give a 'Diamond' reflectance readout with a synthetic moissanite which has been heat treated to lower its RI to the region of diamond's 2.417 (although such a stone was heated by the Evaluation Committee to 1300°C for thirty minutes, this did not appear to reduce the reflectivity of the synthetic moissanite). The Committee also reported that when testing small mounted stones for thermal conductance, the sensitivity of the unit was insufficient to change the display reading from 'Diamond/Moissanite' to 'Metal', and suggested that a metal contact plate with supporting electronics (as incorporated in other thermal conductance probes) could be added. P.G.R.

Elements pratiques de recherche du traitement des émeraudes par analyse spectrométrique infrarouge.

P. MAITRALLET. *Revue de gemmologie*, 138/139, 1999, 15-17. Illus. in colour.

The use of infrared techniques to detect filling matter in emeralds is discussed: graphs and a table are given. M.O'D.

A preliminary investigation of precious opal by laser Raman spectroscopy.

A. SMALLWOOD. *Australian Gemmologist*, **20**(9), 2000, 363-6, 7 graphs, 1 table.

This account of an investigation of precious opal provides an introduction to the use of Raman spectroscopy as a non-destructive identification technique. Raman spectra are obtained by irradiating the sample with an intense monochromatic light (usually laser generated) and then examining the resulting characteristic wavelengths scattered by the sample's molecular structure. The Raman scattered wavelengths are detected, computer analysed and recorded as a graph whose pattern of peaks characterize the molecular structure of the material being examined. In this preliminary investigation a group of selected natural, synthetic and imitation opals were examined using Raman spectroscopy. By attaching a confocal optical microscope to the Raman spectroscope, very small sample areas can be analysed, and this arrangement was used to identify specimens of sedimentary and volcanic opal from various sources in Australia, Mexico and the USA, and to discriminate between them and the types of synthetic and imitation opals used in the manufacture of composite stones. P.G.R.

Synthetics and Simulants

Diamond formation by thermal activation of graphite.

A.V. PALNICHENKO, A.M. JONES, J.-C. CHARLIER, A.S. ARONIN AND J.-P. ISSI. *Nature*, **402**(6758), 1999, 162-5.

The production of high-purity cubic diamond particles (10-100 μm) formed in a highly concentrated, dense C-vapour phase, and followed by deposition of crystal on the substrate, is reported. The C vapour phase was generated by thermal activation of graphite using a short, intense heat pulse. The initial growth rates of diamond (100-500 μm/sec) are ≥ two orders of magnitude higher than previously reported. R.K.H.

Pearl Museum. Human involvement with pearls through the ages

Mikimoto Pearl Island, 1998. Mikimoto Pearl Island, Toba-City, Japan. pp 64, illus. in colour. Price on application.

This is more than a guide to the Pearl Museum on Mikimoto Pearl Island. It is a well-illustrated and informative little book. Starting with the history of pearls through the ages from Roman times until the appearance of the cultured pearl, it then covers Mikimoto's role in the industry and in jewellery. This is followed by descriptions of different pearl types, their structures and the culturing process used in Japan. Little mention is made of pearls from other countries, but the photographs are excellent, the diagrams clear and the text is simple and concise. A very pleasing and high quality publication.

M.C.P.

Jewellery reference and price guide. 2nd revised edn.

M. POYNDER, 2000. Antique Collectors' Club, Woodbridge. pp 359, illus. in colour. Hardcover ISBN 1 85149 309 3. £35.00.

In a welcome re-appearance of a book first published in 1976, prices have been revised and incorporated by Michèle Rowan. As in the previous printings, the text is arranged by periods, types and styles after a short introduction to the major gem species. All items illustrated are described and priced and there is a bibliography and a short glossary. As might be expected with so large a text, there are a few errors and perhaps the backgrounds used for some of the photographs add unwanted colour to colourless stones (especially diamonds) but when the amount of information given is considered the usefulness of the book is not impaired.

M.O'D.

Precious gems; jewellery from eight centuries

Catalogue of an exhibition shown at the Nationalmuseum, Stockholm, 9 June to 15 October 2000 (reviewed in *Gem & Jewellery News*, 2000, 9, 4). The Museum, Stockholm, 2000. pp 239, illus. in colour. Hardcover ISBN 91 7100 619 2. £40.00.

This is a beautifully-produced catalogue which covers medieval to 1930s' jewellery and accompanies an exhibition which opened in Stockholm in June 2000. Many of the pieces shown and described come from Royal collections in Sweden and England; full captions to the photographs, details of the pieces and their provenance and citations to other publications and exhibitions are now *de rigueur* for a book of this kind and this example meets all possible criteria of this sort. To cover eight centuries of any of the decorative arts is a formidable task: the writers of the seven chapters into which the introduction is divided are well chosen. Göran Tegnér writes on medieval monarchs (from mark of favour to royal emblem): Diana Scarisbrick on the jewellery of Mme Pompadour: Magdalene Ribbing on pearls: Brigitte Marquardt on jewellery of the 19th century in mid-Europe: Fritz Falk on Art Nouveau jewellery as art and Derek E. Ostergard on the radiance of perfection (Parisian jewellery between the world wars). There is a bibliography of 68 entries and a comprehensive index. It would be good to see the exhibition as a whole in London.

M.O'D.

BOOK SHELF – NEW TITLES

Jewellery reference and price guide by **M. Poynder** £35.00

Tiffany jewels by **John Loring** £38.00

Rough diamonds: A practical guide by **Nizam Peters** £65.00

Earrings from antiquity to the present by **Daniela Mascetti & Amanda Triossi** £19.95

Gold and platinum jewelry buying guide by **Renée Newman** £12.95

(Prices exclude postage and packing)

Gemmological Instruments Limited,
27 Greville Street,
London EC1N 8TN.
Tel: 020-7404 3334
Fax: 020-7404 8843

Proceedings of the Gemmological Association and Gem Testing Laboratory of Great Britain and Notices

OBITUARY

Charles J. Beraet (D.1931 with Distinction), Harrow, Middlesex, died peacefully on 22 January 2000 aged 91. Mr Beraet's career in the retail jewellery trade spanned almost 60 years, his last position being with Dibdins in Sloane Street where he had worked until his retirement at the age of 81.

Donald R. Cartwright (D.1975), Little Bookham, Surrey, died on 11 June 2000. An engineering consultant, he had worked with W.S. Atkins, Epsom, and was associated with the Guildford Gem, Mineral and Lapidary Club.

Mr Alan Rowlands (D.1991), Calgary, Alberta, Canada, died recently.

Mr Ishiwatari Tamotsu (D.1982), Tokorozawa City, Saitma Pref., Japan, died recently.

MEMBERS' MEETINGS

London

On 12 July at the Gem Tutorial Centre, 27 Greville Street, London EC1N 8TN, Roger Young gave a talk entitled *Faceting revolution*.

On 26 July at the Gem Tutorial Centre, Robert Weldon, Director of Photography and Senior Writer for the *Professional Jeweler* based in Philadelphia, USA, gave an illustrated lecture on *Gemstone photography with a 35 mm camera*.

On 13 September at the Gem Tutorial Centre, Dr Judith Kinnaird gave an illustrated lecture entitled *From geology to jewellery - the platinum millennium*.

Midlands Branch

On 24 June the Midlands' Branch annual summer supper was held at Barnt Green.

North West Branch

On 20 September at Church House, Hanover Street, Liverpool 1, Peter McIvor spoke on *The history of English watches from verge to lever*.

Scottish Branch

On 5 September at the British Geological Survey, Murchison House, West Mains Road, Edinburgh, Roy Huddlestone gave a talk on *The History of diamond grading*.

ANNUAL GENERAL MEETING

The Annual General Meeting of the GAGTL was held on Monday 26 June 2000 at 27 Greville Street, London EC1N 8TN. Michael O'Donoghue chaired the meeting and welcomed those present. The Annual Report and Accounts were approved and signed.

The Council had nominated Professor Alan Collins for the office of President for the term 2000-2002 and the nomination was unanimously carried. Alan Collins is Professor of Physics at King's College London. His main research interest lies in the optical properties of diamond and he has published more than 170 papers on the subject. In addition to a six-month spell at the De Beers Diamond Research Laboratory, Johannesburg, over the last 12 years he has given 33 invited lectures at international meetings. He is an Associate Editor of *The Journal of Gemmology* and of *Diamond and Related Materials*, and is on the Review Board of *Gems & Gemology*. Alan Collins thanked the outgoing President, Professor Howie, for generous support and commitment to the GAGTL during his four years as President.

Professor Robert A. Howie was elected a Vice-President of the Association. Dr Roger Harding and Vivian Watson were re-elected to the Council of Management. Colin Winter was re-elected to the Members' Council; Richard Shepherd did not seek re-election to the Members' Council. Hazlems Fenton were re-appointed Auditors.

Responding to a question from the floor, Dr Roger Harding stated that, as a result of the loss made in 1999, efforts were being made to reduce

GIFTS TO THE ASSOCIATION

The Association is most grateful to the following for their gifts for research and teaching purposes:

Dennis Durham, Kingston upon Hull, East Yorkshire, for a prism spectroscope with a wavelength scale and mirror attachment.

Peter Dwyer-Hickey, South Croydon, Surrey, for an imitation tortoiseshell box.

John R. Führbach, Amarillo, Texas, U.S.A., for rough samples of peridot, oligoclase, amethyst and augite.

Marc Jobin, Buckhurst Hill, Essex, for a rough specimen of orthoclase from Madagascar.

Janice Kalischer, Finchley, London, for a ring set with four garnet-topped-doublets and a pearl.

The Midlands Branch of the GAGTL for a cash donation of £775.00.

W. Nagel, London, for a GIA Synthetic Diamond wallchart.

Bernard D. Shindler, Stanmore, Middlesex, for two Shindler Scales.

Peggy Smithers, London, for faceting equipment, and tumbling and grinding machines, bequeathed by her late husband.

Ian Thomson, Thomson (Gems) Ltd, London, for 13 chipped diamonds.

Pierre Vuillet, Villards d'Heria, France, for a 2. 95 ct langasite, a yellow-green synthetic stone.

Vivian Watson of P.J. Watson Ltd., London, for a display case.

costs in the current year and three redundancies had been made. Income was slightly above that for the same period in 1999 and it was hoped that by the end of the year some benefit would be felt.

Following the Annual General Meeting, a Reunion of Members and Bring and Buy Sale were held. The winners of the 2000 Photographic Competition were announced and entries displayed.

GEM DIAMOND EXAMINATIONS

In June 2000, 105 candidates sat the Gem Diamond Examination, 85 of whom qualified, including 11 with Distinction. The **Bruton Medal** for the candidate who submitted the best set of answers in the Gem Diamond Examinations of 2000 which, in the opinion of the Examiners, are of sufficiently high standard, was awarded to Neil Rose of Wetherby, North Yorkshire. The names of the successful candidates are listed below:

Qualified with Distinction

Dower, Dan G., London
Forbes, Victoria E., Portadown, Co. Armagh, Northern Ireland
Haden, Claire L., Halesowen, Birmingham, West Midlands
Harrison, Tarn J., Leamington Spa, Warwickshire
Hue Williams, Sarah, London
Isacsson, Johanna, Stockholm, Sweden
Qingliang Yang, Wuhan, Hubei, P.R. China
Rythen, L.A. Carolina, Stockholm, Sweden
Wu Weizheng, Beijing, P.R. China
Yan Xuejun, Wuhan, Hubei, P.R. China
Young, Geoff W., Surbiton, Surrey

Qualified

Antoniadis, Antonis, Rhodes, Greece
Axarlian, Sergio, Piraeus, Greece
Barker, Nicola, Tunbridge, Kent
Bicknell, Tim, London
Bolissian, Inge Sahr, Bow, London
Boustany, Denise M., St Johns, Antigua
Brady, John J., Swadlincote, Derbyshire
Chan Har Wei Carrio, Kowloon, Hong Kong
Cheng Youdi, Beidajie, Beijing, P.R. China
Christoulakis, Theodore, Athens, Greece
Damalis, George H., Winchmore Hill, London
Davenport, N. Tristan, Oxford
Ding Weijing, Beidajie, Beijing, P.R. China
Fadlun, Lucy R., Hendon, London
Fukui, Eriko, Tokyo, Japan
Garcia Oliver, Eugenia, London
Giurgiu, Anda, Wanstead, London
Hairong Ye, Wuhan, Hubei, P.R. China
Harrison, Helen Tynan, Yellowknife, North West Territories, Canada
Hill, Stephen E., Croxley Green, Rickmansworth, Hertfordshire
Ho Ka Kit, Frankie, Kowloon, Hong Kong
Hua Deng, Wuhan, Hubei, P.R. China
Jian Weng, Wuhan, Hubei, P.R. China
Jin Wu, Wuhan, Hubei, P.R. China
Jingyu Tu, Wuhan, Hubei, P.R. China
Jones, Adrian M., Harrow, Middlesex
Jue Peng, Wuhan, Hubei, P.R. China
Kaprili, Maria, Athens, Greece

FORTHCOMING EVENTS

GAGTL ANNUAL CONFERENCE

Sunday 29 October - Barbican Conference Centre, London

Keynote speaker: Professor Al Levinson, Calgary, Alberta, Canada
Diamonds in Canada - Geology to Gemmology

Paul Spear, DTC Research Centre, Maidenhead
Synthetic and treated diamonds

Dr Judith Kinnaird, University of Witwatersrand, South Africa
The sparkle in Somaliland

Robert Fawcett, The Cultured Pearl Company Ltd.
The cultured pearl trade today

Harry Levy, President of the CIBJO Diamond Commission
What's in a name?

VISITS
Visits to **De Beers** (Friday 27 October) and guided tours of the **Gilbert Collection at Somerset House** (Monday 30 October) available as optional extras to Conference delegates.

Full details and application forms available from the GAGTL on 020 7404 3334

27 October	**Midlands Branch**. *The works of Peter Carl Fabergé.* ***Stephen Dale***
30 October	**London**. Presentation of Awards
31 October	**Scottish Branch**. *Diamonds in Canada - geology to gemmology.* ***Professor Al Levinson***
15 November	**North West Branch**. *AGM* followed by *Gem collection and anecdotes.* ***John Pyke Snr***
17 November	**London**. *A new process to modify colour of natural (and synthetic) diamonds.* ***Greg Sherman and Branko Deljanin***
23 November	**London**. *Amber - has the bubble burst?* ***Helen Fraquet***
24 November	**Midlands Branch**. *The minerals of Pakistan.* ***Michael O'Donoghue***
2 December	**Midlands Branch**. Annual Branch Dinner
2001	
26 January	**Midlands Branch**. Gemmology Quiz and Bring and Buy
23 February	**Midlands Branch**. *What's new in gemmology?* ***Alan Hodgkinson***
30 March	**Midlands Branch**. *The Toyshop of Europe.* ***Shena Mason***

For further information on the above events contact:

London	Mary Burland on 020 7404 3334
Midlands Branch:	Gwyn Green on 0121 445 5359
North West Branch:	Deanna Brady on 0151 648 4266
Scottish Branch:	Catriona McInnes on 0131 667 2199

Kunvovsky, Martin R., Cardiff, S. Glamorgan
Lao Ieng Kit, Hong Kong
Latsoudis, Sofia, Heraklion, Crete, Greece
Lau Lai Fong, Kowloon, Hong Kong
Lazaridis, Lazarus, London
Lee Hing Fan, Kowloon, Hong Kong
Lee King Fan, Kowloon, Hong Kong
Li Ding, Wuhan, Hubei, P.R. China
Li Chong, Beidajie, Beijing, P.R. China
Liang Wang, Wuhan, Hubei, P.R. China
Lindsay, Tony P., Maidstone, Kent
Liu Yongchao, Beidajie, Beijing, P.R. China
Long Sin Sai, Kowloon, Hong Kong
McCormick, Michelle, Stourport-on-Severn, Worcestershire
Makri, Eleni, Thessaloniki, Greece
Ng Mei Hang, Kowloon, Hong Kong
O'Neill, Michelle, Northfield, Birmingham, West Midlands
Panidis, Lydia, Elefsina, Greece
Petropoulos, Andreas, Athens, Greece
Pollatos, Evonne-Eftyhia, London
Ratiu, Alexandra, London
Roche, Patrick, Hackney, London
Rongjun Cui, Wuhan, Hubei, P.R. China
Rutter, Fay, Walsall, West Midlands
Seitanidis, Nikolaos, Kterini, Greece
Shen Feng, Beidajie, Beijing, P.R. China
Shi Wei, Beidajie, Beijing, P.R. China
Stamatakis, Zoe, Athens, Greece
Stubbs, Annaliese J.C., London
Tai Wai Yee, Hong Kong
Thompson, Mary T., Offerton, Stockport, Cheshire
Tong Tat Wah, Kowloon, Hong Kong
Tsuen Sin Charn, Hong Kong
Waghela, Sunita, London
Ward, Julie E., Upper Belvedere, Kent
Waterfall, Mary C., Tooting, London
Williams, Lorraine A., London
Xiaogang He, Wuhan, Hubei, P.R. China
Xinhai Yu, Wuhan, Hubei, P.R. China
Yang Yuan Yuan, Beidajie, Beijing, P.R. China
Ying Lu, Wuhan, Hubei, P.R. China
Ying Zhou, Wuhan, Hubei, P.R. China
Yue, Louisa, Kew, Richmond, Surrey
Zagana, Aphrodite, Athens, Greece
Zhang Xiaohu, Beidajie, Beijing, P.R. China
Zhiquang Liu, Wuhan, Hubei, P.R. China

EXAMINATIONS IN GEMMOLOGY

In the Examinations in Gemmology held worldwide in June 2000, 145 candidates sat the Preliminary Examination of whom 117 qualified. In the Diploma Examination 231 sat of whom 100 qualified.

The **Anderson Bank Prize** for the best non-trade candidate of the year in the Diploma Examination was awarded to Louise Joyner of London.

The **Diploma Trade Prize** for the best candidate of the year who derives her main income from activities essentially connected with the jewellery trade was awarded to Mina Shin of Seoul, Korea.

The **Anderson Medal** for the best candidate of the year in the Preliminary Examination and the **Preliminary Trade Prize** for the best candidate of the year who derives her main income from activities essentially connected with the jewellery trade were awarded to Helen Dimmick of London.

The Tully Medal was not awarded.

Diploma

Qualified

Abdulrazzaq, Anwar A.H., Muharraq, Bahrain
Al-Alawi, Abeer T., Manama, Bahrain
Anderson, Meredith, Chertsey, Surrey
Ascot, Leon, Urdorf, Switzerland
Ayukawa, Yasuyo, London
Berner, Peter, Gelterkinden, Switzerland
Berry, Shoshana, Salisbury, Wiltshire
Blachier, Helene M.A., Ponsonnas, France
Blomquist, Eva, Jonkoping, Sweden
Bruce-Lockhart, Simon D., London
Cai Shimei, Guilin, Guangxi, P.R. China
Checkley, Emma L., Warley, Birmingham, West Midlands
Chen Hsi Hung, Taichung, Taiwan, R.O. China
Chen Jijuan, Guilin, Guangxi, P.R. China
Chen Peijia, Guilin, Guangxi, P.R. China
Chen Qing Ye, Singapore
Chiu Hsiao Hui, Taichung, Taiwan, R.O.China
Chokshi, Shivang R., Ahmedabad, Gujarat, India
Chow Suet Lai, New Territories, Hong Kong
Cooke, Caroline M., St Margarets, Middlesex
Cropp, Alastair, Brookmans Park, Hertfordshire
Cubbins, Graham, Blackpool, Lancashire
de Landmeter, Edward, Aagtekerke, The Netherlands
Dolomidou-Panoutsopoulou, Georgia, Athens, Greece
Donnelly, Lee-ona F., Ayr, Scotland
Dowling, Siobhan L., London
Droesser, Niklas, Leverkysen, Germany
Fang Liang, Guilin, Guangxi, P.R. China
Faustmann, Alexandra, Quezon City, Philippines
Fok Ki Yu, Lantau Island, Hong Kong
Gravier, Denis, Saint Jean le Vieux, France
Greslin-Michel, Valerie, London
He Jiamu, Guilin, Guangxi, P.R. China

GAGTL GEM TUTORIAL CENTRE, LONDON

SHORT COURSES AND WORKSHOPS

COLOURED STONE UPDATE **Tuesday 24 October**

The treatments, the simulants, the synthetics

Are you aware of the various treated and synthetic materials that are likely to be masquerading amongst the stones you are buying and selling? Whether you are valuing, repairing or dealing, can you afford to miss this day of hands on investigation? This course will cover ruby, sapphire and emerald, as well as other stones including chrysoberyl, opal, jade and tanzanite.

GAGTL member price £99 + VAT (£116.33) **Non-member price £110 + VAT (£129.25)**

DIAMOND - PAST, PRESENT, FUTURE **Tuesday 31 October**

A valuable day of in-depth investigation of diamonds, their treatments, simulants and synthetics. What factors have affected the manufacture of this most prized gemstone in the past and what are the factors which will become more and more of a concern in the future? Includes a presentation by De Beers on how they are facing challenges head on.

GAGTL member price £114.90 + VAT (£135.00) **Non-member price £127.66 + VAT (£150.00)**

SKETCHING FOR SALES **Wednesday 1 November**

This introduction to drawing aims to show participants how to turn an idea into a sketch. The session begins with line drawing and during the day will work towards achieving perspective and shading in jewellery. Anyone can learn to draw. Gain the confidence to put your ideas on paper.

GAGTL member price £66 + VAT (£77.55) **Non-member price £76 + VAT (£89.30)**

TWO-DAY STONE FACETING WORKSHOP **Saturday and Sunday, 4 and 5 November**

Ever wanted to try faceting? This two-day hands-on workshop will enable you to walk away with a stone you have cut yourself! A faceting machine for each participant and expert advice from cutters Roger Young and Jim Finlayson, will ensure that the workshop is both productive and enjoyable for everyone. This faceting weekend is a delight and not to be missed.

Price £175 + VAT (£205.63)

SKETCH II **Wednesday 22 November**

This one-day workshop aims to build on the basic ground-work of perspective, shading and use of colour so that participants can apply these skills to their own design ideas. Areas covered will include effective use of colour, getting the most out of your chosen medium, presentation drawings, and troubleshooting any areas of difficulty on a one-to-one basis.

GAGTL member price £66 + VAT (£77.55) **Non-member price £76 + VAT (£89.30)**

STUDENT WORKSHOPS 2001

Weekend diamond Grading Revision	Saturday and Sunday, 6 and 7 January
Two-day Diploma Practical Workshop	Saturday and Sunday, 6 and 7 January

For further details and a booking form contact Shelley Keating at the GAGTL on 020 7404 3334.

Ho, Anna, New Territories, Hong Kong
Ho Sau Lan, Hong Kong
Ho Sau Wa, Hong Kong
Ho Siu Kei, Paulie, Kowloon, Hong Kong
Holdsworth, Christopher J., Armadale, Victoria, Australia
Hugo, Philippe A.M., Kortrijk, Belgium
Hung Tin Man, New Territories, Hong Kong
Hynes, Lola, Dun Laoghaire, Co. Dublin, Ireland
Ito, Eiko, New Southgate, London
Jo, Midori, Haginodai, Ikoma Shi Nara, Japan
Jung Shin Kim, South Croydon, Surrey
Ladak, Nelina, London
Lamarre, Claude, Lasalle, Quebec, Canada
Lei Shi, Wuhan, Hubei, P.R. China
Li, Mary W.Y., Vancouver, British Columbia, Canada
Lichtsteiner, Patrick, Ormalingen, Switzerland
Limei Kong, Wuhan, Hubei, P.R. China
Lin Yeong Leh, Taipei, Taiwan, R.O. China
Linjun Fu, Wuhan, Hubei, P.R. China
Lo Hung Kin, Kowloon, Hong Kong
Loe She-Mon, Taipei, Taiwan, R.O. China
Long Changzheng, Guilin, Guangxi, P.R. China
Loxton, Sam C., Herne Hill, London
Ma Rui, Guilin, Guangxi, P.R. China
Mason, Stephen R., Sutton Coldfield, Birmingham, West Milands
Matheson, Eric R., Vancouver, British Columbia, Canada
Maulave, Xavier R.L., Yangon, Myanmar
Ndirangu, Joseph K., Nairobi, Kenya
Ng, Bianca Suen Lam, Hong Kong
Oksanen, Tarja, Helsinki, Finland
Pagan, Sabine, Berne, Switzerland
Pajor, Matthias V., Gelterkinden, Switzerland
Price, Sharron A., Rowley Regis, Warley, West Midlands
Qi Chen, Wuhan, Hubei, P.R. China
Rathwell, Eden L., San Francisco, California, U.S.A.
Roberts, Jennifer L., York
Rockman, Gary, Bromley, Kent
Roelofs, Esther W., Schoonhoven, The Netherlands
Saikyo, Kunihiro, Hirakata City, Osaka, Japan
Sheppard, Gary R., Kilbirnie, Wellington, New Zealand
Shi Kai, Guilin, Guangxi, P.R. China
Shin Hyun-Sook, Daejon, Korea
Shirasaki, Tadahiro, Fukui City, Fukui Pref., Japan
Smith, Wendy, London
Solomou, Andreas, Nicosia, Cyprus
Song Xiaohua, Guilin, Guangxi, P.R. China
Su Nan, Guilin, Guangxi, P.R. China
Telfer, Corin, Rickmansworth, Hertfordshire
Terrell, Celia J.W., Atherstone, Warwickshire
Thompson, Mary T., Offerton, Stockport, Cheshire
To, Flora L.H., Kowloon, Hong Kong
To Kwan, Causeway Bay, Hong Kong
Tuckwell, Alice E., Newcastle-under-Lyme, Staffordshire
Uhlin, Christophe R., Leytonstone, London
Verhoeven, P.M.C., Nijmegen, The Netherlands
Williams, Johanna, London
Williams, Lorraine A., London
Winter, Nikki, Herne Hill, London
Wong, Rebecca Lai King, Scarborough, Ontario, Canada
Wu Sung-Mao, Taichung, Taiwan, R.O. China
Xiusong Ding, Wuhan, Hubei, P.R. China
Xu Minyan, Guilin, Guangxi, P.R. China
Yihua Wu, Wuhan, Hubei, P.R. China
Yiren Wang, Wuhan, Hubei, P.R. China
Yorke, Anabel, London
Zhenhong Wu, Wuhan, Hubei, P.R. China
Zhu Yalin, Guilin, Guangxi, P.R. China

Preliminary

Qualified

Abeid, Ahmed, Southall, Middlesex
Amliwala, Panna, Solihull, West Midlands
Balzan, Darlene P., Mill Valley, California, U.S.A.
Bolter, Rachel L., Swindon, Wiltshire
Borruso, Alessandro, Harrow, Middlesex
Bourke, Mary B., Kilkenny, Ireland
Brunt, Emily F., Fivemiletown, Co. Tyrone, N. Ireland
Carter, Andrew, Crewe, Cheshire
Cedeno, Leonor, Sutton, Surrey
Chan Hin Tung, Tony, Hong Kong
Chan Kwong Chi, Hong Kong
Chater, Melanie D., Spratton, Northamptonshire
Cheung Yuet Diana, New Territories, Hong Kong
Christianos, Melina Z., Sydney, New South Wales, Australia
Clayton, Harriet B.E., Edinburgh, Scotland
Cohen, Vanessa, London
Collins, Madeline A., Preston, Lancashire
Cristol, Agata, Marseille, France
Cross, Alice, Warminster, Wiltshire
Cruse, Toby, Eastbourne, East Sussex
Dennis, Roger A., Elstree, Hertfordshire
Dimmick, Helen M., East Putney, London
Dorrell, Clare G., Perth, Scotland
Downes, Lisa E., Handsworth Wood, Birmingham, West Midlands
Eineljung, Lars E., Lannavaara, Sweden
Elliott, Caroline E., Ruislip, Middlesex
Evans, Sarah, Homerton, London
Farrer, Alison M., Stonehouse, Gloucestershire
Field, Karen M., Harborne, Birmingham, West Midlands

Fischer, Karin, Wettingen, Switzerland
Formosis, Dimitris, Athens, Greece
Gregory, Kerry H., Newport, Wales
Gregory, Pauline A., Bishop Auckland, Co. Durham
Griffiths, Victoria C., Cradley Heath, West Midlands
Groves, David A., Hall Green, Birmingham, West Midlands
Hamano, Yumi, West Hampstead, London
Heath, Daniel, Kilkenny, Ireland
Ho Pui Cheung Feony, Kowloon, Hong Kong
Hong Liu, Guilin, Guangxi, P.R. China
Horton, Sophie E., Sevenoaks, Kent
Hsieh Tien Heng, Taichung, Taiwan, R.O. China
Ingridsson, Anna-Lis, Lannavaara, Sweden
Jones, Lorraine D., Farnworth, Bolton, Lancashire
Kato, Ayumi, Nishinomiya City, Hyogo, Japan
Kim Yu-Mi, Kwangju, South Korea
Ko Ji Hea, Kwangjoo, South Korea
Kokkinoy, Anna, A. Glifada, Greece
Kuroda, Makiko, Hirakata City, Osaka, Japan
Kyaw Kyaw Soe, Tarmwe Township, Yangon, Myanmar
Lakshminarayan, S.S., Tamil Nadu, India
Lam Kwi-Peng, Singapore
Lam, Victoria L., Carnforth, Lancashire
Lamarre, Claude, Lasalle, Quebec, Canada
Langdale, Jason, Kowloon Tong, Hong Kong
Leake, Nigel P., Weddington, Nuneaton, Warwickshire
Lee, Helen, London
Lee Wai Kwok, Simon, Kowloon, Hong Kong
Lee Sui Kam, Monita, New Territories, Hong Kong
Leung Hung Wai, Hong Kong
Leung Wing Yee, Hong Kong
Li Xue Ming, Guilin, Guangxi, P.R. China
Li Ting-Ting, Shanghai, P.R. China
Li Yuan-Yuan, Shanghai, P.R. China
Llinares, Luis, Geneva, Switzerland
Lo Pak Sun, Kowloon, Hong Kong
Loukaides, Nicolas, P. Faliro, Greece
Love, Anne C., Glasgow, Scotland
Lowe, Mimi J., San Francisco, California, U.S.A.
Lui, Janice, Manchester
Ma Li Ke, Guilin, Guangxi, P.R. China
Mate, Nikhil S., Mumbai, India
Matsubara, Midori, Osaka City, Osaka, Japan
Mattsson, Simon, Lannavaara, Sweden
McDonagh, Robert, Cairns, Queensland, Australia
Mehta, Jeeta, Braunstone, Leicester, Leicestershire
Moe Moe Shwe Daw, Bahan Township, Yangon, Myanmar
Monney, Christelle V., Chambesy, Switzerland
Morrish, Rachel, Sutton Coldfield, West Midlands
Myo Thant, Pabedan Township, Yangon, Myanmar
Naing Saw, Ahlone TSP, Yangon, Myanmar
Naing Oo Naing, Kyauk Taga Town, Bago Div, Myanmar
Nakayama, Akira, Osaka City, Osaka, Japan
Nuna, Philippe, Montreal, Quebec, Canada
O'Connor, Anne M., Kilkenny, Ireland
Ou Yang Chung Meing, Taichung, Taiwan, R.O. China
Pace, Howard M., Ecceshall, Stafford, Staffordshire
Paraskevopoulos, Michael, Athens, Greece
Parnell, Alexander J., Finchley Central, London
Parr, Louise, Blackburn, Lancashire
Pol, Noelia, Florence, Italy
Ram, Satyen, Richmond, Surrey
Roussou, Zoi-Kiriaki, Athens, Greece
Salt, Sebastian J., Salisbury, Wiltshire
Sasaki, Takako, Hirakata City, Osaka, Japan
Shadbolt, Emma T., Crawley, West Sussex
Shin Whan-Ho, Taejon, R.O. Korea
Sipson, Ian, Trowbridge, Wiltshire
Symes, Evelyn R., Bath
Tang Wai Ling Ng, Elaine, Pinner, Middlesex
Teramae, Ikumi, Ealing, London
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An exhibition on the gems and gem industry of Sri Lanka is to be held from 14 to 16 December at the St Albans Centre, Baldwin's Garden, London EC1N 7AB, in the vicinity of Hatton Garden.

The main objective of the exhibition, as in previous years, is to give a wider publicity to Sri Lanka's gem industry in Europe.

All visitors will be given a chance to examine for themselves some typical Sri Lankan gemstones using many gem testing instruments. There will be five units which include geology, gem mining, gem cutting and polishing, gemstones and education. Over 30,000 gemstones will be displayed, including sapphires of many colours, many of the stones commonly found in Sri Lanka and some rare gemstones.

The entrance fee, which includes a free gemstone and a souvenir brochure, is £3.00 (children under 12 free of charge). To celebrate this first exhibition on the Sri Lankan gem industry to be held overseas in the new millennium, the organizers have donated up to £1000 worth of gems and jewellery.

For further information contact D.H. Ariyaratna on 020 8807 8252 (telephone and fax), e mail sri@lankagems.co.uk, website www.lankagems.co.uk

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ERRATUM

On p.158 above, first column, line 15, for (687 - 381) read (687 - 431)

Letters to the Editor

Maw-sit-sit from Myanmar

From Win Htein and Aye Myo Naing

We refer to the recent article by Colombo, Rinaudo and Trossarelli (2000).

Dr Gübelin (1965a, b) was the first author to describe the gemmological account of maw-sit-sit. In his article there is a coloured photograph showing five polished samples of maw-sit-sit. All his pieces reveal typical colours and patterns of maw-sit-sit which are described as:

'... while strolling around in Mogaung, watching the jade lapidaries and their curious implements (Fig. 1) [i.e. the above-mentioned photo], I noticed a few polished slabs and buttons of an unusual, very bright and pleasant green hue, nicely patterned by dark green to black spots and veins ... They appeared completely unlike any other green opaque gemstones that I had seen before ...'

The mineral composition and coloured photographs of a few maw-sit-sit samples were more recently given by Win Htein and Aye Myo Naing (1995). The proportions of the constituent minerals are greatly variable from one sample to another.

The colour, pattern and appearance in two coloured photographs (Figs 1a and 1b) of the sample studied by Colombo *et al.* (2000) do not look like a maw-sit-sit and also do not meet with Dr Gübelin's description. It is more similar to jade-like material, locally called 'palwan' or 'palun'. The so-called palwan also occurs in the jade mine areas of Myanmar and is mainly composed of albite, quartz and minor epidote with or without other minerals. Judging from the relatively low RI (1.54) and low SG (2.7) values and its dissimilar appearance from maw-sit-sit, the studied sample is more likely to be a palwan. It is probably a misnomer.

Dr Win Htein
Geology Department, Yangon University, Myanmar

Aye Myo Naing
Myanmar VES Joint Venture Co. Ltd, No. 66, Kaba Aye Pagoda Road, Yangon, Myanmar

Reply from C. Rinaudo

We are pleased to respond to the letter by Dr Win Htein and Ms Aye Myo Naing concerning the features of maw-sit-sit.

The remarks they make in their letter sound interesting. Unfortunately, in the articles we consulted, only hints could be found regarding the palwan stone, essentially quoted as a curiosity (*Gems & Gemology*, 1964-65, **11**(8), and *J.Gemm.*, 1995, **24**(5), the latter paper giving a list of the constituent minerals).

Our project started because we were attracted by the plaque and were induced to investigate it, since it really appeared like maw-sit-sit despite the seeming lack of the typical features of this stone, namely the spots and veins from very deep green to black in colour. This absence, hard to cope with, puzzled us from the beginning of the investigation. On the other hand, had these features been visible to the naked eye, the plaque could have been a subject for exchange of aesthetic opinions between its owner, Mr Scardina, and ourselves.

However, study under the polarising microscope revealed the texture typical of the constituent minerals of maw-sit-sit, and also enabled us to detect a (metallic-dark) spot of chromite; this combination induced us to name the plaque maw-sit-sit.

It was our omission not to produce a photograph of the area where the spot of Fig. 4 of our article is visible, taken at low magnification and with an illumination suitable to illustrate its dark appearance, typical of the maw-sit-sit spots reported by Gübelin (1965a, b).

Finally, from all the above, we wonder whether the palwan stone cannot be considered as a 'variety' of maw-sit-sit if the following is considered:

- the qualitative composition of the palwan stone reported by Win Htein and Aye Myo Naing is seemingly the same as maw-sit-sit with only the ratios of the constituents varying;
- the texture of our stone is identical, under the microscope, to that of maw-sit-sit;

- according to the above quoted authors, the inhabitants assign the name 'palwan' after the *macroscopic* appearance (visible to the naked eye) of the stone;
- the quantity of the constituents of maw-sit-sit is variable and apropos of this fact, we refer to Manson (1979) who stated that the composition is essentially natrolite + kosmochlor, implying variation in the constituents of maw-sit-sit. Therefore the stone studied by us might be considered as maw-sit-sit variety particularly poor in spots.

As for the disagreement between the specific gravity of the maw-sit-sit samples studied by Gübelin (1965) (SG = 2.77) and that of our stone (SG = 2.7), it has to be noted that Gübelin's figure gives an *average*. This allows the possibility that the value 2.7 may be close to the lowest value found by Gübelin. The lesser value found by us may be attributed to the lower content in chromite crystals (SG = 4.5-4.8) and kosmochlor (SG = 3.60, calc.). Similarly, our refractive index (1.54) coincides with the higher values found by Gübelin.

In conclusion, the aforesaid is not to say that our position is definite but is presented in a constructive way to advance the discussion about maw-sit-sit and jade.

We welcome the important observations in the letter by Dr Win Htein and Ms Aye Myo Naing and would be very interested to establish collaborative research with them.

Professor C. Rinaudo
Dipmartimento di Scienze e Tecnologie Avanzate, Università degli Studi del Piemonte Orientale, Corso Borsalino, 54, 15100 Alessandria, Italy

Colombo, F., Rinaudo, C., and Trossarelli, C., 2000. The mineral composition of maw-sit-sit from Myanmar. *J.Gemm.*, **27**(2), 87-92

Gübelin, E., 1965a. Maw-sit-sit - a new decorative gemstone from Burma. *J.Gemm.*, **9**(10), 329-44

Gübelin, E., 1965b. Maw-sit-sit proves to be jade-albite. *J.Gemm.*, **9**(11), 372-9

Manson, V., 1979. Recent activities in GIA's Research Department. *Gems & Gemology*, **16**(7), 217-19

Win Htein and Aye Myo Naing, 1995. Studies of kosmochlor, jadeite and associated minerals in jade of Myanmar. *J.Gemm.*, **24**(5), 315-20

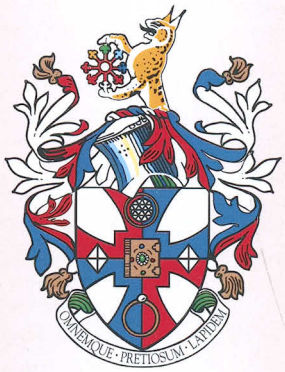

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The World 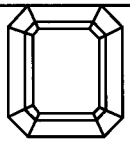 of Gemstones

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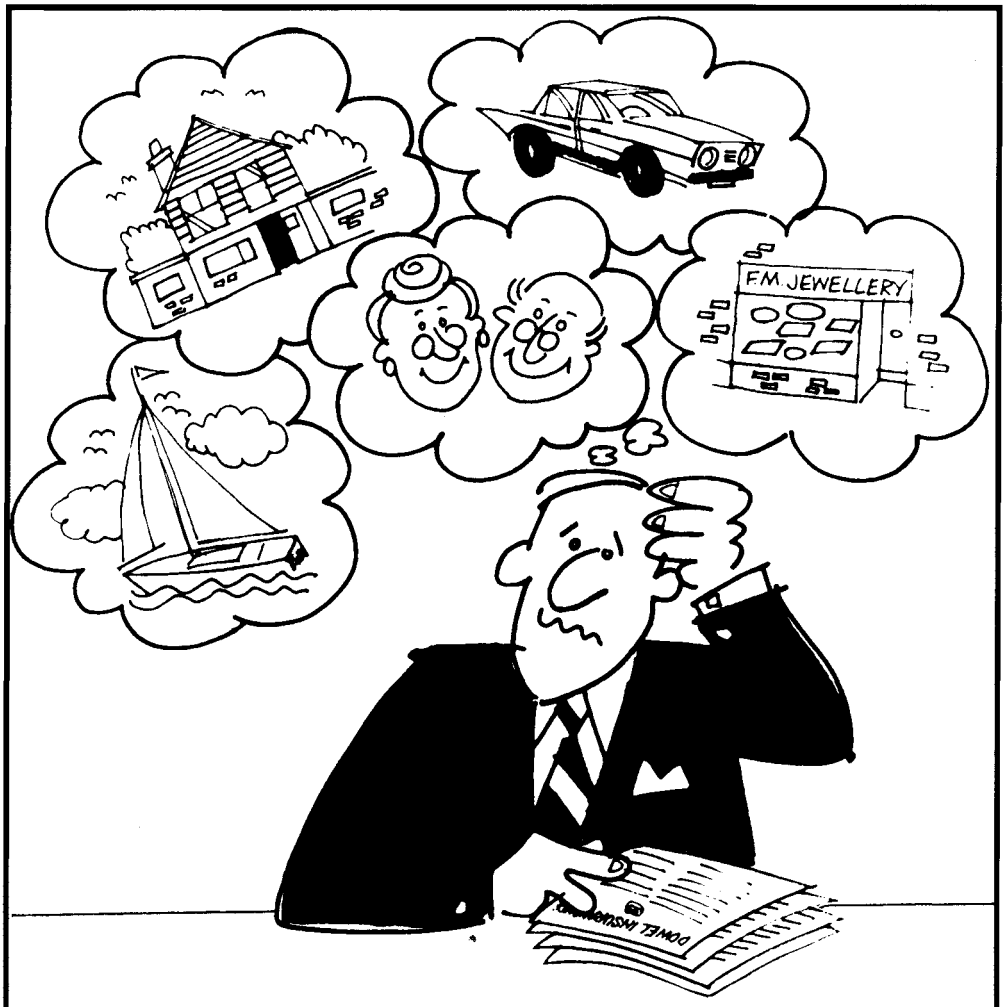

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Chalain *et al.*, 1999. Detection of GE POL diamonds: a first stage. *Revue de Gemmologie*, 138/139, 27-30

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Cover Picture

Lamella in purple spinel from Ilakaka, Madagascar, consisting of polycrystalline rutile.

Photomicrograph by K. Schmetzer

(see 'Oriented inclusions in spinels from Madagascar', pp.229-232)

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Santa Maria aquamarine

Francisco Bank[1], Professor Hermann Bank[1] and Elena Villa[2]
1. Gebruder Bank, Dietzenstrasse 1, D-55743 Idar-Oberstein 2, Germany
2. Die Villa, Bruckenstrasse 22, D-54290 Trier, Germany

ABSTRACT: A Santa Maria aquamarine is the inspiration for the design of a necklace. Details of the stone are given, as well as descriptions of the design and make-up of the necklace.

The aquamarine

Aquamarine of the highest quality and the finest blue has for many years been called 'Santa Maria' after such material was found at the small locality of Santa Maria in Minas Gerais, Brazil. Since there are so many places called Santa Maria in Brazil, it may have been better to have named the aquamarine after the nearby town, Itabira!

The story is told that in 1925 a mule had fallen down a hole and had broken a leg; the owner of the mule saw blue crystals in the hole and so discovered what came to be the most famous aquamarine locality in the world. For some years blue aquamarines have been mined in several 'lavras' (mines) in the region of Santa Maria, and were of such a good sky-blue colour (like the blue of tropical skies) that after 75 years people still dream today of the super colour of Santa Maria aquamarine. After World War II more aquamarines were found near the original localities, but although similar, they did not quite equal the extraordinary stones of 1925.

In c. 1990 blue beryls were found in a secondary deposit in Mozambique which were similar to the Brazilian 'Santa Maria' aquamarines and these have been called 'Santa Maria Africana'; however, in comparison they appear to have a more steely appearance than the lovely sky-blue of the original Brazilian stones.

Gemmological properties

Santa Maria aquamarines have the following properties: RI n_e 1.578-1.581, n_o 1.585-1.588, birefringence 0.007-8; SG 2.68-2.70.

Spectroscopic investigation of the stone used for the necklace gave absorption lines at 370, 426, 557, 833 and 891 nm. The equipment used was a Perkin Elmer Lambda 12 spectroscope.

The necklet

A Santa Maria aquamarine of 16.75 ct was the inspiration for a necklet designed by one

Figure 1: *Santa Maria aquamarine set in a necklet designed by Elena Villa. Photo by Bob Maurer.*

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author (EV), and made by Hans Dieter Krieger of Idar-Oberstein, Germany (*Figure 1*). Details of the stone's internal features can be seen in *Figure 2*. The inclusions are disc-like and oriented parallel to each other with a rather filmy appearance.

The design

The colour of the aquamarine and the inclusions 'reflecting the shiny waves of the ocean' inspired the creation of this unique piece of jewellery named the 'Light-tree-water-being'. EV writes about the concept and development of the piece as follows:

"Like any other real existing being, the invented being also should have a history. Where does it come from? How has it been called into being? For me nature on earth, under water and in space, offers the richest variety of colours and shapes. Inspired by this natural diversity, the basic idea for this piece of jewellery was born. The coincidence of the strong concentrated forms of energy, light, water and earth, as well as the grace of each of these natural elements, unified in the delicate expressiveness of a jewellery piece, stimulated a new interpretation of nature through jewellery.

"Evolution in its progress is thrilling and cannot be foreseen. The attraction to create new forms of expression, and also new possible forms of living, was more than enough reason to realize an evolutionary association between a gem and an invented being. Under such circumstances the gem can arise to life because it is no more just immobile and beautiful, but part of a living being. The form of living and the gem turn to a symbiosis and reach a stage of subtle living effect.

"The aim was not to have a motionless new piece of jewellery but to compose a new living being with the facilities of jewellery creation design. The result is a decorative independent individual who inspires the fantasy of the wearer as well as the viewer, free and powerful with personal radiation."

Manufacture

The piece was cast in platinum, the gold sections being formed by hand and soldered to the platinum. The aquamarine was set and then all pieces were connected by laser; the piece was finally polished with selected areas finished in a satin surface.

Figure 2: *Disc-like inclusions in the aquamarine. Photo by Bob Maurer.*

The light-tree-water-being

In the forests of Canada
where the hugest trees of the world grow
there is a being made out of light and water
living in a remote lake
which has a unique and fascinating under-water world.

At night the being goes on shore
because it feels so lonely.
It gets to know the trees
and has deep conversations with them each night.

One night one tree falls in love with the light-water-being
and from that day on they spend each night together.

From this relationship, protected by trust, tolerance and love,
originates the rarest being in the world
that just can be seen in one single picture:
the light-tree-water-being.

Elena Villa

Acknowledgements

Thanks to Claudio Milisenda for the spectroscopic investigation.

Identification of a new type of laser treatment (KM treatment) of diamonds

Y. Horikawa

Central Gem Laboratory, Tokyo, Japan

ABSTRACT: A new technique of clarity enhancement of diamond using a laser (KM treatment) has been identified. Although this treatment is achieved in a similar manner to that of traditional laser drilling, it produces a continuous fracture. This fracture appears more like a feather than a channel. KM treatment may be recognized from remnants of black coloration which sporadically line the surface of the laser-induced continuous fracture. Also by use of differential interference magnification, determination of whether or not the surface-reaching fracture existed prior to polishing can be made. These criteria can enable identification of most KM-treated diamonds.

Keywords: KM treatment, laser drilling treatment, black inclusion, laser-induced continuous fracture, boiling, differential interference microscope.

Introduction

A new technique of clarity enhancement has been identified and its development has been traced to Israel. The treatment is achieved in the same manner as traditional laser drilling treatment, which aims for improvement of the clarity of a diamond by the elimination of black inclusions. Though the new treatment was initially utilized in Israel, the technique may have been employed in Antwerp since early 2000. This treatment method has yet to be officially introduced to the industry and it appears to have been introduced quietly by some diamond dealers, as laser drilling treatment disclosure has become a growing concern worldwide. This technique is called 'KM treatment' which stands for 'Kiduah Meyuhad' meaning 'special drill' in Hebrew.

Materials and methods

KM treatment is used on black inclusions accompanied by internal fractures. One or more pulsed laser beams are focused on the inclusion itself with the resulting heat creating an internal fracture. The point of focus of the beam(s) is then moved towards the closest surface of the diamond at the same time creating a continuous fracture from the inclusion to the surface. This fracture appears more like a feather rather than the traditional laser-induced channel. After this procedure the diamond is immersed in a solution of strong acid and then boiled, and then subjected to pressure to allow the solution to contact the black inclusion via the newly created fracture. This process results in the bleaching of the inclusion.

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Method of investigation: the Nomarski differential interference microscopy technique

In the mid-1950s a French optics theoretician named Georges Nomarski modified the Wollaston prism used for detecting optical gradients in specimens and converting them into intensity differences. Today there are several implementations of this design, which are collectively called differential interference contrast (DIC).

The plane polarized light enters the beam-splitting modified Wollaston prism and is split into two rays, vibrating perpendicular to each other. The rays intersect at the front focal plane of the condenser, where they pass travelling parallel and extremely close together with a slight path difference.

The split beams enter and pass through the specimen where their wave paths are altered in accordance with the specimen's varying thickness, slopes and refractive indices. When the parallel beams enter the objective, they are focused above the rear focal plane where they enter a second modified Wollaston prism that combines the two beams at a defined distance outside the prism itself. As a result of having traversed the specimen, the paths of the parallel beams are not of the same length (optical path difference) for differing areas of the specimen.

The light then proceeds toward the eyepiece where it can be observed as differences in intensity and colour. The design results in one side of a detail appearing bright (or possibly in colour) while the other side appears darker (or another colour). This shadow effect bestows a pseudo three-dimensional appearance to the specimen.

The colour and/or light intensity effects shown in the image are related especially to the rate of change in refractive index, specimen thickness, or both. The three-dimensional appearance is not a representation of the true geometric nature of the specimen, but is an exaggeration based on optical thickness.

The advantages in using DIC microscopy for this work include:

- absence of halos that may be encountered in phase images;
- striking colour (optical staining) or three-dimensional shadow appearance of images.

Figure 1a: Before KM treatment. Isolated black inclusion is located below the table of a brilliant-cut diamond (at 9 to 10 o'clock).

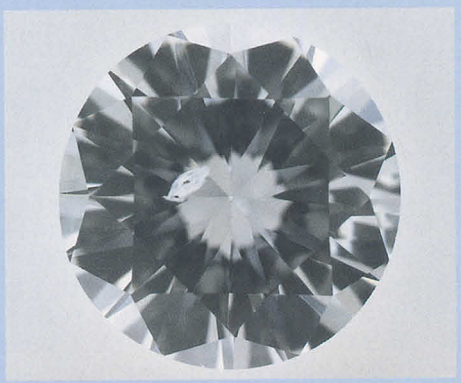

Figure 1b: After KM treatment. Black coloration has been removed from the inclusion. The size of the original inclusion area when viewed from the face-up position does not appear to be changed.

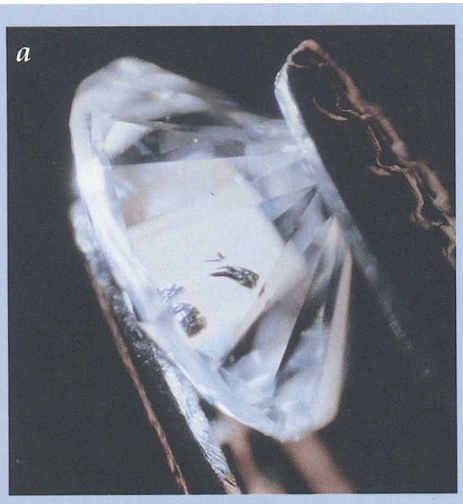

Figure 2a: Before KM treatment. A view of the black inclusion through the pavilion. This shows that the black inclusion is isolated within the diamond and does not reach the surface.

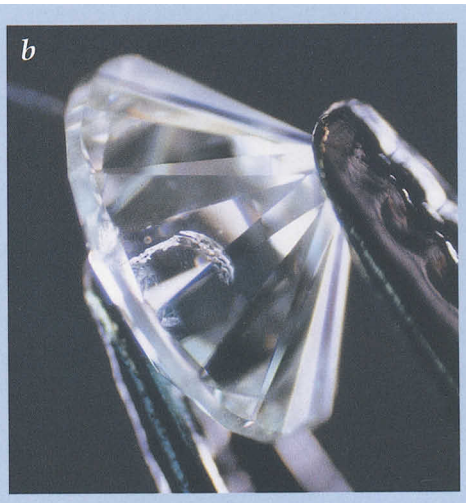

Figure 2b: After KM treatment. The black inclusion has been bleached and the laser-induced continuous fracture is apparent on the left of the inclusion.

Samples

Recently the author observed eight KM-treated diamonds, ranging in weight from 0.30 to 5 carats, and then for this study selected an untreated diamond for treatment in Israel. This diamond is shown in *Figures 1a* and *1b* before and after KM treatment respectively.

Results

Magnification

The author has seen two types of visible characteristics associated with this treatment which may or may not be found together. The first is an unnatural bend at the junction of the induced continuous fracture and the original fracture or cleavage that contained

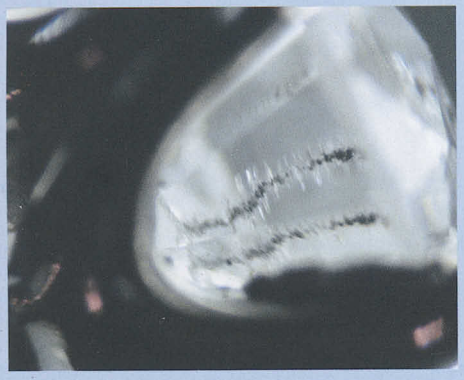

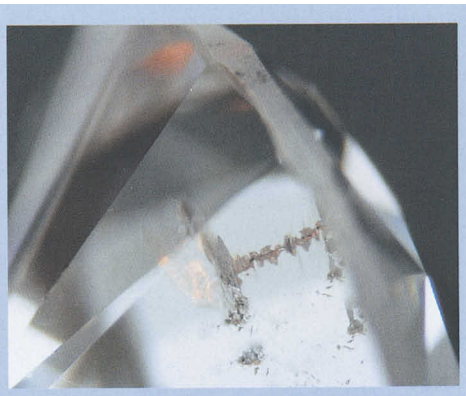

Figure 3: In both of these two KM-treated diamonds, the inclusion (which has the appearance of a centipede) leads to the surface of the table facet and has many smaller cleavages that protrude from its side. Black residue from the inclusion could not be removed completely by the treatment process and can be seen in areas along the laser-induced continuous fracture.

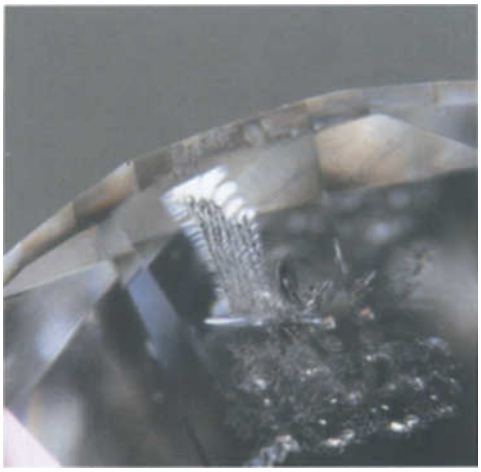

Figure 4: *The remnants of black materials found sporadically lining the surface of the laser-induced continuous fracture are typical of KM-treated diamonds.*

the black coloration (*Figure 2b*). The second type consists of a multitude of smaller cleavages leading out of the laser-induced continuous fracture that are parallel to each other and which create an overall resemblance to a centipede (*Figures 3a* and *3b*). In both types the laser induced continuous fracture retains black spots of coloration that are probably the remnants of the original black inclusions (*Figure 4*).

Nomarski type differential interference microscopy

Examination by differential interference microscopy was employed to judge if the fracture was created before or after the diamond was polished. If the fracture existed before the cutting and polishing of the diamond, depth and thickness of the polishing lines on opposite sides of the cleavage differ and can be visually detected. Where there are polishing drag marks that lead away from the edge of the fracture or where there is rounding of the peripheral edge of the fracture where it meets the surface of the diamond (*Figures 5* and *7*), the fracture was present prior to polishing. For fractures that have been introduced after polishing the diamond, there are no differences in the polishing lines on opposite sides of the fracture and the peripheral edge of the fracture is not rounded (*Figures 6* and *7*). Generally, a surface-reaching laser-induced continuous fracture is too narrow to be observed easily with a 10x loupe. Even at 200x magnification (as in *Figures 6* and *7*) it is still very small. Because of this, it is probable that boiling with acid has to be done under pressure to make it effective in penetrating the fracture and removing any black coloration.

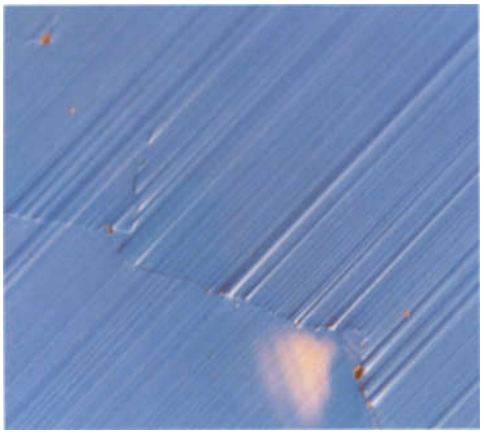

Figure 5: *If the fracture existed before the cutting and polishing of the diamond, depth and thickness of the polishing lines on opposite sides of the fracture would differ (200x magnification).*

Figure 6: *For fractures that have been introduced after the polishing of the diamond, there are no differences between the polishing lines on the opposite sides of the fracture, and the peripheral edge of the fracture is not rounded (200x magnification).*

Figure 7: With observation using the differential interference microscope, it is apparent that the fracture on the right of the photograph existed before the cutting and polishing, and the laser-induced fracture on the left has been introduced after the polishing of the diamond.

Figure 8: This boiled stone displays blue interference colour on the rim of the fracture.

Identification of KM-treated diamonds

The decisive difference between KM-treated diamonds and those with laser drill holes is the presence of a laser-induced continuous fracture, which resembles a feather, and the absence of a narrow straight hole. It may be difficult to distinguish a natural fracture from one generated by KM treatment, but experience should be accumulated from known treated stones. Doubt about the origin of a fracture would in turn lead to problems in reporting or in disclosure of possible treatment.

Although no one distinguishable feature has been present in all of the stones examined to date, one feature, which is unique for stones subjected to the boiling process, has been seen in most of these treated stones. The feature appears similar to the 'flash effect' found in filled diamonds, but it does not show the same colour change when the stone is rotated. Usually, in the experience of the author, boiled stones show interference colour changing from light blue to light brown when the stone is tilted back and forth (see *Figure 8*).

Conclusion

KM treatment is a new method used to remove black coloration from inclusions in order to improve the appearance of diamonds, the same objective for traditional laser drilling methods. Identification of KM treatment may be difficult but two tell-tale signs distinguish it from an untreated stone. The first is the observation (using magnification) of remnant black coloration material sporadically lining the surface of the laser-induced continuous fracture. Secondly, by the use of differential interference magnification, determination of whether or not the surface-reaching fracture existed prior to polishing helps to identify the relative age of the fracture: evidence of KM treatment would lie in the consistency of surface characteristics on opposite sides of the fracture.

Acknowledgements

The author thanks diamond dealers for supplying the samples and for other information. Nobuo Horiuchi of Central Gem Laboratory provided useful suggestions and special thanks go to John Nakama for reviewing this paper. Teramae, Hirata and Soeda, colleagues of mine at Central Gem Laboratory, are thanked for their support.

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Notes from the Laboratory

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ABSTRACT: Pearls are reviewed with anecdotal comments on a cultured pearl farm in China, remarks on non-nucleated cultured pearl growth structures, discussion of the comparative sizes of natural and cultured pearls, a button shape in a cultured pearl, the filling of hollow natural pearls and visible features seen in stained pearls. The stories and identification issues behind a number of synthetic and treated stones are considered, and a 'topaz diffusion' treatment applied to corundum is described.

Pearls

Non-nucleated cultured pearls

A visit to a cultured pearl farm in Wuhan, China, was one of the highlights of attending a conference at the Gemmological Institute of the China University of Geosciences. The cultured pearl farm (*Figure 1*) was one of a number in the province belonging to one company. The freshwater mussels used were subsequently identified by staff in the Zoology Department at the Natural History Museum in London as Hyriopsis cumingii (Lea). At the farm, the procedure consists of placing two or three mussels together in plastic mesh nets (*Figure 2*) and tying them to ropes, which are suspended from plastic bottles acting as buoys (*Figure 3*). The spat size of the mussel can be visualized in an eight month

Figure 1: *The buildings of a cultured pearl farm in Wuhan, China.*

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Figure 2: *The plastic mesh nets used for suspending the mussels in water.*

Figure 3: *Lines of plastic bottle buoys floating in the freshwater lake from which the plastic nets and mussels are suspended.*

old shell (*Figure 4*), where the spat shell has only been extended by one season's growth. The culturing operations are carried out on the mussels when they are between one and three years old. They expect to place about 50 grafts into 50 cm length of shell. Two three-year-old shells were opened up for us. They had been in the water for some two years after the culturing operation. The shell in *Figure 5* shows the cultured pearls in situ on the right-hand side. On the left, some of the cultured pearls had already been removed from the flesh and were returned temporarily for the photograph. The largest shell brought back to London is some five years old (*Figure 6*) and measures 25 x 16 cm.

Figure 4: *An eight-month old shell of Hyriopsis cumingii. The original spat size is evident on the shell surface.*

On the evening after our visit to the farm there was a bring-and-buy sale as part of the annual conference. Several strings of cultured pearls from the company who owned the farm were on display (*Figure 7*). The bags alongside the strings are a health tonic, consisting of a concoction that dissolves powdered cultured pearls. According to the information from the

Figure 5: *An opened shell showing some of the non-nucleated cultured pearls in situ.*

Figure 6: *A five-year old shell of Hyriopsis cumingii.*

Figure 7: Strings of non-nucleated cultured pearls and bags of 'health tonic' containing ground cultured pearls.

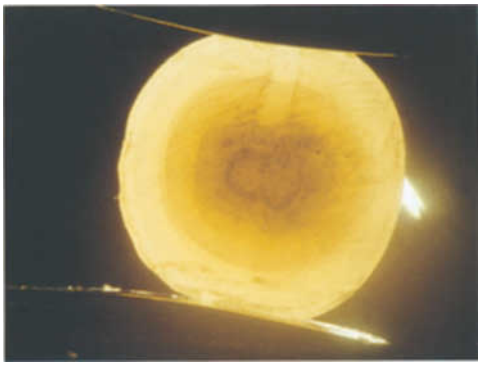

Figure 8: Cross-section of non-nucleated cultured pearl showing an internal cavity and distinct layers of growth.

company, about 70 per cent of the pearls recovered are used for cosmetics and health products, leaving the remaining 30 per cent to find their way into jewellery. While we were at the farm, the manageress showed us a 13 x 10 mm perfect drop-shape cultured pearl, which she reported was found with other pearls totally by chance.

There has been a lot of conjecture in the trade press in recent times on larger round non-nucleated cultured pearls being the result of nucleation with other spherically worked non-nucleated cultured pearls. This reminded me that many months before, one of our customers had engaged in a bit of destructive testing on some of his own pearls. He contacted us wondering if the exposed cross section of his non-nucleated cultured pearl (*Figure 8*) indicated that the Chinese culturers were now using small non-nucleated cultured pearls as nucleii in their mussels. Although this interpretation was understandable, what had actually been observed were the strong demarcations between seasonal growth stages.

Natural and cultured pearls

A recent enquirer wondered whether a pearl was more likely to be natural if it was quite large. No such conclusion can be drawn on this basis. However, the enquiry stimulated a review of some of the larger pearls that we have tested in the London laboratory.

The largest nucleated cultured pearl seen at the laboratory in recent years was a hollow cultured pearl, measuring approximately 41 x 34 x 33 mm and weighing 160.50 ct. The radiograph (*Figure 9*) shows a bead of approximately 11.5 mm ensconced in a corner within the enclosed internal cavity of the cultured pearl. In the 1980s Boris Norman of the Australian Pearl Company used to submit some huge natural South Sea pearls. A cursory glance through the records revealed an undrilled iridescent grey natural blister pearl weighing 177.03 ct and an undrilled baroque natural pearl weighing 119.35 ct. The largest South Sea natural pearl that Mr Norman remembers dealing with was over 130 ct (personal communication).

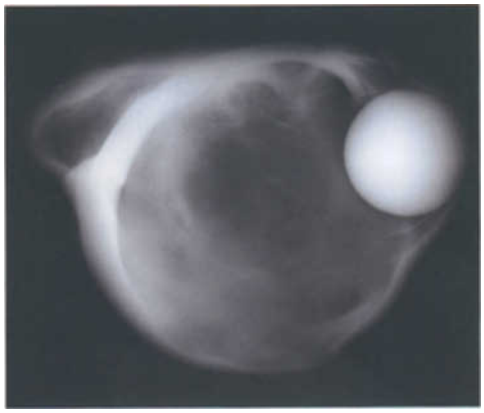

Figure 9: X-ray radiograph of a 160.50 ct nucleated cultured pearl.

Figure 10: The reverse view of the Pearl of Asia (reported weight 600 ct) enclosed in a gem-set foliate mount. In this direction, a pink tourmaline and four jadeite jades surrounding a synthetic ruby are on view. © K. Mikimoto & Co. Ltd., and Al-Tajir of Dubai.

These pearls were solid all the way through and, even after one to two hours exposure to X-rays, the resulting radiographs often only showed growth arcs around the edges of the pearls. Despite their size, these large pearls, of course, do not compare with historical pearls such as the Hope Pearl (Anon, 1989), claimed to weigh approximately 450 ct, and the Pearl of Asia, which measures approximately 76 x 50 x 28 mm (*Figure 10*).

A collection of seven undrilled pearls, submitted by a wholesaler for identification, weighed 35.62 ct, 27.37 ct, 17.69 ct, 17.23 ct, 15.84 ct, 13.04 ct., and 11.44 ct. The latter six pearls were all determined to be non-nucleated cultured pearls, which was based on the irregular shapes of the cavities revealed by radiographing the pearls in three mutually perpendicular directions. The radiograph of the 35.62 ct pearl revealed the presence of a flattened oval shape within the pearl, which was located off to one side. This has also been interpreted as being the result of the tissue implantation process for producing non-nucleated cultured pearls (Scarratt *et al.*, 2000).

The advent of larger non-nucleated cultured pearls has made the identification problem of differentiating between the cavities present in non-nucleated cultured pearls and the cavities present in hollow natural pearls even more acute. The interpretation of the three-dimensional shape of a cavity in a pearl, and its relationship to the outer contours of the pearl, still form an essential part of origin determination (Kennedy, 1996). Once the cavity is assessed as being within a natural pearl, a further check needs to be made on whether the hollow has been filled with artificial material. The determination is

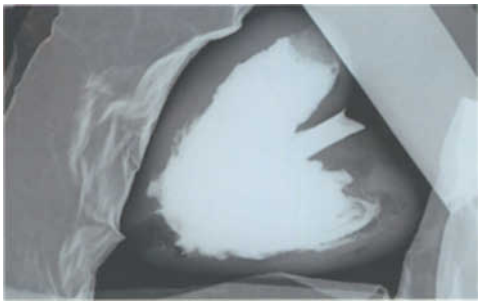

Figure 11: A plan view radiograph of an artificially filled natural hollow pearl. The filler is metallic in nature and is therefore opaque to X-rays, and is revealed as the white area in the centre of the pearl.

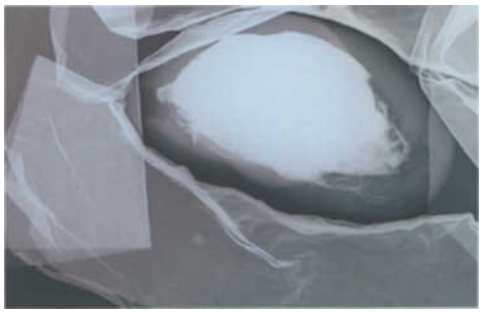

Figure 12: Side view radiograph of the artificially filled natural hollow pearl in Figure 11.

Figure 13: *The radiograph of a drop-shaped natural hollow pearl filled with urea formaldehyde resin.*

Figure 14: *A pearl- and gem-set brooch, which was radiographed in order to determine the origin of the pearl. © J. Boghossian.*

based on the evidence from the radiograph and visual examination of the internal cavity via the drill-hole. If the filling material is opaque to X-rays, in general this means it is metallic, then its presence is obvious on the radiograph (*Figures 11* and *12*). If the filler has the same radiolucency as nacre the only clue to its presence is the absence of growth structure within cavity area – the radiograph of a drop pearl (*Figure 13*) reveals an even central area where a urea formaldehyde resin had been used to fill the natural cavity. The interpretation of the radiographs can be complicated by small amounts of cement debris being present within the cavities of hollow pearls. The brooch in *Figure 14* was radiographed (*Figure 15*) and revealed several pins holding the pearl in place. In this case the traces of cement debris associated with the pin drill-holes were not significant enough to be considered as a filling, so it was reported as being a partially hollow natural pearl.

Figure 15: *The radiograph of the brooch in Figure 14 showing the traces of cement around the pins in the drill-holes.*

Grey/black stained pearls

The staining of natural or cultured pearls with silver nitrate can be established by the detection of silver by trace element analysis, or radiographically by the concentration of silver in the thin growth gaps between nacreous layers and/or between the nacre and a cultured pearl nucleus (observed as thin white lines on the radiograph negative).

Figure 16: *Silver concentrated in an imperfection on the surface of a stained cultured pearl.*

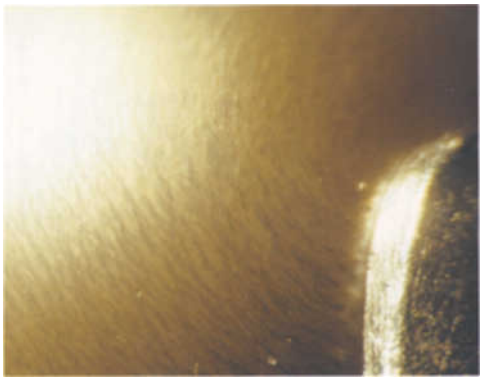

Figure 17: *Silver concentrated within the surface interstices of a stained natural pearl.*

On occasions the silver concentrates around surface imperfections (*Figure 16*) can be observed with a 10x lens. Another form of silver concentration was encountered in a stained natural pearl where the stain preferentially entered interstices all over the surface of the pearl, which produced the observed wavy pattern (*Figure 17*).

Both of these 'pearls' displayed the brownish colour revealed by silver stained pearls (*Figure 18*) when illuminated by a fibre optic light (Kennedy, 1996). Please note, however, that lower quality Tahiti cultured pearls and some natural pearls will appear a similar colour.

Figure 18: *Three cultured grey/black pearls illuminated by fibre-optic light. The upper pearl is a naturally-coloured Tahiti cultured pearl and the two lower pearls are stained cultured pearls. The latter two pearls appear a brownish colour in comparison to the naturally-coloured one above.*

Claim and counterclaim

Occasionally the laboratory is contacted from abroad by the owners of gems who have been led to believe that they possess something quite unique. Some while back a gemstone arrived from the Far East with the customer believing he had a painite – unfortunately it was quickly determined to be an orange/red synthetic flame fusion sapphire.

More recently a 536.5 ct stone was delivered to the laboratory, which had reportedly been cut from ruby rough obtained in East Africa. It was an orange/red colour and had a brilliance that belied its claimed origin. The stone had supposedly been subjected to some sort of elemental spectroscopy technique, which showed the stone to consist mainly of aluminium, hence furthering the belief that the stone was a corundum. The RI of the stone was over the 1.79 limit imposed by the RI of the contact fluid. Unfortunately its size made it impossible to fit into the Brewster angle meter. The hydrostatic determination of its SG at 5.99, the fact that it was singly refracting or isotropic in nature (on the polariscope it displayed a wonderful strain pattern) and its RI being greater than 1.79, proved it to be synthetic cubic zirconia. The client was offered an X-ray powder diffraction anaysis if it was deemed necessary to refute the claimed elemental spectroscopy analysis but our conclusion was accepted without any further testing.

Interesting synthetics

Synthetic sapphire

In the absence of bubbles or curved striae in yellow and orange flame-fusion synthetic sapphires it is common to search for Plato lines as proof of synthetic origin. The method requires the stone to be immersed in di-iodomethane and viewed down the optic axis between crossed polars. The Plato lines are seen as intersecting black shadow lines, which have been attributed to glide planes related to the build up and release of stress within the synthetic boule (Hughes, 1997).

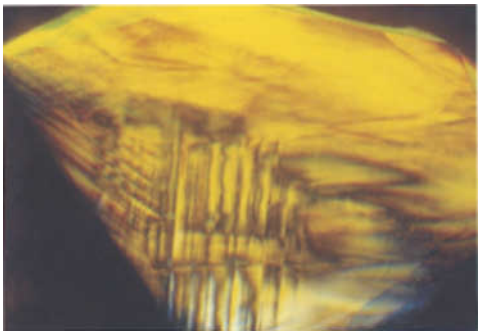

Figure 19: *The Plato lines in a synthetic yellow sapphire. The stone was immersed in di-iodomethane and viewed down its optic axis on a microscope between crossed polars.*

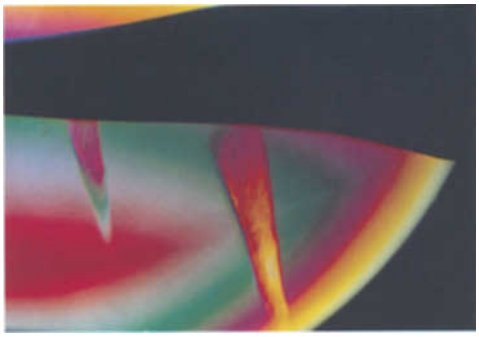

Figure 20: *The wedge-shaped twinning seen in a synthetic amethyst observed on a microscope between crossed polars.*

Recently, an oval yellow synthetic sapphire revealed the sharpest Plato lines that we can remember seeing (*Figure 19*) and also displayed the 120° or 60° angle between the lines very well.

Synthetic amethyst

A parcel of large amethysts was submitted for testing as the client was suspicious that the stones were synthetic. This was confirmed and one of the stones, interestingly, displayed the typical wedge-shaped twinning (*Figure 20*) seen in synthetic quartz (Koivula and Fritsch, 1989).

Synthetic spinel

It is generally known that synthetic flame fusion spinels are normally devoid of inclusions, so it was unusual to observe curved growth bands and stringy air bubbles in a green synthetic spinel (*Figure 21*).

Figure 21: *Curved growth bands and bubbles observed in a synthetic green spinel.*

Diamond treatments and simulants

The presence of glass fracture-filled diamonds on the market has led to an increase in stones submitted by anxious owners who have seen colour flashes in their diamonds. The two stones in *Figures 22* and *23* are typical of untreated diamonds – the open or internal fractures display the sequential rainbow colours expected for iridescence at the thin films that these air-filled fractures generate, which contrast with the more garish monochromatic colours generated by glass-filled fractures (Koivula *et al.*, 1989).

Last year a trading standards officer from one of the UK city councils attended one of our one day courses on the identification of diamond simulants including synthetic moissanite. A few months later he sent what he believed to be two synthetic moissanites to us. He was very pleased with himself to be proved correct. The sad thing about these two stones was the fact that someone had resorted to a hardness test evidenced by the scratches on the tables of both stones (*Figure 24*), caused by a diamond being drawn across them. Unfortunately, due to the differential hardness of diamond, it would be possible for a diamond to be scratched if the 'hard' direction of a diamond is drawn across the 'soft' direction of another diamond (Read, 1999). So the damage caused to the

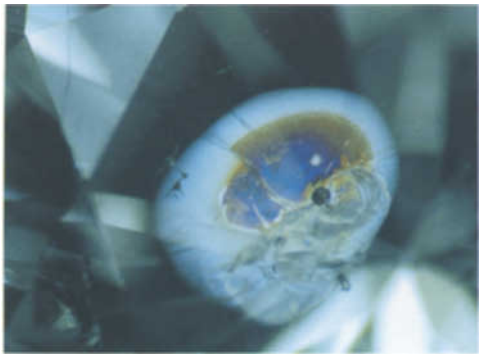

Figures 22 and 23: *The iridescence seen in air-filled fractures of diamonds.*

two synthetic moissanites cannot even be said to have provided conclusive evidence. How much simpler to look for the doubling of the back facets in a synthetic moissanite to differentiate it from singly refractive diamond.

In the majority of enquiries concerning gem-set jewellery, a customer is happy for diamond simulants to be reported as not being diamond. One customer was importing a range of watch cases with a surround of what were claimed to be Russian diamonds, and sent a sample watch case to us for testing. In their backed setting, we verbally informed the customer that they were not diamonds. However, the customer decided that an exact description for the stones was needed. Our first impressions of the stones led us to believe that they might be artificial glass due to the rounded facet edges and chalky green/blue fluorescence. Once a stone had been unset our first impressions were proved incorrect, since the stone had an RI of more than 1.79. An accurate SG determination was impossible due to the small size of the stone, so a single crystal diffraction pattern from the whole stone was obtained and indicated that the stone was synthetic cubic zirconia. We have subsequently seen more cubic zirconias with these more rounded facet edges.

Figure 24: *Scratches on the table of a synthetic moissanite.*

Diffusion treatment of corundum

Two sapphires, weighing 1.86 ct and 3.02 ct, were found to have inclusions indicating natural origin. The stones were checked under diffused lighting conditions for the tell-tale evidence of diffusion treatment. The evidence for the prevalent diffusion treatment is for the facet edges to show a higher concentration of blue colour in comparison to the centre of the facets (Kane *et al.*, 1990). However, the immediately noticeable feature of these stones was that the reverse situation occurred; the facet edges are picked out as being lighter compared to the rest of the stone (*Figures 25* and *26*). The clue that revealed that this was a known treatment was the observation on the surface of the 'sapphires' of blue blotches, a similar effect to that observed by Johnson and Koivula (1998) in 'diffused' blue/green topaz. This was supported by the presence of the same sort of cobalt spectrum, although in one sapphire with an appreciable chromium content the cobalt peaks were difficult to distinguish due to the underlying chromium aborption spectrum.

Richard Pollak of United Radiant Applications in Del Mar, California, who invented the diffusion process for topaz (Johnson and Koivula, 1998), has confirmed that the same process is being applied to sapphire. A cobalt-doped diffusion treatment was reportedly applied to natural corundum in 1984 (Kane *et al.*, 1990) on an experimental basis. A cobalt-diffused process has been applied to pale blue synthetic sapphires and light pink synthetic sapphires by HRI International Corp. of Middletown, NY (Koivula *et al.*, 1994). However, the nature of the diffusion processes and their effects are not mentioned in either of these references.

In the 'topaz-type diffusion process' the stippling or blotchiness effect is difficult to photograph but relatively easily observed with diffused lighting on a microscope. The same lighting conditions are needed to differentiate the more saturated facet faces from the less saturated facet edges – immersion may also be useful for observing the effect. Two pits below the girdle of the larger stone reveal that the diffusion process also stops short of pit edges, but does diffuse into the bases of the pits themselves. The chromium content of this stone makes it appear red on the microscope although in daylight it is a blue stone and the 'diffused deposit' is also blue. In *Figure 27* the pits appear a grey/blue against the red body colour, and the facet and pit edges stand out as lighter in colour than the rest of the stone – indicating that the diffusion process had stopped short of the pit and facet edges.

Figure 26: *Another view of the same surface-diffused corundum shown in Figure 25.*

Figure 25: *Pavilion view of the smaller surface-diffused corundum. The facet edges stand out as lighter in colour from the rest of the stone (diffused lighting conditions or immersion necessary). The parallel colour zoning is an internal feature related to the growth of the sapphire.*

In the Laboratory Report, the same result was given for these stones as for the better known diffusion process, namely 'Found to be Treated Corundum – the colour has been artificially produced by diffusion treatment'. This form of diffusion treatment of corundum seems to be relatively recent and needs to be added to the checklist of features for identifying corundum.

Figure 27: *The larger surface-diffused corundum, which although being blue in daylight has a red hue on the microscope due to its chromium content. The pits below the girdle reveal that the diffusion process stops short of the pit edges but does diffuse into the bases of the pits themselves.*

Acknowledgements

My thanks to Li Liping of Wuhan University for taking me to see the freshwater cultured pearl farm in China. Thanks also to Jean Boghossian for allowing the photograph of the pearl brooch to be published. Thanks also to Al Tajir of Dubai, the owner of the Pearl of Asia, for permission to use the photograph.

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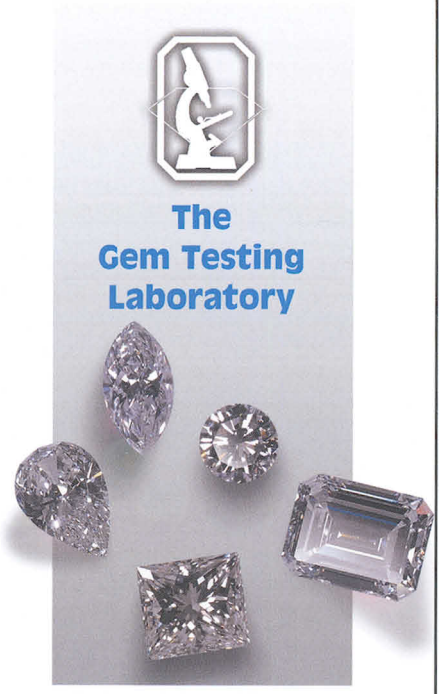

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A glass imitation of blue chalcedony

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ABSTRACT: A new artificial product on the Taiwan gem market, light blue translucent glass, is described and compared to natural blue chalcedony, blue opal and stained chalcedony. The gemmological characteristics of the materials are given and compared. Chemical ED-XFA tests indicate relatively high Na, Ca and low Al values in the glass compared with gemstones of the silica group, and also with such contents in natural glasses. IR spectra of the artificial glass and chalcedony are also quite different. Wollastonite was identified by Raman spectroscopy as a devitrification product forming fine felty fibres or small crystals up to 1 mm thick; they define the degree of translucency of this artificial calcium glass.

Keywords: Taiwan, blue chalcedony, glass imitation, wollastonite, ED-XFA

Introduction

Blue chalcedony is one of the most precious local gemstones in Taiwan. It occurs as irregular small veins in andesitic agglomerate north of Taitung, eastern Taiwan. After having been mined for decades, the deposits are now almost exhausted. Supplies therefore are scarce and many imitations of blue chalcedony are on the market, such as dyed blue chalcedony, dyed blue quartzite and blue opal. In 1998 we found another material resembling blue chalcedony on the market which was declared to originate from China. In the course of our study it turned out to be an artificial blue glass *(Figure 1)*. Natural glasses have been encountered as obsidians, tektites and moldavite (see, for example, Tsai and Wu, 1997).

Figure 1: *A 12.50 ct cabochon-cut glass imitation of blue chalcedony from Taiwan. The 17 mm long sample shows horizontal banding and perpendicular fibrous pattern. Photo by H.A. Hänni, SSEF.*

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The properties of blue chalcedony

Chalcedony is described as a fibrous aggregated form of silica which merges into agate when the banding becomes prominent (Webster, 1983). The microstructure of the sheaf-like fibre array (botryoidal structure) of silica allows some porosity in which natural or artificial pigments can impart colour. The whole structure of this cryptocrystalline material produces, depending on the direction of view, a more or less easily visible banded or polygonal pattern when inspected in transmitted light.

The properties of blue chalcedony from Taiwan have been widely studied by, for example, Huang (1965 and 1982), Chen (1969) and Chen and Zen (1982). So far we have not found any western reference for Taiwan blue chalcedony. The papers conclude that the colour of the Taiwanese blue chalcedony is usually homogeneous sky blue to greenish-blue, the material being semi-transparent to opaque, with a conchoidal fracture. The RI is 1.539, and SG is 2.58. A copper content of 0.01 to 0.02% has been reported, and a small uranium content of 0.002 to 0.0035 %wt gives rise to minor radiation (Huang, 1965).

Imitations

Imitations are substances that may substitute a given gemstone and may be natural gemstones or artificial products. Usually imitations are of lesser value than those that they imitate. The most popular imitations of natural blue chalcedony are dyed blue chalcedony, dyed blue quartzite and blue opal, but the new product described in this paper may also be convincing. Other substances to substitute for blue chalcedony are imaginable such as pectolite (Woodruff and Fritsch, 1989) or hemimorphite (Moses *et al.*, 1998), both of sky-blue colour with a definite structure. The properties of these imitations are listed in *Table I* and some examples in comparison are shown in *Figure 2*.

Figure 2: From left to right: (back) imitation blue chalcedony (glass), dyed blue quartzite, dyed blue chalcedony, (front) natural blue chalcedony (Taiwan), natural blue chalcedony (Taiwan), blue opal (Peru). Photo by H.A. Hänni, SSEF.

Most of the dyed blue chalcedony is free of inclusions and has a homogeneous colour distribution besides a faint 'agate' banding. Such a weak banding structure can be found in most chalcedony (*Figure 3*). Under a Chelsea filter the dyed material appears

Table I: *The properties of blue chalcedony and its imitations.*

Gemstone	*RI (spot reading)*	*SG*	*Hardness*
Blue chalcedony	1.53	2.58	6.5
Dyed blue chalcedony	1.53	2.60	6.5
Dyed blue quartzite	1.54	2.65	7
Blue opal	1.45	2.15	6
Sky-blue glass (chalcedony imitation)	1.54	2.57	5
Pectolite	1.60	2.81	5
Hemimorphite	1.62	3.45	5

reddish-brown. Since RI and SG are the same for the natural and treated blue chalcedony, we cannot distinguish them on the basis of these two properties.

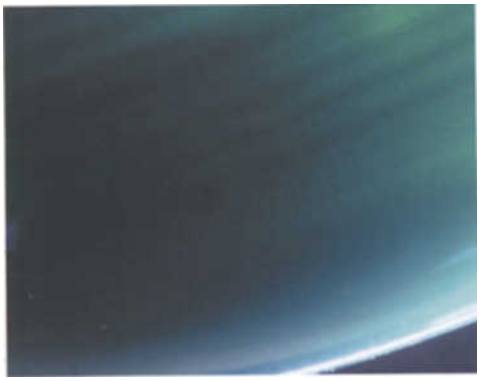

Figure 3: *Banding structure of dyed blue chalcedony. The banding of chalcedony is usually finer and more homogeneous, whereas bands in the imitation (Figure 1) appear more structured by parallel fibres. Photo by S.T. Wu.*

Dyed blue quartzite possesses a slight porosity which allows the staining to penetrate along grain boundaries. Such material shows concentrations of dye between the quartz grains which are easy to detect when a penlight is used (*Figure 4*). The SG of quartzite is 2.65 which is distinctly higher than that of blue chalcedony (2.58).

Figure 4: *In dyed blue quartzite the colour is always concentrated on grain boundaries and along fractures. Length of the stone is 8 mm. Photo by S.T. Wu.*

Blue opal usually shows jelly-like inclusions (*Figure 5*) which may look similar to some inclusions in natural blue chalcedony (*Figure 6*), but with its RI of 1.45 and SG of 2.15 it can be distinguished from chalcedony. Blue opal appeared on the market some years ago and has been reported from Chile (Koivula and Kammerling, 1991) and Peru (Milisenda, 1995).

Figure 5: *Jelly-like inclusions in blue opal from Peru. Length of the stone is 8.6 mm. Photo by S.T. Wu.*

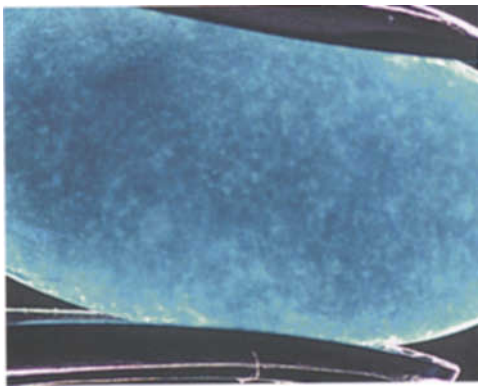

Figure 6: *Jelly-like inclusions in natural blue chalcedony from Taiwan. Length of the stone is 14 mm. Photo by S.T. Wu.*

Artificial blue glass

Artificial blue glass as an imitation for opaque or semi-transparent stones, such as lapis lazuli (Bosshart, 1983) or blue chalcedony could only be a convincing imitation when it is not transparent but has

Figure 7: *Raw material of the sky-blue imitation stone, apparently glass slag. Length of piece is approximately 20 cm. Photo by S.T. Wu.*

the same degree of translucency as the substance it is imitating. In order to make a glass translucent rather than transparent, its composition has to include some components that will oversaturate the melt and form crystals when the glass cools down. The process of devitrification may then allow the formation of, for example, devitrite, apatite, wollastonite, or fluorite and cristobalite, in the glassy groundmass (Hammer *et al.*, 1999). Such crystals can render a glass milky through to opaque (Bosshart, 1983; Harding *et al.*, 1989). The range of SG and RI values of artificial glass were shown by Webster (1983) in a diagram modified after Bannister.

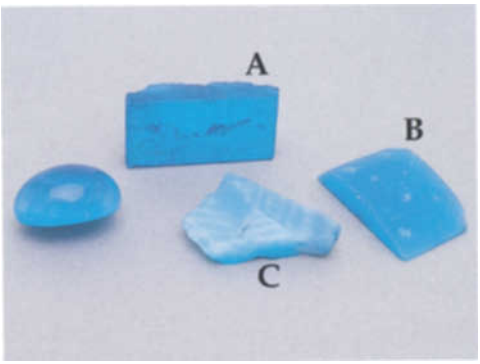

Figure 8: *Three types of sanded samples of blue glass from Taiwan, with decreasing sizes of fibrous inclusions (coarse, medium, fine) correlating with decreasing transparency. A polished cabochon on the left is 17 mm long. Photo by H.A. Hänni, SSEF.*

Macroscopic description

The pieces of rough glass are up to 20 cm across (*Figure 7*); they are inhomogeneous and consist of massive glass with what appears to be a slaggy top zone. Most of the glass is dark or sky blue, but next to the slaggy zone it is green. The degree of transparency is also not uniform. Most of the material is cut into cabochons or bangles. They vary in colour from light sky blue to dark sky blue and range from semi-transparent to semi-translucent (*Figure 8*).

The raw material available for investigation consisted of three different

Glass imitations of blue chalcedony

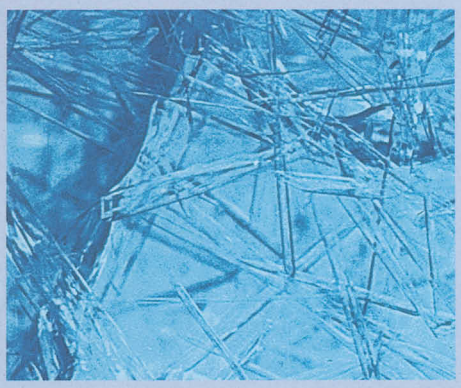

Figure 9: Sample A: Partially devitrified, and containing relatively coarse wollastonite crystals. Magnification approximately 15x. Photo by H.A. Hänni, SSEF.

Figure 10: Sample B: Partially devitrified, with medium sized wollastonite crystals. Magnification approximately 15x. Photo by H.A. Hänni, SSEF.

types, varying in their degree of transparency.

Sample A is semi-transparent and of darker blue colour than the other two types. It contains needle-shaped crystals in random orientation, which are clearly visible at 10x magnification (*Figure 9*).

Sample B is lighter in colour and more milky than sample A. Its inclusions cannot be resolved individually at 10x, but a few oddly shaped bubbles may be visible (*Figure 10*).

Sample C is light blue and almost opaque. Patterns of white banding are eye-visible and are confined to sectoral areas (*Figure 11*).

Figure 11: Sample C: Partially devitrified with very fine wollastonite crystals in a banding pattern. Magnification approximately 15x. Photo by H.A. Hänni, SSEF.

Microscopic description

With a magnification of 10x to 50x the imitation stones display features not expected from their macroscopic appearance. The darker blue and semi-transparent material A contains needle-shaped crystals and inclusions, randomly oriented. They have a four-sided cross-section and may be hollow or filled with glass (*Figure 9*). The medium blue variety of glass B shows similar but finer needles (*Figure 10*); gas bubbles are not common. The light blue variety C is almost opaque and contains dense aggregates of very fine needles. They are arranged as radiating bunches or form a kind of zebra banding (*Figure 11*). Gas bubbles or swirl marks may be hidden by the dense pattern of these inclusions.

Physical data

The RI of 1.54 and SG of 2.57 are values close to those of blue chalcedony. These data are shown in *Table I* with comparable data from other imitations.

The semi-transparent variety A of the glass showed a homogeneous aggregate structure under the polariscope. Under the Chelsea

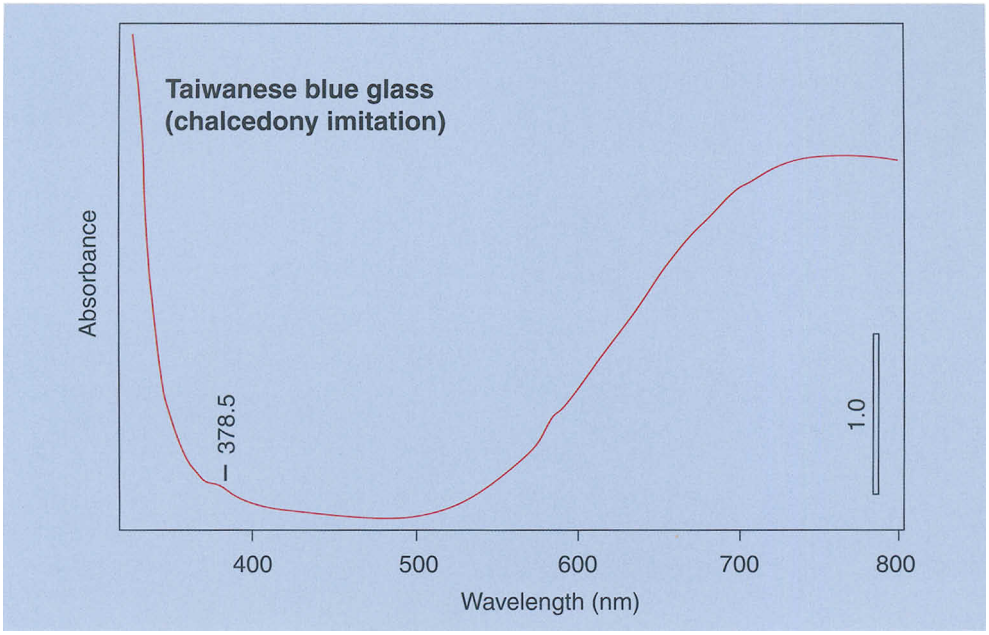

Figure 12: *Blue glass chalcedony imitation absorption spectrum from 300-800 nm recorded on a Varian Cary 500 Scan spectrophotometer. The main transparent area is between approximately 400 and 500 nm (blue colours).*

filter, the imitation stones appear green. With a hand-held spectroscope no spectral lines were observed. The UV-VIS spectrum recorded with a Varian Cary 500 Scan spectrophotometer is shown in *Figure 12*. It is characterized by general transmission between approximately 350 and 550 nm, and a weak absorption at 378 nm.

UV-reaction

In long-wave UV, the glass imitation stones showed weak bluish-white to

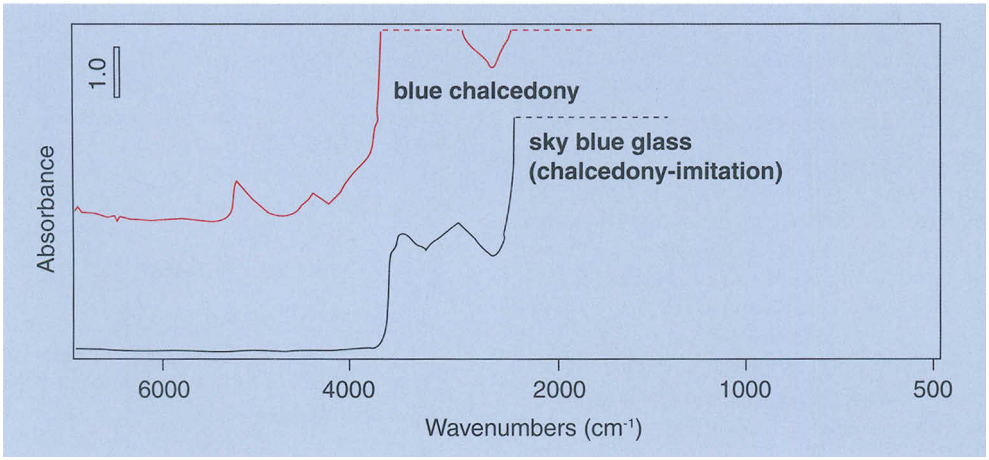

Figure 13: *Infrared absorption spectra of blue chalcedony and its glass imitation recorded on solid samples. The spectra show characteristic differences.*

yellowish-green luminescence, and moderate to strong yellowish-green luminescence in short-wave UV.

Infrared spectroscopic determinations

The infrared spectrum of natural blue chalcedony is shown in *Figure 13 upper*. The curve indicates complete absorption from 400 cm-1 to 2398 cm^{-1}, and strong absorption between 2689 cm^{-1} and 3758 cm^{-1} with two absorption bands at 4434 cm^{-1} and 5231 cm^{-1}.

The sky-blue glass imitation stones (B and C) have two absorption bands at 2927 cm^{-1} and 3464 cm^{-1} (*Figure 13 lower*) and lack peaks in the 4-5000 cm^{-1} region, a spectrum clearly different from that of blue chalcedony.

With a powder method where imitation glass is ground and mixed with KBr, we also found that the most important features of the infrared spectrum are the same as those of artificial glass (*Figure 14*): both have strong absorption in the 'fingerprint' area at 1053 cm^{-1} and pairs of small absorption bands at 651, 776 cm^{-1}, and 2932, 3450 cm^{-1}.

Chemical analyses

In order to obtain further information about the blue glass imitations, their chemical composition was investigated with a Tracor ED-XFA. The chemical analysis had first a qualitative character and helped to rule out the claim that the blue stones were chalcedony. A standardization for a semi-quantitative major element determination was done with artificial glass reference samples from the glass industry by conventional wavelength dispersive X-ray fluorescence spectrometry WDS-XFA

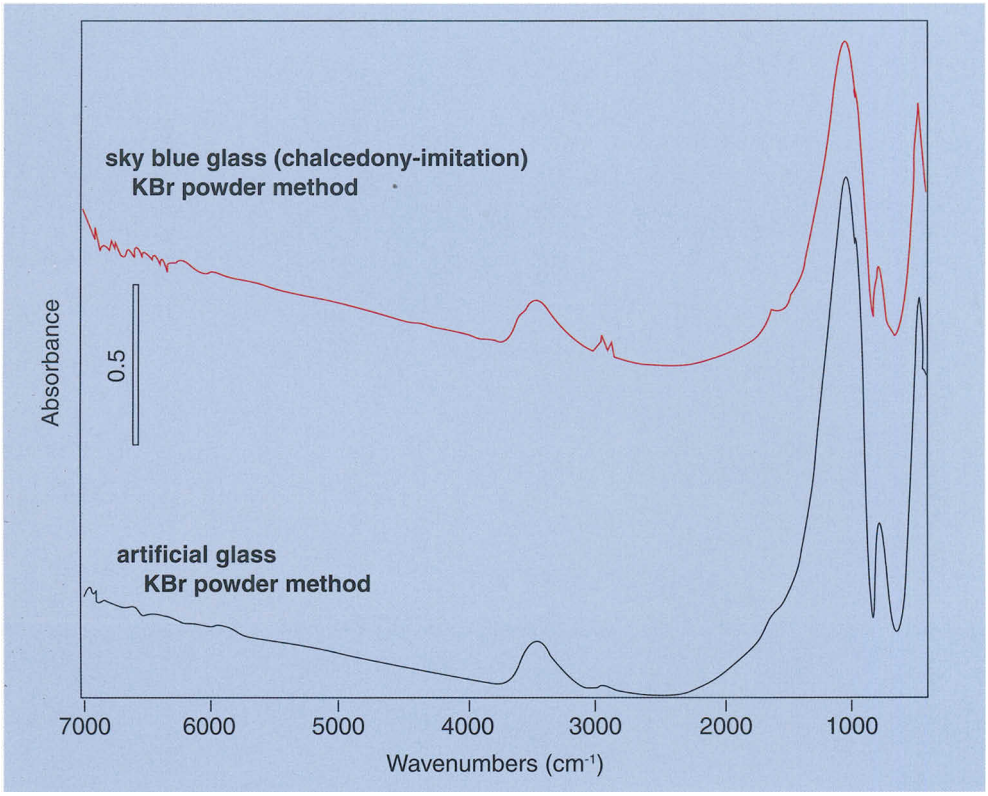

Figure 14: *Infrared absorption spectra of chalcedony imitation and window glass using a powder method with KBr tablets. The spectra show no significant differences.*

Table II: *Chemical composition of natural and artifical glass*

Oxide (%wt)	SiO_2	Al_2O_3	MgO	CaO	K_2O	Na_2O	TiO_2	Fe_2O_3	MnO	Cr_2O_3
Industrial glass references (WD-XRF analyses by J. Cerny)										
Olive standard	71.68	1.96	2.88	10.1	0.51	12.44	0.05	0.10	n.a	0.01
Brown standard	69.65	2.15	3.03	9.73	1.35	13.64	0.05	0.30	n.a	0.03
Green standard	71.57	1.65	2.12	10.29	0.67	12.71	0.06	0.33	n.a	0.22
Dark brown standard	78.02	2.27	2.45	10.43	1.09	12.38	0.06	0.29	n.a	0.03
Natural glass references (EMP analyses by H. Schwander)										
Obsidian Mexico	75.13	12.46	n.d.	0.25	4.75	5.24	0.08	2.01	0.08	n.d.
Obsidian USA	74.61	12.77	n.d.	1.12	5.74	4.50	0.15	1.04	0.08	n.d.
Tektite Thailand	75.13	12.93	0.96	2.32	2.51	0.29	0.61	5.09	0.15	n.d.
Moldavite CS	76.59	9.80	2.07	5.22	4.02	n.d.	0.27	1.75	0.29	n.d.
Taiwanese blue glass (ED-XRF analyses by P. Giese)										
Imitation rough (Sample A)	73.30	0.34	3.85	9.11	0.26	12.98	0.02	0.14	0.01	n.d.
Imitation rough TL (Sample B)	73.01	0.33	3.86	8.54	0.26	13.83	0.02	0.14	0.01	n.d.
Imitation rough TL (Sample C)	72.97	0.45	3.86	9.13	0.31	13.09	0.02	0.17	0.01	n.d.
Natural samples (ED-XRF analyses by P. Giese)										
Dyed quartzite	99.86	n.d.	n.d.	0.09	0.04	n.d.	n.d.	n.d.	n.d.	n.d.
Dyed chalcedony	99.98	n.d.	n.d.	0.02	0.03	n.d.	n.d.	0.01	n.d.	0.06
Blue opal	98.71	0.10	0.03	0.33	0.09	0.73	0.01	n.d.	0.01	n.d.
Taiwanese blue chalcedony	99.62	n.d.	n.d.	0.07	0.03	0.24	0.01	n.d.	0.04	n.d.
Taiwanese blue chalcedony	99.68	n.d.	0.11	0.11	0.05	n.d.	n.d.	0.01	0.04	n.d.

n.a. = not analysed n.d. = not detected Chemical data analysed by WD-XRF and ED-XRF are semi-quantitative; EMP data are quantitative.

Raman spectroscopic identifications

The Raman microspectrometer system (Renishaw 1000) is an excellent instrument for the mineralogical distinction of materials of similar appearance such as the blue chalcedony, stained quartzite, pectolite (larimar), blue hemimorphite, opal or glass (see also Hänni *et al.*, 1997). It is also excellent for identifying inclusions, so the method was used to identify the devitrification products in the blue glass (*Figure 15*). The Raman spectrum of a crystal inclusion (*Figure 16*) was matched with that of natural wollastonite in the SSEF Raman Data Search File, and confirmed its identity.

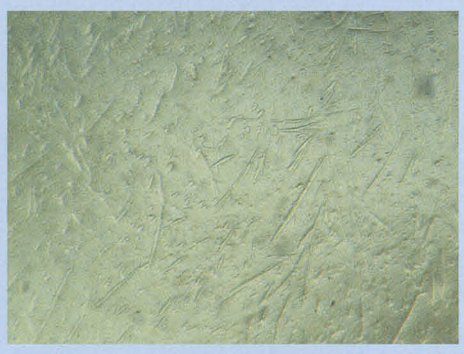

Figure 15: *Surface of blue glass showing devitrification texture indicated by the wollastonite crystals. Some slender crystals are hollow. Magnification approximately 30x. Photo by H.A. Hänni, SSEF.*

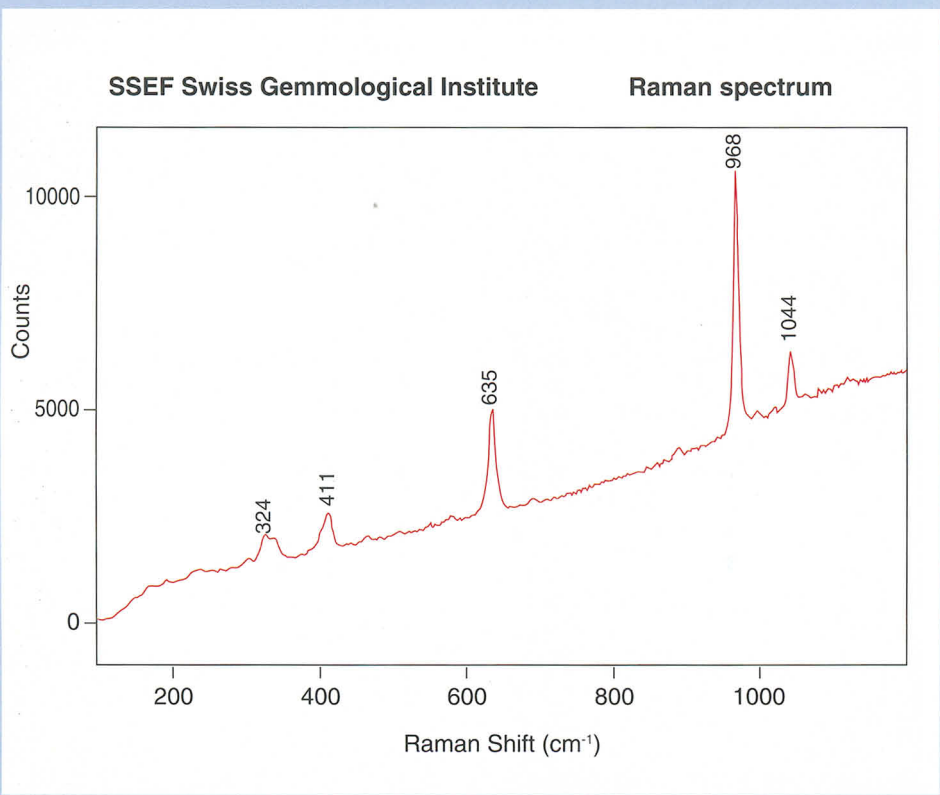

Figure 16: *Raman spectrum of wollastonite crystal in blue glass.*

(Vetroconsult, Bülach, Switzerland). Natural glass samples of obsidian, tektite and moldavite had earlier been analysed by electron microprobe (Geochemical Laboratory, Basel University). The blue glass samples described in this paper were analysed by energy dispersive spectrometry, X-ray fluorescence analysis (EDS-XFA) at SSEF. The results are presented in *Table II*. Cu, Fe and As were found in trace quantities in the blue chalcedony imitation. The natural glasses are richer in Al, K and sometimes Fe, but poor in Ca. In contrast, the artificial glasses are richer in Ca, occasionally also in Na and relatively poor in Al (Weiner, 1983). This is because in the manufacturing of artificial glass Na, Ca, B or Li may be added in order to bring down the melting point.

The blue imitation glass is richer in Ca and Na and poorer in Al than natural glasses, proving its man-made origin and indicating that it belongs to the group of calcium glasses.

Discussion

The glass imitation of blue chalcedony is in many respects similar to natural chalcedony. A close microscopic inspection may however reveal the bundles of randomly oriented devitrification products, which in the lesser transparent material are in bunches or as radiating aggregates. Needles ordered in bands may give a zebra pattern to the sky blue material. The RI and SG of the glass are close to the values of chalcedony. Additional identification features lie in the infrared spectrum where the peak positions are typical for glass; chalcedony peak positions are quite different.

A chemical characterization of the material is most effective since it shows the compositional difference between chalcedony and natural glasses. The ED-XFA results obtained are typical for a calcium glass. The precipitation of wollastonite as a devitrification product is a result of the high calcium content of the material. Traces of Cu and Fe are responsible for the blue colour, traces of As are recommended in the manufacturing to reduce gas bubbles. It is possible that the blue glass is an industrial waste or slag, as proposed by Johnson *et al.* (1999). The relatively small amount of this product in the market is consistent with such an origin.

Conclusions

The described glass imitation of natural blue chalcedony is a convincing substitute which may intrigue gemmologists because of the similarity of their properties. When mounted, the identification of such stones could create difficulties. However, observation of microscopic features such as radiating fine or irregularly displaced coarser fibres of devitrification products, UV reaction and chemical differences, allow a safe identification. The sky blue stone is richer in Ca, Na and poorer in Al than natural glasses and indicates that it is artificial glass.

Acknowledgements

We thank Mr M.L. Lee for providing the blue chalcedony samples, and Ms S.F. Wang and Mr C.C. Huang for the samples of sky blue imitations. The standardization of ED-XFA glass analyses was carried out by Mrs J. Cerny of Vetroconsult (Bülach, Switzerland) and Professor W.B. Stern (Geochemical Laboratory, University of Basel) whom we thank also for fruitful discussions of the topic. We thank Mr P. Giese for analytical ED-XFA work and Dr M. Krzemnicki for graphic refinement, both of the SSEF Swiss Gemmological Institute in Basel.

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Ornamental granite from Ailsa Craig, Scotland

Dr Douglas Nichol

Wrexham, Wales

ABSTRACT: Ailsa Craig granite, a distinctive arfvedsonite-aegirine-microgranite, has achieved international distinction as the premier raw material used for the world's finest curling stones. The geomechanical attributes of the granite that make for superior curling stones also make it an ideal stone for ornamental pieces and curling jewellery. Carefully selected material is amenable to processing using conventional lapidary equipment, and fine grain size together with uniform texture result in even polished surfaces. Although quarrying operations on the island effectively ceased in 1973, Ailsa Craig granite remains the foremost stone associated with the ice-sport of curling. This traditional reputation has combined with increasing scarcity to provide the basis for development of a niche market for highly prized curling trophies and jewellery items.

Keywords: Ailsa Craig, curling, microgranite, Scotland

Introduction

Granites are well established as construction materials and building stones, but are almost never considered for jewellery applications. However, an unusual microgranite from Ailsa Craig, Scotland (*Figure 1*) has gained international esteem and acceptance for certain special jewellery and ornamental pieces, interest being fostered by its traditional association with the ice-sport of curling.

Curling originated as a winter game in Scotland in the 16th century. Players in teams slide hefty, circular, handle-topped stones across a sheet of ice towards a target zone. The stones each weigh almost 20 kg. The objective is to deliver a greater number of stones closer to the centre of the target zone than the opposing team. Today, curling is played worldwide and the sport gained Olympic status in 1998 (*Figure 2*).

Figure 1: *Ailsa Craig, orientation map.*

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Figure 2: *The ice-sport of curling underway at an indoor rink. Great Britain Womens' Team in action at 1998 Olympic Winter Games, Nagano, Japan.*

Rock employed for curling stones must possess special geomechanical properties, not only to provide the appropriate running characteristics over the ice-surface, but also to withstand impact damage during collisions with other stones around the target zone. Ailsa Craig granite is one of the original rocks employed in curling stones. More importantly, it is widely acknowledged amongst the curling fraternity as the pre-eminent rock for curling stones.

The production of ornaments using Ailsa Craig granite also has a long history, having been developed by the early manufacturers of curling stones as a means of utilizing residual stone, reject material or otherwise wasted stone. The principal ornamental objects are miniature curling stones of various sizes (*Figure 3*). Not surprisingly, these miniature stone pieces are frequently awarded as trophies at curling competitions. Interestingly, Ailsa Craig microgranite also appears together with agates and other hardstones in 19th-century Scottish brooches and other jewellery material.

Geological setting

Ailsa Craig is a precipitous, rocky island in the Firth of Clyde that forms a prominent landmark some 14 km off the southwest coast of Scotland. It measures approximately 1.2 km in diameter, occupies nearly 105 ha and rises steeply to almost 340 m above sea level (*Figure 4*).

Geologically, the island comprises an igneous boss of fine-grained granite emplaced in Tertiary time (61-62 Ma, Rb/Sr; Harrison *et al.*, 1987) into red sandstone strata (Mauchline Sandstone equivalents) of Permian age. The granite mass varies from a pale grey, dense microcrystalline and even textured leucogranite, to a slightly coarser and less dense rock with prominent dark patches. It is cut by steeply dipping joints and intruded by vertical dykes of dolerite.

The leucomicrogranite is the principal rock exploited for curling stones. However, except for the occasional collection of loose rocks, formal quarrying of stone products at Ailsa Craig effectively ceased in 1973. Since that time, the manufacture of curling stones

Figure 3: Miniature curling stone made of granite from Ailsa Craig.

has been sustained partly from diminishing stockpiles, but predominantly from granite deposits elsewhere in the world.

The former quarrying sites for curling stones on Ailsa Craig lie on the northwest coast of the island. Curling stone production was carried out almost entirely by hand-working methods (Anon, 1961). Due to closure of the quarries on the island, worn or broken curling stones made from Ailsa Craig granite are increasingly in demand for recycling, either as inserts for the purpose of refurbishing stones or as raw material for making ornaments and jewellery.

At the present time the island is uninhabited and designated a Special Protection Area in relation to its international importance for breeding seabirds. Its rocky shore and cliff habitats support colonies of gannets, guillemots, razorbills, kittiwakes and myriad other seabirds.

Composition

The granite that forms Ailsa Craig is a rare peralkaline variety with an unusual mineralogy that includes arfvedsonite, aegerine, aenigmatite and glauconite-celadonite (Howie and Walsh, 1981; Harding 1983; Harrison *et al.*, 1987).

The granite consists predominantly of small (c. 1-3 mm) phenocrysts of sodic orthoclase, oligoclase and quartz in a groundmass of sodic orthoclase and interstitial quartz, and with poikilitic patches of riebeckitic arfvedsonite. The feldspar commonly shows much cloudy alteration. Aegirine and aenigmatite are present in small quantities, whereas magnetite, fluorite, glauconite-celadonite, zircon, monazite, rutile, apatite, brookite and pyrite occur spasmodically in trace amounts. Drusy cavities form a conspicuous petrographic feature of the granite and throughout the mass, these vary in size, abundance and mineral filling.

***Figure 4:** Ailsa Craig, view looking southwards. The old quarries in leucomicrogranite for curling stones lie in the lower middle foreground. IPR/9-4C British Geological Survey. © NERC. All rights reserved.*

Physical features

Ailsa Craig granite is typically light grey (N7) in colour, although polished surfaces of certain stones may exhibit subtle blue (Ailsa blue-hone), brown, pink or green hues. The green hue predominates throughout much of the granite, whereas the distinctive Ailsa blue-hone, renowned for superior curling stones, appears somewhat restricted in distribution to the leucomicrogranite areas on the upper and northeast parts of the island. Blue hue is attributed to the presence of riebeckitic arfvedsonite. Rare reddened patches are ascribed to hematite staining of granite in proximity to weathered intrusions of dolerite. Rectangular phenocrysts of white (N9) feldspar are prominent in places in the leucomicrogranite.

Granite outcrops of Ailsa Craig appear massive with widely spaced joints. The weathering state of the rock ranges from fresh to slightly decomposed. In addition, the fine grain size, unusual mineralogy and uniform fabric of the stone combine to create a rock of high strength, chemical stability and exceptional toughness.

The geomechanical properties of Ailsa Craig granite appear very uniform. It is an extremely strong rock with compressive strength values between about 350 and 380 MPa. Water absorption ranges up to 0.51%. Bulk density is typically 2.55 Mgm^{-3}, variable by perhaps 1% depending on precise mineral composition. For curling stones, the importance of bulk density relates to the need for stones of standard weights and dimensions. Skid Index measures skid resistance or polishability, and curling stones with low skid indices offer less resistance when sliding on ice. In addition, rebound performance of a stone under collision can be predicted from a qualitative assessment of the coefficient of restitution. Comparative data for some British granites are listed in *Table I*.

Not surprisingly, the physical properties inherent in superior curling stones also apply to various other applications such as sculptural, monumental and architectural stones. Indeed, Ailsa Craig granite has been employed at several prestige sites in Scotland. Prime examples include the National War Memorial within Edinburgh Castle and the floor of the Thistle Chapel within St Giles Cathedral, Edinburgh.

Processing

Ailsa Craig granite can be processed satisfactorily using conventional slabbing, trimming, tumbling and polishing equipment. A wide range of objects has been successfully fashioned, including pendants, earrings, tie pins, cuff links, watch fobs,

***Table I**: Physical properties of some British granites used for curling stones.*

Stone name	Locality	Density (Mgm^{-3})	Compressive strength (MPa)	Skid Index	Rebound property
Ailsa blue-hone	Ailsa Craig, Scotland	2.55	375	1	excellent
Ailsa common	Ailsa Craig, Scotland	2.55	232	1.09	fair
Trevor dark blue	Lleyn, North Wales	2.74	395	1.18	excellent
Trevor coarse-grain	Lleyn, North Wales	2.61	279	1.2	fair
Trevor pink	Lleyn, North Wales	2.67	371	1.15	good
Aberdeen grey granite	Northeast Scotland	2.66	242	1.1	fair
Lennoxtown essexite	Campsie Fells, Scotland	2.99	332	1.2	poor
Bonawe adamellite	West Highlands, Scotland	2.69	202	1.01	fair
Furnace grey granite	West Highlands, Scotland	2.56	302	1.09	good

Figure 5: Fashioned granite from Ailsa Craig. A selection of curling jewellery pieces.

brooches, paperweights, bookends, jewellery pieces and giftware items (*Figure 5*).

Careful selection of material is required in order to avoid specimens with minor voids or cavities that may result in pitting on the polished surface. Materials exhibiting patches of large white feldspar phenocrysts are also avoided for aesthetic reasons.

The variable grain composition may affect the polishing characteristics. The softer minerals, such as the feldspars, tend to undercut compared to the harder minerals such as quartz. However, as both are evenly distributed in the phenocrysts and groundmass of the rock and fine grainsizes predominate throughout, few irregularities on polished surfaces are discernible.

Conclusions

Ailsa Craig granite is a rare arfvedsonite-aegirine-microgranite, typically pale grey in colour and uniform in fabric. The granite is very dense and strong with a bulk density of 2.55 Mgm^{-3} and a compressive strength of 375 MPa.

Ailsa Craig granite has achieved international fame due to its association with the sport of curling and its reputation as the premier raw material for the worlds finest curling stones. Although the extraction of granite from quarries on Ailsa Craig effectively ceased in 1973, the reputation of the stone remains paramount. Traditional esteem together with increasing scarcity of supply has stimulated modern developments in the jewellery sector.

Due to increasing demand for curling trophies and items of jewellery that incorporate Ailsa Craig granite, broken or worn out curling stones will increasingly provide a valuable source of raw material.

An extensive range of ornaments, giftware and jewellery items is produced from Ailsa Craig granite using conventional lapidary equipment.

Acknowledegments

Thanks are extended to Kay Bonspiel for supplying various samples of Ailsa Craig granite used in this study. The World Curling Federation, the British Geological Survey and the Jewellery Division of Beam & Co supplied the photographs for *Figures 2, 4 & 5* respectively. Amco Robertson Mineral Services Ltd and the Royal Caledonian Curling Club kindly provided the author with access to information sources.

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The fashioning of rock crystal for spectacles in Sri Lanka

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ABSTRACT: Rock crystal has been a major component in the spectacle industry of Sri Lanka from ancient times. The remnants of the industry can still be seen today and this article describes the ancient spectacle industry, based on transparent quartz as the raw material. All stages of the manufacturing process and the primitive methods and instruments used in the industry are described in detail.

Keywords: Glass, lens, quartz, rock crystal, spectacles

Introduction

Spectacles are worn as a remedy for long- or short-sighted vision and for some other eye disorders. Sometimes spectacles are worn purely for style and today are made out of glass, plastic or polycarbonate. However, there are old spectacles found in Sri Lanka whose lenses are made from common rock crystal. The spectacle lenses described here are solely fashioned from rock crystal using the most primitive methods and are quite popular among those elders of Sri Lanka who suffer from eye ailments.

The history of the lens industry goes back many centuries. It is believed that the Chinese were the first to produce lenses, long before the trade was introduced to the West. The original lenses would probably have been made from rock crystal which was used in ancient times to kindle fire - thus it was known as fire glass. The Chinese made spectacles from rock crystal but the lenses were planar, lacking any curative effect, and the inference is that they were used for style rather than to correct astigmatism (Jones, 1995).

A unique reference to the use of spectacles during the Roman era was made by Pliny the Elder (23-79 AD), who wrote the following:

"Emeralds are usually concave so that they may concentrate the visual rays. The Emperor Nero used to watch in an emerald the gladiatorial combats."

This quotation appears to be the earliest publication mentioning the use of a monocle as a remedy for short sighted vision. Even though this would have been a success at the time and very many people could have witnessed the incident or read through the passage later on, there is no evidence to establish the fact that spectacles were in use during the next twelve centuries.

According to available data, the revival of a spectacle industry in the west occurred around 1280-1285 in Florence, Italy. Their popularity soon spread among people with defective vision, and some people gave the credit for their invention to a nobleman named Amati who died in 1317 (Jones, 1995).

Most people believe that the spectacle industry started in Asia before Europe. In Sri Lanka the industry is believed to have

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Figure 1: Raw material used in the spectacle industry to make lenses (smoky quartz).

started in 1346, in the famous Kandyan kingdom, and is preserved even to this day.

Today the trade is practised by a Mr Gunasoma who lives in Kahamba, a small hamlet which is situated about 9 km WSW of Kandy and 1 km from the Gadaladeniya temple in Sri Lanka. This temple is famous for its intricate wood carvings. Kahamba was once home to many craftsmen who were engaged in the spectacle trade for generations, but easier more lucrative careers that did not demand such intricate knowledge and craftsmanship induced most of them to quit the industry.

According to the folk-tales narrated among the present generation of craftsmen, they are the descendants of those ancient craftsmen who were the king's spectacle makers at the time of King Bhuvanekabahu IV (1346-1353), ruler of Sri Lanka during the Gampola period. At that time clear beryl was used to produce spectacle lenses, but now they use clear quartz. Even today they adopt the most primitive methods to make the spectacles and only the frame is modern. There is evidence that ancient spectacle frames were made of ivory and tortoiseshell. Some ivory and tortoiseshell spectacle frames which date back to the Kandyan era (during the 18th and 19th centuries) can be seen at the National Museum of Sri Lanka (document reference numbers 06-212-213 and 30-121-445). There is a belief in Sri Lanka that spectacles with natural rock crystal lenses can control a cataract if worn at the initial stages of the disease. Because of this belief, whether it is true or not, the traditional spectacle industry is still popular in Sri Lanka.

Figure 2: Industrial quality corundum crystals (abrasive material).

Materials and methods

Earlier clear beryl, called *tharippu* in Sinhalese, had been used as the raw material for lens making and this gave the name *Diya tharippu* to the spectacles, which is still in use today. Nowadays, due to the scarcity of clear beryl, clear quartz (some of it smoky) is used

Figure 3: *Grinding the quartz slice with a bow driven grinding wheel.*

as the raw material (*Figure 1*). Quartz is uniaxial positive, so in order to manufacture lenses as close to isotropic as possible, the quartz is cut perpendicular to the c-axis. Cutting is done by a manually operated circular blade of steel fed with corundum slurry and it takes about five to six hours to cut one quartz slice.

Abrasive powder

For cutting, grinding and polishing, home-made abrasive of varying fineness is used. In order to prepare this abrasive, industrial quality (not gem quality) corundum crystals (*Figure 2*) are first burned, then ground using a grinding stone and finally mixed with water to make a slurry. The slurry is passed through different sieves to separate the abrasives appropriate for the different purposes of cutting, grinding and polishing. A quartz slice is first ground to an initial shape using a manually operated (bow driven) grinding wheel, fed with corundum slurry as the abrasive (*Figure 3*). This is a time consuming task and needs much patience.

Figure 4: *Grinding the lenses to get the right curvature in a special grinding stone selected from a series of such grinding stones with different curvatures.*

Figure 5: *Bifocal lens (bifocal part constructed at the top owing to the limited capability of grinding implements used).*

After being ground to the initial shape, the lens is fixed to a wooden handle using a home-made adhesive consisting of a compound of paraffin wax (earlier beeswax), shellac and lamp soot. Then it is ground in a grinding stone with a particular curvature selected from a set of grinding stones with different curvatures (*Figure 4*); at this stage fine corundum slurry is used for lubrication. Differently powered lenses can be produced from the grinding stones of different curvatures. There is also a special grinding stone with a variable outward curvature for production of bifocal lenses. Because of the limited grinding facilities available to make bifocal lenses, the lower portion, which is ground and polished to assist reading cannot be made circular or oval as modern lenses are. The traditional lens is one single unit

ground and polished to cater for two specifications (*Figure 5*).

The lenses are finally polished in a long piece of wood (wooden lap) using a very fine corundum slurry. The lap is made from carefully selected 'Katu Erabadu', a tree grown in most parts of the country principally for the soft wood industry (*Figure 6*).

Figure 6: *Wooden lap used for final polishing (made from Katu Erabadu).*

Figure 7: *A pair of spectacles produced for short-sighted vision.*

Finally the lenses made to the doctor's prescription are fitted to a frame of the customer's choice (*Figure 7*). Mostly the spectacles are to correct short-sighted vision, but sometimes orders are taken to cater for special eye problems, such as a squint, which requires spectacles fitted with different lenses on either side.

Spectacles made from rock crystals, fashioned from primitive instruments and methods, are still produced to meet the requirements of many among the elderly who have defective vision.

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Abstracts

Diamonds

Gems and Minerals

Synthetics and Simulants

Instruments and Techniques

Diamonds

Zur Bestimmung von GE POL Diamanten: erste Erkenntnisse.

J.P. Chalain, E. Fritsch and H.A. Hänni. *Gemmologie. Z.Dt.Gemmol.Ges*, **49**(1), 2000, 19-30, 2 photographs, 1 table, 3 diagrams, bibl.

In March 1999 Lazare Kaplan (LKI) and General Electric (GE) announced that for the next ten years their colour-improving process would be marketed by POL (Pegasus Overseas Ltd.), this being a daughter company of LKI, a sight holder of De Beers. All diamonds treated by this process are marked 'GE POL' on the girdle. A two-step identification method for these diamonds is proposed. Almost all GE POL diamonds are type IIa near colourless diamonds; they can be separated from other diamonds of similar colour using the SSEF IIa Diamond Spotter in conjunction with a short wave UV light (254 nm). The results can be checked by FTIR spectrometry. Secondly, a Raman spectrum of these IIa stones is obtained using the 514 nm laser line of the Raman spectrometer. If a luminescence pattern at 3760 cm^{-1} is observed, this proves the presence of a small number of NV centres in the stones. This is believed to be characteristic of the material used for the GE process as all GE POL diamonds exhibit this emission. The non-treated colourless IIa diamonds tested did not show the NV feature. Further research is necessary to confirm preliminary findings. E.S.

Extreme chemical variation in complex diamonds from George Creek, Colorado: a SIMS study of carbon isotope composition and nitrogen abundance.

I.C.W. Fitzsimons, B. Harte, I.L. Chinn, J.J. Gurney and W.R. Taylor. *Mineralogical Magazine*, **63**(6), 1999, 857-78.

Diamonds from a George Creek kimberlite dyke preserve complex intergrowths between two major growth generations: homogeneous diamond with yellow-buff, and diamond with blue-green CL and local growth zonation. Secondary ion MS has revealed large variations both in N concentration and C isotope composition within these diamonds: even within single stones. N contents and $\delta^{13}C$ values can vary from 0 to 750 ppm and 0 to -20 ‰, respectively. The CL characteristics correlate directly with N: diamond with yellow-buff CL has a uniform N content, whereas the zoned diamond has bright blue CL bands with high N (50-70 ppm) and dark blue or green CL bands with low N (0-20 ppm). The $\delta^{13}C$ values also vary between the two growth generations in any one diamond, but show no consistent correlation with either CL or N. R.A.H.

Cr-pyrope garnets in the lithospheric mantle. I. Compositional systematics and relations to tectonic setting.

W.L Griffin, N.I. Fisher, J. Friedman, C.G. Ryan and S.Y. O'Reilly. *Journal of Petrology*, **40**(5), 1999, 679-704.

This is a major study of mantle garnets. Over 12,600 samples of Cr-pyrope garnets with $Cr_2O_3 > 1$ wt.% and $Mg/(Mg+Fe) > 0.65$, derived mainly from kimberlites and lamproites (plus some alluvial samples) mostly from southern Africa, Siberia, Canada and Australia have been analysed for major and trace elements as part of diamond exploration studies. Relative depths of crystallization for each sample have been estimated using Ni-derived temperatures. Mn, Ni and Zn are related to *T*-dependent partitioning between garnet and olivine. Cr content indicates degree of depletion of the host rock; Fe, Y and Ga have been removed by primary depletion. High-*T* re-fertilization metasomatism yields positive correlations between Fe, Zr, Ti, Y and Ga. *P/T* controls Ca/Cr in lherzolite garnets. There are systematic changes with age from > 2500 through 2500-1000 to < 1000 m.y. garnets. Data are shown mainly in scatter diagrams. B.E.L.

Mit High-tech ins nächste Jahrtausend.

V.M.F. Hammer and J. Stefan. *Gemmologie. Z.Dt.Gemmol.Ges*, **49**(1), 2000, 7-17, 1 photograph, 1 table, 1 diagram, bibl.

The authors warn about difficulties in distinguishing new high-tech developments from natural stones. The

Abstractors

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For further information on many of the topics referred to, consult *Mineralogical Abstracts*

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two examples given and discussed are the GE POL diamonds and the Nova Diamonds. The GE POL diamonds are sold with a laser inscription on their girdle, they are usually fairly clean, sometimes a little foggy, colour generally D to G, mainly type IIa, sometimes type I, fluorescence 80%. Since December 1999 the firm Novatek Inc. in Utah has been using a high pressure /high temperature process to improve mainly brown stones, producing lively yellows, yellow-greens and greens; these diamonds are also to be sold with a suitable girdle inscription. The authors discuss whether a stone which cannot definitely be shown to be treated should have to be declared as treated. E.S.

Gem news.

M.L. Johnson, J.I. Koivula, S.F. McClure and D. DeGhionno (eds). *Gems & Gemology*, **36**(2), 2000, 160-73.

Brief descriptions are given of a new 'Tycoon' diamond cut (a rectangular or square mixed cut with step-cut facets on the pavilion and a centred rhombus on the table), designed to provide more brilliance than a standard emerald-cut. R.A.H.

[Accessory minerals from eclogites and diamond-bearing rocks of Kumdykul deposit.]

F.A. Letnikov, N.G. Zvonkova, N.V. Sizykh and B.S. Danilov. *Proceedings of the Russian Mineralogical Society*, **128**(6), 1999, 16-27. (Russian with English abstract.)

The accessory minerals (ilmenite, magnetite, rutile, apatite, zircon, chalcopyrite, pyrite, pyrrhotite and garnet) from eclogites and from diamond-bearing rocks of the Kumdykul deposit were studied by EPMA and the data compared with results for the same minerals from kimberlites. In no cases (except for pyrrhotite) was there any similarity between the compositions of the respective minerals, supporting the hypothesis of a crustal source for the minerals and diamonds of the Kumdykul deposit. The minerals from diamond-bearing tectonites and eclogites are quite different, implying a different genesis. In general, the results confirm the concept that the thinly dispersed diamonds of the Kumdykul deposit were formed within narrow shear zones at points of local superpressure under the effect of reduced fluids from a deep origin. R.A.H.

A new lasering technique for diamond.

S.F. McClure, J.M. King, J.I. Koivula and T.M. Moses. *Gems & Gemology*, **36**(2), 2000, 138-46.

A new laser treatment to remove near-surface dark inclusions in diamonds without leaving a surface-reaching drill hole has recently entered the trade. Observations are here reported on several round brilliant-cut diamonds before and after such treatment. This method causes small cleavages to develop or expand around an inclusion; once the cleavage reaches the surface, it serves as a conduit for the solution that is used to bleach the dark inclusion. Irregular, wormhole-like channels are used to widen the cleavage to facilitate entry of the bleaching solution. The resulting feather has a more natural appearance than the traditional laser drill channel. R.A.H.

Gem Trade Lab notes.

T.M. Moses, I. Reinitz and S.F. McClure. *Gems & Gemology*, **36**(2), 2000, 155-9.

Notes are given on a blue, strongly zoned, irregularly shaped, 3.43 ct rough diamond and the 1.33 ct round brilliant cut from it; IR absorption spectra show the characteristic boron peaks at 1300, 2455, 2800 and 2930 cm^{-1} in the blue portion of the rough stone. R.A.H.

Geology, petrology and geochemistry of Narayanpet kimberlites in Andhra Pradesh and Karnataka.

K.R.P. Rao, T.A.K. Reddy, K.V.S. Rao, K.S.B. Rao and N.V. Rao. *Journal of the Geological Society of India*, **52**(6), 1998, 663-76.

Kimberlites have been found in S India at Wajrakarurand and also around Maddur and Narayanpet, Mahabubnagar district; Landsat imagery and photo-interpretation studies, geological traverses and stream sediment surveys indicate their presence also in W Mahabubnagar and in the adjoining Gulbarga district, Karnataka. Kimberlites of the Narayanpet kimberlite field (NKF) are emplaced along E–W and NW–SE-trending major faults and associated NE–SW tear faults in the peninsular gneissic complex, which contains enclaves of Dharwar greenstones from the Gadwal schist belt. These kimberlites occur as small bodies a few m across and as dykes with a strike length of ~ 2 km, their mineral assemblage (olivine, chrome diopside, magnesian ilmenite, chrome spinel and rare pyrope garnet) and textures indicate they correspond with hypabyssal-facies or root zone kimberlites. Mantle xenoliths are rare; however, spinel lherzolite is abundant in two kimberlites. NKF kimberlites are depleted in SiO_2 (~ 35 wt.%), are potassic ($K_2O > Na_2O$) and Mg-rich ($MgO > 20$ wt.%), and their *REE* abundances are consistent with derivation by partial melting of mantle and subsequent fractional crystallization. Their similar petrology and geochemistry implies derivation from a similar upper mantle source. Whilst processing and testing of some of the kimberlites have not yielded any diamonds, finds in the Krishna and Bhima River gravels suggest diamondiferous kimberlites may occur to the S and SW. J.F.

Contrasting isotopic mantle sources for Proterozoic lamproites and kimberlites from the Cuddapah basin and eastern Dharwar craton: implication for Proterozoic mantle heterogeneity beneath southern India.

N.V.C. Rao, S.A. Gibson, D.M. Pyle and A.P. Dickin. *Journal of the Geological Society of India*. **52**(6), 1998, 683-94.

Kimberlites intruding Precambrian basement at Anantapur (1090 m.y.) and Mahbubnagar (1360 m.y.) near the W margin of the Cuddapah basin, have initial $^{87}Sr/^{86}Sr$ ratios of 0.70205-0.70734 and εNd of +0.5 to +4.68. Mesoproterozoic lamproites (1380 m.y.) from the Cuddapah basin and from its NE margin have initial $^{87}Sr/^{86}Sr$ ratios of 0.70520-0.7390 and εNd of -6.43 to -8.29, suggesting they were derived from enriched sources with time-averaged higher Rb/Sr and lower Sm/Nd values than bulk earth, whereas the kimberlites were derived

from depleted sources with lower Rb/Sr and higher Sm/Nd values. T_{DM} ages suggest lamproite source enrichment (~ 2000 m.y.) preceded that of kimberlites (~ 1370 m.y.). Results show the existence of isotopically contrasting upper mantle sources for S India kimberlites and lamproites, and provide evidence for a lateral, isotopically heterogeneous mantle beneath the Cuddapah basin and E Dharwar craton. How these results might affect diamond exploration is also discussed. J.F.

Identification of HPHT-treated yellow to green diamonds.

I.M. Reinitz, P.R. Buerki, J.E. Shigley, S.F. McClure and T.M. Moses. *Gems & Gemology*, **36**(2), 2000, 128-37.

Examination of recently introduced greenish-yellow to yellowish-green diamonds treated with high-*P* and high-*T* by three companies has revealed several identifying characteristics. These include a highly saturated body colour, well-defined brown to yellow octahedral graining, moderate to strong green 'transmission' luminescence and visible evidence of heating. A strong line at 503 nm, a dark band from ~480-500 nm and green emission lines at 505 and 515 nm are visible in a hand-held spectroscope. Near-IR spectra show a peak at 985 nm, an indicator of high-*T* exposure. R.A.H.

New filling material for diamonds from Oved Diamond Company: a preliminary study.

J.E. Shigley, S.F. McClure, J.I. Koivula and T.M. Moses. *Gems & Gemology*, **36**(2), 2000, 147-53.

Diamonds marketed by the Oved Diamond Co., New York, which have been filled with a new glass formulation (XL-21), are readily identifiable as treated by the intense flash-effect colours seen with magnification (binocular microscope or loupe). Durability testing showed that this filler material is more stable to conditions of normal jewellery repair, such as direct heating with a torch, than the filler produced by this company a decade ago. However, some damage to the filler was seen in half of the Oved diamonds that were subjected to a standard prong retipping. R.A.H.

Gems and Minerals

Photoluminescent properties of defect spinels.

D. Ajó, S. Carbonin, I. Rizzo and G. Pozza. *Neues Jahrbuch für Mineralogie, Monatshefte*, **2000**(2), 91-6.

The photoluminescent behaviour of Cr^{3+} in a series of synthetic gemstones and some smaller gemstones mounted in an old brooch were investigated. In addition to their examination optically, XRD and XRF techniques were used where size allowed. Two of the synthetic stones were found to be corundum, but others were cubic with *a* 7.97 Å, *n* 1.73, and microanalysis indicated a formula of $Mg_{0.39}Al_{2.41}O_4$. The photoluminescence spectra showed the λ_{cr} values of 693.7 and 694.5 nm for the two corundums, but the values for the defect spinels were in the range 690.7-691.5 nm. The use of photoluminescent spectroscopy is recommended for the non-destructive testing of Cr^{3+}-bearing samples of unusual geometry. R.A.H.

Gemmological notes.

H. Bank, U. Henn and C.C. Milisenda. *Gemmologie. Z.Dt.Gemmol.Ges*, **49**(1), 2000, 1-6, 8 photographs.

Four collectors' stones from Sri Lanka are discussed; they are an orangy-purple cassiterite, an oval hessonite, a taaffeite and a grey-green faceted pyrope-spessartine. Recently an increasing number of 'natural' Russian emeralds were submitted to the laboratory and were found to be hydrothermally grown synthetics; they ranged from 2 mm squares to stones weighing 15 ct. Also a 'natural' ruby from Russia was found to be flux-grown; it had very strong red fluorescence. Flux-grown synthetic rubies from Douros in Greece showed minute birefringent solid inclusions under an immersion microscope. A number of dyed quartzes are on the market from the USA; these are rock crystals with various dyes filled into their fractures; they are easy to recognize with a loupe. Opals are often impregnated with resin to improve durability and clarity. The resin should have similar or identical RI to that of the stone. A variety of the mineral pectolite which is found in the Dominican Republic is offered under the trade name larimar. This translucent to opaque blue aggregate is cut as cabochons or used for small objects and sculptures; it may be impregnated with the resin Opticon. E.S.

Lazulithvorkommen in Österreich.

R. Berl. *Mineralien Welt*, **11**(3), 2000, 39-54, 6 maps, illustrated in colour.

Several lazulite-bearing deposits in Austria are described with notes on their geology and on accompanying mineral species. Some of the lazulite is used ornamentally though most material appears to be opaque. M.O'D.

Ruby and sapphire from Jegdalek, Afghanistan.

G.W. Bowersox, E.E. Foord, B.M. Laurs, J.E. Shigley and C.P. Smith. *Gems & Gemology*, **36**(2), 2000, 110-26.

The Jegdalek area some 60 km ESE of Kabul hosts about 20 mines in proterozoic marble interstratified with gneisses. The gem corundum occurs in irregular lenses < 2-3 cm wide within individual beds of coarse-grained marble; pink sapphire forms ~ 75% of the production, with 5% ruby, 5% mixed blue and red-to-pink corundum and 5% sapphire. Most of the material is semi-transparent and is fashioned with cabochons; only ~ 3% of the corundum is facetable with top-quality ruby rarely exceeding 5 ct. These gem corundums have ε 1.760-1.762, ω 1.76-1.770, *D* 3.97-3.99; rubies had Cr_2O_3 0.250-1.971, TiO_2 0.002-0.078, Fe_2O_3 0.016-0.174 wt.%, the corresponding values for sapphires being 0.037-0.445, 0.008-0.145 and 0.068-0.431 wt.%. Common internal features are partially healed fracture planes, lamellar twin planes, colour zoning and inclusions of calcite, apatite, zircon, iron sulphides, etc. R.A.H.

Gemmological miscellany.

G. Brown. *Australian Gemmologist*, **20**(10), 2000, 441-4, 7 illus. in colour, 1 in black-and-white.

The interesting gemstones covered in this miscellany include a faceted colourless tourmalinated quartz, several Sri Lankan pyrope-spessartine garnets with a colour change similar to vanadium-doped synthetic sapphire, a Russian ornamental clinochlore marketed as the healing stone 'Seraphinite', cloudy amber beads from the Baltic region which display a wood-like texture, and a group of 'reconstructed' materials that imitate ornamental materials such as turquoise, lapis lazuli, azurite-malachite, coral, charoite and sugilite. A useful teaching aid consists of four simple two-dimensional clear acrylic models which can be used to demonstrate how light is transmitted through round brilliants with various proportions and finish. P.G.R.

The Slocan Valley sapphire deposit, Nelson, British Columbia, Canada.

R.R. Coenraads and J.W. Laird. *Australian Gemmologist*, **20**(10), 2000, 410-15, 5 illus. in black-and-white, 2 maps.

The main areas of corundum mineralization are confined to two outcrops known as Blu Starr and Blu Moon. These lie at the junction of the Slocan and Little Slocan rivers some 30 km east of the town of Nelson in southern British Columbia. Blu Starr corundum, discovered in 1991, occurs as hexagonal barrel-shaped crystals typical of corundum found in metamorphic environments. Crystals are mainly in the 5-8 mm range, although stones exceeding 250 ct are occasionally found. Blu Moon corundum, discovered in 1993, occurs as hexagonal barrel-shaped crystals, plates and bipyramidal crystals up to 3-4 cm long. Initial heat treatment experiments are currently in progress to optimize the colour range and clarity of the gemstones, which have been turned various shades of blue including the preferred cornflower blue. Commercial viability of the deposits has yet to be proved. P.G.R.

Geologia, mineralogia e storia della Himalaya Mine.

J. Fisher, E.E. Foord and G.A. Bricker. *Rivista mineralogica italiana*, **24**(1), 2000, 16-35, illus. in colour.

Detailed geological and mineralogical account of the Himalaya mine, celebrated for gem-quality tourmaline. The mine is situated within the Mesa Grande pegmatite district of California and was discovered about 100 years ago. An estimated 100 metric tons of tourmaline are believed to have been recovered during the life of the mine. The Mesa Grande pegmatite district is one of about 20 pegmatite districts in the Peninsula Range batholith: the Himalaya dyke system has intruded rocks of Cretaceous age and the event may have taken place around 93 Ma. The fine tourmaline crystals occur with quartz, plagioclase, muscovite, lepidolite and cookeite, with some fluorapatite, beryl and other minerals. The tourmaline is elbaite and occurs as doubly terminated crystals often showing bright green at one end and rose pink to burgundy at the other. M.O'D.

A travers la nomenclature des émeraudes; émeraudes de Puerto Vejo, émeraudes vieilles, émeraudes de vieille roche, émeraudes de vieille mine.

F.H. Forestier. *Revue de gemmologie*, 140, 2000, 26-31.

A survey of the history of emerald with emphasis on nomenclature and on specimens found in Peru. M.O'D.

Schweizer Rubine von Hand geschliffen.

A. Frey. *Schweizer Strahler*, **12**(1), 2000, 20-1.

Brief details of the hand polishing of ruby from Switzerland are given. Material is found at the Val Traversagna. M.O'D.

La mission française AFG en Colombie.

D. Giard. *Revue de gemmologie*, 140, 2000, 7-13, 2 maps.

Account of the visit made by an AFG party to some of the emerald mines of Colombia with notes on the perceived state of the emerald trade. M.O'D.

Historique des gisements d'émeraude et identification des émeraudes anciennes. 2nd part.

G. Giuliani, M. Chaussidon, H.-J. Schubnel, D.H. Piat, C. Rollion-Bard, C. France-Lanord, D. Giard, D. de Narvaez and B. Rondeau. *Revue de gemmologie*, 140, 2000, 32-5.

A survey of the origins of emerald in classical and later times with particular reference in this part to trade routes between South America, India, Afghanistan and Pakistan on the one hand, and European centres on the other. M.O'D.

Zum Stabilisieren von Edelsteinen.

H. Heldner. *Schweizer Strahler*, **12**(1), 2000, 7-9.

Short review of the colour enhancement of some of the major gem species. M.O'D.

Gem news.

M.L. Johnson, J.I. Koivula, S.F. McClure and D. DeGhionno (eds). *Gems & Gemology*, **36**(2), 2000, 160-73.

Mention is made of a bi-coloured cat's-eye beryl from Pakistan, sphene deposits in N Madagascar, and the 'Aurora Borealis', a 131 ct Oregon opal carved to depict the N slope of the Brooks mountain range, Alaska. R.A.H.

Maissau: Amethyst aus Niederösterreich.

G. Knobloch. *Lapis*, **25**(5), 2000, 35-8.

The amethyst deposit at Maissau, Lower Austria, has been worked for at least 150 years. Recently a number of fresh occurrences of gem-quality material have been found: the colour and transparency appear excellent. M.O'D.

[A study on mineralogic and physicochemical characteristics of beryls and aquamarines in pegmatites of different origin.]

W. Li, Z. Li and Y. Mao. *Kuangwu Yanshi (Journal of*

Mineralogy & Petrology), **18**(4), 1999, 423-8. (Chinese with English abstract.)

Beryls and aquamarines from the Mufushan pegmatite, which resulted from magmatic differentiation, and from the Ailaoshan pegmatite, which originated by metamorphic anatexis, have different compositional and fluid inclusion characteristics. Their optical and physical properties, molecular formulae, and the physical and chemical nature of their solid and liquid inclusions are tabulated. R.A.H.

[Study on the mechanism of colour variation for iron-containing beryl.]

X. Li and K. Yuan. *Kuangwu Yanshi (Journal of Mineralogy & Petrology)*, **18**(4), 1999, 1-4. (Chinese with English abstract.)

The colour of Fe-bearing beryl can be altered by exposure to γ-irradiation or heat. The polarized absorption and electron spin resonance spectra, before and after colour enhancement, showed that the γ-irradiation caused the oxidation of channel Fe^{2+} to Fe^{3+} and the reduction of octahedral Fe^{3+} to Fe^{2+}. The Fe^{3+} at octahedral and channel sites was reduced to Fe^{2+} by heating. These changes in the valency of iron ions controlled the colour variation of the beryl. R.A.H.

Edelsteine aus Sambia – Teil 2: Turmalin uns Aquamarin.

C.C. Milisenda, V. Malango and K.C. Taupitz. *Gemmologie. Z.Dt.Gemmol.Ges*, **49**(1), 2000, 31-43, 6 photographs, 6 maps, 3 diagrams, bibl.

Gem-quality tourmalines and aquamarines rarely occur in the same deposit although both are found in core zones of pegmatites enriched with alkalis and rare elements and formed at lowish temperatures. Also minor amounts of red garnets, topaz, moonstone, morganite, amethyst, and smoky and rose quartz, occur occasionally. At present there are about 150 gemstone pegmatites known in Zambia, but relatively few are exploited to their potential. This paper described the recently explored Jagoda mine area with mainly pink, red and green tourmalines and some aquamarines. Also described are the Hofmeyer tourmaline mine, the aquamarine mine at Kapirinkesa and the Lundazi-Chama mine with both tourmalines and aquamarines. Mining and processing are mechanised and well organized in the larger mines. The annual production is estimated at US$10 million, but with much illegal mining and marketing it could be $20-30 million. Capillaries and growth tubes form a typical inclusion pattern in the pink, yellow and green tourmalines examined. Minute fluid inclusions were observed in the aquamarines. E.S.

Gem Trade Lab notes.

T.M. Moses, I. Reinitz and S.F. McClure. *Gems & Gemology*, **36**(2), 2000, 155-9.

Pink and yellow bi-coloured unheated zoisite from Tanzania is described. R.A.H.

Über Achate und vergleichbare Hohlraumfüllungen in Sedimentgesteinen.

G. Niedermayr. *Mineralien Welt*, **11**(3), 2000, 55-60, illustrated in colour.

Agate and other concretions of ornamental quality are reported from a number of different locations, including Madagascar, Iraq, Oman, Austria and California. Some specimens are completely filled with barite and calcite, while others contain discernible individual crystals. M.O'D.

L'euclase bleu-verte de Colombie.

F. Notari and P.-Y. Boillat. *Revue de gemmologie*, 140, 2000, 18-20.

Blue transparent euclase of good colour and suitable for ornamental use is described from Quebrada Negra, Chivor, Colombia. Three-phase inclusions containing liquid, gas and fluorite have been identified: both chromium and iron have previously been identified as the cause of the blue colour in euclase, and both have been identified in the Colombian specimens, but in this instance as Fe^{2+} is involved (Fe^{3+} not being present), iron would appear to have no influence on coloration. Several Cr features are identified in the absorption spectrum. M.O'D.

Nouvelles découvertes d'émeraudes et pierres de Colombie.

C.E. Osorio and J.-C. Michelou. *Revue de gemmologie*, 140, 2000, 14-17.

Among new gem discoveries in Colombia are rubies, sapphires and good quality amethyst from the Mercaderes region of Cauca department. Most sapphire specimens are fancy coloured and need heat treatment before being offered for sale. Some alluvial diamonds have been reported from Guiania department. Pale blue euclase and fluorite are reported in papers by Notary and Vuillet respectively (q.v.), conch pearls of good quality are also noted from locations on the Caribbean coast. M.O'D.

Les inclusions de pyrite dans l'émeraude de Colombie.

P.J. Rotlewicz. *Revue de gemmologie*, 140, 2000, 16-17.

Pyrite inclusions in emerald are briefly described and illustrated with reference to specimens from Colombia. M.O'D.

Okorusu: Fundstelle attraktiver Fluorite in Namibia.

P. Rustemeyer. *Lapis*, **25**(2), 2000, 24-9, illus. in colour.

Fine large ornamental-quality crystals of green and purple fluorite are described from the Okorusu mine situated approximately 300 km north of Windhoek and 48 km north of Otjavarongo, Namibia. Some crystals are green with purple edges or cores: a strong blue fluorescence is displayed by some crystals. Size range up to 15 cm cubes. M.O'D.

Characteristics of nuclei in Chinese freshwater cultured pearls.

K. Scarratt, T.M. Moses and S. Akamatsu. *Gems & Gemology*, **36**(2), 2000, 98-109.

Field research indicates that many Chinese growers of freshwater cultured pearls (FWCPs) are using larger mussels *(Hyriopsis cumingi)*, combined with new tissue-insertion techniques, to grow a larger, better-shaped product. X-radiographs of ~ 41,000 Chinese FWCPs from dozens of farms are examined, and 10 samples were sectioned. All showed evidence of mantle tissue nucleation only. The presence of a bead, whether shell or tissue-nucleated FWCP, would be identified by distinctive features in the X-radiograph. R.A.H.

Ein Besuch beim grössten Opal Australiens.

W. SCHIEBEL. *Mineralien Welt*, **11**(2), 2000, 63.

Describes a sandstone block 2 x 1 x 1 m in size containing precious opal classed as light crystal opal. The source is the Olympic Dam mine, near Andamooka, South Australia. The specimen has been named Atlas. M.O'D.

Proterozoic melting in the northern peridotite massif, Zabargad Island: Os isotopic evidence.

J.E. SNOW AND G. SCHMIDT. *Terra Nova*, **11**(1), 1999, 45-50.

The two very different hypotheses for the geodynamic history of the three Zabargad peridotite bodies have important implications for the origin and age of the whole peridotite complex. In one, Zabargad peridotite bodies are young asthenospheric mantle that was juxtaposed with ancient crustal gneisses during the opening of the Red Sea; whilst in the other, the complex may be a single package of residual mantle and lower crust of pan-African age uplifted during the Miocene. To decide between these two models, five samples of Zabargad peridotite and two pyroxenites were analysed for Os isotopes. $^{187}Os/^{188}Os$ ratios are 0.1198-0.1320, and correlate with Al_2O_3, giving an age for the N body, based on the Os isotope evolution curve for bulk earth, at 1400 ± 300 m.y. This agrees with previous suggestions that the N and central peridotite bodies are probably ancient continental lithospheric mantle, whilst the S body is recent asthenospheric mantle. These results from both central and S bodies are consistent with either crustal age hypothesis. J.F.

Steckbrief: Chrysoberyll.

Lapis, **25**(4), 2000, 8-1, illustrated in colour.

Full properties, modes of occurrence and major chrysoberyl localities accompany five colour photographs of characteristic crystal forms. M.O'D.

[The infrared spectra of Mingxi sapphires, Fujian.]

D. TANG. *Kuang Yanshi (Bulletin of Mineralogy. Petrology and Geochemistry)*, **18**(4), 1999, 385-8. (Chinese with English abstract)

The IR absorption bands at 1090, 795, 776, 642, 606 and 456 cm^{-1} have been recorded in Mingxi sapphires. In comparison to the sapphires from Shangdong, the 790 cm^{-1} band is split into 776 and 795 cm^{-1} bands and there is also a band at 1161 cm^{-1} in the Mingxi sapphires. The absorption bands at 3310, 3234, and 3188 cm^{-1} are related to OH in the sapphires; the H content is estimated on the basis of the absorption of the 3310 cm^{-1} band. The H content is higher in blue sapphires than in yellow sapphires. The IR bands and their relation to the colour are attributed to the presence of defect clusters (Moon and Phillips, *J. Amer. V. Ceram. Soc.*, **77**, 1994, 356). R.A.H.

La fluorite verte de Peñas Blancas.

P. VUILLET À CILES. *Revue de gemmologie*, 140, 2000, 21-5.

Green fluorite of fine quality is described from Peñas Blancas in the Muzo-Coscuez mining district of Boyaca state, Colombia. Three-phase inclusions have been observed and a number of crystals have been faceted and carved. M.O'D.

Neue Überraschungen aus dem Pamir, dem Karakorum und dem Himalaya.

A. WEERTH, V.M.F. HAMMER. *Lapis*, **25**(5), 2000, 22-9.

New minerals of gem quality recently described from the Pamirs, Karakoram and Himalayas include elbaite (rubellite), violet sodalite, purple fluorapatite, and green andradite from Afghanistan; rutile, red zircon and green transparent clinoenstatite from Pakistan. Details of the occurrences are given. M.O'D.

What's new in minerals.

Mineralogical Record, **31**, 2000, 193-6.

Specimens of gem interest at the Munich and Pasadena shows, noted by different correspondents, include: emerald with calcite from the La Pita mine, Boyacá, Colombia; pale green beryl from the Erongo Mountains, Namibia; golden beryl from Dos Barras, Minas Gerais, Brazil; brownish-pink topaz from the Wah Tu Wah mine, Yunnan, China; and yellow fluorapatite from Cedar City, Iron County, Utah, USA. M.O'D.

The Joseph A. Freilich collection.

W.E. WILSON. *Mineralogical Record*, **31**, 2000, 4-79, illustrated in colour.

The Freilich collection is described and its major items illustrated: a history of its formation and curation and a short biography of the owner are also given. The collection includes a number of top-quality gem species crystals. M.O'D.

Instruments and Techniques

Nelson M17 gemstone cooling unit.

T. LINTON AND B. BRETHERTON. *Australian Gemmologist*, **20**(10), 2000, 421-4, 4 illus. (3 in colour), 1 table.

The Nelson M17 cooling unit consists of a modified vacuum flask in which a 13 mm diameter copper rod has been inserted through its screw-on lid, and a test base that holds both a McCrone spectroscope and a transformer-driven light source. When the vacuum flask has been filled with a suitable freezing mixture the exposed top of the metal rod acts as a 'cold finger' to reduce the temperature of a gemstone from 0°C (using crushed ice and water) to the region of minus 200°C (using liquid nitrogen). At these temperatures the VIS fine line

absorption spectrum of many gemstones is enhanced, making it possible to identify irradiated and annealed diamond, and to discriminate between synthetic yellow sapphire and natural yellow sapphire (via the reddish fluorescence of the UV irradiated synthetic stone which is masked at room temperatures). The GAA Instrument Evaluation Committee recommend the use of this low-cost cooling unit for resolving carefully selected problem identifications. P.G.R.

The Hanneman refractometer.

T.LINTON, K. HUNTER AND A. CUMMING. *Australian Gemmologist*, **20**(10), 2000, 432-5.

The original Hanneman-Hodgkinson refractometer was large and difficult to set up, and for these reasons never became widely used. In this new more compact version, two standard distances can be set between the gemstone under test and the scale, the greater distance giving improved accuracy. Two scales are provided to cover gemstones having pavilion angles between 41 and 43 degrees. The range of the scales can be extended by use of a built-in immersion cell to cover high refractive index gems such as diamond and synthetic moissanite. The low cost of the refractometer kit, and the fact that with care it can provide readings almost equivalent to those obtainable with a critical angle refractometer, make this instrument suitable both for gemmological students and for those who wish to measure the refractive indices of high RI gemstones. P.G.R.

The Brewster-angle meter.

T.LINTON, K. HUNTER AND A. CUMMING. *Australian Gemmologist*, **20**(10), 2000, 428-31, 2 illus., 1 table.

The GAGTL Brewster-angle meter uses a 5mW, 670 nm laser to measure the polarisation angle of faceted gemstones and (by means of tables and a graph) determine their refractive indices. The GAA Instrument Evaluation Committee found there was a calibration error of 0.2 of a degree over the instrument's range and some decrease in accuracy at the high end of the scale (both possibly due to transit damage). However, repeatable readings were obtained by four evaluators over a range of eight test stones from quartz to synthetic rutile. [Abstractor's note – although not included in the range of test stones, synthetic moissanite is also well within the instrument's range of 1.43 to 3.3, and can be readily identified.] P.G.R.

Synthetics and Simulants

Garnet dissolution and the emplacement of kimberlites.

D. CANIL AND Y. FEDORTCHOUK. *Earth & Planetary Science Letters*, **167**(3-4), 1999, 227-37.

Dissolution of mantle-derived garnet in H_2O-bearing kimberlite melt was investigated experimentally to provide data on the survival of garnet xenocrysts commonly found in kimberlites. Garnet dissolution was determined by measuring the rate of radius change of garnet spheres, in synthetic kimberlite melt above its liquidus, as a function of T and P, and the results were applied to 80 garnet xenocrysts in an hypabyssal-facies macrocrystic kimberlite of the Slave Province, Canada. The time-scale required to preserve these garnets during kimberlite ascent depends on the magma's T path during ascent. Dissolution data require kimberlite magmas to exist only for minutes near their liquidus T in the mantle, and in conjunction with the existence of newly-formed fritted dissolution rims on cracked garnet xenocrysts, possibly from explosive emplacement, it is likely that the final stage of kimberlite ascent in the crust to the root zone of the diatreme possibly took only seconds/minutes. J.F.

Synthetic fresnoite – a new gemstone simulant.

U. HENN. *Australian Gemmologist*, **20**(10), 2000, 426-7, 2 illus. in colour, 1 table.

The natural mineral fresnoite ($Ba_2Ti(Si_2O_8)$) crystallizes in the tetragonal system with H = 3-4, RI 1.765-1.770. The yellow crystals were first discovered in Fresno County, California, USA. Faceted orange synthetic fresnoite grown by the Czochralski method is being offered on the market as a gemstone simulant under the trade name 'Terbium' (an inappropriate name as terbium is the rare earth element Tb). P.G.R.

Synthetische Alexandritdrillinge.

U. HENN. *Gemmologie. Z.Dt.Gemmol.Ges*, **49**(1), 2000, 51-3, 6 photographs, bibl.

By using the flux method synthetic alexandrites can be produced as twinned crystals. Synthetics of a Russian production have a macroscopical appearance like natural alexandrite triplets. However, the stones can be identified by flux feathers and residues. E.S.

Short gemmological notes.

Gemmologie. Z.Dt.Gemmol.Ges, **49**(1), 2000, 49-50.

A letter by K. Nassau questions the reliability of reflectivity for distinguishing moissanite from diamonds. He points out that the reflectivity of synthetic moissanite can be changed from 116/119 down to 100 (the value for diamonds) or even down to zero. The manufacturers do not intend to use this process and no one else is known to use it at the present time. In an answering letter, J.P. Chalain and M.S. Krzemnicki acknowledge Dr Nassau's argument, but think for the time being reflectivity is a good tool for distinguishing moissanite, but add that the strong double refraction and typical inclusions, such as fine tubes parallel to the optic axis, would be sufficient to make the identification. E.S.

BOOK REVIEWS

Achat: der Edelstein, aus dem Idar-Oberstein entstanden ist

Christian Weise Verlag, München, 2000. pp 96, illus. in colour, softcover. ISBN 3 921656 54 0 (main journal *Lapis* has ISSN 0945 8492). DM 34.80.

Obtainable separately from the subscription to the excellent journal *Lapis*, this beautiful celebration of the agates of Idar-Oberstein (mostly) is a worthy companion to the previous study of rock crystal (*Bergkristall*) in the same series. As usual the text continues without too obvious divisions and covers the agates of the Steinkaulenberg and other areas well-known to British (and German) gemmologists. Some details of agate occurrence, recovery and fashioning are given, but pride of place goes to the superb photographs of some of the innumerable patterns which agate can display. Some account of colour and patterning is given, but we are spared a long list of varietal names (though some of them may well be useful addenda to two, at least, of the recent nomenclature surveys). There are notes on local museums, on a collection of 'eye' agate and on an agate used as a cameo by Ptolemy II. Idar-Oberstein does not have it all its own way as there are descriptions and photographs of remarkable specimens from countries worldwide. Some, but not all, chapters include lists of references but there is no overall bibliography – for obvious reasons. Readers may well contemplate building up a set of *extraLapis*, issues of which, I am told, go out-of-print alarmingly fast. M.O'D.

Handbook of mineralogy. Vol. IV. Arsenates, phosphates, vanadates

J.W. Anthony, R.A. Bideaux, K.W. Bladh and M.C. Nichols, 2000. Mineral Data Publishing, Tucson (PO Box 37072, Tucson, AZ 85740). pp ix, 680, hardcover. ISBN 0 9622097 0 8. US$108.00 plus $6.00 postage and packing.

This is the penultimate volume in this first-rate and essential series in which the format of one species, one page, has been found to work very well. Previous volumes have already been reviewed: they cover elements, sulphides, sulphosalts (Vol. 1), silica and the silicates (Vol. 2, in two parts), halides, hydroxides and oxides (Vol. 3). Confident (with some reason) of the accuracy of the text, the publishers offer $5 reward for any error spotted. While the more avid collectors may regret the necessarily short accounts of localities, the data comes in so convenient and rigorously edited a form that the majority of users will find everything they need: in any case references are given for each species. The text is backed up by the SEARCH software, available from the publishers: this allows searching by chemical constituents as well as by names. Gemmologists will find entries for turquoise, variscite and some rarer ornamental species. M.O'D.

Rediscover opals in Australia

S. Aracic and M. Aracic, 2000. The authors, Lightning Ridge (PO Box 143, Lightning Ridge, NSW 2834). pp 415, illus. in colour, hardcover. ISBN 0 9595830 2 5. A$150 for boxed hardcover special edition for collectors, A$75 for general hardcover, A$45 for softcover.

This magnificently illustrated book updates and revises the authors' previous work, *Discover opals before and beyond 2000*, published in 1996. The collectors' hardcover edition includes a bookmark complete with an opal cabochon – the one in my copy is a very pleasant stone. This is the only occurrence of book + stone that I have seen since the publication of *Let's hunt for Herkimer diamonds* (1950), in which a small rock crystal is attached to the back cover in such a way that it can be seen via a pierced hole from the front.

This reviewer found the previous version of the book (*J.Gemm.*, 1998, **26**(2), 132) well able to rank with seminal works by Wollaston and Murphy and the revision, whose history can be found on page 413-4, has added a number of photographs and commentary on opal fields Australia-wide. Of special interest is an updated reprint of *A prospector's guide to opal in Western Queensland*, first published in *Queensland Government Mining Journal* in 1996: the commentary fits comfortably into the main text. Maps of some of the opal fields also reproduce well but naturally the opals themselves take pride of place. It is interesting to read about the rise of some areas and the working-out of others: Queensland, for example, produces superb opal as well as the attractive but less spectacular boulder opal with which the state is more often associated. Lightning Ridge, too, has seen the closure of some famous deposits and there is a list of new fields discovered since 1996. The mines and their products are not the only topics – claims and counterclaims are recounted, as well as efforts by large mining companies to take over large opal-producing areas and the possible social and economic effects of this kind of action.

Everything you could want to know about opal is here and readers are strongly advised to get this book, whose print-run will not last long if sales overtake stock as quickly as they did the last time out. M.O'D.

Famous diamonds (4th edn.)

I. Balfour, 2000. Christie's, London. pp 320, illus. in colour, hardcover. ISBN 0 903432 65 X. £65.00.

The revised and updated edition of what has now become a classic includes a description and photograph of the Millennium Star, originally 777 ct and the sixth largest rough diamond ever to be found – the polished stone, displayed during 2000 at the Millennium Dome in London, weighs 203.04 ct. The stone is graded D colour and both internally and externally flawless and forms part

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of the De Beers' Millennium Jewels, its companions being 11 variously-shaped blue diamonds with a total weight of 118 ct.

This timely entry is a pattern for all the others, 77 in all, some of which were in the first edition published in 1987. The diamond world is in the news probably as never before and the text has been revised in a number of places to take recent developments into account. These include the much greater prominence of coloured diamonds, which are described from the scientific point of view by Eric Emms, and some of the names carefully chosen for the colours (champagne, cognac) have brought to prominence diamonds which 50 years ago might very well have been classed as industrial goods. The text describes the exciting finds of diamond sources in Canada and Australia as well as the more traditional ones.

More details of well-known diamonds have come to light since the last edition, published in 1997, and one stone, previously believed to have been lost, has surfaced (read the book for details!). The text is equally remarkable for its comments on changing trade conditions and the personalities of celebrated buyers over the years. The pictures are as good as ever and my sole mild complaint is that the bibliography should have been brought up-to-date, as there is no mention, for example, of the recent comprehensive coverage of the Crown Jewels. M.O'D.

Forever brilliant. The Aurora Collection of colored diamonds

A. Bronstein and S.C. Hofer, 2000. Ashland Press/Aurora Gems, New York. pp xiv, 89, illus. in colour, hardcover. ISBN 0 9659410 2 7. £29.00.

The Aurora Collection of coloured diamonds featured in *The Nature of Diamonds*, an exhibition established in the American Museum of Natural History, New York City, in 1997. The collection also formed the basis for a large, important and beautifully-produced book by the second author, *Collecting and classifying colored diamonds*, published in 1998 (reviewed in *J. Gemm.*, 1998, **26**(4), 273). The present venue of the exhibition is Tokyo's National Science Museum.

The book consists almost solely of a catalogue of the Aurora Collection, which comprises 260 coloured and faceted diamonds. Each entry is accompanied by a colour photograph and gives particulars of the stone's weight, colour, measurements, shape, style of cutting, common name for the colour, hue, lightness and saturation. More extensive notes on colour in general are given in a preliminary section. The pictures are good, while those on the dust-jacket are magnificent! Readers with a serious interest in diamond should really try to obtain both books though the present one is easier to carry. M.O'D.

Diamanten

München Mineralientage, Oberhaching (Postfach 1361, D-82034 Oberhaching, Germany), 2000. pp 240, illus. in colour, softcover. DM 50.00.

Diamond is the theme of this year's München Mineralientage, and this well-illustrated catalogue contains a number of short papers including accounts of mining and of exceptional specimens of diamond as a vehicle for feng-shui. Among the illustrations of polished stones and crystals are reproductions of crystal drawings from texts by Fersman and Goldschmidt. Photographs of diamond polishing and of diamond mining, of diamond depicted on postage stamps and of characteristic inclusions occupy a number of pages, and in the remainder of the catalogue are the usual colourful and useful advertisements, book reviews, papers on fossils and details of the show itself. M.O'D.

Edel Steine aus Holz. Katalog zur Austellung im Deutschen Edelsteinmuseum Idar-Oberstein vom 3.9 bis 15.11.1999

Deutsches Edelsteinmuseum, Idar-Oberstein, 1999. pp 79, illus. in colour, softcover. ISBN 3 932515 21 8. Price on application.

This is a multi-author account of the formation, discovery and working of fossil (silicified) wood in different areas of the world, especially in Germany, and was published to accompany an exhibition held in 1999. Particular attention is paid to deposits in Saxony and Thuringia, and there are many useful references to paleobotany and other studies not regularly encountered by gemmologists. The pictures are first-rate, as always from the museum, and altogether the book fills what might easily have become a serious gap in the study of ornamental materials. M.O'D.

La mine de fluorine de Valzergues, Aveyron

E. Guillou-Gotkovsky, 2000. The author, Le Perray-en-Yvelines (46 Petite Rue Verte, F-78610). pp 228, illus. in colour, hardcover. ISBN 2 9514462 0 9. FF290 plus FF80 postage and packing.

Yellow crystals, many of gem quality, distinguish fluorite from the Valzergues mine, Aveyron, France. The present work, whose print run is stated to be 2000 copies with an additional 60 special issues, describes the geology and mineralogy of the mine and gives a detailed account of its mining history, the latter topic producing a number of interesting photographs as well as many mine diagrams. The pictures of the fluorite crystals will, however, be the first stop for the reader: since fluorite on the whole furnishes relatively large specimens, it has been possible to illustrate forms, especially twinning, in such a way that the specimen's appearance is easily understood. Minerals accompanying fluorite are also described and many of them illustrated. There is a useful bibliography. Readers who have an interest in mineral specimens should try to see a copy of this book. M.O'D.

Deutsche Steinschneidekunst aus dem Grünen Gewolbe zu Dresden (Sonderausstellung im Deutschen Edelsteinmuseum Idar-Oberstein 1 Oktober bis 6 Dezember 1998)

J. Kappel, 1998. Deutsches Edelsteinmuseum, Idar-Oberstein. pp 195, illus. in colour, softcover. ISBN

3 932264 09 6. Price on application.

This scholarly survey describes and illustrates major examples of German ornamental hardstone fashioning to be seen in artefacts held in the Green Vaults at Dresden. The book is loosely but usefully arranged by date, place and type of material. The first chapter describes the search for 'precious stones' in Saxony during the 16th to the 18th centuries (mostly agates, but also the fine yellow topaz from Schneckenstein). This is followed by an account of the agate and jasper workings in the upper Nahe area and of the rise of Idar-Oberstein as a gemstone centre. The same area is also described in the following chapter, which pays particular attention to the techniques of agate-cutting used there in 1800. The scene now shifts to Dresden, where the manufacture of hardstone ornaments and the establishment of the Green Vaults are illustrated in the final chapters. There is a most useful bibliography and the many illustrations are very well reproduced. The book will be invaluable for the student of hardstone recovery, working and fashioning, as well as for the connoisseur of the decorative arts. M.O'D.

Dictionary of gems and gemology

M. Manutchehr-Danai, 2000. Springer, Berlin. pp 532 (pagination ends before conclusion of text), hardcover. ISBN 3 540 67482 9. £103.00.

Yet another gemmological dictionary, and from the depths of the reviewer's memory came an adaptation of part of an Irish song: *'They wrote it again/Over and over and over again'*. In general, while some may be worthy, few if any add to science, but the reviewer has still to search wearisomely among the near-pathologically tedious old and never-used names for the odd unexpected nugget that might be worth knowing. I am surprised that so generally adept a publishing house should produce so uneven a book at so high a price. For the gemmologist there is nothing new, the mineralogist is unlikely to bother with it, and the beginner, worst of all – and this is truly regrettable – is led from the start into paths already well-trodden by the tediously prolix, along which he will find many tempting, uncertain and occasionally dangerous fruits. Though described as a Professor of Mineralogy (institution not stated), the author or compiler surely could have, and certainly should have, sought the advice of perhaps more experienced colleagues.

So that the reader will get what I mean, try these out: p 3, *Abbreviations and symbols*, optic sign of uniaxial crystals reversed and, so that the reader won't miss the point, the author in pursuit of consistency gets the biaxial wrong too! Noting that the author had quoted formula units per unit cell, immediately reminiscent of *Hey*, I checked *formula units* but in vain. The entry for *unit cell* does not make the connection. Spessartine (correct formula then given) "may contain Mn" (good to get that learnt); alumina, "an important constituent of aluminium oxide"; allanite, "...radioactive, making it interesting to gem collectors" (!); no mention of the cleavage of kunzite under kunzite but an entry *kunzite – see spodumene*, but not emphasized in that entry where the heat-sensitivity of kunzite is omitted; painite "is prized by collectors".

Probably there are two reasons for this sorry state of affairs: one seems to be a language/translation/printing problem (the original language was Persian) over which the author has been wretchedly served by his proof-reader, whose name unwisely appears in the preface; the other being the difficulty of distinguishing between a dictionary and an encyclopedia – all dictionaries of gemmology, and probably every other subject, suffer from this and it is hard to see how it could be avoided. To be sure, the author has put a great deal into the book, but if a fairly quick read-through turns up so many examples of ignorance or carelessness, how can you trust the remainder of the text?

At so high a price (and the production is nothing to write home about – the paginator nodded off with the tedium of the text?) the publishers should have ensured that the author was at least served by people who knew what they were doing. Possible purchasers beware! M.O'D.

Gem and jewelry pocket guide

R. Newman, 2001. International Jewelry Publications, Los Angeles. pp 156, illus. in colour, softcover. ISBN 0 929975 30 8. US$11.95.

The book measures 18 x 11 cm and will fit into a bag or pocket. It is subtitled *A travelers guide to buying diamonds, colored gems, pearls, gold and platinum jewelry* and the text accurately fulfils this stated aim. As always with this author, the presentation is immaculate and each opening displays high-class pictures of gemstones and jewellery. The book opens with a succinct account of how items are priced, this including a note on how to make best use of the lighting conditions prevailing when a stone is examined. Treatments, synthetic and imitation stones are described next, before the book's largest section in which the major gemstones and organic materials are discussed, followed by consideration of gold and platinum jewellery.

An excellent chapter lists and comments on marketing terms and euphemisms: I was interested to see the adjective *faux* used with pearls to denote imitation pearls – I have seen it used with inorganic materials too and would be interested to know the significance. The reader can learn how to buy, how to choose an appraiser, scrutinize laboratory reports, deal with customs, consult a list of useful web sites and find out who will supply jewellery for photographs – and much more. There is still room for a useful bibliography and for short identification tables. Short guides don't come better than this. M.O'D.

Treatments

B. Sechos, 2000. National Council of Jewellery Valuers, Sydney (PO Box Q605, QVB Post Shop, Sydney NSW 1230, Australia). pp 10, illus. in colour, softcover. Price on application.

An attractively illustrated and concise booklet on the various gemstone treatments likely to be encountered by

the jewellery valuer today, and forming the printed accompaniment to a series of lectures given in each of the Australian capital cities. Though not intended as a stand-alone publication, it none the less fulfils that task very well and would form an excellent and topical background to most courses likely to be held today. M.O'D.

Diamond clarity grading

B. SECHOS, 2000. National Council of Jewellery Valuers, Sydney (PO Box Q605, QVB Post Shop, Sydney NSW 1230, Australia). pp 24, illus. in colour, softcover. Price on application.

Useful and well-illustrated lecture notes designed to accompany a lecture tour held in Australian capital cities, but standing alone perfectly adequately as a simple introduction to diamond clarity grading. The photographs show what is needed and the text gives many useful hints on practice which would serve the grader very well. Examples of certificates are given. A separate sheet, '*SPEED*', outlines five steps involved in clarity grading – Squares of the table (symmetrically aligned?), Point of the culet (open or chipped: are facet edges offset?), Eye (does the specimen show a fish-eye?), Edge and girdle (is the stone round or the girdle too thin, etc?), Depth percentage (how to work out total depth %). M.O'D.

The star and cross polyhedra (forms part 4 of The complete? polyhedra)

P. TAYLOR, 2000. Nattygrafix, Ipswich. pp 78, softcover. ISBN 0 9516701 5 8. £6.00.

Readers with an interest in shapes and forms will welcome the continuation of architect Patrick Taylor's study of the complete? polyhedra. The diagrams and text are very well produced, star and cross forms being the chief topic this time. M.O'D.

Turmalin 2000. Katalog zur Ausstellung im Deutschen Edelsteinmuseum Idar-Oberstein vom 19.2 bis 27.8.2000

Deutsches Edelsteinmuseum, Idar-Oberstein, 2000. (*Editions des Deutschen Edelsteinmuseum Idar-Oberstein, Bd 3.*) pp 96, illus. in colour, hardcover. ISBN 3 932515 22 6. Price on application.

One of a series of small-scale multi-author guides issued by the German Gemstone Museum at Idar-Oberstein, this book would serve many different interests as an introductory guide to the tourmaline group of minerals and the ornamental potential some of the individual species possess. The illustrations are especially good and well worth buying the book for on their own. In addition there are discussions of crystal structure, composition, properties and of the major locations of gem-quality material. The account of the causes of colour is particularly interesting. Each chapter has its own list of references. The book was published to accompany an exhibition held in 2000: I should like to have visited it! M.O'D.

Structure of crystals (3rd revised edn.). Modern crystallography 2

B.K. VAINSHTEIN, V.M. FRIDKIN and V.L. INDENBOM, 2000. Springer, Heidelberg. pp xx, 520, hardcover. ISBN 3 540 67474 8. £68.50.

The excellent series *Modern Crystallography*, with four titles, is now passing into its third edition with the virtually evergreen major text by Professor Boris K. Vainshtein and his co-authors: sadly Professors Vainshtein and Indenbom have died, but have left a fine work behind them and in good hands. This second volume of the four-volume series deals with crystal structure, the first with crystal symmetry. The bibliography has been brought up-to-date and there has been some addition to the text, notably in the timely revision of some of Vainshtein and Indenbom's chapters. M.O'D.

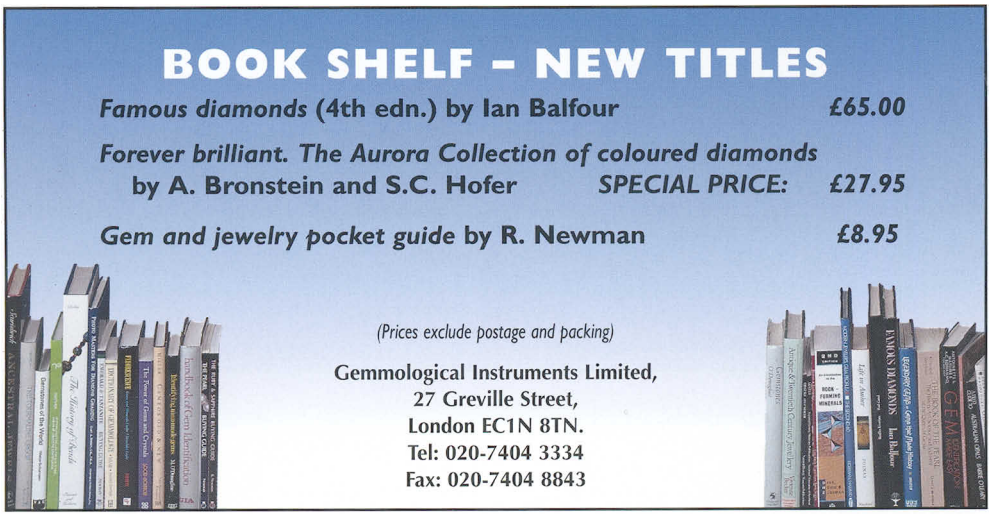

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Proceedings of the Gemmological Association and Gem Testing Laboratory of Great Britain and Notices

OBITUARY

Eric Moore Bruton
President 1994-1996

Eric Bruton of Great Bentley, near Colchester, died on 8 December 2000 at the age of 85. He was well-known for having 'cracked' the secret code of the international Diamond Bourses and Clubs for pricing polished diamonds. He set up courses to teach grading and pricing at the Sir John Cass College in London. The international diamond industry knew him through his textbook *Diamonds*, and he was also recognized as one of the primary writers of books for clock and watch collectors.

Eric was born in 1915 in London. He began his writing career with Iliffe & Sons on a weekly newspaper devoted to transport, before joining a small group of specialists at George Newnes Ltd. producing *Practical Mechanics, Practical Motorist, Practical Wireless*, etc.

During the Second World War he held a commission in the engineering branch of the RAF in charge of technical training, spending some of the time in India. After the war he returned to writing, the most significant event in his life at this time being an offer in 1947 to edit four specialist publications and specialized books after the owner and publisher had succumbed to a severe heart attack. These were the *Industrial Diamond Review, Horological Journal, The Gemmologist and Goldsmiths' Journal*, which were outside his range of knowledge. Immediately he threw himself into as many courses as possible, from silversmithing at the famous Central School of Art and Crafts to horology by correspondence course and gemmology at Chelsea Polytechnic, qualifying for his FGA in 1950.

During this time he married Anne Britton, a fiction editor and author, and started writing books more seriously, the first of these being a crime book set in an old printing works. Thirty-two more books followed over the years, the first eleven crime fiction and the rest serious books mainly on gemmology and antique clocks and watches. One book on automation was chosen by

Eric Bruton in 1997 presenting the Bruton Medal to the first medallist, Rita Tsang Wai Yi of Hong Kong. © Peter Dyer Photographs Ltd.

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the government to be distributed to developing countries along with others on fundamental modern issues.

In 1960 he became a director of a subsidiary publishing company of Thomson International and saw an opportunity to start a colour newspaper, *Retail Jeweller*, in 1962. It was the first publication originated in the Thomson Organization (the rest had been bought) and, having eliminated the competition, remains today the only UK trade publication in the jewellery industry. The experience encouraged him to join the jewellery trade itself in 1967 by founding the Diamond Boutique in Maidenhead, designing, making and selling precious jewellery.

Eric began to devote most of his time to diamonds, some of it visiting diamond and gem mines in all parts of the world, many in almost inaccessible places, where it was noted that the prospectors and miners, and elsewhere the geologists, engineers, crystallographers, sorters and graders, cutters and polishers, brokers and dealers, wholesalers and retailers, knew little of each other's activities although they depended so much upon each other. With this in mind, he carried out a systematic study of all aspects of diamond, especially gem quality, getting to know all the key people in the industry at the time. Then he wrote the comprehensive book *Diamonds*, which remained the international standard work from 1970 to recent times, despite various attempts to supersede it.

In 1997 the GAGTL introduced the Bruton Medal; this is awarded to the candidate who submits the best paper in the Gem Diamond Examination which, in the opinion of the Examiners, is of sufficiently high standard to merit the award.

Over the years Eric Bruton was active on the executives of the British Horological Institute, the Gemmological Association, and the Crime Writers Association, as well as in two City Livery Companies, also becoming President of the National Association of Goldsmiths and later of the GAGTL. He received various awards including one from the Worshipful Company of Goldsmiths and two from America for outstanding contributions to scientific horology and gemmological literature respectively.

* * *

Norman V. Clarke (D.1983, DGA 1996) of Cockburnspath, Berwickshire, died suddenly on 1 September 2000. Norman's interest in all things gemmological stemmed from knowledge of electronic instrumentation and a fascination for geology, and was a 'mature' student when he started his studies.

Sigurd G. Olsen (D.1954 with Distinction), Bergen, Norway, died recently.

John Lewis Toole (D.1965) of South Delta, BC, Canada, died on 19 October 2000.

PHOTO COMPETITION 2001

Born yesterday

Gemstones are mined, cut and refashioned every day, with many more stones being 'created' in laboratories around the world. To celebrate the new Millennium, submit your picture of a gemstone 'born' (or even 'reborn'), loose or set in jewellery, during 2000.

All entries will be judged for originality, beauty and gemmological interest.

The following prizes, sponsored by Harley Advertising Ltd., Bristol, will be awarded:

First Prize £100

Second Prize £75

Third Prize £50

The closing date for the Competition is *30 April*.

MEMBERS' MEETINGS

GAGTL Conference 2000

The Annual Conference was held on Sunday 29 October at the Barbican Centre, London. A full report was published in the December 2000 issue of *Gem & Jewellery News*.

London

On 17 November at the Gem Tutorial Centre, 27 Greville Street, London EC1N 8TN, Greg Sherman and Branko Deljanin gave an illustrated lecture entitled *A new process to modify colour of natural (and synthetic) diamonds.*

On 23 November at the Gem Tutorial Centre Helen Fraquet gave a talk entitled *Amber – has the bubble burst*? Those present were able to examine a number of samples of natural and treated amber.

Midlands Branch

On 29 September at the Earth Sciences Building, University of Birmingham, Edgbaston, a *Gemmology and Gem Testing Quiz* was held.

GIFTS TO THE ASSOCIATION

The Association is most grateful to the following for their gifts for research and teaching purposes:

Professor Hermann Bank, Kirschweiler, Germany, for an alexandrite crystal.

Richard Burton for two botryoidal tourmalines.

Dennis Durham, Kingston upon Hull, East Yorkshire, for a collection of gemstones including tourmaline, garnet, andradite, scapolite, onyx and chalcedony.

Eddie Fan, Hong Kong, for seven samples of jadeite from a new locality in Myanmar.

John R. Fuhrbach, Amarillo, Texas, for a large parcel of Zambian amethyst cobbled rough.

Hassan Hamza, Kotugodella, Sri Lanka, for one blue and two pink sapphires.

Janice Kalischer, Finchley, London, for a selection of stone-set jewellery.

Ioanna Lalaounis Tsoukopoulou, Athens, Greece, for a copy of *Artists' jewellery in contemporary Europe. A female perspective?*

Ing. Romario, Monza, Italy, for a copy of his book *The Iron Crown and Imperial Europe.*

Dr John Saul, Paris, France, for four pieces of Libyan desert glass.

Shen Feng, Director of the National Laboratory of China, Beijing, for a silver, gold, quartz and gem-set pendant.

A.E. Ward & Sons Ltd., London, for synthetic amethysts and colour-change corundums.

Professor Grazia Zini, Ferrara, Italy, for a collection of cut and rough stones and a Ferrara guide book.

On 27 October at the Earth Sciences Building, Stephen Dale, Director of Tessier, gave an illustrated talk on the works of Peter Carl Fabergé.

On 24 November at the Earth Sciences Building, Michael O'Donoghue gave a talk entitled *Minerals of Pakistan.* There was a display of specimens, plans of mines, mine reports and prospects, and published and unpublished literature.

The Branch's 48th Annual Dinner was held on Saturday 2 December at Barnt Green.

North West Branch

On 18 October at Church House, Hanover Street, Liverpool 1, David Lancaster gave a talk entitled *Minerals and gems at the Great Exhibition of 1851.*

The Branch AGM was held on 15 November at Church House, at which Irene Knight, Deanna Brady and Dr John Franks were re-elected Chairman, Secretary and Treasurer respectively. The AGM was followed by a talk by John Pyke Snr entitled *Gem collection and anecdotes.*

Scottish Branch

On 31 October at the British Geological Survey, Murchison House, West Mains Road, Edinburgh, Brian Jackson gave a talk on *Pegmatite minerals.*

On 20 November at the British Geological Survey, Greg Sherman and Branko Deljanin gave an illustrated lecture entitled *A new process to modify colour of natural (and synthetic) diamonds.*

PRESENTATION OF AWARDS

The Presentation of Awards gained in the 2000 Examination was held at Goldsmiths' Hall, Foster Lane, London EC2, on Monday 30 October, despite the storms and flooding which affected many parts of the UK.

Jeffery Monnickendam, a member of the GAGTL Council of Management, presided and welcomed those present, particularly those students who had travelled from as far away as Hong Kong, India, Japan, Kenya and the USA, and those from many European countries. He announced that in January and June 2000 a total of 744 students entered the Gemmology Preliminary and Diploma, and the Gem Diamond Examinations. A total of 100 students qualified in the Diploma examination and 85 students passed the Gem Diamond Examinations.

Jeffrey Monnickendam introduced Alan Collins, Professor of Physics at King's College London and President of the GAGTL, who presented the awards before he delivered his

Neil Rose receiving the Bruton Medal awarded to the best candidate in the Gem Diamond Examination. Neil was the Tully Medallist in 1994. © Peter Dyer Photographs Ltd.

address (see below). A vote of thanks was given by Ian Thomson, who concluded the proceedings by thanking the Goldsmiths' Company for kindly permitting the GAGTL to hold the ceremony at the Hall.

Address by Professor Alan Collins

Tonight's presentation of awards ceremony is the second of the official functions in which I have been involved since being elected as President of the Gemmological Association; both within little more than 24 hours. Yesterday I was delighted to chair the morning session at the Annual Conference.

As you know, I am not myself a gemmologist; my subject is physics. But for many years I have studied the physics of colour centres in diamond. During that time some of my work has been of relevance to the gem trade, and I have had a very fruitful interaction with the Gemmological Association. As a result, I have certainly learned many things about diamond that I would not have known if I had just stuck to physics. Even so, I had not expected to be asked to serve a term as President of the Association, but I am very pleased to have been asked, and I look forward to following in the footsteps of the distinguished presidents who have preceded me.

I am sure that many of you, like me, have sometimes found yourselves at a social function talking to someone that you don't know, and usually one of the questions that comes up is "What sort of work do you do?" I used to reply, "I am a physicist," but I found from experience that that was an excellent conversation-stopper; many people are not very sure what physics actually is, and simply don't know what to say next; others respond, often with a sense of pride, saying that they failed physics at school; and I had one dear lady who asked me to have a look at a rash on her arm. And so, nowadays, if someone asks me what sort of work I do, I tell them that I carry out research on diamond. I think here I may be following the example set by my younger daughter; many years ago when she was in junior school she had to write down what her parents did. She was not really very sure what my work entailed, and, in any case, it sounds jolly boring to say that your father is a university lecturer, and so she wrote "My daddy is a diamond merchant."

Diamond is exciting

But you see, everyone has heard of diamond; everyone thinks they know something about diamond. Diamond is exciting, diamond is glamorous; diamond is Shirley Bassey singing 'Diamonds are forever' in the James Bond film of the same name. Diamond is Marilyn Monroe singing 'Diamonds are a girl's best friend' in the film 'Gentlemen prefer blondes.' Most of you who have received your awards this evening are too young to have seen that film, but those of you who have will, I am sure, agree with me that Marilyn looked a lot better than she sang. And that's why, almost 40 years after her very sad death, pictures of Marilyn Monroe are still used to illustrate articles written about diamonds.

Dr Louise Joyner receiving the Anderson-Bank Prize from Professor Alan Collins. © Peter Dyer Photographs Ltd.

Research

One of the next questions that people often ask is "How long have you been doing research on diamond?" and when I reply "37 years" many of them simply cannot believe it. They will say "How on earth can you spend 37 years doing research on diamond?" Now, of course, as a member of staff in a university, I spend only part of my time on research, but even so, to many people – particularly those who are not scientists – it sounds incredible that someone could be interested in the same material for such a long time. However, those of you who have collected your certificates this evening, particularly those of you who are starting out in your careers, will find that, in the field of gemmology, there is always something new. There may be a new location where a particular gemstone is found; there may be a new way of making the gem material synthetically; there may be new simulants that look more like the real thing; there may be different types of treatment to enhance the appearance of the gemstone; there will be new types of instrumentation which will enable research workers to learn more about the material and better able to detect if it has been treated. And so, whether you are involved in production, in sales, in research, or whatever, what you have learned in your gemmology courses is just the beginning.

In my research, I began by looking at what is called 'Type IIb' diamond. Those of you who have done the Gem Diamond Diploma will know that natural type IIb diamonds are very rare, and can have a beautiful blue colour, like the Hope Diamond and the Eugenie Blue, which are both in the Smithsonian Museum. Unlike all other diamonds, type IIb diamonds conduct electricity, and it was the electrical properties that we were interested in, although it was also necessary to study the diamonds by optical spectroscopy.

Artificially coloured

At about the same time, diamonds that had been artificially coloured using radiation damage were coming onto the market, and one afternoon – I suppose it would have been in the late 1960s – the head of our research group brought a gentleman into the laboratory who had a large pear-shaped blue diamond, and wanted to know whether it was naturally or artificially coloured. The gentleman was Basil Anderson, who was then Director of the London Gem Testing Laboratory and regarded as one of the world's most distinguished gemmologists. He was a graduate of King's College London, and knew that there was a diamond research group in the Physics Department. And so he brought the stone down to the Strand to see if we could do anything with it. Anderson hovered around anxiously while we stuck his diamond into a lump of plasticene and lashed it in front of the spectrometer; then, after half an hour or so, we were able to tell him that the stone was artificially coloured. I don't remember his reaction, and in those days I was certainly not aware of the huge difference in the value of a natural blue diamond and a treated blue diamond.

Preliminary Trade Prize and Anderson Medal winner Helen Dimmick receiving her awards. As Helen was unable to attend the Presentation of Awards because of the severe weather conditions, Professor Alan Collins presented the Medal and Prize to her at the meeting held at the Gem Tutorial Centre on 17 November.

Diamond synthesis

It was also in the 1960s that the first synthetic diamonds became available for study by research groups. These were not the sort of specimens that nowadays worry the gem trade; most of them were less than 1 mm across. Nevertheless, they were large enough to make measurements on, and it soon became clear that, while many of the properties of synthetic diamond were the same as those of natural diamond, there were important differences. Much of this early work is still relevant to the gem trade today. Although the first synthetic diamonds were very small, in 1970 General Electric described a method for manufacturing large gem-quality synthetic diamonds. Initially this caused some anxiety in the gem trade, but it soon became clear that it was cheaper to dig gem-quality diamonds out of the ground than to synthesise them in the laboratory.

NEW PRIZES FOR STUDENTS

The Christie's Prize for Gemmology

The Council of Management is pleased to announce that Christie's have agreed to sponsor the prize awarded to the student who achieves the best marks in the Gemmology Diploma Examination and whose main source of income is in the jewellery trade. It will be called the Christie's Prize for Gemmology. The GAGTL is most grateful to Christie's for this expression of support for excellence in gemmological studies and it underlines a continuing positive attitude towards the value of education.

The Deeks Diamond Prize

The Council is also most grateful to Noel Deeks, for many years a Council member, for the funding of a prize to the student who gains the highest marks in the Gem Diamond Diploma Examination, to be named the Deeks Diamond Prize. Some years ago, Noel taught the diamond course when it was only available to FGAs, but latterly he has been developing instruments to make identification of diamonds and other gems easier.

It is a pleasure to acknowledge this support and the prizes will be added incentives to our many students.

I've already mentioned the artificial coloration of diamond. Research in the 1950s had shown that radiation damage will colour a diamond blue or green, and the diamond that Anderson had brought down to King's had been treated in that way. If such a diamond is then heated to around 800°C the absorption band that produces the blue/green colour disappears and, in most cases, a new absorption band is produced which gives the diamond a yellow colour. For producing fancy-coloured diamonds for the gem trade this is all that it was necessary to know, but in the 1970s physicists began to ask: "What happens if irradiated diamonds are heated to higher temperatures?" and "What happens if synthetic diamonds are heated to very high temperatures (up to 2000°C, or higher)?". This was just curiosity-driven research, but it led to important revisions in the criteria for recognizing diamonds that had been artificially coloured and also to a much better understanding of the differences between natural diamonds and synthetic diamonds.

There isn't time to dwell on all the significant developments in diamond research, but if we move forward to the 1980s, two important announcements from Japan initiated a huge increase in the amount of research carried out world-wide on diamond. One was the claim by Sumitomo that they were able to grow large synthetic diamonds at a cost that was competitive with that of natural diamonds; the other was the revelation that large-area diamond films could be produced by chemical vapour deposition – a process in which a gas containing carbon is decomposed to form diamond. It is the Sumitomo work that has had most impact on the gem trade, and there have been numerous articles comparing the properties of synthetic gem-quality diamonds and natural diamonds.

HPHT treated diamonds

There are now several laboratories and commercial organizations which have the high-pressure high-temperature (HPHT) equipment needed to manufacture large synthetic diamonds. The reason why this is very significant follows from the extraordinary developments announced in the final year of the twentieth century. First General Electric and Lazare Kaplan International showed that they could take natural brown diamonds (which are relatively inexpensive) and convert them to near-colourless or possibly pink or blue specimens. Then, less than a year ago, a company called NovaDiamond showed that some low-quality brown natural diamonds could be converted into fancy yellow and fancy green colours. How is it done? They use the same HPHT equipment that is used to produce synthetic diamonds, but the process is very much quicker than growing a gem-quality stone, and so is much more profitable. I don't remember any topic in diamond research generating so many publications in such a short space of time, and most of these are in the gemmological literature. For me, one of the most satisfying things has been that much of the curiosity-driven research carried out over the last twenty years or so is now allowing us to understand why the HPHT treatment changes the colour of the diamonds, and to devise methods to check whether diamonds have had their properties changed in this way.

I've described just a few examples from the field of diamond research to illustrate the way that interesting and challenging new developments continually occur. I am sure that all of you who are newly qualified in gemmology, or some specialised aspect of gemmology, will have many interesting and challenging years ahead of you, and I wish you all every success.

FORTHCOMING EVENTS

1 February	**London**. *Psst! Wanna buy a diamond, guv? STEPHEN WHITTAKER*
21 February	**Scottish Branch**. *The quest for Scottish diamonds. JOHN FAITHFULL*
23 February	**Midlands Branch**. *The garnet group – understanding solid solution. PROFESSOR DR HENRY HÄNNI*
1 March	**London**. *Gemstones from the Hindu Kush. GUY CLUTTERBUCK.*
21 March	**North West Branch**. *Jewellery of the Art Nouveau era coupled with the art of René Lalique. DAVID CALLAGHAN*
22 and 23 March	**London**. *Visits to De Beers.*
30 March	**Midlands Branch**. *The Toyshop of Europe. SHENA MASON*
27 April	**Midlands Branch**. *A new combination gemstone finger-printer and high RI refractometer. DR JAMIE NELSON. This meeting will include the Branch AGM.*
3 May	**London**. *My 40 years with gems. DR KURT NASSAU*
4-7 May	**Scottish Branch Conference**. Queen's Hotel, Perth. The programme will include: *ULRIKA AL KHAMIS. Averting the Evil Eye: Semi-precious stones in Islamic culture* *RICHARD DRUCKER: Coloured stone guide. Gemstone values: sources of reference* *ERIC EMMS and ANA CASTRO. D is for Gemmology* *CALLY OLDERSHAW. Gem collections of the Natural History Museum: tales behind the gems* *The Conference will also include a workshop session and a field trip.*

For further information on the above events contact:

London	Mary Burland on 020 7404 3334
Midlands Branch:	Gwyn Green on 0121 445 5359
North West Branch:	Deanna Brady on 0151 648 4266
Scottish Branch:	Catriona McInnes on 0131 667 2199

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For up-to-the-minute information on GAGTL events visit our web site on www.gagtl.com

MEMBERSHIP

The following have been elected to membership during September, October and November:

Fellowship and Diamond Membership (FGA DGA)

Cubbins, Graham, Marton, Blackpool. 1999/2000
Kampiotis, George, Athens, Greece. 1996/1997

Fellowship (FGA)

Ascot, Leon, Ruschlikon, Switzerland. 2000
Berner, Peter, Gelterkinden, Switzerland. 2000
Berry, Shoshana, Salisbury, Wiltshire. 2000
Blomquist, Eva, Jönköping, Sweden. 2000
Canty, Jess, London. 1987
Chokshi, Shivang Rajnikant, Gujarat, India. 2000
Chow, Suet Lai, Shatin, Hong Kong. 2000
de Landmeter, Edward, Soesterberg, The Netherlands. 2000
Dowling, Siobhan Loyola, Canary Wharf, London. 2000
Droesser, Niklas Bernd, Leverkusen, Germany. 2000
Fok Ki Yu, Lantau Island, Hong Kong. 2000
Gemin, Nadine, St Julien-en-Genevois, France. 1994
Ho, Anna, NT, Hong Kong. 2000

Ho Sau Lan, Hong Kong. 2000
Ho Sau Wa, Ma On Shan, Hong Kong. 2000
Hung Tin Man, NT, Hong Kong. 2000
Kim, Jungshin, Seoul, South Korea. 2000
Ladak, Nelina, London. 2000
Lamarre, Claude, Lasalle, Quebec, Canada. 2000
Li, Mary, Vancouver, B.C., Canada. 2000
Lichtsteiner, Patrick, Ormalingen BL, Switzerland. 2000
Lo Hung Kin, Macau, China. 2000
Mason, Stephen Richard, Sutton Coldfield, Warwickshire. 2000
Matheson, Eric Ross, Vancouver, B.C., Canada. 2000
Mohideen, Mohamed Fazal, Colombo, Sri Lanka. 1989
Ng, Bianca Suen Lam, Hong Kong. 2000
Oksanen, Tarja Kaarina, Helsinki, Finland. 2000
Pagel-Theisen, Verena, Kronberg, Germany. 1966
Pajor, Matthias Valentin, Gelterkinden, Switzerland. 2000
Price, Sharron Ann, Rowley Regis, Birmingham, West Midlands. 2000
Punchihewa, Leslie Joseph, Colombo, Sri Lanka. 1983
Rathwell, Eden L, California, U.S.A. 2000
Rockman, Gary, Bromley, Kent. 2000
Roelofs, Esther Wendy, Schoonhoven, The Netherlands. 2000
Solomou, Andreas, Lykavitos, Cyprus. 2000
Smith, Wendy, London. 2000
Telfer, Corin, Rickmansworth, Hertfordshire. 2000
Terrell, Celia, Witherley, Warwickshire. 2000
To, Flora L.H., Kowloon, Hong Kong. 2000
Tock, Bryon, Ilkley, Yorkshire. 1990
Tolmie, Nigel Lester, Stratford-on-Avon, Warwickshire. 1975
Tuckwell, Alice Elizabeth, Untersiggenthal, Switzerland. 2000
Verhoeven, Pia M.C., Nijmegen, The Netherlands. 2000
Wang Yiren, Shanxi Province, P.R. China. 2000
Willis, Kathryn, Palmers Green, London. 1996
Wong, Rebecca Lai King, Ontario. 2000
Ziemelis, Ojars, Akersberga, Sweden. 1988

Diamond Membership (DGA)

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Barker, Nicola, Horsmonden, Kent. 2000
Bicknell, Tim, Winchmore Hill, London. 2000
Brady, John Joseph, Swadlincote, Derbyshire. 2000
Chan Har Wei Carrio, Kowloon , Hong Kong. 2000
Christoulakis, Theodore, Athens, Greece. 2000
Damalis, George Herodotou, Winchmore Hill, London. 2000
Harrison, Helen Tynan, Yellowknife, N.T., Canada. 2000
Kaprili, Maria, Athens, Greece. 2000
Lao Ieng Kit, Hong Kong. 2000
Latsoudis, Sofia, Crete, Greece. 2000
Lazaridis, Lazarus, London. 2000
Lee Hing Fan, Shatin, Hong Kong. 2000
Long Sin Sai, Macau, China. 2000
Makri, Helen, Upper Tooting, London. 2000
Ng Mei Hang, Hong Kong. 2000
O'Neill, Michelle Ann, Northfield, Birmingham, West Midlands. 2000
Panidis, Lydia, Elefsina, Greece. 2000
Rutter, Fay, Walsall, West Midlands. 2000
Seitanidis, Nikolaos, Katerini, Greece. 2000
Stamatakis, Zoe, Athens, Greece. 2000
Tong Tat Wah, Sheung Shui, Hong Kong. 2000
Zagana, Aphrodite, Athens, Greece. 2000

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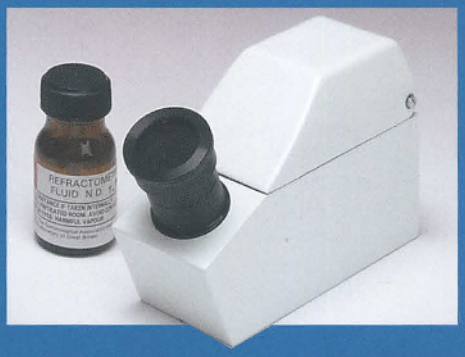

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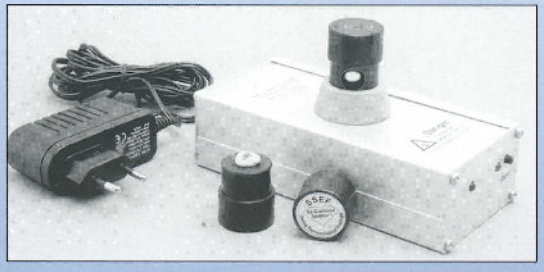

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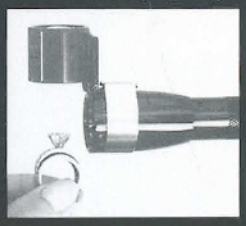

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Title page The title should be as brief as is consistent with clear indication of the content of the paper. It should be followed by the names (with initials) of the authors and by their addresses.

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Abbreviations for titles of periodicals are those sanctioned by the *World List of scientific periodicals* 4th edn. The place of publication should always be given when books are referred to.

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The 'Light-tree-water-being'

The colour and inclusions of the aquamarine inspired the creation of this piece of jewellery by Elena Villa. See Santa Maria aquamarine p. 257. Photo by Bob Maurer.

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The Journal of Gemmology

Volume 27 No. 6 April 2001

Hte long sein

Gemstones of Peru

Gem quality clinohumite

Colour of diamonds

The Gemmological Association and Gem Testing Laboratory of Great Britain

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Hte long sein – a new variety of chrome jadeite jade

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2. *China University of Geosciences, Wuhan, China*

ABSTRACT: A new variety of chrome-jadeite jade called 'hte long sein' is described. The origin of the name is given and the gemmological properties, chemical composition and IR spectrum described. Its main features compared with traditional jadeite jade are evenness of colour, relative coarseness of grain and opacity.

Introduction

At the 27th Rough Auction held at the end of March 1999 in Yangon, Myanmar, the participants did not expect to see nearly a hundred piles of jadeite rough ranging from full green to bright medium emerald green (*Figures 1 and 2*). It was classified in two grades: Grade A material was pure in colour and fine-grained with few fractures; Grade B was more coarsely textured and contained more fractures. The quality can be classified into five grades according to the colour, transparency, texture and clarity. All the grades are generally called hte long sein.

Hitherto, a few private dealers had sold hte long sein for quite high prices, but the floor prices for the lots at this auction were much lower and prompted the feeling that they were very good value – with comments such as 'glad tidings' and 'Gospel from Heaven' being heard! Consequently, bidding was fierce and ran from one afternoon until 4:00 a.m. the next morning, with some bids ten times the floor price for a particular lot.

In April 1999, several tonnes of full green hte long sein were shipped to Hong Kong, where it became the major topic of conversation – especially around the Canton Road where the dealers have long been involved with 'traditional' jadeite. Initially, some doubted that it was jadeite jade and some gem laboratories declined to issue identification certificates. The influx of such a large quantity of jadeite also raised fears of a slump in the jade market – so far, groundless.

Figure 1: *Hte long sein jadeite jade in Yangon auction in 1999.*

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Figure 2: A lens-shaped specimen of hte long sein jadeite jade.

The Hong Kong market soon saw a wide variety of hte long sein full green products including carved butterflies, autumn leaves, carved beadwork and bangles – all thin-based pieces to demonstrate the richness of the colours (*Figures 3 and 4*). Despite the misgivings of a few people, many welcomed the hte long sein to stir up a jade market they likened to a pond of stagnant water!

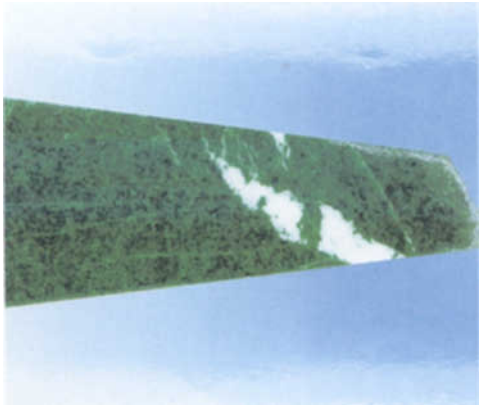

Figure 3: A polished slice of hte long sein jadeite jade.

Origin of the name 'hte long sein'

In 1994 a primary deposit of jadeite was discovered at Longkin worksite, north of Pharkant mining district, northern Myanmar. This jadeite had a full green colour and differed from the more familiar green vein or white jadeite with green spots or patches. This difference led to it being called 'hte long sein' – which means 'full green' in the local language. Later, the Chinese transliterated the name to 'tie long shen' or 'tian long sheng' which sounds close to the original Burmese.

Characteristics of rough hte long sein

Large-scale exploitation of the jade at Longkin started in 1997 and was jointly conducted by the Myanmar Government and private enterprise. However, production could only go to auction under the auspices of the government.

The hte long sein jadeite occurs in veins or lens-shaped masses up to 1 m across enclosed in amphibolite and the occurrences

Figure 4: *Jewellery fashioned in hte long sein jade: (a) dragonfly; (b) flower; (c) beads; (d) butterflies.*

commonly display the following pattern of zoning:

1. core of homogeneous, fine-grained pure green jadeite;

2. each margin consists of jadeite with a glistening mineral resembling hornblende; some veins have margins of white jadeite;

3. country rock of black amphibole and white plagioclase feldspar.

In general, hte long sein has a lovely bright green colour but is poor in transparency.

With this new knowledge about the primary deposit, it is now apparent that similar jadeite has been recovered from secondary deposits for many years, but only in very small amounts.

Gemmological characteristics

Many Hong Kong merchants with more than 20 years experience in the jade trade

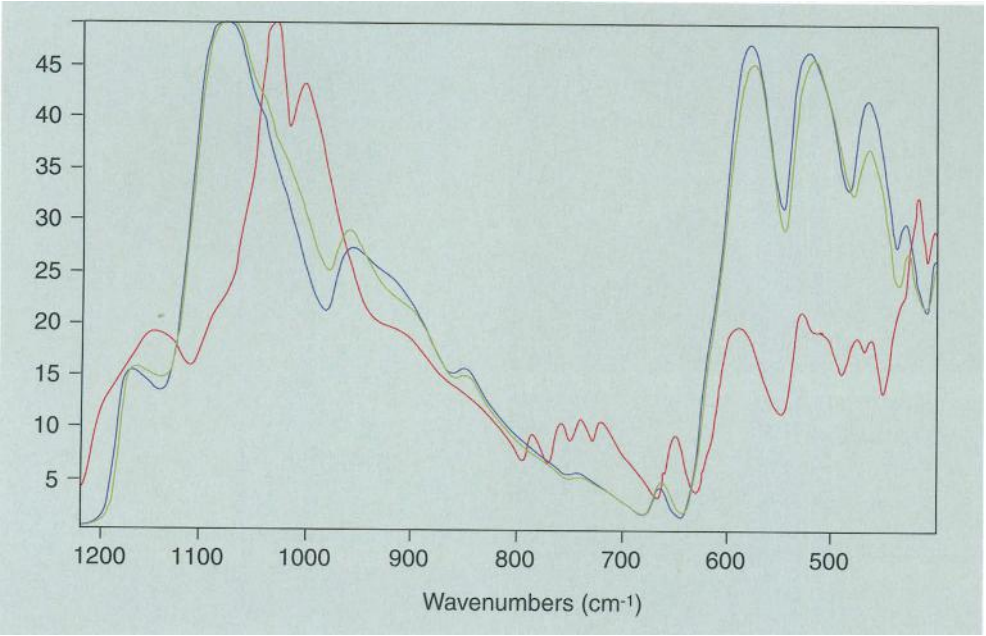

Figure 5: *Infrared spectra of jadeite jade (blue), hte long sein jade (green), and kosmochlor jade (red).*

consider hte long sein to differ significantly from their traditional material, the principal visible differences being the full green colour and 'looser' coarser texture. Its gemmological features are summarized thus:

Appearance: Bright medium green in different shades; some white spots, poor transparency; coarse to medium grained granular texture; the crystals have no preferred directional orientation but some specimens do contain crystals with some degree of preferred orientation. Because hte long sein is relatively opaque, its appearance can be made most attractive in pieces whose thickness is about 1 mm.

Specific gravity: Most specimens measured by the hydrostatic method had SGs of 3.30-3.31, floating in di-iodomethane, but there is some variation due to the coarse textures and variable contents of fine cracks. If the jadeite contains any of the glistening hornblende-like minerals, SGs are lower.

Refractive index: the average RI is 1.66 by the distant vision method.

Chelsea Colour Filter: Appears green under the filter.

Ultra violet radiation: inert under both long and short wave UV.

Infrared spectrum: reflectance infrared spectral measurements were made on ten samples and a typical spectrum is shown in *Figure 5*, green trace. Pure jadeite and kosmochlor spectra (blue and red traces) are shown for comparison, and the similarity of the hte long sein and jadeite traces is evident.

Laser Raman spectrum: laser Raman spectrum measurements were made on ten samples and a typical spectrum is shown in *Figure 6*, trace 2. Pure jadeite and kosmochlor spectra (traces 1 and 3) are shown for comparison, and the similarity of the hte long sein and jadeite traces is evident.

The petrology

In thin section (*Figures 7 and 8*), the hte long sein can be seen to consist of 80-98% jadeite. Some grains are colourless, others are pale green with distinct pleochroism from

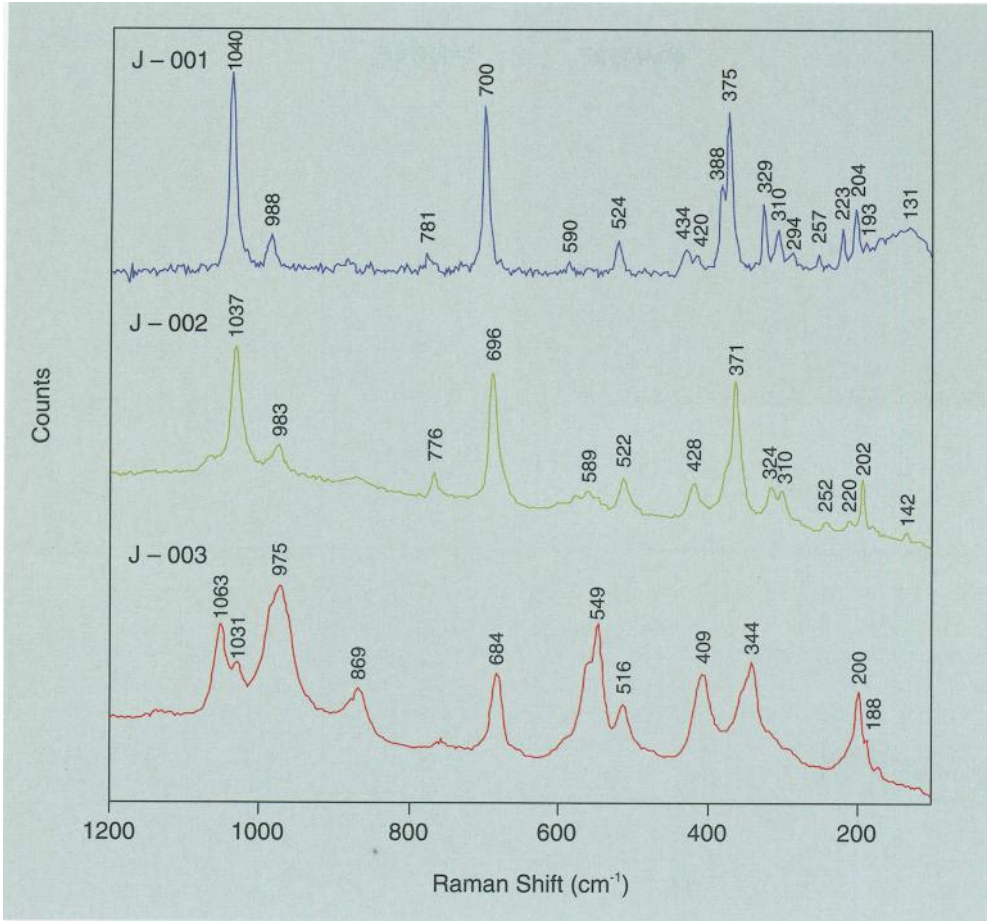

***Figure 6**: Laser Raman spectrum of pyroxene jade: J-001 jadeite jade; J-002 hte long sein; J-003 kosmochlor jade.*

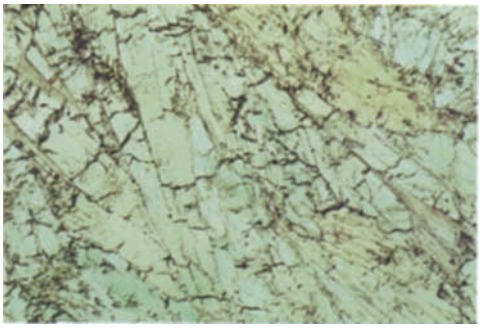

***Figure 7**: Prismatic chrome-rich jadeite in hte long sein jade displays bluish-green / light yellow pleochroism. Field of view 4.25 mm. Plane polarized light.*

***Figure 8:** Fine sub-parallel cracks are visible crossing the c-axis of prismatic crystals of chrome-rich jadeite in hte long sein jadeite jade. Field of view 4.26 mm across. Cross polarized light.*

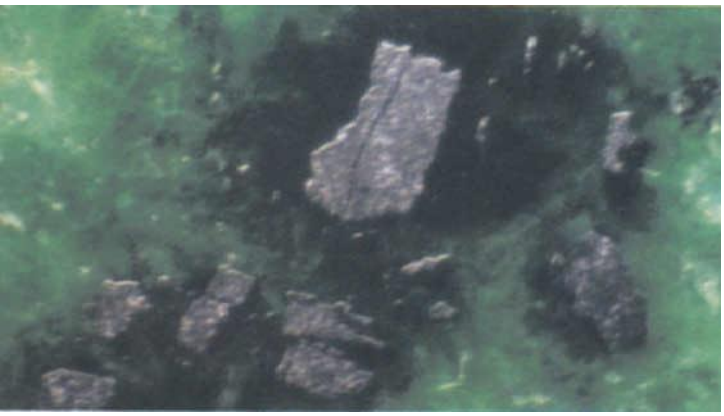

Figure 9: Chromite (black) residual crystal in hte long sein jadeite jade. Field of view 4.8 mm across. Plane polarized light.

light bluish-green to light yellow, and all have the typical pyroxene cleavages. Under crossed polarizers, the maximum angle of extinction from the *c* direction is 36°. In the hte long sein specimens containing chromite, the chromite crystals are residual (*Figure 9*), but the kosmochlor grains and the hornblende grains are holocrystalline, ranging from isogranular to prismatic crystalloblastic, mostly medium coarse grained but ranging from fine to coarse. Many crystals contain closely spaced cleavage cracks parallel to *c* but not continuous along the length of the crystal. Many also have fine cracks across the cleavages.

Chemical composition

The major and minor element contents of ten samples of hte long sein were determined by electron microprobe analyses and are summarized in *Table I*.

The analyses indicate small contents of Fe, Mg, Ca and Cr but the composition is essentially that of jadeite. In some specimens Cr content exceeds Fe. In others, the reverse is true. Technically, it should be classified as a chrome-jadeite jade.

Conclusion

Hte long sein is jadeite jade with between 0.33-2.61% Cr_2O_3, which provides a lovely bright green colour to the stone. It shows wide differences in gem quality, from high quality (fine grain, good transparency and more or less crack-free), to poor quality (very coarse grain, opaque and loose texture). However, most hte long sein on the market is of medium quality with medium grain and a patchy loose texture. Its rather poor transparency is due to abundant fine internal fractures which are probably also responsible for a slightly lower SG than expected for traditional jadeite. Some specimens are more fragile as a result of their loose texture. Such jadeite can be injected with epoxy resin to increase the transparency and enhance the colour to a more vivid emerald green. Such treatment may increase the apparent market value of the jadeite by enhancing its physical

***Table I:** Composition of hte long sein: range and mean of major and minor elements in ten samples.*

wt %	Range	Mean
SiO_2	55-60 - 59.42	57.99
TiO_2	0.05 - 0.70	0.23
Al_2O_3	18.81 - 22.14	20.73
FeO	0.31 - 1.76	1.14
MnO	0.00 - 0.13	0.04
MgO	1.12 - 3.78	2.33
CaO	1.15 - 5.08	2.79
Na_2O	12.70 - 14.87	13.71
K_2O	0.00 - 0.10	0.03
Cr_2O_3	0.33 - 2.61	1.20
NiO	0.00 - 0.03	0.00
Total		100.19

NB: Seven electron microprobe analyses were made by the Mineral Deposit Research Institute (China Academy of Geological Science) and three were made by the Testing Centre of China University of Geosciences, Wuhan.

appearance towards top quality jadeite jade, but can easily be detected by measurements of infrared spectra.

Further reading

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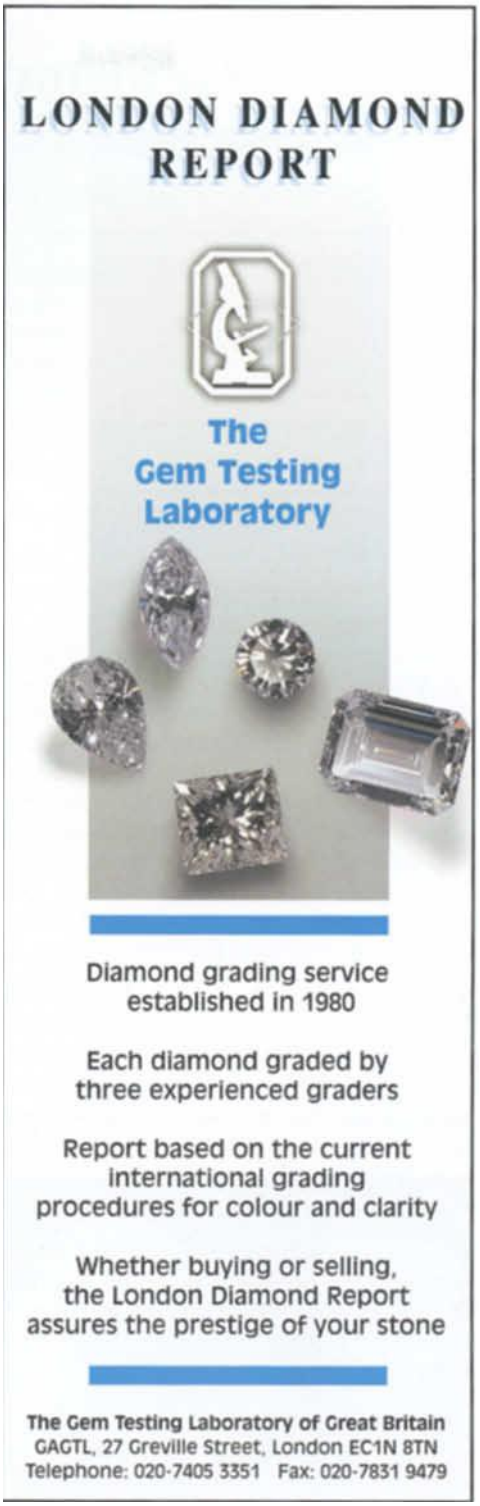

Gemstones of Peru

Dr Jaroslav Hyršl

Kolin, Czech Republic

ABSTRACT: Gem and ornamental stones from Peru are described. The most economically important gems are blue and pink opal, chrysocolla and silicified chrysocolla. Properties of various types of opalised or silicified chrysocolla are discussed. Massive rhodochrosite, aragonite, dumortierite and some rare stones are also described.

Keywords: blue opal, chrysocolla, gemstones, Peru, pink opal

Introduction

Although it has a long history of gemstone use, Peru is a country almost unknown in modern gemmology. Recently, however, there has been a notable production of ore mineral specimens (Crowley *et al.*, 1997). In the past, ancient Indians used many local decorative stones as well as sodalite from Bolivia, and the first Colombian emeralds, used by Incas and imported to Europe by Spaniards, were described as Peruvian by mistake.

This brief survey will deal with two main kinds of opal, stones under the general heading chrysocolla, rhodochrosite and then rare gems including more carbonates, a sulphate, sulphide, fluoride, tungstates and a glass. Finally, ornamental stones will be summarized.

During preparation of this article, it proved very difficult to establish exact localities of some materials. Peruvians are very secretive about origins of minerals and even more so where gemstones are involved. For this reason, some localities could probably be localized more correctly in future.

Figure 1: *Blue opal from Acari, cut stones 8.09 and 2.50 ct.*

Opal

Blue opal

The most interesting recent gemstone produced in Peru and used in local jewellery for at least 25 years, is a greenish-blue opal called 'Andean opal', which is recovered from veins with a thickness between 1 and 5 cm. It is usually translucent and inhomogenous with common black and brown dendrites, but rarely it can be almost transparent and yield very nice faceted stones. Unfortunately, some (but not all) stones turn milky after some time, perhaps a few weeks to months (*Figure 1*). Their transparency can be restored after immersion in water, but for a limited time only. The onset and development of milkiness is probably strongly influenced by humidity of the air surrounding the stone.

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The bluish colour is attributed to the presence of bivalent Cu (Koivula and Kammerling, 1991a), and in a recent study Fritsch *et al.* (1999) found inclusions of chrysocolla in this opal. The RI of the blue opal lies between 1.430 and 1.452 and some (but not all) cut stones may show a birefringence up to 0.005. The SG lies between 2.01 and 2.08, hardness is 5 and it is inert to UV light. Blue opal is collected in a copper mining area called Acari near Nazca in Arequipa department (see map *Figure 2*), where a variety of colourless dendritic opal is also found (Koivula and Kammerling, 1991b). The Czech mineralogist, V. Bouska, collected almost identical bluish opal with black dendrites in 1981 from a vein in Lower Pleistocene andesite volcanic rocks. These belong to the Barroso formation and occur on the SE slope of Misti volcano (5,822 m) near Arequipa; the recent production of blue opal is probably from the same geological position.

Figure 2: *Map of Peru showing the major gem-bearing areas.*

Pink opal

Reputedly the locality that produces blue opal also produces a pink translucent to opaque variety of opal in veins which are said to be very close to the chrysocolla mine (see p.330). The RI of the pink opal is 1.45 - 1.49, the SG is 2.16 - 2.22 and hardness is 6. Pink opal has a pinkish-white luminescence in LW UV and adjoining veinlets of colourless opal are bright green in SW UV. Very nice cabochons can be cut and strongly resemble pink coral (*Figure 3*); their size can exceed 5 cm.

Figure 3: *Pink palygorskite opal from Acari; the rough is 4 cm wide.*

Berdesinski *et al.* (1977) studied very similar pink 'opal' from unknown localities in Peru and Mexico, and found them to be composed of the rare clay mineral palygorskite. Their material from Peru had an RI of approximately 1.55 (higher than the new material) and SG of 2.18, and was accompanied by quartz with minor plagioclase, sericite, sanidine, apatite and ore minerals.

In the present investigation, several specimens of Peruvian blue opal, and pink opal from both Peru and Mexico, were subject to X-ray analysis and the results follow. Blue opal has two very broad peaks (*d*-spacing/intensities of 4.07/100 and 2.50/30) and both peaks are also prominent in pink opal from Peru and Mexico. However, the pink opal has additional broad palygorskite peaks (at 10.3, 4.28, 3.17 and 2.54Å).

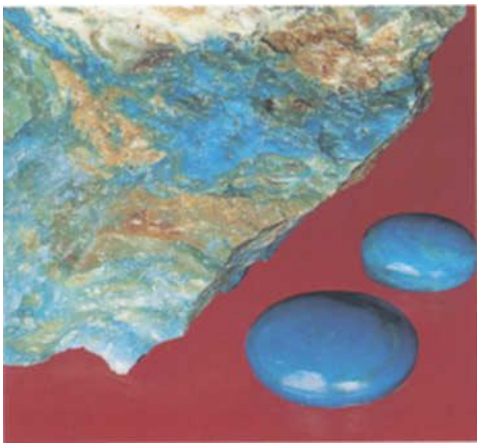

Figure 4: Blue chrysocolla from Acari, rough is 6 cm wide.

The Peruvian pink opal also has sharp quartz lines, which indicates that pink opal from Peru is a mixture of palygorskite, opal and chalcedony, whereas the Mexican material is a simple palygorskite-opal mixture. This also explains the difference in hardness, 6 for the Peruvian and 5 for the Mexican pink opal. There are also differences in associated minerals – Mexican pink opal grows with calcite and white felt-like palygorskite, whereas the vein of Peruvian pink opal is embedded in creamy-white massive rock, which is a mixture of opal and chalcedony (confirmed by X-ray diffraction studies). The cause of the pink colour in the opal is not known.

Figure 5: Bluish-green 'gem silica' from Lily; the rough on the left is 4 cm wide.

Chrysocolla

The Acari copper mine near Nazca in Arequipa department (close to the locality of blue and pink opals), produces a large volume of chrysocolla, a material much used in modern Peruvian jewellery, and known in Peru as 'turquesa' (turquoise), although true turquoise is still unknown in Peru. It is blue-green and very often mixed with green malachite. It does not occur with blue azurite. It is very similar to chrysocolla from Arizona as well as to the famous 'Eilat stone' from Israel (Kammerling *et al.*, 1995). A lot of this material was shipped to Israel in the past to be sold to tourists. The same ore district also produces massive blue covellite with pyrite veinlets, which is sometimes used for cabochons. Very probably from the same area comes the most important recent find in Peru – greenish-blue silicified chrysocolla, called locally 'gem silica' or 'silicia'. There are several types of this material. Blue-green opaque cabochons (*Figure 4*) have RIs 1.49 – 1.51, SGs of 2.27 – 2.30, hardness 4.5 and show a blue streak. The material is probably a mixture of chrysocolla with a small amount of opal. Better for use in jewellery is a greenish-blue opaque homogenous material with a bluish-green streak, with RI 1.54 – 1.57, SG 2.67 – 2.75, and hardness slightly more than 6. The best translucent material, with a hardness of almost 7, is very rare and is reported to be similar to the material from Morenci and other places in Arizona. Chrysocolla specimens with cavities covered by tiny quartz crystals have been used for special pieces of jewellery by some artists.

Another bluish-green to green translucent material (*Figure 5*), comes probably from Lily, a copper mine near Pisco (Hyršl and Rosales, 2000). It has an RI of 1.55, SG 2.61 – 2.65 and hardness 6.5. With magnification, a moss-like structure can be seen, some parts appearing more bluish and homogenous. Clusters of small, irregular quartz crystals and dark green flakes are typical inclusions (*Figure 6*). It is silica, probably chalcedony, and may be stained by traces of chrysocolla or other Cu-minerals (but not by Ni as in chrysoprase). The Lily mine was developed in about 1998

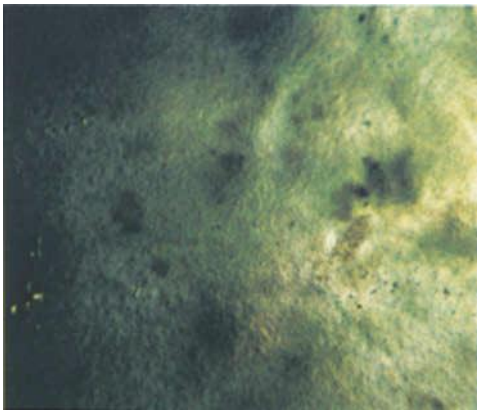

Figure 6: Small quartz crystals and yellowish-green flakes in 'gem silica' from Lily, magnified 10x.

and produces very beautiful specimens of colourless gypsum crystals with perfectly developed green atacamite and malachite inclusions (*Figure 7*), and quartz with rare embedded malachite crystals.

The most recent (spring 2000) source of various types of chrysocolla is another still unnamed but very promising prospect in mountains near Pisco, probably not far away from the Lily mine. This chrysocolla is usually porous, but some parts are hard enough to cut into cabochons. It is light blue to blue-green and some types strongly resemble turquoise. Nevertheless, their X-ray patterns show only two opal lines, comparable with the pattern shown by blue opal. The stones are too soft and porous to be cut, but after treatment (possibly with resin) they could be very appropriate for inexpensive jewellery. The locality has already produced small veinlets of top-quality 'gem silica', which is bright greenish-blue and homogenous. It has RI 1.54 and hardness 6.5, indicating that it is chalcedony stained by copper. All the chrysocolla types described above are inert in UV-light. X-ray diffraction data from opals and all types of 'silica' have been compared. These indicate that green-blue chrysocolla from Acari is silicified by opal, whereas blue-green and green silica from Lily, and from a new prospect, show only well-crystallized quartz lines indicating that they are chalcedony.

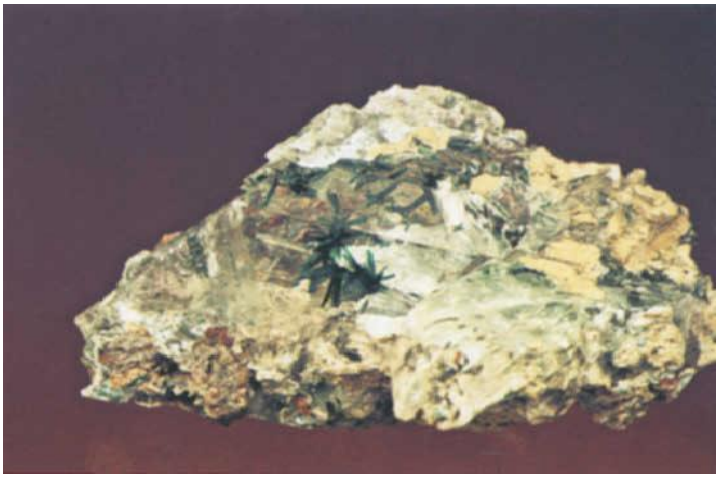

Figure 7: Atacamite crystals in gypsum from Lily, 50 x 25 mm.

Rhodochrosite

Other classic gemstones have not been found in Peru, but several rare minerals have been cut for collectors. The most famous is rhodochrosite, common in many Peruvian ore deposits. The best known of these are the most beautiful raspberry-red crystals growing on quartz druses associated with the tungsten deposit at Pasto Bueno. They are only rarely transparent and have a rhombohedral form. A large silver deposit at Uchucchacua, north of Lima, still produces red transparent crystals of mostly scalenohedral habit (*Figure 8*). The crystals are 2 cm or more long and are very similar to those already known from South Africa. Cut stones

Figure 8: Rhodochrosite crystals from Uchucchacua, width 6 cm.

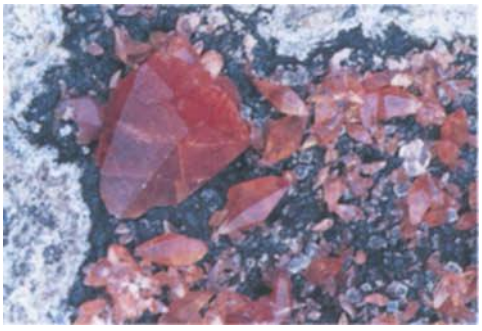

Figure 9: Rhodochrosite from Manuelita; the largest piece is 50 x 35 mm.

can exceed 3 ct. Massive rhodochrosite, useful for tumbling, has recently been recovered from veins at the Manuelita mine in the Morochata ore district. Some specimens have a layered structure similar to Argentinian rhodochrosite (*Figure 9*).

Rare gemstones

Koivula *et al.* (1992) described greenish-blue massive aragonite from a copper mine in Moquegua department. It was marketed under the name 'Victorite' and strongly resembles the better-known 'Larimar', which is pectolite from the Dominican Republic. Aragonite is semi-translucent, with RIs of 1.52 – 1.66, a high birefringence and SG of 2.75. Its colour is probably due to a small copper content.

New bluish-grey material called 'Angelite' was confirmed by X-ray diffraction as a massive variety of anhydrite. It forms concretions with a white crust (*Figure 10*), and probably comes from sedimentary rocks at an unspecified locality.

Silver-bearing veins in the San Genaro mine, Uchucchacua, and in some other mines have produced large transparent red pyrargyrite and proustite crystals. The largest faceted proustite weighs more than 55 ct. In the summer of 2000, an unspecified mine in Huancavelica department produced loose realgar crystals, up to about 2 cm, which are transparent enough for faceting.

Figure 10: Blue anhydrite; the rough is 6 cm wide.

Figure 11: Polished calcite crystals from Ica, each crystal is 45 mm long.

Transparent fluorite is known from several Peruvian mines, the most interesting (and valuable) being nice pink octahedrons, found in 1981 and 1982 in the Huanzala mine. Faceted stones up to 187.65 ct are known. Transparent light green fluorite is common in Pasto Bueno, and the Huaron mine recently produced colourless clean fluorite octahedrons up to 5 cm across. Over the years a number of mines have produced transparent sphalerite in various shades of yellow, pale green and reddish-brown (e.g. Casapalca, Morococha, Manuelita and Carmen Lira). An occurrence of epidote crystals near Ica is accompanied by brown ferroaxinite crystals up to several centimetres in length, some of which have small cuttable areas. Honey-coloured transparent calcite up to more than 5 cm in length may well come from the same place as the epidote and axinite. The scalenohedral crystals are strongly weathered on the surface and are sold with polished facets (*Figure 11*).

Pasto Bueno has produced the world's best hubnerite crystals (Mn end-member of the wolframite series). They are usually brownish-black with a high metallic lustre but some deep red crystals are transparent enough to be cut. The same locality also produces large crystals of quartz, most of which are very clean but some contain interesting macro-inclusions of hubnerite, several kinds of sulphides and green chlorite.

In 1998, a few large orange transparent scheelite crystals appeared at the Tucson show. They are said to come from the Turmalina mine in Piura department, and the largest known faceted scheelite from this find weighs 266.68 ct! They are very similar to scheelites from China.

Makusani near Lake Titicaca is the source of an obsidian glass called 'makusanite'. It is brown and contains rod-like inclusions possibly of andalusite (Henn, 1995), or again they could be sillimanite, as was found in similar obsidian from Chile (Hyršl and Zacek, 1999). An unspecified locality in southern Peru has recently produced brown obsidian with black spots. Cabochons with a high lustre can be manufactured and they are used in Lima for inexpensive jewellery.

Figure 12: Dumortierite from Canta; the cabochon measures 35 x 27 mm.

Figure 13: Sea shell cabochons; the largest measures 20 x 12 mm.

Ornamental stones

Peru is rich in various types of ornamental rock. Massive rhodonite is known from the Pachapaqui ore district. Veins of massive blue dumortierite (*Figure 12*) occur near Canta in Lima department. They contain white patches of fine-grained quartz and muscovite mica as well as dark blue spherulites of pure dumortierite. The Huanzala mine is the world's most abundant source of large pyrite crystals up to about 20 cm across. The production of mineral specimens is estimated to be many thousands of tonnes, the best qualities being faceted in Thailand for 'marcasite' jewellery, while poorer qualities are tumble-polished. Bird and animal carvings made in pink opal, chrysocolla, rhodochrosite, yellowish-green serpentine, pale blue quartzite, blue massive anhydrite and other rocks are exported in thousands from Peru every year. These carvings are not exclusively of Peruvian materials and may also contain foreign materials such as sodalite and ametrine from Bolivia, rock crystal and amethyst from Brazil, or malachite from central Africa.

In Lima, one can also buy nice cabochons made from sea shells (*Figure 13*). They have an attractive orange or purple colour with white or yellow spots and can be easily identified by their low SG and by their structure which may be described as a flame-like layering.

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Gem-quality clinohumite from Tajikistan and the Taymyr region, northern Siberia

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ABSTRACT: The rare collectors' stone clinohumite has been available on the gemstone market for about 20 years. Bright yellow to orange and brownish-orange specimens have come from the Pamir mountains of Tajikistan. A new occurrence has been discovered in the Kugda massif in Northern Siberia which produces dark red-brown clinohumite of gem quality. This article presents the gemmological and other properties of clinohumite from both localities.

Keywords: clinohumite, Pamir mountains, Siberia, physico-chemical properties, internal characteristics

Introduction

Clinohumite is a very rare silicate material and has been sporadically available on the international gemstone market for about 20 years. Because of its fine colour it is an interesting stone for collectors. Clinohumite in gem quality is known from an occurrence in the Pamir mountains of Tajikistan, former Soviet Union (Anderson, 1983; Bank, 1983; Koivula *et al.*, 1988). The colour of the transparent, facetable stones ranges from yellow to yellow-brown and brownish-orange. A new type of clinohumite has been discovered in Siberia, Russia, which is relatively dark reddish-brown.

Clinohumite belongs to the humite group together with norbergite, chondrodite and humite. These orthosilicates have orthorhombic or monoclinic symmetry. The general formula is $A_n(SiO_4)_m(F,OH)_2$ where A = Mg, Ca, Mn, Fe^{2+}; n = 3, 5, 7 or 9; m = 1, 2, 3, 4. The chemical formula of monoclinic clinohumite is $Mg_9(SiO_4)_4(F,OH)_2$ and the structure is described as a hexagonal close-packed arrangement of anions. Iron and titanium commonly substitute for some of the magnesium. Half of the octahedral and one-ninth of the tetrahedral sites are occupied. The octahedrons are arranged in zig-zag chains producing the monoclinic cell. Five distinct octahedra exist, three types of MO_6, and one type each of $MO_5(OH,F)$ and $MO_4(OH,F)_2$. Mg and Fe are ordered in distorted MO_6 octahedra, Ti in $MO_4(OH,F)_2$ sites.

Clinohumite has a hardness of 6 on the Mohs scale and basal (001) cleavage is poor. According to Deer *et al.* (1982) the RIs are n_x = 1.629 - 1.638, n_y = 1.641 - 1.643, n_z = 1.662 - 1.674. The birefringence varies between 0.028 and 0.041. SG ranges from 3.21 to 3.35.

Pamir mountains

Hitherto, the best known clinohumite occurrence has been Kukhi-lal in the eastern part of the Pamir mountain range of Tajikistan, bordering Afghanistan and China.

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Figure 1: *Clinohumite crystal on matrix from the Kukhi-lal area, Pamir mountains (width of view about 2 cm).*

This area is especially known for magnificent pink spinels (Koivula and Kammerling, 1989; Kammerling *et al.*, 1995). Geologically, the Kukhi-lal area is composed of marbles with skarn bodies, and clinohumite occurs together with spinel in both these rocks (*Figure 1*). In the same region (Tura-Kuloma; Spiridonov, 1998) gem-quality rubies are recovered from marbles (Henn *et al.*, 1990; Smith, 1998) as well as gem-quality pale purple scapolite (Kammerling *et al.*, 1995, p.211) and near-colourless forsterite. Several pegmatitic minerals such as tourmaline (mostly red elbaite), yellow and blue topaz, aquamarine and morganite, hambergite, orange danburite and jeremejevite are found in the Rangkul pegmatite field near Kukurt east of Murgap (Skrigitil, 1996).

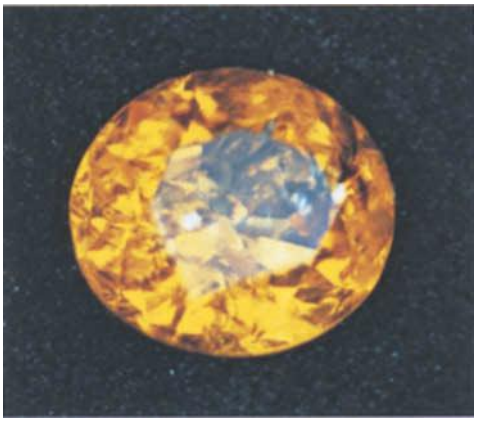

Figure 2: *Faceted yellowish-orange clinohumite of 0.79 ct from the Pamir mountains.*

For about 20 years, the Kukhi-lal occurrence of clinohumite has only produced relatively small specimens up to 3 ct in weight. However, in the last few years some larger stones weighing more than 10 ct have been found, and the largest known specimens weigh 15.25 ct (eye-clean) and 17.87 ct (slightly included) respectively.

The Pamir clinohumites are bright yellow to orange (*Figure 2*) or brownish-orange. RIs were determined as n_x = 1.630, n_y = 1.648, n_z = 1.669, birefringence Δn = 0.039 and SG = 3.19. As summarized in *Table I*, the refractive indices are comparable to the clinohumite data from Pamir as published by Koivula

Table I: *Physical properties of gem-quality clinohumite from Pamir, Tajikistan and Northern Siberia.*

	Pamir mountains			Siberia
	1	2	3	4
n_x	1.630	1.631	1.625	1.640
n_y	1.648	1.642	1.636	1.654
n_z	1.669	1.668	1.659	1.671
Δn	0.039	0.037	0.024	0.031
SG	3.19	3.18	3.18	3.35

NB: 1 and 4: this work
2: Koivula et al., *1988*
3: Bank, 1983

et al. (1998), but are higher than those given by Bank (1983).

Clinohumite from Pamir is inert under long wave ultraviolet radiation, but displays moderate to strong chalky-orange fluorescence under short wave UV.

Table II: *Electron probe microanalyses of clinohumite from Pamir and Siberia.*

Wt %	Pamir	Siberia
SiO_2	37.47	37.05
TiO_2	2.54	0.77
MgO	57.12	53.19
FeO	0.25	5.48
MnO	0.02	0.49
CaO	0.01	0.03
F	2.25	2.18
Number of ions on the basis of 18 (O,OH,F)		
Si	3.94	4.01
Ti	0.02	0.06
Mg	8.95	8.57
Fe	0.02	0.50
Mn	<0.01	0.04
Ca	<0.01	<0.01

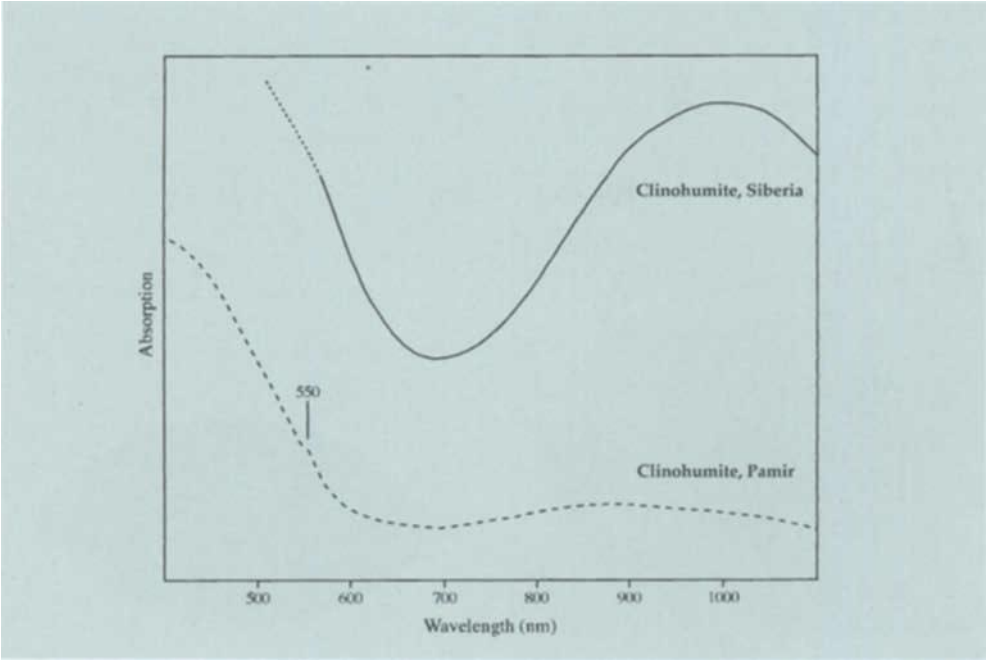

Figure 3: *Non-polarized absorption spectra of two clinohumites; an orange one from Pamir and a red-brown specimen from Siberia.*

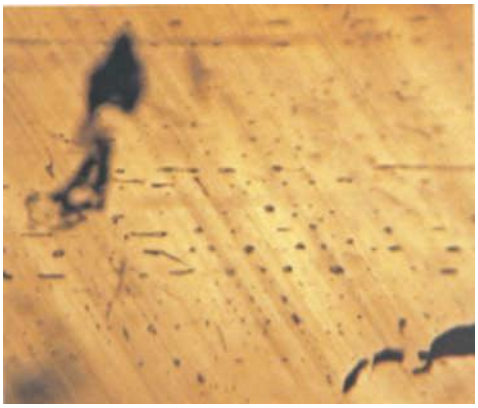

Figure 4: Fluid inclusions and growth zoning in a gem-quality clinohumite from the Pamir mountains. Immersion, magnified 20x.

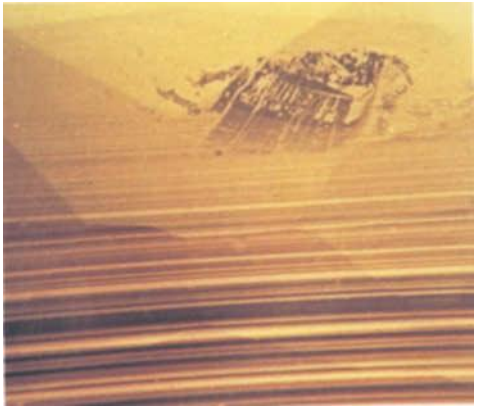

Figure 5: Lamellar twinning in a gem-quality clinohumite from the Pamir mountains. Immersion, magnified 20x.

The chemical analyses are presented in *Table II*. In addition to the major constituents SiO_2 and MgO, the Pamir clinohumite contains significant TiO_2 and minor concentrations of FeO, which both substitute for magnesium. Contents of manganese and calcium are not significant.

The absorption spectrum of an orange clinohumite from Pamir (*Figure 3*) shows a weak but broad band in the near infrared spectral range which is caused by Fe^{2+}. From approximately 600 nm, absorption continuously increases towards shorter wavelengths, with a band at 550 nm, which is also due to Fe^{2+}.

Fluid inclusions, growth-zoning (*Figure 4*) and lamellar twinning (*Figure 5*) in the (100) direction were observed under the microscope.

Figure 6: Red-brown clinohumite crystals from Taymyr peninsula in northern Siberia (width of view about 5 cm).

Siberia

One of the authors (J.H.) obtained a new variety of clinohumite from Russian dealers in 1998, which came from an occurrence in a basin of the Kotui river on the Taymyr peninsula, northern Siberia. Geologically it is located in the Kugda massif where olivine, clinohumite and vermiculite are found in large crystals along with melilite, monticellite, pectolite and perovskite (Evseev, 1994). Clinohumite from that locality forms well-developed red-brown crystals (*Figure 6*) which are up to 2 cm in size and sometimes twinned. Only small parts of the crystals are transparent and a few red–brown stones up to 2 ct in weight have been faceted (*Figure 7*). RI values are

Figure 7: Faceted red-brown clinohumite of 1.33 ct from Taymyr peninsula in northern Siberia.

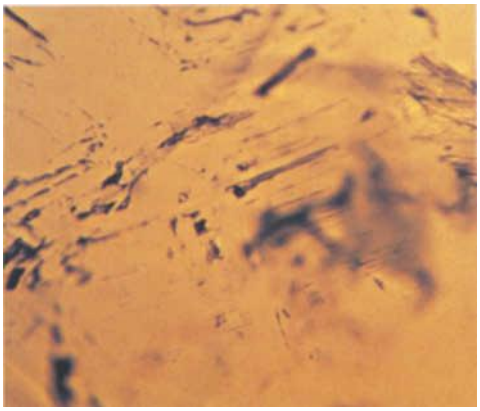

Figure 8: Fluid inclusions in a gem-quality clinohumite from Taymyr peninsula in northern Siberia. Immersion, magnified 20x.

Figure 9: Parallel hollow tubes in a gem-quality clinohumite from Taymyr peninsula in northern Siberia, magnified 10x.

n_x = 1.640, n_y = 1.654, n_z = 1.671, birefringence Δn = 0.031 and SG = 3.35. These are distinctly higher than the data for the Pamir clinohumites. Consideration of the chemical analyses in *Table II* indicates that this can be attributed to the significantly higher FeO concentrations of 5.48 %wt compared to 0.25 wt% in the specimen from Pamir. The inert behaviour under short wave ultraviolet radiation is due to the high iron content. Manganese is also higher in the Siberian clinohumite, whereas the TiO_2 contents are distinctly lower.

The absorption spectrum shown in *Figure 3* is characterized by a strong spin-allowed band in the infrared part of the spectrum, with a maximum at approximately 1000 nm. From approximately 670 nm, there is continuously increasing absorption towards shorter wavelengths. Notable fluid inclusions of the Siberian clinohumites are primary and secondary two-phase inclusions *(Figure 8)*. In addition, growth zoning may be visible under a microscope, and some stones contain parallel hollow tubes *(Figure 9)*.

Conclusions

The Kugda massif in northern Siberia, Russia, is a probable new source of gem-quality clinohumite. The stones are red-brown and have higher optical and SG values than the gem-quality yellow to orange specimens from the well known source in the Pamir mountains in Tajikistan. These differences are predominantly due to higher iron and lower titanium contents.

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The colour of diamond and how it may be changed

Alan T. Collins

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ABSTRACT: The optical centres responsible for many of the naturally-occurring colours in diamond are reviewed. Although there is a good scientific understanding of some of the colour centres, those responsible for orange, brown and pink diamonds remain a puzzle. Chameleon diamonds, and the violet and blue colours that seem characteristic of diamonds with a high hydrogen concentration, are also poorly understood. Methods of adding colour to diamond, using radiation and, if appropriate, annealing, are described, and the high-pressure, high-temperature treatment of natural brown diamonds – to reduce the brown coloration or produce vivid yellow and yellow/green specimens – is discussed in detail. Finally, methods for detecting colour-enhanced diamonds of all varieties are considered.

Introduction

The colour of a gem diamond is one of the four important parameters which determine the value of a cut and polished stone. Until relatively recently a completely colourless diamond would command the highest price, but in the last few years there has been considerable interest in 'fancy coloured' diamonds (Harris, 1994; Hofer, 1998) and some pink diamonds have sold for extraordinary sums. The majority of gem quality diamonds have less attractive colours than those at either the colourless or fancy extremes of the distribution, and many techniques have been used, (see, for example, Bruton, 1978; Harris, 1994), to disguise the slight yellow colour of a diamond or, for more strongly coloured (and therefore less attractive) specimens, to increase the coloration so that the diamond acquires a fancy colour.

In March 1999 the diamond gem trade was staggered by an announcement from Pegasus Overseas Ltd. of Antwerp, Belgium, a subsidiary of Lazare Kaplan International (LKI), that they had begun marketing colour-enhanced diamonds (Rapaport, 1999). The diamonds had been processed by General Electric (GE) and it was generally assumed, and subsequently confirmed (Woodburn, 1999), that the process involved treatment at high pressure and high temperature (HPHT). Information circulating in the trade (Johnson *et al.*, 1999; Moses *et al.*, 1999) indicated that the starting material was brown type IIa diamond (diamond types will be discussed in sections 1.1 to 1.3) and that the GE process substantially reduced the brown colour.

More recently Novatek, which manufactures high-pressure presses used in diamond synthesis, has announced that they are also processing natural brown diamonds (Templeman, 2000). A subsidiary company, NovaDiamond Inc., has been set up to produce and market these diamonds. They are not pre-selecting the diamond type, and many of the stones they process change from brown to yellow/green. Similar colour changes are being produced by research laboratories in Russia, and may have been for some time (Van Bockstael, 1998; Henn *et al.*, 1999).

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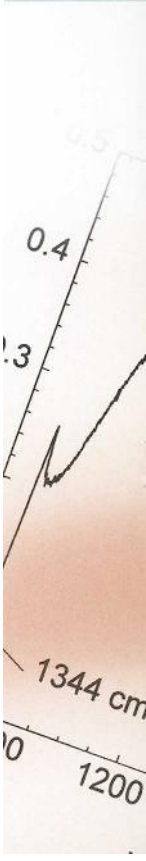

Until these recent developments, it had generally been thought that permanent colour changes to natural diamonds (by, for example, radiation and annealing, see sections 1.6 to 1.7) can only add to the pre-existing colour (Bruton, 1978). Clearly, this is no longer the case.

In this article I shall summarize the current understanding of the major colour centres in diamond, and show how this leads to an explanation of the processes currently being used by GE/LKI, NovaDiamond and others to enhance the colour of natural diamonds. I shall assume that the reader is familiar with an earlier review on colour centres in diamond published in this journal (Collins, 1982); some of the important points will be reiterated here and can also be found in Wilks and Wilks (1991). More recent publications by Fritsch (1998), Harris (1994) and Hofer (1998) also provide many important insights.

Absorption spectroscopy

If a diamond is coloured it must be absorbing visible light in the wavelength range 400 nm (violet) to 700 nm (red), and it is convenient to present this information graphically. To assess the visual appearance of a given diamond it may be appropriate to plot a graph of the percentage transmission as a function of the wavelength. For more detailed analysis it is preferable to plot absorption coefficient as a function of wavelength. This has the advantage that the absorption coefficient is proportional to the concentration of defects producing the absorption, and it is often important to be able to estimate the concentration of defects. Most of the spectra in this article will be plotted to show absorption coefficient. Details of vibronic bands (Collins, 1982) become better defined when the diamond is cooled to liquid nitrogen temperature (77 K) and the vibronic spectra shown here have been recorded at that temperature.

Perfect diamond

Figure 1 illustrates the absorption spectrum of a perfect diamond. Because of the wide spectral range covered, wavelengths are shown in mm (1 μm = 1000 nm) and a compressed (logarithmic) wavelength scale has been used. At short wavelengths (around 0.23 μm) the ultraviolet light has sufficient energy to remove electrons from the electron-pair bonds between each carbon atom, and at wavelengths shorter than this the diamond absorbs strongly, giving rise to the so-called 'absorption edge'. In the infrared part of the spectrum there are characteristic absorption bands at wavelengths where the infrared radiation can set the carbon atoms into vibration. To analyse the interaction with the infrared radiation, the vibrational waves can be represented as particles called 'phonons' which have characteristic frequencies (or energies). In a pure diamond it is not possible for the infrared radiation to generate just one phonon, but it is possible to produce two or three phonons. The peaks between 2.5 and 7.5 μm are referred to as the 'two-phonon' and 'three-phonon' bands, and are identical for all diamonds. It is clear from *Figure 1* that there is no absorption in the visible region, and a perfect diamond is therefore completely colourless.

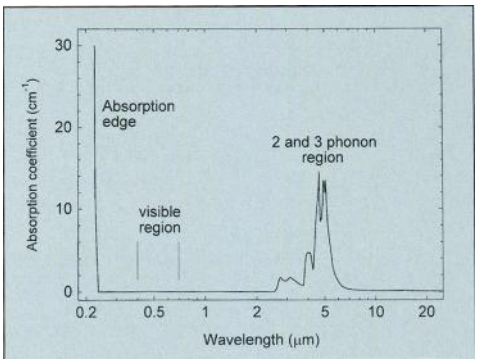

***Figure 1:** Absorption spectrum of pure diamond.*

1. Defects in diamond

Diamonds which absorb in the visible region, and are therefore coloured, do so because they contain defects. These may be 'point defects' which have dimensions comparable with the distance between the carbon atoms in the diamond, or they may be 'extended defects', some of which can be

sufficiently large to see with an optical microscope. The scientific understanding of point defects is more advanced than that for extended defects but, even so, is far from comprehensive. What is clear, however, is that nitrogen, which is a very common impurity in diamond, is involved in many of the point defects. Nitrogen can exist in several different forms in diamond and a brief summary is given in the next section.

There is a further important point which emerges from *Figure 1*. With a perfect diamond there is no absorption in the 'one-phonon' region at wavelengths longer than 7.5 mm. However, when a diamond contains defects, the perfectly regular array of carbon atoms is perturbed and absorption then becomes allowed in the one-phonon region; consequently, that region of the spectrum is frequently referred to as the 'defect-induced one-phonon region'. Each defect produces a uniquely shaped spectrum, and the absorption coefficient is proportional to the concentration of the corresponding defect. Nowadays infrared spectra are normally measured using a Fourier Transform Infrared (FTIR) spectrometer, and the spectra are plotted with the wavenumber in cm^{-1} as the horizontal axis. This is simply the reciprocal of the wavelength expressed in cm and, to retain an appearance which is similar to historical spectra, it is conventional to show the spectra with the wavenumber decreasing from left to right. A wavenumber scale is convenient, because it is proportional to frequency (or energy). The one-phonon region in diamond lies at frequencies less than 1332 cm^{-1} and consists of several broad peaks. Some defects also produce one or more sharp lines at wavenumbers slightly higher than 1332 cm^{-1}; these lines are said to arise from 'localized vibrational modes'. This description is used, since the vibration cannot propagate through the diamond (because the frequency is above the cut-off value of 1332 cm^{-1}), and so is localized at the defect.

Diamonds which contain sufficient nitrogen to produce easily measurable nitrogen-related absorption in the defect-induced one-phonon region are generically known as 'type I.' Other diamonds are generically known as 'type II' and it is important to realise that diamonds classified as type II may, nevertheless, contain small concentrations of nitrogen.

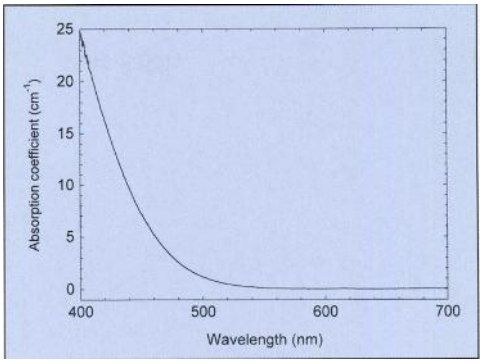

***Figure 2:** Absorption spectrum of a type Ib diamond in the visible region, recorded with the specimen at 77 K.*

1.1 Nitrogen

It is believed that nitrogen is initially incorporated into natural diamonds on isolated substitutional sites. Very few natural diamonds are found with nitrogen in this form, but almost all manufactured diamond produced commercially by HPHT synthesis has most of the nitrogen in the isolated substitutional form. This sort of diamond is referred to as 'type Ib' and *Figure 2* shows the absorption spectrum in the visible region for a typical specimen. The presence of the nitrogen causes an absorption starting at approximately 500 nm and increasing towards shorter wavelengths. Diamonds like this therefore have a distinctive yellow colour; at higher nitrogen concentrations, or in larger diamonds, the colour is yellow/brown.

Nitrogen in this form, frequently referred to as the 'C form', also produces a characteristic absorption in the one-phonon region, shown in *Figure 3*. The major features are the broad band with a maximum at about 1130 cm^{-1} and a sharp line at 1344 cm^{-1} associated with a localized vibrational mode. By measuring the absorption coefficient at either of these locations the concentration of

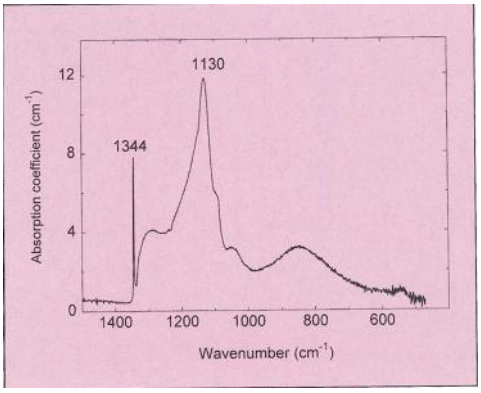

Figure 3: Absorption spectrum of a type Ib diamond in the defect-induced one-phonon region, recorded with the specimen at room temperature.

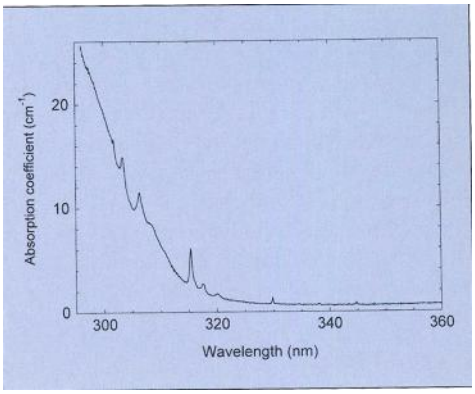

Figure 4: Absorption spectrum of a type IaA diamond in the ultraviolet region, recorded with the specimen at 77 K.

isolated substitutional nitrogen can be determined.

For type Ib diamonds with a low concentration of nitrogen (a few ppm) the absorption spectrum shown in *Figure 2* can be extended into the ultraviolet region right up to the absorption edge, and shows a well-defined broad peak at 270 nm (Dyer *et al.*, 1965; Chrenko *et al.*, 1971). This peak can be used to estimate the concentration of the C-form of nitrogen when determinations from the very weak infrared absorption in the one-phonon region become unreliable.

1.2 Aggregated nitrogen

Many natural diamonds have an absorption spectrum in the ultraviolet region like that shown in *Figure 4*. There is a correlation between the intensities of the sharp lines in this spectrum and the intensity of the absorption in the one-phonon region shown in *Figure 5*. Davies (1976) showed that the absorption in the ultraviolet region is characteristic of a defect consisting of a pair of nearest-neighbour nitrogen atoms. This defect is known as the 'A aggregate'. Diamonds containing aggregated nitrogen are known collectively as 'type Ia' and when most of the nitrogen is present as A aggregates the description 'IaA' is used.

Nitrogen concentrations in type IaA diamond can be determined from the absorption coefficient in the one-phonon region (usually measured at the most intense peak at 1282 cm^{-1}) and are typically 1000 ppm or higher. We see that nature has been very kind to the gem trade; if this concentration of nitrogen were present in the isolated substitutional form the diamonds would have a very unattractive deep yellow/brown colour.

A few natural type Ia diamonds have an infrared absorption spectrum like that shown in *Figure 6*. The most intense peak is at approximately 1175 cm^{-1}. The defect

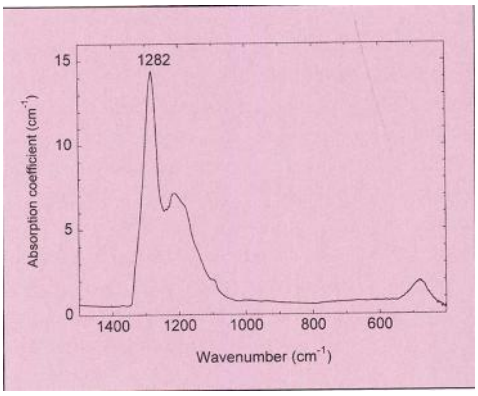

Figure 5: Absorption spectrum of a type IaA diamond in the defect-induced one-phonon region, recorded with the specimen at room temperature.

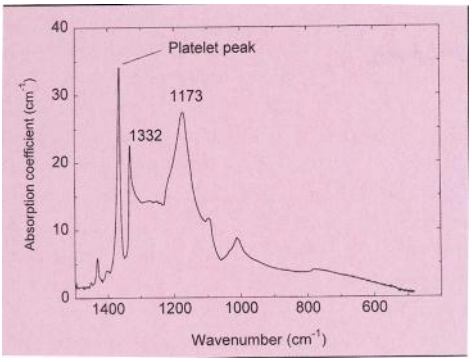

Figure 6: Absorption spectrum of a type IaB diamond in the defect-induced one-phonon region, recorded with the specimen at room temperature.

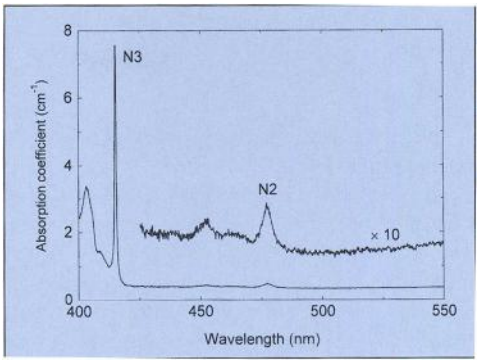

Figure 7: Absorption spectrum of a cape stone, containing the N3 absorption band, recorded with the specimen at 77 K. The spectrum has been offset from zero for clarity, and the long-wavelength region has been expanded by a factor of 10 to show the N2, and related, peaks more clearly.

producing this absorption is referred to as the 'B aggregate', and specimens which have most of the nitrogen in this form are called 'type IaB' diamonds. Studies of the B aggregate indicate that it is comprised of four nitrogen atoms surrounding a vacancy (Loubser and van Wyk, 1981). A vacancy is simply a lattice site from which a carbon atom has been removed and placed into an interstitial position (i.e. in between positions normally occupied by carbon atoms in the diamond structure). In the majority of type IaB diamonds these carbon interstitials come together (perhaps with some nitrogen atoms) to form extended defects called platelets. Absorption at these platelets produces a moderately sharp peak at approximately 1365 cm^{-1}, frequently known as the 'B peak' or simply 'the platelet peak'. In what are termed 'regular diamonds' the intensity of the B peak is proportional to the intensity of the absorption produced by the B aggregates. In the remaining ('irregular') type IaB diamonds the intensity of the B peak is less than expected from this proportionality, or may be completely absent. There is some weak absorption in the one-phonon region, called the 'D band', which is associated with the platelet peak, and this must be taken into account when the concentrations of the A aggregates and B aggregates are being calculated from the infrared spectra.

The B aggregate of nitrogen does not cause any absorption in the visible region. However, when it forms another minor structure is produced which is referred to as the 'N3 centre'. This has three nitrogen atoms on a {111} plane, surrounding a common vacancy. Optical transitions at this centre give rise to the N3 absorption band, shown in *Figure 7*, which has a zero-phonon line at 415.2 nm and a structured band to shorter wavelengths. There is, at the N3 centre, another transition which produces the broad N2 peak at 478 nm with weaker peaks at shorter wavelengths. In regular type IaB diamonds the intensity of the N2 and N3 absorption is proportional to the concentration of the B form of nitrogen. Diamonds containing this absorption are known as 'cape stones'. At low concentrations of the N3 centre the colour of the diamond is just perceptibly yellow when compared with a colourless master stone; at progressively higher concentrations the yellow colour becomes increasingly obvious, eventually tending to a fancy colour.

Much of the above understanding of nitrogen in diamond comes from detailed studies of natural diamonds (Woods, 1986) and HPHT aggregation measurements (see, for example, Chrenko *et al.*, 1977; Brozel *et al.*, 1978; Evans and Qi, 1982; Evans, 1992). The aggregation of single nitrogen to A

aggregates may be represented by the equation

$$N + N \rightleftharpoons A \quad (1)$$

At the temperatures experienced by natural diamonds the reverse reaction is negligible and the aggregation process goes virtually to completion over a very long period of time (Evans and Qi, 1982). In the laboratory, at the temperatures necessary to achieve aggregation in a relatively short time, the reverse reaction is appreciable, and it is not possible to obtain complete aggregation. A type Ib diamond therefore cannot be converted to a completely colourless type IaA stone. Furthermore, if a natural diamond containing only A aggregates is heated at around 2000°C, some of the aggregates decompose to form single nitrogen (Brozel *et al.*, 1978). The diamond, previously colourless, then has a pale yellow colour.

The nitrogen defects have been discussed separately, but most natural type Ia diamonds contain a mixture of the A and B forms of nitrogen. These are normally described as 'type IaA/B'. Also many natural diamonds classified as type Ib do have some (perhaps most) of the nitrogen in the A form.

1.3 Boron

Natural diamonds in which substitutional boron is the major impurity are extremely rare. These are the type IIb diamonds, and the presence of boron results in optical absorption which starts at a wavelength of approximately 4 μm in the infrared region and extends into the red region of the visible spectrum. In favourable cases this absorption gives the diamond an attractive blue colour. Boron also produces some absorption in the defect-induced one-phonon region.

1.4 Donors and acceptors

To understand some of the colour phenomena in diamond we need to use a concept familiar in the study of semiconductors. Single substitutional nitrogen in diamond acts as an electrical donor and boron acts as an acceptor. A nitrogen atom may therefore *donate* an electron to a certain defect if the nitrogen and the defect are sufficiently close together. This causes the defect to be in a negative charge state (because an electron has a negative charge), producing a different absorption than if it had no electrical charge and so were neutral. If, instead, boron were the major impurity, it could, in principle, *accept* an electron from a nearby defect, leaving it in a positive charge state. At present there is no clear evidence for optical absorption associated with positively charged defects in diamond, caused by charge-transfer from boron acceptors. However, a number of defects are known to exist in both the neutral and the negative charge states. One of these, the negative N-V-N centre, plays a pivotal role in many of the stones processed by NovaDiamond, as described in section 2.2. Another, the N-V centre in its neutral and negative charge states, provides important clues that a near-colourless diamond could be a GE POL specimen, as described in section 3.3.2.

1.5 Extended defects

We have already encountered platelets in the previous section. Another type of extended defect in diamond is associated with plastic deformation; it appears that in certain stones an external shearing stress has caused some planes of carbon atoms to slip with respect to each other. Many of the brown and pink diamonds produced from the Argyle mine in Australia are in this category. If the crystals are examined under a microscope it is observed that the colour is not uniform, but is striated with the striations oriented in the direction of slip. These striations are referred to as 'coloured graining' in the gem trade (Fritsch, 1998; Harris, 1994). It is not known in detail why the plastic deformation produces coloured diamonds, or why many are brown and some are pink. Indeed, John Chapman (personal communication) reports finding an Argyle diamond which had three distinct regions – brown, pink and almost colourless. One possibility is that a point defect is also involved, and this is trapped at, or

'decorates' the dislocation. An alternative explanation has been proposed by Tom Anthony (personal communication): he has suggested that the pink colour is associated with small displacements of the planes of carbon atoms and that larger displacements result in a brown colour.

Figure 8 shows absorption spectra of a brown type Ia diamond and an Argyle pink diamond (also type Ia). Both diamonds have some N3 absorption present, and both exhibit the broad absorption band with a maximum near 560 nm. The major difference between the two spectra is that the brown diamond has some additional absorption which gets progressively stronger from long wavelengths to short wavelengths.

The absorption in type IIa brown diamonds differs from that shown in *Figure 8*; it is simply a featureless absorption that rises continuously from the red end to the blue end of the visible spectrum (Fisher and Spits, 2000). Pink diamonds predating the Argyle production were often type IIa, but had a similar absorption spectrum to that shown in *Figure 8*.

1.6 Vacancies

Vacancies can be produced in diamond by irradiation with, for example, electrons, neutrons, alpha-particles, gamma-rays, which have sufficient energy to displace some of the carbon atoms. This process leaves vacant sites in the diamond crystal structure and places the carbon atoms into interstitial positions. Absorption associated with the vacancy in its neutral charge state produces the GR absorption features, with a sharp zero-phonon line at 741 nm (the GR1 line) and a band to shorter wavelengths. This absorption gives the diamond a green or blue-green colour. Many uncut natural diamonds have a green 'skin' which has been produced by alpha particles, but this is only a few mm deep. Diamonds with a naturally-produced absorption due to vacancies throughout their bulk are extremely rare; the Dresden Green is one example (Bosshart, 1989) and Hofer (1998) shows photographs of green diamonds from the Aurora Collection.

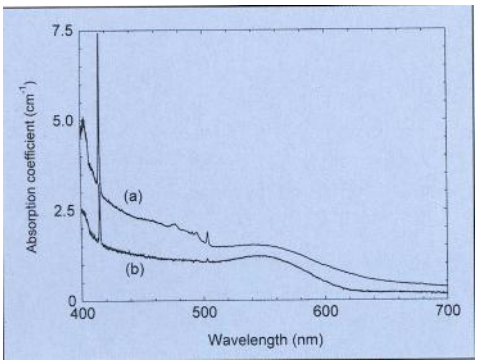

***Figure 8:** Absorption spectra in the visible region, recorded with the specimens at 77 K, of (a) a brown type Ia diamond, and (b) an Argyle pink.*

1.7 Complexes involving nitrogen and the vacancy

When diamonds containing vacancies are heated to 800°C the vacancies become mobile, and after an hour or so the GR1 absorption band disappears. In type I diamonds the vacancies are captured by the nitrogen to form new colour centres. The dominant defect in type Ib diamonds is the nitrogen-vacancy centre in the negative charge state $(N\text{-}V)^0$ which produces an absorption system with a zero-phonon line at 637 nm and a band to shorter wavelengths. This gives the diamond a pink colour or, with larger amounts of radiation, a pink/red colour. Some nitrogen-vacancy centres may be in the neutral charge state $(N\text{-}V)^{\bullet}$ and this defect produces a zero-phonon line at 575 nm. The relative absorption intensity of the 575 nm line to the 637 nm line is higher in diamonds with a low nitrogen concentration because the N-V centres are, on average, further away from the nitrogen donors and so remain neutral.

In type IaA diamonds vacancies are trapped by the A aggregates, and a rearrangement of the atoms occurs to produce the structure N-V-N. Research described below (section 2.1) has shown that when all the nitrogen is in the A-aggregate

form this centre is in the neutral charge state $(N\text{-}V\text{-}N)^{0}$, and produces absorption in the H3 system with a zero-phonon line at 503 nm and a band to shorter wavelengths. This absorption produces a yellow, orange or brown colour, depending on the amount of radiation to which the diamond has been exposed.

Following radiation and annealing of type IaB diamond, the vacancies are trapped by the B form of nitrogen to produce H4 centres which give rise to an absorption band with a zero-phonon line at 496 nm and a band to shorter wavelengths. Again, this results in a yellow, orange or brown colour.

Most type Ia diamonds have a mixture of A and B nitrogen and, after irradiation and annealing, exhibit absorption in both the H3 and H4 systems. In a large suite of such diamonds (Davies, 1972) it was found that [H3] / [H4] = [A] / [B] where the square brackets represent concentrations of the defects. Some natural diamonds, particularly brown type Ia specimens, exhibit H3 absorption but, even when they contain substantial amounts of nitrogen in the B form, the H4 absorption is negligible in all but a very few samples. The reason for this will be considered in section 2.1.

1.8 Orange or amber diamonds

Collins (1982) describes natural diamonds which have a broad absorption band with a maximum near 480 nm and increasing absorption towards shorter wavelengths. The small stones he examined had an attractive amber colour when examined in white light. The same absorption band appears to be responsible for the colour of the diamonds described by Harris (1994) as orange. The defect responsible for this absorption is not known, and the absorption has not been created in the laboratory by any sort of treatment in either natural or synthetic diamonds to the author's knowledge.

1.9 Luminescence

Absorption of light by many vibronic centres can result in luminescence to the long-wavelength side of the corresponding zero-phonon line. Considering only the visible luminescence, for N3 the luminescence is blue, for H3 and H4 it is green, for the 575 nm centre the luminescence is orange and for the 637 nm centre the luminescence is deep red. Long-wave ultraviolet excitation of amber diamonds which contain the 480 nm absorption band gives yellow emission, while absorption in the band itself (at, say, 488 nm with an argon-ion laser) produces red luminescence. Of the other luminescence bands described above, only those from N3 and H3 affect the colour of a diamond.

The efficiency for the production of luminescence is very different in different diamonds. High concentrations of nitrogen in the A form severely quench the H3 and N3 luminescence (Crossfield *et al.*, 1974); this is probably a general phenomenon for most luminescence centres in diamond. However, a near-colourless diamond with a low nitrogen concentration and a weak N3 absorption will, in sunlight, produce enough blue luminescence to mask the slight yellow colour.

Diamonds are occasionally found which have a yellow colour because of naturally-occurring H3 absorption and which produce intense green luminescence under long wave ultraviolet excitation, or even when traversed by a beam of white light. Diamonds with these characteristics are known in the gem trade as 'green transmitters' (Fritsch 1998). The description 'green transmitter' is rather misleading (Fritsch, 1998). The light transmitted by these diamonds is predominantly yellow, but the diamonds appear green in white light because of their intense luminescence.

There is one other luminescence band that has a relevance to the HPHT processing of diamonds to change their colour. Cathodoluminescence studies of type IaB diamonds which showed evidence of plastic deformation demonstrated that the emission system with a sharp line at 490.7 nm, illustrated in *Figure 9*, actually originated at the slip traces (Collins and Woods, 1982).

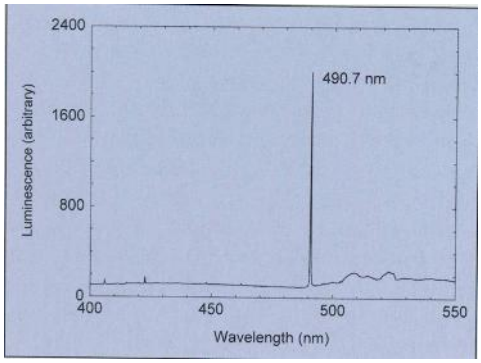

Figure 9: *Cathodoluminescence spectrum, recorded with the specimen at 77 K, from a brown type Ia diamond before HPHT processing. The dominant (yellow) emission is the band with a zero-phonon line at 490.7 nm.*

This emission is not observed in pure type IIa diamonds which have been plastically deformed, and so it is assumed that in the type IaB diamonds the slip traces are decorated with an impurity. Luminescence in the 490.7 nm line is, in fact, observed in some diamonds classified as type IIa (Smith *et al.*, 2000). However, we noted in section 1 that some diamonds classified as type II may contain small concentrations of nitrogen, and Fisher and Spits (2000) and Smith *et al.* (2000) have shown that part of this nitrogen is in the form of B aggregates.

1.10 Coloured diamond collections

The colour centres described thus far, when taken separately or in combination, in a range of intensities, account for most of the magnificent range of colours observed in fancy diamond collections like those described by Fritsch (1998), Harris (1994) and Hofer (1998). I have not dealt with the chameleon diamonds which change colour from green to yellow, either on heating or being left in the dark for extended periods. Neither have I discussed the violet and grey colours which appear to be connected with high concentrations of hydrogen in diamond. Examples of these colours are illustrated by the above authors, but there is, at present, no scientific understanding of the defects causing the colour, and there are no documented examples of these colours being produced artificially.

2. Changing the colour of diamonds

We have already seen (sections 1.6 and 1.7) how radiation and annealing can be used to intensify the yellow colour of type Ia diamonds or produce pink diamonds from type Ib material. To understand the NovaDiamond process which converts brown type Ia diamonds to yellow/green fancy colours we need to review some earlier work on high-temperature annealing of diamonds that had been subjected to radiation.

2.1 High temperature annealing

Collins (1979) examined the effect of 'high-temperature' annealing on diamonds that had been irradiated and annealed to produce the H3 and H4 absorption. In particular, it was found that when a diamond, which contained predominantly H4 absorption after annealing at 800°C, was further annealed at 1500°C, the H4 absorption was considerably reduced in intensity and the H3 absorption had increased, producing a situation more nearly like that seen in natural diamonds. Collins interpreted this behaviour as the H4 centre breaking up to form H3 centres and small concentrations of other defects like N-V centres. In the context of the present paper those measurements show that the H3 centre is more stable than the H4 centre at the high annealing temperatures employed. Recently the author had the opportunity to visit the NovaDiamond facility; there, an irradiated and annealed (800°C) type IaB diamond was subjected to HPHT processing, using the same conditions as those used to process brown type Ia diamonds. The H4 absorption completely disappeared, and some H3 absorption was produced, confirming the earlier conclusion and its relevance to the NovaDiamond process.

Collins (1980) showed further that when synthetic diamonds that had been irradiated and annealed at 800°C were annealed again at 1500°C, substantial aggregation of the

single nitrogen occurred, even though the temperature used was well below that required to produce aggregation in unirradiated specimens. He attributed this behaviour to a vacancy-enhanced aggregation phenomenon. During the annealing, some H3 absorption was produced as a result of vacancies being trapped at the newly-formed A centres.

Mita *et al.* (1990) also investigated the effect of high-temperature annealing of synthetic diamonds that had previously been subjected to radiation and annealing at 800°C. Initially the diamonds had an intense pink colour because of absorption in the $(N\text{-}V)^-$ band. After annealing at 1700°C, a large fraction of the single nitrogen had formed A aggregates, the absorption due to the $(N\text{-}V)^-$ centre had become very weak, and the diamonds had an intense green colour as a result of absorption being produced in the H3 and H2 optical bands. (The H2 system, which will be shown later in *Figure 11*, has a zero-phonon line at 986 nm (in the near-infrared region) and a band to shorter wavelengths which extends into the red part of the visible spectrum.) Their observations led them to propose that the H2 centre was a negative charge state of the H3 centre (i.e. $(N\text{-}V\text{-}N)^-$), and was favoured in their diamonds because of the presence of single substitutional nitrogen (which acts as a donor). Lawson *et al.* (1992) subsequently carried out measurements on the H2 and H3 zero-phonon lines which gave substantial support to the proposal by Mita *et al.*

Note: The temperature quoted for each NovaDiamond run is derived from the thermocouple reading used to monitor the temperature of the heater in the HPHT capsule, and does not necessarily represent the actual temperature of the diamond. In a newer design of capsule, thermocouple readings up to 2300°C are used. In all cases, the value quoted is that recorded near the end of the run, and the diamond experiences the maximum temperature for only a few seconds (Joe Fox, personal communication).

For completeness we recall that Woods and Collins (1986) observed that if a type Ia diamond that has been irradiated and annealed to produce H3 and H4 centres is subsequently given a prolonged annealing at 1400°C, it acquires a 'drab, unappealing green colour'. G.S. Woods (personal communication) subsequently showed that this coloration is a result of H2 absorption being produced, and that in some cases the green colour can be quite attractive. The H2 absorption is occasionally seen in natural diamonds (De Weerdt and Van Royen, 2000), but not at a sufficient strength to affect the colour of the specimen.

2.2 Colour changes produced by HPHT annealing

During the last year, a number of papers in the gemmological literature have described measurements on GE POL and NovaDiamond specimens (see, for example, Chalain *et al.*, 2000; De Weerdt and Van Royen, 2000; Fisher and Spits, 2000; Reinitz *et al.*, 2000; Smith *et al.*, 2000) with some studies being conducted before and after the HPHT processing. The diamonds processed by GE are, for the most part, type IIa and the brown diamonds become near-colourless after HPHT annealing; a very few specimens become pink or blue (Hall and Moses, 2000). The NovaDiamond company processes mainly type Ia brown diamonds, and, after HPHT treatment, these stones become yellow if annealed to 1800°C, and yellow/green if annealed at 2025°C. Many of the NovaDiamonds exhibit bright green luminescence in white light.

Our present understanding of colour centres in diamond allows us to propose the following model for the colour changes:

We have seen that, in many cases, the brown colour of the diamonds under investigation is associated with plastic deformation. In the vicinity of the lattice planes which have encountered slip there is likely to be a high concentration of broken bonds. We have also seen that, in diamonds containing nitrogen in the B form, there is a defect centre localized at the slip planes

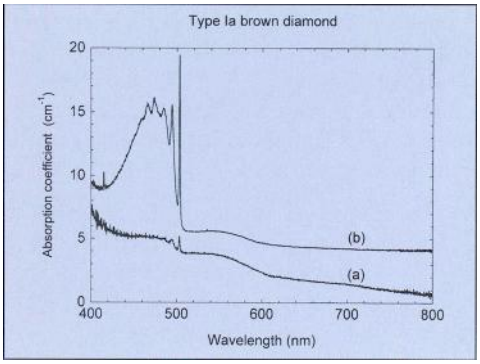

Figure 10: *Absorption spectra, recorded with the specimen at 77 K, of a brown type Ia diamond (a) before, and (b) after HPHT annealing at 1800°C. Spectrum (b) has been moved up by 4 cm⁻¹ for clarity.*

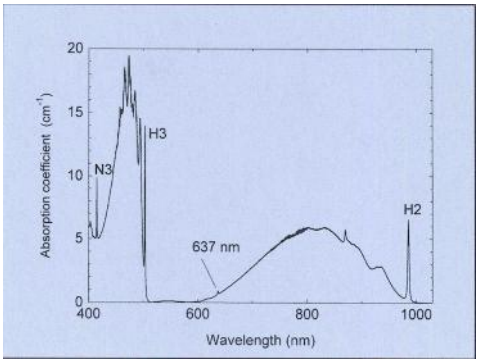

Figure 11: *Absorption spectrum in the visible and near-infrared regions, recorded with the specimen at 77 K, for a brown type Ia diamond after HPHT annealing at 2025°C. The sharp peak at approximately 870 nm is part of the H2 band.*

which gives rise to a luminescence band with a zero-phonon line at 490.7 nm.

When such diamonds are taken to temperatures and pressures where it is known that synthetic diamond can be grown, there will be some healing of any ruptured bonds at the slip planes. This process would result in the release of significant concentrations of vacancies and interstitials. Vacancies may also be released by the interaction between moving dislocations.

We consider first the annealing measurements carried out at 1800°C. Evidence that changes are occurring at the slip planes is the disappearance, reported by Collins *et al.* (2000), of the 490.7 nm luminescence originally present in type Ia brown diamonds.

In diamonds with negligible concentrations of nitrogen we may assume that the vacancies disappear by annihilation with the interstitials. Consequently no new colour centres are formed and the end result is a diamond in which the brown colour is greatly reduced. This is the situation with the GE POL diamonds being processed by Lazare Kaplan and General Electric (Rapaport, 1999; Woodburn, 1999; Johnson *et al.*, 1999; Moses *et al.*, 1999). It is generally believed that GE are treating mainly brown type II diamonds. Occasionally it is possible that they will start with a stone that would have been pink or blue, had the brown colour been absent. Presumably, once such diamonds have been subjected to HPHT processing, the brown colour is greatly reduced and the underlying pink or blue colour is then dominant. (We noted in section 1.3 that type II diamonds that contain boron as the major impurity can be blue and in section 1.5 that some pink diamonds are type IIa.) This seems a reasonable explanation to account for the 11 pink and 4 blue GE POL diamonds examined by Hall and Moses (2000).

Figure 10 shows the absorption spectra of a type Ia diamond before and after annealing at approximately 1800°C. In this case the vacancies are trapped by the nitrogen to form H3 centres (we have shown above (section 2.1) that H4 centres are less stable than H3 centres at high temperature and so presumably do not form at all under these conditions). After the high-temperature annealing we therefore observe an increase in the H3 absorption. There is some nitrogen mobility at the temperature used, and it is perhaps not surprising that the absorption intensity of the N3 band also increases although the processes involved here are less clear at the present time. The annealing also removes some of the brown component of the colour and as a result the diamond,

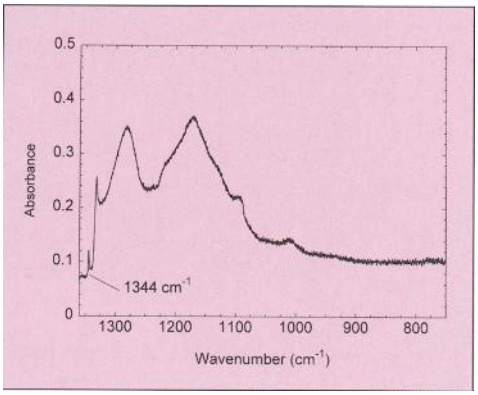

Figure 12: *Absorption spectrum in the defect-induced one-phonon region, recorded with the specimen at room temperature, for a brown type Ia diamond after HPHT annealing at 2025°C. The 1344 cm^{-1} line characteristic of type Ib diamonds is also clearly present.*

originally brown, now has a more attractive yellow/brown colour.

Figure 11 shows the absorption spectrum of a diamond that has been processed at 2025°C by NovaDiamond. At this temperature the reverse reaction in equation (1) becomes significant and appreciable concentrations of single substitutional nitrogen are produced by the break-up of some A aggregates. Consequently, as well as the processes that occur for lower annealing temperatures (1800°C), some N-V-N centres will be in the negative charge state and give rise to an H2 absorption band. In addition, because vacancies trapped at the single substitutional nitrogen form N-V centres, absorption at the 637 nm zero-phonon line may be detected, as in the figure. The relative strength of the H2 to the H3 band will depend on the diamond and on the processing conditions, and the example shown in *Figure 11* has a particularly strong H2 band. As a result of the annealing, the diamond, originally brown, now has an intense green colour because of the transmission 'window' between 500 and 600 nm. Diamonds with a relatively smaller amount of H2 have a yellow/green colour, and most exhibit strong green (H3) luminescence with long-wave UV excitation.

In some cases it is also possible to observe, just outside the one-phonon defect-induced absorption, the 1344 cm^{-1} localized vibrational mode, characteristic of isolated substitutional nitrogen. A typical example is shown in *Figure 12*.

NovaDiamond report that, in order to obtain the strong H3 luminescence which improves the appearance of their product, they need to anneal at 2025°C. More work needs to be carried out to understand why annealing at 1800°C produces H3 absorption without luminescence, whereas a temperature approximately 200°C higher increases the luminescence efficiency in some diamonds.

Finally we examine the effect of HPHT annealing of a typical pale yellow cape stone which has a negligible amount of plastic deformation. The absorption spectra of such a specimen before and after processing are shown in *Figure 13*. The continuous absorption at short wavelengths, present after processing (*Figure 13 (b)*), is caused by single substitutional nitrogen, at a concentration of approximately 25 ppm. In this particular stone, which weighed 1.86 carats, the colour produced was an intense yellow, but with a smaller diamond, or a lower concentration of single substitutional

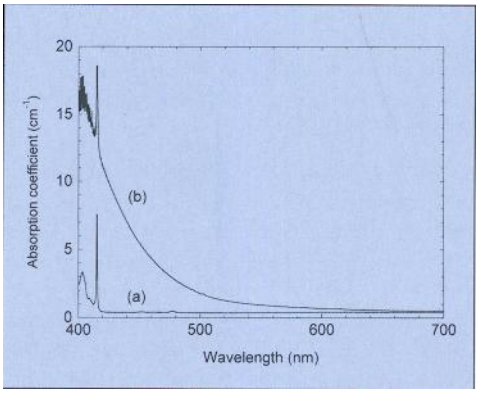

Figure 13: *Absorption spectrum in the visible region, recorded with the specimen at 77 K, for a pale cape stone (a) before, and (b) after HPHT annealing at 2025°C. The absorption in (b) is characteristic of a type Ib diamond.*

nitrogen, a colour similar to 'canary yellow' can be produced. It is just possible in *Figure 13* to detect absorption in the H3 zero-phonon line (and also the H2 which is not shown), but the absorption is negligible in comparison to that produced in the brown diamonds (compare with *Figures 10* and *11*), and makes no significant contribution to the colour.

These observations substantially confirm the interpretations outlined above. Because the cape stone contained a negligible amount of plastic deformation, virtually no vacancies were released during the HPHT treatment and consequently only very small concentrations of H3 and H2 centres were produced. In the absence of H3 absorption, very clear evidence can be seen for the production of single nitrogen atoms (from the break-up of A aggregates – see equation (1)), resulting in the continuous absorption in *Figure 13* (*b*). It was also possible, in this diamond, to detect the 1344 cm^{-1} absorption peak, characteristic of single nitrogen atoms, although this was difficult because of the intensity of the pre-existing absorption in this region.

3. Detection of colour-enhanced diamonds

We will consider in this section ways in which diamonds which have been subjected to radiation to produce fancy colours (with or without subsequent annealing) can be detected, and ways in which diamonds which have been processed using HPHT treatments can be detected. In some cases this is straightforward, and in others it is extremely difficult.

3.1 Green diamonds

Green diamonds can be produced using radiation without annealing, radiation of type Ia diamonds followed by prolonged annealing at 1400°C and by the HPHT processing of brown type Ia diamonds using very high temperatures. In the first case the colour is caused by the GR1 absorption, and in the latter two cases the colour is caused by the combination of H2 and H3 absorption (see *Figure 11*).

3.1.1 Irradiated diamonds

Very few diamonds owe their green colour to naturally-occurring GR1 absorption. The Dresden Green is one (Bosshart, 1989), but the intensity of the band is extremely low; at the peak of the band near 625 nm the absorption coefficient is no more than 0.2 cm^{-1} above the background. The diamond only appears to have a green tint by virtue of its size (40.7 carats). The shape of the absorption spectrum of the Dresden Green differs in no perceptible way from the absorption spectra of some diamonds that have been artificially coloured using radiation. Consequently gem testing laboratories are reluctant to issue origin-of-colour certificates for green diamonds containing the GR1 absorption. However, the author is of the opinion that the Dresden Green, or some other diamond known to have GR1 absorption through natural processes, should be used as a benchmark and that any diamond which exhibited a large GR1 absorption coefficient at 625 nm, compared with the benchmark, should be regarded as a 'treated green'. It would be very helpful in this regard if those diamonds in the Aurora collection (Hofer, 1998), for which the green colour is categorically known to be of natural origin, could be examined spectroscopically.

3.1.2 HPHT-processed type Ia brown diamonds

In the author's experience, H2 absorption does not occur in natural diamonds to a sufficient extent to produce a green coloration. Any diamond that is coloured green or yellow/green because of the presence of H2 absorption should therefore be treated as suspect. The natural brown type Ia diamonds that successfully respond to HPHT processing frequently have low concentrations of nitrogen. Consequently, after processing, a green diamond will exhibit pronounced green (H3) luminescence on excitation with long-wave ultraviolet; this is another indication. Before processing, such

diamonds often exhibit brown graining, and this graining is evident in the green and yellow/green colouring of the end product, and in the distribution of the luminescence, providing further confirmation of colour-enhancement (e.g. Reinitz *et al.*, 2000).

In the NovaDiamond process the diamond is heated for a brief time at pressures where graphite is the stable phase of carbon (Joe Fox, personal communication). Consequently the areas of diamond around inclusions, cracks and feathers generally exhibit severe graphitization, again indicating that the diamond has been subjected to HPHT processing. Surfaces of faceted stones are badly etched during processing, and any residual etching on the repolished stone would also suggest that it has been processed. Reinitz *et al.* (2000) have made a detailed study of the green and yellow/green diamonds produced by NovaDiamond, GE and an unnamed Swedish manufacturer, and all exhibited similar features. However it is possible that other facilities can heat diamonds to the required temperature and maintain the pressure in the diamond-stable region; the absence of graphitization does not therefore indicate that the colour is natural.

3.2 *Yellow diamonds*

Yellow diamonds can be produced by radiation and annealing to approximately 800°C of type IaA diamonds, by HPHT processing of brown type Ia diamonds (to rather lower temperatures than those required to create yellow/green specimens) and by HPHT processing of near-colourless or pale yellow type Ia (cape) stones.

3.2.1 *Radiation and annealing*

Radiation and annealing of type Ia diamonds produces the H3 and H4 absorption bands which are responsible for the yellow colour. If a heavy irradiation is used the diamond becomes almost opaque to wavelengths less than approximately 500 nm, and may then have an orange colour (Collins, 1982). The treatment also produces a sharp absorption line at approximately 595 nm. This line can be eliminated by annealing the diamond to approximately 1000°C but, as the 595 nm line anneals out, two further absorption lines in the near infrared spectrum are created (Woods and Collins, 1986), known as H1b (2024 nm) and H1c (1934 nm). It is exceedingly rare to find any of these three absorption lines, or the H4 line, occurring naturally in diamond, and it is sensible to regard as treated a stone in which the 595 nm, H1b or H1c lines are found. The H1b and H1c lines can be eliminated if the diamond is annealed further to approximately 1400°C, but then the H2 absorption is produced, giving the diamond a green hue, and again providing evidence of treatment.

3.2.2 *HPHT-processing of type Ia brown diamonds*

The yellow diamonds produced by HPHT processing of brown type Ia diamonds generally still have some brown component remaining, and, in particular, the broad band at approximately 560 nm may still be present (see *Figure 10*; also Reinitz *et al.*, 2000; De Weerdt and Van Royen, 2000). In addition, the stones exhibit the coloured graining characteristic of the starting material and may have graphitized inclusions. Intense absorption in the H3 band is extremely rare in naturally coloured diamonds, and it is this feature (*Figure 10*) that would first arouse suspicion.

3.2.3 *HPHT processing of type Ia pale yellow diamonds*

The shape of the absorption spectrum (*Figure 13*) produced by HPHT processing of near-colourless or pale yellow cape stones is virtually identical to that observed in type Ib diamonds and, if the processing conditions are optimised, a colour similar to that of a natural 'canary yellow' diamond can be obtained. (The yellow luminescence in long-wave ultraviolet, characteristic of a true canary yellow diamond, is absent, however.) The infrared one-phonon absorption of the one processed diamond of this sort investigated by Collins *et al.* (2000) was

dominated by absorption associated with the A and B aggregates, and the 1344 cm^{-1} peak was detected only with difficulty. The total nitrogen concentration was estimated to be 1500 ppm, with only 25 ppm in the C form. The diamond also exhibited a weak peak at 1480 cm^{-1} which was not present before processing. A peak at around this position has been reported previously (Kiflawi *et al.*, 1998) in diamonds subjected to HPHT annealing in the range 2500 to 2750°C.

The infrared spectrum of the processed diamond is unlike those of the few natural type Ib diamonds that the author has examined. These have had low nitrogen concentrations (typically 20 to 40 ppm) in the A and C forms only, with no detectable B aggregates. However, Steve Kennedy (personal communication) has visible and infrared spectra on record for diamonds believed to have a natural colour, very similar to the spectra of the processed diamond described here, including the feature at 1480 cm^{-1}. Unless a processed diamond contains other clues, such as graphitised cracks or inclusions, it is therefore difficult at present to be sure that the colour has been created artificially.

3.3 Colourless and near-colourless diamonds

Following the GE/LKI revelation, every colourless or near-colourless diamond is potentially a type IIa diamond that has been colour-enhanced by HPHT processing of brown starting material. The first step in investigating such a stone must be to determine whether it is a type II. A simple procedure is to check the ultraviolet transmission at 254 nm (see, for example, Chalain *et al.*, 2000). Diamonds that contain nitrogen in predominantly the B aggregate form are also transparent at this wavelength, and a specimen that is transparent at 254 nm must subsequently be examined spectroscopically in the defect-induced one-phonon region to check whether it is type IIa or type IaB. If the diamond is type IIa, or contains only very small concentrations of nitrogen, further analysis will be required to assess whether it has been colour-enhanced. The experience of Fisher and Spits (2000) suggests that, on average, for every 1000 colourless or near-colourless faceted gemstones examined, approximately eight will be type IIa. (For colour grades D to F only, this figure rises to approximately 50 per 1000 (Simon Lawson, personal communication).)

Fisher and Spits (2000) and Smith *et al.* (2000) have examined a large selection of diamonds before and after processing, and have identified a number of changes that occur in the absorption and luminescence spectra, which will be briefly reviewed in sections 3.3.1 and 3.3.2 below. Many of the phenomena reported are associated with known nitrogen-related defects (we mentioned in section 1 that a diamond nominally classified as type IIa may nevertheless contain a small concentration of nitrogen) and GE, recognizing this, are now processing diamonds with much lower nitrogen concentrations (Smith *et al.*, 2000). This move will make the detection process more difficult and, indeed, on statistical grounds (Tom Anthony, personal communication) may make it impossible (see section 3.3.3).

3.3.1 Absorption spectroscopy

Some nominally type IIa diamonds contain small concentrations of nitrogen, often predominantly in the B-form, which can be detected by very careful infrared spectroscopy. It may also be possible in some stones to detect the N9 absorption at 236.0 nm. If such a diamond is subjected to the HPHT conditions used to produce the GE POL specimens, some of the aggregated nitrogen decomposes to form single nitrogen, and it may be possible to detect this spectroscopically. For GE POL diamonds with colour grades from I to U/V, Fisher and Spits (2000) were able to detect the 1344 cm^{-1} infrared absorption and the 270 nm broad peak, both characteristic of single nitrogen; the 270 nm peak could also just be detected for some of the stones with colour grades of E and F. The vast majority of GE POL diamonds currently being produced has

colour grades in the range D to G, with the highest percentage being D and E (Smith *et al.*, 2000). Absorption spectroscopy is not likely to provide definitive results for such stones.

3.3.2 Luminescence spectroscopy

Many type IIa diamonds contain defect centres involving nitrogen and vacancies, but at much too low a concentration to detect using absorption spectroscopy. The presence of these centres, in particular N3, H4, H3, 575 nm [i.e. $(N\text{-}V)^0$] and 637 nm [i.e. $(N\text{-}V)^-$] can, however, be demonstrated using laser-excited luminescence spectroscopy. Significant luminescence is only observed at longer wavelengths than the wavelength of the laser and the relative intensities of features in the luminescence spectrum will depend on the wavelength used for excitation. The laser also produces a 'Raman spectrum' which comprises a first-order line shifted by 1332.5 cm^{-1} from the laser line and a second-order band with shifts from the laser line of between 1900 and 2665 cm^{-1}.

Chalain *et al.* (2000) used a 514 nm argon-ion laser to study luminescence from untreated type IIa diamonds and from GE POL diamonds. They observed 637 nm luminescence from the GE POL diamonds, but not from the untreated stones, and concluded that this might be a way of detecting GE POL specimens. However, Fisher and Spits (2000) found that seven out of 16 of their untreated diamonds exhibited luminescence from the 637 nm centre. (This shows the importance of studying a large number of samples.) The former authors (Hänni *et al.*, 2000) subsequently agreed with the findings of Fisher and Spits. They also noted that, for the 637 nm line, the full width at half maximum height is less than or equal to 0.45 nm, whereas for GE POL diamonds it is greater than or equal to 0.53 nm. They attributed this to the greater amount of random strain in the GE POL diamonds. Smith *et al.* (2000) find that, while, in general, the width of the 637 nm line is greater in GE POL diamonds than untreated diamonds, there is some overlap of the distributions. Consequently, measuring the width of the 637 nm line does not provide an unambiguous differentiation.

Fisher and Spits also made the important observation that, for the seven untreated diamonds that exhibited 637 nm luminescence, in only one was the 637 nm luminescence stronger than the 575 nm luminescence, whereas this was true for 12 out of 14 of the GE POL stones. The explanation for this difference is that the GE POL diamonds contain some single nitrogen (as evidenced by the absorption at 270 nm and 1344 cm^{-1}) and this favours the presence of defect centres in their negative charge states (see section 1.4). However, it is clear that the relative intensities of these two lines cannot be used to decide with certainty whether a stone has been subjected to HPHT processing.

Fisher and Spits also noted that of 23 diamonds selected to have a very low nitrogen concentration and subjected to HPHT processing at the Diamond Research Laboratory, 20 showed no luminescence when excited at 514 nm. None of their 16 untreated colourless diamonds showed a complete absence of luminescence and they suggest that the absence of luminescence may therefore be an indicator of HPHT processing.

Smith *et al.* (2000) made very detailed measurements on seven faceted and three rough type IIa diamonds before and after processing by GE; a type IIa fancy light brown 'control' specimen from the Gübelin Gem Laboratory was also processed by GE and examined by Smith *et al.* They measured absorption spectra in the ultraviolet, visible and near infrared regions (200 to 2500 nm) with the specimens at low temperature, and in the infrared (6000 to 400 cm^{-1}) at room temperature; they also measured photoluminescence spectra, with the diamonds at low temperature and at room temperature, using a range of different lasers to excite the luminescence (excitation wavelengths 244, 325, 514 and 532 nm). Broad-band cathodoluminescence spectra

and X-ray topographs were also obtained. The absorption measurements, and photoluminescence measurements using 514 nm excitation, confirmed many of the observations previously reported by Fisher and Spits (2000). The more extensive photoluminescence measurements yielded an interesting, if disappointing, result. Many sharp luminescence lines observed in some untreated type IIa diamonds disappear following HPHT annealing, but no new lines are produced. A few of the lines which disappear on HPHT processing are quite well defined and consequently a diamond in which they are observed could, with reasonable confidence, be certificated as having a natural colour; however, it would be dangerous to assume that a diamond in which they are absent is a GE POL stone.

3.3.3 The statistical problem

The investigations briefly summarised above have compared diamonds known to have been subjected to HPHT processing with those known to be untreated, and in some cases the diamonds have been examined before and after processing. A number of important and interesting results have been obtained. However, this is very different to finding which diamond in a bag of 10,000 type IIa diamonds is the GE POL stone. With the small number of GE POL diamonds in circulation, that is the nature of the problem. (Difficulties will only arise, of course, if the GE POL laser inscription has been fraudulently polished off, otherwise identification is trivial.)

We have seen that:

- The nitrogen content in diamonds now being selected for processing may be too small for the resulting single nitrogen to be detected by absorption spectroscopy after the samples have been processed.
- When the 575 nm and 637 nm luminescence lines are present in the spectrum excited by a 514 nm laser the former line is likely to be the weaker in a GE POL stone, but there are examples where this is also the case for untreated diamonds.
- The width of the 637 nm luminescence line is generally greater in GE POL diamonds, but not always.
- Some HPHT-treated diamonds exhibit no luminescence, but there will almost certainly be a few untreated type IIa diamonds for which this is also true; only a handful of specimens has been investigated so far.

Because of this overlap, or possible overlap, of the all the properties investigated so far for untreated type IIa diamonds and for GE POL diamonds, there is a possibility that a few diamonds will be encountered for which it is not possible to say with certainty whether the colour is natural or enhanced.

In the near future we may have to ask 'Does it matter?'. Up to the end of the twentieth century the knowledge of the laws of refraction and the development of technologies for cutting and polishing diamonds, allowed polishers to turn an unattractive colourless pebble into a highly desirable faceted gemstone. At the beginning of the twenty-first century, knowledge about defects and colour centres in diamond, and the availability of technology for subjecting diamonds to HPHT annealing, combined with the pre-existing knowledge and technology, is allowing polishers to turn unattractive brown pebbles into highly desirable faceted gemstones. People should be encouraged to enjoy the end product, rather than fretting about whether it has been subjected to some extra heat and pressure.

As well as classifying the quality of the colour, cut and clarity, and looking for more obvious treatments, gem testing laboratories will, of course, continue to seek new ways to differentiate colourless GE POL diamonds from untreated natural diamonds. But even at the present stage, it is important to realize that, if the tests described above are unable to make such a differentiation, the diamond will still be an exceedingly rare specimen. Should it be an untreated stone, it will be a type IIa diamond that exhibits negligible luminescence. If, on the other hand, it has been colour-enhanced by HPHT annealing, it

would originally have been a brown type IIa gem-quality diamond with an undetectably low concentration of nitrogen, and very low inclusion content.

Consequently, if a gem testing laboratory has two nearly identical colourless stones, one of which shows clear evidence that it has not been subjected to HPHT annealing, and the other which has insufficient distinguishing features to decide whether it has, or has not, been processed at HPHT, it would be regrettable, in the author's opinion, to regard the latter as less valuable.

Summary

In this article I have described the scientific understanding of some of the common colour centres in diamond. We have noted that there are other colour centres, for example those giving rise to brown, pink, amber, violet and chameleon diamonds, for which the origin of the colour is still not known. Some of the fancy colours that occur naturally – green, yellow, orange, pink – can be simulated by subjecting suitable diamonds to radiation, with or without subsequent annealing, depending on the colour required. Events over the past two years have also made widespread the knowledge that the colour of diamonds can be changed by HPHT processing. I have shown how fundamental studies of diamonds carried out over many years have enabled an understanding of these colour-enhancement processes to be reached. In most cases detailed tests will reveal whether the colour of a stone has been artificially enhanced. Those few colourless or near-colourless diamonds for which discrimination is uncertain will be so rare as to have an intrinsic value in their own right.

Acknowledgments

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- Steve Kennedy of GAGTL for alerting me to spectra in the laboratory records (section 3.2.3).
- Tom Anthony of GE for drawing my attention to the statistical problem outlined in section 3.3.3.

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Letters to the Editor

Diamond synthesis

From W.C.F. Butler

In my letter of 28 July 1997[1], I suggested that Von Bolton[2] might have succeeded in synthesizing diamond by vapour phase deposition in 1911 and, if so, his was almost certainly the first successful synthesis by any route.

I had forgotten an even earlier potential candidate for that achievement, whose experiments appear to have been successfully replicated at the Virginia Polytechnic Institute and State University in 1985.

In a letter to *Nature* in 1905, C.V. Burton[3], a prominent physicist, claimed to have synthesized diamond at ambient pressure by dissolving carbon in a lead-calcium alloy in which carbon is more soluble than in lead alone, then supersaturating the lead by oxidizing the calcium with steam at a dull red heat, thus removing it from the alloy. The carbon precipitated in the form of diamond.

Sebba and Sugarman's[4] attempts to repeat Burton's work yielded a black powder in which were embedded many transparent crystals which scintillated with considerable fire in reflected light. They had a high refractive index and the powder scratched glass. X-ray powder diffraction showed a strong peak at 0.208 nm, which is the strongest peak for diamond but only weak for graphite, although the strongest peak was an unidentified one at 0.251 nm. They concluded that while they could not claim unequivocally that diamond was produced, there was a strong presumption that it had been and, therefore, that Burton had synthesized diamond in 1905.

William Butler

Hatfield, Herts.

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Some light on the 'topaz-type diffusion process' of natural corundum

From Dr Karl Schmetzer

In a recent article in this journal by S. Kennedy[1], two treated natural sapphires were described. According to microscopic and spectroscopic examination (which revealed the presence of a cobalt spectrum), the author concluded that the colour of the samples had been artificially produced by diffusion treatment. The microscopic properties showed similarities with bluish-green treated topaz that was first described by M.L. Johnson and J.I. Koivula[2]. Their treated samples had been supplied by R. Pollak of California, USA. Because details of this diffusion process for topaz were neither available to Johnson and Koivula nor published in later descriptions of similar topaz samples (A. Hodgkinson[3], T. Underwood and R.W. Hughes[4]), some speculation about the experimental treatment conditions and the correct nomenclature of the process, e.g. diffusion or surface coating, and the nomenclature of treated samples remained (see S.F. McClure and C.P. Smith[5]).

Two recently published patent documents[6,7], however, may help to clarify at least the experimental details of the process used. In both documents, R. Pollak of California, USA, is mentioned as inventor and applicant.

Assuming that the experimental descriptions in these documents are complete, only

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one single treatment step is applied for enhancing the colour of gemstones, comprising: "subjecting a combination of a gemstone and at least one powdered (i.e. finely divided) form of cobalt metal or cobalt oxide to conditions suitable to enhance colour of said gemstone, without causing a significant level of surface damage to said gemstone." A wide range of treatment conditions can be employed using a suitable vessel or crucible in which the faceted sample is surrounded by the metal or metal oxide powder. Typically, temperatures in the range of about 900°C to 1250°C are applied for times of about 3 up to 200 hours. In general, the process is performed at ambient pressure. Two mechanisms of colour enhancement are mentioned, (a) diffusion of the colour-enhancing agent into the outer surface of the gemstone, or (b) chemical bonding of the colour-enhancing agent to the surface of the gemstone.

A wide variety of metals or metal oxides can be employed in combination with the cobalt metal or cobalt oxide, e.g. transition metals or transition metal oxides. Examples are given for the treatment of topaz, chrysoberyl, sapphire, quartz and garnet. "Topaz can be modified to have a light blue to dark blue colour, or a light green to dark green colour, or a light blue-green to dark blue-green colour, depending on the treating agent(s) and treating conditions employed. Similarly, chrysoberyl can be modified to have a light green to a deep blue-green colour; sapphire can be modified to have a light blue to dark blue colour (if clear stones are used for treatment) or green, yellow-green or blue-green stones can be produced if the untreated stones are yellow; quartz can be modified to have a light pink to a dark pink colour; garnet can be modified to have a green to a blue-green colour."

Further research is needed for the different gem materials to clarify the individual causes of colour enhancement. It is possible that different mechanisms, i.e. diffusion and surface coating, may be found for different gem materials and/or for different compositions of the powdered metals or metal oxides used.

Dr Karl Schmetzer

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6. International Patent Application, Publication Number WO98/48944, published November 5 1998
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Abstracts

Diamonds | Synthetics and Simulants | Gems and Minerals | Instruments and Techniques

Diamonds

Colour change produced in natural brown diamonds by high-pressure, high-temperature treatment.

A.T. Collins, H. Kanda and H. Kitawaki. *Diamond & Related Materials*, 9(2), 2000, 113-22.

Some suitably chosen natural brown diamonds can be changed to attractive canary-yellow by the 'NovaDiamond' HPHT process. From research involving optical absorption and luminescence spectroscopy, it is shown that the spectra of the treated diamonds are unlike those observed in natural diamonds. It is argued that the brown colour of the natural diamonds is associated with plastic deformation, probably during the ascent of the diamonds to the Earth's surface, resulting in a distortion of the crystal structure. These brown diamonds show clear evidence of internal strain and exhibit 'colour graining' where slip has taken place. On treatment at ~ 2000°C with a stabilizing *P* of ~ 6000 atm, some healing of dislocations and possible re-growth occurs, leading to a reduction of the brown colour. In the case of type IIa diamonds used to produce GE-POL stones, the end result is simply to improve the colour grade of the stones, but in the 'NovaDiamond' process it is mainly the type Ia diamonds typically containing a few hundred ppm of nitrogen.

R.A.H.

Improving the colour of gem-quality diamonds by high-pressure, high-temperature annealing.

A.T. Collins. *Materials Today*, 3(3), 2000, 3-6, illus. in colour.

Reviews with examples and illustrations the present situation with regard to ways in which the colour of gem-quality diamonds can be altered from colours unacceptable to the diamond trade to more attractive and saleable ones using a combination of high pressures and high temperatures. Details on the processes involved are given and there are brief notes on detection.

M.O'D.

[Discovery of diamonds in the south-western Uzbekistan.]

A.V. Golovko, N.E. Yakovenko and N.A. Akhmedov. *Proceedings of the Russian Mineralogical Society*, **129**(1), 2000, 61-4. (Russian with English abstract.)

Diamonds have been found in SW Uzbekistan in unusual diamond-bearing rocks: lamprophyres and shonkinite-porphyries forming dykes and pipes. These rocks contain xenoliths both of the host rocks and some rock types from greater depths: ultrabasites and eclogitized gabbro. The xenoliths also contain chromspinelids, chromdiopside, Cr-bearing olivine and moissanite. Data are given on the morphology of the diamond crystals, their XRD pattern and their TEM images. The diamondiferous xenoliths are related to the non-kimberlite type of rocks - lamprophyres of camptonite-monchiquite composition and/or shonkinite-porphyries.

R.A.H.

Noble gas and halogen geochemistry of mantle fluids: comparison of African and Canadian diamonds.

L.H. Johnson, R. Burgess, G. Turner, H.J. Milledge and J.W. Harris. *Geochimica et Cosmochimica Acta*, **64**(4), 2000, 717-32.

The noble gas and halogen geochemistry of fluids trapped in fibrous and opaque cubic diamonds is presented for 15 diamonds from four kimberlite pipes in the North West Territories, Canada, and 15 from Africa. Ar isotopes and halogens are also presented for diopsides and amphiboles from mantle xenoliths from Bultfontein, South Africa. The Canadian diamonds have Br/Cl and I/Cl ratios higher than those of the African diamonds; Br/Cl ratios are above those for crystal fluids indicating that significant halogen variations occur in the mantle. The lowest of these ratios for both diamonds and xenoliths are close to MORB ratios. $^{40}Ar^{*}/Cl$ ratios are similar for both sets of diamonds, a factor of ~ 100 greater than typical crystal fluids, but agree with a MORB source. Fractional crystallization of a Cl-bearing mineral (e.g. mica, apatite) or partitioning into a low concentration

Abstractors

R.K. Harrison	R.K.H.	M. O'Donoghue	M.O'D.	E. Stern	E.S.
R.A. Howie	R.A.H.	P.G. Read	P.G.R.		

For further information on many of the topics referred to, consult *Mineralogical Abstracts*

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fluid phase in the mantle may account for the high I/Cl and Br/Cl ratios. R.K.H.

Gem Trade Lab notes.

T. Moses, I. Reinitz and S.F. McClure (Eds). *Gems & Gemology*, **36**(3), 2000, 254-9.

Notes are given on blue and pink HPHT annealed diamonds, round brilliants represented as synthetic black diamond but which were identified as very dark bluish-green synthetic moissanite. R.A.H.

Microdiamonds from the Saxonian Erzgebirge, Germany: in situ micro-Raman characterisation.

L. Nasdala and H.J. Massonne. *European Journal of Mineralogy*, **12**(2), 2000, 495-8.

The identity of diamond inclusions in quartz-muscovite gneisses near the Saidenbach reservoir, Saxonian Erzgebirge, was confirmed by laser-Raman micro-spectroscopy, and reinforced by the graphitization of the diamond inclusions by irradiation with a high-energy laser beam. These diamonds are mostly idiomorphic and 1-30 mm in size; they occur mostly in garnet but have also been found in zircon and kyanite. The microdiamond inclusions indicate ultra-high-*P* metamorphism of the host rocks. R.A.H.

GE POL diamonds: before and after.

C.P. Smith, G. Bosshart, J. Ponahlo, V.M.F. Hammer, H. Klapper and K. Schmetzer. *Gems & Gemology*, **36**(3), 2000, 192-215.

A study is reported of 11 (8 faceted stones and 3 crystals) type IIa GE POL diamonds both before and after HPHT annealing by General Electric. The colour-change was dramatic from the N–O range to fancy light brown before, to D–H after. Little change to the inclusions, graining and strain was noted. Photoluminescence (PL) studies (at liquid helium, liquid nitrogen and room *T* in the 245-700 nm range) identified a significant reconfiguration of the lattice involving substitutional impurities, vacancies and interstitials. Key regions of PL activity included the areas of the N3, H3 and N–V centres. X-ray topography identified the extent of lattice distortion. Cathodoluminescence may help to establish that a diamond is not HPHT annealed. A distinction can be made between non-enhanced and colour-enhanced type IIa diamonds by a combination of observations and features. R.A.H.

Fluid regime of diamond crystallization in carbonate-carbon systems.

A.G. Sokol, A.A. Tomilenko, Y.N. Pal'yanov, Y.M. Borzdov, G.A. Pal'yanov and A.F. Khokhryakov. *European Journal of Mineralogy*, **12**(2), 2000, 367-75.

In experiments involving diamond crystallization in the carbonate-carbon systems Li_2CO_3-C, Na_2CO_3-C, K_2CO_3-C, Cs_2CO_3-C, $CaCO_3$-C, $CaMg(CO_3)_2$-C at 7 GPa and 1700-1750°C, the gaseous phase was studied by GC. Unlike in traditional metal-carbon systems, in which diamond forms under highly reducing conditions in the presence of methane-hydrogen fluid, the crystallization of diamond in carbonate-carbon systems occurs in the presence of a H_2O-CO_2-rich fluid. The results provide experimental confirmation of the possibility of diamond crystallization in nature over a wide range of redox conditions. R.A.H.

Gems and Minerals

Waldhambach-klassische Fundstelle für Achata im Pfälzer Wald.

G. Andree and R. Andree. *Lapis*, **25**(8), 2000, 24-5.

Account of the classic ornamental agates found in the region of Waldhambach, Rheinland-Pfalz, Germany. M.O'D.

Granati: nuovo ritrovamenti ad Asbestos e Thetford.

M. Amabili and A. Migliolo. *Rivista Mineralogica Italiana*, **24**, 2000, 80-6, illus. in colour.

Fresh discoveries at the Asbestos and Thetford mines, Quebec, Canada, have included fine, gem-quality specimens of pink, orange and green grossular. This latest garnet occurrence was found as previously in a rodingite vein and as the mine is worked in circles the vein and its mineral contents has been and is expected to be encountered periodically. The occurrence lies approximately three hours' drive east from Montreal. M.O'D.

Gemmological news.

H. Bank, U. Henn and C.C. Milisenda. *Gemmologie. Z. Dt. Gemmol. Ges.*, **49**(2), 2000, 61-4.

A yellow-brown apatite cat's-eye from Madagascar was found to weigh 5.70 ct with SG 3.20, and RI 1.63. A yellow tourmaline from Nigeria was found to be of the elbaite-tsilaisite series comparable to those found in Zambia. Also from Nigeria an orange tourmaline was found amongst a parcel of spessartine garnets; it became conspicuous because of its distinct pleochroism and relatively low brilliance (6.72 ct, RI 1.620-1.640, SG 3.06).

A large amount of enhanced turquoise has been offered under the name 'Zachery-treated turquoise'. The process was invented by J.E. Zachery, an electrical engineer. It decreases the material's porosity and improves lustre and colour. No oils, waxes or colours are used and the gemmological properties are the same as those of untreated material. Only chemical analysis showed a higher potassium concentration in the treated stones. E.S.

Bernd Munsteiner.

Goldsmiths' review **1999/2000**, 2000, 42-5.

Some examples of gemstone cutting by Bernd Munsteiner are illustrated in colour. The artist bases his designs on the forms of the original crystals and fashions sculptures which may reach considerable sizes. M.O'D.

The Alto Ligonha pegmatites, Mozambique.

M. Bettencourt Dias and W.E. Wilson. *Mineralogical Record*, **31**, 2000, 459-97.

Fine mineral specimens were produced from the Alto

Ligonha pegmatite field in central Mozambique between the 1930s and the 1970s and some mines are still in operation. Gemmologists will remember the exceptional crystals of elbaite above all but other ornamental species have also been found: they include green and blue beryl and morganite, dark red gem-quality manganotantalite, pale tan scapolite, stibiotantalite (colourless to pale brown). The paper ends with a short piece 'Memoirs of Alto Ligonha' taken from a forthcoming book, An African name and an African career, by the senior author of the present paper. The present government of Mozambique is encouraging development in the area and a number of prospectors are working the pegmatites. Recently the Naipa mine has produced large and fine clusters of blue-green tourmaline crystals, among other species. M.O'D.

The geology collections of Museum Victoria, Melbourne.

W.D. Birch and D.A. Henry. *Australian Journal of Mineralogy*, **6**, 2000, 83-91.

Account of some of the notable specimens and collections in the Museum: they include gemstones, mostly quartz, faceted by local lapidary clubs and several collections of gold. The Museum has an active programme of collaboration with mineral dealers and others so that specimens can constantly be added to the collections.

M.O'D.

Die Begleiter des Diamants in den Kimberliten Südafrikas.

B. Cairncross. *Lapis*, **25**(6), 2000, 39-42, illus. in colour.

Minerals accompanying diamonds in South African kimberlites are described with notes on their occurrence and on the diamonds. M.O'D.

Aquamarine from Erongo Mtn, Namibia.

B. Cairncross. *Mineralogical Record*, **32**, 2001, 63-4.

Fine deep blue gem-quality aquamarine is described from Erongo Mountain, Namibia, where the occurrence is in a pegmatite. M.O'D.

Spektakuläre Mineralien aus dem Kalahari-Manganerzfeld, Südafrika.

B. Cairncross and J. Gutzmer. *Lapis*, **25**(10), 2000, 13-26.

Gem-quality rhodochrosite is described from the manganese ore deposits of the Kalahari area of South Africa. Geology and mineralization are discussed with references to a number of other, non-gem, materials.

M.O'D.

Les Pegmatites gemmifères à elements rares du sud de la Californie.

J. Fisher. *Le Règne Minéral*, **31**, 2000, 9-36, illus. in colour.

The classic monograph by Jahns and Wright, *Gem and lithium-bearing pegmatites of the Pala District, San Diego County, California*, forming Special report 7A of the California Division of Mines was published in 1951. In 1979 Jahns published something of an update in his paper *Gem-bearing pegmatites in San Diego County*, which formed part of Mesozoic crystalline rocks: *Peninsular Ranges batholith and pegmatites, Point Sal ophiolite*, in Abbot and Todd, *Geological Society of America field trip guide book*, San Diego State University 3-38. A number of other papers have looked at different parts of this area but Fisher has produced a major survey which takes into account the present state of gem mining here, with special reference to tourmaline. Apart from elbaite tourmaline, the mines are North America's chief producers of morganite and kunzite. The Tourmaline King, Tourmaline Queen, Stewart Lithia mine, the Himalaya and Little Three mines are all noted gem crystal producers or have been during past years – fresh discoveries are still being made. At least 400 pegmatite dykes have been identified in the Pala district though relatively few produce gem material. Most California pegmatites are in the lithium and caesium-enriched and tantalum > niobium category and many boron-enriched examples produce tourmaline. The alkali beryls morganite and colourless varieties are commoner than aquamarine and lithium enrichment is indicated by the presence of lepidolite and spodumene, which is abundant in the Pala district but almost always absent in the Mesa Grande and Ramona areas. Topaz from the main Little Three dyke indicates fluorine-enrichment while manganese-enriched dykes such as the Hercules produce spessartine.

The paper includes 67 colour photographs of mines and notable specimens and there is a comprehensive bibliography. *Le Règne minéral* is at Editions du Piat, 1 bis Rue du Piat, 43120 Monistol-sur Loire, France. M.O'D

Eisen in Amethyst: Farbzentren und Zwillingsgefüge.

O.W. Flörke, K. Röller und F. Siebers. *Gemmologie. Z. Dt. Gemmol. Ges.*, **49**(2), 2000, 65-84, 6 photos, 4 tables, 10 diagrams, bibl. [German with English abstract.]

Prepared sections from natural and synthetic crystals were examined with polarized light microscopy, scanning and transmission electron microscopy, X-ray diffraction, X-ray topography, electron spin resonance, low temperature infrared and atomic absorption spectroscopy. The solubility of iron in the crystal structure of quartz is limited to approximately 100-200 ppm/Si. Higher values point to iron inclusions in the microstructure. The article then deals with the amethyst colour centres and the uneven distribution of the iron, and the interaction of these factors with twinning. E.S.

I minerali dell' isola di Caprera.

A. Gamboni and T. Gamboni. *Rivista Mineralogica Italiana*, **24**, 2000, 72-8.

The minerals found in the Arcipelago di la Maddalena National Park in the island of Cabrera include gem-quality dark citrine and smoky quartz as well as small specimen-quality euhedral almandine-spessartine. Smaller-sized (less than 5 mm) crystals of zircon and sphene also occur. M.O'D.

La provenienza geografica degli smeraldi archeologici.

G. Graziani. *Gemmologia Europa*, **VII**, 2000, 154-98, includes 5 unpaginated tables in Italian and English.

Gemstones discovered at an archaeological site in Rome were tested by various methods and the results described. The occurrence is Tomb no. 2 in the Vallerano Necropolis whose use dates from the second and third centuries ad. The body of a girl of about 16-17 was found with personal jewels including gemstones and silver. Speculations on the origin of the items are presented and there is a short bibliography. M.O'D.

Rubinovoje: die roten Korunde von Rai-Iz im Polar-Ural.

V.V. Gryoriev, J.V. Burlakov, J.A. Polenov and V.I. Kuznecov. *Lapis*, **25**(8), 2000, 37-40.

Ruby crystals of ornamental quality at best are reported and described from Rai-Iz in the polar Urals of Russia. Geology and local mineralization are described. M.O'D.

Blühende Fantasie.

H. Heldner. *Schweizer Strahler*, **1**, Fév, 2000, 15-17, 2001.

Gives examples of some of the names used for gem materials, including synthetics. M.O'D.

Chiastolite from Kyaukse, Myanmar.

U.T. Hlaing. *Australian Gemmologist*, **20**(11), 2000, 479-80, 2 illus. in colour, 1 map.

Chiastolite, a variety of andalusite, occurs in gem qualities in the Kyaukse area of the Mandalay Division of central Myanmar. The samples described by the author came from a biotite schist on Kabaw Hill in the Shautaung-U range. The two illustrated cabochons weighed 4.5 and 5.5 carats. P.G.R.

Calcit aus Idar-Oberstein.

R. Hoffmann-Rothe. *Lapis*, **25**(8), 2000, 18-23.

Fine examples of calcite can be found in the area of Idar-Oberstein, Rheinland-Pfalz, Germany. Some remarkable forms are illustrated and described. M.O'D.

Gelbgrüner Opal-CT aus Madagaskar – Ein Beitrag zur Untersuchung mikrokristalliner Opale.

G. Holzhey. *Gemmologie. Z. Dt. Gemmol. Ges.*, **49**(2), 2000, 85-94, 10photos, 2 tables, 1 graph, extensive-bibl. [German with English abstract.]

The yellow-green opals come from Tsivori in South Madagascar, have an RI of 1.460 and SG 2.15. X-ray diffraction showed the water-poor opal as opal CT (lussalite). The opal CT fibres form a line- or grid-like pattern. Under the scanning electron microscope the opal is shown to be characterized by a porous, spongy-spherical structure which is distinct from an aluminium-enriched structured matrix. The diameters of the silica spheres are mainly about 70 nm, but may reach up to 200 nm. E.S.

Determination of relative growth rates of natural quartz crystals.

P.D. Ihinger and S.I. Zink. *Nature*, **404**(6780), 2000, 865-69.

The results are summarized graphically of a micro-IR spectroscopic study of a Brazilian gem-quality quartz crystal, producing the size, shape and relative growth rates of each crystal face during its growth. Abundances of hydrogen-bearing impurities (LiOH, AlOH, HOH) are used as monitors of the growth rates of advancing crystal faces. The results, illustrated as sector zones normal to the c-axis, show that most growth occurs on the top of the crystal ($\{01\bar{1}1\}$ and $\{01\bar{1}0\}$ rhombohedral faces) and not on the $\{01\bar{1}0\}$, prism faces, as constant impurity concentrations do not form concentric zones mimicking the perimeter of the crystal. Concentrations of these impurities embedded in the crystal provide a continuous record of the relative growth rates of the individual crystal faces. R.K.H.

Diffraction colours of opal: First spectrometric data.

M. Istrooumov and H.A. Talay. *Australian Gemmologist*, **20**(11), 2000, 467-72, 3 illus. in black-and-white, 2 tables.

The broad range of diffraction colours displayed by Mexican 'fire' opals is caused by the diameters of the silica spheres that form regular three-dimensional stacks. This paper details the first spectrometric study of the diffraction colours of precious opal. Around fifty polished opals obtained from Mexican deposits were examined in detail using a Hyperfine Analytical Network instrument to plot their diffraction spectra. In the paper one table contains a list of the subjective visual colour of the opal samples. A second table summarizes the measured VIS absorption spectra of these samples. By calculating colorimetric parameters from these spectra it should, among various possibilities, enable the objective discrimination of natural from synthetic opal, the characterization of rare and unique opals, and the accurate determination of colour varieties of opal. P.G.R.

Das blaue Wunder vom Erongo-auf Aquamarin-Jagd im Innern Namibias.

S. Jahn. *Mineralien Welt*, **11**(6), 2000, 34-41.

Describes a successful journey into central Namibia to search for aquamarine, the Erongo area providing gem-quality material. M.O'D

Die miarolen im Erongo-granit: ein Eldorado für Aquamarin, Schörl & Co.

S. Jahn and U. Bahmann. *Mineralien Welt*, **11**(6), 2000, 42-56.

Well-developed crystals of aquamarine are described from miarolitic cavities in granite from the Erongo area of Namibia. Other minerals of interest are green fluorite forming cubes, schorl and purple apatite. M.O'D.

Gem News.

M.L. Johnson, J.I. Koivula, S.F. McLure and D. DeGhionno (Eds). *Gems & Gemology*, **36**(3), 2000, 260-74.

Items mentioned include a triplet composed of tiny angular flakes of iridescent ammonite shell sandwiched between a glass cap and a black opaque backing, gemmy colourless to light pink faceted anhydrite (4–22 ct) from Iran, a 0.69 ct faceted fresnoite, green spots in two pieces of lavender sugilite due to the presence of Cr, and a 2.33 ct tourmaline with an apparent change-of-colour in one pleochroic direction. R.A.H.

Smeraldi dall 'Africa.

J. Kanis. *Gemmologia Europa*, **VII**, 2000, 14-50. (In Italian and English.)

Reviews the occurrence, modes of formation and methods of identification of emeralds from Africa. Deposits in Egypt, Nigeria, Tanzania, Mozambique, Zambia, Madagascar, Zimbabwe and the Republic of South Africa are included with personal notes. There is a short list of references. M.O'D.

Hauyn aus der Eifel – ein attraktiver Edelstein.

L. Kiefert. *Gemmologie. Z. Dt. Gemmol. Ges.*, **49**(2), 2000, 103-14, 9 photos, 1 table, 5 graphs, bibl. [German with English abstract.]

Haüyne is a rare mineral of exceptional blue colour, belonging to the sodalite group of minerals. It is cubic, and found in USA, Canada, Italy, Tenerife, Morocco and in the Eifel, near the Laach lake in Germany. One hundred faceted haüynes, together with some diamonds and a pink sapphire, were made into a brooch which later was sold by Sotheby's in Geneva for S.Fr.45,000. The unset haüyne stones were examined and this article reports on the gemmological, spectroscopical, microscopical and chemical results. E.S.

Gem-quality haüyne from the Eifel district, Germany.

L. Kiefert and H.A. Hänni. *Gems & Gemology*, **36**(3), 2000, 246-53.

An examination of 100 faceted, blue, round and oval haüyne (0.095–0.173 ct) from Laacher See is reported. They have RI *n* 1.498–1.507 and SG 2.46–2.48; their identity was confirmed by Raman spectrometry, with the key maxima at 543 and 988 cm^{-1}. Mineral inclusions are rare, but apatite and augite were identified. R.A.H.

Unusual inclusions in quartz.

J.I. Koivula. *Australian Gemmologist*, **20**(11), 2000, 481/2, 3 illus. in colour.

A piece of rock crystal, which was reported to have come from Madagascar, yielded two emerald cut gemstones of 23.37 and 31.81 carats, each containing a large yellowish inclusion. Although the Raman spectra produced by the inclusions were excellent, they did not match any of the patterns stored in the Renishaw digital spectral library. As one of the smaller visually identical inclusions reached a polished surface, sufficient inclusion material was available to enable an identification of the rare mineral lithiophilite to be made by means of X-ray micropowder diffraction and Becke line microscopy. P.G.R.

Rodochrosit-Stalaktiten.

W. Lieber. *Lapis*, **25**(11), 2000, 13-20.

Rhodochrosite in stalactitic form is described in locations in Catamarca province, Argentina. Details and theories on how the mineral took this form are given. M.O'D.

Gemstone enhancement and detection in the 1900s.

S.F. McClure and C.P. Smith. *Gems & Gemology*, **36**(4), 2000, 336-59.

In the past decade, growing public awareness of treatments and the greater use of sophisticated technology to enhance the colour and/or apparent clarity of gem materials brought to the forefront the need to maintain/regain consumer confidence. The most controversial treatments were the application of heat and diffusion to ruby and sapphire, the 'oiling' of emeralds and fracture filling of diamonds. The decolorization of diamonds by HPHT currently poses one of the greatest identification challenges. Other enhancement processes discussed range from quench-crackled quartz to the novel 'impregnation' techniques used in the Zachery treatment of turquoise. R.A.H.

Mineral stories.

[Various authors.] *Mineralogical Record*, **31**, 2000, 517-18.

The *Record* occasionally features short and usually amusing accounts of the trials of mineral prospectors and miners. This selection includes Al Ordway, 'A highgrader's story' (concerns tourmaline mining in San Diego County, California) and 'Forgotten emeralds' (Hilton Freed) which features emeralds from King's Mountain, North Carolina. Before incorporating either tale in serious abstracts, read them! M.O'D.

Jewelry of the 1900s.

E.B.Misiorowski. *Gems & Gemology*, **36**(4), 2000, 398-417.

The numerous changes that have occurred in the design, manufacture and marketing of jewellery over the past decade are examined. There was an increasing interest in fancy-coloured diamonds, coloured stones in dramatic combinations, and a shift towards the use of platinum and other white metals. R.A.H.

Gem Trade Lab notes.

T. Moses, I. Reinitz and S.F. McClure (Eds). *Gems & Gemology*, **36**(3), 2000, 254-9.

Notes are given on the glass fracture fillings in Mong Hsu rubies, and a rough 19.49 ct bright violet and blue tourmaline, probably from Paraíba, Brazil. R.A.H.

Kronleuchter aus Bergkristall.

J. Mullis, K. Klappenbach and R. Oberhänsli. *Schweizer Strahler* **1**, Fev, 2000, 4-8, 2001.

Illustrates and briefly describes inclusions in rock crystal from Switzerland. M.O'D.

Pre-Columbian gems and ornamental materials from Antigua, West Indies.

A.R. Murphy, D.J. Hozjan, C.N. de Mille and A.A. Levinson. *Gems & Gemology*, **36**(3), 2000, 234-45.

Two recently discovered archaeological sites in Antigua appear to have had flourishing lapidary industries. Excavation of these sites, which have been dated to ~ AD 250–500 (Saladoid period) has revealed beads, pendants and 'zemis' (Caribbean spiritual ornaments). All of the unworked materials (e.g. shell, carnelian and diorite) are of local origin, but amethyst, nephrite, serpentine and turquoise were found only as finished gems; these are not local and their presence implies that trade or exchange existed between Antigua and other parts of the Caribbean at this time. R.A.H.

Die spektakulären Quarze vom Orange River.

G. Niedermayr and H. Soltau. *Mineralien Welt*, **11**(6), 2000, 57-63.

Rock crystal up to 4 cm long and coloured orange from profuse inclusions of hematite is described from the Orange River area of southern Namibia. Amethyst and sceptre forms also occur. M.O'D.

Aragonit-Pseudomorphosen in Achatmandeln aus Idar-Oberstein.

L.C. Patsch. *Lapis*, **25**(11), 2000, 31-34.

Agate pseudomorphs after aragonite have been found in the vicinity of Idar-Oberstein, Rheinland-Pfalz, Germany. Some specimens are illustrated. M.O'D.

The mineral collection of the South Australian Museum, Adelaide.

R. Pogson, L. Sutherland and G. Webb. *Australian Journal of Mineralogy*, 6, 2000, 51-8.

History and review of the collections of the Australian Museum in Sydney with notes on gem specimens and on recent acquisitions which include some faceted items. M.O'D.

The mineralogical collections of the South Australian Museum, Adelaide.

A. Pring. *Australian Journal of Mineralogy*, 6, 2000, 59-70.

History and description of the Museum and its mineral collections, which include a notable collection of South Australian opal. M.O'D.

Rubellitkristalle aus den Pegmatiten von Estepona bei Malága, Spanien.

J.C. Romero Silva. *Mineralien Welt*, **11**(5), 2000, 18-22.

Gem-quality pink tourmaline has been found in pegmatites at Estepona near Malága, Spain. Geological and mineralogical notes are given with a descriptive list of accompanying species. M.O'D.

Die Pegmatite von Alto Ligonha in Nord-Mozambique.

P. Schafer and T. Arit. *Lapis*, **25**(8), 2000, 13-17.

The pegmatites of Alto Ligonha in northern Mozambique are important hosts of tantalum ores and of gem minerals, the latter including tourmaline of high quality in both red and green colours. Emerald from the Morrua mines is already well known: the mines already produce yellow beryl and yellow scheelite. Some crystals of dark red manganotantalite might be faceted into gemstones. The occurrences and local geology of the different species are briefly described. The paper also notes specimens from Alto Ligonha housed in the Bergakademie Freiburg, Saxony. M.O'D.

Farbwechselnde Granate aus Madagascar.

K. Schmetzer and H-J. Bernhardt. *Lapis*, **25**(6), 2000, 46-7, illus. in colour.

Colour-change garnets are reported from Bekily and other locations in Madagascar. Specimens appear blue-green in daylight and yellow to pink or reddish-violet under incandescent light. Rutile needle inclusions have been observed: RI is given between the limits 1.759-1.767 with density between 3.87-3.93 g/cm^3 . The composition shows a mixed crystal of pyrope-spessartine with pyrope content between 43 and 51% and spessartine content between 36 and 44%. Chromium and vanadium oxides contribute towards the colour. M.O'D.

Der Brandberg und die Mineralienfunde in seiner Umgebung.

G. Schneider and S. Jahn. *Mineralien Welt*, **11**(6), 2000, 17-33.

The Brandberg area of north western Namibia produces a wide variety of quartz crystals of considerable size. Interesting sceptre and other forms are described: ornamental-quality green prehnite also occurs. M.O'D.

The Gilbert Collection at Somerset House.

T. Schroder. *Goldsmiths' Review* **1999/2000**, 2000, 38-41.

The Gilbert Collection, formally shown in the United States but now housed in purpose-built galleries in Somerset House, London, includes many items of significance to the gemmologist and jewellery historian. While the gold boxes are of outstanding importance, the hardstones used as inlays are also most attractive. A brief history of the collection is given. M.O'D.

Smeraldi dalle Americhe, dall 'Asia e dall 'Australia.

D. Schwarz. *Gemmologia Europa*, **VII**, 2000, 52-82. (In Italian and English.)

Describes emerald locations in the three continents with emphasis on recent discoveries and their potential. Geological and political factors affecting emerald production are discussed. M.O'D.

Sapphires from Antsiranana Province, northern Madagascar.

D. Schwarz, J. Kanis and K. Schmetzer. *Gems & Gemology*, **36**(3), 2000, 216-33.

Since 1996, large quantities of yellow to blue sapphires have been recovered from alluvial deposits derived from basaltic rocks in the extreme N of Madagascar. Their

morphology, internal growth patterns, mineral inclusions and trace element contents are typical of 'basaltic magmatic' sapphires. UV-Vis-IR absorption spectra and the results of EDXRF analysis for TiO_2, V_2O_3, Cr_2O_3, Fe_2O_3 and Ga_2O_3 are presented; TiO_2 is generally low (~ 0.2 wt.% for facet-quality samples), but Fe_2O_3 is high (in the range 0.33–1.74 wt. %). Correlation diagrams clearly distinguish these Antsiranana sapphires from those of the skarn-related deposits of Andranondambo in SE Madagascar. Most of the Antsiranana sapphires in virtually all hues are heat treated to remove milkiness and produce a better colour. R.A.H.

Gem localities of the 1900s.

J.E. Shigley, D.M. Dirlam, B.M. Laurs, E.W. Boehm, G. Bosshart and W.F. Larson. *Gems & Gemology*, **36(4)**, 2000, 292-335.

The past decade saw growth in gem exploration, production and marketing worldwide. Important coloured stone producing regions included: SE Asia (Myanamar, Thailand, Vietnam), Africa (Tanzania, Kenya, Zimbabwe, Nigeria and Namibia, as well as Madagascar), South America (Brazil and Colombia), central and southern Asia (Sri Lanka, India, Afghanistan, Pakistan, Russia and China) and Australia. The major sources of diamonds were Australia, central and southern Africa, and Russia (mainly Sakha), with exciting discoveries in N Canada. A comprehensive review is given of those gem deposits that were either new or remained commercially significant in the last decade of the 20th century. R.A.H.

Chinese Pearls: their culturing and trading.

M.G. Tao. *Australian Gemmologist*, **20(11)**, 2000, 486-80, 6 illus. in colour.

China's long history of pearl cultivation began in the Song Dynasty (AD 960-1127). From 1990, Chinese pearls, especially freshwater cultured pearls, have played an increasingly prominent role in the pearl jewellery industry worldwide. Production of freshwater pearls is expected to increase to 1500 tons this year. Of total Chinese production (freshwater and saltwater), 40-50% will be sold in China, while 50-60% will be exported. P.G.R.

Lapis lazuli-Lasurit. Zur Kulturgeschichte eines Minerales.

K-L. Weiner and C. Weise. *Lapis*, **25(11)**, 2000, 35-42.

A short history of lapis lazuli from its geology and mineralization to its use in ornament, with notes on some of the classic localities. M.O'D.

What's new in minerals.

Mineralogical Record, **31**, 2000, 273-86.

Gem-quality minerals reported from the 2000 Tucson show include fine greenish-blue topaz from the Zapot claim in the pegmatite near Hawthorne, Mineral County, Nevada: fine small crystals of kunzite from the newly reopened Urucum mine in Brazil: bright yellow-green fishtail twins of chrysoberyl from Anzakobe, Madagascar: aquamarine-blue crystals of kunzite from Kunar, Nuristan, Afghanistan (these crystals are reported to be normal pink after some days' exposure to sunlight): fine deep-coloured aquamarine from a pegmatite near Karur, Tamil Nadu, India: red spinel octahedra from Pein Pyit, Burma (some on white marble matrix). The theme of the main show was the minerals of Brazil and many notable, some historic, specimens were on display. M.O'D.

What's new in minerals.

[Various authors.] *Mineralogical Record*, **31**, 2000, 509-12.

Among gem-quality minerals reported from the Delaware, New Jersey, Bologna and other shows in early 2000 are fine green elbaite from the Mutuca mine, Minas Gerais, Brazil: herkimer-like sceptre rock crystal from Sichuan province, China: root-beer brown transparent enstatite from Mpwa-Mpwa, Tanzania: peach-coloured morganite from Alto Ligonha, Mozambique. M.O'D.

Strawberry quartz.

J.S. White. *Gemmologie. Z. Dt. Gemmol. Ges.*, **49(2)**, 2000, 95-102, 6 photos, bibl.

Strawberry quartz is clear quartz containing wispy filaments of red hematite. Sometimes these inclusions are referred to as lepidocrocite, but in the examined samples were shown to be just hematite. The finest examples come from Chihuahua in Mexico, but recently Kazakhstan has produced excellent strawberry quartz. The hematite is concentrated in thin layers near the surface of the crystal and tends to be denser near the edges of the triangular terminal faces. E.S.

New find of gem quality uvarovite in Tibet.

H. Xuemei, C. Keqin and G. Shan. *Australian Gemmologist*, **20(11)**, 2000, 473-7, illus. in colour and black-and-white, 1 map, 5 tables.

A cabochon-grade quality of uvarovite has been discovered in a valley in the Bo Mi county of the Tibet Autonomous Region of the People's Republic of China. The emerald-green crystals occur abundantly in a size range of 7 to 21 mm and, following further exploration of the Tibetan deposit, could become a new commercial source of this green garnet. P.G.R.

Instruments and Techniques

Smeraldi in Laboratorio.

E. Gambini. *Gemmologia Europa*, **VII**, 2000, 114-52.

Methods used in gemmological laboratories to determine the nature of emeralds are discussed with notes on the use of energy-dispersive X-ray spectrometry [EDS] and the Raman microprobe as well as on other more traditional methods. The use of inclusion studies for locality determination is also discussed. There is a short list of references. M.O'D.

Technological developments in the 1990s: their impact on gemology.

M.L. Johnson. *Gems & Gemology*, **36(4)**, 2000, 380-96.

Significant technological improvements that have had an impact on gemmology include the widespread avail-

ability of computerized communication, the increased prominence of synthetic techniques to gem treatments, and the greater need for expensive instrumentation to solve gemmological problems in general and the broader availability of small dedicated instruments to solve specific problems. R.A.H

Presidium moissanite tester (a GAA Instrument Evaluation Committee report).

T. LINTON AND K. HUNTER. *Australian Gemmologist*, **20**(11), 2000, 243-5, 2 illus. in colour.

The Presidium moissanite tester under evaluation was part of a test kit which also included a Presidium thermal conductivity tester. Both instruments were of the same size and housed in similar cases (black for the thermal tester and grey for the moissanite tester). The moissanite instrument is designed to detect the very small current passed by a semiconductor type material. The user holds the tester with the fingers of one hand in contact with its serrated metal pads and the other hand holding the metal mount of the stone under test. When the instrument's metal probe tip is pressed against the table facet of the mounted gemstone, an electrical circuit is completed through the probe tip, the stone and the hand holding the mount. If the stone is a synthetic moissanite, the instrument detects the minute forward current and illuminates two moissanite red strip indicators. If the stone is a diamond, only the green test indicator is illuminated. A metal test plate is provided for use with unmounted stones. [Abstractor's note: Pure synthetic moissanite is not a semiconductor, and the electrical leakage current detected by this and other synthetic moissanite detectors may be due to impurities in the synthetic material produced so far.] P.G.R.

Synthetics and Simulants

Present Russian synthetic and enhanced gemstones.

V.S. BALITSKY. *Australian Gemmologist* **20**(11), 2000, 458-66, 3 illus. in colour, 2 diagrams, 4 tables.

Before the split, the former USSR was a major synthesizer of single crystals for defence, scientific and technological purposes. As a spin off, synthetic gemstones were also produced and used extensively in Soviet jewellery. After the split, the country's developing free market began to import more expensive natural gemstones to supplement the dwindling high quality sources of its own natural gems. This resulted in a reduction of several magnitudes in the production of its synthetic material, with the synthetic product becoming a major export. For the last two decades, enhancement techniques have also been used to improve the quality of the less expensive varieties of gemstones readily found in Russia and other republics of the former Soviet Union. These techniques include surface colouring, impregnation by inorganic and organic reagents, heat treatment and ionizing radiation. The accompanying four tables list the synthetic gemstones produced in the former USSR, the gemstones presently synthesized in Russia and the current production of enhanced natural gemstones. P.G.R.

Gemmological news.

H. BANK, U. HENN AND C.C. MILISENDA. *Gemmologie. Z. Dt. Gemmol. Ges.*, **49**(2), 2000, 61-4.

Some necklaces bought as ruby were shown to be made of dyed quartz – the red colour was mainly concentrated in cracks in the stones. A translucent synthetic ruby of Russian production showed an interesting inclusion pattern. Viewed in immersion or under crossed polarisers the stones showed glide planes as found in the Verneuil-grown varieties. The transparency was reduced by minute black inclusions, presumably gas bubbles. E.S.

Sintesi e trattamenti degli smeraldi.

H.A. HÄNNI. *Gemmologia Europa*, **VII**, 2000, 114-52. (In Italian and English.)

The main methods of emerald crystal growth are described and discussed with additional notes on colour enhancement. Methods of detection are outlined. There is a short list of references. M.O'D.

Synthetic gem materials and simulants in the 1990s.

J.I. KOIVULA, M. TANNOUS AND K. SCHMETZER. *Gems & Gemology*, **36**(4), 2000, 360-79.

The past decade saw important developments in the commercial viability of gem-quality synthetic diamonds. Improvements in, and new applications for, existing synthetic processes in the production of coloured gemstones such as ruby, sapphire, emerald, quartz and alexandrite are discussed. The development of new synthetic products such as synthetic moissanite and flux-grown spinel also played an important role. R.A.H

Surface reflectivity of synthetic moissanite – a warning about heating.

T. LINTON. *Australian Gemmologist*, **20**(11), 2000, 478, 1 illus.

Correspondence received from M. Kellam, Director of Technology of Charles & Colvard – manufacturer of synthetic moissanite in the USA – advises that some synthetic moissanite set in jewellery gives a diamond response when tested with a reflectance meter. These synthetic moissanites had apparently been heat-treated so that a layer of oxide formed on the surface. On inspection, a sample of heat-treated near-colourless synthetic moissanite revealed a brownish coloration across the surface of all the facets. When cleaned and hand polished using cerium oxide on leather, the sampleís surface reflectivity was restored to 98% that of non-heat-treated material. Jewellers and gemmologists who heat synthetic moissanite to induce colour change as an identifying test, are warned to use relatively low values of heat and apply these for short periods of time to avoid oxidation of the surface. P.G.R.

Gem Trade Lab notes.

T. MOSES, I. REINITZ AND S.F. MCCLURE (EDS). *Gems & Gemology*, **36**(3), 2000, 254-9.

Notes are given on round brilliants represented as synthetic black diamond but which were identified as very dark bluish-green synthetic moissanite. R.A.H.

The retail jeweller's guide (6th edn).

K. Blakemore, revised by E. Stanley, 2000. Butterworth Heinemann, Oxford. pp 306, illus. in black and white and in colour, softcover. ISBN 0 7506 4650 0. £24.99.

It is never easy to assess the value of a textbook which, in remaining in print for more than 30 years, has spanned years in which a great number of developments have taken place over the whole field of retail jewellery and very considerably in gemmology. In matters of style there seems to have been little change, the weight of facts in some places squeezing out rather ponderous sequences of sentences. The impression of learning hardly won, found too in other books of this period, has not entirely vanished. Today's reader will demand some air between the facts which are certainly plentiful.

I would have expected the section on diamond and coloured gemstones to have undergone heavy revision, bearing in mind the recent developments in the diamond and gemstone enhancement contexts, extensively publicized elsewhere. Sadly these have not been incorporated, the reviser having missed the opportunity to incorporate synthetic gem-quality diamond, filling techniques and their identification, and also failing to update the existing sections, clearing them of the stylistic dross that has gathered there and getting some of the facts right. I understand that this chapter is not intended for serious gemmological study and merely forms one part of a much more general text, but students will be puzzled by the appearance of peridot as a sulphate, the resurgence of 'quartz topaz' and 'real topaz' of which they would never have heard had not the author or reviser dragged them out.

The uncertainty pervading this section makes this reader unsure of the validity of the original or the revised material in the remainder of the book. Certainly the glossaries inspire little confidence and the tables are superfluous if they have to be understood with the limited information provided elsewhere. Worst of all there is no bibliography and some of the works cited in the text are of little value or outdated. All this is a pity since the information certainly is interesting and no doubt it is only here that much of it has been collected into so small a compass: the book would even be pleasing to read were it not for the nagging suspicions that all is not well beneath much of the surface.

The real problem with long-established texts of this kind is that the original authors may certainly have collected a great deal of useful information but later on have found themselves increasingly unable to arrange and present it in clear terms by the standards of today. Revisers, on the other hand, may be much less certain of some of the material and lack the detailed knowledge needed to select those parts which need to be retained and omit others on grounds of later-proved incorrectness or obscurity. This seems to be the case at least with the gemstone section of the present book and the only solution would have been to send the text for assessment to competent authorities before printing. As it stands this section is unworthy of publication and performs a serious disservice to students.

M.O'D.

The Iron Crown and Imperial Europe: the Crown, the Kingdom and the Empire: a thousand years of history.

G. Buccellati, 1995. Società di Studi Monzesi, Monza, Mondadori, Milan, 1995. [Distributed by Messsagerie Italiane S.p.A., via Caetano 32, 20141, Milan.] Part 1, *The Crown, the King: a thousand years of history*. Part 2, *In search of the original crown*. Two additional parts deal with science and the plates. Volumes in slip cases. To examine a copy of the book contact the publishers.

The Iron Crown of Monza has played an important part in the history of both Italy and its former constituent states Lombardy and Venetia. Not only are many authors drawn in to discuss the possible history of the crown but gemmologists and archaeologists also make as complete a scientific study as possible. One interesting feature is the small scale of today's crown: it is too small to be worn satisfactorily, as Napoleon found when he was crowned in Milan in 1805 – astutely and elegantly he placed it on his own head for a moment only. It is possible, since the crown is made from gold plates fastened together, that there were originally more plates and so it could have been worn more easily. A computer study of this, and of the metals and the gemstones, features in the separate volume on the science of the crown, the additional volume showing plates of computer simulations of how the crown might have been made and used.

This is only a short account of what must be one of the finest Italian books to be produced in recent years.

M.O'D.

The Agates of northern Mexico.

B.L. Cross, 1996. Burgess International Group Inc. Edina, Minnesota [7110 Ohms Lane, Edina, Minnesota 55439-2143]. pp xviii, 201, illus. in colour, hardcover. ISBN 0 8087 7282 1. Price on application.

Already very well received by mineral collectors and connoisseurs, this is an excellent survey of some particularly interesting and ornamental agate deposits. The first part of the main descriptive text deals with the various types (shapes, colours and patterning) of agate from Northern Mexico in alphabetical order of their type names, but this section is preceded by considerable geological and other detail on the area in general in which both maps and coordinates are given for sites at which type specimens have been found. This section also explains some of the names and puts forward interesting theories of agate formation in the area.

Further parts of the book deal with the supply and marketing of Mexican agate, and with some of the colour-

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ful personalities associated with the deposits. There is a useful list of references and a glossary of Spanish-English mining and locality terms. While most of the illustrations are in black-and-white there is a well-produced colour section in which 30 outstanding specimens are shown. This is a very desirable book for anyone with an interest in agate or in this attractive area of the Americas. M.O'D.

Diamanten.

CHRISTIAN WEISE VERLAG, MÜNCHEN, 2000. pp 104, illus. in colour, softcover. ISBN 3 921656 53 2. *extraLapis* no. 18. DM 50.

While some of the text is devoted to fashioning and the use of diamonds in jewellery, a quick glance through the pages indicates to the reader that the bulk of the content is concerned with diamond formation and diamond crystals. As invariably with *extraLapis* monographs (and with the journal *Lapis* itself) the photographs are beautiful and the multi-author text reads from end to end without obvious breaks. English translations of the whole series are wanted. M.O'D.

Fire into ice: Charles Fipke and the great diamond hunt.

V. FROLICK, 1999. Raincoast Books [1950 Shaughnessy St., Vancouver BC, Canada V6P 6E5]. pp 354, illus. in black-and-white, softcover. ISBN 1 55192 334 3. Price on application.

Rousing and informative biography (to date) of the discoverer of the Ekati diamond claim in the Northwest Territories of Canada. Fipke is still very much around and continues to work on prospecting: a postscript recounts some of his activities seeking gold in the Yemen. The book includes a great deal of dialogue (real and imagined) and details of the diamond claims, while not too detailed (other rich prospects in the area almost certainly exist!) will show the student in particular some of the problems associated with diamond recovery. A section of photographs show the subject as a boy, passing to shots of the extensive Ekati mine. I enjoyed the book and recommend it to anyone with an interest in diamonds or in gemstone mining in general. M.O'D.

Edelsteinkundliches Fachworterbuch. Gemmological Dictionary.

U. HENN. *Z. Dt. Gemmol. Ges.*, 49, 2000, pp 1-107.

This excellent dictionary/glossary of about 3000 German gemmological items, although written for the German gemmologist, will be most useful to any English-speaking reader of German gemmological material. To be recommended for any specialist library. E.S.

Gemstones. [2nd edn]

C. OLDERSHAW, C. WOODWARD AND R. HARDING, 2001. The Natural History Museum, London. pp 76, illus. in colour, softcover. ISBN 0 565 09155 7. £7.95.

It is surprising how relatively little publicity has been given to one of the world's most important collections of gemstones in recent years when photographic and production techniques have taken great strides. The balance has been in part addressed by this excellent and beautiful book, very reasonably priced, in which the temptation towards didacticism has been successfully avoided in favour of the presentation of some of the well-known (and, very commendably, the less well-known) specimens on display. A photograph of the vanadium kornerupine when so many other green stones are in the collection shows a praiseworthy catholicism on the part of the authors, and there are other examples. Some identification techniques are painlessly introduced: there is a short bibliography and though there are one or two insignificant typos they can be ignored. This is a book worthy of the collections. M.O'D.

Planetary materials.

J.J. PAPIKE (Ed.), 1998. Mineralogical Society of America, Washington DC. pp xv, later 7 chapters individually paginated, softcover. ISBN 0 939950 46 4 (*Reviews in mineralogy*, vol.36) US $30.00.

Before anyone queries the relevance of this book to gemmology it should be said that it is one of the best recent texts from which mineral formation can be followed and understood, notwithstanding the described occurrences being extra-terrestrial. Serious students should consider buying this inexpensive though large book for an introduction to their subject. M.O'D.

Artists' jewellery in contemporary Europe: a female perspective.

D. PLANTZOS (Ed.), 2000. Ilias Lalaounis Jewelry Museum, Athens. pp 127, illus. in colour, softcover. ISBN 960 7417 11 9. Price on application.

A catalogue of an exhibition devoted to jewellery designed by women artists, this attractively-produced book includes not only high-quality illustrations of some of the exhibited pieces but also commentaries by women critics. The British designers Wendy Ramshaw, Dorothy Hogg and Jaqueline Mina are among those featured. Each artist is given a useful biography which includes details of pieces exhibited, prizes won and the whereabouts of major collections. M.O'D.

Professione Gemme: Anuario 2000.

Collegio Italiano Gemmologici, 2000. The College, Milano. pp xxvi, 185, illus. in colour, hardcover. Price on application.

This yearbook celebrates the five-year period 1995-2000 and takes the form of invited papers and details of the organization and members of the College. Papers include an illustrated study of inclusions and brief coverage of other topics: most have their own lists of references. Readers can safely disregard perceived language difficulties and will find much useful information. M.O'D.

Proceedings of the Gemmological Association and Gem Testing Laboratory of Great Britain and Notices

AN APPRECIATION OF ERIC MOORE BRUTON

by David Callaghan

I am not sure when I first met Eric, unsure because looking back I seem to have known him virtually throughout my career in the jewellery trade. Certainly it would have been in the 1960s and I suspect shortly after he founded *The Retail Jeweller* in 1962. It is one of the privileges of my life that I met him, a privilege made all the more by our long and close friendship.

Eric's career as a writer has been so well documented that I shall not catalogue it here. However, anyone who writes 11 detective novels, books on clocks, the standard work on diamonds – the title of his finest and enduring book – is obviously a truly remarkable person. And so he was.

Without doubt Eric possessed the most intense curiosity about the world we live in, the nature of our planet, the philosophy of life, man's ingenuity – every aspect of life that came his way. He was so excited by life, so enthusiastic about every project he tackled and he was so adept in all the crafts to which he applied himself. Crafts such as: water colour painting, stained glass, silversmithing, marquetry, sculpture, Chinese brush painting, paper making, decoupage – name it he had done it. And to those of us who may have tried even one of these things – and failed – he was infuriatingly good at all of them. Such hobbies came later in life to a man who in his earlier years had become accomplished in horse riding, tap and ballroom dancing, figure skating, ski-ing and golfing – and in some of these he gave instruction. Yet you would not have known it, for he was the most unassuming of men. This did rebound on him on one occasion and, typically, he did not hesitate to tell me.

He was in a small queue in a branch of W.H. Smith the booksellers not long before Christmas one year, and in front of him was another man and a woman who was about to buy a book. She wished to give the book as a Christmas present but the dust-jacket of the particular volume she had in her hand was torn. She asked the shop assistant if she could have another copy with the jacket in good condition.

"I think this is the last copy we have, madam", said the assistant. "but I will ask to make sure." A departmental manager was then called and confirmed that it was the last copy they had. The customer then asked when the shop would be replacing the book – Eric's book on *The English Longcase Clock*.

"I am sorry, madam, but we shall not be reordering any further copies of this particular book", replied the manager – and before any other question could be asked a voice from further down the queue was heard to ask:

"Why not?" – and to his horror Eric recognized the voice as his own! Before anyone could ask what business it was of his he continued, somewhat lamely, "I wrote it."

At this point the man in front of Eric grabbed the book opened it, turned to a particular page and began a long and involved story about a clock in his family that was exactly the same as the one illustrated. He pointed to a particular clock – except that his had a different dial, a different chapter ring, did not have a lacquered case – and so on, and on, and on!

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Eric in his garden at Great Bentley – aged 82.

It took Eric some 15 minutes or so of prolonged agony to extricate himself from the shop, having learned very definitely to keep his mouth firmly closed against any and all apparent insults to his professionalism as a writer!

Following Anne's death in 1976, he applied himself to cooking and became an excellent cook. He had such boundless energy and all of us who were invited to his house were quite used to seeing him moving from room to room, or to the garden and back to the kitchen at the run ... it wasn't that he was in a hurry, it was simply the way he worked. My family remember well the first time he invited us to his house at Widmer End for Sunday lunch. The five of us arrived to find the cooking in full swing – the fact that three young children were coming didn't faze him in the least. They were under strict instructions to be on their best behaviour as this 'Uncle Eric' was not used to having young children around him. After lunch one of the children sat in a swivel chair in Eric's sitting room, struggling hard to avoid the temptation of swinging round and round. Eric then proceeded to show her exactly how best to do it and soon they were all taking it in turns to swing round and round, he being the ringleader!

His own garden was a pleasure to visit. Planned with the eye of an artist his meticulous attention to detail was shown in the total view from all angles.

In order to achieve this, a plan of the garden was stored on his computer showing the careful positioning of each plant, suitability of the soil, the pruning and feeding of them. He had trained his mind to focus on each and every task in hand, and many of his books are 'littered' with numerous little notes inserted so that he could study various passages of text at a later date.

Nobody could have lived a fuller life. His infectious enthusiasm for life shone through in everything he did and he took as much pleasure in hearing the exploits of others. He had a great sense of humour, particularly a sense of the ridiculous, and with it an infectious laugh. Furthermore, I have yet to see any photograph in which Eric appears where he is not cheerful, listening to others, generally showing interest and being thoroughly involved. His company was always stimulating and very relaxing. Cynicism was not in his nature and, seemingly a shy person, his inner warmth shone through. I never heard anyone speak ill of Eric and he always saw the best in other people.

Many of his fellow retail jewellers travelled on study tours sponsored by *The Retail Jeweller*, tours he organized. They studied diamonds in South Africa, emeralds in South America, cultured pearls

in Japan, the fabulous buildings and collections in St Petersburg and Moscow – to name but a few – all live in the memory of those who toured with him.

Eric was not an acquisitive person yet his house is filled with interesting objects collected from all over the world. And he loved 'useless' information. He and I were always swapping the sort of information that starts with – 'did you know?' and usually finishes with 'Not many people know that.' In his desk was a box labelled 'Useless Information' and many of the contents were cuttings I had sent him. I found an alphabetical list of the countries in the world he had visited. Only two letters of the alphabet are not shown – the letters X and O! And books, literally thousands of books on every subject you can imagine.

For the last 15 years of his life he suffered from leukaemia, and even this he found 'interesting' and studied the subject deeply. Latterly he suffered from short-term memory loss and even in this he saw an advantage. He told me he was now able to re-read books with enjoyment even though he had read them only a short time before!

Although not a churchgoer Eric was a very spiritual person and had read widely of the many main faiths. Indeed he was about to write a book encapsulating his thoughts – and this at the age of 85. His life depicted always the positive – positive thinking, positive action and above all a positive example. He didn't just enrich the lives of those lucky enough to have known him, he extended their horizons.

In the obituary he wrote of himself [published in the January issue of *The Journal*] he spoke of having no direct descendants. That may be so genealogically, but he does leave descendants in us, those who knew him, respected him, studied from his books and who will be ever grateful for the way in which he touched our lives. His, and Anne's, favourite song was 'What a wonderful world'. I believe that if we can follow Eric's enthusiastic example in the way in which we lead our lives we, too, will find that it is a wonderful world in which we live.

BEQUEST

Hugh Boyd Crawford FGA, who died in January 2000, has bequeathed his gem testing equipment to the GAGTL, to be used 'to help and assist Scottish students'. The equipment includes a Rayner model S refractometer, a Rayner prism spectroscope, a Rayner dichroscope, a Rayner polariscope and a Biolam microscope with high intensity light and dark field illuminator.

The Association is most grateful for the bequest which will be used in Scotland for teaching purposes.

OBITUARY

Margaret J. Biggs FGA (D.1929, with Distinction), Farnham, Surrey, died in March 2001. A full obituary will be published in the July issue of *The Journal*.

Judith A. Brown FGA DGA (D.1967), St Columb Major, Cornwall, died recently.

Michael B. Clough FGA DGA (D.1965), London, died on 31 January 2001.

Thomas L. Ellis FGA MBHI (D.1935), died peacefully on 1 January 2001 at the age of 87.

Dr John W. Franks FGA (D.1979), Bowdon, Cheshire, Treasurer of the North West Branch of the GAGTL, died in March 2001. A full obituary will be published in the July issue of *The Journal*.

Jeanne S. Miller FGA (D.1966), Front Royal, Virginia, U.S.A., died on 15 February 2001.

Jacqueline K. Murray FGA (D.1984), Whalton, Morpeth, Northumberland, died on 17 August 2000.

Catherine Osmond FGA DGA (D.1989), London, died on 26 February 2001.

MEMBERS' MEETINGS

London

On 1 February at the Gem Tutorial Centre, 27 Greville Street, London EC1N 8TN, Stephen Whittaker of Fellows & Sons, Auctioneers of Birmingham, gave a talk on jewellery at auction entitled *Psst! Wanna buy a diamond ring, guv?*

On 1 March at the Gem Tutorial Centre, Guy Clutterbuck gave an illustrated talk on the *Gemstones from the Hindu Kush*.

On 22 and 23 March visits to De Beers were held.

GIFTS TO THE ASSOCIATION

The Association is most grateful to the following for their gifts for research and teaching purposes:

Dr Alexander Bulatou, Stillwater, MN, U.S.A., for a synthetic moissanite.

Freda Cartwright, Ivinghoe, Buckinghamshire, for a collection of books, journals and instruments.

Pat Daly, Windsor, Berkshire, for rough specimens including emerald, sapphire and turquoise.

Michael Hendrix, Minarex, San Antonio, NM, U.S.A., for a yellow opal from Nevada.

Robert James, San Antonio, TX, U.S.A., for a colbalt-coated topaz.

Martin Kuncovsky, Intergem, Cardiff, for four stones including two tourmalines.

Roger Kutchinsky, Bushey Heath, Hertfordshire, for a collection of books and instruments that had belonged to the late Joseph Kutchinsky.

Kyaw Khaing Win, Yangon, Myanmar, for a pale green crystal of herderite.

Michael Parsons, Bath, Somerset, for a collection of gemstones.

Andrew H. Phillips, Stevenage, Hertfordshire, for a bag of jig concentrates from an alluvial diamond mining property, containing pyrope, chrysoberyl and corundum.

Mariana Photiou, Mt Olympus Mining Co., San Francisco, CA, U.S.A., for a rough piece of Oregon sunstone from the Dust Devil mine.

Peter G. Read, Bournemouth, Dorset, for *Professione Gemme: Annuario 2000* published by the Collegio Italiano Gemmologi.

Bear Williams, Jefferson City, MO, U.S.A., for rough garnets from the Tocantins region of Brazil.

Midlands Branch

On 26 January at the Earth Sciences Building, University of Birmingham, Edgbaston, a Gemmology Quiz and Bring and Buy event was held.

On 23 February at the Earth Sciences Building a talk entitled *The garnet group – understanding solid solution* was presented by Professor Henry Hänni.

On 30 March at the Earth Sciences Building Shena Mason gave a talk entitled *The toyshop of Europe*.

North West Branch

On 21 March at Church House, Hanover Street, Liverpool 1, David Callaghan spoke on the *Jewellery of the Art Nouveau era coupled with the art of Renée Lalique*.

Scottish Branch

On 16 January at the British Geological Survey, Murchison House, West Mains Road, Edinburgh, a Quiz Night was held.

On 16 February at the British Geological Surrey Gamini Zoysa gave a talk entitled *Gems and gem mining in Sri Lanka*.

On 21 February John Faithfull gave a talk entitled *The quest for Scottish diamonds*.

South West Branch

Inaugural Meeting

The inaugural meeting of the newly formed South West Branch was held on Sunday 21 January at the Royal Literary and Scientific Institute, Bath. The meeting began with the formation of the branch and election of officers. Dr Roger Harding and Alan Hodgkinson were guest speakers.

There was an excellent turnout on the day and thanks are extended to those who attended for their support. The enthusiasm shown has certainly set the scene for a South West Branch.

Details of the next meeting and contact information are given in Forthcoming Events on p. 379.

GEM DIAMOND EXAMINATION

In the Gem Diamond Examination held in January 2001, 78 candidates sat of whom 56 qualified, including 11 with Distinction and eight with Merit. The names of the successful candidates are listed below:

Qualified with Distinction

Chai Shixiu, Beijing, P.R. China
Checkley, Emma L., Birmingham, West Midlands
Cooke, Caroline, London
Cruse, Toby, Eastbourne, East Sussex
Deljanin, Branko, New York, NY, U.S.A.
Greslin-Michel, Valerie, London
Jiao Ning, Beijing, P.R. China
Ngan Hin Wah, Michael, Hong Kong
Sherman, Gregory E., Sea Bright, NJ, U.S.A.
Thomas, Allyson, Birmingham, West Midlands
Zhou Xiaoyang, Beijing, P.R. China

Qualified with Merit

Mayne, Glen R., Reston, VA, U.S.A.
Pala, Sunil Vinod, Coventry, West Midlands
Pelser, Stephan, Freiburg, Germany
Qin Fei, Beijing, P.R. China
Tan Hewen, Beijing, P.R. China
Wong Shuk Ching, Hong Kong
Xu Jun, Beijing, P.R. China
Ye Hong, Beijing, P.R. China

Qualified

Armati, Alexander V., Henley-on-Thames, Oxfordshire
Ayukawa, Yasuyo, London
Backsh, Illahi, Karaikal, India
Basch, Elizaveta Z., London
Bruce-Lockhart, Simon, London
Campbell, Paul, Birmingham, West Midlands
Chen Wei, Tiffany, Kowloon, Hong Kong
Chitondo, Martin Chitalu, Edmonton, London
Efejuku-Inegbenebho, Rosemarie, London
Feldman, Luke, London
Han Yenan, Beijing, P.R. China
Ito, Eiko, London
Kessler, Paul, London
Ko, Yuksan, London
Kwan, Susana, Kowloon, Hong Kong
Lam Koon-Wah, Francis, Kowloon, Hong Kong
Lei Xiong, Wuhan, Hubei, P.R. China
Lin Fan, Wuhan, Hubei, P.R. China
Liu Ying, Wuhan, Hubei, P.R. China
Moltke, Nicholas, London
Parmar, Sejal, London
Pattison, Noel, Eaglescliff, Cleveland
Ricard-Elbek, Rebecca, London
Rimmer, Ray, Bootle, Merseyside
Sang Yan, Wuhan, Hubei, P.R. China
Song Zheng, Wuhan, Hubei, P.R. China
Susser, Jennifer L., London
Tao Feng, Beijing, P.R. China
Tsang, Jasmine, Kowloon, Hong Kong
Tsoi Pui Pui, Karen, Kowloon, Hong Kong
Wei Yakun, Wuhan, Hubei, P.R. China
Wong Kwok Man, New Territories, Hong Kong
Wong Man Kuen, Purdey, New Territories, Hong Kong
Wong Lai Mun, Phyllis, New Territories, Hong Kong
Xianlong Sun, Wuhan, Hubei, P.R. China
Yu Choi Lin, Denise, New Territories, Hong Kong
Zou Hon Wah, Hong Kong

New Merit award

From January 2001, candidates sitting the Gemmology Diploma and the Gem Diamond Diploma Examinations will be eligible for a Merit award.

To gain a Merit in the Gemmology Diploma examination, candidates need to achieve between 70% and 79.5% for the two theory papers, and 80% for the practical paper. To gain a Merit in the Gem Diamond Diploma examination, candidates must achieve between 75% and 79% for each paper.

For both Diplomas, the Distinction award remains at 80% for theory and practical. All awards are at the discretion of the Examiners.

EXAMINATIONS IN GEMMOLOGY

In the Examination in Gemmology held worldwide in January 2001, 122 candidates sat the Diploma Examination of whom 62 qualified, including two with Distinction and eight with Merit. In the Preliminary Examination, 100 candidates sat of whom 89 qualified. The names of the successful candidates are listed below:

Diploma

Qualified with Distinction

Dong Lan, Wuhan, Hubei, P.R. China
Molesworth, Helen, Rotherhithe, London

Qualified with Merit

Keating, Shelley, London
Kim Ah Rong, Jeollanam-Do, Korea
Kim Yu-Mi, Kwangju, Korea
Long Zhen Xing, Guilin, Guangxi, P.R. China

Lwin Pwint Phue, Yangon, Myanmar
Pace, Michael, El Grove, California, U.S.A.
Shin Whan-Ho, Daejon, Korea
Teramae, Ikumi, London

Qualified

Andrade, Fabiana, London
Bastos, Ana Pestana, Lisbon, Portugal
Blairs, Lawrence I.J., Llanrwst, Gwynedd
Chalmers, Marie L., Redditch, Hereford and Worcester
Cheng Mei Yun, Beijing, P.R. China
Cheung Suk Yin, Central, Hong Kong
Comar, Ankush, London
Corcoran, Moya A.M., London
Croucher, Nicola, London
Ding Li, Wuhan, Hubei, P.R. China
George, Douvis, Athens, Greece
Eineljung, Lars, Lannavaara, Sweden
Farrer, Alison, Stonehouse, Gloucestershire
Hanlon, Adrienne, Preston, Lancashire
He Xiaogang, Wuhan, Hubei, P.R. China
Henn, Ingo, London
Jealous, Rosa, London
Jiang Songning, Wuhan, Hubei, P.R. China
Jinyan Xiong, Wuhan, Hubei, P.R. China
Ko Ji Hea, Naju Jellanamdo, South Korea
Kulukundis, John C.A., London
Kanacher, Marly, Singapore
Kaung Nyunt Thar, Yangon, Myanmar
Kuang Shan, Wuhan, Hubei, P.R. China
Lam Chi-Hing, Hong Kong
Li Tingting, Shanghai, P.R. China
Li Xue Ming, Guilin, Guangxi, P.R. China
Liao Chun-Yan, Taipei, Taiwan, R.O. China
Ling Yanhua, Wuhan, Hubei, P.R. China
Liu Ming, Guilin, Guangxi, P.R. China
Long, Charles, Kew, Richmond, Surrey
Lu Zhiqing, Liuzhou, Guangxi, P.R. China
Ma Li Ke, Guilin, Guangxi, P.R. China
Oo Naing Naing, Yangon, Myanmar
Pan Chun Chieh, Taipei, Taiwan, R.O. China
Photiou, Mariana-Maria, San Francisco, California, U.S.A.
Plant, Monika, Knutsford, Cheshire
Qian Xunxiao, Wuhan, Hubei, P.R. China
Quirino Cabrita, Jose Miguel, Turnhout, Belgium
Rweyemamu, Edward J., London
Shwe Moe Moe, Yangon, Myanmar
Sidiropoylou, Maria-Theresa, Thessaloniki, Greece
Soo Hyang Seo, Seoul, Korea
Squires, Caroline, Tring, Hertfordshire
Tsoha, Theodora, Volos, Greece
Wasim, Baber, Karachi, Pakistan
Welsh, Fiona, Wynyard Woods, Cleveland
Win Moh Moh, Yangon, Myanmar
Wong Kwok Man, New Territories, Hong Kong
Xanthoudaki, Aristea D., Chania, Crete, Greece
Xu Jing, Guilin, Guangxi, P.R. China
Yedunath, R., Chennai, India

Preliminary

Qualified

Abimbola, Adedapo, London
Al-Turki, Nohad, London
Allsopp, Chris, London
Amini, Amir, Lannavaara, Sweden
An Jung Hee, Jeollanam-Do, Korea
Aye Tin Tin, Yangon, Myanmar
Aye Nwe Nwe, Yangon, Myanmar
Balzan, Lynda, San Francisco, California, U.S.A.
Balzan, Robert A., San Francisco, California, U.S.A.
Benda, Yves, London
Bi Yu Liang, Guilin, Guangxi, P.R. China
Burdett, Ruth Hazel, Devizes, Wiltshire
Cai Xiaolin, Shanghai, P.R. China
Cao Yuan, Guilin, Guangxi, P.R. China
Chang Chi Fu, Taipei, Taiwan, R.O. China
Chen Chao-Hsiu, Taipei, Taiwan, R.O. China
Chen I. Chun, Taipei, Taiwan, R.O. China
Chen Mei Ling, Guilin, Guangxi, P.R. China
Chen Yu-Ting, Dagenham, Essex
Cheng, Helen S.F., St John's Wood, London
Daswani, Vijayeta, London
Dou Han, Shanghai, P.R. China
Engebretsen, Jan Arthur, Oslo, Norway
Every, Susanne, London
Fang Lan, Guilin, Guangxi, P.R. China
Gordon, Carole, Richmond, Surrey
Greig, Davina, London
Gu Siyuan, Shanghai, P.R. China
Hellstenius, Gabriella, London
Hing, Michael E., London
Honda, Hiroya, Poplar, London
Hsieh Ming Tsung, Taichung, Taiwan, R.O. China
Htun Ngwe Lin, Yangon, Myanmar
Huang Zhan, Guilin, Guangxi, P.R. China
Jang, Shinkuk, Poplar, London
Jin Yanyan, Shanghai, P.R. China
Kalischer, Janice, Finchley, London
Killingback, Harold, Oakham, Leicestershire
Kim Ah Rong, Jeollanam-Do, Korea
Kobayashi, Hiromi, London
Liao Wei-Ching, London
Long Zhen Xing, Guilin, Guangxi, P.R. China
Lu Yanghua, Shanghai, P.R. China
Marshall, Katharyn, London

Meng Xiangdong, Shanghai, P.R. China
Mo Bina, Shanghai, P.R. China
Moltke, Nicholas, London
Ni Linong, Shanghai, P.R. China
Ning Haibo, Guilin, Guangxi, P.R. China
Ogden, Benjamin, London
Oh Ha Na, Jeollanam-Do, Korea
Ok Min Suk, Jeollanam-Do, Korea
Pan Chun Chieh, Taipei, Taiwan, R.O. China
Pan Jingchen, Shanghai, P.R. China
Pennington, Susan E., Bickerstaffe, Lancashire
Ren Qin, Shanghai, P.R. China
Salukvadze, Iamze, Colombo, Sri Lanka
Samarasekera, Palawa P.P., Kandy, Sri Lanka
Shyu Huey-Ting, Southgate, London
Smith, Sonia M., London
Song Ping, Guilin, Guangxi, P.R. China
Steward, Sarah, Hove, East Sussex
Sun Bei, Shanghai, P.R. China
Susser, Jennifer L., London
Thein Myint Myint, Yangon, Myanmar
Thur, Anne-Vibeke, Tervuren, Belgium
Tominaga, Masami, London
Towers, Jill S., Auckland, New Zealand
Tseng Chien Min, Taichung, Taiwan, R.O. China
Tun Soe Moe, Yangon, Myanmar
Vande Vyvere, Vinciane, London
Wai Thin Thin, Yangon, Myanmar
Wang Qian, Shanghai, P.R. China
Woo Ha Na, Jeollanam-Do, Korea
Woodring, Sharrie R., Bound Brook, New Jersey, U.S.A.
Wu Xiaoyi, Shanghai, P.R. China
Xia Zhen, Shanghai, P.R. China
Xie Kefei, Shanghai, P.R. China
Yanagihara, Satomi, London
Yang Chao Yuan, Taipei, Taiwan, R.O. China
Yang Ching-Ho, Taipei, Taiwan, R.O. China
Yang Na, Guilin, Guangxi, P.R. China
Yen Chen-Fang, Taipei, Taiwan, R.O. China
Yun Jing-Wen, London
Zhong Lin, Guilin, Guangxi, P.R. China
Zhou Songsong, Shanghai, P.R. China
Zhou Yujie, Shanghai, P.R. China
Zhu Gongyi, Shanghai, P.R. China
Zhu Haijing, Shanghai, P.R. China

MEMBERSHIP

The following have been elected to membership during the period December 2000 to March 2001.

Fellowship and Diamond Membership (FGA DGA)

Breden, Robert J., Maghull, Merseyside, Liverpool. 1979/1980
Lin Yeong Leh, Chin Cheng Town, Chin Men County, Taiwan, R.O. China, P.R. China. 2000

Fellowship (FGA)

Cai Shi Mei, Guangxi, Guilin, P.R. China. 2000
Chandrasena, Vishwakanthi, Winnipeg, MB, Canada. 1986
Chen Ji Juan, Guangxi, Guilin, P.R. China. 2000
Chen Liang H., Toronto, Ontario, Canada. 2000
Chen Pei Jia, Guangxi, Guilin, P.R. China. 2000
Fang Liang, Guangxi, Guilin, P.R. China. 2000
He Jia Mu, Guangxi, Guilin, P.R. China. 2000
Heaviside, Desmond, Skelton-in-Cleveland. 1974
Hicks, Suzanne C., Yardley, Birmingham. 2000
Holdsworth, Christopher J., Armadale, Victoria, Australia. 2000
Khan, Abdul Jabbar, Mumbai, India. 1991
Kong Bei, Guangxi, Guilin, P.R. China. 2000
Loe Su-Mon, Taipei, Taiwan, R.O. China, P.R. China. 2000
Ma Rui, Guangxi, Guilin, P.R.China. 2000
Ndirangu, Joseph Kirangu, Nairobi, Kenya. 2000
Nootenboom, Winnie Lee-Bing, Yan Yeerd, Sai Kung, N.T., Hong Kong. 1977
Park, Stephen W., Lymington, Hampshire. 1983
Park, Suzanne S., Lymington, Hampshire. 1983
Qu Han, Guangxi, Guilin, P.R.China. 2000
Shi Kai, Guangxi, Guilin, P.R. China. 2000
Song Xiau Hua, Guangxi, Guilin, P.R. China. 2000
Su Nan, Guangxim Guilin, P.R. China. 2000
Tang Yu-Lung, Taichung City, Taiwan, R.O. China, P.R. China. 1999
Thomas, Arthur E., Gauteng, South Africa. 1970
Tzou Jyh-Jeng, Taipei, Taiwan, R.O. China, P. R. China. 1995
Vlahos, Nick, Pireas, Greece. 1995
Wang Xuan, Guangxi, Guilin, P.R. China. 2000
Williams, Johanna, London. 2000
Winter, Nicola Kim, London. 2000
Xu Min Ya, Guangxi, Guilin, P.R. China. 2000
Zhu Ya Lin, Guangxi, Guilin, P.R. China. 2000

Ordinary Membership

Ali, Muhammad Zafar, Raas Salmiya, Kuwait
Asano, Yuko, Kofu City, Yamanashi Pref., Japan
Bakri, Di, London
Barwuah, Max, London
Boeckmann, Susie, London
Bordbar, Hossein Jean-Louis, London
Cameron, Annabel J., Tiverton, Devon

FORTHCOMING EVENTS

25 April	**North West Branch**. *My 40 years with gems. Dr KURT NASSAU.*
27 April.	**London**. *My 40 years with gems. Dr KURT NASSAU.*
27 April	**Midlands Branch**. *A new combination gemstone finger-printer and high RI refractometer. DR JAMIE NELSON. This meeting will include the Branch AGM.*
29 April	**Midlands Branch**. *Light and colour – beautiful complexity. DR KURT NASSAU.*
3 May	**London**. *Light and colour – beautiful complexity. DR KURT NASSAU.*

Scottish Branch Conference
4-7 May 2001
Queen's Hotel, Perth

The programme will include:

RICHARD DRUCKER: Coloured stone guide. Gemstone values: sources of reference

ERIC EMMS and *ANA CASTRO*: D is for Gemmology

ROGER HARDING: Gem collections of the Natural History Museum

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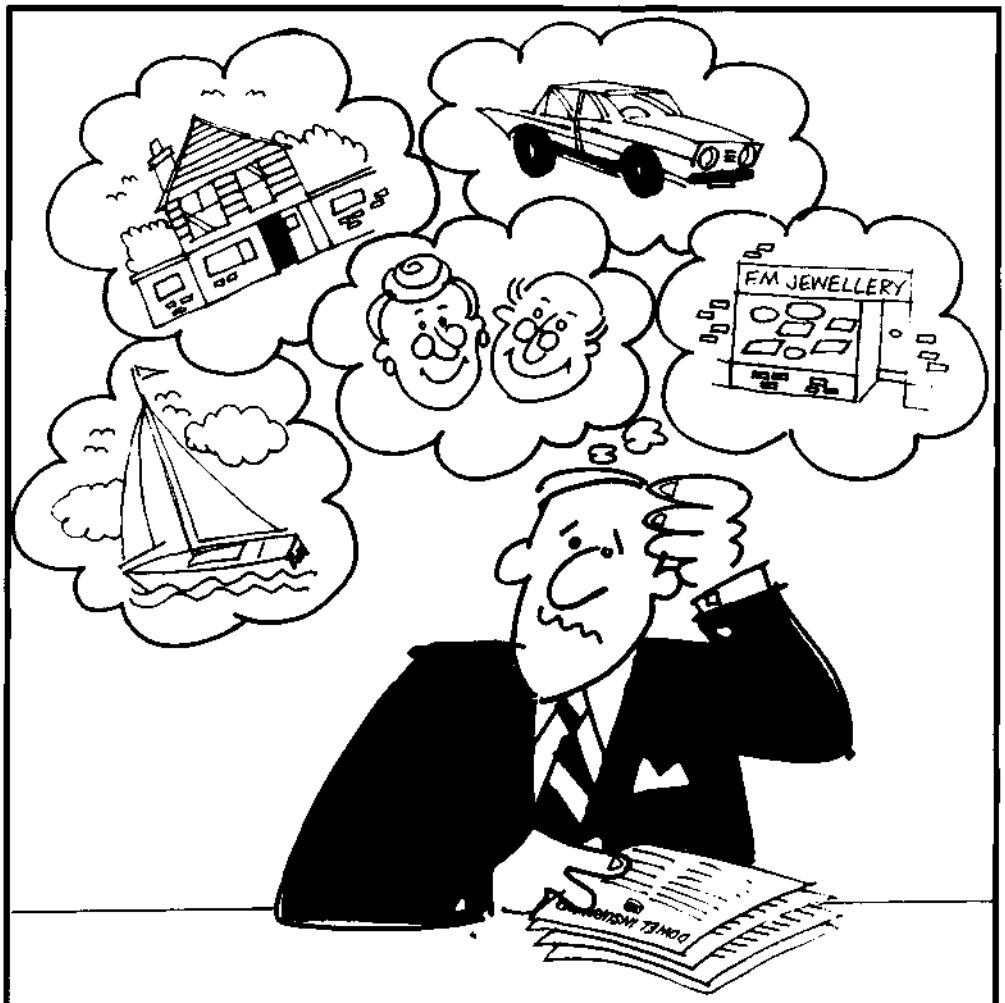

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Cover Picture

A flower carved in hte long sein jade. (See 'Hte long sein – a new variety of chrome jadeite jade' pp.321-7)

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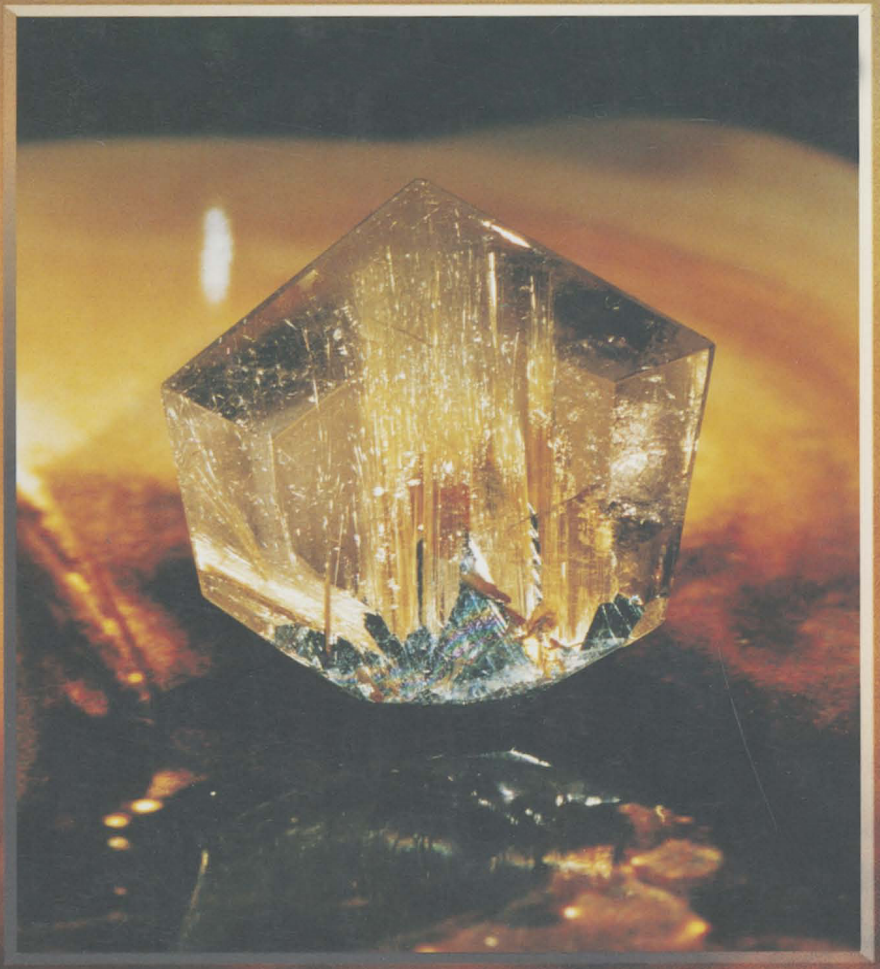

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New gemstone occurrences in the south-west of Madagascar

Dr Claudio C. Milisenda[1], Dr Ulrich Henn[2] and Jürgen Henn[3]

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2. German Gemmological Association (DGemG), Idar-Oberstein, Germany
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ABSTRACT: In late 1998, spectacular gemstone occurrences were discovered in the south-western part of Madagascar. The secondary deposits extend from the south of the Isalo National Park near the town of Ranohira up to the town of Sakahara further west with major mining areas around Ilakaka and south of Ankazoabo. The occurrences produce pink, blue, violet, yellow, orange, green, pale brown and colourless corundum varieties, spinels, chrysoberyls, garnets, aquamarines, tourmalines and other gems. Of particular importance are pink and blue sapphires which are found in large quantities. The gemmological properties of fancy-coloured sapphires correspond to those found in the Umba valley and Tunduru area in Tanzania whereas the blue sapphires are reminiscent of sapphires from Sri Lanka. In addition a number of pinkish-orange corundum varieties show colours and absorption spectra that correspond to Sri Lankan padparadschas. The geological environment of the new deposits in Madagascar is similar to the alluvial deposits of Sri Lanka and Tanzania and the three areas may have been part of single land mass before the break-up of Gondwana.

Keywords: gemmological properties, geology, internal characteristics, Madagascar, padparadscha, sapphire

Introduction

Madagascar has been well known for centuries for its formidable list of gemstones. Already in the 16th century Portuguese, Dutch, English and French sailors had travelled to the island adjoining the continental margin of East Africa and had returned to Europe with various gemstones. After becoming a French protectorate in 1885 and colony in 1896 a systematic exploration of Madagascar took place and Lacroix (1922) provided a detailed description of the minerals that were found. At the beginning of the 20th century Madagascar entered the gemstone supply scene with commercial quantities of aquamarine appearing from 1908, morganite, tourmaline and quartzes from 1911, and spodumene, feldspars, garnets and various other gemstones from 1922. After obtaining independence in 1960 the systematic mining and export of gemstones decreased. The political and economic development in the 1970s, however, resulted in a larger supply of gemstones to the western market. During the 1990s new gemstone occurrences of commercial significance were found, these include as the emerald occurrence of Mananjary on the east coast (Schwarz and Henn, 1992) and the sapphire fields of Andranondambo in the southeast of the island (Milisenda and Henn, 1996; Kiefert *et al.*, 1996). At present Madagascar produces

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Figure 1: *Simplified geographical map of south-western Madagascar.*

more than 50 different varieties of gemstone (Henn *et al.*, 1999).

In late 1998, spectacular gemstone occurrences were discovered in the south-western part of Madagascar (Henn *et al.*, 1999) delivering significant quantities of blue and pink sapphires, and lesser amounts of spinels, chrysoberyls, garnets, tourmalines, zircons, topazes and aquamarines.

Locality and mining

The new gemstone occurrences occupy extensive areas east of Ihosy and north of Ejeda in the south-western part of Madagascar (*Figure 1*). When the first finds were made in late 1998 and news of the discovery spread, people from the whole region rushed to the area seeking their fortune in gemstones.

Since summer 1999 mining has been concentrated in three main areas. The first region includes a 90 x 20 km wide belt between Ranohira and Sakahara. Intensive mining takes place around the village of Ilakaka, which is now well known for the production of blue sapphires. A second important mining area covers a 30 x 20 km wide zone around Fotiyola and Andranolava, south of Ankazoabo with interesting occurrences of pink sapphires. Thirdly, the area around Murarano has rich deposits of blue and pink sapphires as well as alexandrites.

Mining is controlled by the Ministry of Mines and hundreds of claims have been conferred, each measuring approximately 2.4 x 4 km. The gem gravels are excavated by using simple hand tools from numerous pits

Figure 2: *Alluvial gemstone deposit at Ilakaka, south-western Madagascar.*

(*Figures 2 and 3*) and the gems are then separated from the earthy gravels by washing in nearby streams (*Figure 4*). Dealers from overseas may rent small huts and use them as buying offices (*Figure 5*). Local miners crowd round the booths to show the rough, most of which is sold to dealers from Sri Lanka and Thailand.

Geology

The Precambrian of Madagascar formed a segment of crust of Archaean to mid-Proterozoic age that experienced its main thermo-tectonic evolution during the Pan-African event (Andriamarofahatra *et al.*, 1990; Guerrot *et al.*, 1993; Paquette *et al.*, 1993), which is known to have affected large parts of Africa. In a reconstruction of the Gondwana supercontinent, the high-grade rocks of Madagascar formed the eastern part of the Mozambique belt, which is regarded as a collision structure resulting from collision of East Gondwana (India-Antarctica-Australia) and West Gondwana (Africa-South America) some 600 million years (Ma) ago.

The sedimentary Morandava basin of

Figure 3: *Miners working at the pits near Ilakaka.*

Figure 4: Washing the gravels in a nearby stream, Ilakaka.

western and south-western Madagascar form part of a larger basin which finds its continuation on the East African continent. The sediments in this basin were deposited continuously from Carboniferous times (approximately 345 Ma ago) to the Tertiary less than 60 Ma ago. The separation of the basin was due to the break-up of Gondwana and continental drifting some 165 million years ago.

The recently discovered secondary deposits containing gems are located within the Morandava basin. In Africa, the thick continental succession of rocks ranging in age from Upper Carboniferous to Lower Jurassic is commonly defined as Karroo (Schlüter, 1997), and attains a maximum thickness of approximately 9000 m in the southern part of the basin. This Karroo Supergroup can be subdivided into three units as follows:

1. the 'Sakoa-Group' at the base, Carboniferous to Mid Triassic in age with predominantly sandstone and argillitic layers as well as coal beds;
2. the 'Sakamena-Group' of Upper Permian to Mid Triassic age with alternating argillitic and sandstone layers and
3. the 'Isalo-Group', Upper Triassic to Upper Liassic and consisting of alternating sandstone and red argillitic layers.

At Ilakaka the gems are recovered from sediments of the Isalo-Group which were deposited some 200 Ma ago (Andriamanantena, pers. comm, 1999) and originated from the Precambrian basement.

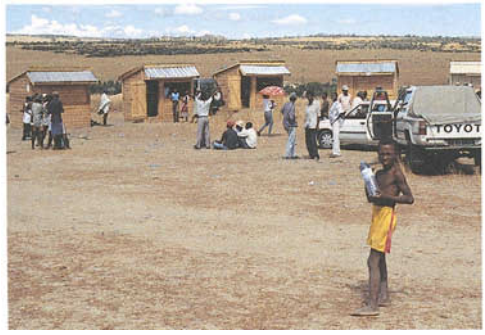

Figure 5: Dealers sit in booths and buy rough from local miners.

Characteristics of the gemstones

A number of representative samples of gemstones from the new deposits in south-western Madagascar are shown in *Figure 6*.

Sapphires

The sapphires from the new finds show an interesting range of colours. Blue and pink stones are of particular commercial significance, but colourless, pale green, yellow, orange, pale brown, brownish-red and violet sapphires are also present (see *Figure 6*). The rough crystals of blue sapphires range in weight from 1 to 30 ct, faceted stones are known up to 15 ct. The rough pink sapphires are 1 to 15 ct in weight and faceted stones up to 6 ct were observed on the market. Fine quality sapphires of a natural blue colour are very rare. Most of the material is thermally enhanced to improve its colour and clarity. With respect to both colour and clarity the Madagascar blue sapphires are similar to material from Sri Lanka. Pinkish-orange varieties also strongly resemble Sri Lankan padparadschas. In contrast yellow, orange and brownish-red stones correspond to the colours of sapphires found in Tanzania (Umba valley and Tunduru). Madagascar has however yielded pink sapphires which vary from a light to fine deep pink in shades not found elsewhere.

The standard gemmological properties of the Madagascar sapphires are in the range known for the mineral species corundum: n_e= 1.760 - 1.762, n_o = 1.768 - 1.770 with Δn = -0.008 and SG = 3.98 - 4.00.

Interesting results were obtained by measuring the absorption spectra. Spectra of blue sapphires from the new occurrences in the south-west of Madagascar are comparable with those of specimens from Sri Lanka (Ceylon-sapphires) and consistent with sapphires derived from high-grade metasedimentary sources. The absorption spectrum is dominated by a broad pleochroic band between 500 and 800 nm with an absorption maximum at approximately 580 nm (*Figure 7*) which is caused by a Fe^{2+}/Ti^{4+} charge transfer. In the blue and violet spectral range absorption bands of Fe^{3+} are present, one at 450 nm and a doublet with maxima at 387 and 377 nm. Total absorption in the violet region starts at approximately 300 nm. In contrast to this specific absorption pattern the blue sapphires from the Andranondambo gem fields in the south east of Madagascar (Milisenda and Henn, 1996) possess spectra with a total absorption starting at about 320 - 330 nm (see *Figure 7*), similar to the spectra of sapphires from Tanzania and Malawi. A third type of blue

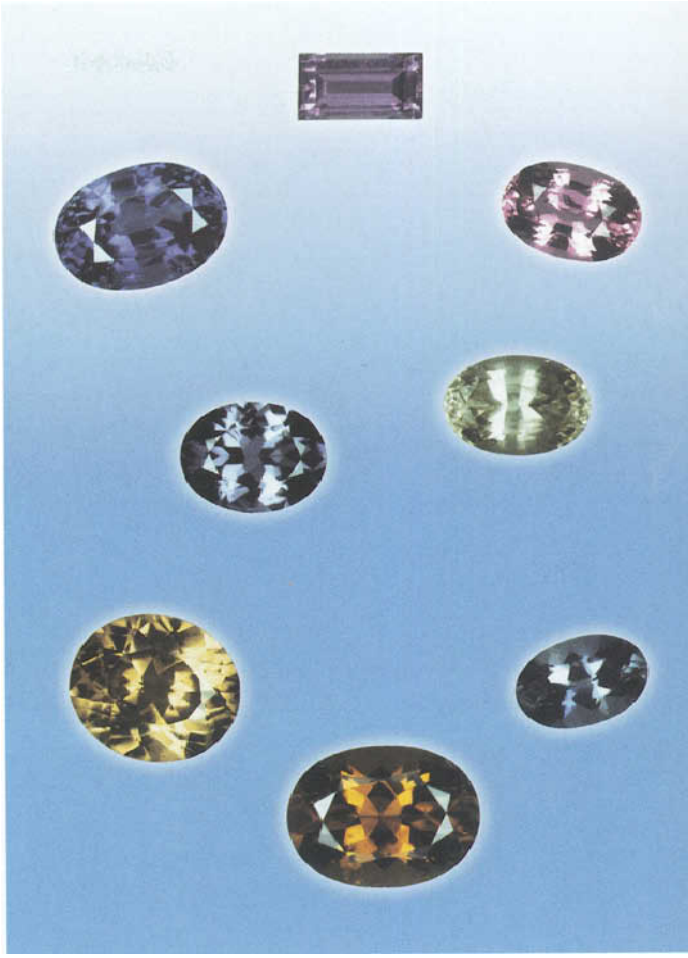

Figure 6: *Gemstones from the new finds in south-western Madagascar. Upper row from left to right: sapphire (5.12 ct), violet sapphire (1.12 ct), pink sapphire (2.30 ct). Middle row: spinel (2.37 ct) yellow-green sapphire (2.16 ct). Lower row: chrysoberyl (5.03 ct), tourmaline (6.02 ct), aquamarine (1.51 ct).*

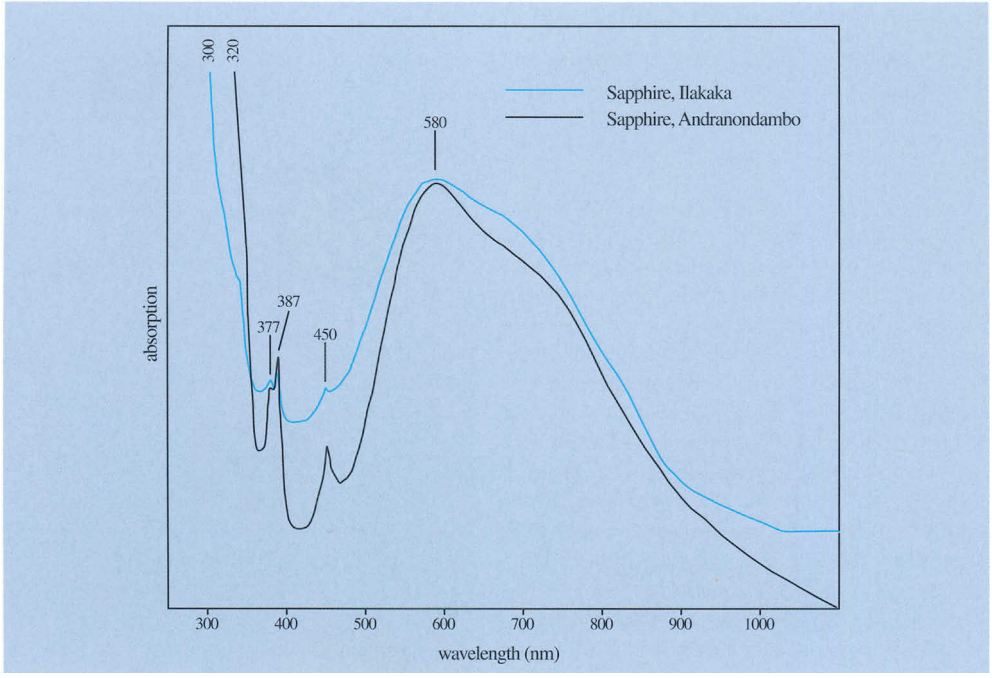

Figure 7: *Non-polarized UV/VIS/NIR - spectra of natural coloured sapphires from the new occurrence near Ilakaka and the known deposit at Andranondambo in south-eastern Madagascar.*

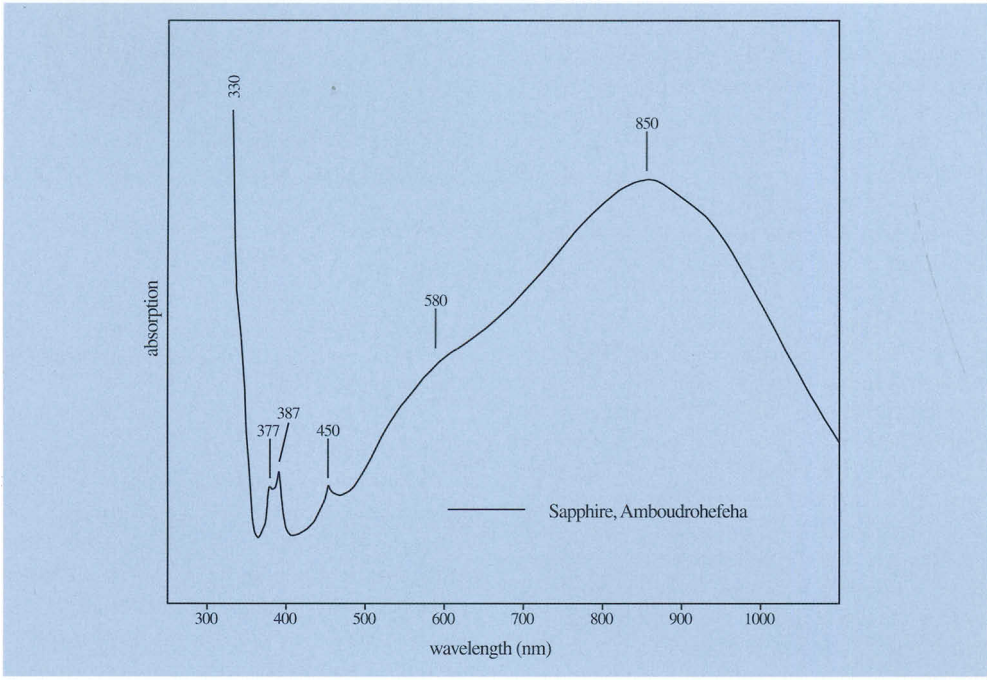

Figure 8: *Non-polarized UV/VIS/NIR - spectrum of a natural coloured, basaltic-type sapphire from Amboudrohefeha in northern Madagascar.*

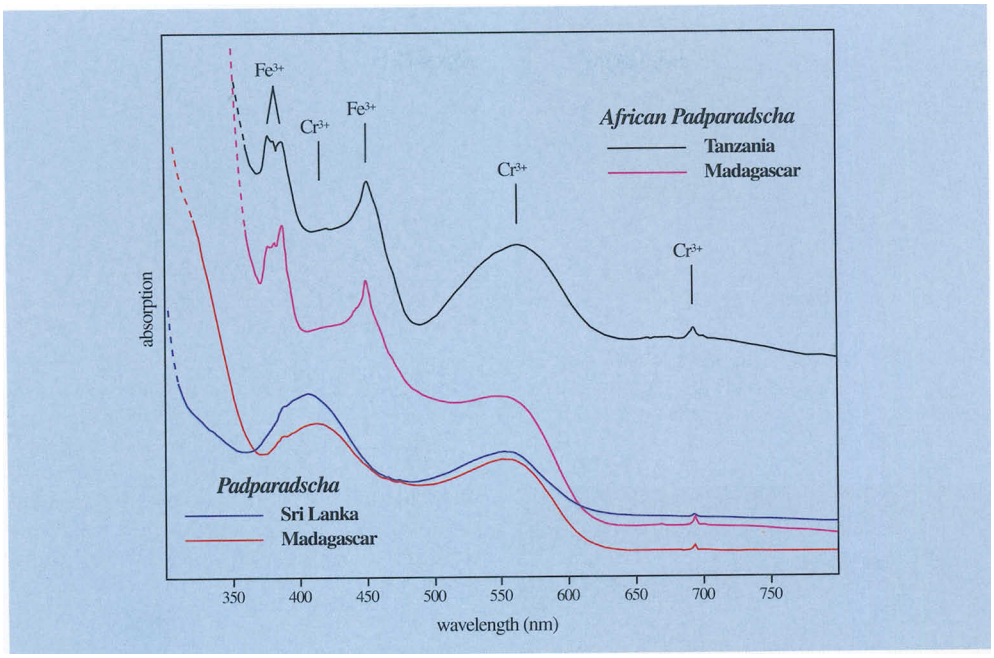

Figure 9: *Non-polarized UV/VIS/NIR - spectra of representative samples of orange to brownish-orange and pinkish-orange corundums from Madagascar, compared with a padparadscha from Sri Lanka and an 'African padparadscha' from Tanzania.*

sapphire originates in the north of Madagascar near Amboudrohefeha. These specimens are recovered from basaltic rocks and show a typical broad absorption band in the near infrared with a maximum at 850 nm due to a Fe^{2+}/Ti^{3+} charge transfer process (*Figure 8*). In a recently examined parcel of Madagascar sapphires all three types were present.

The yellow, orange and brownish-red sapphires from Madagascar possess absorption patterns comparable with those of sapphires from the Umba-valley and the Tunduru/Songea area in Tanzania. The yellow sapphires show the typical Fe^{3+}-spectrum with absorption maxima at 450 nm, 387 and 377 nm. The orange sapphires are coloured by iron and chromium. In addition to the Fe^{3+} bands producing the yellow colour, additional broad pleochroic bands of Cr^{3+} are visible and produce the red component. The absorption maxima are at 555 and 410 nm and the typical Cr-line is situated at 693 nm (*Figure 9*). Increased iron contents change the colour to a brownish tone which is characteristic for orange sapphires from East Africa (Schmetzer *et al.*, 1982; Henn *et al.*, 1989). This range of orange to brownish-orange sapphires is known in the trade as 'African padparadscha'. However, a number of the Madagascar specimens showed a pinkish-orange reminiscent of padparadschas from Sri Lanka. The absorption spectrum measured on a representative specimen is dominated by colour centres and trivalent chromium (± Fe^{3+}) and corresponds to similar spectra obtained from Sri Lankan material (see *Figure 9*).

The inclusion pattern of the blue sapphires from the new gemfields was also compared to that of blue sapphires from Sri Lanka and found to be similar, whereas the internal features of the fancy-coloured sapphires more resemble the East-African type. Typical inclusions in the blue sapphires from Ilakaka include oriented rutile needles (*Figure 10*), zircons with tension cracks, healed-cracks and distinct growth and colour zoning (*Figure 11*). The yellow and orange to

Figure 10: *Oriented rutile needles in a sapphire from the new deposit in south-western Madagascar. Immersion, transmitted light, magnified 20x.*

Figure 11: *Distinct growth and colour zoning and healed crack in a sapphire from the new deposit in south-western Madagascar. Immersion, transmitted light, magnified 20x.*

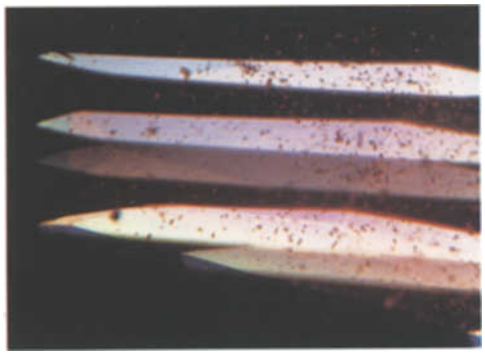

Figure 12: *Lamellar twinning in a fancy-coloured sapphire from the new deposit in south-western Madagascar. Immersion, transmitted light, crossed polars, magnified 20x.*

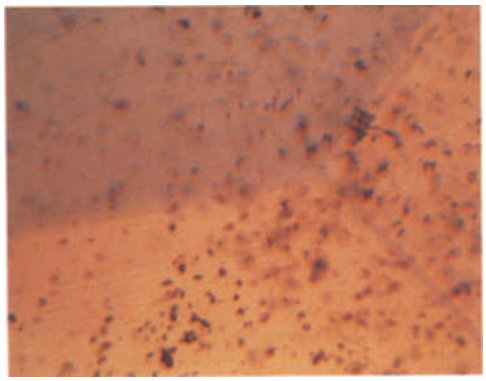

Figure 13: *Numerous small zircons form a typical inclusion pattern in the fancy-coloured sapphires from the new deposit in south-western Madagascar. Immersion, transmitted light, magnified 40x.*

brownish-orange sapphires showed lamellar twinning (*Figure 12*), partly with boehmite tubes, and numerous small zircon grains (*Figure 13*).

Spinel

Corundum of metamorphic origin is commonly accompanied by spinel and this is the situation in the gemstone occurrences of south-west Madagascar. Blue and violet colours (see *Figure 6)* predominate and are caused by divalent iron. The refractive indices measured ranged from 1.716 to 1.720 and the specific gravity varied between 3.54 and 3.63. Black hercynite octahedra are characteristic inclusions and crystallographically oriented rutile needles (*Figure 14*) were observed with the microscope.

Chrysoberyl

This mineral species is present as chrysoberyl, chrysoberyl cat's-eye and alexandrite. The chrysoberyls possess yellow to yellowish-green and yellowish-brown colours (see *Figure 6*) caused by trivalent iron. The following refractive indices, birefringences and specific gravities were determined: n_x = 1.744 - 1.749, n_y = 1.747 - 1.752, n_z = 1.752 - 1.758, with Δn = 0.008 - 0.009 and SG = 3.70 - 3.72. Typical internal features are step-like growth structures, healed-cracks and isolated two-phase inclusions as well as hollow tubes. The presence of numerous oriented hollow tubes may produce a cat's-eye effect. The

alexandrites examined showed a distinct colour-change from bluish-green in daylight to violet-red in artificial light.

Garnets

Specimens of the garnet family are frequently found in the gemfields of south-western Madagascar, especially rhodolites, colour-change garnets and hessonites. The rhodolite garnets possess the typical violet-red to reddish-violet colours caused by divalent iron. Refractive index and specific gravity measurements are in the known range for solid solutions of the pyrope - almandine series: n = 1.764 - 1.772 and SG = 3.75 - 3.81. Oriented rutile needles as well as a distinct tabby extinction under crossed polars were observed with the microscope.

The colour-change garnets are bluish-green in daylight and red to reddish-violet in artificial light. These garnets belong to the binary series pyrope-spessartine and have a refractive index between 1.760 and 1.763 and specific gravity between 3.76 and 3.87. The change of colour is caused by a broad absorption band in the yellow spectral range due to minor contents of trivalent vanadium and/or trivalent chromium.

The hessonite garnets from the new finds are typically brownish-yellow with refractive indices between 1.744 and 1.749 and specific gravities between 3.60 and 3.69.

Beryl

Historically beryl is one of the most important gemstones recovered in Madagascar, but the presence of this species in the new finds is sparse. The standard gemmological properties of some intense blue aquamarines (see *Figure 6*) purportedly from the new deposits were n_e = 1.580 - 1.589, n_o = 1.587 - 1.598 with Δn = 0.007 - 0.009 and SG = 2.72 - 2.74. Fine growth structures and fluid inclusions formed a typical inclusion pattern.

Tourmaline

Another important gemstone group of Madagascar is tourmaline. Occurrences in the new gemfields include pale brown to yellow-brown dravites and uvites (see *Figure 6*) as well as pink elbaites. The following refractive indices, birefringence and specific gravity were determined: n_e = 1.619 - 1.621, n_o = 1.639 - 1.641, Δn = 0.020 and SG = 3.05 - 3.07.

Figure 14: *Crystallographically oriented rutile needles in a spinel from the new deposit in south-western Madagascar. Immersion, transmitted light, magnified 20x.*

Other gems

In addition to the stones mentioned above reddish-brown zircons, pale blue and colourless topazes, kunzites and iolites from the new deposits were examined.

Conclusions

The new finds in south-western Madagascar have significantly increased the commercial importance of blue and fancy-coloured sapphires from Madagascar. However, as was also the case in the Tunduru area in southern Tanzania, the situtation has been complicated both by gems brought in and sold as local produce and by Madagascan stones taken out and sold as Sri Lankan.

Because Sri Lanka and Madagascar once formed a single landmass it is very likely that these sapphires were formed in the same geological environment, namely high-grade metamorphic sediments. The presence of Sri Lankan-type blue and padparadscha sapphires in Madagascar is consistent with

this interpretation. Consequently, our contribution to the current debate in the trade about whether the term 'padparadscha' should be confined only to Sri Lankan specimens is that it should not because the pinkish-orange stones from both Sri Lanka and Madagascar have essentially the same colours, properties and geological source.

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Colour-change garnets from Madagascar: comparison of colorimetric with chemical data

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ABSTRACT: In this study 24 colour-change garnets from Madagascar have been studied to gain data for a correlation between chemical composition and colorimetric calculations. All samples belong to the pyrope-spessartine solid solution series. They contain some traces of vanadium (0.27 to 1.61 wt% V_2O_3), which is responsible for the colour-change in these garnets. Based on visual observations, the investigated samples were separated into five groups of different colour-change behaviour when examined under daylight and incandescent light. Generally, most garnets changed from bluish-green in daylight to purple in incandescent light, although some changed from yellowish-green to pink and brownish-green to brownish-red. Two samples remained almost unchanged, i.e. blue and brown respectively. The visual separation in five groups is consistent with differences obtained by colorimetric calculations. The colorimetric calculations are presented in the CIELab colour space. Comparing colour behaviour with chemical analyses results in a correlation with several intrinsic chemical factors, mainly vanadium, chromium, manganese, magnesium and iron.

Keywords: chemistry, CIELab colour space, colorimetry, colour-change garnet, Madagascar, vanadium

Introduction

The colour-change effect is well known by gemmologists and highly appreciated in the gem trade. The term was originally used for alexandrite, a variety of chrysoberyl, changing its colour appearance distinctly under different 'white' illuminations, e.g. daylight and incandescent light. Gem-quality garnets displaying colour change were first mentioned from East Africa (Crowningshield, 1970; Jobbins *et al.*, 1975). In the following years similar garnets were further reported from Umba valley and Tunduru in Tanzania (Schmetzer and Ottemann, 1979; Schmetzer and Gübelin, 1980; Stockton, 1982; Hänni, 1983; Manson and Stockton, 1984; Stockton, 1985; Koivula and Kammerling, 1988) and from Athiliwewa and Embilipitiya in Sri Lanka (Johnson and Koivula, 1996b; Johnson and Koivula 1998a). However, commercial quantities of colour-changing garnets have entered the gem trade only recently due to the discovery of new gem deposits in south west Madagascar (area of Ilakaka and Bekily; Johnson and Koivula, 1998b); most faceted stones are less than 1 ct.

Generally, colour-change garnets are greenish-blue to almost blue in daylight and purplish to purple in incandescent light (Johnson and Koivula, 1998a). Some change

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Materials and methods

For this study, 24 colour-changing garnets (21 faceted and 3 rough specimens labelled A-D, F-J and L-Z) ranging from 0.25 ct to 2.38 ct have been investigated. They were chosen to represent the largest possible range of colour (*Figure 1*). For comparison we also included a spessartine garnet (K) of light orange colour. All samples, including the spessartine, originate from the recently discovered secondary gem deposit near the town of Bekily in southern Madagascar (W. Spaltenstein, L. Aubert, A. Leuenberger, D. Bontempi, all pers. comm., 1999 and 2000).

Figure 1: *Some of the investigated colour-change garnets from Madagascar under tungsten illumination. Photo by M.S. Krzemnicki, © SSEF*

Apart from standard gemmological testing for internal strain (polariscope), refractive index, specific gravity and fluorescence to long and short-wave ultraviolet radiation, the colour of each sample was determined using daylight and tungsten light (incandescent light). For tungsten light observations, a calibrated light source of 2800 K (similar to CIE illuminant A) was chosen.

In the standard visual observation routine, all samples were placed about 50 cm from the observer and colour was observed when looking straight through the table facet. For daylight measurements, the samples were shielded from direct sunlight and only exposed to diffuse daylight. For colour determination in tungsten light, the light source was slightly inclined to the table facet, as this is the customary way to examine gemstones in the trade.

UV-VIS spectrometric data (800-350 nm) of all specimens were taken with a Varian Cary 500 spectrophotometer, using a scan rate of 60 nm/min in the transmission mode. Based on these absorption spectra, the colorimetric data (CIELab coordinates) were calculated using Mathematica® (calculations kindly provided by G. di Pietro, Institute for Scientific Photography, University of Basel) and our own CIELab calculation program.

The chemical compositions of 18 samples were obtained using a Cameca SX-50 electron microprobe and a JEOL-JXA 8600 electron microprobe with an acceleration voltage of 15 kV and a beam current of 10 nA (Geochemical Laboratories, ETH Zürich and MPI University of Basel); well-characterized oxides and silicates of Al, Si, Ca, Mn, Fe, V, Cr, Ti, Mg were used for standardization. The chromium content in weight percent oxide was corrected for peak overlaps by interfering vanadium-Kβ using the formula:

$$Cr_2O_3(\text{corrected}) = Cr_2O_3(\text{initial}) - 0.1 \times V_2O_3$$

All quantitative chemical data were further corrected for matrix effects by ZAF-type on-line procedure.

Table I: Gemmological properties of the studied colour-change garnets

Samples:	24 colour-change garnets
Weight:	0.25 to 2.38 ct
SG:	3.748 to 4.104
RI:	1.745 to negative reading (> 1.785)
Polariscope:	anomalous double refraction
UV LW:	inert
UV SW:	inert
Colour in light:	daylight: blue, greenish-blue, brownish-green, yellowish-green incandescent: purple, brownish-red, pink
Colour-change:	very slight to distinct
Saturation:	medium to strong
Transparency:	transparent
Lustre:	bright vitreous

their colour from yellowish-green to pink or pale brown (Johnson and Koivula, 1998b).

In the first detailed gemmological study of colour-change garnets from Madagascar, Schmetzer and Bernhardt (1999) separate colour-change garnets into two groups according to their chemistry. Most colour-change garnets are intermediate members of the pyrope-spessartine solid solution series containing minor amounts of vanadium and/or chromium (Jobbins *et al.*, 1975; Stockton, 1982; Manson and Stockton, 1984; Stockton and Manson, 1985; Koivula and Kammerling, 1988; Johnson and Koivula, 1996b; Johnson and Koivula, 1998b; Schmetzer and Bernhardt, 1999). All studied colour-change garnets from Madagascar belong to this group (Johnson and Koivula, 1998b; Schmetzer and Bernhardt, 1999). Only a few colour-change garnets were found to be chromium-rich (Schmetzer *et al.*, 1980).

The colour-change effect has been studied for decades (see references in Bosshart et al., 1982; Liu et al., 1999), mainly concentrating on alexandrite. A comprehensive description of colour-change materials (minerals and artificial products) is given by Liu et al. (1999). They compared colorimetric calculations with standard gemmological observation techniques for colour description. Previously Schmetzer et al. (1980) had studied the relationship between the colour change of different materials and the chemistry and/or crystal structure of a mineral.

In this study, the authors would like to integrate these two research approaches by presenting data on colour-change garnets from Madagascar, with emphasis on the correlation of chemical data with colorimetric calculations and colour observation.

Physical properties

The gemmological properties of the colour-change garnets (sample K, spessartine, excluded) are summarized in *Table I*. The distinct variations in RI (from 1.745 to > 1.785) and SG (3.748 – 4.104) are due to extensive exchange of magnesium by manganese in the samples (members of the pyrope-spessartine solid solution). Chemical analyses revealed a close correlation of RI (and SG) with the chemistry of colour-change garnets (*Figure 2*). Previous studies on colour-change garnets (Jobbins *et al.*, 1975; Stockton, 1985; Johnson and Koivula, 1996a, 1996b; Johnson and Koivula, 1998b; Koivula and Kammerling, 1988; Schmetzer and Bernhardt, 1999) reported RI values between 1.757 and 1.770, a distinctly smaller range than that in the present sample selection.

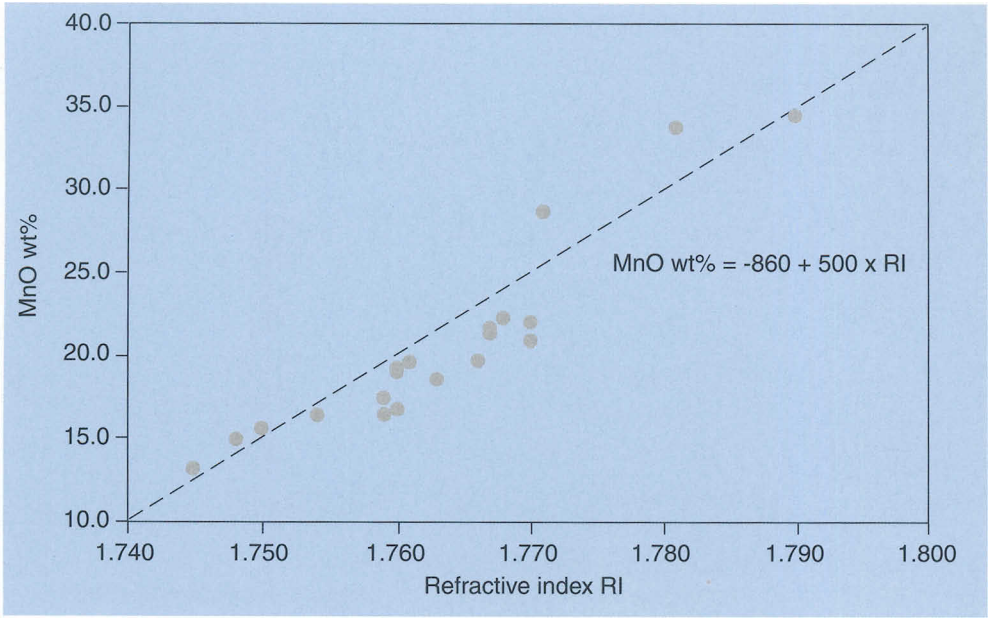

Figure 2: *Correlation of manganese content (MnO wt%) versus refractive index of colour-change garnets from Madagascar. A qualitative correlation line has been drawn to show the direct relationship between main component content (i.e. manganese) and optical property (RI). A similar diagram can be obtained by plotting Mn content against SG.*

All samples remained inert when exposed to long and short-wave ultraviolet radiation. Under the polariscope they showed slight to moderate anomalous extinction, resulting from internal strain within the garnet structure. Regularly oriented long prismatic crystal inclusions, often in a three-dimensional lattice array were found to be rutile.

Visual colour determination

The colour of all samples was determined by a consistent observation technique (see section 'Materials and methods'), similar to that in common practice in gemmological laboratories and in the trade. Nevertheless, visual colour determination of a faceted

Table II: *The colour-change behaviour of the studied garnets from Madagascar*

Group	*Samples*	*Daylight*	*Tungsten light*	*Colour change*	*References*
Group I	J	blue	blue with purplish hue	very slight hue change	9, 11
Group II	A, B, D, F-I, L-N, Q, T-W, Y, Z	blue-greenish blue	purplish-blue – purple	moderate – distinct	1, 2, 4, 6, 7, 11, 12
Group III	P, R. S	yellowish-green	pink – light purple	slight – moderate	3, 5, 6, 7, 11, 12, 13
Group IV	C, X	brownish-green	brownish-red	moderate	6
Group V	O	brown	reddish-brown	very slight	

References:

1. Jobbins *et al.*, 1975
2. Johnson and Koivula, 1996a
3. Johnson and Koivula, 1996b
4. Johnson and Koivula, 1998a
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8. Manson and Stockton, 1984
9. Schmetzer and Ottemann, 1979
10. Schmetzer *et al.*, 1980
11. Schmetzer and Bernhardt, 1999
12. Stockton, 1982
13. Stockton and Manson, 1985

gemstone still remains a challenge, as several aspects contribute to its overall colour appearance (Liu *et al.*, 1999). Usually, the body colour is the most important factor. However, reflections on pavilion facets often display quite different colour hues (Stockton, 1982). The cut of the specimen may enhance or reduce these reflected colours. For this study, each specimen was attributed to its dominating spectral colour (e.g. blue in daylight) under daylight and tungsten illumination, just adding hues (e.g. purplish-blue). Additionally the colour saturation (medium, medium strong, strong) and the strength of colour change (very slight, slight, moderate, distinct) were estimated. Based on this the 24 specimens were separated into five groups of different colour-change behaviour (see *Table II* and *Figures 3 and 4*).

- *Group I* garnets remain blue under both illuminations; only a slight change of colour hue is observed (sample J, *Figure 5*). The colour saturation is strong (Schmetzer and Ottemann, 1979).
- *Group II* garnets change their colour moderately to distinctly from bluish to purplish (daylight/tungsten light). Their colour saturation ranges from medium to strong. In the gem trade, these colour-change garnets are commercially the most important (Schmetzer and Bernhardt, 1999). Samples A, B, D, F-I, L-N, Q, T-W, Y, and Z (a total of 17) belong to this group.

Figures 3 and 4: *Colour-change garnets from Madagascar under daylight illumination (Figure 3, top) and under tungsten light (Figure 4, bottom). Colours slightly adjusted by AdobePhotoshop®. Photos by M.S. Krzemnicki, © SSEF.*

- *Group III* garnets change their colour from yellowish-green to pink (Koivula and Kammerling, 1988; Schmetzer and Bernhardt, 1999). The colour saturation is medium to medium strong, the colour-change slight to moderate (samples P, R, S).
- *Group IV* garnets change their colour moderately from brownish-green to brownish-red. The colour saturation is strong (samples C, X).

Figure 5: *Almost blue garnet from Madagascar (sample J, group I) in daylight. This sample displays only a very slight change of colour hue when examined under tungsten light. Photo by M.S. Krzemnicki, © SSEF.*

Figure 6: *Brown garnet from Madagascar (sample O, group V) in daylight. This sample displays only a slight change of colour hue towards reddish-brown when examined under tungsten light. Photo by M.S. Krzemnicki, © SSEF.*

- *Group V* garnets change their hue slightly from brown (daylight) to reddish-brown (tungsten) (sample O, *Figure 6*). The colour saturation is strong.

The following results and interpretations of colorimetric and chemical data are discussed in relation to the visual separation in groups I-V.

Chemical data

Quantitative chemical analyses (WD-XRF) and calculated end member mol% (Deer *et al.*, 1992) of some of the colour-change garnets from each group are given in *Table III*. All samples (except sample K, a nearly pure spessartine) are intermediate members of the pyrope-spessartine solid solution series. Apart from the major MgO and MnO components, they are characterized by a significant grossular component (CaO up to 7.31 wt%, i.e. 13.8 mol% grossular), and a rather smaller iron content from 0.52 up to 3.10 wt% FeO). In the analyses, all iron is presented as FeO (i.e. Fe^{2+}, almandine component). Due to the low iron concentrations an estimation of Fe^{3+} based on Droop (1987) is not reliable, although small amounts of Fe^{3+} might be present (andradite component).

All samples (except spessartine, sample K) contain distinct amounts of vanadium (from 0.27 in sample R to 1.61wt% V_2O_3 in sample J) and chromium (from 0.11 in sample R to 0.95 wt% Cr_2O_3 in sample M). Only in sample M (group II) is the uvarovite component (Cr_2O_3) slightly higher than the goldmanite component (V_2O_3). In all other samples vanadium content exceeds that of chromium by a factor of 2 to 5.

Table III: *Electron microprobe analyses of some colour-change garnets from Madagascar*

	Group I Sample J	*Group II Sample M*	*Group II Sample A*	*Group III Sample R*	*Group IV Sample C*	*Group V Sample O*	*Spessartine Sample K*
RI	1.763	1.767	1.748	1.760	1.781	neg.	neg.
SG	3.832	3.893	3.748	3.871	4.068	4.104	4.168
Oxide weight%							
MgO	10.45	11.78	15.25	10.49	4.21	0.87	b.d.
MnO	18.49	21.31	14.75	18.89	33.69	34.41	42.27
CaO	7.31	3.01	4.65	5.09	1.73	3.11	0.21
FeO	0.65	2.84	0.96	2.29	0.52	3.10	b.d.
Cr_2O_3	0.38	0.95	0.17	0.11	0.24	0.26	b.d.
V_2O_3	1.61	0.91	0.43	0.27	1.30	0.44	0.01
TiO_2	0.06	0.03	0.04	0.11	0.25	0.51	b.d.
Al_2O_3	21.12	20.48	22.70	21.67	19.99	20.06	20.88
SiO_2	38.63	38.81	41.47	40.22	37.22	37.65	36.65
Total	98.70	100.12	100.42	99.14	99.15	100.41	100.02
Endmember mol%							
Pyrope	39.3	42.6	55.4	40.1	16.9	3.6	0.0
Spessartine	39.5	43.8	30.5	41.0	76.9	80.1	99.4
Almandine	1.4	5.8	2.0	4.9	1.2	7.1	0.0
Uvarovite	1.1	2.9	0.5	0.3	0.8	0.8	0.0
Goldmanite	4.9	2.8	1.3	0.8	4.2	1.4	0.0
Grossular	13.8	2.1	10.4	12.8	0.1	6.9	0.6

For this table, only representative analyses of the studied colour-change garnets from Madagascar were chosen.
Cr_2O_3 was corrected for interference with vanadium – Kß, see section 'Materials and methods'.
b.d. – below detection limit. Endmember calculation after Deer *et al.*, 1992
neg. – negative RI, i.e. above upper limit of the TIR-refractometer at 1.785

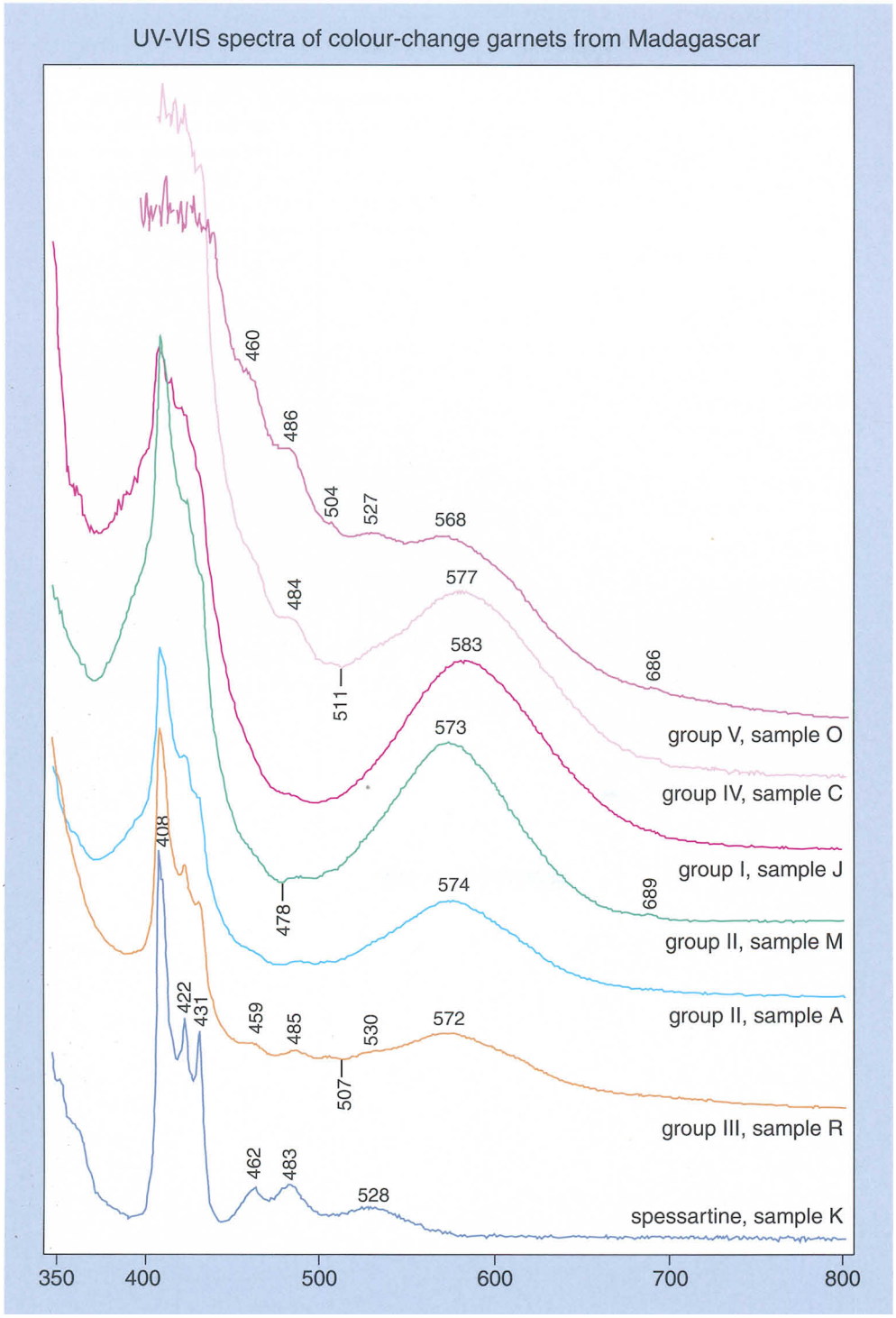

Figure 7: *UV-VIS spectra of colour-change garnets (groups I-V) compared with spessartine.*

Spectrometric data in the UV-visible range

The colours of the present suite of stones are made up of the contributions of each of the solid solution components or garnet end members. Pyrope is colourless and has no absorption bands in the visible region of the spectrum. Pure spessartine is orange and shows its presence even in low quantities by the well known set of absorption bands (see below). Iron, vanadium and chromium contribute to the observed colour as chromophore elements (Nassau, 1983), modifying the basic colour set by the main constituents (pyrope and spessartine). *Figure 7* shows representative UV-VIS absorption spectra of garnets from the different colour change groups (I-V, see *Table III*). They are compared with the spectrum of

Table IV: *Comparison of colorimetric with chemical data of garnets from Madagascar.*

		Hue angle		*Hue angle difference*	*Saturation*		*Chemistry*		*End-members*
Sample	*Colour group*	*Ω(D65)*	*Ω(A)*	*ΔΩ*	*δ(D65)*	*δ(A)*	*MnO wt%*	*V_2O_3 wt%*	*Spessartine mol%*
J	I	210.3	243.2	32.9	48.2	46.0	18.49	1.61	39.5
A	II	161.9	340.0	178.1	3.4	12.8	14.75	0.43	30.5
B	II	158.5	340.6	177.9	7.0	11.5	15.47	0.49	32.0
T	II	137.3	350.1	147.1	3.5	8.0	13.13	0.38	27.6
Q	II	175.9	319.0	143.1	6.3	7.3	n.a	n.a	n.a
L	II	1.79.7	321.4	141.7	5.1	7.6	21.93	0.93	46.8
U	II	192.2	326.8	134.6	4.3	12.1	16.71	0.90	34.7
W	II	183.4	316.7	133.2	12.8	14.6	20.80	1.20	47.9
G	II	193.2	315.8	122.6	9.4	14.0	19.55	1.14	43.0
I	II	190.3	306.7	116.4	12.3	13.1	22.16	1.24	48.7
H	II	171.9	285.1	113.2	17.0	6.6	16.33	0.77	34.6
V	II	212.7	314.8	102.1	6.1	13.4	16.34	0.94	34.7
F	II	210.6	305.3	94.7	11.0	16.5	19.59	1.08	41.8
D	II	212.8	297.7	84.9	13.4	17.9	19.11	1.19	40.6
Y	II	221.3	288.6	67.3	3.8	5.3	19.63	0.87	42.6
Z	II	219.2	281.9	62.7	6.9	8.4	21.60	1.31	47.9
M	II	265.3	324.7	59.5	7.6	25.7	21.31	0.91	43.8
N	II	257.9	311.3	53.4	10.5	21.3	17.36	0.80	36.2
P	III	125.0	35.9	89.2	14.4	11.2	n.a.	n.a.	n.a.
S	III	103.1	59.8	43.3	17.1	15.6	18.90	0.29	40.7
R	III	84.1	42.9	41.2	14.5	17.9	18.89	0.27	41.0
C	IV	84.6	49.4	35.2	27.3	31.8	33.69	1.30	76.9
X	IV	85.2	51.8	33.3	12.8	14.6	28.63	0.89	58.6
O	V	58.3	52.5	5.8	51.3	59.1	34.41	0.44	80.1
K	Spessartine	72.2	65.7	6.6	29.6	33.7	42.27	0.01	99.4

The table has been arranged in order of decreasing hue angle differences ΔΩ within each group of colour-change behaviour.

The colorimetric data (hue angle Ω and saturation δ) are given for both illuminants D65 (daylight equivalent) and A (tungsten equivalent).

n.a. – not analysed chemically by electron microprobe.

spessartine of light orange colour. All spectra show characteristics of spessartine with Mn^{2+} peaks (see e.g. Manson and Stockton, 1984; Schmetzer and Bernhardt, 1999) at 408, 422, 431 nm (or complete absorption around 431 nm). All colour-change garnets (group II-IV) show a distinct broad absorption band with a maximum at about 573 nm. This maximum has been attributed to V^{3+} probably with some Cr^{3+} (see Schmetzer and Ottemann, 1979; Manson and Stockton, 1984; Schmetzer and Bernhardt, 1999). The absorption minimum for garnets changing from bluish to purple is located about 476 nm, whereas garnets with a yellowish-green to pink colour-change have a minimum around 507 nm (Schmetzer and Bernhardt, 1999). Two different spectral characteristics may result in garnets displaying only a very slight change of colour hue (group I and group V). The blue garnet (sample J, group I, *Figure 5*) has the highest vanadium content (1.61 wt% V_2O_3) of all the samples and shows a similar spectrum to colour-change garnets. However, the maximum of the broad absorption band is centred about 583 nm, and is thus slightly above the narrow range between 562–577 nm defined by Schmetzer and Bernhardt (1999) for alexandrite-like colour change materials. The brownish garnet (sample O, group V, *Figure 6*) shows distinct superposition of the characteristic V-absorption band by Fe^{2+} (almandine component) and Mn^{2+} (spessartine component). Due to this no distinct minimum in the range of 507–476 is present. This results in only a very slight change of colour hue, although the vanadium content is the same as in the colour-change garnets of group II (see *Table III*).

Colorimetric calculation

By means of colorimetric calculations, somewhat subjective colour descriptions can be displayed as coordinates in a colour space. In accordance with previous studies (Liu *et al.*, 1994, 1999) the CIELab space was chosen to calculate colour coordinates, as it is a uniform colour space which takes into account the chromatic adaptation of the human eye. In the CIELab space, colour differences are proportional to the distances of the represented colour coordinates (for a detailed discussion of colorimetry in gemmology, please refer to Liu *et al.*, 1999).

Colour is always an integration of hue (spectral colour, e.g. blue), saturation (depth of colour, weak to strong) and brightness (from light to dark). Based on the UV-VIS transmission spectra of our samples, we calculated L* (brightness) and a*, b* (colour coordinates, determining the colour hue) in the CIELab colour space (*Table IV* and *Figure 8*). Formulae can be obtained in any standard colorimetry textbook (Kuehni, 1997) or on the internet (e.g. http://www.cs.rit.edu/~ncs/color/t_convert.html).

The saturation δ of a colour is the distance between the colour coordinates (a*, b*) to the centre point (0, 0) and thus:

$$\delta = \sqrt{(a^2 + b^2)}$$

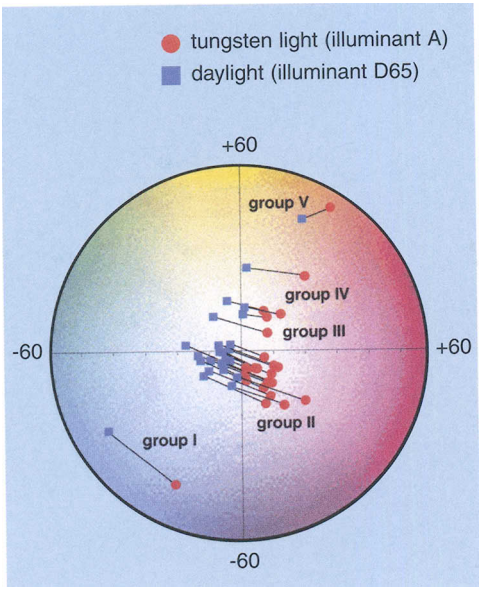

Figure 8: *Colour coordinates of all studied colour-change garnet samples (see Table III) in the CIELab colour space. Daylight coordinates in blue, incandescent coordinates in red. The lines connect the colour coordinates of each sample calculated with illuminants D65 (daylight equivalent) and A (tungsten light equivalent).*

In 1986 the 'Commission International de l'Eclairage CIE' proposed several standard illuminants (theoretical light sources); these include D65 for daylight (light emitted by a blackbody at 6504 K) and A for incandescent (tungsten) light (2856 K). Based on these illuminants and on so-called matching functions (2° standard colorimetric observer), which take into account the ability of the human eye to adapt chromatically between different 'white' light sources, the CIELab coordinates for the samples under each illumination were calculated using our own computer program. All equations and data for variables (i.e. illuminants and matching functions) were found on the internet (see references).

Using a simple trigonometric equation, colour hue angles Ω for each sample under the illuminant D65 and A were calculated:

$$\Omega = \arctan (b/a)$$

The difference between hue angles ΔΩ of each sample is an expression of the calculated colour change behaviour of a gemstone under daylight and incandescent light, respectively.

$$\Delta\Omega = |\Omega D65 - \Omega A|$$

Comparison of colorimetric data with chemical data

The colour appearance of the samples were well reproduced by the calculated colour hue values (*Figure 8*) and we think colorimetry may become a more important tool for colour investigation in gemmology.

A close examination of the calculated hue angle differences ΔΩ (*Figure 9*) fits well with the visual separation into five groups of colour-change behaviour (I-V, see *Table II*).

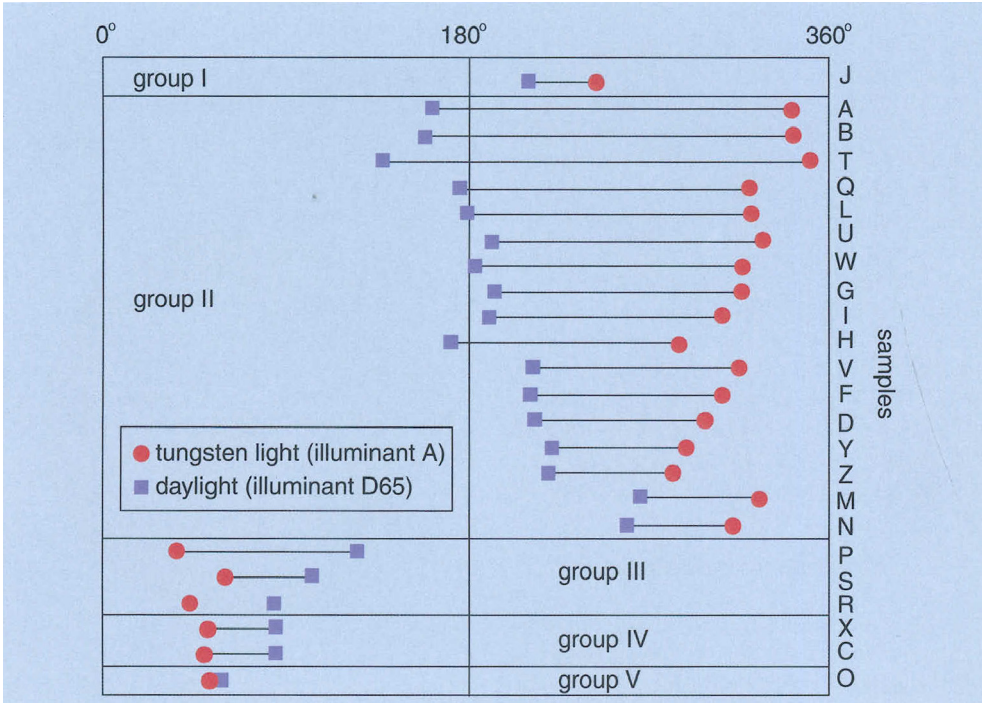

Figure 9: *Calculated hue angle differences ΔΩ of the garnets, listed in five groups of colour-change behaviour and arranged in order of ΔΩ . In daylight, all samples tend in direction to the hue angle 180° (blue-green). Samples such as A, B and Q are characterized by very large ΔΩ but visually appear with a rather slight to moderate colour-change due to their low colour saturation (compare with Figure 10).*

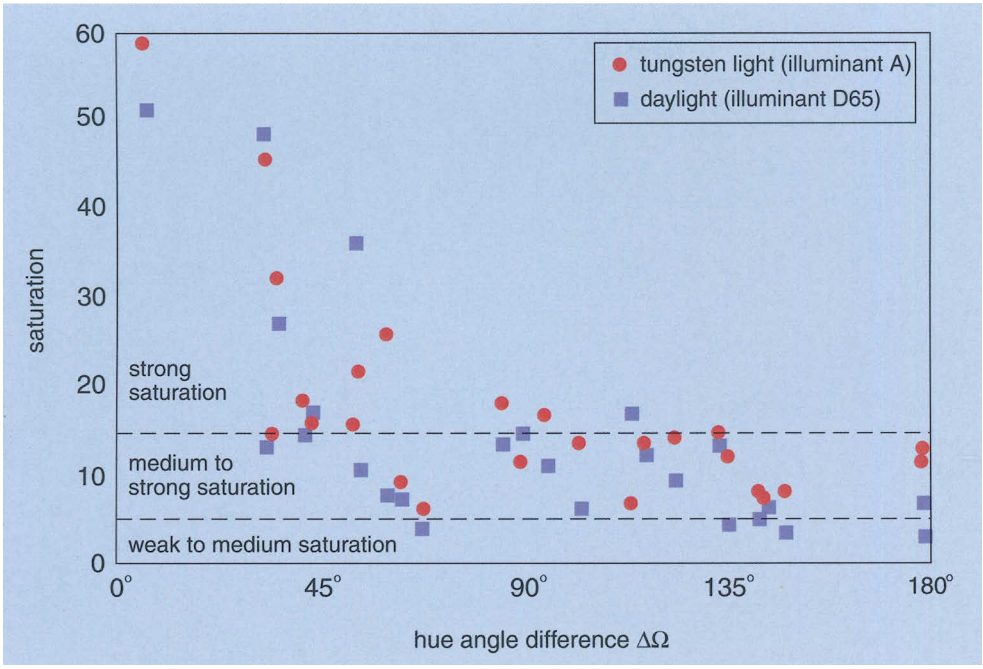

Figure 10: *Calculated saturation δ versus hue angle difference ΔΩ of the garnets. A general trend of reduced saturation for samples with a very large hue angle difference ΔΩ is apparent.*

However, the extent of calculated colour-change, i.e. hue angle difference ΔΩ seems quite high, reaching values almost up to 180, and representing colour-change from nearly red to its opponent colour blue in the CIELab colour space. However, the influence of colour saturation δ (*Table IV*) and brightness L* must also be taken into account. In *Figure 10* the colour saturations are plotted against hue angle differences ΔΩ. Obviously there is a general trend toward weak to medium saturations with increasing hue angle differences ΔΩ. Liu *et al.* (1999) proposed a minimal saturation δ = 5 to rely on colour-change data. All samples with lower saturation than 5 have their coordinates so close to the white centre point of the CIELab colour space (*Figure 8*), that even a barely visible change in colour hue might result in a large hue angle difference ΔΩ. Thus the colour saturation δ of a sample is highly relevant to the visual extent of any colour-change. The calculated values of hue angle differences ΔΩ should be compared only between samples with similar saturation to describe the extent of colourchange in qualitative terms as minor, moderate or distinct.

The correlation of observed colour and colour-change behaviour with the chemistry of the garnets is rather complex. Obviously the vanadium (and some chromium) are responsible for the colour-changing effect in these garnets. However, as shown in *Figure 9*, there is not a simple direct relation between vanadium concentration, colour and extent of colour change. Samples with quite low vanadium may exhibit a large extent of colour change (e.g. sample T, *Figure 9*), whereas vanadium rich samples may show only slight colour hue changes (sample C, *Figure 9*). By plotting the MnO versus V_2O_3 contents (*Figure 11*), the behaviour of the colour-changing garnets may be explained in a more suitable way.

In *Figure 11*, no evident correlation between manganese Mn^{2+} and vanadium V^{3+} ions can be expected, as they are substituting for Mg^{2+} and Al^{3+} on two different lattice positions. However, by attributing to each

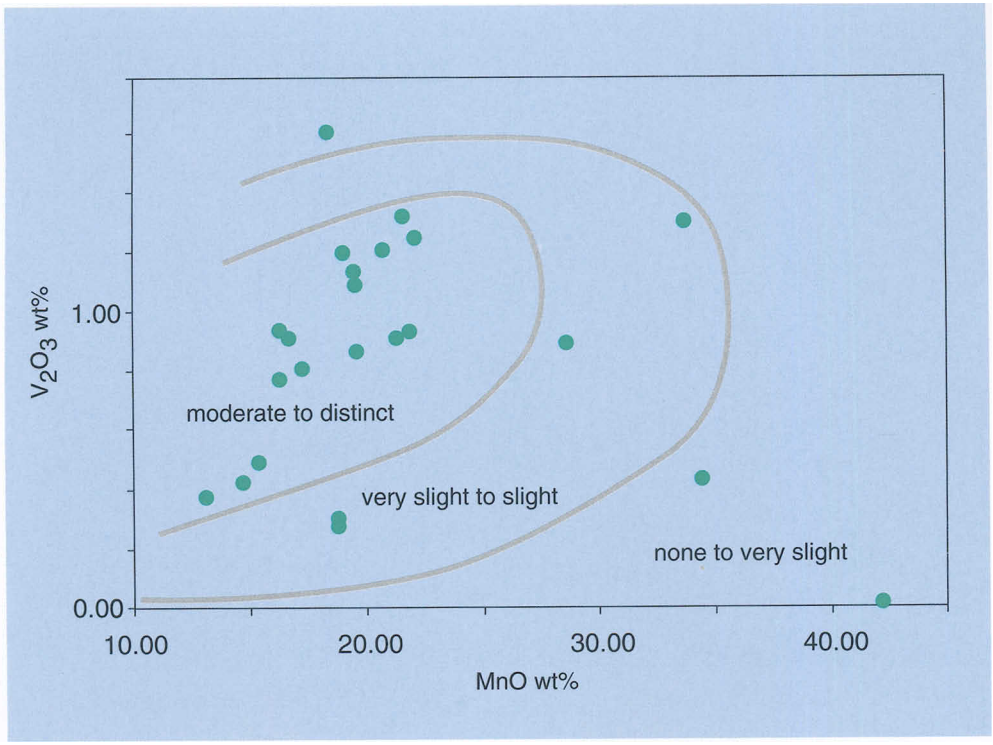

Figure 11: *Bivariate diagram of V_2O_3 versus MnO for colour-change garnets of the pyrope-spessartine series. Three main fields of colour change strength have been introduced qualitatively. The limits of the fields represent a gradual transition rather than steps of different colour-change behaviour.*

sample the observed extent of colour change (i.e. none to very slight, very slight to slight, moderate to distinct), we gain a qualitative diagram with three fields of colour-change behaviour for vanadium bearing garnets of the pyrope-spessartine solid solution series. The limits of these fields should rather be thought of as gradual intervals, e.g. from a slight to moderate colour change, rather than as steps from one field to the other. Garnets of the pyrope-spessartine series containing no vanadium and/or chromium display no colour change at all (e.g. sample K). Their colour saturation δ is correlated to the manganese content (*Figure 10*). Samples characterized by a MgO/MnO ratio of about 1 are potentially colour-change garnets. When containing only low concentrations of vanadium and/or chromium (below about 0.5 wt% V_2O_3) they display a slight to moderate colour change from greenish in daylight to pink in tungsten light (*Figure 11*). The colour saturation remains weak to moderate. The vanadium concentration has to exceed 0.5 wt% V_2O_3 to result in a moderate to distinct colour change from bluish in daylight to purplish in tungsten light and a medium to medium strong colour saturation (*Figure 11*). According to Schmetzer and Otteman (1979) and Schmetzer and Bernhardt (1999), there is an upper limit for the vanadium concentration (about 1.60 wt% V_2O_3, sample J), above which only a slight, if any colour change can be observed. The garnet remains more or less blue under both lighting conditions with strong colour saturation (*Figure 11*). The saturation of all previously mentioned samples is basically proportional to the vanadium concentration. To understand the absence of colour change in vanadium-rich pyrope-spessartine garnets, we assume that above a critical vanadium concentration the lattice parameters are slightly modified by the goldmanite component. Although still showing

an absorption spectrum similar to colour-changing garnets (*Figure 7*), the maximum of the vanadium (and chromium) absorption band has moved to a slightly higher wavelength (583 nm), thus taking it beyond the upper limit for an alexandrite-like colour-change material (562–577) as defined by Schmetzer and Bernhardt (1999).

With increasing MnO content the potential for colour-change behaviour is reduced. Even high vanadium contents (1.30 wt% V_2O_3, sample C) only result in slight colour changes from brownish-green in daylight to brownish-red in tungsten light. For low vanadium contents (0.44 wt% V_2O_3, sample O), a very slight change of colour hue from brown to reddish-brown is observed. In both cases however, the colour saturation δ is strong (*Figure 10)*, mainly controlled by high manganese contents.

Conclusions

In this study of colour-change garnets from a new gem deposit in south west Madagascar the complex relationship between chemistry and colour-change effect has been investigated. The study shows that several intrinsic chemical variables such as the content of vanadium related to chromium, manganese, magnesium and iron contribute to the variations in the visual appearance of these garnets under different 'white' illuminations (daylight and incandescent light). A qualitative diagram for colour-change garnets (*Figure 11*) of the pyrope-spessartine series has been introduced. The diagram shows several fields of different colour change behaviour. Leaving the field of moderate to distinct colour-change due to higher vanadium or manganese concentrations results in a drastically reduced colour-change behaviour (or no colour-change at all), coupled with a high colour saturation. Similar garnets with low vanadium (and chromium) contents display only a weak colour-change coupled with low colour saturations. To conclude, the observed variations of the colour-change effect in garnets is generally an effect of chemical variations in the concentrations of the trace elements, vanadium and chromium and of the major constituents manganese and iron. Using colorimetric calculations, the visual separation into different groups of colour-change behaviour was confirmed and the saturation δ and the extent of colour-change (ΔΩ difference of hue angle under daylight and incandescent light) was calculated. It is, however, important to understand that the term colour-change and its qualitative differentiation into several categories (e.g. slight, moderate, strong), is based on a combination of observed colour hues, colour saturation and brightness, and not only on pure colour difference, i.e. change of colour hues. Therefore, colorimetric data have to be used with caution when drawing conclusions about the degree (strength) of colour-change (*Figure 9*), as the saturation δ (see *Figure 10*) and brightness (L* value in the CIELab colour space, see *Table IV*) both play an important role in how strongly the colour-change is perceived.

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Rubies from the Vatomandry area, eastern Madagascar

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ABSTRACT: Since the beginning of 2001, large amounts of rubies from the Vatomandry area in eastern Madagascar have appeared on the international gem market. Quality and colour of the new production show a pronounced variation, some being comparable to the best Burmese rubies. The Vatomandry rubies have a combination of mineralogical and gemmological properties that allows a distinct separation from rubies from Thailand and Myanmar (Burma). The three most specific inclusion features of Vatomandry rubies are (a) the complete lack of growth structures; (b) the presence of short oriented rutile needles; and (c) innumerable small colourless, transparent or white birefringent zircon crystals, so-called 'zircon clusters'. High iron contents (0.1 – 0.7 wt.% Fe_2O_3) are also characteristic and comparable to those of basaltic type rubies from Thailand.

Introduction

During the last few years, the island of Madagascar has become one of the most important gem-producing country in the world. A large variety of coloured gemstones, including rubies and sapphires, are mined in economically interesting deposits distributed over the entire island. The explanation for the enormous variety and richness in gemstone mineralisations in this new gem paradise lies in the very special and complex geological situation of the island. Madagascar is regarded as part of the eastern border of the so-called Mozambique Belt (Kröner, 1977). This belt hosts many interesting gemstone deposits in East Africa, especially in Kenya and Tanzania. Probably, at least part of the Malagasy gem occurrences result from geological events that took place when Madagascar was still adjacent to East Africa in the former Gondwanaland (see for example Mercier *et al.*, 1999). A geological map of Madagascar reminds one of a patchwork quilt. Sedimentary, metamorphic and volcanic rocks are present. The juxtaposition of different rock types in relatively small areas has created some very special genetic environments, favourable for the formation of a large variety of gem minerals.

Several sapphire and ruby occurrences have been known for decades in Madagascar (Schmetzer, 1986). But only since the beginning of the 1990s has Madagascar become a significant supplier of gem quality sapphires of different colours. The Andranondambo deposit in the south-eastern part of the island is related to skarn-mineralizations, and has produced variable amounts of medium and top gem-quality blue sapphires since 1994 (see for example Schwarz *et al.*, 1996; Kiefert *et al.*, 1996). Since 1996, blue, yellow and green sapphires from basalt-related deposits, situated near the northern tip of the island in the Antsiranana Province (Schwarz *et al.*, 2000) have been on the market. Then a really

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Figure 1: Map of Madagascar showing location of Vatomandry and Andilamena .

dramatic impact on the sapphire market was made by the discovery of huge secondary deposits (producing mainly sapphires of different colours, but also some rubies) west and south of the Isalo National Park (Ilakaka, Sakaraha, Ranohira; Schmetzer, 1999).

Compared to sapphire, Madagascar ruby deposits have been of little importance in the past. Some ruby-producing areas have been mentioned in the literature, but none of these had a significant impact on the national or international gem market; these include Gogogogo and Ejeda-Fotadrevo at the south-western tip of the island (Mercier *et al.*, 1999); Tolanaro at the south-eastern edge; Betroka-Ihosy in the central south; Antanifotsy in the central-eastern region (about 100 km south of Antananarivo). Some of these have been 're-discovered' recently, and this applies to the occurrences in the Vatomandry area. Rubies from this region were reported by Lacroix (1922-23) and the area also supplied small quantities of gem-quality rubies in the 1980s (Schmetzer, 1986).

The new finds in the area of Vatomandry (*Figure 1*) and in another region near Andilamena seem to change drastically the ruby situation in Madagascar. Vatomandry is situated about 140 km south of the eastern coastal town Toamasina/Tamatave and ca. 160 km east/south-east of the capital Antananarivo. The mining area (which comprises mostly eluvial deposits) lies about 30 km south-west of Vatomandry (A. Leuenberger, pers. comm., 2001). Andilamena is situated ca. 240 km north-east of Antananarivo. There is no detailed geological information about the ruby host rocks in the two mining areas yet.

The aim of this paper is to present the first gemmological and mineralogical data to characterize the new rubies originating from the Vatomandry area. Their properties are compared to those of rubies from the 'classic' mining areas in Thailand/Cambodia and Myanmar (Burma). Criteria for the separation of Vatomandry rubies from their south-east Asian counterparts are presented.

Market impact

According to trade information, ruby material from at least two new mining areas in Madagascar became known towards the end of 2000. Since January 2001, larger amounts of gem-quality corundum from these two regions, Vatomandry and Andilamena, have been available in Madagascar and quickly reached the Thai markets in Bangkok and Chantaburi. Holewa (2001) states, that from early March to mid-April 2001, Madagascar ruby rough worth more than US$ 60 million entered the Thai market.

Most of the better-quality rubies are reported to come from secondary deposits in the Vatomandry area. Andilamena produces larger amounts of variously coloured sapphires and relatively dark, somewhat brownish rubies. Many samples from this area show well-developed short-prismatic or plate-like habit. However, the Andilamena rubies and sapphires are mostly of cabochon

quality. According to preliminary mineralogical and gemmological examinations of several lots of differently coloured samples from this area, Andilamena corundums display a larger variation in their properties.

An interesting aspect of these new sources, especially, in a market that has not yet fully recovered from long discussions regarding topics such as 'heat treatment', 'residues' and 'glass fillings' in rubies, is that a considerable portion of the ruby rough does not require heat treatment. But it may be that a promising opportunity to establish an authentic source of good quality untreated ruby may have been lost for the following reason: the relatively low prices of the Malagasy rough material, and the early good results obtained by the Thai 'ruby cooks' with the new production, led to a situation, 'where now nearly all of the ruby material is heat treated to produce stronger reds' (Holewa, 2001).

Most faceted Vatomandry rubies (*Figure 2*) are in the 0.50 to 2 ct range. Stones from 2 to 3 ct are also common. Larger stones (up to 8 ct) are available, but much rarer. No exact production figures for the Madagascar rubies are available and it is impossible to predict reserves. Whilst some dealers believe that the new ruby finds could have an impact comparable to that of the sapphire occurrences in the Ilakaka region, others are more sceptical.

Materials and Methods

Some samples were purchased from or were made available for research purposes through different Thai/Malagasy companies in Bangkok and Chantaburi. Others came from German and Israeli gem merchants who bought the rubies directly in the Vatomandry area.

The total sample set used for this study consisted of 25 faceted rubies in the 0.50 to 8 ct range (including some top-quality stones) and about 80 rough samples. Some of the latter were 'windowed' (i.e. two parallel faces were polished) to facilitate testing. The sample set covered the whole colour range produced in the Vatomandry area. With the exception of a few stones, the rubies were not heat treated.

Figure 2: *Faceted rubies from Vatomandry, east Madagascar. Weight of samples ranging from 0.39 to 1.15 ct; the size of the largest ruby is 5 x 7 mm. Photo by M. Glas.*

About 50 samples (all the faceted stones and some 'windowed' material) were tested by standard gemmological methods for optical properties, fluorescence and density. The inclusion features of the total sample set were examined with standard gemmological microscopes and some samples were also examined with a horizontal microscope using an immersion cell. Solid inclusions were identified by laser Raman micro-spectrometry with a Renishaw microprobe. Twenty-five rubies covering the full colour range of the available samples were analysed by energy-dispersive X-ray fluorescence (EDXRF) spectroscopy (see Schwarz *et al.*, 2000). This method furnished also some additional data for the identification of mineral inclusions, intersected at the surface of the corundum host.

Results

Gemmological properties

All the rough samples seen by the authors were variably rolled pebbles with the typical appearance of gem materials from secondary (alluvial or eluvial) deposits. Quality and colour of the Vatomandry rubies (see again

Figure 3: *Vatomandry ruby with 'chessboard-like' pattern, caused by twin lamellae forming angles of almost 90°. 40x; photo K. Schmetzer.*

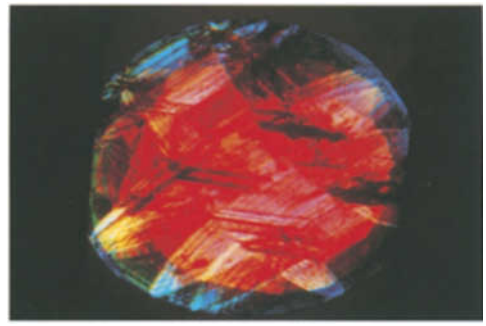

Figure 4: *Twin lamellae and 'intersection tubules'. 30x, crossed polarizers; photo K. Schmetzer.*

Figure 2) display a pronounced variation from purplish-red to a more pure red, the best being colours comparable to those of Burmese rubies; others looked more like rubies from the Thai/Cambodian border region. Some of the new material has been offered as Burmese or Thai rubies in the Thai trading and cutting centres.

Values for optical properties (n_o, n_e, Δn) and density were found to fall into the range considered typical for rubies from different localities. The fluorescence behaviour shows a distinct variation: most Vatomandry rubies do not show any reaction or only a very weak to weak reddish fluorescence when exposed to short-wave UV-irradiation. Under long-wave UV-irradiation, the red chromium-fluorescence is, generally, weak to medium. In a few stones, however, it was quite strong.

Microscopic properties

Quite common in Vatomandry rubies are twin lamellae, oriented in two directions. Three-dimensional arrangements are rarer. Two sets of twin lamellae result in a 'chess-board-like' pattern with angles that are almost 90° (*Figure* 3). Intersections of sets of lamellae are indicated by tube- or needle-like agglomerations of boehmite particles (*Figure* 4). Twin lamellae and 'intersection tubules' (three sets) in Vatomandry rubies look like those observed in Thai rubies and in corundums from the Umba Valley in Tanzania. Pronounced polysynthetic twin lamellae are quite frequent in Vatomandry rubies and are easily visible when observed in polarized light (*Figure* 5). Rubies with similar inclusions are also known from Sri Lanka.

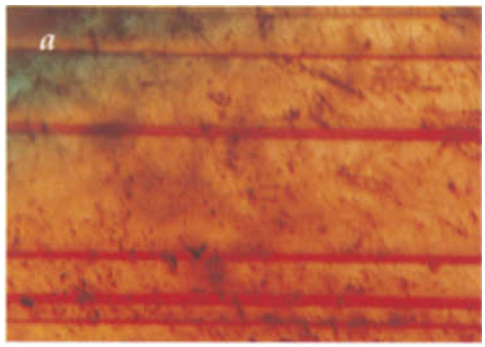

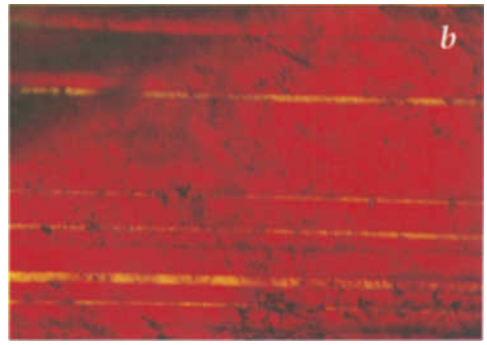

Figures 5 a and b: *Pronounced polysynthetic twin lamellae, observed in polarized light, in different orientations of the polarizer. 50x. Photos K. Schmetzer.*

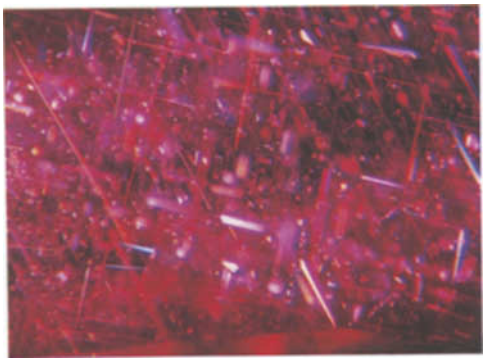

Figure 6: Rutile inclusions: short needles, elongate plate-like inclusions, and twin crystals. 25x; photo E. Gübelin.

Figure 7: Rounded-elongate, dark brown and black opaque rutile crystals, displaying strong lustre. 50x; photo E. Gübelin.

Growth structures have not been seen, so far, in Vatomandry rubies, and in this respect they resemble Thai/Cambodian rubies, and Umba as well as part of the Ilakaka corundums.

The commonest mineral inclusions in Vatomandry rubies are rutile and zircon. Rutile is present mostly as short needles, and also as twinned or elongate plate-like crystals (*Figure 6*). The rutile needles are generally oriented in three directions in planes perpendicular to the c-axis. The appearance of the rutile inclusions in Vatomandry rubies may be quite similar to that of the rutile needles common in rubies from the Mogok district in Burma. But in contrast to their Burmese counterparts, the Vatomandry rubies do not display any growth zoning and they lack the compact nests or clusters of rutile inclusions in certain parts of the host crystal. In the Vatomandry rubies the distribution of the rutile inclusions is more homogeneous with quite an 'open' structure. In several samples, small, rounded-elongate, transparent orange-brown or black-opaque rutile crystals were observed (*Figure 7*). At the surface, these crystals displayed a metallic lustre.

Another specific inclusion type in Vatomandry rubies consists of typical 'clusters', composed of innumerable small, colourless-transparent or whitish, prismatic or elongated to irregularly rounded, birefringent crystals (*Figures 8* and *9*). Some of these crystals have been identified as zircon, but

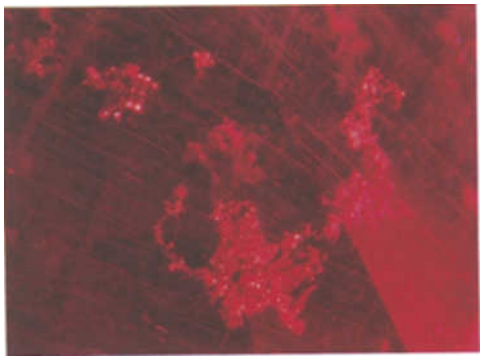

Figure 8: Small transparent colourless or white prismatic or elongate to irregularly rounded birefringent crystals form a 'zircon cluster'. 66x; photo E. Gübelin.

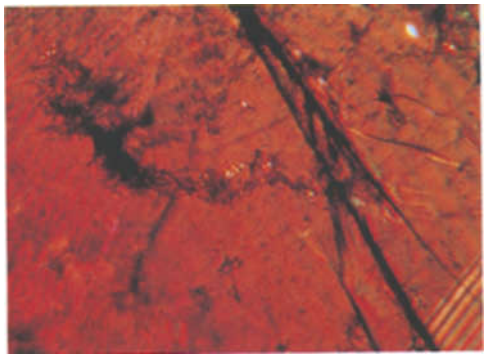

Figure 9: Small birefringent mineral inclusions, mostly zircons, in a 'zircon cluster'. 60x, crossed polarizers; photo K. Schmetzer.

Table I: Trace and minor element concentration in rubies from Madagascar, Thailand and Burma.

wt. %	*Vatomandry*	*Thailand/Cambodia* 'basalt-related'*	*Mogok (Burma)* 'marble type'*	*Mong Hsu (Burma)* 'marble type'*
Cr_2O_3	0.2–0.8	0.1–1.0	0.1–1.5	0.2–2.0
Fe_2O_3	0.1–0.7	0.3–0.8	bdl–0.05	bdl–0.05
TiO_2	bdl–0.03	0.01–0.05	bdl–0.05	0.01–0.25
V_2O_3	0.005–0.07	bdl–0.01	0.01–0.15	0.03–0.10
Ga_2O_3	0.01–0.02	bdl–0.01	bdl–0.03	bdl–0.015

bdl = below detection limit, about 0.005 wt. %
* based on the data bank of the Gübelin Gem Lab, Lucerne, Switzerland

the presence of other mineral species such as apatite or xenotime is likely. The 'clusters' are, sometimes, accompanied by delicate reflective tension fissures with a mirror-like aspect. Although the appearance of the 'zircon clusters' in the Vatomandry rubies is similar to that in Umba or Ilakaka corundums, the 'clusters' in the Vatomandry rubies are generally distinctly smaller.

In addition to twin lamellae, rutile and 'zircon clusters', a very few larger apatite crystals were also identified in the Vatomandry rubies. They also contain healed fissures, displaying varying patterns, and unhealed, reflective fissures.

Heat treatment

As is well-known from rubies and sapphires from other localities, heat treatment may have a pronounced effect on colour and transparency. Thermal alteration effects (for example changes in the texture of healed fissures, melting or dissolution phenomena) displayed by mineral inclusions allow, in general, the experienced gemmologist to detect an annealed stone, and for most of the Vatomandry rubies that had undergone heat treatment (about 15 samples), the indications of heat treatment were quite clear. However, in a few samples that contained only rutile and/or 'zircon clusters' as inclusions reliable indications of heat treatment were not easy to detect. At least some of the Vatomandry rubies seem to have been heat treated at relatively low temperatures (i.e. below 1450°C), sufficient to remove part of the purplish colour of the samples. In such rubies, the thermal alteration effects suffered by rutile and zircon inclusions may be quite minor and subtle.

Chemical composition

Concentration ranges for chromium, iron, titanium, vanadium, and gallium in 25 rubies from the Vatomandry area, eastern Madagascar, are given in *Table I*. For comparison, the concentration ranges considered typical for the basalt-related rubies from the Thai-Cambodian border region, and for the marble-type Burmese Mogok and Mong Hsu rubies are also listed.

The chromium contents of Vatomandry rubies fall into the range known for gem-quality samples from other important ruby producing localities of different genetic environments. The iron concentration shows a large variation, but is always relatively high (0.1 - 0.7 wt.% Fe_2O_3). In many Vatomandry rubies, iron may reach levels considered typical for basalt-related rubies. Vanadium also shows a considerable variation: in some samples, its concentration is near the detection limit of the analytical method, in others the concentration may be as high as in Mogok or Mong Hsu rubies (up to 0.07 wt.% V_2O_3). The highest titanium concentrations in the Vatomandry rubies are about 0.03 wt.% TiO_2. The gallium contents of Vatomandry rubies are surprisingly uniform in the range of 0.01 - 0.02 wt.% Ga_2O_3.

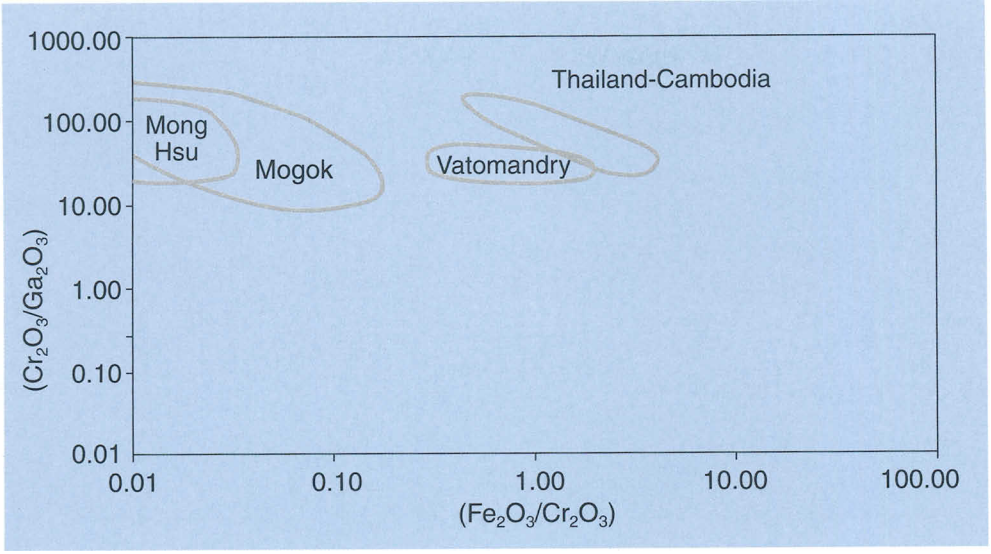

Figure 10: *Correlation diagram of Cr_2O_3/Ga_2O_3 versus Fe_2O_3/Cr_2O_3 for from Mong Hsu, Mogok, Thailand/Cambodia and Vatomandry.*

The correlation diagram (Cr_2O_3/Ga_2O_3) vs. (Fe_2O_3/Cr_2O_3), shown in *Figure 10*, gives the population fields occupied by rubies from the Burmese mining fields in Mogok and Mong Hsu, the Thai-Cambodian border region, and the Vatomandry area. Mong Hsu rubies fall into a small field, characterized by low Fe_2O_3/Cr_2O_3 ratios (< 0.04). The Mogok field is much larger. It completely overlaps the Mong Hsu field and extends to Fe_2O_3/Cr_2O_3 ratios of ca. 0.2.

Both Vatomandry and Thai/Cambodian rubies display Fe_2O_3/Cr_2O_3 ratios that are distinctly higher than those for Burmese rubies ranging from 0.3 to 2 for Vatomandry, and 0.5 to 5 for Thai/Cambodian rubies. However, the overlap for these two populations is so far quite small.

Discussion

The trace and minor element contents (the so-called 'chemical fingerprinting') and the nature of the inclusions (mainly the so-called 'zircon clusters', short rutile needles and the lack of growth structures), permits a reliable distinction of Vatomandry rubies from their Asian counterparts from the Thai-Cambodian border region and the Mogok and Mong Hsu areas of Burma. Iron contents in the Vatomandry rubies are always considerably higher than those known for Burmese rubies from both, the Mogok and Mong Hsu mining areas. In contrast to the Vatomandry rubies, Burmese rubies commonly display various forms of growth patterns. Compared to the basalt-related Thai/Cambodian rubies, which have consistently low contents of vanadium (up to 0.01 wt. % V_2O_3), most Malagasy rubies contain more than 0.02 wt. % V_2O_3 and this is valuable for the separation of these stones from Thai/Cambodian rubies. However, Vatomandry rubies can best be distinguished from Thai/Cambodian rubies by their inclusion features: Thai rubies have no rutile inclusions or 'zircon clusters', and some of the typical Thai inclusion features (for example, different minerals or negative crystals, accompanied by 'rosette-like' healed fissures, or thin primary two-phase fluid films) have not been observed in the Vatomandry samples.

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A discussion on the origin of irregular shapes of type II diamonds

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ABSTRACT: Natural type II diamonds are characterized by their irregular shapes, which are very different from the generally observed octahedral or rounded dodecahedral morphologies of type I diamonds. Daily sorting of type II rough diamonds has been empirically based on this morphological characteristic. The reason why type II diamonds exhibit such an irregular morphology is simple. They are not as-grown crystals, but are the result of crystals fractured during their ascent in magmas. Type II diamonds are much purer with much smaller contents of nitrogen than type I diamonds, making them plastically much weaker than type I. When both type I and type II diamonds experienced similar amounts of stress while being transported from the depths to the surface of the Earth, only type II diamonds were plastically deformed and further fractured into pieces, while type I diamonds retained their original as-grown morphology.

Introduction

Moses *et al.* (1999) have recently reported that more than 80% of GE POL diamonds were fancy cut brilliants, although they gave no explanation as to why this is so. If enhancement of colour grade by HPHT treatment could be realised on any type of natural diamond crystal, this statistic would sound odd. We should expect a much higher proportion of round brilliant cuts, since octahedral or rounded dodecahedral morphologies suitable for the round brilliant cut are more commonly encountered in natural diamond populations. The statistics imply that the rough stones used for HPHT treatment to realize enhancement of colour grade are limited to a particular type of natural diamond, more than 80% of which should have flattened or irregular shapes. It is now well known that only type IIa diamonds can be used to produce GE POL diamonds, as discussed in recent papers by Moses *et al.* (1999), Schmetzer (1999) and Smith *et al.* (2000).

It has been empirically known among diamond sorters that unlike type I diamonds, type II diamonds occur in very irregular or flattened shapes, and do not show crystallographic faces (Wilks and Wilks, 1991). This morphological characteristic has been used as a criterion in the daily sorting of rough diamonds, and this empirical procedure has been proved to be reliable by UV transmission or IR absorption investigations.

The origin of irregular shapes of type II diamonds has been a subject of arguments. Wilks and Wilks (1991) summarized the proposed origins as follows:

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1. the irregular shapes are due to fracture either (a) in the earth at some time in the earlier history of diamond formation or (b) during mining and extraction;
2. variation in rates of dissolution of diamond in the surrounding magma;
3. determined by the contours of the surrounding rocks while diamonds were growng in the interstices of solidified minerals; and
4. octahedral faces can appear due to the presence of nitrogen as an impurity element which affected the growth rates of {111} faces.

The argument (4) considers that type I diamonds contain nitrogen as an impurity which suppressed the normal growth rate of octahedral faces and thus type I diamond crystals exclusively develop as octahedral habit, whereas type II diamonds are much purer containing no impurity nitrogen, and thus they may take any form and not necessarily the octahedral one. It is perhaps fair to state that no conclusive explanation has so far been given to answer why type II diamonds take irregular shapes, while type I diamonds take octahedral or rounded dodecahedral shapes.

In this paper, it is intended to discuss the problem, and to put forward an answer, based on an understanding of growth morphology of crystals in general, and of observations on collections of type II diamonds and their X-ray topographs.

Morphology and internal strain of type II diamond

Morphology

Figure 1 shows a few examples of rough stones grouped as type II. Neither octahedral, rounded dodecahedral nor cuboid forms are encountered. All the crystals are irregular or flattened shapes, showing no crystallographic flat faces. Even when somewhat flattened surfaces are present (see for example *Figure 1 D,E*), they are not crystallographically flat faces, and do not show surface morphological characteristics commonly observed on natural {111} or rounded dodecahedral faces, such as trigons, network ditches, superimposed ring patterns (dissolution features), and growth hillocks (growth features) (Sunagawa, 1984). However, it is commonly observed that the surfaces are rounded or mottled (see for example *Figure 1 A,B,C*), indicating that dissolution took place after an initial irregular shape was formed. Another characteristic of gem quality type II rough is that the majority of stones are colourless, and only a small fraction are tinted brown. The proportion of brown tinted stones of type II in industrial diamonds is reported to be much higher than this (Wilks and Wilks, 1991). This difference in the proportions of pale brown stones between gem quality and industrial stones is attributed to the fact that the stones had already been sorted into gem and industrial categories. The brown coloration is probably due to point defects associated with dislocation induced by plastic deformation.

Internal strain

It has been well known for some time that type II diamonds are more heavily strained than type I diamonds. They show under polarized light anomalous birefringence and the so-called tatami-mat patterns (Takagi and Lang, 1964), which are not seen in type I diamonds. Tatami-mat patterns are easily detectable under crossed polarizers, and have been explained as due to crossing slip lines induced by plastic deformation.

X-ray topography is a well-established powerful method to investigate spatial distribution of lattice defects and strains in nearly perfect crystals. Extensive X-ray topographic investigations have been carried out on natural and synthetic diamonds, see for example Lang (1965). Most X-ray topographs of diamond crystals reported so far are of type I diamonds, which typically show dislocation bundles radiating from a centre nearly perpendicularly to {111} faces. Far fewer X-ray topographs have been reported from type II diamonds.

Figure 1: *Examples showing irregular shapes of type II natural diamonds. A-C from the DTC Research Centre collection, magnification ca. 5-10x photomicrographs. To secure better views of surface features, combined illumination was used, which resulted in the appearance of brown tinted stones, B, C, being darker than they really are. D and E are from the DTC Sorting Room collection, macrophotographs, ca. 2x.*

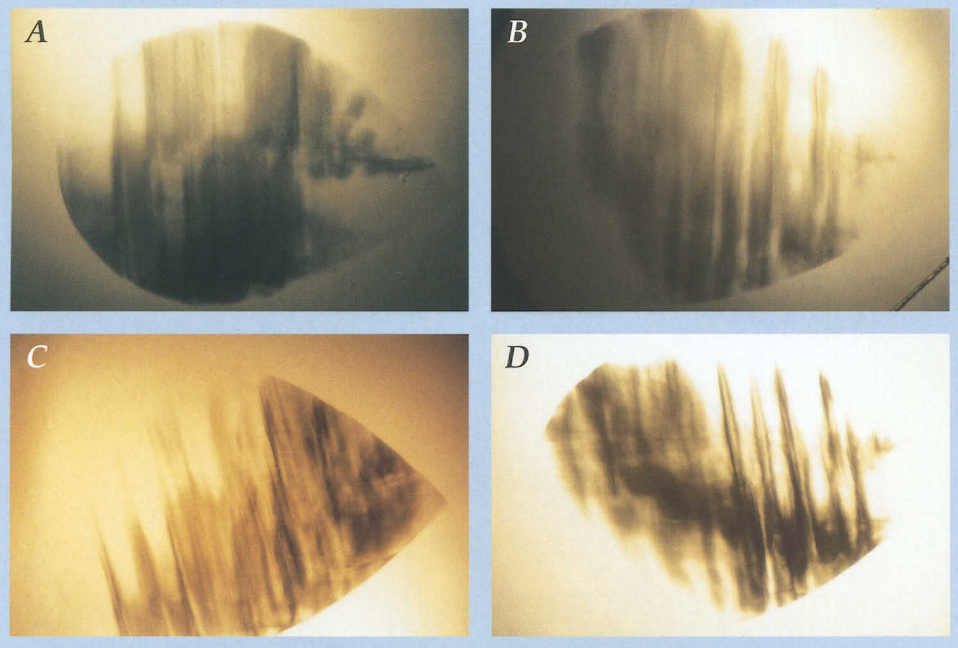

Figure 2: *Examples of X-ray topographs of type II diamond. A and B after HPHT treatment, C and D before treatment of the same pear-shaped brilliant. Topographs were taken by Mr T. Kikuchi; Mo target, 50 kV, 10 mA. Focus size 0.4 mm H x 0.8 mm W. By courtesy of GAAJ.*

At the request of GAAJ, X-ray topographs were taken by Mr T. Kikuchi, Analytical Laboratory of Rigaku-Denki Co., Akishima, Tokyo, of a pear-shaped brilliant cut type II diamond, both after (A, B) and before (C, D) High Pressure High Temperature (HPHT) treatment. These are shown in *Figure 2*. The X-ray topographic images before and after HPHT treatment show no essential difference. In addition, four type II diamonds have been investigated by X-ray topography to investigate changes in perfection before and after HPHT treatment. All five stones examined indicate no significant change in their X-ray topographs after HPHT treatment. They show contrasting images of properly diffracted areas juxtaposed with areas of poor diffraction. The properly diffracted areas show parallel contrast images, whereas the poorly diffracted areas show no contrast. This indicates that the stone is not a perfect single crystal throughout, but consists of mutually bent (inclined or twisted) domains. Parallel contrast lines represent slip lines, due to plastic deformation, and not growth-induced dislocations. The stones, both before and after HPHT treatments, are so highly deformed that the growth-induced dislocations, like dislocation bundles and growth banding are not discernible. In this respect, type II diamonds are markedly different from type I diamonds.

To confirm the validity of this observation, the present author investigated a stock of X-ray topographs of type II diamonds in the DTC Research Centre and confirmed the above observation to be generally applicable. Type II diamonds usually show X-ray topographic images characteristic of heavily distorted or strained crystals. We therefore can conclude that type II diamonds are plastically more deformed than type I diamonds. This is perhaps the reason why less X-ray topography has been reported so far on type II diamonds. Any interesting information relating to crystal perfection and homogeneity, growth morphology, or the growth history of the crystals is disguised by the deformation.

Discussion

Morphology

Growth morphologies of crystals are determined both by internal structural factors and by external factors affecting growth parameters (phases, solute-solvent interaction energies, impurities, driving forces, temperatures, pressure, etc., see Sunagawa, 1987). Much work has been done in the last 200 years to understand theoretically and experimentally how growth and/or dissolution morphologies of crystals are determined. Assuming that the morphology of polyhedral crystals is determined purely by internal factors, and entirely neglecting the effect of external factors , we may deduce a structural or an abstracted morphology of a polyhedral crystal which can be used as a criterion to analyse the effect of external factors on the morphology of polyhedral crystals. Along this line of reasoning, various models have been put forward (see for example Sunagawa, 1987), among which Hartman-Perdok's PBC analysis (Hartman and Perdok, 1955, and also Hartman, 1987) has been most widely accepted. In this model, crystal faces are classified into three types depending on the number of Periodic Bond Chains (PBC) present in different faces. A face containing more than 2 PBCs is called an F (Flat) face, which can develop as a large habit-controlling face. An F-face is an atomically smooth interface, on which growth proceeds through two-dimensional spreading of growth layers parallel to the interface. In other words, an F-face grows either by a two-dimensional nucleation growth mechanism or by a spiral growth mechanism, and thus can develop into a large habit-controlling face. A face containing only one PBC is called an S(Stepped)-face, while a face containing no PBCs is a K(Kinked)-face. These two faces are atomically rough interfaces. The growth of S and K faces is, therefore, not due to two-dimensional spreading of growth layers, nor is it due to spiral growth, but takes place through addition of chains (S face) or growth units (K face). It follows from this that K faces will not appear, and S faces will only develop to a small extent, if at all, on polyhedral crystals. S and K faces cannot be habit-controlling faces. Only when their interface structures are modified by some external factor, which transforms the S or K to an F face, can they develop significantly.

From the diamond structure, we see that the {111} face is the only F face on which growth layers can develop, leading to the well developed, habit-controlling octahedral face. The {110} and {100} faces are S and K faces respectively on which two-dimensional nucleation growth or spiral growth are not expected. Diamond crystals will, therefore, take a simple octahedral habit bounded by flat {111} faces, probably associated with narrow striated {110} but not {100} faces, when they grow under near-equilibrium conditions and with no effects from external factors to modify their interface structures.

This morphology is indeed the morphology of many natural diamond crystals, and single crystalline diamonds are the main source of gem-quality rough stones. Although natural diamond crystals are usually rounded, due to dissolution processes experienced during ascent from depth to the surface of the Earth, we may assume that the as-grown morphology of natural diamond polyhedral crystals is octahedral. It has been well established through surface microtopographic observations of cuboid faces (Sunagawa, 1984) and X-ray topographic investigations of growth banding in {100} growth sectors which display the centre cross pattern (Lang, 1965), that the {100} interface always behaves as a rough interface in natural crystallization. There have been no reliable observations showing that {100} behaves as a smooth interface. We never see natural diamonds with a cubic habit, on whose {100} faces growth layers are observable. It is clear that in natural diamond growth, only {111} behaves as a smooth interface, and {100} exclusively behaves as a rough interface (Sunagawa, 1984). Isotropically rounded or irregular forms cannot be expected as growth forms of single crystalline diamonds when they grow in nature under near equilibrium conditions. Such forms may be expected for polycrystalline aggregates of diamond, but

not for single crystals (Sunagawa, 1984; 1995). It is evident from this that the octahedral habit is a morphology of diamond crystals which is to be expected from the structural considerations and is not a function of the effect of nitrogen impurity. We therefore exclude the argument (4) as a possible origin of the octahedral habit of type I diamond. We can also exclude the argument (3) which says that irregular shapes of type II diamonds are determined by the contours of surrounding rocks, because natural diamonds grow in magma or in a liquid droplet formed by partial melting in high pressure metamorphic rocks, and not by solid state crystallization (Sunagawa, 1984).

If interface roughness is modified for some reason, and an S or K face transforms to an F face, {110} or {100} faces can develop as habit-controlling faces, in addition to the {111} face. Among various external factors which have been suggested as candidates to modify the habit of polyhedral crystals, impurities and solvents are particularly important, since these may newly introduce or break PBCs and modify the interface structure. We have already demonstrated that only the {111} face behaves as a smooth F face, that {110} is an S face and {100} is a K face in the crystallization of natural diamonds grown in magma, or silicate solution, where silicate (or oxygen) is the solvent. Modification or reconstruction of interface structure is not expected to take place in this solvent. In contrast to this, HPHT synthetic diamonds grown in metallic or alloy solution take a cubo-octahedral habit, bounded by flat {111} and {100} faces, on both of which growth spirals may be observed (Sunagawa, 1984, 1995). This implies that in metallic solution, not only {111} but also {100} behave as smooth interfaces, enabling spiral growth to take place on both, resulting in the appearance of a cubo-octahedral habit. There is a clear difference in solute-solvent interaction energies between silicate and metallic solutions, which will modify the interface roughness.

In both natural and synthetic growth environments, when diamond grows under near equilibrium conditions, polyhedral crystals bounded by crystallographic faces are generated and neither spherical nor irregular forms are expected. This is due to anisotropy inherent in the structure, as already explained in terms of F, S and K faces, and smooth and rough interfaces. The {111} face is the only face on which two dimensional nucleation growth or the spiral growth mechanism operates (which therefore develops well in natural diamond formation), whereas {100} behaves as a rough interface, on which neither growth layers nor spirals develop. In HPHT synthetic diamond formation, both {111} and {100} behave as smooth interfaces, and grow by the spiral growth mechanism. Arguments that the irregular shapes of type II diamond are due to chemical purity, and that the octahedral habit of type I is due to the effect of impurity nitrogen do not make sense. Polyhedral crystals of both types of natural diamond should take an octahedral habit, irrespective of the presence or absence of nitrogen, or the difference between types I and II. High partitioning of nitrogen in type I diamonds is a result of selective and directional element partitioning in different growth sectors through the growth processes, and cannot be the cause of the octahedral habit of type I diamond. We therefore have to search for another reason for the origin of the irregular forms of type II diamonds.

Stress

It has been well established that pure metals are plastically much weaker than alloys, and that this is due to the presence of precipitated (exsolved) impurities which act as obstacles to dislocation movement. A representative example is duralumin, an aluminium alloy containing less than 2% Cu. The impurity Cu forms platy precipitates in crystallographic orientations, which act as obstacles to dislocation movement. Duralumin is much harder than aluminium metal. When pure aluminium and duralumin receive the same amount of stress, aluminium deforms plastically at much lower temperatures than duralumin. Plastically

highly deformed materials are more likely to be fractured into pieces than plastically less deformed ones, as they are closer to the plastic limit and fracturing occurs beyond that. By analogy, type II diamonds correspond to pure aluminium, and type I to duralumin. When both types of diamond crystals receive the same amount of stress, type II will be plastically deformed, and even broken into pieces by fracture due to extended deformation, while type I crystals maintain their original as-grown morphology.

Anomalous birefringence, the tatami-mat pattern and X-ray topographic features characteristic of type II natural diamond crystals, which are not seen in type I are all evidence to support the idea that type II diamonds are more heavily plastically deformed than type I. It is likely that type I and type II diamonds experienced similar amounts of stress during transport to the Earth's surface by kimberlite or lamproite magma, but only type II crystals responded and demonstrate the plastic deformation, because they are purer than type I crystals. In such conditions, the plastically deformed type II diamonds are more likely to be fractured than the less deformed type I diamonds. And it is also likely that fracturing took place during ascent and not much later during the mining operation. Readers may argue that if type II diamonds are fractured pieces, there should be cleavage flakes, with flat {111} cleavage surfaces, and not irregular shapes. Indeed flat shapes are commonly encountered among type II diamonds, but the equally common irregular shapes can also be accounted for if we take into consideration that many type II diamonds are plastically deformed and composed of mutually inclined or twisted domains.

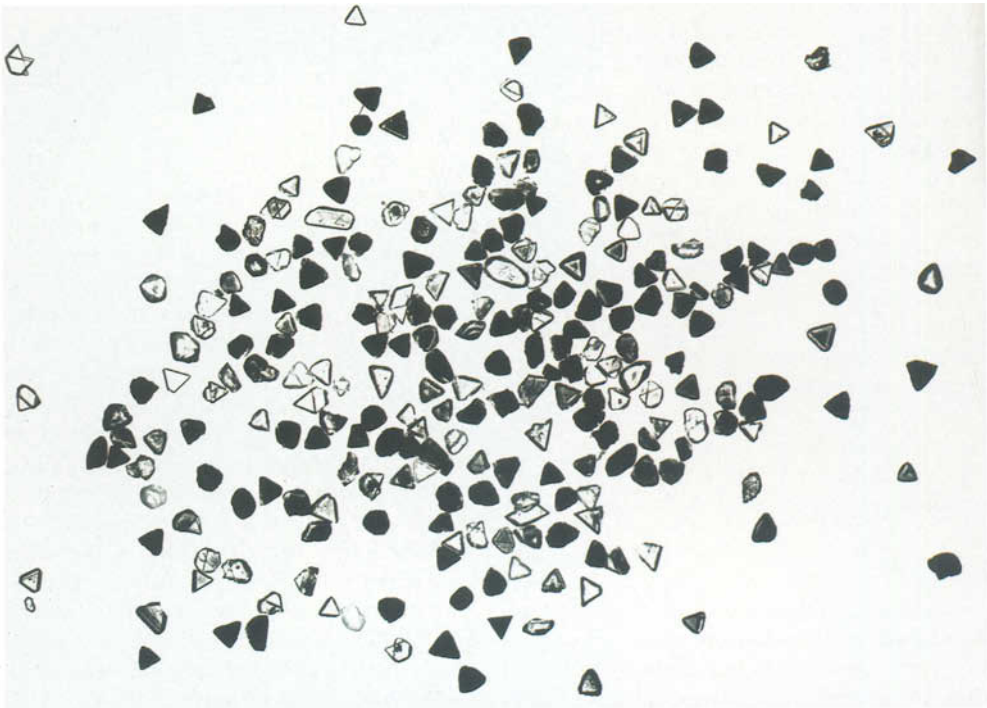

Figure 3: *Positive image of micro-diamonds on a photographic plate under UV irradiation of $\lambda = 2537\mathring{A}$ Black images correspond to type I, transparent ones to type II, and grey crystals composed of types I and II. Magnification x4. No essential difference in morphology is noted between type I and II crystals. Reproduced from Figure 1 of Tolansky and Komatsu, (1967). By courtesy of Prof. H. Komatsu.*

It follows from these arguments that the irregular shapes of type II diamonds do not represent their original as-grown morphology. Although the present shapes are irregular, the original as-grown morphology of type II must be octahedral, similar to that of type I diamonds. This is clearly seen in Figure 1 of Tolansky and Komatsu's paper (1967) where a much higher population of type II diamond in micro-diamonds than in larger diamonds was reported. They observed UV transmission at λ =2537 Å of a sample of micro-diamonds averaging 0.0015 ct (0.8-1.2 mm across), and reported that 16% were completely transparent to UV (i.e. type II), 27% were completely absorbent (i.e. type I), and the remainder transmitted UV partially. The photograph, which is reproduced as *Figure 3* in this paper, clearly shows that type I and II mostly have a good octahedral habit, and that there is no essential difference in morphologies between the two types.

For larger crystals, type II diamonds are too heavily strained to detect and visualize any original as-grown features, such as growth zoning, or radiating dislocation bundles under polarizing microscopy or by X-ray topography. They are also too pure to detect growth zoning by cathodoluminescence. Since features due to plasic deformation are superimposed on growth-induced original features, it is not easy to obtain convincing evidence in larger stones to prove that the original as-grown morphology of type II diamonds was octahedral and the same as that of type I. What we can say definitely is that the present irregular shapes of type II diamonds do not represent the original as-grown form, but the form of fractured pieces.

Dissolution

Surfaces of irregular shapes of type II diamonds are neither flat, nor shiny. They are wavy and mottled. These features indicate that the irregularly shaped fragments were subject to partial dissolution. The argument (2) which suggests that the irregular shapes of type II diamonds are due to variation in dissolution rates in the surrounding magma is not acceptable, since a very anisotropic (and highly unlikely) oxygen fugacity distribution in the magma around a crystal would have to be assumed to account for transformation from a roughly equant near-octahedron to an irregular shape.

Concluding Remarks

It has been demonstrated that the irregular shapes typically shown by type II diamonds are likely to be the result of plastic deformation and fracturing into pieces, while type I crystals retained their original as-grown octahedral morphology and size. Plastic deformation and fracturing probably took place during transportation from the depths to the surface of the Earth. After having been fractured, type II diamonds were present in the ascending magma together with unfractured type I diamonds, and both were similarly subject to partial dissolution. Fracturing is not due to later mining operations.

Moses *et al.* (1999) and Smith *et al.* (2000) reported that the HPHT-treated GE POL diamonds show strong anomalous birefringence colours under cross polarized light. The same optical characteristics may also be exhibited by untreated type II diamonds so a simple qualitative observation of birefringence may therefore not be used as a diagnostic feature in distinguishing between HPHT-treated and untreated type II diamonds. GE POL treatment is applied to irregularly shaped type II brown tinted stones. This is the reason that more than 80% of GE POL are fancy cut stones. In subjecting type II diamonds to HPHT treatment, additional stress is applied to already deformed stones, and the resultant plastic deformation is superimposed. The treatment, in a sense, is more of the same kind of deformation and makes it more difficult to distinguish between natural type II and GE POL stones. However, there must be a way to distinguish between naturally experienced and artificially applied stress through study of their resultant features. To quantitatively investigate the difference in birefringent features between treated and untreated type II diamonds will be an interesting future subject of study.

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The author is grateful to the staffs of the DTC Research Centre and Sorting Room for the opportunity for personal investigation of their collections of type II diamonds. He is also indebted to GAAJ for permission to use X-ray topographs of type II diamonds, and to Prof. H. Komatsu of Iwate Prefectural University for permission to reproduce his photograph as Figure 3.

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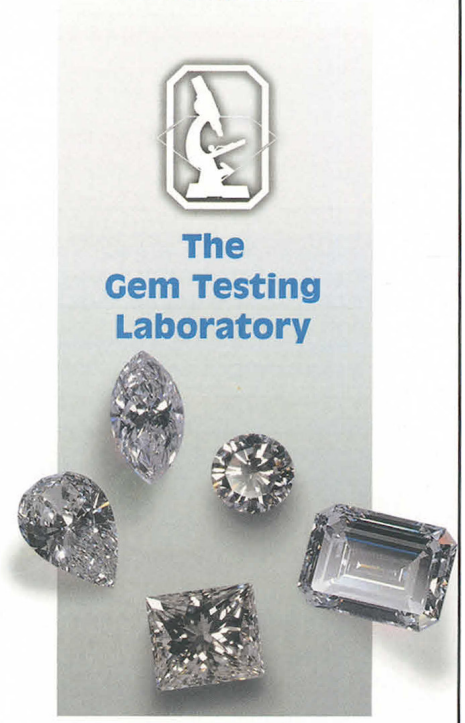

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Disclose, describe, dress-up, disguise, deceive . . . credibility and gem descriptions

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ABSTRACT: Terminology used in the gem and jewellery industry at the end of the twentieth century is discussed. Distinction is made between a statement of identification and advertising. A comparison is made of differing wording, euphemisms and jargon used in purported disclosure statements. Propriety of language is examined from the perspective of a gemmologist's responsibilities.

Keywords: disclosure, origin, condition, synthetic, treated, natural.

Introduction

There is a credibility gap in the gem and jewellery industry regarding disclosure of gem origins and treatments. The industry's reputation is compromised each time someone buys something and later learns it is not what they thought it is and is of less value than they were led to believe!

Public confidence can be increased by a point-of-sale disclosure. Many retailers now use accompanying documentation such as a laboratory report, a certificate of authenticity or a valuation certificate, as a means of public disclosure (and selling tool). But disclosure is only good when it avoids misunderstanding. Misunderstanding damages reputations as easily as misrepresentation. It is only human to try and gloss over defects, and this is often done using euphemism or jargon with, perhaps, a disclaimer: "The opinions expressed here represent the opinions of the author and do not necessarily represent the opinions of those who hold other opinions."[(i)] The gemstone industry is about as international as any industry can possibly be. Rules and regulations vary significantly between jurisdictions; so rather than consider regulations, let us discuss proprieties and when and how they should be applied.

Then and now

Years ago, when synthetic gems first appeared, the question "Is it natural?" in reference to a gemstone was understandably presumed to be a request for information about origin. It was assumed that the full query the questioner intended was "Is it of natural origin or is it man-made?" Basil Anderson's concern was "...namely, is the stone natural or synthetic?"[(ii)] and Robert Shipley's definition was "natural stone. A stone that occurs in nature; as distinguished from a man-made substitute..."[(iii)]. Over the years, the situation has changed and public knowledge about treatments applied to gems has caused the issue of condition also to become a significant concern.

Nowadays, someone looking at a D colour diamond might similarly ask "Is it natural?" in a request for information about condition. In this case, it would be assumed the full query the questioner intended was

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"Is it natural, or high temperature/high pressure (HPHT[iv]) treated?" The same question in reference to an expensive ruby would sensibly be presumed to be requesting information about both origin and condition. The full query intended for the ruby would be "Is it natural or synthetic in origin, or have its properties been altered by a treatment?"

Unfortunately, old habits die hard. Much literature and even course materials speak of 'natural ruby' or 'natural emerald' in contexts where synthetic alternatives are not specified. In each case, the unstated presumption is that only origin is being addressed by the adjective. This unstated presumption, appropriate in a context when identification of synthetic material was the only issue, has induced many in the trade to consider the word 'natural' as jargon unique to the gem industry with the narrow meaning 'neither synthetic in origin nor a man-made substitute'.

The example of the D-colour diamond makes it clear that the adjective 'natural' is context-sensitive as far as limiting presumptions are concerned. We are now in a situation where changes in technology have produced a case within the industry where a widely accepted standard limiting presumption (that gave rise to a jargon label) is refuted by a contrary presumption. In the modern context it is clear to knowledgeable people in the trade that, contrary to the 1940's presumption of what was significant, the possibility of HPHT treatment makes the D colour suspect and condition is the germane point, not origin. Let us examine the issue of jargon.

Jargon

Jargon is terminology peculiar to a particular job or to a field of study. Jargon may be words or phrases that do not exist outside the field, or may use words that exist elsewhere but which have a field-specific narrow meaning.

The purpose of jargon may be one or more of several:

1. to label a concept that does not exist outside the specialized field;
2. as coded communication to limit information to those within a field;
3. for comfortable communication between peers in a field;
4. as 'bafflegab' to impress people outside the specialized field.

An example of jargon, where a specialized field gives a word a meaning that differs markedly from the day-to-day usage, is the word 'form'. This word has a very particular narrow meaning in crystallography. Novice crystallography students may misunderstand 'form' to mean shape, but in this field it is a jargon label that represents a concept so narrow in meaning as to not have a label in ordinary conversation. A crystallographic form is the complete assemblage of all faces required by the symmetry when one face is given. In this example the jargon clearly serves the first purpose, helping clarify basic concepts.

The word 'natural', as gem industry jargon meaning 'not synthetic in origin', is clearly used for a different purpose; originally probably point 3 above. The first purpose cannot be justified because the concept certainly does exist outside the field of gems and jewellery. This and other jargon as well as euphemisms being used in documents purporting to be statements of disclosure are often used for purpose 2, an internal code that limits information about condition.

The five Ds

In the marketing of gemstones, the consumer may encounter declarations serving various functions for vendors. From the perspective of the final consumer, the five declaration Ds in decreasing order of desirability are: disclose, describe, dress-up, disguise and deceive.

More often than not, arms-length disclosure documents are commissioned by prospective vendors of the subject item(s). Vendors are particularly interested in using such documents as selling tools. Other writing that a vendor may commission to assist in marketing would include advertising

copy. A gemmologist should be able to accept either (or both) of these commissions. Difficulty develops, however, when no distinction is made between the two different sets of requirements. The limits as to what should be said differ in each case.

Concern has been expressed that tight restrictions on how gems may be described limit the ability of vendors to 'romance the stone'. There is a difference between selling the steak and selling the sizzle. Anyone who has done the slightest bit of marketing knows that history, mystery, romance and intrigue can greatly increase desirability of a gem. Problems arise from not discriminating between an identification statement and selling the sizzle. Failing to recognize adjectives or jargon that could be misleading to the public can exacerbate difficulties.

The phrase 'diffusion-treated natural sapphire' has been offered as an identification statement suitable for lab certificates or valuations. Proponents of the terminology would claim that 'diffusion-treated' is a full and complete disclosure of how the material's properties have been altered by human intervention, and that 'natural sapphire' is a full and complete disclosure of the origin of the material to which the treatment was applied. There have been cases of diffusion treatment having been applied to synthetic material, and the full disclosure statement for such material would be 'diffusion-treated synthetic sapphire', to which even detractors of the 'treated natural' terminology would agree.

Proponents would point out that an unscrupulous person might misleadingly employ partial disclosure using the phrase 'diffusion-treated sapphire', where the disclosure of the treatment is provided while information about the origin of the material to which the treatment was applied is intentionally omitted because it was synthetic. By specifying the treatment process and confirming the natural origin of the material that was treated, they claim to be acting in the best interest of the consumer. They readily admit that a description emphasizing natural origin makes the subject material easier for vendors to sell. They suggest that, rather than detracting from their arguments, this is a positive thing. They would say that this terminology is good for both the consumer and the trade.

To paraphrase the proponent's argument, "Because some people may lie by omission, we should be able to use the adjective 'natural' to describe this treated product". Does a claim that others might cheat validate using language that some might consider misleading?

If a colourless stone that underwent diffusion treatment had chromium added instead of titanium and iron, would proponents of '... treated natural ...' terminology speak of 'ruby-colour diffusion-treated natural sapphire'? Of course not! Vendors would never market a red corundum as a sapphire, but the raw material that was treated could never have been called ruby. This makes it clear that the intent of the language is to mislead, not inform. The ordinary person, lulled into a purchase by the word 'natural', is likely to be grievously disappointed when apprised of the true situation and unimpressed that the raw material to which the treatment was applied was not synthetic!

The American Gem Trade Association (AGTA) gem identification certificate indicates the extensiveness of treatment present in stones that are identified as ëenhanced naturalí and 'treated natural' with additional qualifying adjectives. The Director of the AGTA Laboratory said "... For the moment, I am happy with using the word Natural for enhanced stones providing that the enhancement is declared."[(v)]

The Gemological Institute of America (GIA) Emerald Report classifies degrees of enhancement while saying **"Conclusion – NATURAL EMERALD"**, in bold print in the centre of the document surrounded by lots of white space. When the issue of inappropriate use of 'natural' was raised[(vi)], a GIA Gem Trade Lab spokesman responded, "... we feel his interpretation of the word 'natural' is too strict."[(vii)]

The Thai Gem and Jewelry Traders Association's 'Ruby Disclosure System'[viii] included three categories:

Category A, Natural Ruby

Defined as "The ruby has been enhanced by heat, but at 10x magnification no residue from the heating process is visible on or within the stone."

Category B, Heat Enhanced Natural Ruby

Defined as "The ruby has been enhanced by heat, and at 10x magnification residue from the heating process is visible within the stone."

Category C, Heat Treated Natural Ruby with Foreign Substances Present

Defined as "The ruby has been enhanced by heat, and at 10x magnification residue from the heating process is visible on the surface of the stone as well as within the stone."

By these definitions, a ruby with obvious evidence of heat treatment (heat-altered inclusions) would qualify as natural ruby without any further comment as long as there was no evidence of glass or other foreign residue in the stone. This 'disclosure' system does recognize the existence of what in normal conversation would be called natural ruby by the added *sub-Category A, Unheated Natural Ruby*, which is a curious convolution in logic to require addition of a modifying adjective for the word *natural* to have its real meaning.

One argument supporting the use of jargon says that all gemstones have been cut and polished. This processing of gems keeps any of them from qualifying as natural. To counter that, it may be observed that cutting someone's hair does not preclude it from being termed natural because cutting of hair, to make it easier to wear and to show it to best advantage, is entirely expected. It is also entirely expected that most gems will be cut to make them easier to wear and show them off to their best advantage. Cut untreated gems are natural gems. Uncut untreated material is natural rough or natural mineral. Uncut untreated crystals are natural crystals.

To identify a lady's stone as 'enhanced natural emerald' is at best inappropriate jargon romancing the stone, and at worst a deliberate attempt to mislead. The euphemism 'enhanced' does not have the same meaning outside the gem industry as the adjective 'treated' and the adjective 'natural' means far more to the average person than 'not synthetic'. She may believe that the identification statement confirms that accompanying diamonds enhance the beauty of her natural condition/natural origin emerald. Such jargon may be considered the norm by some, but it's a sad thing when those of good will blindly accept a self-serving 'norm' as the standard. Inappropriate use of the (unnecessary) jargon reflects the power of the adjective 'natural' as a selling tool, but it is misleading and a disservice to the entire industry. The only place for internal jargon is inside the industry, not to those outside the industry who can't be expected to understand it!

Of course, the word 'natural' can correctly apply in a more limited way when it is referring to one property of an object rather than to the object itself. Examples are the natural origin of a ruby that has been heat treated, or the natural colour of a cultured black pearl. Those examples should not be called 'natural ruby' or 'natural pearl' because it's only one aspect of each that is natural, not the entire stone. When we mean natural origin, we should say exactly that, not 'natural emerald'!

Let's 'get real'

From a perspective sometimes ascribed to the purist "... when a stone is sold as ... sapphire that term alone is sufficient ..."[ix], the name of any gemstone when used without qualification should always mean the genuine article, not an imitation or synthetic gem. If any material originated in nature and has had none of its properties altered by man, then the unqualified name of that material is sufficient and complete to identify it and the adjective 'natural' would be accurate but entirely redundant. If the origin of the material is not natural, the material's name

should be modified by an adjective such as 'synthetic'.

A material that originated in nature and which shows evidence of, or is known to have had, properties altered by man should be identified by the name of that material in equal prominence with the name of the process that altered its properties.

The International Jewellery Confederation (CIBJO) rules in their 1997 *Blue Book* required accurate identification of gemstones and delineated a number of treatments that specifically required disclosure. CIBJO uses the word 'natural' in its everyday meaning, and doesn't suggest anyone should use it as part of the description of a treated stone.

The *Gemstone Enhancement & Man-Made Product Information Guide* was developed by representatives of the American Gem Society, American Gem Trade Association, Jewelers of America, Jeweler's Vigilance Committee, and Manufacturing Jewelers and Silversmiths of America, in 1987. It offered a concise, accurate system for disclosure using letters of the alphabet as symbols to indicate the general frequency of occurrence of enhancement (or the warranted lack of enhancement) and, if enhanced, the specific method of enhancement used. It avoided using the term 'natural' and defined the symbol 'N' to mean 'has Not been enhanced' rather than natural.

Conclusions

Most countries have laws against misleading advertising, usually backed by serious penalties. In Canada, guidelines adopted by the Government in 1994[x] specifically state that it is a misuse of terminology to use the term 'natural' for anything that has undergone any treatment or enhancement. By these rules, descriptions such as those discussed earlier are clearly misleading.

Overstating quality or misrepresenting condition is not a prerequisite to successful competition in the market place. There is nothing wrong with romancing a stone in the selling process, a bit of artistic licence is to be expected in advertising. There's no reason why advertising copy cannot include redundant adjectives, fanciful expressions and seductive language. But gemmologists worth their salt should understand two things. Artistic licence is not a licence to mislead, and the romancing should be entirely separate from any identification statement.

When commissioned to produce a 'disclosure document', as a gemmologist one should consider that the job is to disclose and describe. When commissioned to write advertising copy, the job as a wordsmith is to describe and dress-up. A gemmology background here helps us to understand the product and avoid misrepresentation.

A statement of identification (including disclosures) should be factual. To be accurate it needs to include all known or reasonably presumed information about both origin and treatments. The identification must be accurate and unadorned. Dressing it up with superfluous or misleading adjectives, jargon, or euphemisms is entirely counterproductive.

Critical analysis of wording used in the identification of goods offered for sale allows us to recognize intentional manipulation of the language. When producing an official record of expert opinion that may be used as a 'disclosure document', it is an important responsibility of the gemmologist to exert due diligence and integrity as an expert and present information clearly and concisely with content and format that, as much as possible, precludes anyone misrepresenting the expert opinion to a third party.

An easier approach to avoid innocently adopting misleading words and phrases is to choose, and consistently follow, strict rules that have been carefully crafted to protect the final consumer. Strict rules may yield small improvements by coercing some of the unscrupulous away from fraud, but integrity cannot be forced on anyone. Rules are much more useful for guiding those of good will. The public can rely on the integrity of those who follow strict rules.

There are sensible rules laid out by people of integrity even though the unscrupulous

may evade or ignore them. The key to earning credibility lies in being seen to be forthright and truthful in identifying the goods we sell. In deciding what to say in the identification section of any communication, it helps to put oneself in the shoes of the ultimate consumer and try to see things from their point of view. We, as individuals, must be vigilant at recognizing and avoiding deceptive language and be consistent in following strict rules. When we romance the stone we should remember the five Ds and disdain to disguise and deceive.

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i. This disclaimer, used (with the plural 'authors') in letters to the editor columns *(AIR vents) of Annals of Improbable Research (AIR)* ISSN 1079-5146, is copied here with the specific intention of poking fun at the tendency of some valuers to hide behind the concept of 'opinion' with every identification statement.

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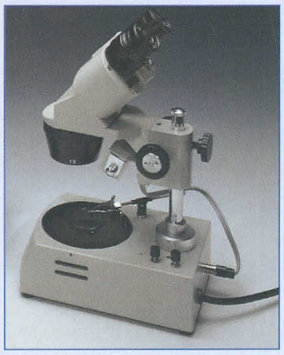

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Abstracts

Diamonds

Gems and Minerals

Synthetics and Simulants

Instruments and Techniques

Diamonds

Die Mineralogie und Gemmologie der Diamanten aus der Serra do Espinhaço, Minas Gerais, Brasilien.

A. Banko and J. Karfunkel. *Gemmologie. Z. Dt. Gemmol. Ges.*, **49**(3), 2000, 127-150. 18 photographs, 1 map, 8 tables, 2 graphs, bibl.

Diamonds from the Espinhaço range deposits are related to three geological periods ranging from the Precambrian, the Precambrian hydraulic redistribution time, to the Phanerozoic period. Up to 98% of these diamonds are cuttable; 34-39% are dodecahedrons, 17-27% octahedrons. These two crystal forms together with combinations of the two types make up 75% of stones found. The average diamonds have clarities in the VS-SI range and colours of I-K. Many have a green or brownish coating. Blue to milky-blue and green to greenish-yellow are the most frequent luminescence colours. 90-95% are type Ia. E.S.

NovaDiamond – colour enhanced yellow and yellow-green diamonds.

A.S. Barnard. *Australian Gemmologist*, **20**(12), 2000, 517-22, 6 illus.

Research by Novatek into the high pressure high temperature (HPHT) treatment of diamond began in 1991. Instead of the GE (GE POL) 'whitening' process, Novatek researchers began focusing on the activation rather than the de-activation of colour using HPHT techniques. In order to activate new colours in diamond it must be exposed to greater temperatures and pressures than those experienced during its formation, and these are obtained by using a specially designed 'Geodynamic' press. The NovaDiamond process transforms natural brownish diamonds of type Ia, or a mixture of type Ia and IIa, into fancy yellow or yellow-green diamonds. Identification features of NovaDiamonds include strong green fluorescence, significant 'bearding' of the girdle and frosted naturals. P.G.R.

Gemmologisches Symposium 2000. Zusammenfassungen/Abstracts.

Gemmologie. Z. Dt. Gemmol. Ges., **49**(3), 2000, 159-71.

A summary of papers presented at the symposium held in Idar-Oberstein. E. Fritsch, J.P. Chalain and H.A. Hänni presented a paper on the identification of diamonds treated at high pressure and high temperature by General Electric. Some of these stones contain characteristic inclusions, but most show luminescence induced by a laser and measured using a Raman spectrometer; in many stones also the width of the 637 nm line in the luminescence spectrum is broader in treated than in untreated stones. V. Lorenz read a paper on the genesis of diamondiferous kimberlite and lamproite diatremes. N.V. Sobolev talked about the influence of mineral inclusions on the quality of diamonds. E.S.

Gems and Minerals

Gemmologie Aktuell.

H. Bank, U. Henn and C.C. Milisenda. *Gemmologie. Z. Dt. Gemmol. Ges.*, **49**(3), 2000, 121-6, 6 photographs.

Grandidierite from Madagascar is a bluish-green boron bearing magnesium-iron-aluminium silicate, orthorhombic, hardness 7, RI 1.590-1.623, DR 0.033, lower than textbook values. SG 3.00. Also from Madagascar a rhodolite coloured corundum; this comes from the south of the island and is found together with blue, yellow, orange, pink and reddish-violet sapphires. Their gemmological values are slightly higher than those of average corundums. A transparent actinolite was found in a parcel of peridot crystals from Pakistan; it was cut and polished; RI 1.60-1.63, DR 0.030. E.S.

Moonstone – a rare Queensland gemstone.

H. Bracewell. *Australian Gemmologist*, **20**(12), 2000, 523-8, 9 illus. in colour, one map.

Although members of the feldspar group of gemstones are mined extensively worldwide, the colourless variety displaying a bluish schiller and termed moonstone is comparatively rare. Sri Lanka is one of the main sources of quality specimens of moonstone, but a small, yet prolific, deposit of this rare gem feldspar exists at Moonstone Hill, north of Hughenden in North Queensland. P.G.R.

Australia's gemstone resources and their markets.

G. Brown. *Australian Gemmologist*, **20**(12), 2000, 534-9.

Australia is the world's largest producer of diamond (by volume) and of precious opal, cultured white South Sea pearls, chrysoprase and nephrite. It is also a major

Abstractors

P.G. Read P.G.R. E. Stern E.S.

For further information on many of the topics referred to, consult *Mineralogical Abstracts*

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producer of sapphire and a minor producer of commercial man-made gemstones (namely the Biron hydrothermally grown synthetic emerald). This paper updates the status of Australia's commercial gemstone resources and discusses known trends in their production and export. Exploration for additional gemstone resources is ongoing but tends to be overshadowed by the search for higher yielding commodities such as coal, iron ore and gold. P.G.R.

Gemmologisches Symposium 2000. Zusammenfassungen/Abstracts.

Gemmologie. Z. Dt. Gemmol. Ges., **49**(3), 2000, 155-71.

A summary of papers presented at the symposium held in Idar-Oberstein. G. Brown talked about Chinese freshwater pearls and solving some problems of their identification. O.W. Flörke discussed the twinning in amethyst, including synthetic amethyst and chalcedony. R.R. Harding disucssed current gem testing and the role of laboratories. U. Henn talked about the problems of nomenclature for padparadscha, while J.I. Koivula described inclusions he had recently studied. C.C. Milisenda discussed the connection between gemstone occurrences and plate tectonics. E.S.

Klar durchsichtiger Rhodonit aus Brasilien.

U. Henn and H. Bank. *Gemmologie. Z. Dt. Gemmol. Ges.*, **49**(3), 2000, 151-4. 6 photographs, 1 graph, 2 tables, bibl.

A new occurrence of clear gem quality transparent rhodonite has been found in Minas Gerais, 85 km south of Belo Horizonte, near Conselheiro Lafaiete, similar to the material from Broken Hill, Australia. There are two types, one with lower RI, DR and SG than the Broken Hill material, the other with higher values due to higher iron content. E.S.

Gemmologische Kurzinformationen. Verschiedenfarbige Saphire aus Brasilien.

U. Henn and E. Petsch. *Gemmologie. Z. Dt. Gemmol. Ges.*, **49**, 2000, 173-4. 6 photographs, 1 graph, bibl.

A new occurrence in the Municipio de Manhuacu near Sacramento in Minas Gerais produces transparent sapphires in pink, violet-red, violet, lilac and blue-lilac, and some specimens are bi-coloured, mainly yellow-blue and yellow-violet. RIs and SGs correspond to average corundum values. Zircons, apatite, mica and crystallographically orientated rutile needles have been observed as inclusions. Healing cracks, twinning lamellae and growth zoning are present. E.S.

Instruments and Techniques

Dispersion measurement with the gemmologist's refractometer - Part 1.

D.B. Hoover and T. Linton. *Australian Gemmologist*, **20**(12), 2000, 506-16, 6 illus.

Part 1 of this paper first discusses the history of the development of the critical angle refractometer from the Bertrand instrument in 1884 and the Pulfrich version in 1886, to the series of more compact models that began to appear from 1920 onwards. However, an important though neglected aspect of the critical angle refractometer is that the measurement of refractive index can be obtained by means of the grazing incidence of light directed into the gemstone under test as well as via light introduced into the rear of the reference glass hemisphere or truncated prism. In the case of grazing incidence the critical angle is determined by the angle above which no light enters the reference glass prism. One advantage of the grazing incidence method is that the contrast between the viewed light and dark fields is more pronounced than that obtained by the more widely used total internal reflection method. Although there are difficulties in the use of grazing incidence measurement of refractive index, the authors indicate how these can be overcome. Another gemstone constant largely ignored by gemmologists is dispersion, measured as the difference in a gem's RI between light wavelengths at the B and G intervals. Only three recent references in the literature have discussed the measurement of dispersion using a refractometer (two by Suhner and one by Hanneman). On the assumption that such a measurement can be a useful identifying feature, this paper first reviews the basic principles of the optics of a refractometer. From this is derived a means of correction for apparent dispersion which disagrees with both Suhner's and Hanneman's methods. Although not simple, practical aspects of dispersion measurement using standards of known dispersion will be discussed in the second part of this paper. P.G.R.

Synthetics and Simulants

Gemmologie Aktuell.

H. Bank, U. Henn and C.C. Milisenda. *Gemmologie. Z. Dt. Gemmol. Ges.*, **49**(3), 2000, 121-6, 6 photographs.

Power beads are very fashionable at the moment, but many are not what they are said to be; dyed quartzites are offered as carnelian, onyx may be marble beads with plastic covering, white howlite may be magnesite. A 2.88 ct Paraiba tourmaline turned out to be dyed. A blue transparent to partly translucent fine grained aggregate from Afghanistan was offered under the name 'Aowien', measurements showed it to be blue diopside. A synthetic colourless diamond weighing 0.25 ct was shown to be a type IIa; strong green fluorescence under UV could be observed. A transparent faceted green stone turned out to be a synthetic quartz, the green colour being due to a green seed plate orientated parallel to the table of the otherwise citrine coloured stone. Several faceted, translucent, red stones from Afghanistan were found to be dyed with the colour concentrated in cracks. E.S.

Gemmologisches Symposium 2000. Zusammenfassungen/Abstracts.

Gemmologie. Z. Dt. Gemmol. Ges., **49**(3), 2000, 170-71.

Summary of a paper by I. Sunagawa on gemmology and the science of crystal growth presented at the symposium held in Idar-Oberstein. E.S.

BOOK REVIEWS

The power of gold.

P. Bernstein, 2000. Wiley, New York. pp xiv, 432, hardcover. ISBN 0 471 25210 7. £17.99.

Brisk and entertaining study of the part played by gold in antiquity and today, with a good deal of interesting material on Greek and Roman history and legend in which the metal has been concerned. There are also fascinating accounts of the gold standard and the upheaval caused by varying attitudes to it and of gold in today's electronic markets. Since gold plays so large a part in the jewellery trade it is worth while learning as much as possible about its unique history. The book is competitively priced and well-produced: there is a 10-page bibliography and a carefully constructed index. M.O'D.

Treasury of the world: jewelled arts of India in the age of the Mughals

M. Keene with Salam Kaoukji, 2001. Thames and Hudson in association with The al-Sabah Collection, Dar al-Athar al-Islamiyyah, Kuwait National Museum. pp 160, illus. in colour, softcover. ISBN 0 500 97608 2. £18.95

The exhibition of which this book is a catalogue is, as the review is being written, displayed at the British Museum and is set to travel to the United States later in 2001. A high proportion of the artefacts on show are illustrated in the catalogue which falls into sections on varieties in stone settings, inlaid hard stones, relief in hammered precious metal, engraved gold-backed jewels, gemstones on gold floral ground, developments in enamels, gold-embellished steel, three-dimensional expressions, relief-carved ornament, carved set gemstones, gemstone forms, inscribed royal gemstones and jewelled magnificence. There is a glossary and a bibliography. Each item illustrated and catalogued is fully described, sized and attributed with later provenance given where known. The photographs are first-rate: readers should look at the inscribed royal gemstones chapter in which the gemstones are rough red spinels and emeralds and also at the chapter on gemstone forms where diamond set items are described. There is a good deal of jade in the exhibition and from the stones less often used in such high company, some attractive carnelian and rock crystal.

The introductory chapters include a map showing the sub-continent during history and details of how Sheikh Nasser formed his collection. Those who wish to see the Timur ruby (red spinel) at closer quarters than usual should try to see the exhibition which contains so many beautiful items. M.O'D.

Jadeite jade [in Chinese]

C. M. Ou Yang, 2000. Cosmos Books Ltd, Hong Kong. 2 vols, pp 511 [about 50 pages outwith the pagination], hardcover, in slip case. ISBN [vol.1] 962 993 080 3 [vol.2] 962 993 081 1. Price HK $1000 for each volume.

Beautifully presented and exhaustive survey of jadeite with comprehensive details of the mineral itself, its geology and occurrence, mining, sale and fashioning. The author has visited many occurrences herself and her visits are preserved by a number of cheerful photographs in which she is accompanied by miners and by examples of jadeite boulders of different qualities. The first volume by and large deals with the geology and mineralogy while the second introduces gem testing, simulants, enhancements and marketing. Jadeite auctions are described (for the first time a monograph identifies the view before a sale as the very best place to examine the finest specimens) as well as the open-air jade markets in Hong Kong and elsewhere. Almost every opening carries at least one photograph and some of them are very good indeed. The print is exceptionally clear to read and very generously spaced; diagrams illustrating jadeite formation are very lucid and usefully coloured.

The bibliography is placed at the end of the second volume and arranged in two sections, Chinese-language and European-language works. Readers familiar with the very large literature of the jade minerals will see that no effort has been made to include every possible work of significance but enough are present to satisfy the present-day gemmologist. The last 50 or so pages of the second volume, unpaginated, include the bibliography and a number of examples of outstanding specimens described from auction house catalogues, giving in some cases the prices paid.

This is a large and expensive book but, though written in a language which will pose problems to European readers (my own studies in Chinese were a long time ago!) it is not too difficult to work out the points made by the author and the photographs are worth paying for. It is worth mentioning, to forestall the occasional question "why do all modern Chinese books on jade deal only with jadeite and not nephrite?" to remind readers that nephrite objects are considered first for their antiquarian, historical and literary value and only then for any ornamental attraction that they may display. In the catalogues of the major auction houses nephrite artefacts appear in oriental antiquities sale catalogues rather than in jadeite ones. M.O'D.

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Proceedings of the Gemmological Association and Gem Testing Laboratory of Great Britain and Notices

PHOTOGRAPHIC COMPETITION

The 2001 Photographic Competition on the theme ***Born Yesterday*** drew entries of a very high standard. Gemstones are minted, cut and refashioned every day, with many more stones being 'created' in laboratories around the world. To celebrate the new Millennium, members were invited to submit pictures of gemstones 'born' (or even 'reborn') during 2000.

First Prize

Marc N. de Regt FGA, Goes, The Netherlands

Rock crystal with hematite base and rutile needles (illustrated on front cover).

'Tom Munsteiner gave birth to this stone,' explained Marc de Regt. 'I bought it from him at Intergem 2000 and immediately the image inspired me. It looked at me like a frozen moment of creation. In the picture the stone seems to come loose, celebrating the new Millennium.'

Second Prize

John Harris FGA, Durdar, Carlisle, Cumbria

Platinum birthmark in Russian flux-grown crystal of synthetic red spinel.

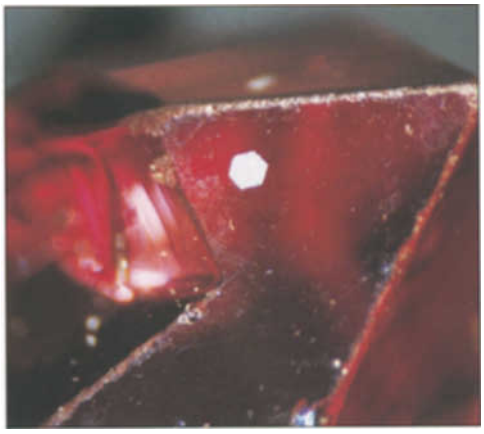

Third Prize

Bob Maurer FGA DGA, London

Chrysocolla from Mexico.

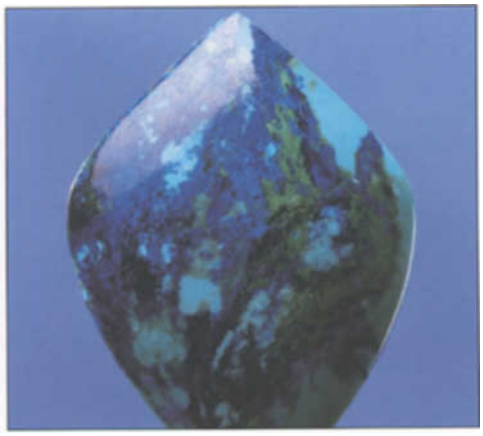

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Margaret J. Biggs, FGA

A tribute by David Callaghan

The death of Margaret Biggs at the age of 90 saddens all of us who knew her, and particularly those of us who worked with her. I did not do so in the conventional meaning of the word, but Margaret became President of the National Association of Goldsmiths (NAG) in 1977 during my term of office.

In 1958 I was sitting the NAG Diploma examination at Goldsmiths' Hall and I was taken from the Livery Hall, where we were sitting the exam, to the Drawing Room where the practical tests were taking place. Somehow I managed to skate past the table with the clocks on, and found myself in front of a lady. She had the appearance of a kind of great-aunt and she had a comforting warm voice. All I remember of the questions that she asked was one that involved me in handling a piece of silver – probably I was asked to identify the date. She then asked me what I should do when I had finished showing it to a customer. I replied that I would replace it in the showcase, and close the door (our showcases behind the counters were not locked). She asked me what else would I do. I thought for a while and couldn't think of anything else I should do, and said so. The kindly great-aunt then said to me: "You should clean off any finger marks before putting the piece back in the showcase." I thought this was being very 'picky' I suppose, being thoroughly spoiled by working in the West End and so I replied: "Oh, I never thought of that! You see where I work we have a man who cleans all the silver for us!" That was the end of the interview and I crept out, confident in my heart of hearts that I had 'blown it'. But I hadn't, so obviously the kind great-aunt had taken pity on the precocious student!

Margaret Biggs was the first woman to pass her FGA with Distinction (1929), sitting the exam that year in the company of none other than Robert Shipley of Los Angeles, Mr R. W. Yeo and Mr E. Trillwood, who was to become Secretary of the NAG in 1933. Margaret had studied for the exam for two years by correspondence, and her own sister Mary followed her in 1931. Interestingly, Mr E.T. Biggs, their brother, qualified in 1933 with Distinction and joined his sisters in the family business in the Maidenhead shop. He translated the Diploma course into German just for practice!

Margaret Biggs

He did not stay in the family business preferring the Diplomatic Service as a career.

Margaret and Mary were to form a unique team in running a family business, at a time when male chauvinism in the jewellery trade was the norm. Margaret was responsible for all aspects of buying and selling and Mary was responsible for all aspects of display and advertising. She was very successful too, winning the NAG Window Dressing Competition several times.

Margaret's great interest was in education and she was chairman of the NAG Education Committee for many years, laying the groundwork for the Diploma Course that has been the backbone of the NAG's lasting success in training. She was the first woman to be NAG Chairman (1948/49) and to date is, uniquely, the only woman to hold the office of NAG President (1977/78).

Many sons and daughters of family jewellers received their training with Margaret and Mary Biggs of Farnham, and the style of their business was very special. Margaret was especially kind to all young people in the trade, generous with her time in imparting her knowledge and always very encouraging. She was such a fine example to all. An example of her generosity of spirit is the letter of welcome and congratulations to Eric and Anne Bruton when they opened their shop 'The Diamond Boutique' in Maidenhead in 1967. After all they were to be Margaret's competitors, but rather than be downhearted or negative about it, she welcomed the healthy competition.

GIFTS TO THE ASSOCIATION

The Association is most grateful to the following for their gifts for research and teaching purposes:

Hossein Bordbar, London, for a bag each of tumbled chrysoberyl and rough corundum (ruby).

Gemsafrica, Richmond, Surrey, for rough rubies from Malawi.

Dr Ulrich Henn of the German Gemmological Association, Idar-Oberstein, Germany, for a copy of his book *Edelstein kundliches Fachworterbuch* with CD Rom

Michael Hendri, San Antonio, New Mexico, U.S.A., for a piece of yellow opal rough.

Kyaw Khaing Win, Yangon, Myanmar, for a brown amphibole crystal from Kyat-pyin, Mogok, and a colourless amphibole cabochon from Ohn-pinsye-htaret, Mogok.

Dan Ly, Cambodia Blue Zircon Co., California, U.S.A., for a brown zircon rough and two pieces of blue heat-treated zircon rough, both from Cambodia.

Penny O'Connor, Grays, Essex, for a simulated jade carving.

Peter G. Read, Bournemouth, Dorset, for a hardback copy of *Fire into ice* by Vernon Frolick.

Susannah van Rose, Glastonbury, Somerset, for a collection of gem-set jewellery.

Pierre Vuillet, Villards d'Heria, France, for a cut fluorite and a euclase crystal from Colombia, and a copy of *Revue de Gemmologie* containing a paper relating to material similar to that donated.

George Weller, Tunbridge Wells, Kent, for a collection of *The Journal of Gemmology* from the 1950s to the present day.

I remember especially her warm voice, her comforting smile and her quiet composure. In her presence the world was a quieter, well mannered, kinder and infinitely more hopeful a place. Although I had not seen her for many years, I realize now how much she is missed. Those of us who knew her will be always grateful to her. To Margaret, and to Mary her sister, we say thank you for all you have done for us.

Dr John Wilson Franks, B.Sc., Ph.D., FGA, DGA

Born in Beverley, Yorkshire, in 1930, John Franks obtained his B.Sc. in botany and zoology at Leicester University and his Ph.D. In 1956 he was appointed Scientific Officer in the Department of Palaeontology at the Natural History Museum, Kensington, moving to the position of Keeper of Botany at the Manchester University Museum in 1959 until his retirement 1994. He regarded gemmology as his 'second string' and qualified for his FGA in 1979 and DGA in 1980.

John Franks supported the North West Branch of the GAGTL for many years, serving as Chairman in 1984 and 1985, and Treasurer from 1997. His interests were manifold and no aspect of gemmology escaped his attention and enquiring scholarship, and he was always ready to share his knowledge.

Despite his failing physical health, he determinedly pursued his cultural interests and in these he was encouraged and supported by his wife Eileen, who is also a member of the North West Branch. His gentlemanly ways and quiet authority shall be missed by all who knew him.

Irene Knight

* * *

Evelyn Twemlow-Krzempek FGA DGA (D.1963), Calvereton, Nottinghamshire, died on 25 April 2001.

MEMBERS' MEETINGS

London

On 27 April at the Gem Tutorial Centre, 27 Greville Street, London EC1N 8TN, Dr Kurt Nassau from Lebanon, NJ, USA, presented an illustrated lecture entitled *My 40 years with gems*.

On 3 May at the Scientific Societies Lecture Theatre, New Burlington Place, London W1, Dr Kurt Nassau gave a lecture and demonstration entitled *Light and colour – beautiful complexity*.

During his presentation he explained that our knowledge of colour comes primarily from our first few years in school and much of what we were taught there is wrong or at least misleading. For example, there are *three* sets of primary colours and *two* very different ways of mixing colour. The

Gem-A The Gemmological Association

The Gemmological Association of Great Britain can trace its origins back to 1908 and has long been renowned for its dedication to the study of gems. Now meeting new challenges, it is putting itself at the cutting edge of communication whilst maintaining the high level of analysis, education and support for the diamond and gem trades which it has provided for almost a century.

To optimize communication the Association now has one easily recognizable and identifiable image and name: ***Gem-A***. As an abbreviation for 'The Gemmological Association and Gem Testing Laboratory of Great Britain' (GAGTL), ***Gem-A*** has many functions. It allows the Association to work efficiently on the internet, it helps with branding and provides a quality trademark for specific projects. ***Gem-A*** will streamline the Association's marketing by enabling Education, Instruments, the Laboratory, Membership and Publications to benefit from a common heritage and a common purpose. It will continue to be the approved UK awarding body and gemmological examination centre.

As well as continuing to support the trade, ***Gem-A*** will serve as a key for people from outside the allied industries and interest groups. The public will be able to access a wealth of information that has never been easy to find. ***Gem-A*** will regenerate public interest in diamonds, gems, jewellery and gemmology. Because of the global nature of the Association, ***Gem-A*** will help to expand this mission: the name ***Gem-A*** is easily understood in many languages and is a truly international symbol.

On the legal and business front, ***Gem-A*** is not replacing 'GAGTL' or superseding the Association's commitments, interests or remits. ***Gem-A*** is the vehicle that will unify, support and expand the existing structure.

nature of light itself remains mysterious. These and other basic concepts also help in understanding the 15 physical and chemical causes of colour, 13 of which occur in gems and minerals.

On 25 June at the Gem Tutorial Centre the Annual General Meeting was held, a full report of which will be published in the October issue of the *Journal*. This was followed by the Reunion of Members and Bring and Buy Sale. During the evening the winners of the 2001 Photographic Competition were announced and Rod Coleman of Harley UK, sponsors of the competition, presented the prizes. The event also included the launch by Jean-Paul van Doren of *Gem-A*, the new image for the GAGTL (see above).

Midlands Branch

On 27 April at the Earth Sciences Building, University of Birmingham, Edgbaston, the Branch Annual General Meeting was held at which David Larcher, Gwyn Green, Elizabeth Gosling and Stephen Alabaster were re-elected President, Chairman, Secretary and Treasurer respectively. This was followed by a lecture by Dr Jamie Nelson entitled *A new combination gemstone finger-printer and high refractive index refractometer*.

On 29 April at Barnt Green Dr Kurt Nassau gave a lecture entitled *Light and colour – beautiful complexity*.

A Summer Supper Party was held at Barnt Green on 23 June.

North West Branch

On 25 April at Church House, Hanover Street, Liverpool 1, Dr Kurt Nassau gave a lecture entitled *My 40 years with gems*.

On 16 May at Church House Alan Hodgkinson ran a workshop as well as presenting a talk entitled *Poking in gemmological corners*.

On 20 June at Church House a Bring and Buy Sale was held.

Scottish Branch

The Annual Conference of the Scottish Branch was held in Perth from 4 to 7 May. A report was published in the June 2001 issue of *Gem and Jewellery News*.

On 12 June at the British Geological Survey, Murchison House, Edinburgh, Murdo McLeod gave a talk entitled *Scottish pebble jewellery*.

FORTHCOMING EVENTS

13 September	**London**. *The literature of gemstones.* MICHEAL O'DONOGHUE
19 September	**North West Branch**. *Reading silver hallmarks.* CHARLES PRESTON
24 September	**Scottish Branch**. *Gemstones and geology of South Central Africa.* ROGER KEY
28 September	**Midlands Branch**. *The implications and problems of gemstones in jewellery valuations.* RICHARD TAYLOR
10 October	**London**. *A portrait of jewels.* MOYA CORCORAN
17 October	**Scottish Branch**. *Inclusions: highlights from twenty years of gemstone photomicrography.* CLIVE BURCH
17 October	**North West Branch**. *Pawnbroking throughout the 20th century.* RAY RIMMER
26 October	**Midlands Branch**. *Beautiful opals, Australia's national gemstone.* JOHN WHEELER

Gem-A Annual Conference

Sunday 4 November – Barbican Conference Centre, London

Keynote speaker: George Bosshart, Lucerne, Switzerland

Further developments in the detection of HPHT – annealed diamonds

Heat treatment of rubies: the Gübelin Gem Lab's disclosure and classification system

Dr Simon Lawson, DTC Research Centre, Maidenhead

Practical screening of HPHT treated diamonds

Haywood Milton and Stephen Whittaker

Auctioneers and Pawnbrokers: our unpopular 'lot'?

Terry Davidson

Who or what is a jeweller?

CONFERENCE VISITS:

Friday 2 November: Guided tour of the gem and mineral galleries at the Natural History Museum

Monday 5 November: **Diamond Trading Company**

Full details and application forms available from Gem-A on 020 7404 3334

20 November	**Scottish Branch**. *Jade.* ROSAMOND CLAYTON
21 November	**North West Branch**. *AGM and social evening*
21 November	**London.** *Analysis of precious stones under thick glass by Mobile Raman Microscopy (MRM). Compositions of jade and garnets by non-destructive Raman Microscopy.* Two Lectures by PROFESSOR DAVID SMITH
30 November	**Midlands Branch**. *Wonderful emeralds.* ALAN HODGKINSON
8 December	**Midlands Branch**. *Annual Dinner, 49th year*

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Midlands Branch:	Gwyn Green on 0121 445 5359 e-mail: gwyn.green@usa.net
North West Branch:	Deanna Brady on 0151 648 4266
Scottish Branch:	Catriona McInnes on 0131 667 2199 e-mail: cm@scotgem.demon.co.uk
South West Branch:	Bronwen Harman on 01225 482188 e-mail: bharman@harmanb.freeserve.uk

GAGTL WEB SITE

For up-to-the-minute informatin on GAGTL events visit our web site on www.gagtl.ac.uk

South West Branch

On 10 June at the Royal Literary and Scientific Society Institute, Bath, the second meeting of the newly-formed South West Branch was held. Talks were given by Michael O'Donoghue on the Sapphires of Montana and by Branch Chairman Richard Slater on *Jewellery at Auction*.

ANNUAL REPORT

The following is the report of the Council of Management of the Gemmological Association and Gem Testing Laboratory of Great Britain for 2000.

Officers, councils and committees

The Gemmological Association and Gem Testing Laboratory of Great Britain (GAGTL) is a company limited by guarantee and is governed by the Council of Management. At the Annual General Meeting in June, Professor A.T. Collins was elected President to succeed Professor R.A. Howie whom we thank for his strong support during two terms of office. Sadly, our recent President and Vice President, Eric Bruton died in December. The other Vice Presidents, A.E. Farn, D.G. Kent and R.K. Mitchell, continued in office.

Following the poor financial results in 1999, the Council of Management set up a working party to review policy. The decision for some immediate action resulted in the loss of three staff, one each in Membership/Education, Accounts and the Laboratory.

Further deliberation by the working party on GAGTL structure led to the creation of the new post of Chief Executive Officer and J-P. van Doren was appointed to it; he was co-opted onto the Council in December. The Council thanks the working party for all their efforts.

C.M. Woodward continued as chairman of the Board of Examiners, which was strengthened by the addition of S. Hue-Williams of London and Li Li Ping of Wuhan, China. E. Stern continued as vice-chairman. J. Monnickendam (chairman) and J. Kessler (vice-chairman) continued in office on the Trade Liaison Committee, which again provided a valuable forum for discussion of contentious trade matters such as diamond treatments and laboratory report terminology. C. Winter (chairman) and P. Dwyer-Hickey (vice-chairman) continued in office on the Members' Council; however, at the AGM in June, R. Shepherd stepped down after seven years support – we thank him for his contribution.

Education

At the Gem Tutorial Centre in Greville Street, the Gemmology and Gem Diamond courses were well subscribed, with students coming to London from many different countries. Development of the *Diamond Grading Manual* was brought to fruition with its publication in the autumn, and new Gem Diamond Diploma theory notes were produced for the start of the term. Development of the gemmology theory and practical course materials continued.

The frequency and variety of tutorials and practical workshops increased significantly in 2000. In response to a request from a major company in the jewellery trade, the Diamond Practical Certificate course was brought forward and will be fully operational in 2001. Overseas tutorials were held in the USA, the AGS Conclave and in Sweden, Norway and Ireland.

A new Allied Teaching Centre was brought closer to establishment in Thailand. Enhanced arrangements for translations have been put in place in Finland and Japan. Talks took place for education in China and the USA.

A total of 891 students entered the GAGTL examinations in 2000 which is fewer than in recent years. Although student quality is relatively good and pass rates were high, no single student was judged worthy of the Tully Medal. In diamond studies, however, the Bruton Medal was awarded to N. Rose of North Yorkshire. Dr L. Joyner of London was awarded the Anderson Bank prize for the best diploma paper in gemmology, and the Diploma Trade Prize was awarded to Mina Shin of Seoul, South Korea. Both the Anderson Medal and the Preliminary Trade Prize were awarded for the best paper in the preliminary gemmology examination to H. Dimmick of London. The Presentation of Awards again was held at Goldsmiths' Hall. J. Monnickendam chaired the ceremony and the president, Professor A.T. Collins, addressed the assembly and presented the prizes and diplomas.

The GAGTL has received sponsorship for two prizes during the year: the first from Christie's who have undertaken to support the prize for a student in the jewellery trade – to be called the Christie's Prize for Gemmology; N.W. Deeks has undertaken to support a new prize for best paper in the Gem Diamond Diploma examination. The Council thanks both sponsors for their generosity.

Two meetings of the Board of Examiners were held to assess results and consider developments,

and the Education Review Meeting – including examiners, tutors, lecturers and GAGTL staff – was held as usual in November.

The GAGTL continued to hold the Secretariat of the Federation for European Education in Gemmology (FEEG) and the 4th General Assembly was held in Leiden, Holland, in January. Four students sat the FEEG examinations in London – a small number compared to the total of 68 throughout Europe.

The Laboratory

Diamond grading work in the Laboratory continues to increase and the team was strengthened in May with the arrival of C. Furze. Coloured stone work also showed a small increase but pearl identification declined. S.J. Kennedy represented the GAGTL at the international laboratory meeting in Tucson, USA, in February and again at the CIBJO annual meeting held in Kobe, Japan. 'Notes from the Laboratory' were published in the April issue of *The Journal of Gemmology* and a further instalment was prepared for publication in the January 2001 issue. In addition to carrying out their normal duties, Laboratory staff are actively involved in teaching and supporting courses at the GAGTL.

The Millennium Trade Dinner

To celebrate the 75th anniversary of the founding of the Laboratory, the GAGTL joined with the London Diamond Bourse and Club (LDBC) to hold a dinner at Goldsmiths' Hall on 5 June. The guest of honour was G. Ralfe, Managing Director of De Beers globally, and in his speech he outlined the De Beers' approach to key issues in the diamond market. F. Hager, President of the LBDC, welcomed guests, the speaker was introduced by J. Monnickendam (chairman, Trade Liaison Committee) and a vote of thanks was given by T.M.J. Davidson (Council of Management).

Trade Fairs

The GAGTL exhibited at three major fairs during the year: in June at Las Vegas (USA), in September at Earl's Court, London, and in Hong Kong. Opportunities were taken at each venue to promote education, laboratory and membership services, new instruments from Gemmological Instruments Ltd, and to widen contacts in the trade.

Visits

In February a group visit to Tucson was organized for GAGTL members, and in April the sixth annual visit to Idar-Oberstein took place in which a coach load of 40 participants enjoyed a week exploring the wide range of gems in what is probably the coloured stone capital of Europe. Visits closer to home were organized for members to De Beers, Kingston University, Goldsmiths' Hall (Treasures of the 20th century) and Somerset House (Gilbert Collection).

Membership

Overall membership remained steady with recruitment just compensating for loss. Much recruitment comes through educational activities and it remains difficult to attract general jewellery trade members.

Activities in the Branches, however, are showing resurgence. The Midlands Branch held eight lectures, an AGM, an Annual Dinner and several 'playgroups' wherein gem activity is spontaneous and inspired by the group. The North West Branch ran five lectures and an AGM, and the Scottish Branch ran five lectures and a very successful Millennium Conference in Perth with overseas and UK speakers. Arrangements were also made to start a South West Branch with the first meeting in Bath. The effort in organizing all these events throughout the country by the Branch officers and their colleagues is much appreciated. In London, a varied programme of ten lectures ranging from British precious minerals to amber, and stone cutting to jewellery design, was held throughout the year.

The GAGTL Annual Conference was again held at the Barbican Centre, London, and attracted a record audience from many European countries, Hong Kong and the USA. The morning session was devoted to diamonds with talks by Professor A.A. Levinson and Dr P. Spear, and in the afternoon Dr J. Kinnaird spoke about Somali gems, H. Levy discussed aspects of disclosure of treatments in gems, and R. Fawcett described the current market in South Sea cultured pearls.

A special appeal was made at the end of 1999 to provide development funds, and Council would like to thank all those who gave generously. Many donors specified instruments or stones for teaching and these wishes have been fulfilled.

Publications

In *The Journal of Gemmology*, 20 papers were published with topics ranging from Russian synthetic sapphires to yellow tourmaline deposits in East Africa, and from nephrite jade to HPHT-treated diamonds. Abstracts totalled 186 and there

were 53 book reviews; a special thank you should go to M.J. O'Donoghue for his prolific contributions in these sections. Council would also like to thank the other Assistant Editor, P.G. Read, the thirteen Associate Editors and the Production Editor, M.A. Burland, for their invaluable support.

Gem and Jewellery News is published jointly with the Society of Jewellery Historians, and in 2000 contained a wide range of reviews and comment on new exhibitions both in the UK and overseas, on new books and on lectures, conferences and courses. We thank the editors for continuing a stimulating and widely-read newsletter and particularly H. Levy for pertinent and authoritative views on the trade.

Photographic competition

The 2000 Photographic competition was on the theme 'The light fantastic: optical effects in gems' and drew a record number of entries of a high standard. The judges are independent of GAGTL and they selected three prizewinners and several more images to grace the calendar for 2001 which is distributed free to members. The winner was D. Durham of Kingston-upon-Hull and he received his prize at the Reunion of Members in June. Council is most grateful to Harley UK, printers of *The Journal of Gemmology*, for their sponsorship of these prizes and for their contribution to Annual Conference expenses.

Finance

The financial result in 2000 for the GAGTL was a great improvement on the previous year; turnover increased in excess of £100,000 with a swing in profitability of almost £140,000. Gemmological Instruments Limited was marginally down on the previous year's turnover, but produced a slightly improved profit.

Gemmological Instruments Limited

Gemmological Instruments Limited is a wholly-owned subsidiary company of the GAGTL with a policy of providing good quality gemmological equipment and books to members and students. The Brewster Angle Meter, developed by P.G. Read and N.W. Deeks, is selling well. Development of gemmologically themed sets of cut stones and gem crystals continues and they sell well to students and Allied Teaching Centres.

The staff and supporters

Financial constraints meant that the year 2000 was not an easy one, but in spite of this the staff have given their full support to all the activities and events in working towards a more effective gemmological presence for the GAGTL. The Council of Management extend their sincere thanks to them for a most positive attitude and trust that it will lead to a buoyant and expanding organization.

The Council also thanks all the committee members, those who selflessly contribute to the education activities and those who supported the GAGTL through bequests, gifts and donations during the year.

MEMBERSHIP

The following have been elected to membership during April and May 2001:

Fellowship and Diamond Membership (FGA DGA)

Sutton, Daniela Nicola, Worcester. 1994
Wong Kwok Man, Shatin, Hong Kong. 2001

Fellowship (FGA)

Bartholomew, Jürgen C., Shoreham by Sea, West Sussex. 1986
Bastos, Ana Pestana, Porztela, Portugal. 2001
Chalmers, Marie L., Redditch, Worcestershire. 2001
Cheng Mei Yun, Singapore. 2001
Cheung Suk Yin, Hong Kong. 2001
Douvis, George, Athens, Greece. 2001
Farrer, Alison Mary, Nympsfield, Gloucestershire. 2001
Henn, Ingo, London. 2001
Hughes, Anthony, Harden, West Yorkshire. 1968
Jealous, Rosa Mary, London. 2001
Kanacher, Marly, Singapore. 2001
Lam Chi-Hing, Hong Kong. 2001
Long, Charlie, Richmond, Surrey. 2001
Loxton, Sam Capel, South Norwood, London. 2000
Quirino Cabrita, Miguel, Turnhout, Belgium. 2001
Rweyemamu, Edward J., London. 2001
Teramae, Ikumi, West Ealing, London. 2001
Tsoha, Theodora, Volos, Greece. 2001
Welsh, Fiona, Wynward Woods, Cleveland. 2001
Xanthoudaki, Aristea, Chania, Crete, Greece. 2001
Yedunath, R., Chennai, India. 2001

Diamond Membership (DGA)

Campbell, Paul., Erdington, Birmingham, West Midlands. 2001
Jones, Adrian Matthew, Harrow, Middlesex. 2000

Kwan, Susana, Central, Hong Kong. 2001
Mayne, Glen Robert, Reston, Virginia, U.S.A. 2001
Pala, Sunil, Coventry, West Midlands. 2001
Pattison, Noel, Eaglescliffe, Cleveland. 2001
Pelser, Stephan, Freiburg, Germany. 2001
Tsoi Karen Pui Pui, Kowloon, Hong Kong. 2001
Wong Lai Mun Phyllis, Hong Kong. 2001

Ordinary Membership

Bockett, David Allen, Rathgar, Dublin, Ireland
Cartmell, Alan Paul, London
Caswell, Amelie Margrit, Bristol, Avon
Chapman, Jackie, London
Davies, Dorian Wynne, Pontardawe, Swansea
Hearn, Caroline Sarah Jane, Aspley Guise, Buckinghamshire
Howitt, Peter J., Westbury, Wiltshire
Ingram, Simon M., Forestmill, Alloa, Scotland
Loyens, Jan, Ghent, Belgium
Muggenburg, Anna Julia, West London
Novak, Maria, London
Perry, David Edwin, Knowle, Solihull, West Milands
Turner, Jon, Walmley, Sutton Coldfield, West Midlands
Vanderhaeghen, Ivan F.D., Gent, Belgium

TRANSFERS

Ordinary Membership to Fellowship (FGA)
Blairs, Lawrence I.J., Llanrwst, Conwy, N. Wales
Eineljung, Lars E., Lannevaara, Sweden
Kulukundis, John C.A., London
Pace, Michael, Elk Grove, California, U.S.A.
Photiou, Mariana-M., San Francisco, California, U.S.A.
Plant, Monica, Knutsford, Cheshire
Squires, Caroline, Tring , Hertfordshire

Ordinary Membership to Diamond Membership (DGA)

Armati, Alexander, Badgemore, Henley on Thames, Oxfordshire
Basch, Elizaveta Z., Hyde Park, London
Chitondo, Martin C., Edmonton, London
Cruse, Toby, Eastbourne, East Sussex
Efejuku-Inegbenebho, Rosemary, London
Ko, Yuksan, Frindsbury, Rochester, Kent
Moltke, Nicholas, London
Ngan Hin Wah, Michael, Hong Kong.
Parmar, Sejal, Southgate, London
Ricard-Elbek, Rebecca, London
Susser, Jennifer L., London

Fellowship to Fellowship and Diamond Membership (FGA DGA)

Ayukawa, Yasuyo, Suginami-Ku, Tokyo, Japan
Bruce-Lockhart, Simon, London
Checkley, Emma, Smethwick, Warley, West Midlands
Cooke, Caroline M., St Margarets, Middlesex
Deljanin, Branko, New York, U.S.A.
Greslin-Michel, Valerie, London
Ito, Eiko, Kawasakishi, Kanagawa-ken, Japan
Kessler, Paul, Berden, Essex
Rimmer, Ray Ian, Bootle, Merseyside
Sherman, Gregory E., Sea Bright, New Jersey, U.S.A.
Thomas, Allyson R., Birmingham, West Midlands

Diamond Membership to Fellowship and Diamond Membership (FGA DGA)

Comar, Ankush, Bushey, Hertfordshire, Keating, Shelley, Surrey Quays, London

ADDENDUM

Following publication of 'Gem-quality clinohumite from Tajikistan and the Taymyr region, northern Siberia' by U. Henn, J. Hyrsl and C.C. Milisenda (*J. Gemm.*, 2001, 27 (6), pp 335-9), C.R. Cavey has drawn attention to the detailed gemmological features of five clinohumites, published in *'Notes from the Laboratory'* in *J. Gemm.*, 1984, **19**(2), pp 115-19. No locality was stated for these clinohumites other than USSR, but the optical constants are closer to those of the Pamir stones.

ERRATA

The colour of diamond and how it may be changed by Alan T. Collins. *J. Gemm.*, 2001, 27(6), pp 341-59 (see adhesive label enclosed)

'mm' should read 'µm' on page 342, col. 2, line 2; page 343, col. 1, line 15; page 347, col. 2, line 13

'B peak' should read 'B' peak' on page 345, col. 1, lines 18, 21 and 24

$(N–V)^0$ should read $(N–V)^-$ on page 347, section 1.7, line 9

$(N–V)^\circ$ should read $(N–V)^0$ on page 347, section 1.7, line 15; page 356, section 3.3.2, line 6

$(N–V–N)^\circ$ should read $(N–V–N)^0$ on page 348, col. 1, line 2

The box on page 350 relates to the first paragraph of section 2.2

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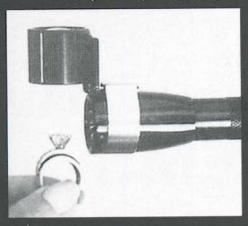

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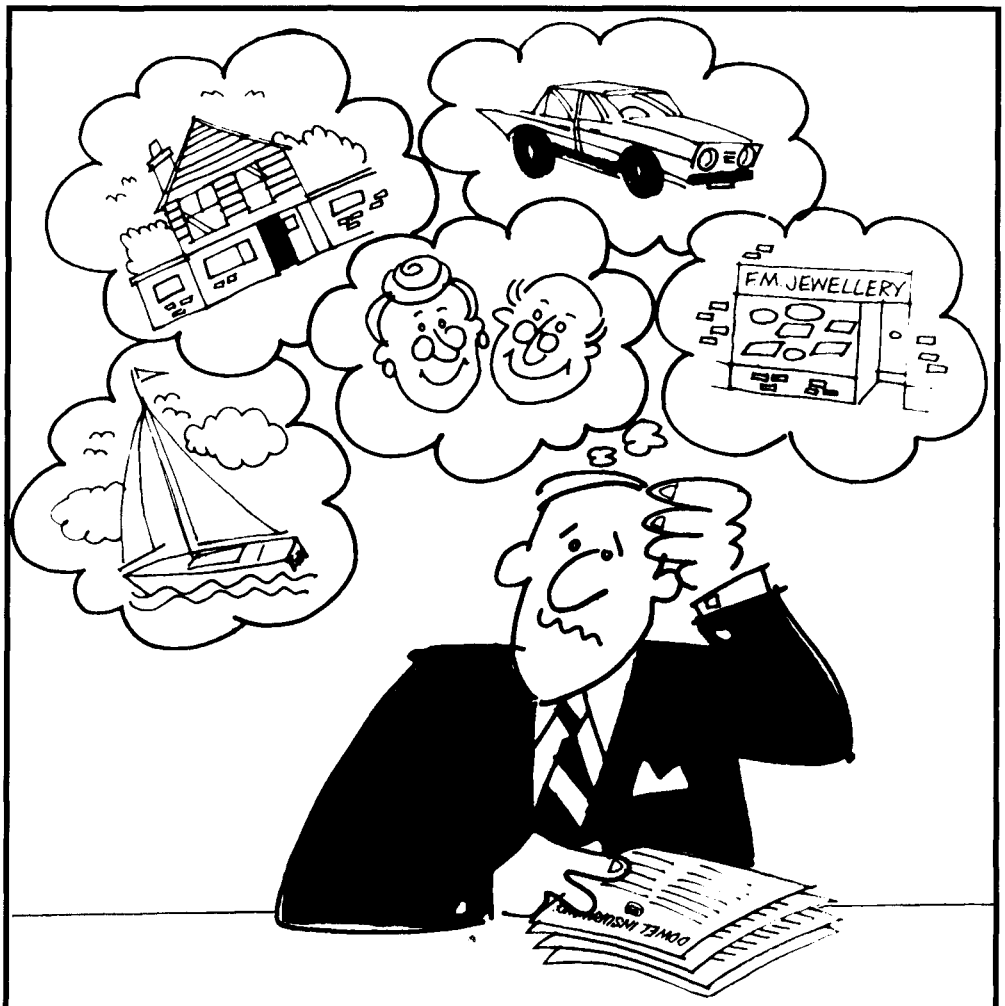

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Guide to the preparation of typescripts for publication in *The Journal of Gemmology*

The Editor is glad to consider original articles shedding new light on subjects of gemmological interest for publication in *The Journal*. Articles are not normally accepted which have already been published elsewhere in English, and an article is accepted only on the understanding that (1) full information as to any previous publication (whether in English or another language) has been given, (2) it is not under consideration for publication elsewhere and (3) it will not be published elsewhere without the consent of the Editor.

Typescripts Two copies of all papers should be submitted on A4 paper (or USA equivalent) to the Editor. Typescripts should be double spaced with margins of at least 25 mm. They should be set out in the manner of recent issues of *The Journal* and in conformity with the information set out below. Papers may be of any length, but long papers of more than 10 000 words (unless capable of division into parts or of exceptional importance) are unlikely to be acceptable, whereas a short paper of 400–500 words may achieve early publication.

The abstract, references, notes, captions and tables should be typed double spaced on separate sheets.

Title page The title should be as brief as is consistent with clear indication of the content of the paper. It should be followed by the names (with initials) of the authors and by their addresses.

Abstract A short abstract of 50-100 words is required.

Key Words Up to six key words indicating the subject matter of the article should be supplied.

Headings In all headings only the first letter and proper names are capitalized.

A **This is a first level heading**

First level headings are in bold and are centred on a separate line.

B *This is a second level heading*

Second level headings are in italics and are flush left on a separate line.

Illustrations Either transparencies or photographs of good quality can be submitted for both coloured and black-and-white illustrations. It is recommended that authors retain copies of all illustrations because of the risk of loss or damage either during the printing process or in transit.

Diagrams must be of a professional quality and prepared in dense black ink on a good quality surface. Original illustrations will not be returned unless specifically requested.

All illustrations (maps, diagrams and pictures) are numbered consecutively with Arabic numerals and labelled Figure 1, Figure 2, etc. All illustrations are referred to as 'Figures'.

Tables Must be typed double spaced, using few horizontal rules and no vertical rules. They are numbered consecutively with Roman numerals (Table IV, etc.). Titles should be concise, but as independently informative as possible. The approximate position of the Table in the text should be marked in the margin of the typescript.

Notes and References Authors may choose one of two systems:

(1) The Harvard system in which authors' names (no initials) and dates (and specific pages, only in the case of quotations) are given in the main body of the text, (e.g. Collins, 2001, 341). References are listed alphabetically at the end of the paper under the heading References.

(2) The system in which superscript numbers are inserted in the text (e.g. ... to which Collins refers.[3]) and referred to in numerical order at the end of the paper under the heading Notes. Informational notes must be restricted to the minimum; usually the material can be incorporated in the text. If absolutely necessary both systems may be used.

References in both systems should be set out as follows, with *double spacing* for all lines.

Papers Collins, A.T., 2001. The colour of diamond and how it may be changed. *J.Gemm.*, **27**(6), 341-59

Books Balfour, I., 2000. *Famous diamonds*. 4th edn. Christie's, London. p. 200

Abbreviations for titles of periodicals are those sanctioned by the *World List of scientific periodicals* 4th edn. The place of publication should always be given when books are referred to.

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Cover Picture

Rock crystal with hematite base and rutile needles. 63.50 ct. *Photograph by Marc de Regt* First Prize in Photographic Competition, see p.435

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The Journal of Gemmology

Volume 27 No. 8 October 2001

Cultured pearls

Cat's-eyes and star stones

Nephrite jade

Synthetic moissanite

The Gemmological Association and Gem Testing Laboratory of Great Britain

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Cultured pearls and colour-changed cultured pearls: Raman spectra

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ABSTRACT: The numbers of coloured pearls on the market have grown over the past few years and include dyed pearls, irradiated pearls and so-called 'lasered' pearls. In this study, different pearl samples have been experimentally dyed or irradiated. Their Raman spectra have been obtained and found to be useful in identifying the colour origin of pearls.

Keywords: colour origin, dyed pearl, irradiated pearl, natural coloured pearl, Raman spectrum

Introduction

Over the years, the range of coloured freshwater cultured pearls generally available has increased significantly and includes black, peacock green, dark purple and bronze varieties. Some are dyed, some are irradiated freshwater cultured pearls, and some are even labelled as 'lasered'. These are in addition to naturally coloured freshwater cultured pearls. Our research work has shown that the so-called 'lasered' freshwater cultured pearls are actually dyed[1]. Our studies have confirmed that colour features, colour distribution, internal characteristics, ultra-violet fluorescence, and chemical tests are useful in identifying some dyed or irradiated pearls (op. cit.). However, many treated cultured pearls do not show any distinctive features. Furthermore, when

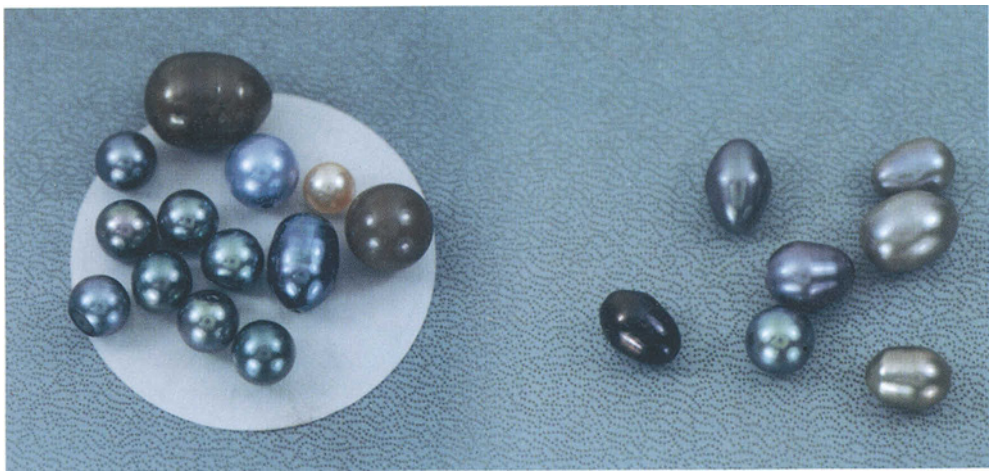

Figure 1: *Some of the pearl samples studied: dyed cultured pearls (left) and irradiated cultured pearls (right).*

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Table I: Chemical data for five pearls.

Sample	*Freshwater pearls*				*Tahiti pearl*
	white	*orange*	*purple*	*dyed dark purple*	
Element					
at.%	*F-1*	*F-2*	*F-3*	*F-4*	*F-6*
Ca	37.98	37.78	37.91	38.17	38.12
Na	0.26	0.26	0.28	0.27	0.75
ppm					
Mg	39	25	48	40	79
Si	840	790	1800	1300	1600
P	210	220	190	170	170
Al	9	8	13	24	14
K	56	52	69	238	238
Sr	394	332	402	373	900
Ba	410	550	390	330	190
Fe	5	36	11	21	49
Mn	286	323	643	241	1
Cu	1	1	1	1	2
Zn	4	3	4	4	5
Ni	1	1	2	<1	<1
Co	<1	<1	<1	<1	<1
Cr	<1	<1	<1	<1	<1

N.B.: Results obtained from Hitchi 180-70 atomic absorption spectrometer.

a pearl is mounted, identification of its colour origin is made more difficult.

For this study, some of the samples were obtained directly from the market and others were treated by dyeing or irradiation (*Figure 1*). Some of the cultured pearls were dyed black by immersion over a twelve day period in either 0.025N silver nitrate, or in silver nitrate diluted with ammonia (*Figure 2*). Some were treated by electron accelerator. Eighteen samples were tested using the Renishaw MK1-1000 laser Raman spectrometer at room temperature with the green line (514.5 nm) of an Ar-ion laser as excitation. In order to obtain comparable Raman spectra, the power and exposure times were kept constant for all the samples.

The chemical compositions of natural-coloured and dyed pearls were obtained by dissolving small samples of pearl and analysing the solutions with a Hitachi 180-70 atomic absorption spectrometer; the results are shown in *Table I*.

In this study, all the freshwater cultured pearls are non-nucleated and all the seawater cultured pearls are nucleated.

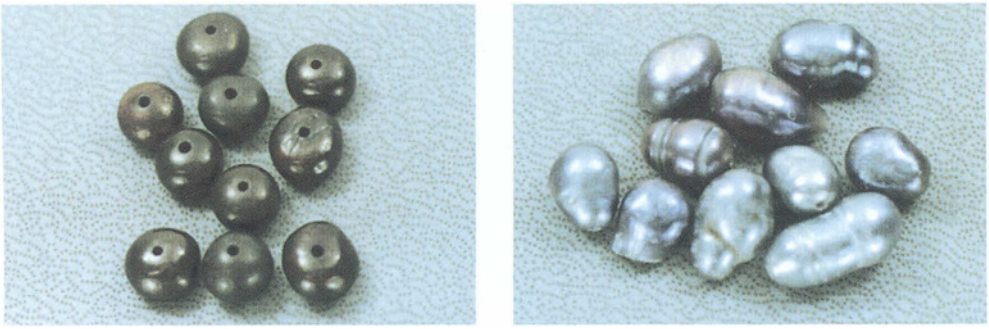

Figure 2: *Cultured pearls dyed with $AgNO_3$ only (left) and pearls dyed using $AgNO_3$ diluted by ammonia (right).*

Results and discussion

Naturally-coloured cultured pearls

Naturally-coloured freshwater cultured pearls are usually white, orange or purple as shown in *Figure 3*. It is easy to distinguish naturally-coloured freshwater cultured pearls from black Tahiti cultured pearls (whether nucleated or non-nucleated) on colour alone. However, the lighter grey Tahiti cultured pearls may prove to be more difficult to differentiate.

The black Tahiti cultured pearl samples show very strong fluorescence under the green laser, and in the Raman spectrum *(Figure 4)* there is a broad low peak at 1605 cm^{-1} beside the typical sharp peaks at 1083 and 702 cm^{-1} of aragonite. As can be seen from the chemical analysis (*Table I*, column F-6) the Tahiti pearl contains very small quantities of minor elements, which probably would have little influence on the colour. The peak at 1605 cm^{-1} is relatively low and comparatively wide, indicating that it may

Figure 3: *Naturally-coloured Chinese freshwater cultured pearls.*

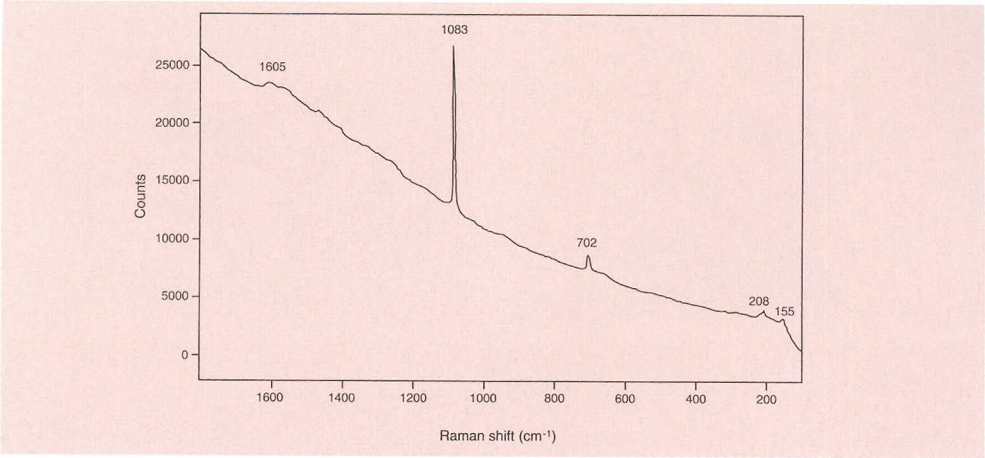

Figure 4: *Raman spectrum of Tahiti cultured pearl.*

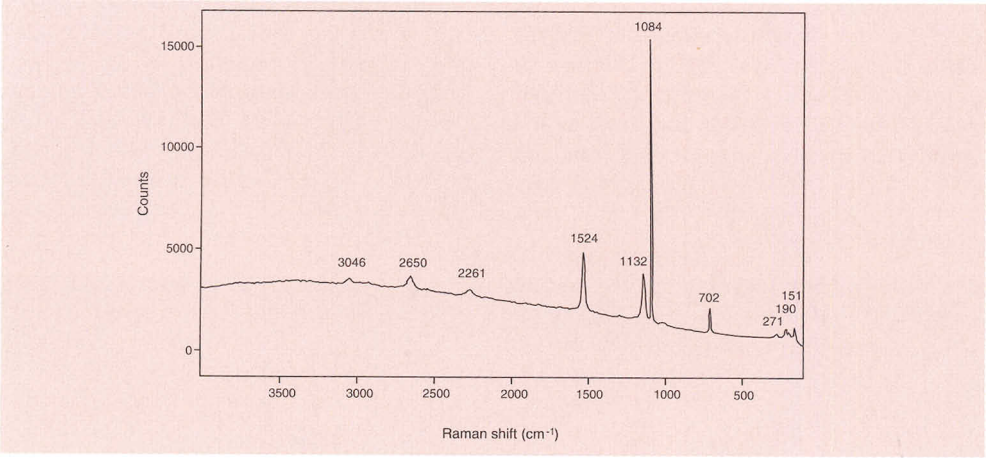

Figure 5: *Raman spectrum of naturally-coloured orange freshwater cultured pearl.*

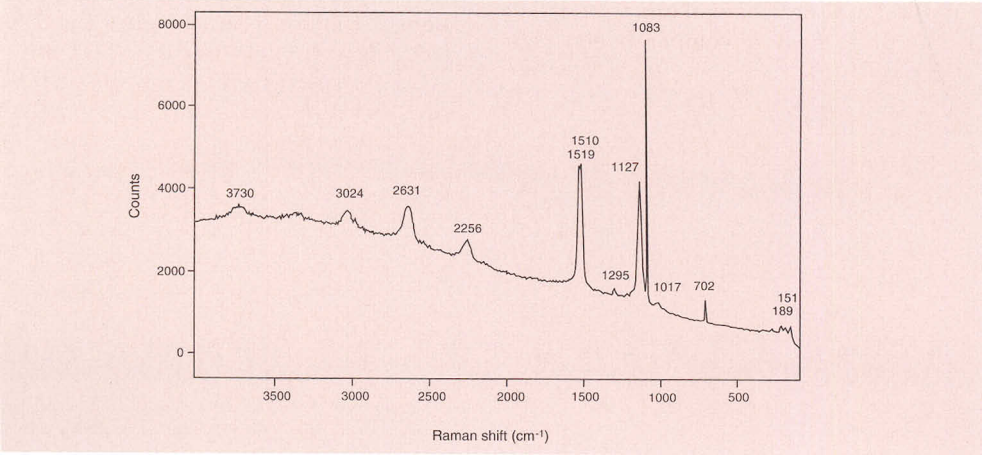

Figure 6: *Raman spectrum of naturally-coloured purple freshwater cultured pearl.*

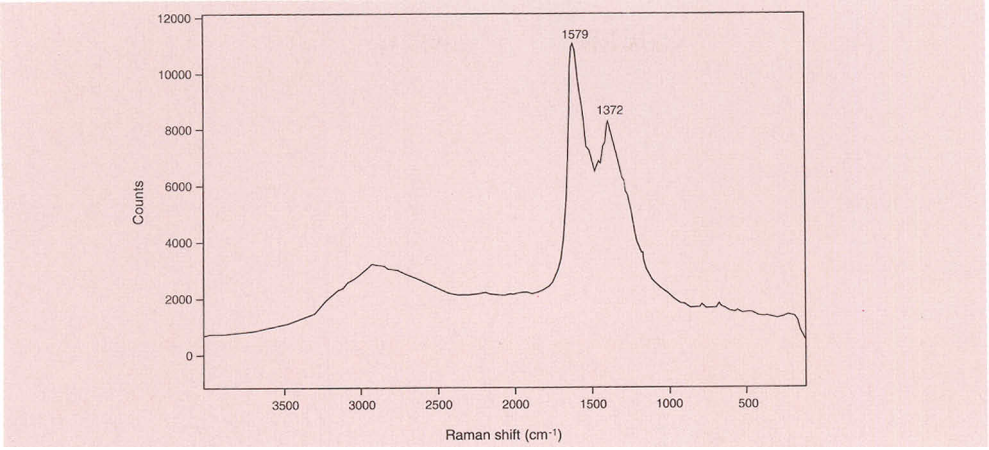

Figure 7: *Raman spectrum of freshwater cultured pearl dyed black by silver nitrate.*

be caused by a substance of low crystalline structure, which would include organic materials. It has been suggested by other researchers (e.g. see[2]) that pigments such as porphyrin seem to be the cause of colour in Tahiti cultured pearls.

For naturally-coloured orange freshwater cultured pearls, the Raman spectrum *(Figure 5)* is very different to that seen in Tahiti cultured pearls. In addition to the sharp and strong peaks of aragonite at 1084 and 702 cm^{-1}, there are sharp peaks at 1524 and 1132 cm^{-1} and also some weak peaks at 2650 and 2261 cm^{-1}. The sharp peaks indicate that the impurities are in the crystal structure. The chemical analyses for the orange freshwater cultured pearls reveal iron (*Table I*, F-2) being present in a comparatively high enough concentration to be a possible contributory cause of the orange colour. Further research is needed to establish if this is the cause of colour.

The naturally-coloured purple freshwater cultured pearls show a complicated Raman spectrum, with sharp peaks at 1127, 1510 and 1519 cm^{-1}, and broad peaks at 2256, 2631 and 3024 cm^{-1} (*Figure 6*). The chemical analyses reveal that contents of Mn, Si, Al and Fe are relatively high (*Table I*, F-3). Once again whether any of these minor elements contribute to the colour will require further research.

Dyed pearls

Many freshwater and saltwater cultured pearls are dyed various colours. The dyed black cultured pearls often show very good iridescence. The iridescent peacock green and purple colours associated with the highly valued natural-coloured black Tahiti cultured pearls can also be seen in the so-called 'lasered' freshwater cultured pearls. The colour distribution in both types is quite even. The 'lasered' freshwater cultured pearls are actually dyed – the process involves immersion for about one year in a new organic dye.

All the dyed cultured pearl samples show very different Raman spectra to the naturally-coloured cultured pearl samples. The three black cultured pearls dyed by silver nitrate methods produced differing colour saturations, but similar Raman spectra. The absorption peaks of aragonite are commonly present but, compared with Raman spectra of undyed cultured pearls, what was also found were peaks relating to carbon as seen in the likes of jet[3] (*Figure 7*). This may indicate that non-crystalline carbon is a degradation product of the organic matrix originally present in the pearl. It can be surmised that the black colour induced in pearls by dyeing with silver nitrate may be caused by the deposition within the layers of the pearl not only of silver oxide, but also of non-

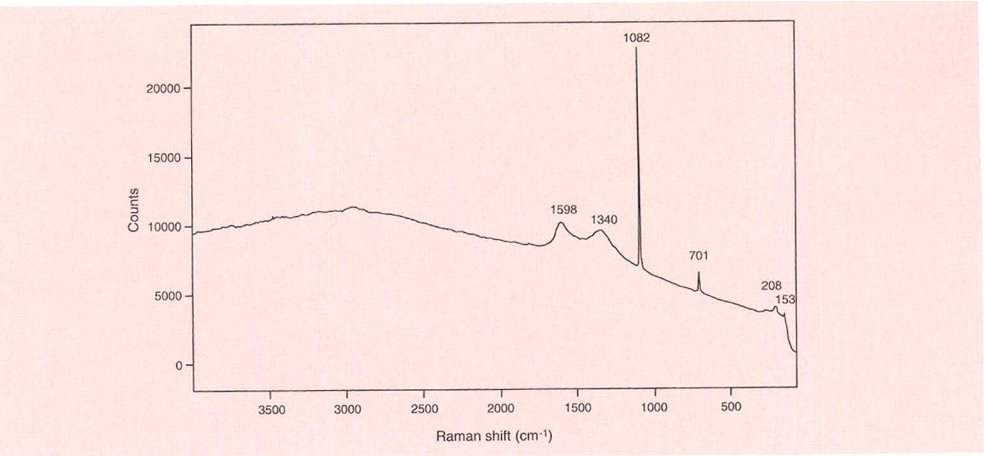

Figure 8: *Raman spectrum of freshwater cultured pearl dyed dark purple ('lasered').*

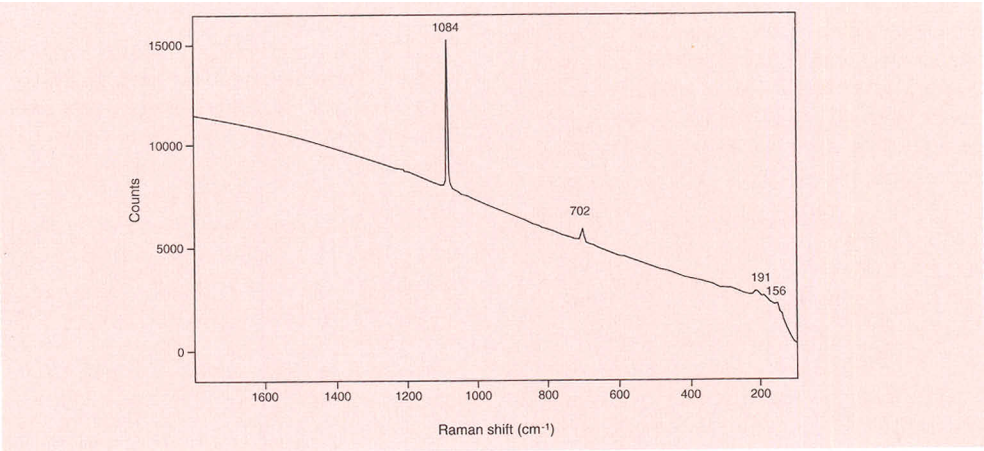

Figure 9: *Raman spectrum of a white freshwater cultured pearl turned black by irradiation.*

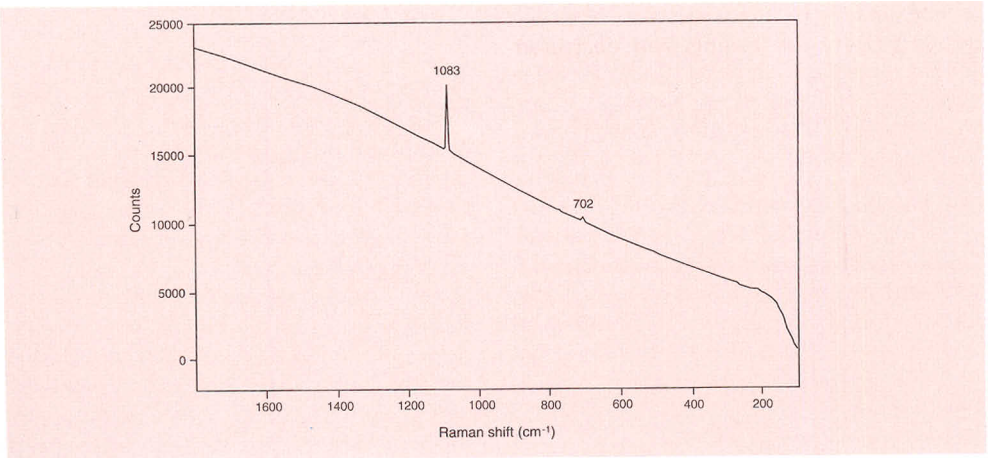

Figure 10: *Raman spectrum of an orange freshwater cultured pearl turned black by irradiation.*

crystalline carbon as a reduction product of organic substances. Two different 'lasered'-pearls that were also tested gave similar carbon peaks in their Raman spectra, one of which is shown in *Figure 8*. The two broad peaks at 1340 and 1598 cm^{-1} are caused by carotene which is a pigment commonly used to dye coral.

Irradiated pearls

Irradiation was carried out under contract; the authors used a TRI-CARB 2250CA Liquid Scintillation Analyzer to confirm that any residual radioactivity was at or close to background level.

It was found that irradiation effectively changed the colour of freshwater cultured pearls. The resulting irradiated colours were often a dark peacock green, dark purple or bronze (as shown in *Figure 1*). The colour produced by irradiation is considered to be stable because it does not fade after exposure to ultraviolet light for 240 hours. The Raman spectra of six pearls were obtained before and after irradiation. White freshwater cultured pearls may change to silver grey, bronze or dark purple, depending on the power of the irradiation. However, no change in Raman spectra occurs after irradiation (*Figure 9*).

On irradiation some orange and purple freshwater cultured pearls changed to dark peacock green, and others to dark purple or bronze. No additional peaks were present in the Raman spectra after irradiation; however the aragonite peak heights had decreased (*Figure 10*).

The fluorescence under the argon-ion laser of all the irradiated freshwater cultured pearls is far stronger than for those that were not irradiated; this and the Raman spectrum could imply that irradiation produces a new fluorescent centre, and destroys the organic substance in pearls.

Conclusions

Raman spectroscopy can be useful in distinguishing naturally-coloured from dyed cultured pearls.

Naturally-coloured Tahiti cultured pearls show a typical broad peak at 1605 cm^{-1}. Naturally-coloured orange or purple freshwater cultured pearls always show sharp peaks at around 1127 and 1524 cm^{-1} and broad peaks in the range between 2256 and 3730 cm^{-1}. Some dark-coloured cultured pearls dyed with organic substances show typical broad peaks at around 1340 and 1598 cm^{-1}. Silver nitrate-dyed cultured pearls may not show the typical peaks of aragonite, but only the broad peaks at 1571, 1594 and 2918 cm^{-1}. The Raman spectrum of an irradiated dark-coloured cultured pearl will only show the structural aragonite peaks. Therefore, apart from general fluorescence observations, the technique is not useful in detecting irradiation treatment.

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Some new unusual cat's-eyes and star stones

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ABSTRACT: Several unusual star and cat's-eye stones are described. Pale blue topaz from Brazil shows chatoyancy caused by flat hollow channels. Four-rayed star aquamarine from Brazil has one direction caused by hollow channels parallel to the *c*-axis and a second perpendicular direction is caused by planes of two-phase inclusions orientated perpendicular to the *c*-axis. A tourmaline-quartz combination from Brazil has an iridescent chatoyancy. Grey orthoclase moonstone from Sri Lanka has a unique combination of a cat's-eye and a six-rayed star, the cause of both is not clear. Sunstone from Russia has a strong cat's-eye caused by an albite-oligoclase orthoclase perthite. Four-rayed star tourmaline (bicolour elbaite) has one direction caused by hollow channels and the second by planes of 'trichites' perpendicular to the *c*-axis. Weak chatoyancy of rhodochrosite from Kazakhstan is caused by its agate-like structure. Four-rayed star rhodochrosite is caused by two directions of a perfect cleavage.

Keywords: aquamarine, chatoyancy, moonstone, rhodochrosite, stars, sunstone, topaz

Large topaz cat's-eye from Brazil

A very unusual example of a cat's-eye was purchased in Brazil by the author in summer 2000. It is an oval cabochon weighing 152.15 ct and measuring 32.94 x 24.91 x 20.25 mm. It was identified as topaz from a spot RI of about 1.62 and from a biaxial image through a conoscope between crossed polars. The stone is light blue with strong pleochroic colours – greenish-blue and almost colourless. It is inert under UV light. When illuminated with a spotlight, it shows a sharp cat's-eye and the line has bright iridescence colours (*Figure 1*).

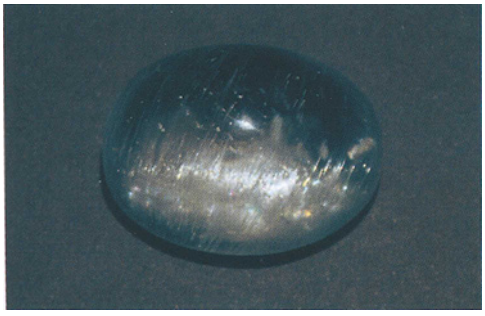

Figure 1: *Chatoyant pale blue topaz from Brazil weighing 152.15 ct. Photo by J. Hyršl.*

The cause of chatoyancy is easily visible – long colourless almost parallel needles in about one half of the volume of the stone. With a microscope, they can be identified as flat hollow channels (cf. Koivula, 1987). Channels in the studied stone contain no limonite colouring and therefore very strong iridescence colours can be seen in an oblique light. In places, three or four channels may radiate from an unidentified crystal (*Figure 2*).

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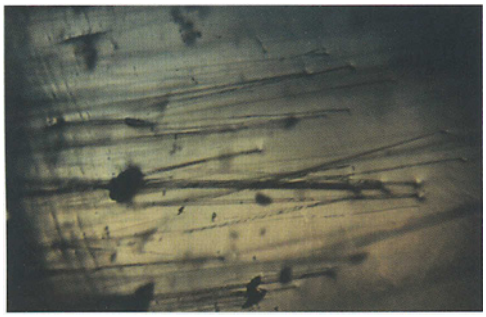

Figure 2: Iridescent flat hollow channels in a topaz cat's-eye grow in one direction from small unidentified crystals. Width 7 mm. Photo by J.Hyršl.

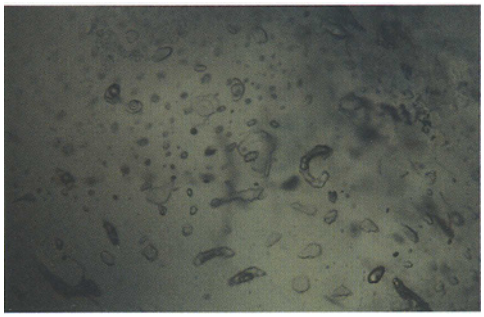

Figure 3: Six-rayed star aquamarine (27.32 ct), with a plane of inclusions perpendicular to the c-axis; some of them contain two immiscible liquids; transmitted light. Width 1.9 mm. Photo by J.Hyršl.

Hoover (1992) has described two topaz cat's-eyes, one blue of 7.98 ct from Brazil and another colourless of 12.20 ct from Sri Lanka, but this specimen is considerably larger.

Two star aquamarines from Brazil

Star beryls, including aquamarines, are very rare but have been known for a long time. They are cut perpendicularly to the *c*-axis and usually show a very weak six-rayed star. The star is caused by abundant parallel films of two-phase inclusions (*Figure 3*), which are typical for many beryls (Gübelin and Koivula, 1992; Henn and Bank, 1997), and several examples of aquamarine and yellow heliodor, and very rarely emerald, have been seen by the author in Brazil. The studied aquamarine with a six-rayed star weighs 27.32 ct, has RI (measured on a flat polished base) of 1.574 - 1.581 and a SG of 2.69. Much more surprising is a similar aquamarine of 30.91 ct, which shows a four-rayed star. Its colour and properties (RI = 1.571 - 1.579 and SG = 2.69) are very similar to the six-rayed star stone and it was cut from the same type of rough, but in a different direction. One ray direction is caused by thin films mentioned already in the six-rayed stone and this means that it is one ray of the star. The second ray direction is perpendicular to the first and is caused by hollow channels, which on their own cause chatoyancy in other aquamarines (*Figure 4*).

Quartz-tourmaline cat's-eye from Brazil

A strange stone weighing 27.58 ct was purchased in Brazil and is reliably reported to come from a pegmatite in Minas Gerais. The base is tourmaline with a transparent light green core with a dark green rim; the rim is nearly opaque and has a fibrous structure. The next phase of growth on the green tourmaline consisted of thin tourmalines and white hexagonal muscovite crystals, and then finally in the last phase all was covered by colourless rock crystal so this quartz-tourmaline stone is a sort of 'natural doublet'.

Figure 4: Four-rayed star aquamarine (30.91 ct) with hollow channels (left-right) and perpendicular small films of two-phase inclusions. Width 1.2 mm. Photo by J. Hyršl.

Figure 5: Tourmaline and quartz (27.58 ct) with an iridescent chatoyancy, a sort of 'natural doublet'. Photo by J.Hyršl.

Figure 6: Chatoyant tourmaline and quartz, side view. Photo by J. Hyršl.

After cutting into a cabochon, a sharp cat's-eye can be seen. Unusually, the eye shows bright iridescent colours which are caused by a very thin layer of air between the tourmaline and the quartz (*Figures 5 and 6*).

Moonstone with a star and cat's-eye combination from Sri Lanka

A stone described as a moonstone was purchased in Germany and probably comes from Sri Lanka, where a similar one was offered to the author in 1999. It is a brownish-grey cabochon weighing 31.42 ct with a spot RI of 1.53 and SG of 2.60. In LW UV it is inert, but in SW UV it shows red fluorescence. These properties indicate moonstone but could also be consistent with scapolite. Therefore a tiny amount of powder for X-ray diffraction analysis was scraped from the girdle; the results indicate orthoclase feldspar, which confirms its identity as a moonstone. It is slightly translucent and has a silvery schiller. In a strong light it shows an extremely unusual phenomenon – a combination of a cat's-eye and a six-rayed star, positioned beside each other (*Figure 7*). Under a microscope, thousands of tiny microcrystals can be seen. Some are black trigonal platy crystals, orientated in the same direction and could be hematite. Small black rods (ilmenite?) are parallel with the edges of the trigonal crystals. Very common are dark tiny anisotropic crystals of irregular shapes similar to snowflakes. Despite the variety, none of the inclusions is abundant enough to explain the unusual optical phenomena. The star is most probably caused by hematite (?) and ilmenite (?), and the chatoyancy could be caused by submicroscopic twin lamellae.

Sunstone cat's-eye from Russia

Chatoyant cabochons from the Vishnevye Mts. in the Urals, a famous pegmatite region about 100 km south of Ekaterinberg, were purchased in Tucson in 2001. The stones have a grey body colour but appear brown from the presence of abundant hexagonal hematite platelets up to about 1 mm in

Figure 7: Moonstone with a combination of six-rayed star and cat's-eye, 31.42 ct. Photo by J.Hyršl.

Figure 8: Two cabochons of sunstone cat's-eye (17.89 and 9.50 ct) from the Urals. Photo by J.Hyršl.

diameter (*Figure 8*). The hematite plates form three crystallographically oriented systems which are almost perpendicular to each other. The RI is 1.530 - 1.537 and the SG is 2.62. In LW UV the sunstone is inert, but in SW UV it shows dark red fluorescence. The cause of chatoyancy is visible with a loupe and is a 'fibrous' structure consisting of thin lamellae of intermixed feldspars (*Figure 9*). The angle between the lamellae and direction of the main cleavage is 19 degrees. According to RI and SG values, the feldspar could be orthoclase, perthite (albite – oligoclase – orthoclase intergrowths) or peristerite (albite – oligoclase intergrowths). X-ray diffraction of a powder scraping proved the stones to be perthite with more albite than orthoclase.

Star tourmaline

Although tourmaline cat's-eyes are quite common, stars are not and it was surprising to find a tourmaline - elbaite with a weak four-rayed star. The stone is an elongated cabochon weighing 11.05 ct, unfortunately without a given locality. One third is green and two thirds are pink. One direction of the star is caused by hollow channels (very common in tourmalines) and the second is caused by abundant 'trichites', most of which are oriented perpendicular to the *c*-axis.

Star and cat's-eye rhodochrosite

Cut rhodochrosite is quite common, but stones with optical phenomena have not been reported in the gemmological literature until now. Both the cat's-eye and the star rhodochrosite come from the former USSR. The cat's-eye weighs 2.27 ct, is pinkish-red, with RI (measured on a flat, polished base) of 1.570 and more than 1.80, and SG of 3.58. The weak chatoyancy is caused by a thin

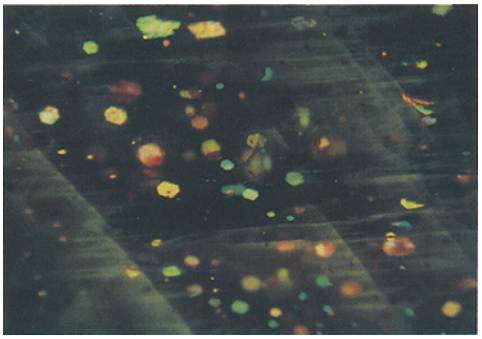

Figure 9: Hematite plates and 'fibres' in sunstone cat's-eye from the Urals. Width 4 mm. Photo by J.Hyršl.

layered 'agate-like' structure. The rough was found a few years ago in Kazakhstan and forms thick translucent crusts on matrix. Similar cat's-eyes probably could be cut from rhodochrosite from the famous Mina Capillitas in Argentina.

The star stone is a dark pinkish-red cabochon of 12.83 ct. Its RIs are 1.695 and more than 1.80 and its SG is 3.73. The well-centred four-rayed star has angles of about 74 and 106 degrees, caused by perfect cleavages in these two directions (*Figure 10*).

Figure 10: *Star rhodochrosite (12.83 ct) showing two directions of cleavage and two-phase inclusions. Width 4 mm. Photo by J.Hyršl.*

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Dr Simon Lawson, DTC Research Centre, Maidenhead

Practical screening of HPHT treated diamonds

Haywood Milton and Stephen Whittaker

Auctioneers and Pawnbrokers: our unpopular 'lot'?

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Nephrite jade from Jordanów Slaski, Poland

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ABSTRACT: Near Jordanów Slaski, deposits of nephrite jade are intimately associated with serpentinized ultrabasic igneous rocks of Precambrian age. The nephrite jade bodies vary from tabular to lenticular in shape and occur together with talc-chlorite schist and rodingite within the contact alteration zone between serpentinite and gabbro/diorite. Predominant colours of the nephrite jade are of green-yellow and green hue. Grain size ranges from fine- to medium-grained and rare accessory constituents of diopside, tremolite, epidote, chlorite, zoisite, pyrite, hematite and magnetite have been recorded. The nephrite jade formed as a result of sudden high-pressure effects due to movements along major faults following the emplacement of the ultramafic rocks around the Sowie Góry block. The deposits at Jordanów Slaski have provided the largest nephrite jade boulder ever recorded from Europe. The nephrite jade itself was fashioned by famous artisans through the ages and examples of hardstone carving works are preserved in museum collections around the world. Modern production is very small in scale but the development of local lapidary facilities is currently under active consideration.

Keywords: Jordanów Slaski, nephrite jade, Poland

Introduction

The nephrite jade deposits at Jordanów Slaski rank among the largest and most significant in Europe and have been worked for over one hundred years for the manufacture of costume jewellery, hardstone carvings and ornamental pieces. Following the break-up of the former Soviet Union and the easing of international travel restrictions, Polish tourism has developed rapidly and growth trends should be strongly upwards. This increasing tourism together with modern advances in lapidary equipment have fostered a renewed interest in Polish gemstone localities in general and the nephrite jade deposits at Jordanów Slaski in particular.

The nephrite jade deposits are located 31.5 km south of the city of Wroclaw in the province of Dolny Slask (Lower Silesia), southwest Poland (*Figure 1*). From the village of Jordanów Slaski access to the deposits is westwards for 2.1 km towards Sobotka (*Figure 2*).

This paper provides a review and a description of the geological setting of the nephrite jade deposits at Jordanów Slaski. It also directs attention to the exploration potential that exists in the surrounding region.

Historical background

Archaeologically, nephrite jade production in the Jordanów Slaski district appears to have commenced in Neolithic times. Indeed, various types of artefacts made of material attributed to this locality have been found scattered throughout central and

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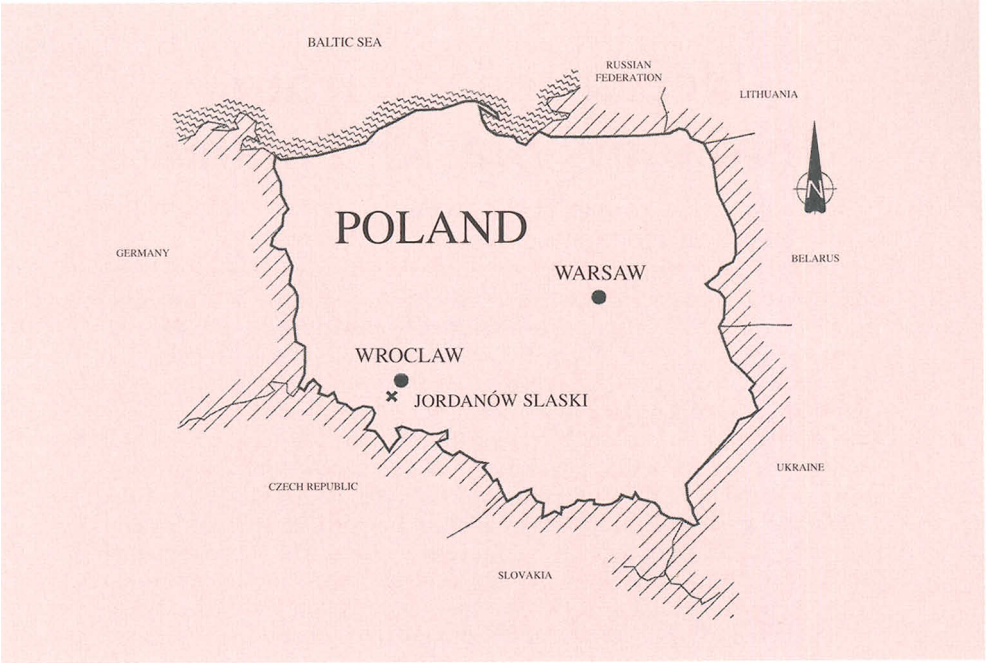

Figure 1: *Orientation map.*

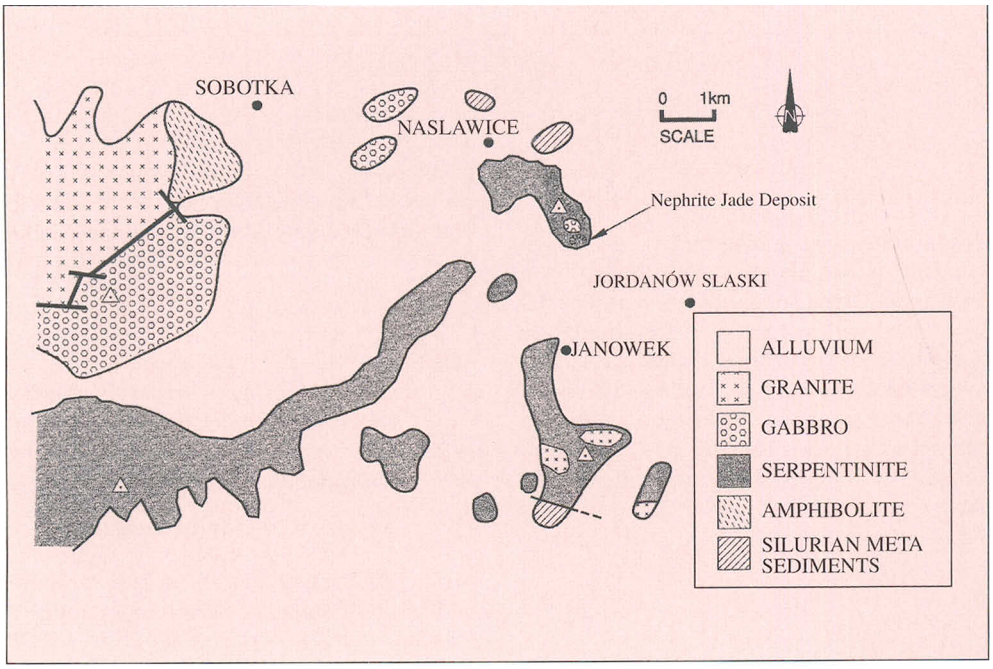

Figure 2: *Sketch map of the regional geology of the Jordanów Slaski district.*

western Europe indicating that it was widely traded and highly prized by prehistoric man.

According to Skelton (1991) nephrite jade from south-western Poland was probably an important source of raw material for the Prague workshops of the Mannersit carvers during the 16th and 17th centuries. Also Visser (1946) contends that brief references to nephrite jade in the Jordanów Slaski district may be discerned in various 18th-century manuscripts.

However, modern discovery of the deposits at the Jordanów Slaski site is generally attributed to Hermann Traube of Wroclaw in 1884. The announcement of his findings created considerable public interest at the time and the deposits were widely heralded as the first *in situ* occurrences of nephrite jade in Europe.

Shortly after discovery, mining operations commenced and a substantial quantity of nephrite jade was produced (Traube, 1885). Subsequently mining operations were disrupted throughout the First World War but the deposits were reopened for exploitation in 1932 by Jordansmuhler Nephrit-Gesellschaft mbH and continuous production was sustained for several years (Klingner, 1943). Records are incomplete but based on the fragmentary evidence available, total production of nephrite jade from the site is estimated at approximately 1200 t.

Ruff (1963) reports that the deposits were again being worked in 1958 but production appears to have been small in scale. As far as can be determined, operations virtually ceased by 1960 although some desultory activity persists to the present day. Part of the site is currently occupied by various items of obsolete plant used for processing industrial minerals (limestone, pigment, etc.) and these tend to obstruct extractive operations.

Moreover, prior to the break-up of the former USSR, the East Sayan Mountains of Siberia were promoted as the principle nephrite-producing region for the Soviet Bloc countries and this appears to have influenced and, indeed, limited the potential for development of the deposits in Jordanów Slaski (*cf.* Prokhor, 1991).

Geological setting

The nephrite jade deposits are situated in the foreland foothills along the eastern flank of the Sudete Mountains of the north-east Bohemian Massif. They occur on the south-eastern slopes of an outlying ridge that stretches north-westwards from Jordanów Slaski. To the north-east, the site overlooks the floodplain of the River Odra.

Geologically, the crystalline basement (*Figure 2*) comprises Precambrian gneiss and amphibolite intruded by gabbro, granite and ultrabasic igneous rocks. The basement rocks form the Sowie Góry block, a major structural high and the oldest tectonic element in the region. These Precambrian rocks are unconformably overlain by metasedimentary strata of Silurian age.

Towards the end of the Precambrian, ultrabasic rocks were emplaced along deep fractures around the peripheral zone of the Sowie Góry block. They consist of serpentinized peridotite, pyroxenite and dunite, that vary from grey-green, massive serpentinites to dark green, foliated serpentinite. These ultrabasic igneous rocks underlie an area of almost 100 km^2 in the region and host economically important mineral deposits of primary chromite and nickel as well as secondary magnesite and chrysoprase (Osika, 1986).

The hilly ground around the nephrite jade deposits consists predominantly of massive serpentinite but diorite and gabbro crop out spasmodically along the southern-most lower slopes at the site. Nephrite jade occurs exclusively within the contact alteration zone along the faulted margins between serpentinite and the dioritic and gabbroic rocks.

Interestingly, a minor occurrence of nephrite jade has also been reported in a similar geological environment near Dzierzoniów, some 21 km to the south-west of Jordanów Slaski (Traube, 1887; Beutell and Heinze, 1914).

Figure 3: *View looking north of the quarry workings. Photo by Douglas Nichol.*

The host contact alteration zone is poorly exposed throughout the region. Accordingly, much of the serpentinite belt remains prospective for additional deposits of nephrite jade and further geological exploration appears warranted.

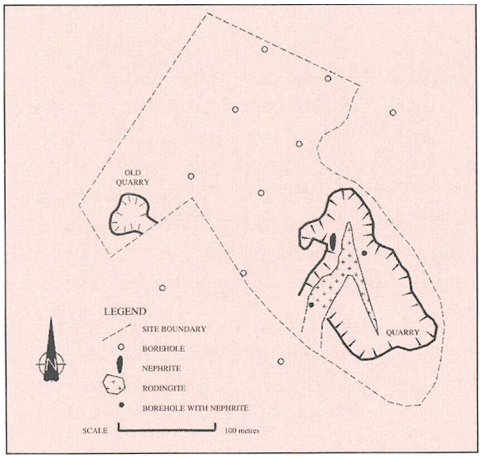

Figure 4: *Site plan (after Kozlowski, 1990).*

The deposits

The nephrite jade deposits at Jordanów Slaski occur within an old serpentinite quarry originally established for the extraction of rock aggregate for road construction purposes (*Figure 3*). The quarry area measures approximately 200 m long and 100 m wide by up to 10 m deep and the nephrite jade workings occupy the north-western corner of the principal quarry (*Figure 4*).

The bedrock is poorly exposed. However, the contact alteration zone between serpentinite and diorite crops out on the floor of the quarry. It is irregular in form, dips steeply, ranges up to 25 m wide and contains massive and sheared serpentinite, talc-chlorite schist, nephrite jade and rodingite (Gawel, 1957). Rock relations are illustrated in *Figure 5*.

The nephrite jade bodies are typically small, lensoid to tabular in shape and, although irregular in structure, generally appear to be concordant with neighbouring

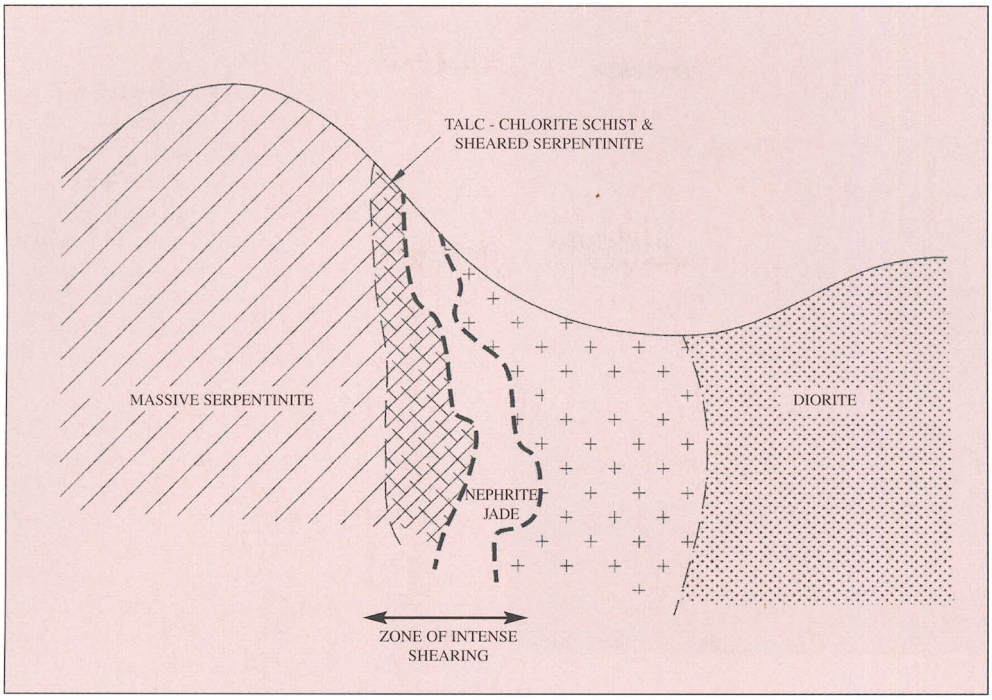

Figure 5: *Cross section illustrating rock relations at the Jordanów Slaski quarry (not to scale).*

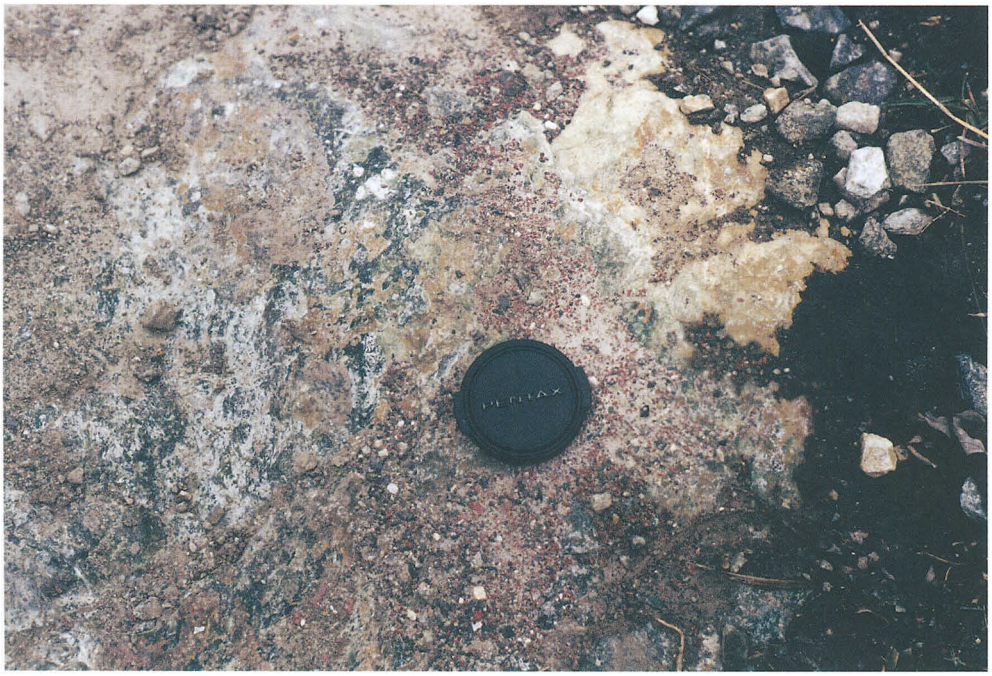

Figure 6: *Outcrop of nephrite jade exposed on the quarry floor at Jordanów Slaski. Photo by Douglas Nichol.*

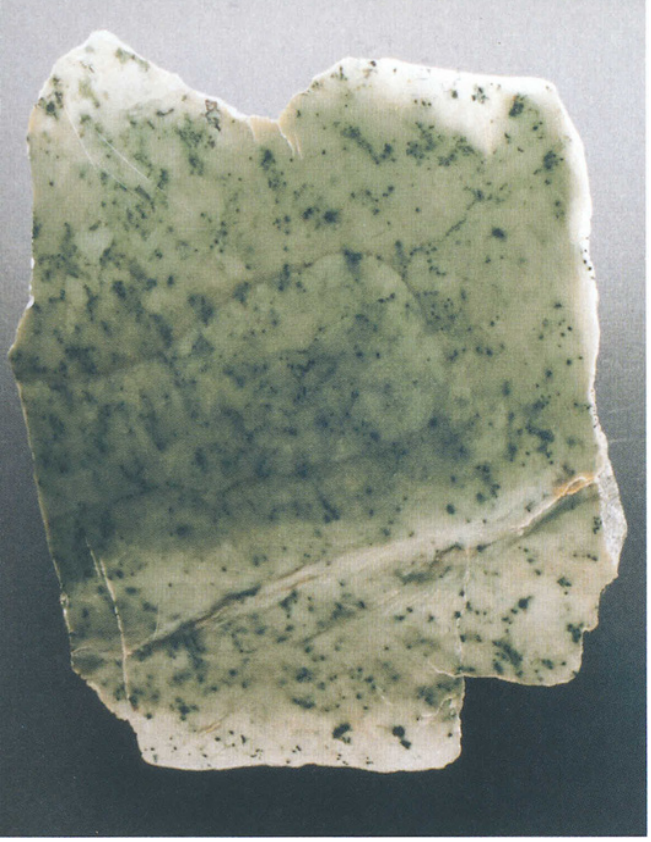

Figure 7: A typical specimen of nephrite jade from Jordanów Slaski. Size approximately 200 mm high. It appears on public display at the Muzeum Mineralogicznego, Uniwersytetu Wroclawskiego, Wroclaw. (Photo by Antoni Stryjewski).

rock formations (*Figure 6*). Size ranges up to 5 m long by 0.4 m wide though most bodies are much smaller. The larger pods give rise to rounded nodules or boulders with a distinctive white surface weathering rind. Sinuous veinlets of nephrite jade ranging from 2 to 150 mm wide seem to penetrate the adjoining serpentinite mass. However, practically all of the usable nephrite jade is obtained from dense elongate patches within the larger pods.

Using the Munsell notation (Rock-Colour Chart Committee, 1980), the nephrite jade ranges from light greenish-grey (5G 8/1) and moderate yellowish-green (10GY 6/4) through greyish-green (10GY 5/2 and 10G 4/2) and dark yellowish-green (10GY 4/4) to dusky green (5G 3/2), dusky yellowish-green (10GY 4/2) and greenish-black (5GY 2/1) but is predominantly dark yellowish-green (10GY 4/4).

Textures range from fine-grained, microfibrous and interfelted to coarse-grained. Certain specimens are veined, mottled or banded, or contain specks, streaks and flecks of minor mineral constituents (*Figure 7*). Accessory minerals include diopside, tremolite, epidote, chlorite, zoisite, pyrite, hematite and magnetite. Typically, specific gravity approaches 2.95 and hardness is about 6.5. Previous chemical analyses are listed in *Table I*.

The talc-chlorite schist and foliated serpentinite are extremely friable and similar in appearance with dark green colour and well-developed foliation. They occur in discontinuous lenses. The rodingite is a distinctive hard leucocratic rock with a highly variable composition and is generally believed to be a metasomatic or metamorphic product developed during serpentinization of the parental ultramafic rock. According to Sachs (1902) and Kolesnik (1970), the rodingite at Jordanów Slaski formed by metasomatic alteration of gabbro and its common mineral constituents include albite, hornblende, garnet, epidote, zoisite, quartz, prehnite and biotite.

A programme of exploration drilling at the quarry has indicated continuity of nephrite jade mineralization beneath the quarry floor (Kozlowski, 1990). However, understanding of the extent of recoverable reserves of nephrite jade at the site remains poor.

Nephrite formation

The nephrite jade lodes at Jordanów Slaski appear intimately associated with serpentinized ultrabasic igneous rocks. Based on the field relationship between the nephrite bodies and the serpentinite and the association of rodingites within the alteration zone, the deposits are classed as orthonephrite in type (Nichol, 2000). The nephrite jade appears to have formed as a reaction product by late stage dynamothermal meta-

Sample No. Analysis (Wt.%)	1	2	3	4	5	6	7	8
SiO_2	57.26	56.93	53.21	57.58	56.39	52.58	56.74	54.44
TiO_2	-	-	-	0.10	-	0.12	-	-
Al_2O_3	1.40	1.01	1.16	1.35	1.63	6.74	0.93	5.92
Fe_2O_3	4.22	4.99	2.40	4.17	5.42	4.48	4.39	6.28
Cr_2O_3	-	-	-	-	-	-	0.13	-
MnO	0.74	0.71	0.80	0.15	0.26	-	0.06	0.22
NiO					0.13	-	0.09	-
MgO	19.96	19.21	20.81	20.65	24.63	21.02	21.75	16.79
CaO	13.19	14.54	14.08	13.10	7.92	9.84	13.09	7.51
Na_2O	-	-	-	0.12	-	0.54	0.22	4.64
K_2O	-	-	-	-	-	0.28	-	0.28
Loss on ignition	2.53	1.93	1.81	2.61	4.07	3.47	2.42	4.12
Total	99.30	99.32	94.27	99.83	100.45	99.07	99.82	100.20

Sample Nos 1, 2 and 3 after Traube (1885)
Sample No. 4 after Heflik (1968)
Sample Nos 5, 6, 7 and 8 after Anonymous (1906)

Figure 8: *Bowl fashioned from nephrite jade. It appears on public display at the Muzeum Mineralogicznego, Uniwersystetu Wroclawskiego, Wroclaw. Photo by Douglas Nichol.*

morphism related to the movement of serpentinites against country rocks with higher silica contents. The following chemical reaction applies:-

$$5Mg_3[Si_2O_5](OH)_4 + 14SiO_2 + 6\,CaO = 3Ca_2Mg_5Si_8O_{22}(OH)_2 + 7H_2O$$

serpentine silica tremolite

Tectonic modification of tremolite by dynamic metamorphism recrystallized coarse-grained tremolite to the fine-grained, interfelted microstructure of nephrite. This tectonic modification is essentially mechanical and involves a sudden release in confining pressures within tremolite bodies that are saturated with water under high partial pressure. According to Dorling and Zussman (1985), the finest grain sizes are attained at the lowest possible recrystallization temperature for the shortest possible time for full crystallization. As such, the process of recrystallization was probably rapid.

Mining and processing

Extraction of nephrite jade from the quarry at Jordanów Slaski was essentially carried out in conjunction with serpentinite mining. Once the individual nephrite jade bodies were exposed they were selectively mined using hand-held tools to prize the crude blocks from the working face and to knap them into various manageable sizes.

The nephrite jade from Jordanów Slaski varies from high quality, monomineralic material suitable for gem cutting to low quality stone with inclusions suitable for ornamental work and hard-stone carving. The proportion of high quality material appears generally less then 10 per cent.

Historically, most of the crude nephrite jade blocks mined at Jordanów Slaski were exported to Idar-Oberstein, the German centre for trading hardstone and precious stones. Here, the nephrite jade was fashioned mainly as ornamental bowls, rings, beads, bracelets and carvings (*Figure 8*). As far as can be determined, finished products were mainly sold under controlled conditions and generally restricted to the German marketplace (Petar, 1936).

At the present time, the factory within the village at Jordanów Slaski that cuts and polishes stone, deals almost exclusively with serpentinite. Only roughly hewn specimens of nephrite jade are extracted to supply the local souvenir trade. Establishment of a modern lapidary factory to process the local nephrite jade is under active consideration and would complement the recent developments in tourism.

Collections

The most important suite of specimens of nephrite jade from Jordanów Slaski is housed in the American Museum of Natural History (AMNH), New York, USA. The suite comprises part of the Heber R. Bishop collection of jade and each item is described in the elaborate catalogue of the collection (Anonymous, 1906). Undoubtedly, the most famous piece is a remarkable block extracted from the quarry at Jordanów Slaski in 1899 and polished on one side by Tiffany & Co. (Sofianides and Harlow, 1990, p. 138). It originally weighed some 2.14 t and is claimed to be the largest single specimen of nephrite jade ever recorded from Europe (Kunz, 1903; 1904; 1907). The block appears on permanent exhibition in the Guggenheim Hall of Minerals at AMNH (*Figure 9*).

Items fashioned from Jordanów Slaski nephrite jade are also found in numerous museum collections throughout the world. Interestingly, nephrite jade was used extensively by Fabergé for hardstone pieces and although many of its chief works incorporate material of certain Russian origin, nephrite jades of other provenances such as Jordanów Slaski were employed for small hardstone carvings of animal

Figure 9: The largest boulder of nephrite jade ever recorded from Europe weighs 2.14 tonnes and was collected in 1899 at the Jordanów Slaski quarry. It was donated to the Metropolitan Museum of Art, New York, and now appears on public display at the American Museum of Natural History, New York. Photo Neg No 5232, Courtesy American Museum of Natural History Library.

figures and ornamental bowls that were produced at Idar-Oberstein (*e.g.* Habsburg-Lothringen and Solodkoff, 1979).

Conclusions

At Jordanów Slaski in Poland, nephrite jade has formed within the contact alteration zone between serpentinite and diorite. As well as nephrite jade, the alteration zone also contains talc-chlorite schist, sheared serpentinite and leucocratic rodingite.

The material is categorized as an ortho-nephrite jade (Nichol, 2000) and occurs in tabular to lensoid orebodies. Colour is predominantly dark yellowish-green (10GY 4/4) and texture ranges from fine- to medium-grained.

Mainly in Idar-Oberstein, an extensive range of ornaments, hardstone carvings and jewellery items has been produced from Jordanów Slaski nephrite jade using conventional lapidary equipment. In addition, museums throughout the world contain representative collections of both the raw nephrite jade and intricately carved specimens of the material from Poland. A programme of further exploration may yield new discoveries of nephrite jade in the Jordanów Slaski district.

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Synthetic moissanite from Russia

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ABSTRACT: Five faceted yellow, green, bluish-green and bluish-brown synthetic moissanites of Russian production are described. Polytypism is characterized by Raman spectroscopy. Gemmological properties as well as chemical and spectroscopic properties in the UV-visible range are given. The samples were found to be of 6H- as well as 4H-SiC single crystals, and the variable coloration is caused by various amounts of nitrogen in the lattice of the synthetic moissanites. The criteria already described for the distinction of colourless American synthetic moissanites from diamonds in general also apply for a microscope characterization of Russian samples, especially to distinguish them from coloured diamonds.

Keywords: colour origin, diamond imitation, polytype, Russia, spectroscopy, synthetic moissanite

Introduction

Silicon carbide – moissanite – has been used since the last decades of the 19th century for technical purposes (Knippenberg, 1963). The growth of large crystals of synthetic moissanite by a sublimation technique from the vapour phase was first described by Lely (1955), but the crystals grown by this so-called Lely technique consist of a mixture of simultaneously grown hexagonal (H), rhombohedral (R) and cubic (C) polytypes (Knippenberg, 1963; Kawamura, 1965; Verma and Krishna, 1966). This disadvantage for the technical usage of the crystals is overcome by the use of oriented seeds of selected polytype (Tairov and Tsvetkov, 1978; 1981). By seeded growth of silicon carbide by sublimation from the vapour phase, it is possible to grow large single crystals consisting of only one silicon carbide polytype, e.g. 6H-SiC, 4H-SiC. This method is described in the literature as the modified Lely technique (see, e.g., Yoo *et al.*, 1991; Tairov, 1996; Tsvetkov *et al.*, 1996; Maltsev *et al.*, 1996; Ohsato *et al.*, 1999; Müller *et al.*, 2000; Yakimova *et al.*, 2000).

The modified Lely technique is also applied for the production of colourless synthetic moissanite crystals used as diamond substitutes (Davis *et al.*, 1989, 1995; Nassau *et al.*, 1997; Nassau, 1999). The colourless synthetic moissanites grown in the United States for jewellery purposes by Cree Inc., Durham, North Carolina and distributed by Charles & Colvard (formally C3 Inc.), Morrisville, North Carolina, consist of single crystals of one of the known hexagonal silicon carbide polytypes, namely 6H-SiC (Nassau *et al.*, 1997; Nassau, 1999), but the growth of other polytypes and/or differently coloured moissanites for gem purposes is also possible (Hunter and Verbiest, 1998a; 1998b; Schmetzer, 2000). By the addition of pairs of charge-compensating trace elements such as

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nitrogen and aluminium, completely colourless crystals can be produced (Carter *et al.*, 1998). Most recently, diamond-coated moissanite was described (Nassau *et al.*, 1999; Hammer and Schmetzer, 2000) and aluminium nitride is also mentioned as a possible new diamond substitute (Hunter, 2000).

Due to its gemmological properties, synthetic moissanite, 6H-SiC, is an ideal diamond imitation, with refractive indices of 2.648 and 2.691 and a hardness of 9 ¼ on the Mohs scale (Nassau *et al.*, 1997). Although strongly anisotropic, the thermal conductivities of synthetic moissanites are so close to those of diamonds that the commonly applied thermal probes react to synthetic moissanites as if they were diamonds (Chalain and Krzemnicki, 1999).

Since the introduction of moissanite as a diamond substitute in 1997, the material has been distributed widely and has appeared worldwide in gemmological laboratories as a diamond imitation, in some instances, even set in antique jewellery!

Synthetic moissanites for gem purposes are also produced in small quantities in St.Petersburg, Russia (Balitsky, 2000a; 2000b), and already the first samples of this material have been seen in the gem trade (Longère, 2000; McClure and Moses, 2000). Recently, faceted synthetic moissanites of Russian production weighing more than 100 ct have been submitted to gemmological laboratories as natural diamonds (Lasnier, 2001). By courtesy of Mrs B. Schaeffer, a gemmologist from Detmold, Germany, the authors were able to study five samples of the Russian production. Gemmological, microscopic, chemical and spectroscopic properties of these five faceted gemstones are presented in this paper.

Materials and methods

The research material consisted of five brilliant-cut synthetic moissanites, which range in colour from yellow, green (two), bluish-green to bluish-brown (*Table I, Figure 1*). The stones weigh between 0.381 and 0.601 ct. According to the supplier all samples were grown in St. Petersburg using, at least basically, the method described by Tairov and Tsvetkov (1978, 1981).

***Table I**: Gemmological properties of Russian synthetic moissanite.*

Sample No.	*Weight (ct)*	*Polytype*	*Colour*	*SG*	*Relative reflectivity**	*Orientation of tube inclusionswith respect to the table facet*	*Pleochroism***
1	0.442	6H	yellow	3.250	118	about 45°	extremely weak
2	0.562	6H	green	3.211	122	parallel	weak: yellowish green/green
3	0.601	6H	green	3.231	121	parallel	weak: yellowish green/green
4	0.381	6H	bluish-green	3.201	120	no tubes observed	moderate: yellowish green/blue-green
5	0.542	4H	bluish-brown	3.207	120	about 5°	distinct: greenish blue/brown

* based on 100 for diamond
** as seen with a dichroscope

For the determination of moissanite polytypes Raman spectra were recorded in the 100-1800 cm^{-1} range using a Renishaw Raman System 1000 spectrometer equipped with a CCD Peltier detector and an argon ion laser (514.5 nm) with a power of 25 mW.

***Figure 1**: Faceted synthetic moissanites grown in St. Petersburg, Russia, by sublimation from the vapour phase. The samples range from 0.38 to 0.60 ct in weight and measure from 4.60 to 5.70 mm in diameter. Photo: © L.Kiefert, SSEF.*

We measured the relative reflectivity of the samples with a Presidio Duotester, where the value 100 was calibrated as the reflectivity of diamond. Specific gravity was determined hydrostatically. Internal features of all samples were examined using a standard gemmological microscope in conjunction with brightfield, darkfield, and oblique fibre-optic illumination. Photomicrographs were taken with a Wild M8/MPS55 stereozoom microscope. Different types of inclusions were examined by micro Raman spectroscopy using the facility at the SSEF Swiss Gemmological Institute.

Qualitative chemical analyses were performed by energy dispersive X-ray fluorescence (EDXRF) using a Tracor Spectrace 5000 instrument. For the examination of colour and colour causes we recorded UV-visible range spectra of all samples using a Varian Cary 500 spectrophotometer in the 300-800 nm range.

Determination of moissanite polytypes with Raman spectroscopy

Various techniques, e.g. X-ray crystallography, can be applied for the determination of silicon carbide polytypes. The examination of the Raman spectrum is one of the non-destructive methods which can be performed on cut gemstones without special preparation of the samples. Using a micro Raman spectroscopy facility, which is now available for routine investigations in some of the major gemmological laboratories, it is also possible to examine the samples with respect to homogeneity in different areas.

We performed Raman spectra on different facets and at different points on the larger tables of all samples including different orientations of the faceted gemstones to the incident beam. Although the spectra obtained, especially the intensities of the main peaks in the 760 to 800 and the 960 to 970 cm^{-1} area, were found to be strongly variable and related to the orientation of the samples (*Figures 2 and 3*), we could not determine any inhomogeneity within the five samples. In other words, the samples were found to be single crystals without any admixtures of different polytypes.

In all samples, the strongest Raman peaks above 700 cm^{-1} were found at similar wave numbers. The spectra of four samples consisted of strong lines at 767, 786 and 965 cm^{-1}, sometimes with an additional line at 795 cm^{-1} (not shown in *Figure 2*). Weak lines above 1000 cm^{-1} were also present. The spectra of the bluish-brown moissanite consisted of three strong lines at 778, 794 and 969 cm^{-1}, again with two weak lines above 1000 cm^{-1} (*Figure 3*). The Raman lines with weaker intensities below 700 cm^{-1}, again were found to be different for the sample with bluish-brown colour (*Figure 4*). The main Raman lines for the first four samples in this range were determined at about 147, 238, and 504 cm^{-1}, with one weaker line observed sometimes at 263 cm^{-1}. The remaining sample, on the other hand, revealed lines with maxima at about 201, 263, and 609 cm^{-1}, with an additional peak of weak intensity at 636 cm^{-1}.

These data are consistent with numerous references describing Raman data of specific silicon carbide polytypes (e.g. Feldman *et al.*, 1968a; 1968b; Colwell and Klein, 1972; Harima *et al.*, 1995; Harima and Nakashima, 1996; Nakashima and Harima, 1997; Burton *et al.*, 1998; 1999) and indicate that four of our five samples belong to the 6H-SiC polytype, whereas the remaining faceted moissanite

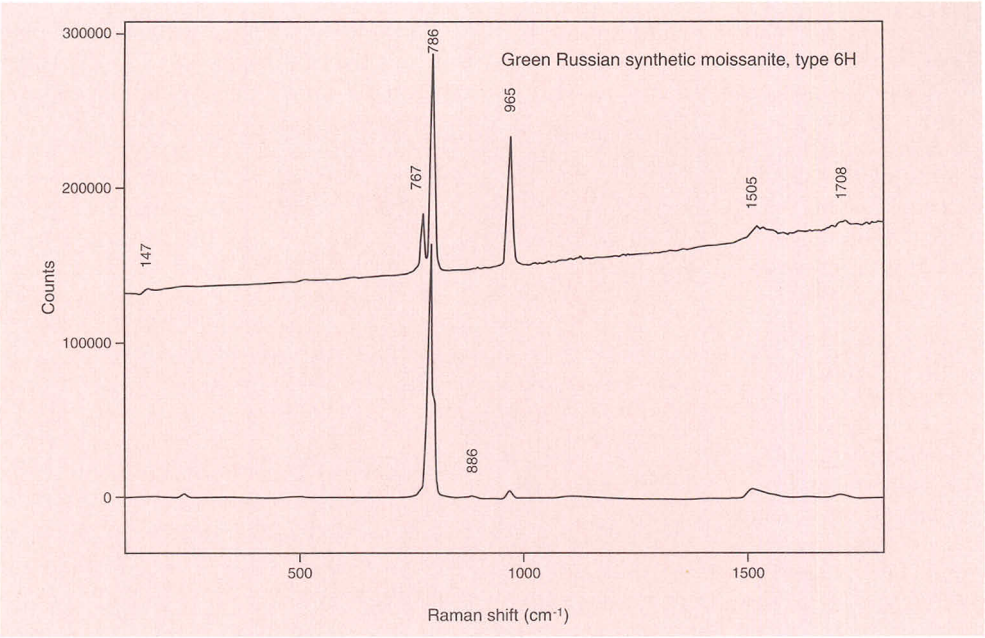

***Figure 2**: Raman spectra of synthetic moissanite (6H-SiC) in different orientations of the crystal with respect to the incident beam reveal a strong intensity variation of Raman lines.*

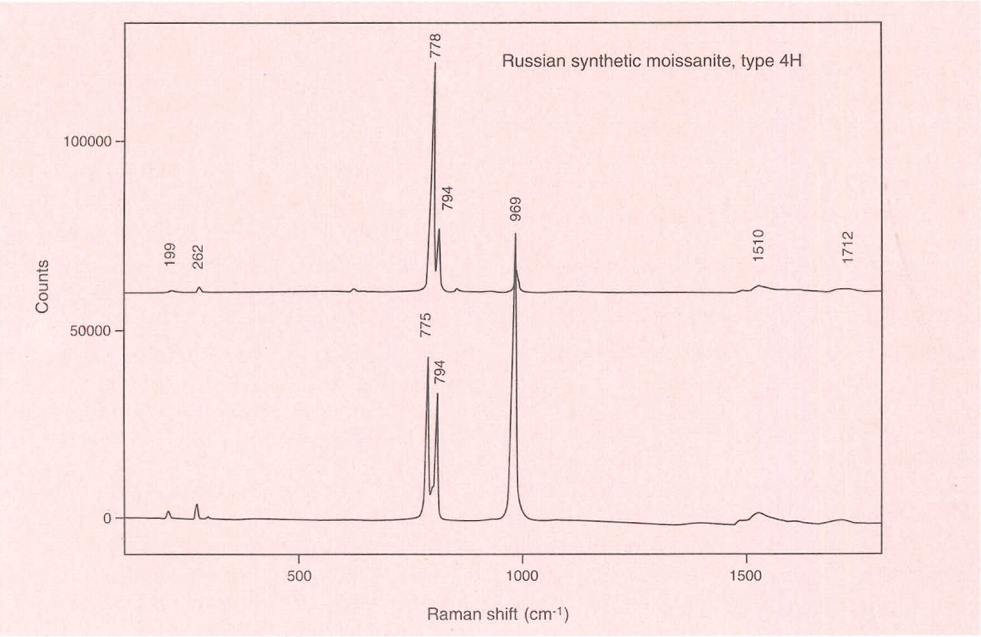

***Figure 3**: Raman spectra of synthetic moissanite (4H-SiC) in different orientations of the crystal with respect to the incident beam reveal a strong intensity variation of Raman lines.*

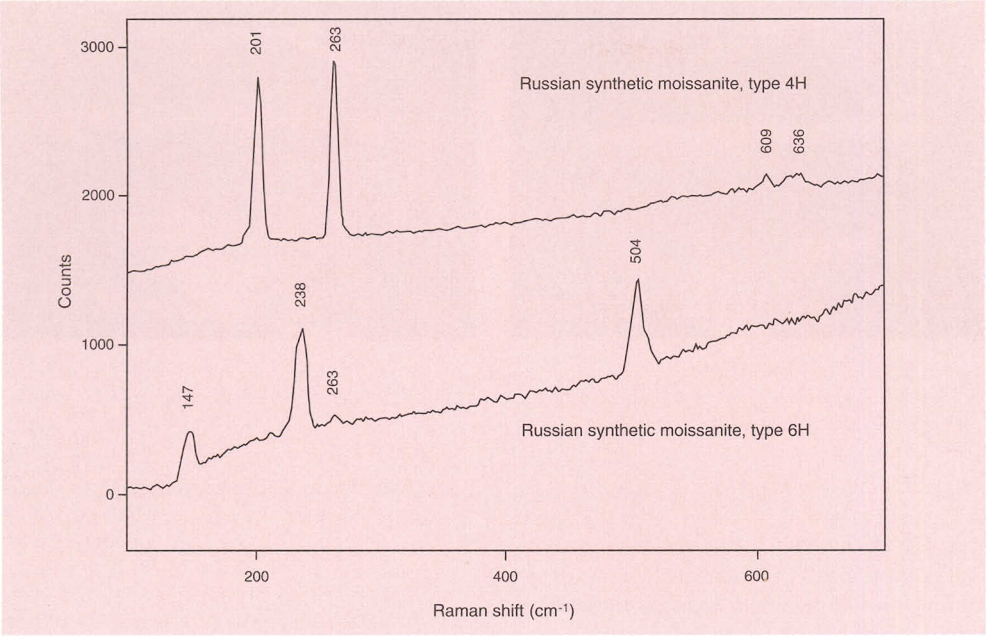

***Figure 4**: Raman spectra of different synthetic moissanite polytypes; the lines below 700 cm⁻¹ are useful for a distinction of 6H-SiC and 4H-SiC silicon carbide polytypes.*

was found to be 4H-SiC (*Table I*). The colourless material produced in the USA for jewellery purposes and released to the trade has been described so far as the 6H polytype of moissanite (Nassau *et al.*, 1997; Nassau, 1999).

Gemmological properties

The gemmological properties of the five examined samples are listed in *Table I*. Refractive indices of synthetic moissanite were not determined. They are given as 2.648 to 2.691 in the literature (Nassau *et al.*, 1997) and are therefore higher than the range of commercially available refractometers. The relative reflectivity with an average value of 120 is distinctively higher than that of a diamond. The specific gravity of the samples ranges from 3.20 to 3.25, which is consistent with the samples grown in the USA as described by Nassau *et al.* (1997).

With the naked eye, only one of the samples which was determined as 4H-SiC revealed different colours (blue and brown) in various directions of view. Using a dichroscope, the different colours observed were greenish-blue and brown (*Figures 5 and 6*). In the other four stones no variation of colour was observed in different orientations of the sample with the naked eye. By use of a dichroscope, a variable pleochroism from extremely weak (yellow sample) to weak (green stones) or moderate (bluish-green moissanite) could be observed (*Table I*). None of the synthetic moissanites had its *c*-axis orientated perpendicular to the table facet, i.e. no optically uniaxial interference figure was observable in a view perpendicular to the table facet. The five Russian samples were inert under short-wave and long-wave ultraviolet light.

The material grown by Cree Inc. in the USA currently on the market is cut in a direction with the table facet more or less perpendicular to the *c*-axis. This material has a colour range from near colourless, through

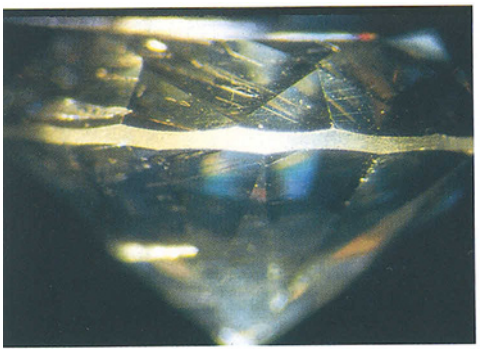

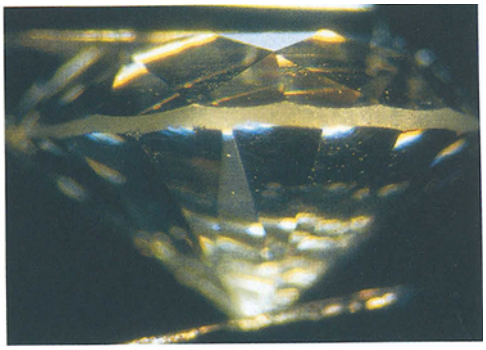

***Figures 5 and 6**: Pleochroism of bluish-brown synthetic moissanite which was determined as 4H-SiC by Raman spectroscopy. Figure 5 blue direction, Figure 6 brown direction. Sample is 5.40 mm in diameter. Photos: © H.A Hänni, SSEF.*

slightly yellow or greyish-yellow to light brownish-yellow, grey and slightly green (Nassau *et al.*, 1997), although the commercial production of Cree Inc. focused on colourless and nearly colourless material in the first years. Near-colourless and grey samples were not encountered in the material of the present Russian production available to the authors. Pale green, bluish-green and grey colours have recently been encountered in faceted stones from the commercial American production submitted to the market (Sluis, 2001).

Microscopic characteristics

The Russian stones show the typical doubling of facet edges (*Figure 7*) as described elsewhere for moissanites grown in the USA (Nassau *et al.*, 1997; Chalain and Krzemnicki, 1999; Chalain, 2000; Shigley *et al.*, 2000).

***Figure 7**: Doubling of facet junctions in Russian synthetic moissanites. This is one of the most concise diagnostic features which is easily determined using a hand-lens or the microscope. Magnified 40 x. Photo: © H.A Hänni, SSEF.*

The presence of elongated tubes, so-called micropipes, is a typical property of sublimation-grown 6H-SiC and 4H-SiC synthetic moissanites using a modified Lely technique (Takanaka *et al.*, 1996; Ohsato *et al.*, 1999; Müller *et al.*, 2000). One stone of our five synthetic moissanites is virtually inclusion-free (sample 4). Four of the five analysed stones contain elongated thin tubes or irregular cavities (*Figures 8 and 9*). In comparison to the Cree stones encountered in the SSEF Swiss Gemmological Institute as diamond imitations and described in the literature, most tubes appear thicker and are orientated parallel or slightly inclined to the table facet (samples 2, 3 and 5) as well as inclined at an angle of 45° to the table (sample 1). The Cree stones generally have thinner tubes that are orientated more or less perpendicular to the table, i.e. parallel to the *c*-axis. This orientation of tubes in American stones is responsible for an image which gives the impression that they are radiating around the centre of the stone (Chalain, 2000). This difference in appearance in stones from the two producers is caused by the different orientation of the optic axis within the faceted stones.

Small crystals or bubbles are common in four of the five stones (*Figures 8 and 9*). One stone (sample 2) shows growth lines that are orientated perpendicular to the tubes

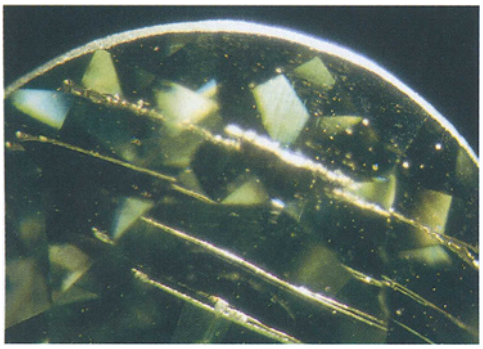

Figure 8: Elongate tubes or irregular cavities in Russian synthetic moissanites; irregular bubbles and/or small crystals are also present; growth planes perpendicular to the tubes are also seen. Magnified 40 x. Photo: © H.A. Hänni, SSEF.

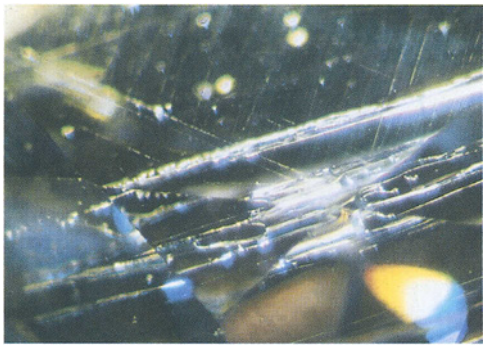

Figure 9: Elongate tubes or irregular cavities in Russian synthetic moissanites; irregular bubbles and/or small crystals are also present. Magnified 40 x. Photo: © H.A.Hänni, SSEF.

(*Figure 8*), and one of the synthetic moissanites (sample 1) contains a highly reflective hexagonal crystal or negative crystal with a hollow tube extending from it (*Figure 10*). Similar defects were described by Takanaka *et al.* (1996) in synthetic 6H-SiC.

Analysis of elongated tubes, small crystals or bubbles, as well as the hexagonal crystal mentioned above, with micro Raman spectroscopy revealed only the common spectra of the host moissanite polytypes. Consequently, all encountered inclusions are likely to be either cavities or inclusions of moissanite crystals, possible in an orientation different from that of the host. However, it is also possible that these inclusions are phases that give only weak or no Raman signals. Although thick tubes, hexagonal crystals, or growth structures are not commonly observed in the synthetic moissanites from Cree, all these features were observed by Groenenboom (2000) in samples grown in the USA. They are, therefore, neither exclusively found in, nor characteristic of synthetic moissanite of Russian production.

Chemical properties

According to Lely & Kröger (1958), hexagonal silicon carbide crystals owe their colour to impurities of N or P (green), or A1 or B (blue). Nitrogen and aluminium are the commonly used dopants for the growth of silicon carbide gem materials in different colours (Hunter and Verbiest, 1998a; 1998b).

The X-ray fluorescence spectrometer used can detect elements with atomic numbers above 11 (Na). Semi-quantitative chemical analysis of the five stones under investigation revealed, besides Si, no other element. Hence, no P or Al was detectable in our samples. This implies that these elements, if present, can only exist in traces below the detection limit of the instrument. The presence of B and especially N, on the other hand, cannot be discerned with the X-ray fluorescence facility applied.

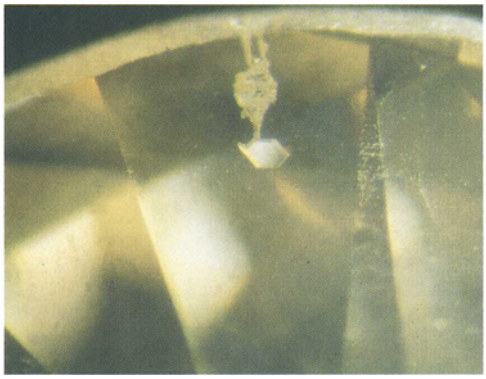

Figure 10: Tiny moissanite crystal or negative crystal with an elongate tube extending from this inclusion in yellow synthetic moissanite from Russia. Magnified 30 x. Photo: © H.A. Hänni, SSEF.

Spectroscopic properties in the visible and UV range

As a consequence of intense internal reflections due to the high refractive indices of moissanites, and of oblique orientations of the optic axis of the faceted samples, we were unable to orient the Russian moissanites properly to the incident beam of the spectrophotometer to obtain conventional polarized spectra parallel and perpendicular to the *c*-axis.

Absorption spectroscopy for yellow and green synthetic moissanites from Russia (samples 1, 2 and 3) revealed a slightly increasing absorption starting at about 600 nm towards the violet range and an absorption edge at about 410 nm (*Figure 11*). The two green samples showed an additional weak absorption band with a maximum at about 635 nm. In the bluish-green sample, both the absorption in the blue to violet range and the absorption band at 635 nm are distinctly increased in intensity, and a weak shoulder at 435 nm is also present (see again *Figure 11*).

Comparing these spectroscopic properties with published data of 6H-SiC (Lely and Kröger, 1958; Violina *et al.*, 1964; Biedermann, 1965; Ellis and Moss, 1965; Sugiyama *et al.*, 1996; Stiasny and Helbig, 1997; Lambrecht *et al*, 1998; Limpijumnong *et al.*, 1999), all absorption features are consistent with those of nitrogen-doped synthetic moissanite. Nitrogen is the most common trace element in synthetic moissanites, originating at least partly from atmospheric air. In order to achieve colourless synthetic moissanites, great efforts are undertaken to grow almost nitrogen-free samples or to reduce the influence of nitrogen by charge compensating trace elements such as aluminium.

Spectra similar to those of our Russian samples 1 to 4 have already been published by Lely and Kröger (1958) for synthetic moissanites grown under different nitrogen-bearing argon atmospheres. The spectrum of our yellow sample 1 is consistent with that of a sample grown at 0.01% N_2, the spectra of the green samples 2 and 3 are consistent with the published spectrum of a sample grown at 0.1% N_2, and the spectrum of the bluish-green sample 4 is similar to that of a synthetic moissanite grown at 10% N_2. Consequently the colour of yellow, green and bluish- green synthetic moissanites is probably due to various concentrations of nitrogen in these 6H-SiC crystals.

For the evaluation of the strong blue and brown pleochroism of sample 5, non-polarized spectra were recorded in those directions which showed these different colours (*Figure 12*). Both spectra revealed an absorption edge in the UV at about 370 nm. The spectrum in the blue-green direction revealed two strong absorption maxima at 566 nm (with a shoulder at 649 nm) and at 465 nm, and the spectrum taken in the brown direction consisted of two distinct absorption maxima at 553 nm and at 458 nm.

A shift of the absorption edge from the violet range in 6H-SiC to the ultraviolet in 4H-SiC is consistent with literature data (Choyke and Patrick, 1961; de Oliveira *et al.*, 1996). The spectra of the Russian sample 5 taken in different orientations are also consistent with reference data for nitrogen-doped synthetic 4H-SiC (Biedermann, 1965; Lambrecht *et al.*, 1998; Limpijumnong *et al.*, 1999). Comparing these literature references and the polarized absorption spectra pictured in these papers with our spectra it may be interpreted that the spectrum taken in the blue direction consists of superimposed polarized spectra with components parallel and perpendicular to *c*, and the spectrum taken in the brown direction represents a polarized spectrum perpendicular to *c*. Thus, the colour and pleochroism of blue to brown synthetic moissanite is probably caused by traces of nitrogen in 4H-SiC.

Conclusions

Hexagonal silicon carbide single crystals of 6H or 4H polytype have been grown in St. Petersburg, Russia, using the modified Lely

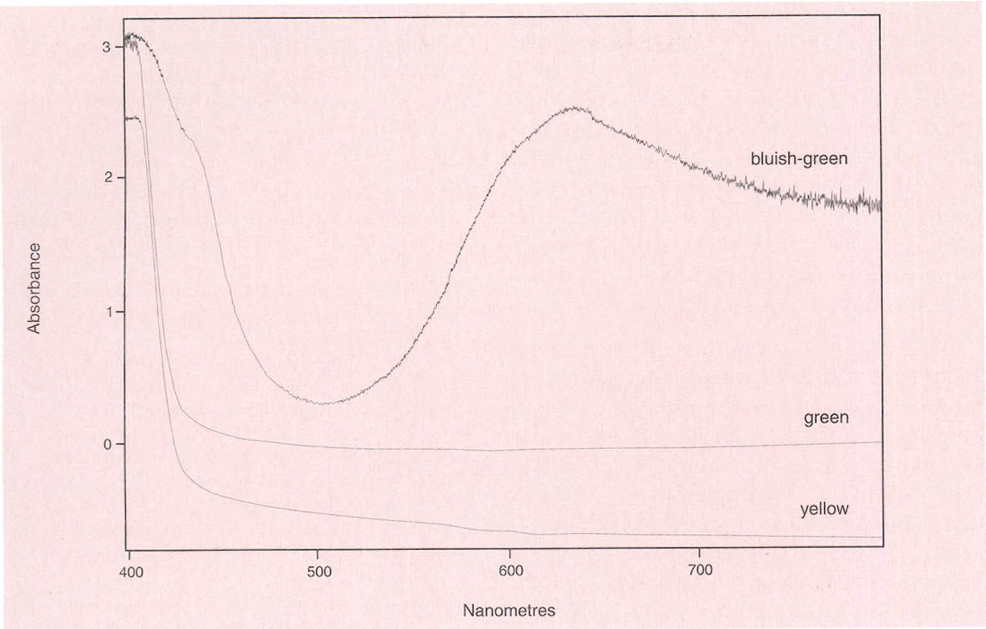

***Figure 11**: Absorption spectra of yellow [bottom], green [middle] and bluish-green [top] synthetic moissanites (6H-SiC) doped with different amounts of nitrogen.*

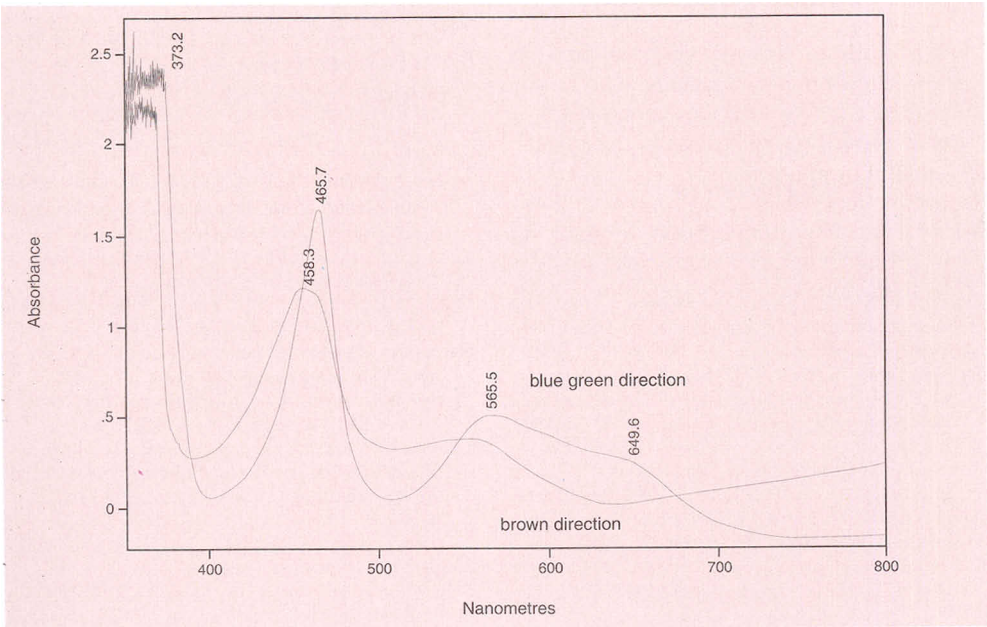

***Figure 12**: Absorption spectra of bluish-brown synthetic moissanite (4H-SiC) doped with traces of nitrogen recorded in the directions of the blue-green coloration and the brown coloration.*

technique by sublimation from the vapour phase. Faceted gemstones with yellow, green and bluish-green colour were determined as synthetic 6H-SiC, the variable coloration being caused by various amounts of nitrogen. As with colourless or near-colourless synthetic moissanite, these Russian stones could be mistaken for coloured diamonds by the inexperienced jeweller. A bluish-brown sample with distinct pleochroism was determined as nitrogen-doped 4H-SiC.

The physical properties of moissanite samples of both polytypes are in the range of those of colourless or almost colourless 6H-SiC grown in the USA for jewellery purposes. Doubling of facet junctions is commonly observed in all samples. In most synthetic moissanites, elongated tubes or somewhat irregular cavities may also be observed by microscopic examination. However, the orientation of these characteristic inclusions tends to be sub-parallel to the table facet in contrast to a near perpendicular orientation in American synthetic moissanite material seen normally on the market.

Acknowledgement

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ABSTRACT: A spate of ruby and emerald rough imitations are considered. The cutting of 'prize' emeralds to order is questioned. The authenticity of an archaeological intaglio is unresolved. More on 'power' bracelets. Zachery-type treated turquoise and diffused corundums are encountered. Bangladesh pearl fishing information. The problems of lax pearl terminology presented.

The fraudulent practice of circulating imitations of rough emerald, ruby, sapphire, and diamond are well known. Recently, there has been a spate of larger specimens being passed off as ruby and emerald. One of the ten specimens, weighing 40 grams, was found to be green artificial glass (*Figure 1*). A matrix of 'earthy' material is glued onto the surface to make the specimen appear more authentic.

The remaining specimens were all determined to be artificially coloured composite stones, consisting of pieces of colourless (or near-colourless) quartz. The quartz components are glued together and it is the designated dyed colour of the glue which gives the specimen its perceived body colour. The 'earthy' matrix glued onto the surface once again adds 'authenticity' but in these specimens it also covers over the joins between the quartz sections. Enough of the transparent seemingly high quality areas of the stones are revealed at the surface to persuade an unwitting purchaser that there are lucrative profits to be made. However the size of these 'windows' will not allow the casual untrained observer to see any internal clues to the true identity of the stone. The four ruby imitations were an orangish-red colour and ranged in weights from 50.3 grams to 96.6 grams (*Figure 1*). The colour would be considered somewhat artificial to anyone acquainted with handling natural ruby.

Figure 1: *Green artificial glass imitating a piece of emerald rough, which weighs 40 grams, and an artificially coloured quartz composite imitating ruby rough, weighing 96.6 grams.*

The rough green specimens varied in weight from a lowly 29.7 grams to an astounding 0.82 kilograms (*Figure 2*). At some stage, the latter specimen had been polished down one side. This action revealed the join between the quartz pieces, allowed a closer view of the internal joins and, with

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Figure 2: An artificially coloured quartz composite stone, weighing 0.82 kilograms.

Figure 3: The advertisement accompanying a rough piece of emerald, which was the 'winning' prize from a scratch card competition.

the use of a pen torch or fibre optic light, enabled an observer to clearly differentiate between the colourless quartz and the green coloured adhesive.

These composites are produced for fraudulent intent and normally form part of an elaborate scam drawing in potential buyers to part with their money. The clients involved in submitting the composites had obviously realised that something was amiss and hopefully were able to curtail their financial losses. One wonders how many transactions have occurred where purchasers have become wise after the event.

You've won this genuine emerald

So goes the advertisement attached to a rough piece of what is claimed to be an emerald (*Figure 3*). The stone and advertisement are the free gift sent out to the winners of a scratch card. In revealing 'winning' boxes on the scratch card they are instructed to telephone through their details on a premium rate telephone line. The advertisement then encourages the 'winner' to send off his piece of emerald to have it cut and mounted in a 'Lucky Horseshoe Pendant'.

The Laboratory has been shown five of these rough emerald pieces, one of which was submitted by a local authority trading standards body. Two of them were green in colour - one opaque, which was submitted by the trading standards body, and the other translucent. Both can be described as emeralds. The trading standards authority was informed that the pendant may have been imported with an emerald (assuming it is) already mounted. It was suggested that by chemical analysis as well as microscopic examination an attempt could be made to establish whether the faceted stone was cut from the stated piece of rough. Unfortunately the authority did not take it any further.

Subsequent pieces of rough that have been seen would have fallen foul of trade descriptions in that the bulk of the stone seems to be a mica schist with only grains of emerald in it. Trading standards have been informed of this.

Roman intaglio?

An oval black intaglio, measuring approximately 12 x 10 x 3 mm, was submitted with the request to establish its identity and age. The intaglio, a holiday purchase in Turkey, had been sold as a Roman artefact. It was established that the material was a dark purple artificial glass and that the depicted image of a 'Roman-like' bust of a man was a moulding. It was suggested that the client show it to an expert at the British Museum. It was interesting to learn that the Romans were able to produce moulded intaglios. The expert was unable to prove its age one way or another but his instincts were that it was a modern reproduction. The lack of wear to the stone would support his instincts. Apparently original Roman artefacts are

being found in Turkey, which makes the sale of reproductions to unsuspecting tourists that much easier!

Poor man's onyx, etc

Amongst a number of low priced 'power' bracelets being tested was one assumed to be onyx. However instead of the expected smooth cryptocrystalline structure there was a granular texture (*Figure 4*). On contacting the company, who had submitted the sample, we were informed that their Far East supplier had located this material since onyx bead bracelets had not been within the price range sought by the company! Chemical analysis proved the material to be quartz. The composition of the black specks visible, which contribute to the natural black colour of the material, were not determined. The result given for the beads was black quartzite.

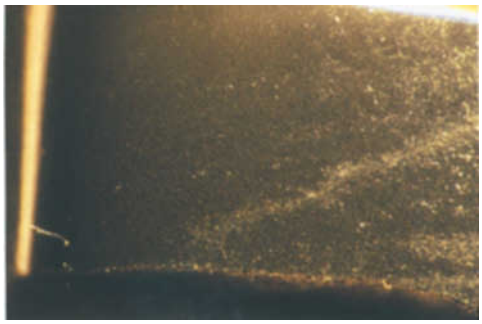

Figure 4: *The granular texture of black quartzite.*

In another onyx bracelet six 'black' (actually dark purple when viewed with a fibre-optic light) artificial glass beads were discovered. Another surprise was to find that someone had considered treated blue topaz to be too expensive or hard to find and had used dyed quartz instead. In testing other 'power' bracelets the most common false descriptions relate to turquoise and jade. The 'turquoise' bracelets tend to be various types of man-made imitations. The carbonate-based imitations will effervesce with a drop of dilute hydrochloric acid. In others, the admixture of dye is visible under magnification. The 'jade' bracelets are generally other materials altogether – yellow calcite, green aventurine quartz, dyed chalcedony and dyed quartzite. The prices of these bracelets mitigate against nephrite, jadeite or turquoise being used. A number of importers in describing the likes of imitation turquoise have resorted to the practice of using the French word 'faux' (literal translation – false, although in French it has a wider and in this context more relevant meaning) in smaller less prominent type in front of the word 'turquoise'. This practice falls foul of the International Jewellery Confederation (CIBJO) guidelines, which state:

"An imitation....shall be described by the name of the natural material it imitates, immediately preceded by the word 'imitation', which shall appear, in the event of a written presentation, with equal emphasis and prominence, with characters of the same size and colour as those of the name itself" (Gemstones – Terminology and Classification, 2001).

Treated turquoise

A pair of turquoise earrings were chemically analysed to establish whether they been treated by a Zachery-like process (Fritsch, E., *et al.*, 1999). There was no specific feature that caused suspicion. The fine quality of the turquoise would make you cautious since the value would be relatively high. The analysis by EDXRF (EDAX Eagle II) revealed an appreciable potassium content. The result given on the report was given as Treated Turquoise. This was the first Zachery-like treated turquoise submitted to the Laboratory for commercial testing.

Obvious diffusion treatment

The admonition to always check your sapphires for diffusion treatment normally entails the immersion of the stone in di-iodomethane or the diffusion of the light when viewing the stone on a microscope (a piece of tissue paper under the stone will often suffice). None of this was required to see the superficial colour diffusion penetrat-

ing the surface of the cabochon stone in *Figure 5*, which was in the process of being faceted.

After treatment and repolishing, diffused red corundum normally displays a patchier colour than the equivalent diffused blue corundum. This reflects the greater technical problems in diffusing the much larger chromium atoms into the corundum than in diffusing the iron and titanium into corundum, which is used to obtain the more widely available blue diffused corundum. One of our members brought in some low quality diffused red samples, where the resulting patchiness is very evident (*Figure 6*) to the extent that some of the centres of the facets lack any colour at all (*Figure 7*).

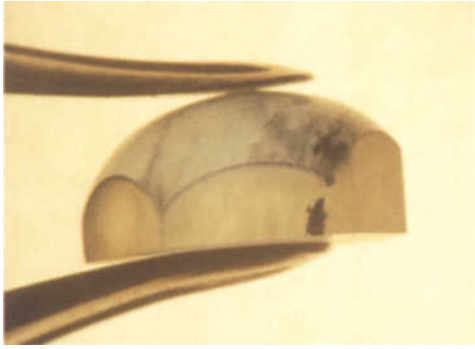

Figure 5: *The superficial colour diffusion penetrating into a cabochon, which was in the process of being faceted.*

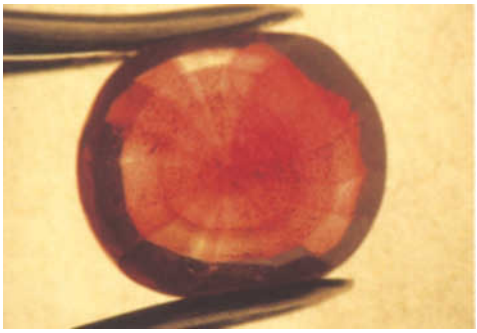

Figure 6: *A diffused red corundum showing the typical patchy colour distribution.*

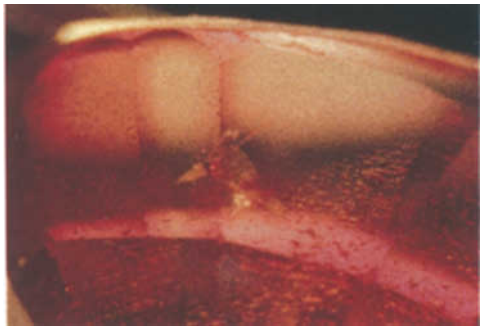

Figure 7: *The lack of colour evident on some facets of a diffused red corundum.*

Bangladeshi pearls

A white 'pearl' and a purplish grey/black 'pearl' described as originating from Bangladesh were submitted for identification. The white, irregular shaped, drilled 'pearl' was believed to be from coastal water bivalves and the black one from a River Meghna mussel. The client submitting these pearls regularly visits Bangladesh on business and was given to understand that they are natural pearls. The white 'pearl' was one from a necklace bought at a village bazaar south of Chittagong. The related pearl-bearing bivalves are fished in that area and another area 25 km from Dhaka. The client sent further samples of 'pearls' that he had personally retrieved or had seen being retrieved (*Figure 8*). In the laboratory we must ignore all provenance claims and give our objective opinion. In these circum-

Figure 8: *Bangladeshi 'pearls' - the 'pearls' on the right were identified as non-nucleated cultured pearls (© Pertti Tilus).*

stances we had to inform the client that we would report these pearls as being non-nucleated cultured pearls.

Pearl fishing in Bangladesh is known but the question is whether natural pearls exist in any numbers. Over the years, the Laboratory has received enquiries from the government and from a leading local jeweller on the development of their pearl trade. However the enquiries were not followed up. It would be interesting to hear more about the pearl situation in Bangladesh.

Freshwater pearls

It is common for non-nucleated cultured pearls to simply be labelled as freshwater pearls. In following CIBJO guidelines the jewellery trade is encouraged to call them freshwater cultured pearls. The lax practice of describing non-nucleated cultured pearls as freshwater pearls has been taken to its logical conclusion by a mail order firm, who have headlined their advertisement 'Stunning natural freshwater pearls'. This advertisement is also being brought to the attention of our trading standard authorities.

Acknowledgements

Trevor Tyler for their co-operation over the intaglio, David Davis for the loan of the red diffused corundum, and Pertti Tilus of Finbax Ltd for his picture and information on Bangladesh Pearl Fishing. Also Norman Harding, who sent in one of the rough emeralds involved with the scratch cards.

References

Fritsch, E., McClure, S.F., Ostrooumov, M., Andres, Y., Moses, T.M., Koivula, J.I., and Kammerling, R.C., 1999. The identification of zachery-treated turquoise. *Gems & Gemology*, **35**(1), 4-16

Gemstones – Terminology and Classification, 2001. *The Gemstone Book of the International Jewellery Confederation (CIBJO)*

LONDON DIAMOND REPORT

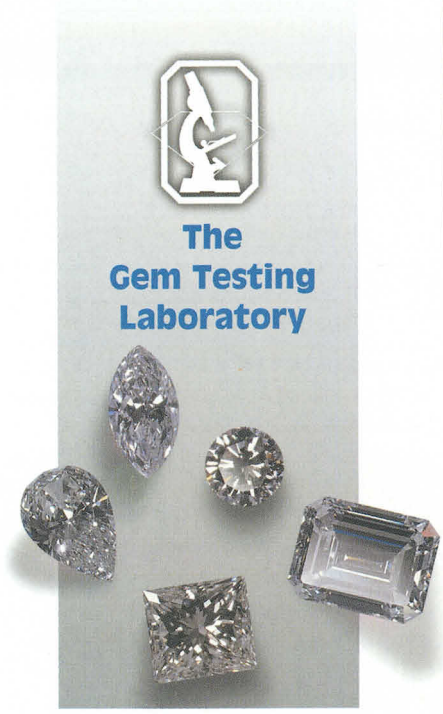

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Abstracts

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Diamonds

Luminescences sous excitation visible des diamants noirs irradiés.

P.-Y. Boillat, F. Notari and C. Grobon. *Revue de Gemmologie*, 141/142, 2001, 37-9.

Most irradiated black diamonds examined under light at ± 420 nm show strong luminescence at facet junctions: examples are shown. M.O'D.

Diamants de type IIa et traitement HPHT: identification.

J.-P. Chalain, E. Fritsch and H. A. Hänni. *Revue de Gemmologie*, 141/142, 2001, 50-53.

Type IIa brown diamonds have been treated by high pressure/high temperature methods with colourless specimens resulting. Gem testing details are supplied. M.O'D.

Petrology of the Abloviak aillikite dykes, New Québec: evidence for a Cambrian diamondiferous alkaline province in north-eastern North America.

S. Digonnet, N. Goulet, J. Bourne, R. Stevenson and D. Archibald. *Canadian Journal of Earth Sciences*, **37**(4), 517-33, 2000.

A dozen ultramafic lamprophyre dykes occur in the E part of Ungava Bay, Quebec. They consist of macrocrysts of olivine and phlogopite with rims of tetra-ferriphlogopite, included in a matrix of fine-grained phlogopite, olivine, spinel, perovskite, rutile, diamond, apatite and interstitial carbonate. Rock and mineral chemistry and an Sm-Nd isotopic signature indicate that these rocks are carbonated ultramafic lamprophyre dykes. Chemical zoning of the micas and the presence in two of the dykes of andradite (TiO_2 7.54 and 11.42 wt.%) suggest a complex sequence of crystallization; an Ar isotope correlation analysis indicates an age of ~550 m.y. The dykes were emplaced in tension gashes in the Tasiuyak gneiss during reactivation of major Palaeoproterozoic structures associated with the opening of the Iapetus Ocean. The age, geochemical characteristics, isotopic evidence and geological environment are all analogous to similar dykes in SW Greenland. Their pre-drift geographical proximity, prior to the opening of the Labrador Sea, is taken to suggest that they are related to a common magmatic event which constitutes a diamondiferous alkaline province in NE North America. R.A.H.

Morphology of diamonds as a possible indicator of their genesis.

M.D. Evdokimov, M.Y. Ladygina and A.R. Nesterov. *Neues Jahrbuch für Mineralogie; Abhandlungen*, **176**(2), 2001, 153-77.

The hypothesis ascribing the formation of rounded diamonds to the processes of crystal growth is reviewed before a presentation of 34 SEM photographs of 18 representative diamonds, many from the Yakutian deposits. Growth and dissolution forms each have distinct morphological features. The crystallization of diamonds in eclogites led to plane-faced crystals. Melting at asthenospheric levels caused corrosion of diamond xenocrysts derived from the eclogite substrate. As the kimberlite magma became saturated in carbon, dissolution processes gave cyclic changes in growth and corrosion episodes responsible for the curved-face forms such as octahedroids and dodecahedroids. External sources (e.g. jets of juvenile methane) could supply enough C to trigger nucleation of a new generation of plane-faced octahedral crystals. Diamonds of the most complex morphology (including sceptre and skeletal forms) result from a combination of corrosion and rapid growth during the explosive emplacement of kimberlite magmas. The possibility of metastable crystallization of diamond directly from a juvenile gas should not be ruled out. R.A.H.

Les diamants de type I traités à HPHT: Novatek, General Electric, russes et suédois.

E. Fritsch. *Revue de Gemmologie*, 141/142, 2001, 54-8.

Brown type Ia diamonds treated by high pressure/high temperature methods may change to green. The process devised by Novatek is the only one to have been published: specimens are treated between 2000 and 2100°C and at approximately 60 kbars in the graphite stability field, using prismatic presses which are illustrated. Unusually saturated colour enhanced by fluorescence, high-pressure annealing signs, including discoidal fractures, graphite and etching, strong green luminescence under UV or visible light seen only in

Abstractors

J. Flinders	J.F.	M. O'Donoghue	M.O'D.	E. Stern	E.S.
R.A. Howie	R.A.H.	P.G. Read	P.G.R.	I. Sunagawa	I.S.

For further information on many of the topics referred to, consult *Mineralogical Abstracts*

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yellow-grained areas and very rare in natural diamonds (caused by the development of the H3 centre during treatment), and the presence of the H2 absorption line at 985 nm and below, absent from natural diamonds, are all indications of treatment. M.O'D.

[Discovery of diamonds in south-western Uzbekistan.] (Russian with English abstract)

A.V. Golovko, N.E. Yakovenko and N.A. Akhmedov. *Proc. Russian Min. Soc.*, **129**(1), 2000, 61-4.

Diamonds have been found in SW Uzbekistan in unusual diamond-bearing rocks: lamprophyres and shonkinite-porphyries forming dykes and pipes. These rocks contain xenoliths both of the host rocks and some rock types from greater depths: ultrabasites and eclogitized gabbro. The xenoliths also contain chromspinelids, chromdiopside, Cr-bearing olivine and moissanite. Data are given on the morphology of the diamond crystals, their XRD pattern and their TEM images. The diamondiferous xenoliths are related to the non-kimberlite type of rocks - lamprophyres of camptonite-monchiquite composition and/or shonkinite-porphyries. R.A.H.

Gemmologische Kurzinformationen. Eine neue Lichtquelle von kurzwelligem UV-Licht für den SSEF IIa Diamond Spotter™ zum Nachweis des Diamanttyps IIa.

H.A. Hänni. *Gemmologie. Z. Dt. Gemmol. Ges.*, **50** (1), 2001, 57-8, 1 graph, 1 photograph.

Most GE POL treated diamonds are type IIa and are transparent to short-wave UV radiation (SWUV); this test can be applied for preselection of possible HPHT treated IIa diamonds. The SWUV light source can be used with the SSEF IIa Diamond Spotter and is now produced under the name of 'SSEF IIa Diamond Illuminator'. E.S.

Superdeep diamonds from the Juina area, Mato Grosso State, Brazil.

F.V. Kaminsky, O.D. Zakharchenko, R. Davies, W. L. Griffin, G.K. Khachatryan-Blinova and A.A. Shiryaev. *Contributions to Mineralogy and Petrology*, **140**(6), 2001, 734-53.

Alluvial diamonds from the Juina area in W Brazil have been characterized in terms of their morphology, syngenetic mineral inclusions, carbon isotopes and nitrogen contents. Like other Brazilian diamonds, they show a predominance of rounded dodecahedral crystals; however, their mineral inclusions are unique. The inclusion paragenesis of Juina diamonds are dominated by ultra-high-*P* ('superdeep') phases differing from those found elsewhere. Ferropericlase is the dominant inclusion; it coexists with ilmenite, Cr-Ti spinel, a phase with the major element composition of olivine, and SiO_2. CaSi-perovskite inclusions coexist with titanite, ëolivineí and native Ni. MgSi-perovskite coexists with TAPP (tetragonal almandine-pyrope phase). Neither Cr-pyrope nor Mg-chromite occur. The spinel inclusions are low in Cr and Mg, and high in Ti (Cr_2O_3 <36.5 wt.% and TiO_2 > 10 wt.%). Most ilmenite inclusions have low MgO and some have very high (<11.5 wt.%) MnO. This suite of inclusions is consistent with derivation of most of the diamonds from depths near 670 km, and adds ilmenite and relatively low-Cr, high-Ti spinel to the known phases of the superdeep paragenesis. These diamonds have a narrow range of $\delta^{13}C$ (-7.8 to -2.5‰), low nitrogen contents and a predominant aggregated B centre. These observations have practical consequences for diamond exploration. R.A.H.

Diamond from the Guaniamo area, Venezuela.

F.V. Kaminsky, O.D. Zakharchenko, W.L. Griffin, D.M. DeR. Channer and G.K. Khachatryan-Blinova. *Canadian Mineralogist*, **38**(6), 2000, 1347-70.

More than 5000 diamond crystals (or fragments) from kimberlite sills and placer deposits in the Guaniamo area of W Bolivar State, Venezuela, have been characterized by morphology, internal structure, $\delta^{13}C$ values, syngenetic mineral inclusions, and the abundance and aggregation state of N. Some 50% of the crystals are resorbed dodecahedral forms; octahedral are the next most common form. The diamonds are generally colourless but a high percentage show radiation-induced pigmentation. About 20% are type II, the remainder belonging to the transitional IaAB type, with B>A. Ninety-three mineral inclusions were extracted from 77 crystals; EPMA and LAM-ICP-MS techniques were used to establish their trace element compositions and the *P–T* conditions of diamond crystallization. In all, 86% of the diamonds contain eclogitic inclusions, the remainder indicating peridotitic paragenesis. The $\delta^{13}C$ of 108 diamonds range from -3.2 to -28.7‰, but most stones have $\delta^{13}C$< -10‰. The authors consider that the diamonds in the placer deposits were derived mostly from the Guaniamo kimberlite sills. *P–T* estimates that most originated near the base of the lithosphere (*T*1200–1300°C) in a zone which may contain a substantial proportion of eclogite formed by subduction of crustal material. Parallels are drawn with the Australian Argyle deposit. R.A.H.

Evidence for crystals from the lower mantle: baddeleyite megacrysts of the Mbuji Mayi kimberlite.

L. Kerschhofer, U. Shärer and A. Deutsch. *Earth & Planetary Science Letters*, **179**(2), 2000, 219-25.

Results of a TEM study on previously dated, cm-sized baddeleyite xenocrysts (ZrO_2) from the Mbuji Mayi kimberlite are presented. Crystallographic analysis of their microstructures shows they transformed to their present monoclinic phase from a cubic parent phase. The high-T stability field of the cubic parent phase implies a lower mantle origin. This is further evidence that the idea of transfer of solid material across the 670 km mantle discontinuity is valid, and agrees with previous phase-petrology investigations of tiny ferro-periclase inclusions in diamonds for which a lower mantle origin has always been proposed. However, unlike the ferro-periclase inclusions, baddeleyites also record chronological information, and hence might provide new data on mantle dynamics' history. J.F.

Gemmologie Aktuell.

C.C. MILISENDA. *Gemmologie. Z. Dt. Gemmol. Ges.*, **50** (1), 2001, 1-4, 6 photographs.

A 'fancy-white' pear-shaped modified brilliant-cut diamond of 0.71 ct was translucent with a milky white colour due to a high concentration of sub-microscopic inclusions of an unknown nature that scatter the incident light. Colour flashes can produce an appearance similar to white opal. Possession of magnetism can often be used to separate natural from synthetic diamonds, but a natural cubic, black diamond of 2.02 ct was found to be magnetic probably due to magnetite inclusions. The body colour was brownish, but it appeared black due to many graphite inclusions; irradiated 'black' diamonds usually have a greenish-black body colour. E.S.

Gem Trade Lab notes.

T.M. MOSES, S.F. MCCLURE AND M.L. JOHNSON (EDS). *Gems & Gemology*, **37**(1), 2001, 56-63.

Items noted include a strongly colour-zoned diamond showing pseudo-dichroism. R.A.H.

Industrial diamond: applications, economics and a view to the future.

C. OWERS, *Industrial Diamond Review*, **60**(3), 2000, 176-81.

Diamond has extreme properties in the mechanical, thermal, optical, chemical and electronic fields and it is the combination of these properties which gives diamond its industrial importance. The world superabrasive tooling market is estimated to be worth almost $4 billion. Applications are continuing to be developed, but in addition to the quantifiable effects include less noise for less time, less dust, dry grinding rather than wet and more neutral waste. R.A.H.

Discovery and mining of the Argyle diamond deposit, Australia.

J.E. SHIGLEY, J. CHAPMAN AND R.K. ELLISON. *Gems & Gemology*, **37**(1), 2001, 26-41.

The Argyle mine in north-western Australia was established in 1983 and almost immediately became the world's largest source of diamonds. In its peak year (1994) it produced >42 million carat of rough diamonds, representing 40% of the world's production. A large proportion of these diamonds are small (mean size <1 ct) brown to yellow stones, with some near-colourless and colourless rough diamonds. The type 1a brownish and yellowish cut stones are marketed as 'champagne' and 'cognac' diamonds. The Argyle mine is also noted for the production of a very limited amount of rare pink diamonds (sold in auction at >US $ 100 000 per ct). The ore grade is 3 ct/tonne of olivine lamproite host rock; secondary alluvial deposits are also worked. R.A.H

Diamonds and their mineral inclusions, and what they tell us: a detailed 'pull-apart' of a diamondiferous eclogite.

L.A. TAYLOR *et al.* [9 others]. *International Geology Review*, **42**, 2000, 959-83.

Three-dimensional high resolution X-ray computed tomography of an eclogite xenolith from Yakutia has proved able to image diamonds and their textural relationships with coexisting minerals. Thirty specimens >.1 mm were found in an eclogite from Udachnaya, Russia: the diamonds appeared to be associated with zones of secondary alteration of clinopyroxene, the presence of secondary minerals suggested that the diamonds formed after the eclogite in conjuction with metasomatic inputs of C-rich fluids. Inclusions studied showed variations in major and trace-element chemistry within and between specimens and do not correspond to the minerals in the eclogite. M.O'D.

Gems and Minerals

The Rist and Ellis tracts.

D.L. BROWN AND W.E. WILSON. *Mineralogical Record*, **32**, 2001, 129-40.

North Carolina is virtually the only significant emerald producing state in the United States, the Hiddenite area (which also produces Cr-green spodumene) having yielded crystals of fair to good gem quality since the first discovery in 1875. The Rist and Ellis properties are in Alexander County and close to the small town of Hiddenite. The bedrock geology in which the emerald-bearing veins occur consists of Precambrian quartz-mica schists and gneisses in which sets of steeply-dipping fractures are penetrated by late-stage pegmatitic fluids with associated quartz and quartz-mica veins. These veins contain emerald-bearing vugs and pockets. Details of the emeralds are given: crystals are almost always etched and range from pale-green to blue-green. Some contain a colourless core while Cr-rich portions show a rich blood-red through the Chelsea filter. Amethyst, smoky quartz and gem-quality dark red rutile crystals also occur in the area, as well as hiddenite spodumene and fine jet-black crystals of tourmaline. Dark green tourmaline is also reported. M.O'D.

Tourmaline and aquamarine deposits from Brazil.

J. CESAR-MENDES, H. JORT-EVANGELISTA AND R. WEGNER. *Australian Gemmologist*, **21**(1), 2001, 3-6, 3 illus. in black-and-white.

Brazil is one of the world's largest producers of aquamarine and gem-quality tourmaline. These gemstones are found in granitic pegmatites and in the states of Minas Gerais, Bahia, Espirito Santo, Ceara, Paraiba and Rio Grande do Norte. Although aquamarines and tourmalines had been known for around 300 years, the Brazilian deposits only started to be exploited during this last century. The authors discuss in detail the very different mineralogical compositions of these various pegmatite deposits. P.G.R.

Jadeite in Japan.

K. CHIHARA. *Journal of the Gemmological Society of Japan*, **20**(1-4), 1999, 5-21, 18 figs., 7 tables.

Archaeological, geological, petrological and mineralogical description of jadeite in Japan, principally in the Himekawa and Itoigawa regions, Niigata Prefecture, are given. I.S.

Identification du traitement thermique à haute température des corindons par spectrométrie infra-rouge.

C. DAVID AND E. FRITSCH. *Revue de Gemmologie*, 141-142, 2001, 27-31.

The detection of high-temperature treatment of ruby and blue sapphire, mostly of high-quality specimens has up to now relied upon the identification of inclusions and growth fractures with the microscope. IR spectrometry was first used to examine sapphires from Rock Creek, Montana when absorption at 3309 cm^{-1} [3021 nm] was found in heated stones, the absorption being the most prominent of a group of 5, caused by an OH-dipole linked to Fe and Ti atoms in the corundum lattice. A Fourier transform IR spectrometer was used in the present study in which specimens from 20 different localities were examined: tests (shown in graph form) were found to be effective for metamorphic sapphires when the absence or smallness of a peak at 3309 cm^{-1} indicates that the specimen has not been treated. In treated specimens the peak is significant. Sapphires of volcanic origin cannot be tested by this method. Specific absorptions of alumina hydrates (diaspore, boehmite) are seen only in sapphires which have not undergone HT treatment. The tests are also found useful for heated/unheated Mong Hsu rubies on the basis of the 3309 cm^{-1} signal. M.O'D.

The geology, mineralogy and rare element geochemistry of the gem deposits of Sri Lanka.

C.B. DISSANAYAKE, R. CHANDRAJITH AND H.J. TOBSCHALL. *Bulletin of the Geological Society of Finland*, **72**(1-2), 2000, 5-20.

Nearly all the gem-bearing formations of Sri Lanka are located in the central high-grade terrain of the Highland complex. They include sedimentary, igneous and metamorphic rocks, but sedimentary deposits are the most abundant; the gemstones include corundum, chrysoberyl, beryl, spinel, topaz, zircon, tourmaline garnet and sphene. The trace elements in sediments from the three main gem fields were determined; some of the host sedimentary rocks are considerably enriched in certain elements compared to their average crustal abundances. The Walawe Gorge sediments are anomalously enriched in the high-field-strength and associated elements, particularly Zr, Hf, W and Ti. This is attributed to the presence of accessory zircon, monazite and rutile in the heavy minerals, which may amount to <50 wt.%. The geochemical enrichment of some trace elements is taken to indicate that highly differentiated granites and associated pegmatites provided the source material for these sedimentary rocks. R.A.H

Minerals of the Brumado magnesite deposits, Serra das Eguas, Bahia, Brazil.

A. FALSTER, W.B. SIMMONS, K.L. WEBBER, J.W. NIZAMOFF, C.P. BARBOSA AND R.V. GAINES. Friends of Mineralogy/Tucson Gem & Mineral Show/Mineralogical Society of America. 21st Annual Symposium. *Mineralogical record*, **31**, 2000, 177-83.

A mineral assemblage associated with the magnesite deposits at Brumado, Serra das Eguas, Bahia, Brazil, includes uvite and dravite ranging from black to green to red to fine yellow, orange, pink or purple crystals of topaz up to several centimetres in length, aquamarine and emerald. M.O'D.

Cuprian elbaite from the Bocheiron Zinho pegmatite, Paraíba, Brazil.

A.U. FALSTER, W.B. SIMMONS, J.W. NIZAMOFF AND K.L. WEBBER. Friends of Mineralogy/Tucson Gem & Mineral Show/Mineralogical Society of America. 21st Annual Symposium. *Mineralogical Record*, **31**, 2000, 177-83.

Elbaite of vivid blue to green colour and showing prominent colour zoning with either pink cores and deep blue rims or blue cores with several outer zones of purple, green, blue or grey ['Paraíba tourmaline'] was found during 1988 from Mina da Batalha, Sao Jose da Batalha, Paraíba, Brazil. Analyzed specimens were found to contain up to 1.4 wt. % CuO in the blue zones, 0.2 wt. % MnO in the pale pink cores and 1.2 wt.% FeO in the deep green rims. Deep green specimens found in the footwall of the pegmatite held up to 3.0 wt.% FeO and many contained thin, platy inclusions of native copper. Causes of the coloration are briefly reviewed. M.O'D.

Ornamental variety of pink marble with apatite found near Eppawala, Sri Lanka.

M.D.P.L. FRANCIS AND P.G.R. DHARMARATNE. *Australian Gemmologist*, **21**(2), 2001, 91-4, 4 illus. in colour, 2 maps.

Because Sri Lanka is a major source of transparent to translucent gemstones, little attention has been paid to the many varieties of ornamental stones that also occur on the island. A deposit of one such ornamental rock, a variety of pink marble with apatite, is located at Galmaduwa 5 km south-east of Eppawala. In spite of its impurities (embedded apatite crystals), the pink marble is a very attractive, easily worked and inexpensive carving material. P.G.R

Origine de la couleur dans les gemmes.

E. FRITSCH AND G.R. ROSSMAN. *Revue de Gemmologie*, 141/142, 2001, 65-74.

Describes the various methods by which gemstones are coloured. Body-colour, phenomenal colour and play of colour are included. M.O'D.

Le traitement des perles.

J.-P. GAUTHIER. *Revue de Gemmologie*, 141/142, 2001, 42-5.

The various methods used to alter the colour of pearls are reviewed and their identification briefly noted. M.O'D.

Prehnite from La Combe de la Selle, Saint Christophe-en-Oisans, Isère, France.

L. GAUTRON AND N. MEISSER. *Mineralogical Record*, **32**, 2001, 223-32.

Fine large crystals of prehnite capable of being fashioned are reported from a classic alpine cleft deposit at La Combe de la Selle, Isère, in the French Alps – the famous axinite deposit of Bourg d'Oisans is not far away. The mineral was first described in 1789. Details of the local geology and mineralization are given, together with a descriptive list of associated minerals. Prehnite occurs as isolated and intergrown green translucent to partially transparent crystals up to 5 cm on an amphibolitic matrix. M.O'D

Descriptive mineralogy of inclusions in some faceted gem topaz from Brazil.

B. GELLER. Friends of Mineralogy/Tucson Gem & Mineral Show/Mineralogical Society of America. 21st Annual Symposium. *Mineralogical Record*, **31**, 2000, 177-83.

In a study of seven faceted topaz specimens from unidentified sites in Brazil the following minerals were identified: ilmenorutile, limonite, muscovite, rutile, struverite, tourmaline, zinnwaldite and three unknown phases. Optical and scanning electron microscopy and x-ray fluorescence were used in the investigation. The Virgem de Lapa region was ruled out as a site for the specimens as no recognizable lepidolite was identified. M.O'D.

Dal 'negorsk, Primorskiy Kray, Russia. (Famous mineral localities.)

R. GRANT AND W.E. WILSON. *Mineralogical Record*, **32**, 2001, 3-30.

The Dal'negorsk area in the east of Russia produces many fine minerals, some with ornamental application. These include exceptional calcite, danburite, found only in the Danburitiy mine and forming crystals exceptionally reaching 40 cm (some of this material has been irradiated to produce a deep golden-orange colour), datolite in green (attributed to Cr), honey-yellow to brown (RE) as well as colourless crystals, exceptional fluorite crystals, some occurring as green octahedra and some as yellow, rarely blue and purple. Some specimens have been called 'invisible fluorite' from their clarity. M.O'D.

Canadian emeralds: the Crown showing, south-eastern Yukon.

L.A. GROAT, T.S. ERCIT, D.D. MARSHALL, R.A. GAULT, M.A. WISE, W. WENGZYNOWSKI AND W.D. EATON. *Newsletter of the Mineralogical Association of Canada*, **63**, 2000, 1 and 12-13.

Numerous emerald-bearing float trains were discovered in a 900 x 400 m area on the Goal Net property, 600 m E of a granitic pluton in the Finlayson Lake district of SE Yukon. Washing and hand-sorting of ~ 6 m^3 of material yielded 6 kg of emeralds. The emeralds occur where quartz veins cut mica-rich layers in a chlorite-mica schist; they range in size from <1 mm to 4 cm in length. EPMA on 25 crystals gave average values of Cr 3209, V 171 ppm (some have Sc ≤ 499 ppm). Some of the smaller crystals (0.25 ct) and parts of larger crystals are of gem quality with excellent clarity and colour. R.A.H.

Jade: occurrence and metasomatic origin.

G.E. HARLOW AND S.S. SORENSON. *Australian Gemmologist*, **21**(1), 2001, 7-11, 2 maps.

The term jade refers to two extremely tough rocks; nephrite with a felted microcrystalline habit and jadeite/jadeitite with micro- to macro-crystalline textures. Nephrite is the more common and less valuable of the two jade types with important deposits in Canada, China, Russia, South Australia and New Zealand. Jadeite/jadeitite is much less common and only occurs as bodies in subduction-related serpentinite along major fault zones in Northern Myanmar, Guatemala, Russia and Kazakhstan, also in Japan. Recent investigations show that the jades share some common geological characteristics, and both result from and record important earth processes. P.G.R.

The gemstone occurrences of Madagascar.

U. HENN AND C. MILISENDA. *Australian Gemmologist*, **21**(2), 2001, 76-82, 8 illus. in colour, 2 tables.

For centuries Madagascar has been well known for its wealth of gemstones. By the beginning of the 20th century the island was supplying the world with commercial quantities of gems including beryl, tourmaline, various quartzes, spodumene, amazonite, labradorite and garnet. More recently, commercially important occurrences of blue and pink sapphires have also been discovered. This paper details the geology of the island's occurrences, and tabulates the gems in order of chemistry and of location. P.G.R.

Scottish gem lab news.

A. HODGKINSON. *Australian Gemmologist*, **21**(2), 2001, 83-7, 12 illus. in colour.

The author describes the use of the Hanneman tanzanite filter in the separation of tanzanites from their two look-alikes, synthetic forsterites and glass imitation tanzanites. When illuminated by incandescent light, tanzanites showed pinkish when viewed through the filter, unlike the synthetic forsterites. However, the glass imitations also showed pinkish, and to differentiate these from tanzanite, two polaroid strips, orientated so that their vibration directions are at right-angles, are added alongside the main filter. Any questionable gems which appear pink through the main filter are then scanned through the paired polaroid filters. The glass imitations remain the same blue colour, while the tanzanites display their diagnostic pleochroic colours. The author also describes and illustrates how visual optics can be used to separate tanzanite from these two simulants, and how visual optics and the Hanneman-Hodgkinson refractometer were used to identify a suspect pink synthetic perovskite as an orthorhombic yttrium aluminate. P.G.R.

New gemmological study of large garnets of supposedly Czech origin.

J. Hyrsl. *Gemmologie. Z. Dt. Gemmol. Ges.*, **50**(1), 2001, 37-42, 2 photographs, bibl.

Supposedly the largest Bohemian pyrope garnet is in the Green Vaults in Dresden and set in the Order of the Golden Fleece, which was made in Prague by Diessbach in 1749. The RI of this stone is 1.78, with a typical almandine spectrum. This specimen measures 34 x 27.4 x 9 mm and has a form of a reversed saucer with an actual thickness of about 3.5 mm. In an ancient inventory the weight was given as 46.75 ct (47.9 metric ct). The largest supposed Bohemian pyrope is in a Czech museum and weighs 13.21 ct; it has an RI of 1.79, an almandine spectrum and zircon inclusions. Examining other Bohemian garnet jewellery in the National Museum in Prague, the author found the pyropes to be usually smaller than 4 mm and found only rare examples up to 6.5 mm. E.S.

Minas Gerais – past and present.

A.R. Kampf. Friends of Mineralogy/Tucson Gem & Mineral Show/Mineralogical Society of America. 21st Annual Symposium. *Mineralogical Record*, **31**, 2000, 177-83.

Describes the discovery and exploitation of some of the gem-bearing pegmatites in the Brazilian state of Minas Gerais and more recently of some of the metamorphic deposits which have produced alexandrite, emerald and other species. M.O'D.

The identification of gems in Japan.

H. Komatsu. *Journal of Gemmological Society of Japan*, **20**(1-4), 1999, 111-25, 5 figs., 13 photos.

The macroscopic structure of pearl, the microscopic structure of the nacreous layer, origin of colour and lustre, and the shape of pearls are explained first. Appropriate methods to investigate these properties are pointed out. Following these explanations, methods to differentiate imitation pearls, nucleated and non-nucleated pearls, physically treated pearls, chemically treated pearls, thickly coloured pearls by treatment, and to identify mother oysters are explained. Basic procedures for distinguishing pearls are summarized in five steps; visual observation, microscopic observation, observation by light transmission method, by soft X-ray, and by precision analytical apparatus. I.S.

Gem News International.

B.M. Laurs (Ed.). *Gems & Gemology*, **37**(1), 2001, 64-78.

Mention is made of the first production of emeralds from Piteiras, Minas Gerais, Brazil; an 8.25 ct precision-cut block of iolite to demonstrate pleochroism; semi-transparent to translucent, greenish-yellow prehnite from Australia; and yellow-green faceted vesuvianite from California. R.A.H.

[SEM study of jadeite jade.] (Chinese with English abstract)

X.-w. Liu. *Yanshi Kuangwu. (Journal of Mineralogy & Petrology)*, **21**(1), 2001, 5-7.

The mineral composition, grain size and microstructural features of the green part of a specimen of jadeite were studied by SEM imaging, and the variation of scattering and intensity of colour were correlated with the grain size. SEM images of the cleavage planes show they are not smooth, but characterized by linear and sawtooth cleavage steps. R.A.H.

Gem pegmatites of the Ural Mountains, Russia.

P. Lyckberg and V. Ye Zagorsky. Friends of Mineralogy/Tucson Gem & Mineral Show/Mineralogical Society of America. 21st Annual Symposium. *Mineralogical Record*, **31**, 2000, 177-83.

The northern section of the central Ural Mountains of Russia includes notable miarolitic pegmatites carrying beryl, topaz and tourmaline in the western endo and exocontact of the Mursinka-Adui intrusions and the desilicated pegmatites surrounded by emerald-alexandrite-phenakite mineralization. Fine blue topaz with smoky quartz and albite is found at the Mokrusha, Golodnij, Tyazhitnitza, Staraja Mylnitsa, Starzewa Jama and Kazionnitsa mines. Gem-bearing pegmatites NW of Mursinka are enclosed in a serpentine and contain miaroles with coloured tourmaline: pegmatites to the W and SW contain green and yellow beryl and yellow or light blue topaz. The Sarapulka and Shaitanka pegmatites are thin veins with rubellite and rhodizite in the W and green and blue aquamarine in the E. Large amounts of emerald, alexandrite and phenakite have been produced since 1830 from the Takovaja district schists. Specimens recently discovered include combinations of phenakite/emerald and alexandrite/emerald. The southern Ural region centred on Miass in the Ilmen Mountains produced clear topaz crystals up to 3-4 kg and uncommon green beryl associated in miarolitic pegmatites with amazonite. M.O'D.

Laboratoire Français de Gemmologie: principaux examens pratiqués pour identifier le traitement thermique des saphirs.

P. Maitrallet and H. Garcia. *Revue de Gemmologie*, 141/142, 2001, 14-17.

Describes the examination of sapphires at the Paris Laboratoire Français de Gemmologie and the methods used to detect specimens whose colour has been affected by heat treatment. The authors make the point that traditional gemmological tests enable quite effective diagnosis to be made in many cases though examples cited show the usefulness of UV/visible spectroscopy. M.O'D.

Les corindons diffusés.

L. Massi and E. Fritsch. *Revue de Gemmologie*, 141/142, 2001, 18-26.

Details of tests carried out on 11 polished blue sapphires diffused with Fe and Ti, two blue sapphires diffused with cobalt and six red to orange sapphires diffused with Cr are given. The easiest method of detection was magnification using diffused lighting while

specimens were immersed in di-iodomethane, when uneven colour distribution was apparent with concentration near facet junctions and at the edges. Absorptions at 3310 and 3232 cm^{-1} and related to (OH) groups were found in the blue treated specimens: the peaks were not detected in the stones before treatment nor in the treated red stones. Their presence is ascribed to the reducing, H-containing atmosphere used. A red luminescence detected in the Co-diffused red stones was found to arise from Cr rather than Co. SEM examination of residues at the surface of treated stones shows the presence of molten alumina but also zones rich in Na, Al and K among other elements. Iridium and carbon (graphite) traces were presumed to be from crucible material. M.O'D.

Gemmologie Aktuell.

C.C. MILISENDA. *Gemmologie. Z. Dt. Gemmol. Ges.*, **50** (1), 2001, 1-4, 6 photographs.

Yellow and green sapphires from Malawi were examined. E.S.

Demantoide aus Pakistan.

C.C. MILISENDA, U. HENN AND J. HENN. *Gemmologie. Z. Dt. Gemmol. Ges.*, **50** (1), 2001, 51-6, 1 map, 1 table, 1 graph, 7 photographs, bibl.

Fifty samples of garnet came from a peridot mine in the Pakistan part of Kashmir. They were yellowish-green to emerald-green faceted stones, weighing between 1.04 and 11.38 ct. SG ranged from 3.77 to 3.85. chemical analysis showed relatively pure andradites with 0.25 wt. % of Cr_2O_3. The acicular, fibrous and felt-like mineral inclusions were shown to be chrysotile. E.S.

Composition and colour of uvite-dravite tourmaline from Brumado, Bahia, Brazil.

P.J. MODRESKI, E.E. FOORD AND C.P. BARBOSA. Friends of Mineralogy/Tucson Gem & Mineral Show/Mineralogical Society of America. 21st Annual Symposium. *Mineralogical Record*, **31**, 2000, 177-83.

Fibrous to prismatic reddish-brown dravite with up to 4-7 wt. % FeO, deep red platy to tabular crystals, identified as sodic uvite with 3 to 4% FeO, tabular green to brown discoidal crystals flattened on *c*, identified as uvite to calcic dravite and prismatic predominantly green but some colour-zoned crystals range from uvite through dravite, all from the magnesite deposits of Brumado, Bahia, Brazil, have been investigated by microprobe and other analytical methods. M.O'D.

What's new in minerals: Tucson Show 2001.

T. MOORE. *Mineralogical Record*, **32**, 2001, 245-57.

Among gem and ornamental specimens on display at the 2001 Tucson Show were fine green fluorite crystals from the Homestake (former gold mine site) in Oatman County, Arizona, where they occur as simple octahedra up to 4 cm. Purple fluorite crystals from the Sweet Home mine, Alma, Colorado, were also shown. Very large crystals of elbaite from a recently-struck large pocket at the Pederneira mine, Minas Gerais, Brazil, were coloured pink to deep red to smoky green: some reached 10 cm. Apple-green elbaites from a pocket at the Arqueana mine in the same state were also shown. A new find of brazilianite from the Telirio mine in Minas Gerais has produced pale yellow and yellow-green crystals. Fine crystals of kunzite were on display, the source being a pegmatite province located between the towns of Jos and Ibadan, Nigeria. Some of the crystals reached 10 cm and showed pronounced surface etching with pink/purple pleochroism. M.O'D.

Inklusen-Bernsteine: Informationsträger vergangener Erdepochen.

H.J. MÜLLENMEISTER. *Gemmologie. Z. Dt. Gemmol. Ges.*, **50** (1), 2001, 5-36, 85 photographs, bibl.

Beautiful photographs of fauna and flora of more than 25 million years ago preserved in amber. The inclusions which vary from animals (or parts of animals) with vertibrae, to insects and their eggs to plant parts, are described in detail. Fake inclusions and their provenance are discussed. E.S.

Ammolite: iridescent fossilized ammonite from southern Alberta, Canada.

K.A. MYCHALUK, A.A. LEVINSON AND R.L. HALL. *Gems & Gemology*, **37**(1), 2001, 4-25.

Ammolite is a form of aragonite obtained from vivid iridescent fossilized ammonite shells from the late Cretaceous Bearpaw formation, mainly mined S of Lethbridge, Alberta. Because the iridescent layers are thin and fragile, typically coming from naturally crushed and compacted specimens, it is generally marketed as doublets or triplets; some material may be stabilized by epoxy resin. R.A.H.

La tanzanite (ß zoïsite): detection de traitement thermique.

F. NOTARI, P.-Y. BOILLAT AND C. GROBON. *Revue de Gemmologie*, 141/142, 2001, 34-36.

Despite general belief it has been found possible to distinguish between heated and unheated transparent zoisite (tanzanite) by examination of the nature of the near-UV spectrum. Heated tanzanites transmit deeper into the UV; findings are shown in graph form and the technique is reported to have been 100% successful up to now. M.O'D.

Chronological table of events related to gemstones and jewellery in Japan.

H. OHTANI. *Journal of the Gemmological Society of Japan*, **20**(1-4), 1999, 175-89.

This paper presents chronological tables of events relating to finding and polishing of gemstones, jewellery making and gemmological studies in Japan, starting from the paleolithic stone age, the Jyomon, Yayoi and Kofun ages to historic ages. Japan has the oldest history in the

world in use of jadeite for religious and ornamental stones, which started in the earliest period of the Jyomon age, ca. 7000 BC. The use of natural minerals for ornamental purposes stopped entirely after the end of the Kofun age, ca. AD 500. However, Japan is now the second biggest importer of gemstones, after the USA. I.S

Sogdianite and sugilite from Dara-i-Pioz massif (Tajikistan).

L. A. PAUTOV, P. V. KHVOROV, V. A. MUFTAKHOV AND A. A. AGAKHANOV. *Proceedings of the Russian Mineralogical Society*, **129**(3), 2000, 66-79.

Chemical, optical and powder XRD data are reported for a new find of sogdianite in six different associations in pegmatite of the Dara-i-Pioz massif. A new variety of sogdianite with Sn 1.97% is described. Sugilite also occurs here, and the existence is demonstrated of an isomorphous series between sugilite and sogdianite. An unnamed hexagonal phase $KLi_3Zr_2Si_{12}O_{30}$ with milarite-type structure has been discovered in pseudomorphs after eudialyte; it is uniaxial positive with ω 1.578, ε 1.582; *a* 10.325, *c* 14.325 Å; H. 6.5, *D* 2.78 g/cm^3. A relationship was established between the cation occupation of octahedral site *A* and the filling of polyhedral *B* with Na while there is constant K in site *C*; when the *A* site is completely occupied by tetravalent cations, the *B* position is vacant giving the sodium-free silicate $KLi_3Zr_2Si_{12}O_{30}$. R.A.H.

The eastern Brazilian pegmatite province.

C. PREINFALK AND G. MORTEANI. Friends of Mineralogy/Tucson Gem & Mineral Show/ Mineralogy Society of America. 21st Annual Symposium. *Mineralogy Record*, **31**, 2000, 177-83.

The province includes the whole of the state of Minas Gerais, the southern part of the state of Bahia, the western margin of Espirito Santo and the northern part of Rio de Janeiro. Exploration of the area produced green tourmaline as long ago as the early 16th century. The pegmatites are often found in Proterozoic mica-schists and amphibolites, the major pegmatite-forming event taking place between 525 and 545 million years ago. Gem species found include tourmaline, aquamarine, topaz, brazilianite, kunzite, columbite-tantalite, spodumene and pollucite. M.O'D.

The chemical composition of biotite from granitic pegmatites and from metamorphic emerald deposits in the Eastern Brazilian Pegmatite Province [EBPP].

C. PREINFALK AND G. MORTEANI. Friends of Mineralogy/Tucson Gem & Mineral Show/ Mineralogical Society of America. 21st Annual Symposium. *Mineralogical Record*, **31**, 2000, 177-83.

Two theories of the genesis of schist-type emerald deposits (by exometasomatism or by a regional and usually multi-stage reaction between already emplaced Be-rich and alkali-rich rocks) are examined with respect to the EBPP. M.O'D.

Brazilian gem provinces.

C.P. PINTO AND A.C. PEDROSA-SOARES. *Australian Gemmologist*, **21**(1), 2001, 12-16, 1 map.

Emerald, alexandrite, aquamarine, tourmaline, topaz, chrysoberyl, amethyst, opal and morganite are the main coloured gemstones mined in Brazil. The Eastern Pegmatite Province is a major source of the beryl and chrysoberyl gems and of the kunzite variety of spodumene, the Southern Gem Province (Rio Grange do Sul) is the major world producer of amethyst and agate, the Piaui Gem Province produces opals, and the Bahia and Central Gem Provinces are Brazil's major emerald sources. P.G.R.

The history of Brazilian pegmatite gem mining.

K. PROCTOR. Friends of Mineralogy/Tucson Gem & Mineral Show/Mineralogical Society of America. 21st Annual Symposium. *Mineralogical Record*, **31**, 2000, 177-83.

Describes gem mining from the pegmatites in the NE portion of the Brazilian state of Minas Gerais. Gem crystals were first found by gold prospectors over 400 years ago. M.O'D.

The development and present geologic environment of the most important gem crystals and mines of Minas Gerais, Brazil.

K. PROCTOR. Friends of Mineralogy/Tucson Gem & Mineral Show/Mineralogical Society of America. 21st Annual Symposium. *Mineralogical Record*, **31**, 2000, 177-83.

Describes how the uplifting of pegmatite bodies and erosion of their cover has led to the discovery of many varieties of gem quality minerals. M.O'D.

The famous tourmaline, aquamarine and kunzite mines of Minas Gerais and their greatest gem crystals.

K. PROCTOR. Friends of Mineralogy/Tucson Gem & Mineral Show/Mineralogical Society of America. 21st Annual Symposium. *Mineralogical Record*, **31**, 2000, 177-83.

The primary deposits of Cruzeiro, Jonas, Xanda, Limoeiro, Golconda, Medina and Corrego do Urucum and the secondary deposits of Barra de Salinhas, Ouro Fino, Santa Rosa, Morro Redondo, Frade and the Pioneer mine in the Tres Barros area near Marambaia produce some of the world's finest tourmaline, aquamarine and kunzite. M.O'D.

Uber das Salz der Erde und vom Gold aus Ophir-Mineralogisches aus der Bibel.

H. ROESER. *Aufschluss*, **52**, 2001, 129-67.

Four primary classes of references to minerals in the Bible are: minerals in the manufacture of tools, of jewellery, of religious artefacts and for popular use. Naming conventions are discussed and in spite of nomenclature problems it is still possible to establish

which species is meant in a particular context. Gold and salt have a particular significance in the Bible. A table giving names and compositions of the minerals cited refers to the book, chapter and verse and there is an extensive bibliography. M.O'D.

Glass-filled rubies ou rubis rebouches.

K. SCARRATT. *Revue de Gemmologie*, 141/142, 2001, 11-13.

Summary with appended questions and answers on glass-filled rubies with special reference to material from Mong Hsu. M.O'D.

Emerald deposits – a review.

D. SCHWARTZ AND G. GIULIANI. *Australian Gemmologist*, **21**, (1), 2001, 17-23, 1 map.

Emerald is scarce because the juxtaposition of Cr/V and Be in nature is rare in that it requires exceptional geological and geochemical conditions. Sources of chromium and vanadium are mafic-ultramafic igneous rocks found in suture zones and volcano-sedimentary series, as well as in sedimentary formations such as black shales. Sources of beryllium are pegmatitic and A1/Si-rich magmas, black shales and metamorphic rocks. The review describes the conditions which make it possible for emerald mineralisation to occur in worldwide green beryl deposits. P.G.R.

Gem tourmaline chemistry and paragenesis.

W.B. SIMMONS, K.L. WEBBER, A.U. FALSTER AND J.W. NIZAMOFF. *Australian Gemmologist*, **21**(1), 2001, 24-9, 12 illus., 1 map.

Tourmaline is a well-known and widely mined variety that is recovered from highly fractionated granitic pegmatites worldwide. The wide range of colours, good durability and reasonably ample supply make this mineral one of the most important gemstones. The study examines the colour and chemistry of gem tourmaline from pegmatites in Russia (Transbaikalia), Madagascar, North America and northern Brazil. P.G.R.

Quartz crystals twinned after Brazil and Japan laws – origin of their morphological and textural characteristics.

I. SUNAGAWA. *Journal of The Gemmological Society of Japan*, **20**(1-4), 2000, 23-36, 12 figs.

Brazil twins are formed by joining polymerized particles of 10 nm size with right-hand and left-hand quartz structures and develop as polysynthetic twin lamellae. A large number of Brazil twin lamellae co-operate to form Brewster fringes, which are observed in natural amethysts. Brazil twin is a growth twin formed when natural quartz crystals grow under low temperature conditions, in the presence of impurity ions. But, even under high temperature synthetic conditions, generation of a Brazil twin can be triggered by a strain field associated with inclusions of impurity components, mainly ferric iron oxide or hydroxide, and with dislocations therefrom. Japanese twins are formed during the nucleation stage by joining two quartz individuals of the same structure on their well developed rhombohedral faces. At this stage, quartz crystals take a hexagonal bipyramidal habit with no prism faces developed. Dislocations concentrate in the twin junction plane, and act as preferable sites for step generation, resulting in an 'apparent' or 'pseudo' re-entrant corner effect, so far as rhombohedral faces meet at twin junction. A more flattened habit and larger size of Japanese twins compared with the co-existing single crystals, and the morphological evolution as growth proceeds can be explained in terms of the 'apparent' re-entrant corner effect and the difference in effectiveness of dislocations as active growth sources between rhombohedral and prism faces. V- and fan-shapes of Japanese twins represent the upper half of a Y-shape, and not of and X-shape, indicating that they belong to a contact twin. Freely developed Japanese twins show a Y-shape. I.S.

Origin of gem corundums from basaltic fields.

F.L. SUTHERLAND AND D. SCHWARTZ. *Australian Gemmologist*, **21**(1), 2001, pp.30-3, 2 illus., 2 tables.

Gem corundums, both sapphire and ruby, are eroded from particular basaltic eruptives. They are recorded in six continental regions, within fifteen countries and involve over forty main basalt fields. These fields discharge both magmatic and metamorphic origin corundums from underlying sources. Several fields with bimodal origins are now known. 'Magmatic' sapphire suites exhibit more consistent trace element variations that 'metamorphic' sapphire-ruby suites, which encompass a diversity of metamorphic origins. P.G.R.

The geology of Australian opal deposits.

I.J. TOWNSEND. *Australian Gemmologist*, **21**(1), 2001, 34-7, 1 map.

The many variations of opal depend on a number of factors. Firstly, the climate must provide alternating wet and dry periods, creating a rising or more importantly a falling water table which concentrates any silica in solution. The silica itself is formed either by volcanic activity or by deep weathering of Cretaceous clay sediments producing both silica and white kaolin. Each local opal field or occurrence must have contained voids or porosity of some sort to provide a site for opal deposition. Silica spheres, once formed, are deposited in a regular array in these voids from a receding water table to produce precious opal. P.G.R

Recent mineral occurrences from north-eastern Brazil.

R. WEGNER. Friends of Mineralogy/Tucson Gem & Mineral Show/Mineralogical Society of America. 21st Annual Symposium. *Mineralogical Record*, **31**, 2000, 177-83.

Gem-quality minerals recently found in the states of Paraiba and Rio Grande do Norte, NE Brazil include apatite with distinct colour zoning from yellow cores to blue or green rims from the Alto Feio pegmatite, Paraiba:

perfectly crystallized cognac-coloured herderite crystals up to 12 cm from the Alto des Flechas pegmatite near Pedra Lavada, Paraiba (this pegmatite has produced fine golden beryl in the past) and amethyst sceptre crystals with milky quartz bases from the area of Santana de Mangeiras, Paraiba. M.O'D.

Gallery review: the R S McLaughlin Mineral Hall, Royal Ontario Museum.

J S WHITE. *Mineralogical Record*, **32**, 147-151, 2001.

Review of the newly-arranged Treasures of the Earth portion of the new Dynamic Earth display at the Royal Ontario Museum, Toronto. Treasures of the Earth comprises the mineral and gem exhibits. Following some recent display history and a description of the collections which are excellent in themselves, notes on presentation find, as well as a number of positive points, serious inadequacies in labelling both in quantity and content, as well as in the general arrangement of some of the specimens. Some ancillary services do not work too well and there were no booklets available in one of the rooms although they were advertised. It should be possible to rectify some if not all of the shortcomings (including poor commentaries from guides) with minimum effort and expense. M.O'D.

The minerals of Russia.

Annual FM-TGMS-MSA Mineralogical Symposium, 22nd, 2001, Tucson, 2001. *Mineralogical Record*, **32**, 2001, 39-47.

Papers on various aspects of Russian minerals are abstracted. Those concerning gem and ornamental species include: Famous mineral localities and mineral collecting in the former Soviet Union: Nomenclature of quartz colour variations - pink and rose: Gem pegmatite and greisen deposits of Russia during the twentieth century: Gem pegmatites of Ukraine, Kazakhstan and Tajikistan: Gem beryl and topaz of Sherlovaya Gora, Transbaikal, Russia. M.O'D.

What's new in minerals.

[Various authors.] *Mineralogical Record*, **32**, 2001, 53-64.

The mineral shows covered this time are Springfield and Denver: notable examples of Colorado gem minerals available include rhodochrosite from the Sweet Home and Sunnyside mines, aquamarine from Mount Antero, zircon as sharp lustrous brown crystals in matrix from St Peter's Dome. At the same show were a few gem-quality brownish-green elbaite crystals, their characteristic oily lustre indicating their origin from the Gillette quarry, Haddam Neck, Connecticut. Deep yellow-green sphene crystals were available from the classic locality of Capelinha, Minas Gerais, Brazil (such specimens have been rare for a number of years). Some dealers at Springfield were showing pale translucent pink elbaite said to be from the Mogok district of Burma: a most unusual transparent pale smoky-brown phlogopite from the same area was on show.

At the Denver show crystals of brazilianite were available – they were pale to medium-intense greenish-yellow, some on a matrix of albite. The location was the Telirio mine, Linopolis, Minas Gerais. Raspberry-red elbaite was on view from Nigeria 'near Oyo City' and fine deep blue aquamarine with schorl on feldspar was being sold – the location Bergsig 274, Erongo mountains, Namibia. Afghanistan has produced deep orange danburite from 'somewhere in Nuristan' [but see Grant and Wilson above for irradiated danburite]. M.O'D.

Instruments and Techniques

Dispersion, birefringence, and the critical angle refractometer.

W.W. HANNEMAN. *Australian Gemmologist*, **21**(2), 2001, 88-90, 3 illus.

The author first outlines the basic determinative value of the critical angle refractometer in measuring the RI and, more importantly, the DR of a gemstone. Concurrently, the gem's optical character and optic sign are easily determined on the same instrument, and these four properties provide sufficient information to identify the majority of gem materials within the RI range of 1.4 to 1.80. In discussing the practical value of a proposed method for measuring the dispersion of a gemstone on the standard refractometer, a plot of dispersion values against RI over the range of 1.4 to 1.81, produces a cluster of points which the author claims to be of limited determinative value. P.G.R.

The present status of application of instrumental methods of gem identification – examples of identifications using EDS, X-radiography, FT-IR.

M. HAYASHI. *Journal of Gemmological Society of Japan*, **20**(1-4), 1999, 99-110, 22 figs., 4 tables.

Several examples are given to demonstrate how EDS, soft X-ray transmission, FT-IR spectroscopy can be applied to gem identification. These include identification of flux inclusions in Kashan ruby by EPMA, XRF, EDXRF analyses of natural, GE and Sumitomo synthetic diamonds, of natural, synthetic, and heat-enhanced sapphire, X-radiographic investigation of Koss, Yehuda-treated diamond, emerald, jadeite, FT-IR investigation of natural of natural and synthetic alexandrite, natural and resin-impregnated jadeites. I.S.

Quantification and visualization of diamond brilliancy.

K. INOUE. *Journal of Gemmological Society of Japan*, **20**(1-4), 1999, 153-67, 11 figs, 13 photos., tables.

The degree of brilliance is quantified by evaluating intensity of light reflected in stones. A computer algorithm was applied to calculate ray trajectories in three dimensional space for the case of a round brilliant diamond. The principles to calculate the intensity in light reflected in three dimensional models of a round brilliant

diamond are explained first. Computer analyses are applied to a lumpy stone, an ideally cut stone, and three cut stones with proportions commonly encountered in the market. How the degree of brilliance changes depending on the proportions is demonstrated. I.S.

Re-examination of optimum cutting angles between main facets of gemstones based on geometrical optics

A. KATO. *Journal of Gemmological Society of Japan*, **20**(1-4), 1999, 127-43, 21 figs., 2 tables.

This is a summarized English translation of Kato's paper in Japanese published in the same Journal, **9**(1), 3-17, 1982, with supplementary comment and selective bibliography on diamond cutting by W. Funnel. I.S.

A method for computation of gem faceting.

M. KATO. *Journal of Gemmological Society of Japan*, **20**(1-4), 1999, 144-51, 6 figs.

Mathematical formulae based on solid geometry are derived to calculate the best faceting design of any gemstone. The formulae are applied to calculate appropriate cutting angles and edge proportions, and the results are illustrated using the orthogonal projection. I.S

Cathodoluminescence method and its applications to gemmology.

T. MIYATA, H. KITAWAKI AND M. KITAMURA. *Journal of Gemmological Society of Japan*, **20**(1-4), 1999, 63-78, 28 figs, 8 tables.

Observations on growth banding revealed by cathodoluminescence (CL) images of diamonds have demonstrated that (1) growth morphology of natural diamonds consists of flat {111} faces with or without curved {100} faces, whereas that of synthetic diamonds consists of flat {111} and {100} faces, and (2) each diamond has its characteristic pattern of growth banding. These characteristics can be used as diagnostic features to be used in discriminating natural from synthetic diamonds, as well as fingerprinting an individual stone. CL observations on 10 pieces of synthetic emerald, which were identified beforehand by ordinary gemmological tests and NIR spectroscopy, have demonstrated that flux-grown emeralds show straight parallel growth banding or 'aurora-like' bright spots, whereas hydrothermally-grown emeralds show 'comet-like' spots arranged in certain directions or show a unique rhombic pattern. It is therefore anticipated that natural and synthetic emeralds and flux- and hydrothermally-grown synthetic emeralds can be distinguished by CL observations. I.S.

A new method to identify a cut gemstone.

C. RINAUDO, B. CAPELLE AND R. NAVONE. *Gemmologie. Z. Dt. Gemmol. Ges.*, **50** (1), 2001, 43-50, 1 table, 2 sketches, 8 photographs, bibl.

X-ray transmission topography allows fingerprinting of a cut gemstone which enables recognition after a re-cut. When a white beam of a synchrotron is applied, a few seconds are sufficient to record the topography on a plate film placed behind the stone. The features shown are quite distinctive on each individual stone. E.S.

Laser tomography; a new powerful method to identify natural, synthetic and treated stones – case study of corundum.

J. SHIDA. *Journal of Gemmological Society of Japan*, **20** (1-4), 1999, 79-98, 30 figs, 1 table.

Laser tomography is a non-destructive method to visualize light scattering centres of sub-micron size and associated luminescence in nearly perfect transparent single crystals. The method was designed by Moriya and Ogawa (1983), and can visualize distribution of laser scattering centres in transparent crystals by scanning laser beams and recording the image on photographic film. The method was applied to many gem quality samples of natural, synthetic and heat-enhanced corundum. It was possible to obtain information relating to distribution of impurities, growth sectors, dislocations in these crystals, both rough and cut stones. Flux-grown, hydrothermally grown, and melt-phase grown (Verneuil, CZ, FZ) synthetic rubies, overgrowth rubies, and heat-enhanced rubies show respectively different characteristic laser tomographs. Also sapphire from Kashmir exhibits different tomographs from those of other localities. Heat-enhanced sapphires give diagnostically different features from non-enhanced sapphires. It was demonstrated that laser beam tomography is a powerful new method in gem identification. I.S.

La tracabilité des émeraudes: une avancée décisive obtenue par microscopie infrarouge.

A. CHEILLETZ, P. DE DONATO AND O. BARRÈS. *Revue de Gemmologie*, 141/142, 2001, 181-3.

Microscopy in the IR region with Fourier transforms has been found useful in the determination of the nature and locality information of emerald. Examples and background are discussed. M.O'D.

Synthetics and Simulants

Growth of high pressure synthetic diamonds.

H. KANDA. *Journal of the Gemmological Society of Japan*, **20**(1-4), 1999, 37-46, 6 figs.

HPHT synthesis of large size, gem-quality diamonds, and colour control of synthetic diamonds are summarized. HPHT growth technique has been highly improved to produce 30 ct diamonds of type II. Yellow, blue, green and brown coloured diamonds have also been obtained. The colour depends on composition of the alloy used as solvent and on the growth temperature. The colours are changed by annealing. I.S

Gemmologie Aktuell.

C.C. MILISENDA. *Gemmologie. Z. Dt. Gemmol. Ges.*, **50** (1), 2001, 1-4, 6 photographs.

Samples of hydrothermally grown synthetic corundum from Russia were blue, red, purplish-blue, bluish-green and yellow. A transparent eye-clean faceted stone was offered as sapphire but was shown to be CZ. E.S.

Gem Trade Lab notes.

T.M. MOSES, S.F. MCCLURE AND M.L. JOHNSON (EDS). *Gems & Gemology*, **37**(1), 2001, 56-63.

Items noted include a 3 ct synthetic apatite (with appreciable Nd) showing a colour change from purple-pink in incandescent light to violet-blue in fluorescent light and a bangle of quartzite dyed three colours to imitate jadeite. R.A.H.

Quartz α SiO_2: discrimination des améthystes et des citrines naturelles et synthétiques.

F. NOTARI, P-Y. BOILLAT AND C. GROBON. *Revue de gemmologie*, 141/142, 75-80, 2001.

While IR methods will distinguish amethyst and citrine grown on flat seeds they cannot be used when growth takes place upon a crystal of natural habit. Use of the microscope to interpret interference patterns remains the best method of detection: techniques are described and illustrated. M.O'D.

Hydrothermal synthetic red beryl from the Institute of Crystallography, Moscow.

J.E. SHIGLEY, S.F. MCCLURE, J.E. COLE, J.I. KOIVULA, T. LU, S. ELEN AND L.N. DEMIANETS. *Gems & Gemology*, **37**(1), 2001, 42-55.

Hydrothermal red beryl has been synthesized for use in jewellery by the Institute of Crystallography and Encom Ltd., both in Moscow. Diagnostic features include a tabular crystal morphology, chevron-like and sub-parallel or slightly wavy internal growth zoning, sharp absorption bands at ~ 530, 545, 560, 570 and 590 nm due to Co^{2+}, water-related absorption bands between 4200 and 3200 cm^{-1} in the IR spectrum, and the presence of Co and Ni peaks in EDXRF spectra. These red beryls have ε (purplish-red) 1.569-1.573, ω (orange-red to orange-brown) 1.576-1.580; SG 2.67-2.70; electron microprobe analyses are given for three samples. R.A.H.

Disclosure – gemstones and synthetics.

TAY THYE SUN. *Australian Gemmologist*, **21**(2), 2001, 67-75, 15 illus. in colour.

The worldwide gemstone and jewellery industries are becoming increasingly aware of the importance of appropriate disclosure of the true nature of synthetics, value-enhanced gemstones and imitations to purchasers of these materials. In this paper the author discusses the relevance of such disclosure to the economic survival of the gemstone and jewellery business, and as an example of modern gemstone treatment focuses on A-, B-, C- and B+C- jade. Although advanced instrumentation, such as FTIR spectroscopy, is generally considered essential for positive identification of these materials, practical advice is offered on some basic observations which can be used to recognize these treated jadeite jades. P.G.R.

Formation and quality of pearls.

K. WADA. *Journal of the Gemmological Society of Japan*, **20**(1-4), 1999, 47-62, 23 figs.

Based on optical and electron microscopic observations on microtextures of iridescent and non-iridescent pearls (natural and cultivated pearls formed by the family *Pteriidae*, Conch Pearl formed by sea-water gastropod *Strombus gigas*, Calm pearl produced by the calm and the short necked calm, etc.), the kind and quality of pearls are classified into several types depending on the microtextures, components and formation. The quantities of cultured pearls are systematically analyzed based on the surface and body colour, thickness of nacreous layer, flaws, shape and size. The biological function and regulation applied to control the pearl quality are discussed to help the evolution of technological studies in controlling the quality of cultured pearls. I.S.

Russian colourless synthetic diamond.

J.C.C. YUAN. *Australian Gemmologist*, **20**(12), 2000, 529-33, 13 illus., 1 table.

Since January 1999, Russian-made gem-quality colourless to near colourless synthetic diamonds have been available on the US market at prices more than double that of natural diamond. These type IIa diamonds have identifying metallic inclusions, are magnetic and display SWUV luminescence and phosphorescence which differs from that of natural diamonds. Images from the De Beers DiamondView instrument are also diagnostic for these synthetic diamonds. It is believed that as the 'split sphere' synthesis technology used in Russian factories (or in factories licensed to use this technology outside Russia) becomes more productive and cost effective, the colourless synthetic diamond will eventually be in a position to compete against the natural diamond. P.G.R.

Characterization of a new Chinese hydro-thermally grown emerald.

C. ZHENQIANG, Z. JILANG, C. KEQIN, Z. CHANGLONG AND Z. WEINING. *Australian Gemmologist*, **21**(2), 2001, 62-6, 3 illus. (two in colour), 2 tables.

Five sample emerald crystals of a new hydrothermal type synthesised by the Gemological Institute of Guangxi in the People's Republic of China were evaluated in this report for their gemmological, chemical and spectroscopic characteristics. Common diagnostic features of the new synthetic included a strong reaction under the Chelsea colour filter, a moderate red LW UV fluorescence and a much lower chlorine and higher alkali element content. P.G.R.

BOOK REVIEWS

Ammolite 2. A guide for gemmologists, jewellers and lapidaries.

D. BARNSON, 2000. The author, P O Box 179, Selkirk, Manitoba, Canada. pp 116, illus. in colour, softcover. ISBN 0 9688580 0 7. Price on application.

Ammolite has gained in popularity from its first appearance in the late 1970s. In 1981 it was recognised as a gemstone by CIBJO and the various names originally proposed for it have now, fortunately, been subsumed into ammolite. This second extensive and well-illustrated text gives a history of its discovery and of the realisation that it has considerable gem potential. Various types and localities are described and there are useful notes on fashioning what can prove to be quite a difficult material which does, however, easily lend itself to use in composites, as in opal. There are short notes on identification (though ammolite, once seen, is very distinctive), high-quality pictures of the play of colour seen under magnification (the use of colour throughout the book is excellent), notes on colour grading, a glossary and a bibliography. This is a very attractive book and seems likely to become the standard work on ammolite for the foreseeable future. M.O'D.

The Mineralogical record index, volumes I-XXV, 1970-1994.

E.L. CLOPTON AND W.E. WILSON (Eds), 1996. The Record, Tucson. pp 312, hardcover. Price on application.

Five-year author/title index to vols 26-30, 1995-1999 [Comprises pp 119-134 of vol.. 31] issued as separate pamphlet.

In 1985 the Friends of Mineralogy, an independent non-profit organization, published an index to volumes 1-14 of *The Mineralogical record* which, apart from binding problems and some awkwardness of structure, has served well up to the present. Information in the new index is divided between author/title and general/subject sections, with full bibliographic details given in the author/title section. Searching is by keyword taken from the titles, making it easy for the searcher to find the complete citation. Adoption of the new structure made re-editing of the previous 10-year index and additional material in the same form necessary. There will be no further indexes cumulative back to volume 1: the next indexing project is expected to cover volumes 26-35. For this reason the present index is strongly bound with sewn rather than glued pages.

Readers will find considerable pleasure and much useful information in just leafing through the index, whose print run is said to be small. M.O'D.

Mineralogy of Maine. Volume 2: mining history, gems and geology.

T.V. KING (Ed.), 2000. Augusta, ME 04333: Maine Department of Conservation, Maine Geological Survey, Station #22. pp vi, 524, illus. in black-and-white and in colour, hardcover. US $50

This is the second volume of *Mineralogy of Maine*, the first one having been published in 1994 (reviewed in *J.Gemm.* 1996, **25**(3), 241), edited by King and the now sadly late Eugene E Foord. This is described in the present book as a greatly expanded species-localities checklist. The Maine Department of Conservation deserves the warmest thanks of all connected with the minerals and gemstones of the State for persisting with this publication, whose richness mirrors that of the minerals described. This should be the ideal for all area surveys.

In the words of the editor, this book attempts to give a wider picture of Maine's minerals. In succeeding in this aim, several authors have been called into service and tables of other contributors show how great has been the interest in one of the most important mineralized areas of the United States. The book starts with geological history, describes the five recorded meteorites and then begins on the select history of Maine mining and minerals which begins in the 17th century and continues to the present day. In the course of the account, which extends over approximately 240 pages there are many references both to geologists and others prominent within the state and to workers of world stature. In this way the reader can learn a great deal of general mineralogical history as well as the more local events and occurrences. During this section details of many important publications are also given.

The Maine Geological Survey and its work are described next, by the present State Geologist and this section is followed by an account of the gem-cutting machine devised by Loren B. Merrill and then by three sections, each with very great gem importance, describing Mount Mica in 1964 and 1965, the Newry tourmaline discovery of 1972 and extracts from a diary kept by a miner at the Dunton mine. For the reader's information, all three locations are celebrated for their tourmaline, though the state also produces fine garnet, purple apatite, morganite and beryl.

A chapter by John Marshall deals with the gemstones of Maine, photographs of which appear in the colour section immediately following. Later chapters include Maine literature for the collector, a Maine mineral locality list and Addenda to the mineralogy described in the first volume of 1994. A section of black-and-white photographs and an index complete the book

I cannot imagine this work being equalled let alone surpassed by work in any other of the world's great mineral locations. To possess such a survey for a major gem-producing area is a bonus and the book can be picked up and consulted at any time for general reading while containing everything needed for strict scientific evaluation of the minerals encountered. The price is amazingly reasonable and the standard of the production high without being exotic. The lists of references are a

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model of their kind and the photographs show the distinctive colours of Maine tourmaline. The maps in the mineral locality section are easy to read and scattered through the texts are advertisements for machines and other mining equipment from the early days. M.O'D.

Mogôk – Valley of rubies and sapphires.

T. THEMELIS. 2000. A & T Publishing, Los Angeles. pp 270, illus. in colour, hardcover. £79.00.

In a profusely-illustrated study the author presents the Mogôk area of Burma, beginning with notes on the pre-history and history of the country as a whole and passing on to the gradual establishment of communities and local rulers by the middle of the tenth century. Established fact is mixed with fable and the whole account presented in a readable and lively way. The reigns of the chiefs and sovereigns from 1044-1287 and the establishment of British rule in Burma began to coincide with the development of ruby mining by the nineteenth century and a number of authorities are cited: photographs of early mining scenes and of documents are very attractively inserted into the text at the appropriate places and there are also reproductions of relevant maps.

The historical account takes the reader up to 2000 when, the author tells us, up to 1200 ruby mining sites were in operation in Mogôk, which town is now introduced on page 83. There is a good deal of physical and commercial geographical and local historical detail here and chapters 3 and 4 introduce us to the people of the region with their ethnic origin, religion, customs and folk-lore recounted. The fifth chapter discusses the commercial aspect of gemstones and there is a good deal of interesting history of how the stones are traded: as in the previous chapters photographs, newspaper cuttings and text are pleasingly intermingled. The work of the Mogôk lapidaries is described in chapter 6 and notable Mogôk rubies and sapphires in the following chapter. The specimens are very well illustrated with what appear to be accurate colour rendering: named rubies and some sapphires are listed with their history and present whereabouts where known. Chapter 8 gives details of the Burmese court regalia and the final chapter deals with jewellery and jewelled artefacts made in the area and set with the local stones.

A selected bibliography includes welcome citations of East India Company documents (now held in the British Library) as well as most other relevant monographs and papers. The two important works by Harbans Lal Chhibber, *The mineral resources of Burma, 1934 (Sinkankas #1280)* and *The geology of Burma* (1934) and one by Bender, *Geology of Burma* (1983) [with a very large and scholarly bibliography] could well be added to any future edition, though the present work is not intended as a scientific study.

It is, however, an admirable introduction to a fascinating area with pleasures on every page. M.O'D.

Colour and the optical properties of materials.

R. TILLEY, 2000. John Wiley & Sons Ltd, Chichester. pp xii, 335, illus. in colour, softcover. ISBN 0 471 85198 1. £24.95.

A useful and well-produced book which can be read alongside Nassau: *The physics and chemistry of color* (1983). While gemstones are covered briefly in the text, with plentiful opportunities for complexity and hard thought on the part of the reader, the book is arranged into 13 chapters in which considerations of colour in many wider contexts are provided. The first chapters cover the nature of light and colour, refraction and dispersion, crystals and light, the production of colour by reflection, colour due to scattering and to diffraction, from atoms, ions and molecules and from charge transfer and luminescence. The reader can then proceed to discussion of metals, semiconductors and insulators (this chapter includes band theory), fibre optics and data transmission, displays (cathodoluminescence is here) and finally lasers and holograms.

Chapters include problems and exercises (with answers to the numerical ones at the back) and each chapter has a very short list of references. There are some attractive colour plates and the colour of red wine is introduced in the chapter dealing with colour from molecules.The print is very easy to read and the price reasonable for a stimulating work. M.O'D.

BOOK SHELF – NEW TITLES

Mogôk – Valley of rubies and sapphires by T.Themelis £79.00

Diamond Grading Manual. The Gemmological Association £17.50

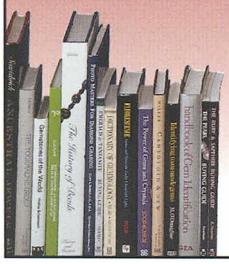

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Proceedings of the Gemmological Association and Gem Testing Laboratory of Great Britain and Notices

AWARD

At the Inter/Micro-2001 Conference and SMSI Awards Banquet held at the Knickerbocker Hotel, Chicago, on 27 June 2001, **Dr Jamie Nelson** (GA Research Diploma) received the August Köehler Medal Award of the State Microscopical Society of Illinois for 'Outstanding contributions to microscopy'. On the following day Dr Nelson presented a lecture to the conference entitled 'A Raman spectra database and its application to gemmological science' and a talk on 'The microscopy of gemstones'.

GEM-A OPEN DAYS

On 15 August at the Gem Tutorial Centre, 27 Greville Street, London EC1N 8TN, an Open Day was held which included displays and hands-on gem sessions. A report was published in the September issue of *Gem & Jewellery News*. A Gem-A open day was also held in Birmingham on 22 August.

ANNUAL GENERAL MEETING

The Annual General Meeting of Gem-A was held on Monday 25 June 2001 at 27 Greville Street, London EC1N 8TN. Jeffrey Monnickendam chaired the meeting and welcomed those present. The Annual Report and Accounts were approved.

Terry Davidson, Michael O'Donoghue and Ian Thomson were re-elected and Jean-Paul van Doren elected to the Council of Management. Dr Tony Allnutt, Sally Everitt, Brian Jackson and Peter Wates were re-elected and Sheila Burgoyne elected to the Members' Council. Amanda Good did not seek re-election. After lengthy discussion regarding the remit of the Members' Council and a possible conflict of interests, the nomination of Laurent Kellerson for election to the Members' Council was not approved. However, the establishment of a group to consider members' and educational matters was discussed. Hazlems Fenton were re-appointed auditors.

Following the Annual General Meeting, a Reunion of Members and Bring and Buy Sale were held, at which winners of the 2001 Photographic competition were announced. During the evening Gem-A, the new image for the GAGTL, was launched.

GEM DIAMOND EXAMINATION

In the Gem Diamond Examination held in June 2001, 97 candidates sat of whom 65 qualified, including six with Distinction and eight with Merit.

The **Deeks Diamond Prize** for the best candidate of the year in the Gem Diamond Examinations has been awarded to Allyson Thomas of Birmingham, West Midlands.

The Bruton Medal has not been awarded

The names of the successful candidates are listed below:

Diploma

Qualified with Distinction

Dines, Rachel S., North Dulwich, London
Kai Wang, Wuhan. P.R. China

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FORTHCOMING EVENTS

26 October	**Midlands Branch**. *Beautiful opals, Australia's national gemstone.* JOHN WHEELER
4 November	**Gem-A CONFERENCE 2001. Barbican Conference Centre, London**
	Keynote speaker: GEORGE BOSSHART, ***Gübelin Gem Lab, Lucerne***
	Further details are given on p. 460
5 November	**London**. *Presentation of Awards and Reunions of Members*
20 November	**Scottish Branch**. *Jade.* ROSAMOND CLAYTON
21 November	**London**. *Analysis of precious stones under thick glass by Mobile Raman Microscopy (MRM) and Compositions of jade and garnets by non-destructive Raman Microscopy.* PROFESSOR DAVID SMITH
21 November	**North West Branch**. *AGM and social evening*
25 November	**South West Branch**. *Everything included.* DOUG GARROD *Pearls of Wisdom.* MARCUS MCCALLUM
30 November	**Midlands Branch**. *Wonderful emeralds.* ALAN HODGKINSON
6 December	**London**. *The literature of gemstones.* MICHAEL O'DONOGHUE
8 December	**Midlands Branch**. *Annual Dinner, 49th year*
9 January	**London**. *An orgy of organic gem materials.* E. ALAN JOBBINS
25 January	**Midlands Branch**. *Gemmology quiz and Bring & Buy*
22 February	**Midlands Branch**. *An orgy of organics.* E. ALAN JOBBINS

Midlands Branch

A day in celebration of fifty years of gemmology

A one-day conference, including celebration lunch, to be held on
Sunday 24 February at Barnt Green near Birmingham

Speakers will include:

PROFESSOR DR HENRY HÄNNI

E. ALAN JOBBINS

IAN MERCER

For further information contact Gwyn Green (details below)

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South West Branch:	Bronwen Harman on 01225 482188 e-mail: bharman@harmanb.freeserve.co.uk

Gem-A WEB SITE

For up-to-the-minute informatin on Gem-A events visit our web site on www.gagtl.ac.uk

GIFTS TO THE ASSOCIATION

The Association is most grateful to the following for their gifts for research and teaching purposes:

Argos Ltd, Milton Keynes, for nine CZ-set rings.

Paul R. Cassarino, Rochester, NY, U.S.A., for a set of original GA course notes from the 1950s for the Association's archives.

Jane Kalischer, Finchley, London, for a marble carving and collection of gem-set jewellery.

Kyaw Khaing Win, Myanmar, for an aquamarine crystal from Thitseintkone mine, Myanmar.

Dian Packer, London, for three pieces of nephrite and a piece of margarite.

Preseli Bluestone Ltd, Pembrokeshire, Wales, for cabochons and rings of Preseli bluestone.

Christopher Tarratt, of George Tarratt, Stoneygate, Leicestershire, for a Tully refractometer in its original box also containing the instructions.

Thomson Gems, London, for a group of fire opals.

Osbourne-Shaw, Lisa M., London
Price, Sharron, Halesowen, West Midlands
Ruckel, Daphne, London
Speake, Malcolm, F., Ladywood, Birmingham, West Midlands

Qualified with Merit

Ankama, Silvester Kwabena, London
Frodin, Peter John, West Kirby, Merseyside
Greenfield, Dawn, Eynsford, Kent
Hackett, Helen, Market Harborough, Leicestershire
Jiahua Tian, Wuhan, P.R. China
Thiel, Miriam, Ealing, London
Yao Wang, Wuhan, P.R. China
Wu Weijuan, Beijing, P.R. China

Qualified

Alderman, Chris, Guildford, Surrey
Amarasinghe, Ashan Sudeera, Colombo, Sri Lanka
Bakri, Dalilah A., London
Barwuah, Maximus A., Clapham, London
Bordbar, Hossein Jean-Louis, London
Bourke, Mary, Enniscorthy, Co. Wexford, Ireland
Browning, Matthew, Brighton, East Sussex
Chu Xiao, Beijing, P.R. China
Daramy, Soulaiman B., London
Darby, Iain, Birmingham, West Midlands
Day, Glen, Redditch, Worcestershire
Dowling, Siobhan L., Canary Wharf, London
Farrer, Alison Mary, Stonehouse, Gloucestershire
Gan, Shaojun, Beijing, P.R. China
Ge Lin, Beijing, P.R. China
Gouros, Artemis, Coulsdon, Surrey
Hellstenius, Gabriella, Fulham, London
Hicks, Suzanne Carole, Yardley, Birmingham, West Midlands
Holdsworth, Isabel, Surbiton, Surrey
Jia Liu, Wuhan, P.R. China
Ju Ye, Beijing, P.R. China
Junwen Huang, Wuhan, P.R. China
Khurana, Ruma, Kenton, Harrow, Middlesex
Koundouraki, Evagelia, Katerini, Greece
Lawrence, Kerry, London
Li Nan, Beijing, P.R. China
Li Xiaobo, Beijing, P.R. China
Lin Xinhao, Beijing, P.R. China
Lin Yan, Beijing, P.R. China
Loe Su-Mon, Taipei, Taiwan, R.O. China
Morris, Celia J.W., Nuneaton, Warwickshire
Ndemumana, Zarina K.C., London
O'Connor, David William, Birmingham, West Midlands
Pecku, George Otu, London
Powell, Diane E, Birmingham, West Midlands
Rockman, Gary, Bromley, Kent
Rogers, Emily Irene, London
Rupo Su, Wuhan, P.R. China
Shen, Tingting, Beijing, P.R. China
Siddiqui, Farah, Golders Green, London
Sidiropoulou, Maria-Theresa, Thessaloniki, Greece
Sinnamon, Sonya, Co. Wicklow, Ireland
Smith, Alan J., Bethnal Green, London
Smith, Eloise, Stratford-upon-Avon, Warwickshire
Teramae, Ikumi, Greenford, Middlesex
Wang Xu, Beijing, P.R. China
Wen Lin, Wuhan, P.R. China
Xiaojie Zhu, Wuhan, P.R. China
Xuemei Du, Wuhan, P.R. China
Yun Jing Wen, London
Zhou Fan, Beijing, P.R. China

EXAMINATIONS IN GEMMOLOGY

In the Examination in Gemmology held worldwide in June 2001, 195 candidates sat the Diploma Examination of whom 82 qualified, including two with Distinction and nine with Merit. In the Preliminary Examination, 168 candidates sat of whom 126 qualified.

The **Anderson Bank Prize** for the best non-trade candidate of the year in the Diploma Examination has been awarded to Dong Lan, Wuhan, Hubei, P.R. China.

The **Christie's Prize for Gemmology** for the best candidate of the year in the Diploma Examination who derives his/her main income from activities essentially connected with the jewellery trade has been awarded to Ian Sipson, Trowbridge, Wiltshire.

The **Anderson Medal** for the best candidate of the year in the Preliminary Examination has been awarded to Patricia Wong Bick San, Hong Kong.

The **Preliminary Trade Prize** for the best candidate of the year who derives his/her main income from activities essentially connected with the jewellery trade has been awarded to Karen McKinley, Abington, Northampton.

The Tully Medal has not been awarded.

The names of the successful candidates are listed below:

Diploma

Qualified with Distinction

Bangert, Julie C., West Kensington, London
Sipson, Ian, Trowbridge, Wiltshire

Qualified with Merit

Bi Yu Liang, Guilin, P.R. China
Cao Yuan, Guilin, P.R. China
Huang Zhan, Guilin, P.R. China
Jung Hee An, Jeollanam-Do, Korea
Moltke, Nicholas D., Klamenborg, Denmark
Ning Liu, Wuhan, P.R. China
Warner, Rachel Fleur, Reading, Berkshire
Woo Ha Na, Jeollanam-Do, Korea
Ying Zhou, Wuhan, P.R. China

Qualified

Abu-Nassr, Mohammed-Maher, Toronto, Ontario, Canada
Al-Turki, Nohad, London
Amliwala, Panna, Solihull, West Midlands
Barber, Emily Anne, London
Biuokzadeh, Hossein, Toronto, Ontario, Canada
Bolter, Rachel Louise, Swindon, Wiltshire
Borruso, Alessandro, Harrow, Middlesex
Chater, Melanie Dawn, Northampton
Chen Mei Ling, Guilin, P.R. China
Chen Yu-Ting, London
Cruse, Toby, Eastbourne, East Sussex
Dimmick, Helen Margaret, London
Downes, Lisa, Birmingham, West Midlands
Eensaar, Karin, Tallinn, Estonia
Elder, Maureen, Vancouver, B.C., Canada
Epa, W. S. Damayanthi, Colombo, Sri Lanka
Goyal, Neha, Coimbatore, India
Gregory, Kerry Honor, Newport, Wales
Greig, Davina R., London
Ha Na Ho, Jeollanam-Do, Korea
Hassan, Fatima Chamade, London
Honda, Hiroya, Tokyo, Japan
Hoshino, Takako, Vancouver, B.C., Canada
Howard, Avrom Eric, Toronto, Ontario, Canada
Htun Ngwe Lin, Yangon, Myanmar
Jang, Shinkuk, London
Jogia, Sushila Das, Vancouver, B.C., Canada
Kakehashi, Kotaro, Nagoya, Japan
Ke Zhou, Shanghai, P.R. China
Kobayahi, Hiromi, London
Kumagai, Hiromi, Sendai City, Miyagi Pref. Japan
Kumagai, Jiro, Tokyo., Japan
Li Sang, Wuhan, P.R. China
Liao Wei-Ching, Ping Tong, Taiwain, R.O. China
Llinares, Luis, Geneva, Switzerland
Manaka, Yuji, Kashiwa Cty, Chiba pref., Japan
Mariani, Geoffry, M., Toronto, Ontario, Canada
Miyazaki, Tomohiko, Takarazuka City, Hyogo Pref., Japan
Mo Bina, Shanghai, P.R. China
Morrish, Rachel, Birmingham, West Midlands
Nakagawa, Eriko, Sapporo, Hokkaido, Japan
Ngo Minh-Si, Toronto,Ontario, Canada
Ning Haibo, Guilin, P.R. China
Ok Min Suk, Jeollanam-Do, Korea
Orimo Taeko, Maebashi City, Gunma Pref., Japan
Pace, Howard Michael, Eccleshall, Stafford
Pala, Sunil, Coventry, West Midlands
Ren Qin, Shanghai, P.R. China
Renming, Shen, Wuhan, P.R. China
Salukvadze, Iamze, Dubai, U.A.E.
Sasaki Takako, Hirakata City, Osaka, Japan
Smith, Dana, Port Perry, Ontario, Canada
Song Ping, Guilin, P.R. China
Sutton, Collette Stefania, Solihull, West Midlands
Takayama, Rie, Itabashi-ku, Tokyo, Japan
Thouvenot-Villie, Fabienne, London
Tominaga, Masami, London
Trudel-DeCelles, Maureen, Hudson, Quebec, Canada
Wong Vina, Hong Kong

Woodring, Sharrie R., New Jersey, U.S.A.
Xianlong Sun, Wuhan, P.R. China
Xie Kefei, Shanghai, P.R. China
Xuhua Gu, Wuhan, P.R. China
Yang Na, Guilin, P.R. China
Ying Liu, Wuhan, P.R. China
Yorke, Anabel, London
Yoshida, Sachiyo, Osaka City, Osaka, Japan
Zhong Lin, Guilin, P.R. China
Zhou Songsong, Shanghai, P.R. China
Zhu Haijing, Shanghai, P.R. China
Zuo Xin Mo, Guilin, P.R. China

Preliminary

Qualified

Ahde, Petra, Lahti, Finland
Anders, Cynthia Lorette, Koog Aan De Zaan, The Netherlands
Argyrou, Anastasia, Athens, Greece
Asano, Yoko, Gifu Pref., Japan
Au Kai Leung, Albert, Hong Kong
Aubert, Rebecca, London
Aung, Toe, Yangon, Myanmar
Bai, Yunlong, Guilin, P.R. China
Bennett, Martin, Sherfield English, Hampshire
Bjorklund, Niina Carita, Helsinki, Finland
Brady, John Joseph, Swadlincote, Derbyshire
Bryant, Helen, Lantau, Hong Kong
Chan May Kuen, Hong Kong
Chan Chi Kin, Hong Kong
Chan Miu Ching, Lavinia, Hong Kong
Cheng Wai Yee, Hong Kong
Cherchi, Sonia, Horgen, Switzerland
Cheung Fung Wan, Hong Kong
Cheung Pui Lai May, Hong Kong
Choi Jung-Hae, Daejon, Korea
Chow Ching Yee, Hong Kong
Chung Yee Donna, Hong Kong
Clark, Darel James, Farnham, Surrey
Clark, Alice Hald, Sandnes, Norway
Clarke, Julia, London
Conejero, Jennifer Helen, Boston, Lincolnshire
Danks, James, Geoffrey, Dudley, West Midlands
Dawson, Jane Marie, Codsall, Wolverhampton, West Midlands
Deligiannis, Marios, Athens, Greece
Duff, Sara Margaret, Banbridge, Co. Down, N. Ireland
Eastwood-Barzdo, Elizabeth Louise, Vinzel, Switzerland
El, Thida, Yangon, Myanmar
Epelboym, Marina, New York, U.S.A.
Fagelund-Gjersoe, Sandra, London
Falnes, Lene, Hafrsfjord, Norway
Firth, Richard Anthony, London
Fisher, Fiona Jane, Dublin, Ireland
Fujimoto, Akiko, Yamanashi Pref., Japan
Furze, Cindy, Cheshunt, Hertfordshire
Gandusio, SU.S.A.nna, Lugano, Switzerland
Gaskin, Hans Dominic, London
Gerenstein, Helen, Stockholm, Sweden
Grieve, Sharon, Barwell, Leicestershire
Grigoraki, Christianna, Athens, Greece
Htun Su Su, Yangon, Myanmar
Hui Chau Ming, Hong Kong
Hussain, Arshid, Birmingham, West Midlands
Ishida, Kohei, Wakayama Pref., Japan
Jappinen, Virpi, Turku, Finland
Jenakom, Pimmas, Bangkok, Thailand
Jiang Linhui, Guilin, P.R. China
Kakehashi, Kotaro, Nagoya, Japan
Kwok Nai Chiu, Hong Kong
Kwok Hei, Hong Kong
Lai Pui Sha,n Peggy, Hong Kong
Landolf-Csizmas, Zsuzsanna, Zurich, Switzerland
Lau Kam Yin, Mabel, Hong Kong
Lee Hin Chi, Hong Kong
Lee Man Wah, Hong Kong
Leung Wai Yue, Winnie, Hong Kong
Li Yikuang, Guilin, P.R. China
Li Yuet Yau, Hong Kong
Lo Ka Lok Carold, Hong Kong
Loong Suk Ming, Hong Kong
Maeland, Egil, Sandnes, Norway
Mak Sio In, Hong Kong
Mak Kin Yeung, Kenny, Hong Kong
Malinowska, Rossita, Beckenham, Kent
Marlow, Carol, Sutton Coldfield, West Midlands
Mathiesen, Lisbeth Susanne, Kobenhavn, Denmark
McKinley, Karen, Abington, Northampton
Mo Bixun, Shanghai, P.R. China
Moger, Adam, Huntingdon
Nakagawa, Miho, Hyogo Pref., Japan
Nessi, Veroniki, Athens, Greece
Ng, Wing Yee, Winnie, Hong Kong
Ng, Wai Ling, Hong Kong
O'Leary, Dominique, London
Oh, Minkyung, London
Pavaro, Thitintharee, Bangkok, Thailand
Phillips, Paul, Nuneaton, Warwickshire
Preston, Anne Victoria Rhodes, London
Randawa, Sukhwant Singh, Otford, Kent
Rantanen, Ari-Pekka, Hameenlinna, Finland
Rintanalert, Porntip, Bangkok, Thailand
Rolph, Liz, Corringham, Essex
Roy, Maryse, Montreal, Quebec, Canada
Sakkaravej, Somruedee, Nonthaburi, Thailand
Sancheti, Amishaa, Indore, India
Sanchez, Sierra Maria Fernanda, London
Sideras, Despina Nicole, Nairobi, Kenya
Sikanen, Essi Maarit, Lahti, Finland

Smith, Anna, Pinner, Middlesex
Somboon, Chaniya, Bangkok, Thailand
Sun Jiexian, Shanghai, P.R. China
Suraseth, Peerapol, Bangkok, Thailand
Takala, Ville, Lannavaara, Sweden
Tam Cheuk Kuen, Hong Kong
Tangsubkul, Hiranya, Bangkok, Thailand
Tantisiriphaiboon, Yenrudee, Bangkok, Thailand
Tennekoon, Indrani, London
Thant, Zin Mar, Yangon, Myanmar
Thiel, Miriam, London
Thouvenot-Villie, Fabienne, London
Thu Latt Myat, Yangon, Myanmar
Tong Yung, Hong Kong
Tyrrell, Siobhan Ann, London
Uberoi, Tina, London
Ullal, Vidhya, Surat, India
Valvio, Raija Leila Maria, Jyvaskyla, Finland
Visitpanich, Theeraya, Chiang Mai, Thailand
Von Schantz, Casimir, Helsinki, Finland
Waelti, Nicole, Lenk, Switzerland
Westling, Jonny, Stockholm, Sweden
Whitehouse, Keith Percival, Stafford
Williams, Cara Marie, Jefferson City, Missouri, U.S.A.
Williams, Adrienne Victoria, London
Wong Bick San, Patricia, Hong Kong
Wong Yin Yan, Sandy, Hong Kong
Wong Lai Cheng, Hong Kong
Wong Tai-Wai, Hong Kong
Wu Mingyang, Shanghai, P.R. China
Xue Fuzhen, Luton, Bedfordshire
Yokokawa, Naomi, London
Yu Chung Wah, Hong Kong
Zar Aye Tin, Yangon, Myanmar

MEMBERSHIP

Between 29 June to 11 September 2001 the Council of Management approved the election to membership of the following:

Fellowship and Diamond Membership (FGA DGA)

Li Ding, Shenyang, P.R.China. 2001
Weston, Jonathan, Brierley Hill, West Midlands. 1988, 1989
Yihua Wu, Taipei Shiann, Taiwan, R.O. China. 2000

Fellowship (FGA)

Barber, Emily Anne, London. 2001
Berkowitz, Roza, Toronto, Ontario, Canada. 1974
Collier, Rowley W., Hornchurch, Essex. 1966
Corcoran, Moya Ann Marie, London. 2001
Croucher, Nicola, London. 2001
Gregory, Kerry Honor, Newport, Wales. 2001
Moe Moe Shwe, Banhan Township, Yangon, Myanmar. 2001
Molesworth, Helen, Rotherhithe, London. 2001
Naing Naing Oo, Latha Township, Yangon, Myanmar. 2001
Pace, Howard Michael, Eccleshall, Staffordshire. 2001
Pwint Phue Lwin, Yankin Township, Yangon, Myanmar. 2001
Sidiropoulou, Marie-Theresa, Panorama, Thessaloniki, Greece. 2001
Spencer, Jonathan Peter, Staple Hill, Bristol. 1986
Tominaga, Masami, London. 2001
Wasim, Baber, Gulshan-E-Iqbal, Karachi, Pakistan. 2001

Diamond Membership (DGA)

Ankama, Silvester Kwabena, Ilford, Essex. 2001
Day, Glen, Redditch, Worcestershire. 2001
Rogers, Emily Irene, Putney, London. 2001
Tsang, Jasmine, Kennedy Town, Hong Kong. 2001
Wong Man Kuen Purdet, Fanling, N.T., Hong Kong. 2001
Wong Shuk Ching, Hong Kong. 2001

Ordinary Membership

Adebowale, Rabiu Adedokun, Isleworth, Middlesex
Akintonde, Olubunmi, Plumstead, London
Berry, Susan, London
Bertrand, Sylvia, London
Choi, Daeshik, Sutton, Surrey
Clay, Robert Mossman, Islesteds, Dumfries, Scotland
Croukamp, Anna-Luise, Edinburgh, Scotland
Cuba, Grant, San Angelo, Texas, U.S.A.
Danks, James Geoffrey, Netherton, Dudley, West Midlands
De Lasteyrie du Saillant, Valentine, London
English, Bernard, Drogheda, Ireland
Grumitt, Peter, Tadworth, Surrey
Gurevich, Lina, Golders Green, London
Hakkaku, Tomoko, Kew, Surrey
Hall, Michael, Derby, Derbyshire
Hedenskog, Elin, Camberwell, London
Hornsleth, Henriette, Copenhagen, Denmark
Huish, Irene, Liverton, Newton Abbot, Devon
Kamani, Priscilla, Arkley, Barnet, Hertfordshire
Leader, Lucille, London
Longy, Bruno P.B., London
McKinley, Karen L., Abington, Northamptonshire
Man Chun Yin Christy, Windsor, Middlesex
Martin, Jennifer M., Padworth Common, Berkshire
Middle, Geoffrey Edward, Bangkok, Thailand
Rayatchi, Ali Reza, Finchley, London

Riley, Patricia, West Didsbury, Manchester
Rossi, Paola, El Fraile, Arona, Tenerife
Ruangrung, Thitima, Brighton, East Sussex
Sanghani, Kantilal, Elstree, Hertfordshire
Scarr, Graham, Stapleford, Nottingham
Selvamani, Parvathi, London
Sillitoe, Alvin F.J., London
Singh, Jaspal, Seven Kings, Ilford, Essex
Skinner, James, Ripley, Nr. Guildford, Surrey
Stinglhamber, Renata, Fulham, London
Strinati, Maria Aparecida, Kingston upon Thames, Surrey
Thein, Myint Myint, Willesden, London
Ukrainski, Krystof J., Fleet, Hampshire
Valia, Tulsi, London
Veraria, Dev, Bexley, Kent
Wenham, Diana Lesley, North Harrow, Middlesex
Whalley, Joanna, Walthamstow, London
Williams, Gail, Whitchurch, Cardiff
Wood, Valerie, Floral Park, New York, U.S.A.
Yanagihara, Satomi, London

TRANSFERS

Ordinary Membership to Fellowship (FGA)

Al-Turki, Nohad, London
Borruso, Alessandro, Harrow, Middlesex
Yu-Ting Chen, Taichung, Taiwan, R.O. China.
Eensaar, Karin, Tallinn, Estonia
Greig, Davina R., London
Honda, Hiroya, Tokyo, Japan
Jang, Shinkuk, Cambridge, Cambridgeshire
Kakehashi, Kotaro, Jyoto-Ku, Osaka, Japan
Kobayashi, Hiromi, London
Kumagai, Hiromi, Sendai City, Miyagi Pref., Japan
Kumagai, Jiro, Chuo-ku, Tokyo, Japan
Liao Wei-Ching, Ne Pu, Ping Tong, Taiwan, R.O. China
Llinares, Luis, Geneva, Switzerland
Manaka, Yuji, Kashiwa City, Chiba Pref., Japan
Miyazaki, Tomohiko, Takarazuka City, Hyogo Pref., Japan
Nakagawa, Eriko, Sapporo, Hokkaido, Japan
Orimo, Taeko, Maebashi City, Gunma Pref., Japan
Salukvadze, Iamze, Dubai, United Arab Emirates
Sasaki, Takako, Hirakata City, Osaka, Japan
Sutton, Collette S., Solihull, West Midlands
Takayama, Rie, Itabashi-ku, Tokyo, Japan
Warner, Rachel F., Reading, Berkshire
Yoshida, Sachiyo, Osaka City, Osaka, Japan

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The following are the membership subscription rates for 2002. Existing Fellows, Diamond Members and Ordinary Members will be entitled to a £5.00 discount for subscriptions paid before 31 January 2002.

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Bakri, Di, London
Barwuah, Max, London
Bordbar, Jean-Louis H., London
Daramy, Soulaiman B., Colindale, London
Gouros, Arte, Coulsdon, Surrey
Hellstenius, Gabriella, Fulham, London
Khurana, Ruma, Kenton, Harrow, Middlesex
Siddiqui, Farah, Golders Green, London
Smith, Alan J., Bethnal Green, London
Thiel, Miriam, Ealing, London
Yun Jing Wen, London

Diamond Membership to Fellowship and Diamond Membership (FGA DGA)

Bangert, Julie C., West Kensington, London
Cruse, Toby, Eastbourne , East Sussex
Moltke, Nicholas D., Klamenborg, Denmark
Pala, Sunil, Coventry, West Midlands
Fellowship to Fellowship and Diamond Membership (FGA DGA)
Bourke, Mary, Enniscorthy, County Wexford, Ireland
Dines, Rachel S., North Dulwich, London
Dowling, Siobhan L., Canary Wharf, London
Farrer, Alison M., Nympsfield, Stonehouse, Gloucestershire
Frodin, P.J., West Kirby, Wirral, Merseyside
Greenfield, Dawn M., Eynford, Kent
Hicks, Suzanne C., Yardley, Birmingham
Loe Su-Mon, Taipei, Taiwan, R.O. China
Morris, Celia J.W., Nuneaton, Warwickshire

Osborne-Shaw, Lisa M., London
Price, Sharron A., Halesowen, West Midlands
Rockman, Gary, Bromley, Kent
Sidiropoulou, Maria-Theresa, Panorama, Thessaloniki, Greece
Speake, Malcolm F., Ladywood, Birmingham
Teramae, Ikumi, Greenford, Middlesex

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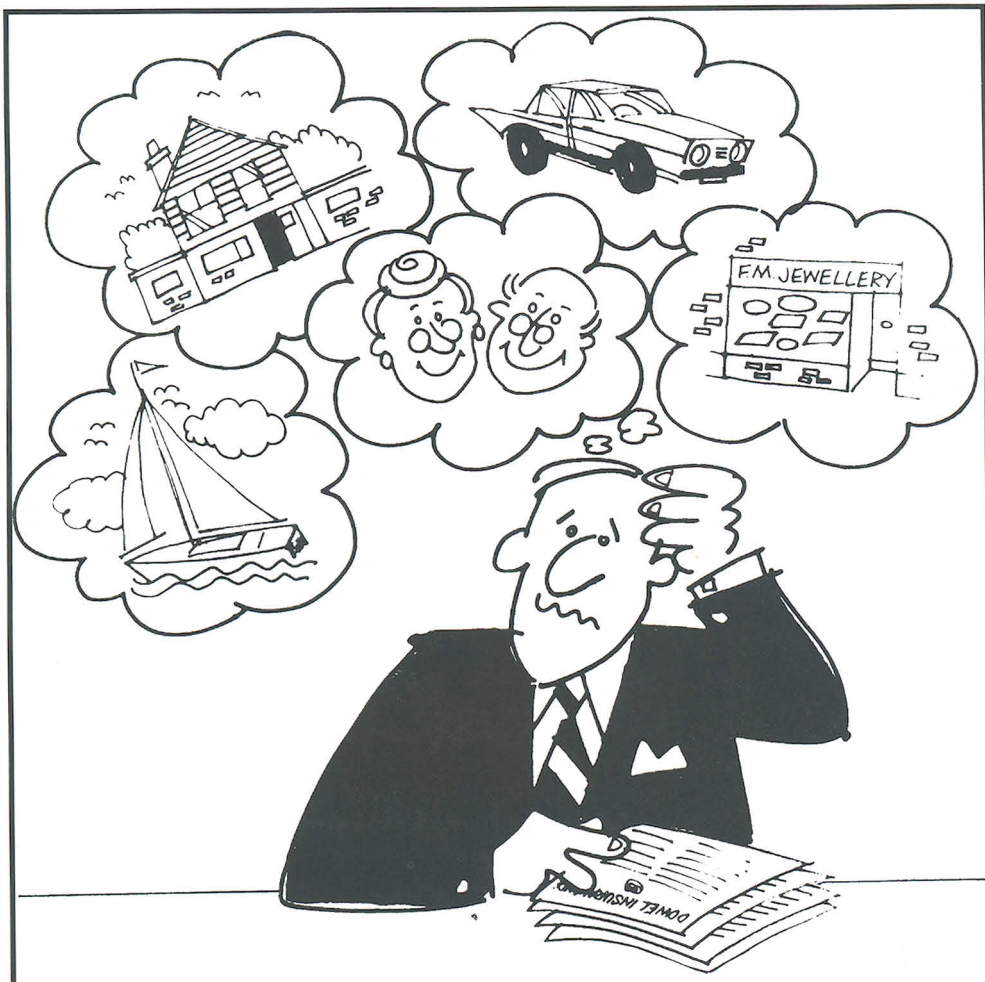

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Bangladeshi 'pearls'
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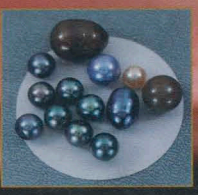

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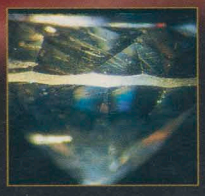

Synthetic moissanite

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The abalone *Haliotis rufescens*

Star stones

An unusual deposit in Sri Lanka

'Kakuten' (crane crown)

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Iridescence of a shell of the abalone *Haliotis rufescens* caused by diffraction

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ABSTRACT: The iridescent colours of bivalve mollusc shells and pearls are caused by diffraction due to the characteristic groove structure that acts as a reflection grating. The shell of the gastropod *Haliotis rufescens* also shows very strong iridescence, but scanning electron microscope (SEM) images of its surface show a tile structure arranged in a statistically regular pattern rather than a groove grating structure. This specific tile structure serves as a two-dimensional reflection grating that causes the iridescence.

Keywords: abalone, diffraction, iridescence, regular tile structure, SEM images, shell, two-dimensional reflection grating

Introduction

The inner surface of gastropod shells and the surface of pearls often show very strong iridescence. In pearls the iridescence is commonly attributed to interference caused by the aragonite layers (Nassau, 1983; Fritsch and Rossman, 1988). Liu *et al.* (1999) demonstrated that the iridescence of bivalve mollusc shells and pearls is caused by diffraction produced by the reflection grating structure.

The abalone *Haliotis rufescens* has been used to study the biofabrication of the nacre layers or 'flat pearls' (Fritz *et al.*, 1994). We were interested in studying this abalone shell because its inner nacreous layer also showed very strong iridescence (*Figure 1*), (Liu *et al.*, 1999). In order to investigate the cause of this iridescence, we took SEM images from different areas of an abalone shell from northern California. These images all showed a statistically regular tile arrangement. Our investigation indicates that the iridescence of the abalone shell is caused by diffraction, but the grating structure is different from that of the shell *Pinctada margaritifera.*

Surface structure of the shell

Haliotis rufescens (red abalone) can be found along the west coast of North America from northern California in the United States to Baja California in Mexico. Mature specimens, 8 to 10 years old, range in size from approximately 15 to 20 cm long. The outer layer of its shell appears red to brown and consists of prismatic calcite. The inner layer consists of aragonite and shows strong iridescence (see *Figure 1*). This inner layer does

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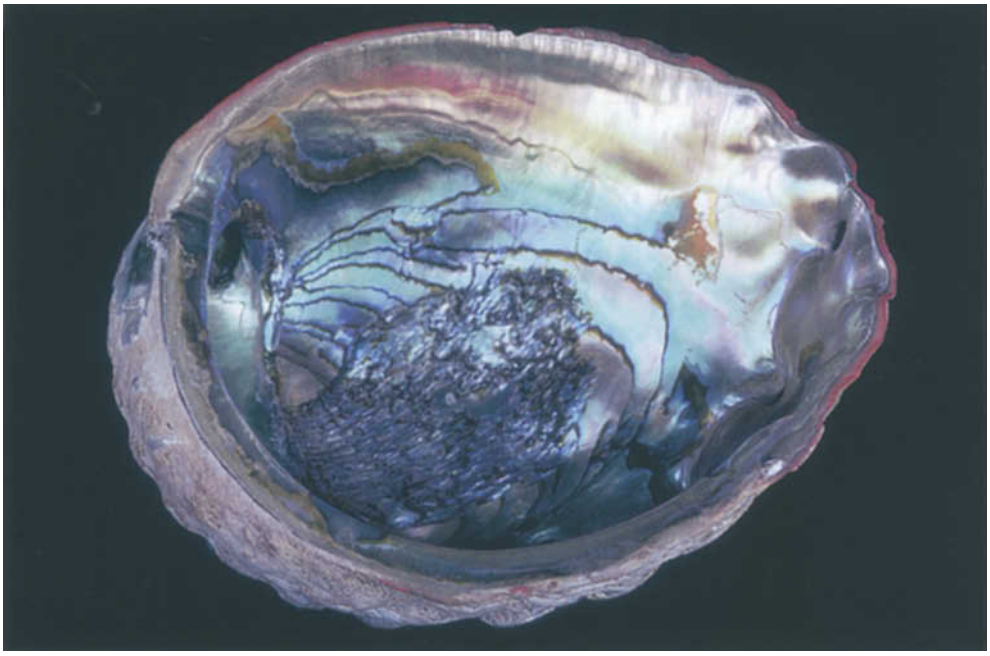

Figure 1: *Inside view of an iridescent abalone* (Haliotis rufescens) *shell (21 x 16 x 4.5 cm).*

not show the same micro-groove structure as the shell of the bivalve mollusc we had previously examined (Liu *et al.*, 1999). Instead, the aragonite tiles in the abalone shell have a structure that is arranged in a statistically regular pattern and *Figure 2a* shows the SEM image of an area of an inner layer that displays strong iridescence. Schaffer *et al.* (1997) and Addadi and Weiner (1997) have described how aragonite grows to form tiles, the size and arrangement of which are controlled by a matrix.

The aragonite tiles in the abalone nacre are relatively rough, slightly convex in cross section and much larger in size compared to those in *Pinctada margaritifera* (see *Figure 2b*). They range from 3 µm to 7 µm, averaging approximately 5 µm in long dimension. The holes in the tiles that allow the building materials to enter (so that the nacre can grow as described by Schaffer *et al.* (1997) and Liu (2001)) and the conchiolin boundaries between the tiles are also clearly visible in the SEM images. The width of the conchiolin boundaries between the tiles is of the order of 0.5 µm, which is much wider than that of 0.05 µm in *Pinctada margaritifera*. The size of the average aragonite tile (5 µm) is larger than the width of the grooves (3.38 µm) in *Pinctada margaritifera* (see *Figure 2c*). Therefore, since each groove consists of at least several aragonite tiles, the aragonite tiles of the *Haliotis rufescens* can not form a groove structure at the scale of the *Pinctada margaritifera* shell (3.38 µm).

Cause of the iridescence

Diffraction can be produced by a groove structure, and also by a two-dimensional structure such as a square array or a round array, either of which function as two-dimensional gratings (Loewen and Popov, 1997). The surface structure of the abalone nacre is formed by aragonite tiles, which although variably polygonal, can be considered to function as a rounded-corner square array, with each 'square' averaging approximately 5 µm. *Figure 3* shows a

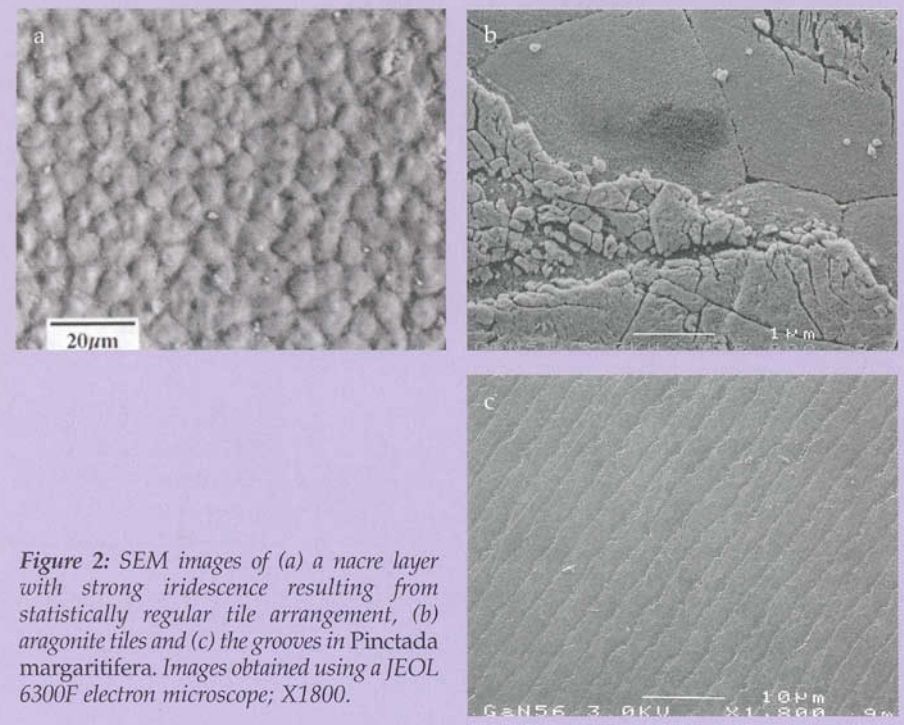

Figure 2: SEM images of (a) a nacre layer with strong iridescence resulting from statistically regular tile arrangement, (b) aragonite tiles and (c) the grooves in Pinctada margaritifera. *Images obtained using a JEOL 6300F electron microscope; X1800.*

theoretical array model of the surface structure, which functions as a 200 x 200 tiles/mm^2 two-dimensional reflection grating. When light is incident onto the surface it is reflected and diffracted. The diffracted light produces the iridescence. In any direction of observation, the iridescence is a combined effect of light from all possible diffraction orders and from different incident directions. The iridescence caused by the groove grating structure in *Pinctada margaritifera* is very directional. It cannot be observed along the groove direction. In addition, directly reflected light does not produce iridescence since it is the zero-order reflection (Liu *et al.*, 1999). In contrast, in the abalone shell with its two-dimensional grating structure, the iridescence can be observed in any direction, including the direction opposite to an incident beam, and under direct sunlight as well. The rough convex surface of the tiles also enhances this non- directional phenomenon. Depending on the alignment and smoothness of the tile array structure the colour saturation of the iridescence in the abalone nacre will vary.

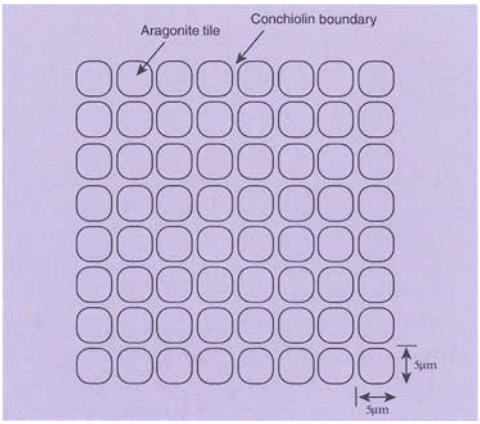

***Figure 3:** Schematic model of two-dimensional square array of the surface structure of the abalone nacre.*

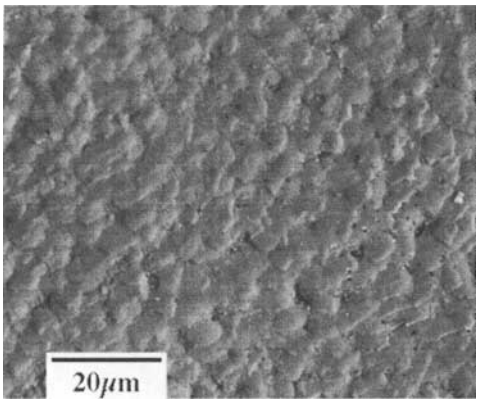

Figure 4: *SEM image of a nacre layer with irregular tiling which results in little iridescence. Equipment and conditions similar to those for Figure 2; X1800.*

At the edge of the inner shell and in some other areas in the nacre, the iridescence appears very weak or is even absent and *Figure 4* shows a typical SEM image of an area that displays a weak iridescence. Here the structure may more closely resemble the groove structure found in *Pinctada margaritifera*. The nacre tiles in *Pinctada margaritifera* are irregular in shape and size, are separated by conchiolin and are considered as being optically non-uniform. It is evident from *Figures 2* and *4* that the nacre layers in the abalone are also not optically uniform. Therefore, it is unlikely that interference is the cause of iridescence in the abalone shell.

Figure 5: *A typical diffraction efficiency curve of a reflection grating. The maximum efficiency occurs at the wavelength* λ_B.

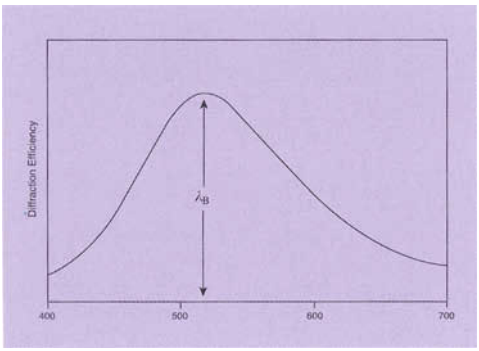

The dominant colour

The iridescence colour of the abalone shell is commonly dominated by one or two colours. These are usually blue-green over much of the area and pink with a purple hue over a smaller area.

The dominant colour of the iridescence is caused by the uneven wavelength efficiency of diffraction of the shell. The diffraction efficiency of a reflection grating refers to the intensity of diffracted light relative to the intensity of incident light. *Figure 5* shows that the typical diffraction efficiency of a reflection grating is a curve (Palmer, 2000). The maximum efficiency of the grating occurs at the peak wavelength. The dominant colour of the iridescence corresponds to the most efficient wavelength. By inference, the most efficient wavelength of the shell is in the blue-green part of the visible range. The diffraction efficiency curve of a reflection grating corresponds to a specified diffraction order. It depends on many factors such as the material, the widths of any grooves, and the angles of both incident light and diffracted light. The hue of the dominant colour changes with a change in viewing angle. This phenomenon is caused by the peak wavelength change of the diffraction efficiency with the change of angles of incident and diffracted light.

(In fact, the efficiency of diffraction is optically similar to the efficiency of reflectance. The efficiency curve versus wavelength of diffraction is similar to the reflectance curve of a colour sample. In the case of reflectance, light may be reflected more in one wavelength range and less in another wavelength range. The hues of reflectance samples usually correspond to the wavelength at which the colour sample has the highest reflectance.)

Conclusion

The iridescence of this sample shell of the gastropod *Haliotis rufescens* is caused by diffraction of light from a reflection grating formed by a two-dimensional tile array

structure. The observed iridescence is not directional due to the rough surface condition of the tiles and the irregular alignment of the tile array structure in the nacre. In effect, the iridescence is a combined effect of the diffracted light from all possible diffraction orders and different incident directions. The dominant colour corresponds to the wavelength of the peak efficiency in the visible range. The iridescence colour changes with the viewing angle. This phenomenon is caused by the shift of the peak efficiency when the angles of incidence and diffraction change.

Acknowledgement

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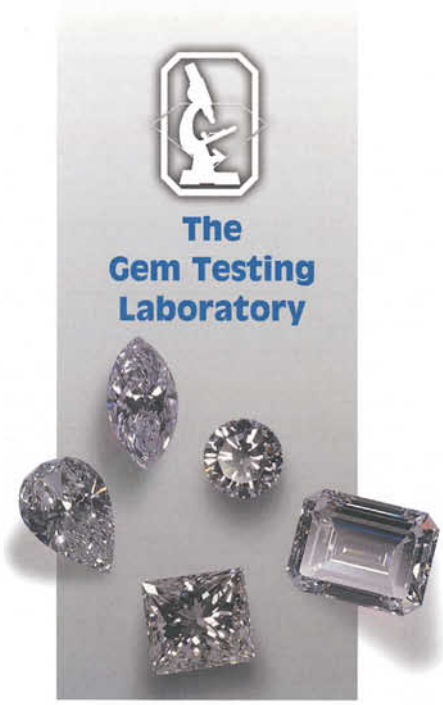

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A highly unusual, 7.34 ct, Fancy Vivid purple diamond

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ABSTRACT: This article documents the gemmological properties of a 7.34 ct modified heart-shape brilliant-cut purple diamond. This diamond was described as 'Fancy Vivid' purple on a coloured diamond grading report issued by the GIA Gem Trade Laboratory. When viewed with magnification through the pavilion facets, the diamond exhibited banded purple colour zoning and reflective surface graining. It also exhibited unevenly distributed, weak to medium intensity yellow fluorescence when excited with UV radiation. Its visible spectrum contained a broad absorption band centred at about 550 nm, as well as increasing absorption below 450 nm. Opportunity was provided to observe the manufacturing of this coloured diamond from the rough to the polished states. Purple diamonds of this saturated colour and carat weight are quite unusual.

Keywords: colour, diamond, gemmological properties, purple, spectra

Introduction

Coloured diamonds have become increasingly popular and sought after in the jewellery trade. This popularity has been enhanced by publicized auction sales of coloured diamonds, with prices attained on repeated occasions of US $100 000 and more per carat for certain colours. The number of such diamonds brought to the GIA Gem Trade Laboratory for coloured diamond reports has increased dramatically during the past decade.

Among coloured diamonds, certain colours such as pink, blue and green are both rare and highly valued. When submitted to the GIA Gem Trade Laboratory, the documentation of these unusual coloured diamonds is an important event. Diamonds with a saturated, pure purple colour are even less common, and gemmologists have had little opportunity to study them. Brief mentions of purple diamonds have been provided in the books on coloured diamonds by Harris (1994, 172-3) and Hofer (1998, 281-93 and 678-9).

This article presents one of the few descriptions of a strongly coloured purple diamond in the gemmological literature. Our earliest experience with diamonds of this colour was in the 1970s; their reported origin was Russia (see Federman, 1995). At that time we thought that this source might provide a supply of diamonds with this colour. Since then, however, we have seen very few purple diamonds from either Russia or anywhere else. When encountered they have been small sizes and usually a pale colour.

Description

The diamond studied is a modified heart-shape brilliant-cut measuring 11.17 x 11.97 x 7.14

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***Figure 1**: Photograph of the 7.34 ct modified heart-shape brilliant diamond that was graded as 'Fancy Vivid' purple by the GIA Gem Trade Laboratory. Photograph by Elizabeth Schrader. © GIA.*

mm in dimension and weighing 7.34 ct (*Figure 1*). According to the grading terminology used by the GIA Gem Trade Laboratory (King *et al.*, 1994), its colour description is 'Fancy Vivid purple', a terminology used to describe a limited population of coloured diamonds that are categorized by a high degree of saturation for a given colour hue. This is one of the very few, and among the most intensely coloured purple diamonds examined by the laboratory staff, since most have a pink component to their colour and are not pure purple.

Materials and methods

The gemmological properties of this diamond were documented with standard testing equipment, including a binocular microscope, a desk-model prism spectroscope, and a long- (366 nm) and a short-wave (254 nm) ultraviolet lamp unit. An absorption spectrum was recorded over the range of 360 to 760 nm with a Hitachi U-4000 spectrophotometer, with the diamond being cooled to liquid nitrogen temperature (about -196°C). Several infrared spectra were recorded with a Nexus 670 Fourier-transform infrared (FTIR) spectrometer over the range of 400 to 10500 wavenumbers (cm^{-1}). Photographs were taken with a Kodak DCS315 digital camera.

Gemmological examination

When the diamond was examined in a face-up position in the controlled colour-grading environment, the purple colour appeared to be evenly distributed (see again *Figure 1*). However, when viewed with magnification in other orientations, the purple colour was seen to occur along distinct, parallel graining planes with intervening zones that showed little if any colour (*Figure 2*). This banded coloration is typical of purple diamonds, and is similar to the colour zoning often seen in brown, brown-pink, and pink to red diamonds. Although some scientific uncertainty still exists about the details of the cause of colour, it is generally accepted that all these types of coloration result from plastic deformation while the diamonds were in the earth's mantle. The atomic-level deformation is concentrated along the same planar zones where the purple, brown, pink or red coloration is seen (Kane, 1987; Fritsch, 1998). Surface graining with an almost reflective appearance was also evident during this visual examination (see again *Figure 2*).

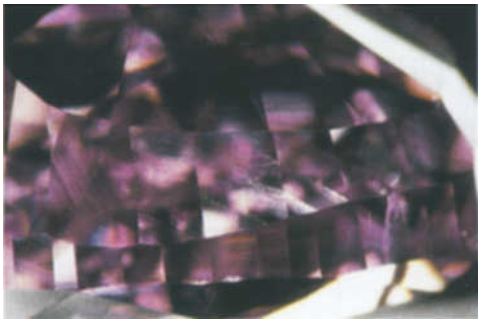

***Figure 2.** When examined with magnification, this diamond exhibited banded purple coloration and reflective surface graining. Photomicrograph by Vincent Cracco; magnified 15x, copyright GIA.*

Under long- and short-wave ultraviolet illumination, this purple diamond exhibited weak to medium, and very weak, yellow fluorescence, respectively. The long-wave ultraviolet fluorescence was unevenly distributed. When viewed between crossed polarizing filters, the diamond displayed strong anomalous birefringence in the form of a cross-hatched strain pattern that was aligned with the planar colour zonation. The diamond's clarity grade was I_1 on the GIA grading scale, based on the prominent graining and a tension feather that extended into the graining plane. When examined with a desk-model spectroscope, the diamond exhibited no sharp bands in its absorption spectrum.

Visible and infrared spectra

The visible spectrum of this diamond exhibited increasing absorption below 450 nm, and a broad absorption band centred at about 550 nm (with a weak side band at about 475 nm; see *Figure 3*). This combination of absorption features produces the purple colour. The broad 550 nm absorption band is the same feature that is seen with increasing strength in the spectra of pink to red diamonds (Shigley and Fritsch, 1993; also see *Figure 4*) and is thought to be due to plastic deformation of the diamond. This deformation created colour centres capable of absorbing wavelengths of light in the region of the spectrum between about 450 and 650 nm. The direct association between the purple coloration and the banded coloured graining confirms that the cause of the colour is the same as the cause that gave rise to the graining.

Based upon the infrared spectrum (*Figure 5*), this is a type IaA diamond with a relatively high amount of nitrogen and a very low amount of hydrogen.

Manufacture

The rough crystal initially weighed 15.31 ct and had a 'blocky' shape. A slight surface coating hindered the ability of the manufacturer to readily see into the crystal to evaluate how it could best be fashioned. Although it appeared to have a dark pink colour in some directions, the diamond also displayed something different about its colour appearance. When the crystal was originally 'opened' with a few small facets to examine its clarity, it was also noted at the time that the colour was not that of a typical pink diamond. The coloration was quite unusual,

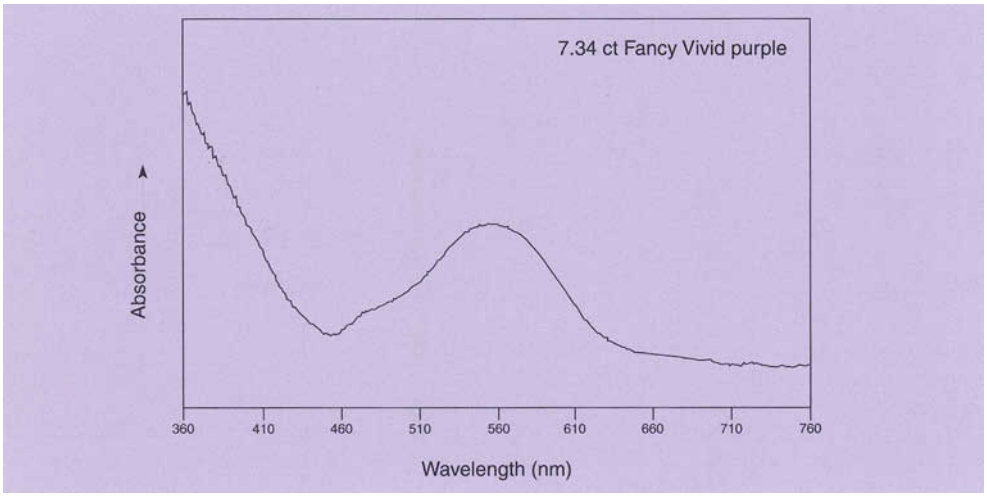

Figure 3. *The spectrum of this coloured diamond shows increasing absorption below 450 nm, and a broad region of absorption centered at about 550 nm (with a weak side band at about 475 nm). This combination of features gives rise to the saturated purple colour.*

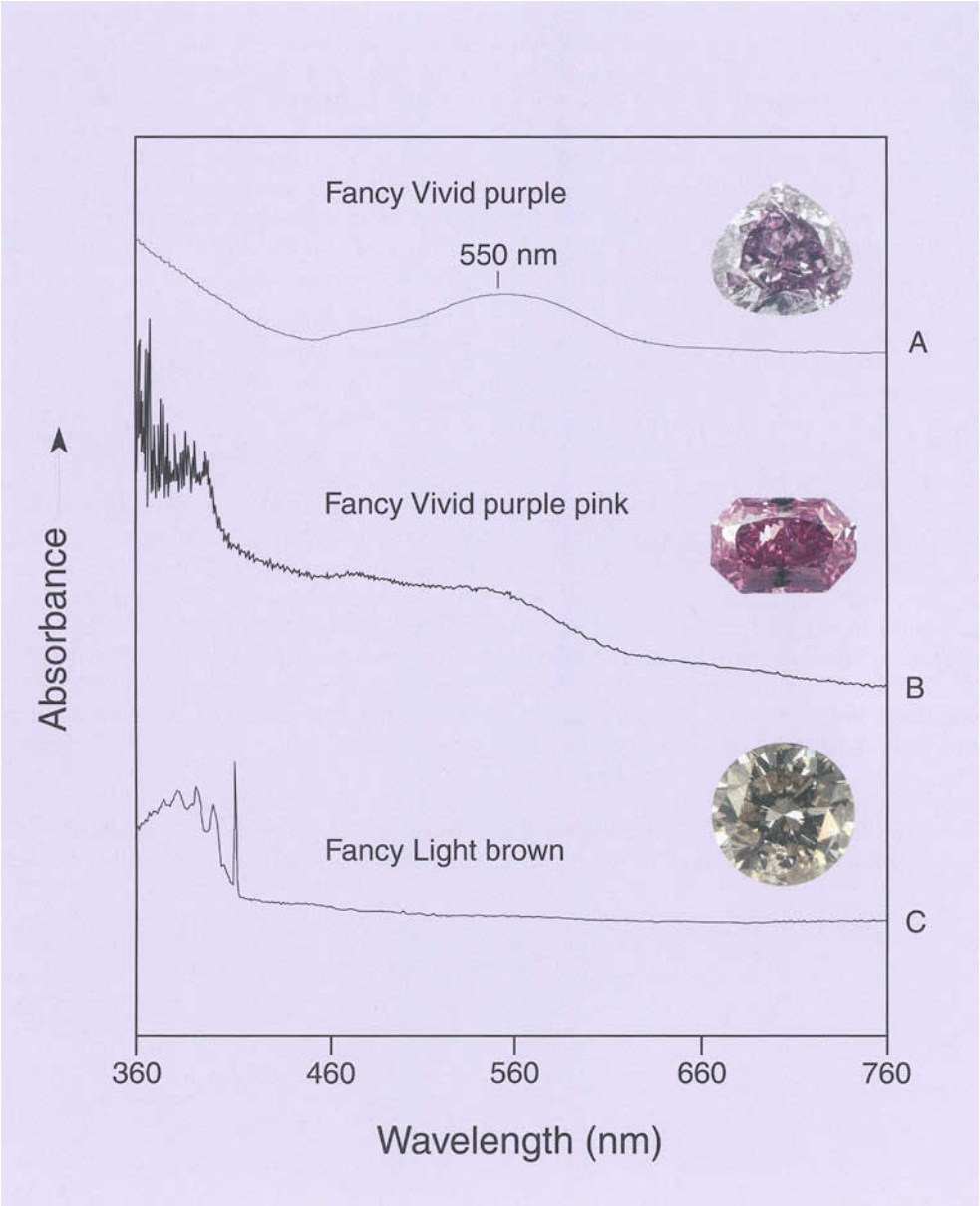

***Figure 4**: A comparison of visible absorption spectra (all recorded at liquid nitrogen temperature) for three coloured diamonds to illustrate some similarities in their spectra. From top to bottom, the spectra are for the 7.34 ct Fancy Vivid purple diamond described here (A), a 5.04 ct Fancy Vivid purplish-pink diamond (B), and a 4.60 ct Fancy Light brown diamond (C). The 550 nm band is most pronounced in spectrum (A); it is also present in spectrum (B), but is absent in spectrum (C). The 550 nm absorption is thought to be due to plastic deformation of the diamond. This deformation created colour centres capable of absorbing wavelengths of light in the region of the spectrum between about 450 and 650 nm. Photographs by Elizabeth Schrader, copyright GIA.*

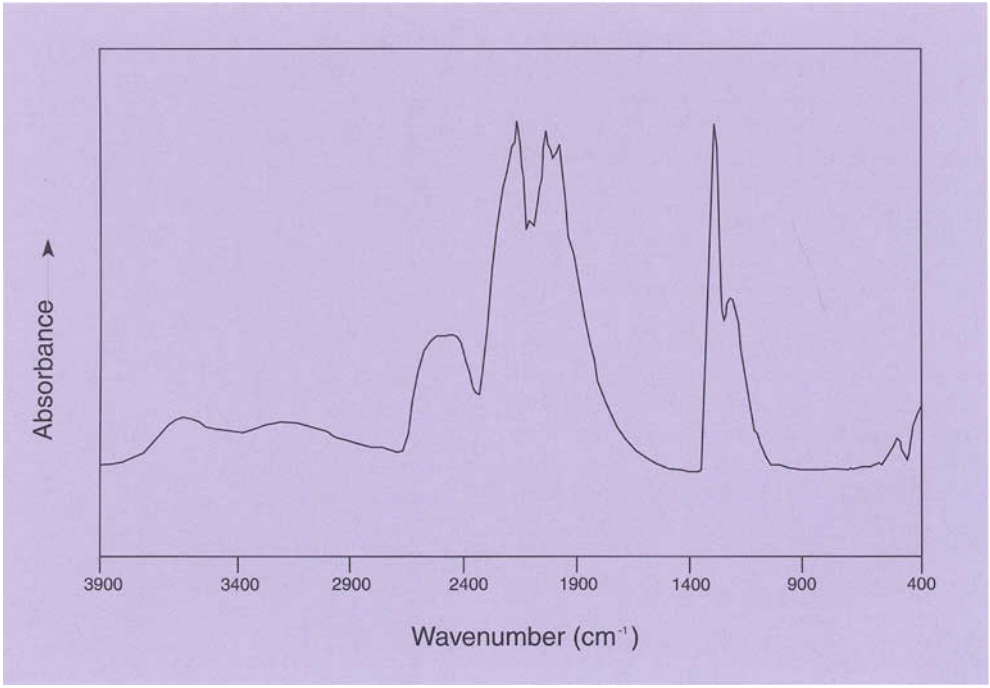

Figure 5. *The mid-infrared spectrum indicates that this purple diamond is type IaA with high nitrogen and a very low amount of hydrogen.*

and was mainly confined to slip planes. As with every rough diamond, the manufacturer had several factors to consider when deciding the shape and faceting style in which to polish it. Coloured diamonds like this further complicate this polishing problem due to their inherent colour zoning. Without the proper orientation of this colour zoning with respect to the planned faceting style, the maximum colour potential could be lost.

There were several options in manufacturing the diamond. Prior to the final decision, a traditional round brilliant and a pear shape were considered but ultimately rejected in favour of a modified heart-shape to maximise the face-up colour appearance. The purple colour zoning associated with the graining was strategically positioned so that the face-up appearance of the polished diamond was both evenly and intensely coloured. This was made even more challenging by the surface grain lines that encircled the entire diamond. With this kind of graining, optimal polishing directions may be different on the same facet, making the final polishing even more difficult. When we encounter diamonds of this colour with similar gemmological properties, they often show small tension fractures extending into the diamond along the graining planes.

Conclusion

Gem diamonds with a pure purple colour are exceedingly rare, and few have been gemmologically documented. With the exception of its saturated colour, this 7.34 ct purple diamond exhibits gemmological properties typical of other purple diamonds that we have encountered (Hargett, 1988, 1990). Its colour zoning, graining, and a visible absorption spectrum are similar to the corresponding features of brown and pink to red diamonds. The strong region of absorption centred at 550 nm in the spectrum con-

tributes to the resulting colour, in contrast to the situation in pink and brown diamonds where the intensity of this absorption band is weaker. This is one of very few coloured diamonds examined by GIA that has a pure purple colour, and its rarity is even more astonishing given its substantial carat weight.

Acknowledgements

We thank the company of Julius Klein Diamonds Inc. in New York City for the opportunity to document this very unusual coloured diamond. Matthew Hall, Elizabeth Schrader, and Vincent Cracco of the staff of the GIA Gem Trade Laboratory helped compile spectral data and photographic images on this diamond.

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Star garnets and star garnet cat's-eyes from Ambatondrazaka, Madagascar

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ABSTRACT: Mineralogical and gemmological properties of star garnets from Ambatondrazaka, Madagascar, are given. All samples examined are intermediate members of the almandine-spessartine series with an appreciable pyrope component. Asterism is caused by a dense network of rutile needles that are orientated parallel to the three-fold axes of the cubic garnet hosts. In addition to the white four-rayed stars, reddish-brown cat's-eyes are present in two garnet cabochons. This additional light band is caused by orientated sillimanite lamellae. The formation of different four- and six-rayed stars in garnets is discussed.

Introduction

Asteriated garnets are known from India, Sri Lanka, and Tanzania, as well as from Idaho and North Carolina, U.S.A. Samples have been described as almandine or intermediate pyrope-almandine garnets (rhodolite), rarely also as grossular or spessartine. Cabochons with four-rayed stars (*Figure 1a, b*) are commonly observed, and garnets with both four- and six-rayed stars (*Figure 2a, b*) have also been mentioned (Rouse, 1986; Zeitner, 1986; Rohrbach, 1986; Arem, 1987; Kammerling and Koivula, 1990; Barot *et al.*, 1995; Kumaratilake, 1997; Hamer, 1998). Extraordinarily large samples are known from India (*Figure 1b*).

Asterism in garnets is caused by orientated needle-like inclusions, which are most commonly designated as rutile or rutile silk. The most frequently observed orientation of these tiny needles is parallel to the edges of the dodecahedron, i.e. parallel to the four three-fold axes <111> of the cubic system. With that particular orientation, twelve four-rayed stars can be observed on samples cut as complete spheres (Holland, 1896; Brauns, 1907; Goldschmidt and Brauns, 1911; Maier,

Figure 1a: *Asteriated garnet cabochon from India, revealing a white four-rayed star. It measures 24.2 x 21.5 mm, and weighs 69 ct. Photograph by M. Glas.*

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Figure 1b: Asteriated garnet cabochon from India, revealing a white four-rayed star. It measures 95 x 82 mm and weighs 1.147 kg (5737 ct). Collection of the Precious Stones Museum, Antwerp, Belgium; photograph by P. Entremont.

1943; Mellis, 1966; Strunz, 1968; Barot *et al.*, 1995; Kumaratilake, 1998). Chatoyancy is rarely mentioned in garnets. It is observed in 'normal' four-rayed star garnets which are misorientated (Fryer *et al.*, 1985) or in samples that show a four-rayed star with two arms of the star being extremely weak (Fryer *et al.*, 1988).

Asteriated garnets have been offered in local markets in Madagascar since about 1997. The rough materials for these cabochons or sometimes complete garnet spheres originate from a place about 25 km north-east of the town of Ambatondrazaka which is located south of Lake Alaotra, about 160 km north-east of the capital Antananarivo. The aim of this paper is to present a mineralogical and gemmological description of these garnets, including those showing chatoyancy. These garnets from Ambatondrazaka have been determined as almandines with high spessartine components and differ from another type of asteriated garnet, a more transparent pyrope-almandine from the Ilakaka mining area in

Figure 2a: Asteriated garnet cabochon from India, revealing a white six-rayed star. It measures 27.1 x 21.0 mm, and weighs 132 ct; collection K. Fischer, Starnberg. Photograph by M. Glas.

Figure 2b: Oval cabochon of almandine garnet weighing 28.88 ct and showing a four-rayed and a six-rayed star. Source: India. Photograph by E.A. Jobbins.

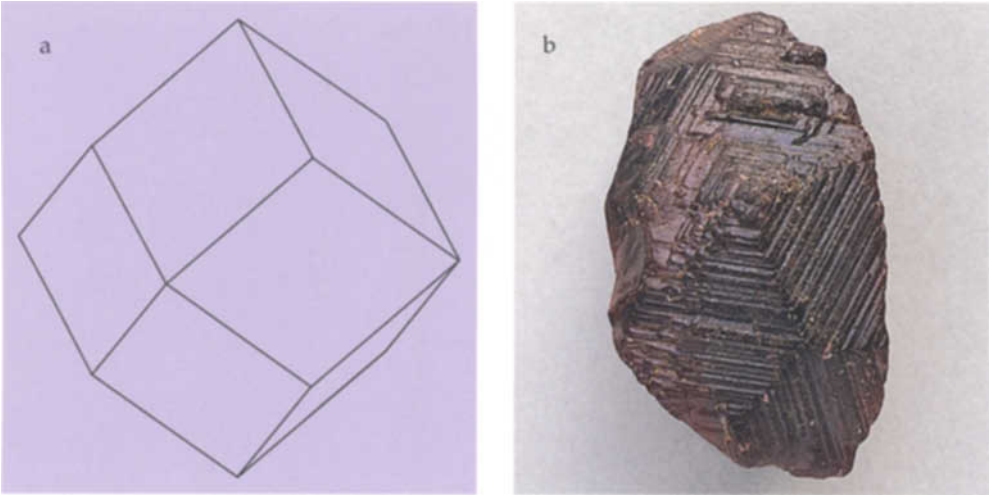

Figure 3: *Normally observed habit of garnet crystals from Ambatondrazaka, Madagascar, showing only the dodecahedron crystal form {110}:*

a) Idealized drawing (clinographic projection)

b) Fragment of a crystal showing three dodecahedral {110} faces; striations parallel to the edges <111> of the dodecahedron are also seen. Size of the sample is about 31 x 15 mm. Photograph by M. Glas.

southern Madagascar (Schmetzer and Bernhardt, 2002).

Geology of the occurrence

The region east and south-east of Lake Alaotra is one of the numerous pegmatite areas of Madagascar and is well known as a source of cyclic twins of chrysoberyl (Pezzotta, 1999). Rough garnet crystals up to 25 cm in diameter are recovered from one of these pegmatites which also contains K-feldspar, quartz, muscovite, and schorl (Pezzotta, 2001). The work in the pegmatite has been abandoned because of a landslide that covered the pits of local miners.

Visual appearance of rough garnet crystals and gemmological properties

The rough material available for the present study consisted of about 50 irregular fragments of garnet crystals measuring up to 8 cm in their longest dimension. In some samples, faces of the dodecahedron {110} were developed which show distinct striations parallel to <111>, i.e. parallel to the edges of the dodecahedral faces (*Figure 3*). Two crystals are strongly distorted with trigonal habit and both are elongated along one of the cubic three-fold axes (*Figure 4*). The dominant faces are the trapezohedron {211} in combination with the hexoctahedron {431}. Smaller trisoctahedral {221} and octahedral {111} faces are also present.

All samples are non-transparent and only lightly translucent with a reddish to purplish-brown colour. Refractive indices of the samples are above the limit of normal gemmological refractometers. Specific gravities of the samples lie in the range of 4.21 to 4.26.

Asterism and chatoyancy

For the present study, 40 cabochon-cut garnets up to 50 ct in weight and 15 samples cut as complete spheres were available. Samples cut as cabochons revealed distinct asterism forming sharp four-rayed white stars (*Figure 5*). According to the orientation of the surfaces of an individual cabochon, up to three of these four-rayed stars may be present (*Figure 6*). Garnet crystals cut as

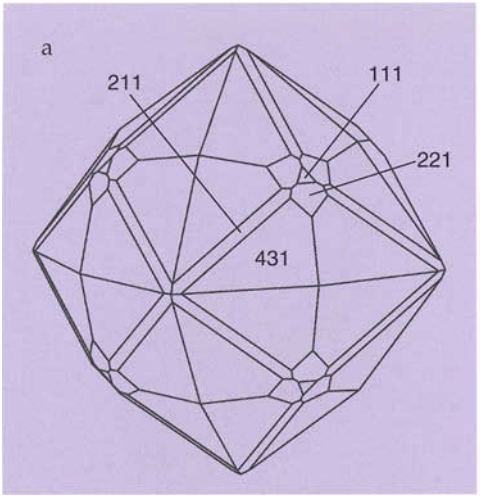

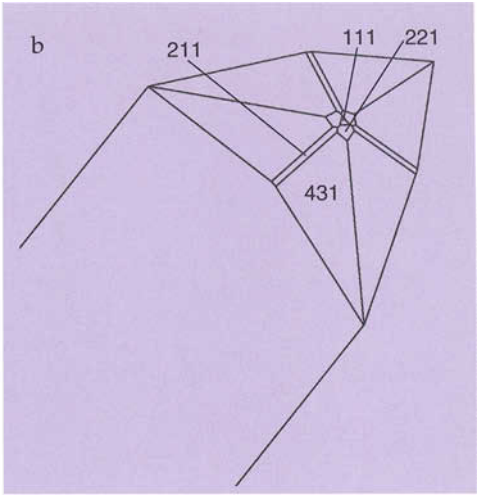

Figure 4: *Trigonally distorted garnet crystal from Ambatondrazaka, Madagascar:*

a) Idealized drawing (clinographic projection) of an undistorted cubic crystal showing the trapezohedron {211} in combination with the hexoctahedron {431} as dominant crystal forms; subordinate faces are the trisoctahedron {221} and the octahedron {111}.

b) Idealized drawing (clinographic projection) of a trigonally distorted crystal, the sample is elongated parallel to one of the three-fold axes <111> of the cubic garnet crystal (faces designated as in (a) above.

c) Photo of the trigonally distorted crystal drawn in (b) above, rotated compared with the idealized drawing.

Size of the sample is about 24 x 15 mm; photograph by M. Glas.

complete spheres (*Figure 7a, b*) showed 12 four-rayed stars on their surfaces, the centres of which were observed in a direction parallel to the six cubic two-fold axes <110>, i.e. in a view perpendicular to one of the twelve dodecahedral {110} faces.

One exceptionally large garnet sphere (*Figure 8a, b, c*) measuring 67.8 mm in diameter weighs 676 grams (3380 ct after recutting and repolishing in Germany). This sphere also revealed sharp four-rayed asterism in directions parallel to all of the cubic two-fold axes and is regarded as one of the largest

Figure 5: *Asteriated garnet cabochon from Ambatondrazaka, Madagascar, revealing a white four-rayed star. It measures 19.5 x 15.4 mm and weighs 34 ct. Photograph by M. Glas.*

Figure 6: *Asteriated garnet cabochons from Ambatondrazaka, Madagascar, revealing white four-rayed stars. The light bands of the four-rayed stars appear at different angles according to the orientation of the two-fold axis of the garnet in relation to base and dome of the cabochon. The cabochon in the centre is cut with a base perpendicular to a three-fold axis and shows the light bands of three four-rayed stars. Sizes of the samples are 19.5 x 15.4 mm to 11.1 x 8.9 mm, and weights vary from 34 ct to 5 ct. Photograph by M. Glas.*

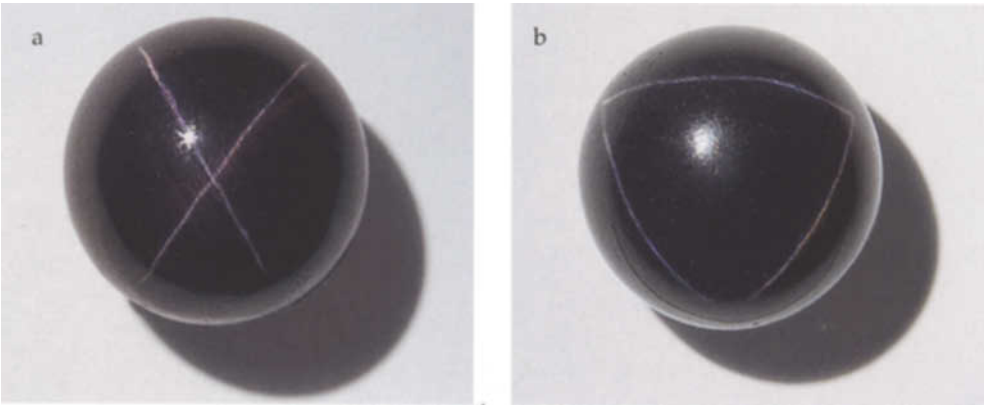

Figure 7: *Garnet from Ambatondrazaka, Madagascar, cut as a complete sphere: a) In a view parallel to one of the two-fold axes a four-rayed star is observed. b) In a view parallel to one of the three-fold axes, the light bands of three four-rayed stars are observed. The diameter of the sphere is 13.0 mm, weight 18 ct. Photographs by M. Glas.*

Figure 8: *Garnet from Ambatondrazaka, Madagascar, cut as a complete sphere:*

a) In a view parallel to one of the two-fold axes a four-rayed star is observed.

b) In a view parallel to one of the three-fold axes, the light bands of three four-rayed stars are observed.

c) In a view inclined to one of the two-fold axes a four-rayed star is observed.

The diameter of the sphere is 67.8 mm, weight 676 grams (3380 ct). Photographs by M. Glas.

asteriated garnet spheres known to date (see e.g. Brauns, 1907; Sinkankas, 1959).

In addition to the commonly observed asterism of the material from Ambatondrazaka, two of the garnet cabochons weighing 32.74 and 19.76 ct show a distinct reddish brown cat's-eye (*Figure 9*). The orientation of this additional light band is oblique to the different light bands forming the commonly observed white four-rayed stars of these samples.

Chemical composition

Microprobe analyses of three samples are given in *Table I*. These data represent average concentrations measured in scans of 20 point analyses each across the plane bases of the samples. In these scans, no distinct chemical zoning was observed.

The garnets are members of the almandine-spessartine series with almandine components of 70-73 mol.% and high spessartine components in the range of 18-21 mol.%. Appreciable pyrope percentages between 7 and 9 mol.% were also determined, and a small grossular component of 1-2 mol.% was also present. Calculating the garnet composition for 12 oxygens and for both iron valencies, iron in the trivalent state is always present in small amounts (between 0.035 and 0.045 Fe^{3+} atoms per formula unit). These data indicate a small component of about 1-2 mol.% of andradite in the garnet samples.

Table I: *Composition of almandine-spessartine garnets from Ambatondrazaka, Madagascar; electron microprobe analyses.*

Sample (wt%)*	1	2	3
MgO	2.17	1.90	2.00
CaO	0.60	0.36	0.47
MnO	8.02	8.60	8.96
FeO**	32.48	32.50	31.71
V_2O_3	0.01	0.01	0.02
Cr_2O_3	0.02	0.01	0.01
Al_2O_3	20.90	20.87	20.93
SiO_2	36.50	36.28	36.32
TiO_2	0.14	0.06	0.04
Total	100.84	100.59	100.46
Cations based on 12 O			
Mg	0.263	0.231	0.243
Ca	0.052	0.032	0.041
Mn	0.551	0.594	0.618
Fe	2.202	2.215	2.161
V	0.001	0.001	0.001
Cr	0.002	0.001	0.001
Al	1.997	2.005	2.009
Si	2.959	2.957	2.959
Ti	0.008	0.004	0.003
Mol. % end-members			
Pyrope	8.57	7.51	7.94
Grossular	1.69	1.03	1.33
Spessartine	17.96	19.34	20.18
Almandine	71.78	72.12	70.55

** Each composition reported is an average of 20 analyses.*
*** Total iron is given as FeO.*

Figure 9: *Asteriated garnet cabochon from Ambatondrazaka, Madagascar, revealing a white four-rayed star and a reddish-brown cat's-eye. It measures 19.2 x 17.2 mm, and weighs 33 ct. Photograph by M. Glas.*

Microscopic properties observed in thin sections and determination of acicular inclusions

For the examination of needle-like inclusions in the slightly translucent samples, and especially for the evaluation of the causes of asterism and chatoyancy, we prepared four polished thin sections of rough fragments of garnet crystals. These sections were not cut parallel to specific faces or according to specific crystallographic orientations.

Figure 10: *Dense network of rutile needles in an orientation parallel to two edges of the dodecahedron. Thin section, width of the sample about 0.45 mm.*

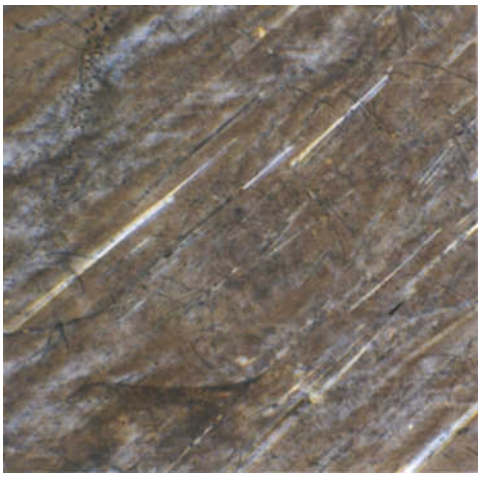

Figure 11: *Lamellar inclusions of birefringent sillimanite crystals in garnet from Ambatondrazaka, Madagascar. Thin section, crossed polarizers, width of the sample about 1.75 mm. Photograph by O. Medenbach.*

All samples showed a network of fine needle-like inclusions (*Figure 10*). In one of the four thin sections, the needles are somewhat thicker than in the other three and were large enough to be analysed by electron microprobe. Only titanium was found as a major component of these needles, and this is consistent with the results from micro Raman spectroscopy, which indicated the needles to be rutile.

In all four thin sections a variable concentration of a second type of microscopic lamellar inclusion was also observed (*Figure 11*). These birefringent lamellae are orientated in one direction which in every instance, differed from the orientation of the rutile needles. Occasionally, the lamellae are slightly inclined or bent. In one of the four thin sections that revealed a relatively high concentration of this second type of acicular inclusion, several lamellae could be measured quantitatively by electron microprobe. The analyses gave the exact composition of Al_2SiO_5 with iron contents in the range of 1.5 to 1.7 wt.% Fe_2O_3. Additional examination of these lamellae by micro Raman spectroscopy indicated that they are sillimanite.

Formation of asterism in garnets

In specific orientations of garnet hosts, asteriated samples typically show six and/or four-rayed stars formed by dense networks of needle-like inclusions. In both cases the stars are formed by bands of light which are orientated perpendicular to the needle axes. In the first case, a four-rayed star is observed in each direction of view perpendicular to a dodecahedral face. In the second case, a six-rayed star is observed in each direction of view perpendicular to an octahedral face. In a view perpendicular to a cube, the arms of six-rayed stars intersect and thus form a four-rayed star (Maier, 1943; Strunz, 1968; Kumaratilake, 1998).

In samples which show only four-rayed stars, the stars are formed by needles which are orientated parallel to <111>, i.e. parallel to the edges of the dodecahedron (*Figure 12a*). In a view perpendicular to a dodecahedral face, a rhomb with angles of 70° and 110° is seen, the edges of which are parallel to two <111> directions. The light bands causing asterism are oriented perpendicular to these edges. Consequently, four-rayed stars are observable in each view perpendicular to one of the twelve {110} faces. The stereographic projection (*Figure 12b*) shows the four light bands and their intersection points. On the surface of garnet crystals that are cut as complete spheres (*Figure 12c*), the centres of the stars are located at the positions of the two-fold axes <110>, that are perpendicular to the dodecahedral faces {110}. Turning a sphere through a certain angle α causes the light bands to move through an angle of 2α. Consequently, the spherical triangles of light bands observable on the surface of a garnet sphere are double the size of the spherical triangles drawn in *Figure 12c*.

In samples which show both four and six-rayed stars, the stars are formed by needles that are oriented parallel to <110>, i.e. parallel to the edges of the octahedron (*Figure 13a*). In a view perpendicular to an octahedral face, a triangle with three equal 60° angles is seen that is formed by three <110> directions, i.e. by three sets of needles. The light bands

Four-rayed stars

Figure 12: With an orientation of needle-like inclusions parallel to the edges of the dodecahedron, i.e. parallel to the four three-fold axes of garnet, four-rayed stars are formed in directions perpendicular to the dodecahedral faces; the arms of the stars are perpendicular to the long axes of the inclusions.

a) Clinographic projection of a cubic crystal with dodecahedral faces {110}, the theoretical positions of light bands perpendicular to the edges of the {110} faces are also shown.

b) The stereographic projection shows four intersection points of four light bands on the upper part of the projection sphere, four additional intersection points are found at the equatorial line of the sphere and another four intersection points are located on the lower half of the sphere (not shown).

c) Three dimensional view of a garnet sphere with four-rayed asterism caused by four light bands perpendicular to the cubic three-fold axes (orientation according to (a) above); the four light bands intersect at the dodecahedral faces. In a view of a sphere in different orientations, only two or three of these intersection points are seen (Figures 6, 7, 8). In a view parallel to one of the two-fold axes (Figures 7a, 8a) two intersecting light bands are observed. With a fixed orientation of the sphere, all intersection points are observable with an incident light rotated around the surface of the sphere.

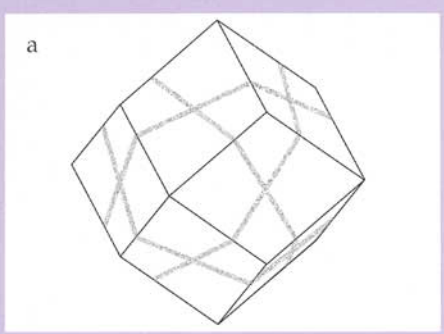

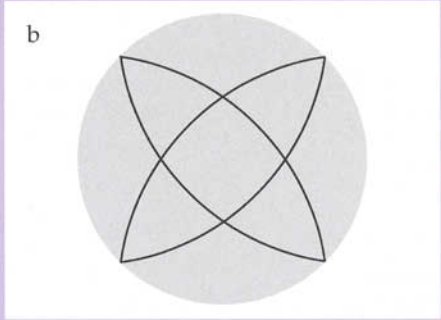

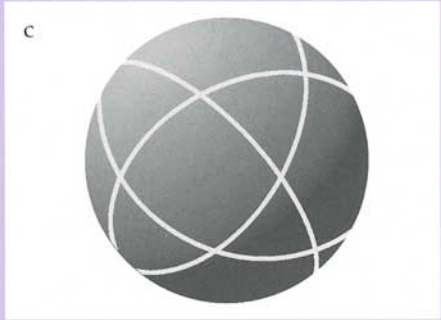

causing asterism are orientated perpendicular to these edges. Consequently, six-rayed stars are observable in each view perpendicular to one of the eight {111} faces. In a view perpendicular to a cube {100}, two sets of needles intersect at right angles. Consequently, six four-rayed stars with their centres at the position of the cubic four-fold axes <100> are seen. The stereographic projection (*Figure 13b*) shows the six light bands and their intersection points. On the surfaces of garnet crystals that are cut as complete spheres (*Figure 13c*), eight six-rayed stars are observable with the centres of the stars at the position of the cubic three-fold axes <111>, that are perpendicular to the octahedral faces {111}. In addition, six four-rayed stars are observable with the centres of the stars at the position of the cubic four-fold axes <100>.

Six- and four-rayed stars

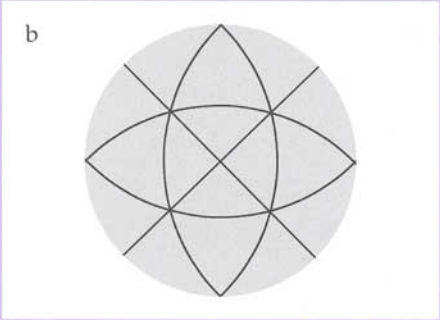

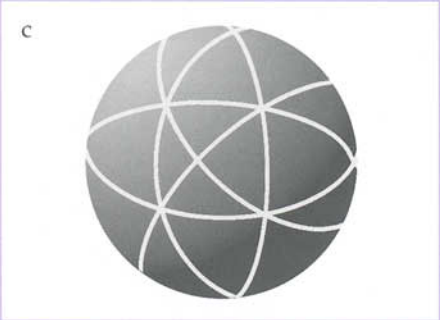

Figure 13: *With an orientation of needle-like inclusions parallel to the edges of the octahedron, i.e. parallel to the six two-fold axes of garnet, six-rayed stars are visible in directions perpendicular to the octahedral faces. Viewed in directions perpendicular to cube faces, four-rayed stars are formed by intersecting arms of six-rayed stars. The arms of both types of star are perpendicular to the long axes of the inclusions.*

a) Clinographic projection of a cubic crystal with octahedral faces {111} and cube faces {100}, the theoretical positions of light bands perpendicular to the edges of the {111} faces are also shown.

b) The stereographic projection shows four intersection points of three light bands on the upper part of the projection sphere; four identical intersection points are located on the lower half of the sphere (not shown); four additional intersection points of two light bands are found at the equatorial line of the sphere, one intersection point is located in the upper pole of the sphere and another one in the lower pole of the sphere (not shown).

c) Three-dimensional view of a garnet sphere with six- and four-rayed asterism caused by six light bands perpendicular to the cubic two-fold axes (orientation according to a) above); the six bands that intersect at the octahedral and at the cube faces form six- and four-rayed stars (see also the detailed explanation of Figure 12).

As well as the two types of star-forming needles parallel to <111> and parallel to <110> mentioned above, a third type of orientated needles in garnets is also described in the literature (Holland, 1896; Mellis, 1966; Strunz, 1968). These needles are found parallel to the cubic four-fold axes <100>, i.e. perpendicular to the cubic planes of garnets from India and Madagascar. Until now, star garnets with this particular orientation of needles have not been described, probably because the needles in this orientation do not form a dense silk-like network that is necessary for the formation of asterism.

Conclusions

Asteriated garnets from Ambatondrazaka near Lake Alaotra, Madagascar, are almandines with high spessartine and somewhat lower pyrope contents. The ordinary asterism of the samples is caused by orientated

rutile needles forming white four-rayed stars. Additional chatoyancy is due to orientated lamellae of sillimanite. To our knowledge, this is the first report of garnet cat's-eyes that show a certain type of acicular inclusion in one single orientation only. The formation of different six- and/or four-rayed stars in garnets is explained by the intersection of light bands that are formed perpendicular to dense networks of acicular inclusions.

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An unusual gem deposit (man-made) at Pallebedda, Sri Lanka

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ABSTRACT: An unusual gem deposit (man-made) lies in the remote village of Pallebedda in Sri Lanka. This deposit is known as 'walankatu illama' which lies within the bund or embankment of an abandoned tank called Kandiyapalle (alias Bisokotuwa). Second rate material from a jewellery industry of ancient times was included probably at the time of its construction. This deposit contains many archaeological artifacts including many varieties of beads, rough gems, gem carvings, glass and coins, but it is mined by villagers mainly for the precious stones because they can be most easily marketed.

Keywords: beads, bund, cameos, carving, clay utensils, intaglios, tank

Introduction

Sri Lanka is renowned for its wide variety of fine quality gemstones such as sapphire, ruby, chrysoberyl, alexandrite, spinel and beryl. Most of these gems are found as alluvial deposits in ancient buried or existing stream beds and low-lying areas. There are several primary outcrop deposits but the gems found in them are commonly not of the best quality, other than those found at the moonstone deposit of Meetiyagoda.

Gem deposits in Sri Lanka are classified according to their distance of transportation from the source, by the shapes and sizes of the rock and mineral fragments found. Gem-bearing beds where angular minerals and rocks have been deposited in situ are named as residual gem deposits. Gem-bearing layers found on the hill slopes with minerals and rock fragments that are semi-rounded or rounded are termed eluvial gem deposits. The third type of gem deposit is alluvial, which is by far the most prevalent in Sri Lanka. These deposits generally lie in old stream beds, far away from their sources and are characterized by the presence of well rounded heavy minerals, indicating longer distances of transportation (Dhanayake, 1980) (*Figure 1*).

In Sri Lanka there is currently no scientific approach towards gem exploration. Established gem miners who can afford to invest in land, to purchase a licence to prospect for gems and other expenses, always follow the trails of illicit gem miners. Some people find gems during their day-to-day activities such as construction of a well or while ploughing their farmlands.

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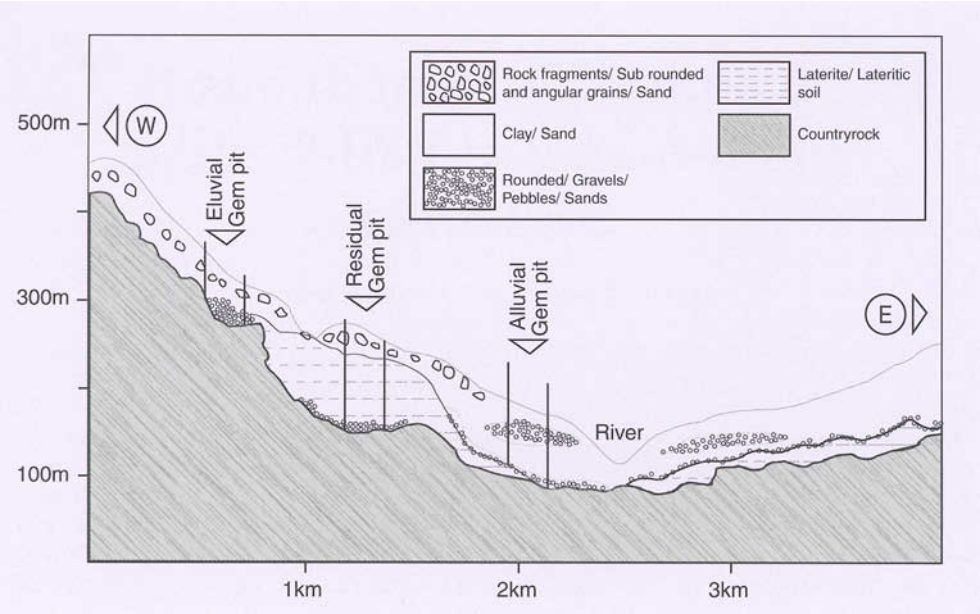

Figure 1: Schematic cross section showing different modes of occurrence of gemstones (modified after Dhanayake, 1980).

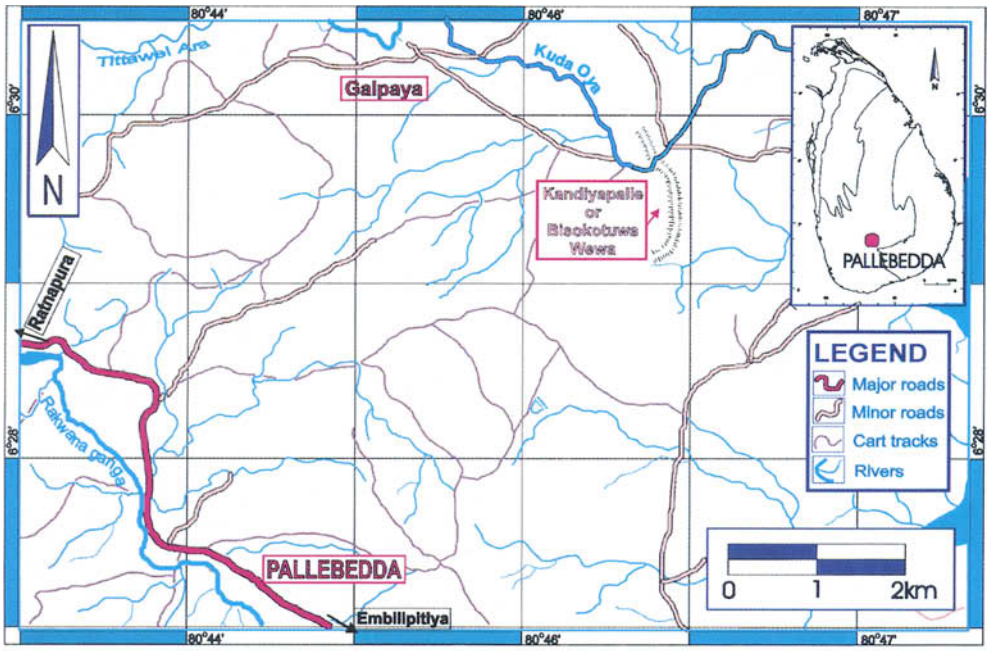

Figure 2: Location of Pallebedda and the abandoned tank called Kandiyapalle alias Bisokotuwa (source: Survey Dept. 1:63360 topographic map of Timbolketiya).

However, the type of gem deposit to be discussed in this paper is somewhat different to the three kinds of deposit outlined above.

Along the Ratnapura-Embilipitiya road, 21 km from Embilipitiya, is the village of Pallebedda, a gem-trading centre, which has existed since ancient times. Six km north east of Pallebedda is the small village of Galpaya, with an abandoned tank named Kandiyapalle alias Bisokotuwa Wewa (*Figure* 2). The bund (embankment) which encloses the tank contains hidden treasure consisting of a variety of gems, beads and carvings made of different materials. These artifacts and gems occur in a layer in the bund, 60 to 180 cm thick, which local people call 'walankatu illama'. In Sinhalese, 'walankatu' refers to pieces of earthenware and 'illama' refers to gem deposit. The artifacts bear witness to how knowledgeable the ancient civilization of Sri Lanka was and to their standard of living. The gem carvings exhibit the most intricate and delicate workmanship and provide evidence of a sophisticated technology of the time.

Historical records

According to several authors there is evidence that this area was once a flourishing agricultural village. R.L. Brohier, Surveyor General during colonial times, describes this tank with reference to a Mr Collins and a Mr Mitford who was Assistant Government Agent, Sabaragamuwa Province in 1848. According to the quotes this tank was quite beautiful at the time and had watered nearly a thousand acres of paddy fields (Brohier, 1934). There is an ancient stone pillar situated in the village with an inscription dating to the tenth century AD, which indicates that

Figure 3: *Cross section of the gem-bearing layer showing the embedded pieces of earthenware (walankatu illama).*

Figure 4: *Various types of beads found in the deposit.*

the village was called Girimandula (Nichal, 1979). It is not certain as to who built the tank but according to folklore the builder was King Vijayabahu I (1055–1110).

Materials found

For the villager, 'walankatu illama' is merely a gem deposit, unique because artifacts were found among the buried potsherds. This deposit is located along the tank bund that extends for more than 3.2 km (two miles). At a depth of 60 to 120 cm from the top surface lies the layer called the 'walankatu illama' with an abundance of potsherds. The thickness of the layer ranges from 60 to 180 cm (*Figure* 3). The layer is easily identified and the material is washed as usual in large wicker baskets to extract the gem material. A general idea as to the percentage of the earthenware material contained in the illama can be formed from the heaps of debris found in the vicinity of the washing sites. The miners are interested only in the gems, carvings and beads that fetch high prices. The highest prices are obtained for gems such as sapphire, geuda, pushparaga (yellow sapphire), chrysoberyl, etc. Even among these gems there are instances of finding stones with drill holes to indicate that they were once discarded as valueless, owing to imperfections detected during the process of drilling. Other than these, various kinds of objects have been found within the area, and these include many kinds of beads, clay utensils, glass bangles, stone cameos, intaglios, coins and bones.

The illama contains many types of large and small beads in a variety of shapes. These include glass, carnelian, agate, amethyst, terracotta, garnet, feldspar, rock crystal, chrysoberyl and zircon (*Figure* 4). These stones are called 'mukkaru gal' by the

Figure 5: Corundum bead (specimen of National Museum of Sri Lanka, No. 56-2-32).

Figure 6: Amethyst bead.

villagers, because most have drill holes which identify them as the raw material of a trade practised for a living by a segment of society known as mukkaru. The most sought-after beads (mukkaru gal) were the beads made of gem materials such as corundum (*Figure 5*) or amethyst (*Figure 6*).

At this site agate beads and clear glass beads have also been found in large quantities. According to archaeological dating, clear glass was made at a later date than coloured glass. As in many other places, carnelian beads of many shapes and sizes found at this site are believed to be from India. Pieces of beads broken during production, unfinished beads and discarded second-rate material suggest that there had been jewellery workshops here during ancient times.

Terracotta beads of various shapes and sizes are very common, the majority being disc-shaped; the larger ones are embedded with a tiny copper wire to strengthen the bead – an example of the ingenuity of the ancient craftsmen.

Figure 8: Several drill holes in a spinel as a result of testing the gauges of drill bits.

Figure 7: Drill hole through a bead showing slight disorientation in the middle.

Figure 9: Chrysoberyl carved with the figure of an elephant (1.8x).

Figure 10: *(a) Carnelian carved with the figure of a hunter along with his weapon and the dead animal (22 mm). (b) Carnelian carved with the figure of a female dancer (16 mm). (c) Carnelian carved with the figure of a reclining cow (13 mm). (d) Rock crystal carving depicting three cows drawn similar to the manner shown in Egyptian frescos (18 mm). (e) Rock crystal carving depicting a seated posture of Buddha in meditation (19 mm). (f) Carnelian carved with the figure of a woman adorned with masks, meant to be either a dancer or more probably a goddess (22 mm). (g) Scratched drawing on a rock crystal depicting a man dragging a child bound with ropes ('Wessantara jatakaya', a parable of Buddhism) (20 mm).*

Almost all the beads show clear evidence of how they were drilled. The abrasion marks indicate that they were drilled from both ends to meet in the middle, and commonly this resulted in a slight disorientation in the centre (*Figure 7*).

The question arises as to how they drilled tiny holes through these very hard substances. Some are of the opinion that emery powder and iron drill bits were used. If this is the case, how were the hard materials like sapphires drilled? Even for other gem species, it could have taken a very long time using this method to drill a single bead. Large numbers of beads found in the area suggest that the drillers were experts. Is it possible that they could have used diamond drill bits exported from India for the purpose of drilling? According to Henry Parker the bow-driven drill was familiar to locals in Sri Lanka from the second century BC onwards (Parker, 1981). So it is a fair assumption that they used this type of drill along

with diamond drill bits to drill with ease large quantities of beads and to cope with the harder gems such as sapphire. A number of stones of hard materials such as sapphire and spinel that contain multiple drill holes of the same gauge or different gauges have been found. This could have happened as a result of testing the gauges of drill bits on these stones (*Figure 8*).

The most interesting materials found in this deposit are not the beads or the clay utensils but the most intricately carved cameos and intaglios. These carvings are mostly in materials such as carnelian, rock crystal and coloured glasses, and very rarely in other types of material – one such rare type is chrysoberyl (*Figure 9*). Some carvings depict a cow in a seated position (*Figure 10c*) and three cows carved are similar to an ancient painting of an Egyptian goddess (*Figure 10d*). The human figures carved are of both males and females. The female figures are mainly of dancers (*Figure 10b*) and of a semi-nude woman meant to be either a dancer or more probably a goddess adorned with masks (*Figure 10f*). Male figures include a hunter with his weapon and a dead animal (*Figure 10a*), a seated Buddha in meditation (*Figure 10e*) and a man dragging a child bound with ropes, scratched on rock crystal ('Wessantara jatakaya', a parable of Buddhism) (*Figure 10g*).

Conclusion

These materials are much older than the date of construction of the dam, and this layer found within the dam was the fill material for the bund excavated from the nearby ancient work sites, where the clay utensils, beads and other carvings were manufactured. According to many experts, the materials can be dated from the first to the twelfth century AD. Therefore the assumption is that at the time the mukkaru people lived and worked in this vicinity in large numbers. The artifacts are of very good craftsmanship although they were made using the most primitive methods and instruments. In terms of the intricacy of the carvings and the quality of the drill holes in the sapphire they are not inferior to today's standards. They are also remarkable aesthetically.

This is an unusual gem deposit because it contains artifacts that had been once discarded by people who were only interested in gems of value (precious material). Sometimes a villager who has found a carved artifact of a precious stone may try to erase the carving by grinding it on a lap to make a faceted gem. This would find a more ready market than the carvings, which are considered as archaeological artifacts and cannot be sold on the open market.

Acknowledgements

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'Kakuten' (crane crown), an 'ojime' made from the tooth of a grass-eating animal

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ABSTRACT: 'Kakuten' is a kind of 'ojime', an ornamental craft product of the Edo era used to tighten the connecting strings between a 'netsuke' and an 'inro', or between a cylindrical container of khsier (a tobacco pipe) and a pouch for shredded tobacco. These craft products have attracted world-wide attention owing to their exotic motifs and delicate craftsmanship. 'Kakuten' has been highly praised as a magical ornament and was believed to consist of the red crown of the Japanese crane. Gemmological data obtained on a sample of 'kakuten' has now discredited this origin. Textural observations and micro-area FTIR spectroscopy have been applied to selected areas of a 'kakuten' showing a featureless white band and a porous band stained vermilion. The tests indicated that the 'kakuten' is made of an animal tooth. The white featureless bands correspond to enamel, and the porous vermilion bands correspond to the dentine part of an animal tooth. The texture of the tooth indicates that it is from a grass-eating animal but the species has not yet been identified.

Introduction

'Netsuke' and 'ojime' are small ornamental craft products of the Edo era and have been regarded as Japanese magical jewels by collectors[1]. 'Ojime' is smaller than 'netsuke' and usually spherical or die-shaped and engraved in exotic design, and used to tighten strings connecting a 'netsuke' and an 'inro'. 'Netsuke' is an ornamental craft product engraved in symbolic or exotic figures on various materials, and 'inro' is a set of lacquered portable boxes containing pills for an emergency. 'Ojime' is also used to tighten strings connecting a pouch for shredded tobacco and a cylindrical container that contains a 'khsier' (a tobacco pipe, consisting of two metal ends for bowl and mouthpiece, connected by a bamboo pipe-stem). All these items have attracted the enthusiastic interest of mainly European and American collectors, owing to their delicate craftsmanship and exotic motifs, and many went abroad after Japan opened up during the Meiji period. High quality examples of these craft

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Figure 1: *A set comprising a tobacco pouch (A), an 'ojime' ('kakuten') (B), a 'khsier' container (C) and strings. The size of the 'kakuten' is 2.1 cm across.*

Figure 2: *A collection of 'kakuten'. Bar indicates 1.0 cm. By courtesy of Ms Reiko Fujita.*

products may be seen these days mainly in European and American museums, such as the British Museum and the Victoria and Albert Museum in London, but not in Japan. There are books describing art, magic and materials used in 'netsuke' and 'ojime', and also clubs or societies which concentrate on collections and studies[1,2]. *Figure 1* shows a good example of a set, and the mutual relations between a tobacco pouch, a 'khsier' container and an 'ojime' (in this case 'kakuten').

A wide variety of materials have been used to make 'ojime' and 'netsuke'[1] and the most frequently used are ivory, narwhal, stag antler, amber, ebony, agate, malachite, silver, red copper, nickel and brass. Problems of weight, abrasion and fragility have restricted the number of materials practical for 'netsuke', but because of their comparatively smaller size, 'ojime' have been largely exempt from such limitations. The materials used for 'ojime' include coral, amber, ivory, vegetable ivory, fossilized mammoth tusk, narwhal, rhinoceros horn, stag antler, shell of mother-of-pearl, boxwood, rosewood, teak, sandal wood, mahogany, ichii (Japanese yew, *Taxus cuspidata*), bamboo, gold, silver, iron, brass, red copper, nickel silver, cloisonne, stained glass, ceramic, agate, tiger's-eye, jade, malachite, serpentine,

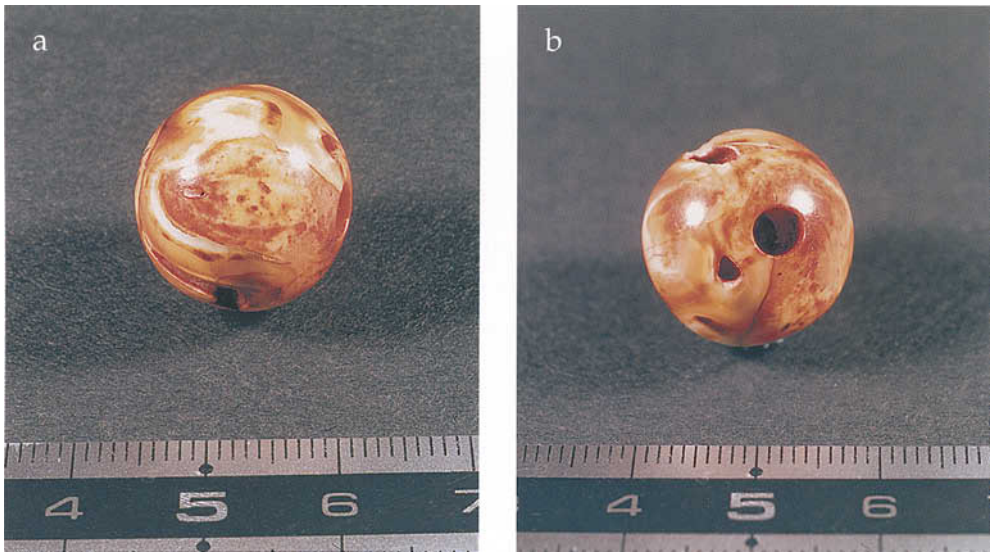

Figures 3a and b: *Two views of the 'kakuten' sample investigated; it is 1.7 cm in diameter.*

goldstone and turquoise[1,2].

Among the various materials used for 'ojime', 'kakuten' whose literal translation is a head (red crown) of a Japanese crane, has attracted particular interest among collectors. 'Kakuten' is fashioned in a small ball ca. 1.2 to 2.0 cm diameter with a hole, and shows an irregular pattern of alternating white and vermilion (or dark brown to reddish-brown) bands. It is also said that there are 'kakuten' with black and white or brown and white irregular bands. In *Figure 2*, a collection of 'kakuten' is shown.

In the oldest book of the Edo era published in 1781[3] describing how ornamental craft products were used to decorate swords, 'soken-kisho' (literal translation – highly praised ornamental crafts of swords), the word 'ho-ten' was used instead of 'kakuten'. 'Ho' is a Chinese imaginary bird such as a phoenix, and 'ten' is a crown or casque, a process on the upper mandible or on top of the head. The casque of the extinct helmeted hornbill (*Rhinoplax vigil*), an unusual substitute for ivory of bird origin, has an alternative name of 'ho-ting'[4], which also originated from China. The pronunciations of 'ho-ten' in Japanese and 'ho-ting' in Chinese apply to the same Chinese characters. It follows from this that the word 'kakuten' most probably originated from 'ho-ten' or 'ho-ting', a casque of an extinct species of bird that once lived in Borneo. The particular interest in and high praise for 'kakuten' are due to this fact.

One of the authors (I. Kimura) is a collector of 'ojime', particularly of 'kakuten', and considered it necessary to investigate the material of her collection to give a correct description. So she offered a sample for testing to I. Sunagawa. Gemmological tests of specific gravity (SG) and refractive index (RI) by Y. Takahashi revealed that the sample can neither be the red crown of a Japanese crane, nor the casque of a helmeted hornbill. So the sample was submitted for further investigation to check the texture under higher magnifications and the composition by micro-area FTIR spectroscopy; these were carried out by T. Sakae and I. Sunagawa. From these data, it has been concluded that the 'kakuten' is made of the tooth of a grass-eating animal. Since ornamental objects made from the teeth of animals are very rare and not recorded in gemmological textbooks, we considered it worthwhile to report the results in this journal.

Table I: *Gemmological properties of 'kakuten'*

RI (by spot method)	Dark brownish part	1.57
	Vermilion band (reddish-brown)	1.58
	White band	1.60
	Mean	1.58
SG (by hydrostatic method)		2.176
Fluorescence	The white band displays dull bluish-white fluorescence under long wave UV. The white band displays dull yellowish-white fluorescence under shortwave UV. The vermilion bands are inert.	
Spectroscopy	No absorption peaks in the UV-visible range of the spectrum.	
Chelsea colour filter	Colour reduction is observed only in the vermilion band. Ivory stamps that used the classical cinnabar inkpad show similar behaviour.	
Specific point	The vermilion dyestuff is partially soluble in distilled water and traces of colour were seen during the SG measurements.	

Table II: *RI and SG values of various ivories, 'kakuten' and adult human teeth.*

		RI	*SG*
Elephant		1.535	1.70-1.90
Hippopotamus		1.545	1.90-1.95
Walrus		1.560	1.95-2.00
Narwhal		1.560	1.95
Cachalot		1.560	1.95
Bone		1.54	2.60
Vegetable ivory:	Corozo nut	1.54	1.40-1.43
	Egypt nut	1.54	1.38-1.40
Helmeted hornbill		n.f.	n.f.
Keratin (main constituent of helmeted hornbill)		ca. 1.54	ca. 1.26-1.35
'Kakuten'		1.57-1.60	2.176
Adult teeth (mean)	as a whole, after drying		2.12
	Enamel	1.62	2.92
	Dentine	n.d.	2.26
	Cement	n.d.	2.11

N.B.: Data cited from references 4 and 5. n.d. = not determined, n.f. = not found

Sample description and gemmological investigation

The sample is a polished spherical bead, 1.7 cm in diameter, and has a hole (*Figure 3*). It shows an irregular pattern of alternating white and vermilion (or dark brownish to reddish brown) bands, and is reasonably similar to other 'kakutens' (compare *Figures 2 and 3*).

Standard gemmological tests were applied to the sample, and the data are shown in *Table I*. The data indicate that the 'kakuten' is not made of any known ivory or ivory-like materials, including the casque of the helmeted hornbill (see *Table II*). SG and RI values of the 'kakuten' are markedly different from those of any kind of ivory. Although no RI and SG data have been reported for the casque of the helmeted hornbill, or for the red crown of a Japanese crane, the values are assumed to be in the range given in *Table II*, since the material is essentially a keratin. Keratin is a major protein constituting hard skin, horn, nail and hair; it is tough and elastic, chemically stable, and insoluble in water.

The specific point in *Table I* also indicates that the vermilion bands of the sample are stained. Comparison of the appearance of the vermilion bands of the 'kakuten' under the Chelsea Colour Filter with the classical cinnabar inkpad indicate a close similarity and it is probable that the dyestuff used is cinnabar ink.

Texture and micro-area FTIR spectroscopy

Under higher magnification the white bands and the bands stained vermilion show distinctly different textures. *Figures 4a and b* show higher magnification photographs showing these differences in texture. The white bands are nearly featureless, with a fine and compact texture, and not being stained, faint features due to the internal scattering of light can be seen in the interior. In contrast, the vermilion bands are porous, with many spots selectively stained. The spots are only a few µm across, and the vermilion colour diffuses around them. The texture of the vermilion bands closely resembles the textures of dentine in mammalian teeth including those of humans. Stained spots correspond to the outcrops of dentinal tubules. White, featureless bands without any stain appear to correspond to the enamel portions of these teeth. The correspondence of respective

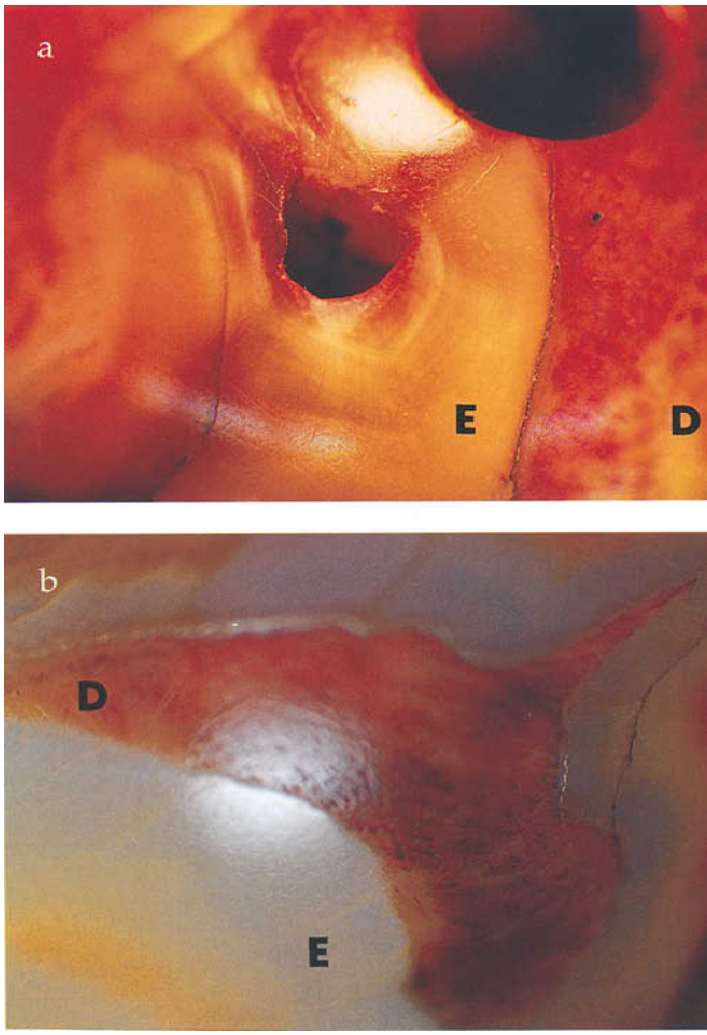

Figures 4a and b: *Photomicrographs of white (E) and stained vermilion (D) bands of 'kakuten', showing differences of texture. Bar indicates 200 µm.*

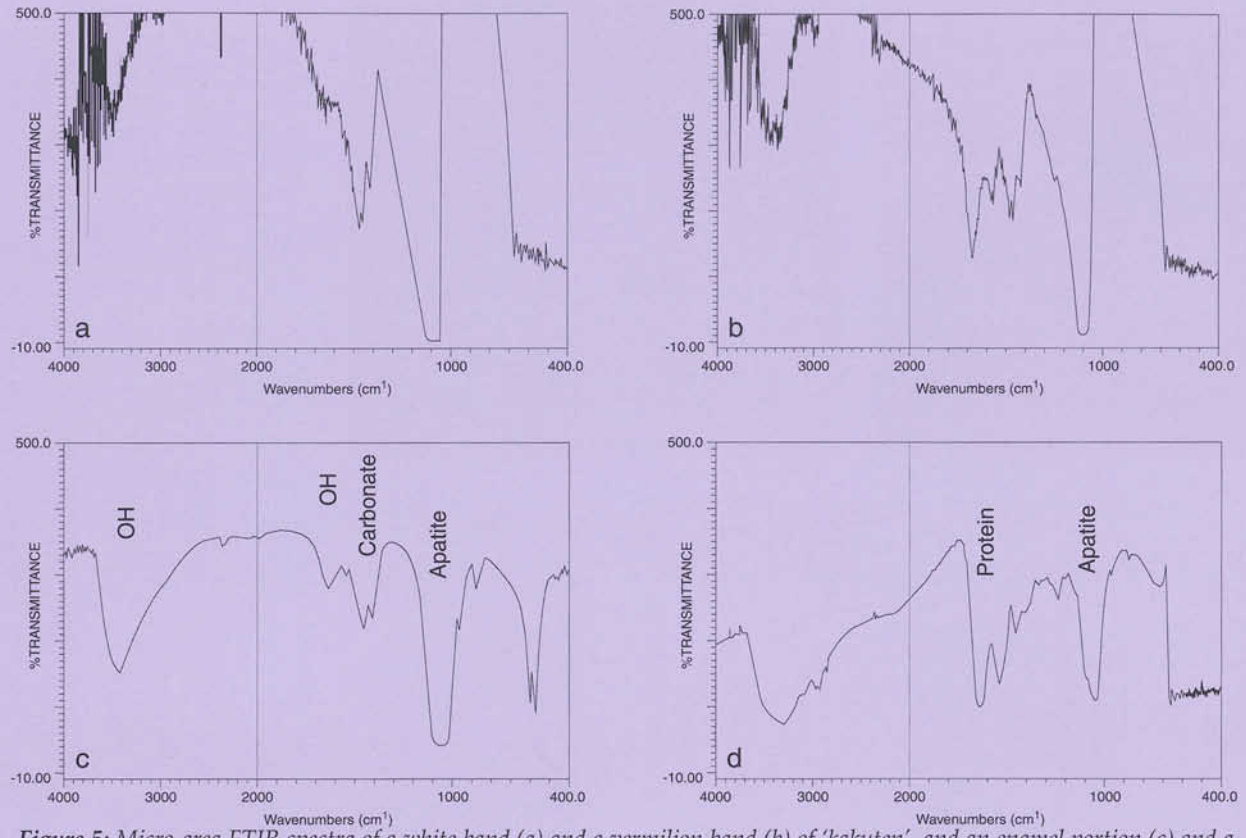

Figure 5: Micro-area FTIR spectra of a white band (a) and a vermilion band (b) of 'kakuten', and an enamel portion (c) and a dentine portion (d) of healthy adult human teeth. Spectra of (a) and (b) are K-K transformed spectra from reflected light measurement, and those of (c) and (d) are obtained by the powder KBr method. In (c) and (d), the absorption peaks are assigned on the basis of references 6-8.

bands between 'kakuten' and tooth material is based on the long experience of one author (TS) as a dental anatomist. Faint internal features observable in the white bands are attributed to internal light scattering at grain boundaries of hydroxyapatite crystals which constitute the enamel portion.

It is well known among dental anatomists that the teeth of mammals, irrespective of species, consist of enamel, dentine and cement components. Cement is a smaller and less important component than enamel and dentine. Enamel and dentine differ in composition, texture and function[6]. Irrespective of species, the enamel portions consist of 97 to 98% of hydroxyapatite and 2% protein, plus a small amount of carbonate and water, whereas dentine consists of ca. 30% hydroxyapatite and ca. 70% protein and water with no carbonate[6,7]. Hydroxyapatite crystals in enamel are much larger than those in dentine, and adopt well-formed hexagonal platy or prismatic habits. The average width of hydroxyapatite crystals in the enamel of adult human teeth is ca. 70 nm, the thickness is ca. 26 nm, and the length is commonly as long as 50 μm, occasionally attaining 100 μm. Hydroxyapatite in the dentine is much smaller, being less than 1 μm in length; it shows an ill-formed platy form and is poorly crystalline. The dentine contains dentinal tubules ca. 1 μm in cross section. These data are for healthy adult human teeth but essentially the same composition, constituents and functions, and sizes and forms of hydroxyapatite crystals are applicable to the teeth of any mammal[5–8]. The only difference among different species is the texture. Grass-eating and flesh-eating mammals show very different textures. Among grass-eating mammals detailed textures, i.e. form, thickness, distribution and proportion of enamel and dentine portions are different depending on species[9].

To confirm whether the 'kakuten' investigated is really made from the tooth of a mammal or not, micro-area Fourier Transform Infrared (FTIR) spectroscopy was applied to selected small areas (ca. 30 μm^2) of white and vermilion bands. A micro FTIR spectroscope manufactured by Horiba, Kyoto, Model FT-530 was used to obtain direct spectra by reflected light, since sectioning of the specimen was not permitted. The conditions of measurements were reflected light, selected area 30 μm^2, liquid nitrogen temperature, range 4000 – 750 cm^{-1}, resolution 2 cm^{-1}, time for measurement 100 sec. The direct reflected light spectrum can be transformed to a transmission spectrum by means of a computerized Kramers-Kroning (K-K) transformation, installed in the apparatus. In *Figure 5* K-K transformed FTIR spectra of white (a) and vermilion (b) bands are shown respectively. For comparison, transmission FTIR spectra of enamel and dentine portions of adult human teeth (taken by the KBr powder method and using the same spectroscope) are shown in *Figures 5c and d*, respectively, where the absorption peaks assigned to hydroxyapatite, protein, carbonate and OH are indicated. These assignments are well established in dental anatomy[6–8]. One may clearly notice the difference of composition between enamel and dentine in adult human teeth. By comparing (a) and (c) one immediately notices their close similarity, and the same applies to (b) and (d). From these observed similarities we may conclude that the white bands of the 'kakuten' correspond to enamel and the vermilion bands to the dentine portion of human teeth. Combining the SG and RI data, texture observations and micro-area FTIR spectroscopy, it is therefore concluded that 'kakuten' is made from the tooth of some species of mammal, and not from one of the better-known kinds of ivory or the casque of the helmeted hornbill.

From the viewpoint of biomineralization the enamel corresponds to the well crystallized (matured) component and the dentine to the poorly crystallized (prematured) component of the tooth. Irrespective of species, the enamel consists of larger and well-formed hydroxyapatite crystals, whereas the dentine is made of much smaller, poorly crystalline and ill-formed hydroxyapatite crystals. The different texture and function of these two components are due to this difference which

is attributed to differences in the proteins. It should also be noted that composition, constitution and texture of teeth themselves are essentially the same throughout all species of mammals. However, distribution of the enamel and dentine components in a tooth (which cause the different textural patterns) must be different depending on what food is eaten. The teeth of flesh-eating and grass-eating animals should have different patterns of distribution of enamel and dentine and in Hilton's book on teeth[9], patterns formed by distributions of enamel and dentine portions are illustrated for a variety of animals. The teeth of grass-eating animals show more complicated patterns than those of flesh-eating animals. Judging from the complicated patterns of distribution of the white and vermilion bands seen in 'kakuten', we consider that the tooth must be that of a grass-eating animal. To identify the species, investigation in detail of the distribution of the two bands, and comparison and correlation with the patterns recorded by Hilton[9] and other literature, would need to be undertaken. For this purpose the specimen would have to be sectioned which was not allowed, so the species could not be determined. It was suggested (G. Brown, pers. comm.) that the tooth may be from a hippopotamus. But the published SG and RI values (see *Table II*) are different, and questions would be raised about whether such teeth were imported into Japan during the Edo era.

In conclusion, this rare 'kakuten' has been identified as part of a tooth of a grass- eating animal.

Acknowledgements

Mr J-P. Poirot of Paris is acknowledged for information on the collections of the Musee Fragonard d'Alfort, Mr H. Fukushima of the Gemmological Association of All Japan for information on ivory and its substitutes, Dr K. Suzuki of Nihon University for information on FTIR spectroscopy and Dr G. Brown of the Australian Gemmological Association for the suggestion of a possible species origin for the 'kakuten'.

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Fake asterism – two examples

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ABSTRACT: Two cabochon-cut natural gem materials with artificially produced asterism are described. The light bands of the imitation stars are caused by sets of parallel scratches on the surfaces of the cabochons. A reddish-brown garnet of the pyrope-almandine series and a black tourmaline (schorl) are examples of this new type of imitation asterism.

Introduction

A new type of artificially produced asterism in natural gem materials was recently described by McClure and Koivula (2001). The optical phenomenon is caused by a series of man-made parallel scratches on the surfaces of cabochon-cut gemstones. Although the artificial production of asterism by oriented scratches in metal plates has been generally known since the middle of the nineteenth century and was described and explained in detail by Maier (1943), a similar technique has not been applied to natural gem materials until recently. The following minerals with artificially produced fake asterism were described by McClure and Koivula (2001): sinhalite, cassiterite, chrysoberyl, garnet, rutile and samarskite (?). Details of the production process are not known.

Garnet and tourmaline

The examination of two natural cabochon-cut gemstones with asterism which were purchased by one of the authors recently in Europe revealed that their asterism was artificially produced. Both cabochons were said to originate from Sri Lanka or India and they are described briefly.

The first gemstone of 3.08 ct (*Figure 1*) was determined as reddish-brown garnet. Absorption spectroscopy showed the common iron spectrum known for members of the pyrope-almandine series. Microscopic examination of the completely transparent garnet revealed only a few rutile needles in orientations, oblique to the surface of the cabochon. In these orientations, and especially in the low concentration present, a possible contribution to the asterism observed in the sample could be excluded. The star itself consisted of nine sharp rays (*Figure 1*) which were produced by several sets of parallel scratches on the surface of the cabochon.

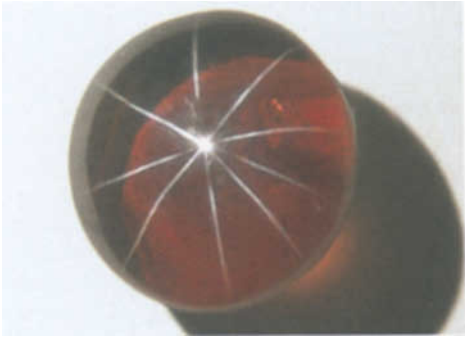

Figure 1: *Asteriated reddish-brown garnet of 3.08 ct; the star consists of nine sharp rays. Diameter of the sample 7.7 mm. Photograph by M. Glas.*

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Figure 2: Asteriated black tourmaline of 15.04 ct; the star consists of six sharp rays and two 'satellite' lines. Diameter of the sample 14.1 mm. Photograph by M. Glas.

Figure 3: Several sets of parallel scratches on the surface of the asteriated black tourmaline pictured in Figure 2. Photograph by M. Glas.

The second gemstone of 15.04 ct (*Figure 2*) was non-transparent and identified as black tourmaline. The high refractive indices of 1.625 to 1.646 indicate a relatively high iron content, i.e. an iron-bearing black member of the tourmaline group (schorl). The star shows six sharp rays at angles consistent with the trigonal symmetry of tourmaline. One of these six light bands, however, is accompanied by a strong and sharp 'satellite' line emanating from the centre of the cabochon to about half its diameter (*Figure 2*). A second somewhat weaker 'satellite' line was also observed in association with another light band of the six-rayed star. Again the surface of the cabochon showed various sets of parallel scratches (*Figure 3*).

Detection of fake stars

To date the recognition of artificially produced asterism is straightforward using simple visual observation of the unusual appearance of the star followed by microscope examination. A certain number of light bands and/or a symmetry of the star that does not fit with the symmetry of the gem material may be the first warning that the star is not natural. The presence of incomplete and/or misoriented 'satellite' lines is also indicative of man-made asterism as is the microscopic observation of oriented sets of scratches on the surface of an asteriated cabochon.

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Abstracts

Diamonds | Instruments and Techniques | Gems and Minerals | Synthetics and Simulants

Diamonds

Diamond genesis, mantle fractionations and mantle nitrogen content: a study of $\delta^{13}C$-N concentrations in diamonds.

P. CARTIGNY, J.W. HARRIS AND M. JAVOY. *Earth and Planetary Science Letters*, **185**(1-2), 2001, 85-98.

$\delta^{13}C$-N data from well-characterized diamonds show a correlation of the maximum diamond N content and $\delta^{13}C$, those with low $\delta^{13}C$ have low N contents (~ 0ppm at $\delta^{13}C$ < -30‰), those with high $\delta^{13}C$ have variable N contents (~ 3500 ppm at $\delta^{13}C$ = -4.5‰). Slow growth produces diamonds with N contents lower than the maximum value, and these are interpreted as having fractionated the N/C ratio relative to their growth medium. Since the limit sector is applicable to every diamond paragenesis, this implies every diamond type may be derived from a similar isotope source. Assuming a mantle $\delta^{13}C$ of -4.5‰, it is shown that the initial C/N value of mantle melts that crystallize diamonds is 200-500; similar to that for MORB. Subcontinental and oceanic mantles give samples with similar $\delta^{13}C$, $\delta^{15}N$ and C/N, suggesting an overall homogeneity of volatiles within these parts of the Earth since the Archaean. If N is incompatible during partial melting, a mantle N content of ~ 2 ppm could be expected, provided the mantle C content is ~ 40 ppm. However, evidence presented in this study shows that N is not completely incompatible, and a higher mantle N content (≤ 40 ppm) is preferred. J.F.

Chemical heterogeneity in carbonado, an enigmatic polycrystalline diamond.

S. DE, P.J. HEANEY, E.P. VICENZI AND J. WANG. *Earth and Planetary Science Letters*, **185**(3-4), 2001, 315-30.

Carbonado, a polycrystalline variety of diamond, has unusual C isotope compositions, with bulk $\delta^{13}C$ values clustering at -23 to -30‰ (PDB); significantly lighter than harzburgitic diamond (-1 to -10‰), and near the lower extreme for eclogitic diamond (+3 to -34‰). Studying textural and inclusion data and these isotope compositions has caused some workers to re-investigate whether carbonado originated in the mantle or the crust. Previous carbonado studies showed a bimodal grain size distribution that correlates with CL emissions, and is believed by these authors to result from a two-step growth process. Ion microprobe analyses of a Central African carbonado show a bimodal distribution of $\delta^{13}C$ (-24 to -26‰; instrumental precision ± 0.29‰). Also, secondary ion MS analyses show this $\delta^{13}C$ distribution coincides with variations in N abundance and both of these chemical zonations correlate with CL emission signatures. 1D analysis of self-diffusion of C in diamond suggests isotopic homogenization is extremely slow, even under upper mantle conditions. While the microscale distribution of C isotopes in carbonado does not constrain the *T*, *P* or t of carbonado formation, it does provide a geochemical signature that recorded the dynamics of the growth process. J. F.

Implications of the carbon isotope and mineral inclusion record for the formation of diamonds in the mantle underlying a mobile belt: Venetia, South Africa.

P. DEINES, F. VILJOEN AND J.W. HARRIS. *Geochimica et Cosmochimica Acta*, **65**(5), 2001, 813-38.

Analyses are presented of 199 diamonds from the Venetia kimberlite for $\delta^{13}C$ (range from -2.23 to -18‰) PDB; samples were grouped on the basis of previous chemical analysis of inclusions, by Viljoen *et al.*, (*Proc. VIIth Int. Kimberlite Conf., Cape Town*, 1998, pp 888- 895). Analyses are also presented of inclusions - chromites, olivines and garnets for $\delta^{13}C$ and major constituents. $\delta^{13}C$ distribution of these diamonds which includes a few highly $\delta^{13}C$ depleted samples, is similar to that of diamonds from kimberlites of the central Kaapvaal craton, and this supports the concept that the Limpopo belt is underlain by old, thick craton. The results support the hypothesis that the diamond suite represents several mantle environments that underwent several petrogenetic processes in which C of variable isotopic composition formed diamond. On the basis of chromite and olivine inclusions, fo_2 values are 2.9-3.5 orders of magnitude below that of the QFM buffer extending to 5.8 orders below QFM; large $\delta^{13}C$ variations would not be produced in diamond formation. The inclusions from the lowest $\delta^{13}C$ value

Abstractors

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samples do not indicate an unusual low fo_2 that might be expected in an organic source of diamond. R.K.H.

Metamorphic diamonds: mechanism of growth and inclusion of oxides.

L.F. Dobrzhinetskaya, H.W. Green II, T.E. Mitchell and R.M. Dickerson. *Geology*, **29**(3), 2001, 263-66.

A detailed series of EM observations are reported of metamorphic microdiamonds included in and separated from garnets and zircons from a single specimen of garnet-biotite-feldspar gneiss from the Kokchetav massif, Kazakhstan. The morphology of the diamonds ranges from skeletal forms composed of thin {111} plates to cuboid and octahedral forms. Included within the diamonds is a diverse suite of nanometric oxides, suggesting that the C-O-H fluid from which the diamonds grew may have carried chemical components derived from both the sediments and the mantle. The spectrum of morphologies and their abundant tiny inclusions can all be explained by a simple model based on the ratio of the rate at which {111} plates grow and the rate of random nucleation of new plates at their edges. P.B.L.

Diamond in its primary rocks with special reference to the diamond deposits of Mbujimayi, East Kasai, Zaire.

M.R. Fieremans and C.L. Fieremans *Geologie. Bulletin de la Société belge de Géologie*, **101**(1-2), 1992, 9-39.

The kimberlitic formations are described on the basis of recent data available for the kimberlite- and lamproite clans of rocks. The lower crust and mantle xenoliths are essentially eclogites. Megacrysts show unusual rutile- silicate intergrowths. The inclusions in Kasai diamonds suggest a peridotitic paragenesis. R.V.T.

Evidence for the transition zone origin of some [Mg, Fe]O inclusions in diamonds.

T. Gasparik. *Earth and Planetary Science Letters*, **183**(1-2), 2000, 1-5.

Inclusions of [Mg, Fe]O (fPc, ferropericlase, magnesiowüstite) occur in natural diamonds from several localities. Whilst fPc is typically absent from upper mantle assemblages, the expectation that it is common in the lower mantle in assemblages with [Mg, Fe]SiO_3 perovskite led to proposals that the inclusions originated in the lower mantle. Results from new experiments that produced fPc-bearing assemblages at 20-24 GPa and 1800-2000°C, suggest some fPc inclusions could have originated at the base of the transition zone if the mantle *T* were >1800°C. If so, reaction of garnet with fPc could cause a seismic discontinuity at ~ 660 km. J.F.

In situ discovery of shock-induced graphite-diamond phase transition in gneisses from the Ries Crater, Germany.

A. El Goresy, P. Gillet, M. Chen, F. Künstler, G. Graup and V. Stähle. *American Mineralogist*, **86**(5-6), 2001, 611-21.

Reflected-light microscopy and fine-scale laser micro-Raman spectroscopy of shocked garnet-cordierite-sillimanite gneisses in suevites of the Ries meteorite impact crater, Germany, has led to the discovery of impact diamonds in their pristine graphite-diamond assemblages. Graphite diamond textural relations permit a clear determination of the solid-state nature of the formation of diamond from graphite, which is estimated to have occurred at a peak shock *P* between 30 and 40 GPa. Shock-induced transformations were promoted in only unkinked and undeformed graphite booklets at the graphite-garnet, graphite-sillimanite, or graphite-rutile interfaces, where the difference in shock impedance is very high. Reverberations of shock waves with short wavelengths similar to the grain sizes at the phase boundaries are probably important constraints for dynamic graphite-diamond phase transformation. Raman spectroscopic investigations of hard transparent carbon platelets intercalated between fine-grained diamond and deformed graphite revealed the platelets to be Raman inactive. The platelets are either dense amorphous carbon or an unknown dense crystalline carbon phase that is Raman inactive. P.M.W.

Timing of eastern North American kimberlite magmatism: continental extension of the Great Meteor hotspot track?

L.M. Heaman and B.A. Kjarsgaard. *Earth and Planetary Science Letters*, **178**(3-4), 2000, 253-68.

Twenty-nine new U-Pb perovskite ages for kimberlite and other CO_2-rich ultramafic rocks from five localities in E North America (Rankin Inlet, Attawapiskat, Kirkland Lake, Timiskaming and Finger Lakes), show at least five distinctive periods of Mesozoic kimberlite magmatism, four of which at 196, 180-176, 148-146 and 142-134 m.y., were previously unrecognized. The detailed emplacement history of Kirkland Lake Jurassic kimberlites indicates magmatism occurred over a period of 13 m.y. (165-152 m.y.) with approximately half the kimberlites emplaced in <2 m.y. (156.9-155.3 m.y.). These U-Pb results show a NW-SE Triassic-Cretaceous age progression in kimberlite magmatism that extends more than 2000 km from Rankin Inlet through to the Attawapiskat, Kirkland Lake and Timiskaming fields. This is interpreted in part as the continental expression of magmatism associated with the Great Meteor mantle plume hotspot track. If correct, the timing and location of this magmatism more rigidly constrains the position of the hotspot, and the relative direction and rate of North American plate motion during the Mesozoic opening of the North Atlantic Ocean. J.F.

Brine inclusions in diamonds: a new upper mantle fluid.

E.S. Izraeli, J.W. Harris and O. Navon. *Earth and Planetary Science Letters*, **187**(3-4), 2001, 323-32.

Microinclusions in cloudy diamonds from the Koffiefontein kimberlite in the S Kaapvaal craton, South Africa, are either silicates, carbonates or brine. The silicates, of either eclogitic or peridotitic paragenesis, are associated with carbonates and brine. The brine has composition $(K, Na)_8(Ca, Fe, Mg)_4SiO(CO_3)_4Cl_{10}(H_2O)_{28-44}$, and differs from fluids trapped in fibrous diamonds mainly by its high Cl and low SiO_2. Average mass proportions are 30-42% H_2O, 19-22% Cl, 14-17% Na and K, 22-25% Fe-Ca-Mg-carbonates and 3-4% SiO_2.The close association of C-bearing brine, silicate minerals and diamonds suggests

such brines are important for diamond growth in eclogitic and peridotitic environments, and the similar composition of the brine in both environments, and the similar composition of the brine in both environments implies diamonds of both suites grew in a single event. J. F.

Electric lithosphere of the Slave craton.

A.G. Jones, I.J. Ferguson, A.D. Chave. R.L. Evans and G.W. McNeice, *Geology*, **29**(5), 2001, 423-6.

The Archean Slave craton in NW Canada is an ideal natural laboratory for investigating lithosphere formation and evolution, and has become an international focus of broad geoscientific investigation following the discovery of economic diamondiferous kimberlite pipes. Three deep-probing magnetotelluric responses reveal an unexpected and remarkable anomaly in electrical conductivity, collated with the kimberlite field that is modelled as a spatially confined upper mantle region of low resistivity (<30 m) at depths of 80-100+ km, and is interpreted to be due to dissolved hydrogen or carbon in graphite from. This geophysically anomalous upper mantle region is also spatially coincident with a geochemically defined ultradepleted harzburgitic layer. The tectonic processes that emplaced this structure are possible related to the lithospheric subduction and trapping of overlying oceanic mantle at 2630-2620 m.y. P.B.L.

Gem news international.

B.M. Laurs. *Gems & Gemology*, **37**(2), 2001, 138-59.

Items include an update on the Ekati diamond mine in the North West Territories of Canada, which in 2000 produced ~ 2.6 million ct of rough with an average value of US$ 170/ct, representing ~ 2.5 % of world production by weight and 5% by value. At least 250 additional occurrences of kimberlite, many diamond- bearing, have been found in the Slave Province. R.A.H.

Nitrogen distribution in diamonds from the kimberlite pipe No. 50 at Fuxian in eastern China: a CL and FTIR study.

F.-X. Lu, M.-H. Chen, J.-R. Di and J.-P. Zheng. *Physics and Chemistry of the Earth. Part A: Solid Earth and Geodesy*, **26**, 9–10, 2001, 773-80.

Cathodoluminescence (CL) and Fourier transform infrared techniques were used to study the internal structure, variable nitrogen contents, and state of aggregation of diamonds from kimberlite pipe # 50 at Fuxian, Liaoning Province, China. Single-stage growth, multi-stage complex growth and a rare agate-like structure were identified; most of these diamonds show complex growth histories. Diamonds with bright blue CL have higher nitrogen contents than those with dark green or green-blue CL. One diamond (LC35), a brown octahedron of 0.26 ct (3.2 x 3.6 mm), that had experienced at least four growth stages, has N varying in the range 244–679 atom ppm. Sharp increases and decreases at the growth-stage boundaries imply different conditions during crystallization. Before 1.3–1.4Ga, unstable conditions produced a rapid rate of growth, whereas after that time stable conditions gave a slower growth rate and enhanced fluid activity. R.A.H.

Short gemmological notes.

C.C. Milisenda. *Gemmologie. Z. Dt. Gemmol. Ges.*, **50**(2), 2001, 61-4, 8 photographs.

A number of intense greenish-yellow diamonds each weighing approx. 1 ct were identified as HPHT treated. They showed green fluorescence under long wave ultraviolet light, they also showed discoidal tension cracks and black inclusions probably resulting from graphitization during treatment. E.S.

Gem Trade Lab notes.

T.M. Moses, I. Reinitz, S.F. McClure and M.L. Johnson. *Gems & Gemology*, **37**(2), 2001, 130-38.

Items noted included a natural 14.07 ct elongated diamond with a black area in the middle and colourless, twinned portions at each end, representing different stages and conditions of growth. R.A.H.

Gems and Minerals

Esperienze tra Pakistan ed Afganistan.

G. Agozzino. *Rivista Mineralogica Italiana*, **25**, 2001, 86-95.

Minerals encountered during a visit to Pakistan and Afghanistan include a number of gem species, especially from pegmatite deposits. Areas described include the Hunza valley, the Dassu area around Haramosh, Shengus and Skardu. M.O'D.

The current status of Chinese freshwater cultured pearls.

S. Akamatsu, L.T. Zansheng, T.M. Moses and K. Scarratt. *Gems & Gemology*, **37**(2), 2001, 96- 113.

Although Chinese freshwater cultured pearls are assuming a growing role in the gem market, it is difficult to obtain information on quantities produced, in what qualities and the culturing techniques used. Recent visits to Chinese pearl farms in Hanzou Province examined the latest pearl culturing techniques being used there, both in tissue nucleation and, much less commonly, bead (typically shell but also wax) nucleation. With improved techniques, using younger *Hyriopsis cumingi* mussels, pearl cultures are producing freshwater cultured pearls in a variety of attractive colours that are larger, rounder and with better lustre. Tissue-nucleated examples can be distinguished from natural and bead-nucleated pearls by using X-radiography. R.A.H.

Schleifwürdiger grüner Lazulith aus Pakistan.

M. Andrut, V.M.F. Hammer, C.L. Lengauer, T. Ntaflos and G.J. Redhammer. *Gemmologie. Z. Dt. Gemmol. Ges.*, **50**(2), 2001, 65-74.

In 1998 some gem-quality deep green lazulite from the Gilgit district in Pakistan came on the market; originally these were only expensive samples for collectors, but in 2000 large crystals the size of a fist were on the market for about US $500 per ct. Hardness 5.5-6, SG.3.12, RI between 1.61 and 1.64, from yellow-green to blue-green with strong dichroism, almost iron-free. E.S.

Rhodochrosit aus Kassel, Nordhessen.

K. BELENDORFF. *Lapis*, **26**(9), 2001, 21-6.

Rhodochrosite of at least ornamental quality is described with other minerals from Kassel, northern Hesse, Germany. Some notes on the mining history of the area are given. M.O'D.

'Alpine' Bergkristalle von Piramida im Polar-Ural.

J.V. BURLAKOV AND J.A. POLENOV. *Lapis*, **25**(5), 2001, 27-31.

Rock crystal of alpine cleft type is described from Piramida in the Polar Urals of Russia. Details of the occurrence are given with examples of the crystal forms shown. Other minerals from the location are mentioned. M.O'D.

Kämmererit 'kirmizi rüya' – der rote Traum.

R. DIETRICH AND M. DIETRICH. *Mineralien Welt*, **12**(2) 2001, 40-53.

Fine quality dark red crystals of chrome-rich clinochlore (kammererite) are described from several locations in Anatolia, Turkey. Some crystals have been faceted despite their very easy cleavage. Notes on the geology and mining practices in the area are given, together with a descriptive mineral list. M.O'D.

Achat-Fundstellen in der Slowakei.

R. DUD'A AND B. BALÁZ. *Mineralien Welt*, **12**(4), 2001, 28-34.

Details of ornamental-quality agate are given for a number of sites in Slovakia. The modes of occurrence are described. M.O'D.

Spectral reflectance and fluorescence characteristics of natural-color and heat-treated 'golden' South Sea cultured pearls.

S. ELEN. *Gems & Gemology*, **37**(2), 2001, 114-23.

A comparison study is reported between the yellow and white nacre of the gold-lipped *Pinctada maxima* oyster shell and 65 yellow cultured pearls, both natural and treated colour, made from this mollusc. The yellow nacre has a characteristic absorption feature in the UV region between 330 and 385 nm; the strength of this feature increases as the colour becomes more saturated. White shell nacre fluoresces very light blue or very light yellow to long-wave UV radiation, whereas yellow nacre fluoresces greenish to brownish yellow or brown. Natural-colour yellow cultured pearls from *P. maxima* show absorption and fluorescence characteristics similar to those of the yellow shell nacre. In contrast, the absorption feature in the UV was either weak or absent in yellow cultured pearls reportedly produced by a method involving heat treatment, and their fluorescence was generally very light blue or light yellow. R.A.H.

La 'Rogerley mine' (Weardale, Durham, Inghilterra).

J. FISHER AND L. GREENBANK. *Rivista mineralogica italiana*, **25**(3), 2001, 150-65.

Geological and mineralogical survey of the Rogerley mine in Weardale, County Durham, north-east England, with notes on the exceptionally transparent green fluorite found there. The earliest mining records from the Northern Pennine Orefield date back to the 12th century. A table of rare earth contents in the fluorite and notes on mining history up to the present day are given. M.O'D.

Cala Francese, Sardinien.

A. GAMBONI AND T. GAMBONI. *Lapis*, **25**(12), 2000, 33-41.

The granite quarries on the island of La Maddalena (Sassari) in north-east Sardinia produce especially large crystals of quartz. Specimens are illustrated and other species from the area described. M.O'D.

The fluid inclusions of pegmatites with lithium mineralisation of the Araçuaí pegmatite district (eastern pegmatite province, Minas Gerais, Brazil).

I. GATTER, C. PREINFALK AND G. MORTEANI. *Chemie der Erde: Geochemistry*, **59**(4), 2000, 307-27.

Araçuaí district pegmatites are economically significant because of their Li, Be, Nb and Ta mineralization, and gemstones (tourmaline, aquamarine, morganite, kunzite). Fluid inclusions within the highly differentiated and zoned LCT-type pegmatites of Urubu, Barreiro, Maxixe and Morro Redondo, are either type-A, aluminosilicate-rich melt ± CO_2, type-B, mostly CO_2 but with variable, low H_2O contents, or type-C, H_2O with occasional daughter minerals. *Th* (fluid), *Te* (Tc) and Tm_{ice} were determined for type-C, and $ThCO_2$ and $TmCO_2$ for type-B inclusions. Pegmatite fluids evolved from a very H_2O- poor, CO_2-bearing aluminosilicate-rich melt, to an H_2O- dominated hydrothermal fluid. This change in fluid composition during early pegmatite crystallization resulted from early crystallization of tourmaline, which reduced H_2O solubility in the silicate melt. Increasing inclusion salinity with decreasing pegmatite crystallization *T* results mainly from incorporation of water into late (secondary) micas. J.F.

L'exploitation des mines d'émeraude D'Autriche et de la haute Egypte à l'époque Gallo-romaine: mythe ou réalité?

G. GIULIANI. *Revue de gemmologie*, **143**, 2001, 20-4.

Study of the working in classical times of the emerald mines in Austria and Upper Egypt with particular reference to the chemical composition of emeralds in artefacts from a number of museum collections. M.O'D.

La composition isotopique de l'oxygène des émeraudes de la mine de la Pita.

G. GIULIANI, *Revue de gemmologie*, **143**, 2001, 13-14.

Details are given of the isotopic oxygen content of emeralds from a new location at La Pita, Colombia. M.O'D.

Aluminium in quartz as an indicator of the temperature of formation of agate.

J. GÖTZE, M. PÖTZE, M. TICHOMIROWA, H. FUCHS AND J. PILOT. *Mineralogical Magazine*, **65**(3), 2001, 407-13.

An Al-thermometer was applied to agates from volcanic rocks, the *T* being calculated from the concentrations of $[AlO_4]^{\circ}$ centres as determined by e.p.r. measurements. The calculations for agate bands in some cases yield *T* of ≤ 655°C assumed to be invalid (the result of non-equilibri-

um crystallization processes). In contrast, the formation *T* (60-198°C) estimated for associated quartz encrustations within the agate geodes are in good accord with those calculated from the $\delta^{18}O$ data. Direct estimation of the formation *T* of agate is problematic. It is considered that the most useful results are those obtained by analyses of associated phanerocrystalline quartz encrustations. R.A.H.

Twenty years in minerals: mineral collecting.

D.I. GREEN. *UK Journal of mines and minerals*, **21**, 2001, 2-8.

Overview of the changing role of the mineral collector, museum collections and associated research, the mineral and gem trade and of useful recent publications. M.O'D.

Twenty year in minerals: Ireland.

D.I. GREEN AND S. MORETON *UK Journal of mines and minerals*, **21**, 2001, 29-36.

Blue beryl from two locations in the Mourne Mountains of Northern Ireland is described and illustrated in a general survey of mineral collecting in Ireland over the past 20 years. M.O'D.

Twenty years in minerals: Scotland.

D.I. GREEN AND J.G. TODD. *UK Journal of Mine and Minerals*, **21**, 2001, 9-27.

Illustrated survey of mineral species, varieties and notable specimens found in Scotland over the last 20 years. Items illustrated include elbaite from Glenbuchat, Grampian Region, aquamarine from northern Arran, amethyst from the Dalbeattie area of Dumfries and Galloway, agate from Broughty Ferry, Tayside. A comprehensive bibliography is appended. M.O'D.

Rubine aus neuen Vorkommen in Madagascar.

H.A. HÄNNI, C.C. MILISENDA AND U. HENN. *Gemmologie. Z. Dt. Gemmol. Ges.*, **50**(2), 2001, 89-94.

The latest deposit was found in the north-eastern province of Taomasina; there seem to be two mines, one near Vatomandry, east of the capital Antananarivo, known as the 'Charlyne Mine', the other, known as 'Zwtkoff Mine', is in the north-east of the island, south of the Alaotra Sea. This district also yields very beautiful yellow chrysoberyl trillings. Both deposits have great potential. Cut stones up to 12 ct have been seen. Inclusion patterns with clusters of zircons resemble these found in corundum from the Umba Valley in Tanzania and from the fancy coloured sapphires from the Ilakaka area in South-western Madagascar. The colour is purple-red and requires heat treatment. E.S.

Sapphirin aus Sri Lanka.

U. HENN. *Gemmologie. Z. Dt. Gemmol. Ges.*, **50**(2), 2001, 112-15.

Various faceted sapphirines and a rough specimen were examined. The cut stones weighed up to 0.69 ct each, colour varied from blue to grey-blue and came from Sri Lanka, near Kolonne, not far from Embilipitya; SG 3.42–3.51, RI 1.701–1.711, DR 0.006–0.007. An iron content of 2.04% FeO is responsible for the colour. There were healing cracks and zircon with tension cracks as inclusion patterns. E.S.

Lapis lazuli – Eigenschaften und Vorkommen, Imitationen und kuenstliche Eigenschaftsveraenderungen.

U. HENN AND C. BRAUN. *Gemmologie. Z. Dt. Gemmol. Ges.*, **50**(2), 2001, 95-108.

Lapis lazuli is one of the oldest known gemstones. It is largely an aggregate of lazurite but diopside, calcite and pyrite may be present. Commercially important occurrences are in Afghanistan, Chile, Russia and Tajikistan. There are several imitations on the market which are not easily distinguishable from the natural material. Unset stones can be identified by their RI and SG, stones set in jewellery are best identified by using infrared spectroscopy. E.S.

Stabilisierter gruener Tuerkis aus China.

U. HENN AND I. QUINTENS. *Gemmologie. Z. Dt. Gemmol. Ges.*, **50**(2), 2001, 109-11.

Apple-green turquoise has been on the market for some months. The apple-green colour is caused by a distinct iron content. Infrared spectroscopy showed the turquoise to be impregnated with artificial resin. E.S.

Batiferrit, ein neues Mineral aus der Eifel.

G. HENTSCHEL. *Lapis*, **25**(5), 2001, 37-8.

Small crystals of batiferrite are reported from the Eifel region of Germany where three distinct locations are identified. The flattened crystals, up to 2 mm across, show a dark metallic lustre with a pronounced cleavage parallel to {2001}. The composition is given as $Ba(Fe^{2+}, Mg, Mn^{2+})_2Fe_8^{3+}Ti_2^{4+}O_{19}$. M.O'D.

The Gem Emporium in Myanmar.

U.T. HLAING *Australian Gemmologist*, **21**(3), 2001, 117-9.

Myanmar's unique method of selling its gemstones consists of a combination of tender and bidding processes. Periodic 'Gem Emporiums' organised by the Myanmar Gem Enterprise (MGE) and by the Union of Myanmar Economic Holding Limited (UMEHL) are held in a hall next to the Gemstone Museum, Yangon. The MGE Emporiums started in 1964 and soon became popular with foreign gem merchants. The UMEHL began holding its own gem sales in 1994 and remains popular with local gem merchants. The paper briefly describes the differences between the sales of the two Gem Emporiums. P.G.R.

Rare earth element chemistry of zircon and its use as a provenance indicator.

P.W.O. HOSKIN AND T.R. IRELAND. *Geology*, **28**(7), 2000, 627- 30.

Sedimentary mineral assemblages commonly contain detrital zircon crystals as part of the heavy-mineral fraction. Age spectra determined by U-Pb isotopic analysis of single zircon crystals within a sample may directly image the age composition – but not the chemical composition – of the source region. *REE* abundances have been measured for zircons from a range of common crustal igneous rock types from different tectonic environments, as well as kimberlite, carbonatite and high-grade metamorphic rocks, to assess the potential of using zircon *REE* characteristics to infer the rock types present in sediment source

regions. Except for zircon with probable mantle affinities, zircon *REE* abundances and normalized patterns show little intersample and intrasample variation. To evaluate the actual variation in detrital zircon *REE* composition in a true sediment of known mixed provenance, zircons from a sandstone sample from the Statfjord formation (North Sea) were analysed. Despite a provenance including high-grade metasediment and granitic rocks and a range in zircon age of 2820 m.y., the zircon *REE*s exhibit a narrow abundance range with no systematic differences in pattern shape. These evidences show zircon *REE* patterns and abundances are generally not useful as indicators of provenance. P.B.L.

Quartz-Zwillinge nach dem Japaner-Gesetz aus Bolivien und Peru.

J. HYRSL AND A. PETROV. *Mineralien Welt*, **12**(4), 2001, 46-9.

Large quartz crystals displaying Japan-law twinning and of collectors' or near ornamental quality are described from locations in Bolivia and Peru. M.O'D.

Fluorapatit und seine Begleitmineralien vom Cerro del Mercado in Durango, Mexico.

M. JURGEIT. *Mineralien Welt*, **12**(4), 2001, 56-60.

Transparent yellow apatite of gem quality is described from the Cerro del Mercado mine in the state of Durango, Mexico. Notes on the mineralization of the occurrence are given. M.O'D.

Macro and micro anatase-rutile combinations in quartz.

J. I. KOIVULA, *Australian Gemmologist*, **21**(3), 2001, 129-31.

Both rutile and anatase can occur as inclusions in quartz. Although these inclusions are both polymorphs of titanium oxide and crystallize in the tetragonal crystal system, they can be identified by their appearance (long thin needles for rutile, slightly elongated octahedrons for anatase). Another factor which separates rutile and anatase is their formation temperature (high for rutile, low for anatase). Their presence as interconnected inclusions in the same quartz host helps to define that host's paragenesis, their physical relationship indicating which started growing first as the temperature rose or fell. P.G.R.

Gem news international.

B.M. LAURS. *Gems & Gemology*, **37**(2), 2001, 138-59.

Items include a 2.12 ct orange stone from Afghanistan/Pakistan represented as bastnäsite was identified as sphene, and canary-yellow tourmaline is reported from Malawi (heat treated to remove the brown colour component). A crystal of Nigerian tourmaline had a purplish-pink rim of Ca-rich elbaite on a pale orange- pink core of liddicoatite; it also had Bi_2O_3~0.3 wt.% in the core and ≤ 1.23 wt.% in the rim. R.A.H.

A new method for imitating asterism.

S.F. MCCLURE AND J.I. KOIVULA, *Gems & Gemology*, **37**(2), 2001, 124-8.

Several gemstones recently examined showed stars with an unnatural appearance or an unusual number of rays. In some of the species represented, asterism is very rare or had not been reported previously. Microscopic examination revealed that these 'stars' were produced by apparently using a rough polish to scratch lines in an orientated fashion onto the upper surface of the cabochons. R.A.H.

Gem Trade Lab notes.

T.M. MOSES, I. REINITZ, S.F. MCCLURE AND M.L. JOHNSON. *Gems & Gemology*, **37**(2), 2001, 130-38.

Items noted included a 40 ct cabochon of orthoclase (moonstone) with chrome diopside inclusions and a gibbsite bead dyed to imitate nephrite. R.A.H.

Mostre Verona 2000.

Rivista Mineralogica Italiana. **25**(1), 2001, 42-53.

Among specimens on show at the 2000 Verona mineral show were aquamarine and transparent colourless beryl from Erongo, Namibia, light green tourmaline from Pech, Afghanistan and fine blue apatite crystals from Minas Gerais, Brazil. M.O'D.

Les nouvelles mines de La Pita (Colombie)

J-C. MICHELOU. *Revue de gemmologie*, **143**, 2001, 9- 12.

Emerald is reported from a site known as La Pita, close to the municipality of Maripi which is situated between Muzo and Coscuez, approximately 100 km north-west of Bogota, Colombia. The site lies in an area known locally as El cinturon esmeraldifero occidental, in the eastern cordillera of Colombia. The emeralds occur in the Paja formation which consists of a thick series of dark schists intercalated with gravelly clays. Details of the establishment of the mine and its method of functioning are given: crystals up to 1563 ct have been recovered. M.O'D.

Nouvelles de Bogota.

J-C. MICHELOU. *Revue de gemmologie*, **143**, 2001, 8.

Emerald production at the Muzo mines in Colombia has been in decline over the past few years, productive areas having been worked for the last 500 years. Brief details of the mines and workings are given. M.O'D.

Edelsteinvorkommen und Plattentektonik.

C. C. MILISENDA. *Gemmologie. Z. Dt. Gemmol. Ges.*, **50**(2), 2001, 75-88.

The genesis of a large variety of gemstones is associated with the development of the lower continental crust, i.e. the bottom half of the continental crust. Rocks from deep crustal levels are restricted either to granulite-facies terrains at the earth's surface or xenoliths carried in alkali basaltic magmas. Virtually all corundum deposits are found in these two types of environments. A good example of the correlation of gemstone occurrences and plate tectonics is the Mozambique belt, which includes Madagascar, Sri Lanka and Southern India. In Africa, the Mozambique belt can be traced to the north in Ethiopia and Somalia and south to Mozambique. These countries have a potential for gem occurrences that have not yet been realised. Also where continents collided and sedimentary assemblages were buried to lower crustal levels

and then uplifted (e.g. the Himalayas), gemstones are and will be found. E.S.

Short gemmological notes.

C. C. MILISENDA. *Gemmologie. Z. Dt. Gemmol. Ges.*, **50**(2), 2001, 61-4.

Bi-coloured ametrine from the Yuruty mine, near the Anahi mine, Bolivia, has been on the market for some time. From the same source 'aluminium quartz' is offered, the name probably derived from the fact that the smoky quartz layers are aluminium enriched which by natural irradiation gives rise to the smoky quartz colour. Some intense yellow beryls from Nigeria were examined. A stone of 8.61 ct is illustrated showing an attractive inclusion pattern; the radially arranged needles have not yet been identified, but resemble goethite. E.S.

Ste Marie-aux-Mines 2001.

G. NEUMEIER, *Lapis*, **26**(9), 2001, 43-5.

Among gem-quality mineral specimens on display at the St Marie-aux-Mines mineral show held in 2001 were fine crystals of pink and green tourmaline from the Pedernerira mine, 100 km north of Governador Valadares and green tourmaline associated with transparent blue apatite from Paraíba, Brazil. M.O'D.

Bastnäsit aus Pakistan-ein neuer Schmuckstein?

G. NIEDERMAYR. *Mineralien Welt*, **12**(3), 2001, 51.

Transparent dark orange-brown bastnäsite-(Ce) of potential gem quality is reported from Pakistan. A faceted stone of around 8 ct is illustrated and shows needle- or channel-like inclusions. M.O'D.

Spektakuläre Funde von väyrynenit aus Nuristan, Afghanistan.

G. NIEDERMAYR. *Mineralien Welt*, **12** (3), 2001, 52-3.

Fine dark pink crystals of vayrynenite up to 1 cm long and of potential gem quality are described from pegmatites at the Afghanistan-Pakistan border. Some crystals are associated with green gem-quality tourmaline. M.O'D.

Achate aus der Lausitz.

R. NOACK. *Mineralien Welt*, **12**(5), 2001, 40-5.

Attractively-patterned polished agates are described and illustrated from the Lausitz area of eastern Germany. A short bibliography is appended. M.O'D.

India: alcuni minerali della provincia vulcanica del Deccan. Parte II.

B. OTTENS. *Rivista Mineralogica Italiana*, **25**(1), 2001, 4-24.

While this paper concentrates on mineral species available to collectors in the traprocks of the Deccan, India, collectors of unusual gemstones may welcome the opportunity to find out more about yugawaralite (which has sometimes been faceted) and fine crystals of calcite. M.O'D

Ätzfiguren und Auflösungserscheinungen an Fluoritkristallen.

P. RUSTEMEYER. *Lapis*, **25**(12), 2001, 11-23.

In an illustrated review of etch and dissolution marks on fluorite crystal faces theories of formation are discussed with reference to large and attractively-coloured specimens from a number of localities. M.O'D.

Spinelle aus Ilakaka, Madagascar.

K. SCHMETZER. *Lapis*, **26**(2), 2001, 33-4.

Gem-quality spinel of different colours is described from Ilakaka, Madagascar. Red and pink stones are coloured by chromium, cobalt and iron in conjunction colour blue to blue-violet specimens and bluish-green to greenish-blue specimens are coloured by Fe and a charge transfer Fe^{2+}/Fe^{3+}. Details of the absorption spectra are given. M.O'D.

Zwölfstrahliger Sternsaphir aus Bang-kha-cha, Thailand.

K. SCHMETZER AND M. GLAS, *Lapis*, **26**(11), 2001, 40- 42.

12-rayed star sapphires with dark body colours are described from Bang-kha-cha, Thailand. Diagrams illustrate the light paths involved when the crystals are cut en cabochon. M.O'D.

Ti-Fe mineral inclusions in star sapphires from Thailand.

S. SRINAKHARINWIROT. *Australian Gemmologist*, **21**(3), 2001, 125-8.

Black star corundums occur in Bang Kacha in more abundance and in larger average sizes than elsewhere in Thailand. The use of an electron probe microanalysis-wavelength dispersive spectrometer (EPMA-WDS), and the techniques of element mapping and spot analyses, produced results suggesting that the exsolved 'needles' causing the star are not rutile or hematite as indicated in the literature, but probably a mineral of the ilmenite-hematite series, ilmenite or a spinel. P.G.R

Porkura-ein klassischer Amethystfundort in Rumänien.

W. STÖHR, *Lapis*, **26**(9), 2001, 13-20.

Amethyst, some of fine gem-quality colour, is found in crystal groups at Porkura in west-central Rumania. Details of the local geology and mineralization are described with some notes on mining history in the district. M.O'D.

Clinopyroxene-corundum assemblages from alkali basalt and alluvium, eastern Thailand: constraints on the origin of Thai rubies.

C. SUTTHIRAT, S. SAMINPANYA, G.T.R. DROOP, C.M. B. HENDERSON AND D.A.C. MANNING. *Mineralogical Magazine*, **65**(2), 2001, 277-95.

A clinopyroxene xenocyst with an inclusion of ruby, in alkali basalt from the late Cainozoic Chanthaburi-Trat volcanic rocks of E Thailand, is found to be chemically similar to clinopyroxene inclusions in rubies from nearby alluvial gem deposits, suggesting a common origin for both types of occurrence. The clinopyroxene is fairly sodic, highly aluminous and magnesian (mg>0.9); sapphirine and garnet also occur as inclusions in the alluvial rubies. Thermodynamic calculations on the equilibrium 2Di + 2Cor = 2 CaTs + En constrains the *T* of clinopyroxene + corundum crystallization to between 800 and 1150 ± 100°C. Other equilibria indicate a limit on *P* of crystallization of 10-25 kbar, implying depths of between 35 and 88

km. The rubies are presumed to have crystallized in rocks of mafic composition, i.e. garnet clinopyroxenites or garnet pyroclasites, within the upper mantle. R.A.H.

Les inclusions en double hélice dans les émeraudes de Colombie.

P. VUILLET AND J. ROTLEWICZ. *Revue de gemmologie*, **143**, 2001, 15-19.

Double screw inclusions are described from Colombian emeralds: the cause of the phenomenon is not yet understood. M.O'D.

Notes from the Museum - focusing on travertine.

G. WEBB, *Australian Gemmologist*, **21**(3), 2001, 124.

A brief description of the composition, formation, appearance and use of the decorative rock travertine, examples of which can be seen in the mineral section of Sydney's Australian Museum. P.G.R.

Onyx im Mainzer Becken.

H. WEYGANDT. *Lapis*, **26**(2), 2001, 26-31.

Fine banded black and white onyx is described from the Mainz basin, Germany, and notes on its formation and that of differently coloured banded agate specimens from the same area are given. Jasper and carnelian are also described. M.O'D.

An overview of China's pearl industry.

H. XIE AND L. LI, *Australian Gemmologist*, **21**(3), 2001, 120-3.

The Chinese were the first to learn how to cultivate pearls about 900 years ago. China's modern pearl culturing industry began during the 1950s to 60s. Later, under the reforming policies of the People's Republic Chairman Deng Xiaoping, the cultured freshwater pearl industry flourished, reaching its peak in 1987 with a production of over 300 tons of pearls. As a result of this over-production, the price of pearls fell and by the end of the '80s China's pearl industry had become severely depressed. By 1990 production was rising again and eventually hit a new high with exports exceeding US$100 million. This serious over- production caused a second crisis, which resulted in the implementation of output control and an improvement in farming techniques. By 1998, the production and marketing of Chinese freshwater cultured pearls were in balance with demand, and the sale price had stabilized. On November 18, 2000, the Chinese National Pearl Association was founded in Beijing. This new organisation, drawing on the lessons of the past, will ensure that market order is maintained while establishing effective trade standards and setting up a competitive system for the cultivation and marketing of Chinese pearls. P.G.R.

A fluid inclusion study of an amethyst deposit in the Cretaceous Kyongsang Basin, South Korea.

K.H. YANG, S.H. YUN AND J.D. LEE, *Mineralogical Magazine*, **65**(4), 2001, 477-87.

The Eonyang deposit is considered to be spatially and temporally related to biotite granite of the Kyongsang Basin. Euhedral quartz crystals in cavities in the aplite which intrudes the granite are white at their base to amethystine at the top. Examination of fluid inclusions in these crystals and in rock-forming quartz in the granitic rocks showed three types of primary inclusions and three isochores for inclusions of each type were constructed. The intersection of the isochore representing the early fluid inclusions with solidus *T* of the host granite indicates initial quartz formation at ~600°C and 1.0-1.5 kbar. Intermediate quartz associated with high salinity inclusions occurred at ~ 400°C and 1 kbar, and the amethystine quartz formed from H_2O-CO_2-NaCl fluids at 400-280°C and ~ 1 kbar. The host granitic rocks including amethystine quartz probably crystallized in the root zones of porphyry-type systems. R.A.H.

Synthetics and Simulants

Conversion of silicon carbide to crystalline diamond-structured carbon at ambient pressure.

Y. GOGOTSI, S. WEIZ, D.A. ERSOY AND M.J. MCNALLAN. *Nature*, **411**(6835), 2001, 283-7.

The synthesis is reported on nano- and microcrystalline diamond-structured C with cubic and hexagonal structure, by extracting Si from SiC and Cl-containing gases at ambient *P* and < 1000°C. H_2 in the gas mixture leads to a stable conversion of SiC to diamond-structured C of average grain size 5–10 nm. Hardness values of >50 GPa, and Young's modulus < 800 GPa are reported for the nanocrystalline coatings. R.K.H.

New routes for the preparation of ultramarine.

CH. GURRIS, C. MIGOWSKI AND J. CH. BUHL. *Applied Mineralogy* (Rotterdam, Balkema), D. Rammlmair *et al.* (eds.), 2000, 787-90.

The alkaline transformation of kaolinite in the presence of sodium rhodanide produced a basic hydrosulphide sodalite $Na_8[AlSiO_4]_6(SH)_{1.3}(OH)_{0.7}.0.7H_2O$, which after heating at 1093-1153 K gave a pure blue sodalite. The Raman spectra are presented. R.A.H.

[Effect of oxygen partial pressures on the growth of oxide single crystals by the floating zone method.] (In Japanese with English abstract.)

M. HIGUCHI AND K. KODAIRA. *Journal of the Japanese Association for Crystal Growth*, **27**(5), 2001, 288- 92, 4 figs.

Rutile single crystals are grown under a low oxygen partial pressure of about 10^3 Pa to avoid formation of low-angle grain boundaries. Zr-doping is effective to grow rutile single crystals without low-angle grain boundaries and bubble inclusions at a high growth rate of 10 mm/h under a high oxygen partial pressure of 10^5 Pa. Cr^{4+}-rich Cr-doped forsterite single crystals are grown under a high oxygen partial pressure of 1-2 x 10^5 Pa. This was not possible by the conventional Czochralski method using an Ir crucible. I.S.

Short gemmological notes.

C.C. MILISENDA. *Gemmologie. Z. Dt. Gemmol. Ges.*, **50**(2), 2001, 61-4, 8 photographs.

An oval translucent, green cabochon of 2.20 ct, RI 1.50, SG 2.55 was shown to be a glass-jadeite-glass triplet. E.S.

BOOK REVIEWS

Rock-forming minerals. 2nd edn. Vol. 4A, Framework silicates: feldspars.

W.A. Deer, R.A. Howie and J. Zussman, 2001. The Geological Society, London, 2001. pp x, 972. Hardcover ISBN 1 86239 081 9. £50 (to Fellows of the Geological Society).

Geologists and mineralogists will find no difficulty over one mineral group having a whole, large volume to itself when it is the feldspar group! Of course the feldspars were dealt with in the previous edition of 1962 but, as expected, the present work includes a very much larger body of data, due almost entirely to the development of modern analytical techniques, including electron probe microanalysis and computer modelling among many others. Differences between this and the previous edition include the provision of bibliographies at the end of major chapters rather than a single very large listing in one place – this makes for ease of consultation – and the inclusion of more data on diffusion, chemical alteration and surface studies. Gemmologists straying into the text will find that alkali and plagioclase feldspars occupy the major sections and that both have a sub-section on optical and physical properties that will be found useful and very interesting. Those with an interest in crystals will find profuse, well-drawn diagrams. Readers should try to get a sight of the book which is very reasonably priced for today. M.O'D.

French jewellery of the nineteenth century: a loan exhibition.

Wartski, London, 2001,. pp 72, illus. in colour. Soft-cover. £7.00.

The exhibition was held to mark the publication of a translation of Vever, *La bijouterie française au XIXe siècle* and includes beautifully ornate and imaginative pieces, many of the Art Nouveau style. The catalogue descriptions are brief but entirely adequate and the whole publication is excellently produced. Provenances are given. M.O'D.

Elba: die klassische Urlaubinsel der Mineralogie.

Christian Weise Verlag, München, 2001. pp 96, illustrated in colour. Softcover. ISBN 3 921656 57 5 [ISSN of parent journal *Lapis* 0945 8492] *extraLapis* no 20. DM 34.80.

Elba is important to gemmologists as fine specimens of tourmaline are found there, many distinguished by black terminations on differently- coloured crystals. Tourmaline occurrences and types are extensively discussed in this multi-author monograph in the now accepted *extraLapis* style and presentation, both being first class. Fine orange crystals of spessartine occur with tourmaline and albite from the Rosina mine and both aquamarine and morganite are found in the Monte Capanne area. Colourless petalite has been faceted. Details of the Elba pegmatites are very useful and there are excellent maps and crystal diagrams. M.O'D.

Christie's guide to jewellery.

S. Hue-Williams, 2001. Assouline Publishing, New York. pp 95, illustrated in colour, hardcover. ISBN 2 84323 302 X. US $18.95.

Very pleasing small guide to the kinds of jewellery the reader might very well encounter in the major auction houses and especially in Christie's whose catalogues have provided the excellent illustrations. After a short conspectus of jewellery styles and periods the text takes the major gemstones, describing them and illustrating them usually but not invariably set in jewellery. Comments on precious metals, a brief note on the history of Christie's and short biographies of some of the major jewellery designers complete the book. M.O'D.

Kremlin gold: 1000 years of Russian gems and jewels.

Harry N. Abrams Inc., New York. 2000. pp 204, illustrated in colour, hardcover. ISBN 0 8109 6695 6, about £30.

This is an exhibition catalogue in which each individual item is not described minutely but in which the history of Russian jewellery and gemstones are presented as a background to the country's history. The pieces, selected from the Kremlin Museums in Moscow, were taken for display to the Houston Museum of Natural Science and to the Field Museum in Chicago. The illustrations are first-rate and a pleasing section at the end of the main text gives a short account, illustrated with paintings of some gem crystals, of the gem species found in Russia. The captions are informative and the general production very good: authors are in the main drawn from the leading Russian museums. M.O'D.

Pearls, a natural history.

N.H. Landman, P.M. Mikkelsen, R. Bieler and B. Bronson, 2001. Harry N. Abrams Inc., New York. pp.232, illus. in colour, hardcover. ISBN 0 8109 4495 2. US $49.50.

There are not many books about pearls and recent ones have not been especially good starting-points for the student, though they have often been attractively produced. This one, with general supervision by the senior author, a staff member of the Division of Palaeontology of the American Museum of Natural History, New York, comes close to filling this awkward gap. Illustrated by many beautiful photographs, the text opens with a description of pearl-producing molluscs with illustrations of the creatures involved – the first time I have seen anything like this. Not only does the reader feel that they could be recognized in the street from the

pictures but from the insides too – 'so this is how pearls get formed' [or, at least, where]. This is a quite excellent start to what continues as a really good effort to make pearls understandable and accessible.

Succeeding chapters cover the mechanisms of pearly lustre, pearls in human history (divided into European and non-European), the recovery of pearls, pearl culture and the preservation of pearl-producing molluscs. Each chapter has its own list of references and these are a lot better than usual. At last, a reasonable academic/popular study of a difficult subject. M.O'D.

Handbook of Raman spectroscopy from the research laboratory to the process line.

I.R. Lewis and H.G.M. Edwards (Eds), 2001. New York: Marcel Dekker. pp xiii, 1054, hardcover. ISBN 0 8247 0557 2 (Practical spectroscopy series. vol. 28) US $225.00.

A most useful and up-to-date multi-author coverage of what has become one of the most powerful tools in specimen determination. Gemmologists will first turn to the paper by Kiefert, Hänni and Ostertag, *Raman spectroscopic applications to gemmology*. Emphasizing the need for a powerful but non-destructive testing method for gemstones it outlines several applications: analysis on a lot of gemstones; analysis on taaffeite and musgravite; analysis on a purple jadeite consisting of jadeite and albite; analysis on stones set in a reliquary cross from the Basel Cathedral. The authors then describe the usefulness of the technique in the identification of inclusions and in treatments where the nature of filling materials can be determined. Examples are the analysis of impregnated jadeite; analysis of dyed quartzite to imitate jadeite; analysis of artificially coloured pearls; analysis of fissure fillers in emerald where the spectra of several types of oils and artificial resins are presented. There is a useful list of references.

This paper is not the only one with relevance to gem and ornamental materials. Apart from introductory descriptions of the theory of Raman spectroscopy and why it is so powerful an investigative tool, there are notes on its application to the characterization of archaeological materials and to crystals: Smith and Carabatos-Nédelec introduce crystal structures for the general reader and then proceed to describe Raman analysis of solid solutions and ways in which the techniques can be used to identify Bravais lattices (space lattices). Raman analysis can also be employed in crystal optics. Useful examples are given along the way: spectra from a Roman intaglio show that it was made from chrysoprase with some moganite [chalcedony polymorph] and contains a microinclusion of zircon.

Though the book is not intended in the first instance for non-scientific readers it certainly should be looked into by those concerned with the identification of unknown solids of any kind. Each chapter has its own list of references but the subject has already extended too widely for a general bibliography to form a part of what is already a very large work. The book is well printed and appears adequately bound: the price is not excessive for the work that has been devoted to its compilation.

M.O'D.

Diamond ring buying guide.

R. Newman, 2002. Los Angeles: International Jewelry Publications. Sixth edition. pp 156, illustrated in colour, softcover. ISBN 0 929975 32 4. US $17.95.

Never behind the times, Newman unerringly hits the right spot once more. This time it is with diamond treatments (HPHT stones among others), the growing interest in coloured diamonds and how they are to be graded. There is also a commentary on the diamond pricing system: here the 4 Cs as the only criteria for judgement come under unfavourable comment - read the book to find out why. There are more photographs in colour and a piece on the detection of synthetic moissanite. I like the questions (I look at the answers to try and find out what the question was) and the general style just as much as I ever have and the pictures even more.

M.O'D.

Diamond Grading ABC – The Manual.

Verena Pagel-Theisen, 2001. 9th new revised and enlarged edition. £39.50.

This much enlarged edition of the *Manual* includes an introduction to the history of the diamond trade and the occurrences and mining of rough diamonds. But it is the chapters dealing with the evaluation of colour, clarity, cut and weight of cut and polished diamonds which make this handbook essential for every diamond laboratory, grader and gemmologist as a reference book. These chapters are exceedingly well illustrated and explain the grading procedure carefully and in detail. A particularly useful chapter deals with modernizing old cuts and re-cutting damaged stones. The newer techniques of treating diamonds, like HPHT, are described and discussed. There are informative chapters on fancy cuts and fancy colours and there is a survey of imitations and simulants and their identification. Many instruments and tools of the trade are discussed.

Altogether there are 750 photographs and figures with a number of useful tables. The book is dedicated to Dr E.J. Gübelin, who has also written the preface. Extensive bibliography. E. S.

Gemstones, quality and value. Volume 3 Jewelry.

Y. Suwa, 2001. Sekai Bunka Publishing Inc., Tokyo, Japan. pp. 144, illustrated in colour, hardcover. ISBN 4 418 01902 2. £75.

This is in every way a worthy successor to the two previous volumes which dealt with the classic gem species with detailed notes on how values were arrived at and what were considered the finest colours and styles of fashioning. The present book does the same thing for jewellery and is the only one I know in which the design, construction, appearance and stones used are all

considered in minute detail so that the reader will be able to follow these stages in the creation of, for example, a diamond necklace and see just how some stones are preferred to others. Colours are compared once more as in the two earlier books and the matching of stones is illustrated. Large and clear diagrams show the different parts of pieces of jewellery and convertible pieces are also described. The photographs rank with the finest I have seen in this area of jewellery study and the book closes (?) a superb trio. M.O'D.

Emeralds. Revised edition.

F. WARD, 2001. Gem Book Publishers, Bethesda, MD, U.S.A. pp 63, illus. in colour, softcover, ISBN 1 887651 05 5 [*Fred Ward gem series*] 2001. £9.95.

Just as I had begun to wonder when another Fred Ward short colourful guide would come out, two more appeared in revised editions, this one and *Jade*. First published in 1993, *Emeralds* now covers a world in which a great deal has been happening. Fred still includes his experiences in Colombia but also updates such vital areas as the work of emerald crystal growers – his remarks on synthetic gemstones are absolutely correct – if the customer cannot try to learn about something for which he is willing to pay a great deal of money it is his own fault if he comes to grief (what Fred actually said was that synthetic gemstones fill a real need [they do and are beautiful as well] but the intention is there). As always the pictures are first-class and some show areas very little photographed, in Pakistan and Afghanistan. M.O'D.

Jade. Revised edition.

F. WARD, 2001. Gem Book Publishers, Bethesda, MD, U.S.A. pp. 64, illus. in colour, softcover, ISBN 1 887651 06 3 [*Fred Ward gem series*]. £9.95.

A welcome revision of the text first published in 1996, *Jade* now includes fresh as well as the original material with particular reference to some of the jade found from 1998 in Guatemala where jade of different colours occurs. The pictures, as expected, are excellent and the book gives a good introduction to the jade minerals for the student and the connoisseur. M.O'D.

Jades of Mesoamerica.

F. WARD, 1997. Gem Book Publishers, Bethesda, MD, U.S.A. pp 16, illus. in colour. Softcover ISBN 1 887651 00 4 [*Fred Ward Gem Books*]. £9.95.

Short but delightful guide to the jades of the Pre-Columbian period in central America, the text largely subsumed into the second edition (2001) of *Jade* (reviewed above). M.O'D.

BOOK SHELF – NEW TITLES

Diamond Grading ABC – The Manual by V. Pagel-Theisen £39.50

Diamonds: In the heart of the Earth, in the heart of stars, at the heart of power £40.00

Gemstones (2nd edition) by C. Oldershaw, C. Woodward and R. Harding £7.95

Gemstones, quality and value. Volume 3 Jewelry by Y. Suwa £75.00

Rediscover opals in Australia by S. Aracic £37.50

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Proceedings of the Gemmological Association and Gem Testing Laboratory of Great Britain and Notices

90TH BIRTHDAY

Our Vice President, R. Keith Mitchell, celebrates his 90th birthday on 28 February 2002. We congratulate him and wish him good health in the coming years.

APPOINTMENT OF NEW VICE PRESIDENT

At a meeting on 12 December, the Council of Management unanimously appointed Noel Deeks a Vice President of the Association. The appointment is for life and he joins Alec Farn, Bob Howie, David Kent and Keith Mitchell.

Noel has supported the Association for nearly 40 years and, in the last ten of those, has been particularly active in overseeing the day-to-day financial activities of the company. He obtained his FGA in 1969 while working in the jewellery trade, and after passing what was then the Diamond Certificate, started teaching the diamond course with Alec Pickett at the Sir John Cass College, and the summer diamond courses with Eric Bruton.

He was chairman of the Education Committee at the National Association of Goldsmiths for eleven years and has maintained his strong interest in course development, chairing the Diamond Committee that led to the Gemmological Association's correspondence course for gem diamonds.

Trained as a watchmaker, he has maintained an active interest in gem testing instruments and collaborated with Peter Read on the Brewster Angle meter; he has also developed his own synthetic moissanite tester.

OBITUARY

Michael S. D'Arcy FGA DGA (D.1967), Holt, Norfolk, died on 24 December 2001.

MEMBERS MEETINGS

Gem-A Conference 2001

The Annual Conference was held on Sunday 4 November at the Barbican Centre, London. A full report was published in the December 2001 issue of *Gem & Jewellery News*.

London

On 10 October at the Gem Tutorial Centre, 27 Greville Street, London EC1N 8TN, Moya Corcoran gave an illustrated lecture entitled 'A portrait of jewels'.

On 21 November at the Gem Tutorial Centre Professor David Smith gave lectures entitled 'Analysis of precious stones under thick glass by Mobile Raman Microscopy' and 'Compositions of jade and garnets by non-destructive Raman Microscopy'.

On 6 December at the Gem Tutorial Centre, Michael O'Donoghue gave a talk on the 'Literature of gemstones'. Those present had the opportunity to examine many of the books held in the Gem-A library.

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GIFTS TO THE ASSOCIATION

The Association is most grateful to the following for their gifts for research and teaching purposes:

Mrs M. Bird, Ransey, Isle of Man, for her late husband's gem collection of crystal models, crystals and cut stones.

Maggie Campbell-Pedersen, London, for *Amber* by the Danish Amber Museum.

Professor Akira Chikayama, Tokyo, Japan, for peridot crystals from three different localities, together with maps of the mines.

The Diamond Trading Company, London, for the permanent loan of a DiamondSure ™1.

H. Gerald Stonley, Haddenham, Buckinghamshire, for a wide range of cut stones typical of the market over 40 years.

Pierre Vuillet, Villards d'Heria, France, for photographs of screw inclusions in Colombian emeralds and topaz from Pakistan; also for a cut and polished synthetic berlinite.

Julia Woods, Spetisbury, Dorset, for a collection of stones.

Midlands Branch

On 28 September at the Earth Sciences Building, University of Birmingham, Edgbaston, Richard Taylor gave a talk on 'The implications and problems of gemstones in jewellery valuations'.

On 26 October at the Earth Sciences Building John Wheeler of Tamborine, Queensland, Australia, gave a talk entitled 'Beautiful opals, Australia's national gemstone'. His presentation included a video of opal mining at Lightning Ridge and a display showing top-quality black opal, boulder opal and white opal specimens.

On 30 November at the Earth Sciences Building Alan Hodgkinson spoke on the characteristics and identifying features of natural, synthetic, treated and composite emeralds.

The 49th Annual Dinner of the Branch was held at Barnt Green on 8 December.

North West Branch

On 19 September at Church House, Hanover Street, Liverpool 1, Charles Preston gave a talk entitled 'Reading silver hallmarks'.

On 17 October at Church House Ray Rimmer spoke on 'Pawnbroking throughout the 20th century'.

The Branch AGM was held on 21 November at Church House, at which Deanna Brady, Ray Rimmer and Eileen Franks were elected Chairman, Secretary and Treasurer respectively. The AGM was followed by a social evening.

Scottish Branch

On 24 September at the British Geological Survey, Murchison House, West Mains Road, Edinburgh, Roger Key gave a talk on 'Gemstones and geology of South Central Africa'.

On 17 October at the British Geological Survey, Clive Burch gave an illustrated lecture on 'Inclusions: highlights from twenty years of gemstone photomicrography'.

On 20 November at the British Geological Survey, Rosamond Clayton gave a talk entitled 'Jade then and now'.

South West Branch

A meeting of the Branch was held during the afternoon of 25 November at the Royal Literary and Scientific Society Institute, Bath. A video-microscope demonstration was given by Doug Garrod entitled 'Everything included', and Marcus McCallum gave a hands-on demonstration on pearls.

PRESENTATION OF AWARDS

The Presentation of Awards gained in the 2001 examinations was held at Goldsmiths' Hall, Foster Lane, London EC2 on Monday 5 November. Professor Alan Collins, President of Gem-A, presided and welcomed those present, particularly those students who had travelled from as far away as Canada, China, Japan, Korea, Hong Kong and the U.S.A., as well as many European countries. He announced that in January and June 2001, a total of 760 students and entered the Preliminary and Diploma Gemmology and Gem Diamond Diploma examinations. A total of 143 students had qualified in the Gemmology Diploma examination and 121 in the Gem Diamond.

Professor Collins then introduced Raymond Sancroft-Baker, Senior Director of the Jewellery Department at Christie's, who presented the awards.

(a) Raymond Sancroft-Baker (right) presentating the Christies's Prize for Gemmology to Ian Sipson of Trowbridge, Wiltshire. © Peter Dyer Photographs Ltd.

(b) Dong Lan of Wuhan, PR. China, receiving the Anderson-Bank Prize. © Peter Dyer Photographs Ltd.

Mr Sancroft-Baker delivered his address (see below) and a vote of thanks was given by Vivian Watson, who also thanked the Goldsmiths' Company for kindly permitting Gem-A to hold the ceremony at the Hall.

A Reunion of Members was held following the ceremony, attended by over 200 members and students.

Raymond Sancroft-Baker's address

"It gives me great pleasure to be standing here presenting the awards for 2001. I do know how difficult it is to obtain these diplomas and how proud you all must be feeling – and that the many many hours of hard work are soon forgotten.

"The qualifications you now have give you a head start in the world of jewellery; being

(c) Karen McKinley of Northampton receiving the Preliminary Trade Prize. © Peter Dyer Photographs Ltd.

(d) Allyson Thomas of Birmingham receiving the Deeks Diamond Prize. © Peter Dyer Photographs Ltd.

(Left to right) Vivian Watson, Raymond Sancroft-Baker, Dr Roger Harding and Professor Alan Collins at the Presentation of Awards ceremony. © Peter Dyer Photographs Ltd.

qualified is vital for the analysing and grading of jewellery which becomes more complicated with simulants and treatments reaching new heights of sophistication. This situation inevitably raises questions of ethics; for instance, when sapphires are sold should it be stated that they are heat treated, and are glass-filled rubies, rubies at all? It should be remembered that many Mong Hsu rubies are often heated to 1600°C in order to eradicate the inner blue core and heating more gently can remove inclusions – especially silk – from corundum, as well as giving the stone a more even distribution of colour. Should it be compulsory for laser-drilled diamonds to be so described on both sides of the Atlantic? I certainly think so.

"The use of Opticon has had a huge effect on the value, and confidence in emeralds. It is difficult to know where to stop, as tanzanite is brown when found and only becomes its vibrant blue colour when heated. I find it amazing that a New York firm who sell treated diamonds (high pressure, high temperature), say that it does not really matter as nobody can tell the difference. It is the same in many spheres of life; people are just trying to get something for nothing and this is certainly nothing new. Now at least you will be able to know how to go about the problems that gemstones present.

"I know there are moves afoot to create a jewellery centre in Hatton Garden and I am very much in favour of such an enterprise. it could become a real attraction not only from people just looking but also buying, especially if they could actually see a diamond or indeed any gemstone being cut and polished. London also lacks a museum devoted to 20th century jewellery and all there is to see are the wonderful galleries in the Victoria and Albert Museum that specialize in antique jewellery without much concern for more modern creations. People do need to be educated and I know from having organized short jewellery and gemmology courses that there is a great thirst for knowledge by not only members of the public but also those belonging to the trade. I just hope that sufficient funds are available as projects such as these inevitably absorb more money, time and resources than were envisaged at the outset. Hopefully there are people in this room that will help in this exciting idea.

"What I have said reinforces the need for London to have an effective and efficient gemmological laboratory that can grapple with the complex puzzles of today's jewellery world. Its importance was brought home to me in my first week in the Jewellery Department at Christie's. I had been in the Coin Department for 18 years but

this was a small hobby getting smaller and I was lucky enough to be offered the opportunity of becoming the administrative director of Jewellery. During the first week of my new vocation in January 1988, a man came to our front counter with a large sapphire which he claimed to be Burmese and wanted the appropriate price; but my colleague thought it was from Ceylon which upset the client and he demanded to see the Director. I remember going down the lift chanting ruby red, emerald green, sapphire blue. After a close examination of the sapphire I said that while I was sure he was right, my colleague was of a sensitive nature and maybe the best solution was to send it to the famous gem lab for certification.

"I was asked to explain the role of the auctioneer in today's fast changing world. Some people think that I spend my time with dowager duchesses selecting a few baubles for our next auction. I can assure you that the vast majority of old family jewellery has already been sold. It is true that once this country was a huge repository of wealth but with two World Wars and high taxation there is little left; our sales are filled to some extent from what people can't wear any longer because jewellery in general makes people nervous either from the insurance angle or they fear that they might be mugged. In recent years as less jewellery has come from the public more has been consigned by the trade as we can reach a huge audience compared with a shop in Manchester, Milan or Madrid. Particularly if the piece they are thinking of selling is of a specialist nature. The dealers know they would have their jewellery shown in New York and Geneva before being sold in London. The 4000 catalogues that are printed reach a huge audience and in a recent sale we had 144 different buyers from 28 different countries which gives you an idea how international the business is today. It does give me great pleasure to put together an entire sale of Cartier jewels or an auction solely devoted to Art Deco as this involves research which leads to new knowledge. I feel that the auction houses have an obligation to educate as well as just sell jewellery. In fact one of your examiners, Sarah Hue-Williams, and I have produced a small book called *Christie's Guide to Jewellery* to answer the most common questions I am asked. The most common problem that I have come across is in the area of valuation. What is a piece of jewellery worth? This of course depends on whether it is for sale or insurance or indeed is it going to be replaced by making an exact replica? The price of a piece of jewellery is inevitably much higher in a retail shop in Bond Street as they have a great number of expensive overheads. But at the end of the day you are paying for choice as they have a large selection from which to choose, and at auction we only have what we are given and often this is not the most attractive of pieces, but the trade and the auction houses do get on well as they have become interdependent on each other.

"I would like to finish by wishing you all the very best in your future endeavours and to keep looking at gemstones be they with a dealer or at auction and never stop learning!"

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Errata

In *J.Gemm.*, 2001, 27(8), p. 506, second column, third line, 'Gandusio, SU.S.A.nna' should read 'Gandusio, Susanna'. We apologize for the error.

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The World 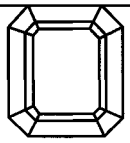 of Gemstones

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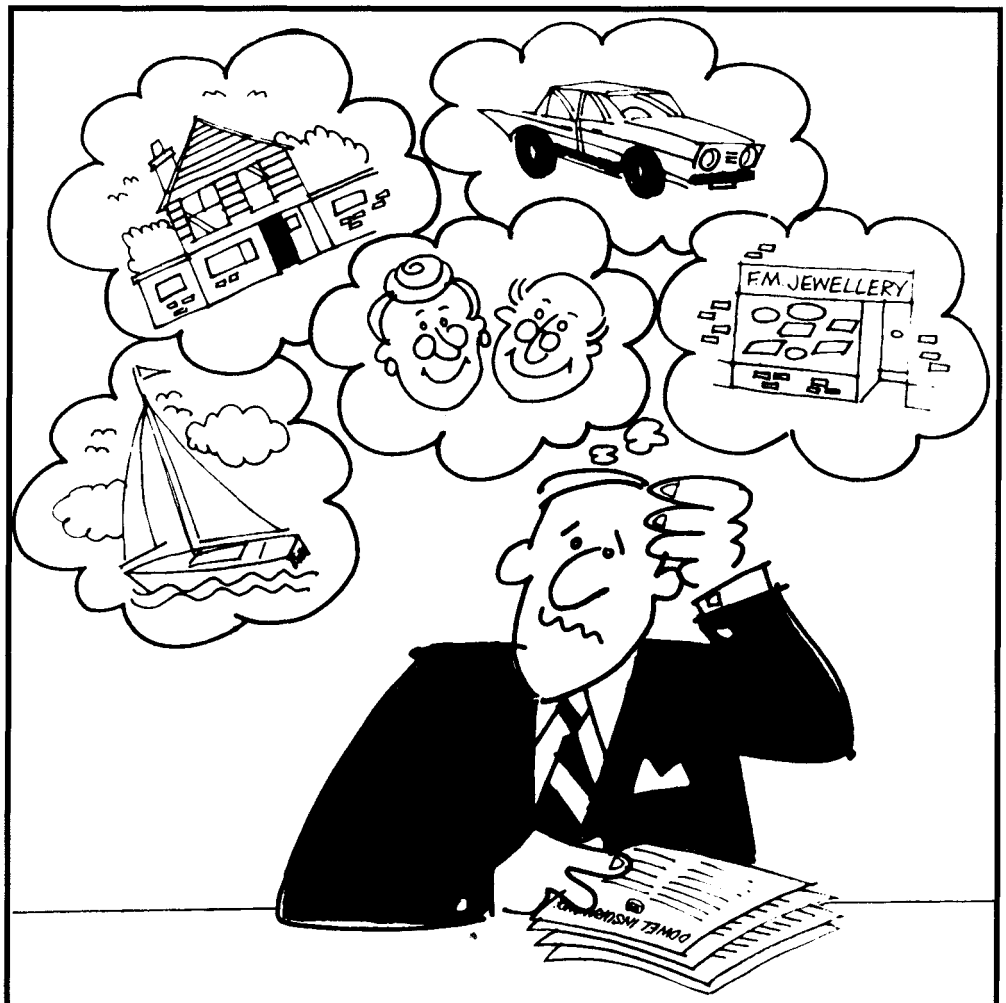

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20 March	**North West Branch.** Visit to the Geology and Archaeology Room at the Liverpool Museum.
29 March	**Midlands Branch.** *The art of the goldsmith and silversmith.* MARTYN PUGH
9 April	**London.** Private viewing and guided tour by GEOFFREY MUNN of the ***TIARAS*** exhibition at the Victoria and Albert Museum.
17 April	**North West Branch.** *Gems in the collection of the Natural History Museum, London.* DR ROGER HARDING
26 April	**Midlands Branch.** *The importance of the microscope in Gem ID.* GWYN GREEN AND KATE HOPLEY
3 May	**London.** Lecture by Joseph Tenhagen of Miami, Florida.
15 May	**North West Branch.** *Diamonds – the fourth dimension (cut).* ROSAMOND CLAYTON
19 June	**Midlands Branch. Gem Club.** *Photomicroscopy* with DOUG MORGAN AND DAVID LARCHER
19 June	**North West Branch.** Bring and buy.
22 June	**Midlands Branch.** Supper Supper Party.

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The Editor is glad to consider original articles shedding new light on subjects of gemmological interest for publication in *The Journal*. Articles are not normally accepted which have already been published elsewhere in English, and an article is accepted only on the understanding that (1) full information as to any previous publication (whether in English or another language) has been given, (2) it is not under consideration for publication elsewhere and (3) it will not be published elsewhere without the consent of the Editor.

Typescripts Two copies of all papers should be submitted on A4 paper (or USA equivalent) to the Editor. Typescripts should be double spaced with margins of at least 25 mm. They should be set out in the manner of recent issues of *The Journal* and in conformity with the information set out below. Papers may be of any length, but long papers of more than 10 000 words (unless capable of division into parts or of exceptional importance) are unlikely to be acceptable, whereas a short paper of 400–500 words may achieve early publication.

The abstract, references, notes, captions and tables should be typed double spaced on separate sheets.

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Abstract A short abstract of 50-100 words is required.

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A **This is a first level heading**

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Abbreviations for titles of periodicals are those sanctioned by the *World List of scientific periodicals* 4th edn. The place of publication should always be given when books are referred to.

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Cover Picture

Three coloured diamonds: Fancy Vivid purple, Fancy Vivid purplish-pink and Fancy Light brown. (A highly unusual, 7.34 ct, Fancy Vivid purple diamond, pp. 7-12).

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The Journal of Gemmology

Volume 28 No. 2 April 2002

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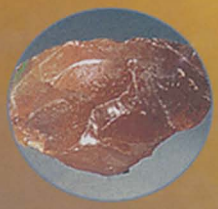

Chocolate-brown Opal

Inclusions in Gemstones

Natural Amethyst

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Natural and heat-treated corundum from Chimwadzulu Hill, Malawi: genetic significance of zircon clusters and diaspore-bearing inclusions

Professor A. H. Rankin

School of Earth Sciences and Geography
Kingston University, Surrey, KT1 2EE

ABSTRACT: Laser Raman Microspectrometry (LRM) has been used to identify the solid, liquid and gaseous components of inclusions in colourless to pale yellow/green corundum and gem-quality rubies from the eluvial deposits of Chimwadzulu Hill, Malawi. Zircons and multiphase-diaspore-CO_2 inclusions are the dominant types present, but tiny rutile needles (less than a few microns) and a single inclusion of amphibole have also been identified. The zircons typically occur in clusters of elongate crystals up to a few hundred microns in size, with length to breadth 'aspect' ratios usually between 1.8 and 4.2. Multiphase diaspore-CO_2-bearing inclusions, with or without calcite, occur in planar groupings. These are interpreted as the heterogeneous products of once homogeneous fluids trapped at some elevated temperature and pressure. The overall inclusion characteristics suggest a 'metamorphic' rather than an alkali basaltic 'magmatic' source for the corundums. Whilst the overall inclusion assemblage may help to distinguish Chimwadzulu corundums from those from other areas, individually, the different inclusion types are not unique to this locality.

In heat-treated samples the diaspore-bearing inclusions are destroyed. Diaspore converts to corundum, and water and CO_2 are driven out from the inclusions via microfractures. Similar, thermally-induced microfractures are also developed as 'feathers' around zircons. In the wider context, it is suggested that the presence of radiating planes surrounding zircons, in untreated corundum samples, provides a useful criterion for recognizing alkali basalts as the primary host rocks for a particular specimen.

Introduction

Gem-quality corundum has been recovered intermittently from the eluvial soils of Chimwadzulu Hill, southern Malawi, since the 1960s. Previous, small-scale mining produced pale-coloured blue, green and yellow sapphires which required enhancement through heat-treatment (Emmett, 2000). In the mid-1990s

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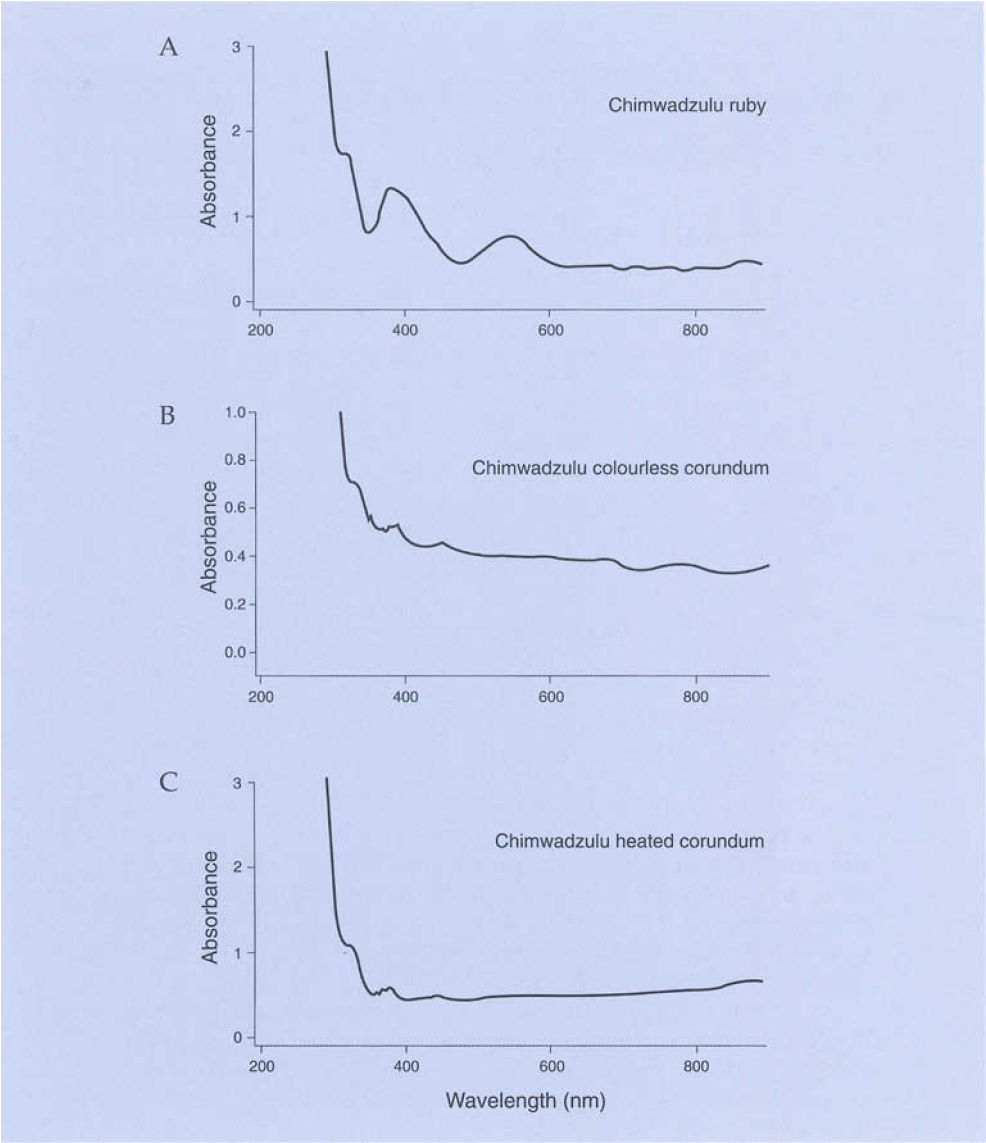

Figure 1: *Absorption spectra (unpolarized) of Chimwadzulu corundums.*
(A) Gem-quality ruby showing strong absorbance bands at 550 nm and 380-400 nm attributable to Cr^{3+}.
(B) Colourless corundum.
(C) Heat-treated pale blue corundum.

further exploration revealed sizeable deposits of gem-quality rubies that do not require heat treatment. These are currently being mined and extracted on a much larger scale by London-based, Agricola Resources plc with monthly shipments (July 2001) reported to be in excess of 10,000 carats.

As part of a more general investigation of the microscopic characteristics and geological significance of fluid inclusions in sapphires and rubies, the author has undertaken a preliminary study of inclusions in Chimwadzulu samples. This

paper provides a first report on the identification and occurrence of distinctive zircon clusters and diaspore-bearing multiphase inclusions in natural ruby and heat-treated sapphire from this locality and discusses their gemmological and genetic significance.

Geological setting and gemmological properties

The gemmological and mineralogical features of the rubies, together with a geological overview have recently been summarised by Emmett (2000). Gem-quality rubies, and associated colourless and pale green/yellow corundum, occur as secondary deposits in eluvial soils associated with a weathered, serpentinized, ultramafic body intruded within a metasedimentary sequence of gneisses and schists; this ultramafic body is located at 15° 02'S, 34° 39' 30"E, about 80 km WNW of Zomba. Further details of the geology of Chimwadzulu Hill and notes on the occurrence of corundum in the deeply weathered soils at this locality are provided by Bloomfield (1958). However, the primary source(s) for these secondary corundum deposits has yet to be ascertained.

Uncut rubies typically form hexagonal or stubby euhedral crystals up to a few centimetres in size and range in colour from pale pink to blood red. One of the notable features of the gem rubies is that, unlike some current Burmese counterparts, they do not require heat treatment to enhance their colour. Consequently, Chimwadzulu rubies are able to attract a high price. A recent press release issued by David Williamson Associates Limited (July 2001), on behalf of Agricola Resources, reported on the sale of a fine 3.69 ct gem ruby at a price of $3600 per carat.

The colourless to pale yellow/green corundum crystals provided were less regularly-shaped crystals up to several centimetres in size. In heat-treated samples, pale blue and blue-green colours are developed, and the treatment imparts a glassy lustre to the surface of rough stones. Unfortunately, details of the heat treatment and temperatures involved are unavailable to the author.

The UV-visible spectra for heat-treatment and colourless corundum and also for deep red are shown in *Figure 1*. The only significant difference in the overall shape of the spectra between colourless and heated corundum is the disappearance of the minor absorbance peak at 350 nm in the heated sample. The UV-visible spectrum for ruby shows strong absorbance bands at c. 380–400 and 550 nm attributable to Cr^{3+}. This spectrum is very similar to those recently published for padparadscha samples from Sri Lanka and Madagascar (Milisenda *et al.*, 2001).

Samples studied and analytical methods

A total of 25 representative run-of-mine samples of uncut gem quality rubies, natural pale yellow / green to colourless corundum and pale blue sapphires formed from the pale yellow to green corundum by heat treatment were provided by Dr David

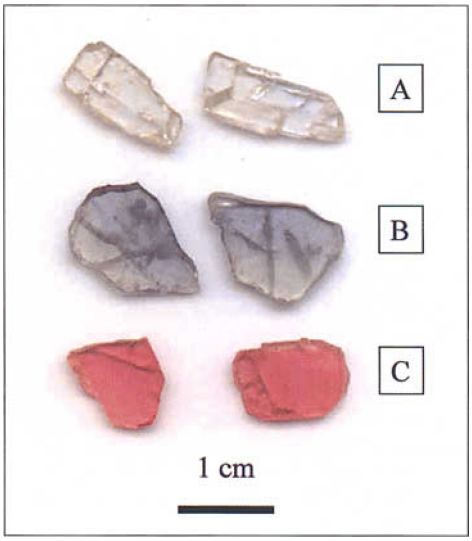

Figure 2: *Polished slices of Chimwadzulu corundum.*
(A) Colourless corundum.
(B) Pale blue, heat-treated corundum.
(C) Deep red, gem ruby.

Hargreaves, Managing Director of Agricola Resources plc. Individual crystals were between 0.5 and 1.5 cm in size and of variable clarity. In some of the rubies direct observation of inclusions was possible under the microscope through well-developed crystal faces, but in others this was only possible in cut and polished samples. A total of nine inclusion wafers, approximately 1 mm thick, were prepared using the procedures described by Shepherd *et al.* (1985). Parallel slices were cut using a diamond saw. These were then lapped and polished on both sides using progressively finer diamond grits down to 1 µm.

The inclusion wafers (*Figure 2*) were studied using a standard Olympus petrographic microscope attached to a Renishaw Laser Raman Microspectrometer (LRM). Inclusions were studied in plane polarized light and under crossed polars using both transmitted and reflected light. Magnifications up to x600 were used and Raman spectra were obtained, in confocal mode, using an Ar-ion laser (at 514.5 nm). Count times of 30 seconds were generally adequate to produce reasonable spectra. A pure silicon standard, with a single strong peak at 521 cm^{-1}, was used to calibrate the system at regular intervals. Raman shifts are reproducible to within ±1 cm^{-1}.

Some difficulties were experienced in obtaining reasonable Raman spectra from inclusions in the ruby samples. This was partly due to the strong laser-induced fluorescence above 1000 cm^{-1} but also because of a strong absorption of the laser light by the host ruby from inclusions deeper in the sample. The latter difficulty could sometimes be minimized by confining analysis to near surface inclusions.

Identification of the mineral and fluid components was based on their characteristic Raman peaks utilizing the fully-searchable Renishaw mineral database © and published reference spectra (Schubnel *et al.*,

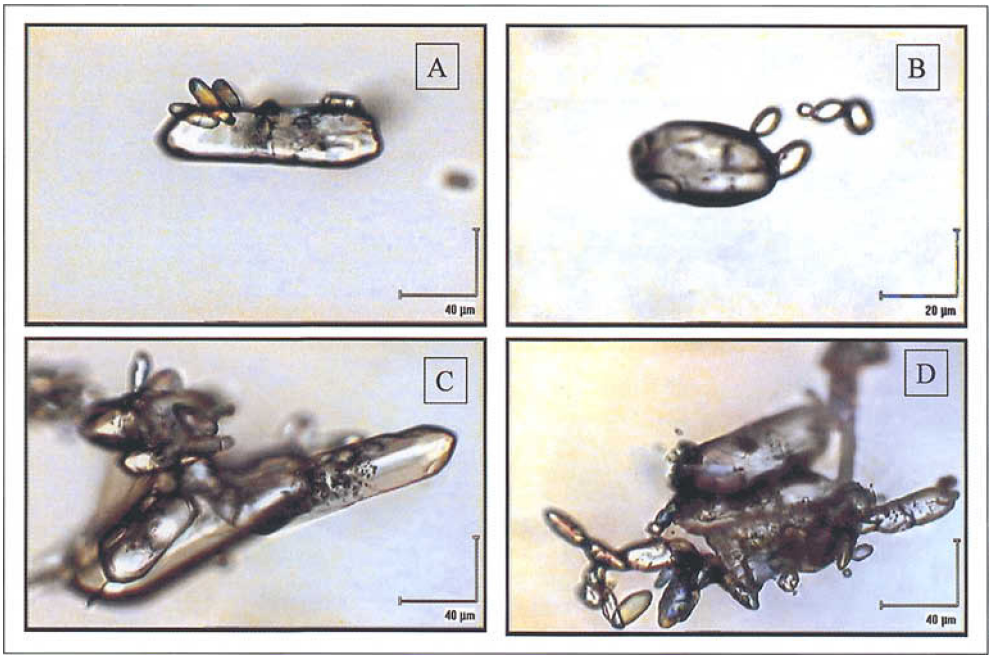

Figure 3: *Zircon clusters in colourless corundums (partially crossed polars). Scale bar represents 40 µm for A, C and D, and 20 µm for B.*

1992; Burke, 2001; California Institute of Technology, 2001).

Results

Zircon

Zircon ($ZrSiO_4$) is the most common solid inclusion in pale yellow / green to colourless corundum and in heat-treated sapphire. It has been tentatively identified in only two samples of ruby using optical methods because of strong absorption of light in these deeply coloured samples. The zircon inclusions are colourless and typically occur in clusters of between 5 and 10 crystals *(Figure 3)*. The clusters occur in planar arrays that appear to delineate crystal growth zones. Isolated crystals are rarely observed. Individual crystals in each cluster are randomly orientated. They range from a few microns up to 140 µm in size *(Figure 3)* and mostly fall in the size range 10 to 50 µm. The zircons typically occur as well-formed, elongate to stubby, sub-rounded crystals with variable length to breadth, or 'aspect', ratios of up to 5.8 *(Figure 4)*. In heat-treated samples the zircon clusters have a pronounced turbid appearance with clearly defined, radiating haloes of planes of secondary inclusions and darkened rims surrounding individual crystals *(Figure 5)*. Attempts to obtain Raman spectra from these haloes were unsuccessful due to the small size of individual inclusions therein. It is noteworthy that whilst these haloes are universally present in heated corundum, they have not been reported in untreated stones.

Diaspore-bearing multiphase inclusions

Diaspore, α-AlO(OH), was readily identified from its characteristic Raman peaks at 449 and 332 cm^{-1} as shown in *Figure 6* (California Institute of Technology, 2001) and platy crystalline form (Deer, Howie and Zussman, 1992). It is present in both yellow-green to colourless and in ruby

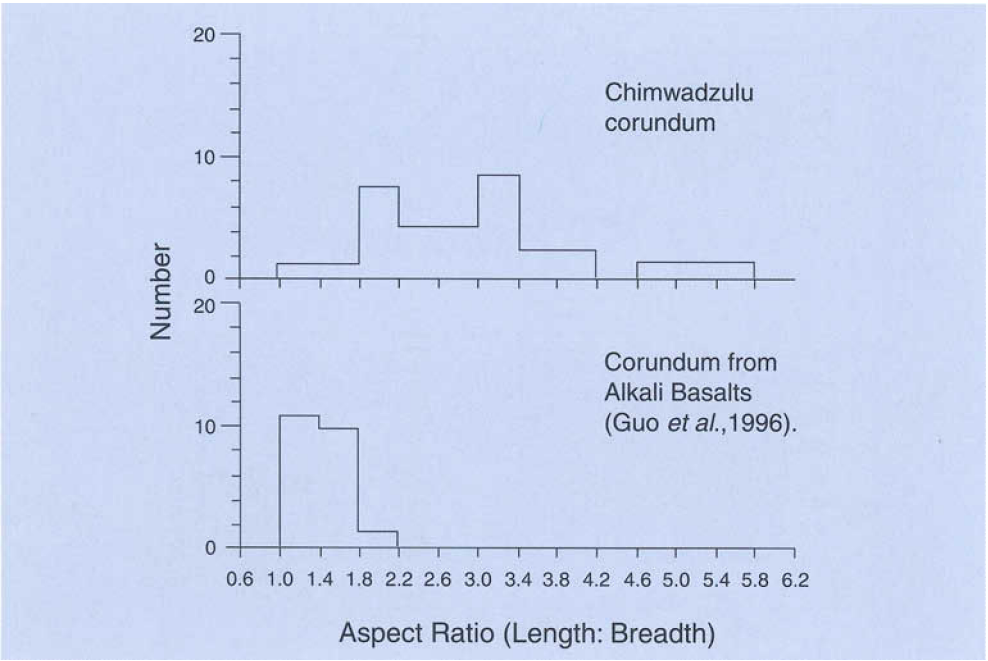

Figure 4: *Histogram of aspect ratios for zircon inclusions in Chimwadzulu corundums compared to published ratios for zircons in corundum from alkali basalts (Guo* et al.*, 1996).*

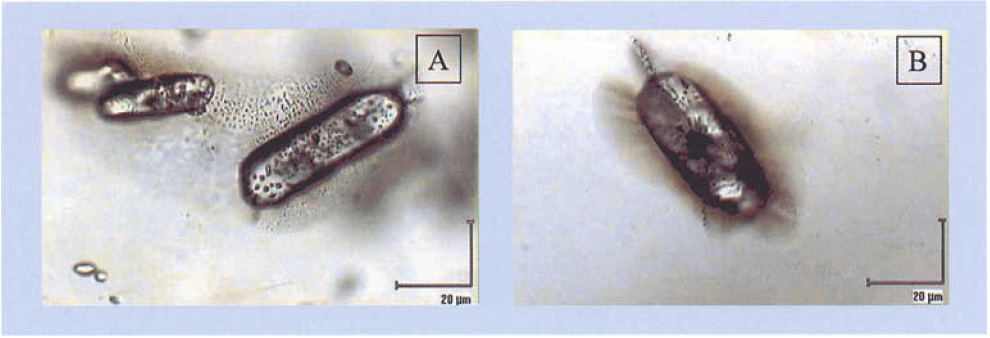

Figure 5: *Zircon inclusions in heat-treated corundum with characteristic dark outlines, 'feathers' and trails of secondary inclusions in discontinuous fractures associated with each zircon. Scale bar represents 20 µm.*

samples but has not been observed or detected in heat-treated Chimwadzulu sapphire samples. It characteristically occurs as the dominant crystalline component of multiphase inclusions in which a darkened area constitutes a consistent volumetric proportion of the inclusion between 30 and 40%. These inclusions typically occur as irregularly shaped cavities approximately 10 to 50 µm in size as planar groupings and arrays *(Figure 7)*. These have the characteristic appearance and distribution of pseudosecondary inclusions according to the criteria of Roedder (1984). The broad

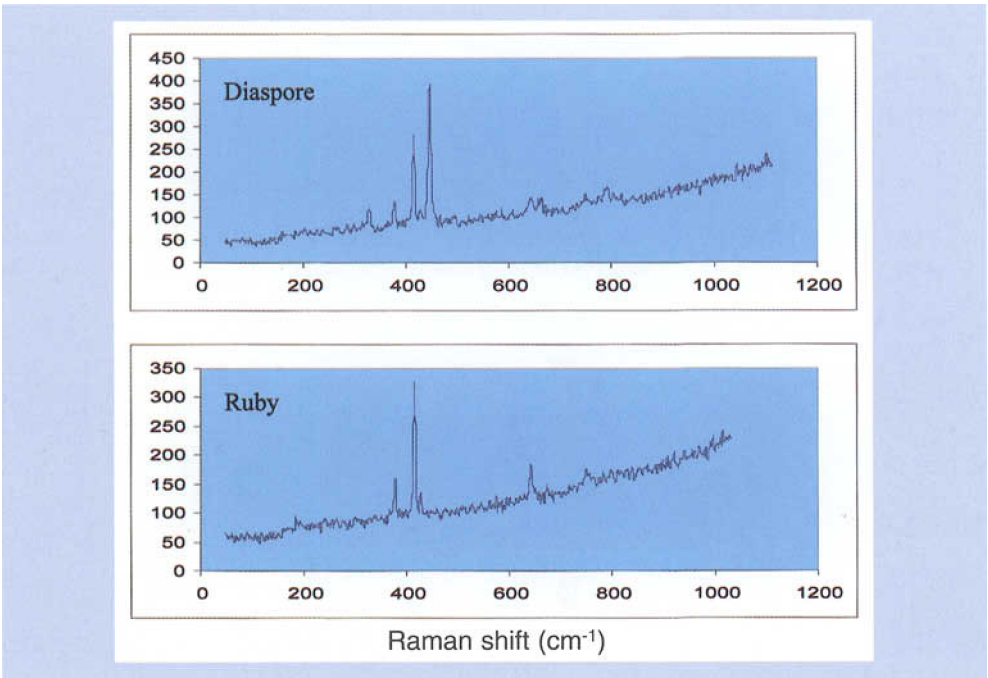

Figure 6: *Raman spectrum of a single crystal of diaspore from unheated, colourless, Chimwadzulu corundum. Spectrum of ruby shown below for comparison.*

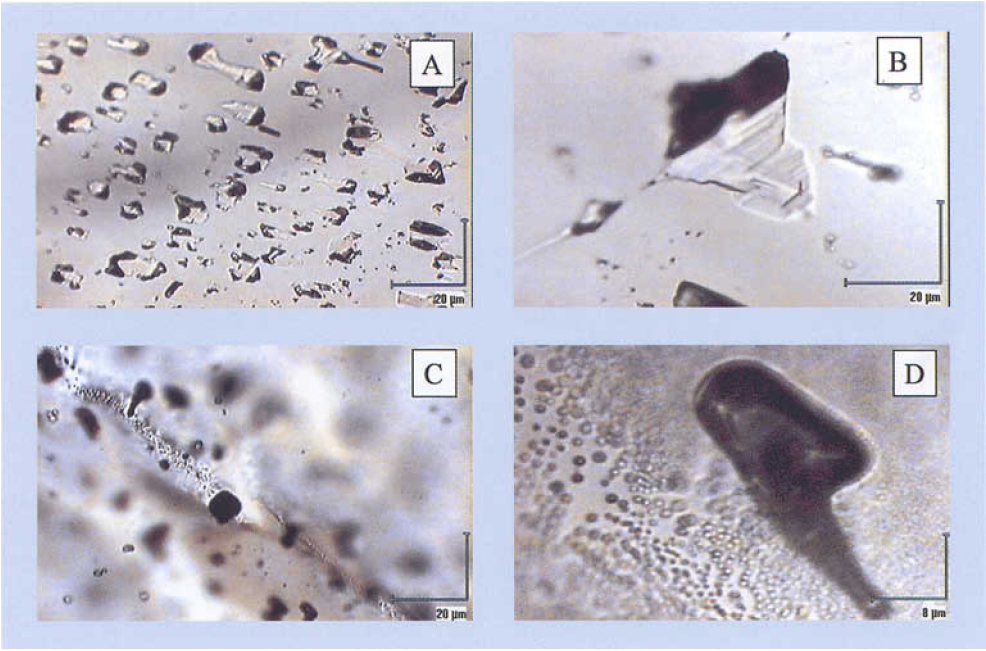

Figure 7: (A) Planar grouping of pseudosecondary, diaspore-CO_2 inclusions in colourless corundum. (B). Close-up of one of the inclusions in (A) showing a large diaspore crystal (lighter area) and a CO_2-rich phase (dark area). (C) and (D) Dark 'empty' inclusions in heat-treated corundum with associated trails of smaller, empty inclusions in microfractures. Scale bar for A, B, C: 20 µm. Scale bar for D: 8 µm.

consistency in the volumetric proportions of the light and dark components of the inclusions supports the view that they represent trapped portions of an originally homogeneous fluid at some elevated, but unknown, temperature. These components subsequently re-equilibrated on cooling to room temperature to form a heterogeneous mixture. Less commonly, isolated diaspore-bearing inclusions are found. Attempts to

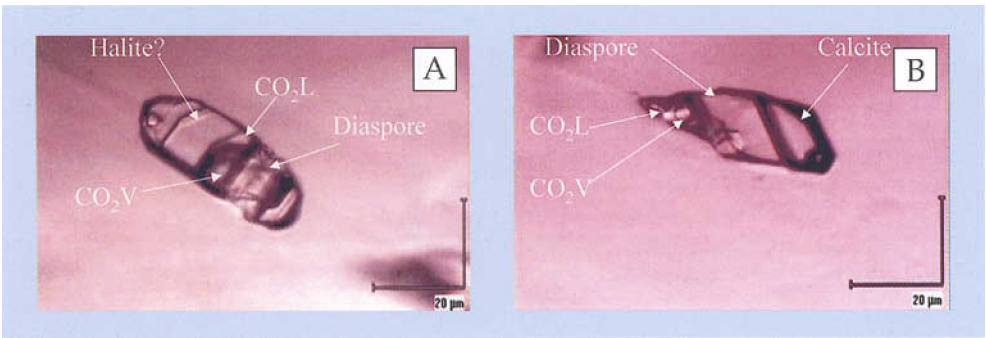

Figure 8: Multiphase CO_2-diaspore inclusions in gem ruby. Both CO_2 liquid and vapour are visible at room temperature (c. 20°C). (A) The inclusion also contains a cubic daughter phase believed to be halite. (B) The inclusion also contains calcite confirmed by LRM (see Figure 9).

optically resolve and obtain Raman spectra from the dark components of these multiphase inclusions were difficult. In general, the only identifiable Raman peaks are those ascribed to CO_2. However, in one sample of ruby containing a well-developed group of diaspore-bearing inclusions *(Figure 8)*, both CO_2 liquid and vapour, and a small crystal of calcite were observed at room temperature and identified by LRM *(Figure 9)*. Halite, which is Raman-inactive, was also tentatively identified in these inclusions on the basis of its cubic crystal form and common occurrence as a daughter mineral in fluid inclusions (Roedder, 1984). Attempts to identify water in these multiphase inclusions based on the characteristic Raman band at around 3400 cm^{-1} proved impossible due to fluorescence from the host ruby at high wave numbers.

Inclusion trails in heated corundum

In the heat-treated corundum samples, CO_2-diaspore inclusions were not observed. Instead, inclusions showing a similar planar distribution and size range distribution were apparent. These lack the characteristic light and dark components observed in unheated samples, and the inclusions appear completely dark or 'empty'. The larger inclusions are typically surrounded by haloes of smaller inclusions (*Figure 7C, D*). Attempts to obtain Raman signals, other than those attributable to the host corundum, from any of these darkened and associated minion inclusions proved unsuccessful. The observed optical and textural features are characteristic of fluid inclusions that have suffered thermal decrepitation on heating (Shepherd *et al.*, 1985; Roedder, 1984). The mechanism by which this occurs involves a progressive increase in fluid pressure. As the inclusions are heated along an isochoric Pressure-Temperature (*P-T*) path, a point will be reached whereby the host crystal is unable to withstand the build-up of internal fluid pressure (mostly from CO_2) and decrepitation and/or partial leakage will occur. Expelled fluid would, in most crystals, migrate along thermally-induced, radiating fractures, and subsequent healing would form the characteristic planes of radiating micro-inclusions. The size, shape, distribution, darkened appearance and lack of any Raman-notable signals from these inclusions supports the view that they represent thermally decrepitated CO_2-diaspore inclusions whose contents have been expelled from the inclusions during excessive heating.

Other inclusions

A single large inclusion of amphibole, with well-developed crystal faces and characteristic green colour, and groups of crystallographically-orientated needles of rutile are the only other phases positively identified by Raman spectroscopy in the Chimwadzulu corundum samples.

Discussion

Zircon inclusions are common in corundum from a number of different gem localities (Guo *et al.*, 1966; Sutherland *et al.*, 1996). Most recently, Schwarz and Schmetzer (2001) reported on the occurrence of zircon clusters in rubies from Madagascar. Partly on the basis of these clusters and associated rutile needles, and partly on the basis of their chemical signatures, these authors suggest that it is possible to distinguish the Vatomandry rubies of Madagascar from their Asian counterparts from localities in Myanmar, Thailand and Cambodia. The present study shows that the combination of zircon clusters and rutile needles is by no means unique to Madagascar but can now be extended to include Malawi examples. Quantitative data on the major and trace element chemistry of Chimwadzulu corundum are currently unavailable. However, preliminary semi-quantitative point analyses of a single gem quality ruby from Chimwadzulu using the Laser ICP-MS technique (Williams and Greenwood, 2001, pers. comm.) shows Fe/Cr weight ratios of the order of 10 (±2 based on the mean of five analyses). These values are much closer to the ratios reported for rubies from

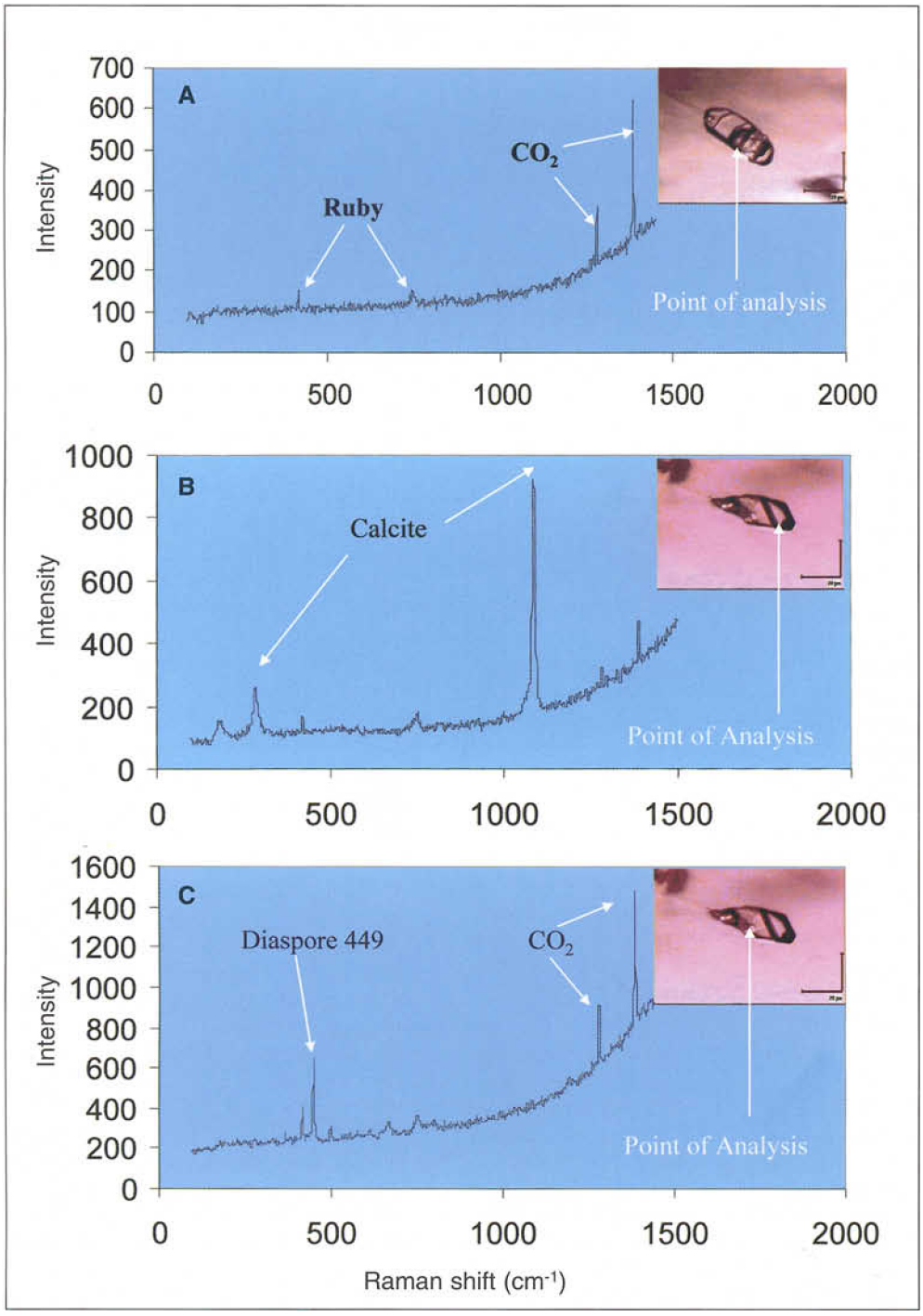

Figure 9: *Raman spectra of diaspore, CO_2 and calcite of inclusions shown in Figure 8 above. (A) CO_2-rich phase: note also peaks from the host ruby. (B) Calcite; note weaker 'interference' peaks from CO_2 and ruby. (C) Diaspore; note 'interference' peaks from CO_2 and ruby.*

Vatomandry and Thailand-Cambodia than those from Mong Hsu and Mogok (Schwarz and Schmetzer, op. cit.).

In a systematic study of zircon inclusions in blue, yellow and zoned blue corundum crystals from alkali basalts of Australia and China, Guo *et al.* (1996) showed that the aspect ratios for the majority of zircons are in the range 1.2 to 1.8. This contrasts with the aspect ratios of zircons from Chimwadzulu corundums, which are mostly between 1.8 and 4.2. Guo *et al.* (op.cit.) also noted that radiating cracks surrounding these zircons are a characteristic feature of corundum from these alkali basalt terrains. This feature also appears to be common in Thai sapphires associated with alkali basalts (Srithai and Rankin, 1999). Again this contrasts with the Chimwadzulu samples where heat-treated corundum typically shows fractures and feather-like planes of micro-inclusions emanating from the zircons. Such features are absent in unheated samples. Differential thermal expansion and contraction of zircon and host corundum on heating and cooling is one of several mechanisms proposed by Guo *et al.* (1996) to account for these features in natural corundum samples. Based on the current study this is undoubtedly the mechanism whereby heat-treated corundum from Chimwadzulu acquired these features. This adds weight to the argument that in natural corundums, derived from alkali basalts, overheating through incorporation of corundum megacrysts into a hot >1200°C ascendant alkali basalt magma, is the most probable cause of such features.

Sutherland *et al.* (1996) in their systematic study of inclusions in corundum from basalt fields, mostly from Asia and Australia, compiled a comprehensive list of primary solid inclusions that characterised the so-called BYG (Blue-yellow-green) 'magmatic' suite of corundum. Diaspore and amphibole, though present in Chimwadzulu samples, have not been reported from the BYG suite. Conversely, Fe- and Si-rich glassy inclusions, whilst common in the BYG corundums are absent from the Chimwadzulu specimens. In summary, the solid inclusion evidence strongly suggests that Chimwadzulu corundums do not belong to the 'magmatic' suite of Sutherland *et al.* (1996) and are unrelated to alkali basalts. This is consistent with the geological setting of Chimwadzulu Hill where such rocks are absent.

Multiphase diaspore-CO_2 inclusions in unheated Chimwadzulu corundum provide an additional clue for their primary origin. It is apparent from the consistency of phase proportions that these inclusions represent trapped portions of an originally homogenous fluid phase present during the primary growth and/or recrystallization of the host corundum. It is beyond the scope of this present study to provide a meaningful estimate of the *PT* trapping conditions for these inclusions in the absence of homogenisation temperature measurements. However, the trapped fluid has an Al-rich, CO_2-H_2O ($\pm$NaCl-$CaCl_2$) composition more compatible with a metamorphic or hydrothermal fluid than a silicate magma (see Roedder, 1984). Unfortunately, diaspore-CO_2 inclusions, though characteristic of Chimwadzulu corundums, do not appear to be unique to this locality. They are also reported to occur in Mong Hsu (Myanmar) rubies (Perretti and Mullis, 1997).

In heated Chimwadzulu samples it is suggested that the groups of darkened inclusions are the result of leakage and transformations within original CO_2-diaspore multiphase inclusions. The apparent 'emptiness' is due to the thermal decomposition of diaspore to corundum (Perkins *et al.*, 1979):

$$2AlO(OH) = Al_2O_3 + H_2O$$

The build up of internal fluid pressure on heating (from CO_2 and released water) would induce decrepitation and leakage of these volatiles out from the inclusions. The aluminium oxide produced would crystallize as corundum either inside the inclusions or within the heat-induced micro fractures as a sealant.

Conclusions

Clusters of zircon crystals and planes of multiphase diaspore-CO_2-bearing inclusions are the predominant inclusion types so far recognised in Chimwadzulu corundums. Rutile needles and a large amphibole crystal have also been identified. The observed inclusion assemblage, aspect ratios and lack of radial features surrounding individual zircon crystals, together with preliminary chemical data strongly suggest a primary metamorphic/hydrothermal rather than a magmatic alkali basalt source for the eluvial corundums and rubies of Chimwadzulu Hill.

The diaspore-CO_2-bearing inclusions are thought to represent trapped portions of Al-rich, CO_2-H_2O (±Ca-Na-Cl) metamorphic/hydrothermal fluids responsible for primary corundum deposition.

In heat-treated corundum, the diaspore-bearing inclusions have been destroyed. Thermal decomposition of diaspore to corundum takes place with the concomitant expulsion of CO_2 and H_2O from the inclusions. By analogy, the radiating features (so-called 'saturns') commonly reported around zircon inclusions in untreated corundums associated with alkali basalts from other localities have similar origin. They appear to be caused by differential expansion and contraction between zircon and corundum when cool corundum xenocrysts are incorporated into hot basaltic magma. In the wider context, therefore, it is suggested that their occurrence in untreated samples, may provide a simple criterion for distinguishing this environment from other primary geological/genetic environments (e.g. hydrothermal, metamorphic, pegmatitic).

Acknowledgements

David Hargreaves (Agricola Resources) kindly provided samples from Chimwadzulu and some background information on mine production. The author is grateful to Ian Gill, Vic Mansell and June Falla (Faculty of Science, Kingston University) for their help with sample preparation and UV-visible spectroscopic analysis, and to Dr J. Williams and Ms Joanne Greenwood (NERC ICP-MS facility, Kingston University) for providing preliminary Laser-ICP-MS analysis.

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Notes from the Laboratory

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ABSTRACT: An unusually pungent amber imitation is encountered. YAG as an emerald imitation, a Gilson N-type synthetic emerald, a large synthetic amethyst and an annealed synthetic diamond are considered. An unusual situation of natural pearls being coated is presented.

Sweet smelling amber imitation

A bracelet of ten yellow beads (*Figure 1*), each including readily recognizable bees (*Figure 2*), was quickly identified as being plastic. In handling the bracelet you were also very quickly made aware of a pungent honey-like smell. It was difficult to ascertain if this was an intentional ploy or had occurred simply by accident. In some of the beads the included bee insects have been exposed at the surface and this could be the source of the sweet but somewhat unpleasant odour. The bracelet was quickly returned to the customer!

Figure 1: *A bracelet of 10 yellow plastic beads, each with an included bee insect.*

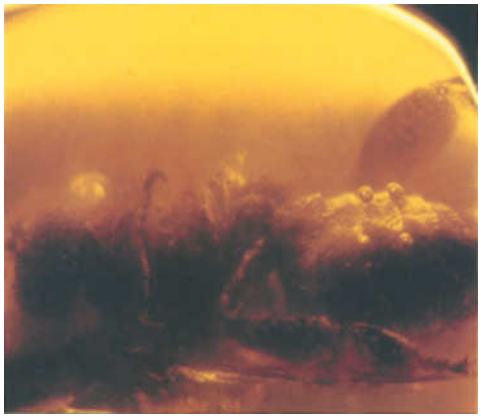

Figure 2: *A close-up view of a bee insect in a yellow plastic bead.*

An old favourite

A 10.29 ct green rectangular, cut-cornered, fancy-cut stone was submitted in the hope that it was an emerald. Some years ago a collection of rough green stones were similarly believed to be emeralds. All the stones were yttrium aluminium garnet (YAG) with rare-earth spectra. The faceted stone had an SG of 4.54 and a Brewster angle of 60.5 degrees. Green YAG does not duplicate the hues of emerald very well but it can still prove to be a problem.

Colourless YAG was the main diamond simulant used before the advent of cubic zirconia. It is rare to come across these in the trade today. The dispersion is lower than

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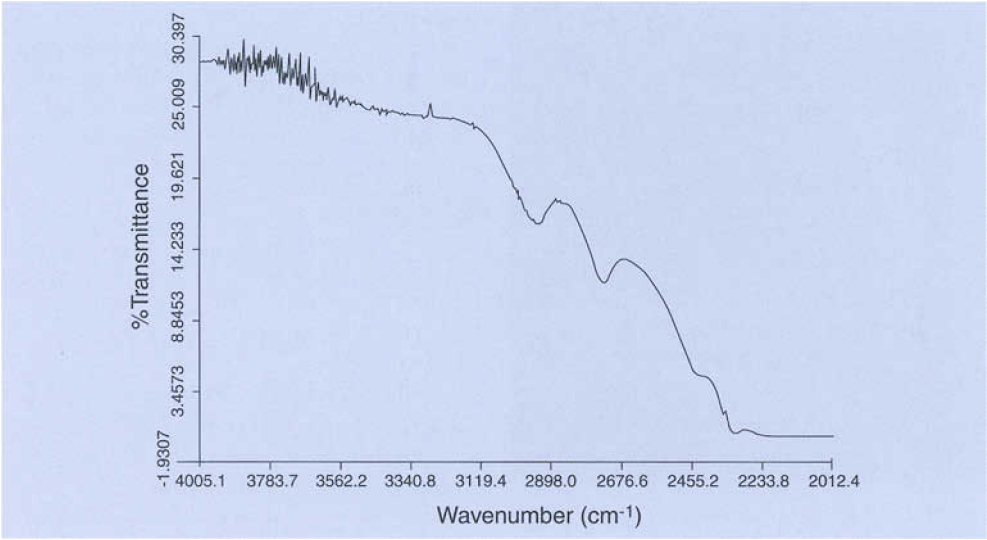

Figure 3: *FTIR spectrum of the Gilson N-type flux-melt synthetic emerald showing the lack of absorption between 3400 cm^{-1} and 4000 cm^{-1}.*

that of cubic zirconia, which makes YAG a less effective diamond simulant than CZ. Yellow YAG can more easily be confused with a fancy yellow diamond, since the perceived differences in dispersion are masked by the body colour. The confusion can be compounded if a fancy step-cut is utilized rather than a brilliant cut. The lack of brilliance may be mistakenly attributed to the way in which the stone has been cut, whereas in reality the stone is not diamond at all. Coloured YAG is becoming scarce.

Gilson N-type synthetic emerald

After a gap of fifteen years or more an uncommon synthetic flux-melt emerald was submitted mounted in a ring. The emerald-cut stone, weighing 2.05 ct, had refractive indices of 1.576 and 1.581. These refractive indices would normally be those expected for either a natural emerald or a hydrothermal synthetic emerald. The presence of vague twisted veils and straight zoning within the stone were more indicative of a flux-melt synthetic, and the FTIR spectrum (*Figure* 3) provided the evidence that the stone was synthesized in a non-aqueous environment – there is no absorption

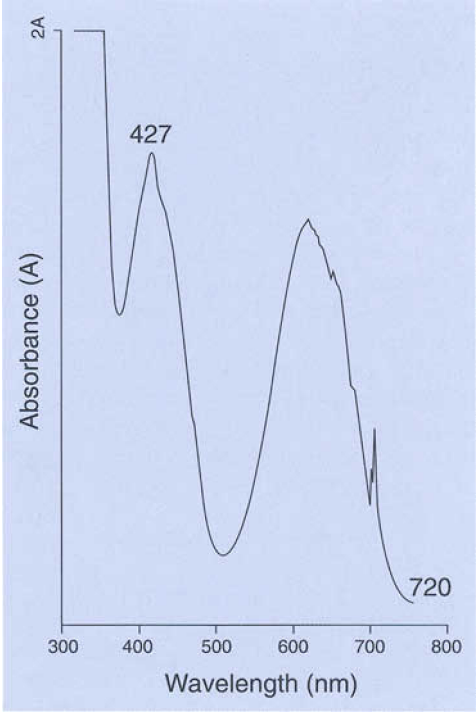

Figure 4: *The UV/Visible spectrum for a Gilson N-type flux-melt synthetic emerald displaying the 427 nm absorption band.*

Figure 5: The cubic, octahedral and dodecahedral growth sectors of a 0.34 ct yellow synthetic diamond as seen on the DiamondView™.

between 3400 cm^{-1} and 4000 cm^{-1} typical of natural emeralds and hydrothermal synthetic emeralds (Stockton, 1987). Gilson synthesized a limited quantity of his flux-melt emeralds with a small percentage of iron in the formula (Fryer,1969/70). These N-type synthetics have higher refractive indices and an absorption line in the violet at 427 nm. The absorption band in the violet can be observed with a hand spectroscope and is seen to be of similar strength to the absorption lines of aquamarine i.e. it is not strikingly apparent. The ultra-violet/visible spectrum (*Figure 4*) reveals that the 427 nm band is superimposed on the general absorption seen in emerald centred at 430 nm. A known sample from our collection showed a similar spectrum with refractive indices of 1.570 – 1.575.

Synthetic amethyst

The Laboratory was requested to determine whether a 63.96 ct amethyst was natural or synthetic. A colourless zone within the pavilion area was immediately noticeable. Immersed in water, this was seen to be a colourless band not quite parallel to the girdle and marked by two milky planes containing unrecognizable detritus but also including a few short needles. Furthermore all the zoning within the purple areas was parallel to the colourless zone. This had all the hallmarks of a seed crystal in a synthetic, and this interpretation was supported by the infrared spectrum, which revealed the 3542 cm^{-1} which is normally taken to be indicative of synthetic amethyst (Zecchini and Smaali, 1999).

Synthetic diamond

A round brilliant yellow diamond weighing 0.34 ct was submitted for an origin of colour determination. The stone was found to be a synthetic diamond, which had been subsequently annealed. The diamond fluoresced and phosphoresced a strong yellow under ultra-violet light, marginally stronger under long wave than short wave. However the presence of an inert narrow cross-shape observed on the pavilion side indicated that the diamond was synthetic. *Figure 5* shows the pattern to better effect as displayed on the DiamondView™. The inert cross-shape is related to the narrow sectors seen between the fluorescent blue areas (the fluorescing colours are different under the ultra-violet lamp), which are respectively the dodecahedral and octahedral growth sectors of the synthetic diamond crystal (Welbourn *et al.*, 1996) from which the stone was cut. The area above these sectors, seen as a relatively inert section of a rectangle, is the cubic sector of the cubo-octahedral crystal, which is a typical crystal habit for synthetic diamond. The phosphorescence on the DiamondView™ exceeded two minutes and was typical for a synthetic diamond.

The visible spectrum of the stone was recorded with a Pye Unicam PU8800 UV/VIS spectrophotometer with a liquid nitrogen cryogenic facility. The following peaks were noted: 468, 473, 478, 491, 494, 501, 503, 511, 516, 518, 527, 540, 547, 553 and 639 nm. These peaks have been attributed to nitrogen-containing synthetic diamonds grown in a nickel-containing flux and

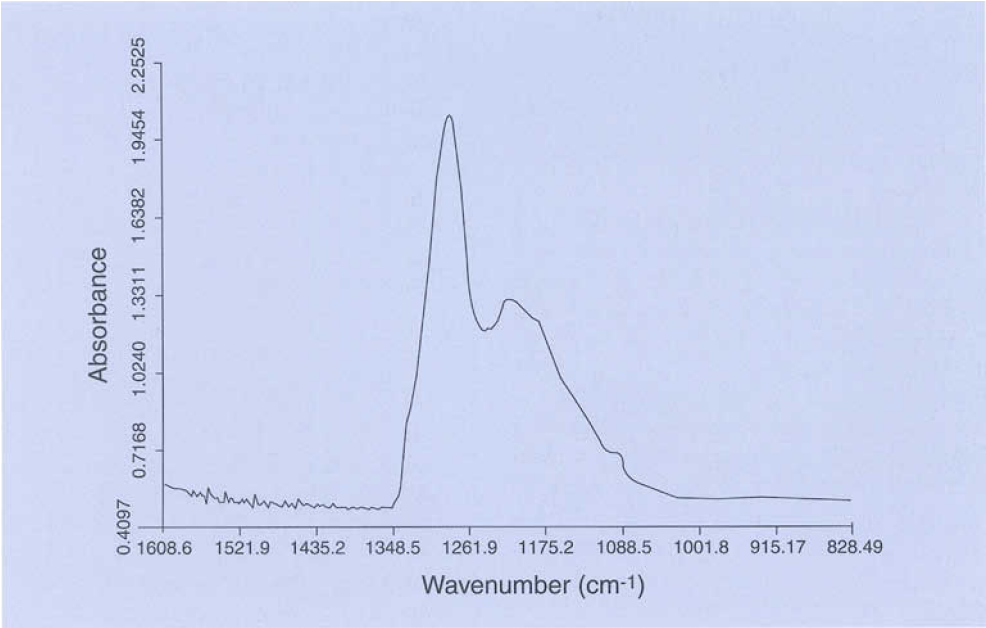

Figure 6: *The FTIR spectrum of the 0.34 ct yellow synthetic diamond. The main peak at 1282 cm^{-1} categorizes the diamond as type IaA (pairs of nitrogen atoms). The shoulder on the left-hand side of the peak is in the general area of the 1344 cm^{-1} peak, which indicates a small amount of type Ib (single nitrogen atoms).*

Figure 7: *Partly coated natural pearls. The grainy surface of the applied coating can be observed next to the platy nacreous surface.*

subsequently annealed to 1600° – 1900° Celsius (Shigley *et al.*, 1993). The conversion of dispersed nitrogen in the as-grown synthetic diamond to A aggregates (pairs of nitrogen atoms) after annealing is confirmed by the infrared spectrum (*Figure 6*), which categorizes the diamond as mainly type IaA with only a small amount of Ib (single nitrogen atoms) remaining.

It transpired that the Laboratory was being tested to see if it could differentiate between natural and synthetic diamonds. The diamond originated in Russia from an established industrial synthetic diamond supplier. The client had presented his stone to a British university, who had simply confirmed that it was a diamond. This situation has arisen before with other synthetic stones being submitted to academic institutions with similar results. Scientists in other fields may not necessarily be aware of the existence of the synthetic counterparts of natural minerals.

Coated pearls

Can you change an imitation pearl into a natural pearl? Yes, if what appears to be an imitation pearl is in fact a natural pearl to which an imitation-like coating has been applied!

Three bags of pearls were submitted for testing in advance of being strung as a three-row necklace. The X-ray radiograph isolated six nucleated cultured pearls and one non-nucleated cultured pearl. From the radiograph, samples of the remainder showed features typical of natural pearls. However, very early in the examination it had been noted that some of the pearls were partly or fully coated (*Figure 7*). In fact 78 out of the 233 pearls were partly or fully coated including one of the nucleated cultured pearls. For what reason would anyone want to do this? Especially as it was the larger pearls that had been coated (the 78 pearls are 56% of the weight of the 233 pearls). Admittedly the pearls were irregular in shape and many had been ground and buffed but still the nacreous surface was better than the coated appearance.

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A note on chocolate-brown opal associated with volcanic rocks in Somaliland

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ABSTRACT: Precious opal from Somaliland comes from the Qabri Bahar area near Jodha close to the border with Ethiopia and Djibouti. The opal occurs as nodules associated with acid volcanic rocks of Miocene age and a range of colours are present; the best precious opal has a chocolate-brown body colour.

Introduction

Opal from Ethiopia has been reported in literature (Johnson *et al.*, 1996) and is now widely available in various markets. More recently, opal from Somaliland has also been shown to dealers and cutters on various continents and it was reported at the 1999 Tucson gem show (Weldon, 1999). However, the origin of the Somaliland opal has been questioned, with the implication that it too is of Ethiopian origin. It is the intention of this short paper to document the source of these Somaliland opals and to introduce them to a wider

Figure 1: *Uncut opal nodules 25 mm and 42 mm in diameter. The larger nodule shows the typical white crust, whilst the smaller nodule shows a little green fire (top left).*

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community. Although the opal occurs in a variety of colours, the best gem material is unusual because of its brown body colour.

Opal characteristics

The opals occur as nodules with a thin white outer crust varying from 1-5 mm. The nodules are generally more or less spherical and range in size from 1 cm in diameter to more than 5 cm. The nodules are solid with no empty space at the centre, one onyx nodule with 'horizontal' brown and white colour bands has also been noted. There is a broad colour range in the opal nodules, and common opal varies from white to yellow, orange, red or chocolate-brown and may be transparent to translucent (*Figure 1*). Orange-coloured fire opal and other colours show a little play of colour, which is most easily visible in transmitted light. However, it is the chocolate-brown material that displays the most striking play of colours, with intense flashes of red and green and more rarely, royal blue. Colour patches are irregular, rounded or elongate, commonly reaching 5 mm or more in size. In some cabochons, there is a suggestion of banding with different colour flashes within each 'band' (*Figure 2*). Other patches of colour seem to derive from an amalgamation of smaller pin-fire colour spots. In some polished cabochons, irregular dark patches of a leopard-skin pattern characterise the stone, and are reminiscent of patterns described from artificial opal.

Figure 2: *Chocolate-brown opal 21 x 19 mm in size weighing 8.10 ct showing faint banding and elongate red colour patches extending up to 5 mm or more in size. Green colour patches in this cabochon appear to be derived from an amalgamation of smaller pinfire colour spots. Cut by Mike Weston of Johannesburg, photographed by Paul Nex.*

Tens of kilos of opal nodules from Somaliland have been examined in the rough. Less than half of these are of gem quality and only a very small proportion, probably around 5% have a good play of colour. However, the abundance of the nodules on sale from artisanal miners and traders means that there is an abundance of good-quality gem material available. Because the nodules are spheroidal and solid with no central cavity, it is possible to cut any gem material with an intense play-of-colour into quite large thick pieces. A 65 ct opal measuring 30 x 27 mm across is shown in *Figure 3*. Brown opals, showing good colours, have been made into fine individual pieces of jewellery by Mike and John Weston of Johannesburg. These have attracted much attention both in local markets and in North America.

Stability of this brown gem material is good, with little or no crazing developing in the twelve months after cutting. Although sawn and cobbed paler stones have been known to develop crazing, the more precious material appears less likely to crack. A review of stability and durability of these opals is in progress. The water content of one precious brown opal was found to be 5%. Qualitative EDXRF on Somali samples showed the presence of calcium, iron, strontium, zirconium, potassium, niobium and sulphur as trace elements (Kinnaird and Jackson, 2000).

Origin of the opals

The Somaliland opals bear a remarkable similarity in terms of size, colour, nodular appearance and trace element chemistry to opals from the Shewa Province in Ethiopia, some 300km to the west (Johnson *et al.*, 1996). However, there are no descriptions of any brown opals with intense colour flashes from this source. The Shewa opals occur as nodules in acid volcanic rocks in a layer of welded tuff (approaching obsidian in character) about 3m thick, between sub-horizontal rhyolite layers (Johnson *et al.*, 1996). The volcanic pile is 300-400m thick and believed to be of Miocene age (8-27 Ma). Similar Miocene volcanic rocks occur in Somaliland west of Cabdulqaadir near the border with Ethiopia (Abbate *et al.*, 1993). The chocolate-brown opals from Ethiopia are said by traders to come from the Awash Valley area. On the Somaliland side of the border, opals are currently being exploited in the Qabri Bahar area close to a place called Jodha near the Ethiopian/Djibouti border. At present the nodules are simply collected from the surface and pits have not yet been developed.

Opals originating from rhyolites are known from elsewhere in the world especially Mexico, Honduras, Indonesia, the United States and Coromandel, New Zealand (O'Donoghue, 1988). Smith (1988) reported 'thunder eggs', in which geodes occur in glassy basal vitrophyric rhyolite at Opal Butte, Oregon, which has locally been altered to a pastel-coloured clay. Approximately 70% of the geodes contain botryoidal or stalactitic agate, banded agate, quartz, etc, with no opal, 20% of the geodes contain common opal and <10% contain some gem opal with only 1% having opal with a prominent play of colour. Spencer *et al.* (1992), suggested that orange-to-red fire opals from rhyolites at Querétaro, Mexico formed at temperatures <160°C from fluids with moderate salinity and a high proportion of silica in solution. In these localities, the opal is found as secondary fillings in gas cavities and voids within the lava.

Figure 3: *A 65 ct chocolate-brown opal measuring 30 x 27 mm across showing a good play of green and red colours. Cut by Mike Weston of Johannesburg, photographed by Paul Nex.*

Discussion

Opals in volcanic environments generally have a structure based on disordered interlayering of cristobalite and tridymite, with the play in spectral colours produced from a three-dimensional array of silica spheres and voids which have to be regularly stacked for diffraction to take place (O'Donoghue, 1988). Whilst the size of these spheres is commonly regarded as ranging from 150-400 nm, according to Fritsch *et al.* (2001) the spheres in Mexican and Ethiopian fire opals are 10-40 nm in size and the nanoparticles may be fully disordered. Opals with a play of colour from Mexico and Ethiopia show higher degrees of organisation in which the nanoparticles form pseudospheres or aggregates of appropriate size (about 200 nm) with diffraction due to contrast in index of refraction between spheres of different degrees of crystallinity (Fritsch *et al.*, 2001). Thus volcanic opals from Mexico and Ethiopia have much smaller spheres (10-40 nm) than the building blocks of typical Australian opals (140 to 250 nm). Fritsch *et al.* (2001) have also shown that the orange-to-brown colour in Mexican orange-to-

brown fire opal is due to nanoinclusions of needles of an iron-containing mineral such as hematite 10-20 x 100-200 nm in size rather than to dispersed metal ions. Although it remains to be proved, it is envisaged that the Somaliland chocolate-brown colour may also be due to the occurrence of such nanoinclusions, possibly of iron, strontium, zirconium or niobium phases based on EDXRF analyses of the opals.

Conclusion

What makes the Somaliland/Ethiopian occurrence of gem opals of such interest is the size, unusual colour and availability of the gem material. The nodular form of the chocolate-brown gem opals means that when nodules with a good play of colour are found, large cabochons can be cut and the durability of the material so far produced is encouraging for the development of this gem material from Somaliland. In addition, there is the potential for a sustained and long-term supply.

Acknowledgements

The author would like to thank Kasbo International and particularly Mohammed Abubakar for organizing a trip around Somaliland. Thanks to all those people who helped to get me to various remote gem localities on my last visit. Mike Weston and Paul Nex are thanked for their help and infectious enthusiasm.

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Inclusions in gemstones: their cathodoluminescence (CL) and CL spectra

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ABSTRACT: From a study of inclusions in gemstones by means of cold-cathode CL microscopy and microspectrophotometry ten examples containing different inclusions are described. The results of visual microscopic tests of the luminescing inclusions with photomicrographs and spectral curves render valuable information on the type of inclusions present. Strongly luminescing, even small colourless inclusions such as apatite, fluorite or diopside can easily be detected which otherwise may escape notice. Further details on both inclusions and host can be obtained when running CL spectra in the spectral range from 380 to 950 nm. Due to the small penetration depth of electrons into solids, all CL investigations can be carried out only if the inclusions intersect the surface of a facet of the gemstone host. Striking colour differences between the CL colour of the host and the inclusion will assist their differentiation. This method also assists in the distinction between inclusions which otherwise are difficult to separate by optical microscopy. The cold-cathode CL is a non-destructive fast method using commercially available instruments on samples which need no coating or other treatment.

Introduction

Luminescence excited by means of electrons has long been used in research work on minerals and gemstones, primarily on diamonds. Natural and synthetic crystals have been studied within the last forty years, although the beginning of testing gemstones by this method dates back to the beginning of the last century, when Michel (1926) in Vienna carried out many tests on a series of gemstones. About two years ago while studying various rough ornamental gems, traces of ruby and other luminescing substances in the polishing medium could be detected by means of cathodoluminescence (CL). Subsequently, when the idea of using CL to study inclusions reaching the surface of the host crystal was discussed with E. Gübelin and received a favourable response, the author decided to test the applicability of CL for the recognition and differentiation of inclusions in gemstones and ornamental gems.

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Cathodoluminescence apparatus

An electron beam of 5 to 15 kV has a penetration depth into solids of not more than 2 µm. Thus, the method of cathodoluminescence (CL) – like the SEM and microprobe – is suitable for the study of surface effects. Inclusions become luminescent only if they reach the surface of the host crystal when they are hit directly by the electron beam. Then textures, growth structures, surface irregularities and crystal defects are made visible which otherwise may not even become noticeable under the microscope. Even very small inclusions enclosed in the surface of the host can be detected and photographed as soon as their CL colours differ from those of the host. CL spectra of inclusions can also reveal the chemical nature of the activator ions that cause the CL effect, give notice of minute differences of the same mineral inclusion in different host gemstones, or can indicate defect centres.

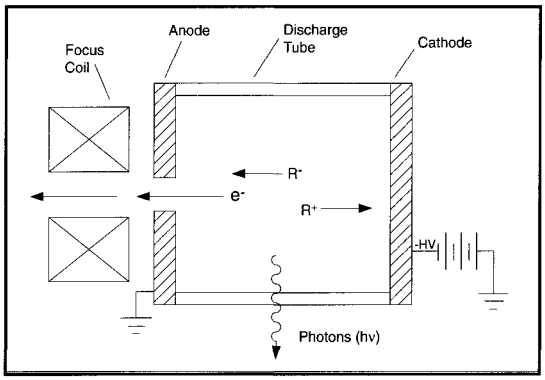

Figure 1: *Schematic diagram of a cold cathode electron gun. Discharge tube, focus coil and compartment are flanged together and filled with a carrier gas at a low pressure. (Reproduced from Marshall, 1993.)*

Two different ways exist to excite electrons which provoke CL, and these are commonly known as the 'hot cathode' and the 'cold cathode' methods. The first, often called 'scanning CL', operates in a high vacuum of $<10^{-6}$ mbar. The electrons are emitted from a hot filament and although this technique is used world-wide in television tubes, electron microscopes and microprobes, small 'hot cathode' instruments which can be combined with a microscope have not yet been commercially produced (Walker, 1991).

Other devices work by means of the 'cold cathode' method, also called 'microscopic CL'. These instruments are much more easily operated and are commercially manufactured. They operate in a vacuum of less than 100 mbar (Marshall, 1988) and are easily mounted on the table stand of a microscope. The sample rests in an evacuated compartment. The electrons are produced in a small evacuated glass discharge tube which is filled with the carrier gas, either air, nitrogen, or helium (*Figure 1*). During the gas discharge the electrons travel from the cathode through a hole in the anode horizontally into the sample compartment.

On its way through a solenoid (focusing coil) the electron beam can be broadened to about 3 cm diameter or narrowed to 1-2 mm. When entering the sample chamber the electron beam is deflected obliquely onto the surface of the sample (inclusion or host gemstone) by means of two ceramic magnets (not shown in *Figure 1*). The electron beam impinging on the surface of the sample excites luminescence which can be visually observed by the microscopist, or photographed. In contrast to the 'hot cathode method' the sample needs no conductive coating, which increases the brightness of CL images. Today long exposure times for photomicrography are not needed when using 800 ASA colour films. Recently developed digital imagery and processing will also help to improve CL photomicrography.

An electron beam of even less than 5 kV will create secondary X-rays. Therefore, the vacuum compartment is screened against leakage of X-rays by an upper and lower lead glass window. Microscopic inspection of samples is best carried out with long distance objectives (4 to 20 ×) resulting

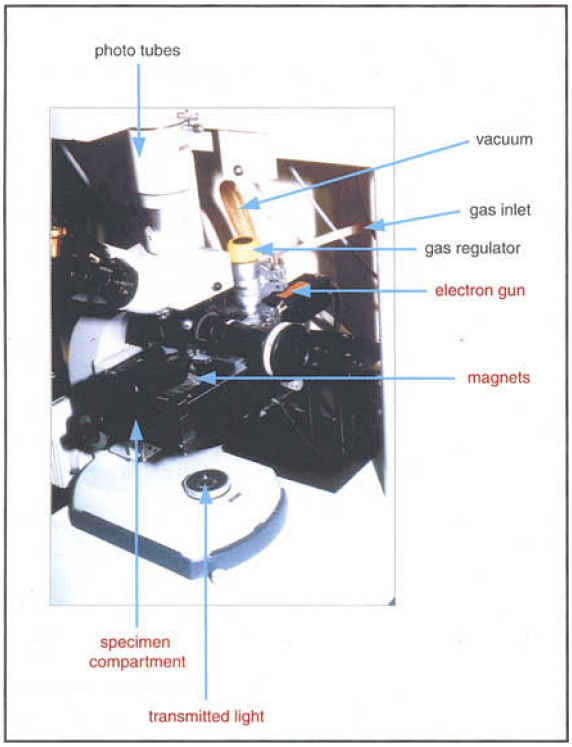

Figure 2: *The 'cold-cathode' unit with the electron gun flanged to the compartment rests on the table stand of a binocular microscope. For microspectrophotometry the whole assemblage is set in a frame on which the motor-driven monochromator and photomultiplier is mounted. Vacuum pump, amplifier and computer are not shown.*

in magnifications up to 125 ×. Stereomicroscopes may also be used, if there is no need for CL microspectrometry. But the latter method is an excellent complementary means for CL studies as documented in the following paragraph.

Figure 2 shows an unsophisticated version of a CL apparatus for taking CL spectra of a wide range of small and larger samples, crystals and cut stones. The trinocular research microscope is combined with a monochromator and a photomuitiplier both of which can be seen on top of the metallic frame of *Figure 2*. The CL signals of the sample pass the microscope and the monochromator, are transformed into electrical signals in the photomultiplier and amplified and processed in a computer (not shown). The whole assemblage is controlled by a software programme. All CL spectra can be taken in less than 25 seconds, and are processed by means of Sigma Plot 5.0. and Origin 5 software programmes (Ponahlo, 2000).

'Hot cathode' CL attachments to SEMs exist which enable the researcher to take CL spectra between 260 and 800 nm, of areas as small as a few μm^2, but only black and white SEM photomicrographs can be taken. Because of their lead glass windows 'cold cathode' instruments do not transmit radiation below 380 nm. To cover the UV range below 380 nm a quartz glass window has to be used with the CL apparatus mounted on the table stand of a quartz microscope. Such rather expensive outfits would enable the microscopist to observe luminescent objects up to 400× magnification and to obtain CL spectra between 240 and 1000 nm. In the present study a binocular research microscope was used which can yield spectra between 380 and 950 nm.

Results

The following descriptions contain both photomicrographs of the visual impressions and CL spectra that the gemmologist obtains when studying an inclusion during the bombardment by electrons. Ten examples are presented to give an idea of the kind of information obtained by this new non-destructive method.

Depending on the activator ions present in the host and in the inclusions a variety of effects may be anticipated. With the far larger area of the host offered to the impinging electron ray, the CL effects of the host gemstone are usually easier to study. But by narrowing the ray to a thin pencil of not more than two millimetres, good CL spectra can be obtained from most

luminescing inclusions if the size is not too small. Sometimes it may be necessary to re-adjust the stone so as to offer a horizontal crown or pavilion facet of the host which contains the inclusion to be tested. Some CL spectra of minerals that occur as inclusions are already well known to the gemmologist, which greatly facilitates an assignment of the CL band in question. But different environments of a mineral inclusion often change the spectra of the inclusion obtained rendering a careful chemical analysis obligatory. To study an inclusion by means of CL it is an indispensable prerogative that the inclusion must reach the surface of the facet of the host. The electron ray has to hit a perfectly clean surface to guarantee results free of doubt.

No.	Host gemstone	Inclusion
1	spinel	apatite
2	spinel	dolomite
3	topaz	quartz and fluorite
4	garnet	apatite
5	kyanite	rutile
6	tourmaline	diopside and zircon
7	kornerupine	apatite
8	plagioclase	ruby
9	calcite	albite
10	dolomite	pargasite

Table I: *List of gemstones and their inclusions.*

(1) Spinel with apatite inclusions

The host is a rose-red round-cut spinel from Mogok, Myanmar (Burma), weighing 4.007 ct that contains numerous globular apatite inclusions, some of which themselves have very small black or red crystal inclusions. A luminescing apatite inclusion reaching the surface of the host is reproduced in *Figure 3*. The host shows a strong whitish-green CL which is caused by divalent manganese ions incorporated in the spinel lattice. After long electron bombardment the CL colour of the host changes to red which is caused by trivalent chromium. The true CL colour of the inclusion is partially masked by two strong CL bands of the host (*Figure 4*). CL spectroscopy at higher magnification reveals the presence of the apatite inclusion by a distinct shoulder in the greenish-yellow spectral range at ~ 600 nm. Other spectral features are Cr^{3+} bands at 676, 688 and 698 nm and a strong Mn^{2+}-based band at 526 nm which all belong to the spinel host.

Figure 3: *CL of a globular apatite inclusion showing an orange CL colour. Its true colour is masked by the strong CL of the host crystal. Excitation conditions: 12 kV; 0.85 mA. Enlargement: 40* x.

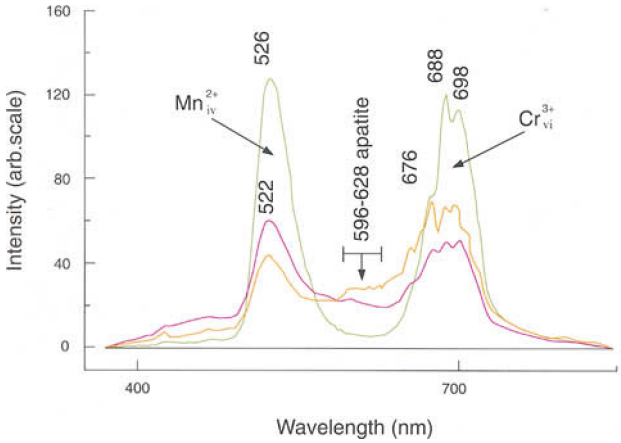

Figure 4: *CL spectra of the host spinel with two distinct bands. The shorter wavelength one is caused by Mn^{2+} ions in tetrahedral configuration, the other by Cr^{3+} ions in octahedral configuration. The shoulder between both bands can be ascribed to Mn^{2+} ions of the apatite inclusion, sevenfold co-ordinated.*

(2) Spinel with dolomite inclusions

Another spinel (1.367 ct) of orange colour, also from Mogok, Myanmar, hosts a number of colourless dolomite inclusions with tension haloes. One euhedral dolomite crystal reaches the surface of one facet. It can be recognized by both normal microscopic methods and under the impact of electrons (*Figure 5*) when it luminesces red and exhibits the well-known band system (organ-pipe structure) in its spectrum (*Figure 6*). The weak band at 518 nm is ascribed to Mn^{2+} activator ions in the host, whereas the inclusion is indicated by a broad shoulder at 645 nm (*Figure 6*). In contrast to the tetrahedral co-ordination of manganese ions in the spinel lattice, the Mn^{2+} ions in the dolomite are octahedrally configurated which causes a shift of the manganese band from green to orange-red. The noisy bands in the short-wave spectral range are caused by the carrier gas air.

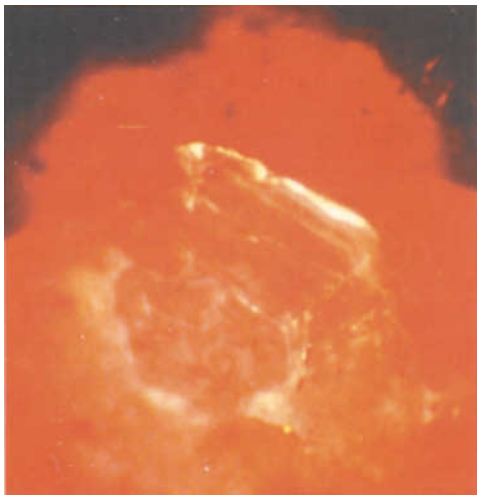

Figure 5: *Yellow CL of a euhedral dolomite crystal inclusion at the surface of the spinel. Part of the inclusion and tension haloes are very near to the surface of the host as yellow luminescing clouds. Excitation conditions: 16 kV; 0.8 mA. Enlargement: 100* x.

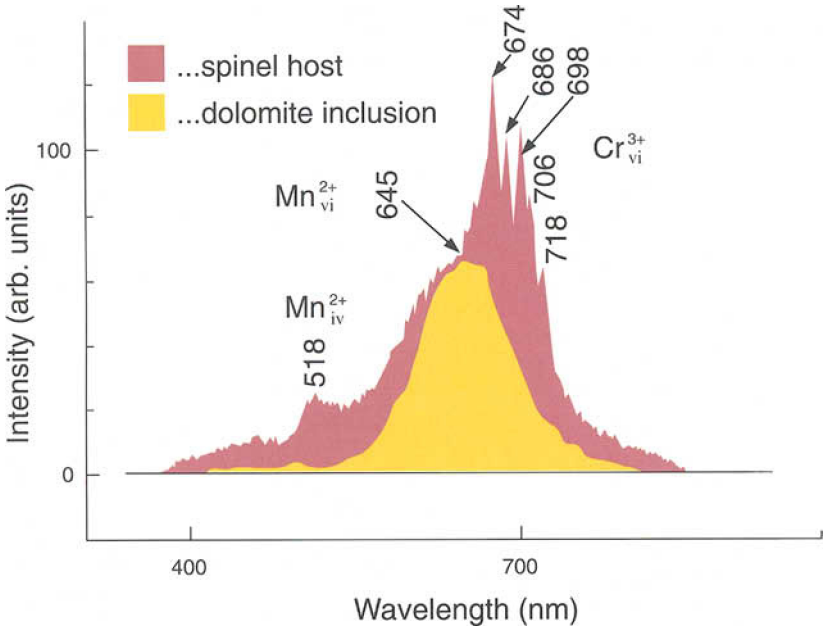

Figure 6: *CL spectra of the spinel host (pink) and curve-fitted dolomite spectrum (orange). Excitation conditions: same as in Figure 5.*

(3) Colourless topaz with quartz and fluorspar inclusions

A plate of polished topaz from Nigeria weighing 6.104 ct, contains numerous small quartz and colourless fluorite inclusions (see *Figure 7*). The host luminesces in a subdued steel blue, while the inclusions show a reddish-brown and a green CL colour for the two quartzes and the euhedral cubes of fluorite respectively. The CL spectra of *Figure 8* are characterized by a multitude of small bands which can be ascribed to the trivalent rare earth ions, dysprosium, terbium and samarium. The first element can be recognized in the CL spectra of both types of inclusion, the latter two are identified in the CL spectra of the fluorites, exclusively. Additionally, the broad short-wave bands of the host topaz indicate the influence of an intrinsic CL feature (defect centres).

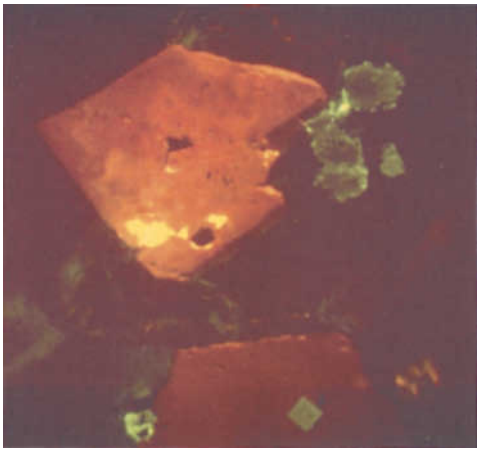

Figure 7: *Reddish-brown CL of quartz and green CL of fluorite inclusions both activated by rare earth elements. Steel-blue CL colour of the host (to the eye) has turned into dark maroon in the photomicrograph. Enlargement: 125 x. Excitation conditions: 12.5 kV; 0.9 mA.*

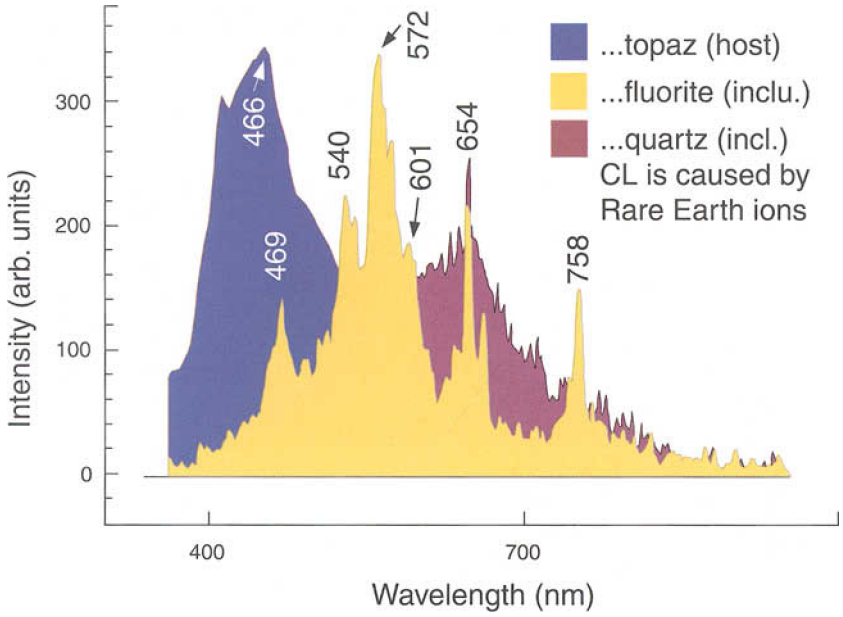

Figure 8: *CL spectra of host and inclusions. Topaz is shaded blue (dark maroon in Figure 7), quartz is shaded violet, and fluorite yellow. Excitation conditions 12.5 kV; 0.9 mA.*

(4) Garnet with apatite and quartz inclusions

Non-luminescing garnets may host a number of luminescing inclusions. An orange umbalite of 3.43 ct containing two apatite and one quartz inclusions which partly penetrate the surface of the rough host, is shown in *Figure 9*. The quartz houses a small zircon daughter crystal. Bombarded by electrons the apatite inclusion shows a bright yellow CL colour (*Figures 9 and 10*) while the quartz displays a greyish-white CL which could not be photographed because of its weak intensity. The CL spectrum of the apatite, as reproduced in *Figure 11*, consists of a broad, medium strong band at 569 nm caused by Mn^{2+} ions superimposed on a range of narrow bands of REE-activator ions of which Dy^{3+}, Sm^{3+} and Sm^{2+} ions are prominent. The broad quartz CL spectrum exhibits additional CL bands which are also caused by REE-activator ions. Such spectra demonstrate the wealth of information that can be obtained by CL microspectrophotometry, provided the inclusion intersects the surface of a stone.

Figure 9: *An orange umbalite with an apatite inclusion. The luminescing quartz inclusion is not visible. Excitation conditions: 15 kV; 0.95 mA. Enlargement: 40* x.

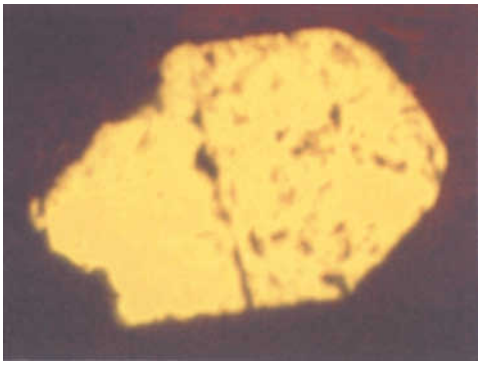

Figure 10: *The yellow luminescent apatite at higher magnification. The colour is caused by Mn^{2+}, Dy^{3+}, Sm^{3+} and Sm^{2+} ions replacing Ca^{2+} ions in the apatite structure. Excitation conditions: 15 kV; 0.95 mA. Enlargement: 125* x.

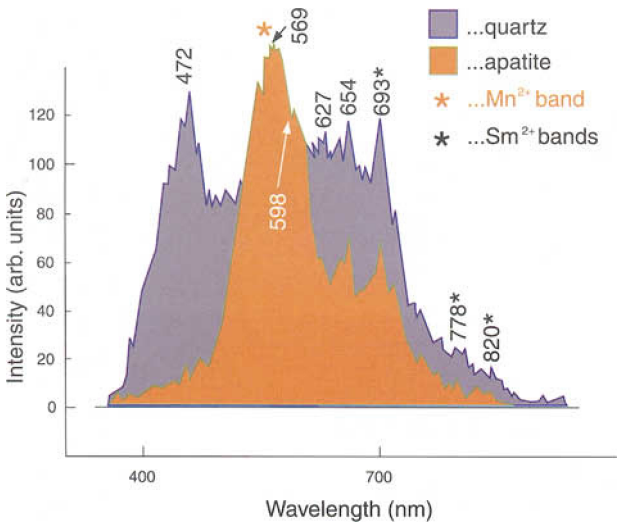

Figure 11: *The Sm^{3+} band of the apatite at 598 nm (white arrow) is hidden by the prominent Mn^{2+} band at 569 nm. Note that even the quartz spectrum contains Dy^{3+}, Sm^{3+} and Sm^{2+} bands documenting the same growth history as the apatites.*

(5) Kyanite with rutile inclusions luminescing in the NIR

A faceted steel-blue kyanite of 6.925 ct contains a number of irregularly distributed euhedral rutile inclusions (*Figure 12*). The CL colour of the host is a saturated red whereas the rutile inclusions penetrating the surface of a pavilion facet which, although apparently non-luminescent (*Figure 13*), show a pleasing wine-red colour in incandescent light. The red CL colour of the host kyanite manifests itself by two prominent very narrow CL bands in the red at 688 and 704 nm which are a characteristic CL feature of kyanite caused by Cr^{3+} ions in the lattice. An additional spectrum of the non-luminescent rutile inclusion reveals a strong signal in the near infrared (NIR) with a broad band peaking at ~ 800 nm (*Figure 14*). This band cannot be assigned to a special activator ion at present, but there is no doubt that the signal has to be attributed to the rutile inclusion in the kyanite host.

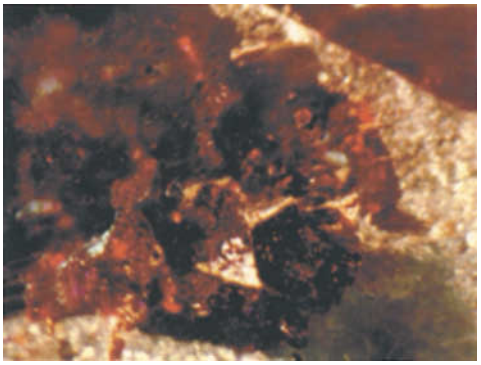

Figure 12: *Rutile inclusions in kyanite at the surface of a pavilion facet. Incandescent light, stereomicroscope ZEISS STEMI 2000C.*

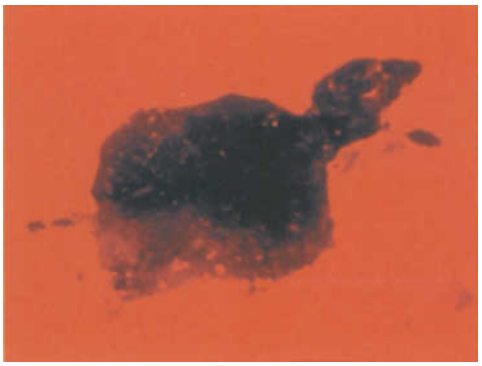

Figure 13: *Red CL of the host crystal with an inert rutile inclusion. It exhibits a strong broad CL band in the NIR. Excitation conditions: 11.0 kV; 0.9 mA. Enlargement: 40* x.

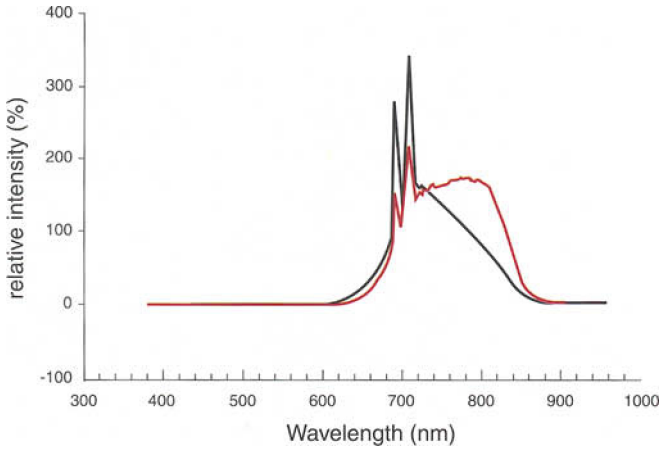

Figure 14: *CL spectra of the kyanite host (black) with its two characteristic narrow R-lines (see text). The rutile inclusion exhibits a broad band in the NIR at ~ 800 nm. Excitation conditions: 9.0 kV, 0.9 mA.*

(6) Tourmaline with a diopside and a zircon inclusion

Among the gemstones investigated, a green polished rough tourmaline of 3.884 ct was of special interest. It contained, besides a number of apatite inclusions, a small diopside crystal luminescing in a yellowish-white CL colour turning pale red after prolonged bombardment (*Figure 15*). The mineral diopside has a very characteristic CL spectrum and, as it has not been reported as an inclusion in tourmaline, SEM analyses were carried out (*Figure 16*). SEM X-ray analysis using an energy-dispersive detector yielded the spectrum shown in *Figure 17* and quantitative analyses of two spots are listed in *Table II*. The diopside inclusion was partly covered by a tiny zircon crystal, but this was too small for CL spectral analysis. The CL spectrum of the diopside (*Figure 18*) consists of three bands: a strong band at 578 nm is always combined with two weaker ones on each side at ~ 470-480 and at 730 nm in the NIR. The 578 nm main band can be ascribed to Mn^{2+} ions (Walker, 1985), the short-wave band is an intrinsic feature, and the band in the NIR is caused by trace amounts of Fe^{3+} ions.

Wt.%	I	II
SiO_2	49.26	48.71
TiO_2	0.62	0.92
Al_2O_3	10.43	11.45
Cr_2O_3	0.15	0.43
FeO	0.00	0.00
MgO	13.04	12.31
CaO	25.41	25.97
Na_2O	0.46	0.00
K_2O	0.40	0.20
Total	99.77	99.99

Table II: *Energy Dispersive XRF analyses of two spots in a colourless diopside inclusion in a green tourmaline host from Tanzania.*

Figure 15: *Pale red CL of a colourless diopside inclusion in a green non-luminescent tourmaline, Langenai, Tanzania. Excitation conditions: 0.8 mA; 11.0 kV. Enlargement: 125* x.

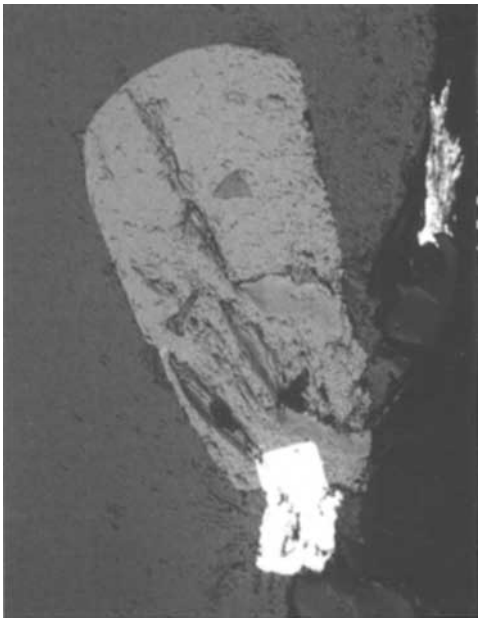

Figure 16: *SEM photo of the diopside inclusion in a green tourmaline (dark grey) with an adhering zircon crystal (white). Compare also the X-ray diagram of Figure 17.*

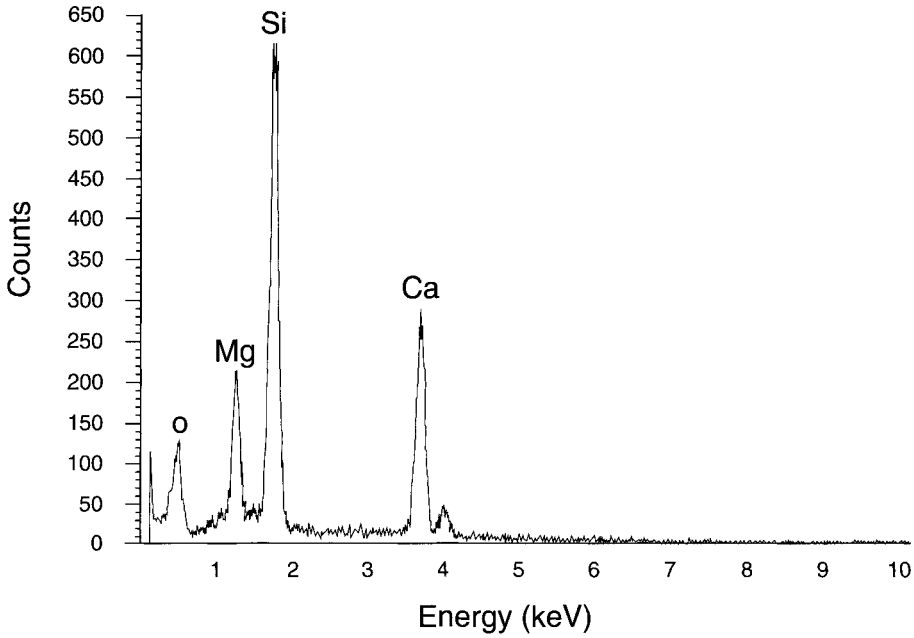

Figure 17: *Energy-dispersive X-ray fluorescence spectrum showing the major elements in the diopside inclusion. See also Table II.*

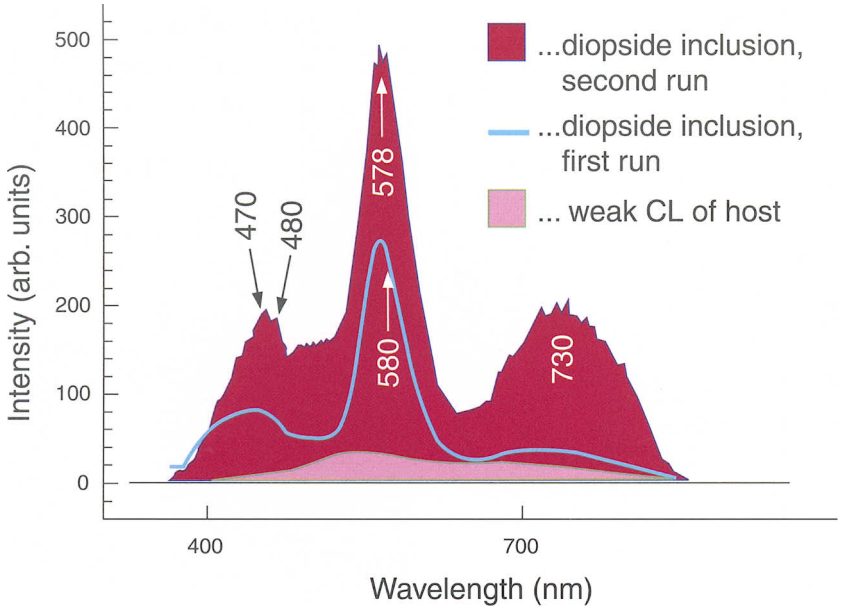

Figure 18: *The CL spectra of the colourless diopside inclusion shows a diagnostic band at 578 nm. The different intensities between the first and the second run reflect the CL colour change of the inclusion from yellowish-white to pale red during longer bombardment. Excitation conditions: 9.0 kV; 0.8 mA.*

(7) Kornerupine with apatite and zircon inclusions

Kornerupine gemstones commonly contain large euhedral apatite crystals and metamict zircons with tension cracks, a good example is the olive green navette of 5.02 ct from Sri Lanka. An apatite inclusion which reaches the table facet luminesces brownish-yellow (*Figure 19*) in contrast to the host which remains inert; this is due to a significant iron content that extinguishes any CL effect. *Figure 19* also shows some brownish-yellow luminescing small zircon crystals which apparently seem to adhere to the apatite inclusion. In reality they are not more than 1-2 µm below the surface of the table facet. The CL spectrum (*Figure 20*) of this apatite inclusion is instructive. While most apatites from pegmatitic, metamorphic or Alpine veins contain enough trace amounts of divalent manganese ions to form a strong band at ~ 570 nm, many apatites originating from other geological environments host a number of di- and trivalent rare earth ions which are responsible for their blue, greenish-yellow to bright yellow or brown CL colours. The CL spectrum reproduced in *Figure 20* reveals the presence of dysprosium, terbium and samarium, whose narrow bands are distributed over the entire visible spectral range and which combine to give the visual impression of brown.

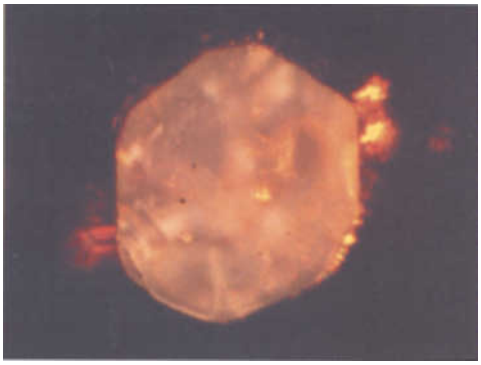

Figure 19: *Brownish-yellow CL of a euhedral apatite in a non-luminescing kornerupine host. Excitation conditions: 9.0 kV; 0.9 mA. Enlargement: 125* x.

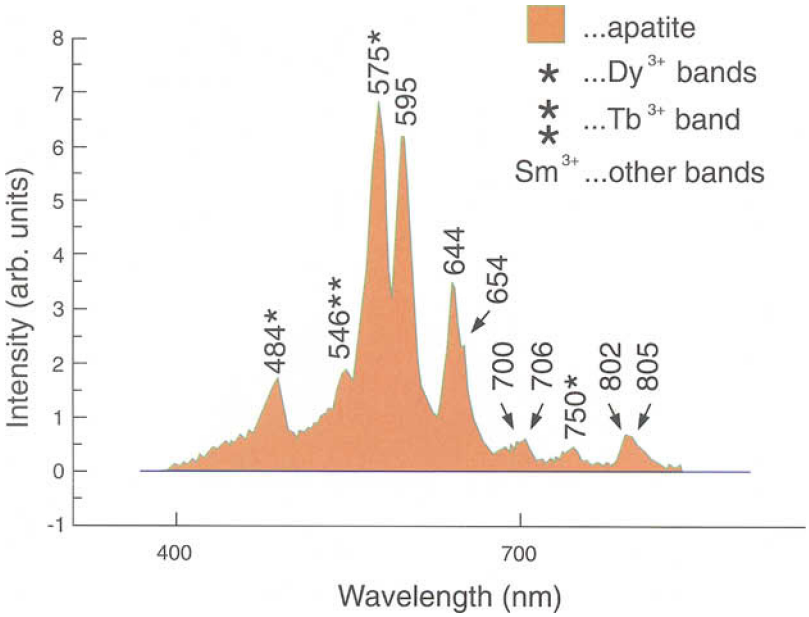

Figure 20: *CL spectrum of a brownish-yellow luminescing apatite inclusion in a green kornerupine from Sri Lanka exhibiting narrow REE^{3+} bands caused by trivalent dysprosium, terbium and samarium. Excitation conditions: 9.0kV, 0.9 mA.*

(8) Plagioclase with ruby and pargasite inclusions

A pleasing white ornamental cabochon from Mogok of 6.39 ct contained large red and small dark brown blotches which turned out to consist of rubies and pargasite respectively. During electron bombardment the host feldspar luminesced green, a vivid contrast to the strong red CL of the ruby inclusions and to the almost inert brown to dark grey CL colour of the pargasite amphibole which is evident in *Figure 21*. The CL spectra in *Figure 22* display a similar contrast between the strong ruby CL spectrum and the less intense broad band of the plagioclase host peaking at 550 and 558 nm. Using cold cathode CL even tiny ruby inclusions of less than 10 µm may become noticeable under the microscope during a bombardment with electrons.

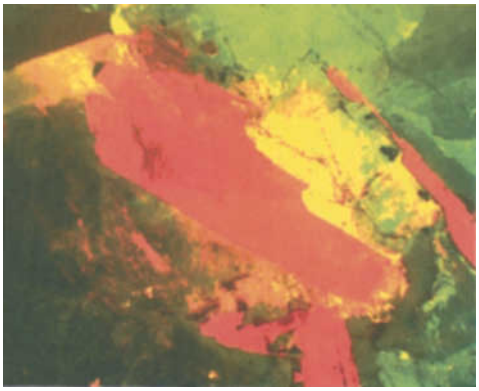

Figure 21: *The bright red luminescence of ruby inclusions provides a perfect contrast to the green CL colour of the plagioclase host. The CL colour of the latter is evoked by Mn^{2+} ions. The dark areas on the left are pargasite and the small black blotches are caused by picotite grains. Excitation conditions: 10.5 kV; 0.8 mA. Enlargement: 40* x.

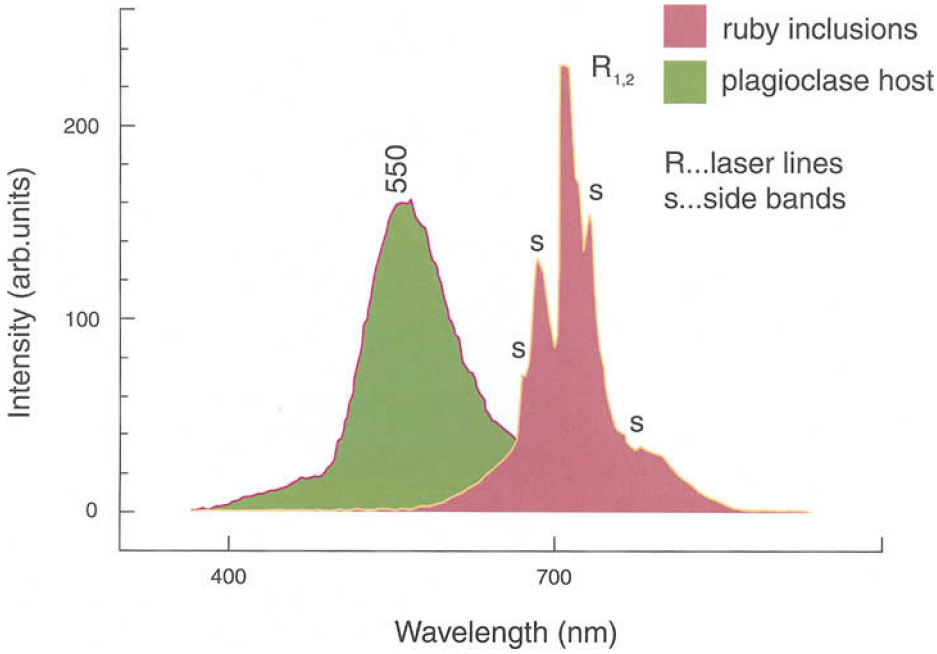

Figure 22: *CL spectra of the plagioclase host and ruby inclusions. Excitation conditions: 5.0 kV; 0.4 mA*

(9) Calcite host with albite inclusions

Grey to blue calcite is mined in Sri Lanka and supplies material for collectors. A sample of 51.8 ct, apparently clean, was inspected using CL and two small bluish luminescing spots (*Figures 23 and 24*) became visible within the overall red CL colour of the rough host. The red CL colour of the calcite stems from divalent manganese ions replacing divalent calcium ions in the carbonate structure. The bluish-white luminescence comes from small albite inclusions which show a typical spectrum (*Figure 25*). During the microscopic investigation the sky-blue luminescing inclusion could not be detected when using incandescent light.

Figure 23: *Red CL of a greyish-blue rough calcite with two whitish luminescing dots of albite. Excitation conditions: 9 kV; 0.9 mA. Enlargement: 10* x.

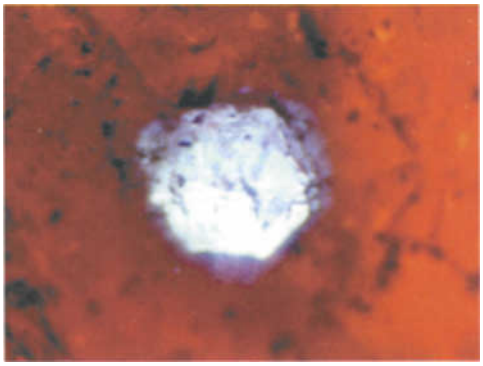

Figure 24: *At higher magnification the CL of the dots appear blue with a CL spectrum characteristic of albite. Excitation conditions: 8 kV; 0.8 mA. Enlargement: 125* x.

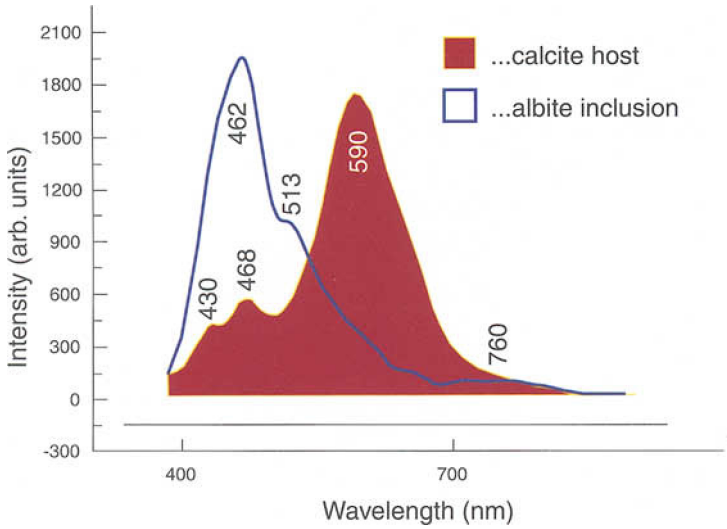

Figure 25: *CL spectra of the rough calcite that hosts two albite inclusions. The host spectrum is dominated by a Mn^{2+}-band at 590 nm characteristic for the CL of calcites. The albite inclusion shows a strong band in the violet-blue with its tail reaching into the NIR. This band shape is indicative for defect centres causing the blue CL of the albite inclusion. The intensity of the calcite spectrum is multiplied by a factor of 10.*

(10) Dolomite with a pargasite inclusion simulating mottled white jade

CL microscopy and spectrophotometry are fast and efficient methods to differentiate between natural jadeititic jades and a great number of simulants. One such simulant consisted of a white natural dolomite cabochon of 6.09 ct that contained a bright green blotch of pargasite (*Figure 26*). Bombarded by electrons the cabochon fluoresced an intense violet-tinted red (*Figure 27*) with the non-luminescent amphibole pargasite remaining black. Natural jadeite does not react in this manner. The CL spectrum clearly reveals a broad and intense Mn^{2+} band with divalent manganese ions replacing divalent calcium and magnesium in the dolomite structure. For convenience a Mn^{2+}-based CL spectrum of calcite has been added in *Figure 28* to compare the CL bands of both carbonates.

Figure 26: *Dolomite with a green patch of pargasite simulating green-mottled mutton-fat jade. Total length of the cabochon: 14.8 mm.*

Figure 27: *Dolomite under electron bombardment shows up in a violet-tinted red, the pargasite remains inert. Excitation conditions: 9 kV; 0.8 mA.*

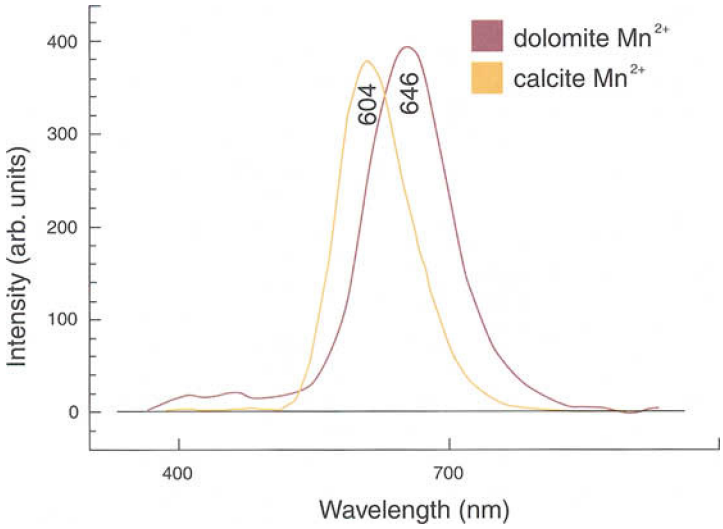

Figure 28: *CL spectra of dolomite and calcite hosts, the first used as a simulant of jade (Figure 26). In both minerals CL is provoked by manganese ions. Calcite shows a more orange to brick-red CL colour, whereas dolomite luminesces violet-tinted red. The main peak of the latter is shifted into the red by more than 40 nm.*

Discussion and outlook

From the above results some basic conclusions about the behaviour of a gemstone host and its inclusion can be drawn:

(a) When host and inclusion exhibit strong CL and show different CL colours, the CL effects of both the host and the inclusions can easily be studied. Representative samples are Nos 3 and 8.

(b) When both host and inclusion are luminescent, but the CL intensity of the host is less intense than that of the inclusion, this also facilitates a close study of the CL properties of the inclusion by both photomicrography and microspectrophotometry. An example is given by No. 9.

(c) When both host and inclusion are known to show strong luminescence, but the high CL intensity of the host masks completely that of the inclusion, CL microspectrophotometry should be used. Examples are given by sample Nos 1 and 2.

(d) When the host luminesces or remains inert when bombarded by electrons, with the inclusion showing no luminescence either, then the CL could have shifted further into the NIR. In this case, the spectral range up to 950 nm should be searched for CL bands. An example is given by No. 5 showing the NIR luminescence of rutile inclusions in blue kyanite.

Considering the many examples of inclusions presented in the *Photoatlas* (Gübelin and Koivula, 1986), it becomes evident that the field of luminescing hosts and inclusions will be enlarged and deepened by future studies which are under way.

The compartments of commercial cold cathode CL instruments are large enough to house more than six 5-10 ct gemstones which can be tested consecutively without opening the evacuated compartment, an advantage that speeds up CL investigations. Occasionally one comes across gemstones that host more than one type of inclusion (see No. 3). It is of advantage, then, to repeat the CL test with all inclusions that reach the surface of facets and run several CL spectra in order to characterize the different types of inclusions. One has to keep in mind that neither by visual CL nor by CL spectrophotometry is it possible to determine the chemical nature of all these inclusions. Use of SEM X-ray analysis may be necessary for conclusive answers. Such an example is documented by No. 7, when a second small inclusion (zircon) was detected by means of SEM.

Sometimes one may discover a strongly luminescing host with an apparently non-luminescent inclusion. This can be puzzling if the latter is known to exhibit a strong CL intensity in the normal spectral range when tested as a rough or cut mineral. Examples are the emeralds from Santa Terezinha in Brazil which frequently contain colourless dolomite inclusions that do not react to an electron bombardment. The mineral dolomite, however, generally luminesces strongly red as documented by sample No. 10. There are also rubies which host non-luminescent calcite inclusions. The mineral calcite, on the contrary, is well known for its strong CL (see Nos 4 and 10).

The reason for the lack of luminescence of some inclusions in gemstones which are well known to be strongly luminescent as minerals, is still obscure. The main obstacle for a reliable answer to this question is the quantitative determination of low concentrations of activator elements which are responsible for the CL effects. Our preliminary tests indicated concentrations of the activator elements chromium and manganese of not more than 13 and 23 ppm respectively (Ponahlo, 1993, tables 5 and 6). These tests were carried out by means of energy dispersive polarized X-ray fluorescence (EDPXRF) using table facets of gemstones and single crystals as large as ~ 6 x 4 mm. However, EDPXRF and similar non-destructive methods cannot be applied to small inclusions covering areas of less than 200 μm^2 and for these, other approaches will be necessary.

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I am much obliged to Prof. Dr Edward Gübelin for his generous loan of all the gems needed for this investigation and for his continuous and lively interest in this study. Likewise, my thanks to go to Prof. Dr Gero Kurat, Director of the Department for Mineralogy and Petrography at the Museum for Natural History, Vienna, and to Dr Franz Brandstätter who is responsible for the SEM and Microprobe equipment in that department for carrying out the SEM analyses.

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Natural amethyst from the Caxarai Mine, Brazil, with a spectrum containing an absorption peak at 3543 cm^{-1}

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ABSTRACT: Natural amethysts from the Caxarai mine in Rondônia State, Brazil, show markedly different characteristics from those from other well known localities. Their z $\{01\bar{1}1\}$ sectors show deeper colour than their r $\{10\bar{1}1\}$ sectors, and colour zoning in the z sectors is quite sharp with some showing strong purplish-blue pleochroism. An absorption peak in the infrared region at 3543 cm^{-1} is present in about 50% of these Caxarai stones. Due to the presence this 3543 cm^{-1} peak, these amethysts are liable to be misidentified as synthetic amethyst if investigation is not thorough since the peak has been taken as a diagnostic feature for synthetic amethyst.

Keywords: blue-purple pleochroism, Brazil twinning, Caxarai mine, colour zoning, z sectors, 3543 cm^{-1} absorption peak

Introduction

Since amethysts were commercially synthesised in 1970, identification of amethysts has become one of the most difficult tasks for gemmologists. Although the reasons for manufacture of synthetics to imitate rather cheap natural amethysts, or the significance of identifying them are not clear, overproduction of synthetic amethysts and mixing them with natural materials at the place of origin have made their identification an international issue. Following the reorganization of the former USSR, the technique of growing crystals in Russia became focused on jewellery production for export as the market economy grew, and the price for rough synthetic amethysts dropped radically. Furthermore, with growing competition from China the price has fallen as low as that of Verneuil synthetics; thus the importance of amethyst identification is inevitably increasing.

Background

Many identification methods to distinguish between natural and synthetic amethysts have been reported and practised at different laboratories. The chemical composition and crystal structure of natural and synthetic amethysts are the same, so that their physical properties such as RI and SG can not be effective indicators in their identification. At present, the following identification methods are employed as standard.

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Figure 1: *The location of the Caxarai mine in Rondônia State, Brazil.*

1. Observation of inclusions

Amethysts with inclusions can be identified using a loupe or a microscope. Goethite is commonly known as a typical solid inclusion in natural amethysts. On the other hand, breadcrumb-like inclusions imply a synthetic origin and if the presence of a seed crystal is detected, this forms decisive proof of synthetic origin. Liquid inclusions are rarely observed in synthetic amethysts, and if internal features or colour zoning in the form of tiger stripes, which are related to Brazil twinning are observed, the stone is most likely to be natural.

2. Observation of colour zoning

Most amethysts on the market are flawless to nearly flawless and do not contain characteristic inclusions useful for identification. Under such circumstances, observation of colour zoning that universally exists in amethysts becomes very important in identifying the stone. Understanding crystal morphology of natural and synthetic amethysts is critical as the colour zoning obviously corresponds to the changes of morphology in the crystal growth process. In natural amethysts, sequences of purple or violet and colourless zones in two or more directions, which correspond to r $\{10\bar{1}1\}$ or z $\{01\bar{1}1\}$ faces, are generally observed, and their boundaries are clear and generally straight. In contrast, mass-produced synthetic amethysts generally show light and dark purple zoning in one direction parallel to z faces. Conical colour zoning that corresponds to the vicinal form on the z faces (i.e. at only a few degrees inclination to the z faces) implies synthetic origin.

3. The presence of twinning

Almost all natural amethysts are twinned on the Brazil law whereas most synthetic

amethysts are not twinned. Based on this fact, certain identification methods for amethysts have been suggested and practised, e.g. Schmetzer (1986) and Crowningshield *et al.* (1986). In these methods, the stones are observed along the direction of the optic axis under crossed polarized light using for example, a polariscope. If Brewster fringes are observed in the test, the stone is regarded as a natural stone, and if simple colour rings caused by interference are observed, the stone is most likely synthetic.

4. Infrared spectrophotometry

The application of infrared spectrophotometry to amethyst identification has been attempted for a long time, e.g. Lind *et al.* (1983).

Nowadays, with the development of FTIR, infrared spectrophotometry is performed routinely in gemmological laboratories. The absorption at 3543 cm^{-1} in amethyst is commonly regarded as a characteristic feature of synthetics (Balitsky *et al.*, 1993, and other papers), and a clear absorption at 3543 cm^{-1} in over 80% of more than a hundred synthetic amethysts tested in our laboratory has been confirmed.

Samples and methods

The samples of natural amethyst from the Caxarai mine in Rondônia State, Brazil, tested in the present study include two rough stones, six roughly-cut or cut stones and 18 faceted stones. According to Carlos Rohmann, who is developing the Caxarai mine, the mine was only started in September 1999 and amethyst production has not yet reached the market in any quantity. The amethyst mine is located about 130 km north of the capital of Rondônia state, in the north west of Brazil (*Figure 1*). It is on the west bank of the Madeira River, one of the main tributaries of the Amazon River. Mining in the region was very active 50 years ago when columbite/tantalite minerals were discovered 15 km away from the location of the Caxarai mine. According to Rohmann (pers. comm.), there is a possibility that other mineral species in the Caxarai mine will be found as mining progresses. The deposit is most probably of pegmatitic origin.

Figure 2: *A rough crystal of natural amethyst from the Caxarai mine (weighing about 120 g).*

Shown in *Figure 2* is a rough crystal from the Caxarai mine, weighing about 120 g. Its crystal morphology and liquid inclusions clearly indicate its natural origin. Stones to

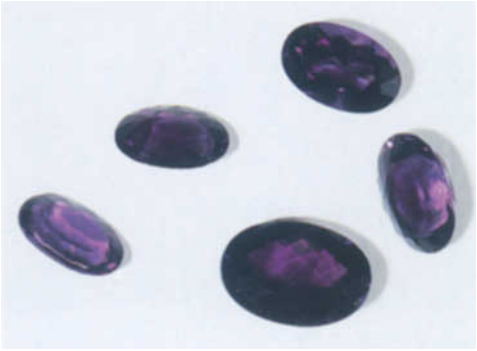

Figure 3: *Faceted pieces of natural amethyst from the Caxarai mine, ranging in weight from 3.65 to 8.97 ct.*

Figure 4: The rough stone shown in Figure 2 was cut along the direction of the c-axis. The top end of the piece shows intense purple.

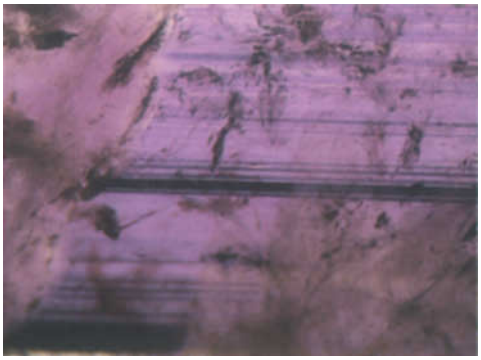

Figure 5: A piece of Caxarai amethyst sliced perpendicular to the c-axis is observed along the direction of the z {01$\bar{1}\bar{1}$} face. Extremely sharp colour zoning is present.

be faceted are said to be less included and clearer than our samples.

To inspect colour zoning and the presence of twinning, a sample was sliced both perpendicular and parallel to the *c*-axis of the crystal.

High-quality faceted amethysts (3.65ct – 8.97 ct) from the Caxarai mine are shown in *Figure 3*. In addition to the general gemmological tests, their colour zoning was observed under magnification with diffused light through a white filter while the samples were immersed in water. The presence of twinning in all stones was also detected under crossed polarising sheets which were attached to a binocular gemmological microscope.

The six cut and 18 faceted stones were also analysed by infrared spectrophotometry using a Shimadzu FTIR 8300 spectrophotometer with a resolving power of 4 cm^{-1}. Each stone was measured three times or more in random orientations.

Results

Figure 4 shows a rough crystal sliced along the direction of the *c*-axis, with deep colouring at one end. Shown in *Figure 5* is a crystal sliced perpendicular to the c-axis direction and observed along the direction of

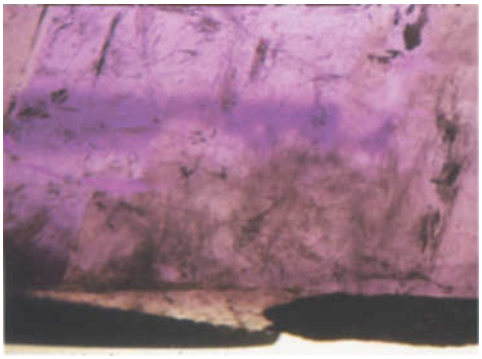

Figure 6a: A piece of Caxarai amethyst sliced perpendicular to the c-axis is observed along the optic-axis direction. The z sector appears dark purple.

Figure 6b: The same piece in Figure 6a is observed under cross polarised light. The z sector displays a uniform interference colour of violet, indicating that the area has no Brazil twinning.

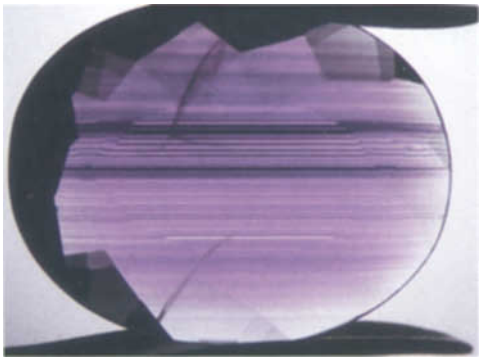

Figure 7: *The straight and clear colour zoning parallel to the z face.*

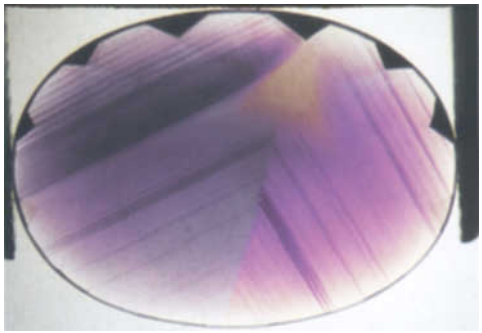

Figure 8: *The colour zoning in two directions parallel to the z face.*

a rhombohedral face. The amethysts from the Caxarai mine also show a Brewster fringe which originates from Brazil twinning. We interpreted the area that shows the fringe as the r sector, and rhombohedral faces that do not show the fringe as the z sector.

The same piece was observed along the optic axis direction and this is shown in *Figure 6a*, and under crossed nicols in *Figure 6b*. The area showing purple colour zoning in *Figure 6a* shows a uniform violet interference colour in *Figure 6b* (this means than the stone is not Brazil twinned), and it corresponds to the z sector.

Roughly-cut or faceted samples all showed very straight and clear colour zoning. Some samples were cut only from the z sector (*Figure 7*) and did not show Brazil twinning, Many showed colour zoning in two directions parallel to the z face (*Figure 8*), and a few other stones showed a yellow colour in the r sector (*Figure 9a, b*). All samples showed strong pleochroism, some in deep and pale purple, and some in purple to bluish purple (*Figure 10a, b*); according to Rohmann (pers. comm. 2001), the colour of the latter stones is called 'tanzanite colour' at the mine.

Only one sample showed Brazil twinning with conical form combined with Dauphiné twinning which is characteristic of synthetic amethysts (*Figure 11a, b*). In this case, the r sector appeared yellow in colour. The

Figure 9a: *The r {10$\bar{1}$1} sector appears yellow.*

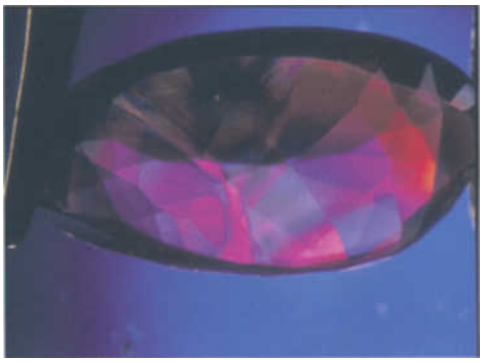

Figure 9b: *The piece shown in Figure 9a is observed under cross polarised light. The yellow area clearly shows Brazil twinning.*

Figure 10a: *Some z sectors show strong bluish-purple to purple pleochroism (the picture was taken by using a polariser).*

Figure 10b: *The polariser used in Figure 10a was rotated to observe the pleochroic change of colour.*

differences in Brazil twinning in natural and synthetic amethysts have been discussed by Lu Taijing *et al.*, 1990, and I. Sunagawa, 1999.

Infrared spectra

Infrared spectra of 12 of the 24 cut stones showed absorption at 3543 cm^{-1}. Most of the samples that showed this absorption were dominated mainly by the z sector and did not show Brazil twinning, and indeed the absorption at 3543 cm^{-1} was only recognized in the deeply coloured z sector (*see Figure 12*). Before the Caxarai samples arrived we had tested several hundred natural amethysts and none of them showed clear absorption at 3543 cm^{-1}. So the natural amethysts from the Caxarai mine are quite extraordinary. The cause of the absorption at 3543 cm^{-1} has not yet been clarified, but it may well be related to the z sector, as the mass-produced synthetic amethysts are z sector-dominant.

Conclusions

The unusual features of natural amethysts from the Caxarai mine in Rondônia State, Brazil may be summarized thus:

1. Unlike the amethysts from most localities the z sectors show deeper colour than the r sectors, and their beautiful colours are suitable for gem use.
2. The boundaries of light and dark purple zoning observed in the z sector are straight and very sharp.

Figure 11a: *The r sector (pale yellow) that may be induced by the Dauphiné twinning is seen in the z sector (purple).*

Figure 11b: *The same piece in Figure 11a is seen under cross polarised light. The Brazil twinning is present in the r sector.*

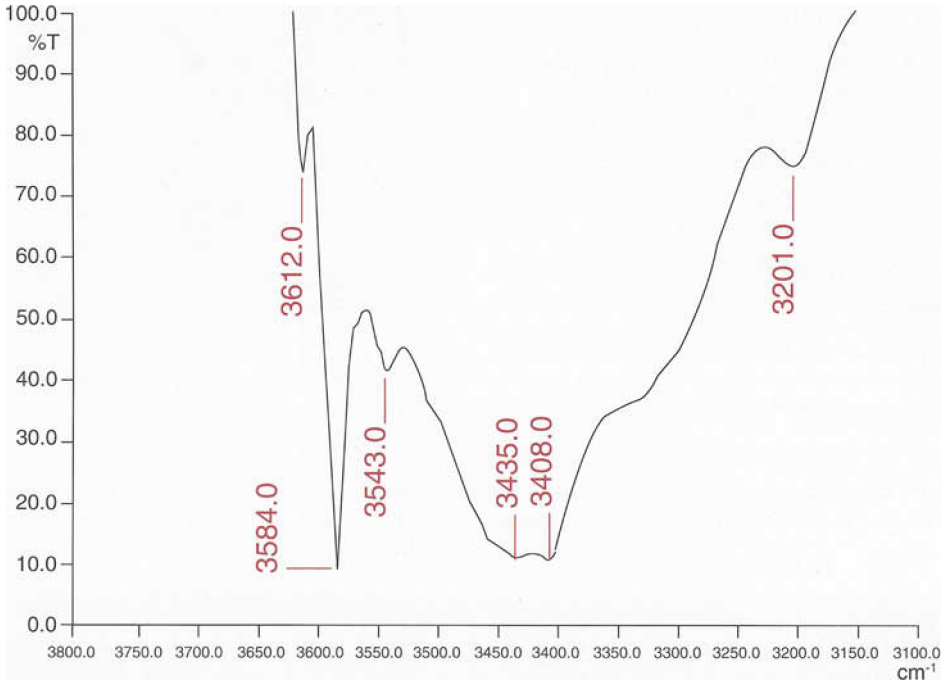

Figure 12: *The infrared absorption spectrum of a natural amethyst from the Caxarai mine. Absorption at 3543 cm^{-1} is clearly seen.*

3. Strong bluish-purple to purple pleochroism is present in parts of certain stones.
4. The Brazil twinning with conical form combined with Dauphiné twinning is present and has been considered as characteristic of Brazil twinning in synthetic amethysts.
5. Infrared spectra mainly of z sector stones contain an absorption at 3543 cm^{-1}, which is generally regarded as a characteristic identifying feature of synthetic amethysts.

It follows from these results that, if only the beautifully coloured z sector is used to cut gemstones from the natural amethyst from the Caxarai mine, they may possibly be misidentified as a synthetic amethyst

(a) because of the peculiar colour zoning;

(b) because of the lack of Brazil twinning; and

(c) the presence of infrared peak at 3543 cm^{-1}.

If a gemmologist has little knowledge of crystal morphology and twinning in quartz and relies too much upon infrared spectrophotometry, the risk of misidentification is increased.

Acknowledgements

I express my deepest thanks to Mr Akira Ito of the ITO Co., Ltd for supplying the samples, to Mr Rikiya Kameyama of the Miyuki Co., Ltd for cutting rough samples, and to our technical staff at GAAJ for assistance with the analysis, discussion of the problems and for providing constructive advice. I am also grateful to Dr Ichiro Sunagawa for revising the first draft of this manuscript.

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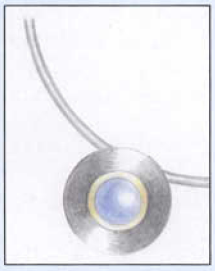

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Letter to the Editor

Production of fake asterism

Introduction

A 'new' method for imitating asterism in natural cabochon-cut gem materials was recently described by McClure and Koivula (2001). The optical phenomenon is caused by a series of man-made parallel scratches on the curved surfaces of the gemstones. Although no details of the production process of this 'new' type of artificially produced asterism were given, it was suggested that 'the use of a polishing wheel with a coarse grit' and 'some type of spinning wheel' is involved. Sinhalite, cassiterite, chrysoberyl, garnet, rutile and samarskite(?) cabochons with this type of fake asterism were described by McClure and Koivula (2001). Garnet and tourmaline were recently mentioned by Schmetzer and Steinbach (2002) as further examples of manipulated gem materials with artificially induced asterism.

Searching for patents dealing with special gem cuts and light effects in gemstones, the author accidentally discovered an old United States patent document by Mukai (1950), in which a process for the production of man-made asterism in cabochon-cut gem materials is described. The procedure mentioned in this document or a variation of this process has possibly been applied in the recent production of fake asterism in natural gem materials. The technical part of the description given by Mukai (1950) is cited in the following section. This description is self-explanatory:

"Referring now to Fig. 1 (left) the cabochon-cut stone 10 has a plane base 11. The stone and base may be finely ground and polished; that is, there is usually no need for further grinding or polishing after the asterism-producing step. The stone 10 may be set in cement 12 on a dop stick 14 for support (Fig. 2). Then, using means such as the cylindrical iron bar 15 suitably held in a rotating chuck 16 and fine gem-polishing dust, the base 11 is given a great multiplicity of minute, sharp, shallow cuts or grooves over the three intersecting areas 17. Three areas of engraving intersection as shown in Fig. 1 (left) will produce a six-rayed star. This is the desired treatment because it simulates the asterism of a natural gem. The individual cuts or engravings are short and may be considered to be substantially

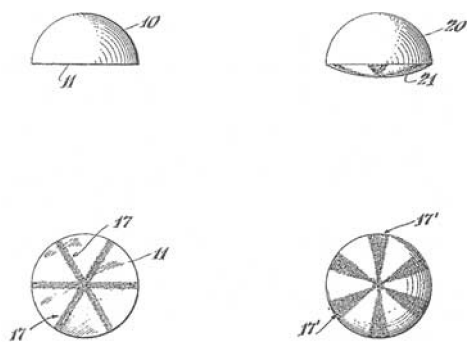

Figure 1: By scratching the flat (left) or curved (right) surface of a cabochon-cut gemstone in different regions, asterism is produced which can be seen as a moving star from various directions relative to a light source; 10, 20 cabochon-cut gemstones, 11 flat base of the gemstone, 21 curved surface of the gemstone, 17, 17' engraved areas with artificially produced scratches or grooves (from Mukai, 1950).

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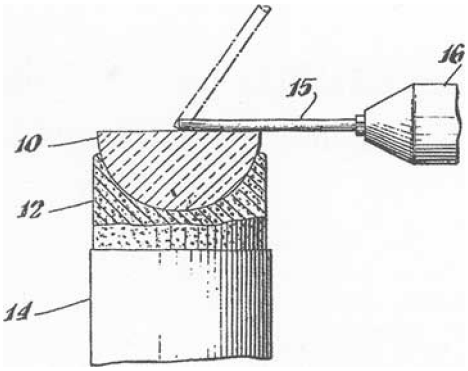

Figure 2: *Production of scratches on the flat base of a cabochon-cut gemstone by use of a rotating or vibrating iron rod; for the artificial production of scratches or grooves on curved surfaces, the rod is held at an angle to the surface (dot and dash lines); 10 cabochon-cut gemstone, 12 cement, 14 support, 15 iron rod, 16 rotating chuck (from Mukai, 1950).*

parallel one with the other. The individual cuts should extend at an angle, preferably a right angle, with respect to the radii of the back of the stone.

"In the Fig. 1 (right) embodiment the stone 20 has a double cabochon-cut in that the base 21 is also convex. A somewhat different pattern of engraving has been employed, as will be noted: the respective engraved areas 17' are wider at the girdle than at the center of the base. Preferably said areas are not truly triangular in that there is no clearly defined apex. The asterism thus produced is also characterized by a bright center and well-defined luminous rays.

"The engravings or markings of the forms of Fig. 1 (right) are perhaps best accomplished by holding the rod 15 at an angle as shown in dot-dash lines of Fig. 2. A vibrating tool, rather than a rotating tool, may be employed, and other mechanical expedients will suggest themselves to the skilled lapidary.

"It should be understood that the respective figures exaggerate the prominence of the engraved areas. In fact, the individual lines of engraving are exceedingly fine and when the stone is viewed under indirect light are hardly discernible.

"The asterism is produced by the reflection of rays of direct light from the multitudinous facets or side walls of the engraved lines. A feature of asteriae produced by my method is that the stars thereof seem to move within the stone as the stone and the light source are moved relative to each other."

It is evident that the technique described in US patent 2,511,510 by Mukai (1950) or a slightly varied embodiment may be used for the recent production of fake asterism. The irregularities of the artificially produced stars as described recently (e.g. 'satellite lines', asymmetrical or curved rays) indicate an individual, non-automatic production procedure.

Dr Karl Schmetzer

Taubenweg 16, D-85238 Petershausen, Germany

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Schmetzer, K., and Steinbach, M.P., 2002. Fake asterism – two examples. *Journal of Gemmology*, **28**(1), 41-2

Abstracts

Diamonds

Gems and Minerals

Instruments and Techniques

Synthetics and Simulants

Diamonds

Study of diamonds from chromitites in the Luobusa ophiolite, Tibet. (Chinese with English abstract)

W. Bai, J. Yang, P. Robinson, Q. Fang, Z. Zhang, B. Yan and X. Hu. *Acta Geologica Sinica*, **75**(3), 2001, 404-9.

A newly discovered occurrence of diamonds in chromitites of the Luobusa ophiolite, Tibet, is described, together with details of the diamonds and of their numerous metallic inclusions. Examination of 25 grains of diamond recovered from the chromite ores revealed about 70 varieties of native elements (Cr, Cu, Ni, Fe, C, Si, Au, Pb, W, Ir, Os, Ru), alloys (Fe-Ni, Fe-Co, Fe-Mn, Fe-Si, Fe-Ni-Cr, Fe-Ni-Co, Si-C, Cr-C, Ir-Os, Os-Ir, Os-Ir-Ru, Fe-Pt), silicates and sulphides. Photomicrographs of the diamonds are accompanied by IR and Raman spectra and a plot of their B-defects vs H (x 10^{-6}). R.A.H.

A non-cognate origin for the Gibeon kimberlite megacryst suite, Namibia: implications for the origin of Namibian kimberlites.

G.R. Davies, A.J. Spriggs and P.H. Nixon. *Journal of Petrology*, **42**(1), 2001, 159-72.

Unaltered kimberlites, clinopyroxene and garnet megacrysts have Sr and Pb isotopic disequilibrium between the kimberlites and the megacrysts showing that the latter are not cognate. The megacryst *REE* (data given) indicates equilibrium with an alkali basaltic magma. Rb-Sr phlogopite ages, ~72 m.y., show that kimberlite volcanism occurred between 5 and 10 m.y. after the inferred passage of the Discovery plume beneath the Gibeon region of Namibia, but the Sr-Nd-Pb isotopes of the kimberlite and clinopyroxene and garnet megacrysts (data listed) are distinct from those of the plume and so it presumably contributed little to the volcanism. The megacrysts have a strong DUPAL Pb isotope signature, believed to be derived from the sub-continental lithospheric mantle due to Discovery plume-provoked 'basaltic' asthenospheric-derived melts that ponded at the base of and interacted with the sub-continental lithosphere with polybaric fractionation. Less likely is a lower mantle source for the DUPAL Pb isotope signature. B.E.L.

Identification of GE POL™ diamonds.

E. Fritsch, J-P. Chalain and H.A. Hänni. *Australian Gemmologist*, **21**(4), 2001, 172-7.

GE POL diamonds, also marketed as Pegasus and Bellataire diamonds, are brownish type IIa stones that have been colour enhanced by the General Electric Company of the USA using a high-pressure high-temperature (HPHT) process. The Bellataire diamonds currently marketed by Lazare Kaplan are being laser-inscribed on the girdle with the inscription GE POL™, which as a possible identifying feature, can be removed by repolishing. Other identifying features include transparency to SW UV, cross-hatched tatami graining of weak to moderate intensity, generalized haziness, etched surface-reaching cleavages and rare mineral inclusions surrounded by disc-like stress fractures. A more sophisticated confirmation of identity can be obtained by the use of luminescence excited by the 514nm laser beam of a Raman spectrometer. This, with the diamond cooled to the temperature of liquid nitrogen, reveals the treated stone's N-V (nitrogen vacancy) centre either as an absorption of light at 637 nm or an emission at 575 nm. Also using a Raman spectrometer with liquid nitrogen cooling, the research scientists at De Beers have proposed use of the ratio of the intensity of luminescence at 637 nm and 575 nm. The 637:575 nm ratio is always less than 1.6 for untreated type IIa diamonds, while that of GE POL diamonds is higher than 2.5. P.G.R.

Composition chimique et isotopique des mégacristaux et des diamants des kimberlites du Kundulugu (Zaïre).

D.M. Kampata, J. Demaiffe, J. Hertogen, J. Moreau and P.H. Nixon. *Annales de la Société géologique de Belgique*, **119**(1), 1996, 55-70.

EPMA results are given for megacrysts of olivine, pyroxene, garnet and ilmenite occurring in a matrix of

Abstractors

R.R. Harding	R.R.H.	G. Raade	G.R.	I. Sunagawa	I.S.
R.A. Howie	R.A.H.	P.G. Read	P.G.R.	R.Van Tassel	R.V.T.
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M. O'Donoghue	M.O'D.				

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olivine, spinel, perovskite, monticellite, serpentine and carbonate. The kimberlites contain some diamonds, ultramafic and crustal inclusions. Parental liquid in equilibrium with diopside has been similar to that of alkali basalts. The liquid in equilibrium with garnet was much more enriched in LREE. The low $^{87}Sr/^{86}Sr$ ratios of the diopsides indicate a source more depleted in Rb, but the Sm/Nd ratio is comparable to the source of the 'host' kimberlite. Garnet is probably contaminated by Sr, and orthopyroxene by Sr and Nd. Diamond shows a large range of $\delta^{13}C$ from -24.5 to -4.5‰ corresponding with a peridotitic or eclogitic type. R.V.T.

Oxidation during metasomatism in ultramafic xenoliths from the Wesselton kimberlite, South Africa: implications for the survival of diamond.

C. A. McCammon, W. L. Griffin, S. R. Shee and H. S. C. O'Neill. *Contributions to Mineralogy and Petrology*, **141**(3), 2001, 287-96.

Garnets in xenoliths in the Wesselton kimberlite show significant zoning in major and trace elements. Their study by Mössbauer spectroscopy showed an increase in $Fe^{3+}/\Sigma Fe$ from core to secondary rim. Determination of *T* and *P* using garnet-olivine, garnet- orthopyroxene and Ni in garnet formulae indicate conditions near 1000°C and 37 kbar for most of these garnets. Calculations of fo_2 show an increase of ~1 log-bar unit from garnet core to secondary rim, relative to the Q-F-M buffer curve. Combined with re-analysis of literature data from unaltered material, from the same locality, there was an increase in relative fo_2 of ~2 log-bar units during the course of the metasomatism. Existing data for other South African garnet peridotites when similarly recalculated indicate relative fo_2 that lie at least 2 log-bar units below the diamond-carbonate equilibrium in peridotitic systems, which define the maximum limit of diamond stability in peridotite. Hence diamond would be preserved during the final stages of metasomatism, but in later stages, fluid would react with the diamonds leading to their re-absorbtion and eventual destruction. R.A.H.

Modelling the appearance of the round brilliant-cut diamond: an analysis of fire, and more about brilliance.

I.M. Reinitz, M.L. Johnson, T.S. Hemphill, A.M. Gilbertson, R.H. Geurts, B.D. Green and J.E. Shigley. *Gems & Gemology*, **37**(3), 2001, 174-97.

The latest results are presented of research into the interaction of light with fully faceted colourless symmetrical round brilliant-cut diamonds of various proportions. 'Fire' is the visible extent of light dispersed into spectral colours. As fire is best seen with directed (spot) lighting, the measure of fire (dispersed coloured light return or DCLR) uses this lighting condition. DCLR values were computed for more than 26,000 combinations of round brilliant proportions. In general, different sets of proportions maximize DCLR and WLR (weighted light return), but there are some proportion combinations that produce above-average values. Analysis of these values with variations of five proportion parameters showed that every facet contributes to the appearance of a round brilliant diamond. In particular, star and lower girdle facet lengths could have a noticeable effect on WLR and DCLR. R.A.H.

Are Majhgawan-Hinota pipe rocks truly group-I kimberlite?

R. Shanker, S. Nag, A. Ganguly, A. Absar, B.P. Rawat and G.S. Singh. *Proceedings of the Indian Academy of Sciences – Earth and Planetary Sciences*, **110**(1), 2001, 63-76.

Although the four or more diamond-bearing, Proterozoic (1170 ± 20 – 974 ± 30 m.y.) pipe rocks in Majhgawan-Hinota occur as intrusives in sandstones in the SE margin of the Aravalli craton and have been called 'micaceous kimberlite', it is considered that this name is not justified. The absence of primary monticellite, the abundance of cognate phlogopite, and the presence of baryte and primary carbonate, coupled with their ultrapotassic and volatile-rich nature and high contents of incompatible elements, indicate a close similarity to the orangeites of South Africa. R.A.H.

Gems and Minerals

Bunte Calcite aus Spanien.

R. Augsten. *Lapis*, **26**(10), 2001, 27-31.

Fine red gem-quality sphaerocobaltite is reported, with other carbonates, from three Spanish locations. M.O'D.

Zebra Rock: an ornamental stone from the East Kimberley, Western Australia.

A.W.R. Bevan. *Australian Gemmologist*, **21**(4), 2001, 165-8, 5. Illus. in colour.

Zebra rock, also known as zebra stone and ribbon stone, is a distinctive reddish-brown and white banded sedimentary rock first discovered in 1924 near the present day diamond source at Argyle, south of Kununurra in the East Kimberley. The rock consists of small particles of quartz with fine-grained white mica, the clay mineral kaolinite, dickite and alunite. Because of its softness and high clay content it does not take polish, and items of hollow ware made from this ornamental rock have to be varnished to give them a high gloss and to protect the surfaces. P.G.R.

La collezione di gemme del Vicentino al Museo Civico 'G. Zannato' in Montecchio Maggiore (Vicenza).

M. Boscardin. *Mineralogia Scientifica.*, **16**(1), 2000, 51-60.

A collection of some 500 samples, including faceted and cabochon gemstones, and polished or engraved ornamental stones, has been assembled in this museum in Vicenza, NE Italy. Prominence is given to the 'enhydros' (a variety of chalcedony also termed 'Vicenza drop'), and to specimens of xonotlite and johannsenite (gems peculiar to the Vicenza district). R.A.H.

Fibrous nanoinclusions in massive rose quartz: the origin of rose coloration.

J. S. Goreva, C. Ma, and G. R. Rossman, *American Mineralogist*, **86**(4), 2001, 466-472.

Pink nanofibres with widths of 0.1-0.5 μm were extracted from rose quartz from 29 different pegmatitic and massive vein localities throughout the world. Optical absorption spectra of the fibres and the initial rose quartz imply that these nanofibrous inclusions are the cause of coloration of massive rose quartz worldwide. These fibres do not occur in the rare, euhedral variety of pink quartz. Redox and heating experiments showed that the pink colour of the fibres is due to Fe-Ti intervalence charge transfer that produces an optical absorption band at 500 nm. Based on the XRD patterns and characteristics of pleochroism, the best match for these inclusions is dumortierite. However, FTIR and Raman spectra consistently did not exactly match the standard dumortierite patterns, suggesting that this fibrous nano-phase may not be dumortierite itself, but rather a closely related material. P.M.W.

Pyrope from the Dora Maira massif, Italy.

A. Guastoni, F. Pezzotta, M. Superchi and F. Demartin. *Gems & Gemology*, **37**(3), 2001, 198-204.

Large crystals of pyrope containing gem-quality portions occur in Dora Maira massif in the Western Alps. These crystals have yielded pale purple to purplish-pink gemstones ≤1 ct. Electron microprobe results show 87-97 mol. % of the pyrope component. They have n 1.717–1.730, with SG 3.58–3.67 and contain several types of microcrystalline inclusions (including ellenbergerite) and show undulatory extinction with cross-polarized light due to strain caused by tectonic deformation. The IR spectrum has four sharp bands in the 3660–3600 cm^{-1} region. R.A.H.

Beobachtungen an hitzebehandeltem Rubin mit künstlicher Rissheilung.

H.A. Hänni. *Gemmologie. Z. Dt. Gemmol. Ges.*, **50**(3), 2001, 123-36, 12 photographs, 1 table, 1 graph, 1 diagram, bibl.

This paper deals with heat-treated rubies with glass fillings in fractures and subsequently healed fissures examined over the last twenty years. Flux assisted heat treatment with borax, lithium tetraborates and additives of glass, quartz or melted natural inclusions may form a melt that spreads over the surface and is drawn into cavities and fractures during subsequent heat-treatment. The flux character of such melts produced during the treatment helps recrystallization of some fissures. During cooling a small portion of synthetic ruby is formed that heals the former fissures. The flux may stay amorphous and glassy, but often precipitation of devitrification products are seen. This results in healing characteristics similar to natural 'fingerprints', and also residual portions of flux (commonly called 'glass') in fine droplets, channels, or thin films, up to the surface-reaching larger cavities. The different amounts of foreign substances in ruby led to a request for a quality scale, which has now been widely accepted. The amounts are divided into minor, moderate and significant/prominent. E.S.

Staurolite from the Lai Hka and Mong Keng areas, Myanmar.

U.T. Hlaing. *Australian Gemmologist*, **21**(4), 2001, 169-70, 4 illus. in colour, 1 map.

Crystals of reddish-brown to brownish-black cabochon grade staurolite crystals were discovered in schists to the west of the townships of Lai Hka and Mong Keng in Myanmar's Shan State. The crystals have a prismatic untwinned habit and are pseudomorphic, belonging to the monoclinic crystal system. P.G.R.

Sapphires and their imitations on medieval art objects.

J. Hyrsl. *Gemmologie. Z. Dt. Gemmol. Ges.*, **50**(3), 2001, 153-62, 17 photographs, 1 table, bibl.

Most sapphires used in medieval objects come from Sri Lanka; they have been common in Europe since Roman times. The stones are usually blue, sometimes yellow, pink, purple or colour-changing. Some show asterism. Almost all old sapphires are pierced pebbles; faceted stones did not appear before the 9th to 14th centuries. Dark blue translucent sapphires of basaltic origin are much rarer; they probably came from the LePuy region in central France. Sometimes iolites and aquamarines were confused with sapphires. Common sapphire imitations included blue glass, colourless foiled glass and doublets. The Ardennes cross in Nuremberg which was probably made in France in the 9th century contains 15 stones assumed to be sapphires. They turned out to be quartz pebbles which had been thrown into molten blue glass; they were then polished leaving remnants of blue glass on the surface. E.S.

Micro organisms associated with gemstones.

M.R. Khan, M.L. Saha and H. Afroz. *Bangladesh J. Bot.*, **30**(2), 2001, 93-6.

A total of 21 gems, including varieties of beryl, chrysoberyl, corundum, feldspar, opal and turquoise were tested for microbial growth. Thirteen species of the genus Bacillus were identified but all were in an inactive-moribund state. Under normal conditions there was no appreciable microbial growth but after incubation, bacterial colonies grew from the gems and demonstrated their chemoautotrophic nature. R.R.H.

Gem news international.

B.M. Laurs (Ed.). *Gems & Gemology*, **37**(3), 2001, 222-45.

Items of interest include reports on the progress of the Ekati and Diavik diamond mines in the Northwest Territories of Canada, Maxixe-type green-blue beryls with eye-visible pleochroism (with UV-VIS and EDXRF spectra), a vanadium-coloured green beryl from China, an account of recent gem discoveries (morganite, tourmaline and kunzite) at mines in Pala (California), cultured pearls from Tahiti and Australia, faceted translucent green powellite from Chile, and blue-to-green and also purplish-red faceted tourmaline from Nigeria. R.A.H.

Gemmologie Aktuell. Kupferhaltige Turmaline aus Nigeria.

C.C. Milisenda. *Gemmologie. Z. Dt. Gemmol. Ges.*, **50**(3), 2001, 121-2, 4 photographs.

The gem-quality tourmalines which owe their colour to the trace elements manganese and/or copper come from the Edoukou mine in the Nigerian State of Oyo near the Benin border. The stones weighed between 2 and 25 carats and were of blue-violet to amethyst colour. Heating produces an aquamarine colour. The stones are marketed in Idar-Oberstein under the name of 'Indogo Tourmaline'. E.S.

Edelsteine aus Sambia - Teil 3: Amethyst.

C.C. Milisenda, V. Malango and K.C. Taupitz. *Gemmologie. Z. Dt. Gemmol. Ges.*, **50**(3), 2001, 137-52, 11 photographs, 3 maps, 2 tables, 2 graphs, 1 diagram, bibl.

Amethyst was the first gemstone to be mined in Zambia in 1959 at the Kundalilla Mine (now the Kariba Minerals Mines) in the Kalomo Mapatizya field. Since then many hundreds of occurrences have been found over an area of 750 sq. km, being perhaps the largest deposit of high grade amethyst in the world. The occurrences can be divided into two types, long veins which are only 10–60 cm wide, but contain a good percentage of quality gems and the so-called 'stockworks' or giant breccia which are large rocks with many small veins but not high quality stones. The resources overall are very substantial, but there is a need to introduce underground mining; where this has been tried, it has yielded good results. E.S.

Gem trade lab notes.

T.M. Moses, I. Reinitz, S.F. McClure and M.L. Johnson. *Gems & Gemology*, **37**(3), 2001, 212-19.

Notes are given on a faceted 0.54 ct brown baddeleyite, a 13 ct yellowish-green datolite, blue and pink high-*P*/high-*T* processed diamonds, carved beads of maw-sit-sit, and a star sapphire with stars of two different colours (silvery white on one side and golden on the other side). R.A.H.

[Chromium-bearing garnets from rodingites of Dlinnogorsky mafic-ultramafic massif, Valizhgen Peninsula, Russia.]

A.B. Osipenko, E.G. Siderov, L.G. Osipenko and E.N. Grib. *Proceedings of the Russian Mineralogical Society*, **130**(1), 2001, 72-80.

New data are reported for Cr-rich garnets in peripheral zones of the Dlinnogorsky massif, Valizhgen Peninsula, SW Koryakia, NE Russia, in which bright emerald-green Cr-Ti uvarovite is found in association with light green Cr-bearing and colourless Cr-poor grossular. EPMA results are given for 10 garnets ($Uv_{33-62}Gr_{7-64}And_{2-25}$) and for Cr-spinels, diopside, titanite and Cr-chlorite (kammererite). The uvarovite is relatively rich in Ti (TiO_2 1.3-1.69 wt.%) and is related to the process of primary accessory Cr-spinel decomposition during rodingitization of gabbro inclusions in serpentine. High alkalinity of the metasomatic fluids led to an increase in Cr and Ti mobility (both are usually immobile) with their release, redistribution and accumulation in newly formed garnet and chlorite. R.A.H.

Jeremejevite: a gemological update.

K. Scarratt, D. Beaton and G. Du Toit. *Gems & Gemology*, **37**(3), 2001, 206-11.

A large cut (4.54 ct) yellow jeremejevite from Namibia is described, together with details of two blue stones from Namibia and two yellow examples from E Tajikistan. They have ε 1.640–1.642, ω 1.649–1.651, with SG 3.27–3.31. UV, IR and Raman spectra are presented. R.A.H.

The origin of colour of chrysoprase from Szklary (Poland) and Sarykul Boldy (Kazakhstan).

M. Sachanbinski, J. Janeczk, A. Platonov and F.J.M. Rietmeijer. *Neues Jahrbuch für Mineralogie, Abhandlungen*, **177**(1), 2001, 61-76.

A study is reported of chrysoprase from the Szklary type locality, using analytical transmission electron microscopy and both optical and infrared spectroscopy. The allochromatic 'apple green' colour of the chrysoprase results from nanometre-size inclusions of aggregates of Ni-bearing sheet silicates, mainly Ni-kerolite and minor pimelite, that occur on sub-grains of silica. There is no evidence for the presence of bunsenite (NiO). Mineral inclusions containing Fe^{3+} ions modify the green colour of the chrysoprase by adding a yellowish hue. The bluish hues result from light scattering on microdefects in the chalcedony matrix, e.g. silica globules, nano- and micrometre mineral inclusions and gas-liquid inclusions. R.A.H.

The chemical composition of Burma jadeite ore and its significance. (Chinese with English abstract)

J. Yang. *Kuangwu Yanshi (Journal of Mineralogy and Petrology)*, **21**(4), 2001, 28-30.

The results of EPMA, trace element and *REE* analyses for jadeite from Burma [Myanmar] are reported, and the colour-producing mechanisms are discussed. The characteristic assemblage of trace elements and *REE* are considered to indicate that the jadeite was derived from serpentinized peridotite. This conclusion should be of help in prospecting for jadeite. R.A.H.

Instruments and Techniques

Raman microspectrometry of fluid inclusions.

E.A.J. Burke. *Lithos*, **55**(1-4), 2001, 139-58.

For many kinds of fluid inclusions, the coupling of microthermometry and Raman microspectrometry is still the only viable option to obtain compositions of single fluid inclusions. A review is given on the basis of 16 years' experience and helped with about 120 references of the instrumentation, analytical conditions and methodology of the application of Raman microspectrometry to gaseous, aqueous and hydrocarbon inclusions, and their daughter minerals. [Author's abstract] G.R.

Dispersion measurement with the gemmologist's refractometer – Part 2.

D.B. HOOVER AND T. LINTON. *Australian Gemmologist*, **21**(4), 2001, 150-60, 5 graphs, 2 tables.

Continuing on from Part 1 of their paper, the authors explain the problems in calculating a gem's RI at wavelengths other than that of sodium. This is because the relationship between RI and wavelength is a non-linear curved function rather than a linear one, and large errors occur if a constant function (such as the ratio of the wavelength differences) is used in the calculation. If dispersion is to become a useful determinative property, and the literature values of dispersion converted accurately from C-F (or any other wavelength interval) to B-G values, then the dispersion curves must first be linearized. This the authors have done by using the Sellmeier linearizing equation in their calculations. The paper gives details of the procedures used by the authors to obtain an empirical calibration of two commercial gemmological refractometers. This procedure involves the selection of light sources, linearization of dispersion curves by the Sellmeier equation, and the measurement process. Empirical calibration is necessary because the manufacturers of refractometers do not provide users with dispersion calibration curves of their refractometer glass. Unfortunately, empirical calibration compounds any errors, and this limits the potential use of refractometer dispersion measurements for determinative use. The situation could be resolved if manufacturers provided users with the RI and dispersion properties of their refractometer glass. P.G.R.

Brandt proportion loupe.

T. LINTON, A. CUMMING, N. MASSON AND B. SWEENEY. *Australian Gemmologist*, **21**(4), 2001, 161-4, 4illus. in colour.

Light directed to a red ring surrounding the objective lens of the Brandt loupe generates red reflections of table and crown facets from the pavilion facets of a diamond. The size and geometry of this characteristic image can be directly related to the size of the table, the pavilion angle, and the thickness of the crown and the girdle, all of which can be related to the diameter of the girdle as percentages. This Instrument Evaluation Report found the rapid sight method of assessing the cut of a faceted diamond to be very accurate for estimating the pavilion angles that produce maximum brightness. Reference is made to earlier papers on the assessment of cut, advice is given on the use of the Brandt loupe, and illustrations show the pattern of red reflections produced by a shallow cut, a well cut and a deep cut diamond. P.G.R.

Synthetics and Simulants

Gemmologische Kurzinformationen. Synthetischer Moissanit – ein kurzer historische Rückblick.

H. BANK, U. HENN. *Gemmologie. Z. Dt. Gemmol. Ges.*, **50**(3), 2001, 163-6, 3 photographs, bibl.

Since 1997 synthetic moissanite (SiC) in gem quality has been marketed as a new product and diamond imitation. However, artificially produced silicon carbide has been known since 1948 and some transparent green specimens were cut in 1956. The natural product was found by Henri Moissan as tiny, green hexagonal crystals in Arizona in 1904. Synthetic SiC has been and is being used as industrial grit under the name of Carborundum. E.S.

[Quartz crystals: their device industry status and numerical simulation of convection in autoclave.] (In Japanese with English abstract)

K. HIRANO AND K. NAGAI. *Journal of The Japanese Association for Crystal Growth*, **27**(2), 2000, 69-75, 11 figs.

Due to increasing industrial demand for larger single crystals of synthetic quartz with higher perfection, the present-day requirements for an autoclave are a size over 600 mm diameter and up to 2500 kg capacity. It is necessary to know and control convection in such a large scale autoclave. Numerical simulation of natural convection in an autoclave with a baffle has been performed with the finite element method. When the length of the heated part on the autoclave wall becomes greater than 2% of the height of the autoclave with 60% baffle closure, circulating flows in the upper and lower sections of the autoclave oscillate periodically. As the Rayleigh number is increased, the frequency and the amplitude of the flow oscillation increases. I.S.

An experimental demonstration of diamond formation in the dolomite–carbon and dolomite–fluid–carbon systems.

A.G. SOKOL, Y.M. BORZDOV, Y.N. PAL'YANOV, A.F. KHOKHRYAKOV AND N.V. SOBOLEV. *European Journal of Mineralogy*, **13**(5), 2001, 893-900.

A study of diamond crystallization in dry and fluid-rich dolomite–carbon systems is reported. For the dry system, an induction period before spontaneous diamond nucleation was found to be ~ 4 h at 7 GPa, 1700°C. No diamonds were observed after 42 h of reaction at 5.7 GPa, 1420°C. The addition of H_2O and H_2O-CO_2 fluids to the dolomite–carbon system resulted in spontaneous diamond nucleation at 1420°C, and growth of diamond on seed crystals at 1300–1420°C. In the presence of H_2O or H_2O-CO_2 fluids, dolomite decomposes to dolomite solid solution + brucite + aragonite. Experimental results indicate that dolomitic melts in the mantle, enriched in H_2O and CO_2, promote the formation of natural diamond. R.A.H.

Tropical gemstones.

C. CLARK, 1998. Periplus Editions (HK) Ltd., Hong Kong. pp 64. Illus. in colour. Hardcover, ISBN 962 593184 8. £6.50.

Very small but quite pleasantly illustrated book describing a number of gem species of Asian origin. Apart from the same photograph appearing (or seeming to appear) up to three times in different guises, it easily fits into a pocket or handbag and is good to look at when you want to see attractive gemstones. M.O'D.

A history of White Cliffs opal 1889-1999.

L. CRAM, 2002. The Author, Lightning Ridge (PO Box 2, Lightning Ridge, NSW 2834, Australia). pp 368. Illus. in colour. Hardcover, ISBN 0 9585414 5 0. [*A journey with colour.* Vol. 2 Part A.] A$168.

A journey with colour began with a magnificently illustrated study of Queensland opal and the project has the aim of covering all the opal fields of Australia in three volumes. Part B of Volume 2 will cover Lightning Ridge and Volume 3 the three mines of South Australia. This reviewer is impatient for the next two volumes! Readers should note that the print run of 1500 is small and copies will quickly be hard to come by.

As before, Cram gives us not only a set of beautiful photographs of specimens but also has found and reproduced pictures of mining and social activity which would otherwise almost certainly have been lost. The first mention of White Cliffs (New South Wales) was in 1852 and the fields still produce a small amount of opal. Cram makes the point that the community has shrunk but developed very successfully after the output from the fields had diminished and is well worth a visit.

The opal is beautiful and specimens include pseudomorphs after fossils, especially the torpedo-shaped belemnites. As always, the standard of reproduction is excellent and the many mining scenes, from original pictures which were not always in very good condition, have come out very well. There is a glossary and a useful bibliography in which a number of government publications are included. M.O'D.

Beautiful Coober Pedy, home of the desert opal.

L. CRAM, 2001. The Author, Lightning Ridge (PO Box 2, Lightning Ridge, NSW 2834, Australia). pp 32. Illus. in colour. Softcover, ISBN 0 9585414 42. Price on application.

Len Cram continues to perform good service to the Australian opal industry through his most beautifully illustrated books covering the major opal-producing areas. This one describes the settlement of Coober Pedy in South Australia and some of the opal specimens found there, the photographs accompanying a text giving some of the history and details of the celebrated underground houses used by the miners. M.O'D.

Queensland minerals: A summary of major mineral resources, mines and projects. (1st edn)

P.G. GARRAD *et al.*, 2000. Queensland Department of Mines and Energy, Brisbane. pp 356, includes maps and diagrams, softcover. ISBN 0 7242 7245 3 ISSN 1443 8747. Includes CD-ROM containing digital data. A$55.

While gemmologists will look first for the sections dealing with opal, corundum and chrysoprase, it does no harm for them to consult material in which geology, mineral occurrences and mining organization also find a place. While the greater part of this first directory of the mining industry of Queensland gives an alphabetical listing of mining companies with, in some cases, their results. Preliminary material covers geology and mineralogy with maps and a good deal of other useful information. Since many of Queensland's mines produce gold, details of that material are also welcome. In recent years Queensland opal has progressed from boulder opal only, to production of some of the finest specimens to be found in Australia and the world's finest chrysoprase still comes from the Marlborough mine, about 90 km north-west of the town of Rockhampton. M.O'D.

Ultraviolet spectroscopy and UV lasers.

P. MISRSA AND M.A. DUBINSKII (EDS), 2002. Dekker, New York. pp XV, 569. Hardcover ISBN 0 8247 0668 4. [Practical spectroscopy series, Vol. 30] Price on application.

While having no direct bearing on gemmology or mineralogy this review volume covers the application of UV techniques to a variety of problems and in particular to lasers. The use of doped crystals is featured in a number of chapters which also cover chemical physics, photolithography and laser spectroscopy. Each chapter has its own, often extensive, list of references. M.O'D.

Lovozero massif: history, pegmatites, minerals.

I. V. PEKOV, 2000. Ocean Pictures Ltd, Moscow. pp 497. Illus. in colour, hardcover. ISBN 5 900395 27 8. DM 169.

Though I was unable to find any mention in the text the book is a companion to *Dalnegorsk* and other works in the monographic series succeeding *Mineralogical almanac*. As there is no other survey of this important area (part of the geologically celebrated Kola Peninsula), at least in English, it will immediately achieve the status of a standard work – the extensive 13-page bibliography covers the many Russian papers on the area. The book is well presented and the colour photographs reasonably good, considerable support for the project was provided by Lomonosov State University and the Russian Geological Society.

While the area provides no regular ornamental species, those gemmologists and species collectors who

are concerned with minerals and their occurrence will find this in-depth study of a major pegmatite body of considerable interest, and some attractive, possibly gemmy specimens do occur: on the pre-title page is a fine transparent red villiaumite crystal! The main sections of the book cover history of exploration (including some graphic accounts of how the miners lived in a most inhospitable area), the pegmatites and the mineral species – a list of names, full descriptions, chemical classification, a list of species found as new in other locations but also found at Lovozero at the same time or earlier, crystal structures, fluorescent minerals, giant crystals and a section on geographic names in which Saami words used for local geological features and place names are translated and explained.

I strongly recommend early ordering of any book in this series as I know from experience how soon the small print-run is exhausted. The publishers are at Box 368, Moscow 103009, fax/phone (from the UK) 00 7 095 203 3574. M.O'D.

Las otras piedras preciosas.

M.A. PELLICER, 2001. Zaragoza. pp 350. Illus. in colour. Softcover, ISBN 84 607 1826 3. Euro 36.

A comprehensive survey of the mechanisms of crystallization and of the details of the methods used to grow gem-quality crystals. The text is well illustrated with diagrams showing how the growth methods work and the occasional colour plate shows examples of crystals and some characteristic inclusions. Although the book could not seriously be used as an everyday adjunct to testing in the laboratory as this would not seem to have been the main aim of the author (perhaps more testing details would be necessary). Nevertheless the text gives a good picture of crystal growth (notoriously difficult to explain to non-growers) and it would certainly be very useful to Spanish-speaking gemmology students. The colour pictures are quite good without achieving excellence; each major section includes a list of references and the production as a whole is very good value for its comparatively low price. M.O'D.

The amber forest: a reconstruction of a vanished world.

G. POINAR JR and R. POINAR, 1999. Princeton University Press, Princeton, NJ. pp xviii, 239. Illus. in colour. Softcover, ISBN 0 691 05728 1. £13.95.

A survey of the amber fossils from the ancient forests of the Dominican Republic constructed as a natural history of the area's ecosystem at the time of the amber's formation. This is a beautiful and well-illustrated book with a central section containing 171 colour photographs of insects included in amber specimens and continuous comment on their life and behaviour. Each chapter has its own list of references to biological literature, providing students of amber with an insight into aspects of the material which deserves more scholarly treatment than it has hitherto received. M.O'D

Cristal de roche.

S. RAULET, 1999. Editions Assouline, Paris [26-28 rue Danielle-Casanova, 75002]. pp 239. Illus. in colour. Hardcover, ISBN 2 84323 26 137 X. FF560.

Beautifully produced survey of rock crystal used in and as ornament from Classical times to the present. After introducing rock crystal with notes on its geology and occurrence the book takes quite large historical periods at a time to describe how it was worked and, in the case of the Egyptian civilizations, how it acquired magical and medicinal significance.

The mostly large illustrations are attractive and there is a useful bibliography; disregard some quaint and inaccurate gemmology! M.O'D.

Les types d'espèces minérales et les collections de synthèses anciennes du Muséum National d'Histoire Naturelle.

H-J. SCHUBNEL, 1999. Galerie de Minéralogie et de Géologie [36 Rue Geoffroy Saint-Hilaire, 75005 Paris]. pp 28. Illus. in colour. Softcover ISBN 2 85653 259 4 (*Dossiers de la Galerie*, numéro spécial) FF 50.

A completely admirable short and beautifully illustrated introduction to the classification of mineral species on the basis of their composition and crystallography, using material, often of great historical interest, from the collections of the Museum, including specimens once in the collections of Haüy, De Bournon and others. This would be quite enough in itself to make an excellent guide but the author even more admirably goes on to describe some of the early syntheses of minerals, including and illustrating beryl and spinel crystals grown by Ebelmen, Hautefeuille and Perrey's synthetic emeralds and De Berthier's synthetic diopside among others. M.O'D

Trésor du Muséum: cristaux précieux, gemmes et objets d'art.

H-J. SCHUBNEL, 1998. Muséum National d'Histoire Naturelle, Paris. pp 119. Illus. in colour. Hardcover, ISSN 1168-4798 [as numéro spécial of *Dossiers de la Galerie*] FF 50.

A fairly brief but far more than adequate account describing some of the specimens and artefacts to be found in the Mineral Gallery of the Muséum National d'Histoire Naturelle, Paris. All photographs are in colour, examples illustrated carry their Museum accession number and their size where relevant and references to the appropriate literature are plentiful. Details of the history of the collections are given: many of the specimens were collected by celebrated French scientists of the past and many of the photographs display gem crystals and in some cases fashioned stones. There is a short bibliography and the whole book is a model at whose standard I wish other national museums could aim. M.O'D

Strunz mineralogical tables. (9th edn)

H. STRUNZ and E.H. NICKEL, 2001. E. Schweizerbart'sche

Verlagsbuchhandlung, Stuttgart, Germany. pp ix, 870. Illus. in black-and-white. Hardcover, ISBN 3 510 65188 X. US$142.00.

This welcome reappearance of an old friend reminds the reviewer that the first edition was published in 1941 and the previous (eighth) edition in 1978. Such large gaps are easily explained: despite the title, *Strunz* is much more than a table of mineral names and compositions – there are several good versions extant – as it includes its own classification based upon a chemical-structural system. In this system all species are assigned to one of ten classes according to its principal anionic constituents: each class is subdivided into divisions, subdivisions and groups, still based on composition and structure and within the groups each species carries its own unique alphanumeric identification (gaps make the system capable of expansion as new species are validated).

Entries where possible include references to the literature as well as structure diagrams for the more important species and groups, and the presentation is in tabular form. Group membership is given where applicable. Taking at random an example of a gem mineral, the beryl group unique number is 9.CJ.05 and the diagram shows the structure projected on (0001). The group is dealt with on a single page.

The index carries the names of validated species in bold, making it easy to read and the presentation and typeface of the main text are well chosen. The binding seems satisfactory on first examination though, as with all such reference books, heavy use may strain it eventually. This is a most valuable addition to mineralogical references literature. M.O'D.

Gem care. (Revised edn)

F. WARD, 2002. Gem Book Publishers, Bethesda, MD. pp 33. Illus. in colour. Softcover, ISBN 1 887651 07 10. [*Fred Ward Gem Series*] £8.95.

Excellently produced and attractive guide to some of the ways in which gemstones may suffer accidental and unexpected damage. Metals (gold and silver) are included and there are many sensible remarks which wearers and collectors could well take to heart. It is surprising how much information can be accommodated in so small a compass, especially when the text has to share space with the fine colour photographs. M.O'D.

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* Reviewed in *Gem & Jewellery News*, March 2002

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Proceedings of the Gemmological Association and Gem Testing Laboratory of Great Britain and Notices

MEMBERS' MEETINGS

London

On 9 January at the Gem Tutorial Centre, 27 Greville Street, London EC1N 8TN, E. Alan Jobbins gave an illustrated lecture entitled 'An orgy of organic gem materials'.

On 5 and 6 March visits to the Diamond Information Office at the DTC were held.

On 9 April there was a private viewing and tour of the Tiaras exhibition at the Victoria and Albert Museum, South Kensington, with exhibition curator Geoffrey Munn.

Midlands Branch

On 25 January at the Earth Sciences Building, University of Birmingham, Edgbaston, a Gemmology Quiz and Bring and Buy were held.

On 22 February at the Earth Sciences Building, E. Alan Jobbins gave a talk entitled 'An orgy of organics'.

On 24 February a one-day conference to celebrate the 50th anniversary of the Midlands' Branch was held at Barnt Green. Speakers included Professor Dr Henry Hänni, E. Alan Jobbins and Ian Mercer. A report of the event will be published in the June issue of Gem & Jewellery News.

On 29 March at the Earth Sciences Building, Martyn Pugh gave a talk entitled 'The art of the goldsmith and silversmith'.

North West Branch

On 20 February at Church House, Hanover Street, Liverpool 1, Irene Knight gave a talk on her time as Branch Chairman entitled 'The Chairman's mantra – don't forget the speaker's name'.

On 20 March members of the Branch visited the Archaeology, Egyptian and Mineral Department of the Liverpool Museum.

Scottish Branch

A Quiz Night was held on 16 January at the College Club of Glasgow University.

On 25 February at the British Geological Survey, Murchison House, West Mains Road, Edinburgh, Professor Dr Henry Hänni gave a lecture on 'Pearls in close up'.

On 6 March at the Hunterian Museum, Glasgow University, Alan Hodgkinson gave a talk entitled 'Poking in gemmological corners'.

GEM DIAMOND EXAMINATION

In the Gem Diamond Examination held in January 2002, 80 candidates sat of whom 50 qualified including five with Distinction and nine with Merit. The names of the successful candidates are listed below:

Qualified with Distinction

Leeks, David R., Java, Indonesia
Morrish, Rachel, Sutton Coldfield, West Midlands
Read, Julian, Goole, East Yorkshire
Wen Chun, Wuhan, Hubei, P.R. China
Xing Yuan, Beijing, P.R. China

Qualified with Merit

Cui Xiwen, Beijing, P.R. China
Deng Xin, Beijing, P.R. China
Ding Yifei, Beijing, P.R. China
Falnes, Lene, Birmingham, West Midlands

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GIFTS TO THE ASSOCIATION

The Association is most grateful to the following for their gifts for research and teaching purposes:

Terry Davidson, London, for a laptop computer to be used for presentation purposes.

The Diamond Trading Company, London, for the permanent loan of a DiamondView™1. This will complement the DiamondSure™1 loaned by the DTC in 2001.

John A. Kessler, London, for faceted blue topaz and irradiated brown topaz

Michael Parsons, the Gold and Silver Studio, Bath, for a selection of study gemstones.

Mariana-Maria Photiou, San Francisco, California, U.S.A., for rough and cut specimens of Oregon sunstones from a variety of mines.

Gerald H. Stonely, Haddenham, Aylesbury, Buckinghamshire, for a box of cut gemstones for student use.

Bear Williams, Bear Essentials Co., Jefferson City, Missouri, U.S.A., for a large quantity of emerald crystals and cut amethysts.

An anonymous donation of £5000.

He Zixi, Wuhan, Hubei, P.R. China
Liu Wei, Beijing, P.R. China
Squires, Caroline A., Tring, Hertfordshire
Yin Wei, Beijing, P.R. China
Yu Lijun, Beijing, P.R. China

Qualified

Amliwala, Panna, Solihull, West Midlands
Bolter, Rachel L., Chiseldon, Swindon, Wiltshire
Borahan, Fatma O., Kalamis, Istanbul, Turkey
Cheung Li, Alex, Kowloon, Hong Kong
Child, Catherine J., Lewes, East Sussex
Cristol, Agata, Marseille, France
Dyre, Pablo, Nairobi, Kenya
Gu Jing, Beijing, P.R. China
Hei Kwok, Tsing Yi, New Territories, Hong Kong
Ho Sau Lan, Tsuen Wan, Hong Kong
Humphrey, Brian, Fulham, London
Kamani, Priscilla, Arkley, Barnet, Hertfordshire
Kaushal, Opinder J.S., Reading, Berkshire
Lai Mei Oi, Emily, Tuen Mun, Hong Kong
Lau Chun Kit, New Territories, Hong Kong
Mafara, Ezekiel M., Harare, Zimbabwe
Mei Chuan Ma, Kowloon, Hong Kong
Monney, Christelle V., Geneva, Switzerland
Petrozello, Ryan J., Randolph, New Jersey, U.S.A.
Qingren Ji, Wuhan, Hubei, P.R. China
Stinglhamber, Renata, Brussels, Belgium
Sutton, Collette S., Hampton in Arden, Solihull, West Midlands
Tsuor Wai Hing, Shatin, Hong Kong
Verdi, Nasib, Edgbaston, Birmingham, West Midlands
Wang Pei, Wuhan, Hubei, P.R. China
Wang Weina, Wuhan, Hubei, P.R. China
Wong Sau Han, Branda, Kowloon, Hong Kong
Wong Sheung Ling, Shirley, Kowloon, Hong Kong
Wu Derong, Wuhan, Hubei, P.R. China
Wu Jiatao, Wuhan, Hubei, P.R. China
Yanagihara, Satomi, Ehime, Japan
Yeung Yee Wai, Margery, Kwun Tong, Hong Kong
Zhang Hong, Beijing, P.R. China
Zhang Shuling, Beijing, P.R. China
Zhang Xiao Ling, Kowloon, Hong Kong
Zhou Yi, Wuhan, Hubei, P.R. China

EXAMINATIONS IN GEMMOLOGY

In the Examinations in Gemmology held worldwide in January 2002, 120 candidates sat the Diploma Examination of whom 63 qualified, including one with Distinction and five with Merit. In the Preliminary Examination, 107 candidates sat of whom 88 qualified. The names of the successful candidates are listed below:

Diploma

Qualified with Distinction

Hudson, Sally, Battersea, London

Qualified with Merit

Gordon, Carole, Kew, Richmond, Surrey
Holt, Jason B.A., London
Hudson, Lawrence M., London

Roy, Maryse, Montreal, Quebec, Canada
Steward, Sarah, Hove, East Sussex

Qualified

Abimbola, Adedapo, London
Allsopp, Christopher J., St Saviour's, Guernsey, Channel Islands
Bai Yunlong, Guilin, Guangxi, P.R. China
Basile, Appadoure, London
Chan See Lan, Shirley, Kowloon, Hong Kong
Choi Jung-Hae, Daejon, Korea
de Vries, Yvonne, Den Haag, The Netherlands
Fang Lan, Guilin, Guangxi, P.R. China
Francis, Melanie, Toronto, Ontario, Canada
Furze, Cindy, Cheshunt, Hertfordshire
Gu Siyuan, Shanghai, P.R. China
Ho Pui Cheung, Kowloon, Hong Kong
Hsieh Ming Tsung, Taichung, Taiwan, R.O. China
Htay Yin, Bago, Myanmar
Htun Su Su, Yangon, Myanmar
Jiang Linhui, Guilin, Guangxi, P.R. China
Jinnam-olarn, Wichuda, Udonthani, Thailand
Kalischer, Janice, Finchley, London
Kwok Hei, Tsing Yi, New Territories, Hong Kong
Lee Soo-Jin, Seoul, South Korea
Li Yikuang, Guilin, Guangxi, P.R. China
Lowe, Mimi J., San Francisco, California, U.S.A.
Lwyn Mon Mon Myat, Yangon, Myanmar
Mate, Nikhil Shripad, Mumbai, India
Meng Xiangdong, Shanghai, P.R. China
Mitch, Alexandra, Atlanta, Georgia, U.S.A.
Morton, Aude Alexandra, London
Myint Kyaw, Yangon, Myanmar
Pan Jingchen, Shanghai, P.R. China
Pavaro, Thitintharee, Bangkok, Thailand
Pi Zhengfan, Wuhan, Hubei, P.R. China
Rademaker, Gerriedina J., Weekt, The Netherlands
Roberts, Justin J., Wembley, Middlesex
Sakkaravej, Somruedee, Nonthatburi, Thailand
Schraa, Catharina N., Goes, The Netherlands
Smeets-van den Berg, Wopje R., Wassenaar, The Netherlands
Soe Moe Tun, Yangon, Myanmar
Sun Jiexian, Shanghai, P.R. China
Suraseth, Peerapol, Bangkok, Thailand
Susser, Jennifer L., London
Symes, Evelyn R., Bath, Avon
Takala, Ville P., Lannavaara, Sweden
Tang, Elaine Wai Ling Ng, Chesham, Buckinghamshire
Tangsubkul, Hiranya, Bangkok, Thailand
Tantisiriphaiboon, Yenrudee, Bangkok, Thailand
Toullic, Nathalie, Brentford, Middlesex
Tsang, Judy, Kwai Chung, Hong Kong
van der Made, B.C., Ermelo, The Netherlands
Vyvere, Vinciane Vande, London
Wang Kai, Wuhan, Hubei, P.R. China
Wu Lai Ngor, Kowloon, Hong Kong
Xia Zhen, Shanghai, P.R. China
Yanagihara, Satomi, Ehime, Japan
Yang Chau Yuan, Taipei, Taiwan, R.O. China
Yuanyuan Li, Shanghai, P.R. China
Yun Jing Wen, London
Zhou Yujie, Shanghai, P.R. China

Preliminary

Agarwal, Vibha, New Delhi, India
Ayer, Elizabeth, Cambridge
Barnett, Catherine, Balham, London
Berry, Susan E., London
Bertrand, Sylvia, London
Carmichael, Jeanie A., London
Chan Kok Nang, Eric, Bahru, Malaysia
Chen Shanxi, Guangzhou, P.R. China
Cheung Li, Alex, Kowloon, Hong Kong
Cheung See Ming, Myra, Kowloon, Hong Kong
Chiu Yung-Tung, Taipei, Taiwan, R.O. China
Choudhary, Gagan, Rajasthan, India
Dash, Sandra Y., London
De Lasteyrie Du Saillant, Valentine, London
Deuling, Elsbeth M., De Haag, The Netherlands
Eleen, Lynn, Halewood, Knowsley, Merseyside
Fitzgerald, John, Flanagan, Illinois, U.S.A.
Gao Boqian, Guilin, Guangxi, P.R. China
Giancola, Maria L.C., Milan, Italy
Govindara Julu, Suresh, Ilford, Essex
Gregory, Nualchan, London
Gurevich, Lina, Finchley, London
Hedenskog, Elin M.S., London
Houghton, Agnes, London
Htin Lynn Aung, Yangon, Myanmar
Hu Zhikun, Shanghai, P.R. China
Jinnam-olarn, Wichuda, Udonthani, Thailand
Jose, Kadavi F., Ilford, Essex
Juan Chun Wei, Taichung, Taiwan, R.O. China
Karimjee, Farida N., Chingford, London
Kontopoulou, Theoni, London
Kuo Chi-Cheng, Taipei, Taiwan, R.O. China

2001 Gemmology Awards

Patricia Wong travelled to London from Hong Kong to receive the Anderson Medal at the Presentation of Awards held at Goldsmiths' Hall on 5 November 2001. This medal is awarded to the best Preliminary candidate of the year.

Patricia Wong Bick San, Hong Kong, receiving the Anderson Medal from Raymond Sancroft-Baker. © Peter Dyer Photographs Ltd.

Dong Lan of Wuhan, P.R. China, receiving the Anderson-Bank Prize from Ian Mercer.

Dong Lan received the Anderson-Bank prize during Ian Mercer's visit to China in November 2001. The prize is awarded to the best non-trade Gemmology Diploma candidate of the year.

We apologize for confusing the caption and photograph of these award winners in the January issue of The Journal.

Kwan, Susana, Kowloon, Hong Kong
Lam Koon-Wah, Francis, Kowloon, Hong Kong
Lee Chun Ming, New Territories, Hong Kong
Lee Hing Fan, Kowloon, Hong Kong
Lee Kuang Chung, Taichung, Taiwan, R.O. China
Lee Kwok Wai, Joe, Kowloon, Hong Kong
Lee Ting-Ju, Cristina, Yangon, Myanmar
Lee Ting-Ju, Michelle, Yangon, Myanmar
Lei Jiali, Guilin, Guangxi, P.R. China
Li Wenjian, Guangzhou, P.R. China
Li Wing Chiu, Kowloon, Hong Kong
Lian Poh Chu, Yvonne, Johor, Malaysia
Liao Yueh-Hua, Taipei, Taiwan, R.O. China
Liao Zhonghua, Guilin, Guangxi, P.R. China
Liem, Deborah A., Singapore
Liu Chun, I., Taichung, Taiwan, R.O. China
Liu Lili, Guilin, Guangxi, P.R. China
Liyana Arachchige, Nilmini S., Kandy, Sri Lanka
Lui Sze-Wai, Alice, Quarry Bay, Hong Kong
Luk Sau Nam, Kowloon, Hong Kong
Luo Xuan, Matthew, Camberwell, London
Luther, Jane, Shepton Mallet, Somerset
Maier, Mona, Valencia, California, U.S.A.
Mukhopadhyay, Nita, Kolkata, West Bengal, India
Ngan Hin Wah, Michael, Kowloon, Hong Kong
Okazaki, Maki, London
Phyu Thin Khine, Yangon, Myanmar
Robinson, David, Shankill, Co. Dublin, Ireland
Rogers, Emily I., Putney, London
Ruckel, Daphne, London
Rupani, Nalina, Nairobi, Kenya
Sabah, Yaffa, Kraainem, Belgium
Sayed, Shakir, Harrow, Middlesex
Scott-Dawkins, Jacqueline, West Malling, Kent
Selvamani, Parvathi, Poplar, London
Stephens, Pippa H., Groby, Leicester
Stephenson, Michelle D., London
Stevenson, Polly V., London
Tanapad, Kiattikun, Patumtanee, Thailand
Thin Thin Hlaing, Yangon, Myanmar
Tsang, Jasmine, Kennedy Town, Hong Kong
Tsoi Pui Pui, Karen, Kowloon, Hong Kong

Tulsi Valia, London
Wang Donglei, Guilin, Guangxi, P.R. China
Wei Xiaoling, Guilin, Guangxi, P.R. China
Wenham, Diana L., North Harrow, Middlesex
Whalley, Joanna, Walthamstow, London
Wong Nga Sze, Kowloon, Hong Kong
Wong Ka Yee, Kowloon, Hong Kong
Wong Man Kuen Purdey, Kowloon, Hong Kong
Xiongfeng Xin, Shanghai, P.R. China
Xing Zengmin, Guilin, Guangxi, P.R. China
Xu Banghui, Guilin, Guangxi, P.R. China
Yaddanapudi, Pratima, Hounslow, Middlesex
Yin Yu, Guilin, Guangxi, P.R. China
Zhu Xulei, Guilin, Guangxi, P.R. China

MEMBERSHIP

Between 1 January and 31 March 2002 the Council of Management approved the election to membership of the following:

Fellowship and Diamond Membership (FGA DGA)

Russell, Lionel H., Hampstead, London, 1969/ 1971

Fellowship (FGA)

Chan, Albert Hiu Sang, Hong Kong, 1988
Cheng Chan Fan, Henry, Kowloon, Hong Kong, 1987
de Wit, Lambertus, Westervoort, The Netherlands, 1992
Heasman, David J., Tonbridge, Kent, 1961
Lai Sau Ha Melody, Kowloon, Hong Kong, 1990
Maxwell, John A., London, 1956
Ou Yang, Chiu Mei, Central, Hong Kong, 1979

Ordinary Membership

Anderson, Ian, Shipley, West Yorkshire
Aki, Miou, Osaka City, Osaka, Japan
Arjan, Anand, East Ham, London
Ashida, Eisuke, Koyoto City, Kyoto, Japan
Balls, Serra, London
Banno, Norihisa, Nagoya City, Aichi Pref., Japan
Bogomolova, Yana, London
Borahan, Fatma Oya, Istanbul, Turkey
Cheshire, Anna E., Littledean, Gloucestershire
Cowley, Vivien, Ballaghaderreen, Co. Roscommon, Ireland
Daouk, Ziad, Beirut, Lebanon
Deares, Haydon M., Southend-on-Sea
Droujinina, Valentina, Highgate, London
Dryburgh, William, Kirkcaldy, Fife, Scotland
Fiala, Adele, London
Firth, Richard Antony, Kennington, London
Forbes-McCaig, Charlotte, Belfast, Northern Ireland
Fukuoka, Yoshimi, Kisarazu City, Chiba Pref., Japan
Guldman, Melanie, Maritou Springs, Colorado, U.S.A.
Hamaoka, Minako, Takasuki City, Osaka, Japan
Hardwick, Christine J.E., Crail, Fife, Scotland
Ingridsson, Anna-Lis, Lannavaara, Sweden
Inoue, Koichi, Suita City, Osaka, Japan
Ito, Ayako, Nishikyo-ku, Kyoto City, Kyoto, Japan
Kaffo, Bassiti Moulero, Hounslow, Middlesex
Kamara, Malcolm M., London
Kendirci, Ibrahim, Stone, Staffordshire
Loaker, Alistair, Stevenage, Hertfordshire'
Lucic, Radoslav, London
Maruyama, Sawako, Shibuya-ku, Tokyo, Japan
Matoba, Ayumi, Minoo City, Osaka, Japan
Mayumi, Kaneyama, Higashi-Osaka City, Japan
Mitani, Toshiyasu, Tokushima City, Japan
Muhammad, Taimur Ali, Islamabad, Pakistan
Nakamura, Aki, Chuo-ku, Osaka City, Japan
Nakazawa, Kenichi, Mitaka City, Tokyo, Japan
Nishitani, Yumi, Nishi-ku, Osaka City, Japan
Odfjell, Abraham, London
Ohara, Yasuko, Koshien, Nishinomiya City, Japan
Partridge, Caroline, London
Ritchie, Sara, Glen Ridge, New Jersey, U.S.A.
Rohm, Peter, Linz, Austria
Rose, Charles L., Germantown, Tennesee, U.S.A.
St John Lewis, Delyth, Winchmore Hill, London
Satake, Rika, Chou-ku, Osaka City, Osaka, Japan
Scoles, Eric, Newbury, Berkshire
Shelementiev, Yuri, Moscow, Russia
Tanaka, Yumi, Toyonaka City, Osaka, Japan
Tonomoto, Noriko, Wakayama City, Japan
Tsutani, Miho, Osaka City, Osaka, Japan
Wakefield, Dominic, Horesham, West Sussex
Washi, Shogo, Matsudo City, Chiba Pref., Japan
Yasutake, Megumi, Shizuoka City, Japan
Zheng, Lisa, South Kensington, London

TRANSFERS

Fellowship to Fellowship and Diamond Members (FGA DGA)

Amliwala, Panna, Shirley, West Midlands
Bolter, Rachel L., Chiseldon, Swindon, Wiltshire

Dyre, Pablo, Nairobi, Kenya
Ho Sau Lan, Tsuen Wan, Hong Kong
Mafara, Ezekiel M., Harare, Zimbabwe
Morrish, Rachel, Sutton Coldfield, West Midlands
Read, Julian, Goole, East Yorkshire
Squires, Caroline A., Tring, Hertfordshire
Sutton, Collette S., Hampton-in-Arden, West Midlands

Diamond Membership to Fellowship and Diamond Membership (FGA DGA)

Furze, Cindy, Cheshunt, Hertfordshire
Gordon, Carole, Kew, Richmond, Surrey
Susser, Jennifer L., London
Yun Jing-Wen, London

Ordinary Membership to Fellowship (FGA)

Allsopp, Christopher J., St Saviour's, Guernsey, Channel Islands
Hudson, Sally, Battersea, London
Hudson, Lawrence M., London
Kalischer, Janice, Finchley, London
Smeets van den Berg, Wopje R., Wassenaar, The Netherlands
Symes, Evelyn R., Bath, Avon
Tang Wai Ling Ng, Elaine, Chesham, Buckinghamshire
Vyvere, Vinciane Vande, London
Wu Lai Ngor, Kowloon, Hong Kong

Ordinary Membership to Fellowship and Diamond Membership (FGA DGA)

Yanagihara, Satomi, Ehime, Japan

Ordinary Membership to Diamond Membership (DGA)

Borahan, Fatma O., Istanbul, Turkey
Child, Catherine J., Lewes, East Sussex
Cristol, Agata, Marseille, France
Kamani, Priscilla, Arkley, Barnet, Hertfordshire
Kaushal, Opinder J.S., Reading, Berkshire
Stinglhamber, Renata, Brussels, Belgium

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FORTHCOMING EVENTS

3 May	**London.** *New aspects of cut in round brilliant-cut diamonds.* *JOSEPH TENHAGEN of Miami, Florida*
15 May	**North West Branch.** *Diamonds.* *ROSAMOND CLAYTON.*
19 May	**South West Branch.** The colour of money. *MICHAEL NORMAN.* Followed by 'Do you know right from wrong?' – a practical gemmology session.
19 May	**Midlands Branch. Gem Club.** *Photomicroscopy* with *DOUG MORGAN AND DAVID LARCHER.*
21 May	**London.** Private viewing and curatorial tour by *GEOFFREY MUNN* of the Tiaras exhibition at the V&A.
19 June	**North West Branch.** Bring and Buy Social Evening.
22 June	**Midlands Branch.** Summer Supper Party.
18 September	**North West Branch.** *Chasing rainbows.* *JOHN HARRIS.*
26 September	**Annual General Meeting and Lecture**
16 October	**North West Branch.** *Jewels for a Royal occasion.* *ROSEMARY I. MCIVER.*
4 November	**Presentation of Awards and Reunion of Members.** Goldsmiths' Hall, Foster Lane, London EC2

Gem-A Conference 2002

To be held on

Sunday 3 November

at Kempton Park Racecourse, Sunbury on Thames, Middx.

In conjunction with the Rock 'n' Gem Show

Speakers will include:

Prof. Dr Edward J. Gübelin

Professor Andrew Rankin

Dr Robert Symes OBE

Full details will be published in the June issue of *Gem & Jewellery News*

Contact details

(when using e-mail, please give Gem-A as the subject):

London:	Mary Burland on 020 7404 3334; e-mail gagtl@btinternet.com
Midlands Branch:	Gwyn Green on 0121 445 5359; e-mail gwyn.green@usa.net
North West Branch:	Deanna Brady 0151 648 4266
Scottish Branch:	Catriona McInnes on 0131 667 2199; e-mail scotgem@blueyonder.co.uk
South West Branch:	Bronwen Harman on 01225 482188; e-mail bharman@harmanb.freeserve.uk

Gem-A Website

For up-to-the-minute information on Gem-A events visit our website on www.gagtl.ac.uk

Guide to the preparation of typescripts for publication in *The Journal of Gemmology*

The Editor is glad to consider original articles shedding new light on subjects of gemmological interest for publication in *The Journal*. Articles are not normally accepted which have already been published elsewhere in English, and an article is accepted only on the understanding that (1) full information as to any previous publication (whether in English or another language) has been given, (2) it is not under consideration for publication elsewhere and (3) it will not be published elsewhere without the consent of the Editor.

Typescripts Two copies of all papers should be submitted on A4 paper (or USA equivalent) to the Editor. Typescripts should be double spaced with margins of at least 25 mm. They should be set out in the manner of recent issues of *The Journal* and in conformity with the information set out below. Papers may be of any length, but long papers of more than 10 000 words (unless capable of division into parts or of exceptional importance) are unlikely to be acceptable, whereas a short paper of 400–500 words may achieve early publication.

The abstract, references, notes, captions and tables should be typed double spaced on separate sheets.

Title page The title should be as brief as is consistent with clear indication of the content of the paper. It should be followed by the names (with initials) of the authors and by their addresses.

Abstract A short abstract of 50-100 words is required.

Key Words Up to six key words indicating the subject matter of the article should be supplied.

Headings In all headings only the first letter and proper names are capitalized.

A **This is a first level heading**

First level headings are in bold and are centred on a separate line.

B *This is a second level heading*

Second level headings are in italics and are flush left on a separate line.

Illustrations Either transparencies or photographs of good quality can be submitted for both coloured and black-and-white illustrations. It is recommended that authors retain copies of all illustrations because of the risk of loss or damage either during the printing process or in transit.

Diagrams must be of a professional quality and prepared in dense black ink on a good quality surface. Original illustrations will not be returned unless specifically requested.

All illustrations (maps, diagrams and pictures) are numbered consecutively with Arabic numerals and labelled Figure 1, Figure 2, etc. All illustrations are referred to as 'Figures'.

Tables Must be typed double spaced, using few horizontal rules and no vertical rules. They are numbered consecutively with Roman numerals (Table IV, etc.). Titles should be concise, but as independently informative as possible. The approximate position of the Table in the text should be marked in the margin of the typescript.

Notes and References Authors may choose one of two systems:

(1) The Harvard system in which authors' names (no initials) and dates (and specific pages, only in the case of quotations) are given in the main body of the text, (e.g. Collins, 2001, 341). References are listed alphabetically at the end of the paper under the heading References.

(2) The system in which superscript numbers are inserted in the text (e.g. ... to which Collins refers.[3]) and referred to in numerical order at the end of the paper under the heading Notes. Informational notes must be restricted to the minimum; usually the material can be incorporated in the text. If absolutely necessary both systems may be used.

References in both systems should be set out as follows, with *double spacing* for all lines.

Papers Collins, A.T., 2001. The colour of diamond and how it may be changed. *J.Gemm.*, **27**(6), 341-59

Books Balfour, I., 2000. *Famous diamonds*. 4th edn. Christie's, London. p. 200

Abbreviations for titles of periodicals are those sanctioned by the *World List of scientific periodicals* 4th edn. The place of publication should always be given when books are referred to.

Volume 28 No. 2 April 2002

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Zircon cluster in sapphire. (Natural and heat-treated corundum from Chimwadzulu Hill, Malawi: genetic significance of zircon clusters and diaspore-bearing inclusions, pp 65-75.)

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Open channels in near-colourless synthetic moissanite

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ABSTRACT: Open, tube-like channels are one of the most noticeable internal features visible in some gem-quality synthetic moissanite. These channel inclusions can reach exterior surfaces, or they may terminate against other internal defects or fractures. They usually display a hexagonal cross section, and are elongated in a direction parallel to the optic axis of the host crystal. Their appearance differs from that of natural etch channels seen on rare occasions in some gem diamonds. The origin of the channels in synthetic moissanite is discussed. They are thought to result from the relaxation of strain around a kind of enlarged screw dislocation in the crystal during the crystallization.

Introduction

Near-colourless synthetic moissanite (silicon carbide, SiC, 6H polytype) was first introduced as a new diamond simulant into the jewellery marketplace at the beginning of 1997. Since that time, gemmologists have focused on establishing practical identification criteria, or developing simple testing instruments, for its detection (Nassau *et al.*, 1997; Nelson, 1998; Hodgkinson, 1998a,b; Shigley *et al.*, 1998; Zhang and Li, 1999; Nassau, 1999). With the exception of its non-isotropic optical character, specific gravity and distinctive inclusions, many of the remaining gemmological properties of synthetic moissanite are similar to those of diamond. However, the separation of synthetic moissanite from diamond should not be difficult for trained gemmologists. Shigley *et al.* (2000) recently published a chart of gemmological properties, with illustrations of the distinctive visual characteristics of synthetic moissanite (as compared to those of both diamond and cubic zirconia, CZ).

Like many gem materials, synthetic moissanite has its own internal characteristics that can be seen with magnification. Lower-clarity faceted synthetic moissanite may contain inclusions, the most common being subparallel, needle-like, open channels. In this article, detailed features of these channels, such as their size, crystallographic orientation and relationships with other features, are described. A possible formation mechanism for these channels in synthetic moissanite, and comments on the differences between them and the rare etch channels observed in natural diamonds, are also discussed.

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Review of synthetic moissanite crystal growth

Synthetic moissanite crystals (in the form of boules) are grown by a seeded sublimation method, derived from the 'Lely' process (see Davis *et al.*, 1990; Stein, 1993; Nassau, 1999). In this process, silicon carbide (SiC) is vaporized and then is condensed to a solid without ever passing through a liquid state. Crystallization of SiC takes place in a radio frequency-heated graphite furnace at temperatures around 2300°C. A porous graphite cylinder is placed inside a graphite crucible in the furnace. The space between the crucible wall and the porous cylinder is filled with SiC powder as source material, and at the bottom of the crucible, the seed is positioned in the coolest region of the furnace. SiC, vaporized from the feed powder, passes through the porous cylinder to crystallize on the seed, forming a crystal boule of synthetic moissanite. The temperature of the seed is between 2150 and 2350°C. The temperature gradient within the growing crystal is about 20°C per cm. The temperature difference between the SiC feed powder and the seed is about 100°C. More detailed information on the SiC crystal growth techniques can be found in Davis *et al.* (1990), Nakashima *et al.* (1996), and Nassau (1999).

Materials and methods

The US manufacturer does not distribute rough samples, so our observations have all been made on approximately 300 polished pieces of faceted synthetic moissanite with various shapes (including a polished cube). These pieces represent a good sample of the kind of material that has been sold for use in jewellery by the manufacturer Charles and Colvard (formerly C3 Inc.).

Standard gemmological equipment was used to document these samples (as described in Nassau *et al.*, 1997). In addition, strain images were observed at magnifications of 7× to 45× using a Nikon microscope fitted with crossed polarizing filters and a specially designed immersion cell containing methylene iodide (RI 1.74). To check the detectability and visibility of the channel inclusions under the microscope, a fibre optic light source was placed at various incident angles to the immersion cell.

Results

From our observations, the channel inclusions appear to be elongated empty tubes (see *Figure 1*). Their diameters generally range from about 10 to 50 µm, but can occasionally reach 500 µm (Stein, 1993). The lengths of the channels also vary, ranging from 0.2 mm to 6.0 mm; in some faceted pieces they can extend across the entire sample.

The channels are commonly parallel or sub-parallel to each other, and are elongated along the optic axis of the host crystal (*Figure 2*). Channels rarely appear to radiate from a source, an optical effect which can be due to multiple reflection in faceted samples (*Figure 3*). Occasionally, a slightly bent or discontinuous channel was seen (*Figure 4*). The number and location of the channels vary depending on the samples. High-clarity pieces of synthetic moissanite are relatively free of channels, whereas in low-clarity samples the channels can be quite abundant.

In most samples, the channels were observed to start and finish at polished surfaces, due to the fact that the samples were faceted from a region of the crystal at some distance from the seed where the channels originate. At these surfaces, the terminations were difficult to see because of their small diameter, but they could be located from strain patterns visible under crossed polarizing filters.

In some samples, the channels terminate at internal defects. The types of defects seem unimportant in terms of channel terminations, but the sizes of these defects are usually greater than the diameters of the associated channels. *Figure 5* shows several examples of channel terminations by (a) a hexagonal plate-like inclusion (negative

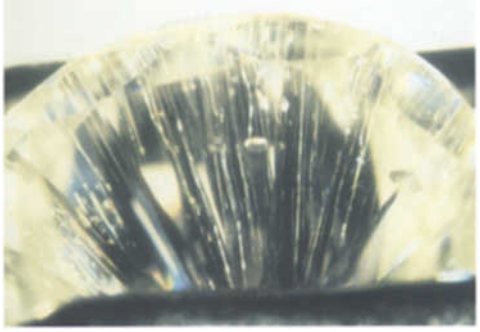

Figure 1: Needle-like channels observed in a faceted synthetic moissanite. Magnification 10× transmitted light. Photo by J. Shigley. © GIA.

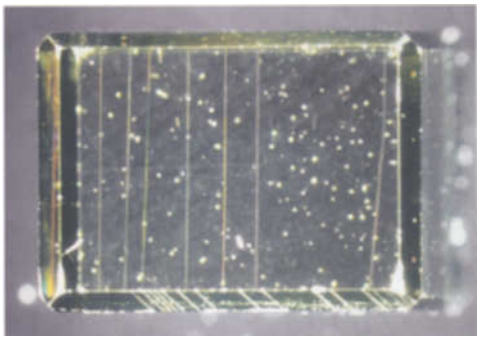

Figure 2: Parallel channels elongated along the optic axis observed in a synthetic moissanite cube. Magnification 10×, transmitted light dark field. Photo by T. Lu. © GIA.

crystal?), (b) a fracture, (c) an amorphous carbon inclusion (Koivula, 2000) and (d) a cavity larger than the channel diameter.

Channels were easily observed by both bright field and dark field illumination, but their appearances are different under these two lighting conditions. In bright field illumination, the channels appear as black lines (e.g. *Figures 4 and 6*), while in dark field illumination they appear as bright lines due to light scattering (see *Figures 1 and 3*). Channels can be easily seen in all orientations of the crystal, except when looking parallel to their elongation direction (the optic axis direction). By simply rotating the sample off parallel to the elongation direction, the channels will usually be seen.

Double images of inclusions were sometimes seen (*Figure 7*). This doubling becomes more apparent as the angle increases between the optic axis of the crystal and the direction of observation.

Possible formation mechanism of the channels

Despite much study, the formation mechanism of the channels is still uncertain. To understand the possible formation mechanism of the channels in synthetic moissanite, a basic knowledge of the SiC crystal growth and possible post-growth reactions is important (see Davis *et al.*, 1990; Stein, 1993; Nassau, 1999). As mentioned above, synthetic moissanite crystals are

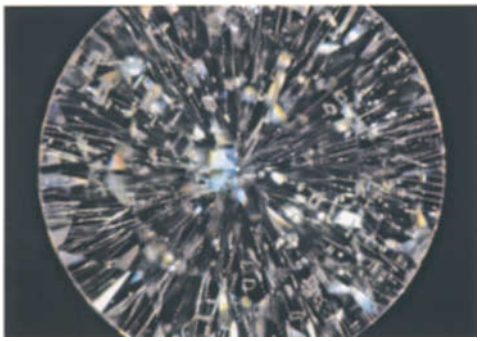

Figure 3: In this view, the channels appear to radiate because of facet reflection. Magnification 5×, transmitted light dark field. Photo by J. Koivula. © GIA.

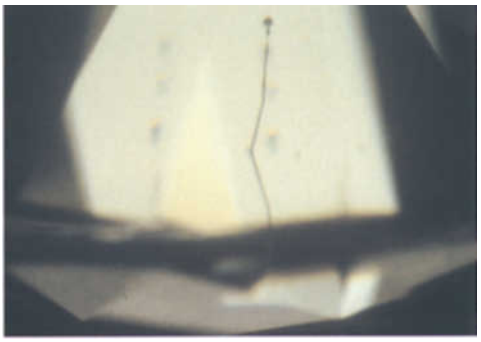

Figure 4: Bent channels were occasionally observed in synthetic moissanite. Magnification 5×, transmitted light. Photo by J. Shigley. © GIA.

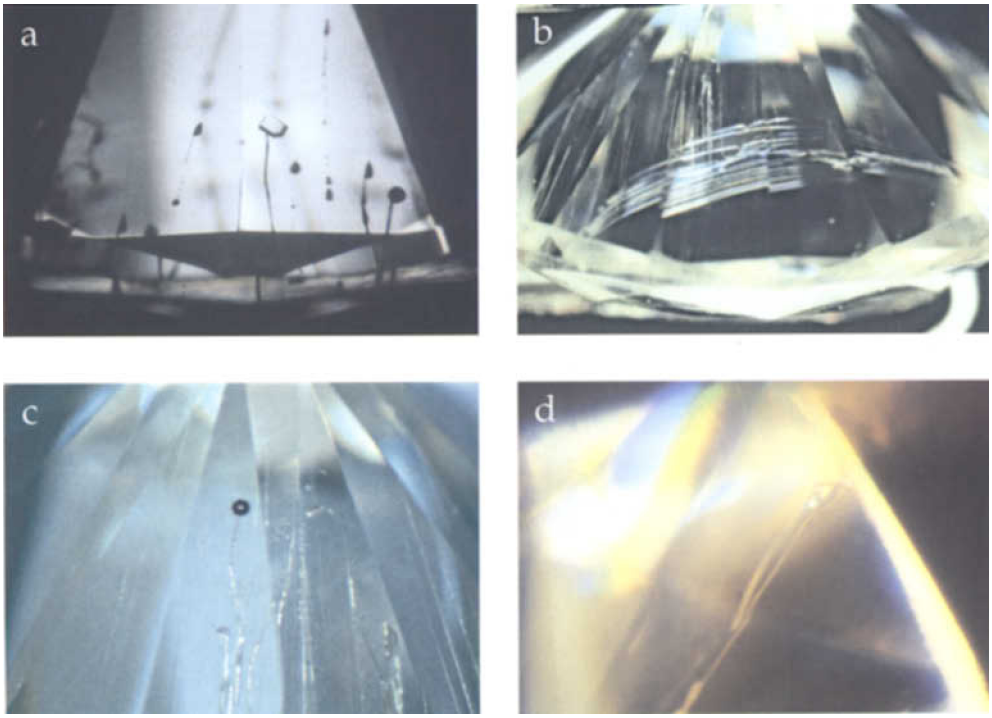

Figure 5: *Several examples showing the channels terminated by a) plate-like inclusions (negative crystals), magnification 10×, photo by J. Koivula; b) a fracture, magnification 10×, photo by J. Shigley; c) an amorphous carbon inclusion, magnification 15×, photo by J. Koivula; and d) a cavity larger than the channel diameter, magnification10×, photo by T. Lu. All the photos were taken in dark field illumination. © GIA.*

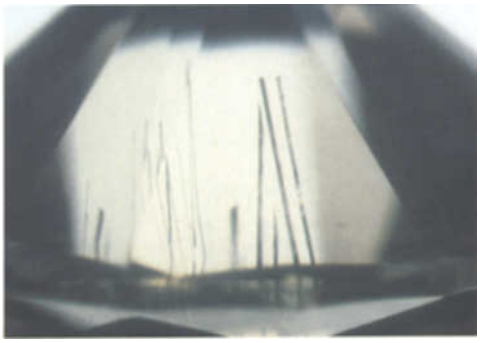

Figure 6: *The channels appeared as dark lines in a faceted synthetic moissanite. Magnification 10×, transmitted light dark field. Photo by J. Shigley. © GIA.*

Figure 7: *Double images of plate-like inclusions observed in a faceted synthetic moissanite. Magnification 20×, transmitted light dark field. Photo by T. Lu. © GIA.*

grown by a sublimation process. The channel inclusions aligned along the direction of growth of the crystal have been called micropipes, macro-defects, vertical defects, or holes by the scientists who study crystal growth (Stein 1993; Dudley *et al.*, 1995; Heindl and Strunk,1996; Nakashima *et al.*, 1996; Ohtani *et al.*, 2001). The formation mechanisms of these channels are not fully understood, although several mechanisms or combinations of mechanisms have been proposed (Sunagawa and Bennema, 1981; Stein, 1993; Dudley *et al.*, 1995; Tsvetkov *et al.*, 1998; Ohtani *et al.*, 2001). Basically, most proposed mechanisms are interpreted in the framework of Frank's model of 'hollow core of dislocations' (Frank, 1951). The origin of the hollow cores is due to relaxation of crystallographic strain around combined multiple c-screw dislocations which had acquired a very large Burgers vector during the crystal growth stage. In Frank's model, if the Burgers vector of a screw dislocation exceeds a critical value (approximately 1 nm, which is much larger than the lattice unit cell) then it is, due to the very high strain energy, energetically more favourable to remove the crystal material near the dislocation line and to create an additional surface in the form of a channel. Heindl *et al.* (1997) provided experimental support for this theory by measuring the total step heights and radii of the channels with an atomic force microscope and compared these data with the ideas proposed by Cabrera and Levine (1956) who extended Frank's model with respect to kinetic aspects. Recently, Ohtani *et al.* (2001) proposed a surface step model by which they try to explain how dislocations are brought together to produce the channels, and why such enlarged screw dislocations are stable in the crystal.

Another proposed formation mechanism for the channels suggests that they are a product of a secondary evaporation during the post-growth stage following

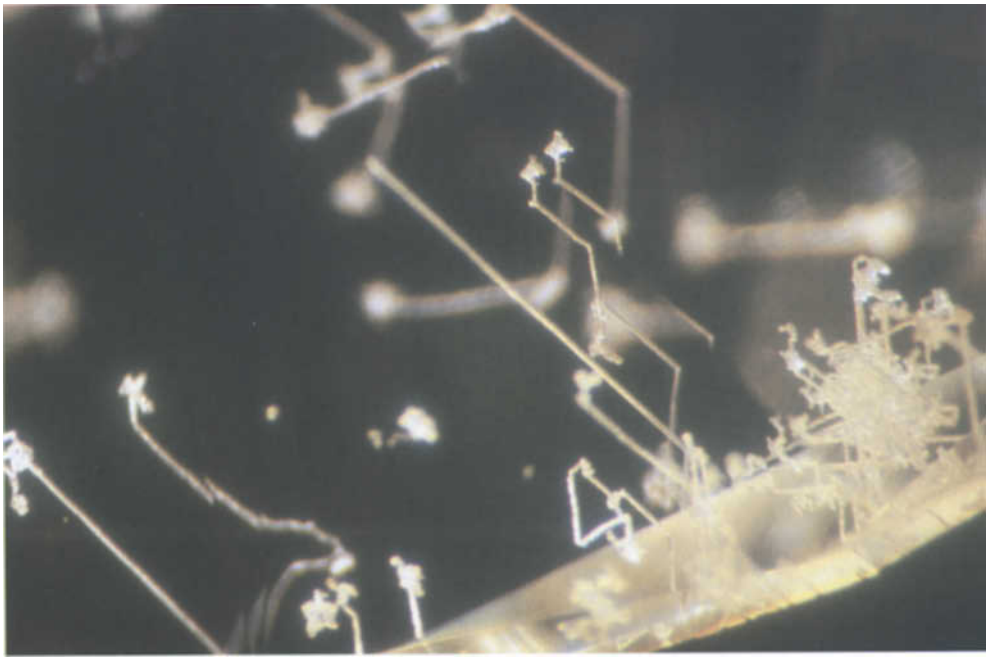

Figure 8: *Etch channels observed in a natural diamond crystal. Magnification 25×, transmitted light dark field. Photo by J. Koivula. © GIA.*

Table I: Comparison of channels in synthetic moissanite and natural diamonds

	Channels in synthetic moissanite	*Channels in natural diamonds*
Appearance	Usually elongated hexagonal tubes, 10 – 50 µm in diameter, and 1 – 5.0 mm in length. Oriented parallel to the *c*-axis of the crystal. Occasionally slightly bent.	Usually elongated tubes with various widths and lengths, and a square, rectangular, or hexagonal cross section. Channels may be zig-zag or bent. Channels taper as they extend inwards, and may be striated perpendicular to the length.
Associated other defects	Sometimes terminated by plate-like inclusions (negative crystals), dark spots (amorphous carbon) and fractures. Plate-like inclusions or other tiny inclusions may be seen.	Some are terminated by inclusions. Other minerals, cleavage planes, growth zoning and colour zoning may be seen.
Visibility in different conditions	Dark lines under bright field light, bright lines under dark field illumination. Multiple images may be seen due to birefringence.	Dark lines under transmitted light, bright lines under dark field illumination. Usually associated with a strong strain pattern.
Possible formation mechanisms	Formed by relaxation of crystallographic strain around enlarged screw dislocations during the crystallization.	Formed by a natural chemical dissolution process during post-growth stages along dislocation bundles.

crystallization (Stein, 1993). However, this hypothesis does not provide an explanation of the possible destinations of the evaporated material when the bottom and top of the crystal are closed.

Our observations appear to support the model of hollow cores of enlarged screw dislocations generated during the crystal growth stage. Once the channels are generated, they will extend to the as-grown surface unless they meet other internal defects and/or fractures with a greater diameter, which cause the channels to terminate (see again *Figure 5*). Therefore, the overall number of the channels will be reduced with increasing distance from the seed surface.

Distinguishing channels in synthetic moissanite from etch channels in natural diamonds

Open channel structures can occur in many natural gemstones (such as beryl, diamond, garnet, spodumene and topaz). They are rarely observed in synthetic gem materials, although some have been seen in synthetic quartz after chemical etching (Iwasaki, 1977). Because synthetic moissanite is a diamond simulant, we

compared the differences in appearance between the etch channels observed in natural diamonds (*Figure 8*) and the channels seen in the synthetic moissanite (see *Table I*). We believe that channels in both materials are formed in association with dislocations, but by different processes. In synthetic moissanite, the channels are formed by relaxation of crystallographic strain around the screw dislocations with a very large Burgers vector. These screw dislocations started from irregular sites in the SiC crystal at or near the seed during the crystallization. In contrast the channels in natural diamonds are formed by chemical dissolution extending inward from the crystal surface along dislocations during the post crystal growth stage (Koivula, 2000; Lu *et al.*, 2001).

Conclusion

The open channels can be an important identification characteristic of synthetic moissanite. These channels usually start from irregular sites at or near to the seed and are elongated along the optic axis. They exhibit a hexagonal shape in cross-section, and some are terminated by plate-like inclusions, amorphous carbon inclusions, or fractures inside the crystal. They may be formed by relaxation of crystallographic strain around enlarged screw dislocations during the crystallization. Their appearance is different from the etch channels observed occasionally in natural diamonds.

Acknowledgements

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A comparison between a flux grown synthetic ruby and an untreated natural ruby

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ABSTRACT: Flux grown synthetic rubies appear occasionally set in traditional jewellery, most often wrongly taken for a natural stone. Some untreated metamorphic rubies have properties that overlap those of flux grown synthetic rubies (especially the 'fingerprints' and features of the infrared spectrum), making a separation more difficult. Such is the case for the flux grown synthetic and Mong Hsu ruby analysed in this article.

Introduction

Recently the author was asked to identify a 3.54 ct pear-shaped red stone of a pleasing colour, set in a pendant, framed by brilliant-cut and marquise-cut diamonds, mounted in 18 carat white gold (*Figure 1*), and an unmounted 3.28 ct cushion-shaped red stone of a very convincing colour, cut and general appearance (*Figure 2*). The measurements, weight and gemmological properties of these two stones are described below.

Gemmological properties

The 3.54 ct pear-shaped red transparent gemstone (length 12.76 mm, width 8.68 mm, depth 4.26 mm), and the 3.28 ct cushion-shaped red transparent stone (length 8.80 mm, width 8.32 mm, depth 5.43 mm), both displayed a vitreous lustre.

The refractive index (RI) determinations were carried out using a Rayner Dialdex refractometer and monochromatic sodium light. The indices obtained from the table facet were $\omega = 1.768$, $\varepsilon = 1.760$, giving a birefringence of .008, with optic sign (-), and showing that the table facet was cut perpendicular to the *c*-axis (confirmed by a uniaxial interference figure obtained on each stone's pavilion, made visible by a glass sphere between crossed polars).

Under a calcite dichroscope, with fibre optic illumination, strong dichroism in pale yellowish-red to deep red was observed in the stones' girdle planes.

The absorption spectra were observed in daylight conditions through a Beck spectroscope and revealed a spectrum typical of chromium, a fluorescent line in the red at 695 nm, with three fine lines visible in the blue at 478, 474, and 469 nm, and a very strong broad band from the blue to the violet at 460 to 400 nm.

The stones were examined with a Multispec combined LW/SW ultraviolet unit and fluoresced a strong red in SW but moderate dark red in LW.

The specific gravity (SG) was obtained by hydrostatic weighing in distilled water using a Mettler PL 300C carat scale, and the stones were found to have a value of 4.00.

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***Figure 1**: The 3.54 ct pear-shaped flux grown ruby surrounded by brilliant- and marquise-cut diamonds.*

The inclusions were examined using a Bausch & Lomb Mark V Gemolite binocular microscope using dark field illumination or overhead lighting as appropriate.

***Figure 2**: Enlarged view of the 3.28 ct cushion-shaped ruby. Notice the important break visible in the bottom right corner of the stone.*

The main features encountered in the 3.54 ct pear-shaped stone were:

- Parallel colour zones showing straight and angular (V-shaped) growth features (*Figure 3*).
- Numerous dark and opaque, small to large, thin to rather thick, hexagonal, triangular and rod-like platinum platelets were easily seen (*Figure 4*).
- A long, and extremely thin 'phantom-like' acicular inclusion (unidentified, *Figure 5*).
- Unmelted flux residual filling a large inclusion (*Figure 6*).
- Veil-like 'flux feathers' (*Figure 7*).

***Figure 3**: Parallel angular (V-shaped) growth zones observed in the 3.54 ct flux grown pear-shaped ruby. (Dark field illumination 40×).*

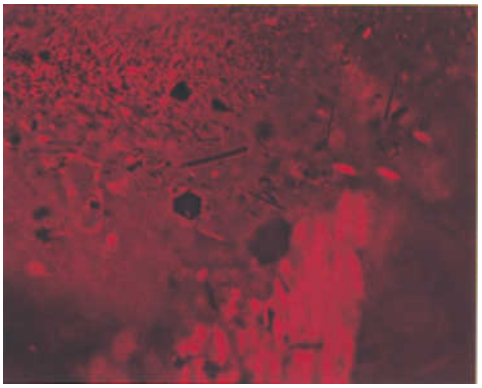

***Figure 4**: Dark or opaque hexagonal, triangular and rod-like platelets of platinum are present in the 3.54 ct flux grown pear-shaped ruby. (Dark field illumination 50×).*

***Figure 5**: A long and extremely thin phantom-like acicular inclusion (unidentified) in the 3.54 ct flux grown pear-shaped ruby. (Dark field illumination 60×).*

- Blue zones confined to some of the flux inclusions.

In the 3.28 ct cushion-shaped stone the main features are:

- An important break in one of the corners of the cushion-shape (*Figure 2*).
- A large oval-shaped open cavity on the pavilion (*Figure 8*).
- Parallel colour zones showing straight and angular (V-shaped), growth features.
- A long, white and extremely thin undisturbed acicular inclusion (unidentified, *Figure 9*).

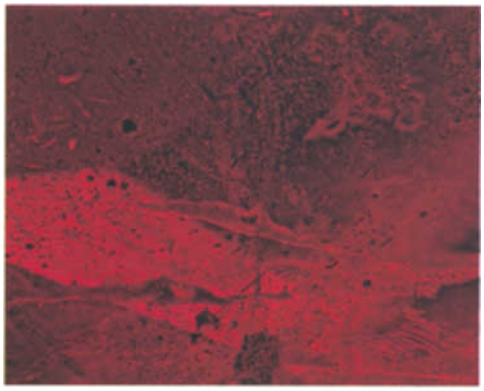

***Figure 6**: A large inclusion filled with flux residuals in the 3.54 ct flux grown pear-shaped ruby. (Dark field illumination 60×).*

***Figure 7**: A veil-like 'flux feather' in the 3.54 ct flux grown pear-shaped ruby. (Dark field illumination 60×).*

***Figure 8**: A large oval-shaped open cavity on the pavilion of the 3.28 ct cushion-shaped ruby from Mong Hsu. (Dark field illumination 10×).*

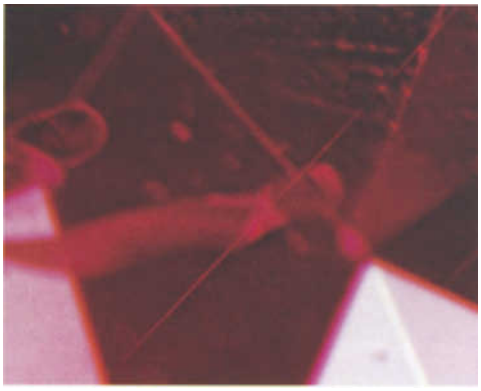

***Figure 9**: A long and extremely thin undisturbed white acicular inclusion in the 3.28 ct cushion-shaped ruby from Mong Hsu. (Dark field illumination 40×).*

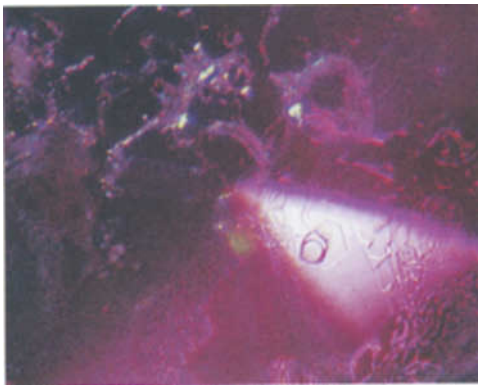

Figure 10: A 'fingerprint' showing a pattern of 'phantom-like' negative crystals of colourless transparent hexagonal outline, sometimes accompanied by two-phase inclusions (most probably CO_2), observed in the 3.28 ct cushion-shaped ruby from Mong Hsu. (Dark field illumination 40×).

- Numerous 'feathers', some showing twisted, wispy veil-like 'feathers', others displaying a pattern of 'phantom-like' negative crystals of colourless transparent hexagonal outline, sometimes accompanied by two-phase inclusions (most probably CO_2 fluid inclusions, *Figure 10*), or filled with precipitated substances (not analysed), giving rise to patterns reminiscent of those observed in amethysts and described as 'zebra stripes' (*Figures 11 and 12*).

Figure 11: A 'feather' filled with precipitated substances (not analysed), observed in the 3.28 ct cushion-shaped ruby from Mong Hsu. (Dark field illumination 40×).

- When the stone, immersed in methylene iodide was observed between crossed polars through a horizontal microscope it showed polysynthetic twinning that penetrated the entire stone (*Figure 13*).

Infrared absorption (FTIR) spectra were obtained for both stones with a Nicolet Magna-IR ESP System 560 spectrometer. Both displayed rather featureless IR spectra in the region of 2400-3400 cm^{-1}, and four peaks only were present at 2852 cm^{-1}, 2873 cm^{-1}, 2916 cm^{-1} and 2955 cm^{-1}. These correspond to those released by our fingers

Figure 12: Enlarged view of the 'feather' in Figure 11 with patterns reminiscent of those observed in amethysts and described as 'zebra stripes'. (Dark field illumination, 80×).

Figure 13: Polysynthetic twinning that penetrates the entire stone, observed in the cushion-shaped Mong Hsu ruby of 3.28 ct. (Immersed in methylene iodide and between crossed polars, 40×).

or Blu-tack (paste used to hold the sample to be tested), or residues of plastic or resin, and therefore must be considered as an artefact (David *et al.*, 2001).

The fact that the cushion-shaped ruby of 3.28 ct does not exhibit a peak located in the region of 3310 cm^{-1} present in all the tested samples of heat-treated metamorphic rubies confirms, with the inclusions observed, that the present stone has not suffered high temperature heat-treatment, thus proving the colour origin to be natural (McClure and Smith, 2000).

Discussion

It is a well established fact that inclusions will generally provide identification characteristics to distinguish natural from synthetic, treatments undergone, and sometimes a key to the possible origin of the gem examined. Platelets similar in appearance to platinum platelets but of ilmenite or hematite can be present in natural corundum (see Gübelin and Koivula, 1986; Hughes, 1997; Kane, 1981, 1982).

Had the 3.54 ct pear-shaped synthetic ruby been cut from part of the crystal free of platinum platelets but with the straight and angular growth markings (observed in most natural corundum), acicular inclusions (one of the main characteristics of a natural corundum) and 'fingerprints' (also very deceptive since these can look very similar to those observed in natural corundums from Mong Hsu, Myanmar), its identification would have been more difficult and could have bluffed many a jeweller and stone dealer.

Concerning the 3.28 ct cushion-shaped ruby, the large break on one corner is most probably due to an accident during setting or unsetting the stone in jewellery. It is very unusual to receive for testing a stone so badly damaged prior to being repaired.

The cutting style, referred to as 'antique cut', is most often observed in fine quality natural rubies, but can (like any cutting style) also be observed in synthetics. The cut cannot therefore be used as a firm indicator of a natural stone.

As for the large oval-shaped surface cavity on the pavilion, it could correspond to a possible 'earth hole' observed on many rough alluvial corundums. In heat-treated corundums (where temperatures as high as 1300 to 1900°C are used), similar 'openings' which have been treated with a 'firecoat' such as borax (hydrous sodium borate), may be filled with glass; this filling then can be removed by hydrofluoric acid, leaving an open cavity (Peretti *et al.*, 1995; Themelis, 1992). However, since the infrared spectrum indicates that the stone has not suffered high temperature heat-treatment, the surface cavity is probably original.

The parallel colour zones showing straight and angular (V-shaped) growth features, the long and extremely thin acicular inclusion, the numerous feathers, the polysynthetic twinning and fluid inclusions (Koivula, 1986), are all characteristics reported in natural corundum.

According to the fluorescence, the infrared spectrum and the low content of iron impurity in this ruby, it is probably of metamorphic origin, and its inclusions are similar to those in rubies from Mong Hsu (Peretti *et al.*, 1995).

Conclusion

The physical and optical properties are consistent with those of corundum, variety ruby, either natural or synthetic.

The inclusions observed in the 3.54 ct pear-shaped ruby are characteristic of flux fusion synthetic corundum, variety synthetic ruby, and correspond to those described in the literature (Kane, 1981, 1982; Gübelin and Koivula, 1986; Liddicoat, 1989; Nassau; 1980; Scarratt, 1999; Webster, 1994).

The appearance of the 3.54 ct pear-shaped is a reminder that flux grown synthetic rubies (considered a sophisticated synthesis compared to the more widely produced Verneuil flame fusion or Czochralski

'pulling' synthetics) appear from time to time on the gem market and are mistaken for natural ruby.

The 3.28 ct cushion-shaped ruby, with at first sight similar characteristic inclusions, is more tricky and needed a combination of a very close examination of its internal characteristics and infrared spectroscopy to understand its nature and confirm its origin and colour.

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Symmetrical clouds in diamond – the hydrogen connection

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ABSTRACT: Diamonds with symmetrical clouds (composed of numerous micro-inclusions) are investigated. Infrared absorption analysis of selected regions with varying cloud densities reveals a close relationship between the intensity of hydrogen absorption and the density of the cloud. The symmetrical clouds follow the <100> direction of the diamond. These observations support the hypothesis that hydrogen in diamond is physically bonded at internal surfaces such as the inclusion-host interfaces, and impurities of hydrogen combined with the high surface energy of the {100} faces could be the controlling factors for the formation of the symmetrical clouds. Such diamonds could form at a relatively stable environment in the Earth's upper mantle, and exhibit a special type of natural beauty.

Keywords: diamond, hydrogen, infrared, symmetrical cloud

Introduction

Clouds are fairly common inclusions in natural diamond. Under a microscope at approximately 30× magnification, it is clear that such clouds are composed of numerous micro-inclusions. Most clouds are irregular in shape, and usually occupy less than 20% of the diamond's volume (Izraeli *et al.*, 2001). Several examples of regular and symmetrically shaped clouds have also been reported (e.g. Humble, 1982; Koivula, 1999; Koivula and Tannous, 2001). In contrast to individual mineral inclusions such as olivine and garnet in diamond, little is understood of the mineralogy and chemistry of the micro-inclusions in clouds. In particular, the mechanism responsible for forming symmetrically shaped clouds and their crystallographic relationship with the host diamond is not widely understood.

Diamond is well known for its relatively pure chemical composition (~99.9% carbon). However, very low concentrations (tens to hundreds of parts per million by weight) of impurities may occur as trace elements in diamond, which strongly affect its colour and other physical properties. Common impurities include nitrogen, hydrogen and boron. The existence of hydrogen in natural diamond was first reported by Chrenko *et al.* (1967). Following an extensive investigation of hydrogen in diamond, Woods and Collins (1983) concluded that hydrogen was practically of universal occurrence in type Ia natural diamonds, and was bonded to the diamond lattice. Two fundamental absorptions at 3107 and 1405 cm^{-1} in the infrared absorption spectrum are due to C-H stretching and bending vibration, respectively. A close relationship between micro-inclusions and hydrogen in diamond was proposed, that is, the most likely

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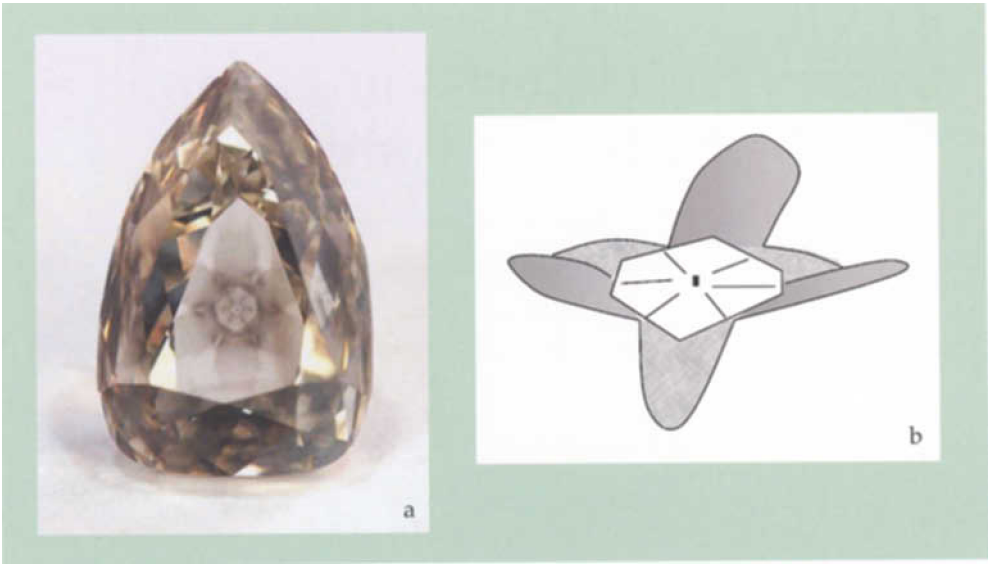

Figure 1: *(a) Fancy brown-greenish yellow diamond of 3.02 ct (9.64 × 6.39 × 5.48 mm), with a pear-shaped modified brilliant-cut, containing a flower-shaped cloud (sample A). The cloud, which is composed of tiny needle-like inclusions, can be clearly seen through the two large parallel facets. (b) Three-dimensional map of the flower-shaped cloud. Starting from a small black inclusion, the shape of the cloud changes from six one-dimensional rays to six two-dimensional petals. Three petals radiate upward and the other three downward, thus the axis of the flower cloud is parallel to the <111> crystal direction. Photograph by Elizabeth Schrader.*

bonding sites for hydrogen in diamond would be at internal surfaces such as inclusion-matrix interfaces (Melton and Giardini, 1974, 1975; Woods and Collins, 1983; Fritsch and Scarratt, 1993). However, few direct observations of this relationship have been published. Using recently developed quantitative microscopy with a 15 MeV Si^{7+} microbeam for minor distributions of bulk hydrogen in solid samples, Maclear *et al.* (1998) found a striking correlation between the hydrogen distribution and the optically visible micro-inclusions in a natural diamond. This is the first direct evidence associating aggregations of hydrogen with clouds of micro-inclusions in natural hydrogen-rich diamonds. It should be noted that these observations were limited to surface/near-surface hydrogen only.

In this study, we report on two hydrogen-rich diamonds with symmetrically shaped clouds. Using gemmological observations and results of instrumental analysis, the physical location of the hydrogen impurities and the possible significance of hydrogen controlling the formation of such symmetrically shaped clouds in natural diamonds are discussed.

Materials and methods

For this study, we examined two diamonds, each containing a symmetrical six-petalled flower-shaped cloud.

Sample A

A 6.23 ct partly rounded rough octahedral crystal with a translucent etched surface (Mayerson and Reinitz, 2000). Through two natural cleavage surfaces, the flower-shaped cloud was quite visible. We had a second chance to examine sample A after it was cut into a 3.02 ct pear-shaped modified brilliant (*Figure 1a*). The faceted stone measured 9.64 × 6.39 × 5.48 mm and was colour graded as Fancy brown-greenish yellow. Specifically cut to display the flower-shaped cloud, this

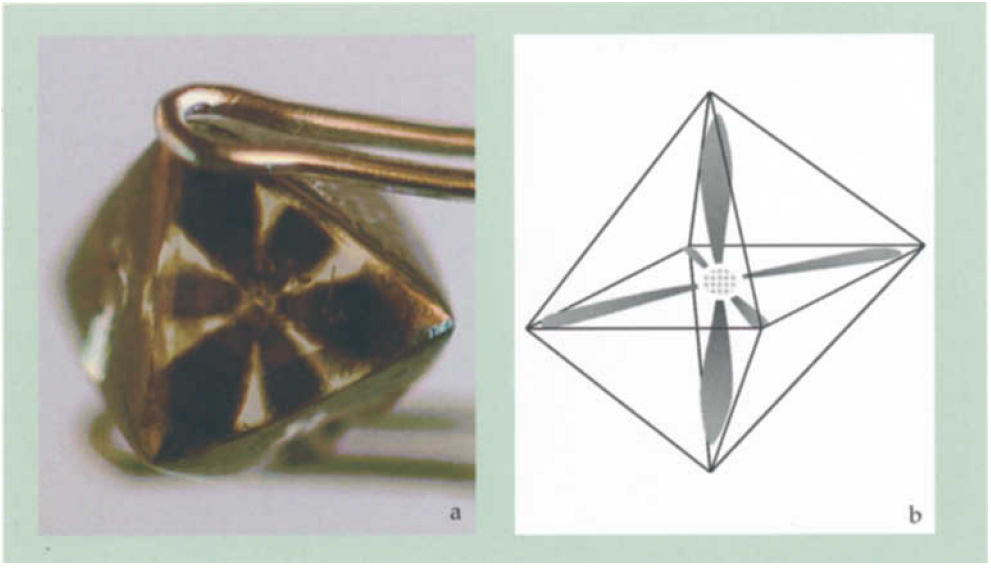

Figure 2: (a) The six-petalled flower cloud (micro-inclusions) in sample B, an octahedral diamond of 3.40 ct, viewed through a (111) face. (b) The sketch map shows the spatial arrangement of the cloud inclusions and their crystallographic relationship with the host octahedral diamond. Note that the sketch map and the real diamond are shown in slightly different orientations. The cloud is dark brown with grey fringes and originates from the centre of the crystal. The six petals perfectly follow along the <100> direction to all six corners of the crystal. This is good evidence for crystallographically controlled growth of the cloud. Photograph by Elizabeth Schrader.

stone has an extra large culet facet parallel to and only slightly smaller than the table facet. The table measures approximately 3.92 mm. Because the axis of the flower-shaped cloud is almost perpendicular to the table and culet, this arrangement not only allows for an excellent view of the cloud, but it also provides an ideal 'window' for spectroscopic measurement.

Sample B

A 3.40 ct octahedral diamond crystal measuring approximately 9.36 × 9.27 × 8.67 mm (*Figure 2a*). Known in the trade as a 'glassy', this extremely well formed crystal has fairly smooth crystal faces and good transparency which allow very clear views of the cloud and its crystallographic orientation.

Both diamonds were examined with a binocular gemmological microscope, a Leica research microscope with magnification capability up to 500×, and a GIA GEM viewing cabinet and UV lamp set. Visible-range spectra were observed at room temperature and at liquid nitrogen temperature, with a desk-model Beck prism spectroscope.

Infrared spectra were recorded at room temperature with a Nexus 670 Fourier-transform infrared (FTIR) spectrometer over the range of 400 to 10500 cm^{-1}, fitted with a microbeam chamber that allows for maximum energy output. Resolution is 4.0 cm^{-1}. Spectra with good signal/noise ratios were obtained by averaging 1024 scans for both mid- and near-infrared ranges. Ultraviolet-visible (UV-VIS) absorption spectra were recorded over the range of 360 to 760 nm using a Hitachi U-4000 spectrophotometer with a resolution of 0.1 nm and a slit width of 0.5 nm. For this measurement, the sample was held in a cryostatic cell cooled by liquid nitrogen. Metal disks with holes of various diameters were employed as masks to analyse selected regions of the diamond.

Figure 3: *A close-up of the flower-shaped cloud in sample A taken at 70× magnification. Note: the small dark needle-like crystalline inclusion in the centre of the cloud appears white due to reflections in this photomicrograph. Photomicrograph by Wendi Mayerson.*

Results

Magnification

Examination of sample A with magnification up to 60× revealed that the brownish symmetrical cloud was actually composed of numerous tiny inclusions. At 100× magnification, these inclusions appeared as short, randomly scattered needles.

The transparency of the diamond varied from the centre of the stone to the rim, depending on the density of the cloud. The whole cloud (*Figure 3*) is centred around a small black crystalline inclusion from which it radiates outward in the shape of a six-rayed star, approximately 1.5 mm in diameter. All six rays are well developed in one plane. This star is bordered by a hexagonal cloud with each of the six rays meeting their end at the midpoint of a side of this cloud's denser border creating a right angle. Further from the centre, beginning at the edge of the hexagon, the shape of the cloud changes from rays (straight lines) to petals (pseudo-elliptical forms), which appear mainly two-dimensional and extend through a large part of the crystal. It is at the end of each ray that the corners of each petal begin, and this specific orientation truly enhances the 'flower' image. The six petals are arranged in two groups. Relative to the central plane, three petals radiate upward, and the other three downward (*Figure 1b*). This implies that the axis of the flower cloud coincides with the <111> crystal direction – the only direction along which diamond has three-fold symmetry.

This alignment is more easily seen in sample B because the crystal form remains for reference. Sample B (*Figure 2b*) illustrates that the petals of the flower cloud point to the six corners of the octahedron, i.e., in the <100> directions, thereby aligning themselves with the a, b and c cubic crystallographic axes of the diamond. The clouds in sample B are also brown, but are outlined by a grey border.

Fluorescence

In sample A, the flower cloud showed weak-medium orangy-yellow fluorescence to long-wave and weak yellow fluorescence to short-wave UV *(Figure 4)*. In sample B, the grey border surrounding the flower cloud showed very weak yellow fluorescence to both long- and short-wave UV.

Spectra

With the desk-model spectroscope and transmitted light, we observed strong 415 nm lines in both samples A and B. Sample B also contained a weak line at 478 nm. Both of these lines are nitrogen related. Cooling the diamonds to liquid nitrogen temperature and using transmitted light, we resolved a line at 563 nm in both stones. This line, along with one at 545 nm that was not observed in either sample, has been associated with hydrogen by Fritsch and Scarratt (1993).

Four areas of sample A were analysed by both infrared and visible spectrometers, and their positions are shown in *Figure 5*. These spots sampled different densities of micro-inclusions within the flower cloud. Spot 1 is

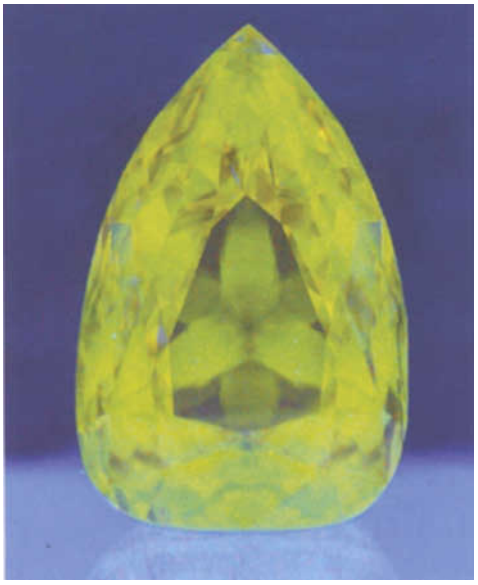

Figure 4: The flower-shaped cloud in sample A, the 3.02 ct pear-shaped modified brilliant, fluoresced weak-medium orangy yellow in long-wave UV. Photograph by Elizabeth Schrader.

at the centre of the flower cloud, and has the highest density of micro-inclusions. In contrast, spot 4 is smaller in size, and located at a clean part between two petals, it has the lowest density of micro-inclusions. Densities at spots 2 and 3 are intermediate. Because there were no polished parallel faces on sample B, light entering the sample would have been scattered to some extent, therefore test spots could not be located with certainty.

UV-visible absorption spectra of spots 1 and 2 from sample A are shown in *Figure 6*. Both spots show almost identical spectra, with a moderately strong N3 absorption at 415.1 nm, its side band at about 404 nm, and a weak peak at 563 nm. The same features of UV-visible absorption were observed from sample B, but with much stronger intensity.

Infrared spectra for sample A are summarized in *Figure 7*. Absorption at the one-phonon range of 1350-1000 cm^{-1} is saturated (off-scale), as is normal for the high concentration of nitrogen in type Ia diamonds. Existence of a peak around 480 cm^{-1} indicates that a substantial concentration of nitrogen is present in the coupled aggregation state ('A' form nitrogen). An outstanding feature is the high but varying concentration of hydrogen. Multiple hydrogen-related peaks consistently appear throughout different regions of the stone. For all four spots, strong and sharp peaks at 3107 and 1405 cm^{-1} reveal that this diamond is hydrogen-rich. In addition to the above two fundamentals, many other H-related absorptions as reported by Fritsch and Scarratt (1993) have also been observed (2785, 2813, 3050, 3080, 3153, 3170, 3188, 3236, 3255, 4167, 4495, 4704, 5888, 6070 cm^{-1}).

Quantitatively, the concentration of hydrogen can be described in comparison with intensity of the intrinsic two-phonon diamond absorption around 2450 cm^{-1}, because the intensity of this absorption per unit path-length is the same for all

Figure 5: The four locations in sample A analysed using infrared and VIS/UV spectrometers to check the distribution of impurities and defects. Spot 1 has the highest cloud density, and spot 4 has the lowest. The two large parallel facets make this diamond an excellent specimen for spectroscopic measurement. The diameters of spots 1–3 are 2.0 mm and that of spot 4 is approximately 0.6 mm. Photograph by Elizabeth Schrader.

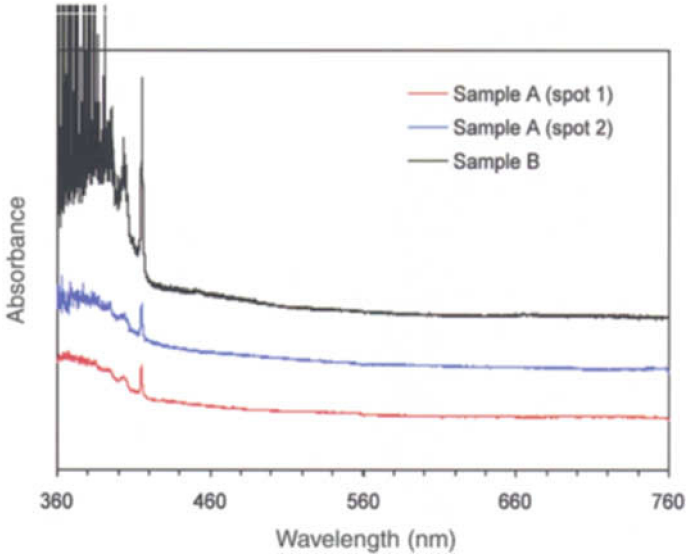

Figure 6: *Visible/ultraviolet absorption spectra. In sample A, both spots 1 and 2 show a moderately strong N3 (415.1 nm) absorption line and its side band at ~ 404 nm. No evident difference was detected between these two spots, consistent with the homogeneous distribution of body colour. In sample B, the same features were observed, but with stronger absorption.*

diamonds. Peak heights in absorption coefficient are used for the comparison in this study. The greater the ratio of the 3107 cm^{-1} peak relative to the two-phonon peak, the more abundant the hydrogen concentration. At spot 1, which has the highest cloud density (i.e. greatest number of micro-inclusions for a given area), the ratio is 1.14. It decreases to 0.40 at spot 4, which has the lowest density of micro-inclusions. In a consistent way, spots 2 and 3 show moderate ratios from 0.60 to 0.70. Such a strong correlation between hydrogen concentration and the cloud density has an important implication in the discussion of the physical location of hydrogen in diamond. Techniques are currently not available to measure structurally bonded hydrogen quantitatively in diamond (which would allow a basis of comparison), so absolute concentrations of hydrogen in the studied diamonds could not be calculated. The infrared absorption spectrum of the octahedral rough diamond (B) is shown in *Figure 8*. Generally, it shows the same features as sample A, and weaker absorption lines due to hydrogen can also be detected in the range 4000-6000 cm^{-1}.

Discussion

The fact that diamonds with cloud inclusions usually contain substantial amounts of hydrogen has been known for a long time. It was postulated that the bonding sites for hydrogen in diamond would be at internal surfaces such as inclusion-matrix interfaces (Melton and Giardini, 1974, 1975; Woods and Collins, 1983). In a very recent study of clouds and the micro-inclusions in diamonds from southern Africa, Izraeli *et al.* (2001) found that the clouds were composed of silicate, carbonate and brine inclusions. The silicates belong to either the eclogitic or the peridotitic paragenesis, but both are associated with carbonates and brine. We attempted to identify the micro-inclusions in our samples by Raman analysis but failed to get any discernible signal, probably due to the tiny grain size of the micro-inclusions. Since neither carbonate phases nor a CO_2 component were detected in the studied diamonds, micro-inclusions as clouds in

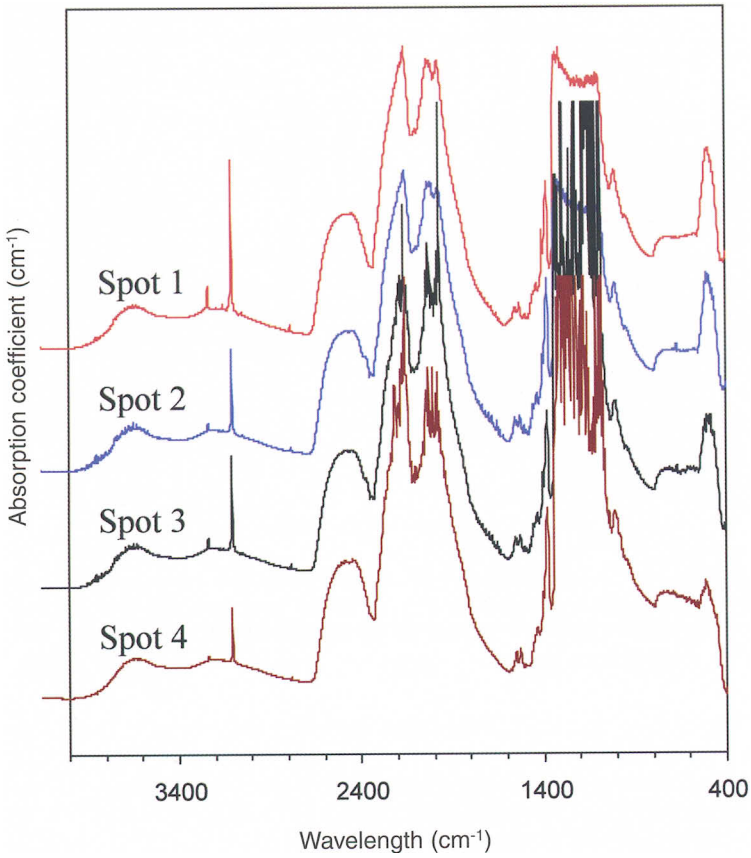

Figure 7: Infrared spectra of spots 1–4 in sample A. An outstanding feature is the high but varying concentration of hydrogen. Positive correlation between the intensity of the 3107 cm^{-1} peak and the density of the cloud (micro-inclusions) strongly suggests that hydrogen is bonded at the interface of the host diamond and the micro-inclusions.

diamond could have a wide range of chemical composition.

Although the mineralogy and chemistry of the micro-inclusions in the studied diamonds is unclear, there is no doubt that the observed hydrogen-related absorptions in the mid-infrared range are not from the micro-inclusions themselves. This conclusion is based on the fact that the stretching vibration of H-O in both silicate and oxide phases, some of the most likely candidates as inclusions in diamonds, would appear in the range of 3450-3700 cm^{-1}. This is at a much higher wavenumber than the persistent 3107 cm^{-1} feature observed here and in numerous other analyses by Woods and Collins (1983) and our own unpublished data. Some minerals, like amphibole, could contain significant amounts of constituent hydrogen, but these minerals are not stable within the diamond stability region and thus are rather unlikely to occur as inclusions in diamond. In addition, although sulphides are common inclusions in diamond (Meyer, 1987), no hydroxy-sulphide has ever been reported as an inclusion in diamond.

The positive relationship between the hydrogen concentration and the density of micro-inclusions in diamond, as observed in this study, strongly indicates that micro-

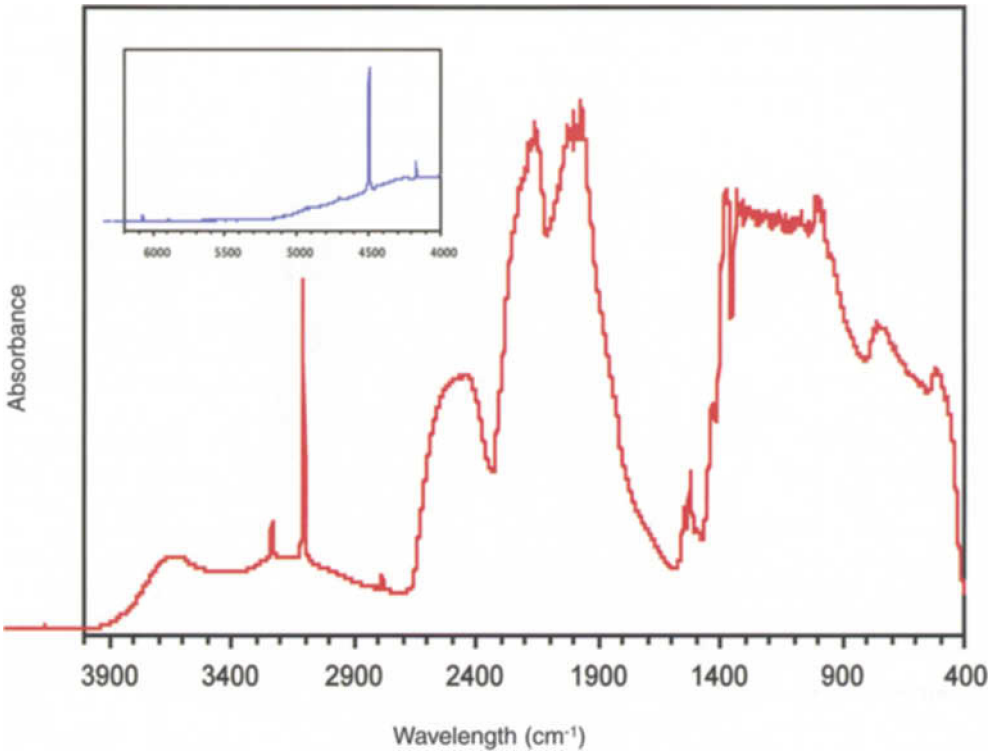

Figure 8: *Infrared spectrum of sample B. It shows strong absorptions of hydrogen at both middle infrared and near infrared (inset) regions. Absorption in the range of 1350 -1000 cm^{-1} is saturated, due to the high concentration of nitrogen (see also sample A, Figure 7).*

inclusions could be an important factor in controlling the incorporation of hydrogen in diamond. Ten diamonds studied by Melton and Giardini (1975) contained mineral inclusions with some evidence of irregular opaque regions at the interface between inclusion and host diamond. They found that the volume of gas (H_2O, H_2, CO_2, CH_4) released from crushing the diamond specimens appeared to be directly related to the number and sizes of the inclusions. They speculated that the gas was released from the interface zone between the inclusions and the host diamond. Similar observations were also indicated in Woods and Collins (1983). The results obtained in the present study more clearly demonstrate the relationship between the intensity of the hydrogen absorption and the density of clouds of micro-inclusions, and thus supports the suspicion that hydrogen is most likely bonded at the interfaces between the diamond matrix and its micro-inclusions (Melton and Giardini, 1974, 1975; Woods and Collins, 1983).

Hydrogen-rich diamonds commonly exhibit greyish or brownish colours (Fritsch and Scarratt, 1993; Fritsch, 1998), and in many cases they exhibit less transparency than those that are H-poor. A possible reason could be the scattering of light by the numerous micro-inclusions. Some of these micro-inclusions are visible under a conventional gemmological microscope, but many are not, due to their extremely small size. Hence, even diamonds that might be graded as flawless may contain some micro-inclusions. It should be noted that not all diamonds with cloud inclusions are

necessarily rich in hydrogen. For instance, a diamond described by Mayerson and Reinitz (2000) showed a flower-shaped cloud, but no absorptions related to hydrogen were detected.

A diamond with a 'star/flower' patterned cloud was first reported by Alfred Descloizeaux in 1845, but the formation of this regular pattern was not well understood. As shown in sample B (see *Figure 2a*), the six-petalled cloud originates from the centre of the octahedral crystal. The petals precisely follow the <100> directions, and extend to each of the six corners of the crystal. This spatial orientation is consistent with the flower pattern seen in sample A (see *Figure 1a*). All of the observations of the morphology of the diamonds in this study demonstrate that the growth of clouds (micro-inclusions) in such regular patterns is controlled by the growth of the {100} sector of diamond.

Surface energy, originating from the uncoupled electrons of the outermost layer of carbon atoms at the surface, plays an important role in controlling diamond nucleation. Among all the materials, diamond has the highest surface energy – the property that governs how efficiently new material is added to the surface during crystal growth. The calculated surface energies for a freshly cleaved plane are 5.3 Jm^{-2} for the (111) plane, 6.5 Jm^{-2} for the (110) plane, and as high as 9.2 Jm^{-2} for the (100) plane (Pierson, 1993). This high surface energy allows it to absorb and capture adjacent materials (impurity elements or tiny crystals) efficiently. Originating from a defect such as the inclusion observed in each of the two diamonds in this study, growth of the cloud preferentially follows the <100> direction of diamond due to the extremely high surface energy of the {100} faces. The uncoupled electrons of the carbon atoms at the interface of the diamond with the micro-inclusions could be balanced by absorbing hydrogen atoms and forming a carbon-hydrogen bond, when hydrogen is available. This process may help to explain why hydrogen in diamond is bonded at the interface of the micro-inclusions. A cloud formed in this way will appear as a six-rayed star or flower, when viewed through a (111) face. Since the (111) plane of diamond is extremely difficult to cut and polish, and the polish of both the table facet and the parallel culet of sample A are near-perfect, we believe that these facets are not exactly parallelto the (111) plane, but probably offset by a few degrees.

Diamonds with similarly shaped clouds having the same orientation with the host diamonds have been reported by Humble (1982) and Mitchell (1982). More recently, Koivula (1999) reported on a diamond with a hexagonal cloud of micro-inclusions, which exhibited the shape of a six-rayed star. From the crystal growth viewpoint, these types of patterns may reflect a stable growth environment and/or relatively rapid growth rate. In different conditions, the micro-inclusions would perhaps have aggregated and formed the larger crystal inclusions more commonly observed.

Conclusion

In the two diamonds studied, the hydrogen-related absorption is strongest in regions where the cloud appears to be optically most dense. This supports previous proposals that hydrogen in diamond is physically bonded at internal surfaces such as inclusion-matrix interfaces. Regular and symmetrical patterns of clouds form through crystallographic control of the {100} sector of the host diamond, in which trace hydrogen impurities combined with the high surface energy, may have played a significant role. To form these regular patterns, relatively rapid growth rate of the diamond and a stable mantle environment are necessary.

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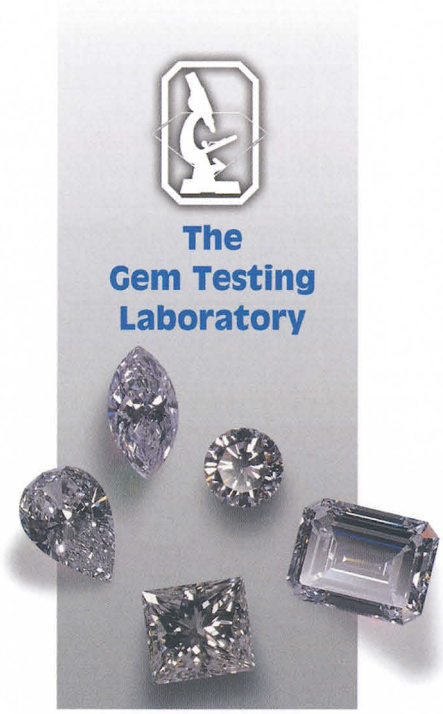

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Gem mining and sustainable environmental management in Sri Lanka

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ABSTRACT: Various methods of accessing alluvial gem gravels (known as *illama*) in Sri Lanka for the extraction of gemstones, such as open pits, shafts and tunnels, and dredging, are briefly summarized. The methods adopted to minimize environmental damage caused by mining include: introduction of legislation, restriction on types of mining methods permitted, awareness programmes and restoration of mined-out lands. The lessons learned by the Sri Lankan gem industry, with centuries of experience, can be applied to other gem-producing countries.

Introduction

Mining of minerals for the consumption by human beings started many centuries ago and if it were not for minerals and their products, the world would be without many of the material comforts for its population today. For example, life can not be imagined without having metal for machinery and motor vehicles, cement for construction, fuel and minerals for energy production, all of which are products of mining. Gems, though not an essential commodity, on the other hand make life more beautiful and attractive. So it can be said that minerals bring comforts for the body while gems give comfort for the senses and the eye in particular. Since minerals play such an important role in the lives of people, it is the duty of all of us to extract them with the least possible damage to the environment in which we live.

Gem mining

Introduction

Sri Lanka has been identified as one of the earliest sources of gems in the world (Hughes, 1999), and is still a leading producer. Mining activities were not properly organised until the early 1970s; before 1970, gem mining was done haphazardly and different regulations were in force in different districts. With the establishment of the State Gem Corporation, predecessor to the National Gem and Jewellery Authority (NGJA), in 1972 all the activities were brought under one institution and many regional offices were established to issue licences for mining and thereby supervise and minimise the impact on the environment. One of the main objectives of the State Gem Corporation was the development, regulation and control of the gem industry (SGC Act No. 13, 1971).

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Mining increased rapidly with provision of many facilities to gem exporters. While legalised mining reduced the damage to the environment, illicit mining also continued and unlike licensed mining, this caused more extensive damage to the environment.

Mining by means of open pits

A gem-bearing gravel bed occurring on or near the surface is exploited using mammoties and crowbars to excavate open pits most of which are without any support on their side walls. The miner fills bamboo baskets with gravel, and throws them upward to the waiting hands of another man at the pit-head. The method used for bailing out water from the pit depends on the rate of water seepage. It can be done by hand with buckets or by using mechanised water pumps. When the gem-bearing gravel is reached, it is collected separately at the pit-head, and washed in running water in closely woven conical bamboo baskets (*Figure 1*). If there is a shortage of water, material from surface digging can be dry sieved after removing the larger rocks by hand. Only the remaining material needs to be washed to remove dust and clay. With the correct techniques of washing, gemstones can be concentrated at the bottom of the sieve.

The use of bulldozers and scrapers has been allowed in special circumstances such as where very thin gem gravel beds occur, or in areas which have been mined-out by open pits or shafts and tunnels. This machinery is used to remove the overburden, since open-pit mining is no longer economical in such situations.

Mining by shafts and tunnels

The placer deposits of gems (*illama*) and in situ deposits occurring below a certain depth are mined by sinking shafts and excavating tunnels. In Sri Lanka, only placer deposits are mined by sinking pits, but for deeper deposits, recovery of the *illama* by successively deeper pits becomes uneconomical. In such situations, it is

***Figure 1**: Washing of gem gravel using bamboo baskets.*

Figure 2: Typical gem pit, showing timbering and lagging of walls.

common practice to excavate horizontal tunnels at the level of the gem-bearing gravel layer in order to recover gemstones. In small operations through hard ground, the shafts are either round (2 m diameter) or square (2 m sides), but in soft ground (e.g. beneath paddy fields), they are rectangular in section, measuring about 2 × 4 m (*Figure 2*).

The shaft is reinforced with timber crossbeams (from rubber trees) while fern foliage is pushed between the sides of the shaft and vertical struts (arecanut trunks) are driven behind the crossbeams, to prevent the damp sidewalls from caving in. When shafts are 3 – 4 m deep, clay and sand shovelled into small bamboo baskets are manually lifted up to the shaft head. Deeper shafts utilise manually operated winches to lift excavated material and water. As the rate of water flow increases, traditional methods of removing water are replaced by water pumps.

The *illama* is collected separately near the shaft at a place where the ground is specially levelled. The *illama* can be up to a few metres thick, and generally rests directly on decomposed rock (*malawa*) or unweathered rock (*parugala*). Washing the *illama* is done in a nearby stream or in a pond specially constructed for the purpose. The miners stand waist deep in the pond and move the baskets in a circular motion to remove all the lighter materials (*Figure 1*). Washing is continued for about half an hour with more *illama* being intermittently fed into the baskets. During the washing, lighter material collects at the top of the basket and is hand sorted and thrown out of the pond, while the heavy gem-bearing material settles at the bottom of the basket. After washing, the baskets are stacked. Later, an experienced miner collects the gems while sweeping the gravel back and forth by hand.

When the *illama* is at a fairly deep level (>8 m) horizontal tunnels, 1 – 2 m high, are excavated from the bottom of the shaft so that the floor of the tunnel follows or lies on the rock layer underlying the *illama*. As the tunnels are excavated deeper into the

Figure 3: River dredging by manual methods (courtesy of Gemstones and their origins *by Peter C. Keller).*

surrounding area, an adequate supply of fresh air and oxygen for breathing as well as for lighting candles, becomes more difficult. In such situations, air pumps are installed to provide fresh air into the mine. The tunnels are supported with timber and crossbeams similar to those of the main shaft. In Sri Lanka, over 60 percent of the mining is done by shafts and tunnels.

River dredging

When the gem-bearing placer deposits occur at the bottom of a shallow river, long-handled mammoties (a type of manual scraper with the blade perpendicular to the handle so that material can be scooped up towards the user) are used to scoop up the gravel (*Figure 3*). To prepare for this process, a brushwood dam is erected at a place where the river slows down naturally, and the water is allowed to escape from one side of the dam. Using long-handled mammoties, the overlying sand and gravel are scooped over the place where water passes through. This procedure is continued until the *illama* is reached. The *illama* is then loosened by using long pointed steel rods and is also scooped into the moving water which removes the lighter and finer minerals, leaving heavy gem minerals behind. Good gemstones can be easily seen and hand picked and the rest of the gravel is washed in the same manner as discussed earlier (*Figure 1*).

In the past, gravel pumps and dredgers could be used to extract the overburden and gem gravel, but they are banned at present because of the damage they cause to river banks.

Environmental management

Causes of environmental damage

Damage to the environment due to gem mining has been discussed by de Silva (1989), Rupasinghe and Cooray (1993) and Dharmaratne (1994).

1. *Damage to land and vegetation cover*

   Most damage to land caused by mining activities is due to open-pit methods. In particular, mining for topaz involves

moving large volumes of earth to recover gemstones. Illicit miners leave behind large craters and pits, particularly in the forests, which fill with water and become breeding grounds for mosquitoes; this in turn endangers the lives of people and animals.

Tree trunks are used to support the walls and roofs of shafts and tunnels and the flow of earth into the workings is prevented by lagging with a variety of fern (*kekilla*). This fern has strong roots which bind the soil and prevent erosion. Large areas of fern cover are harvested annually to support many thousands of gem pits, and consequently, during the monsoon rains heavy erosion occurs in these areas.

2. *Damage to plantations*

When near-surface gem deposits are discovered in plantations of tea, rubber, coconut or pepper, mining is carried out without any consideration or respect for the trees. Valuable trees are either removed deliberately or fall down due to excavation. The loss of good plantations, damages the national economy.

3. *Damage to rivers and river banks*

Gem mining in rivers and streams is allowed by the NGJA only because of the uncontrollable nature of illicit mining. Illicit miners not only dredge the river bottom but also damage river banks by undercutting. Their operations may take place by day and by night. During dredging, fine clay particles can be released into suspension in the water and cause the death of river species; they can also prevent use of the water for bathing and drinking. Furthermore, the sedimentation of waterways and dams reduces the efficiency of hydroelectric power plants.

4. *Damage to buildings and properties*

Tunnelling under roads, buildings, canals, culverts and other structures can cause untold damage. There are many instances of land owners literally undermining their own properties, because it is sometimes worth the risk of forgoing a property in the hope of recovering high-value gemstones.

Legislature

The State Gem Corporation Act No. 13 of 1971 was repealed in 1993 and the National Gem and Jewellery Authority Act No. 50 of 1993 came into effect with regard to the gem and jewellery industry. The Act states (p. 48) that:

> 'No person shall carry-on the gem industry except under the authority of a licence issued by the Authority and every person who commits an offence under this Act shall on conviction after a trial before a magistrate, be liable to a fine not exceeding one million rupees or to imprisonment for a period not exceeding five years or to both such fine and imprisonment.'

The NGJA can, with the consent of the relevant parties, having regard to the circumstances in which any offence under this act was committed, compound such offence for a sum of not exceeding one-third the maximum fine imposable.

The regulations in respect of the gem and jewellery industry were gazetted in 1972. Accordingly a licence for mining for gems is issued under the following conditions:

1. The land owner/co-owners should give consent in writing to the prospective licensee.
2. If the land in question is cultivated; the consent of the cultivator too should be obtained if he is not the owner of the land.
3. In the case of cultivated land the consent of the regional office of the Agrarian Services Department (ASD) should be obtained and the ASD takes a security deposit for each pit to ensure that the licensee restores the land after mining. The NGJA also takes a security deposit for each pit to ensure that the pits are closed, as it is the responsibility of the NGJA to

restore lands after mining. In the case of river dredging, substantial security deposits are required by the NGJA for the possible work involved is much larger than that for restoration of mining damage on high ground.

4. In mining cultivated land and rivers, water pumps are the only machinery allowed. Backhoes are permitted only in special circumstances and only with a very large security deposit since the excavations created are much larger than in normal pit mining.

Control of illicit gem mining

Raids are conducted with the assistance of the police to enforce the regulations and to apprehend offenders, because sometimes illicit gem miners attack unarmed field officers. There have been occasions in the past when even armed police have been the victims of illicit gem miners who sometimes flock in their thousands to new gem deposits discovered near the surface. The police have the authority to conduct their own raids and on such occasions, offenders are brought before a court of justice and due punishments are given.

Illicit mining in State lands, rivers and roads, or their reservations, is treated very seriously and the punishments are high compared with those for illicit mining on private land. Roads, rivers and their reservations, which comprise about 10 metres on each side of the road or river, belong to the government, and construction or excavation is not allowed in the reservations in order to safeguard these routes. If, for example, a water pump is seized on private land, it may be released with a fine of Rs 2500 (about US$25), whereas if the same pump were seized in one of the above-mentioned locations, the fine may be a third of the value of the pump if it is a first offence, two-thirds of the value if the offence is repeated and on a third offence the pump is forfeited to the State. Water pumps are the most common machines used in gem

***Figure 4**: Conducting awareness programmes to reduce the environmental damage caused by improper mining practices.*

Figure 5: Restoration of river banks by planting trees after the damage caused by river dredging (the river is on the left).

mining, and although gravel pumps, bulldozers and scrapers are rarely used, they too can be seized if used illicitly. This practice has been in operation for many years. However it has now been found that it is not a sufficient deterrent and therefore action has been taken to increase the severity of the punishment and to seize the machinery on the first offence. This is done particularly to discourage the use of gravel pumps in rivers and bulldozers and scrapers in large scale excavations in illicit mines.

Restoration of mined-out lands

The security deposits kept at the NGJA are released only if the pits are closed and the lands are restored in a fit state for cultivation. Most often, when the value of gemstones found is very high, miners ignore the need to close pits and reclaim the land. The NGJA has established a rehabilitation fund with the money from those unclaimed deposits. During the recent past this fund has financed the following activities:

1. Conducting seminars for the gem mining community to educate them in environmentally friendly mining methods and restoration of lands (*Figure 4*).
2. Restoration of river banks by erecting brushwood dams along the original river boundary and filling the excavated area behind it; also planting suitable trees along the river banks (*Figure 5*).
3. Restoration of mined-out land by using bulldozers and scrapers and planting trees (*Figure 6*).

Conclusions

Mining by any method and for any mineral causes environmental damage and the only action that can be taken is to ensure that the damage is minimized. In the case of gem mining in Sri Lanka, many hundreds of thousands of people are engaged in gem mining, with or without a licence from the NGJA. While the damage to the environment

***Figure 6**: Restoration of mined-out land by (a) filling pits and (b) planting coconut and mango trees.*

by legalised mining is minimal, the greatest harm comes from illicit mining and results in unfilled pits, soil heaps and pollution of waterways.

Illicit gem mining is not a problem specific to Sri Lanka, but one faced by all gem-producing countries. The discoveries of near surface deposits have caused gem rushes involving thousands of people in Sri Lanka, Madagascar, Tanzania, Brazil and in many other countries. Licensed mining can be supervised and strict rules can be enforced to reduce the environmental degradation. The field officers of the NGJA with the assistance of police make every effort to stop illicit mining, but the nature of such operations and the number of people involved prevent its complete eradication. The damage that illicit mining causes is offset to some extent by a rehabilitation fund established by the NGJA which is used to restore mined-out lands.

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Gem-quality chondrodite from Balangoda, Sri Lanka

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ABSTRACT: Chondrodite, a humite group mineral, has only rarely been described before as a gemstone. It has been found as small orange-brown crystal fragments in dolomitic limestone, near Balangoda, in Sri Lanka. Until now, only a few stones have been cut, in sizes up to 3 ct. The properties of this mineral are very close to the properties of clinohumite, which is rare and a collector's stone, known since the mid-1980s.

Keywords: Balangoda, chondrodite, gemmological properties, Sri Lanka

Introduction

Chondrodite is a member of the humite group, together with norbergite, humite and clinohumite. The general chemical formula of the group is $nM_2SiO_4.M(OH,F)_2$, where n = 1, 2, 3, 4 for norbergite, chondrodite, humite and clinohumite respectively. M is Mg, Fe^{2+}, Mn, Ti, Zn, etc. (Deer *et al.*, 1982). The chemical formula of monoclinic chondrodite is $2Mg_2SiO_4.\ Mg(OH,F)_2$.

The hardness is 6.5 on the Mohs' scale, which is slightly higher than the hardness of clinohumite. {100} cleavage is poor, sometimes distinct, and {100} twinning is common. According to Deer *et al.* (1982) the refractive indices are n_α = 1.592–1.617, n_β = 1.602–1.635, n_γ = 1.621–1.646. The birefringence varies between 0.028 and 0.034. Specific gravity ranges from 3.16 to 3.26. Known colours are yellow, brown, red and grey.

Until now, among the humite group minerals, only clinohumite has seriously been described as a gemstone (see e.g. Fryer, 1986; Hurwit, 1988; Henn *et al.*, 2001; Hyrsl, 2001). Known localities are Mahenge in Tanzania, the Pamir mountains of Tajikistan, and the Taymyr region, northern Siberia.

Only Webster (1962), Pough (1965) and O'Donoghue (1988) mentioned chondrodite as gemmy material from the Tilly Foster Mine, near Brewster, New York. The red-brown crystals contain gemmy parts, though dark in colour, and are suitable only for the cutting of rather small stones. Webster (1962) also mentioned Pargas and Kafveltorp in Sweden, as potential sources, but Pough (1965) disregarded these localities, because the crystals are a greyish and rather unattractive brown, with only 'a suggestion of clarity'.

The chondrodite fragments that were discovered in Balangoda (6° 40' N, 80° 44' E), about 20 miles E of Ratnapura, Sri Lanka, are orange-brown, and look very similar to the described clinohumite from other sources. It may therefore not come as a surprise that at first, these crystal fragments were presented to us as 'clinohumite' from a new occurrence in Sri Lanka. They are found in a quarry, in which dolomite is the main rock type. Chondrodite crystal fragments are found in

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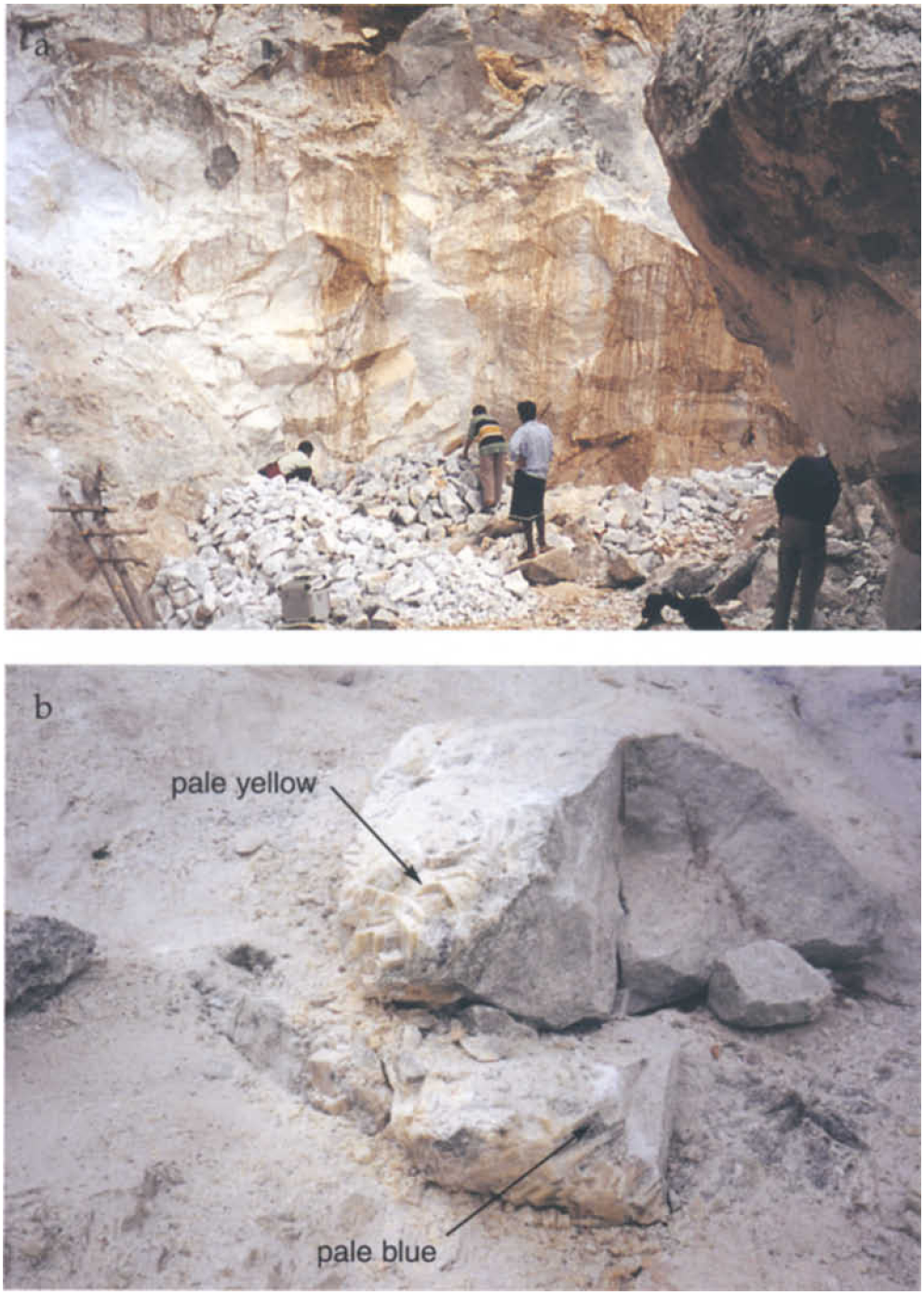

Figure 1: (a) Dolomite quarry, near Balangoda, Sri Lanka, produces gem-quality chondrodite. (b) Chondrodite fragments are found in pale blue and pale yellow calcite veins, which are present in dolomite.

pale blue and pale yellow calcite veins, which are present in the dolomite (*Figure 1*).

The dolomitic marble in which chondrodite has been found is part of the Highland Complex: an intimate association of interbanded ortho- and paragniesses including pelitic gneiss, metaquartzite, marble and charnockitic gneiss, which forms the broad belt of rocks extending from northeast to southwest through the central highlands of the island. Limestones and dolomites (among other sediments) are thought to be deposited 2.0 Ga ago (Cooray, 1994). Intrusion of granitoids in the area took place at 1.8 to 1.9 Ga ago, after which high grade regional metamorphism turned the dolomites into dolomitic marble, between 550 and 610 Ma ago.

So far, only a small number of stones have been polished. Cleaner stones up to 0.5 carats are faceted, while stones up to 3 ct are cut 'en cabochon'.

Table I: *Physical properties of gem-quality chondrodite from Balangoda, Sri Lanka.*

Colour:	orange-brown
Transparency:	transparent to translucent
Cleavage:	distinct
Refractive indices:	1. 1.609 – 1.636 2. 1.610 – 1.638 3. 1.612 – 1.639
Birefringence:	0.027 – 0.028
Specific gravity:	3.17 – 3.22
Dominant pleochroic colours:	orange-brown and yellow-brown
Fluorescence:	Inert to long- and short-wave ultraviolet radiation.

Figure 2: *One of the investigated gem-quality chondrodite crystal fragments from Balangoda, Sri Lanka, weighing 1.24 ct.*

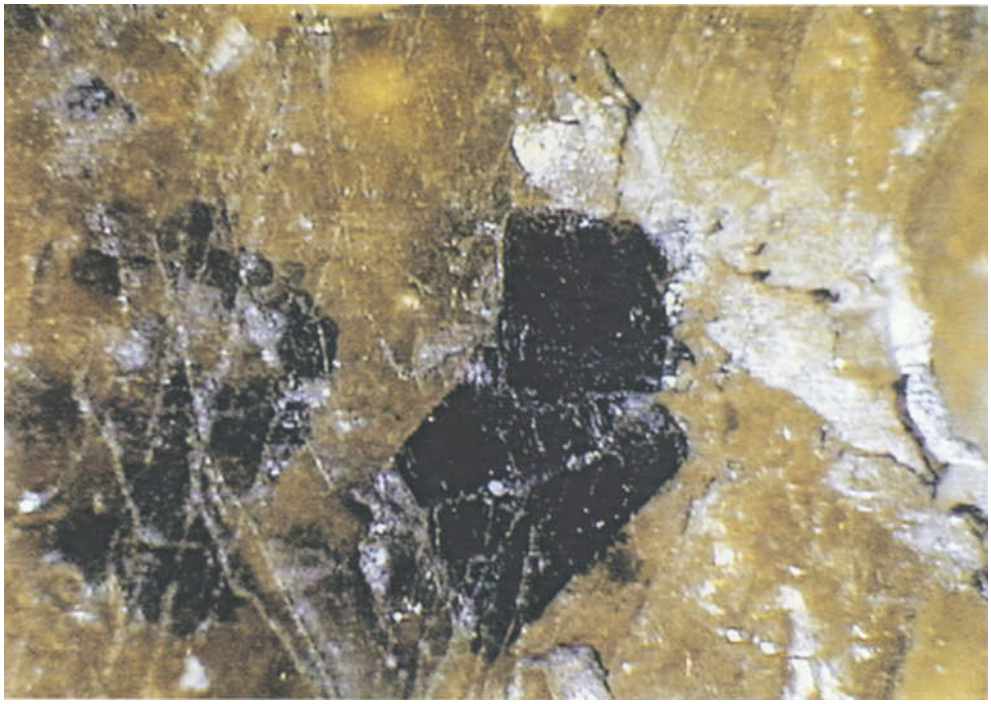

Figure 3: Spinel octahedra (dark) at the surface of chondrodite. Spinel crystals are common inclusions in chondrodite from Balangoda, Sri Lanka. Width of view: 4 mm.

Materials and methods

Three crystal fragments (*Figure 2*) were studied; the gemmological properties were measured, using standard gemmological equipment. After preliminary investigations using Energy Dispersive X-ray Fluorescence (EDXRF), chemical analyses were carried out with EPMA (Electron Probe Micro Analysis, JEOL model JXA-8800M). EPMA analyses were performed at the Faculty of Earth Sciences, Vrije Universiteit, Amsterdam.

Physical properties

The measured physical properties are presented in *Table I*. As the fragments were presented to us as 'clinohumite', it is immediately apparent that the refractive indices are much too low for that mineral (cf. the range of 1.63–1.67 reported by Henn *et al.*, 2001).

Chemical analysis

After preliminary investigation of each crystal fragment with micro-EDXRF, it became clear that this method poses some problems in obtaining satisfactory analyses. EDXRF can be considered as a standard instrumental technique that is used by many gemmological laboratories to get (semi-) quantitative analyses of gemstones, but in this case, the technique is not suitable for two reasons: the fluorine content is significant but cannot be measured, and an unusual content of copper (more than 0.05 wt%) was found. It could not be decided from the EDXRF analyses whether this copper is due to contamination or really is within the lattice of the analysed mineral. In order to find more reliable answers it was necessary to do further and detailed EPMA analysis on one crystal fragment.

The electron microprobe analyses are presented in *Table II*.

Table II: Electron probe spot analyses of chondrodite from Balangoda, Sri Lanka.

Oxides (wt.%)	1	2	3	4	5	Average
SiO_2	34.2	34.8	34.3	34.6	34.5	34.5
TiO_2	0.43	0.42	0.49	0.44	0.44	0.45
Al_2O_3	0.03	0.02	0.02	0.02	0.02	0.02
FeO	0.90	0.85	0.93	0.88	0.89	0.89
MnO	-	-	-	0.02	0.02	0.01
MgO	56.0	56.3	55.8	55.9	55.9	56.0
CaO	0.04	0.03	0.02	0.03	0.02	0.03
Na_2O	0.02	0.02	0.01	0.01	0.03	0.02
K_2O	0.02	0.02	0.02	0.03	0.02	0.02
F [(a)]	5.47	5.61	5.37	5.31	5.38	5.43
Cl	-	-	-	-	-	-
	97.11	98.07	96.96	97.24	97.22	97.37
-O = F	2.30	2.36	2.26	2.24	2.27	2.29
Total [(a)]	94.81	95.71	94.70	95.00	94.95	95.08
H_2O [(b)]	2.52	2.51	2.56	2.60	2.57	2.55
Numbers of ions on the basis of 10 (O, OH, F)						
Si^{4+}	2.008	2.021	2.012	2.023	2.018	2.017
Ti^{4+}	0.019	0.018	0.022	0.019	0.019	0.020
Al^{3+}	0.002	0.001	0.001	0.001	0.001	0.001
Fe^{2+}	0.044	0.041	0.046	0.043	0.044	0.044
Mn^{2+}	0.000	0.000	0.000	0.001	0.001	0.000
Mg^{2+}	4.894	4.875	4.881	4.867	4.875	4.878
Ca^{2+}	0.002	0.002	0.001	0.002	0.001	0.002
Na^{+}	0.003	0.002	0.002	0.001	0.003	0.002
K^{+}	0.002	0.002	0.002	0.002	0.001	0.002
Number of cations	6.974	6.962	6.967	6.959	6.963	6.966
F^{-}	1.015	1.029	0.996	0.981	0.997	1.003
OH^{-}	0.985	0.971	1.004	1.019	1.003	0.997

- not detected
(a) low totals are due to conductivity which was not optimal
(b) calculated

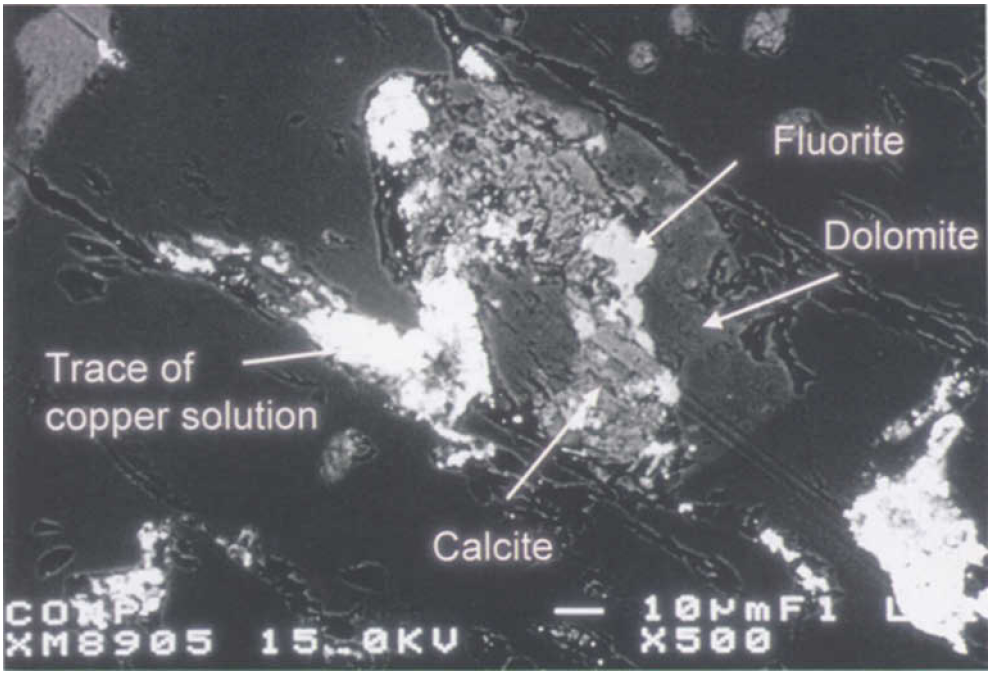

Figure 4: Electronphotomicrograph, showing the presence of small fluorite, calcite and dolomite inclusions in chondrodite, indicating the dolomitic marble environment, in which chondrodite was found. Traces of a dried-up copper iodide/iodate and/or sulphate solution are present on the surface and in cracks.

Internal features

The crystal fragments that were investigated contain many dark grey to grey-green crystal inclusions, octahedral shapes, as well as rounded crystals (*Figure 3*). Qualitative analyses of a few crystal inclusions at the surface confirmed that this cubic mineral is spinel ($MgAl_2O_4$), which only shows a trace of iron. Other relatively small inclusions that were identified are fluorite, Mg-bearing calcite and dolomite (*Figure 4*).

Discussion

It is difficult to distinguish the humite group minerals optically. Although the refractive indices (and specific gravities) increase progressively from norbergite to clinohumite, they show considerable overlap.

However, the refractive indices of the crystal fragments (*Table I*) are clearly within the field of either chondrodite or humite and substantially lower than the values known for clinohumite (Deer *et al.*, 1982, report RIs between 1.628 and 1.674, birefringence 0.028-0.041, and SGs between 3.17 and 3.35, for clinohumite). The SGs are in line with chondrodite, but appear too low for humite. Distinct cleavage can only occur in chondrodite. Humite and clinohumite both show poor cleavage. The presence of twinning is common in chondrodite, whereas it is absent in humite. In the crystal fragments, twinning was difficult to recognize, because the material could not properly be observed in the right direction. However, in thin sections made of one crystal, the presence of twinning was confirmed. Chondrodite from Balangoda can be distinguished from the described gem quality clinohumite from other sources by short-wave ultraviolet radiation. Chondrodite is inert under SW-UV, whereas clinohumite shows a moderate to strong orangey-yellow fluorescence (compare Fryer,

1986; Hurwit, 1988; Henn *et al.*, 2001; Hyrsl, 2001).

The chemistry indicates Mg/Si ratios of 2.43 to 2.46 (average 2.44), which indicates chondrodite. Theoretically chondrodite has a Mg/Si ratio of 5/2 = 2.50, whereas clinohumite has Mg/Si = 2.25 and humite Mg/Si = 2.33. The chondrodite analysed, contains little iron (0.89 wt%), at the lower end of the range 0.4–7.3 wt% FeO reported by Jones *et al.* (1969). The fluorine content is substantial, which is normal for chondrodite. It always shows a great degree of fluorine replacement of hydroxyl. The average F/(F+Cl + OH) ratio is slightly above 0.50, which is near-average compared to the ratios of 0.34–0.94 in chondrodites from other occurrences (Kearns *et al.*, 1980). The high fluorine content is consistent with the low iron content: in general, the replacement of (OH) by F decreases, when the replacement of Mg by Fe increases (Deer *et al.*, 1982).

The indicated presence of copper by EDXRF turned out to be a contamination problem. With EPMA, it was discovered that traces of a dried-up copper iodide/iodate and/ or sulphate solution are present on the surface and in cracks (*Figure 4*). Thus copper was not found in the chondrodite itself. This is consistent with the results of Jones *et al.* (1969), who found that Al, as well as P, Cl, Cr, Co, Ni, Cu and Pb, were not individually detected at the 0.05 wt.% level, in humite group minerals.

Conclusions

Until now, chondrodite has only rarely been described as a possible gemstone. Gem-quality chondrodite from Balangoda, Sri Lanka, is extremely rare, and as at mid-2002 only a few stones have been polished. Compared to clinohumite, another mineral of the humite group, which has been cut and polished as a gemstone, chondrodite is characterised by low refractive indices, birefringence and specific gravity. It also is inert under short-wave UV, whereas gem-quality clinohumite shows an orangey-yellow fluorescence. Typical inclusions of chondrodite from Balangoda, are grey green spinel crystals. The chondrodite shows a low iron content and contains a substantial amount of fluorine.

Acknowledgements

Electron microprobe facilities were provided by the Free University of Amsterdam, the Netherlands, and by NWO, the Netherlands Organisation for Scientific Research.

Wim J. Lustenhouwer is thanked for helping with chemical analyses and Dirk van der Marel is thanked for general assistance.

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Light emitting diodes as light sources in portable gemmological instruments

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ABSTRACT: Light emitting diodes (LEDs) can be used as light sources substituting for incandescent light bulbs in portable battery-operated gemmological instruments. They are small, have an average life span in excess of 100 000 hours, are bright and are cold as they produce light by luminescence. This article reviews a 590 nm (yellow) and a white LED used as sources in a polariscope and refractometer and a blue 472 nm light source used with a red filter (cross-filter apparatus) to observe red fluorescence in a Cr-bearing gem material.

Keywords: Battery-operated, colour change, cross-filter apparatus, light emitting diode, polariscope

Introduction

What are light emitting diodes (LEDs)?

LEDs essentially consist of a PN junction specifically designed to emit light when forward biased. They are solid state lamps and various types are available that can emit light ranging from ultraviolet (370 nm) to infrared (950 nm). Although LEDs have been around commercially since the late 1960s, it is only during this past decade that blue, white and UV light emitting diodes have made their appearance. Over the years the brightness of these devices has improved to a level that allows their use as traffic lights and other full colour displays that can be seen in broad daylight.

LEDs emit light by luminescence and a schematic diagram of an LED is shown in *Figure 1*. When the charge carriers within the semiconductor PN junction – the electrons and holes – recombine with one another, electrons are transferred from the conduction band to the valency levels with consequent release of energy. This release of energy and its wavelength(s) depend on the materials forming the semiconductor. The outside energy source is the electric current applied to forward bias the device.

LEDs are current-operated devices in contrast to incandescent light bulbs which are voltage-operated. Electric current is a flow of electrons in a circuit while voltage is a potential difference applied to an electrical circuit to produce a current flow. In the average current-regulated LED system, the electronic control circuit supplies a constant current (of about 20 milliampere) to the LED over a wide range of voltage. A basic

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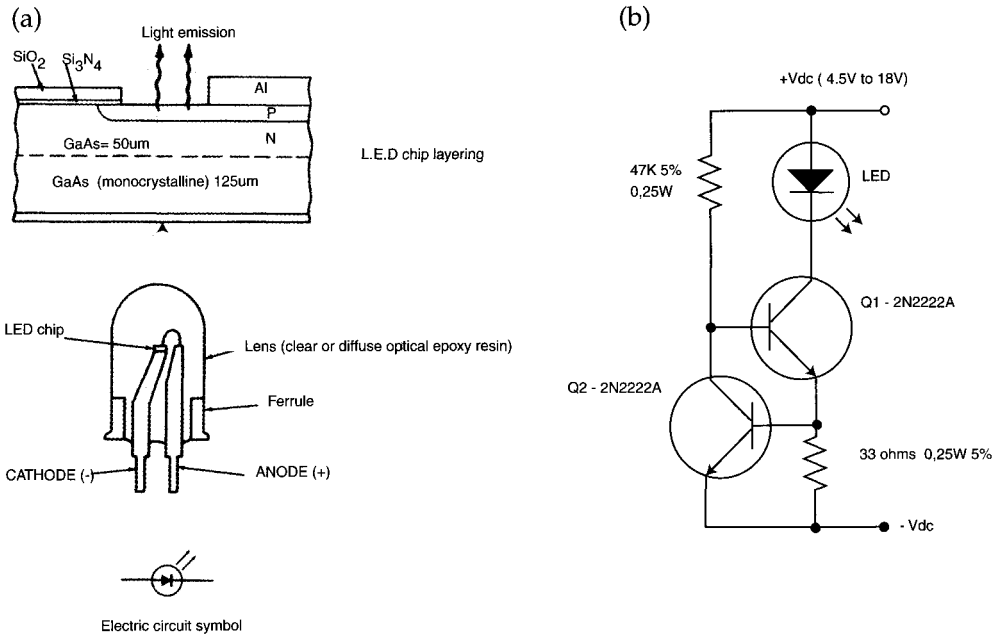

Figure 1: *(a) Schematic diagram of an LED and its chip construction; the ferrule is not present in all LEDs. (b) Basic constant current source (18 ma) appropriate for LEDs.*

constant current source (18 ma) appropriate for LEDs is shown in *Figure 1b*. Therefore, current-regulated LEDs with an electronic control circuit can be run by a range of portable batteries and will provide optimum brightness over the whole life span of the battery.

LEDs provide non-coherent ordinary light sources and are near monochromatic in nature. Visible colour LEDs available are red, orange, yellow, green, blue-green and blue. There are also LEDs that produce white light in a way similar to that produced by a fluorescent tube. These are blue LEDs with their junction coated with YAG which is fluorescent: the blue emission stimulates the YAG coating to produce fluorescent white light.

Most LEDs have a spectral bandwidth of about 35 nm. The colours most useful to the gemmologist are the 590 nm yellow, the 472 nm blue and the white LED. The 370 nm UV LED produces no visible light and can be used as a LWUV source. LEDs have many advantages over incandescent light sources: they are rugged, do not possess a filament that can break under shock and produce no noticeable heat under normal conditions. Their life span of over 100 000 hours far exceeds that of any incandescent bulb, and their low current consumption compared with incandescent bulbs make them a natural choice for portable battery-operated equipment. LEDs can also be pulsed, their rise and fall time being measured in nanoseconds. They are encapsulated in clear or diffuse optical epoxy resin terminated by a lens with two electrodes protruding for electrical connection. A typical diameter is 5 mm.

An instrument performing the functions of a portable polariscope, refractometer light sources and a cross-filter apparatus using LEDs has been designed by the author and the configurations are shown in *Figures 2, 3* and *4*. Power is supplied by battery or by the mains via an AC/DC transformer. Suitable LEDs are supplied by Agilent Technology Inc. (www.agilent.com). UV LEDs are supplied by Roithner Lasertechnik of Austria (www.roithner-laser.com).

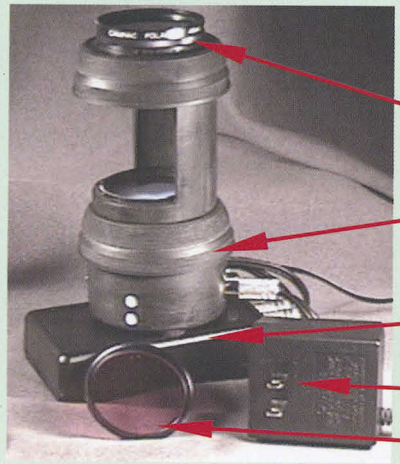

Figure 2: Portable polariscope with LED illuminator unit.

Analyser

Polariser / diffuser / illuminator module

Electronic control module

AC / DC transformer

Photographic red filter R2

Figure 3: Refractometer illuminator with white and yellow sources.

Polariser / diffuser / illuminator module

White LED source

Yellow 590nm LED source

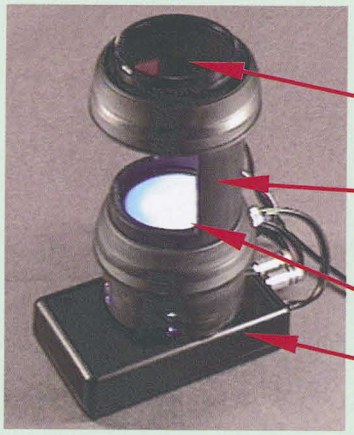

Figure 4: Apparatus set up for cross-filter work with blue LED illuminator and red filter.

Red photographic filter

Specimen chamber (50mm diameter x 75mm height) (Will accomodate a standard immersion cell)

Blue LED illuminator

Electronic control circuit

Use of white and yellow light emitting diodes

The white light produced by fluorescence in LEDs has a general spectral distribution somewhat similar to that of fluorescent tubes but without the sharp emission lines that the tubes produce. Through an OPL spectroscope the LEDs show a broad peak in the blue and a rather smooth continuous spectrum from red to violet. They are very useful for the detection of colour-change gems such as alexandrite or colour-change garnets. Used as a light source in the polariscope unit (see *Figure 2*) they are also useful in parallel filter configuration, to observe pleochroic colours. Compared to a standard incandescent light in a bench polariscope, the colours displayed are easier to distinguish and truer. In addition, the polariser does not heat up during use so the unit can be left on for extended periods without risk of damaging the filter or the lamp – a major advantage for use in the classroom.

The yellow LED with a peak at 590 nm constitutes an excellent near-monochromatic light source for the refractometer (see *Figure 3*). This application of an LED was first reported by Read (1980, p. 82-4) and was the first ever application of LEDs to gemmological instruments.

The white LED can also be used with the refractometer for distant vision readings or for locating the colour fringe prior to using the yellow source.

Use of blue light emitting diodes

Owing to their near monochromatic emission, coloured light emitting diodes can be used instead of colour filters in the observation of internal growth features. One example is the use of a blue LED to examine polysynthetic twinning in yellow chrysoberyl. Other colours of LEDs may show useful effects and are currently being investigated.

Another use of the blue LED is in combination with a red filter as a crossed filter configuration to observe fluorescence (see *Figure 4*). When a chromium-bearing gem is placed between the blue source and the red filter, a red fluorescence can generally be observed. A yellow filter can be substituted for observation of apricot-yellow fluorescence in natural unheated yellow sapphire from Sri Lanka. However, the main reason for building such an apparatus was for a classroom demonstration to investigate the reddish fluorescence of natural-colour black pearls. Over 200 specimens of Tahitian black cultured pearls were tested for fluorescence but none was observed; however, further investigation will be needed as it is possible that the intensity of the LED is insufficient to have produced any noticeable effect.

An interesting effect is observed when chromium-bearing pyrope, which is non-fluorescent, is illuminated by the blue LED against a white background: its colour changes to blue-green, while most other red gems that do not contain chromium show a darker red (*Figure 5d*). The reason for this phenomenon is simple: chromium-bearing gems all have a broad absorption band in the yellow area of the spectrum and absorption of the violet up to the blue region of the spectrum. They transmit freely the red and green wavelengths. The blue LEDs emit light at peak intensity around 472 nm. Emission diminishes rapidly on each side of the 472 nm peak (*Figure 5b*). The human eye is most sensitive to the green portion of the spectrum (*Figure 5a*). So in red chromium-bearing non-fluorescent gems illuminated with a blue LED, too little red is being emitted by the LED and since all the yellow is absorbed by the gem this leaves only the blue and green wavelengths from the source to be freely transmitted from the gem to the eye and brain of the observer; the gem therefore appears blue-green (*Figure 5c*).

Conclusions

Modern light emitting diodes are very useful as a source of illumination in gemmological instruments. Their advantages over incandescent light bulbs

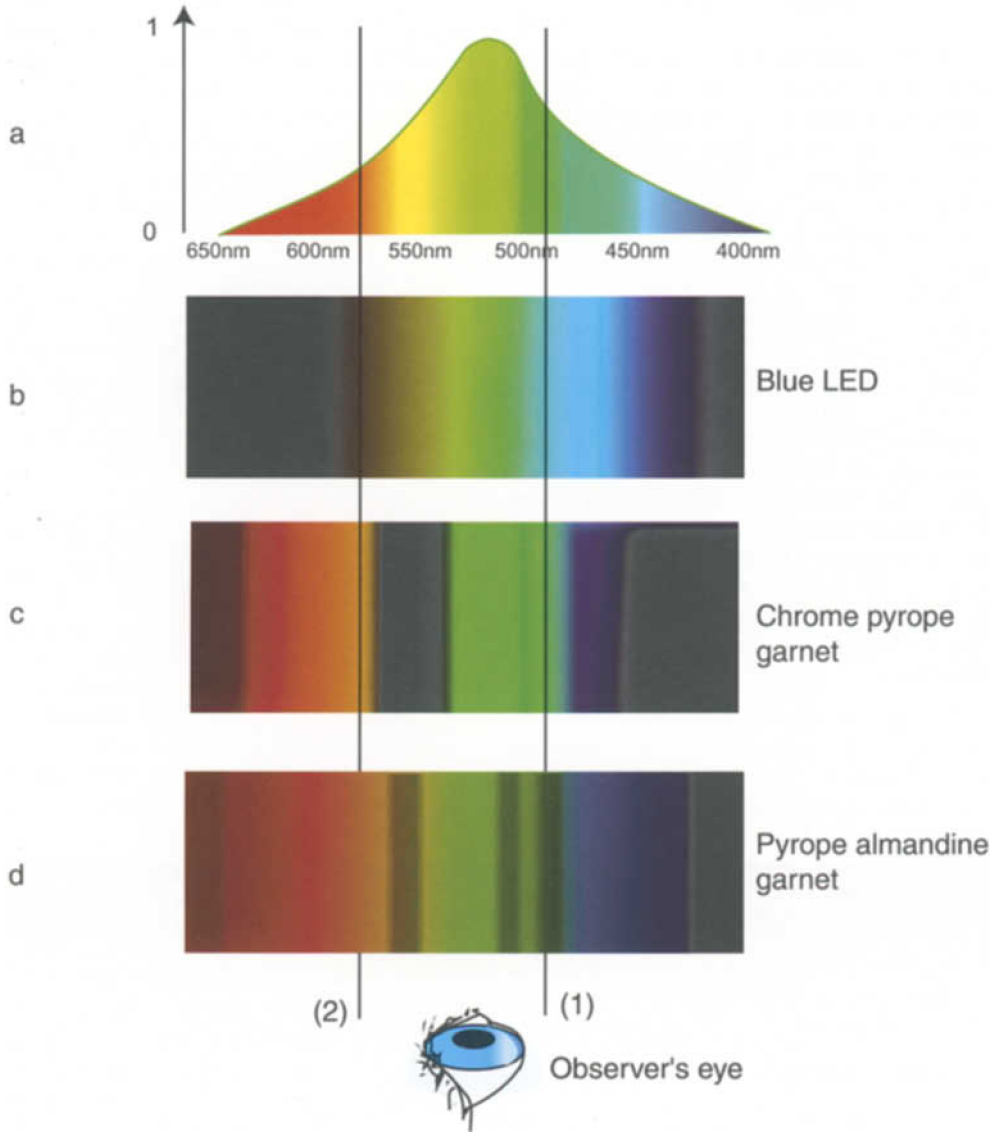

Figure 5: *(a) Spectral sensitivity of the average human eye.*

(b) Diffraction grating spectrum of blue LED with maximum emission at 472 nm.

(c) Chrome pyrope garnet spectrum (diffraction grating); the garnet is seen as blue-green in the blue LED illumination (1).

(d) Pyrope almandine garnet spectrum (diffraction grating); the garnet is seen as darker red in the blue LED illumination (2).

include their small size and cold operation, and their brightness and low power consumption make them ideal for portable battery operation and classroom / laboratory instruments. Many instruments can be combined in one compact unit that can be operated in the field as well as in the laboratory giving more flexibility to the gemmologist.

LEDs with a peak wavelength of 370 nm and no emission of visible light are potentially useful as a portable LWUV source and their use is being explored.

Acknowledgements

The author is grateful to Odile Civitello GG FGA of Montreal, Canada, Director of Ecole de Gemmologie de Montréal, for access to gem testing facilities and loan of specimens, to Maureen DeCelles of Montreal, Canada, for the loan of specimens and to François Longère F.C.gma of Montreal, Canada, for the loan of black natural-colour Tahitian cultured pearls.

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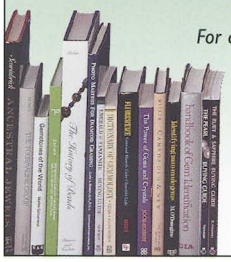

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Abstracts

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Diamonds

Diamanten im Amazonasgebiet.

M.L. Da Costa and H. Höhn. *Aufschluss*, **53**, 2002, 6-18.

The geology and mineralogy of diamond deposits in the Brazilian state of Amazonas are discussed with notes on mining methods and on the crystals recovered.

M.O'D

Characteristics of nitrogen and other impurities in diamond, as revealed by infrared absorption data.

F.V. Kaminsky and G.K. Khachatryan. *Can. Min.* **39**(6), 2001, 1733-45.

Diamond crystals from Siberian, Arkhangelsk, South African, Canadian and South American deposits were analysed for structurally bound nitrogen, hydrogen and 'platelet' defects using IR absorption spectroscopy. Wide variations in total nitrogen and hydrogen contents and in the state of nitrogen aggregation were established from different areas and deposits. On this basis, three groups were distinguished: (1) low-nitrogen, highly aggregated-nitrogen diamond, (2) intermediate diamond crystals and (3) high-nitrogen, poorly-aggregated-nitrogen diamond (occasionally with high contents of hydrogen and 'platelets'). These represent, in general terms, three major stages of diamond formation: (1) the initial stage at high *P–T* conditions, which occasionally occur in super-deep areas (e.g. lower mantle and transition zone, (2) the main stage and (3) the final stage, which represents the latest episodes of magmatic evolution and is characterized by high oversaturation of the crystallization medium and high internal *T*-gradients. These data may be used for 'fingerprinting' diamonds, in prospecting for new deposits in diamondiferous areas and in the evaluation of diamond crystals from newly discovered deposits.

R.A.H.

Post-eruptive processes in kimberlites – implications for diamond exploration.

K. Leahy. *Transactions of the Institution of Mining and Metallurgy (Section B: Applied Earth Science)*, **110**(1), 2001, 1-4.

Deposits of primary diamond ore (kimberlite and less commonly, lamproite volcanic and intrusive rocks) are rare, and even in highly prospective terrains geochemical and geophysical techniques are required to help locate these tiny volcanic targets. The environmentduring eruption and more importantly, the environments to which the diamond-bearing volcanic material has been subjected since eruption, determine the response of the targets to these techniques. Post-eruptionprocesses within (serpentinization) and beyond (erosion) the crater are outlined, and the Fort à la Corne kimberlite field in western Canada is used as an example. The consequences for exploration of groundwater and sea-water levels, and uplift and climate are presented.

J.F.

Abundance and composition of mineral inclusions in large diamonds from Yakutia.

N.V. Sobolev, E.S. Efimova, A.M. Logvinova, O.V. Sukhodol'skaya and Yu.P. Solodova. *Doklady Earth Sciences*, **376**(1), 2001, 34-8 (English translation).

The abundance of inclusions in 2334 diamonds from the Mir, Udachnaya and Aikhal kimberlite pipes is presented. Chromite, garnet and olivine inclusions are abundant and EPMA results for garnet and chromite are given. The results indicate that the inclusion assemblages are similar in diamonds of varying size from the same pipe. Sulphide inclusions are predominant only in large diamonds from the Mir pipe.

A.M.C.

Gems and Minerals

The Barra de Salinas pegmatites, Minas Gerais, Brazil.

F.M. Bastos. *Mineralogical Record*, **33**, 2002, 209-16.

Fine gem-quality crystals of tourmaline are among the minerals to be found at the Barra de Salinas pegmatite, Minas Gerais, Brazil. The pegmatites have been worked since the 16th century. Maps and a mining history are included as well as colour photographs.

M.O'D.

Abstractors

A.M.Clark	A.M.C.	R.A. Howie	R.A.H.	P.G. Read	P.G.R.
J. Flinders	J.F.	M. O'Donoghue	M.O'D.	E. Stern	E.S.

For further information on many of the topics referred to, consult Mineralogical Abstracts

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Rare Australian gemstones - The Springsure deposit of precious opal.

R. BEATTIE. *Australian Gemmologist*, **21**(5), 2002, 207-10.

While the Springsure deposit of precious opal represents Queensland's first discovered source of volcanic opal, and is capable of producing occasional gem quality specimens, this opal's tendency to dehydrate and crack after mining and exposure to ambient atmospheric conditions limits its commercial potential. P.G.R.

North Queensland mabé pearls.

G. BROWN. *Gemmologie. Z. Dt. Gemmol. Ges.*, **50**(4), 2001, 193-108. 1 map, 5 photographs, bibl.

Bead nucleated half pearls are being cultivated in the bivalve *Pteria* (*penguin* or blackwing) shell in the tropical reef waters off Orpheus Island, North Queensland. The valves of these molluscs are lined with silver aragonitic nacre from its hinge outward towards an intermediary arc of gold to brown aragonite nacre and a rim of calcite nacre. Polymer hemispheres of various sizes are glued to the inner surfaces of the valves of one year old *P. penguin* shells. Eighteen months later the molluscs are harvested and the half pearls cut away. These true mabé pearls show very attractive colours ranging from gold to brown, silver and also grey hues with strong iridescence. E.S.

Rutilquartz vom Oberon Parnuk im Polar-Ural.

J.V. BURLAKOV AND J.A. POLENOV. *Lapis*, **27**(2), 2002, 35-40.

Rutilated quartz of ornamental quality is described from Verchny Parnuk in the Polar Urals of Russia. Details of crystal forms and of the inclusions are given. M.O'D.

Sri Lanka gem industry: past, present and future.

P.G.R. DHARMARATNE. *Gemmologie. Z. Dt. Gemmol. Ges.*, **50**(4), 2001. 199-206, 1 map, 3 tables, bibl.

Sri Lanka has been known for gem mining for many centuries. It was first mentioned in literature in 250 BC and there are many early legends. The alluvial deposits are now dwindling and there is a move towards primary deposit mining. The author discusses how legislation with regard to mining, trading, cutting and polishing exports and imports has changed over the years. There have been big fluctuations in the number of licences issued for the various aspects of the industry over the years. E.S.

Corundum/spinel reaction textures in carbonate-origin rocks, Sri Lanka.

M.D.P.L. FRANCIS AND P.G.R. DHARMARATNE. *Australian Gemmologist*, **21**(5), 2002, 211-14.

Carbonate-source rocks containing corundum and spinel are ubiquitous as thin bands in almost all gem producing areas in Sri Lanka. Marble, composed mainly of calcite and dolomite with phlogopite mica, is the dominant lithology within some of the major gem fields. Where both corundum and spinel are present within the marble rock, reaction textures are visible. These textures indicate sequential reactions during corundum and spinel formation. One reaction is balanced, where corundum and phlogopite react to produce rims of spinel and K-feldspar around the corundum. Another reaction involves corundum and spinel replacement, but this reaction is unbalanced and requires more detailed analyses of the phases for its specification. P.G.R.

Les nouvelles mines d'émeraude de La Pita (Colombie). 2e partie.

E. FRITSCH, B. RONDEAU, F. NOTARI, J-C. MICHELOU, B. DEVOUARD, J-J. PEUCAT, J-P. CHALAIN, Y. LULZAC, D. DE NARVAEZ AND C. ARBOLEDA. *Revue de gemmologie*, **144**, 2002, 13-21.

Up to 33 claims are established in the La Pita mining district between Muzo and Coscuez, Colombia. Typical RI and SG of the emeralds found are ε 1.570– 1.571, ω 1.578–1.581: 2.69-2.70. Stones show distinct colour zoning and notably strong pleochroism. Inclusions are characteristic of Colombian emeralds in general. La Pita emeralds can be distinguished from all others by a predominance of V over Cr, a low concentration of Rb and characteristic Mg values. Stones are Fe-poor. M.O'D.

Gem kaleidoscope from Asahi.

Industrial Diamond Review, **62**, 2002, 11, 2 photographs.

The idea was triggered by a previous collector's piece – the De Beers hourglass. The gems used in the kaleidoscope are emerald, tsovorite and paraiba tourmaline for green, amethyst for purple, spinel and ruby for red, sapphire for pink, sapphire, iolite and topaz for blue, sapphire and citrine for yellow, and diamond and topaz for white, and altogether 21 ct of gems are used in each kaleidoscope. Each gem is a little different in size. The body is 24 carat gold plated. Since each instrument is hand-made, only 40-50 can be produced per month and the total production is planned to be 2000 kaleidoscopes. The price is 1 million yen per piece. E.S.

Rubis trapiches de Mong Hsu, Myanmar.

V. GARNIER, D. OHNENSTETTER, G. GIULIANI AND D. SCHWARZ. *Revue de gemmologie*, **144**, 2002, 5-12.

Describes the trapiche ruby crystals found at Mong Hsu, Myanmar with notes on the local geology and on the formation of the crystals. Cathodoluminescence tests are noted and there is a table of included minerals in which the trapiche rubies are compared with non-trapiche Mong Hsu material. M.O'D.

Imperialtopase aus Ouro Preto, Minas Gerais, Brasilien.

A.L. GANDINI, R.M.S. BELLO, H.M.P. ROESER AND J. CESAR-MENDES. *Aufschluss*, **53**, 2002, 154-8.

Topaz of the highest quality and near-red in colour is mined at different locations in the Brazilian state of Minas Gerais. Details of the geology and mineralization of the topaz-producing areas are given. M.O'D.

Gemmologische Kurzinformationen. Rote Turmaline aus Nigeria.

U. HENN. *Gemmologie. Z. Dt. Gemmol. Ges.*, **50**(4), 2001, 225-8. 7 photographs, 1 graph, bibl.

Since 1998, Nigeria has produced large amounts of red tourmalines from an occurrence near Ibadan in the

western province of Oyo. The tourmalines have a good red to pink colour in contrast to other Nigerian localities which produce stones of a browner tint. The physical characteristics are those of elbaite and the red colour is due to trivalent manganese; fluid inclusions as well as crystal inclusions and growth zoning were observed. E.S.

Edelsteine der Feldspatgruppe.

U. HENN. *Gemmologie. Z. Dt. Gemmol. Ges.*, **50**(4), 2001. 179-92, 12 photographs, 4 diagrams, 3 tables, bibl.

Feldspars are the most common minerals on the earth, but good gem quality varieties are rare. Optical effects can be seen in a large spectrum of commercially available moonstones, amazonites, and labradorites. Other feldspars are being cut, but are of interest only to collectors. The author discusses occurrence and physical properties of sanidine, orthoclase, microcline, larvikite, albite, oligoclase, andesine, labradorite, bytownite and anorthite amongst others. E.S.

Die Achate vom Finkenberg in Idar.

R. HOFFMANN ROTHE, *Lapis*, **27**(2), 2002, 13-17.

Agate of exceptional quality is described from the Finkenberg area near Idar-Oberstein, Germany. Red predominates in the patterning and the material has been used to good effect in the fashioning of cameos. M.O'D.

John Jago Trelawney.

A.R. KAMPF. *Mineralogical Record*, **33**, 2002, 217-24.

Biography of a collector [born John Jago] who gave a gemstone collection to the Natural History Museum of Los Angeles County and a mineral collection to the Smithsonian Institution. M.O'D.

Flashstones – Zeugen 'versteinerter' Blitze.

J. KARFUNKEL AND B. PEREGOVICH. *Gemmologie. Z. Dt. Gemmol. Ges.*, **50**(4), 207-16, 2001. 4 photographs, 1 map, 2 graphs, bibl.

Deformed quartz crystals struck by lightning which were found in deep channel-forming elongated pits in colluvial deposits in the 'Sierra do Espinhaco', a narrow mountain range in Central Eastern Brazil. The artisan miners call these 'pedra de raio' – flashstones. They are single quartz crystals struck by lightning which were macroscopically deformed by shock energy. Special environmental and atmospheric conditions explain their genesis. Such crystals become collectors' pieces. E.S.

Gem News International.

B.M. LAURS (Ed.). *Gems & Gemology*, **37**(4), 2001, 326-43.

Notes are given of distinct colour changes observed in cut stones of spodumene, zircon and sapphire after subjection to ionizing radiation from a synchrotron similar to the technique used by the U.S. Postal Service on a small portion of the mail to eliminate a potential threat from anthrax spores. Descriptions are given of cut iolites (0.36–1.33 ct) and pink sapphires from quartzofeldspathic gneiss in the Palmer Canyon area of Wyoming, a 3.54 ct green kyanite from Bahia, Brazil, and of large crystals of pink tourmaline from the Cryo-Genie mine in Warner Springs, California. R.A.H.

Spessartine garnet from Ramona, San Diego County, California.

B.M. LAURS AND K. KNOX. *Gems & Gemology*, **37**(4), 2001, 278-95.

Two pegmatites in the area around the Little Three mine near Ramona, the Hercules-Spessartine and the Spaulding dykes, yielded most of the estimated 40 000– 50 000 ct of facet grade rough mined from 1956 to 1994. Details are given of the history and mining of these pegmatites and electron microprobe results are given for four spessartines (ranging from light orange-yellow to yellow-orange) with composition $Sp_{94.8-88.8}Alm_{4.7-11.0}Gro_{0.5-0.2}$, with n 1.799–1.802; the absorption spectra of all samples show strong peaks for Mn^{2+} and subordinate Fe^{2+} bands. Typical internal features are wavy two-phase partially healed fractures, negative crystals, needles and/or tubes, growth patterns and anomalous birefringence; mineral inclusions are rare. R.A.H.

Korund in Brasilien.

A. LICCARDO AND H. JORDT-EVANGELISTA. *Aufschluss* **53**, 2001, 121-5.

Both ruby and blue sapphire are found in Brazil and over 20 locations are listed and shown on a map. Some stones are colour-enhanced. M.O'D.

Formation of the Denchai gem sapphires, northern Thailand: evidence from mineral chemistry and fluid/melt inclusion characteristics.

P. LIMTRAKUN, K. ZHAW, C.G. RYAN AND T.P. MERNAGH. *Mineralogical Magazine*, **65**(6), 2001, 725-35.

The Denchai gem sapphire deposits in Phrae Province, N Thailand, are closely associated with late Cainozoic alkaline basaltic rocks. The sapphires occur in placer deposits in palaeo-channels at shallow depths. EPMA gave Fe_2O_3 0.32–1.98, TiO_2 0.01–0.23, Cr_2O_3 <0.01, Ga_2O_3 0.01–0.03 and V_2O_5 <0.03 wt.%. Three types of primary fluid/melt inclusions could be recognised: type I are CO_2-rich inclusions with three phases (LH_2O, LCO_2 and V) with the vapour phase comprising 10–15 vol.%; type II are polyphase inclusions (vapour + liquid + solid) with a fluid bubble (20 –30 vol.%), an aqueous phase (10-15 vol. %) and several solid phases; type III are silicate-melt inclusions of vapour bubbles, silicate glass and solid phases. PIXE analyses reveal high K (~ 4 wt.%) as well as Ca (~ 0.5 wt. %), Ti (~ 1 wt.%), Fe (~ 2 wt.%), Mn (0.1 wt.%), V (< 0.03 wt.%), Rb (~70 ppm) and Zr (~ 200 ppm) in the silicate glass. The Ga_2O_3 contents and Cr_2O_3/Ga_2O_3 values (< 1) of the sapphires favour their formation by magmatic processes. The presence of CO_2-rich fluids and high K in the silicate melt inclusions link the origin of these sapphires to CO_2-rich alkaline magmatism. R.A.H.

Gemmologische Kurzinformationen. Padparadscha und/oder Padmaraja.

U.W. LIPPELT. *Gemmologie. Z. Dt. Gemmol. Ges.*, **50**(4), 2001. 228-30.

There is a need in the trade for a definition of the colour of padparadscha, as various fancy-coloured corundums have been given this name. The name refers to the colour of the lotus flower and in southern Asia the

name padmaraja has always been given to a corundum with the colour of a lotus flower; however, padparadscha was the name given to an orange coloured corundum. The author suggests there is only one variety and that the golden yellow sapphire should be called by its proper Sanskrit name of padparadscha. E.S.

Kupferhaltige Turmaline aus Nigeria.

C.C. Milisenda and U. Henn. *Gemmologie. Z. Dt. Gemmol. Ges.*, **50**(4), 2001, 217-23, 4 photographs, 1 map, 2 graphs, bibl.

The Oyo State in western Nigeria produces gem quality tourmalines which owe their colour to trace amounts of manganese and/or copper, similar to tourmalines from Paraiba in north-eastern Brazil. Most of these stones show an amethyst colour and can be heated to an attractive aquamarine blue. Chemical analysis shows that these stones are typical elbaites with traces of Ti, Fe, Cu, Mn, Bi, Pb and occasionally Zn. They are sold under the trade name 'Indigo tourmalines' and also 'Paraiba Africana' however, the very vivid neon blue of the Paraiba stones is hardly seen in the Nigerian specimens. E.S.

Five centuries of Mexican pearls.

D.M. Moreno and E.A. Castillo, *Australian Gemmologist*, **21**(5), 2002, 190-201.

This review covers the history of the Mexican pearling industry in the Gulf of California (also known as the 'Sea of Cortez') from the pre-Columbian Period, through the pervading influence of the Japanese pearl culturing industry which created the Sea of Cortez™ bead nucleated cultured pearl, and of the innovative Mexican methods used to produce loose (whole) cultured pearls from the indigenous pearl oyster (*Pteria sterna*). P.G.R.

Gem Trade Lab Notes.

T.M. Moses, I. Reinitz, S.F. McClure and M.L. Johnson (Eds). *Gems & Gemology*, **37**(4), 2001, 318-25.

Notes are given of a 292 ct charoite host to a large X-shaped spray of tinaksite, a 4.54 ct cat's-eye chrysoberyl cabochon with α 1.780, γ 1.793 and SG 3.81 which was found to be unusually rich in Fe (9–10 wt.% Fe_2O_3 as total Fe), faceted quartz with a large almost spherical inclusion of rhodochrosite, and semi-translucent dark blue star sapphires in which only the stars had been diffusion-induced. R.A.H.

Observation des émeraudes traitées en luminescence U–VISIO

F. Notari, C. Grobon and E. Fritsch. *Revue de gemmologie*, **144**, 2002, 27-31.

Emeralds previously treated with synthetic resins have the resins replaced by cedar wood oil when they come to be cleaned. IR spectrometry and Raman techniques are able to detect the resins but do not precisely establish how much resin remains after the cleaning process: the resins need to be completely removed before replacement with the oil. Luminescence aging is found to be the best method of establishing the complete removal of resin material. M.O'D.

Amethyst und Achat aus S-Brasilien

H. Pöllmann, M.L. Da Costa and R. Wegner. *Aufschluss*, **53**, 2002, 167-80.

Amethyst and agate-producing sites in southern Brazil are identified, shown on a map and discussed with reference to local geology and mineralization. M.O'D.

Zur Geschichte des Smaragds in Brasilien.

H.M.P. Roeser, J. Cesar-Mendes and A.L. Gandini. *Aufschluss*, **53**, 2002, 135-50.

History of emerald mining in Brazil with notes on the different locations which are shown on a map. Chemical compositions of specimens from different mining areas are given. All contain different amounts of Cr, Fe and V. There is an extensive bibliography. M.O'D.

Pink to pinkish orange malaya garnets from Bekily, Madagascar.

K. Schmetzer, T. Hainschwang, L. Kiefert and H.-J. Bernhardt. *Gems & Gemology*, **37**(4), 2001, 296-308.

Garnets from Bekily, SE Madagascar, are predominantly pink to pinkish-orange, with some stones orange to red; electron microprobe results for 11 cut stones and 12 garnets from rock samples show the majority to be intermediate members of the pyrope-spessartine series with variable contents of almandine and minor grossular. The refractive index, specific gravity and colour of these garnets are related to their Fe and Mn contents; in general, they contain less Mn than most malaya garnets from East Africa. Inclusions identified by Raman spectroscopy are platelets and needles of rutile, as well as graphite, quartz, apatite, zircon and sillimanite. R.A.H.

Sterngranate aus Madagaskar.

K. Schmetzer, M. Glas, and H-J. Bernhardt. *Lapis*, **27**(2), 2002, 20-27.

Fine quality asteriated dark red almandine is described from the area of Ambatondrazaka, Madagascar and compared to star garnet from India. Similar material from Ilakaka, Madagascar is also described. Specimens from both places show four rays and a description of the mechanism causing the effect is given. M.O'D.

Star garnets from Ilakaka, Madagascar.

K. Schmetzer and H.-J. Bernhardt. *Australian Gemmologist*, **21**(5), 2002, 202-6.

The three star garnets examined were found in mixed parcels of gem materials originating from the Ilakaka area and are intermediate members of the pyrope-almandine series. Microscopic examination showed that the four and six rayed stars are caused by dense networks of needle-like inclusions orientated parallel to the two-fold axes or parallel to the three-fold axes of the host garnets. P.G.R.

An update on "Paraíba" tourmaline from Brazil.

J. E. Shigley, B.C. Cook, B.M. Laurs and M.O. Bernardes. *Gems & Gemology*, **37**(4), 2001, 260-76.

Vivid blue, green and purple-to-violet elbaites continue to be recovered in small amounts in NE Brazil. Mining is currently taking place at Mina de Batalha and adjacent workings in Paraíba State, and at least two pegmatite local-

ities (the Mulungu and Alto dos Quintos mines) in neighbouring Rio Grande do Norte State. All these pegmatites occur within late Proterozoic metamorphic rocks of the Equador formation; the source of the Cu is unknown. Electron microprobe optical and specific gravity data are given for six cuprian elbaites (Cu 0.40–0.69 wt. %) from the Mulungu mine; these six specimens were 'oiled' to minimize the visibility of surface-reaching fractures. The bright blue tourmaline exhibits minimal pleochroism, so faceting can be done in any orientation. R.A.H.

"Voices of the Earth": transcending the traditional in lapidary arts.

S.E. Thompson. *Gems & Gemology*, **37**(4), 2001, 310-7.

An account is given of work and techniques used by gemstone artists, including the production of convex facets and the use of diamond grits for polishing. Colour photographs are given of some of the pieces by nine leading designers. R.A.H.

Compositions and formation conditions of fluid inclusions in emerald from the Maria deposit (Mozambique).

Y. Vapnik and I. Moroz, *Mineralogical Magazine*, **66**(1), 2002, 201-13.

Fluid inclusions in emerald and quartz from the Maria hydrothermal vein deposit cutting Precambrian ultrabasic rocks were studied using microthermometric and Raman microprobe techniques. In the emeralds, inclusions contain fluids within the Na–Ca–Mg–$(HCO_3)^-$–$(CO_3)^-$–C1–H_2O system saturated in carbonic acid brines. Nahcolite is a main daughter solid phase, the mean nahcolite and NaCl contents being 25 and 5 wt.% respectively. Mg-calcite, magnesite, calcite and aragonite also occur as daughter phases in the fluid inclusions. Groups of nahcolite crystals may amount to ~ 50 vol. % of necked-down inclusions. Zones of fluid inclusions with numerous birefringent solid phases are typical of the Maria emerald deposit. The probable conditions of emerald growth are 400–500°C at 3–5 kbar. R.A.H.

What's new in minerals.

Various Authors. *Mineralogical Record*, **33**, 2002, 255-75.

Among the specimens on display at the Munich show of 2001 were transparent green pargasite from Burma, amethyst from Ambatondrazaka, Toamasina, Madagascar, an octahedral diamond crystal of 2.6 cm from Mbuji-mayi, Congo, fine single crystals of jeremejeevite from Namibia as well as aquamarine from the Erongo mountains in the same country.

At the Pasadena show 2001, were fine transparent tsavorlite crystals of 1.5 and 2 cm, from Arusha, Tanzania. These are unusually large sizes for this material. Specimens at the Tucson show 2002 included some rare hiddenite and emerald from North Carolina, multi-coloured tourmaline crystals from the Baixo mine, Taquaral, Minas Gerais, Brazil, fine rose quartz crystals on quartz from Paroon, Afghanistan and dark purple crystals of fluorite from Yiwu, Zhejiang, China. M.O'D.

Instruments and Techniques

Gemchecker™ professional valuation and appraisal module.

T. Linton and K. Frazer. *Australian Gemmologist*, **21**(5), 2002, 215-8.

This report, by the G.A.A. Instrument Evaluation Committee, concentrates on the professional valuation and appraisal module which is part of the Gemchecker™ computer based system. The complete system has provision for the entry of company and customer records, and gemstone identification data, and contains gemstone image scanning procedures, a comprehensive database of gemstone properties for identification purposes, current price lists for diamonds and coloured stones, and valuation (appraisal) protocols. Familiarity with the modules and operational use is the key to rapid and efficient use of this system. The programme could appear daunting to valuers due to both its size and facilities. However, as it is a modular system, only those parts necessary for operational use need to be purchased. P.G.R.

BOOK REVIEWS

Jewels of the Nizams.

V.R. Bala Krishnan, 2001. Department of Culture, Government of India, New Delhi. Distributed by Antique Collectors' Club, Woodbridge, IP12 4SD, UK. Illus. in colour. Hardcover ISBN 81 7508 306 9. £50.00.

The jewel collections of the Nizams of Hyderabad were offered for sale to the Indian Government in 1972. It took 23 years for the negotiations to be concluded: tax issues were involved. At last in 1991, the Supreme Court of India ruled that the Government would pay the trusts set up to handle the effects of the Nizam more than 2 billion rupees for 173 items of jewellery. Modifications to the ruling with a diminution of the sum and the incorporation of the whole of the jewellery collections were made subsequently in 1993. This was not the end of the story since the final settlement was not made until 12 January 1995 when the collections finally became the property of the people of India.

The wealth of the Asaf Jah dynasty is recorded as far back as the 14th century and the book summarizes the history of the dynasty before describing the ways in which the collections were formed and augmented by astute purchasing, often from dealers in Europe and the United States.

The book then becomes a 159 page *catalogue raisonné* in which all the pieces are illustrated in colour with full descriptions, including measurements, stone and metal details. Former owners are identified where possible.

The book continues with a list of references and a glossary of Indian jewellery terms, a bibliography and an index. The standard of reproduction is high and the price most reasonable for a book of this kind. M.O'D.

Geschönte Steine.

B. Bruder, 1998. Neue Erde, Saarbrücken [Rotenbergstr 33, D-66111 Saarbrücken]. pp 109, illus. in colour, softcover. ISBN 3 89060 025 5. Price on application.

After a brief introduction to gem testing methods, the text examines treated stones in alphabetical order and includes a number of photographs of quite pleasing quality. The text is quite well organized but an adequate bibliography should have been provided. Nonetheless, this is a useful introduction to an ever-changing subject, though serious study would require a much greater depth of coverage. M.O'D.

Handbook of near-infrared analysis. (2nd edn, revised and expanded.)

D.A. Buns and E.W. Ciurczak, 2001. Marcel Dekker Inc., New York. pp xv, 814. Hardcover, ISBN 0 8247 0534 3. US$225.00.

This is a very large general survey of the many uses of near-IR analysis, covering such varied topics as history and development of techniques, calibration and applications. Those with an interest in gem materials will note the section dealing with the detection of counterfeit turquoise. Here the problem was the use of coloured plastic to imitate the natural material and consequent unfavourable media attention given to the problem in the south-western areas of the United States where turquoise was traditionally produced. Near-IR analysis quickly identified plastic substitutes for natural turquoise showing peaks in the spectrum in the areas where natural turquoise is usually flat. Notes on the use of organic fillers in other gem minerals are given and there are short notes on how they may be detected. Readers browsing in this area of the book will also find good coverage of the detection of counterfeit currency! Each section has its own list of references and the diagrams and tables are easy to read. M.O'D.

Diamond: the story of a cold-blooded love affair.

M. Hart, 2001. Fourth Estate, London. pp 287. Hardcover ISBN 1 84115 279 X. £15.99.

An account of the work of the De Beers organization with a number of sketches illustrating diamond recovery and sales in different parts of the world. The entry of the company into the polished goods market is described as well as the effects of the Canadian diamond rushes of recent years. Among the stories is a step-by-step account of the polishing of the Centenary diamond by Gabi Tolkowsky in 1998. The style is clear and concise – the book can be read at a single sitting. There is a useful bibliography and an index. The book is recommended to gemmologists and diamond specialists who will enjoy the politico/ commercial issues raised. M.O'D.

Tektites in the geological record: showers of glass from the sky.

G.J.H. MacCall, 2001. The Geological Society, London. pp vii, 256, illus. in black-and-white. Softcover, ISBN 1 86239 085 1. £65.00 (£25 to Fellows of the Geological Society).

Tektites, some of which have been used ornamentally and more as collectors' prizes, are found on Earth only in four *strewn fields* which are described in this excellent, easily-understood and timely survey. Tektites are mostly formed from projected melt from terrestrial rocks at a site of impact, a process still not fully understood. The velocities and trajectories of the melt projected from these sites are still being studied and some details of the work being carried out accompany descriptions of the major impact sites.

Discussion of glasses related to tektites includes some of the latest thinking on Darwin Glass and Libyan Desert Glass, this being familiar to gemmologists. There appears to be no close connection between Libyan Desert Glass

and tektites though there is almost certainly a meteoritic relationship. The glass (which is almost pure silica) has never been found in any form other than dispersed lumps and these may have originally formed part of a melt sheet. An impact source is at least probable.

There is a glossary and a first-rate bibliography, and discussions of topics other than the two I have selected are equally well written and interesting. The Society is to be congratulated on accepting this monograph for publication. M.O'D.

Black opal. A comprehensive guide to cutting and orientating.

GREG PARDY, 1999. GP Creations, PO Box 340, Urangan, QLD 4655, Australia. pp 203. Hardback and videotape. ISBN 0 646 37266 1. Price on application.

This is a very well produced book dealing with the whole process of cutting black opal from the rough material to the finished gemstone. The writing is somewhat 'homespun' in a conversational manner but this does not detract from the quality of information contained in its pages, and it is obviously written by a master of this branch of lapidary work. The book opens with a detailed account of the occurrence of opal in Australia and the types of opal to be found in various mining regions of Queensland, but is primarily concerned with black opal found in the Lightning Ridge, Sheepyards, Grawin-Glengarry Fields and Coocoran opal fields.

The various types of opal 'nobbies' (rough opal as mined) and their local names are illustrated with excellent photographs. This is followed by an account of the latest mining methods also accompanied by clear illustrations of the equipment. The main body of the book then deals with orientation, lapidary equipment and Greg Pardy's technique for producing solid, doublet and triplet opal gems. This is clearly written and easy to follow, with clear illustrations accompanying the various stages of the processes.

The photographs of finished black opal gems by Len Cram and Pasquale Giorgio are superb, particularly those of the 17 ct Eye of Destiny, the 100 ct green on black gem, and the triplet mosaic oval cabochon.

The book is accompanied by a video cassette running for 1 hour 52 minutes produced and filmed by Pasquale Giorgio, and edited by Megan Turner. This shows the processes described in the book in clear detail with a running commentary by Greg Pardy as the opal is gradually converted from a rough nobby to a beautiful black opal gemstone. There is no hurrying, in fact the only criticism that might be made is that the film seems rather slow, but this is only because the cutting process is followed faithfully with no omission of practical details. There are no unnecessary comments or detracting background music, and the video would serve well as a basic teaching method for producing gem cabochons applicable not only to black opal but to most materials. The book and video should be in every gem cutter's library and can be recommended. A.D.M.

Royal treasures: a Golden Jubilee Celebration.

J. ROBERTS (Ed.), 2002. Royal Collection Enterprises Ltd., London. pp 496, illus in colour. Softcover ISBN 1 902163 52 4. £27.00.

The Royal collections contain all forms of fine art, including jewellery, and a selection of the finest items has been placed on display in a new purpose-built gallery at Buckingham Palace. While the present arrangement commemorates the Golden Jubilee of The Queen, no doubt the exhibits will be regularly changed. The catalogue is very well produced, lies flat when opened and is reasonably priced.

Readers will first look for the items of jewellery which are described in pages 219-235. There are 18 pieces, including several cameos, the Darnley Jewel (attributed to Scotland), the Diamond Diadem made in 1820 for the coronation of George IV, the Cullinan Brooch of 1908-10 made by Joseph Asscher & Co. and containing Cullinan diamonds 3 and 4 of 94.4 and 63.6 ct, Queen Victoria's diamond necklace and drop earrings of 1858, the necklace supporting a pendant diamond of 22.48 ct. The Great and Lesser Georges, Garter collar and sash badges respectively, are of considerable historical interest: both are set with diamonds.

Hardstone flowers and plants form a separate section of the catalogue, some of the examples making use of diamonds and rubies as well as hardstones and enamels. Specimens of Fabergé work are included in this section.

Indian works of art include jewelled daggers and the emerald belt of Maharajah Sher Singh, made around 1840. This formed part of the exhibition of Mughal jewels held at the British Museum in 1999. Foremost among the items in this section is the Timur Ruby necklace in which the red stones are spinels, the centre stone with an engraved inscription.

This is a selection only and the exhibition should be visited at least once. Those readers interested in coronations will be pleased to see John Whittaker's *Ceremonial of the Coronation of His Most Sacred Majesty King George the Fourth*, 1823 and printed in gold throughout. Tortoiseshell at its finest can be seen as the binding material for *Holy Bible*, 1776, which is accompanied by the *Prayer Book* of 1815. *Corals, fossils and mineral specimens* is the title of a watercolour by Vincenzo Leonardi, dated between 1630-40. M.O'D.

Gem-A Education

Short courses and Workshops

Wednesday 25 September	**Bead stringing workshop** *Gem-A Member price £126.90 (Non-Member price 138.65)*
Wednesday 2 October	**Welcome to gemmology** *Gem-A Member price £99.88 (Non-Member price £112.80)*
Wednesday 9 October	**Diamond buying guide** *Gem-A Member price £116.33 (Non-Member price £129.25)*
Wednesday 23 October	**Gemstones for jewellers** *Gem-A Member price £116.33 (Non-Member price £129.25)*
Tuesday and Wednesday 29-30 October	**Synthetics and enhancements (two-day workshop)** *Gem-A Member price £232.65 (Non-Member price £258.50)*
Friday 1 November	**Sketching for sales** *Gem-A Member price £126.90 (Non-Member price £138.65)*
Monday 4 November	**Glorious technicolour – an insight into the world of opal** Guest lecturer: David Callaghan *Gem-A Member price £126.90 (Non-Member price £138.65)*
Saturday and Sunday 9-10 November	**Stone faceting weekend** Guest lecturers: Roger Young and Jim Finlayson *Gem-A Member price £211.50 (Non-Member price £235.00)*
Wednesday 20 November	**All about pearls** Guest lecturers: Ann Margolis and Stephen Kennedy *Gem-A Member price £126.90 (Non-Member price £138.65)*

Student Workshops

Tuesday – Thursday 26-28 November	**Three-day preliminary workshop** *Gem-A student price £183.30*
Thursday 28 November	**Preliminary theory review** *Gem-A student price £64.63*
Saturday and Sunday 4-5 January	**Weekend diamond grading revision** *Gem-A student price £164.50*
Saturday and Sunday 4-5 January	**Two-day Diploma practical workshop** *Gem-A student price £164.50*
Monday 6 January	**Diploma theory review** *Gem-A student price £64.63*

All workshops held at the Gem Tutorial Centre, 27 Greville Street, London EC1N 8TN

For further information and a booking form contact Rachel Warner on 020 7404 3334 or visit our website at www.gagtl.ac.uk

Proceedings of the Gemmological Association and Gem Testing Laboratory of Great Britain and Notices

Photographic Competition

The 2002 Photographic Competition on the theme of ***Out of the Ordinary*** drew a record number of unusual and interesting stones or unusual cuts of the better-known gem species.

First Prize

Bob Maurer FGA DGA, London

Amethyst 34.52 ct by Bernd Munsteiner from the collection of Thomson Gems (also illustrated on front cover).

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Second Prize

Michele White, FGA, DGA, RBSA, Moseley, Birmingham, West Midlands

Landscape agate mounted in an 18ct gold hand-made brooch by Michele Wight.

Third Prize

John Harris FGA, Durdar, Carlisle, Cumbria

Feathers applied to a mother-of-pearl background gold brooch, mid-19th century.

We are pleased to announce that the prizes were sponsored by Harley UK, and the Association is most grateful to them for their generosity. The prizes will be presented and the winning entries exhibited at the Annual General Meeting to be held on 25 September.

OBITUARY

John Sinkankas, the finest gem cutter of his time, the most lucid of writers in English on mineral and gem topics and the kindest and most approachable of men, died after a short illness on 17 May 2002.

John was born to Lithuanian immigrant parents on 15 May 1915, and grew up close to the traprocks of New Jersey in which he soon took an interest during boyhood. The proximity of New York City with its museums and the existence of mineral collecting groups inspired an interest that was never to leave him. It was not the only one however, since he developed a considerable skill in water-colour painting which is well shown in his *Gemstones of North America and Emerald and other beryls.*

At the same time, John came to love flying and in fact spent many years as an aviator with the United States Navy, concluding his active career there in 1961. He had been through the Second World War and the Korean War.

After the war John was able to pursue his mineral and gem interests more fully and became a celebrated lapidary, combining practical skill with a gift for teaching which comes out in all his books. He found ways to facet crystals which were previously thought too fragile to fashion, and at the same time he owned interests in a number of celebrated gem mines in the United States.

John built up a superb library of gem books which are now part of the collections of the Gemological Institute of America: with Marge his wife he operated Peri Lithon Books which was an eye-opener to me when I first visited it – even after curating the British Museum's earth science books for years.

What I have written is a very small part of one of the most active lives I have known, but it does not quite show how nice a man he was. He had great times looking for and finding fine tourmalines in southern California some years ago: I remember best his frequent use of "y'know" and "y'see" which I have made, quite inadequately, my own. A fine way to access John is

to listen to his commentary on part of the video *Gemstones of North America.*

John included a brief autobiography to pages 1163-6 of the second volume of *Gemology: an annotated bibliography* (1993) and I have drawn on this for John's earlier years. This major work is as good as it could be, like all John's productions.

We offer our sympathy to Marge who is just as much a distinctive character as her husband and who ran Peri Lithon Books with great skill and kindness. Michael O'Donoghue

* * *

Maurice M. Whitehead FGA (D.1950), East Horsley, Surrey, died recently.

GIFTS TO THE ASSOCIATION

The Association is most grateful to the following for their gifts for research and teaching purposes:

Stuart Dennis of Asprey & Garrard, London, for cut gemstones and diamonds.

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Joseph Tenhagen, FGA, Miami, Florida, U.S.A., for a large collection of cut gemstones.

The Worshipful Company of Goldsmiths, London, for a donation of £50,000.

MEMBERS MEETINGS

London

On 3 May at the Gem Tutorial Centre, 27 Greville Street, London EC1N 8TN, Joseph Tenhagaen of Miami, Florida, gave a talk on 'New aspects of cut in round brilliant-cut diamonds'. A report was published in the June issue of *Gem & Jewellery News*, **11**(3), 2002), p. 56.

On 21 May there was a private viewing and tour of the Tiaras exhibition at the Victoria and Albert Museum, South Kensington, with exhibition curator, Geoffrey Munn.

On 26 June at the Gem Tutorial Centre, Richard W. Hughes of Fallbrook, California, gave a talk on Burma ruby and new corundum treatments. A report will be published in the September issue of *Gem & Jewellery News*.

Midlands Branch

On 26 April at the Earth Sciences Building, University of Birmingham, Edgbaston, Dr Jamie Nelson gave a fascinating insight into the behaviour of light in gemstones and the idiosyncrasies of gemstone cuts. The meeting also included the Branch AGM when David Larcher, Gwyn Green, Elizabeth Gosling and Stephen Alabaster were re-elected, President, Chairman, Secretary and Treasurer respectively.

On 19 June a Gem Club was held at Barnt Green when Doug Morgan and David Larcher ran a practical session on photomicroscopy.

The annual Summer Supper Party was held on 22 June at Barnt Green.

North West Branch

On 17 April at Church House, Hanover Street, Liverpool 1, Dr Roger Harding gave a talk entitled 'Gems in the collection of the Natural History Museum, London'.

On 15 May at Church House Rosamond Clayton gave a talk entitled 'Diamonds – the fourth dimension (cut)'.

A Bring and Buy was held on 19 June at Church House.

Scottish Branch

The Annual Scottish Branch Conference was held in Perth from 3 to 6 May, keynote speaker Ted Themelis. A report was published in the June issue of *Gem & Jewellery News*, 11(3), pp. 52-54.

On 30 June at the National Museum of Scotland, the George Lindley & Co. Lecture was given by Richard Hughes entitled 'Crossing gemmological frontiers'.

South West Branch

On 19 May at the Bath Royal Literary and Scientific Institution, 16-18 Queen Square, Bath, Michael Norman, Chairman of the Guild of Independent Valuers, gave a talk entitled 'The colour of money'.

The talk was followed by a practical session on red stones with Richard Slater, Keri Slater and Bronwen Harman.

Gem-A BRANCH LAUNCHED IN USA

In response to a demand by members in America, a new branch of Gem-A has been launched – Gem-A USA.

Internationally-renowned diamantaire Gabi Tolkowsky spoke at the Gem-A USA launch in Las Vegas held on Sunday 2 June, reminding us that "Education generates the future for thousands of people around the world", adding 'Education is eternal like the diamond – it starts and never stops'.

Anne Ferrara Dale FGA GG, has been appointed Director of Gem-A USA. She is the owner of a retail jewellery store in Louisiana and is a federal expert witness for the Internal Revenue Service. Anne is a Fellow of Gem-A having qualified in the Gemmology Diploma Examination in 1987, and is also a graduate of the Columbia School of Gemology and the GIA.

In her work as Gem-A USA Director, Anne will concentrate on promotion of Gem-A Education and Membership, coordinating with trade organizations and aiming at unified and supportive relationships with the trade through Gem-A Education.

Gabi Tolkowsky speaking at the launch of Gem-A USA.

Anne Ferrara Dale, Gabi Tolkowsky and Terry Davidson at the JCK Show, Las Vegas.

MEMBERSHIP

Between 1 April and 30 June the Council of Management approved the election to membership of the following:

Fellowship and Diamond Membership (FGA DGA)

Kwok Hei, Tsing Yi, New Territories, Hong Kong, 2002/2002

Fellowship (FGA)

Beck, Cyril Anthony, Sale, Cheshire, 1967
Chaudhari, Ruchi, West Lafayette, Indiana, U.S.A., 1997
de Vries, The Hague, The Netherlands, 2002
Dimmick, Helen Margaret, London, 2001
Douthwaite, Elaine, Shipley, West Yorkshire, 1982
Francis, Melanie, Toronto, Ontario, Canada, 2002
Green, James E.W., Pelsall, Walsall, 1979
Ho, Feony P.C., Kwun Tong, Kowloon, Hong Kong, 2002
Hsieh, Ming-Tsung, Feng-Yuan City, Taichung, Taiwan, R.O.C., 2002
Knight, James Harry, London, 1988
Lwin, Mon Mon Myat, Kamayut Township, Yangon, Myanmar, 2002
Mitch, Alexandra F., Galveston, Texas, U.S.A., 2002
Roberts, Justin John, Wembley, Middlesex, 2002
Roy, Maryse, Montreal, Quebec, Canada, 2002
Schraq, Catharina Neeltje, Gaes, The Netherlands, 2002
Segal, Neil Conrad, Umhlanga Rocks, South Africa, 1979
Tangsubkul, Hiranya, Bangkok, Thailand, 2002
Toullic, Nathalie, Brentford, Middlesex, 2002
van Dam, Anita Johanna, Maasland, The Netherlands, 2000
van der Made, Barbara Claudia, Ermela, The Netherlands, 2002

Diamond Membership (DGA)

Leeks, David, Semarang, Indonesia, 2002
Ma Mei Chuan, Sai Kung, New Territories, Hong Kong, 2002
Petrozello, Ryan, Randolph, New Jersey, U.S.A., 2002
Zhang, Xiao Ling, Kowloon, Hong Kong, 2002

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1–4 September – Earls Court 2, London

NEW! Gem Seminar Theatre

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Passion for pearls. CHRISTIANNE DOUGLAS, Christianne Douglas Pearls
Myths and magic of gemstones. DOUG GARROD, Gem-A
Is it orange or just skin deep? MARTIN HARMON, GIA
Diamond: demystifying cut. MARTIN HARMON, GIA
Buying gemstones at auction. DAVID LANCASTER, Christie's South Kensington
You buy what you see. HARRY LEVY, Chairman, BJA
How much will you give me for my reputation? HAYWOOD MILTON, Miltons (Liverpool) Ltd, Jewellers and Pawnbrokers

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FORTHCOMING EVENTS

4 September	**Scottish Branch.** *Colourful corundum – a view from 'down-under'.* LIN SUTHERLAND. *The Portuguese Crown Jewels.* RUI GALOPIM DE CARVALHO.
18 September	**North West Branch**. *Chasing rainbows.* JOHN HARRIS.
25 September.	**London**. Annual General Meeting and lecture (free of charge – Gem-A members only).
27 September.	**Midlands Branch**. *Diamonds, certification, appraisal and valuation.* RICHARD TAYLOR.
16 October	**North West Branch.** *Jewels for a Royal occasion.* ROSEMARY I. MCIVER.
25 October	**Midlands Branch.** *Tucson surprises – the highlights of Tucson 2002.* ALAN HODGKINSON.

Gem-A Conference 2002

To be held on
Sunday 3 November
at Kempton Park Racecourse, Sunbury on Thames, Middx.
In conjunction with the Rock 'n' Gem Show
Speakers:
Professor Dr Edward J. Gübelin
Professor Andy Rankin
Dr Bob Symes OBE
Stephen Webster

4 November	**Presentation of Awards and Reunion of Members.** Goldsmiths' Hall, Foster Lane, London EC2.
19 November	**Scottish Branch.** The Crown Jewels. E. ALAN JOBBINS.
20 November	**North West Branch.** AGM and social evening.
29 November	**Midlands Branch.** *Fabulous Fabergé expert, auctioneer and buyer.* STEPHEN DALE.
7 December	**Midlands Branch.** Celebration 50th Anniversary Dinner.

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(when using e-mail, please give Gem-A as the subject):

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Midlands Branch:	Gwyn Green on 0121 445 5359; e-mail gwyn.green@usa.net
North West Branch:	Deanna Brady 0151 648 4266
Scottish Branch:	Catriona McInnes on 0131 667 2199; e-mail scotgem@blueyonder.co.uk
South West Branch:	Bronwen Harman on 01225 482188; e-mail bharman@harmanb.freeserve.uk

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Guide to the preparation of typescripts for publication in *The Journal of Gemmology*

The Editor is glad to consider original articles shedding new light on subjects of gemmological interest for publication in *The Journal*. Articles are not normally accepted which have already been published elsewhere in English, and an article is accepted only on the understanding that (1) full information as to any previous publication (whether in English or another language) has been given, (2) it is not under consideration for publication elsewhere and (3) it will not be published elsewhere without the consent of the Editor.

Typescripts Two copies of all papers should be submitted on A4 paper (or USA equivalent) to the Editor. Typescripts should be double spaced with margins of at least 25 mm. They should be set out in the manner of recent issues of *The Journal* and in conformity with the information set out below. Papers may be of any length, but long papers of more than 10 000 words (unless capable of division into parts or of exceptional importance) are unlikely to be acceptable, whereas a short paper of 400–500 words may achieve early publication.

The abstract, references, notes, captions and tables should be typed double spaced on separate sheets.

Title page The title should be as brief as is consistent with clear indication of the content of the paper. It should be followed by the names (with initials) of the authors and by their addresses.

Abstract A short abstract of 50-100 words is required.

Key Words Up to six key words indicating the subject matter of the article should be supplied.

Headings In all headings only the first letter and proper names are capitalized.

A **This is a first level heading**

First level headings are in bold and are centred on a separate line.

B *This is a second level heading*

Second level headings are in italics and are flush left on a separate line.

Illustrations Either transparencies or photographs of good quality can be submitted for both coloured and black-and-white illustrations. It is recommended that authors retain copies of all illustrations because of the risk of loss or damage either during the printing process or in transit.

Diagrams must be of a professional quality and prepared in dense black ink on a good quality surface. Original illustrations will not be returned unless specifically requested.

All illustrations (maps, diagrams and pictures) are numbered consecutively with Arabic numerals and labelled Figure 1, Figure 2, etc. All illustrations are referred to as 'Figures'.

Tables Must be typed double spaced, using few horizontal rules and no vertical rules. They are numbered consecutively with Roman numerals (Table IV, etc.). Titles should be concise, but as independently informative as possible. The approximate position of the Table in the text should be marked in the margin of the typescript.

Notes and References Authors may choose one of two systems:

(1) The Harvard system in which authors' names (no initials) and dates (and specific pages, only in the case of quotations) are given in the main body of the text, (e.g. Collins, 2001, 341). References are listed alphabetically at the end of the paper under the heading References.

(2) The system in which superscript numbers are inserted in the text (e.g. ... to which Collins refers.[3]) and referred to in numerical order at the end of the paper under the heading Notes. Informational notes must be restricted to the minimum; usually the material can be incorporated in the text. If absolutely necessary both systems may be used.

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Papers Collins, A.T., 2001. The colour of diamond and how it may be changed. *J.Gemm.*, **27**(6), 341-59

Books Balfour, I., 2000. *Famous diamonds*. 4th edn. Christie's, London. p. 200

Abbreviations for titles of periodicals are those sanctioned by the *World List of scientific periodicals* 4th edn. The place of publication should always be given when books are referred to.

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Amethyst 34.52 ct.
Photograph by Bob Maurer
First Prize in the Photographic Competition, see p. 183

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The Journal of Gemmology

Volume 28 No. 4 October 2002

Development of concave faceting

Verneuil synthetic sapphire

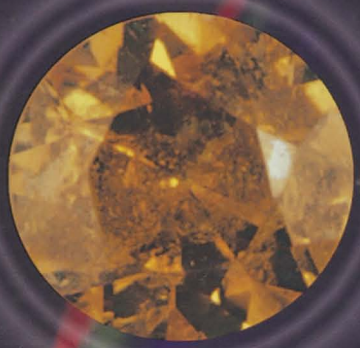

Gem-quality spessartine-grossular garnet

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Development of concave faceting of gemstones

A.D. Morgan

Birmingham, West Midlands

ABSTRACT: A brief review of gem faceting methods intended to enhance the visual appearance of the stone is introduced, with illustrations of stones with various special cutting designs. Machines recently developed for producing concave facets on gem stones are illustrated and discussed. A detailed description of a machine for amateur use developed by the author is given, and the problems encountered in this method of faceting are outlined. The result of an experiment with a specially cut triangular prism having simple flat and cylindrically concave facets to compare the refracted ray patterns is shown, together with the computer-calculated theoretical ray path of a pencil of light impinging on a combination of concave lenslets and convex mirrors. Two concave faceted stones cut by the author, one in CZ and one in fluorite are featured and the patterns obtained with a Nelson Gem Fingerprinter are illustrated.

Keywords: Concave facet, faceting, gem cutting machines

"is it original
it was once I answered truthfully
and may be again"

don marquis, 1930

Introduction

The faceting of rough gem material to produce an optically attractive gem is a highly specialized and skilled art. Over many years, several facet designs claiming to enhance visual appearance and scintillation have been published. This is particularly so in the case of diamond, where apart from its colour and weight a considerable proportion of the value of the stone is related to the geometry and correct placing and polishing of flat facets. This has resulted in the development of standard cuts for round brilliants and other shapes to give maximum brilliance and weight yield from the rough crystal. Further developments include the introduction of the Profile (Princess) cut by Arpad Nagy (1960), which has a series of V-grooves cut into the back of the stone, enabling flat crystals to be cut economically, and the Barion Cut by Basil and Marion Watermeyer (*c.* 1970).

In the case of coloured stones, whilst rarity, colour and weight are the predominant factors determining the value, the overall appearance has considerable influence on the attractiveness of the stone, and heart shaped, shield, navette, cushion, mixed cut and many other geometrical designs have appeared.

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***Figure 1**: 42 ct (Nd) YAG 'Pinwheel' design (Ed Hume 1997) cut by Doug Morgan 1997 showing 'wheel' in the bottom of the stone.*

Although there are ideal optimum cutting angles for the pavilion facets so that total internal reflection of the refracted rays will take place and give brilliance and dispersion, depending upon the refractive index of the gem material, commercial considerations often override this ideal in order that maximum yield in weight and size can be obtained. From the jewellery design aspect, often stones are cut with a shallow pavilion for mounting in finger rings. This can result in low refractive index stones having a 'fish eye' where light rays incident to the table pass straight through the stone without contributing to the brilliance and dispersion.

Cutting for special effects

Many novel effects have been produced however by deliberately cutting selected pavilion facets at angles below the critical ideal, for example the 'Pinwheel' design by Ed Hume (1997) which shows the 'wheel' as a dark pattern in the bottom of the stone (*Figure 1*). Other novel effects have been produced by frosting certain facets such as in the Canadian Maple Leaf Cut by Al Manastar (1999). In this some of the pavilion facets in the design of the maple leaf are frosted and so stand out from the remaining polished pavilion facets (*Figure 2*). This frosting technique has also been used to amusing effect as in the faces by Art Grant where a domed crown is frosted and a caricature face is polished into this background (*Figure 3*). Another novel effect is produced by cutting the crown as a domed hemisphere on which a pattern of small flat facets are placed, as in the 'Dandelion' cut. This was designed by the Finnish cutter Tauno Paronen, and a photograph of a stone cut by the author in quartz to the diagram[1] by W.J. Maloney Jr. is shown in *Figure 4*.

***Figure 2**: 'Canadian Maple Leaf' design cut by Al Manastar 1999.*

***Figure 3**: 'Funny face' design cut by Art Grant.*

***Figure 4**: 'Dandelion' design by Tauno Paronen and W.J. Maloney Jr. cut by Doug Morgan 2002.*

***Figure 5**: Early groove cut 3.33 ct amethyst.*

In 1992, computer aided design (CAD) was applied to faceting by Robert W. Strickland, and his program GemCad 4.0 became available for amateur use. The program enables one to draw a gemstone pattern directly on the computer screen, it then calculates all the necessary cutting angles, shows the light ray paths and prints an expected view and brilliance factor for that particular design. A skilled user of this program can thus calculate the best cutting data for any rough material without wasting time and material. A data base (DATAVUE) of over 3500 patterns having standard flat facets is also available, and it is apparent that facet design is now on a sound mathematical foundation. The formation of lapidary societies, guilds and clubs in America, Australia and more recently in this country, has been instrumental in bringing together the large number of individual cutters with their design contributions, and there is a continual forward movement to invent and introduce new and novel facet designs, as shown in the regular contributions to the American *Lapidary Journal* and various club and guild newsletters.

In recent years considerable interest has been shown in the cutting of concave facets on gemstones as a design feature both of novelty value and to increase the attractiveness of the stone.

***Figure 6**: Early groove cut 35.44 ct citrine.*

***Figure 7**: Early groove cut 17.58 ct rock crystal.*

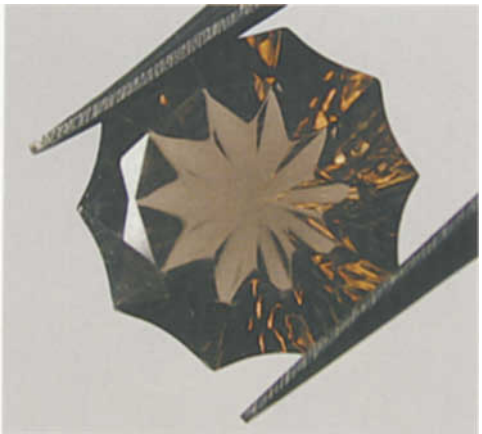

Figure 8: 7.5 ct smoky quartz 'Daisy' cut 1960 design.

Cutting of concave facets

Concave facets have been cut on diamonds, and two small triangular diamonds with spherically concave crown facets are reported in Gem Trade Laboratory Notes in *Gems & Gemology*, p.161, 1981. Nearly a century ago (1910), Jean Louis Gonard was granted US Patent 946,939 for a method of cutting concave crown facets on diamonds "with the object of securing increased brilliancy" and a 2.68 ct old mine cut with a concave table is shown in *Gems & Gemology* Gem Trade Laboratory Notes, p.171-2, 1989. It is believed that this diamond may be related to this patent. These are said to be the only three diamonds with concave facets ever seen in the GIA Gem Trade Laboratory.

With regard to coloured fancy stones, the 'Freehand Sandstone Faceters' in the area around Idar-Oberstein over 100 years ago were producing stones with concave cut facets on the pavilion. The sandstones were over 100 cm diameter and had a 20 cm face with profiles to give concave grooves in the stones. These became quite fashionable around 1920, and later in 1950-1965, some synthetic stones were cut using metal lap wheels[2]. Typical examples of these stones are shown in *Figures 5, 6 and 7*. As freehand cut stones they represent masterpieces of the cutters art.

Figure 9: Modern groove cut 8 ct citrine.

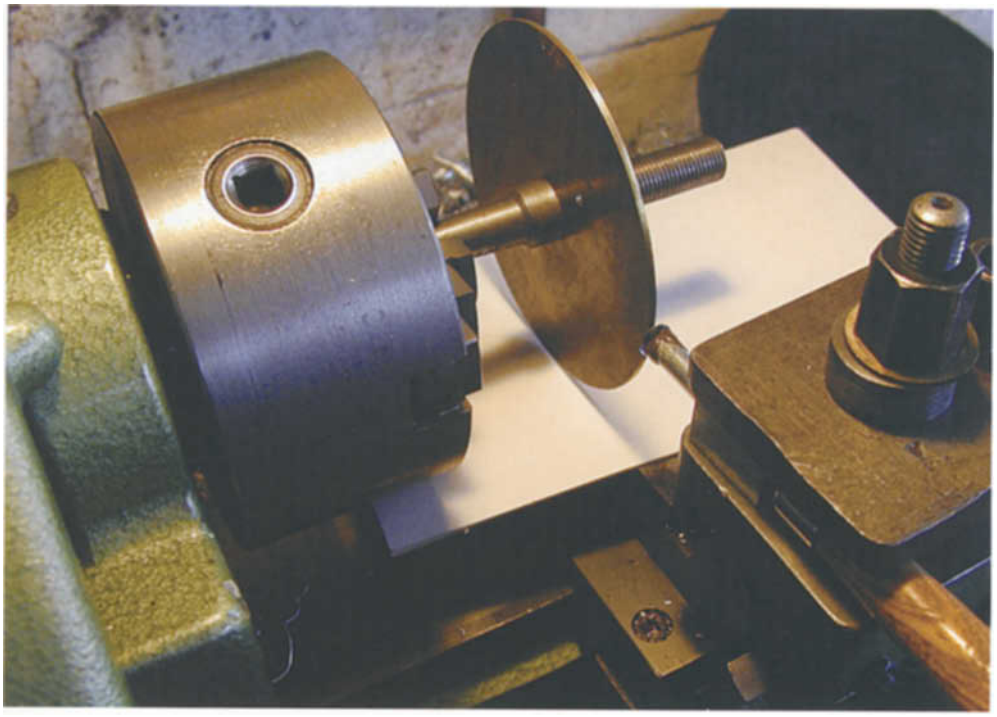

***Figure 10**: Lathe set-up for cutting concave table.*

An attempt was made in c.1960 to introduce cylindrically concave faceted fancy stones into the British Gem Trade as 'Daisy' cut but at the time the somewhat conservative outlook deemed these unfashionable, and they also presented a design problem in mounting[3]. One of these cut from smoky quartz, having a 10-sided scalloped girdle, is shown in *Figure 8*. A modern cut stone in citrine having a pavilion with grooved facets is shown in *Figure 9*.

Practical considerations

As part of a research project the author was asked to produce a specially cut stone in (Nd)YAG with a spherically concave table facet of accurate radius of 50 mm. Traditional lens making methods were considered, but an alternative method which gave greater flexibility was developed using a normal machine shop lathe as follows.

A disc 2 mm thick in brass was machined to the required radius, and the rim profiled to the same radius of curvature, i.e. the surface of the sphere. This was mounted on a mandrel held in the three-jaw chuck and charged with diamond grit. The stone, previously cut and polished to the required specification was mounted on the end of a spindle acting as a dop, and the spindle was mounted in a bearing clamped to the lathe tool post with its axis corresponding with the disc centre axis. The diamond charged disc was rotated at 300rpm, whilst the previously polished stone table could be applied to the disc rim via the spindle which was rotated by hand, this enabled the required spherically concave profile to be generated and ground into the surface. Subsequent use of discs having finer diamond grit, and using a tin disc charged with 1micron diamond powder for polishing gave the required result. Changes in required radius could easily be made by using discs of differing diameters. The lathe set-up is shown in *Figure 10*.

An alternative method for producing spherically concave depressions is to use a rotating sphere as a cutting lap, and this is in

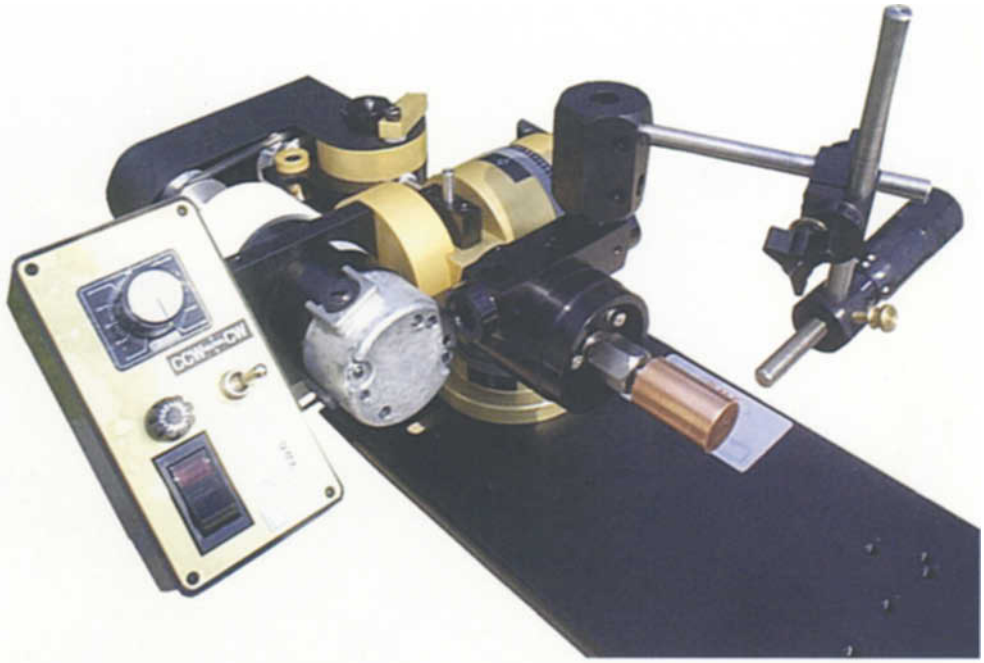

Figure 11: OMF Faceter. General view.

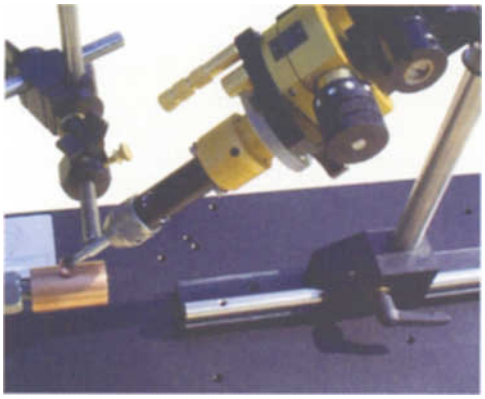

Figure 12: OMF Faceter. Detail of adjustable stop.

effect a carving ('cutting') operation such as that used by crystal glass cutters and engravers. If a series of depressions is required then some form of indexing is used.

The main development in gem cutting which is the subject of this paper however, uses a cutting lap which is a rotating cylinder charged with abrasive diamond grit, and the gemstone held on a dop stick in a faceting head is presented to the cutting surface to give a depression of the required depth at indexed positions. A number of machines for carrying out this operation referred to as 'Concave cutting' have been developed. The operation would more strictly be classed as 'Cylindrically concave cutting'.

Cutting machines

The stones having concave pavilion facets cut in Idar Oberstein were fastened to a dop stick and held by hand against a sandstone grinding wheel. Subsequent polishing of the facet by hand took place on a lead lap wheel. No machinery having an indexing system and facet angle indication was used. The profiles on the sandstone wheels gave grooves of 15 mm and 3 mm diameter as determined by measuring a sectioned plaster cast made from a specimen gemstone. The culet and some pavilion mains angles were cut below the critical angle and showed a pattern similar to the Pinwheel cut described earlier.

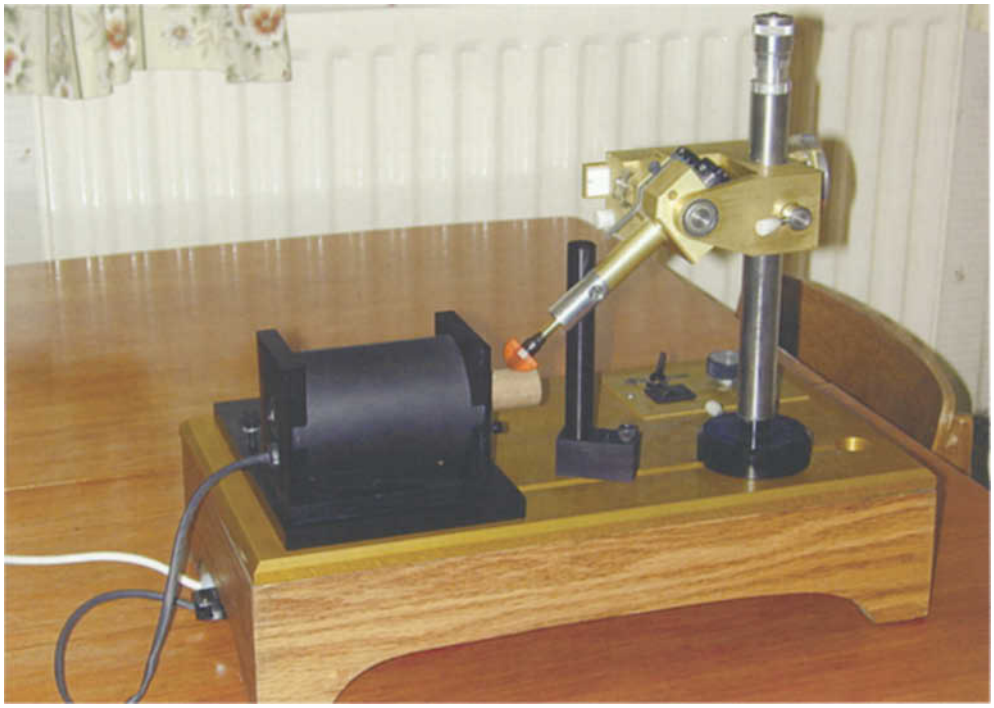

***Figure 13**: Facetron Special Cut Machine. General view.*

The OMF Concave Faceting machine

On 3 September 1991, USA patent No. 5,044,123 filed 22 March 1990 was granted to Douglas Hoffman for a "Concave-convex faceting method and apparatus". The abstract for this patent reads as follows:

"An apparatus is described for producing concave or convex optically magnified facets about a gem, each facet being on a curved surface that is a section of a cylinder. It utilizes a mandrel having an exterior and/ or interior cylindrical abrasive surface. The surface is contacted by a gem indexed and adjustably held by a gem support structure. The mandrel is angularly moveable about its central axis. It can also be reciprocated along the axis to prevent the formation of random striations across the facet surfaces. An adjustable stabiliser can be preset to engage a dop attached to a gem at a location adjacent to the mandrel. This assures accurate reengagement of the gem after movement from the mandrel for interim inspections during the faceting procedure. The method of producing the optically magnified facets requires successive indexing of the gem and bringing it into contact with an angularly moving cylindrical abrasive surface. The resulting gem can have one or more curved facets about its outer surface having the form of a section of a cylinder. The facet surfaces can be either concave or convex. A preselected pattern of grooved facets can be

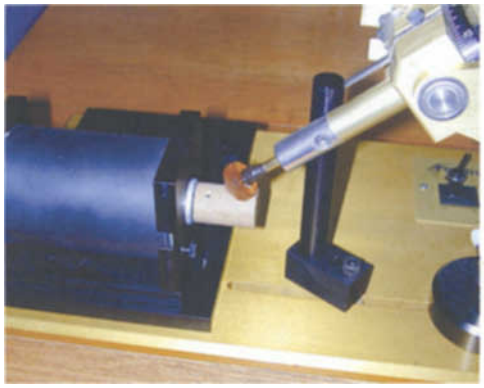

***Figure 14**: Facetron Special Cut Machine. Detail of dop arm hard stop post.*

produced across the curved facets by polishing them against a complementary moving mandrel surface."

Of particular interest is the so-called 'adjustable stabiliser' and this will be referred to later in this paper. The full specification covers every conceivable pattern of concave facets and also grooves of various axial spacings which can be cut across the previously formed concave facets.

The apparatus to which this patent refers is a faceting machine shown in *Figures 11* and *12*, marketed as the OMF Faceter manufactured by Poly-Metric Instruments, Clayton, Washington, USA. The title OMF stands for 'optically magnified facets'. Douglas Hoffmann died in 1997. A recent visit to the Internet web site http://www.polymetricinc.com/about.html produced by Zane Hoffmann shows the machine in detail and various accessories such as a range of cutting and polishing mandrels of ½ to 1¾ inch diameter, and costs. The basic machine costs approx. $1500. It is of course necessary to have a suitable faceting head to go with the machine and R.P. Homer suggests using the Scintillator 88 mast type designed by Hoffmann.

***Figure 15**: 'Hall of Mirrors' concave cut in CZ by Chris Algar 2001.*

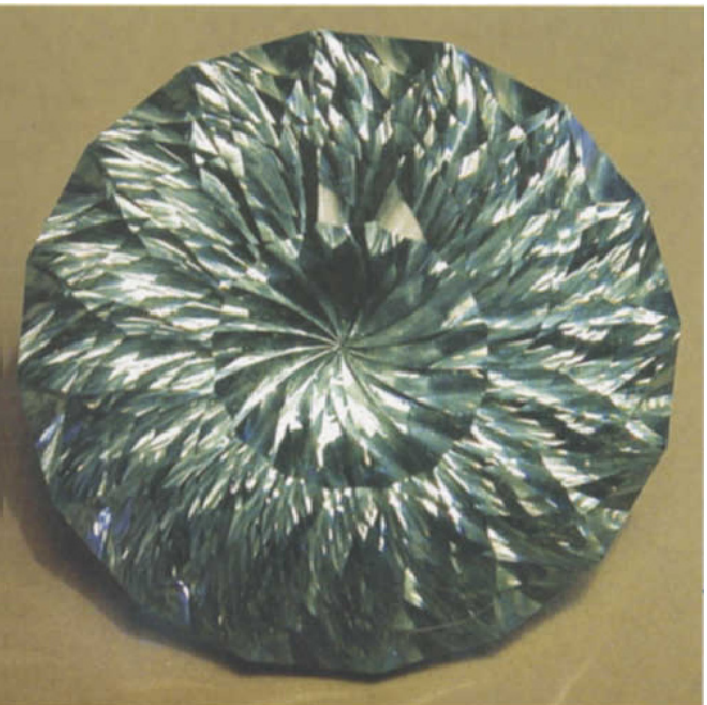

A description of the machine and its use together with an illustration of a 6.35 ct citrine cut with the faceter in an article by Richard P. Homer was published in *Lapidary Journal*[4]. A recent article by Prosper[5] also deals with cutting award winning stones using the O.M.F. Faceter using laps of ¼ and ½ inch diameter.

The Facetron Special Cut Machine

This machine is produced by the Jarvi Tool Company, Anaheim, CA, USA, as an accessory to their well known Facetron Gem Cutting machine, although most mast type faceting heads can be used or adapted for use with the accessory. It is shown in *Figure 13* with the Facetron indexing head in position. The accessory costs approximately $600.

In this machine the cylindrical cutter pushes on to the end of a variable speed motor spindle, and the whole unit is attached to a plate and arranged to reciprocate by means of a cam driven by a second motor beneath the plate. The plate can be turned through 90 degrees, so enabling cross cutting to be carried out like a radial arm saw, and the machine can also be used like a horizontal drill press. The accessory outfit is provided with three laps of a vee groover, a round cylinder for concave cutting, a round wheel cutter and a ball cutter.

The need for what is called the 'dop arm hard stop post', is satisfied by a pillar fastened perpendicular to the machine table, as shown in *Figure 14*, although no provision is made for micrometer movement of the stop position as in other machines.

The cutters used for cylindrical concave work are made from ABS plastic, similar to Tufnol in the UK (a fabric or paper-filled cured phenol formaldehyde resin). These are charged with 600 and 1200 grade diamond grit by coating the cutter with a layer of gel type Superglue (cyanoacrylate resin) into which is rolled the diamond grit and the glue allowed to harden. When worn, the cutter is resurfaced with steel wool abrasive, and recharged with diamond grit in a similar manner.

***Figure 16**: 'Pineapple' concave cut in CZ by Chris Algar 2001.*

***Figure 17**: 'Pentanne' concave cut in CZ by Chris Algar 2001.*

At present no-one is known to be using this machine in this country[6].

The Algar Concave Faceting Machine

The only faceter in the UK who has published information and methods for producing concave faceted stones is C. Algar, who uses a machine of his own design. This is not produced commercially. In an article in *Rock 'n' Gem Magazine*[7] he shows several faceted gems of unique design cut in cubic zirconia. These have concave cylindrical facets, and demonstrate well the extraordinary brilliance resulting from this method of faceting, as shown in *Figures 15, 16* and *17*.

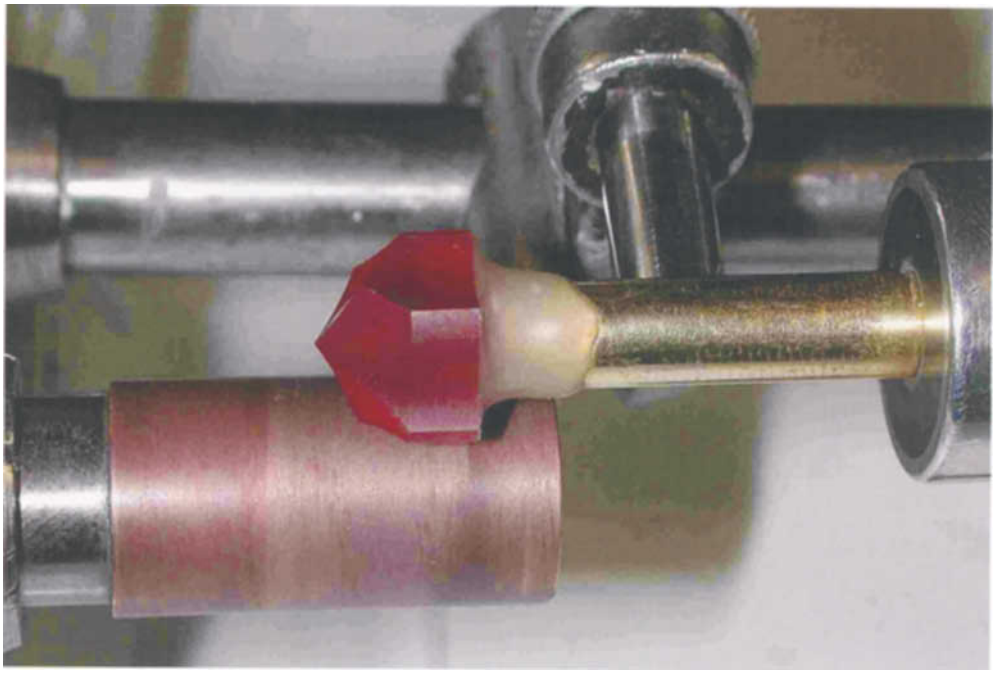

***Figure 18**: Stop bar with micro adjustment of Algar machine.*

Figure 19: 'Son of Domet' concave cut by Chris Algar 2001.

Algar also has an Internet web page, http://www.btinternet.com/~chrisalgar/concave.html where details of his method and latest designs of cut stones are shown.

The Algar machine, as in the previously mentioned OMF and Facetron machines, consists essentially of a rotating and oscillating cylindrical grinding surface to which a gemstone can be presented by an indexing dop at desired angles as in normal faceting practice. The spindle with the chuck holding the cutting cylinders revolves in a specially designed bearing and is oscillated back and forth by means of a camshaft rotating at 250 rpm against a return spring, with a linear movement of approximately 8 mm (0.3 inches).

The cylindrical laps originally used were made from lengths of standard 15 mm diameter copper water pipe fastened to a ½ inch shaft, and prepolish laps are made from cast resin/copper powder machined to the required diameter. Other lap materials are being investigated at the present time[8].

The machine has a 'stop bar' with micrometer adjustment as shown in *Figure 18* to enable the axis of the dop to be accurately set in relation to the rotating lap, and to enable repeat positioning of the dop after intermittent inspection of the stone during cutting.

Recently Algar has produced stones with true spherically concave surface facets, i.e.

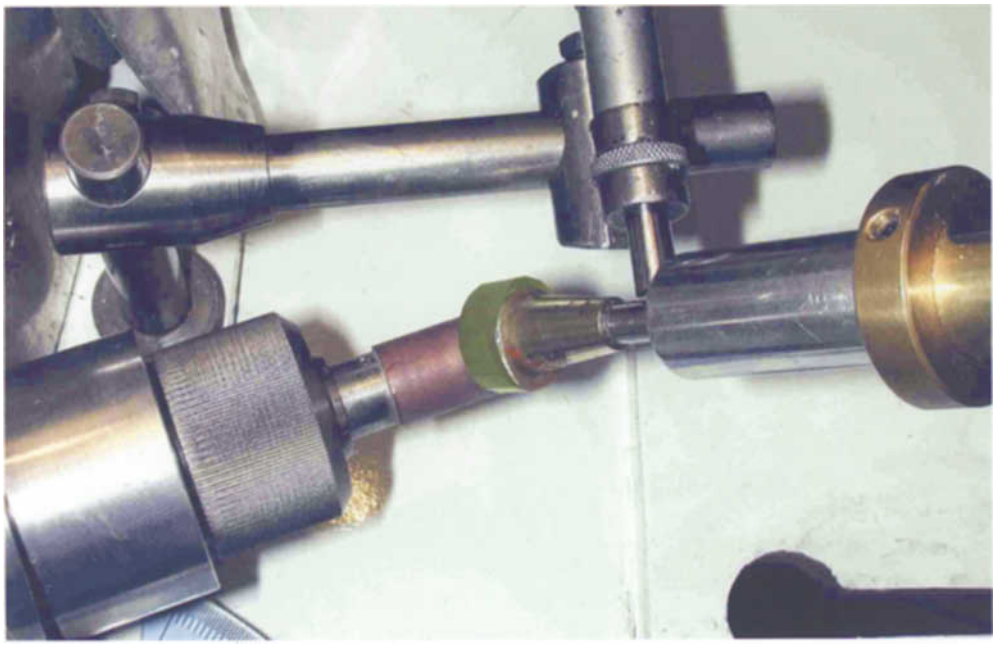

Figure 20: Dop axis inclined to lap axis in Algar machine.

negative spherical depressions placed at selected positions on a gemstone with a domed crown, as in his 'Domet's Aunty' cut, and a combination of negative spherical and cylindrical facets, as in 'Son of Domet' (*Figure 19*) giving a highly complex pattern of scintillation to the finished article.

Algar's machine and that of the OMF faceter have the ability to cut with the axis of the dop at an angle to the axis of the lap, as shown in *Figure 20*, producing even more complex cutting designs.

The Morgan faceting machine

Early design

During the latter half of 1998 the author was experimenting with a lathe as the driving spindle of cylindrical copper laps made from water pipe, and using a modified copy of the Ultra Tec machine faceting head for cutting concave facets. The normal horizontally hinged movement of the faceting head was omitted so that movement of the stone across the cylindrical lap could not take place. The whole system was attached to the saddle of the lathe and so was able to move in a direction parallel to the spindle axis and also across the lap axis.

A number of small gems were cut using this set-up, one of which is shown in *Figure 21*. This is an amethyst with a double row of simple flat step facets on the crown, and eight cylindrical concave facets replacing the normal mains of the (brilliant) cut pavilion. A very small culet facet at the same index as the mains was left on the pavilion. The simplicity of this design and ensuing brilliance aroused considerable interest in fellow gemmologists and a larger exhibition stone was attempted. After several unsuccessful trials it was realised that the faceting head which was located against the square mast produced by the author was not sufficiently rigid to withstand the twisting forces produced during cutting, and other means to prevent movement must be developed. At this stage, other more pressing duties caused the project to be temporarily shelved.

***Figure 21**: 5.6 ct amethyst with concave cut pavilion by Doug Morgan 1998.*

It was not until late in 2001 that the author was introduced to Chris Algar, although he had heard of the spectacular gems being produced by this cutter, and at this time was able to inspect the machine being used and admire his exhibition of cut stones. As a result of this meeting the project was reopened, and a new approach to machine design was adopted.

Latest design of machine

The basic requirements of a machine to carry out this method of faceting can be broken down into simple items as follows:

1. A rotating spindle.
2. A chuck or collet on this spindle to hold a replaceable cylindrical cutter.
3. A means of moving the spindle back and forth by reciprocating along the axis.
4. A faceting head which can be clamped rigidly in various positions in relation to the cutter.

Bearing these requirements in mind the author considered that when constructing a prototype machine, off-the-shelf engineering products should be used where possible, thereby reducing the amount of machining needed to a minimum. Accordingly, the machine was designed around the small Peatol lathe which is readily available in the

***Figure 22**: Morgan concave facet machine. General view.*

UK. A schematic diagram of the assembled components is shown in *Figure 22*.

Spindle

The Peatol lathe[9] is produced in America and sold as an easily assembled kit of parts. It has a bed made from hardened ground steel, the remaining items being precision aluminium alloy extrusions. The headstock has sealed bearings and its spindle can be fitted with chucks or collets, so fulfilling the specified requirements.

Spindle mounting

The headstock houses the spindle in a light alloy mounting which slides along the bed in machined grooves and is normally fastened to the bed by locking screws. However, it was considered that as a loose component the situation was ideal for allowing the spindle in its mounting to be reciprocated backwards and forwards along the bed by a suitable oscillating drive, so fulfilling these requirements. The locating slides were fitted with bronze bearing strips

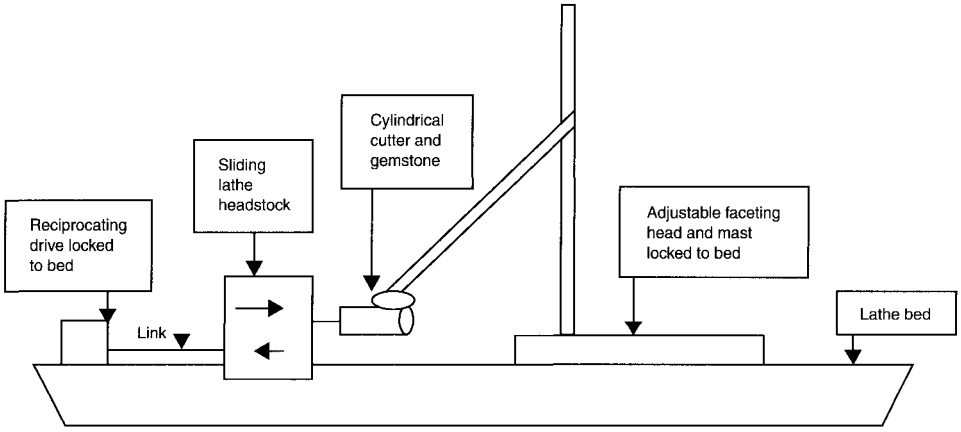

***Figure 23**: Schematic arrangement of Morgan concave faceting machine.*

to minimise wear, and the bearing surfaces were lubricated with grease, giving a smooth sliding movement.

Oscillating mechanism

A standard type of automobile windscreen wiper drive provided a satisfactory means of obtaining a reciprocating motion and accordingly a unit was modified to fasten on to the lathe bed. The stroke was reduced to give ¾ inch movement and an adjustable link was made to attach the drive to the headstock spindle mounting, so satisfying the need for a reciprocating spindle.

Faceting head

Normal gem faceting by the author was carried out on an Ultra Tec Machine[10] which has an indexing spindle with a tapered bore to accommodate removable tapered dop holders. The author also had a Lee[11] faceting head and mast in his possession, in which the dop holder indexing spindle unit could be removed for inspection during cutting. This had considerable advantages over a fixed dop spindle system, and so a new dop indexing spindle with a tapered bore to accommodate the Ultra Tec removable tapered dop holders was made to replace the original Lee spindle. Thus the gem stone could be faceted in the normal manner using the Ultra Tec machine to provide flat facets, and then the preformed stone still attached to the tapered dop holder was transferred to the modified Lee indexing head fixed to the concave cutting machine for concave cutting. The general layout of the machine is shown in *Figure 23*.

There is a considerable frictional drag experienced by the stone when in contact with the rotating lap, and rigidity in the equipment is essential to prevent unwanted movement of the stone and dop. The 'adjustable stabiliser' of the OMF machine, the 'dop arm hard stop post' of the Facetron machine, and the 'stop bar' of the Algar machine are vital components in ensuring satisfactory operation of each machine.

***Figure 24**: Detail of parallel bar hard stop with micro adjustment in Morgan concave facet machine.*

Bearing this in mind, a new stop system for accurate positioning of the dop spindle in relation to the cylindrical cutters was developed. This essential component consisted of two parallel bars, one fixed to the movable faceting head, and the other fixed to the vertical mast spindle, as shown in *Figure 24*. A fine pitch screw enabled the two bars to be moved accurately in relation to one another and maintain this relationship

***Figure 25**: Copper cylindrical lap of Morgan concave facet machine showing 30 micron and 3 micron cutting positions (left and right on the copper cylinder).*

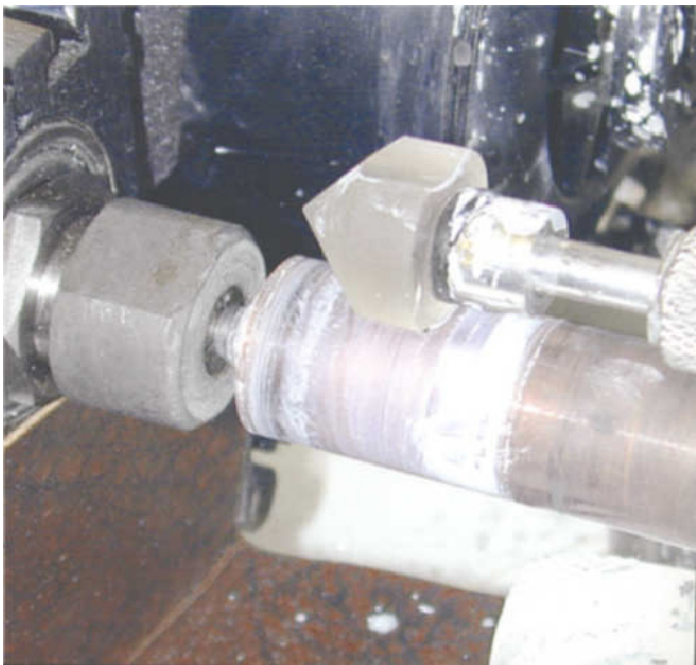

***Figure 26**: 59 ct CZ with concave cut by Doug Morgan 2002.*

***Figure 27**: 18.6 ct fluorite with concave cut by Doug Morgan 2002.*

as the faceting head was moved up or down the mast to give the required facet angles. This unit thus became an integral part of the faceting head itself and obviated the need to reset the stop when using the machine with the dop stick at an angle to the cylindrical cutters.

The whole faceting head and mast was fastened to a base plate by means of an adjustable clamp, and in turn this was fastened to the lathe saddle in place of the usual tool post and cross slide, so that it could be turned to any required angle on an axis situated in line with the cutter spindle axis. Since the unit was attached to the saddle, it could be traversed along the lathe bed enabling a multiple cutter with grits of different grade to be used in sequence as shown in *Figure 25*, without the necessity of stopping the machine and changing cutters. This also facilitated positioning the stone over the cutter as the facet angles were changed.

Concave cutting laps

Since there was a ready supply of domestic copper water pipe available, this was used for making cutting laps as follows. The shank of a suitable bolt was machined to fit the headstock spindle collet, leaving a portion of the thread and the bolt head so that this fitted into the copper tube. A tube length was arbitrarily chosen to be about 30 mm long. The bolt was positioned centrally in the tube by a fixture, and cemented in place using automobile repair plastic filler. When the filler had hardened, the machined spindle was held in a lathe and the outer copper tube turned to the required diameter to produce the concave cutting lap. A set of such cutters was also made using smaller diameter tubing.

Two polishing laps were made, one from pure tin cast around a central spindle in a metal split mould and machined to match the diameters of the copper laps, and the other from heavy walled Perspex tubing machined to match the copper lap diameters.

The copper laps were charged with 30 micron and 3 micron diamond grits respectively, and the tin lap with 1 micron diamond, all used with water as lubricant applied with a brush. The Perspex lap was coated with spray-on cerium oxide polish, and was also lubricated with water.

Results using the machine

It was found that the copper laps readily cut amethyst, cubic zirconia, and fluorite. The quartz was readily polished with the Perspex lap charged with cerium oxide, and the tin lap charged with 1 micron diamond grit was satisfactory for cubic zirconia. A

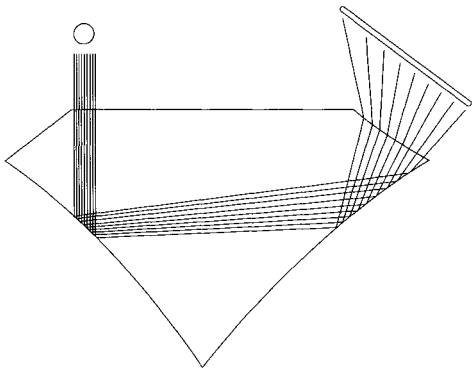

Figure 28: ZEMAX computer generated two-dimensional ray trace diagram for single concave lens and single convex mirror combination showing diversion of pencil of rays into a streak.

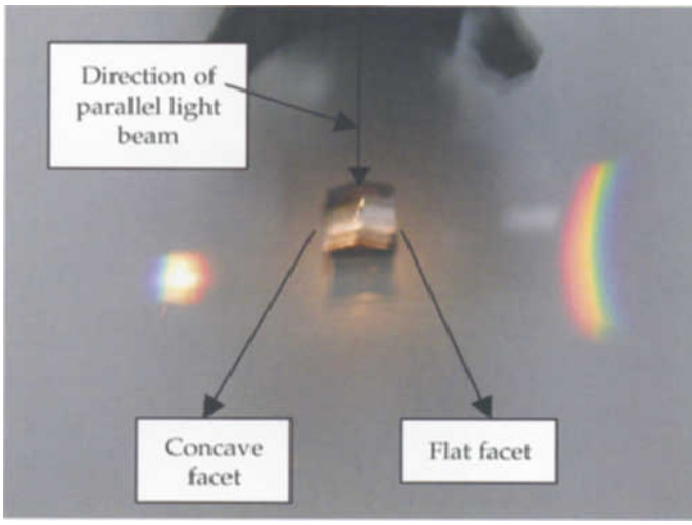

Figure 29: Nelson type dispersion image produced by CZ prism with cylindrically concave facet and flat facet.

brilliant polish was obtained on fluorite using ½ micron diamond on tin, and it is considered that this combination would give superior results on cubic zirconia albeit a very slow polishing process.

The stone shown in *Figure 26* was cut from colourless cubic zirconia. It weighs 59.0 ct. and is 22.2 mm across the girdle points. The facet pattern was copied from the 'Pin wheel' cut by Ed Hulme previously mentioned, but has an octagonal concave cut girdle. As the finished stone was so spectacular when cut in a high refractive index material, an experimental stone cut from colourless fluorite was produced for comparison purposes with the results shown in *Figure 27*. This weighs 18.6 ct and is 16.7 mm across the girdle points. Having had much experience in cutting fluorite using a variety of facet designs, the author considers that the brilliance of this stone, whilst obviously not as great as that of the cubic zirconia, was quite remarkable for a stone of low refractive index and supports the claims of increased brilliance made for stones with concave facets.

Optical considerations

In a normally cut gemstone with flat facets, the ray path of a pencil of light impinging on a facet is determined by the refractive index of the stone and the angular positions of flat facets acting like plane mirrors to give total internal reflection. There is no divergence of the ray which, unless it is monochromatic, will undergo dispersion to give a spectral image.

In the case of a stone having cylindrical concave facets on the crown and pavilion, the pencil of light first passes through a concave lens, and then is totally internally reflected by a convex surface acting as a mirror, and escapes via a concave lens. Thus in a gemstone having indexed facet positions the pencil of rays is subjected to a highly complex system of concave lenslets and convex mirrors. Both the concave lens and the convex mirror surface cause divergence of the pencil of light, as is shown by the theoretical ray trace diagram in *Figure 28* produced by computer program ZEMAX V.6[12] for a gem-shaped transparent medium of R.I ~ 2.0. The concave and convex cylinders transform the pencil from a spot to a streak.

This divergence of the ray by a concave cut facet to form an elongated image can be

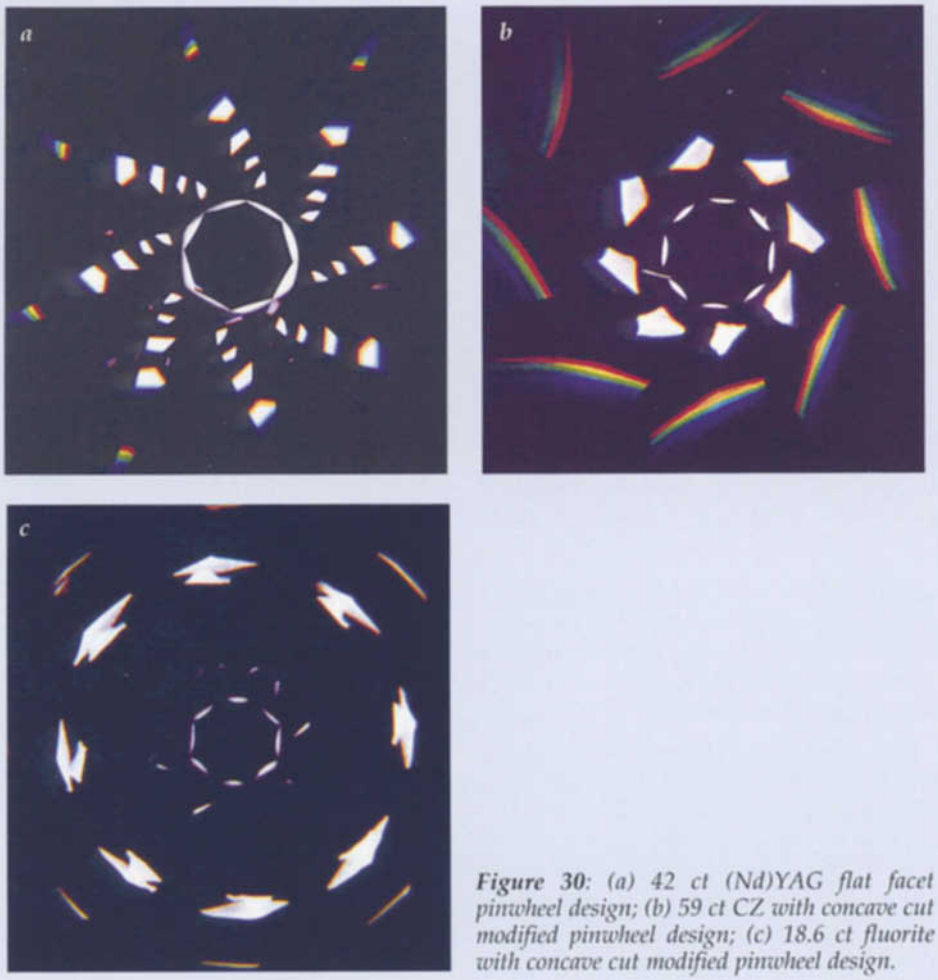

Figure 30: (a) 42 ct (Nd)YAG flat facet pinwheel design; (b) 59 ct CZ with concave cut modified pinwheel design; (c) 18.6 ct fluorite with concave cut modified pinwheel design.

seen using the arrangement as shown in *Figure 29*. Here a triangular prism was cut in CZ and polished to give one facet a flat surface and the adjacent facet a concave surface of radius 11 mm. The prism was supported above a white screen, and a collimated beam of white light (quartz-iodine) projected on to the facets as in the Nelson Gem Fingerprinter[13] so that the emerging refracted rays after passing through the prism could form images on the screen and be photographed. The left-hand image shown in *Figure 29* was produced by the beam refracted and dispersed by passing through the facet, whereas the right-hand image produced by refraction of the beam passing through the concave facet shows that it is lengthened perpendicularly to the axis of the cylinder owing to divergence of the beam as well as producing a spectrum by dispersion.

The 42 ct (Nd)YAG pinwheel flat facet design stone as shown in *Figure 1*, and the cubic zirconia and fluorite as shown in *Figures 26* and *27* having a modified concave faceted pattern were submitted to Dr J. Nelson for characterization in the Nelson

Gem Fingerprinter, and the remarkable images, clearly showing the divergence of the emerging rays, are shown in *Figure 30 a, b* and *c*.

Conclusion

The cutting of concave facets on a gemstone in place of the normal flat facets has a profound effect upon the appearance of the stone, in terms both of overall brilliance and of aesthetic beauty, and further enhancement may be achieved by a concave girdle replacing the round or rectangular cutting.

The stone becomes a transparent medium consisting of cylindrically concave lenslets and convex mirror surfaces, resulting in divergence of incident ray paths to produce elongated streaks of light instead of plane reflections of the light source.

The faceting equipment needed to cut the concave facets is not complex, but needs to be rigidly constructed and have facilities for microadjustment of related components. It is an advantage for the cutting cylinders to oscillate along the cylindrical axis so avoiding formation of wear grooves on the cylinders. The cutting grits, polishing sequence and type of material used for the cylindrical laps need not differ from those used in normal lapidary practice.

Although the use of concave cut facets is not new to the lapidary industry, the introduction on the market of commercial equipment for this special method of faceting has opened up a new avenue for exploration of cutting designs. The work of American concave faceters is in great demand for custom jewellery, and has already attracted the attention of skilled amateur faceters in this country.

Acknowledgements

The author would like to thank C. Algar, London, for helpful information concerning his faceting machine and supplying photographs of his specially cut stones; Professor H. Bank of Gebruder Bank, Idar Oberstein; Manfred Wild of Emil Becker, Kirschweiler, for the loan of stones and details of the cutting methods; Jim Finlayson, Alsager, for details of the Facetron machine; Zane Hoffman for photographs and details of the OMF machine from his web site; Dr J. Fletcher, Nottingham, for the ZEMAX computer ray tracing; Gwyn Green, Birmingham, for information and the loan of the 'Daisy' cut smoky quartz; Alan Hodgkinson, Portencross, Ayrshire, for photographs of the stone by Art Grant; Al Manestar, Toronto, for allowing the author to photograph the Canadian Maple Leaf stone; Dr Jamie B. Nelson, London, for the Gem Fingerprinter photographs; K. Pitt, IT consultant for much help and advice, and Neil Rose of Gem-Ro Associates Ltd, Leeds, for the ImageDome photographs of the CZ and fluorite concave cut stones.

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Doubling of images in gemstones

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ABSTRACT: Equations for determination of the doubling effect in uniaxial minerals are presented for the first time in the gemmological literature. Diagrams are constructed in order to avoid calculations involving trigonometric functions. These diagrams can also be used for estimates of the doubling in biaxial minerals.
The importance of the view point is discussed and determination of the doubling in synthetic moissanite is given as an example.

1. Introduction

Doubling of images can downgrade the appearance of an otherwise perfectly cut gem. For example, a sharp pavilion edge viewed through a gem table may appear as two lines or as a broad line (if two images are very close) and the edges may appear 'fuzzy'. To the best of the author's knowledge, this is the first attempt to present equations and diagrams for determination of doubling effects.

Ideally, any presentation of the new ideas must be supported by enough evidence or facts, so that an author's reasoning and conclusions can be independently duplicated and verified. This need should be balanced with the known unwillingness of some readers to follow complex calculations and detailed explanations.

For this reason the paper is divided into a main part (giving diagrams for determinations of doubling effects) and Appendices A and B (giving all other relevant information).

1.1. Birefringence and doubling of images

In general, when light enters a birefringent mineral, it is split into two rays. These two rays have different refractive indices (birefringence) and different vibration directions. There is also another important difference – these two rays may move in slightly different directions resulting in the separation (doubling) of images (*Figure 1*).

To show the effect of birefringence on these two rays, the difference in their refractive indices and their difference in speed are calculated. It is an easy calculation as the speed is reciprocal to refractive index. From this we can find the distance by which one ray is ahead of the other as they exit the gemstone. They can be separated (move in slightly different directions) or they can move in exactly the same direction as they travel through the gemstone, but we are only concerned with the difference in speed and how far one ray is ahead of the other when they exit the gemstone. They keep this distance as they move through the air to the observer but the human eye cannot observe this effect. *A polariscope or polarizing microscope must be used to identify birefringence effects.*

To show the effect of doubling, the separation of images can be calculated and expressed in millimetres. The human eye can observe a very small separation of

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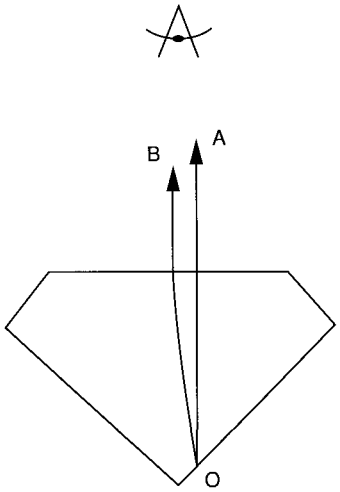

***Figure 1**: Light reflected at point 0 is split into two rays A and B. The position of the eye is indicated by arrows at the end of the light rays.*

images – as small as 0.1 to 0.2 mm. For example, in *Figure 1* the image of a point on the pavilion facet moves through a gemstone as two separate rays. The angle of separation between the two rays determines the eventual observed distance between the two images. It is not important how far ahead one ray is compared with the other – *the doubling of images depends only on the difference in direction of the two rays.*

- 'Birefringence' is the numerical difference in the refractive indices of the two rays.
- 'Doubling of images' or 'separation of images' are terms used to describe the effect caused by the separation of directions of the two rays.

Terms such as 'anisotropic minerals', 'birefringent minerals' or 'doubly refractive minerals' have the same meaning. They refer to minerals in which light is split into two rays except when it is moving in the special directions called 'optic axes'.

1.2. Examples of differences between doubling effects and birefringence

Birefringence and the doubling of images are both directional properties of minerals. They depend on the direction in which light moves through a gemstone. However, they are not identical and separate methods must be used to calculate their effects. The following examples show that the direction of maximum birefringence is not the direction of maximum separation of images – it could be just the opposite in some minerals.

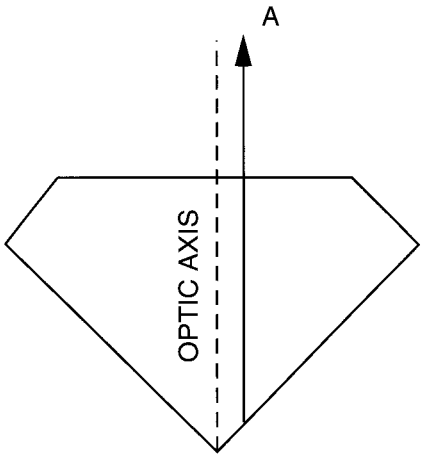

***Figure 2**: **Uniaxial minerals**. Light travels in a direction parallel with the optic axis. It is not split into two rays but moves as a single ray. No doubling of images is observed.*

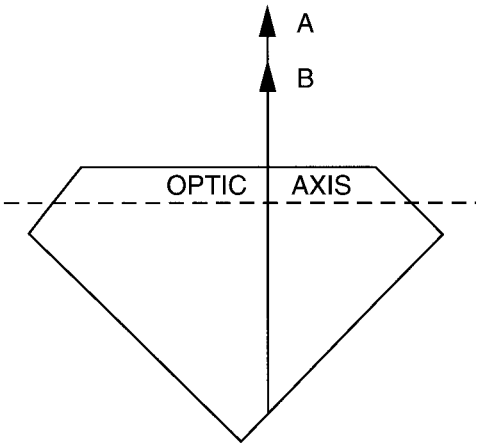

***Figure 3**: **Uniaxial minerals.** Light rays travel in a direction perpendicular to the optic axis. It is split into two rays A and B that move in the same direction. No doubling of images is observed.*

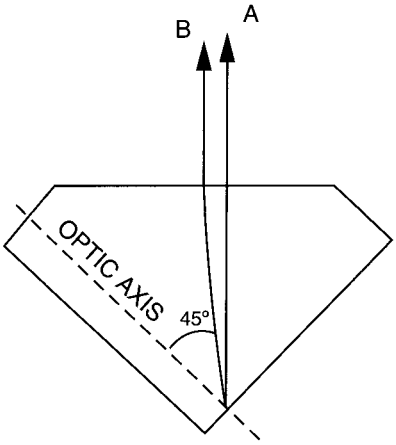

Figure 4: Uniaxial minerals. *Light travels in a direction making an angle of about 45° with the optic axis. Light is split into two rays with the maximum separation of images.*

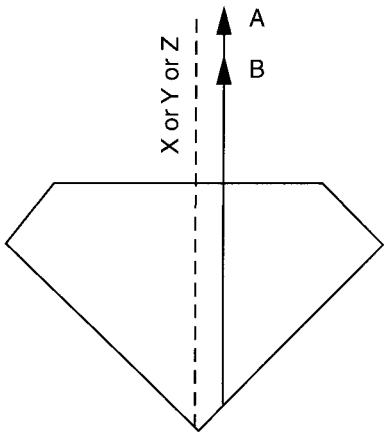

Figure 5: Biaxial minerals. *Light travels in the direction of one of the principal vibration directions Z, Y or X. It is split into two rays A and B that move in exactly the same direction. No doubling is observed.*

Uniaxial minerals
Tetragonal and hexagonal

When light travels in the **direction parallel to the optic axis**, it continues as a single ray (*Figure* 2). There is no birefringence and **no doubling of images is observed**.

When lights travels in the **direction perpendicular to the optic axis** it is split into two rays (*Figure* 3). These two rays show the maximum difference in the refractive indices for this mineral – maximum birefringence but the light rays continue to travel in exactly the same direction. **No doubling of images is observed.**

When light travels at **an angle of about 45° to the optic axis** it is split into two rays (*Figure* 4). These two rays show birefringence that is about half of the maximum for this mineral, but the rays are separated by the maximum possible angle of separation. **Maximum doubling of images is observed**.

Biaxial minerals
Orthorhombic, monoclinic and triclinic

When light travels in the direction of one of the three principal vibration directions (X, Y, Z, also given as α, β, γ) it is split into two rays with different refractive indices, but they continue to travel in exactly the same direction (*Figure* 5). **No doubling of images is observed.**

These examples clearly show that the effects of birefringence and effects of doubling of images must be presented and calculated in different ways.

1.3. Factors determining doubling of images

The actual observed doubling of images (distance D in *Figure* 6) depends on two factors:

- **The size of the gemstones** – thickness of the gemstone in *Figure* 6. Simply stated, larger gemstones will show more pronounced doubling of images than smaller gemstones. The effect of gemstone

size can be calculated from a simple equation given later.

- **The angle of separation of two rays** – angle α in *Figure 6*. This angle of separation (in uniaxial minerals) can be calculated from two different equations.

  a) A relatively simple equation can be used to calculate the maximum possible angle of separation for a particular mineral from its main refractive indices. This presumes that the gemstone table is oriented in the worst possible position relative to the optic axis.

  b) The second equation is more complex because it involves orientation of the gemstone table in relation to the optic axis. Calculations show how angles of separation change as the angles between optic axis and gem table vary from 0° to 90°.

Diagrams 1 and *2* are prepared from these equations so that calculations involving trigonometric functions can be avoided. Detailed descriptions of each diagram and its use are given in separate sections on uniaxial minerals. This is followed by description of the use of diagrams for estimates of doubling effect in biaxial minerals. The equations used for the construction of the diagrams are given in Appendix A.

The importance of the view point is explained in Appendix B1. *Figures 1–9* and both diagrams are based on observation through a gem table with the eye set over the centre of the gem table. In this arrangement rays that are perpendicular to the gem table as they exit the gemstone are observed. In Appendix B2 synthetic moissanite is used as an example of identification of doubling effects as they are observed from different viewpoints. Finally, in Appendix B3 instructions are given on the use of calcite plates in observing the effects of various degrees of doubling or separation.

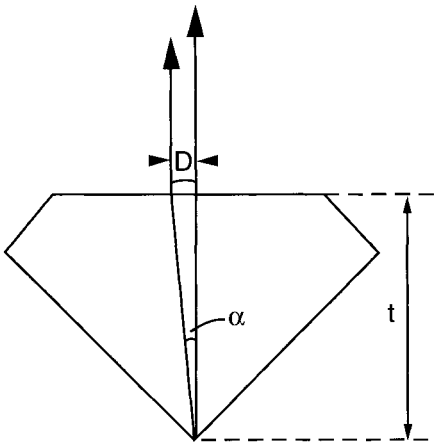

***Figure 6**: Distance between images D depends on the separation angle α and the thickness t of the gemstone.*

2. Gem size

The actual visible doubling of images in a particular gemstone depends on the angle of separation of the two rays and the distance they travel in a gemstone (*Figure 6*). In this section the effect of size is examined and in the following sections determination of the separation angle α is discussed.

The effect of gemstone size can be calculated from the simple equation

$$D = t \,.\, \tan \alpha \qquad \textbf{Equation 1}$$

where D is the observed distance between images (*Figure 6*), t is the thickness of a gemstone and angle α is the separation angle of the two rays. Separation angle α can be calculated from equations 2 and 3 described in the following sections.

- In order to avoid calculation involving trigonometric functions, two diagrams have been constructed for gemstones 10 mm thick, here called the 'standard' thickness to show the doubling effect.

We can get a fairly good estimate of doubling effect just by comparing the size of a particular gemstone to a 'standard' size (10 mm) used in the diagrams. A gemstone twice as large (about 20 mm in depth) shows twice the doubling effect.

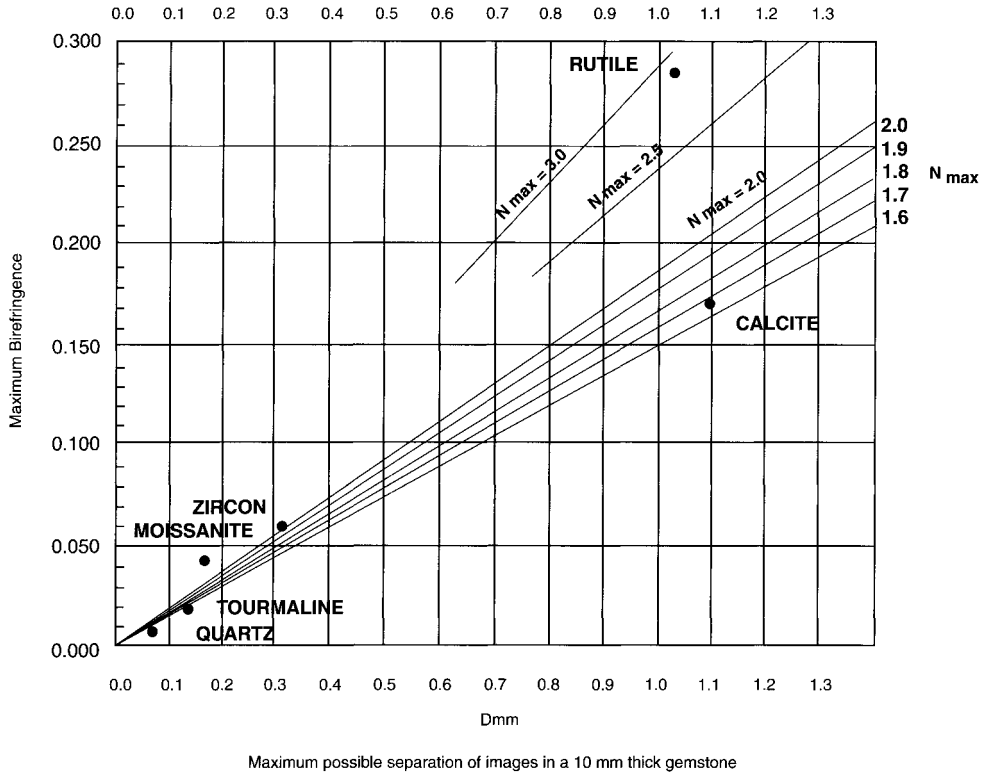

***Diagram 1**: The maximum possible separation of images for a particular mineral. Use of diagram: plot the maximum birefringence on the vertical axis, move horizontally to diagonal lines representing N_{max} and read the maximum separation of images on the horizontal axis. Diagram is based on calculations for 10 mm thick gemstones.*

- For more accurate estimates the thickness of a particular gemstone should be measured and compared with the 'standard' size used in the diagrams (10 mm). For example, in *Diagram 1* we see that a 10 mm zircon can show a maximum doubling effect (separation of images) of 0.31 mm. (A detailed description of the use of *Diagram 1* is given in the next section.) A zircon gemstone with a thickness of 7 mm shows separation of images of 0.7 × 0.31 mm = 0.22 mm and one with a thickness of 13.5 mm shows separation of images of 1.35 × 0.31 mm = 0.42 mm.

Simple multiplication combined with the use of diagrams can give fast and fairly accurate estimates of the doubling effect if the size (thickness) of the gemstone is known.

3. Uniaxial minerals

3.1. Maximum possible separation of images in a mineral

The optical properties of a mineral, namely the maximum birefringence and the refractive indices can be used to calculate the maximum possible doubling effect that can be observed in a particular mineral.

- In uniaxial minerals the maximum possible doubling effect is observed when light travels in directions which are at about 45° to the optic axis (*Figure 4*).

In Appendix A.1 the information is given (Equation 2) for determination of the maximum possible separation angle α for a particular mineral (see *Figure 6*). In order to

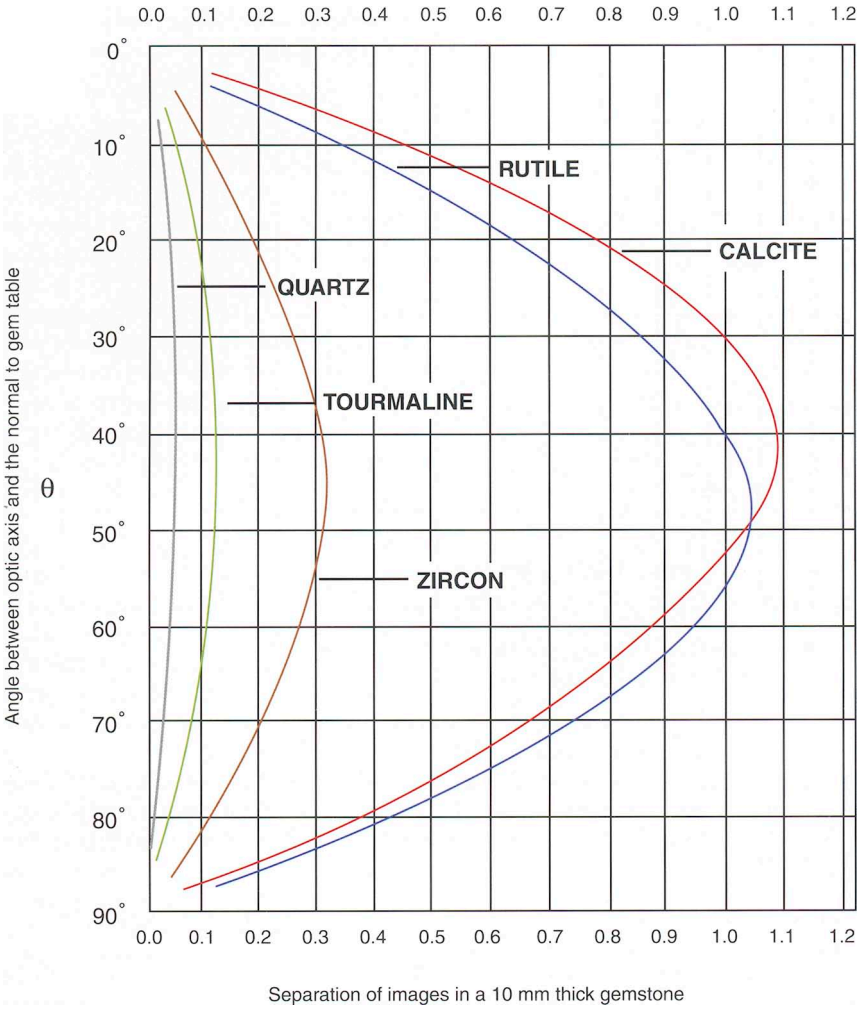

***Diagram 2**: Orientation of gem table and doubling effect. Use of the diagram: plot the angle θ (the angle between the optic axis and the normal to the gem table) on the vertical axis, move horizontally to curved lines representing selected minerals and read the separation of images on the horizontal axis. Diagram is based on calculations for 10 mm thick gemstones.*

avoid complex calculations this equation was used with Equation 1 (concerning gem size) in construction of *Diagram 1*. A 10 mm thick gemstone was used as the 'standard'.

The use of the diagram is very simple. The maximum birefringence of a mineral is read from the vertical axis. Then one moves horizontally to the diagonal line representing the maximum refractive index and on the horizontal axis of the diagram the maximum possible separation of images for a gemstone of the 'standard' size (10 mm) is read.

- The only calculation left to do is to compare the size of the particular gemstone to the standard size. Examples are described in the section on gem size.

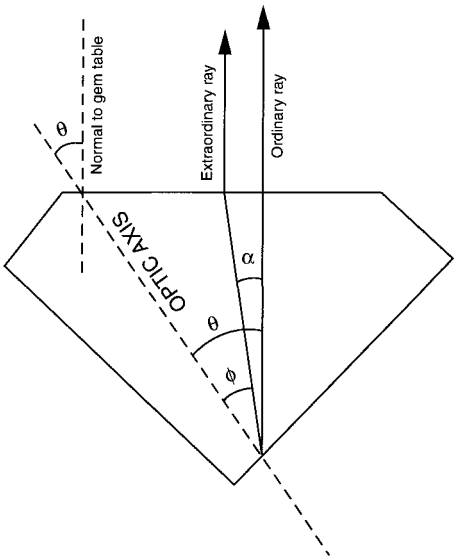

***Figure 7**: The separation angle α is the difference between angles θ (optic axis and ordinary ray) and φ (optic axis and extraordinary ray). Note that the angle θ is identical to the angle between the optic axis and the normal to the gem table.*

A quick overview of *Diagram 1* shows that maximum birefringence plays a very important role in the calculation of doubling effects for a particular mineral. Minerals with strong maximum birefringence show strong separation of images. However, a minor but important role is played by the maximum refractive index (whether the ray with maximum refractive index is N_o or N_e does not matter in this context).

For example, rutile and calcite show a similar maximum possible distance between images in 10 mm thick gemstones. Rutile has almost twice the birefringence of calcite but this is compensated by the much higher refractive indices of rutile. Evidently, both factors determine the maximum doubling effect that can be observed in a particular mineral.

- Maximum birefringence plays a major role; minerals with larger birefringence show larger maximum possible doubling effect.
- Refractive indices play a minor role: minerals with larger refractive indices show smaller maximum doubling effect.

3.2. Orientation of the optic axis in the gemstone

Until now we have discussed the maximum possible doubling that can be observed from a particular mineral – 'the worst case scenario'. It is observed in gemstones cut from uniaxial minerals when the optic axis is set at about 45° to the gem table. It was mentioned in the introduction that no doubling is observed when the optic axis is either parallel or perpendicular to the gem table. In all other orientations of the optic axis doubling effects vary from the maximum possible to zero. These are shown in *Diagram 2*.

Appendix A.2 contains the equations used in construction of *Diagram 2* which was prepared in a similar way to *Diagram 1*. A 10 mm thick gemstone is used as 'standard'. This means that the only calculation left to do is to compare the thickness of a particular gemstone with the 'standard' – as shown in the section on gem size.

The vertical axis of *Diagram 2* shows the angle θ – the angle between the optic axis and the normal to the table facet of the gem (see *Figure 7*). The angle θ is 0° when the optic axis is perpendicular to the gem table and it is 90° when it is parallel to it. In these positions the separation of images is 0.

The use of the diagram is as follows: plot the angle between the optic axis and the normal to the gem table (angle θ) on the vertical axis, move horizontally to the curve representing the particular mineral and read the separation of images (doubling effect) on the horizontal axis of the diagram.

- The most striking feature of *Diagram 2* is that the curves are almost symmetrical. For example, almost the same doubling effect (separation of images) is observed when the angle between the optic axis and gem table facet is θ = 20° or when it is θ = 70°.

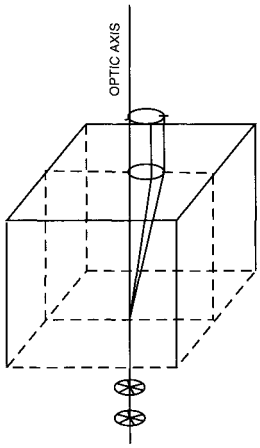

Figure 8: *Conical refraction in biaxial minerals. Light travelling in the direction of an optic axis in biaxial minerals becomes a hollow cone as it moves through the gemstone and continues in the air as a hollow cylinder.*

- Another important feature is that the maximum doubling effect is observed when the angle θ is about 45°. It is not exactly 45° (see calcite and rutile curves) but in practice this value can be used as the position with the maximum doubling effect.

On *Diagram 2* curves for five minerals have been plotted to indicate how the doubling effect changes at various orientations of optic axis in the gemstones. The curve of any other mineral can be plotted by using *Diagram 1* to determine the maximum possible separation of images in a particular mineral; then plot this on *Diagram 2* at the position of θ = 45°. From this point draw symmetrical curves to 0° and 90°. For practical purposes this will enable sufficiently good estimates to be made.

4. Biaxial minerals

Calculations of the doubling of images for birefringent biaxial minerals (orthorhombic, monoclinic and triclinic) are more complex than for uniaxial minerals. However, the diagrams presented for uniaxial minerals can be used as fairly reliable estimates of the doubling effect.

In uniaxial minerals there are two important directions – parallel to the optic axis and perpendicular to it. In biaxial minerals there are three important directions called the principal vibration directions which are marked as X, Y and Z, or α, β and γ. Related to these directions are the principal refractive indices often marked as N_x, N_y, and N_z, or as N_α, N_β and N_γ.

In addition, in biaxial minerals there are two special directions – two optic axes that can be compared to the optic axis of the uniaxial minerals. The angle between the optic axes is known as 2V and can lie between 0° and 90° with either X or Z as acute bisectrix. The angle 2V depends on the values of N_x, N_y, and N_z. Minerals with a very small 2V behave similarly to uniaxial minerals as far as estimates of birefringence and doubling of images are concerned.

- *Diagram 1* was constructed for uniaxial minerals but can be used for estimates of the maximum possible doubling effects for biaxial minerals if N_z is used for N_{max} and N_x for N_{min}.

In biaxial minerals there are three directions where the separation angle α is 0° and there is no doubling of images. It is a similar effect to that seen in uniaxial minerals when light travels perpendicular to the optic axis (*Figures 3* and *5*).

- When light travels parallel to the principal vibration direction Z, Y or X, it is broken into two rays with different refractive indices, but both rays move in exactly the same direction and no separation of images is seen.
- Strong doubling of images is seen when light travels in a direction equally inclined to all three principal vibration directions

or in the directions which are at 45° between Z and Y, or X and Y.

An additional adverse effect that may be observed in biaxial minerals is known as conical refraction (*Figure 8*). Light travelling in the direction of an optic axis becomes a hollow cone of light within a gemstone, and continues in the air as a hollow cylinder. This may cause unpredictable optical effects in gems and should be avoided. In uniaxial minerals, a gem table set perpendicular to the optic axis is a very desirable position. In biaxial minerals it may not be.

5. Conclusion

Doubling of images in uniaxial minerals can be accurately calculated from the equations given in Appendix A. However, very fast and reliable estimates can be obtained from the presented diagrams.

Diagram 1 gives the maximum possible doubling effect for a particular mineral and is based on its maximum birefringence and refractive indices. *Diagram 2* shows how the doubling effect changes with the angle between the optic axis and table facet of the gem.

In uniaxial minerals no doubling is observed when light travels in directions perpendicular or parallel to the optic axis. The maximum doubling effect is observed when light travels in the directions making about 45° with the optic axis.

Diagrams and equations are presented for uniaxial minerals. However, they can also be used for fairly good estimates of the doubling in biaxial minerals. In biaxial minerals no doubling is observed when light travels in directions of the principal vibration directions (Z, Y or X).

The position of the eye over the gemstone plays a very important role. Diagrams and equations relate to light rays that are perpendicular to the gem table as they enter the air. These rays are observed when we look through the gem table with the eye positioned directly above its centre (*Figure 1*). Determination of the doubling effects for other view points is a more complex process, but diagrams can be used for fast and useful estimates.

Determination of the doubling effect can be a useful tool in identification of gemstones. It can also be useful in deciding the orientation of rough gem material for cutting the table facet and in the ultimate size of the stone.

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Appendix A

Equations for doubling in uniaxial minerals

A.1. Maximum possible separation of images in a mineral

Baric (1967) gives a simple equation for calculation of the maximum possible separation angle α for a particular mineral:

$$\tan \alpha_{max} = \frac{N_{max}^2 - N_{min}^2}{2 \times N_{max} \times N_{min}} \qquad \textbf{Equation 2}$$

where α_{max} is the maximum possible separation angle between two rays (*Figure 6*) and N_{max} and N_{min} are the main refractive indices N_o and N_e.

We do not have to differentiate the optically positive minerals from the optically negative and for this reason we use symbols N_{max} and N_{min} in Equation 2.

If this separation is to be expressed as a distance D (in millimetres) in *Figure 6* the size of a gemstone must be known. A larger gemstone will produce a larger distance between the images. Therefore, in the calculations Equation 2 is first used to determine the maximum possible separation angle (α_{max}) and then the size of a gemstone is introduced using Equation 1 to calculate the actual separation of images (distance D in *Figure 6*).

A.2. Orientation of the optic axis in the gemstone

Figure 7 shows an example of the paths of the ordinary ray and the extraordinary ray in a uniaxial positive mineral. If we set our eye over the centre of the gem table, then the ordinary ray is perpendicular to the gem table and is undeviated as it passes from gem to air. The extraordinary ray moves in a slightly different direction in the gemstone, but is bent as it exits the gemstone to become parallel to the ordinary ray. In the air these two rays are parallel and maintain the separation they had at the gem surface.

The following equation (modified from Wahlstrom, 1979) can be used to calculate the angle between the extraordinary ray and the optic axis (angle ϕ) as it moves through the gemstone:

$$\tan \phi = \frac{N_0^2}{N_e^2} \times \tan \theta \qquad \textbf{Equation 3}$$

where ϕ is the angle between the extraordinary ray and the optic axis, N_o and N_e are refractive indices and θ is the angle between the ordinary ray and the optic axis (*Figure 7*).

In uniaxial positive minerals the extraordinary ray is refracted toward the optic axis and in uniaxial negative minerals it is refracted away from the optic axis. Therefore, angle ϕ can be either larger or smaller than θ.

However, we are only interested in the difference between angles θ and ϕ – the separation angle α in *Figure 7*. Thus:

$$\alpha = \theta - \phi \text{ or } \alpha = \phi - \theta \qquad \textbf{Equation 4}$$

If we wish to determine the doubling effect in a gemstone made from a particular mineral, angle ϕ is first calculated from Equation 3 and then the separation angle α from Equation 4. Then the size of the gemstone is inserted in Equation 1 to determine the actual distance between images in millimetres.

- More rapid estimates can be obtained using *Diagram 2* which was constructed using Equations 3, 4 and 1. Calculations are based on a 10 mm thick gemstone.

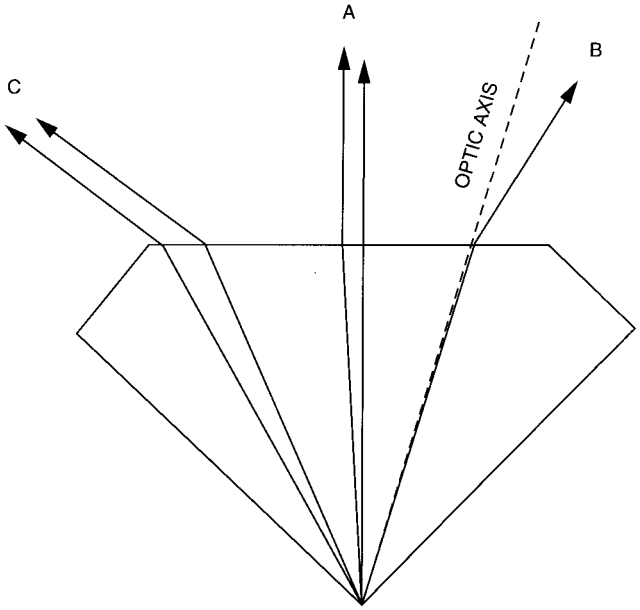

Figure 9: Ray A is split into two rays – the ordinary ray is perpendicular to the gem table. Ray B travels in a direction parallel to the optic axis – it continues as a single ray. Ray C travels in a direction at about 45° to the optic axis – it shows the maximum doubling effect.

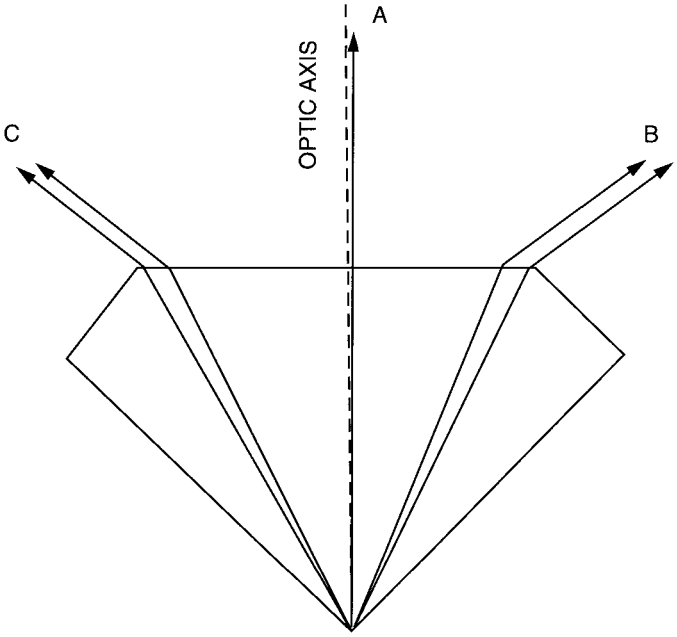

Figure 10: Ray A moves in the direction of the optic axis as a single ray. Rays B and C travel in directions at about 20°–30° to the optic axis and show a doubling effect that is about half of the maximum possible doubling effect for this particular mineral.

Appendix B

Importance of the view point

B.1. Moving the position of the eye over the gem table

In order to see light rays which are perpendicular to the gem table the eye should be positioned perfectly over the centre of the table. *Figures 1–9* and both diagrams have been made for this arrangement. This is a natural position to assume for careful examination of a gemstone.

- However, gemstones are also observed from other positions as they are tilted from side to side. In these positions we see rays that are not perpendicular to the gem table, but travel through the gemstone in many different directions, make different angles with optical elements and, consequently, show different doubling effects.

For example, in *Figure 9*, ray A has a doubling effect that can be determined by using *Diagram 2* as described above. Ray C shows a stronger doubling effect, because it makes a larger angle θ with the optic axis. Ray B travels along the optic axis and shows no doubling effect at all.

We do not have to calculate the doubling effect for all rays exiting the gemstone but we just need to examine the rays that show the maximum doubling effect. If we prepare a simple drawing such as the one in *Figure 9*, we can easily find rays which make the largest angle θ with the optic axis (in uniaxial minerals) and estimate the doubling only for these rays.

Very often the table facet is cut perpendicular to the optic axis of the uniaxial gem minerals (*Figure 10*). In this case, looking through a gem table – no matter how much we tilt the gem (rays C and B in *Figure 10*) – no rays make an angle θ with the optic axis of more than about 30°. These rays will show about one half of the maximum possible doubling effect for that mineral.

Thus, for uniaxial minerals, if the optic axis is **perpendicular to the gem table** we can observe about half of the maximum possible doubling effect (*Diagram 1*) as we look through a tilted gem table.

When making a decision on the orientation of the table facet in rough material of a biaxial mineral that may show a doubling effect – the best way to minimize doubling effects through the table is to set one of the three principal vibration directions (Z, Y or X) perpendicular to the gem table.

B.2. Example: observations on synthetic moissanite

A very fast and reliable test for identification of synthetic moissanite is the observation of the doubling effect. *Diagram 1* shows that the maximum possible separation of images is relatively small – D = 0.16 mm in a 10 mm thick gemstone. In smaller gemstones it will be even less, for example a 5 mm thick gemstone can show a maximum separation of images of D = 0.08 mm.

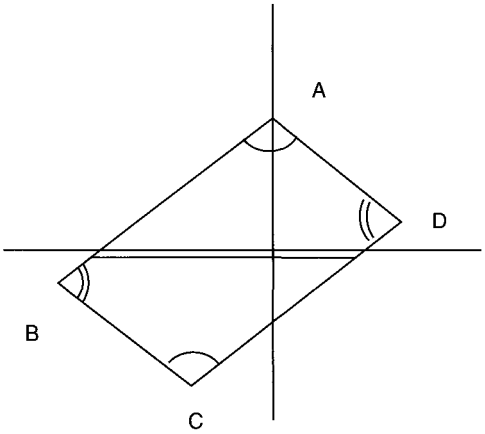

***Figure 11**: Calcite cleavage plate placed over a cross marked on paper shows doubling of the horizontal line. The vertical line is unaffected.*

This would be observed in gemstones where the table facet is at about 45° to the optic axis. However, in most synthetic moissanites the optic axis is perpendicular to the gem table. No matter how much we tilt the gemstone, the doubling effect is difficult to observe in such orientations if we look through the table. Therefore, observation should be through the crown facets.

In practice *Diagram 1* could be used to determine the maximum possible doubling effect for a moissanite gemstone of a certain size, and then checked with a lens or a microscope.

Once we know what to expect and how images should look at different magnifications, we can start the examination of a gemstone. First examination should be through the table facet from various view points, followed by observation through several crown facets – again from various view points. All observations are then compared to arrive at an identification.

B.3. Estimates of the separation of images

Observing a millimetre scale through a lens or a microscope immediately after the observations on a gemstone can give a fairly good estimate of the distance between the images expressed in millimetres.

However, the easiest way to become familiar with the visual effect of various separation distances is to prepare a series of calcite cleavage plates with thicknesses between 1 and 5 mm. A calcite cleavage plate is then set over a cross inked on a sheet of paper and observed from a point directly above the plate.

The calcite cleavage plate is rotated into position as shown in *Figure 11*. One cross line through A appears as a single sharp line (it is actually two lines set exactly one over the other) but the line at the right angle shows doubling. The distance between the doubled lines can be easily calculated by multiplying the thickness of the cleavage plate by 0.11. The orientation of the optic axis in a cleavage plate gives almost the maximum possible separation of images for calcite *(see Diagram 2)*.

Birefringence vs. double refraction divergence

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ABSTRACT: A problem endemic in the field of gemmology that arises from long-standing terminology misuse is discussed. It is posited that refraction refers to action taken by light, while birefringence refers to properties of a medium. The author recommends that use of the plural, the singular, and contractions maintain the same conceptions throughout to avoid optics theory confusion. 'BI' is proposed as a contraction for birefringence and 'DD' is proposed as a contraction for double refraction divergence. It is recommended that 'DR' be discontinued because for too long it has been confused with birefringence.

To describe a medium as doubly refracting is generally considered much the same as describing the medium as birefringent. However, there is an important, if subtle, difference between these descriptions, a difference in root concepts. A birefringent medium has two numerically different indices of refraction which allows double refraction of light. Double refraction requires birefringence, but happens only when refraction (a change in the direction of travel) occurs.

In his classic text on optics[1], Ernest Eugene Wahlstrom elucidates, "The power of a substance to refract light waves is sometimes described as *refringence*. Substances of high refractive index have high refringence; those of low refractive index have low refringence." This clearly indicates that refringence, more commonly referred to in gemmological texts and notes as optical density, is a property of a medium.

The measure of refringence is refractive index (RI), which is sometimes defined as the velocity of light in a vacuum divided by the velocity of light in the medium. In most fluids or crystalline materials of the cubic system, all light of one wavelength will travel at the same velocity set by the refringence. Upon entering the medium, light will experience a transition in velocity, but may or may not change direction of travel. When there is a change in direction, it is controlled not only by refringence, but also by the angle of incidence. Perpendicular incidence will result in a full reduction in velocity while the light travels straight on.

Birefringence of a medium describes two simultaneous differing optical densities, and this results in two different refractive indices. The measures of the two differing refringences are the refractive indices (RIs) of the medium. The term birefringence, as a quantifiable property, has come to mean the numerical difference between two refractive index readings in one medium for the same wavelength of light. As a measurable property of the medium, birefringence may vary with direction. One may speak of the birefringence in a particular reading, which would be the difference in RI values for the

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two mutually perpendicular vibration directions associated with one propagation direction. In a broader context, one may speak of the birefringence of the medium itself (suggested contraction BI rather that DR), which would be the maximum difference in RI value when considering all possible vibration directions within the medium.

Refraction is a change in direction taken by light entering into a material at an angle (usually oblique) to the surface. Double refraction occurs when an incident ray entering into a material experiences being sorted into two rays, each following a different path. Double refraction is an action taken by light passing through a surface into the control of the birefringence of the medium[2] to yield two rays travelling in different directions; it is simple pluralization of refraction. Strong birefringence can produce easily visible double images, sometimes called doubling. Double refraction refers to what happens to one incident ray, while doubling refers to the more complex situation with a larger number of rays producing images.

Refraction, double refraction, birefringence and refringence should have continuity of concept between the singular and the plural. Refraction and double refraction are actions taken by light in response to interaction with a medium. They can only exist in reference to travelling rays of light. Birefringence and optical density (refringence) should both be considered properties of a medium. They exist whether light is travelling through the medium or not.

A problem endemic in gemmology is use of the phrase 'double refraction' as well as the contraction 'DR' when the concept that is intended is birefringence. Contractions that are more appropriate would be 'Bi', 'Bir' or 'BI' or even 'RI-RI'. The mistaken use of 'DR' leads to a major misunderstanding, incorrectly implying that a ray experiencing birefringence must be doubly refracted. Webster did point out the error of expecting to see double images in the direction of maximum birefringence[3], but he still mistakenly used the term 'double refraction' when he meant birefringence. Understanding the theory is easier when considering a single incident ray, rather than the multiple rays needed to produce an image.

When double refraction happens there must be birefringence, but the reverse is not true at all. Examining a crystal of calcite, the stone renowned for its high birefringence and often used to exemplify double refraction, exposes the error of labelling birefringence as 'DR'. It is perfectly possible to have unorganized light sorted into two polarized rays with different properties, and yet neither of the two rays change their direction of travel. Calcite shows that we can easily have birefringence without refraction much less double refraction.

The direction along the length of a prismatic calcite crystal is the optic axis, and therefore shows zero birefringence (BI = nil) and no double refraction divergence (DD = nil). A prismatic crystal of calcite allows us to look squarely through a prism face. This direction is 90° to the optic axis, so must be the direction of maximum birefringence (BI = max). A ray of light entering squarely through the prism face experiences this maximum birefringence. It will be sorted into two rays one travelling at the fastest velocity allowed in the crystal, the other travelling at the slowest velocity imposed by the crystal. Because the incidence is along the wave normal, no refraction takes place. If there is no refraction, it logically follows that there is no plural refraction because there is no degree of divergence (DD = nil). Both rays travel straight on, the fast ray racing ahead, the slow ray lagging behind.

This concept of the degree of divergence between doubly refracted rays that originated from one incident ray, can logically be contracted to 'DD' while 'BI' could serve as the abbreviation for birefringence. The following summary uses these designations to indicate, in general terms, the relationship between double

Uniaxial stones (tetragonal, hexagonal, and trigonal crystals; *one optic axis*)		
U.1	One reversible direction along the optic axis[5]	BI=nil, DD=nil
U.2	All reversible directions 90° to the optic axis	BI=max, DD=nil
U.3	All reversible directions equally oblique to optic axis at angle of maximum doubling	BI=intermediate, DD=max
U.4	All other directions	BI=intermediate, DD=intermediate
Biaxial stones (orthorhombic, monoclinic, and triclinic crystals; *two optic axes*)		
B.1	Two reversible directions along the optic axes[6]	BI=nil, DD=nil
B.2	One reversible direction 90° to both optic axes	BI=max, DD=nil.
B.3	One reversible direction centred in the acute angle between the optic axes	BI=intermediate, DD=nil
B.4	One reversible direction centred in the obtuse angle between the optic axes	BI=intermediate, DD=nil
B.5	Two reversible directions equally oblique to both optic axes	BI=intermediate, DD=max
B.6	All other directions	BI=intermediate, DD=intermediate

refraction and birefringence for directions of normal incidence into anisotropic materials. It is based on the understanding that when a ray coincides with a wave normal there will be no refraction at normal incidence[4].

Comparing the U.3 and B.5 conditions in the summary suggests a potential explanation why the most familiar cases where doubling is easily visible occur in uniaxial stones such as calcite, zircon and synthetic moissanite. In uniaxial stones, there are theoretically an infinite number of reversible directions of maximum double refraction divergence while in biaxial stones there are only two reversible directions of maximum double refraction divergence!

Conclusions

Birefringence and double refraction are related, but should be considered as two different concepts; one concerns properties of the medium, the other, actions of light. If the root of a word is 'refract' then the essential consideration is action taken by light (with regard to changing the direction of travel). If the root of a word is 'refringe' then the essential consideration concerns the properties of a medium (with regard to setting the velocity of light). A prismatic crystal of calcite is a doubly refracting medium for light incident oblique to a prism face or for light incident normal to a rhombohedron face. It is not doubly refracting, however, for light travelling along the length of the crystal or for light incident normal to a prism face because this light does not refract and there is no divergence. If a contraction or short form of birefringence is desired, then perhaps 'BI' could serve instead of the erroneous 'DR'.

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2. In some cases, the angle of incidence can be normal to the surface, and in some cases only one of the two rays refracts, but oblique incidence with both polarized rays refracting is the most common case of double refraction.
3. *Gems*. 5th Edition. pp. 667-8.
4. Any good optics text will contain diagrams of the wave-vector surface or ray velocity surface for anisotropic cases to help clarify these instances where normal coincidence will yield no refraction. One recommended example would be *Introduction to Modern Optics*, 2nd Edition. ISBN 0-48665957-7, Figure 6.9, p.174, by G.R. Fowles. (The wave normal direction is perpendicular to the tangent on the surface.) Wahlstrom shows a good diagram of the relationship between ray-velocity surfaces, the indicatrix, and the two kinds of optic axes in his Figure 11-8, p. 280.
5. Circular birefringence, which produces optical activity (rotation of linear vibration), is ignored because cases of coherent circularly vibrating incident light are seldom encountered or considered, and in cases of optical activity velocity is constant for linearly polarized light.
6. Conical refraction, which occurs in the direction of the optic axes in biaxial media (when every vibration direction that shares the same wave normal has a slightly different velocity), is ignored because this optic axis is defined by wave-normal velocity, not ray-velocity.

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Verneuil synthetic sapphire showing an iron absorption spectrum

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ABSTRACT: Normally iron absorption spectra are characteristic of natural sapphires which owe their colour mainly to traces of iron. If titanium is also present, the $Fe^{2+} \rightarrow Ti^{4+}$ inter-valence charge transfer gives sapphire its blue colour. The intensity of the absorption depends on the iron content which varies according to the origin of the sapphire (basaltic or non-basaltic) and can be further modified if heat treatment or diffusion treatment is applied. An iron spectrum has been observed in a 7.02 ct Verneuil synthetic sapphire which is most unusual and this is described in detail.

Introduction

Recently the author was asked to identify a 7.02 ct oval brilliant-cut blue stone measuring 12.49 × 10.67 × 6.35 mm which looked very similar to heat treated sapphires from Sri Lanka (*Figure 1*). Careful examination however, revealed some unusual features and the gemmological properties of the stone are described below.

Gemmological properties

The gemstone displayed a vitreous lustre, and its SG, obtained by hydrostatic weighing, is 4.00.

The refractive index (RI) determinations were carried out using a Rayner Dialdex refractometer and monochromatic sodium light, and those obtained from the table facet were ω = 1.768, ε = 1.760, giving a birefringence of .008 with optic sign negative. This indicated that the table facet was cut parallel to the *c*-axis and was confirmed when a uniaxial interference figure was obtained on the stone's girdle plane. Under a calcite dichroscope, a distinct dichroism in pale greenish blue and deep blue was observed.

The absorption spectrum, visible through a Beck hand-held spectroscope, revealed an absorption ray typical of iron, at 450 nm,

Figure 1*: Oval brilliant-cut blue stone weighing 7.02 ct.*

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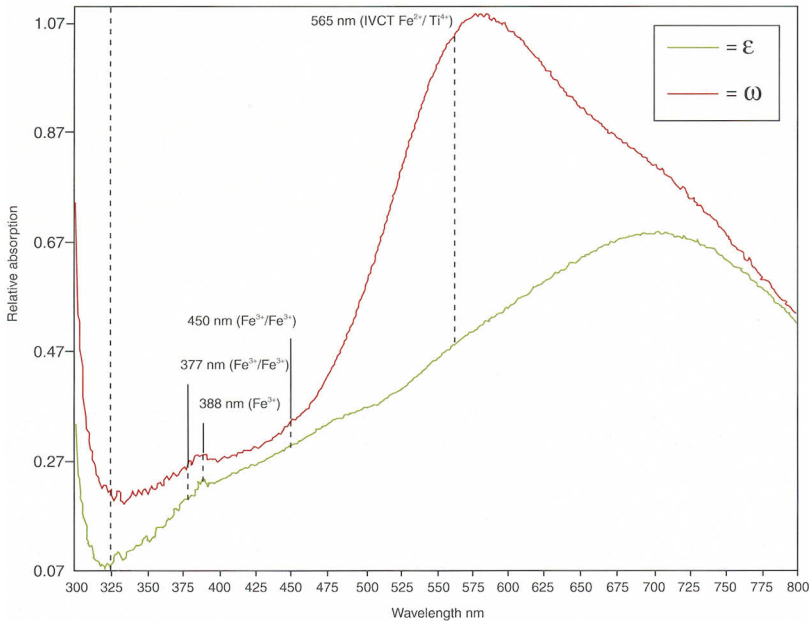

***Figure 2**: UV-visible spectra of ordinary and extraordinary rays in a Verneuil synthetic sapphire of 7.02 ct.*

visible in the optic axis direction, parallel to the table facet. This was confirmed in spectra obtained using the UV-visible spectrophotometer (*Figure 2*), which revealed:

- Two broad absorption bands around 585 nm for the ω-ray, and around 703.5 nm for the ε-ray (although slightly higher than the figures of 565 nm and 700 nm usually mentioned in literature and ascribed to $Fe^{2+} \rightarrow Ti^{4+}$ inter-valence charge transfer (IVCT), which is responsible for the blue colour of the sapphire)[1,2,3,4]
- The absorption lines at 328 nm, 377 nm, and 388 nm, present in the ω-ray and ε-ray spectra.

***Figure 3**: Polishing 'fire marks' near facet junctions on the pavilion. 40 ×.*

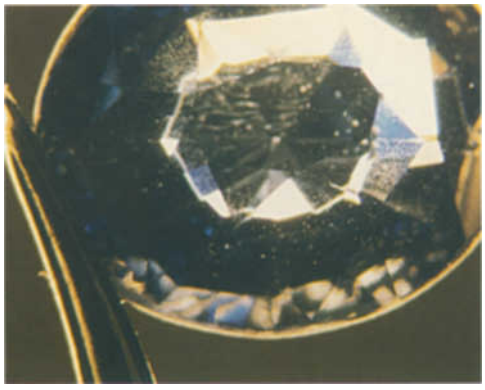

***Figure 4**: Numerous gas-filled pin-point inclusions forming a 'phantom-like' fingerprint under the table facet. 15 ×.*

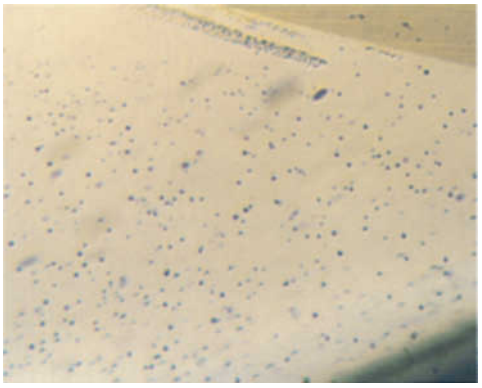

Figure 5: Enlarged view of the halos around the pin-points shown in Figure 4. 60 ×.

Figure 6: A small healed fracture containing glass-like and other material - probably undissolved dopant powder. 80 ×.

- A weak line centred at 450 nm in the ω-ray spectrum, but absent in the ε-ray spectrum.

The stone was examined with a Multispec combined LW/SW ultraviolet unit and fluoresced a strong chalky green to SW but remained inert to LW.

The inclusions were examined using a Bausch & Lomb Mark V Gemolite binocular microscope using dark field illumination or overhead lighting as appropriate. Polishing 'fire marks' were observed near facet junctions on the stone's crown and pavilion (*Figure 3*). Numerous blue-coloured pinpoint inclusions, some of which form 'phantom-like' fingerprints were observed under the table facet (*Figures 4* and *5*). Also very near the surface towards the girdle, two small healed fractures are filled with a 'glass-like' substance, and solid material which may be undissolved alumina, titanium or iron (*Figure 6*). Large isolated perfectly spherical colourless gas bubbles are also present.

When the stone, immersed in methylene iodide, was examined in the optic axis direction between crossed polars, it showed two sets of straight twinning lamellae intersecting each other at 120° and 60° characteristic of the 'Plato striation', which betray Verneuil synthetics (*Figure 7*).

Broad, uneven, curved growth bands ranging from colourless to deep blue are

Figure 7: 'Plato striations' visible when looking at the stone parallel to the c-axis while immersed and between crossed polars. 15 ×.

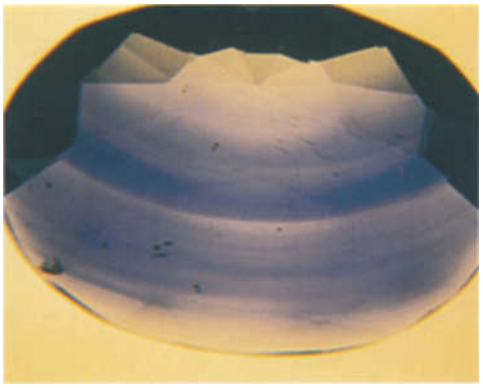

Figure 8: Curved colour bands visible with the stone immersed in xylol and using a different light source. 15 ×.

readily apparent parallel to the optic axis direction while the stone is immersed in liquid (*Figure 8*).

Discussion

In the Verneuil process, to obtain the blue colour of sapphire, titanium and iron dopants (± 1.5% Fe_2O_3 and ± 0.5% TiO_2) are added to the alpha form of Al_2O_3. If most of the iron and titanium burns off in the furnace's intense heat, before these elements fuse, only sufficient Fe and Ti remain to produce the blue colour of sapphire[5]. Not enough iron remains to influence the spectrum. This is why the Verneuil synthetic sapphires lack the 450, 460 and 470 nm absorption lines typical of natural sapphires [6, 7, 8, 9, 10].

Bearing this in mind, the stone was checked for diffusion treatment which could be responsible for the iron absorption spectrum observed.

- When examined in methylene iodide it did not appear as diffusion treated sapphires normally do: it did not show a colour concentration along the facet junctions; rather, the colour variations were not related to facet outline.
- The blue spherical inclusions of different pinpoint sizes, observed in abundance in this stone, must originate from some of the powders containing the trace elements iron and titanium, which had mixed unevenly, and had not been homogenized during burning. The high temperature necessary to produce the Verneuil synthetic sapphire began to melt the perhaps rather coarse powders containing the trace elements, and these interacted with one another (IVCT $Fe^{2+} \rightarrow Ti^{4+}$) before fusing, causing accidental internal diffusion, resulting in the small blue halos[11] as observed in *Figure 5*.

Conclusion

The physical and optical properties are consistent with those of synthetic flame fusion synthetic corundum, variety synthetic sapphire.

The stone probably did not suffer a deliberate diffusion treatment, but an accidental internal diffusion. The internal diffusion of the trace elements iron and titanium that cause the blue haloes and the weak iron absorption line could be due to accidental over-heating of the stone in a furnace. There is a distinct possibility that the synthetic sapphire found its way into a batch of natural sapphires which were then subject to heat treatment.

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A note on two star stones

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ABSTRACT: A polished cabochon of rutile of 16.57 ct engraved to display a star effect is described. The rutile contains significant Nb and Fe, and minor Ta, Sn and W, and its nomenclature is discussed. An unusual crystal of colourless beryl, variety goshenite, contains three zones of tiny inclusions which impart a distinct star effect, weak in some lighting conditions, but strong when lit at an angle by a single light source.

Rutile with a 13-ray imitation star

Recently the author obtained an opaque cabochon of 16.57 ct which displays a strong star when lit by a single source. The stone was described as rutile and the star was the result of artificial engraving (cf. McClure and Koivula, 2001; Schmetzer and Steinbach, 2002). The cabochon averages approximately 13.7 mm in diameter and 6.9 mm in thickness, and has an unpolished base.

The star effect is shown in *Figure 1* and at this angle, displays 13 rays, of which one is very short. At other angles, fewer rays are displayed and this inconsistency of appearance together with the unsymmetrical nature of a 13-ray pattern should prompt questions in the mind of any gemmologist about the origin of such a stone. In detail, the reflection of light in each ray of the star comes from minute closely-spaced parallel grooves on the cabochon surface. In natural star stones, the tiny acicular or tube inclusions commonly lie in two or three orientations quite close to each other, but in the engraved stars the grooves lie in one direction only for each arm.

The stone was sold in the trade as rutile, but opaque gems are not easy to identify by traditional gem testing methods and an analysis was sought at the Natural History Museum. From a scanning electron microscope (SEM), images of the polished surface of the cabochon indicate that at least two phases are present – a host mineral and oriented inclusions or exsolution lamellae, some elongate and some platy in shape (*Figure 2*). An attached energy dispersive analytical system (EDS) on the SEM provided qualitative data indicating that both phases are oxides rich in titanium with variable contents of iron, niobium, tantalum, tin and manganese. The only clear difference between the host and inclusions appears to be the presence of up to 8% tungsten in the inclusions. Approximate compositions of

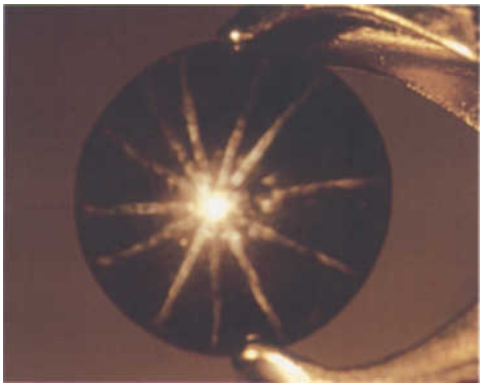

***Figure 1**: Rutile cabochon approximately 13.7 mm in diameter with artificial star.*

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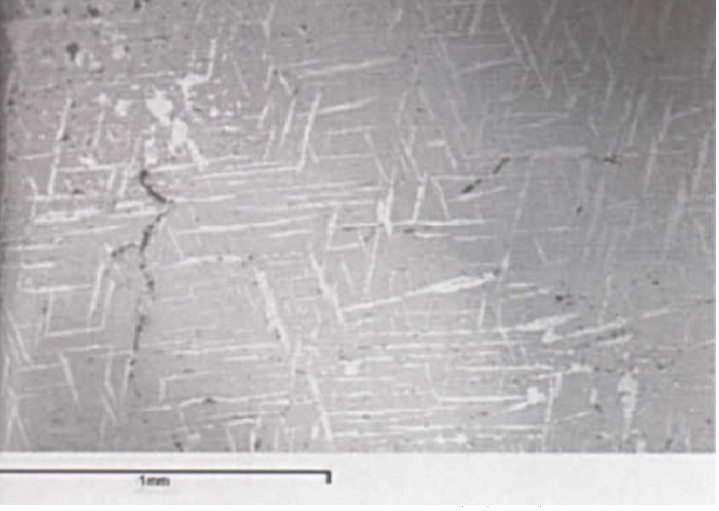

Figure 2: Detailed structure of mineral phases on the polished surface of the rutile cabochon. Back-scattered electron image showing the pale grey exsolution lamellae with a higher tungsten content than the darker host rutile. The scale bar is 1 mm. Photograph by J. Spratt.

two sample spots each of host and inclusion are given in *Table I*.

From *Table I*, it is apparent that titanium (Ti) comprises approximately half the cations and that niobium (Nb) is the next most abundant cation. The stone is therefore not a pure rutile – TiO_2 – as gemmologists have become familiar with it as inclusions in sapphire or ruby for example. However, in the mineral world, the rutile group comprises a number of multiple oxides containing Nb and Ta. Gaines *et al.* (1997, p.237) state: "Nb, coupled with Ta, Fe^{2+} and/or Fe^{3+} enters the composition of rutile up to a maximum of about 33% Nb_2O_5 ..." and "The point at which the Nb_2O_5 content justifies the name ilmenorutile rather than niobian rutile is arbitrary and not fixed ...". So, in mineralogical terms, the stone would be called niobian rutile or ilmenorutile depending on what further comprehensive analyses revealed.

Table I: Compositions of sample spots of host mineral and exsolution lamellae in star rutile.

Element	Element content based on 4 cations and 8 oxygen atoms			
	Host mineral		Exsolution lamellae	
Ti	2.23	1.56	0.99	2.22
Mn	b.d.	b.d.	0.04	b.d.
Fe	0.63	0.86	1.00	0.61
Nb	0.93	1.35	1.62	0.89
Sn	0.03	0.04	0.02	0.06
Ta	0.17	0.19	0.14	0.16
W	b.d.	b.d.	0.18	0.06

b.d. = below detection
Analyst: J. Spratt, The Natural History Museum

However, for gem trade purposes, the procedure for precisely naming complex minerals is often not economic and more general names have to be adopted. For the star stone described above, the analyses clearly indicate that it belongs to the rutile group, a vindication of the name given to it in the trade – and it is up to gemmologists to be aware that this rutile is not quite the same as the rutile one commonly sees as inclusions.

Star beryl

Recently a most unusual crystal was submitted by John Saul to the Laboratory for examination. It is a colourless beryl, variety goshenite, and was recovered about ten years ago from Lavra do Verdinho, Marilac, Minas Gerais, Brazil.; its longest dimension, from 11 o'clock to 5 o'clock in *Figure 3*, is approximately 51.4 mm, and the height is approximately 43 mm and thickness 13.8 mm. The crystal displays approximately 36 faces of which the basal pinacoids and first order prisms are dominant; it is shown in *Figure 3* resting on a first order prism face.

The pinacoids are very smooth and allow a clear view of the internal features of the crystal. *Figures 3* and *4* show concentric growth features parallel to the first order prisms which distort transmitted light and cause a rippled effect. Curiously, this effect is more visible on film when the crystal is out

Figure 3: View parallel to the c-axis of a beryl crystal measuring approximately 49.5 mm across, 43 mm high and 13.8 mm thick. The crystal contains numerous inclusions and displays growth zones (seen as 'ripples') parallel to the prism faces.

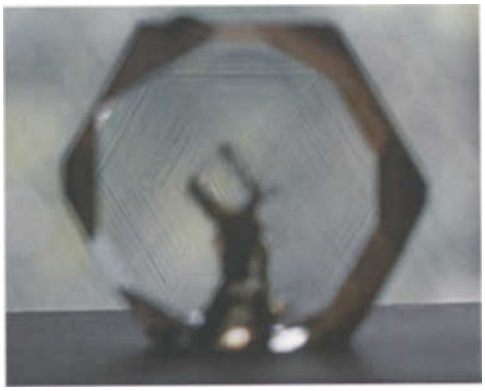

Figure 4: In this view, the concentric growth zones in the beryl crystal are visually emphasized at the expense of the focus of the crystal.

of focus (*Figure 4*). A complex fissure inclusion rises from the prism face at the bottom of the picture through the centre of the crystal and parts of it display iridescence (see *Figures 5* and *6*).

This is a spectacular beryl crystal by any standard, but its interest is enhanced further by the presence of bands of inclusions in the form of a six-rayed star (*Figures 5* and *6*). In *Figure 5*, a star with its arms perpendicular to the main prism faces is displayed and this rather weak degree of visibility obtains for many lighting conditions. Only when the crystal is correctly oriented in a strong directional light beam is a distinct star revealed – as in *Figure 6*.

According to Sinkankas (1981, p.194), "Asterism in beryls is extremely rare", and he subsequently describes the different kinds of chatoyancy and asterism found in the varieties of this species. Sinkankas (op. cit. p.195) states: "The few examples of asterism that have been recorded are due to three sets of inclusions, crossing mutually at angles of 60°, and lying in the plane at right angles to the *c*-axis." He draws a contrast between the "shimmering stars ... caused by reflections from numerous fibrous inclusions" and the "fixed star" of trapiche emeralds from Colombia caused mainly by narrow zones of dark inclusions. Another kind of asterism found in aquamarine (also p.195) is due to minute grains of ilmenite or to pyrrhotite aligned on the basal planes in the beryl structure and producing a rather weak star.

The star in this Brazilian crystal is caused by bands of minute inclusions aligned in the

Figure 5: Beryl crystal viewed from the direction opposite to that in Figures 3 and 4 showing a band of fissures and solid inclusions in the lower centre, some iridescence in a fissure left of centre, and a star structure caused by abundant tiny round and elongated inclusions in three major zones. Small second order prism faces can be seen silhouetted at 3 o'clock, 9 o'clock and about 11 o'clock.

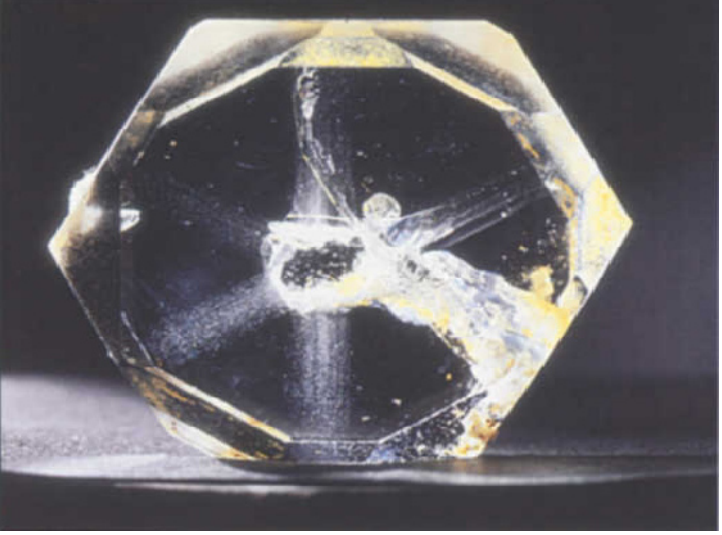

Figure 6: In favourable light, the star effect of the bands of inclusions is very marked. Iridescence is also visible to the right of centre.

basal plane perpendicular to the first order prism faces, and thus is consistent with the first kind of asterism described by Sinkankas. Within the bands the inclusions consist mainly of equidimensional grains or cavities with less abundant elongate or acicular grains oriented at low angles to the basal plane or to the c-axis. Most are between 10 and 100 µm long and some contain liquid and gas.

Acknowledgements

Thanks are due to E. Gamini Zoysa for supplying the imitation star rutile, to Dr J. Saul for loan of the beryl crystal, and to J. Spratt and P. Tandy of the Natural History Museum for providing microprobe and X-ray data and for interesting discussion.

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Gem-quality spessartine-grossular garnet of intermediate composition from Madagascar

Dr Karl Schmetzer[1] and Dr Heinz-Jürgen Bernhardt[2]

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2. Central Microprobe Facility, Ruhr-University, D-44780 Bochum, Germany

ABSTRACT: Gemmological, chemical and spectroscopic properties of a light yellowish-orange gem-quality garnet from Madagascar are reported. The sample is composed of 49 mol.% spessartine, 41 mol.% grossular, 5 mol.% almandine and 5 mol.% pyrope. A SG of 3.97 and a RI of 1.770 are in the range commonly observed for intermediate pyrope-almandine or pyrope-spessartine garnets. The colour of the spessartine-grossular garnet and its absorption spectrum are similar to that of low iron-bearing spessartine.

Introduction

Gem-quality natural garnets are considered as members of four major solid solution series, i.e. the three groups of the pyralspite series (pyrope-almandine, pyrope-spessartine, spessartine-almandine), and grossular-andradite (Stockton and Manson, 1985; Johnson *et al.*, 1995; Hanneman, 1997). Although natural intermediate garnets between grossular and members of the pyralspite series are known (see, e.g. Deer *et al.*, 1982), gem-quality grossular described so far forms only a limited solid solution with pyrope, almandine and spessartine. In general, the grossular component exceeds 75 molecular per cent in numerous chemical analyses (see e.g. Manson and Stockton, 1981; Stockton and Manson, 1982). In gem-quality spessartine, on the other hand, only minor molecular percentages of grossular are present (Laurs and Knox, 2001). In intermediate pyrope-spessartine garnets, the molecular percentage of grossular only rarely exceeds 15 per cent (Jobbins *et al.*, 1978; Schmetzer and Bank, 1981; Stockton and Manson, 1982; Schmetzer *et al.*, 2001). An extraordinary pyrope-spessartine sample from Umba Valley, Tanzania, with a grossular percentage of 24% was described by Schmetzer (1982) and a sample with similar properties was mentioned by Bank and Henn (1989).

Intermediate pink to pinkish-orange pyrope-spessartine 'malaya' garnets from Bekily, Madagascar, were recently described by Schmetzer *et al.* (2001). In order to compare the chemical and spectroscopic properties of the Bekily samples with the properties of spessartines from Madagascar, 12 samples from unspecified locations in Madagascar were also analysed. These gemstones were selected from several parcels totalling about 200 spessartine and spessartine-almandine garnets in the yellowish-orange, orange, orange-brown, and brownish-red to almost red colour

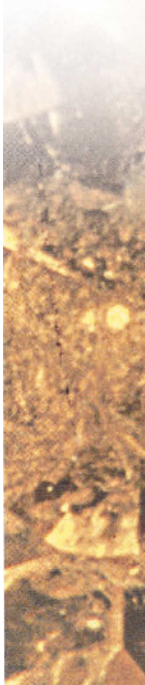

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***Figure 1**: Three spessartines (left) and three hessonites from Madagascar revealing an almost identical colour range. The hessonites range from 3.9 to 4.2 mm across. Photo by Maha Tannous.*

range. These spessartine parcels also contained about 50 faceted grossulars (hessonites) of similar colours (*Figure 1*) and so five samples of this garnet variety were also chemically analysed. Surprisingly, the microprobe analyses revealed one sample with an extraordinary composition intermediate between spessartine and grossular (*Figure 2*), which is described below (for experimental details refer to Schmetzer *et al.*, 2001).

All garnet parcels mentioned above were bought by a German dealer within the last five years on various occasions in Madagascar and all samples had already been faceted in their country of origin. Therefore we are unable to indicate the exact locations of either the spessartine or the grossular garnets, or the locality for the intermediate spessartine-grossular sample.

Properties

Spessartines

Microprobe analyses revealed 34.7 – 39.1 wt.% MnO and 2.4 – 8.2 wt.% FeO. Traces of calcium were present (0.2 - 0.5 wt.% CaO) and MgO was below 0.05 wt.% in all samples. The chemical data indicate 80.4 – 93.2 molecular per cent spessartine and 5.5 – 18.9 molecular per cent almandine. Grossular ranges from 0.6 to 1.5 molecular per cent, and pyrope contents were approximately 0.1 molecular per cent. With increasing iron (i.e. almandine content), the colour changed from bright yellowish-orange or orange to orange-brown and almost red (see again *Figure 1*). Also, as iron contents increased, the RI and SG values increased from 1.800 to 1.808 and from 4.15 to 4.22 respectively.

Hessonites

Microprobe analyses revealed 36.5 – 36.8 wt.% CaO and 2.7 – 5.7 wt.% Fe_2O_3. Traces of manganese (0.05 – 0.2 wt.% MnO) and magnesium (0 – 0.6 wt.% MgO) were also present. The chemical data indicate 84.3 – 93.8 molecular per cent grossular and 6.0 – 15.5 molecular per cent andradite. Spessartine varies from 0.1 to 0.3 molecular per cent, and pyrope contents were between 0 and 0.6 molecular per cent. With increasing iron (i.e. andradite content), the colour changed from yellowish-orange or orange to orange-brown and reddish-brown (see again *Figure 1*). Also, as iron contents increased, the RI and SG values increased from 1.740 to 1.753 and from 3.61 to 3.67 respectively.

Description of the intermediate spessartine-grossular

Gemmological, chemical and spectroscopic properties of the 0.42 ct round, light yellowish-orange garnet sample from Madagascar are summarized in *Table I*. SG and RI values are intermediate between those commonly observed for natural spessartine and natural grossular (see, e.g., Stockton and Manson, 1985; Hanneman, 1997). Specifically, the values for SG and RI are in the range commonly observed for intermediate members of the pyrope-almandine and pyrope-spessartine series (Manson and Stockton, 1981; Stockton and Manson, 1982, 1985; Lind *et al.*, 1998; Schmetzer *et al.*, 2001). Microscopically, only a healing feather and some anomalous double refraction were observed as is commonly seen in garnet members of the pyralspite (pyrope-almandine-spessartine) series. Unfortunately, no mineral inclusions were present to indicate a possible paragenesis of the garnet sample.

Chemical data (see *Table I*) indicate a composition intermediate between spessartine and grossular with distinct contents of the almandine and pyrope molecules. A calculation of the garnet composition for 12 oxygens and for both Fe^{2+} and Fe^{3+}, indicates the presence of a small amount of Fe^{3+} in the range of 0.5 molecular percentage of the andradite end member. Only traces of vanadium and chromium are present.

Spectroscopic examinations reveal an absorption spectrum almost identical to that of low iron-bearing spessartine, e.g. from Namibia, Nigeria or California (Lind *et al.*, 1993; Milisenda and Zang, 1999; Lind and Henn, 2000; Laurs and Knox, 2001). Thus, the assignment of absorption bands is consistent with that of other members of the pyrope-spessartine and spessartine-almandine series with low iron contents (for details of the assignment, see also Schmetzer *et al.*, 2001). Consequently, the colour of the sample is comparable with the colour of low iron-bearing spessartine, e.g. with the colour of some of our spessartine samples from Madagascar with iron contents in the range of 2 – 3 wt.% FeO.

***Figure 2**: Intermediate spessartine-grossular from Madagascar. Diameter of the sample 4.4mm. Photo by Maha Tannous.*

Discussion

The properties of the spessartines and the hessonites from Madagascar are those commonly observed for these varieties of gem-quality garnets, i.e. for members of the spessartine-almandine or of the grossular-andradite series. So far, the intermediate spessartine-grossular is a unique sample, and further garnets that might be of similar composition were not found within the lots from Madagascar available to us (e.g. by a routine determination of the RI of garnet samples with similar coloration).

The composition of the spessartine-grossular from Madagascar is intermediate between two non-gem-quality garnets reported by Deer *et al.* (1982), i.e. between sample 28 of Table 56 with 33 mol.% grossular and 51 mol.% spessartine and sample 17 of Table 58 with 58 mol.% grossular and 36 mol.% spessartine.

The distinction of intermediate spessartine-grossular garnet from spessartine or grossular (hessonite) is possible by comparison of physical properties, especially by the determination

Table I: Properties of an intermediate spessartine-grossular garnet from Madagascar.

Gemmological properties		Chemical properties		Spectroscopic properties	
		Microprobe analysis (wt.%)[a]	Cations based on 12 oxygens	Absorption maxima (nm) intensity[c]	Assignment
Weight	0.42 ct	SiO_2 37.88	Si 2.990	687 medium	Fe^{2+}
Size	4.4 mm round	TiO_2 0.15	Ti 0.009	610 weak	Fe^{2+}
Colour	Light yellowish-orange	Al_2O_3 21.39	Al 1.989	569 very weak	Fe^{2+}
		Cr_2O_3 0.02	Cr 0.001	525 strong	Fe^{2+}/Mn^{2+}
SG	3.97	V_2O_3 0.04	V 0.003	503 medium	Fe^{2+}
RI	1.770	FeO[b] 2.37	Fe 0.156	483 very strong	Mn^{2+}
Microscopic features	Healing feather	MnO 21.91	Mn 1.464	459 very strong	Fe^{2+}/Mn^{2+}
	Anomalous double refraction	MgO 1.36	Mg 0.160	430 strong	Mn^{2+}
		CaO 14.58	Ca 1.233	421 strong	Mn^{2+}
		Total 99.70		410 very strong	Mn^{2+}
		Mol.% end members	Almandine 5.18 Spessartine 48.59 Pyrope 5.31 Grossular 40.92		

Notes: [a] Mean of 10 analyses
[b] total iron as FeO
[c] Intensity is qualitatively assessed from weak to very strong

of SG and RI. The distinction from intermediate members of the pyrope-almandine or pyrope-spessartine series is, so far, performable on the basis of colour and spectroscopic properties. An overlap of gemmological features, however, may be expected if more intermediate samples within the complete grossular-spessartine series are found and particularly if the samples have different contents of colour-causing trace elements, e.g. with somewhat higher iron, vanadium or chromium contents.

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Letter to the Editor

Rare Gemstones: Chondrodite

After the appearance of our article (Zwaan and Zoysa, 2002) Willow Wight kindly sent me some additional information on another locality where gem-quality chondrodite was found, but which was not mentioned in our article. Apart from the mentioned localities, such as the Tilly Foster mine, near Brewster, New York, and Pargas and Kafveltorp in Sweden, the Cameron quarry, about 45 km west of Ottawa, near Carlton Place, Lanark County, Ontario, has also produced some very small gem-quality chondrodites. A bright orange-yellow faceted chondrodite of 0.25 ct was reported from this mine by Wight (1998).

Hanco Zwaan
National Museum of Natural History
Leiden, The Netherlands

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Proceedings of the Gemmological Association and Gem Testing Laboratory of Great Britain and Notices

OBITUARY

It is with great sadness that we report the death of **Richard T. Liddicoat**, Chairman of the Gemological Institute of America and Hononary Fellow of Gem-A on 23 July. A personal tribute by David Callaghan follows.

Richard 'Dick' T. Liddicoat Jr

A personal tribute

It doesn't need me to write of the achievements of this consummate gemmologist: there are others far more qualified and capable than I am that have done so. However, there are many people who never met 'Dick'. It is to those of you that I address this tribute in the hope that I can give you a picture of this remarkable man.

Let me ask you to allow your mind to conjure up a picture of the person you would like to have as a favourite uncle. He will need to possess at least one of the following attributes: a warm smile; a welcoming handshake; a comforting voice; a sense of humour – perhaps occasionally a teasing humour; the ability to make you feel at home; the kindness of manner to make you feel that you have his whole attention. The 'uncle' I hope to introduce had all these attributes. That is rare indeed.

I first met Dick during a visit to GIA's New York Lab in 1980. Having been elected Chairman of the Gemmological Association of Great Britain I had introduced myself to the late Eunice Miles and to 'Bob' Crowningshield. Whenever my work took me to New York they made me very welcome and it was on one of my visits that I was introduced to Dick. His admiration of the work of the GA, and of his great friend B.W.Anderson was made very clear to me. He, like Basil Anderson, greatly respected the dealers in the trade.

In 1981, during the Golden Jubilee celebrations of the GA, he joined B.W. Anderson, Dr E. Gübelin and 'Bob' Crowningshield in London as guest lecturers. It was at this time that he was given the Honorary Fellowship of the GA, an honour of which he was very proud. So much so that, whenever he knew he and I were scheduled to meet somewhere, he would always pointedly wear his GA necktie!

He was naturally a polite man and did not take offence easily. An example of this came about during that 1981 visit to London. My wife and I invited him to join us for lunch on Sunday and we decided to take him to a restaurant in Windsor. We duly collected him from the Royal Lancaster Hotel and over lunch we talked of family matters and the like. In telling us of his upbringing in his Michigan hometown he expressed disappointment that he was not able to go home as often as he would like. He told us of his elderly father, now over 90, and we asked, ingenuously and perhaps patronisingly, "Who looks after your father?" To our astonishment he replied, "My mother!" She was also over 90. He took no offence at the implication behind our question that he, Dick, looked older than he was!

I was also a victim of his impish humour on more than one occasion. One was in 1985 when I attended the ICA Conference in Idar-Oberstein in my capacity as Gemmological Association Chairman. I was due to leave the Conference before the close and faced an awkward train journey to Frankfurt. As I was checking out of the hotel Dick saw me and said I would be very welcome to

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accompany him by car. He, Glenn Nord and the late Vince Manson were to drive there. He brushed aside my gentle protests saying there would be no problem and I would be very welcome. I had not met Glenn Nord at the time nor did I know Vince Manson. Throughout the two hour journey Glenn seemed quietly bemused at my presence and Vince was pre-occupied with driving. I discovered later that Dick had told them that I was "a very quiet sort of guy"; those of you who know me will certify that it is impossible for me to keep quiet for the whole two hours of a car journey!!

As I sit compiling this tribute I have in front of me a photograph of Dick in an off-duty moment. Also in the photograph is my great friend the late Eric Bruton of whom Dick was very fond. Dick does not look like a man to have a species of tourmaline named after him, one with a long and complicated chemical formula completely incomprehensible to me!

His contribution to gemmology is immense and enduring. An artist could give you an accurate painting of the man – but I am no artist. I may be accused of being facetious when I say that, in his appearance, he reminded me of the great American screen actor E.G. Marshall combined with Jack Benney. The first because of his obvious sincerity and integrity – the other for his rich voice and the smile that leads you to think of some gentle mischief in the making!

Richard Liddicoat at the Presentation of Awards held on 28 October 1985 at Goldsmiths' Hall, London.

He kindly wrote a personal dedication in the flyleaf of a copy of his *Handbook of Gem Identification* and I treasure his words to me. Those of us who had the privilege of knowing Dick have had our lives enriched. We are thus the poorer in the knowledge that he is no longer with us.

* * *

Trevor M. Brook FGA (D.1953 with Distinction), Leicester, died suddenly on 10 July 2002.

GIFTS TO THE ASSOCIATION

The Association is most grateful to the following for their gifts for research and teaching purposes:

Bronwen Fraser of Christiana, South Africa, for an oxidized diamond, and samples of kimberlite and alluvial gravel 'batontoms'.

Charles Green & Son Ltd., Birmingham, for a selection of gemstones.

Ian Thomson of Thomson Gems Ltd., London, for a large selection of gemstones for use in education.

MEMBERS' MEETINGS

London

On 25 September 2002 at 27 Greville Street, London EC1N 8TN the Annual General Meeting was held, a report of which will be published in the January 2003 issue of *The Journal*. The AGM

was followed by a talk by Stephen Kennedy entitled 'Notes from the Laboratory: detection, disclosure and false descriptions'.

Midlands Branch

On 27 September at The Earth Sciences Building, University of Birmingham, Edgbaston, Richard Taylor gave a talk on 'Diamonds certification, appraisal and valuation'.

North West Branch

On 18 September at Church House, Hanover Street, Liverpool 1, John Harris gave a talk entitled 'Chasing rainbows'.

Scottish Branch

Two talks were given on 4 September at the British Geological Survey, Murchison House, West Mains Road, Edinburgh. Dr Lin Sutherland spoke on 'New developments in dating gem corundum sources below basaltic gemfields' followed by Dr Rui Galopim de Carvalho with a talk entitled 'The Portuguese Crown Jewels'.

ANNUAL REPORT

The following is the Report of the Council of Management of the Gemmological Association and Gem Testing Laboratory of Great Britain for the period 1 January 2001 to 31 March 2002.

Officers, councils and committees

The Gemmological Association and Gem Testing Laboratory of great Britain (GAGTL) is a company limited by guarantee and is governed by the Council of Management. With decreasing involvement in the day-to-day activities of the Association, N.W. Deeks resigned from the Council of Management in July but agreed to the unanimous wish of the Council that he become a Vice President. In November, J-P. van Doren left his post as Chief Executive Officer and resigned from the Council, and Council wishes to thank him for his contribution towards raising the visibility of the Association worldwide. Following the departure of J-P. van Doren, Council appointed Council member T.M.J. Davidson, FGA, as acting CEO. The President, Professor A.T. Collins, continued in office as did Vice Presidents A.E. Farn, R.A. Howie, D.G. Kent and R.K. Mitchell. C.M. Woodward and E. Stern continued as Chairman and Vice-Chairman respectively of the Board of Examiners. At the July meeting of the Trade Liaison Committee, J. Monnickendam completed a two-year term of office as chairman and handed over to J. Kessler; W. Roberts was elected Vice-Chairman of the committee. C. Winter (chairman) and P. Dwyer-Hickey (Vice-Chairman) continued in office on the Members' Council. At the Annual General Meeting in June, S. Burgoyne was elected to the Members' Council and A. Good stepped down after serving for three years - for which she is warmly thanked.

Education

During the two academic years straddled by this report, both the regular gemmology and gem diamond courses were full, with students coming from many different countries. The teaching is shared between Association staff and independent practitioners in the jewellery trade, and Council thanks all for their commitment and dedication. New Gemmology Diploma Course Notes and a new Practical Handbook were completed and brought into use at the beginning of the autumn term in 2001, and work on a foundation course in gems commenced.

A wide variety of short courses and tutorials was held at the Gem Tutorial Centre in Greville Street, and although sadly M. Keating left to further her jewellery career in Ireland, R. Warner joined us and has continued to develop the programme. D. Garrod has also developed his programme of customized tutorials for firms in the jewellery trade throughout the UK and participated in a training video for one firm. He also ran five half-day courses for the British Jewellers' Association.

A new Allied Teaching Centre (ATC) was established in Bangkok, Thailand, and the one in Jaipur, India, was re-established. Further expansion in Japan and Taiwan is under discussion.

This report covers three examination sessions, and a total of 1067 students sat the gemmology or gem diamond papers. In gemmology, the pass rate for the Preliminary examination was 81%, which is better than normal; the Diploma pass rate was 46%. In the Gem Diamond examination, 67% of candidates were successful.

The Presentation of Awards was again held at Goldsmiths' Hall where the President, Professor A. Collins, presided and welcomed the successful students and their families. He introduced the Guest of Honour, R. Sancroft-Baker, FGA, Senior Director of the Jewellery Department at Christie's, who presented diplomas to the successful students and also announced the following prizes: the Preliminary Trade Prize to Mrs Karen McKinley, Abington, Northampton, England; the Anderson Medal to P. Bick San Wong of Hong Kong; the Christie's Prize for Gemmology to I. Sipson of Trowbridge, Wiltshire; the Anderson-Bank Prize to Dong Lan of Wuhan, China; and the Deeks Diamond Prize to A. Thomas of Birmingham, West Midlands. In the opinion of the Examiners no student submitted papers of sufficient quality to be awarded either the Tully or Bruton medals.

The Board of Examiners met three times under its Chairman, C.M. Woodward. On the recommendation of the Board, Li Liping of Wuhan, China, was appointed a Gem Diamond Practical Examiner by the Council of Management, and the Board also approved the introduction of a practical element into the Preliminary course. Council very much appreciates the contributions of all the examiners in maintaining and developing the Association's qualifications, and also thanks B. Hunt and L. Dean for their dedication and resourcefulness.

The Education Review Meeting was held as usual in November and provided a valuable forum for the direct exchange of views between tutors, lecturers, examiners and staff of the education department. Details of course content, ways of introducing practical instruction and marking schemes were discussed.

In November I.F. Mercer and J-P. van Doren travelled to Shanghai for talks with the China Diamond Promotion Service and the British Council and both delivered lectures at the Wuhan Gemmological Institute of China (GIC) Tenth Anniversary Conference and the Gemmological Association of Hong Kong jewellery conference in Hong Kong.

After government changes in the regulations dealing with approval of qualifications in the UK, the Association, through meetings and completion of paperwork, fulfilled the requirements of the Qualifications and Curriculum Authority (QCA) to maintain the accreditation of the Diploma in Gemmology.

After holding office for four years, the Secretariat of the Federation for European Education in Gemmology (FEEG) passed from Gem-A to the Dutch Gemmological Association in 2001. I.F. Mercer serves on the Examination Committee of FEEG and attended the annual meeting in January 2002 held in Vicenza, Italy.

Laboratory

Diamond grading in the Laboratory continues to grow and provides a major part of Laboratory income. Increased numbers of coloured stones were also examined and there is a growing demand for opinions on whether stones have undergone heat treatment.

S.J. Kennedy and S. Kimber represented the Laboratory in 2001 at the Gem Industry and Laboratory Conference (GILC) in Tucson, USA. S.J. Kennedy attended the CIBJO annual meetings in Paris (2001) and Munich (2002), at which further meetings of the GILC were also convened. 'Notes from the Laboratory' were published in the January and October 2001 issues of *The Journal of Gemmology* and short accounts of laboratory activities have been published in jewellery trade magazines.

The Laboratory's international reputation was a major factor in securing a consultancy for a major project undertaken by a state in the Middle East and this will involve supply of equipment and training of staff.

Gem-A

On taking office as CEO in January 2001, J-P. van Doren held regular meetings with staff and others to work towards a new image for the Association. Designs were considered and by April, one had been selected. Gem-A was launched at a reception following the AGM in June 2001 and has since won general approval as a trading image. The new style was introduced to members, the trade and to the public at trade fairs and at 'Open Days' held in London and Birmingham.

Trade Fairs

In 2001 I.F. Mercer and S. Kimber ran a show stand at the American Gem Trade Association (AGTA) Show in Tucson, Arizona; in 2002, D.J. Garrod accompanied I.F. Mercer at Tucson, and for both shows grateful thanks are expressed to C. Balzan of San Francisco for his generous support. T.M.J. Davidson also supported the Association effort in 2002 and he took positive steps towards setting up a presence in the USA under the name 'Gem-A USA'. This will be a subsidiary company of GAGTL and Anne Dale has agreed to be the Director.

The Association also exhibited at four other major fairs during 2001: the NEC, Birmingham, in February, Las Vegas, Nevada, in June, and the International Jewellery London (IJL) and the Hong Kong Gem and Jewellery Fair in September. Gemmology was brought to a different audience with the Association's presence at four Rock 'n' Gem shows at Kempton Park, where the many enquiries for courses, books, instruments and membership are handled by A.J. Clark, D.J. Garrod and L.F. Stather.

Visits

In April 2001 the seventh annual visit to Idar-Oberstein was organized by S. Kimber and was enjoyed by over 40 participants who appreciated the warm welcome at all the venues they visited – the mine, the museums, the private collections and the gem-cutting workshops.

Visits closer to home were organized for members to the Diamond Trading Company (DTC) and the Mineral Gallery at the Natural History Museum, South Kensington.

Membership

Overall membership declined slightly with recruitment (mainly from educational courses) just failing to compensate for losses. The fall in Laboratory membership reflects a trend in the jewellery trade in which numerous small firms are giving away to fewer larger organisations.

Activity in the Branches continues to grow. The Midlands Branch held 14 meetings and celebrated their 50th anniversary at a weekend conference with guest speakers E.A. Jobbins, Prof. Dr H. Hänni and I.F. Mercer, with contributions by A.D. Morgan and T.M.J. Davidson. The North West and Scottish Branches both held eight meetings and the latter ran an excellent conference in Perth with Richard Drucker the main speaker. The inaugural meeting of the South West Branch was held in January 2001 and although meetings have been fewer, attendances have been good – members travelling from Devon and South Wales.

In London, a varied programme of 10 lectures was held, including a double presentation by Dr Kurt Nassau, and again the Annual Conference was held at the Barbican Centre. The keynote speaker was G. Bosshart of the Gübelin Gem Laboratory who talked about diamonds and ruby treatments, Dr S. Lawson of the DTC talked about screening of treated diamonds, S. Whittaker (of Fellows Auctioneers) and H. Milton (Miltons, Liverpool Ltd) then gave a stimulating view of the pawnbroking and auction aspects of the trade, and TM.J. Davidson looked at some aspects of 'Who or what is a jeweller?'

Publications

In the period January 2001 to March 2002, 26 papers were published in *The Journal of Gemmology* with topics ranging from Madagascan and Peruvian gemstones to jades and ornamental granite, and from fake asterism to the reasons for colour in diamond. Abstracts totalled 285 and there were 47 book reviews, and again, thanks go to M.J. O'Donoghue, to our abstractors and to the Mineralogical Society for permission to reproduce abstracts of possible relevance to the gem world. Council would also like to thank the Assistant Editors and the Production Editor, M.A. Burland, for their invaluable support, and a special acknowledgement is due to R. Coleman (of Harley UK) for his intense involvement in designing fresh and interesting Journal covers and in monitoring production.

Gem and Jewellery News is published jointly with the Society of Jewellery Historians and in 2001-2 contained a wide range of lecture and exhibition reviews, comments on new books, reports of activities at the branch events, the Gem Discovery Club highlights, and the often-quoted column 'Around the Trade' by H. Levy. As with *The Journal*, design is important, and a fresh look (again designed by R. Coleman) and expansion to 20 pages were introduced for Volume 11.

Photographic competition

The 2001 competition on the theme 'Born yesterday' drew entries of a high standard. The judges are independent of Gem-A and they selected three prizewinners and several more images to grace the calendar for 2002 which is distributed free to members. The winner was Marc de Regt of the Netherlands and he received his prize at the Reunion of Members in June. Council is most grateful to Harley UK, producers of *The Journal of Gemmology* for their sponsorship of these prizes and for their contribution to Annual Conference expenses.

Finance

Although there have been regular updates in recent years, the Association's computer system, installed in 1990-1, needed replacement. Installation of a new accounts package proved more complex than originally thought and after discussion with our accountants, Hazlems Fenton, Council decided to change the account reference period to terminate on 31 March rather than 31 December.

The financial result for Gem-A for the 15 month period to 31 March 2002 is a loss of £62,124. This compares with a surplus for 2000 of £22,384 and comes after considerable initiatives in launching Gem-A and promoting the Association at selected venues, particularly overseas.

Gemmological Instruments Limited

Gemmological Instruments Limited is a wholly-owned subsidiary company of GAGTL. It supplies good-quality gem testing equipment at keen prices and there is a constant search for improvement in performance and alternative sourcing of components by its executive director, A.J. Clark. Advances introduced in 2001-2 include a widefield dichroscope, a new version of the gemmologist's refractometer with a widefield eyepiece in secure housing, and thermal diamond testers available at much lower prices than previously. Although new gem books regularly appear on the market it is worth commenting that of the standard works used for teaching, Webster's *Gems* is becoming out of date, Bruton's *Diamonds* is out of date and out of print, as is Anderson's *Gem Testing*. With increased costs, there was an overall loss during the period of £14,039, and improved profitability is being sought with reviews of stock and assessment of the various instrument and book ranges.

The staff and supporters

The period under review has been one of change and financial constraints have meant that many good ideas remain to be implemented. Nevertheless the staff have participated and given their full support to the actions initiated and the Council of Management thanks them for their positive attitude. This attitude carried through to support the new acting Chief Executive Officer, T.M.J. Davidson, whose first action was to draw up a Corporate Plan for the next three years. This was completed in March and has been presented to major bodies in the UK jewellery trade.

The Council of Management recognizes the wide extent of general goodwill towards the Association and would particularly like to thank those generous donors who have augmented our teaching collections and those who have given their time in furthering the positive work of the committees.

GEM DIAMOND EXAMINATION

In the Gem Diamond Examination held in June 2002, 102 candidates sat of whom 73 qualified, including seven with Distinction and eleven with Merit.

The **Deeks Diamond Prize** for the best candidate of the year in the Gem Diamond Examinations has been awarded to Julian Read of Goole, East Yorkshire.

The **Bruton Medal** was not awarded.

The names of the successful candidates are listed below:

Qualifed with Distinction
Dimmick, Helen M., Pinner, Middlesex
Joshirao, Ajey A., Maharashtra, India
Li Yaoyao, Wuhan, Hubei, P.R. China
Wakefield, Dominic, Horsham, West Sussex
Warner, Rachel F., London
Yuling Mao, Wuhan, Hubei, P.R. China
Zhang Tao, Beidajie, Beijing, P.R. China

Qualifed with Merit
Avery, Hilary E., Bangor, Co. Down, N. Ireland
Borruso, Alessandro, Harrow, Middlesex
Clark, Antony, Bolton, Greater Manchester
Corcoran, Moya A.M., London

Croucher, Nicola, London
Cruse, Suzanne, Wickford, Essex
Getgood, Fiona J., St Leonards on Sea, East Sussex
Plant, Monika, Knutsford, Cheshire
Taylor, Andrew, Basingstoke, Hampshire
Toullic, Nathlie, Brentford, Middlesex
Weidong Niu, Wuhan, Hubei, P.R. China

Qualified
Abimbola, Adedapo, Clapham South, London
Anderson, Ian, Heaton, Bradford, West Yorkshire
Arjan, Anand, East Ham, London
Balls, Serra, London
Baskerville, Fenella J., Upper Holloway, London
Besli, Selim, Hackney, London
Bryant, Susan, Sutton Coldfield, West Midlands
Burton, Lola C., Hastings, East Sussex
Callaway, Heather, Stone, Staffordshire
Cheadle, Sonia, Dalston, London
Collins, Steven J.C., Letchworth, Hertfordshire
Daswani, Vijayeta, St Johns Wood, London
Donnelly, Lee-ona F., Heathfield, Ayr, Scotland
Droujinina, Highgate, London
Forbes-McCaig, Charlotte, Newtownabbey, Belfast, N. Ireland
Formosis, Dimitris, Athens, Greece
Fraser, Bronwen C., Christiana, South Africa
Greenstein, Saul, London
Greer, Paul F., Chatham, Kent
Hassan, Fatima, Totteridge, London
Hui Yee-Wan, Elsie, Kowloon, Hong Kong
Kam Ka Wai, Hong Kong
Leader, Lucille, London
Loaker, Alistair, Stevenage, Hertfordshire
Macrae, Margaret, Isle of Lewis, Scotland
McLeod, Fiona J., Yellowknife, North West Territories, Canada
Matharu, Rajinder, Handsworth Wood, Birmingham, West Midlands
Oh Minkyung, Busan, South Korea
Oshida, Reiko, Singapore
Pace, Howard M., Eccleshall, Stafford
Paraskevopoulos, Michael, Athens, Greece
Pearson, Heather A., Belper, Derbyshire
Quilley, Claire J.A., Aylesbury, Buckinghamshire
Rweyemamu, Edward J., Leytonstone, London
St John Lewis, Delyth, Palmers Green, London
Salukvadze, Iamze, Dubai, United Arab Emirates
Selvamani, Parvathi, Poplar, London
Shah, Monica, Cheadle, Cheshire
Sinclair, Harvey, Hendon, London
Stevens, Jill, Stonnall, Lichfield, Staffordshire
Sutton, Janine R., Harborne, Birmingham, West Midlands
Tam Lai Fong, Betty, Kowloon, Hong Kong
Taylor-Leigh, Susan J., Kings Heath, Birmingham, West Midlands
Tong Chi Cheung, Kowloon, Hong Kong
Tong Tong, Beidajie, Beijing, P.R. China
Tuckwell, Alice E., Untersigennthal, Switzerland
Varnava, Sofia, Polihmi, Thessaloniki, Greece
Verganelakis, Vassilis, Athens, Greece
Wang Ying, Beidajie, Beijing, P.R. China
Waugh, Elizabeth S., Rochford, Essex
Wong Sze Chai, Kowloon, Hong Kong
Xu Yuehong, Beidajie, Beijing, P.R. China
Yen Kwan, Humphrey, Hong Kong
Zhang Yaqiong, Beidajie, Beijing, P.R. China
Zhou Hao, Beidajie, Beijing, P.R. China

EXAMINATIONS IN GEMMOLOGY

In the Examinations in Gemmology held worldwide in June 2002, 222 candidates sat the Diploma Examination of whom 121 qualified, including three with Distinction and eleven with Merit. In the Preliminary Examination, 157 candidates sat of whom 125 qualified.

The **Anderson Bank Prize** for the best non-trade candidate of the year in the Diploma Examination has been awarded to Sally Hudson of London.

The **Christie's Prize for Gemmology** for the best candidate of the year in the Diploma Examination who derives his/her main income from activities essentially connected with the jewellery trade has been awarded to Nilmini Liyana Arachchige of Kandy, Sri Lanka.

The **Anderson Medal** for the best candidate of the year in the Preliminary Examination has been awarded to Neha Sehgal of New Delhi, India.

The **Preliminary Trade Prize** for the best candidate of the year who derives his/her main income from acivities essentially connected with the jewellery trade has been awarded to Avneet Verma of New Delhi, India.

The **Tully Medal** was not awarded.

The names of the successful cnadidates are listed below:

Diploma

Qualified with Distinction

Liyana Arachchige, Nilmini S., Kandy, Sri Lanka
Morel, Francine, Ville Mont Royal, Quebec, Canada
Sehgal, Neha, New Delhi, India

Qualified with Merit

Ashida, Eisuke, Kyoto City, Kyoto, Japan
Berry, Susan, London
Every, Susanne, London
Goumaz, Benoit, Geneva, Switzerland
Lacasse, Marie-Elise, Westmount, Quebec, Canada
Sueters, Brigitta M.T.H., Aalsmeer, The Netherlands
Tiyu Duan, Wuhan, Hubei, P.R. China
Towers, Jill S., St Heliers, Auckland, New Zealand
Yi Zhou, Wuhan, Hubei, P.R. China
Zhu Xulei, Guilin, Guangxi, P.R. China
Zixi He, Wuhan, Hubei, P.R. China

Qualified

Agarwal, Vibha, New Delhi, India
Asano, Yoko, Gifu City, Gifu Pref., Japan
Aubert, Rebecca L., L.ondon
Aung Toe, Yangon, Myanmar
Aye Tin Tin, Yangon, Myanmar
Balzan, Patrick A., San Francisco, Calfornia, U.S.A.
Balzan, Robert A., San Francisco, Calfornia, U.S.A.
Bertrand, Sylvia, Barcelona, Spain
Blanshard, Ruth H., Devizes, Wiltshire
Bruls, Irene C.W., Maastricht, The Netherlands
Cai Xiaolin, Shanghai, P.R. China
Chan Miu Ching, Lavinia, Hong Kong
Cheng Wai Yee, New Territories, Hong Kong
Cheung Fung Wan, Happy Valley, Hong Kong
Chohan, Tarun, Putnoe, Bedfordshire
Choi, Daeshik, Wimbledon Park, London
Chookruvong, Kanjana, Bangkok, Thailand
Choudhary, Gagan, Jaipur, India
Chun Wen, Wuhan, Hubei, P.R. China
Cristol, Agata, Marseille, France
Dongjian Hu, Wuhan, Hubei, P.R. China
Dorrell, Clare G., Perth, Scotland
Falnes, Lene, Hafrsfjord, Norway
Fujimoto, Akiko, Kotu City, Yamanashi Pref., Japan
Govindarajulu, Suresh, St Johns, Antigua, West Indies
Griffiths, Victoria C., Cradley Heath, West Midlands
Guiping Wu, Wuhan, Hubei, P.R. China
Gurevich, Lina, Finchley, London
Hedenskog, Elin M.S., London
Hessels, L.A., Schoonhoven, The Netherlands
Hirano, Kiyomi, Kawanishi City, Hyogo Pref., Japan
Hoff, J.S., Schoonhoven, The Netherlands
Hui Chau Ming, Kowloon, Hong Kong
Infuehr, Nicole C., Vienna, Austria
Ito, Ayako, Kyoto City, Kyoto, Japan
Jin Yanyan, Shanghai, P.R. China
Jinglei Bai, Wuhan, Hubei, P.R. China
Jose, Kadavi F., St Johns, Antigua, West Indies
Killingback, Harold, Oakham, Rutland
Lakshmi, Narayan S.S., Trichirapalli, India
Lam, Victoria L., Bolton-le-Sands, Carnforth, Lancashire
Lam Kwi-Peng, Singapore
Lau Kam Yin, Mabel, Taipo, Hong Kong
Lee Ching, North Point, Hong Kong
Lee Chun Ming, New Territories, Hong Kong
Lee Kwok Wai, Joe, New Territories, Hong Kong
Lee Sui Kam, Monita, New Territories, Hong Kong
Lei Jiali, Guilin, Guangxi, P.R. China
Li Wing Chiu, Kowloon, Hong Kong
Liou Mun-Feng, Taipei, Taiwan, R.O. China
Longfei Gui, Wuhan, Hubei, P.R. China
Lu Ho Sheng, Taichung, Taiwan, R.O. China
Lui Sze-Wai, Alice, Quarry Bay, Hong Kong
McKinley, Karen, Abington, Northampton
Marlow, Carol, Sutton Coldfield, West Midlands
Middleton, Tara T., Toronto, Ontario, Canada
Mukhopadhyay, Nita, Kolkata, West Bengal, India
Nessi, Veroniki, Athens, Greece
Ning Jiao, Wuhan, Hubei, P.R. China
Ogden, Ben J., Harrogate, North Yorkshire
Oh Minkyung, Busan, South Korea
Pei Wang, Wuhan, Hubei, P.R. China
Peng Li, Wuhan, Hubei, P.R. China
Petkovic, Katarina, Surrey, BC, Canada
Phillips, Paul, Nuneaton, Warwickshire
Pitt, Sahra, Brockworth, Gloucestershire
Quinn, Elizabeth, Vista, California, U.S.A.
Rajap, Azeena, Eastbourne, East Sussex
Rantanen, Ari-Pekka, Hameenlinna, Finland
Roussou, Zoi K., Athens, Greece
Salt, Sebastian J., Salisbury, Wiltshire
Samarasekera, Prabha, Kandy, Sri Lanka
Sancheti, Amishaa, Indore, India
Schooling, Clare, London
Sikanen, Essi M., Lahti, Finland

Simonian, Siran, Krimpen a/d Ijssel, The Netherlands
Somboon, Chaniya, Bangkok, Thailand
Su Lin, Elizabeth, Shanghai, P.R. China
Sun I-Ching, Tracy, Harrow, Middlesex
Sun Bei, Shanghai, P.R. China
Tennekoon, Indrani, Maida Vale, London
Thanapatra, Jitsiri, Bangkok, Thailand
Thein, Myint Myint, Willesden Green, London
Thu, Latt Myat, Yangon, Myanmar
Ting-Ju Lee, Christina (a), Yangon, Myanmar
Tong Yung, Tony, Kowloon, Hong Kong
Uberoi, Tina, Northwood, Middlesex
Verma, Avneet, New Delhi, India
Voutsinas, Dimistris, Athens, Greece
Wachiruksasawakul, Suvilai, Bangruk, Bangkok, Thailand
Wei Shi, Wuhan, Hubei, P.R. China
Wei Xiaoling, Guilin, Guangxi, P.R. China
Whitehouse, Keith P., Stafford
Williams, Adrienne V., London
Wong Bick San, Patricia, North Point, Hong Kong
Wong Tai-Wai, New Territories, Hong Kong
Wu Mingyang, Shanghai, P.R. China
Xiaoling He, Wuhan, Hubei, P.R. China
Xin Xiongfeng, Shanghai, P.R. China
Xu Banghui, Guilin, Guangxi, P.R. China
Yan Zhou, Wuhan, Hubei, P.R. China
Yao Tong, Wuhan, Hubei, P.R. China
Yoshida, Naoshige, Osaka-City, Osaka, Japan
Zar Aye Tin, Yangon, Myanmar
Zhiqiang Liu, Wuhan, Hubei, P.R. China
Zhou Fangfang, Bangkok, Thailand
Ziyu Song, Wuhan, Hubei, P.R. China

Preliminary

Qualified

Adams, Stephen, Dorking, Surrey
Aki, Miou, Osaka City, Osaka, Japan
Andren, Stina E.M., Falsterbo, Sweden
Andronikou, Stamatina, Manchester
Anemogiannis, Spyridon, Athens, Greece
Appleton, Susan E., Gillingham, Dorset
Bagnall, Helen, Sheffield, South Yorkshire
Bailey, Elaine, Stoke-on-Trent, Staffordshire
Bergman, Marit, Uppsala, Sweden
Bostock, Caroline, Antwerp, Belgium
Brading, Kerry, Greenwich, London
Bramwell, Gordon F.R., Kendal, Cumbria
Canoel, Michelle, Lancaster
Carnell, Sallie, Solihull, West Midlands
Caron, Marie-Chantale, Montreal, Quebec, Canada
Chan Lim Chi, Hong Kong
Chen Chiao Yen, Taichung, Taiwan, R.O. China
Chen Yi Chun, Taichung, Taiwan, R.O. China
Cheng K.P., William, Hong Kong
Cheung Ka Yiu, Harvey, Hong Kong
Cheung Wing Man, Cynthia, Hong Kong
Ching Mei Kit, Jennifer, Hong Kong
Ching Chin Pang, Hong Kong
Chohan, Tarun, Putnoe, Bedford
Choi, Daeshik, Wimbledon Park, London
Chookruvong, Kanjana, Bangkok, Thailand
Conalty, Leo, Kilkenny, Ireland
Cuba, Grant, San Angelo, Texas, U.S.A.
Deprez, Guillaume, Roehampton, London
Ferris, Edward W., Winchester, Hampshire
Filadelfeos, Eleni-Anna, Athens, Greece
Fisher, Abigail, London
Fleming, Jane S., Glasgow, Scotland
Fleming, John J., Glasgow, Scotland
Fujii, Eiko, Harrow, Middlesex
Goumaz, Benoit, Montreal, Quebec, Canada
Guillaud, Pauline, Montreal, Quebec, Canada
Halasz, Erika J., Zurich, Switzerland
Henri, Martyne, Montreal, Quebec, Canada
Hillstrom, Anders, Lannavaara, Sweden
Holmes, Lissa, London
Htun, Kahliar, Yangon, Myanmar
Huang Shi, Jenny, Taichung, Taiwan, R.O. China
Huang Dong, Guilin, Guangxi, P.R. China
Hun Lai Chan, Hong Kong
Inagaki, Yuko, London
Kam Shuk Yi, Shummy, Hong Kong
Kampanas, Christos, Athens, Greece
Kan Ying, Cindy, Hong Kong
Kandalepa, Theophano, Athens, Greece
Kiamos, George, Athens, Greece
Ko Man Wai, Hong Kong
Konstantinidoy, Maria, Athens, Greece
Koyama, Yumika, Nagoya City, Aichi Pref., Japan
Kuo Yaw Bao, Taichung, Taiwan, R.O. China
Kwok Sau Mei, Halisa, Hong Kong
Lacasse, Marie-Elise, Montreal, Quebec, Canada
Lai Mei Oi, Emily, Hong Kong
Lappin, Annette, Kilkenny, Ireland
Lau Siu Ying, Emily, Hong Kong
Law Cheuk Yee, Hong Kong
Lee Hsiang Ju, Taichung, Taiwan, R.O. China
Lee Fung Mei, Hong Kong
Leung Suk Kay, Hong Kong
Li Mo Ching, Hong Kong
Li Xinyan, Guilin, Guangxi, P.R. China

Lo Heung Ling, Rosella, Hong Kong
McCaul, David A., Kilkenny, Ireland
McCrabbe, Julie, Hackney North, London
McMillan, Emma, Leamington Spa, Warwickshire
Manolia, Evgenia, Athens, Greece
Mathur, Chetna, Indore, India
Milton, Paul R., Liverpool
Morel, Francine, Montreal, Quebec, Canada
Munawar, Mirza S., Gothenburg, Sweden
Mutuma, Roy K., Nairobi, Kenya
Ng Chau Ping, Hong Kong
Nilsson, Annica H., Hong Kong
Nishitani, Yumi, Osaka City, Osaka, Japan
O'Connor, David W., Birmingham, West Midlands
Ohara, Yasuko, Nishinomiya City, Hyogo Pref., Japan
Okada, Hiroko, Birmingham, West Midlands
Pang Chi Chung, Hong Kong
Pang, Bowen, Guilin, Guangxi, P.R.China
Papadopoulos, John, Athens, Greece
Parker, Carl J., Kilkenny, Ireland
Pearson, Isabel J., Reading, Berkshire
Petrozello, Ryan J., Randolph, NJ, U.S.A.
Plain, Lyndsey, Sheffield, South Yorkshire
Poon King Hong, Hong Kong
Poon Kit Ling, Hong Kong
Pornpilailuck, Anchalee, Bangkok, Thailand
Pradervand, Emilie, Montreal, Quebec, Canada
Redding, Collette, Yateley, Hampshire
Richmond, Sonia, London
Ross, Alexander J., Bath, Avon
Sai Kyaw Kyaw Win, Yangon, Myanmar
Sehgal, Neha, New Delhi, India
Shen, Shaoqin, Guilin, Guangxi, P.R. China
Shih Ming Nga, Hong Kong
Su Chen Hui, Taichung, Taiwan, R.O. China
Su Lin, Elizabeth, Bali, Indonesia
Takhar, Satwinder N. K., Telford, Shropshire
Tanaka, Yumi, Toyonaka City, Osaka, Japan
Thawanrat, R., Bangkok, Thailand
Tsang Yuen King, Hong Kong
Tsang Ka Hong, Hong Kong
Tsuor Wai Hing, Hong Kong
Tsutani, Miho, Osaka City, Osaka, Japan
Udomthanakij, Sorawut, Bangkok, Thailand
Verma, Avneet, New Delhi, India
Wilson, David E., Kilkenny, Ireland
Wong Man Nea, Rosemary, Hong Kong
Wong Ying, Hong Kong
Wordon, Valerie, Tarporley, Cheshire
Wu Li Chen, Taichung, Taiwan, R.O. China
Xi Xing Shu, Shanghai, P.R. China
Xie Jing, Shanghai, P.R. China
Yasutake, Megumi, Shizouka City, Japan
Ye Jing Yin, Shanghai, P.R. China
Yeung Ho Man, Hong Kong
Yu Yuen-Fun, Victoria, Hong Kong
Zaw Win Tun, Yangon, Myanmar
Zhou Wei Yong, Shanghai, P.R.China
Zhu Juntao, Guilin, Guangxi, P.R.China

MEMBERSHIP

Between 1 July and 1 October the Council of Management approved the election to membership of the following:

Diamond Membership (DGA)

Falnes, Lene, Hafrsfjord, Norway, 2002
Pearson, Heather A., Belper, Derbyshire, 2002
Loo Shun Lee Andrew, Kwai Chung, Hong Kong, 1999
Yeung Yee Wai, Laguna City, Kwun Tong, Hong Kong, 2002

Fellowship (FGA)

Basile, Appadoure, London, 2002
Dawson, Jane, London, 1982
Jinnam-olarn, Wichuda, Ampur Muang, Udonthani, Thailand, 2002
Joyce, Sandra R., Maidstone, Kent, 1983
Li Wing Chiu, Kowloon, Hong Kong, 2002
Liao Chun-Yan, Taipei, Taiwan, R.O. China, 2001
Marlow, Carol, Sutton Coldfield, West Midlands, 2002
Morel, Francine, Ville Mont Royal, Quebec, Canada, 2002
Pavaro, Thitintharee, Bangkok, Thailand, 2002
Quick, Fiona A., Francistown, Botswana, 1998
Rademakers-Boek, Gerriedina J., Weekt, The Netherlands, 2002
Sakkaravej, Somruedee, Bangkok, Thailand, 2001
Sharma, Rashmi, Lusaka, Zambia, 2000
Shepherd, Louis, Long Eaton, Nottinghamshire, 1996
Thompson, Ian, Wood Green, London, 2000
Tsotros, Alexios, Athens, Greece, 1987
Wright Feng, Wendy E., Greenwood, Indiana, U.S.A., 1990

Ordinary Membership

Andén, Lennart, Malmö, Sweden
Austin, Paul, West Drayton, Middlesex

Aw Soh Choo, Singapore
Ayer, Elizabeth, Cambridge
Banks, Jessica, London
Barilits, Maria M., London
Biggs, Fiona, Minchinhampton, Gloucestershire
Blankson-Amankwah, Noble, London
Bluestone, Anna, Hassocks, Brighton
Bolamba, Tony Cassius, Romero, France
Breuer, Lisa, London
Cangelosi, Karen, St Louis, Missouri, U.S.A.
Cheng, K.P. William, Ho Man Tin, Hong Kong
Conejero, Jennifer H., Boston, Lincolnshire
Curry, Stella C., Dartmouth, Devon
Danon, Jerry, Bradford, West Yorkshire
Dirir, Ahmed, London
Domec, Cedric, Forest, Belgium
Dunbar, Barry G., Islington, London
Ecknauer, Marc, Wood Green, London
Firmin, James H., Rutland, Leicestershire
Fixley, Jonathan, Omaha, U.S.A.
Gering, David, Tempe, Arizona, U.S.A.
Graham, Michael R., Brentford, Middlesex
Gregory, Nualchan, London
Heber-Percy, Sophie, Drayton, Shropshire
Holman, Meryan Janice, Truro, Cornwall
Hornsby, Rebecca A., Spalding, Lincolnshire
Hotson, Peter John, Berkhamsted, Hertfordshire
Inagaki, Yuko, London
Jackson, Antoinette, London
Jain, Mayank, Lenton, Nottingham
Jegaloua, Irina, Hounslow, Middlesex
Katende, Laetitia, Waterside, Oxford
Kebbay, Gifty K., London
Kim, Junghyo, London
Lambert, John K., Clowbridge, Burnley, Lancashire
Landmark, Vivienne Jane, Harpenden, Hertfordshire
Lee Young Ji, Ealing, London
Muhandiramge, Shyam V.W., Walton-on-Thames, Surrey
Pindar, Zoe Louise, Moortown, Leeds, West Yorkshire
Pumphrey, Jessica K., Hammersmith, London
Rupani, Nalina, Nairobi, Kenya
Salt, Sebastian J., Salisbury, Wiltshire
Samuels, Clinton, London
Shaw, Sinead, London
Shikatani, Kohei, Haverstock Hill, London
Stephenson, Michelle, London
Sykes-Gomez, Heidi, London
Thompson, Jeff, Balcombe, West Sussex
Underwood, Thom, San Diego, California, U.S.A.
Watanabe, Tomoko, London
Wilkie, William, Dumbarton, Scotland
Wild, Hans-Georg, Kirschweiler, Germany
Yeung, John K.M., Harrow, Middlesex
Zwordiak-Southall, Ania W., Old Warden, Bedfordshire

Laboratory Membership

Theo Fennell plc, 2B Pond Place, London SW3
Benny Moussaieff, 45-46 New Bond Street, London W1

Transfers

Fellowship to Fellowship and Diamond Members (FGA DGA)

Avery, Hilary E., Bangor, Co. Down, N. Ireland
Borruso, Alessandro, Harrow, Middlesex
Clark, Antony, Bolton, Greater Manchester
Croucher, Nicola, London
Dimmick, Helen M., Pinner, Middlesex
Donnelly, Lee-ona F., Heathfield, Ayr, Scotland
Getgood, Fiona J., St Leonards on Sea, East Sussex
Hassan, Fatima, Totteridge, London
Oshida, Reiko, Singapore
Pace, Howard M., Eccleshall, Stafford
Pierotti, Moya A.M., London
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Sky-blue glass

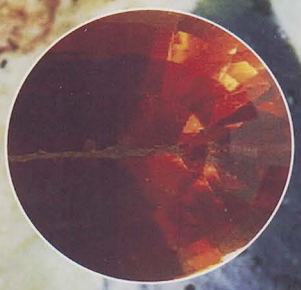

Brazilian imperial topaz

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Some effects of extreme heat treatment on zircon inclusions in corundum

A. H. Rankin and W. Edwards

School of Earth Sciences and Geography, Faculty of Science, Kingston University, Kingston upon Thames, Surrey KT1 2EE

ABSTRACT: The mottled appearance and darkening of zircons in heat-treated corundum from Chimwadzulu Hill, Malawi, is due to melting and interaction of zircon with the surrounding corundum. At high temperature the original zircons are partially or completely replaced by monoclinic m-ZrO_2 (baddeleyite), and a glass-like phase. These two phases show regular intergrowths comprising rounded to elongate blebs of m-ZrO_2 distributed within a glassy matrix that may extend into the host corundum via healed microfractures. The glass shows variable compositions within the Al_2O_3-ZrO_2-SiO_2 system and only minor amounts of other components are present. The m-ZrO_2 phase contains up to 4.8% HfO_2 and is readily distinguishable from other Zr-phases by its characteristic Raman bands, notably the doublet at 180 and 192 cm^{-1}. Fluorescence peaks at 1091, 1146, 1169, 1199, 1220 and 1270 cm^{-1} and several others in the range 1390 to 1660 cm^{-1} provide an additional aid to identification. The observed intergrowths are interpreted as quench melt textures in the Al_2O_3-ZrO_2-SiO_2 system in which case heating above the eutectic temperature (*c.* 1750°C) is inferred. Identification of these quench phases and textures in zircon pseudomorphs can provide a useful criterion for recognizing cases of extreme heat treatment in other gem sapphires and rubies.

Keywords: baddeleyite, quench melt, Raman, ruby, sapphire, zircon

Introduction

Heat treatment is commonly used to improve the colour of natural corundums, sapphires and rubies for use as gemstones. Recognition of the extent to which stones have been heat-treated is of increasing importance within the gem trade because of the effect on market value. Various criteria may be used (Hughes, 1997). These include identification of glassy surface features, colour gradations and zoning, the destruction or modification of pre-existing fluid and solid inclusions and the development of planes of new groups of secondary inclusions, especially surrounding older ones.

In a recent paper it was noticed that zircon inclusions in corundum from

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Analytical methods

A JEOL JSM-6310 Scanning Electron Microscope (SEM) equipped for Energy Dispersive X-ray (EDX) analysis was used to analyse 15 zircon inclusions and their thermal decomposition products exposed on the surface of three carbon-coated, polished wafers. SEM Images were recorded at magnifications up to × 10,000. X-ray spectra were recorded on small areas (1 × 1 microns) using an accelerating voltage of 15kV and beam current of 1nA. Quantitative and semi-quantitative analyses, with an accuracy of ± 2 and ± 10 wt.% respectively, were carried out using pure metals, metal oxide and silicate standards and established ZAF correction procedures. Detection limits were of the order of 0.2 wt.% for all the elements analysed.

A Renishaw micro-Raman system equipped with an Ar-ion laser (514.5 nm) and attached to an Olympus microscope was used to record the Raman and related spectra of phases associated with the original zircon inclusions. Magnifications up to 600 × were used and spectra were obtained, in confocal mode, using count times of some 30 seconds. A pure silicon standard was used to calibrate the system at regular intervals. Raman shifts were reproducible to within 1 or 2 cm^{-1}.

Chimwadzulu Hill, Malawi (Rankin, 2002) show distinctive changes in heat-treated samples. The most notable features are mottling, darkening and the development of aureoles of emanating trails of secondary inclusions.

In the present paper we report on the phase changes that accompany this darkening and associated fracture-filling and discuss the temperature controls on their formation with reference to the system ZrO_2-SiO_2-Al_2O_3. The extent to which the identification and recognition of these phase changes may be used to distinguish heat-treated samples from other localities is also discussed.

Description of samples studied

Polished slices (1-2 mm) were prepared from three large crystals (1 cm) of heat-treated, pale blue/green sapphires from the Chimwadzulu Hill deposit of Malawi. Details of the temperatures to which these specimens had been heated were unknown to the authors. However, the gemmological features, geological occurrence and inclusion characteristics of these samples, including the distribution and morphologies of zircon crystals and clusters, have already been summarised and illustrated (Rankin, 2002). The zircons typically occur as well-formed, transparent, stubby or elongate crystals up to 150 microns in size. They commonly occur in clusters or groups of between 5 and 10 crystals. In heat-treated samples the zircons appear turbid, with darkened rims and radiating haloes of secondary inclusions within healed fractures.

Results

SEM/EDAnalysis

Many of the zircon inclusions when viewed under the SEM appeared well-formed, with sharp planar boundaries (*Figure 1*). They have stoichiometric compositions close to the idealized formula for zircon, $ZrSiO_4$, (*Table 1*) with HfO_2 contents in the range 1.3 to 3.4 wt.%

Table 1: *Representative analyses of unaltered zircon and m-ZrO_2 associated with thermally decomposed zircons.*

	Zircon	*ZrO_2 phase*
Wt.%	*J1 198*	*J1204*
SiO_2	32.88	1.33
ZrO_2	65.97	98.77
HfO_2	1.34	3.87
Total	100.19	103.97

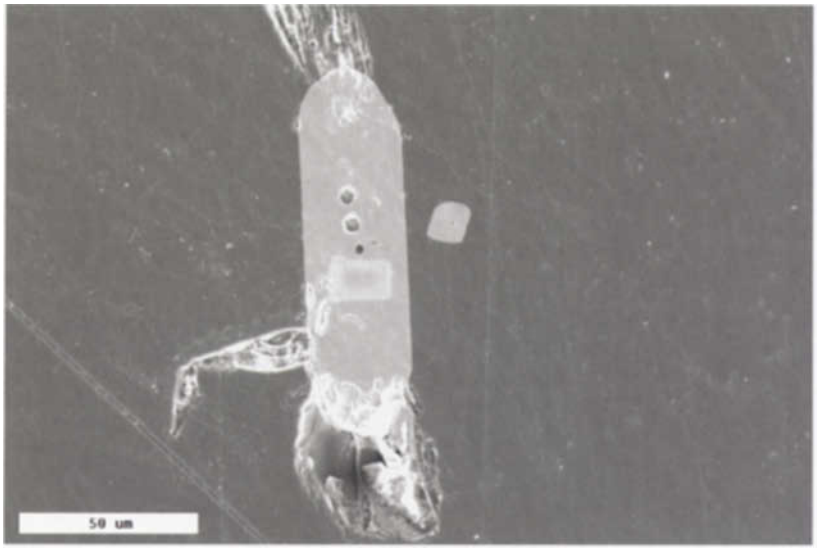

Figure 1: *Back-scattered electron image from a scanning electron microscope (SEM) of a single zircon inclusion exposed on the polished surface of heat-treated corundum. Note the sharp contacts between zircon and the host corundum, the radiating fractures and the three spheroidal inclusions in the centre of the zircon. The lighter rectangular area in the middle of the zircon is due to electron beam damage caused by rastering during analysis. Bar scale in microns.*

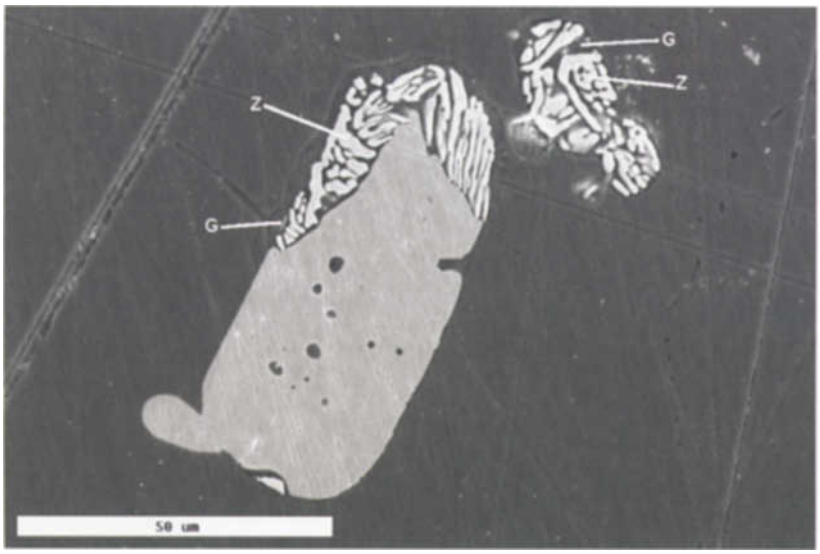

Figure 2: *Back-scattered electron image of two original zircon inclusions showing the extreme effects of thermal decomposition and replacement by a regular intergrowth of a bright ZrO_2 phase (Z) within a grey ZrO_2-SiO_2-Al_2O_3 glass-like phase (G). The larger zircon shows partial, and the smaller inclusion total, replacement. Note the irregular contact between the glass like phase and the host corundum in contrast to the sharp contacts between the unaltered zircon and corundum. Bar scale in microns.*

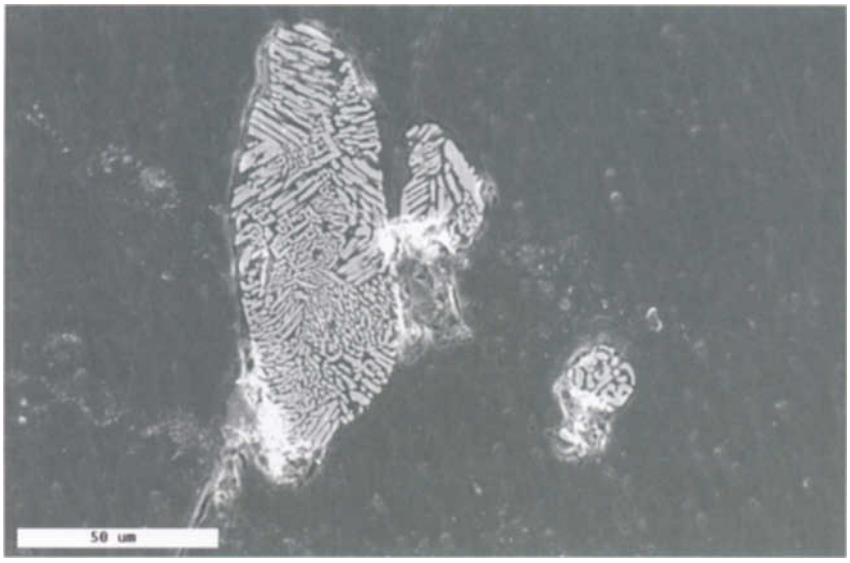

Figure 3: *Back-scattered electron image of original zircon inclusions showing total replacement by ZrO_2 and the glassy phase. Note the distinctive and regular intergrowths characteristic of quench melt textures of these two phases. Bar scale in microns.*

(13 analyses gave a mean of 2.44 wt.%). Niobium was the only other element significantly above background (up to 0.9 wt.% Nb_2O_3). However, traces of thorium and phosphorous were also tentatively identified. Radiating fractures and spheroidal cavities within the zircons are also apparent, in keeping with previous observations under a normal light microscope (Rankin, 2002).

Other zircons displayed unusual embayment features (*Figure 2*). On closer inspection these appeared as two separate phases; brighter, sub-rounded to elongate blebs, up to about 10 microns in size, and a darker interstitial phase with irregular, sinuous boundaries with both the host corundum and unaltered zircon. In other areas, these light and dark features predominate (*Figure 3*) and even totally replace the original zircon. The light blebs typically showed preferred orientations and distinctive interlocking textures suggestive of eutectoid quenched melt textures commonly observed in high temperature melting experiments by petrologists (J. Clemens, pers. com., 2002). The X-ray spectra for these lighter and darker areas are distinctly different. The only elements detected in the lighter blebs, other than those attributable to interference from the host corundum, were Zr, Hf and O. The stoichiometric compositions are very close to ZrO_2 (*Table I*), with between 3.1 and 4.8 wt.% HfO_2 (n = 15, mean = 4.19) substituting for ZrO_2 in the crystal structure.

The X-ray spectra for the darker areas revealed significant but variable quantities of SiO_2, Al_2O_3 and ZrO_2 and minor amounts of Na, K, Ca and Fe. Semi-quantitative analyses showed variable compositions (*Table II*). These analyses do not correspond to the stoichiometric compositions for any known crystalline phase in the system ZrO_2-Al_2O_3-SiO_2 (Guo *et al.*, 1996; Lebeau *et al.*, 1995) and are more likely to reflect quenched silica-alumina-zirconia glass compositions as discussed later.

Only qualitative analyses of the contents of the radiating fractures and rounded inclusions within the zircons (e.g. *Figure 2*) were possible because of their non-planar surfaces. But, interestingly, their

Table II: Representative analyses of the institial glass-like phase between zircon and the m-ZrO_2 phase (A) and between zircon and corundum (B) in thermally decomposed zircons.

	A			B	
Wt.%	J1 213	J1 200	J1 197	J1 202	J1 187
Na_2O		2.52	1.97	3.02	
Al_2O_3	62.61	13.67	12.36	13.16	73.65
SiO_2	28.84	48.10	41.46	56.18	23.52
K_2O		0.37	0.39	0.48	
FeO		0.76	0.58	0.61	
ZrO_2	5.01	31.06	39.36	24.17	0.78
Total:	96.46	96.48	96.12	97.62	97.95

compositions are similar to the interstitial material surrounding the ZrO_2-rich blebs associated with altered zircons.

Optical properties and Raman/fluorescence spectra

Under a normal petrographic microscope the rounded ZrO_2-rich blebs exposed on polished surfaces appeared weakly birefringent whereas the darker interstitial phase appeared isotropic. The Laser-Raman spectra for these two phases were also distinctly different. The interstitial dark phase showed insignificant peaks between 100 and 1000 cm^{-1}, and only a strong to moderate, broad, continuous spectrum more typical of fluorescence commonly observed in corundums and rubies (e.g. Rankin, 2002). In contrast, the lighter blebs showed a number of major and minor peaks both above and below 1000 cm^{-1} (*Figure 4*).

Interpretation of the Raman spectra and identification of phases present

There are three known polymorphs of crystalline ZrO_2, or zirconia (e.g. Stefanc *et al.*, 1999), and the observed ZrO_2-rich phase could be any one of these:

- monoclinic m-ZrO_2 – stable below 1170°C (the mineral baddeleyite)
- tetragonal t-ZrO_2 – stable between 1170°C and 2370°C
- cubic c-ZrO_2 – stable between 2370°C and 2680°C (up to the melting point)

Monoclinic zirconia (baddeleyite) is the expected stable phase at room temperature, but the tetragonal or cubic forms could also exist as metastable phases at this temperature (Stefanc *et al.*, 1999). Cubic zirconia can be ruled out because of the complete mismatch with the Raman spectrum for this phase. Only a broad peak at around 600 cm^{-1} is observed in ZrO_2-rich end-members in yttrium and scandium stabilized samples (Nomura *et al.*, 2000. Raman spectra for both m-ZrO_2 and t-ZrO_2 up to 1000 cm^{-1} have been published recently by Stefanc *et al.* (1999) and Fredericci and Morelli (2000). The characteristic Raman peaks reported for t-ZrO_2 at 148, 267, 280 and 462 cm^{-1} are absent in the Raman spectra for the ZrO_2-rich blebs. However, the characteristic doublet at around 180 and 192 cm^{-1} noted for m-ZrO_2 by both sets of authors, together with additional peaks and bands for m-ZrO_2 at 224, 308, 335, 349, 383, 476, 503, 539, 561, 617 and 637cm^{-1} (Fredericci and Morelli, 2000) and for natural baddeleyite (McKeown *et al.*, 2000) are in excellent agreement with those for the ZrO_2-rich blebs which we can now

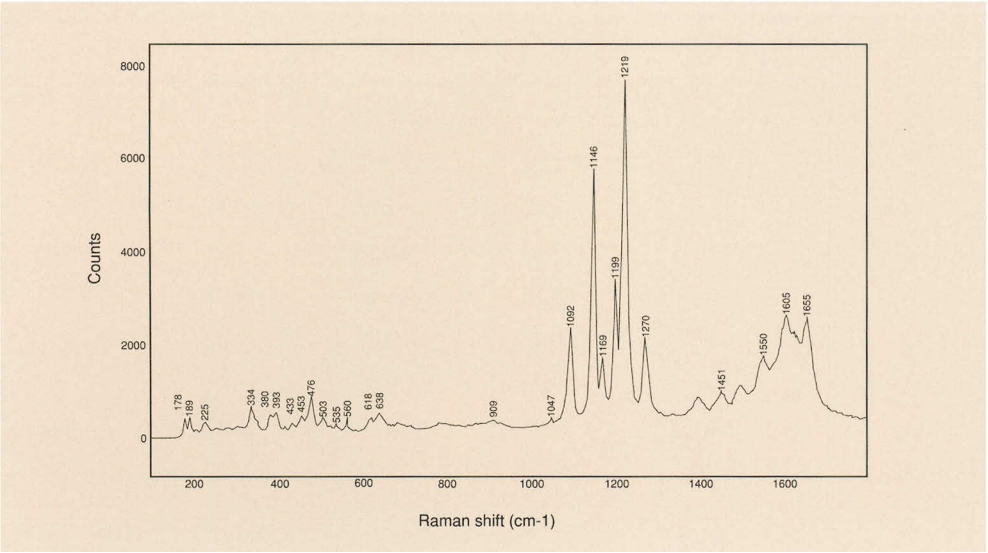

Figure 4: *Laser-Raman and laser-induced fluorescence spectra of the ZrO_2 phase in altered zircons. The Raman bands below 640 cm^{-1} are characteristic of m-ZrO_2 (baddeleyite). The peaks above 1000 cm^{-1} are not true Raman bands but are attributable to laser-induced fluorescence.*

positively identify as m-ZrO_2 (baddeleyite). Raman bands above 1000 cm^{-1} (*Figure 4*) have neither been reported nor predicted on theoretical grounds by any of these authors. The observed regularities in peak shapes and distributions are more characteristic of fluorescence spectra as often seen, for example, in fluorite where it is attributable to rare-earth element and associated luminescence activators (Burruss *et al.*, 1992). However, it is beyond the scope of the present paper to assign these peaks to rare earth elements or other trace elements.

The lack of significant Raman peaks, optical isotropism, non-stoichiometric and variable chemical composition of the darker interstitial phase leaves little doubt that it is an alumino-silicate-(zirconia) glass.

Discussion and estimates of heating temperatures

The observed embayment textures and identification of m-ZrO_2 (baddeleyite) within an alumino-silicate-(zirconia) glass demonstrates that the thermal breakdown of zircon was accompanied by melting and reaction with the corundum. Reactions can be modelled within the Al_2O_3-ZrO_2-SiO_2 system and may be summarized as follows:

Equation 1:

$$\underset{\text{(corundum)}}{Al_2O_3} + \underset{\text{(zircon)}}{ZrSiO_4} = \underset{\text{(melt)}}{SiO_2\text{-}Al_2O_3\text{-}ZrO_2}$$

represents melting on heating

Equation 2:

$$\underset{\text{(melt)}}{SiO_2\text{-}Al_2O_3\text{-}ZrO_2} = \underset{\text{(t-zirconia)}}{ZrO_2} + \underset{\text{(glass)}}{SiO_2\text{-}Al_2O_3\text{-}ZrO_2}$$

represents crystallization of t-zirconia and quenching of the residual melt to a glass on cooling

Equation 3:

$$\underset{\text{(t-zirconia)}}{ZrO_2} = \underset{\text{(m-zirconia)}}{ZrO_2}$$

represents solid-state recrystallization of t-zirconia to m-zirconia below 1170°C

The melt developed in Equation 1 also appears to have migrated into associated thermally-induced fractures to become

trapped as planes of secondary inclusions during cooling and subsequent rehealing.

Melts within the system Al_2O_3-ZrO_2-SiO_2(AZS), co-existing with crystalline ZrO_2, only occur above the eutectic (minimum) melting temperature of 1750°C (Fredericci and Morelli, 2000). This suggests that in the Chimwadzulu corundum where melt textures are observed, and the resulting glass has a simple Al_2O_3-ZrO_2-SiO_2 composition (e.g. analyses J1 213 and J1 187 in *Table II*), heating is likely to have occurred above this temperature.

As previously noted, t-ZrO_2 is the stable zirconia polymorph at this elevated temperature but it readily converts to m-ZrO_2 (analogous to the mineral baddeleyite) below 1170°. This is the stable phase at room temperature, as observed in the present study and indicated in equation 2. Only exceptionally, as a result of extremely rapid quenching, for example, following fusion in an arc imaging furnace, is metastable t-ZrO_2 likely to be detected at room temperature (Yoshimura *et al.*, 1985).

Below the solidus in the model AZS system, mullite should appear as a stable aluminosilicate phase. However, the lack of characteristic Raman bands for this phase at 411 and 309 cm^{-1} (Shoval *et al.*, 2001), coupled with non-stoichiometric compositions shown in *Table II* suggest that it is not present, at least in significant quantities. Instead, the melt appears to have quenched to an amorphous glass.

Wider implications

In the wider context, the recognition of quench melt textures in zircon inclusions may be used as an indication of extreme heat treatment in rubies, sapphires and corundums (above 1750°C). However, this does not imply that all zircon inclusions displaying radiating haloes and dark borders in either heat treated or natural corundums (Guo *et al.*, 1996) have been heated above the eutectic melting temperature for the Al_2O_3-ZrO_2-SiO_2 system. Solid-state subsolidus, crystalline decomposition products can produce ZrO_2, and if the glass contains significant amounts of other components the liquidus and eutectic temperatures may be lowered somewhat (Rao *et al.*, 1997). Recognition of both crystalline ZrO_2 (as the stable monoclinic form) and an Al_2O_3-ZrO_2-SiO_2 glass would be needed to infer these higher temperatures. In subsurface inclusions it would not be possible to use ED analysis, and the relatively weak Raman bands for m-ZrO_2 might be difficult to detect if there is significant absorption of the Raman-scattering. However, the characteristic fluorescence spectrum for this phase between 1000 and 1800 cm^{-1} is very much stronger and would be much easier to detect. This provides a more widely applicable criterion for recognition of this phase as a thermal decomposition product of zircon inclusions in these and other ruby, sapphire and corundum samples from other localities.

Acknowledgements

We thank Dr David Hargreaves, Agricola Resources, plc for providing samples from Chimwadzulu. We also thank our colleagues at Kingston University, Ian Gill for producing the polished wafers, Dr Pam Murphy for her help with the interpretation on the Raman/Fluorescence spectra, and Professor John Clemens for helpful discussions on phase diagrams and the interpretation of melting behaviour in the AZS system.

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A new chrome chalcedony occurrence from Western Australia

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ABSTRACT: Chrome chalcedony, an ornamental rock variety new to Australia, has been identified from an occurrence in the Newman area of Western Australia (WA). Formed by silicification of serpentinite, some relict mineralogy and texture is retained. Gemmological properties are within the range characteristic of chalcedony with RI 1.539 and SG 2.57. The dark green colour is attributed to chromium (Cr_2O_3 0.24%) with strong red reaction to the Chelsea filter. The petrology and mineralogy of the material are described. The material was characterized using the techniques of XRF, XRD, UV-Vis-NIR and Raman spectroscopy. Mogánite, recognized in 1999 as a silica polymorph, was detected by XRD, and confirmed by Raman spectroscopy. Mogánite and α-quartz form part of the chalcedony matrix. Mtorolite, a variety of chrome chalcedony first described from Zimbabwe, was used for comparison.

Keywords: chrome chalcedony, mogánite, Raman spectroscopy, serpentinite, silicification, XRD

Introduction

Thirty years ago a prospector in the northwest of Western Australia (WA) noticed flaked chips of a green rock in an area of brown boulder rubble. In 1990 the area was registered as a mining tenement and the site investigated for the source of the green rock.

Identification now confirms that the rock is chrome chalcedony, a new variety to Australia. Where fractured pieces are sufficiently thin it is translucent, and of a fairly uniform deep green hue. When traversed by later quartz veins the colour grades to brown.

Several forms and varieties of siliceous gem materials are already exploited from many localities within WA. Most valuable is chrysoprase, a pale green chalcedony, with colour due to nickel. The green chrome chalcedony from this new occurrence in WA differs from chrysoprase in two significant aspects:

- The colour is attributable to chromium rather than nickel.
- It occurs in masses representing whole-rock silification of the original serpentinite. Chrysoprase, in contrast, occurs as late-stage well-defined fracture fillings.

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Terminology

α-Quartz: Stable silica polymorph, trigonal, occurs in lenses, crystalline granular anhedral form within chalcedony groundmass and as euhedral encrustations, and vug fillings.

Chalcedony: An assemblage of micro-fibrous α-quartz, occurring as:

- granular groundmass type.
- wall-lining type where fibres nucleate from points (grains), and radiate at right angles to vein borders.
- spherulitic and sub-radiating groups within groundmass.

Mogánite: Metastable silica polymorph, monoclinic. Aggregates composed of platelets ranging in thickness from 110Å to 1000Å (Miehe and Graetsch, 1992). Occurs as an infilling of seams, etc., in some of the ignimbrite flows of the Mogán Formation on Gran Canaria. Also occurs in agate, chalcedony and chert (Heaney and Post, 1992).

This mode of occurrence also differs from other documented occurrences of chrome chalcedony, notably those in Zimbabwe and Bolivia (Smith, 1967: Hyrsl, 1999).

Location

The deposit is located in the northwest of Western Australia within Sheet SF 50-16, Newman, of the 1:250 000 State Government

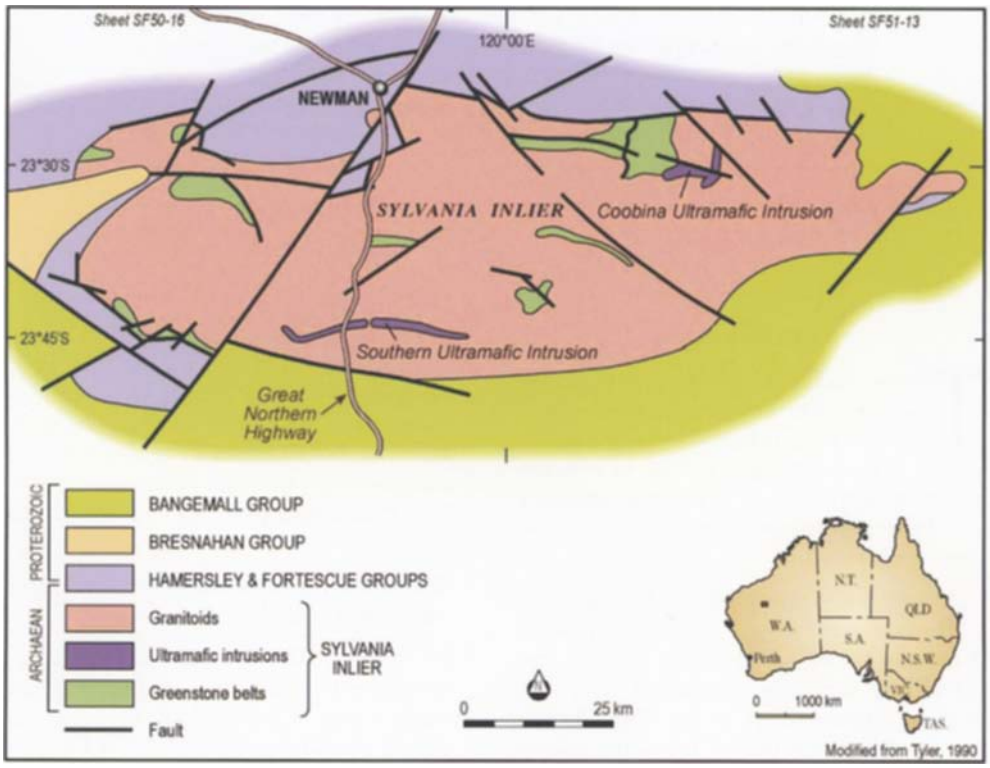

Figure 1: *Simplified geological map of the Sylvania inlier showing the Southern Ultramafic Intrusion (SUI). Map of Australia inset with the position of the area shown by a square.*

geological and topographical map series (Daniels and Macleod, 1965).

The important economic focus of the region is the mining of the huge iron ore deposits occurring within the extensive banded iron formations (BIF) that make up much of the Hamersley Ranges. The town of Newman is the main centre of mining in the eastern Hamersley Ranges; others, located further west, are Tom Price, Paraburdoo and Panawonnica.

The chrome chalcedony deposit lies within the southern portion of the Sylvania Inlier and is located 40 km south-southeast of the town of Newman, and a few kilometres to the east of the Great Northern Highway at approximately lat. 23° 43' S, long. 119° 50' E *(Figure 1)*.

Geological Setting

The Sylvania Inlier which is some 5600 square kilometres in area, comprises a geologically discrete terrain of mixed granite-greenstone of Archaean age (> 2 500 Ma). Within the Inlier are several mafic and ultramafic intrusions, including dolerite dykes of varying ages and crosscutting relationships (Tyler, 1990 a and b). The Inlier is bordered by some Archaean and younger Proterozoic units; namely the Hamersley and Fortescue Groups to the north, the Bresnahan Group to the west and Bangemall Group to the south and east.

There are two significant ultramafic bodies, Coobina and the Southern Ultramafic Intrusion (SUI). The smaller, Coobina, is situated near the northeastern margin of the Inlier. It is a remnant of a differentiated complex containing narrow lenses of chromite and is currently being mined. The host rock serpentinite was generally deeply weathered during the Tertiary resulting in the development of magnesite veins and widespread surface silicification.

The SUI is more dyke-like and has a sinuous east-west strike of around 40 km and width varying between 200 and 800 m.

Figure 2: *Typical red-brown boulder of source rock. Photo: J. Flint.*

Figure 3: Boulder with irregular zones of chrome chalcedony (dark) and relict parent rock (light). Photo: J. Flint.

Although the actual age of the SUI has not been determined, it is considered to be Archaean-Proterozoic (I.M. Tyler, pers. comm.). It post-dates the granites of the Inlier, and aplites and pegmatite veins common in the granitoid are absent from the ultramafic. It also truncates one of the series of dolerites (Tyler 1991).

The recently discovered chrome chalcedony deposit is located on a small hill of red-brown stained rubble and boulders overlying weathered serpentinite, which forms part of the eastern section of the SUI. The effects of the pervasive and intense weathering during the Tertiary are readily observable and fresh outcrop is rare. Much of the bedrock is obscured by Recent colluvium and alluvium.

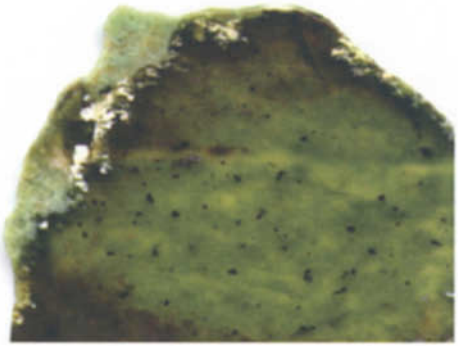

Figure 4: Thin polished slab of chrome chalcedony showing colour variation and opaque mineral inclusions. Scanned image: M. Willing.

The geology of the SUI as described from fresh rock exposed only at its western extent, is serpentinite (Tyler, 1991). It consists dominantly of serpentine with minor talc and secondary magnetite, derived by low-grade metamorphism of an olivine and olivine-pyroxene bearing parent rock.

Chalcedony, chrysoprase and common opal are all reported as common capping materials over ultramafic rocks within the Inlier (Tyler, 1991 and Nagase *et al.*, 1997). Some of these materials have already been exploited for their gem potential (Geol. Survey, 1994).

The new occurrence of chrome chalcedony and chrysoprase occur in close proximity in geologically similar environments and were formed as a result of the same processes.

Field Occurrence

The red-brown stained boulder rubble rock at the mine site is shown in *Figure 2*. In these boulders the boxwork appearance of the gem ore is apparent.

Irregular dark-coloured zones of green chrome chalcedony form the dominant component between subordinate areas of light green relict serpentinite, the parent rock *(Figure 3)*.

The chrome chalcedony is a tough material, breaking with a conchoidal fracture, resulting in flakes with sharp edges. Fractured surfaces have a waxy lustre. The colour appears to be a fairly uniform deep green; however, examination by transmitted light shows a banded texture and colour variation in the greenness with a speckled appearance due to finely disseminated grains of an opaque ore mineral *(Figure 4)*.

Fine veins of quartz traverse the rocks, and in places have developed into small agate-filled vugs. Quartz encrusts some of the chrome chalcedony as a thin bluish coating *(Figure 5)* that fluoresces bright yellow/green under short wave ultraviolet light.

Figure 5: *Chrome chalcedony (dark) with surface encrustation of coarse quartz. Scanned image: M. Willing.*

Characterization of WA chrome chalcedony

Materials and methods

Chrome chalcedony (mtorolite) from Zimbabwe was used in the ultraviolet/visible/near infrared (UV-Vis-NIR) and Raman spectroscopy methods as a reference material. Mtorolite was discovered in 1955 and is mined from the 'Jester' claims.

Comparative results: Data from this study were compared with published gemmological data on chrome chalcedony from Bolivia ('chiquitanite') and one intaglio from a private collection in Vienna.

Petrology: Petrographic sections were prepared from the massive green chalcedony and a sample of the present serpentinite material and studied by polarized light microscopy (PLM). Polished sections were examined by reflected light microscopy.

Gemmological properties: Determined on cut cabochons *(Figure 8a)* and one faceted chrome chalcedony. Refractive Indices were taken with an Eickhorst refractometer illuminated with a monochromatic sodium light source. Specific Gravity was determined by the hydrostatic method using a Sartorius electronic balance. Fluorescence to ultraviolet radiation was observed using a LW and SW ultraviolet light. Absorption Spectrum was observed with an MGL-450 prism spectroscope.

Mineral Composition: Determined using X-ray diffraction (XRD) analysis in packed powder mounts of the sample. A Phillips X'Pert system with copper Kα and diffracted beam monochromator was used for the analysis.

Chemical composition: Quantitative chemical analysis was determined by X-ray fluorescence (XRF) analysis of fused glass discs prepared from 1.6 g sample powder and 6.4 g lithium borate flux. A Phillips PW1480 XRF instrument was used under routine conditions. Detection limits for most trace elements reported are ~ 10 ppm; major oxides have detection limits between 0.002% and 0.01%.

Chromophore, water speciation: Ultra-violet-visible-near infrared (UV-Vis-NIR) spectroscopy using a Fieldspec Pro instrument (ASD Inc.) with a fibre-optic probe 50 watt DC light. Probe height set at 15mm, area of illumination 0.34 cm^2, angular field of view (25°) 'Spectralon' was used as the reflectance standard. The UV-Vis reflectance spectra of the polished slabs were collected from 350nm to 700nm. The NIR reflectance spectra were collected from 0.8 to 2.5 μm.

Raman Spectra: The Raman spectra were measured with a Dilor Labram 1B instrument equipped with an Olympus (BX40) optical microscope with ×50 objective for micro sampling. The 488 nm line from a Uniphase 2010 Ar^+ laser was directed at 0° incidence with 180° collection angle. The beam power was 10 mW. Data accumulation occurred over a 10 minute period.

Petrology

Silicified serpentinite parent rock

A prepared thin section of the serpentinite shows a mixed association of serpentinite with zones of invasive microcrystalline quartz *(Figure 6a)*. The serpentinite is heterogeneous with schistose texture and is composed dominantly of fibrous antigorite in lenticular layers (0.5 mm to 2 mm in thickness) intercalated with zones of shredded flaked serpentine talc that is altered and clouded by ultra-fine undetermined minerals, possibly smectitic clay. These latter zones have a white clouded appearance in reflected light.

Chalcedony occurs in regular small lenses up to 5 mm across with stringers and veinlets together forming about 15% of this section, representing minor silicification of the parent rock. Examined in polished section an opaque mineral, representing about 2–3% of the section, occurs throughout the rock. These grains are easily visible and are ~ 0.5 mm in diameter, anhedral in form, highly fractured with finely dissected margins, intergrown with antigorite. They represent residuals of primary chromite and magnetite, now partly converted to hematite. Some with very small cores of chromite are evidence of the original ultramafic nature of the rock. Since its formation as a dunite or olivine pyroxenite the rock has been sheared, serpentinized and finally partially silicified.

Chrome chalcedony

Sections of the massive chrome chalcedony are shown in *Figures 6b* and *6c*. The groundmass of microcrystalline silica, forming about 90% of the sample, has an ultrafine texture, with individual grain size of about 0.02 mm (20 μm) characteristic of chalcedony. Texturally the rock is homogeneous and unbanded, and individual grains are of a fibrous nature demonstrating undulose extinction. Quartz fibre orientation is length fast.

Localized rosettes and micro-fans of sub-radiating chalcedony, ± 0.5 mm diameter, occur within the groundmass *(Figure 6b)*. These rosettes display a cross-pattern of extinction in polarised light as a result of fibre-orientation and behave as single crystals of quartz. In PPL a botryoidal texture appears where several rosettes are grouped together.

As in the parent rock, opaque mineral grains occur throughout the gem rock *(Figure 6c)*. Examined in polished section, the grains were identified as magnetite with irregular margins altered to hematite and small cores of original chromite *(Figure 6d)*.

Rarely small shreds of very fine micaceous mineral (0.15 × 0.6 mm) occur in the section. These minor residuals of schistose serpentinite together with the chromite grains are considered to be evidence of the original ultramafic rock.

Figure 6a: *Photomicrograph of silicified serpentinite parent rock showing fibrous antigorite/talc and lenses of chalcedony. A late veinlet of fibrous quartz crosscuts the section. Photomicrograph: S. Stocklmayer.*

Figure 6b: *Chrome chalcedony showing a granular texture with groundmass of fairly even-sized grains. Centre – a coarse chalcedony rosette of 0.58 mm diameter, with fibres producing a cross pattern and undulose extinction in PL. Photomicrograph: S. Stocklmayer.*

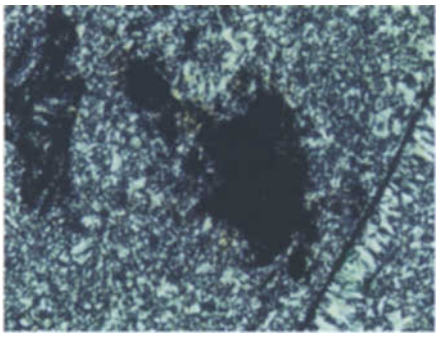

Figure 6c: *Chromite grains within the chalcedony groundmass. A late veinlet of chalcedony has a boundary of opaque granules. Photomicrograph: S. Stocklmayer.*

Figure 6d: *Polished section of chrome chalcedony with an ore grain inclusion. The relict core is chromite (0.05 mm) with border of magnetite and hematite. Photomicrograph: Pontifex.*

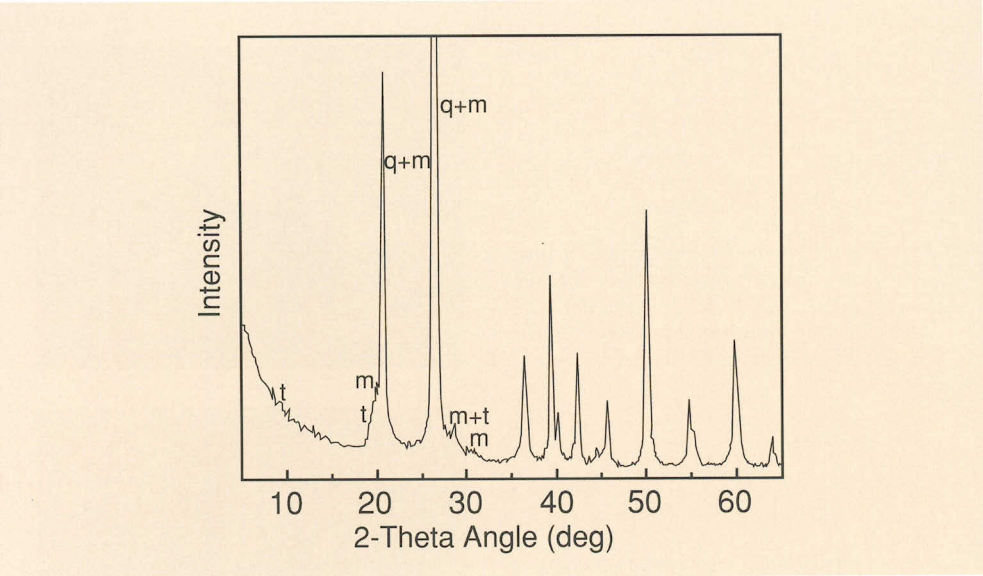

Figure 7: *X-ray powder diffraction pattern of chrome chalcedony with peaks labelled q-quartz, m-mogánite and t-talc.*

Mineral composition

X-ray diffraction

The X-ray diffraction (XRD) pattern *(Figure 7)* of chrome chalcedony shows quartz as the major mineral component with traces of talc and mogánite, a monoclinic polymorph of microcrystalline silica. 'Silica-G' was initially proposed as a working name for the new silica polymorph (Flörke *et al.*, 1976); after further characterization the mineral name 'mogánite' was introduced (Flörke *et al.*, 1984). The mineral occurs in ignimbrites of the Mogán Formation on Gran Canaria.

Examination of 150 microcrystalline quartz-rich silicas from the mineral collection of the US National Museum of Natural History, by Rietveldt refinement of the powder X-ray diffraction patterns (Heaney and Post, 1992) confirmed the presence of mogánite, in varying amounts, in agates, chalcedonies, cherts and flints. In 1999, the Commission on New Mineral Names of the International Mineralogical Association accepted 'mogánite' as a new mineral.

Mogánite has been detected in XRD patterns of dark green chrysoprase from Marlborough Creek, Australia (Gawel *et al.*, 1997). Concentrations of mogánite in the order of 15-29 vol.% have also been recorded in light green chalcedonic chrysoprase from Eucalyptus (WA) and Marlborough Creek, Queensland (Rodgers and Cressey, 2001).

Chemical composition

X-ray fluorescence analysis

The bulk chemical composition of the chrome chalcedony determined by X-ray fluorescence (XRF) analysis is listed in *Table I* below. The major component is silica. The Cr_2O_3 and Fe_2O_3 contents are 0.24 and 1.45 wt.%, respectively, and the NiO content is negligible (0.01 wt.%). Traces of aluminium and magnesium are present.

Water content

Water loss *(Table I)* at 100°C (H_2O) 0.56%, is attributed to the desorption of loosely bonded molecular 'water' ($H_2O_{(mol)}$) whereas the loss at 1050°C (H_2O^+) 1.66% is due to tightly bound molecular 'water' and

chemically bound silanol-group 'water' ($H_2O_{(SiOH)}$).

Although chrome chalcedonies from Zimbabwe and Bolivia and intaglios fom various sources are described in the gem literature (Hyrsl and Petrov, 1998, Hyrsl, 1999) different analytical methods and incomplete data make comparison of results difficult.

Gemmological properties

Optical/Physical

A summary of the gemmological properties of chrome-chalcedony is listed in *Table II.*

Diaphaneity and lustre: the chrome chalcedony cabochons tested in this study are dark green, translucent with a vitreous lustre *(Figure 8a).*

Hardness: due to texture, variable, ~ 7, sharp edges able to score quartz crystal surfaces.

Polariscope reaction: the samples remained light under crossed polarised filters, due to aggregate polarization.

Refractive index: the RI was determined to be 1.539, corresponding to the upper limit quoted by Webster, 1994, p.233.

Figure 8a: *Cabochons of chrome chalcedony from Western Australia. Digital image: M. Willing.*

Table I: *XRF analysis of chrome chalcedony.*

	Wt.%
SiO_2	95.01
Al_2O_3	0.29
Fe_2O_3	1.45
MnO	0.01
MgO	0.46
Cr_2O_3	0.24
NiO	0.01
H_2O^-	0.56
H_2O^+	1.66
Total	99.70

Figures 8b and c: *Carvings in chrome chalcedony from Western Australia. Digital images: M. Willing.*

Specific gravity: was determined as 2.57.

Absorption spectrum: shows a diffuse band in the orange from 570nm to 640 nm, absorption of the blue violet and transmission of the green region. All specimens appeared intense red under the Chelsea colour and Hanneman-Hodgkinson (HH) filters. In contrast, chrysoprase remains green.

Table II: *Summary of gemmological properties.*

Diaphaneity	Translucent
Hardness	~ 7
Fracture	Conchoidal (brittle)
Structure	Microcrystalline aggregate
SG	2.57
RI	1.539
Absorption spectrum	Absorption of orange; sharp increase in absorption from blue to violet.
Luminescence under UV, LW and SW	Inert
Chelsea colour filter and Hanneman-Hodgkinson filter	Intense red

Figure 8 shows cabochons and small carvings fashioned in chrome chalcedony mined from the new WA deposit. In selected material the intense greenness and high translucency is demonstrated by transmitted light in the objects shown in *Figures 8b* and *c*.

Results from spectroscopic methods

UV-Vis reflectance spectrum – WA chrome chalcedony

Comparison ultraviolet visible reflectance (UV-Vis) spectra for chrome chalcedony and mtorolite are shown in *Figure 9*. The UV-Vis spectrum for the chrome chalcedony reveals a decrease in reflectance due to absorption between ~ 540 and ~ 660 nm with a maximum absorption at ~ 610 nm. A distinct small absorption peak is present in the red at 681 nm. There is heavy absorption in the blue-violet/violet region from ~ 450 nm to

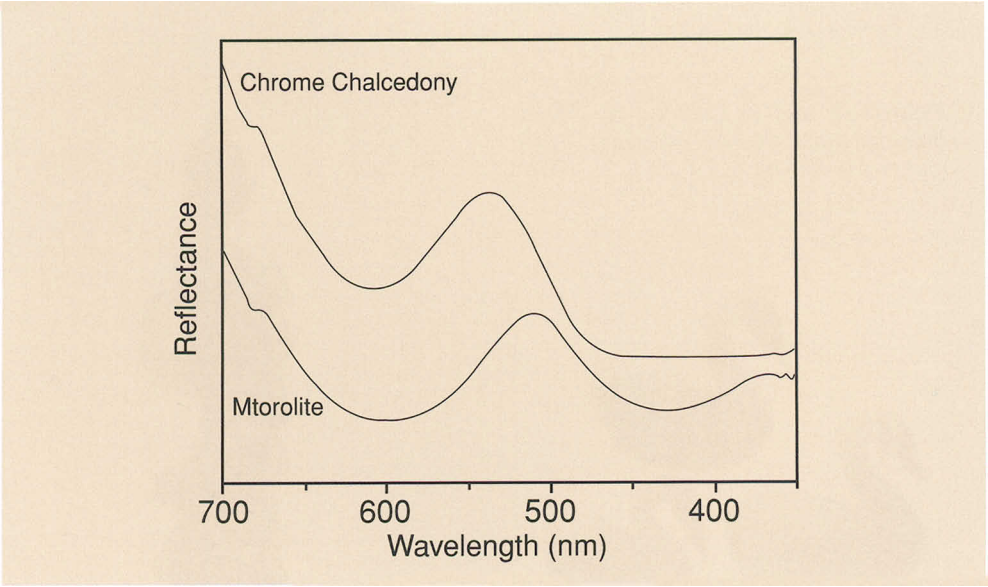

Figure 9: *UV-Vis reflectance spectra for chrome chalcedony (WA) and mtorolite (Zimbabwe). Spectra displaced vertically for clarity.*

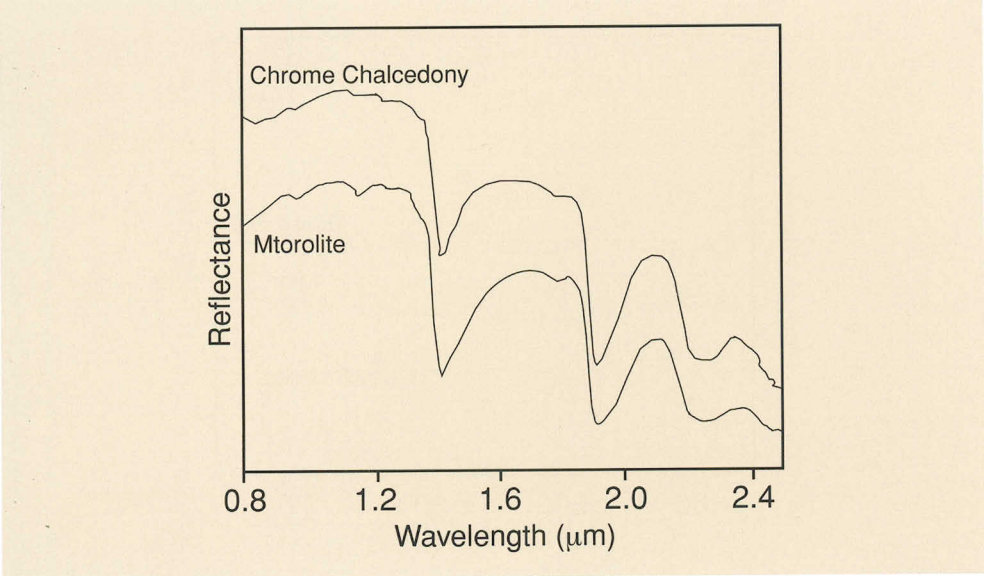

Figure 10: *Near-infrared spectra of chrome chalcedony and mtorolite obtained from plane-polished plates: 2 mm thick for the chrome chalcedony, and 4.2 mm thick for the mtorolite Spectra displaced vertically for clarity.*

shorter wavelengths and maximum reflectance occurs in the green at ~ 535 nm.

UV-Vis reflectance spectrum – Zimbabwean mtorolite

The UV-Vis spectrum for the mtorolite reveals a decrease in reflectance due to broad absorption from the edge of the blue-green at ~ 510 nm to 670 nm with a maximum absorption at ~ 600 nm. A broad absorption band extends from the blue at 475 nm beyond the violet with a maximum at ~ 427 nm. A distinct small absorption peak occurs in the red at 681 nm, reflectance occurs in the blue-green at ~ 510 nm.

The reflectance spectrum shown by the WA chrome chalcedony exhibits absorption characteristics similar to that reported by Hyrsl (1999) for the Mercury intaglio. The reflectance spectrum for the mtorolite examined in this study is similar to the spectral data for mtorolite and 'chiquitanita', Bolivia (Hyrsl and Petrov, 1998 and Hyrsl, 1999).

The chalcedonies examined show absorption bands characteristic of Cr^{3+}, confirming the presence of the chromophore (Rossman, 1988). The reflectance curves also reflect slight differences in the hue of the materials; chrome chalcedony tending toward green, mtorolite, towards blue-green.

Near infrared spectroscopy

Near infrared (NIR) reflectance spectra of chrome chalcedony and mtorolite are graphically displayed in *Figure 10*. The chrome chalcedonies show strong absorption features due to 'water' and hydroxyl (OH). The absorption features at 1.4 and 1.9 μm result from vibrations of molecular water (H_2O), with the 1.9 μm feature being diagnostic for water. The 1.4 μm feature indicates an overtone which may be in H_2O or hydroxyl in the structure (R.N. Clark, pers. comm.). Weaker features caused by vibration of silanol (Si-OH) groups occur at 2.22 and 2.27 μm, as an unresolved doublet. In a comprehensive infrared study of chalcedony, Frondel (1982) assigned the absorption feature at 2.2 μm to weakly

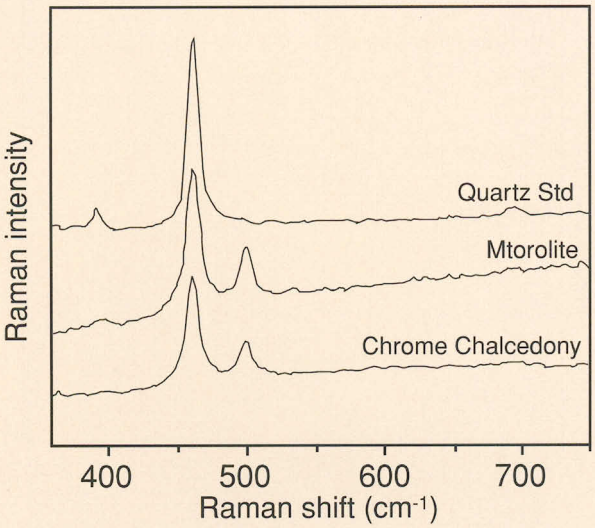

Figure 11: *Raman spectra of quartz standard, chrome chalcedony and mtorolite, obtained from plane-polished plates: quartz 3.5 mm, chrome chalcedony 2.0 mm, and mtorolite 4.2 mm thick. Spectra displaced vertically for clarity.*

H-bonded internal silanol (Si-OH). In the study of water in agates, Flörke *et al.* (1982) assigned the 2.27 μm absorption feature to strongly H-bonded surface silanol (Si-OH). In studies of Brazilian agate geodes, Graetsch *et al.* (1985) found water and silanol groups on hydrated surfaces.

The NIR spectral data in this study compare favourably to the NIR characterization of water in opal (Langer and Flörke, 1974) and recorded NIR spectra of opals (Fritsch and Stockton, 1987) including natural white and black opal from Australia, transparent yellow opal from Idaho and transparent red-orange opal from Mexico.

The NIR spectra of the chrome chalcedony and mtorolite examined in this study confirm the existence of three categories of water (Frondel, 1982).

The water content of this microcrystalline variety of quartz may account for the low refractive indices and density in comparison with the values for coarse quartz (Frondel, 1982; Heaney, 1993).

Raman micro-spectroscopy

Gem quality α-quartz comprising SiO_2 as the ideal formula was the standard used to characterize chrome chalcedony and mtorolite by Raman micro-spectroscopy. The Raman spectrum of the α-quartz standard *(Figure 11)* displays a characteristic peak at ~ 463 cm^{-1} due to vibrations of Si-O-Si (six-membered rings of SiO_4 tetrahedra).

Chrome chalcedony and mtorolite *(Figure 11)* show an additional Raman active mode at ~501 cm^{-1}, corresponding to the most intense Raman peak for the pure phase of mogánite. This peak, uncharacteristic of α-quartz, may be attributed to the four-membered rings of SiO_4 tetrahedra in mogánite (Kingma and Hemley, 1994).

In this study, the XRD pattern *(Figure 7)* of chrome chalcedony shows evidence of the intergrowth of the two silica polymorphs, α-quartz and mogánite. Raman spectroscopy, sensitive to minor differences in crystal structure, confirmed the presence of mixed phases of α-quartz and mogánite in the WA chrome chalcedony and the mtorolite.

The Raman spectra of the chrome chalcedonies in this study are similar to the results from a mixed-phase chalcedony containing α-quartz and mogánite from near Johannesburg, California (Kingma and Hemley, 1994). The spectra are identical to the Raman spectra of Roman chalcedonic chrysoprase intaglios in Paris (Smith and Robin, 1997); however, the name chrysoprase was based only on the apple-green colour, and it is possible that these are of chrome chalcedony as no analytical data are yet available (D.C. Smith, pers.comm.).

Discussion

Genesis

Vast areas of Western Australia were subjected to the weathering, leaching and depositional processes that resulted in widespread lateritization in the Tertiary (<65 Ma) during what was a warm temperate climate. The most obvious effect of this is the iron duricrust of hydrated iron oxides that characterize much of the landscape. In places, laterite thickness attained hundreds of metres.

Within the Sylvania area, the siliceous gem materials – chrome chalcedony, chrysoprase and chrome opal all occur within laterite horizons overlying serpentinite and all in close proximity to one another. Silica derived by leaching of ferromagnesian minerals from the original olivines and pyroxenes of the ultramafic rocks was deposited by secondary processes as nodules, veins or boxworks at or near the palaeo watertable. With climatic change to increasing dryness, these horizons, deposited under ambient temperatures, have been preserved due to lack of seasonal water to remove them. This secondary silica is usually of little gem interest, occurring as a grey or brown banded opaque jaspilitic material and its widespread occurrence in the area on hilltops overlying ultramafic rocks has already been discussed.

In more unusual circumstances, as happened in the Newman area, the processes of silica deposition have resulted in partial replacement of the original weathered country rock and the chrome chalcedony represents a whole-rock pseudomorph. In the process of replacement the original banded nature of the rock with its lenses of antigorite and talc and scattered chromite-magnetite granules have been preserved. Chromium, responsible for the green colouration of the chalcedony (0.24% Cr_2O_3) is most likely to have originated from chromite, which exists in relict form largely leached and oxidized to magnetite and hematite. As previously described, chromite occurs regularly throughout the chalcedony and serpentinite country rock. XRF analysis *(Table I)* shows negligible nickel. Crosscutting fractures filled by vein quartz and chalcedony represent a final process in the rock formation and silica of this generation is not coloured green.

Although silicified serpentine has been described from a nearby part of the SUI (Nagase *et al.*, 1997) and from the Widgee area of Queensland (Krosch, 1990) this occurrence near Newman is the first report of quality material with gem-potential formed by whole-rock replacement and coloured green by chromium.

Worldwide occurrences

Zimbabwe

The first discovery of chrome chalcedony in modern times was made in 1955 in Zimbabwe (Smith, 1967). The material derives from a horizon of the Great Dyke, a chrome-bearing differentiated ultramafic complex of Archaean age. Chrome chalcedony occurs as a boxwork of narrow veins varying in width from 5 mm to 25 mm. Although serpentinization may have reached depths of 300 m in the Great Dyke, the chrome chalcedony was formed in more recent times by silica deposition from near-surface ground waters in ambient temperatures and weathering conditions similar to those described for chrysoprase development. The material is known commercially as mtorolite, and was named after the settlement nearby at Mtoroshanga. Gem material is still exploited at the 'Jester'

claims, the source of the original discovery (J. Rheiner, pers.comm.)

Bolivia

Chiquitanite is the commercial name for chrome chalcedony found recently in Bolivia (Hyrsl and Petrov, 1998). The material as described, varies from opaque to translucent and some stones show a fine agate-like structure and network of brown iron oxides. The best quality material compares favourably with mtorolite (Hyrsl, 1999).

Archaeological material–Museum and private collections

Chrome chalcedony is one of a range of green siliceous materials that have been identified among Roman artifacts, engraved as intaglios. An intaglio forming part of the Roman finds from Wroxeter, Shropshire, England is described as translucent, coloured green by chrome and speckled with black spots (M. Hutchinson, pers. comm.).

A recent review of chrome chalcedonies used in ancient and antique gems includes Roman intaglios (3rd century AD) in the Cabinet de Medailles, Paris, two intaglios forming part of a necklace in the collection of the Museum of Decorative Arts (age uncertain), two intaglios (13th century) housed in Prague, Czech Republic and one intaglio in a private collection in Vienna (Hyrsl, 1999). The origin of the chrome chalcedony intaglios described above could not be from any of the sources so far described. Recent communication (C. Whipp, pers. comm.) on chrome chalcedony found in Anatolia, Turkey indicates that this may be the source material for some of these intaglios.

Conclusions

There are limitations in the mineralogical and petrological nomenclature which hamper one in accurately classifying occurrences of secondary silica formed in the weathering environment such as described in this paper. The WA chrome chalcedony, characterized in this study, is an ornamental rock composed of silica polymorphs. The name is derived from its dominant mineralogy comprising α-quartz as chalcedony and macroquartz; however mogánite, the metastable silica polymorph is also present. Minor talc is also present according to the XRD pattern.

No commercial name has yet been adopted for the rock, unlike mtorolite and chiquitanite for other worldwide occurrences herein described. The range of objects shown *(Figure 8 a–c)* is the first to have been produced and to date excavation work indicates that a reasonable tonnage exists.

The potential for the production of large decorative objects is good as the chrome chalcedony is not restricted to veins but occurs in massive form.

Acknowledgements

The authors wish to thank the following persons for their helpful discussions and contributions: John Flint and Robert Heaton for bringing the rock samples and carvings to our notice, freely discussing all aspects of the field of occurrence, and loan of carvings and photos used in this study; Michael Willing, fashioning of cabochons and preparation of the plane-polished plates; Dr E. Nickel, Research Fellow, CSIRO (ARRC) is acknowledged for verification of the X-ray diffraction data and manuscript consultation; Ass. Prof. W. Van Bronswijk, Dept. Chemistry, Curtin University, for Raman spectral analyses and manuscript consultation; Martin Wells CSIRO (ARRC) for collection of the UV-Vis and NIR spectra; Dr Ian Robertson, CSIRO (ARRC) is thanked for the use of the camera for photomicroscopy; Dr Vernon Stocklmayer for editorial comment and encouragement. We would also like to thank the Library staff at the Geological Survey WA, CSIRO (Divisions) WA and Geological Society, London for their kind assistance. Michael O'Donoghue is thanked for some reference sources.

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A note on sky-blue glass with needle-like inclusions

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ABSTRACT: The gemmological properties of a sky-blue square cut stone of 2.44 ct indicate that it is glass. These properties are similar to those of ekanite, and needle-like inclusions might mislead the unwary into thinking the stone was natural.

Introduction

Recently the author was asked to identify a 2.44 ct square cut sky-blue stone which looked very similar to aquamarine or blue topaz (*Figure 1*).

As mentioned in the literature: "Any stone which is isotropic (especially when showing anomalous double refraction) and has RI between 1.50 and 1.70 is more likely to be glass than anything else." [1] It is also known that most glasses used as gemstone simulants have specific gravities (SG) that lie in a range from 2.2 to 4.2.

Figure 1: *Enlarged view of the sky-blue square cut stone of 2.44 ct.*

The SG is especially affected by the lead content. The higher the lead content, the higher the SG of the glass[2]. What is less well known is that occasionally glass can show the same refractive index (RI) and SG as that displayed by a natural species. When the inclusions contained in the glass consist of needles intersecting in different planes, this adds to the possible confusion with a natural gemstone. Such is the case of the sky-blue square cut stone of 2.44 ct described in detail below.

Gemmological properties

The 2.44 ct square cut sky-blue transparent gemstone (length 8.08 mm, width 8.00 mm, depth 4.84 mm) displayed a vitreous lustre.

The RI determinations were carried out using a Rayner Dialdex refractometer and monochromatic sodium light. A single value of 1.593 was obtained from the table facet and showed that the stone was singly refractive (isotropic). The absorption spectrum was observed in daylight conditions, through a Beck spectroscope, and revealed an

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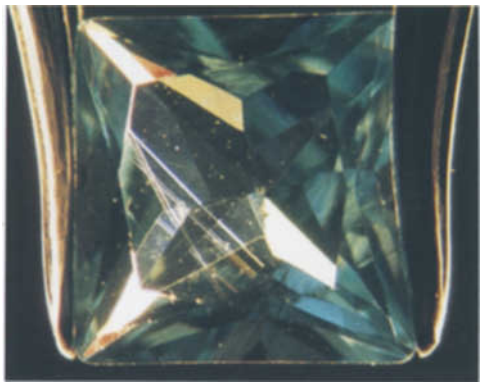

Figure 2: Numerous intersecting needle-like inclusions in the sky blue square cut stone of 2.44 ct (dark field illumination 10×).

Figure 3: Enlarged view of the intersecting needle-like inclusions of Figure 2 (darkfield illumination 15×).

absorption from 400–420 nm, with three fine lines at 640, 660 and 670 nm.

The stone was examined with a Multispec combined LW/SW ultraviolet unit and fluoresced a strong chalky greenish-yellow to SW, and a moderate orange to LW.

The SG was obtained by hydrostatic weighing in distilled water using a Mettler PL 300C carat scale; the stone was found to have a value of 3.28.

Except for the sky-blue colour, these properties are similar to those encountered for ekanite, a metamict radioactive calcium thorium silicate[3], with the chemical formula $ThCa_2Si_8O_{20}$.[4] Ekanite is typically dark green although some is chalky greenish-yellow, but it has not been reported as sky blue; it is also typically strongly radioactive, so the next test was to determine its radioactivity. The stone was submitted to a Solar Electronics Radiation Alert Monitor 4, and was found to be free of radioactivity.

The inclusions were examined using a Bausch & Lomb Mark V Gemolite binocular microscope using dark field illumination or overhead lighting as appropriate. Numerous intersecting 'needle-like' inclusions (*Figures 2 and 3*) as well as few gas pinpoint inclusions (*Figure 4*), were observed under the table facet or lying in the pavilion.

The composition of the stone was determined by Energy-Dispersive X-ray fluorescence (EDXRF), and indicates the presence of silica, lead, potassium and calcium, with minor contents of copper, iron, titanium, zinc and nickel.

Discussion

The RI of 1.593 and the SG of 3.28 alone could lead a novice to think that the stone might be ekanite. Had the colour been green instead of blue, this would have added even more to the confusion.

Figure 4: Enlarged view of a gas bubble lying at the junction of intersecting needle-like inclusions, in the sky-blue square cut glass of 2.44 ct (dark field illumination 25×).

It is a well established fact that glass is characterized by gas bubbles and swirl marks. Although a very few tiny isolated gas bubbles were observed, these can easily be missed and could lead to a wrong identification. Sometimes angular material (copper flakes mainly) has been included in glass to simulate natural inclusions displayed by certain species of gemstones (eg. aventurine quartz), but this is the very first time that the author has encountered long intersecting needles in a glass.

Bearing this in mind, the needles encountered were carefully examined and are most probably hollow canals similar to those used in fibre optics. Nevertheless, this 'gemstone' was most probably cut deliberately to fool a potential buyer.

A cursory inspection with a 10× lens by such a buyer could have led to a view that the stone was natural.

Conclusion

The physical and optical properties are consistent with those given by Bannister's graph for lead glass[5] and is confirmed by the composition determined by EDXRF.

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Behaviour of Brazilian imperial topaz at high temperature

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ABSTRACT: The effect of heating on the structure and composition of imperial topaz has been studied by thermal mechanical analysis, magnetic nuclear resonance and X-ray diffraction. It was found that imperial topaz is a stable mineral below 1000°C, i.e. it does not undergo any structural or chemical alterations on heating. However, at higher temperatures, there are structural changes and chemical decomposition of imperial topaz due to the loss of fluorine, hydrogen, and silicon leading to a complete transformation to mullite above 1300°C.

Keywords: Imperial topaz, mullite, thermal stability

Introduction

Imperial topaz from Ouro Preto, Brazil, with colours ranging from yellow orange to reddish-brown, are considered the rarest and most precious in the world.

The mineral topaz is a fluorine aluminium silicate and its varieties can be described by a chemical formula given by $Al_2SiO_4[F_x(OH)_{1-x}]_2$, where the hydroxyl group can replace fluorine up to ~30 mol% (Barton 1982). In a recent work it was shown that for imperial topaz the value of x is close to 0.8 (da Costa *et al.*, 2000).

The geological and gemmological characteristics of imperial topaz varieties from Ouro Preto are described elsewhere (Olsen, 1971; D'Elboux and Ferreira, 1975; Cassedane and Sauer, 1987; Menzies, 1995; Sauer *et al.*, 1996). In this region, it occurs in hydrothermal veins associated with quartz, dolomite and sometimes muscovite, hematite and rutile. The colours commonly found are orange-yellow, brownish-orange, orange-pink and violet.

Heat treatment of imperial topaz has been empirically performed for a long time in some mines in Ouro Preto (Sauer *et al.*, 1996) in order to give a pink colour to the reddish-brown crystals (*Figure 1*), which is appreciated in the gem market. This pink colour is formed at about 600°C and is stable up to 900°C; on further heating a white and opaque material is formed. In addition, depending on the temperature, topaz may decompose with the loss of hydrogen, fluorine and silicon, giving a new phase, mullite, which is an aluminium silicate of composition $2SiO_2.3Al_2O_3$.

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Figure 1: *Pink topaz obtained from imperial topaz by thermal treatment.*

In order to improve the yield from the topaz heat treatment in Ouro Preto, we have initiated a profound and systematic study that includes a description of the thermal stability and chemical behaviour of imperial topaz from room temperature up to its transformation to mullite.

It is worth noting that the knowledge of the chemical and structural behaviour of topaz at high temperature is important not only for the treatment of imperial topaz, but also for giving to colourless topaz a certain colour by means of thermochemical treatment, as shown in *Figure 2*. This treatment consists of heating colourless topaz mixed with chemical reactants at a previously well-defined temperature. Different colours and hues, which are stable at normal conditions, can be obtained by using different dopants; some details of this treatment are the subjects of patent applications (Sabioni and Ferreira, 2000, Sabioni *et al.*, 2000).

The present work, a continuation of da Costa *et al.* (2000), deals with the study of the behaviour of imperial topaz when it is heated from room temperature to 1400°C.

Thermal mechanical analysis, together with X-ray diffraction have been used to check the structural changes upon heating, and nuclear magnetic resonance (NMR) has been used to follow the changes that occur in the chemical composition of topaz during its transformation to mullite.

Experimental

Topaz samples

This work was performed using imperial topaz from the Capão Mine in Ouro Preto, Brazil. The characteristics of the topaz from this mine are described elsewhere (Sauer *et al.*, 1996; da Costa *et al.*, 2000). A number of samples were cut from one large single-crystal specimen in order to ensure that all samples had very similar characteristics.

Thermal treatments

Samples were submitted to a range of thermal treatments: raising the temperature from 300°C to 1400°C in one hour; a few samples were heated from 800°C to 1400°C over four hours; and finally isothermal treatments were carried out at 1000°C for 1, 2, 4, 6 and 23 hours. All thermal treatments were performed in static air.

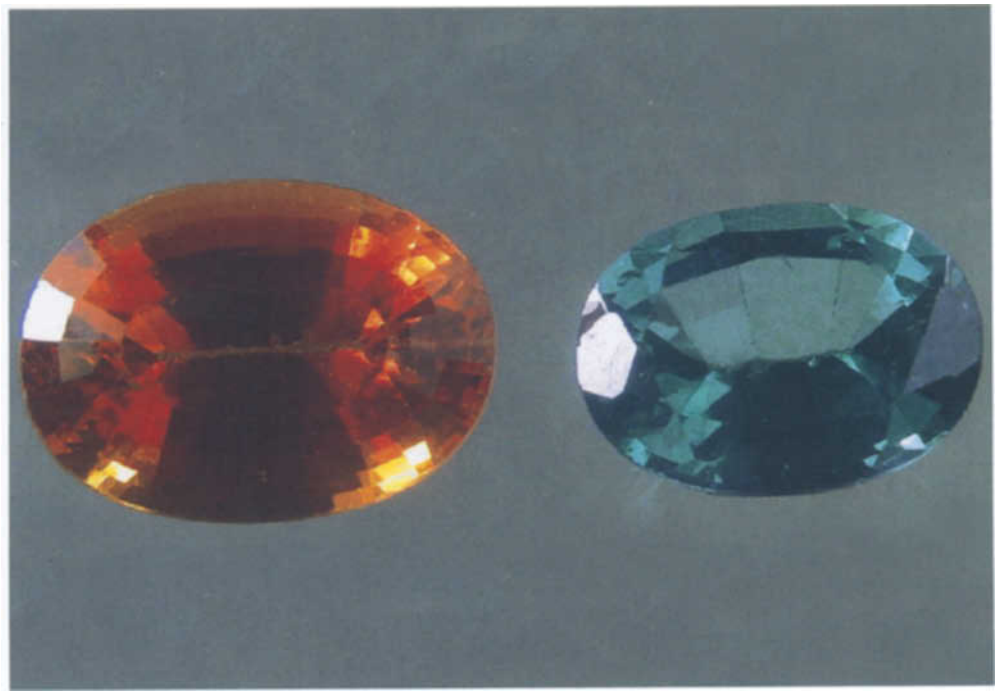

Figure 2: Orange and blue topazes obtained by thermochemical treatment of colourless topazes.

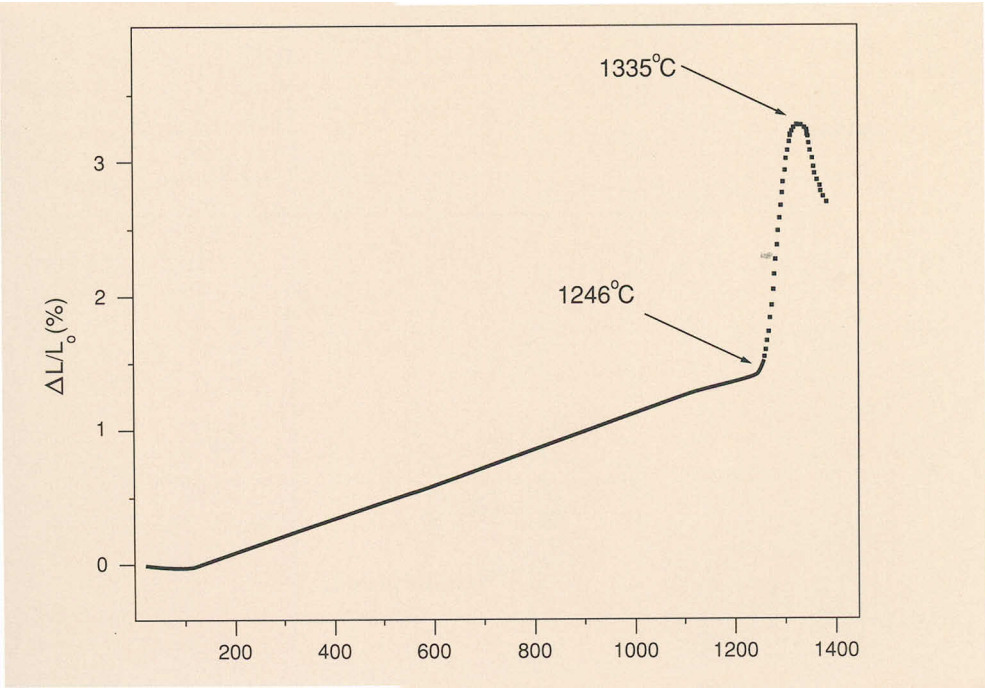

Figure 3: Thermal mechanical analysis of imperial topaz. The graph shows linear expansion ($\Delta L/L_o$) over the temperature range 0–1380°C.

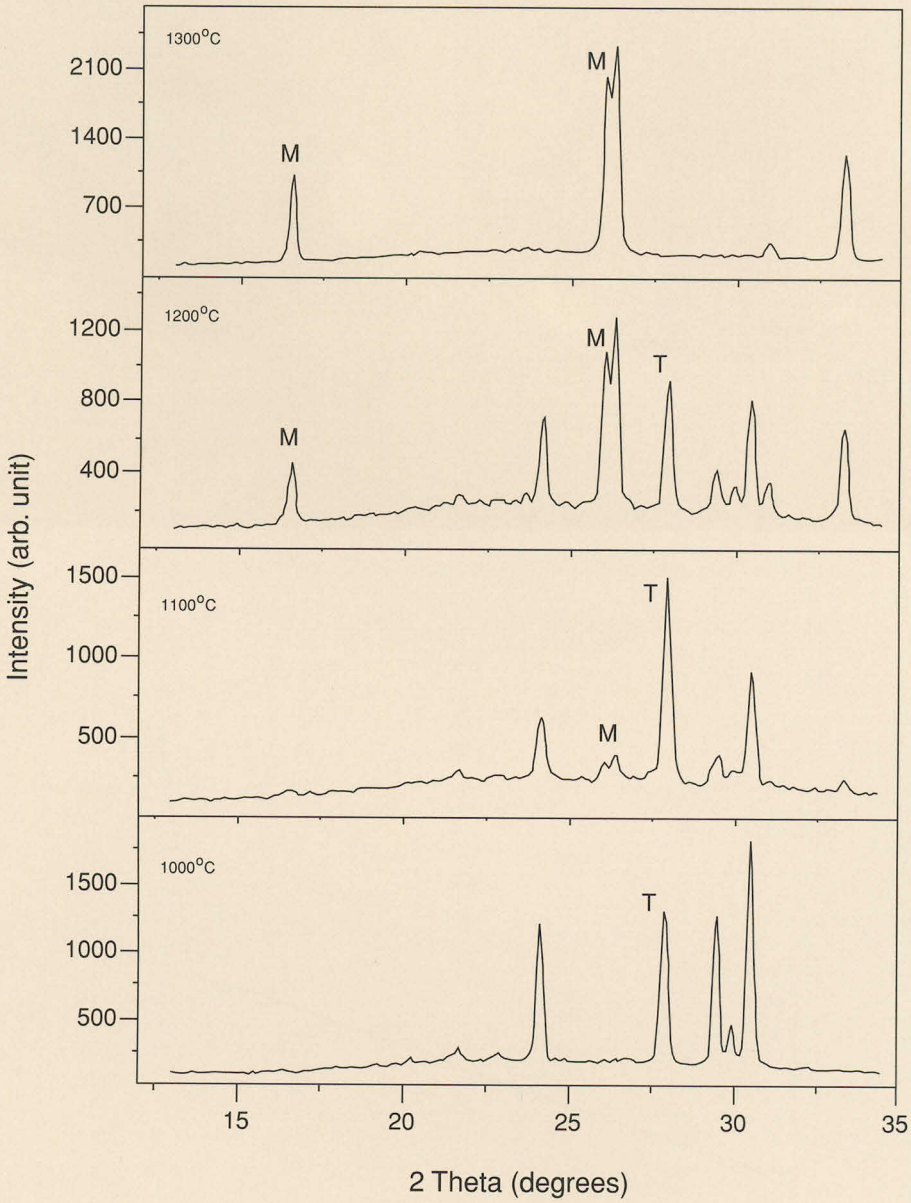

Figure 4: *Powder X-ray diffraction patterns for topaz samples heated for 4hrs at 1000°C, 1100°C, 1200°C and 1300°C; characteristic peaks for topaz (T) and mullite (M) are marked.*

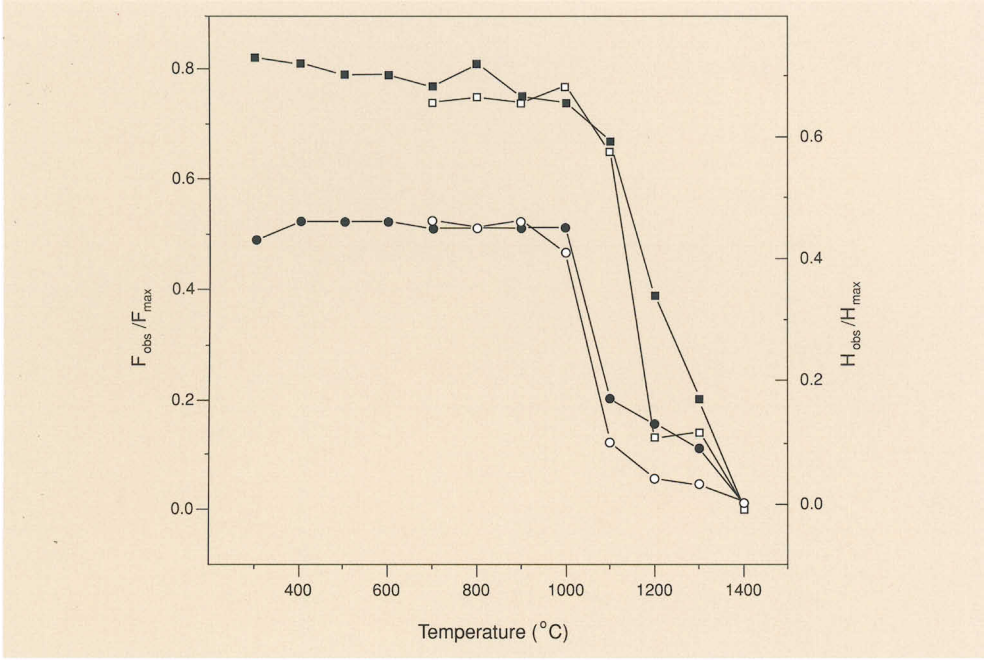

Figure 5: *Fluorine (squares) and hydrogen (circles) contents in topaz samples heated up to 1400°C for one hour (full symbols) and four hours (open symbols). Solid lines are a guide for the eye.*

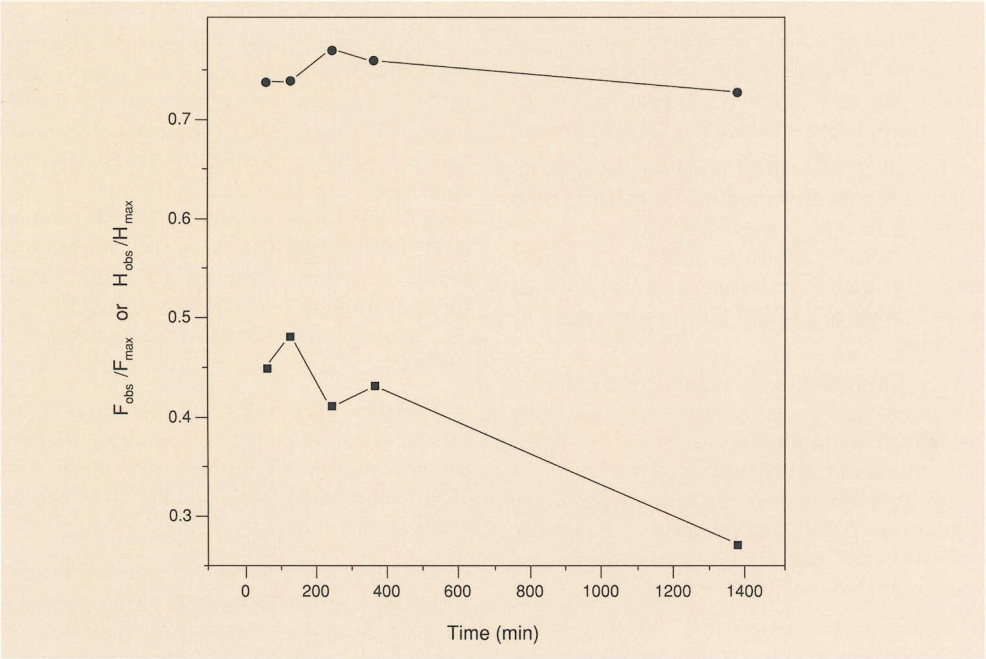

Figure 6: *F (circles) and H (squares) contents in samples heated at 1000°C for different times. Solid lines are a guide for the eye.*

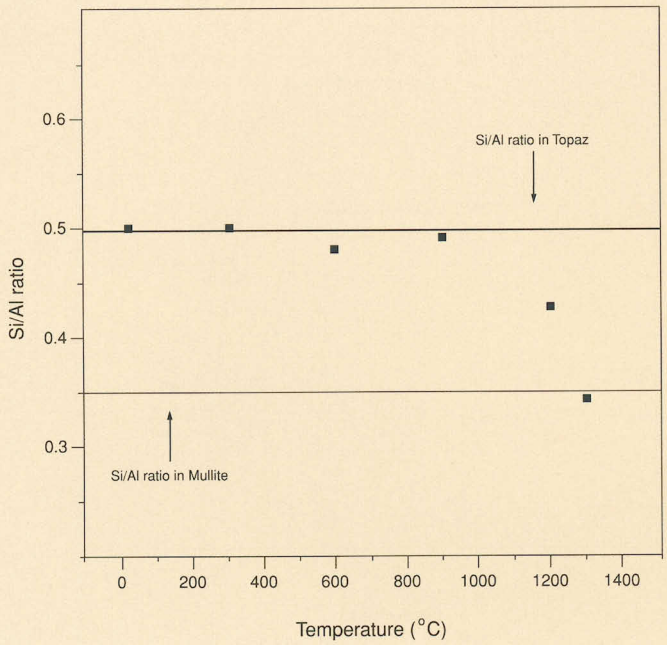

Figure 7: Si/Al ratio in samples heated up to 1300°C.

Characterization techniques

The thermal mechanical analysis was performed from room temperature to 1380°C, in static air with a heating rate of 10°C/min, using a Netzsch 402 E apparatus.

The structural variation of the topaz upon heating was determined by X-ray diffraction using a Rigaku Geigerflex diffractometer with CuKα radiation and a graphite monochromator. The scans were performed in the range of 15°–70° (2θ) at a speed of 1° per min.

The fluorine and hydrogen contents were determined by using nuclear magnetic resonance. Quantitative ^{1}H and ^{19}F NMR measurements were obtained by using a small (20°) flip angle and a rather long (5 sec) relaxation time. Calibrations were made using known quantities of saccharose and sodium fluosilicate.

Unpolarized uv-visible spectra were obtained using a Shimadzu spectrophotometer in the range of 300–1100 nm using 1 mm thick slabs.

Results and Discussion

Figure 3 shows the results of the thermal mechanical analysis. From room temperature up to 123°C, there is no thermal expansion. From 123°C to 1246°C, thermal expansion occurs with a linear thermal dilation coefficient equal to 1.27×10^{-5} per °C. At 1246°C the topaz to mullite transformation starts and during the phase transformation, between 1246°C and 1321°C, the linear thermal dilation coefficient is 25.14×10^{-5} per °C. The phase transformation ends at 1335 °C.

Powder X-ray diffraction patterns for the samples heated for four hours show that the transformation to mullite has started at 1100°C and is complete at 1300°C, as shown in *Figure 4*.

The effect of the temperature on the fluorine and hydrogen contents was determined by nuclear magnetic resonance. The results observed for the F and H contents after the thermal treatments from 300°C to 1400°C, for one and four hours, are shown in *Figure 5*.

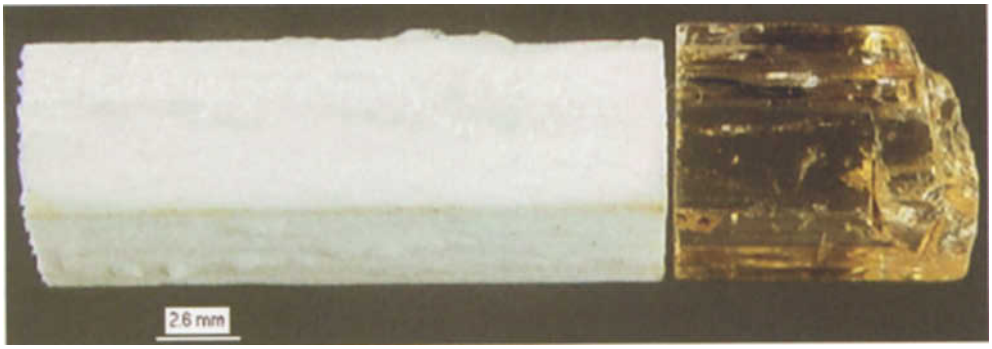

Figure 8: *Mullite on the left formed by heating topaz at high temperature. The apparent difference in thickness is due to different orientation of the two crystal samples and is not an effect of the heat treatment.*

Up to 1000°C, the F and H contents in the treated samples are constant and equal to their contents in the untreated samples. Above 1000°C, there is a steady loss of both elements, but the loss of hydrogen is faster at 1100°C, whereas the fluorine is rapidly lost at 1200°C.

The influence of time on the hydrogen and fluorine contents when the topaz is heated at 1000°C is shown in *Figure 6*. Hydrogen and fluorine contents in topaz remain approximately constant when the sample is heated at 1000°C for up to six hours, but when heated for 23 hours, the

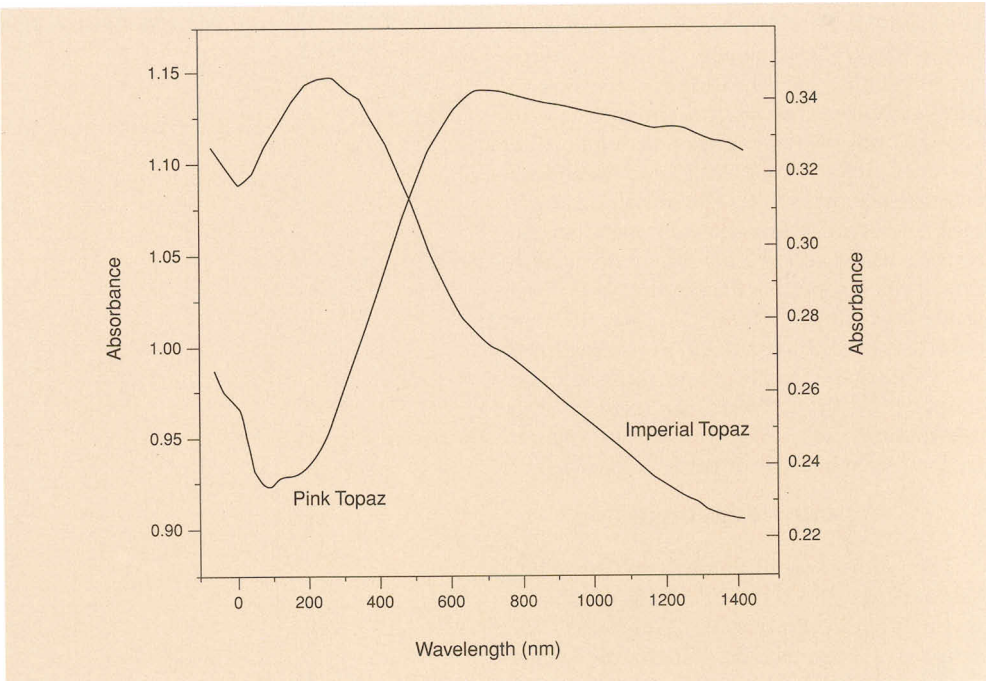

Figure 9: *Unpolarized uv-visible spectra of imperial (right axis) and pink topaz (left axis). The pink topaz was obtained by heating the imperial topaz at 600°C.*

hydrogen content falls to about 60% of its original value, whereas the fluorine content remains approximately constant. These results are in good agreement with those reported by da Costa *et al.* (2000) who proposed that the first loss of mass in the thermogravimetric analysis is due to the release of OH groups.

The chemical decomposition of topaz is due to the loss of fluorine, hydrogen and also of silicon as shown in *Figure 7*. It can be seen that the Si/Al ratio decreases, above 1000°C, from 0.5 (in natural topaz) to 0.34 at 1300°C (0.33 in mullite), which means that silicon has been released from the structure, probable as SiF_4 or SiO_2 (Day *et al.*, 1995). According to the X-ray diffraction results there are no traces of topaz in the samples heated above 1300°C and they appear opaque and white, as shown in *Figure 8*. Mullite is stable up to ca 1850°C, where it congruently melts.

In conclusion, the results presented in this work, by using different characterisation techniques, clearly show that imperial topaz is a stable material below 1000°C, i.e. it does not undergo any structural or chemical modifications upon heating. In contrast to this stability, the optical properties do change: on heating, imperial topaz first becomes pink at about 600°C, and then turns colourless above 900°C. The unpolarized uv-visible spectra of imperial topaz and of the sample heated at 600°C are shown in *Figure 9*. The former shows a maximum absorption centred at about 400 nm, similar to that reported by Schwarz (1997), whereas the latter shows the maximum near 700 nm. The changes in the colours are due to the destruction of colour centres, by a mechanism which is not yet well known.

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Natural versus hydrothermal synthetic Russian red beryl: chemical composition and spectroscopic measurements

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ABSTRACT: Two natural red beryl samples from Utah have been compared with six hydrothermal synthetic specimens recently produced in Russia, in order to determine the most significant chemical-physical parameters for discrimination. Classical gemmological observations have been coupled with results from electron probe microanalysis wavelength-dispersive spectrometry (WDS) and measurements by Fourier transform infrared (FTIR) and Raman spectrometry. The results are discussed in the light of previous published investigations.

Keywords: chemical composition; FTIR; natural red beryl, Raman spectroscopy; synthetic red beryl

Introduction

In the last decade beryl has grown significantly in importance among hydrothermal synthetic gemstones, in terms of the amounts produced and marketed (Koivula *et al.*, 2000). In particular, hydrothermal synthetic emeralds from China and Russia have motivated many a study devoted to investigate growth mechanisms and physical-chemical properties helpful for characterisation (see for instance: Schmetzer, 1988; Brown *et al.*, 1989; Sosso and Piacenza, 1995; Koivula *et al.*, 1996; Schmetzer, 1996; Schmetzer *et al.*, 1997a; Sechos, 1997). Coloured synthetic beryl has attracted much interest too, especially as to the possibility of controlling its colour by means of addition of appropriate ionic species: purple is attained by doping with a combination of chromium and manganese, pink by manganese alone (like morganite and natural red beryl from Utah), blue by copper and orange-red by traces of cobalt (Koivula and Kammerling, 1988; Koivula and Kammerling, 1991; Johnson *et al.*, 1999a). Biron synthetic pink beryl has been reported by Fritsch (1992)

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Techniques and equipment

IR and Raman measurements were carried out (i) by a Nicolet NEXUS FTIR spectrophotometer equipped with a diffuse reflectance (DRIFT) accessory, operating over the range 400-7400 cm^{-1} at a resolution of 2 cm^{-1}, and (ii) by a BRUKER 100 FT-Raman spectrophotometer in backscattering mode, with a Nd-YAG laser at 1064 nm, operating over the range 50-4000 cm^{-1} at a resolution of 2 cm^{-1}, respectively. A 2 mm^2 facet is sufficient to carry out FTIR measurements in reflectance mode, while Raman spectra can be collected regardless of the shape of the surface (Tretyakova *et al.*, 1997). All the samples were studied by FTIR using two settings to assess the dependence of the IR-spectra on the specimen's orientation (Stockton, 1987; Fritsch and Stockton, 1987; Martin *et al.*, 1989). In the case of 1b, 2b, 3b, 4b and 6b measurements were performed with the samples oriented with their *c*-axis first parallel and then normal to the light path in the instrument; the *c*-axis in specimens 5b, 7b and 8b, was not located and they were studied using two facets at approximately 90° to each other. Before performing Raman and FTIR measurements the samples were meticulously cleaned by acetone to remove residual traces of grease or of any other environmental organic contamination.

Quantitative chemical analyses were carried out using an Allied Research Laboratories electron microprobe equipped with six wavelength dispersive spectrometers and a Tracor Northern energy dispersive spectrometer. The system was operated using an electron beam at an accelerating voltage of 15kV, a sample current on brass of 15 nA and a counting time of 10 or 20 sec on the peaks, and of 5 or 10 sec on the backgrounds. The samples were embedded in a resin, and their facets used as flat surfaces for analysis. A series of minerals (kaersutite for Mg, Na, Ti, K; rhodonite for Mn; sodalite for Cl; niccolite for As and Ni; galena for S and Pb) and pure elements (for Co and Cu) were used as compositional standards. The results were corrected for matrix effects by a conventional ZAF routine from the Tracor Northern TASK set of programmes. The instrument sensitivity can be estimated about 0.05% in weight of the analysed element, on the basis of previous calibrations on standards; elemental concentrations smaller than 0.05% in weight, though detected, cannot be considered fully reliable. A normalization according to 15 oxygen atoms per formula unit was used, in the case of beryl. The chemical composition of each sample was determined as an average over 10 independent measurements, to account for compositional inhomogeneities, which were of the same order or less than the variation due to instrument sensitivity. The detection of the light elements Be and Li, is not possible with this microprobe, though their presence is indicated by the apparently non-stoichiometric contents of the other oxides.

and by Brown (1990); bicoloured 'water melon' synthetic beryl was produced in Japan (see Koivula *et al.*, 1986), while hydrothermal synthetic aquamarine from Russia has been described by Schmetzer (1990). Henn and Milisenda (1999) gave a detailed account of hydrothermal synthetic red beryl from Russia, characterizing their samples by IR-spectroscopy, in terms of atomic scale properties, and by optical observations, to describe inhomogeneous growth structures. Shigley *et al.* (2001) have recently reconsidered the comparison between natural and synthetic red beryl for diagnostic identification purposes.

We here report a study of natural versus hydrothermal synthetic red beryl based on a combination of classical gemmological observations with Raman and FTIR measurements, and with chemical

composition determinations from electron probe microanalysis in wavelength dispersion mode (WDS = Wavelength Dispersion Spectroscopy). The present investigation complements the earlier ones in terms of a characterization of the samples over the infrared energy range by means of both FTIR and Raman spectroscopy, and provides a precise compositional determination by WDS, which is particularly appropriate to determine the minor element contents (Potts, 1987). Note that hereafter we often address 'natural (synthetic) red beryl' simply as 'natural (synthetic) beryl', for the sake of brevity.

Specimens

In total eight red beryl samples were studied: six synthetic (1b, 2b, 3b, 4b, 5b, 6b) and two natural (7b, 8b) specimens. The former, from Russia, obtained by hydrothermal synthesis and between 1.4 and 4.1 ct in weight, were kindly supplied by ARS AURA (Milan, Italy); the latter, from Utah and less than 0.5 ct in weight, were provided by the Italian Gemmological Institute (IGI). Four

Table I: *Gemmological details of six synthetic and two natural samples of red beryl.*

Sample no.	*Weight ct*	*Dimensions mm*	*Colour*	*Pleochroism*	*UV fluorescence*	*Inclusions*
Hydrothermal synthetic red beryl from Russia						
1b	1.42	9.0×7.0×3.7	purplish-pink	medium: ω violet ε rose	none	inhomogeneous growth structures
2b	2.28	10.0×8.0×4.1	purplish-pink	medium: ω violet ε rose	none	inhomogeneous growth structures
3b	3.70	12.1×10.0×4.9	red	strong: ω red ε orange	none	inhomogeneous growth structures
4b	4.10	12.0×10.0×6.2	red	strong: ω red ε orange	none	inhomogeneous growth structures
5b	19.37	rough	red	strong: ω red ε orange	none	inhomogeneous growth structures
6b	15.87	rough	red	strong: ω red ε orange	none	inhomogeneous growth structures
Natural red beryl from Utah						
7b	0.40	4.8×2.9×3.2	purplish-pink	weak: ω violet ε rose	none	no inhomogeneous growth structures
8b	0.27	5.0×4.0×2.0	purplish-pink	weak: ω violet ε rose	none	no inhomogeneous growth structures

out of the six synthetic beryl samples are faceted, whilst the others are cut as parallelepipeds.

Results and discussion

Gemmological features

The results obtained from traditional gemmological testing are summarized in *Tables I* and *II*. Inhomogeneous growth structures, common in Russian synthetic hydrothermal emeralds (Schmetzer, 1988; Schmetzer, 1996; Brown *et al.*, 1989; Sosso and Piacenza 1995; Koivula *et al.*, 1996; Schmetzer *et al.*, 1997b; Sechos, 1997), have been observed in our synthetic samples using a microscope at 50× magnification. These inhomogeneous growth patterns, described as 'chevron' or 'zig-zag' growth structures by Sechos (1997), or as 'angular' growth patterns by Schmetzer (1988), are among the most significant diagnostic features for

Table II: *SG and RI of red beryl samples, from the present study and from literature.*

SG	*RI*	*Sample no.*	*Reference*
Russian hydrothermal red beryls			
2.69	n_ω 1.580 n_ε 1.572	1b	
2.68	n_ω 1.580 n_ε 1.573	2b	
2.70	n_ω 1.580 n_ε 1.573	3b	
2.70	n_ω 1.580 n_ε 1.573	4b	
2.70	n_ω 1.580 n_ε 1.572	5b	
2.70	n_ω 1.580 n_ε 1.572	6b	
2.63-2.65	n_ω 1.578-80 n_ε 1.570-76		Henn and Milisenda (1999)
2.67	n_ω 1.576 n_ε 1.570		Henn and Milisenda (1999)
2.69	n_ω 1.580 n_ε 1.574		Henn and Milisenda (1999)
2.68	n_ω 1.572 n_ε 1.568		Johnson and Koivula (1997)
2.68	n_ω 1.581 n_ε 1.575		Johnson and Koivula (1997)
Natural beryls from Utah			
2.66	n_ω 1.570 n_ε 1.565	7b	
2.65	n_ω 1.570 n_ε 1.564	8b	
	n_ω 1.572 n_ε 1.568		Harding (1995)
2.63-2.72	n_ω 1.567-71 n_ε 1.561-65		Hosaka *et al.* (1993)
2.66-2.70	n_ω 1.568-72 n_ε 1.564-69		Shigley and Foord (1984)
2.67	n_ω 1.568-77 n_ε 1.561-70		Flamini *et al.* (1983)
2.65	n_ω 1.569 n_ε 1.561		Miley (1980-81)
2.67	n_ω 1.576 n_ε 1.570		Nassau and Wood (1968)
2.66-2.70	n_ω 1.568-72 n_ε 1.564-69		Webster (1994)
2.67	n_ω 1.570-77 n_ε 1.561-68		Leone and Cumo (1985)

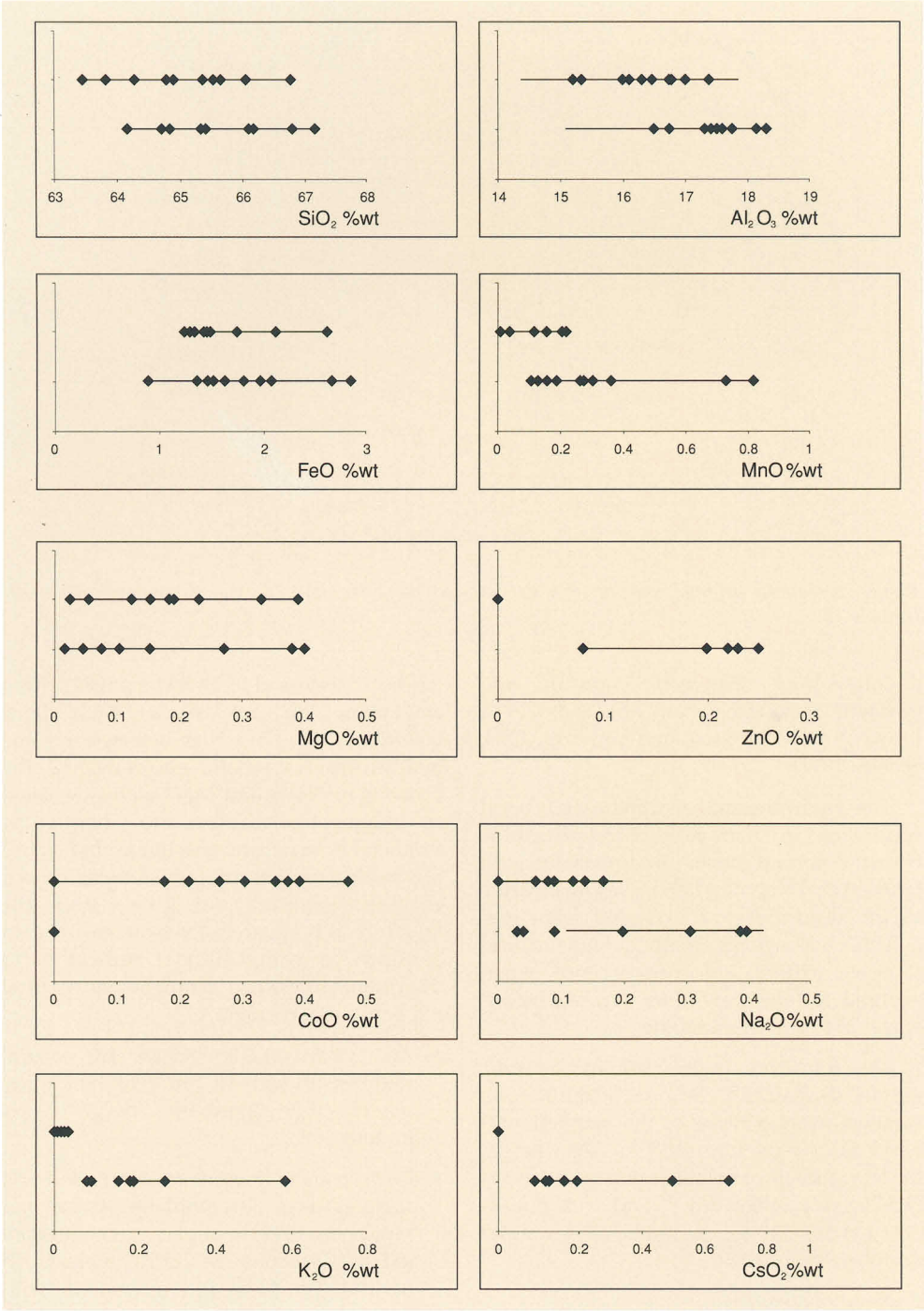

Figure 1: *Oxide contents in red beryl from the present study and from the literature. Contents in synthetic beryl are plotted on the upper line, those in natural beryl on the lower line.*

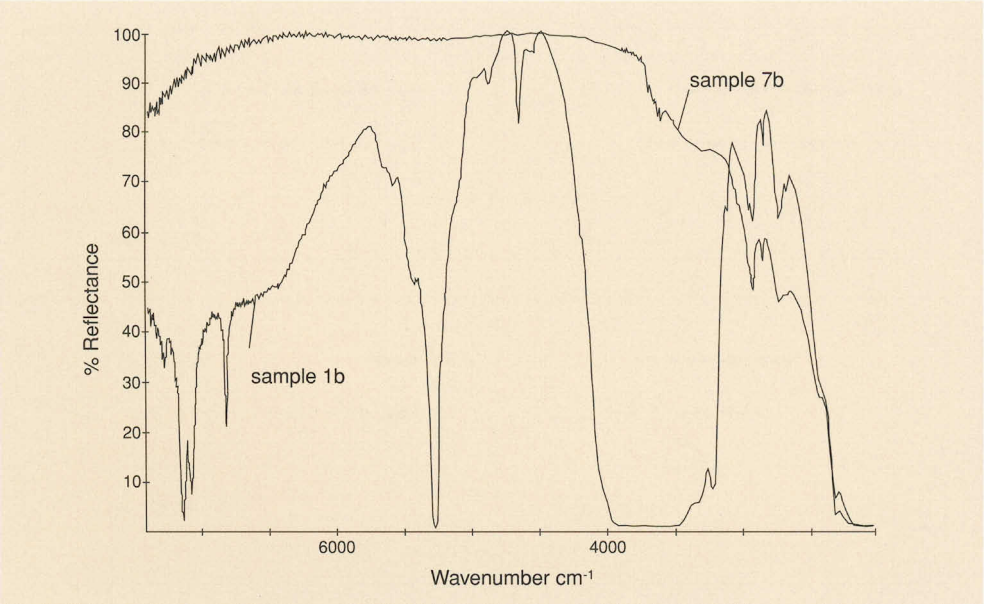

Figure 2: *Typical infrared spectra of a natural red beryl (sample 7b) and a synthetic red beryl (sample 1b).*

distinguishing between natural and synthetic beryl (Henn and Milisenda, 1999; Brown *et al.*, 1989: Sosso and Piacenza, 1995; Sechos, 1997).

The hydrothermal synthetic red beryl specimens are markedly more pleochroic than the natural stones (in agreement with Johnson and Koivula, 1997), presumably due to the occurrence of extended structural defects, but neither synthetic nor natural samples exhibit any fluorescence when exposed to long-wave (365 nm) and short-wave (254 nm) UV radiation.

The refractive index (RI) and specific gravity (SG) values (*Table II*) of the natural samples overlap those of the synthetic red beryl. SG ranges from 2.63 to 2.72 whereas the RI values lie in the following intervals: n_ω (1.572-81)/n_ε(1.568-76) and n_ω(1.564-77)/n_ε(1.561-72) for synthetic and natural samples, respectively.

Chemical composition

The distinction between natural and synthetic emeralds using chemical criteria has been discussed by Stockton (1984), Stern and Hänni (1982) and Schrader (1983). Minor quantities of Cl have been detected in some hydrothermal synthetic emeralds and the contents of Na_2O and MgO were suggested as diagnostic markers to distinguish synthetic from natural specimens. In *Figure 1* the oxide contents of our samples of red beryl are plotted with those from the literature. It is apparent that some oxides can be used as compositional indicators to discriminate between synthetic and natural red beryl in particular:

- Zn systematically occurs in natural samples, though in different quantities, whereas in synthetic beryl it is undetectable;
- Co is usually present in synthetic beryl samples as a chromophore (Henn and Milisenda, 1999) to impart a more marked red hue; in contrast, cobalt is absent in natural samples, in agreement with Sinkankas and Read (1986). However Co is also absent in our synthetic samples 1a and 1b, and this

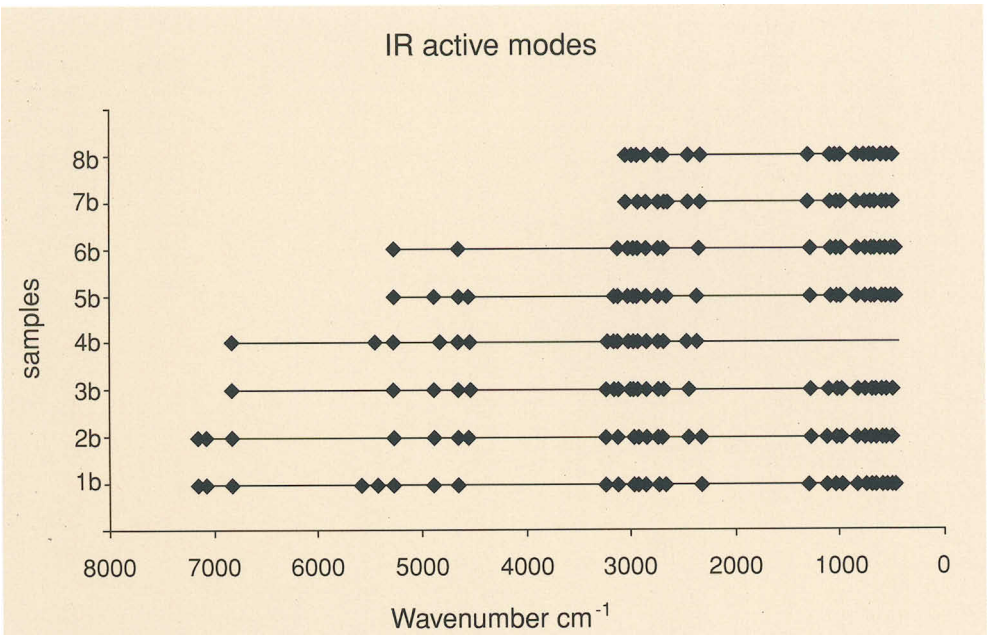

Figure 3: *Infrared vibrational frequencies of the eight red beryl samples studied.*

absence causes the colour of the stones to tend towards a purplish-red;

- K occurs in significantly larger amounts in the natural samples than in the synthetic ones, where it is below the detection limit of the instrument;
- Cs has been detected in natural samples only, and it can be a distinctive indicator of the growth environment of natural beryl;
- Na and Mn occur in larger amounts in natural than in the synthetic samples, although if their concentration values lie below about 0.20% they cannot be considered reliable indicators for discrimination.

The other elements analysed are not useful for diagnostic purposes, as their ranges in natural and synthetic red beryl overlap.

Infrared spectra FTIR

The observed infrared spectra (*Figure 2*) yield vibrational frequencies which allow one to readily distinguish synthetic from natural red beryl (*Figure 3*). In the former the region ranging from 3500 to 3800 cm^{-1} is characterised by vibrational modes involving H_2O molecules (Stockton, 1987) and are seen as broad and intense bands; in contrast, weak peaks are only just detectable in the natural stone (*Figure 2*). The synthetic samples exhibit peaks at 5100, 5270 and 5455 cm^{-1}, corresponding to combination modes of water molecules of type I related to the low amount of alkali (Wood and Nassau, 1967; Wood and Nassau, 1968), consistent with the composition reported above. H_2O combination modes are also observed at 7150 cm^{-1}. The chlorine related bands in the 2500-3100 cm^{-1} range which were described by Schmetzer *et al.* (1997), Fritsch *et al.* (1992) and Stockton (1987) for some kinds of hydrothermal synthetic emeralds, are not present in the red beryl. This is consistent with the absence of chlorine indicated by the chemical analyses.

In the natural red beryl samples, very weak peaks appear in the spectral range 2000–7400 cm^{-1}; in particular, there are

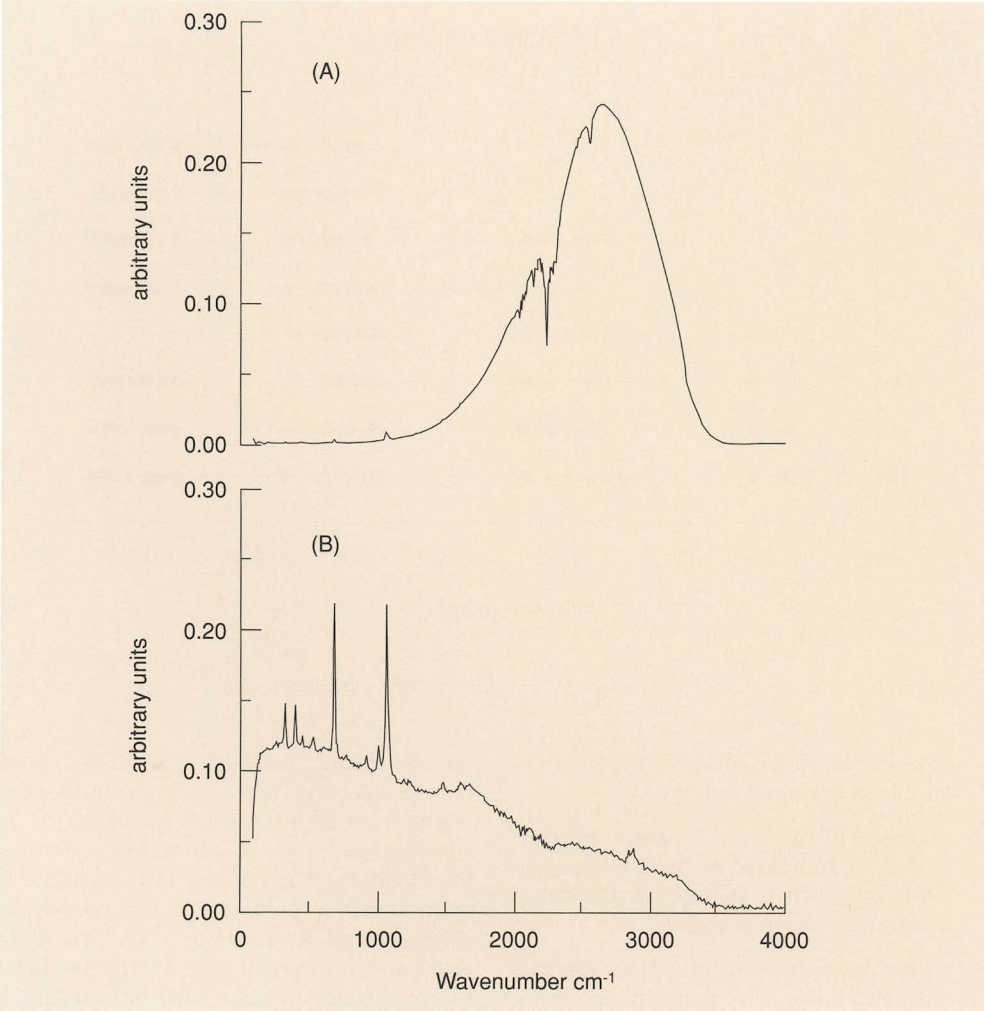

Figure 4: *Raman spectra of (A) synthetic sample 5b and (B) natural sample 7b.*

signals at 3692 cm^{-1}, attributable to water molecules of type I, and at 3651 and 3598 cm^{-1}, due to asymmetric and symmetric stretching modes of water molecules of type II, respectively (Wood and Nassau, 1968). The nearly negligible amount of water in natural red beryl is ascribable to the growth conditions, as claimed by Nassau and Wood (1968), Flamini *et al.* (1983) and Shigley and Foord (1984). Hence, H_2O plays a role helpful for discrimination between natural and synthetic red beryl, given that (i) it is present in significantly different amounts, and (ii) it occurs as types I and II in the former, and as type I only in the latter. More generally, features due to water are easily detected by the infrared spectroscopy of beryl, and are useful in discriminating natural stones from their synthetic counterparts (Fritsch and Stockton, 1987; Stockton, 1987; Martin *et al.*, 1989; Schmetzer, 1990; Schmetzer and Kiefert, 1990; Yan *et al.*, 1995).

Lastly, we also observed vibrational bands in the range 3100–2800 cm^{-1} (in particular at 2957, 2925 and 2851 cm^{-1}) attributed to fissure fillers such as resins or

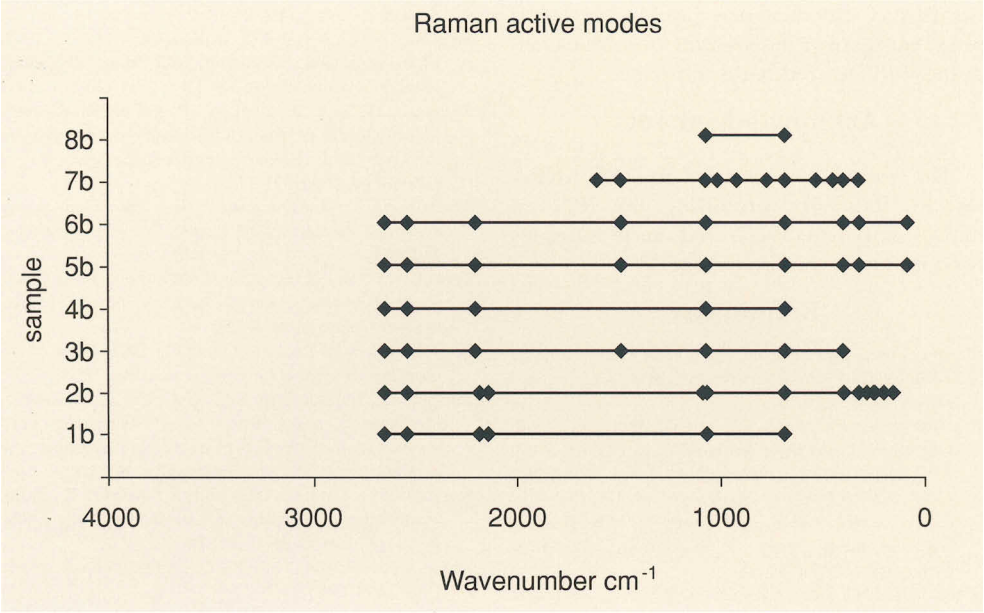

Figure 5: *Vibrational frequencies observed by Raman spectroscopy in the eight red beryl samples.*

oil impregnations (Kiefert *et al.*, 1999; Johnson *et al.*, 1999b; Johnson and Muhlmeister, 1999) in both synthetic and natural samples.

Raman scattering

Raman spectra of natural and synthetic beryl have been collected by a variety of techniques (see Tretyakova *et al.*, 1997; Zwaan and Burke, 1998; Hänni *et al.*, 1997; Pilati *et al.*, 1997; Hageman *et al.*, 1990; Hofmeister *et al.*, 1987; Adams and Garden, 1974). *Figure 4* displays the spectra collected for samples 5b and 7b. Natural and synthetic samples reveal the presence of typical Raman peaks between 50 and 1200 cm^{-1}, and the strongest ones occur at 685 and 1070 cm^{-1} (*Figure 5*). The significant differences between synthetic and natural samples are that the former give Raman spectra characterized by:

(i) additional signals above 2000 cm^{-1}, due to overtones and extended structural defects;

(ii) a broad hump between 1500 and 3500 cm^{-1}, which is tentatively ascribed to fluorescence. This is consistent with the common presence of significant structural strain, indicated by broad X-ray diffraction peaks, in synthetic beryls.

NB: Detailed figures for the compositions, infrared and Raman spectral peaks can be obtained from Dr A. Pavese.

Conclusions

Traditional gemmological tests and observations allow one to distinguish synthetic from natural red beryl only on the basis of the occurrence of inhomogeneous growth structures in the former; such properties as refractive index and specific gravity are not diagnostic. Chemical composition may help in distinguishing natural from synthetic, because of the likely occurrence of Co in synthetic beryl or the characteristic presence of K, Na, Mn, Cs and Zn in natural samples. Infrared spectroscopy and Raman spectroscopy provide further indication for discrimination; with reference to the synthetic samples, the former reveals the significant presence of water, the latter shows additional peaks above 2000 cm^{-1}. Furthermore, the 1064 nm laser light causes

significant fluorescence, appearing as a broad hump over the interval 1500-3500 cm^{-1}, in the synthetic red beryl samples.

Acknowledgements

The authors are grateful to ARS AURA (Milan, Italy) for providing the Russian hydrothermal synthetic red beryl samples used in the present investigation.

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Letter to the Editor

Birefringence vs. double refraction divergence

I am grateful to an individual who requested anonymity after asking for a specific clarification (case B.5) in my article 'Birefringence vs. double refraction divergence' (*J.Gemm.*, 2002, **28**(4), 223-6). I offer the following clarification as well as a correction to a typographical error in the references.

Reference 4 (p.226), "...instances where normal coincidence will yield no refraction" should read "...instances where normal incidence will yield no refraction".

On p.225 the final sentence in the paragraph before the Conclusions should say "...there are only two reversible directions of maximum double refraction divergence (max DD) for each optic axis!"

In the summary chart (p.225), the description for case B.5 that reads, "Two reversible directions equally oblique to both optic axes" should be changed to read, "Four reversible directions, two equally oblique to the optic plane at each optic axis".

Use of the term 'direction' in the above means wave-normal direction and not ray direction. Wave-normal coincides with ray direction when DD is nil, but is at a slight angle to at least one ray when there is DD.

Richard Cartier
Toronto, Canada

Abstracts

Diamonds

Gems and Minerals

Instruments and Techniques

Synthetics and Simulants

Diamonds

Les diamants de Guyane et le problème de la "Deuxième source".

R. Capdevila. *Revue de gemmologie*, 145/146, 2002, 61-5.

Discussion of the metamorphosed komatiites of the Dachine area of Guyana and their role as a diamond host. M.O'D.

La certification des diamants de type II.

J.-P. Chalain. *Revue de gemmologie*, 145/146, 2002, 37-9.

Type II diamonds pose some problems when certificates need to be issued. HPHT stones are discussed in this context. M.O'D.

Le Koh-i-Noor.

M.-E. Girard and D. Girard. *Revue de gemmologie*, 145/146, 2002, 30-5.

History of the Koh-i-Noor diamond with speculations on its origin and on the trade routes along which it may have travelled from its presumed Indian source which is shown on a map of Indian mines. M.O'D.

Noirs diamants bien incolore.

E. Gonthier and F. Roumet, *Revue de gemmologie*, 145/146, 2002, 74-7.

Discusses the possibility of some diamonds which appear black in portraits taking their colour from alterations over time of the pigments used. In the pictures under consideration the black colour is now assumed to be an accurate representation of the stones. M.O'D.

Un diamant noir exceptionnel: Le Vulcain.

C. Grobon, *Revue de gemmologie*, 145/146, 2002, 78-9.

A diamond of 178.88 ct has a natural black colour and has been named 'Le Vulcain'. The black colour is due to the presence of graphite and ferric iron compounds as inclusions and the stone is H- and N-rich.

Noirs diamants bien incolore.

E. Gonthier and F. Roumet, *Revue de gemmologie*, 145/146, 2002, 74-7.

Discusses the possibility of some diamonds which appear black in portraits taking their colour from alterations over time of the pigments used. In the pictures under consideration the black colour is now assumed to be an accurate representation of the stones. M.O'D.

Characterization and grading of natural-color pink diamonds.

J.M. King, J.E. Shigley, S.C. Guhin, T.H. Gelb and M. Hall. *Gems & Gemology*, **38**(2), 2002, 128-47.

The GIA Gem Trade Laboratory (GTL) has collected gemmological data on 1490 natural-colour pink gem diamonds, including both types I and II. There is some overlap in gemmological properties between these two types; they show differences in their colour ranges, UV fluorescence, absorption spectra and microscopic features. The colour description terminology used for pink diamonds in GIA GTL grading reports is discussed and illustrated with a fold-out colour chart with purplish-pink, pink and orangy-pink subdivisions. There is a separate discussion on the very rare red diamonds. R.A.H.

Gem Trade Lab notes.

T.M. Moses, I. Reinitz, S.F. McClure and M.L. Johnson (Eds). *Gems & Gemology*, **38**(1), 2002, 80-4.

Notes are given on a 1.55 ct oval diamond containing eclogitic inclusions (omphacite and garnet) and on only the second occurrence of a faceted 8.16 ct orange-red gem-quality genthelvite. R.A.H.

Traitement du diamant noir par graphitization "interne".

F. Notari. *Revue de gemmologie*, 145/146, 2002, 42-60.

Increasing numbers of black diamonds owing their colour to 'internal graphitization' have appeared on the markets in recent years. The diamonds so treated are of low quality and need to have many closed fractures and

Abstractors

R.A. Howie	R.A.H.	P.G. Read	P.G.R.
M. O'Donoghue	M.O'D.	E. Stern	E.S.

For further information on many of the topics referred to, consult *Mineralogical Abstracts*

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cavities in order that induced pyrolitic graphites are isolated from oxygen. Four methods of achieving a satisfactory black are outlined. M.O'D.

Star of the South: a historic 128 ct diamond.

C.P. SMITH AND G. BOSSHART. *Gems & Gemology* **38**(1), 2002, 54-64.

Star of the South, discovered in 1853, became the first Brazilian diamond to achieve international acclaim. This paper provides the first complete gemmological characterization of this 128.48 ct stone. The clarity grade is VS_2 and the colour grade Fancy Light pinkish-brown; it has the gemmological and spectroscopic characteristics of a type IIa diamond, including graining and strain patterns, UV–VIS–NIR and mid- to near-IR absorption spectra, and Raman photoluminescence. Khande Rao, Gaekwar of Baroda, had it mounted in a necklace also containing the 78.5 ct English Dresden from the same area in Minas Gerais, but it was sold in 2001 to owners who wish to remain anonymous, and was submitted to the Gübelin Gem Lab for a diamond grading report (hence this article). R.A.H.

Diamant, réalité fabuleuse.

G.S. TOLKOWSKY. *Revue de gemmologie*, 145/146, 2002, 66-8.
Short discussion and illustration of different styles of polishing diamonds originated by the author. M.O'D.

Gems and Minerals

Investigations and studies in jade. The Bishop collection.

H.R. BISHOP. *Bulletin of the Friends of Jade*, **10**, 2002, 27-158.

This text is a near-complete reprint of the text of a celebrated work published in 1906 and includes short papers by Kunz, Pirsson and others. The original book [Sinkankas 661] was published in two volumes and is very rare, only 100 copies having been printed. M.O'D.

Louisiana opal.

G. BROWN. *Australian Gemmologist*, **21**(6), 2002, 244-6, 6 colour illus., 1 map.

A unique variety of precious opal consisting of a light to dark sandstone cemented with precious opal has been found at Monks Hammock, central western Louisiana, USA. This deposit of opalised sandstone was originally discovered in the early 1990s, was worked as a commercial mining lease for about three years, fossicked intermittently, but has not been mined commercially since closure. Access to the deposit is no longer possible as it lies within the pine forest of the Bois Cascade Paper Company. Samples of this rare variety of opal can still be purchased on the internet. P.G.R.

Identification of some yellow-orange gemstones from Sri Lanka.

P.G.R. DHARMARATNE. *Gemmologie. Z. Dt. Gemmol. Ges.*, **51**(1), 2002, 41-6, 1 photograph, 2 tables, bibl.

Sri Lanka is a small country and gem dealers can visit the major gem mines and centres in a short time and thus come across most gem varieties found in the country. The more common varieties are bought for trade, but often the unidentified stones are purchased for their own collection. This paper discusses the contents of such a parcel of yellow-orange stones found over a large part of the island; there were seventeen varieties, including enstatite, heliodor, chrysoberyl, citrine, zircon, yellow sapphire, hessonite, spessartine, orthoclase, tourmaline, aventurine feldspar, danburite, apatite, scapolite and moonstone. E.S.

Liddicoatite tourmaline from Anjanabonoina, Madagascar.

D.M. DIRLAM, B.M. LAURS, F. PEZZOTTA AND W.B. SIMMONS. *Gems & Gemology*, **38**(1), 2002, 28-53.

Most of the remarkable polychrome specimens of liddicoatite with varied geometric patterns of zoning have come from the Anjanabonoina pegmatite in central Madagascar, mainly sold as polished slices or carvings. Liddicoatite has physical and optical properties that overlap those of elbaite, necessitating quantitative chemical analyses to distinguish these two species; both may occur in a single crystal. The most common internal features are colour zoning, strain patterns, partially healed fractures, feathers, needle-like tubes, negative crystals and inclusions of albite. Liddicoatite has also been reported from several other localities in the world; results of microprobe analyses for specimens from non-Madagascar localities are tabulated. R.A.H.

Identification of yellow cultured pearls from the black-lipped oyster Pinctada margaritifera.

S. ELEN. *Gems & Gemology*, **38**(1), 2002, 66-72.

Although the *Pinctada margaritifera* oyster is usually associated with the black pearls cultured in French Polynesia, it also can produce attractive large yellow cultured pearls, among other colours. An absorption feature at 700 nm can be used to distinguish these yellow cultured pearls from their more common counterparts produced in the area by the *Pinctada maxima*. This absorption feature has been attributed to the presence of black pigments and has been reported as an identifying characteristic of black cultured pearls from *Pinctada margaritifera*. An additional absorption feature in the UV region between 330 and 385 nm, is indicative of natural yellow colour in cultured pearls from the *P. margaritifera*. R.A.H.

Update on the identification of treated "golden" South Sea cultured pearls.

S. ELEN. *Gems & Gemology*, **38**(2), 2002, 156-59.

Most of the 'golden' South Sea cultured pearls in a single strand were found to exhibit unusual brownish-

orange fluorescence in long-wave UV radiation and atypical features at 405 and 558 nm. On this basis, and from visual examination, 33 of the 35 cultured pearls were identified as colour treated. This work shows how atypical absorption features, particularly in the blue region of the spectrum, can be used to positively identify colour treatment, even in the presence of the 330-85 nm UV absorption feature characteristic of natural-colour 'golden' pearls from *Pinctada maxima*. R.A.H.

Jade in British Columbia and Alaska and its use by the natives.

G.T. EMMONS. *Bulletin of the Friends of Jade*, **10**, 2000, 183-98 plus 4 pages in colour.

Reprint of a paper first published as no. 35 in the series *Indian notes and monographs* (New York Museum of the American Indian, Heye Foundation, 1923). M.O'D.

Mexican gem opals.

E. FRITSCH, M. OSTROOUMOV, B. RONDEAU, A. BARREAU, D. ALBERTINI, A.-M. MARIE, B. LASNIER AND J. WERY. *Australian Gemmologist*, **21**(6), 2002, 230-3, 7 black-and-white illus.

This paper, which includes nano- and micro-structure details of Mexican opals, origin of colour and a comparison with other common opals of gemmological significance, is based on a lecture presented to the XXVIII International Gemmological Conference, Madrid, Spain on 8 October 2001. The elementary building blocks of all but highly porous play-of-colour opal, hydrophane or cachalong are shown to be formed by small silica grains grouped as fibres, blades or larger spheres. The body colour in opal is generally due to inclusions, sometimes submicroscopic. For example, fire opal is coloured by nanometre-size fibres of an iron-containing compound. P.G.R.

The peculiarity of olivine from Sri Lanka.

G. GRAZIANI, L. MARTARELLI AND G. ZOYSA. *Gemmologie. Z. Dt. Gemmol. Ges.*, **51**(1), 2002, 29-39. 7 photographs, 1 map, 3 tables, bibl.

Although olivines are wide-spread, clear, transparent, yellowish-green peridot is much rarer. This paper deals with yellow-green to brownish-green stones found in Sri Lanka. Tests show that this magnesium-rich olivine has Mg/(Mg+Fe+Mn) ratios ranging from 0.77 to 0.85. Some dark crystals show a lot of inclusions, such as healed fractures, decrepitation haloes, fluorapatite, calcite, spinel group minerals, iron oxides and hydroxides, Mg-calcite, chrysotile and saponite. The data obtained seem to be consistent with olivine formation in a high-grade metamorphic environment. E.S.

Gemmologische Kurzinformationen. Cassiterit aus Bolivien.

U. HENN. *Gemmologie. Z. Dt. Gemmol. Ges.*, **51**(1), 2002, 50-1, photographs, bibl.

The author describes some botroyoidal laminated cassiterite from Bolivia. Originally found in Cornwall and Bohemia (Ore Mountains), it is now found in South East Asia, Africa and South America in Brazil and Bolivia. Cassiterite is pure tin oxide SnO_2, crystallizes tetragonally and has a hardness of 6.5, SG 6.95, RI 2.003-2.101, and birefringence 0.098. Some cassiterite is called 'wood tin' as its concentric composition is not unlike that of a tree. In the past it has sometimes been offered in the trade as petrified wood. E.S.

Gemmologische Kurzinformationen. Farbwechselnder Fluorit aus Indien.

U. HENN. *Gemmologie. Z. Dt. Gemmol. Ges.*, **51**(1), 2002, 52-4, 5 photographs, 1 graph, bibl.

The colour change fluorite offered to the author was an emerald cut weighing 75.44 ct. It was clear, transparent and changed from smoky brown in daylight to mauve in artificial light. SG 3.18, RI 1.432. The colour change is caused by an absorption in the yellow part of the spectrum with a maximum at 580 nm which is due to a colour centre. E.S.

Gemmologische Kurzinformationen. Schleifwürdiger Lithiophilit aus Brasilien.

U. HENN. *Gemmologie. Z. Dt. Gemmol. Ges.*, **51**(1), 2002, 47-9.

Gem-quality lithiophilite of a greenish-brown colour is found in the pegmatites of Minas Gerais, Brazil. RI 1.688-1.693, DR 0.005, SG 3.50, composition $Mn_{47}Fe_{53}$. The spectra show several absorption lines due to bivalent manganese and one broad band due to Fe^{2+}. E.S.

Burma Gazetteer. Myitkina District. Volume A, 1960.

W.A. HERTZ. *Bulletin of the Friends of Jade*, **10**, 2002, 159-78.

Useful reprint of a work covering the jade-producing Myitkina District of Burma (Myanmar) and including a useful bibliography of similar sources. [The British Library's Oriental and India Office Collections holds the finest coverage extant of this type of literature: a Reader's ticket is needed to use the Library and is not issued lightly.] M.O'D.

A note on nephrite etymology.

D.B. HOOVER. *Bulletin of the Friends of Jade*, **10**, 2002, 5-9.

Speculations on the origin of the noun nephrite draw upon classical and later sources. The word is believed to refer to a stone with curative powers in cases of kidney disorders or those of neighbouring parts of the body. M.O'D.

Sources of jade in Brazil.

D.B. HOOVER. *Bulletin of the Friends of Jade*, **10**, 2002, 11-18.

Results of a literature search for references to occurrences of the jade minerals in Brazil with some comments on the quality of the 28 sources listed in the bibliography. M.O'D.

Interesting American Opals: wood replacement.

J.I. KOIVULA AND M. TANNOUS. *Australian Gemmologist*, **21**(6), 2002, 242-3, 4 colour illus.

The four dark brown opalised wood cabochons that were examined all came from the Rainbow Ridge opal mine,

Virgin Valley, Nevada, USA. All four opals still showed in detail the banded structure of the original wood. Three of the cabochons showed streaks of precious opal that were the result of opal filling cracks in the original wood before it was opalised. P.G.R.

Gem News International.

B.M. LAURS (Ed.). *Gems & Gemology*, Vol. **38**(1) 2002, 86-106.

Mention is made of a new high-T treatment producing orange and yellow sapphires from a variety of coloured corundums; it seems that the diffusion of Be may be involved. Other items include red andesine from Congo, faceted and cabochon-cut green fluorites from the Rogerley mine in Weardale, black spinels from Mexico, faceted blue biaxial positive kyanite from Nepal, vivid green pargasite from China and a 6.80 ct six-rayed star emerald from Madagascar. R.A.H.

Gem News International.

B.M. LAURS (Ed.). *Gems & Gemology*, **38**(2), 2002, 170-86.

Brief details are given of diamond-bearing kimberlites in the province of Quebec, faceted cassiterite from the Viloco mine in Bolivia, cabochons from Brazil of emerald in a plagioclase matrix, sapphires reportedly from a new locality in Afghanistan, a tourmaline slice from Vietnam resembling Madagascar liddicoatite, bluish green zoisite from Tanzania and a 9.84 ct irradiated fluorite which appears deep blue in daylight and purple in incandescent light. R.A.H.

A survey of jade literature.

R. MERK. *Bulletin of the Friends of Jade*, **10**, 2002, 179-82.

Short bibliography of the jade minerals with comments on content and availability. M.O'D.

Gemmologie Aktuell.

C.C.MILISENDA. *Gemmologie. Z. Dt. Gemmol. Ges.*, **51**(1), 2002, 7-12, 6 photographs.

Short note on the origin determination of Paraíba tourmalines by working out the ratio between copper and structurally related trace elements which allow the separate identification of Nigerian and Brazilian copper-bearing tourmalines. A number of pinkish-orange corundums weighing between 1.5 and 4 ct have been offered on the market. The colour is the result of a heat treatment of pink sapphires from Madagascar. The thermal enhancement can be identified by altered crystal inclusions surrounded by expansion halos. Bicoloured beryls were recently mined in Tajikistan. A photograph shows a good blue-yellow sample weighing 13.81 ct, RI 1.570-1-578, SG 2.70. Some synthetic emerald druses have been produced in Russia by the flux method; they are clusters of synthetic emeralds grown on seed plates. E.S.

Update on Guatemala jadeite.

A. M. MILLER. *Bulletin of the Friends of Jade*, **10**, 2002, 3-4.

A mine in the Motagua River valley of Guatemala is reported to be producing outstanding lavender jadeite as well as multi-coloured varieties; pink, blue, yellow and white varieties have been found. A short description of the find and of the local geology is given. M.O'D.

Gem Trade Lab notes.

T.M. MOSES, I. REINITZ, S.F. MCCLURE AND M.L. JOHNSON (Eds). *Gems & Gemology*, **38**(2), 2002, pp.161-8.

Notes include details of a double-strand necklace of graduated diamond 'pearls', high-quality synthetic jade produced by General Electric, and cobalt-'diffused' sapphire. R.A.H.

Serendibite from Sri Lanka.

K. SCHMETZER, G. BOSSHART, H.-J. BERNHARDT, E.J. GÜBELIN AND C.P. SMITH. *Gems & Gemology*, **38**(1), 2002, 73-9.

Two samples (0.35 and 0.55 ct) of faceted serendibite from secondary deposits in Sri Lanka are described. The bluish-green to green-blue cut stones are similar in colour, physical and optical properties, and chemical composition to low-iron-bearing non-gem-quality serendibite from various other occurrences. The cut serendibites may be confused with sapphirine or zoisite, but can be distinguished by their refractive indices, twinning and spectroscopic features. Microprobe analytical results are reported. R.A.H.

New chromium- and vanadium-bearing garnets from Tranoroa, Madagascar.

K. SCHMETZER, T. HAINSCHWANG, H.-J. BERNHARDT AND L. KIEFERT *Gems & Gemology*, **38**(2), 2002, 148-55.

Spessartine-pyrope garnets from Tranoroa, 60 km SW of Bekily, S Madagascar, contain Cr_2O_3 0.68-0.75 an V_2O_3 0.35-0.51 wt.%. Despite having the elements often responsible for colour-change behaviour, these garnets show only a slight change in appearance from brownish-red in daylight to purplish-red in incandescent light. They contain characteristic inclusions of rutile needles and strain patterns causing anomalous double refraction. EPMA results, together with n and D are reported for six of these garnets and for a Cr-bearing spessartine ($spe_{88.46}$). R.A.H.

Gemmological study of corundum from Madagascar.

J. SHIDA. *Australian Gemmologist*, **21**(6), 2002, 247-52, 7 colour illus.

The most important variety of Madagascan corundum is sapphire, and as it is relatively inexpensive it is sometimes supplied to the market as sapphires from Myanmar, Sri Lanka and Kashmir. It is therefore of particular importance to a laboratory such as that of the GAAJ to be able to determine the country of origin of a sapphire. This paper also describes methods for discriminating natural coloured from heat treated Madagascan ruby and sapphire. The usefulness of laser tomography to assist in these discriminations is emphasised. P.G.R.

Nephrite in Brazil.

A.C. SIMOENS DA SILVA. *Bulletin of the Friends of Jade*, **10**, 2002, 19-26.

Description and discussion of greenish nephrite artefacts found in Brazil and manufactured by the ancient inhabitants of that country. M.O'D.

Spectroscopic properties of Möng Hsu ruby.

S. Siripaisarnpipat, T. Pattharakorn, S. Sanguanruang, N. Koonsaeng, S. Achiwawich, M. Promsurin and P. Hammungthum. *Australian Gemmologist*, **21**(6), 2002, 236-41. 2 colour, 1 black-and-white illus., 4 graphs, 1 table.

The electronic (UV-Vis) and infrared spectra of 140 Mong Hsu rubies were analysed to find any differences between unheated and heat-treated specimens. There were no significant changes in electronic spectra that would indicate heat treatment, but differences between infrared spectra of rubies that have and have not been heat-treated may be used as evidence of heat treatments in rubies. P.G.R.

Instruments and Techniques

Portable instruments and tips on practical gemology in the field.

E.W. Boehm. *Gems & Gemology*, **38**(1), 2002, 14-27.

Most purchases of gems or jewellery are made in environments that make it difficult to carry anything more than a loupe, a torch and a pair of tweezers. Practice with these and the addition of portable gemmological instruments described in this article should enable the buyer to develop the keen senses necessary to better ascertain the identity and quality of the material being considered. Descriptions are given of the darkfield loupe, the new London dichroscope, a long-wave portable UV lamp, a portable refractometer and a portable hardness kit. Practical tips are given on the use of all of these in the field. Common sense must dictate how a clue is applied; some tests will merely help narrow down the possibilities. R.A.H.

The magnetic index.

W. Wm. Hanneman. *Australian Gemmologist*, **21**(6), 2002, 234/5, 2 black-and-white illus., 1 graph, 1 table.

Figures obtained from B.W. Anderson's empirical formula for the magnetic pull of a gem material are tabulated against magnetic index readings produced by Hanneman using his magnetic index meter. This meter uses a combination of a vertically suspending nylon thread and a rare earth magnet to record the angle of rotation at which the gemstone breaks free of its magnetic attraction to the magnet. The scale of the meter is calibrated in terms of the sine of the angle of rotation multiplied by 100. The results, plotted against Anderson's readings for magnetic pull show a linear relationship between the two sets of figures. P.G.R.

Tri de diamants par les instruments de la DTC.

S. Lawson, *Revue de gemmologie*, 145/146, 2002, 69-71.

Appraisal by the Director of the Gem Defensive Projects group of DTC, a De Beers Group company, of the DiamondSure and DiamondView testing instruments devised by the Group. M.O'D.

Synthetics and Simulants

Zusammengesetzte Steine -eine aktuelle Betrachtung.

U. Henn. *Gemmologie. Z. Dt. Gemmol. Ges.*, **51**(1), 2002, 13-28. 20 photographs, bibl.

Due to the development in the production of synthetic stones and improvements in various treatments of gemstones, composite stones have been thrust into the background. However, there are many examples to be found in the market, which can be divided into four groups. (a) doublets and triplets as simulants of classical gemstones, (b) composite stones manufactured to protect materials of lower hardness by covering it with a harder substance, (c) composite stones made up of gem materials which occur in thick layers, or are more attractive in thin layers, and (d) assembled stones. Usually any unset, loose composite stone is easily recognized, while identification of a set composite needs greater care, although usually air bubbles in the adhesive layers between the stones and small colour alterations can be observed. E.S.

Recent observations of composite stones.

U. Henn. *Australian Gemmologist*, **21**(6), 2002, 253-7, 16 colour illus., 1 table

Daily work in a gemmological laboratory shows that the most frequently seen simulants of precious stones found in jewellery are Verneuil synthetic corundums and spinels, artificial glass and composite stones such as doublets and triplets. This paper provides descriptions and illustrations of classic, new and unusual composite stones seen at both the German Gemmological Association and the laboratory of the German Foundation of Gemstone Research in Idar Oberstein. P.G.R.

BOOK REVIEWS

Blood diamonds.

G. CAMPBELL, 2002. Westview Press. pp xxv, 251.

Survey in journalistic style of the political breakdown in Sierra Leone following the rise of the Revolutionary United Front (RUF) and the eventual arrival of the United Nations Mission in Sierra Leone (UNAMSIL). The chain of events parallels to some extent the recent history of Angola and the part played by Unita in that country.

The author suggests that the sale of smuggled rough diamonds for guns was the secondary cause of the breakdown and that the activities of the De Beers organization in West Africa were the primary or at least the underlying cause. As always it is not easy to disentangle truth from convenient fiction when citations are few and mostly to general media sources. Details of the way diamonds are handled by the De Beers organization are described in somewhat pejorative terms and the description of the author's adventures place him safely on the side of the angels. M.O'D.

The Snettisham Roman jeweller's hoard.

C. JOHNS, 1997. The British Museum London. pp 128, illus. in black-and-white. Hardcover ISBN 0 7141 2310 2. £34.

Silver jewellery and engraved gems form part of the hoard of Roman treasure found at Snettisham, Norfolk, England, in 1985. The hoard was acquired by The British Museum after careful application of the laws of Treasure Trove concluding with the statutory Inquest. The book deals with the archaeological context and the varied contents of the hoard including textiles and the container. The catalogue of the hoard occupies pages 75-120 and the study concludes with a bibliography and index. M.O'D.

Photographic guide to minerals of the world.

O. JOHNSEN, 2002. Oxford University Press, Oxford. pp 439, illus. in colour. Hardcover. ISBN 0 19 851568 5. £17.99.

This is easily the best illustrated guide to minerals to be published for some years. First published in Danish under the title *Minerales verden* by Gads Forlag in 1994, the book draws for its illustrations on the collections of the Geological Museum of the University of Copenhagen. While the really beautiful photographs catch and retain the eye, the text is equally worthy of respect: clearly written and giving just the right amount of information it makes the book the ideal beginner's guide and as it is in quite a small format (21 × 15 cm) it can accompany its owner to museums and mineral shows without discomfort or inconvenience.

The explanation of the simpler rules of crystal morphology is the best I have seen so far in a popular book. In the descriptive section chemical composition, crystallographic and chemical notes, names and varieties, details of occurrence and diagnostic features, are given for each species included. The size of specimens illustrated is also given. Diagrams illustrating crystals are provided in many cases. There are also some ball-and-stick diagrams, in colour, illustrating some of the commoner structures.

Anyone with an interest in minerals should get this book, even if they already have an extensive personal library. M.O'D.

Gemstone buying guide. 2nd edn.

R. NEWMAN, 2003. International Jewelry Publications, Los Angeles. pp 156, illus. in colour. Softcover. ISBN 0 929975 34 0. £14.50.

This is a book that should be at hand for everyone dealing with gemstones. As with all this author's publications, reviewed *passim* in *The Journal*, the text is concise, up-to-date and accompanied by very fine photographs, with price ranges for most of the major species. Enhancement and synthetic materials are described and there is a useful bibliography. This would be the ideal book for the beginner in gemmology as details of the simpler gemmological tests are given in a concise and lucid form. A great book. M.O'D.

Identification of gemstones.

M. O'DONOGHUE AND L. JOYNER, 2002. Butterworth-Heinemann, Oxford. xiv, 313 pp., illus in colour. Softcover. ISBN 0 7506 5512 7. £40.00.

In a style similar to that used in Michael O'Donoghue's *Synthetic, imitation and treated gemstones* (published by Butterworth-Heinemann in 1997) the authors have produced a work of reference which is packed with a mass of determinative information. The first chapter, however, is the only one which contains references to gem test instruments and their use, as it is argued that these subjects have been exhaustively covered in other gemmology textbooks. Instead, 23 of the following chapters contain identification information enabling the main inorganic and organic gem materials to be separated from their synthetic or imitation substitutes.

Natural and imitation glass have a chapter to themselves, and two more chapters deal with *Metals/ceramics and plastics*. Another chapter covers *Composite stones*, and three more deal with *Less common gemstones*, *Rarely fashioned gemstones*, and *Gemstones in their rough state*. The final four chapters are titled *How crystals are grown*, *Synthetics crystals for the collector*, *The enhancement of gemstones* and *Locality information*. Each of the gem chapters concludes with a section 'reports of interesting and unusual examples from the literature'. Here, the authors have gathered together a valuable hoard of information from articles, laboratory reports gem shows and their own personal gem observations to give the reader faced with a puzzling specimen the chance to

discover matching features among the more unusual gems described.

The book concludes with a glossary and *The literature of gemstone identification*. Although at first glance the many pages of unrelieved text may appear daunting (all the 60 colour plates illustrations are contained in two sections of four pages each) use of both the contents section and the index will quickly reveal a wealth of material to aid specific identification problems. A companion web page to the book is mentioned in the preface and on the back cover, and when eventually available will provide a useful method of updating the text. P.G.R.

Perlen.

ELISABETH STRACK, 2001. Rühle-Diebener-Verlag, Stuttgart, Germany. 696 pp, 657 illus. Hardcover ISBN 3 00 008636 6. Price on application.

This is a very well researched, comprehensive textbook on the history and development of the pearl industry up to the present time. Each chapter has its own bibliography and there are comprehensive indices to pinpoint any subject.

Roughly half of the book deals with natural pearls and their biological and physiological properties. The various geographical occurrences with the diverse characteristics of the pearls are described. There is a chapter on sweet [fresh] water pearls, mainly those found in Europe and North America. Pearls found in gastropods are not forgotten, especially abalone pearls which are described in detail. The market for and valuation of natural pearls is briefly described with the suggested values in DM. This part of the book finishes with quite an interesting survey of large and/or historical pearls or objects incorporating pearls ('Little Willie' is mentioned on p.306).

The second half of the book deals with cultured pearls. This is perhaps of greater interest to the commercial jeweller, who deals mainly with cultured pearls. It is comprehensive. The history as well as the geography and biology of these pearls are described. The grading systems are detailed and well arranged, but again, the valuation advice is in DM apart from the table of production and the one showing US $ prices from 1953-1998 (p.381).

The book finishes with a survey of available methods of examination, identification and differentiation between natural, cultured and imitation pearls. Methods of dyeing and other enhancement treatments are described. Care of pearls and nomenclature are mentioned. There is a register of useful addresses, although no UK addresses are given.

The illustrations are interesting and good, and the maps are comprehensive. For the serious gemmologist, this is an important book. E.S.

Myanma jade.

U NYAN THIN, 2002. Mandalay Gem Association [91(a) 77th St., Btn 26th and 27th St] Mandalay. pp 149. Illus. in colour. Softcover. Price on application.

This attractive and authoritative book was first published in Burmese and is especially welcome in English. After an introduction to Myanma jade, its properties and gemmological characteristics are discussed together with notes on simulants and how they may be distinguished. The marketing of jade is also described and the reader is told how dealers in the rough material assess the finest specimens. Appraisal and evaluation of finished pieces is also described.

The book now turns to the place of jadeite in the past and to the role of jadeite production in the history of Myanmar. The jade-producing regions of Myanmar are introduced with their locations quite closely stated and map coordinates given – the traveller could find them without too much difficulty. Their geology and the mode of working of particular deposits are also described.

Details of the way in which rough jade is sold will interest the reader – a diagram shows the way in which the dealers hold one another's fingers during negotiations over price. The book ends with tips for jade buyers: all kinds of useful hints are included, with the names and qualities of simulants given with identification points. There is a short bibliography.

In addition to the wealth of information there are many excellent colour photographs and the text is accompanied by advertisements which also show jade in a variety of colours. This is a charming and most useful book and throws light on an area of gemmology which has not been covered before in English. M.O'D.

NEW TITLES FROM GEM-A INSTRUMENTS

Identification of gemstones by M. O'Donoghue and L. Joyner **£40.00**

Gemstone buying guide (2nd edn) by R. Newman **£14.50**

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Proceedings of the Gemmological Association and Gem Testing Laboratory of Great Britain and Notices

Professor Dr Edward J. Gübelin

We send our congratulations to Professor Dr Edward J. Gübelin in celebration of his forthcoming 90th birthday.

Professor Gübelin has made a major contribution to gemmology during his extensive career and it is a pleasure to acknowledge his continuing involvement in the inspiring world of inclusions.

MEMBERS' MEETINGS

Gem-A Conference 2002

The Gem-A Annual Conference was held on Sunday 3 November at Kempton Park Racecourse. The Conference was followed on Monday 4 and Tuesday 5 November by visits to the DTC, a curatorial tour of the Jewels of JAR exhibition at Somerset House and a private viewing with David Thomas, the Crown Jeweller, of the Crown Jewels at the Tower of London.

A full report of the Conference was published in the December 2002 issue of *Gem & Jewellery News*.

London

On 25 October at 27 Greville Street, London EC1N 8TN, Joseph Tenhagen gave an illustrated talk entitled 'Emeralds of Colombia – a visit to the emerald mining districts of Colombia, South America'.

Midlands Branch

On 25 October at the Earth Sciences Building, University of Birmingham, Edgbaston, Alan Hodgkinson gave a talk entitled 'Tucson surprises – the highlights of Tucson 2002'.

On 7 December the Celebration 50th Anniversary Branch Dinner was held at Barnt Green.

North West Branch

On 16 October at Church House, Hanover Street, Liverpool 1, Rosemary McIver gave a talk entitled 'Jewels for a royal occasion'.

The Branch AGM was held on 20 November at Church House, at which Deanna Brady, Ray Rimmer and Elizabeth Franks were re-elected Chairman, Secretary and Treasurer respectively. The AGM was followed by a social evening.

Scottish Branch

On 15 October at the British Geological Survey, Murchison House, West Mains Road, Edinburgh, Joseph Bonnar gave a talk entitled 'Cameos and engraved gems: a history'.

On 19 November at the British Geological Survey Alan Jobbins gave an illustrated lecture on 'The British Crown Jewels'.

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DONATIONS

The appeal for donations to enhance membership and educational services has brought a good response, and the Council of Management would like to thank all those members who have contributed.

A list of those who have responded to the appeal will be published in the April issue of *The Journal*.

South East Branch

At the inaugural meeting of the South East Branch held on 8 December at Christie's, South Kensington, Colin Winter, Sally Everitt and Lawrence Hudson were elected Chairman, Secretary and Treasurer of the Branch respectively.

David Lancaster gave an illustrated talk entitled 'Gemstones at auction' and the meeting was followed by a private viewing of a jewellery sale being held at Christie's on 10 December.

South West Branch

On 17 November at the Bath Royal Literary and Scientific Institution, Queen Square, Bath, a practical afternoon was held to examine synthetic, imitation and treated gemstones under the title 'Trick or Treat?'.

OBITUARY

James (Jimmie) K. Cairncross FGA (D.1940), family jeweller of Perth, Scotland, died on 15 November 2002 at the age of 82. A tribute to him will be published in the April issue of *The Journal*.

Freda M.M. Parsons FGA, Bickley, Bromley, Kent, died recently.

ANNUAL GENERAL MEETING

The Annual General Meeting of Gem-A was held on 25 September 2002 at 27 Greville Street, London EC1N 8TN. Vivian Watson chaired the meeting and welcomed those present. The Annual Report and Accounts were approved.

Professor Alan Collins was re-elected President of the Association for the period 2002-2004. Noel Deeks was elected a Vice-President of the Association.

Ian Mercer, Jeffrey Monnickendam and Evelyne Stern were re-elected to the Council of Management. It was announced that Noel Deeks and Jean-Paul van Doren had resigned from the Council on 14 July 2002 and 22 November 2001 respectively.

Peter Dwyer-Hickey, John Greatwood and Laurence Music were re-elected to the Members' Council. Hazlems Fenton were re-appointed auditors.

Following the AGM, Stephen Kennedy gave a talk entitled 'Notes from the Laboratory: detection, disclosure and false description'.

PRESENTATION OF AWARDS

The Presentation of Awards gained in the 2002 examinations was held at Goldsmiths' Hall, Foster Lane, London EC2 on Monday 4 November. Professor Alan Collins, President of the Association, presided and welcomed those present, particularly students who had travelled from as far away as Canada, China, Hong Kong, India, Japan, Korea, Sri Lanka and the USA, as well as those from the UK and Europe. He announced that in January and June 2002 a total of 795 students had sat for the Preliminary and Diploma Gemmology and Gem Diamond Diploma examinations. A total of 184 students had qualified in the Gemmology Diploma examination and 123 in the Gem Diamond.

Professor Collins then introduced Noel Deeks, Vice-President of the Association, who presented the awards.

Noel Deeks delivered his address (see below) and a vote of thanks was given by Vivan Watson, who also thanked the Goldsmiths' Company for kindly permitting Gem-A to hold the ceremony at the Hall.

A Reunion of Members was held following the ceremony, attended by over 200 members and students.

Noel Deeks' address

"It has been a great pleasure for me to present the diplomas and awards this evening. Although it

GIFTS TO THE ASSOCIATION

The Association is most grateful to the following for their gifts for research and teaching purposes:

Sampat Singh Kothari, of Mumbai, India, for a collection of gemstones

David Pratt of Bradford, West Yorkshire, for ivory and other gem materials

Maria Sanchez of London for a Colombian emerald cabochon

Manfred Szykora of Munich, Germany, for two books about the old Hungarian opal mines: *Dubnicke opalove bane* by Semrad and Kovac, and *Dubnicky opal* by Barok and Semrad; also for copies of *extraLapis No. 23 – Beryl* and *extraLapis English No. 2 – Emerald*

Joseph Tenhagen of Miami, Florida, U.S.A., for a large collection of crystals and cut gems for use in education.

Included was a wonderful suite of natural emerald crystals of both geological and historical significance.

Joe is pictured below during his visit to London in October 2002 when he gave an illustrated talk to members entitled 'Emeralds of Colombia – a visit to the emerald mining districts of Colombia, South America'

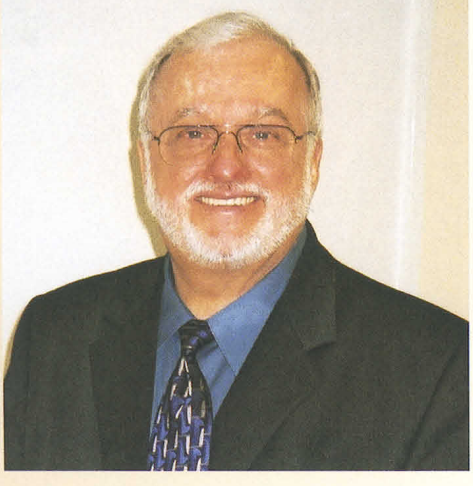

PROAPEX INC., TAIPEI, TAIWAN

Two stereo zoom microscopes donated by Jack Liao of Proapex Inc.

These microscopes were first used for the Gem-A's 'Family day' workshop held at Somerset House, and are now installed in the London Gem Tutorial Centre as part of the teaching equipment used by students studying the Association's gemmology courses.

PRESIDIUM INSTRUMENTS PTE. LTD. SINGAPORE

Five Presidium Multi Testers (pictured below) and five Presidium Gauges donated by Paul Yeo on behalf of Presidium Instruments Pte. Ltd.

These instruments are used by Gem-A students studying diamonds in the Diamond Diploma Course and the Six-day Diamond Certification Course.

is over thirty years since I clambered up these steps to receive my diploma, I can remember it as if it were yesterday, and so it will be for those of you who have made your way up these steps tonight, in this magnificent Goldsmiths' Hall. You will remember this event for many years to come.

"Everyone at Gem-A looks forward to the Presentation of Awards; it is a time when we congratulate all those who have been successful in the examinations, whilst the staff at Gem-A can enjoy the satisfaction of a job well done. On behalf of all the Officers of the Association, I would like to express very sincere thanks to all the staff of the Education Department, together with the lecturers, tutors and the many other people in the training centres, who have worked hard to make your achievements possible.

"Those of you who are holding that nice new diploma in gemmology for the first time, who are already Ordinary Members of the Association, will automatically become Fellows. If you are not currently a member of the Association, it will be necessary for you to apply for membership. You are only able to call yourself a Fellow and put the letters FGA after your name whilst you remain a fully paid up member, as is the case with many other professional people such as solicitors, accountants and doctors.

"In fairness, you should be warned that in recent years qualified gemmologists who have claimed to be an FGA have been challenged in the courts if their membership has lapsed. So make sure your membership is up-to-date at all times if you display your qualifications after your name, especially if you are appearing as an expert witness or giving an opinion in circumstances where your qualifications could be questioned.

"In exchange for your continued membership you will receive the full support of the Association, including the quarterly publications *The Journal of Gemmology* and *Gem & Jewellery News*, and discounts on instruments, books and regalia. You will also benefit from reduced fees for admission to lectures, workshops and the Annual Conference, and may use the Laboratory services for testing purposes when you feel the need for a second opinion.

"The Gemmological Association of Great Britain is the most senior association in the world. It was on 6 July 1908, at the National Association of Goldsmiths' annual conference in Manchester, that a gentleman by the name of Samuel Barnett proposed that courses and examinations in gemmology should be organized. The resolution was adopted, which prompted the birth of the NAG's Education Committee with Mr Barnett as

Prize winners from Jaipur, India. Noel Deeks awards the Anderson Medal to Neha Sehgal (left) and the Preliminary Trade Prize to Avneet Verma (right).

chairman. A gemmology course was prepared and teaching began, followed by the first examinations in 1913. The list of passes in that first year contained just six names. Top of the list was Samuel Barnett, the man that had sown the very first seed just five years earlier.

"It was not until 1931 that the Gemmological Association was formally inaugurated and holders of diplomas became eligible for Fellowship of the new Association. In 1938 the title of the Association was to change yet again to the Gemmological Association of Great Britain, and in 1947 it was incorporated under the Companies Act as an independent organization.

"The Association has from those early days always upheld very high standards in its teaching and examination. However, in many respects the science of gemmology is still quite young and is still moving forward at a very rapid pace.

"The vast amount of treatments that gemstones are subjected to today, especially diamonds in recent years, have made our work and yours that much more of a challenge. There is so much more to teach and for the students to assimilate compared to the more simple course in the earlier days. Instead of just a single course in gemmology, today we have a number of courses, some of which are highly specialized especially where diamonds are concerned. Much of the work needed to identify the existence of treatments now falls to the better equipped laboratories and hopefully some of you here tonight will aspire to this level of opportunity.

"We would claim, even with our high standards, not to have done much more than place your feet on the rungs of the learning ladder where serious gemmology is concerned. We have been told on a number of occasions by our members that they have a difficulty in understanding some of the more technical papers in *The Journal of Gemmology*. So even after qualifying there are still many things left for us to learn, in fact one has to almost run to keep up with changes that are constantly taking place, including the so-called 'improvements' applied to natural gemstones.

"I really came into the jewellery trade by accident. Having agreed to help a friend for just a few weeks to re-open a jewellers in 1946, I stayed with the company for 38 years. I had originally trained as an engineer and this was to have been my career. However, I also had a fair knowledge of watchmaking, as this had been my father's trade, and it was this that caused me to be side-tracked into the jewellery trade.

Prize winners at Goldsmiths' Hall. From the left, Liyana Arachchige from Kandy, Sri Lanka (Christie's Prize for Gemmology), Julian Read of Goole, East Yorkshire (the Deeks Diamond Prize) and Sally Hudson from London (the Anderson-ank Prize).

"For the first few years I spent most of my time in the workshops repairing clocks and watches. I was awarded Craft Membership of the Horological Institute in 1953 and it was this that helped to get me noticed. However, it was about this time that I realized that I was limited, to some extent by what I could do with just one pair of hands. So I moved from the workshops shortly after qualifying into the jewellery sales side of the business and not long after into management. Having arrived at the sharp end of the business, I was soon fascinated by gemstones and wanted to know more about them. This led me to the Gemmological Association and more studying followed by examinations and to several trips up these steps.

"This all happened just at the time when the Distributive Industries Training Board came into being. I soon found myself creating a new training department for the company and responsibility for over two thousand staff. I very much enjoyed this period of my working life and it convinced me that good training does bring its rewards.

"From time to time I have asked students the question, 'What are you going to do with your newly acquired qualification?' Not all of them have been too sure. The best advice I can give is *make it work for you*. Ensure that your employment allows you to use your knowledge as often as possible. You must be worth more to your employer, but conversely your employer will expect you to be more professional and earn more for him, as well as yourself. It should also help to get you noticed, possibly for promotion to a better job. You may have your own business; it should help you to expand your horizons and enhance your reputation. Whatever you do, make good use of your knowledge.

"Earlier I told you something of the beginning of the Gemmological Association. It would not be too difficult to write a substantial book on the history of such an organization, but that is not my intention tonight. However, it would be very remiss of me not to mention a very important addition that was added in 1990 and that is the Laboratory which has a very interesting history of its own. In the early 1920s the London Chamber of Commerce was under some considerable pressure to protect the status of the natural pearl business which was being seriously upset by the importation of cultured pearls from Japan. It was therefore decided that a testing station should be set up to distinguish natural pearls from cultured pearls. A laboratory was duly set up and was officially known as the Diamond, Pearl and Precious Stone Section of the London Chamber of Commerce and Industry. I wonder if they ever used the abbreviation DPPSSLCCI – it certainly makes GAGTL sound quite attractive! "It was fortunate for the London Chamber of Commerce that, in 1925, there was a young man with a recently acquired degree in chemistry and geology who was looking for employment. He was Basil Anderson, a name you will all know and one that did so much in the ensuing years to further the cause of gemmology. The diaries that were kept at the time reveal the long hours worked and the very considerable volume of items tested. In 1928 Basil Anderson tested no less than 49,000 pearls (using an endoscope) and many gemstones – a great achievement.

"Shortly after this in the late 1920s Basil Anderson was joined by another famous name – C.J. Payne. Later in the post war years Robert Webster and Alec Farn were added to the team. These four highly respected gemmologists worked together for 25 years during which time they tested thousands of pearls and gemstones. They also lectured on gemmology, were authors of a number of books which are still used as textbooks today, and also found time for research which included the development of the 1.81 contact fluid for the refractometer and much more.

"In 1990 the Gemmological Association parted from the NAG and merged with the Gem Testing Laboratory who occupied the third floor at 27 Greville Street. The Gemmological Association moved into the first floor which it shared with Gemmological Instruments Ltd. The following few years saw a rapid expansion of the Education Department in London, during which time we took over the second and fourth floors at Greville Street which are used as teaching floors. This has enabled the department to hold more regular classes both for gemmology and diamond students. This is in addition to the many students who are taught our courses in other London colleges.

"I trust that this very sparse potted history may help you to understand the work that has been carried out by a number of very dedicated people to help raise the gemmological standard of knowledge, not only in the UK but in many other countries as well.

"I have been heard to say on a number of occasions, 'Life is like a garden, you only get out of it what you are prepared to put into it.' I hope that some of you will become gemmological gardeners and play your part."

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The World 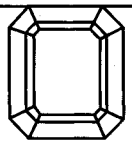 of Gemstones

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28 February	**Midlands Branch.** *Pearls of wisdom.* MICHAEL HOUGHTON
25 March	**Scottish Branch.** *Tucson surprises.* ALAN HODGKINSON
26 March	**North West Branch.** *Jewellery at auction.* RICHARD SLATER
28 March	**Midlands Branch.** *An auctioneer's lot is not a happy one.* STEPHEN WHITTAKER
6 April	**South East Branch.** *Tucson 2003.* ALAN JOBBINS, PETER WATES AND COLIN WINTER
25 April	**Midlands Branch.** Annual General Meeting followed by *The interface of gem and jewel.* JOHN WRIGHT

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21 May	**North West Branch.** *A jade tour.* IAN MERCER
18 June	**North West Branch.** *Crystal care.* WENDY SIMKISS
21 June	**Midlands Branch.** Midsummer Supper

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Guide to the preparation of typescripts for publication in *The Journal of Gemmology*

The Editor is glad to consider original articles shedding new light on subjects of gemmological interest for publication in *The Journal*. Articles are not normally accepted which have already been published elsewhere in English, and an article is accepted only on the understanding that (1) full information as to any previous publication (whether in English or another language) has been given, (2) it is not under consideration for publication elsewhere and (3) it will not be published elsewhere without the consent of the Editor.

Typescripts Two copies of all papers should be submitted on A4 paper (or USA equivalent) to the Editor. Typescripts should be double spaced with margins of at least 25 mm. They should be set out in the manner of recent issues of *The Journal* and in conformity with the information set out below. Papers may be of any length, but long papers of more than 10 000 words (unless capable of division into parts or of exceptional importance) are unlikely to be acceptable, whereas a short paper of 400–500 words may achieve early publication.

The abstract, references, notes, captions and tables should be typed double spaced on separate sheets.

Title page The title should be as brief as is consistent with clear indication of the content of the paper. It should be followed by the names (with initials) of the authors and by their addresses.

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Abbreviations for titles of periodicals are those sanctioned by the *World List of scientific periodicals* 4th edn. The place of publication should always be given when books are referred to.

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Cover Picture

Boulder with irregular dark-coloured zones of chrome chalcedony and light green relict serpentinite, the parent rock. Photo: J. Flint. (See 'A new chrome chalcedony occurrence from Western Australia', pp. 265-79.)

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Multi-star quartzes from Sri Lanka

Dr Karl Schmetzer[1] and Maximilian Glas[2]

1. *Taubenweg 16, D-85238 Petershausen, Germany*
2. *Theresienstr. 12, D-82319 Starnberg, Germany*

ABSTRACT: The patterns of intersecting light bands in multi-star quartzes from Galle, Sri Lanka, are described. Different groups of light bands form various types of networks consisting of numerous four-, six- and even eight-rayed stars. The orientations of needle-like inclusions, the axes of which are perpendicular to these light bands, have been determined. The most common type of a multi-star network is caused by two groups of nine (three plus six) symmetry equivalent sets of inclusions forming nine intersecting light bands. Up to five different groups of inclusions forming 18 intersecting light bands may be present in quartzes with more complex multi-star networks.

Introduction

Asteriated quartz, especially rose quartz, has been known for more than a century. Samples cut as cabochons or as complete spheres, in general, reveal a single six-rayed star which is caused by three sets of needle-like inclusions that are orientated parallel to the basal plane (see e.g. Goldschmidt and Brauns, 1911; Kalkowsky, 1915). The centre of this star is coincident with the *c*-axis of the quartz crystals. Rarely, twelve-rayed stars are also observed in quartz or rose quartz (Cassedanne and Roditi, 1991; *Figure 1*). Occasionally, complete spheres of rose quartz show additional, mostly weak light bands that are not related to the six-rayed or twelve-rayed centre star. These light bands are due to various groups of needle-like inclusions in different orientations in the host crystal (Kalkowsky, 1915; Maier, 1943; von Vultée, 1955). Speaking simply about asterism of cabochon-cut gemstones or of

Figure 1: *Sphere of very lightly coloured Brazilian rose quartz revealing twelve-rayed asterism. The diameter of the sphere is 55 mm, weight 279 g.*

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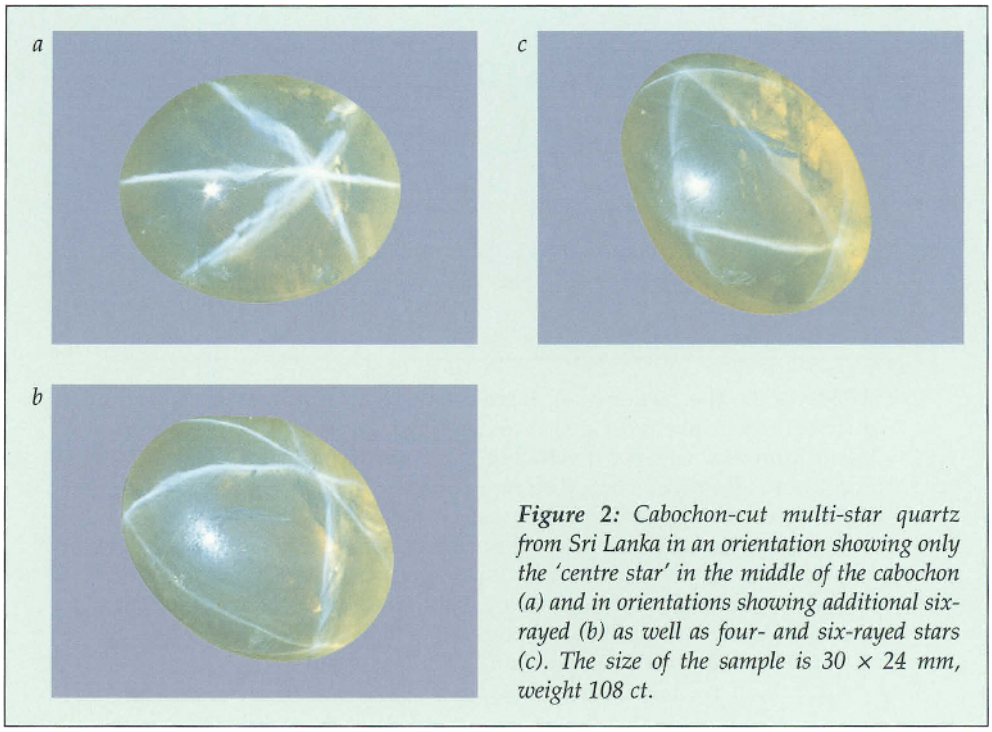

Figure 2: Cabochon-cut multi-star quartz from Sri Lanka in an orientation showing only the 'centre star' in the middle of the cabochon (a) and in orientations showing additional six-rayed (b) as well as four- and six-rayed stars (c). The size of the sample is 30 × 24 mm, weight 108 ct.

samples cut as a complete sphere, we normally describe observations in reflected light. This type of asterism is also called epiasterism. In contrast, asterism observed in transmitted light is called diasterism (see e.g. Kalkowsky, 1915; Maier, 1943; Fryer *et al.*, 1981).

Multi-star quartzes, i.e. quartzes that reveal more than one single star on the surface of a cabochon or a quartz sphere, on the other hand, are quite rare (*Figure 2*). Samples have been briefly described from Sri Lanka (Fryer *et al.*, 1984; Kumaratilake, 1997; Johnson and Koivula, 1999), from Alabama, USA (Fryer *et al.*, 1985) and from California, USA (Koivula and Kammerling, 1990). According to these descriptions, multi-star quartzes show either a six-rayed or a twelve-rayed star with a network of several additional six- and four-rayed stars. A schematic drawing of Kumaratilake (1997) shows a network of six-rayed stars, but the position of the four-rayed stars within this network is not indicated and the position and orientation of the different six-rayed stars relative to the quartz crystal structure is not known. The cause and orientation of multi-stars in other minerals, especially in spinel and garnet, on the other hand, is well understood (Switzer, 1955; Kumaratilake, 1998; Schmetzer *et al.*, 2002).

Specimens

For the present study, the authors obtained 32 cabochon-cut asteriated quartzes from different private collections. Some of these samples were originally bought on various occasions in trade fairs and were said to originate from Sri Lanka, and some were bought directly in Sri Lanka. The samples range from 2 to 108 ct in weight. In addition, one rose quartz cabochon of 12 ct that was studied also comes, most probably, from Sri Lanka. Asteriated quartzes from Sri Lanka originate from alluvial deposits at the village of Panchaliya near the town of

Dikkumbura, about 15 km east of the city of Galle. The local people call the stone 'Kiri palingu' which means milky quartz (D. Kumaratilake, W. Molligoda, P. Entremont and G. Zoysa, pers. comm., 2002).

All cabochons were originally cut with curved upper and lower surfaces and a small flat base. In general, only the upper halves of these cabochons were polished. In order to examine the complete star network of some samples, six cabochons were recut in Germany as complete spheres and polished over the whole surface.

Visual appearance and macroscopic observation

Although diasterism in transmitted light shows a number of interesting and sometimes complex phenomena (*Figure 3*), we shall refer in the following part only to epiasterism, i.e. to observations in reflected light, simply called asterism.

A minority of six samples revealed only a six-rayed 'centre-star' and some weak to very weak additional light bands, but no complete star network (*see Figure 8a*). The majority of 20 samples as well as the rose quartz cabochon, on the other hand, showed an identical complete three dimensional star network, consisting of:

(a) A six-rayed star, the centre of which was observed in a view parallel to the three-fold axis (*c*-axis) of the quartzes (*Figure 4a*).

(b) Following the arms of these stars from the centre to the rim, on each of the six

Figure 3: Diasterism of a multi-star quartz from Sri Lanka cut as a complete sphere with different orientations (a, b and c) of the sample relative to the transmitted sunlight. The diameter of the sphere is 18 mm, weight 41 ct.

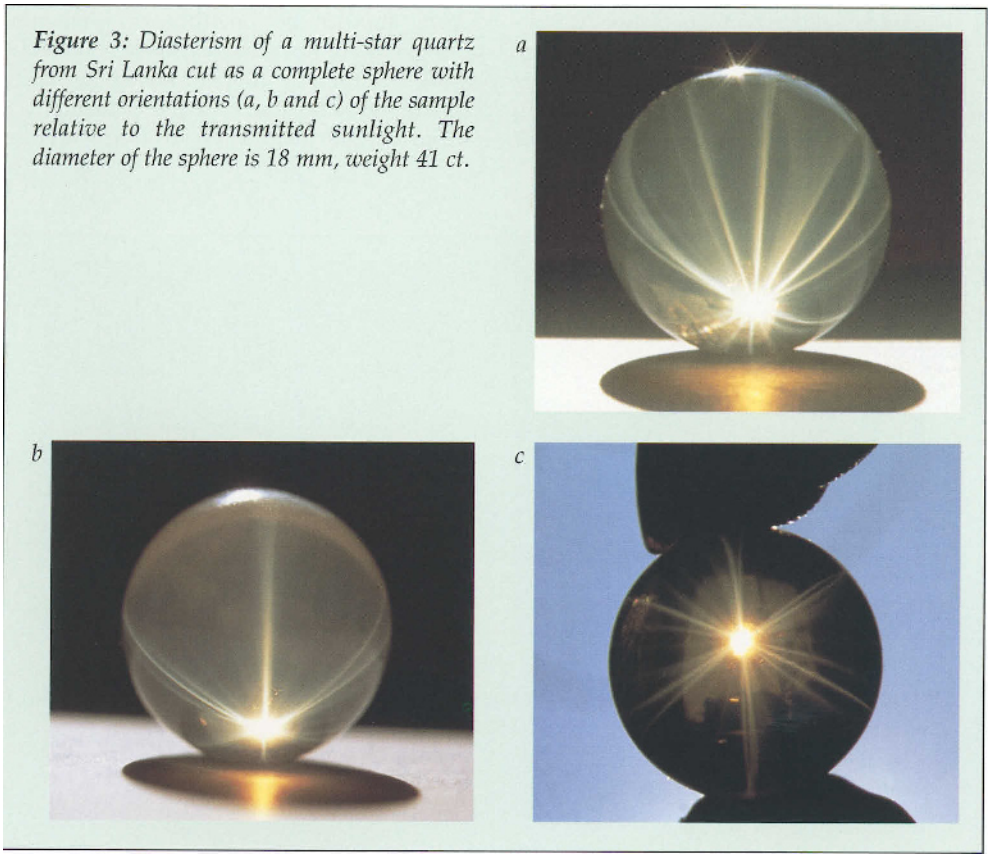

arms of these 'centre stars' one six-rayed 'middle star' (*Figure 4b*) and one six-rayed 'outer star' (*Figure 4c*) were observed; occasionally the 'middle stars' as well as the 'outer stars' were formed by one more intense light band (the light band of the 'centre star') intersecting with two somewhat weaker light bands, that were not part of the 'centre star'.

(c) The light bands or arms forming the six-rayed 'middle stars' and the six-rayed 'outer stars' intersect and form numerous four-rayed stars (*Figure 4d*).

(d) The arms of the so-called 'centre stars', 'middle stars' and 'outer stars' are connected to each other, in that way forming a three-dimensional network of six-rayed and four-rayed stars (*Figure 4e, f*). The whole network on the surface of a complete sphere consists of two 'centre-stars' (one upper and one lower star), twelve 'middle stars' (six on the upper and six on the lower part of the sphere) as well as six 'outer stars' the centres of which are located at an angle of 90° to the *c*-axis, i.e. perpendicular to the three-fold axis of the quartzes. In addition, six four-rayed stars are located on the upper and six four-rayed stars are located on the lower half of a cabochon or sphere. Thus, the network normally seen on a complete sphere consists of 20 (two 'centre stars' plus twelve 'middle stars' plus six 'outer stars') six-rayed stars and of twelve (six upper and six lower) four-rayed stars (*see Figure 8b*). On the upper (polished) half of a cabochon, as seen normally in the trade, seven (one 'centre star' plus six 'middle stars') six-rayed and six four-rayed stars are observable, and on samples with more or less polished girdles, the six 'outer stars' (or at least part of these stars) are also observable.

It should be mentioned, that the orientation of the cabochons was not always with a 'centre star' more or less in the centre of the curved surface of the cabochon. In some samples, we observed an orientation

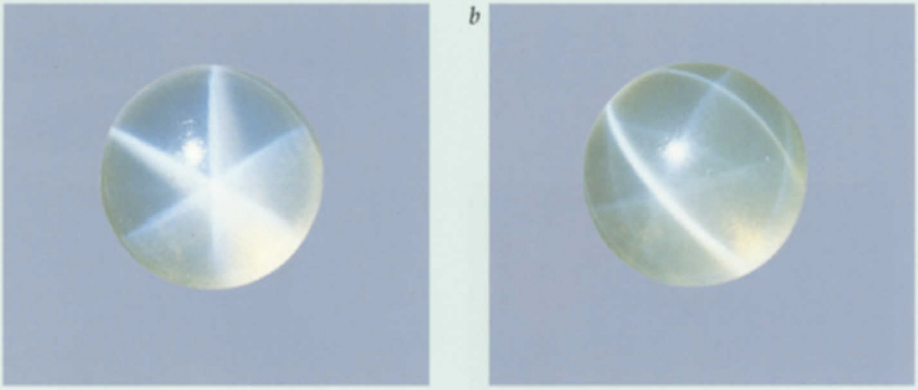

Figure 4: *Asterism of a multi-star quartz from Sri Lanka cut as a complete sphere with different orientations of the sample relative to the illuminant:*
(a) six-rayed 'centre star' consisting of three intersecting light bands of almost identical intensity;
(b) six-rayed 'middle star' consisting of one more intense and two less intense light bands;

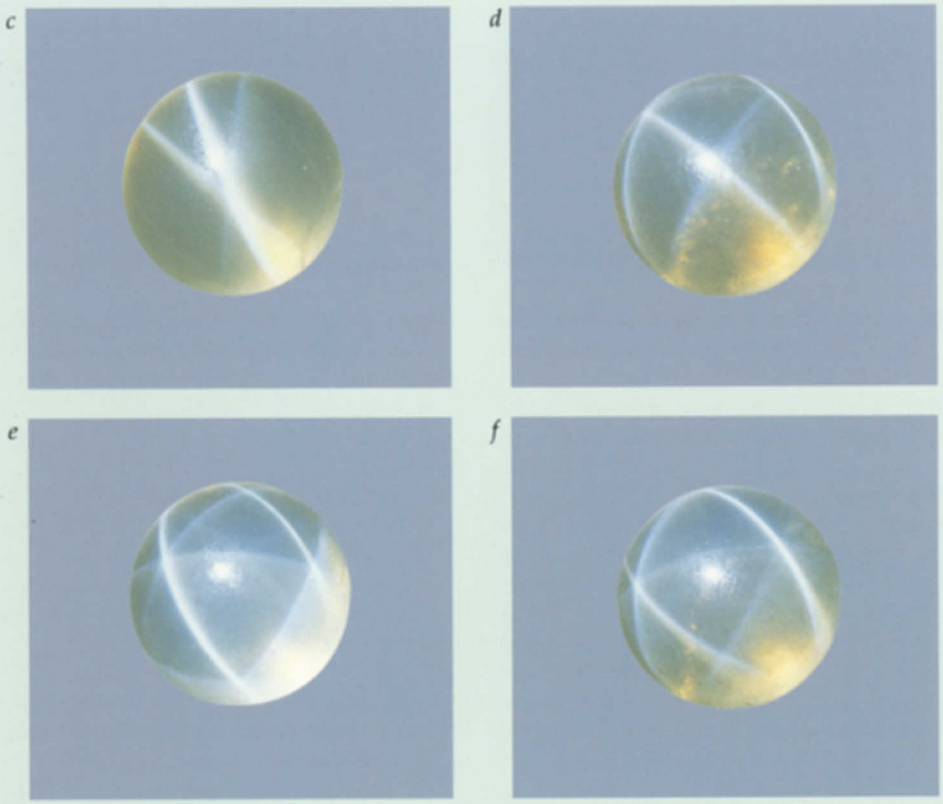

(c) six-rayed 'outer star' consisting of one more intense and two less intense light bands;
(d) four-rayed star consisting of two intersecting light bands;
(e) three-dimensional network of six- and four-rayed stars, in this orientation three six-rayed and one four-rayed stars can be seen;
(f) three-dimensional network of six- and four-rayed stars, in this orientation two six-rayed and one four-rayed stars can be seen. The diameter of the sphere is 18 mm, weight 41 ct.

with one of the 'middle stars' in the centre of the cabochon or with other orientations (*Figure 5*).

In six samples, the 'centre star' revealed more than six, i.e. eight, ten or twelve arms. These stars consist of four, five or six light bands intersecting at angles of 30° or 60°, respectively. Three samples show an eight-rayed star (*Figure 6*), in one quartz the 'centre star' had ten arms (*Figure 7*) and in two quartzes, twelve-rayed stars consisting of eight more intense arms and four weak to very weak arms were observed. No star quartzes with twelve arms of identical intensity were found in the 33 samples.

Comparable to the variable intensity of the light bands forming the eight-, ten- or twelve-rayed 'centre stars', additional light bands of variable intensity forming 'middle stars' and 'outer stars' are also present in these six samples (*Figure 7*). Some of these light bands are extremely weak.

Figure 5: Cabochon of a multi-star quartz from Sri Lanka with an orientation of the c-axis oblique to the centre of the sample; in this orientation two six-rayed and one four-rayed stars can be seen. The size of the sample is 10 × 9 mm, weight 4 ct.

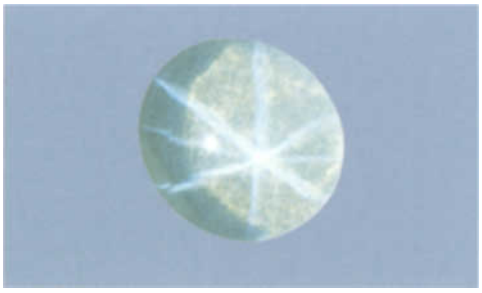

Figure 6: Asterism of a multi-star quartz from Sri Lanka cut as a cabochon with an eight-rayed 'centre star'. The size of the sample is 15 × 14 mm, weight 20 ct.

Consequently it was difficult to establish a general scheme for the three dimensional star network in samples with 'centre stars' formed by more than three light bands. Following the arms of these eight-, ten- or twelve-rayed 'centre stars' from the centre towards the rim of the cabochon, four-, six- or eight-rayed 'middle stars' are observable. Three types of multi-star networks were found:

(I) In addition to the network described in (a) to (d) above, one, two or three additional light bands through the 'centre stars' were observed in three samples. On each of these additional arms through the 'centre star', one four-rayed and one six-rayed star is located (*see Figure 8d*).

(II) In addition to the network described in (I) above, three additional light bands which do not intersect the middle of the centre star are present in one sample. As a consequence, on three of the six more intense arms belonging to the 'centre

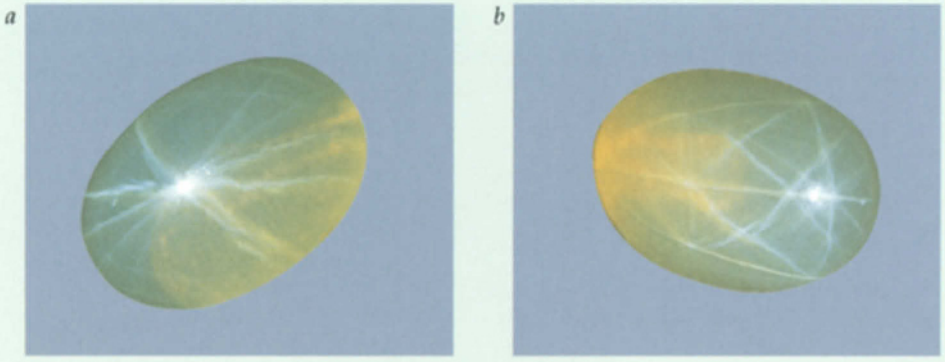

Figure 7: Asterism of a multi-star quartz from Sri Lanka cut as a cabochon with a ten-rayed 'centre star' in different orientations of the sample relative to the illuminant: (a) ten-rayed 'centre star'; (b) complex network of numerous four-, six- and eight-rayed stars. The size of the sample is 19 × 14 mm, weight 23 ct.

star', two six-rayed 'middle stars' are observed. On the remaining three of the six more intense arms belonging to the centre star one four-rayed and one six-rayed 'middle stars are observed. On the other six sometimes weaker arms of the 'centre star', two six-rayed stars are observed. At the rim of the cabochon, i.e. at an angle of 90° to the centre, the light bands of the 'centre star' intersect with the light bands of the 'middle stars' and form either one six-rayed or one four-rayed 'outer star'.

Again, the light bands or arms forming the 'middle stars' and the four- and six-rayed 'outer stars' intersect and form numerous four-rayed stars (*see Figure 8e*).

(III) In addition to the network described in (I) above, six light bands which do not intersect the middle of the centre star are present in two samples. As a consequence, on each of the six more intense arms belonging to the 'centre star', one four-rayed and two six-rayed 'middle stars' were observed. On the other sometimes weaker arms of the 'centre star', one eight-rayed and one six-rayed 'middle star' were present. All 'outer stars' on the arms of the 'centre star' consist of six arms in this type of multi-star quartz. Again, the light bands or arms forming the four-, six- and eight-rayed 'middle stars' and the six-rayed 'outer stars' intersect and form numerous four-rayed stars (*see Figure 8f*).

Some samples also contain additional weak to very weak light bands which do not belong to the general networks described so far.

Microscopic observation

With the magnification of the ordinary gemmological microscope (up to 100×), in general, only healing fissures were observed, and no oriented needle-like inclusions were seen.

Formation of the multi-star networks

Asterism, in general, is caused by orientated needle-like inclusions in various mineral species. Four-, six- or eight-rayed asterism is caused by two, three or four sets of intersecting needle-like inclusions. Each set of inclusions causes a light band with an orientation perpendicular to the commonest axial direction of the needles. Without preparation of thin sections and additional examination by microanalytical techniques, e.g. electron diffraction, it is impossible to determine the exact nature of the inclusions in quartzes from Sri Lanka causing the multi-star networks.

The most common needle-like inclusions in quartzes, especially in rose quartz revealing asterism, are rutile needles of microscopic to submicroscopic size, in numerous orientations (Goldschmidt and Brauns, 1911; Kalkowsky, 1915; von Vultée, 1955, 1956). In a six-rayed asteriated quartz from Sri Lanka, the presence of three sets of orientated submicroscopic sillimanite needles was determined by electron diffraction (Weibel *et al.*, 1980; Woensdregt *et al.*, 1980). Randomly distributed dumortierite needles, on the other hand, have been found in rose quartzes from different sources (Applin and Hicks, 1987; Goreva *et al.*, 2001; Ma *et al.*, 2002).

The different types of needles observed in multi-star quartzes from Sri Lanka and their crystallographic orientation in the quartz hosts are summarized in *Table I*. These different orientations are drawn in *Figure 8a* to *f* and examples for multi-star networks consisting of numerous intersecting light bands are also given in *Figure 8b* to *f*.

A normal six-rayed star consisting of three light bands intersecting at angles of 60° to each other is due to one group of three sets of oriented needle-like inclusions. Considering the trigonal symmetry of quartz (crystal class D_3 or 32) with one three-fold

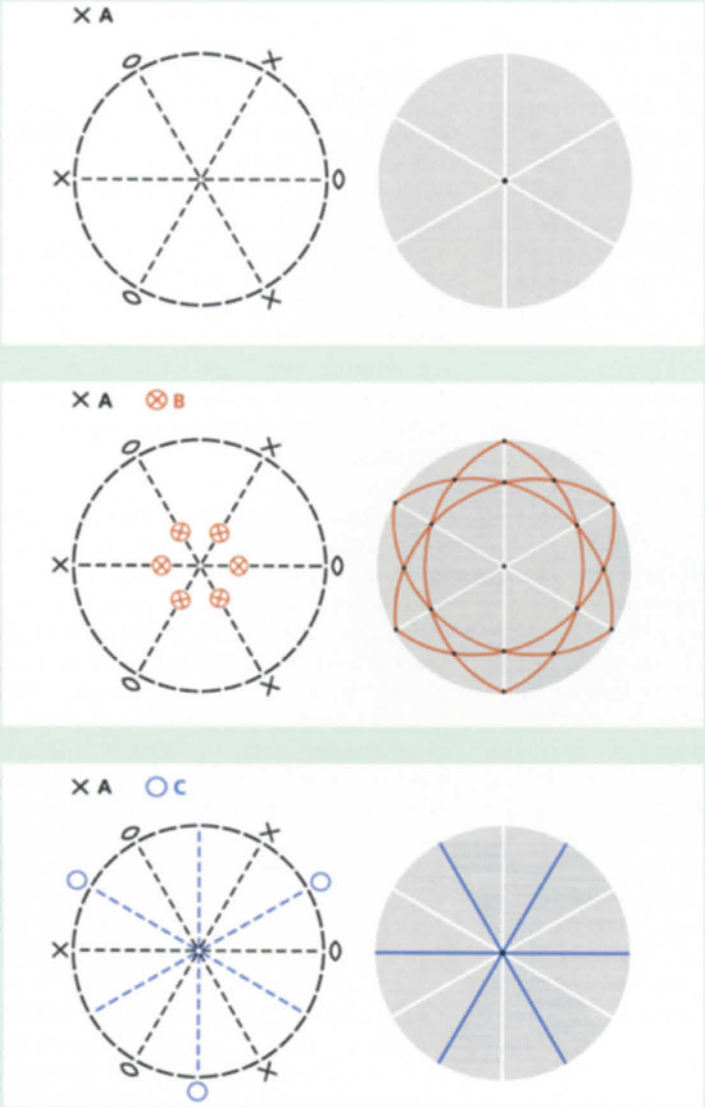

Figure 8: *Stereographic projection of oriented needle-like inclusions (left) and light bands of multi-star networks in quartz from Sri Lanka (right, only the upper hemispheres of the projection spheres are drawn); five different groups of needle-like inclusions were found to occur in asteriated quartzes from Sri Lanka; two groups of needles (designated as groups A and C) are oriented perpendicular to the c-axis; one group of needles (designated group B) is inclined at an angle of 24.4° to the c-axis, two groups of needles (designated as groups D and E) are inclined at an angle of 27.6° to the c-axis; the centres of the stars are indicated by black dots:*

(a) one group of needles (A, three light bands) forms a six-rayed star;

(b) two groups of needles (A, three light bands, and B, six light bands) form the most

d

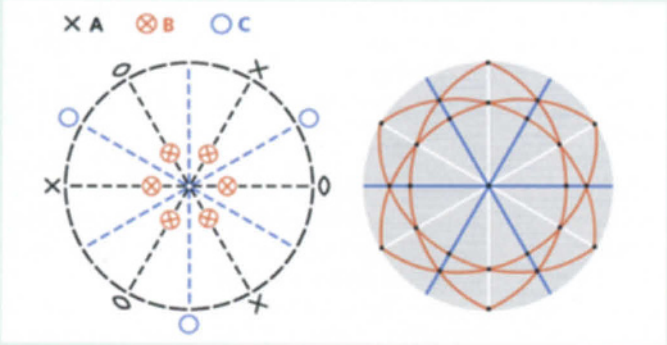

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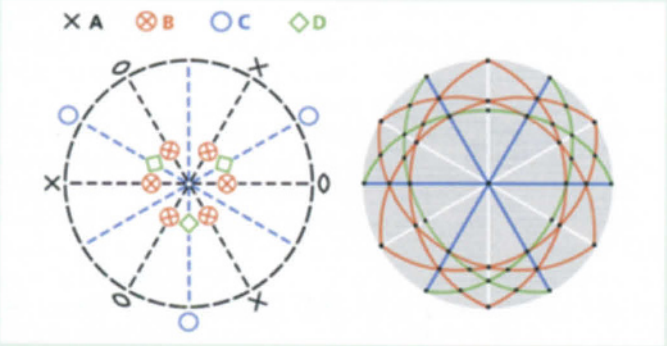

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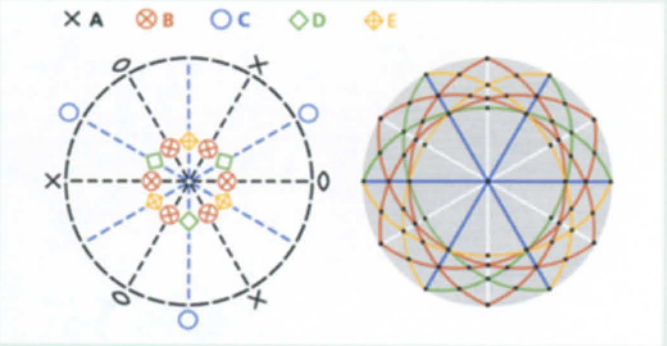

commonly observed multi-star network consisting of 20 six-rayed and 12 four-rayed stars;

(c) two groups of needles (A and C, three light bands each) form a twelve rayed star;

(d) three groups of needles (A, three light bands, B, six light bands, and C, three light bands) form a more complex multi-star network;

(e) four groups of needles (A, three light bands, B, six light bands, C, three light bands and D, three light bands) form a more complex multi-star network;

(f) five groups of needles (A, three light bands, B, six light bands, C, three light bands, D, three light bands and E, three light bands) form a more complex multi-star network.

axis parallel to the *c*-axis and three two-fold axes perpendicular to the *c*-axis, it is evident, that an ordinary six-rayed star is caused by three sets of inclusions (designated as group A) with an orientation perpendicular to the *c*-axis (*Figure 8a*).

According to the orientation of light bands that are not part of the 'centre star' of the multiple star network in quartz from Sri Lanka, it is estimated that the different sets of inclusions causing these light bands are oriented with an inclination of about 20° to 30° to the *c*-axis of the quartz crystals. With this approximation, we first tried to solve the problem graphically. Using the stereographic projection, a quick overview of the number, type and orientation of stars is obtainable. With this means it became evident, that the 'ordinary' network observed most frequently and described above under points (a) to (d) is explained by two groups of oriented needle-like inclusions (*Figure 8b; see Table I*):

(A) A first group consisting of three sets of needles that are oriented perpendicular to the *c*-axis forming an angle of 60° to each other.

(B) A second group consisting of six sets of needles that are inclined at about 20° to 30° to the *c*-axis; in addition, two sets of these needles belonging to group B are always in one plane together with one set of needles from group A.

The nine (three plus six) light bands perpendicular to these nine (three plus six) sets of needles from groups A and B form the complete three-dimensional multi-star network that is frequently observed in our samples from Sri Lanka (*Figure 8b*).

A twelve-rayed star in trigonal minerals is due to two groups of needles, each of which consist of three sets of parallel inclusions that are related to each other by 30° rotation about the *c*-axis (*Figure 8c*). This situation is observed in twelve-rayed star sapphires (see e.g. Weibel, 1985; Schmetzer and Glas, 2001).

Table I: Asterism in quartz from Sri Lanka.

Designation of needles	Crystallographic orientation [uvow]	Inclination of the needle axis to the quartz *c*-axis	Angle of light bands relative to the *c*-axis	Number of symmetry equivalent directions = number of symmetry equivalent sets of needles	Remarks
Group A	$[1\,\bar{2}\,1\,0]$	90°	0°	3	common
Group B	$[1\,\bar{2}\,1\,6]$	24.4°	65.6°	6	common
Group C	$[1\,\bar{1}\,0\,0]$	90°	0°	3	rare
Group D	$[1\,\bar{1}\,0\,3]$	27.6°	62.4°	3	very rare
Group E	$[1\,0\,\bar{1}\,3]$	27.6°	62.4°	3	very rare

Combinations observed in samples in this study:

A: common; six samples

A+B: common; twenty samples and one rose quartz

A+B+C: rare; three samples

A+B+C+D: very rare; one sample

A+B+C+D+E: very rare; two samples

Note added in proof: In addition, a quartz specimen from Sri Lanka with a combination of A+B+D+E has been recorded.

All samples described under point (I) revealing 'centre stars' with eight, ten or twelve arms consist of the already described first and second groups of needles (groups A and B) and a third group consisting of three sets of needles, designated as group C.

(C) As already described for sapphires (Schmetzer and Glas, 2001), this group consists of three sets of needles that are oriented perpendicular to the *c*-axis forming an angle of 60° to each other; in addition, group C is related to the needles of group A by 30° rotation about the *c*-axis (*Figure 8d*). The light bands belonging to the needles of group C intersect with the light bands related to the needles of group B, thus forming the additional four- and six-rayed 'middle stars'. Twinning according to one or both of the common twin laws found frequently in quartzes, i.e. the Dauphiné and the Brazil laws (see e.g. Frondel, 1962), cannot be responsible for the formation of asterism with eight-, ten- or twelve-rayed 'centre stars' because these twin laws are not related to a 30° rotation about the *c*-axis. According to the different intensities of the three light bands caused by the three sets of needles of group C, it is evident that the number of needles in the three symmetry equivalent directions is not identical. The cause of this phenomenon which is observed in all six samples with eight-, ten- or twelve-rayed 'centre stars' is not known; it may or may not be related to twinning in these samples.

The networks in the three samples described above under points (II) and (III) revealing 'centre stars' with eight, ten or twelve arms and additional light bands not related to the needles of groups A, B and C is more difficult to explain. According to the fact that no exact measurements of the angles of inclusions and the angles of light bands relative to the *c*-axis were performable for our cut samples, we calculated those angles determined for various sets of needles in quartzes in thin sections by von Vultée (1955, 1956) by means of a universal stage. Only three of his twelve groups revealed angles in the range of 20° to 30° as roughly determined for our samples, namely three groups of needles with angles of 24.4°, 27.6°, and 27.6°, respectively. According to the orientation of these needles relative to the quartz lattice, these three groups of needles should consist of six sets at 24.4°, or of three sets at 27.6° or of another three sets of needles at 27.6°, respectively. Plotting the light bands of the six sets of needles of group B according to an inclination angle of the needles of 24.4° together with the light bands for three sets of needles with an inclination of 27.6°, yielded a star network which was consistent with our visual observations in one sample (*Figure 8e*). Consequently, it may be concluded that group:

(D) consists of three sets of needles with an inclination of 27.6° to the *c*-axis and group B consists of six sets of needles with an inclination of 24.4° to the *c*-axis. The light bands belonging to the needles of group D intersect with the light bands related to the needles of groups A, B and C, thus forming additional six-rayed 'middle stars' as well as the additional four-rayed 'outer stars'. Plotting three additional light bands of a fifth group of needles designated.

(E) with an angle of 27.6°, the full network of four-, six- and even eight-rayed stars observed so far in two samples is obtained (*Figure 8f*). This last group of needles of group E is related to the needles of group D by rotation through an angle of 60° about the *c*-axis.

Consequently, all observed networks are consistent using the well established orientations for five groups of needle-like inclusions as determined by von Vultée (1955, 1956) in thin sections of quartzes. A summary of all observed types of multi-star quartz networks as well as all calculated

angles together with the exact crystallographic orientations of the needles is given in *Table I*. Using the angles determined by von Vultée (1955, 1956) as a model for the orientation of three groups of needles of our groups B, D and E, which could not be determined directly in our samples, the number and sequence of four-, six- and/or eight-rayed stars observed in the complex multi-star network of some samples is understandable.

Conclusions

Various types of multi-star networks observed in quartzes from the Ratnapura District, Sri Lanka, are explained by the presence of up to five different groups of needle-like inclusions, each group consisting of three or six sets of symmetry equivalent directions for the needle axes. The frequently observed type of multi-star network consists of nine intersecting light bands caused by two groups of nine (three plus six) sets of needle-like inclusions. In more complex patterns of star-networks with eight-, ten- or twelve-rayed 'centre stars', up to five groups of 18 (three plus six plus three plus three plus three) sets of needles may be present, thus causing 18 intersecting light bands with numerous four-, six- and eight-rayed stars.

Acknowledgements

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Horse-tail inclusions in demantoid garnet from Val Malenco, Italy

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ABSTRACT: Gem-quality bottle-green demantoid garnet from Val Malenco, northern Italy, may contain fibrous hair-like inclusions. Previously described as byssolite (tremolite-actinolite-amphibole), powder X-ray diffraction and electron microprobe analyses show the inclusions to be chrysotile-serpentine and confirm a previous report by Gübelin (1993). Although the presence of chromium in demantoid may be a primary cause of colour, our observations and data indicate that the intensity variations of the green-hue is related to variable density of green-brown chrysotile inclusions.

Introduction

Demantoid is the name given to bottle-green andradite members of the garnet group of minerals. The name, demantoid, is derived from the Dutch word *demant* which means diamond. These garnets are 'diamond-like' because of their impressive yellow-orange dispersion. This variety of garnet is a popular gemstone which was sought after in the past by royalty. For example, detrital demantoid from the Bobrovka River, Russia, adorns jewellery, crowns and sceptres of the Russian czars and czarinas, particularly those crafted by the famous Russian imperial court jeweller, Karl Faberge (Phillips and Talantsev, 1996). Few localities of large demantoid have been located so far, yet famous gem-quality localities include the alluvial deposits of the Sissersk District and the Bobrovka River, both of the central Ural region of Russia (Phillips and Talantsev, 1996); Val Malenco, northern Italy (Bedogné and Sciesa, 1993); and the Erongo Range, Karibib, Namibia. There are less important localities in Korea, Iran, China, Azerbaijan, Mexico, and Eritrea (Milisenda and Hunziker, 1999).

Inclusions in demantoid from Val Malenco

The rocks of northern Val Malenco (*English*: the Malenco Valley) were derived from the upper mantle and were altered to serpentinite after Alpine orogenesis and exhumation (Bedogné and Sciesa, 1993). Demantoids occur in asbestos filled joints that formed during the processes of serpentinization (Amthauer *et al.*, 1974). The crystals range in size from 0.05-10 mm, with rare larger crystals up to 30 mm. The common crystal form is well-formed dodecahedra. Crystals from three locations

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Table I: *Electron microprobe analyses* (wt.% oxide) of horse-tail inclusions of chrysotile asbestos in demantoid garnet from Val Malenco, Italy.*

Oxide	1	2	3	4	5
SiO_2	43.09	43.06	43.15	45.36	44.48
TiO_2	0.04	-	-	-	0.04
Al_2O_3	0.23	1.93	1.84	0.18	0.11
Cr_2O_3	0.03	0.64	0.84	0.03	0.07
Fe_2O_3	2.42	2.71	2.92	1.72	1.45
MnO	0.04	0.03	0.02	0.02	0.01
MgO	38.14	39.00	39.19	40.92	40.91
CaO	0.06	0.02	0.06	0.06	0.07
Na_2O	0.01	0.01	-	-	0.01
K_2O	-	-	-	-	0.01
Total	84.06	87.40	88.02	88.29	87.16
Cations calculated on the basis of 9 (O, OH); OH by difference (100% minus measured total); all iron as Fe_2O_3.					
Si	1.9433	1.9766	1.9949	2.0885	2.0281
Al	0.0122	0.1044	0.1003	0.0098	0.0059
Fe^{3+}	0.0821	0.0936	0.1016	0.0596	0.0498
Cr	0.0011	0.0232	0.0307	0.0011	0.0025
Ti	0.0014				0.0014
Mn	0.0015	0.0012	0.0008	0.0008	0.0004
Mg	2.5638	2.6687	2.7009	2.8086	2.7807
Ca	0.0029	0.0010	0.0030	0.0030	0.0034
Na		0.0009			0.0009
K					0.0006

**Analyses performed by wavelength dispersive spectrometry on a Cameca SX100 electron microprobe; acceleration voltage 15 kV; beam current 20 nA; beam-size 1-5 μm; analysis time 80 s; all standards used were natural minerals; raw intensity data was ZAF corrected.*

- denotes analysed for but below the limit of detection.

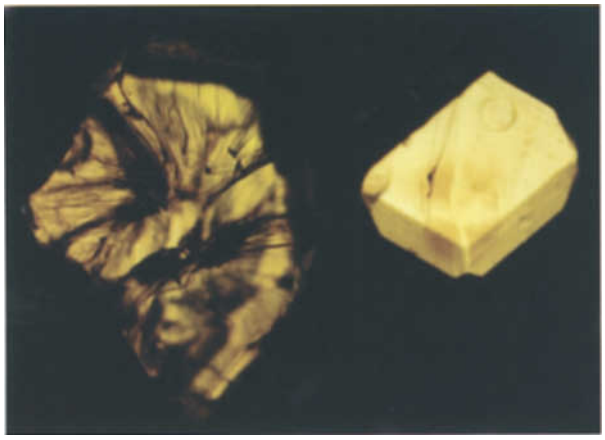

Figure 1: *Horse-tail inclusions in demantoid from Val Malenco. The darker-green crystal (left) has a high density of inclusions and the lighter-green crystal (right) has few inclusions. The width of the crystal on the left is 3.5 mm.*

within Val Malenco indicate that none of the crystals are zoned. The demantoids may also have mineral inclusions. These inclusions are long fibres, or hairs (up to about 2 mm long), up to 100 times longer than they are thick. The fibre width does not significantly vary along the length. Where the fibres are numerous, they form a radiating mat that may look like a horse's tail (*Figure 1*). Less dense occurrences may be spiral-shaped (*Figure 2*) or along one direction. The presence of fibrous minerals in demantoid is thus known as 'horse-tail' inclusions. These are well known for Russian demantoid occurrences, where inclusions of horse-tail byssolite (Phillips and Talantsev, 1996) and diopside (Krzemnicki, 1999) add considerable value to demantoid crystals. This is a rare example of where inclusions add monetary value to a gemstone specimen. The supposed occurrence of byssolite in demantoid from Val Malenco has been reported previously by Feather (1990). The identification of the included mineral as byssolite was on the basis of analogy to Russian demantoid occurrences and the assumption that the matrix-support mineral for samples from Val Malenco was tremolite-amphibole. A report of chrysotile inclusions in demantoid by Phillips and Talantsev (1996) was subsequently correctly attributed (*Gems and Gemology* 1996, p 155) to Dr. E. Gübelin who had presented his results in a lecture to the International Gemmological Conference in 1993. The lecture was entitled 'Mineral inclusions in gemstones recently observed, analysed and identified' and in it, Gübelin indicated that the chrysotile had been identified in Val Malenco demantoid (M. Superchi, pers. comm.). Unfortunately the abstract of the lecture contained no analytical details, so printed supporting data for the identification seem to be lacking.

We performed X-ray powder diffraction analysis of the asbestiform joint fill which forms the matrix-support for the demantoid at Val Malenco, and electron probe microanalysis for fibrous inclusions within the demantoid. Results from both analytical methods indicate that the matrix mineral and the phase included in demantoid is the asbestiform serpentine mineral chrysotile (*Table I*). Other minerals intergrown with the matrix chrysotile and demantoid are chromite, and minor quartz and augite-pyroxene. Our data confirm that the

Figure 2: *A spiral-shaped horse-tail inclusion radiating from a small (50 μm) mineral inclusion within the larger demantoid crystal.*

previous determination of the presence of byssolite is incorrect and that Val Malenco horse-tail inclusions are chrysotile. Transmitted light optical examination of demantoid crystals, cut in half, reveals that the chrysotile fibres have a typical light green to brown colour. This observation is most easily made for the lightest-coloured demantoid crystal (very light-green to colourless). We have found that demantoid with a deeper-green colour has a higher density of chrysotile inclusions, where demantoid with a lighter-green hue has few or no inclusions. The cause of colour variation in demantoid is related by Amthauer *et al.* (1974) to the presence and abundance variation of chromium in the crystal structure. We detected chromium by electron probe microanalysis in our demantoids, but found no systematic relation between green-colour intensity and Cr_2O_3 abundance. Although the occurrence of chromium in demantoid may be a primary cause of colour, our observations and data indicate that the intensity variations of green-colour is related to the variable density of green-brown chrysotile inclusions.

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Recent studies on inky black omphacite jade, a new variety of pyroxene jade

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ABSTRACT: A dark green jade has recently become more common in the Hong Kong and Chinese gem markets under the name 'inky jadeite jade'. Its gemmological properties are slightly different from pure jadeite with higher RI and SG and it consists of 85% or more of the pyroxene omphacite. Infrared and Raman spectra and microprobe analyses are presented.

Introduction

Among the many colours of jadeite on the market, the most precious is the emerald green variety, called by many imperial jade. Recently however, other colours have started to gain in popularity and have been incorporated in new designs, giving a fresh and attractive feeling to the pieces. One of these colours is an inky green in transmitted light if the piece is thin enough, but appears black in reflected light (*Figures 1 and 2*). This 'hidden nature' of the colour gives the jade a special character which is attractive to many as its name is 'inky jadeite jade'.

The inky green jade differs from the black-skin-chicken jade described recently by Ou Yang and Li (1999) in that it is fine-grained and more transparent. It is usually cut in saddle-shaped cabochons or carved into Guanyin or Buddha figures, but is also found as finger rings, bangles or antique-style pendants in the markets in Taiwan, Hong

Figure 1: *Inky black omphacite jade under reflected light.*

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Figure 2: Inky black omphacite in transmitted light.

Kong and China. Examples of the inky jade which are pure and of good quality are quite difficult to find so prices are not low. There are also many black simulants in the jade markets being sold as inky jade and this stimulated the authors to investigate the inky jade in more detail.

According to jadeite dealers in Myanmar and Hong Kong, this kind of jade has been available for over twenty years, but nothing appears to have been published about it. Traditionally, the Chinese have not been particularly interested in black stones so the inky jade was not noticed, but with changes in fashion more people are now interested in the range of jadeite jade colours.

Rough inky jade can be bought at the jade auctions in Yangon, Myanmar, where it is sold typically as smooth pebbles which have a thin greyish-yellow or brown skin (*Figures 3 and 4*). The shapes of the pebbles suggest a source in secondary alluvial deposits. Traders looking for inky jade have learned from experience to examine a polished surface and to choose those pieces in which a reflection of the viewer can be seen.

***Figure 3:** Rough inky omphacite jade with a white skin in the jade market.*

Figure 4: *Rough inky omphacite jade and polished beads of the same material.*

To investigate the characteristics of inky jade, the authors collected more than 30 samples for SG and RI measurements, thin section analysis, and investigation by electron microprobe, X-ray diffraction and infrared and Raman spectroscopy.

Gemmological characteristics

Colour: Black or blackish-green, if thin enough, in reflected light; blackish-green to intense green in transmitted light. The green itself ranges from bright to dark green.
Lustre: Vitreous strong reflectivity is due to the fine-grained texture and thus very smooth polished surface.
Transparency: Good sub-transparent to translucent.
Texture: Very fine; under transmitted light, it shows microfibrous texture and less commonly, micro-granular.
Hardness: 7 on the Mohs' hardness scale.
SG: 3.34-3.44 (by the hydrostatic method), slightly higher than jadeite jade.
RI: 1.667-1.670 (by the distant vision method).
Chelsea colour filter: Appears black.
Fluorescence under LW and SW ultra-violet: Inert.

X-ray powder diffraction analysis

The X-ray powder diffraction methods are not standard analytical techniques in most gemmological laboratories. However, in order to get more accurate information from inky jade, colleagues in Wuhan have applied this technique to study the mineral composition of inky pyroxene jade. The results were compared with the ICDD data and they indicate that the inky jade is composed of pure omphacite.

Infrared spectrum

Infrared spectra were obtained from the inky jades by reflectance and by KBr powder methods. Typical omphacite spectra were obtained and one is shown next to that of jadeite for comparison in *Figure 5*.

Laser Raman spectrum

Laser Raman spectral measurements were made on 10 samples of omphacite jade and a typical spectrum is shown in *Figure 6*. A Raman spectrum of jadeite is also shown for

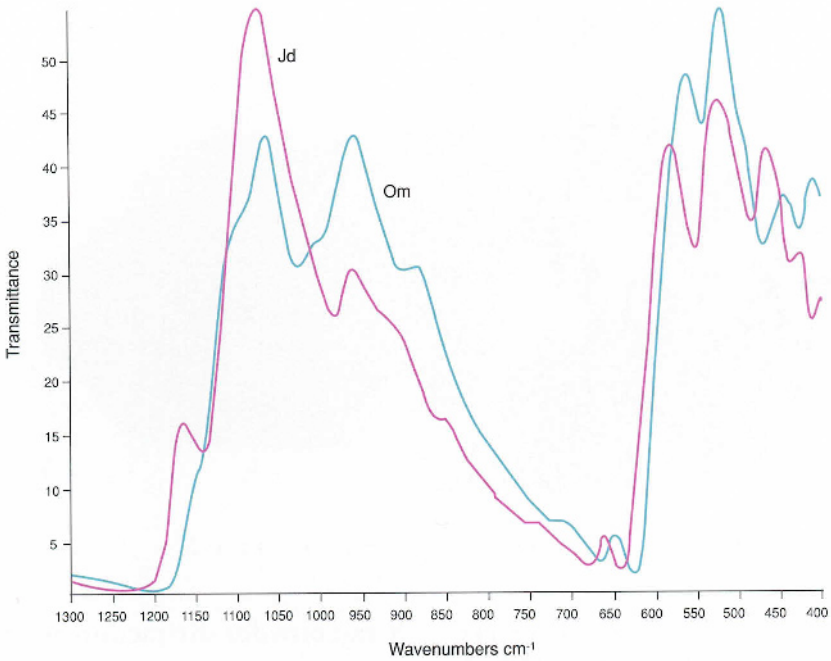

Figure 5: *Infrared spectra of omphacite jade (Om) and jadeite jade (Jd).*

comparison. Since jade is a polycrystalline aggregate with minerals in random orientation, all the main peaks should be displayed and there should be no orientation effect.

Petrology

The authors selected 10 samples for thin section observations. Omphacite comprises 80-90% of the jade and there are minor amounts of jadeite, kosmochlor and small grains of opaque material. These small black opaque materials seem to be metallic, but further work is needed to identify them. In thin section, omphacite is colourless to greyish-green or bluish-green with a distinct pleochroism of yellowish-green to bluish-green. It shows second order interference colours (*Figures 7 and 8*) and is biaxial positive with a 2V angle of 70°. The crystals have a fine-grained fibrous habit, and commonly the fibres are grouped into a granular pattern: technically they are microfibroblastic aggregates, and some specimens show a porphyroblastic texture. These larger grains are generally not well orientated but some may be sub-parallel with sizes ranging from 0.5 × 0.8 mm to 0.4 × 0.9 mm. According to the microprobe analyses, the omphacite is diopsidic, and the textures indicate that it is a product of re-crystallization where calcium was available. Although small amounts of omphacite are commonly found towards the margins of jadeite grains in jadeite jade (Ou Yang and Li, 1999), this is the first description of a virtually monomineralic decorative rock composed of omphacite. Jadeite and omphacite forming a concentric zoned structure are a very common phenomenon. The compositions of zoned crystals are gradational from jadeite at the cores to omphacite and then diopside towards the rims. This compositional zoning is shown by the electron microprobe analyses which

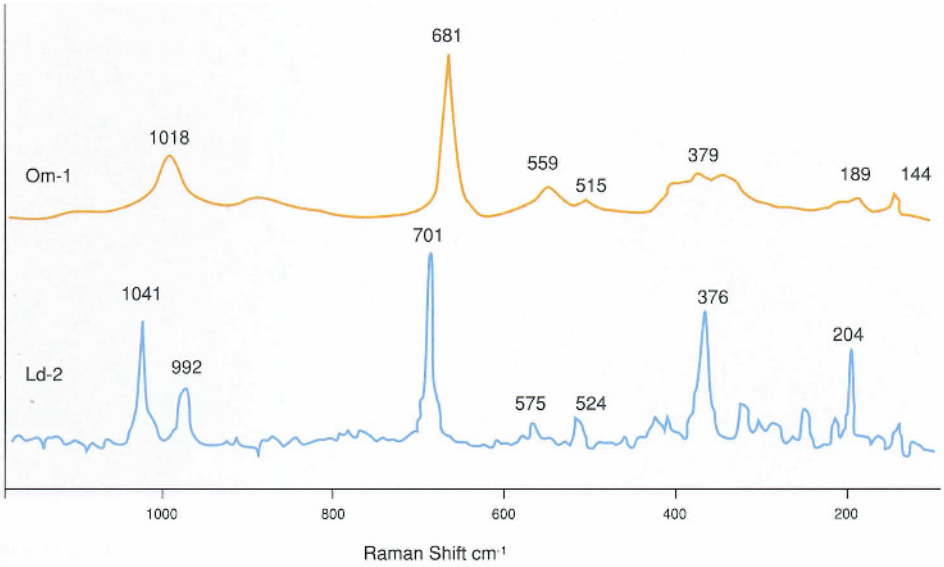

Figure 6: *Raman spectra of omphacite jade (Om-1) and jadeite jade (Ld-2) labelled with the wavenumbers of the main peaks.*

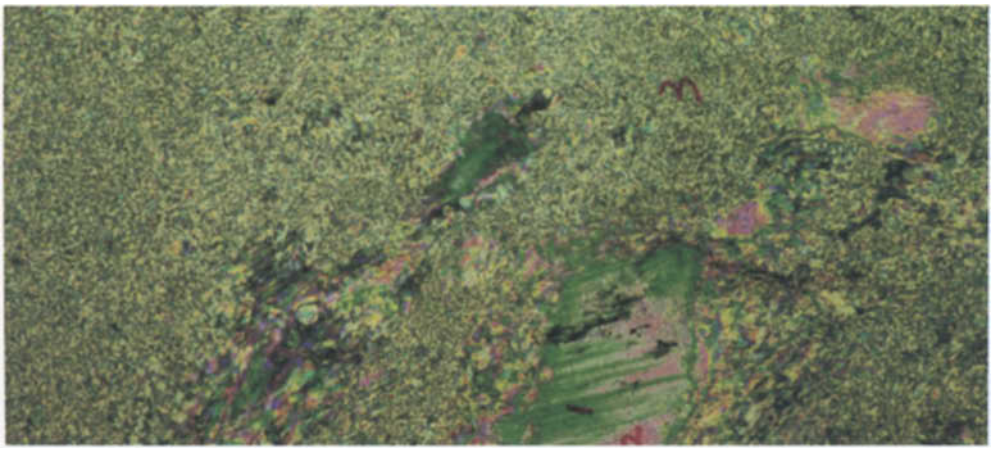

Figure 7: *Thin section of inky black jade in cross polarized light. A few large grains of original omphacite lie in very fine grained omphacite, some diopsidic, which has replaced the original texture. Field of view about 6 mm across.*

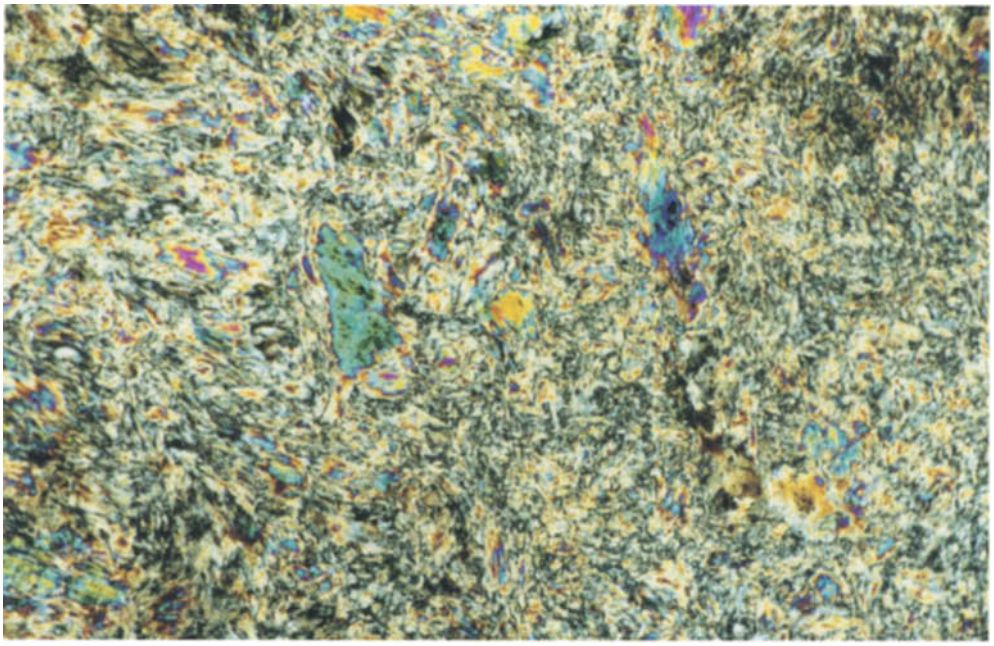

Figure 8: Thin section of omphacite jade showing intergrown fibrous texture. Field of view about 6 mm across; cross polarized light.

Table I: Composition of inky black omphacite jade: summary of electron microprobe analyses of 29 spots in 10 samples.

Wt.%	Minimum	Maximum	Mean
SiO_2	53.59	58.39	56.45
Al_2O_3	8.83	12.86	11.19
MgO	5.52	10.31	7.84
FeO	1.27	6.59	3.97
CaO	10.42	14.37	11.84
Na_2O	6.38	9.02	7.91
Cr_2O_3	0	3.51	0.16
Total			99.36
Na/Na + Ca	0.313	0.458	0.402
Al/Al + Fe	0.602	0.910	0.742

indicate that Ca content increases from core to margin of the grains at the expense of Na (Ou Yang and Li, 1999). This indicates that the crystallization environment changed from first providing Na to later providing Ca during the crystallization of jadeite and omphacite.

Chemical composition

The major and minor element contents of ten samples of inky black jade were analysed by electron microprobe and are summarized in *Table I*. The results indicate that the samples are omphacite jade.

The chemical formula of omphacite is (Ca, Na)[Mg, Fe^{2+}, Al, Fe^{3+}](Si_2O_6) which lies between jadeite and diopside. The limits of these three pyroxenes, based on their chemistry, are as follows: Na/(Na + Ca) > 0.8 for jadeite; 0.8-0.2 for omphacite and < 0.2 for

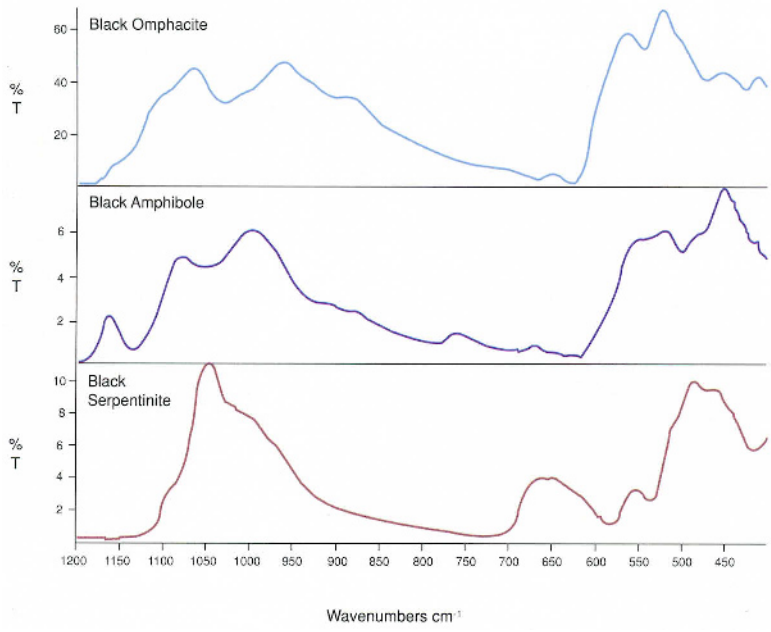

Figure 9: Infrared spectra of omphacite jade and its simulants, black amphibole jade and black serpentinite.

diopside. Also, based on Deer *et al.* (1978) and Wang Pu *et al.* (1984), the Al/(Al + Fe) ratio in omphacite is > 0.5. In terms of these ratios, the results in *Table I* show that the inky black jade falls well in the omphacite field. In addition, concentration of chromium in omphacite jade ranges from 0.00 – 0.16% Cr_2O_3 and in the larger quantities, is the cause of an attractive bright green colour.

Simulants

There are many simulants in the Hong Kong and Chinese jade markets, with appearance, colour, texture and transparency very similar to black omphacite jade. The traditional identification procedure practised by the Chinese has been to examine a 'black jade' under a strong light, and if it appears green then, it is real black jade.

However, the authors believe that there are two main simulants which can also show this effect, so it is not a conclusive test. These simulants are black amphibole jade (mainly composed of minerals of the amphibole group) and black serpentinite, both with mineral compositions and physical properties which differ from pyroxene jade. They may be distinguished from omphacite jade by their SG and RI (*see Table II*), but if such tests are not practical their infrared spectra are also characteristic (*Figure 9*).

Discussion

In the 1990s, with the development of jadeite mining methods, more detailed research on jadeite jade and more advanced techniques for research, omphacite has been found to be consistently present in deep green Burmese jadeite jades, especially the inky green stones. The authors have found

Table II: Comparison of gemmological properties of black omphacite jade and two simulants.

Simulant	*Hardness (Mohs' scale)*	*SG*	*RI*
Black omphacite jade	7	3.34-3.44	1.667-1.670
Black amphibole jade	6	3.00±	1.62±
Black serpentinite	4.5	2.52±	1.52

that Russian and Japanese jadeite jades also contain some omphacite (Ou Yang and Qu. 1999). The presence of omphacite in jadeite jade is not unexpected because it is the central member of the pyroxene series between jadeite and diopside. In thin-sections of dull green jadeite jade, jadeite and omphacite are often in a concentric zoned structure. Ou Yang and Li (1999) suggest that such a structure indicates a variable composition in the host rock and fluctuating conditions of temperature and pressure. The contents of omphacite in dull green jadeite jade are always variable below 25%. However in the inky black jade, the omphacite content is over 80% and this leads to significant differences in colour, structure, SG and RI.

The authors suggest that:

- jade with more than 75% omphacite should be known as omphacite jade;
- jade with between 50% and 75% omphacite should be called jadeite omphacite jade; and
- jade with between 25% and 50% omphacite should be called omphacite jadeite jade.

Conclusion

The inky black jade with fibroblastic texture and good transparency is essentially monomineralic consisting of more than 90% omphacite. The best name for it is omphacite jade. The dark green colour is due to omphacite, small amounts of opaque metallic oxides, and to the presence of tiny specks of graphite or possibly a black organic material. The refractive index and specific gravity are slightly higher than those of jadeite jade. From the infrared spectra, this variety can be easily distinguished from jadeite and from black simulants of jade. It is worth noting that in jadeite jade from Myanmar and from Sayan, Russia, the presence of omphacite commonly adds an element of grey or dark green to the colour of the jadeite.

Acknowledgements

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Ornamental marble from Ledmore, Scottish Highlands

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ABSTRACT: Near Ledmore in Assynt, Cambrian limestones and dolomites lying within the thermal aureole of an alkaline intrusive complex are recrystallized to calcite-marble and associated serpentine-dolomarble (ophicalcite) and brucite-marble. Exploitation of the marble for industrial applications also yields coloured and patterned stone suitable for ornamental and artistic applications. White crystalline marble predominates and grain size ranges from fine- to medium-grained; selected material contains a wide variety of attractive features highlighted by yellow and greenish-yellow hues imparted by serpentine minerals (after forsterite). The variegated marble is fashioned by contemporary sculptors, artisans and jewellers, and examples of their works are exhibited in galleries around the world.

Keywords: Ledmore, marble, Scotland

Introduction

In the Northwest Highlands of Scotland, a marble deposit at Ledmore is extracted mainly for white filler and industrial mineral applications. However, as a by-product of the mining operations, high-quality specimens are selected for the manufacture of carvings, ornamental pieces and costume jewellery, interest being fostered by availability, modern advances in lapidary equipment and the ease of working of the material as well as the growing importance of Scottish tourism.

The marble deposit is located in the geologically classic Assynt district of central Sutherland, about 77 km northwest of Inverness (*Figure 1*). From Ledmore junction,

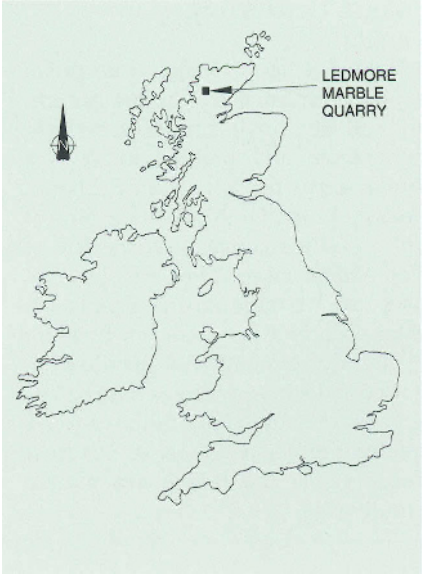

Figure 1 (right): *Location of Ledmore in northern Scotland.*

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access to the deposit is northwards along the A837 Lochinver-Bonar Bridge road for 1.4 km thence 0.6 km eastwards along the quarry access track. National Grid Reference NC 252137 applies. This paper provides a description of the geological setting of the marble deposit and directs attention to the diversity in its ornamental application.

Historical background

According to the historical record, mining operations for marble at Ledmore can be traced as far back as 1796. However, early operations were very small in scale and almost invariably short-lived.

More recently, the marble deposit was opened up initially for the production of white calcium carbonate as a filler and coating agent in paper manufacturing. However, variable marble quality prompted interest in other end-uses and subsequent operations have concentrated on a wider range of markets including architectural rock, harling chips (see below), decorative aggregates and ornamental stone.

Harling

Harling is an exterior wall finish composed of mortar against which, while still wet, small chips of stone have been thrown and pressed in. It is a popular finish for houses in Scotland, especially in the Highlands (e.g. almost all of the white cottages on the Isle of Skye). Other names for this type of finish are pebble-dash, roughcast, spatter-dash and dry-dash but they are also slightly different (e.g. pebble-dash has rounded stones whereas harling has angular fragments). In addition, harling provides a protective layer against frost damage while the others are mainly decorative.

The marble deposit is operated by Ledmore Marble Limited and production commenced in January 1991. Programmes of exploration drilling around the quarry area have indicated more than two million tonnes (Mt) of all grades of marble available for extraction from the site. Additional deposits of similar marble also exist in other nearby areas (Smith *et al.*, 1992).

Interestingly in 1996, 190 t of marble blocks were exported from Ledmore to Carrara in Tuscany, Italy (Anonymous, 1996).

Geological setting

The Ledmore marble deposit is situated in the lower southwestern foothills of the Ben More range and between Loch Borralan and Loch Awe.

Geologically, the oldest bedrocks in the district comprise Precambrian Lewisian gneiss to the west and Torridonian sandstone to the north. A sequence of limestones and dolomites of the Durness Limestone Group of Cambrian age overlie these basement rocks. At Ledmore, the Cambrian strata are intruded by the Loch Borralan Igneous Complex, an unusual suite of alkaline plutonic rocks of Lower Silurian age (430 ± 40 Ma, U-Pb zircon; van Breemen *et al.*, 1979). The geological setting is then further complicated by extensive structural deformation and faulting associated with the development of the Moine Thrust Belt of northwest Scotland (*Figure 2*).

The Loch Borralan Igneous Complex underlies an area of about 26 km^2. It is described in detail by Johnson and Parsons (1979) and Parsons (1979). The rocks of the Complex have been shown by Woolley (1970) to be divisible into an earlier suite composed of feldspathic syenites injected as a sheet-like body and a later suite composed of feldspathic syenites emplaced as a plug. The latter form the prominent ridge of Cnoc na Sròine (390 m).

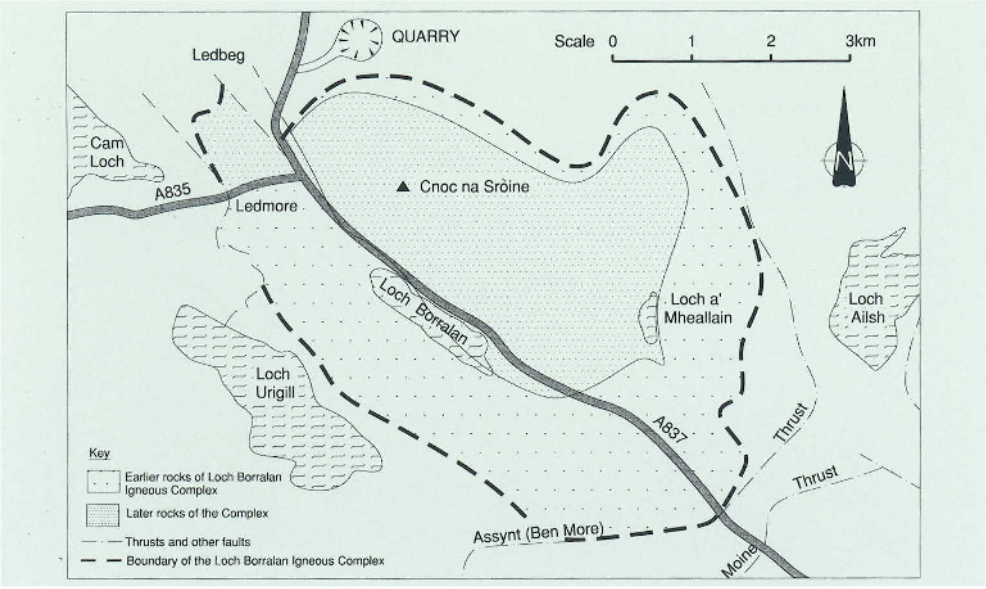

Figure 2: General Geology of the Ledmore area and the Loch Borralan Igneous Complex. The country rock (unshaded) consists predominantly of Cambrian limestone and dolomite strata of the Durness Limestone Group.

The deposit

At Ledmore quarry, the marble deposit crops out on a topographic platform surrounded by higher ground that shields the workings from general view and prevents obtrusion on the local landscape. Minor pockets of overburden consist of glacial moraine with thin blankets of peat.

The deposit comprises a wedge-shaped mass of marble up to 120 m in width that dips to the southeast and is traceable continuously for 450 m along strike (*Figure 3*). Resistant quartzite (basal Cambrian) forms a low ridge along the western flank of the operational area. It appears in thrust relationship to the marble with a thin sheared basic intrusion intervening along the thrust plane. The eastern boundary of the marble is traceable discontinuously across the surface and abuts the Cnoc na Sròine syenite. Boreholes through the mass of marble encountered syenite and associated igneous rocks at depth that are interpreted as irregular sheets with many complex interdigitations within the marble. The marble deposit lies within the thermal aureole surrounding the Loch Borralan Igneous Complex and contact metamorphism of the carbonate beds was probably effected by the Cnoc na Sròine syenite. However, the patterns of alteration exposed in the quarry suggest that reactions with underlying igneous intrusions have exerted greater influence than previously thought. Indeed, Allen *et al.* (1994) postulated three separate and distinct phases of contact metamorphism in the quarry area. In any case, where the original carbonates were particularly pure, extremely white marble has resulted from the contact metamorphism. More specifically, limestones have transformed to calcite-marbles whilst dolomites have produced brucite-marbles and carbonate beds containing impurities have produced attractively coloured marbles.

Mineralogically, calcite and dolomite predominate in the marble. Both minerals are usually present but proportions are variable with interlayers parallel to stratigraphy on a

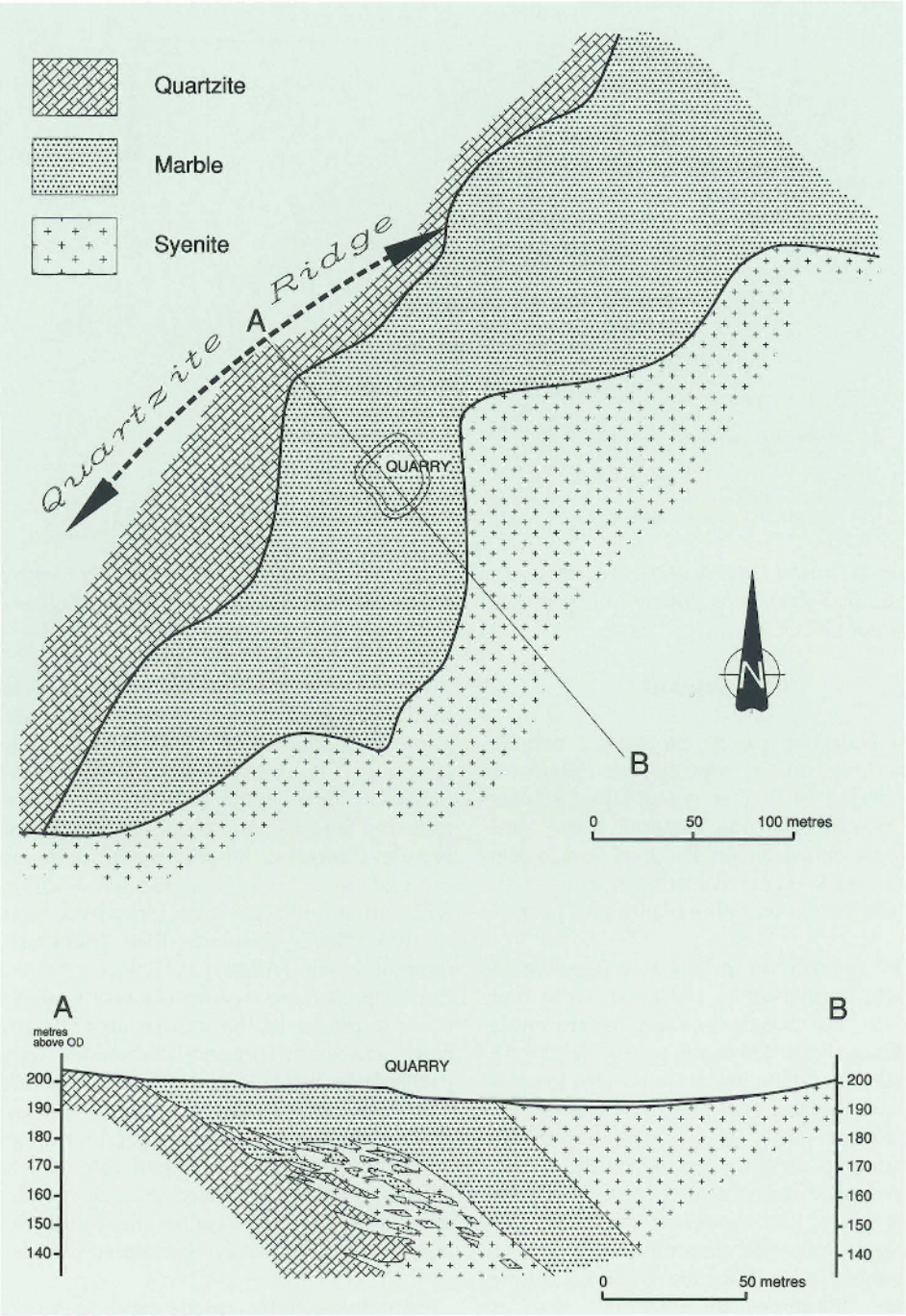

Figure 3: *Geological sketch map and cross section of the Ledmore marble deposit (after Smith et al., 1992).*

Figure 4: Ledmore marble quarry. View looking westwards at wire-saw cut faces. Hills in the background consist of Cnoc na Sròine syenite. Photo by Douglas Nichol.

Figure 5: Ledmore marble quarry. Slabs of grey architectural marble showing typical deformation textures. Photo by Douglas Nichol.

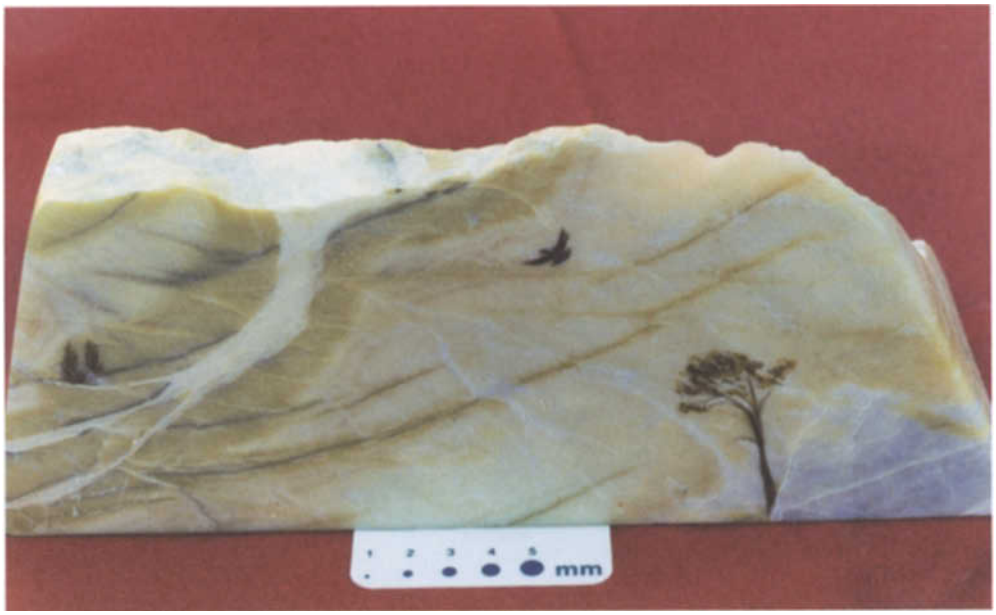

Figure 6: Landscape in stone. Black ink on Ledmore marble; length about 200 mm. Artist, Murray Henderson. Photo by Douglas Nichol.

metre scale that probably reflect different compositions of the original sediments. Textures range from fine-grained crystalline to medium-grained and granular. During the process of alteration to marble, chert nodules present in the original carbonate beds reacted with magnesia in the dolomites to form forsterite (Mg_2SiO_4) which in turn was partially or fully hydrated to form serpentine minerals. The serpentinous marble is also called ophicalcite. Another characteristic mineral found in the marble is brucite ($Mg(OH)_2$). It constitutes as much as 28% of certain bands and resulted from the hydration of periclase (MgO). Other accessory minerals that have been identified in trace amounts include tremolite, diopside, larnite, chlorite and rare magnesium titanium oxides.

Within the marbles there are concordant bands on a millimetre to centimetre scale. Lenses, specks, streaks, flecks and lenticles contain non-carbonate components and impart a range of attractive yellow, green, grey and cream-brown patterns. In addition, deformation features and brecciated zones that formed during tectonic disruption are also present and create different styles of textural patterns.

Mining and processing

The quarry measures approximately 100 m long and 100 m wide by up to 10 m deep and the processing and stockpiling areas occupy the adjoining ground (*Figure 4*). Extraction of marble involves conventional quarrying methods for bulk stone but monofilament wire-saw techniques are employed to extract blocks of architectural stone (*Figure 5*). Minor northwest trending dykes cut through the marble deposit and, as far as possible, these are avoided during mining operations.

Figure 7: Turtle LVIII. Ledmore marble. Length 540 mm. Sculptor Laurence Broderick. Photo by Michelle Sadgrove.

Figure 8: Jewellery and giftware items of, or containing, Ledmore marble. Fashioned by Orcadian Stone Company Ltd. Photo by Douglas Nichol.

The marble from Ledmore varies from pure white (N9) material suitable for industrial markets to coloured and textured stone suitable for ornamental applications and sculptural stone carving. Based on the Munsell system of colour identification (Rock-Colour Chart Committee, 1963) the predominant colours of ornamental grades of ophicalcite range from moderate yellow-green (5GY 7/4) through moderate greenish-yellow (10Y 7/4) to dark greenish-yellow (10Y 6/6).

Roughly hewn blocks of ornamental stone (gallets) are selected in the quarry and stockpiled for direct supply to the local trade. The proportion of ornamental grades is generally much less than 10 per cent. The small-scale soundness or quality of the marble in the gallet is important but not crucial because the processed item tends to be smaller then the fracture spacings. More important are colours and textures, and for this reason gallets are selectively extracted from certain parts of the deposit whenever suitable pockets of material are encountered during quarrying operations.

Individual artists and sculptors fashion a wide variety of ornamental pieces and figurines from Ledmore marble that are displayed in galleries and studios throughout the world (*Figures 6 and 7*). Distinctively patterned greenish-yellow marbles and ophicalcite are also used for jewellery, as well as small giftware and souvenir items with a high craft content (*Figure 8*).

Conclusions

At Ledmore in Scotland, white marble and variegated ophicalcite have formed within a multiply deformed and metamorphosed terrain adjacent to the Loch Borralan Igneous Complex. Ornamental grades of marble and ophicalcite are available as a by-product of quarrying operations for industrial stone.

Ornamental grades feature irregular patches, bands and streaks through the rock mass that typically range in colour from yellow to greenish yellow. Texture ranges from fine- to medium-grained.

The quantity of marble available for extraction appears substantial and ornamental material is anticipated to increase in variety as the quarry reaches deeper levels. An extensive range of ornaments, giftware and jewellery items is produced from Ledmore marble using conventional lapidary equipment.

Acknowledgements

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A critical review of the 'Hanneman refractometer'

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ABSTRACT: A recent paper in this journal by W.W. Hanneman describes the Hanneman refractometer, an inexpensive device, which measures the deviation angle of a light beam as it passes through a faceted gemstone. In the paper Hanneman states that he believes that the treatment of the concepts of the refractometer should be incorporated in gemmological studies programmes. Because of errors relating to basic optical principles, and omissions of necessary constraints on the device, this author disagrees. Problems with the device are detailed, and simple experiments are described for the reader to better understand deviation angle refractometers.

Keywords: deviation angle refractometers, Hanneman refractometer

Introduction

Refractometers which determine a transparent solid's refractive index (RI) by measuring the deviation angle of a beam of light passing through a prism of the solid have been around for over 100 years, yet are seldom used by gemmologists. This lack of use by gemmologists is due in part to their expense and in part to the attention to detail required for accurate measurement. However, because they are capable of providing extremely accurate RIs as well as dispersion values, they are often described in gemmological texts where they are usually called goniometers (e.g. Walton, 1952) or prism spectrometers (e.g. Webster, 1994). Webster even gives details on the use of the instrument for RI determination, but notes that considerable skill and calculation is required to obtain results. Although Walton (1952) gives details of a simplified version of the goniometer or table spectrometer which he developed, his instrument has not found much use.

More recently work by Alan Hodgkinson (1979, 1989, 1994, 1995), who extended a visual method due to Crowningshield and Ellison (1951) for estimating optical properties to include estimation of RI, has resulted in renewed interest in deviation angle methods. Hanneman (2000) in a recent paper in this Journal has described the 'Hanneman refractometer' in which the deviation angle of light passing through a faceted gem is presumed to be determined in order to find its RI or RIs. In this paper Hanneman (2000, p.155) states that his 'Hanneman refractometer' "... has culminated in a new unlimited range refractometer. Surprisingly, it can be constructed by any student at a cost of only a few pennies. Because of the educational features offered

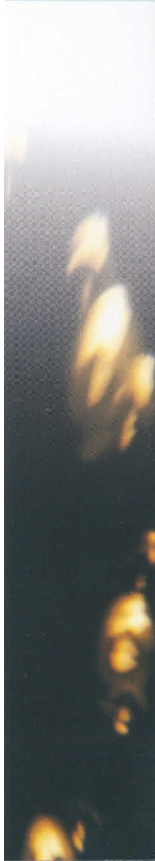

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by this instrument, the author believes a treatment of the concepts should be incorporated into the basic programme of every gemmological student."

There are only three essential elements in Hanneman's device: a light source, the gem to be measured, and a scale to measure deviation angles. This great simplification makes his device inexpensive to construct, but results in so many measurement problems that it is of questionable utility. *Caveat emptor!* However, of much greater concern to this author are the claimed educational features for students of gemmology and comments are made about the optical principles of the 'Hanneman refractometer' and omissions of necessary constraints in its operation.

Let us look at the problems with the 'Hanneman refractometer', and some simple demonstrations any student can make by which he or she will be able to appreciate these problems and obtain a better understanding of prism optics.

Background

Before we examine the 'Hanneman refractometer', we need to know a little about the conventional table spectrometer. Details of this instrument can be found in various editions of the classic text *Gems* by R. Webster (1994). Readers not familiar with the instrument should review this material. Major components of this instrument include a light source, typically a gas discharge tube to give accurately known wavelengths of light, although for crude work an incandescent source may be used. Light from the source passes through a slit and achromatic lens combination called a collimator, which gives a light beam containing parallel rays. A pin-hole could be used in place of the slit. The collimator is positioned to point at the centre of a rotatable table, at the centre of which the prism or gemstone to be measured is placed. The collimator may or may not be constructed to rotate around the centre of the table. Means are provided so that the gemstone can be orientated so as to place both facets to be used perpendicular to the axis of the collimator. The measurement is then made with a telescope which can be rotated about the centre of the table, and an angle scale is provided to measure the angle of rotation of the telescope. The telescope needs to be focused at infinity and must have provision to be brought exactly in line with the axis of the collimator.

Linton and others (2000) have evaluated the Hanneman refractometer and have concluded that it could give readings 'almost equivalent' to the conventional critical angle instrument gemmologists use. However they did not recognize the various technical deficiencies, nor give an evaluation of the accuracy or precision of the device. This paper addresses those problems, and suggests that the 'Hanneman refractometer' will not give 'almost equivalent' readings.

The problems

Problem 1 – the pinhole

First, the 'Hanneman refractometer' is described as a 'pinhole refractometer', presumably because an opaque 'pinhole' shield as shown in his *Figure 2* is used. While Hanneman is free to describe his device in terms of his choosing, his 'pinhole' doesn't function as an optical pinhole in the device. He states that the 'pinhole' is to be made a little larger than the diameter of the faceted gem. Thus for measuring gems up to several carats a 'pinhole' of something like 15 mm is needed. Linton and others (2000) note that Hanneman recommends a 5mm hole. If one looks at texts on optical physics where pinholes and pinhole cameras are described (e.g. Wood, 1961) one finds that a pinhole can act as a simple lens. A 15 mm pinhole lens can form a good image of the sun, but unfortunately it is at a distance of some 65 m from the pinhole. It should be clear that the 'pinhole' in Dr Hanneman's refractometer is functioning only as a shield against stray

light from the light source, and not as an optical pinhole or simple lens.

Problem 2 – "any light source will do"

In his construction notes Hanneman (2000) states: "Any light source will do." The reader can easily test this. Take a faceted quartz gem in the range of 5 to 10 ct, a brilliant cut is best because of the pattern produced. Cut a hole just larger than the table in a piece of stiff cardboard or similar material, and affix the gem with its table centred in the hole with an adhesive wax. Hold the card with its gem about 150 mm from a light-coloured wall with the pavilion away from the wall. If a scale were placed properly on the wall, this configuration would constitute the essential components of Hanneman's device. The distance between the wall, or scale, and the gem in Hanneman's device will play a part later, so we need to consider that now. Hanneman does not state what that distance is, but Linton and others (2000) indicate that it is adjustable from 50 to 100 mm (about 2 to 4 inches).

Next, shine the light from a small penlight or torch on the pavilion and observe the pattern of light on the wall, as the penlight is positioned first at the pavilion and then drawn farther away. With the light close to the pavilion you will see no clear pattern. But, as the light source is withdrawn farther and farther away the pattern will sharpen. Further, the pattern mimics the shapes of the pavilion facets. For a brilliant-cut gem eight diamond-shaped and 16 triangular light spots should be seen on the wall arranged in a circular pattern as shown in *Figure 1*. Note also that as the light source recedes from the gemstone the size of each individual facet pattern becomes smaller (*Figures 1a and 1b*), but that each is larger than the facet on the gem. What is happening is that as the source moves away, the light entering the gem becomes more nearly parallel or collimated. These patterns are, in effect, shadow patterns from light refracted through the stone.

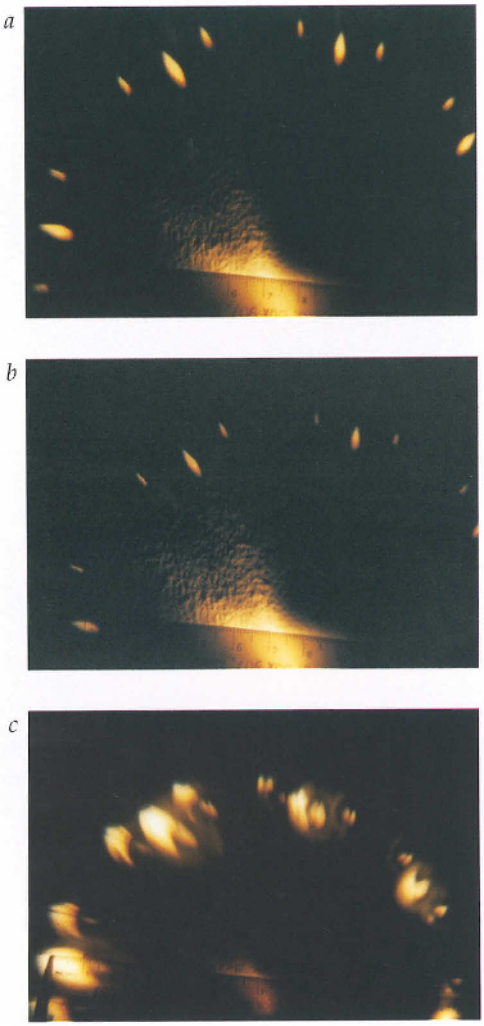

Figure 1: *Photographs showing the effects of different light sources at different distances from a gem. The 4.43 ct quartz was fixed at 150 mm from the viewing wall, and camera fixed for all illustrations. Note the centimetre scale. 1a shows a diamond pattern from a small lens-in-bulb torch held at 300 mm from the gem. 1b shows the same torch held at 600 mm from the gem. Note the smaller diamond pattern. 1c shows a distorted pattern from a small torch with an aluminium reflector behind a bulb held at 150 mm from gem. Distortion arises from multiple light paths at differing angles.*

Figure 2: *Photograph of the spectral images of a distant light source as seen by photographing the light passing through a faceted gem held at the lens, when illuminated from the pavilion side. Colour reproduction is poor, but the overlapping spectra of the ordinary and extraordinary rays of quartz are clear. This is the image that would be seen if the faceted gem were held close to the human eye. The camera has simply substituted for the eye.*

Now measure, approximately, the length of the diamond-shaped facet pattern from the inner to outer edge. This will provide an idea of the error involved as will be developed later.

Also, a decrease in the intensity of the light patterns occurs either as the torch is withdrawn, or as the cardboard and gem are moved farther away from the wall. Thus, if an expanded scale (for greater precision) is desired, an intense light source would be required.

If available, other small torches should be tested and those with a more uniform beam intensity will perform better than others. Two examples are shown in *Figures 1a and 1c*. If this test is tried with a frosted incandescent source, the light source must be much farther away before any clear pattern is seen. These tests indicate rather clearly that not all light sources are suitable but that one really needs a collimated source just as is needed in a conventional table spectrometer.

Problem 3 – "spectral images should appear"

Under operation notes, Hanneman (op. cit. p.159) tells the reader that for a brilliant-cut stone a symmetrical circle of spectral images will appear. We have already determined that the pattern of lighted areas mimics the facet shapes, and that they are not spectra. This is interesting, since in the table spectrometer the spectral images seen are of the slit of the collimator. Because Hanneman uses no slit or true pin-hole in such position, nor a telescope, what spectral image is he referring to? It appears that Hanneman, who has championed Hodgkinson's 'Visual Optics', may believe that what one sees when looking into a gem with the 'visual optics' method is identical to what is seen if one simply projects the light onto a flat surface. This is not so, and *Figure 1* shows the shadow patterns seen on a wall using a 4.43 ct faceted quartz. This is what is seen with the experiment described under Problem 2. In *Figure 2*, a faceted quartz was simply placed at the front of the 35 mm camera focused at infinity and titled slightly; the image is of sharp small spectra associated with a few of the pavilion facets. The camera does not have a lens of wide enough angle to view the refraction patterns from all facets. This is what the eye would see if substituted for the camera. Note that one does not see triangular and diamond-shaped patterns that mimic the facets, but a series of bright overlapping spectra corresponding to each of the bright shadow patterns seen in *Figure 1*. What is happening?

Go back to the cardboard-held gem and look at the patterns you see on the wall; look very closely and darken the room. If your penlight is bright enough you should see a faint red coloration at the inner part of each facet pattern and a blue fringe on the outer part. Look closely as the coloured part will be less than 1.5 mm broad.

A clean pure spectrum is not produced because each facet image on the wall consists of infinite series of overlapping spectra produced by light refracting along the entire

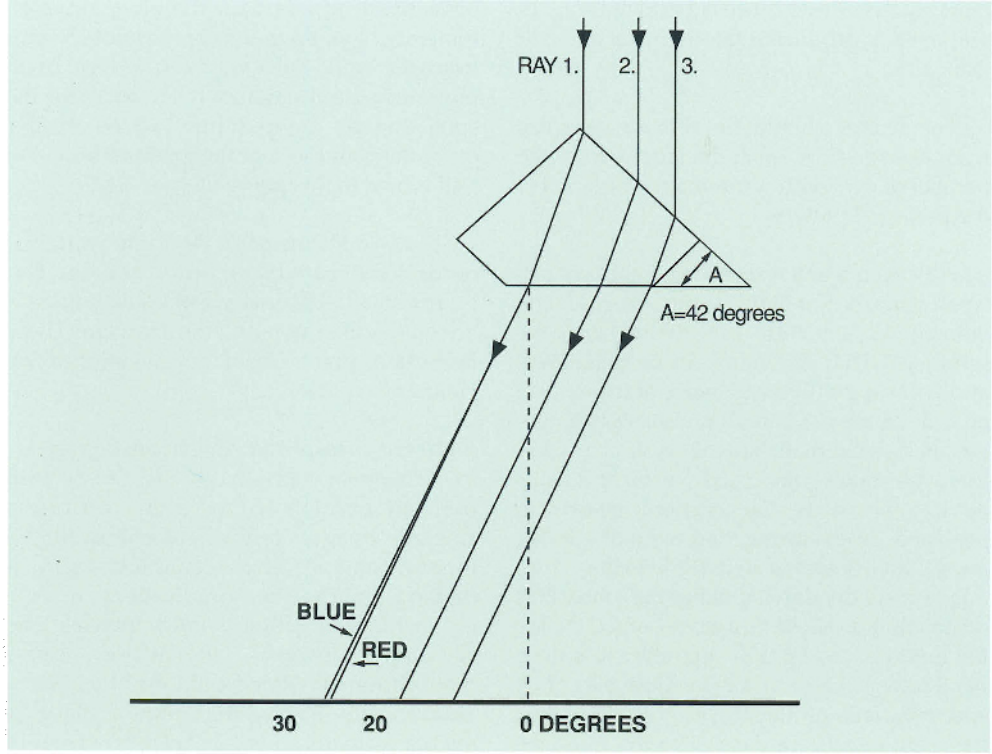

Figure 3: Diagram illustrating the ray paths through a quartz gemstone and falling on a distant surface. Incident rays are normal to the table surface. Ray 1 shows, to scale, the difference in deviation angle for red and blue light.

length of the pavilion facet and incident at various angles. The bulk of the image shows the colour of the light source where images overlap; only the outer part shows blue and the inner part red where there is incomplete overlap. These are *not* spectra. This very serious problem results from the absence of collimated light and a lens following the gemstone.

Figure 3 may help to explain the true situation. This shows ray paths for collimated light which is normal to the table facet, passing through a stone with indices of refraction and dispersion similar to quartz. Look at ray 1 that enters the pavilion just to the right of the culet. This is bent to the left with an angle of refraction of 25.677 degrees for the O ray within the stone, and exits the table at 25.729 degrees. The angles are for sodium light. If another parallel ray impinges further down the main facet, the angles and directions will be the same, but each offset, such as rays 2 and 3. If a flat surface is placed in the ray path beyond the gem, the heavy line in *Figure* 3, one obtains a projection of the facet shape on that surface such as was seen with the cardboard experiment. If, instead of monochromatic light, white light is used, then because of the small differences in RIs with wavelength, the deviation angles will be slightly different for each colour. For quartz that difference is 0.6 degrees, shown for ray 1 with the blue and red ends indicated. Thus, except for a small region on the inner and outer edges of the

facet pattern, the spectral colours of each ray will overlap producing the colour of the light source.

The reader should be able to visualize from *Figure 3* how small deviations from the parallel of rays within the beam would affect the projected pattern.

However, if one restricts the light rays to a small bundle or limits the size of the gemstone, a crude spectrum can be produced. That size limit can be calculated, and will vary with the distance of the surface or scale to the gem, its RI and its dispersion. Let us assume that the scale distance is 150 mm, 1.5 times that used in Hanneman's device, so there is greater measuring precision. And, assume that we will tolerate quite a bit of overlap so that the yellow from one ray will overlap the red of the other. This means that in *Figure 3*, if rays 1 and 2 define the limits of the light beam, how close does ray 2 have to be so that the yellow part of its spectrum falls on the red of ray 1? For this, the light beam, or facet length, must be smaller than 0.37 mm for quartz. Hanneman's device obviously does not meet the requirement with its large light beam. Since the dispersion of quartz (0.0131 B–G for the O ray) and its birefringence (0.0091) are similar in magnitude, it should be clear that one would not be able to measure either with the device.

One can more readily appreciate this by placing a piece of aluminium foil over the pavilion of the gem mounted on the cardboard and carefully punching a very small hole at the culet. Illuminate this configuration on the wall with your torch, and note that this provides a much smaller spot that does not reflect the shape of the facet and shows a better spectrum. The room should be darkened to be able to see this.

To understand what is happening, remember that the red component of the light as it passes through the gem is bent at a slightly smaller angle than the green which is bent just a bit less than the blue, etc. Also remember that the gem is only about 150 mm from the wall. Thus we need a very small pinhole in the aluminium foil in order for the spot due to the red light to be visibly separate from those of the green or blue. We will return to this point later.

Thus for Hanneman's device to work one needs a collimated light beam, and one that is very small in diameter, especially if there is no lens in the ray path after the gem. These important points were not mentioned by Hanneman (2000).

Problem 4 – reading the refractive indices

Hanneman states that the RI can be read from the position of the yellow part of the spectral image on his scale, and that a monochromatic filter could be used if desired, with the implication that a monochromatic filter would increase the accuracy. However, in his device a monochromatic filter would do little, as the reader can easily determine. Place a monochromatic filter or just a piece of strongly coloured glass in front of your light source and project the facet images on the wall. The same large images of the pavilion should be there, but without the coloured edges. It should be apparent that if we had an angle scale on the wall, a facet image would still cover a wide range of angles, and that that range would increase in direct proportion to the size of the gem. Hanneman does not discuss what part of this large image to use, nor how much error is represented by the angular span of the image. Note, also, that there is no evidence for birefringence in the wall images.

One can calculate by how much this shadow image of the facet is too large for precise determination of RI. The 4.43 ct quartz has an 8 mm long main pavilion facet, and when projected on the horizontal surface as shown in *Figure 3* its image length is about 6 mm. How does this compare with the length you measured under problem 2? At a 150 mm radius 6 mm represents an angular

range of 2.25 degrees. The B–G dispersion in quartz would give only an angular range of 0.591 degrees. Thus, the image is four times the width of the entire spectrum and many more times that of the width of the sodium doublet.

Another simple experiment may help, but knowledge of Hodgkinson's visual optics is needed. If the reader does not know how to observe images with this technique, consult the references and you will be more than adequately rewarded for your time.

Take the cardboard in which the quartz gem is mounted, and the same torch used previously to observe the refracted images. Hold the gem's table close to your eye as is normal in visual optics. If the torch is say 3m away, the spectral images will be sharp and birefringence clearly seen. Now, move closer to the light and observe the deterioration of the spectral images. However, even when fairly close, one still sees bright spectra, not simple images of the facets as seen when projected on the wall. You will also see that even when the torch is at some distance, the spectra are still very bright. Here, the eye is functioning as the telescope used in the table spectrometer. Thus Hodgkinson's technique for estimating RI has all the elements of the table spectrometer except for a scale to measure angles.

There is yet another unstated problem concerning how to read the proper position on Hanneman's scale. This can best be appreciated by going back again to the simple wall experiment. When a pattern of facet images on the wall has been obtained, change the angle of the light beam as it shines on the gemstone. You will see a corresponding change in position of each facet image, corresponding to a change in deviation angle, measurable if a scale were present. Hanneman's scale is calculated on the assumption that the light is collimated and that the beam is perpendicular to the table facet, but this very important point is not mentioned in the paper. How much difference does this make? If your gem has a pavilion angle of 42 degrees and an RI of 1.55, the deviation angle would be 26 degrees. If your measurement is off by 2.4 degrees you would erroneously believe that its RI would be 1.60 (see Hoover, 1998 for detailed tables), an error that is too large for accurate identification.

To test this idea, have an associate hold the cardboard with the gem 150 mm from a wall. Then shine the beam of a laser pen on the pavilion while trying to hold the beam perpendicular to the gem's table. Make sure you are not able to see where the laser spot is located on the wall. Have your associate mark where the beam is, and repeat the procedure to obtain a scatter pattern showing how much perpendicularity error you would have in making such a measurement.

Problem 5 – measuring dispersion

Hanneman explains (2000, p.158) that dispersion can be measured with his device by measuring the angles, and thus RIs, at which the blue and red ends of the image spectrum are seen. It has been shown above that his device does not produce true spectra, so dispersion cannot be measured. However, even if the spectra were adequate, comments about the measurement of dispersion in this and in a previous paper (Hanneman, 1992) on dispersion are in error (see also Hoover and Linton, 2000). A minor error was corrected in the following issue (erratum 2000), but many remain. What are these errors?

First, that the maximum and minimum wavelengths observed using the Hanneman refractometer are 760 nm in the red, and 397 nm in the violet. These wavelengths correspond approximately to the maximum range of human vision. However, the range of human vision is dependent partly on the visual input. To see this, look at an incandescent source through a spectroscope. You should be able to distinguish colours from about 700 to 420 or 430 nm. Now,

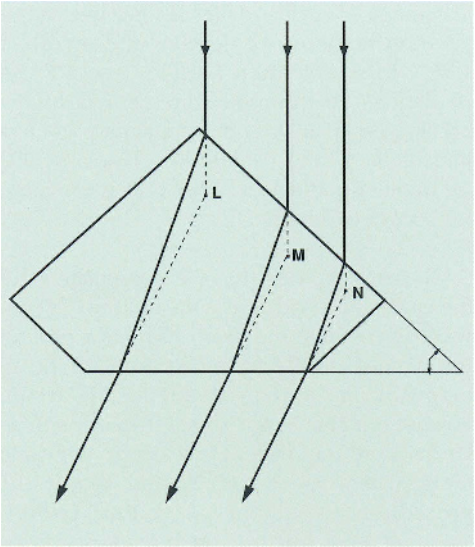

Figure 4: *Diagram illustrating the ray paths through a quartz gemstone. Incident rays are normal to the table surface. Points L, M and N show the intersections of each pair of incident and exiting rays within the gemstone.*

without changing anything else just place your Chelsea colour filter in the light path. The bright full spectrum will be gone and all you will see are the Chelsea colour filter bands. These are in the yellow-green and red with the red extending from about 700 to 750 nm where no colour was discernible without the filter.

Additionally, Hanneman's assignment of 760 to 397 nm to the observed red and violet ends of the spectrum does not take into consideration absorption in many coloured gemstones of either the red or blue/violet ends of the spectrum. One only has to look at absorption spectra of gems given in many gemmological texts to appreciate how this may affect assigning fixed wavelength values to the end colours seen. Thus, a user of Hanneman's device could not be certain of the end wavelengths for any particular gem.

Hanneman (2000, p.158) states that in order to correct the 760 to 397 dispersion value to the more generally used B–G interval one only has to multiply by the ratio of the wavelength intervals. This introduces further possible errors, since a plot of RI versus wavelength (a dispersion curve) is not linear but curved. Means to correct dispersion values between differing wavelength intervals have been known for many years, but are rather more complicated that a simple linear conversion (see Hoover and Linton, 2001).

Problem 6 – where is the zero position?

To position the scale in Hanneman's device he states that the gemstone should be placed so that it is centred above the O, or origin, of the scale. In another section he states that the height of the bottom (table) of the gem should be exactly equal to the distance of the 45 degree line on the scale. If one could do this precisely, and if the table were also perpendicular to the light beam, a necessary requirement, then the device would still not necessarily read properly. The requirements set forth by Hanneman are valid only if the gem is infinitely small. This can be illustrated with reference to *Figure 4*, with quartz as an example. If a narrow ray enters at the culet, then the position for measuring the deviation angle (if the plane of the table is reference) is near the left edge of the table and not the centre as suggested by Hanneman. It should be clear that the exit position will vary with the RI, which is also unknown. *Figure 4* shows several ray paths within a faceted stone, and the intersection points, L, M and N, for the entering and exiting rays. If the scale is to be centred below the culet, then the height of the gem to the scale zero point must be adjusted to reflect the depth of the point L within the gem. But clearly this height varies with RI as well, meeting the table for an RI near that of diamond. Thus positions L, M and N, and points of exit, cover a major fraction of the depth and width of a stone. For larger gems this can amount to large errors in RI. If one considers that for quartz with a birefringence of 0.0091 the two rays show an angular range of only 0.43 degrees. At Hanneman's 100 mm

working distance, 0.43 degrees spans a length of only 0.75 mm. Thus a 3 mm error would be equivalent to an error in RI of 0.036.

Error analysis

A true error analysis of Hanneman's device would be difficult because they come from three principal sources. The first is the measurement of the deviation angle itself, where the error is a function of stone size, RIs and dispersion, and not having true spectra displayed by the device. This is the most difficult to quantify, but may be quite large as discussed. The second is knowing the error in the angle between the light beam and the table of the gem, assuming the beam is collimated. The author estimates that this could be of the order of a few degrees. The third is the error in measurement of the pavilion angle, which has not been discussed. Unless the goniometer or optical comparator is used, the author estimates this at a few degrees also.

The final measurement error is a compound of these three errors. In some cases one may cancel another, but in other cases all three may add together producing great uncertainty in the result.

With the device, one can distinguish between RIs of gems as different as quartz and cubic zirconia. But, until there is a way to rigorously calibrate the device and to quantify the errors, the actual errors of measurement will remain unknown.

Summary

In attempting to simplify a deviation angle refractometer Hanneman has produced a device which is not sufficiently accurate for much gemmological work.

Further, instructions for its use are inadequate, or erroneous. The device can be used to demonstrate the refraction of light, but this is something better done by other, simpler means.

In this author's opinion, Hanneman's explanation of the device contains erroneous explanation and application of optical principles and it would be wrong to use these as educational material for gemmological students. It is hoped that the above discussion helps to make clearer to students the basis of deviation angle refractometers. The author also recommends that all readers should make appropriate amendments to their copies of Hanneman's paper.

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Abstracts

Diamonds

Gems and Minerals

Instruments and Techniques

Synthetics and Simulants

Diamonds

Impact origin of ancient diamonds with eclogitic and meteoritic parageneses of mineral inclusions.

V.N. ANFILOGOV. *Doklady, Russian Academy of Sciences, Earth Sciences Section*, **377**(2), 2001, 219-20. (English translation.)

Diamonds can be divided into three paragenetic assemblages: eclogitic (E-type), peridotitic (P-type) and meteoritic (M-type). Geochronological and carbon isotope data on diamonds revealed that the E-type diamonds are dated at 500-300 ± 300 m.y. whereas the P-type diamonds and rims of E-type diamonds widely range in age up to the timing of kimberlite emplacement in the upper horizons of the Earth's crust. Also, the carbon isotopic composition of P-type diamonds approximates that of the mantle-derived variety, whereas E-type diamonds are enriched in light carbon. A.M.C.

High-pressure coesite inclusions in diamond: Raman spectroscopy.

B.A. FURSENKO, S.V. GORYAINOV AND N.V. SOBOLEV. *Doklady, Russian Academy of Sciences, Earth Sciences Section*, **379A**(6), 2001, 749-52. (English translation.)

Coesite inclusions 60 and 200 μm in size were localized at a depth of 170-250 μm beneath the (111) face of a flattened octahedral diamond crystal, 1.5 mm in diameter. The smaller inclusion had a typical triangular shape of a negative diamond crystal. Measurements were made with a multichannel Raman microspectrometer and the spectra from each of the inclusions were virtually identical, yielding the same shift of the 521 cm^{-1} line; 8 ± 0.5 cm^{-1} for the large inclusion and 10.5 ± 0.5 cm^{-1} for the smaller inclusion. A.M.C.

Diamonds in Canada.

B.A. KJARSGAARD AND A.A. LEVINSON. *Gems & Gemology*, **38**(3), 2002, 208-38.

A newcomer (since 1998) as a supplier of rough diamonds to the world market, Canada is currently the seventh most important diamond producer by weight and fifth by value. In this paper, the history of the explanation for, and the discovery of, primary diamond deposits throughout Canada (538 kimberlites reported) is chronicled, with particular emphasis on the important kimberlite pipes in the Northwest Territories. These pipes typically are small but have high diamond grades. Sales of the rough diamonds, and the developing cutting and polishing industry in Canada, are described. The Lac de Gras area in the Slave craton contains the most important Canadian deposits so far recognized, with economic pipes at Ekati and Diavik. R.A.H

Legal protection for proprietary diamond cuts.

T.W. OVERTON. *Gems & Gemology*, **38**(4), 2002, 310-25.

Proprietary brand names can be protected by trademark registration (typically noted by a registration symbol [®] next to the brand name), while proprietary designs or products can be protected by patents. Both methods have limitations, but it is important to protect a valuable diamond cut. A list of recent U.S. proprietary designs is given in an appendix. [The author is a licensed attorney and a gemmologist.] R.A.H.

Report on the diamondiferous kimberlite fields in the State of Chattisgarh and neighbouring states based on various papers presented at the International Conference on Diamonds and Gemstones held at Raipur from 9th-15th February 2002.

J. PANJIKAR, M. DHANDIA AND K.T. RAMCHANDRAN. *Indian Gemmologist*, **10**(4), 2002, 11-21.

General survey of the diamondiferous areas of the State of Chattisgarh, western India and neighbouring states with respect to recently discovered occurrences. M.O'D.

[On the discovery of diamonds in the Msta River middle stream (Novgorodsky region).]

E.G. PANOVA AND A.P. KAZAK. *Proceedings of the Russian*

Abstractors

R. Arnaudova	R.A.	R.A. Howie	R.A.H.	P.G. Read	P.G.R.
A.M.Clark	A.M.C.	M. O'Donoghue	M.O'D.	E. Stern	E.S.
J. Flinders	J.F.				

For further information on many of the topics referred to, consult *Mineralogical Abstracts*

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Mineralogical Society, **131**(1), 2002, 45-7. (Russian with English abstract.)

In the East European platform, kimberlites are related to the Middle Devonian stage of platform development. In this epoch, the kimberlites of the Belomorsko-Kuloiskoye plateau and the Middle Timan ridge pipe-shaped alkaline-ultramafic bodies of the Arkhangelskaya region and the complex of kimberlites and alkaline-ultramafic rocks of the Tersky coast of the White Sea were intruded. A new aureole of diamonds and associated minerals is reported from the central Devonian field; they were found in a 20 litre sample and include one 2 mm octahedron and four fragments. R.A.H.

Crystalline inclusions in diamonds from kimberlites of the Snap Lake area (Slave Craton, Canada): new evidences for the anomalous lithospheric structure.

N.P. Pokhilenko, N.V. Sobolev, J.A. McDonald, A.E. Hall, E.S. Yefimova, D.A. Zedgenizov, A.M. Logvinova and L.F. Reimers. *Doklady, Russian Academy of Sciences, Earth Sciences Section*, **380**(7), 2001, 806-11. (English translation.)

This kimberlite dyke complex is the largest American native diamond deposit. The compositions of crystalline inclusions in 109 diamond crystals are reported, the distribution demonstrating that most of the diamonds examined contain inclusions of minerals of ultramafic paragenesis. Olivine inclusions occurred in 84 crystals. Analyses are tabulated of garnet and clinopyroxene inclusions in ten diamonds. The data obtained confirm the assumption of the anomalous composition of kimberlites and the unusual structure of the lithosphere beneath them. A.M.C.

Coesite inclusions in rounded diamonds from placers of the northeastern Siberian Platform.

A.L. Ragozin, V.S. Shatsky, G.M. Rylov and S.V. Goryainov. *Doklady, Russian Academy of Sciences, Earth Sciences Section*, **384**(4), 2002, 385-9. (English translation.)

The diamond crystals studied (3–4 mm in size) have a dark grey to almost black colour caused by abundant fluid inclusions with graphite-type carbon on the walls. In addition, colourless faceted mineral inclusions were also present. The chemical composition and intense band at 521 cm^{-1} in the Raman spectra indicate the presence of coesite in the inclusions. A table is presented of impurity centres and nitrogen content in eight diamonds from these placers. The discovery of coesite inclusions significantly constrains the genesis of the diamonds, suggesting that they belong to an eclogite paragenesis. A.M.C.

A note on diamond incidence in Wairagarh area, Garhchiroli District, Maharashtra.

K. Sashidharan, A.K. Mohanty and A. Gupta. *Journal of the Geological Society of India*, **59**(3), 2002, 265-8.

During an ongoing search for kimberlite-lamproite rocks in the W Bastar craton, a single octahedral crystal (0.15 ct) of gem-quality diamond with a light greenish tint was found in a highly deformed polymictic conglomerate of probable early Proterozoic age in the Wairagarh area of central India. R.A.H.

Kankan diamonds (Guinea) III: $\delta^{13}C$ and nitrogen characteristics of deep diamonds.

T. Stachel, J.W. Harris, S. Aulbach and P. Deines. *Contributions to Mineralogy & Petrology*, **142**(4), 2002, 465-75.

Kankan diamonds formed over a large depth profile from the cratonic mantle lithosphere through the asthenosphere and transition zone, and into the lower mantle. Diamonds from this whole depth range have had their C isotope composition, N impurity content and N aggregation level determined. Lithospheric peridotitic and eclogitic diamonds have $\delta^{13}C$ of –5.4 to –2.2‰ (peridotitic) and –19.7 to –0.7‰ (eclogitic), and N contents of 17–648 atomic ppm (peridotitic) and 0–1313 atomic ppm (eclogitic) typical for these diamonds worldwide. Geothermobarometry on these two suites implies they formed under similar conditions, inconsistent with derivation of diamonds with light C isotope composition from subducted organic matter within subducting oceanic slabs. Diamonds with majorite garnet inclusions are isotopically heavy ($\delta^{13}C$ of –3.1 to –0.09‰) and have N contents of 0–126 atomic ppm, precluding prolonged exposure within the transition zone. This implies rapid upwards transport and coincident Kankan diamond formation and Cretaceous kimberlite activity. Similar to the asthenosphere and transition zone diamonds, those from the lower mantle are also isotopically heavy ($\delta^{13}C$ of –6.6 to –0.5‰). This shift towards heavier isotope compositions of sub-lithospheric diamonds suggests a common C source that may have inherited this heavy composition from a subducted carbonate component. J.F.

Evidence to show the presence of seed in natural diamond crystals and its implication to the genesis of diamond.

I. Sunagawa, T. Yasuda and H. Fukushima. *Indian Gemmologist*, **10**(4), 2002, 8-10.

In two brilliant-cut diamonds proved to have come from the same rough crystal it was shown that growth took place on a cuboid diamond seed which after formation in one environment was transported to another in which the major growth took place. The cuboid may have formed in ultra-high pressure metamorphic rocks in a subduction zone. M.O'D.

[Change of colour produced in natural brown diamonds by HPHT-processing.]

V.G. Vins. *Proceedings of the Russian Mineralogical Society*, **131**(4), 2002, 111-17. (Russian with English abstract.)

The change in colour produced by high-*P*–high-*T* processing of natural brown diamonds at 5.0–6.0 GPa and 2100–2300 K has been investigated by absorption spectroscopy in UV, visible and IR ranges. Such treatment of the IIa type makes them colourless, but occasionally

they acquire a light pink colour. Diamonds of the Ia type change from brown to bright yellow-green of various tints. The depth of colour, as well as the ratio between yellow and green tints, depends on the absorption intensity of N3, H4, H3 and H2 nitrogen-vacancy centres formed during the HPHT treatment. It is concluded that annealing of plastic deformation takes place during the HPHT treatment and thus the density of dislocations decreases. The energy activating the dislocation movement due to the plastic deformation annealing amounts to 6.4 eV. Models of the colour centre transformations are discussed and colour photographs of diamonds faceted after HPHT processing are presented. R.A.H.

[Lattice distortion in diamonds.]

Z.-Z. YUAN, Z.-J. YANG AND M.S. PENG. *Bulletin of Mineralogy, Petrology and Geochemistry*, **21**(2), 2002, 114-16. (Chinese with English abstract.)

Although diamond is isotropic, it shows anisotropism in polarized light. The optical properties of 24 diamonds have been examined and their oriented IR spectra measured ⊥ (100), ⊥ (110) and ⊥ (111). The occurrence of anisotropism is due not only to the uneven distribution of impurities such as N, B and H, but also to the presence of inclusions which induce lattice distortion. R.A.

Ferropericlase inclusions in a diamond microcrystal from the Udachnaya kimberlite pipe, Yakutia.

D.A. ZEDGENIZOV, E.S. YEFIMOVA, A. M. LOGVONOVA, V. S. SHATSKY AND N. V. SOBOLEV. *Doklady, Russian Academy of Sciences, Earth Sciences Section*, **377A**(3), 2001, 319-21. (English translation.)

In a small diamond several prismatic inclusions of yellow-brown ferropericlase were found. EPMA of two inclusions are presented and these contain respectively 23.6 and 21.0 wt.% and 21.0 wt.% FeO and 1.44 and 1.39 wt.% NiO. Two possible explanations for their presence in diamond are proposed. The mineral may be formed at the expense of olivine decomposition in the lower mantle or it may represent a product of peridotite and eclogite formed under extreme reducing conditions. A.M.C.

Gems and Minerals

Gemmological observations as clues to problems of ore and rock genesis and vice-versa.

G.C. AMSTUTZ. *Gemmologie. Z. Dt. Gemmol. Ges.*, **51**(2/ 3), 2002, 61-6, 1 table, bibl.

Successful exploration of ore and gemstones depends on sound ideas about where to find them and sound ideas as to why they were formed in particular places. Gemstones are amongst the most investigated of all minerals and it is logical that we should use the results of gemstone research as guidance in our attempt to understand their mode of formation. A few examples are mentioned and it is recommended that we stick to sound facts instead of jumping on new bandwagons of dogmatic interpretation. E.S.

Mineralien finden! Abenteuer alpine Strahlerei.

C. BODENMANN. *Lapis*, **27**(5), 2002, 13-29.

An Alpine crystal collector reviews some of his expeditions and describes some of the more spectacular crystals he has found. They include amethyst and rock crystal, kyanite and sphene. M.O'D.

Some lesser known Australian opals.

G. BROWN. *Gemmologie. Z. Dt. Gemmol. Ges.*, **51**(2/3), 2002, 97-106. 1 map, 13 photographs, 5 diagrams, bibl.

Australia produces 95% of the world's precious opal. This is exported mainly as rough consisting of a mix of black, dark and light type 1 natural opal, boulder opal (type 2 natural opal) and type 3 natural opal or opal matrix. Australia also produces a range of lesser known opals that display properties and features of interest to gemmologists, although most have little commercial value. The article describes some lesser known opals, such as the White Cliffs opal 'pineapples', Tintenbar volcanic opal which are of historic interest, Andamooka matrix opal, opal associated with 'thunder eggs' and some facetable common opals, such as siliciophyte cat's-eye. E.S.

New imitation gemstones from Australia.

G. BROWN AND T. LINTON. *Australian Gemmologist*, **21**(7), 2002, 283-6, 11 illus. in colour, 2 tables.

Controlled devitrification of melts based on finely ground chrysoprase is being used in Brisbane, Queensland, by Australian Crystallization Technology Pty Ltd, to produce a range of semitranslucent to opaque imitations of chrysoprase, jadeite, turquoise, and other ornamental materials including a number of attractive transparent glasses of various colours. Details are given of the method of manufacture of these products and of their gemmological properties and features. P.G.R.

Faszination blauer Bernstein.

R. BURGLER. *Schweizer Strahler*, 2/2002. 12-14.

A description of amber in general and in particular of a specimen in the Natural History Museum, Stuttgart, which was found to show a blue colour in sunlight, under a halogen lamp and under fluorescent light. In the light from a traditional incandescent source the blue colour was less pronounced. Under UV radiation the specimen gave an intense blue. M.O'D.

Orange sapphires or just lemons?

T. COLDHAM. *Australian Gemmologist*, **21**(7), 2002, 288-93, 15 illus. in colour.

Parcels of orange sapphire from Songea in Tanzania, which had been subjected to a 'new' form of heat treatment, initiated the start of investigations by the author and other gemmologists into this new colour enhancement process. Songea ruby, when subjected to the new Thai process, lost its brownish shade and became the colour of burmese red spinel. More importantly poor colour Songea material in the brownish-yellows, reddish-orange and palish yellows also changed colour to various shades of

bright orange through to reddish-orange. By January of 2001 the new process was being applied to Malagasy pink sapphires making these stones look like naturally coloured 'padparadscha' sapphires and in some instances being certified as such. By the time of the Tucson Gem Show, the GIA reported the presence of small quantities of beryllium in the orange rim of these sapphires which increased in concentration towards the surface of the stone, indicating that the new treatment was a bulk diffusion process. The biggest problem identifying corundum treated by the new process occurs when no outer rim is visible, either because the rough was treated before cutting or the induced colour continues through to the core of the stone or the colour and size of the stone make visual detection of a differently coloured rim difficult. P.G.R.

Some aspects of precious opal synthesis.

S.V. Filin, A.I. Puzynin and V.N. Samoilov. *Australian Gemmologist*, **21**(7), 2002, 278-82, 10 illus., 1 table.

The total production time of the multi-step synthesis process as researched and developed by the authors is around 10 months. All the properties of the opals synthesized by this method (their 'closed' porosity, chemical composition of silica and up to 8% water, and hardness) are identical to those of natural precious opal. In addition, the rough synthetic opal can be easily cut and polished. P.G.R.

Gem and rare-element pegmatites of southern California.

J. Fisher. *Mineralogical record*, **33**, 2002, 363-407.

The pegmatites of the Himalaya, Tourmaline Queen, Stewart, Pala Chief and Little Three mines are among the world's leading producers of high-quality tourmaline, morganite and spodumene, together with aquamarine, topaz and spessartine. The history of gem mining in the region is described with reference to well-documented previous sources of which Jahns and Wright's study of this area (1951) is probably the most important. Individual mines are described in detail with diagrams and some of the claims and workings. Notable gem mineral specimens are illustrated and there is a bibliography of more than 50 entries. M.O'D.

Vom Smaragd zum Tanteuxenit.

F. Girlanda. *Schweizer Strahler*, 1/2002, 10-14.

Emerald is among the minerals found in the Val Vigezzo, Piedmont, Italy where it occurs in a pegmatite together with yellow-green beryl and other minerals. Two faceted stones are illustrated but their size is not given. M.O'D.

Amethyste vom Schöderhorn.

D. Grolig. *Mineralien Welt*, **14**, 2003, 41-8.

Well-formed crystals of amethyst are described from the Schöderhorn region of the Hohe Tauern national park, Austria. Sceptre crystals of deep colour have been found. Citrine was discovered during prospecting in 2000. M.O'D.

Die weltbesten Kosnarite aus Brasilien und das Amblygonit-Montebrasit-Problem.

J.C. Hyrsl and J. Sejkora. *Mineralien Welt*, **14**, 2003, 60-2.

Very fine crystals of kosnarite are described from a pegmatite at Limoeiro, Minas Gerais, Brazil, and crystals of montebrasite of exceptional quality from pegmatites between Linopolis and Galilea and between Virgem da Lapa and Taquaral, NW of Teofilo Otoni, in the same State. The relationship between the two minerals and with amblygonite is discussed. M.O'D.

Piteiras, Brasilien: erfolgreiche Smaragdsuche mit modernen Methoden.

J. Kanis. *Lapis*, **27**(3), 2002, 13-18.

Modern methods of recovery are in use at the Piteiras emerald deposit in Minas Gerais, Brazil where emerald is found with phlogopite and biotite. A crystal 18 cm in length is illustrated. M.O'D.

Zuchtperlen vom Golf of Kalifornien, Mexiko.

L.Kiefert. *Gemmologie. Z. Dt. Gemmol. Ges.*, **51**(2/3), 2002, 121-32.

In the Mexican part of the Gulf of California, natural black pearls have been found for a long time. Because of their high commercial value efforts to produce cultured pearls have been tried for some time with varying success. Now cultured mabe pearls have been produced in the indigenous pearl oyster *Pinctada mazatlantica* and round loose beaded cultured pearls have been produced in the indigenous *Pteria sterna*. The medium sized pearls are marked by a grey to dark grey body colour which is overlaid by interference colours caused by the stacking of aragonite tiles of 0.2–0.3 microns. Their colour is considered natural if their fluorescence in long wave UV light is red. E.S.

Bernstein an den Küsten und im Binnenland von Dänemark.

K. Krause. *Aufschluss*, **54**, 2003, 2-10.

Brief illustrated account of amber deposits around the coasts and on land sites in Denmark. M.O'D.

Gem news international.

B.M. Laurs (ed). *Gems & Gemology*, **38**(3), 2002, 258-75.

Items mentioned include aquamarine and spessartine from Tanzania, a dark brown beryl from Mozambique, gem tourmalines with a range of colours even from a single mine, three faceted morganites (3.34 – 4.19 ct) from a new pegmatite mine near Ambositra, Madagascar, and emeralds from Somaliland. R.A.H.

Gem news international.

B.M. Laurs (ed). *Gems & Gemology*, **38**(4), 2002, 348-69.

Items reported include alexandrite from Mananjary, Madagascar; a gem-quality colour-change apatite from

Kazakhstan; the reactivated San Pedro emerald mine in the Chivor region of Colombia; boulders of bluish-green and greenish-blue jadeite from Guatemala; faceted rossmanite and other tourmalines from Nigeria; brownish-orange uvite from Kunar Province, Afghanistan; new SIMS analyses of 20 examples of yellow, orange, pink or red Be-diffused corundum from Thailand; and a 2.95 ct topaz coloured orange by a thin coating of synthetic hematite applied to the pavilion. R.A.H.

Rhodizite-londonite from the Antsongombato pegmatite, central Madagascar.

B.M. LAURS, F. PEZZOTTA, W.B. SIMMONS, A.U. FALSTER AND S. MUHLMEISTER. *Gems & Gemology*, **38**(4), 2002, 326-39.

The rare Al-Be borate londonite is the caesium-rich analogue of rhodizite (which has K>Cs), these two end-members being distinguishable only by quantitative chemical analysis. Gem-quality londonite is recorded from the Antsongombato pegmatite in the Betafo region of central Madagascar, where colourless to greenish-yellow rhodizite-londonite has *n* 1.689–1.691, H. 8, SG 3.34–3.42. EPMA results are given for eight faceted specimens, showing that two are londonite, four are rhodizite and two contain both londonite and rhodizite. Raman, visible and FTIR spectra are discussed. R.A.H.

Die schönen Kiesel des Osterzgebirges.

M. LÜTTICH. *Lapis*, **27**(3), 2002, 19-24.

Fine ornamental agate is described from the eastern Erzgebirge of Germany: individual locations include Altenberg near Bärenstein, Cunnersdorf, Dönschten, Hartmannsdorf, Hirschsprung, Johnsbach, Bobritzsch, Carsdorf and Reichstädt. M.O'D.

Eine neue Opalsynthese aus Russland.

C.C. MILISENDA. *Gemmologie. Z. Dt. Gemmol. Ges.*, **51**(2/3), 2002, 115-20. 8 photographs, 1 table, 2 graphs, bibl.

Four types of synthetic opal have recently been produced by the Scientific Centre for Allied Research in Dubna, Russia. Type 1 and 2 resemble plastic impregnated material such as Gilson and earlier Russian productions. Type 3 resembles a natural white opal with distinct play-of-colour. It has no organic compounds and is virtually free of water. In a strict sense these samples have to be designated as opal imitations. However, Type 4 resembles natural opal not only in appearance but also in water content and can therefore be called 'synthetic'. It can be detected by the well known mosaic 'lizard-skin' pattern. E.S.

Gem Trade Lab notes.

T.M. MOSES, I. REINITZ, S.F. MCCLURE AND M.L. JOHNSON (EDS). *Gems & Gemology*, **38**(3), 2002, 250-7.

Notes are given on three faceted colourless crystals of synthetic bromellite (BeO), inclusions of charoite in a quartz-feldspar rock and a 9.80 ct oval greenish-blue cabochon of hemimorphite. R.A.H.

Gem Trade Lab notes.

T.M. MOSES, I. REINITZ, S.F. MCCLURE AND M.L. JOHNSON (EDS). *Gems & Gemology*, **38**(4), 2002, 340-7.

Notes are given on high-temperature Be lattice diffusion in corundum to yield pinkish-orange, orange, orangey-red and yellow sapphires as well as ruby. A bleached, polymer-impregnated and dyed bangle of jadeite jade is also reported. R.A.H.

Agate: a study of ageing.

T. MOXTON. *European Journal of Mineralogy*, **14**(6), 2002, 1109-18.

The degree of crystallinity in wall-lining agates from host rocks of varying ages has been measured using XRD. A plot of agate crystalline size *vs* log age of host rock shows a general increase in crystalline size with increasing age of the host rock: a regression line: size =106 log host rock + 211 was obtained. The SEM confirms that ageing produces a growth in the surface globulites and development of plate edge-like structures within the white bands. This dynamic growth of crystallites results in an increase in density. A high correlation between agate crystallite size and age of the host rock shows that the formation of wall-banded agates is penecontemporaneous with the formation of the host rock. The determination of crystallite size in such agates allows either an estimation of the approximate age of the host rock or an identification of a known agate region. R.A.H.

Tucson 2002 – Nichts ist mehr so, wie es früher einmal war!

G. NEUMEIER. *Lapis*, **27**(5), 2002, 35-9.

Among gem-quality minerals on display at the 2002 Tucson Gem and Mineral Show were crystals of the hackmanite variety of sodalite from Kiran in the Kokcha valley, Badakshan, Afganistan and green transparent fluorapatite crystals on stilbite, from Shird, Ahmednagar District, Maharashtra, India. M.O'D.

Vanadium-Berylle aus dem östlichen Himalaya.

G. NIEDERMAYR, F. BRANDSTÄTTER, J. PONAHLO AND E. SCHWARZER-HENHAPL. *Gemmologie. Z. Dt. Gemmol. Ges.*, **51**(2/3), 2002, 107-14. 7 photographs, 2 tables, 2 graphs, bibl.

Vanadium beryls from a new occurrence, probably Sikkim or Bhutan, are described. Further details of their occurrence could not be established. Eight emeralds were examined, weighing 0.22–0.48 ct. They have a very low chromium content and relatively high contents of Fe and V. Although the stones contain three-phase inclusions, they are dissimilar from those offered from Russia, Africa, India, Brazil or Colombia; therefore one can assume that these stones come from a new source. E.S.

Liddicoatite von Sandnessjøen, Nord-Norwegen.

F.S. NORDRUM. *Mineralien Welt*, **14**, 2003, 49-52.

Crystals of liddicoatite are described from a lithium-bearing granite pegmatite in the Sandnessjøen area of

northern Norway. Specimens found in lepidolite-rich and quartz matrixes ranged up to 5 cm and some are of ornamental or gem quality. M.O'D.

Die Seltenheit der Edelsteine aus petrologischer Sicht.

M. OKRUSCH AND H. BANK. *Gemmologie. Z. Dt. Gemmol. Ges.*, **51**(2/3), 2002, 67-96. 7 tables, 14 photographs, 5 diagrams, bibl.

The majority of gem materials are distinguished by outstanding physical properties mostly leading to attractive optical phenomena. Diamonds, emeralds, alexandrites and rubies are used as examples to describe specific conditions and geological processes which lead to the formation of the gem material. In each of these cases the authors describe the specific conditions which have to be met and explain the subsequent rarity of the stone. E.S.

Schmucksteine aus Nussbach.

W. OPPELT. *Der Erzgräber*, **16**, 2002, 7-10.

Describes the occurrence, mining history and fashioning of a pale blue porphyry found at Nussbach, Germany. M.O'D.

Comparative study of corundum from various Indian occurrences – corundum from Kerala.

J. PANJIKAR. *Indian Gemmologist*, **10**(4), 2002, 23-8.

Corundum found at Noolpuzha in the Indian State of Kerala is red with a strong tint of blue. Properties are in the normal range for ruby. The most prominent solid inclusions are rounded dark brown crystals surrounded by liquid films: similar solids in Thai rubies have been identified as garnet. Twin lamellae are also prominent. M.O'D.

Basalt-Opal aus Honduras.

P. PRÜFER. *Lapis*, **27**(4), 2002, 35.

Short note on a gem-quality opal found in basalt at Erandique, Honduras. The photograph shows a dark cabochon with attractive play-of-colour. M.O'D.

Einschlüsse und Begleiter der 'Schaumberger Diamanten' con Extertal, Weserbergland.

P. PRÜFER. *Lapis*, **28**(1), 2003, 11-17.

Pyrite, marcasite and goethite pseudomorphs after pyrite have been noted as inclusions in well-formed clear specimens of rock crystal from Extertal, Weserbergland, Germany. The name 'Schaumberger diamonds' has been given to the crystals. M.O'D.

Classification of natural opal type 1.

J. SCHELLNEGGER. *Australian Gemmologist*, **21**(7), 2002, 270-77, 5 illus., 1 glossary, 1 reference guide, 1 table.

The author describes a practical method, devised by the Opal Advisory Service of Lightning Ridge, New South Wales, Australia, for the evaluation of natural opal. The method quantifies the positive factors that determine the value of opal (including body tone, brilliance, pattern, thickness of colour bar and colour). From these factors are deducted certain fault features (such as cracks and crazing, colour not facing, poor cut, shape and polish). Use of an associated code allows individual opals to be accurately and reproducibly described. P.G.R.

Falsche "Sternsteine": Manipulationen an Edelsteinen zur Erzeugung oder Intensivierung von Asterismus.

K. SCHMETZER AND M. GLAS. *Lapis*, **28**(1), 2003, 22-41.

Asterism in cabochon-cut gemstones can be induced or enhanced by a variety of techniques which are described and illustrated. M.O'D.

Die berühmten Jaspachate von Giuliana/Sizilien.

R. SCHMIDT. *Lapis*, **27**(12), 2002, 21-37.

Fine coloured specimens of jasp-agate are described from Guiliana, Sicily. Notes on the use of the material as an ornamental hardstone are given. M.O'D.

How grey limestones become white marbles.

J. SCHMIDT AND I. FLAMMER. *European Journal of Mineralogy*, **14**(4), 2002, 837-48.

In the contact aureole of the Adamello pluton, N. Italy, nearly pure calcite rocks ($CaCO_3$ > 99 wt.%) undergo a transition from dark and light grey very low-grade metamorphic limestones to white and dull white marbles close to the intrusive contact. The grey colour of the limestones is caused by as little as 0.05 wt.% finely dispersed organic carbon. On nearing the contact, the C_{org} content decreases with increasing metamorphic grade, producing a pure white to dull white marble with C_{org} < 0.02 wt.%. Grain size and grain-boundary width have a secondary effect by controlling light absorption, and thus brightness. R.A.H.

Chart of commercially available gem treatments.

C.P. SMITH AND S.F. MCCLURE. *Gems & Gemology*, **38**(4), 2002, 294-300 (+ large folding chart).

A chart is included which combines a comprehensive listing of commercially available treatments for the more commonly used gem materials with an indication of the current status of their detectability. The information provided includes the use of dyes, chemical bleaching, surface coating, impregnation, thermal enhancement, diffusion treatment, irradiation and clarity enhancement. R.A.H.

Magaliesberg ist Marble Hall! Über die neuen Amethyste aus Südafrika.

K. SPRICH, S. KÖNIG AND S. JAHN. *Mineralien Welt*, **14**, 2003, 53-9.

Gem-quality amethyst of fine quality is described from the Magaliesberg area of South Africa. The workings at Marble Hall are close to Groblersdal on route N11. Details of the local geology and mine workings are given. M.O'D.

History of the Tourmaline Queen mine, San Diego County, California.

E.R. SWOBODA. *Mineralogical record*, **33**, 2002, 409-25.

The Tourmaline Queen mine, Pala, southern California, has produced some of the world's finest crystals of tourmaline and morganite. It is still in production. The geology and mineralization of the mine are described and illustrated, and anecdotes of the discovery of major specimens accompany photographs of many of them. M.O'D.

Method for determining the cleavability of fluorite.

O. VITOV AND L. KONSTANTINOV. *Comptes Rendus de l'Académie Bulgare des Sciences*, **54**(3), 2001, 55-8.

A simple method is proposed for quantitative evaluation of the cleavability of fluorite. This method is based on statistical averaging of the numbers of differently shaped fragments of fluorite crystals and crystalline grains broken mechanically into small (~1 mm) pieces. The coefficient of 'imperfect' cleavability, K (*hkl*) and 'perfect' cleavability along (111), K(111), are introduced. In these terms, the cleavability of 'real' fluorite crystals can be presented through a point in Cartesian coordinates with abscissa K(111) and ordinate K(*hkl*). The position of this point with respect to that for a perfect single crystal of fluorite, can serve as an indication of perfection of a given crystal. This method makes it possible to classify the material for growth to CaF_2 single crystals of optical quality. R.A.

Zepterquarze und Amethyst aus dem Maltatal, Kärnten, Österreich.

S. WEISS. *Lapis*, **27**(12), 2002, 13-20.

Well-formed crystals of amethyst and rock crystal of collecting quality are described from the Maltatal, Carinthia, Austria. Sceptre habit is particularly notable. M.O'D.

Jeremejevite from Namibia.

W.E. WILSON, C.L. JOHNSTON AND E.R. SWOBODA. *Mineralogical record*, **33**, 2002, 289-301.

Cornflower-blue and water-clear crystals of jeremejevite were reported from Mile 72, north of Swakopmund, Namibia, in 1973 and the site was reworked in 1999, this time producing only colourless to pale yellow material. A location in the Erongo Mountains worked in 2001 has produced fine transparent blue crystals. Many of the Namibian crystals are of potential gem quality. The first occurrence of jeremejevite was reported in 1883 from a pegmatite on Mount Soktuy, Chitinskaya Oblast in the Nerchinsk district of Transbaikalia, Russia. M.O'D.

Instruments and Techniques

Microminerals.

Q. WIGHT. *Mineralogical record*, **33**, 2002, 337-9.

Describes a microscope lighting system devised by A.D. Morgan of the British Micromount Society. White high-intensity LEDs give light at 8000°K and use very little power. The light is towards the blue end of the spectrum but this can be compensated for by the use of the appropriate filters. M.O'D.

Stabvilisierung, Re paratur und Rekonstruktion von Mineralstufen: Was ist erlaubt?

M.L. WILSON. *Lapis*, **27**(12), 2002, 38-9.

Notes on the repair and reconstruction of mineral specimens consider techniques and propriety. M.O'D.

Synthetics and Simulants

Spectroscopic studies of coloured, synthetic corundums and spinels produced in Skawina.

M. CZAJA. *Mineralogia polonica*, **31**, 2000, 55-69.

Crystals of corundum and spinel have been produced at the Research and Development Laboratories at the aluminium plant near Kraków, Poland. Optical differences between specimens of both species are described. The main reason for colour-changes observed is the presence of more than a single colouring ion. All spinel colour varieties were non-stoichiometric with an $MgO:A1_2O_3$ ratio of 1:2.6. Results show tetrahedral coordination of Co^{2+} in the spinels and Mn^{2+} in the $A1_2O_3$. M.O'D.

Gemesis laboratory-created diamonds.

J.E. SHIGLEY, R. ABBASCHIAN AND C. CLARKE. *Gems & Gemology*, **38**(4), 2002, 301-9.

High-quality yellow, orange-yellow and yellow-orange laboratory-created type 1b diamond crystals up to 3.5 ct are being produced commercially by the Gemesis Corp. of Sarasota, Florida. In some samples, colour zoning (yellow and narrower colourless zones) and a weak UV fluorescence pattern (a small green cruciform zone combined with an overall weak orange luminescence) provide means of identification; when present, metallic inclusions also indicate laboratory growth. In the absence of such features, all of these Gemesis synthetic diamonds can be identified either by the DiamondView luminescence imaging system or by the presence of Ni or Co in the energy dispersive XRF pattern. Mention is also made of other kinds of synthetic diamonds produced by Gemesis. R.A.H.

'Diffusion ruby' proves to be synthetic ruby overgrowth on natural corundum.

C.P. SMITH. *Gems & Gemology*, **38**(3), 2002, 240-8.

In a relatively new production of red corundum, claimed to be red diffusion-treated corundum (i.e. shallow coloration) by the lattice diffusion of Cr, the surface layer is actually an overgrowth of synthetic ruby on natural colourless or near-colourless corundum. After recutting, the overgrowth layer is seen to typically range from <0.1 to 0.3 mm thick. This material can be distinguished from red lattice-diffusion treated corundum by the presence of a boundary plane and two different types of inclusion features. R.A.H.

BOOK REVIEWS

Le Mont Chemin.

S. Ansermet, 2001. Musée cantonale d'histoire naturelle, Sion. pp 302, illus. in colour. Softcover ISBN 2 940145 28 8. Sfr 70.

For those readers who are also mineral collectors this attractive book is worth buying. Mont Chemin is in the Swiss canton of Valais, near the town of Martigny. The main text comprises a full descriptive mineral list arranged alphabetically and there are also sections on local geology and mineralization. The location is especially noted for fine orange crystals of wulfenite. M.O'D.

Aquamarin & Co.

Christian Weise Verlag, Munich, 2002. pp 96, illus. in colour. Softcover ISBN 3 921656 61 3 (ISSN of parent journal *Lapis* 0945-8493, *extraLapis* no. 23) Euros 17.80.

Previous numbers of *ExtraLapis* (1, revised in 21) dealt with emerald. This issue describes aquamarine, golden/yellow, pink, red and colourless beryl. As in other issues of the series the work of individual authors is submerged in the general text though there are stand-alone papers on beryl from Alpine regions and from Madagascar, and on synthetic beryls. There is a short bibliography. The quality of the colour photographs (including reproductions from early mineralogical works) is exceptional. Sets will soon be hard to acquire: the subscription to *Lapis* does not cover the monographic series. M.O'D.

The World's mineral masterpieces.

E. Equit, 2002. Eberhard Equit & Co., Berlin [Fehrbellinerstr 49, D-10119]. In German and English, pp 289, illus. in colour. Hardcover, in slip case. Limited Edition (700 copies). ISBN 3 930874 06 7. Euro 260.

In more than 30 years of reviewing and general familiarity with mineral and gem books from all over the world, I have seen nothing to compare with this collection of mineral and gem crystal paintings by the author. Each specimen is described by its present owner, the first ones by Bill Larson of Pala International fame and others by collectors of similar authority who in many cases describe how and where the specimens are acquired. The paintings themselves are exquisitely done with colours as close as possible to the originals, whose sizes are given. There is a short bibliography whose entries extend the material given in the descriptions.

Gemmologists will find that quite a lot of the minerals depicted are of gem quality and have been selected for that reason. They include tanzanite, ruby and blue sapphire from Myanmar and Sri Lanka, emerald from Colombia, red beryl from Utah, tourmaline from major Brazilian localities, epidote and emerald from the Habachtal, Austria, and many more. The reader should bear in mind that these specimens have been acquired by their owners in recent years and that the paintings are not of specimens already well illustrated in earlier books.

For such wealth of beauty and imaginative presentation of information the price is very reasonable: the whole production, on specially-chosen and very appropriate paper and housed in a strong slip-case will delight and inform for a lifetime. M.O'D.

Minerals of Scotland, past and present.

A. Livingstone, 2002. National Museums of Scotland Publishing Ltd, Edinburgh. pp xvi, 212, illus. in colour. Softcover, ISBN 1 901663 46 9. £35.00.

The unusual format serves very well to present this excellent survey of the minerals of Scotland, their collectors, repositories and properties. Visitors to the collections at Chambers Street will know that the presentation there is among the best anywhere and serious work continues to be carried out behind the scenes.

The book begins with a geological survey of Scotland with maps in colour and notes on its geological evolution, continuing with a history of collectors and their collections. As always, not all of them can now be located, or, rather, some individual specimens described years ago cannot now be found. Nevertheless this account is excellently presented with illustrations of some of the collectors and pages from their notebooks and catalogues.

The author now describes the major extant mineral collections in Scotland, both institutional and personal (I salute those private collectors who have allowed details of their collections to be published). The institutional collections are described extensively with some notes on their foundation and subsequent history.

From pages 93 to 130 selected minerals are described in alphabetical order with history and considerable detail; this section is followed by the colour photographs of common and unusual, species – 'The mineral album'. Here the quality is as high as the rest of the book, name, dimensions, location and provenance being given in each case. The album serves also as a display of how well minerals can now be photographed.

From pages 155-187 the entire 552 species native to Scotland are described in Appendix 1, with short entries giving name, composition, crystal system, description and localities. Appendix 2 describes the 29 species originally found in Scotland and Appendix 3 contains 33 species additional to those not already listed in previous published lists of 1981 and 1993. An excellent section of references, a bibliography and index complete the book.

Are the Scottish gemstones listed? Yes: there are details (not too specific) of the occurrence of blue sapphire at Carishader, Loch Roag, Lewis, Outer Hebrides and illustrations of a fine crystal and faceted stone from that locality. The tourmaline (a fine blue elbaite crystal) from Glenbuchat, Aberdeenshire, is also shown. M.O'D.

The physics and chemistry of color.

K. NASSAU, 2002. 2nd edn. Wiley Interscience, Chichester. pp xx, 481. Hardcover. ISBN 0 471 391069. £80.50.

A welcome re-appearance of this major text enables the reviewer to recommend it to a new generation of readers. The book had just appeared as I write in December 2002 though the preface is dated 2000, but this has made no difference to topicality. In the preface Nassau in characteristic style lists several areas in which errors are consistently found in both the popular and scientific media: all of them are examined and explained. New sections and those expanded from the first edition include details on colour vision defects, the measurement and display of colour and the construction and use of colour order systems.

Gemmologists will find a description and explanation of the Usambara effect (it is found in some plastics as well as in some gem minerals) as well as the better-known causes of colour: they are all most lucidly explained. A feature of this edition is the incorporation of references into the main text as an exhaustive bibliography of the subject is not easy to handle. There is one, however, in Appendix G, *Recommendations for future reading*. As before, each chapter ends with a set of problems (answers not provided) and a central section contains 42 colour photographs, many not included in the previous edition. The quality of reproduction is excellent.

One fallacy from the 14 listed by Nassau in the preface is that for each wavelength of the spectrum there is a unique perceived colour; for example, 590 nm light is orange to everyone and at all times. If you want to find out the fallacy here this book is still, probably, the only one in which you will find it discussed. This is only one reason why gemmologists should try to obtain a copy. It has given me at least as many enjoyable hours as any book I have ever read. M.O'D.

Mogok: eine Reise durch Burma zu den schönsten Rubinen und Saphiren der Welt.

R. SCHLÜSSEL, 2002. Christian Weise Verlag, Munich. pp 280, illus. in colour. Hardcover, ISBN 3 921 65660 5, Euros 108.

Elegantly written and most beautifully produced travel guide to the Mogok area of Myanmar with intensive study of ruby and sapphire production, this book seems to indicate a very slight easing of travel restrictions in this area (cf.Themelis, *Mogok, valley of rubies and sapphires*, 2000). Whatever the reason, this book is most welcome: it deals first with the country as a whole with notes on history, religion, customs and building in a clear text which occupies approximately half of the book. The remainder takes the reader to the Mogok stone tract (good to hear this traditional name once more) and to the rubies and sapphires found there as well as to peridot, johachidolite, painite, thorite, danburite, poudrettite [potassium sodium borosilicate of the osumilite group, purple to violet] and periclase which are the only other species with full descriptions though a full name and list of gem and ornamental minerals is given (not all Myanmar gem minerals come from the Mogok area). Jadeite rough is mentioned in an earlier chapter.

The gemmological properties of ruby and sapphire have a chapter to themselves, in which the main features of specimens from other major world occurrences are also given. This section contains some excellent photographs of inclusions. Later chapters deal with fashioning, testing and certification, mounting in jewellery and one or two other major Mogok species including spinel. All the photographs come close to the best I have yet seen in a monograph. There is a glossary and a bibliography in which, though the entries are brief, a large number of items unlikely to be familiar to gemmologists are included. The only desideratum is an index.

While the book is partly intended to give pleasure and to introduce a little-known area of the Earth, it is well able to stand up as a study of the corundum gems and to act as a gemmological reference tool. M.O'D.

Smaragde der Welt.

Christian Weise Verlag, Munich, 2001. pp 96, illus. in colour. Softcover. ISBN 3 921656 58 3 (ISSN of parent journal *Lapis* 0945-8493, *extraLapis* no.21) DM39.80.

This is a new edition, by various authors, of the first *ExtraLapis* published in 1993. As always so far the different papers run together without obvious breaks and while covering the traditional emerald-producing areas the authors bring in new deposits and further details of the crystals more recently found. It is not easy to single out one particular section but I particularly admired the coverage and illustrations of the celebration of 100 years of emerald crystal growing (look at the inclusion pictures!) and of the surveys of the deposits in Nigeria (Jos Plateau), Pakistan (Swat), Russia (Malyshewo), and more traditional sites. Somalia and Namibia are added to the review of African emerald locations. There is much more but all gemmologists should buy this book (and its companions). M.O'D.

Sammlerglück: die Achatfundstelle Geisberg bei Schweighausen.

INGO STENGLER, 2000. Verlag Weissmoos, Lahr-Schwarzwald. pp 285, illus. in black-and-white and in colour. Hardcover ISBN 3 00 006801 5. DM 69. (Available through Verein der Freunde von Mineralien und Bergbau, D-77709 Oberwolfach, Germany: payment details – Kto 513003 Sparkasse Haslach-Zell, BLZ 664 515 48.)

A guide to the attractive agate specimens to be found in the central German Schwarzwald, the book is clearly a long-planned labour of love and succeeds admirably in presenting the geology and formation of the agates, nearly 70 of which are well illustrated in colour. The collector will be able to follow the author's trail and perhaps find attractive specimens too since the main areas are not too difficult to pin down from what is given in the text: I should imagine, though, that some thoughts of conservation have very properly been in the author's mind since coordinates are not provided: there is a quite adequate bibliography. Probably many readers with an

interest in agate colour and patterning will find the book of particular appeal since the author obviously likes speculation in this field and also in the history of the working of the deposits. M.O'D.

Südtirol und die Dolomiten.

Christian Weise Verlag, Munich, 2002. pp 95, illus. in colour. Softcover, ISBN 3 921656 59 1 (ISSN of parent journal *Lapis* 0945-8493, *extraLapis* no. 22) Euros 17.80.

Seamless treatment by a number of authors (names given) of the mineral deposits of the southern Tirol, Austria. Among the species described and excellently illustrated are green crystals of sphene from the Sattelspitz and small crystals of aquamarine from the Griesferner, Pfitsch. Many of the finest crystals are micromount or thumbnail size. Maps and details of the geology and different mineralizations are given, but only six references are provided and there is no index. Nonetheless this is a beautiful book as all in this series are and it will certainly be welcomed by the many collectors focusing on this productive area. M.O'D.

Edelsteine in der Bibel.

W. Zwickel (ed.), 2002. Philipp von Zabern, Mainz am Rhein. pp vii, 99. Hardcover ISBN 3 8053 2912 1, £18.00.

It is many years since a study, however short, of the gemstones mentioned in the Bible appeared on the market and even then most of them contained few if any notable illustrations. This beautifully designed and printed study by four authors deals with selected topics and illustrates artefacts which form an exhibition planned to visit several cities in Germany.

The objects are fully described by professional archaeological standards; gemmologists will find the whole text worth serious study but the chapter on the High Priest's breastplate will probably attract the attention first as the minerals used are described and illustrated, given their proper names and shown in their rough form.

There is an extensive general bibliography and several well-presented maps help the reader to pinpoint areas of biblical significance. Biblical texts are given in all relevant places. Archival quality paper has been used. M.O'D.

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Proceedings of the Gemmological Association and Gem Testing Laboratory of Great Britain and Notices

J. (JIMMIE) K. CAIRNCROSS

A tribute by David Callaghan

Mr J. (Jimmie) K. Cairncross FGA (D.1940), family jeweller of Perth, Scotland, died on 15 November 2002 at the age of 82. Notices such as these are so abrupt, cold yet factual and tell you only the end of a life but none of the impact made during its span. Let me tell you just a little of this special man, a personal friend for over 35 years. Jimmie was born into a jewellery family, his grandfather and great uncle having founded the firm of A. & G. Cairncross, Perth, in 1869.

He began his career in the trade, training with the renowned Edinburgh firm of Hamilton & Inches just before the onset of World War II. On the outbreak of War he joined the Royal Navy where he saw action on three of the convoys to Northern Russia. After the War he entered the family firm and, not long afterwards, he was joined by his younger brother, Alastair. Together they formed a business partnership that epitomized everything that is to be admired in a family business. Alastair (D.1948) was a highly talented artist and many of the pieces of jewellery containing Scottish fresh water pearls – for which Cairncross of Perth were justly famous – were designed by him. Sadly he was to die suddenly in 1988 (obituary *J. Gemm.*, **21**(3), 1988, p. 199).

Jimmie was a man of outstanding generosity: with his friendships; his courteous manner and manners; and his wide range of interests. He was passionately interested in sports notably sailing, rugby and golf. Above all he, and Alastair, showed their generosity of spirit and purpose in the great encouragement they gave to young people. Jimmie loved the jewellery trade not only for the wonderful gifts of nature we handle, but for the people who serve it. The brothers Cairncross were great supporters of the trade, particularly the National Association of Goldsmiths (NAG) and the former GA. In recognition of this Jimmie served a two-year term as NAG President in 1987/88.

Jimmie loved his native land of Scotland and particularly his annual August 'pilgrimage' to Iona. A man of steadfast Christian faith this was not a religious outing, however; he and a group of friends were there to renew their friendship and to play golf. I think back to the many, many occasions over the years when he and I played golf, particularly in Scotland, and every one was a pleasure for me. I think I never won!

Jimmie never married and always said his friends were his family. He was a copious writer of letters and any visit, telephone call or gift resulted in a post card of thanks written in his own inimitable handwriting, so small that you could imagine that it had been written in a secret almost furtive way in case he was seen doing so! My wife, Mary, and I visited him on many occasions during our holidays in Scotland and this always prompted a card with the closing sentence *'haste ye back'*. During his last illness he received many cards, messages of good will and visitors. So numerous were these goodwill messages that one of his nurses was prompted to say to him, *"Mr Cairncross, you do seem to have an awful lot of friends."* This prompted Jimmie's reply, *"Yes I have, and I have an awful lot of friends where I'm going!"*

His life enriched that of a countless number of people all of whom will say God Bless Jimmie – rest in peace.

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The Council of Management are most grateful to the following for responding to the appeal for donations to enable the Association to extend our membership and education services. Donation levels were Diamond (£1000 and above), Ruby (£500 to £999), Emerald (£250 to £499), Sapphire (£100 to £249) and Pearl (£25 to £99). All donors will be recognized at a Gala Dinner to be held in London early next year.

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John N. Bardsley, Epsom, Surrey

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Dennis Durham, Kingston upon Hull, East Yorkshire

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Peter R. Dwyer-Hickey, South Croydon, Surrey

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Tak Yi Yung, Shau Kei Wan, Hong Kong

Zeng Chun Guang, Singapore

GIFTS TO THE ASSOCIATION

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W. Attanayake, Kuruwita, Sri Lanka, for pink and purple corundum in granite host rock from south west Sri Lanka.

Professor Dr Hermann Bank, FGA, Kirschweiler, Germany, for a very attractive slab of polished agate.

Simon Bruce-Lockhart, FGA DGA EG, Thaigem.com, Chanthaburi, Thailand, for samples of orange sapphire.

Thomas Chatham, Chatham Created Gems Inc., San Francisco, California, U.S.A., for a large collection of Chatham Created gemstones, both rough and cut.

Christopher Cuss, FGA DGA, Cheam, Sutton, Surrey, for a collection of cut gemstones.

John R. Fuhrbach, FGA, Amarillo, Texas, U.S.A., for a petrified log of red cedar, alibates flint from Texas, and a collection of other rough and cut gemstones.

Colin Nunn, Worth Matravers, Dorset, for a collection of coloured pastes.

OBITUARY

Professor Pieter C. Zwaan FGA (D. 1954 with Distinction), Leiden, The Netherlands, died on 7 November 2002.

MEMBERS' MEETINGS

Midlands Branch

On 31 January a Quiz and Bring and Buy Sale were held at the Earth Sciences Building, University of Birmingham, Edgbaston.

On 28 February at the Earth Sciences Building, Michael Houghton gave a talk entitled 'Pearls of wisdom' and ran a pearl workshop.

On 28 March at the Earth Sciences Building, Stephen Whittaker gave a talk entitled 'An auctioneer's lot is not a happy one'.

North West Branch

On 26 March at Church House, Hanover Street, Liverpool 1, Richard Slater gave a talk entitled 'Jewellery at auction'.

Scottish Branch

On 15 January at Jury's Hotel, Great Western Road, Glasgow, Colin Towler gave a talk entitled 'Diamonds at Finsch – bullets in Angola'.

On 26 February at Jury's Hotel Alan Hodgkinson gave a talk and hands-on session entitled 'Gem surprises'.

On 25 March at the British Geological Survey, Murchison House, West Mains Road, Edinburgh, Doug Morgan gave a talk entitled 'Some gemmological and lapidary diversions'.

South East Branch

On 6 April at Christie's, South Kensington, Peter Wates and Colin Winter gave a presentation entitled 'Tucson 2003'.

GEM DIAMOND EXAMINATION

In the Gem Diamond Examination held in January 2003, 53 candidates sat of whom 26 qualified including three with Distinction and four with Merit. The names of the successful candidates are listed below:

Qualified with Distinction

Chen Xiumei, Wuhan, Hubei, P.R. China
Marlow, Carol C., Sutton Coldfield, West Midlands
Ross, Alexander, Bath, Somerset

Qualified with Merit

Cheung Shuk Han, Alice, Kowloon, Hong Kong
Li Kun, Wuhan, Hubei, P.R. China
Pace, Michael, Elk Grove, California, U.S.A.
Wong Ying, Shatin, Hong Kong

Qualified

Akintonde, Olubunmi, Woolwich, London
Chalmers, Marie L., Redditch, Worcestershire
Champetier, Marie-Pierre, London

Chan Pui-Sze, Percy, Sheung Shui, Hong Kong
Chaudhary, M. Ali, London
Cheung Suk Yin, Kowloon, Hong Kong
Cheung Yee Ming, New Territories, Hong Kong
Giannakakis, Vasileios, Athens, Greece
Hu Jiahao, Wuhan, Hubei, P.R. China
Ka Tsz Man, Kowloon, Hong Kong
Kwok Ling, New Territories, Hong Kong
Lee Chun Ming, New Territories, Hong Kong
Nei Xiaomei, Wuhan, Hubei, P.R. China
Okada Hiroko, Birmingham, West Midlands
Tominaga, Masami, West Finchley, London
Tse Shim Fong, Kowloon, Hong Kong
Wong Ching Man, Discovery Bay, Hong Kong
Zhang Dingzhi, Wuhan, Hubei, P.R. China
Zhou Tie, Wuhan, Hubei, P.R. China

EXAMINATIONS IN GEMMOLOGY

In the Examinations in Gemmology held worldwide in January 2003, 125 candidates sat the Diploma Examination of whom 69 qualified, including one with Distinction and nine with Merit. In the Preliminary Examination, 115 candidates sat of whom 88 qualified. The names of the successful candidates are listed below:

Diploma

Qualified with Distinction

Xie Jing, Shanghai, P.R. China

Qualified with Merit

Ayer, Elizabeth C., Cambridge
Barnett, Catherine Elizabeth, Balham, London
Guillaud, Pauline, Montreal, Quebec, Canada
Hing, Michael E., London
Houghton, Agnes, London
Lam Koon-Wah, Francis, Kowloon, Hong Kong
Ma Hongyu, Wuhan, Hubei, P.R. China
Pennington, Susan E., Bickerstaffe, Lancashire
Ruckel, Daphne, London

Qualified

Caron, Marie-Chantale, Montreal, Quebec, Canada
Chang Chi Fu, Kowloon, Hong Kong
Chen Chen, Wuhan, Hubei, P.R. China
Chen Zhao, Wuhan, Hubei, P.R. China
Chung Yee, Donna, Kowloon, Hong Kong
Du Congyan, Wuhan, Hubei, P.R. China
Epelboym, Marina, Brooklyn, New York, U.S.A.
Fisher, Fiona J., Dublin, Ireland
Gao Bo, Wuhan, Hubei, P.R. China
Gao Boqian, Guilin, Guangxi, P.R. China
Geng Yunying, Beijing, P.R. China
Giancola, Maria Luisa, Milan, Italy
Gregory, Pauline A., Bishop Auckland, Co. Durham
Henri, Martyne, Montreal, Quebec, Canada
Hillstrom, Anders, Lannavaara, Sweden
Hu Zhikun, Shanghai, P.R. China
Jia Nan, Beijing, P.R. China
Jiatao Wu, Wuhan, Hubei, P.R. China
Jones, Lorraine D., Farnworth, Greater Manchester
Kanaan, Dominique, London
Knight, Jennifer J., Selby, North Yorkshire
Kuang Chung Lee, Taichung, Taiwan, R.O. China
Lee (a) Ting Yu, Michelle, Yangon, Myanmar
Lee Hin Chi, Cheung Chau, Hong Kong
Li Wenjian, Guangzhou, P.R. China
Li Xinyan, Guilin, Guangxi, P.R. China
Li Yaoyao, Wuhan, Hubei, P.R. China
Liu Lili, Guilin, Guangxi, P.R. China
Luo Lulu, Wuhan, Hubei, P.R. China
Maeland, Egil, Sandnes, Norway
Mak Sio In, Hong Kong
Moger, Adam D.D., Little Raveley, Cambridgeshire
Ng Wai Ling, Kowloon, Hong Kong
Okazaki, Maki, London
Parnell, Alexander J., Finchley Central, London
Pe Thu Aung, Yangon, Myanmar
Randhawa, Sukhwant Singh, Hounslow, Middlesex
Selvamani, Parvathi, Ilford, Essex
Shen Shaoqin, Guilin, Guangxi, P.R. China
Su Chen Hui, Taichung, Taiwan, R.O. China
Tan Ke, Wuhan, Hubei, P.R. China
Thin Thin Hlaing, Yangon, Myanmar
Tse Yiu Yu, Stephen, Kowloon, Hong Kong
Tun, U Myint, Lannavaara, Sweden
Tyrrell, Siobhan A., New Cross, London
Valia, Tulsi, London
Van Rooij-Roeloffzen, Almere Buiten, The Netherlands
Vyas, Meenu B., Mumbai, Maharashtra, India
Wang Ying Ling, Taichung, Taiwan, R.O. China
Wang Dan, Wuhan, Hubei, P.R. China
Wang Minmin, Wuhan, Hubei, P.R. China
Whalley, Joanna, Walthamstow, London
Xi Xingshu, Shanghai, P.R. China
Xing Yuan, Beijing, P.R. China
Ye Jing Yin, Shanghai, P.R. China
Yu Ying, Wuhan, Hubei, P.R. China
Zhao Jinglong, Wuhan, Hubei, P.R. China
Zhou Wei Yong, Shanghai, P.R. China
Zhu Juntao, Guilin, Guangxi, P.R. China

Preliminary

Ahren, Anna, Johanneshov, Sweden
Akashi, Nana, Highgate, London
Anderson, Ian, Heaton, Bradford, West Yorkshire
Avakian, Sevan, Los Angeles, California, U.S.A.

Baciocco, Leona T., San Bruno, California, U.S.A.
Banks, Jessica, London
Behennah, Andrew C., Didcot, Oxfordshire
Breuer, Lisa, London
Canisius, Alexandra, London
Champetier, Marie-Pierre, London
Chan Pak Lin, Tsuen Wan, Hong Kong
Chan Yuk Yee May, Kowloon, Hong Kong
Cheng Chong Chuen, Tsuen Wan, Hong Kong
Chung Yim Ling, Mandy, Kowloon, Hong Kong
De Souza, Luciano P., London
Domec, Cedric, Forest, Belgium
Doyle, Cindi, Carlsbad, California, U.S.A.
Drijver, Joyce M-L., Utrecht, The Netherlands
Ecknauer, Marc, Wood Green, London
Firmin, James H., Burley-on-the-Hill, Rutland
Garner, Robert B., Pinner, Middlesex
Glasgow, Sarah A., Fulham, London
Greenstein, Saul, London
Hirst, Catherine, Harborne, Birmingham, West Midlands
Holman, Meryan, London
Hotson, Peter J., Berkhamsted, Hertfordshire
Huang Teng Feng, Taichung, Taiwan, R.O. China
Huang Chi-Hua, Taipei, Taiwan, R.O. China
Hui Siu Fan, Gloria, Yuen Long, Hong Kong
Ino, Shinji, Moseley, Birmingham, West Midlands
Jackson, Antoinette, London
Kelly, Jennifer Liu, London
Kilby Hunt, Judith, London
Kumar, Dhanendra, Jamshedpur, Jharkhand, India
Landmark, Vivienne J., Harpenden, Hertfordshire
Lau Chun Kit, New Territories, Hong Kong
Lee Tsung Han, Taipei, Taiwan, R.O. China
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Liu Chia Hui, Taipei, Taiwan, R.O. China
Lu Yi Fen, Taichung, Taiwan, R.O. China
Ma Cho Ping, Kowloon, Hong Kong
Mai Zhiqiang, Guangzhou, P.R. China
McQuoid, Sarah, Forest Hill, London
Mensah, Michael Osei, London
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Moore, Katherine H., Glasgow, Scotland
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Shih Meng Hsin, Taichung, Taiwan, R.O. China
Shikatani, Kohei, London
Sillem, Hayaatun, London
Sue-A-Quan, Dona M., Yangon, Myanmar
Sykes-Gomez, Heidi, Belsize Park, London
Sylvester, Sheila E., Brussels, Belgium
Tolliss, Jonathan C., York, Yorkshire
Tuen Sai Hing, Shaukei Wan, Hong Kong
Tun Zaw Myo, Yangon, Myanmar
Tung Boon-Ngai, Kowloon, Hong Kong
Vyas, Meenu B., Mumbai, India
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Wang Ying Ling, Taichung, Taiwan, R.O. China
Wang Chenchun, Shanghai, P.R. China
Wang Duo, Guilin, Guangxi, P.R. China
Wang Jun, Shanghai, P.R. China
Wang Liang, Guilin, Guangxi, P.R. China
Watanabe, Tomoko, London
Webb, Stephen C., Nelson, New Zealand
Wei Wei, Guilin, Guangxi, P.R. China
Wills, Emily, London
Wong Sau Han, Branda, Kowloon, Hong Kong
Wong Sheung Ling, Shirley, Kowloon, Hong Kong
Wood, Naoko Wakabayashi, Kensington, London
Yang Yang, Guilin, Guangxi, P.R. China

MEMBERSHIP

Between 28 January and 31 March 2003 the Council of Management approved the election to membership of the following:

Fellowship and Diamond Membership (FGA DGA)

Birrell, Andrew T., St Heliers, Auckland, New Zealand. 1992, 1996
Glover, David G.B., Chelsea, London. 1987/1988

Fellowship (FGA)

Balzan, Patrick A., Fairfax, California, U.S.A. 2002
Goumaz, Benoit, Geneva, Switzerland. 2002
Griffiths, Victoria, Cradley Heath, West Midlands. 2002
Kumarasuriar, Krishna, Los Angeles, California, U.S.A. 1983
Lei Jiali, Guilin, Guangxi, P.R. China. 2002
Mackay, Collin, Catford, London. 1996
Myint, Kyaw, Hounslow, Middlesex. 2002
Ogden, Benjamin J., High Birstwith, Harrogate, N. Yorkshire. 2002
Phillips, Paul, Bulkington, Warwickshire. 2002
Sehgal, Neha, New Delhi, India, 2002
Soe Moe Tun, Yangon, Myanmar. 2002
Wei Xiaoling, Guilin, Guangxi, P.R. China. 2002

Xu Banghui, Guilin, Guangxi, P.R. China. 2002
Zhu Xulei, Guilin, Guangxi, P.R. China. 2002
Zuo Xin Mo, Guilin, Guangxi, P.R. China. 2001

Diamond Membership (DGA)

Collins, Steven John, Letchworth, Herts. 2002
Greer, Paul, Chatham, Kent. 2002
Li Cheung, Alex, Hong Kong. 2002

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von Fullman, Paul John Edmund, Chiswick, London
Warde-Norbury, Lucianne Claire, London
Xu Bin, Hackney, London
Ynal, Izzet, Stone, Staffordshire
Yoshioka, Yumi, Minato-Ku, Tokyo, Japan

Corrigendum

J.Gemm., 2003, **28**(5), p. 310, South East Branch. Sally Hudson was elected Branch Secretary and not Sally Everitt as stated.

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The World 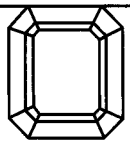 of Gemstones

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Cover Picture

A multi-star quartz from Sri Lanka cut as a complete sphere. (See 'Multi-star quartzes from Sri Lanka' pp. 321-332.)

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An anorthite-ruby-pargasite-picotite assemblage

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ABSTRACT: The mineral assemblage of cabochon-cut samples, probably from Myanmar, was determined by a combination of X-ray powder diffraction and electron microprobe analysis. The matrix consists of colourless plagioclase, which contains between 93 and 96 mol.% anorthite. The inclusions were determined as rubies, green chromium-bearing pargasites and black picotites. The possible origin of the samples is discussed.

Keywords: anorthite, Cr-pargasite, electron microprobe analyses, ruby

Introduction

In the mid-1990s, cabochons composed of ruby crystals in a transparent matrix of feldspar were briefly described by Koivula *et al.* (1994). These cabochons (*Figure 1*) were purchased by a German gem merchant in northern Thailand and were said to originate from Myanmar by local dealers. During further trips to Thailand, our supplier was able to obtain some similar cabochons with a colourless matrix and green inclusions (*Figure 2*); also some of the cabochons contained red and green minerals together as inclusions in a transparent matrix. In the mid-1990s cabochons of similar appearance (*Figure 3*) were also found elsewhere in the Asian market (Tay Thye Sun, pers. comm., 1995). Cathodoluminescence of this particular material was described recently by Ponahlo (2002).

The following study was undertaken to characterize the various components of this mineral assemblage.

Figure 1: *Ruby crystals in a matrix of colourless anorthite. Size of the sample on the left: 10.5 × 8.3 mm; photo by M. Glas.*

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Figure 2: *Pargasite crystals in a matrix of colourless anorthite. Size of the sample on the left: 21.3 × 16.3 mm; photo by M. Glas.*

Figure 3: *Ruby and pargasite crystals in a matrix of colourless anorthite. Size of the sample about 17 × 13 mm, photo by Tay Thye Sun.*

Materials and methods

For the present study about 40 cabochons in the range of about 3 to 20 ct were examined. For mineralogical phase determination, all four components of the cabochons were examined by microscope and by X-ray powder diffraction. Four samples were selected for electron microprobe analyses. After repolishing the originally slightly curved (almost plane) backs of these cabochons, analyses were made at 98 points in the different components of the mineral assemblage, namely 68 of the colourless to whitish matrix, 18 of the red component, eight of the green mineral and four of the black crystals.

Results

X-ray phase determination

Examination of the four components of the mineral assemblage by X-ray powder diffraction showed the following phases to be present (see *Figure 4*):

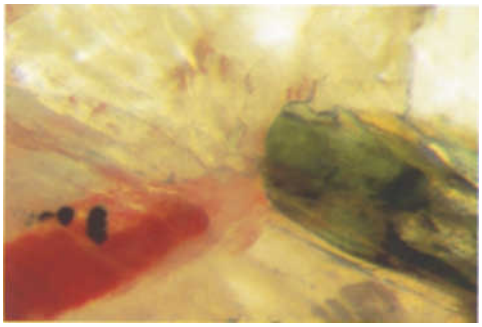

Figure 4: Mineral assemblage with ruby, green pargasite and black picotite in a matrix of colourless anorthite. Photo by E.J. Gübelin, magnified 60 ×.

- colourless to whitish matrix: plagioclase feldspar
- red inclusions: corundum (ruby)
- green inclusions: amphibole
- black inclusions: spinel

Microscopic observations

The crystals forming the colourless plagioclase matrix occasionally reveal parallel striations due to polysynthetic twinning. Healing feathers are also common. The ruby crystals show tabular habit with dominant basal pinacoids (0001) and appear as lath-like cross sections on the curved surfaces of the cabochons (*Figures 5 and 6*). Occasionally, the ruby crystals appear as if several platelets of different diameters are piled up to form an irregular stack. The green amphiboles are developed as long prismatic crystals (*Figure 7*). Cross sections typically consist of four {110} faces, some with two smaller {010} prisms (*Figure 8*). The spinels are small opaque grains or clusters with metallic lustre and sporadic development of small octahedral crystal faces (*Figures 4 and 9*).

Chemical compositions

The matrix consists of a transparent, colourless to light grey plagioclase feldspar. Microprobe analyses (*Table I*) showed that plagioclase is almost pure anorthite within the compositional range of 93 and 96 mol.% anorthite and 7 to 4 mol.% albite, thus showing only small variation.

The red corundum crystals (rubies) show a relatively large variation of chromium contents from 0.14 to 1.80 wt.% Cr_2O_3 (*Table II*). However, iron contents are small, titanium contents are extremely low and vanadium is below the detection limit of the electron microprobe.

The analyses of the green amphiboles (*Table I*) show a limited variability and reveal an aluminium-rich calcic amphibole with a composition close to pargasite:

$$NaCa_2(Mg, Fe^{2+})_4AlSi_6Al_2O_{22}(OH)_2$$

Figure 5: Ruby crystals in a matrix of colourless anorthite. Size of the sample 19.0 × 13.4 mm; photo by M. Glas.

Figure 6: Mineral assemblage with tabular ruby crystals in a matrix of colourless anorthite. Photo by K. Schmetzer, magnified 50 ×.

Table I: *Compositional ranges of feldspars (F1-3), amphiboles (A1-3) and spinels (S1-3) shown by microprobe analyses of selected samples.*

Wt.%	*F1*	*F2*	*F3*	*Wt.%*	*A1*	*A2*	*A3*	*Wt.%*	*S1*	*S2*	*S3*
SiO_2	43.77	43.35	43.09	SiO_2	41.78	41.59	42.75	SiO_2	0.06	0.07	0.05
Al_2O_3	35.20	35.64	35.95	Al_2O_3	19.22	19.30	18.43	Al_2O_3	30.47	32.74	38.27
TiO_2	0.02	0.05	0.04	TiO_2	0.14	0.13	0.10	TiO_2	0.05	-	0.05
Cr_2O_3	0.02	0.05	0.06	Cr_2O_3	0.88	0.67	0.15	Cr_2O_3	31.44	29.44	25.11
MgO	-	-	-	MgO	14.85	15.01	15.43	MgO	4.21	4.51	6.36
FeO*	0.03	0.04	0.10	FeO*	5.09	4.90	5.11	FeO*	30.86	29.95	27.61
MnO	-	0.04	-	MnO	0.07	0.09	0.06	MnO	0.77	0.65	0.63
CaO	19.20	19.18	19.44	CaO	13.26	13.21	13.57	ZnO	0.63	0.74	0.70
Na_2O	0.78	0.53	0.42	Na_2O	2.50	2.47	2.54	CaO	0.13	0.10	0.07
K_2O	-	-	-	K_2O	0.50	0.55	0.49	Na_2O	0.03	0.01	-
								K_2O	-	-	-
Sum	**99.02**	**98.88**	**99.10**	**Sum**	**98.29**	**97.92**	**98.63**	**Sum**	**98.65**	**98.21**	**98.85**
Number of ions on the basis of 8 O				*Number of ions on the basis of 23 O*				*Number of ions on the basis of 4 O*			
Si	2.046	2.028	2.013	Si	5.918	5.916	6.032	Si	0.002	0.002	0.001
Al	1.939	1.964	1.980	Al	2.082	2.084	1.968	Al	1.152	1.226	1.374
Ti	0.001	0.002	0.001	**Sum T**	**8.000**	**8.000**	**8.000**	Ti	0.001	-	0.001
Cr	0.001	0.002	0.002	Al	1.133	1.151	1.097	Cr	0.798	0.740	0.605
Mg	-	-	-	Ti	0.015	0.014	0.011	Mg	0.201	0.214	0.289
Fe	0.001	0.002	0.004	Cr	0.098	0.075	0.017	Fe	0.828	0.796	0.704
Mn	-	-	-	Mg	3.144	3.181	3.241	Mn	0.021	0.018	0.016
Ca	0.961	0.961	0.974	Fe	0.605	0.583	0.603	Zn	0.015	0.017	0.016
Na	0.071	0.048	0.038	Mn	0.008	0.011	0.008	Ca	0.004	0.004	0.002
K	-	-	-	**Sum C**	**5.003**	**5.015**	**4.977**	Na	0.002	0.001	-
				Ca	2.018	2.013	2.050	K	-	-	-
				Na	0.689	0.682	0.695	**Sum**	**3.024**	**3.018**	**3.008**
				K	0.091	0.099	0.089				
				Sum A+ B	**2.798**	**2.794**	**2.834**				

* Total iron as FeO; - means below detection

Table II: *Compositional range and mean of ruby obtained from microprobe analyses.*

Wt.%	*Range (18 analyses)*	*Mean*
Al_2O_3	98.08–99.85	99.07
Cr_2O_3	0.14–1.80	0.77
Fe_2O_3	0.21–0.32	0.25
TiO_2	0.00–0.04	0.01
MnO	0.00–0.03	0.01

*Total iron as Fe_2O_3

The site occupancies of the T, C and A+B positions in the amphibole structure also show the presence of a limited percentage of the tschermakite molecule:

$$Ca_2(Mg, Fe^{2+})_3A_2lSi_6Al_2O_{22}(OH)_2$$

and a limited percentage of the sadanagaite molecule:

$$NaCa_2(Mg, Fe^{2+})_3Al_2Si_5Al_3O_{22}(OH)_2$$

(see Leake, 1997; Deer *et al.*, 1997). Small but distinct amounts of chromium are present in all the amphibole analyses. Consequently, the amphiboles are designated as chromium-bearing pargasites with about 10% each of the tschermakite and sadanagaite molecules.

The black spinels show a larger variation in chemical composition (*Table I*). These crystals are magnesium-iron-aluminium-chromium spinels with atomic ratios of Fe>Mg and Al>Cr. The compositions of these spinels lie in the range represented by the simplified formulae

$$(Mg_{0.2}Fe_{0.8})(Al_{1.2}Cr_{0.8})O_4 \text{ and}$$

$$(Mg_{0.3}Fe_{0.7})(Al_{1.4}Cr_{0.6})O_4$$

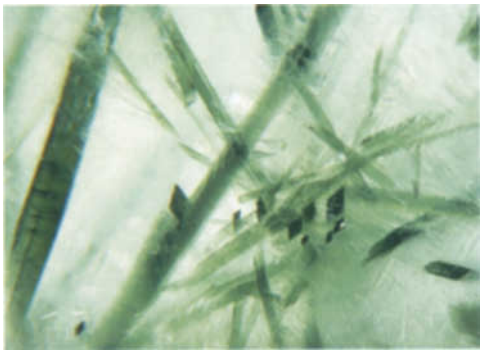

Figure 7: *Mineral assemblage with pargasite crystals in a matrix of colourless anorthite. Photo by K. Schmetzer, magnified 30 ×.*

Figure 8: *Cross section of a prismatic pargasite crystal consisting of four {110} and two smaller {010} prism faces. Photo by K. Schmetzer, magnified 60 ×.*

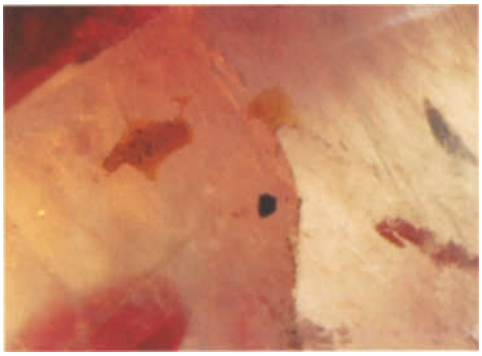

Figure 9: *Mineral assemblage with ruby and a black picotite grain in a matrix of colourless anorthite. Photo by K. Schmetzer, magnified 80 ×.*

Consequently, the spinels are chromian hercynite, which are also called picotite in the mineralogical nomenclature (see, for example, Deer *et al.*, 1975)

Discussion

The mineral assemblage described in this paper consists of a matrix of anorthite with major contents of Al-rich, chromium-bearing pargasites and rubies, and minor contents of chromium-bearing Fe-Al-spinels (picotite). Worldwide, ruby occurs mainly in three types of primary metamorphic rocks, i.e. in marbles, amphibolites (including anorthosites) and gneisses (Hunstiger, 1989, 1990 a, b). To date, two mineral assemblages in metamorphic rocks with ruby in an anorthitic matrix are known to the authors:

- in the ruby deposit of Rubinovoje, Polar Urals, Russia, ruby is found in metasomatic anorthosites and in mica-bearing anorthosites (Grygoriev *et al.*, 2000). Inclusions in ruby are black chromium-bearing spinel, plagioclase and chromium-bearing mica (fuchsite);

- in the ruby occurrence of Fiskenässet, Greenland, red corundum is found in an anorthosite matrix associated with green amphibole which is described as pargasite (Gübelin, 1979) or tschermakite (Petersen and Secher, 1985).

There are, in addition, several occurrences of rubies in amphiboles currently known, for example, Valle d'Arbedo, Switzerland; Chantel, France; Harts Range, Australia. A general overview is presented by Hunstiger (1989). The amphiboles found in these rocks are described as pargasites or tschermakites, and occasionally distinct percentages of chromium up to 1.15 wt.% Cr_2O_3 are reported from microprobe analyses. Frequently the feldspars in these mineral assemblages are anorthites or plagioclases with high percentages of the anorthite molecule. In rock specimens of the ruby-bearing zoisite-amphibolite from Longido, Tanzania, pargasitic amphiboles are found in association with anorthite and magnesium-iron-aluminium-chromium spinel (picotite). Amphibole analyses quoted by Leake (1971) and Hunstiger (1989) also show the presence of distinct amounts of chromium in the Longido pargasites.

Aluminium-rich pargasitic amphiboles similar to those analysed in our samples have also been described by Bunch and Okrusch (1973). These amphiboles were found in a corundum- and spinel-bearing marble from Pakistan (exact locality not given in the paper cited but confirmed subsequently as the Hunza area; M. Okrusch, pers. comm. 2002). The two hand specimens examined also contained anorthitic feldspars. Similar mineral assemblages were also mentioned later from the ruby marble deposit of Hunza, Pakistan (Okrusch *et al.*, 1976). The minerals described from Pakistan in these papers indicate the stability of this particular mineral assemblage – Al-rich pargasite, corundum, spinel and anorthite – not only in the anorthosites and amphibolites but also in metamorphic marbles. The ruby-bearing marble occurrence of Stirigma, Greece, in which pargasite and anorthite are also found, was briefly mentioned by Hunstiger (1990b).

Searching for the exact origin of the samples in this study which were quoted to come from Myanmar by local dealers in Thailand, marbles, amphibolites and anorthosites can therefore be considered. The most famous marble of Myanmar is known to all gemmologists as the host of the rubies in Mogok. Consequently, an origin for the samples from the large metamorphic mining area in Mogok, in which different types of metamorphic rocks other than marbles also occur, seems possible.

This assumption is supported by information obtained recently from T. Themelis (pers. comm. 2002),who reported that material similar to that described in this study was seen on several occasions during frequent visits to the Mogok area from 1994 to 2001.

It has to be mentioned, however, that there has also been a rumour in the trade about a possible origin for such samples from Africa, for example from Longido, indicating that the material was brought from its country of origin into Thailand and offered for sale in a local market in Northern Thailand. The similarity of chemical compositions of the anorthites, pargasites and picotites in our samples with data from the same minerals in Longido material could support this origin.

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Identification of an impregnated quartz imitation of jade

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ABSTRACT: The imitation of high-quality green jadeite has become more prevalent mainly because the jadeite commonly known as 'imperial jade' is now less commonly available. Fourier transform infrared (FTIR) and energy-dispersive X-ray fluorescence (EDXRF) spectroscopic techniques have been found to be accurate non-destructive techniques in identifying common imitations of jade. Therefore imitations of jade, natural jadeite (grade A jade) and treated jadeite (grade B jade) can be reliably distinguished. A selection of six stones was investigated to verify this assertion. The surface technique of EDXRF has a particular advantage in testing for jadeite close-set in jewellery on which measurements of refractive index and specific gravity can be impossible. In this study, transmission FTIR spectra of impregnated quartz imitations of jade show strong absorption peaks which correspond to those of quartz and of green polymers which are commonly used for impregnation of jadeite. Identification of the elemental content (C, O and Si) and calculations of X-ray peak intensity ratios of C/Si and O/Si in the investigated jadeite imitations and in quartz using EDXRF spectroscopy support the finding that the imitation is polymer-impregnated quartz. The EDXRF results from the imitations are compared to those of grade A and grade B jades, and specific gravity and ultraviolet fluorescence tests were conducted on all eight jade imitation and jadeite samples.

Keywords: energy-dispersive XRF, FTIR, jadeite, polymer

Introduction

Massive jadeitic rock, one of the two jade varieties, has always been highly valued in Asia and has often been associated with power, longevity and academic achievement (Chung, 2000). The proliferation of treated jadeite has been known in the jade market for at least ten years as the international jade business has expanded (Anon, 1991a, 1991b; Hurwit, 1989). As the skill of doctoring of jadeite by impregnation with polymers improves, more sensitive detection methods have become critical (Fritsch and McClure, 1993). In 1992, Fritsch *et al.* reported the successful application of transmission Fourier transform infrared (FTIR) spectroscopy in differentiating

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bleached and polymer-impregnated jadeite (grade B jade) from natural jadeite (grade A jade). Quek and Tan (1997) extended this infrared technique using diffuse reflectance on the surfaces of jadeite. Further studies of grades A and B jade on their elemental content by X-ray photoelectron spectroscopy (XPS) were reported by Tan *et al.* (1995). A polymer known as *polystyrene* was detected in some jadeite samples by Quek and Tan (1998) using the FTIR and XPS techniques. Tay *et al.* (1993) used a scanning electron microscope (SEM) to study damaged crystal structure in impregnated jadeites. Recently, dyed polymer-impregnated jadeite, considered as grade C, has become prevalent in the jade market (Tay, 2001).

Although scientific studies on treated jadeite have become more sophisticated and numerous (Gao and Zhang, 1998), studies on impregnated quartz imitations of jadeite remain very limited (Wu, 1991). An imitation or simulant usually displays a good colour such as translucent green to resemble a good jadeite, but it does not have the same physical properties. However, if an imitation gem is recognized with similar physical properties such as refractive index (RI), specific gravity (SG) and hardness, as the natural gem, then identification becomes difficult and a more sensitive scientific tool is required. Furthermore, accurate measurements of these physical properties are not possible for jewellery with close metal mountings.

In our present investigation, FTIR and EDXRF spectroscopic techniques were used together for the first time to accurately identify some material used for the imitation of jade.

Materials

Two samples of jade imitation (samples 1 and 2), two samples of natural quartz SiO_2 (samples 3 and 4), two samples of grade A jade, natural green jadeite (samples 5 and 6),

Figure 1: *The test stones, samples 1-8: impregnated quartz imitation of jade (1 and 2); natural quartz (3 and 4); grade A jade (5 and 6) and grade B jade (7 and 8).*

Table I: *Gemmological and spectroscopic data on jadeite imitation, natural quartz, grade A jade and grade B jade samples.*

Sample	*Sample No.*	*Description, microscopic observations*	*Behaviour in di-iodomethane (SG 3.32)*	*Fluorescence in LW UV radiation*	*Infrared absorption peaks (cm^{-1})*	*EDXRF elemental peaks*	*O/Si, C/Si intensity ratios*
Cabochons of imitation jade	1	Green veins, uneven patches of pale and dark green. Few fine fissures. No white or colourless areas.	float	weak chalky blue	2136, 2241, 2493, 2597, 2673 2873, 2932, 2965	C, O, Si	O/Si 1.21 C/Si 0.03
	2	Common green veins, uneven patches of pale and dark green. Fine fissures. No white areas.	float	weak chalky blue	2136, 2241, 2493, 2597, 2673 2873, 2932, 2965	C, O, Si	O/Si 0.22 C/Si 0.03
Quartz	3	Clear natural rock crystal with few fissures.	float	none	2136, 2241, 2493, 2597, 2673	O, Si	O/Si 0.11
	4	Clear natural quartz or 'rock crystal' some fissures, tinted with very light brown.	float	none	2136, 2241, 2493, 2597, 2673	O, Si	O/Si 0.12
Cabochons of grade A jadeite	5	Dark green with patches of white, fine fissures.	sink	none	2850, 2919	C, O, Na, Mg, Al, Si, Ca, Fe	O/Si 0.19 C/Si 0.01
	6	Light green with white and clear colourless patches, fine fissures.	sink	none	2850, 2919	C, O, Na, Mg, Al, Si, Ca, Fe	O/Si 0.18 C/Si 0.01
Cabochons of grade B jade	7	Green with white patches, large pit marks and fine fissures.	float	chalky-blue	2875, 2930, 2967, 3037, 3060	C, O, Na, Mg, Al, Si, Ca, Fe	O/Si 0.35 C/Si 0.05
	8	Green with large white patches, pit marks and fine fissures.	float	chalky-blue	2875, 2930, 2967, 3037, 3060	C, O, Na, Mg, Al, Si, Ca, Fe	O/Si 0.36 C/Si 0.06

Experimental methods

A Bio-Rad Excalibur Fourier transform infrared spectrometer was used to record the FTIR spectra of all samples with a resolution of 5 cm^{-1} in the wavenumber range of 400 to 4000 cm^{-1}. Immediately before the FTIR experiments the samples were thoroughly rinsed in propanol to remove any organic contaminant on their surfaces due to handling. Spectra were obtained from infrared transmission through whole samples and the investigations were non-destructive. Taking into account the spectrometric resolution of 5 cm^{-1} and other possible systematic errors, the positional accuracy of the absorption peak is ± 1 cm^{-1}.

All the samples were further tested using energy-dispersive X-ray fluorescence (EDXRF) to determine their chemical composition. The EDXRF spectra were collected using a scanning electron microscope JEOL JSM-5600LV SEM/ EDX with working accelerating voltage of 20 kV. Surface analysis by EDXRF is accomplished by bombarding a sample with high energy electrons and detecting and analysing the energy of the emitted X-rays. These electrons have penetrating power in a solid extending from 1 to 5 μm depending on their energy and the nature of the substance. EDXRF is a surface-sensitive technique of chemical characterization of the surface of a solid. The surfaces of all samples were thoroughly cleaned with a light dose of the volatile propanol in order to remove any contaminant present due to handling. The method has been shown to be useful in studies of gemstones (Muhlmeister and Devouard, 1992).

and two samples of grade B jade treated jadeite (samples 7 to 8) were used in this investigation and are shown in *Figure 1*. All the samples originated from Myanmar (Burma). The results of microscopic surface observations, immersion in di-iodomethane for SG estimates and exposure to ultraviolet radiation fluorescence are summarized in *Table I*.

The approximate test of immersion in di-iodomethane of SG 3.32 is commonly used to differentiate jade of grades A and B (Fritsch *et al.*, 1992; Tan *et al.*, 1995) The two jade imitation samples (1 and 2) and the quartz samples (3 and 4) were found to float. As expected, both grade A jade samples (5 and 6), which have an SG slightly above 3.32, sink in di-iodomethane. Both grade B jade samples (7 and 8), were found to float in the liquid because of their polymer impregnation which lowers the SG of the stones as a whole. Therefore the SG test is not effective in differentiating jadeite imitations from grade B jades.

The two jadeite imitation samples (1 and 2) and two grade B jade samples (7 and 8) give a strong chalky blue fluorescence under long wave ultraviolet radiation (*Table I*). The natural quartz and grade A jade samples are all inert in ultraviolet radiation. These results suggest that the jade imitations and the grade B jades were impregnated with a similar polymer material. Microscopic observation of the two jadeite imitations at 20× magnification showed that their colour is patchy pale and darker green with few fine fissures, and an absence of any white or colourless minerals. By comparison, the natural quartz is slightly smoky with transparent patches and some fine fissures. Of the four jadeite samples, three are patchy white and green, and only the grade B jade sample 7 was uniformly green and with an absence of white patches.

Results and discussion

In the FTIR transmission studies, the samples are nearly opaque to infrared radiation in the 400-2000 cm^{-1} region, and therefore the useful region of study is from 2000-4000 cm^{-1}. The positions (in cm^{-1}) of the infrared absorption peaks of all samples are listed in *Table I*. Typical sharp peaks in the infrared spectra of the jadeite imitation

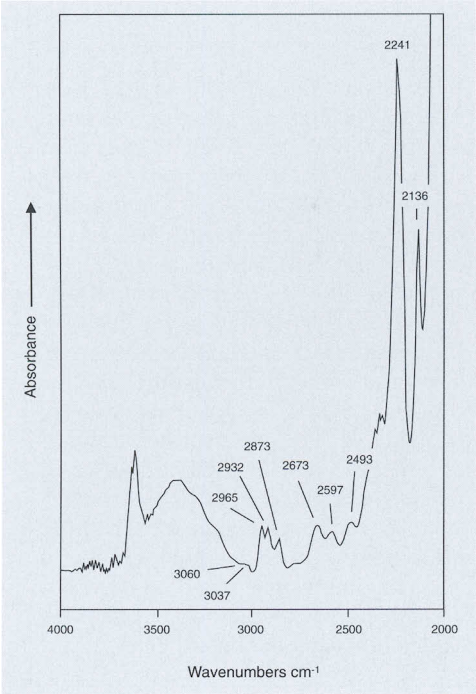

Figure 2: *Infrared absorption spectrum of impregnated quartz imitation of jade (samples 1 and 2).*

samples (1 and 2) are found at 2136, 2241, 2493, 2597, 2673, 2873, 2932 and 2965 cm^{-1}, while a broad absorption ranges from 3200 to 3700 cm^{-1}, as shown in *Figure 2*. A comparison in *Figure 3* of the spectra of the jade imitation (samples 1 and 2) with that of natural quartz (samples 3 and 4) reveals that both have common peaks at 2136, 2241, 2493, 2597 and 2673 cm^{-1}, and a broad absorption from 3200 to 3700 cm^{-1}. The agreement of these five absorption peaks strongly implies that the jadeite imitation is composed of quartz.

The transmission infrared spectra of the grade B and grade A jade samples are shown in *Figure 3c and d* respectively. Strong absorption peaks at 2875, 2930, and 2967 cm^{-1}, and weaker peaks at 3037 and 3060 cm^{-1} are typical of polymers in grade B jades (Fritsch *et al.*, 1992; Quek and Tan, 1998) The wax on the surface of grade A jade (*Figure 3d*) is manifested by two weak peaks at 2850 and 2919 cm^{-1}, in agreement with several previous works (e.g. Fritsch *et al.*, 1992, Quek and Tan, 1998). Three strong peaks at 2873, 2932, and 2965 cm^{-1} in jade imitations (samples 1 and 2) as shown in *Figure 2*, agree with those in grade B jade (*Figure 3c*) within experimental error of ± 1 cm^{-1}. This indicates the presence of polymers in the jade imitations. The spectra of the jade imitations (samples 1 and 2) and grade B jade (samples 7 and 8) are shown in *Figure 3b and c* and the presence in both of absorption peaks in the 2800-3000 cm^{-1} region clearly demonstrates the polymer contents.

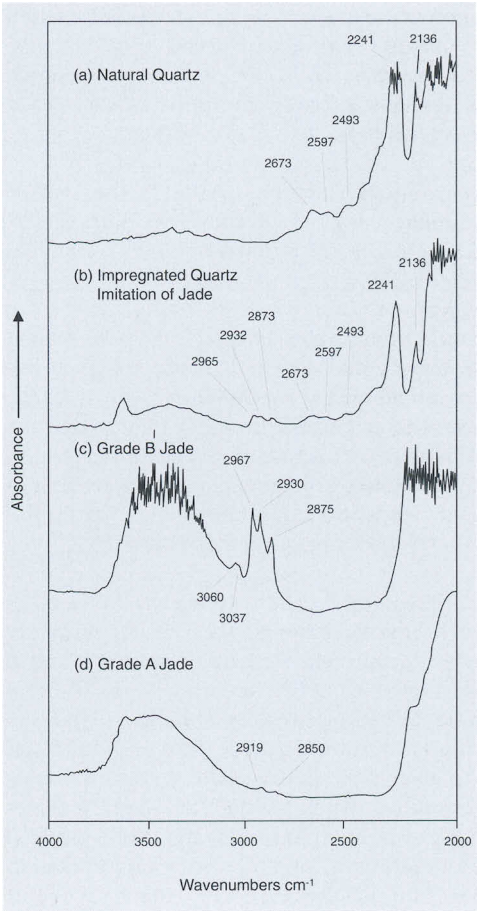

Figure 3: *Infrared absorption spectra of:*

a) Natural quartz (samples 3 and 4)
b) Jade imitation (samples 1 and 2)
c) Treated jade, grade B (samples 7 and 8)
d) Natural jade, grade A (samples 5 and 6)

Therefore all eight strong absorption peaks in the infrared spectra of the jade imitation samples (as given in *Table I*) could be assigned to natural quartz and the impregnation polymers typical of grade B jades. The absorption peaks in grade B jades, jade imitations and in natural quartz may be compared in *Figure 3 (c), (b) and (a)* respectively, and indicate that the jade imitations consist of green polymer-impregnated quartz material.

In the EDXRF experimental studies, a typical spectrum from the surface of a jade imitation (samples 1 and 2) is shown in *Figure 4b*. The spectrum recorded in the X-ray energy range of 0 to 9 keV indicates all the major elements present on the surface of the jadeite together with the gold coating added in sample preparation. The strong peaks from the sample are silicon Si $K_{\alpha 1}$ at 1.74 keV, oxygen O $K_{\alpha 1}$ at 0.525 keV and carbon C $K_{\alpha 1}$ at 0.277 keV (Blake, 1990). The presence of Si, O and C is consistent with the conclusions from FTIR work that the jadeite imitation is polymer-impregnated quartz, carbon (C) being attributed to the polymer. For sample 1, the X-ray peak intensity ratio of O/ Si is 0.21 and that of C/Si is 0.03 (*Figure 4b* and *Table I*). Corresponding values of 0.22 and 0.03 were obtained from sample 2.

The typical EDXRF spectrum of natural quartz (samples 3 and 4) is shown in *Figure 4a*. Si and O peaks are prominent, the O/Si ratio is 0.11 and carbon (C) was not detected (C/Si ratio is 0) in either sample. The presence of C and of higher O/Si ratio values in the jade imitation samples 1 and 2, compared to that in natural quartz indicate the presence of polymer in the imitations. These EDXRF results are in good agreement with the results of the FTIR work.

The EDXRF spectrum typical of grade B jade (samples 7 and 8) is shown in *Figure 4c*. The strong X-ray energy peaks of O, Na ($K_{\alpha 1}$ at 1.04 keV), Al ($K_{\alpha 1}$ at 1.49 keV), and Si are consistent with the ideal composition of jadeite, $NaAl(SiO_3)_2$. Traces of C, Mg ($K_{\alpha 1}$ at 1.25 keV), Ca ($K_{\alpha 1}$ at 3.69 keV) and Fe ($K_{\alpha 1}$ at

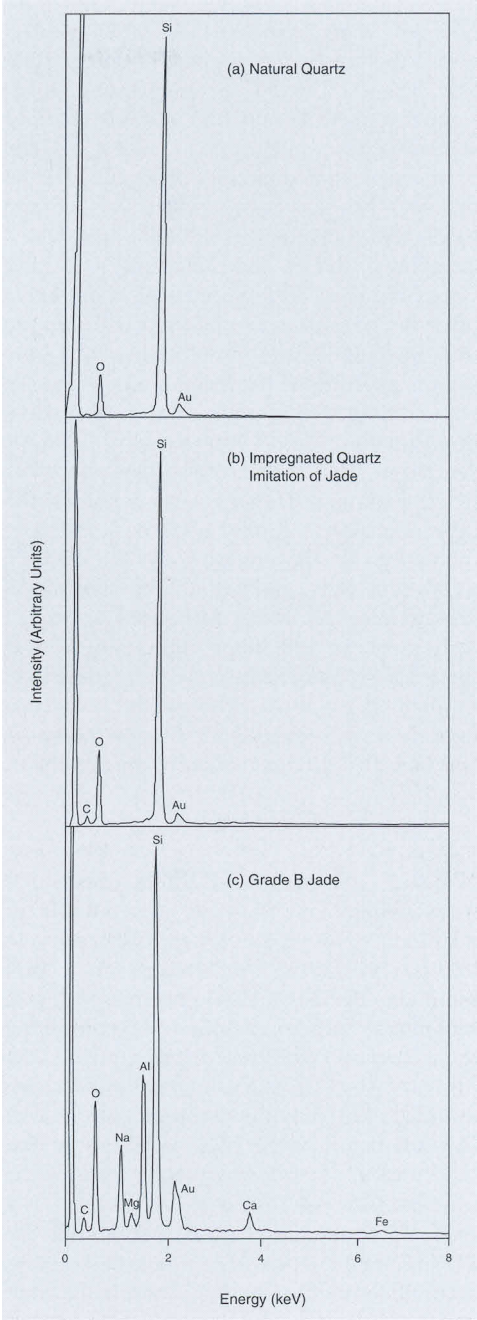

Figure 4: *EDXRF spectra of:*

(a) natural quartz (samples 3 and 4)
(b) jade imitation (samples 1 and 2)
(c) treated jade, grade B (samples 7 and 8)

6.40 keV) were also found. The carbon peak is due to the presence of polymer in the grade B jade. The O/Si and C/Si intensity ratios for sample 7 are 0.35 and 0.05 respectively, and similar values were obtained for sample 8. The presence of small quantities of Mg, Ca, and Fe in jadeite jade has been reported by Ou Yang (1993) and is not unexpected. For grade A jade (samples 5 and 6), the O/Si and C/Si ratio values are close to 0.19 and 0.01 respectively (*Table I*). The low values of C/Si of 0.01 indicate that the grade A jade samples have very little carbon, probably in the form of a thin layer of wax rather than the more extensive impregnation. This is supported by the FTIR spectrum in *Figure 3d*. The accurate determination of the various elements and the calculations of O/Si and C/Si peak intensity ratios for all the samples by the EXDRF techniques has proved to be useful in identifying the jade imitations, and in distinguishing imitations from natural and treated jades. Since Fritsch *et al.* (1992) described the method, advances in techniques now enable light elements such as C and O to be measured and make the detection of polymers possible.

Conclusion

Basic gemmological tests such as measurement of SG and observation of ultraviolet fluorescence can only provide limited indications for identifying a jade imitation. By using FTIR spectroscopy, jade imitations can be identified by comparing their spectra with standards and in the present investigation a jade imitation has been found to be polymer-impregnated quartz. One limitation of the FTIR technique is that the samples must be sufficiently thin for the transmission of infrared radiation. The present investigation has also shown that the EDXRF method provides a non-destructive, accurate technique for identification of a wide variety of elements including C and O present at the sample surface. Calculations of the X-ray peak peak intensity ratios O/Si and C/Si give useful quantitative chemical data for polymer-impregnated materials like quartz, which is used as a jade imitation, and of polymer-impregnated (grade B) jadeites.

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Trace elements in Thai gem corundums

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ABSTRACT: Thai gem corundums fall into two discrete populations on the basis of their trace element fingerprinting. Sapphires are rich in Ga (up to 0.101 wt % Ga_2O_3) and poor in Cr (<0.053 wt% Cr_2O_3) whereas rubies are rich in Cr (up to 0.564 wt% Cr_2O_3) and poor in Ga (<0.009 wt% Ga_2O_3). The trace element study of corundums from well-characterized geological environments suggests that Thai sapphires crystallized from syenitic gneiss metasomatised by a highly evolved magma such as carbonatite. Rubies could have crystallized in a metamorphic environment probably in a pre-existing metamorphic rock with mafic composition.

Keywords: EPMA, LA-ICP-MS, ruby, sapphire, Thailand, trace element

Introduction

Trace element geochemistry has been used to distinguish natural from synthetic corundums (e.g. Stern and Hänni, 1982; Tang *et al.*, 1989; Muhlmeister *et al.*, 1998; Joseph *et al.*, 2000) and to differentiate rubies from different localities (e.g. Tang *et al.*, 1988; Osipowicz *et al.*, 1995; Sanchez *et al.*, 1997; Calligaro *et al.*, 1999). However Sutherland *et al.* (1998b) were able to classify corundums derived from basaltic terrains into a metamorphic suite and a basaltic suite by use of their trace element contents and their metamorphic and magmatic mineral inclusions (previously studied by Sutherland and Coenraads, 1996; Sutherland and Schwarz, 1997). This differs from the model of corundum genesis proposed by Guo *et al.* (1996) who focused only on sapphire genesis. The mineral inclusions in rubies also may yield information on their provenance and clarify the options possible for corundum origin (e.g. Sutthirat *et al.*, 2001). However more research on the metamorphic-related genesis of rubies and sapphires needs to be done. In the present study, the trace element 'fingerprints' of corundums from Thailand are compared with those of other corundums from well-characterized geological environments as one of the approaches that can be used to deduce their origin.

Transition group elements (V, Ni, Fe, Mn, Cr, and Ti) are expected to substitute in the structure of corundum and some of them are known to cause body colour. For example Cr

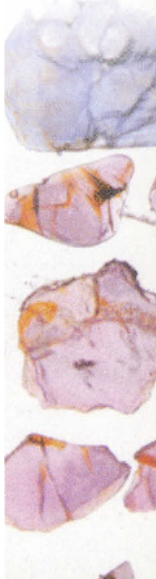

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is responsible for the red colour of ruby, Ti and Fe for the blue colour of sapphire (Nassau, 1983) and V, Cr, Ti and Fe for colour change sapphire (purple-red colour under incandescent light, blue-green colour under fluorescent light) (Schmetzer and Bank, 1980). Gallium is akin to Al and it uses the Al as a camouflage due to the closeness of their atomic radii (0.620 Å for Ga^{VI} and 0.535 Å for Al^{VI}) and charge, 3+ (Frye, 1974, 39-40; Krauskopf and Bird, 1995, 542-545). To determine the presence and quantity of other trace elements, laser ablation inductively coupled plasma mass spectrometry (LA-ICP-MS) was used (Pearce *et al.*, 1992). This gives an identification of all elements between Li and Pb in the periodic table, with only a few exceptions. On the basis of exploratory results obtained using LA-ICP-MS, the following elements were sought using the

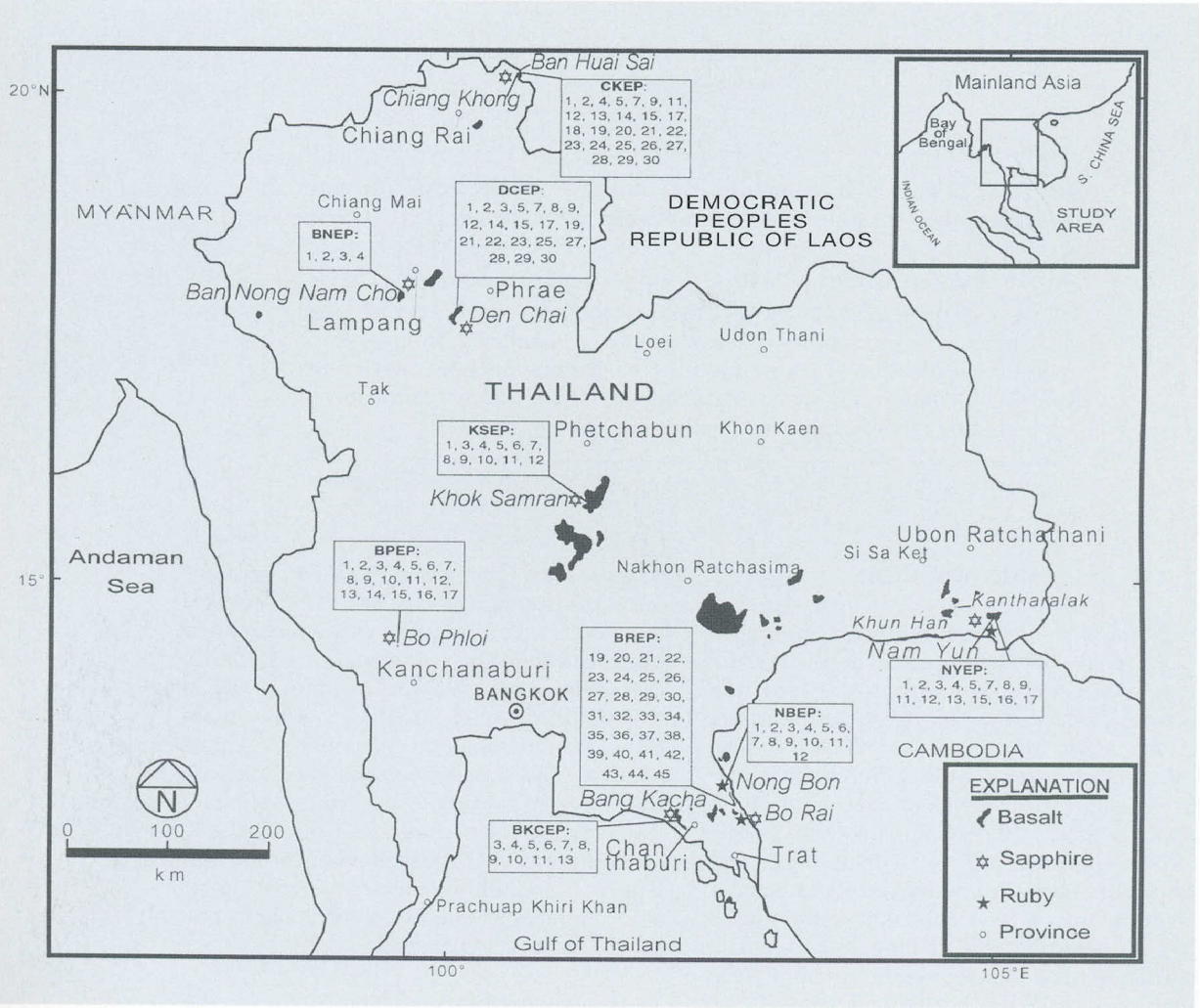

Figure 1: *Map of Thailand showing the localities of corundum samples (rubies and sapphires) and the distribution of basalts (modified from Vichit, 1992). The sample numbers are given in boxes.*

electron microprobe. Lanthanum (radius of La^{3+} = 1.032 Å for La^{VI}) and yttrium (radius of Y^{3+} = 0.900 Å for Y^{VI}) were investigated as possible substitutes for Al. Sn, Ta, Nb, W and Cu were examined in order to confirm unexpected high values indicated for some samples by LA-ICP-MS. Although Si prefers to substitute for Al in minerals with IV co-ordinated sites, VI co-ordinated Si is possible, and thus it was analysed for experimentally in corundum in this work. Moreover Si may be controlled by the presence of divalent cations, e.g. Fe^{2+} and Mg (Schmetzer and Bank, 1980).

Samples

The corundum samples from Thailand and Ban Huai Sai, in the Democratic People's Republic of Laos, were purchased from, or donated by, mine operators at the localities shown in *Figure 1*. They consist of rubies

Table 1: *Corundum samples from outside Thailand.*

Corundum variety	*Host rock composition*	*Rock type/main mineralogy*	*Locality*	*Reference*	*Field Nos (Fig. 4)*
sapphire (grey)	Al-rich 'diorite'	pegmatitic plumasite	? Natal, S. Africa	DuToit, 1918	1
sapphire (blue)	Al-rich pelite (restite)	corundum mullite buchite	Mull, Scotland	Thomas, 1922; Brearley, 1986; Schairer and Yagi, 1952	2
ruby (purple)	Al-rich pelite (restite)	corundum plagioclase hornfels	Bushveld, S. Africa	Willemse and Viljoen, 1970	
ruby (purple)	ultramafic	actinolite – gneiss	S. India (Kodaikanal)	–	3
sapphire (grey)	syenitic	syenite gneiss	Bancroft, Ontario, Canada	Moyd, 1949	4
sapphire (blue)	'normal pelitic'	corundum – biotite – hornfels	Loch Awe, Etive, Scotland	Droop and Treloar, 1981, Moazzen, 1999	5
sapphire (colourless in thin section)	'normal pelitic'	corundum – sillimanite – cordierite – hornfels	Belhelvie, Scotland	Droop and Charnley, 1985	
ruby (pink)	'normal pelitic'	corundum – staurolite – muscovite – schist	Stoer, NW. Scotland	Cartwright and Barnicoat, 1986	
sapphire (colourless in thin section)	Al, Mg rich pelitic (? restitic)	corundum cordierite gneiss	Baffin Island, Canada	–	6
ruby (purple)	Al, Mg – rich pelitic (? restitic)	corundum – biotite schist	Limpopo Belt, Zimbabwe	Droop, 1989	

Corundum variety	*Host rock composition*	*Rock type/main mineralogy*	*Locality*	*Reference*	*Field Nos (Fig. 4)*
sapphire (colourless in thin section)	Al, Mg – rich pelitic (? restitic)	garnet – sapphirine – granulite	Limpopo Belt, Zimbabwe	Droop, 1989; Horrocks, 1983	6
sapphire (colourless in thin section)	bauxitic	chloritoid – corundum – rock	Cape Emerion, Naxos, Greece	Feenstra, 1985	7
sapphire (colourless in thin section)	bauxitic	spinel – biotite – plagioclase granulite	Limpopo Belt, Zimbabwe	Droop, 1989	
sapphire (colourless in thin section)	Al – rich pelite (restite)	corundum – spinel – hornfels (emery)	Sithean Sluain, Scotland	Smith, 1969	
ruby (purple)	calcareous	corundum – marble	Mong Hsu, Myanmar	Peretti *et al.*, 1995; 1996	8
ruby (purple)	marly (Al, Ca, Si – rich)	corundum – zoisite rock	Tanzania	Game, 1954; Dirlam, *et al.*, 1992	
sapphire (blue)	unknown origin		Vietnam		
sapphire (blue)	unknown origin		Nigeria, Africa		
ruby (purple)	unknown origin		North Vietnam		
ruby (purple)	unknown origin		Africa		

Notes: A Igneous corundums fall in Field 1.
B Corundums in pelite xenoliths less than 10 cm across in mafic magma fall in Field 2.
C Corundums in metamorphosed igneous rocks fall in Fields 3 and 4.
D Corundums in metamorphosed sedimentary rocks fall in Fields 5, 6, 7 and 8.
E Corundums from unknown origin.

The data for mineral assemblages, sample numbers and geological setting for each rock are available from the author.

(red, pink and purple) and sapphires (blue, green, yellow, brown and black varieties and varieties with chatoyancy and asterism). The average diameter of the samples is *ca.* 5 mm.

Corundum samples from well-characterized geological environments elsewhere in the world were chosen to compare with Thai corundum samples. Eight types of host-rock composition ranging from igneous rock (pegmatitic plumasite), pelite xenoliths in dolerite and gabbro, and metamorphosed igneous rocks to metasedimentary rocks were studied. The descriptions of these rocks are presented in *Table I*.

Methods and techniques

Several techniques have been used to obtain trace-element concentrations in corundum: energy dispersive X-ray fluorescence (ED-XRF), proton-induced X-ray emission (PIXE) and neutron activation analysis (NAA) (e.g. Stern and Hänni, 1982; Tang *et al.*, 1989; Muhlmeister *et al.*, 1998). However laser ablation – inductively coupled plasma – mass spectroscopy (LA-ICP-MS) and electron probe microanalysis – wavelength dispersive spectrometry (EPMA-WDS) have been employed in this work as they have relatively low detection limits, easy sample preparation and are suitable for a large number of samples.

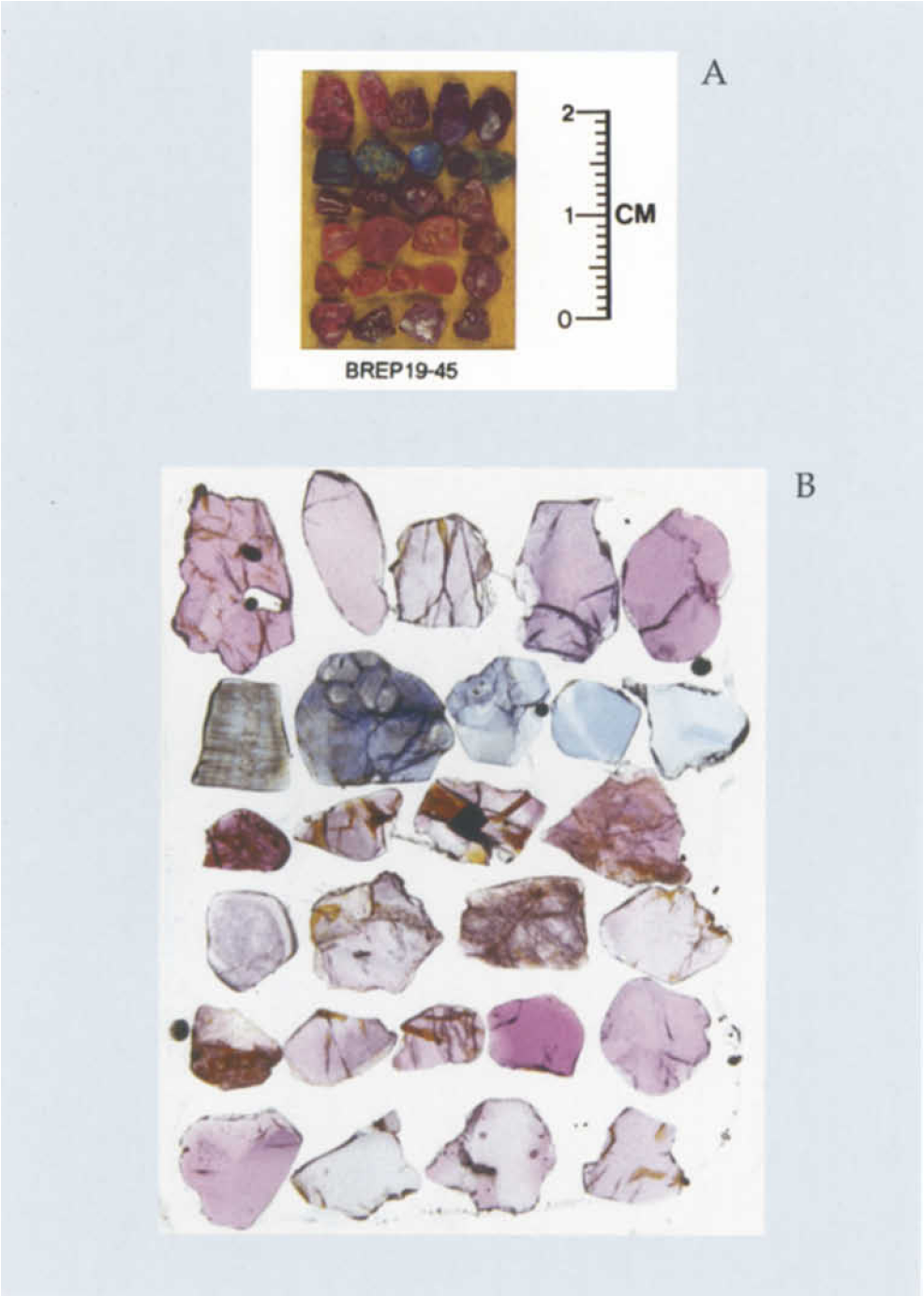

Figure 2: *(A) Corundum samples from Bo Rai, Thailand (sample numbers BREP 19-45, from left to right and top to bottom), being prepared to cut and polish and turn into the polished section as in (B).*

Table II: *Range of trace element concentrations (wt%) in corundum samples from Thailand and the Democratic People's Republic of Laos.*

Locality (prefix)	*Ban Huai Sai (CKEP)*	*Ban Nong Nam Cho (BNEP)*	*Den Chai (DCEP)*	*Bo Phloi (BPEP*	*Khok Samran (KSEP)*	*Bang Kacha (BKCEP)*	*Nam Yun (NYEP*	*Bo Rai (BREP*	*Bo Rai (BREP)*	*Nong Bon (NBEP)*	*Mean detection limit*
variety	sapphire								ruby		
V_2O_5	bdl-0.014	0.001-0.008	bdl-0.013	bdl-0.032	bdl-0.004	bdl-0.007	bdl-0.006	bdl-0.004	bdl-0.011	0.002-0.007	0.0026
Ga_2O_3	0.013-0.101	0.007-0.017	0.015-0.040	0.011-0.030	0.011-0.019	0.014-0.034	0.020-0.047	0.018-0.034	bdl-0.009	0.002-0.007	0.0019
Fe_2O_3	0.296-1.458	0.478-1.114	0.300-1.966	0.302-0.931	1.367-1.833	0.705-3.334	0.795-1.684	0.559-1.195	0.349-0.882	0.360-0.692	0.0047
MnO	bdl-0.001	bdl	bdl	bdl-0.001	bdl-0.003	bdl-0.007	bdl	bdl	bdl-0.004	bdl-0.003	0.0043
Cr_2O_3	bdl-0.042	bdl-0.011	bdl-0.018	bdl-0.053	bdl-0.007	bdl-0.007	bdl-0.010	bdl-0.003	0.086-0.564	0.028-0.355	0.0047
La_2O_3	bdl-0.003	bdl-0.003	bdl-0.002	bdl-0.003	bdl-0.002	bdl-0.005	bdl-0.003	bdl-0.002	bdl-0.002	bdl-0.004	0.0016
TiO_2	0.002-0.554	0.022-0.067	0.007-0.242	0.003-0.264	0.008-0.182	0.003-0.375	0.004-0.037	0.009-0.089	0.007-0.073	0.017-0.062	0.0003
SnO_2	bdl-0.075	bdl-0.001	bdl-0.004	bdl-0.004	bdl-0.004	bdl-0.005	bdl-0.003	bdl-0.001	bdl-0.005	bdl-0.003	0.0033
SiO_2	bdl-0.009	bdl-0.003	bdl-0.013	bdl-0.007	bdl-0.002	bdl	bdl-0.007	bdl-0.024	0.002-0.049	bdl-0.024	0.0059
Y_2O_3	bdl-0.005	bdl-0.004	bdl-0.004	bdl-0.004	bdl-0.001	bdl-0.004	bdl-0.004	bdl-0.001	bdl-0.007	bdl-0.006	0.0112
Ta_2O_5	bdl -0.271	na	na	bdl-0.006	na	na	na	na	na	na	0.0018
Nb_2O_5	bdl-0.382	na	na	bdl-0.003	na	na	na	na	na	na	0.0012
WO_3	bdl-0.023	na	na	bdl-0.093	na	na	na	na	na	na	0.0103
CuO	bdl-0.004	na	na	bdl-0.006	na	na	na	na	na	na	0.0037

Notes: The shaded cells contain the maximum values; na = not analysed; bdl = below detection limit; NiO was sought but not detected.

Table III: *Range of trace element concentrations (wt%) in corundum samples outside Thailand.*

Field Nos. (Fig. 4)	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*
Locality (Sample No.)	Natal (Δ1556)	Mull (SVI/1) Bushveld (18058)	S. India (Δ793)	Bancroft (BC21)	Etive (MM125A) Behelvie (Δ1192) Stoer (Δ16136)	Baffin (Δ440) Limpopo (BB14A) Limpopo (BB29F)	Naxos (Δ577) Limpopo (BB19) Sithean Sluain (Δ1378)	Mong Hsu (TYEP, MSEP) Tanzania (CRM/ZOI-1)	Vietnam (VNEP) Nigeria (NAEP)	N. Vietnam (NVEP) Africa (AFEP)
variety*	sapphire	sapphire/ ruby	ruby	sapphire	sapphire/ CL/ruby	CL/ruby/CL	CL/CL/CL	ruby/ruby	sapphire/ sapphire	ruby/ruby
V_2O_5	bdl-0.005	0.046-0.196	0.002-0.004	bdl-0.002	0.001-0.046	0.002-0.009	bdl-0.045	bdl-0.102	0.001-0.012	bdl-0.047
Ga_2O_3	0.017-0.024	0.006-0.015	bdl-0.004	0.006-0.014	0.004-0.033	0.002-0.013	bdl-0.016	bdl-0.015	0.023-0.054	0.001-0.006
Fe_2O_3	1.191-1.467	0.150-0.451	0.497-0.521	0.209-0.354	0.098-0.257	0.129-0.653	0.383-4.895	bdl-0.216	0.247-1.431	0.001-0.281
MnO	bdl	bdl-0.001	bdl-0.001	bdl	bdl-0.004	bdl-0.001	bdl	bdl-0.001	bdl	bdl
Cr_2O_3	0.001-0.003	0.089-0.674	1.252-1.466	bdl-0.004	0.007-0.196	bdl-0.037	0.002-0.279	0.332-1.700	bdl-0.004	0.311-1.218
La_2O_3	bdl-0.002	bdl-0.002	bdl-0.000	bdl-0.004	bdl-0.003	bdl-0.002	bdl-0.004	bdl-0.003	bdl-0.002	bdl-0.001
TiO_2	0.007-0.043	0.095-0.600	0.005-0.007	0.002-0.060	0.005-0.915	0.007-0.030	0.004-0.469	0.003-0.502	0.008-0.047	0.009-0.188
SnO_2	bdl-0.004	0.000-0.004	bdl-0.001	bdl-0.003	bdl-0.003	bdl-0.005	bdl-0.004	bdl-0.003	bdl-0.002	bdl-0.001
SiO_2	bdl-0.097	bdl-0.040	bdl	bdl	bdl-0.098	bdl-0.053	bdl-0.256	bdl-0.044	bdl-0.016	bdl
Y_2O_3	bdl-0.325	bdl-0.006	bdl-0.397	bdl-0.001	bdl-0.006	bdl-0.003	bdl-0.009	bdl-0.003	bdl-0.004	bdl-0.004

* Purple and pink colours are called ruby for the purposes of this study and the other colours are called sapphires. CL = Colourless in thin section.
The shaded cells contain the maximum values. bdl = below detection limit; NiO was sought but not detected.

Analyses of minerals using LA-ICP-MS were made from a range of mineral groups using samples prepared in a variety of ways (see Jackson *et al.*, 1992; Pearce *et al.*, 1992; Jeffries *et al.*, 1995; Christensen *et al.*, 1995; Sylvester and Ghaderi, 1997). At this stage results were qualitative.

For EPMA investigation, single grains of corundum were hand-picked on the basis of colour, low abundance of cracks, and minimum degree of weathering and staining. The grains were placed, in an array, on a piece of adhesive tape in order to be able to recognize them (*Figure 2a*). They were then embedded in epoxy resin, cut, polished and made into sections without a cover glass as shown for example in *Figure 2b*. The sections are approximately 100 µm thick due to the high hardness of corundum. The samples of corundum-bearing rocks from outside Thailand were cut and polished in the standard way to a thickness of about 30 µm. All sections before analysis were coated with carbon by the carbon-arc technique to provide a conducting path for the probe current and thus prevent build-up of charge (Reed, 1996; Reed, 1997).

The polished sections were analysed with the CAMECA SX-100 electron microprobe at the Department of Earth Sciences, University of Manchester. Clean areas in the samples, without visible inclusions, were chosen for analysis. The computer software, SXRAY, was set to automatically run the machine under the 'trace analysis programme' (without collecting the count rates of Al and O) for collecting the count rates of 15 trace elements (V, Ni, Ga, Fe, Mn, Cr, La, Ti, Sn, Si, Y, Ta, Nb, W and Cu).

Five spectrometers were used to collect the counts; the details of the crystals and standards used are available from the senior author. The run time for one analysis was 12 minutes. The 'trace analysis programme' (assuming Al = 52.4 wt% and O = 46.6 wt%) was used at 30 kV and 60 nA (at 25 kV and 200 nA for repeat analysis of samples from CKEP and BPEP) to optimize count rates for trace elements. Altogether, 491 analyses were collected (307 analyses from Thai-Laos corundum samples and 184 analyses from world corundum samples).

Results

Although the LA-ICP-MS method requires further refinement to produce accurate results, it is still useful for screening a wide range of elements within a short time. In this study Ta, Nb, W and Cu have been found in samples from Ban Huai Sai (CKEP) and Bo Phloi (BPEP) by using LA-ICP-MS and the EPMA has been used to verify their presence and abundance. The only trace element results presented here are results obtained from the EPMA analysis.

Compositions to three decimal places are given in *Tables II* and *III* and some oxides and ratios are plotted in the diagrams of *Figures 3* and *4*. Note that the limit of detection (*Table II*, column 12) is the concentration of background at $x+3\sigma$ of its signal distribution (Potts, 1987, 16; Walsh, 1997). All analysed elements are described below (the results of the corundum samples from Ban Huai Sai are grouped with the Thai corundum samples).

Vanadium

Thai corundum samples have vanadium contents of less than 0.032 wt% V_2O_5 and in most samples, the element is below the limit of detection (0.0026 wt% of V_2O_5), bdl in *Table II*. The highest value (0.032 wt%) belongs to a violet sample from Bo Phloi.

Corundum samples from outside Thailand have higher contents of vanadium than the Thai samples, ranging between 0.001 and ca 0.200 wt% V_2O_5. Of these, the Al-rich restite pelitic xenoliths from Mull and Bushveld have corundums with relatively high vanadium contents and the highest value (0.196 wt%) is from the Bushveld sample.

Nickel and manganese

Nickel contents in corundum were beneath the limit of detection. Manganese contents are also very low but above the detection limit (0.001%) in 17 samples. However, of these, only two analyses show significant MnO concentrations: BKCEP9, 0.0070 wt% and BREP22, 0.0044 wt%.

Gallium

Gallium, like titanium and iron, is present in almost all samples. The plots of Ga_2O_3 contents for Thai corundum samples show a bimodal distribution (*Figure 3*). Most ruby samples (in purple, red and pink) contain Ga_2O_3 between 0.001 and 0.010 wt%. Most sapphire samples (in blue, green, yellow and brown) contain Ga_2O_3 between 0.010 and 0.100 wt%.

The corundum samples from outside Thailand contain Ga_2O_3 from 0.001 to 0.054 wt%. A sample from an unknown geological origin from Vietnam (VNEP) contains the highest Ga_2O_3 (0.054 wt%).

Iron

Thai corundum samples contain relatively high iron contents compared to the samples from other parts of the world. The Fe_2O_3 contents of most Thai corundum samples fall in a range between *ca.* 0.300 and 3.000 wt%, rather narrower than that found for samples from outside Thailand. The sample BKCEP9 contains the highest value (3.334 wt% of Fe_2O_3) beyond the major range. The Fe_2O_3 values of the samples with high iron contents (BKCEP and NYEP) match those of the igneous corundum sample from Natal (Δ1556).

The Fe_2O_3 contents of corundum samples from outside Thailand lie mainly in the range 0.100 to 2.000 wt%. Exceptionally, the restitic emery samples from Sithean Sluain (Δ1378) have high values of Fe_2O_3, including the highest value found (4.895 wt%). In contrast, ruby samples from marble at Mong Hsu (TYEP, MSEP) and from an unknown geological origin in North Vietnam (NVEP) have very low iron contents (less than 0.010 wt%).

Chromium

Chromium contents in the corundum samples from Thailand show a bimodal distribution in the graph, like gallium (*Figure 3*). The ruby samples have Cr_2O_3 values between 0.028 and 0.564 wt%, while the sapphire samples have lower values of Cr_2O_3 from 0.053 wt% down to below the limit of detection (0.0047 wt%).

In corundums from outside Thailand Cr_2O_3 contents are up to 1.700 wt%. The highest value belongs to a sample from Mong Hsu (MSEP4), while the Cr_2O_3 contents of the igneous corundum from Natal (Δ1556), the corundum in the meta-syenite-gneiss from Bancroft (BC21), and the corundums of unknown geological origin from Vietnam (VNEP) and Nigeria (NAEP) are below the limit of detection (0.0047 wt%).

Lanthanum

Thai corundum samples contain very low concentrations of lanthanum compared to V, Ga, Fe, Cr and Ti. In most samples, La could not be detected (limit of detection 0.0016 wt% La_2O_3). Sample BKCEP9 contains the highest La_2O_3 (0.0053 wt%).

In corundum samples from outside Thailand, the highest La_2O_3 content is 0.004 wt% in metabauxite from Naxos, 577, but in most samples La_2O_3 was below the limit of detection (0.0016 wt%).

Titanium

The limit of detection for TiO_2 is 0.0003 wt% (*Table II*) which is low compared with the limits for other elements analysed in this study. Thai ruby samples have TiO_2 contents mainly between 0.007 and 0.073 wt%, but in Thai sapphires, there is a wider range from 0.003 to 0.554 wt% with those from Ban Huai Sai (CKEP) at the upper end of this range.

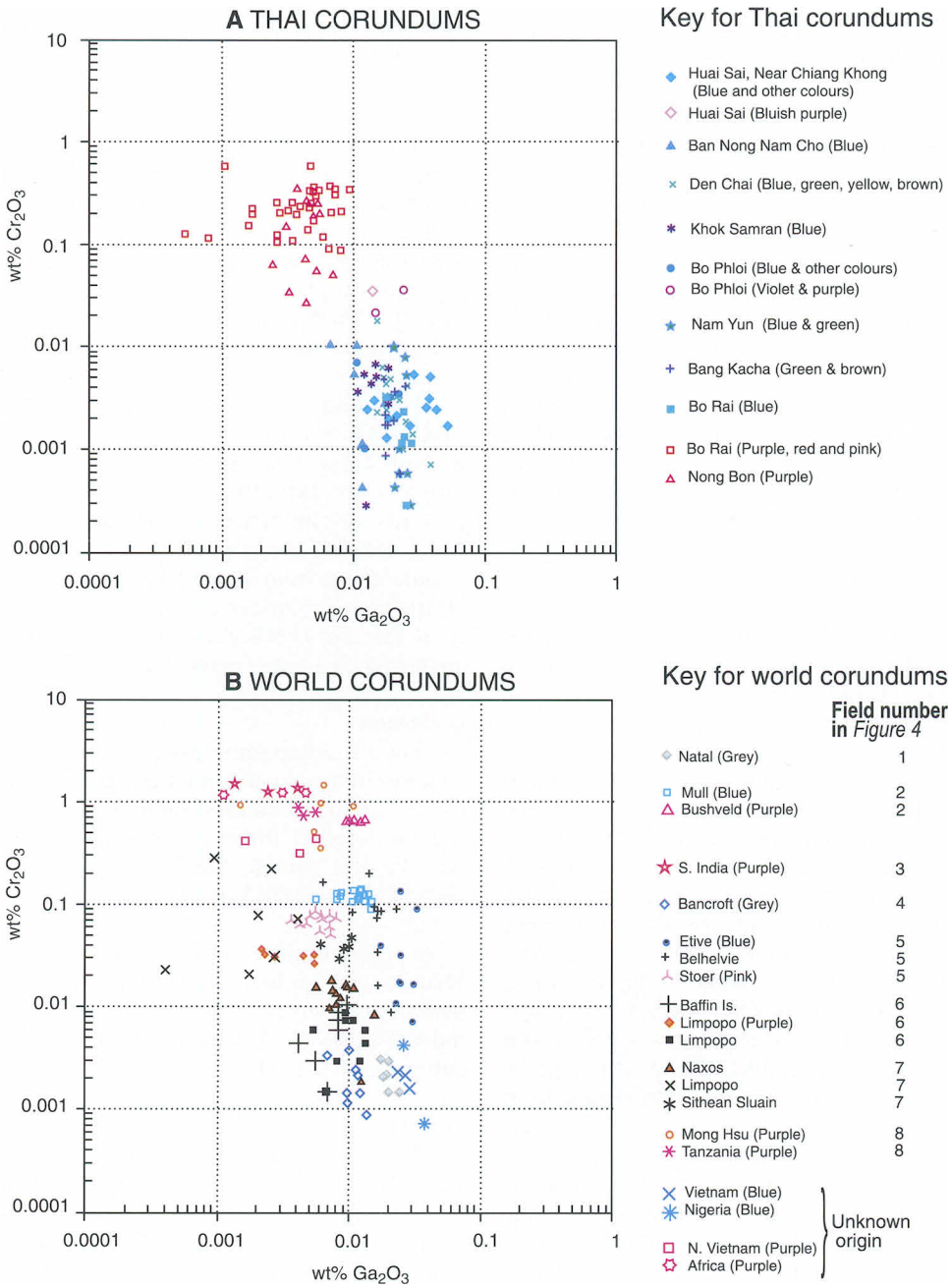

Figure 3: *Plots of wt% of Cr_2O_3 against Ga_2O_3 for Thai corundum and corundum outside Thailand. Thai corundum (A) shows two discrete populations compared to the corundum outside Thailand (B).*

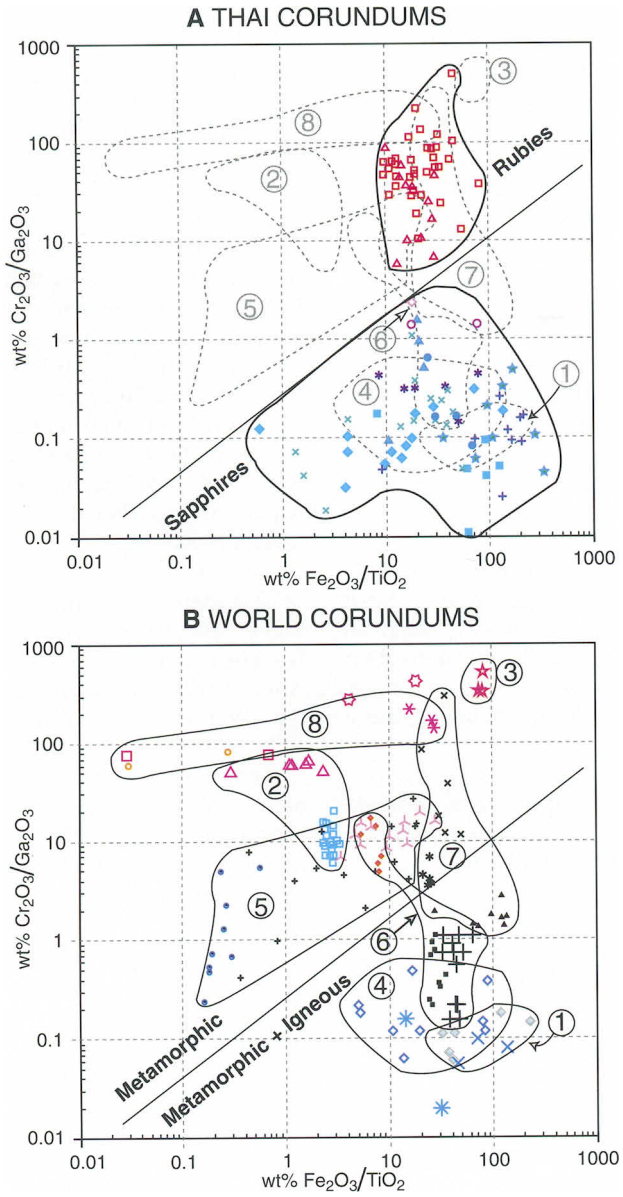

Figure 4: *(A) Plot of wt% Cr_2O_3/Ga_2O_3 against wt% Fe_2O_3/TiO_2 in Thai corundums for comparison with the well-characterized origins of the world corundums in B. Thai corundums can be considered as two groups: group I), rubies with high Cr and low Ga contents and group II), sapphires of all colours other than red with high Ga and low Cr contents. (B) Plot of similar ratios for the world corundums separated into 8 groups on geological criteria.*

Note: Key for **Figure 4** is the same as in **Figure 3**.

Titanium in the corundum samples from outside Thailand shows a wide range with the highest value of TiO_2 (0.915 wt%) in a pelitic hornfels from Etive (MM125A) and the lowest value (0.002 wt%) in a meta-syenitic corundum from Bancroft. Note that the wide range of TiO_2 in the samples is probably due to patchy rutile inclusions.

Tin

Tin is one of the granitophile metals (Sn, Nb, Ta, W, Be, Li) derived from crustal sources (Smirnov, 1968). The limit of detection of this element can be relatively high (min. 0.0025, max. 0.0317 wt% SnO_2) compared to those of the other elements. A blue sapphire sample from Ban Huai Sai contains the highest value of SnO_2 (0.075 wt%) and other samples from this locality have relatively high Sn contents. Most samples from Ban Huai Sai have high Sn contents, which are generally above the limit of detection (Min. = 0.025 wt% of SnO_2). This agrees with the results obtained using the LA-ICP-MS.

The corundum samples from outside Thailand show very low concentrations of tin and in most SnO_2 was not detected.

Silicon

Like tin, silicon has a very high detection limit and there is low precision in measurements of background.

In Thai corundum, silicon is more abundant in ruby than in sapphire. Moreover most SiO_2 values in the rubies are higher than the limit of detection and the highest is in sample BREP37 (0.049 wt%).

In most corundum samples from outside Thailand, SiO_2 is below the limit of detection (0.0059 wt%). A sample in a meta-bauxite from Naxos (577) has an anomalously high SiO_2 value of 0.256 wt%.

Yttrium

All values of Y_2O_3 for Thai corundum samples are lower than the mean of the limit of detection. The results of the samples from outside Thailand are also lower than the limit of detection except for the igneous corundum in plumasite from Natal (sample 1556) which shows the highest Y_2O_3 value (0.325 wt%).

Tantalum niobium, tungsten and copper

Four elements were measured in samples from two Thai localities: Ban Huai Sai and Bo Phloi. The tantalum and niobium contents in samples from Ban Huai Sai are highest (up to 0.271 wt% of Ta_2O_5; 0.382 wt% of Nb_2O_3), whereas in samples from Bo Phloi both are very low. The maximum values of Ta_2O_5 and Nb_2O_5 in Bo Phloi samples are only 0.006 wt% and 0.003 wt% respectively. These results are consistent with those obtained using LA-ICP-MS.

Tungsten in sapphires from Bo Phloi is higher than in the samples from Ban Huai Sai. The maximum value in Bo Phloi samples is 0.093 wt% of WO_3, compared with 0.023 wt% WO_3 in the sample from Ban Huai Sai.

The copper contents are low with most below the limit of detection. The maximum values found were 0.004 wt% and 0.006 wt% of CuO in the samples from Ban Huai Sai and Bo Phloi respectively.

Discussion

Several models for the origin of the corundum in basaltic terrains have been generated. Most models involve plutonic crystallization from melt, although regional metamorphism of Al-rich rocks subducted below the continental crust has been proposed by Levinson and Cook (1994). In the Thailand context, this model has the weakness that the subduction zone (Sunda trench, west of Myanmar and Indonesia) is too far away (>1000 km) from the basalt outcrops. Corundum-bearing basalts also occur in Cambodia, Viet Nam and China, having a similar age range (Cenozoic) to that in Thailand (e.g. Barr and Macdonald, 1981). They do not seem to be related to a subduction zone. Several models invoke

alkaline Si- and Al-rich melts, either evolved from basaltic magmas (Coenraads *et al.*, 1990; Coenraads, 1992a) or derived from melting of amphibolitised mantle (Sutherland, 1996). A more complex melt origin was proposed by Guo *et al.* (1996), who claimed that mineral inclusions in the corundums reflect the reaction between Si-rich and carbonatitic magmas under relatively low temperatures around 400°C at mid-crustal levels around a depth of 10-20 km. Although this model is consistent with the origin of sapphires, it does not clearly account for rubies. Sutherland *et al.* (1998a) proposed the means of generating basaltic-type gem corundum and favoured melting of mantle source-rocks containing amphibole at depths of 35–40 km near the crust-mantle boundary; such melting could produce a final Si- and Al-rich rock with over 5 wt% corundum. Moreover the different metamorphic or pegmatitic sources and assemblages (e.g. corundum-sapphirine-spinel assemblage) must exist under basaltic regions. Using trace-element and inclusion approaches, Sutherland *et al.* (1998b) and Sutherland (1998) classify corundum in basaltic terrains into metamorphic corundum (including ruby) and basaltic-type (including blue, green, yellow, brown, white, grey, opaque and black corundums).

The trace element variation diagram using data from this study (*Figure 3, A*) shows that Thai corundums have a bimodal distribution based on the Cr and Ga contents. The purple and pink ruby samples (simply called rubies) contain high chromium (up to 0.57 wt% Cr_2O_3 but low gallium (<0.01 wt% Ga_2O_3). The samples with blue, green, brown and violet colours (simply called sapphires) contain high gallium (up to 0.10 wt% Ga_2O_3) but low chromium (<0.05 wt% Cr_2O_3). This evidence agrees well with the results obtained by Sutherland *et al.* (1998b) who designated the ruby group as having a metamorphic origin and the sapphire group as having an igneous origin. Thus although both sapphire and ruby occur together in the same deposits in Thailand, their origins are most probably different.

Sapphire genesis

Both Ga and Cr substitute readily for Al in corundum, which can be explained by the simple rules of similar ionic charge and radius (Ga^{3+} = 0.620 Å, Cr^{3+} = 0.615 Å and Al^{3+} = 0.535 Å; 6-coordinate). Moreover Ga has chemical properties similar to Al and it is always present with Al. Ga is enriched in felsic and intermediate rocks, whereas Cr is enriched in ultramafic and mafic rocks (Krauskopf and Bird, 1995, 542-5).

Figure 4A shows the plots of Thai sapphire samples superimposed on the fields of corundums in syenitic gneiss from Bancroft (field 4), in pegmatitic plumasite from Natal (field 1), in Al, Mg-pelite from Baffin Island and Limpopo (part of field 6). A high-grade metamorphic rock consisting of corundum, sillimanite, minor zircon and a trace of hercynite and found in alluvium of a corundum mine in Bo Phloi is believed to be derived from the same source as the corundums brought to the Earth's surface by alkali basalt (Pisutha-Arnond *et al.*, 1999). Hercynite is also found as inclusions in sapphires from this locality (Saminpanya, 2000, 216-7). On this basis, the crystallization of sapphires from Thailand in magma of pegmatitic plumasite or directly from an alkali basalt magma will be ruled out. An origin related to metamorphism is more likely.

However the study of fluid inclusions in sapphires from Bo Phloi (Srithai and Rankin, 1999) suggested a magmatic source. Moreover the U-Pb dating of zircon inclusions in sapphires from New South Wales and a zircon associated with sapphire from Chanthaburi (Coenraads *et al.*, 1990; Coenraads *et al.*, 1995) suggested that sapphires have a genetic link to alkali basalt. Guo *et al.* (1996) suggested that at the high temperatures of basaltic magmas, the U-Pb in zircons can be reset within the time of the magma's eruption and cooling due to Pb diffusion so that the results could then give the same age as the basalt and not the true age of sapphire. Other circumstantial

evidence includes: failed experimental attempts to grow corundum from a corundum-bearing basaltic composition under different pressure, temperature and hydrous conditions have been reported (e.g. Green *et al.*, 1978); and surface features of sapphires (e.g. Coenraads, 1992a, 1992b; Krzemnicki *et al.*, 1996; Saminpanya, 2000, 116-22) indicate that the sapphires were not in equilibrium with the magma of basalt host rock. These factors suggest that sapphires crystallized elsewhere and that the alkali basaltic magma picked them up and carried them to the Earth's surface.

In *Figure 4*, the Thai sapphire data lie mostly in the field of the syenitic gneiss from Bancroft. The pre-existing rock of the corundum-bearing syenitic gneiss from Bancroft is a dark paragneiss of the Precambrian Grenville series (Gummer, 1946). According to Gummer (1946) and Moyd (1949), metasomatic alteration converted the dark paragneiss, into a nepheline-corundum syenitic gneiss. By analogy to the syenitic gneiss of Bancroft, Thai sapphires could have originated from Precambrian paragneiss that experienced metasomatism by emanations from felsic magma (enriched in gallium and incompatible elements) or carbonatite (enriched in Nb-Ta) at deep levels beneath Thailand. Note that the main source of Nb-Ta is granitic pegmatites, carbonatite or peralkaline granite (Möller *et al.*, 1989). In this case a carbonatite magma might have intruded the gneiss source rock to form fenite (syenitic composition). In addition to Bancroft, another corundum-bearing fenite has been reported from the Khibina alkaline complex, Russia (Barkov *et al.*, 1997; Barkov *et al.*, 2000). However, as Thai sapphires occur extensively throughout the country, any such process or processes will have to have been widespread and not necessarily limited to a single intrusive complex. The process introduced in this study is slightly different from that described by Guo *et al.* (1996) who said that the carbonatite reacted with the pegmatitic magma giving corundum-bearing lenses at mid-crustal levels.

The abundances of Ga, Ti and Fe, incompatible elements (e.g. Ta, Nb, Sn) and mineral inclusions in sapphires (zircon, alkali feldspar, nepheline and spinel) suggest that the sapphires formed in a highly evolved melt of peralkaline syenitic or granitic composition. This agrees well with the studies of some authors, e.g. Aspen *et al.*, (1990) and Upton *et al.* (1999), but it is different from those of Sutherland *et al.* (1998a) who maintain that sapphires crystallized when amphibole-bearing mantle underwent partial melting because of an advancing thermal aureole.

Nb, Ta and Sn could possibly have been carried to the country rocks by felsic or carbonatitic magma during a process in which the gneissic country rock was metamorphosed to the syenitic gneiss as in the Bancroft area. Nepheline ($Ne_{68.3}Ks_{28.6}Q_{3.0}$; n=4) is found as an inclusion in corundum from Bo Phloi (Saminpanya, 2000, 215). This is consistent with the sapphire originating in a nepheline-corundum syenitic gneiss. Nepheline coexisting with sapphire is also found in syenitic rock and nepheline-aegirine intrusive rock (urtite) in Mogok, Myanmar (Waltham, 1999).

The lower crust beneath Thailand is thought to be composed of Precambrian-metamorphic granulite-facies rocks (Bunopas, 1992). The data in *Figure 4B* show that the plots of Thai sapphires also overlap the field of corundum from Al- and Mg-rich pelites from Baffin Island, Canada and Limpopo, Zimbabwe. This suggests that the parent rocks could have been the Precambrian paragneiss of Thailand, which originated from the marine (flysch) sediments of a continental margin (of Gondwanaland) and were deeply buried and metamorphosed (Bunopas, 1992).

Ruby genesis

The ruby group, consisting of red, pink and purple corundum is confined to the areas of Bo Rai and Nong Bon. In *Figure 4*, their analyses lie in or close to field 7, corundum of bauxitic origin (e.g. BB19 from the Limpopo belt). Some analyses fall in the gap between field 8 (corundums in marble) and field 5 (corundums in normal pelitic rocks), and this suggests that Thai rubies probably crystallized in a different environment from these rocks. The inclusion suite in the rubies which includes garnet, sapphirine and fassaite pyroxene, also suggests that Thai rubies have a metamorphic origin (Sutthirat *et al.*, 2001).

In Thailand rubies are always found with sapphires. Sapphires are dominant in the localities in the western part of the country (Shan-Thai block) but rubies are dominant in the east (Indochina block). The proportional change from sapphire to ruby is apparent in the Chanthaburi and Trat areas (Vichit, 1992; Hughes, 1997, 427-43). This suggests that the source beneath Thailand which produced both rubies and sapphires was at the base of very thick continental crust or within the upper mantle. The fact that rubies are rich in chromium and poor in gallium suggests that they formed in pre-existing metamorphic rock with mafic composition. Sapphires are rich in Ga and high field strength elements and poor in Cr, and these features are consistent with their formation in syenitic metamorphic rocks by reaction with a highly evolved fractionated magma such as a carbonatitic magma. It is envisaged that such a magma might move from the mantle to deep in the crust where it reacted with the syenitic metamorphic rock. Cr is generally precipitated early in magmatic fractionation (Matzat and Shiraki, 1978) and so in highly fractionated magmas such as carbonatites and syenites is not available for reaction. In contrast, Ga is present in fractionated magmas and they and the host rocks could be the source of gallium in sapphires.

Conclusions

Thai sapphires contain high Ga, Ti and Fe and incompatible elements (e.g. Ta, Nb, Sn) whereas Thai rubies are rich in Cr but poor in those elements found in Thai sapphires. However both the rubies and the sapphires have metamorphic-related origins. Thai sapphires could have originated from Precambrian paragneiss that experienced metasomatism by emanations from felsic magma (enriched in Ga and incompatible elements) or carbonatite (enriched in Nb-Ta) at deep levels beneath Thailand. Thai rubies have a metamorphic origin and formed in a pre-existing metamorphic rock with mafic composition. It was at a later stage that alkali magmas penetrated the metamorphic rocks and carried sapphires and rubies to the surface to be erupted as basalts in many localities in Thailand.

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15:30 *Violet Bailey*. Recruiting staff for profit

Monday 1 September

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13:00 *Matthew Hall*, GIA. Research update on coloured stone treatments
14:30 *Dr Christopher Corti*, World Gold Council. What is a white gold? – the consumer may be confused
15:30 *Violet Bailey*. Recruiting staff for profit

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11:30 *Vicky Morrison*, Platinum Public Relations in association with NAG – Get yourself talked about
13:00 *Matthew Hall*, GIA. Research update on coloured stone treatments
15:00 *Richard Bailey and Nigel Lubbock,* legal advisors to the BJA. Money laundering Regulations 2003/Proceeds of Crime Act 2002 – *Risks for jewellery retailers*
16:00 Doug Garrod, Gem-A. Everything included – internal features of gemstones

Wednesday 3 September

10:30 *Carrie Soucy*, JCK Magazine. What women want – why fashion matters to jewellers
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Caesium-rich morganite from Afghanistan and Madagascar

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ABSTRACT: Quite saturated pink beryl of Madagascar and Afghanistan are described. They display densities between 2.91 and 3.10 g/cm^3 and RI values up to 1.608 (n_e) and 1.615 (n_o) which exceed the values reported so far in the literature. Chemical analyses reveal very high caesium concentrations (up to 15.18 wt.% Cs_2O). The incorporation of Cs in the structural channels of beryl is mainly coupled with a substitution on the tetradhedrally-coordinated beryllium site. Such stones belong to the so-called tetrahedral beryls. UV-Vis-NIR spectra show manganese and water absorption features typical for morganite. XRD data and Raman spectra reveal a distinct increase in cell parameters (mainly c_0) compared to pure beryl, thus underlining the unusual character of the studied material. While the sample from Afghanistan is semi-transparent, transparent stones are found among the samples from Madagascar. Inclusions consist mainly of fine tubes parallel to the *c*-axis, flat fluid-filled inclusions parallel to the basal pinacoid, and tension fractures. Based on chemical composition, spectral data and colour saturation we suggest that the simple term morganite be retained to describe the stones, unless a new term is approved by the IMA to recognize the extraordinary composition and structure of the material.

Introduction

In mid-2002 a small quantity of pink to raspberry-red beryls were mined in Madagascar (*Figure 1*). Some time before that, a minor amount of similar specimens had already been found in Afghanistan. Pink to red varieties of beryl have been reported with various names in the gemmological literature. In this paper we intend to describe the new stones and compare them with earlier material of similar colours, i.e. morganite and red beryl. Initial measurements have indicated high values for refractive indices and density, and therefore we felt it necessary to determine not only the customary gemmological properties, but also to carry out a sound mineralogical investigation including chemical analyses, structural data and spectral characteristics in UV-Vis and NIR.

When the composition of beryl is close to the ideal formula $Be_3Al_2Si_6O_{18}$, it is considered as n-beryl (normal beryl). The crystal structure of beryl is characterized by Be-O tetrahedra and distorted Al-O octahedra, linked with six Si-O tetrahedra forming a hexagonal ring structure. The stacking of the Si_6O_{18} rings forms large

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Figure 1: *Morganite crystals from Madagascar and Afghanistan from left: M2, M1, M3 and A1; faceted stones from Madagascar, from left: M5, M4, M6. The largest faceted stone is 3.025 ct.*

structural channels parallel to the crystallographic *c*-axis of the beryl and the structure offers a large number of possible substitutions both on the different lattice sites and in the channels (Deer *et al.*, 1992).

When the main substitution takes place on the octahedral lattice site, commonly occupied by aluminium, we speak of o-beryl (octahedral beryl). Partial substitutions of Al^{3+} by ions such as Fe^{3+}, Cr^{3+}, V^{3+}, or Mn^{3+} are common in this kind of material. Bivalent ions such as Mg^{2+}, Fe^{2+}, Mn^{2+} require a charge compensation that may be satisfied by monovalent alkalis (e.g. Na^{+}), which are incorporated in the channels of the structure. Most emeralds and aquamarines are o-beryls. When Be^{2+} on the tetrahedral lattice site is partially replaced, we speak of t-beryl (tetrahedral beryl). Based on our investigations it soon became obvious that the new pink beryls belong to this group. Substitution of Be^{2+} by monovalent ions (mainly lithium) requires a charge compensation, which may be realized by introducing a further monovalent ion in the channel structure (Bakakin *et al.*, 1970). The structural channel can accommodate large alkali ions and other large molecules such as H_2O or CO_2.

Both substitutions, octahedral and tetrahedral, as well as the absorption of ions and molecules in the channels, have the effect of increasing the density and refractive indices of beryl (Cerny and Hawthorne, 1976; Hänni, 1980; Sinkankas, 1981). We can thus assume that beryls with high constants contain more substitute elements and are relatively impure. Data from the literature demonstrate that high constants are usually related to high alkali contents, particularly of the heavy alkalis Cs and Rb (Evans *et al.*, 1966).

Sample description and origin

The present report is based on a small number of samples, which were obtained in March 2002 and January 2003. The first sample (A1) of a surprisingly strong pink colour was presented to one of the authors by Haleem Khan, of Hindukush Mala Gems & Minerals, Pakistan. It consists of a tabular crystal with flat hexagonal hillocks on the basal plane, similar to those described as a consequence of rapid growth by Flamini *et al.* (1983) on red beryl from Utah (*Figure 2*). The translucent material is more saturated than would be expected in morganite in the gem trade, but it is less saturated than the red beryl from Utah, USA. The sample was reported to have come from

the Deva mine, Paroon Valley (Konar, Nuristan) in Afghanistan (Haleem Khan, pers. comm. 2002). The other samples are from Madagascar and are similar in colour to sample A1. Sample M2 is a flat hexagonal tabular crystal of an orangey-pink colour. Alexander Leuenberger (Switzerland) provided that stone in December 2002. A short time later, five more samples were obtained from Denis Gravier (Le Mineral Brut, St. Jean-le-Vieux, France) during the Tucson Mineral and Gem Show 2003. Two of the samples (M1, M3) consist of rough translucent stones with broken surfaces. Three more samples (M4, M5, M6) are faceted transparent and semi-transparent stones. They are reported to come from Mandrosonoro, approximately 150 km SW of Antsirabe (Central Madagascar). Some dealers give Ambatovita as the local name for the origin of Madagascar samples. The source is described as a pegmatite which also contains danburite, tourmaline and kunzite. The pink beryls are intergrown with lepidolite and amazonite feldspar (F. Danet, pers. comm., 2003). On one of our rough samples dark green tourmaline is also present, and this supports a pegmatitic origin.

As reference samples, red beryl (R1, R2) from the Wah Wah Mountains and Thomas Range, Utah (courtesy Ted and Rex Harris, Delta, 1983), and light pink morganite (R3) from Madagascar (courtesy Werner Spaltenstein, Chanthaburi) were used. Red beryl is well described in the literature (Nassau and Wood, 1968; Hänni, 1980; Flamini *et al.*, 1983; Shigley and Foord, 1984). A remarkable property of the rhyolitic red beryls is their sectorized colour zoning which resembles an hourglass pattern. The prismatic growth sectors are intensely coloured as they attracted more Mn and Fe, while the basal growth sector is pale.

The colours of the faceted samples were compared with the Biesalski Pflanzenfarben-Atlas DIN 6164 colour chart. Since the stones possess a distinct pleochroism (orangey-red and purplish-pink), the perceived colour depends on the orientation selected for the cutting. When viewed in the *c*-axis direction the colour was orangey-pink and described as 7.5:3:1 following DIN 6164 (observed in samples M4 and M5). Perpendicular to the *c*-axis the colour is more purplish-pink and described as 10.5:2:1.5 (sample M6).

Figure 2: *From left to right: Morganite from Madagascar (M2), red beryl from Utah (R1), and morganite from Afghanistan (A1).*

Specific gravities and refractive indices

Specific gravity (SG), refractive index (RI) and birefringence were determined by usual gemmological testing methods. Both SG and RI of the new material from Afghanistan and Madagascar distinctly exceed the values so far reported in the literature (*Table I*). The birefringence, however, is not affected by these increases. The values for the reference samples (light pink morganite and red beryl) are consistent with those reported in the literature. The increases in SG and RI correlate with the amount of substitution by the heavy alkali ions, Cs and Rb (*Table I*).

UV-Vis spectra

Spectra of morganite and red beryl have been published by Wood and Nassau, 1968; Nassau and Wood, 1968; and Shigley and Foord, 1984. Both pink and red colours in beryl have been attributed to the incorporation of manganese on the aluminium site in the beryl structure, but the situation is complicated by the possibility of two manganese related colour types of beryl,

Table I: Specific gravities, refractive indices and caesium contents of morganites and red beryl.

Sample		SG	RI n_e	RI n_o	Birefringence	Cs_2O wt.%
pink morganite (Madagascar)	M4	3.103	1.608	1.615	-0.007	14.27
	M5	3.101	1.608	1.615	-0.007	14.63
	M6	3.089	1.604	1.611	-0.007	14.31
pink morganite (Afghanistan)	A1	2.906	1.598	1.606	-0.008	9.70
morganite (Madagascar)	R3	2.760	1.592	1.600	-0.008	1.09
red beryl (Wah Wah, Utah)	R1	2.670	1.564	1.570	-0.006	0.13
red beryl (Thomas Range, Utah)	R2	2.670	1.568	1.575	-0.007	

which are dependent on the valence state of manganese (Mn^{2+} or Mn^{3+}) (after Deer *et al.*, 1992 and Wood and Nassau, 1968).

In morganite (light pink), bivalent manganese is incorporated probably by substitution for Al according to the formula [Mn^{2+} + alkali$^+$ = Al^{3+}] where the alkali (e.g. Na^+, K^+, Rb^+, Cs^+) is in the structural channels of beryl. Other substitutions involving Mn^{2+} may also be possible in morganite. As the concentration of Mn^{2+} generally is much lower than the alkalis in such morganites, the proposed substitution remains essentially based on charge balance and bond length considerations.

In red beryl from Utah trivalent manganese acts as a chromophore element by a simple substitution of Mn^{3+} for Al^{3+} in o-beryl. Platonov *et al.* (1989) have described the spectral characteristics of the two Mn-related colours and underlined a clear difference in pleochroism: morganite exhibits distinct dichroism despite having a weaker colour saturation.

UV-Vis-NIR spectra were recorded on the samples from Afghanistan (A1), Madagascar (M5) and Utah (R1) with a Varian Cary Scan 500 spectrometer, using polarization filters to obtain ω- and ε-absorption spectra (*Figure 3*). The spectra of samples Al and M5 showed a strong correlation with spectra reported by Platonov *et al.* (1989) for morganite. In the spectrum of the o-vibration a strong maximum at 570 nm and a general absorption below 370 nm are present. The ε-vibration curve is characterized by a main absorption at 489 nm, with a side peak at 476 nm, and a second maximum at 550 nm, with an absorption edge at 370 nm.

Red beryl from the Wah Wah Mountains, Utah (R1) produced an ω-ray spectrum with an absorption maximum at 562 nm, and a peak at 428 nm, with general absorption below 350 nm. The ε-ray spectrum has its maximum at 535 nm, and a very weak peak at 428 nm. The 370 nm peak is absent, and the absorption edge is again at about 350 nm (compare also Shigley and Foord, 1984).

Near infrared (NIR) spectra

The NIR spectra of our samples were studied with a Varian Cary Scan 500 spectrometer between 800 and 2500 nm. A polarization unit could only be used from 250–900 nm. For morganite samples A1 and M2, three main absorption features near 1412 nm (7082 cm^{-1}), 1907 nm (5244 cm^{-1}) and 2267

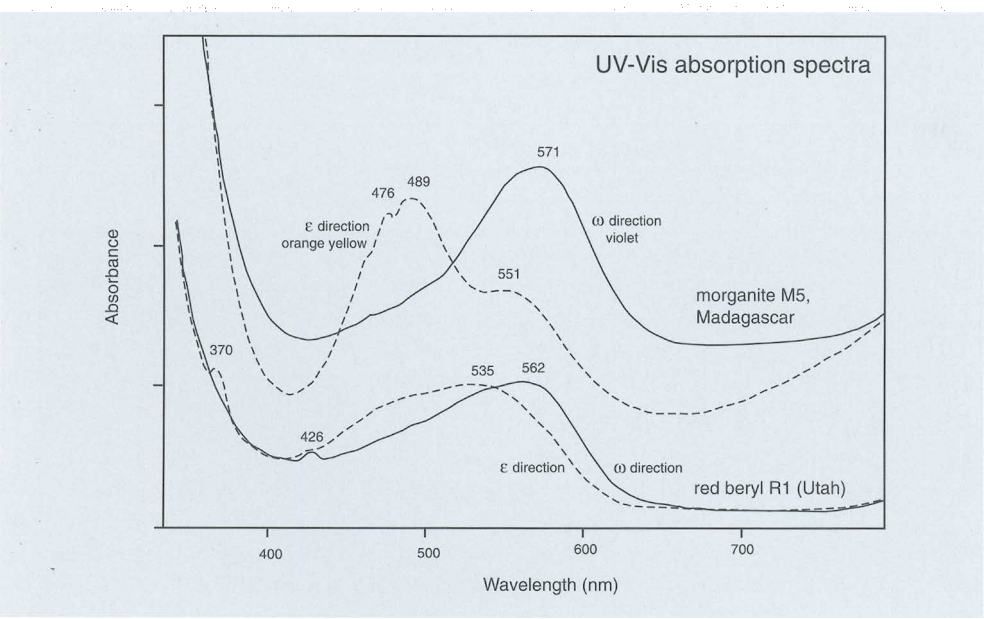

Figure 3: *UV-VIS spectra of morganite M5 from Madagascar and red beryl R1 from Utah (USA). The spectra reveal a distinct difference between these two beryl varieties with manganese Mn^{2+} as chromophore in morganite and Mn^{3+} in red beryl.*

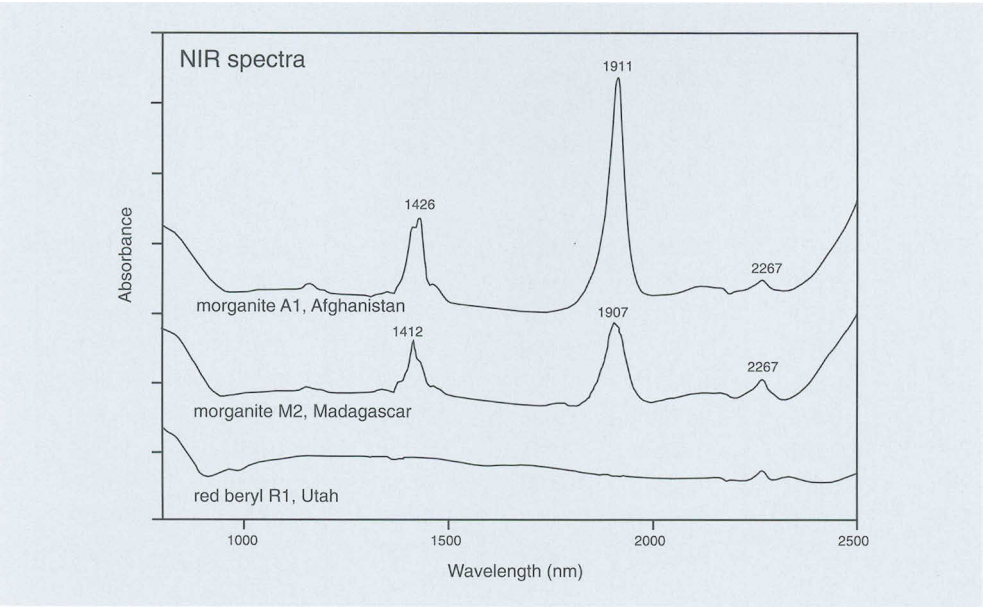

Figure 4: *Unpolarized NIR spectra of morganites A1 (Afghanistan), M2 (Madagascar), and red beryl R1 (Utah). Absorption peaks due to water occur near 1420 and 1910 nm in the morganite spectra but are absent in the red beryl spectrum.*

Table II: *Electron microprobe analyses of morganites from Madagascar and Afghanistan, and red beryl from USA.*

Wt.%	*Pink morganite*				*Morganite*	*Red beryl*	
	Madagascar			*Afghanistan*	*Madagascar*	*Utah, USA*	
	M4	*M5*	*M6*	*A1*	*R3*	*R1*	
BeO^*	6.36	6.21	6.28	8.13	11.20	13.78	Be-site
Li_2O^*	1.84	1.86	1.83	1.35	0.68	0.09	
Cs_2O	14.27	14.63	14.31	9.70	1.09	0.13	channel
Na_2O	0.56	0.50	0.52	1.15	1.35	0.07	
K_2O	0.14	0.16	0.15	0.03	0.07	0.20	
Rb_2O	0.38	0.39	0.39	0.14	0.09	0.14	
MgO	b.d.	b.d.	b.d.	b.d.	b.d.	0.11	
CaO	0.17	0.17	0.19	0.98	0.01	b.d.	
Al_2O_3	15.84	15.70	15.62	15.72	17.52	16.59	Al-site
Cr_2O_3	b.d.	b.d.	b.d.	b.d.	b.d.	b.d.	
V_2O_3	0.05	0.09	0.09	0.06	b.d.	0.04	
Fe_2O_3	0.03	0.03	0.02	0.02	0.02	2.10	
TiO_2	b.d.	b.d.	b.d.	b.d.	b.d.	0.27	
MnO	b.d.	b.d.	b.d.	0.02	b.d.	0.29	
Sc_2O_3	b.d.	b.d.	b.d.	b.d.	b.d.	b.d.	
SiO_2	59.01	58.60	58.42	61.32	64.82	66.91	Si-site
Total	98.65	98.33	97.82	98.60	96.85	100.69	
Normalization to a total of 11 cations							
Be^{2+}	1.552	1.528	1.549	1.910	2.490	2.968	
Li^+	0.753	0.765	0.755	0.532	0.298	0.032	
Cs^+	0.619	0.639	0.626	0.405	0.043	0.005	
Na^+	0.110	0.099	0.103	0.218	0.242	0.012	
K^+	0.018	0.020	0.020	0.004	0.009	0.023	
Rb^+	0.025	0.026	0.026	0.009	0.005	0.008	
Mg^{2+}	0.000	0.000	0.000	0.000	0.000	0.015	
Ca^{2+}	0.019	0.018	0.021	0.103	0.001	0.000	
Al^{3+}	1.899	1.895	1.890	1.813	1.911	1.753	
Cr^{3+}	0.000	0.000	0.000	0.000	0.000	0.000	
V^{3+}	0.004	0.007	0.008	0.004	0.000	0.003	
Fe^{3+}	0.002	0.002	0.001	0.001	0.001	0.142	
Ti^{4+}	0.000	0.000	0.000	0.000	0.000	0.018	
Mn^{2+}	0.000	0.000	0.000	0.001	0.000	0.022	
Sc^{3+}	0.000	0.000	0.000	0.000	0.000	0.000	
Si^{4+}	6.000	6.000	6.000	6.000	6.000	6.000	
Total	11.000	11.000	11.000	11.000	11.000	11.000	
H_2O^*	0.460	0.570	0.749	0.456	0.973	0.000	

N.B. *BeO, Li_2O and H_2O have been calculated. b.d. = below detection limit

nm (4411 cm^{-1}), are present (*Figure 4*). Without polarisation measurements detailed attributions could not be made and the above absorptions could only be attributed to H_2O vibrations in general. H_2O molecules may be present in two perpendicular positions (type I or II) in the beryl channels (Wood and Nassau, 1968; Charoy, 1998). Infrared analysis of beryl sample powder mixed with KBr would allow an identification of water type and this work is planned for the future. According to the literature, however, most of the water molecules in morganites possess a molecular axis parallel to the structural channels in beryl and are type II. The red beryl reference sample did not show molecular response in the NIR spectral range except for a small peak at 2267 nm, which is in agreement with the H_2O-free nature of this material (Nassau and Wood, 1968; Hänni, 1980).

Chemical composition

Preliminary compositions of the new material were obtained from ED-XRF analyses, which indicated major Si, Al and also the presence of minor Fe, Mn, Cs and Rb in all samples (red beryl and morganite).

Quantitative chemical analyses of pink samples A1, M4, M5 and M6, light pink morganite R3 (Madagascar) and a red beryl R1 (Utah, USA) (see *Table II*) were carried out. On each sample six measurements were taken along a traverse of about 3 mm, to gain some information about their homogeneity.

The analyses were carried out with a JEOL-JXA 8600 electron microprobe (Geochemical Laboratory, University of Basel, Switzerland), operated in wavelength-dispersive mode (WDS) at an accelerating potential of 20 kV and a beam current of 20 nA. Fourteen elements were measured on their $K\alpha_1$ or $L\alpha_1$ lines, respectively, using well-characterized silicates (pollucite for caesium) and oxides as standards. The raw data were fully corrected for matrix effects by a ZAF-type online procedure. Vanadium was further corrected for peak overlap by caesium $L\beta_5$.

The measurements revealed (*Table II*) that the pink samples are relatively homogeneous and that the red beryl has zones of different composition. Samples M4, M5 and M6 contain caesium (Cs_2O) up to 15.18 wt.%, which is distinctly higher than reported so far in the literature (11.3 wt.% Cs_2O reported by Evans and Moore, 1966). Specimen A1 is less rich in caesium (Cs_2O up to 10.05 wt.%), whereas morganite with Cs_2O up to 1.25 wt.% and red beryl with Cs_2O up to 0.19 wt.% are in the range commonly determined in such beryls (Deer *et al.*, 1992; Nassau and Wood, 1968). Further R^+ and R^{2+} in pink beryl M4, M5 and M6 are sodium, rubidium, potassium and calcium, whereas magnesium is below detection limit. Compared to this, specimen A1 has higher contents of sodium, but shows lower values for rubidium. Potassium and magnesium are at or below detection limit. Based on these data, the new pink samples from Afghanistan and Madagascar belong to the alkali beryls, further classified as lithian caesian beryls after Deer *et al.* (1992).

The aluminium concentration is slightly below that required for ideal stoichiometry. This may perhaps be explained by single-site substitutions on the Al-site, but is more likely to be due to the presence of coupled substitution involving caesium. Transition elements, such as iron, chromium, vanadium, titanium and manganese, commonly involved in such substitutions on the Al-site, were only found at the detection limit or below using either the microprobe or the ED XRF. As vanadium had to be corrected for Cs $L\beta_5$ interference, these values near the detection limit are only indications. We suspect that the pink beryls do not contain any vanadium. Although there is a general consensus that manganese is the chromophore for the pink and red colours in natural beryl (Nassau and Wood, 1968; Deer *et al.*, 1992), only in the red beryl could the manganese be measured quantitatively (*Table II*, column 6). However, UV-Vis spectra of the samples where the manganese was below the detection limit of the electron microprobe contain absorption peaks typical for manganese.

All data were further normalized, on a basis of six silicon atoms per formula unit (pfu), assuming full site occupancy on the tetrahedrally-coordinated Si sites (see *Table II*). Furthermore, beryllium and lithium were calculated for a stoichiometric total of 11 cations, although some Cs-rich beryls with total cations up to 11.25 have been described (Deer *et al.*, 1992).

Since beryllium and lithium contents can not be obtained by means of the electron microprobe, these contents were calculated taking into account any possible substitution mechanisms. Although several single-site and coupled substitutions involving alkalis have been described, most of them are based on unsupported stoichiometry (Wood and Nassau, 1968). Based on the data for the pink beryls, and on charge balance and bond length considerations, the most important substitution mechanism in samples A1, M4, M5 and M6 may be formulated as:

$$\text{(i) } Be^{2+} = Li^{+} + Cs^{+}$$

where for charge balance reasons, lithium on the beryllium site (Hawthorne and Cerny, 1977) is coupled with caesium in the channels of the beryl structure. Due to their large ionic size compared to tetrahedrally coordinated beryllium, all alkalis except lithium can only occupy positions in the channels of the beryl structure. This suggests that the other alkalis present (Na^{+}, K^{+}, Rb^{+}) may be charge balanced mostly by a similar mechanism with the possibility of involvement also with a coupled mechanism involving the Al site,

$$\text{(ii) } Al^{3+} = R^{2+} + R^{+}$$

where R^{2+} stands for bivalent ions (Mg^{2+}, Ca^{2+}, Fe^{2+}, Mn^{2+}) and R^{+} stands for monovalent alkalis except lithium (Na, K, Rb).

Usually substitution mechanisms can be confirmed by plotting the quantities of the involved cations against each other in a diagram. A distinct correlation with a negative slope between Be and Cs would support the most important suggested substitution mechanism in our pink samples. However, as beryllium and lithium have been calculated in relation to the total amount of cations (in our pink samples basically dependent on the caesium concentration), any diagram representing beryllium content plotted against caesium (or lithium) would necessarily produce a very good negative correlation, due to the so-called constant sum effect (Rollinson, 1993). Therefore no correlation diagram is given in this study.

The indicated amounts of beryllium and lithium in *Table II* are necessarily given as approximate concentrations. Light elements can now be measured in gemstones by laser ablation inductively coupled mass spectrometry LA ICP MS, if a small amount of damage on the surface is acceptable (Hänni and Pettke, 2002).

Laser ablation inductively coupled mass spectrometry (LA ICPMS) results, produced after delivery of the manuscript of this paper confirm the presence and quantities of calculated values for BeO and Li_2O. The Afghan sample A1 gave BeO 7.93 wt%, LiO_2 2.30 wt% and Cs_2O 9.21 wt%. The Madagascar sample M3 gave BeO 8.09 wt%, LiO_2 2.04 wt% and Cs_2O 13.85 wt%.

NIR-spectrometry revealed the presence of water in the structural channels of pink beryl from Madagascar and Afghanistan, whereas the sample from Utah showed no water peaks. This was also confirmed by the chemical analyses. Based on total sum considerations, the pink samples A1, M4, M5, and M6 contain 1/2 H_2O molecule per formula unit. This is in good agreement with published analyses, which mention H_2O concentrations commonly from 0.3 to 0.8 molecules (Charoy, 1998). The light pink morganite specimen contains 1.0 molecules of H_2O per formula unit, whereas the calculated water concentration in the red beryl from Utah is zero, which

again is in good agreement with published figures (Nassau and Wood, 1968; Hänni, 1980).

Crystal structure

Bakakin *et al.* (1970) described a correlation between chemical composition and unit cell parameters of beryl. This was further confirmed by Hänni (1980), who showed that an increase of a_0 in o-beryls was correlated to the extent of substitution on the octahedral Al-site, whereas the c_0 value remained virtually unaffected. The c/a ratio commonly is slightly below 1.0 in such beryls. For alkali (caesium) rich beryl, Sosedko (1957) demonstrated an increase in c_0 related to the content of caesium, with a_0 remaining reasonably constant. They show c/a values slightly above 1.000, consistent with the results of Sosedko (1957) and Charoy (1998) for caesium rich t-beryls (see *Table III*).

Preliminary crystal structure investigations by powder XRD (X-ray diffraction) seem to confirm this correlation. However, ongoing studies by the authors will clarify if and how the high caesium content affects (enlarges) the crystal structure of these samples. First powder XRD analyses revealed that two of the most important diffraction reflections of beryl are not present in samples M2 and A1.

Raman spectra

The Raman-shift spectra of samples M4, M5, M6 and A1 have been obtained using a Renishaw Raman microprobe. These are compared with spectra from o-beryls (red beryl from Utah, synthetic red beryl and aquamarine) and in *Figure 5* a partial peak shift of the pink caesium-rich specimens compared to the above-mentioned o-beryls can be seen. The pink caesium-rich samples show a distinct peak at 1097 cm^{-1}, which compares with 1069 cm^{-1} of the reference samples. A second but less distinct shift can be observed at 402 cm^{-1} (M4, M5, M6, A1), compared to 394 cm^{-1} fc reference samples. All other peaks are con or show only minor peak shifts. This ma explained by the fact, that substitution

Table III: *Cell parameters and contents of Cs and Al.*

Beryl variety	*Beryl sample*	a_0	c_0	*c/a*	*Substitution type*	*Wt.%* Cs_2O	Al_2O_3	*Source*
morganite	Madagascar M2				tetrahedral	14.4		this study
	Afghanistan A1					9.7		
	Russia 3*	9.200	9.227	1.003	tetrahedral	4.13		Sosedko 1957
	Russia 2*	9.202	9.209	1.001		0.67		
	Russia 1*	9.202	9.183	0.998		0.27		
red beryl	Utah R1 light centre	9.214	9.206	0.999	octahedral		17.42	this study
	Utah R1 red rim	9.227	9.205	0.998			15.74	
colourless beryl	Switzerland, Hänni 4	9.211	9.196	0.998	octahedral		18.1	Hänni 1980
aquamarine	Switzerland, Hänni 1	9.233	9.208	0.997	octahedral		15.5	
	Switzerland, Hänni 3	9.257	9.197	0.994			14.6	
	Switzerland, Hänni 3	9.288	9.189	0.989			10.6	

* after Deer *et al.*, 1962

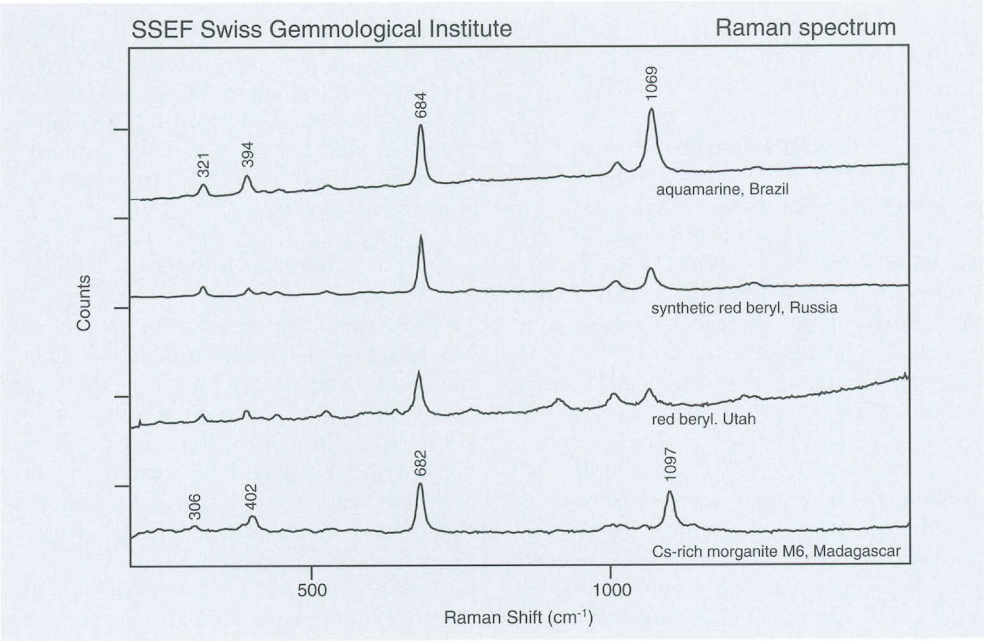

Figure 5: *Raman spectra of morganite M6 red beryl R1, synthetic red beryl (Russia), and aquamarine (Brazil). Cs-rich morganite from Madagascar shows a distinct peak shift at 1097 cm^{-1} compared with the other beryls.*

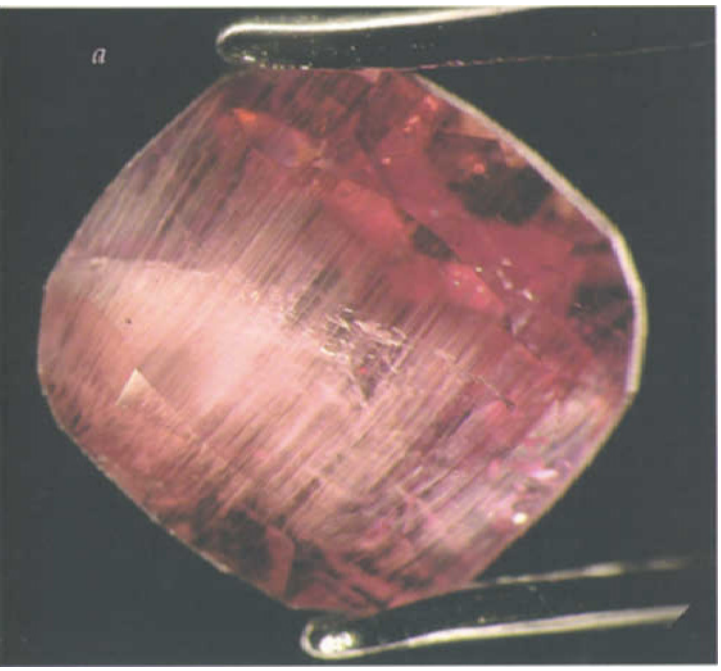

Figure 6: *(a) Morganite from Madagascar (M5) with hollow tubes parallel to the c-axis.*

(b) Detail of M5 showing hollow tubes parallel to the c-axis, flat fluid inclusions parallel to the basal pinacoid, and tension fractures (magnification 20×).

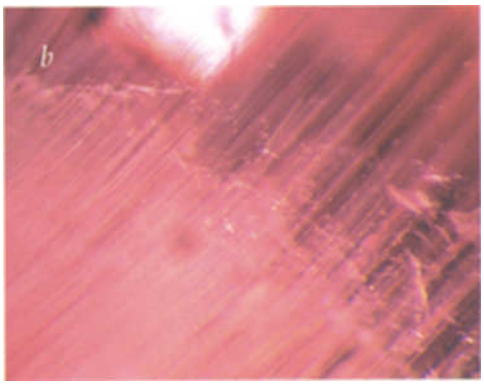

Figure 7: Cat's-eye Cs-rich morganite from Madagascar, provided by D. Gravier (magnification 10×).

place mostly on the Be-site (coupled with incorporation of large alkalis in the structural channels) enlarging locally the structure, whereas the aluminium- and silicon-sites remain virtually unchanged. Further studies will be done to attribute molecular vibrations to their relative Raman peaks.

Inclusions

The specimen from Afghanistan shows strong basal growth zoning and a few tension fractures of conchoidal shape. The samples from Madagascar contain fine tubes parallel to the *c*-axis, and fluid inclusions flattened along the basal plane. The tubes may be so dense in parts that cat's-eye stones may be expected from this source. (*Figure 6a, 6b and 7*). With only a small number of samples, only a few inclusions have been encountered and a wider range may emerge when more stones are seen.

Comparison with synthetic pink, red or purple beryl

For some years hydrothermally grown red and purple beryl has been available. The crystals appear in different colours and owe their colours to different chromophore elements. Some of the stones have been described for example by Henn and Milisenda (1999) and Shigley and Foord (1984). None of the synthetic crystals contain Rb or Cs, but are characterized by distinct concentrations of Ti, Mn or Ni (unpublished SSEF analyses).

The oldest commercially available synthetic material seems to be the pink synthetic beryl from Biron (Australia), which contains Ti as a chromophore element (Brown, 1993). Later, crystals with darker

Figure 8: Hydrothermally grown synthetic beryls from Biron (right) and Novosibirsk, Russia (left).

colours appeared; these were produced in Russia (*Figure 8*) and showed distinct contents of Mn, Fe and Ni. Henn and Milisenda (1999) reported on synthetic red beryl from Russia and found that Co^{2+} was the chromophore. For all these hydrothermal synthetic beryls, the reported densities and refractive indices are clearly lower than for natural morganite as described in this study. It should thus not be difficult to distinguish them from natural morganites. Furthermore, in most of the red to purple and pink hydrothermal synthetic material, characteristic chevron-like growth inhomogeneities could be expected (Johnson and Koivula, 1997).

Terminology considerations

A number of terms are related and used for rose coloured, pink or red beryls. Not all of them are, however, applied in current gemmological publications. Vorobyevite is a caesium beryl of colourless or pink colour, first described in 1908 from Lipovka, Ural Mountains (Sinkankas, 1981). Rosterite is another name for caesium beryl of colourless or pink colour from Elba, Italy. However, these variety names are nowadays only rarely found in the literature.

Much better known is the term morganite (Sinkankas, 1981), given to pink beryl by G.F. Kunz in 1910 to honour J.P. Morgan. Most authors relate the pink colour to the incorporation of some manganese and, at the same time, mention the presence of Cs, which is however not contributing to the colour. Red beryl from Utah owes its name to the intensity of its redness which is far more saturated than the colour associated with morganite. The weak pleochroism of red beryl compared with morganite is a further hint that colour is not the only difference between these minerals.

The new samples studied from Afghanistan and Madagascar strongly resemble in all aspects the properties attributed to morganite. In the trade the investigated samples were sold as 'raspberry beryl' or 'pink beryl', rather than morganite. It seems that for the trade the term morganite is related to a weak colour, and this might negatively influence the new material. However, reconsidering the literature, the term morganite has for a long time precisely described the available light to intensely saturated rose to pink beryl varieties with variable amounts of Mn, Cs and Rb, and no fancy name is required to describe these stones. In the CIBJO rules (CIBJO 2002), application of morganite is related to a mineralogical variety, while morganite, pink beryl and red beryl are also mentioned as commercial names.

Discussion

Caesium and lithium are typical lithophile elements involved in formation of minerals in rhyolites (Christiansen *et al.*, 1983) and pegmatites. While these elements are found only in trace levels in the red beryl from Utah, in the samples from Afghanistan and Madagascar they are present in minor to major quantities. The Madagascar samples are particularly rich in caesium and exceed the Cs_2O contents of other beryls reported in the literature. A consequence of the higher Cs contents is the higher RI and SG values, which exceed the values quoted in many gemmological identification tables for morganite.

Several substitution mechanisms are proposed for the incorporation of alkalis and manganese in these samples. It has been confirmed that Mn^{2+} colours these pink beryls in the same way that it does in morganite (Shigley and Foord, 1984; Platonov *et al.*, 1989) whereas red beryl shows a different manganese absorption pattern, which is attributed to Mn^{3+} (Wood and Nassau, 1968; Lehmann, 1978). Preliminary structural data and the Raman-shift spectra support the idea that incorporation of Cs and perhaps other alkalis has caused an increase of cell dimensions mainly along the *c*-axis.

Summarizing, studied morganites from Afghanistan and Madagascar represent an extreme position in respect to all measured data (density, RI, Cs-concentration, cell parameters) compared to any beryls described so far in the literature. The new material might require a new mineral name due to chemical and structural differences to the classical morganite.

Acknowledgements

The authors are grateful to Haleem Khan (Hindu Kush Minerals, Peshawar, Pakistan), Alexander Leuenberger (Switzerland) and Denis Gravier (Le Mineral Brut, St. Jean-le-Vieux, France), for providing research samples. Fabrice Danet gave valuable information about the occurrence of the morganite samples from Madagascar. Light pink morganite reference material was donated by Werner Spaltenstein (Chantaburi, Thailand). Ted and Rex Harris, Delta, U.S.A., kindly provided the red beryl reference material in 1983. We acknowledge contributions by Dr K. Schmetzer (Petershausen) and Prof. S. Graeser (Mineralogical Institute, University of Basel, Switzerland) for offering the X-ray diffraction facility, Dr T. Pettke, Isotope Geochemistry and Mineral Resources, Swiss Federal Institute of Technology (Zürich) for LA ICP MS data of the Madagascar caesium beryl material, and Peter Giese (SSEF, Basel) for measuring the UV-Vis and NIR spectra. The manuscript was reviewed by our colleagues Dr Lore Kiefert and J.-P. Chalain at SSEF, Basel.

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Abstracts

Diamonds

Gems and Minerals

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Synthetics and Simulants

Diamonds

Study of diamonds from chromitites in the Luobusa ophiolite, Tibet. (Chinese with English abstract.)

W. Bai, J. Yang, P. Robinson, Q. Fang, Z. Zhang, B. Yan and X. Hu. *Acta Geologica Sinica*, **75**(3), 2001, 404-9.

A newly discovered occurrence of diamonds in chromitites of the Luobusa ophiolite, Tibet, is described, together with details of the diamonds and of their numerous metallic inclusions. Examination of 25 grains of diamond recovered from the chromite ores revealed about 70 varieties of native elements (Cr, Cu, Ni, Fe, C, Si, Au, Pb, W, Ir, Os, Ru), alloys (Fe-Ni, Fe-Co, Fe-Mn, Fe-Si, Fe-Ni-Cr, Fe-Ni-Co, Si-C, Cr-C, Ir-Os, Os-Ir, Or-Ir-Ru, Fe-Pt), silicates and sulphides. Photomicrographs of the diamonds are accompanied by IR and Raman spectra and a plot of their B-defects *vs* H (x 10^{-6}). R.A.H.

Two age populations of zircons from the Timber Creek kimberlites, Northern Territory, as determined by laser-ablation ICP-MS analysis.

E.A. Belousova, W.L. Griffin, S.R. Shee, S.E. Jackson and S.Y. O'Reilly. Australian Journal of Earth Sciences, 48(5), 2001, 757-65.

Two populations of kimberlite zircons are present in the Timber Creek kimberlites, Northern Territory, Australia. Laser-ablation ICP-MS U-Pb dating yields age ranges of 1483 ± 15 and 179 ± 2 m.y. this distinction being supported by Hf isotope data. The trace element patterns of both populations are typical of mantle-derived zircons, but there are differences that indicate the two populations were derived from different magma sources. The dating results indicate that the emplacement age of the Timber Creek kimberlites cannot be older than the age of the younger zircon population. These data clarify an inconsistency between previously reported SHRIMP age of Timber Creek zircons (1462 ± 53 m.y.) and the much younger age (1200 m.y.) of the sediments into which the kimberlites have intruded. The Timber Creek kimberlites are therefore a newly recognized extension of widespread Jurassic kimberlite activity in Western Australia and South Australia. W.D.B.

The mystery about coloured diamonds.

C. Carrington. *Australian Gemmologist*, **21**(8), 2002, 295-8.

Australia's Argyle mine has become famous for its coloured diamonds, which include brown (champagne and cognac) and pink to red stones. The chemistry and physics of coloured diamonds is discussed, valuing and marketing of the Argyle brown and pink/red diamonds is described. P.G.R.

Morphology of diamond crystals from the Bingara range, northern New South Wales, Australia.

J.D. Hollis. *Australian Gemmologist*, **21**(9), 2003, 350-9, 4 plates, 3 tables.

Due to their unusual occurrence and certain rare features, diamonds from the Bingara range are of special interest and are representative of diamonds from the other scattered locations along the length of eastern Australia. This paper is based on a study of over 300 diamond euhedra selected from over 8700 crystals sampled from bulk at the Monte Christo Prospect, Bingara by Cluff Resources Pacific NL during 1999-2000. The crystal forms observed in the study are illustrated as sketches 1-54 in four plates. These are referred to in the text by their sketch number, and a description of their morphology is listed in one of the tables. Diamond morphology of these crystals is largely the result of oscillations between etching and resorption stages prior to eruption. Subsequent events imprinted crystals with final eruption and post-eruption experiences. The crazing, impacting and pitting stages are most unusual and distinguish the Bingara range diamonds from classical suites. P.G.R.

Mineral inclusions in diamonds: associations and chemical distinctions around the 670 km discontinuity.

M.T. Hutchison, M.B. Hursthouse and M.E. Light. *Contributions to Mineralogy and Petrology*, **142**(1), 2001, 119-26.

New mineral associations within diamonds from the Juina district of Brazil include a previously unrecorded Na-Al-(Mg, Fe)SiO_3 phase, associated with ferropericlase and the tetragonal almandine-pyrope phase, an association of corundum with aluminous pyroxene, and an olivine

Abstractors

W.D. Birch	W.D.B.	R.A. Howie	R.A.H.	P.G. Read	P.G.R.
A.M.Clark	A.M.C.	R.K. Harrison	R.K.H.	E. Stern	E.S.
J. Flinders	J.F.	P.B. Leavens	P.B.L.	P.M. Whelan	P.M.W.
		M. O'Donoghue	M.O'D.		

For further information on many of the topics referred to, consult *Mineralogical Abstracts*

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phase associated with ferropericlase. The minerals in each association occur within the same diamonds, and also within individual diamonds in different combinations. High-*P* experimental data show these associations formed at different depths within ~ 60 km either side of the upper–lower mantle boundary. Mineral compositions show the sampled regions of the deep transition zone and lower mantle are distinct and heterogeneous. Also, contrary to some recent experimental studies, Al is not solely accommodated within perovskite-structured (Mg, Fe)SiO_3 in the uppermost lower mantle. J.F.

Rb-Sr of kimberlites and lamproites from eastern Dharwar craton, south India.

A. Kumar, K. Gopalan, K.R.P. Rao and S.S. Nayak. *Journal of the Geological Society of India*, **58**(2), 2001, 135-41.

Rb-Sr phlogopite isochron ages for Kotakonda and Mudaebid kimberlites, in the Narayanpet kimberlite field NW of the Cuddapah basin, of 1085 ± 14 and 1099 ± 12 m.y. respectively, are younger than recently reported K-Ar (1363 ± 48 m.y.) and ^{40}Ar-^{39}Ar (1402 ± 5 m.y.) ages for the Kotekonda kimberlite. This supports previous conclusions from these authors that S Indian kimberlites erupted episodically at ~ 1090 m.y. Rb-Sr ages of lamproites from Ramannapeta (1224 ± 14 m.y., NE basin margin), and Chelima and Zangamarajupalle (1354 ± 17 and 1070 ± 22 m.y. respectively), within the Cuddapah basin are distinctly different. While this Rb-Sr age of the Ramannapeta lamproite is younger than an earlier K-Ar age (1381 ± 18 m.y.), it is similar to many spatially close alkaline complexes (Elchuru, Kunavaram). The Chelima and Zangamarajupalle ages are considered imprecise, since these rocks contain a large secondary carbonate component whose Sr isotope composition is genetically unrelated to that of their phlogopites. J.F.

Gem Trade Lab Notes.

T.M. Moses, I. Reinitz, S.F. McClure and M.L. Johnson (Eds). *Gems & Gemology*, **39**(1), 2003, 38-46.

Notes are given on two intensely coloured type IIa diamonds, one was 1.15 ct pear-shaped brilliant which had been subjected to HPHT treatment and was graded fancy intense green-yellow and the other was a 4.15 ct natural diamond graded fancy vivid pinkish-orange; both stones contained substantial nitrogen-related defects. Also noted are quartz coloured greyish-blue by inclusions of indicolite and a metamict zircon from Sri Lanka showing bright play-of-colour. R.A.H.

Diamond, former coesite and supersilicic garnet in meta-sedimentary rocks from the Greek Rhodope: a new ultra high-pressure metamorphic province established.

E.D. Mposkos and D.K. Kostopoulos. *Earth and Planetary Science Letters*, **192**(4), 2001, 497-506.

The discovery of UHP indicator minerals and textures from the Rhodope metamorphic province (RMP), N. Greece, is reported. Exsolution of quartz, rutile and apatite in sodic garnet from metapelites (garnet-biotite-kyanite gneisses) identifies a Si-Ti-Na-P-rich precursor garnet phase. These textures in garnet have only once before been reported, from eclogites in Su Lu UHP metamorphic province, China. Microdiamonds and multicrystalline quartz pseudomorphs after coesite occur in garnet from both both eclogites and metapelites. It is argued that these rocks were transported into the upper mantle, to depths >220 km, establishing the RMP as a UHP metamorphic belt. J.F.

Archean subduction recorded by Re-Os isotopes in eclogitic sulfide inclusions in Kimberley diamonds.

S.H. Richardson, S.B. Shirey, J.W. Harris and R.W. Carlson. *Earth & Planetary Science Letters*, **191**(3-4), 2001, 257-66.

Eclogitic sulphide minerals within diamonds from the deepest part of the continental mantle keel beneath the Kaapvaal craton, and brought to the surface in kimberley kimberlites, have low Ni and Os contents and high Re/Os, typical of a basaltic protolith. Sulphide inclusions with the lowest Os give late Archaean single-grain absolute ages, whereas those with higher Os give a well-constrained 2900 m.y. isochron age and radiogenic i_{Os} (γ_{Os} = +45). This implies a significant time between basaltic precursor generation and eclogitic diamond crystallization, consistent with lengthy residence in a near-surface environment before subduction, resulting from accretion of the Kimberley block to the craton, and subsequent diamond formation. These data suggest subduction-related crustal recycling was viable during continent formation in the mid-Archaean, and may have been involved in eclogitic diamond formation ever since. J.F.

Découvertes diamantifères au Québec-Novembre 2002.

G. Riondet. *Revue de Gemmologie*, **147**, 2003, 7-10.

Update of diamond finds in Quebec, Canada, from the first discovery of two diamondiferous kimberlites in December 2001 to the present. A short history and maps are given. M.O'D.

Abundance and composition of mineral inclusions in large diamonds from Yakutia.

N.V. Sobolev, E.S. Efimova, A.M. Logvninova, O.V. Sukhodol'skaya and Yu. P. Solodova. *Doklady, Russian Academy of Sciences Section*, **376**(1), 2001, 34-8. (English translation.)

The abundance of inclusions in 2334 diamonds from the Mir, Udachnaya and Aikhal kimberlite pipes is presented. Chromite, garnet and olivine inclusions were abundant and EPMA results for garnet and chromite are given. The results indicate that the inclusion assemblages are similar in diamonds of varying size from the same pipe. Sulphide inclusions are predominant only in large diamonds from the Mir pipe. A.M.C.

Tectonic controls on kimberlite location, southern Africa.

S. Vearncombe and J.R. Vearncombe. *Journal of Structural Geology*, **24**(10), 2002, 1619-25.

A geometric method of spatial analysis (SpaDiS™), which requires neither statistics nor algebraic models, has been used to show that crustal architecture is critical in the location of kimberlites. Distinct corridors of kimberlites are parallel to, but not within prominent shear zones and crustal faults. Instead the kimberlites occur in relatively homogeneous, strong crust capable of maintaining the very high CO_2 *P* necessary for rapid emplacement. Archaean directional trends in kimberlite distribution are recognised on the craton, whereas Proterozoic and Carboniferous-Permian (Karoo) age trends are recognized both on and off the Archaean craton. R.A.H.

Gems and Minerals

Anwendung der Laser-Raman-Spektroskopie zur Identifizierung von synthetischen Opalen aus Russland.

A. Banerjee. *Gemmologie. Z. Dt. Gemmol. Ges.* **51**, 2002, 191-3. 1 diagram, bibl.

Short description of the use of Raman spectroscopy in distinguishing synthetic opal from Russia, when other methods do not yield satisfactory results. E.S.

Update of Australia's gemstone and pearl resources.

G. Brown. *Australian Gemmologist*, **21**(8), 2002, 273-7, 1 map.

This status report covers Australia's diamond, opal, South Sea cultured pearl, sapphire and ruby, chrysoprase and nephrite industries, and suggests reasons for economic changes that have occurred over recent years. P.G.R.

Der Stein ist wirklich echt!

W. Bürgi. *Schweizer Strahler*, 2003/1, 37-8.

Note on an exceptional specimen of rough transparent quartz containing pyrite crystals of considerable size. The specimen was due to be shown at a special exhibition at the Lucerne Bourse during April 2003. M.O'D.

On the problem of the occurrence of dispersed bunsenite (NiO) in chrysoprases.

K. Dyrek, Z. Sojka, W. Zabinski and F. Bozon-Verdura. *Mineralogica Polonica*, **32**(2), 2001, 308.

The nickel oxide bunsenite is identified as the source of nickel from which chrysoprase obtains its green colour. UV-VIS-NIR spectroscopic tests showed that the Ni^{2+} ions were attached to the SiO_2 crypto-crystalline matrix in positions of distorted octahedral symmetry outside the framework. Specimens from Lower Silesia, Poland, Marlborough Creek, Australia and an unspecified African location were examined. M.O'D.

Edelsteinbergbau im Festgestein: zwei Beispiele aus Pakistan.

H.C. Einfalt. *Gemmologie. Z. Dt. Gemmol.* **51**, 2002, 153-170. 10 photographs, 1 table, 3 flow-charts, bibl.

The article is a revised version of the lecture given to the German Gemmological Association in spring 2001. It deals with the geological and mineralogical background of two mines in Northern Pakistan, the Katlang topaz mine (and the newly opened Shomzo mine nearby) and the Gujar Kili emerald mine. In both cases geology and actual mining are described and the future prospects discussed. E.S.

Eine grosse Topasdruse am Waldstein im Fichtelgebirge.

J. Frankenberger. *Lapis*, **27**(6), 2002, 46-8.

Light blue crystals of topaz are described from Waldstein in the Fichtelgebirge of Bavaria, Germany, where they occur with orthoclase and light green crystals of apatite. M.O'D.

Le nouveau traitement produisant des couleurs orange à jaune dans les saphirs.

E. Fritsch, J.-P. Chalain, H. Hänni, B. Devouard, G. Chazot, D. Giuliani, D. Schwarz, C. Rollion-Bard, V. Garnier, S. Barda, D. Ohnenstetter, F. Notari and P. Maitrallet. *Revue de gemmologie*, 147, 2003, 11-23.

Detailed description of recent treatments of sapphire giving orange to yellow colours. Sapphires from Songea, Tanzania, Ilakaka, Madagascar, and some from Burma and Thailand have been heated at high temperatures in an oxidizing atmosphere and with the diffusion of beryllium into the stone from outside. Notes on appearance, properties and testing are given. M.O'D.

Le jade, valeur et terminologie en Occident et en Chine.

E. Gonthier. *Revue de gemmologie*, **147**, 2003, 31-35.

Notes on jade classification, valuation and varietal nomenclature in China and in the West. The Chinese characters for 'jade' and 'precious stone' are explained. M.O'D.

Geochemistry of agates; a trace element and stable isotope study.

J. Götze, M. Tichomirowa, H. Fuchs, J. Pilot and Z.D. Sharp. *Chemical Geology*, **175**(3-4), 2001, 523-41.

Trace-element and stable isotope data on Precambrian-Tertiary agate within felsic-mafic volcanic rocks from 18 locations worldwide, help elucidate agate formation and the origin of mineral-forming fluids. Samples are generally LREE-enriched, while some have a positive Eu anomaly. Similar REE patterns for the agates and their parent volcanic rocks suggests mobilization of elements by circulating fluids during syn- and post-volcanic wallrock alteration. Deuterium (δD-44 to -130‰) and O($\delta^{18}O$+16.4 to +33.4‰) data on agates and associated quartz incrustations show variable compositions for samples

from different localities, but also within single agates (<10‰ for $\delta^{18}O$); attributed to either kinetic effects during isotope fractionation or mixing of meteoric and magmatic fluids. High $\delta^{18}O$ of parent volcanic rocks (<+19.5‰) suggest circulation of ^{18}O-enriched hydrothermal fluids that originated from heated meteoric water and/or residual magmatic fluids. Agate formation occurred at 50-250°C. J.F.

Tiefblaue Afghanit-Kristalle von Sar-e-Sang, Badakshan, Afghanistan.

A. GUASTONI AND F. DEMARTIN. *Lapis*, **27**(6), 2002, 22-3.

Dark blue crystals of afghanite, some translucent and perhaps of ornamental quality, are described from Sar-e-Sang, Badakshan, Afghanistan. Prismatic crystals show pyramidal terminations. M.O'D.

Eine neue Diffusionsbehandlung liefert orangefarbene und gelbe Saphire.

H.A. HÄNNI AND T. PETTKE. *Gemmologie. Z. Dt. Gemmol. Ges.*, **51**, 2002, 137-52. 10 photographs, 1 table, 3 graphs, bibl.

New orange sapphires appeared on the market in 2001. They had been treated in Thailand and showed an orange to yellow thick layer parallel to the cut surface. It became obvious that the corundum originated in Tanzania and Madagascar and were heat treated together with foreign substances, but it was shown that beryllium plays an important role in the coloration. The terminology of the new material is debated as it presents an identification problem as the diffusion of beryllium may penetrate the complete stone. E.S.

The occurrence of gagate in southern Soltykow (The Holy Cross Mts).

V. HEFLIK, B. KWIECINNSKA AND A. ZMUDZKA. *Mineralogia Polonica*, **32**(2), 2001, 47-55, 3 colour photographs.

Gagate [jet] is found with brown coals of the Zagaje series in Lower Jurassic sediments at a nature reserve, Gagates of Soltykow, near Kielce, Poland. The material was found to be a fossil coal with a banded structure and jet-black colour. Despite its fine colour the material is not easily fashioned into ornaments due to the high pyrite content. Details of chemical analyses are given, showing that the jet can be placed within the mixed terrestrial-marine type of organic matter. M.O'D.

Mikrokristalline SiO_2 – mineralisationen in rhyolithischen Rotliegendvulkaniten des Thüringer Waldes und ihre Genese.

G. HOLZHEY. *Aufschluss*, **54**, 2003, 95-110.

Lower Rotliegend-age volcanic rocks of the Thüringer Wald, Germany, host agate-bearing rhyolite spherulites. While the paper discusses the genesis of the spherulites there are also implications for the types of patterns observed in many specimens. The paper was first published in *Chemie der Erde*, **59**, 1999, 183-205. M.O'D.

Australian sedimentary opal - why is Australia unique?

D. HORTON. *Australian Gemmologist*, **21**(8), 2002, 287-94, illus. in colour, 1 table.

Sedimentary opal deposits are widely scattered throughout central Australia and constitute about 95 per cent of the world's precious opal. These opal deposits occur along generally flat-lying horizontal layers within 30 metres of the surface. The unique combination of geological events (deposition, weathering, remobilisation, preservation) that gave rise to these deposits over a 100 million year period may account for the conditions which resulted in Australia's many sedimentary opal fields. P.G.R.

Agate Creek agates.

P. HOWARD. *Australian Gemmologist*, **21**(8), 2002, 299-300, illus. in colour.

Agates are one of the most attractive varieties of crypto-crystalline quartz. In Australia, an important source of quality agates is located in north Queensland in the vicinity of three creeks (Agate Creek, Spring Creek and Black Soil Creek) some 100km south of George Town. At this abundant source, agates occur as nodules in the valley at the head of the three creeks. When polished the agates display a great variety of colour and pattern as is demonstrated in the accompanying illustrations. P.G.R.

Bergkristalle als funkelnde Meisterwerke der Kunst.

G. KANDUTSCH. *Lapis*, **28**(3), 2003, 31-8.

Notes on an exhibition of worked rock crystal shown at the Kunsthistorisches Museum in Vienna during 2003. M.O'D.

Edelsteine aus dem Gebiet nördlich von Araçuai (Minas Gerais, Brasilien): Vorkommen, Eigenschaften und Behandlungsmethoden.

J. KARFUNKEL, J. QUÉMÉNEUR, K. KRAMBROCK, M. PINHEIRO, G.O. DIAS AND R. WEGNER. *Gemmologie. Z. Dt. Gemmol. Ges.*, **51**, 2002, 171-84, 5 photographs, 4 graphs, 1 diagram, 1 map, glossary, bibl.

Gemstones have been mined in this area for over 100 years, the main ones being: tourmaline (green, red, blue and multi-coloured), beryl (colourless, blue, pink and yellow), spodumene (colourless, yellow and green), quartz (smoky quartz, rock crystal and citrine), amblygonite, petalite and andalusite. The geology of the district is discussed as are the various possibilities of treatment, mainly in order to purify the desired colour. E.S.

Genesis and gemmology of sapphires from the Nezametnoye deposit, Primorye region, Russia

A. KHANCHUK, B. ZALISHCHAK, V. PAKHOMOVA, E. ODARICHENKO AND V. SAPI. *Australian Gemmologist*, **21**(9), 2003, 369-75, 8 illus., 1 map, 4 tables.

Corundums and sapphires from the Nezametnoye placer deposit in far eastern Russia are found both as

crystals of about 20mm size and sometimes larger, and as derived fragments. Both the crystals and fragments are rounded to varying degrees. The problem of determining an origin for corundum – one of the fundamental questions in geology – until now has remained debatable. Based on the established association of this sapphire's mineral inclusions (columbite, albite, zircon, zinc-bearing hercynite, rutile), the composition of the sapphire's glassy inclusions, and the presence of accessory corundum in the granite- and granosyenite porphyries that underlie the Nezametnoye deposit of alluvial sapphires, the conclusion was made that the sources of the corundums in this deposit were rare-metal pegmatites, greisens, and metasomatites associated with Mesozoic granitoid bodies that are widespread in the area. P.G.R.

Achat vom Donnersberg, Pfalz.

K. KOHOUT. *Lapis*, 27(6), 2002, 51.

Specimens of agate are described from Donnersberg in the German Pfalz. Some examples contain amethyst. M.O'D.

Gem news international

B.M. LAURS (ED.). *Gems & Gemology*, **39**(1), 2003, 48-64.

Items mentioned include the occurrence and faceting of a purplish-pink Cs-'beryl' from Madagascar; this had ε 1.608, ω 1.616-1.617, SG ~ 3.10. EPMA for one with a purplish-pink core and pale pinkish-orange rim gave Cs_2O 13.57 and 15.33 wt.%, respectively. Also mentioned are a new find of demantoid at a historic Russian site in the Urals and 'LifeGem' synthetic diamonds grown using purified carbon derived from human remains during cremation as a personal individualized memorial. R.A.H.

Achate aus dem Vorland des Riesengebirges, Tschechien.

M. LÜTTICH. *Lapis*, **8**(4), 2003, 21-6.

Agate with attractive patterning is described from several sites in the Riesengebirge, Czech Republic. M.O'D.

Nouvelles expositions à Lausanne.

R. MARCHANT. *Schweizer Strahler*, 2003/1, 5-9 and 23-7.

French- and German-language descriptions of the re-arranged exhibits at the Musée cantonale de géologie, Lausanne, Switzerland [the canton is Vaud], include notes on gem materials displayed. Text and illustrations in both French and German versions need to be consulted as they do not correspond. M.O'D.

The processing and heat treatment of Subera (Queensland) sapphire rough.

M. MAXWELL. *Australian Gemmologist*, **21**(8), 2002, 279-86.

The author of this paper is the Technical Services Manager of Great Northern, a subsidiary of GTN Resources. The Subera corundum deposit, located some 5km east of Rubyvale, is mined by Great Northern. This deposit has large reserves of low quality sapphire and several attempts have been made to develop a viable bulk heat treatment programme aimed at enhancing the colour of the sapphire rough. Despite modifications none of these treatments was successful, and the latest process introduced experimentally by Crystal Chemistry resulted in as many stones being reduced in value as those gaining value. From this it was concluded that the economic bulk heat treatment of Subera sapphire rough was not feasible and the process has been discontinued. P.G.R.

Prächtiger Spessartin-Granat aus den Pegmatiten von Fujian, China.

B. OTTENS. *Lapis*, **28**(4), 2003, 13-20

Fine quality well-crystallized spessartine is reported from a pegmatite in the area of Tongbei-Yunling, Fujian Province, China. The spessartine is associated with well-formed rock crystal: other minerals from the area are described. M.O'D.

Luminescent geochemical anomalies in the lithosphere and haloes of ore bodies.

A. PORTNOV, B. GOROBETS, A. ROGOZHIN, A. BUSHEV AND T. KVITKO. *Periodico di Mineralogia*, **71**(1), 2002, 85-100.

Haloes of luminescent minerals occur around kimberlite pipes, emerald-bearing bodies in metasomatic rocks, gold-bearing bodies, mica pegmatites and quartz veins. These are special cases of luminescent geochemical anomalies which occur in those parts of the Earth's crust where considerable interaction has taken place between rocks and abyssal fluids. These fluids leached trace elements, including the luminogenous transition metals of 3*d*, 4*f* and some other groups from the country rocks, accumulating and then depositing them. Accumulations of Mn, *REE*, U and other luminogenous elements form glow centres in secondary minerals. Outcrops of photoluminescent calcite, apatite, zircon, fluorite, cerussite, chlorargyrite and uranyl minerals in altered rocks may serve as indicators of mineral deposits. Photoluminescent grains of apatite with a violet-blue glow (Ce^{3+}, Eu^{2+}) detected by sand analysis allow mapping of secondary mechanical haloes (scattering), of help in prospecting for kimberlite pipes. R.A.H.

From mastodon ivory to gemstone: the origin of turquoise colour in odontolite.

I. REICHE, C. VIGNAUD, B. CHAMPAGNON, G. PANCZER, C. BROUDER, G. MORIN, V.A. SOLÉ, L. CHARLET AND M. MENU. *American Mineralogist*, **86**(11-12), 2001, 1519-24.

Heat-induced colour changes of fossilized Miocene mastodon ivory (13-16 m.y.) have been known at least since the Middle Ages. Cistercian monks are believed to have created odontolite, a turquoise-blue 'gemstone' by heating mastodon ivory found in Miocene geological layers next to the Pyrrenean chain, France, to use it for the decoration of medieval art objects. This material has been the object of investigations of European naturalists and gemmologists, among them Rèaumur (1683-1757). Although vivianite [$Fe_3(PO_4)_2.8H_2O$] is the commonly accepted colouring phase supposed to appear when heating fossilized mastodon ivory, previous spectroscopic studies using PIXE/PGE and TEM-EDX

indicate that the chemical composition of collection odontolite and heated mastodon ivory corresponds with well-crystallized fluorapatite [$Ca_5(PO_4)_3F$] containing trace amounts of Fe (230-890 ppm), Mn (220-650 ppm), Ba (160-620 ppm), Pb (40-140 ppm), and U (80-210 ppm). No vivianite has been detected. New insights into the physico-chemical mechanism of the colour transformation of fossilized ivory come from a combination of UV/visible/near-IR reflectance spectroscopy, time-resolved laser-induced luminescence spectroscopy (TRLIF), and X-ray absorption near-edge structure (XANES). Contrary to what had formerly been described as the colour origin in odontolite, the present study conclusively identifies traces of Mn^{5+} by UV/visible/near-IR reflective spectroscopy, TRLIF, and XANES inside the fluorapatite. Thus odontolite owes its turquoise-blue colour to Mn^{5+} ions in a distorted tetrahedral environment of four O^{2-}ions. XANES also documents oxidation of disordered octahedral Mn^{2+} ions to tetrahedral Mn^{5+} species in apatite during the heating process. P.M.W.

Seltenheiten aus Mogok, Myanmar.

R. Schlüssel, C.C. Milisenda and F. Bärlocher. *Gemmologie. Z. Dt. Gemmol. Ges.*, **51**, 2002, 185-90. 6 photographs, 1 map. bibl.

Three recently found gems are described. A violet poudretteite weighing 3 ct was found in snow-white marble. An orange-yellow periclase rough was cut as a 27.81 ct cabochon - it showed adularescence due mainly to numerous minute liquid inclusions. The third specimen was a 14 ct thorite cabochon. E.S.

The first transparent faceted grandidierite, from Sri Lanka.

K. Schmetzer, M. Burford, L. Kiefert and H.-J. Bernhardt. *Gems & Gemology*, **39**(1), 2003, 32-7.

A 0.29 ct faceted greenish-blue grandidierite is described from Sri Lanka. It has α (greenish-blue) 1.583, β (very pale yellow) 1.620, γ (blue-green) 1.622, $2V_a 25°$; SG 2.96. EPMA results show FeO 1.71 wt.% distinguishing it from lazulite; the FTIR and Raman spectra are presented. R.A.H.

Poudrettite: a rare gem species from the Mogok Valley.

C.P. Smith, G. Bosshart, S. Graeser, H. Hänni, D. Günther, K. Hametner and E.J. Gübelin. *Gems & Gemology*, **39**(1), 2003, 24-31.

A 3 ct faceted poudrettite was bought in Mogok, Myanmar [Burma], in 2000 and is the first recorded gem-quality specimen of this rare borosilicate hitherto only known in small crystals from the Mont Saint-Hilaire complex, Quebec. Its identity was confirmed (using minute scrapings) by XRD, IR, Raman spectroscopy and LA-ICP-MS; it has ω (purple-pink) 1.511, ε (very pale brown) 1.532, and also shows colour zoning; SG 2.527; trace amounts of Li and Mn were higher in the purple zone, and Ca, Rb and Cs were lower. R.A.H.

Prächtige Morionkristalle vom Blausee, Binntal, Schweiz.

I. Stalling and Y. Pellmont. *Lapis*, **28**(20), 2003, 31-4.

Well formed crystals of ornamental-quality smoky quartz (morion) are described from Blausee in the Swiss Binntal. An occurrence of blue tourmaline is also described. M.O'D.

Colour in quartz; from atomic substitutions to nanoinclusions.

P. Vasconcelos, B. Cohen and N. Calos. *Australian Gemmologist*, **21**(8), 2002, 278.

Colour in amethyst and citrine may be caused by the presence of multiple atoms and colour centres; in rose quartz, chrysoprase and precious opal the colour may be due to band gap and interference phenomena. The application of high-resolution analytical techniques (such as ICP-MS, HRTEM, XRD, XAFS and TEM) permits unambiguous identification of dispersed elements or mineral inclusions, thus clarifying our understanding of colour in this mineral. P.G.R.

The *Mineralogical record* library: fifty early collection catalogs.

W.E. Wilson. *Journal of the Geo-Literary Society*, **18**(1), 2003, 4-28.

The library of the *Mineralogical Record* has concentrated on assembling mineral collection catalogues which are notoriously hard to find on the second-hand market. The catalogues listed in chronological order range from the 16th to the early 20th century: some collections contain ornamental materials and many collections have been broken up and are now hard to trace. Some illustrations are reproduced in black-and-white. M.O'D.

Origin of a dolomite-related jade deposit at Chuncheon, Korea.

T.-F. Yui and S.-T. Kwon. *Economic Geology*, **97**(3), 2002, 593-601.

The Chuncheon nephrite deposit is among the world's largest; it is hosted in Precambrian dolomitic marble and amphibole schist that were intruded by the late Triassic Chuncheon granite. Carbonates in the marble have O and C isotope composition in the range of -0.1 to +18.2 and -4.3 to + 0.9‰, and -0.4 to + 3.5 and -9.9 to 4.7‰, respectively. These data are in agreement with the decarbonation process driven by fluid infiltration forming the nephrite deposit from dolomitic marble in the T range 330-430°C. Stable isotope compositions of silicates from the nephrite are homogeneous and extremely depleted in ^{18}O and D. It is suggested that formation of the deposit post-dated metamorphism of the country rocks. Model calculations show that the fluid/rock ratios were high, and that both O and H isotope compositions of nephrite were mainly buffered by the fluid phase, and that XCO_2 of the fluid phase was very low during nephrite formation. R.A.H.

Instruments and Techniques

A compilation of infrared absorption spectra of some specific gemstones as an aid to their identification.

S. Fernandes, M. Khan and G. Choudhary. *Australian Gemmologist*, **21**(9), 2003, 361-7, 1 illus., 6 tables.

Although the individual gemstones selected for this study can usually be identified by their unique optical and other physical properties, these gemstones were also chosen because they shared a common colour (e.g. blue stones such as iolite, kyanite, sapphire and blue glass). In this study comparative observations were made of the IR spectra recorded from twenty-five samples of each selected species, each group consisting of faceted stones, rough specimens and, when these were the only samples available, fine chips. Spectra were recorded using a Nicolet Avatar 360 FTIR spectrometer that was equipped with a diffuse reflectance attachment. The study has resulted in the production of several sets of 'fingerprint' IR patterns for consideration as a possible means of identification for five colour ranges of gemstones and similarly coloured man-made materials. In some cases clearly defined regions of their IR spectra have to be investigated before a positive identification can be made for some of the gemstones of similar colour. P.G.R.

Photomicrography for gemologists.

J.I. Koivula. *Gems & Gemology*, **39**(1), 2003, 4-23.

The basic requirements for gemmological photomicrography are reviewed and new techniques, advances and discoveries in this field are introduced. Just because you don't see it, doesn't mean it isn't there. Proper illumination is the most critical factor in obtaining the best results with gem material, coupled with the cleanliness of the photomicroscope and its surroundings. Also critical is the understanding of the features seen and the role they might play in the identification process. R.A.H.

Spectrométrie de fluorescence du chrome (Cr^{3+}) dans les spinelles. Identification des spinelles synthétiques produits par dissolution anhydre et des autres matériaux dits "spinelles synthètiques" produits par fusion Verneuil.

F. Notari and C. Grobon. *Revue de gemmologie*, **147**, 2003, 24-30.

Fluorescence spectroscopy is useful in the detection of synthetic red spinels. Details of the procedures and results are given. M.O'D.

Synthetics and Simulants

Diamond nucleation and growth by reduction of carbonate melts under high-pressure and high-temperature conditions.

A. Arima, Y. Kozai and M. Akaishi. *Geology*, **30**(8), 2002, 691-4.

Experiments were carried out in the $CaMg(CO_3)_2$-Si and $CaMg(CO_3)_2$-SiC systems at 7.7 GPa and *T* of 1500-1800°C. No graphite was added to the run powder as a carbon source; the carbonate-bearing melts supply the carbon for diamond formation. Diamond grows spontaneously from the carbonatitic melt by reducing reactions: $CaMg(CO_3)_2 + 2Si = CaMgSi_2O_6 + 2C$ in the $CaMg(CO_3)_2$-Si system, and $CaMg(CO_3)_2 + 2SiC = CaMgSi_2O_6 + 4C$ in the $CaMg(CO_3)_2$ -SiC system. The results provide strong experimental support for the view that some natural diamonds crystallized from carbonatitic melts by metasomatic reducing reactions with mantle solid phases. P.B.L.

Imaging the atomic arrangements on the high-temperature reconstructed α-Al_2O_3 (0001) surface.

C. Barth and M. Reichling. *Nature*, **414**(6859), 2001, 54-7.

Dynamic scanning force microscopy is used to image directly the atomic structure of the (0001) surface of α-Al_2O_3 heated to >1300°C in ultrahigh vacuum. The results show surface domains with hexagonal atomic symmetry at the centre, and disorder of the periphery. The dominant feature of the surface shortly after preparation is figured and is a rhombic grid representing the unit cell. On exposing the surface to H_2O and H_2, the surface structure forms hydroxide clusters forming rings attributed to self-organization involving cluster-surface and cluster-cluster interactions. R.K.H.

[Influence of silicates upon the growth of synthetic diamond crystals.]

A.A. Chepurov, V.M. Sonin and A.I. Chepurov. *Proceedings of the Russian Mineralogical Society*, **131**(1), 2002, 107-10. (Russian with English abstract.)

The synthesis and growth of diamond crystals at 5.5 GPa and 1500°C in the system Fe-Ni-C was performed with the aid of silicate components (natural olivine and balsalt) up to 20 wt.%. The introduction of >5% of silicates leads to changes in the morphology of the diamond crystals, manifested in the loss of morphological stability by the {111} faces, with triangular vicinal hillocks with step-like lateral surfaces becoming transformed into sub-individuals. In so doing, the initial single crystal is eventually transformed into a parallel aggregate. In the growth process, the diamond crystals accept the inclusion of silicate phases, with local concentrations screening off diamond growth and stopping it entirely at 20% silicate content. R.A.H.

Evolution of crystal morphology of natural diamond in dissolution processes: experimental data.

A.F. Khokhryakov, Yu. N. Pal'yanov and N.V. Sobolev. *Doklady, Russian Academy of Sciences, Earth Sciences Section*, **381**(8), 2001, 884-8. (English translation.)

This was an experimental study of the morphological evolution of the main types of natural diamond crystals during their dissolution in modelled systems at mantle *P-T* conditions; 112 crystals (55 pseudo-octahedra, 27 pseudorhombic dodecahedra and 30 cubic crystals) were investigated. The experimental data are tabulated and the results show that the dissolution of diamond with the formation of ditrigonal layers occurs at 2.5-5.7 GPa and 1100-1450°C. The rate of diamond dissolution in water-containing silicate systems is an order of magnitude higher than in carbonate systems due to the carbonization reaction. The semi-rounded and rounded crystals of the natural diamonds serve as an indication of a fluid regime. A.M.C.

Crystallization of metamorphic diamond: an experimental modelling.

Yu N. Pal'yanov, V.S. Shatsky, A.G. Sokol, A.A. Tomilenko and N.V. Sobolev. *Doklady, Russian Academy of Sciences, Earth Sciences Section*, **381**(8), 2001, 935-8 (English translation).

This study was aimed at determining whether diamond crystallized in the metamorphic host-rock medium or was formed elsewhere and later captured as inclusions. The experimental results confirm the critical role of water-bearing carbonate melt in the genesis of metamorphic diamonds. Garnet-pyroxene rock from the Kumdykol deposit in the Kokchetav Massif does not melt and remains inert relative to diamond and graphite. Therefore, it may be regarded as a restite. The experiments succeeded in obtaining the joint experimental crystallization of diamond and garnet. A.M.C.

Diamond formation through carbonate-silicate interaction.

Y.N. Pal'yanov, A.G. Sokol, Y.M.B.F. Khokhryakov and N.V. Sobolev. *American Mineralogist*, **87**(7), 2002, 1009-13.

Crystallization of diamond and graphite from the carbon component of magnesite occurs upon the latter's decarbonation in reactions with coesite and enstatite at *P* of 6-7 GPa and *T* of 1350-1800°C. In a series of experiments, diamond was obtained in association with enstatite, coesite and magnesite, as well as with forsterite, enstatite and magnesite. Octahedral diamond crystals were studied by FTIR spectroscopy and were found to contain nitrogen and hydrogen, which are known as the most abundant impurities in natural type 1a diamonds. Growth of diamond on the cubic faces of seed crystals proceeds with formation of a cellular surface structure, which is similar to natural fibrous diamonds. The isotopic composition of synthesized diamonds ($\delta^{13}C$ = -1.27‰) was close to that of the initial magnesite ($\delta^{13}C$= -0.2‰). P.M.W.

Crystallization of diamond and syngenetic minerals in melts of diamondiferous carbonatites of the Chagatai Massif, Uzbekistan: experiment at 7.0 Gpa.

Yu. A. Litvin, A.P. Jones, A.D. Beard, F.K. Divaev and V.A. Zharikov. *Doklady, Russian Academy of Sciences, Earth Sciences Section*, **381A**(9), 2001, 1066-1069. (English translation.)

The aim of this work was an experimental study of the possibility of high-*P* diamond crystallization in the melts of the diamondiferous carbonatites in the melts of the diamondiferous carbonatites of the Chagatai Massif, as well as high-*P* transformations of natural carbonate-silicate rocks under *P-T* conditions of diamond stability. Major element analyses are given for 12 mineral phases crystallizing simultaneously with diamond in these experiments with deep-seated carbonatites. It was established that carbon-oversaturated melts of natural diamondiferous mantle carbonatites serve as a highly intense diamond-forming medium within the diamond stability field. A.M.C.

Mechanisms of layered spiral growth of synthetic diamond crystals based on SEM data.

N.D. Samotoin. *Doklady, Russian Academy of Sciences, Earth Sciences Section*, **381**(8), 2001, 925-8. (English translation.)

High-voltage (100 kV) SEM was applied to the study of fine growth surface morphology of diamond crystals. Various factors governing the layered spiral growth of diamond were found and investigated. Their contributions, abundances and factors controlling the minimum height of growth steps were estimated. The data obtained show that the diamond crystal growth from a hydrocarbon gas phase is provided by various mechanisms even under the same physiochemical conditions. The layered spiral mechanism generated by various sources dominates in the collective formation of diamond crystals. A.M.C.

Opal identification and value.

P.B. DOWNING, 2003. Majestic Press, Inc., Estes Park, CO, U.S.A. pp xii, 212, illus. in colour. Hardcover: ISBN 0 9625311 8 9. £32.00.

A revised, expanded and updated edition of a book first published in 1992, this is a beautifully illustrated coverage of all gem varieties of opal, their man-made counterparts and the qualities that make some colour varieties more desirable than others in the world's opal markets. Pricing is also discussed and there are also useful notes on opal in jewellery.

Opal from different world locations is described, the sites including not only Australia and Mexico but also Ethiopia, Brazil, Canada and Indonesia. Each chapter concludes with a brief summary. The book is attractively produced with excellent photographs and can be highly recommended. M.O'D.

Colored gemstones. The Antoinette Matlins buying guide.

A. MATLINS, 2003. Gemstone Press, Woodstock, Vermont (Sunset Farm Offices, Route 4, PO Box 237, Woodstock VT, U.S.A.). pp xv, 180, illus. in colour. Softcover. ISBN 0 943763 33 9. US $16.95 (higher outside the US).

Simple and easy-to-read guide to the major gemstones, their qualities and how they are priced. While the text is adequate there is insufficient colour differentiation in the photographs so that the red stones in particular appear the same colour. The best parts of the book are those dealing with buying and its possible pitfalls. Some small inaccuracies have crept in but they are nothing to worry about. M.O'D.

Diamonds. The Antoinette Matlins buying guide.

A. MATLINS, 2003. Gemstone Press, Woodstock, Vermont (Sunset Farm Offices, Route 4, PO Box 237, Woodstock VT, U.S.A.). pp xv, 184, illus. in colour. Softcover. ISBN 0 943763 32 0. US $16.95 (higher outside the US).

Useful guide to the commerce of gem diamond with notes on diamond qualities and grading systems, buying at auction, on the internet and on gemstone investment telemarketing scams (there are lots of them). Most of the facts given would be found in a gemmology text but this book is aimed at a different audience and should suit it quite well. M.O'D.

Jewelry and gems at auction. The definitive guide to buying and selling at the auction house and on internet auction sites.

A. MATLINS, 2003. Gemstone Press, Woodstock, Vermont (Sunset Farm Offices, Route 4, PO Box 237, Woodstock VT, U.S.A.). pp xiv, 309, illus. in colour. Softcover. ISBN 0 943763 29 0. US $19.95 (higher outside the US).

This is not only the best guide devoted to buying jewellery and gemstones by auction and through the internet: it appears to be the only one so far. The experience of the author virtually guarantees reliability and the whole text is easy to read for recreation as well as for common-sense information.

A particularly welcome feature which recurs throughout the book is the publicizing of various scams (including the dealers' ring). Anyone who, having read the book, thinks, "I would never have fallen for that" may be deceiving themselves just a little – the tricks are legion and the coming of internet selling has opened up fresh minefields to the feet and purses of the careless buyer.

The text is arranged by species and needs no particular comment, apart from the welcome introduction of appraisals. This is another area of anxiety: read the book to find out why. M.O'D.

Jadeite jade: a stone and a culture.

C. M. OU YANG, 2003. Yang Mulia Gems Ltd, Hong Kong [26/F Tung Hip Comm. Bldg, Des Voeux Rd, Central, Hong Kong]. pp. xiv 184, illus. in colour. Hardcover ISBN 962 86987 1 0. Price on application.

The first impression given by this attractively produced and illustrated book is that it covers the commerce of jade particularly well although other details that the reader might expect are present. Should any reader contemplate starting in the jade business this would be an excellent book to begin with (a knowledge of Chinese and family connections would have their uses too). The world of jade is just as individual as that of diamond.

The text begins with a mineralogical description of both nephrite and jadeite, and a note on the probable origin of the term *Fei-Tsui*, used today to denote Burmese jadeite of especially fine colour. Gemmological characteristics are given before the text embarks upon a study of the occurrence and deposits of jadeite. Even now, the author tells us, there appears to be no known deposit of jadeite in mainland China. She makes the interesting point that the name *Yunnan jade* referred originally to the jadeite from the Myitkyina are of Burma which borders Yunnan. Boundaries were not clearly marked and confusion would have been easy.

The jadeite deposits of Burma are described in considerable detail as the reader might expect. Deposits currently known in the area as *Old mine* and *New mine* might, the author believes, be better classified as primary [New mine] and secondary deposits [Old mine] since this would take into account the geological times of formation.

The next chapters describe the colours and varieties of jadeite with notes on their relative popularity (in China): Chinese names are appended. Chapter 5 deals with the classification of rough jadeite, including the different types of skin to be found on the boulders. Chapter 6 describes

processing techniques and the classification of finished jade products, including carving. The jade processing centres of China are introduced.

Jade-like minerals and simulants are described in the next chapter: the gemmologist will be familiar with them and will probably turn quickly to the descriptions of treatments in chapter 8. Here we have examples of B type, B+C type and C types of jadeite and how to detect treatments and composites. The accompanying photographs are very helpful and the best available I have seen in any gemmological text so far published. It has always been difficult to find really well-illustrated accounts of these processes and tests since so many of the most authoritative ones are in Chinese.

Chapter 9 tells the reader how to appraise and value jadeite, and chapter 10 describes the operation of jade markets and the government-run auctions in Burma. The main text concludes at this point with a set of photographs of fine examples of worked jadeite. There is a useful bibliography which includes mostly papers, citations of which may be hard to root out elsewhere. Only an index is lacking. One or two typos do nothing to distract the eye and this is a most welcome book. M.O'D.

Beryllium-treated rubies and sapphires.

T. THEMELIS, 2003. The Author, Bangkok, Thailand (distributed in the UK by *Aspara*, PO Box 230, Tadworth, Surrey KT20 5ZA). pp 48, illus. in colour. Softcover. ISBN 0 940965 40 2. Price on application.

The author summarizes and illustrates some of the techniques used in the heat treatment of rubies and sapphires involving the addition of beryllium. Using a series of colour photographs Themelis (a pioneer and well-known author in this field) describes the apparatus necessary for this treatment, noting on the way the health hazards of beryllium and the stages of the process from the cleaning of the material to the finished stone. Particular attention is given to surface abnormalities.

Examples of beryllium treatment are given for rubies and sapphires from Madagascar, Songea, Morogoro and Umba (Tanzania), Montana, Australia, Sri Lanka, Mong-Hsu and Vietnam. Notes follow on the gemmological features of the treated stones and their characteristic inclusions. Notes on stability, disclosure and future prospects for this kind of treatment complete the main text which is followed by a short but very useful bibliography in which the author's presentations and useful references are given.

The standard of production is high and the pictures a welcome sight – few illustrations of these processes seem to get published and the same can be said of the notes on techniques. This is a welcome addition to the literature of treatments. M.O'D.

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Proceedings of the Gemmological Association and Gem Testing Laboratory of Great Britain and Notices

Photographic Competition

The 2003 Photographic Competition on the theme All Shapes and Sizes drew a record number of entries of a particularly high quality, illustrating interesting crystal shapes, fascinating inclusions, and unusual cuts and carvings.

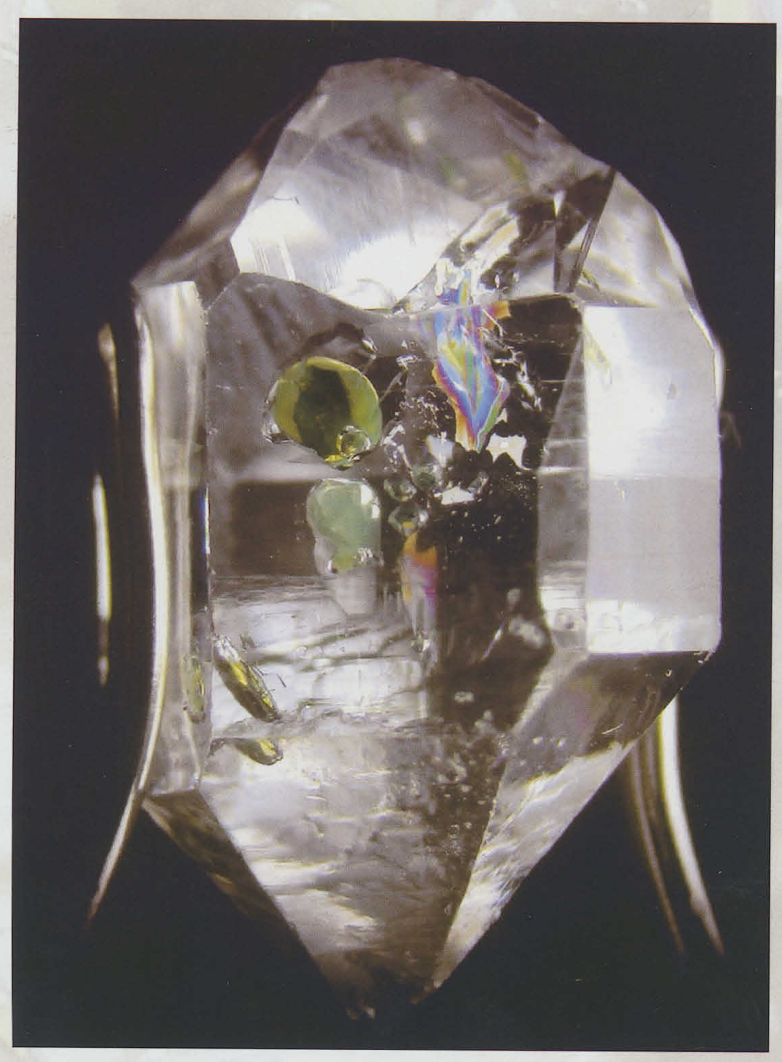

First Prize

Zeng Chunguang FGA, Singapore

Quartz with green and iridescent inclusions

(also illustrated on front cover).

© Gemmological Association and Gem Testing Laboratory of Great Britain

ISSN: 1355–4565

Second Prize

Anthony de Goutière GG, Victoria, BC, Canada
Topaz cleavage

Third Prize

Luc Genot FGA, Brussels, Belgium
Mabe pearl

We are pleased to announce that the prizes were sponsored by Harley UK, and the Association is most grateful to them for their generosity. The winning entries will be exhibited at the Annual General Meeting to be held on 9 September and at the Gem-A Annual Conference on 2 November 2003.

ASSOCIATE MEMBERSHIP

A number of members have expressed the view that the 'Ordinary member' is not a particularly desirable title. Therefore, at a meeting of the Council of Management held on 30 April 2003 it was agreed that Ordinary membership of the Association should be retitled Associate membership.

Anyone with an interest in gemstones may apply for Associate membership – no qualifications are necessary.

Membership subscriptions and donations are vitally important for the Association to continue its work in studying and testing gemstones, and in the publication and promotion of reliable gemmological knowledge. The Council of Management is therefore most grateful to all members for their continued interest in and support of the Association.

MEMBERS' MEETINGS

London

On 15 May at the Gem Tutorial Centre, Gem-A, 27 Greville Street, London EC1N 8TN, a talk entitled 'The gem market of Chanthaburi and the heat treatment of gems in Thailand' was presented by Professor Theerapongs Thanasuthipitak of Chiang Mai University, northern Thailand, and his two colleagues from Chanthaburi, Anuphap Chinudompong and Prajak Angkahiran. A summary of their research results and views on terminology will be published in the September issue of *Gem & Jewellery News*.

Midlands Branch

On 25 April 2003 at the Earth Sciences Building, University of Birmingham, Edgbaston, John Wright gave a talk entitled 'The interface of gem and jewel'. He briefly explored the design, materials used and manufacturing processes where gems come into contact with precious metals. The meeting also included the Branch AGM when David Larcher, Gwyn Green, Elizabeth Gosling and Stephen Alabaster were re-elected President, Chairman, Secretary and Treasurer respectively.

On 18 May at Barnt Green a one-day conference was held. The event openedwith a talk by Doug Morgan entitled 'Gemmological Diversions'.

DONATIONS

The Council of Management are most grateful to the following for responding to the appeal for donations to enable the Association to extend our membership and education services. Donation levels were Diamond (£1000 and above), Ruby (£500 to £999), Emerald (£250 to £499), Sapphire £100 to £249) and Pearl (£25 to £99). All donors will be recognized at a Gala Dinner to be held in London early next year.

A list of those who have responded to the appeal follows:

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Elaine Wai Ling Ng Tang, Chesham, Buckinghamshire

Following lunch, a presentation was given on the gem market and heat treatment of corundum in Chanthaburi, Thailand. The Thai team comprised Professor Theerapongs Thanasuthipitak of Chiang Mai University, northern Thailand, and his two colleagues, Anuphap Chinudompong and Prajak Angkahiran, both of whom have long experience of treating sapphires at Chanthaburi. Dr Bill Gaskarth from Birmingham University explained how the connection between Birmingham and Thailand had started and introduced the members of the team. A summary of the presentation will be published in the September issue of *Gem & Jewellery News*. An identification competition of rough and cut gemstones was held during the day.

On 21 June at Barnt Green the annual Midsummer Supper was held.

North West Branch

On 21 May at Church House, Hanover Street, Liverpool 1, Ian Mercer, Director of Education at Gem-A, gave a talk entitled 'A jade tour'.

On 18 June at Church House, Wendy Simkiss gave a talk on 'Crystal care'.

Scottish Branch

The Annual Scottish Branch Conference was held in Perth from 2 to 5 May, keynote speaker Professor Henry Hänni. A report was published in the June issue of *Gem & Jewellery News*, **12**(3), pp. 47-9.

On 18 June at the British Geological Survey, Murchison House, West Mains Road, Edinburgh, Vanessa Paterson gave a talk entitled 'Amber – yellow, orange, green, blue, red: the ins and outs'.

South East Branch

On 8 June at Christie's South Kensington, Peter Buckie gave a talk on valuation today.

North East Branch

We are pleased to announce that a new Branch of Gem-A is to be established in the North East of England. The inaugural meeting is to be held on Wednesday 10 September 2003 in Leeds.

Full details will be circulated to all Gem-A members in the area.

OBITUARY

Nikolas Lambrinides FGA, Athens, Greece, died on 30th June 2003. A full obituary will be published in the October issue of *The Journal.*

Rodolfo Moller Duran FGA DGA (D.1978), Barcelona, Spain, died on 31 March 2003.

Reginald A. Smith FGA (D.1961), Shaftesbury, Dorset, died recently.

MEMBERSHIP

Between 1 April and 1 June 2003 the Council of Management approved the election to membership of the following:

Fellowship and Diamond Membership (FGA DGA)

Ruckel, Daphne, London. 2003/2001

Fellowship (FGA)

Brook, Judith Margaret, Leicester, 1985
Epelboym, Marina, New York, U.S.A. 2003
Fisher, Fiona Jane, Dublin, Ireland. 2003
Hing, Michael E., London. 2003
Lee Hin Chi, Cheung Chau, Hong Kong. 2003
Maeland, Egil, Sandnes, Norway. 2003
Rickard, Patricia, Dollack Pines, California, U.S.A. 1986
Ng, Wai Ling, Kowloon, Hong Kong. 2003
Pi, Zhengfan, Shenzhen, P.R. China. 2002
Tong Yung, Tony, Kowloon, Hong Kong. 2002
van Rooij-Roeloffzen, M., Almere Buiten, The Netherlands. 2003

Associate Membership

Adams, Stephen Alexander, Dorking, Surrey
Ajodah, Nawjeet, London
Blackwood, Francesca, Richmond, London
Cabaniss, Jelks H. Jr, Alexandria, U.S.A.
Cardellini, Cristina, London
Donnelly, Kerry, Palmers Green, London
Eferemo, Henry, London
Fischgrund, Edward, London
Jimanez, Mary Rosa, Paris, France
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Laboratory Membership

Cookson Precious Metals, Birmingham, West Midlands

GIFTS TO THE ASSOCIATION

The Association is most grateful to the following for their gifts for research and teaching purposes:

Victor Ely, London, for a Rayner spectroscope and a Rayner SG measurement set.

Pauline Gregory FGA, Westgate-in-Weardale, Durham, for cut fluorite samples.

Maria Sanchez Sierra, Tooting, London, for emerald crystals from the Coscuez Mine in Colombia.

Transfers

Fellowship (FGA) to Fellowship and Diamond Membership (FGA DGA)

Cheung Suk Yin, Kowloon, Hong Kong
Chun Ming Lee, Hong Kong
Marlow, Carol, Sutton Coldfield, West Midlands
Pace, Michael, Elk Grove, California, U.S.A.
Tominaga, Masami, West Finchley, London

Diamond Membership (DGA) to Fellowship and Diamond Membership (FGA DGA)

Selvamani, Parvathi, Ilford, Essex
Tse Yiu Yu, Stephen, Kowloon, Hong Kong

Associate Membership to Fellowship (FGA)

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Giancola, Maria Luisa, Milan, Italy
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Jones, Lorraine D., Farnworth, Greater Manchester
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FORTHCOMING EVENTS

27 July	**South East Branch.** *Fifty years plus in gemmology.* E. ALAN JOBBINS
7 September	**South East Branch.** *Workshop on spectroscopic techniques.* COLIN WINTER
9 September	**London.** AGM followed by *Jewellery of the Art Nouveau period.* DAVID CALLAGHAN
10 September	**North East Branch.** Inaugural meeting.
11 September	**Scottish Branch.** *Organics in ornamentation.* E. ALAN JOBBINS
17 September	**North West Branch.** *Scottish minerals.* BRIAN JACKSON
26 September	**Midlands Branch.** *Nineteenth-century jet and other black jewellery.* PEGGY HAYDEN
15 October	**North West Branch.** *Notes from the laboratory – detection, disclosure and false description.* STEPHEN KENNEDY
15 October	**Scottish Branch.** *The Cheapside Hoard.* JAMES GOSLING
19 October	**South East Branch.** *'Jem Jumble' bring-and-buy*
31 October	**Midlands Branch:** *The Naughty Nineties (1890s).* BRIAN DUNN

Gem-A Conference 2003

To be held on
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In conjunction with the Rock 'n' Gem Show

Speakers:

William E. Boyajian, Paula Crevoshay, Professor Henry Hänni
Dr Jack Ogden and Clive Wright

Further details are given on p. 391

3 November	**Presentation of Awards.** Goldsmiths' Hall, London
17 November	**Scottish Branch.** *Tales of a gemstone dealer: thoughts from a broad.* TRACY DUKES
28 November	**Midlands Branch.** *British gemstones with a Scottish flavour.* BRIAN JACKSON
6 December	**Midlands Branch.** *51st Anniversary Dinner*

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Guide to the preparation of typescripts for publication in *The Journal of Gemmology*

The Editor is glad to consider original articles shedding new light on subjects of gemmological interest for publication in *The Journal*. Articles are not normally accepted which have already been published elsewhere in English, and an article is accepted only on the understanding that (1) full information as to any previous publication (whether in English or another language) has been given, (2) it is not under consideration for publication elsewhere and (3) it will not be published elsewhere without the consent of the Editor.

Typescripts Two copies of all papers should be submitted on A4 paper (or USA equivalent) to the Editor. Typescripts should be double spaced with margins of at least 25 mm. They should be set out in the manner of recent issues of *The Journal* and in conformity with the information set out below. Papers may be of any length, but long papers of more than 10 000 words (unless capable of division into parts or of exceptional importance) are unlikely to be acceptable, whereas a short paper of 400–500 words may achieve early publication.

The abstract, references, notes, captions and tables should be typed double spaced on separate sheets.

Title page The title should be as brief as is consistent with clear indication of the content of the paper. It should be followed by the names (with initials) of the authors and by their addresses.

Abstract A short abstract of 50-100 words is required.

Key Words Up to six key words indicating the subject matter of the article should be supplied.

Headings In all headings only the first letter and proper names are capitalized.

A **This is a first level heading**

First level headings are in bold and are centred on a separate line.

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Illustrations Either transparencies or photographs of good quality can be submitted for both coloured and black-and-white illustrations. It is recommended that authors retain copies of all illustrations because of the risk of loss or damage either during the printing process or in transit.

Diagrams must be of a professional quality and prepared in dense black ink on a good quality surface. Original illustrations will not be returned unless specifically requested.

All illustrations (maps, diagrams and pictures) are numbered consecutively with Arabic numerals and labelled Figure 1, Figure 2, etc. All illustrations are referred to as 'Figures'.

Tables Must be typed double spaced, using few horizontal rules and no vertical rules. They are numbered consecutively with Roman numerals (Table IV, etc.). Titles should be concise, but as independently informative as possible. The approximate position of the Table in the text should be marked in the margin of the typescript.

Notes and References Authors may choose one of two systems:

(1) The Harvard system in which authors' names (no initials) and dates (and specific pages, only in the case of quotations) are given in the main body of the text, (e.g. Collins, 2001, 341). References are listed alphabetically at the end of the paper under the heading References.

(2) The system in which superscript numbers are inserted in the text (e.g. ... to which Collins refers.[3]) and referred to in numerical order at the end of the paper under the heading Notes. Informational notes must be restricted to the minimum; usually the material can be incorporated in the text. If absolutely necessary both systems may be used.

References in both systems should be set out as follows, with *double spacing* for all lines.

Papers Collins, A.T., 2001. The colour of diamond and how it may be changed. *J.Gemm.*, **27**(6), 341-59

Books Balfour, I., 2000. *Famous diamonds*. 4th edn. Christie's, London. p. 200

Abbreviations for titles of periodicals are those sanctioned by the *World List of scientific periodicals* 4th edn. The place of publication should always be given when books are referred to.

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Cover Picture

Quartz with green and iridescent inclusions

Photograph by Zeng Chunguang FGA, Singapore

First Prize in the Photographic Competition (see p. 440)

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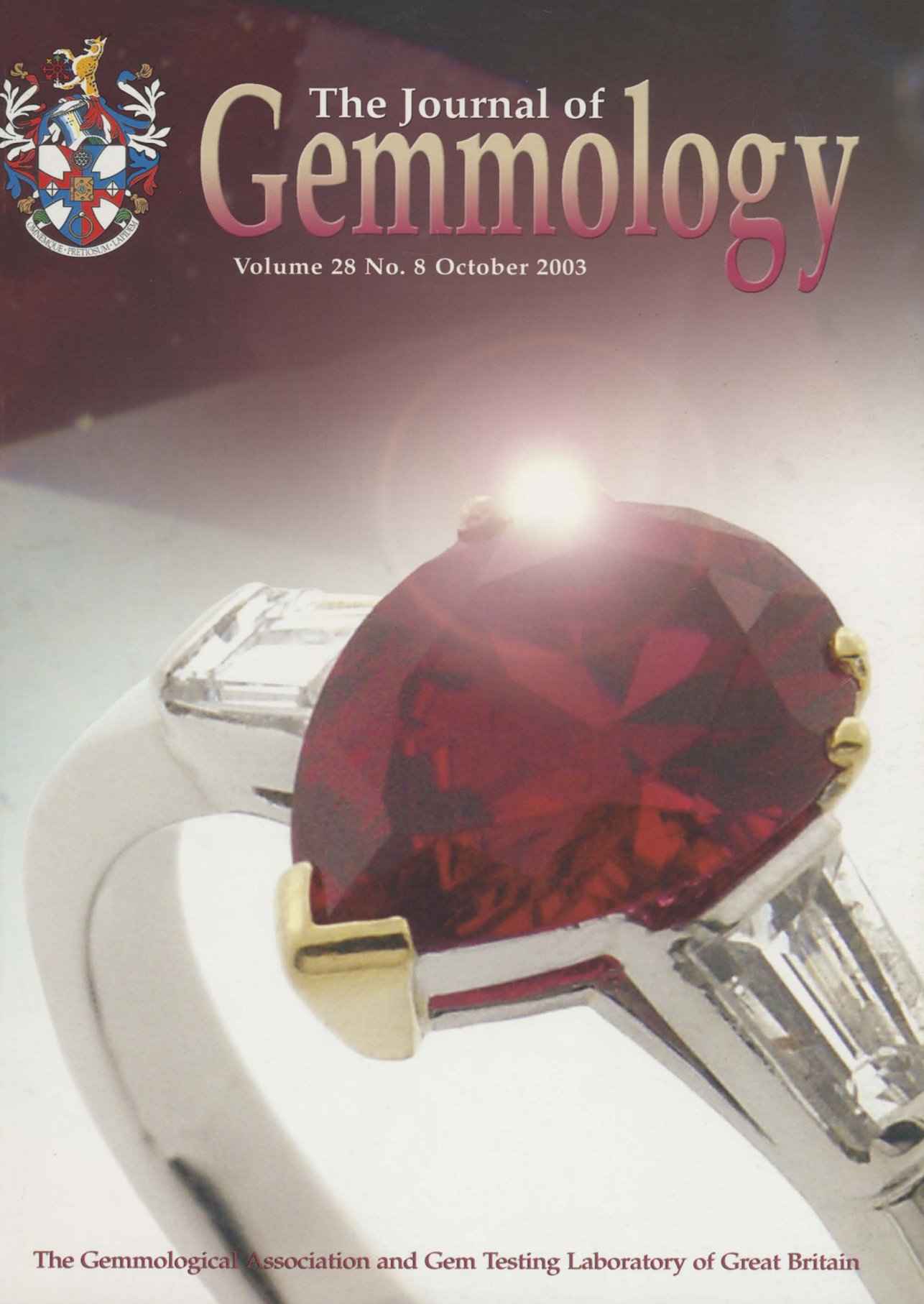

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Pearl cultivation in Donggou, Ezhou, Hubei, and cathodoluminescence of cultured pearls

Huang Fengming, Yun Xinqiang, Yang Mingxing and Chen Zhonghui

Gemmological Institute, China University of Geosciences, Wuhan 430074, P.R. China

ABSTRACT: The paper summarizes the cultivation in Ezhou city, Hubei, P.R. China, of freshwater pearls in four stages: (1) the choosing and rearing of parent mussels, (2) the rearing of pearl-producing mussels, (3) the grafting operation and (4) the after-care of the mussels followed by the recovery of the non-nucleated cultured freshwater pearls. Additionally, the luminescent properties of cultured pearls under cathode rays are considered. Non-nucleated cultured freshwater pearls luminesce yellow, yellowish-green and green under cathode rays, with local orangey-red areas in some specimens. In contrast, nucleated cultured seawater pearls display no cathodoluminescence. These results are related to the environments in which the respective cultured pearls grew. Dyeing and irradiation treatments were found to suppress the luminescence of freshwater cultured pearls under cathode rays. The Raman spectra of orangey-red areas in some non-nucleated cultured freshwater pearls are characterized by peaks at 281, 712 and 1085 cm^{-1}, resembling those observed in inorganic calcite. The presence of a diffuse matrix of protein, such as carotenoid, may reduce the intensity of cathodoluminescence in coloured non-nucleated cultured freshwater pearls.

Pearl cultivation in Donggou, Ezhou

It has been recorded that pearl cultivation occurred as early as 1082 during the Song Dynasty in ancient China (Pang, 1167, from Xie 1995 *et al.*), but the greatest development of the pearl culturing industry has taken place over the last 20 years (He, 1999; Shen, 2001). At present, the production of cultured freshwater pearls predominates, forming more than 90% of total world production, and is estimated to be around 1600t annually (Sun, 2001). This compares with the annual production of 15-20t of cultured seawater pearls.

The cultured pearl farm in Donggou is one of the more important cultured freshwater pearl farms in China. The town of Donggou is located on the shore of Lake Liangzi, which is the second largest lake in Hubei Province. Donggou is about 20 km away from the Wuhan-Huangshi expressway and is two hours by car from Wuhan.

The pearl culturing industry in Donggou started more than 20 years ago and a wealth of experience in rearing pearl-producing mussels and in producing pearls has been accumulated. In recent years there has been an increase in local government funds for

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Figure 1: Hyriopsis cumingi *used to produce cultured freshwater pearls in Donggou.*

the development of agriculture, which includes the pearl culturing industry. At present in Donggou there are more than 20 sites covering about 2 × 10^7 km^2 rearing approximately two hundred million pearl-producing mussels. These produce more than 90t of cultured freshwater pearls annually. The cultured pearls from the Donggou farm account for 85% of the total production of cultured freshwater pearls by weight and about 67% by value for Ezhou city.

The stages of cultivation

Choosing and rearing parent mussels

Generally, for producing cultured freshwater pearls, the mussels *Hyriopsis cumingi* and *Cristaria plicata* can be used, and in Donggou, *Hyriopsis cumingi (Figure 1)* is the preferred species. The mussels are either found wild in lakes, rivers or pools or are bred. As parent mussels, they must be healthy and strong. The adductor muscle should be strong and the shell must be of good shape. The parent mussels should be three to six years old and over 17 cm in width (Bian, 2001 a, b; Li, 2000; Wang, 2001). The male and female mussels should be from different sources in order to avoid inbreeding problems. Normally for breeding purposes the ratio of female to male mussels in a body of water is 2:1 (Bian, 2001 b). The parent mussels must be suspended in gently flowing water.

The rearing of pearl-producing mussels

The sexual glands of *Hyriopsis cumingi* mature during the last ten-day period of April and the first ten-day period of May. Normally, mature *Hyriopsis cumingi* start to ovulate when water temperature reaches 18°C. In ideal growth conditions, including suitable water temperature, full food and oxygen supplies, and a supply of fresh and flowing water, each mussel can ovulate seven to eight times annually. If the water temperature is low, the ovulation period may be delayed until September. The female mussels ovulate mature ova into their outer branchial or gill cavities, where the ova combine with the sperm discharged into the water by male mussels to form glochidiums. Since the glochidiums cannot obtain nutrition directly from water, they then must attach themselves to the fins or gills of fish, which are deliberately placed in the pools for this purpose, in order to absorb nutrition. There are two kinds of fish available to act as parasitic hosts – the yellowhead *(Pseudobagrus fulvidraco)* and the bighead (a variegated carp). In Donggou, *Pseudobagrus fulvidraco (Figure 2)* are used. On average, one fish may have 150-200 glochidiums attached. After four to fifteen days depending on the water temperature (Li, 2000), the glochidiums metamorphose to become young mussels, at which time they fall from the fishes. The young mussels are usually 0.3–10 mm long, and are transparent (*Figure* 3). Groups of 80 to 100 young mussels are placed in bamboo baskets about 40 cm × 40 cm × 11 cm in dimensions. During growth the young mussels must be fed, and protected from disease and from attack by other animals such as fishes, shrimps, ducks, water birds and other predators.

The grafting operation

When the young animals are about one year old and about 7-10 cm in length, they are lifted out of the water and are ready for

***Figure 2**: Yellowhead* (Pseudobagrus fulvidraco) *used as the parasitic host for glochidiums.*

the grafting operation. In order to produce non-nucleated cultured freshwater pearls pieces of mantle from a sacrificed mussel are inserted into the incisions made in the pearl-producing host mussel. The sacrificed mussel variety is the same as the host mussel variety, i.e. *Hyriopsis cumingi*. Normally, the mussels providing the mantle tissue are less than one year old and about 6–9 cm in length. These young mussels have mantles with a strong metabolism, which are able to secrete nacre at a high rate, which is ideal for the formation of pearl sacs.

The mantle tissue preparation is as follows (Bian, 2001c):

(a) The adductor muscle is cut and the two halves of the bivalve are opened out to reveal the fleshy organism inside.

(b) The coloured outer margin of the mantle is cut away, and then a strip of mantle with an elongate depression (along a similar depression in the shell underneath) (*Figure 4*) is removed.

(c) The strip of mantle is placed on a glass plate with the other epidermis facing upwards. The inner epidermis, which is facing downwards is sliced away.

***Figure 3**: Young mussels which have just fallen from a yellowhead* (Pseudobagrus fulvidraco).

***Figure 4**: The mantle from the sacrificed mussel to be removed. (1) Coloured outer margin of mantle; (2) part of mantle to be used, with the coloured outer margin cut away; (3) impression of mantle.*

(d) The mucus on the outer epidermis is removed with a disinfected swab. The mantle is then cut into regular pieces of about 3.5 mm by 4 mm which becomes square due to shrinkage.

(e) A drop of disinfectant or nutrient is placed on each piece of mantle in order to avoid deaths of cells due to dehydration. The whole of this mantle tissue preparation should be finished within two to three minutes. These pieces of mantle then go to the grafting operators.

Normally, a grafting operator has a specially-designed small knife used to cut an incision in the mantle in the left hand, and a pointed tool used to pick the small pieces of mantle in the right hand.

The grafting operation takes place as follows (Bian, 2001c):

(a) The two halves of the host animal are opened and a wood wedge is inserted between the two shells. The mantle cavity is cleaned.

(b) A small piece of mantle is picked with a pointed tool. An incision is cut with a small knife from left to right, in the mantle of the mussel. The small piece of mantle is inserted into the incision in the connective tissue between the upper and lower epitheliums of the mantle, at a depth of about 0.5 cm (Zhang, 2000).

(c) The point holding the piece of mantle is removed by pressing the incision with the knife.

(d) The small piece of mantle is made round by pulling, pressing, squeezing and pushing with the point.

(e) The steps (a) to (d) are repeated until 36 to 40 pieces have been inserted in the mantle of the host mussel from upper to lower and left to right (*Figure 5*).

(f) The wedge is removed and the operated mussels are then temporarily held in containers of water with disinfectant.

The whole of the grafting operation should be complete within 3 to 5 minutes.

***Figure 5**: A piece of mantle being inserted into an incision in the mantle of a host mussel.*

After-care and recovery of pearls

The operated mussels are then suspended in fresh clear water with a gentle flow and left undisturbed for the first 15 to 30 days. After a month, the operated mussels are inspected. The surviving healthy mussels are placed in separate plastic nets and suspended in the water from plastic bottle buoys (*Figure 6*), where they are left to grow. The mussels must be supplied with various foods appropriate to the water condition, and must be protected from disease and from attack by other animals (Bian, 2001d, 2002; Li, 2000). For better quality, pearls are left to grow for three to five years before recovery. However many pearl farmers remove the

***Figure 6**: Lines of plastic bottles from which the pearl-producing mussels are suspended.*

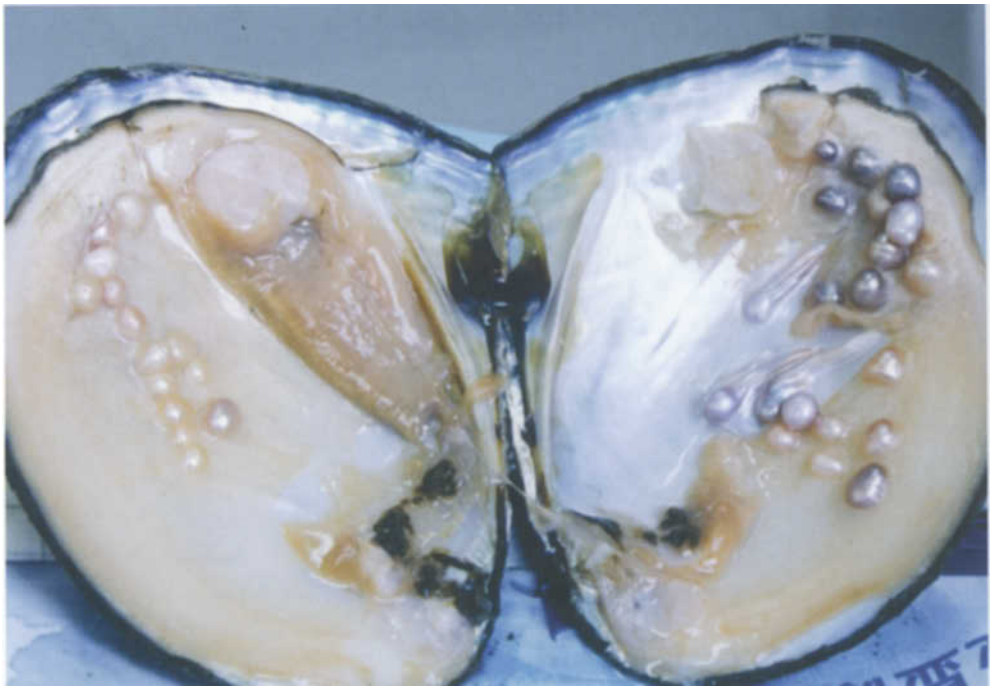

***Figure 7**: An opened mussel from which pearls are obtained.*

pearls from the mussels after only one year's growth or less and these cultured pearls are of lower quality (*Figure 7*). Traditionally, cultured pearls have been recovered during the winter, but recently the pearl farmers have started to harvest the pearls at any time.

Cathodoluminescence of cultured pearls

Cathodoluminescence (CL) technology was first applied in gemmology to survey coloured stones and to identify synthetic diamonds (Ponahlo, 1992). Now, cathodoluminescence is starting to be more widely applied and with the advent of cheaper instruments and the fact that it is a non-destructive test, it is likely that it will become more and more significant in gem identification.

Pearl forms in a unique fashion compared to other gem materials. Cultured freshwater and seawater pearls contain different types and/or concentrations of trace elements, which may cause differences in the observed colour and/or intensity of luminescence under cathode rays. Cathodoluminescence therefore has the potential of providing a method of differentiating freshwater from seawater cultured pearls.

In order to understand the cause of cathodoluminescence emitted by non-nucleated cultured freshwater pearls, the Raman spectra of all were also studied. These were compared with the spectra of calcite and aragonite crystals. The Raman spectra were recorded using a Renishaw System RM-1000-type Raman spectrometer at room temperature with an Olympus BH2-type microscope and a computerized data acquisition system. The samples were excited by an Ar ion laser at a wavelength of 514 nm and focus diameter of 1μm. All samples were tested directly without pretreatment.

Instrument and Materials

The Gem Cathodoluminescence-scope (Model YJ-1) used to examine cultured pearls was developed by the Gemmological Institute of China of the China University of Geosciences (*Figure 8*). The experimental conditions were as follows: accelerating voltage, 4.5–5.0 kV, and the beam current, 0.8–1.10 mA.

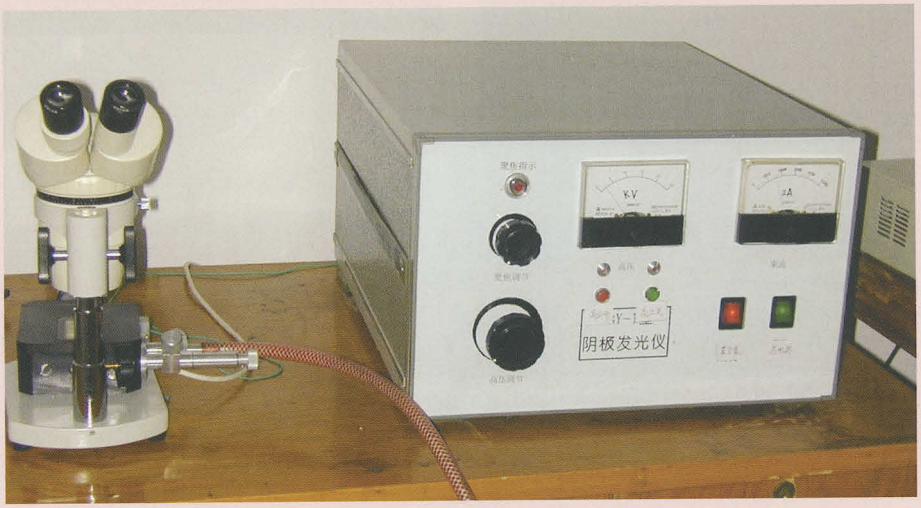

Figure 8: Gem Cathodoluminescence-scope (Model YJ-1).

This study concentrated on non-nucleated cultured freshwater and nucleated cultured seawater pearls. The non-nucleated cultured freshwater pearls were obtained from Ezhou, Hubei Province, and Zhuji, Zhejiang Province, and were of the following colours: pale purple, golden-yellow, yellowish-pink, and white and blackish-grey (this pearl is blackish-grey at one end and the colouring is about 1 mm deep). The nucleated cultured seawater pearls were obtained from the Polynesian Islands (Tahiti), Indonesia, Beihai in Guangxi and from other unknown localities, and were of the following colours: black, grey, white, pale yellow and dark grey. Additionally, two dyed black and two dyed grey nucleated cultured seawater pearls, one dyed black non-nucleated cultured freshwater pearl, one dyed pale purple with grey Mabé cultured pearl, and three irradiated greyish-black non-nucleated cultured freshwater pearls were tested. For comparison purposes two pieces of calcite and two pieces of aragonite were also studied. Thirty-six non-nucleated cultured freshwater pearls and one nucleated cultured seawater pearl were sectioned in order to observe cathodoluminescence of their interiors.

Results and discussion

Results

1. Non-nucleated cultured freshwater pearls: all the non-nucleated cultured freshwater pearls of differing colours, whether whole or sectioned, from Ezhou and Zhuji displayed yellow, yellowish-green or greenish luminescence under cathode rays (*Figures 9 and 10*).

***Figure 9a and b**: Cathodoluminescence of non-nucleated cultured freshwater pearls.*

The intensity of the luminescence varies depending on the colour of the specimens. Generally, the deeper the colour of the specimens, the weaker the intensity of luminescence displayed by the specimens. For example, white pearls display the strongest luminescence, golden and purple pearls fluoresce weaker, and blackish-grey specimens give either a very weak luminescence or are inert. On the surface of some freshwater cultured pearls rings of weaker luminescence relate to perceived growth bands of darker colour. This relationship is also observed in all the cross-sections of the freshwater cultured pearls where the differing layers of growth have different intensities of luminescence. Orangey-red

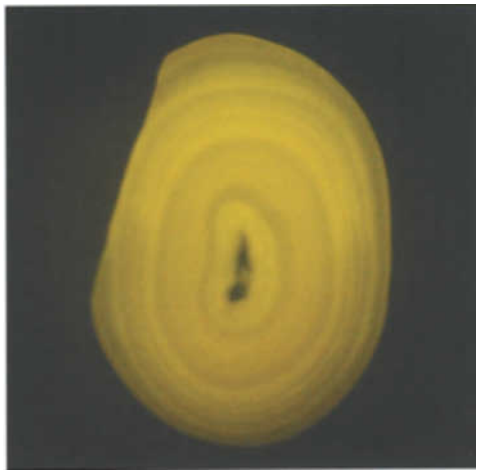

***Figure 10**: Cathodoluminescence of ordered three-dimensional growth of a non-nucleated cultured freshwater pearl.*

***Figure 11**: An area of a non-nucleated freshwater pearl showing orange fluorescence to cathode rays.*

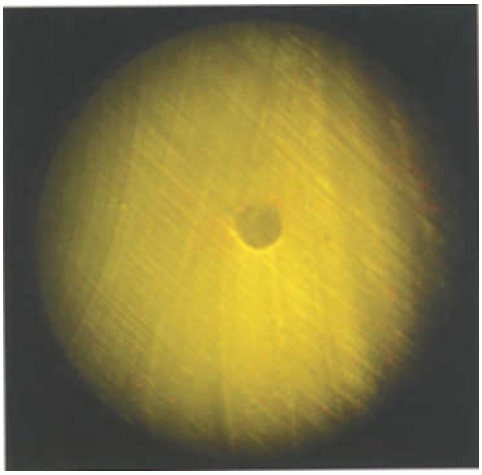

***Figure 12**: Cathodoluminescence of the freshwater shell bead nucleus of a nucleated cultured pearl.*

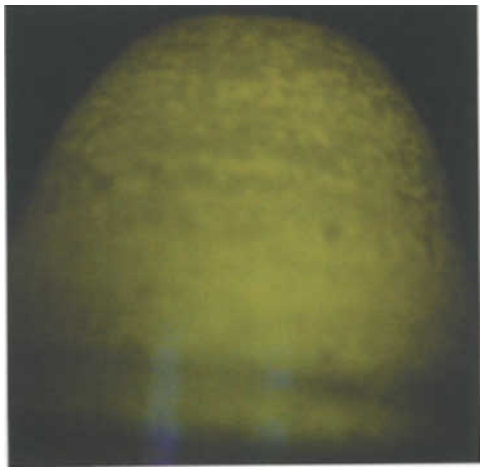

***Figure 13**: Cathodoluminescence of a dyed black non-nucleated cultured freshwater pearl.*

luminescent areas (*Figure 11*) correspond generally to white areas on the surface or contained within the freshwater cultured pearls that have undergone irregular growth. In contrast the ordered three-dimensional growth of the cultured pearl in *Figure 10* reveals no orangey-red luminescence.

2. Nucleated cultured seawater pearls: all of the nucleated cultured seawater pearls were inert to the cathode rays on the surface, but when sectioned, the underlying freshwater shell bead nucleus luminesced a yellowish-green (*Figure 12*) with the thin nacreous layer remaining inert.

3. Dyed and irradiated cultured pearls: the dyed nucleated cultured seawater pearls including the dyed Mabé cultured pearl were inert to cathode rays. The stained

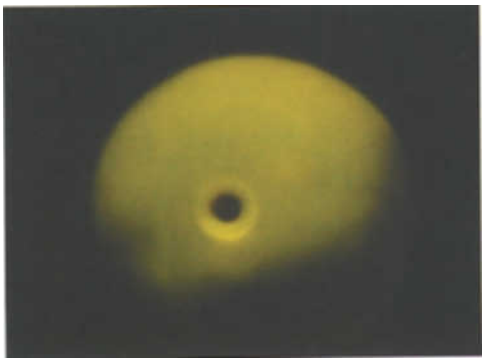

***Figure 14**: Cathodoluminescence of an irradiated greyish-black non-nucleated cultured freshwater pearl.*

***Figure 15**: Cathodoluminescence of a calcite crystal.*

black and irradiated greyish-black cultured freshwater pearls still showed a yellowish-green luminescence (*Figures 13 and 14*).

4. Inorganic carbonate minerals: calcite shows orangey-red luminescence under cathode rays (*Figure 15*), a colour which is similar to that seen in the white growth domains of cultured freshwater pearls. Aragonite, however, exhibits a very weak yellowish-green fluorescence.

5. The Raman spectra of calcite and aragonite are shown in *Figures 16* and *17*. Calcite is characterized by bands at 282, 712, 1086 and 1436 cm^{-1}, and aragonite is characterized by bands at 285, 700, 704, 1084 and 1460 cm^{-1}. The main difference between the Raman spectra of calcite and aragonite is that the former shows a peak at 712 cm^{-1}, and the latter two peaks at 700 and 704 cm^{-1}. These three bands are internal E_g modes corresponding to in-plane bending (v_4) modes of carbonate ions (Urmos *et al.*, 1991). The v_4 in-plane bending mode of the carbonate ion in aragonite occurs as a doublet consisting of bands at ~701 cm^{-1} (B_{1g}) and ~705 cm^{-1} (A_{1g}), which is in contrast to the single band at ~711 cm^{-1} band in the calcite spectra (Urmos *et al.*, 1991). The laser Raman spectra of white growth domains are characterized by peaks at 281, 712 and 1085 cm^{-1} (*Figure 18*), which are similar to those of calcite. Therefore, the orangey-red luminescence seen in white growth domains of cultured freshwater pearls may well be caused by calcite.

Discussion

It can therefore be concluded that freshwater pearls and shell will luminesce yellow, yellowish-green or green under cathode rays, with localized orangey-red luminescence in some areas relating seemingly to areas of calcite concentration. The darker the colours of the freshwater cultured pearl, whether as a whole or localized to growth rings, the lower the intensity of the cathodoluminescence perceived. The nacre deposited by seawater oysters on nucleated cultured pearls appears to be inert to cathode rays.

The trace element concentrations of manganese and strontium have been found to be different between freshwater and seawater pearls (K. Wada *et al.*, 1988, as quoted in D. Habermann, *et al.*, 2001; Xie, 1995; Li, 2001; Ma *et al.*, 1998; Zou *et al.*, 1996). Cultured freshwater pearls have higher manganese concentrations than cultured seawater pearls, averaging about three times as much according to SSEF (1998). The difference in manganese contents is proposed as the reason for the differences in X-ray fluorescence of natural, nucleated and non-nucleated cultured pearls. Habermann *et al.* (2001) have suggested that manganese is found not only in the shell, but also in the fleshy organism itself, which implies that it is involved in the biochemical secretion process. It is also proposed (op. cit.) that manganese in aragonite gives rise to green cathodoluminescence and when present in calcite causes orange luminescence.

The intensity of luminescence seen in cultured freshwater pearls may be related to organic materials. Based on the laser Raman spectra of cultured freshwater pearls, the main Raman bands of white pearls or white growth domains without orangey-red luminescence are at 702 and 1084 cm^{-1}, similar to those of aragonite. With the exception of black cultured pearls, pale pinkish, yellow, golden and purple pearls on the surface or in growth layers, show bands at 702, 1084, 1130 and 1524 cm^{-1} (*Figures 19 to 21*). Similar results were obtained by Zhang *et al.* (2001). Urmos *et al.* (1991) suggested that the peaks at 1130 and 1524 cm^{-1} are characteristic vibrational modes of the carotenoid pigment. The fundamental Raman band at 1524 cm^{-1} (v_1) is produced by the stretching vibrations of -C=C- double bonds, and that at 1130 cm^{-1} (v_2) is produced by the stretching of -C-C- single bonds. This indicates that the presence

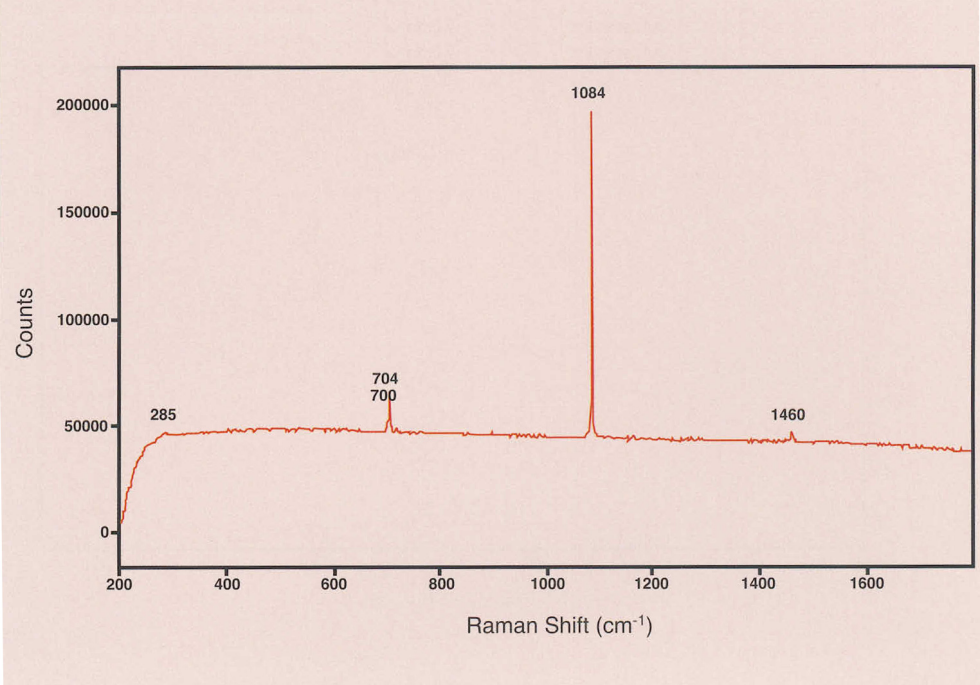

***Figure 16**: Raman spectrum of an aragonite crystal.*

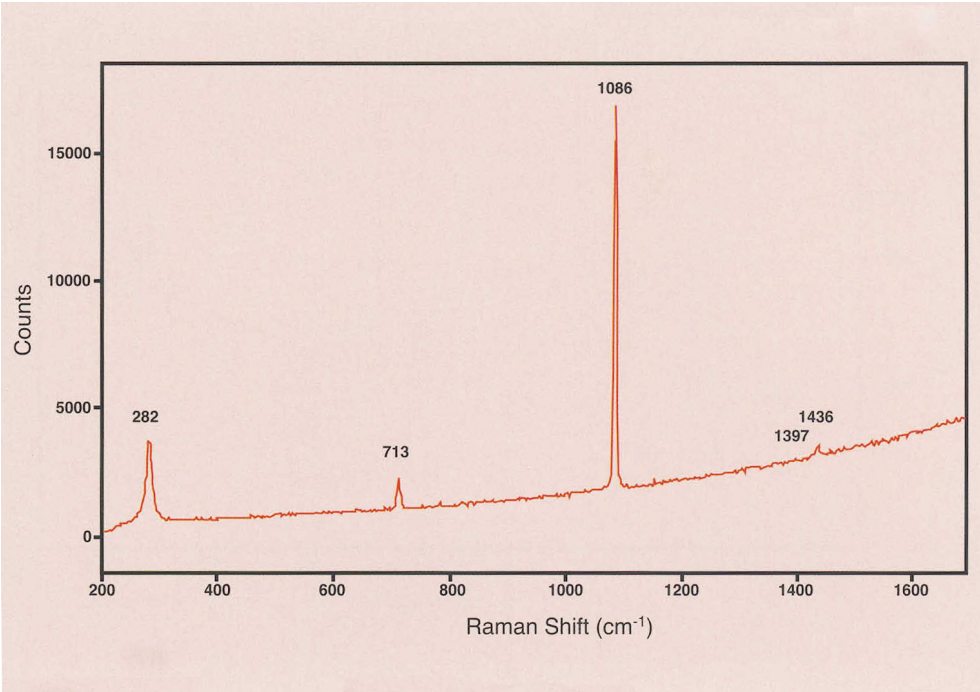

***Figure 17**: Raman spectrum of a calcite crystal.*

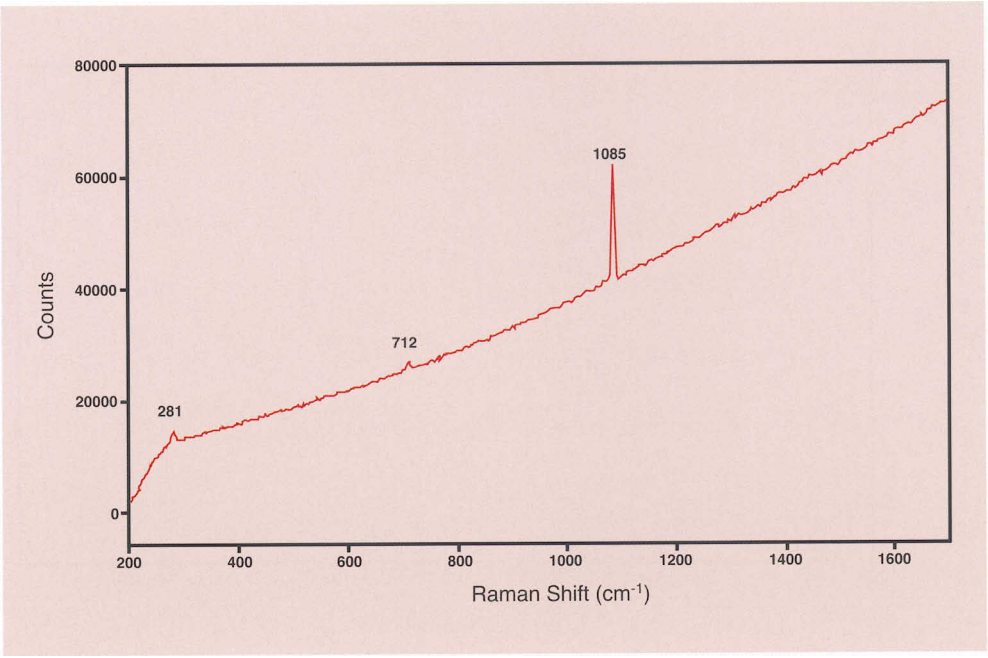

***Figure 18**: Raman spectrum of the orangey red luminescent area in the non-nucleated cultured freshwater pearl shown in Figure 11.*

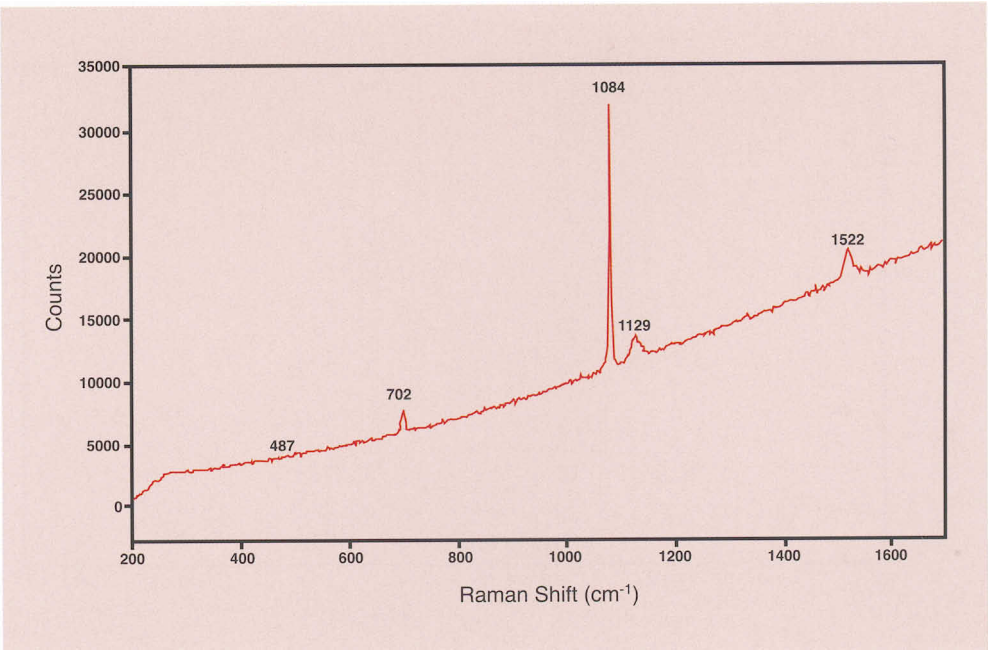

***Figure 19**: Raman spectrum of a golden yellow non-nucleated cultured freshwater pearl from Ezhou, Hubei Province.*

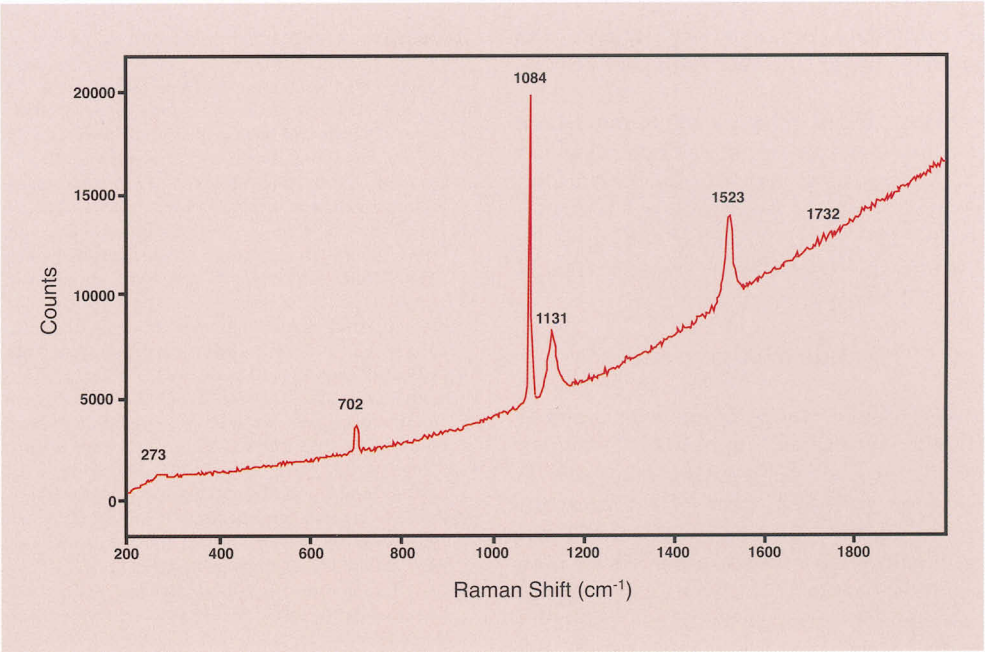

***Figure 20**: Raman spectrum of a pale purple non-nucleated freshwater pearl from Ezhou, Hubei Province.*

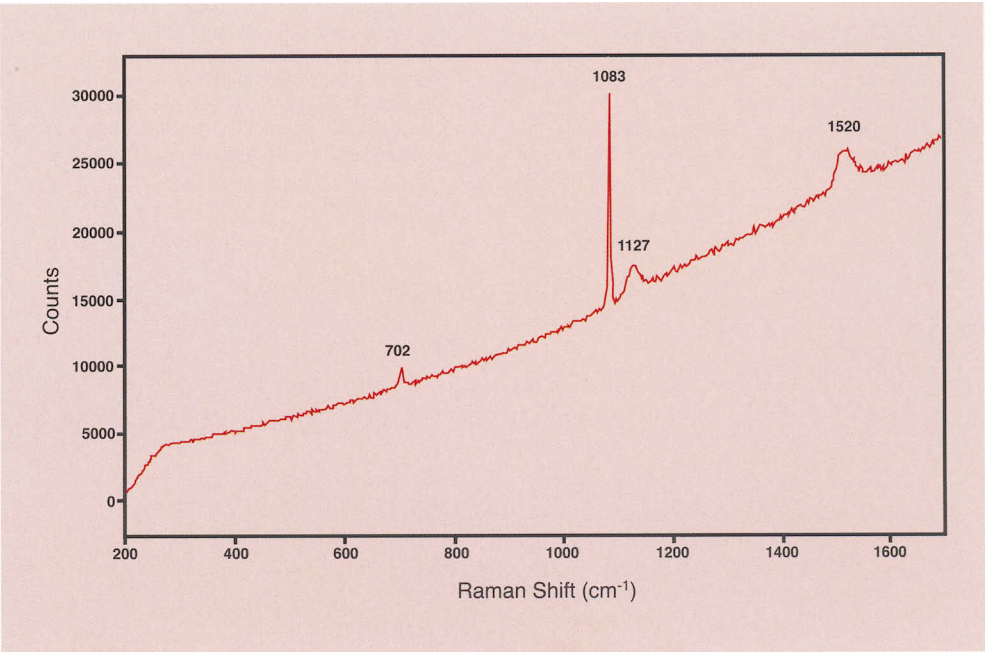

***Figure 21**: Raman spectrum of a pale purple non-nucleated cultured freshwater pearl from Zhuji, Zhejiang Province.*

of carotenoid pigment may reduce the luminescence of cultured freshwater pearl.

Many factors influence the luminescence of cultured pearls under cathode rays, and CL can be used to distinguish cultured freshwater pearls from cultured seawater pearls. However, it cannot be used to distinguish untreated from treated cultured pearls.

Acknowledgements

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Nephrite jade from Sestri Levante, Italy

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ABSTRACT: In the vicinity of Sestri Levante, deposits of nephrite jade are intimately associated with serpentinized peridotite in an Apennine ophiolite complex of Jurassic age. The nephrite jade bodies are mainly thin veins and occasionally podiform nodules that formed within serpentinite, chloritite or rodingite near contact alteration zones between serpentinite and metagabbro. Predominant colours of the nephrite jade are of uneven greyish-green hues and surface lustre is dull. Grain size varies from fine- to medium-grained and subordinate constituents of apatite, diopside, magnetite, picotite, sphene and talc have been recorded. The nephrite jade formed as a result of metasomatism and high pressure effects following the emplacement of the ultrabasic rocks and serpentinization. Although the deposits are frequently cited in the literature, doubts remain in relation to their prospectivity. Surface exploration has failed to identify a single mass of nephrite of sufficient size to warrant mining operations and so far, exploitation has been limited to collecting material from outcrops and fossicking for nodules in the regolith. The small pieces found are scarcely ever fashioned by lapidaries except for minor items of costume jewellery. Nevertheless, the deposits remain of considerable geological and historical interest.

Introduction

The existence of nephrite jade in the Ligurian Apennines of Italy has been known for around a century and the locality is widely referred to in the extensive literature on jade. Indeed, it is frequently cited as the largest deposit of nephrite jade in Europe (e.g. Kolesnik, 1970; Frey and Skelton, 1991). Surprisingly however, commercial exploitation has failed to eventuate. In addition, few specimens of the nephrite are displayed in major mineral collections and the history of the deposits remains shrouded in mystery.

The nephrite jade locality lies some 40 km east of the city of Genoa in Northern Italy and near the picturesque town of Sestri Levante on the Riviera Ligure (*Figure 1*). Here, the Northern Apennines meet the coast and create steep terrain with spectacular cliffs and rugged mountains. Recorded occurrences of nephrite jade lie almost entirely within the Cinque Terre Regional Park.

The writer carried out field investigations at Sestri Levante during October 2002 as part of a wider study of nephrite jade in Europe. This paper provides a review and a description of the geological setting of the deposits and comments on the exploration potential of the district.

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Figure 1: Orientation map.

Historical background

In a landmark paper, Kalkowsky (1906) first reported the discovery of primary deposits of nephrite jade in the vicinity of Sestri Levante. He described the principal deposit near Monte Bianco and identified ten other occurrences within a belt stretching from Sestri Levante for almost 25 km in a south-eastwards direction to Monterosso al Mare (*Table I* and *Figure 2*, Sites 1-11 inclusive). (This Monte Bianco should not be confused with the mountain on the border between Italy and France which is also known as Mont Blanc.) The area was later visited by Steinmann (1908) who confirmed the findings of Kalkowsky (1906) and also identified three further occurrences (*Table I* and *Figure 2*, Sites 12–14 inclusive). More recently, Antofilli *et al.* (1983, p.167) mentioned Sites 1, 5 and 9 in a general account of the geology and mineralogy of the Ligurian region.

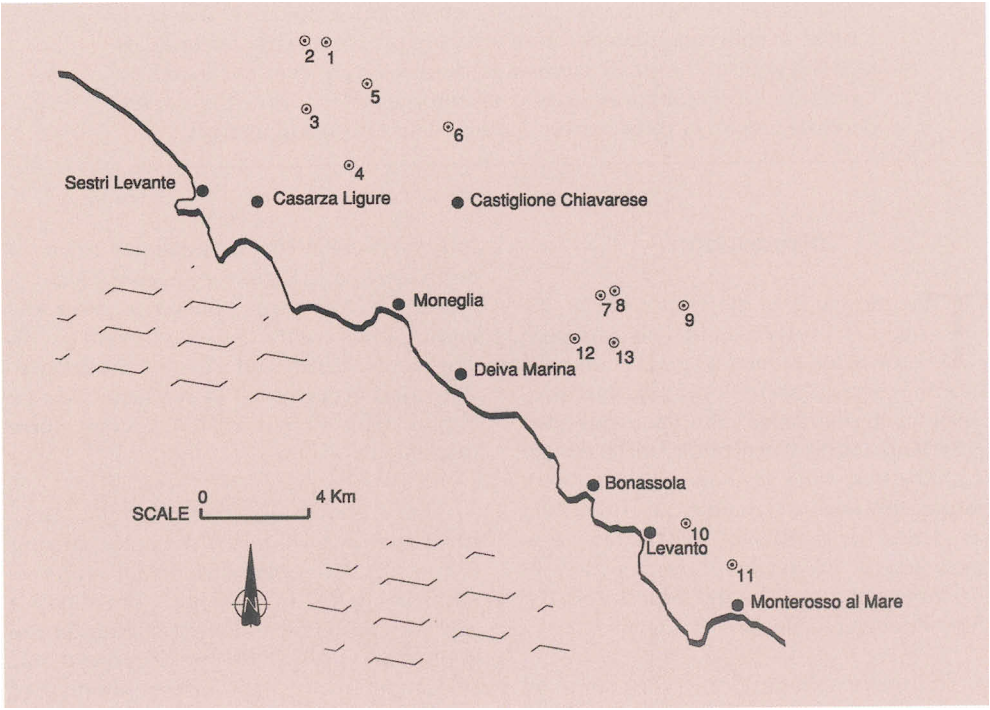

Figure 2: Nephrite jade occurrences between Sestri Levante and Monterosso al Mare (see Table I).

***Table I**: Nephrite jade occurrences between Sestri Levante and Monterosso al Mare (see Figure 2).*

Ref No	*Locality name*	*Nephrite occurrence*	*Grid ref.*
1	Monte Bianco	main deposit; veins and nodules	5357 9081
2	Domenico Pass	patches and swirls in rodingite	5353 9080
3	Libiola Hill	veins in chloritite	5354 9058
4	Gallinaria Mine (Casarza Ligure)	vein in serpentinite	5372 9038
5	Casa di Bonelli (Monte Tregin)	vein network in serpentinite	5380 9065
6	Casa di Monte Pu	irregular bands	5406 9046
7	La Spezia Road A	irregular patches	-
8	La Spezia Road B	angular block at roadside	-
9	Mattarana	patches in serpentinite and talc	-
10	Levanto	pebbles in riverbed	-
11	Monterosso al Mare	patches in serpentinite	-
12	La Baracca-Castagnola Path	deformed vein in serpentinite	5455 8980
13	Monte Guaitarola Road	veins in roadside cuttings	5470 8980
14	Aulla-Bibola (Val Magra)	veins (16 km NE of La Spezia)	-

Although the discoveries of nephrite jade at Sestri Levante aroused widespread interest and the potential for exploration in the surrounding area appeared encouraging, further information on the deposits in the technical literature is singularly lacking. This seems rather surprising because despite certain restrictions throughout the war years due to the strategic importance of the region for naval purposes, the area appears reasonably accessible.

Geological setting

Ophiolite complexes are widespread along the Northern Apennines. They basically consist of associations of serpentinized peridotite, gabbroic rocks, and basalts overlain by marine sedimentary sequences, including radiolarian cherts and limestones, the whole having been affected by mild metamorphism. These ophiolitic complexes are interpreted as remnants of Jurassic oceanic crust and upper mantle, formed in a palaeo-Apennine basin that

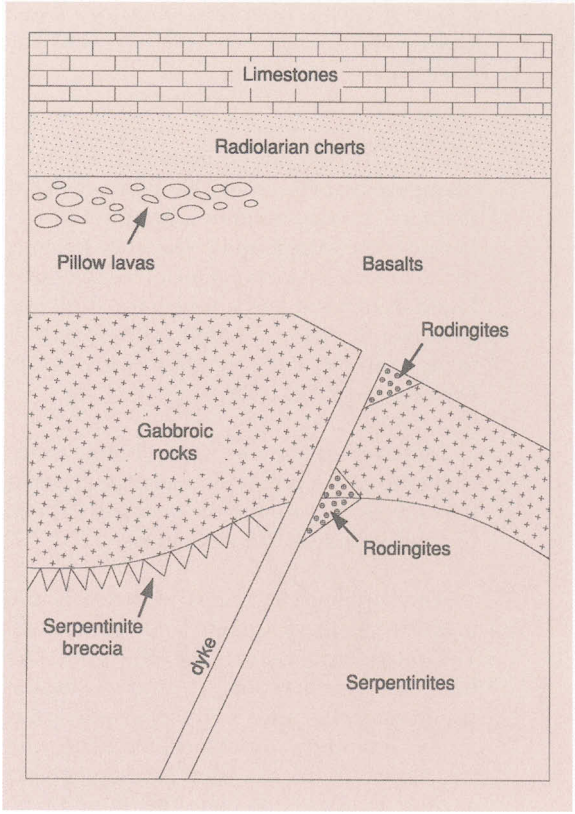

***Figure 3**: Schematic section through Apennine ophiolite showing stratigraphic setting.*

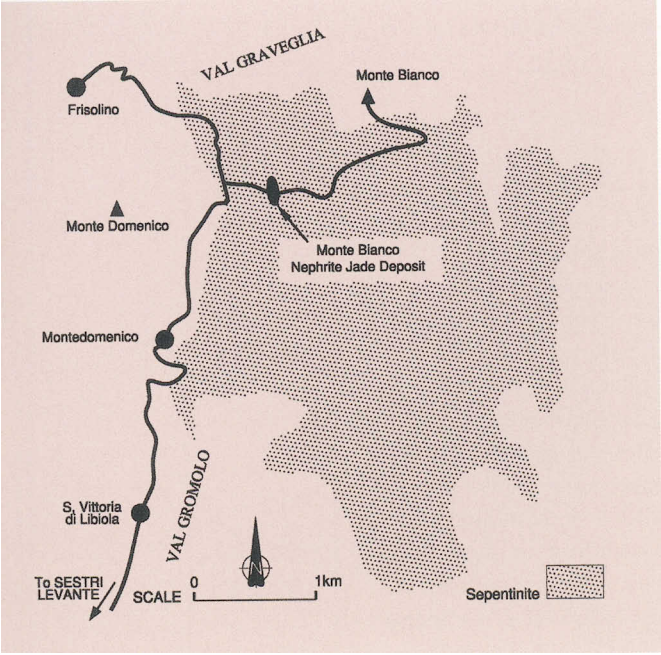

Figure 4: Monte Bianco nephrite jade deposit. Locality and geology plan (after Decandia and Elter, 1972).

closed in Cretaceous to early Tertiary time (Rampone and Piccardo, 2000, and references therein). In the neighbourhood of Sestri Levante, the stratigraphic sequence belongs to the Bracco-Val Graveglia Unit of the Inner Ligurian Domain and a schematic synthesis is shown in *Figure 3*, based on the work of many authors (Abbate and Sagri, 1970; Decania and Elter, 1972).

Massive serpentinite, metagabbroic rocks, rodingite and serpentinite melange underlie the hilly ground around the principal deposit of nephrite jade at Monte Bianco.

The serpentinite ranges from black and massive to dark green and brecciated. The main constituents of the rock are lizardite, chrysotile and bastite pseudomorphs after orthopyroxene, plus minor quantities of chlorite, brucite and magnetite. In places, sheared serpentinite appears to grade into chloritite. In addition, closely spaced veins composed of calcite are commonplace.

The gabbroic rocks (mainly troctolite to olivine-bearing gabbro) comprise discrete intrusive bodies and dykes emplaced within the serpentinite. They are variably altered and crop out mainly as small, scattered outcrops. According to Tribuzio *et al.* (1997), they also have a complex metamorphic and deformational history.

The rodingite is a distinctive hard and compact rock with highly variable composition. Common mineral constituents include albite, chlorite, diopside, epidote, garnet, prehnite, pumpellyite, sericite, vesuvianite and zoisite. According to Bezzi and Piccardo (1969) and Rösli *et al.* (1991), the rodingite is metasomatic product associated with interaction between gabbro and serpentinite.

The Monte Bianco deposit

The main deposit of nephrite jade is situated on the south facing slope of Monte Bianco in the upper Gromolo Valley (*Figure 4*). From Sestri Levante, access to the site is northeastwards for 8 km via Santa Vittoria di Libiola to the village of Montedomenico thence northwards for 1.7 km along Frisolino Road to the col and eastwards by track for 0.5 km.

The nephrite site occupies an area some 150 m long by up to 40 m wide and elongated down the hillslope. It is characterized by stony ground and vegetation of Mediterranean scrub (*Figure 5*). Serpentinite comprises the dominant rock type subcropping on the hillside although chloritite and rodingite are abundant in places. Rock relationships are unclear due to poor exposure.

The nephrite jade bodies chiefly comprise either networks of veinlets or more commonly single, steeply dipping veins typically 2–5 mm wide that cut through the serpentinite (*Figure 6*). In places, some bodies

Figure 5: Monte Bianco nephrite jade deposit. The site appears in the central part of the picture. View looking north.

form irregular masses of lensoid to podiform shape ranging from 10 to 200 mm across though most are much smaller. The larger pods give rise to rounded nodules. Kalkowsky (1906) reported nodules and masses of larger dimensions that may subsequently have been removed from the site. Importantly, most of the pod shaped masses are heterogeneous and contain significant quantities of other minerals. Not uncommonly, the nodules feature a core of leucocratic rodingite, an inner rim of mixed diopside and chlorite and an outer rim of nephrite that graduates almost imperceptibly into the internodular serpentinite (*Figure 7*).

Using the Munsell notation (Rock-Colour Chart Committee, 1980), the nephrite jade ranges from pale green (10G 6/2) and pale yellowish-green (10GY 7/2) through greyish-green (5G 5/2 and 10G 5/2) to dusky green (5G 3/2) and dusky yellow-green (5GY 5/2) but is predominantly greyish-green (10G 5/2). Localized zones contain an unusual

***Figure 6**: Vein of green nephrite jade alongside pen. Host rock is serpentinite with white calcite veining. Monte Bianco site.*

Figure 7: Cut and polished specimen of a typical nodule. Core of leucocratic rodingite, inner rim of mixed diopside and chlorite and outer skin of nephrite. Size approximately 100 mm across. Monte Bianco site.

variety of nephrite of medium bluish-grey (5B 5/1) colour with light bluish-grey (5B 7/1) mottles. Colours generally are patchy and uneven and surface lustre typically appears dull and somewhat sheared.

X-ray and petrographic examinations of an array of samples obtained from outcrops and a roadside cutting has revealed that the nephrite jade consists of microcrystalline tremolite-actinolite that is intimately associated with appreciable but variable quantities of chlorite and diopside and to a lesser extent talc. The majority of the tremolite-actinolite shows incipient preferred orientation and occurs as very fine fibrous crystals, less than 0.005 mm in width.

Certain specimens are porphyritic or contain distinct inclusions. Kalkowsky (1906) identified the following list of minor coexisting minerals – apatite, chlorite, diopside, garnet, hematite, magnetite, picotite and sphene.

Nephrite classification and origin

Almost invariably, the nephrite jade localities in the vicinity of Sestri Levante are intimately associated with mafic and ultramafic rocks. Based on the field relationships between the nephrite bodies and the ophiolite belt as well as the association of rodingite within contact alteration zones, the deposits are classed as ortho-nephrite in type (Nichol, 2000).

Following the discovery of nephrite jade in the Sestri Levante district, controversy arose on the origin of the deposits and at least two schools of thought evolved. The first group led by Kalkowsky (1906) considered that the nephrite originated

entirely within serpentinite as a result of tectonic movements combined with hydrothermal modifications. The second group led by Steinmann (1908) rejected the concept of tectonic control over nephrite genesis and maintained that the transformation process resulted from pressures induced by the volume increase of 15–20% associated with the alteration of olivine to serpentine. Steinmann also contended that the process operated predominantly in the contact alteration zone between serpentinite and metagabbroic rocks. Although the latter gained widest acceptance, our understanding of the formation of ortho-nephrite has seen great progress since that time. We now attribute the origin of the mineral to contact or infiltration metasomatism of silicic rocks by serpentinite fluids or a blackwall-like boundary reaction between silicic rocks and Ca-Mg-rich aqueous fluids from serpentine (see Karpov *et al.*, 1988; Suturin, 1986). Nevertheless, the insights of these early workers based on their observations at Sestri Levante provided profoundly significant contributions to the theories on the subject.

Figure 8: *Cabochon brooch fashioned in nephrite jade from Monte Bianco site.*

Production and exploration potential

No commercial development of the nephrite jade deposits at Sestri Levante has been recorded. This was probably due to the dispersed distribution of the material through the serpentinite and the apparent lack of a single mass of sufficient dimensions to warrant mining operations or to encourage deeper exploration beneath the ground surface. Consequently, output has been limited to intermittent fossicking for nodules in the regolith and prising small pieces from outcropping veins. These fragments are suitable only for small crafted items (*Figure 8*).

Another consideration is quality which appears generally low for most gemmological purposes with the proportion of monomineralic material estimated at less than 5 per cent. Moreover, the material lacks the vitreous lustre usually associated with nephrite and typically, the size of stone is too small to be used for ornamental and hardstone carvings.

Although surface indications of nephrite are widely scattered in the region, the historical records and desultory production suggest a lasting story of small size and low quality. However, despite the lack of workable deposits to date, the region appears to remain under-explored for nephrite. The full potential may not have been realized because of inadequate support for prospecting and geological studies. As far as can be determined, no subsurface investigations have been carried out and potential exists for possible improvements in the quality of the material at deeper levels in fresh rock. This could be tested at the Monte Bianco site by a modest programme of investigations involving a series of inclined boreholes through the deposit to obtain core samples of subsurface material. However,

Figure 9: Polished specimen of nephrite jade from Sestri Levante. Approximate size 70 × 40 mm. Kalkowsky collection, Museum für Mineralogie und Geologie, Dresden.

special permissions and restrictions may apply because the site lies within a designated Regional Park.

Museum collections

Three small specimens of nephrite jade from the neighbourhood of Sestri Levante are held in the Tiragallo collection at the Museo Civico di Storia Naturale 'G. Doria' in Genoa but they are not on public display.

The largest collection of nephrite jade specimens from the Sestri Levante district is held in the Museum für Mineralogie und Geologie, Dresden. It comprises some 70 cut and uncut rock samples including several polished pieces (*Figure 9*). Interestingly, the collection was assembled by Ernst Kalkowsky while he held the positions of Professor of Mineralogy and Geology at the Technical University of Dresden as well as that of Director of the Museum für Mineralogie und Geologie, Dresden (Mathé, 1993). One of the specimens from the collection appears on public display at the Schatzkammer Museum in the Zwinger, Dresden.

A general survey of other museum collections throughout Europe failed to disclose any further noteworthy specimens.

Conclusions

At Sestri Levante in Italy, nephrite jade is associated with contact alteration zones between serpentinite and metagabbro. As well as nephrite jade, the alteration zones also contain sheared serpentinite, chloritite, talc and rodingite.

The nephrite jade is categorized as an ortho-nephrite and occurs mainly in narrow veins and small lensoid to podiform bodies. Colour is predominantly greyish green (10G 5/2), texture ranges from fine- to medium-grained and surface lustre is typically dull.

Specimens of nephrite jade from Sestri Levante are held in only a few museum collections and the material is scarcely ever fashioned by lapidaries except for minor items of costume jewellery.

Although surface indications of nephrite are widely scattered throughout the region, the occurrences generally appear small in size and poor in quality. No commercial production is recorded and doubts remain in relation to Sestri Levante being regarded as a significant nephrite jade province. However, scope exists for further exploration work in the district: in particular, at the Monte Bianco site where subsurface investigations are needed to examine the distribution and quality of the nephrite at deeper levels in fresh rock.

Acknowledgements

The author is grateful to Herr Herbert Giess for considerable assistance with the interpretation of technical literature in the German language. I wish to thank Angelo Stagnaro of Museo Parma Gemma at Casarza Ligure for hospitality and guidance during my field visit to Sestri Levante. I also wish to thank Professor Dr Klaus Thalheim, Curator of Mineralogy, Museum für Mineralogie und Geologie, Staatliche Naturhistorische Sammlungen Dresden for kindly making arrangements for me to examine the nephrite jade specimens in the Kalkowsky collection at the museum. The X-ray diffraction analyses were carried out by X-Ray Mineral Services Ltd, Penmachno, North Wales and the diagrams were prepared by Angela Hughes.

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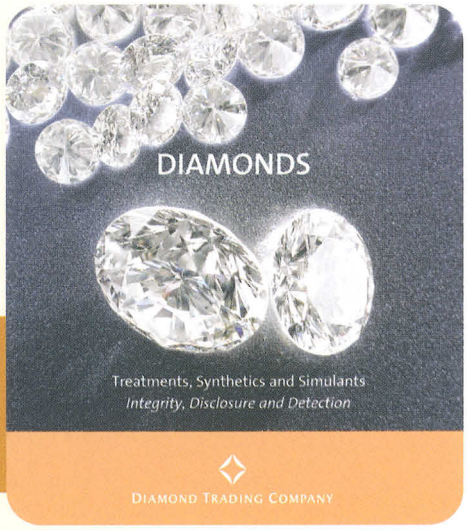

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Chemical fingerprinting of some East African gem rubies by Laser Ablation ICP-MS

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ABSTRACT: Laser Ablation ICP-MS is a suitable method for determining the trace element chemistry of gem rubies because of its sensitivity (ppm levels) and high spatial resolution (less than 100 μm^3). The method is best described as *Quasi non-destructive* because of laser damage induced during the ablation process. Analyses of gem rubies from the Longido and Chimwadzulu deposits of Tanzania and Malawi respectively show that Mg, V, Cr, Fe, Ga, Cu and often Ca, are typically above detection limits. The Ga, V and Cu (0.001 to 0.05 wt.%) and Ca values (0.03 to 0.5 wt.%) show good 'within sample' reproducibility and similar ranges for both deposits. In contrast, the Mg values (0.0001 to 0.49 wt.%) are highly variable and show poor 'within sample' reproducibility. The Fe and Cr values, respectively, are typically from 0.027 to 1.1 wt.% and from 0.084 to 0.71 wt.% (but up to 2.53 wt.% in two samples). These elements show marked differences between the two deposits. Together with Ga they define different areas on published Cr/Ga vs. Fe/Cr discriminant plots, but there is some overlap with fields defined for Burmese and Thai rubies. Combined with published data for Kenyan and Madagascan samples, the Chimwadzulu and Longido samples define a broad 'East African Trend' probably reflecting their similar geological setting within the Proterozoic Mozambique Metamorphic Belt.

Keywords: chemical composition, East Africa, Laser Ablation ICP-MS, ruby

Introduction

The gemmological and inclusions characteristics of rubies and sapphires may be used to help identify their likely source or geographical location (Hughes, 1997). This is important for a number of reasons. Firstly, gemstones from certain localities attract a much higher price than others. Secondly, the information can help archaeologists to establish the provenance of artefacts containing gems, and thirdly, these features can also assist geologists and mineralogists in their understanding of the geological controls on gem formation.

A wide variety of solid and fluid inclusions have been reported in sapphires and rubies from a number of different

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localities and deposit types (e.g. Gübelin and Koivula, 1986; Hughes, 1997). However, even when present, the inclusions are not always readily identifiable because of either their small size or their inaccessibility deep within the sample.

An alternative approach in recent years has been to use the trace and minor element chemistry of gemstones as indicators of both their provenance and genesis. These so-called 'chemical fingerprints' are present either as atomic substitutions in the crystal lattice, (e.g. Cr, Fe and Ga), or as components of solid and liquid inclusions (e.g. Zr from zircon). Previous authors have used chemical data to help discriminate between natural and synthetic rubies (e.g. Tang *et al.*, 1989; Joseph *et al.*, 2002), to identify the provenance of rubies in jewellery and historical artefacts (e.g. Calligaro *et al.*, 1998, 1999), and to characterize corundums from different geological environments (Sutherland *et al.*, 1998; Schwartz *et al.*, 2000).

Systematic trace element analyses of rubies and sapphires from specific localities may also reveal broad geographical (and perhaps geological) differences. Osipowicz *et al.* (1995), for example, elaborating on earlier work by Tang *et al.* (1988), showed that there are marked differences between the Ti, V, Cr, Fe and Cu contents of Burmese and Thai rubies. Calligaro *et al.* (1999) used a database of some 200 analyses of rubies from nine different regions to define three main groupings based on a simple Cr versus Fe discriminant plot, and Schwarz and Schmetzer (2001) used a Cr/Ga versus Fe/Cr discriminant diagram to define different fields for rubies from Burma, Thailand- Cambodia and Madagascar.

To date, X-ray fluorescence (XRF), electron microprobe analysis (EMPA) and proton induced X-ray emission (PIXE) spectroscopy have been the preferred methods of gem analysis, because of their sensitivity and non-destructive nature. But they all have their limitations. To be effective, EMPA needs to be carried out on a flat polished surface, the instrumentation required for PIXE is very expensive, and XRF is generally less sensitive and usually requires bulk samples.

Laser Ablation Inductively Coupled Plasma Mass Spectrometry (L-ICP-MS) is a recently developed, alternative method with the required sensitivity (Jarvis and Williams, 1993). It involves ablating a small sample area (*c.*100 microns^2) down to a depth of about 10 microns, using a laser focused on the surface of the sample through a microscope. The ablated material is swept into a plasma, held at about 10,000 K, via a stream of argon where it is completely ionized. The charged particles are then passed into a mass spectrometer which is capable of determining the quantities of different elements (and their isotopes) depending on their different mass to charge (m/e) ratios. Instrumentation is now widely available, little sample preparation is required and sensitivities are high – simultaneous multi-element analyses can be carried out even if contents are low (in the $\mu g\ g^{-1}$ range or less) within minutes. Inevitably, some laser damage will occur on the surface. This is undesirable in faceted stones, unless analyses are carried out on the underside or edges. However, in a recent study Guillong and Gunther (2001) successfully applied L-ICP-MS to the systematic analyses of Cr, Fe, Ga, V, Ti in 25 sapphires from five unspecified localities with minimal laser damage to the extent that they considered the technique to be *Quasi 'non-destructive'*.

In this paper we report on the L-ICP-MS analyses of trace elements in gem rubies from the Chimwadzulu and Longido deposits of East Africa, which are comparable in terms of their broad geological settings. The main objectives are to:

1. Assess the extent to which trace elements show significant variations between different stones from the same locality.

2. Compare the overall data sets from the two localities with published data from other major ruby localities, worldwide, to

determine whether they can be used as geographical or genetic discriminants.

Geological setting, sample description and preparation

The Chimwadzulu and Longido gem deposits (*Figure 1*) are located within the Proterozoic Mozambique Metamorphic (Mobile) Belt, which is a major structure extending south to north from Mozambique to Arabia. As summarized by Levitski and Sims (1997), late Proterozoic sediments were subjected to several phases of folding and suffered amphibolite to granulite facies metamorphism, with localized alkali metasomatism and granitization. Graphitic gneisses, schists and marbles are locally abundant, and ultramafic rocks occur in belts within gneisses adjacent to their contacts with marbles. On a regional scale, the primary ruby deposits of East Africa and Madagascar are generally associated with ultrabasic rocks (Mercier *et al.*, 1999).

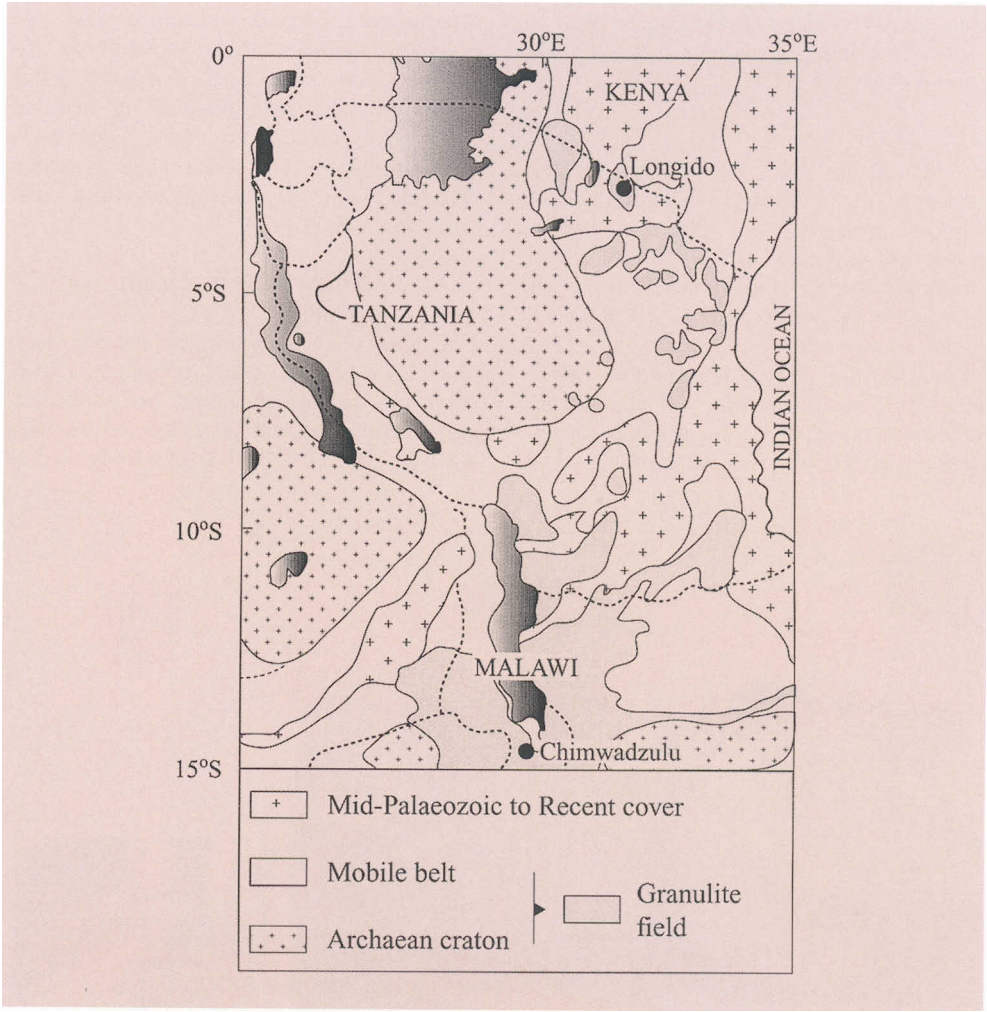

***Figure 1**: Simplified geological map of East Africa and Madagascar (after Mercier et al., 1999) showing the location of the Longido and Chimwadzulu ruby deposits in relation to Proterozoic granulite terrains within the Mozambique mobile belt.*

Figure 2: Uncut rubies from Chimwadzulu mounted on double-sided sellotape ready for introduction into the ablation chamber of the Laser ICP-MS system.

The Chimwadzulu rubies, recently described by Rankin (2002), have been worked from surface eluvial deposits associated with a weathered and metamorphosed (amphibolitic) ultramafic body within a metasedimentary sequence of gneisses and schists. The Longido rubies occur within a chrome-green zoisite-amphibole rock (Game, 1954), locally referred to as 'anyolite'. The anyolite forms a zone about 1 m wide and some 500 m long within a weathered ultrabasic rock intruded into a sequence of metamorphic rocks, including marbles (Hughes, 1997).

Samples of gem rubies were collected *in situ* from mine workings. The selected rubies were deep to fresh-blood-red in colour, up to 1.5 cm in size and with variable, but usually tabular, shapes. Individual crystals, containing areas as free as possible from visible mineral inclusions, were chosen for study (*Figure 2*). Most analyses were carried out on natural crystal faces and cleavage planes, while others were carried out on lapped and polished surfaces. Prior to analysis the samples were washed in de-ionized water, buffed dry and then cleaned with acetone. Some Longido rubies contain rounded blebs of Fe-sulphide on the surface, and particular care had to be exercised in avoiding these areas during analysis.

Analytical methods

Batches of up to 15 samples at a time were placed inside a specially constructed laser ablation chamber mounted on an optical light microscope with a camera attachment. A CETAC™ Nd: YAG UV laser operating at

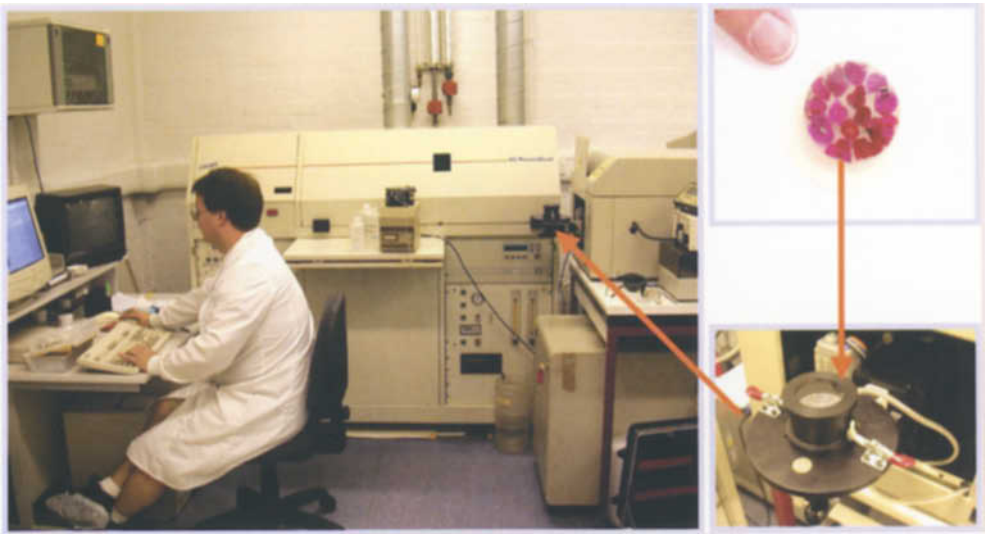

Figure 3: General view of the NERC Laser-ICP-MS system showing close-up views of the ablation chamber and a batch of Longido rubies prior to analysis.

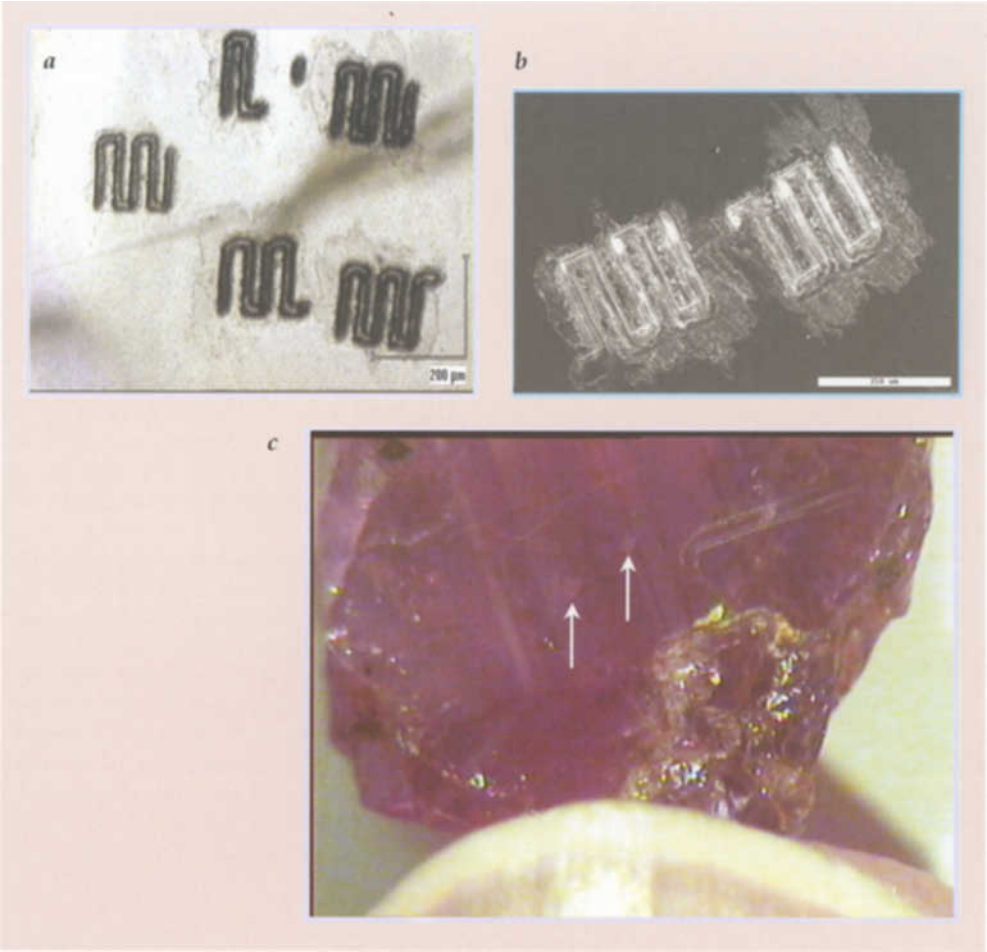

***Figure 4**: Laser ablation tracks on the surfaces of rubies (a) in transmitted light showing the traverse lines of the lasers and surrounding patchy damage caused from right to left by low, medium and high laser energies and (b) under a scanning electron microscope showing surrounding sputter zones produced under normal operating conditions (80% laser power); (c) at approximately ×10 magnification showing the barely visible tracks (arrowed). Note thumbnail for scale.*

266 nm, and with an output power of 2 mJ, was focused through the microscope onto the surface of the sample. The power was adjusted both to optimize elemental response and to avoid excessive spallation and damage to the sample. Ablated material was transferred into the inlet system of a Thermo Elemental Plasma Quad™ ICP-MS instrument, via a stream of argon carrier gas (*Figure 3*).

The ablation process was carried out along linear tracks some 10 μm wide and 10 μm deep over a distance of some 500 μm (*Figure 4*). Elemental data were acquired sequentially along the track over three, 30-second intervals, and the data reported here for each element represent the mean of these three runs. Duplicate sets of data were collected from two separate areas of each crystal. Altogether, duplicate analyses were obtained from different areas within 10 Chimwadzulu and 14 Longido ruby crystals.

Table I: Detection limits (3 x standard deviation) in µg/g (ppm) for selected elements analysed by Laser ICP-MS in three batch runs.

Element	Batch 1	Batch 2	Batch 3
Ni	401	147	369
Ca	269	269	81
Ti	58	46	49
Fe	11	6.4	8.0
Cu	3.0	12.7	5.2
Mn	3.3	2.8	0.8
Mg	1.8	3.2	2.5
Cr	1.4	1.2	1.1
V	1.4	0.4	0.4
Ga	0.7	0.6	0.7
Zr	0.8	0.7	0.8
Y	0.3	0.4	0.8
Ce	0.04	0.14	0.11

Gas blanks were used to determine the detection limits for each element at regular intervals (*Table I*). Calibration was carried out using the internationally recognized NIST 610 glass standard based on an average Al_2O_3 content of 98.1% for the host rubies, as determined by EMPA. Further details of the L-ICP-MS method and procedures are provided by Jarvis and Williams (1993) and Mason *et al.* (1999).

Results

The data are summarized in *Table II*. The elements Mg, V, Cr, Fe, Ga and Cu are usually present in concentrations significantly above background in samples from both localities. Ca and Mn are above background levels in only a few samples. Ce has only been detected in one sample from each locality, but Ti, Zr, Ni and Y are characteristically below their detection limits.

In general, the duplicate analyses for Mg, V, Cr, Fe, Ga and Cu on different areas of the same crystal (*Figure 5*) are in good agreement and plot close together, except for Mg which shows a much greater variability compared to other elements (*Figure 5*). For clarity, error bars, estimated from the standard deviation of the mean of three analyses of scanned areas for each sample, are omitted from these plots. However, the errors are generally better than 50% RSD except for Mg which are

Table II: Summary of Laser ICP-MS trace element data for Chimwadzulu and Longido ruby samples (wt.%) compared with some ranges reported in Hughes (1997)

Element	Chimwadzulu (n=20)	Longido (n=20)	Other data (PIXE) (Hughes 1997, p. 50)
Fe	0.350-1.099	0.024-0.439	0.049-0.545
Cr	0.084-0.204	0.153-2.530[b]	0.148-0.870
Ga	0.002-0.004	0.003-0.014	
V	<.001-0.003	0.004-0.055	0.002-0.046
Cu	<.002-0.008	<.001-0.013	
Mg	<.001-0.071	0.001-0.049	
Ca	<.08-0.81[a]	<0.03-0.40	0.013-0.069

Values with a < sign are below the detection limit (see Table I)
Notes: (a) One data point at 1.03% rejected because duplicate was below detection (<.08%)
(b) Except for three values at 2.27, 2.43 and 2.53 wt.%, the maximum value is 0.721 wt.%

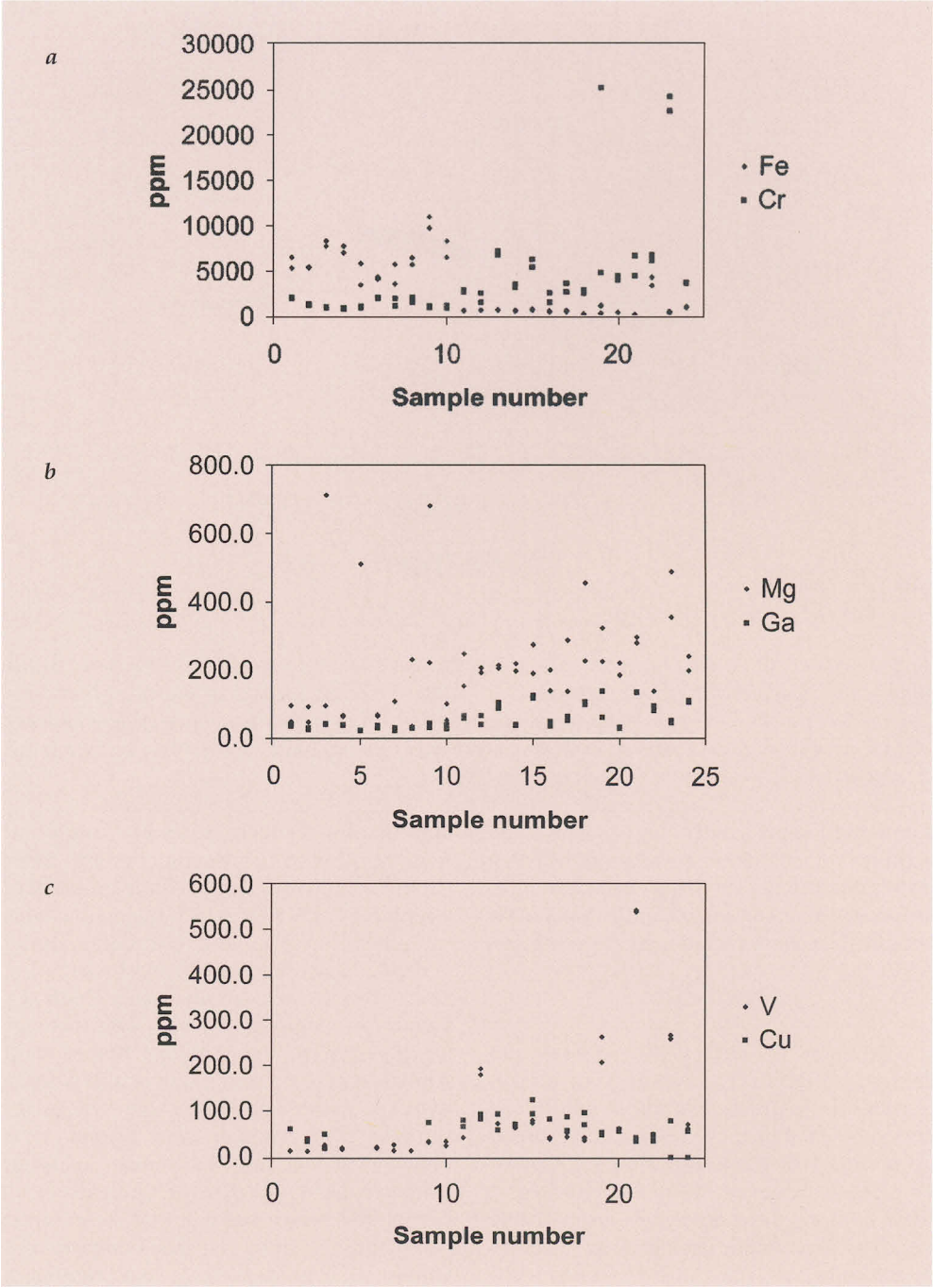

***Figure 5**: Duplicate analyses of (a) Fe, Cr; (b) Mg, Ga; (c) V and Cu in different areas of 24 rubies from Chimwadzulu (samples 1-10) and Longido (samples 11-24). The paired data illustrate 'within' and 'between' sample variability. In many cases (notable Cr, Fe and Ga) within sample variability is low (sometimes indistinguishable). In others (e.g. most Mg results; Cr data for sample 19) it is significant.*

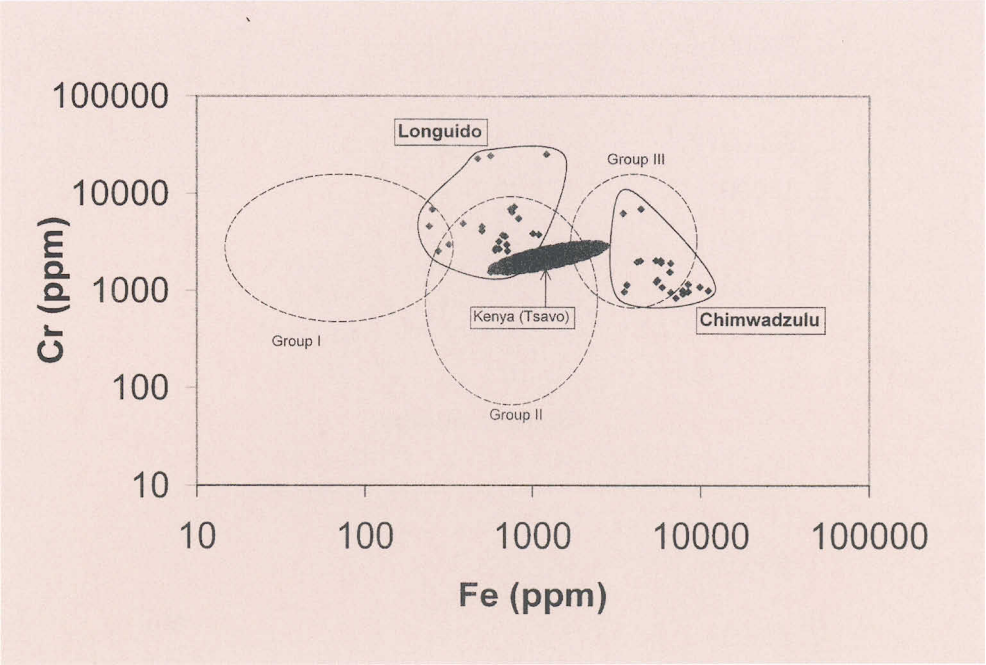

***Figure 6**: Plot of Cr vs. Fe contents in ppm for Longido and Chimwadzulu rubies superimposed on the three main groupings defined by Calligaro et al. (1999) based on analyses of 64 rubies from nine geographical regions. Data from Tsavo, Kenya (the only East African samples analysed by these authors) plot within a separate field between those for Longido and Chimwadzulu; together they define a broad E. African trend straddling the recognized groupings.*

sometimes significantly higher and may account for the poor correlation between duplicate analyses for this element. No plots are presented or considered for Ca, Mn and Ce because data above background are too sparse.

Discussion

Calligaro *et al.* (1999) carried out comprehensive PIXE analyses on a number of rubies from different localities worldwide and showed that they defined three broad groupings (I, II and III) on a simple Cr versus Fe plot, as shown in *Figure 6*. According to these authors, these groupings are probably linked to three main geological occurrences or environments. The L-ICP-MS data for the Longido and Chimwadzulu samples show clear separation on this plot. This is somewhat surprising in view of their similar geological occurrence in association with amphibolites which probably represent metamorphosed ultramafic bodies. Most Chimwadzulu samples lie within group III of Calligaro *et al.* (1999), which mainly includes samples from Thailand/Cambodia, India and Madagascar. Most Longido samples, apart from three anomalously high Cr values, lie in group II which also includes samples from Sri Lanka, Kenya and Afghanistan. However, there is also a small overlap with group I which comprises samples from Vietnam and Burma. It is noteworthy that the five Kenyan analyses, extracted from the data of Calligaro *et al.* (1999), and which occur in the same broad geotectonic setting as the Longido and Chimwadzulu deposits, also define a separate area. When considered together, all three data sets for Chimwadzulu, Longido and Tsavo appear to define a broad 'East African' grouping.

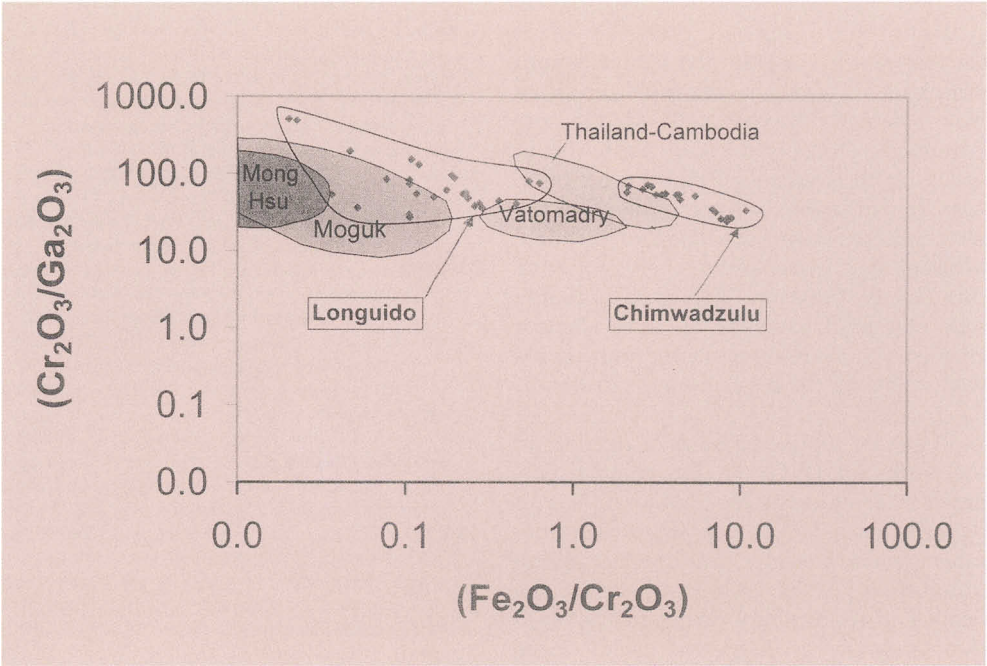

***Figure 7**: Plot of Cr/Ga vs. Fe/Cr ratios (wt% oxides) for Longido and Chimwadzulu samples in relation to fields for rubies from some other geographical localities as defined by Schwarz and Schmetzer (2001). There is clear separation of many Longido and Chimwadzulu samples, but some overlap with other areas. As with Kenyan samples in Figure 6, the Vatomandry (Madagascar) samples straddle these two main fields, reinforcing the concept of a broad E. African grouping related to the Mozambique mobile belt.*

Discriminant plots of Cr/Ga versus Fe/Cr ratios, based on XRF analyses of rubies from similar world occurrences, have also recently been presented by Schwarz and Schmetzer (2001). *Figure 7* shows the L-ICP-MS data for the Longido and Chimwadzulu rubies compared to the groupings indicated (op.cit) for rubies from these other localities. It can be seen that these plots are more effective at separating the Chimwadzulu from the Thai/Cambodian rubies, but that the overlap between Burmese and Longido samples is enhanced. Interestingly, the field for Madagascan (Vatomandry) samples, as with the Kenyan (Tsavo) samples, which also occur in the same broad, geotectonic setting, also straddles the data sets for Longido and Chimwadzulu samples, again defining a broad East African trend as previously suggested.

Conclusions

These initial studies have shown that L-ICP-MS is an appropriate and effective method for determining the trace element contents of natural gem rubies. Laser damage, though small, is still significant and care must be taken to avoid analyses on the upper surface of polished stones and to restrict analyses to less visible areas. For consistency and reproducibility care must be taken to avoid analysis of areas containing admixed solid phases.

A number of trace elements have been detected in the range normally expected for rubies from other worldwide localities. The elements Cr, Fe and Ga are present in levels consistently above background but their ranges are quite different to those reported in

synthetic rubies (Tang *et al.*, 1989). Plots of Cr, Ga and Fe for Longido and Chimwadzulu samples, in comparison with published data from Kenya (Tsavo) and Madagascar (Vatomandry), show a broad 'East African grouping'. It is suggested that this defines a broadly comparable geological (amphibolitic/ ultramafic?) environment within the Proterozoic Mozambique Metamorphic Belt, with the differences between deposits probably reflecting local variations in trace element chemistry of the host rocks and/or the fluids responsible for the crystallisation of ruby.

There are significant areas of overlap on the published Cr, Ga, Fe discriminant plots between samples of the four east African deposits considered here and those from other world localities. Additional criteria (notably types of inclusions) would be needed to confirm any distinction between these deposits as suggested by the trace element data. Conversely, the trace element signatures would be particularly helpful in distinguishing rubies from different east African localities where the inclusion assemblages are very similar. This is illustrated in *Figure 7*, with reference to Chimwadzulu and Vatomandry (Madagascar) rubies where the chemical fingerprints are quite distinct even though their inclusion characteristics, notably the presence of zircon clusters, are very similar (Schwarz and Schmetzer, 2001; Rankin, 2002).

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A Verneuil synthetic ruby showing diverse veil-like 'fingerprints'

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ABSTRACT: Although 'fingerprints' have been observed sporadically in synthetic Verneuil corundums, the novelty here consists of numerous veil-like 'fingerprints', some of which resemble those observed in Mong Hsu (Myanmar) rubies, while others proved similar to those frequently observed in sapphires from Myanmar or to those seen in flux grown synthetics (e.g. corundum and emerald). The gemmological properties and characteristics of this synthetic Verneuil ruby are described.

Introduction

Recently the author was asked to inspect a parcel of rubies for determination of origin, amongst which was a 2.60 ct oval-shaped red stone (*Figure 1*). With all the concern there is nowadays to recognize the treatments undergone by gemstones, one tends to overlook the danger of a synthetic stone finding its way into a parcel of natural stones. Such is the case of a flame fusion Verneuil synthetic ruby, displaying 'fingerprints', which was found in a parcel of natural rubies.

The measurements, weight and gemmological properties of this stone are described below.

Gemmological properties

The 2.60 ct oval-shaped red transparent gemstone (length 9.01 mm, width 7.28 mm, depth 4.60 mm) displayed a vitreous lustre.

The refractive index (RI) determinations were carried out using a Rayner Dialdex refractometer and monochromatic sodium light. The indices obtained from the table facet were $\omega = 1.773$, $\varepsilon = 1.765$, giving a birefringence of 0.008, with optic sign negative. A uniaxial interference figure indicating the *c*-axis was obtained using a glass sphere between crossed polars and proved to be inclined to the girdle plane at about 45°.

Figure 1: *Oval Verneuil synthetic ruby of 2.60 ct.*

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Figure 2: Curved growth lines readily visible through the table facet of the Verneuil ruby (dark field illumination 15×).

Figure 3: Numerous twisted wispy veil-like 'fingerprints' in the 2.60 ct Verneuil ruby, similar to those present in some Mong-Hsu (Myanmar) rubies (dark field illumination 30×).

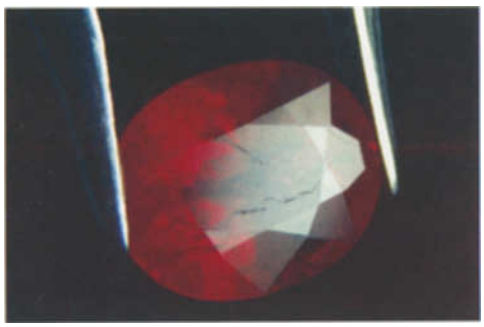

Figure 4: Several sinuous cracks breaking the surface of the 2.60 ct Verneuil ruby marking the positions of the 'fingerprints' (dark field illumination 10×).

Under a calcite dichroscope, with fibre optic illumination, a strong dichroism in pale yellowish-red to deep red was observed through the stone's table facet.

The absorption spectrum was observed in daylight conditions, through a Beck spectroscope, and revealed a spectrum typical of chromium: a fluorescent line in the red at 695 nm, a very strong broad absorption band from the yellow to the bluish-green at about 610 to 490 nm, with two fine sharp lines visible in the blue at 480 and 474 nm, and a very strong broad band from the blue to the violet at 460 to 400 nm.

The stone was examined with a Multispec combined LW/SW ultraviolet unit and fluoresced a strong brick red to SW and a less strong darker red to LW.

The specific gravity (SG) was obtained by hydrostatic weighing in distilled water using a Mettler PL 300C carat scale, and the stone was found to have a value of 4.00.

The stone was immersed in methylene iodide between crossed polars and observed along the optic axis direction to see if 'Plato striations' (Liddicoat, 1989) were present but none were found.

The inclusions were examined using a Bausch & Lomb Mark V Gemolite binocular microscope using dark field illumination or overhead lighting as appropriate.

The main features encountered in the 2.60 ct oval-shaped stone were:

- numerous and very apparent curved growth lines visible through the table facet (*Figure 2*);
- small groups or clouds of pinpoint gas bubbles trapped between curved growth lines, confined in two zones on one side of the crown, near the edge of the girdle;
- numerous twisted, wispy veil-like 'fingerprints', similar to those observed in Mong-Hsu (Myanmar) rubies (Peretti *et al.*, 1995), readily observed through the crown (*Figure 3*);

Figure 5: Some 'fingerprints' found with a glassy dark red substance (healing flux?), in the 2.60 ct Verneuil ruby (dark field illumination 35×).

Figure 6: A flat 'fingerprint' showing large net-like patterns, resembling the 'fingerprints' in some flux grown synthetics (dark field illumination 40×).

- several of these 'fingerprints' breaking the surface of the stone (*Figure 4*);
- some 'fingerprints' filled with a glassy dark red substance which is possibly flux healing reflecting red from the stone's saturated colour. (*Figure 5*);
- a flat surface 'fingerprint' showing large net-like patterns (*Figure 6*), reminiscent of the 'fingerprints' currently observed in flux grown synthetics (Gübelin and Koivula, 1986);
- a small flat surface 'fingerprint' displaying a formation of 'folds' (*Figure 7*) similar to those typical of Myanmar sapphires (Gübelin, 1974; Gübelin and Koivula, 1986);
- some parallel straight polishing lines meeting at an angle at a facet junction (*Figure 8*).

Figure 7: Verneuil ruby with a flat surface 'fingerprint' showing 'folds' similar to those in some sapphires from Myanmar (dark field illumination 50×).

Composition and spectroscopy

The composition was determined using a Philips PV 9500 EDXRF spectrometer with an X-ray tube voltage of 25 kV and a current of 200mA. In addition to the corundum's aluminium (Al), and the colouring agent (Cr), the only significant trace element recorded was iron (Fe).

Infrared absorption spectra (FT-IR) were obtained for this stone using a Nicolet Magna-IR ESP System 560 spectrometer. The IR spectrum is compared with those of two

Figure 8: Parallel straight polishing lines intersecting at a facet junction (dark field illumination 20×).

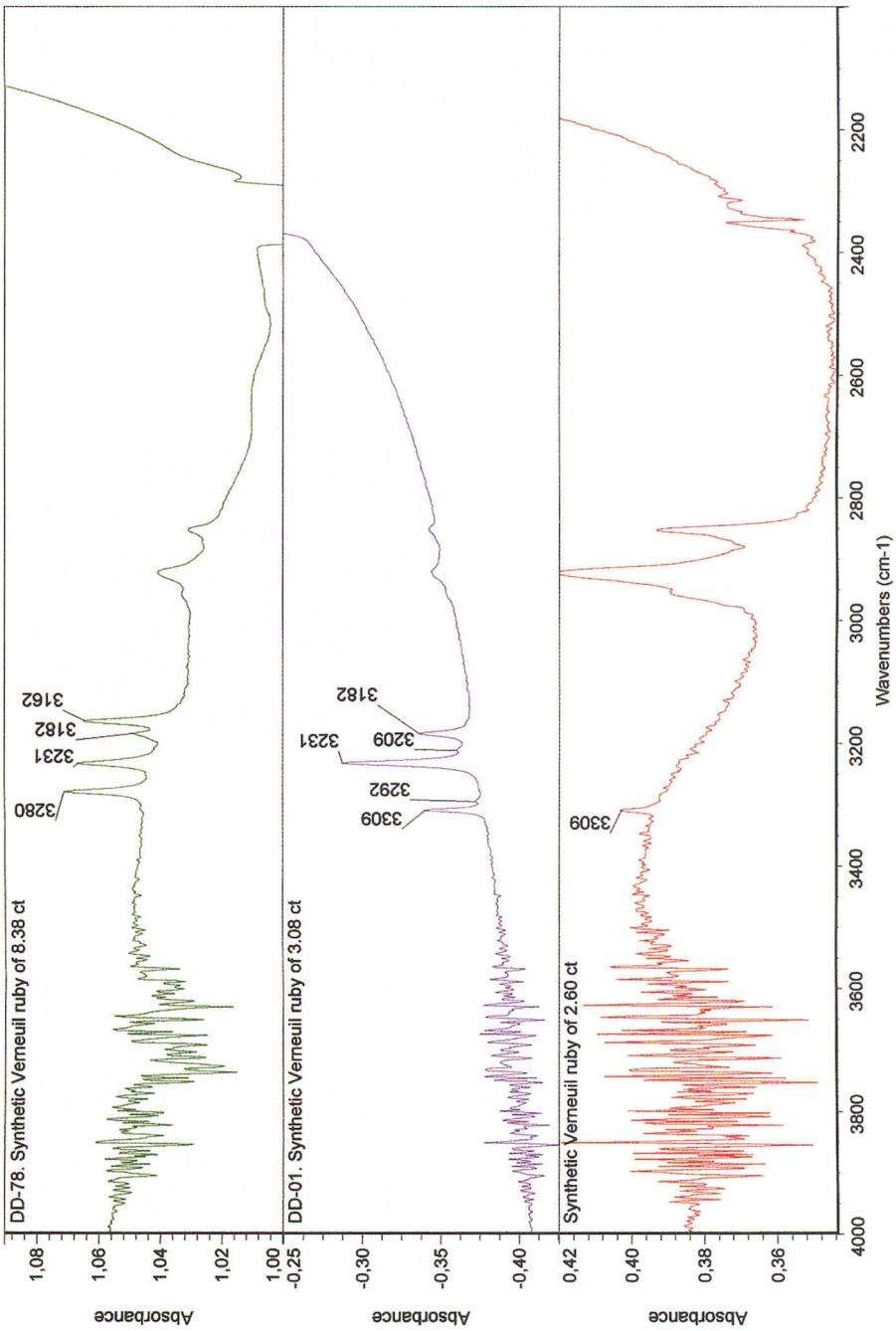

***Figure 9**: Infrared spectra of 2.60 ct Verneuil ruby with two other Verneuil ruby spectra for comparison.*

other Verneuil synthetic rubies in *Figure 9*. They all display two sets of absorption peaks. A first set is at ± 2850, ± 2921 and ± 2950 cm^{-1} (not indexed in *Figure 9*) and these are due to Blu-tack supporting the sample, to finger grease, or to residues of plastic or resin; therefore they are considered as an artefact (David and Fritsch, 2001). The second set generally comprises three peaks with one or several minute shoulders, or less often a single peak at 3309 cm^{-1}. The strongest is usually that at 3309 cm^{-1}; this peak is caused by an OH-dipole linked to a pair of atoms of iron and titanium inside the corundum lattice (David and Fritsch, 2001) . It must be said here that similar spectra may be displayed by basaltic rubies and sapphires; heat-treated non-basaltic rubies and sapphires may also show the 3309 cm^{-1} peak like the synthetic ruby described in this paper (Duroc-Danner, 2002). Although the presence of titanium (Ti) is indicated, its concentration is below the detection limit of the EDXRF equipment.

Discussion

If 'fingerprints' are not usually observed in Verneuil synthetics, it is nevertheless well-known that these can be induced by the process of 'quench-crackling' (Koivula, 1983; Schmetzer and Schupp, 1994). Since many of the 'fingerprints' seen in this stone break the surface, this clearly points towards such a treatment. The danger of the twisted veil-like 'fingerprints' observed in this Verneuil synthetic ruby lies in their similarity to those seen frequently in Mong-Hsu (Myanmar) rubies.

The flat surface 'fingerprint' showing large *net-like* patterns, similar to those encountered in flux-grown synthetics, and the small flat surface 'fingerprint' exhibiting a formation of 'folds' similar to those typical of Myanmar sapphires, shows how diverse 'fingerprints' can be, even in a single specimen, and why one should be careful not to jump too rapidly to a conclusion.

The induced 'fingerprints' that mask the otherwise too-apparent curved striae, and the polishing lines on the facet surface which visually interfere with the curved striae (*Figure 7*), could be created intentionally to fool a potential buyer. Viewing these with a 10× lens, and wrongly interpreting them as natural 'fingerprints' and angular growth zones would lead to a wrong conclusion.

To give a pink to red colour to the synthetic corundum, only 1 to 3 per cent of the chromium oxide (Cr_2O_3) are added to the alpha form of aluminium oxide (Al_2O_3) (in accordance with the intensity of the pink-to-red desired). Iron should be avoided, since even a small addition will produce a brownish ruby (Nassau, 1980), but small amounts can be present – possibly contamination from the blowpipe.

Conclusion

The physical and optical properties, and the curved striae and gas bubbles observed in the 2.60 ct oval-shaped ruby, are characteristic of synthetic Verneuil corundum, variety synthetic ruby.

The fact that the Plato lines were not detected is not surprising since these are not always visible (Elen and Fritsch, 1999). Heat treatment of flame-fusion synthetics can also make these Plato lines less apparent (Nassau, 1981) and it appears that this stone has undergone heat treatment and quench crackling to induce 'fingerprints' in the created cracks. Such inclusions and the curved growth lines are still more reliable indicators of the origin of a stone than the infrared spectra.

Acknowledgements

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A note on the directions of maximum double refraction divergence (DD) in uniaxial and biaxial stones

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ABSTRACT: A method of visualizing the significant directions related to DD in uniaxial and biaxial stones is presented. Explanations are specifically tailored for a non-mathematical understanding, although mathematical justifications are included.

1. Introduction

In a recent paper, Cartier (2002, p.225) summarized the factors relating birefringence (BI) and double refraction and commented on the directions of maximum double refraction divergence (DD) in crystals. Maximum DD is discussed in more detail in 2 below; this is followed by the relationships of angles in section 3, and construction and equations of the ellipse in section 4.

2. Directions of maximum DD in uniaxial and biaxial stones[1]

The angle of 45° has been offered as a reasonable approximation of the direction of maximum DD for the uniaxial case[2], although the actual angle depends on the proportions[3] of the ellipse[4] in the birefringent wave front. These proportions correspond to the ratio[5] of the extreme velocities of light or to the inverse of the ratio of the two refractive indices. When the ratio is larger, the angle differs more significantly from 45°, but as the ratio approaches unity (when the ellipse would become a circle) the angle to the wave-normal direction of maximum DD approaches 45°.

The variation from 45° will be in the direction that tilts the wave-tangent plane toward the major axis of the ellipse. This then tilts the wave-normal for the direction of maximum DD toward the minor axis, which is the vibration direction for the lowest RI (α). It is helpful to merge uniaxial and biaxial concepts and consider lowest RI as α and highest RI as γ with the uniaxial case being considered an extreme biaxial case with β, the RI of the optic axis, coinciding with either α or γ.

It is interesting to note that it is RI ratio, not BI, which controls the maximum DD. The RI ratio for any gemstone is generally only slightly greater than unity even for cases of extreme birefringence. For malachite and smithsonite the RI ratios are

1. Explanation of summary; Birefringence vs. double refraction divergence. Cartier, 2002. *Journal of Gemmology*, **28**(4), 225
2. Doubling of images in gemstones. Sturman and Back, 2002. *Journal of Gemmology*, **28**(4), 210-22
3. Ellipse formulae actually use the square of the ratio, but "depends on the proportions" is fair comment.
4. The author would like to thank Doug Mabee of Toronto for helpful guidance regarding the mathematics of the ellipse.
5. The larger number divided by the smaller number is presumed for ease of discussion. If the smaller number is divided buy the larger, the ratio would, of course be less than one and we would need to talk about departure from unity rather than size.

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1.1535 and 1.1406 respectively, but the more common extremely birefringent stone rhodochrosite (which at 1.816-1.597 has higher BI than the renowned calcite), would have the RI ratio of 1.1371 for faceted specimens. This ratio sets the direction of maximum DD at 48.7° from the major semiaxis of the ellipse, which direction is 3.7° toward the optic axis because of the negative optic sign. Other stones will be nearer to 45°.

The following visualizations of the significant directions for the uniaxial and the biaxial cases are offered, which many will find more easily understandable than mathematics formulae. The word 'direction' when unqualified in this explanation means 'wave-normal direction' which is the direction 90° to the wave front. The expression '~45°' is intended to mean 'the angle near 45° established by the ratio of the refractive indices as the wave-normal direction of maximum DD'.

The directions of maximum DD for the uniaxial case are in a ~45° cone around the optic axis. For the biaxial case, if you imagine a ~45° cone around each optic axis with the vertex of each cone at the intersection of the optic axes, the linear directions of maximum DD will be where the cones stand proudest from the optic plane. Clearly, the directions on each cone that lie in the optic plane will be of intermediate DD because they are nearer to the principal vibration direction (either α or γ) where DD is nil. The greater the 2V angle[6], the greater will be the difference in DD between the maximum in the directions along the cone in a plane perpendicular to the optic plane, and the minima in the directions along the cone within the optic plane. The smaller the 2V angle, the less will be the difference in DD between the maximum at the spot on the edge of the cone proudest from the optic plane and the minima within the optic plane. As the 2V angle approaches 90° (optically neutral) the DD minima in each cone approach nil. As the 2V angle approaches 0° the difference in DD between the minima and maxima in each cone reduces to nil and the medium approaches the appearance of being uniaxial.

For those with some facility for mathematics, general equations of the angular relationships can be expressed using standard RI symbols with differing lower case Greek letters used as symbols to represent the significant angles. By convention α (alpha) means the lowest RI, β (beta) means the RI of the optic axis, and γ (gamma) means the highest RI. We can use θ (theta) to represent the wave-normal angle to the major axis, ϕ (phi) to represent the DD angle (between the wave-normal and the ray), and ζ (zeta) to represent the ray angle to the major axis. The prefix '*tan*' means the numerical tangent of the subsequently named angle. Then, for any elliptical wave front of light, the following two equations show the relationship between the extreme RI values and those three angles: first $\theta = \phi+\zeta$ and then $((\gamma^2/\alpha^2)-1)\ tan\zeta) \ / \ ((\gamma^2/\ \alpha^2)tan^2\zeta+1) = tan\phi$. (A derivation of this equation is presented in Section 4.) One can use these equations with tangent values looked up in standard tables to run a series of calculations for various ray angles (ζ) from the ellipse's centre[7] (for any material with known refractive indices) to find the wave-normal angle (θ) that yields the highest DD. This angle θ is the angle ~45°.

3. Relationships of angles and dimensions

Imagine that a single-point light source inside the medium produces a momentary flash of light, somewhat like a pinpoint size photographic flash bulb. Using our imagination to stop time a little while after our pulse of light is produced, we can picture the shape of the wave front at any particular

6. The 2V angle is the acute angle between the two optic axes.
7. It has been suggested in peer review of this article that the value of zeta that maximises DD can be directly calculated by application of a little calculus. Independent derivation of a suitable formula would be welcomed. The intention of the author of this article is to offer explanations accessible to a readership that may not be mathematically adept.

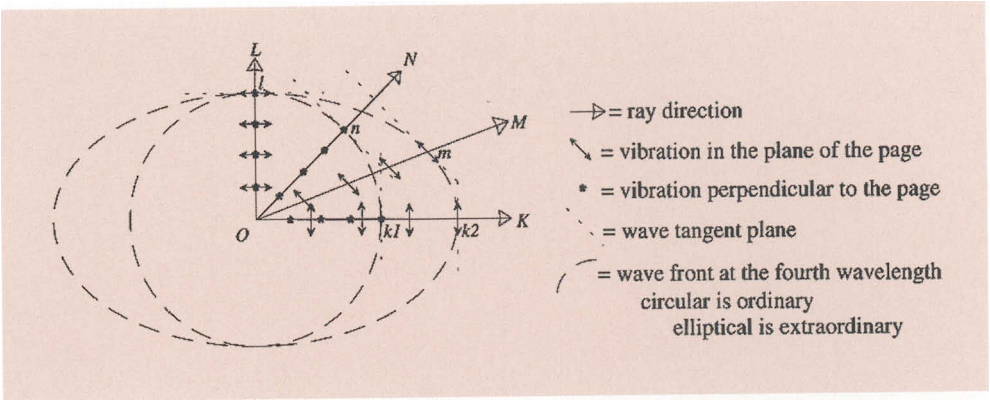

***Figure 1**: Uniaxial negative wave fronts, with optic axis top to bottom in the plane of this page*

moment as it progresses through the medium. The three-dimensional shape of the progressing wave front(s) is called the ray velocity surface in optics jargon. *Figure 1* depicts a centre section through unixial negative wave fronts. The wave front section for all ordinary rays is circular and the wave front section for all extraordinary rays is elliptical.

The ray-velocity surface of a birefringent medium will have unequal dimensions that give cross-sections with various circular and elliptical shapes. The most pronounced ellipse is in the optic plane, which is that centre section through the ray-velocity surface that contains both the fastest and the slowest rays for all possible ray directions through the medium.

To calculate the divergence of the extraordinary ray, we must consider the relationships to the elliptical wave front. *Figure 2* shows the relationships between the angles and dimensions used in the equations cited in section 2 above.

The first equation, $\theta = \phi + \zeta$, shows the simple geometric relationship between the three angles. This relationship is based on the fundamental geometric principle that the sum of the three interior angles of a plane triangle must always equal 180°, and the sum of the two different angles formed by the intersection of two straight lines must also always equal 180°.

The second equation, $((\gamma^2/\alpha^2)-1)\tan\zeta) \,/\, ((\gamma^2/\alpha^2)\ \tan^2\zeta+1) = \tan\phi$ incorporating the square of the RI ratio, arises from

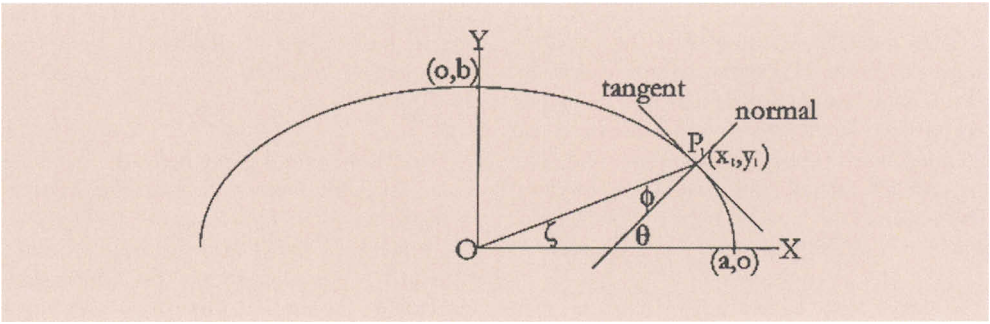

***Figure 2**: Positions of ϕ, θ and ζ in the ellipse.*

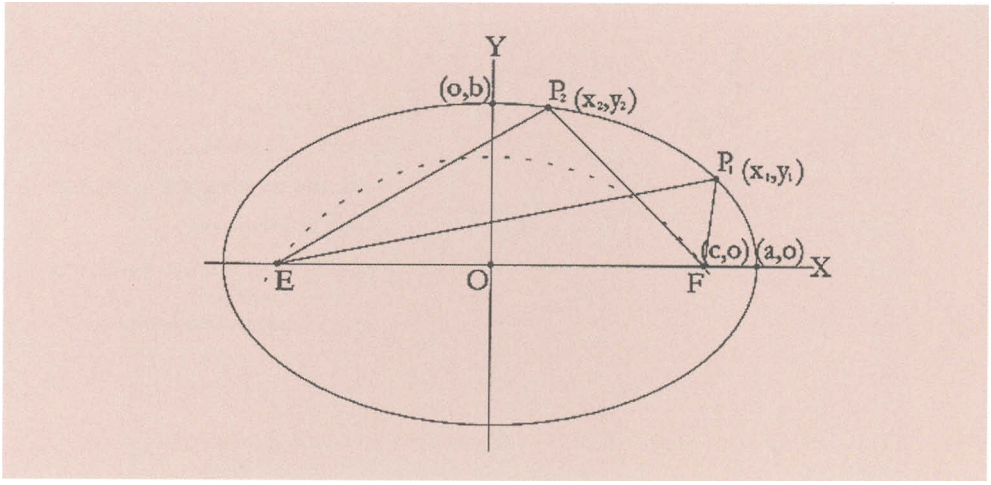

***Figure 3**: Foci and coordinates of the ellipse.*

substitution of γ for the major semiaxis 'a' together with the substitution of α for the minor semiaxis 'b' in the equation $((a^2/b^2)-1)\tan\zeta)/((a^2/b^2)\tan^2\zeta+1) = \tan\phi$ derived from the standard general equation for an ellipse (for derivation see section 4).

Given the understanding that velocity of light is the reciprocal of the refractive index, it is easy to understand that the length and width of the ellipse can represent the distances the rays travelled, can represent the velocities of the extreme rays (because the time component of velocity is identical for all rays), or can represent the highest RI and the lowest RI because the ratio of $a/b = 1/(\alpha/\gamma) = \gamma/\alpha$.

With a calcite example (RI 1.486-1.658) ... if we are going to imagine stopping time to observe the size and dimensions of the wave fronts, we can decide to measure in millimetres and choose to stop time when the distance the fastest light travels is 1.658 mm. The distance the slowest light travels is then (1.658 mm multiplied by α/γ) = 1.486 mm.

Clearly, the RI values γ and α can legitimately replace 'a' and 'b' in an equation of the ellipse.

4. Construction and equations of the ellipse

An ellipse is an out-of-round shape with special characteristics (*Figure 3*). The line across the greatest dimension of an ellipse is called the major axis and the line across the least dimension is called the minor axis. The major and minor axes intersect at the centre, which is called the origin, usually labelled O. A semiaxis is from the origin to one end of the axis.

The dimension of the major semiaxis is 'a' and the dimension of the minor semiaxis is 'b'. An arc centred at the end of a minor semiaxis with radius a will intersect the major axis at distance c each side of the origin. Each point at distance c along the major axis (E and F in *Figure 3*) is a focus of the ellipse.

For every point on an ellipse, the distance from that point to one focus plus the distance to the other focus is a constant. In *Figure 3*, $EP_1 + P_1F = EP_2 + P_2F$ and this holds for any arbitrarily chosen point on the ellipse. The bisector of the angle formed by those lines from the foci to the point on the ellipse is normal to the ellipse.

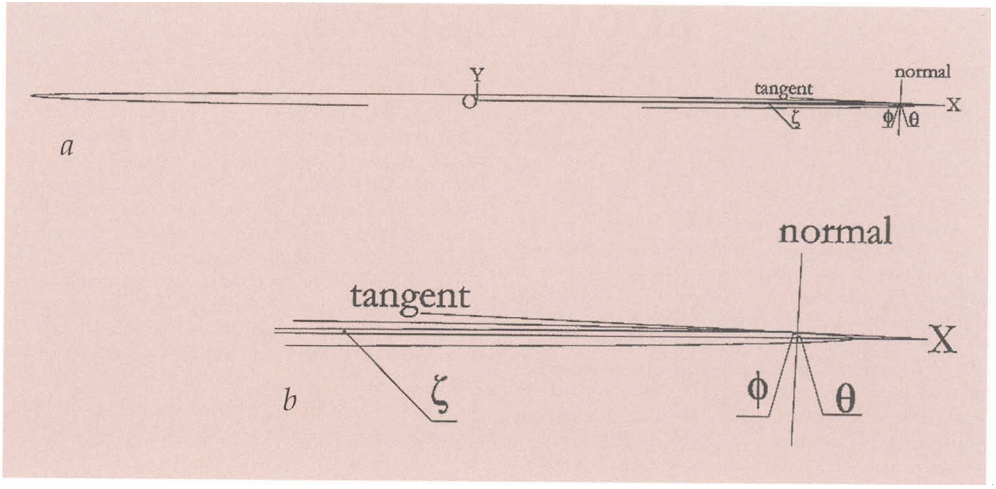

***Figure 4**: (a) Ellipse with extreme length to width ratio. (b) Detail of Figure 4a.*

Points in the plane of the ellipse can be precisely located in a grid coordinate system with distance along the major axis being the X direction and distance along the minor axis being the Y direction. In *Figure 2* and *Figure 3* any X coordinate to the right of the origin O is positive while to the left is negative. Any Y coordinate above O is positive while those below are negative. For an ellipse a>b; a, b, and the (x, y) coordinates conform to the basic equation of the ellipse:

$$b^2x^2+a^2y^2 = a^2b^2 \quad [1]$$

The slope of the normal at P_1 (the bisector of angle E-P_1-F) is ...

$$(a^2y_1)/(b^2x_1) = \tan\theta \quad [2]$$

$$\text{From } [2] \rightarrow (a^2/b^2)(y_1/x_1) = \tan\theta \quad [3]$$

As was pointed out earlier ... $\theta = \phi+\zeta$ [4]

$$\text{From } [4] \rightarrow \tan\theta = \tan(\phi+\zeta) \quad [5]$$

Conforming to the definition of a tangent...

$$\tan\zeta = y_1/x_1 \quad [6]$$

$$\text{From } [3, 5] \rightarrow (a^2/b^2)\tan\zeta = \tan(\phi+\zeta) \quad [7]$$

$$[7] \rightarrow (a^2/b^2)\tan\zeta = (\tan\phi + \tan\zeta) / (1 - \tan\phi\tan\zeta) \quad [8]$$

$$[8] \rightarrow (a^2/b^2-1)\tan\zeta = (a^2\tan^2\zeta+b^2)\tan\phi \quad [9]$$

In section 3 it was concluded that RI values can appropriately replace semiaxis dimensions, so replacing a and b with γ and α in [9] $\rightarrow ((\gamma^2/\alpha^2)-1)\tan\zeta) / ((\gamma^2/\alpha^2)\tan^2\zeta+1) = \tan\phi$ [10]

This series of combinations and transformations of equations gives the final equation suggested previously in section 2 for testing ray angles (ζ) to find the one that yields the maximum $\tan\phi$. From standard tables, $\tan\phi$ can be looked up to get ϕ. Then ζ and ϕ will add together to give θ, the wave-normal direction for maximum DD. Alternatively, the angle ζ that yielded maximum $\tan\phi$ can be used to calculate $\tan\theta$ by the formula $(\gamma^2/\alpha^2)\tan\zeta = \tan\theta$ [11], then $\tan\theta$ used to look up θ.

In an ellipse with an extreme length to width ratio, angle ϕ can approach 90° (*Figure 4*). Elliptical wave fronts in birefringent media, however, usually have an a/b ratio less than 1.14 so angle $\theta_{max\phi}$ is never more than a few degrees away from 45° to the major axis of the ellipse.

Gems and gem industry in India.

R.V. KARANTH, 2000. Geological Society of India: Memoir 45, Bangalore, xii 405 pp. ISBN 81-85867-41-0. Price on application.

India has a strong tradition of gem cutting, with the total value of exports of gemstones and jewels amounting to nearly 20% of the country's total exports, much of it consisting of imported raw diamonds cut and set in jewellery, and employing some 500,000 people. Written for the Indian market, this book provides an introduction to the chemical, physical and optical properties of the hundred or so species of minerals used as gemstones, with particular reference to Indian gemstones. Details are also provided of inclusions and other internal features, synthetic stones and gem cutting, before descriptions of the principle gem materials, grouped into isotropic, uniaxial and biaxial gems. There is an inset of colour plates and a geographical index detailing the latitude and longitude of localities, and in addition to subject and author indexes there is a geographical index listing the latitude and longitude of localities mentioned. R.A.H.

Gem identification made easy.

A. MATLINS AND A.C. BONANNO, 2003. Third edn. Woodstock, VT, USA. pp xxii, 330. Illus. in black-and-white and in colour. Hardcover ISBN 0 943763 34 7. £28.90.

Since the first edition of this useful guide aimed specifically at the jeweller and dealer was published in 1978 with a second edition some years afterwards, a number of important developments have had to be added to a cheerful, homespun text which is easy to follow. HT/HP diamonds, new diffusion techniques for treating near-colourless sapphires are some of the new additions.

While the text is very readable it may sometimes be hard to find some items in the index which for some reason I found difficult to work with because of its layout and the typeface used. Some of the books recommended for further reading would be hard to obtain now and there are much better ones around. I found a number of statements which need further investigation (the account of the operation of the diamond wand, for example) and I couldn't track down in the text what is new about 'chromium-type emeralds' from North Carolina [I described them in the 1970s] which are mentioned in the preface.

None the less this is a keenly priced and useful book, though it needs to be read with caution. M.O'D.

A student's guide to spectroscopy.

C.H. WINTER, 2003. Leatherhead: OPL Press, Leatherhead, Surrey. pp 85. Illus. in colour. Softcover ISBN 0 9544853 0 0. £9.99

Attractively produced, accurate and very reasonably priced guide to the use of the direct vision spectroscope in the testing of gemstones. After some remarks on the construction of the OPL [Orwin Products Ltd] hand spectroscope and on the nature of absorption spectra in the visible region, the book's main section describes the spectra of the gem species which can be tested by using the spectroscope.

Most examples are illustrated in colour and the reproduction is easily the best that I have seen so far – idealized representations in earlier textbooks do not always help students as they expect to see a clearer effect than is usually possible. This book is more reasonable in this area and the accompanying remarks will help in the resolution of difficult cases. M.O'D.

BOOK SHELF — NEW TITLES

Gem identification made easy by Antoinette Matlins and A.C. Bonanno £28.90

A student's guide to spectroscopy by C.H. Winter £9.99

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Proceedings of the Gemmological Association and Gem Testing Laboratory of Great Britain and Notices

E. Alan Jobbins

We send our congratulations to E. Alan Jobbins in celebration of his forthcoming 80th birthday.

Alan is an Honorary Life Member of Gem-A, and was for many years Editor of *The Journal of Gemmology* and Chairman of the Board of Examiners.

Alan Jobbins has made a major contribution to gemmology during his career and we acknowledge his continuing involvement in the world of gemstones.

GEM DIAMOND EXAMINATION

In the Gem Diamond Examination held in June 2003, 133 candidates sat of whom 75 qualified, including seven with Distinction and nine with Merit.

The **Deeks Diamond Prize** for the best candidate of the year in the Gem Diamond Examinations has been awarded to Lu Lili of Wuhan, Hubei, P.R. China.

The **Bruton Medal** was not awarded.

The names of the successful candidates are listed below:

Qualified with Distinction

Lu Lili, Wuhan, Hubei, P.R. China
McKenzie, Wilma A., South Surrey, British Columbia, Canada
Pennington, Susan E., Bickerstaffe, Lancashire
Rafter, Jacinta, Kensington, London
Wells, Miranda E.J., Hartlebury, Worcestershire
Whitehouse, Keith P., Marston, Stafford
Winter, Nikki, Chiswick, London

Qualified with Merit

Brown, Mary Josephine, Bangkok, Thailand
Dash, Sandra Y., London
Huang Jin, Wuhan, Hubei, P.R. China
Lam, Victoria L., Carnforth, Lancashire
Nessi, Veroniki, Athens, Greece
O'Leary Al-Khayaali, Dominique, London
Phillips, Paul, Bulkington, Warwickshire
Xu Sha, Beijing, P.R. China
Zhang Ao, Beijing, P.R. China

Qualified

Allsopp, Christopher J., St Saviour's, Guernsey, Channel Islands
Appadoure, Basile, London
Aubert, Rebecca, Islington, London
Chan So-Ha, Anna, Hong Kong
Choi, Daeshik, Incheon, S. Korea
Chu Hon Chung, New Territories, Hong Kong
Deligiannis, Marios, Athens, Greece
Douvis, George, Athens, Greece
Facey, Emma L., Shirley, West Midlands
Firmin, James H., Burley on the Hill, Rutland
Georma, Titika, Athens, Greece
Godfrey, Kay, Halstead, Essex
Hadley, John, Stratford-upon-Avon, Warwickshire
Haycock, Ian P., Sheldon, West Midlands
Hayward, Johnathon D., Oldbury, West Midlands
Hui Chau Ming, Kowloon, Hong Kong
Jiang Weiwei, Wuhan, Hubei, P.R. China
Kalischer, Janice, Finchley, London
Ke Jia, Beijing, P.R. China
Kelly, Christopher, High Wycombe, Buckinghamshire
Koraki, Christina, Athens, Greece
Lee Ka Yan, Audrey, New Territories, Hong Kong
Lee Lok Chi, Simon, New Territories, Hong Kong
Leung Ka Lok, Kowloon, Hong Kong
Leung Ka Yi, Kowloon, Hong Kong
Li Chen, Beijing, P.R. China
Li Heung Hung, Kowloon, Hong Kong
Liao Wei-Ching, Ping Tong, Taiwan, R.O. China
Manchanda, Anu Dippal, Smethwick, West Midlands
Marsh, Claire L., Wollaston, Stourbridge, West Midlands
Miller, Steve, Crawley, West Sussex

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Najda, Marina, London
Ng Pui Wa, Joe, New Territories, Hong Kong
O'Dwyer, Michael, Dun Laoghaire, Co. Dublin, Ireland
Randhawa, Sukhwant Singh, Hounslow, Middlesex
Riedel, Richard W., Lewes, East Sussex
Roussou, Zoi-Kiriaki, Athens, Greece
Rynhold, Emma N.C., London
Sanchez Sierra, Maria F., Tooting, London
Sarri, Santino, Brighton, East Sussex
Sheikh, Musa M., Norbury, London
Shi Lei, Beijing, P.R. China
Singh, Harjit, Bilston, West Midlands
Sipson, Ian, Trowbridge, Wiltshire
Somaiya, Kaushal Kirti, Finchley Central, London
Song Jie, Beijing, P.R. China
Spear, Paul M., Maidenhead, Berkshire
Suen Ka Kwan, Athena, Kowloon, Hong Kong
Townsend, Rachel E., Tamworth, Staffordshire
Tse Chui Yin, Angela, Causeway Bay, Hong Kong
Velliniati, Ekaterina, Athens, Greece
Watanabe, Tomoko, Mitsukaiudo-shi, Ibaraki, Japan
Wenwei Kong, Wuhan, Hubei, P.R. China
Williams, Adrienne V., Chesham, Buckinghamshire
Williams, Benjamin J., Moreton-in-Marsh, Gloucestershire
Yao Lin, Beijing, P.R. China
Yip Siu Ling, New Territories, Hong Kong
Yung Mou Cheung, Shau Kei Wan, Hong Kong
Zhang Runbei, Beijing, P.R. China

EXAMINATIONS IN GEMMOLOGY

In the Examinations in Gemmology held worldwide in June 2003, 265 candidates sat the Diploma Examination of whom 88 qualified, including two with Distinction and ten with Merit. In the Preliminary Examination, 189 candidates sat of whom 139 qualified.

The **Anderson Bank Prize** for the best non-trade candidate of the year in the Diploma Examination has been awarded to Jessica Banks of London.

The **Christie's Prize for Gemmology** for the best candidate of the year in the Diploma Examination who derives his main income from activities essentially connected with the jewellery trade has been awarded to Xie Jing of Shanghai, P.R. China.

The **Anderson Medal** for the best candidate of the year in the Preliminary Examination and the **Preliminary Trade Prize** for the best candidate of the year who derives her main income from activities essentially connected with the jewellery trade has been awarded to Antoinette Jackson of London.

The **Tully Medal** was not awarded.

The names of the successful candidates are listed below:

Diploma

Qualified with Distinction
Banks, Jessica, London
Jackson, Antoinette, London

Qualified with Merit
Conejero, Jennifer H., Boston, Lincolnshire
Domec, Cedric, Forest, Belgium
Firmin, James H., Burley on the Hill, Rutland
Inagaki, Yuko, Kawaguchi-shi, Saitama-Ken, Japan
Lee Tsung Han, Taipei, Taiwan, R.O. China
Phillips, Patrick E., Toronto, Ontario, Canada
Richmond, Sonia, London
Shikatani, Kohei, Yudogawaku, Osaka, Japan
Tuen Sai Hing, Shau Kei Wan, Hong Kong
Wong Ying, Shatin, Hong Kong

Qualified
Ahde, Petra M.E., Helsinki, Finland
Balabhadra, Naga V.R.S., Hyderabad, India
Breuer, Lisa, London
Chen Xiumei, Wuhan, Hubei, P.R. China
Cherchi, Sonia, Zurich, Switzerland
Cheung Wing Man, Cynthia, New Territories, Hong Kong
Ching Mei Kit, Jennifer, Kowloon, Hong Kong
Cho Young Mi, Nam-Gu, Incheon, Korea
Dash, Sandra Y., London
Deprez, Guillaume, London
Ecknauer, Marc, Stein, Switzerland
Eguchi, Yumi, Fukuoka City, Fukuoka Pref., Japan
Fisher, Abigail, London
Fitzgerald, John, Peoria, Illinois, U.S.A.
Fleuranceau, Annie M., Brossard, Quebec, Canada
Fujii, Eiko, Bunkyo, Tokyo, Japan
Guo Tianshun, Wuhan, Hubei, P.R. China
Hayashida, Shoko, Minato-ku, Tokyo, Japan
Henry-Stogdon, Sarah A., West Norwood, London
Hiraoka, Kenji, Suginami-ku, Tokyo, Japan
Holmes, Lissa, Balham, London
Hotson, Peter J., Berkhamsted, Hertfordshire
Huang Chi-Hua, Taipei, Taiwan, R.O. China
Kuo Chi-Cheng, Taipei, Taiwan, R.O. China
Lau Chun Kit, Shatin, New Territories, Hong Kong
Lau Siu Ying, Emily, Hong Kong
Lee Hsiang Ju, Taichung, Taiwan, R.O. China
Lee Young Ji, Ealing, London
Leung Suk Kay, Hong Kong

Li Cheung, Alex, New Territories, Hong Kong
Li Dandan, Wuhan, Hubei, P.R. China
Li Hui, Guilin Guangxi, P.R. China
Liang Liang, Shanghai, P.R. China
Liang Yuhui, Wuhan, Hubei, P.R. China
McCrabbe, Julie A., Hackney North, London
McMillan, Emma L., Leamington Spa, Warwickshire
Mathiesen, Lisbeth S.G., Virum, Denmark
Mathur, Chetna, Indore, India
Milton, Paul R., Liverpool, Merseyside
Mo Bixun, Shanghai, P.R. China
Mo Yu, Guilin, Guangxi, P.R. China
Munawar Mirza, Sohail, Angered, Sweden
Nilsson, Annica H., Uppsala, Sweden
Pang Bowen, Guilin, Guangxi, P.R. China
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Pearson, Isabel J., Tilehurst, Berkshire
Phillips, Gregory J., Toronto, Ontario, Canada
Phyu Thin Khine, Yangon, Myanmar
Plantagenet, Ian, Heaton, Bradford, West Yorkshire
Pui Pui Tsoi, Karen, Kowloon, Hong Kong
Pumphrey, Jessica K., London
Ren Yuan, Guilin, Guangxi, P.R. China
Rutter, Fay, Walsall, West Midlands
Sai Kyaw Kyaw Win, Yangon, Myanmar
Sanchez Sierra, Maria, Tooting, London
Schwabe, Arnold R., Burnaby, British Columbia, Canada
Shang Wenjing, Shanghai, P.R. China
Shaw, Sinead, London
Smith, Anna, Pinner, Middlesex
Sykes-Gomez, Heidi M., Cornelius, North Carolina, U.S.A.
Taylor, Louise, Gresford, Clwyd
Thornhill, Helen V., Greenhill, South Yorkshire
Tsuor Wai Hing, Shatin, Hong Kong
Velez Melendez, Ana Maria, Bogota, Colombia
Wang Chenchun, Shanghai, P.R. China
Wang Duo, Guilin, Guangxi, P.R. China
Wang Liang, Guilin, Guangxi, P.R. China
Watanabe, Tomoko, Mitsukaido-shi, Ibaraki, Japan
Wei Wei, Guilin, Guangxi, P.R. China
Wenham, Diana L., North Harrow, Middlesex
Westling, Jonny, Stockholm, Sweden
Wijetunga, Lettietia C., Colombo, Sri Lanka
Williams, Cara M., Jefferson City, Missouri, U.S.A.
Xu Wenxing, Wuhan, Hubei, P.R. China
Yang Yang, Guilin, Guangxi, P.R. China
Ye Dong, Wuhan, Hubei, P.R. China

Preliminary

Qualified
Ahlgren, Anne M., Espoo, Finland
Anderson, Judith S., Manchester, New Hampshire, U.S.A.

GIFTS TO THE ASSOCIATION

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Christine Woodward FGA DGA, London for a selection of dyed beads.

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Forbert, Maile M., Vallejo, California, U.S.A.
Gadd, Craig A., Horfield, Bristol, Avon
Gaskin, Clare K., Wimbledon, London
Gemmill, Tanya C., Hampstead, London

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The Council of Management are most grateful to the following for responding to the appeal for donations to enable the Association to extend our membership and education services. Donation levels were Diamond (£1000 and above), Ruby (£500 to £999), Emerald (£250 to £499), Sapphire £100 to £249) and Pearl (£25 to £99). All donors will be recognized at a Gala Dinner to be held in London early next year.

The following join those donors listed in previous issues of *The Journal:*

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Manfred Szykora, Munich, Germany

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Miao Fu-Chiang, Taipei, Taiwan, R.O. China
Michalcova, Silvia, Finchley, London
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Pereira, Anisha, Mumbai, India
Piacenza, Maria R., Croydon, Surrey
Po Hok Yee, Dorothy, Kowloon, Hong Kong
Promies, Marina C.S., Montreal, Quebec, Canada
Pumpang, Sureeporn, Nakoonpathom, Thailand
Scott, John R.J., Vancouver, British Columbia, Canada
Scragg, Claire P., Great Missenden, Buckinghamshire
Shetakis, Avgerinos, Voula, Greece

Singh, Gurmit, New Delhi, India
Skiadopoulos, Marios A., Thessaloniki, Greece
St John Lewis, Delyth, Palmers Green, London
Stanyer, Natasha L., Lewes, East Sussex
Storro, Klara, Ranheim, Norway
Strinati, Maria, A., Kingston-upon-Thames, London
Stumpf, Harry, Oakmont, Pennsylvania, U.S.A.
Su Min Hui, Taipei, Taiwan, R.O. China
Tammilehto, Eero J., Helsinki, Finland
Tchakerian, Silva, Montreal, Quebec, Canada
Tenhunen, Henriikka, Helsinki, Finland
Tooth, Helen J., Keresley, West Midlands
Trevanion, Christina H.J., Shrewsbury, Shropshire
Turku, Jenni J., Helsinki, Finland
Velez Melendez, Ana Maria, Bogota, Colombia
Wai Yee Tak, Elise, New Territories, Hong Kong
Wells, Miranda E.J., Hartlebury, Worcestershire
Welton-Cook, Elsa M., West Kensington, London
Werattarakul, Tanawut, Bangkok, Thailand
Westwood, Lauren, Godalming, Surrey
Williams, Benjamin J., Moreton-in-Marsh, Gloucestershire
Wold, William, Joure, The Netherlands
Wong Chung Yan, Kowloon, Hong Kong
Wong Hing Yee, New Territories, Hong Kong
Wu Pei Hua, Taipei, Taiwan, R.O. China
Xu Ping, Shanghai, P.R. China
Yu Po Ching, Shanghai, P.R. China
Yung Suk Hing, Tung Chung, Hong Kong
Zhu Jia, Shanghai, P.R. China

MEMBERS' MEETINGS

London

On 9 September 2003 at 27 Greville Street, London EC1N 8TN the Annual General Meeting was held, a report of which will be published in the January 2004 issue of *The Journal*. The AGM was followed by an illustrated talk by David Callaghan entitled 'Jewellery of the Art Nouveau period'.

Midlands Branch

On 26 September at The Earth Sciences Building, University of Birmingham, Edgbaston, PC Terry Lewis of the West Mercia Constabulary gave a talk on 'Crime prevention in the jewellery industry'.

North East Branch

The inaugural meeting of the North East Branch was held on 10 October at Gem-Ro Associates, Millshaw, Leeds. Neil Rose, Jane Howe and Helen Prior-Chappell were elected Chairman, Secretary and Treasurer respectively.

The evening began with a wine and buffet reception followed by a talk by John Benjamin entitled 'Jewellery from Elizabeth I to Elizabeth Taylor'.

The evening was generously sponsored by Tracy Jukes of e-jewel Ltd.

North West Branch

On 17 September at Church House, Hanover Street, Liverpool 1, Brian Jackson gave a talk entitled 'Scottish minerals'.

Scottish Branch

On 24 August members of the Branch gathered at Tyndrum where gold panning expert Bob Sutherland demonstrated panning techniques.

On 11 September at the British Geological Survey, Murchison House, West Mains Road, Edinburgh, Alan Jobbins gave a lecture entitled 'Organics in ornamentation'.

South East Branch

On 27 July at the County Club, Guildford, Alan Jobbins gave an illustrated talk entitled 'Fifty years of gemmology'.

On 7 September at Christie's South Kensington Colin Winter presented a 'Spectroscope workshop'. This included an illustrated talk, a practical demonstration and a quiz.

South West Branch

On 17 September at the Bath Royal Literary and Scientific Institution, Bath, Stephen Kennedy gave a talk entitled 'Insider Trading'.

ANNUAL REPORT

The following is the Report of the Council of Management of the Gemmological Association and Gem Testing Laboratory of Great Britain for year ending 31 March 2003.

Officers, councils and committees

Gem-A The Gemmological Association and Gem Testing Laboratory of Great Britain is a company limited by guarantee and is governed by a Council of Management. In August 2002 Council member and acting Chief Executive Officer T.M.J. Davidson accepted the full-time position of CEO.

Professor A.T. Collins was re-elected President of the Association. Vice Presidents N.W. Deeks, A.E. Farn, R.A. Howie, D.G. Kent and R.K. Mitchell continued in office. Council member

Name	*Position*	*Activities*	*Advisory/Consultative Bodies*
Terry Davidson	CEO	Marketing and PR Office Services	
Ian Mercer	Director of Education	Courses Examinations	Board of Examiners Education Review Board
Stephen Kennedy	Director of Laboratory	Diamonds Coloured Stones Pearls Consultancy Editorial	Trade Liaison Committee
Mary Burland	Director of Commerce	Membership Events Publications	Members' Council Editorial Boards
Y J Thien	Director of Office Services	Accounts Personnel Premises Security	
Alan Clark	Director of Gemmological Instruments Ltd	Books Instruments	T.M.J. Davidson and R.R.Harding are also Directors of GIL

Dr R.R. Harding who at the age of 65 was due to retire in February 2003 has at the request of the CEO agreed to continue in the roles of Company Secretary and as Editor of *The Journal of Gemmology* and to remain on the editorial board of *Gem & Jewellery News*. C.M. Woodward and E. Stern continued as Chairman and Vice-Chairman respectively of the Board of Examiners. J Kessler and W. Roberts continued as Chairman and Vice-Chairman respectively of the Trade Liaison Committee. C. Winter and P. Dwyer-Hickey continued as Chairman and Vice-Chairman respectively of the Members' Council. P.G. Read resigned from the Members' Council and has been thanked for the support he has given Gem-A as a Council member. We are fortunate that Mr Read is to continue as a correspondence course tutor and as an assistant editor of *The Journal of Gemmology*.

Gem-A

The financial year 2002–2003 has been interesting and challenging. We had drawn up a strategic plan for the years 2002/3 – 2004/5. We have redefined the roles and responsibilities of the senior staff (see organigram above). There is now in place an open and informed system of management with regular monthly meetings with department directors and quarterly meetings with all staff members.

We applied for and were most grateful to receive a grant of £50,000 from the Worshipful Company of Goldsmiths which has enabled us to replenish and purchase equipment for use in education and by the laboratory.

Gem-A Board of Directors 2002/3

The body with legal responsibility for directing and managing the Association is the Council of Management. The Council has delegated day-to-day running of the company to the CEO and the Board of Directors (see organigram above) who remain responsible to the Council.

Education

The last year has again seen the gemmology and gem diamond courses fully subscribed, attracting students from many different disciplines and professions, and from many countries. A first in the history of Gem-A occurred in July when at the JA Show in New York Gem-A gemmology course scholarships, sponsored by EGL USA and

the *National Jeweller*, were awarded to five lucky winners selected from over 40 applications. A wide range of courses and tutorials are held at the Greville Street Gem Tutorial Centre, including bead stringing and jewellery sketching. Custom built tutorials have been held for firms in the jewellery trade such as de Beers, Christie's and SWAG with D.J. Garrod travelling to Norway and giving gemmology lectures on board a ship!

This report covers two examination sessions for a total of 831 students who sat the gemmology and gem diamond papers in June 2002 and January 2003. In gemmology the pass rate for the preliminary examination was 78%, slightly higher than the previous year; the diploma pass rate was 46%, the same as the previous year. For the gem diamond examination the pass rate was 54%. The Anderson Bank Prize was awarded to S. Hudson, Ealing, London. The Christie's Prize for Gemmology (Diploma Trade Prize) was awarded to N.L. Arachchige, Kandy, Sri Lanka. The Anderson Medal was awarded to N. Sehgal, New Delhi, India. The Preliminary Trade Prize was awarded to A. Verma of New Delhi, India. The Deeks Diamond Prize was awarded to J. Read, Goole, East Yorkshire. Neither the Tully nor the Bruton Medal was awarded.

The Presentation of Awards was again held at Goldsmiths' Hall where the President, Professor A. Collins, presided and welcomed the successful students and their families and friends, who had travelled from as far afield as China, Hong Kong, India, Japan, Korea, Sri Lanka and the USA, as well as those from the UK and Europe. Vice-President Noel Deeks presented the awards.

On the recommendation of the Board of Examiners G.M. Green was appointed an examiner for diploma theory, and M.A. Medniuk a diploma practical examiner. P.A. Sadler resigned as an examiner. The education review meeting was held in November and provided a valuable forum for discussion and exchange of views between tutors, lecturers, examiners and staff of the education department.

Two new projects were introduced in the Autumn when Gem-A ran a course and a workshop at the Gilbert Collection in Somerset House. 'A practical introduction to precious stones' was held on Tuesday afternoons for eight weeks, and included tours of the Gilbert Collection. A one-day family workshop 'Exploring precious stones' for both adults and children to discover more about gemstones in a fun environment was held in November 2002 and repeated in March 2003.

The last year has been spent putting the final touches to the Foundation Course, consolidating existing and negotiating potential new Allied Teaching Centres and Allied Gem Tutorial Centres.

Laboratory

Diamond grading continued to grow with an increase of 9% year on year. Gem identification showed an increase of 12% with 45% tested for origin and heat treatment. S. Kennedy attended and represented Gem-A at the gem industry and laboratory conference in Tucson. S. Kennedy regularly writes articles on gemstone testing and identification in the trade publication *The Jeweller* and has attended branch meetings where he has given updates on what is happening in the laboratories. With part of the grant received from the Worshipful Company of Goldsmiths the laboratory has been able to replace three microscopes, the UV-VIS and FTIR spectrometers, purchase a digital camera and update IT. The diamond and gemstones reports have been redesigned and 'branded' in our corporate colour, and have met with approval from the trade.

Gem-A USA

Gem-A USA was formally launched at the Tucson Gem Fair in February 2003 with an inaugural dinner. The renowned diamantaire Gabi Tolkowsky was the guest speaker. Anne Dale, Director of Gem-A USA, is supported by an advisory council comprising leading figures in the American jewellery industry and they meet four times a year. Over the last twelve months a lot of PR, hard work on the laying of a strong foundation for Gem-A USA has taken place ranging from a champagne and chocolate book signing to lectures given by D. Garrod and S. Kennedy. We also exhibited at the JCK Show Las Vegas show and Gem-A USA has given workshops in Atlanta.

Trade fairs and shows

Gem-A has also exhibited at International Jewellery London 2002 at Earls Court in September with D. Garrod giving three lectures. I. Mercer and L. Stather represented Gem-A at their stand at the Hong Kong Jewellery Show in September. Three staff members, A.J. Clark, D.J. Garrod and L.F. Stather, spent four weekends promoting Gem-A at Rock 'n' Gem Shows at Kempton Park, where they answered enquiries on membership and education, and sold books and instruments.

In common with many non-profit association and learned societies, we lack the funds for capital

expenditure to maintain and improve standards in membership and education. We therefore launched an appeal for funds to improve our in-house teaching and computer facilities to extend our membership and education services, and for the acquisition of rough and polished diamonds to expand teaching and exam sets. Through the generosity of our members by the end of the financial year we had raised £10,000.

Visits

During the current financial year there were two visits organized by D.J. Garrod to Idar-Oberstein, Germany, once in April 2002 and again in March 2003. These trips are always appreciated and enjoyed by the participants. The visits to the gem cutting workshops, the mine and museums, never fail to impress.

Membership

There was a slight increase in Fellow, Diamond and Ordinary membership during the year, with Laboratory membership remaining static.

The Gem-A Branch network was expanded in 2002 with the launch of the South East Branch which held its inaugural meeting at Christie's South Kensington on 8 December. The Midlands Branch held eight meetings as well as their Summer Supper Party in June and a Celebration 50th Anniversary Dinner in December. The North West Branch held seven meetings. The Scottish Branch held seven meetings at venues in both Edinburgh and Glasgow, and their Annual Conference in Perth in May with T. Themelis as the keynote speaker, which attracted a record attendance. The South West Branch held two meetings in Bath which included talks and practical sessions. An informal members' group established in Belgium in 2002 held their first meeting in October when they visited the Living Diamonds exhibition in Antwerp's new diamond museum. This event was followed in the New Year by visits to the Europalia exhibition of gold from archaeological finds in Bulgaria and to Diamscan and Diamondland in Antwerp. Council is most grateful to the Branch Officers and Committee Members who work so hard to present interesting and varied programmes of activities each year.

In London guest lectures were given by two visiting gemmologists. J. Tenhagen gave two presentations, 'New aspects of cut in round brilliant-cut diamonds' (May) and 'Emeralds of Colombia' (October), and R. Hughes 'Burma ruby and new corundum treatments' (June). Private viewings and curatorial tours of the Tiaras exhibition at the Victoria and Albert Museum with G. Munn were held in April and May.

The Annual Conference moved to a new venue in 2002; the event was held at the Kempton Park Racecourse during the late autumn Rock 'n' Gem Show giving delegates the opportunity to browse and buy at the Show during the lunch break. The keynote lecture 'The significance of inclusions in garnets' was presented by Professor Dr E. Gübelin of Lucerne, Switzerland. Professor A. Rankin gave a talk entitled 'Inclusion and chemical fingerprints for sapphires and rubies', Dr R. Symes spoke about sites of precious minerals in England and Wales and jewellery designer S. Webster described the growing influence of women purchasing their own jewellery. A curatorial tour of the Jewels of JAR, Paris, exhibition, at Somerset House and a private viewing of the Crown Jewels at the Tower of London with Crown Jeweller D. Thomas were arranged for the conference delegates.

Publications

In the period April 2002 to March 2003, 22 papers were published in The Journal of Gemmology with topics ranging from garnets in Madagascar to amethyst in Brazil, from diode light sources in gem instruments to concave faceting of gems, and from zircons in corundum to synthetic moissanite. Abstracts totalled 110 and there were 27 book reviews; M. O'Donoghue is warmly thanked for his major contributions to these sections of the Journal and E. Stern, P.G. Read and R.A. Howie are also thanked for supplying a steady stream of abstracts. The Associate Editors are warmly thanked for their support through their academic and technical expertise. The Mineralogical Society is thanked for their permission to reprint mineralogical abstracts that are relevant to gemmology. R. Coleman (of Harley, UK) continued to provide fresh and attractive covers and design for the *Journal*.

Gem & Jewellery News is published jointly with the Society of Jewellery Historians and in 2002/3 contained a wide range of lecture and exhibition reviews, comments on new books, reports on activities of the Gem-A branches, and conference reports. In addition, Harry Levy is thanked for his 'Around the Trade' column which kept everyone up-to-date with the gem scene and, at international level, the Kimberley Process.

Photographic Competition

The 2002 competition on the theme 'Out of the Ordinary' drew a record number of images of unusual cut stones and crystals, and several were

selected to grace the 2003 calendar. The winner was B. Maurer of London with runners-up M. White of Birmingham and J. Harris of Carlisle. Council is most grateful to Harley (UK) for their sponsorship of the three prizes and for their contributions to conference expenses.

Finance

For this report and in the future our financial year is from 1 April through to 31 March. One must remember when comparing figures that year 2001/2 was for a fifteen month period. Prior to the writing of the strategic plan we reviewed the charges made for our services. As a first stage for the financial year 2002/3, we increased the prices for education courses and margin of Gemmological Instruments Ltd. We budgeted to break even for 2002/3 and with rigid control of expenditure we have managed to turn round a deficit for Gem-A of £62,874 into a surplus of £124,823, and for Gemmological Instruments Ltd a deficit of £14,759 into a surplus of £15,330. The accounting system installed to date is now functioning and has contributed to improved reporting. However, we need to link it into the other departments. This will incur an investment in additional computer software, and will take place as funds become available.

Staff and Supporters

Two of the laboratory staff left to travel round the world. They have been replaced with two new members of staff, both with FGA and DGA qualifications, who have settled in very well. One member of staff retired and another left to work in the new de Beers store in Bond Street. This year's surplus figures are due in no small way to the hard work of a compact dedicated team and the Council of Management wish it to be known that they are very much aware of this contribution to the Association's success. We are also fortunate to have worldwide support which is identified by the generous donations of gemstones and the response we had from members to our appeal.

Gemmological Instruments Ltd.

Gemmological Instruments Ltd is a wholly-owned company of Gem-A. It supplies gem-testing equipment of good quality at competitive prices and ranging from stone tweezers to top-of-the-range microscopes, books on gems, gemmology and gem-set jewellery, and a range of thematic sets of gems for students. Introduced in 2002/3 were a new electronic 500 ct balance, a lower-prized thermal tester for diamond, and well-designed and equipped portable gem kits. Following the loss reported in the 2002 accounts, profit margins were reviewed in order to generate more resources for the company. This met with some success with a profit for the year of £15,330, but the world market is extremely competitive and continuing efforts are made to find better equipment at lower prices.

The Council of Management

MEMBERSHIP

Between 1 June and 30 September 2003 the Council of Management approved the election to membership of the following:

Fellowship and Diamond Membership (FGA DGA)

Stevens, Peter, Swanage, Dorset. 1972/1973

Fellowship (FGA)

Boyens, Christine P., Virginia Water, Surrey. 1994
Henri, Martyne, Montreal, Quebec, Canada. 2003
Horikawa, Yoichi, Tokyo, Japan. 1982
Pe Thu Aung, Yangon, Myanmar. 2003
Richmond, Sonia, London. 2003
Simonian, Siran, Krimpen a/d Ijssel, The Netherlands. 2002
Takeuchi, Tomoko, Takarazuka-city, Hyogo Pref., Japan. 1971
Tyrrell, Siobhan, London. 2003

Diamond Membership (DGA)

Champetier, Marie-Pierre, London. 2003
Gandhi, Amar A., Stanmore, Middlesex. 1998
O'Dwyer, Michael, Dun Laoghaire, Co. Dublin, Ireland. 2003

Associate Membership

Abbot, Janetta, Edinburgh, Scotland
Akintola, Akinjide, Catford, London
Anderson, Tricia, Montreal, Quebec, Canada
Arai, Kie, Sandwich, Kent
Bae Sang Hee, Kingston-upon-Thames, Surrey
Bassi, Balvinder Singh, Canary Wharf, London
Bedimo Ngomba-Morin, Emmanuelle, Streatham, London
Berthault, Alexandra, London
Blanco, Bea, St. John's Wood, London
Burnapp, John Edward, Welwyn, Hertfordshire
Callaghan, Neil, Sidcup, Kent
Castel, Anne, London
Clarke, Carl, Seaford, East Sussex
Collins, Shelley E., Sandwich, Kent
Davila, Marc, London
Dawson, Jane M., Ashbourne, Derbyshire

Desai, Yunus, Bradford
Drexler, Steven, Palo Alto, California, U.S.A.
Drummond, Jean, Farnham, Surrey
Fairhurst, Holly, Tarporley, Cheshire
Faysal, Aamin, London
Fitzgerald, Addrianna M.E., Dublin, Ireland
Garfield, Emma-Rose, Banbury, Oxfordshire
Gibson, Suzanne Peplo, London
Haythornthwaite-Shock, Lucy P., Bristol, Avon
Hislop, Donna, London
Howe, Jane, Millshaw, Leeds, West Yorkshire
Klimek, Karina S., Truro, Cornwall
Lee, Young Shin, Ealing, London
Lesetedi, Madichaba Maria, Billesley, Warwickshire
Levine, Gail Brett, Rego Park, New York, U.S.A.
Maranhao, Priscilla P., London
Rebmann, Olivier, Geneva, Switzerland
Nilaratanakul, Chiraphong, Bangrak, Bangkok, Thailand
Owen, Deborah Louise, Crewe, Cheshire
Prior-Chappell, Millshaw, Leeds, West Yorkshire
Richart, Christian, Candlor, North Carolina, USA
Rowley, Elaine, London
Sowa, Ali Med, Tilbury, Essex
Szymanska, Zofia, London
Trikha, Shashi, Weybridge, Surrey
Ye, Hui Hui, Preston, Lancashire

Laboratory Membership

Spicer-Warin Antiques, London

TRANSFERS

Fellowship to Fellowship and Diamond Members (FGA DGA)

Allsopp, Christopher J., St Saviour's, Guernsey, Channel Islands
Appadoure, Basile, London
Aubert, Rebecca, Islington, London
Brown, Mary Josephine, Bangkok, Thailand
Choi, Daeshik, Incheon, South Korea
Douvis, George, Athens, Greece
Hui Chau Ming, Kowloon, Hong Kong
Kalischer, Janice, Finchley, London
Lam, Victoria Lucy, Carnforth, Lancashire
McKenzie, Wilma A., South Surrey, British Columbia, Canada
Nessi, Veroniki, Athens, Greece
Pennington, Susan E., Bickerstaffe, Lancashire
Phillips, Paul, Bulkington, Warwickshire
Roussou, Zoi-Kiriaki, Athens, Greece
Sipson, Ian, Trowbridge, Wiltshire
Townsend, Rachel E., Tamworth, Staffordshire
Liao Wei-Ching, Ping Tong, Taiwan, R.O. China
Whitehouse, Keith P., Marston, Staffordshire
Winter, Nikki, Chiswick, London

SUBSCRIPTIONS 2004

The following are the membership subscription rates for 2004. Existing Fellows, Diamond Members and Associate Members will be entitled to a £5.00 discount for subscriptions paid before 31 January 2004.

	Fellows, Diamond Members and Associate Members	Laboratory Members
UK	£70.00	£250.00 + VAT
Europe	£77.00	£250.00
Overseas	£82.00	£250.00

Associate to Fellowship and Diamond Membership (FGA DGA)

Sanchez Sierra, Maria F., Tooting, London
Firmin, James H., Burley on the Hill, Rutland

Diamond Membership to Fellowship and Diamond Membership (FGA DGA)

Li Cheung, Alex, New Territories, Hong Kong
Plantagenet, Ian, Bradford, West Yorkshire
Pui Pui Tsoi, Karen, Kowloon, Hong Kong
Rutter, Fay, Walsall, West Midlands

Associate Membership to Fellowship (FGA)

Banks, Jessica, London
Breuer, Lisa, London
Conejero, Jennifer H., Boston, Lincolnshire
Eguchi, Yumi, Fukuoka City, Fukuoka Pref., Japan
Fisher, Abigail, London
Hayashida, Shoko, Minato-ku, Tokyo, Japan
Henry-Stogdon, Sarah A., West Norwood, London
Hiraoka, Kenji, Suginami-ku, Tokyo, Japan
Hotson, Peter J., Berkhamsted, Hertfordshire
Jackson, Antoinette, London
Lee Hsiang Ju, Taichung, Taiwan, R.O. China
Lee Young Ji, Ealing, London
Milton, Paul R., Liverpool, Lancashire
Munawar Mirza, Sohail, Angered, Sweden
Nilsson, Annica H., Uppsala, Sweden
Pearson, Isabel J., Tilehurst, Berkshire
Pumphrey, Jessica K., London
Shaw, Sinead, London
Taylor, Louise, Gresford, Clwyd
Wenham, Diana L., North Harrow, Middlesex
Williams, Cara M., Jefferson City, Missouri, U.S.A.

Associate Membership to Diamond Membership (DGA)

Chan So-Ha, Anna, Hong Kong
Godfrey, Kay, Halstead, Essex
Miller, Steve, Crawley, West Sussex
Najda, Marina, London
Riedel, Richard W., Lewes, East Sussex
Sarri, Santino, Brighton, East Sussex
Watanabe, Tomoko, Mitsukaiudo-shi, Ibaraki, Japan

ISLAND OF GEMS

The eighth exhibition of the gems and gem industry of Sri Lanka is to be held in London on 15 and 16 November. The venue for this year's event is the Kensington Close Hotel, Wright Lane, London W8 5SP (nearest underground High Street Kensington).

The exhibition will be opened by His Excellency the High Commissioner for Sri Lanka in London, Mr F. Musthapa PC, and Terry Davidson, Chief Exeuctive Officer of Gem-A.

The entrance fee, which includes a souvenir brochure and a sample gemstone, is £5.00 (children under 12 years of age free of charge).

For further details contact Don Ariyaratna on 020 8807 8252; e-mail sri@lankagems.co.uk website: www.lankagems.co.uk

OBITUARY

Nikola Kielty-Lambrinides FGA RSM, BWG (1924-2003)

A tribute by Alexandra Krikos

Nikolas Kielty-Lambrinides was without a doubt one of the most important figures of Hellenic gemmology and glyptography. His passing has left a vacuum that is unlikely to be filled by one single person. I vividly recall his unique amber collection and his ivory antiques, rubies, emeralds, melanites, enstatites, moldavites, bowenites, elbaites, rhodonites, apatites, nephrites, calcites and eilat stones flooding the classrooms of Athens, captivating our interest during the first round of gemmology lectures he gave in Greece at the end of the seventies and beginning of the eighties. Until their revival through these lectures, gemmology and glyptography were forgotten words in Greece. At the time Nick, as his friends called him, worked closely with Goulandris Natural History Museum and the Hellenic American Union in Athens.

The Birth of an Era

Of Irish Greek descent, N. Kielty-Lambrinides' background was from Constantinople (now Istanbul) where his grandfather was a diamond and precious materials merchant in the Cheshli street market. His family moved to Manchester where, during the Second World War, Nick completed his school education and developed a passion for miniature sculpture. He did his National Service in the British Army before attending Chelsea Polytechnic to study Gemmology (1958/61). He continued to study gemmology at Manchester Polytechnic while attending studies in silversmithing/

Nikola Kielty-Lambrinides

goldsmithing, design and retail jewellery. He then went on to read Philosophy and Theology (1964/68) at the University of Athens. He believed that to understand art one had to study the culture and milieu in which the art was created. He is quoted as saying in the magazine *The Greek Jeweller* "How can a person understand Spanish or Byzantine Art, without having understood the religion of those areas?". He deepened his understanding of glyptic arts and antiques by travelling throughout the world and conducting research in places as far apart as India, the Far East, Spain, Italy and Greece.

On returning to England he completed his seven years' apprenticeship and furthered his studies in glyptography and glyptology under the tutelage of Cecil Thomas OBE 'Master of Mint'

who also introduced Nick to the methodologies employed by his colleague and famous Master of the Fabergé House, Alfred Lyndhurst Pocock. At about this time Nick was also close with the well known Beth Bento Sunderland from America. Nikolas Kielty-Lambrinides became successor of both Master Glyptographers after their deaths, continuing traditions dating back to the 14th century.

Lambrinides also worked at the central administrative office in the House of Lords. On completion of these duties, there was plenty of time left in the afternoons and evenings for other responsibilities, such as restoration and repair of art objects for his Kensington High Street antique business, which was booming at the time. Michael Theodosius Hatiris was brought on board in 1965 to aid in the buying and selling of antiques in the capacity of a business partner.

N. Kielty-Lambrinides, a full member with following Licentiate of the Royal Society of Miniature Painters Sculpters and Gravers (RSM) and also a full member of the Brothers of Art Workers Guild (AWG), believed that his duty as a Master Glyptographer was to found an Academy of Glypotography, so that traditional methods could be revived and enriched by the development of new ones.

Nick Lambrinides returned to Greece to realize his goal. He reasoned that Greece was the cradle of European glyptography and so the rightful home of such a school, and he began lecturing in gemmology, antiques, archaeogemmology and glyptography. The influence that Cecil Thomas had on him was profound. Cecil Thomas had thoroughly researched themes through Ancient Greek tradition and also the subjects of crystal carvings and engravings, working with Sir Arthur Evans the renowned Minoan civilization archaeologist who discovered the treasures of Knossos in Crete. During this initial campaign for the reintroduction of the above-mentioned subjects to the academic world, Lambrinides was also in close contact with certain well-known Greek jewellers such as Ilias Lalaounis, M. Athiniotakis and co-worked with the late P. Tsaktanis, president of the Athens Retail Jewellers and Watchmakers Association. Tsaktanis inaugurated the first seminar ever for jewellers in Greece and it was Lambrinides who was called upon to deliver the inaugural lecture in Rhodes. This was followed by a six-month seminar in Athens under the auspices of EOMMEX, the Hellenic Organization for Small/Medium Sized Enterprises and Handicraft. These activities led to long lists of applicants for the gemmology and glyptography seminars all over Greece, which marked the beginning of the materialization of the Lambrinides' vision which was, as we have stated, the re-establishment and development of gemmology and glyptography in Greece. In addition to lecturing, Lambrinides founded a Center of Gemmology and Glyptography, which was run with assistance from Eric Bruton, Alan Clark, Alan Jobbins, Roger Harding, Ian Mercer and many more.

The movement that Lambrinides inspired and founded in Greece has grown from humble beginnings to the size it is today. Many of Lambrinides' students are now respected lecturers and specialists in their fields, and have taken up the gauntlet that he laid down to take the movement forward. Many of these students and Nick himself, the representative for the Gemmological Association of Great Britain in Greece, have lectured in the schools of Athens, Volos, Crete, Larissa, Salonica and elsewhere. This group has also been teaching at his ATC (Allied Teaching Centre) for the Gem-A classes and has prepared students for the gemmology exams under the aegis of GNHM which were held until 1997 at the EOMMEX centre in Athens, where he was the Director of Studies.

The culmination of all this effort was the foundation of the Gemmological Association of Greece. This achievement was realized by the first group's communal effort and Lambrinides rightfully became the first president. The ATC for Gemmology in Greece, was by then well established, as was Gem-A under the aegis of the British Council. Teaching of gemmology in the Greek language has started, and Gem-A exams were held until 2002 at ELKA's (Hellenic Silver and Goldsmith Centre) laboratory, housed at the EOMMEX building, where Nick Lambrinides was Director of 'Gemmology, Diamondology and Glyptography Studies' until June 2003, while co-working with EIMA A. Krikos – R. Hopper Ltd, which has become the Gem-A examination centre. In his spare time he organized activities for the Greek Irish Society as a founder member.

The man and his creative work

As a person N. Kielty-Lambrinides was a calm and collected man, as a tutor he was a strict task master and was uncompromising in his demand for excellence from his students as any of them will tell you. We all enjoyed his classes – while lecturing about tusk and tooth dentine ivory he once asked, "How many teeth has a sea lion?" After all it is a lion, so ... a hundred or at least thirty

two, stated some students with a wary smile. "The answer is none ... only a moustache!", he replied. "You must always engage and even intrigue your students, let them experiment with the magnetism of the pyrope garnet for example." Lambrinides compiled the first bilingual (Greek-English and English-Greek) dictionary of gemmology, and the books *Notes of Gemmology and Elements of Glyptography*. He wrote countless books, papers and magazine articles on the above subjects, and gave information on a wide range, with a variety of themes such as jewellery, crystal and herbal alternative therapy.

Nick Lambrinides' carvings, at times three-dimensional figures, "... portraying such details as worry lines and smiling eyes, or unfriendly mouths ... have been on display in the V and A's man-made exhibition. He made a Queen Victoria's 1½ inch head from a piece of white topaz which was on show in the Geological Museum, London", as Adam Joseph published in the *Evening Standard* in January 1977. A male hologlyph smoky quartz head and other pieces are permanently on display in the Mineralogy and Petrology Museum of Athens University.

A unique Glyptography exhibition was held at EOMMEX in 1985 where his pieces and those of his students were displayed together. This exhibition received widespread public recognition. Other exhibitions of his work in galleries in London and Athens, and demand for pieces that have been acquired by private collections, demonstrate how sought-after his craftsmanship and the great works of art he skilfully achieved in small scale have become.

The end of an era

His teaching attracted the interest of both professionals and amateurs alike. Lambrinides lectured and carried out workshop demonstrations in such places as the Geological Museum and Natural History Museum (where his pieces were on display since 1975), the Victoria and Albert Museum, the Polytechnic of Isleworth, London, at EOMMEX, and at the Department of Mineralogy and Petrology, Faculty of Geology, National and Kapodistrian University of Athens, School of Sciences, where gemmology was taught by him and his assistants as an applied part of the mineralogy studies course. Nick could also be found on 'search and rescue' missions in flea markets or gemstone shops, or carrying out other tasks, such as testing the acoustics of the new lecture room at 1 Agias Irinis Street, Athens, now home of the Gem-A examinations. He would devote hours of research to organic precious metals while stroking his beloved Siamese cat.

Many students, 'his family' as his friends referred to us, visited our 'Thaskalos' (Master), just before his passing. He gave creative input to each and every one of us and patiently discussed each of our future careers.

He managed to study and practice the art of science and the science of art, as Leonardo Da Vinci suggested. Nick Lambrinides, operating with the vigour and passion of an 18-year-old, the drive and determination of a 25-year-old, the professionalism and precision of a 50-year-old, and with the wisdom that only a man of his advanced years could attain, and having the desire throughout his career that everything should continue to operate unimpeded and smoothly, will be dearly missed.

Acknowledgements

The author is grateful to Yannis Arnaoutelis for supplying the photo of N. Kielty-Lambrinides, Michalis Theodosious Hatiris for supplying most of the data, Andrew Clements for his assistance and Barbara McConnell from the Greek Irish Society.

* * *

Christopher R. Masters FGA (D.1960), Bispham, Lancashire, died recently.

Erratum

In *J.Gemm.*, 2004, **28**(7), p. 411, in the caption to the photograph winning third prize in the Photographic Competition, for 'Mabe pearl' read 'Blister pearl'

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6 December	**Midlands Branch.** *51st Anniversary Dinner.*
7 December	**South East Branch.** Cartier: the 20th century. TERRY DAVIDSON

2004

20 January	**Scottish Branch.** Some unusual and historical synthetics. MICHAEL O'DONOGHUE
30 January	**Midlands Branch:** Annual Bring and Buy and Team Quiz
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Carl Fabergé – a Russian Revolution

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25 February	**South East Branch.** Tavernier and his stones. NIGEL ISRAEL
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The Editor is glad to consider original articles shedding new light on subjects of gemmological interest for publication in *The Journal*. Articles are not normally accepted which have already been published elsewhere in English, and an article is accepted only on the understanding that (1) full information as to any previous publication (whether in English or another language) has been given, (2) it is not under consideration for publication elsewhere and (3) it will not be published elsewhere without the consent of the Editor.

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Cover Picture

A natural Malawi ruby, 2.70 ct, mounted in a ring. (See 'Chemical fingerprinting of some East African gem rubies by Laser Ablation ICP-MS', pp 473-82)

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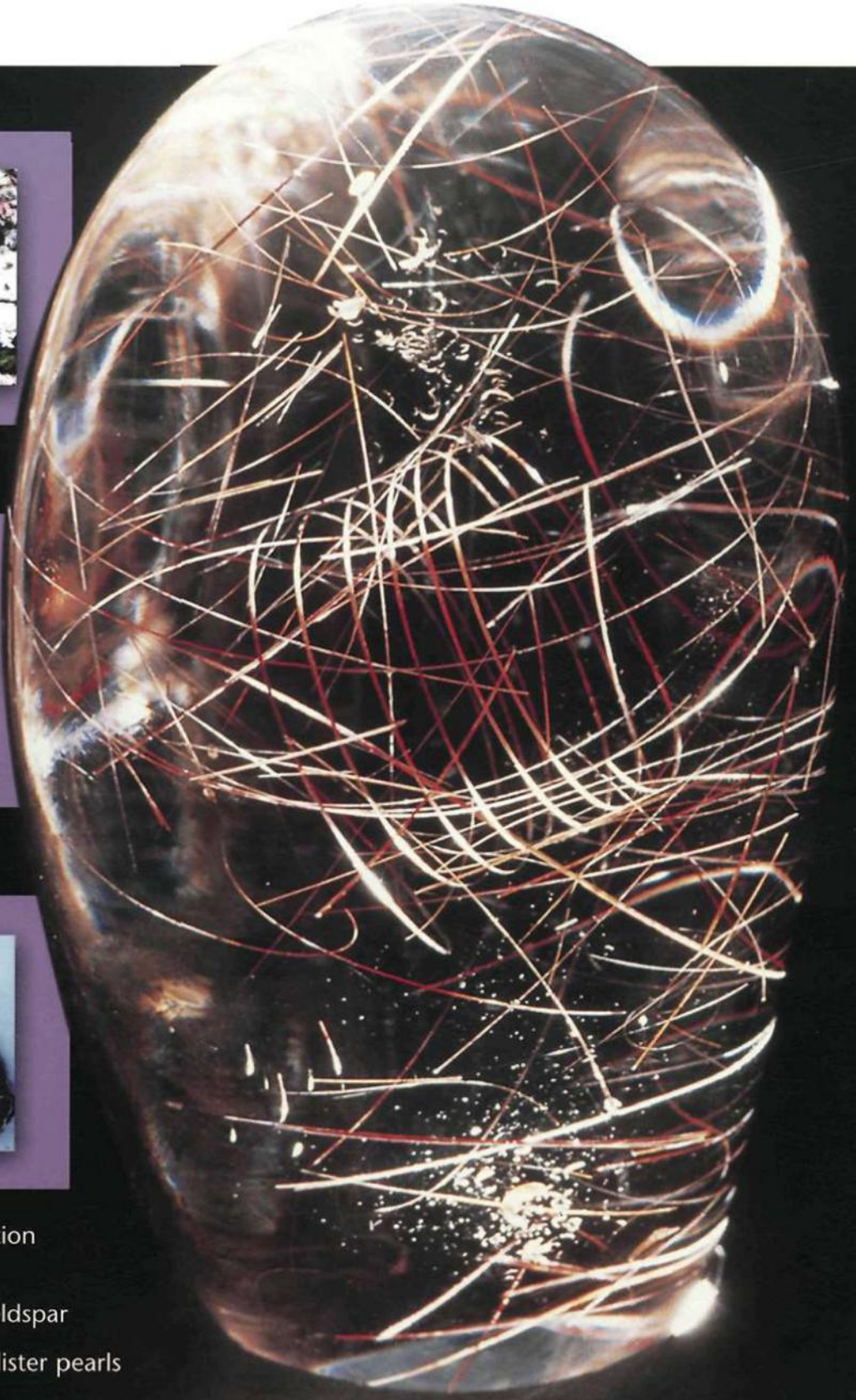

Colour zoning and composition of ruby-sapphire

Red and green labradorite feldspar

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Coiled 'rutile' whiskers in a quartz single crystal

Ichiro Sunagawa[1], E. Alan Jobbins[2] and Emma Tinnyunt[3]

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Abstract: *'Rutile' whiskers showing a range of habits in a single crystal of quartz from Mogok, Myanmar, are described. The whiskers are thin and sometimes solid or thicker and hollow and may be straight, slightly curved or tightly curved into coils or spirals. The thicker whiskers are hollow tubes with the walls composed of aggregated thin fibres of 'rutile'. Their mode of formation by dislocation leading to the Eshelby twist, and their incorporation into the later-growing quartz are discussed. Later weathering is considered to cause pale brown axial and spotty peripheral staining.*

Keywords: *bundle whiskers, coiled whiskers, growth mechanism, rutilated quartz, rutile whiskers*

Introduction

Crystals sometimes exhibit habits very different from those expected from their structural characteristics. When NaCl or KCl crystals grow in a bulk aqueous solution, they take the cubic form bounded by {100} faces, i.e. the structurally expected form. When a supersaturated aqueous solution of NaCl or KCl is kept in a wineskin in dry shade, extremely elongated needle-like NaCl or KCl crystals bounded by {100} faces appear as if they are sprouting up from the outer skin. In this case, the needles are hollow, but many other crystal species can occur as solid needles. Taking examples from natural minerals, we may mention for example jamesonite, $Pb_4FeSb_6S_{14}$, millerite, NiS, and hair silver, Ag. A wide variety of artificial compounds is also known to show such morphology, e.g. metals: Fe, Cu, Ag, Sn; semiconductors: Si; sulphides: NbS_3; selenides: $NbSe_3$; carbides: SiC; nitrides: Si_3N_4; and oxides: Al_2O_3. Such crystals with extreme length to breadth ratios are called whiskers and have attracted both scientific and technological interests (Doremus *et al.*, 1958; Givargizov, 1986); they have also been called anisotropic crystals but this could be potentially confusing where optical properties may also be discussed.

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Scientific interest arises from pure curiosity to understand how such unusual morphology is realized. Technological interest comes from the fact that whiskers have much higher crystal structure perfection and thus are elastically stronger than 3D bulk crystals. The high perfection of whiskers leads to potential materials to strengthen composites.

As to the mechanism of whisker formation, various hypotheses have been put forward, among which well established mechanisms are (1) the Vapour-Liquid-Solid (VLS) mechanism (Wagner and Ellis, 1964), and (2) the capillary mediated mechanism (Aoki, 1972). In the VLS mechanism, which was originally put forward for Si whiskers, Si supplied in the vapour phase (V) reacts with solid gold particles placed on a solid substrate of silicon and forms an Au-Si eutectic liquid droplet (L). Since the phase to nucleate and grow in such a eutectic liquid is determined by the liquid composition, only Si nucleates and grows (S) in the liquid droplet. There is only one growth site for Si in the Au-Si eutectic droplet, the crystal grows in one direction only and takes an extremely elongated needle habit. In the VLS mechanism a sphere of solidified eutectic Au-Si liquid always remains at the top of a Si whisker even after the completion of growth. The capillary mediated mechanism is applicable to KCl and NaCl whiskers. These are grown from a supersaturated solution which is kept in a wineskin and oozes through the skin by capillary action. As soon as the solution comes out on the skin surface, it evaporates, becoming more supersaturated; this results in immediate crystallization around the tiny capillary channel outlets. Crystallization continues perpendicular to the skin as a cylinder for as long as the capillary remains open and the solution is supplied continuously. Therefore, the whisker becomes a hollow one.

Figure 1: Polished quartz with numerous 'rutile' whiskers. Note the central thick coil and faint, much thinner coil at upper left and lower right (arrows). A partial loop, part of a widely spaced coil, is also visible at lower left centre. Height 56 mm.

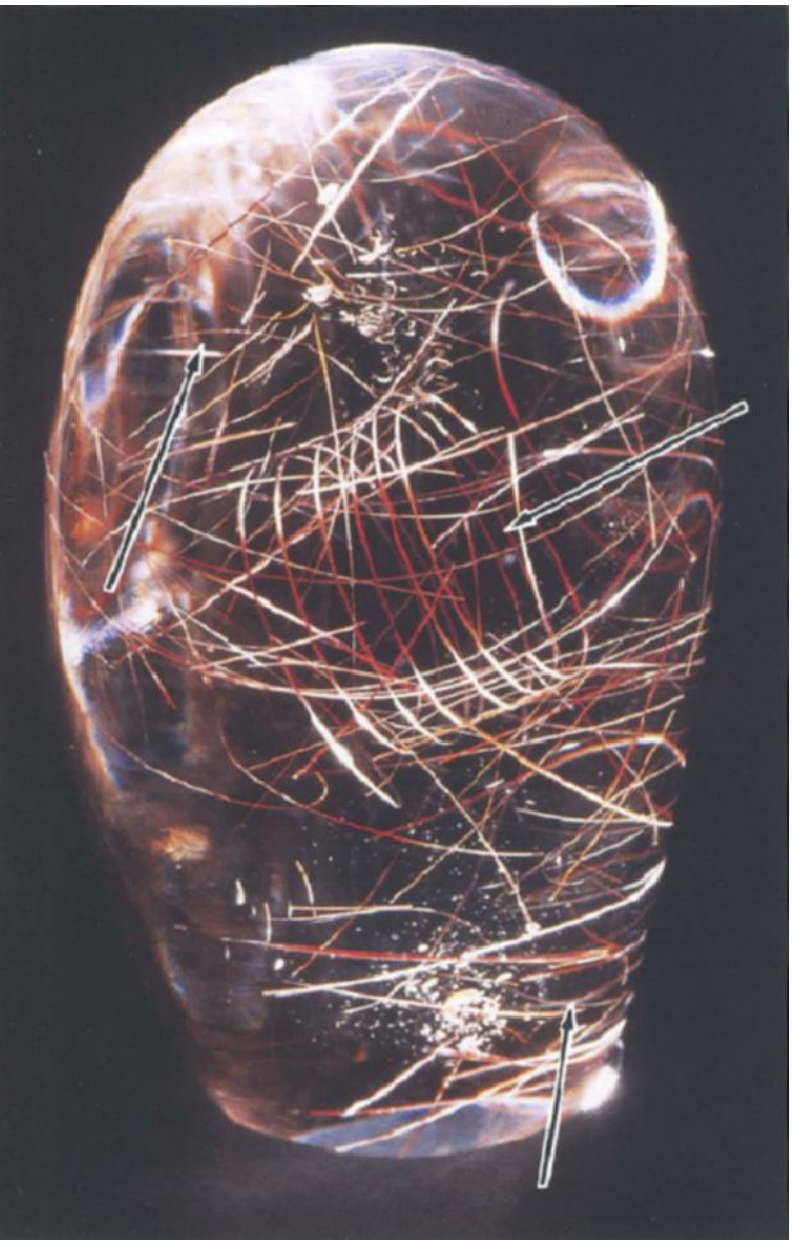

Whiskers have long been known in the mineral kingdom. Hair silver, millerite, and jamesonite are representative examples. Also known are pyrite FeS_2 and galena PbS, but these occur only rarely in whisker forms. Rutile (TiO_2) is another example showing whisker morphology that gemmologists often encounter in rutilated quartz (Gübelin and Koivula, 1986). The structurally expected polyhedral form of this rutile is short and prismatic, bounded by prisms {110} and pyramids {111}, but in rutilated quartz, they are whiskers and hitherto, gemmologists have not realized or been aware of their significance.

Most whiskers observed in natural crystals are straight, with aspect ratios (length *vs* thickness or height *vs* diameter) of a few tens

Figure 2a: Photomicrograph of the central thick coil. Note the axial pale brown line. Straight and slightly curved whiskers much thinner than the coil are also visible. Bar 0.5 mm.

to a few hundreds. Kinked (pyrite and galena), twisted (jamesonite) or ribbon (hair silver) whiskers are also known. But whiskers showing helical, coil, rope and other unusual morphologies in natural crystals have not to our knowledge been reported.

Recently, in 2001, when one of the authors (ET) visited Mogok, Myanmar, she obtained a specimen of colourless quartz full of needle inclusions polished in the form of an elongate egg. Most rutile whiskers in quartz are straight, but in this specimen there are some which show very unusual coil habits. Since whiskers with this spiral habit have not been reported from natural gem-quality mineral crystals, the sample was studied to try and understand its possible growth mechanism. This paper reports the results of observations on the sample, and presents an hypothesis for its origin.

Sample description

The sample is polished as an egg shape, maximum length 56 mm, maximum width 33 mm and weighs 75.45 g, with inclusions of straight, curved and coiled whiskers. *Figure 1* is a photograph of the specimen showing a distinct thick coil with an inclined axis, upper right to lower left, a faint but larger coil around the edge of the specimen, top right, together with slightly curved and straight whiskers. Arrows indicate coiled whiskers.

The RI of the specimen is approximately 1.54-1.55. The optic axis is at an angle to the length of the specimen, but a uniaxial figure is just visible and shows a typical quartz interference figure with a 'hollow' centre. The specimen is thus unambiguously identified as a single crystal of quartz. A small feather which reaches the polished surface shows a series of tiny spiky two-phase (liquid/gas) inclusions. Between crossed polars, the large coil appears a dull brownish-red, but is not noticeably birefringent. However, some straight and slightly curved whiskers (with sparse or no enclosed reddish deposits) are birefringent in first order grey colours.

Figure 2a shows an enlarged photograph representative of the central thick coil. The length, diameter and the spacing of the coil are 9 mm, 15 mm, and 1.8 mm, respectively, with 6 turns. There is also a much thinner, less visible coil at upper right of

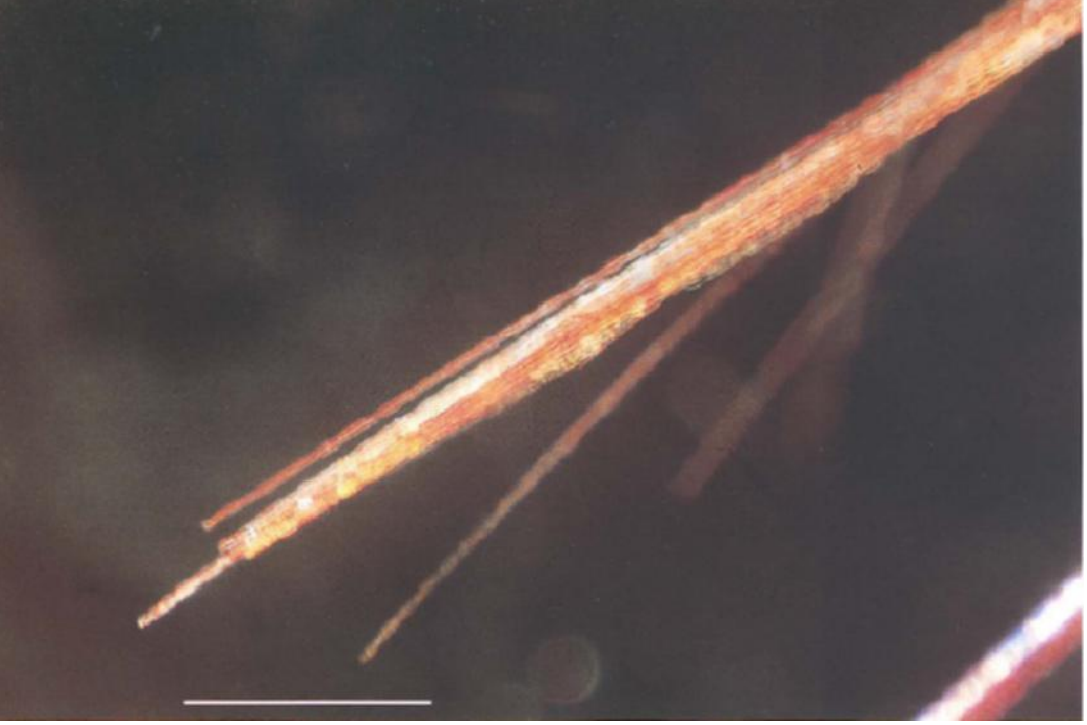

Figure 2b: One end of a hollow tube showing the splitting into several discrete and finer whiskers. Bar 0.1 mm.

Figure 1, with length, diameter and spacing of 9 mm, 10 mm, and 1.5 mm, respectively, and with only three turns. At both ends of these coils the curvatures change and divert from the turn of the coil. The ends of both hollow coils split into several discrete and finer whiskers (see *Figure 2b*). Some straight whiskers with elongations of 20 to 30 mm are 0.1 mm thick while others of similar length may be as thin as 20 μm. Most whiskers are hollow and many show ends split in to several finer whiskers.

In *Figure 3* are photomicrographs of the thick coil (*a*. view perpendicular to the elongation; *b*. oblique view). The two photographs indicate that the thick coil is a hollow tube with a pale brownish deposit on the wall surface of the hollow and sporadically distributed brownish dots within the wall layer. They also indicate that the thick coil is not an isolated and independent whisker, but a bundle of whiskers. Brown coloration may or may not be present in the thin straight whiskers. In *Figure 3a* the arrow in the upper centre indicates where the straight and coiled whiskers cross. A noteworthy point is that the straight whisker shows a distinct prism face and does not have a pale brown axis. Compared with the single crystalline nature of the straight whisker, the coiled whisker with the brown axial deposits is hollow and seems to represent a bundle of whiskers. The coil is 50 to 100 μm thick.

After the initial study of the specimen it became apparent that the inclusions were different from the usual rutile needles encountered in gemstones. Because of the specimen's size and its rounded surface, precise identification of the needles was not easy, but Professor Andy Rankin of Kingston University offered to attempt to check their identity using Raman techniques. This was carried out on fibres 10 to 50 microns below the surface and on two with a surface outcrop. Because of the fine needle form confirmation was lacking, but in his experience the rutile peak at 610 cm^{-1} is often very weak on such needles. Thus the presence of rutile is not disproven, but confirmation of actual rutile could not be substantiated. Strong fluorescence encountered above 500 cm^{-1} may have obscured the rutile peak – or weathered material in the tubes might have caused this.

We have had useful discussions with other gemmologists and mineralogists regarding the nature and origin of this specimen. We do not agree with suggestions that the coils could have been produced by computer-controlled laser beams, nor do we think that the coils are pseudomorphous after plant or other organic life. It has also been suggested that the existing coils are replacements of the original mineral.

Discussion

These inclusions show unusual habits for a crystalline material. The thicker whiskers are hollow with pale brown deposits, and some

thinner whiskers are solid, so in order to understand how they formed, the following questions need to be answered: (1) whether the inclusions are crystalline or amorphous, and (2) whether they were formed before or after the growth of the host quartz crystal.

If the inclusions were formed before the growth of the quartz, they are whiskers, and the observed coil habit represents the original as-grown morphology of whiskers which was not modified to any significant extent by the later growth of quartz. If they were formed after the growth of the quartz, their formation must have an intimate relationship with dislocations in the quartz structure. Since there is more strain along dislocations than elsewhere in the structure, dislocations are preferable sites for later chemical attack. Dislocations which were subject to later chemical attack and show axial deposition of foreign material are called decorated dislocations. A method to decorate dislocations by appropriate metals deposited from a vapour phase was used as a powerful method to visualize dislocations in the earlier days of dislocation studies.

Very elongated needles of rutile are commonly observed inclusions in single crystals of quartz. They are usually straight and may be in ordered arrangements, or in random distribution and orientation. Growth-induced dislocations in single crystals of quartz usually show characteristic features such as divergent bundles starting from solid inclusions and running nearly perpendicularly to rhombohedral or prism faces. The needles in this specimen of quartz occur at random and do not show such characteristic distribution. We therefore believe that the rutile inclusions in quartz showing random frequency and orientation are not decorated growth-induced dislocations, but must have been formed before the growth of their host crystal, with little, if any, modification of morphology by the later growth of quartz.

Recently, whiskers showing unusual spiral morphology (Kishi *et al.*, 1995), microcoil (Motojima, *et al.*, 1995), ring (Tanaka, *et al.*, 1999, 2000), Möbius strip (Tanda *et al.*, 2002) and figure-of-eight crystal strip (Tanda and Tsuneta, 2002) have been observed on metal (Cu), sulphide and selenide (TaS_3, NbS_3, $NbSe_3$, $TaSe_3$) and nitride (Si_3N_4) crystals. All these whiskers are synthesized by CVD (chemical vapour deposition) methods. These have attracted renewed interest as topological materials and/or potential materials for CDW (charge-density-wave) interference, superconducting electron and two-component electron systems.

VLS mechanisms (Wagner and Ellis, 1964) or quasi-VLS mechanisms have been suggested as possible growth mechanisms for most of

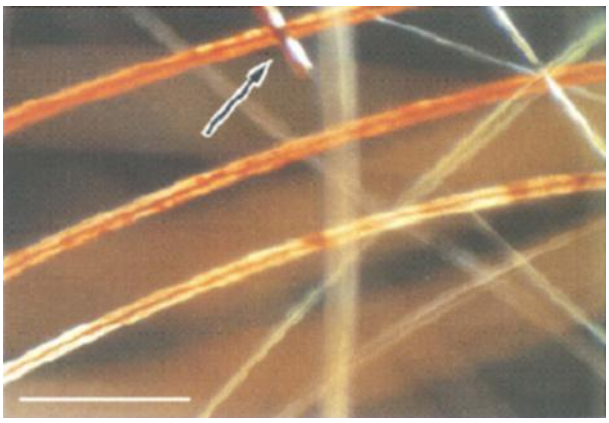

Figure 3a: Part of the thick coiled whisker showing axial and sporadically distributed pale brown deposits. Note crossing of coil and straight whiskers at the upper centre of the picture (arrow). Bar 0.2 mm.

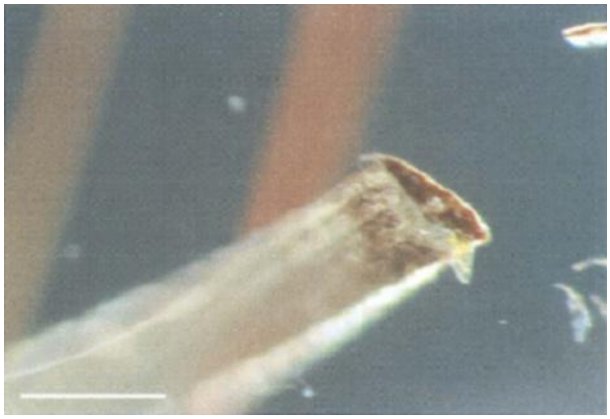

Figure 3b: Relatively thick coiled whisker very near the quartz surface and showing fibres making up the walls of a hollow cylinder. Bar 0.05 mm.

these whiskers. Cu whiskers may grow via a thin liquid layer of copper iodide (CuI), which is supplied by CuI vapour; the formation of a Si_3N_4 micro-coil whisker is activated by the presence of impurity, Fe or Co, from SiO-NH_3-H_2-Ar gas mixture; sulphide and selenide whiskers are synthesized by reacting nutrients Ta or Nb and S or Se in powder form in an evacuated quartz tube at elevated temperatures, which forms a eutectic liquid droplet of impurity component + Ta or Nb+S or Se.

Another possible mechanism for the formation of hollowed needles and whiskers is morphological transition of interface roughness due to adsorption of impurity on the tip surface of a prismatic crystal. This has recently been demonstrated for TiO_2 needles and whiskers grown by the LPE (Liquid Phase Epitaxy) method (Kawamura *et al.*, 2001). Due to substitution of Ti^{4+} ions by trivalent cations with similar ionic radius, oxygen ions around Ti^{4+} in the structure are destabilized to maintain electrical neutrality, resulting in breaking the Periodic Bond Chains (PBC) in the {111} face (Hartman and Perdok, 1955). This results in the transition of the {111} interface originally containing one PBC to a rough interface containing no PBC. This roughness occurs on the surface at the tip of a prismatic crystal, while the prism {110} faces remain unchanged as smooth interfaces, each containing two PBCs. As a result of this smooth to rough interface transition at the tip, growth proceeds rapidly in the direction of the *c*-axis, resulting in needle or whisker morphology. Formation of a hollow tube rather than a solid needle is due to preferential two-dimensional nucleation along the edges of the tip and prism faces. In both the VLS mechanism and the roughening transition on the tip surface, impurity cations play an important role, and these cations appear to be the essential reason why rutile crystals adopt a whisker morphology. However, since we have so far not observed direct evidence of the presence of a frozen liquid droplet at the tip of a whisker, we can not be certain that the VLS mechanism is the explanation. Various models have been proposed for the origin of the unusual habits of whiskers such as spirals, coils, Möbius strips and figures-of-eight. For those shown by sulphide and selenide whiskers, encircling of growing whiskers around a S or Se liquid droplet was suggested (Tanda and Tsuneta, 2002; Tanda *et al.*, 2002). For Si_3N_4 micro-coils, the beginning of curling occurs at a lump-like deposit on a straight whisker, which is assumed to be a liquid droplet with impurities such as Fe or Co. According to Motojima *et al.* (1995), all straight whiskers are single crystals of Si_3N_4, but micro-coils give electron diffraction patterns of an amorphous state. Moving from straight, via slightly curved, to micro-coil, the structural state changes from entirely single crystalline (straight) to axial centre single crystalline and peripheral amorphous (slightly curved) to amorphous and polycrystalline (beginning of coil) and eventually amorphous (micro-coil). In contrast, whiskers of sulphides and selenides showing unusual morphology are all single crystalline, and not amorphous.

Although no diffraction work has been done on 'rutile' inclusions in the present study we think that they were originally crystalline. If whiskers are thin and straight, they may be single crystals of rutile. These whiskers are not hollow tubes. Hollow tubes are only seen among the thicker whiskers. Thick whiskers are bundles of much thinner, single whiskers. If whiskers are bundled, they are more likely to be curved, twisted, curled or coiled in habit rather than straight. When a single whisker contains an axial dislocation, strain associated with the dislocation may cause an Eshelby twist. If Eshelby-twisted whiskers grow together in a bundle, it is highly possible that the bundle may take a helical or coil habit.

Stimulated by the observation of coiled 'rutile' whiskers, one of the authors (IS) re-examined other samples of twisted, curved, helical, coiled and rope-like bundles of whiskers of amphibole in the druse of a Japanese skarn. Micro-area XRD investigations of these whisker bundles indicate that they are all crystalline, and not amorphous. The results of investigations on these amphibole whiskers showing unusual morphology

will be reported in a forthcoming paper (Sunagawa *et al.*, 2003).

Brown deposits in the axes of whiskers and spots around their margins are considered to be of secondary origin, formed by later weathering processes.

Conclusion

An unusual coil morphology exhibited by 'rutile' whiskers in single crystal quartz is reported. We conclude that both straight and coil whiskers were formed before the growth of the quartz crystal, and that their original forms have survived unmodified. There are thin single whiskers and thicker bundles of thin whiskers. The bundles consist of thin whiskers aggregated in a cylindrical manner with a hollow axis but the thin whiskers are solid. It is postulated that impurity cations influenced formation of rutile whiskers through destabilizing the tip interface and transforming it to a rough interface. As to the origin of the coiled morphology, twist caused by dislocation and strain in whisker structure is suggested. Later weathering of bundles of whiskers caused formation of brown axial deposits and sporadic peripheral brown spots.

Acknowledgement

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Colour zoning and composition of ruby-sapphire from Westland, New Zealand

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Abstract: *Ruby rock ('goodletite') is a ruby-sapphire-bearing fuchsite-margarite rock from the Southern Alps of New Zealand. The typically barrel-shaped ruby-sapphire shows a spectacular diversity of colours including rose-red, carmine, deep purple-red, pale-pink, pale-blue, deep-violet, as well as colourless examples that can be related to variable concentrations of* Cr_2O_3 *together with minor (typically <0.5 wt.%) iron oxide and* TiO_2*. Most crystals are colour-zoned, having pink or blue centres and colourless terminations. Individual ruby-sapphire crystals can exhibit extreme Cr-zonation, for example from 2.67 to 6.24 wt.%* Cr_2O_3 *in one example documented in this paper. Substitution of Cr into the corundum structure is a function of Cr-rich metasomatism involving reaction between Cr-poor quartzofeldspathic schist and ultramafic rock at elevated temperature and pressure. Substitution of iron (*Fe^{3+} *and* Fe^{2+}*) +* Ti^{4+} *to form sapphire rather than ruby corundum probably correlates with diminished* Cr^{3+} *concentration in the fluid phase during crystal growth.*

Introduction

During the 1890s rare boulders of a unique 'ruby rock' (informally named 'goodletite') were found (and continue to be found) in moraine derived from the Southern Alps in north Westland, New Zealand (McKay 1893; Ulrich 1894; Bell and Fraser 1906; Morgan 1927; Mason 1989; Grapes and Palmer 1989, 1992, 1996; Brown and Bracewell 1996; Grapes 1999). The rock consists of clusters of ruby-sapphire crystals set within a matrix of emerald-green chromian muscovite (fuchsite), margarite, with accessory chlorite, chromite, Ti-magnetite, and with dravitic tourmaline forming single crystals that overgrow the micaceous matrix and also occur in veins (see Figure 2 of Grapes and Palmer, 1996). Bulk rock and mineral analyses are given in Grapes and Palmer (1996).

The corundum was originally described by Ulrich (1894) as 'oriental ruby', presumably from the fact that some of the crystals were, as he described, "*... a fine rose-red, approaching carmine ...*", although most "*... are of a deep purple-red and rather dull, the larger ones generally showing dark, dull terminations with clearer portions of brighter red intermediate. Perfectly clear and finely coloured grains can, however, easily be picked out for proving the characteristic strong pleochroism of the ruby.*" Morgan (1927) records one crystal of nearly 25 mm in diameter that is "*... of a beautiful red transparent colour.*"

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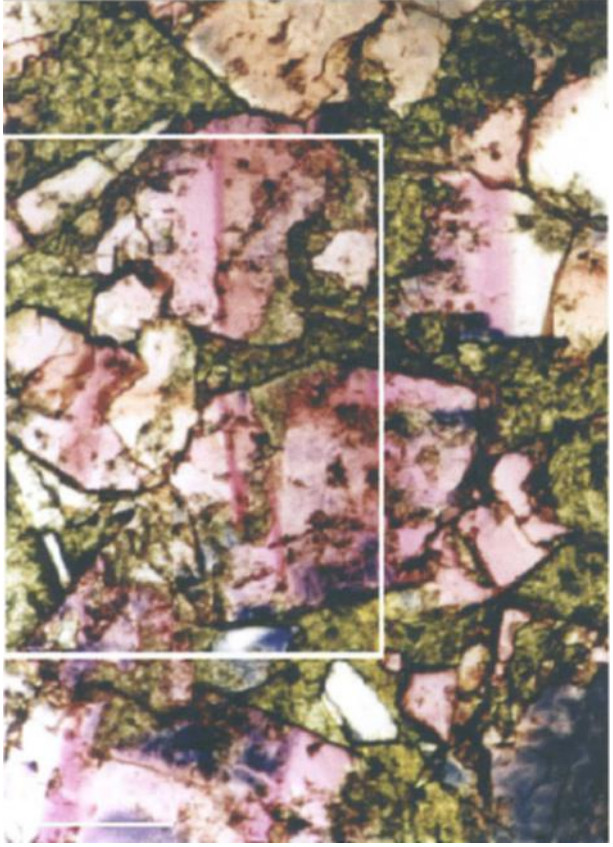

Figure 1a: Thin section photomicrograph (plane polarized light) of ruby-sapphire crystals within a matrix of margarite and chromian muscovite (fuchsite). The thin section is 0.035 mm-thick. Thin, darker-pink lamellae have the highest Cr-content (up to 12.9 wt.% Cr_2O_3) and abundances decrease with lighter-pink coloration, to <0.3 wt.% in colourless parts of the crystals. Areas of blue sapphire (see bottom-right crystal) contain 0.04-0.6 wt.% TiO_2. White box delineates area shown in (b). Scale bar is 0.5 mm.

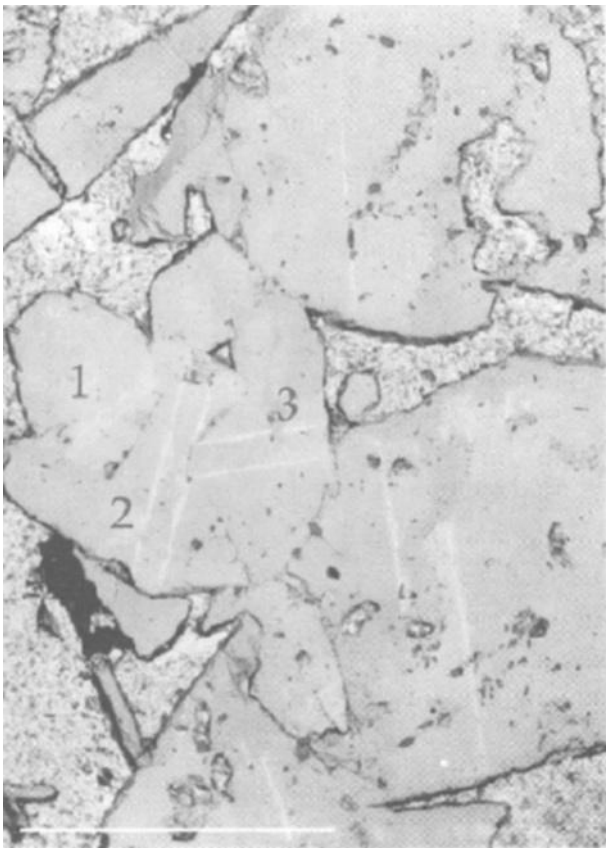

Figure 1b: A backscattered electron image of the outlined area in (a) showing three inter-penetrating crystals (labelled 1, 2 and 3), each with two parallel Cr-rich lamellae (white lines) in the central parts of the crystals. Scale bar is 1 mm.

Although the ruby rock is a rare and highly prized jewellery-grade ornamental stone, individual crystals of the ruby-sapphire corundum are typically strongly colour zoned, often intergrown, contain inclusions of the mica matrix, and commonly fractured, so that they are seldom of gem quality.

Crystal habit and colour zoning

Mineral separates from lightly crushed samples of the 'ruby rock' indicate that the corundum generally has a barrel-shaped habit with hexagonal dipyramids; some crystals have very small rhombohedral faces. Individual crystals are highly variable in size and typically range from 2–6 × 1–2 mm. The crystals are horizontally striated and many occur as interpenetrating clusters as shown in *Figures 1a and 1b*.

In 0.035 mm-thick thin section, the New Zealand corundum is invariably spectacularly coloured and in the red range, may be pale-pink/pinkish-orange/carmine/dark ruby-red; in the blue range it may be pale-blue/bluish-green/deep-violet (*Figure 2*). In sections approximately parallel to the *c*-axis the corundum is often colourless at both extremities and shows a gradual increase in pink coloration towards the central part where there are usually two thin parallel ruby-red bands separated by a thicker central band of either pale-pink or blue/violet colour (*Figures 1a and 2*). While pink and blue growth zoning is clearly present, the development of partial rims of sapphire in many crystals appears to be a replacement that extends inwards along parting planes (*Figure 3*). The patchy distribution of blue coloration such as that shown in *Figure 3* is also suggestive of replacement. As separates, such grains appear dark bluish-grey.

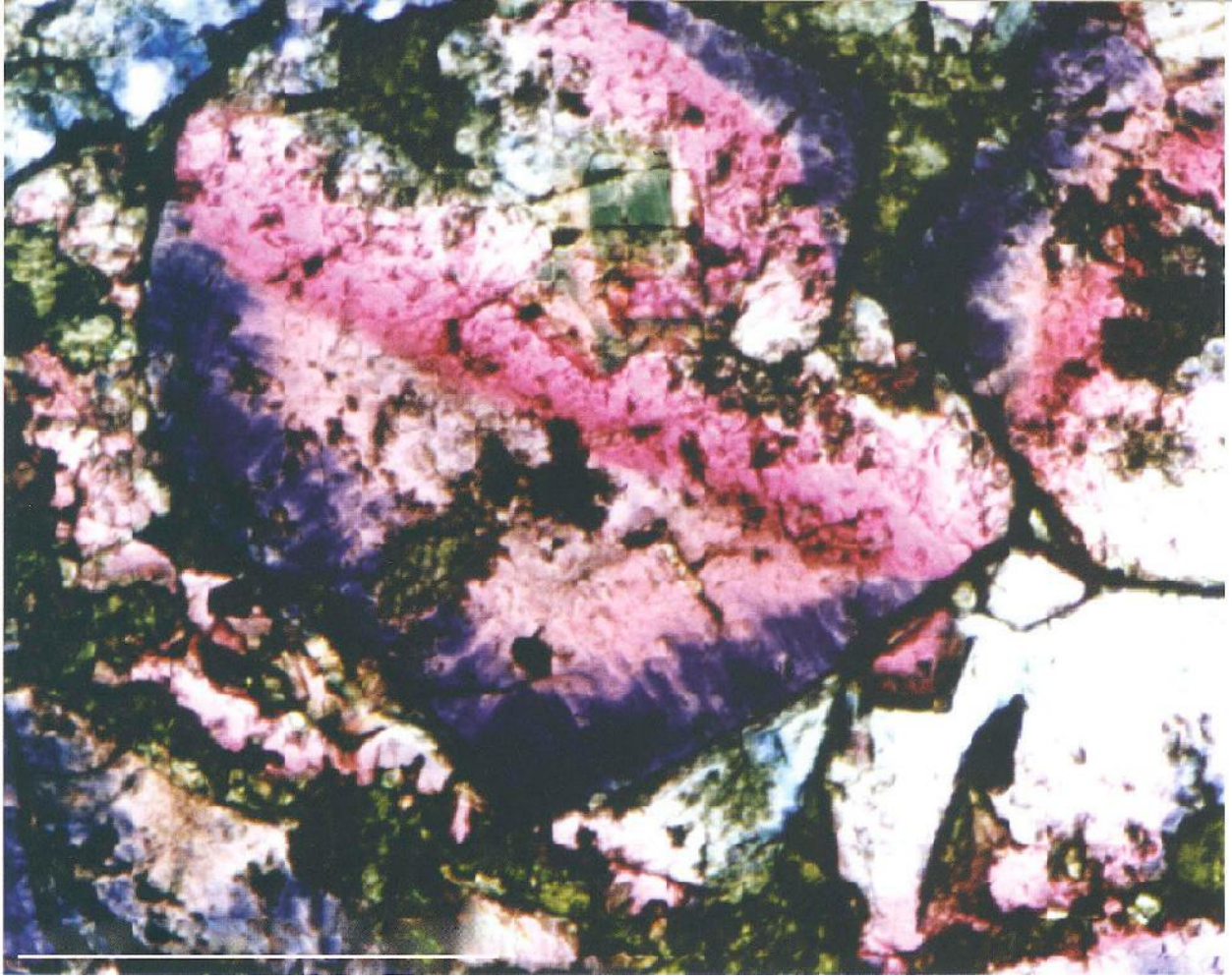

Figure 2: Thin section photomicrograph (plane polarized light) of a zoned corundum crystal showing marginal sapphire (blue) zoning and possible inward replacement along parting planes. Scale bar is 2 mm.

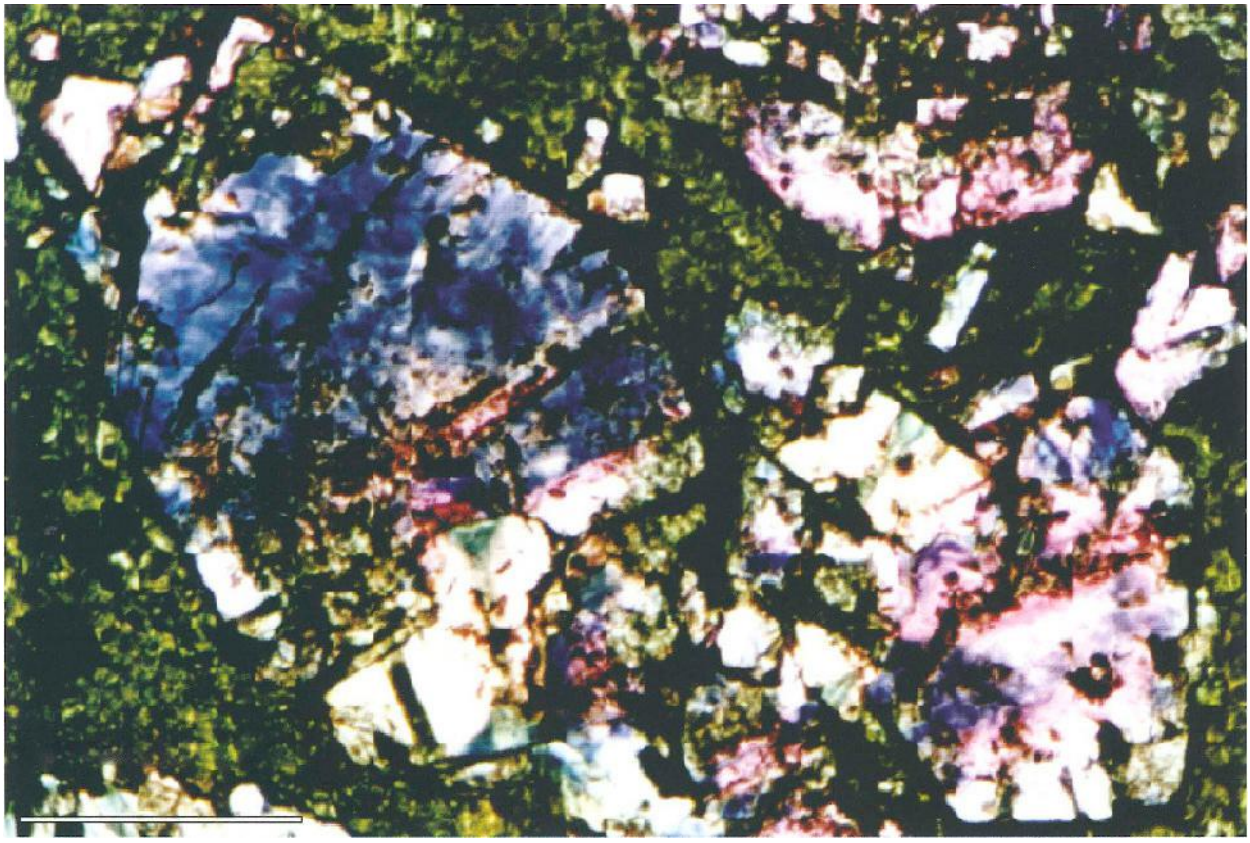

Figure 3: Thin section photomicrograph (plane polarized light) showing patchy blue coloration in pale pink-colourless corundum crystals within a chromian muscovite-margarite matrix. Scale bar is 2 mm.

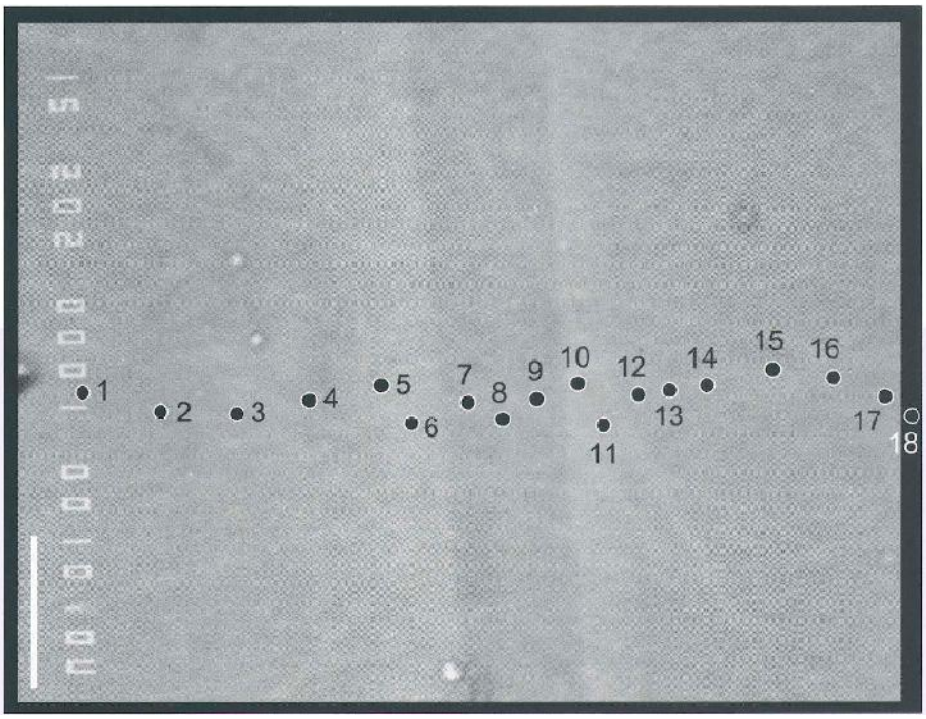

Figure 4: Backscattered electron image of the central part of a zoned corundum crystal. In plane polarized light, the central dark grey band is blue (analyses 7–9); the light grey marginal zones are dark ruby-red (analyses 5, 6, 10 and 11); the remainder of the crystal is pale to very pale-pink. Numbered spots are locations of electron microprobe spot analyses listed in Table I and plotted in Figure 5. Scale bar is 10 μm.

Chemical Composition

Electron microprobe analyses across the central part of a zoned corundum crystal (*Figure 4*) are given in *Table I* and show that Cr_2O_3 ranges from 2.67–6.24 wt.%, Fe_2O_3 (as total iron) from 0.13–0.54 wt.%, and TiO_2 from 0.01–0.18 wt.%. Compositional variation across the zoned crystal is shown in *Figure 5*. The central blue band has the lowest Cr and highest Fe and Ti contents; adjacent thin red bands have the highest Cr and lowest Fe and Ti contents. Chromium progressively decreases outwards from the central red bands and iron increases in the very pale pink areas of the crystal furthest away from the red bands. These variations may result from a number of possible substitutions, such as, $Cr^{3+} \leftrightarrow Al^{3+}$, $Fe^{3+} \leftrightarrow Al^{3+}$, and $Fe^{2+} + Ti^{4+} \leftrightarrow 2Al^{3+}$.

The spot analyses listed in *Table I* also indicate the presence of SiO_2 ranging from 0.06–0.14 wt.%. These values are significantly higher than microprobe values of between 0.005–0.02 wt.% in corundum recorded by Schmetzer and Bank (1981). However, ruby corundum (0.98–3.83 wt.% Cr_2O_3) from O'Briens Claims, Zimbabwe, analysed by Schreyer *et al.* (1981), lack iron and have between 0.02 and 0.94 wt.% TiO_2 and between 0.00 and 0.66 wt.% SiO_2. An inverse relation between Ti and Si in two analyses listed by Schreyer *et al.* (1981) suggests that Si may proxy for Ti according to the substitution $Si^{4+} \leftrightarrow Ti^{4+}$. However, the data from the New Zealand corundum show no such inverse relationship (*Table I*), and the status of Si in corundum remains problematical. Backscattered electron imaging of many corundum crystals indicates the presence of 'ghost-like' crystal shapes of matrix mica (muscovite and margarite) from which the corundum grew (e.g. see Figure 7 of Grapes and Palmer, 1996). This suggests that some or possibly all SiO_2 analysed in the corundum (*Table I*) is due to contamination caused by the electron beam impinging on subsurface mica in the 0.035 mm-thick thin section. Although not routinely analysed for,

Table I: Electron microprobe analyses (wt.% oxide) of a colour zoned corundum‡.

Analysis	1	2	3	4	5	6	7	8	9
	PP	PP	PP	P	DP	DP	B	B	B
TiO_2	0.02	0.01	0.04	0.02	0.01	0.03	0.18	0.17	0.15
Al_2O_3	96.50	96.35	96.62	96.22	94.08	93.97	96.31	96.71	96.31
Fe_2O_3†	0.20	0.23	0.18	0.17	0.19	0.24	0.47	0.52	0.54
Cr_2O_3	3.17	3.62	3.73	4.05	5.52	6.09	2.67	2.69	2.72
Total	**99.89**	**100.18**	**100.57**	**100.46**	**99.80**	**100.33**	**99.63**	**100.09**	**99.72**
SiO_2	0.07	0.06	0.11	0.09	0.12	0.11	0.09	0.10	0.13
Fe_2O_3*	0.18	0.22	0.14	0.15	0.16	0.21	0.29	0.35	0.39
FeO*	0.02	0.01	0.04	0.02	0.01	0.03	0.16	0.15	0.13
Analysis	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**
	DP	DP	P	P	P	PP	PP	PP	PP
TiO_2	0.01	0.04	0.03	0.02	0.01	0.04	0.03	0.02	0.03
Al_2O_3	93.77	94.56	95.01	95.70	95.16	95.98	95.68	95.95	96.35
Fe_2O_3†	0.18	0.16	0.20	0.13	0.24	0.21	0.18	0.23	0.26
Cr_2O_3	6.24	5.44	4.20	4.01	4.00	3.68	3.41	3.45	3.31
Total	**100.20**	**100.20**	**99.44**	**99.86**	**99.41**	**99.91**	**99.30**	**99.65**	**99.95**
SiO_2	0.13	0.14	0.09	0.12	0.13	0.08	0.11	0.06	0.06
Fe_2O_3*	0.17	0.12	0.15	0.10	0.20	0.15	0.13	0.18	0.11
FeO*	0.01	0.04	0.03	0.02	0.01	0.04	0.03	0.02	0.03

‡Analysis numbers correspond with locations shown in backscattered electron image (*Figure 4*).
†All iron as Fe_2O_3
* FeO and Fe_2O_3 calculated on the basis of rhombohedral stoichiometry of 3 oxygens and 2 cations. SiO_2 values not included in the recalculation.
Colour observed in plane polarized light in a 0.035 mm thick microscope thin section. PP = pale pink; P = pink; DP = dark pink; B = blue.

detectable amounts of Ca and K in some corundum analyses would support this assumption.

Recalculation of the corundum on a rhombohedral oxide basis (i.e. 2 cations and 3 oxygens) gives stoichiometric amounts of FeO (0.01–0.16 wt.%) and Fe_2O_3 (0.10–0.39 wt.%) that are also given *Table I*, and the relation between Cr^{3+}, Fe^{3+} and (Fe^{2+} + Ti^{4+}) is shown in *Figure 6* and allows the intensity of pink coloration to be contoured.

Discussion

The observed colour of corundum is explained in terms of Cr, Fe, Ti and V (e.g. Loeffler and Burns, 1976; Schmetzer and Bank, 1981) which are often present in trace amounts. Red colour is due to the presence of Cr^{3+} (intensified by V^{3+}), green coloration is due to Fe^{3+}, and blue colour is caused by the presence of Fe^{2+} + Ti^{4+}. The most striking feature of the New Zealand corundum is its high chromium content and colour zonation. Grapes and Palmer (1996) showed that Cr contents in the corundum range from <0.5 to as high as 13 wt.% Cr_2O_3 with such variation occurring over only a few micrometres; a smaller range, but still significant is shown in *Figure 5*. The highest Cr-contents of the corundum are recorded in the thin ruby-red growth zones that typically occur on two opposing {0001} planes within the central parts of crystals and formed during the early stages of growth.

Figure 5: Plot of wt.% oxide versus distance (μm) along the electron microprobe traverse across the central part of the zoned corundum crystal shown in Figure 4. Analysis 1 is at 0 μm. Data are tabulated in Table I. Colour shading represents colours and colour intensity observed optically in plane polarized light.

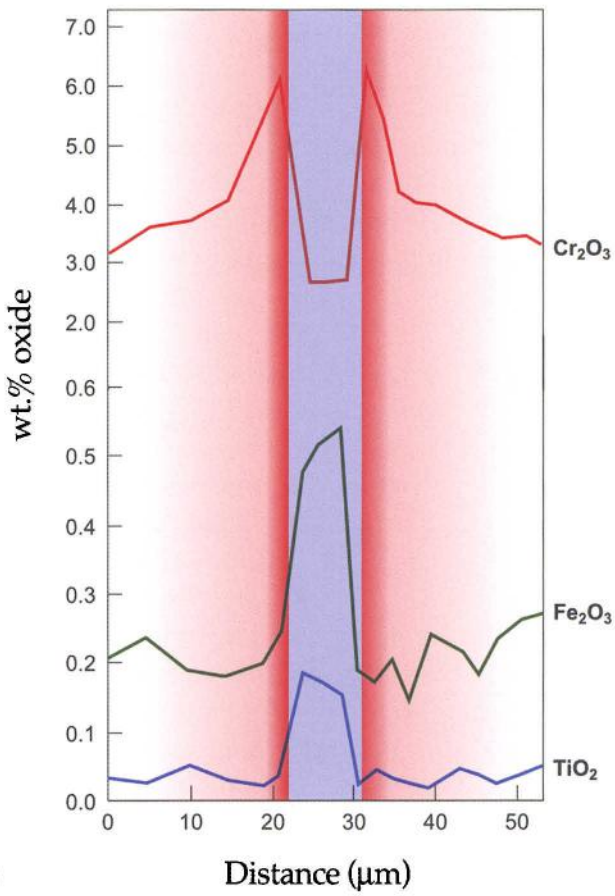

Subsequent growth to form the characteristic steep pyramidal terminations and barrel-shaped habits was accompanied by a decreasing amount of Cr-substitution, presumably reflecting gradually diminishing amounts of Cr in the fluid leading to the development of optically colourless corundum with <0.5 wt.% Cr_2O_3. The central blue sections of many crystals and areas of marginal sapphire replacement also have significant Cr_2O_3 ranging between 1.32 and 3.06 wt.%, TiO_2 contents of 0.04–0.63 wt.% and computed FeO contents of 0.13–0.25 wt.% (Grapes and Palmer, 1996) that can be related to intensity

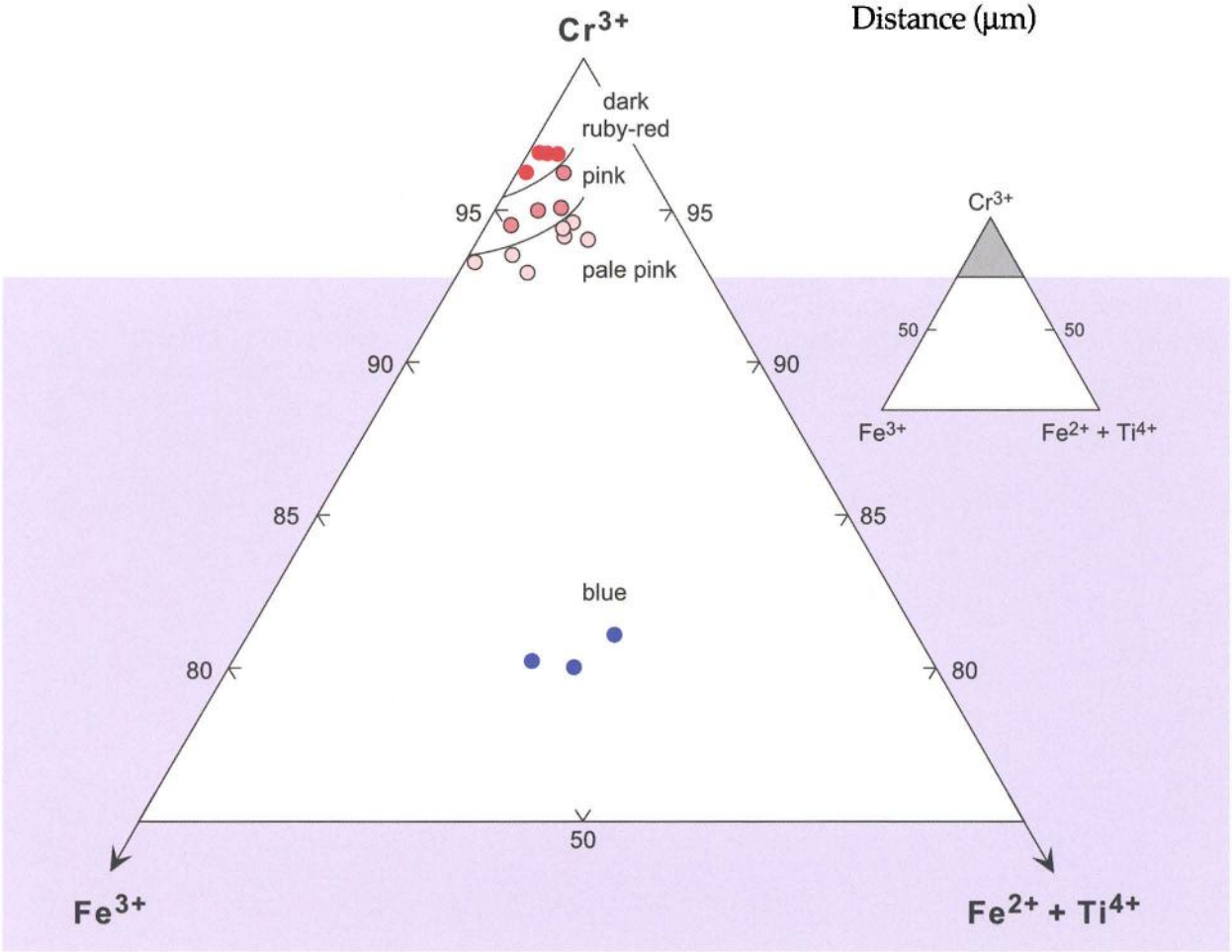

Figure 6: Plot of corundum compositions given in Table I in terms of Cr^{3+}, Fe^{3+} and (Fe^{2+} + Ti^{4+}) showing relationship to colours observed under plane polarized light in a microscope thin section with a thickness of 0.035 mm.

of blue coloration. A change in colour from pale-blue to dark violet-blue is associated with increasing Ti and Fe; in thin section this masks the usual pink coloration imparted by Cr^{3+} (*Figure 2*), but in hand-specimen it shows as a characteristic deep-purple in many crystals (e.g. see Figures 1 and 2 of Brown and Bracewell, 1996).

The Cr-rich environment in which the corundum grew is considered to be the result of metasomatic reaction between ultra-mafic rocks with a mean of 2023 ppm Cr and inclusions of Cr-poor quartzofeldspathic schist (mean of 45 ppm Cr); this took place under *T-P* conditions of 450±20°C and 5–6 kbar (Grapes and Palmer, 1996) to produce the corundum-margarite-fuchsite-tourmaline assemblage. While substitution of Cr into the corundum structure was clearly a function of the Cr-rich environment, the entry of iron (Fe^{3+} and Fe^{2+}) + Ti^{4+} may simply reflect periods at the initial and latest phase of corundum growth of diminished Cr^{3+} concentration in the fluid phase, rather than any change in redox potential.

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Red and green labradorite feldspar from Congo

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Abstract: *Two red and one green transparent cut feldspars from the Democratic Republic of Congo have been investigated and are compared with similar material from Oregon (USA). The specimens from Congo display a deeper colour saturation, which make these new findings very attractive gemstones. The studied specimens belong to the labradorite variety of plagioclase feldspar. Microscopically the stones are rather clean, and only some twin lamellae, hollow channels and fine inclusions are present.*

The red and green colours in labradorites from both Congo and Oregon are due to copper, and the differences in colour are attributed to tiny copper colloids of different size. The Congo labradorites contain about 20× more copper than the Oregon stones.

General considerations about commercial terms and mineralogical nomenclature of feldspars are presented.

Keywords: *Congo, copper, feldspar, labradorite, plagioclase*

Introduction and sample description

Recently, the SSEF Swiss Gemmological Institute received two feldspars from Dr Laurent Sikirdji (Gemfrance, St.-Ismier, France) for testing. Specimen RC1 (1.967 ct) is intensely red and specimen GC1 (4.856 ct) is of a saturated green colour. A similar red specimen (RC2) of 2.969 ct was provided by Peter Salzmann (Lucerne, Switzerland). The location of the source is not yet exactly known; however, they are said to originate from the Democratic Republic of Congo (L. Sikirdji, pers. comm., 2003). The author has seen several faceted red feldspars from Congo up to 10 ct during the 2003 Tucson show. These feldspars (*Figure 1*) strongly resemble sunstone labradorite from Oregon in the USA (Pough, 1983; Hofmeister and Rossman, 1985; Johnston *et al.*, 1991), but display a more vivid and saturated colour than the latter. The occurrence of red and green plagioclase is not uncommon. Hofmeister and Rossman (1985) and Johnston *et al.* (1991) described in detail that such colours may even occur within a single specimen, often accompanied by a spangling effect (aventurescence or schiller) as a result of oriented small red platelets. The red and green samples examined in our study showed no spangling effect (aventurescence), although Fritsch (2002) observed such an effect in stones from the same general location.

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Figure 1: Labradorite feldspar from Congo (two intense red stones on the left, and one intense green on the upper right) and Oregon (all other stones), showing the colour variations from intense red and green (Congo) to pale red, pale yellow, pale green and colourless (Oregon). © Dr Michael S. Krzemnicki, SSEF Swiss Gemmological Institute.

On the market (Tucson 2003), the red and green stones from Congo have been offered as red andesine (an intermediate member of the plagioclase feldspar solid solution series). In the literature, gem-quality red andesine from Congo was first mentioned by Fritsch (2002). Below, physical, chemical and spectroscopic data of the studied samples are compared to similar feldspars from other sources (Hofmeister and Rossmann, 1985; Johnston *et al.*, 1991; Laurs, 2002). Then the nomenclature of sunstone feldspar is discussed, taking into account the controversy among gemmologists in 1992 (Gübelin, 1992; Hanneman, 1992; Hoover, 1992; Johnston, 1992; Liddicoat, 1992a, 1992b).

Table I: Gemmological properties of labradorite and andesine from Congo and Oregon (USA).

	Labradorite from Congo	Andesine from Congo	Labradorite from Oregon
	(this study)	Fritsch (2002)	(this study)
weight	1.97 to 4.856 ct	1.04 to 8.95 ct	2.91 and 3.63 ct
SG	2.68 to 2.70	2.67	2.70 and 2.72
RI	RIα 1.553 to 1.555 RIγ 1.562 to 1.563	1.551 1.560	1.560 and 1.565 1.570 and 1.572
birefringence	0.007 to 0.011	0.009	0.007 and 0.010
optic nature	biaxial (positive)	biaxial (negative)	biaxial
colour	red (RC1 and RC2) and green (GC1)	red	pale red (RO1) and pale green (GO1)
pleochrosim	very weak (red samples RC1 and RC2) to distinct (green sample GC1)	very weak	very weak (red sample RO1) to distinct (green sample GO1)
transparency	transparent	transparent	transparent
LW-UV	weak to distinct orange	weak to medium orange	none
SW-UV	none	weak red	none
observations	milky turbidity green labradorite: red under incandescent light	'schiller' effect	slight 'schiller' effect

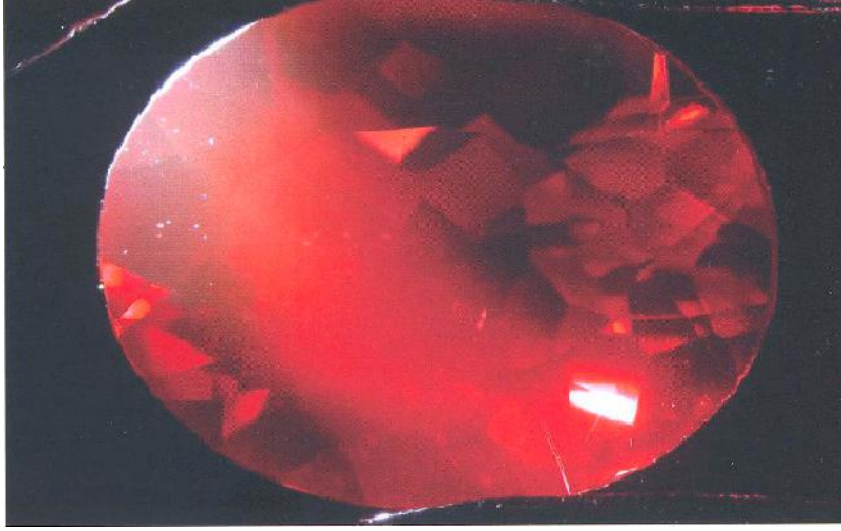

Figure 2: Red labradorite RC2 from the Congo revealing its milky turbidity. © Dr Michael S. Krzemnicki, SSEF Swiss Gemmological Institute.

Gemmological properties

The samples were first studied using classical gemmological equipment and methods, namely, the refractometer, hydrostatic balance, polariscope, long- and short-wave ultraviolet light (LW-UV and SW-UV) and microscope. RC1, RC2 and GC1 showed more or less equal values for refractive indices, birefringence and specific gravity (*Table I*). All samples were determined as optically biaxial positive. The red specimens (RC1, RC2) showed only very weak pleochroism, whereas the green sample (GC1) presented a distinct pleochroism from greenish-yellow to bluish-green. Hofmeister and Rossman (1985) also found only minor pleochroism in the red sunstone labradorites from Oregon (USA), but a distinct dichroism in their green samples. Under LW-UV, the red samples showed a weak orange glow, whereas the green stone appeared distinctly orange. Under SW-UV, no fluorescence was observed in RC1, RC2 and GC1, in contrast to Fritsch (2002) who reported a weak red fluorescence and even some surface related bluish luminescence in his stones from Congo.

Microscopic observations

All samples are rather clean with only a few inclusions. The red stones show a relatively uniform colour distribution, which was confirmed in immersion liquid.

Specimen RC1 shows a step-like healing fissure along a cleavage direction. RC2 (*Figures 2* and *4*) contains several distinct twin lamellae and a few parallel hollow channels; in some parts along but not within the twin lamellae, very tiny particles were observed. These particles are responsible for a general milky turbidity, which may be concentrated in zones. No reflecting inclusions producing aventurescence were observed.

The colour of the green stone (GC1) is distinctly lamellar zoned. With high magnification, small parallel fluid channels and trails of tiny inclusions are visible. Furthermore, the specimen shows a milky turbidity and a reddish hue in white incident light (*Figure 3*).

UV-Vis spectroscopic analyses

Spectra were recorded with a Hitachi U-4001 spectrophotometer from 800 to 280 nm (UV-Vis) and from 2500 to 280 nm to record absorption in the near-infrared region.

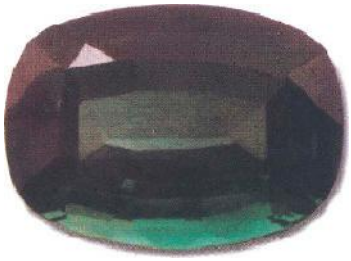

Figure 3: Green labradorite GC1 from the Congo displaying a trace of pale red in white incident light. © Dr Michael S. Krzemnicki, SSEF Swiss Gemmological Institute.

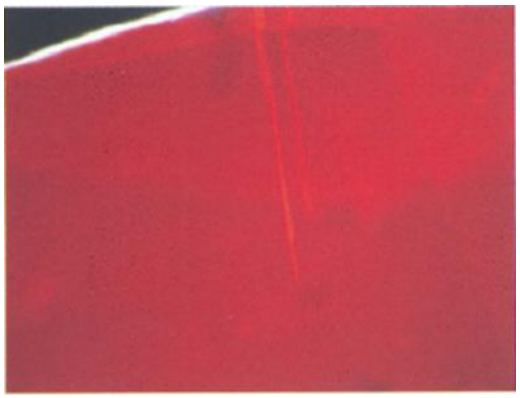

Figure 4: Lines of tiny inclusions and milky turbidity in specimen RC2 from the Congo. Magnification 50×. © Dr Michael S. Krzemnicki, SSEF Swiss Gemmological Institute.

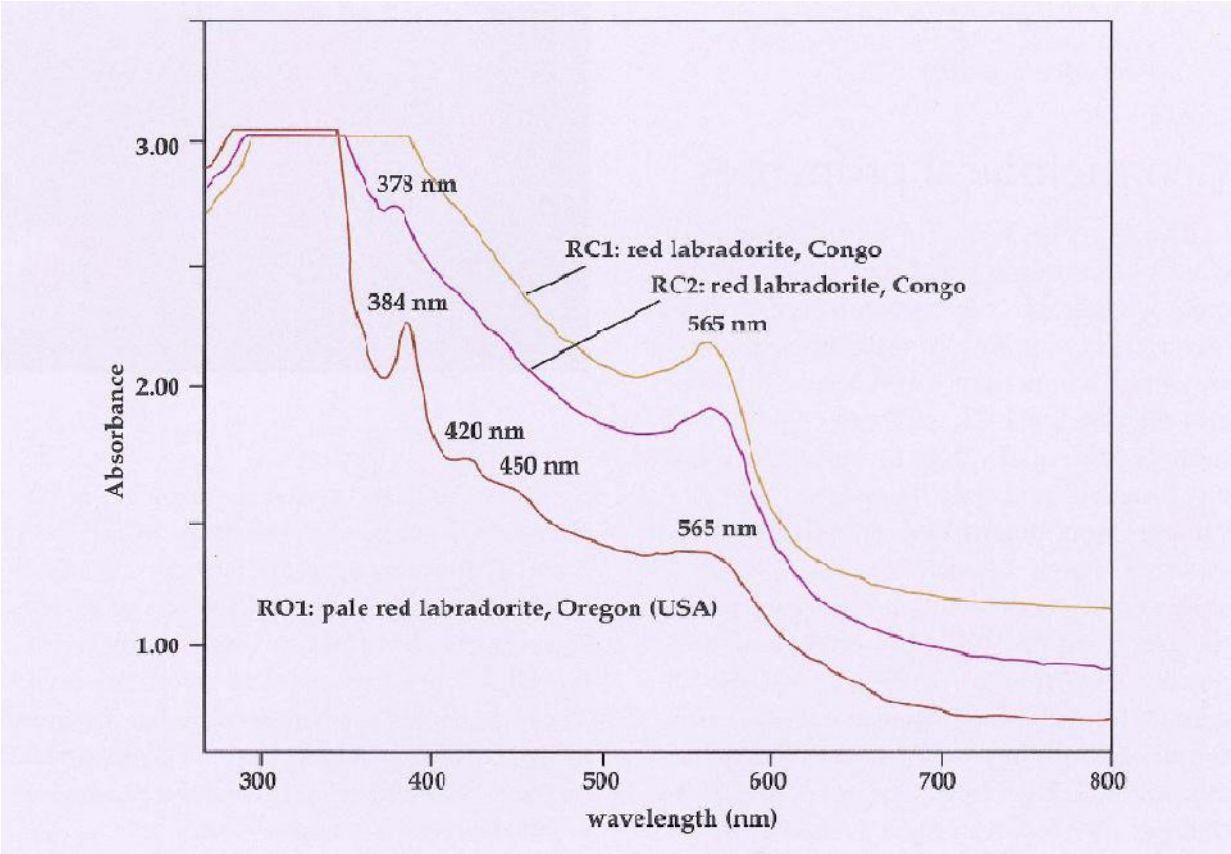

Figure 5a: Unpolarized UV-Vis spectra of red labradorite from Congo and Oregon (USA). Both curves are quite similar with a distinct absorption band at 565-580 nm due to copper.

The red specimens (*Figure 5a*) were measured without a polarizing filter, as only very weak pleochroism was observed. The UV-Vis spectra are characterized by a general increase in absorption towards ultraviolet (strong UV tail). However, two distinct absorption bands at 565 and 380 nm are present. In *Figure 5a* the spectra of RC1 and RC2 are compared with a pale red sunstone labradorite (RO1) from Oregon (USA).

The green sample (*Figure 5b*) shows two different absorption curves for the yellowish-green and bluish-green directions. The yellowish-green direction is a rather flat curve with a broad minimum at 620 nm and a small absorption band at about 430 nm, partly masked by the steep increase of absorption towards ultraviolet (total absorption at ~370 nm). The bluish-green direction shows no distinct minimum at 620 nm, and a broad absorption band is centred at 680 nm. The spectra of green labradorite from Oregon (sample GO1) are somewhat similar. However, if the bluish-green and green direction spectra are compared (*Figure 5b*), the broad absorption band is shifted towards 620 nm and is less pronounced. In the light red direction, no minimum is found at 620 nm, but there is a general decrease in absorption towards the near-infrared. Furthermore, the green labradorite from Oregon shows not only absorption at 420 nm, but also two bands at 450 nm (weak) and 380 nm.

Discussion of UV-Vis spectra and colour cause

According to Hofmeister and Rossman (1985) the colour in labradorites from Oregon (USA) is correlated with the concentration of copper. Red labradorites show the highest copper content (150-200 ppm CuO), whereas yellow varieties contain the lowest concentrations (0-40 ppm).

The colour is further dependent on Cu exsolution temperature, rate of Cu diffusion and aggregation (Cu^0 colloids) and state of copper (Cu^0 or Cu^+).

(a) Red labradorites

After Hofmeister and Rossmann (1985), the band at 560 to 585 nm combined with a general increase of absorption towards ultraviolet is attributed to intrinsic absorption by tiny Cu^0 particles which are too small to scatter light (< 22 nm), and produces a red colour. The band-shift from 560 nm towards shorter wavelengths, coupled with a broadening of the absorption band is related to increasing size of the Cu^0 colloids. As the spectra of the red samples from Congo (RC1 and RC2) are very similar to that from Oregon (RO1) in the 565 nm spectral region, the copper colloids are most probably of a very similar size and measure only a few nanometres (Hofmeister and Rossman, 1985).

According to Hofmeister and Rossman (1985), the bands at 380, 420 and 450 nm are due to Fe^{3+} in tetrahedral sites in the feldspar structure. In the samples from Congo, the band at 380 nm is present but smaller, and those at 420 nm and 450 nm are absent. The latter, however, may be masked by the strong UV absorption, probably resulting from a much higher copper concentration in stones from Congo (up to 0.329 wt.% CuO in RC1) compared to material from Oregon (0.015 wt.% CuO in RO1). When extending the spectra into the near-infrared (NIR) up to 2000 nm, the samples from Congo show a broad absorption band at about 1260 to 1310 nm. According to Hofmeister and Rossman (1985), this absorption band can be attributed to Fe^{2+}.

(b) Green labradorites

In 1985, Hofmeister and Rossman presented several models involving tiny copper clusters (i.e. pairs of Cu^0 atoms) or $Cu^0 - Cu^+$ intervalence charge transfer to explain the green colour, but still the cause of the green colour in copper-bearing labradorite remains rather an enigma.

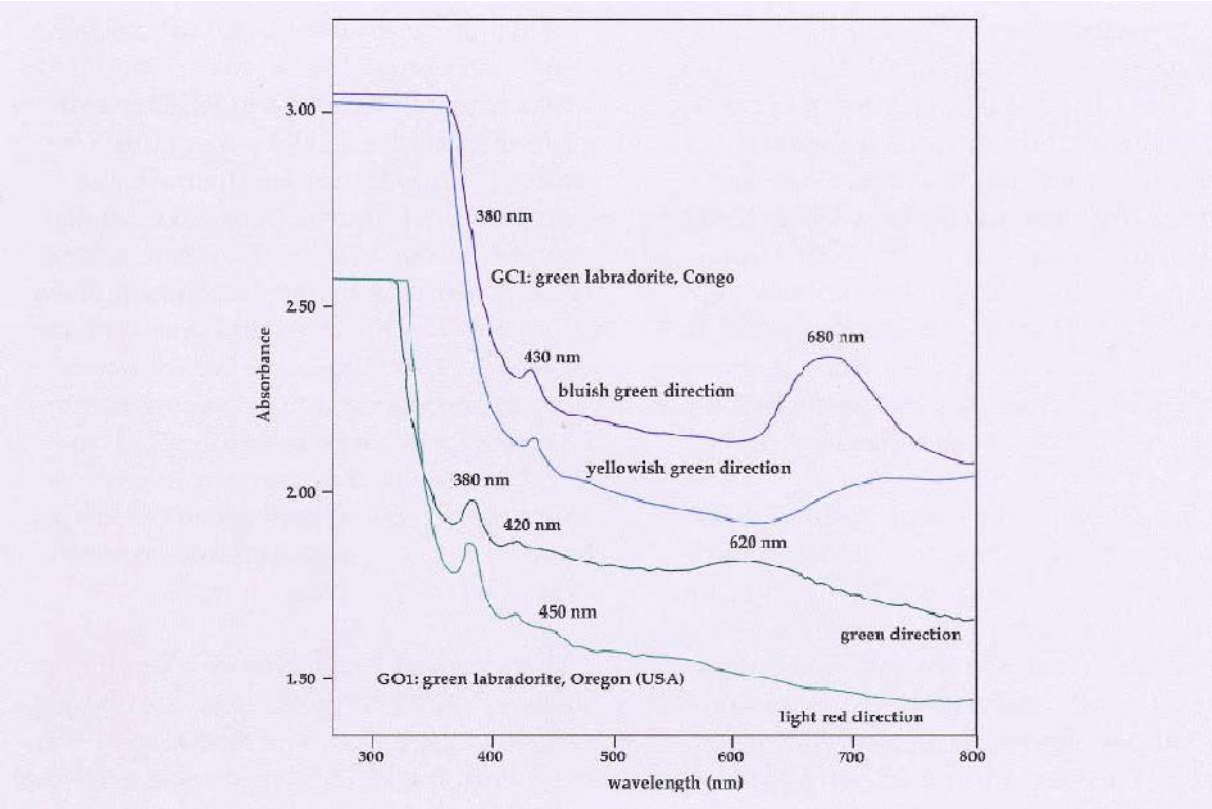

Figure 5b: Polarized UV-Vis spectra of green labradorite from Congo and Oregon (USA). Both labradorites are characterized by distinct pleochroism.

Table II: Chemical compositions of labradorites from Congo and Oregon, USA.

Sample	RC1*	RC2*	GC1*	RO1	Johnston 1991	GO1*
Colour	red	red	green	pale red	pale red	green
Origin		Congo			Oregon, USA	
SiO_2	53.865	55.958	57.570	51.56	51.83	52.370
Al_2O_3	30.182	28.139	25.612	30.23	30.51	31.018
CaO	9.766	10.018	10.845	13.53	13.43	11.902
Na_2O	5.051	4.950	4.914	3.78	3.74	3.744
K_2O	0.195	0.097	0.098	0.02	0.11	0.197
MgO	b.d.	b.d.	b.d.	0.16	b.d.	b.d.
TiO_2	0.149	0.160	0.141	0.02	0.043	0.081
Fe_2O_3	0.448	0.470	0.549	0.48	0.03	0.641
MnO	0.001	0.002	0.004	0.06	0.010	0.021
Cr_2O_3	0.007	b.d.	b.d.	n.a.	n.a.	0.010
V_2O_3	0.007	b.d.	0.006	n.a.	n.a.	b.d.
CuO	0.329	0.205	0.260	0.015*	0.011	0.010
ZnO	b.d.	0.001	0.001	n.a.	n.a.	0.006
Total	**100.00**	**100.00**	**100.00**	**99.83**	**99.73**	**100.00**
anorthite%	52	53	55	66	66	64
albite%	48	47	45	34	34	36

*determined with ED-XRF
n.a. not analysed; b.d. below detection limit

The green colour in labradorite sample GC1 from Congo is also attributed to copper and, as in the red labradorites, this causes strong absorption towards the ultraviolet. The band at 430 nm is attributed to Fe^{3+}, whereas the other iron bands at 450 and 380 nm, which are present in the UV-Vis spectrum of green labradorite from Oregon, may be masked by the strong absorption. Again, this is due to the higher copper content of the Congo stones compared to those from Oregon (0.26 vs. 0.01 wt.% CuO respectively).

The difference in pleochroism of green labradorite from Oregon (GO1) and the specimen from Congo (GC1) is clearly illustrated in the spectra. In sample GC1, the minimum at 620 nm combined with an increase in absorption towards the near infrared (800 nm) is responsible for the yellowish-green hue, whereas the green specimen from Oregon (GO1) shows a constant decrease in absorption towards the near-infrared, thus resulting in a pale red pleochroic colour.

When using incident light, the red specimens from Congo display an off-white milky turbidity (*Figure 2*), which is attributed to scattering (Steffen, 2000) by tiny particles (probably copper) apparently not large enough to produce aventurescence. Similar incident illumination of the green sample (GC1) produces a distinct red, most probably due to the presence of relatively larger copper colloids (a few nm to 22 nm in diameter); these are also thought to be responsible for the colour of the red labradorites RC1 and RC2. These colloid clusters add their red component to the overall green colour, produced by smaller Cu^0 clusters and possibly Cu^0 – Cu^+ intervalence charge transfer.

In conclusion, it can be stated that the causes of colour in these feldspars are quite complex. Hofmeister and Rossman (1985) and Johnston *et al.* (1991) established that 100 ppm copper is sufficient to cause a red colour in sunstone labradorite from Oregon. In the studied samples from Congo, the Cu con-

centration exceeds this value by a factor of >20 (2000 – 3300 ppm Cu), and could explain the much more pronounced UV absorption of these stones.

Chemical investigations

Semi-quantitative chemical analyses were carried out with a Spectrace 5000 Tracor ED-XRF on three cut stones from Congo. The results are listed in *Table II*, together with analyses of Oregon stones. Apart from the main constituents Si and Al, the specimens reveal calcium dominating sodium (about 10 wt.% CaO versus 5 wt.% Na_2O). Potassium is only a minor constituent. Furthermore, all samples contain minor amounts of copper (up to 0.33 wt.% CuO), iron (0.55 wt.% Fe_2O_3), titanium, and traces of Mn, Cr, V and Zn.

Most feldspars may be classified in the ternary K-Na-Ca-diagram (*Figure 6*) with the end members orthoclase (potassium-feldspar), albite (sodium-feldspar) and anorthite (calcium-feldspar). The classification of feldspar is rather complex, involving variation of both chemical composition and structural state (ordering of Si and Al on distinct tetrahedral sites), the latter depending on the temperature of crystallization and on subsequent thermal history (Deer *et al.*, 1992; Hänni, 1989). At high temperature, there is solid solution between albite and orthoclase (alkali feldspar series) and between albite and anorthite (plagioclase series), respectively. At lower temperature, there are some miscibility gaps, which result in exsolution of different feldspar phases, often causing optical effects such as iridescence and light scattering. The plagioclases are classified chemically into the varieties albite, oligoclase, andesine, labradorite, bytownite and anorthite, characterized by a gradual increase in RI and SG towards the calcium end member anorthite. The intermediate plagioclase varieties are basically defined for convenience and have no structural significance (Deer *et al.*, 1992).

The investigated feldspars from Congo are very low in potassium and thus belong to the plagioclase series. When calculating their composition and their place in the plagioclase solid solution series, the Congo feldspars lie in a range slightly over the 50% mark of the anorthite component, which is the limit between andesine and labradorite. In *Figure 6* they are plotted together with labradorite samples from Oregon. Their position in the labradorite field is near the andesine boundary, and thus they may be considered as sodic labradorite, in contrast to the calcic labradorites from Oregon. This conclusion is supported by RI and SG values, which are at the lower end of the labradorite range. As these samples from Congo are very close to the andesine/labradorite boundary, it is possible that further sampling of red and green feldspars from Congo may reveal a wider range of chemical compositions which could extend into the andesine field of the ternary feldspar plot (Fritsch, 2002; L. Sikirdji, pers. comm., 2003).

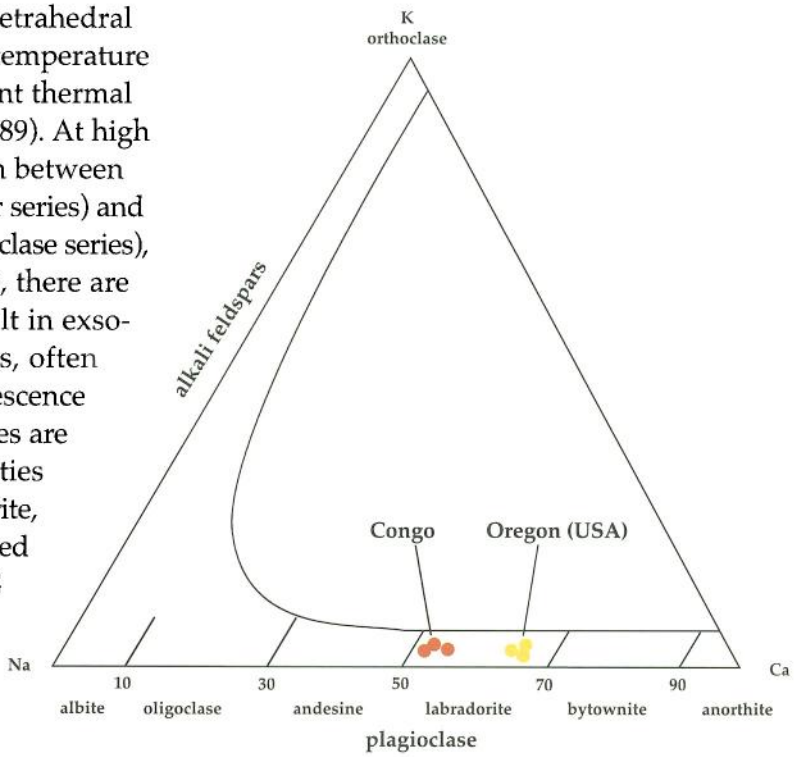

Figure 6: Ternary feldspar plot indicating the composition of the samples from Congo and Oregon (USA).

The labradorites from Congo are in many aspects very similar to the material from Oregon (USA), but have a lower anorthite content (less Ca, see *Table II*), also reflected by slightly lower RI values (Congo: RI 1.553 to 1.563; Oregon: RI 1.560 to 1.572).

Discussion of feldspar nomenclature in gemmology

There are many commercial names for different feldspar varieties such as sunstone, moonstone, spectrolite, amazonite, etc. These names are generally based on the appearance of the feldspar, but more or less connected also to the chemistry, structure and inclusions. The discussions about sunstone or heliolite as a commercial name for the material from Oregon (Gübelin, 1992; Hanneman, 1992; Hoover, 1992; Johnston, 1992; Liddicoat, 1992a, 1992b) have illustrated that the use and correct designation of names remains a matter of discussion in the gemmological community.

Since the term sunstone is merely a matter of appearance, describing golden to red feldspars with more or less schiller (aventurescence) due to tiny inclusions (e.g. hematite platelets, copper colloids), it is well fitted to be used in the trade for many varieties of feldspar in both the plagioclase and alkali feldspar ranges (see Hänni *et al.*, 2003). It is suggested, however, that the commercial name should be followed by the correct mineralogical name, e.g. sunstone labradorite, variety of feldspar.

The term moonstone, however, should be restricted to alkali feldspars (Deer *et al.*, 1992; Hänni, 1989) showing a filmy white to pale blue sheen; this is due to scattering of light from tiny domains caused by perthitic exsolution (irregularly-shaped intergrowth of potassium-rich and sodium-rich feldspar). Stones resembling these but with a plagioclase composition (also called peristerites) may display a white sheen or a rainbow-coloured iridescence, depending on the sizes of the submicroscopic intergrowths of the calcium-rich and calcium-poor plagioclase lamellae (Deer *et al.*, 1992). When the lamellae are thick enough, multiple reflections produce iridescence (labradorescence). If all spectral colours are visible, these iridescent plagioclases (labradorites) may be called spectrolite, regardless of how much ore mineral inclusions are providing a dark background. Such iridescent plagioclases should not be called moonstones for three reasons, they differ not only in appearance (pale blue sheen vs. iridescence), but also in their structure (perthitic exsolution vs. peristeritic lamellar intergrowth) and chemical composition (alkali feldspar vs. plagioclase feldspar).

In conclusion: it is recommended that commercial names for feldspar varieties should be linked with the correct mineralogical names to avoid any confusion.

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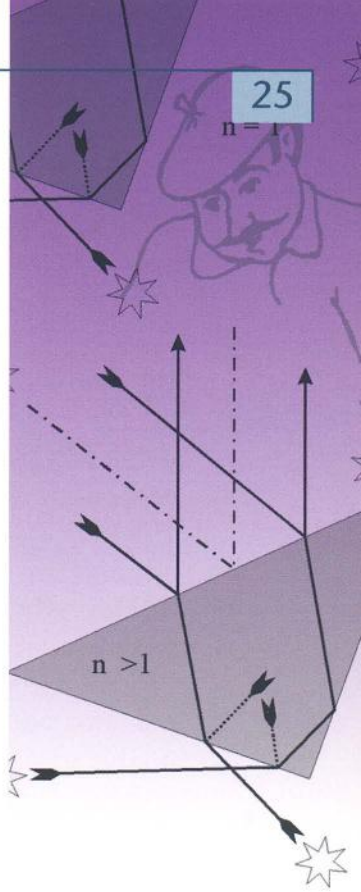

Optimizing faceting for beauty

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from the *Russian Gemological Bulletin*, 2002, 5(2), 33-41

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Abstract: *Demands for beauty of a gem are related to the level of cutting technology that has been attained. Working the stone unavoidably results in its loss of weight, so the beauty of a gem is in conflict with its potential value. The appearance of a faceted stone is produced by optical effects; therefore the problem of optimizing the faceting of a stone is reduced to determining the criteria which affect its beauty and defining the faceting parameters which best satisfy those criteria. A correctly faceted stone is a compromise between different criteria.*

This selection of optimum parameters is affected by the physical properties of the gem and how it will be used. A faceted gem is an optical device which transforms light sources into light specks on the surface, which is different for each position of a viewer. The stone will be set in a jewellery article which will most probably be seen from certain directions, thus its appearance should be optimized for the most likely combinations of viewer and light source positions. For example, for a viewer looking perpendicularly into the table, one can determine the directions of light sources which are visible in the stone. In optimizing the directions of light sources it is important to consider the influence of the viewer's head and body, which are not light sources. The body of the observer can lead to asymmetrical distribution of light on the surface of the stone and incorrect facet slopes can lead to 'dead' regions of the gem.

To optimize the arrangement of facets an artist will consider the appearance of the entire item.

Translator's Note

It is impossible to translate exactly. Word-for-word does not read properly and re-phrasing requires some word changes. In technical writings many terms have unique meaning in the subject field and are different from those in dictionaries or not listed at all; in such cases the translator must interpret the best meaning from context. It is necessary to know the subject and, ideally, the author and his intent. In this case we were fortunate to talk often with the author via Internet to clarify meanings, and ultimately, to have him review the translation.

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The history of faceting

The desire for beauty has been a characteristic of mankind throughout his history. This is shown by cave paintings and archeological excavations. Natural stones have played an enormous role in evolution of society; note the term 'Stone Age'. However, the ways of using minerals for adornment, their variety and popularity, have depended on methods of working them at the time.

The earliest stones used for adornment were probably water-worn alluvial pebbles. Later, for greater lustre, their surfaces were polished with abrasives. Because men were unable to sort abrasives by grain size, final polishing was probably done with a soft abrasive-carrier such as leather or wood. It was impossible to achieve a perfect flat surface but convex surfaces were relatively easy to polish. The hardness of accessible abrasives did not exceed that of alumina (Al_2O_3), which limited the variety of workable materials. Such materials were not valued then as they are today. Archeological discoveries and etymological studies of the names of precious stones[1, 2] show that before mastery of fine polishing techniques was common, only vividly coloured opaque minerals were popular – lazurite, turquoise, jasper, nephrite, jadeite, coloured chalcedony, etc. It was easy to approach fine polishing of the surfaces of most cryptocrystalline minerals in this list. Materials such as ruby, sapphire or emerald, and especially diamond, probably were not used then.

The next step must have been the flattening of one side of a pebble to facilitate its attachment to the surface of everyday objects, weapons or adornments. Thus arose an early form of gem-cutting called the 'cabochon'. The skills of working different stones improved considerably: carving appeared on hematite and chalcedony, and work began on transparent stones. At this time diamond was still not valued or used in adornments. Although diamond is sometimes found in nature as a well-formed octahedral crystal, the configuration of its natural faces, in combination with its optical properties, means that it does not effectively show its 'fire' (colour flashes) so valued in modern diamond cuts. Stones with convex surfaces, however, showed the phenomena caused by oriented inclusions such as 'asterism' and 'chatoyancy' very well. Stones with these effects were most highly-valued until the development of faceting with flat faces. The values of such stones were uncommonly high in regions where the quality of faceting remained poor until recently.

You need only to turn over a transparent cabochon – so that the base faces upward – to see that it looks better, that it reflects more light into the eye of the observer. Note the similarity of the form of faceted stones from regions with less advanced faceting with the form of the inverted cabochon. The evolution of cutting by flat faces is entirely natural – from the cutting of cabochons the cutters learned that a perfectly smooth rounded surface was harder to obtain than the interrupted surface formed by flat faces of arbitrary form. To form truly flat faces it is necessary to use a flat metallic disc (copper, tin or lead), like that used by a potter, for grinding and/or polishing. Initially the arrangement of facets was random, determined largely by the shape of the rough. The criterion of quality was the beauty of the external view of the gem. Cutters noticed that some stones looked better than others and tried to repeat the special features of the more beautiful ones. Thus evolved, by trial-and-error, good (but certainly not the best) proportions for faceting[3]. This was before the first attempt to mathematically define these forms. The irregular shapes of crystal fragments and alluvial pebbles did not suggest symmetrical arrangement of the facets; exceptions were the elongated crystals of beryl and tourmaline, the shape of which became the basis of the baguette and emerald cuts.

Generally the evolution of faceting follows the example of diamond[4]. Actually, when man first thought to polish the top of the diamond octahedron, the faceting of other minerals was already well-known and the proportions of these stones sufficiently perfected. Fortunately, the cubic face is the softest for diamond. The slopes of the octahedron faces

were so imperfect that it was necessary to polish a facet at the opposite end – the culet[5] – of significant size, but still the stone did not look good. Therefore cutters began to change the slopes of all the faces and, in embellishing the stone, added additional bevels with reduction and gradual disappearance of the culet. The resulting arrangement of facets is due to the four-fold symmetry of the initial octahedron. Thus was born the modern arrangement of diamond facets, with the shape of the girdle being defined by the square form inherited from its original octahedron. This style of cutting is now called 'antique' or 'cushion'. Only the tendency to form the diamond like other faceted stones explains the cutting-off of the top, for one, and subsequent efforts to alter the natural octahedron. The start of its faceting was the key to the destiny of diamond; as a result diamond acquired exceptional popularity and high price universally. As cutting experience was gained, the proportions of the gem changed and its beauty increased. In the course of time, beauty of the gem gained greater importance than its weight whereby, in modern cutting, the girdle of the most popular diamond cut, the standard round brilliant (SRB) has become perfectly circular. Here, for the first time, we see conflict between the weight and beauty of the gem; this subject will be pursued in detail later. The first attempts to calculate the parameters of faceting were made in the 18th century[6, 7], and best-known in our time came the book of Marcel Tolkowsky in 1919[8, 9]. Despite some errors[9] it was an attempt to mathematically explain the successful solution which had, by that time, already been found by the best cutters in the trade. The wide reputation of this book explains its timeliness – it appeared when the public was ready to consider that diamond should be cut only with precisely correct proportions. However, the main merit of this book is that it drew attention of a wider audience to the problem of correct parameters for faceting and served as the source of ideas for a series of other studies[10-12]. Tolkowsky's SRB solution became the basis of several standards, including some modern systems for appraising the cut-quality of diamonds. Similar studies were also conducted in Russia[13, 14].

Beauty and value or value vs. beauty

The faceted gem may serve one of two main purposes. On the one hand, the gem is the embodiment of beauty and part of jewellery, whose primary purpose is to please the eye. On the other hand, there is its material value as an investment, when it is, perhaps, kept in a bank. Strictly speaking, for the second purpose the stone can exist by itself and need not be seen – there are only important documents confirming its existence and indicating its characteristics which determine its value. Very frequently for trading (especially wholesale) there is the need for commercial transactions without seeing the stones or by people incapable of determining their quality. For this there are special systems to define and evaluate the qualitative and quantitative parameters of the stone. In modern systems the quality of cutting is appraised by separate parameters. A specialist-expert appraises the stone according to one of these systems (certification) and issues a correspondingly designed form (certificate). The illusion can result that the criteria by which the stone is certified completely represents its beauty and desirability to a consumer, which is generally not true. Certainly they try to select grading system parameters so that they do not conflict with the consumer's perception of the stone, but complete agreement is impossible to attain. The main problem of any system of certification is to provide simple and universal guidelines as to how to rank the stones. In this sense it is not required that the certification criteria fully characterize beauty, which is a very complex property of the gem and depends upon too many environmental factors including our subjective perception. The beauty of a stone and its cost are two aspects of the same thing; we should not blindly subjugate beauty to cost, or to an appraisal system unless the stone is cut exclusively for investment purposes. More than any other mineral, the beauty of diamond suffers from this double standard. From here on we will consider only questions related to achieving beauty, not looking for the best compromise

of beauty and cost, but developing each cut according to artistic taste, preference, experience and objectives.

Let's now list the four cases where existing systems of appraisal and trade operate at the expense of beauty.

1. Shape vs. weight

The sum total of beauty, rarity and durability determines the attractiveness of a stone and its price. Demand for beauty of a cut stone has changed according to changes in technology of cutting and the results which it made attainable. For people outside the gem cutting industry the beauty of gems was determined only by their colour and size (weight). Since the beginning of gem-cutting, form has become a large factor, unavoidably accompanied by its loss of weight. Form began to play an especially important role in the faceting of transparent gems. Historically, in regions where the technology of faceting lagged, the main consideration was conservation of the stone's weight. However, in countries with developed faceting technology, the priority is the correct shape of the faceted gem. Thus the majority of Indo-Chinese and Indian cutters do not favour losing weight when cutting rubies and sapphires like diamonds and European and American jewellers have a problem mounting stones in jewellery which are faceted in this way from Southeast Asia. We expect that the correct shape of the stone and its resulting beauty will improve in the course of time.

2. Weight vs. size

It is understandable that a dimensionally larger stone pleases the eye more than a small one. But people have become accustomed to buying goods by weight; they typically do this both with potatoes and with precious stones! However, the weight of a stone is not always proportional to its visible size. Round stones faceted in a country with developed faceting technology, having the same girdle diameter (that is, the same visible size) will be lighter but more beautiful than some faceted in Southeast Asia. Unfortunately some cutters cut a gem worrying only about retention of its weight, not taking its beauty into consideration. The consumer suffers. Judge for yourself – you get a heavier stone for more money, but less beautiful. For less beauty the buyer is forced to pay more money! This approach is most common in those countries where the cutters do not know how to cut or cut badly; they sell them as a certain substance by weight (they can pour more than 100 stones into one bag); in such cases the price of the finished stone differs little from the cost of the raw material from which it is made. This is like appraising a painting by the cost of its paint and canvas (this approach is justified for some paintings!). Thus stones sell by weight, not that weight is their best characteristic, but because weight is a simpler quantity to measure, and is the tradition.

3. Discrete price lists

To price stones the trade creates price lists, which are sometimes complex tables in which, as a collection of charts, the parameters of stones are divided into discrete intervals. The price of a stone jumps when it crosses an interval boundary. For example, on all price lists the price of a stone weighing 0.99 carat is considerably less that a stone weighing 1.01 carat. If the faceting of these stones is identical they cannot be visually distinguished from each other. Cutters, concerned with profit, cut stones to dimensions which correspond approximately to carat sizes, but to obtain the larger profit will deviate from the best proportions and, to be sure not to miss, will try to add a little extra; thus the beauty of the stone may suffer considerably. Similar step-grading is also used for other parameters of the stone.

4. Restriction of shape and other parameters

Systems for appraising the quality of cutting for diamonds use the standard set by Tolkowsky which, although good, is not best for specific jewellery articles. Its very specific arrangement of facets is accepted as the standard, therefore the faceting of a more beautiful stone with small deviations from these parameters can cause a reduction in its price. Non-standard faceting, even if more beautiful, is often met with hostility by stone dealers although the jeweller, to implement his design ideas, may need gems of non-standard shape and facet arrangement.

Two approaches to improving the form of faceted gems

Faceted gems involve rather complex optics. Two fundamentally different approaches are possible for the solution of any complex problem.

1. *General* (also called 'synthetic') consists of examining the problem as a whole. This method applies to improving the appearance of a faceted gem. A cutter, after completing his work on the stone, can evaluate the result by critically examining the item; it is possible to determine the best combination by comparing stones faceted with different parameters. So, by trial-and-error, experimenting cutters searched for their favourite solutions. This method is good in that it uses the exact 'image' of the faceted gem! However, this approach involves expenditure of raw material and time, although, under conditions of production manufacture this can be minimized by controlled variations in faceting parameters of individual stones. This is exactly how M. Tolkowsky found the solution which he tried to verify in his book[8]. Appearance is subjective but we can photograph a real stone in real lighting, and quantitatively evaluate its real image.

   Only recently, with the advent and wide acceptance of computers, did it become possible to mathematically simulate a faceted stone with sufficient accuracy [15-18], to draw and analyse its image by program[17, 18]. Speed and elimination of raw material loss are the advantages of this method. It is possible to criticize many possible re-reflections of rays (to discuss the finer points) taking into account partial polarization of refracted beams, and similar small deficiencies, but we must acknowledge that the best of such programs provide quality representations and make it possible to draw valuable practical conclusions[18]. The results are very entertaining and produce an especially strong impression on unenlightened people. However, the computer image, at best, only approximates an appearance of a real gem; therefore, with this method, in principle, it is not possible to gain more information than by cutting and studying real stones. Most important – a single external view does not give direct answers to numerous questions, such as: why this stone, under certain conditions behaves one way and not another. Having received answers to such questions, it is possible to learn how to design a faceted gem.

2. An *analytical* approach consists of separating the total problem into less complex components and examining them separately; for example, analysis of rays incident to the stone from a specific chosen direction, or a single row of facets, or only in one plane. It is possible to study only the influence of table size on the appearance of the stone or separately calculate only the ability of the gem to return light to the eye of the viewer. Until now the majority of researchers have adopted this approach and 'could not see the forest because of the trees'. Usually one researcher would focus on one method of solving only one part of the problem without considering other aspects. Even precise answers to the question – why does this facet work precisely so, in this condition, and not otherwise? – does not make it possible to estimate the beauty of the entire stone.

In reality these approaches are never encountered in such pure form. Even those who attempt to evaluate appearance by the method of computer simulation, divide the problem into smaller parts; for example, they separately evaluate light return and dispersion colours of rays. Even here there is unavoidable simplification – limitation to a number of re-reflections of rays, or the number of colours in the spectrum, etc. Those who choose the analytical approach must, in the end, combine the solutions of all the components of the problem. The best results in this case are obtained by those researchers who are intimate with all aspects of gems

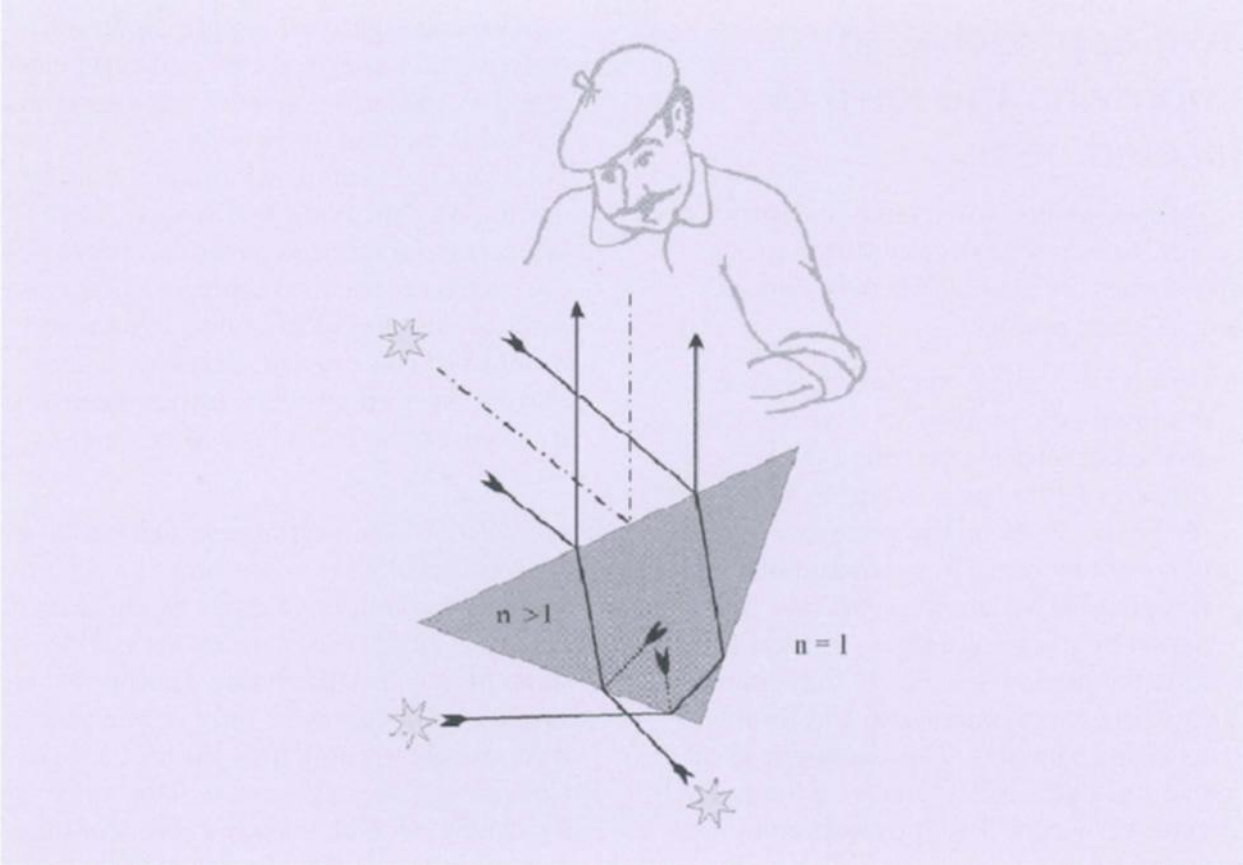

Figure 1: Light rays in a faceted gem of arbitrary shape.

from physics and mathematics to the cutting and manufacture of finished products (Marcel Tolkowsky, Bruce Harding, Anton Vasiliev*).

From here we will attempt to find how to optimize the form of a faceted gem to achieve its maximum beauty by using both approaches. One must treat the results of such studies not as the final truth, but only as tools, similar to the brushes and paints of the artist. The artist is required to create beauty, and he can use any combination of brushes and paints.

What we see in faceted stones

The appearance of a faceted stone, despite the subjectivity of the concept of beauty, is defined by optical effects. Therefore the problem of optimizing the stone by its facets is reduced to determining criteria on which its beauty depends, and to selecting faceting parameters (shape, facet slopes, and their arrangement) to best satisfy the selected criteria.

First of all, let us list what we generally see in a faceted gem, which is a convex polyhedron of arbitrary form, bounded by flat surfaces. First, consider only stones in air, of faceted, colourless, optically isotropic material with a refractive index more than one. After defining the position of the stone and the observer (*Figure 1*) we can then trace the path of each ray that leaves the stone and enters the pupil of the viewer's eye. For such rays to exist the following three factors are necessary:

1. source or sources of light;
2. the stone itself;
3. the viewer.

Usually the distance from the eye to the stone is much more than the size of any facet, the distance to the light source is still more, and the width of the light source exceeds any

*Vasiliev added by translator

facet of the gem. What the viewer sees in each part of the stone can be defined by extending all rays from the eye to the gem to their intersection with surrounding objects (*Figure 1* shows these as stars). If, in this direction, there is an object radiating light, we will see a speck of bright light in the corresponding place on the stone. If a dark object is encountered, the corresponding spot on the stone will be dark. Since the eye of the viewer is focused on the stone, a sharp picture is focused on the retina (the rear focal plane of the eye's lens) which is a mosaic of these light and dark spots. Each spot corresponds to one (or more) objects surrounding the stone. Consequently we see in the stone only reflected and refracted images of the surrounding space. Directions (relative to stone) to objects visible in the stone can be assigned corresponding angles, for example by azimuth and inclination. *Thus the faceted stone is an optical device which converts a distribution of light sources into the pattern of light specks seen on its surface.* The geometry of the faceted stone defines the manner of this conversion.

The more bright specks of light we see on the surface of the stone, the stronger it will shine. Let's call this quantitative characteristic the 'brightness' of the stone (the concept of 'brightness' is used here in the everyday sense, not in the physics sense). We can optimize the stone's brightness: if lights are placed in the same directions as each ray, the entire surface of the stone will shine! If they are moved the stone will become dark. Thus the degree of brightness of the stone depends not on its form but on the arrangement of the light sources. It depends on the form of the stone only where the light sources must be in specific places. We obtain the paradoxical conclusion that there is no poor faceting, only unsuccessful arrangement of the light sources!

It is a simple fact that the task to optimize faceting of a stone to increase its brightness for the most general case, does not make sense. There cannot always be 'ideal' cutting; it is possible to optimize one faceting parameter or another to achieve greater beauty only for given specific conditions. Now let us put limits on relative positions of light, stone and viewer.

Light return

A real faceted stone is an adornment, more precisely part of an adornment because it is rarely used for this purpose in loose form. Therefore we will study the faceted stone fastened to the surface of jewellery or other article. Let us represent this surface with a plane which passes through the stone, dividing all surrounding space into two halves. Momentarily, let us call these halves the top and bottom so that the major part of the jewellery article is found in the lower half and the viewer and light sources in the upper. Since the light source and viewer are found in the same half of space, to return light rays to the viewer the stone must *reflect* them. Simple refraction is usually insufficient to make them hit the eye of the viewer.

The polished surface of any crystal will shine by directly reflecting light. This Fresnel partial reflection does not depend on the shape of the stone (the reflected beam does not enter the stone) – it is determined by the refractive index (and angle of reflection) – therefore there is no sense in trying to optimize this lustre. Total reflection can be ensured by spraying on a metallic reflecting film, an amalgam coat, or a simple layer of foil under the stone; however, all such reflective layers are destroyed in the course of time, violating a criterion of treasure – its eternity. In most modern types of faceting the reflection of light into the eye of the observer is achieved by double total internal reflection by the facets of the pavilion. We will examine other methods of recovering light in future publications.

Let us trace the path of a ray, shown in *Figure 2*, via two opposing pavilion facets inclined at angle α from the plane of the girdle (the 'belt' of the gem). The conditions for total internal reflection of both facets are satisfied only for rays whose directions of incidence lie inside angle ϕ formed by limiting rays A-A and B-B. (Note that this range of directions ϕ inside the stone will be broader outside the stone because of refraction.) Total internal reflection is lost for ray C-C at the

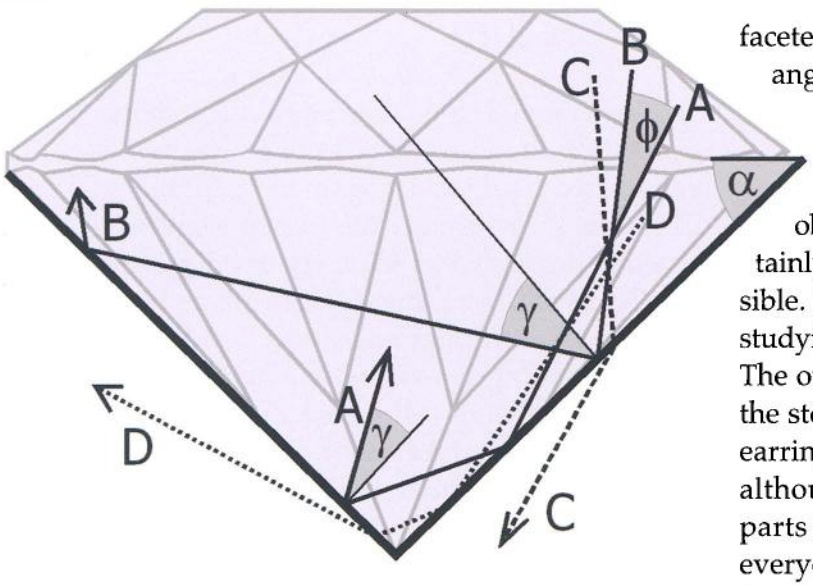

Figure 2: Internal reflections from pavilion facets.

first facet and for ray D-D at the second. Violation of total internal reflection does not mean that the ray does not entirely cease to be reflected, but the portion of the beam which is reflected drops rapidly as the angle of incidence reduces below the critical angle γ. The range of directions for all incident beams which satisfy the condition for total internal reflection can be calculated:

$$\phi = 180° - 2\gamma - 2\alpha \quad (1)$$

where $\gamma = \arcsin(1/n)$ – the critical angle for total internal reflection for the given material with refractive index n. It follows from this expression that as α decreases, ϕ increases, and the more incident rays in the stone are turned back, the greater is the possibility of their being seen, with consequently greater brightness of the stone. However, this slope (α) cannot be decreased below a certain limit. If we make the slope of these faces less than the critical angle, with the stone viewed perpendicular to its table, everything located below the stone is visible through it and all regions of the gem under the table become transparent. As a result, perception of the stone's solidity is lost and it looks 'like glass'. When tilting the stone one or more faces of the pavilion may become transparent, (especially with low refractive index) but if condition $\alpha > \gamma$ is met, only a small part of the total number are transparent, which is not as noticeable as transparency of the entire middle. In the opinion of experimental faceters[23] slope α must exceed the critical angle by 1.5-2 degrees:

$$\alpha > \gamma + 2° \quad (2).$$

The direction of the view of the observer perpendicular to the table is certainly important but not the only view possible. The priority of viewing directions for studying a stone depends on its application. The owner of a ring will most likely examine the stone perpendicular to its table. Stones in earrings are viewed from various directions, although mainly from the front (i.e. those parts not enclosed by the mount). Notice that everyone except the wearer sees a ring stone from arbitrary positions that the wearer does not.

Figure 2 shows the advantages of open-sided settings for holding gems; since parts of the casting leave the pavilion accessible to ambient light, rays D-D cannot be considered lost. This is especially advantageous for colourless stones since the absorption of such rays is less (their path through the stone is shorter, therefore they are lighter) and dispersion – that is, caused by the dispersivity of the material of the gem – is sometimes higher than usual. Consideration of rays D-D demonstrates that the optimum form of faceting depends also on how the stone is held in the jewellery.

In order to see a ray reflected by the stone, it is necessary not only to return it via the pavilion, but also to ensure its exit to air through the top of the gem. If the slope β of the crown facets is too great, instead of leaving the gem, the ray will be reflected back into it, as shown in *Figure 3*. Although faceting methods were proposed[20], by calculations for repeated internal reflections (6 and more times), it is unlikely that the authors actually tried this in practice; the effects of imperfect polishing, inaccurate geometry and un-flatness of facets in real gems accumulate with an increase in the number of reflections, and the path of a ray becomes unpredictable. It is possible to avoid internal reflection by the crown facets if we cut them at slope angle β not exceeding...

$$\beta < \gamma + 90° - 2\alpha \quad (3).$$

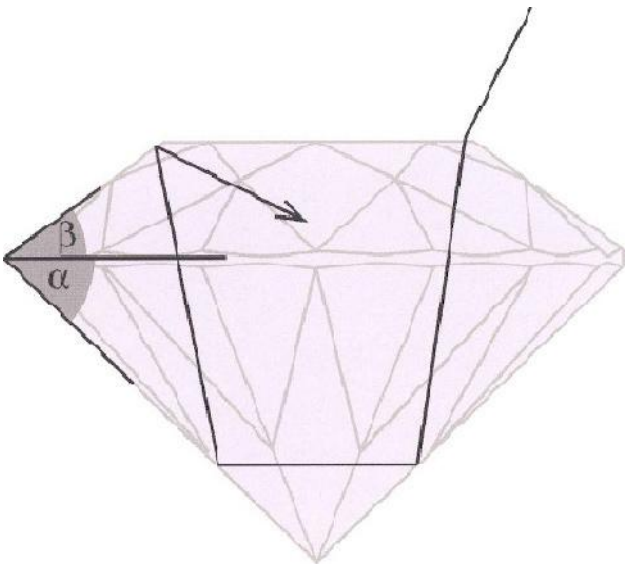

Figure 3: Total reflection of ray from crown back into gem.

Effect of the viewer

The presence of a viewer puts additional limits on arrangements of light sources. The fact is that the head and body of the viewer are not light sources (at least not bright). The head is in the same direction as the eye but has a significant angular size (usually the light source is farther from the stone than the viewer), it is desirable to facet so that the viewer will not see reflections of his own head in the stone. Areas of the gem which reflect the viewer's head will be dark for any positions of the light sources. The shape of the head and arrangement of the eyes vary for different people; shapes and sizes of hairdos and headwear even more so. To simplify analysis, we consider the head as a sphere with an eye in the centre. Thus light rays exiting the stone must diverge from their direction of entry by more than half the angular size of the head. Ignorance of this fact lead to the design of Johnsen[10-12], which calculated, in essence, that the viewer would see only his reflection and only the lamp saw all of the light specks. To this day, researchers fall into this trap[21]. Divergence of the exiting ray from the entering ray must be assured for the three possible paths of the ray through the gem:

1. Entry through the table and exit from the same.
2. Entry through the table but exit from the bezel (side facets of the crown). According to the principle of reverse ray-tracing, this is the same as entry into the bezel and exit through the table.
3. Entry through one side of the bezel and out the opposite side of the bezel.

Consideration of the viewer's head was first presented by Bruce Harding in an article[19] as early as 1975. He cut a garnet according to a published recommendation (40° slope of the main facets, top and bottom[3]). Upon examining it closely (by a lamp behind his head) Harding noticed that, as the stone neared his face (increasing the angular size of his head) it darkened, but it brightened as it was moved away from himself. He investigated this effect and published an article with analytical expressions for calculations, and graphs whose coordinates were the slope angles of the pavilion and bezel facets. He shaded those areas which did not provide sufficient divergence of the exiting beam (similar to *Figure 4*), assuming that the viewer looks into the top of the stone perpendicular to the table. To illustrate this, Harding later (1986) wrote a computer program which showed the paths of rays through the stone. The author became aware of this work in the early 80s and expanded the results to include the case where the viewer looks at the stones from other directions[22].

Figure 4 shows shaded areas designated by letters **E**, **G** and **F** for faceted corundum, inside which facet slopes do not assure 10° ray divergence, for arbitrary positions of the viewer, for the three routes cited above, respectively. These areas are somewhat wider than those presented by Harding and more severely limit the acceptable regions, but they ensure the necessary beam divergence in those remaining regions for any inclination of the stone relative to the direction of viewing. Shaded areas **H** and **I** do not satisfy equations (2) and (3) respectively.

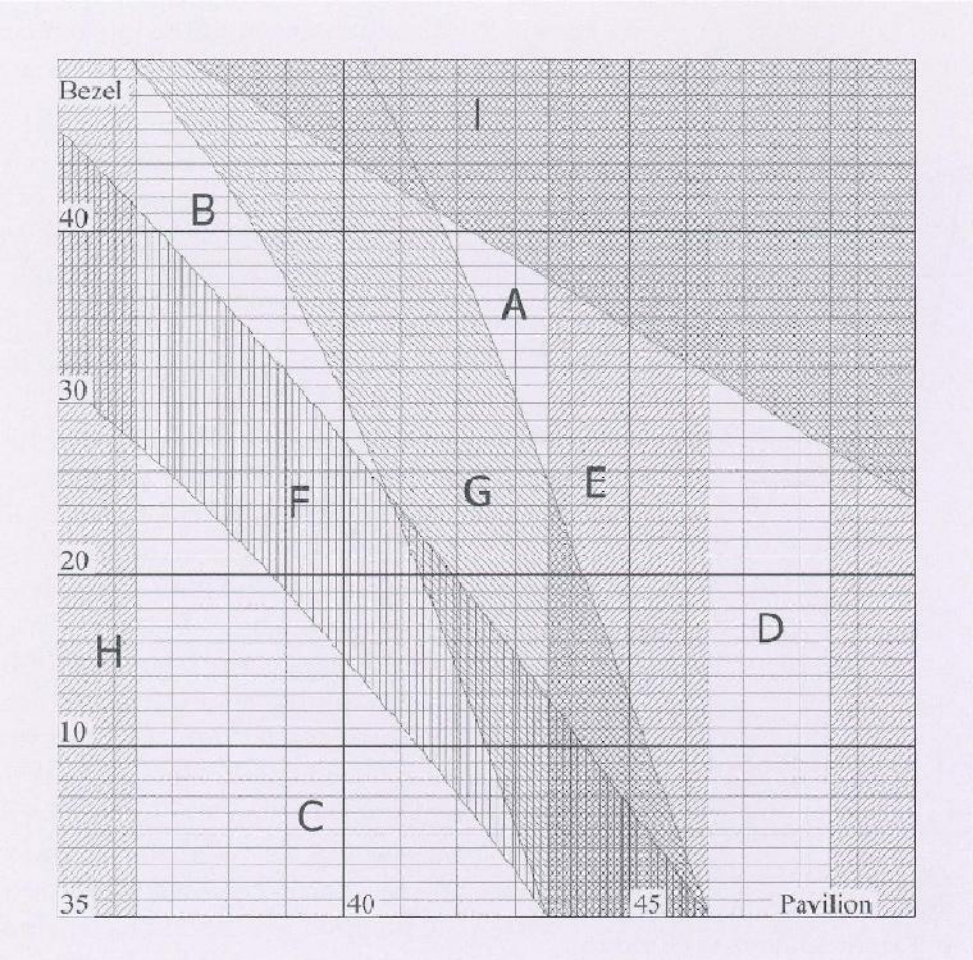

Figure 4: Regions of pavilion and bezel slope combinations.

Four regions – **A**, **B**, **C** and **D** – remain unshaded. To compare them it is necessary to consider the body of the viewer, which is also reflected in the stone and blocks light. For stones in regions **C** and **D** the body of the viewer is reflected predominantly only in one half of the stone (near to the viewer for **D** and away for **C**). This one-sidedness seriously affects the beauty of the stone, so we exclude such slope combinations as unsuccessful.

The location and shape of the remaining acceptable regions (**A** and **B**) depend on the refractive index of the material being cut and the angular size of the viewer's head – that is, the distance from which the gem is viewed. The final results of calculation for different materials and 10° minimum ray divergence, are shown in *Figure 5*. Other details are considered less important and are omitted in this diagram. In this diagram zone **B** does not exist for quartz; actually it appears only for minerals with refractive index greater than 1.62. For materials with lower refractive index there is only one region of solutions (**A**), which disappears if $n < 1.47$. Apparently natural glass occupies last place in the list of minerals which can be faceted satisfactorily, and minerals such as fluorite and opal cannot satisfy the requirements we have defined.

Other things being equal, stones of region **B** have high brightness and give more rays, but those from region A have greater colour intensity. Without going into detail, let it be said that stones from the upper left of region **A** have the best colour dispersion of exiting rays. Although calculations are carried out only for rays in the plane of the paper in *Figures 2* and *3*, the results apply generally also to oblique rays (lying in other planes),

with the exception of rays exiting into the air through bezel facets [formula (3)]. To avoid loss of skew exit rays it is necessary to use either additional facets (upper triangles of the crown = 'stars') or to use crown main facet slopes 3-5° below the upper boundary of region **A**. Small deviations beyond the recommended limits do not significantly affect the beauty of the gem; they are permissible.

In this article we examined only rays reflecting from facets which are opposite to each other. The majority of rays incident perpendicular to the girdle plane go exactly this way; however, other rays can enter adjacent or remote facets. In the latter case the path of a ray may change sharply and the majority of such rays pass through the stone by more complex routes, often with a large number of internal re-reflections. The number of such rays increases with tilting the gem; their main feature is a radical change in the mode and number of interacting facets by the tiniest rotation of the gem. The rays we studied comprise the majority and repeated part of all rays forming the exterior appearance of the gem. Therefore it is most important to consider them in the optimizing of faceting. If we seriously violate even one of the criteria set above, we will get a noticeable negative effect on the beauty of the stone. Precise calculation of all possible rays is possible but exceeds the scope of this article.

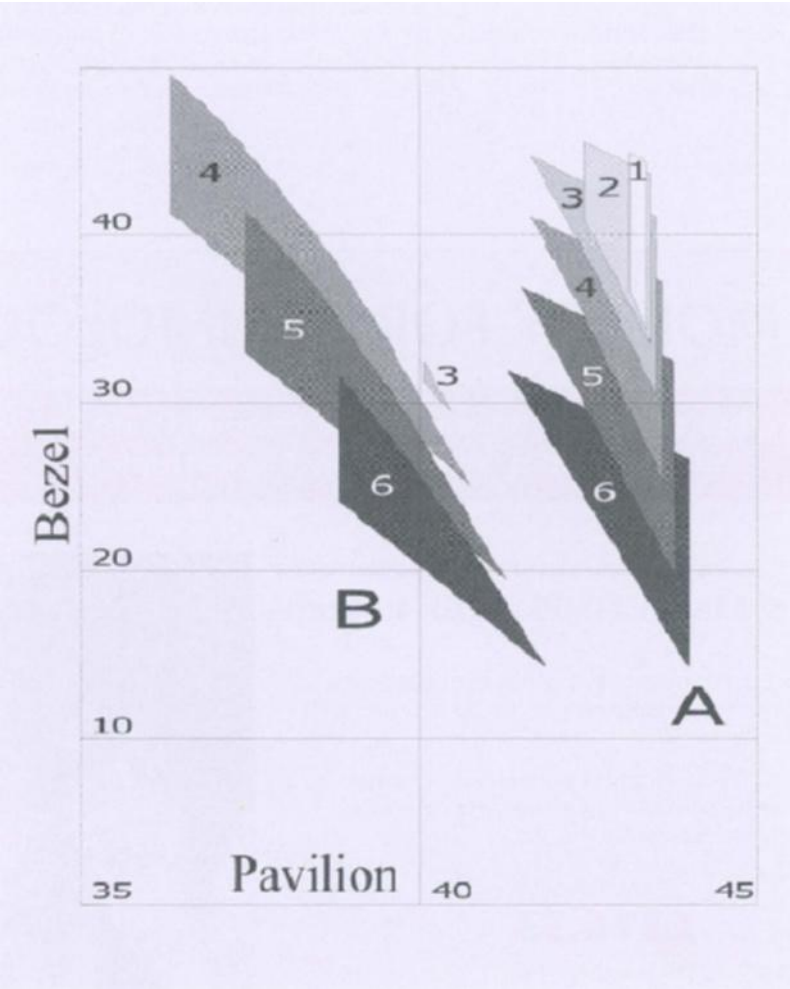

Figure 5: Best slope combinations for various gem materials:
1) obsidian 2) quartz 3) topaz
4) corundum 5) zircon 6) diamond

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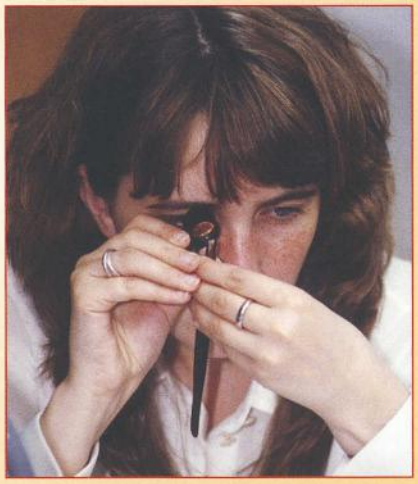

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The microstructure of the shell and cultured blister pearls of *Pteria penguin* from Sanya, Hainan, China

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Abstract: *The microstructure of the shell and cultured blister pearls of* Pteria penguin *from Sanya, Hainan, were examined using a scanning electron microscope and are described in detail. The results indicate that the shell of* Pteria penguin *consists of an outer organic layer (conchiolin), a middle prismatic layer and an inner nacreous layer. The prismatic layer shows multiple sub-layers (commonly 3 or 4) with a total thickness of 0.3-0.9 mm. Single calcite prisms are 13-55 μm wide, and show five- or six-sided sections. Organic matrix lies between the calcite prisms. The nacreous layer of the shell shows a characteristic step-like structure through labyrinthic structure (fingerprint-like) to spiral-like structure from the margin to the umbonal region of the shell. The nacreous layer consists of aragonite and organic matrix, with a total thickness of 1.0-1.5 mm. Single aragonite platelets have a thickness between 0.3 and 0.8 μm. The cultured blister pearls consist of a bead nucleus, a prismatic layer and a nacreous layer, the layers totalling 0.15-1.00 mm in thickness.*

Keywords: *conchiolin, cultured blister pearl, nacre,* Pteria penguin, *SEM, shell structure*

Introduction

Pteria or *Magnavicula penguin* (Röding) belongs to the *Phylum Mollusca*, Class *Pelecypoda*, Order *Anisomarya* and Family *Pteriidae* (Xie, 1995). The animals live in subtidal areas in the tropics and subtropics, such as the shores of Australia, Indonesia, Japan, New Caledonia, New Guinea, and Guangdong and Hainan, China (Zhang *et al.*, 1994; Xie, 1995; Meng *et al.*, 1995; Fu and Liang, 2000; Liang *et al.*, 2001). *Pteria penguin* is large in size, has great vitality and a fast growth rate, and their mantles have a strong capability for secretion. Therefore, they are ideal for producing large pearls, especially large blister pearls. The blister pearls grown in *Pteria penguin* are large in size, with a thick nacreous layer and a strong lustre, and so have a high commercial value. Reports involving development and artificial propagation of *Pteria penguin* have been published by Liang *et al.* (2001) and Yu *et al.* (2000), and of cultivation of blister pearls

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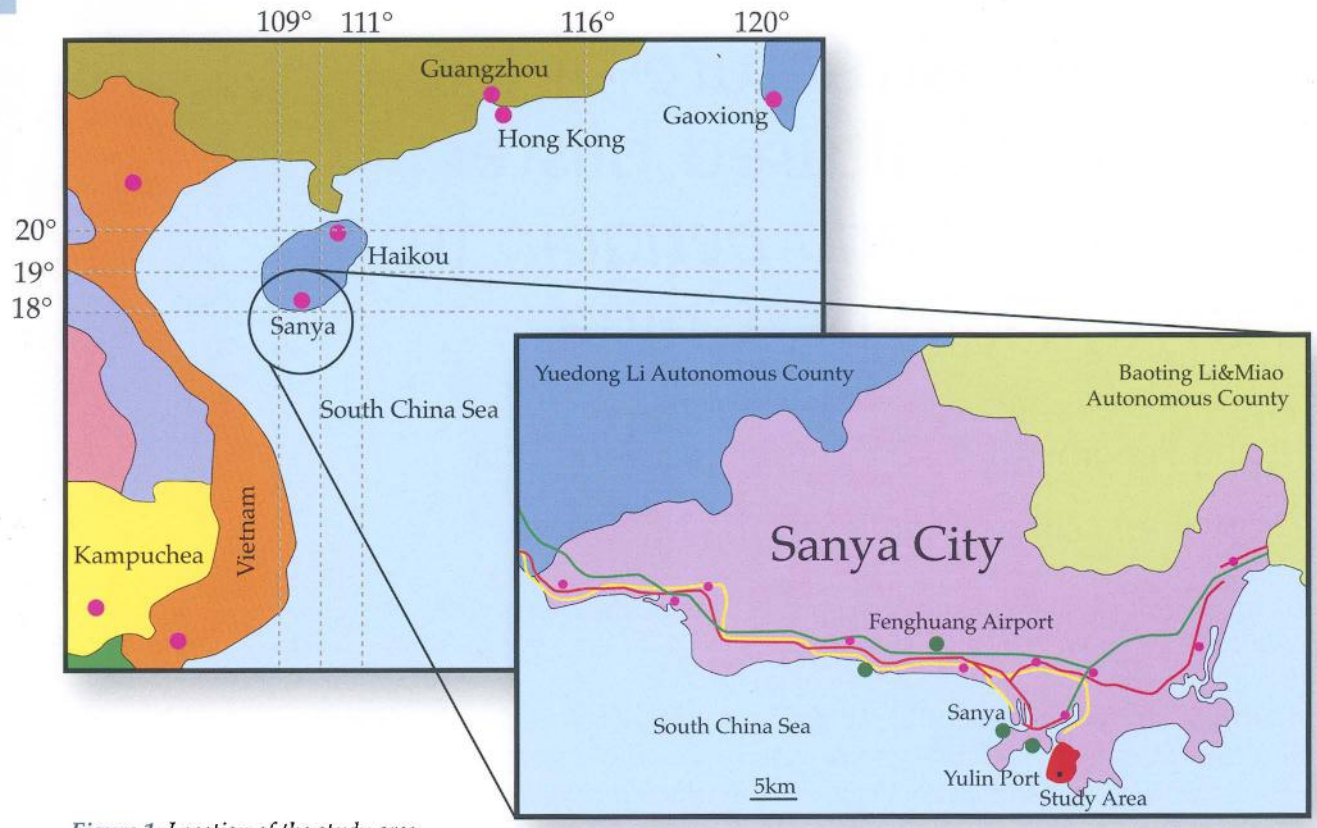

Figure 1: Location of the study area.

using *Pteria penguin* by Zhang *et al.* (1994), Xie (1995), Liang *et al.* (1998) and Fu and Liang (2000), but a study of the structure of the shells of *Pteria penguin* and blister pearls produced by *Pteria penguin* from China is lacking. The work presented here aims to fill this gap with a study, using a scanning electron microscope, of shells and cultured blister pearls of *Pteria penguin* from Sanya, Hainan Province.

Materials and Methods

The shells

The shells of *Pteria penguin* and the cultured blister pearls produced by *Pteria penguin* were obtained from Lupearl Aqua-culture Co. Ltd. in Sanya, Hainan Province. This cultured pearl farm is in the famous Yulin port, and is 20 km away from Sanya, about forty minutes drive by car *(Figure 1)*. The sea area of the farm is approximately 70 hectares and over 300 people are employed. At present, *Pteria penguin*, *Pinctada maxima* (white lip oyster) and *Pinctada margaritifera* (black lip oyster) are being reared. The growth rates of the oysters are controlled from incubation through to maturity. This produces a stock of oysters of similar maturity which are ready for the culturing operation at the same time.

The shells for this study were adult shells (more than two years old) and the cultured blister pearls had been grown for approximately six months. Both shells and blisters were first immersed in 5% NaOH solution for about ten minutes to remove some impurities, then washed with distilled water and dried in air. The shells were cut directionally for different purposes: ribbons of 2 cm × 0.5 cm were cut for observing the section structure and squares of 1 cm × 1 cm for observing the surface structure. For determining the change in surface structure of the nacreous layer, a continuous traverse from one margin to the other of a shell was preserved in six adjacent samples *(Figure 2)*. The specimens of cultured blister pearls were obtained by cutting the shells and removing the outer layers.

Equipment

A Hitachi Scanning Electron Microscope (SEM) was used to observe the surface and section structures of the shells and cultured

blister pearls under the following conditions: an acceleration voltage of 20 kV, and beam current of 5×10^{-10}A.

Results

Shell

Nacreous layer: In the nacreous layer of the shell, the following three kinds of surface structures were observed: step-like, labyrinthic (fingerprint-like) and spiral.

In the step-like surface structure, the growth layers of aragonite crystals are parallel to each other *(Figure 3a)*, with a distance of about 13 μm between the neighbouring two growth layers of aragonite, measured from the Figure. The aragonite crystals have round outlines and occur in a range of sizes. At the front edges of the growth layers, the aragonite crystals appear as irregular and isolated crystals. Away from these growth edges, the crystals are unresolvable by the SEM and appear as a single mass *(Figure 3b)*.

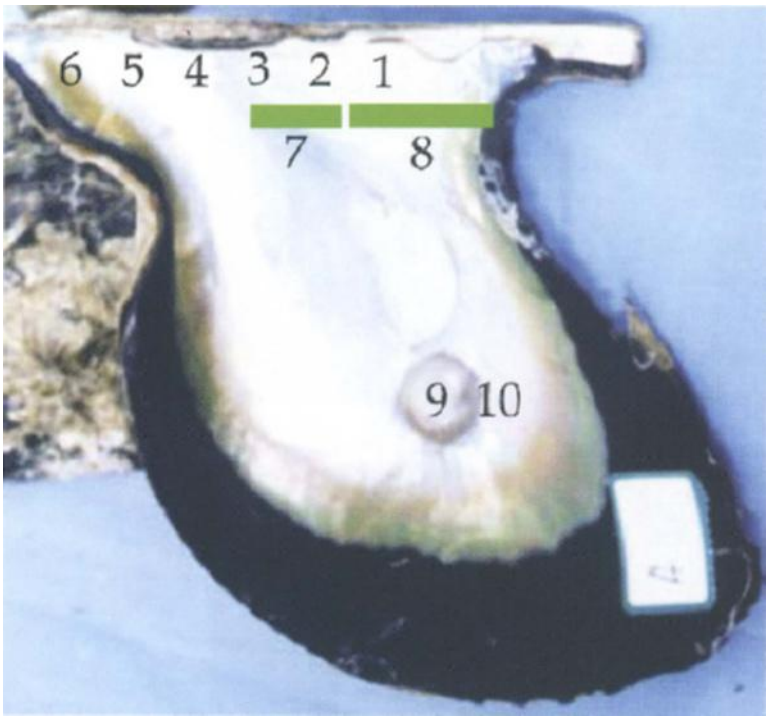

Figure 2: A diagram showing the locations of the specimens of the shell and cultured blister pearl.

1-6: Six adjacent specimens for observing surface structure of the nacreous layer, with 3 being the sample of the umbo.

7-8: Representative specimens for studying the thickness changes in the nacreous and prismatic layers.

9-10: Cultured blister pearl specimens.

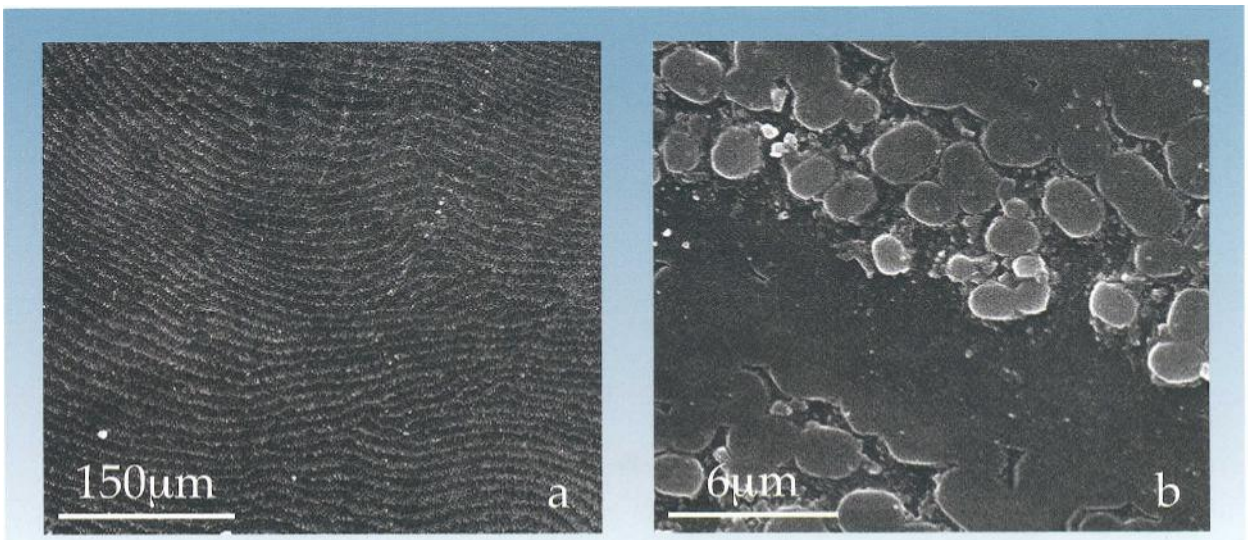

Figure 3a & b: Step-like surface structure of nacreous layer of shell.

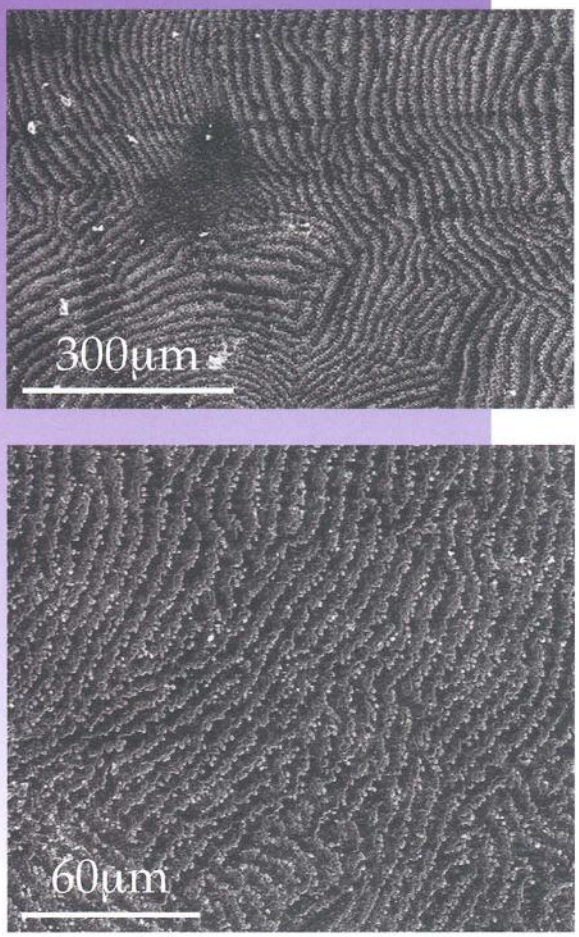

Figure 4: Labyrinthic surface structure of nacreous layer of shell.

In the labyrinthic (fingerprint-like) structure, the growth layers of aragonite overlap each other *(Figure 4)*, with a distance of 4–13 μm between the neighbouring two growth layers.

The spiral structure of shell is characterized by spiral growth layers of aragonite crystals *(Figure 5)*, including right-hand spirals and left-hand spirals, but usually right-hand spirals. Locally, several spirals may connect together. The distance between the neighbouring two growth layers of aragonite increases from outer to inner layers.

The surface structures observed in specimens 1–6 *(Figure 2)* show regular variations. Specimen 1 is characterized by step-like and labyrinthic (fingerprint-like) surface structures, while in specimens 2 and 4 labyrinthic structure predominates, with local development of spiral structure. Spiral structure dominates in specimen 3 and labyrinthic structure dominates in specimens 5 and 6. This indicates a regular variation from step-like surface structure through labyrinthic structure to spiral structure from the margin to the umbo of the shell.

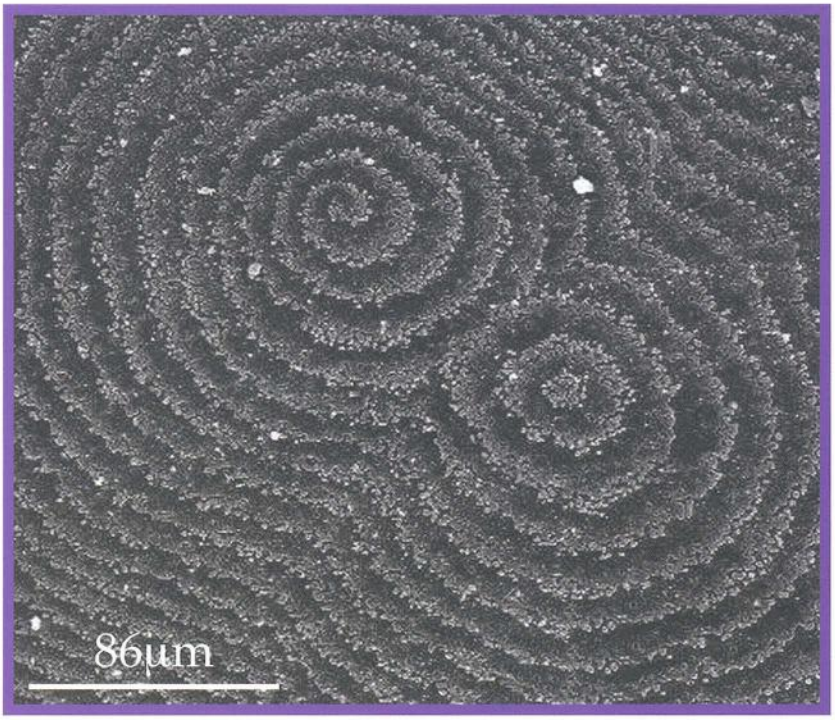

Figure 5: Spiral surface structure of nacreous layer of shell.

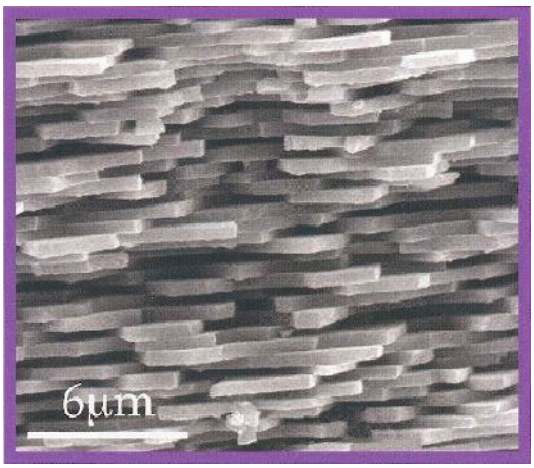

Figure 6: The regular aragonite platelets of the shell.

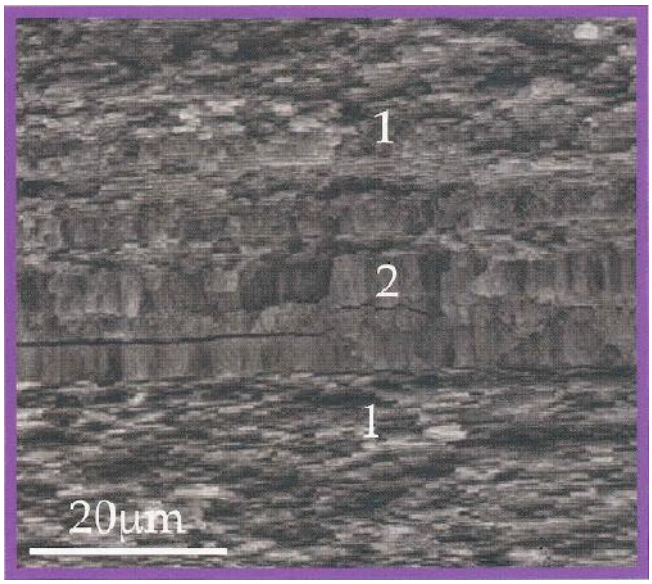

Figure 7: Prismatic interlayer in nacreous layers: (1) nacreous layer (2) prismatic layer.

In the section through the shell, the nacreous layer consists of platelets of aragonite crystals *(Figure 6)*, with a total thickness of 1.0-1.5 mm. The aragonite platelets range in thickness from 0.5 to 0.8 µm at the umbo, and from 0.3 to 0.4 µm at the margin of the shell. Additionally, prismatic layers of calcite are visible between nacreous layers *(Figure 7)*.

Prismatic layer: In plan the calcite prisms appear five- or six-sided *(Figure 8)*. Between the calcite prisms are thin films of dark organic material. The pitted texture visible in *Figure 8* indicates that the calcite prisms are composed of many minute calcite crystals rather than only one crystal.

In the transitional growth zone between the nacreous and prismatic layers *(Figure 9)*, aragonite grains first grow along the boundaries of the calcite prisms and then cover the prism layers completely, indicating the organism's control over the growth of aragonite.

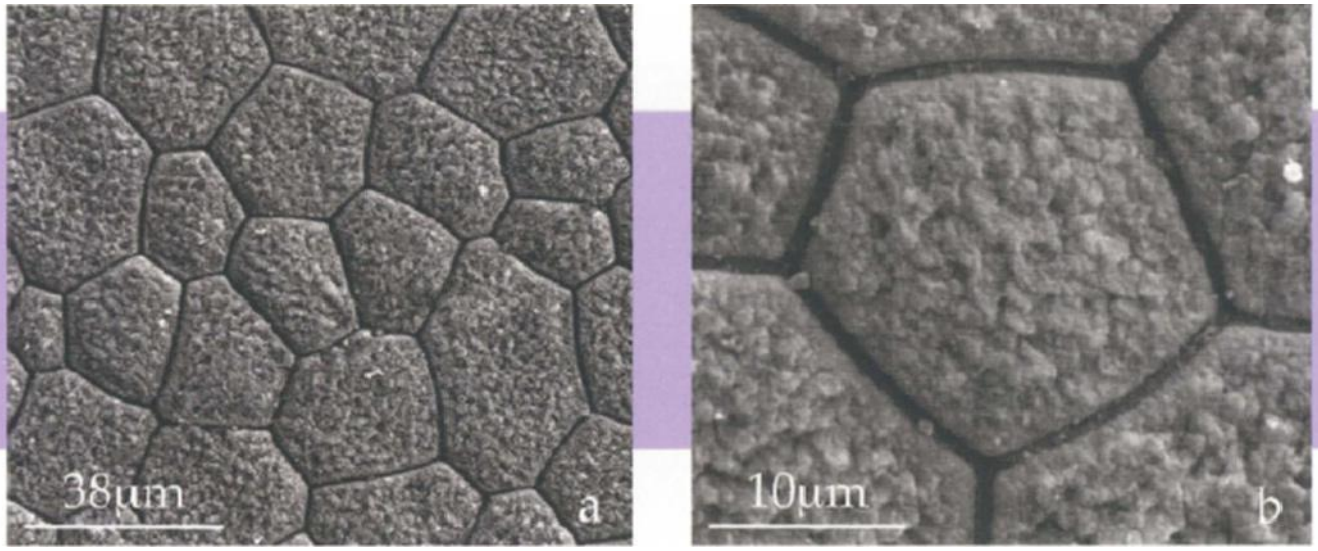

Figure 8a & b: Five- and six-sided calcite prisms and organic matter at boundaries.

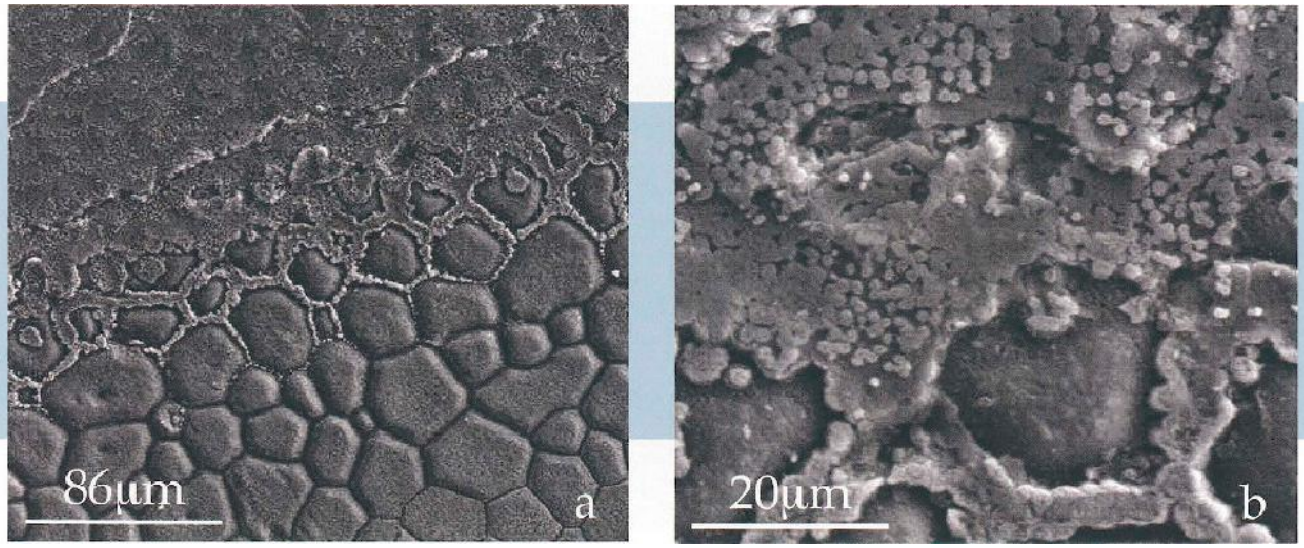

Figure 9a & b: Surface features of the transitional growth zone between the nacreous and prismatic layers:
a. Prismatic calcite (bottom) is penetrated along prism boundaries by aragonite and eventually completely covered (top).
b. Detail of later stages of aragonite growing around calcite.

The initial aragonite grains appear to be poorly defined and to be close-packed,while those grown later appear loose, with round outlines and variable size *(Figure 9b)*.

In section, sharply defined boundaries are visible between the nacreous and prismatic layers *(Figures 7 and 10)* with local development of an organic layer *(Figure 10a)*. However, at the margin of the shell, the nacreous and prismatic layers are interlayed with more complexity *(Figure 10b)*, with the prism layer showing several sub-layers, usually 3–4 *(Figure 11)*. The boundaries are still sharp and the layers range in thickness from 0.30 to 0.80 mm. Each calcite prism has a width of about 13–15 µm *(Figure 12)* and in detail shows an irregular sheet-like overlapping structure *(Figure 13)*. The organic material on the prism surfaces shows a net-like structure *(Figure 14)*.

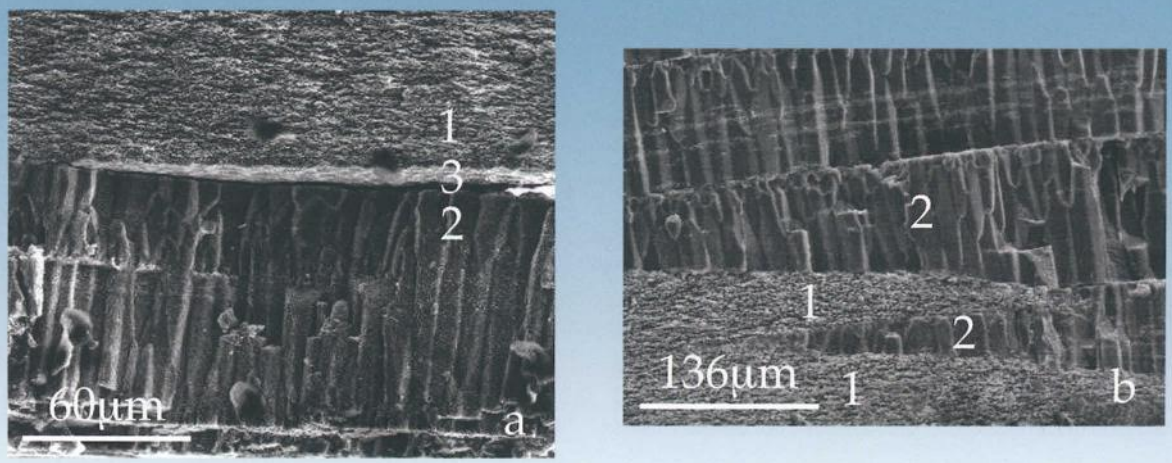

Figure 10a & b: The relationship between the nacreous and prismatic layers: (1) nacreous layer; (2) prismatic layer; (3) organic matrix.

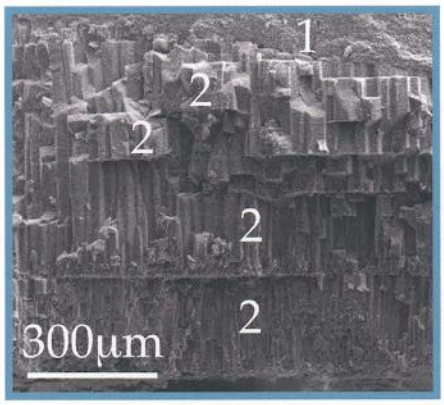

Figure 11: Section showing multiple prism sub-layers (2). A nacreous layer (1) is at the top.

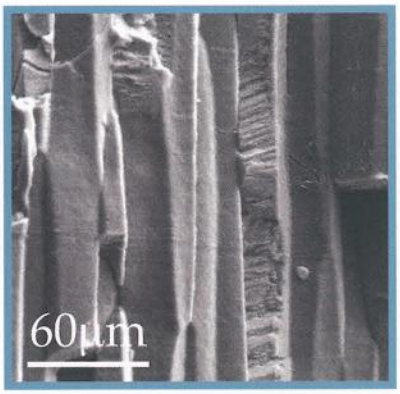

Figure 12: Section showing the boundaries of calcite prisms.

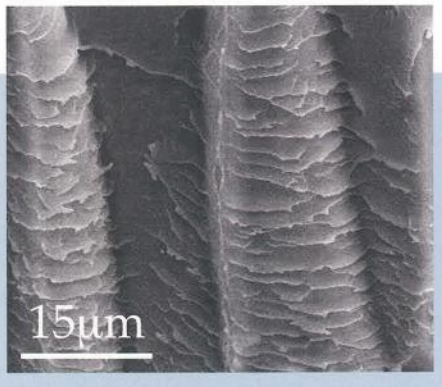

Figure 13: Irregular overlapping sheet-like structure in calcite prisms.

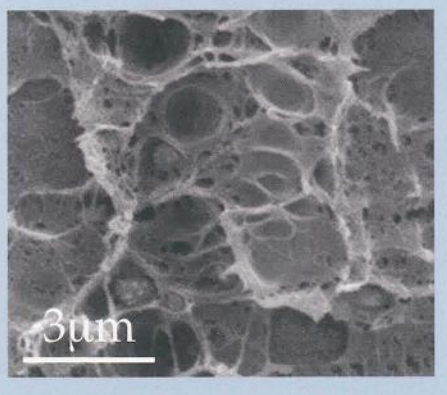

Figure 14: Net-like structure of organic material visible on calcite prisms.

Cultured blister pearl

The cultured blister pearl specimens show mainly step-like and labyrinthic (fingerprint-like) surface structures in the nacreous layer *(Figure 15)*, with no spiral structure visible. The overlap gap in the growth layers of aragonite is wider in the labyrinthic (fingerprint-like) structure compared to that in the step-like structure *(Figure 16)*.

In section, cultured blister pearls also show prismatic and nacreous layers, with a sharply-defined vacant boundary *(Figure 17)*. The nacre consists of regularly arranged aragonite platelets *(Figure 18)*, each approximately 0.5 µm thick. The calcite prisms show prism boundaries, an irregular sheet-like structure and net-like structure of organic material *(Figure 19)*, which, however, are all less distinct than those seen in the prismatic layers of the shell.

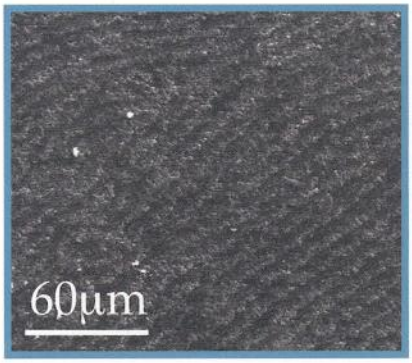

Figure 15: Step-like surface structure of nacreous layer at the top of the cultured blister pearl.

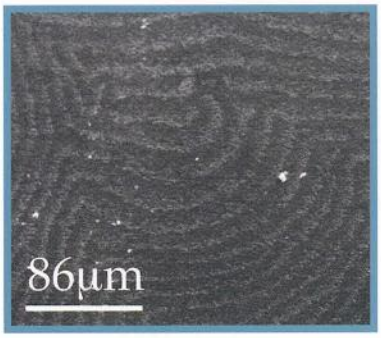

Figure 16: Step-like and labyrinthic surface structure of nacreous layer at the margin of the cultured blister pearl.

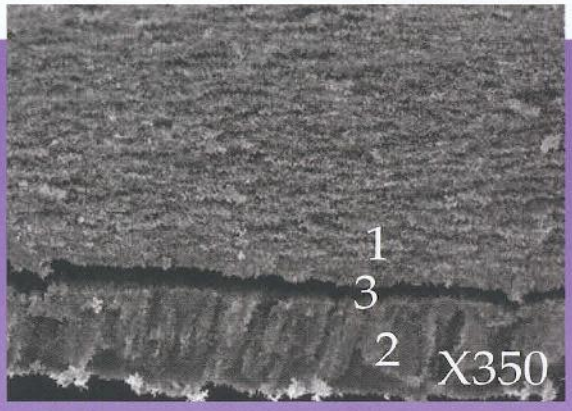

Figure 17: The relationship between the nacreous and prismatic layers of the cultured blister pearl.

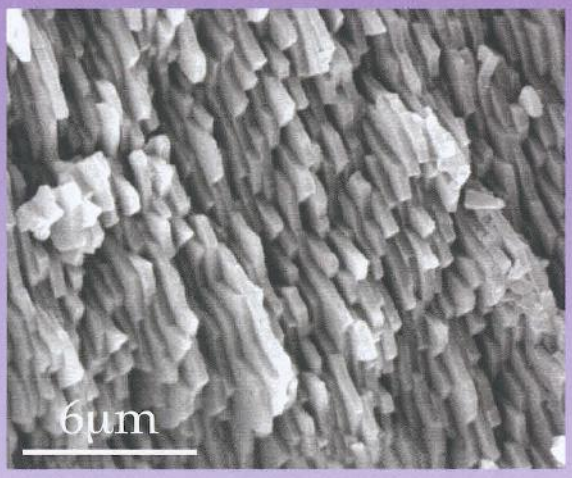

Figure 18: The regular aragonite platelets of the cultured blister pearl.

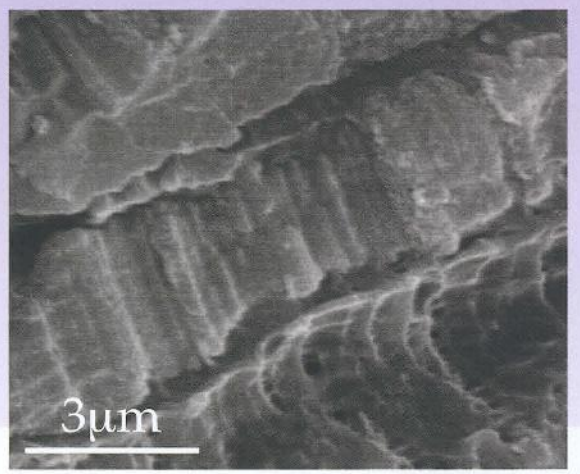

Figure 19: The calcite prisms in the cultured blister pearl; an indistinct sheet-like structure and net-like structure are visible.

Discussion

The aim of this study on the structures of shells and cultured pearls, especially the microstructures, is to learn more about the formation of shells and pearls.

From the descriptions above, the shell of *Pteria penguin* consists of three layers, an outer organic (conchiolin) layer, a middle prismatic layer and an inner nacreous layer. As is generally known, the outer conchiolin layer is mainly composed of horny protein; the middle prismatic layer is dominated by calcite prisms; and the inner nacreous layer consists mainly of aragonite platelets (Zhou, 1993; Xie, 1995; Zhang *et al.*, 1996; Smith, 1998; Li, 2001; Li *et al.*, 2001; Shi and Guo, 2001). The outer conchiolin layer can protect the carbonate layers of the shell from dissolution (Vermeij, 2002; Xie, 1995), and the middle prismatic layer is highly resistant to impact (Tong *et al.*, 2002). The inner nacreous layer acts as a stock for storing Ca^{2+} ions which are then transmitted to the middle prismatic layer (Tong, 2002; Tong *et al.*, 2002). The outer layer of the cultured blister pearl also shows a three-layered structure, the inner conchiolin layer, a middle prismatic layer and an outer nacreous layer, but with an altered arrangement compared with that of the shell *(Figure 20)*. The conchiolin is very thin, approximately 0.02 mm, but is very tough. When cultured blister pearls are cut from the shells, this conchiolin layer is seen to cover the bead nucleus and can easily be separated from the bead below and the prismatic layer above. This similar construction of the shell and the cultured blister pearl implies a similar mode of origin from the same soft body.

The step-like, labyrinthine and spiral growth structures in the shell's nacreous layer represent changes in the manner of growth of the shell. Mao *et al.* (2001) observed the microstructural changes on the inner surfaces of nacreous layers during development of the Polynesian pearl oyster, *Pinctada margaritifera var. cumingii*, from planktonic larval shells to two-year-old adult shells. Five growth zones Z_0, Z_1, Z_2, Z_3

and Z_4 were recognized: the Z_0 zone shows a homogeneous structure, without any steps or contours, present on one-month-old shells; the Z_1 zone shows contour lines parallel to the growing shell edge, which grades into a labyrinthic pattern (Z_2) or growth pattern perpendicular to the edge (Z_3). The Z_4 zone shows spiral growth and was observed in the umbonal region. The three kinds of surface structure, i.e. step-like, labyrinthic and spiral, described above for *Pteria penguin* show regular changes from step-like through labyrinthic to spiral structure from the margin to the umbo of the shell. This indicates that the margin of the shell is the growth front. Step-like growth allows the shell to increase its length and width, while spiral growth allows the shell to increase its thickness (Mao *et al.*, 2001; Vermeij *et al.*, 2002).

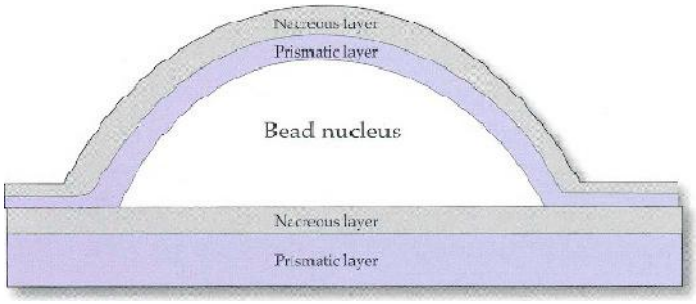

Figure 20: A diagram showing the construction of cultured blister pearl from Pteria penguin, *with organic matrix layers not be shown.*

The initial growth of aragonite along the organic matter on the calcite prisms in both shell and cultured blister pearl indicates that the growth of carbonate minerals in shells and pearls may be controlled by the organic matter. Although aragonite would normally change into calcite at normal temperature and pressure (Lippman, 1973, as quoted in Li *et al.*, 1995), these calcium carbonate polymorphs are able to coexist stably in shells and pearls in completely different shapes. It is impossible to explain this fact with an inorganic phase diagram, and it seems that the organism must control the formation of calcite and aragonite in shells and pearls. However, since the organic matter in shells and pearls is complex and in low concentration, there is little published information available. Organic matter in shells is classified into two kinds: soluble matter (SM) and insoluble matter (IM) (Levi *et al.*, 1998; Weiner and Hood, 1975). The insoluble organic matter can provide the network for the formation of soluble organic matrix and crystal nuclei (Falini *et al.*, 1996; Belcher *et al.*, 1996; She and Xie, 1998; Zhang and Xie, 2000b; Jiang *et al.*, 2002). The soluble organic matrix consists mainly of glycoproteins, rich in acidic amino acids such as aspartic acid and glutamic acid. Both aspartic and glutamic acids possess carboxyl groups, which can capture Ca^{2+} ions. Additionally, glutamic acid can regulate the concentration of CO_3^{2-} in water, controlling the formation of aragonite (Miyamoto *et al.*, 1996). However, the details of the control of such organic matter on the formation of shells and pearls are not clear, although several models have been proposed by Watabe, 1981, as quoted in Zhang and Xie, 2000a; Huang and Li, 1991; Arnold, 1992; Dai, 1994; Xie, 1995; Zhang and Xie, 2000b.

Conclusions

The following conclusions may be drawn:

1. The shell of *Pteria penguin* consists of three layers, an outer conchiolin layer, a middle prismatic layer, and an inner nacreous layer.
2. The prismatic layer of the shell consists of multiple sub-layers (usually 3-4), with a total thickness of 0.3-0.9 mm. The calcite prisms are five- or six-sided in cross section, show an irregular overlapping sheet-like structure and have net-like structures on the prism surfaces. Each prism consists of numerous minute calcite grains rather than one calcite crystal. Dark organic matter is visible between calcite prisms.
3. The nacreous layer of the shell shows step-like, labyrinthic (fingerprint) and

spiral surface structures. The step-like structure is typical of the margin of the shell and this changes through labyrinthic to spiral in the umbonal region of the shell. This represents changes in the manner of growth. Step-growth gives rise to the increase in length and width of the shell, and spiral growth increases thickness of the shell. The nacreous layer consists of regular aragonite platelets (0.3-0.8 μm thick) and organic matter, with a total thickness of 1.0-1.5 mm. The single aragonite platelets increase their thickness from the growth edge to the umbonal region of the shell.

4. The cultured blister pearl consists of a bead nucleus with conchiolin, prismatic and nacreous layers. The conchiolin layer is about 0.02 mm thick while both prismatic and nacreous layers total 0.15-1 mm; in the specimen studied, the prismatic layer is about 44 μm and the nacreous layer is about 0.15 mm thick. The nacreous layer consists of regular aragonite platelets about 0.5 μm thick and organic matter. The prismatic layer consists of calcite prisms between 8 and 33 μm wide.
5. The initial growth of aragonite next to organic matter and the similar structures of shell and cultured blister pearl indicate similar causes of growth, probably controlled by organic matter.

Acknowledgements

John Lu and Johnny Lu from Lupearl Aquaculture Co. Ltd. are acknowledged for their help during the collection of *Pteria penguin* shells and cultured blister pearls.

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Abstracts

Diamonds

Exhumation of lower mantle inclusions in diamond: a TEM investigation of retrograde phase transitions, reactions and exsolution.

F.E. Brenker, T. Stachel and J.W. Harris. *Earth and Planetary Science Letters*, **198**(1-2), 2002, 1-9.

TEM data on a multiphase inclusion in a diamond from the Kankan deposits, Guinea, show it comprises a large (300 μm) diopside crystal with a small symplectitic intergrowth of olivine and tetragonal almandine pyrope. A ferropericlase inclusion in the same diamond implies a primary origin within the lower mantle. The clinopyroxene formed through the reaction sequence: MgSi-perovskite + CaSi-perovskite MgSi-ilmenite + CaSi-perovskite ringwoodite + stishovite + CaSi-perovskite clinopyroxene + relict ringwoodite. Al-rich bulk symplectite suggests ringwoodite as a coexisting precursor phase with clinopyroxene. SiO_2-depletion during the diopside-forming reaction produces a small amount of relict ringwoodite coexisting with diopside. Subsequent breakdown of ringwoodite to wadsleyite + tetragonal almandine pyrope produces the symplectitic intergrowth. During transformation of wadsleyite to olivine, exsolution of Mg-Al-chromite decreases the original solubility of Al, Cr and Ti, in agreement with experimental data on element partitioning between wadsleyite and olivine. These results suggest tetragonal almandine pyrope forms as a retrograde phase within the mantle transition zone, and is restricted to the upper lower mantle. J.F.

Characteristics of nitrogen and other impurities in diamond, as revealed by infrared absorption data.

F.V. Kaminsky and G.K. Khachatryan, *Canadian Mineralogist*, **39**(6), 2001, 1733-45.

Diamond crystals from Siberian, Arkhangelsk, South African, Canadian and South American deposits were analysed for structurally bound nitrogen, hydrogen and 'platelet' defects using IR absorption spectroscopy. Wide variations in total nitrogen and hydrogen contents and in the state of nitrogen aggregation were established from different areas and deposits. On this basis, three groups were distinguished: (1) low-nitrogen, highly aggregated-nitrogen diamond, (2) intermediate diamond crystals and (3) high-nitrogen, poorly-aggregated-nitrogen diamond (occasionally with high contents of hydrogen and 'platelets'). These represent, in general terms, three major stages of diamond formation: (1) the initial stage at high *P-T* conditions which occasionally occur in super-deep areas (e.g. lower mantle and transition zone), (2) the main stage and (3) the final stage, which represents the latest episodes of magmatic evolution and is characterized by high oversaturation of the crystallization medium and high internal T-gradients. These data may be used for 'fingerprinting' diamonds, in prospecting for new deposits in diamondferous areas and in the evaluation of diamond crystals from newly discovered deposits. R.A.H.

Kimberlites from the Wawa area, Ontario.

F.V. Kaminsky, S.M. Sablukov, L. Sablukova V.S. Shchukin and D. Canil. *Canadian Journal of Earth Sciences*, **39**(12), 2002, 1819-38.

Two newly discovered kimberlites from the Wawa area, Ontario, are group-1 kimberlites in their petrographic, mineralogical, geochemical and isotopic features. They contain mantle minerals and xenoliths of the Fe-Ti-association (magnesian ilmenite, iron-rich olivine, orange Ti-pyrope garnet, augite and ferroan enstatite) and of the Cr-association (chromian spinel, forsteritic olivine, purple Cr-pyrope garnets, chromian diopside and enstatite); minerals of Fe-Ti-association are much more abundant. Minerals of eclogitic association are absent. Both G-10 pyrope garnets and high Cr-spinels typically associated with diamond are represented in the Cr-association. The average age of the kimberlites is 1097 ± 7 m.y., i.e. contemporaneous with other alkaline igneous rocks in the Wawa area. Equilibration *P* and *T* of mantle xenoliths plot close to a 40-45 mW/m² geotherm. On the basis of the Ni-in-garnet geothermometer, garnets from the Wawa kimberlites equilibrated at 800-1350°C, and at least in part within the diamond stability field. It is likely that kimberlitic magma was derived from *LREE*-enriched asthenospheric mantle. G.L.B.

An important exhibition of seven rare gem diamonds.

J.M. King and J.E. Shigley. *Gems & Gemology*, **39**(2), 2003, 136-43.

A temporary display at the Smithsonian Institution in Washington DC contained one colourless 203.04 ct diamond (the De Beers Millennium Star) and six coloured diamonds (the 101.29 ct Fancy Vivid yellow Allnatt, the 59.60 ct Fancy Vivid pink Steinmetz pink, the 27.64 ct Fancy Vivid blue Heart of Eternity, the 5.54 ct Fancy Vivid orange Pumpkin, the 5.51 ct Fancy Deep blue-green Ocean Dream and the 5.11 ct Fancy red Moussaieff), all of which are shown in coloured illustrations. R.A.H.

The pressures and temperatures of formation of diamond based on thermobarometry of chromian diopside inclusions.

P. Nimis. *Canadian Mineralogist*, **40**(3), 2002, 871-84.

The *T* and *P* of formation have been calculated for >100 inclusions of chromian diopside (mostly isolated) in diamond crystals also containing inclusions of peridotite material, and for peridotite xenoliths from worldwide occurrences, using single-clinopyroxene thermobarometers. The results provide constraints on the conditions and relative timing of diamond genesis. Inclusions in diamonds and xenoliths from the same source commonly yield similar *P-T* values,

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suggesting that diamond crystals formed when the lithospheric mantle had already attained a conductive thermal regime comparable to or even colder than that extant at the time of emplacement of the host kimberlite or lamproite. Some inclusions record thermal or metasomatic events, which can be ascribed to the ascent of hot C-rich fluids from which the diamond precipitated. In general, there is no evidence for the occurrence of diamond being concentrated at particular levels in the lithosphere. R.A.H.

Growth habit of needle crystals in coats of coated diamonds.

N. SHIMOBAYASHI AND M. KITAMURA. *Journal of Mineralogical and Petrological Sciences*, **96**(5), 2001, 188-96.

Needle diamond crystals constituting the coat portion of coated diamond from Zaire are bounded by curved {100} faces (cuboid) and small {111} facets, showing distinct sector zoning in CL brightness under CL microscopy. It is argued that the needle morphology is responsible for 'random walk model', which can also explain the whole external morphology of coated stones. The needle crystals were formed by co-precipitation of inclusions and due to the rapid growth controlled by the kinetic roughening of the octahedral faces and the kinetic smoothing of the cuboid faces. It is suggested that both coated stones and mixed-habit growth were grown under similar conditions, except for the co-precipitation of inclusions in the former. I.S.

Gems and Minerals

Sir Victor Sassoon and his ivories.

P. ALLEN. *Transactions of the Oriental Ceramic Society*, **66**, 2003, 95-105.

Brief description of the collection of Chinese ivory artefacts formed by Sir Victor Sassoon (1881-1961). Accounts of some of the vicissitudes of the collection and comments on the catalogues are included. M.O'D.

The Bishop copper prospect.

H. BARWOOD. *Mineralogical Record*, **34**, 2003, 215-22.

The Bishop copper prospect is the source of the world's best crystals of turquoise. Situated about one mile west of Lynch Station in Campbell County, Virginia, USA, the prospect produces turquoise crystals either on a mica schist or on a white quartz brèccia. Crystals are too small for ornamental use but are sought by collectors who still find specimens on the mine dumps. M.O'D.

An unusual crystal from the Central Queensland sapphire fields.

R. BEATTIE. *Australian Gemmologist*, **21**(10), 2003, 408, 4 illus.

An unusual crystal fragment of around 17 carats was recovered from the Great Northern Mining's Subera sapphire mine located 5 km east of Rubyvale. The pyramidal crystal displayed the distinct features of both ruby and sapphire. Light transmitted along its c-axis made it glow bright red and revealed the hexagonal orientation of 'silk' included sapphire in the base of the crystal. When this transmitted light was analysed with a hand-held spectroscope the identifying spectrum of both ruby (fine lines in the red and a broad absorption in the green-yellow) and sapphire (strong absorption band at 450nm) were revealed. P.G.R.

Jewelled gifts of the Mughal court.

S. CANBY. *Transactions of the Oriental Ceramic Society*, **66**, 2003, 57-64.

Text of a lecture given by the author to the Society on 4 December 2001. The tradition of presenting expensive and elaborate gifts characterized the courts of the first five Mughal emperors from 1526 to 1658 and some of the rituals of giving and receiving are described. Some of the gifts were set with important gemstones. M.O'D.

Rare gem mineral deposits from Brazil – Part 2: Lazulite and scorzalite.

M.L.C. CHAVES, J. KARFUNKEL, A.H. HORN AND D.B.HOOVER. *Australian Gemmologist*, **21**(10), 2003, 390-9, 6 illus., 4 maps, 3 tables.

The lazulite group members, lazulite and scorzalite, form a solid solution series between the magnesium and iron end members and are valued because of their fine blue colour. However, their relatively low hardness and rarity as gem-quality specimens make them collectors' stones. Brazil is the main source of these two minerals and this paper identifies the deposits and regions where they occur, discusses their genesis, and describes their gemmological characteristics. P.G.R.

Beryllium diffusion of ruby and sapphire.

J.L. EMMETT, K. SCARRATT, S.F. MCCLURE, T. MOSES, T.R. DOUTHIT, R. HUGHES, S. NOVAK, J.E. SHIGLEY, WUYI WANG, O. BORDELON AND R.E. KANE. *Gems & Gemology*, **39**(2), 2003, 84-135.

Although initially only orange to orange-pink ('padparadscha'-like) sapphires were seen, it is now known that a full range of corundum colours, including yellow and blue as well as ruby, have been produced or altered by the heat treatment of corundum involving lattice diffusion of Be at $T >$ 1800°C. An extension of the current understanding of the causes of colour in corundum is presented to help explain the colour modifications induced by Be diffusion. The examination of hundreds of rough and faceted Be-diffused sapphires reveals that standard gemmological testing will identify many of these treated corundums, though in some cases MS analysis may be necessary. Potential new methods to provide additional aids in their identification are being investigated. A fold-out colour chart is provided to assist in appreciating visual diagnostic clues. R.A.H.

The Rogerley mine, Weardale, County Durham, England.

J. FISHER AND L. GREENBANK. *UK Journal of mines and minerals*, **23**, 2003, 9-20.

The Rogerley mine is producing very fine green crystals of fluorite, many of which are gem quality. The history of mining in the area, with the local geology and mineralization, is described with notes on the chemistry. REE, though present in the crystals, are not thought to cause the colour on their own. M.O'D.

CO_2-H_2S-COS-S_8-AlO(OH)-bearing fluid inclusions in ruby from marble-hosted deposits in Luc Yen area, North Vietnam.

G. GIULIANI AND 10 OTHERS. *Chemical Geology*, **194**(1-3), 2003, 167-85.

Fluid inclusions have been studied in rubies from marble-hosted deposits in the Luc Yen mining distinct, N. Vietnam. Raman and IR spectroscopy combined with microthermometry

investigations on primary and secondary fluid inclusions provided evidence of CO_2-H_2S-COS-S_8-AlO(OH)-bearing fluids with native sulphur and diaspore daughter minerals without visible water. Diaspore formed as an invisible film 2-3 μm thick coating the walls of the fluid inclusion cavity, and native sulphur was generally nucleated during Raman irradiation. The presence of diaspore and COS in the fluid inclusions indicates that water was present in the palaeofluid. The mole fractions of H_2O and CO_2 are ~10^{-2} and the expected concentration in the fluid inclusions is in the 1-10 mol.% range. Crush-leach identified sulphates and chlorides that are assigned to the presence of anhydrite and Na-Ca-Cl salts found by SEM in the ruby crystals. The CO_2-rich inclusions which do not coexist with an aqueous phase by immiscibility process demonstrate that ruby grew from this CO_2-rich and water-poor fluid at equilibrium with Na-Ca-Cl salts. Thermal reduction of evaporitic sulphates based on an initial assemblage of anhydrite, calcite and graphite, originating from the metamorphism of organic matter is proposed to explain the original fluid chemistry of these marble-hosted rubies. The marbles acted as a closed system and the carbonic composition of the parent fluids in ruby indicates that aluminium can be transported in CO_2-rich fluids at high *T* and *P*. G.L.B.

Über Amethystvorkommen in Sachsen.

R. HAAKE. *Mineralien Welt*, **14**(4), 2003, 12-25.

Amethyst of ornamental and sometimes near-gem-quality is described from different locations in Saxony, Germany. Details of the local geology are given for some locations. M.O'D.

The distribution of rare earth elements in north Pennine fluorspar and fluorite.

R.A. IXER. *UK Journal of mines and minerals*, **23**, 2003, 21-6.

Though fluorite from the north Pennine orefield is REE-rich, it is not thought that they are the cause of the range of colours shown. Details of experiments are given. M.O'D.

Imilchil.

S. JAHN. *Mineralien Welt*, **14**(4), 2003, 42-64.

Geological and mineralogical survey of the Imilchil region of Morocco. A full descriptive species list is given. Transparent gem-quality apatite crystals over 2.5 cm are noted. M.O'D.

Amazonitization in granite resulting from the intrusion of pegmatites.

H. JORDT-EVANGELISTA, J. CÉSAR-MENDES AND A.L.C. LIMA. *Revista Brasileira de Geociências*, **30**(4), 2000, 693-98.

Borrachudos-type granite from Santa Maria do Itabira, in Minas Gerais is cut by amazonite-bearing pegmatites, being marginally transformed into a green granite due to amazonitization. This paper deals with the processes and the mineralogical and chemical variations involved in the transformation of the normal granite into a green granite. The metre-wide pegmatite is composed of decimetre size amazonite crystals of intense green colour, cleavelandite, biotite, quartz and small amounts of black tourmaline, galena, fluorite and anatase. The alkaline anorogenic granite is composed of quartz, nearly pure albite, microcline with triclinicities of 0.68–0.93, Fe-biotite and accessory minerals. The mean SiO_2 content is 74 wt.%, but in quartz-poor samples it decreases to 62%. MgO is very low (<0.05 wt.%), Fe_2O_{3total} reaches 4.4% and alkalis 8.5%. A strong negative Eu anomaly could be due to the retention of Eu in the calcic plagioclases left over in restitic rocks which generated the alkaline magma by partial melting. The intensity of the green colour in the granite increases towards the pegmatite contact. Chemically this colour variation is accompanied by an increase in the Pb (and to a lesser extent also in Rb) contents, while no difference could be registered for the major and other trace elements. Pb varies from 37 to 302 ppm, reaching 406 ppm in the amazonite. It is possible that the subsolidus introduction not only of Pb but also of water from the pegmatite into the country rock was responsible for the generation of H_2O–Pb pairs in the microcline, which are postulated as the cause of the green colour of amazonites. Considering the relatively low *T* of pegmatitic magmas and the massive structure of the granite, the metasomatic process of amazonitization was very efficient since the aureoles locally reached a width equal to the width of the pegmatite. H.A.H.

Gem News International.

B.M. LAURS (ED.). *Gems & Gemology*, **39**(2), 2003, 152-65.

Items mentioned include a 1372 ct faceted pink fluorite from Pakistan, chatoyant reddish-brown cabochons of Na-meionite with abundant inclusions of hematite, an 83.53 ct quartz cabochon from Kola containing stalks and fibres of astrophyllite, and a bi-coloured synthetic diamond showing both blue and yellow zones (due to B-induced absorptions). R.A.H.

Sapphire in diamond alluvial deposits at Coxim River region, Mato Grosso do Sul, Brazil.

A. LICCARDO AND J.E. ADDAD. *Revista Brasileira de Geociências*, **31**(3), 2001, 635-8.

Alluvial diamondiferous deposits of Coxim, Mato Grosso do Sul, contain corundum grains (sapphire type) in association with diamonds. These sapphires were analysed by electron microprobe for Al, Fe, Ti, Cr and Ga. The relation Cr/Ga < 1 indicates an alkaline basaltic source for the corundum and the Coxim sapphires presented values around 0.25-0.5. High iron content, between 1.03 and 1.26%, and low Ti, from 0.0 to 0.31%, suggests the cause of colour by charge transfer between Fe^{2+} and Fe^{3+}, typical basaltic sapphires. High levels of resistance to chemical attack through hardness and density of both corundum and diamond, point to sedimentary reworking survival and depositional convergence at fluvial traps. The high roundness of the sapphires from Coxim indicates a long distance vector. H.A.H.

Relationship between the groove density of the grating structure and the strength of iridescence in mollusc shells.

Y. LIU, K.N. HURWIT AND L. TIAN. *Australian Gemmologist*, **21**(10), 2003, 405-7, 2 illus.

A scanning electron microscope and a laser were used to study the iridescence of a shell of the mollusc *Pinctada margaritifera* and to measure the groove structure which acts as a reflection diffraction grating. The studies have shown that the range of groove density in a shell is between 80 grooves-per-mm for the weakest iridescence and 300 grooves-per-mm for the strongest iridescence. If two shells have the same groove density, the one with the higher quality diffraction grating will produce the stronger iridescence. P.G.R.

Fibrous nanoinclusions in massive rose quartz: HRTEM and AEM investigations.

C. MA, J.S. GOREVA AND G.R. ROSSMAN. *American Mineralogist*, **87**(2-3), 2002, 269-76.

Examination of pink fibrous crystals within massive rose quartz from localities in California, South Dakota, Brazil, Madagascar and Namibia with high-resolution transmission electron microscopy (HRTEM) and analytical electron microscopy (AEM) reveals that the nanofibres in all samples are related to dumortierite. Selected-area electron diffraction (SAED) patterns and HRTEM images indicate that the dumortierite-related fibres have a superstructure with a doubled periodicity along the a and b axes of dumortierite, giving cell parameters $a = 2a_{dum} = 2.36$ nm, $b = 2b_{dum} = 4.05$ nm, $c = c_{dum} = 0.47$ nm. Computer simulations suggest that periodic arrangements of two different *M*1 site occupancies in the octahedral face-sharing chains give rise to the superstructure. One type of *M*1 site is occupied mainly by Al, whereas the other type is dominated by Ti and Fe. Simulated HRTEM images based on the proposed model match the experimental images. Most of the fibres, elongated along the *c*-axis, are free of defects. AEM analysis shows that the dumortierite-related fibres have a composition similar to well-characterized dumortierite, but that they contain a greater amount of Fe substituting for Al and the *M*1 sites. Boron was detected in all fibres examined by electron energy loss spectroscopy as well as in sillimanite crystals found as a minor component in one rose quartz from Brazil. P.M.W.

Pressure, temperature and fluid conditions during emerald precipitation, southeastern Yukon, Canada: fluid inclusion and stable isotope evidence.

D. Marshall, L. Groat, G. Giuliani, D. Murphy, D. Mattey, T.S. Ercit, M.A. Wise, W. Wengzynowski and W.D. Eaton. *Chemical Geology*, **194**(1-3), 2003, 187-99.

The Crown emerald veins are somewhat enigmatic, displaying characteristics that are common to emerald deposits of tectonic-hydrothermal origin and of igneous origin. The veins cut the Fire Lake mafic metavolcanic rocks, occurring within 600 m of an outcrop of Cretaceous S-type granite. Fieldwork and vein petrography are consistent with a polythermal origin for the veins. The primary vein mineralogy is quartz and tourmaline with variable sized alteration haloes of tourmaline, quartz, muscovite, chlorite and emerald. The veins weather a buff brown colour due to jarosite, scheelite and minor lepidocrocite, which were precipitated during the waning stages of vein formation. Microthermometric studies of primary fluid inclusions within emerald growth zones are consistent with emerald precipitation from H_2O-CO_2-CH_4 ($\pm N_2 \pm H_2S$)-bearing saline brines. The estimated fluid composition is ~ 0.9391 mol.% H_2O, 0.0473 mol.% CO_2, 0.0077 mol.% CH_4 and 0.0059 mol.% NaCl (~2 wt.% NaCl eq.). Fluid inclusion and stable isotope studies are consistent with vein formation in the *T* range 365-498°C, with corresponding *P* along fluid inclusion isochore paths ranging from 700 to 2250 bar. These data correlate with a very slow uplift rate for the region of 0.02-0.07 mm/year. Emerald deposits are generally formed when geological conditions bring together Cr (± V) and Be. Cr and V may have been derived locally from the mafic and ultramafic rocks during hydrothermal alteration. The Be was most likely derived from the nearby Cretaceous granite intrusion. G.L.B.

Lab notes.

T.M. Moses, I. Reinitz, S.F. McClure and M.L. Johnson (eds). *Gems & Gemology*, **39**(2), 2003, 144-51.

Notes are given on a green cut stone of chrysoberyl with V as chromophore, a Guatemalan jade with inclusions of reddish-brown lawsonite, a 'red' spinel whose pink body colour was increased to orange-red by exsolved inclusions of hematite along octahedral planes and two natural marquise-cut brown-yellow diamonds with strong parallel pink lamellae. R.A.H.

Proceedings, 4th Indian Gemmological Seminar.

Udaipur, 2002. In: *Indian Gemmologist*, **11**(1/2), 2003, 2-64.

Papers presented include Understanding colour in diamonds; Padparadscha, natural or treated?; Priority areas for exploration of gem minerals in India; The Kashmir sapphire; Identification of fracture filled diamonds; Gemstones of Orissa – an overview. M.O'D.

What's new in minerals?

J. Scovil and T. Moore. *Mineralogical Record*, **34**, 2003, 275-85.

Specimens of gem interest seen in the Tucson and Carnegie [Pittsburgh] shows of 2002 included an emerald theme at the Carnegie show, fine almandine from the Two Fat Guys mine, Erving, Massachusetts, deep rose-coloured beryl from Mandrasonora, west of Ambatofinandronara, Madagascar, aquamarine from Taplejung, Taplejung district, Nepal, diopside from Xinjiang Uygur province, China, spessartine in a deep raspberry-red colour from the Urucum mine, Galileia, Minas Gerais, Brazil and elbaite from the Terra Corrida mine near Coronel Murta in the same state. Some of the crystals were deep red at both ends with a deep green in the centre. M.O'D.

First finding of sapphire from Cenozoic alkali-basaltic volcanoes in the Primor'e region.

S.V. Vysotskii, S.A. Shcheka, V.P. Nechaev, V.P. Soroka, A.V. Barker and A.I. Khanchuk. *Doklady, Russian Academy of Sciences, Earth Sciences Section*, **387A**(9), 2002, 1100-3 (English translation).

To test the hypothesis that rare metal pegmatites, greisens and granite-related metasomatites were the source of the corundum in this region, extensive heavy concentrate sampling of alluvial sediments and talus in the Cainozoic alkali-basaltic fields was carried out. The chemical compositions of basalt, garnet, pyroxene, spinel, amphibole and biotite from the Konfetka and Podgelbanochnyi volcanoes are tabulated, together with TiO_2, Al_2O_3 and FeO analyses of sapphires from these localities and also from the Nezametnaya placer and the Kedrovka River placer. The authors regard this region as the N segment of the Australian and East Asian sapphire-bearing belt. A.M.C.

Gem quality petalite from Myanmar (Burma).

U.K.K. Win and T. Themelis. *Australian Gemmologist*, **21**(10), 2003, 409, 1 illus.

Petalite, a lithium aluminium silicate, occurs in Khet-chal, Molo district near Momeik, Myanmar as gem-quality transparent colourless crystals having a glassy appearance and as water-worn pebbles with a characteristic waxy lustre. Although confused locally with quartz, petalite has a distinctively different SG, RI and habit. This is the first report of Myanmar gem-quality petalite in the literature, and only a handful of these rare gemstones are known. P.G.R.

Instruments and Techniques

Limitations of the pavilion depth rapid sight estimates method.

G. HOLLOWAY. *Australian Gemmologist*, **21**(10), 2003, 400-3, 5 illus., 3 tables.

The *Rapid sight estimates* method, as proposed by Liddicoat (*Gems & Gemology*, 1962) is a way of estimating the pavilion depth of a brilliant cut diamond by visually assessing the relative size of the table reflection compared with the actual size of the table facet. However, if either the crown angle is very steep, or the girdle is very thick, then Liddicoat's visual depth estimation leads to an under-estimate of the pavilion depth. Research by the author also reveals that diamonds with combined steep crowns and slightly deep pavilions can cause a significant amount of light entering the crown to leak out of the pavilion, resulting in reduced brilliance. This increases the possibility of incorrect appraisal when assessing the cut proportions of a brilliant cut diamond. In the author's opinion, the most effective alternative is to use a Sarin™ proportion measurement analyser, although this is an expensive option at US$6,000. P.G.R.

Large OPL™ diffraction grating spectroscope.

T. LINTON, A. CUMMING AND K. HUNTER. *Australian Gemmologist*, **21**(10), 2003, 410-12, 3 illus.

This report by the GAA Instrument Evaluation Committee compares results obtained with the well known small OPL diffraction grating spectroscope with those obtained on the new larger version. Both models employ a fixed slit which is set for maximum resolution of fine line absorption spectra. This fixed slit has the disadvantage of requiring stronger illumination when checking the absorption spectra of darker gemstones. Although diffraction grating spectroscopes are supposed to be in focus across the complete spectrum, one member of the Evaluation Committee noted differences in focus between red and blue on the larger model. The new instrument's size made it easy to use, and the spectroscope's large eyepiece lens provided easy viewing of the bigger spectrum available, features making it particularly suitable for teaching purposes. The image quality of complex absorption spectra was better than that obtained with the smaller version and matched the quality of those produced by most prism spectroscopes. The report includes general recommendations for the use of spectroscopes in the identification of gemstones. P.G.R.

Diamond cut grading based on red reflection instruments.

T. LINTON AND G. HOLLOWAY. *Australian Gemmologist*, **21**(10), 2003, 413-19, 4 illus., 2 tables.

Four instruments designed for diamond cut grading are compared and their methodologies described. Each instrument, the Brandt, Schindler, Fire Scope and the Ideal-Scope, is based on a 10× lens surrounded by a red reflector. Comparisons are made by using the instruments to analyse four diamonds of differing proportions. Neither the Brandt nor the Schindler instruments functioned as effectively as the Fire Scope and the Ideal-Scope in allowing the user to make a good subjective judgement of diamond cut quality, light return and light leakage. P.G.R.

Synthetics and Simulants

50th anniversary of first successful diamond synthesis.

R. CAVENEY. *Industrial Diamond Review*, **2003**(1), 2003, 13-15.

After a brief review of earlier unsuccessful attempts to synthesize diamond, an account is given of the successful experiment by the Swedish company ASEA on 15th February 1953. Iron carbide and graphite were used, with a thermite; the latter was activated by an electric pulse sent through a wire between the anvils in a spherical *P* intensifier (the Quintus press) which started the exothermic reaction to provide the required *T*. The crystals were confirmed as diamond by XRD. The yields in the successful runs were 20-50 crystals, from 0.1 to 0.5 mm in size; they had irregular faces and were mostly transparent and colourless, but a few were green, yellow or grey. R.A.H.

Spectroscopy of natural silica-rich glasses.

E. FAULQUES, E. FRITSCH & M. OSTROUMOV, *Journal of Mineralogical and Petrological Sciences*, **96**(3), 2001, 120-28.

By means of IR and Raman spectroscopy and optical microscopy, impactites, tektites and obsidian have been investigated and compared with artificial glasses with silica-rich and alkali-rich compositions. IR spectra are strongly dependent on silica content: frequencies of the ν_3 and ν_D bands increase with the silica content. Raman spectra of tektites show relationship between silica, alumina, sodium contents and the presence of vibrational bands peaked at very specific energies. Raman spectra of Libyan desert glass, Darwin glass and vitreous silica are almost identical with the typical doublet at 440-490 cm^{-1}, whereas in tektites the band at 440 cm^{-1} has a relatively less pronounced doublet structure. A common character of Raman spectra of tektites and obsidians is the appearance of broad bands centred around 1000 and 1600 cm^{-1} due to substitutions of Si by metals. Tektites have a strong absorption band at 1100 cm^{-1} due to Fe^{2+} ions. In the other glasses, this absorption is slightly shifted towards 1100-1130 nm. Additional sharp features of impactites and obsidians at 1380, 2210-2250 nm are completely absent in the absorption spectra of tektites. These bands are the signature of molecular water trapped inside the structure. I.S

Abstractors

G.L. Barron	G.L.B.	H.A. Horn	H.A.H.	P.G. Read	P.G.R.
A.M.Clark	A.M.C.	R.A. Howie	R.A.H.	I. Sunagawa	I.S.
J. Flinders	J.F.	M.O'Donoghue	M.O'D.	P.M. Whelan	P.M.W

For further information on many of the topics referred to, consult *Mineralogical Abstracts*

Book Reviews

Gem and ornamental materials of organic origin.

M. CAMPBELL PEDERSON, 2004. Elsevier, Oxford. pp xiv 268, illus. in colour. Hardcover, ISBN 0 7506 58525. £33.25.

This is a very interesting book which draws together a vast amount of information which would otherwise require delving into many sources from a wide range of disciplines. The author advocates identification by visual observation (if necessary aided by a 10× hand lens) since she feels that standard gemmological tests are often not feasible on account of the shape and size of many 'organic' objects, and that some tests might damage delicate surfaces. She could be correct.

The book is well bound and the overall design is admirable. The author's photographic skills show through in the prolific illustrations, but the fine details in some of the pale coloured objects (notably the ivories) is often poorly reproduced, which may be caused by inadequacies in the printing processes. The magnification is not given in many enlarged photographs.

There are fourteen chapters, which in the case of the amber chapter (38 pages) is divided into sections on localities and species, structures and properties, treatments and uses, identification and history. Some chapters may have fewer sections while conservation status and availability are also discussed in others. Other chapters are Jet (17 pages), Ivory (29), Bone (8), Antler (9), Rhino horn (6), Horn (17), Tortoiseshell (17), Pearl (27), Coral (27), and Miscellaneous organics (18) which includes such diverse materials as baleen, byssus, calabash, coconut, feathers, fossilised molluscs, hair, hornbill ivory, insect wings, lacquer, shagreen, vegetable ivory and others. The chapter on Plastics (12) is excellent. The final chapter is a series of seven identification charts (tables) which compare and contrast the properties of similar species described in the book.

The book does not deal with some methods which might be conducted in a gemmological laboratory, but it does list three seemingly simple tests which individuals might be able to use; (1) the hot-point – not recommended by this reviewer except by those with *very* considerable expertise, (2) the burning test, using a tiny scraping from an inconspicuous part of the object – again much experience is needed and (3) ultraviolet light which can be a useful indication, but this apparatus can be expensive although there are now some small UV lights which fit into the pocket and cost much less.

There is a useful glossary and a good bibliography, but surprisingly, this does not mention R. Webster's book *Gems* which does describe many simple and useful gemmological tests on organic materials. For the antique dealer, jeweller and gemmologist this book would be a most useful addition to their bookshelves. E.A.J.

Diamonds. Revised edn.

F. WARD, 2003. Fred Ward Gem Series. Gem Book Publishers, Bethesda, MD. pp 64, illus. in colour. Softcover ISBN 1 887 651 09 8. £10.95.

Well-written and illustrated as readers have come to expect from this excellent series, this new member of the Gem Books series includes up-to-date information on synthetic diamond and some of the recent developments in the sale of rough by the De Beers organization. Photographs of diamonds in jewellery are particularly effective and the whole page illustrating pink to near-red Argyle stones is one of the first to catch the eye. The author's continuing services to gemmology and jewellery are most welcome. M.O'D.

Rubies & sapphires. 4th edn.

F. WARD, 2003. Fred Ward Gem Series. Gem Book Publishers, Bethesda, MD. pp 65, illus. in colour. Softcover ISBN 1 887 651 10 1. £10.95.

Along with the fine photographs come up-to-date details of synthesis and treatment. In particular there is an account of beryllium diffusion and other treatments, one showing the before and after state of Montana sapphires. Traditional corundum examples have not been forgotten and, as always in this series, many specimens are shown set in jewellery. All students should buy this. M.O'D.

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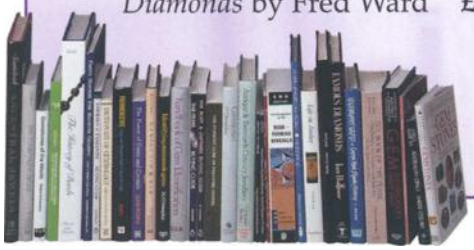

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Proceedings of the Gemmological Association and Gem Testing Laboratory of Great Britain and Notices

The Presentation of Awards ceremony held in the magnificent Livery Hall at Goldsmiths' Hall, London. (Photo: Lewis Photos Ltd.)

Presentation of Awards

The Presentation of Awards gained in the 2003 examinations was held at Goldsmiths' Hall, Foster Lane, London EC2, on Monday 3 November. Professor Alan Collins, President of the Association, presided and welcomed those present, particularly students who had travelled from as far away as Canada, Colombia, Hong Kong, Sri Lanka and the U.S.A., as well as from the UK and Europe. He announced that in January and June 2003 a total of 861 students had sat the Preliminary and Diploma Gemmology and Gem Diamond Diploma examinations.

Professor Collins introduced Anthony Hirsh who presented the awards.

Anthony Hirsh then delivered his address (see below) and a vote of thanks was given by Ian Thomson who also thanked the Goldsmiths' Company for kindly permitting Gem-A to hold the ceremony at the Hall.

A reception was held following the ceremony, attended by over 200 members, students and their guests.

Anthony Hirsh's Address

First off, congratulations! This evening is for all of you wonderful and clever students who passed your FGA/DGA exams, so give yourselves a hand. You deserve it!

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Have you ever stood back and pondered why? Why do teachers instruct us in various skills which we will probably never use in our everyday lives? They ask us all sorts of questions and then we must present the answers. Well I am here to tell you that you will use these skills; it is just a question of time and place.

In life – that is in the real business world – everything that you have learned in the past and will continue to learn in the future will benefit you at some point in your lives. You may not agree now, but believe me, this is true. All that you have learned, studied and read will eventually bear fruit. Realize the only ingredient you have not acquired thus far is *experience*. That really is the crux of the matter.

The work that you have input, along with your teachers aid and guidance, are so that you will not only know the answers but also so that you will understand and begin to know why.

For better understanding, let us break down those key components which will lead you to a successful career in any given field: first, comes the learning; second, comes the studying; and third and most importantly, comes the *application*. With that in mind, then ask yourselves three vital questions: what can I... and what should I do with all of that knowledge? Will I be able to make an impact on the business and in what aspect of the business can I apply myself?

Naturally, you want a job, but as you will find out or may have already discovered, it is not so easily obtainable – even with having expert knowledge and qualifications. Possessing a diploma does not automatically guarantee you a job. You and you alone must work at it continuously. Simply replying to advertisements, sending out CVs, emailing, phoning or pounding the pavement alone can, and often will, prove ineffective unless you know someone or are recommended by someone reputable. Today, networking is crucial for securing yourself a position within an organization. During the interview process try and meet with either the boss or senior manager in order to develop a positive rapport and make an unforgettable impression.

Just remember, no matter how large or small the company, good people are hard to come by and most employers know this to be the case. *You* know how good you are – but they do not. Bear in mind that you probably are better informed, more skilled and certainly better qualified than most of the people that will be conducting the interview. So what is the problem? Basically, there are far too many clever people out there competing for similar jobs. By the way, it is the same in every country all over the world today.

Therefore, it is up to you to prove yourself! You must invest in yourself before anyone else will do the same. Start by subscribing to the trade presses. Constantly be aware of the trends, the competition and the current happenings within your chosen industry. By continuing to grow and being receptive to new ideas, you will be adding to your job credibility and marketability. If you pace yourself and choose the businesses which are right for you – whether it be in design, manufacturing or selling – you should have no trouble locating

Anthony Hirsh presenting the Anderson-Bank Prize to Jessica Banks. (Photo: Lewis Photos Ltd.)

Anthony Hirsh presenting the Anderson Medal and the Preliminary Trade Prize to Antoinette Jackson. (Photo: Lewis Photos Ltd.)

that perfect job in which you can shine. Consider you have three very important assets: yourself, your knowledge and do you know what the third asset is?... your certificate!

Now, some helpful tips you may wish to consider at this time on your careers. Finding employment at a small company rather than a large firm will provide you with the opportunity to hone up on your skills and learn all aspects of the industry. Also, allow your employer to train you in their personal style of working instead of having them conform to your work traits. Likewise, be familiar with the difficulties that go into creating your own business and the amount of capital that goes into making a successful company. Always remember that your reputation will follow you throughout your career, whether you are just beginning or at the top of the corporate ladder, maintain your integrity, practice a high work ethic and be trustworthy to all those around you.

The best advice I can give you today, according to my personal experience, is that your enthusiasm about your work will play the most important role in how you achieve success in your careers. Naturally when you radiate enthusiasm, whether in your personal or professional lives, you become a positive influence on those around you. This kind of passion will be contagious. Your employer, your peers and the public will automatically sense this enthusiasm about you and share in your excitement toward a particular product or jewellery design.

You are probably asking yourselves, so how did I end up in this wonderful and challenging business? In 1969, I met a young (we were all young then - some of you were not even thought of, let alone, born) dynamic man by the name of Lawrence Graff. He asked me to change the direction of my career and come and work for him at the then Graff Diamonds Ltd. In a matter of months, I became a sales director. Even though I found the gem side very interesting, especially since we handled and sold some of the largest gems in the world, my main job was to increase the sales side of the company. I accomplished this by travelling all over the world, meeting people and establishing valuable business contacts. The excitement of selling, travelling and creating were so exhilarating. Graff then went on to create the largest jewellery company which today is recognized as the leader in the field. Opening a store in Knightsbridge in 1974, at the time of the Arab boom, demonstrated great timing. It not only showed impeccable vision, but proved very profitable as well.

As with most companies that grew rather large, there arose differences of opinion. As a result, I resigned and began my own company in 1980. I began in wholesale and then in 1986, I took over a lease at no. 10 Hatton Garden. It was there that I started retailing under my own name *Hirsh*. Then, in 2001, I opened our flagship store in Burlington Arcade located in the West End.

I am very proud to stand before you today and say that our company is known throughout the world for our fine handmade jewellery, for our one-of-a-kind designs and for our exceptional sales service. However, I cannot

take all the credit. Our team is lucky to be led by one of the UK's finest gemmologists, Anne Bailey FGA DGA. Anne came to us in 1992 at 19. Through her ingenious and original designs and establishing a solid client-base; she can now call herself Director of Hirsh – in charge of purchasing loose diamonds and gemstones, as well as, creating the beautiful jewellery designs.

In addition, my staff and I have established our own in-house manufacturing, design and PR facility. Over the past 24 years we have worked very hard to build up a highly reputable and competitive business. When we began, we constantly underwent changes regarding the upgrading of our quality and services. Whether we were selling wholesale within the trade or later to the public, we knew the only way to make a name for ourselves was to deliver an exceptional piece of jewellery and to establish an impeccable reputation amongst the industry and public. Once those factors were in place, we turned our attention toward selling – one of the most difficult and unpredictable aspects of this business. In the end, if you follow these ethical guidelines, you too can have a rewarding and profitable career in this industry.

I am fortunate to have established in my company a team-oriented work environment where fresh ideas and an open-door policy are encouraged. For these reasons, I have a loyal and content staff; therefore, my company will continue to grow and flourish.

It is vital to keep the lines of communication open at all times. Although I am the boss in my company that does not automatically mean that I am correct in all my decisions. I must always remember to listen to any advice or criticism in order to improve my quality of management or the overall welfare of my staff.

Of course, I would not be here today without the continual love and support that I receive from my family. They say that behind every great man is a fine woman. That can be said of my lovely wife, Diane. Likewise, I could not be any prouder of my two daughters, Tracy and Lianne, and of my two sons, Mark and Jason. Only last month, Jason, my youngest, began working for Asprey in New York where he already is proving to be one of their top salesmen.

I hope you are still listening because I want to wish you all much success and happiness in all your future endeavours. Please feel free to ask me any questions or advice this evening. I look forward to hearing only great things about you in the years to come.

Thank you.

Members' Meetings

Gem-A Conference 2003

The Gem-A Annual Conference was held on Sunday 2 November at Kempton Park Racecourse, Sunbury-on-Thames, Middlesex. Keynote speaker was William E. Boyajian, President of the Gemological Institute of America.

The Conference was followed on Monday 3 and Tuesday 4 November by visits to the Diamond Trading Company and the Julius Werhner Collection at the Ranger's House, Greenwich, and a private viewing of the Crown Jewels with David Thomas, the Crown Jeweller.

A full report of the Conference was published in the December 2003 issue of *Gem & Jewellery News*.

Midlands Branch

On 31 October at The Earth Sciences Building, University of Birmingham, Edgbaston, Brian Dunn gave a talk entitled 'The Naughty Nineties (1890s)'.

On 28 November at the Earth Sciences Building, Brian Jackson gave a talk on 'British gemstones with a Scottish flavour'.

On 6 December the 51st Anniversary Branch Dinner was held at Barnt Green.

The Midlands Branch has a new Gem Club which meets monthly for informal practical sessions at Elliott's Deli in Birmingham's Jewellery Quarter. The inaugural meeting was held on Friday 3 October when the topic

Gifts to the Association

The Association is most grateful to the following for their gifts for research and teaching purposes:

Selim Besli, London, for a large collection of rough and cut gemstones.

David Kent FGA, London, for his boxed collection of 46 cut and polished colourless gemstones. Details of the collection were published in *The Journal of Gemmology*, 1987, 20(6), 344-5 and 1996 25(2), 87-9

Aung Kyaw Khaing, Myanmar, for amphiboles from Mogok, Myanmar

Rosemary Ross, FGA, Islington, London, for treated sponge coral beads

was inclusions. The November and December meetings focused on gem treatments and synthetics respectively.

North West Branch

On 15 October at Church House, Hanover Street, Liverpool 1, Stephen Kennedy gave a talk entitled 'Notes from the laboratory – detection, disclosure and false descriptions'.

On 19 November at Church House the Branch Annual General Meeting was held when Deanna M. Brady, Raymond I. Rimmer and Elizabeth Franks were re-elected Chairman, Secretary and Treasurer respectively. The AGM was followed by a social evening.

Scottish Branch

On 15 October at the British Geological Survey, Murchison House, West Mains Road, Edinburgh, James Gosling gave a talk on 'The Cheapside Hoard'.

On 17 November at the British Geological Survey, Tracey Jukes spoke on her experiences in the trade in a talk entitled 'Tales of a gemstone dealer: thoughts from a broad'.

South East Branch

On 7 December at Christie's South Kensington the Branch AGM was held when Colin Winter, Sally Hudson and Lawrence Hudson were re-elected Chairman, Secretary and Treasurer respectively. The AGM was followed by a presentation by Terry Davidson, Chief Executive Officer of Gem-A, entitled 'Cartier: the 20th century'.

Membership

Between 1 October and 30 November 2003 the Council of Management approved the election to membership of the following:

Fellowship and Diamond Membership (FGA DGA)

Hadden, Elizabeth Anne, Stotfold, Hertfordshire. 1987/88

Kanaan, Dominique, London. 2003/2003

Fellowship (FGA)

Cherchi, Sonia, Zurich, Switzerland. 2003

Cheung, Wing Man Cynthia, Hong Kong. 2003

Ching Mei Kit, Jennifer, Kowloon, Hong Kong. 2003

Deprez, Guillaume, London. 2003

Fitzgerald, John, Peoria, Illinois, USA. 2003

Fleuranceau, Annie M., Brossard, Quebec, Canada. 2003

Ku Kai Leung, Kowloon, Hong Kong. 1992

Kwong Yi Hang, Agnes, Kowloon, Hong Kong. 1992

Li Wenjian, Nanshan, Shenzhen, P.R. China. 2003

McMillan, Emma Louise, Leamington Spa, Warwickshire. 2003

Mak Sio In, Joey, Hong Kong. 2003

Mathiesen, Lisbeth S. C., Virum, Denmark. 2003

Ng Chee Keong, Quarry Bay, Hong Kong. 1991

Phillips, Gregory, Toronto, Ontario, Canada. 2003

Phillips, Patrick Edward, Toronto, Ontario, Canada. 2003

Rosas, Manuel, Maria Ramos Pinto, Porto, Portugal. 1949

Schwabe, Arnold R., Burnaby, British Columbia, Canada. 2003

Su Chen-Hui, Taiwan, Taipei, R.O. China. 2003

Thornhill, Helen Victoria, Sheffield, South Yorkshire. 2003

Tsang, Judy, Kwai Chung, Hong Kong. 2002
Vélez Meléndez, Ana Maria, Bogota, Colombia. 2003
Westling, Jonny Anders, Stockholm, Sweden. 2003
Wijetunga, Lettietia Chandra, Colombo, Sri Lanka. 2003

Diamond Membership (DGA)

Deligiannis, Marios, Athens, Greece. 2003
Facey, Emma, Solihull, West Midlands. 2003
Georma, Titika, Pireaus, Greece. 2003
Hadley, John William, Stratford-upon-Avon, Warwickshire. 2003
Haycock, Ian Phillip, Sheldon, Birmingham, West Midlands. 2003
Hayward, Johnathon, Oldbury, West Midlands. 2003
Kelly, Christopher, High Wycombe, Bucks. 2003
Koraki, Christina, Athens, Greece. 2003
Lam Siu Wing, Hamilton, Ontario, Canada. 2003
Lee Ka Yan, Audrey, New Territories, Hong Kong. 2003
Lee Lok Chi, Kowloon, Hong Kong. 2003

Gem-A Photo Competition 2004

Imaginative Images

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Professor Bob Howie

We send our congratulations to Gem-A Vice-President Professor Bob Howie on his election as a Foreign Member of the Lynxes – the Accademia Nazionale dei Lincei. This body became the Italian national academy of sciences (and was founded in 1603 before even the Royal Society). Professor Howie won the honour for his work in fostering the international promulgation of mineralogical knowledge via his books and 40 years' Editorship of *Mineralogical Abstracts*.

Lindsay, Antony Peter, Blackheath, London. 2000
Manchanda, Anu Dippal, Smethwick, West Midlands. 2003
Rafter, Jacinta Maree, Kensington, London. 2003
Rynhold, Emma N.C., London. 2003
Singh, Harjit, Bilston, West Midlands. 2003
Suen Ka Kwan, Athena, Kowloon, Hong Kong. 2003
Tse Chui Yin, Angela, Causeway Bay, Hong Kong. 2003
Wells, Miranda E.J., Hartlebury, Worcestershire. 2003
Yip Siu Ling, New Territories, Hong Kong. 2003

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Yasa, Muhammad, Lahore, Pakistan
Yeoman, Michael Charles, Kingsbridge, Devon

Transfers

Fellowship to Fellowship and Diamond Membership (FGA DGA)

Watanabe, Tomoko, Ibaraki, Japan. 2003

Associate Membership to Fellowship (FGA)

Domec, Cedric, Forest, Belgium. 2003
Ecknauer, Marc, Stein, Switzerland. 2003
Inagaki, Yuko, Kawaguchi-shi, Saitama-Ken, Japan. 2003
Shikatani, Kohei, Yudogawaku, Osaka, Japan. 2003
Sykes-Gomez, Heidi, Cornelius, North Carolina, U.S.A. 2003

Obituary

We very much regret to announce the death of **Alexander E. Farn FGA**, a Vice President of the Gemmological Association since 1992. A full obituary will appear in the April issue of *The Journal*.

Roy De Rosa FGA (D.1950), Southgate, London, died on 19 September 2003.

Edward J. Soukup FGA (D.1955), San Diego, California, U.S.A., died on 19 November 2003 aged 95. Mr Soukup was an avid rockhound, silversmith, facetor and teacher, but will be best remembered for his work and publications in gemmology and jewellery. He was an active member of the Gemological Society of San Diego and the San Diego Lapidary Society.

Errata

In *J.Gemm.*, 2003, **28**(8), 505, under Obituary, for Nikola read Nikolas. We do apologize for this error.

In *J.Gemm.*, 2003, **28**(8), pp. 479-81, due to a technical error, figures 5, 6 and 7 were printed in black-and-white; a leaflet replacing those pages was circulated in December. We apologize for the error.

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18 February **North West Branch:** Gems in Space: An introduction to the world of meteorites. *Alan Bowden*

Midlands Branch One-day Conference

22 February – Barnt Green
Stephen Dale – Keynote speaker
Carl Fabergé – a Russian Revolution
Where are they now? *Michael O'Donoghue*
The minerals of Scotland. *Roy Starkey*

23 February **Scottish Branch (Edinburgh)**: Quiz and Bring and Buy

27 February **Midlands Branch**: The latest from the SSEF and the University of Basel. *Professor Henry Hänni*

25 February **South East Branch**: Tavernier and his stones. *Nigel Israel*

17 March **North West Branch**: Cartier: the 20th Century. *Terry Davidson*

23 March **Scottish Branch (Glasgow)**: The feldspar family. *Brian Jackson*

26 March **Midlands Branch**: The hallmark. *Chris Tarratt*

30 April **Midlands Branch**: Branch AGM followed by
Bond Street jewellers of the 19th and 20th centuries. *Terry Davidson*

Scottish Branch Conference

30 April to 3 May – Lovat Hotel, Perth
Speakers will include:
John I. Koivula – Keynote speaker
Peter Buckie, Alan Hodgkinson, Elisabeth Strack, Colin Trowler and Chris Walton

contact details

When using e-mail, please give Gem-A as the subject:

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Gem-A Website

For up-to-the-minute information on Gem-A events visit our website on **www.gem-a.info**

Guide to the preparation of typescripts for publication in *The Journal of Gemmology*

The Editor is glad to consider original articles shedding new light on subjects of gemmological interest for publication in *The Journal*. Articles are not normally accepted which have already been published elsewhere in English, and an article is accepted only on the understanding that (1) full information as to any previous publication (whether in English or another language) has been given, (2) it is not under consideration for publication elsewhere and (3) it will not be published elsewhere without the consent of the Editor.

Typescripts Two copies of all papers should be submitted on A4 paper (or USA equivalent) to the Editor. Typescripts should be double spaced with margins of at least 25 mm. They should be set out in the manner of recent issues of *The Journal* and in conformity with the information set out below. Papers may be of any length, but long papers of more than 10 000 words (unless capable of division into parts or of exceptional importance) are unlikely to be acceptable, whereas a short paper of 400-500 words may achieve early publication.

The abstract, references, notes, captions and tables should be typed double spaced on separate sheets.

Title page The title should be as brief as is consistent with clear indication of the content of the paper. It should be followed by the names (with initials) of the authors and by their addresses.

Abstract A short abstract of 50-100 words is required.

Key Words Up to six key words indicating the subject matter of the article should be supplied.

Headings In all headings only the first letter and proper names are capitalized.

A This is a first level heading

B *This is a second level heading*

First and second level headings are in bold and are ranged left on a separate line.

Third level headings are in italics and are indented within the first line of text.

Illustrations High resolution digital files, for both colour and black-and-white images, at 300 dpi TIF or JPG, and at an optimum size, can be submitted on CD or by email. Vector files (EPS) should, if possible, include fonts. Match proofs are essential when submitting digital files as they represent the colour balance approved by the author(s).

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Notes and References Authors may choose one of two systems:

(1) The Harvard system in which authors' names (no initials) and dates (and specific pages, only in the case of quotations) are given in the main body of the text, (e.g. Collins, 2001, 341). References are listed alphabetically at the end of the paper under the heading References.

(2) The system in which superscript numbers are inserted in the text (e.g. ... to which Collins refers.[3]) and referred to in numerical order at the end of the paper under the heading Notes. Informational notes must be restricted to the minimum; usually the material can be incorporated in the text. If absolutely necessary both systems may be used.

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Papers Collins, A.T., 2001. The colour of diamond and how it may be changed. *J.Gemm.*, **27**(6), 341-59

Books Balfour, I., 2000. *Famous diamonds*. 4th edn. Christie's, London. p. 200

Abbreviations for titles of periodicals are those sanctioned by the *World List of scientific periodicals* 4th edn. The place of publication should always be given when books are referred to.

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Gemmology

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Cover Picture: *Polished quartz crystal with numerous coiled 'rutile' whiskers. (See Coiled 'rutile' whiskers in a quartz single crystal pp 1-7).*

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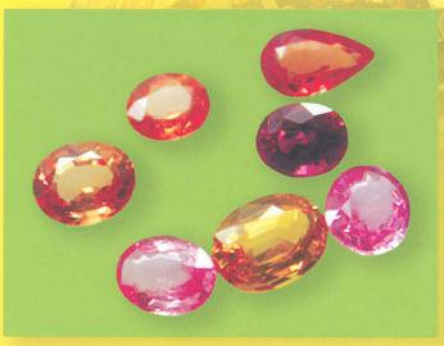

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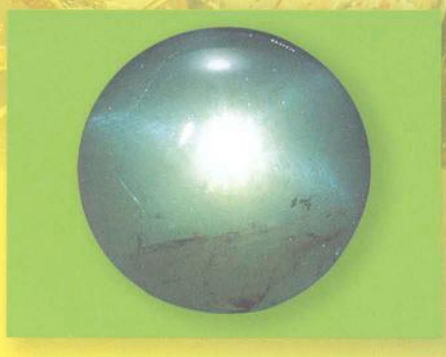

Asterism in beryl, aquamarine and emerald – an update

Nephrite jade in Finland

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Asterism in beryl, aquamarine and emerald – an update

Dr Karl Schmetzer[1], Dr Lore Kiefert[2] and Professor Dr Henry A Hänni[2]

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2. SSEF Swiss Gemmological Institute, Falknerstr. 9, CH-4001 Basel, Switzerland

Abstract: *An overview about present knowledge of asterism in beryl, aquamarine and emerald is presented. A bronze-brown beryl from Brazil and several aquamarines from Madagascar revealing six-rayed asterism were examined. An emerald specimen from Madagascar showing four- and six-rayed stars is studied in detail. The asterism of this specimen is due to a combination of a six-rayed star emerald and an emerald cat's-eye. Three causes for six-rayed stars in various members of the beryl family are known: (a) needle-like mineral inclusions, (b) elongated thin fluid films and (c) elongated negative crystals.*

Introduction

Recently, a German dealer purchased a rough emerald specimen in Madagascar, which was – according to the information given by a local gem merchant – most probably originating from the well-known Mananjary emerald mining area. Due to the visual appearance of the rough, it was assumed that the sample could yield another six-rayed star emerald similar to a specimen obtained in 2001[1]. However, after cutting as a cabochon, the emerald showed a weak four-rayed star in the centre of the convex surface. Examining this four-rayed star emerald, we took the opportunity to compare the sample with a six-rayed star beryl from Brazil and several star aquamarines from Madagascar, and to review and summarize the present knowledge about asterism in members of the beryl family.

Beryl with mineral inclusions

Beryl, aquamarine and emerald showing asterism are among the rarer gem materials. Gemmological literature dealing with asterism in beryl and its varieties is presented in *Table I*. In the 1950s, rough beryl with a specific type of inclusion was discovered in Brazil[2,3,4]. Cabochons with six-rayed asterism were cut and found their way onto the international market and into public or private collections (*Figure 1*). Examination of the cut sample in *Figure 1* and some rough material available to the present authors confirmed the descriptions published in the 1950s. The samples frequently quoted in textbooks and articles dealing with asterism in beryl or other minerals[5,6,7], have been described as almost colourless beryl to very light green aquamarine. The body colour of these specimens, however, is a much more intense bronze or bronze-brown when viewed in a direction parallel to the *c*-axis. This impression is due to a dense pattern of mineral inclusions which are located on planes parallel to the basal pinacoid, i.e. on planes perpendicular to the *c*-axis (*Figure 2*). A mineralogical

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Table 1: Asterism in aquamarine, beryl, and emerald.

Locality	Host	Asterism	Inclusions	References
Minas Gerais, Brazil	almost colourless beryl to light green aquamarine, with a dark brown or bronze-brown colour in a view parallel to the *c*-axis	six-rayed	skeletal elongated ilmenite crystals on planes parallel to the basal pinacoid	2, 3, 4, 5, 6, 7, this study
Brazil	greenish-grey, almost opaque beryl	six-rayed	tabular plates or flakes of pyrrhotite parallel to the basal pinacoid, other mineral inclusions without specific orientation	7, 8, 9
Sri Lanka	aquamarine	six-rayed	thin fluid films on planes parallel to the basal pinacoid	7, 10
unknown	emerald	six-rayed	channels parallel to prism faces consisting of two-phase inclusions	7, 11
Nova Era, Minas Gerais, Brazil	emerald	six-rayed	needle-like channels	7, 12
Santa Terezinha, Brazil	emerald	six-rayed	not mentioned	13
Santa Terezinha (?), Brazil	emerald	six-rayed	channels parallel to the *c*-axis, three series of elongated particles perpendicular to the *c*-axis	14
Brazil	aquamarine	six- or four-rayed	thin films on planes parallel to the basal pinacoid, hollow channels parallel to the *c*-axis	15
Mananjary area, Madagascar	emerald	six-rayed	tabular birefringent inclusions parallel to the basal pinacoid	1
Madagascar	aquamarine	six-rayed	three series of elongated channel-like inclusions (thin fluid films) perpendicular to the *c*-axis	this study
Mananjary area, Madagascar	emerald	six- and four-rayed	channels parallel to the *c*-axis, three series of elongated channel-like inclusions (negative crystals) perpendicular to the *c*-axis	this study

N.B.: The items are arranged chronologically in order of their discovery or reporting in the literature.

Figure 1: Bronze-brown six-rayed star beryl from Minas Gerais, Brazil. Diameter of the sample 6.0 mm, weight 1.41 ct.

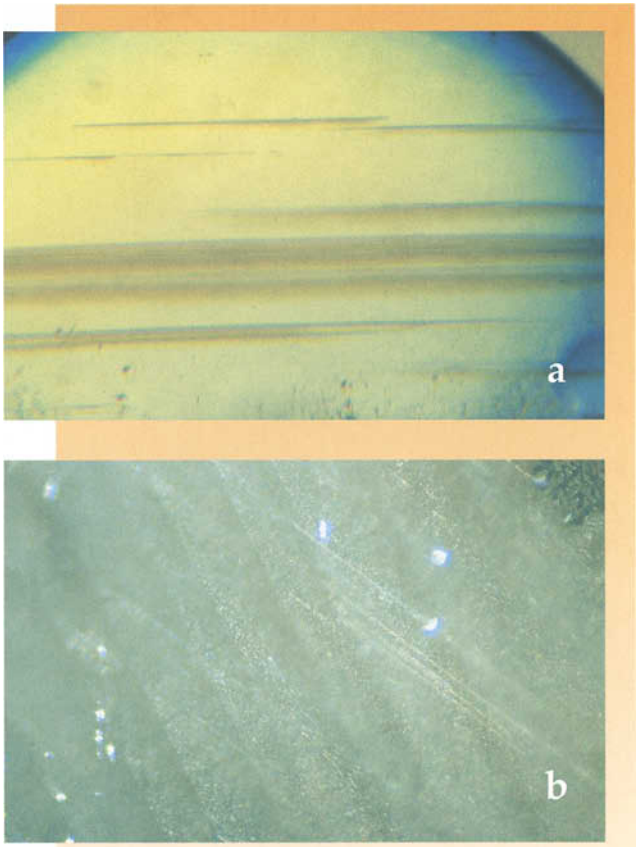

Figure 2: Bronze-brown six-rayed star beryl from Minas Gerais, Brazil; layers parallel to the basal pinacoid with a dense pattern of skeletal crystals, (a) view perpendicular to the c-axis, immersion, 40×, (b) view oblique to the c-axis, 100×.

examination of these inclusions described them as skeletal ilmenite crystals (*Figure 3*), the elongated directions of which were oriented parallel to prism faces of the beryl host[4], in this way causing the six-rayed star of the beryl cabochons.

A piece of an almost opaque, greenish-grey beryl originating also from Brazil, was described by Eppler (1960)[8]. Asterism in this sample is caused by plates or flakes of pyrrhotite, which are oriented parallel to the basal pinacoid of the host[8,9]. This specimen shows a number of extraordinary inclusions[9] and since no similar material has been described in the gemmological literature, it seems to be unique.

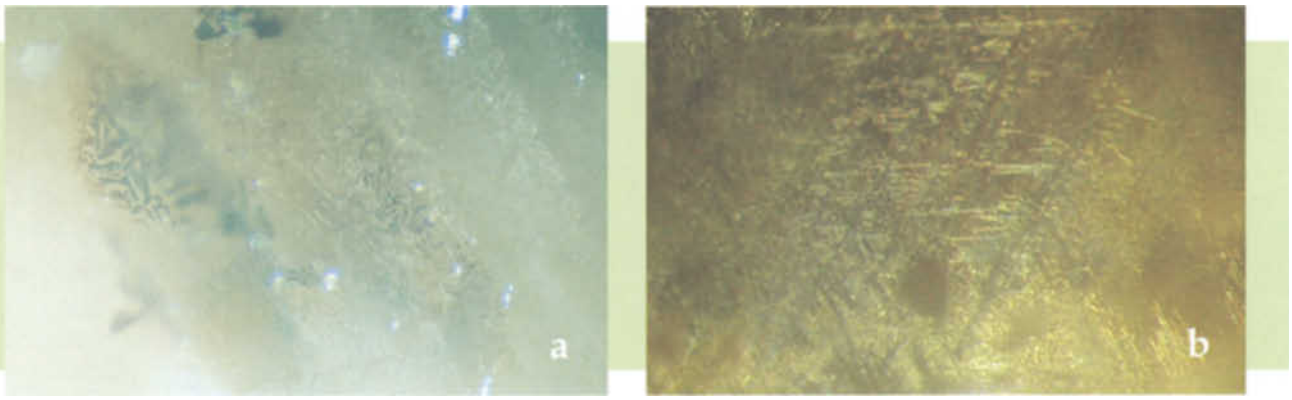

Figure 3: Bronze-brown six-rayed star beryl from Minas Gerais, Brazil; dense pattern of oriented ilmenite skeletal crystals, (a) view oblique to the c-axis, 100×, (b) view parallel to the c-axis, 100×.

Figure 4: Six-rayed star emerald from Brazil. Diameter of the specimen 12.5 mm, weight 10.03 ct. Photo by Tino Hamid, © GIA (reproduced by permission).

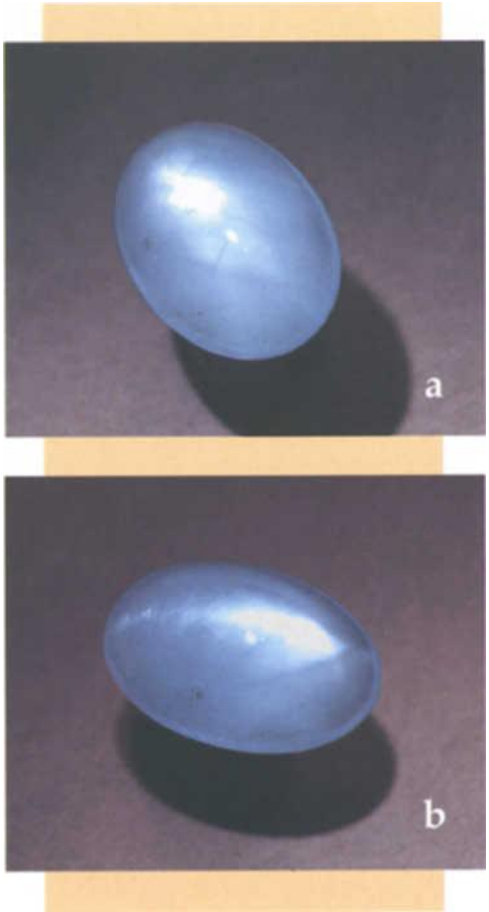

Figure 5: Six-rayed star aquamarine from Madagascar; in different orientations (a, b), an intense white sheen in the centre of the aquamarine and the weaker arms of a six-rayed star are visible. Size 18.4 × 12.6 mm, weight 9.53 ct.

Aquamarine with thin fluid films

Several cabochons of asteriated emerald (*Figure 4*) or aquamarine have been reported since the 1980s. These have come from different localities in Brazil as well as from Sri Lanka and Madagascar [1,7,10,11,12,13,14,15]. Microscopic examination commonly reveals that the star emeralds and aquamarines contain three series of small elongated particles[14], needle-like channels[7,12] or channels consisting of two-phase inclusions[7,11]. These inclusions are oriented perpendicular to the *c*-axis and parallel to prism faces of the host. In some samples, thin fluid films on planes parallel to the basal pinacoid[7,10,15] or tabular birefringent inclusions in the same orientation[1] are also present in asteriated beryl cabochons. Asterism has also been attributed to such fluid films[7].

Fluid films similar to those described by Henn and Bank[7] are also present in four star aquamarines from Madagascar which were available for the present study. In three specimens, the six-rayed star is weak and best seen when moving the cabochons back and forth. The specimen with the most intense star was examined in detail and showed a strong white sheen as well as the somewhat weaker arms of a six-rayed star (*Figure 5*). The asteriated aquamarine contains both disc-like fluid films and oriented channel-like or needle-like inclusions (*Figure 6*). The fluid films are located on planes perpendicular to the *c*-axis (*Figure 7*). Parts of the fluid discs show irregular outlines, but also

Figure 6: Six-rayed star aquamarine from Madagascar; thin disc-like fluid films and channel-like or needle-like inclusions, view parallel to the c-axis, 100×.

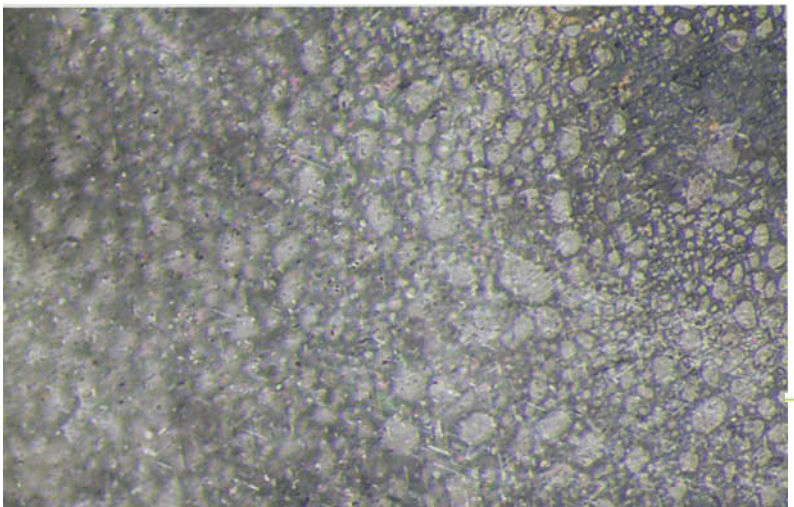

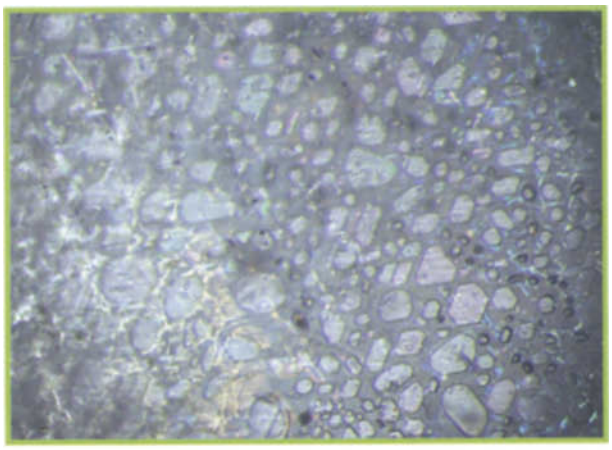

Figure 7: Six-rayed star aquamarine from Madagascar, thin fluid films on planes parallel to the basal pinacoid, the films show irregular and hexagonal or trigonal forms, view parallel to the c-axis, 200×.

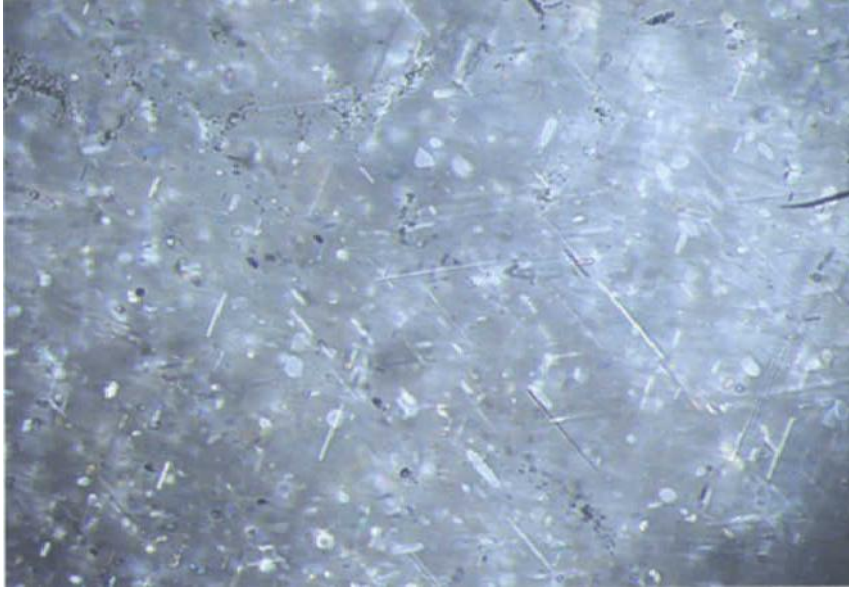

Figure 8: Six-rayed star aquamarine from Madagascar; three series of oriented channel-like or needle-like inclusions are responsible for the asterism; view parallel to the c-axis, 200×.

clear hexagonal or trigonal forms with boundaries parallel to prism faces are seen. In addition, three series of minute, channel-like or needle-like inclusions are present, which are oriented perpendicular to the *c*-axis in directions parallel to prism faces (*Figure 8*). In other words, the orientation of these minute elongated channels or elongated flat fluid films is parallel to the hexagonal boundaries of the flat fluid discs. In this specimen, an examination of the tiny oriented channels with the Raman microprobe did not show any characteristic Raman lines other than those of the beryl host.

Although the fluids on planes parallel to the basal pinacoid reflect at a certain angle to the incident light and cause a white sheen at the centre of the cabochon, they cannot be responsible for the six-rayed asterism of the aquamarine. The star is caused by three sets of elongated channel-like or film-like inclusions oriented in three different directions perpendicular to the *c*-axis. Because both types of inclusion are present, the white sheen of the sample is superimposed on the star and causes a pattern consisting of both optical phenomena. According to the results of the microscopic examination, both types of inclusion are disc-shaped and channel-like thin negative crystals (fluid films) showing boundaries parallel to basal and prism faces.

Multi-star emerald with negative crystals

A four-rayed star aquamarine from Brazil was recently described by Hyrsl (2001)[15]. The specimen was cut from the same type of rough as another cabochon, which yielded a star aquamarine with the ordinary six-rayed asterism but in another orientation. It is assumed that the four-rayed star is caused by a combination of the inclusions that are responsible for the six-rayed asterism and hollow channels which normally cause chatoyancy in beryl[15].

The four-rayed emerald from Madagascar (*Figures 9 and 10*) mentioned above belongs to the same type of beryl, i.e. the sample combines the inclusions causing the ordinary six-rayed asterism with chatoyancy in beryl due to channels parallel to the *c*-axis. The sample shows an absorption spectrum which consists of the absorption bands of Cr^{3+} in emerald superimposed on a strong aquamarine component. This spectrum is consistent with spectra reported for other emeralds from the Mananjary area in Madagascar[1].

The *c*-axis of the emerald is more or less parallel to the elongation of the cabochon which weighs 7.78 ct and measures 12.3 × 10.5 mm. Although the specimen is only semitransparent

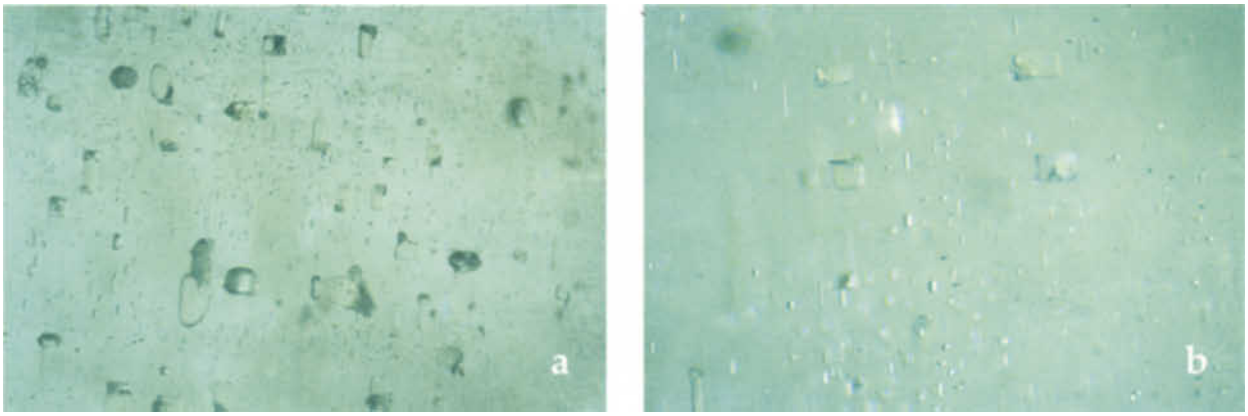

Figure 9: Emerald from Madagascar with six- and four-rayed asterism; short prismatic negative crystals and elongated channels parallel to the c-axis, view perpendicular to the c-axis. (a) 50×, (b) 100×.

(due to numerous inclusions and healing fissures), we observed a series of short prismatic negative crystals or elongated channels in a direction parallel to the *c*-axis with birefringent solid, liquid and two-phase fillings (*Figure 9*). At high magnification, it was also observed that three series of channel-like or needle-like inclusions are present in directions perpendicular to the *c*-axis (*Figure 10*). These channels are negative crystals elongated perpendicular to the *c*-axis and confined by basal and prism faces. An examination with the Raman microprobe showed only the spectrum of the beryl host.

According to the orientation of the different types of channels in this emerald (*Figure 11*), the centre of the four-rayed star in the middle of the dome of the cabochon is observed in a view perpendicular to the *c*-axis. Turning the cabochon towards a view along the *c*-axis, i.e. in a view parallel to the curved surface of the sample, one weak six-rayed star is seen at each end of the elongated cabochon. Consequently, the asterism of the emerald is caused by four light bands. The two six-rayed stars, which are observed in views parallel to the *c*-axis (at both ends of the elongated cabochon), consist of three light bands intersecting at angles of 60° to each other. The four-rayed stars, which are observed in views perpendicular to the *c*-axis, are formed by intersections of one of the three light bands of the six-rayed star with a fourth light band oriented perpendicular to the *c*-axis.

This interpretation is confirmed by the results of the microscopic examination described above. The six-rayed stars are formed by three light bands due to three sets of channel- or needle-like inclusions (negative crystals) which are oriented perpendicular to the *c*-axis intersecting at angles of 60° to each other. These are the light bands of the 'ordinary' six-rayed star in this beryl. Because additional channels or elongated channel- or needle-like inclusions parallel to the *c*-axis are present, a fourth light band can be observed. This is the light band of an 'ordinary' beryl cat's-eye. The intersection of each of the three 'six-rayed star light bands' and the 'cat's-eye light band' causes the four-rayed stars observed.

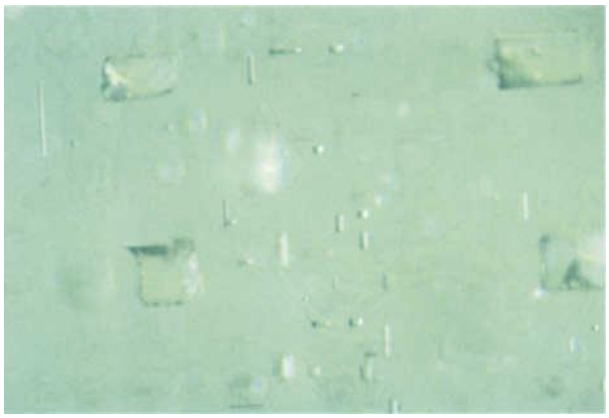

Figure 10: Emerald from Madagascar with six- and four-rayed asterism; short prismatic negative crystals and two series of elongated channels in directions parallel and perpendicular to the c-axis, view perpendicular to the c-axis. 200×.

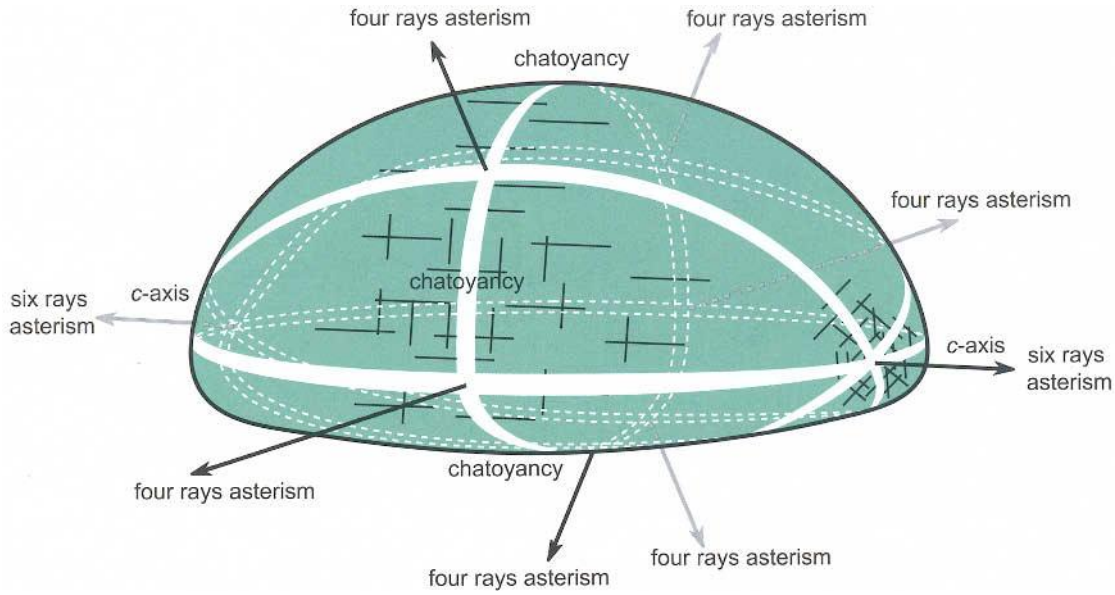

Figure 11: Schematic drawing of the orientation of the four sets of parallel inclusions in the emerald from Madagascar producing four intersecting light bands and a four- and six-rayed multi-star network (artwork by M.S. Krzemnicki).

Conclusion

In summary, asterism in members of the beryl family is caused by oriented solid and fluid inclusions. If three sets of elongated particles (e.g. ilmenite or elongated channel-like fluid films or elongated channel-like negative crystals) oriented perpendicular to the *c*-axis are present, a six-rayed star can be observed. With additional channels parallel to *c*, four- and six-rayed stars are formed. The mineral inclusions causing asterism in beryl which have been determined so far are ilmenite and pyrrhotite. The elongated channel-like inclusions are thin fluid films or negative crystals, both of which are terminated by basal and prism faces. The inclusions are elongated parallel to one of the three equivalent directions parallel to the prism faces of the host.

Acknowledgements

We thank Dr M.S. Krzemnicki for the preparation of the diagram presented in Figure 11 and Tino Hamid and the GIA for permission to reproduce Figure 4.

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Aventurescent oligoclase feldspar from Oregon, USA

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Abstract: *Transparent oligoclase feldspars from Oregon, USA are described. They contain euhedral hematite inclusions, which cause aventurescence.*

Keywords: *aventurescence, chemical composition, gemmological properties, hematite inclusions, oligoclase feldspar, Oregon*

Introduction

Although minerals of the feldspar group are the most abundant minerals in the Earth's crust, gem-quality feldspars are rather rare. However, they can fascinate by their optical phenomena which may be present as adularescence, labradorescence or aventurescence (Henn and Bank, 1992; Henn, 2001).

The feldspars are divided into two main groups on the basis of their composition: the alkali feldspars, aluminosilicates of potassium and sodium, and the plagioclase feldspars, aluminosilicates of sodium and calcium.

The best-known gemstones of the alkali feldspars are moonstone, yellow orthoclase and amazonite, while the most important gem-quality species of the plagioclase group are labradorite and sunstone. The name sunstone or heliolite (from the Greek *helios* = sun and *lithos* = stone) is used for transparent feldspar crystals which were discovered in basaltic rocks in the state of Oregon, USA, in the 1960s by local mineral collectors. The main occurrence is located in the Rabitt Hills, approximately 22 miles north of Plush in Lake County (Pough, 1983). A second locality has been found in Harney County. Small scale mining at several claims has been carried out by local miners since the mid-1970s.

The feldspar crystals of Oregon possess unusual sizes of 8 cm and more and come in a wide range of colours including yellow, yellowish-green, blue-green, violet, orange, red-orange and red. Compositionally, the Oregon sunstones are mixed-crystals in the solid-solution series of the plagioclase feldspars with a range of Na/Ca-ratios.

The most abundant species is labradorite with typical iridescence commonly visible parallel to the cleavage planes, but also bytownite (Bank, 1970), andesine and oligoclase have been found.

Recently, the author had the opportunity to investigate spectacular specimens of transparent oligoclase which were cut by the renowned gemstone cutter Tom Munsteiner.

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Figure 1: Faceted colourless oligoclase feldspar from Oregon, USA, with red inclusions of hematite (45.18 ct, cut by Tom Munsteiner).

Figure 2: Faceted oligoclase feldspar from Oregon, USA. The pale red colour is due to concentrations of hematite inclusions (30.90 ct, cut by Tom Munsteiner).

Description and characteristics

The faceted stones are colourless (*Figure 1*) with red tabular inclusions which are responsible for the pale red colour (*Figure 2*) of some specimens. The pattern of the red inclusions also causes the optical phenomenon of aventurescence which is a spangled sheen caused by the reflection of light from the tiny red platelets. Such aventurescent stones are described as sunstones; they are rather rare and represent only about 1 per cent of the gem-quality Oregon feldspars.

The red inclusions (*Figure 3*) were identified as hematite by microscopical and chemical studies. Aventuescent feldspars from Norway contain a similar inclusion pattern and these also are called sunstone in the gemstone trade.

The refractive indices were measured on a standard refractometer, the SGs were measured by the hydrostatic method and composition was obtained using an energy-dispersive XRF attachment on an electron microscope.

The refractive indices, birefringence, specific gravity and classical composition of the Oregon feldspars are listed in *Table I*. These values classify the feldspars unambiguously as oligoclase. The albite/anorthite-ratio (*Table I, column 3*) characterizes a typical oligoclase composition. Compared with the Norway sunstones and colourless oligoclase from Brazil (Henn and Bank, 1992), the Oregon oligoclases have a lower anorthite content and lower refractive indices.

Acknowledgement

The author thanks Dr Tobias Häger of the University of Mainz, Germany, for the microprobe analyses.

Figure 3: Microscopic image of euhedral hematite inclusions in oligoclase feldspar from Oregon, USA. Immersed, magnified 30×.

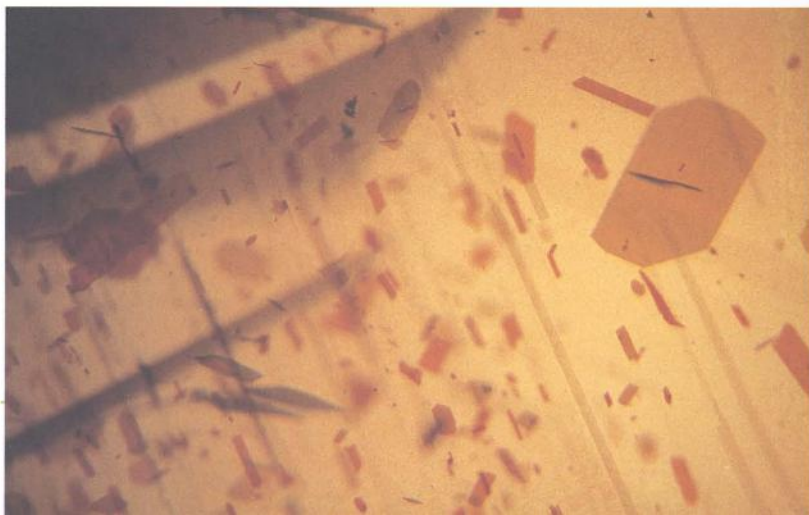

Table I: Physical characteristics and chemical composition of aventurescent oligoclase feldspar from Oregon, U.S.A.

Physical characteristics	Chemical composition of one representative sample. Average of 5 analyses			
n_x = 1.535-1.536	Wt.%		No. of ions on the basis of 32 O	
n_y = 1.538-1.539	SiO_2	64.85	Si	11.35
n_z = 1.545-1.547	Al_2O_3	22.04	Al	4.62
Δn – 0.010-0.011	Fe_2O_3	0.08	Fe	0.01
	Na_2O	10.31	Na	3.58
	K_2O	0.24	K	0.04
	CaO	2.57	Ca	0.53
	Total	100.09	Feldspar end-member proportions	
			Ab	86.06
			An	12.74
			Or	0.96

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Pezzottaite, a new mineral and gem
(supplement to 'Caesium-rich morganite from Afghanistan and Madagascar')

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Abstract: *Nomenclature used to describe new pink mineral specimens from Afghanistan and Madagascar is brought up to date. Structural differences between beryl and pezzotaite are illustrated.*

Keywords: *Afghanistan, Cs-beryl, Madagascar, pezzottaite*

What appeared to be extraordinary pink beryl with high Cs content in samples from Afghanistan and Madagascar (Hänni and Krzemnicki, 2003) has been found to be a new mineral (Laurs *et al.*, 2003). Our recent publication (op.cit.) was based on results obtained before a decision was available from the 'Commission for new minerals and new mineral names' of the International Mineralogical Association (IMA). The decision of the IMA to accept pezzottaite as a new mineral was issued on 5 September 2003 and a definitive article by Hawthorne *et al.* is expected in the *Mineralogical Record*.

Consequently the terminology used by Hänni and Krzemnicki (2003) relating to pink morganite, pink beryl or Cs-beryl should be replaced by the name pezzottaite when the Li-Cs-rich analogue of beryl is meant (see *Figure 1*). With quantitative Be and Li data from ICP-MS measurements, and lattice dimensions calculated from

Figure 1: A selection of pezzottaite crystals with characteristic tabular habit. The cut stones are from 1.5 to 3.00 ct, (the step-cut sample in the middle is 12 mm long). Pezzottaites with a dense array of fine tubes (parallel to c) are cut as cabochons and produce cat's-eyes.

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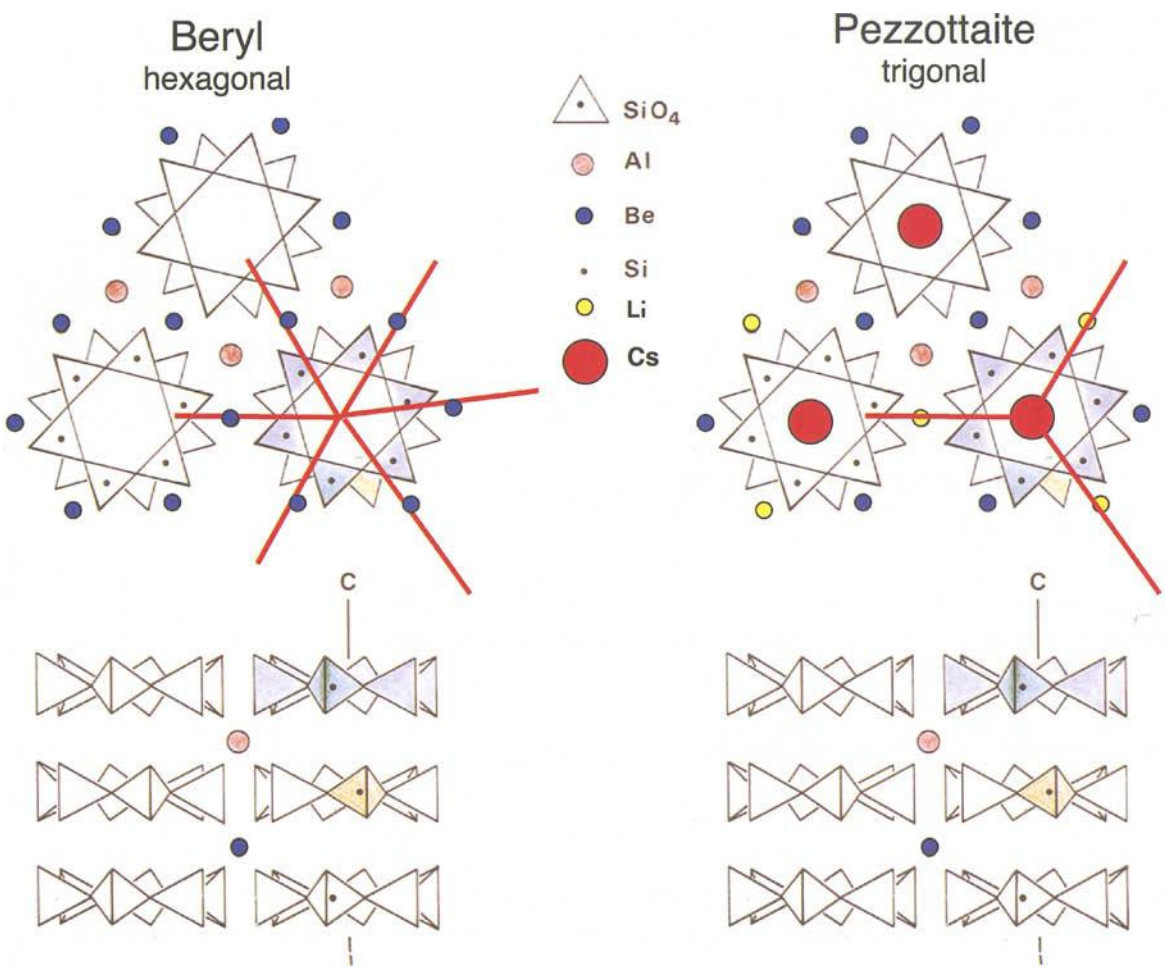

Figure 2: Schematic diagram of the crystal structures of beryl and pezzottaite. The upper parts show structures projected on a basal plane (perpendicular to c). The lower parts show a side view of the axial direction (parallel to c) with stacked Si_6O_{18} rings and cation positions. The ordered coupled substitution $Be^{2+} = Li^{+} + Cs^{+}$ implies a trigonal symmetry for pezzottaite.

single crystal X-ray data, the space group of pezzottaite was determined as R3c. Although similar to the beryl structure, the systematic and symmetrical positions of the Li and Cs in the structure of these samples from Afghanistan and Madagascar justify establishment of the new mineral. The similarities and differences in structure between the two minerals are illustrated in *Figure 2*. Ongoing research will show whether or not there is solid solution between pezzottaite and beryl.

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Yellow and brown coloration in beryllium-treated sapphires

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Abstract: *The causes of yellow and brown coloration in Be-treated sapphires have been investigated by a series of irradiation and Be-heating experiments on synthetic and natural colourless sapphires. UV-Vis spectra have been recorded and the stones have been analysed for trace elements by LA-ICP-MS. Based on these results it is likely that the Be-heating process could activate stable yellow colour centres in natural sapphires, which are also related to oxygen in the atmosphere and iron; these are stabilized by the diffusion of Be. Brown colour centres could be activated in the synthetic sapphires without iron. Therefore Be is able to act in the same way as has been previously proposed for Mg.*

Keywords: *beryllium treatment, colour centres, diffusion, heat treatment, irradiation, yellow sapphires*

Introduction

Gemstone enhancement is traditional in human history. For several hundred years, rubies have been heated in coal furnaces to reduce the blue hue (Nassau, 1984, 1994; Hughes, 1997). The 'classical' high temperature treatment of corundum has been known for thirty years (Tombs, 1980; Harder, 1980; Crowningshield and Nassau, 1981; Nassau, 1982). Today we understand the mechanisms and the causes of colour much better than in the past. Nevertheless, the gemstone industry of Thailand has surprised us once again with a 'new' corundum enhancement technique that shows new and unexpected colour distribution and reactions. Examples have been presented on a number of websites (e.g. AGTA, GRS) and from Hughes (2002) and McClure *et al.* (2002).

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Typical examples of the product of this 'new' heating process can be seen in *Figure 1*. Many of those samples show surface-related yellow zones or if the stone contains chromium, an orange colour rim was observed (*Figures 2* and *3*). To get a better inside view, the stones were put into an immersion liquid (methylene iodide) and to improve the contrast a blue glass filter was placed between the light source and the stones. The thickness of the surface-related colour zone is about 2.5 mm in *Figure 2* and about 1.2 mm in *Figure 3*. However, colour rims up to 4 mm have been observed in the lab.

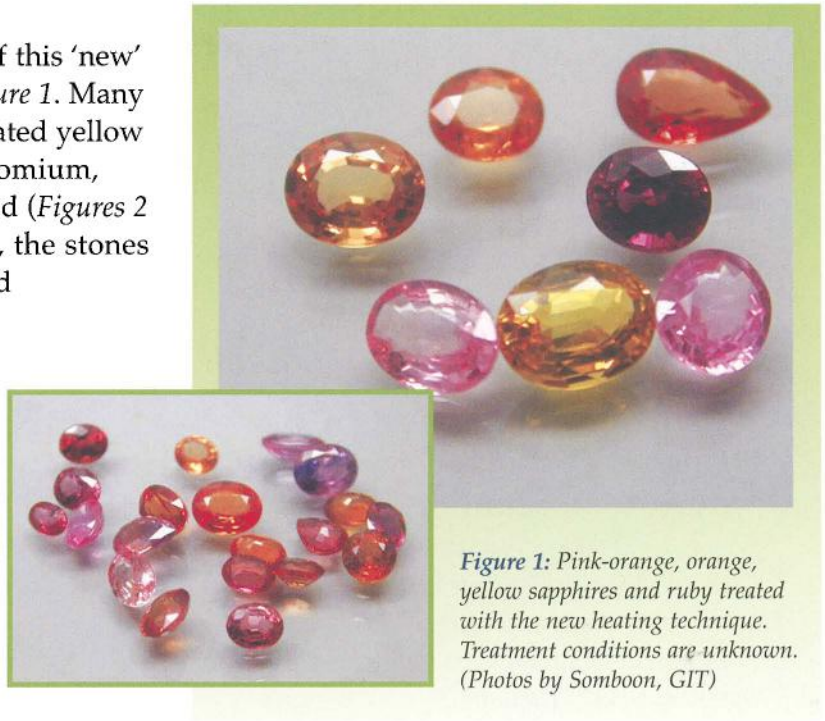

Figure 1: Pink-orange, orange, yellow sapphires and ruby treated with the new heating technique. Treatment conditions are unknown. (Photos by Somboon, GIT)

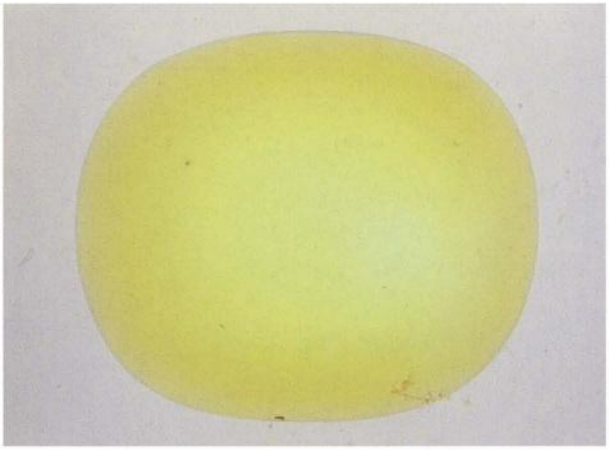

Figure 2: Surface-related colour zones in a yellow sapphire, 10.06 × 11.57 mm. (Immersion, photo by Leelawatanasuk, GIT)

Because the colour zones are parallel to the surface, it suggests that the stones have been subject to diffusion of a foreign element or combination of elements. Hitherto, diffusion of a colour-producing element into a gem mineral lattice on the scale of millimetres has not been observed. The penetration depth of the traditional diffusion treatment shown in *Figure 4*, where Ti and Fe are introduced into the sapphire from outside is about 0.09 mm; this is known as external diffusion. Of course, the penetration depth can vary slightly

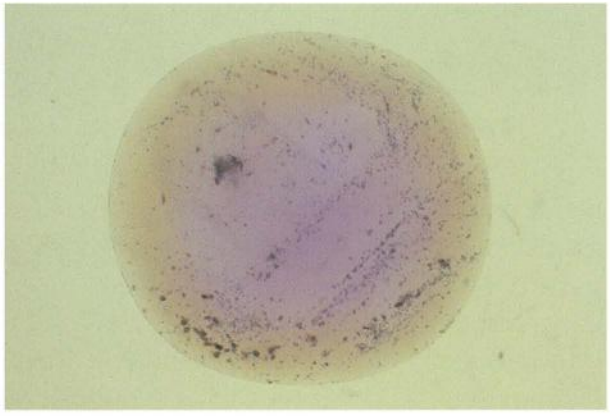

Figure 3: Surface-related colour zones in a pink-orange sapphire, 5.20 × 6.63 mm. (Immersion, photo by Somboon, GIT)

Figure 4: Slice of colourless sapphire with blue rim caused by external diffusion of Ti into the stone; 4 × 7 mm. (Immersion, photo by Häger)

depending on time and temperature of treatment. A similar order of diffusion thickness (0.06 mm in *Figure 5*) can be observed in the case of internal diffusion, where titanium diffuses from natural rutile inclusions into the corundum lattice.

To understand the new enhancement technique applied to create yellow and orange sapphires, it is necessary to understand the causes of colour of natural yellow sapphires in detail. Two groups of natural yellow sapphires exist. The first group owes its colour to a spin forbidden transition of Fe^{3+} (Lehmann and Harder, 1970; Krebs and Maisch, 1971; Ferguson and Fielding, 1971, 1972; Nassau and Valente, 1987). However, the probability of this transition is very low, therefore, approximately 1 weight % Fe^{3+} is needed to create an intense yellow with this mechanism. Sapphires of this group originate for example from the basaltic-type occurrences in Thailand, Australia and North Madagascar, or from the metamorphic occurrence in Umba, Tanzania (D. Schwarz, pers. comm., 2003). Typical spectra resulting from this kind of mechanism are shown in *Figure 6*.

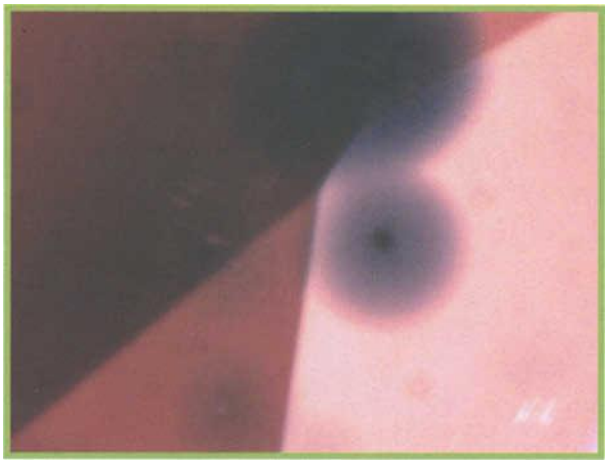

Figure 5: Internal diffusion of Ti from rutile inclusions into the corundum lattice showing the blue haloes. (Photo by Häger)

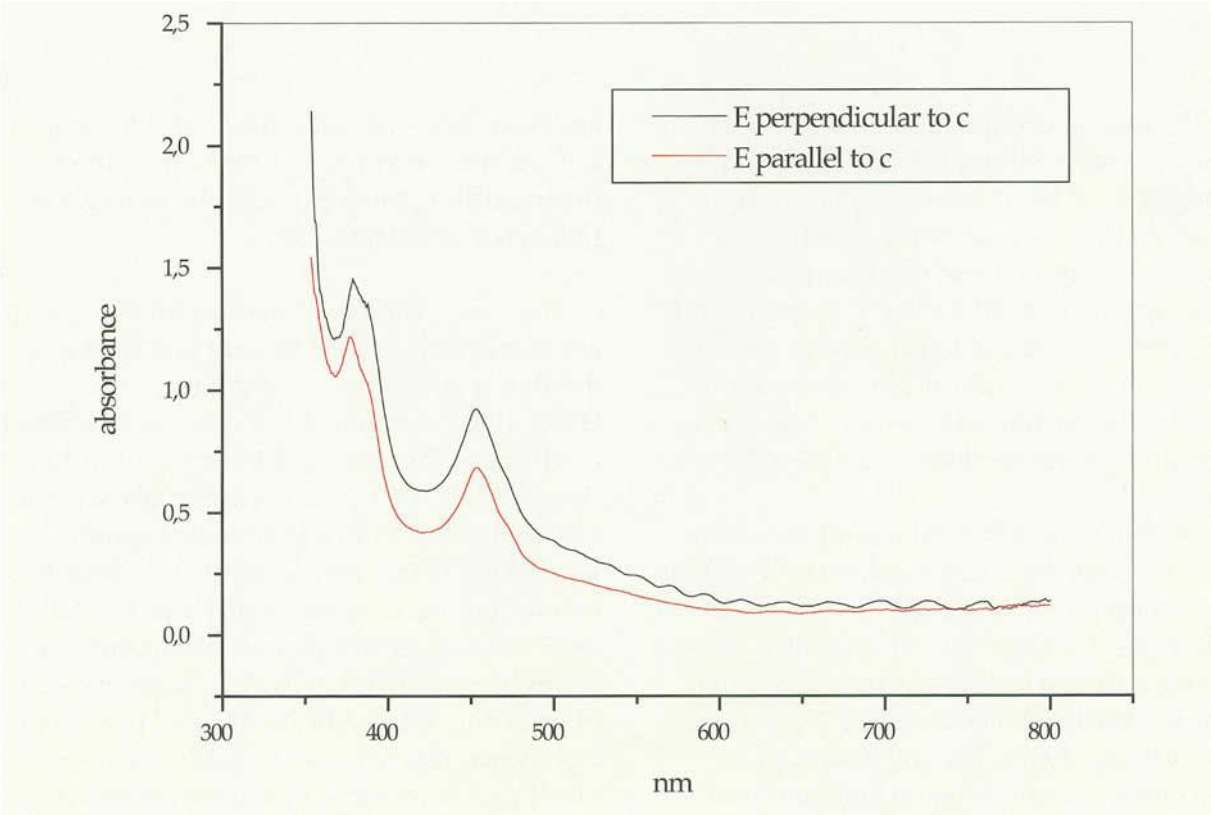

Figure 6: UV-Vis-spectra of an untreated yellow sapphire from Thailand (Khao Phloi Wean Chanthaburi) with E perpendicular to c-axis (o-ray, black) and E parallel to c-axis (e-ray, red). The colour is due mainly to Fe^{3+} forbidden transition.

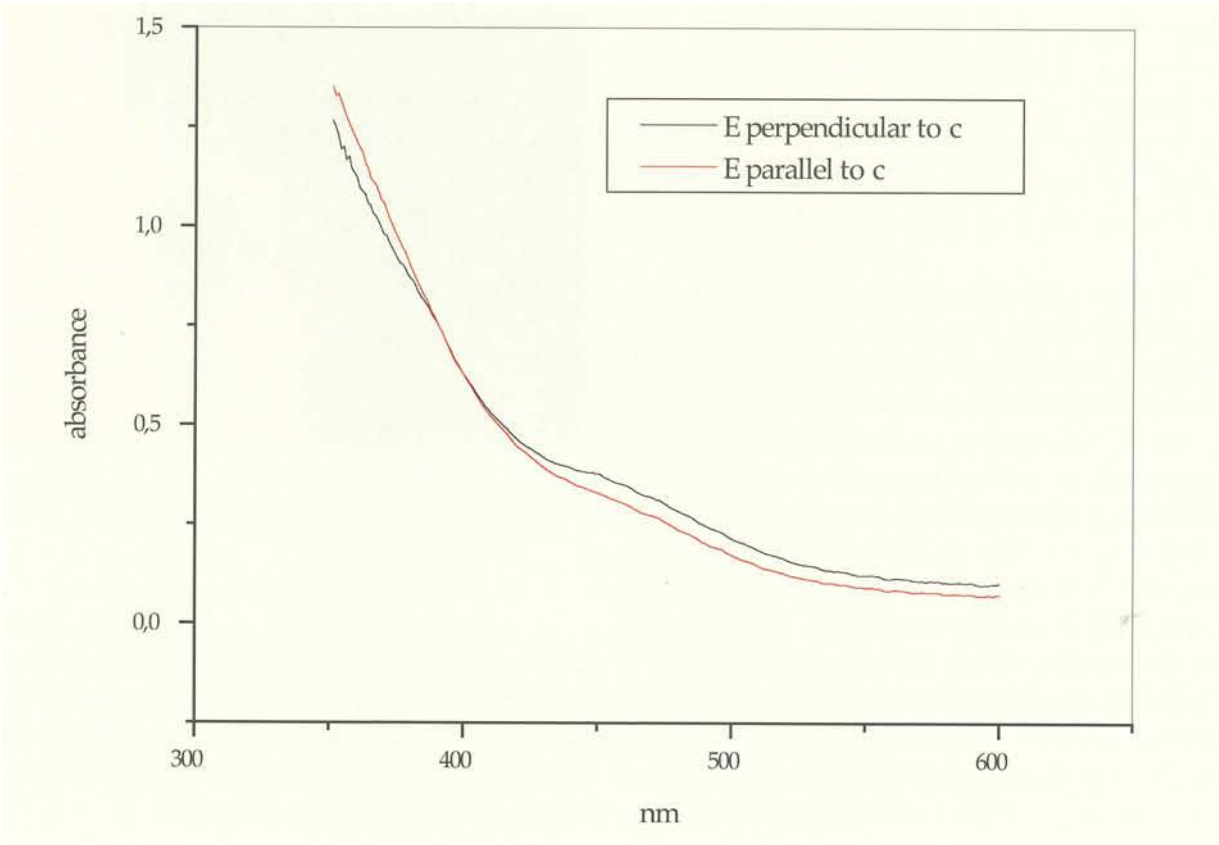

Figure 7: UV-Vis spectra of a heat-treated natural yellow sapphire from Sri Lanka with E perpendicular to c-axis (o-ray, black) and E parallel to c-axis (e-ray, red). The colour is due to stable defect centres.

The second group is coloured by so-called colour centres whose UV-Vis-spectra are characterized by an increase of absorption towards the UV-part of the spectrum (*Figure 7*). Sapphires of this group originate for example from Sri Lanka. The spectrum E (the electric vector of light) parallel to *c*-axis (e-ray) is very similar to the spectrum E perpendicular to *c*-axis (o-ray), and such sapphires therefore show weak pleochroism.

On the basis of the stability of the colour or defect centres, it is possible to differentiate this group into two sub-groups. The first sub-group contains natural sapphires whose colour is due to irradiation (Lehmann and Harder, 1970; Nikolskaya *et al.*, 1978; Nassau and Valente, 1987). The colour centres of this group are not stable to light and heat. The defect centres of the second sub-group are stable to UV light and to heat up to about 500 or 600°C. It is not possible to differentiate between these two sub-groups on the basis of UV-Vis spectroscopy, and the best method of distinguishing them is to use the fading test (Nassau and Valente, 1987).

The defect centres of the second sub-group are stable with respect to light and heat in an oxidizing atmosphere. Schmetzer *et al.* (1982, 1983) mentioned that the colour centres might be stabilized by divalent cations like Fe^{2+} or Mg^{2+}, by trivalent cations like Cr^{3+} or Fe^{3+} or by several di- and tri-valent cations. Häger (1993) and Emmett and Douthit (1993) pointed out the importance of Mg as a stabilizer of the colour centres in natural sapphires and strongly indicated that Mg has to be in excess of intrinsic Ti. In addition, Häger (1996, 2001) has shown that Mg+Fe, an oxidizing atmosphere and high temperature are necessary to develop stable yellow colour centres. Interactions of trace elements in corundum are briefly summarized in Box I.

Box I: Interaction of trace elements in corundum at high temperatures

Based on several quantitative experiments it has been shown that in addition to the classical trace elements like Fe and Ti which influence the colour of blue sapphire, Mg is also important. This element is able to form colourless $MgTiO_3$-clusters. If Ti exceeds the Mg-content, the excess of Ti leads in combination with Fe to colour-active $FeTiO_3$-clusters (Häger, 1992). In the case of a yellow sapphire which is coloured by stable defect centres, Mg is in excess after the calculation of the colourless $MgTiO_3$-clusters (Häger, 1993; Emmett and Douthit, 1993). But in contrast to Emmett and Douthit, it was shown that the excess of Mg in combination with low Fe causes stable colour centres identical to those of natural yellow sapphires from Sri Lanka, while Mg by itself stabilizes another kind of colour centre (Häger, 1996). If Ti-content exceeds the sum of Mg + Fe, the excess of Ti will precipitate during heat treatment at 1850°C in an oxidizing atmosphere. To summarize the above, the following diagrams were developed (Häger, 1996, 2001).

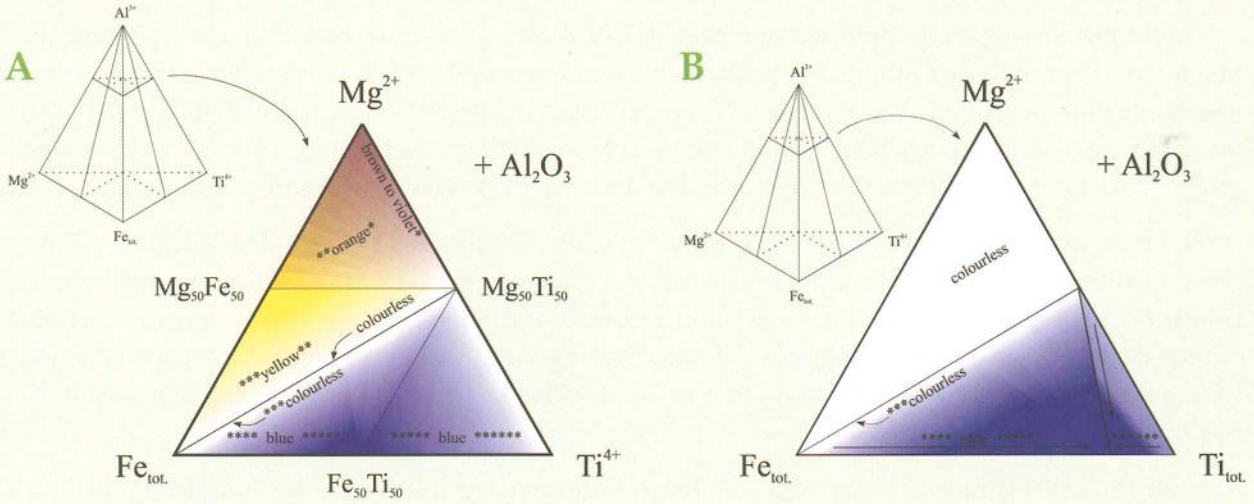

*	**colour centre due to Mg**	**	**colour centre due to Mg and Fe**
***	**yellow due to Fe^{3+}**	****	**Fe^{2+}/Fe^{3+}-charge transfer green due to Fe^{3+}**
*****	**Fe^{2+}/Ti^{4+}-charge transfer**	******	**precipitation of TiO_2**

Figure I: *Model representing the interaction of trace elements in the system Mg, Fe, Al and Ti for samples which were heat treated in oxidising (A) and reducing atmospheres (B) at high temperatures.*

The diagram in *Figure IA* represents the system Al-Mg-Fe-Ti (tetrahedron). Out of this tetrahedron a slice is cut. This slice represents sapphires with total trace element content in the ppm region. The resulting diagram is a triangle. Sapphires of this composition were heat treated at 1850°C in an oxidizing atmosphere (*Figure IA*) and at 1750°C in a reducing atmosphere (*Figure IB*). The most important line in the large triangle in *Figure IA* is the connecting line between the Fe corner and the $Mg_{50}Ti_{50}$ point where the Mg to Ti ratio is always 1:1; there, the samples neither show any kind of colour centres nor an Fe^{2+}/Ti^{4+} charge transfer band. Above this line are stable yellow colour centres such as found in natural sapphires from Sri Lanka. In the Mg corner are stable defect centres, but not with the same UV-Vis spectral pattern as the samples containing both Fe and Mg. Below the line, where Ti:Mg ratio is more than 1:1, are the Fe^{2+}/Ti^{4+} charge transfer bands. If the titanium content exceeds the sum of Mg + Fe a titanium-containing phase can precipitate. If the sapphires are treated in reducing conditions, the colour centres are destroyed completely and additional titanium precipitates are dissolved (*Figure IB*). The amount of additionally dissolved precipitates now depends on the kinds of the reducing gases used.

Box II: Materials and methods

In this study two flame-fusion-grown colourless sapphires, a disc of synthetic colourless corundum or 'watch glass', and three natural colourless sapphires were heat-treated under unknown conditions by a Thai heater. Five yellow, orangey-yellow and blue sapphires, reportedly the results of heat-treatment by the Be-technique in Thailand were also studied. A similar set of samples (two flame-fusion-grown colourless and nine natural colourless sapphires) was also irradiated by soft X-rays (4 mA, 80 kV) for four hours.

The heat-treatment experiments were also carried out by one author (TH) to confirm results. A synthetic colourless ('watch glass') and two natural colourless, one natural blue and many natural pink sapphires mixed with ground chrysoberyl in the crucibles were heated in a resistance furnace with Super Kanthal 1900 heating elements at 1750°C in air (i.e. under oxidizing conditions) for 30 hours.

The samples were photographed and their UV-Vis spectra were recorded before and after the heating and irradiation. Only if the spectrum was not recorded with E perpendicular to the *c*-axis (o-ray), is this fact noted. The Hitachi UV-Vis-NIR spectrophotometer (model U4001) was used for most measurements with additional measurements using a Leica/Leitz UV-Vis microscope attached to a spectrometer and a Perkin-Elmer Lamda 9 UV-Vis-NIR spectrophotometer.

The heat-treated and irradiated samples were subjected to a fading test. The samples were placed under a 100 W light bulb at a distance of 4 cm for several hours to fade any unstable colour centres. The samples were then photographed and UV-Vis spectra were recorded again. An irradiated natural sample was placed on a heating stage under a Leica microscope coupled with a spectrometer with a resolution of 1 nm. A UV-Vis-spectrum was recorded at every 10°C rise in temperature up to 300°C.

After the UV-Vis measurements, a set of representative samples were cut in half, lightly polished on the cut surfaces and then analysed for trace element content by Laser Ablation Inductively-Coupled-Plasma Mass Spectrometry (LA-ICP-MS). This set of samples includes three synthetic colourless sapphires (one Be-treated flame-fusion-grown, one original flame-fusion-grown cut from the same boule and one disc of synthetic corundum or 'watch glass'), two natural colourless sapphires (one Be-treated, one original sample obtained from the same gemstone dealer), three yellow and orangey-yellow Be-treated natural sapphires and two Be-treated natural blue sapphires obtained from different heaters. The 5-points profile analysis (Rim1, Mid-Point1, Core, Mid-Point2, Rim2) and 3-points profile analysis (Rim1, Core, Rim2) were performed across the cut surface by this technique.

Detailed descriptions of LA-ICP-MS instrumentation, analytical and calibration procedures are similar to those given by Norman *et al.* (1996). The UV laser ablation microprobe (a New Wave Research 266 nm Nd: YAG) is coupled to an Agilent 7500 ICP-MS. All analyses were done with a pulse rate of 5 Hz and beam energy of approximately 0.5 mJ per pulse, producing a spatial resolution of 30-50 µm in diameter on the samples. Quantitative results of isotopes for nine trace elements (Be9, Na23, Mg24, Ti47, V51, Cr53, Mn55, Fe57 and Ga71) were obtained through calibration of relative element sensitivities using the NIST-610 multi-element glass standard and pure Al_2O_3 as internal standards. The BCR2G basaltic glass standard was also used as an external standard. The contents are reported as µg/g or ppm by weight. The detection limits vary from analysis to analysis and are typically less than 1 ppm for Be, V and Ga; less than 4 ppm for Mg, Ti and Mn; less than 13 ppm for Cr; less than 40 ppm for Na and less than 80 ppm for Fe.

With the 'new' heating technique, pink-orange or orange sapphires can be produced from original pink or reddish-brown corundum, and colourless or white sapphires can be enhanced by addition of a yellow hue to the stones. Some yellow sapphires can even be obtained by heat-treatment of original green or blue sapphires by the 'new' technique (Coldham, 2002). In the press release from the Chantaburi Gem and Jewelry Association (CGA) on 20 February 2003, the 'new' heating technique was disclosed as 'Be-treatment or Be-heating' technique. Hence, understanding how this yellow hue is caused by this technique is very important.

Results

Irradiation

In the first series of tests, the irradiation experiment was carried out on a flame-fusion-grown colourless sapphire and a natural colourless sapphire (*Figures 8-12*). The synthetic sample is relatively pure Al_2O_3 in which most of the trace elements including Be are below the detection limits; a typical analysis, taken from the core of a stone, is shown in *Table I*. The natural sample contains relatively higher trace element content, in particular Mg, Ti and Fe, while the Be content is below the detection limit (*Table I*). After the irradiation the synthetic stone turned slightly

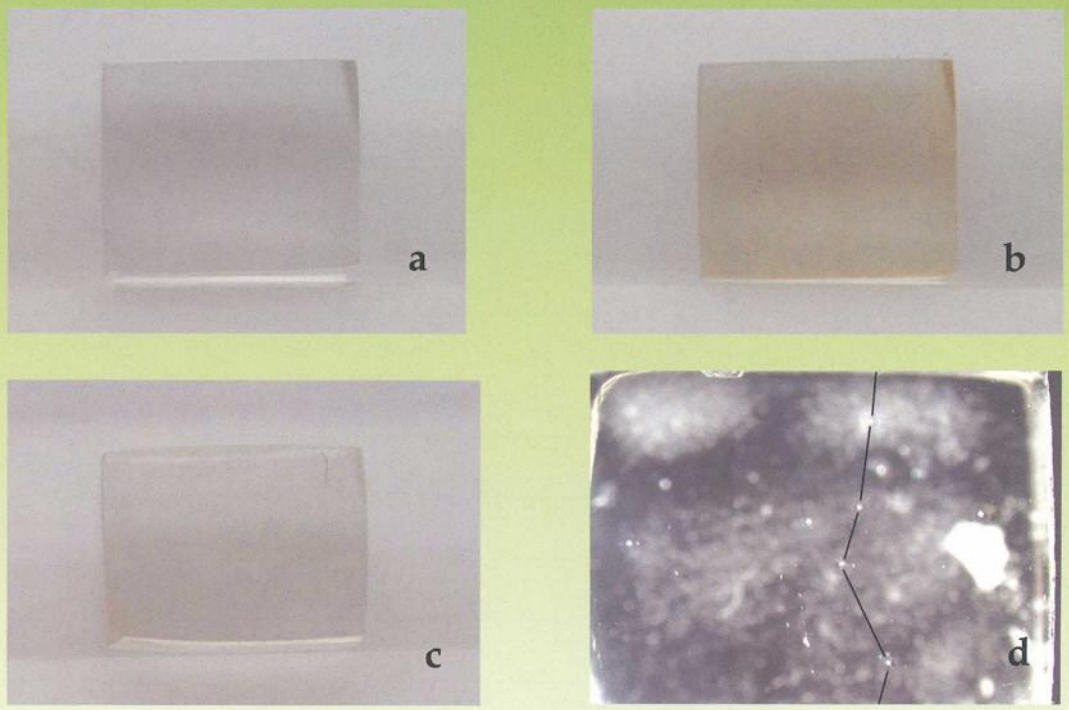

Figure 8: Photos of the 2.44 ct flame-fusion-grown colourless sapphire (PKSCS02) before treatment (a), pale brown after X-ray irradiation treatment (b), and almost colourless after a fading test (c). Afterwards the sample was cut in half and six-points on a traverse (d) were analysed across the cut surface using LA-ICP-MS (see also Table I and Figure 9). (Photos by Somboon, GIT and Lomthong, KU)

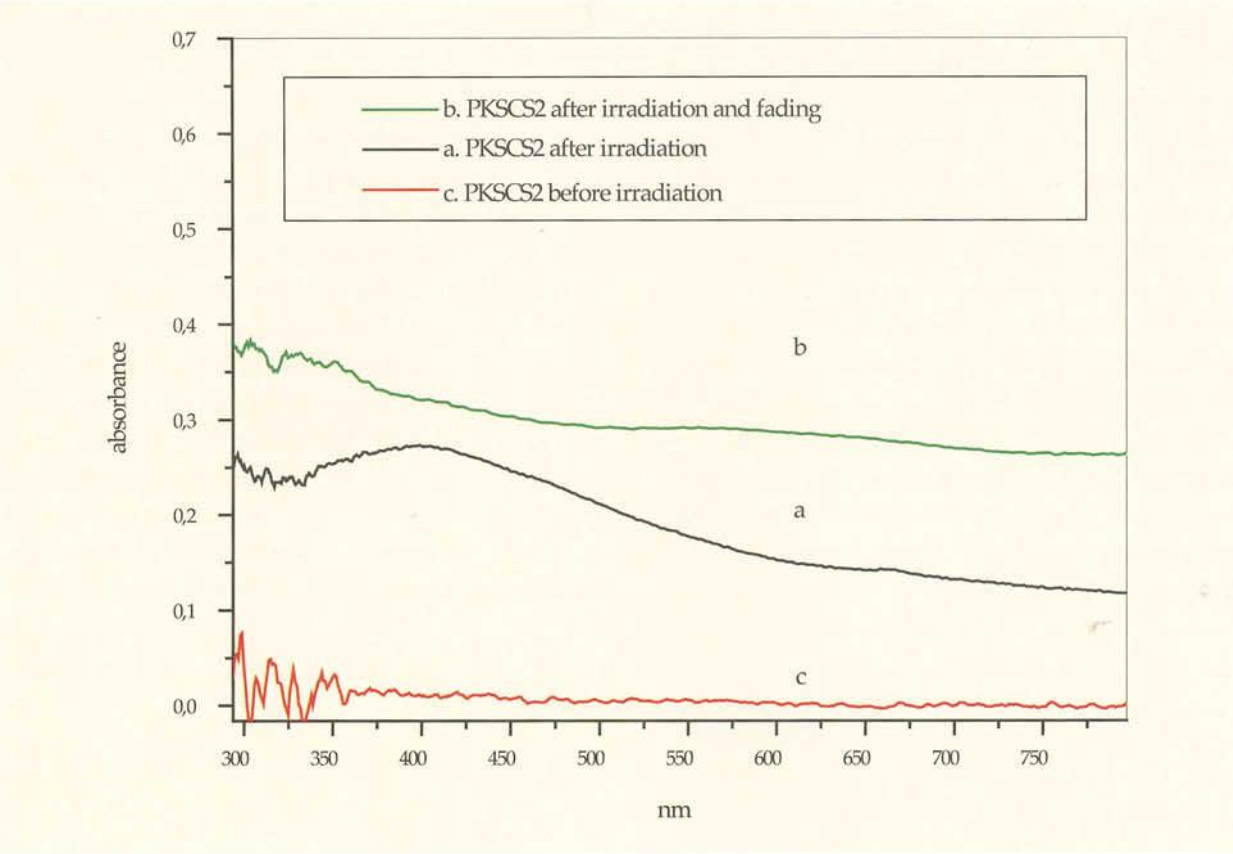

Figure 9: UV-Vis spectra of the 2.44 ct cube of flame-fusion-grown colourless sapphire (PKSCS02) before treatment (c), pale brown after X-ray irradiation treatment (a), and after a fading test (b).

Table I: Some typical trace element contents of a flame-fusion-grown colourless sapphire (PKSCS02), and a natural colourless sapphire (POMCS04), both untreated with Be, obtained by LA-ICP-MS.

µ/g	Core of synthetic sapphire PKSCS02	Core of natural sapphire POMCS04
Be	<0.95	<0.75
Na	<40.97	57.55
Mg	5.50	81.01
Al	529250.40	529250.40
Ti	<3.74	129.98
V	<0.59	17.44
Cr	<12.58	15.40
Mn	<2.85	<2.26
Fe	<77.93	719.27
Ga	<0.55	89.82
Total %	52.93	53.04
< = below detection limit		

brown (*Figure 8b*) whereas the natural one became intense yellow (*Figure 10b*). The UV-Vis spectra of the synthetic sample (*Figure 9*) changed from a flat line before irradiation to a broad absorption band at approximately 400 nm with only a weak absorption in the UV-part of the spectrum after irradiation (see also Kvapil *et al.*, 1972, 1973). The UV-Vis spectra of the natural sapphire (*Figure 11*) changed from a flat line before irradiation to a pronounced increase in absorption in the UV-part of the spectrum with a distinct shoulder at approximately 460 nm after irradiation (similar results have previously been reported by Schmetzer *et al.*, 1982, 1983; Nassau and Valente, 1987). The colour of all the irradiated samples was not stable during the fading test and they returned to their original 'colourless' state (*see Figures 8* and *10*). The same results were obtained from several runs on synthetic and natural colourless samples.

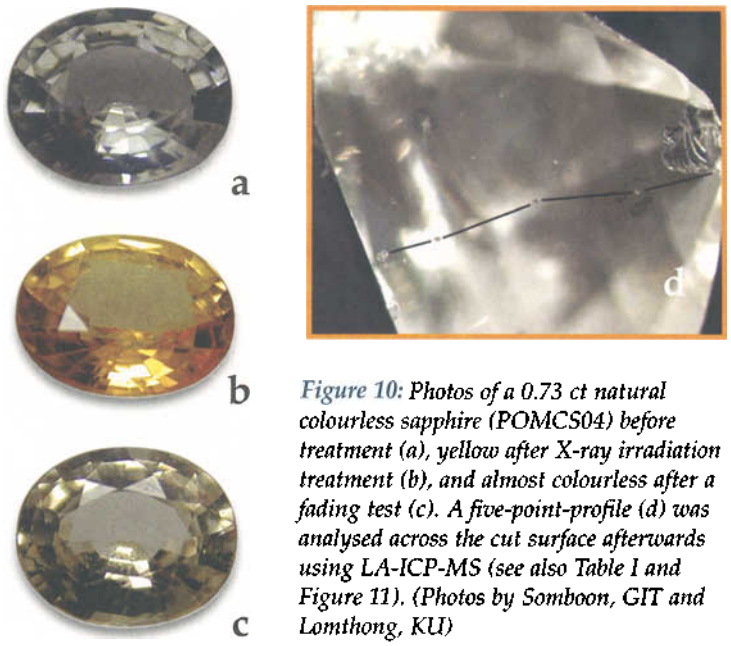

Figure 10: Photos of a 0.73 ct natural colourless sapphire (POMCS04) before treatment (a), yellow after X-ray irradiation treatment (b), and almost colourless after a fading test (c). A five-point-profile (d) was analysed across the cut surface afterwards using LA-ICP-MS (see also Table I and Figure 11). (Photos by Somboon, GIT and Lomthong, KU)

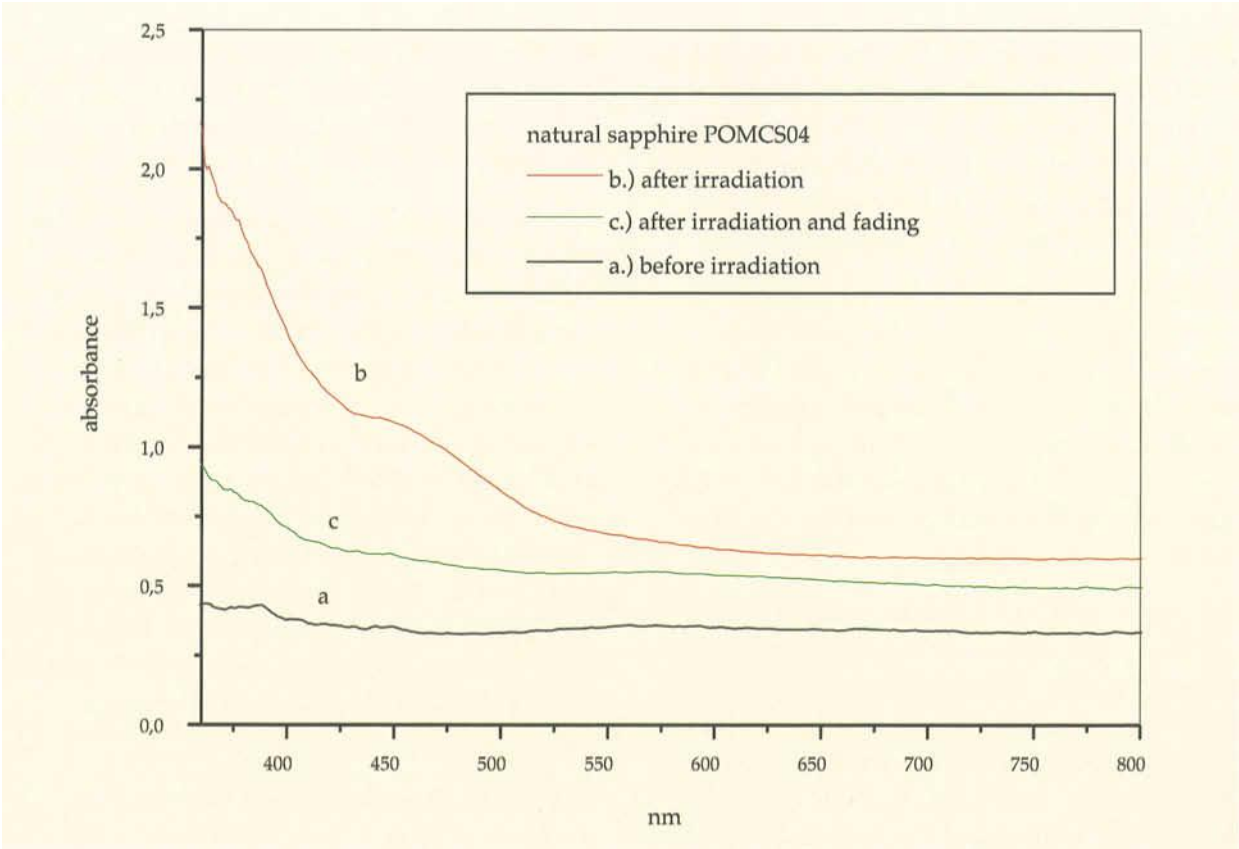

Figure 11: UV-Vis spectra of the 0.73 ct natural colourless sapphire (POMCS04) before treatment (a), after X-ray irradiation treatment (b) and after a fading test (c).

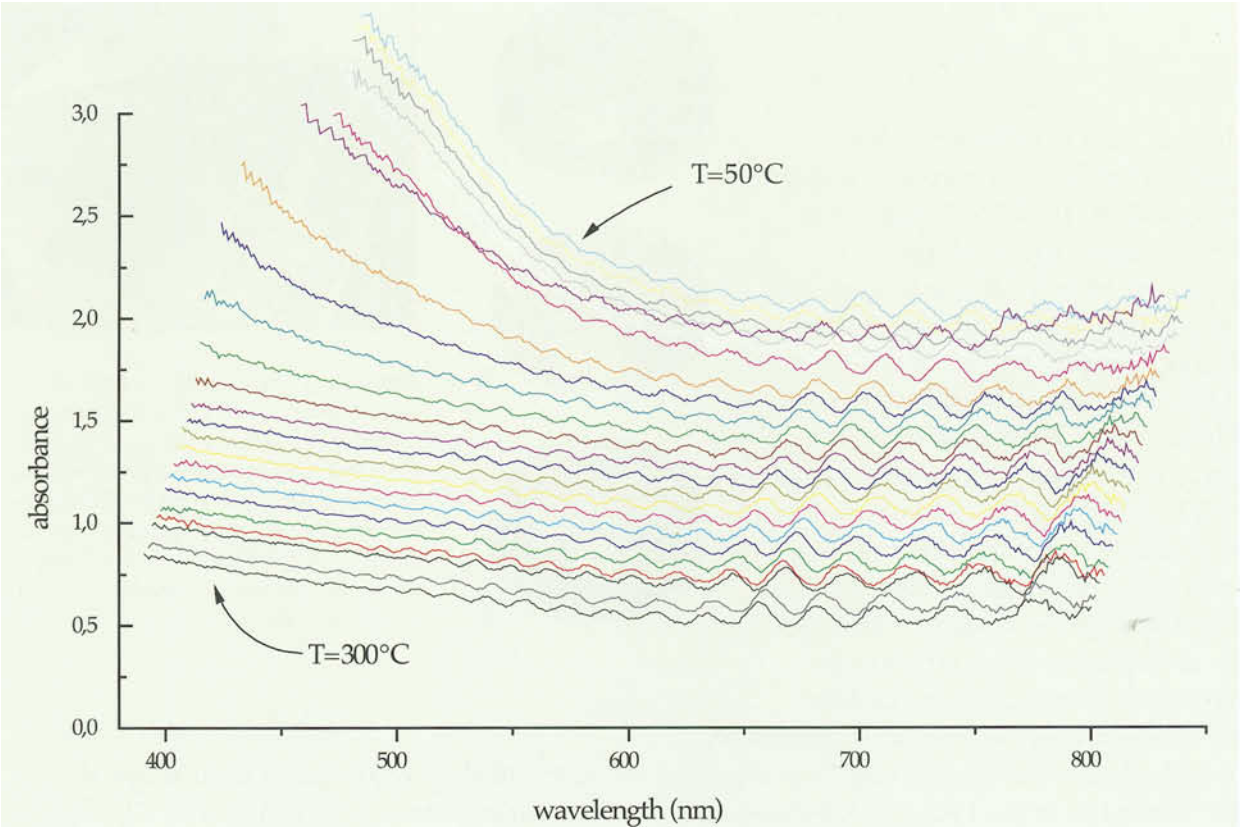

Figure 12: UV-Vis spectra of an irradiated natural sapphire heated up at a rate of 2°C/min; spectra were recorded every 10°C and a selection is shown. The main point to note is that the intensity of colour fades to near-colourless at 300°C.

Figure 12 shows clearly the changes in spectra relating to instability of the colour of an irradiated natural sample. After irradiation, the sample faded during heating especially in the temperature range between 50°C and 150°C and returned to its original colour.

Beryllium heat-treatment

In the second series of tests, Be-heat-treatment was carried out by a Thai heater on both synthetic and natural colourless sapphires. A similar set of samples was used for our own heating experiment. The precise conditions and procedure used by the Thai heater were not divulged.

Be-treated synthetic colourless sapphires

The 3.85 ct cube of colourless flame-fusion grown sapphire (*Figure 13a*) treated by the Thai heater, turned pale brown at the rim with a gradual decrease in intensity towards the colourless core (*Figure 13b*). The pale brown rim and colourless core are better seen in the immersion liquid (*Figure 13c*). This sample turned colourless after heating in reducing conditions and returned to pale brown again after re-heating in oxidizing conditions (*Figure 13e* and *f*).

Another 11.03 ct square-cabochon sample cut from the same boule and heat-treated under the same conditions gave exactly the same result (not shown here). A similar pale brown colour was observed in our own experiment on a colourless 'watch glass' sample mixed with ground chrysoberyl and heated at 1750°C in oxidizing conditions for 30 hours. Moreover, the same brown coloration was also reported by Emmett and Douthit (2002), Emmett *et al.* (2003) and Themelis (2003) on colourless flame-fusion-grown, Czochralski-grown (high purity) and heat-exchanger-grown (ultra-high purity) sapphires.

The UV-Vis spectrum of the synthetic sapphire changed from a flat line before heating to a broad absorption band at

Figure 13: Photos of a 3.85 ct flame-fusion-grown colourless sapphire (PKSCS01) before treatment (a) and pale brown after Be-treatment under unknown conditions (b). The pale brown rim and colourless core are better seen under immersion (c). After the treatment the sample was cut in half and a five-point profile (d) was analysed across the cut surface using LA-ICP-MS (see also Table II, Figures 14 and 15). The other half was then cut into three pieces; one piece was kept as the reference and the other two were heated in a pure nitrogen atmosphere at 1650°C for three hours, which turned the stones colourless (e). One of the colourless pieces was then re-heated in air (i.e. oxidation conditions) at 1650°C for 1 hour, which turned the sample back to pale brown (f). (Photos by Somboon, GIT and Lomthong, KU)

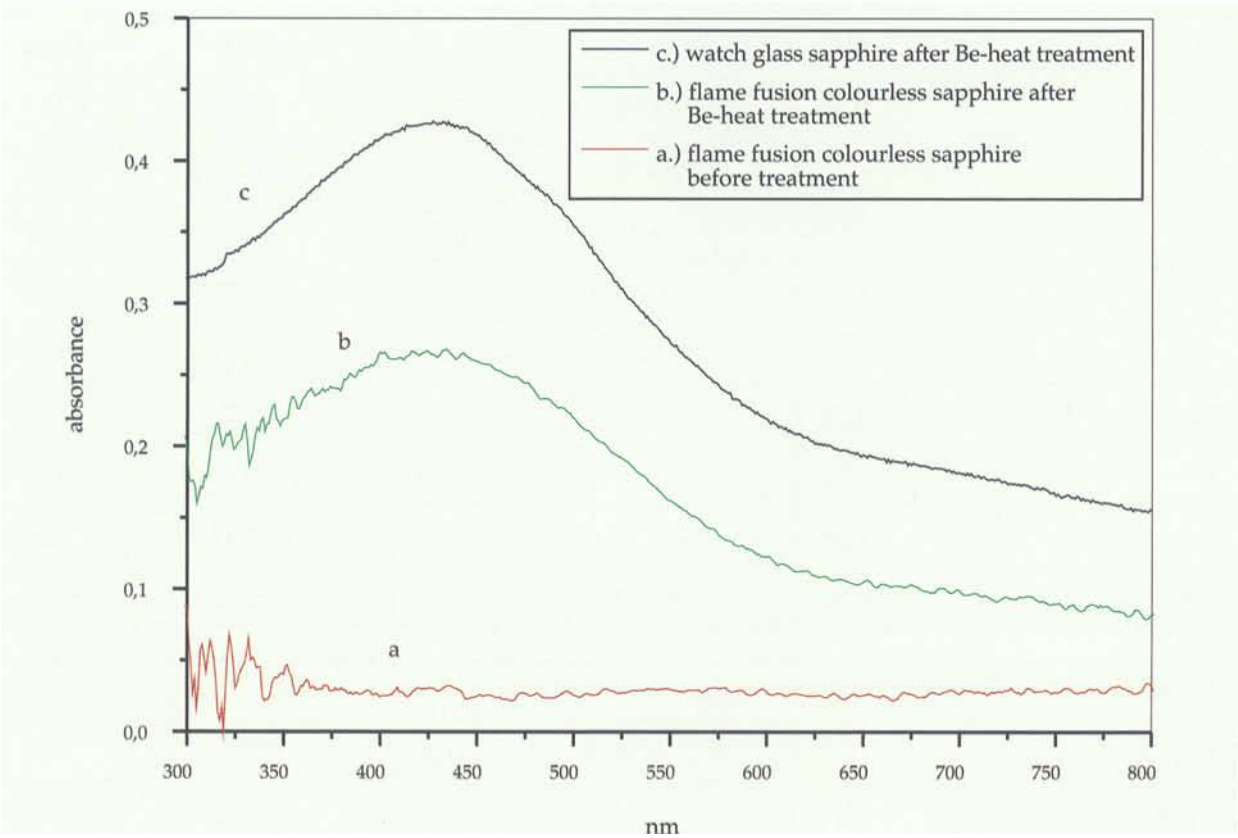

Figure 14: UV-Vis spectra of the flame-fusion-grown sapphire (PKSCS01) before treatment (a) and after Be-heat treatment (b) under unknown conditions. Spectrum c was recorded from a 'watch glass' sapphire (WG02) which had been turned pale brown from originally colourless material by heating at 1750°C in an oxidizing atmosphere with chrysoberyl in the crucible.

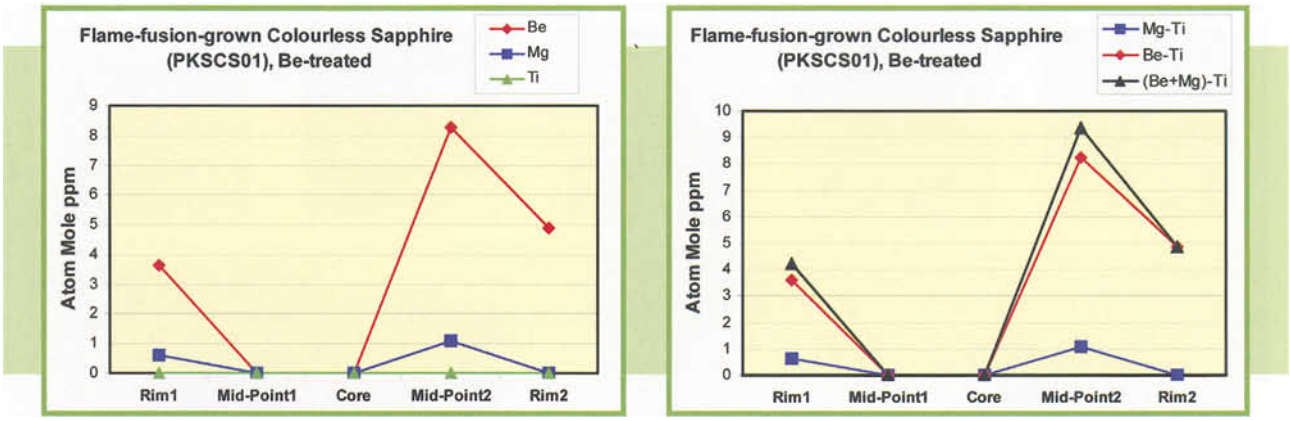

Figure 15: Plots of trace element content variation across the cut surface of the pale brown Be-treated flame-fusion-grown sapphire (PKSCS01), see Figure 13d and text for discussion.

Table II: Trace element contents of the pale brown Be-treated flame-fusion-grown sapphire (PKSCS01) obtained by LA-ICP-MS.

μ/g	Rim 1	Mid-Point 1	Core	Mid-Point 2	Rim 2
Be	1.60	<1.02	<0.99	3.65	2.15
Na	<17.83	<39.36	<38.43	<38.41	<16.54
Mg	0.73	<1.23	<1.26	1.31	<0.51
Al	529250.40	529250.40	529250.40	529250.40	529250.40
Ti	<2.04	<4.42	<4.14	<3.99	<1.5
V	<0.26	<0.56	<0.57	<0.53	<0.25
Cr	<5.79	<12.7	<12.01	<12.11	<5.25
Mn	<1.26	<2.78	<2.7	3.20	<1.17
Fe	<35.74	<78.59	<77.61	<76.8	<33.21
Ga	0.38	<0.53	<0.51	<0.47	0.29
Total %	52.93	52.93	52.93	52.93	52.93
Element factors based on atom mole ppm					
Mg-Ti	0.61	0.00	0.00	1.10	0.00
Be-Ti	3.62	0.00	0.00	8.26	4.86
(Be+Mg)-Ti	4.23	0.00	0.00	9.36	4.86
< = below detection limit					

approximately 420 nm with only weak absorption in the UV-part of the spectrum after heating (*Figure 14*). The same UV-Vis spectrum was also obtained from our own run on the 'watch glass' sample (*Figure 14*). A similar result was also found by Emmett *et al.* (2003). The brown colour of all the samples produced by the Thai heater and our Be-treated sample was stable during the fading test. Furthermore both colour and UV-Vis spectra produced by the Be-heating process are very similar to those produced by irradiation. The only difference is a small shift of the absorption peak from approximately 400 nm (irradiated sample) to 420 nm (Be-treated sample).

The LA-ICP-MS results of the five-point-profile analysis on the cut surface of the 3.85 ct cubic sample (*Figure 13d*) are listed in *Table II*. In order to compare the trace element contents and understand their interaction, all cations are calculated as atom mole ppm (or abbreviated as amp) and normalized to 40 atoms of cation, which corresponds to 60 atoms of oxygen in the Al_2O_3 structure. As shown in *Table II* and plotted in *Figure 15*, slightly elevated Be contents appear at the rims as compared to those at the core and correspond well with the brown rim. The extremely low Be content at the colourless core is also similar to those analysed in the unheated sample cut from the same boule (*Table I*). Other important trace element contents such as Mg, Ti, V, Cr, Fe and Ga are extremely low without noticeable variation from the core to the rim. These contents are comparable to those in the unheated sample (mostly below the detection limits) suggesting rather pure Al_2O_3 originally. A similar result was also obtained from the three-point-profile analysis across the cut surface (not shown here).

As shown in *Figure 15* and *Table II*, the brown rims are strongly correlated with Be. These data therefore suggest that the divalent Be (without Mg) could play an important role in the creation of the brown coloration. This is because it is very unlikely that colour can be created in a pure Al_2O_3 system by simple heating without the introduction of an element or elements from an external source.

The synthetic sapphire treated by the Thai heater was heated without addition of any

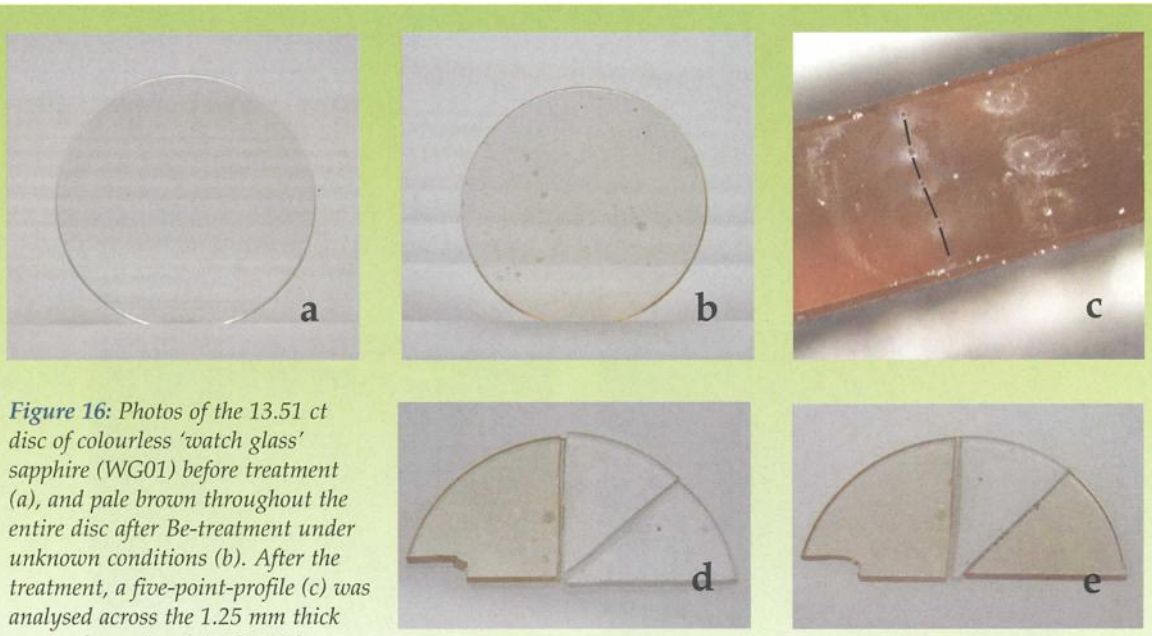

Figure 16: Photos of the 13.51 ct disc of colourless 'watch glass' sapphire (WG01) before treatment (a), and pale brown throughout the entire disc after Be-treatment under unknown conditions (b). After the treatment, a five-point-profile (c) was analysed across the 1.25 mm thick cut surface using LA-ICP-MS (see also Figure 17). The other half of the sample was then cut into three pieces; one piece was kept as the reference and the other two pieces were heated in a pure nitrogen atmosphere at 1650°C for three hours which turned the stone colourless (d). One of the resulting colourless pieces was re-heated in air (in oxidation conditions) at 1650°C for one hour, which turned the sample back to pale brown (e). (Photos by Somboon, GIT and Lomthong, KU)

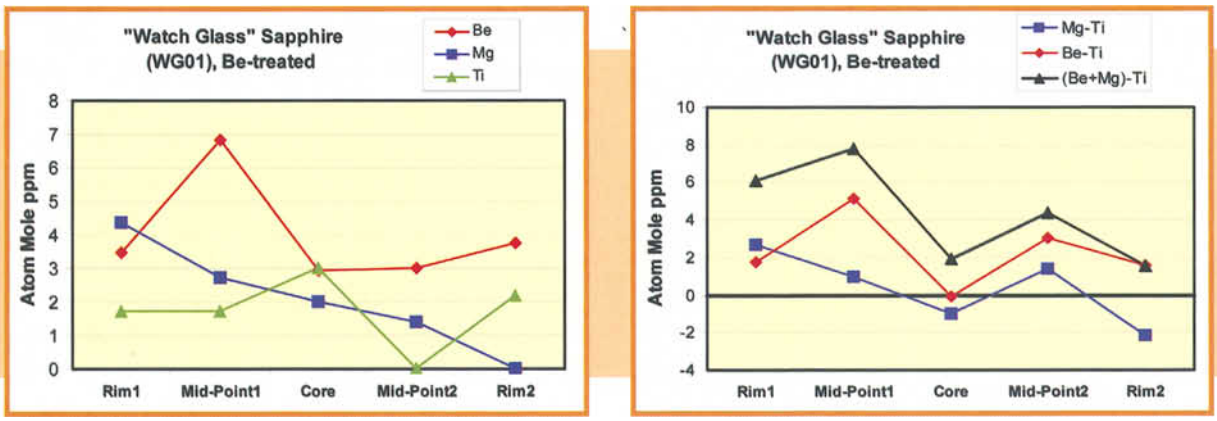

Figure 17: Plots of trace element content variation across the 1.25 mm thick cut surface of the pale brown Be-treated 'watch glass' sapphire disc (WG01). The contents of Be are dominant over those of Mg and Ti in almost all the points analysed, and (Be+Mg) > Ti in all analysed points (cf. Figure 16c).

Be-containing substance, e.g. chrysoberyl. Nonetheless, the LA-ICP-MS results have proved without doubt that a few ppm of Be must have entered the sample from an external source. The Be might have come from the crucible and/or furnace that previously had been heat-treated with Be-containing substances. This could explain why there are such low Be contents in this batch of samples (see also the next two samples) as compared with ten of ppm in the other samples obtained from other heaters (see later section). It is also surprising to realize that only a few ppm of Be are enough to create a pale brown colour in this relatively pure Al_2O_3 sample. A 'watch glass' of colourless synthetic sapphire (WG01) was heat-treated under the same conditions as those used for the flame-fusion stones and gave similar results, shown in *Figures 16* and *17*.

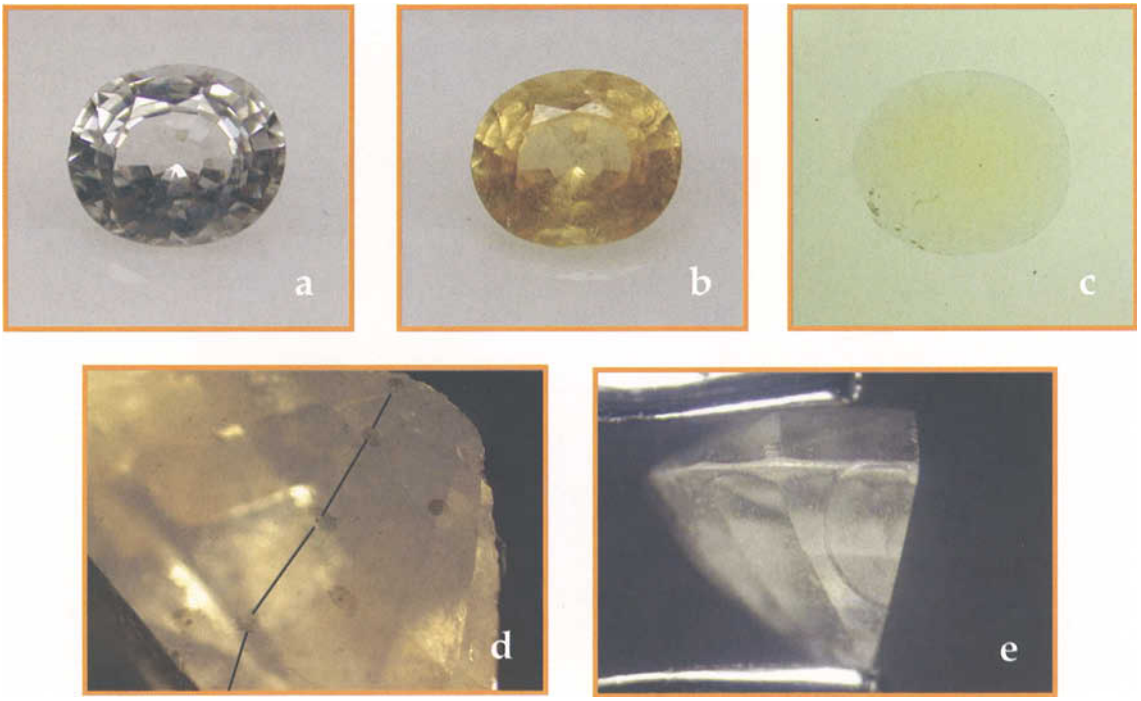

Figure 18: Photos of a 0.80 ct natural colourless sapphire (POMCS03) before treatment (a), yellow after Be-heat treatment (b) and in the immersion liquid (c). A five-point profile (d) was analysed across the cut surface after the treatment using LA-ICP-MS (see also Table III and Figure 20). The other half was heated in a reducing atmosphere at 1650°C for three hours, which turned the stone colourless (e). (Photos by Somboon, GIT and Lomthong, KU)

Be-treated natural colourless sapphires

The 0.80 ct oval natural colourless sapphire was heat-treated by the Thai heater under the same conditions as the flame-fusion grown specimen. The sample has turned intense yellow throughout without any particular surface-related colour after the treatment (*Figure 18*). Of two other natural samples (obtained from the same gemstone dealer) in the same run, however, one turned slightly yellow and in the other there was almost no colour change. Similar yellow colours were also observed in our own heating experiment on two natural colourless sapphires mixed with ground chrysoberyl and heated at 1750°C in an oxidizing atmosphere (in air) for 30 hours. The UV-Vis spectra of the intense yellow one changed from a flat line before heating to a pronounced increase of absorption in the UV-part of the spectrum with a shoulder at 460 nm after heating (*Figure 19*). The yellow colour was stable under a fading test.

The LA-ICP-MS results of the 5-point profiles across the cut surface (*Table III* and *Figure 20*) reveal a few ppm of Be (all values are above the detection limits) without noticeable concentration in the rims. These Be values are distinctly higher than those of the unheated sapphire where all Be values are below the detection limits (*Table I*). These data therefore suggest that a small amount of Be has been diffused into the stone from an external source – similar to the conclusion reached for the flame-fusion grown and the 'watch glass' samples, again probably from a contaminated crucible and/or furnace.

All the points analysed show rather high Mg content (*Table III* and *Figure 20*) compared with Ti and Be contents but there is no particular concentration in core or rim of any of the trace elements measured. The Cr contents are extremely low (below detection limit). When Mg and Ti are

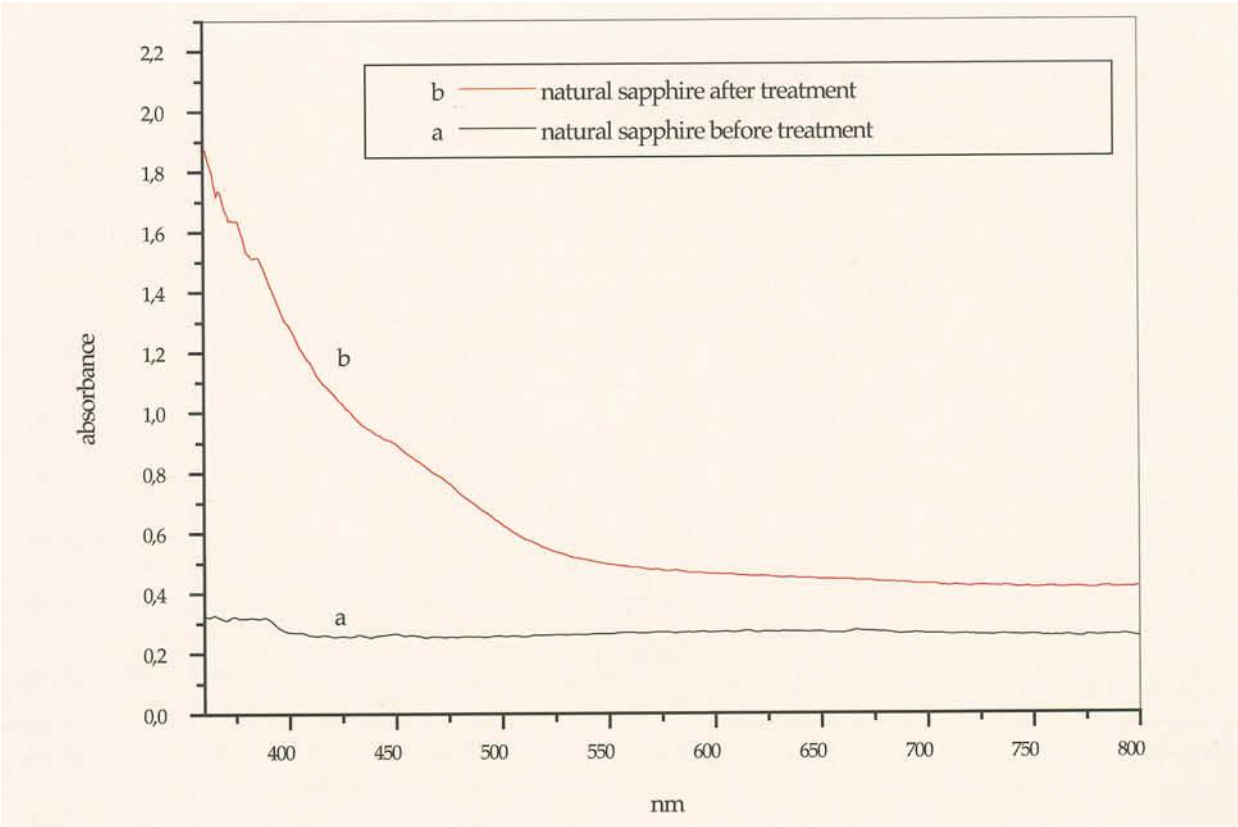

Figure 19: Spectra of the natural colourless sample (POMCS03) before treatment (a) and after the Be-heat treatment (b) (see also Figure 18a, b).

Table III: Trace element contents of the 0.80 ct Be-treated natural colourless sapphire (POMSC03) which became yellow after the treatment, obtained by LA-ICP-MS.

µg/g	Rim 1	Mid-Point 1	Core	Mid-Point 2	Rim 2
Be	1.23	4.68	2.52	2.79	2.90
Na	<18.10	<33.67	<29.32	<29.56	<18.11
Mg	95.38	144.81	71.52	67.48	80.15
Al	529250.40	529250.40	529250.40	529250.40	529250.40
Ti	74.48	78.19	65.95	58.30	51.33
V	2.44	2.82	2.47	2.33	1.98
Cr	<5.28	<9.51	<8.30	<8.73	<5.37
Mn	<1.25	<2.32	<2.01	<2.05	<1.27
Fe	347.76	402.65	348.55	325.47	342.53
Ga	68.88	61.42	58.20	61.22	64.24
Total %	52.98	52.99	52.98	52.98	52.98
Cations (Atom Mole ppm)					
Be	2.78	10.58	5.7	6.31	6.56
Na	0.00	0.00	0.00	0.00	0.00
Mg	79.97	121.39	59.97	56.58	67.20
Al	399737.57	399668.81	399761.10	399774.71	399759.85
Ti	31.69	33.26	28.06	24.80	21.84
V	0.98	1.13	0.99	0.93	0.79
Cr	0.00	0.00	0.00	0.00	0.00
Mn	0.00	0.00	0.00	0.00	0.00
Fe	126.89	146.89	127.18	118.76	124.98
Ga	20.13	17.95	17.01	17.90	18.78
Total (Atom Mole%)	40.00	40.00	40.00	40.00	40.00
Mg-Ti	48.28	88.13	31.91	31.78	45.36
Be-Ti	-28.90	-22.68	-22.36	-18.49	-15.28
(Be+Mg)-Ti	51.06	98.71	37.61	38.09	51.92

< = below detection limit of which 0.00 value is used for calculation of atom mole ppm

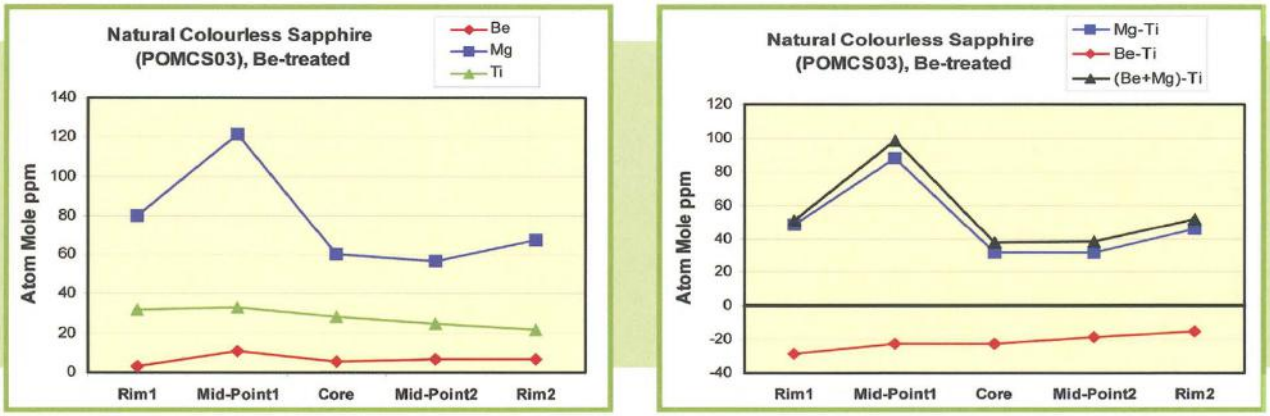

Figure 20: Plots of trace element content variation across the cut surface of the Be-treated natural colourless sapphire (POMCS03), which became yellow after the treatment, cf. Figure 18d and see text.

present in corundum they commonly form $MgTiO_3$ clusters, and it is the amount of excess Mg over Ti that is significant in forming yellow colour centres (see Box I; Häger, 1996, 2001; and Emmett *et al.*, 2003). This sample has strong excess of Mg and Mg-Ti contents range from 32 to 88 amp. Hence, the excess Mg or Mg+Be could lead to the formation of a stable yellow colour in this sample.

Yellow and orangey-yellow Be-treated sapphires

All three yellow and orangey-yellow sapphires stated to have been heat-treated in Thailand also gave similar results. The LA-ICP-MS results reveal rather high Be contents in the samples and an excess of Be+Mg over Ti content in all the points analysed (two samples are shown in *Figures 21-24* and *Tables IV* and *V*). Although Cr is present, it appears to be too low to create a pink hue in sample PPYS1, but in MadaRough01 (*Table V*) it is sufficient to make the stone appear orange.

Be-treated blue sapphires

Two blue sapphires from an unknown source reportedly heat-treated with Be by a Thai heater show a thin surface-related yellow zone surrounding a blue core (one is shown in *Figure 25*). High magnification shows that the blue core contains oriented blue dots probably resulting from partial dissolution of rutile needles. The LA-ICP-MS data (*Table VI* and *Figure 26*) reveal the elevated Be contents of the yellow rims and its absence at the blue core, again indicating Be diffusion from an external source. All the analysed points in the cores show an excess of Ti after calculation of colourless $MgTiO_3$ or $BeTiO_3$ clusters (i.e. Mg–Ti and Be–Ti content show negative values). In the yellow rim there is an excess of Be+Mg over Ti, while in the blue core Be+Mg is lower than Ti.

Figure 21: Photo of a yellow sapphire (PPYS1) reportedly heat-treated with Be under unknown conditions by a Thai heater. The sample appears yellow throughout the entire stone and lacks a surface-related colour zone. A five-point profile was analysed across its cut surface (see Table IV and Figure 22). (Photo by Somboon, GIT, and Lom-thong, KU)

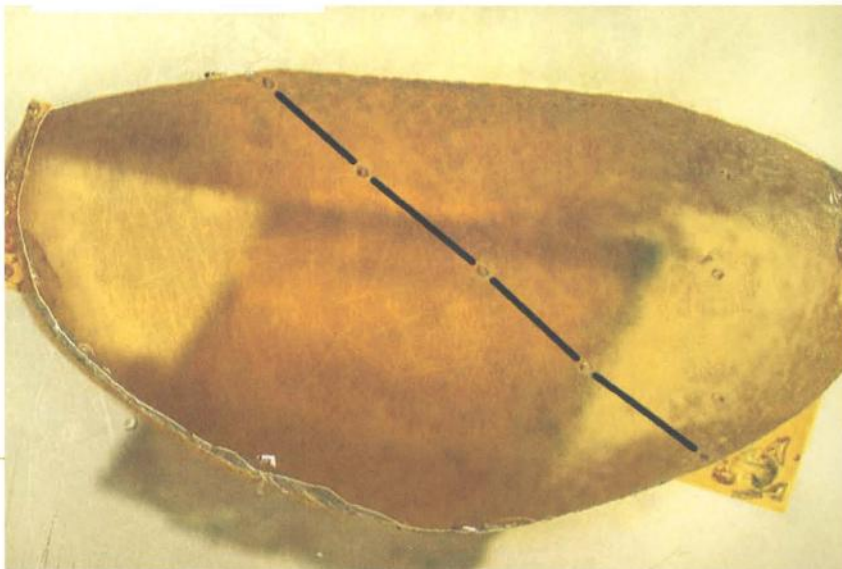

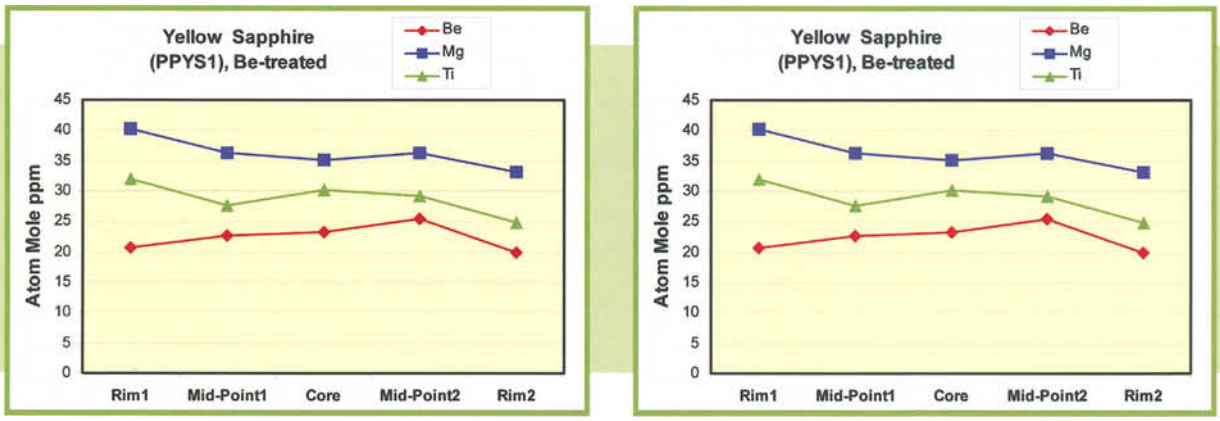

Figure 22: *Plots of trace element content variation across the cut surface of the yellow Be-treated sapphire (PPYS1). No significant variation of Be, Mg and Ti content is apparent (see Table IV) across the profile. All the points analysed (Figure 21) however, show (Be+Mg)>Ti contents.*

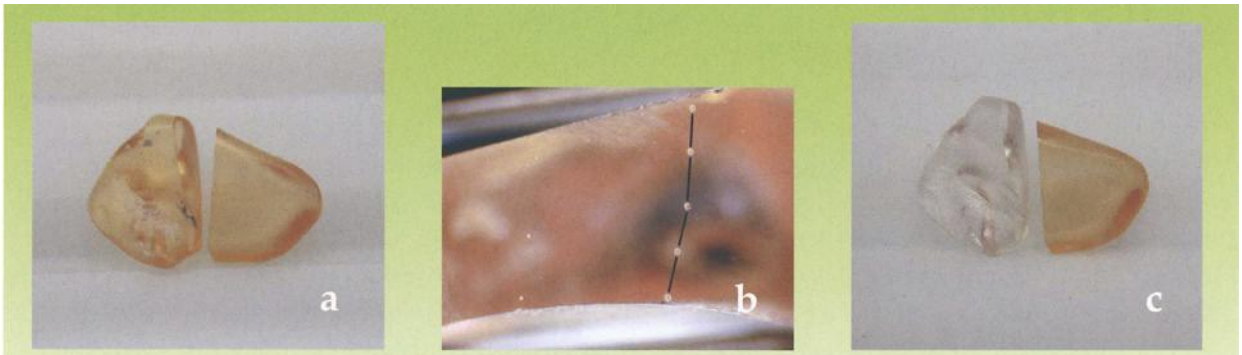

Figure 23: *Photos of a 2.44 ct Madagascan orangey-yellow rough sapphire (MadaRough01) reportedly heat-treated with Be under unknown conditions in Thailand (a). The sample appears orangey-yellow throughout the entire stone and lacks a surface-related colour zone. A five-point profile was analysed across the cut surface (b) on one half (see also Table V and Figure 24); the other half was heated in a reducing atmosphere at 1650°C for three hours, which turned the stone colourless (c). (Photos by Somboon, GIT and Lomthong, KU)*

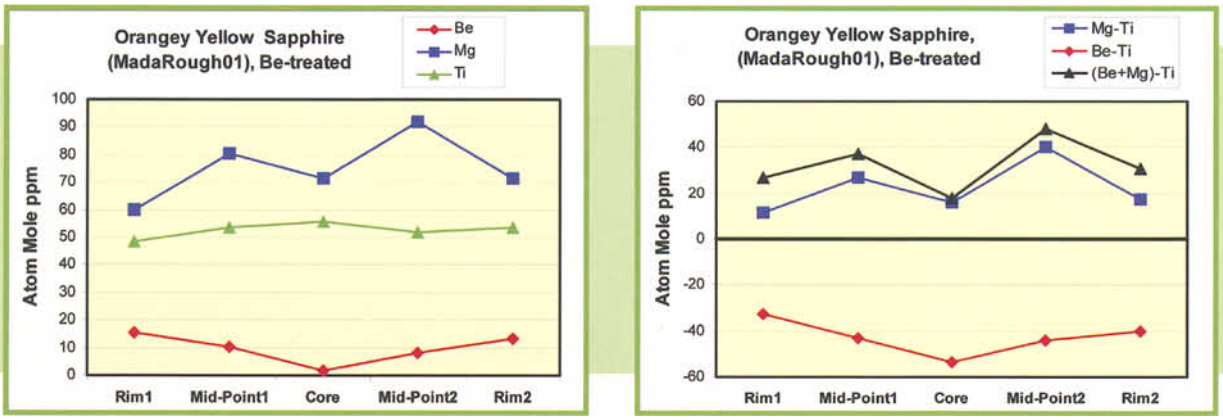

Figure 24: *Plots of trace element content variation across the cut surface of the orangey-yellow Be-treated rough sapphire (MadaRough01, Figure 23b) The analyses show higher Be contents at the rims, gradually decreasing toward the core. The contents of Mg, Ti and other trace elements (see Table V) however, show no consistent variation across the profile. At all the points analysed (Be+Mg) > Ti.*

Table IV: Trace element contents of a yellow Be-treated sapphire (PPYS1) showing rather high content of Be, Mg, Ti and Fe but low Cr content across the profile. Results obtained from LA-ICP-MS.

μ/g	Rim 1	Mid-Point 1	Core	Mid-Point 2	Rim 2
Be	9.14	10.02	10.29	11.27	8.86
Na	<13.54	<11.63	<13.89	<11.89	<11.30
Mg	48.01	43.39	42.03	43.44	39.61
Al	529250.40	529250.40	529250.40	529250.40	529250.40
Ti	75.47	65.06	71.09	68.82	58.36
V	20.11	19.62	18.88	19.76	21.50
Cr	32.58	35.65	35.68	32.94	34.43
Mn	<0.67	<0.58	<0.72	<0.58	<0.55
Fe	2237.19	2210.06	2119.11	2375.70	2424.42
Ga	73.94	74.56	73.07	76.35	81.14
Total %	53.17	53.17	53.16	53.19	53.19
Cations (Atom Mole ppm)					
Be	20.63	22.62	23.23	25.44	20.00
Na	0.00	0.00	0.00	0.00	0.00
Mg	40.18	36.32	35.18	36.35	33.15
Al	399049.91	399064.88	399096.62	399000.72	398993.41
Ti	32.05	27.63	30.19	29.22	24.78
V	8.03	7.84	7.54	7.89	8.58
Cr	12.75	13.95	13.96	12.89	13.47
Mn	0.00	0.00	0.00	0.00	0.00
Fe	814.87	805.02	771.95	865.21	882.94
Ga	21.57	21.76	21.32	22.27	23.67
Total (Atom Mole%)	40.00	40.00	40.00	40.00	40.00
Mg-Ti	8.13	8.69	4.99	7.13	8.37
Be-Ti	-11.42	-5.01	-6.96	-3.79	-4.78
(Be+Mg)-Ti	28.76	31.31	28.22	32.57	28.36
< = below detection limit of which 0.00 value is used for calculation of atom mole ppm					

Table V: Trace element contents of the orangey yellow Be-treated rough sapphire (MadaRough01), obtained from LA-ICP-MS.

µg/g	Rim 1	Mid-Point 1	Core	Mid-Point 2	Rim 2
Be	6.87	4.52	0.82	3.54	5.88
Na	45.25	96.93	<11.99	15.76	17.37
Mg	71.34	95.96	85.65	110.10	85.21
Al	529250.50	529250.50	529250.50	529250.50	529250.50
Ti	113.57	125.74	131.06	122.41	126.47
V	7.42	8.94	9.43	10.72	9.07
Cr	74.00	90.48	90.78	100.04	92.79
Mn	<0.39	<0.67	<0.60	<0.69	<0.23
Fe	3575.26	4099.17	4355.35	4697.28	3939.04
Ga	100.22	116.12	122.64	142.13	124.44
Total %	53.32	53.39	53.40	53.45	53.37
Cations (Atom Mole ppm)					
Be	15.49	10.18	1.85	7.97	13.25
Na	39.98	85.59	0.00	13.91	15.34
Mg	59.62	80.15	71.54	91.92	71.19
Al	398475.31	398208.18	398213.11	398043.06	398338.32
Ti	48.16	53.29	55.54	51.86	53.61
V	2.96	3.56	3.76	4.27	3.62
Cr	28.91	35.32	35.44	39.04	36.24
Mn	0.00	0.00	0.00	0.00	0.00
Fe	1300.37	1489.92	1583.06	1706.61	1432.19
Ga	29.20	33.81	35.71	41.37	36.24
Total (Atom Mole%)	40.00	40.00	40.00	40.00	40.00
Mg-Ti	11.46	26.86	15.99	40.06	17.58
Be-Ti	-32.68	-43.11	-53.70	-43.88	-40.37
(Be+Mg)-Ti	26.95	37.04	17.84	48.03	30.83
< = below detection limit of which 0.00 value is used for calculation of atom mole ppm					

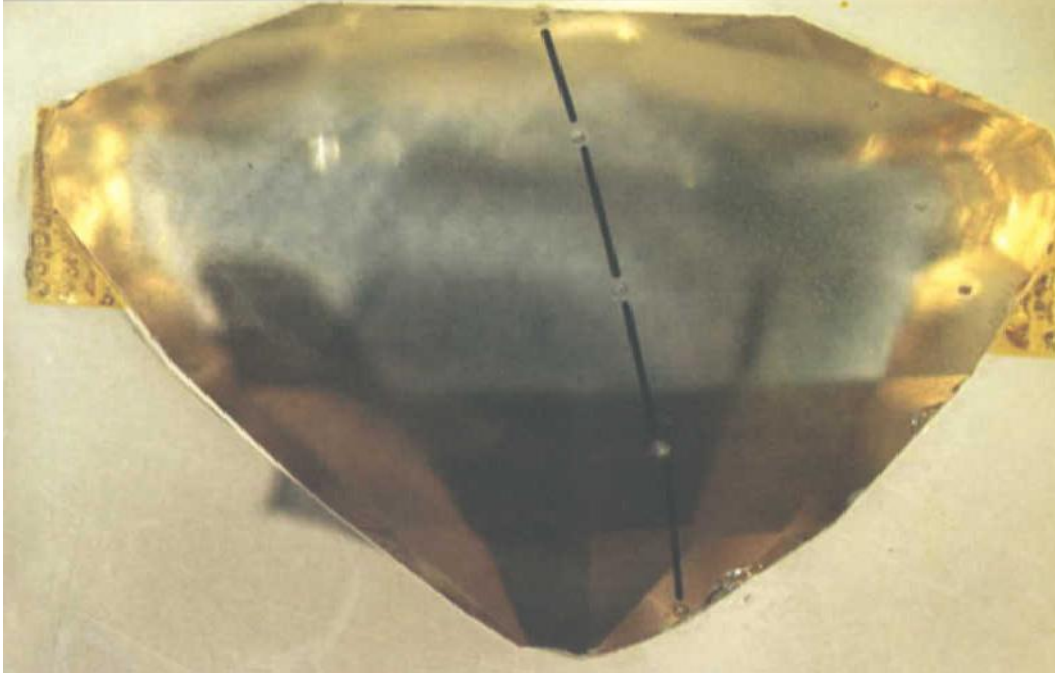

Figure 25: *Photo of a blue sapphire (PPBS1) reportedly heat treated with Be under unknown conditions by a Thai heater. The sample shows a thin surface-related yellow rim surrounding the blue core. High magnification reveals that the blue core contains oriented blue dots probably resulting from partial dissolution of rutile needles. A five-point profile was analysed across the cut surface with two points in the surface-related yellow zone (rims) and three points in the blue core. (Photo by Somboon, GIT and Lomthong, KU)*

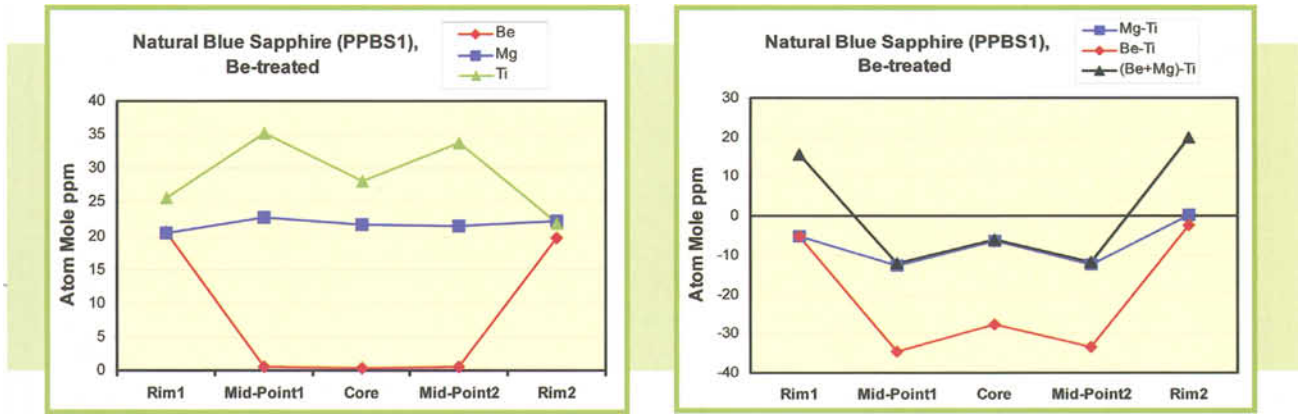

Figure 26: *Plots of the trace element content variation across the cut surface of the Be-treated blue sapphire (PPBS1, Figure 25). The Be contents are obviously high at the yellow rims and are negligible in the blue core. The contents of Mg and Ti (also other trace elements, see Table VI) however show no consistent variation across the profile. The analyses also show (Be+Mg)>Ti at the yellow rims in contrast to Ti > (Be+Mg) in the blue core.*

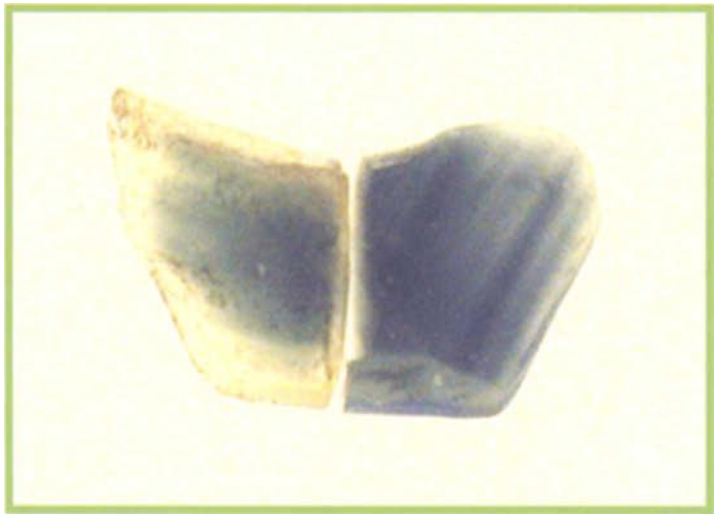

Figure 27: *A natural blue sapphire was cut in half; the left half was heat treated with ground chrysoberyl in a crucible while the right half was heated in another crucible without chrysoberyl. The heating procedure for both crucibles was 1750°C for 30 hours in air. After heat treatment the left half shows a surface-related yellow rim whereas the right half is blue throughout the stone. (Photo by Häger)*

Table VI: Trace element content of a Be-treated blue sapphire (PPBS1), obtained from LA-ICP-MS.

μ/g	Rim 1	Mid-Point 1	Core	Mid-Point 2	Rim 2
Be	9.15	0.26	<0.17	<0.22	8.71
Na	<10.82	<9.77	<10.63	<14.53	<12.40
Mg	24.54	27.14	25.86	25.66	26.55
Al	529250.40	529250.40	529250.40	529250.40	529250.40
Ti	60.45	83.16	65.99	79.49	51.58
V	12.83	12.87	12.47	12.53	12.23
Cr	36.34	37.86	32.32	31.33	38.61
Mn	<0.53	<0.48	<0.53	<0.73	<0.62
Fe	3013.78	4303.34	3015.91	3139.35	3182.56
Ga	51.66	56.00	53.22	53.84	54.13
Total %	53.25	53.38	53.25	53.26	53.26
Cations (Atom Mole ppm)					
Be	20.64	0.58	0.00	0.00	19.65
Na	0.00	0.00	0.00	0.00	0.00
Mg	20.53	22.68	21.63	21.46	22.20
Al	398801.73	398340.61	398819.35	398769.19	398742.19
Ti	25.66	35.25	28.01	33.73	21.89
V	5.12	5.13	4.98	5.00	4.88
Cr	14.21	14.79	12.64	12.25	15.09
Mn	0.00	0.00	0.00	0.00	0.00
Fe	1097.05	1564.65	1097.87	1142.66	1158.31
Ga	15.06	16.31	15.52	15.70	15.78
Total (Atom Mole%)	40.00	40.00	40.00	40.00	40.00
Mg-Ti	-5.13	-12.58	-6.38	-12.27	0.32
Be-Ti	-5.02	-34.67	-28.01	-33.73	-2.24
(Be+Mg)-Ti	15.51	-12.00	-6.38	-12.27	19.96

< = below detection limit of which 0.00 value is used for calculation of atom mole ppm

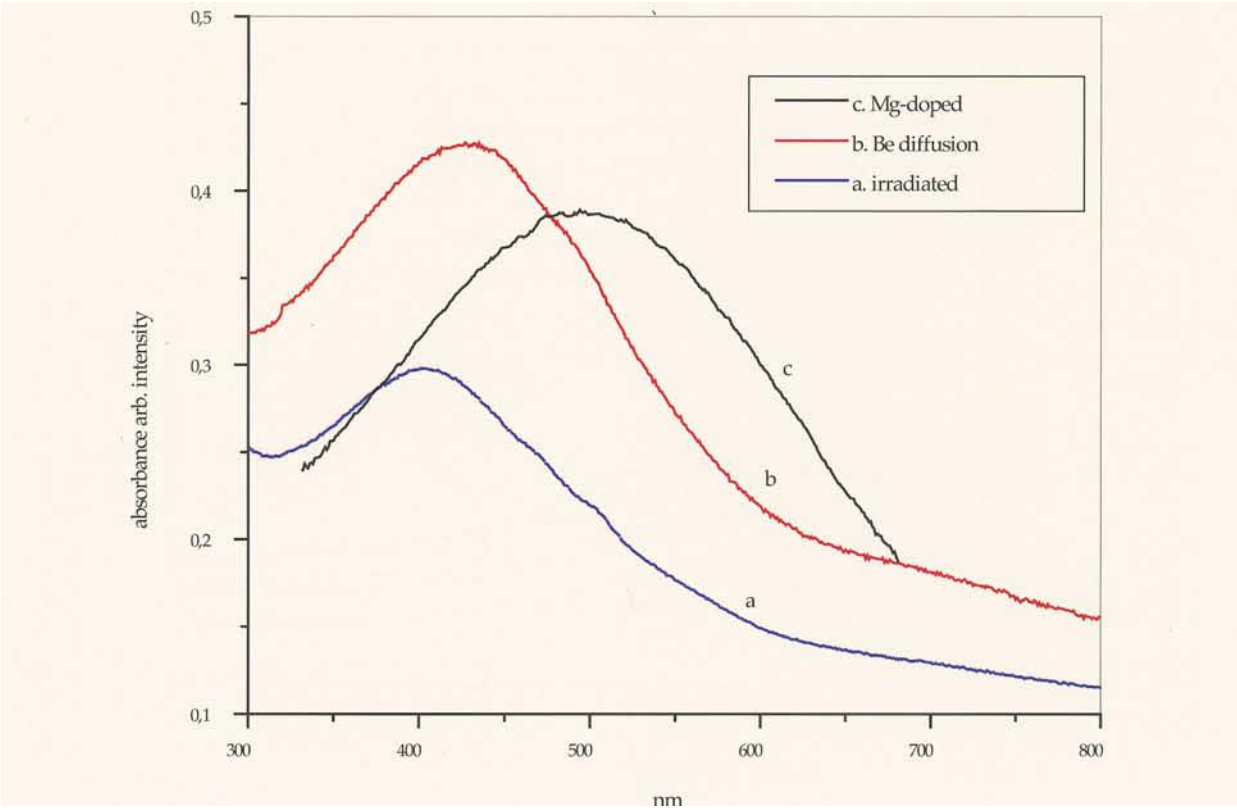

Figure 28: Three UV-Vis spectra of synthetic corundums: pale brown after irradiation with X-rays (a), pale brown after diffusion treatment with Be (b), and brown to violet after doping with Mg (c).

Discussion

The samples can be divided into two groups on the basis of their trace element contents. The first group consists of synthetic colourless sapphires with extremely low trace element contents, and the second group is dominated by trace contents of iron.

First group: 'pure' colourless sapphires

In the first group, the irradiation experiments with colourless flame-fusion grown sapphires produced a pale brown colour and a broad absorption band near 400 nm. This absorption band is unstable to normal heat and light and can be attributed to irradiation-related colour centres (see *Figure 28*). The detailed assignment of this absorption band is outside the scope of the present paper and will be discussed in another paper.

After Be-treatment, the synthetic colourless sapphires also turned pale brown and although the absorption pattern is similar to that of the irradiated sapphire, the broad absorption band is centred at about 420 nm. LA-ICP-MS analyses of sapphires supplied by the trade and our own Be-heating experiments indicate that Be has diffused into the stones from an external source. Be is directly related to the brown coloration. The other trace element contents remained unchanged. This absorption band is stable to normal daylight and to heating in an oxidizing atmosphere and has been clearly influenced by the diffusion of Be. In the corundum structure there are probably Be-related colour centres (or Be-trapped hole centres) which are created and stable only in an oxidizing environment and which can easily be eliminated by heating in a reducing environment (see also Emmett *et al.*, 2003).

Synthetic Mg-doped sapphires show a broad absorption band with a maximum at about 500 nm (*see Figure 28*) and are brownish-violet. Similar spectra of Mg-doped

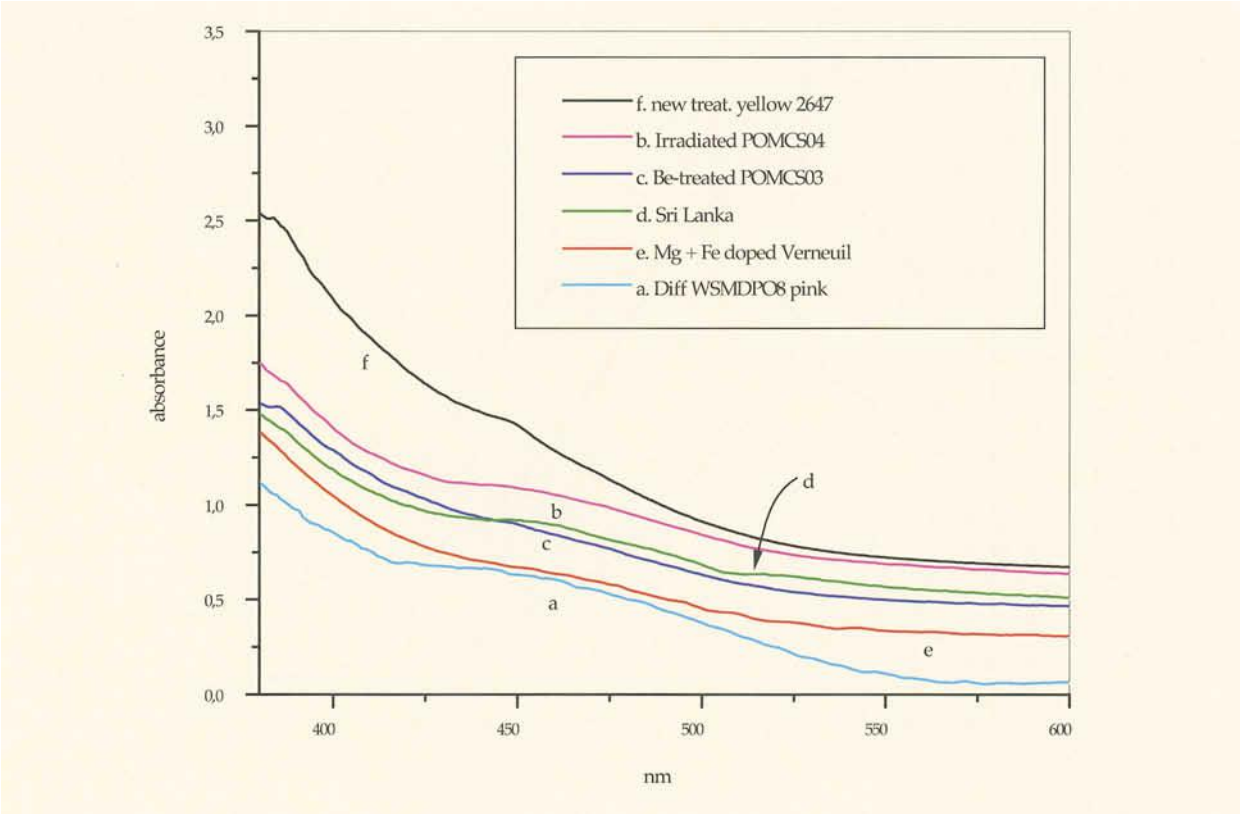

Figure 29: UV-Vis spectra of yellow sapphires: a natural sample irradiated with X-rays (b), natural samples after Be-treatment (c and f), a natural sample from Sri Lanka (d), the residual spectrum obtained by the subtraction of the spectrum of a pale pink natural sapphire before treatment from that of an orange Be-treated natural sapphire (a), a synthetic sample double-doped with Mg and Fe (e).

sapphires have been described by Andreev *et al.* (1976), Wang *et al.* (1983) and Häger (1996, 2001). The Mg-related colour centres (or Mg-trapped hole centres) are created only by heating in an oxidizing atmosphere and can easily be eliminated by reduction heating (e.g. Kvapil *et al.*, 1972, 1973; Andreev *et al.*, 1976; Wang *et al.*, 1983; Emmett and Douthit, 1993; Häger, 1996; 2001; Emmett *et al.*, 2003).

Hence, based on their similar behaviour, we believe that Be^{2+} and Mg^{2+} act in a very similar way as stabilizers of colour centres in these synthetic sapphires. It has been shown in this study that yellow coloration cannot be produced by irradiation or by Be-heat treatment in the pure Al_2O_3 system. The absorption spectra of brown and yellow sapphires are shown in *Figures 28* and *29* and do not have absorption bands in common. It seems that combination with other trace element(s) is required to produce yellow colour centres.

Second group: sapphires with significant Fe content

Natural colourless sapphires and a synthetic sapphire double-doped with Fe and Mg belong to the second group. Irradiated samples with a significant Fe content show an intense yellow colour after treatment. The UV-Vis spectra of the irradiated samples show a pronounced increase of absorption in the UV-part of the spectrum and a shoulder at about 460 nm (*Figure 29*). Similar colours and spectra can be observed in natural unheated Sri Lankan yellow sapphires and in the synthetic sapphire double-doped with Fe+Mg (*Figure 29*).

Elevated Be contents have been found in the treated stones obtained from a number of heaters in Thailand, but no consistent variation in Mg or any other trace element was detected in the core to the rim. This is in contrast to the observation of Peretti and

Günther (2002) who found a decrease in Fe, Cr, Ti, V, Ga and Mg towards the rim. This discrepancy might be due to different kinds of flux material being used in those runs. The Be-treated samples are generally intense yellow and show an excess of Be+Mg content after calculation of $MgTiO_3$ and /or $BeTiO_3$ clusters. Some samples however show only a very pale yellow or almost no colour change; such stones probably have more or less the same amount of Ti and Mg+Be. The absorption spectra are essentially identical to those of the natural untreated yellow sapphire from Sri Lanka, the Mg+Fe doped synthetic crystals and the irradiated samples (see *Figure 29*). As pointed out above, the irradiated samples are unstable to daylight and heat, while all the others are stable in daylight and oxidizing heat.

The blue sapphire (PPBS1) shown in *Figures 25* and *26* is a stone in which Ti exceeds the Mg content in all analysed points. However, in the yellow rim the sum of Be+Mg exceeds the Ti content. These data strongly suggest that the yellow hue can only be formed if there is an excess of Be+Mg over Ti content in the lattice. With the 'classical' heat treatment, it was not possible to turn such a sample yellow, but with diffusion of Be into the corundum lattice it is now possible to change the balance of the Ti/(Be+Mg) ratio. This is confirmed by our own heating experiment (see *Figure 27*). Although at first sight this result seems to be in contrast to that reported by Peretti and Günther (2002), their analytical data are presented in ppm by weight (D. Günther, pers. comm., 2002) and not in atom mole ppm. If the data are recalculated into atom mole ppm in all yellow stones and yellow zones, the sum of Mg+Be exceeds the Ti contents and the results are in fact consistent with ours.

In summary, the results lead us to believe that the unstable yellow colour produced by irradiation is caused by a combination of iron and a defect centre, and the stable yellow colour centre produced by heat and Be diffusion in an oxidizing atmosphere is caused by a combination of excess Be+Mg over Ti, the presence of Fe and a defect centre. Because of the important role of iron in this scenario, the absorption spectra presented in *Figure 29* might be called Fe-related stable (if it is stabilized by a divalent element) or unstable (if it is due to irradiation) colour centres. In orange Be-treated sapphires, besides chromium and iron related absorption bands, an absorption band near 470 nm was reported by Hänni and Pettke (2002), and UV absorption at 380 nm was reported by Fritsch *et al.* (2003) and Emmett *et al.* (2003). Those absorption spectra are somewhat different from our Fe-related colour centres spectra and might be due to a high amount of Cr in those samples.

Conclusion

It was found that elevated Be contents have been detected in the treated synthetic and natural sapphires obtained from a number of heaters in Thailand and that Be has diffused into the stones from an external source. Yellow or brown coloration could develop in the Be-treated stones depending upon the (Be + Mg) /Ti ratio, the presence or absence of iron and the heating atmosphere. It is obvious that the excess of the divalent elements, Be+Mg, after calculation of colourless $MgTiO_3$ and/or $BeTiO_3$ clusters, in combination with iron and heat treatment in an oxidizing atmosphere can produce stable yellow colour centres. These yellow colour centres show similar UV-Vis patterns to those of the natural yellow sapphires from Sri Lanka and the synthetic sample double-doped with Mg and Fe. In synthetic samples without iron, however, the situation is somewhat different. The divalent Be could act in the same way as was found earlier for Mg, as a stabilizer of brown colour centres, but with a shift in the absorption maxima. If the Be-treated sapphires are heated in a reducing atmosphere, the yellow or brown colour centres are destroyed completely. Therefore it is possible to change the presented two diagrams in Box I in such a way that we add Be into the Mg corner.

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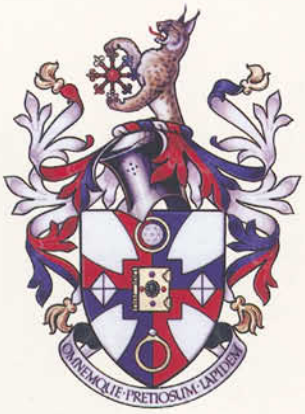

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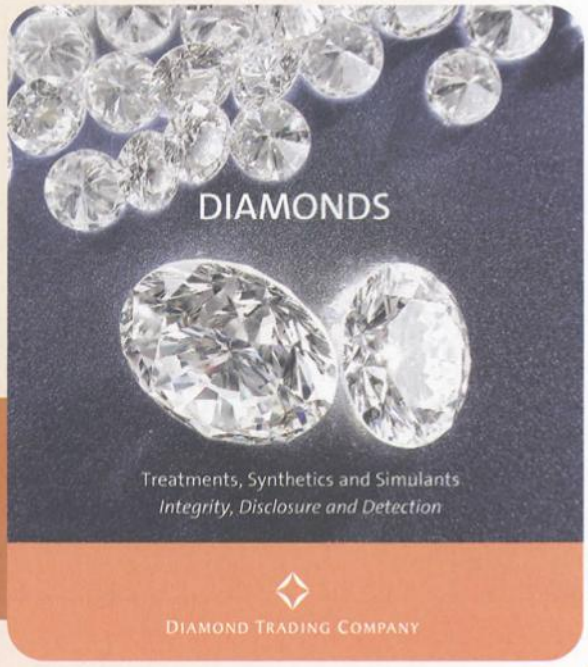

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Nephrite jade in Finland

Dr Douglas Nichol

Wrexham, Wales

Abstract: *Three occurrences of nephrite jade have been found in Finland; ortho-nephrite at Paakkila, para-nephrite at Stansvik and glacially transported material at Hakkila. No commercial production is recorded. However, mineral specimens have been won for museums and private collections.*

Introduction

In the extensive literature on jade, Finland receives frequent mention as one of the nations in Europe where nephrite jade is found (e.g. Kolesnik, 1970; Leaming, 1978). Although no commercial production of nephrite has actually taken place in Finland, the known localities are of considerable geological interest and provide an indication of exploration potential. This note provides a brief review and description of the Finnish occurrences as part of a wider study of nephrite jade in Europe. Colours are quoted using the Munsell notation (Rock-Colour Chart Committee, 1980).

Background

During the 19th and 20th centuries, numerous boulders of nephrite jade were discovered throughout northern Europe, the finds in Germany at Potsdam, 30 km SW of Berlin, and at Schwemsal, 35 km NNE of Leipzig, being the most frequently cited (e.g. Ruff, 1963; Kolesnik, 1970). Since the boulders were believed to be glacial erratics transported by glaciers from a sourceland to the north, the whole of Scandinavia was generally considered to be prospective for primary deposits of nephrite jade.

Subsequently, an outcrop of nephrite-like rock was found in Sweden (Törnebohm, 1886; Meyer, 1886) but more significantly, three occurrences of nephrite jade were reported in Finland at Paakkila, Hakkila and Stansvik (*Figure 1*).

Figure 1: Location of nephrite jade occurrences in Finland.

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Geological setting

The bedrock of Finland comprises a wide variety of metasedimentary and meta-igneous rocks of Precambrian age that form part of the Baltic Shield. However, thick glacial deposits, peatlands and countless lakes cover the Precambrian crystalline basement. Indeed, it has been estimated that only about 3 per cent of the bedrock crops out at the surface.

Paakkila occurrence

The old, abandoned Paakkila quarry is located in the municipality of Tuusniemi, 70 km southeast of Kuopio and 18 km west of Outokumpu in central Finland. It is a former mining area for anthophyllite asbestos that closed in 1975 when demand for asbestos slumped (*Figure 2*). The asbestos is associated with a series of elongate bodies of serpentinized ultramafic rock enclosed by Precambrian gneiss and the Maarianvaara granite. According to Isokangas (1978), the lenses of serpentinite exhibit a zonal structure arranged as follows: (1) mica zone, (2) tremolite-actinolite zone, (3) talc zone, and (4) core zone of anthophyllite asbestos.

The discovery of nephrite jade at the Paakkila asbestos quarry is attributed to the geologist Eberhard Rimann of Dresden who visited the site in 1930 during a field excursion organized by the German Mineralogical Society. Based on detailed studies of samples of rock from a 60-70 mm wide vein within the working quarry, he concluded that the vein was nephrite jade (Rimann, 1936). The rock consisted predominantly of nephrite ranging from greyish green (10G 4/2) to dusky green (5G 3/2) in colour with occasional patches of talc. Also contained within the nephrite jade were minute inclusions of anthophyllite of similar chemical composition and optical properties to the anthophyllite in the host serpentinite. Based on the intimate field relationship with serpentinite, the occurrence is classed as ortho-nephrite in type (Nichol, 2000).

Although the discovery of nephrite jade at Paakkila aroused widespread interest at the time, further information is singularly lacking. The site where Rimann collected his specimen was apparently destroyed during the course of mining operations and, according to the Geological Survey of Finland, reconnaissance exploration for nephrite jade in other serpentinite bodies around Paakkila has so far proved negative.

Interestingly, Rimann's original specimens from Paakkila are held in the collection of the Museum für Mineralogie und Geologie, Dresden, under catalogue number 9863 Sy (MMG Dresden). However, samples of the nephrite appear to be missing and only pieces of anthophyllitic serpentinite remain.

Figure 2: The Paakkila asbestos quarry. Circa 1967. (after Palomäki and Halonen, 1968).

Hakkila occurrence

A few pebbles and boulders of nephrite jade have been found in glacial deposits in the Vantaa district on the northern outskirts of Helsinki. Specimens collected from gravel pits in an esker at Hakkila were described by Lindqvist and Kinnunen (1985). The pebbles and boulders are rounded to subrounded with smooth surfaces. Typically, the nephrite jade ranges from dusky yellow-green (5GY 5/2) through light olive grey (5Y 5/2) to yellowish-grey (5Y 7/2) in colour and varies from fine- to medium-grained in texture (*Figure 3*).

Figure 3: Polished nephrite pebble from Hakkila esker (diameter 24 mm). Finder, V. Kotilainen. Photo by K.A. Kinnunen.

According to the Geological Survey of Finland this locality is no longer available for collection purposes due to urban development.

Stansvik occurrence

Numerous small iron-ore mines were worked in pre-industrial times throughout coastal areas of southern Finland. They served local demands for iron in populated areas where both charcoal and labour were readily available (Puustinen, 1997; Saltikoff *et al.*, 1994). The discovery of nephrite jade at one of these historical sites, the Stansvik iron mine, was first reported by Lindqvist and Kinnunen (1985). The site is located on the western part of the island of Laajasalo in the southern suburbs of Helsinki.

At the old Stansvik iron mine, discontinuous, narrow (<1 mm) veins composed of very fine-grained tremolite fill fractures in the ancient mine walls. The veins vary in composition between nephrite and mixtures of tremolite and nephrite with the latter predominant. Typically, the colour ranges from moderate yellowish-green (10 GY 6/4) to pale greenish-yellow (10Y8/2) (*Figure 4*).

The veins appear restricted to lensoid bodies of massive tremolite that have developed within a skarn assemblage of rocks.

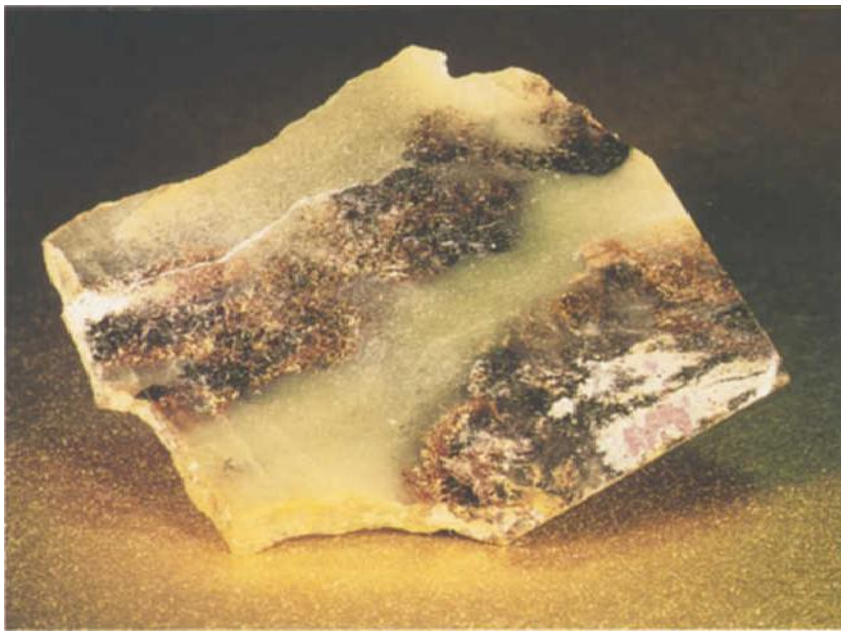

Figure 4: Slab of nephrite jade from the old Stansvik iron mine, Helsinki (size 27 × 19 mm). Photo by K.A. Kinnunen.

The skarns are a suite of banded calc-silicate rocks of complex mineralogical composition formed by contact metamorphism and metasomatism of limestone and dolomite. Based on the close association of the nephrite with metasedimentary strata, the occurrence is classed as para-nephrite in type.

According to the Geological Survey of Finland, the quantity of nephrite jade at the Stansvik locality appears very small. In addition, prospecting work carried out in similar geological formations elsewhere in the region has failed to identify further occurrences of nephrite.

Conclusion

In Finland, primary occurrences of jade of ortho-nephrite and para-nephrite types are recorded at Paakkila and Stansvik respectively and a secondary occurrence is recorded in glacially transported gravel at Hakkila.

Although no commercial production has eventuated, these minor occurrences indicate that some scope exists for further exploration work, especially in central Finland where numerous serpentinite bodies are scattered throughout the Precambrian crystalline basement.

Acknowledgements

Dr Kari A. Kinnunen of the Finnish Geological Survey provided helpful information and also suggested several improvements to an early draft of the manuscript. Prof. Dr Klaus Thalheim, Curator of Mineralogy, Museum für Mineralogie und Geologie, Dresden, kindly tracked down Rimann's original specimens from Paakkila and carried out XRD analysis to check the compositions.

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Letters to the Editor

Optimizing faceting for beauty*

We read with interest the above article and whilst we agree with the majority of it, we felt we would like to clarify one main point in the section Shape vs. weight (p.28), where Anton Vasiliev criticizes rubies and sapphires cut in Indo-China, India and Southeast Asia as not being cut like diamonds. We would like to know if Mr Vasiliev is a diamond cutter or a lapidary.

Whilst we agree that most rubies and sapphires in these countries are cut for weight, we would like to stress most strongly that they should not be cut like diamonds. The modern diamond cuts have been scientifically designed to give a diamond maximum brilliance as this is the only quality that a diamond has to give it beauty, whilst the main quality that a ruby or sapphire has is its colour.

Most sapphires and rubies do not have an even saturation of colour like synthetic stones which are often cut like diamonds. In reality most natural sapphires and rubies have a secondary colour, i.e. blue sapphires have either grey, purple or green as a secondary colour and rubies, purple or brown. If these stones are diamond-cut the secondary colour comes into play, thus reducing its beauty, and colour will be lost.

We have nearly 80 years' gem-cutting experience between us at Chas. Mathews, and Peter Rome had a couple of years before that cutting diamonds.

We have noticed a worrying trend over the last few years of notable institutions associated with our trade that are teaching people to cut coloured gems like diamonds, who have no experience at all!

Cutting diamonds is a science; cutting rubies, sapphires and emeralds is an art.

Peter R. Rome and John M. Taylor
Chas. Mathews (Lapidaries) Ltd.,
5 Hatton Garden, London EC1N 8AR

Anton Vasiliev replies:

Be assured, the author is a technologist of a cutting factory (coloured gems only) and a practising facetor. There is no contradiction between diamonds and other gems in this article; it must help facetors to make any gem more beautiful. The author agrees with opinion about narrowness of modern diamond design and noted the role of traditions in this article. There are many beautiful designs for coloured gems and one object of this article is to help facetors choose the best. The author's main opinion is that beauty is primary!

Responding to the second paragraph of the letter, investigation of the nature of colour of gems is one of the directions of scientific investigation at the LAL company. A special article devoted to optimizing colour is in the author's plans. The faceting factory LAL (well-known in Russia) has extensive experience of recutting Indo-Chinese cutting. The gems lose weight (up to 30%) but become much more beautiful and usually don't lose colour. Indeed, in some cases the colour improves!

* *J.Gemm*, 2004, **29** (1), 25

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I agree with the comments made in the penultimate paragraph of the letter. Diamond is just one kind of gem. Other gems must not be cut like a diamond; all gems must be cut for maximum beauty. Sometimes the brilliant arrangement of facets is preferable, but slopes of main facets at least must be different.

Cutting any gem must be an art! It's the subject of this article. But the cutting of rubies and sapphires in Indo-China, India and Southeast Asia is usually a native art, which can be improved with input of new technical knowledge.

Anton Vasiliev
LAL Scientific & Industrial Firm,
Moscow, Russia

Having just finished reading 'Optimizing faceting for beauty' by Vasiliev in the January issue of the Journal, I would say that in terms of numbers, the majority of faceted gems, and particularly diamond, have found their way to the 'round' shape through the ages. Oftentimes when lecturing on gems over the past 50 or more years, the question coming from the audience has been 'Just how much is *lost* in cutting a gem, from the rough material to the finished gem?'

In response, I pointed out that for practical work, we could assume a round brilliant being cut from a cube. Within the cube, the pavilion can be thought of as a cone (without the facets) and the crown as a truncated cone (a frustum), and calculation of their volumes indicates that such a 'preform' of the round brilliant would constitute between 30 and 31% of the volume of the original cube. Most rough, of course, does not conform to ideal shapes for optimum recovery, but much of it dictates that a 'cube of sorts' be preformed before faceting begins. So yields will generally be much smaller than the figure given above.

In the past 55 years, I have kept meticulous records of yield from rough in a wide variety of coloured gems and find that, if you cut to the ideal angles for the different species, you are fortunate to recover an average of 25% from all the rough.

John R. Führbach
Jonz Fine Jewels, Amarillo, Texas, U.S.A.

Anton Vasiliev replies:

Gems cut in Indo-China are often recut at LAL company. Generally they lose from 10 to 30% weight but gain very much beauty! But if we cut gem from rough directly with correct proportions, the loss is much smaller. This value depends more upon the expertise of the facetor (positioning and orienting the gem into the rough piece) than on choosing the best facet slopes. With best cutting we recover an average of more of 25% from rough using correct slopes.

Translator's note: I too have recut foreign-cut stones (mostly Brazilian) to improve their beauty. They make great 'preforms'! Yes, there is loss (less than on Indo-Chinese stones) and it is worth it to a gem connoisseur (sadly, it makes no difference to the average buyer). Bruce Harding

Abstracts

Diamonds

Diamonds from Myanmar and Thailand: characteristics and possible origins.

W.L. Griffin, T.T. Win, R. Davies, P. Wathanakul, A. Andrew, I. Metcalfe and P. Cartigny. *Economic Geology*, **96**(1), 2001,159-70.

Diamonds occur in modern alluvial deposits at several localities in Myanmar, Thailand and Sumatra. These deposits do not contain typical diamond indicator minerals, and no obvious primary sources have been found in the surrounding terrain, which is characterized by Phanerozoic tectonic and magmatic activity. Detailed studies of diamonds from Theindaw and Momeik in Myanmar and Phuket in Thailand have been undertaken to clarify their origin. Syngenetic mineral inclusions in the diamonds are largely of the peridotitic paragenesis, with a smaller eclogitic component. Carbon and nitrogen isotope compositions are typical of kimberlitic and lamproitic diamond suites worldwide. Nitrogen aggregation states indicate a long residence and/or significant deformation at mantle *T*; many stones show plastic deformation features. The rounded and polished surfaces of most of the diamonds reflect resorption in a corrosive magma. The isotopic data and the dominantly peridotitic nature of syngenetic inclusions rule out the Argyle lamproite as a possible source and also distinguish the Myanmar-Thailand diamonds from morphologically similar stones from E Australia. G.L.B.

Obtaining U.S. copyright registration for the Elara square cut-cornered brilliant diamond.

H.B. Rockman. *Gems & Gemology*, **39**(3), 2003, 210-13.

The U.S. Copyright Office has granted what is believed to be the first copyright registration covering a gemstone design, when the application to register the Elara cut was accepted. Previously, it had been argued that cut design lacked artistic or sculptural authority. R.A.H.

[A study of X-ray diffraction of diamond inclusions from Luobusha, Tibet.]

N. Shi, W.S. Bai, Z. Ma, Q. Fang, M. Xiong, B. Yan, M. Dai and J. Yang. *Acta Geologica Sinica*, **76**(4), 2002, 496-500. (Chinese with English abstract.)

Diamonds have been found in podiform chromitites and olivine-bearing rocks from ophiolite in the Yarlung Zangbo River, Tibet; some of the diamonds have silicate inclusions. Using the charge-coupled detector system for XRD, the authors have obtained powder XRD patterns for inclusion minerals only 20 μm in size; these were found to be talc and chrysolite, confirming the natural origin of these diamonds. R.A.H.

An investigation into the cause of colour in natural black diamonds from Siberia.

S.V. Titkov, N.G. Zudin, A.I. Gorshkov, A.V. Sivtsov and L.O. Magazina. *Gems & Gemology*, **39**(3), 2003, 200-9.

Black and dark grey diamonds from Siberia were studied by analytical scanning and TEM. Their colour was found to be due to the presence of dark inclusions, not of graphite but predominantly magnetite in the black diamonds, and hematite and native iron in the grey diamonds. The black diamonds exhibited anomalously high magnetic susceptibility, which may serve as one criterion for determining the natural origin of the black colour. R.A.H.

An infrared investigation of inclusion-bearing diamonds from the Venetia kimberlite, Northern Province, South Africa: implications for diamonds from craton-margin settings.

K.S. Viljoen. *Contributions to Mineralogy & Petrology*, **144**(1), 2002, 98-108.

The Venetia kimberlites sampled diamonds from the lithosphere underlying the central zone of the Limpopo Belt, an anomalous tectonic setting. A suite of diamonds from the Venetia mine spans a large range of N contents (from less than the detection limit to 1355 ppm). Diamond N contents are higher in the eclogitic diamond population relative to websteritic and peridotitic diamonds. Nitrogen aggregation states vary from pure type 1aA (poorly aggregated N) to pure type 1aB diamond (highly aggregated N). Two groups of diamonds can be distinguished: a minor population with N>500 ppm and N aggregation states of <40% 1aB and a dominant population with higher and more variable N aggregation. The unusually aggregated diamonds are unique to Venetia relative to other intrusives on the Kaapvaal–Kalahari craton, but similar to other craton margin or adjacent mobile belt settings such as the Argyle lamproite, though the Argyle setting involved a higher level of deformation (with a higher abundance of brown diamonds). R.A.H.

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Gems and Minerals

The history and importance of heat treatment of Australian sapphire.

T. COLDHAM. *Australian Gemmologist*, **21**(11), 2003, 450-62, 14 illus.

This paper appears in the special Geoff Tombs Memorial issue (Part 1) together with a reproduced article by Geoff Tombs ('Synthetic-like fluorescence in a natural sapphire') which first appeared in the *Australian Gemmologist*, **12**(3) in 1974.

Geoff Tombs's interest and articles on heat treatments are mentioned in the preamble to the Coldham paper. The author believes that Tombs's references to SW U-V fluorescence in a natural sapphire may mean that he was examining a heat-treated Ceylon blue sapphire a few years before such a treatment became generally known to the gemmological community. The author then reviews the heat treatment processes used to enhance Australian sapphires from 1969 to the present time. While the advent of the Thai heat treatment processes dramatically increased the demand for Australian rough, the profits made by the Thais enabled them to invest in buying, mining, processing and treating rough sapphire from around the world. The resulting competition now threatens to destroy the Australian mining industry. He concludes with the question: "Will the discovery of the beryllium treatment process be the straw that broke the camel's back?" P.G.R.

Some preliminary observations of primary corundum occurrences from Balangoda region, Sri Lanka.

M.D.P.L. FRANCIS, P.G.R. DHARMARATNE AND R. GIERE. *Gemmologie. Z. Dt. Gemmol. Ges.*, **52**(2/3), 2003, 81-90. 2 maps, 12 photographs, 2 diagrams, bibl.

The region of Balangoda lies midway along the Colombo-Badulla road and is famous for top quality stones, including rubies and sapphires. Most finds are alluvial, but some corundum deposits are found, producing good quality stones. The corundum bearing granulitic gneisses were found as a narrow band near to Balandoga and consist of corundum, biotite, sillimanite, perthitic K-feldspar and plagioclase together with graphite, zircon, apatite, sapphirine and spinel. Most of the region's corundums contain zircon inclusions. E.S.

Cäsiumreiche Morganite aus Afghanistan und Madagaskar.

H.A. HÄNNI AND M.S. KRZEMNICKI. *Gemmologie. Z. Dt. Gemmol. Ges.*, **52**(2/3), 2003, 67-80. 7 photographs, 3 diagrams, 3 tables, bibl.

The beryls have a very saturated pink colour and their physical and optical data exceed previously reported details. SG = 2.91-3.10, RI = 1.608-1.615, caesium concentration was up to 15.18%. Samples from Afghanistan are semi-transparent, but transparent stones are found among the Madagascar stones. Inclusions are mainly fine tubes parallel to the *c*-axis, flat fluid inclusions parallel to the basal pinacoid, and tension fractures. Based on chemical composition, spectral analyses and colour saturation, the authors suggest that these stones are morganites. Because of the extremely high content of caesium a new mineral name within the beryl group will be discussed in the IMA. [This material has been approved by the IMA as a new mineral – pezzottaite – E.S.] E.S.

Lapis lazuli from Sar-e-Sang, Badakshan, Afghanistan.

W. HEFLIK AND L. NATKANIEC-MOWAK. *Gemmologie*, **52**, 2003, 11-24.

Fresh mineralogical and petrological details are provided for the classic lapis lazuli locality of Sar-e-Sang, Badakshan, Afghanistan. Tests involved SEM electron microscopy with energy-dispersive X-ray analysis and chemical determinations using NAA, ICP-AES. The lapis-lazuli arises from contact metamorphism. M.O'D.

Aventurisierender Oligoklas aus USA.

U. HENN. *Gemmologie. Z. Dt. Gemmol. Ges.*, **52**(2/3), 2003, 117-8. 2 photographs, bibl.

The author describes transparent oligoclase feldspars from Oregon with euhedral haematite inclusions, which cause aventurescence. E.S.

Bestrahlter farbwechselnder Fluorit aus Brasilien.

J. HYRSL AND C.C. MILISENDA. *Gemmologie. Z. Dt. Gemmol. Ges.*, **52**(2/3), 2003, 115-6. 1 photograph, bibl.

Some faceted dark sapphire-blue fluorites came on the market in Brazil in 2002. The stones showed the rare blue colour both in day and under fluorescent light. Under incandescent light the colour changed from blue to an amethyst-like violet. The original stones were colourless to yellow and came from the Espirito Santo state and were irradiated with a Co-source in Sao Paulo. RI = 1.432. There are numerous two-phase inclusions. The colour seems to be evenly distributed, but under a microscope one can see dark coloured patches. Apparently thousands of carats of faceted stones have been sold, mainly to Japan. E.S.

Mineral inclusions in zircon from diamond-bearing marble in the Kokchetav massif, northern Kazakhstan.

I. KATAYAMA, M. OHTA AND Y. OGASAWARA. *European Journal of Mineralogy*, **14**(6), 2002, 1103-8.

Zircon is known to protect inclusions of UHP phases from late-stage overprinting. Matrix diopsides contain abundant exsolved phengite lamellae, whereas the exsolution is absent in the inclusions in zircon. The diopside inclusions contain more K_2O (< 0.56 wt.%) and Ca-Eskola component (< 3.5 mol.%) than those of the matrix (0.14 wt.% and 2.1 mol.%, respectively). Thus phengite exsolution occurs in matrix pyroxene with low K_2O and Ca-Eskola components compared to the inclusions in zircon, indicating that decreasing K_2O and Ca-Eskola components during decompression resulted in the phengite exsolution in diopside. The peak metamorphic *P-T* conditions of the impure marble are estimated to be 60-80 kbar and 960-1050°C. R.A.H.

Amethyst mit Eisenrosen aus dem Zillertal.

A. KUGLER. *Lapis*, **28**(10), 2002, 55-9.

Fine crystals of amethyst have been found in association with 'iron roses' of hematite in the Zillertal, Austria. M.O'D.

Gem news international.

B.M. LAURS (ED.). *Gems & Gemology*, **39**(3), 2003, 222-49.

Items mentioned include Australia's largest gem-quality rough diamond (104.73 ct) found in the Gareth pipe at the Merlin project in the Northern Territory, the Koala kimberlite at Ekati in the Canadian Northwest Territories, an alexandrite-emerald intergrowth from Russia, an unusually large crystal (3.7 cm long) of hiddenite from North Carolina, bright pink Cs-'beryl' (pezzottaite) from a pegmatite near Ambatovita, Madagascar, and three synthetic diamonds (0.14-0.31 ct) grown by chemical vapour deposition. R.A.H.

Gemmologie Aktuell.

C.C. MILISENDA. *Gemmologie. Z. Dt. Gemmol. Ges.*, **52**(2/3), 2003, 63-6. 6 photographs.

Strawberry quartzes are colourless quartzes with haematite inclusions; they came from Mexico in the 1960s, then from Kazakhstan in the 1990s and are now on the market from Madagascar. Faceted specimens were about 2 cm in length.

A dark brown scapolite cat's-eye from Tanzania, weighing 14.45 ct, 18.5 × 10.85 × 9.61mm, had an RI = 1.56, SG = 2.76. The chatoyancy was caused by parallel orientated acicular mineral inclusions. These are two-phase inclusions and under the microscope one can see brownish-red platelets, resembling those found in the strawberry quartzes described above.

Iridescent ammonites from Russia, resembling the specimens from Alberta, Canada known as 'ammolite' in the trade, were examined. The specimens weigh about 12.5 g each and measure roughly 5.5 × 2.5 × 0.5 cm. They show only a vague shadow on the refractometer at about 1.52 and 1.67, with a birefringence of 0.15. Thin aragonite layers are responsible for the iridescent effect. E.S.

Lab Notes.

T.M. MOSES, I. REINITZ, S.F. MCCLURE AND M.L. JOHNSON (EDS). *Gems & Gemology*, **39**(3), 2003, 214-21.

Notes include details of a faceted 6.34 ct colourless leadhillite (reportedly from Tsumeb), a 4.75 ct yellow beryllium-diffused sapphire and a 6.97 cabochon of stichite with pinkish-purple floral masses apparently nucleated around minute crystals of chromite. R.A.H.

Eine fossile Perle aus den Niederlanden.

J. SCHLÜTER AND M. DANNER. *Gemmologie. Z. Dt. Gemmol. Ges.*, **52**(2/3), 2003, 91-6. 4 photographs, bibl.

The fossil pearl was found in the Langenboom pit, district of Mill in the Netherlands in Neogene marine sediments in 2002. It is estimated to be 3.3 million years old. It is round, white to beige, 4.4 mm in diameter, weighing 0.096 g. It is built up of concentric aragonite layers and is non-nacreous. The pearl has alternating layers of aragonitic cross lamellae and prismatic aragonite, common to mollusc shells. The pearl was found close to shell fragments from the gastropod genus Xenophora. The colour, internal structure and reaction to ultra-violet light suggest that pearl and shell fragments have a common origin. E.S.

Geochemie und Petrologie von Smaragdvorkommen – Erfahrungen aus dem Smaragdbergbau in Sambia und Simbabwe. Teil I: Kafubu, Sambia.

K.C. TAUPITZ. *Gemmologie. Z. Dt. Gemmol. Ges.*, **52**(2/3), 2003 97-114. 5 maps, 3 tables, 1 diagram, bibl.

The Zambian emeralds occur in the early Proterozoic Kafubu formation and crystallized during the Pan African orogenesis and metamorphism, whereas the Sandawana emeralds occur in the mid-Archaean Sandawana formation below the lower Bulawayo greenstones of the Zimbabwe craton. Borates and potassium predominate in Kafubu, while in Sandawana it is mainly sodium with a little potassium and lithium. The Kafubu emeralds mainly crystallized as porphyroblasts in the host rocks. In the regional metamorphism nothing was added and nothing removed except volatile fluids. Only where enough beryllium and sufficient chromium (and of course Si, Al, Na and Fe) was present, could emerald porphyroblasts grow under the conditions of strong metamorphism.

It was concluded that the emerald pockets and ore shoots (only about 10-20% of the ore zone) are due to beryllium enrichment during or shortly after the sedimentary deposition. Influences by tectonic structures or hydrothermal activity could not be found. E.S.

Lambina opalfield: An update.

J. TOWNSEND. *Australian Gemmologist*, **21**(12), Geoff Tombs Memorial Issue (Part 2), 2003, 490-4, 8 illus. in colour, 3 maps.

The Lambina opalfield diggings are situated some 200 km north west of Coober Pedy. Although they have been worked intermittently for at least 30 years, it has only been in the last decade that production of precious opal from this field has become significant. This update includes details of the geology of opal occurrence, annual estimates of Lambina opal production from 1995 to 2002 and characteristics of the opal recovered from this site. P.G.R.

Instruments and Techniques

Annealing radiation damage and the recovery of cathodoluminescence.

L. NASDALA, C.L. LENGAUER, J.M. HANCHAR, A. KRONZ, R. WIRTH, P. BLANC, A.K. KENNEDY AND A.-M. SYDOUX-GUILLAUME. *Chemical Geology*, **191**(1-3), 2002, 121-40.

The structural recovery upon heat treatment of a highly metamict actinide-rich zircon (U ~ 6000 ppm) was studied in detail using a range of techniques including XRD, Raman spectroscopy, SHRIMP ion probe, EPMA, TEM and CL analysis. The structural regeneration of the amorphous starting material depends on random nucleation. It starts between 800 and 900°C when amorphous $ZrSiO_4$ decomposes to form crystalline ZrO_2 and amorphous SiO_2. At ~ 1100°C, well-crystallized $ZrSiO_4$ grows at the expense of the oxides. U has been retained in the newly grown zircon whereas Pb was evaporated during the heat treatment. This process is in marked opposition to the reconstitution of moderately metamict minerals, which experience a gradual recovery controlled by the epitaxial growth at the

crystalline-amorphous boundaries. Both recovery processes are not the direct inverse of metamictization. The structural regeneration is connected with a significant increase in the emission of CL. In all cases (annealing heavily damaged zircon and moderately damaged zircon and monazite), it was observed that the final, well crystallized annealing products emit more intense CL than their radiation-damaged starting minerals, although having almost identical elemental composition. The observations are taken as evidence that the CL is not only determined by the chemical composition of the sample but also strongly controlled by structural parameters such as crystallinity or the presence of defect centres. G.L.B.

Spectra of gem materials.

G. PEARSON. *Australian Gemmologist*, **21**(12), Geoff Tombs Memorial Issue (Part 2), 2003, 478-85. 7 illus.

This paper discusses the usefulness of the hand spectroscope in the identification of gemstones. The author compares transmission spectra derived from a UV-Visible scanning spectrophotometer with the spectra observed using a prism spectroscope. His research raises questions about the visibility of spectral absorption features which have been long published as characteristic of many gemstones. The Relative Luminous Efficiency curve indicates the sensitivity of human vision across the visible wavelength range and is used to develop a parameter termed the *RLE Corrected Transmission*. This parameter is based on the relative intensities of the various wavelengths that can be seen by observers having average visual sensitivity and indicates that some of the absorption spectra presented in many gemmology texts cannot be seen with the hand-held spectroscope. P.G.R.

Synthetics and Simulants

[Growth of diamond from solution in the $CaCO_3$ melt.]

A.F. KHOKHRYAKOV, YU. M. BORZDOV. YU. N. PAL'YANOV AND A.G. SOKOL. *Proceedings of the Russian Mineralogical Society*, **132**(2), 2003, 87-95. (Russian with English abstract.)

Diamond nucleation and growth kinetics on the [100] and [111] faces of seed diamond crystals in the $CaCO_3$-C system were studied in a non-pressing device of 'cross-cut sphere' type at 7 Gpa and 1700-1750°C in experiments of 10 min to 18 h duration. The growth on [100] develops in the diffusion-limiting regime, and growth on [111] is determined mainly by the kinetics of superficial processes. Evolution of the surface accessories on the [111] faces was traced from triangular frame defects up to large trigonal pyramids. Comparison with similar Si and Ge patterns shows that the trigonal pyramids are complex twins. The only stable cubic forms of diamond growth in the $CaCO_3$-C system are tetragontrioctahedron faces; among them only {322} faces achieve the habit scale of development. R.A.H.

Alkaline-chloride components in processes of diamond growth in the mantle and high-pressure experimental conditions.

YU. A. LITVIN. *Doklady, Russian Academy of Sciences, Earth Sciences Section*, **389A**(3), 2003, 388-91. (English translation.)

An experimental study was carried out into the spontaneous nucleation and crystallization of diamond and its growth on monocrystal seeds in melts of the key system (potassium chloride-carbon) at high *P*. The investigations have shown that spontaneous nucleation is effectively realized in melts of the KC1-C system, which is an essential aspect of the problem of alkaline-chloride brines in natural diamond-hosted cloud-like microinclusions. The author concludes that the growth of natural diamonds in the parent carbonate-silicate will not cease during local high concentrations of alkaline-chloride aqueous solutions. A.M.C.

35 years on: a new look at synthetic opal.

A. SMALLWOOD. *Australian Gemmologist*, **21**(11), *Geoff Tombs Memorial Issue (Part 1)*, *2003*, 438-47. 22 illus., 2 tables.

This paper appears in the special Geoff Tombs Memorial issue (Part 1) and follows a reproduced article by Geoff Tombs ('Notes on identification of Gilson opal') which first appeared in the *Australian Gemmologist*, **12**(6) in 1975.

The Smallwood paper reviews the history of opal synthesis from the early days of Pierre Gilson's original production to the more recent manufacture of synthetic and imitation opals from Japan, Russia and China. Tables of gemmological constants are provided and compared with those of the natural material. P.G.R.

Abstractors

G.L. Barron	G.L.B.	R.A. Howie	R.A.H.	P.G. Read	P.G.R.
A.M. Clark	A.M.C.	M. O'Donoghue	M.O'D.	E. Stern	E. Stern

Book Reviews

Handbook of mineralogy. Borates, carbonates, sulphates

J.W. ANTHONY, R.A. BIDEAUX, K.W. BLADH, M.C. NICHOLS, 2003. Mineral Data Processing, Tucson, AZ, pp ix, 813. Hardcover ISBN 0 9622097 4 0. US $ 150.00.

This is the final volume to be published of this excellent series in which the aim of one species, one page has been triumphantly achieved without the loss of any major data. Previous volumes covered elements, sulphides and sulphosalts (volume 1), silica and the silicates (volume 2, in two parts), halides, hydroxides and oxides (3), arsenates, phosphates and vanadates (4). Species are presented in alphabetical order of name throughout.

Gemmologists may find the price of the complete set or even a single volume sends them to the nearest major library but the convenience of the single page of data is considerable. Since the publication was commenced in 1970 the compilers have made use of the GEOREF database of the American Geological Institute and the GEOBASE database of Elsevier Science Ltd.

In the present volumes the gem minerals rhodochrosite, sinhalite, jeremejevite and johachidolite are among species with ornamental application, as well as calcite which succeeds in not over-running its page despite the more than 1000 forms attributed to it. M.O.D.

Calcite: the mineral with the most forms

Lapis International LLC, East Hampton, Conn., U.S.A. pp 114, illus. in colour. Softcover. ISBN 0 971 5371 3 5. *extralapis English no 4*. Price on application.

English version of the monograph first published in German. M.O'D.

Fluorspar in the North Pennines

R.A. FAIRBAIRN (ED.), 2003. North of England Lead Mining Museum, Killhope. pp iv, 132, illus. in black-and-white. Softcover ISBN 0 9518939 3 9. £8.50.

This is a most useful multi-author survey of the occurrence and working of fluorite in the Northern Pennine orefield of England. The first chapter deals with the properties, origin and distribution of fluorite both in the area described and on the Earth in general. Following chapters cover the activities of dealers and collectors, the demand for fluorite in the steel industry and the rise and fall of fluorite mining in the area.

The remainder of the book describes ore mining and dressing including a description of the Frazer's Grove mine, the last of the major fluorite mines to work (the Frazer's Hush portion of the mine ceased production by the end of July 1999). The site is said to be mothballed. This reviewer went underground during the 1980s when production was still in progress.

Each chapter has its own excellent list of references and the whole book reflects the greatest credit on the publishers and contributors as well as on the Friends of Killhope who have done and are doing so much to preserve the history of mining in one of England's major mining areas. M.O'D.

Pearling in the Arabian Gulf: A Kuwaiti Memoir

SAIF MARSOOQ AL-SHAMLAN translated from Arabic by P. CLARK, 2000. London Centre for Arab Studies. pp 190, 19 black-and-white photographs, 1 map, glossary and index. ISBN 1900 404 192. Price on application.

This is an edited version in translation of a two volume work first published in Arabic in 1970. Based on documentary and oral evidence, private archives and the author's memory, it describes the pearl industry between 1900 and 1930 when the arrival of the Japanese cultured pearl brought disaster to the industry. It records the conditions of the divers, their food, tools of their trade, their illnesses and generally their difficult life at sea. There are many anecdotal stories of divers, captains and pearl merchants, which make reading of this little book very enjoyable. E.S.

Pearl Buying Guide. 4th edn

RENEE NEWMAN, 2004. International Jewelry Publications, Los Angeles, CA,U.S.A. pp 156, illus. in colour. Softcover. ISBN 0 929975 35 9. £14.50.

This is the book to get whether or not you intend to buy pearls. It is also ideal for examination preparation! Matters which can seem rather confusing when studied in the abstract are clarified by the many photographs and the questions set for each chapter are excellent ways in which to test your knowledge. In more than one place the author states that to all intents and purposes any pearl likely to be encountered in general commerce is going to be cultured. This is an interesting point and almost certainly true. M.O'D.

Burma ruby: a history of Mogok's rubies from antiquity to the present

S.K. SAMUELS, 2003. SKS Enterprises Inc., Tucson, AZ, U.S.A. pp xvii, 254. Illus. in black-and-white and in colour, Hardcover ISBN 0 9725323 0 7. Price on application.

Studies of Myanmar and its rubies are leaving the presses with increasing frequency. Two recent ones are Themelis, *Mogok, valley of rubies and sapphires* (2000) and Schlüssel, *Mogok, Myanmar* (2002), both of which are

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general surveys of the Mogok area with plenty of space given to the ruby mines and their products. The author of the present book has long experience of the country, having worked in the medical profession in different capacities from the 1950s and returning there in 1971. After studying gemmology in the 1980s, he returned to the country to assess the state of the ruby and gem markets after years of political and commercial uncertainty.

The book begins with a short history of the place held by ruby in the lore of Myanmar and then proceeds to a description of the area and the place held by ruby in early Burmese kingdoms, from the 16th century, during which travellers from the west began to publish accounts of their travels, supplementing with fertile imaginations those places, objects and customs actually seen. Exceptional ruby specimens were known to the Burmese population and by the end of the 17th century the published writings of Tavernier had brought them to the notice of Europeans.

The next chapter describes Mogok during the second Burmese dynasty roughly corresponding to the 16th century. During this time the ruby mines in the area had begun to provide major (and some legendary) specimens: by the time of the last Burmese dynasty (1752-1885), the history of which is comprehensively described, royal treasures were well known, many featuring fine rubies. The whereabouts of some of them have been investigated and are discussed.

Details of the history of Burma on annexation by the British in 1852 and of the subsequent events of the Second World War are given in some detail. The Oriental and India Office collections of The British Library contain great amounts of information but it is uncertain whether or not the author has been given access to them. However, he has drawn comprehensively from the publications of the Burma Research Society. The occasional remarks and speculations on the motives behind British policies in south Asia are less well-informed.

So far we have an interesting overview of historical events against which the activities of the ruby mines have been taking place. By page 101 we turn, profitably, to accounts of the development or re-development of the gem trade in Burma.

First we see how relations between government and miners became the subject of regulations and how the establishment of a gem emporium affected ruby production and sales. By 1988/89 and under a new government the 29th Emporium included some exceptional rubies though by 1995 there was a decline in ruby production and quality. Some of the provisions of a new law aimed at improving relations between government and ethnic groups are set out. The author has been able to reproduce entries from some of the sale catalogues of the mid-1990s.

The next chapter describes the stone tract with brief notes on the geology and a list of the mines operating in 2002. Some mines produce only ruby, others sapphire and some other species. The properties of ruby and sapphire are then introduced and I have the impression that the author now finds himself on less familiar ground. Names of authorities are frequently and persistently misspelt; rutile needles are said to be negative crystals; 'crystallites of olive' have not turned up in any corundum I have encountered.

There is no doubt that the sudden diminution of accuracy from this point makes this reviewer less confident about the previous chapters. It is all too easy to pick up scraps of history, very little of which can be verified, but much harder to deal with specimens whose essential nature and properties science has already established. The carelessness shown here makes me wonder why the MS was not scrutinized by a competent authority. Gemmologists could staple together pages 143-50 without losing any vital information.

The bibliography is uneven and there is no index, the most serious fault of the book. The colour photographs have not reproduced well: the inclusions mentioned in the captions are not always visible and the blues of the sapphires are too dark.

I should add here that despite some strictures I found this a very readable book with valuable notes on and photographs of the more recent emporia. There is also advice on buying gemstones in Myanmar (internet sales are promised).

M.O'D.

Flux-enhanced rubies and sapphires

T. Themelis, 2004. The author, Bangkok, Thailand [www.themelis.com]. pp 48, illus. in colour. Softcover ISBN 0 940965 42 9. Price on application.

The book describes the processes involved in the heat treatment of rubies and sapphires. This is very nearly a step-by-step recipe for the treatment as all stages are illustrated on each side of the text which occupies the centre of each page. The all-colour illustrations and the strong red page headers make the book seem quite aggressive and the effect is memorable.

The text is, too, or should be as this is probably the best account so far of this type of treatment. Several authorities are cited and the dangers of doing it yourself are emphasized in a general disclaimer. There is a glossary and a short bibliography. The final part of the text deals with identifying treatment of this kind: disclosure and market value are also briefly discussed. Questions and answers cover several of the areas which gemmologists could well study.

M.O'D.

Secrets of the gem trade

R.W. Wise, 2003. Brunswick House Press, Lenox, MA, U.S.A. pp 274, illus. in colour. Hardcover. ISBN 0 9728223 9 9. US $79.95.

This book, which is partly an autobiography, gives a readable account of many of the major gem materials as seen through the eyes of an experienced dealer and editor. The book's appearance is particularly attractive with an airy typeface and good spacing. The photographs are of a good standard and there is a fairly complete bibliography. The text gives an imaginative introduction to gemstones, just the thing to start off a career in gemmology.

M.O'D.

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Tribute

Alexander E. Farn (1916-2004)

A tribute by Kenneth Scarratt

I first had the pleasure of meeting Alexander E. Farn (Alec as he was widely known) towards the end of 1973. As the then Director of the Laboratory of the Diamond, Pearl, and Precious Stone Trade Section of the London Chamber of Commerce (usually known as 'the Laboratory') he greeted me with a warm yet formal smile as I walked into an interview that was to place a stamp upon my future as a professional gemmologist. The office was that of Denis Bradshaw, a noted Hatton Garden coloured stone merchant, who was then the Chairman of the DPPS Trade Section of the London Chamber of Commerce (and the Laboratory Committee) and who in the same vein as Alec was one of the industry's true gentlemen. I remember sitting before these two and several other members of this initially forbidding and exceptionally formal 'selection panel'– a young gemmologist with no history, just a desire for knowledge and a hope that this could be the start of my gemmological career. Within moments of sitting I can remember feeling the warmth in the questions coming towards me from Alec and my fears of rejection melting away, allowing me to be myself and ultimately being given the honour of working for and alongside Alec until his retirement on St. Patrick's Day 1981.

Working with Alec from early 1974 to 1981, I was privileged to hear some of the anecdotal history of the Laboratory through his first hand knowledge of his colleagues' sometimes incredible experiments. At the same time I learned something of the man himself. As a child he lived over a jeweller/pawnbroker's shop and he began his gemmologically-oriented career as a pawnbroker's assistant (again living over the shop) in an area known as 'World's End' Chelsea, an area of London that he described as being 'not the best' at the time he was working there. He eventually graduated to work in George Attenborough & Son, pawnbrokers, jewellers and silversmiths, in Oxford Street, where one of the tasks he related was 'smashing' sterling silver teapots, candelabra, etc, with a sledge hammer and throwing the remains into a large walk-in vault. It was while working at Attenborough's and pondering over some wonderful coloured gemstones that a good friend and colleague, George Ratcliffe, said to him, "God, you are ignorant, you need to get yourself gemmologically educated."

Motivated by his colleague's comments, Alec joined Basil Anderson's gemmology class at Chelsea Polytechnic just before World War II. He revelled in this new and fascinating direction and, like so many of us, "caught the gemmological bug". Also present in this class was a future Secretary of the Gemmological Association, Harry Wheeler. Both he and Harry passed their first year examinations but unfortunately for them both their careers were interrupted by

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World War II. Alec served his country admirably during the war in the Royal Pioneer Corps while Harry was in the Royal Army Service Corps.

Following the end of the war, in 1946 both Alec and Harry Wheeler enrolled for their second year gemmology course and passed the Diploma Examination with distinction. A short time later Basil Anderson asked Alec to join the Laboratory to work alongside himself, Robert Webster and Cecil (C.J.) Payne. An offer he was delighted to accept.

During his time at the Laboratory Alec provided the solid base that the UK trade came to rely upon. It was to him that fell the task of ensuring the trade's needs were met, and that the reports were both accurate and on time. The other members of the phalanx of four provided the vital research needed to ensure accuracy and keep the world informed, Alec put the research into practice, "testing scores of thousands of pearls and rubies annually". After the war, the greatest need along with pearl testing was testing coloured stones, mostly calibrated rubies. At its peak in the post war years, the Laboratory tested more than 100,000 coloured stones annually. Alec was indeed the 'trade's gemmologist', never leaving his roots but embracing the scientific and technical in so far as it served a clear purpose. His numerous publications were always lucidly presented, stemming from his many years of practical gem testing, and this continued into the writing of his book Pearls, Natural, Cultured and Imitation. This much needed text was published in 1986 and is still one of the few volumes that are available on the subject. He describes the use of such instruments as the pearl endoscope and radiography units and the practical testing of pearls from personal experience rather than from the repetition of others.

His work with the industry was not restricted to laboratory reports or papers in journals. He worked diligently with the then President of the CIBJO Coloured Stone Commission, E.A. Thomson, to correct the CIBJO Blue Book and attended CIBJO meetings as an advisor to the UK delegation.

Upon the retirement of Basil Anderson, Alec took over the helm of the worlds' first and most noted Gemmological Laboratory. During his tenure he led the first tentative steps taken towards the use of modern analytical techniques in gemmological laboratories. One of his first improvements was the installation of an X-ray powder diffraction camera and this was closely followed by the introduction of low temperature (liquid nitrogen cooled) spectroscopy, which was a first for any gemmological laboratory. Apart from these and other technical improvements he was responsible for the introduction of a CIBJO diamond grading service at the Laboratory.

The 'phalanx of four' in the laboratory; (from the left) Robert Webster, Alec Farn, C.J. Payne and, standing, Basil Anderson.

(From the left) C.J. Payne, Alec Farn, Denis Bradshaw, Basil Anderson and Robert Webster, at Goldsmiths' Hall in 1975 on the 50th anniversary of the Laboratory.

Alexander Farn was an exceedingly private person who loved the challenges of his hillside garden at Riddlesdown in Surrey, a small village- like community nestled in a valley but only 25 minutes from Central London. He developed his love for 'caravanning' and levelled off the land in front of his house to accommodate his caravan. Each year he and his wife Ethel would travel through France discovering the wonders of that incredibly beautiful country and fast becoming devoted Francophiles. They both regularly attended French language classes and it pleased him greatly to converse in French when meeting with gemmological colleagues from the Paris laboratory. It was during a vacation in France that he noticed an irritation in one eye that was subsequently diagnosed as shingles. For many years thereafter he struggled with the ongoing pain caused by this problem. However, his professionalism was such that few knew of this. He and his wife moved from Riddlesdown to a flatter garden in Selsdon and after retirement they moved to Frinton-on-Sea and then later to Seaford.

Alec Farn, the last of the phalanx of four passed away on 6 January 2004. On the 50th anniversary of the Gemmological Association he wrote:

"Far from being a scientist I am a member of the trade, fortunate enough to have secured a job in the Laboratory, a job I was not seeking but when offered I accepted. I hoped some mistake in identity had not occurred but if so I hoped I could be kept on."

There is no question that Basil Anderson was not mistaken in choosing Alec Farn as his eventual successor.

He will be greatly missed by his wonderful wife Ethel and his son Edward, and all those who were fortunate enough to come into contact with him. I was one of those fortunate enough to have gained in so many ways from having been acquainted with him and like others mourn his death, and with this the passing of the most significant era in the UK's gemmological history.

Proceedings of the Gemmological Association and Gem Testing Laboratory of Great Britain and Notices

Members' Meetings

Midlands Branch

On 30 January at the Earth Sciences Building, University of Birmingham, Edgbaston, the Branch's annual Bring and Buy Sale and Team Quiz were held.

The Midlands Branch Conference was held on 22 February at Barnt Green, Worcestershire. The keynote speaker, Stephen Dale, a specialist in the works and techniques of Carl Fabergé, gave a talk entitled 'Carl Fabergé – a Russian Revolution'. Michael O'Donoghue gave a presentation on imitation gemstones entitled 'Where are they now?' and Roy Starkey spoke on various aspects of Scottish geology and mineralogy.

On 27 February at the Earth Sciences Building Professor Henry Hänni gave a presentation entitled 'The latest from the SSEF and the University of Basel'.

On 26 March at the Earth Sciences Building Chris Tarratt gave a talk on the history and development of hallmarking.

North West Branch

On 18 February at Church House, Hanover Street, Liverpool 1, Alan Bowden gave a talk entitled 'Gems in space: an introduction to the world of meteorites'.

On 17 March at Church House Terry Davidson gave a talk on 'Cartier: the 20th century'.

Scottish Branch

On 20 January at the British Geological Survey, Murchison House, West Mains Road, Edinburgh, Michael O'Donoghue gave a talk on 'Some unusual and historical synthetics'.

On 23 February at the Bruntsfield Hotel, Bruntsfield Place, Edinburgh, a social evening was held which included a Quiz, a Bring and Buy Sale and a buffet.

On 23 March at Jury's Hotel, Great Western Road, Glasgow, Brian Jackson gave an in-depth review of the feldspar family entitled 'Feldspar; the forgotten gem'.

South East Branch

On 25 February at the Society of Antiquaries of London, Burlington House, Piccadilly, London, Nigel Israel gave a talk entitled 'Tavernier, his travels and gemstones'.

Gem-A USA

Gabi Tolkowsky was guest-speaker at the Gem-A USA Dinner held during the AGTA show at the Tucson Gem and Mineral Fair in February. The dinner was well attended and attracted Gem-A members from Australia, Austria, Canada, China, Madagascar and the UK as well as from America.

Annual General Meeting

The 2003 Annual General Meeting of Gem-A was held on 9 September 2003 at 27 Greville Street, London EC1 8TN. Michael O'Donoghue chaired the meeting and welcomed those present. The Annual Report and Accounts were approved.

Continued on page 124

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Donations

The Council of Management are most grateful to the following for responding to the appeal for donations to enable the Association to extend its membership and education services. Donation levels were Diamond (£1000 and above), Ruby (£500 to £999), Emerald (£250 to £499), Sapphire (£100 to £249) and Pearl (£25 to £99).

The following join those donors listed in previous issues of *The Journal:*

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Naomi Yokokawa, London

Yung Tak Yi FGA, Hong Kong

Gifts to the Association

The Association is most grateful to the following for their gifts for research and teaching purposes:

Professor Dr Hermann Bank FGA, Idar- Oberstein, Germany, for alexandrite, brazilianite and dioptase crystals

Maggie Campbell Pedersen FGA, London, for a nautilus shell, a shellac case and a piece of Borneo amber

Charles & Colvard (HK) Ltd, Hong Kong, for 40 round and fancy-shape moissanites, and a J-Fire Unit for testing moissanite

John R. Führbach, FGA, Amarillo, Texas, U.S.A., for samples of feldspar, emerald, amethyst and calcite

Gem-A Awards

Gem-A Examinations were held worldwide in January 2004. In the Examinations in Gemmology 130 candidates sat the Diploma Examination of whom 39 qualified, including one with Distinction and three with Merit. In the Foundation Examination, 129 candidates sat of whom 85 qualified. In the Gem Diamond Examination 73 candidates sat of whom 51 qualified, including six with Distinction and ten with Merit. The names of the successful candidates are listed below:

EXAMINATIONS IN GEMMOLOGY

Gemmology Diploma

Qualified with Distinction

Miao Fu-chiang, Taipei, Taiwan, R.O. China

Qualified with Merit

Kelly, Jennifer Liu, London
Sillem, Hayaatun, London
Wood, Naoko W., Kensington, London

Qualified

Andronikou, Stamatina, Didsbury, Greater Manchester
Aye, Nwe Nwe, Yangon, Myanmar
Behennah, Andrew C., Didcot, Oxfordshire
Borahan, F. Oya, Istanbul, Turkey
Cheng Yili, Wuhan, Hubei, P.R. China
Cui Xiwen, Wuhan, Hubei, P.R. China
Deligiannis, Marios, Athens, Greece
Fan Yu-Hsiang, Taipei, Taiwan, R.O. China
Filadelfeos, Eleni-Anna, Athens, Greece
Glasgow, Sarah A., Fulham, London
Holman, Meryan, London
Huang Jin, Wuhan, Hubei, P.R. China
Ingridsson, Anna-Lis, Lannavaara, Sweden
Kwok Nai Chiu, Hong Kong
Lal, Sumit Kumar, Surat, India
Lalitha, R., Rajasthan, India
Latumena, Warli, Jakarta, Indonesia
Law Cheuk Yee, Annie, New Territories, Hong Kong
Lee Fung Mei, Kowloon, Hong Kong
Leung Kit Ling, Neon, Kowloon, Hong Kong
Ma Danni, Wuhan, Hubei, P.R. China
Mohamed, Ahmed, Lannavaara, Sweden
Naing, Saw, Yangon, Myanmar
Ngan Hin Wah, Michael, Hong Kong
O'Donnell, Craig, Smethwick, West Midlands
Okada, Hiroko, Kamakura, Kanagawa, Japan
Park, Sang-Suk, Seoul, Korea
Peeters, Irene F., Warmond, The Netherlands
Petrozello, Ryan J., Randolph, New Jersey, U.S.A.
Plain, Lyndsey, Barnsley, South Yorkshire
Singh, Gurmit, New Delhi, India
Tseng Chien Min, Taichung, Taiwan, R.O. China
Underwood, Thom, San Diego, California, U.S.A.
Wang Chun, Wuhan, Hubei, P.R. China
Zhang Guochen, Wuhan, Hubei, P.R. China

Gemmology Foundation Certificate

Qualified

Ahmed, Abdirashid F., Lannavaara, Sweden
Alliston, Erica, Hammersmith, London
Anderson, Tricia K.W., Montreal, Quebec, Canada
Appleyard, Catherine J., Lewes, East Sussex
Aung Htet Su, Yangon, Myanmar
Barqadle, Mahamed M., South Harrow, Middlesex
Blanksma, Eelco, Arnhem, The Netherlands
Callaway, Heather, Stone, Staffordshire
Cao Lu, Guilin, Guangxi, P.R. China
Chan Ye-Lay, Daniel, Kowloon, Hong Kong
Chen Manli, Zhongshan, Guangzhou, P.R. China
Chen Li Zhen, Zhongshan, Guangzhou, P.R. China
Cheung Yiu Hung, Kowloon, Hong Kong
Chien Kuo Shan, Taichung, Taiwan, R.O. China
Chiu Wai Yu, Yuki, Hong Kong
Chow Lai-Kwan, Kwinnie, Hong Kong
Clement, Jenny, London
Delpachitra, Malintha, Kandy, Sri Lanka
Fong Tik Kwan, Kowloon, Hong Kong
Fu Ming, Guilin, Guangxi, P.R. China
Gerber, Doris C., Zurich, Switzerland
Gu Jun, Singapore
Henning, Sarah A., Edgbaston, West Midlands
Ho Hay Mo, John, Yangon, Myanmar
Holdsworth, Isabel, Surbiton, Surrey
Hong Da Wun, Buk-Gu, Daegu, Korea
Hornsby, Rebecca A., Spalding, Lincolnshire
Hu Ruoxin, Guilin, Guangxi, P.R. China
Isse, Abdirisak H. Abdi, Lannavaara, Sweden
Jiang Huijing, Guilin, Guangxi, P.R. China
Johns, Catherine M., London
Ka Tsz Man, Kowloon, Hong Kong
Kahari, Risto, Helsinki, Finland
Kim You Mi, London
Kiviniemi, Sanna M., Ojakkala, Finland
Kueon, Seon-Il, Bupyong-ku, Inchon, South Korea
Kwok Chi Fu, Hong Kong
Lee, Sharon, Norwich, Norfolk
Lee, Phyllis E., Sacramento, California, U.S.A.
Lee Jeong Im, Seoul, South Korea
Lee Siu Ling, Kowloon, Hong Kong
Lek Chin Kwang Leon, Singapore
Leung Shuk Fun, Kowloon, Hong Kong
Li Mengjie, Guilin, Guangxi, P.R. China

Gem-A Awards

Li Yue, Shanghai, P.R. China
Liang Liming, Guilin, Guangxi, P.R. China
Liao Baoli, Guilin, Guangxi, P.R. China
Lin Shu-Zhen, Taipei, Taiwan, R.O. China
Lin Qingchun, Guilin, Guangxi, P.R. China
Liu Jing, Guilin, Guangxi, P.R. China
Luk Sau Wai, Kowloon, Hong Kong
Lwin Min, Yangon, Myanmar
Ma Mei Chuan, Kowloon, Hong Kong
Mak Tze Him, Gary, New Territories, Hong Kong
Pang Taotao, Guilin, Guangxi, P.R. China
Rosas, Jose L.M., Porto, Portugal
Rowley, Elaine, London
Ruan Yaohua, Guilin, Guangxi, P.R. China
Saw Kalaya Kyi, Yangon, Myanmar
Sien Pe (a) Yang Cheng Pei, Yangon, Myanmar
Singh, Amrinder P., Delhi, India
Song Dong, Shanghai, P.R. China
Southam, Karen L., Oldbury, West Midlands
Surawy, Laura K., Haywards Heath, West Sussex
Tang Wai-Leung, Kowloon, Hong Kong
Taylor, Richard E., Carlsbad, California, U.S.A.
Thet Phu Ngon, Yangon, Myanmar
Tsui, Cary, Melbourne, Victoria, Australia
Tun Tun U., Yangon, Myanmar
Van Spaendonk, Ann, Kalmthout, Belgium
Wong Ka Wai, Hong Kong
Wong Ching Man, Discovery Bay, Hong Kong
Wong Ka Yee, Clarie, Kowloon, Hong Kong
Wong Yuen Ching, Kowloon, Hong Kong
Wreford, David, London
Xie Shanshan, Guilin, Guangxi, P.R. China
Xu Xue Ying, Shanghai, P.R. China
Yang Xiao, Guilin, Guangxi, P.R. China
Yang Zhi, Guilin, Guangxi, P.R. China
Yee Yee Mon, Yangon, Myanmar
Zee Gar Bo, Kowloon, Hong Kong
Zhang Li, Shanghai, P.R. China
Zhao Zhan, Zhongshan, Guangzhou, P.R. China
Zhou Xihua, Shanghai, P.R. China
Zhu Jingjing, Shanghai, P.R. China

GEM DIAMOND EXAMINATION

Qualified with Distinction
Johnson, Adam J., Edgbaston, West Midlands
Johnson, Sally G., Welwyn Garden City, Hertfordshire
McMillan, Emma L., Solihull, West Midlands
Ng Wai Ling, Kowloon, Hong Kong
Ren Ming, Wuhan, Hubei, P.R. China
Watling, David, Sidcup, Kent

Qualified with Merit
Barnett, Catherine E., Balham, London
Cheng Suk Man, Hong Kong
Jackson, Antoinette, London
Lu Xi, Beijing, P.R. China
Ma Yuli, Wuhan, Hubei, P.R. China
Wong Ching Ping, Kowloon, Hong Kong
Xiong Jin, Wuhan, Hubei, P.R. China
Yeung Ka Yee, Anthea, Kowloon, Hong Kong
Yiu Ka Wah, Kowloon, Hong Kong
You Hongwen, Wuhan, Hubei, P.R. China

Qualified
Bennett, Martin C., Sherfield English, Hampshire
Berthault, Alexandra, London
Chan Kin Yuen, Wan Chai, Hong Kong
Chow Lai-Kwan, Kwinnie, Hong Kong
Filadelfeos, Eleni-Anna, Athens, Greece
Guzadhur, Carlos M.V., Dunstable, Bedfordshire
Ha Lai, Kowloon, Hong Kong
Heywood, Natalie L., Enfield, Middlesex
Hislop, Donna, London
Ho Lai Ho, Kowloon, Hong Kong
Ho Siu Ming, Hong Kong
Johnson, Lisa A., Kinver, Staffordshire
Kaffo, Moulero B., Hounslow, Middlesex
Kau Yuk Ming, Eddie, Hong Kong
Konstantopoulos, Konstantinos, Athens, Greece
Kwan Ka Lun, Karen, Hong Kong
Lam Wai Han, Kowloon, Hong Kong
Lee Sui Kam, Monita, New Territories, Hong Kong
Lee Wai-Kwok, Kowloon, Hong Kong
Lee Young Ji, Goyangshi, Kyunggido, South Korea
Lesetedi, Madichaba N., Billesley, West Midlands
Leung Sui Bong, Central, Hong Kong
Leung Yee Wai, Rosa, Kowloon, Hong Kong
Li Chi Wai, Kowloon, Hong Kong
Ng Yick Ling, Kowloon, Hong Kong
Paterson, Deborah L., Northampton
Prince, Ronald F., Richmond, London
Ren Lei, Beijing, P.R. China
Riley, Deborah M., Kowloon, Hong Kong
Shing Tsz Ki, Kowloon, Hong Kong
Szemencsuk, Galina, Goodmayes, Essex
Tuen Sai Hing, Hong Kong
Udeshi, Sheela, Stourbridge, West Midlands
Wat Wing Suet, Hong Kong
Yeung Ho Man, New Territories, Hong Kong

Continued from page 120

Dr Roger Harding and Vivian Watson were re-elected and Lawrence Hudson elected to the Council of Management.

Sally Everitt, Dr Jamie Nelson and Colin Winter were re-elected to the Members' Council.

Hazlems Fenton were re-appointed auditors.

The AGM was followed by an illustrated talk by David Callaghan entitled 'Jewellery of the Art Nouveau period'.

Membership

Between 1 December 2003 and 31 March 2004 the Council of Management approved the election to membership of the following:

Fellowship (FGA)

Choudhary, Gagan, Jaipur, India, 2002
Gaynor, David, Tyne and Wear, 1987
Holt, Jason Bruno Acker, London, 2002
Lam Koon-Wah, Francis, Kowloon, Hong Kong. 2003
Phyu, Thin Khine, Yangon, Myanmar, 2003
Vyas, Meenu, Jaipur, India, 2003

Diamond Membership (DGA)

Chaudhary, Mazafar, Ali, Upton Park, London, 2002
Sheikh, Mohammed, 2003
Spear, Paul M., Maidenhead, Berkshire, 2003

Associate Membership

Ahmed, Mohammed Salikh, Bradford, West Yorkshire
Ayabe, Hiroko, Nishinomiya City, Hyogo Pref., Japan
Brard, Jagvindersingh, Hatch End, Middlesex
Broglie, Nicole, London
Campbell, William, Monmouth
Chung, Geum-Lyul, South Korea
Clark, Katherine, Piccadilly, London
Curtis-Taylor, Tracey, London
Dillingham, Annabella Louise, Watford, Hertfordshire
Fullagar, Suzannah, London
Furuya, Satoshi, Bunkyo-ku, Tokyo, Japan
Gettleson, Anita R., Scottsdale, Arizona, U.S.A.
Hayashi, Kinya, Tokushima City, Tokushima Pref., Japan
Hill, David John, Morriston, Swansea, West Glamorgan
Jaipuria, Anuja, Stevenage, Hertfordshire
Johnson, David, Mitcham, Surrey
Kamo, Kenichi, Hirohata-ku, Himeji City, Japan
Kishimoto, Yoshiko, Nishinomiya City, Hyogo Pref., Japan
Lambert, Joyce, Wisbech, Cambridgeshire
Larsson, Jacqueline, London
Lu, Shan, Kofu City, Yamanashi Pref., Japan
Mera, Kanako, Toyonaka City, Osaka, Japan
Moreaux, Claudette, Court St Etienne, Belgium
Mori, Miyako, Yokohama City, Kanagawa Pref., Japan
Muratsu, Takamichi, Neyagawa City, Osaka, Japan
Natsuka, Masaki, Toyonaka City, Osaka, Japan
Newman, Ralph M., Tregaron, Dyfed
Ogata, Etsuko, Suita City, Osaka, Japan
Rae, Gillian, E., Reigate, Surrey
Ramerison, Tokinomena A., London
Rivers, Michael, London
Rolls, Shirley Ann, London
Rouse Huth, Dee, Carmichael, California, U.S.A.
Sakata, Yuko, Kanazawa City, Ishikawa Pref., Japan
Sàlerno, Pierre Stephane Landry, Luynes, France
Schwarzenberg, Al, River Ridge, Louisiana, U.S.A.
Segi, Naoko, Nagoya City, Aichi Pref., Japan
Shiralkar, Vinod, Wallasey, Merseyside
Singh, Gurmit, New Delhi, India
Skaraas, Sonia C., London
Tabar, Mahyar A., London
Takahata, Yoshichika, Takamatsu City, Japan
Tsutsui, Kazumi, London
Wessels, Jurie H.W., Roosendaal, The Netherlands
Whistance, Mary Margaret Nancy Tolladay, Exeter, Devon
Wiltshire, William E., London

Obituary

Kenneth W. Findlay FGA (D.1974), Randburg, South Africa, died on 19 January 2004.

Gem-A Website

For up-to-the-minute information on Gem-A events visit our website on www.gem-a.info

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KEMPTON PARK RACECOURSE
Sunbury-On-Thames, Middx (A308)
7 - 8 AUGUST

NEWTON ABBOT RACECOURSE
Newton Abbot, Devon
4 - 5 SEPTEMBER

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Forthcoming Events

30 April	**Midlands Branch:** Branch AGM followed by Bond Street jewellers of the 19th and 20th centuries. *Terry Davidson*

Scottish Branch Conference
30 April to 3 May – Lovat Hotel, Perth
Speakers:
John I.Koivula – Keynote speaker
Peter Buckie, Alan Hodgkinson, Elisabeth Strack, Colin Towler and Chris Walton

19 May	**North West Branch:** Diamonds. *Mark C. Barrows*
19 May	**North East Branch:** Organics, gems from life. *Maggie Campbell Pederson*

South East Branch Conference
28 to 31 May – Idar-Oberstein, Germany
Speakers:
David Lancaster, Bernd Munsteiner, Gerhard Becker and Julius Petsch

16 June	**North West Branch:** Some gemmological and lapidary diversions. *Doug Morgan*
26 June	**Midlands Branch:** Summer Supper Party.
26 July	**North East Branch:** Putting the 'Gee' back into gemmology. *Alan Hodgkinson*
14 September	**London:** Annual General Meeting.
15 September	**North West Branch:** Emeralds. *Alan Hodgkinson*
20 October	**North West Branch:** The trade industry today. *Marcus McCallum*
31 October	**Gem-A Annual Conference:** Kempton Park Racecourse
16 - 30 Nov	**Thailand Gem Jamboree:** Visit to Thailand. Further details from Doug Garrod on 020 7404 3334

contact details

When using e-mail, please give Gem-A as the subject:

London:	Mary Burland on 020 7404 3334; e-mail gagtl@btinternet.com
Midlands Branch:	Gwyn Green on 0121 445 5359; e-mail gwyn.green@usa.net
North East Branch:	Neil Rose on 0113 2070702; e-mail gema.northeast@gemro.com
North West Branch:	Deanna Brady 0151 648 4266
Scottish Branch:	Catriona McInnes on 0131 667 2199; e-mail scotgem@blueyonder.co.uk
South East Branch:	Colin Winter on 01372 360290; e-mail info@ga-seb.org
South West Branch:	Richard Slater on 01635 553572; e-mail rslater@dreweatt-neate.co.uk

Gem-A Website

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Guide to the preparation of typescripts for publication in *The Journal of Gemmology*

The Editor is glad to consider original articles shedding new light on subjects of gemmological interest for publication in *The Journal*. Articles are not normally accepted which have already been published elsewhere in English, and an article is accepted only on the understanding that (1) full information as to any previous publication (whether in English or another language) has been given, (2) it is not under consideration for publication elsewhere and (3) it will not be published elsewhere without the consent of the Editor.

Typescripts Two copies of all papers should be submitted on A4 paper (or USA equivalent) to the Editor. Typescripts should be double spaced with margins of at least 25 mm. They should be set out in the manner of recent issues of *The Journal* and in conformity with the information set out below. Papers may be of any length, but long papers of more than 10 000 words (unless capable of division into parts or of exceptional importance) are unlikely to be acceptable, whereas a short paper of 400-500 words may achieve early publication.

The abstract, references, notes, captions and tables should be typed double spaced on separate sheets.

Title page The title should be as brief as is consistent with clear indication of the content of the paper. It should be followed by the names (with initials) of the authors and by their addresses.

Abstract A short abstract of 50-100 words is required.

Key Words Up to six key words indicating the subject matter of the article should be supplied.

Headings In all headings only the first letter and proper names are capitalized.

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Transparencies, photographs and high quality printouts can also be submitted. It is recommended that authors retain copies of all illustrations because of the risk of loss or damage either during the printing process or in transit.

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Tables Must be typed double spaced, using few horizontal rules and no vertical rules. They are numbered consecutively with Roman numerals (Table IV, etc.). Titles should be concise, but as independently informative as possible. The approximate position of the Table in the text should be marked in the margin of the typescript.

Notes and References Authors may choose one of two systems:

(1) The Harvard system in which authors' names (no initials) and dates (and specific pages, only in the case of quotations) are given in the main body of the text, (e.g. Collins, 2001, 341). References are listed alphabetically at the end of the paper under the heading References.

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Cover Picture: *Faceted colourless oligoclase feldspar with red inclusions of hematite. (See Aventurescent oligoclase feldspar from Oregon, USA, pp 72-74.)*

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Gem corundum deposits in Vietnam

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Abstract: *Since 1983, gem-quality rubies have been recovered from the Luc Yen and Quy Chau mining areas in northern Vietnam. Since 1991, 'basaltic'-type blue-green-yellow ('BGY') sapphires have been mined in southern Vietnam. This article briefly reviews the history and geology of these different areas and shows the importance of marble and basalt-type deposits. Other types of corundum occurrences are found in amphibolite, pegmatite, gneiss and metasomatite. The gemmological, chemical and isotopic characteristics of these different types of corundum are described.*

The most notable features of rubies contained in marbles are that many crystals have blue colour zones, and inclusions of rutile, anhydrite and salts. The primary fluid inclusions are composed of carbon dioxide and hydrogen sulphide with native sulphur and diaspore daughter minerals. Sapphires from placers in basalts are characterized by inclusions of columbite, pyrochlore and baddeleyite. The trace element contents of corundums allow distinction of rubies in marbles from sapphires in basalts and metamorphic rocks. Rubies have high chromium ($0.54<Cr_2O_3<0.66$ wt.%) and low iron ($0.01<FeO<0.07$ wt.%) contents. The geological origin of Vietnam corundums can be clearly determined from the isotopic composition of their structural oxygen, i.e. $\delta^{18}O = 21.0 \pm 0.9‰$ for rubies in marbles and $\delta^{18}O = 6.6 \pm 0.4‰$ for sapphires in basalts.

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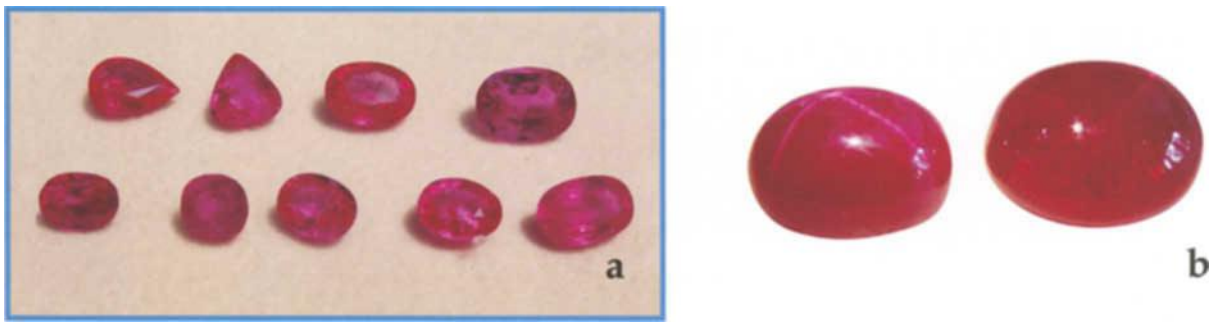

Figure 1: (a) Gem-quality rubies from the Quy Chau deposit in Vietnam. The samples range from 1.36 to 6.21 ct. (b) Two stars rubies from Tan Huong deposit (13.67 and 15.86 ct, respectively). Photographs by Pham Van Long.

Introduction

Gem corundums have been known in Vietnam since 1983. During the last ten years, Vietnam has become a significant ruby and sapphire-producing country in south-east Asia (*Figure 1*).

In this paper, the term ruby is used for Cr-bearing corundum including pink and purple coloured crystals.

Development of the gem industry is due to the important programme of geological field mapping maintained by the Vietnamese government. These geological investigations resulted in the first discovery of rubies in marbles and in the development of prospecting programmes leading to the discovery of corundum-bearing placer deposits. At the same time, thousands of local peasants searched for ruby and sapphire and in 1991, alluvial sapphires related to basalts were found in Southern Vietnam. Scientific investigations of the genesis of these deposits led to several publications (Kane *et al.*, 1991; Dao *et al.*, 1996; Dao and Delaigue 2000, 2001; Garnier *et al.*, 2002; Pham Van, 1999, 2002) and international workshops (Hofmeister *et al.*, 2001). The aim of this paper is to present a detailed review of the main types of gem corundum deposits in Vietnam within their geological framework. Their gemmological and mineralogical properties are compared with the intention of finding features which would allow one to identify Vietnamese corundums after removal from their geological environment.

Discovery of gem corundum in Vietnam

Rubies and sapphires have been found and mined in many places in Vietnam (*Figure 2*). Rubies and blue sapphires are now exploited in the northern part of the country, respectively

Figure 2: Map of Vietnam showing the location of basalt-hosted and other types of gem-corundum sources. There are more details of areas indicated in Figures 3 and 8.

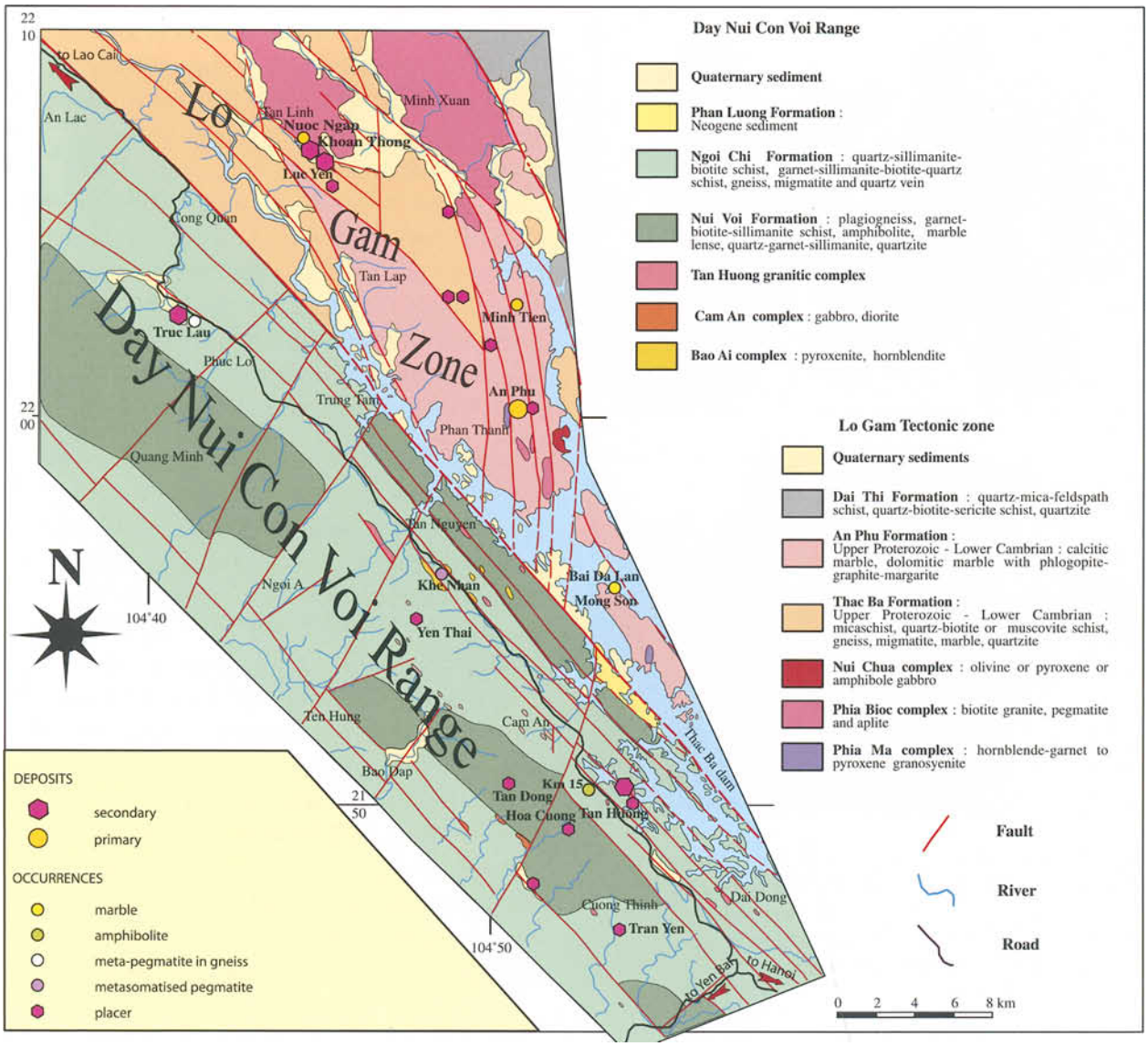

Figure 3: Geological map showing the major tectonic domains of the Red River shear zone with locations of the main corundum occurrences and deposits (adapted from Phan Trong and Hoáng Quang, 1997).

in the Yen Bai province from the Luc Yen and Yen Bai mining districts and in the Nghe An province from the Quy Chau deposits. In southern Vietnam, the corundums commonly include blue-green-yellow sapphires called 'BGY'-sapphires by Sutherland *et al.* (1998a), which are now exploited in the Dak Nong and Binh Thuan deposits in the Dak Lak and Lam Dong provinces respectively.

In 1983, ruby was discovered by a geologist during field mapping in the An Phu area (Luc Yen district), 270 km north of Hanoi (*Figure 3*). This corundum occurrence was investigated in detail and mining started in 1987. In March 1988, Vinagemco (Vietnam gemstones company) was set up by the Vietnamese Government to control the mining activity. In the same year, Vinagemco and Boonsing-Hang Mining Company from Thailand established a joint-venture with the aim of mining the Khoan Thong placer (*Figure 3*). From November 1989 to March 1990, the company recovered about 244 kg of gem-quality corundums. Almost all the production was cut and traded in Bangkok.

From 1990 to 1994, thousands of independent miners swarmed over the area and some new gem-quality corundum occurrences were found in places such as Minh Tien, Nuoc Ngap, Hin Om, Khau

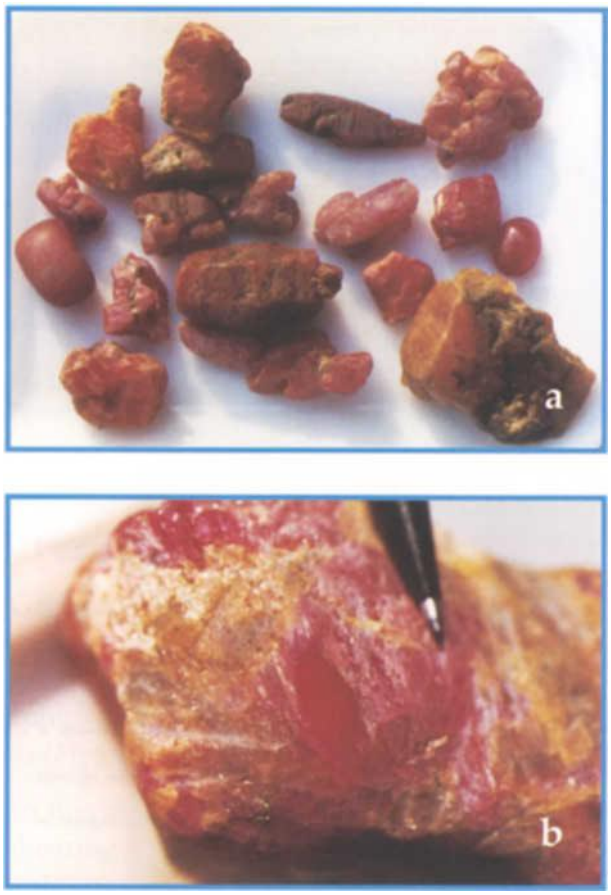

Figure 4: (a) Tan Huong ruby rough and one cabochon cut from ruby found in the Tan Huong placer located on the Day Nui Con Voi metamorphic range (northern Vietnam). (b) Ruby boulder from Tan Huong placer mine. Photographed in 1998 by Gaston Giuliani.

Nghiem, Vang Sao, May Thuong and May Ha (*Figure 3*). At the same time rubies, sapphires and other minerals already sorted in placers were found, and with corundum crystals from the marbles, were brought to the gemstone market in Luc Yen.

Between 1994 and 1995, rubies were discovered in the Tan Huong and Truc Lau areas (*Figure 3*). These two mines are now directly managed by the Yen Bai Gem and Gold Company. Boulders of corundum up to 1 kg with zones of gem quality ruby are common in these placers (*Figure 4a, b*). In April 1997, two huge ruby crystals were found in the placer of Tan Huong with weights respectively of 2.58 and 1.96 kg. These two stones of very high quality have been declared State treasure and can be displayed but not sold.

The Quy Chau mining district is located about 120 km north-west of the city of Vinh (Nghe An Province), about 300 km south of Hanoi (*Figure 2*). In 1988, rubies and blue sapphires were discovered in concentrates from alluvial deposits. Between 1989 and 1990, 10,000 miners migrated to the region from all over Vietnam. The illegal mining activities were outside the control of the Nghe An People's Committee and hundreds of people died when, in July 1990, there was a collapse in the Ho Ty mine (Billion hill mine, *Figure 5a*).

In addition to the monthly auctions of the rubies held by the provincial government, thousands of carats of rough rubies of high gem-quality have been sold to Thai traders. In an auction in 1996, a 56 ct rough ruby was sold for US $562,000. In 1996, the management of the Quy Chau deposits was taken over by the Nghe An Gem and Gold Company. Since then, hundreds of kg of rubies have been recovered. Production was first displayed for auction on September 15, 2001, and since July 2002, weekly auctions have been held at the head office in Hanoi of the Vietnam National Gem and Gold Corporation (which organized the sale of gems mined by the Nghe An Gem and Gold Company).

Since 1991, 'BGY' sapphires have been found in many places in southern Vietnam. The first discovery occurred in Dak Nong (Dak Lak province) and the second in Di Linh (Lam Dong province). Very dark blue sapphires have been found also in Ham Thuan (Binh Thuan province). These sapphires range from transparent to translucent or opaque, but the percentage of transparent gem quality material has been very low. From 1992 to 1995, the mine was exploited by local peasants and hundreds of kg of sapphires were illegally mined and sold. In 1996, the Tay Nguyen Gem and Gold Company was created to manage the mining of the deposits. The company carried out a detailed investigation and the mine opened in 1997. Although thousands of kilograms of sapphires were mined, they were mostly of very low gem quality and the mining activities in Tay Nguyen ceased finally in 2000.

Figure 5: The Quy Chau mining area. (a) View of the famous Billion hill mine which became a lake after the end of its exploitation in July 1990. (b) The Doi San placer in 1998. (c) View of the new dressing plant in October 2001. (d) The ruby-free skarn in Quy Chau consisting of alternating bands of green calc-silicates and brown to black phlogopite in marble.

Materials and methods

The corundums used for this study were purchased by the authors during different field seasons at the mine sites and consist of faceted and rough rubies and sapphires. Optical properties of the samples were obtained by standard gemmological methods. Internal features were examined with a gemmological microscope, a Hitachi 2500 scanning electron microprobe (SEM) and the inclusion compositions obtained by energy-dispersive spectrometry (EDS). Rubies and sapphires from different geological environments and covering the full colour range of the samples were analysed by a CAMECA Camebax SX 50 electron microprobe with wavelength-dispersive spectrometers (WDS). The operating conditions of the electron microprobe were: an accelerating voltage of 10 kV, beam current of 10 nA, collection time of 10 s for major elements, and 20 kV, 100 nA, 30 s respectively for trace elements. The 'BGY' sapphires were also analysed by a semi-quantitative EDXRF method using a spectrace 5000 EDXRF system (Stern, 1984). The compositions of selected fluid inclusions and solid inclusions were obtained using a Labram Jobin-Yvon Raman micro-spectrometer. The excitation radiation was the 514.5 nm line of an Ar-ion laser (2020 Spectra-physics) that delivered 10-20 mW at the sample surface. The oxygen isotopic composition of rubies and sapphires was analysed following a modification of the laser-fluorination technique described by Sharp (1990).

Gem corundum deposits

Two main types of gem-corundum deposits are found in Vietnam: rubies and sapphires in metamorphic rocks (northern Vietnam) and 'BGY'-sapphires in basalts (southern Vietnam).

Corundum in northern Vietnam

The Yen Bai and Luc Yen mining districts

1. The primary corundum occurrences of Yen Bai occur within the high-grade metamorphic gneisses forming the Day Nui Con Voi range (*Figure 3*), which extends to the southeast from the Ailao Shan in Yunnan (China). This range is bounded by lateral strike-slip faults forming the major Cenozoic geological discontinuity in East Asia known as the Ailao Shan-Red River shear zone.

The Day Nui Con Voi range is composed of high-grade metamorphic rocks with sillimanite-biotite-garnet gneisses, mica schists with local successions of marbles and amphibolites. The deformation occurred under amphibolite facies conditions (pressure = 4-6.5 kbar and temperature = 600-750°C, Phan Trong *et al.*, 1998; Leloup *et al.*, 2001). Corundum occurs (A) as grey to blue sapphires in garnet-sillimanite-mica schists and gneisses containing leucosome and leucocratic granitoid dykes (Truc Lau gneisses and Khe Nhan metapegmatite); (B) in amphibolites transformed by metasomatism into biotite schists with some layers containing centimetre-sized grey to dark-grey sapphires (north of Tan Huong mine, Km 15 occurrence; *Figure 3*); (C) as rubies in large marble boudins intergrown with

Figure 6: (a) Partial view of the Khoan Thong placer worked from 1989 to 1996 in the Luc Yen area. In the middle distance are karst hills showing the classical karst erosion patterns of marbles. (b) Part of the washing plant at the Tan Huong mine. (c) The primary Bai Da Lan ruby deposit hosted in marbles viewed from the Thac Ba dam. (d) Typical fresh section of banded marbles characterized by alternating bands of white and dark marble consisting of carbonates, phlogopite and graphite. All photographs by G. Giuliani in 1998.

Figure 7: Mineral features of gem corundum deposits in the Luc Yen mining district. (a) Ruby in a marble from the Min Thien mine. Calcite and phlogopite mica (dark brown) are the gangue minerals in the language of mining. Size of the corundum up to 1.5 cm. (b) Rubies at the gem market in Luc Yen town. These and rough crystals of coloured sapphires have been recovered from placers. The biggest crystal is around 4 cm long. (c) A 3 cm long crystal of ruby from Luc Yen associated with flakes of graphite (black) in a white marble. (d) Red spinel and green amphibole (pargasite) in marble from the primary An Phu ruby deposit. (e) A bipyramidal corundum from the gem market of Luc Yen. Photographs by G. Giuliani.

gneiss, mica schist and amphibole (Tan Huong drill cores). These marbles represent previous limestones interleaved with mudstones, which were sheared and metamorphosed during the tectonic activity along the Red River shear zone.

The gems occur in placer deposits along the shear zone such as at Tan Huong (*Figure 6b*) and Truc Lau. The paleoplacer of Truc Lau consists of 10 m of sediments overlying bedrock. The rubies and blue sapphires are contained in a gravel layer, 5 m thick, overlain by 3.5 m of Quaternary sediments and 1-1.5 m of soil. In 2002, up to two boulders (1-2 kg) of ruby were recovered every month in the paleoplacer. In the Tan Dong placer, assemblages of blue sapphire-margarite-plagioclase are the remnants of metasomatized pegmatites. Blue trapiche-like sapphires are found together with rubies and grey to pale blue sapphires in the placers of the Yen Bai area.

2. The ruby and sapphire deposits of Luc Yen occur in moderate-to-high temperature recrystallized marble units of Upper Proterozoic-Lower Cambrian age in the eastern side of the Red River shear zone: the Lo Gam zone (*Figure 3*). Primary ruby occurs (A) as crystals disseminated within marbles (*Figure 7c*) with phlogopite (*Figure 7a*), dravite, margarite, pyrite, rutile, spinel, edenite, pargasite (*Figure 7d*) and graphite (Bai Da Lan, An Phu, Minh Tien, Nuoc Ngap, Luc Yen and Khoan Thong mines); (B) in veinlets associated with calcite, dravite, pyrite, margarite and phlogopite (An Phu mine); (C) in fissures with graphite, pyrite, phlogopite and margarite (Bai Da Lan mine, *Figure 6c*; Minh Tien region, *Figure 6d*). Gravels form placer deposits in karst topography (*Figure 6a*) and in alluvial fans in the Luc Yen valleys with blue, pale yellow and colourless sapphires, rubies and trapiche rubies (*Figure 7b*), and bipyramidal grey to brown sapphires (*Figure 7e*).

The Bâ Be sapphire occurrence

The Bâ Be sapphire occurrence is located in the Bac Kan province, 320 km north of Hanoi (*Figure 3*). It is close to the granite of Nui Chua and the gabbro-monzonite of Hoang Tri. The colourless to pale blue sapphire occurs in a pegmatite composed of quartz, K-feldspar and muscovite which intrudes schists and marbles.

The Quy Chau mining district

In this area, located 200 km south of the Red River shear zone, the Bu Khang dome (*Figure 8*) consists of a broad antiform of Paleozoic and Mesozoic sedimentary and meta-sedimentary rocks overlying a core of mica schists, granitoid rocks, paragneisses and orthogneisses (Jolivet *et al.*, 1999). The north-eastern part of the dome is limited by the major extensional Cenozoic shear zone of Quy Chau where the corundum deposits are located.

Rubies and blue sapphires have been mined since 1987 in the placer deposits of Doi Ty, Doi San, Mo Coi and Quy Hop (*Figure 8*). The corundums occur mainly in the Quy Chau area (A) as very rare (and non-economic) rubies disseminated in marbles associated with pyrite and graphite, and (B) in placers which form the economic deposits (*Figures 5a, b, c*). In the Doi San and Doi Ty area, granitic intrusions linked with the injection of pegmatites are responsible for calcium-magnesium-rich skarns in the surrounding marbles, amphibolites, gneisses and mica schists (*Figure 5d*). Ruby has not been found in either the skarn or the pegmatite and its genesis remains unclear. Blue sapphire is very rare.

Corundum in southern Vietnam

In the Dak Nong area, sapphires are found in weathered residual soils lying above alkali basalt flows and also in placer deposits in the river and stream fans (*Figure 9a*). Generally, the alluvial corundums resemble megacrysts found *in situ* in the basalts, but in Dak Nong, 'BGY'-sapphires have not been found in the host rocks. Their colours range from dark blue, through blue, green to yellow and some are colourless. The crystals occur as broken fragments but remains of the original habits are often present. Prisms and bipyramidal crystals may be up to 15 mm long and 2-4 mm wide.

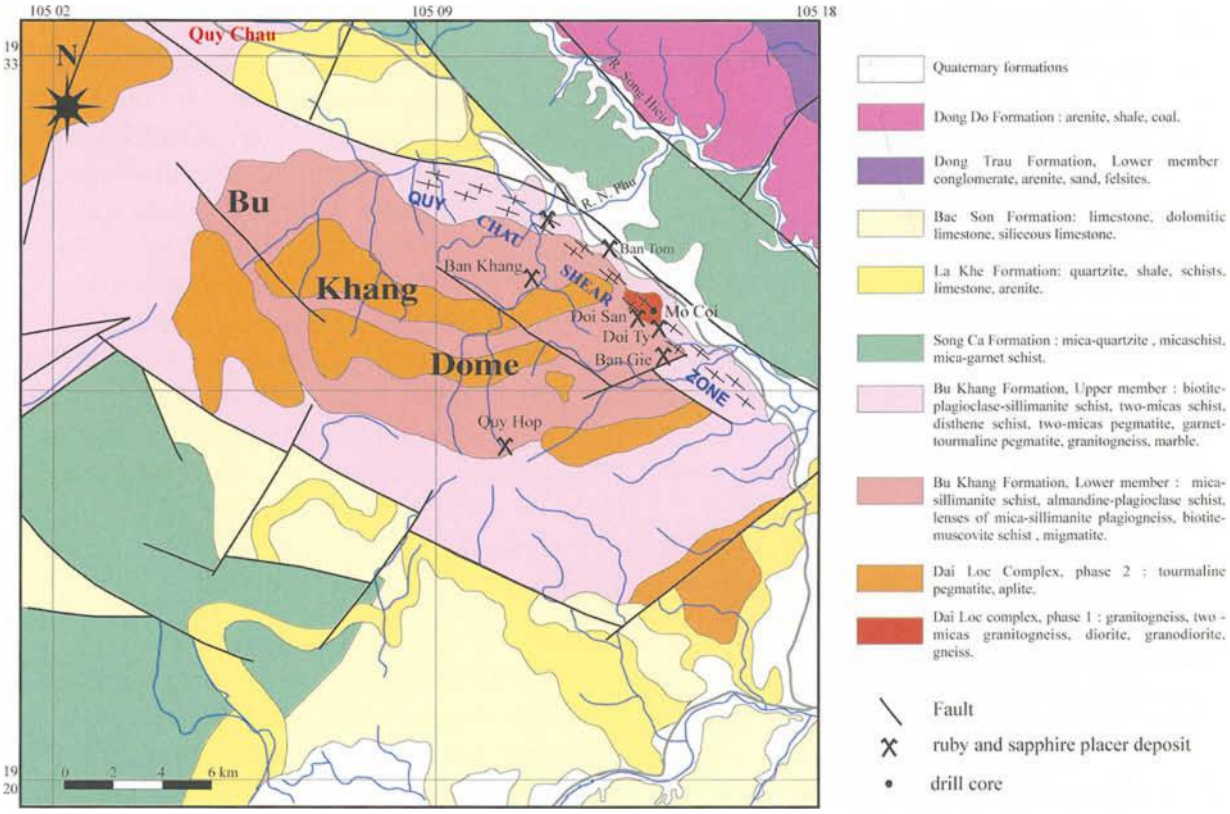

Figure 8: Geological map of the Bu Khang dome showing the location of the ruby and sapphire deposits of the Quy Chau and Quy Hop mining districts (map modified after Jolivet et al.*, 1999).*

Figure 9: The 'BGY'-sapphire deposits related to basalts in southern Vietnam. (a) View in 2001 of the Dak Nong placer deposit located in alluvial fans. (b) Corundum crystal found in alluvial soils above a basalt. (c) Alluvial corundum from the Bin Thuan area showing reflective surface attributed to high temperature corrosion which is indirect evidence of magma transport (small dots on the crystal surface). (d) Barrel-shaped habit of a deep-blue sapphire originating from the Binh Thuan area. Photographs by G. Giuliani.

In the Binh Thuan area, the sapphires have barrel-shaped habits (*Figures 9b, d*), and are blue to very dark blue. Some crystals show rounded glassy-looking margins indicating high-temperature corrosion, indirect evidence of transport in a magma (*Figure 9c*). In the Da Ban area (Binh Thuan province) megacrysts of dark-blue sapphires are sometimes found within alkali-basalts.

Gemmological properties

Optical characteristics

Colour: Corundums from the Quy Chau deposits range from moderate to high saturations of purplish red to purplish pink for ruby to blue for sapphire. In contrast, the corundums from the Yen Bai and Luc Yen deposits show all tones from red to pink (ruby), and grey to blue and colourless to pale yellow sapphire. The rubies from Luc Yen are usually less saturated than those from Quy Chau.

Corundum from southern Vietnam is commonly dark blue or greenish-blue and less commonly yellowish-blue. A small proportion of the corundums from the Binh Thuan deposit possess a very dark tone and yield deep blue cut stones.

Refractive index (RI): The RIs of rubies and sapphires were obtained in the Centre for Gem and Gold Research and Identification (VCCG) using a Gem Duplex II instrument and all results were in the range 1.762 to 1.770, birefringence 0.008, which are normal for corundum.

Specific gravity (SG): SGs were determined by the hydrostatic weighing method. The samples from Quy Chau (faceted and rough stones) gave values between 3.94 and 4.05; those from Luc Yen have values between 3.92 and 4.01. In both deposits, the SGs of the blue sapphires tend to be higher than those of red and pink rubies. Compared to the rubies and sapphires from Luc Yen and Quy Chau, most 'BGY'-sapphires from southern Vietnam gave SG values between 3.97 and 4.00 but some had SGs up to 4.08, which are exceptionally high for corundum.

UV luminescence: All the red and pink samples from Quy Chau and Luc Yen appeared red when exposed both to long-wave (366 nm) and short-wave (254 nm) ultraviolet radiation. The Quy Chau crystals tended to show stronger fluorescence than those from Luc Yen. Interestingly, some blue sapphires from Luc Yen (Khoan Thong area) also appeared red under both long- and short-wave ultraviolet radiation.

Internal characteristics

Twinning: The samples from Quy Chau and Luc Yen commonly show both lamellar and polysynthetic twinning.

Growth features: Straight and angular parallel growth features are quite common in rubies and sapphires from Luc Yen and Quy Chau. Other investigations (Kane *et al.*, 1991) have described a swirl-like growth effect that is common in Burmese rubies and coloured sapphires from Vietnam.

Colour zoning: Some samples in this study show colour zoning. The colour zones range in size from narrow to broad areas generally parallel to the largest flat face of the sample. In many samples, dot-like and band-like colour zones are present. These are easily seen by immersion in methylene iodide, and even a blue zone can be distinguished against a background of red and pink zones.

The sapphires from southern Vietnam usually show alternation of colour bands indicating consecutive growth layers of light blue, colourless, greenish-blue or yellowish-blue.

Solid inclusions: The different solid inclusions identified in Vietnamese corundums are listed in *Table I*. The most common mineral inclusions found in the Luc Yen and Quy Chau rubies are calcite, dolomite, rutile, diaspore and phlogopite. These minerals are also found in the marbles. SEM studies also confirmed the common occurrences of crystals of anhydrite and other salts (of Na-Cl; Ca-Cl; K-Cl).
In contrast to the sapphires originating from basalts, rubies do not contain any columbite, ilmenite, pyrochlore or baddeleyite inclusions. In rubies, rutile is characteristically present as short needles and also as twinned plate-like crystals; less commonly, it appears as transparent orange brown or opaque crystals trapped along the growth zones. Zircons are found in corundums from both types of deposit and they have allowed indirect dating by the U/Pb method. The calculated ages of corundum formation are between 38 and 34 Ma for the Luc Yen and 34 to 27 Ma for the Quy Chau ruby deposits (Garnier *et al.*, 2002), and 6 to 1 Ma for the Dak Nong sapphires (Garnier *et al.*, 2004).

Fluid inclusions: Three main types of fluid inclusions were recognized in the rubies from Luc Yen and Quy Chau on the basis of their relative chronology (Hoàng Quang *et al.*, 1999; Giuliani *et al.*, 2003 a, b).

1. Type A fluid inclusions (primary) are 20 to 200 µm long and occur as isolated or oriented clusters from the core to the rim of the crystals (*Figures 10a, b*); they are best observed in longitudinal sections. Type A inclusions are commonly two-phase fluids (liquid and vapour carbon dioxide phases) but some are associated in a single growth zone with single phase carbon dioxide-rich inclusions. The volumetric fraction of the carbon dioxide-rich liquid in the carbon dioxide-rich phase shows degrees of filling (Flc) ranging between 60 and 100% (*Table II*).

   These inclusions display two kinds of morphology: (i) euhedral negative crystals with polygonal or square outlines found in planes parallel to the basal pinacoid *c* (0001); (ii) flat or broad tubes, some with a cap of a mineral inclusion. Diaspore is found either

Table I: Solid inclusions identified in Luc Yen and Quy Chau rubies from marbles and in sapphires from basaltic deposits.

Solid Inclusions	Luc Yen rubies	Quy Chau rubies	Basaltic sapphires
Anatase	2	2	
Andalusite		1	
Anhydrite	8	8	
Anorthite		1	
Apatite	6	6	1
Baddeleyite			1
Boehmite	6	6	
Brookite	2	2	
Calcite	6	6	
Columbite			5
Corundum	2	2	
Diaspore	2	2	
Dolomite	4	4	
Goethite			5
Graphite	2	2	
Halite	8	8	
Hematite	2		
Hercynite	2		
Ilmenite			5
Limonite	7	7	
Margarite	4	4	5
Monazite	7		
Muscovite	2	2	
Nepheline	7	7	
Nostrandite	6		
Phlogopite	6	6	
Plagioclase			5
Pyrite	4	4	
Pyrochlore			5
Pyrrhotite	6		
Rutile	6	8	
Titanite	7	7	
Na, Ca, K-Cl salts	8	8	
Spinel	1	1	
Tourmaline	2		
Zircon	2	2	1
Zoisite		2	

1: this study; 2: Pham Van (1999); 3: Pham Van (2002); 4: Hoang Quang *et al.* (1999); 5: Smith *et al.* (1995); 6: Kane *et al.* (1991); 7: Dao *et al.* (1996); Dao and Delaigue (2000, 2001); 8: Giuliani *et al.*, (2003 a, b)

2. Type B fluid inclusions (pseudo-secondary). These appear as small clusters or isolated in crystals and are mainly related to small intra-granular fractures. Planes of fluid inclusions are related to micro-cracks and subsequent fractures healed during crystal growth. At room temperature, Type B inclusions are single or two-phase (liquid and vapour carbon dioxide phases) with degree of filling (Flc) between 40 and 100%. Inclusions may range in size from 20 to 125 µm and display various shapes resembling negative crystals. Some of the negative crystals are capped by mineral inclusions (mainly calcite) at one end and contain calcite, rutile and daughter crystals of diaspore and native sulphur - all identified using Raman spectrometry.

3. Type C fluid inclusions (secondary). These occur along healed fracture planes which cross-cut several growth zones and show an elongated (*Figure 10a*) or rounded-morphology. Some inclusions are irregularly or crescent-shaped and they are interpreted as products of textural equilibration.

Figure 10: Photomicrographs of fluid inclusions in ruby from the Luc Yen area. (a) Isolated primary fluid inclusion (labelled I), 100 µm long, containing a liquid phase composed of CO_2, H_2S and COS. Trail of secondary inclusions (labelled II) crosscutting the ruby crystal. (b) Primary two-phase fluid carbonic inclusion containing a liquid (L) and vapour (V). The size of the inclusion is 80 µm long. Crossed nicols. Photographs by G. Giuliani.

as very rare solid inclusions present in fractures or as isolated prismatic crystals with a length up to 15 µm. Also, diaspore occurs in the fluid inclusion cavities as an invisible film, 2-3 µm thick, coating the wall of the whole inclusion cavity. The film was identified from its Raman lines at 331 and 448 cm^{-1}, respectively (*Figure 11*). Native sulphur is present at room temperature, as very rare vitreous globules in the inclusions but it is commonly nucleated from an invisible thin layer during laser irradiation. S_8 was identified from its characteristic Raman peaks at 220 and 462 cm^{-1} (*Figure 11*).

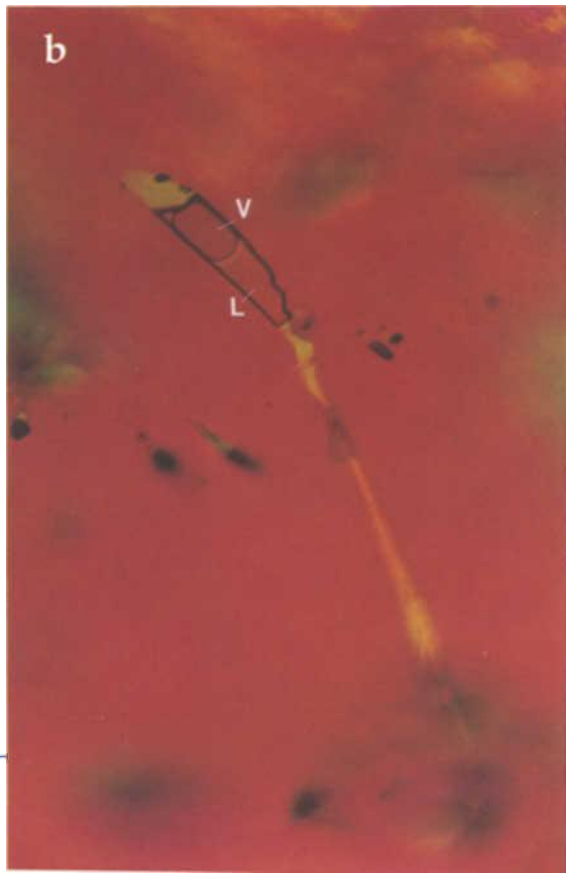

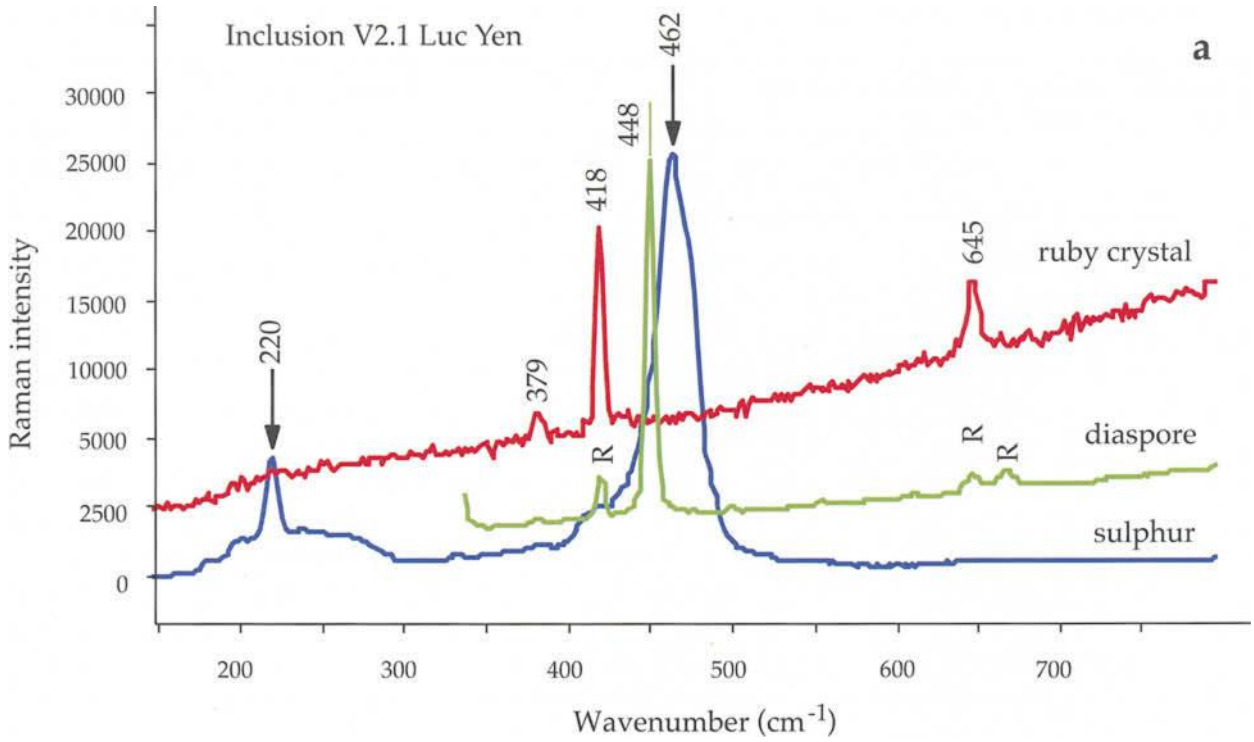

Figure 11: Raman spectra of the different phases analysed in fluid inclusion cavities in ruby. (a) Diaspore and amorphous sulphur detected in the same fluid inclusion (Luc Yen sample). The peaks of sulphur are obtained during irradiation of the liquid phase. The diaspore spectrum was obtained from the invisible diaspore film, 2-3 µm thick, which coats the wall of the fluid inclusions cavity. (b) Raman spectra of the volatile phase found in a primary fluid inclusion in a Quy Chau ruby. The components are CO_2, H_2S, COS, S_8 and diaspore as found for the fluid inclusions in Luc Yen rubies. R denotes peaks due to the ruby matrix.

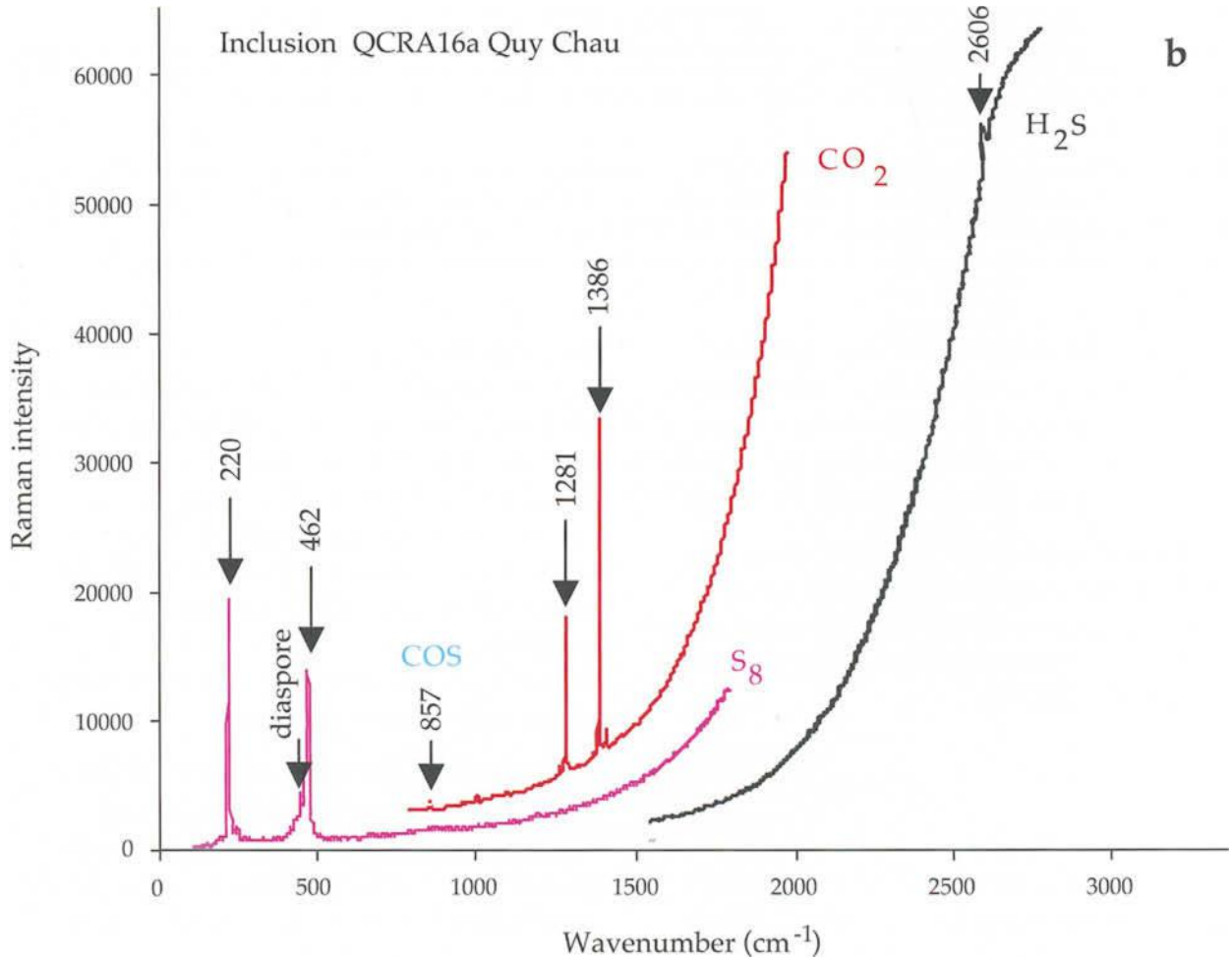

Table II: Microthermometric and Raman data for fluid inclusions in rubies from Luc Yen and Quy Chau.

Inclusion type	Sample number	Microthermometry			Raman data							
		Flc	$TmCO_2$	$ThCO_2$	CO_2	H_2S	COS	native sulphur	diaspore	rutile	dolomite	calcite
Luc Yen ruby mines												
A	V.5.1	100	-61.3	16.5L	87.9	12.1	+	+				
A	V.5.1.1	100	-61.8	15.1L	90.4	9.6		+	+			
C	V.5.2	100	-61.0	13.9L	91.2	8.8	+	+	+			
A	V.1.1	100	-60.1	22.4L	93.8	6.2	+	+	+			
C	V.1.2	75	-59.7	29.3L	92.0	8.0	+	+				
A	V.1.4	90	-60.2	23.5L	93.3	6.7	+	+				
A	V.2.1	65	-62.0	33.9L	86.5	13.5	+	+	+			
B	V.3.2	100	-57.8	22.8L	+	+						
B	V.4.1	40	-62.6	28.8V	+	+		+	+			
A	LY399B-10	40	-64.3	36.4L	76.8	23.2	+	+	+		+	
A	LY399A2	80	-63.7	26.7L	84.7	15.3	+		+	+		
A	LY399B-1	90	-65.0	31.8L	87.0	13.0	+	+	+			+
An Phu ruby mine												
C	V.6.2	85	-59.9	28.5L	96.1	3.9	+	+	+			
Knoan Thong ruby mine												
A	K.1.1	90	-59.9	30.9L	96.7	3.3	+					
Quy Chau ruby mine												
A	QCRA16a	70	-64.7	30.5L	88.5	11.5	+	+	+			
A	QCR2A-11a	60	-65.2	20.8L	85.5	14.5	+	+		+		
A	QCR2A-11b	60	-63.7	34.0L	90.9	9.1		+				
A	QCRB-2.1	80	-66.7	34.9L	90.8	9.2	+	+	+			

NB: Inclusion types A, B and C see text. Microthermometry Flc: volumetric fraction of CO_2 rich liquid in carbon-dioxide-rich phase. $TmCO_2$: melting temperature of CO_2 in °C. $ThCO_2$: homogenization temperature of CO_2: V vapour, L liquid.

Raman data compositions of CO_2 and H_2S in mol.%; + means presence detected. The mole fraction of each gas was calculated from the formula given by Dhamelincourt *et al.* (1979); the relative cross sections of Raman scattering are those given by Schrötter and Klöckner (1979), i.e. CO_2 = 1.5 and H_2S = 6.4.

Their size ranges from 10 to 100 µm. At room temperature, they contain one or two-phases and the volumetric fraction of the carbon dioxide-rich liquid in the carbon dioxide-rich phase is between 35 and 100%.

Raman analyses of the three types of fluid inclusion revealed that the carbon dioxide phase is always composed of major CO_2, with smaller amounts of H_2S and COS (*Figure 11, Table II*).

Geochemical properties

Chemical composition

Chemical analyses of 128 corundums from Vietnamese primary and secondary occurrences are shown in *Table III*. The correlation diagram of (Cr_2O_3/Ga_2O_3) vs (Fe_2O_3/TiO_2) for corundums from the primary deposits from northern Vietnam is shown in *Figure 12*. This shows a clear separation of rubies in marbles from the coloured sapphires in gneiss, amphibolite and (meta-) pegmatite, with the one exception of the sapphires from the Khe Nhan pegmatite which fall within the field of the ruby-hosted marbles.

Corundums from the secondary deposits (placers) have clear chemical signatures. All the rubies and 'trapiche' rubies found in placers from northern Vietnam fall within the population field defined by marble-hosted

ruby. All the 'BGY' and colourless sapphires originating from Southern Vietnam and linked to placers in basalts define another distinct population (basaltic field) which is characterized by its very low chromium and gallium and high iron contents.

Chemical analyses obtained by the EDXRF method show that Dak Nong sapphires have higher gallium contents (0.03 to 0.045 wt%) and a wider range of Fe_2O_3 (0.65 to 2.4 wt%) than the other types of sapphire from basaltic areas in southern Vietnam, especially from Lam Dong Province (*Figure 13*). The chemical ratio Cr_2O_3/Ga_2O_3 vs Fe_2O_3/TiO_2 of the sapphires match values recorded for 'basaltic' corundums by Sutherland *et al.* (1998a). Nevertheless, the wide variation of gallium content in the Dak Nong sapphires results in a correspondingly wide geochemical field (*Figure 12*).

The blue and colourless sapphires from Luc Yen and the blue (including the trapiche-like) sapphires from Yen Bai occupy a common field which partly overlaps the marble domain. Their field is defined by an Fe_2O_3/TiO_2 ratio around 1 and low concentrations of Cr_2O_3 and Ga_2O_3. Although these sapphires were not observed in their parental rocks, they do not appear to originate

Table III: Electron microprobe analyses of rubies and sapphires from Vietnam.

Corundum from placers	Northern Vietnam						Southern Vietnam					
	Quy Chau		Luc Yen				Dak Nong				Binh Thuan	
Wt%	ruby	σ (n=40)	ruby	σ (n=4)	colourless sapphires	σ (n=16)	blue sapphire	σ (n=14)	green sapphire	σ (n=11)	black sapphire	σ (n=6)
TiO_2	0.03	0.03	0.01	0.00	0.13	0.17	0.04	0.05	0.02	0.01	0.04	0.04
Al_2O_3	99.28	0.72	99.76	0.84	99.81	0.46	99.14	0.74	99.11	0.47	98.14	0.24
Cr_2O_3	0.58	0.55	0.54	0.45	0.02	0.01	0.00	0.00	0.01	0.01	0.00	0.00
Fe_2O_3	0.07	0.07	0.01	0.00	0.15	0.16	1.35	0.34	1.19	0.39	1.86	0.19
V_2O_3	0.02	0.05	0.07	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ga_2O_3	0.01	0.00	0.01	0.02	0.01	0.00	0.03	0.01	0.03	0.00	0.03	0.00
MgO	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.01	0.01
Total	99.99	0.56	100.40	0.63	100.13	0.41	100.56	0.74	100.36	0.47	100.08	0.11

Corundum from primary deposits	Luc Yen		Yen Bai						Ba Be	
	Luc Yen marble		Tan Dong metapegmatite		Tan Hung amphibolite		Truc Lau pegmatite		Ba Be pegmatite	
Wt %	ruby	σ (n=29)	blue sapphire	σ (n=8)	blue sapphire	σ (n=7)	blue sapphire	σ (n=8)	blue sapphire	σ (n=4)
TiO_2	0.02	0.01	0.19	0.18	0.00	0.00	0.01	0.00	0.00	0.00
Al_2O_3	99.42	0.64	99.31	0.71	99.04	0.48	99.19	0.43	99.90	0.27
Cr_2O_3	0.37	0.58	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00
Fe_2O_3	0.02	0.01	0.67	0.15	0.94	0.07	1.31	0.06	0.44	0.01
V_2O_3	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ga_2O_3	0.01	0.01	0.03	0.00	0.01	0.00	0.02	0.00	0.02	0.00
MgO	0.02	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	99.87	0.40	100.21	0.72	100.01	0.47	100.53	0.46	100.36	0.27

NB: Zinc was also sought but below detection except for 0.02% ZnO in ruby from Luc Yen marble

σ = one standard deviation; n = number of analyses.

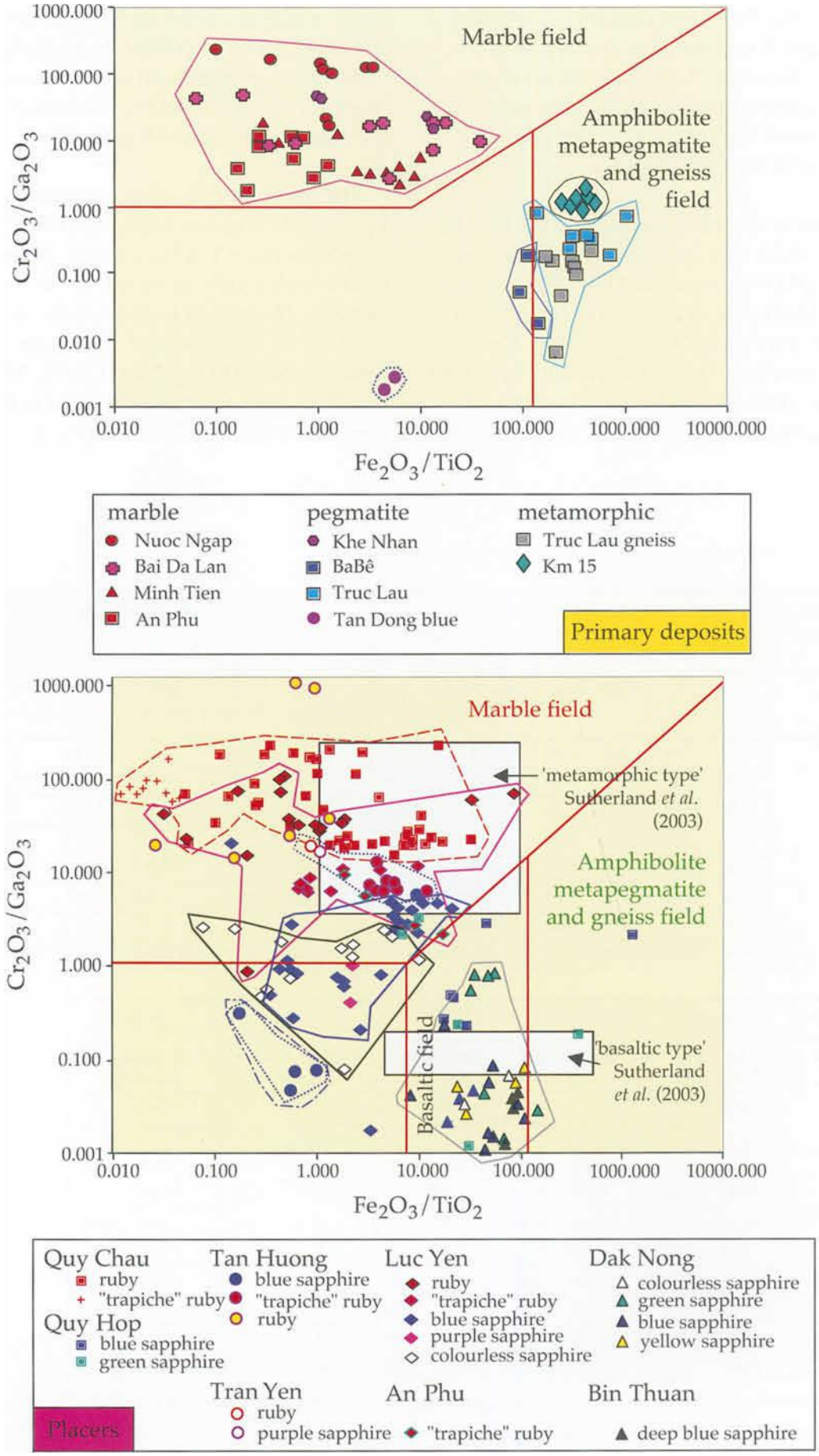

Figure 12: Correlation diagram of Cr_2O_3/Ga_2O_3 versus Fe_2O_3/TiO_2 for corundums from primary and secondary deposits in Vietnam. The fields of the metamorphic and basaltic types defined by Sutherland et al. *(1998a, 2003) for the Eastern Australian and South East Asian corundums are shown for comparison.*

from marbles, gneiss, amphibolite or pegmatite. Their origin is unclear but the presence of the primary Tan Dong blue sapphire in the same field could indicate that some of these blue sapphires could be related to metasomatic alteration of pegmatites or other metamorphic rocks (hydrothermal field?).

The Tran Yen rubies originated probably from marbles; but different Quy Hop sapphires from placers in the Bu Khang dome plot in the basaltic, gneiss, amphibolite and metapegmatite fields and could come from a range of sources.

Oxygen isotope geochemistry

The rubies from Luc Yen have oxygen isotopic compositions ($\delta^{18}O$, in ‰ versus SMOW) between 19.3 and 22.4‰ (average $\delta^{18}O = 21.0 \pm 0.9$‰, 8 samples) and are in the same range as those from Quy Chau (average $\delta^{18}O = 22.2 \pm 0.05$‰, 3 samples). The oxygen values of the rubies fall within the oxygen isotopic range defined for marbles from Luc Yen and Quy Chau. Thus, the isotopic composition of ruby is apparently buffered by the host rock (Giuliani *et al.*, 2003b). In contrast, the oxygen isotopic compositions of the Dak Nong sapphires are quite different from the rubies whatever their colour may be (*Figure 13*). The oxygen isotopic compositions are between 6 and 6.9‰ (average $\delta^{18}O = 6.6 \pm 0.4$‰, n=5) and are outside the range of the associated alkali basalts ($4.9 < \delta^{18}O < 5.7$‰), but within the range of syenitic rocks (Garnier *et al.*, 2004).

Conclusions

Corundum is found in Vietnam in a number of different geological environments; these include amphibolite, gneiss, marble, basalt, pegmatite and metasomatized pegmatite. Of these, only two types of deposits are economically viable for gem production: marbles mined since 1983 in the Luc Yen, Yen Bai and Quy Chau districts, and basalts mined since 1991 in the Dak Lak, Lam Dong and Binh Thuan provinces. The appearance and characteristic features of the rubies and coloured sapphires from the Vietnamese gem deposits are generally related to their respective geological environments.

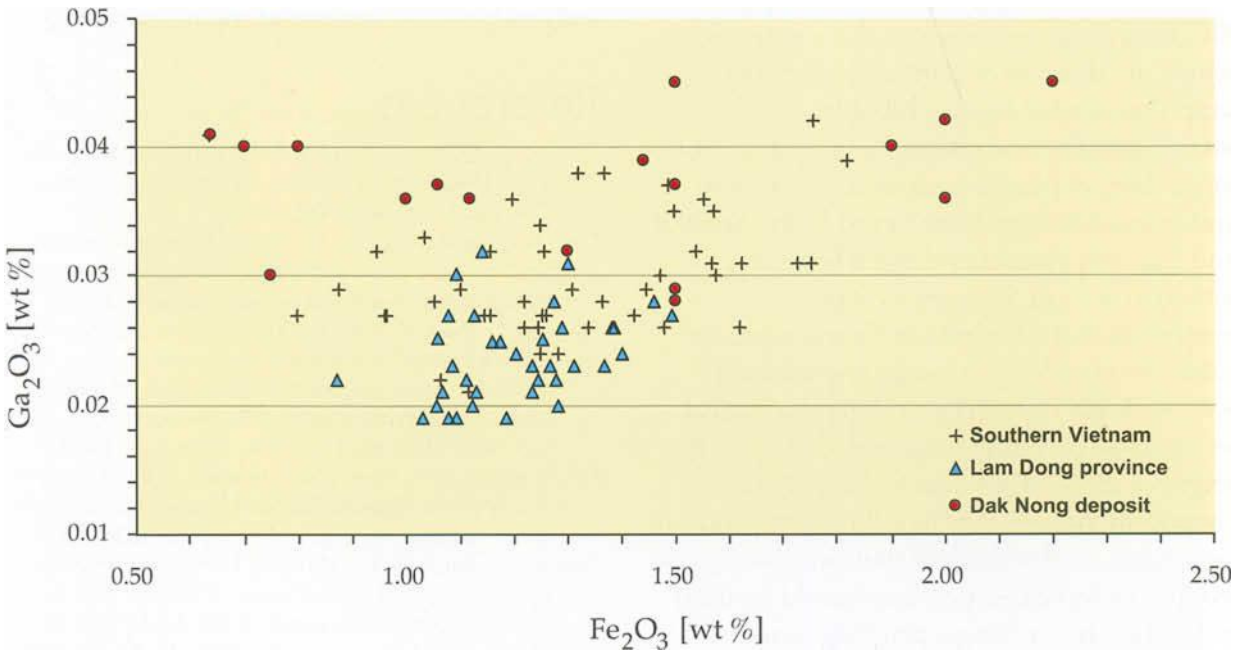

Figure 13: Chemical variation diagram showing wt% plots of gallium (Ga_2O_3) versus iron (Fe_2O_3) contents of corundums from alkali basalts in southern Vietnam. The red circles – sapphires from Dak Nong; blue triangles – sapphires from the Lam Dong province; black crosses – sapphires of unknown locality.

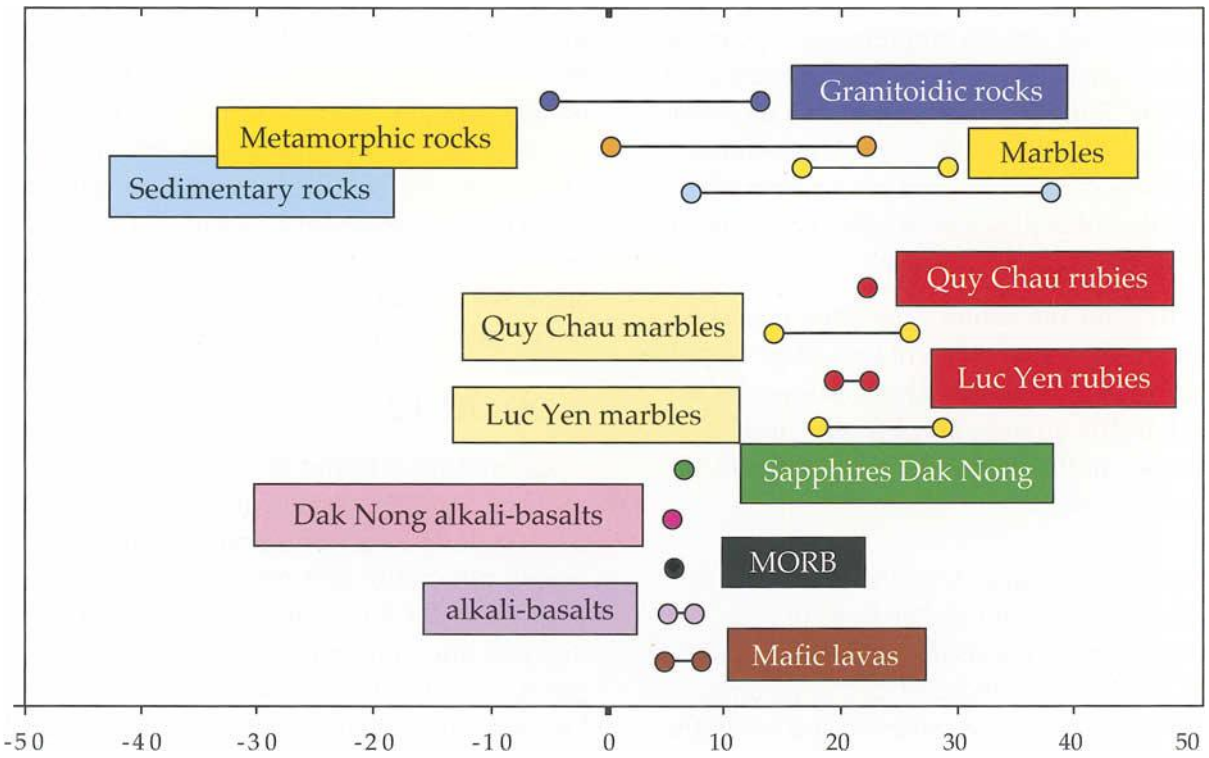

Figure 14: Oxygen isotopic composition of rubies from the Quy Chau and Luc Yen deposits versus 'BGY'-sapphires from Dak Long. The isotopic values of associated marbles and a range of basalts, sedimentary rocks and metamorphic rocks are shown for comparison (Hoefs, 1987).

Corundums exhibit consistent trace element variations which underline the diversity of their host-rocks. The Cr_2O_3/Ga_2O_3 versus Fe_2O_3/TiO_2 geochemical diagram divides the corundums into three main fields which are discrete or partly overlapping: sapphires hosted by amphibolite, metapegmatite and gneiss, basalts, and rubies in marbles. A fourth domain contains blue and colourless sapphires found in the Yen Bai and Luc Yen placers and these have an unknown origin. Oxygen isotopic composition studies which clearly separate rubies in marble from sapphires in basalt will, with the use of classical gemmological techniques, probably help in deciphering the origin of these sapphires. Rubies in marbles commonly have distinctive fluid composition signatures, and studies of their inclusions and oxygen isotopic compositions could be used in the future for 'fingerprinting' and determining the origin of rubies found in placers.

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15.30 *DTC* – Consumer Confidence in the Diamond Industry

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The causes of colour in untreated, heat treated and diffusion treated orange and pinkish-orange sapphires – a review

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Abstract: *Colours and the causes of colour in untreated, heat treated and beryllium diffusion treated sapphires in the yellow to red colour range are summarized. An overview of the major types of colour centres in sapphire is given. Properties of thermally unstable 'yellow' and 'orange' colour centres are compared with characteristic features of thermally stable 'orange' colour centres which are produced by high temperature heat treatment or by beryllium diffusion treatment. The models for understanding the formation of orange colour centres according to trace element contents of the samples as suggested by Häger and Emmett are described and discussed in detail. Both models are based on trace element ratios in the Mg-Fe-Ti and in the (Be+Mg)-Fe-Ti triangular diagrams. The causes of colour in untreated and heat treated padparadscha from Sri Lanka are compared with those of beryllium diffusion treated samples from Ilakaka, Madagascar, and from Songea, Tanzania. The great colour variability of untreated and treated samples is due to large variations of iron and chromium contents and to the concentration of colour centres.*

Introduction

Since the appearance of orange sapphires 'enhanced' with a 'new heat treatment technique' on the market at the end of 2001 (see for example McClure *et al.*, 2002), the distinction of treated from untreated samples (*Figure 1 a, b*) as well as the definitive detection of the treatment technique applied has become one of the major challenges for gemmological laboratories and scientists working in the gemmological field. Knowledge of the exact nature of the treatment technique and the mechanism of colour change or colour improvement are necessary for a correct nomenclature of treated samples.

Figure 1a: Untreated padparadscha from Sri Lanka of 3.09 ct (left) and Be-diffusion treated Ilakaka sapphire of 1.82 ct (right). (Photo by M. Glas)

Figure 1b: Sapphire of 1.28 ct (left) showing the colour typical of heat treated material from Sri Lanka and Be-diffusion treated Ilakaka sapphire of 1.70 ct (right). (Photo by M. Glas)

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Many papers have been written containing a description of the history of this major issue and several public events such as panel discussions, related to the nomenclature problem have been held in 2002 and 2003. Summaries of the present knowledge about the new heat treatment technique and properties of treated samples are given by, for example, Coldham, 2002; Peretti and Günther, 2002; Wang and Green, 2002; Hänni, 2002; Hänni and Pettke, 2002; Fritsch *et al.*, 2003; and Emmett *et al.*, 2003.

Meanwhile, the new 'heat treatment technique' unquestionably involves a diffusion of beryllium from outside sources, e.g. from powdered chrysoberyl or from a beryllium-bearing melt, into the corundum lattice. Trace element analyses of the new type of treated sapphires reveal elevated amounts of beryllium, the highest amounts being detected in the rims of the samples. Samples of ruby or sapphire treated by this 'new heat treatment process' were first used in Thailand for ordinary heat treatment but either did not respond at all or became of unmarketable quality. Such types of corundum, e.g. purplish to purple material from Songea, Tanzania, and Ilakaka, Madagascar, are at least in part not convertible to bright ruby or bright pink sapphire by simple high temperature heat treatment.

To the knowledge of the present authors, diffusion treatment of corundum was first applied by Eversole and Burdick (1954) by introduction of titanium into the lattice of synthetic Verneuil-grown corundum; after subsequent heat treatment, this enabled formation of rutile needles and caused asterism in these samples. Later titanium was also diffused into natural corundum to develop or improve the desired blue colour of sapphires (Carr and Nisevich, 1975, 1976, 1977). The reaction mechanism of both processes is well understood (see Schmetzer and Glas, 2003).

However, the diffusion of beryllium into natural corundums causes internal reaction and diffusion of Be and the already-present trace elements, mainly Mg, Ti, V, Cr, and Fe, as well as with the major chemical components of corundum, aluminium and oxygen. These processes are most probably very complex and not yet fully understood. In natural iron- and/or chromium-bearing corundums this reaction and diffusion mechanism caused the formation of an 'orange' colour centre with a broad absorption maximum in the visible range at about 460 to 470 nm combined with an additional ultraviolet absorption component. These absorption features are the major causes of colour change from, for example, pink to various shades of orange. A certain intensity of the 460 to 470 nm band in combination with the always present ultraviolet component is necessary for the desired colour change of natural sapphires. It is now generally accepted that without diffusion of beryllium from a solid or melt from outside into the corundum lattice, this absorption band would not be created with the intensity necessary for a distinct colour change or colour shift. Consequently, these stones should be called Be-diffusion treated sapphires.

Recent papers have focused on trace element determination of diffusion treated sapphires, and especially on beryllium analysis, and these have led to the first steps in understanding the mechanism of colour change by diffusion treatment (see, for example, Peretti and Günther, 2002; Hänni, 2002; Hänni and Pettke, 2002; Fritsch *et al.*, 2003; Emmett *et al.*, 2003; Peretti *et al.*, 2003; Pisutha-Arnond *et al.*, 2004). However, a general summary of present knowledge about various colour centres, which might influence sapphire colour, and of colour change by diffusion treatment, is not available in the gemmological literature.

A brief characterization of untreated padparadscha from Sri Lanka (the orangey-yellow, yellowish-orange, orange, pinkish-orange, rose orange, orangey-pink, or reddish-orange sapphire variety –

to summarize some colour descriptions commonly used) and heat treated sapphires in the same colour range (treated without Be-diffusion) with respect to colour and its causes has been published by Notari (1996, 1997). In the latter paper, however, only general statements about the nature of 'colour centres' are found with no detailed comparison of properties of natural corundum with defects produced in doped synthetic corundum.

In gemmological literature generally there is not sufficient detail available about comparison of untreated and heat treated material from Sri Lanka with diffusion treated samples, especially according to the locality of origin of the untreated material. The present needs of the trade require recognition and distinction of untreated from diffusion treated material, and it is necessary to clearly characterize the types of untreated, heat treated and diffusion treated material available in the trade. The present paper tries to fill at least part of this gap and to contribute to resolving these problems.

Figure 2a: Sapphires with this colour originating from Sri Lanka are called padparadscha in the trade; in the upper row two untreated samples representing the pinkish-orange (left) and the yellowish-orange (right) padparadscha type are shown; in the lower row heat treated reddish-orange (left) and pinkish-orange sapphires (right) are shown; range of samples from 4.43 to 2.23 ct. (Photo by M. Glas)

Padparadscha and brownish-orange sapphire

The orangey-pink to pinkish-orange coloured corundum variety is called padparadscha in the trade. Natural padparadscha is considered to be the rarest sapphire variety. They originate from different mining areas in Sri Lanka, mainly from Ratnapura (G. Zoysa, pers. comm. 2003), but also from Elahera and Buttala (Gunawardene and Rupasinghe, 1986; Notari, 1996).

There is still an ongoing debate about the correct and appropriate definition of the term 'padparadscha' in the trade (*Figure 2a*). If we consider only colour, it is unquestionable that sapphires with a bright orangey-pink or pinkish-orange colour are called padparadscha and are considered as extremely fine samples (*Figure 2b*; see also Crowningshield, 1983; Kane, 1986; Gunawardene and Rupasinghe, 1986). There is, however, some discussion in the trade about the borderlines between padparadschas and yellow sapphires on the one side, and between padparadschas and rubies or pink sapphires on the other. Thus, the designation of individual padparadschas close to these borders might be handled differently in the trade and also by different gemmological laboratories.

Figure 2b: This untreated padparadscha of 9.05 ct has an extremely fine intense orange colour. (Photo by M. Glas)

Notari (1996, 1997) subdivided padparadschas from Sri Lanka into a more yellowish-orange to orange, sometimes pastel coloured type (which he called 'original' type) and a more orange to pinkish-orange type (which he called 'antique' type). According to their colour (see again *Figure 2 a, b*), both types may overlap. The more yellowish-orange to orange type of Notari is definitely not heat treated. The more orange to pinkish-orange type may have been heat treated at high temperatures (F. Notari, pers. comm., 2003). In other words: heat treated and non-heat treated samples with a specific pinkish-orange colour are known to exist. It is also possible to cause a shift of colour from yellowish-orange or orange stones towards pinkish-orange by very careful low temperature heat treatment (F. Notari, pers. comm., 2003).

According to G. Zoysa (pers. comm., 2003), somewhat milky-appearing Sri Lanka sapphires with a distinct pink or orange shade are used for high temperature heat treatment to obtain pinkish-orange or reddish-orange sapphires with a colour comparable to that of untreated padparadscha. F. Notari (pers. comm., 2003) mentioned that pale to medium pink sapphires with colour zoning consisting of colourless and pale pink areas are used for the high temperature heat treatment process.

Another way of defining padparadscha is by using its spectroscopic properties (Schmetzer and Bank, 1981; Schmetzer *et al.*, 1983). Absorption spectra of untreated padparadschas from Sri Lanka consist of an almost continuously increasing absorption from red to violet (similar to that of yellow sapphires due to 'yellow' colour centres) on which are superimposed the absorption bands of chromium. Upon heat treatment to about 500°C, the absorption of 'yellow' colour centres is normally removed and padparadschas turn pink or red, according to the chromium content of the sample (Schmetzer *et al.*, 1983). With careful heat treatment at low temperatures, the colour of a sample may be shifted slightly from yellowish-orange towards pinkish-orange. This is understandable by removing only part of the 'yellow' colour centres present in untreated stones.

Upon heat treatment at high temperatures, a pinkish-orange padparadscha from Sri Lanka turned yellowish-orange (Kane, 1986). In this case, most probably, thermally unstable 'yellow' colour centres disappeared and more intense thermally stable 'orange' colour centres were formed, with some chromium being always present. Kane's description is consistent with numerous heat treatment experiments and spectroscopic investigations performed by one of the authors in the 1980s and 1990s (KS, unpublished data).

Figure 3: The colour of untreated brownish-orange sapphire from Ilakaka (left) occasionally resembles that of pinkish-orange untreated padparadscha from Sri Lanka (right), although the Ilakaka material is coloured by chromium and iron, and the colour of the Sri Lanka material is caused by 'yellow' and/or 'orange' colour centres and chromium; weight of samples are 1.20 and 1.66 ct. (Photo by M. Glas)

Sapphires with brownish-orange colours similar to those of untreated and heat treated padparadschas (*Figure 3*) have been known for several decades from Umba, Tanzania (Schmetzer and Bank, 1981; Gunawardene, 1984; Hänni, 1987; Notari, 1996, 1997; see also Schmetzer and Peretti, 1999) and have been called 'padparadscha' or 'African padparadscha' in the trade. Some brownish-orange sapphires from

Umba are coloured by high amounts of iron and chromium (Schmetzer *et al.*, 1983) and similar stones coloured by iron and chromium from Malawi have also been called 'padparadscha' (Henn *et al.*, 1990). Recently, samples from Ilakaka, Madagascar (see also *Figure 16b*), with this type of chromium-iron coloration have also been described by Schmetzer (1999). However, the colours in the brownish-orange sapphires from Tanzania (Umba), Malawi, and Madagascar (Ilakaka) have different causes and the present authors cannot support the designation of these samples as padparadschas.

Colour centres in corundum

Before discussing causes of colour in Be-diffusion treated sapphires, we have to summarize briefly the present knowledge about colour centres in natural and synthetic corundum.

Various colour centres in natural and synthetic corundum have been created by different types of irradiation and/or heat treatment in oxidizing or reducing atmospheres. An overview of the most prominent colour

Table I: Colour centres in corundum.

Type	Designation	Description	Absorption maximum (nm)	References
Anion defect centres	F	Oxygen vacancy with two trapped electrons	203-207	Evans and Stapelbroek, 1978; Crawford, 1984; Pogatshnik *et al.*, 1987; Chen *et al.*, 1991; Brock *et al.*, 2001
	F^+	Oxygen vacancy with one trapped electron	197-206; 225-230; 258	
	F_2	Two oxygen vacancies with four trapped electrons	300-302	
	F_2^+	Two oxygen vacancies with three trapped electrons	355	
	F_2^{2+}	Two oxygen vacancies with two trapped electrons	450-459	
Cation defect centres	V^{2-}	Aluminium vacancy with hole trapped at an adjacent oxygen	403	Kvapil *et al.*, 1972, 1973; Govinda, 1976; Lee *et al.*, 1977; Lee and Crawford, 1977; Valbis and Itoh, 1991; Jacobs *et al.*, 1993
	V^-	Aluminium vacancy with two holes trapped at two adjacent oxygens	403	
	V_{OH}^-	Aluminium vacancy with hole trapped at an adjacent oxygen plus adjacent OH	420	
Magnesium related centres	Mg^0	Magnesium with hole trapped at an adjacent oxygen	*See Table II*	*See Table II*
	F^-_{Mg}	Oxygen vacancy with two trapped electrons adjacent to magnesium	170; 200; 280	Kulis *et al.*, 1979, 1981; Kortov *et al.*, 1985; Kotomin *et al.*, 1995 a, b; Brock *et al.*, 2001
	F_{Mg}	Oxygen vacancy with one trapped electron adjacent to magnesiu	217; 247	

Table II: Colour centres in natural, treated and synthetic corundum which relate particularly to Mg and Be.

Dopant	Synthetic (s); Natural (n); Diffusion treated (d); Heat treated (h)	Absorption maximum (nm)*	Remarks	Reference
Mg + Mn	s	469 + uv component		Geschwind *et al.*, 1962
Cr + N	s	460, 370 shoulder	orange	Hoskins and Soffer, 1964
Mg	s		orange	Townsend and Hill, 1965
Mg + Ti	s, irradiated		brown	Cox, 1971
Mg	s	400-480 range	yellow to brown	Kvapil *et al.*, 1973
Mg Mg + Cr	s s	470, 380 470, 380	orange orange	Sidorova *et al.*, 1973
Mg	s	475, 260		Andreev *et al.*, 1976
Mg	s	468, 380	intense orange	Mohapatra and Kröger, 1977
Be + Cr	s		orange, all colours in the yellow to red range	Lor'yan and Rassvetaev, 1979
Orange colour centres, Mg + Cr + Fe	n/h	465 + uv component	orange-brown	Schmetzer *et al.*, 1983
Mg Mg + Fe Mg + Cr	s s s	480	greyish-purple yellow to brown orange	Wang *et al.*, 1983
Mg	s	495, 250, 217		Kortov *et al.*, 1985
Mg	s	460 + uv component	green	Boiko *et al.*, 1987
Mg	n/h	470 + uv component	yellowish-orange	Emmett and Douthit, 1993
Mg	s	496, 260	grey-purple	Tardio *et al.*, 2001
Mg Mg + Fe	s s	500 470 + uv component	brownish-violet	Häger, 2001
Mg Mg	n n/d	Visible + uv range Visible + uv range	brownish-orange, yellow, orange	Peretti and Günther, 2002
Mg Be Mg + Fe Be + Fe Be + (Cr, Fe)	s s/d s n/d n/d	500 420 470 + uv component 470 + uv component 470 + uv component	brownish-violet pale brown yellow yellow pink orange	Pisutha-Arnond *et al.*, 2002
Be + (Cr, Fe)	n/d	460 + uv component	yellow to orange	Hänni and Pettke, 2002
Be + (Cr, Fe)	n/d	470 + uv component		Fritsch *et al.*, 2003
Be Be + Cr Be + (Cr, Fe)	s/d s/d n/d	420 460, 380 460, 380	orangey-brown orange	Emmett *et al.*, 2003
Be Be + Cr Be + (Cr, Fe)	s/d s/d s/d	 470 + uv component 470 + uv component	brown orange orange-red	Peretti *et al.*, 2003
Be Be + (Fe, Mg) Mg Mg + Fe Be + (Cr, Fe, Mg)	s/d n/d s n n/h s n/d	420 460 + uv component 500 460 + uv component 460 + uv component 460 + uv component 460 + uv component	pale brown yellow brownish-violet yellow yellow yellow orangey-yellow	Pisutha-Arnond *et al.*, 2004

* from some papers the approximate positions of absorption maxima were taken from the spectra pictured; for the ultraviolet range, frequently only the presence of absorption bands is evident, but no specific position of the absorption maximum can be given.

centres is given in *Table I* with literature references. Physicists subdivide these colour centres into *anion defect centres* (related to oxygen vacancies) and *cation defect centres* (related to aluminium vacancies). Most of these colour centres reveal prominent absorption maxima in the ultraviolet, occasionally also in the violet part of the visible range (see also *Table I*). *Magnesium-related colour centres* reveal a hole trapped at an adjacent oxygen (trapped hole centres) or may be found adjacent to an oxygen vacancy. The latter, which are called F^{-}_{Mg} or F_{Mg} centres, reveal broad absorption maxima in the ultraviolet which may extend to the visible range (*Table I*).

Numerous papers have provided information about orange, yellow, brown or brownish-purple magnesium-related colour centres (*Table II*). The most prominent 'orange' colour centre is characterized by an absorption band at about 460 to 470 nm, which always is accompanied by a shoulder or second maximum at about 380 nm and/or an additional ultraviolet component without an exactly specified maximum. In beryllium diffusion treated sapphires, the 380 nm maximum is commonly hidden by an unspecified ultraviolet component and is only detected in difference spectra, i.e. in spectra in which the 'before' spectrum of the untreated samples is subtracted from the 'after' spectrum of the beryllium diffusion treated sapphire (Emmett *et al.*, 2003.). A spectrum of a sample showing the 460 to 470 nm absorption band alone, i.e. without an additional 380 nm band and/or without an additional ultraviolet component, has not yet been found.

The 460 to 470 nm absorption band can be produced by doping synthetic corundum feed material with Mg alone (Sidorova *et al.*, 1973; Andreev *et al.*, 1976; Mohapatra and Kröger, 1977; Boiko *et al.*, 1987) or with both Mg and Cr (Sidorova *et al.*, 1973), or with a combination of Mg and Fe (Wang *et al.*, 1983; Häger 2001; Pisutha-Arnond *et al.*, 2002, 2004). The absorption band in the 460 to 470 nm range is also typical for natural high temperature heat treated yellow to orange sapphires (Schmetzer *et al.*, 1983). The intensity of this colour centre is increased by heat treatment in an oxidizing atmosphere and reduced by heat treatment in a reducing atmosphere.

The exact nature of the 'orange' colour centre, also called a trapped hole centre (THC) in the literature, and the complex reaction forming this colour centre in natural sapphire is still debated although a simple model for the formation of an absorption band at 470 nm in synthetic orange corundum doped with magnesium or with chromium and magnesium has been known for a long time (Sidorova *et al.*, 1973; Andreev *et al.*, 1976; Mohapatra and Kröger, 1977). This model is based on an electron hole trapped for charge compensation at an oxygen adjacent to magnesium on aluminium lattice sites and may be described with the symbol $[Mg_{Al}^{2+}O^{-}]$. In the physics literature, the symbol $[Mg]^{0}$ is also commonly used, reflecting the electrical neutrality of this magnesium-oxygen-centre relative to the surrounding corundum lattice.

An absorption maximum is also produced in the range of the 'orange' colour centre by doping of corundum with magnesium and manganese (Geschwind *et al.*, 1962) or with chromium and nitrogen (Hoskins and Soffer, 1964). In these examples, Mn^{4+} is assumed to form the necessary charge compensation for Mg^{2+}, and, in the second case, Cr^{4+} is found to charge compensate for the N^{3-} present in oxygen sites.

Synthesis of corundum doped with Mg using extremely pure Fe- and Cr-free nutrient produces sapphire crystals which reveal an absorption maximum in the 480 to 500 nm range (Wang *et al.*, 1983; Kortov *et al.*, 1985; Tardio *et al.*, 2001; Häger 2001; Pisutha-Arnond *et al.*, 2002, 2004). Such sapphire samples are described as greyish-purple or brownish-violet. It was suggested, that, in contrast to these pure Mg-bearing sapphires, the 470 and 380 nm absorption bands mentioned above are due to Mg-related colour centres (trapped hole centres) combined with or needing some 'impurities' or traces of Fe and/or Cr to form Mg-Fe or Mg-Cr clusters.

This complex situation is duplicated by natural and synthetic Be-doped or Be-diffusion treated sapphires. As early as 1979, Lor'yan and Rassvetaev reported that the synthesis of sapphire doped with a combination of chromium and beryllium produces bright orange sapphires and, according to the Cr:Be ratio of the feed material, all colours intermediate between yellow and red may be produced.

Natural iron- and/or chromium-bearing corundum, which was diffusion treated with Be commercially in Thailand or in different laboratories in America and Europe for research purposes, also shows the absorption bands at 470 and 380 nm or an absorption band at about 470 nm and a strong ultraviolet absorption without an exactly specified maximum, i.e. spectra similar to 'impure' Mg-doped synthetic corundum (Peretti and Günther, 2002; Pisutha-Arnond *et al.*, 2002, 2004; Hänni and Pettke, 2002; Fritsch *et al.*, 2003; Emmett *et al.*, 2003). However, this situation is further complicated by Be-diffusion treated synthetic corundum, which was produced from Fe-free nutrient because it shows neither the 'pure' Mg absorption at 500 nm nor the 'impure' Be-related (Mg-Fe-Cr) cluster absorption bands at 470 and 380 nm, but an absorption maximum at about 420 nm (Pisutha-Arnond *et al.*, 2002, 2004; Emmett *et al.*, 2003).

It is evident from this complex situation that the nature of the 'orange' colour centre produced by Be-diffusion treatment and an exact reaction mechanism are not yet fully understood. A model for understanding the causes of colour and colour changes in Mg-, Fe- and Ti-bearing sapphires was developed by Häger (1992, 1993, 1996, 2001). His interpretation, based on heat treatment experiments in combination with absorption spectroscopy and trace element analysis, was described using an Mg-Fe-Ti triangle representing trace element contents in natural or synthetic sapphires (*Figure 4a*). This diagram represents natural or synthetic sapphires with relatively low iron contents, e.g. metamorphic sapphires, in which the

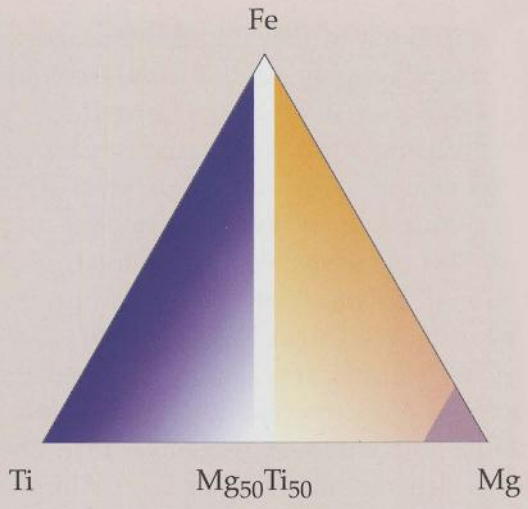

Figure 4a: *This triangular Mg-Fe-Ti diagram for samples with low iron content (see text) illustrates a model for the development of colours in sapphires at 1850°C in an oxidizing environment. Samples on the Fe-$Mg_{50}Ti_{50}$ line, i.e. samples with equal atomic concentrations of magnesium and titanium are colourless; in samples right of this line, i.e. in samples with Mg > Ti, Mg-related colour centres are developed; in samples left of this line, i.e. in samples with Ti > Mg, the Fe^{2+}/Ti^{4+} charge transfer absorption of blue sapphire is present; the special role of Mg-related colour centres in 'pure' iron-free corundum is indicated at the right corner; after Häger (2001).*

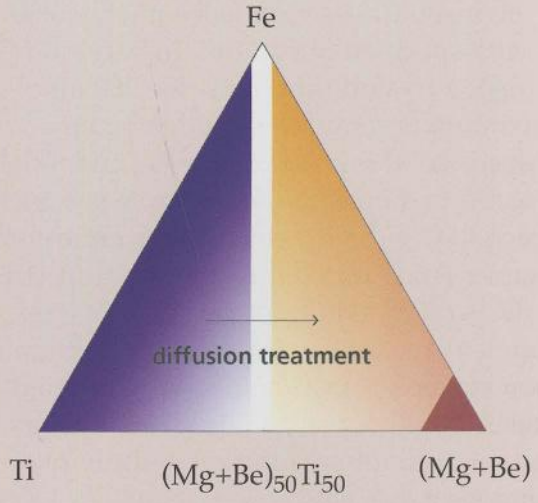

Figure 4b: *Schematic model representing the colour development in beryllium diffusion treated sapphires adopted from the proposal of Emmett et al. (2003). In this triangular (Mg+Be)-Fe-Ti diagram, samples on the Fe-$(Mg+Be)_{50}Ti_{50}$ line, i.e. samples with equal atomic concentrations of (magnesium+beryllium) and titanium are colourless; in samples right of this line, i.e. in samples with (Mg+Be) > Ti, Mg-related 'orange' colour centres are developed; in samples left of this line, i.e. in samples with Ti > (Mg+Be), no orange colour centres are found; the special role of Be-related colour centres in 'pure' iron-free corundum is indicated at the right hand corner.*

The beryllium diffusion treatment causes samples, which are left of the 'colourless' line, to shift to the right of this line and to develop 'orange' colour centres.

absorption bands of Fe^{3+} are weak and do not produce a yellow coloration. For simplicity, basaltic sapphires are not covered by this schematic diagram. It is summarized that all iron-bearing corundums with equal concentration of Mg and Ti atoms, i.e. all compositions that lie on the line Fe-$Mg_{50}Ti_{50}$, are colourless. This is understandable if one imagines complete charge compensation by Mg-Ti clusters or Mg-Ti interaction, with neither Mg-related hole centres nor Fe-Ti pairs (causing the blue sapphire colour) being formed.

All corundums with compositions right of this line, i.e. with Mg > Ti, reveal Mg-related colour centres and are yellow, orange or brownish-violet. Most samples left of the line Fe-$Mg_{50}Ti_{50}$, i.e. with Ti > Mg, are blue, which is caused by the presence of the Fe^{2+}/Ti^{4+} charge transfer absorption bands in the red to green part of the visible range (for further details see Häger, 1996, 2001).

Emmett *et al.* (2003) adopted this model to explain the reaction mechanism and colour change caused by Be-diffusion into the corundum lattice (see also Hänni and Pettke, 2002; Fritsch *et al.*, 2003) but did not go on to use their chemical data to test this model and any of their consequent rules. If these rules and the general model prove to be correct, this theoretical approach should be supported by a correlation of colour, colour change reaction and chemical properties of treated and untreated samples.

Emmett's model (*Figure 4b*) describes the addition of Be to change the already existing trace element distribution by diffusion treatment, especially the Mg:Ti ratio to a new (Mg + Be):Ti ratio. By the addition of beryllium to the already-present trace elements, the ratios of some corundums are moved from left of the line Fe-$Mg_{50}Ti_{50}$ (representing colourless sapphires) to a trace element composition right of this line. Consequently, if - after Be-diffusion – the relationship is (Mg + Be) > Ti, the orange colour centre is developed and the desired colour change or colour improvement of the sample is achieved.

It may be assumed that Be acts as a charge compensator for Ti and, in this way, liberates Mg from this role. This 'free' Mg may form 'orange' Mg or (Mg-Fe) or (Mg-Cr) or (Mg-Fe-Cr) colour centres or clusters, i.e. Mg or (Mg-Fe) or (Mg-Cr) or (Mg-Fe-Cr) trapped hole centres with absorption maxima in the 470 and 380 nm and /or ultraviolet range. It may also be assumed that beryllium by itself can form orange Be or (Be-Fe) or (Be-Cr) or (Be-Fe-Cr) trapped hole centres with absorption maxima in the 470 and 380 nm and/or ultraviolet range (for further discussion see also Häger, 2001; Peretti and Günther, 2002; Hänni and Pettke, 2002; Pisutha-Arnond *et al.*, 2002, 2004; Fritsch *et al.*, 2003; Emmett *et al.*, 2003).

The chemical data presented in three recent publications (Peretti *et al.*, 2003; Pisutha-Arnond *et al.*, 2002, 2004) support the adoption of Häger's model by Emmett *et al.*, i.e. the application of the model describing the colour change of heat treated corundum (based on Mg contents) also to Be-diffusion treated corundum (based on Be + Mg contents). These authors (*op. cit.*) conclude from trace element analyses that a yellow or orange coloration is formed in samples with (Mg + Be) > Ti, and that no orange colour component is formed in rubies with Ti > (Mg+Be).

Within the rules described by Emmett *et al.* (2003), silicon is assumed to be effective in the corundum lattice and should therefore be added to titanium. The resulting conditions or rules are (Mg+Be) > (Ti+Si) for the formation of orange colour centres and an orange coloration. In contrast, sapphires with a trace element ratio of (Mg+Be) < (Ti+Si) should not show an orange coloration after diffusion treatment.

Peretti *et al.* (2003) outline specific analytical data from treated and untreated samples which are useful to check the silicon-related part of Emmett's model. These data indicate that silicon is heterogeneously distributed in the corundums and thus, the silicon contents measured might be due to minute inclusions and not to Si that is

Table III: Sources, colours and treatment history of corundums in this study.

Locality	Colour	Untreated	Heat treated	Beryllium diffusion treated
Sri Lanka	Yellow	16	14	
Sri Lanka	Yellowish-orange to orange	21	31	
Sri Lanka	Orange to pinkish-orange or reddish-orange	20	18	
Ilakaka, Madagascar	Pink, purplish-pink, purple, purplish-violet, violet	75	10	
Ilakaka, Madagascar	Yellowish-pink, yellowish-orange, brownish-orange, orange-brown, yellowish-brown	14		
Ilakaka, Madagascar	Yellowish-orange, orange, pinkish-orange, orangey-red, reddish-orange, brownish-orange			45
Songea, Tanzania	Colourless to red or pink, purplish-red, purple, violet (sometimes zoned with a colourless core)	22	10	
Songea, Tanzania	Colourless to yellowish-orange, orange, pinkish-orange, orangey-red, reddish-orange (sometimes zoned with a colourless core)			52

dispersed in the corundum lattice. In addition, a better correlation between the observed colour change by beryllium diffusion and the trace element composition was observed when the silicon content of the sapphires was completely neglected. According to the paper of Pisutha-Arnond *et al.* (2004), the role of silicon as described above is not proven at present and it is questionable if silicon is really present in the lattice of natural corundum in amounts capable of influencing any colour change by heat or diffusion treatment.

However, even with the data available now, it is still not clear how Be is involved in any of the recently designated 'orange' colour centres, or in the possible (Be-Mg-Fe-Cr) clusters, or if the Be is only involved in a charge compensating mechanism for Ti. In other words: the difference between the orange colour centres creating the 470 nm absorption maximum and those colour centres with an absorption maximum at 420 nm, created by Be-diffusion in pure samples, is not completely understood. Furthermore, the role of bivalent and trivalent iron within this complex reaction system and its role as charge compensator for titanium in Be-, Mg-, Ti- and Fe-bearing, diffusion treated sapphires is not completely understood. Similar problems exist for chromium and a possible formation of Cr^{4+} as charge compensator for Mg^{2+} and/or Be^{2+}.

Box I: Materials and methods

The sources, colours and treatment history of the 349 natural corundum samples examined in the present study are listed in *Table III*. All samples were highly transparent, gem quality rubies and sapphires ranging from about 0.2 ct to 9 ct in weight. With the exception of some slices polished on both sides (originating from Songea, Tanzania), only faceted samples were used for this research project.

The first lots of diffusion treated sapphires were obtained by one author (DS) during several visits to Bangkok and Chantaburi, Thailand, in 2002. According to the properties of the sapphires (see results) and the information given by the suppliers, these lots represented either Be-diffusion treated samples from Ilakaka, Madagascar, or from Songea, Tanzania. Further lots of Be-diffusion treated sapphires were obtained by colleagues of gemmological laboratories in Europe, USA and Thailand as well as from different European companies. Some of these lots – based on the properties of the samples – represented either Ilakaka or Songea material, some other lots were mixed and contained samples from both localities. A limited number of diffusion treated samples were excluded from the study, because the sapphires did not show the characteristic properties of one of these two localities mentioned or were – according to their characteristic features – definitely from other sources, e.g. from Sri Lanka.

The comparison of properties of Be-diffusion treated samples from Ilakaka and Songea with untreated natural sapphires from these localities is based on several lots of untreated Ilakaka material obtained by one of the authors (KS) from a German dealer soon after the locality was discovered (see Schmetzer, 1999). According to the colour and absorption spectra of the treated material, we used untreated Ilakaka samples in the pink to purple and the pink to orange-brown colour ranges for the present study, because samples from these ranges were submitted to Be-diffusion treatment. Knowing the properties of rubies from Vatomandry, Madagascar, and of rubies and sapphires from Andilamena, Madagascar (see Schwarz and Schmetzer, 2001), this information was used to reject any corundum that was not from Ilakaka.

Untreated Songea material (see Schwarz, 2001) was obtained by one author (DS) in 1997 directly in the Tunduru-Songea mining area in southern Tanzania. From about 200 polished slices or faceted gem-stones of different colours available, 22 chromium-bearing samples were in the range red to purplish-red to colourless (zoned with colourless cores and red to purplish-red rims); these turn yellowish-orange, orange or reddish-orange after Be-diffusion treatment. From Ilakaka a number of heat treated pink sapphires were studied, and from Songea there were also heat treated rubies. The reader should be aware, however, that not only sapphire and ruby material from Ilakaka and Songea, which was first used for this new treatment, but corundum from many natural sources might be diffusion treated and released on the market (see, e.g., the summary of possible treatment results of ruby and sapphire material from worldwide sources presented by Themelis, 2003).

Untreated yellowish-orange, orange, pinkish-orange or reddish-orange Sri Lanka material, designated padparadscha in the trade, as well as untreated yellow sapphires were obtained from private collections as well as from old stock of different European companies. Heat treated yellow, yellowish-orange to orange (chromium-free) or orange to reddish-orange (chromium-bearing) samples of Sri Lankan origin were obtained from different companies who could establish from internal notes or personal knowledge, that these samples had been in stock for several years, at least before the turn of the millennium (i.e. before Be-diffusion treatment started). In this way, any diffusion treated material was excluded from this group of samples.

continued overleaf

Trace element contents of 152 samples were obtained by energy-dispersive X-ray fluorescence (EDXRF) spectroscopy. These analyses were performed with a Tracor Northern Spectrace 5000 system, using a program specially developed for trace element geochemistry of corundum. The samples for chemical analyses (Sri Lanka 26, Madagascar 84, Tanzania 42) were selected in order to cover the full range of colours seen in untreated, heat treated and diffusion treated material from all three sources. Although the non-destructive analytical technique applied is unable to detect the presence of light elements such as beryllium, EDXRF spectroscopy has become an important routine method for the characterization of rubies and sapphires, especially for origin determination.

Absorption spectra of all samples were recorded in the UV-visible-NIR range with both a Leitz-Unicam SP 800 UV-Vis spectrophotometer and a Perkin-Elmer Lambda 19 spectrophotometer.

Results

Chemical properties

General remarks

In the present paper, we describe iron and chromium contents which are the dominant transition elements which are the cause of colour. The analytical data are summarized in *Table IV*. Trace element contents were obtained from the tables of faceted samples or from polished surfaces of some sapphire or ruby slices. The X-ray beam incident to the samples covered an oval surface of about 2 × 1 mm. Consequently, the analytical data represent bulk chemical analyses and cannot discriminate fine variation of composition in colour zoned samples. Such information could be obtained by spot analyses using e.g. an electron microprobe.

The distribution of trace elements in corundums from the three sources studied do not fall into different population areas related to whether they are untreated or heat treated (Sri Lanka) nor can untreated and diffusion treated samples from Madagascar and Tanzania be distinguished in this way. Thus, in order to avoid confusion, the analysed samples in *Table IV* are not subdivided into untreated or treated groups. A chromium-iron correlation diagram (*Figure 5*) also summarizes the analytical results.

Sri Lanka

The Sri Lankan padparadschas are located in a small population area near the lower left corner of the chromium-iron correlation diagram (*Figure 5*). This means that their iron- and chromium-contents are, in general,

Table IV: *Chromium and iron contents of untreated and heat treated Sri Lankan padparadschas and yellowish orange sapphires, and of untreated and beryllium diffusion treated rubies and sapphires from Madagascar and Tanzania.*

Wt.%	Sri Lanka (26 samples)	Ilakaka, Madagascar (84 samples)	Songea, Tanzania (42 samples)
Cr_2O_3	bdl. – 0.11	0.02 – 0.21* 0.06 – 0.15**	0.11 – 0.53
Fe_2O_3	0.03 – 0.25	0.05 – 1.95* 2.64 – 3.20**	1.04 – 1.80

bdl. = below detection limit.
* 80 treated and untreated samples in different colours.
** 4 untreated samples with orange-brown or yellowish-brown colour.

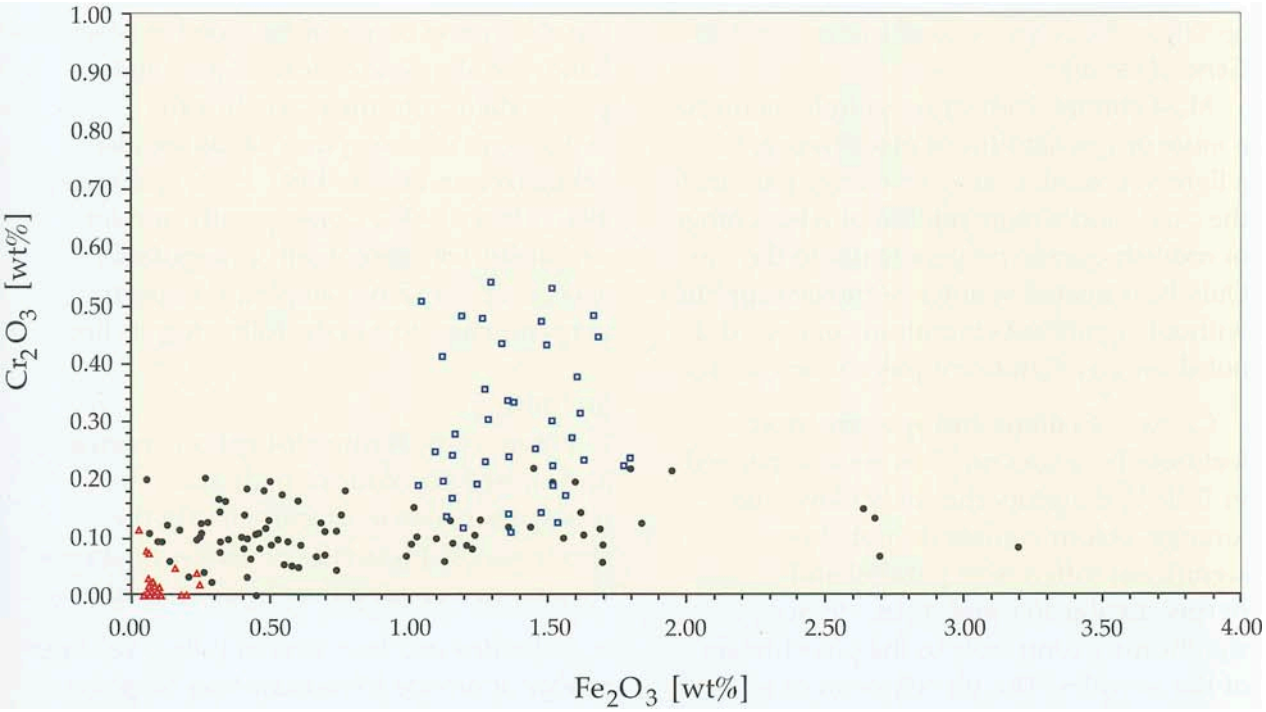

Figure 5: Graphical representation of iron and chromium contents determined for 152 samples from Sri Lanka, Madagascar and Tanzania by energy-dispersive X-ray fluorescence spectroscopy (EDXRF); red triangles represent heat treated and untreated samples from Sri Lanka, black circles represent untreated and diffusion-treated samples from Ilakaka, Madagascar, blue squares represent untreated and diffusion-treated samples from Songea, Tanzania (for further characterization of samples see Table III). It is evident, that the population fields for Sri Lanka and Madagascar samples partly overlap as do the population fields for Madagascar and Tanzania samples.

very low: Cr_2O_3 up to about 0.11 wt.% and Fe_2O_3 up to about 0.25 wt%. As mentioned above, the contents of Cr and Fe in the untreated and heat treated samples overlap and, thus, these samples are not subdivided into separate groups. These analytical results are consistent with data published by Notari (1997) for 11 padparadschas from Sri Lanka.

Ilakaka

The examined sapphires from the Ilakaka mining region in Madagascar display a wide range of iron content: most values from untreated and diffusion treated samples lie in a population field that covers the range 0.05 to 1.95 wt.% Fe_2O_3. Four untreated orange-brown or yellowish-brown samples contain even larger iron values of 2.64 to 3.20 wt.% Fe_2O_3. These samples revealed absorption spectra with Fe > Cr or Fe >> Cr, i.e. with stronger iron than chromium absorption bands (see *Figure 15*). Compared to this large variation in iron contents, the chromium range is relatively small: the highest Cr_2O_3 values are 0.21 wt.% and some are as low as 0.02 wt.% Cr_2O_3.

Songea

The iron and chromium contents of untreated and diffusion treated rubies and sapphires from the Songea mining area in southern Tanzania lie in a well-defined population field. The iron concentration is always high (in the range of 1.04 to 1.80 wt.% Fe_2O_3) and chromium contents vary between 0.11 and 0.53 wt.% Cr_2O_3 (see also Schwarz, 2001).

Considering only iron and chromium contents, it is evident from *Figure 5* that the population fields for Sri Lanka and Madagascar samples overlap, as do the population fields for Madagascar and Tanzania samples.

Spectroscopic properties and causes of colour

General remarks

Most chromium-bearing samples showed a more or less significant pleochroism, i.e. a light yellowish-orange or orange parallel to the *c*-axis and a more intense pinkish-orange or reddish-orange perpendicular to the *c*-axis. Only heat treated yellowish-orange sapphires without significant chromium contents did not show any significant pleochroic colours.

Causes of colour and spectroscopic features of orange sapphires are summarized in *Table V*; the properties of 'yellow' and 'orange' colour centres do not show significant differences parallel and perpendicular to *c* and, thus, do not significantly contribute to the pleochroism of the samples. The pleochroism of all chromium-bearing sapphires is caused by the significant differences in the intensity of chromium absorption bands parallel and perpendicular to c (*Figure 6*). If a blue sapphire component is present (mostly in untreated purplish and purplish-red sapphires from Ilakaka and Songea), the Fe^{2+}/Ti^{4+} absorption also contributes to the pleochroism of the samples. The intensities of the absorption bands of Fe^{3+}, on the other hand, are almost identical parallel and perpendicular to the *c*-axis (for the assignment of absorption bands see also Schmetzer and Bank, 1980, 1981; Schmetzer 1987; Häger 1996). Consequently and for simplicity, we present only non-polarized spectra or, for some samples, the spectra perpendicular to *c* in the following section.

Sri Lanka

Before considering absorption spectra and causes of colour of padparadschas, it is appropriate to discuss briefly the spectroscopic properties of yellow to orange, chromium-free sapphires from Sri Lanka.

a. Untreated and heat treated yellow, yellowish-orange or orange (chromium-free) sapphires

Untreated yellow sapphires (*Figure 7*), in general, show a light yellow coloration, which is caused by colour centres. Yellow colour centres in corundum from Sri Lanka are normally unstable to heat treatment, and samples turn colourless after heating to temperatures in the range of 500 to 600°C (Schmetzer *et al.*, 1983; Nassau and Valente, 1987). The yellow coloration of heat treated,

Table V: Assignment of absorption maxima shown by orange sapphires.

Cause of colour	Maximum (nm)	Strength of peak according to polarization direction
Fe^{3+}	450 388 376	$\parallel c \approx \perp c$ $\parallel c \approx \perp c$ $\parallel c \approx \perp c$
Cr^{3+}	693 556 $\perp c$; 542 $\parallel c$ 410 $\perp c$; 397 $\parallel c$	Sharp line $\perp c > \parallel c$ $\parallel c > \perp c$
Fe^{2+}/Ti^{4+}	699 559	$\parallel c \approx \perp c$ $\perp c > \parallel c$
yellow colour centres	increasing absorption from red through violet to the ultraviolet (uv component)	$\parallel c \approx \perp c$
orange colour centres	470 380 and/or increasing absorption from red through violet to the ultraviolet (uv component)	$\parallel c \approx \perp c$ $\parallel c \approx \perp c$

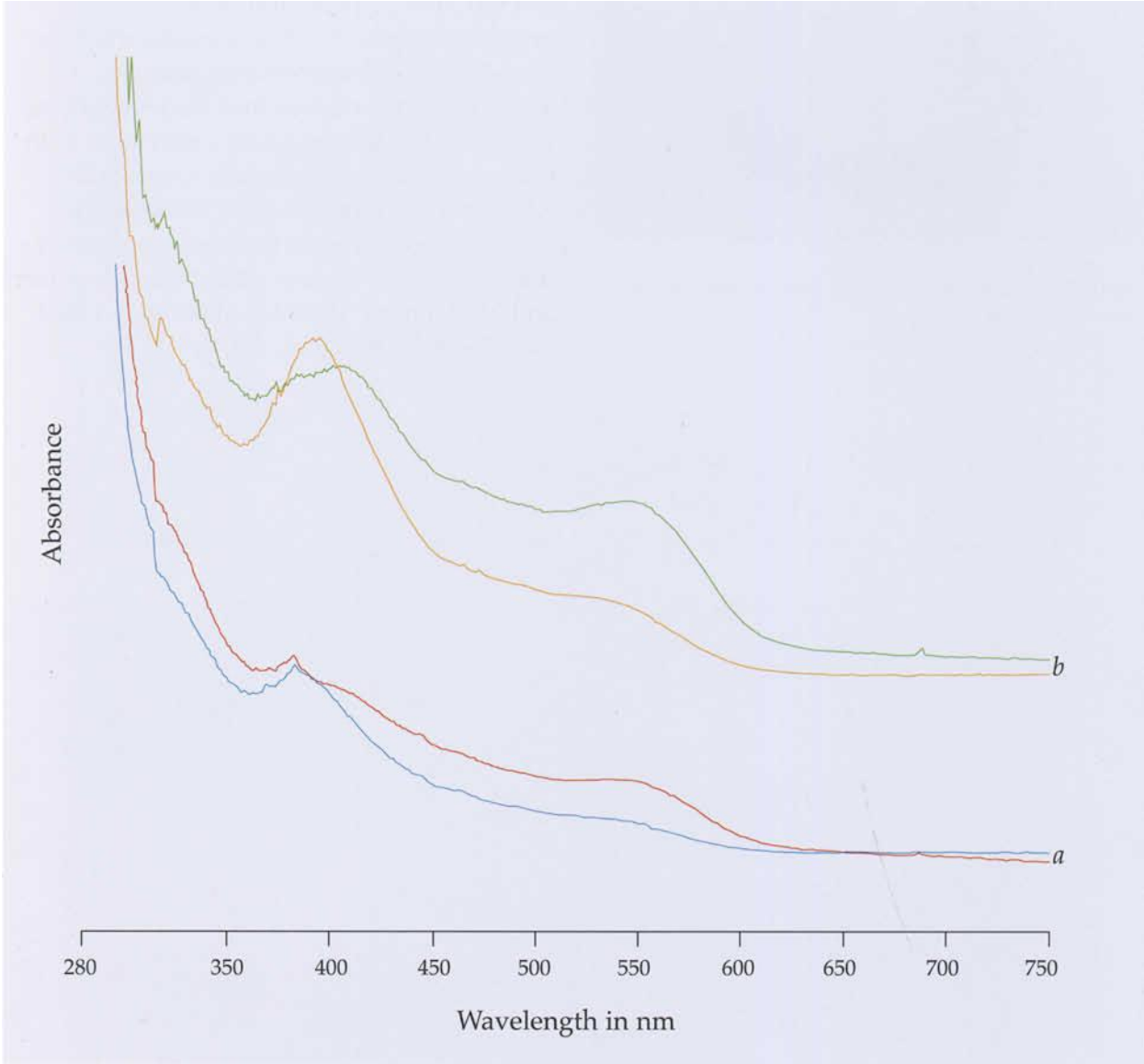

Figure 6: Polarized absorption spectra of an untreated yellowish-orange (a) and an untreated pinkish-orange (b) padparadscha from Sri Lanka; pleochroism of the samples is mainly due to differences in the chromium spectrum parallel (blue, yellow) and perpendicular (red, green) to the c-axis.

The label above all spectra shows the position of absorption maxima and their assignment, OCC = 'orange' colour centres.

colourless Sri Lanka sapphires is restored by exposure to various types of radiation, for example sunlight, UV light, X-ray or gamma-radiation (Nassau and Valente, 1987; for further details of the reaction of yellow Sri Lanka sapphires to various types of treatments the reader should refer to this detailed paper).

Absorption spectra of yellow Sri Lankan sapphires reveal an almost continuously increasing absorption from red to the violet part of the visible range, occasionally with small absorption bands of Fe^{3+} (Schmetzer and Bank, 1981; Schmetzer *et al.*, 1983). According to the low iron concentration (*Table IV, Figure 5*), the intensity of Fe^{3+}-

Figure 7: Untreated yellow sapphire from Sri Lanka of 5.97 ct. (Photo by M. Glas)

related absorption bands of such samples (see *Table V*), in general, is too small to influence the colour of the samples. An additional weak absorption band at about 470 nm may be present in a few yellow sapphires (*Figure 8*), i.e. at a position where the Mg-related absorption maximum of 'orange' colour centres may be present (see *Table II*). After a long search a specimen with these spectroscopic properties was found, which showed undisturbed three-phase inclusions, confirming that this sapphire was not heat treated (see Koivula, 1986; Schmetzer and Medenbach, 1988; De Maesschalck and Oen, 1989; Francis *et al.*, 2003).

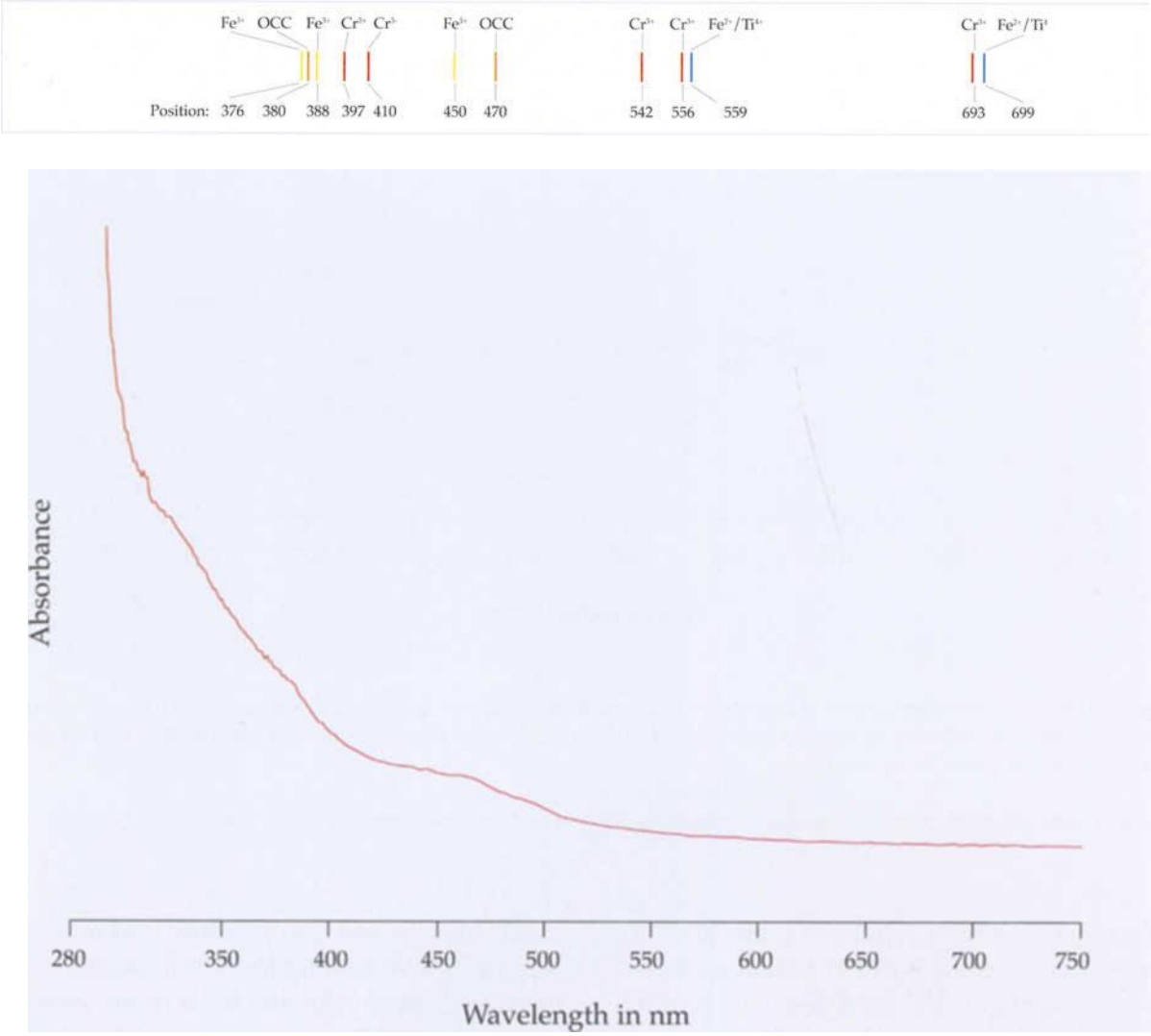

Figure 8: Absorption spectrum of untreated yellow sapphire from Sri Lanka; the spectrum shows an increasing absorption from the red to the violet part of the visible range; small iron bands as well as a weak absorption band due to 'orange' colour centres (OCC) are also present.

The 470 nm absorption and the always-present ultraviolet component can be produced or intensified by irradiation of originally colourless or pale yellow sapphires from Sri Lanka. The coloration of such orange irradiation-treated samples is unstable and the absorption band of the 'orange' colour centres can be removed by low temperature heat treatment and even in sunlight (see Schmetzer *et al.*, 1983; Pisutha-Arnond *et al.*, 2004).

Probably, the two spectroscopic features described above for yellow sapphires from Sri Lanka are independent of each other, but it is not yet possible to identify which may be the cause of colour in any one stone. Because almost all defect centres known in sapphires, whether or not related to Mg, reveal an absorption band in the ultraviolet or violet (see *Tables I* and *II*), the low energy tail of which extends into the visible range, an assignment to one of these centres is not possible at present. It is conceivable that the 470 nm absorption is caused by Mg-related 'orange' colour centres, but no further data exist to support this assignment. Further research, for example careful heat treatment experiments of untreated Sri Lankan samples combined with spectroscopic examination, is needed to resolve these problems.

Heat treated chromium-free yellow, yellowish-orange or orange sapphires (*Figure 9*) reveal an absorption spectrum consisting of two components, i.e. an absorption in the ultraviolet extending to the visible and small peaks or distinct shoulders in the 450-470 nm range (*Figure 10*); some of these spectra are also superimposed by weak Fe^{3+} bands at 450, 388 and 376 nm (see *Figure 10a*). According to the intensity of both components of this absorption spectrum, i.e. the maximum in the UV extending to the visible and the 470 nm band, these samples are yellow (weaker absorption) or become more or less yellowish-orange to almost orange (more intense absorption).

At present, it is not clear if the 380 nm maximum known from synthetic Mg-doped 'impure' sapphires is also present. It should be mentioned, however, that the 470 nm absorption is always accompanied by a strong UV component. Thus, if we speak about sapphires with thermally stable 'orange' colour centres, we have to consider the presence of the 470 nm absorption band together with the 380 nm maximum and/or a distinct UV component (see *Table II*). Both components of the spectrum of heat treated yellow to yellowish-orange sapphires might be independent of each other, or both might be caused by an orange, Mg-related colour centre. The maximum in the UV, however, might also be due to another defect with or without Mg (see *Table I*).

Upon radiation treatment of heat treated, chromium-free corundums of this type, 'orange' colour centres are produced and the 470 nm absorption band is intensified. These colour centres are unstable and can be removed by low temperature heat treatment (Schmetzer *et al.*, 1983), as described above for non-heat treated irradiated Sri Lankan sapphires.

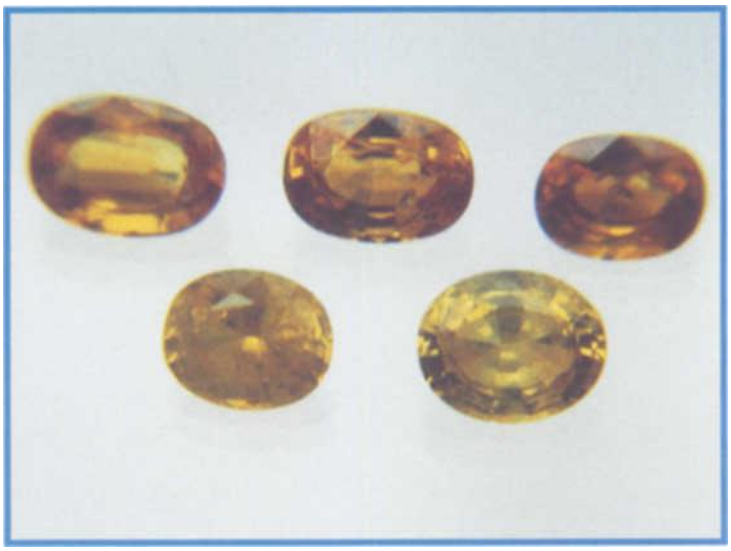

Figure 9: Heat treated yellow (lower row) and yellowish-orange (upper row) sapphires from Sri Lanka; range of samples from 1.59 to 2.33 ct. (Photo by M. Glas)

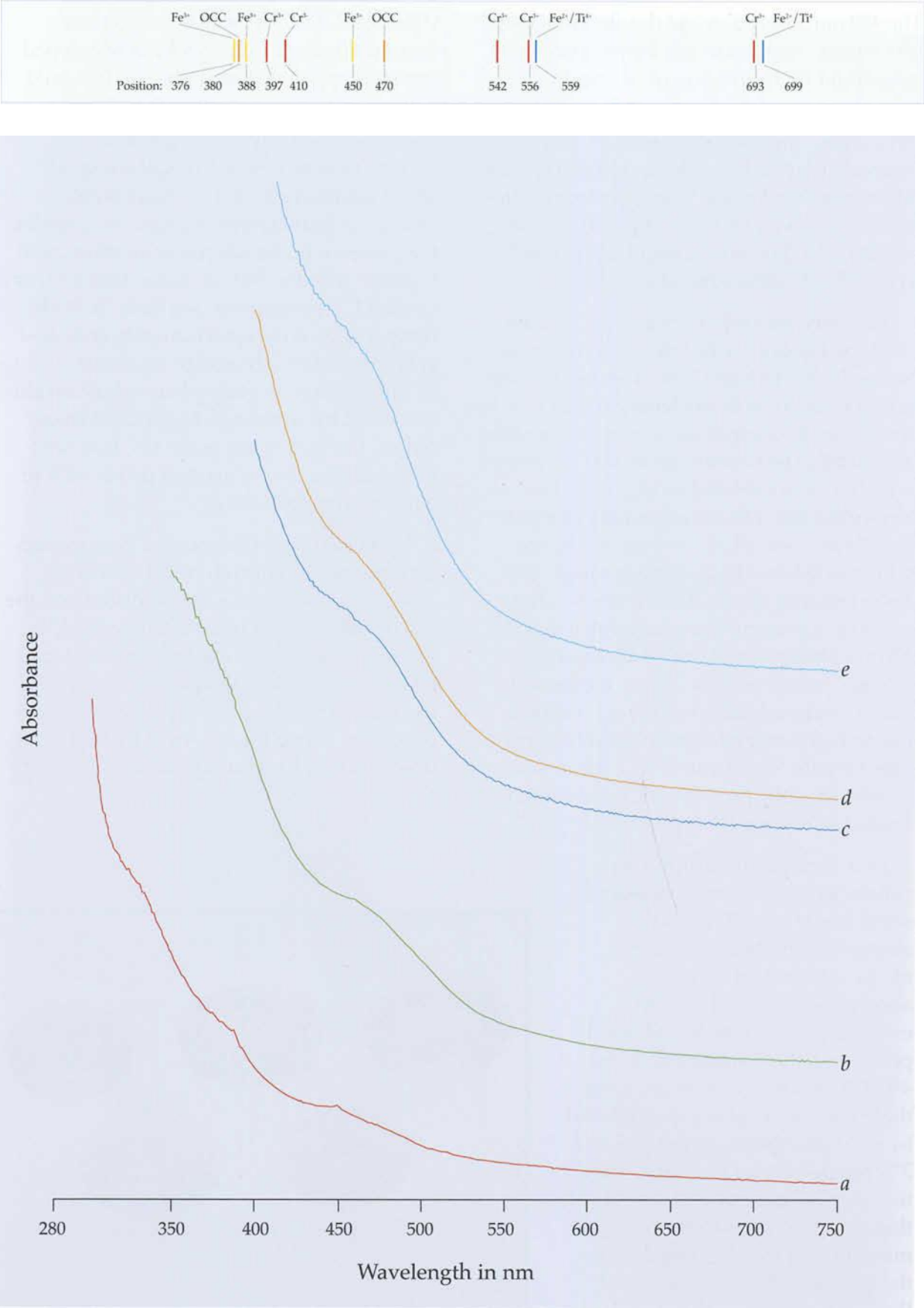

Figure 10: *Absorption spectra of heat treated yellow and yellowish-orange sapphires from Sri Lanka; the spectra show increasing absorption from red to the violet part of the visible range on which is superimposed an absorption band of the 'orange' colour centre (OCC); with increasing intensity of both absorptions (a to e), the colour of the samples changes from yellow to yellowish-orange; weak absorption bands of Fe^{3+} are also present occasionally; spectra b to e are vertically displaced for clarity.*

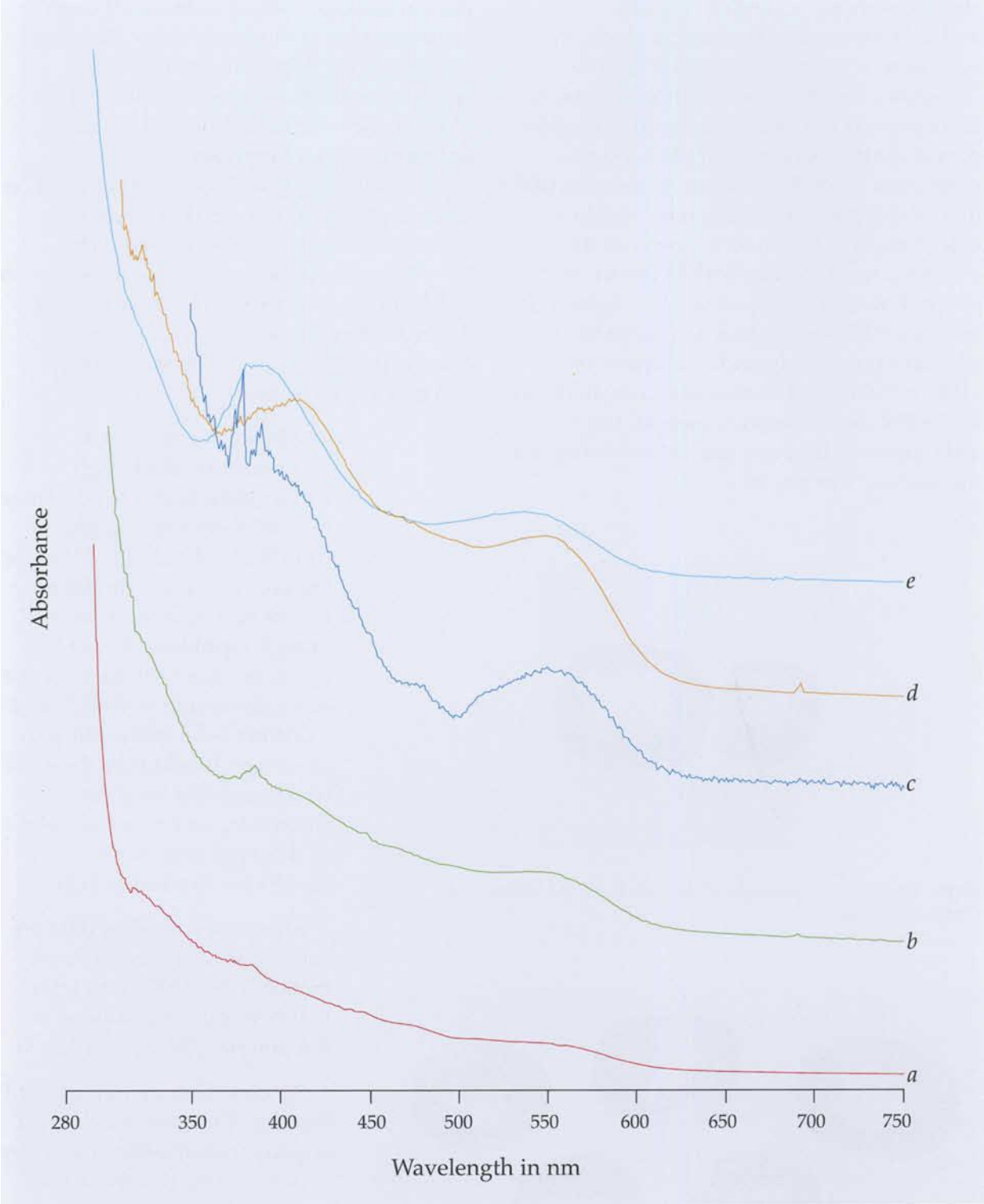

Figure 11: Absorption spectra of untreated yellowish-orange and pinkish-orange padparadscha sapphires from Sri Lanka; the spectra show increasing absorption from red to the violet part of the visible range on which is superimposed the absorption bands of chromium; weak absorption bands of Fe^{3+} are sometimes present, and the presence of a weak band at 470 nm assigned to 'orange' colour centres is also shown. Yellowish-orange samples reveal a strong absorption caused by 'yellow' colour centres and weak chromium bands, and with increasing chromium absorption (a to e), the colour of the samples changes to pinkish-orange or even reddish-orange; spectra b to e are vertically displaced for clarity.

b. Untreated and heat treated yellowish-orange to reddish-orange chromium-bearing sapphires (padparadschas)

Spectroscopic properties of the untreated chromium-bearing samples (*Figures 2 a, b,* and *12*) examined in the present study are consistent with literature data (*Figure 11*). In yellowish-orange samples, the increasing absorption in the visible range due to yellow colour centres is dominant over the two chromium absorption bands, and in pinkish-orange samples the reverse relationship is observed. Between the two however, there is a continuous transition both in colour and in spectral peak heights and no clear separation between yellowish-orange to orange to pinkish-orange padparadscha 'types' is evident. Additional weak maxima or shoulders in the UV are sometimes present, but the assignment of these spectral features is beyond the scope of this paper.

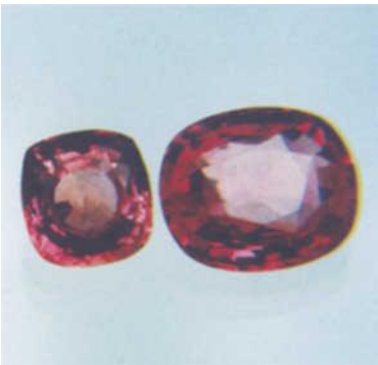

Figure 12: Untreated padparadschas from Sri Lanka of 1.88 and 3.04 ct. (Photo by M. Glas)

Figure 13: Heat treated padparadschas from Sri Lanka; range of samples from 1.08 to 3.20 ct. (Photo by M. Glas)

It is extremely difficult to decide whether 'orange' colour centres with an absorption at 470 nm together with an additional UV component are present in all untreated padparadschas from Sri Lanka. Although some samples in this study show these peaks they are never dominant. In most such spectra, the weak 470 nm absorption appears in intensities comparable to that found in untreated yellow sapphires (see *Figure 8*). In some samples a weak Fe^{2+}/Ti^{4+} absorption (blue sapphire component) or weak Fe^{3+} absorption bands are also present. The Fe^{2+}/Ti^{4+} absorption is seen only in orange to reddish-orange Sri Lankan sapphires with distinct colour zoning, i.e. with yellow, orange, pinkish-orange or reddish-orange and blue colour zones.

Absorption spectra of chromium-bearing, high temperature heat treated orange to reddish-orange sapphires from Sri Lanka (*Figure 13*) show features which are similar to that of heat treated yellowish-orange sapphires (*Figure 14*, compare *Figure 10*); they consist of an absorption in the UV and a distinct band in the 450-470 nm range. In addition, there are two absorption bands of chromium, and many samples of this type also show absorption bands due to Fe^{3+}.

These spectroscopic data are consistent with the results of Notari (1996, 1997), and with the chemical compositions of the samples (*Table IV, Figure 5*).

As described by Emmett and Douthit (1993), the production of padparadscha-like colours by oxidizing heat treatment of pink Montana sapphires is also

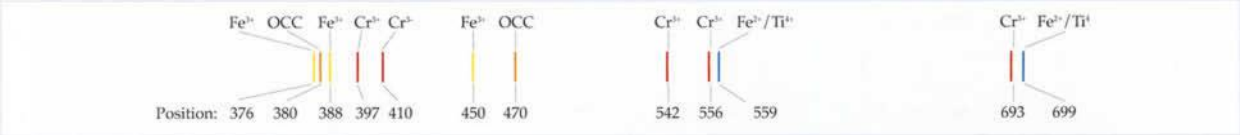

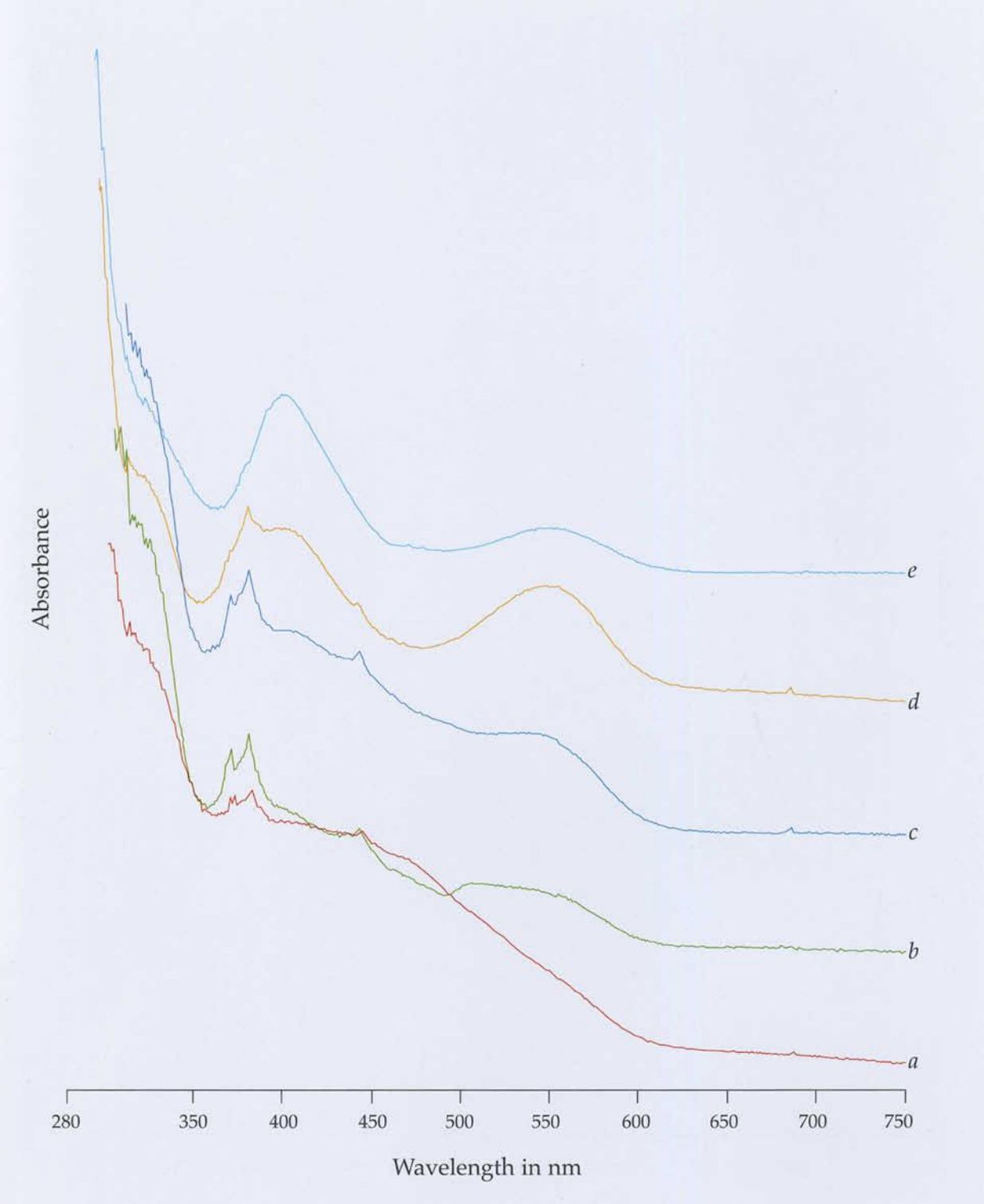

Figure 14: *Absorption spectra of heat treated orange to reddish-orange padparadscha from Sri Lanka; the spectra consist of the absorption bands of 'orange' colour centres at 470 nm with an additional UV component and the absorption bands of chromium in corundum; weak absorption bands of Fe^{3+} are sometimes present. Yellowish-orange samples reveal a strong absorption caused by 'orange' colour centres and weak chromium bands; with increasing chromium absorption (a to e), the colour of the samples changes to pinkish-orange or reddish-orange; spectra b to e are vertically displaced for clarity.*

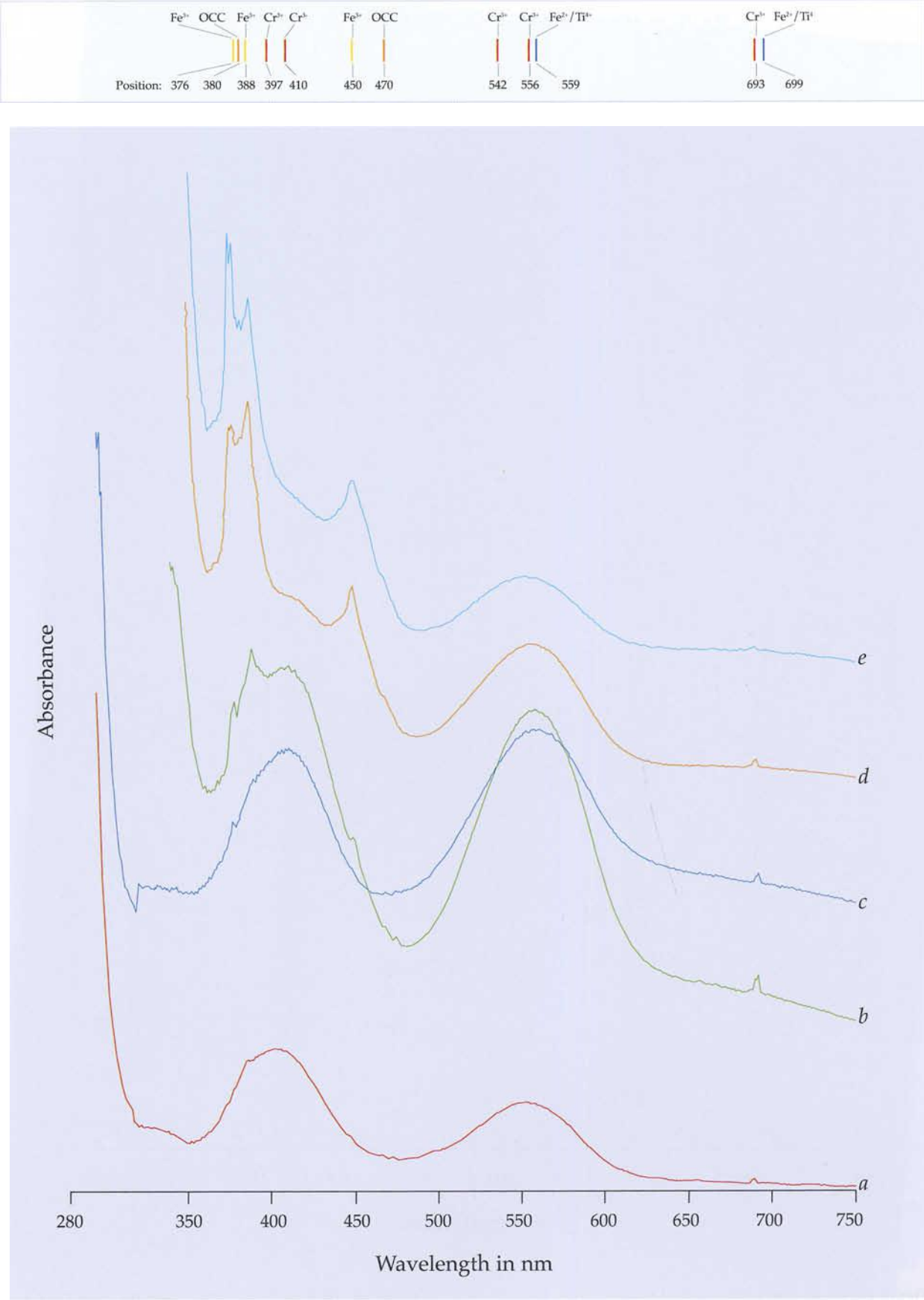

Figure 15: *Absorption spectra of untreated sapphires from Ilakaka, Madagascar; pink samples (a) show the absorption spectrum of chromium and, occasionally, weak absorption bands of Fe^{3+}; samples with additional Fe^{2+}/Ti^{4+} absorption (blue sapphire component) are purple or violet (b, c); samples with strong absorption bands of Fe^{3+} are yellowish-orange (d) to brownish-orange or orange-brown (e); spectra b to e are vertically displaced for clarity.*

possible. This colour change is caused by the development of 'orange' colour centres in the heat treatment process giving absorption spectra similar to those obtained from Sri Lankan corundums in the present study.

Ilakaka

Ilakaka sapphires show a wide range of colours, dependent on their trace element contents. The wide colour range is comparable to that found in sapphires from Umba, Tanzania and these also show similar spectroscopic and microscopic features (see for example Schmetzer and Bank, 1980, 1981; Gunawardene, 1984; Hänni, 1987; Notari, 1996, 1997, Schmetzer, 1999).

a. Untreated sapphires

According to the chemical (see *Table IV*, *Figure 5*) and spectroscopic properties and colour of diffusion treated samples, the untreated samples used for colour improvement by Be-diffusion are related to two colour series, i.e. to samples of the series pink, purplish-pink, purple, purplish-violet, violet (*Figure 16a*) and to samples of the series pink, yellowish-pink, yellowish-orange, brownish-orange, orange-brown, yellowish-brown (*Figure 16b*). The brownish-orange colour of some samples with high iron and chromium contents may resemble that of pinkish-orange padparadscha from Sri Lanka (see *Figure 3*). Most samples of both colour series reveal a distinct shift of colour when moved from daylight to incandescent light.

The absorption spectra obtained from all untreated Ilakaka sapphires of the first series (*Figure 15*) show the absorption bands of Cr^{3+} (pink). Also present are weak bands of Fe^{3+} and the strong Fe^{2+}/Ti^{4+} absorption of blue sapphire. With increasing intensity of the latter absorption band, the colour of chromium bearing samples changes from pink to violet. By simple heat treatment in an oxidizing atmosphere, the band is, at least partly, removed and the samples turn more or less intense pink. A large percentage of the pink Ilakaka sapphires in the trade are heat treated originally purple to violet stones, but there are a few untreated pink sapphires from this source.

Ilakaka sapphires of the second colour series show spectra (*Figure 15*) with strong overlapping Cr^{3+} (pink) and Fe^{3+} absorption bands (yellow). With increasing intensities of the iron bands, the colour of this type of sapphire changes from pink through yellowish-orange to brownish-orange, orange-brown and yellowish-brown.

b. Beryllium diffusion treated sapphires

Just as there is a wide variety of colour in the untreated material, so the colours of

Figure 16a: Untreated Ilakaka sapphires of the pink to violet colour series; range of samples from 0.51 to 1.38 ct. (Photo by M. Glas)

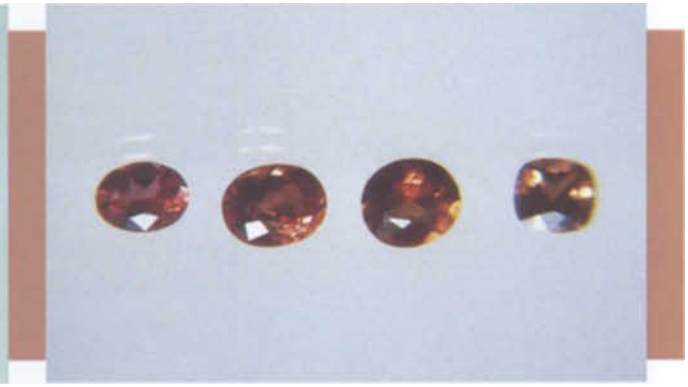

Figure 16b: Untreated Ilakaka sapphires of the pink to orange-brown colour series; range of samples from 0.48 to 1.30 ct. (Photo by M. Glas)

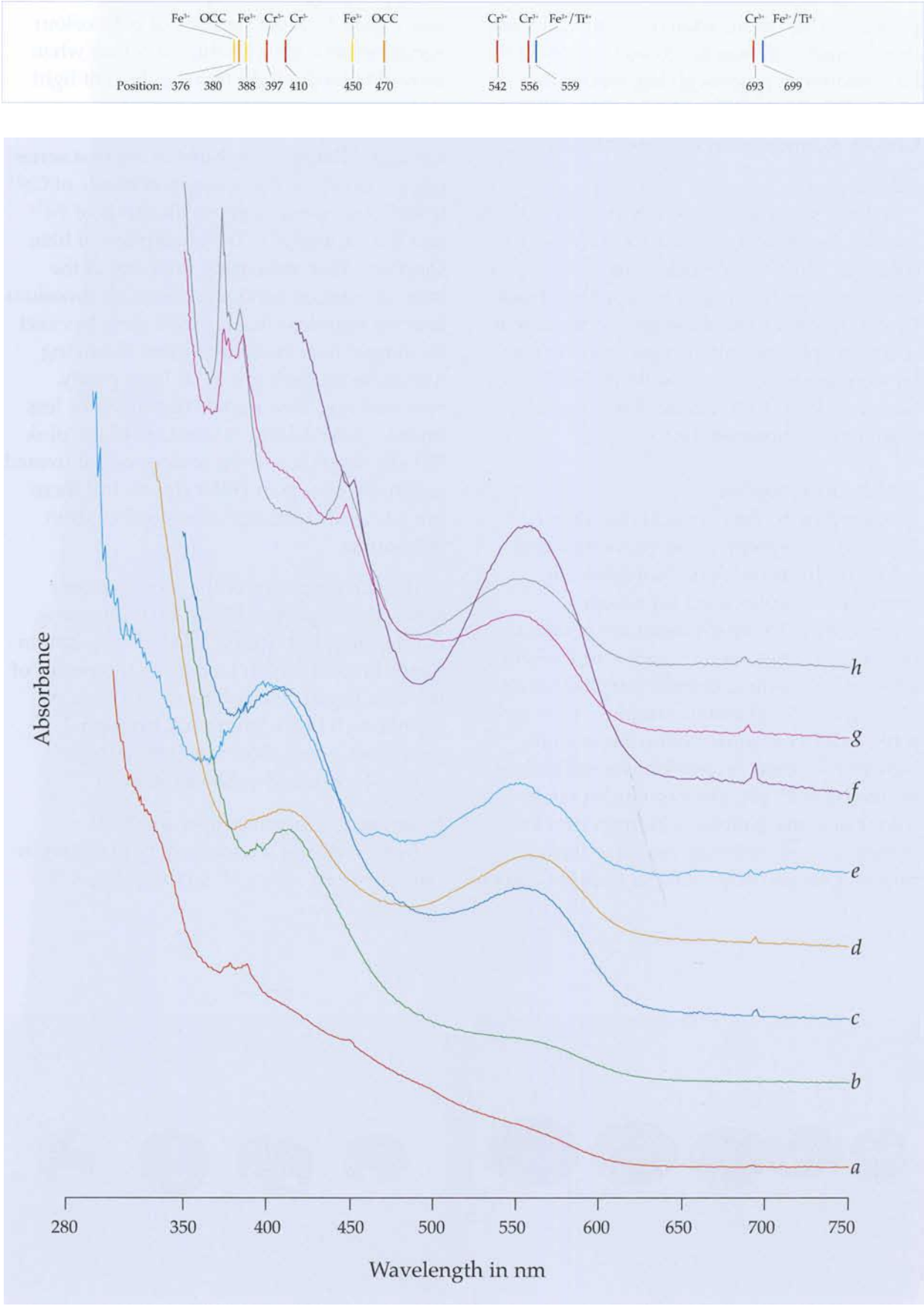

Figure 17: Absorption spectra of Be-diffusion treated sapphires from Ilakaka, Madagascar; differences in the Cr:Fe ratio and the intensity of the 'orange' colour centre cause a wide variety of colours; samples with low chromium and iron contents (a) are yellowish-orange; with increasing chromium contents (b to f), the colour changes to orange, pinkish-orange and orangey-red; samples with higher iron contents (g, h) are reddish-orange or brownish-orange; spectra b to h are vertically displaced for clarity.

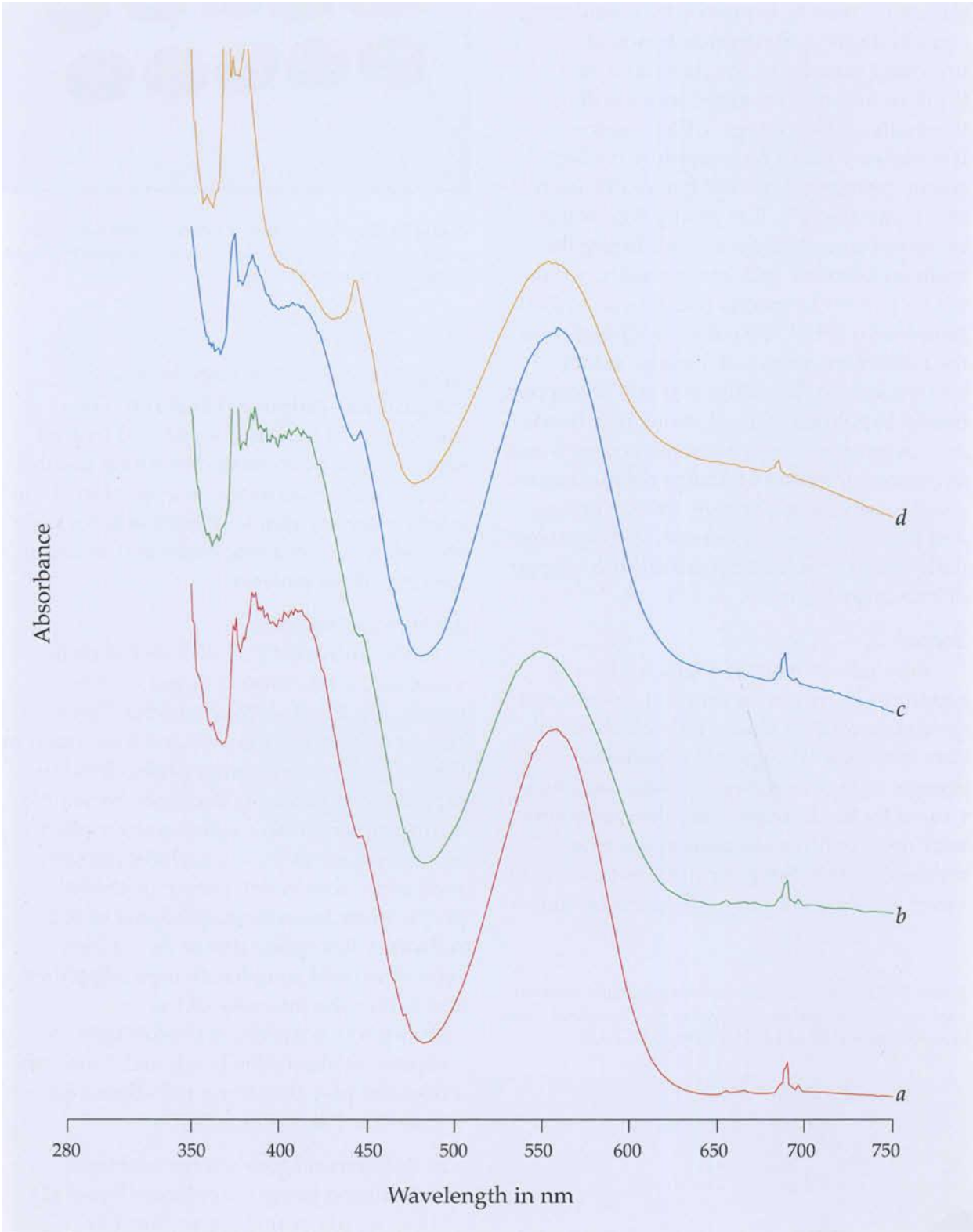

Figure 18: Absorption spectra of untreated rubies and purple to violet sapphires from Songea, Tanzania, consist of a chromium absorption spectrum combined with a more or less intense blue sapphire component; more of the latter causes a colour shift from red towards violet (a to d); spectra b to d are vertically displaced for clarity.

Be-diffusion treated sapphires may be of different shades of pinkish-orange, yellowish-orange, orange and brownish-orange (*Figure 19*). All absorption spectra (*Figure 17*) may be explained by considering combinations of absorption bands of untreated samples of the chromium-iron (pink to brownish-orange) series with thermally stable 'orange' colour centres. If there were also a blue sapphire (violet) colour component present before diffusion treatment, the Fe^{2+}/Ti^{4+} absorption would be almost completely removed during the treatment process and, consequently, would not be present in spectra of diffusion treated samples. In detail, the colour is a function of the relative intensities of 'orange' colour centres and the chromium and iron absorption bands. Sapphires without strong iron bands are – with increasing chromium contents and decreasing intensity of orange colour centres – yellowish-orange, orange, intense orange and pinkish-orange or orangey-red; samples with higher iron contents are reddish-orange or brownish-orange.

Songea

Although untreated Songea rubies and sapphires show a wide range of colours and spectra, according to spectral and chemical data (see *Table IV*, *Figure 5*) of yellowish-orange, orange or reddish-orange sapphires treated by Be-diffusion, only the chromium-bearing sapphires are used as starting materials. Many Songea rubies and purple to violet sapphires reveal a colourless or almost colourless core and a more intense red, purplish-red, purple or violet rim. Thus, the colours of both untreated and treated sapphires are often related to strong colour zoning; i.e. the coloration is a function of the relative sizes of almost colourless cores and the different colour intensities and shades in the rims of the material.

Figure 19: Beryllium diffusion treated Ilakaka sapphires reveal a great variation in colour; range of samples from 0.34 to 0.65 ct. (Photo by M. Glas)

Figure 20: Untreated Songea sapphires which are commonly used for diffusion treatments are red to purple or violet; range of samples from 0.48 to 3.45 ct. (Photo by M. Glas)

a. Untreated sapphires

In the untreated purplish-red, purple, violet and a few brownish-red sapphires (*Figure 20*), the absorption spectra (*Figure 18*) consist of chromium (ruby) and iron-titanium (blue sapphire) absorption peaks. This blue sapphire component is decreased by simple heat treatment in an oxidizing atmosphere and the colour of these sapphires changes somewhat from violet, purple or reddish-purple more towards purplish-red or red. A distinct absorption due to Fe^{3+} is also present in most samples. In these sapphires and rubies the intensity of the Fe^{3+} absorption, however, is weaker than the chromium absorption bands and, thus, iron does not play the strong role discussed above for Ilakaka samples.

b. Beryllium diffusion treated sapphires

Diffusion treated sapphires (*Figure 22*) show no remaining significant blue sapphire component because this absorption has been almost completely removed by the Be-diffusion treatment.

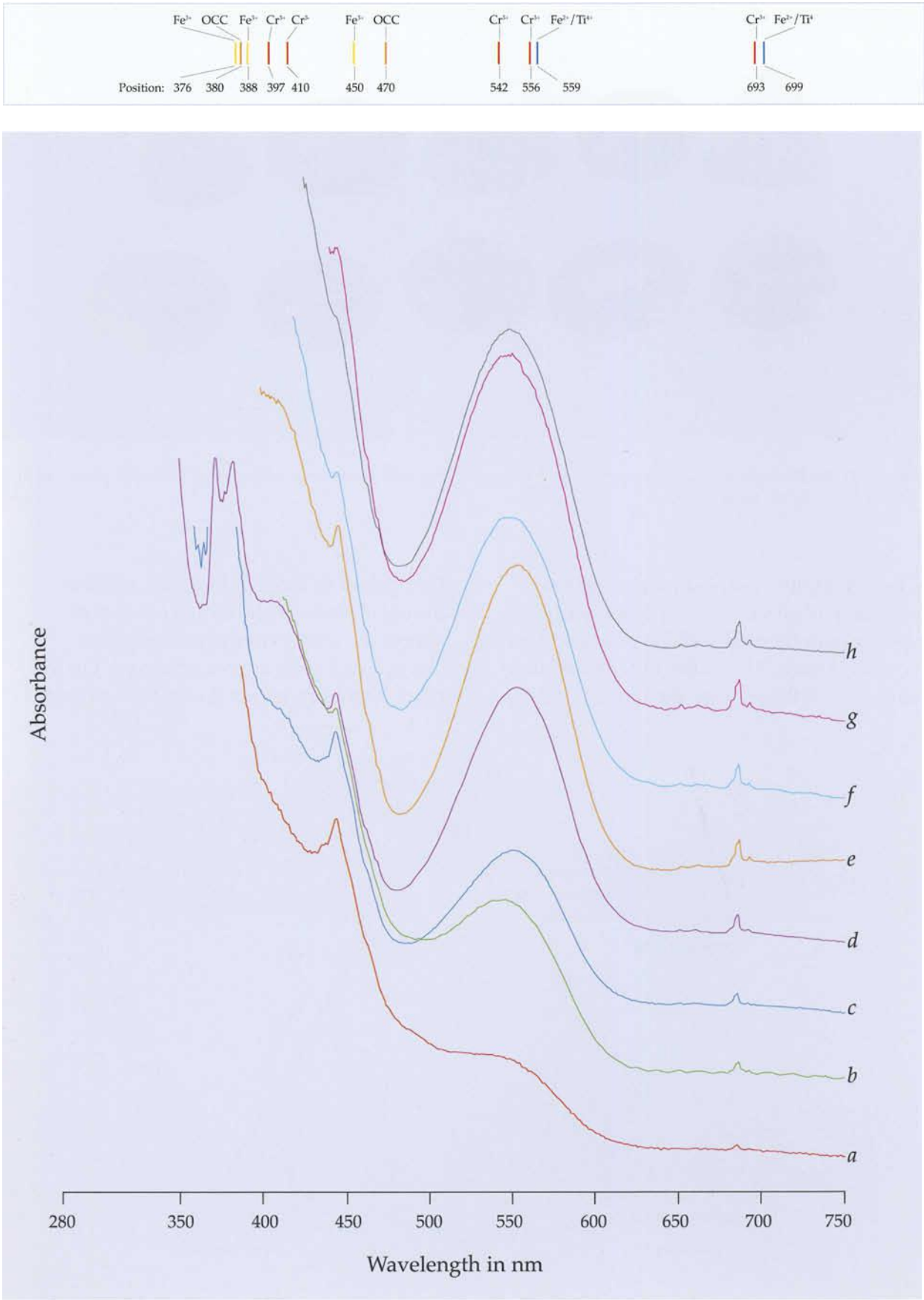

Figure 21: *Absorption spectra of Be-diffusion treated sapphires from Songea, Tanzania; according to the chromium content and the intensity of orange colour centres, orangey-yellow, yellowish-orange, orange, pinkish-orange or orangey-red sapphires may be observed (a to h); samples with higher iron contents are reddish-orange; spectra b to h are vertically displaced for clarity.*

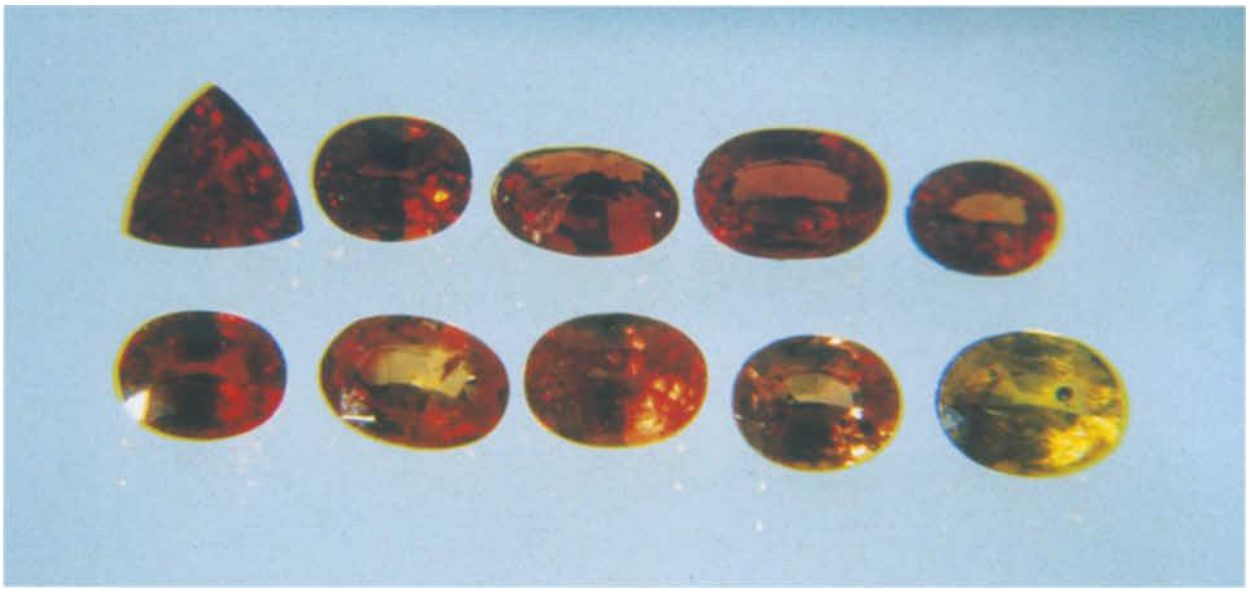

Figure 22: Beryllium diffusion treated sapphires from Songea reveal a great variation in colour; range of samples from 0.30 to 0.64 ct. (Photo by M. Glas)

These samples revealed an absorption spectrum of chromium combined with a spectrum of thermally stable orange colour centres (*Figure 21*) and the different relative strengths of these cause the range in colours.

Compared to Ilakaka samples, reddish-orange or brownish-orange colours of sapphires with extremely strong iron absorption bands are not observed. On the other hand, orangey-red samples are more

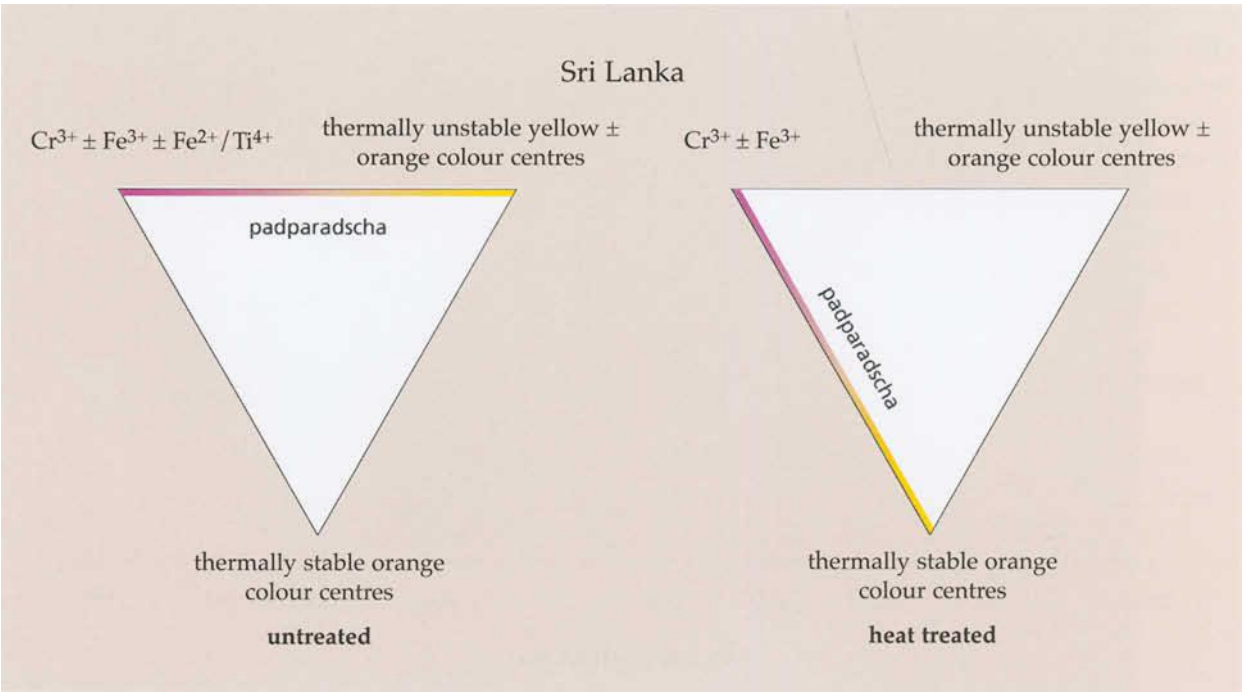

Figure 23a: Schematic representation of causes of colour in untreated and heat treated padparadscha and yellowish-orange sapphire from Sri Lanka; in untreated samples, the dominant causes of colour are thermally unstable 'yellow' colour centres and chromium, with some 'orange' colour centres also being present; in heat treated padparadschas, thermally stable 'orange' colour centres and chromium are present.

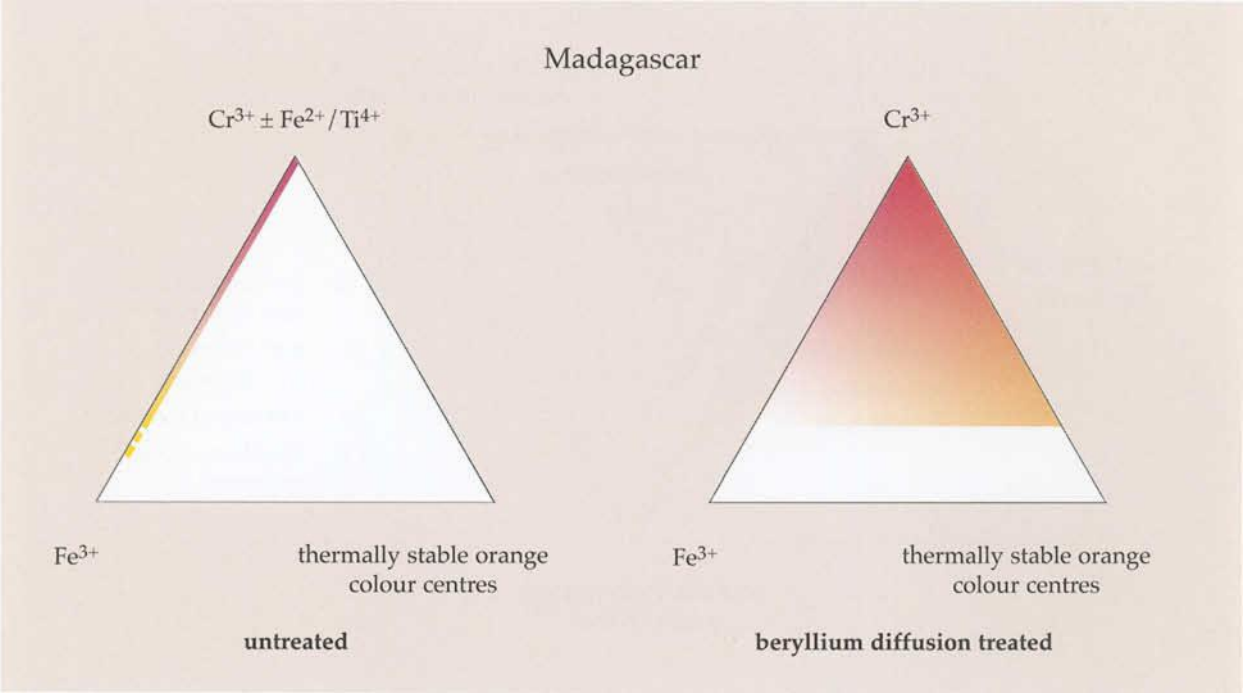

Figure 23c: Schematic representation of causes of colour in untreated and Be-diffusion treated sapphires from Ilakaka, Madagascar; in untreated samples the dominant causes are chromium and iron, with a blue sapphire component also being present in some purple or violet samples; in diffusion treated samples, chromium, iron and thermally stable 'orange' colour centres are present and cause the wide variation of colours observed.

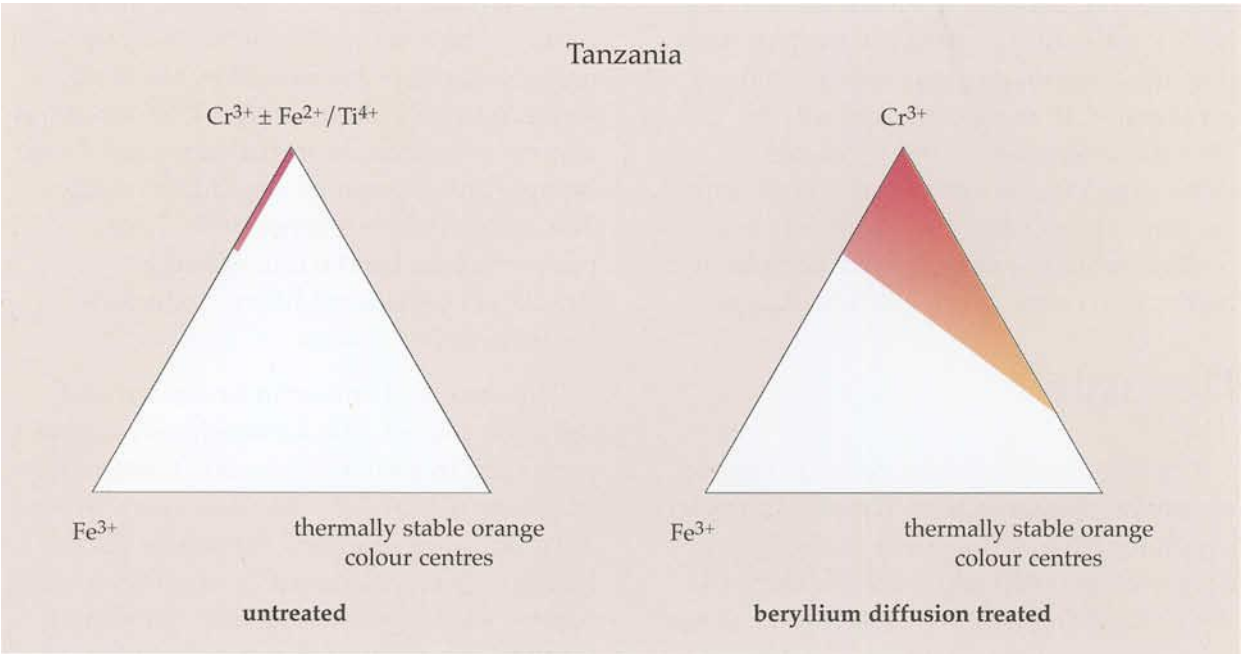

Figure 23b: Schematic representation of causes of colour in untreated and Be-diffusion treated sapphires from Songea, Tanzania; in untreated samples the dominant cause is chromium with a blue sapphire component also being present in some purple or violet samples, absorption bands of Fe^{3+} are subordinate; in diffusion treated samples, chromium and thermally stable 'orange' colour centres are present and cause the wide variation of colours observed.

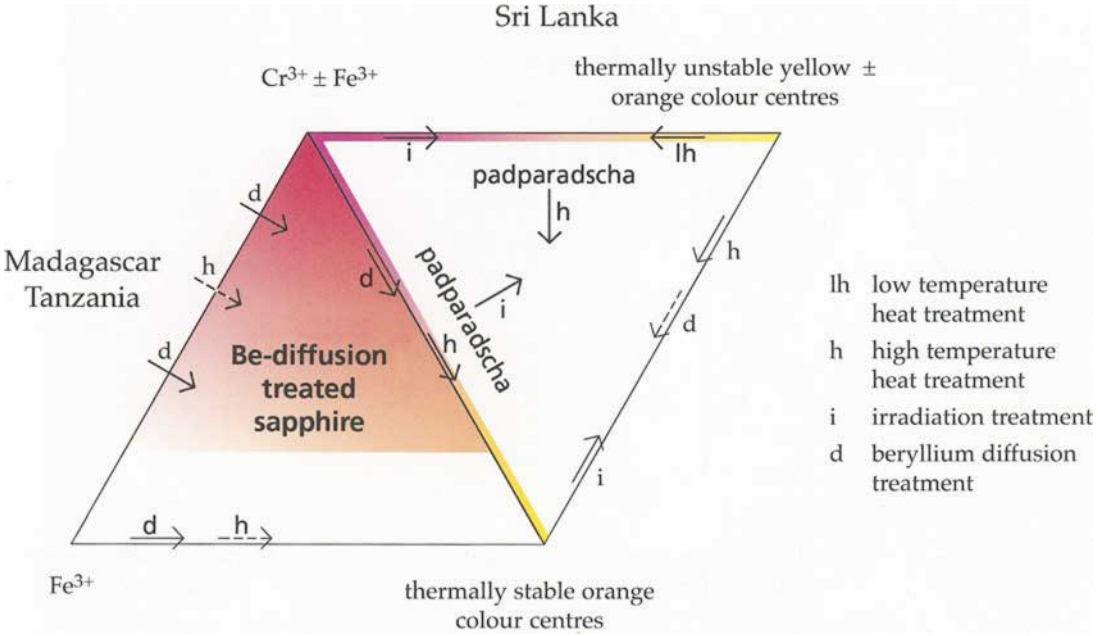

Figure 24: This schematic diagram summarizes the causes of colour in untreated, heat treated and diffusion treated sapphires in the yellow to red colour range; approximate directions of the change of colour by heat treatment, diffusion treatment and irradiation are indicated with arrows. Dashed arrows indicate possible colour changes due to various treatments of specific samples (for example heat or diffusion treatment of originally yellow, chromium-free sapphires), which were not explicitly described in the text.

Thermally unstable 'yellow' and/or 'orange' colour centres are present in untreated padparadscha and yellow sapphires from Sri Lanka. Thermally stable 'orange' colour centres are developed by simple heat treatment or by diffusion treatment of samples from different localities. These thermally stable 'orange' colour centres add to the main causes of colour present before treatment, i.e. iron and chromium.

often found, and this is consistent with the higher chromium contents of samples from this area. Again, a colour series can be arranged with increasing intensity of chromium absorption bands versus decreasing intensity of orange colour centres, i.e. from yellowish-orange to orange and pinkish-orange or orangey-red, samples with higher iron contents are reddish-orange.

Discussion

Considering the results presented above, we might present untreated and heat treated sapphires from Sri Lanka in triangular diagrams to better illustrate the causes of their colour (*Figure 23a*). Even if some visual colour impressions might be very similar, there is a clear separation between unheated and heat treated materials. The colours of unheated sapphires are due to thermally unstable 'yellow' colour centres and chromium and may show also an additional weak 470 absorption of 'orange' colour centres. The colours of heat treated yellowish-orange sapphires are caused by thermally stable 'orange' colour centres. If chromium is also present, these heat treated sapphires are orange, pinkish-orange or reddish-orange. The colours of both types of Sri Lanka padparadscha can be intensified by irradiation causing additional extremely unstable colour centres.

The causes of colour in untreated and diffusion treated Ilakaka sapphires are also presented in similar schematic triangular diagrams (*Figure 23b*). The dominant causes are chromium, iron and thermally stable colour centres; no thermally unstable colour centres are found in sapphires from this locality. It is evident that orange colour centres are added to the iron- and chromium-related coloration of untreated sapphires by the diffusion process. The Fe:Cr ratio varies widely in natural and treated material causing the great variety of colours observed.

Triangular diagrams (*Figure 23c*) show the causes of colour in untreated and diffusion treated samples from Songea, Madagascar. As for the Ilakaka sapphires, the basic causes are iron, chromium and thermally stable colour centres, but the Fe:Cr variation is smaller. More intense colours are due to generally higher chromium contents. Colour changes on treatment are due to the formation of orange colour centres and the decrease in any blue sapphire component. None of the diffusion treated orange samples examined contained more iron than chromium.

A schematic diagram (*Figure 24*) summarizes colours, their causes and the reaction to various treatments of untreated, heat treated and beryllium diffusion treated sapphires from all three localities. Thermally unstable 'yellow' and/or 'orange' colour centres are removed by low temperature heat treatment. High temperature heat treatment causes the development of thermally stable 'orange' colour centres. By beryllium diffusion treatment, similar or identical 'orange' colour centres are developed. By irradiation, unstable colour centres are added to the pre-existing coloration. This type of radiation induced coloration is extremely unstable and can be removed by low temperature heat treatment or upon simple exposure to daylight.

Further research

What could be the next steps in research? According to the fact that some samples, which became yellow or orange-yellow by diffusion treatment, had trace element ratios with (Mg + Be) > Ti, but also with Mg > Ti (see, for example, the analyses presented by Pisutha-Arnond *et al.*, 2004), the difference in colour change between normal heat treatment and diffusion treatment in such samples is questionable. In other words: the real necessity of beryllium diffusion for samples with Mg > Ti is not clear because such samples do not need the addition of beryllium to create a trace element distribution with (Mg + Be) > Ti. Thus, such sapphires should transform to yellow or orange-yellow also without the addition of beryllium (according to the models of Häger and Emmett).

To evaluate the colour change of such samples and to confirm the model described above, slices or pieces of colourless samples should be subjected to both heat and diffusion treatment in order to compare the intensity of colour change of treated samples originating from the same crystal after both types of treatments. It would be of considerable interest if the model were to be confirmed by determination of the trace element chemistry of sapphires which do not become yellow or orange-yellow by normal heat treatment but do so by Be-diffusion treatment. The trace element chemistry should confirm that the Ti-Mg-Be ratio is really Mg < Ti for samples which do not turn yellow or orange-yellow by simple heat treatment, but (Mg + Be) > Ti for the same samples, which become yellow or orange-yellow by diffusion treatment. At present, such analytical data are available for one originally blue diffusion treated sapphire (Pisutha-Arnond *et al.*, 2004), and data from more samples should confirm the model. Furthermore, it would be interesting to search for originally colourless samples which do not become yellow following heat or Be-diffusion treatment. Is the chemistry of such samples after diffusion treatment really Ti > (Mg + Be)?

To clarify the role of iron and chromium and the charge compensating mechanism between Be, Mg, Ti, Cr and Fe, the reaction of samples with different magnesium, titanium, iron and/or chromium contents to both, heat and diffusion treatment, should also be examined. For this research the treatment of colour zoned samples, e.g. the diffusion treatment of zoned Songea rubies and sapphires and the comparison of trace element contents and colour change in identical growth zones within untreated and treated parts of the same sample should provide interesting information. Up to now, traverses across treated samples have mostly been done without detailed knowledge of any zoning within the untreated material and without information about the crystallographic growth sectors that were analysed and their orientation within the sapphire crystals studied.

Additional research is also necessary to understand:

- The structure of 'yellow', 'orange', 'brownish' and 'brownish-violet' colour centres in detail (related to various absorption maxima such as 500, 470, 420 and 380 nm);
- The nature of the defect or defects causing thermally unstable 'yellow' and/or 'orange' colour centres in untreated Sri Lankan sapphires, which is as yet unknown;
- For synthetic and natural Be- and/or Mg-bearing untreated or diffusion treated sapphires, the detailed structures of defect centres which are related to various possible (Be-Mg-Fe-Cr) clusters and how they cause colour; and details of their formation and reaction upon heat treatment.

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Book Reviews

Crystal growth and development interpreted from a mineral's present form

B.Z. KANTOR, 2003: The Mineralogical Almanac, Moscow. pp 128, illus. in colour, softcover. ISBN 5 900395 46 4. Price €39.00. *The Mineralogical Almanac* 6/2003.

As almost every opening (double-page spread) of this quite attractively illustrated book shows at least two photographs of fair size the text is in fact quite short. The author's thesis is that the present appearance of a mineral can give you clues to at least some of the vicissitudes which it has undergone through (I suppose, recent) geological time. The chapters cover, among other subjects, twinning, crystal families, order and disorder and the development of stalactites. There is a bibliography but it is too short to be really useful: the quality of the photographs is fair. It is not carping to say that the author's style and perhaps some uncertainty in the translation from the original Russian to English do not make for easy reading. It is not quite clear what points, rather than descriptions, the author is trying to make. None the less the various roads taken by the author can be followed by the reader even if he reaches a destination different to the one imagined at the opening of the text. M.O'D.

Geology of gems

E. YA KIEVLENKO, 2003. English edn. Ocean Pictures Ltd., 4871 S. Dudley St, Littleton CO 80123-1942, U.S.A. pp 432, xxxii, illus. in colour, hardcover. ISBN 5 900395 25 1. Price [from Germany] €99.

This very large text on appropriate and attractive heavy paper and translated from the Russian, is a praiseworthy attempt to review and describe the geological occurrence of inorganic ornamental materials (other than diamond but including amber) and is the only survey of this kind to appear in English for many years. I am discounting Van Landingham's rather misleadingly titled *Geology of world gem deposits* (1985), as this was a compilation and reproduction of papers by various authors.

The present text covers the major gem minerals in general order of importance. Each chapter follows a similar scheme in which a general description of the material is followed by notes on geological genetic types of deposits. Taking beryl as an example, the author lists pegmatites, greisens (ultramafic and carbonate black shale) hydrothermal and placer deposits. For tourmaline we are given pegmatites, contact metasomatic deposits, metamorphic and placer deposits.

Careful attention to the contents is necessary as there is no index, a very serious omission to say the least. There is no heading for quartz though both amethyst and chalcedony have individual entries. While allowing for the inevitable difficulties in translation it is hard to escape a first suspicion that the treatment of the main subject may be eccentric – this is always a possibility with a large single-author work. Further reading dispels this impression to a large extent.

Though the book is large there are no black and white photographs; however most openings show at least one diagram. Coloured illustrations are placed together in a separate section at the end of the text. The type-face is clear and the lines double-spaced, considerately for the determined reader.

To examine the text more closely I chose the chapter on tourmaline, expecting to find at least a mention of the work on California pegmatites by Jahns and Wright (1951) – it is there and includes two reproduced diagrams. This was a relief! The major tourmaline deposits are well presented. In general in this and other chapters Russian deposits are covered first. The garnet group is equally well handled and includes some descriptions of kimberlite pipes, making up for the absence of a diamond chapter!

More than 900 references are given in a separate section at the end of the main text. The abbreviations of titles of the major journals in Russian are expanded before the reference section begins. The colour plates at the end of the book show spectacular examples of gem minerals and are, in general, well reproduced (though it is hard to distinguish between azurite and malachite in the picture of St. Isaac's Cathedral at St Petersburg – this is hardly a serious fault. Sizes and provenance are given.

Though it is not cheap, I am happy to be able to recommend this book not only on the grounds of the scarcity of similar monographic treatments of the subject in English but also because so much information is so well presented. There are some inconsistencies – nomenclature includes some names not now encouraged – but faults are few. M.O'D.

The petrographic microscope

D.E. KILE, 2003. The Mineralogical Record, Tucson, AZ, U.S.A. pp 96, illus. in colour. Softcover. Special publication no.1.

This account of the history, aim, design and workings of the petrographic microscope forms the first of a new and welcome series from *The Mineralogical Record*. Microscopes of this kind are collected as much as used and no doubt dealers in scientific instruments will welcome this issue. The sub-title is 'Evolution of a mineralogical research instrument' and the first chapter explains the author's use of the adjective petrographic rather than the more familiar petrological through the terms refer to the same instrument – it is only the usage which varies. Succeeding chapters deal with plane-polarized light with the evolution and development of the microscope through the early 1900s. Accessory equipment could be quite considerable and is described. The use of the universal stage made the microscope a formidable tool and other devices, including the Michel-Levy comparator and the numerous accessories used with reflective light microscopy are not forgotten.

The bibliography extends to 10 pages and the photographs are clear and informative. M.O'D.

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Gem-A Conference 2004

To be held on Sunday 31 October at Kempton Park Racecourse, Sunbury on Thames, Middlesex

In conjunction with the late autumn Rock 'n' Gem Show

Keynote lecture

Tom Chatham: Created diamonds ... a stone who's time has come ... are you ready?

Dr Ronald L. Bonewitz: Placer sapphire mining is Montana, USA

Elisabeth Strack: Cultured pearls

Ross N. Chapman: Australian opal

Adrian Levy: The Amber Room – the fate of the world's greatest lost treasure

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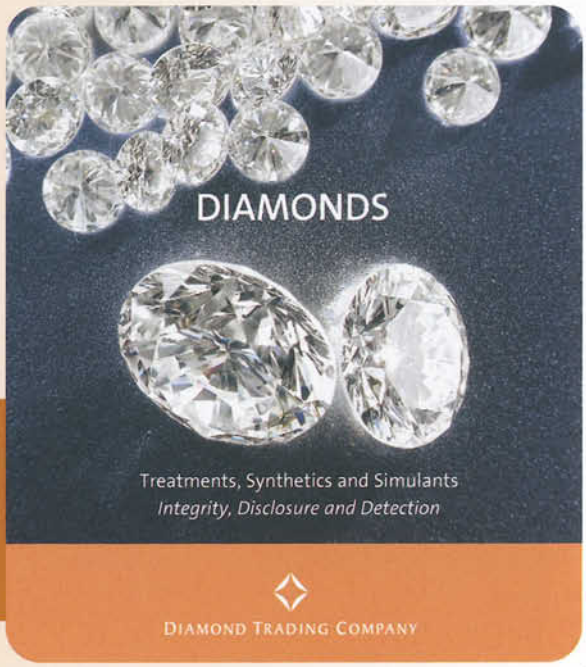

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Proceedings of the Gemmological Association and Gem Testing Laboratory of Great Britain and Notices

Photo Competition

The 2004 Photographic Competition on the theme 'Imaginative Images' drew a record number of entries of very high quality, illustrating creative gem cuts and mineral carvings, fanciful inclusions and gems, as the inspiration of jewellery design.

First Prize
Alan Hodgkinson FGA DGA, Portencross by West Kilbride, Scotland – *Limonite framework in topaz*

Second Prize
Zeng Chunguang FGA, Singapore – *Macle diamond*

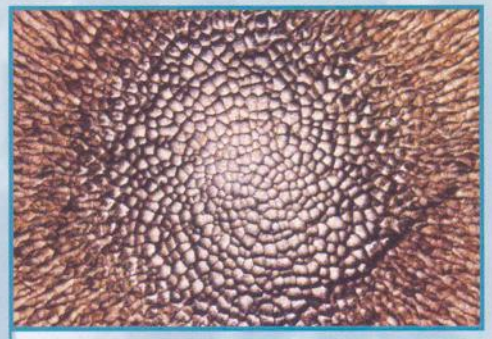

Third Prize
Susan Stocklmayer FGA, Perth, Western Australia – *Pearl centre*

We are pleased to announce that the prizes were sponsored by Harley UK, and the Association is most grateful to them for their generosity. The winning entries will be exhibited at the Annual General Meeting to be held on 14 September and at the Gem-A Annual Conference on 31 October.

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Donations

The Council of Management are most grateful to the following for responding to the appeal for donations. Donation levels were Circle of Benefactors (£5000 and above), Diamond (£1000 to £4999), Ruby (£500 to £999), Emerald (£250 to £499), Sapphire (£100 to £249) and Pearl (£25 to £99).

The following join those donors listed in previous issues of *The Journal*.

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Christopher D.Tarratt FGA, Stoneygate, Leicestershire

Gifts

The Association is most grateful to the following for their gifts for research and teaching purposes:

Maggie Campbell Pedersen FGA, London, for a plastic statuette of a horse purchased on E-bay for £7.00 but described as '17th century rare cherry amber'!

The **Diamond Trading Company** for literature on diamonds and mining.

Makhmout Douman, Arzawa Mineralogical Inc, for natural and synthetic yellow diamond grit, and a faceted demantoid from Russia; crystals and faceted samples of diaspore and kammererite, a blue chalcedony cabochon and a faceted honey-coloured opal from Turkey; demantoid garnet crystals from Iran; tourmaline rough from East Africa; Mali garnet rough; spinel crystals from Vietnam; and a faceted 5.17 ct aquamarine from Pakistan.

Jean-Marie Duroc-Danner FGA, Geneva, Switzerland, for a half boule and a brilliant-cut sample of colbalt-doped green synthetic Verneuil sapphire imitating emerald, produced by Djeva, Monthey, Switzerland.

John R. Führbach FGA, Amarillo, Texas, U.S.A., for the following rough: agate, alabaster, obsidian, moldavite var. bediasite, opalized chert (UV fluorescent), Whitetail deer teeth, petrified palm tree root and petrified wood from Texas; shells from Texas/Gulf of Mexico; augite, labradorite (not bytownite), peridot (including specimens from Kilbourne Hole) and smithsonite from New Mexico; amethyst and baboon teeth from Zambia; orthoclase feldspar from Nevada; amethyst from Brazil/Zambia; beryl and emerald from Brazil; serpentine sawn rough with demantoid crystals attached from Canada; volcanic rock from Tien Shan Mts, Kyrzygstan; flint, quartz and pink crystals (not identified).

Vanessa Paterson, Arnold, Nottingham, for crystals including peridot from Pakistan, garnet, feldspar, spinel octrahedra in matrix and black onyx; faceted danburite and black onyx; and synthetic specimens including cubic zirconia, colourless and bi-coloured flame fusion corundum boules, hydrothermal and flame fusion ruby, flux spinel, flux melt emerald, Kyocera Polar opal, opal doublet, faceted alexandrite, faceted colourless and yellow YAG, and synthetic zincite.

Alexandros Sergoulopoulos FGA DGA, Athens, Greece, for a 0.32 ct laser drilled diamond.

Members' Meetings

Midlands Branch

On 30 April at the Earth Sciences Building, University of Birmingham, Edgbaston, Terry Davidson gave an illustrated talk entitled Bond Street Jewellers of the 19th and 20th centuries. The meeting also included the Branch AGM when David Larcher, Gwyn Green, Elizabeth Gosling and Stephen Alabaster were re-elected President, Chairman, Secretary and Treasurer respectively.

On 26 June at Barnt Green the annual Summer Supper Party was held.

North East Branch

On 19 May at the offices of Evans of Leeds Ltd, Millshaw, Leeds, Maggie Campbell Pedersen gave a presentation entitled 'Organics – gems from life'.

North West Branch

On 19 May at Church House, Hanover Street, Liverpool 1, Mark Barrows gave a talk on gem diamonds as a commercial commodity and an overview of the diamond industry in general.

On 16 June at Church House Peter Buckie gave a presentation entitled 'Valuations – are they worth it?'

Scottish Branch

The Annual Scottish Branch Conference was held in Perth from 30 April to 3 May. The keynote speaker was John Koivula of the GIA Research Laboratory. A report was published in the June issue of *Gem & Jewellery News*, **13**(2), pp 44-45.

On 14 June at the British Geological Survey, Murchison House, West Mains Road, Edinburgh, Fred Woodward, an expert in the study of molluscs and their conservation, gave a talk entitled 'Scottish pearls'.

South East Branch

The Annual South East Branch Conference was held from 28 to 31 May in Idar-Oberstein, Germany. A report will be published in the September issue of *Gem & Jewellery News*.

Membership

Between 1 April and 30 June 2004 the Council of Management approved the election to membership of the following:

Honorary Life Members

It was unanimously agreed that Professor Dr Edward J Gübelin of Lucerne, Switzerland, and John I. Koivula of Carlsbad, California, U.S.A., be awarded Honorary Life Memberships in recognition of their work on gemstone inclusions.

Fellowship (FGA)

Andronikou, Stamatina, Didsbury, Lancashire, 2004
Kwok Nai Chiu, Hong Kong, 2004
Lalitha, R., Chennai, India, 2004
Latumena, Warli, Jakarta, Indonesia, 2004
Leung Kit Ling, Junk Bay, Hong Kong, 2004
Lowe, Mimi, San Francisco, California, U.S.A., 2002
Panjikar, Jayshree, Mumbai, India, 1997
Sequeira, Sylvia, Mumbai, India, 1996
Tseng Chien Min, Changhua City, Taiwan, 2004
Yeung Ho Man, Hong Kong, 2004

Diamond Membership (DGA)

Chan Kin Yuen, Hong Kong, 2004
Cheng, Suk Man, Hong Kong, 2004
Heywood, Natalie L., Enfield, Middlesex, 2004
Ho Siu Ming, Hong Kong, 2004
Johnson, Adam Jules, Edgbaston, West Midlands, 2004
Kau Yuk Ming, Eddie, Hong Kong, 2004
Paterson, Deborah Louise, Northampton, 2004
Wat Wing Suet, Hong Kong, 2004

Associate Membership

Bayoumi, Nevin, London
Di Dio, Alfredo, Avellino, Italy
Harris, Nigel, Cockermouth, Cumbria
Hewa Gamage, Srinath Prasanna, Nugegoda, Sri Lanka
Jensen, Karen, L, Houston, Texas, U.S.A.
McQuaid, Rory, Otley, West Yorkshire
Makohon, Galina, Harrow, Middlesex
Meechan, Margaret, London
Michalcova, Silvia, London
Music, Laurence, Northwood, Middlesex
Olumuyiwa, Remi, Brentford, London
Plain, Lyndsey, Pogmoor, Barnsley, South Yorkshire
Price, Carol, Calgary, Alberta, Canada
Pugh, Madeleine, Canterbury, Kent

Pye, Collette, Liverpool, Merseyside
Quinlan, Doe, London
Quint, Camilla M., London
Rentsch, Jean-Marc, Zurich, Switzerland
Steller, Helen Rachael, Whitefield, Greater Manchester
Sumanaweera, Hiran K, Dar es Salaam, Tanzania
Sutton, Bruce David, Windsor, Berkshire
Tosinthiti, Chom, Chiang Mai, Thailand
Wilkinson, June, Peterborough, Cambridgeshire
Williams, Yvona, Newmarket, Suffolk
Yartey, Eric, Southall, Middlesex

Laboratory Membership

Gabi S. Tolkowsky & Sons BVBA, Antwerp, Belgium

Transfers

Diamond Membership to Fellowship and Diamond membership (FGA DGA)

Borahan, Fatma O., Instanbul, Turkey
Deligiannis, Marios, Athens, Greece
Ngan Hin Wah, Michael, Hong Kong

Fellowship to Fellowship and Diamond membership (FGA DGA)

Barnett, Catherine E., Balham, London
Jackson, Antoinette, London
Lee Young Ji, Kyunggido, Korea
McMillan, Emma L., Solihull, West Midlands

Associate membership to Fellowship and Diamond membership (FGA DGA)

Filadelfeos, Eleni-Anna, Athens, Greece

Associate Membership to Fellowship (FGA)

Holman, Meryan, London
Singh, Gurmit, New Delhi, India
Underwood, Thom, San Diego, California, U.S.A.

Associate Membership to Diamond Membership (DGA)

Berthault, Alexandra, London
Hislop, Donna, London
Kaffo, Moulero Bassiti., Hounslow, Middlesex
Lesetedi, Madichaba-Nzapheza, Billesley, Birmingham, West Midlands
Prince, Ronald F., Richmond, Surrey

Obituary

Anthony French FGA

A tribute by Michael O'Donoghue

Tony French, one of the best-known dealers in rare gemstones and pioneer of the gemstones for students scheme by which items from his stock were lent to examination candidates and others, died suddenly and unexpectedly near his Somerset home on Tuesday 27 April 2004.

Tony was born in Peckham, south London, but was evacuated in the early years of the Second World War to Horsham, Sussex. Sadly, during this time his mother and an aunt were killed in an air raid. Tony began to study for and succeed in many of the examinations of the textile trade in which he spent a number of years.

The London gemmology world will remember Tony's partnership with the late Alan Fleming and Christopher Cavey, both FGA's, in Roughgems, a near-unique venture which became well-known first for charoite and then for Russian specimens of diamonds in matrix. When Alan retired to New Zealand and Christopher started his own business, Tony carried on Roughgems until moving to Brockenhurst in the New Forest to take on a jewellery shop with his wife Nola. Tony then ran his gemstone business from their home in Evercreech, Somerset, and commuting, for Nola, became a fixed feature of their life until recently when she retired.

Both ends of the two enterprises were supervised by a succession of 'French' dogs – the late André and Pierre, and Raoul who is still happily with Nola and helping her in many ways.

Tony had an enviable stock of fine and rare gemstones, most from Sri Lanka but including unusual synthetic stones too. His manual skills enabled him to produce beautiful furniture and ornaments in wood, many of which he sold.

Tony was a big man in every way and could have been nothing but English; he was able to keep critical thoughts and opinions to himself rather than voice them - this was a notable victory. He was very kind. His epic battles with computers and printers remained unresolved at the end with honours about even. Though he had ceased smoking his pipes which ought to be in a smokers' museum as a lesson to rookie smokers, I shall always think of him when I encounter pipe smoke. I already miss him.

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Forthcoming Events

22 August	**South East Branch:** Can provenance be valued? *David Lancaster*
12 September	**South West Branch:** An afternoon with organics. *Maggie Campbell Pederson*
14 September	**London:** Annual General Meeting.
15 September	**North West Branch:** Emeralds. *Alan Hodgkinson*
24 September	**Midlands Branch:** Colour in natural and artificial diamonds. *Professor Alan Collins*
29 September	Private Viewing of the Crown Jewels with David Thomas, the Crown Jeweller
6 October	**Scottish Branch:** The coloured stone business from a global perspective. *Guy Clutterbuck*
19 October	**Scottish Branch:** Inclusions in amber. *Neil Clark*
20 October	**North West Branch:** The trade industry today. *Marcus McCallum*
29 October	**Midlands Branch:** Gems of the seven continents. *E. Alan Jobbins*

Gem-A Conference 2004

To be held on Sunday 31 October at Kempton Park Racecourse, Sunbury on Thames, Middlesex

In conjunction with the Rock 'n' Gem Show

Keynote speaker: Tom Chatham

Further details are given on p.184

1 November	**Presentation of Awards:** Goldsmiths' Hall, London EC2
16 November	**Scottish Branch:** Gemstones of Mozambique. *Roger Key*
17 November	**North West Branch:** Branch AGM and social evening
26 November	**Midlands Branch:** Bring and Buy Sale and Quiz
4 December	**Midlands Branch:** 52nd Anniversary Dinner

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Guide to the preparation of typescripts for publication in *The Journal of Gemmology*

The Editor is glad to consider original articles shedding new light on subjects of gemmological interest for publication in *The Journal*. Articles are not normally accepted which have already been published elsewhere in English, and an article is accepted only on the understanding that (1) full information as to any previous publication (whether in English or another language) has been given, (2) it is not under consideration for publication elsewhere and (3) it will not be published elsewhere without the consent of the Editor.

Typescripts Two copies of all papers should be submitted on A4 paper (or USA equivalent) to the Editor. Typescripts should be double spaced with margins of at least 25 mm. They should be set out in the manner of recent issues of *The Journal* and in conformity with the information set out below. Papers may be of any length, but long papers of more than 10 000 words (unless capable of division into parts or of exceptional importance) are unlikely to be acceptable, whereas a short paper of 400-500 words may achieve early publication.

The abstract, references, notes, captions and tables should be typed double spaced on separate sheets.

Title page The title should be as brief as is consistent with clear indication of the content of the paper. It should be followed by the names (with initials) of the authors and by their addresses.

Abstract A short abstract of 50-100 words is required.

Key Words Up to six key words indicating the subject matter of the article should be supplied.

Headings In all headings only the first letter and proper names are capitalized.

A This is a first level heading

B *This is a second level heading*

First and second level headings are in bold and are ranged left on a separate line.

Third level headings are in italics and are indented within the first line of text.

Illustrations High resolution digital files, for both colour and black-and-white images, at 300 dpi TIFF or JPEG, and at an optimum size, can be submitted on CD or by email. Vector files (EPS) should, if possible, include fonts. Match proofs are essential when submitting digital files as they represent the colour balance approved by the author(s).

Transparencies, photographs and high quality printouts can also be submitted. It is recommended that authors retain copies of all illustrations because of the risk of loss or damage either during the printing process or in transit.

Diagrams must be of a professional quality and prepared in dense black ink on a good quality surface. Original illustrations will not be returned unless specifically requested.

All illustrations (maps, diagrams and pictures) are numbered consecutively with Arabic numerals and labelled Figure 1, Figure 2, etc. All illustrations are referred to as 'Figures'.

Tables Must be typed double spaced, using few horizontal rules and no vertical rules. They are numbered consecutively with Roman numerals (Table IV, etc.). Titles should be concise, but as independently informative as possible. The approximate position of the Table in the text should be marked in the margin of the typescript.

Notes and References Authors may choose one of two systems:

(1) The Harvard system in which authors' names (no initials) and dates (and specific pages, only in the case of quotations) are given in the main body of the text, (e.g. Collins, 2001, 341). References are listed alphabetically at the end of the paper under the heading References.

(2) The system in which superscript numbers are inserted in the text (e.g. ... to which Collins refers.[3]) and referred to in numerical order at the end of the paper under the heading Notes. Informational notes must be restricted to the minimum; usually the material can be incorporated in the text. If absolutely necessary both systems may be used.

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Papers Collins, A.T., 2001. The colour of diamond and how it may be changed. *J.Gemm.*, **27**(6), 341-59

Books Balfour, I., 2000. *Famous diamonds*. 4th edn. Christie's, London. p. 200

Abbreviations for titles of periodicals are those sanctioned by the *World List of scientific periodicals* 4th edn. The place of publication should always be given when books are referred to.

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Cover Picture: *Limonite framework in topaz.*
Photography by Alan Hodgkinson, FGA DGA, Portencross by West Kilbride, Scotland.

First Prize in the 2004 Photographic Competition (see p.185).

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Pearls from the lion's paw scallop

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In memory of Alexander E. Farn, former Director of the London Chamber of Commerce DPPS Laboratory, Vice President of the Gemmological Association and Gem Testing Laboratory of Great Britain, author and gentleman.

Abstract: *Pearls from the Lion's Paw scallops* Nodipecten (Lyropecten) nodosus *L. 1758 and* Nodipecten (Lyropecten) subnodosus *Sowerby 1835 are rare and have only recently come to the notice of the gemmological community. They are non-nacreous but differ in surface appearance and composition to other non-nacreous pearls such as the Conch and Melo varieties. The surface appearance is comprised of a patchwork of cells with each cell being formed from three sub-cells. The orientation of these sub-cells and the low magnification fibrous appearance of structures within them give the scallop pearl a peculiar surface sheen. SG and Raman data indicate that the perfectly round 5.91 ct scallop pearl described is composed in the main of calcite rather that being dominated by aragonite as is the case for the Melo and Conch pearls. In addition the chemistry, infrared, and UV/visible spectra for the 5.91 ct scallop pearl are described. These data are compared with similar data from lion's paw shells and detailed submicroscopic structures are described for the shells.*

Keywords: *lion's paw scallop,* Nodipecten magnificus, Nodipecten nodosus, Nodipecten subnodosus, *USA*

Introduction

Not frequently seen but relatively well known to gemmologists are those often quite valuable (Shigley *et al.*, 2000) natural pearls, formed within molluscs that do not produce nacre (Gutmannsbauer and Hänni, 1994; Hänni, 1999). Examples of these non-nacreous pearls are the Conch pearl from *Strombus gigas* (Farn, 1977; Fritsch and Misiorowski, 1987; Moses, 2001), the clam pearl from *Tridacna gigas* (Anderson, 1971), the horse-Conch pearl from *Pleuroploca gigantean* and the Melo pearl from any of the various Melo volutes (Brown and Kelly, 1990; Scarratt, 1992, 1996; Traub, 1999). The most

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Figure 1: A Nodipecten subnodosus *shell.*

common of these rare non-nacreous pearls is the spectacular variety produced by *Strombus gigas* or the Queen Conch, and the rarest being the spectacular Melo pearls. Of late another non-nacreous pearl variety, the scallop pearl has become known and thus far a very limited number recorded. The following briefly describes *Nodipecten (Lyropecten) nodosus* L. 1758 (Atlantic Lion's Paw) and *Nodipecten (Lyropecten) subnodosus* Sowerby 1835 (Pacific Lion's Paw) and one particular pearl that was produced by one of these colourful scallops. Another scallop pearl produced by the Atlantic Sea Scallop (Placopecten magellanicus) has also been recently described (Wight, 2004).

The lion's paw scallop: its description, distribution and habitats

The scallops or pectens are bivalves that have been a part of man's existence from the earliest of times, both as a source of food and adornment. The shapes of the shells and wide variety of colours and patterns have caused them to be a significant collector's item, to be the focus of scientific study, to serve as industrial symbols such as that of the oil company Shell, and to feature as the centre piece of art forms. A particularly impressive art form where the focal point is the lion's paw shell (*Figure 1*) (so called as the shell resembles a lion's paw (Anonymous, 2003)) may be seen in a brooch created by Cartier (Paris) *ca.* 1958 (*Figure 2*). The shell is accompanied by turquoise and sapphires and set in gold (Anonymous, 2004), the brooch being valued in the region of $28,000 (Fitzpatrick, 2002).

Of the many scallops there are three bearing the common name Lion's Paw. One of these is the exceedingly rare *Nodipecten magnificus* (Sowerby, 1835) which is largely restricted to the Galapagos Islands (although one was recently dredged off the coast of

Colombia (Hill and Carmihael, 2004)) and given this rarity is not a focus of this paper. The other two are *Nodipecten (Lyropecten) nodosus* L. 1758 (Atlantic Lion's Paw) and *Nodipecten (Lyropecten) subnodosus* Sowerby 1835 (Pacific Lion's Paw), the largest pectinid in tropical waters and the one described as the probable source of the scallop pearl portrayed herein. *N. nodosus* is found in the seas off the south-eastern USA to Brazil and *N. subnodosus* in the seas off western Central America at depths between 25 and 150 m. Together the shell colours are exceptional both in their variety and depth (Hill and Carmihael, 2004). The outer surface of the shell may be several shades of brown, sometimes described as chocolate brown (Norris, 2003) and yellow to orange while the interior varies from pearly white to shades of purple and brown (*Figure 1*). The outer surface of the *N. nodosus* shell most commonly displays several rows of rounded nodular protuberances located on about eight rounded ribs (although many from the southern Caribbean are smooth (Hill and Carmihael, 2004)) potentially differentiating it from shells of *N. subnodosus* which typically have no such protuberances. Both the Atlantic and Pacific Lion's Paws have fan-shaped (typical of scallops in general) equal valves with unequal ears (Wye, 1991).

Scanning electron microscope studies give some insight into the architecture of the lion's paw shell. Classical nacre consists of fine tabular aragonite which provides the typical nacreous lustre.

Non-nacreous shell material from *Strombus gigas* consists of aragonite fibres lying in bunches in crossed arrays (Kamat *et al.*, 2000). The scallop shell displays a different structure. A surface image shows fibres lying in bunches in different directions almost parallel to the surface (*Figure 3*).

The thickness of the fibres is around 0.5 μm. An image of a broken section shows that under the surface the bunches of fibres still have a crossed orientation (*Figure 4*). At higher magnifications the fibres can be seen as geometrically not very well defined rods with the width and depth almost equal (*Figure 5*). At a magnification of 10,000× there is no trace of organic material in or between the fibres.

From the SEM images of the shell (*Figures 3, 4* and *5*) it becomes clear that depending on the direction of light the fibres will be in either a 'conducting' (ends of the fibres towards the light) position and appear dark, or 'reflecting' (other directions towards the light) position and appear light. This phenomenon is also responsible for the shimmering silk-like appearance seen in other shells that have a similar construction, e.g. *Strombus gigas* and the Melo volutes. In these shells too, bunches of fibres are in crossed orientation (Kamat *et al.*, 2000) and either reflect or conduct incoming light but in this case producing the ubiquitous flame-like pattern (Farn, 1977) well known for these materials.

Barrios-Ruiz reports (Barrios-Ruiz *et al.*, 2003) that *N. subnodosus* was cultured in La Paz Bay (1995-1996) and noted that the culture is feasible. However, high water temperatures in La Paz Bay in summer reduced growth and survival rates.

Figure 2: A brooch consisting of turquoise, sapphires and gold set on a lion's paw shell, created by Cartier (Paris) ca. 1958; courtesy of Primavera Gallery, New York, photo Noel Allum.

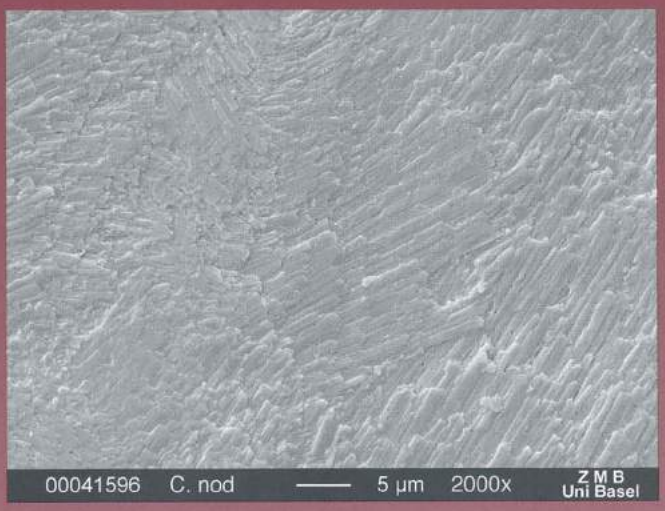

Figure 3: Fibres lying in bunches in different directions almost parallel to the surface of the scallop shell.

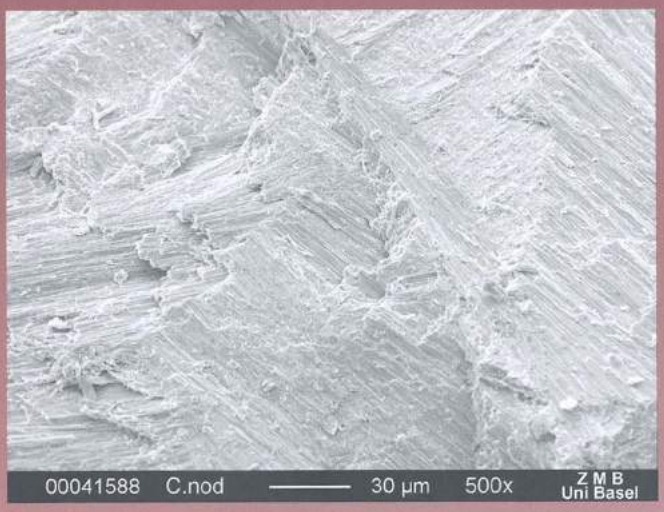

Figure 4: A broken section of a scallop shell shows that under the surface the bunches of fibres still have crossed orientations.

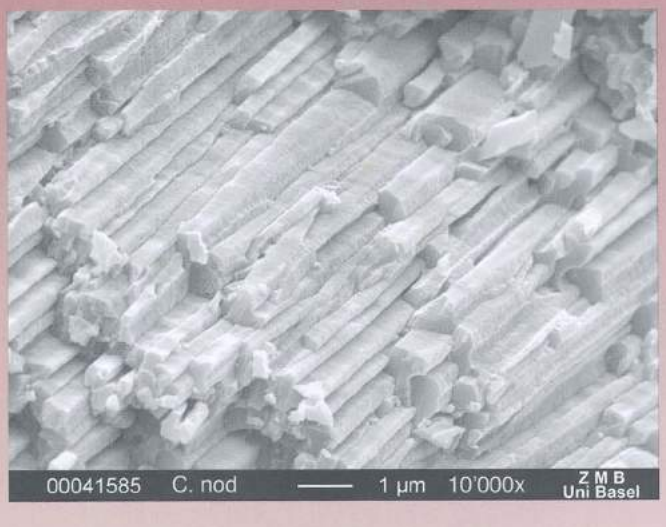

Figure 5: At higher magnifications the fibres in the scallop shell can be seen as rods with width and depth almost equal, but neither round nor square, and not geometrically well defined in cross section.

A natural pearl from the lion's paw scallop

Materials and methods

While the authors have been given the opportunity to view and perform limited examinations on several, they have had the opportunity to complete a detailed examination on only one scallop pearl which is said to be derived from *Nodipecten (Lyropecten) subnodosus*. The data included in this paper are gathered from that one pearl which is perfectly round and weighs 5.91 ct (*Figures 6* and *7*). Several shells of both the Atlantic and Pacific lion's paw types have also been examined and these data are compared with the pearl.

Analytical techniques employed by the authors include microscopy using gemmological microscopes at magnifications ranging from 15 to 60× and the Leica DMLM connected to a Raman microscope at magnifications of up to 1000×. Scanning electron microscopy of shell sections was performed at the University of Basel (ZMB SEM Laboratory) with a Philips ESEM XL 30 FEG with magnifications up to 10,000×; specific gravity (SG) determinations were determined hydrostatically using an appropriately fitted Mettler electronic balance with water at room temperature; UV/visible spectra were recorded in reflectance mode using a Zeiss MCS 500/501 spectrometer recording data for these purposes between 250 and 800 nm; infrared data were obtained using a Thermo-Nicolet Avatar 360 FTIR spectrophotometer utilizing a diffuse reflectance accessory (pearl) and a Thermo-Nicolet Magna 560 using a 4× beam condenser (shell), both at a resolution of 4 cm^{-1}; Raman data were recorded from a Renishaw Raman system 1000 spectrometer incorporating a 512 nm argon ion laser; and qualitative chemical compositions were measured using an Energy Dispersive X-ray Fluorescence Spectrometer (EDXRF) manufactured by EDAX (DX95) operating in vacuum at 35 kV and 450 μA. X-radiographs were produced using a Faxitron X-ray unit at 90 kV and 3 ma.

The LA ICPMS instrument used is a prototype excimer ArF laser (193 nm). Sample material is ablated (craters of 5 - 80 μm in diameter) and then flushed into an Elan 6000 quadrupole ICP mass spectrometer for 'simultaneous' multi-element analysis. The laser optics were developed in collaboration with Microlas (Göttingen). With this prototype instrument we can quantify as little as 0.01 ppm of trace elements in minerals, gemstones or archaeological samples from single spot ablations.

Figure 6: The 5.91 ct scallop pearl on a scallop shell which shows the two colour zones at the rim and centre.

Results

Appearance

Natural pearls from the lion's paw scallop, *N. subnodosus*, occur in a variety of shapes and colours and have been described as resembling high-fired pottery (Norris, 2003). They may be drop-shaped, oval, button, round, off-round or baroque, while the colour range has been variously described as white to deep royal purple with varying shades of oranges, pinks and plum (Hurwit, 1998; Anonymous, 2003). The surface of the pearls displays a shimmering sheen effect particularly when viewed under a bright light. The first short gemmological reports appeared on these rare pearls in 1998 and 1999 (Hurwit, 1998, 1999). A further general description appeared in 2004 (Federman, 2004).

The inside of the lion's paw shell shows two colour zones indicating different materials; a wide ruffle-like margin at the edge with a distinctive sheen which is an orange to purple colour (*Figures 6* and *8*) and a white interior. The external mantle tissue

Figure 7a: A close-up of the 5.91 ct scallop pearl from the collection of Mr. Olivier Galibert and described in the text.

Figure 7a: A group of four scallop pearls of various qualities and shapes (from the collection of K.C. Bell)

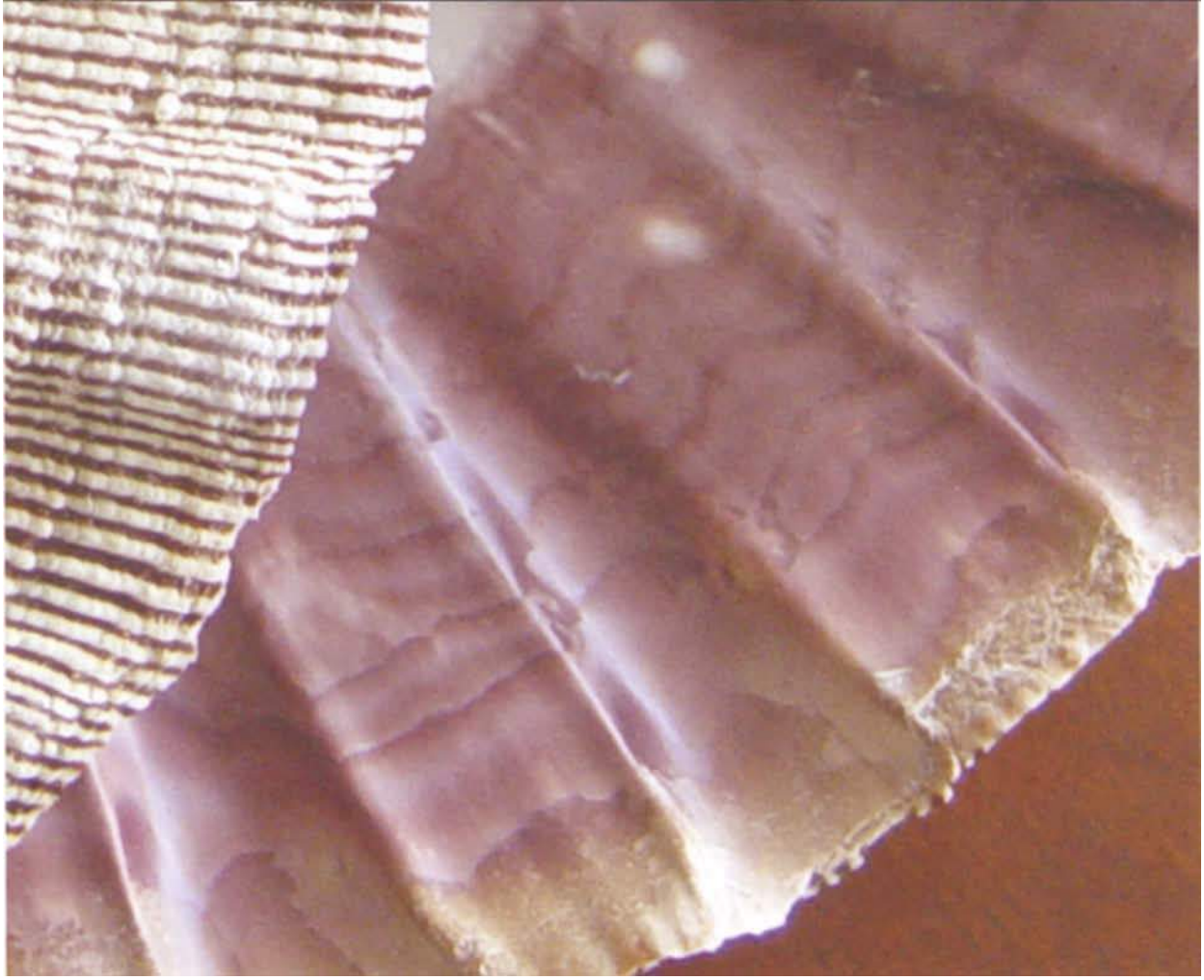

Figure 8: A wide ruffle-like margin with a distinctive sheen at the edge of a scallop shell.

produces two materials as a function of age (Gutmannsbauer and Hänni, 1994); the younger mantle tissue produces the pigmented purple material and at a genetically programmed moment in the life of the mantle tissue cell, this production changes and the cell precipitates the white material, with no pigment.

It thus depends upon the moment of a pearls harvest, whether it is purple (produced by the mantle tissue in the juvenile period) or white (produced by the epithelium that has shifted to the second stage) or a combination of the two. The purple margin on the shell is relatively wide when compared with the *Pinctada* or *Pteria* shells where the columnar growth produces smaller rims. We can thus expect a large number of lion's paw pearls to be of a plum colour with only the older pearls having a white coating.

Chemical composition

As is common with pearls of all varieties, scallop pearls are composed principally of calcium carbonate (Hurwit, 1998). An examination of the chemistry of the 5.91 ct scallop pearl using EDXRF confirmed Ca as being dominant with Sr also showing a significant presence. An examination of the lion's paw shells revealed similar data. In both the pearl and the shells examined, various trace elements were also recorded, but since some are possibly the result of contamination picked up since recovery, they are not reported here.

A few shell samples (see *Table I*) were analysed by LA ICPMS to compare their trace element composition with that of a Pacific lion's paw shell. LA ICPMS is a method that is increasingly used in gemmology for the detection of low concentrations and for light elements (Heinrich *et al.*, 2003). In *Table I* concentrations of some elements are shown, the figures (in microgram per gram – ppm) are mean values from three point analyses. The sample shell of the Pacific Lion's Paw shows the highest magnesium concentration compared to all other shells. With its low manganese content

Table I: Trace element contents in (ppm) of some shell materials identified by LA ICPMS.

	Lion's Paw (Pacific)	P. maxima (Australia)	P. margaritifera (Tahiti)	Hyriopsis schlegeli (China)	Unio (China)	A. plicata (China)
Na	2119	6674	8019	2092	1857	2369
Mg	813	185	508	20	31	20
B	18	20	22	4	4	4
P	311	34	35	188	113	137
K	54	62	113	12	65	13
Mn	0.6	3	0.7	760	658	733
Sr	924	1077	926	666	2588	384
Ba	0.4	0.4	0.1	253	509	137

it is in line with other saltwater shell material.

Structure

The structure at the surface of pearls produced by the lion's paw scallop is unique and upon sight is sufficient to identify the origin of such a pearl. The structure at the surface may be described as a segmented patchwork of cells, each cell comprising three differently oriented sub-segments. Within each sub-segment there is what appears to be at low magnifications a 'fibrous structure' (*Figures 9* and *10*) that is differently oriented for each sub-segment. Light reflecting from these 'fibrous structures' produces a shimmering effect similar to that produced by tiger's-eye and this is a unique feature of this type of pearl. Although the light shimmering effect is also seen in the shells of both *N. nodosus* and *N. subnodosus* (*Figure 8*) it is not in the segmented form as observed on the pearl.

SG and X-radiography

The SG of the 5.91 ct scallop pearl was determined to be 2.65 which is rather low for non-nacreous pearls. SGs determined for the Melo pearls have been found to be fairly consistent and are generally 2.84 to 2.85 (Traub *et al.*, 1999), although a few lower values down to 2.78 have been recorded. However, these lower values can be attributed to a greater amount of organic/less X-ray absorbent material contained within these pearls. For Conch pearls Webster (Webster, 1994) gave an SG range of 2.81 to 2.87. From this it has been suggested (Fritsch and Misiorowski, 1987) that a composition for Conch pearls of 40% calcite and 60% aragonite was likely, the individual specific gravities for calcite and aragonite being 2.71 and 2.93 to 2.95 respectively. The 2.65 SG recorded for the 5.91 ct scallop pearl suggests a higher content of calcite than aragonite. This conclusion is strengthened by the Raman data.

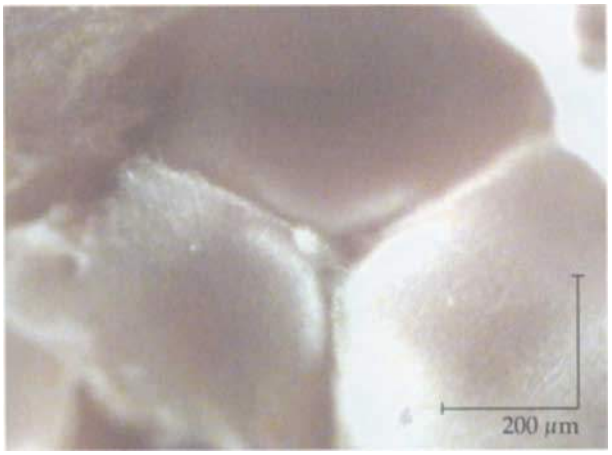

Figure 9: The structure at the surface of the scallop pearl may be described as a segmented patchwork of cells, each cell comprising three differently oriented sub-segments.

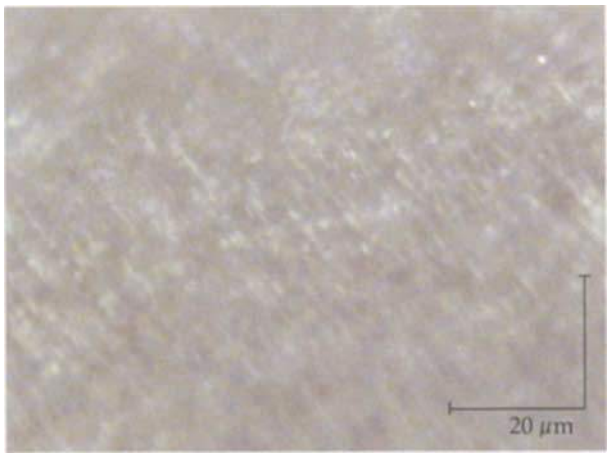

Figure 10: Within each sub-segment (see Figure 9) there is what appears to be at low magnifications a 'fibrous structure'.

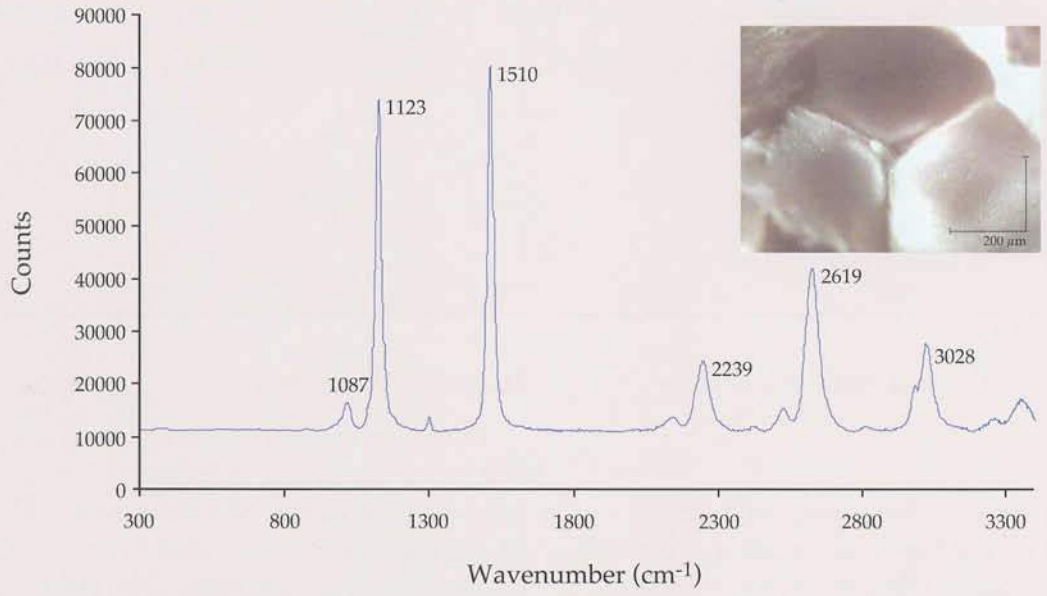

Figure 11: The Raman spectrum of the 5.91 ct scallop pearl.

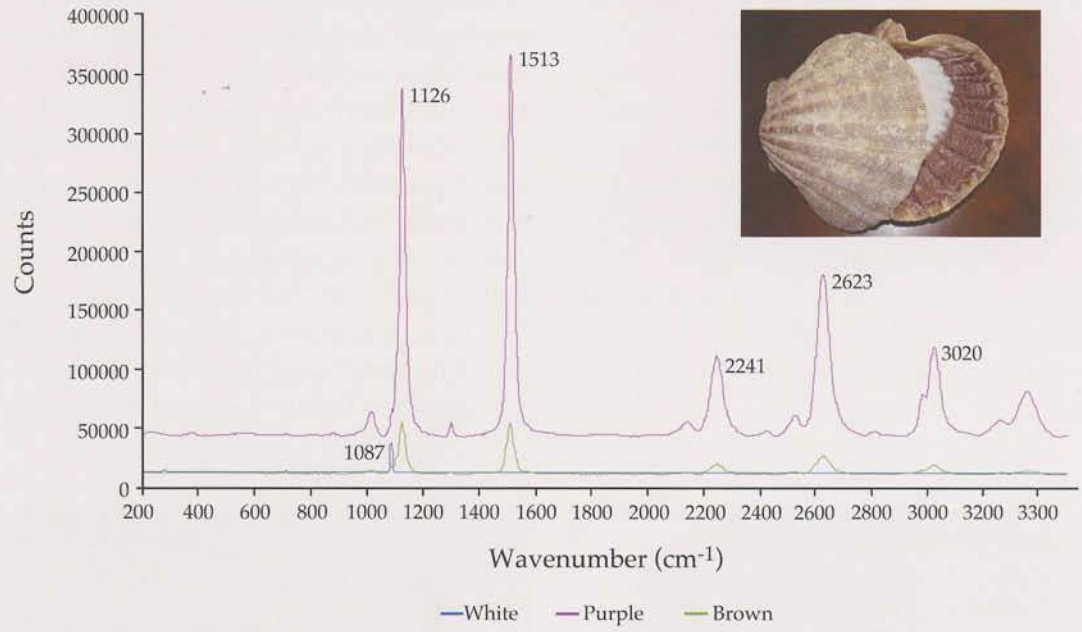

Figure 12: Raman spectra of the purple, brown and white areas of the interior of a N. subnodosus *shell.*

While being the most powerful technique in the arsenal of the gemmologist when distinguishing natural from cultured pearls, X-radiography relies upon the differences in X-ray absorbance between the alternating crystalline and organic layers that are generally present within a nacreous pearl (natural or cultured) (Kennedy, 1998; Akamatsu *et al.*, 2001) but these differences are not necessarily obvious in non-nacreous pearls. Non-nacreous pearls tend to have a structure that consists of dense closely packed crystal arrays without large amounts of organic material being present. Therefore,

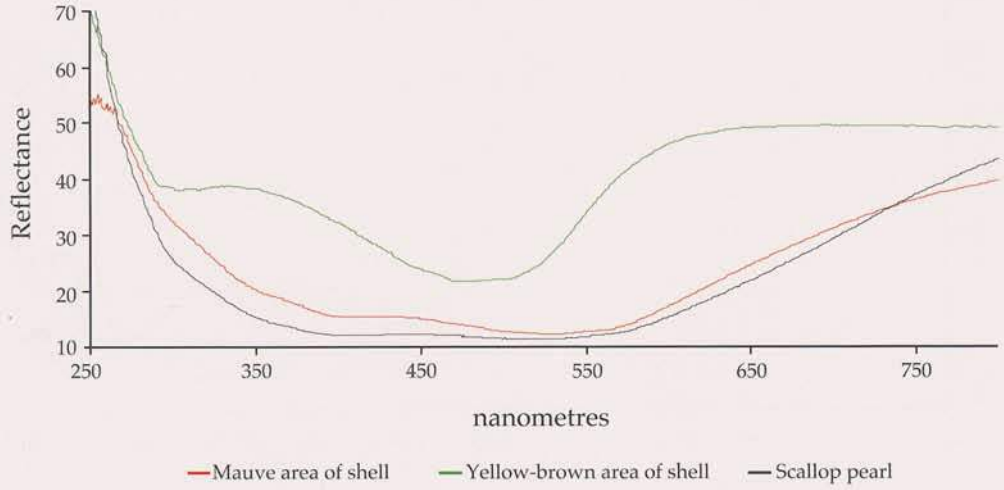

Figure 13: The UV/visible spectra recorded for the 5.91 ct scallop pearl and the yellow-brown and purple areas of the scallop shell.

in general non-nacreous pearls are opaque to X-rays and only occasionally show the presence of organic material by X-radiography. As was to be expected, radiographs taken of the 5.91 ct scallop pearl revealed only a small centrally placed dark arc partially surrounding a dark but extremely small central core, and a few very faint arcs towards the periphery of the pearl. While these structures were sufficient to confirm that it was a cyst-type pearl and of natural origin the apparent small amount of organic material present could not explain the low SG (Traub *et al.*, 1999) but rather supported the conclusion that calcite rather that aragonite is the main component of this scallop pearl.

Raman, UV/visible and infrared spectra

Raman spectra (Kiefert *et al.*, 2001) for the 5.91 ct pearl were collected from several different areas and compared. All areas examined produced the same spectrum with primary peaks located at 1123, 1510, 2239, 2619 and 3028 cm^{-1} (*Figure 11*). These peaks are due to the carotenoids (Fritsch and Misiorowski, 1987; Moses, 2001; Huang *et al.*, 2003; Withnall, *et al.*, 2003) present in the pearl. A peak of comparatively very weak intensity located at 1087 cm^{-1} and which we can attribute to calcite (Li and Chen., 2001; Huang *et al.*, 2003; Kiefert *et al.*, 2004) was also noted. The spectrum for this pearl differs from those recorded for other non-nacreous pearls such as those produced by *Strombus gigas* (the Conch pearl) and the Melo volutes (the Melo pearl). Both the Conch and Melo pearls show peaks normal for aragonite (rather than calcite) at 1085 cm^{-1} and 703 and these are also dominant over the carotenoid peaks. The Raman spectrum for the scallop pearl is similar to that shown by natural red coral.

The Raman spectrum of the 5.91 ct scallop pearl was compared with the spectra produced from the white, purple and brown areas on the interior of one *N. subnodosus* shell (*Figure 12*). The white area produced the complete Raman spectrum typical of calcite with peaks at 281, 713, 1087 and 1433 cm^{-1} and none indicating the presence of any carotenoids; the brown area showed relatively low intensity carotenoid peaks at

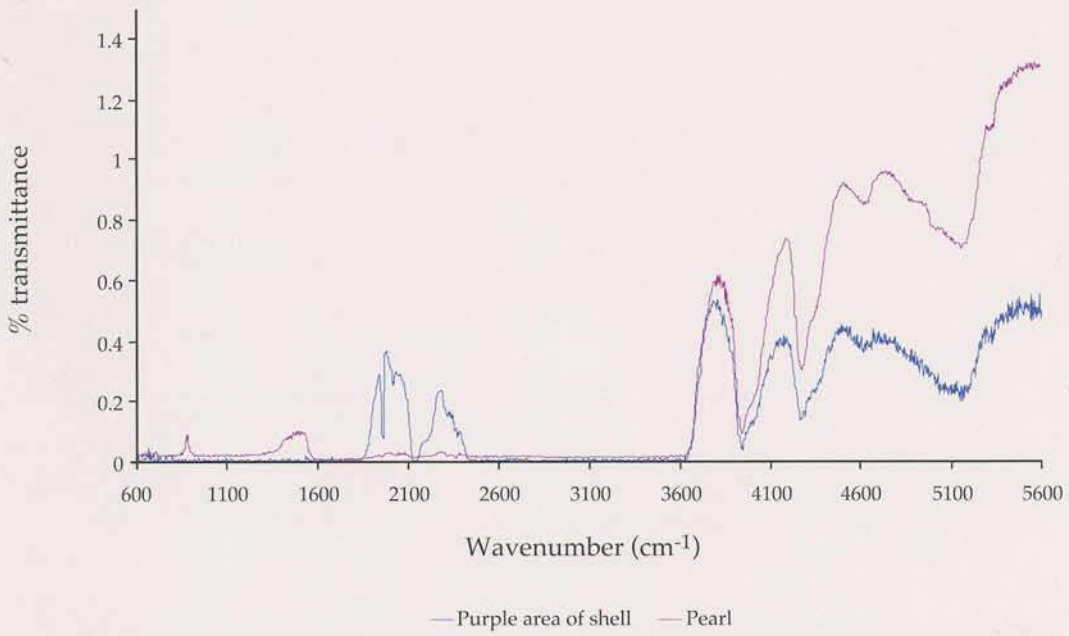

Figure 14: The infrared spectra recorded for the scallop pearl and the purple area of a scallop shell.

1126, 1513, 2241, 2623 and 3020 cm^{-1} that allowed the main calcite peak at 1087 cm^{-1} to be clearly recorded. In contrast, the spectra from the purple area showed carotenoid peaks of such intensity (about six times the count rate) as to completely obscure the strongest calcite peak.

UV/visible spectra were recorded in reflectance mode for the 5.91 ct pearl, and for white, purple and brown areas on the interior of one *N. subnodosus* shell (*Figure 13*). The spectra recorded for purple areas of the shell's interior and that for the pearl showed similar features. Broad but shallow absorption features were noted centred at 540 and 410 nm. For the yellow-brown areas on the shell two merging features were noted at approximately 510 and 460 nm; and for the white areas, as to be expected, only a flat line with no features was recorded.

The infrared spectra were obtained from both the 5.91 ct pearl and the purple area of a lion's paw shell *(N. nodosus) (Figure 14).* Above 1550 cm^{-1} both spectra were similar with features at 1960, 2018, 2140, 3932, 4264, 4593 and 5133 cm^{-1}. Below 1550 cm^{-1} the scallop pearl had additional features at 1508 and 1457 cm^{-1}.

Discussion

The shell of the lion's paw scallop is one of the most beautiful of all seashells (Hill and Carmihael, 2004) and it is therefore not surprising that any pearls produced by this mollusc should also be beautiful. However, it is surprising that given the beauty of the shells and their desirability to collectors, that knowledge of the scallop pearl has not reached gemmologists until recently.

Pearls from the lion's paw scallop are distinctive in so much as their surface structure is dissimilar to that of any other non-nacreous pearl. They are probably composed predominantly of calcite rather than aragonite and the strength of the carotenoid Raman peaks (in relation to the calcite peaks) is very distinctive. The combination of colour, structure and optical effects is unique among pearls and without doubt as a gem material they are exceedingly rare.

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A treatment study of Brazilian garnets

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Abstract: *Over the past decade, there has been noticeable growth in interest in coloured stones worldwide, which has led to an increase in gem exploration, production and marketing. Since garnet displays a very large variety of colours, it deserves further attention. Although reports on enhanced gemstones are widespread in the gemmological literature, very few studies have been performed on the enhancement of garnets. We report the first systematic, scientific treatment study on Brazilian garnets from known geological localities, including thermal and diffusion treatment. Iron-containing species become opaque and produce a 'silvery skin'. Light yellow grossular turns to orange similar to that of Imperial-topaz. Other garnet varieties have stable colours, confirming the absence of colour centres. A preliminary diffusion treatment of some rough grossular has produced attractive green and orange stones. Since orange gemstones are becoming increasingly popular and since the diffusion-treated green grossulars resemble some emeralds in colour, they may be of economic importance in the future if quantities are confirmed to justify commercial mining.*

Introduction

Colour is one of the most important aspects of the beauty of a gemstone and it is a significant contributor to a gemstone's value. Members of the garnet family have been used as gems since prehistoric times, and they are found in a wide range of colours. Red pyrope and almandine are probably the most common and most widely used gem varieties. In recent years, purplish-red rhodolite garnet has become increasingly popular. Andradite is the most lustrous of all garnets and has three gem varieties, viz. green demantoid, yellow topazolite, and opaque, black or dark red melanite. New finds of spessartine in Namibia, Nigeria (Shigley *et al.*, 2000) and Brazil (Ferreira, 1997) have sparked renewed interest in the rare orange variety. Grossular garnet is found in various colours, with the varieties hessonite (cognac) and tsavorite (green) being the most popular. Uvarovite, the rarest of the familiar garnets, is seldom used as a gem. It is the only garnet variety that does not occur in Brazil (Delaney, 1996). Colour-change garnets found in Madagascar change from blue-green in daylight to purple in incandescent light (Schmetzer and Bernhardt, 1999).

Many Brazilian museums have garnet specimens but their locations are usually

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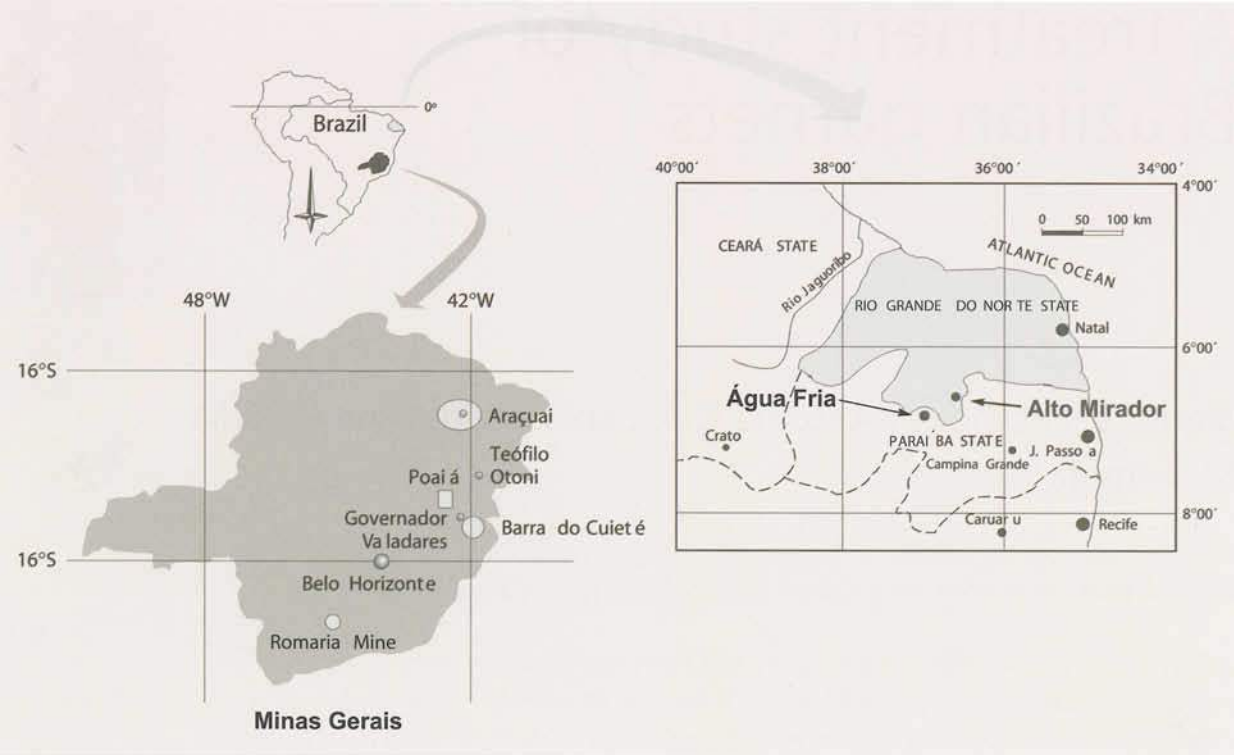

Figure 1: *Maps of parts of Brazil indicating localities of the studied garnets.*

poorly described. Furthermore, details of the geological environment or the mineralogical affinities of Brazilian garnet occurrences reported in the literature are very scarce. As a consequence, the range of Brazilian garnets, including pyrope, almandine-pyrope, almandine-spessartine, spessartine, spessartine-almandine, grossular and the gem-varieties rhodolite and hessonite, will be outlined before describing our experimental work.

Since gem treatment is a field of high potential wherein less attractive gemstones are transformed to more desirable stones by various methods such as chemical treatment, heating and irradiation, a range of garnet varieties was assembled for study. Although reports on enhanced gemstones are widespread in the gemmological literature (e.g. Nassau, 1994; McClure and Smith, 2000, and references therein), very few studies have been performed on the enhancement of garnets. During the first stage of our experimental work on gem garnets from Brazil, heat treatments were performed on representative samples, since thermal enhancement is the most common and easiest type of treatment for gems. Furthermore, the results of heat-treatment on most stones are stable and permanent under normal conditions of wear. In the following stage some selected grossular garnets were diffusion treated and preliminary results were obtained.

Materials and methods

Occurrence and geology of garnet samples

Garnets occur in many geological environments in Brazil. These include metamorphic rocks, igneous rocks, pegmatites, kimberlites and in sediments as detrital grains (Deer *et al.*, 1982). However, gem-quality garnets have been found in only two of these environments, namely pegmatites and alluvial deposits, and recovered as a byproduct of some other gemstone mining objective (Delaney, 1996). Localities of the studied garnets are shown in *Figure 1*.

Pyrope

Pyrope is one of the main locator minerals in diamond prospecting. Pyrope garnets have

been recovered from the Romaria mine (originally called Água Suja) which is now defunct, on the Marrecos Ranch, SW of Monte Carmelo, Minas Gerais state. The geology of the Romaria mine has been described by Svisero *et al.* (1981).

Almandine-pyrope

The almandine-pyrope garnets are from the Fazenda Balisto, Município Peixe, WSW of São Valério da Natividade, Tocantins state. They possess an unusual, attractive, purplish-red colour and are therefore called rhodolite in the jewellery trade (Wegner *et al.*, 1998). They are found in alluvial gravels and their source is not yet known.

Almandine-spessartine

The almandine-spessartine garnets are from the Serra dos Marimbondos granitic pegmatite, Carnaúba dos Dantas, Seridó district, Rio Grande do Norte state (Ferreira, 2001, pers. comm). The garnets are concentrated in ore-shoots with feldspar, quartz and muscovite.

Spessartine

Gem-quality spessartine samples have been recovered from the Alto Mirador granitic pegmatite, Seridó district, NE of Carnaúba dos Dantas, Ermo village, Rio Grande do Norte state (Ferreira, 1984, 1997; Ferreira *et al.*, 2000). The highly fractured, complex and internally zoned Alto Mirador pegmatite belongs to the lithium-rich Borborema sub-province of the northeastern gemmological province (Pinto and Pedrosa-Soares, 2001). The garnets occur in fracture fillings and in open cavities or pockets and the colours range from reddish orange and yellowish orange to orange. (*Figure 2*).

Spessartine-almandine

Spessartine-almandine varieties were collected from the substitution bodies of the Poaiá pegmatite. Sao José da Safira district, Minas Gerais state. The Poaiá pegmatite is one of the most important garnet-bearing pegmatites of the Sao José da Safira district and the gemstones possess orange-red, reddish-orange or cognac colours (*Figure 2*) (Cassedanne and Cassedanne, 1977).

Figure 2: Samples of rough spessartine with diameters up to 2.5 cm and spessartine-almandine garnets with colours varying from reddish orange and orange to yellowish orange.

The pegmatite is situated in the Eastern gemmological province (Pinto and Pedrosa-Soares, 2001).

Grossular

Grossular samples were collected from (1) the Barra do Cuieté pegmatite, Governador Valadares district, Minas Gerais state and (2) the Água Fria skarn, Santa Luzia, Paraíba state (Tavares *et al.*, 2000). The Barra do Cuieté pegmatite belongs to the Eastern gemmological province, whereas the Água Fria skarn belongs to the lithium-rich Borborema sub-province of the northeastern gemmological province (Pinto and Pedrosa-Soares, 2001). Transparent cognac-red grossular (hessonite) samples were found in the tailings of an old mine in Água Fria.

Characterization of samples

For the garnets listed in *Table I*, refractive indices were measured with an Eickhorst Gem Led refractometer on faceted stones (12 for the spessartine samples and 3 for the other compositions) and specific gravities were obtained from rough stones (10 for the spessartine samples and 4 for the other varieties) by hydrostatic weighing.

Three selected crystals of each garnet type mentioned in *Table I* were characterized

Table I: Chemical composition and physical properties of Brazilian garnets.

Variety	Pyrope	Almandine-pyrope	Almandine spessartine	Spessartine			Spessartine almandine			Grossular
Locality	Romaria mine	Fazenda Balisto	Serra dos Marimbondos pegmatite	Alto Mirador pegmatite			Poaiá pegmatite			Barra do Cuieté pegmatite
Colour	red	purplish red	red	reddish orange	orange	yellowish orange	reddish orange	reddish orange	cognac colour	light yellow
n	Not measured	>1.79	>1.79	>1.79	>1.79	>1.79	1.755-1.760	1.755-1.760	1.755-1760	1.740
SG	4.17	4.08-4.11	4.17	4.11-4.22	4.11-4.22	4.11-4.22	4.16-4.18	4.16-4.18	4.16-4.18	3.86
Wt.%				Chemical composition						
SiO_2	40.03	37.88	36.97	36.74	36.82	36.71	35.21	35.17	35.16	37.55
TiO_2	0.29	0.03	0.02	0.15	0.20	0.06	0.01	0.02	0.00	0.04
Al_2O_3	21.13	21.79	21.35	21.12	21.19	21.14	20.80	20.68	20.75	21.01
FeO	9.12	36.49	28.37	2.69	2.72	1.23	11.94	17.44	14.54	1.47
Fe_2O_3	0.00	0.00	0.00	0.30	0.30	0.13	0.00	0.00	0.00	0.00
MnO	0.43	0.04	11.98	38.06	38.28	40.41	30.90	25.85	28.47	0.03
MgO	21.33	4.54	1.55	0.85	0.86	0.50	0.00	0.00	0.00	0.05
CaO	4.24	0.06	0.42	0.22	0.20	0.39	0.15	0.21	00.19	37.35
Cr_2O_3	2.32	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	98.89	100.83	100.66	100.13	100.57	100.57	99.01	99.37	99.11	97.50
Mol%										
Pyrope	71.7	18.3	6.3	3.3	3.3	2.0	0.0	0.0	0.0	0.3
Almandine	17.0	81.7	64.7	6.7	6.7	3.0	27.3	40.4	33.3	3.0
Grossular	10.3	0.0	1.3	0.7	0.7	1.0	0.3	0.3	0.3	96.7
Spessartine	1.0	0.0	27.7	89.3	89.3	94.0	72.4	59.7	66.4	0.0

Note: FeO obtained by microprobe was calculated as FeO + Fe_2O_3 based on the results of a Mössbauer study, and this for all samples.

by powder X-ray diffraction with a Rigaku Geigerflex diffractometer using CuKα radiation and graphite monochromator. Additional diffraction patterns were recorded on powders, which were scraped from the surface of heat-treated pyrope, almandine-spessartine and spessartine-almandine garnets.

Chemical analyses were performed on thin sections of one selected, rough sample of each type mentioned in *Table I* using a JEOL JXA-8900RL electron microprobe (15 kV and 20 nA). The standards used were albite for Si, olivine for Fe and Mg, rhodonite for Mn, anorthite for Al and Ca, rutile for Ti and Cr_2O_3 for Cr, and raw data were corrected using the ZAF program. Several line scans across each sample were made to look for any chemical zoning. Data were collected from five points on spessartine samples and from ten points on other samples. The elements determined were Si, Fe, Mg, Mn, Ca, Al, Cr and Ti, and to ensure that no other elements with an abundance above the microprobe detection limit were present preliminary, qualitative runs in wavelength-dispersive mode were performed on three spots of each sample in the complete spectral area. The structural formulae were calculated on the basis of 12 oxygen atoms. To do this, total iron obtained by microprobe was converted to FeO and Fe_2O_3 based on the results of a Mössbauer study on similar samples of all garnet types. Mössbauer spectra (MS) were collected at room temperature (RT) using a conventional, constant acceleration spectrometer in conjunction with a 1024 multi-channel analyzer. Mössbauer experiments were additionally performed at room temperature on hessonite samples which previously had been subjected to heat treatments in air at 800°C for four hours and at 600°C for seven days.

For the UV-Vis spectroscopic measurements, platelets 1mm thick were

cut from representative rough samples of each garnet mentioned in *Table I*. The platelets were cut from the samples used for the chemical analyses. The platelets were polished on both sides to obtain a thickness ranging from 0.25 to 0.35 mm. To facilitate handling, small crystals were embedded in epoxy, which was later removed by dissolution in acetone. All platelets were checked optically for the absence of both liquid and solid inclusions. UV-Vis spectra were measured, before and after treatment, using a Hitachi U-3501 spectrophotometer in the spectral region 300 to 1100 nm.

In order to identify the diffusion-treated, rough, non-transparent grossular stones, the Rutherford back-scattering technique was used. This is a non-destructive, analytical tool that uses elastic scattering of 1-3 MeV charged particles to analyse the surface and the outer few micrometres of solids.

Treatments

Heating experiments were performed in oxidising, inert and reducing atmospheres and at various temperatures up to 1000°C. For the heating experiments, a batch of 9 to 10 representative, rough stones from each of the following types was assembled: pyrope, almandine-spessartine, reddish-orange and yellowish-orange spessartine, cognac coloured spessartine-almandine, grossular and hessonite. Only the pyrope and grossular samples were not of gem quality.

One representative sample of each variety and colour was not treated, and was retained as a comparator for the heat-treated garnets. The heating experiments were conducted under the following conditions:

1. in air at 800°C for four hours
2. in air at 900°C for four hours
3. in air at 1000°C for four hours
4. in air at 900°C for 24 hours
5. in an oxygen saturated atmosphere (P_{O_2} = 1 atm) at 800°C for four hours
6. in an oxygen saturated atmosphere (P_{O_2} = 1 atm) at 900°C for four hours
7. in an argon saturated atmosphere (P_{Ar} = 1 atm) at 900°C for four hours and
8. in a reducing atmosphere (P_{H_2} = 1 atm) at 900°C for four hours.

The hessonite sample was further heated in air for seven days at 600°C, and rough rhodolite was heated in air at 600°C for 24 hours and at 800°C for four hours. After cooling down in air, each heat-treated garnet was compared with the non-treated, reference sample.

In subsequent experiments, four representative light yellow grossular rough samples were subjected to diffusion treatments. The diffusion-treatment process usually involves embedding rough or fashioned stones in a powder consisting of a colouring agent such as iron oxide, within a corundum crucible. The crucible is then subjected to heating in a furnace at relatively high temperatures (900°C). Before the diffusion experiments on the four stones one was kept as a comparator for the diffusion-treated garnets, one was put in iron oxide, one in chromium oxide and one in cobalt oxide; only a very small amount of material was used in each crucible, and they were then placed in a furnace at 900°C for 44 hours.

Results

Characterization of the natural garnet samples

Chemical composition

X-ray diffraction confirmed that all the samples studied belong to the garnet family, and the compositions determined and summarized in *Table I* confirm this.

Physical properties

The refractive index, n, and the specific gravity, SG, of most of the garnets studied are summarized in *Table I*. The pyrope samples studied are small and well rounded. The almandine-pyrope garnets show distinctly weathered surfaces, but the dodecahedral

Figure 3: Rough garnet species before (upper row) and after (lower row) heat treatment at 800°C for four hours in an oxygen saturated atmosphere (P_{O_2} = 1 atm). The following stones are depicted from left to right: reddish-orange and yellowish-orange spessartine, hessonite, almandine-spessartine, grossular, cognac colour spessartine-almandine and pyrope. The average size of the stones is 0.5 cm in diameter.

habit remains visible. The almandine-spessartine garnets occur as anhedral or intergrown crystals with diameters of up to 10 cm. The majority of the spessartine garnets are euhedral with well-developed crystal faces, commonly dodecahedral {011} or trapezohedral {112}; they show lively and brilliant colours varying between reddish orange, orange and yellowish orange *(Figure 2)*. The spessartine-almandine garnets occur as dispersed crystals within the primary minerals (quartz, microcline, muscovite, biotite and K-feldspar) or as gem-quality aggregates, up to several decimetres, within the substitution bodies which are composed of quartz, K-feldspar, albite, muscovite and lepidolite. The spessartine and spessartine-almandine samples are transparent, have vitreous lustre and possess few or no inclusions. No colour-change phenomena were observed when viewed in natural and incandescent light.

Spectral features

UV-Vis spectroscopy was used to determine the causes of colour differences both within and between the garnet varieties. Characteristic absorption peaks for the various types of garnets studied are listed in *Table II*. All pyrope, almandine-pyrope, and almandine-spessartine spectra are characterized by a broad band at ~570 nm, a band at 526 nm, and a broad band at 505 nm. A sharp absorption band at 410 nm and shoulders at

Table II: Characteristic absorption peaks in spectra of the Brazilian garnets studied.

	Pyrope	Almandine-pyrope	Almandine spessartine	Spessartine	Spessartine-almandine	Hessonite	Assignment
Absorption maxima (nm)							
370						•	Fe^{3+}
<390				•	•		ultraviolet charge transfer
410				•	•		Mn^{2+}
421				•	•		Mn^{2+}
429				•	•		Mn^{2+}
459				•	•		$Mn^{2+} + Fe^{2+}$
482				•	•		Mn^{2+}
505	•	•	•				Fe^{2+}
526	•	•	•				Fe^{2+}
529				•	•		$Mn^{2+} + Fe^{2+}$
~570	•	•	•				Fe^{2+}

Table III: ***Results of garnet heat treatment.***

	Pyrope	Almandine-pyrope	Reddish-Orange spessartine	Yellowish-Orange Spessartine	Cognac colour Spessartine-almandine	Grossular	Hessonite
In air at 800°C for 4 hours	silvery lustre	silvery lustre	no changes	no changes	silvery lustre	Imperial-topaz colour	no changes
In air at 900°C for 4 hours							
In air at 1000°C for 4 hours		opaque with burned appearance			opaque with burned appearance		
In air at 900°C for 24 hours							
P_{O_2} = 1 atm at 800°C for 4 hours		silvery lustre			silvery lustre		
P_{O_2} = 1 atm at 900°C for 4 hours							
P_{Ar} = 1 atm at 900°C for 4 hours							
P_{H_2} = 1 atm at 800°C for 4 hours	no changes	no changes			no changes	no changes	

421, 429, 459, 482 and 529 nm characterize the spectra of the spessartine and spessartine-almandine garnets. Furthermore, a broad absorption below 390 nm extends into the visible region. The strong band at 370 nm is the main characteristic of the absorption spectrum of hessonite.

Garnet treatment

Heat treatments

After heat treatments *(Table III)*, both in oxidizing (in air or in an oxygen saturated atmosphere of P_{O_2} = 1 atm) and inert atmospheres (P_{Ar} = 1 atm), on Brazilian pyrope, almandine-spessartine and spessartine-almandine garnets, a silvery lustre was observed over the whole surface of each heat-treated stone. This silvery lustre is caused by formation of a hematite coating, which was confirmed by powder X-ray diffraction. The silvery lustre is more spectacular on heat-treated almandine-spessartine and spessartine-almandine than on pyrope *(Figure 3)*. In a reducing atmosphere, however, no changes were observed and the colours of the treated stones remained unchanged; UV-Vis spectra also remained unchanged. After heat treatment in air at 1000°C for four hours and at 900°C for 24 hours, these iron-rich varieties become opaque and have a completely burned, charcoal-like appearance, which remains even after recutting or repolishing. The powder X-ray diffraction spectrum of such a 'burned' stone indicates that no crystal structure changes occurred and that no hematite was formed.

Following a report that some rhodolite garnets change from purple to a hessonite-type brown on heating at about 600°C (Nassau, 1994), we additionally conducted heating experiments in air on rhodolite. After heating at 600°C for 24 hours, no differences were detected and the absorption spectrum before and after heat-treatments remains the same.

It is apparent from *Table III*, columns 4, 5 and 8, that the heating experiments performed on spessartine and hessonite caused no change of colour (see also *Figure 3*), and there were no changes in their UV-Vis spectra. On the basis of the Mössbauer

results, the small amount of total iron in the non-treated hessonite contains 48% Fe^{3+}, that in the hessonite heated at 800°C for four hours contains 51% Fe^{3+} and in the hessonite heated at 600°C for seven days the iron is 55% ferric. So, although no changes in colour were detected after the treatments, there was slight oxidation of the iron.

In all treatments except that in a reducing atmosphere, light yellow grossular turns to orange, showing the Imperial-topaz colour (see *Table III*, column 7 and *Figure* 3). The stone remains light yellow after treatment in a strongly reducing atmosphere (P_{H_2} = 1 atm).

Figure 4: Light yellow, orange and green grossular. The orange and green colours were obtained after diffusion treatment of the light yellow material with Fe and Co, respectively. The stones have a diameter of about 8 mm.

Diffusion treatments

The preliminary diffusion treatments produced an orange diffusion layer on the pale yellow grossulars in the presence of either Fe or Cr oxide and a green diffusion layer in the presence of Co oxide. The diffusion-treated pale yellow grossular stones in oxides of iron or chromium show an Imperial-topaz colour, comparable to that of the heat-treated grossulars.

Discussion

The structural formula of garnet is generally represented as $X_3Y_2Si_3O_{12}$, where X and Y refer respectively to eight- and six-fold coordinated cationic sites. The X sites are occupied by rather large, divalent cations, generally Ca^{2+}, Mn^{2+}, Fe^{2+} or Mg^{2+}, whereas the Y sites are occupied by smaller trivalent cations, such as Al^{3+}, Fe^{3+}, V^{3+} or Cr^{3+}. When each site is occupied by only one type of ion, the result is identified as an end member of the garnet mineral group.

Physical properties

The measured refractive index, n, and specific gravity, SG, of the garnets studied, as listed in *Table I*, correspond well with published data (Deer *et al.*, 1982; Ferreira, 1997; Tavares *et al.*, 2000; Wegner *et al.*, 1998). All values fall within the ranges mentioned by Stockton and Manson (1985).

Spectral features

The UV-Vis absorption spectra of pyrope, almandine-pyrope and almandine-spessartine are characterized by common iron bands (Schmetzer *et al.*, 2001). These are a broad band at ~570 nm, a band at 526 nm and a broad band at 505 nm and according to Frentrup and Langer (1982), the Fe^{2+} ions in the eight-coordinated site produce the near-red colour.

The spectra of all spessartine and spessartine-almandine garnets in our study are characterized by iron and manganese bands (Schmetzer *et al.*, 2001). They show a sharp absorption band at 410 nm [Mn], and broad or weak maxima at 421 [Mn], 429 [Mn], 459 [Mn + Fe], 482 [Mn] and 529 [Mn + Fe] nm. The broad absorption below 390 nm, extending into the visible region, is due to ultra-violet charge transfer, caused by electron transfer from O^{2-} ligands to a central Fe^{3+} metal ion (Rossman 1988). Frentrup and Langer (1982) further suggested that a broad band at 370 nm, present in synthetic spessartine, might additionally point to the presence of ferric iron in octahedral

coordination. The overall shapes of the absorption spectra correspond very well with the one of synthetic spessartine (Frentrup and Langer, 1982). Comparison between the three spectra reveals, however, that the small differences in colour within the spessartines cannot be explained fully from the spectra. A qualitative correlation between the presence of chromophore atoms (iron and manganese in the present case), microprobe analyses, and the colour of these spessartines might be that the reddish hue is due to the presence of somewhat larger amounts of iron *(Table I)*. The absorption band at 370 nm of hessonite is due to the presence of Fe^{3+} at the dodecahedral sites and causes the cognac colour (Frentrup and Langer, 1982).

Heat treatments

A silvery lustre was observed on pyrope, almandine-spessartine and spessartine-almandine after heat treatment in air, in an oxygen-saturated atmosphere (P_{O_2} = 1 atm) and in an inert atmosphere (P_{Ar} = 1 atm) *(Table III)*. Friedman (1988) was the first to report that on heating almandine in air, the surface acquired a silvery lustre. This author attributed the silvery lustre to the formation of specular hematite, but did not confirm it. In the present study all powders scratched from the surfaces of heat-treated pyropes and almandines were confirmed as hematite. This means that garnet decomposes at the surface to form hematite. The fact that the silvery lustre is more spectacular on heat-treated almandine-spessartine and spessartine-almandine than on pyrope *(Figure 3)* can be related to the somewhat lower iron content of the pyrope *(Table I)*. In a reducing atmosphere, however, no transitions were observed and the colour of the treated stones remained unchanged.

Although Mössbauer experiments performed at room temperature on hessonites pointed to slight oxidation of Fe^{2+} to Fe^{3+} in the garnet lattice after heat treatment, this had no effect on the already distinct colour of the stones.

The Imperial-topaz colour caused by heating pale yellow grossular *(Table III)* may well be caused by a change in the valence state of iron, but due to its very low concentration this could not be confirmed by Mössbauer spectroscopy. The grossular remains light yellow after treatment in a strongly reducing atmosphere.

Diffusion treatments

The diffusion treatments produced an orange diffusion layer on the rough grossular stones in the presence of Fe and Cr and a green diffusion layer in the presence of Co. Oxides of cobalt are typically used to produce a blue diffusion layer which, when applied to an orange stone, produces the green colour. Pollack (1999) recently reported that diffusion treatment on light yellow garnet in the presence of Co produces stones which are green to blue-green. Rutherford Back Scattering reveals that the coloration occurs as a layer near the surface, hence recutting or repolishing of the surface may seriously affect the stone's appearance. It is important to keep in mind that the properties described are based on a very small amount of sample material. Furthermore, experimentation is continuing with the goal of confirming the results and of increasing the depth of penetration of the diffused layer. Generally speaking, the higher the temperature maintained and the longer the period used for the heating, the greater will be the depth of colour. However, at excessively high temperatures, the surface may be damaged.

Conclusions

Orange stones are an increasingly popular choice in jewellery, and the imperial-topaz colour derived from light yellow grossular offers potential for economic interest. However, the amounts of this mineral in gem-quality likely to be available from Brazil are relatively small and would not justify commercial mining on this basis alone. Consequently, enhancements of most garnets are unlikely to really threaten the gem trade.

The heat-treated, iron-containing garnet varieties are easily detected, even by the unaided eye, since they become opaque and produce a 'silvery skin'. For the other varieties, it is more difficult to make a decision between the treated and natural stones as they are most likely due to small internal modifications. For the rough, non-transparent, diffusion-treated grossulars, Rutherford Back Scattering reveals that the coloration occurs in a surface layer.

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The nature of channel constituents in hydrothermal synthetic emerald

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Abstract: *Hydrothermal synthetic emeralds manufactured by Biron, Regency and Tairus have been distinguished from natural and synthetic emeralds using chemical analysis and infrared (IR) spectroscopy. Polarized IR spectra have been obtained from plates. Hydrothermal synthetic emeralds possess infrared absorption features not present in natural emeralds, and these features have been investigated. We infer that the system of five narrow bands in the 3000-2600 cm^{-1} region is related to the dimer formation of HCl molecules, which have been incorporated in the channels parallel to the* c*-axis during growth of Biron and Regency emeralds. In Regency emeralds, a double band with maximum at 3295 and shoulder near 3232 cm^{-1} and a broad band between 3000 and 2500 cm^{-1} are attributed to hydrogen-bonded NH_4^+ ions. In Russian hydrothermal synthetic emeralds the strong infrared spectral features related to molecular water are generally similar to those of some natural emeralds but there are also broad bands due to Ni^{2+} and Cu^{2+} ions in the near-infrared regions which enable one to distinguish Russian hydrothermal synthetic from natural emeralds. Other bands unrelated to water in hydrothermal synthetic emeralds are also discussed.*

Keywords: *ammonium ion, emerald, HCl molecule, IR spectroscopy*

Introduction

The hydrothermal syntheses of emeralds have much in common with the growth of natural emerald. As a consequence of improving techniques, identification of synthetic stones has become increasingly difficult. As the gemmological properties of hydrothermal synthetic emerald overlap those of natural emerald, the most conclusive results are obtained by the microscopic examination of their inclusions. However, even this technique becomes ineffective when the emerald is clean or does not have diagnostic inclusions. Therefore, advanced testing by such techniques as absorption and infrared (IR) spectroscopy and/or energy-dispersive X-ray fluorescence (EDXRF) analysis should be used for conclusive diagnosis of synthetic gems (Koivula *et al.*, 1996; Schmetzer, 1996). The application of these tools is based on the distinction of the minor impurity contents of natural and synthetic emeralds. In synthetic emeralds there are impurities which have not been detected in any natural emeralds. For example, chlorine is present as a structural constituent in the Biron and Linde or Regency hydrothermal

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synthetic emeralds, as well as in recent Chinese synthetic emeralds (Hänni, 1982; Stockton, 1984; Kane and Liddicoat, 1985; Schmetzer *et al.*, 1997). In some Colombian emeralds, chlorine has been found but only as a brine component and, probably, in NaCl crystals in three-phase inclusions (Bosshart, 1991). Recently, using a micro-proton-induced X-ray emission (micro-PIXE) technique for bulk analysis of an inclusion-free region in some Colombian, Zambian and Brazilian emeralds, chlorine was found as a structural component but in lower amounts than in Biron hydrothermal synthetic emeralds (Yu *et al.*, 2000). Measurable amounts of nickel and copper were found in Lechleitner fully synthetic and Russian hydrothermal synthetic emeralds (Hänni, 1982; Schmetzer, 1988; 1990).

Spectroscopy in the visible and IR regions is a powerful method for gem identification and research (Fritsch and Stockton, 1987; Fritsch and Rossman, 1987, 1988). To date, papers concerning the spectroscopic distinction of natural from synthetic emeralds include Wood and Nassau, 1968; Leung *et al.*, 1986; Stockton, 1987; Schmetzer and Kiefert, 1990; Diaz *et al.*, 1994; and Zecchini and Maitrallet, 1998. The method is promising because the technique is non-destructive, extremely rapid, and comparatively inexpensive.

The main features in the IR spectra of natural emeralds are the presence or absence of absorption features from two types of water molecules (type I is observed in alkali-free emerald and type II is bound to alkalis) incorporated in channels parallel to the *c*-axis (*c*-channels) of the beryl structure (Wood and Nassau, 1967, 1968; Flanigen *et al.*, 1967; Nassau, 1976; Schmetzer and Kiefert, 1990). Flux-grown emeralds have no spectral features in the range of water absorption, as has been revealed by previous authors. Linde and Biron hydrothermally-grown synthetic emeralds have absorption bands associated with only type I water molecules, whereas the natural emeralds have absorption bands of both type I and II water molecules (Wood and Nassau, 1967, 1968; Schmetzer and Kiefert, 1990). But the absorption of water molecules is a poor criterion to use in distinguishing natural from synthetic emeralds, as practical problems in the examination of large faceted gems arise from low transparencies in the mid-infrared range (4000 – 3400 cm^{-1}) where the absorption peaks of the water molecules are located. There are also difficulties in taking oriented spectra in the near-infrared range (8000 – 5000 cm^{-1}). Two polarized spectra corresponding to the two principal optical directions in the crystal are needed if one is to clearly distinguish the two types of water molecules (Wood and Nassau, 1967, 1968; Schmetzer *et al.*, 1997). Furthermore, in some emeralds from Colombia the absorption due to type II water is weaker than in most natural emeralds (Zecchini and Maitrallet, 1998). Also, Lechleitner and Russian hydrothermally-grown synthetic emeralds show the absorption bands associated with both type I and type II water molecules (Schmetzer and Kiefert, 1990). Fortunately however, additional measurements in other spectral ranges enable one to solve these problems. A very sharp absorption at 2357 cm^{-1} is characteristic of natural emeralds (Zecchini and Maitrallet, 1998), an absorption which is due to carbon dioxide within the natural crystal (Wood and Nassau, 1967, 1968). Lechleitner and Russian hydrothermal synthetic emeralds can be identified by either visible-range absorption spectroscopy (Schmetzer, 1988, 1990) or by the weak absorption features in mid- and near-infrared ranges (Stockton, 1987; Koivula *et al.*, 1996). There are distinct absorption features in the range from 3400 to 2600 cm^{-1} of Biron and Linde hydrothermal emeralds (Leung *et al.*, 1986; Stockton, 1987; Zecchini and Maitrallet, 1998) and in Chinese hydrothermal emeralds (Schmetzer *et al.*, 1997).

We have tentatively assigned a doublet at 3295 and 3232 cm^{-1} to ammonia, and a system of five strong bands in the 3000 – 2600 cm^{-1} range to various forms of HCl molecules which are incorporated in the *c*-channels of Biron and Regency hydrothermal synthetic emeralds (Mashkovtsev, 1996; Mashkovtsev and Solntsev, 2002). Also Schmetzer *et al.* (1997) associated an identical system of

absorption bands with the chlorine-bearing hydrothermal synthetic emeralds (Biron, Chinese, and Linde or Regency). In the present paper we wish to gain an insight into the cause of the IR spectroscopic features of hydrothermally-grown emeralds in the range between 10000 and 2000 cm^{-1}, in the main, using data obtained from polished plates of emerald.

Materials and methods

Samples of the major commercially-produced hydrothermal synthetic emeralds and of natural emerald from the Ural Mountains, Russia, have been tested to obtain their IR absorption spectra. Detailed investigations were performed on 11 rough and 10 faceted stones. Biron synthetic emerald was represented by four halves of gem-quality rough crystals, sawn parallel to seed, of 17.20 to 107.40 ct and five faceted stones of between 1.370 and 1.750 ct. Two slices from different rough crystals and one 1.46 ct emerald-cut samples of Regency (Linde) hydrothermal synthetic emerald were examined. Tairus hydrothermal synthetic emeralds from Novosibirsk, Russia were represented by 4 oval mixed cuts weighing between 0.2 and 0.5 ct and by many rough crystals. As there is no difference in chemistry of the growth processes for crystals of types 1 and 2 according to the Tairus Research scientists (see also Koivula *et al.*, 1996), we used only type 1 emeralds as representative for recent commercial Tairus production. Natural emeralds from the Urals (Malyshev mine) were represented by three rough crystals and one 1.161 ct rectangular faceted stone. Polarized spectra were obtained from 0.6 to 3.3 mm thick plates cut from rough crystals.

Mid-infrared absorption spectra were obtained using a Brucker IFS 113v Fourier transform infrared (FTIR) spectrometer in the range 4500-2000 cm^{-1} and a Specord M80 (Karl Zeiss, Jena) spectrometer in the range 4000-2000 cm^{-1}. Near-infrared spectra were obtained using a SF-20 (LOMO, St. Petersburg) spectrometer in the range 10000-4000 cm^{-1}. The FTIR spectrometer is equipped with a microscope attachment which was used to focus the beam when faceted stones were being measured. In this study the beam was directed perpendicularly to table facet of the stone on the microscope stage.

The emerald specimens were analyzed for Na_2O, FeO, V_2O_3, Cr_2O_3, NiO, CuO, Al_2O_3, SiO_2, and Cl by a Camebax Micro electron microprobe at an operating voltage of 15 kV and beam current of 20 nA. Samples of Biron hydrothermal synthetic emerald were also qualitatively studied using secondary ion mass spectroscopy (SIMS) using a Cameca S-6 ion microprobe.

Results

Chemical composition

Elements substituting major beryl components (Si, Al and Be)

Microprobe and wet chemistry analyses of emeralds studied are presented in *Table I*. One can conclude from *Table I* that the most important impurities in the emeralds are the chromophoric elements Cr, V and Fe. Tairus synthetic emeralds commonly have negligible V and higher Cr contents in comparison to Biron synthetic emerald. Tairus synthetic emeralds also contain traces of Ni and Cu which are commonly acquired during growth by solution from the walls of the steel autoclaves. Detailed zone analyses revealed that in Tairus synthetic emeralds the Cr_2O_3 and FeO contents gradually decreased away from the beryl seed, while in Biron synthetic emeralds there was a more uniform element distribution across the overgrowth.

Almost equal Cr and V contents are one of the most important chemical features of the Biron synthetic emeralds. They are also extremely low in iron and this contrasts with the Tairus emeralds which contain significant quantities of this element (*Table I*). No other elements are present that can substitute for Al in the octahedral site of the beryl structure.

Natural emerald from the Malyshev mine has a low Cr_2O_3 content in contrast to the Biron and Tairus synthetic emeralds. The highest Cr_2O_3 content of intensely coloured

Table I:: Chemical compositions of synthetic and natural emeralds.

Biron synthetic emerald*						Tairus synthetic emerald***				Ural	
Wt.%	R29(6)	R30(4)	R32(7)	R34(13)	R35(22)	420	361/1	310	309	U1(1)	U2(1)
SiO_2	66.35	66.63	66.75	65.66	65.46	65.90	65.70	66.00	65.80	63.99	64.86
Al_2O_3	17.91	18.66	18.29	18.16	17.87	15.31	16.36	16.00	16.40	16.63	16.89
Cr_2O_3	0.625	0.110	0.288	0.498	0.653	0.61	0.22	0.39	0.23	bdl	0.165
V_2O_3	0.756	0.132	0.348	0.874	0.917	bdl	bdl	bdl	bdl	bdl	bdl
BeO	nd	nd	13.72**	13.63**	nd	13.80	13.60	13.50	13.30	nd	nd
FeO	bdl	bdl	bdl	bdl	bdl	2.54	2.05	2.32	0.28	0.28	0.28
MgO	bdl	bdl	bdl	bdl	bdl	bdl	0.05	0.02	0.04	1.74	1.29
NiO	bdl	bdl	bdl	0.023	bdl	0.15	0.20	0.10	0.10	bdl	bdl
CuO	bdl	bdl	bdl	bdl	0.034	0.10	0.00	0.00	0.00	bdl	bdl
Na_2O	bdl	bdl	bdl	bdl	bdl	0.06	0.07	0.01	0.00	1.11	0.82
Cl	0.329	0.386	0.410	0.378	0.397	bdl	bdl	bdl	bdl	bdl	bdl
LOI	nd	nd	nd	nd	nd	1.00	1.20	1.10	1.20	nd	nd
Total	86.00	85.94	99.80	98.71	85.37	99.47	99.45	99.44	99.27	83.75	84.32

bdl – below detection limit;
nd – not determined, LOI – loss on ignition;
U1 – pale coloured zone of Ural emerald,
U2 – intensely coloured zone of the same crystal;

** – average composition: number of probe points are shown in parenthesis;*
*** – BeO concentrations for R32 and R34 were determined by wet chemistry;*
**** – wet chemistry analyses of Tairus emerald; Li_2O content is 0.1 wt.%, MnO and K_2O contents are around the detection limit.*
Cl and V_2O_3 were determined by electron microprobe and appeared to be below the detection limit.

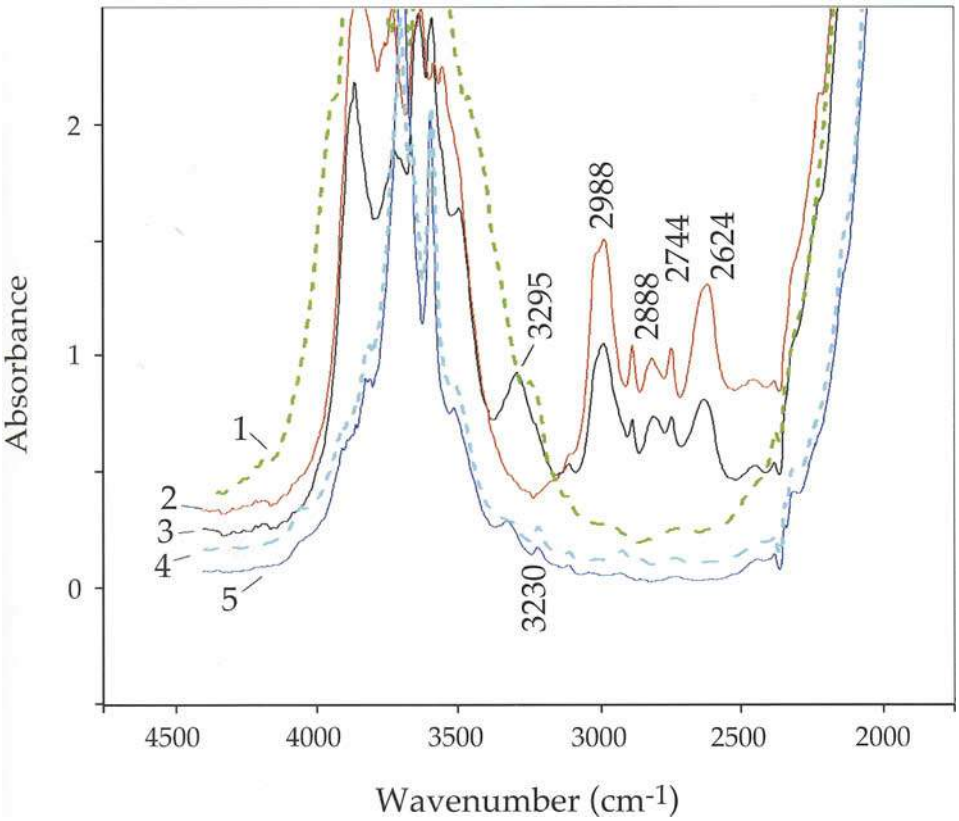

Figure 1: The mid-infrared spectra of natural emerald from the Urals (1) and hydrothermal synthetic emeralds Biron (2), Regency (3), and Tairus (4, 5). Note that the Tairus hydrothermal synthetic emerald spectra were obtained from two stones with different orientations of their table facet relative to the optic axis, namely angles of 30 degrees (4) and 60 degrees (5) to the optic axis.

Ural emeralds of about 0.2 wt. % was measured in the studied sample (*Table I*). A similar maximum Cr_2O_3 content (up to 0.5 wt.%) might be expected from the reports by Vlasov and Kutakova (1960), Schmetzer *et al.* (1991) and Schwartz (1991). In contrast, average Cr_2O_3 contents of Tairus and Biron synthetic emeralds are 0.54 – 1.24 wt. %. The average Cr_2O_3 content of Biron synthetic emerald (0.11–0.65 wt.%) is close to the upper limit of that of Ural stones. The colours and compositional zoning can be characteristic features of natural emeralds, and the Cr_2O_3 contents of Ural emeralds do vary significantly from zone to zone, resulting in contrasting intense and pale colours. On the basis of the reported (Schmetzer *et al.*,1991) and our own data (*Table I*), we conclude that the FeO content of Ural emerald is comparable with the lower limit of Tairus synthetic emerald and is much higher than that of Biron synthetic emerald.

MgO may be present in Tairus emeralds in quantities up to 0.1 wt.%, but its average is 0.04 wt.%. Biron synthetic emeralds usually do not contain detectable MgO, but it is worth noting that Pool synthetic emerald, which is analogous to Biron synthetic emerald, contains relatively high MgO (Bank *et al.*, 1989).

Elements occupying channel sites in the beryl structure

The most important chemical feature of the Biron synthetic emeralds is the relatively high Cl content, which is consistent with previous work (Hänni, 1982; Stockton, 1984; Kane and Liddicoat, 1985; Bank *et al.*, 1989; Yu *et al.*, 2000). It is worth noting that all the studied synthetic emeralds are low in or free of alkalis, while the Ural emeralds have relatively high Na_2O contents.

Infrared spectroscopy

The infrared spectra of the faceted stones are demonstrated in *Figure 1*. High absorbances are generally present in the range of the water absorption bands between 3400 and 3900 cm^{-1} for large faceted stones. Also atmospheric CO_2 has hindered the measurements in the range between 2300 and 2400 cm^{-1} when using the microscope attachment of the FTIR spectrometer. So for faceted emeralds the narrow range from 2400 to 3400 cm^{-1} is more accessible for measurements. To measure

Table II: The main features of IR spectra of hydrothermal synthetic and Ural emeralds and their appearance in emeralds of different origin.

Peak location cm^{-1}	Polarization relative to *c*-axis	Emerald type					
		Biron*	Regency*	Tairus*	Ural*	Assignment**	
2360	⊥				s	CO_2	[a]
2624	⊥	m	w-uo			HC1	[b]
2744	⊥	m	w-uo			HC1	[b]
2816	‖	vs	s-w			HC1	[b]
2888	⊥	m	w-uo			HC1	[b]
2988	⊥	s	m-uo			HC1	[b]
3230	‖			m-w	s-m	H_2O II	[a]
3232	⊥		sh			NH_4^+	[b]
3295	‖, ⊥		s-m			NH_4^+	[b]
3520	⊥	w	w	w	m	H_2O I	[a]
3560	⊥			w	w	H_2O I	[a]
3600	‖	vw	vw	m	s	H_2O II	[a]
3608	‖	w	w	w		OH	[d]
3650	⊥			w	m	H_2O II	[a]
3700	‖	s	s	s	vs	H_2O I	[a]
3888	⊥	m	m	m	s	H_2O I	[a]
4065	‖			w	w	H_2O II	[b,e]
5097	⊥	w	w	w	w	H_2O I	[a]
5271	⊥			m	s-m	H_2O II	[a]
5274	‖	s	s	s	s	H_2O I	[a]
5460	⊥	m	m	m	m	H_2O I	[a]
5520	‖	w				HC1	[b]
6494	‖			m-uo		Ni^{2+}	[c]
6820	‖	m	m	m	m	H_2O I	[a]
6990	⊥	w	w	w	w	H_2O I	[a]
7042	⊥	w				OH	[b]
7072	‖			w	w	OH	[d]
7092	⊥				w	H_2O II	[a]
7143	‖	s	s	s	s	H_2O I	[a]
7320	⊥	m	m	m	m	H_2O I	[a]
8475	⊥			m-uo		Cu^{2+}	[c]

* m - moderate, s - strong, w - weak, vw - very weak, vs – very strong, uo – unobserved, sh – shoulder

** References: [a] Wood and Nassau (1967, 1968); [b] Mashkovtsev and Solntsev (2002) and this work; [c] Solntsev (1981); [d] Mashkovtsev and Lebedev (1992); [e] Koivula *et al.* (1996)

polarized spectra in the range 2000 to 10000 cm^{-1} (*Figures* 2 and 3), emerald plates cut from the crystals were used.

The main spectroscopic data are listed in *Table II*. The well-known bands related to type I water molecules were observed in the spectra of all the samples. Type II water peaks are clearly present in Ural and Tairus emeralds, but in Biron and Regency emeralds, absorption traces related to type II water are weak or not present. Five absorption bands in the range 2600 – 3000 cm^{-1} are always present in Biron emeralds (cf. Leung *et al.*, 1986; Schmetzer *et al.*, 1997; Zecchini and Maitrallet, 1998). This system of bands may be so weak in Regency emeralds that only the central band at 2816 cm^{-1} may be observed on the background of other broad bands between 2400 and 3050 cm^{-1} (*Figure 2A*). Regency emerald spectra also display a double band with the maximum at 3295 and shoulder near 3232 cm^{-1} and a broad band between 3000 and 2500 cm^{-1} with a transmission window near 2870 cm^{-1}.

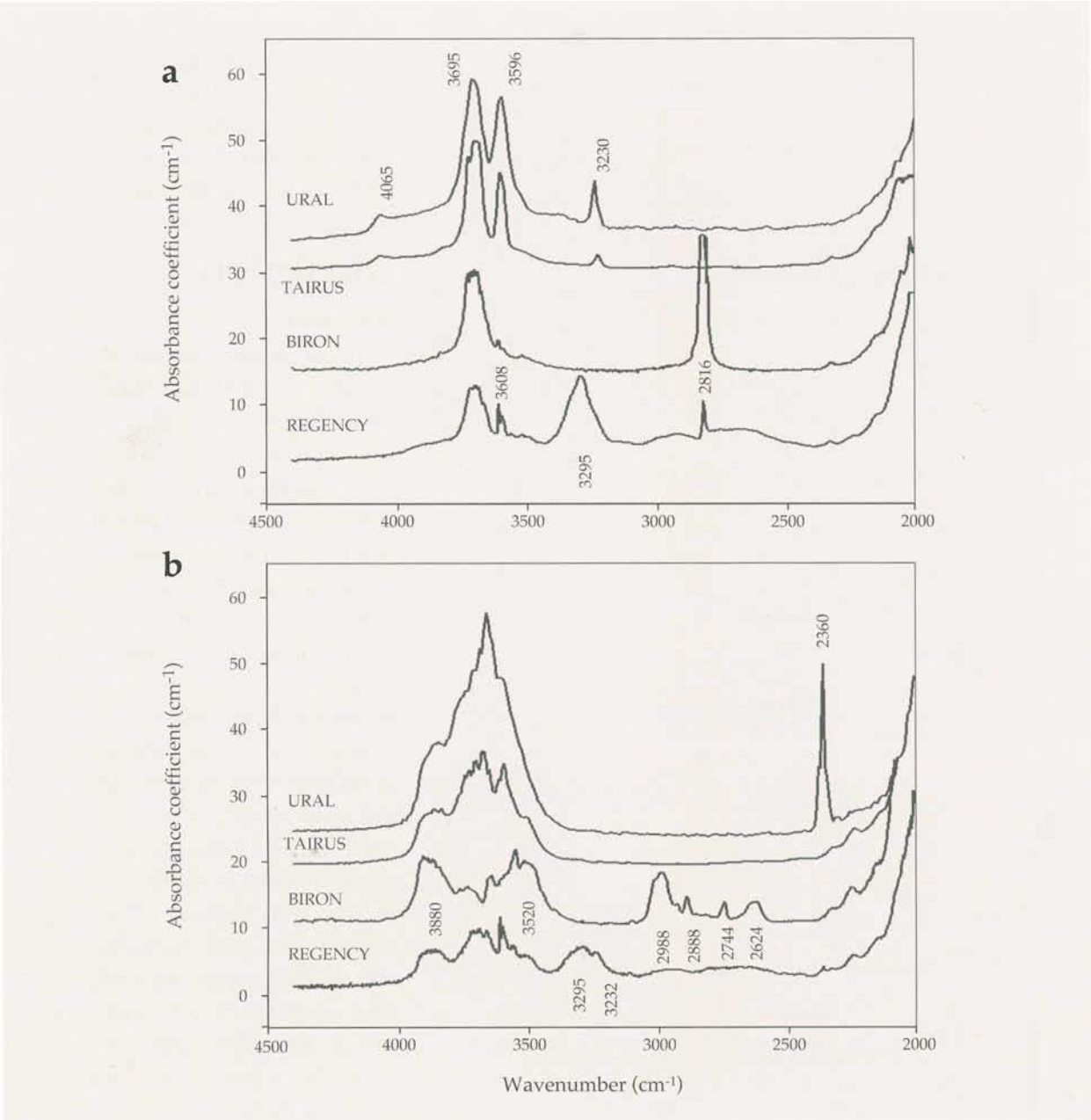

Figure 2: ***Mid-infrared extraordinary-ray (a) and ordinary-ray (b) spectra of thin plates of Regency (thickness t=0.65 mm), Biron (t=0.95 mm), Tairus (t=1.4 mm) hydrothermal synthetic emeralds and natural emerald from the Urals (t=0.6 mm). The main spectral features shown are discussed in the text and listed in*** **Table II.**

In comparing the most intense bands in natural and Tairus emeralds, these are similar except that in the Ural emeralds, there is an intense band at 2360 cm^{-1} related to the CO_2 molecule (Wood and Nassau, 1967, 1968). In synthetic emeralds, this peak is vanishingly small or absent. In Tairus emeralds there are the bands at 4065 and 3230 cm^{-1} which relate to type II water (Wood and Nassau, 1967; Koivula *et al.*, 1996), and there are weak peaks in the region around 2300 cm^{-1} as well as in the region between 2700 and 3105 cm^{-1} which are not related to water (see *Figures 1* and *2*); this system of bands between 2700 and 3105 cm^{-1} was obtained from Tairus faceted stones (*Figure 1*), but only certain of these were observed in thin plates (*Figure 2*). Also, the Tairus emeralds are the only emeralds to contain the broad bands at 6494 cm^{-1} and at 8475 cm^{-1} related to optical transitions in Ni^{2+} and Cu^{2+} ions respectively (Solntsev, 1981; see also Koivula *et al.*, 1996). The band at 3608 cm^{-1} is present in all three synthetic emeralds. Weak peaks visible near 7000 cm^{-1} include the line

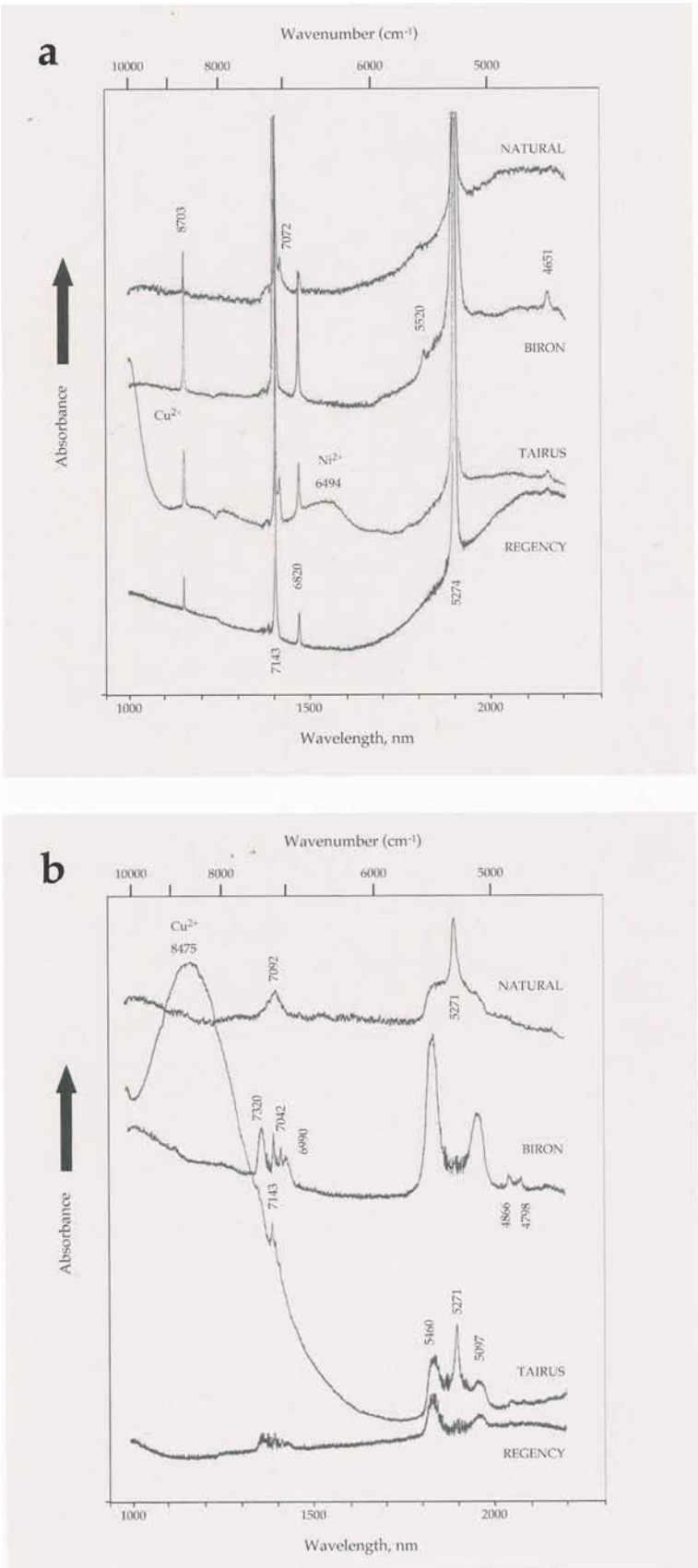

Figure 3: Near-infrared extraordinary ray (a) and ordinary-ray (b) spectra of the same plates as shown in Figure 2 except that the Biron plate is 3.3 mm thick. Note the broad absorption bands due to Ni^{2+} and Cu^{2+} ions in Tairus emerald, the additional peak at 5520 cm^{-1} due to HCl in Biron emerald, and other peaks which are discussed in the text and listed in Table II.

at 7042 cm^{-1} in Biron emerald and one at 7072 cm^{-1} in Tairus and natural emeralds (*Figure* 3). The relative thickness of the Biron plate enabled the weak band at 5520 cm^{-1} to be detected.

Discussion

Impurities

It has already been stated (Stockton, 1984) that composition of synthetic emeralds is of great importance in their identification. In this context, the components, which either are not present in natural mineral-forming solutions, or can not be incorporated in beryl structure under natural conditions are of the greatest interest, and chlorine is one example. Cl is one of the most important constituents of natural mineral-forming solutions. The concentrations of chlorides in the mineral-forming medium of a schist-type emerald deposit average about 5 – 10 wt. % (Moroz and Vapnik, 1999), and in evaporite type deposits, concentrations are typically as high as 38 wt. % (Cheilletz *et al.*, 1994). Very high salinities (up to 38 wt. % of NaCl) have also been detected in fluids at the Gravelotte schist-type deposit in South Africa (Nwe and Morteani, 1993). In contrast, Cl contents of most natural emeralds determined by PIXE (proton-induced X-ray emission) methods typically are very low, about 0.01 – 0.09 wt. % (Yu *et al.*, 2000), although in some Colombian, Zambian and Brazilian emeralds, contents can be as high as 0.12 – 0.18 wt. % (Yu *et al.*, 2000). Thus a content of more than 0.2 wt. % Cl is a very powerful indication that the emerald is hydrothermal synthetic.

Using our own data on composition of the emeralds and data available from the literature, synthetic emeralds may be roughly divided into two groups: low-chlorine and high-chlorine. Typically low-chlorine are flux emeralds, excluding some Gilson and Lennix stones (see Yu *et al.*, 2000), Russian hydrothermally-grown emeralds and most natural emeralds. In this study Cl was not detected in Tairus synthetic or in Ural emeralds, thus they belong to low-chlorine emeralds. High-chlorine emeralds include hydrothermally-grown Linde or Regency, Biron and new Chinese synthetic emeralds. It is known that hydrochloric acid and alkali chloride water solutions were used to grow Linde or Regency synthetic emeralds (Nassau, 1976). It has also been found that alkali chlorides are the major salt constituents of nail-head and spicule-like fluid inclusions in Biron synthetic emeralds (Smirnov – unpublished data). Although there are no obviously appropriate sites within the beryl structure that chlorine ions could occupy, the high Cl-contents in synthetic emeralds, determined by electron microprobe or PIXE analyses, indicate that Cl is a structural impurity rather than a constituent of inclusions. We therefore suggest that channels in the beryl structure are the only appropriate sites for chlorine.

IR spectroscopy

From infrared spectroscopic data we conclude that five bands in the range 2600-3000 cm^{-1} observed in Biron and Regency emeralds are related to HCl molecules arranged in the channels of the beryl structure (Mashkovtsev, 1996; Mashkovtsev and Solntsev, 2002). Schmetzer *et al.* (1997) also associated this group of bands with chlorine content. In support of this conclusion it was noted that (i) in these emeralds chlorine was invariably detected by Hänni (1982), Stockton (1984), Kane and Liddicoat (1985) and by other authors (see *Table I*), and (ii) the vibrational frequencies of various forms of HCl molecules trapped in inert matrices stretch from 2700 to 3000 cm^{-1} (Hallam, 1973). Here we want to refine the early assignment (Mashkovtsev, 1996) to various forms of HCl molecules (single HCl, dimer and trimer) and state that all five of the absorption bands in the 2600 – 3000 cm^{-1} region are related to the HCl dimer (two bound HCl molecules). In a solid Ar matrix at a temperature of 20 K, the spectrum of the HCl dimer has one very weak band at 2855 cm^{-1} and another strong band at 2817.5 cm^{-1}, which depends only slightly on the matrix (Mailard *et al.*, 1979). Therefore we assume that the strong band at 2816 cm^{-1} observed in chlorine-bearing hydrothermal synthetic emeralds is related to the HCl dimer (the band near 2855 cm^{-1} in our case is probably too weak to be observed). The two pairs of the bands (one at 2624 and 2988 cm^{-1} and another at 2744 and 2888 cm^{-1}) are near-symmetrical about the main band at 2816 cm^{-1}, whereas the intensities of the bands at 2624 cm^{-1} and at 2744 cm^{-1} are always weaker than those of their counterparts at 2888 and at 2988 cm^{-1}. We assume that these so-called combination bands have resulted from the hindered rotation (or libration) of the HCl dimer about two axes of the dimer compound. The full justification will be published elsewhere. Here we note only that in a similar way the libration of molecular water gives rise to the combination bands at 3520 and 3888 cm^{-1}, which are near-symmetrical about a strong band at 3700 cm^{-1} and are related to the type I H_2O (Wood and Nassau, 1967). The uneven intensity and slightly asymmetrical disposition of these combination bands about the main band are explained by a dissimilar mechanism of their excitation (Herzberg, 1945).

Hence we suggest that the system of the bands in the 2600-3000 cm^{-1} region is related to an L-shaped dimer of two HCl molecules (*Figure* 4). The extraordinary-ray near-infrared spectra show a narrow absorption band at 5520 cm^{-1} related to an overtone (it is a replica of the main band at nearly double the frequency but with very weak intensity) of dimer HCl vibration at 2816 cm^{-1} (see *Figure* 3).

It is known that for the growth of Linde hydrothermal emeralds, ammonium halides were used (Nassau, 1976). Furthermore, the Tairus experimental beryl, synthesized

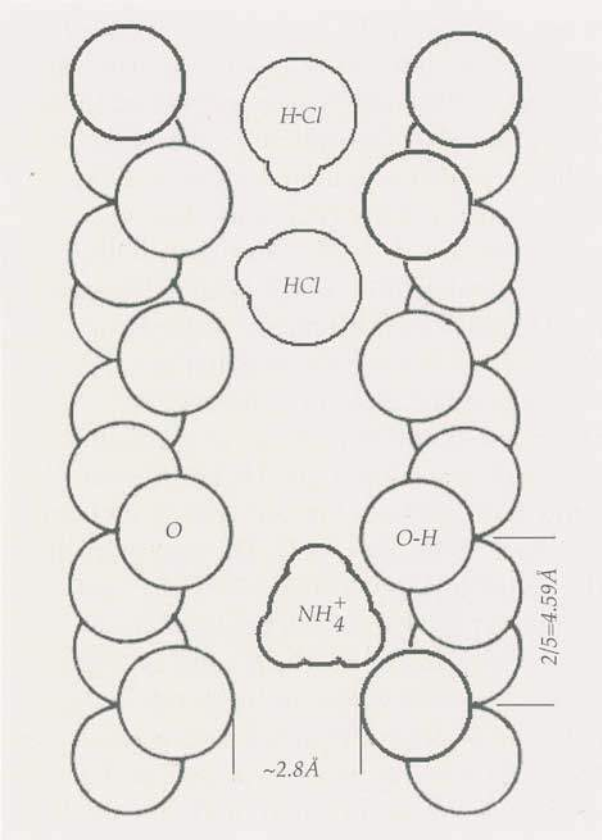

Figure 4: The proposed model for ammonium ion and HCl molecules in the structural c – channel of beryl. Shown are the H-Cl bond of one HCl molecule which is hydrogen-bonded with another HCl molecule, and the O-H bond of structural oxygen which is hydrogen-bonded with an ammonium ion.

hydrothermally in an NH_4Cl salt solution, shows IR spectral features similar to those of a Linde emerald (Mashkovtsev and Solntsev, 2002). Hence we have proposed that the band at 3295 cm^{-1} (with shoulder at 3232 cm^{-1}) and the broad band between 3000 and 2500 cm^{-1} are related to NH_3 molecules and NH_4^+ ions, respectively, in the structural *c*-channels. This conclusion was supported by careful study of the NH_3^+ radical observed after γ-irradiation by the use of electron paramagnetic resonance (Mashkovtsev and Solntsev, 2002). However, more data are needed for unambiguous determination of the cause of all the above-mentioned bands. Besides the stretching bands between 3000 and 3400 cm^{-1}, in the IR spectra there are characteristic bending modes at 1630, 968 and 930 cm^{-1} for NH_3 molecules and at 1680 and 1450 cm^{-1} for NH_4^+ ions (Nakamoto, 1978; Likhacheva *et al.*, 2002) but these bands were not detected in beryl because they are veiled by lattice vibrations. The IR spectrum in the range from 5000 to 4000 cm^{-1} for a thick plate of Tairus emerald was also obtained (Mashkovtsev *et al.*, 2004) and revealed a weak peak at 4651 cm^{-1} (related to an overtone of a water molecule (Wood and Nassau, 1967)) superimposed on a background band with a broad maximum centred near 4770 cm^{-1}; this is probably a result of the linear combination of the ammonium bending mode (typically near 1680 and 1450 cm^{-1}) and the stretching mode at 3295 cm^{-1}. Furthermore we can explain the origin of the broad band between 3000 and 2500 cm^{-1} with a transmission window near 2870 cm^{-1} in the following way (Mashkovtsev *et al.*, 2003; Mashkovtsev *et al.*, 2004). Ammonium can be regarded as a proton donor; it results in a hydrogen-bonded complex with oxygen in the lattice and forms an O-H bond (see *Figure 4*) which gives rise to an absorption continuum in the range 3000 – 2500 cm^{-1}. Fermi resonance produces a transmission window in this continuum at 2870 cm^{-1} because of interaction with a sharp overtone of the bending mode near 1450 cm^{-1} (Wood, 1973).

The narrow peaks at 3608 and the overtone at 7072 cm^{-1} (*Figures 2* and *3*) have been observed previously in Russian hydrothermal synthetic beryls and assigned to OH groups (Mashkovtsev and Lebedev, 1992). Analogously the band at 7042 cm^{-1} observed in Biron emeralds (*Figure 3*) may be an overtone of the main band near 3600 cm^{-1}. In this region the main band is masked by the intense water absorptions. Aines and Rossman (1984) showed how to distinguish the spectrum of the H_2O molecule from that of an OH group in the 7000 and 5200 cm^{-1} region. In contrast to H_2O molecules the OH groups have no bending vibrations with a frequency near 1600 cm^{-1}, which give, together with stretching vibrations near 3600 cm^{-1} for H_2O, the combination band near 5200 cm^{-1}. In our case there are no weak peaks near 5200 cm^{-1} associated with the intense bands related to the type I and type II molecular water. The presence or absence of the bending-related absorption near 1600 cm^{-1} is the primary

criterion of distinction between H_2O and OH. According this criterion the band at 7042 cm^{-1} observed in Biron emeralds may be assigned to an OH group, and the difference in the frequencies of this (7042 cm^{-1}) and the Tairus emerald (7072 cm^{-1}) may relate to substitution of OH for oxygen at different positions in the emerald structure.

Visibility of an additional system of the weak bands between 2700 and 3105 cm^{-1} in Tairus emeralds (*Figure 1*) depends on the orientation of cut stones relative to the incident light and, probably, has been camouflaged in other emeralds by intense absorption bands in this range. This system may be related to the overtones of beryl lattice vibrations. The Tairus emerald is the only synthetic emerald which displays the bands at 3230 and 4065 cm^{-1}; these are related to type II water (cf. Stockton, 1987; Koivula *et al.*, 1996).

Obviously the detection of the weak absorption bands in cut stones depends on sensitivities of the instruments used, dimensions of the gems and on the orientation of the polished facet to the incident light. So although Koivula *et al.* (1996) did not reveal any weak band at 7072 cm^{-1}, their mid-infrared spectra did show a peak at 3608 cm^{-1} in Russian synthetic emeralds. Although the Tairus emeralds studied here failed to show a number of bands around 2300 cm^{-1} reported by Stockton (1987) and Koivula *et al.* (1996), there are a sufficient number of strong distinguishing features to enable separation of natural from Russian hydrothermal synthetic emeralds. The broad bands in the near-infrared range, which we attributed to Ni^{2+} and Cu^{2+}, have been reported by Koivula *et al.* (1996). In some modern Tairus emeralds the peaks are small, indicating only traces of Ni and Cu. In the visible range spectra, any bands relating to Ni^{2+} and Cu^{2+} are camouflaged by the intense bands due to Cr^{3+}, Fe^{3+} and Fe^{2+}, especially when the concentrations of Ni^{2+} and Cu^{2+} are small (cf. Schmetzer, 1988). In this case, it is more productive to measure the near-infrared range which lacks interfering bands.

Conclusion

So far as we know, HCl (the system of the bands in the range between 2600 and 3000 cm^{-1}) and ammonium (double band near 3300 cm^{-1} and broad band between 3000 and 2500 cm^{-1} with transmission window near 2870 cm^{-1}) molecules have not been found in natural beryls. It is known that ammonium halides and acid media are used in the growth of synthetic emeralds (Nassau, 1976). Therefore, detection of HCl and ammonium in the IR spectra of emeralds serves to identify them as hydrothermal synthetic emeralds. Incorporation of different impurities in the beryl structure originates from the chemical reagents and autoclaves used for crystal growth by different manufacturers, so, if required, hydrothermal synthetic emeralds of the different well-known manufacturers should be distinguishable. In Biron hydrothermal emeralds for example, strong bands in the range from 2600 to 3000 cm^{-1} due to HCl molecules are visible, and Regency (Linde) emeralds show an additional strong double band near 3300 cm^{-1} due to ammonium (*Figures 1, 2* and *Table II*). The important distinguishing features of Russian hydrothermal synthetic emeralds are the broad bands in the near-infrared range due to Cu^{2+} and Ni^{2+} ions which result from dissolution of the autoclave walls (*Figure 3, Table II*). Now the use of IR spectroscopy is a powerful tool in separation of natural from synthetic emeralds. However, it is still preferable to combine the techniques of trace-element analysis, microscopic study and spectroscopic method for the unequivocal determination of whether an emerald is synthetic or natural.

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A new definition of optic axis for gemmology

and the four kinds of optic axis

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Abstract: *Longstanding misuse of terminology in gemmological literature and course notes has allowed an inaccurate definition of optic axis to confuse understanding of this simple and fundamental concept. The problem is addressed with the proposal of a succinct new definition for* ***optic axis****. A review of anisotropic optics and discussion of the four kinds of optic axis explains how the proposed definition accords with optics theory.*

Keywords: *birefringence, double refraction, optic axis, polarization*

Introduction

The common definition of optic axis in gemmology, 'a direction of single refraction in a doubly refracting crystal[1]', is unsatisfactory because light at normal incidence in this direction would not refract at all, so refraction is irrelevant. Even when it is reworded to eliminate the refraction / refringence[2] confusion, 'an isotropic direction in a birefringent medium' does not leave an opening for minerals with optical activity[3]. This inadequate wording would not allow, for example, that quartz has an optic axis. Careful consideration of optical properties in biaxial media will show that, unlike the simpler uniaxial media, there are no isotropic directions in a biaxial medium. There is clearly a need for a new definition of optic axis that is in accord with modern understanding of optics. A definition that uses the phrase 'single refraction' is simply wrong, and a definition that specifies *isotropic* excludes some uniaxial and all biaxial material.

The proposed new definition for optic axis is:

Optic axis: a propagation direction in a birefringent medium that by some criterion has zero birefringence. It is a direction where birefringence (BI) = 0 in a medium with BI>0.

Isotropic and anisotropic media

A brief iteration about isotropic and anisotropic media may be a logical place to start. The measure of refringence[4] (optical density) is refractive index (RI), and materials that have more than one RI are said to be birefringent. The numerical difference between the lowest and the highest RI along one propagation direction is called the birefringence (BI) of that reading. A test in another direction through that same medium can yield other RI values with a changed birefringence particular to that new direction tested. Each direction through the medium

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will have its own birefringence value. When referencing the medium (rather than one specific test direction) all possible test directions are considered. The 'birefringence' (BI) of the medium is presumed to mean 'maximum birefringence'. The BI of the stone will almost always be greater than the BI of one direction tested.

To understand the interaction of light with an anisotropic medium, one must consider the vibration direction of the light. It must be appreciated that randomly vibrating light can be sorted by a medium into one portion of light having specifically definable vibration, and another portion of light vibrating in a direction perpendicular[5] to the vibration of the first portion. Where birefingence is observed, the different RI readings are related to different vibration directions in the medium. For each propagation direction, the birefringence is for mutually perpendicular[5] directions of vibration. Light vibrating in specifically definable directions is called polarized light.

For most birefringent media, the mutually perpendicular vibrations that each medium produces will be two sets of plane-polarized light. One set of linear vibrations will be at 90° to the vibration of the companion set. For most directions of propagation through the medium, each direction of vibration interacts differently with the medium in terms of velocity of transmission, which interactions result in birefringence. The numerical value of birefringence will vary according to the propagation direction tested because vibrations are limited to within the wave front[6] in transverse relationship[7] to the direction of travel.

Optic axes

There will always be at least one direction through a birefringent medium where the numerical value of birefringence is zero. This special propagation direction in a birefringent medium is an optic axis.

As stated above, an optic axis is a propagation direction in a birefringent medium that *by some criterion* has zero birefringence (BI=0). The qualifying *by some criterion* in the definition of optic axis allows insertion of specifics to enable distinction of different kinds of optic axes.

There are four different kinds of optic axis; each is definably monorefringent.

1. An isotropic propagation direction in a birefringent medium[8].
2. An optically active propagation direction with nil birefringence for linearly polarized light.
3. A ray direction in which mutually perpendicular vibrations travel at the same velocity.
4. A propagation direction in which all vibrations travel at the same wave-normal velocity.

Materials with tetragonal, hexagonal, or trigonal structure have[9] either the first or the second type of optic axis. Materials with orthorhombic, monoclinic or triclinic symmetry, have[10] both the third and the fourth kinds of optic axes.

Uniaxial minerals

In uniaxial media, the direction parallel to the *c* axis differs from and is 90° to the directions in the plane of the '*a*' axes. In biaxial media, all the crystal axes differ. To visualize the optical properties of a medium it is helpful to consider the shapes of wave fronts of light as they progress. The relationship between the wave front, the direction of travel, and the direction of vibration can be understood by considering the activity of the light at one point on the wave front.

Imagine that a single-point light source inside the medium produces a momentary flash of light, somewhat like a pinpoint size photographic flash bulb. Using our imagination to stop time a little while after our pulse of light is produced, we can picture the shape of the wave front at any particular moment as it progresses through the medium.

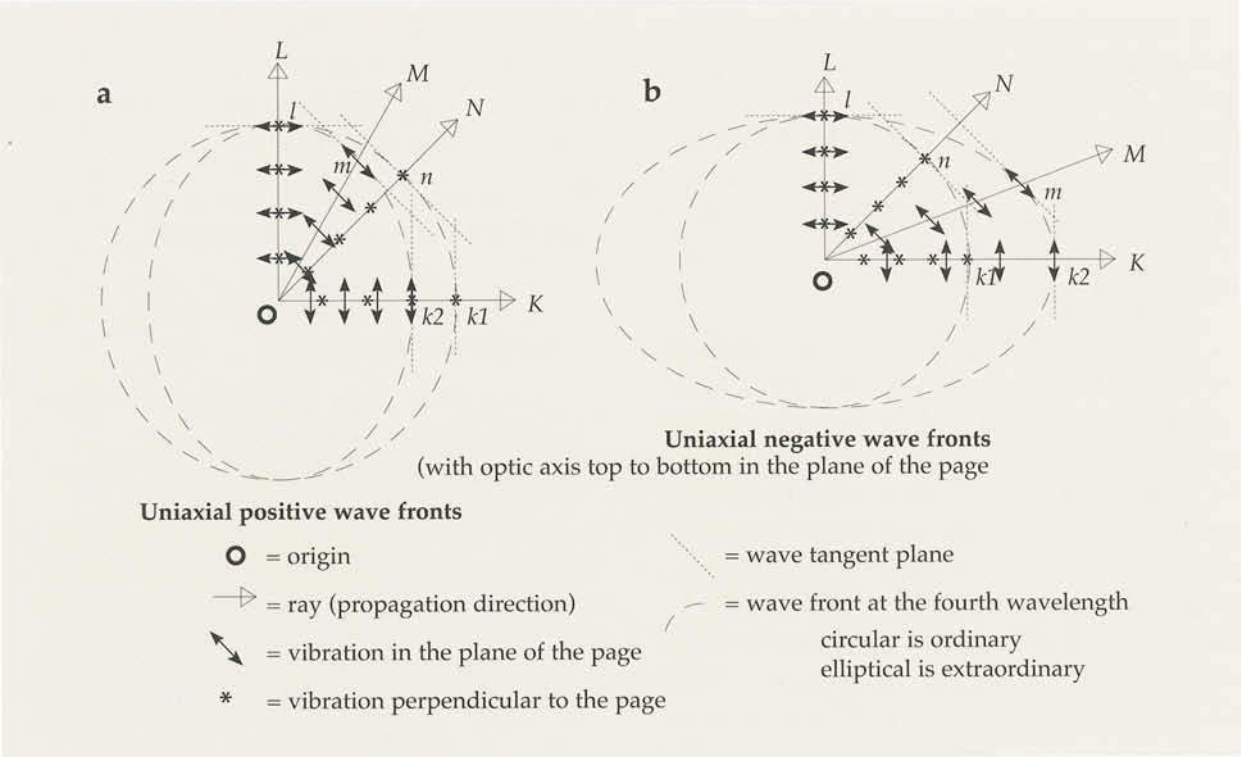

Figure 1: *Uniaxial wave fronts: (a) positive, and (b) negative. The optic axis is top to bottom in the plane of the page.*

The three-dimensional shape of the progressing wave fronts is called the ray-velocity surface in optics terminology.

Figure 1 shows a central cross-section of wave fronts of light radiating from a point light source and travelling in a uniaxial medium (positive (a) and negative (b)) with the direction of vibration indicated once every wavelength and the shape of the wave front shown by dashed lines at the fourth wavelength. With the optic axis set top-to-bottom in the plane of the diagram, each diagram shows the direction of propagation for rays vibrating in a plane perpendicular to the optic axis, for rays vibrating in a plane parallel to the optic axis and for rays vibrating in a plane at 45° to the optic axis. In simple cases, such as zircon, beryl, calcite or tourmaline, the two wave fronts are in contact with each other at two diametrically opposite points that locate the optic axis. All normally incident light in this propagation direction will travel (without refracting)[11] with no optical variation for differing vibration directions. In terms of refringence, every ray will travel at the same velocity regardless of direction of vibration. Every vibration will continue at the velocity imposed by the refringence with no change in the sense of vibration; that is the vibration direction will not be altered by the medium. This direction is isotropic.

Quartz

To show the wave fronts and vibration directions for the more complex case of quartz, a perspective view of a wedge section is more helpful than a cross-section. For *Figure 2*, which shows the vibration directions for dextrorotatary and laevorotatary quartz[12], imagine that the single point light source is at floor level in the corner of a room that is completely filled, wall-to-wall and floor to ceiling, with quartz crystal structure. The optic axis is oriented parallel to the edge where the floor and a wall meet on our left as we look down into the corner. Stopping time a moment after a pulse of light is produced, we can see the shape of the wave fronts against the floor and the two walls. Either of these sections together with the missing seven comparable sections would show

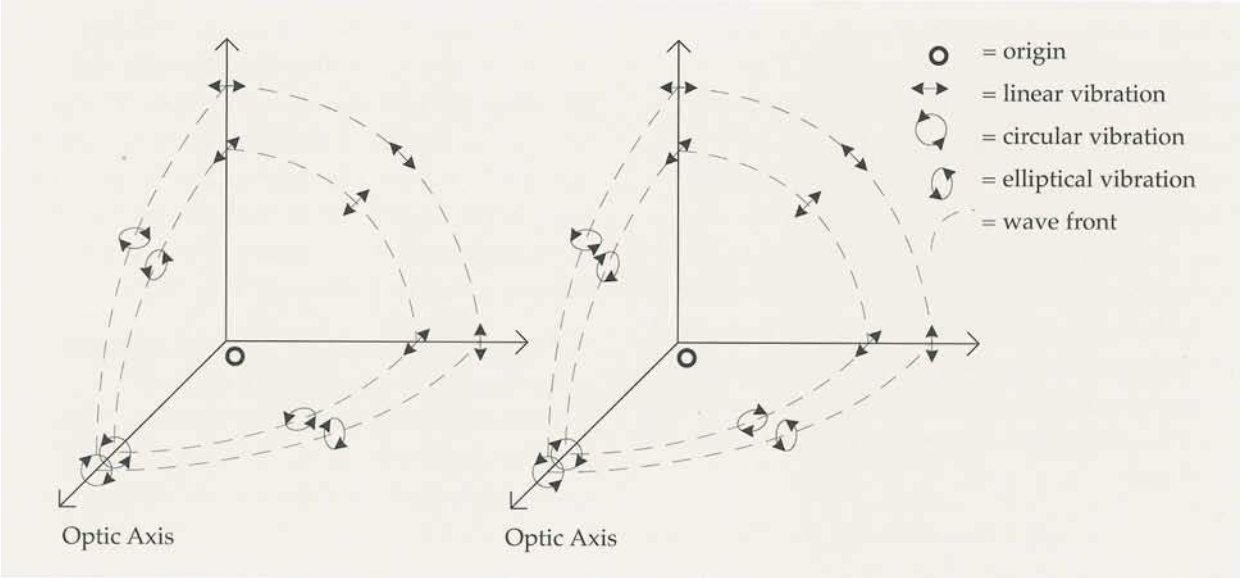

Figure 2: Vibration directions in quartz.

a fully rounded three-dimensional shape indicating proportional velocity from the centre for all vibration directions.

The vibration direction of the light is shown in six points on each of the two wave fronts. The vibration direction for light travelling perpendicular to the optic axis is linear[13], the vibration direction for light travelling along the optic axis is circular[14], and the vibration direction for other directions of travel is elliptical[15].

In this helical medium, two circularly polarized rays with opposing sense of rotation yield circular birefringence in one propagation direction, but this circularly birefringent direction is monorefringent with respect to the wave-normal velocity[16] of linearly polarized light. For this, the second kind of optic axis, velocity is the same regardless of the direction of linear vibration, whilst the direction of linear vibration changes over the course of transmission. This rotation of the direction of linear vibration is called optical activity, which is produced by the circular birefringence.

Biaxial minerals

These first two kinds of optic axes, which are seen in uniaxial media, are too highly symmetrical to be found in media with orthohombic, monoclinic, or triclinic structure. When these lower-symmetry structures are tested it is found that birefringence does vary from maximum to zero, however.

For these cases narrow and more specific language is needed to define a special direction that can be termed an optic axis. There are two different directions that can be defined as monorefringent in biaxial media; one relates to light rays and the other to light waves. These two directions are the third and fourth kinds of optic axis.

In every birefringent medium, there will be at least one direction of propagation through the medium where mutually perpendicular vibrations can progress along the same path at the same velocity. In uniaxial media this defined direction coincides with the one optic axis, but in the lower symmetry media two directions within the optic plane[17] satisfy this definition. These materials are said to be biaxial. This direction is monorefringent with respect to ray velocity and is the optic axis for light rays. In optics texts it is called the secondary optic axis. This direction is easier to recognize in a wave-front diagram but, as will be shown, has optical properties that make it deserve the status of secondary.

For every birefringent medium, there will be at least one direction into the medium

where vibrations in all normally incident light continuously share the same wave-tangent plane as the light progresses through the medium. In uniaxial media this defined direction coincides with the one optic axis, but in the lower symmetry media two directions within the optic plane satisfy this definition and the biaxal label is reinforced. This direction is monorefringent with respect to wave-normal velocity and is the optic axis for light waves. In optics texts this direction is called the primary optic axis, or just the optic axis.

It may be helpful to consider the directions defined in terms of equal ray velocity as the internal optic axes. *Figure 3* shows[18] a centre section in the optic plane through the wave fronts of light travelling in a biaxial medium. Two rays with mutually perpendicular vibrations are travelling along one internal optic axis sloped to the right; the other internal optic axis has that same slope to the left through the other point where the two wave fronts cross. This internal optic axis is a direction shared by the rays for two mutually perpendicular vibration directions. The ray vibrating in the optic plane and the ray vibrating perpendicular to the optic plane travel at exactly the same velocity in this direction through the biaxial medium. Even though they are travelling at the same velocity, each vibration has a different wave-normal. It must be remembered that the wave-normal is perpendicular to the vibration and not necessarily in the ray direction. The wave front containing the vibration perpendicular to the optic plane is circular, so that wave-normal continues in a straight line from the origin. The wave front containing the vibration in the optic plane is an ellipse, so that vibration direction sets the wave-normal in a different direction.

The special directions defined in terms of the continuously coinciding plane of vibrations have been called 'primary optic axes' or just 'optic axes'. It may be helpful to consider them as the **external optic axes**. *Figure 4* shows a centre section through the wave fronts in the optic plane with one optic axis direction detailed. The other external optic axis is sloped in from the other side at that same angle.

This optic axis direction is oblique, within the optic plane, and normal to the wave-tangent plane shared by both wave fronts. Collimated light incident at the normal in the direction of the external optic axis[19] will experience conical refraction upon passing through an incident surface at AB. Vibrations in the principal vibration direction for β travel straight on. Vibrations in all other directions are refracted as the vibrations travel in shared parallel planes through the medium. In the *Figure 4* side view, vibrations 90° to the page are β. In the end view, vibrations in the tangent shared by all the circular wave front sections are β as they

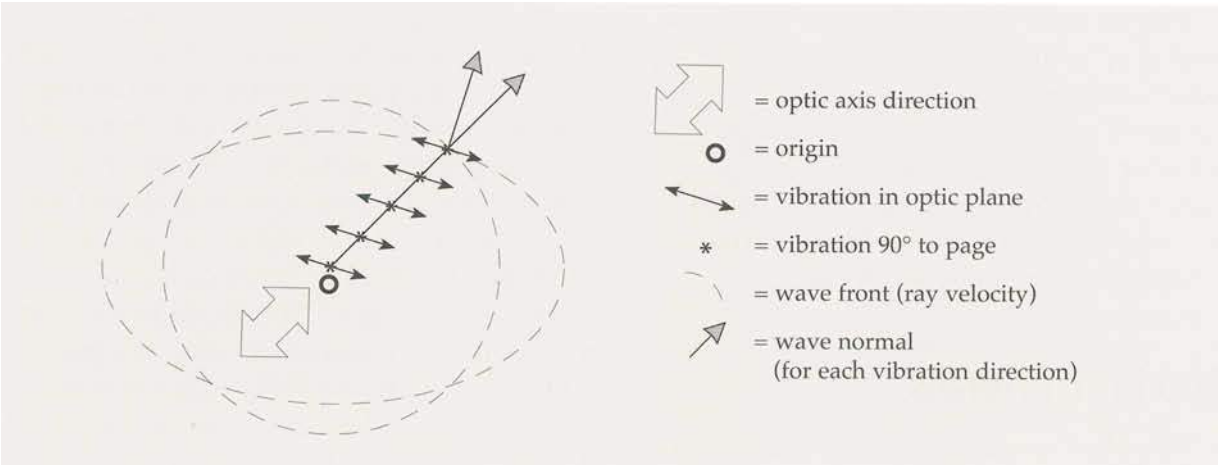

Figure 3: ***Internal (secondary) optic axis.***

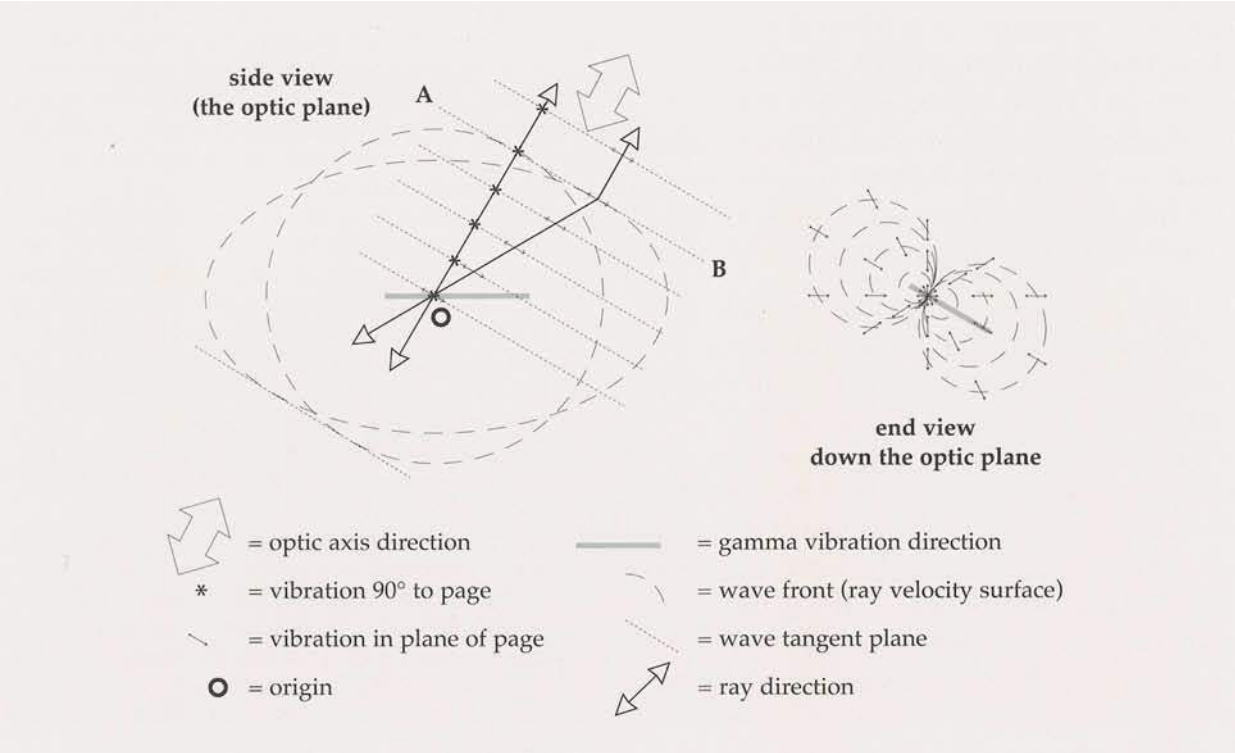

Figure 4: External (primary) optic axis wave-front diagram.

continue past the origin of the ray-velocity surfaces depicted in the side view.

Discussion

Practical testing related to optic axes involves examining material from an exterior perspective. Looking in from the outside, external optic axes are being observed. External optic axes are defined as monorefringent with respect to wave-normal velocity, and wave-normal directions are easiest to consider in understanding refraction. External optic axes are the optic axes for waves of light, and waves actually exist. Internal optic axes are the optic axes for rays of light, and rays do not exist except in our imagination. It is therefore understandable that external optic axes are routinely considered as *the* optic axes while the internal optic axes are considered secondary.

Curiously, the internal optic axis is monorefringent because it provides one velocity for mutually perpendicular vibrations, whilst it is doubly refracting because of the different wave-normal directions (although the angle between the diverging refracted rays would be smaller than the angle between the internal wave-normals). The idea of a doubly refracting optic axis sounds self-contradictory, but that clearly is the case here.

The case of a doubly refracting monorefringent direction in biaxial media also reinforces the importance of differentiating double refraction from birefringence[2]. This peculiar state of affairs underlines the suitability of considering the internal optic axes as secondary. Discussions of biaxial optic axes, therefore, usually sensibly refer to only the two external optic axes.

For readers having difficulty with the subtle difference between the two kinds of biaxal optic axes, a careful comparison of the optic axis direction shown in *Figure 4* (side view), with the secondary optic axis shown in *Figure 3*, should help clarify the concepts. For most people a ray is relatively easy to visualize, so the direction of the secondary

optic axis shown in *Figure 3* makes sense. Wave fronts are more difficult to visualize, so the optic axis depicted in *Figure 4*, as perpendicular to shared wave tangent planes, requires careful consideration to understand that this direction differs (by a small angle) from the secondary optic axis direction.

Finally, correct use of terminology can help avoid misunderstanding. The contraction 'DR' should be expunged from future texts and articles in favour of 'BI'. 'Doubly refracting' or a variation of this phrase is usually a misuse of terminology that clouds the issue by confusing a property of a medium with action taken by light. The word 'refract' (and all variations of it) should only and always refer to light, not a medium. If a medium is birefringent, some of the light it transmits experiences double refraction. If double refraction of light is observed, the medium is birefringent. It is incorrect to refer to a medium as 'doubly refracting' because the medium does not bend, it is only the light that bends.

References

1. Webster, R., edited by Read, P.G., 1994. *Gems*. 5th edn. Butterworth-Heinemann Ltd., Oxford, p. 668
2. Cartier, R.H., 2002. Birefringence vs. double refraction divergence. *Journal of Gemmology*, 28(4), 223-6
3. Optical activity, which is the rotation of linearly polarized light during transmission, occurs along the optic axis of a uniaxial crystal structure that spirals around in one direction (such as quartz), in different crystal systems where units of internal structure can be described in terms of mirror isomerism (such as the optic axes of Rochelle salt) or enantiomorphism (such as the four triad axes in sodium chlorate), and can also occur in amorphous media that include left- or right-handed molecules (such as fluids containing some organic molecules such as sucrose). See: E.E. Wahlstrom, *Optical Crystallography*, 5th edn, chapter 13
4. Wahlstrom, E.E., 1979. *Optical crystallography*. 5th edn. John Wiley & Sons, New York. p. 50, first paragraph
5. (and/or of reverse sense, if rotation is involved)
6. The two-dimensional space containing the vibration is usually represented by a flat plane. If the wave front is not flat, the plane of vibration is represented by a flat plane tangent to the wave front at the point under consideration. This is called the wave-tangent plane.
7. The phrase 'transverse relationship' holds for the isotropic case, where the vibration may be any random direction within a plane perpendicular to the direction of propagation. It also holds for all anisotropic cases including polarized light (with linear, circular, or elliptical polarization) and a flat vibration plane that is tilted from being perpendicular to the ray direction (to conform with the wave-tangent plane).
8. This first kind of optic axis is monorefringent (exhibits zero birefringence) for all criteria that are not self-limiting. That is, for any kind of polarized light, for ray velocity, and for wave-normal velocity this optic axis is a propagation direction that will exhibit zero birefringence.
9. One of (so uniaxial because when looking for one kind of optic axis only one will be found).
10. Two of each (so biaxial because when looking for one kind of optic axis two of that kind will be found).
11. Much literature has referred to this as a direction of 'single refraction' but such wording is clearly inaccurate when no refraction takes place.
12. After G.R. Fowles, *Introduction to modern optics*, 2nd edn, reprinted 1989. Dover Publications, New York. Figure 6.19, p.190 (with correction)
13. Companion vibrations have mutually perpendicular vibrations.
14. Companion vibrations have reverse sense of rotation.
15. Companion vibrations have reverse sense of rotation and the ellipses' major axes are mutually perpendicular.
16. Wave-normal velocity is velocity in that direction perpendicular to the wave tangent plane. In isotropic media, in uniaxial optic axes, and in anisotropic propagation directions that coincide with a principal vibration direction, this corresponds with the ray direction.
17. The optic plane is that plane that contains both the highest RI (γ) and the lowest RI (α) vibration directions.
18. *Figure 3* also shows the wave-normal for each of the rays travelling along the internal optic axis. The ray direction of the refracted external rays will depend, of course, upon the slope of the exit surface. The exit surface cannot be tangent to both wave fronts at the same time, so the external rays cannot be along the internal wave-normal. If, for example, the exit surface is tangent to the elliptical wave front at the internal optic axis, then the ray vibrating in the circular wave front will refract toward the ray at the wave-normal for the elliptical wave front. If the exit surface is tangent to the circular wave front at the internal optic axis, then the ray vibrating in the elliptical wave front will refract toward the wave-normal for the circular wave front while the other ray travels straight on. Other slopes of the exit surface will cause both rays to refract, and they will always be travelling with an angle between them significantly less than the angle between the internal wave-normals.
19. Every ray direction is reversible, so the double-headed depiction of rays allows that this diagram could be interpreted as showing light travelling from the origin 'O' to exit through the surface 'AB' and then travel as collimated light.

Abstracts

Diamonds

Gem News International.
B.M. LAURS (ED). *Gems & Gemology*, **39**(4), 2003, 322-46.

The gemmological properties of three famous blue diamonds (the Hope, Blue Heart and Heart of Eternity) are described, together with those of natural yellow diamond with Ni-related optical centres. R.A.H.

Diamond formation and source carbonation: mineral associations in diamonds from Namibia.
I. LEOST, T. STACHEL, G.P. BREY, J.W. HARRIS AND I.D. RYABCHIKOV. *Contributions to Mineralogy & Petrology*, **145**(1), 2003, 15-24.

Mineral inclusions in diamonds from Namibia document a range of mantle sources, including eclogitic, websteritic and peridotitic parageneses. Based on unusual textural features a group of inclusions showing websteritic, peridotitic and transitional chemical features is assigned to an 'undetermined suite' (12% of the studied diamonds). The mutual characteristic of this group is the occurrence of lamellar intergrowths of clinopyroxene and orthopyroxene. In addition, the 'undetermined suite' is associated with a number of uncommon phases: in one diamond $MgCO_3$ is enclosed by clinopyrozene. Other minerals that form touching inclusions with the pyroxene lamellae are: 1) a SiO_2 phase observed in three diamonds, together with $CaCO_3$ in one of them, 2) phlogopite and a Cr-rich 'titanite' (probably lindsleyite). The inclusions document a metamorphic path of decreasing *P* and *T* after entrapment in diamond. First, homogeneous low-Ca clinopyroxenes were entrapped at high *T*, then they exsolved orthopyroxene and probably also SiO_2 (coesite) on cooling along a *P*, *T* trajectory that did not allow garnet to be exsolved. Phlogopite, carbonates and LIMA phases are the result of overprint of a peridotitic source rock by a carbon-rich agent. The resulting unusual, olivine-free mineral association and the host diamonds are interpreted as products of extensive carbonation of the peridotite. G.L.B.

Diamond geezer.
J. MCCALL. *Geoscientist*, **14**(3), 2004, 10-11.

Short review of the history of diamond recovery in India. M.O'D.

Diamond crystals.
T. MOORE. *Mineralogical record*, **35**(1), 2004, 9-63.

Notes on the crystallization of diamond are followed by descriptions and illustrations of diamond crystals from various parts of the world. Many are linked to individual mines. M.O'D.

On unusual deep-violet microcrystals of diamonds from placers of Ukraine.
M.N. TARAN, V.M. KVASNYTSYA AND K. LANGER. *European Journal of Mineralogy*, **16**(2), 2004, 241-5.

Ukrainian deep-violet diamond crystals have a distinctive broad absorption band centred at ~560 nm (17850 cm^{-1} or 2.21 eV). The intensity of this band is almost two orders of magnitude greater than that in a light rose diamond from Yakutia. Although previously this band was attributed to the N-V centre because the absorption spectrum of the negative N-V centre in irradiated and unannealed type 1b diamonds is known to have an absorption band with a maximum at a similar wavelength, this assignment is not confirmed. At ~ 77 K, the 17850 cm^{-1} band displays no fine structure that unambiguously shows that it cannot be the band at ~ 2.2 eV, commonly attributed to the N-V centre. This band is probably caused by 'plastic deformation', typical of pink diamonds from the Argyle field. R.A.H.

Carbonatitic melts in cuboid diamonds from Udachnaya kimberlite pipe (Yakutia): evidence from vibrational spectroscopy.
D.A. ZEDGENIZOV, H. KAGE, V.S. SHATSKY AND N.V. SOBOLEV. *Mineralogical Magazine*, **68**(1), 2004, 61-73.

Micro-inclusions (1-10 μm) in 55 diamonds of cubic habit from the Udachnaya kimberlite have been shown by IR and Raman spectroscopy to contain a multiphase assemblage which includes carbonates, olivine, apatite, graphite, water and silicate glasses. These micro-inclusions preserve the high internal pressure and give confidence that the original materials were trapped during growth of the host diamond. These internal pressures, extrapolated to mantle temperatures, lie within the stability field of diamond; the relatively low temperatures are typical for the formation of cuboid diamonds. In contrast to previous data for African diamonds, the micro-inclusions in the Udachnaya cuboids are extremely carbonatitic in compostion, $(H_2O)/(H_2O + CO_2)$ ~ 5-20%, with an observed assemblage of micro-inclusions similar to some types of carbonatites. The low water and silica content testify that the material in the micro-inclusions of the Udachnaya diamonds was near-solidus carbonatitic melt. R.A.H.

Gems and Minerals

Recent discoveries at the Jeffrey mine, Asbestos, Quebec.
M. AMABILI, A. MIGLIOLI AND F. SPERTINI. *Mineralogical record*, **35**, 2004, 123-35.

A short history of the Jeffrey mine, Asbestos, Quebec, Canada, describes a number of gem-quality minerals, including orange grossular, clear colourless grossular with emerald-green cores (a speciality of this location) and pink grossular. Emerald-green, deep violet and multi-coloured vesuvianite are also described. Collecting at the mine, always restricted to professionals, has

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now ceased due to safety problems as full-scale mining has ceased. M.O'D.

Achate aus Nordwestsachsen: 14 Fundstellen.

W. BECK, U. THONFELD AND H. PRAWITZ. *Lapis*, **29**(2), 2004, 29-34.

Fourteen locations are described for agate in the NW of Saxony, Germany. Many specimens are of ornamental quality. M.O'D.

Crazy Lace-ein bemerkenswerter Achat aus Mexiko.

W. BECK, *Lapis*, **29**(6), 2004, 26-7.

An ornamental agate with elaborate white markings and known as 'Crazy lace' is described from the Santa Rita claim in the Sierra Santa Lucia, north-west Chihuahua, Mexico. Some examples are pseudomorphous after calcite. M.O'D.

Achate aus Nordwestsachsen: 14 Fundstellen.

W. BECK, U. THONFELD AND H. PRAWITZ. *Lapis*, **29**(2), 2004, 29-34.

Fourteen locations are described for agate in the NW of Saxony, Germany. Many specimens are of ornamental quality. M.O'D.

Topaz from Killiecrankie, Flinders Island, and other Bass Strait islands.

R.S. BOTTRILL, R.N. WOOLLEY AND A.B. FORSYTH. *Australian Gemmologist*, **22**(1), 2004, 2-9, 1 illus., 1 map.

Flinders Island is one of the Furneaux group of islands in Bass Strait between Tasmania and the Australian mainland. The main occurrence of colourless to pale-coloured gem topaz on Flinders Island is in the fossicking area around Killiecrankie Bay at the north-eastern end of the island. Gem topaz crystals, locally known as *Killiecrankie diamonds*, have been recovered in some abundance from around the Bay since at least 1803. Some of the topaz occurs as well formed, pale-coloured glassy crystals, but most are moderately to highly rounded and frosted in the alluvial deposits. The primary deposits are in cavities in granitic pegmatite veins up to a metre or more wide. Details are given of the chemistry, crystallography and the typical inclusions of the topaz crystals. P.G.R.

The origin of precious opal – a new model.

B. DEVESON. *Australian Gemmologist*, **22**(2), 2004, 50-8, 1 map, 1 illus.

This new model for the formation of precious and potch opal is based on the association between opal and natural artesian springs called mound springs. The Lightning Ridge opal field lies on a line of such springs, and active and extinct mound springs are found in the general proximity of several sedimentary opal fields in New South Wales, South Australia and Queensland. Where the mound spring waters have the appropriate chemistry (i.e. alkaline with a high silica content), a mechanism is suggested in which the physico-chemical properties of the water are changed so that suitable silica spheres and then linear chains of these spheres are formed. A final component of the new model is the presence of suitable voids lined with clay that can act as a semi-permeable membrane to concentrate and purify the silica spheres by ultra filtration and dialysis. P.G.R.

Recent study of fluid inclusions in corundum of Sri Lanka.

M.D.P.L. FRANCIS, H. MATSUEDA, J. TORIMOTO, P.G.R. DHARMARATNE AND G. GIULIANI. *Gemmologie. Z. Dt. Gemmol. Ges.*, **52**(4), 2003, 163-76. 10 photographs, 1 map, 4 diagrams, bibl.

It was possible to confirm the theory that fluid inclusions in Sri Lankan corundum contained more or less pure CO_2 and that the most common daughter minerals included were graphite and diaspore. The necking observed was similar to that found in Malawi material. The fluid inclusions were classified into four categories according to shape, size and microscopically visible contents of the voids. A model was formulated to describe the fluid inclusions in relation to the formation of corundum in Sri Lanka.E.S.

Le contexte minéralogique des gisements d'opale de la région de São Geraldo do Araguaia, Etat de Pará (Brésil).

J-P. GAUTHIER, D.B. ROSA, S. RANTSORDAS AND J-C. SAMAMA. *Revue de gemmologie AFG*, **149**, 2004, 11-14.

Opal of ornamental quality is described from the area of São Geraldo do Araguaia, Pará, Brazil. Specimens have SG between 2.0-2.65, RI 1. 43-1.46, H 5.5-6.5. M.O'D.

L'opale d'Ethiopie: gemmologie ordinaire et caractéristiques exceptionelles.

J-P. GAUTHIER, F. MANDABA MAZZERO AND E. FRITSCH. *Revue de gemmologie AFG*, 2004, **149**, 15-23.

Details of gem opal from Ethiopia are given; SG 1.39-2.06, RI 1.40-1.46. Values are affected by porosity. The opal shows a play-of-colour against a brownish background. Traces of strontium, lead and niobium have been found in some specimens. Internal features are described; parallel lines probably associated with grain boundaries may turn out to be helpful in distinguishing these opals. The opal-bearing sites are located approximately 250 km from Addis Ababa in the province of Shewa. Opal is found as rhyolitic nodules which are often near-spherical and may reach 20 cm. M.O'D.

New interpretation of the origin of tiger's-eye.

P.J. HEANEY AND D.M. FISHER. *Geology*, **31**(4), 2003, 323-6.

Tiger's-eye is an attractive and popular gemstone. For more than a century, textbooks and museum displays have identified the material as an archetype of pseudomorphism, i.e. the replacement of one mineral by another with the retention of the earlier mineral's shape. This new study has revealed that the textures responsible for the shimmer of tiger's-eye do not represent pseudomorphic substitution of quartz after pre-existing crocidolite asbestos. Rather, it is argued that tiger's-eye classically exemplifies synchronous mineral growth through a crack-seal vein-filling process. P.B.L.

Sapphire-blue kyanite from Nepal.

U. HENN. *Australian Gemmologist*, **22**(1), 2004, 35-6, 5 illus.

Kyanite is known to be an important rock-forming mineral, but gem-quality specimens are relatively rare and mostly used as a collector's stone. Attractive intense blue kyanite of high transparency was recently brought into the gemstone market from a new occurrence in Nepal. The faceted stones investigated are of up to 12.2 ct in weight and possess the typical physical characteristics of blue gem kyanite. P.G.R.

Spinel from Kayah State (Myanmar).

U.T. HLAING. *Australian Gemmologist*, **22**(2), 2004, 64-6, 1 map, 1 illus.

A sample of gem-quality mainly pink to red spinels from Kayah State in the east of Myanmar was given to the author for testing and evaluation. Kayah State is one of the smallest states in Myanmar and is bounded on the east by Thailand, to the south and west by Karen State and to the north by the Shan State. The approximate location of this new alluvial deposit is indicated in the paper and on the accompanying map, and details are given of the area's geology. P.G.R.

Amino acids in the nacre layers of shell from *Magnavicula penguin* and blister pearls from Sanya, China.

HUANG FENGMING, CHEN. ZHONGHUI, ZHOU YING AND YANG MINGXING. *Australian Gemmologist*, **22**(1), 2004, 29-31, 1 table.

The compositions and contents of amino acids in the nacre layers of shells of the oyster *Magnavicula penguin* from Sanya, China, and in blister pearls produced in the same oyster, were determined using a Model 835-50 Hitachi automatic meter. Comparison measurements were also taken from cultured freshwater pearls from Ezhou, Hubei, and cultured seawater pearls from Indonesia and Beihai, Guangxi, China. Tabulated results showed that the shells and blister pearls of the *Magnavicula penguin* from Sanya both contained similar amino acids. Other measurements showed that the total concentration of amino acids in the nacre layer close to the hinge line is higher than that of amino acids in the margins of the shell. Blister pearls produced by the *Magnavicula penguin* contain the highest concentration of amino acids in all the tested samples. P.G.R.

Culturing abalone half-pearls.

P. HUTCHINS. *Australian Gemmologist*, **22**(1), 2004, 10-20, 19 illus.

New Zealand is presently the one of at least two successful abalone pearl culture operations utilising the New Zealand paua, *Haliotis iris*. Roger Beatie, Managing Director of the Eyris Blue Pearl Company, is responsible for the creation of the Eyris cultured half pearl after becoming interested in farming paua. He currently has three pearl farms (in the Whangamoe inlet on New Zealand's Chatham Islands, in Akaroa Harbour on the Banks Peninsular, and at Tory Channel in the Marlborough Sounds). These farms are geographically isolated from each other to minimise the risk of loss of stock due to algal bloom and other natural disasters. The paper provides information on the history of the abalone and then describes the technologies and methods used by the Eyris Company to culture and harvest half pearls. Criteria used to grade the pearls are also illustrated and briefly described. P.G.R.

Achate aus der Sierra Pintada, Argentina.

P. JECKEL AND M. HENKEL. *Lapis*, **28**(10), 2003, 33-7.

Agate of strikingly deep red and white patterning is described from locations in the Sierra Pintada, Argentina. A brief description of the occurrences is given. M.O'D.

Der Stein des Regenbogens: 'Rainbow Calsilica'.

L. KIEFERT, J. HÄNNI, P. VANDENABEELE, L. MOENS AND V.M.F. HAMMER. *Gemmologie. Z. Dt. Gemmol. Ges.*, **52**(4), 2003 151-62. 7 photographs, 4 diagrams, bibl. (English abstract)

The spectacularly colourful gem material from Mexico was offered on the market as 'rainbow calcilica', 'calcilica' and 'fossilized clay'. It was marketed as a natural material with pictures of the mine and certified by a laboratory in Arizona. Examination by Raman spectra showed the material to be artificial, partly coloured by artificial pigments and stabilised by a waxy resin. E.S.

Pink gem quality orthoclase from the Mogok Stone Tract, Myanmar.

U.H. KYI AND U.K. THU. *Australian Gemmologist*, **22**(1), 2004, 29-34, 4 illus.

Although transparent pink orthoclase is rare, particularly in Myanmar, a pink gemstone discovered in the rough in the Mogok Stone Tract was studied and found to be a facetable orthoclase feldspar. This paper provides details of the feldspar's physical/optical properties, XRD features and trace element analysis. P.G.R.

Moonstone from the Karkonosze pegmatites (the Sudety Mountains, Poland).

W. LAPOT AND E. SZELEG. *Mineralogia polonica*, **34**(1), 2003, 27-36.

Gem-quality moonstone is described from pegmatites in the Karkonosze area of the Sudety Mountains, Poland. The nature of the K-feldpar structure determines the shade of blue seen: thus micromezoperthite gives a pale blue, microperthite blue and cryptoperthite violet-blue. The quality of the moonstones is said to be the equal of good Sri Lanka material. M.O'D.

Gem News International.

B.M. LAURS (Ed.). *Gems & Gemology*, **39**(4), 2003, 322-46.

A 23 x 14.5 mm crystal and five cabochons of afghanite (the latter speckled with inclusions of lazurite) are reported as is a variety of rough and polished quartz crystals ('platinum quartz') containing blades of brown or tan brookite coated with precisely oriented needles of rutile. A 3.84 ct faceted yellow stolzite and a 147 ct golden orange scapolite are also described, along with new synthetic opal varieties and carved plastic imitation 'scrimshaw' walrus tusks. R.A.H.

Pezzottaite from Ambatovita, Madagascar: a new gem material.

B.M. LAURS, W.B. SIMMONS, G.R. ROSSMAN, E.P. QUINN, S.F. MCCLURE, A. PERETTI, T. ARMBRUSTER, F.C. HAWTHORNE, A.U. FALSTER, D. GÜNTHER, M.A. COOPER AND B. GROBÉTY. *Gems & Gemology*, **39**(4), 2003, 284-301.

Pezzottaite, ideally $Cs(Be_2Li)Al_2Si_6O_{18}$, is a new Cs, Li-rich member of the beryl group. It was discovered in a granitic pegmatite near Ambatovita in central Madagascar. The limited number of transparent faceted stones and cat's-eye cabochons that have been cut usually show a deep purplish-pink colour. Pezzottaite can be distinguished from beryl by its higher RI (typically ε 1.607-1.610, ω 1.615-1.619) and *D* of 3.09-3.11 g/cm³. The IR and Raman spectra and XRD pattern are also distinctive, while the visible spectrum is similar to that of morganite. The colour is probably caused by radiation-induced colour centres involving Mn^{3+}. R.A.H.

Iridescence of a shell of *Pteria Sterna* (Gould 1851): an optical and structural investigation.

Y. LIU, K.N. HURWIT AND L. TIAN. *Gemmologie. Z. Dt. Gemmol. Ges.*, **52**(4), 2003, 145-50, 7 photographs, bibl.

The shells of the pearl-producing *Pteria sterna* show strong iridescence, usually green and purple, but also violet blue and golden yellow. The aragonitic nacre layers are characterized by growth lines or grooves which form diffraction reflection gratings. The density of these grooves changes with the position within the shell. Change of the groove density corresponds directly to a change in the strength of the iridescence. E.S.

Inclusions in Vietnamese Quy Chau ruby and their origin.

P.V.LONG, H.Q.VINH AND N.X.NGHIA. *Australian Gemmologist*, **22**(2), 2004, 67-71, 10 illus.

Samples of rubies from Quy Chau, Vietnam, were collected for this study by the authors during several field trips. The characteristics of the inclusions were examined by optical microscopy, and their compositions were analysed by Raman scattering and SEM. The abundant inclusions listed in the paper are quite diverse in chemical composition, suggesting the possibility of two origins – by metamorphism or by metasomatism. P.G.R.

Heliotrop in Sachsen... und Fluoritachat.

M. LÜTTICH. *Lapis*, **28**(12), 2003, 44-5.

Ornamental-quality opaque green chalcedony with red flecks and agate with fluorite banding are described from areas of Saxony, Germany. M.O'D.

The Trimouns quarry, Luzenac, Ariège, France.

F. MARTY. *The Mineralogical record*, **35**, 2004, 225-47.

Among mineral species occurring as crystals of possible ornamental quality at the Trimouns quarry, Luzenac, Ariège, France, is bastnasite-(Ce). M.O'D.

Gemmological Notes.

C.C.MILISENDA. *Gemmologie. Z. Dt. Gemmol. Ges.*, **52**(4), 2003, 123-6. 4 photographs.

Some translucent, apple green rough material weighing between 1 and 3 g was found to be opal, said to come from a locality near the border of Croatia and Macedonia. SG 2.08-2.10. Some other green opal was submitted with similar appearance, but with much lower SG (1.33-1.37); this material melted when touched with a hot needle and was found to be artificial. Some emerald imitations on the market proved to be dyed quartzes.

Some cabochons weighing approximately 5 g each were made of an intergrowth of ruby with fuchsite and kyanite. The material comes from India, but is not dissimilar to material from Zimbabwe and Mashishimala in South Africa. The suggested name is corundum fuchsite; the combination of red (ruby), green (fuchsite) and blue (kyanite) is very attractive.

Some transparent yellow-brown to orange-brown rough weighing up to 5 g and a faceted specimen weighing 3.19 ct were examined and found to be bastnasite. The material comes from a new source in the Peshawar district of Pakistan. It is hexagonal with a low hardness of 4-4½ and is a rare earth carbonate. It is named after a locality in Sweden. E.S.

What's new in minerals.

T. MOORE. *The Mineralogical record*, **35**, 2004, 249-63.

Among crystals and gemstones exhibited at the Tucson Show of 2004 were: a dark greenish-blue euclase crystal from Colombia measuring near 18 cm, pink scapolite crystals from Badakhshan, Afghanistan, a colourless natrolite crystal about 3.9 cm, Mont St Hilaire, Quebec, Canada, and blue scheelite crystals from Baia Sprie (formerly Felsőbánya), Maramures, Romania. M.O'D.

Lab Notes.

T.M. MOSES, I. REINITZ, S.F. MCCLURE AND M.L. JOHNSON (Eds). *Gems & Gemology*, **39**(4), 2003, 314-21.

Items noted include artificially coated diamonds, a bluish-green dichroic emerald, a high-RI violet-blue glass (n 1.700) simulating tanzanite, blue sapphires treated to give an unusual colour zoning and filled cavities in a cut spinel. R.A.H.

Moganite and water content as a function of age in agate: an XRD and thermogravimetric study.

T. MOXON AND S. RÍOS. *European Journal of Mineralogy*, **16**(2), 2004, 269-78.

The crystallite size, and the content of moganite, molecular surface water and internal water in agates from volcanic host rocks ranging from 38 to 1100 Ma have been measured. Water is shown to be involved in the transformation of moganite into chalcedony; the maximum amount of moganite found in agate was 14%, but after ~ 410 Ma it is only present in trace amounts. Changes in the degree of crystallinity of agates from 10 host rocks < 412 Ma have been determined; for eight regions, agate genesis appears to have been roughly penecontemporaneous with formation of the host rock; in the other two regions hydrothermal activity from a second volcanic event may have occurred. R.A.H.

L'émeraude de la Vallée de Binn.

T. MUMENTHALER AND A. FREY. *Schweizer Strahler*, **4**, 2003, 4-11 and 24-30.

Emerald of near-gem quality is described from the Binn valley, Valais, Switzerland where aquamarine has also been found. Speculations on origin are presented. Illustrations in this French issue differ from those in the German version on pp 24-30. M.O'D.

Agates and geodes from the Khur area, Central Iran.

M. NAZARI. *Australian Gemmologist*, **22**(1), 2004, 21-8, 38 illus. (27 on separate insert).

The Khur agates of Central Iran have long been celebrated for their fine blue banding and this paper is the first scientific study of the agates and their associated minerals. These minerals have been identified either visually, microscopically, and/or by XRD, SEM and EDS. The numerous colour illustrations are individually supported by descriptive texts. P.G.R.

Zagi Mountain, Northwest Frontier Province, Pakistan.

H. OBODDA AND P. LEAVENS. *The Mineralogical record*, **35**, 2004, 205-20.

Bastnasite-(Ce) of gem quality is described from Zagi Mountain, which is located about 5.5 km SE of Warsak Dam on the Kabul River in the Peshawar District, North West Frontier Province, Pakistan. Crystals and an orange-red transparent faceted stone are illustrated; transparent rutile and orange zircon are also found in the area. The rutile contains Hg as a trace element, a composition not previously reported. M.O'D.

Der Pegmatit von Anjiahamiary bei Fort Dauphin, Madagaskar.

F. PEZZOTTA AND M. JOBIN. *Lapis*, **29**(2), 2004, 24-8.

A pegmatite located at Anjiahamiary, NE of Fort-Dauphin, Madagascar, has produced gem-quality tourmaline group species (liddicoatite and rossmanite) in pink, green and blue colours. M.O'D.

Rätsel im breenendheissen Sand: das libysche Wustenglas.
C. PINTER AND H. STEHLIK. *Lapis*, **28**(10), 2003, 11-6.

Natural transparent lemon-coloured glass is found as lumps in the Libyan desert. Specimens are described and their origin speculated upon. M.O'D.

Ungewöhnliche Turmaline vom Erongo, Namibia.
P. RUSTEMEYER. *Lapis*, **28**(11), 2003, 29-41.

Tourmaline of ornamental quality is described from the Erongo massif in Namibia, north-west of Windhoek. Crystal forms and habits are investigated and colour zoning effects illustrated. M.O'D.

Mineralien der Turmalingruppe. Anwendungsmöglichkeiten in Technik, Haushalt und Medizin.
K. SCHMETZER. *Lapis*, **28**(10), 2003, 38-50.

Minerals of the tourmaline group find many uses other than ornamental ones. Some technical, household and medicinal applications are described. M.O'D.

Red beryl from Utah: a review and update.
J.E. SHIGLEY, T.J. THOMPSON AND J.D. KEITH. *Gems & Gemology*, **39**(4), 2003, 302-13.

The Ruby Violet (or Red Beryl) mine in the Wah Wah Mts of Beaver County, Utah, is the only known commercial occurrence of gem-quality red beryl in the world. It is found along fractures (often clay-filled) in a topaz rhyolite, and crystallized as a vapour-phase mineral from the reaction of rhyolite-derived gases, vapours originating from heated groundwaters and pre-existing minerals and volcanic glass in the rhyolite. The production over the past 25 years is estimated to have been >60 000 ct, of which about 10% were facetable. R.A.H.

Crocoite.
S.P.SORREL. *Australian Gemmologist*, **22**(2), 2004, 59-63, 1 map, 7 illus.

Tasmania has long been famous among mineralogists and geologists for its specimens of crocoite, a brilliant orange to red lead chromate. Its fame may now spread as the result of crocoite being chosen as Tasmania's Mineral Emblem. Apart form Russia, Tasmania is one of the few places in the world where such beautiful specimens are found. This paper describes the occurrence and gemmological properties of the rare mineral. A group of crystal specimens and two faceted specimens are illustrated. P.G.R.

Geochemie und Petrologie von Smaragdvorkommen – Erfahrungen aus dem Smaragdbergbau in Sambia und Simbabwe – Teil 2: Sandawana, Simbabwe.
K.C. TAUPITZ. *Gemmologie. Z. Dt. Gemmol. Ges.*, **52**(4), 2003, 127-44, 4 maps, 1 diagram, 2 tables, bibl.

Detailed article about the local geological conditions around Sandawana. The two occurrences of Sandawana in Zimbabwe and Kafutu in Zambia are compared. E.S.

Grün, gelb, rot und blau. Über die Färbung von Titanitkristallen in alpinen Klüften.
S. WEISS AND B. HOFMANN. *Lapis*, **28**(10), 2003, 30-2.

Titanite (sphene) crystals originating in Alpine-cleft deposits show a variety of colours whose origin is discussed. M.O'D.

Sphenkristalle aus der Laghetti-Amphibolitzone, Narètgebiet, Schweiz.
S. WEISS AND F. RIZZI. *Lapis*, **28**(10), 2003, 17-29.

Crystals of sphene and accompanying minerals are described from the amphibolite zone at Laghetti, Ticino, Switzerland. Other Swiss locations for sphene are described. M.O'D.

The early history of the Mineralogical Record.
J.S. WHITE. *Mineralogical Record*, **35**(1), 2004, 73-85.

The origins and development of the *Record* are described by its founder, John S. White. M.O'D.

Quality enhancement of Vietnamese ruby by heat treatments.
P. WINOTAI, P. LIMSUWAN, I.M. TANG AND S. LIMSUWAN. *Australian Gemmologist*, **22**(2), 2004, 72-77, 8 illus.

A suitable heat treatment specifically designed for a particular ruby must be used to enhance both its quality and value. Results of experiments at various temperatures in an oxygen atmosphere suggest that Vietnamese rubies should be treated only at 1500-1600°C to convert them into more valuable rubies of enhanced colour and clarity. Higher temperatures will only yield slightly bluish-red rubies. All samples exhibited better clarity after the treatment, which enhanced the colour of the stones but could not eliminate inclusions. P.G.R.

What's new in minerals.
VARIOUS AUTHORS. *Mineralogical record*, **35**, 2004, 143-79.

Among gem and ornamental-quality specimens described from various mineral shows in Europe and North America are elbaite from Paprock, Kunar, Afghanistan (in the specimen shown the outer green zone has been selectively removed), near-transparent amazonite, clear pink scapolite and clear light green diopside, also from Afghanistan. Pakistan has produced some greenish-grey fluorite octahedra from a locality in the Hunza area. Fine orange-red 'imperial' topaz has been found in the Kolwezi area in the Republic of Congo close to the border with Zambia, and sherry-brown topaz is reported from Pakistan. M.O'D.

Instruments and Techniques

The sclerometer and the determination of the hardness of minerals.
U. BURCHARD. *Mineralogical record*, **35**, 2004, 109-20.

While Mohs' scale is still used for determining the approximate scratch hardness of minerals the sclerometer was developed in the 19th century to give a more precise value of hardness. Different models are described and illustrated. M.O'D.

Synthetics and Simulants

L'opale de synthèse.
J-P. GAUTHIER. *Revue de gemmologie AFG*, **149**, 2004, 24-6.

The difference between synthetic and natural gem-quality opal is reviewed. Hexagonal markings within colour patches continue to be the distinguishing features of the synthetic product. M.O'D.

[Growth of diamond from solution in the $CaCo_3$ melt.]
A.F. KHOKHRYAKOV, YU.M. BORZDOV. YU.N. PAL'YANOV AND A.G. SOKOL. *Proceedings of the Russian Mineralogical Society,* **132**(2), 2003, 87-95 (Russian with English abstract).

Diamond nucleation and growth kinetics on the [100] and [111] faces of seed diamond crystals in the $CaCO_3$-C system were studied in a non-pressing device of 'cross-cut sphere' type at 7 GPa and 1700–1750°C in experiments of 10 min to 18 h duration. The growth of [100] develops in the diffusion-limiting regime, and growth on [111] is determined mainly by the kinetics of superficial processes. Evolution of the surface accessories on the [111] faces was traced from triangular frame defects up to large trigonal pyramids. Comparison with similar Si and Ge patterns shows that the trigonal pyramids are complex twins. The only stable cubic forms of diamond growth in the $CaCO_3$-C system are tetragontrioctahedron faces; among them only {322} faces achieve the habit scale of development. R.A.H.

[About mechanism of the fibrous structure appearing in cubic diamond crystals.]
V. M. SONIN, D. G. BAGRYANTSEV, A.I. CHEPUROV AND J.-M. DEREPPE. *Proceedings of the Russian Mineralogical Society,* **132**(2), 2003, 95-8 (Russian with English abstract).

The growth of diamond crystals at high *P* in the Fe-Ni-C system was studied in terms of a *T* decrease of ~1-2°/sec. A phenomenon has been detected of octahedral crystals re-facing via the transformation of numerous tiny cubic sub-individuals on their faces. Data show that this is possibly the formation mechanism of natural cubic diamond crystals with a fibrous structure. This is based on the growth of cubic sub-individuals parallel to one another in the {111} direction with the formation of subparallel fibres. Because of this phenomenon, sectors of cubic growth become enlarged while the octahedral growth sectors are declining; the main cause of this change in the growth mechanism is the sharp increase of supersaturation in the crystallization media provided by the falling *T*. R.A.H.

Gem-quality synthetic diamonds grown by a chemical vapor deposition (CVD) method.
W. WANG, T. MOSES, R.C. LINARES, J.E. SHIGLEY, M. HALL AND J.E. BUTLER. *Gems & Gemology,* **39**(4), 2003, 268-83.

Brown to grey and near-colourless single-crystal type IIa synthetic diamonds grown commercially using a chemical vapour deposition technique have gemmological properties that are distinct from those of both natural diamonds and HPHT-grown synthetic gem diamonds. The tabular crystals range from up to 1 ct or more and a few millimetres thick, and consist of an overgrowth on a natural or synthetic diamond substrate. Faceted CVD synthetic diamonds generally cannot be distinguished from natural diamond (unless portions of the substrate are still present). In a gemmological laboratory, however, they can be identified by the combination of a strong orangey-red fluorescence seen with the DiamondView deep-UV imaging system, a characteristic anomalous birefringence (strain) pattern and distinctive features in their IR absorption spectra. R.A.H.

Abstractors

G.L. Barron	G.L.B.	P.B. Leavens	P.B.L.	P.G. Read	P.G.R.
R.A. Howie	R.A.H.	M. O'Donoghue	M.O'D.	E. Stern	E.S.

Book Review

Rock-forming minerals. Vol. 4B. (2nd edn). Framework silicates: silica minerals, feldspathoids and the zeolites.
W.A. DEER, R.A. HOWIE, W.S. WISE AND J. ZUSSMAN, 2004. The Geological Society, London. pp xiv, 982. Hardcover ISBN 1 86239 144 0. £62 (to Fellows of the Geological Society).

Minerals of especial interest to readers of *The Journal* include quartz and opal, petalite, leucite, species of the sodalite group and the scapolite group; mineral collectors will welcome the revision of the zeolite group. Readers unfamiliar with the series will find unexpected treasures. The authors state their criteria for a mineral's inclusion in the preface to the first edition (1962): [the text will include] only those minerals which, by their presence or absence, serve to determine or modify the name of a rock. In their preface to the second edition the editors make the point that a far greater sophistication in determinative methods has enabled them to improve the quality of information formerly available. This is particularly true of chemical compositions.

For the most part each mineral or group is considered in five distinct parts. These are structures, chemistry, optical and physical properties, distinguishing features (details of determinative tests are given here), and paragenesis, giving the rock types in which the mineral is found and outlining some characteristic mineral assemblies. A concise table of properties precedes each entry and a list of references ends it.

Many will find it pleasing that "light microscopy remains the basic petrological tool underpinning all other methods" but clearly the use of electron microprobe analysis and, to take one example quoted in the preface to the new edition, of environment-controlled specimen stages, will lead to a far deeper understanding of mineral formation and determination. For any serious study of minerals, 'DHS' is vital. M.O'D.

Proceedings of the Gemmological Association and Gem Testing Laboratory of Great Britain and Notices

New appointments at Gem-A

President

We are delighted to announce that at the Annual General Meeting held on Tuesday 14 September E Alan Jobbins was elected President of the Association for the term 2004-2006.

E Alan Jobbins BSc CEng FIMM FGA was Curator of Minerals and Gemstones at the Geological Museum in London from 1950 to 1983. During these years he acted as consultant to a wide range of enquirers from which a series of research papers developed. These included, among many others, a major study of East African garnets, the first papers characterizing the structure and identification of synthetic opals, the discovery of a new mineral magnesio-axinite and the field study of the Barwell meteorite fall. His many overseas assignments (for the United Nations and the British Government) included setting up a gemmological laboratory in Rangoon, Burma (now Myanmar) and the subsequent training of a cadre of students who successfully passed the Gemmology Diploma examinations; a major study of the Pailin ruby and sapphire deposits in Cambodia with recommendations for improved working methods; an assessment of diamond and opal deposits in Piaui State, Brazil; a survey of the Sri Lankan gemstone industry to improve cutting techniques and many other projects. In 1988 he gave a series of lectures and initiated gemmological training with new laboratory facilities at the China University of Geosciences in Wuhan. In the UK his record includes 32 years as a gemmological lecturer at the Sir John Cass College (now the London Metropolitan University), some 20 years as an examiner for the Association's gemmology examinations and eight years as Editor of *The Journal of Gemmology*. He is a popular lecturer and has presented papers in some 30 countries around the world. In 1986-89 he was privileged to be a member of the team which conducted the first gemmological examination of the English Crown Jewels. These researches were published as part of a major two volume catalogue. He is an Executive Member of the International Gemmological Conference and is currently President of the Society of Jewellery Historians.

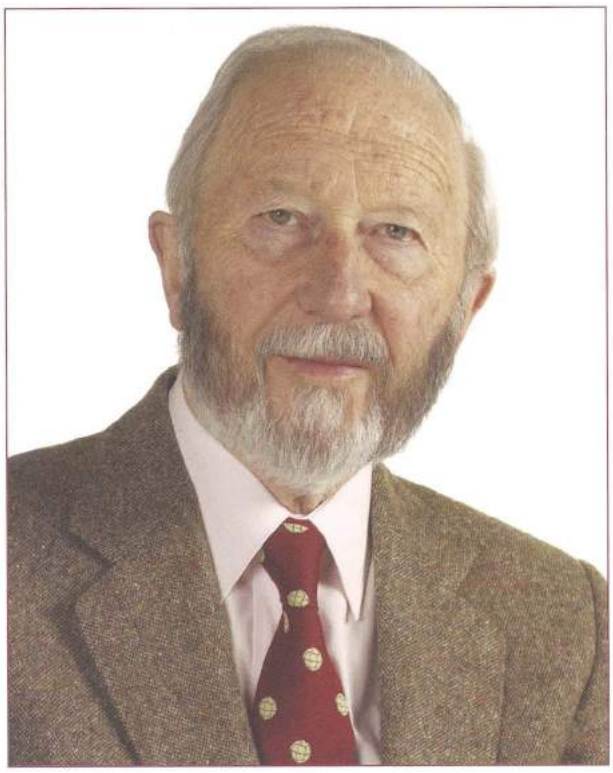

E Alan Jobbins, President

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Chief Executive Officer

Dr Jack Ogden, a Fellow of Gem-A and a founder member of the SJH, has been appointed Chief Executive Officer of Gem-A on the retirement of Terry Davidson on 1 November 2004. A report of the appointment was published in the September 2004 issue of *Gem & Jewellery News*.

Honorary Life Member

Ian Thomson, who retired from the Council at the Annual General Meeting after serving for 14 years, has been awarded an Honorary Life Membership in recognition of his substantial contribution and commitment to the Association.

Members' Meetings

London

On 27 July at 27 Greville Street, London EC1, an Extraordinary General Meeting was held, a report of which appears below. The EGM was followed by a talk by Terry Davidson on the jewellers of Bond Street.

Midlands Branch

On 24 September at the Earth Sciences Building, University of Birmingham, Edgbaston, Professor A T Collins gave a lecture entitled 'Colour in natural and artificial diamonds'.

North East Branch

On 26 July at Evans of Leeds Ltd, Millshaw, Alan Hodgkinson gave a talk and practical workshop entitled 'Putting the Gee back into gemmology'.

On 19 October at Evans of Leeds Ltd, Millshaw, Martin Vainer gave a talk with the title 'Fancy diamonds?!'

North West Branch

On 15 September at Church House, Hanover Street, Liverpool 1, Alan Hodgkinson gave a talk and workshop entitled 'A few of my favourite things'.

On 20 October at Church House Marcus McCallum gave a talk entitled 'Pearls: the trade industry today'.

Scottish Branch

On 26 September a gold panning field trip to Tyndrum was arranged.

On 6 October at the British Geological Survey, Murchison House, West Mains Road, Edinburgh, Guy Clutterbuck gave a talk entitled 'The coloured stone business from a global perspective'.

On 19 October at the Hunterian Museum, University of Glasgow, Neil Clark, the Curator of Palaeontology at the Hunterian Museum, gave a talk on the inclusions in amber.

South East Branch

On 22 August at Gem-A headquarters at 27 Greville Street, London EC1, David Lancaster gave a presentation entitled 'Can provenance be valued?'

South West Branch

On 12 September at the Bath Royal Literary and Scientific Institution, 16-18 Queen Square, Bath, Maggie Campbell Pedersen gave a presentation and practical session entitled 'Organics in the afternoon'.

Annual Report

The following is the Report of the Council of the Gemmological Association and Gem Testing Laboratory of Great Britain for the year ending 31 March 2004.

Officers, Councils and Committees

Gem-A The Gemmological Association and Gem Testing Laboratory of Great Britain is a company limited by guarantee and is governed by the Council of Management. The Council of Management was strengthened by the election of L M Hudson FGA, an American financier and private investor with international banking and investment portfolio experience.

J Kessler retired as chairman of the Trade Liaison Committee. W Roberts and J Evans-Lombe were elected chairman and vice-chairman respectively of the Committee. C Winter and P Dwyer-Hickey continued as Chairman and Vice-Chairman respectively of the Members' Council. *(Continued on p.246)*

Gem-A Awards

Gem-A Examinations were held worldwide in June 2004. In the Examinations in Gemmology 258 candidates sat for the Diploma Examination of whom 92 qualified, including two with Distinction and 13 with Merit. In the Foundation Gemmology Examination, 178 candidates sat of whom 121 qualified. In the Gem Diamond Examination 95 candidates sat of whom 60 qualified, including ten with Distinction and seven with Merit.

The Anderson Bank Prize for the best non-trade candidate of the year in the Diploma in Gemmology Examination, the Anderson Medal for the candidate who submitted the best set of answers in the Foundation Certificate examination which, in the opinion of the Examiners, are of sufficiently high standard, and the Hirsh Foundation Award for the best candidate of the year in the Foundation Certificate examination, have been awarded to Jiang Huijing, Zhuhai City, Guangdong, P.R.China.

The Christie's Prize for Gemmology for the best candidate of the year in the Diploma Examination who derives his or her main income from activities essentially connected with the jewellery trade has been awarded to Anu D. Manchanda, Smethwick, West Midlands.

The Deeks Diamond Prize for the best candidate of the year in the GemDiamond Examination has been awarded to Emma L. McMillan, Dalkeith, Midlothian.

The Tully and Bruton Medals were not awarded.

The names of the successful candidates are listed below:

EXAMINATIONS IN GEMMOLOGY

Gemmology Diploma

Qualified with Distinction

Jiang Huijing, Zhuhai City, Guang Dong, P.R. China
Scott, John R.J., Vancouver, British Columbia, Canada

Qualified with Merit

Choi, Eun Jung, Jeolanam-Do, Korea
Landmark, Vicky, Harpenden, Hertfordshire
Lee Yu Mi, Gyeonggi-Do, Korea
Liao Baoli, Guilin, Guangxi, P.R. China
Manchanda, Anu Dippal, Smethwick, West Midlands
Ramerison, Tokinomena A., Antananarivo, Madagascar
Ren Ming, Wuhan, Hubei, P.R. China
Sordini, Federico, Cagli, Italy
St John Lewis, Delyth, South Norwood, London
Tsutsui, Kazumi, London
Wells, Miranda, Hartlebury, Worcestershire
Wong Ching Man, Discovery Bay, Hong Kong
Zhang Kui, Wuhan. Hubei, P.R. China

Qualified

Agrawal, Puru, New Delhi, India
Aki, Miou, Osaka City, Osaka, Japan
Anderson, Tricia, Helen's Bay, Bangor, N. Ireland
Aung, Htet Su, Yangon, Myanmar
Aura, Kimmo, Espoo, Finland
Blanksma, Eelco, Arnhem, The Netherlands
Brard, Jagvinder Singh, Pinner, Middlesex
Broglie, Nicole, Zurich, Switzerland
Chandhok, Jasmeet Singh, New Delhi, India
Curtis-Taylor, Tracey, London
Dong Xinzhi, Wuhan, Hubei, P.R. China
Drijver, Joyce M-L., Utrecht, The Netherlands
Fu Ming, Guilin, Guangxi, P.R. China
Gaskin, Clare Kathryn, Putney, London
Gerber, Doris C., Zurich, Switzerland
Goel, Amita, New Delhi, India
Gray, Matthew N., Lismore, New South Wales, Australia
Hasegawa, Akemi, Akashi City, Hyogo Pref., Japan
Hearnden, Rachel C., Sheffield, South Yorkshire
Hemlin, Colette, Anjou, Quebec, Canada
Hirst, Catherine, Harborne, West Midlands
Hsin Shih Meng, Wuhan, Hubei, P.R. China
Htin Lynn Aung, Yangon, Myanmar
Huang Qiulan, Wuhan, Hubei, P.R. China
Ideno, Yumi, Nishinomiya City, Hyogo Pref., Japan
Inoue, Koichi, Suita City, Osaka, Japan
Kao Oi Shan, Patsy, Chai Wan, Hong Kong
Khaing Win Win, Yangon, Myanmar
Kueon, Seon-Il, Bupyong-ku, Inchon, R. of Korea
Kwok Sau Mei, Halisa, Tai Po, Hong Kong
Lai Mei Oi, Emily, Tuen Mun, Hong Kong
Lee Young Shin, Kyunggido, Korea
Lee Jeong Im, Seoul, Korea
Lee Kyu Ho, Jeonlanam-Do, Korea
Li Mo Ching, Hong Kong
Li Yue, Shanghai, P.R. China
Liu Bao, Wuhan, Hubei, P.R. China
Liu Fang, Wuhan, Hubei, P.R. China

Gem-A Awards

Lovelock, Justina E., London
Lyons, Annabel H., London
Manolia, Evgenia, Zografou, Greece
Marsh, Claire, Stourbridge, West Midlands
Moe Tin Tin, Yangon, Myanmar
Moore, Katherine, Symington, Ayrshire
Pai, S. Vishnunarayan, Kerala, India
Pang Shing Kwan, New Territories, Hong Kong
Pang Taotao, Guilin, Guangxi, P.R. China
Piacenza, Maria Rene, Sutton, Surrey
Pumpang, Sureeporn, Nakoonpathom, Thailand
Ruan Yaohua, Guilin, Guangxi, P.R. China
Sien Pe (a) Yang Cheng Pei, Yangon, Myanmar
Singh, Amrinder Pal, Nagar, Delhi, India
Song Dong, Shanghai, P.R. China
Stanyer, Natasha, Lewes, East Sussex
Turku, Jenni J., Helsinki, Finland
Valvio, Raija L.M., Vaajakoski, Finland
van Gorkom, Annemarie, Utrecht, The Netherlands
van Schaik, Persis L., Groot-Ammers, The Netherlands
Visschers-Villerius, Cornelia, Heerde, The Netherlands
Wai Yee Tak, Elise, New Territories, Hong Kong
Welton-Cook, Elsa, West Kensington, London
Wessels, Jurie H.W., London
Williams, Benjamin J., Blockley, Gloucestershire
Wold, William, Joure, The Netherlands
Wong, Rosemary M.N., New Territories, Hong Kong
Wong Chung Yan, Kowloon, Hong Kong
Wu Shengfan, Wuhan, Hubei, P.R. China
Xu Ping, Shanghai, P.R. China
Yang Jiaru, Wuhan, Hubei, P.R. China
Yang Ruochen, Wuhan, Hubei, P.R. China
Zhang Tao, Wuhan, Hubei, P.R. China

Gemmology Foundation Certificate
Qualified
Alcock, Kate, Byford, Hereford and Worcester
Asavaroengchai, Suwanna, Bangkok, Thailand
Barker, Matthew, Taipei, Taiwan, R.O. China
Baskerville, Fenella, London
Bayoumi, Nevin, London
Chan Ching Han, New Territories, Hong Kong
Chan Fung Ping, Kowloon, Hong Kong
Chau Lok Yuen, Amy, Kowloon, Hong Kong
Chiu Shu-Fen, Taipei, Taiwan, R.O. China
Chiu Ka Ming, Kowloon, Hong Kong
Choi Eun Jung, Jeolanam-Do, Korea
Chu Yan Yan, Joey, New Territories, Hong Kong
Chu Hon Chung, New Territories, Hong Kong
Coene, Helena I.I., Wezembeek Oppem, Belgium
Comerford, Elaine-Sarah, Dunhill, Co. Waterford, Ireland
Costello, Michael P., Pen-y-lan, South Glamorgan
Costin, Charlotte, Horsham, West Sussex
Cullen, James, Dublin, Ireland
Dawson, Jane, Ashbourne, Derbyshire
Devitt, Isobel, Dublin, Ireland
Eakins, June E., Heswall, Merseyside
Eddery, Colette M., Dublin, Ireland
Eeckhout, Tiphaine, Thomery, France
Espinoza, Juls, Roseville, California, U.S.A.
Fellows, Andrew S., Aldridge, West Midlands
Fong Yan, William, Kowloon, Hong Kong
Gibbons, Timothy B., Battersea, London
Gigg, Daryl B., Stevenage, Hertfordshire
Gillman, Scott, Sudbury, Massachusetts, U.S.A.
Godfrey, Kay, Halstead, Essex
Gogna, Sanjeev, Distt Una, Himachal Pradesh, India
Goodwille, Zoe F., Battersea, London
Hardwick, Christine J.E., Crail, Fife
Heltzel, Christopher, Kilkenny, Ireland
Huang Shieh-Yen, Taipei, Taiwan, R.O. China
Huang, Yvonne, Taipei, Taiwan, R.O. China
Huck, Perry, Stanford-in-the-Vale, Oxfordshire
Hui Wan Man, Kwun Tong, Hong Kong
Hunter, Sara, Athboy, Co. Meath, Ireland
Huth, Melvin G., Orangevale, California, U.S.A.
Kitching, Katherine, London
Ko Hoi Fu, Kowloon, Hong Kong
Kwok Men Yee, New Territories, Hong Kong
Kyaw Cho Cho, Yangon, Myanmar
Kyaw Swar Htun, Yangon, Myanmar
Kyaw Tun Aung, Yangon, Myanmar
Lai Sau Han, Winnie, Kowloon, Hong Kong
Lai Suk Kwan, Eleanor, Kowloon, Hong Kong
Lawton, Sarah, Huncote, Leicestershire
Lee Mi Yu, Gyeonggi-Do, Korea
Lee Kyu Ho, Jeonlanam-Do, Korea
Lee Tin Wan, New Territories, Hong Kong
Leung Chi Fai, Hong Kong
Leung Ka Lok, Kowloon, Hong Kong
Leung Ka Yi, Kowloon, Hong Kong
Li On Kei, New Territories, Hong Kong
Lim Yee Lam, Hong Kong
Lima Pontes, Beatriz, Rio de Janeiro, Brazil
Lin Wai Kei, Tseung Kwan, Hong Kong
Lindstrom, Christina, Spanga, Sweden
Liu Haimei, Guilin, Guangxi, P. R. China
Liu Xianyu, Guilin, Guangxi, P.R. China
Lo Wing See, Kowloon, Hong Kong
Looney, Eimear, Dublin, Ireland
Lu, Shan, Kofu City, Yamanashi Pref., Japan
Malone, Helena, Portlaoise, Co. Laois, Ireland
Marsh, Shona K., Birmingham, West Midlands

Gem-A Awards

Maury-Laribiere, Volodia, Saint Trieix, France
Mera, Kanako, Toyonaka City, Osaka, Japan
Miller, Jodie L., Hinckley, Leicestershire
Mo Mo Win, Yangon, Myanmar
Munich, Lita E., Sacramento, California, U.S.A.
Murphy, Lawrence C., Sacramento, California, U.S.A.
Naw Htar Phyu, Yangon, Myanmar
Newton, Naomi C., Birmingham, West Midlands
O'Dwyer, Michael, Wicklow Town, Co. Wicklow, Ireland
Ogata, Etsuko, Suita City, Osaka, Japan
Palmares, Richard P., Sale, Cheshire
Pan Han, Guilin, Guangxi, P.R. China
Pany, Emmanuel, Clotilde Reonion, France
Peers, Sofia L.R., Leamington Spa, Warwickshire
Pelletier, Lise, Montreal, Quebec, Canada
Pham Quoc, Sacramento, California, U.S.A.
Phisuthikul, Piyamaporn, Bangkok, Thailand
Poole, Jessica, Portadown, Co. Armagh, Northern Ireland
Powar, Krishna, Hockley, Birmingham, West Midlands
Pun Kwok Kong, Kowloon, Hong Kong
Rakotoson, Eric, Montreal, Quebec, Canada
Rana, Ashka, Sureshkumar, Vastapur, Gujarat, India
Ravaoarimalala, Fanjaniaina V., Antananarivo, Madagascar
Ray, Stuart, Gillingham, Dorset
Rouni-Belhadj, Khedidja, London
Ruan Qingfeng, Guilin, Guangxi, P.R. China
Russell, Marie, Bromsgrove, Hereford and Worcester
Sanders, Jacqueline, Towcester, Northamptonshire
Sardjono, Grace W., New Territories, Hong Kong
Saull, Elanor Nico, Stourbridge, West Midlands
Serafim, Evangelia, Glyfada, Greece
Shwe Li, Yangon, Myanmar
Sinclair, Michelle, Nottingham
Smithie, Sheila B., Boston, Massachusetts, U.S.A.
Sordini, Federico, Cagli, Italy
Surangsuriyakul, Nualwan, Samut Prakarn, Thailand
Takahata, Yoshichika, Takamatsu City, Kagawa Pref., Japan
Tam Tin Sang, Daniel, Kowloon, Hong Kong
Tang Yin Tung, Chai Wan, Hong Kong
Taylor, Daniel, Moseley, West Midlands
Teng, Terry, West Hampstead, London
Tripathi, Pooja, Jaipur, Rajasthan, India
Tsang Kwai Ying, Yau Yat Tsuen, Hong Kong
Tsoi Mei Yu, New Territories, Hong Hong
Underwood, Anthony D., Sumner, Texas, U.S.A.
Voulgaris, Apollo, Athens, Greece
Ward, John E.C., London
Wong Lok Yin, Rocky, Kowloon, Hong Kong
Wong Oi Chun, New Territories, Hong Kong
Wongkar, Franky, London
Yamout, Sabah I., Leeds, West Yorkshire
Yang Ping, Guilin, Guangxi, P.R. China
Zhong Lihong, Zhongshan, Guangzhou, P.R. China
Zong Yu, Zhongshan, Guangzhou, P.R. China

Gem Diamond Diploma

Qualified with Distinction

Chen Jianzhi, Wuhan, Hubei, P.R. China
Edwards, Trevor, London
Hanlon, Adrienne K., Ingol, Lancashire
Hira, Vijender Singh, New Delhi, India
Lam Kwi Peng, Singapore
Lim Yee Lam, Hong Kong
Ren Chunhua, Wuhan, Hubei, P.R. China
Surawy, Laura K., Haywards Heath, West Sussex
Tavelov, Dan, Moseley, West Midlands
Thornhill, Helen V., Sheffield, South Yorkshire

Qualified with Merit

Claydon, Louise, Carshalton, Surrey
Fisher, Abigail, London
Lau Siu Ying, Emily, Hong Kong
Pearson, Isabel J., Tilehurst, Berkshire
Shaw, Sinead, London
Tan Mingwei, Wuhan, Hubei, P.R. China
Van Rooij-Roeloffzen, Marjolein, Almere Buiten, The Netherlands

Qualified

Chan Chee Pang, Hong Kong
Chan Lim Chi, Hong Kong
Chan Wing Tung, New Territories, Hong Kong
Chan Ying Hon, New Territories, Hong Kong
Chan Yun Ping, Anna, Southall, Middlesex
Chang Wing Chi, Vivian, Kowloon, Hong Kong
Cheng Wai Yee, New Territories, Hong Kong
Cheung Ching Ping, Candy, Kowloon, Hong Kong
Chie, Christine, Hong Kong
Ching Chin Pang, Kowloon, Hong Kong
Ching Chin Ping, Tung Chung, Hong Kong
Farrell, Ann Marie, Greenford, Middlesex
Hui Wai Wai, Hong Kong
Huo Zhi Yong, Beijing, P.R. China
Hynes, Lola, Dublin, Ireland
Jelinska, Emma, London
Jones, Lorraine, Farnworth, Greater Manchester
Kiamos, George K., Athens, Greece

Gem-A Awards

Kwok Sau Mei, Halisa, Hong Kong
Lawattanatrakul, Thidarat, London
Leung Suk Kay, Hong Kong
Li Bo, Beijing, P.R. China
Lin Yang, Beijing, P.R. China
Manolia, Evgenia, Zografou, Greece
Pennington, Maria, Sprowston, Norfolk
Rebmann, Olivier, Carlsbad, California, U.S.A.
Richmond, Sonia, Herne Hill, London
Romero, Michelle A., St Andrews, Fife
Simo Ooi Kok, London
So Yiu Ki, Eric, Hong Kong
Southam, Karen L., Oldbury, West Midlands
Sowa, Ali Med, Tilbury, Essex
Szymanska, Zofia, London
Thein Myint Myint, Whetstone, London
Thesia, Ashish P., Northolt, Middlesex
Van Rensburg, Stefan, Ealing, London
Wells, John, Bickerstaffe, Lancashire
Whalley, Joanna, Walthamstow, London
Xie Hui, Beijing, P.R. China
Ye Hui Hui, Preston, Lancashire
Yeung Wing Chuen, Benny, New Territories, Hong Kong
Zhang Rui, Beijing, P.R. China
Zhang Yilin, Wuhan, Hubei, P.R. China

(Continued from p.242)

In January 2004 the death was reported with great regret of Alexander E. Farn FGA, a Vice President of the Gemmological Association since 1992.

Gem-A

The financial year 2003/2004 proved to be even more challenging than the previous year. Business in the jewellery trade faced increasing competition from other 'Must have' products and saw the closure and restructuring of many retail and manufacturing companies. Even so, Gem-A managed a modest increase over budgeted income.

Monthly departmental meetings have continued which ensure a continuous flow of up-dated information and the cross fertilization of ideas.

The 2003/2004 appeals to members and the UK trade resulted in 446 donations totalling £12,180. Donations of specimens, including rough and cut stones, synthetics and simulants, has enabled the Association to expand educational courses and examinations.

Education

The Education Office Team have worked tremendously hard over the past year, with final development and promotion work on the new Foundation Certificate Course notes and exam, preparation and launch of the new bi-annual Five-month course, and the varied and new short courses and travelling tutorials. The last year has again seen the London gemmology and gem diamond courses fully subscribed, with students coming from far and wide.

A range of courses and tutorials was held at the Greville Street Gem Tutorial Centre, including a very successful new rough diamond short course. Custom built trade tutorials have continued. D.J. Garrod gave his popular short talks and tutorials at various venues including Norway, Hong Kong, Tucson and several locations around Great Britain.

A greater number of students attended the gemmology and gem diamond examinations compared with the previous year. The Anderson Bank Prize was awarded to Jessica Banks of London. The Christie's Prize for Gemmology was awarded to Xie Jing of Shanghai, China. The Anderson Medal and Preliminary Trade Prize were both awarded to Antoinette Jackson of London. The Deeks Diamond Prize was awarded to Lu Lili of Wuhan, China. Neither the Tully nor the Bruton Medal was awarded.

The Presentation of Awards was again held at Goldsmiths' Hall where the President, Professor A. Collins, presided and welcomed the successful students and their families and friends, who had travelled from as far afield as Hong Kong, Japan, Canada, Sri Lanka and the USA, as well as those from the UK and Europe. Anthony Hirsh presented the awards.

The new Hirsh Foundation Award of £1000 per year had a well-attended press launch at the Las Vegas show. The existing

Gifts

The Association is most grateful to the following for their gifts for research and teaching purposes:

Maggie Campbell Pedersen FGA, London, for an imitation tortoiseshell decorative box.

Mrs K. Findlay, Randburg, South Africa, in memory of her husband, the late Kenneth Findlay FGA; a portable diamond balance in a travel box with a set of weights, a Beck prism spectroscope with wavelength scale, a Beck UV spectroscope and a Beck wavelength reversion spectroscope.

John R. Führbach FGA, Amarillo, Texas, U.S.A., for a collection of specimens including the following: rough specimens of selenite, opalized chert (UV fluorescent), an obsidian slab (New Mexico),quartz and agate (Texas), peridot in lava (Moorea, Tahiti), sugilite slabs (Africa), amethyst (Brazil and Zambia), corundum (Georgia, U.S.A.), turquoise slabs (New Mexico) and a packet of miscellaneous quartz, calcite, agate, chert and garnet; a selection of crystals including rubies (India and North Carolina, U.S.A.), beryl (Colorado, U.S.A.), sapphire (Georgia, U.S.A.), tourmaline (Brazil), emerald (Brazil), calcite slabs (New Mexico), Chatham synethic emerald (very early production), and a large packet of tourmaline; organics including whale 'ivory', shells from Texas.

Mark Saul, Arusha, Tanzania, for a selection of rough specimens from Tanzania including five pieces of vesuvianite, two samples of kornerupine displaying strong pleochroism, and a packet of actinolite from the Tanga district.

Adrian S. Smith FGA, Perth, Scotland, for a Perfect Diagram CD showing different types of facet arrangements.

Abe K. Suleman, Arusha, Tanzania, for a sample of metamorphic emerald source rock from the Manyara emerald deposit, Tanzania.

Ian Thomson FGA, London, for a framed cultured pearl collage.

M. Walsh, Beckenham, Kent, for a presentation set of CZ master cuts.

Anderson Medal is now a discretionary award, on a similar basis to that of the Tully and Bruton Medals.

On the recommendation of the Board of Examiners, S Greatwood and N Rose were appointed examiners for Foundation Certificate in Gemmology and Gem Diamond theory respectively. R Lake was appointed to shadow E Stern on the diamond examination. The Education Review Meeting was held in November and provided useful discussion and exchange of views between tutors, lecturers, examiners and staff of the Education Office.

Lorne Stather's development work on courses, examinations and promotion has increased in scope and included bringing the Diploma in Gemmology notes into continuity with the new Foundation course during the normal process of updating; the development of a new promotional, annual Education Prospectus, now into its second edition; a Gem-A Education leaflet produced for widespread circulation; and a new CD-ROM of Tutor Help and Advice, provided for all ATC and Correspondence Course tutors.

Several new Allied Teaching Centres are at various stages of development world-wide, under the eye of Ian Mercer, with Brenda Hunt's coordination.

Ian Mercer initiated the re-accreditation of Gem-A courses with the QCA during the year; this will include renewal of the levels for our qualifications; to be followed by a European-led credit transfer system.

Gem-A hosted the Federation of European Education in Gemmology (FEEG) General Assembly and Seminar, from 22 to 25 January. Ian Mercer oversaw the FEEG Seminar, held at the Royal College of Surgeons of England, which proved to be a success, with the great organizational assistance of Mary Burland.

Membership

There was a slight decrease in Fellow, Diamond and Associate membership during the year, with Laboratory membership remaining static.

The Gem-A Branch network was expanded in 2003 with the launch of the North East Branch which held its inaugural meeting in Leeds on 10 October. The Midlands Branch held eight meetings as well as their Summer Supper Party and a 51st Anniversary Dinner, and a one-day Conference in February with keynote speaker Stephen Dale. The North West Branch held seven meetings. The Scottish Branch held eight meetings at venues in both Edinburgh and Glasgow, and their Annual Conference in Perth at the beginning of May with John Koivula of the GIA's Gem Trade Laboratory as the keynote speaker. The South East Branch held seven meetings during the year at venues in Central London and Guildford, Surrey. The South West Branch held a meeting in Bath in September. Council is most grateful to the Branch Officers and Committee Members who work so hard to present interesting and varied programmes of activities each year.

Laboratory

Stephen Kennedy, head of the Gem Testing Laboratory, resigned in August 2003 to enable him to spend more time with his family. He has continued on a consultancy basis working two days a week producing reports for coloured stones and pearls. Diamond grading continues to develop with an increasing demand for the new Gem Testing Laboratory of Great Britain report. There was an increase in the number of larger fine quality diamonds and also an increase in type IIa diamonds recorded.

T M J Davidson represented the laboratory at the gem industry and laboratory conference in Tucson in February 2004.

Gem-A USA

Our national office in the United States grew steadily, increasing in visibility with workshops, lectures and exhibits at trade shows including JCK Las Vegas, JA New York and AGTA Tucson Gem Fair. Gem-A USA became a member of AGTA and the Gem Fair contributed much to Gem-A's American exposure; Colin Winter and Jerry Root donated their time and knowledge in hands-on Workshops. A book-signing event for Colin's new Student's Guide to Spectroscopy was a big hit during the show. The splendid annual dinner gathering for members and friends of Gem-A USA brought in many international and American supporters to hear our Gem-A USA Honorary Consultant, Gabi Tolkowsky who, as always, dazzled his audience with passion for the trade while expressing the importance of gemmological education.

The Stuller Annual Workshop was a 'hands-on' gem identification event at Lafayette Louisiana. This Gem-A USA production was recognized as being the most liked presentation by attendees. During the year Gem-A maintained their arrangements with two Allied Teaching Centres, with four further centres preparing to start ATC operations. Additional ATC and Correspondence Course tutors were assigned.

The nationwide Jewelers of America organization offers an annual $100,000 scholarship program to qualifying members. Gem-A USA was qualified as a participant for those JA members seeking gemmological education.

Publications

The Journal of Gemmology underwent its second major change of format since its first publication in 1947 with an increase in size to A4 in January 2004. This enables more scope for larger illustrations and more varied presentation of the continuing technical advances in gemmology.

In the period April 2003 to March 2004, 19 papers were published with topics ranging from Sri Lanka multi-star quartzes to Scottish marble, and from pearl cultivation in China to the compositions of Thai rubies and sapphires. Abstracts totalled 149 and there were 22 book reviews. The Assistant Editors, Associate Editors and abstractors are warmly thanked for their continued support with academic and technical expertise – more and more appreciated these days as technologies continue to advance. The Mineralogical

Donations

The Council is grateful to the following for responding to the appeal for donations. Donation levels were Circle of Benefactors (£5000 and above), Diamond (£1000 to £4999), Ruby (£500 to £999), Emerald (£250 to £499), Sapphire (£100 to £249) and Pearl (£25 to £99).

The following joins those donors listed in previous issues of *The Journal*.

Pearl Donations
Ikuo Sato FGA, Sendai-Shi, Miyagi-Ken, Japan

Hong Kong Jewellery and Watch Fair 2004

The Council is also most grateful to the following for their generous sponsorship of the Gem-A stand and seminars at the Hong Kong Jewellery and Watch Fair:

Charles & Colvard (HK) Ltd, Central, Hong Kong
www.charlesandcolvard.com

Aaron Shum Jewelry Ltd, Kowloon, Hong Kong
www.aaronshum.com

Opalight Artcrafts & Gems Co. Ltd, Kowloon, Hong Kong
www.opalight.com

Society is also thanked for their permission to reprint mineralogical abstracts that are relevant to gemmology. R. Coleman (of Harley UK) is thanked for his part in developing the new A4 format in January and making the publication much more attractive.

Gem and Jewellery News is published jointly with the Society of Jewellery Historians and in 2004 it too benefited from the change to A4 size and publication in full colour. Another change was the acceptance of advertisements, which helps to offset the increased printing costs, and the whole project has benefited from the expertise of Shelley Nott on the new design and John Goodall on production. As ever, Mary Burland has coordinated and managed this development and continued to pull together a wide range of stimulating articles from both our regular contributors and people new to gemmology.

Conference

The Annual Gem-A Conference was held for the second time at the Kempton Park Racecourse during the late autumn Rock 'n' Gem Show giving delegates the opportunity to browse and buy at the Show during the lunch break. The keynote lecture 'An update on research activities at GIA' was presented by William E. Boyajian, President of the GIA. Professor Henry A. Hänni gave a presentation on gem identification carried out at the SSEF Swiss Gemmological Institute, Dr Jack Ogden explained how jewellery mounts could be scrutinized to authenticate jewellery, Clive Wright gave an update on the Kimberley Process and Paula Crevoshay spoke about Crevoshay designs and using gemmology as a designer tool. Two of the Gem-A USA Advisory Board Members, Gail Levine and Theresa Shannon as well as Director A Dale, attended the conference to show support for the Association in the UK.

A private viewing of the Crown Jewels at the Tower of London with Crown Jeweller David Thomas, a visit to the DTC, and a private viewing and guided tour of the Wernher Collection at the Ranger's House, Greenwich, were arranged for the conference delegates. The Council is most grateful to the Conference sponsors Marcus McCallum

and T.H. March Insurance Brokers, and supporters Fellows & Sons, Dreweatt Neate, and Malca-Amit (UK) Ltd.

Visits

The annual visit organized by D J Garrod to the world-famous Idar-Oberstein gem centre in Germany was again very successful. Visits to new venues in Idar and Oberstein were organized, while our 'traditional' visits in and around the twin towns were as popular as ever.

Photographic Competition

The 2003 competition on the theme 'All shapes and sizes' drew a record number of images of particularly high quality, and several were selected to grace the 2004 calendar. The winner was Zeng Chungguang of Singapore, with runners-up Anthony de Goutière of Victoria, BC, Canada, and Luc Genot of Brussels, Belgium. Council is most grateful to Harley (UK) for their sponsorship of the three prizes and for their contributions to conference expenses.

Trade fairs and shows

Gem-A exhibited at International Jewellery London 2003 at Earls Court in September with D Garrod giving a series of lectures. T Davidson, I Mercer, D Garrod and L Stather represented Gem-A at the Hong Kong Jewellery Show in September, where a good attendance was enjoyed at our show booth and seminar. A Clark, D Garrod and L Stather attended Rock 'n' Gem Shows at Kempton Park promoting Gem-A.

Finance

For 2003/2004 Gem-A exceeded its budgeted turnover. Although a small increase on budgeted turnover was achieved, unbudgeted expenditures in cost of sales, consultancy and unforeseen costs in repairs and maintenance along with an increased investment in education expenditure planned to produce dividends in 2004-2005 reduced our operating profit. We have continued to show improvement in our accountancy procedures and have reduced our debtors in Gem-A and Gemmological Instruments Ltd.

Staff and Supporters

Three members of staff left and have been replaced. There have been three additions to the staff: Hayley Smith joined the education team as an examination and course administrator, Michell Henry was employed in office services as a cleaner and Stephen Bennett was appointed IT person responsible for routine PC software, network maintenance, Gem-A website upkeep and development, reporting to YJ Thien, along with Gem-A promotion, education development support including graphics and CD Rom production, reporting to Lorne Stather.

Through the continued dedication and hard work of our staff we continue to strengthen the foundation and build for the future of Gem-A.

Gemmological Instruments Ltd.

Gemmological Instruments Ltd is a wholly-owned company of Gem-A. The company supplies gem-testing equipment of good quality at competitive prices, ranging from stone tweezers to top-of-the-range microscopes, books on gems, gemmology and gem-set jewellery, and a range of thematic sets of gems for students. The turnover and profit generated by GI Ltd were very similar to the figures for the previous year and reflect the need for constant development and improvement in a competitive market. Introduced in the second half of 2003/2004, and for which we have sole world distribution, was the Diamond Trading Company's Diamonds CD ROM on Treatments, Synthetics and Simulants. The world market for gemmological equipment remains highly competitive. We continue to search the world for the best equipment to market at good and realistic retail prices.

Extraordinary General Meeting

At an Extraordinary General Meeting held at 27 Greville Street, London EC1 on 27 July 2004, the following Special Resolutions were approved:

THAT the Gemmological Association and Gem Testing Laboratory of Great Britain should seek registered charity status.

THAT the Gemmological Association and Gem Testing Laboratory of Great Britain adopts the Memorandum and Articles of Association dated 2 June 2004 as posted on their website at www.gem-a.info, subject to any changes required by the Charity Commission, for application for registration as a charity.

Membership

Between 1 July and 31 October 2004 the Council approved the election to membership of the following:

Fellowship (FGA)

Adzovic, Senada, Sarajevo, Bosnia Herzegovina, 1997
Aura, Kimmo T. , Espoo, Finland, 2004
Aziz, Khalid, Karachi, Pakistan, 1987
Chandhok, Jasmeet Singh, New Delhi, India, 2004
Hearnden, Rachel Claire, Sheffield, S Yorkshire, 2004
Jennings, Rick, Roanoke, VA, USA, 1979
Kao Oi Shan, Patsy, Hong Kong, 2004
Li Mo Ching, Hong Kong, 2004
Michaelides, Mapia, Athens, Greece, 1999
Peters, Judith Anne, Falmouth, Cornwall, 1976
Sillem, Hayaatun, London, 2004
Valvio, Raija, Vaajakoski, Finland, 2004
Visschers-Villerius, Conny, Heerde, The Netherlands, 2004
Wong, Chung Yan, Kowloon, Hong Kong, 2004
Wong Man Nea, Rosemary, Hong Kong, 2004

Diamond Membership (DGA)

Beattie, Rosamund, Manor Park, London, 1999
Lam Wai Han, Hong Kong, 2004
Li Chi Wai, Kowloon, Hong Kong, 2004
So Yiu Ki, Eric, Hong Kong, 2004

Associate Membership

Akar, Farah, Finchley, London
Archibong, Elizabeth, London
Anderson, Michael R., Chillerton, Isle of Wight
Bamarra, Jaspac, London
Barrie, Brenda, Woking, Surrey
Berden, Angela C.M., Balham, London
Brennan, Aidan, Dundalk, Co Louth, Ireland
Cader, Lazhar, London
Cardosa Rodriques, Isadora, Surbiton, Surrey
Chang Yuan-Cheng, London
Chawla, Jaspreetkaur, London
Cheong Mun Fong, London
Dowell, Vanessa C.D., Cambridge
Duncan, Barry John, Littlehampton, West Sussex
Groenenboom, Peter, Arnhem, The Netherlands
Hafeez, Mohammed, Dewsbury, West Yorkshire
Hague, Des, Sheffield, South Yorkshire
Hazra, Dibyendu, West Bengal, India
Hemeryck, Marine, Brighton, Sussex
Huck, Perry, Stanford-in-the-Vale, Oxfordshire
Johnson, Bede, Lewes, East Sussex
Kashaka, Jean-Claude M., Surbiton, Surrey
Katembwe, Joseph C., Southsea, Hampshire
Kiilu, Kyalo, Mayfield, East Sussex
Leadbeater, Craig C., Dulwich, London
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Guide to the preparation of typescripts for publication in *The Journal of Gemmology*

The Editor is glad to consider original articles shedding new light on subjects of gemmological interest for publication in *The Journal*. Articles are not normally accepted which have already been published elsewhere in English, and an article is accepted only on the understanding that (1) full information as to any previous publication (whether in English or another language) has been given, (2) it is not under consideration for publication elsewhere and (3) it will not be published elsewhere without the consent of the Editor.

Typescripts Two copies of all papers should be submitted on A4 paper (or USA equivalent) to the Editor. Typescripts should be double spaced with margins of at least 25 mm. They should be set out in the manner of recent issues of *The Journal* and in conformity with the information set out below. Papers may be of any length, but long papers of more than 10 000 words (unless capable of division into parts or of exceptional importance) are unlikely to be acceptable, whereas a short paper of 400-500 words may achieve early publication.

The abstract, references, notes, captions and tables should be typed double spaced on separate sheets.

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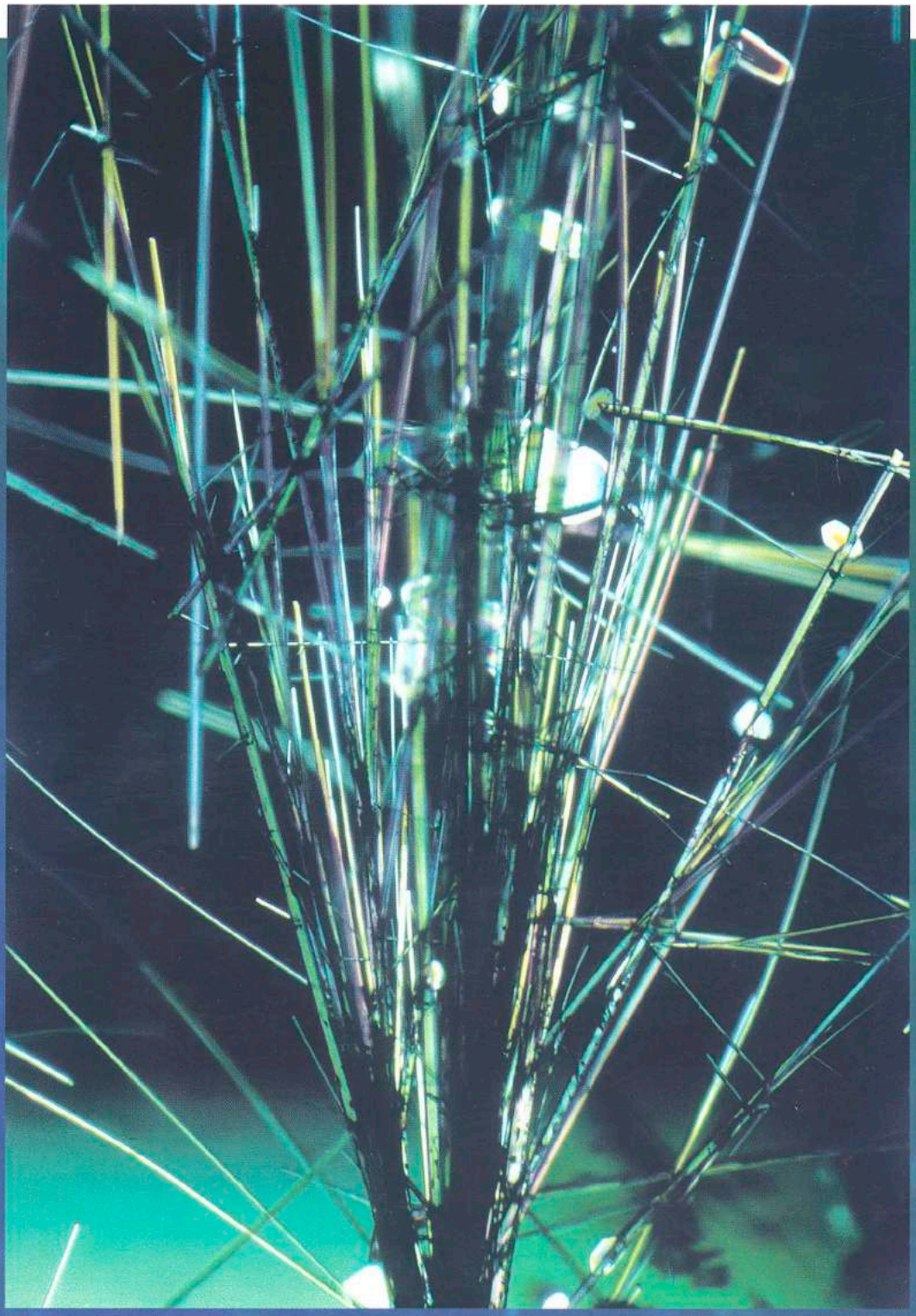

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Tribute

Professor Dr Edward Joseph Gübelin

A tribute by E. Alan Jobbins

It is with great sadness that we report the passing of Edward Gübelin on the 15 March 2005, only a day before his 92nd birthday. With his death the worldwide gemmological fraternity has lost a most remarkable and inspirational scientific leader. He was a very early proponent of the use of inclusions in the identification of gem materials and their treatments. He was widely respected internationally and became a mentor to generations of gemmologists (including this writer) through his enthusiastic writings and beautiful inclusion photomicrographs and topographical photographs.

Edward Joseph Gübelin was born in Lucerne, Switzerland, on the 16 March 1913 into a family of *grands joailliers* where he was given great encouragement

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by his father, even to the extent of being treated to a new winter overcoat when he made a particularly successful jewellery sale. Following his father's establishment of a private gemmological laboratory in the early '30s, he continued its development with constant updating with the latest instrumentation. He initially studied mineralogy and the history of art at Zürich. In 1936/37 in Vienna he worked under Professor H. Michel (who had introduced 'microgemmology' some years earlier) where his fascination for inclusions in gemstones was nurtured. Later in 1937 he was working with Professor K. Schlossmacher in Idar Oberstein – a major lapidary centre. He also worked, and began a firm friendship, with Basil Anderson at the London Gem Testing Laboratory. They shared a passion for Burmese gems and many fine specimens from A.C.D. Pain in Burma were then available and being marketed by Charles Mathews in Hatton Garden in the 1940s and '50s.

Edward gained his doctorate in 1938 and his formal gemmological qualification (GG) in residence at the Gemological Institute of America in California in 1939, and was the first recipient of their Research Diploma. He was awarded his FGA in 1946 with Distinction and the GA Research Diploma followed in 1957 for his work on 'Inclusions that occur in gemstones'.

Edward was the founder member of a small group of early laboratory specialists, including B. W. Anderson (UK), O. Dragsted (Denmark), G. Gobel (France), K. Schlossmacher (Germany) and H. Tillander (Finland), who met in various European countries to discuss ongoing problems facing the gemstone industry, such as synthetic corundums and spinels. These annual meetings widened in scope and developed in the early 1950s into the International Gemmological Conference. Edward was an active participant from its inception and was made an Honorary Member in 1985. His seminal paper 'Differences between Burma and Siam rubies' using their distinctive inclusions appeared in *Gems & Gemology* as early as 1940. In 1953 his classic book *Inclusions as a Means of Gemstone Identification* was published in monochrome, and he introduced a systematic classification of inclusions based on their age relative to the host gemstone mineral. This was followed in 1974 by his inspirational book *Internal of World of Gemstones* with colour plates. Over the decades he wrote over two hundred papers – many of groundbreaking research importance – and published in many international journals with fine colour illustrations.

In 1978 he met John Koivula at the Gemological Institute of America in California; both had visions of a profusely illustrated work on gemstone inclusions, and the *Photoatlas of Inclusions in Gemstones* was the outcome, published in 1986 – a significant work of science and art. By 1989 gemmological research had moved on and planning for a second volume of the *Photoatlas* was initiated on an excursion of the International Gemmological Conference from the Alps to Vesuvius in Italy. The work involved in producing such a volume inevitably meant a long gestation period. The final text and photographs for this volume, which will contain a cornucopia of over 2000 plates of gemmological 'works of inclusion art' by the two gifted authors, was completed in late 2004, but tragically Edward did not live to see their *opus magnum*, now expected to be published in late 2005. His interest and comprehension of art history continued throughout his life, and he was eager to take opportunities to visit art galleries on his journeys around the world. In 1999 his popular book *Gemstones: Symbols of Beauty and Power*, co-authored with Franz-Xavier Erni, appeared in German, followed by an English edition in 2000. Aimed at a

wider readership, it was graced by a stunning series of colour plates by the gifted photographers Harold and Erica Van Pelt and others.

Edward was an intrepid traveller and visited gem deposits in many inhospitable lands. In the early 1960s, before the military government was in power, he was able to visit Mogok in Upper Burma with his eldest daughter, Marie-Helen, and made an excellent and timely film of the traditional gemstone workings, which he subsequently took great pleasure in showing to many audiences – Mogok then being difficult of access until the early '90s. He was also a great collector, and I remember an occasion in his home in Lucerne discussing with him the rare colourless chrysoberyls and pale bluish-green alexandrites from Mogok, whereupon he produced several fine specimens from his Burma (locality) collection only to follow them with other beauties from his equally comprehensive species collection.

He was a prolific correspondent, always ready to provide helpful advice and information, invariably written in his own inimitable and flowing English, and I treasure my file of letters from him going back nearly forty years.

His lovely wife Idda died in 1991, but he is survived by his five daughters, 12 grandchildren and 11 great-grandchildren.

He was a kind and generous man, a gemmological polymath and visionary. Throughout the world many gemmologists and mineralogists will share with me the thought that our distinguished friend Edward will be as in the words of Homer "Forever honour'd, forever mourn'd" *(Iliad)*.

In honour of Professor Dr Edward J. Gübelin

Contributed by John I. Koivula

Reflecting an adventurous life, this 10 mm spray of acicular tourmaline crystals protogenetically embellished with microcrystals of quartz rests for eternity encased in rock crystal, a true symbol of beauty in nature. Sample personally collected in 1987 by Edward J Gübelin and John I. Koivula at the Golconda Mine in Minas Gerais, Brazil, during a field excursion at the XXI International Gemmological Conference. Polarized light with compensator. Photomicrograph by John I. Koivula, courtesy of microWorld of Gems.

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HPHT treatment of different classes of type I brown diamonds

Thomas Hainschwang[1], Andrey Katrusha[2] and Heiner Vollstaedt[3]

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Abstract: *As part of a study of the classification and origin of colour of brown diamonds by one of the authors (Hainschwang, 2003), seven stones belonging to defined classes were selected and treated by the HPHT process. Each diamond was tested extensively before and after the treatment using standard and advanced gemmological methods, including FTIR spectroscopy, low temperature Vis/NIR and photoluminescence spectroscopy. On treatment, all diamonds except the CO_2 and 'Pseudo CO_2' diamonds lost their brown coloration and exhibited various shades of yellow. It was found that the spectra of all diamonds except CO_2 and 'Pseudo CO_2' diamonds showed very apparent changes of which the elimination of the amber centre with its primary peak between 4070 and 4165 cm^{-1} in the FTIR spectra is of particular interest. The results of the treatment are discussed in detail and correlated with the proposed classification, of which a summary is presented. One of the major results of this research is the identification of several origins of the brown colour in diamonds, including plastic deformation with associated defects and impurities such as CO_2.*

Introduction

Diamonds have been artificially coloured for a very long time. Until the late 1990s this was done either by superficial coating, by painting or by the creation of lattice defects by irradiation, sometimes followed by annealing. The primary treatment since the early 20th century was irradiation/annealing, by which the colours of mainly type Ia and Ib yellow to pale brown diamonds can be changed. In this treatment, the high energy particles in the radiation displace some carbon atoms and thus create vacancies and interstitials (Bienemann-Kuespert *et al.*, 1967); annealing causes these defects to diffuse through the lattice where the vacancies will be mostly trapped by nitrogen to form various nitrogen-vacancy defects, such as the NV^-centre with absorption (zero phonon line(ZPL)) at 637 nm (Bienemann-Kuespert *et al.*, 1967). The primary radiation treatment results in green to greenish-blue to blue coloration, which can be changed to yellow, greenish-yellow or orange in type Ia pale yellow diamonds and to pink or purple in

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type Ib diamonds by annealing at 600°–800°C (Bienemann-Kuespert *et al.*, 1967). The majority of brown type Ia diamonds, particularly the darker colours, are unsuitable for irradiation/annealing and are still mainly brown after such treatment. In the late 1990s, relatively large numbers of intensely coloured yellow to yellow-green diamonds with very strong green luminescence – also visible as transmission – appeared in the gemstone market. Such stones, which are frequently termed 'green transmitters', were very rarely seen before and are considered to be extremely scarce in nature. Buerki *et al.* were the first group to postulate in 1999 that these stones were produced by a new treatment: they proposed that the diamonds were treated by irradiation followed by very high temperature annealing at stabilizing pressure. However, Collins *et al.* (2000) doubted that irradiation was involved and thought that these diamonds were treated by high temperature annealing at stabilizing pressure only; the treatment was called the high pressure high temperature (HPHT) treatment and conditions of 1700°–2500°C at about 6.5 GPa were reported. Since then, several publications have covered the subject of the HPHT treatment; these include papers about the decoloration of type IIa brown diamonds (e.g. Smith *et al.*, 2000) and the production of green transmitters from type Ia brown diamonds (Reinitz *et al.*, 2000; Katrusha *et al.*, 2003) by HPHT. It was postulated that the reduction of the brown coloration is caused by the realignment of distortions in the crystal lattice; such distortion was (and by some still is) believed to be the sole cause the brown coloration of diamonds. According to this theory, vacancies are released during the realignment. The vacancies are trapped by nitrogen in type Ia diamonds but are mostly annihilated in type IIa diamonds since there is not enough nitrogen present; therefore type Ia diamonds will change colour while type IIa diamonds change to (near-) colourless after HPHT treatment. More recently, it has been suggested, that the brown colour of diamonds is due to graphitic (Ewels *et al.*, 2001) or amorphous carbon (E. Fritsch, pers. comm. 2002), i.e. sp^2 bonded carbon; this may be recrystallized by the HPHT process causing release of vacancies and changes of colour like those described above.

Experiment

A classification of brown diamonds has been established by Hainschwang (2003) based on standard and advanced gemmological analysis of 63 samples selected from 900 brown diamonds using FTIR spectroscopy. Research on the possible formation of brown coloration and a detailed study of certain defects, notably the 'amber centre'(see Box A) were also carried out. To investigate some of the theories and ideas, it was decided to take one or several samples from most of the proposed classes and treat a total of seven stones by HPHT at 2000°C and 6.5 GPa. The total HPHT cycle or process lasted 30 minutes and consisted of an increase of temperature to the maximum value of 2000°C, holding this for ten minutes and then switching off the power with rapid cooling. For the run, the stones were placed in a graphite capsule.

Materials and methods

The seven brown diamonds were analyzed using standard and advanced gemmological techniques before and after the HPHT treatment. The diamonds included one brown diamond each of type IaA, IaB, IaA/B, Ib, Ia containing solid CO_2 (Schrauder and Navon, 1993), Ia 'Pseudo-CO_2' (Hainschwang, 2003) and one olive-brown stone of type IaA. The colour of the stones was observed using 6200 K daylight illumination; and colour distribution was observed with the stones immersed in methylene iodide using diffuse transmitted light. The diamonds were examined with a binocular microscope fitted with crossed polarizing filters to see any strain and extinction patterns. Luminescence to long-wave and short-wave ultraviolet radiation was observed, including any observable phosphorescence after the UV source was shut off. Advanced analysis included FTIR spectroscopy and Vis/NIR as well as

photoluminescence (PL) spectroscopy. The IR spectra were recorded with a Perkin Elmer Spectrum BXII FTIR spectrometer using a DIGS detector, at resolutions of 4 cm^{-1} and 2 cm^{-1}. The Vis/NIR spectra covering the range of 400-1000 nm were recorded on an SAS2000 system equipped with an Ocean Optics SD 2000 dual channel spectrometer with a resolution of 1.5 nm. A 2048-element linear silicon CCD detector was employed. The samples were analysed in an integration sphere; all spectra were recorded at 77K. The direct measurement in the integration sphere causes a particular phenomenon when the spectra of strongly luminescent diamonds are recorded: in such stones emission bands can be apparent on the lower energy side of the ZPL of a luminescent centre such as H3; thus for the H3 centre with its ZPL at 503 nm, a vibronic structure as seen in luminescence can be found with three emission bands at 511, 520 and 528 nm *(see Figure 6)*. The photoluminescence spectra were also measured with the stones immersed in liquid nitrogen using an SAS2000 Raman system equipped with a 532 nm semiconductor laser and having a resolution of 1.5 nm. This system employed the same spectrometer and detector as mentioned above.

Table I: The colours of seven diamonds before and after HPHT treatment.

Sample number, type based on FTIR and features	Colour before HPHT	Colour after HPHT
DUG 7 Ib		
DUG 10 IaA, double amber centre 4070 cm^{-1} /4165 cm^{-1}		
DUG 18 IaA/B, very strong absorption due to platelets		
DUG 22 IaB (very little A), high hydrogen		
DUG 46 IaA		
DUG 3 Ia, solid CO_2		
DUG 30 Ia, 'Pseudo CO_2'		

NB: The stones were not repolished after the treatment, therefore they display matt surfaces.

Results

Visual appearance

Before: The seven samples included six 'regular' brown diamonds and one olive-brown stone. Their tones varied from medium to dark.

After: In five stones, the brown colour was practically eliminated; the treatment did not change the colour of the CO2 and 'Pseudo CO2' diamonds significantly. The other five stones exhibited a yellow hue after the treatment, some with a pale green and one with a pale pink modifying colour (Table I). The stones were not re-polished after HPHT, and display matt surfaces.

Colour distribution

Before: when discussing brown (and pink) diamonds, most people in the jewellery trade

BOX A: Summary of classification of brown diamonds

The proposed classification is based on the analysis and characterization of 900 brown diamonds between 0.03 and 4.09 ct by standard and advanced gemmological methods. Full details of the classification are in the Diplôme d'Université, Gemmologie (DUG) at the University of Nantes (Hainschwang, 2003). The basic characterization can be made by observation of the colour distribution and the infrared spectrum of each stone. The most important distinctions are made by the presence or the absence of an amber centre and by the presence or absence of coloured graining. The amber centre is a term describing a complex collection of peaks in the range ~8000 to 4065 cm^{-1} with a primary peak at 4165, 4115 or 4070 cm^{-1}, and this structure was observed in 97.4% of the analysed diamonds *(see Figures 1 and 2)* It has been found to be related to single atoms and A-aggregates of nitrogen (also known as C-centres and A-centres in some literature) combined with plastic deformation. Thus the amber centre cannot be found in type IaB, IIa and IIb diamonds nor in stones which have not experienced plastic deformation. Truly brown diamonds, which have not experienced such deformation, are rare and include stones containing solid CO_2 (Schrauder and Navon, 1995), 'Pseudo-CO_2' diamonds (Hainschwang, 2003), some very high nitrogen-containing type Ib diamonds and certain hydrogen-rich brown diamonds (Massi, 2003).

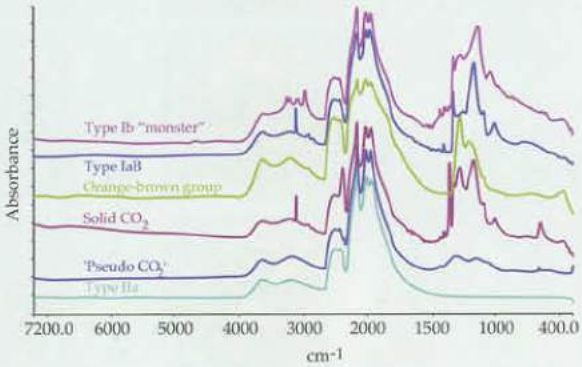

Figure 1: Spectra of the classes lacking the amber centre.

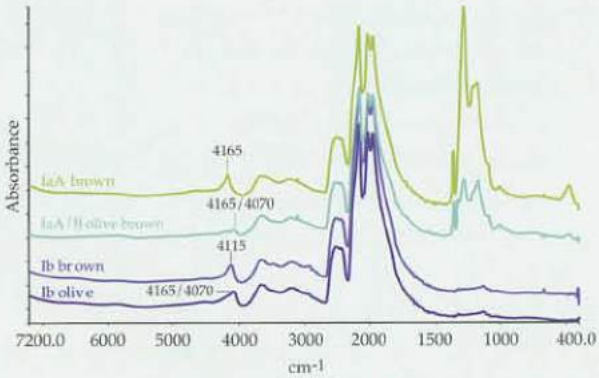

Figure 2: Spectra of the classes exhibiting an amber centre.

These rare stones were also found to show entirely different colour distribution, either patchy or around a phantom inclusion, and they have apparently a very different origin of colour *(Figure 3)*. Around 98% of all brown diamonds have brown graining, i.e. parallel narrow planar brown bands *(Figure 3)*. The list below contains all the determined classes; it must be mentioned that although hydrogen-rich brown diamonds were reported by Massi (2003), no such stones were found among our 900 brown diamonds.

Figure 3: Colour distributions of brown diamonds (left to right): graining, patchy colour, colour around phantom.

No	Class	Characterized by	Approx %
		Exhibiting an amber centre	
1	Typical brown (Ia)	4165 cm^{-1} peak, brown 'graining'.	95%
2	Double amber centre (Ia+Ib)	4165 cm^{-1}/4070 cm^{-1} peaks, olive and brown graining.	2%
3	Regular Ib	4115 cm^{-1} peak, weak graining.	0.4%
		Exhibiting no amber centre	
4	Orange-brown group (Ia/Ib)	Brown colour modified by orange, quite homogeneous.	Not represented in this study
5	Typical brown IaB pure	Colour usually distributed as 'graining'.	0.2%
6	Extreme Ib	Very high single nitrogen content. Colour around phantom.	0.3%
7	Type IIa	Generally little or no 'graining'.	0.6%
8	Solid CO_2	2390 cm^{-1} and 645 cm^{-1} absorptions. Patchy colour.	0.9%
9	'Pseudo-CO_2'	Unusual nitrogen absorptions, no 2390 cm^{-1} / 645 cm^{-1} peaks. Patchy colour, 'colour banding'.	0.6%

will associate such diamonds with 'coloured graining'; this graining appears as sharp narrow parallel colour bands along octahedral growth directions *(Figure 3)*. Five of the selected brown diamonds exhibited such brown graining albeit in variable strengths; the CO_2 diamond showed no graining but contained an irregular brown patch *(Figure 3)*; the colour in the 'Pseudo CO_2' diamond was half irregular and patchy and half strongly developed brown graining.

After: Since the stones were not repolished they showed a burnt skin which did not permit an undisturbed view of the interior of the diamonds; immersion in methylene iodide helped but any faint colour irregularities could not be confirmed: nevertheless, immersion revealed that the graining had been practically eliminated and that the colour appeared quite homogeneous. The CO_2 diamond did not show any change and both before and after the HPHT run the same irregular brown patch was present. The colour distribution of the 'Pseudo CO_2' diamond also did not change noticeably after annealing: after HPHT the colour bands reminiscent of brown graining were still present and thus are apparently different in nature from the graining in classic brown diamonds; thus these colour bands were called 'colour banding'.

Luminescence to UV radiation

The defects and changes of nitrogen aggregation, which are caused by the HPHT process, result not only in the formation of yellow to orange coloration, but also in a change of luminescence. This is also the case with the seven samples analysed in this study: all except the CO_2 and the 'Pseudo CO_2' diamond showed a very marked change in luminescence when excited by long-wave and short-wave ultraviolet radiation and a summary is given in *Table II*. Interestingly, none of our samples showed the typical strong 'pure' green luminescence, which has been described before (e.g. Reinitz *et al.*, 2000).

Table II: Luminescence of seven brown diamonds before and after HPHT treatment.

No(type)		Before HPHT		After HPHT	
		LW UV	SW UV	LW UV	SW UV
DUG 7	(Ib)	Faint reddish-orange	Weak reddish orange	Med. greenish blue	Strong chalky yellow
DUG 10	(IaA olive-brown)	None	None	Faint greenish yellow	None
DUG 18	(IaA/B)	Weak blue	Faint yellowish blue	Medium chalky blue	Medium chalky yellow
DUG 22	(IaB)	Weak chalky blue	Faint chalky blue	Strong chalky blue, lasting phosphorescence	Very strong greenish yellow, lasting phosphorescence
DUG 46	(IaA)	Faint yellow	None	Medium chalky blue	Medium chalky greenish yellow
DUG 3	(Ia CO_2)	Medium yellow	Weaker yellow with weak lasting phosphorescence	Same as before	Same as before
DUG 30	(Ia'Pseudo-CO_2')	Medium yellow	Weak yellow	Same as before	Same as before

Infrared spectroscopy

Changes of nitrogen aggregation: It was noted in all except the CO_2 and Pseudo-CO_2 diamonds that the treatment had changed the aggregation state of nitrogen to some degree; in the type IaA and IaA/B diamonds, the amount of B-aggregates increased while the amount of A-aggregates decreased; thus it was concluded that the A-aggregates had been transformed into B aggregates. It was also notable that the type Ib brown diamond had been almost completely transformed into

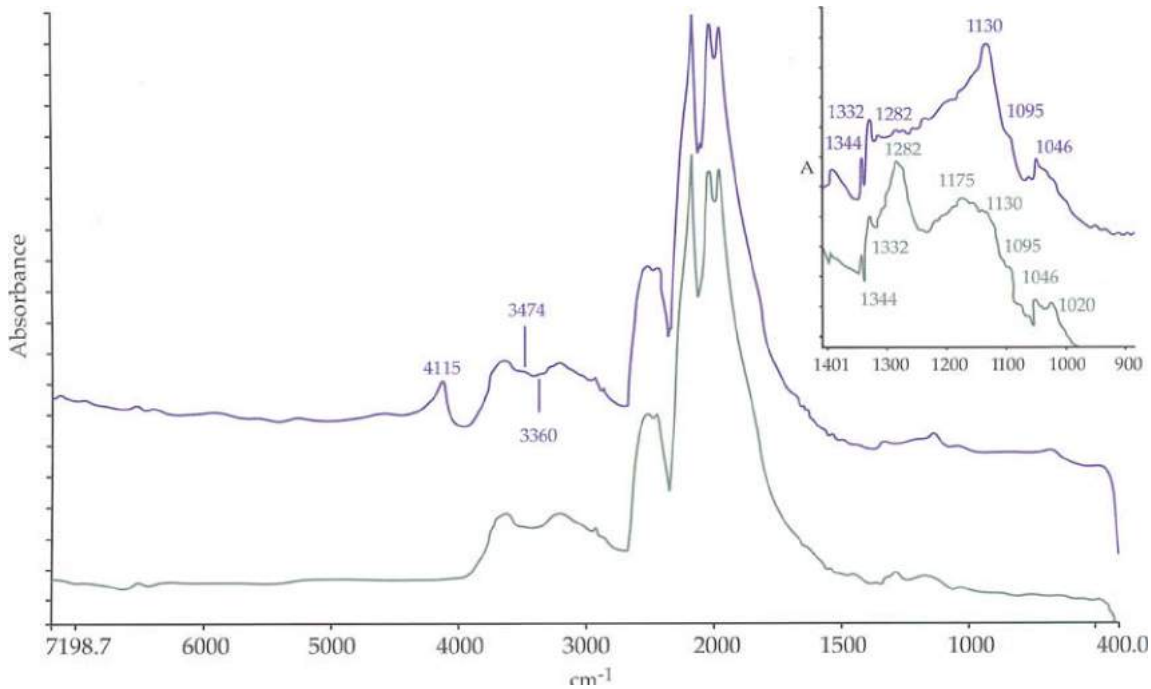

Figure 4: The FTIR spectrum of sample DUG 7, originally a brown type Ib diamond, before (blue trace) and after (green trace) HPHT treatment.

Figure 5: The FTIR spectrum of sample DUG 18, a brown IaA/B diamond, before (purple trace) and after (teal trace) HPHT treatment.

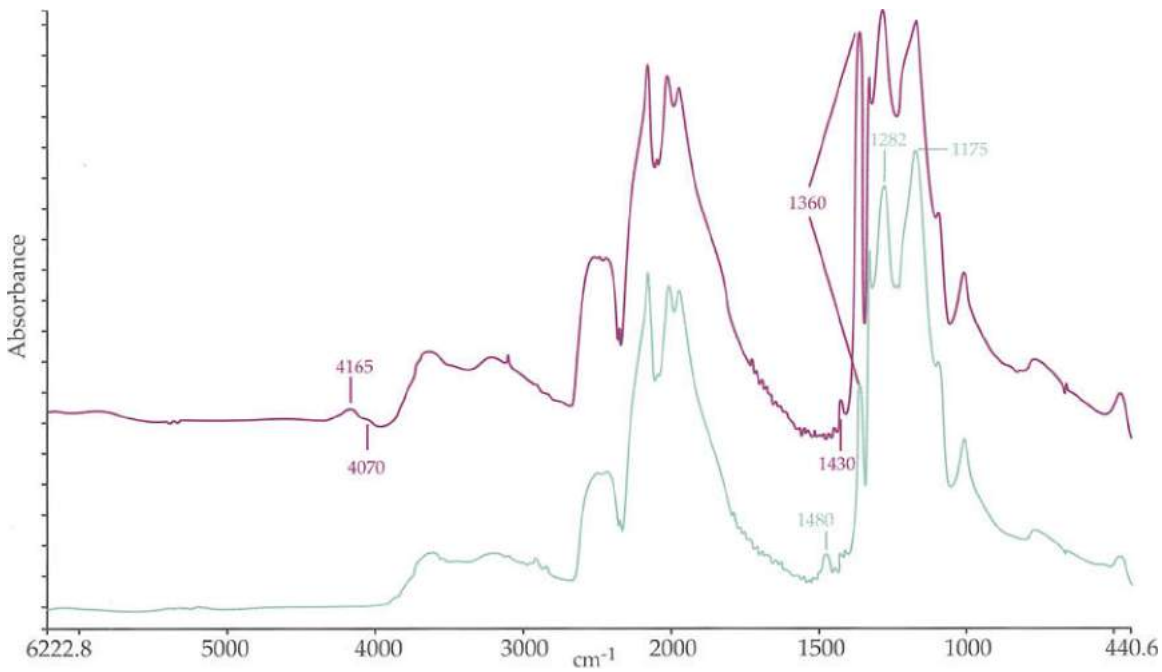

a type IaA/B diamond by aggregation of single nitrogen atoms into A- and B-aggregates (*Figure 4*).

Effects on other defect-induced absorptions

It has been described before that a defect called the 'amber centre' was eliminated by HPHT treatment (Reinitz *et al.*, 2000); Du Preez (1965) identified the main peak of this complicated structure at 4165 cm^{-1} in type I brown diamonds, but Hainschwang (2003) and Massi (2003) found that the main peak of this defect (the peak will be further referred to as the 'amber centre') was not only found at 4165 cm^{-1} but could also be found at several different positions between 4070 and 4165 cm^{-1} (see also Box A). During the HPHT experiment, all these peaks and the

Table III. Major changes observed in the FTIR spectra of the analyzed samples (CO_2 diamond not included [DUG 3]: no changes found)

Sample		Peak position, cm^{-1}								Type
7	Before				4115	3474, 3360				Ib
	After				none	none				IaA/B, some b
10	Before			4165	4070		1430	1405	1370 medium	IaA
	After			none	none		none	1405	1370 weak	IaA, some B
18	Before			4165	4070	none	1430		1360 strong	IaA/B, A>B
	After			none	none	1480	none		1360 weak	IaA/B, A<B
22	Before	4668	4494	4165			1430	1405	1362 strong	IaB, some A
	After	none	none	none			none	none	1362 weak	IaB, less A
46	Before			4165					1360 medium	IaA
	After			none					1360 very weak	IaA, some B
30	Before					none	615 weak		1360 medium	Ia, A>B 'Pseudo CO_2'
	After					2415	615 medium		1360 weak	No changes CO_2 (?)

associated structure were eliminated by the treatment *(Figures 4 and 5)*. A strong reduction of the platelet peak, which can be found in the vicinity of 1360 cm^{-1}, was apparent *(Figure 5)* and has been reported before (e.g. Reinitz *et al.*, 2000).

Other defects, which were reduced or eliminated, include some of the hydrogen related features like the 3307, 4494, 4667, 1405 and 1430 cm^{-1} absorptions. In sample DUG 18, a type IaA/B diamond with a very strong platelet peak, an absorption at 1480 cm^{-1} was formed by the HPHT treatment *(Figure 5)*. This feature has only very rarely been observed in untreated diamonds (S. McClure, pers. comm. 2004). In sample DUG 7, a pure type Ib diamond before HPHT, the bands seen in the diamond intrinsic at 3474 and 3360 cm^{-1} were eliminated *(Figure 4)*. In the spectrum of the CO_2 diamond, practically no changes were observed. In the 'Pseudo-CO_2' diamond, a peak at 2415 cm^{-1} was formed and the broad band around 650 to 400 cm^{-1} was strengthened. The major changes induced by the HPHT treatment in the IR spectra are summarized in *Table III*.

Vis/NIR Spectroscopy

The Vis/NIR spectra of the brown diamonds before HPHT were categorized as follows:

Ia with very weak to undetectable N3, very weak H3, 550 nm band

Ib with distinct NV^- centre absorptions, 550 nm band

CO_2 and 'Pseudo CO_2' with continuous absorption but without distinct absorption bands other than a weak broad band at 480 nm.

After the HPHT treatment, weak to strong N3, H3 and H2 absorptions were formed in all samples except the CO_2 and 'Pseudo CO_2' diamonds. In the samples with distinct to strong H2 absorption, a related peak at 871 nm was observed. Besides a distinct N3 absorption, the H3 and H2 defects were weak

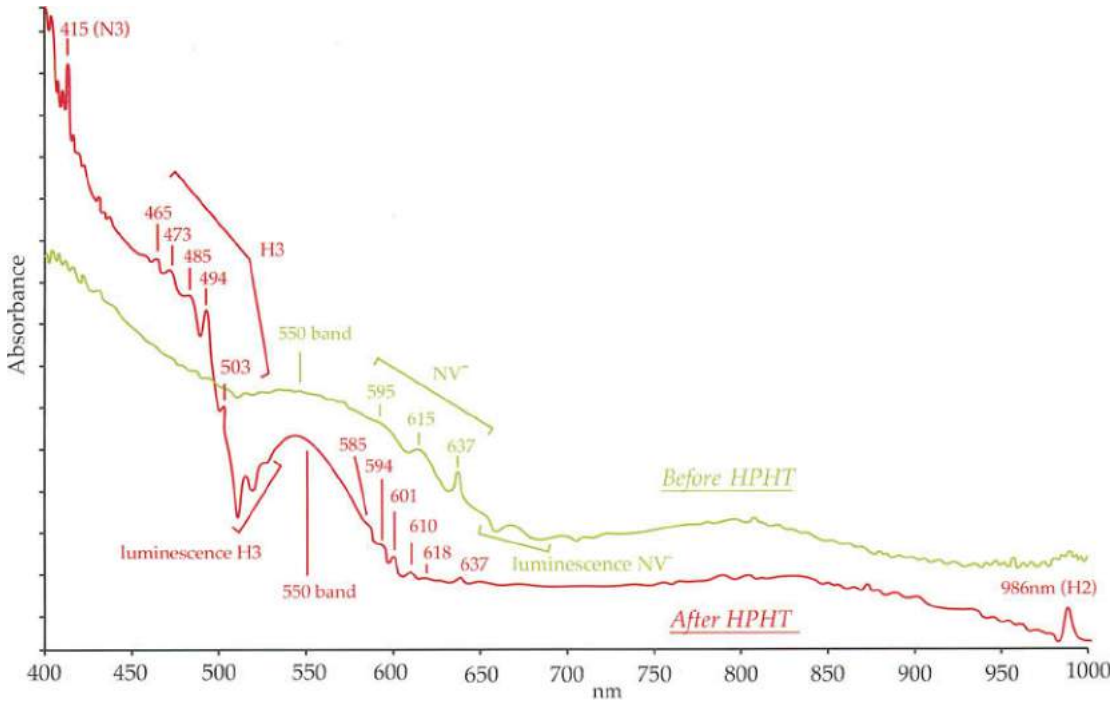

Figure 6: The Vis/NIR spectrum of sample DUG 7, originally a brown type Ib diamond, before and after HPHT. The spectrum before (green trace) exhibits only a distinct NV^- centre which causes the broad band at 550 nm. The aggregation of the single nitrogen by HPHT produced H3, H2 and distinct N3 absorption (red trace). Note that after HPHT, the NV^- centre was nearly eliminated and the stronger 550 nm band is due to the vibronic structure between 585 and 610 nm, and not to the NV^- centre.

Table IV. The changes observed in the Vis/NIR spectra of the analysed diamonds (CO_2 and 'Pseudo CO_2' diamonds not included: no changes observed).

Sample		Peak position, nm													
7	Before						550					615	637		
	After	415	465	485	494	503	550	585	601	610	618		637	871	986
			473					594							
10	Before	415 weak		very weak H3			560								
	After	415			494	503								871	986
18	Before	415 weak		very weak H3			560								
	After	415	473	485	494	503	560							871	986
22	Before	415 weak		very weak H3			560								
	After	415	473	485	494	503	560								986
46	Before	415 weak		very weak H3			560								
	After	415	473	485	494	503	560							871	986

NB: The 494, 485, 473 and 465 nm peaks form the vibronic structure of the H3 centre with its ZPL at 503 nm; the 871 nm peak is part of the vibronic structure of the H2 centre with its ZPL at 986 nm; the 615 nm peak is a vibronic band of the NV^- centre with its ZPL at 637 nm; and the bands at 618, 610, 601, 594 and 585 are the vibronic structure forming the 550 nm band.

in sample DUG 10, which represents an olive-brown diamond of type IaA. Only a weak H2 centre combined with distinct H3 and N3 absorptions were present in sample DUG 22, a near-pure type IaB brown diamond. An interesting 'transformation' was observed in sample DUG 7, a pure type Ib brown diamond before HPHT: the apparent absorptions at 615 and 637 nm due to the NV^- centre present before HPHT were strongly reduced while rather strong H3 and H2 defects and a vibronic structure between 585 and 618 nm were formed; it is notable that there was a strong N3 peak at 415 nm after the HPHT treatment (*Figure 6*). The observed changes seen by Vis/NIR spectroscopy are summarized in *Table IV*.

Photoluminescence (PL) spectroscopy

Before treatment, the emission of the brown diamonds excited by a green laser was mostly very weak; the only exception was the

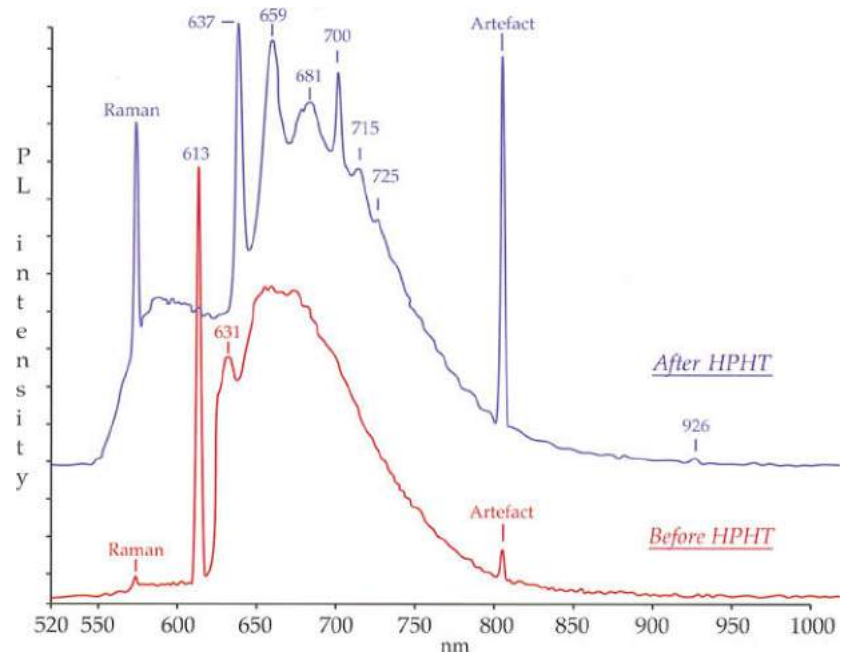

Figure 7: The PL spectra of sample DUG 10, an olive-brown type IaA diamond, before (red trace) and after (blue trace) HPHT. After HPHT, the spectrum indicates a clear type Ib character with strong peaks at 637, 659 and 681 nm.

The 659 and 681 nm peaks are the strongest bands of the vibronic structure of the NV^- center with its ZPL at 637 nm. The formation of the 700 nm centre with its 700 nm ZPL and vibronic bands at 715 and 725 nm plus the 926 nm feature tentatively indicate a nickel-nitrogen related defect.

Table V. The changes observed in the PL spectra of the analyzed diamonds (CO_2 and 'Pseudo CO_2' diamonds not included: no major changes observed).

Sample		Peak position, nm																
7	Before			587		600		620		637		659	681		707			
	After	566	575	587		600				637		659	681		707			
10	Before						613		631									
	After									637 strong		659	681	700		715	725	926
18	Before		575		596		613		626	637 weak								
	After		575							637 strong		659	681		707			
22	Before		575			600	613	620		637 weak								
	After		575	588	596			620		637 strong		659	681		707			
46	Before		575			600	613			637 weak		659	681					
	After		575							637 strong		659	681		707			

NB: The 659, 681 and 707 nm peaks are the vibronic bands of the NV^- centre with its ZPL at 637 nm; and the 715 and 725 nm peaks are the vibronic bands of the 700 nm centre with its ZPL at 700 nm.

Ib diamond, which exhibited very strong photoluminescence. PL spectra of brown diamonds show a large variety of emissions; a typical PL spectrum for olive-brown diamonds is given in *Figure 7* (red trace). Most peaks observed in brown diamonds have been described before, but some features present in CO_2 and 'Pseudo-CO_2' diamonds have not been described. Many of these emissions have been ascribed to brown diamonds but not explained so far (see for example Smith *et al.*, 2000). The NV^- centre peak at 637 nm was present in most samples, but except for the type Ib diamond, it was very weak. After HPHT treatment, all type Ia samples (except the CO_2 and 'Pseudo-CO_2' diamonds) showed PL spectra characteristic for type Ib diamonds with a very strong NV^- emission at 637 nm and peaks at 659 and 680 nm (*Figure 7*, blue trace); in contrast, the NV^- emissions in sample 7, the Ib diamond, were reduced. Some of the most interesting findings were made in the spectra of sample 10: besides distinct NV^- centres, the HPHT treatment resulted in a system with peaks at 700, 715 and 725 nm with an additional weak feature at 926 nm (*Figure 7*, blue trace).

Except for the reduction of certain emissions, no dramatic changes were observed in the PL spectra of the CO_2 and 'Pseudo-CO_2' diamonds. *Table V* summarizes all noted changes in the PL spectra of the analyzed samples.

Discussion

The results of the HPHT treatment of seven brown diamonds indicate that they may be divided into at least two groups with distinctly different origins of colour. These include diamonds coloured by plastic deformation with an associated defect, and diamonds owing their brown colour to other defects such as solid CO_2 (Schrauder and Navon, 1993) or hydrogen (Massi, 2003). In the diamonds coloured by plastic deformation the brown colour is reduced by HPHT treatment while the treatment has little effect on other brown diamonds. The same conclusion can be drawn from fluorescence behaviour and from spectroscopic analysis: the observations and the interpretations are discussed in detail below.

FTIR spectroscopy

On treatment, changes in the aggregation state of nitrogen were observable; typically, B-aggregates increased at the expense of the A-aggregates, while single N atoms (C centres) were transformed into A- and even B-aggregates. It appears surprising that such changes in aggregation occur under the

HPHT conditions used in our experiments since A to B centre aggregation has been predicted to occur at temperatures of >2600°C (Kiflawi and Bruley, 2000), clearly above 2000°C. To explain the enhanced nitrogen aggregation in treated brown diamonds it may be proposed that aggregation at temperatures around 2000°C may be more likely with high concentration of dislocations and other defects in the brown diamonds; this is supported by the fact that the two diamonds not associated with plastic deformation did not show any apparent change of nitrogen aggregation. A similar effect has been described by Collins *et al.* (2000) who reported that A-aggregates could be formed in type Ib synthetic diamonds at temperatures as low as 1500°C, when the stones were irradiated prior to heating (vacancy-enhanced aggregation phenomenon). The temperatures indicated for the formation of A-aggregates from single nitrogen in untreated synthetic diamonds are in the proximity of 2000°C (Chrenko *et al.*, 1977). The changes in nitrogen aggregation have limited influence on the observed colour changes; the production of single nitrogen and of N3 aggregates by A to B centre aggregation or dissociation of A centres induce a yellow colour; unless elevated amounts of single nitrogen are produced, the main change of colour is not caused by nitrogen, but by a distinct H3 centre, which causes strong yellow colour and green luminescence.

The amber centre absorptions found between 4070 and 4165 cm^{-1} are one of the main features of interest. Apparently, the amber centre is very closely related to the defect responsible for the brown coloration of diamonds, and Hainschwang (2003) and Massi (2003) have found that it could be correlated either with the presence of single N atoms (C-centres) or with A-centres; B-centres were found not to be involved in this defect, since pure type IaB brown diamonds do not exhibit the amber centre. Also, since type IIa diamonds do not show this absorption, the defect is nitrogen-dependent. The absorption has only been observed in brown to olive diamonds (both coloured by 'graining') or stones showing a brown to olive component, and it can be assumed that the defect responsible for the brown and olive colours is a component of the amber centre; thus the A centre or the single nitrogen combined with the defect, which is responsible for the brown colour, could possibly cause the amber centre absorption. Thus, if, the brown colour is indeed caused by graphitic or amorphous carbon, a combination of this sp^2 bonded carbon with the A or C centres may cause this feature; recrystallization of the sp^2 carbon into sp^3 carbon by HPHT treatment would accordingly eliminate the amber centre peaks, which would explain our findings. Another point to consider is one raised by Massi (2003) who reports that EPR measurements have indicated that the 4165 cm^{-1} absorption could be due to a deformed A-aggregate.

Vis/NIR spectroscopy

The increased absorption due to the H3 centre and the appearance of absorption due to H2 are well known effects of HPHT treatment. In our samples, weak to strong absorptions due to H3 and H2 were shown by all treated stones except the CO_2 and 'Pseudo CO_2' diamonds. The appearance of the absorptions H2, which is the negative charge state of the H3 centre, is believed to be caused by an electron transfer from single substitutional nitrogen to H3 centres (Buerki *et al.*, 1999). During HPHT treatment, substantial amounts of single nitrogen appear to be produced either as a by-product of the formation of B from A centres or simply by dissociation of the A-aggregates. The N3 absorption at 415 nm, which was generally weak or even undetectable before treatment of the brown diamonds clearly became more distinct. Most interesting is the fact that the type Ib diamond, which on treatment was transformed into a IaA/B stone, then exhibited a rather strong N3 absorption; the N3 aggregates were apparently formed as an intermediate product of A- to B-aggregation, as suggested by Kiflawi and Bruley (2000). The N3 absorption confirms our observation of the transformation from type Ib to type

IaA/B by HPHT. The vibronic structure between 585 and 618 nm has been observed by Shigley and Fritsch (1993) in a red diamond and has been interpreted as the vibronic structure of the 550 nm band. The formation of this structure in a formerly type Ib diamond, which originally showed a weak 550 nm band caused by the NV^- centre, is surprising and remains unexplained. The general formation of N3 and H3 has some influence on the observed colour; N3 will add pale yellow and a blue luminescence while H3 will add yellow and a green luminescence. The H2 absorption, if sufficiently strong, will give a green hue to a diamond (Collins *et al.*, 2000); none of our samples had strong enough H2 absorptions to exhibit a green face-up colour (which is not caused by H3 emission).

Photoluminescence spectroscopy

Photoluminescence spectra have clearly shown that significant amounts of single nitrogen were formed in the type Ia diamonds by the HPHT process, although this was not detected by FTIR spectroscopy. All stones which showed typical 'brown diamond PL spectra' before HPHT exhibited spectra characteristic of type Ib diamonds post HPHT; thus a very strong Ib character in PL, with strong NV^- and weak NV^0 emission, is typical for most of such treated diamonds. In the type Ib diamond, the NV^- centre emission was reduced due to the formation of A- and B-aggregates from single nitrogen atoms. The emission system with the zero phonon line (ZPL) at 701 nm and associated vibronic replicas at 715 and 725 nm plus the additional weak feature at 926 nm formed in sample DUG 10 *(Figure 7)* was identified by Iakoubovskii and Adriaenssens (2001) in natural hydrogen or nitrogen rich type Ia diamonds from Argyle, Australia. The 701 nm centre was tentatively assigned to a nickel-related defect. The same features were found by one author (TH) in similar Argyle stones and in chameleon diamonds. However, the PL spectra observed in the natural Argyle diamonds are very different and do not show strong 575 and 637 nm peaks. The appearance of these spectra following HPHT may indicate that this centre is due to a nickel nitrogen defect; single substitutional nickel atoms are commonly bound to nitrogen atoms as found from annealing experiments of nickel-containing synthetic diamonds by Lawson and Kanda (1993).

Conclusions

Conclusions from the studies of the classification and origin of colour of brown diamonds indicate that there are four possible causes of the brown colour in natural diamonds: deformation with associated defect, CO_2+ 'Pseudo CO_2', high single nitrogen with associated defects, and hydrogen. Also, the absorption complex known as the amber centre is directly correlated with the cause of the brown colour in plastically deformed diamond; this feature is thus most important for the determination of the defect responsible for the colour in these stones.

From a gemmological standpoint, it can be stated, that a diamond with a type IaA/B infrared spectrum with an apparently unusually weak platelet peak and a 'type Ib' PL spectrum with 637 nm >> 575 nm, may be strongly suspected of having undergone HPHT treatment. If additionally, H2 absorption is visible in the Vis/NIR spectrum, HPHT treatment must be assumed. In the experience of the authors the presence or absence of the H3 absorption cannot be used as an indication for the HPHT treatment.

A PL spectrum with a 'type Ib' character, with the 701 nm centre and vibronic sidebands at 715 and 725 nm, plus a 926 nm absorption has not so far been observed in an untreated diamond.

In rare cases, especially at higher annealing temperatures of 2400° to 2500°C, we observed 1344 cm^{-1} peaks due to single substitutional nitrogen together with A- and B-aggregates, even at standard resolution of 4 cm^{-1}; the presence of all three A, B, and C

centre absorptions in one stone, although mentioned as a personal communication in a paper by Collins (2000), seems extremely unlikely in natural green to yellow to orange diamonds, and again, could be an indication of a treated stone. Some very rare and unusual diamonds exhibiting A, B and C-centres and H2 absorption have been identified by Hainschwang, Notari and Fritsch (in prep.) but these stones have properties very different from those shown by diamonds treated by HPHT.

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Describing diamond beauty – assessing the optical performance of a diamond

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Abstract: *A diamond's optical performance is the visual interaction of the diamond reflecting and refracting the surrounding light to the viewer. It is this performance of the diamond that results in its beauty. This work advances the idea that the best diamond cuts 'evolved' to have the highest optical performance in a variety of typical viewing and illumination circumstances.*

Current and historical descriptors of diamond beauty and performance are reviewed. The rationale is put forward for the need to augment the current, single, quantitative measure of brilliance - light return intensity with the qualitative aspect of 'contrast brilliance'. Contrast brilliance is explained, and illustrated with diamond photography. The relationship between contrast brilliance and scintillation is also examined.

Introduction

When a gemmologist or appraiser evaluates a diamond, it is rated in four categories: cut, colour, clarity and carat weight. Known as the '4 Cs', these characteristics, which are related to the diamond's beauty and rarity, are assessed when arriving at its value. Of the four Cs there is general agreement that cut has the greatest influence on the diamond's beauty. The term cut may bring to mind any of three features of a polished diamond.

1. Shape such as round, pear, oval, cushion or rectangular.
2. Style of facet pattern such as radiant, step cut or princess cut.
3. The angles and proportions of a particular style and shape.

This article confines the meaning of cut to the angles and proportions of a particular shape and style of a diamond, such as the familiar 57-facet round brilliant.

There are several elements to the quality of cut. Judgement of these elements falls in two distinct categories.

The first category is craftsmanship. Examples of craftsmanship are perfection of polish, facet meet points, facet alignment, symmetry, facet angles and proportions. Most grading of diamond cut being done today makes judgements that fall within this category.

The second category is an assessment of the extent to which all the various factors of craftsmanship have or have not actually resulted in a beautiful diamond. This category is 'direct assessment' of aspects of diamond beauty as opposed to the indirect assessments of beauty in the first category. Two important examples that fall in this second category are measures of brilliance and fire.

The quantity together with the 'quality' of the light returned from a diamond to the eye of the viewer is critical to the viewer's judgement of the diamond's performance and beauty.

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Diamond beauty – brilliance, fire and sparkle

A well-cut diamond has the ability to reflect colours and light from a broad range of surrounding directions and angles. A well-cut round brilliant diamond reflects and refracts the surrounding panorama of light to the viewer in a mosaic – even artistic – composition possessing vibrancy and vitality.

This article refers to the visual interaction of the diamond reflecting and refracting the surrounding light to the viewer as the diamond's 'optical performance'. This optical performance results in the diamond's beauty. The beauty that results from this unique performance has stirred emotions and engendered devotion unsurpassed by any other gemstone.

Historical and contemporary terms describing diamond beauty

Brilliance, fire and scintillation (sparkle with movement) are three words that have evolved to describe diamond beauty. These are the terms currently used in the diamond industry by gemmologists, diamond cutters and sellers to convey aspects of diamond beauty with simplicity and clarity.

The most beautiful diamonds have 'the most vivid fire and the greatest brilliancy,' proclaimed Marcel Tolkowsky (1899-1991), the historically influential Belgian diamond cutter and mathematician who was credited with the key design proportions of the ideal round brilliant. Both he and his contemporaries used these two terms, brilliance and fire, to describe the beauty of a diamond. The third descriptor of diamond beauty called scintillation has since been added.

Combined with 'contrast brilliance', a related fourth aspect of diamond beauty introduced by this article, the jeweller is armed with the necessary vocabulary to convey the beauty of one diamond cut compared to another.

Brilliance

The *Diamond Dictionary* (Gaal, 1977) defined brilliance as: 'the intensity of the internal and external reflections of white light to the eye from a diamond or other gem in the face up position.' It is important to note here that brilliance was being defined as the intensity of light return. This 'brightness' measure which is a single value lacks any detail of the important variations in intensity across the diamond. This intensity variation or 'contrast' is needed to complete the picture of the historical meaning of brilliance.

Fire

Called the diamond's fire, an important aspect of the quality of light return is the diamond's dispersion of light into rainbow colours.

Scintillation or sparkle

Characterization of diamond beauty by fire and brilliance leaves all features other than fire as aspects of brilliance. A definition of brilliance narrowed to the single quantitative measure of average brightness necessitates additional descriptors of other quality aspects of diamond brilliance.

Scintillation is one such descriptor. Scintillation is the word used to describe a quality aspect of brilliance historically referred to as the diamond's 'life'. It is the diamond's sparkle occasioned by movement of the diamond, the illumination or the observer. This quality of light return is the sharp, on-off, bright-dark sparkle or flashes of light 'dancing' from the crown of the diamond.

These three terms used today to describe diamond beauty - brilliance, scintillation and fire - were the respective qualities that Tolkowsky noted in *Diamond Design* (Tolkowsky, 1919, p.24). He said: "The general trend of European diamond polishing is the constant search for greater brilliancy, more life, a more vivid fire in the diamond, regardless of the loss of weight." These are the qualities that diamond cutters of his day were seeking in their search for the most beautiful diamond cut. Maximizing these qualities of diamond beauty has remained the goal of diamond cutters from that time to the present.

Contrast quality of brilliance

In addition to scintillation, another descriptor is needed to augment the single, quantitative definition of brilliance as average brightness.

Why is this additional descriptor of brilliance needed? Human perception of brilliance goes beyond the brightness of the light returned from the crown of a diamond.

Figure 1: *Photograph of a scene printed with less contrast.*

Figure 2: *Photograph of* Figure 1 *printed with greater contrast.*

Intensity variation or contrast in light and dark areas across the diamond gives it an aspect of brilliance that has been described as 'snappy', 'dramatic' and by Bruton (1978, p.227) as 'hard' or 'sharp'.

These descriptions are the opposite of 'watery' and 'glassy' used in The Diamond Dictionary (Gaal, 1977) to describe the weak appearance of a poorly cut, 'fish-eye' diamond.

In this article the term 'contrast brilliance' is adopted to describe this aspect of brilliance. The term is needed because this aspect of diamond beauty influences our judgement of which diamond cuts are the most brilliant. Recognizing this contrast aspect of brilliance gives us a means for explaining why one diamond cut may be perceived as less brilliant than another even though it may have had an equal or greater average brightness.

It is worth noting that an emerald cut diamond is normally perceived to be less brilliant than a round cut mainly because it has less contrast brilliance even though it may have a similar brightness.

A second need for introducing contrast brilliance involves its relationship to scintillation. Scintillation will be shown to be the dynamic form of contrast brilliance. Because of its dynamic nature, scintillation eludes measurement, while contrast can be measured from static diamond images. The relationship between contrast and scintillation enables an assessment of both, through the characteristics they have in common.

Simultaneous contrast

The contrast aspect of brilliance is linked to a property of human vision called 'simultaneous contrast'. When a bright reflection is close to a darker one, our vision enhances the perception of the difference, and the bright reflection looks brighter because of its proximity to the dark reflection. The greater the contrast in a diamond, the brighter it appears to our eye.

One consequence of this phenomenon is our attention to variation or contrast in a scene. For example, we are generally attracted to greater contrast in a picture. Note the example in *Figures 1* and 2. Most people would agree that the greater contrast in *Figure 2* makes the photograph more appealing.

The following experiment is designed to illustrate and support the idea that contrast in a diamond influences the perception and

judgement of brilliance. The diamond image in *Figure 3* was printed with maximum contrast. The same diamond image in *Figure 4* was printed with less contrast between the bright reflections and the adjacent dark reflections.

Using the current quantitative definition of light return intensity, the *Figure 4* image would emerge as having the greater brilliance. However, we would probably all perceive the *Figure 3* diamond image as more brilliant. The perception of greater brilliance in *Figure 3* is due to the white reflections in that diamond appearing brighter and more intense because of greater contrast with the dark reflections. Actually, the white reflections in both *Figures 3* and *4* have the same intensity.

This demonstration illustrates and supports the influence and importance of contrast to the perception and judgement of brilliance.

Figure 3: Diamond image printed with maximum contrast; it has a lower light-return intensity than the image in Figure 4.

Dependence of diamond beauty upon viewer and illumination circumstances

Both the brightness and contrast aspects of brilliance depend not only upon the cut of the diamond, but also its illumination and viewer circumstances.

Figures 5 and *6* are two photographs of the same diamond illuminated in different ways. In *Figure 5* the diamond was uniformly illuminated from above with no obstruction from the presence of the viewer. This resulted in a diamond image with high light return intensity but low contrast. This type of uniform illumination, lacking contrast, results in an unfamiliar and undesirable diamond appearance, which also lacks contrast.

The illumination of the diamond in *Figure 6* consisted of high contrast lighting. As a result this particular diamond cut exhibited a high contrast aspect of brilliance.

Figures 5 and *6* have demonstrated that the brightness and contrast aspects of brilliance are interrelated with the diamond's illumination. It is often overlooked that the perception of diamond beauty in all its aspects is influenced by the character of the illumination.

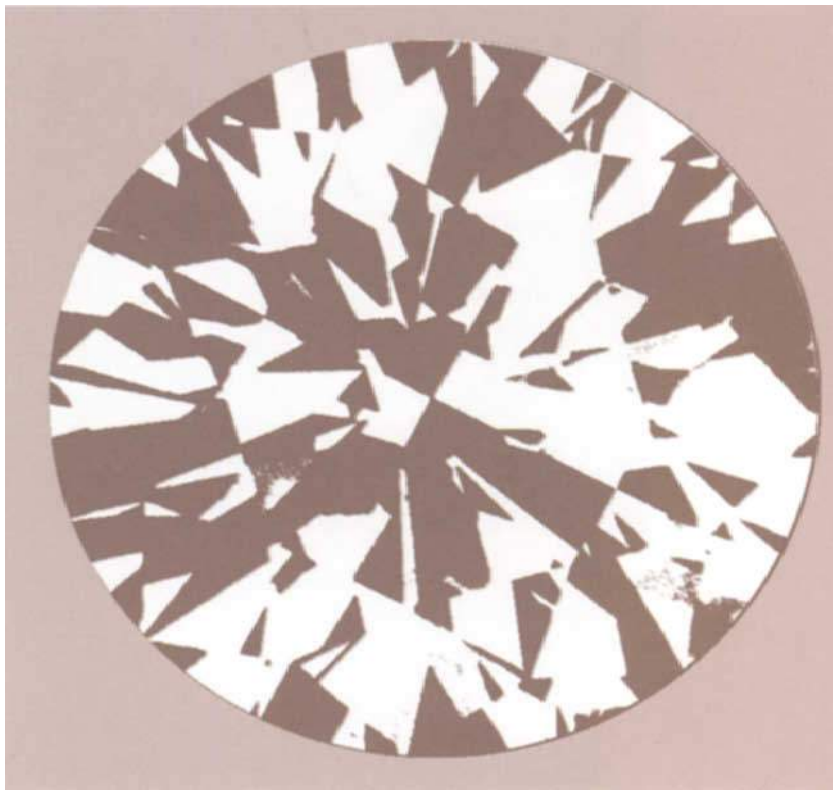

Figure 4: Diamond image printed with less contrast but a greater intensity of light return than that in Figure 3.

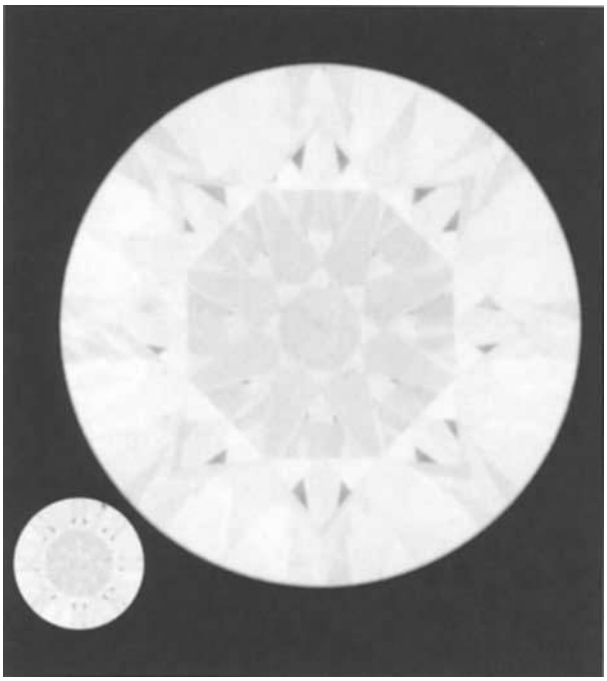

Figure 5: Diamond exhibiting high light return brilliance but low contrast brilliance.

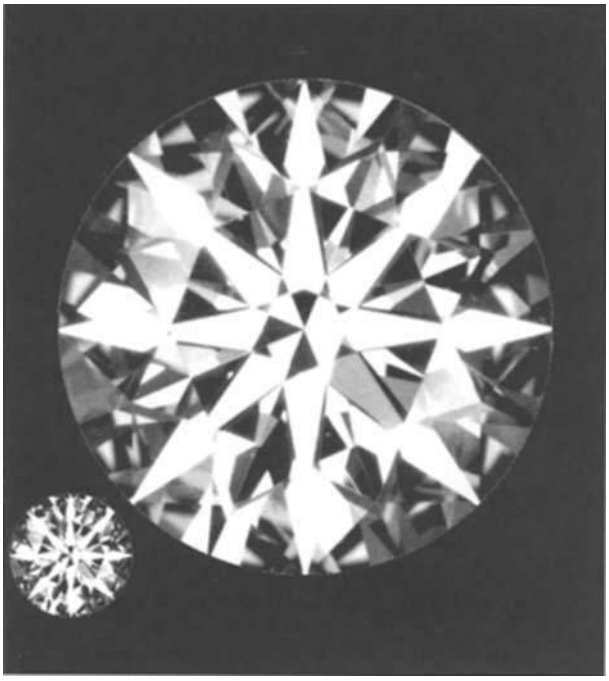

Figure 6: Same diamond as that in Figure 5 *exhibiting high contrast brilliance.*

It is crucial to note that the perception that a diamond is beautiful depends upon the ability of the cut to take full advantage of the lighting under which it is being viewed.

Evolution of excellence in diamond cutting

The development of diamond cutting judged most beautiful evolved through 'cut and try' experimentation. Because success was judged under standard or typical illumination (discussed below), which was not uniform, the finest cutting inevitably evolved to have the greatest beauty in those typical viewing and non-uniform illumination circumstances.

This article advances the idea that diamond cuts judged to have ideal optical performance and beauty possess brighter, more evenly distributed, higher contrast reflections in a variety of typical illumination circumstances.

The worth of a measure of diamond beauty depends upon how well it agrees with human judgement.

'Perception of beauty is everything.' To be meaningful, measurements of diamond beauty should be made in illumination typical of circumstances in which human judgement of that beauty is made. Measurements of beauty in atypical lighting can give high scores to cuts that have lower scores in typical illumination. For example, measurements of brilliance in uniform lighting (such as that illuminating the diamond in *Figure 5*) can give high brilliance scores to cuts that have lower perceived brilliance in typical illumination.

Typical illumination and viewer obstruction

There is a short list of key characteristics of typical viewing circumstances that has influenced the evolution of the most beautiful and highest performing diamond cuts. One key, ever-present feature of typical viewing circumstances is the influence of the presence of the viewer on the illumination of a diamond.

Although this 'viewer obstruction' at first sounds disadvantageous, in well-cut diamonds it most often adds contrast to the illumination that is favourable to beauty. That same viewer obstruction results in poor optical performance in a badly cut diamond. For

Figure 7: Face-up photograph of a 2.25 ct diamond exhibiting brilliance and blue fire occasioned by bright, overcast sky partially obscured by the viewer.

Figure 8: The pattern of illumination of the diamond in Figure 7 *as seen mirrored in the ring's prong. The overcast sky is partially obscured by the silhouette of the viewer's head, torso and outstretched hand and arm.*

Figure 9: Tilted round brilliant cut diamond displaying fire and contrast brilliance under the partially obscured illumination of bright, overcast sky.

Figure 10: Face-up view of a round brilliant cut diamond displaying fire and contrast brilliance under the partially obscured illumination of bright, overcast sky.

example, in *Figures 7, 9* and *10*, where there is open sky illumination, it is the viewer obstruction that introduces contrast to otherwise diffuse illumination. This illumination is seen mirrored in the ring's prong in *Figure 8*. The prong acts as a convex mirror reflecting the entire panorama of illumination.

The dark appearance of the viewer in the prong is the factor providing the primary contrast in illumination. It is the synergy of the diamond's cut taking advantage of this contrast in illumination that produces the contrast and fire present in the diamonds in *Figures 7, 9* and *10*. Without contrast in its

illumination even the best diamond cut will lack contrast brilliance and fire, as *Figure 5* demonstrates.

The factors that characterize this contrast quality of brilliance are the sharpness, number, sizes and uniformity of the distribution of the diamond's mosaic-appearing pattern of reflections.

How can we assess this contrast aspect of brilliance?

The answer is simple. All these aspects may be observed and evaluated from stationary images or 'snapshots' of a diamond under a representation of typical viewing and illumination circumstances. Because diamonds are most often viewed in the face-up position, the most important snapshot to examine for contrast brilliance is this normal, face-up view (see *Figure 10*). Snapshots at other angles of observation representing usual tilts of the diamond also need to be examined.

Relationship between the contrast quality of brilliance and scintillation

What is the difference between contrast brilliance and scintillation? Clearly, the diamond's mosaic pattern of reflections has aspects common to both contrast and scintillation such as those already mentioned. However, the contrast quality of brilliance is the diamond's 'static contrast', whereas scintillation is the 'dynamic contrast' due to movement. Contrast brilliance is one frame or snapshot of the moving picture of scintillation. In fact, the change in contrast brilliance with movement from one moment to the next *is* scintillation. Contrast brilliance and scintillation are perceptually and mathematically related in this way. (Mathematicians may recognize scintillation as the partial derivative of contrast brilliance with respect to movement.)

Conclusions

These examples, illustrations and photographs support the need for the additional descriptor of contrast brilliance. Contrast brilliance complements the light return intensity aspect of brilliance, which is the current widely used definition.

Recognizing this stationary aspect of brilliance gives us a means for explaining why one diamond cut may be perceived as less brilliant even though it has an equal or greater intensity of light return.

The established language for describing diamond beauty includes the principal terms brilliance, fire and scintillation or sparkle. Contrast brilliance adds another dimension to the measure of brilliance, which is currently confined to the average brightness or intensity of light return. In addition, evaluation of contrast in snapshots of diamonds provides a way to deal with the more difficult to measure, dynamic aspect of scintillation.

Recognition and judgement of this additional quality aspect of brilliance helps complete our understanding of why one diamond cut is preferred over, and is seen as more beautiful than, another.

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Gem-quality musgravite from Sri Lanka

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Abstract: *Gemmological, chemical and spectroscopic properties of a transparent, gem-quality rough musgravite from Sri Lanka are presented. A detailed analysis of musgravite samples reveals that applying X-ray diffraction and/or electron microprobe analysis and/or micro-Raman spectroscopy are decisive in establishing the identity of this rare gemstone. The greyish-blue pebble of 1.42 ct consists of a musgravite crystal with lamellar inclusions of spinel. With refractive indices of 1.721 (n_e) and 1.717 (n_o) and a specific gravity of 3.61, the musgravite has an iron content of 0.91 wt.% FeO, while the spinel exsolution lamellae reveal higher amounts of 1.89 wt.% FeO.*

Introduction

Over the last few years, the gem island of Sri Lanka has supplied some new and extremely rare gem materials such as bromellite, serendibite and grandidierite (McClure and Muhlmeister, 2002; Schmetzer *et al.*, 2002, 2003). From all these gem minerals, only a limited number of faceted samples are known. Another gem species from Sri Lanka which could be placed on a list of extremely rare gem materials is musgravite, a beryllium-magnesium-aluminium oxide, which is chemically and structurally related to taaffeite. Both minerals, taaffeite $BeMg_3Al_8O_{16}$ and musgravite $BeMg_2Al_6O_{12}$, were originally regarded as polytypes of one single mineral species. Chemical and structural examinations proved the existence of two independent mineral species with different chemical formulae, unit cell dimensions, space groups and crystal structures (Schmetzer, 1983 a, b; Nuber and Schmetzer, 1983). Due to a recently published nomenclature, the two minerals are now regarded as so-called polysomatic members of the taaffeite group, in which taafffeite is designated as magnesiotaaffeite-2N'2S and musgravite becomes magnesiotaaffeite-6N'3S (Armbruster, 2002).

Since the discovery of the first taaffeite as a cut gemstone in 1945, faceted and rough taaffeites of gem quality have come predominantly from Sri Lanka, with only a few rare samples reported to come from Myanmar and Tanzania. In 1993 two faceted 'taaffeites', probably from Sri Lanka, weighing

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Figure 1: This water-worn pebble of 1.42 ct, size about 8.4 × 5.5 mm, represents the first rough gem-quality musgravite found in Sri Lanka.

Figure 2: Needle-like structures form a characteristic inclusion pattern in the musgravite pebble. Magnified 200 ×.

0.30 and 0.37 ct, were identified as musgravites by means of X-ray single crystal diffraction. The colour of this material was described as greyish-mauve with a greenish cast (Demartin *et al.*, 1993).

Because the difference in BeO content between taaffeite and musgravite is only 1.56 wt.%, similar physical properties such as refractive indices and specific gravity are observed for both mineral species. Due to the overlapping ranges of gemmological properties an examination by X-ray diffraction (powder or single crystal techniques) or a quantitative chemical analysis (e.g. by electron microprobe) was necessarily applied for an unambiguous distinction of musgravite and taaffeite. More recently, micro-Raman spectroscopy has also been found to be useful as a non-destructive routine technique for identification of both species (Kiefert and Schmetzer, 1998; McClure, 2001).

Subsequent to the first description of the two faceted samples by Demartin *et al.* (1993), a number of 'possible musgravites' were examined in gemmological laboratories and determined as taaffeites. In this search to find other musgravites of gem quality, to the knowledge of the present authors, the finds of only two faceted gemstones have so far been published, both of unknown provenance. These two stones of 0.60 and 0.36 ct, brownish-purple and greenish-grey respectively, were identified in the GIA Trade Lab and described briefly by Johnson and Koivula (1997) and by McClure (2001).

In addition to Sri Lanka, musgravite is known from a limited number of localities in only three countries: Australia, Greenland and Madagascar, as well as Antarctica (see the detailed compilation of data by Grew, 2002). The colour of the samples is described in the Musgrave Ranges, Australia (type locality) as pale olive green (Hudson *et al.*, 1967), at Casey Bay, Antarctica, as dark green (Grew, 1981; Grew *et al.*, 2000), at Dove Bugt, Greenland, as black (Chadwick *et al.*, 1993) and at Sakeny, Madagascar, as light grey to colourless (Rakotondrazafy, 1999). In these localities, musgravite occurs in high-grade metamorphic rocks and is not of gem quality.

The rough musgravite pebble of 1.42 ct to be described in this paper (*Figure 1*) was found among a group of mixed gem samples including some 'possible musgravites' which were submitted for examination to one of the authors (MB) by W. Molligoda, a gem collector residing in Kohuwela, Sri Lanka. According to the information obtained from Molligoda (pers. comm., 2003), the water-worn pebble was bought in 2000 and, most probably, came from the Horana area, which is about 37 km west of Ratnapura.

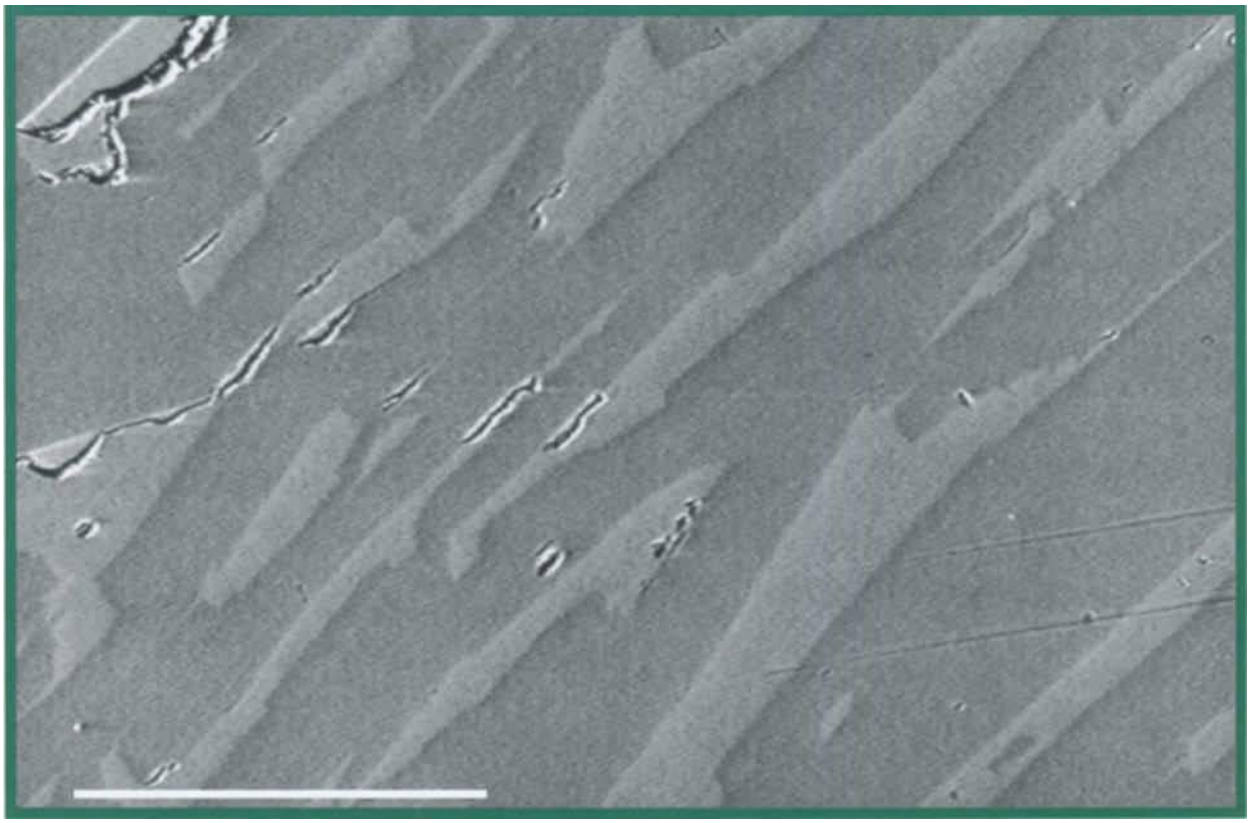

Figure 3: Back-scattered electron (BSE) image of spinel lamellae (pale grey) in a matrix of musgravite (dark grey); the length of the bar represents 200 μm.

Materials and methods

The water-worn pebble received for further examination and identification was provided with a polished window to measure refractive indices. Standard gemmological methods were used to determine refractive indices (RI), optic character, specific gravity (SG) and fluorescence under long- and short-wave ultraviolet radiation. Standard microscopic techniques were used to examine the internal features under different lighting conditions, both with and without immersion liquids.

To perform X-ray powder diffraction analysis a minute amount of material was scraped from the rough surface of the specimen. In order to obtain adequate resolution, a Gandolfi camera with a diameter of 114.6 mm and CuK_{α} radiation was used.

To further characterize the sample, a Cameca Camebax SX 50 electron microprobe was used to obtain 15 point analyses from a traverse across the polished window of the gemstone. In order to be sure of obtaining quantitative data of both the host and its inclusions (i.e. to analyse single mineral phases), the different points of the traverse were located by means of back-scattered electron (BSE) images. These are sensitive to composition, with darker greys indicating lower average atomic number elements and lighter greys, those of higher atomic number (see *Figure 3*).

Non-polarized UV-Vis (300-800 nm) absorption spectra were recorded using a Cary 500 Scan spectrophotometer. In addition, we analyzed the sample and its solid inclusions by laser Raman microspectrometry using a Renishaw 1000 system. Although it was impossible to recognize clear differences between the host and its inclusions by microscopic examination of the polished surface, we obtained different spectra of both phases using a simple trial and error procedure, by examining numerous points on the polished face.

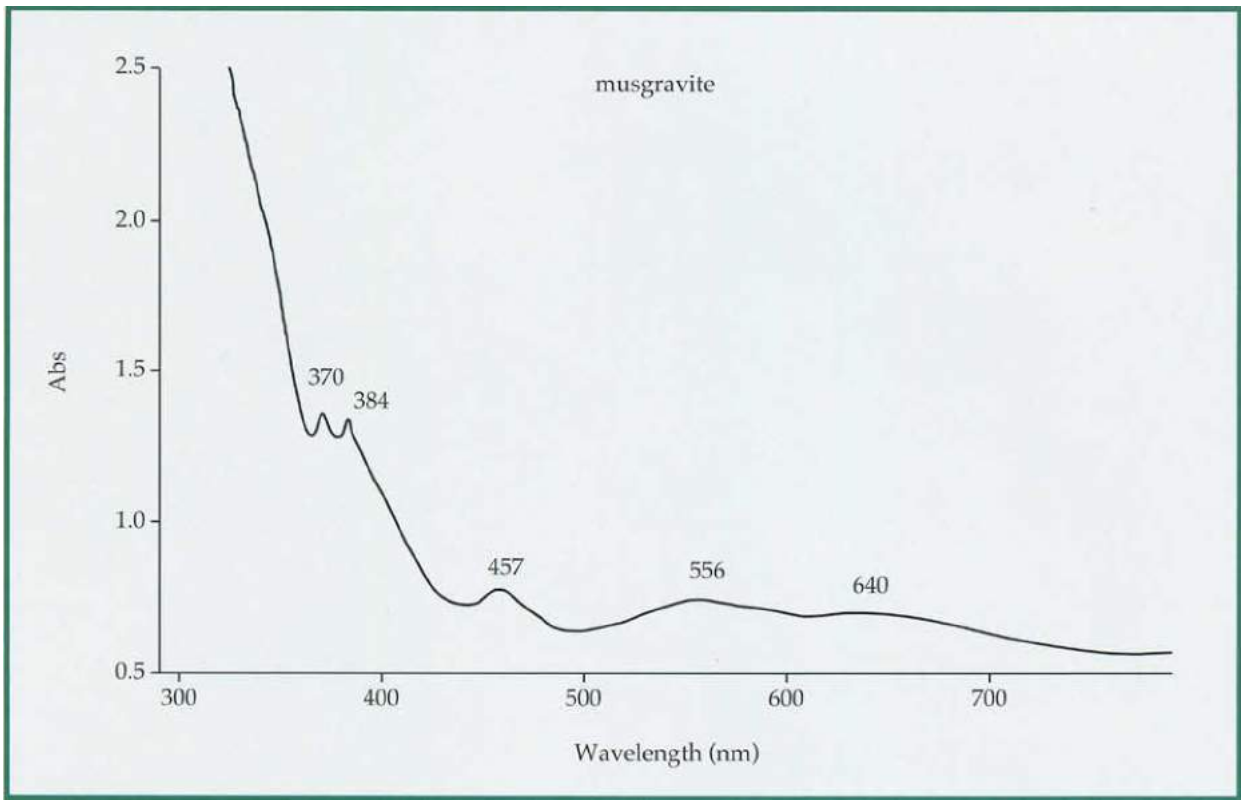

Figure 4: Non-polarized UV-Vis absorption spectrum of musgravite with lamellar spinel inclusions from Sri Lanka; direction of the incident beam is slightly inclined to the c-axis of the musgravite host.

Results

Gemmological properties

The colour of the transparent musgravite (*Figure 1*) is greyish-blue with a light green tint. The stone is uniaxial negative and showed clear RI readings with n_o 1.721, n_e 1.717; pleochroism was not detected. The SG was determined as 3.61. The sample was inert to both long- and short-wave UV radiation.

Features observed with the microscope

In the immersion microscope, an undistorted interference figure of an optically uniaxial crystal was observed with crossed polarizers. The optic axis is slightly inclined to the polished window of the water-worn pebble. In reflected light, the polished surface of the sample does not show any structures such as phase boundaries, which could indicate the presence of two different phases. However, by means of a differential interference contrast device, the presence of lamellar structures within the host is visible (compare *Figure 3*). In the gemmological microscope, using different lighting conditions with and without immersion, a special type of needle-like structure present throughout the whole stone (*Figure 2*), was detected. The exact nature of these needles has not yet been determined, but probably the needle-like pattern is related to edges or boundaries of the included spinel lamellae (see below).

X-ray diffraction

The powder pattern of the stone clearly indicates the presence of two mineral phases, namely musgravite and spinel. Additional lines that might indicate taaffeite were sought but not found.

Chemical composition

Although there are no clear optical differences between musgravite and spinel in reflected light, a back-scattered electron (BSE) image, obtained from the electron microprobe, revealed that the musgravite contains lamellar inclusions (*Figure 3*). Quantitative electron microprobe analyses of both phases, the musgravite host and lamellar spinel inclusions, are given in *Table I*.

No distinct chemical zoning was observed in either of the minerals analysed. In detail, the range of iron in the musgravite host is 0.88-0.93 wt.% FeO (9 point analyses) and 1.79-1.94 wt.% FeO for the lamellar spinel inclusions (6 point analyses of different lamellae). It is clear that the average iron content of the spinel is distinctly higher than that in the musgravite host. Only small traces of other transition metals, especially zinc, are present in both minerals.

UV-Vis spectroscopy

The non-polarized absorption spectrum of the sample is shown in *Figure 4*. The relative intensity and position of the strongest iron-related absorption maxima observed at 640, 556, 457, 384, and 370 nm are almost identical with the spectrum of gem-quality taaffeite and spinel from Sri Lanka (Schmetzer 1983b; Schmetzer *et al.*, 1989, 2000). It must be emphasized, however, that this spectrum represents a combination of the individual

Table I: Chemical composition of musgravite with lamellar spinel inclusions from Sri Lanka.

Oxide (wt.%)	Musgravite[c]	Spinel[d]
Al_2O_3	73.07	70.48
V_2O_3	0.01	0.01
Cr_2O_3	0.01	0.01
TiO_2	0.01	0.01
MgO	19.09	26.34
FeO[a]	0.91	1.89
ZnO	0.04	0.09
MnO	0.02	0.03
BeO[b]	6.00	–
Sum	99.16	98.86
cation proportions	based on 12 oxygens (assuming Be = 1.000)	based on 4 oxygens
Al	5.979	2.007
V	0.001	–
Cr	0.001	–
Ti	–	–
Mg	1.976	0. 949
Fe	0.053	0.038
Zn	0.002	0.002
Mn	0.001	0.001

a. Total iron as FeO.

b. Since beryllium is not detectable by microprobe analysis, the BeO figure has been calculated for 1 BeO per formula unit; for the theoretical composition of musgravite ($BeMg_2Al_6O_{12}$) an amount of 6.08 wt.% BeO is required.

c. Average of 9 point analyses using a Cameca electron microprobe.

d. Average of 6 point analyses using a Cameca electron microprobe.

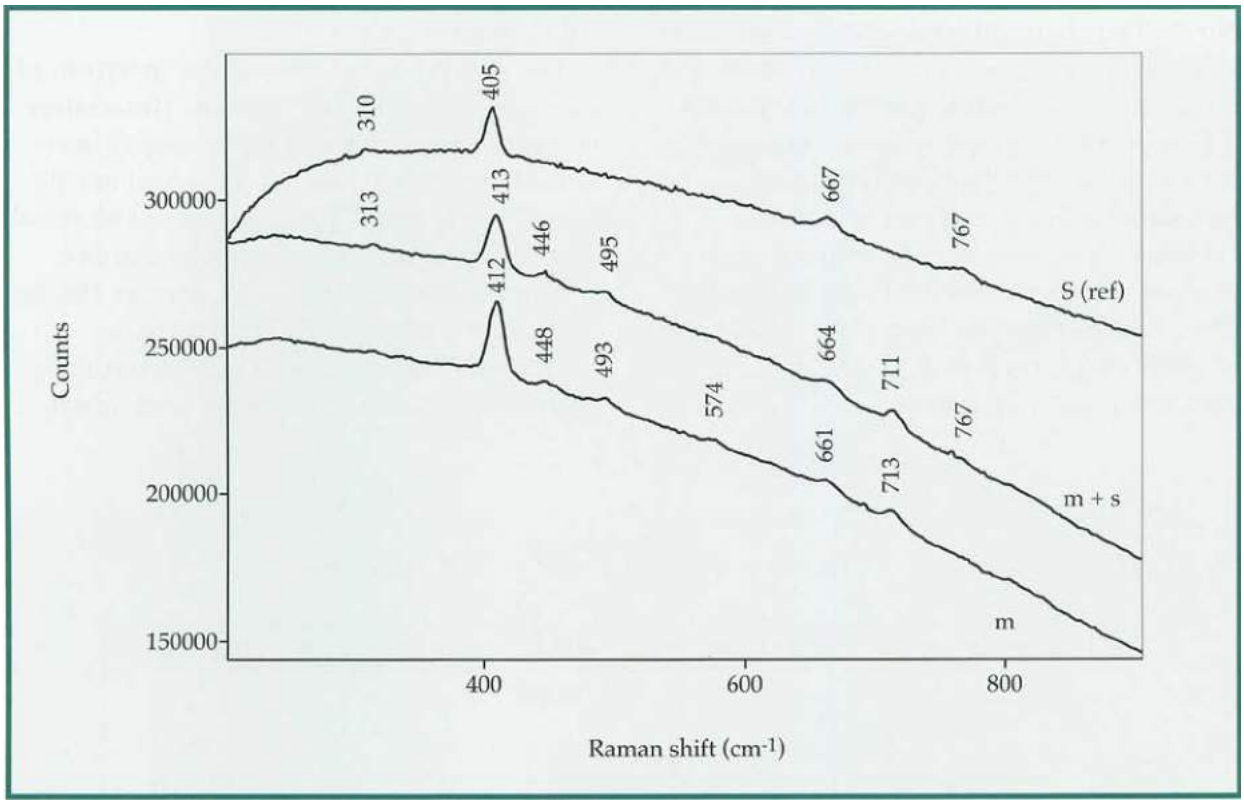

Figure 5: Raman spectra of musgravite (m), of a combination of musgravite and spinel (m + s), and for comparison, of a gem-quality spinel (s(ref)). The ordinate scale of Counts is arbitrary and the spectra have been moved vertically to avoid overlap.

spectra of the musgravite host and the lamellar iron-bearing spinel inclusions. Thus, it should not be quoted as a spectrum typical of pure musgravite.

Raman spectroscopy

The Raman spectrum of the musgravite host is almost identical with literature data (Kiefert and Schmetzer, 1998), with the strongest lines at 412, 448, 493, 574, 661 and 713 cm^{-1} (*Figure 5*). In several spectra taken at different points of the polished window, additional lines at 313 and 767 cm^{-1} were observed and these are due to the presence of lamellar spinel inclusions. Two Raman lines of spinel at 405 and 667 cm^{-1} overlap with those of musgravite. A Raman spectrum purely of spinel, i.e. without any characteristic lines of the musgravite host, was not obtained from this stone.

Discussion and conclusions

The various tests carried out on the transparent gem-quality pebble clearly indicate that it is another musgravite, albeit the first to be confirmed from Sri Lanka. This water-worn crystal fragment contains inclusions of lamellar spinel. Some of the data obtained represent properties of the pure host (refractive indices, chemical composition, Raman spectrum) or the spinel inclusions (chemical composition). Other data have to be considered as values representing combinations of various proportions of host and inclusions (specific gravity, colour, UV-Vis absorption spectrum, part of the Raman spectra). These data indicate how complex the results obtained from different highly sophisticated techniques may be and how it still may be necessary to combine several different analytical methods for an adequate identification and characterization of a gem.

At present, no definite distinction of musgravite and taaffeite in the field, i.e. by means of ordinary gemmological properties and without a detailed laboratory examination, is possible. Among the gem-quality musgravites known to date (*Table II*), four samples show a slight green tint, which has not been observed in taaffeite. Non-gem-

Table II: Physical and chemical properties of musgravites.

Gem-quality musgravites					
Weight (ct)	0.30	0.37	0.60	0.36	1.42
Faceted / rough	faceted	faceted	faceted	faceted	rough
SG	3.64	3.62	3.69	3.61	3.61
RI: n_o	1.726	1.725	1.728	1.726	1.721
n_e	1.720	1.719	1.721	1.719	1.717
Colour	greyish-mauve with greenish cast	greyish-mauve with greenish cast	brownish-purple	greenish-grey	greyish-blue with light green tint
X-ray diffraction	yes	yes	yes	yes	yes
Chemical analysis	no	no	yes	yes	yes
FeO[a] (wt.%)	n.d.	n.d.	present	present	0.91
ZnO (wt.%)	n.d.	n.d.	present	present	0.04
Raman spectra	no	no	no	yes	yes
Source / locality	Sri Lanka?	Sri Lanka?	collector	collector	Sri Lanka
Reference	Demartin *et al.* (1993)	Demartin *et al.* (1993)	Johnson and Koivula (1997)	McClure (2001)	this paper

Non-gem-quality musgravites*				
Location	**Musgrave Ranges, Australia**	**Casey Bay, Antarctica**	**Dove Bugt, Greenland**	**Sakeny, Madagascar**
SG	3.68			
RI: n_o	1.739	1.754		
n_e	1.735	1.744		
Colour	pale olive green	dark green	black	light grey to colourless
Colour in thin section	almost colourless	pale green	grey	
FeO[a] (wt.%)	7.14	8.92-12.13	6.76-7.89	1.98-2.42
ZnO (wt.%)	n.d.	4.65-5.18	3.20-4.47	n.d.
Reference	Hudson *et al.* (1967)	Grew (1981); Schmetzer (1983b); Grew *et al.* (2000)	Chadwick *et al.* (1993)	Rakotondrazafy (1999)

a. Total iron as FeO. n.d. = not determined. * See note (p. 288) added in proof.

quality musgravite is described as pale olive green, dark green, black or grey (see again *Table II*). These musgravites show higher iron and zinc contents than the gem material known from Sri Lanka or elsewhere – exact locality data are lacking for the faceted samples. Such differences in chemical composition are responsible for the higher refractive indices and, most probably, also for the different colours of non-gem-quality material.

For gem samples with typical gemmological properties of the taaffeite group of minerals, such as SG and RI, the slightly different colours of some musgravites might be a useful hint towards these species. An unambiguous determination of such samples, however, needs definite confirmation by X-ray crystallography and/or quantitative chemical analysis and/or Raman spectroscopy (Kiefert and Schmetzer, 1998; McClure, 2001).

Phase relationships in the BeO-MgO-Al_2O_3 system, especially along the chrysoberyl ($BeAl_2O_4$)-spinel ($MgAl_2O_4$) join, may be complex and are not completely understood. According to Kawakami *et al.* (1986), the two ternary phases along this join, namely taaffeite and musgravite, are incongruently melting compounds (for a new phase diagram of the pseudobinary system chrysoberyl-spinel see Franz and Morteani, 2002). At high temperatures, there is extensive solubility of $BeAl_2O_4$ and $MgAl_2O_4$. This high temperature compound, i.e. the Be-Mg-Al-oxide, exsolves taaffeite and/or musgravite and/or spinel with decreasing temperature. In other words: with decreasing temperature a homogeneous single phase may cool and transform into finely intergrown spinel and/or taaffeite and/or musgravite (see also Schmetzer *et al.*, 1999).

These known phase relationships may explain the composition differences and exsolution lamellae in the specimen described in this paper. A possible scenario is one where grains of a Be-Al-Mg-oxide with a composition close to musgravite, but with some excess of the spinel molecule were present at an elevated temperature in a high-grade metamorphic environment, which is typical for all known musgravite-bearing host rocks. With decreasing temperature, the grains of a high temperature phase referred to above would cool to a musgravite host with the excess of the spinel molecule present as exsolution lamellae.

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The authors are grateful to Dr O. Medenbach of Ruhr-University, Bochum, Germany, for obtaining X-ray diffraction data of several Be-Mg-Al-oxide minerals (taaffeite and musgravite). Professor E.S. Grew, University of Maine, Maine, USA, provided copies of special references and critical comments.

Note added in proof:

The authors have just received information about another occurrence of non-gem-quality musgravite at Costabonne Peak, Pyrenees, France. For further details see Schmetzer *et al.* (2005), *Neues Jahrbuch für Mineralogie, Abhandlungen (in press).*

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Iron- and zinc-rich gem-quality taaffeites from Sri Lanka

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Abstract: *Gemmological, chemical and spectroscopic properties of a semitransparent, gem-quality rough (water-worn) taaffeite crystal of 2.52 ct and of two transparent, faceted taaffeites of 1.48 and 0.30 ct from Sri Lanka were determined. The rough crystal was identified by X-ray single crystal diffraction and Raman spectroscopy. By electron microprobe analysis an extraordinarily high value of 5.62 wt.% FeO was determined. This high iron content is consistent with the high refractive indices and the high specific gravity of the taaffeite crystal. The two faceted gemstones were identified by Raman spectroscopy and electron microprobe analysis which revealed extraordinarily high zinc values of 8.87 and 5.27 wt.% ZnO. These high zinc contents are responsible for the high refractive indices and the high specific gravities of both taaffeites.*

Introduction

The taaffeite group consists of three independent mineral species, namely taaffeite, musgravite and pehrmanite (Armbruster, 2002). Only taaffeite and musgravite are known in gem quality, especially from Sri Lanka. Taaffeite, $BeMg_3Al_8O_{16}$, is a rare collector's stone, and musgravite, $BeMg_2Al_6O_{12}$, is considered as one of the rarest gem species known to date. Due to the similar chemical composition and crystal structure of taaffeite and musgravite (Schmetzer, 1983 a,b; Nuber and Schmetzer, 1983), the gemmological properties of these independent species overlap. Consequently, for an unequivocal determination of faceted gems of this group a combination of special physical techniques such as X-ray diffraction (powder or single crystal techniques) and/or quantitative chemical analysis (e.g. by electron microprobe) and/or micro-Raman spectroscopy is needed (see, e.g., Kiefert and Schmetzer, 1998; McClure, 2001; Schmetzer *et al.*, 2005).

Numerous localities in Sri Lanka are known as sources for gem-quality taaffeites (Gunawardene, 1984), but a correlation of individual properties and localities of origin has not been performed to date. Taaffeites from Sri Lanka, in general, contain minor amounts of transition metals, especially iron

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and zinc. The maximum values reported so far are 2.59 wt.% FeO and 4.66 wt.% ZnO; in red to purplish-red specimens traces of Cr_2O_3 are also present (Schmetzer, 1983b; Schmetzer and Bank, 1985; Schmetzer *et al.*, 2000). Gemmological properties of taaffeites such as specific gravity and refractive indices were found to be correlated with trace element contents of individual specimens (Schmetzer *et al.*, 2000).

In the course of a research project describing Sri Lankan gemstones of the taaffeite group (see Schmetzer *et al.*, 2005), the authors examined several samples with unusually high refractive indices. In order to exactly determine the mineral species and to understand the physical properties of these gem specimens, several different techniques to determine their physical and chemical properties were applied.

Materials and methods

The rough taaffeite crystal of 2.52 ct to be described in this paper (*Figure 1*) was purchased in 2004 by one of the authors (MB) in Sri Lanka. The sample was said to originate from a gem pit near the small village of Delwela, south-east of the town Karawita, which is located about 11 km south of Ratnapura. The water-worn 2.52 ct crystal from Sri Lanka already had a window polished on it to enable internal examination and to measure refractive indices.

The two faceted gemstones of 1.48 and 0.30 ct (*Figures 2* and *3*) were recognized by one of the authors (DPG) as members of the taaffeite group with special properties due to their high refractive indices and, thus, submitted for further examination. The 1.48 ct specimen originates from the Mudunkotuwa area, the 0.30 ct taaffeite from the Ratnapura area of Sri Lanka.

Standard gemmological methods were used for all three samples to determine refractive indices (RI), optical character, specific gravity (SG) and fluorescence under long- and short-wave ultraviolet radiation. Standard microscopic techniques were used to examine the internal features under different lighting conditions, both with and without immersion liquids.

Figure 1 (Specimen A): This water-worn crystal of 2.52 ct with pyramidal habit, size 5.9 × 9.1 × 4.9 mm, is a high ferrous iron-bearing taaffeite from Sri Lanka. The c-axis of the crystal is approximately north-south and its base (not shown) is a polished window.

Figure 2 (Specimen B): This faceted taaffeite of 1.48 ct from Sri Lanka, size 6.9 × 8.5 × 3.4 mm, has the highest zinc content known to date for gem-quality and non gem-quality taaffeites.

Figure 3 (Specimen C): This faceted taaffeite of 0.30 ct, size 3.9 × 4.6 × 2.6 mm, is a high zinc-bearing taaffeite from Sri Lanka.

Non-polarized UV-Vis (300-800 nm) absorption spectra were recorded using a Cary 500 Scan spectrophotometer. In addition, we analysed all three samples and their solid inclusions by laser Raman microspectrometry using a Renishaw 1000 system.

To perform X-ray diffraction analysis a small fragment of the rough 2.52 ct crystal was removed and examined with an Excalibur automatic single crystal diffractometer from Oxford Diffraction using MoK_{α} radiation, a graphite monochromator and a CCD-detector.

To further characterize the specimens, a Cameca Camebax SX 50 electron microprobe was used to obtain several point analyses from traverses across the polished window of the rough or the table facets of the two faceted gemstones.

Results

I. Iron-rich rough taaffeite of 2.52 ct

Gemmological properties

The water-worn 2.52 ct crystal (*Figure 1*) showed pyramidal habit similar to that in other water-worn taaffeite crystals reported from Sri Lanka (Kampf, 1991). Our sample was broken diagonally and, thus, showed only three complete and two broken pyramidal faces. At the opposite end to the pyramids and parallel to its basal face the sample is terminated by a polished face.

In the immersion microscope and using crossed polarizers, an undistorted interference figure of an optically uniaxial crystal was observed. The optic axis is slightly inclined to the normal of the polished window of the water-worn crystal. The stone is uniaxial negative and showed clear RI readings with n_o 1.732, n_e 1.726. The colour of the semitransparent (translucent) taaffeite is a very dark purplish violet and pleochroism was not detected. The SG was determined as 3.69. The crystal was inert to both long- and short-wave UV radiation.

Identification, X-ray crystallography and spectroscopy

The crystal was identified as taaffeite by a combination of X-ray single crystal diffraction and laser Raman microspectrometry. Unit cell dimensions were determined as 5.69 Å for a_o and 18.35 Å for c_o; they are consistent with known crystallographic data of taaffeite (Schmetzer, 1983b; Nuber and Schmetzer, 1983). The major peaks of the Raman spectrum of the specimen were also identical with the taaffeite data published by Kiefert and Schmetzer (1998), and Schmetzer *et al.* (2005).

The UV-Vis absorption spectrum of our specimen, although of somewhat low quality because of the low transparency of the taaffeite crystal, showed the known iron-related absorption bands of purplish violet samples of this mineral species (see, e.g., Schmetzer, 1983b; Schmetzer *et al.*, 2000). The absorption spectrum reveals several maxima in the green to red part allowing more transmission in the blue-violet range.

Features observed with the microscope

Under the gemmological microscope, using different lighting conditions with and without immersion, the taaffeite crystal appears extremely clean without major fractures or healing feathers. Only two small mineral inclusions are present: these were identified by laser Raman microspectrometry as feldspar (*Figure* 4) and as a carbonate mineral such as dolomite or magnesite.

Figure 4: Feldspar inclusion in iron-rich taaffeite crystal of 2.52 ct from Sri Lanka; magnification 200 ×.

Chemical composition

The results of electron microprobe analysis are presented in *Table I*. No distinct chemical zoning was observed in a traverse across the polished window of the sample. In addition to the principal components of taaffeite, Al_2O_3, MgO and BeO (which is not detectable directly by electron microprobe), the sample contains major percentages of iron. In addition, there are minor amounts of zinc and smaller traces of other transition metals such as chromium and manganese.

Theoretically, the oxide percentages obtained by electron microprobe (which cannot be used to determine the valence state of iron), can be calculated as cations for a formula with 16 oxygens (related to taaffeite) or for a formula with 12 oxygens (related to musgravite). For our specimen, a calculation for 12 oxygens would fit to a musgravite formula, but would require a high percentage of the iron present as Fe^{3+} (ferric iron). This indicates that for such a sample with high iron contents, the quantitative microprobe analysis alone is not always sufficient for an identification of the gem.

However, according to the results of X-ray crystallography and Raman spectroscopy, which both identified the sample as taaffeite, cation proportions were calculated for 16 oxygens per formula unit (*Table I*). The figures obtained are in good agreement with the theoretical formula of taaffeite, which – in addition to 1 Be per formula unit – requires 8 trivalent cations (Al, Cr, V) and 3 bivalent cations (Mg, Fe. Zn, Mn) per formula unit. The calculated values, 7.970 and 3.046 cations, respectively, indicate, that the larger percentage of iron is present as Fe^{2+} (ferrous iron) and only a smaller percentage of iron is present in the ferric state. A calculation of the taaffeite formula with both ferric and ferrous iron would require 0.30 wt. % Fe_2O_3 for our sample.

II. Zinc-rich faceted taaffeites of 1.48 and 0.30 ct

Gemmological properties

Both samples (*Figures* 2 and 3) are uniaxial negative with, compared to 'normal' taaffeites from Sri Lanka, relatively high refractive indices of n_o 1.735, n_e 1.730 (specimen B) and n_o 1.729, n_e 1.724 (C). The colours were a greyish violet (B) or light violet (C). Both stones were cut with the table facet almost perpendicular to the optic axis. Pleochroism is extremely weak in specimen B and invisible in C. The SG was determined as 3.78 for B and 3.69 for C. The two faceted taaffeites are inert to both long- and short-wave UV radiation.

Table I: Physical properties and chemical composition of iron- and zinc-rich taaffeites from Sri Lanka.

Physical properties

Specimen	A	B	C	D[a]
Locality	Delwela, Sri Lanka	Mudunkotuwa, Sri Lanka	Sri Lanka	Sri Lanka
Weight (ct)	2.52, rough	1.48, faceted	0.30, faceted	1.25, faceted
Size (mm) diameter height	5.9 × 9.1 4.9	6.9 × 8.5 3.4	3.9 × 4.6 2.6	6 × 7
Colour	very dark purplish violet	greyish violet	light violet	intense reddish violet
Specific gravity	3.69	3.78	3.69	3.71
Refractive indices n_o n_e	1.732 1.726	1.735 1.730	1.729 1.724	1.730 1.726
Birefringence	- 0.006	- 0.005	- 0.005	- 0.004

Chemical composition (microprobe analysis, average, wt.%)

Number of analysis points	13	20	15	5
Al_2O_3	70.58	70.13	71.05	71.10
V_2O_3	bdl	0.02	0.01	n.d.
Cr_2O_3	0.02	0.01	0.01	0.15
TiO_2	0.03	0.01	0.01	n.d.
MgO	17.74	15.63	17.80	17.69
FeO[b]	5.62	1.76	1.40	1.88
ZnO	0.82	8.87	5.27	4.66
MnO	0.05	0.06	0.04	0.06
BeO[c]	4.35	4.31	4.36	4.37
Sum	99.21	100.79	99.95	99.91
Sum of transition metal contents (wt.%)	6.54	10.73	6.74	6.75

Cation proportions based on 16 oxygens

Al	7.966	7.980	7.988	7.990
V	-	0.001	0.001	-
Cr	0.002	0.001	0.001	0.011
Ti	0.002	0.001	0.001	-
Sum trivalent cations	7.970	7.983	7.991	8.001
Mg	2.533	2.249	2.531	2.515
Fe	0.450	0.142	0.112	0.150
Zn	0.059	0.633	0.371	0.328
Mn	0.004	0.005	0.004	0.005
Sum divalent cations	3.046	3.029	3.018	2.998
Be	1.000	1.000	1.000	1.000

bdl = below detection limit n.d. = not detected

a. Schmetzer and Bank (1985).

b. Total iron as FeO.

c. Since beryllium is not detectable by microprobe analysis, the BeO figure has been calculated for 1 BeO per formula unit; for the theoretical composition of taaffeite ($BeMg_3Al_8O_{16}$) an amount of 4.52 wt.% BeO is required.

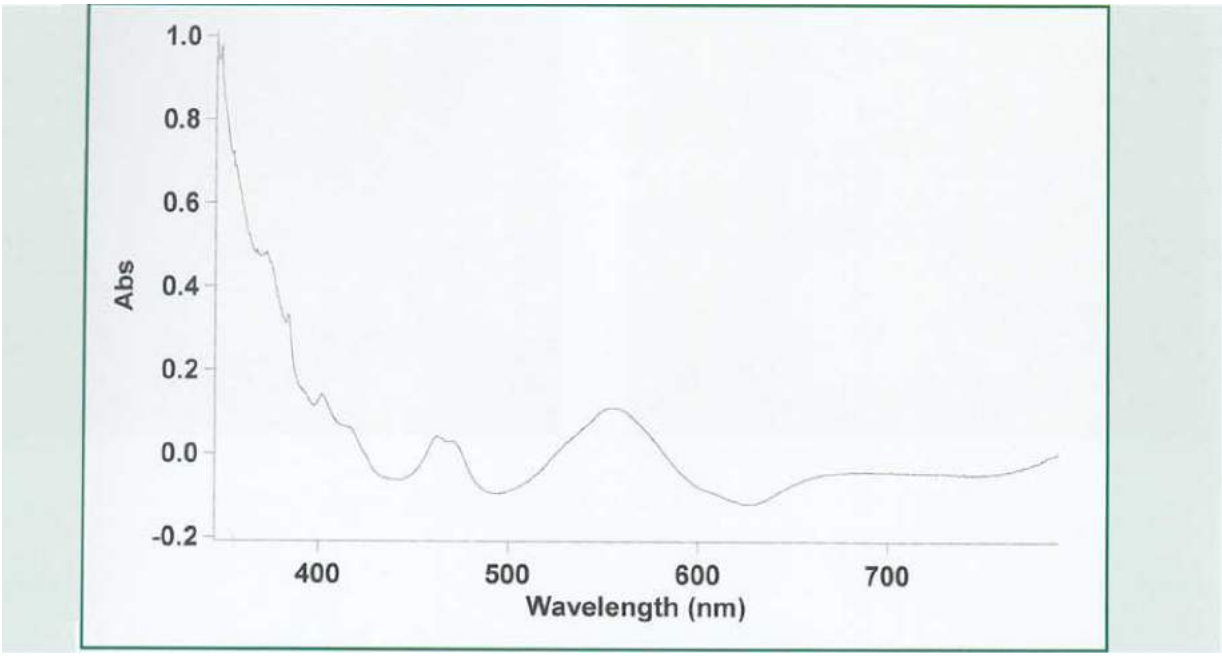

Figure 5: The non-polarized absorption spectrum of a zinc-rich taaffeite of 1.48 ct from Sri Lanka reveals the iron-related absorption bands consistent with those in low zinc-bearing taaffeite samples; the direction of the incident beam is almost parallel to the c-axis; the most characteristic absorption maxima are located at 555, 471, 462, 417, 402, and 370 nm.

Identification and spectroscopy

The major peaks of the Raman spectra of both stones are consistent with the taaffeite data published by Kiefert and Schmetzer (1998), and Schmetzer *et al.* (2005). Consequently, these results and the quantitative chemical data described later confirm identification of both faceted stones unequivocally as taaffeites.

Absorption spectra in the UV-Vis range (*Figure 5*) are identical with those of violet to greyish violet taaffeites from Sri Lanka with lower zinc contents as described by Schmetzer (1983b) and Schmetzer *et al.* (2000).

Features observed with the microscope

Both taaffeites are extremely clean gemstones. Specimen B contains a healed fracture with two-phase (solid and liquid) inclusions. The minute birefringent material in these cavities was too small for a determination by laser Raman microspectrometry. The smaller stone C revealed another healed fracture with similar appearance. The elongated negative crystals with multiphase fillings (either two-phase, solid and liquid, or three-phase, solid, liquid and gas; *Figure 6*) contain somewhat larger birefringent components (*Figure 7 a,b*). Any distinctive Raman peaks which these mineral inclusions may have shown were masked by an extremely strong continuous background fluorescence signal of the taaffeite host. In several taaffeites from Sri Lanka the birefringent inclusions in healed feathers have been determined as magnesite (Schmetzer *et al.*, 2000). Thus, since the minerals in the healed fractures of stones B and C are of similar appearance, they may also be magnesite.

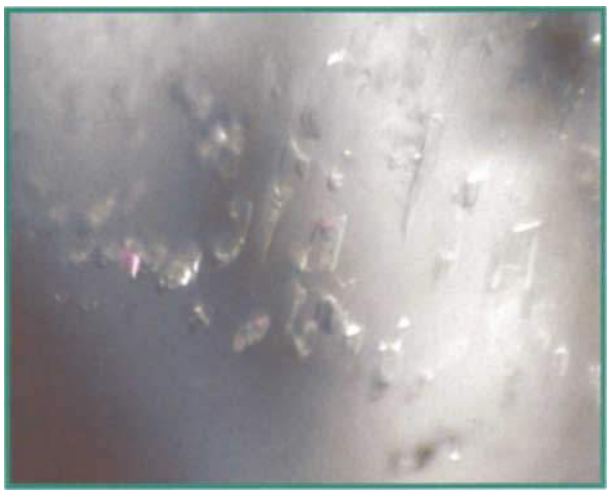

Figure 6: Negative crystals with multiphase fillings in zinc-rich taaffeite of 0.30 ct from Sri Lanka; magnification 100 ×.

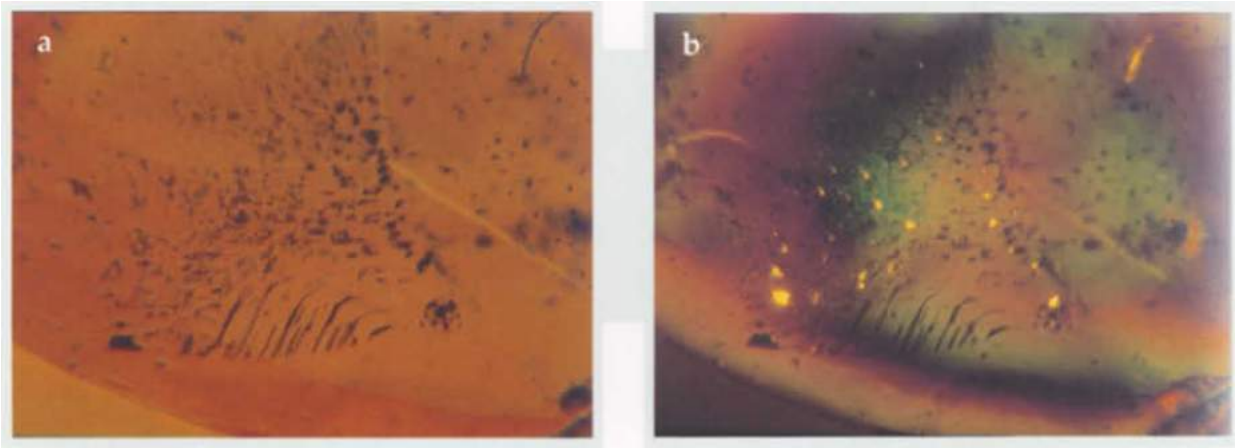

Figure 7: Healed fracture with multiphase inclusions in zinc-rich taaffeite of 0.30 ct from Sri Lanka (a); tiny birefringent crystals are visible with crossed polarizers (b). Immersion, magnification 80 ×.

Chemical composition

The two stones contain elevated zinc contents of 8.87 and 5.27 wt.% ZnO (*Table I*). These values exceed the highest zinc content of 4.66 wt.% ZnO measured to date in taaffeite from Sri Lanka (Schmetzer and Bank, 1985; see column D in *Table I*). Iron contents, on the other hand, are in the range frequently found in Sri Lankan taaffeites.

The chemical composition calculated according to the chemical formula of taaffeite for 16 oxygens atoms and 1 beryllium atom per formula unit is close to ideal cation proportions. The sum of trivalent cations is only slightly below the theoretical value of 8.000 and the sum of bivalent cations is slightly above the ideal value of 3.000. These data indicate that only a small fraction of total iron is present as Fe^{3+} with the majority of iron replacing magnesium as Fe^{2+}.

Discussion and conclusions

The various tests carried out on the semi-transparent gem-quality crystal and the two transparent faceted stones clearly indicate that all three gemstones are taaffeites. The refractive indices of our samples (n_o between 1.729 and 1.735, n_e between 1.724 and 1.730) as well as the specific gravities (3.69 to 3.78) are distinctly higher than normally found for gem taaffeites from Sri Lanka.

For numerous Sri Lankan taaffeites analysed, the iron values obtained to date have been distinctly lower with a maximum value obtained in one sample of 2.59 wt.% FeO (Schmetzer, 1983b; Schmetzer *et al.*, 2000). Zinc contents determined in taaffeites from Sri Lanka, in general, were up to 2.24 wt.% ZnO with one exception of 4.66 wt.% ZnO described by Schmetzer and Bank (1985). The values of this sample are quoted in *Table I*, column D, for comparison.
Our new data consequently expand the compositional range and the range of physical properties, e.g. specific gravity and refractive indices, known so far for gem-quality taaffeites from Sri Lanka. In addition to zinc-bearing spinel (gahnospinel) which has been known for a long time as gem material from Sri Lanka (Schmetzer and Bank, 1986), zinc-bearing taaffeite is another gem mineral from this country which shows an extensive isomorphic replacement of magnesium and zinc.

The zinc value of 8.87 wt.% ZnO determined for the faceted stone of 1.48 ct, represents the highest zinc content of gem-quality and non gem-quality taaffeites found to date. The zinc content of stone C of 5.27 wt.% ZnO is also considered as extraordinarily high for samples from Sri Lanka, but is not too different from the 4.66% ZnO in the stone analysed by Schmetzer and Bank (1985). A comparable high zinc content of 4.27 wt.% ZnO was determined for a taaffeite from Pitkäranta mining district, Lake Ladoga, Russia (Schmetzer, 1983b).

The iron content of 5.62 wt.% FeO in stone A is, up to now, considered as extraordinarily

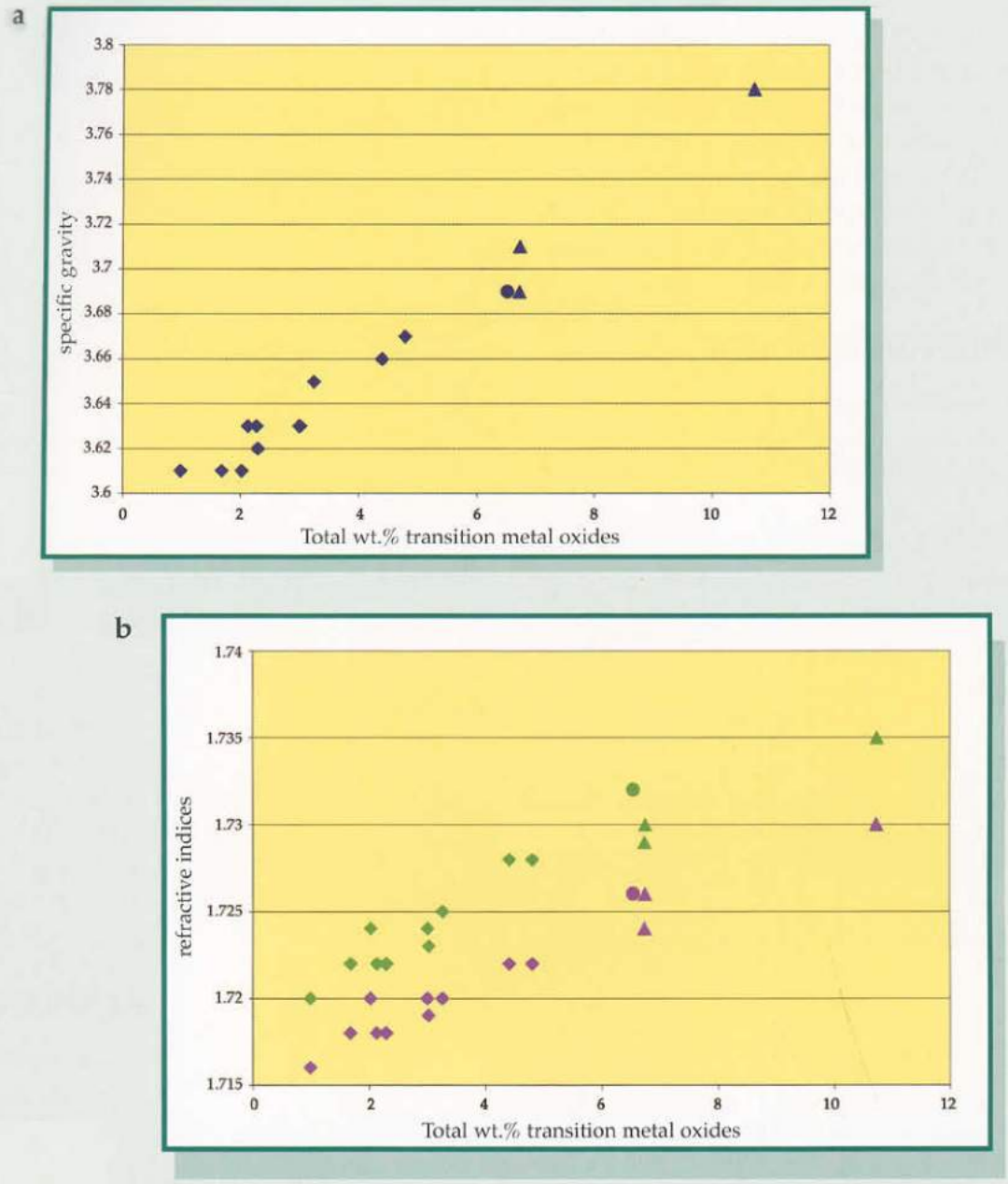

Figure 8 a,b: A correlation of the sum of transition metal contents (wt.% oxides) with specific gravity (a) and refractive indices (b) such as n_o (green) and n_e (purple) indicates the influence of chemical composition on gemmological properties of taaffeite samples from Sri Lanka; data from Schmetzer and Bank (1985), Bank and Henn (1989), Schmetzer et al. *(2000), and this paper. The specimens which are the subject of the present study are indicated by full circles (iron-rich taaffeite) or triangles (zinc-rich taaffeites).*

high for gem-quality taaffeites from Sri Lanka. Similar iron values, on the other hand, have already been obtained by electron microprobe from non gem-quality taaffeites from other localities, e.g. between 5.52 and 5.88 wt.% FeO for samples from China which also contained from 1.89 to 2.78 wt.% ZnO (Schmetzer, 1983b).

RIs and SGs of taaffeites from Sri Lanka are compared with the individual sum of transition metal contents (TiO_2 + V_2O_3 + Cr_2O_3 + MnO + FeO + ZnO) of different samples in *Figures 8a* and *b*. In addition to iron, higher zinc contents distinctly increase the refractive indices and specific gravity of taaffeite (Schmetzer *et al.*, 2000). The data obtained and plotted for the crystal (A) and the two faceted stones (B and C) are consistent with these conclusions. Most probably, the taaffeite with similar refractive indices

and specific gravity described by Burford (1997) but not chemically analysed is also a sample with high iron and/or zinc contents.

The extremely dark, translucent purplish-violet coloration of specimen A is also explained by its high iron content. In contrast, specimens B and C with high zinc but distinctly lower iron values, are transparent gemstones with little colour.

Acknowledgement

The authors are grateful to Dr O. Medenbach of Ruhr-University, Bochum, Germany, for obtaining X-ray diffraction data.

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Note on nephrite jade from Val Faller, Switzerland

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Abstract: *In the Oberhalbstein area of southeastern Switzerland, 12 occurrences of nephrite jade are recorded in intimate association with serpentinized peridotite within an alpine ophiolite complex of Mesozoic age. These include two roadside localities in Val Faller that have been enlarged as a result of highway improvement schemes through the valley. Fresh rocks exposed in new rock cuttings reveal the contact alteration zones between serpentinites and the country rocks. The small pods and irregular patches of nephrite jade are classed as orthonephrite in type. Predominant colours are of uneven greyish-green hue, grain size varies from fine- to coarse-grained and the surface is rough with vitreous lustre in parts.*

The nephrite jade formed as a result of metasomatism and high-pressure effects following the emplacement of the ultrabasic rocks and serpentinization.

Although the occurrences of nephrite are of insufficient size to warrant mining operations, the sites in Val Faller have considerable historical significance and remain popular with collectors of mineral specimens.

Introduction

From the time of their discovery around 1910, the nephrite jade occurrences within the valley of Val Faller in southeastern Switzerland have been the subject of widespread interest not only because they crop out at readily accessible positions alongside a public road but also because of their historical significance as the first *in-situ* deposits of nephrite jade found in Switzerland *(Figure 1)*.

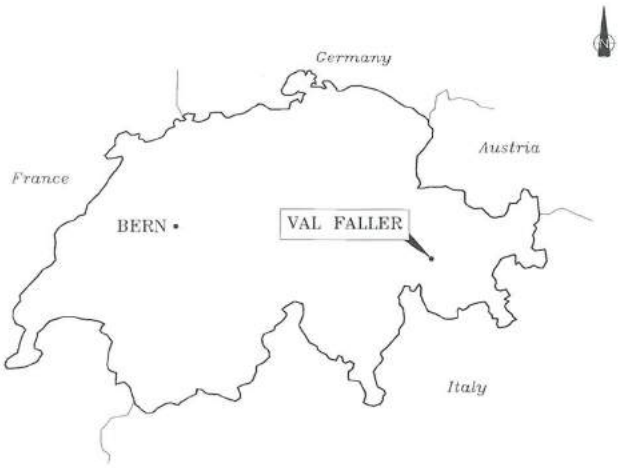

Figure 1: Location of Val Faller in the Oberhalbstein area, southeastern Switzerland.

During recent highway improvement schemes in the lower valley of Val Faller, the excavation of road cuttings through two nephrite jade localities has created fresh exposures and provided the opportunity to collect geological specimens as well as samples for lapidary testing.

The valley of Val Faller forms part of the geological and geographical area referred to as Oberhalbstein. The valley itself lies some 35 km south of the town of Chur and near the village of Mulegns which is situated on the Julier Pass road between Tiefencastel and St Moritz. Here, the eastern Swiss Alps form steep terrain with spectacular and rugged mountain scenery.

The writers carried out field investigations at Val Faller during September 2003 as part of a wider study of nephrite jade in Europe.

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Table I: Nephrite jade occurrences associated with serpentinite in the Oberhalbstein area (see Figure 2).

Ref No.	Locality name	Nephrite occurrence	Swiss National Grid co-ordinates	Reference
1	Salux	Boulder found at roadside	not known	Welter (1910)
2	Piz Martegnas	Rockfall material on northern slope of mountain	760.000 / 160.590	Streiff (1939)
3	Crap Farrèras	Thin band (~200 mm) between serpentinite and basalt	761.500 / 159.920	Streiff (1939)
4	Sblocs	Pod associated with serpentinite	766.715 / 155.260	Dietrich and de Quervain (1968)
5	Val Faller - locality A	Patches at contact of sheared serpentinite	767.170 / 154.850	Welter (1911); this paper
6	Val Faller - locality B	Lens at contact of pillow basalts and serpentinite	767.060 / 154.820	Welter (1911); this paper
7	Furschela	Lenses and veins in serpentinite	765.950 / 152.950	Welter (1910)
8	Marmorea Castle dam	Band (~250 mm) at contact of basalt and serpentinite	767.940 / 152.710	Dietrich and de Quervain (1968)
9	Muntognas digls Lajets	Lenses in sheared serpentinite	765.680 / 150.530	Staub (1926)
10	Seeflüe	Nephrite layers with sheared serpentinite and gabbro	765.140 / 147.630	Dietrich and de Quervain (1968)
11	Cuolms	Lenses (<400 mm) in sheared serpentinites	769.790 / 145.800	Dietrich and de Quervain (1968)
12	Fuorcla da la Valletta	Thin lenses in sheared serpentinite	766.350 / 144.190	Staub (1926)

This paper provides a brief review of the nephrite jade occurrences in the Oberhalbstein area and describes the two sites at Val Faller.

Geological setting

Geologically, the central feature of the Oberhalbstein area is an extensive ophiolite complex of Mesozoic age that crops out within the Platta nappe (Upper Penninic), an oceanic nappe with relicts of continental crust. The Oberhalbstein ophiolite is exposed discontinuously for a distance of some 30 km between the Albula Valley to the north and the Engadine Line to the south (*Figure 2*).

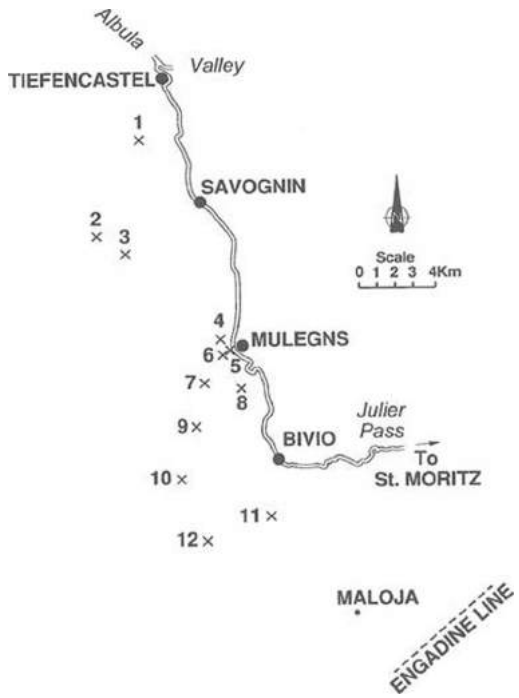

Figure 2: Nephrite jade occurrences associated with serpentinite in the Oberhalbstein area (see Table I).

It comprises the close association of serpentinized peridotites, gabbroic rocks, and pillow basalts overlain by marine sedimentary sequences, including radiolarian cherts and pelagic limestones, the whole having been affected by mild metamorphism. The serpentinized peridotites are interpreted as subcontinental mantle rocks that were exhumed along low-angle detachment faults in Cretaceous to early Tertiary time (Desmurs *et al.*, 2001, and references therein).

A total of 12 occurrences of nephrite jade have been identified within the dismembered blocks of the Oberhalbstein ophiolite belt *(Table I* and *Figure 2)*. Detailed descriptions and discussions of these nephrite occurrences and their significance are given by Dietrich and de Quervain (1968) and Giess (1994). However, the two localities in Val Faller *(Table I* and *Figure 2, Sites 5* and *6)* are perhaps the best known and observationally accessible sites.

In the neighbourhood of Val Faller, massive serpentinites and pillow basalts underlie the hilly ground and are to be found together with associated metasediments in the rock cuttings alongside the road through the valley.

The Val Faller occurrences

Welter (1910,1911) reported the first discovery of primary deposits of nephrite jade in Switzerland in the valley of Val Faller. He identified two localities approximately 200 m apart along a short stretch of road within the lower reaches of the narrow valley *(Figure 3)*. From Mulegns, access is westwards for 0.25 km. Stony ground and vegetation of conifer forest characterize the surrounding country.

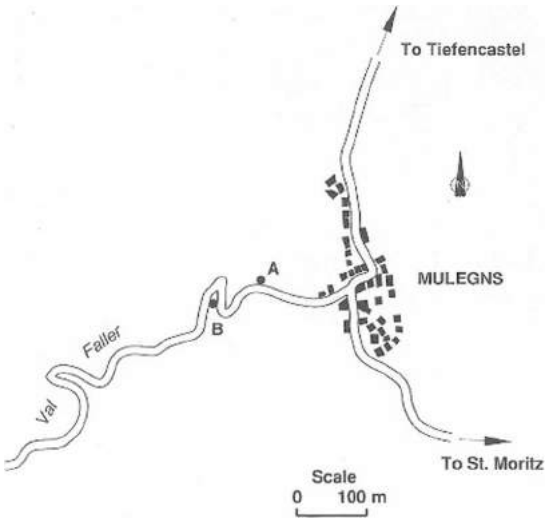

Figure 3: Val Faller nephrite jade sites at A and B near Mulegns.

Locality A

According to Welter (1911), this locality originally comprised an irregular outcrop alongside the road with bare rocky hillside above. He observed a wide variety of rock types and identified two minor patches of nephritic material.

A new road cutting was excavated at the site during 2002-2003 *(Figure 4)*. It measures over 30 m long by up to 3 m high and exposes a sharp tectonic contact between serpentinite and metasedimentary strata. The serpentinite forms a sheet-like body that ranges from black and massive to dark green and foliated. Its main constituents are

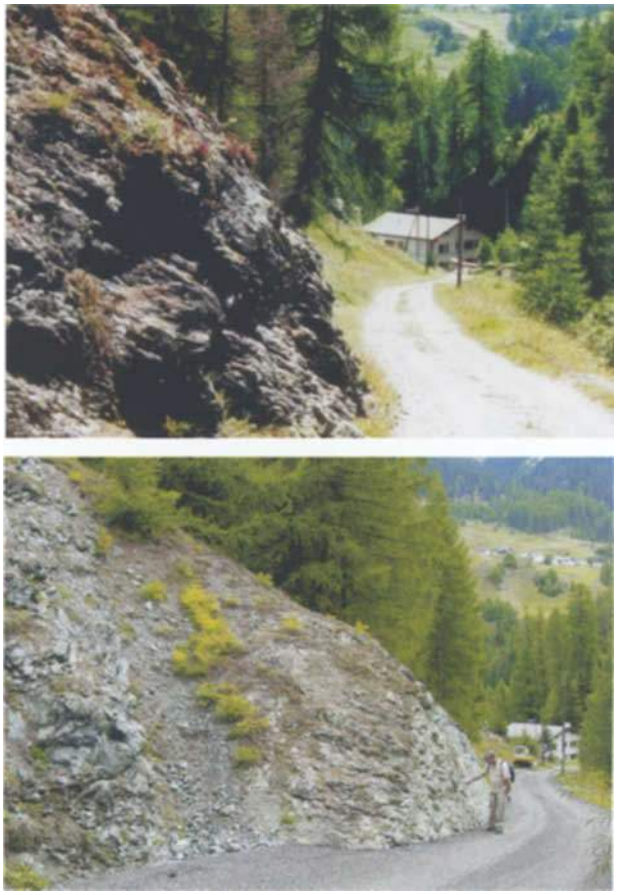

Figure 4: Locality A. Views looking southeastwards. (Upper) small roadside cutting in summer 1993 and (lower) new road cutting in autumn 2003. Serpentinite crops out in the left of the picture whereas metasedimentary rocks form the face in the fresh rock cutting on the right of the picture. Photos by Herbert Giess.

lizardite and chrysotile plus minor quantities of chlorite and magnetite.

The metasediments are mainly grey, green and red variegated, calcareous and pelitic phyllites and schists (Bündnerschiefer) with minor veins of milky quartz and veinlets of white asbestiform tremolite-actinolite. The nephrite jade is present in very small patches within the contact alteration zone but good specimens are uncommon.

Locality B

According to Welter (1911), this locality originally comprised a large outcrop of nephrite at the contact between serpentinite and pillow basalt. Part of the site was disturbed during road-widening operations carried out in 1972 but relatively unaffected by the recent road improvements *(Figure 5)*. Here the nephrite jade crops out discontinuously on the upslope side of the road over a stretch of some 20 m. The cutting slope ranges up to 3 m high. The near surface material is highly weathered to a soft and friable, white, powdery schistose material containing talc, tremolite, chlorite and clay minerals *(Figure 6)*.

Figure 6: Locality B. Roadside outcrop of white weathered nephrite. Photo by Herbert Giess.

Outcrops of serpentinite, pillow basalt and metasedimentary rocks (Bündnerschiefer) are to be found nearby.

Using the Munsell notation (Rock-Colour Chart Committee, 1980), the nephrite jade ranges from pale green (5G 7/2) through greyish green (10G 5/2) to dark yellowish green (10GY 4/4) but is predominantly greyish green (10G 5/2). Colours generally are

Figure 5: Locality B. Views looking southwards. (Upper) roadside sketch by Welter (1911) and (lower) the same outcrop site in autumn 2003. Photos by Herbert Giess.

Figure 7: Specimen of nephrite jade frpm Locality B, Val Faller. Natural surface of greyish-green nephrite with black dendrites of secondary manganese. Field of view approximately 10mm across. Photo by Russell J. Beck.

Figure 8: Specimen of nephrite jade from Locality B, Val Faller. Approximately 40 x 20mm. Photo by Herbert Giess.

patchy and uneven and surface lustre typically appears vitreous in parts and somewhat sheared. Almost invariably, textures show very fine fibrous crystals of microcrystalline tremolite-actinolite and incipient preferred orientation *(Figure 7)*.

Nephrite classification and origin

The nephrite jade localities throughout Oberhalbstein are all spatially associated with serpentinites. Based on the field relationships between the nephrite bodies and the ophiolite belt, the occurrences are all classed as orthonephrite in type (Nichol, 2000). The nephrite jade formed as a result of metasomatism and high-pressure effects following the emplacement of the ultrabasic rocks and serpentinization.

Production

In several parts of Switzerland, archaeologists have unearthed a considerable number of nephrite jade axes, chisels and other cutting tools at the sites of Neolithic lake dwellings. Indeed, several thousand nephrite artifacts were discovered on the shores surrounding Lake Constance and are held in museum collections in Germany and Switzerland. Although some uncertainty remains about the sources of nephrite jade exploited by the Neolithic lake-dwellers, it is considered likely that a certain proportion of their material was collected as cobbles and boulders from the rivers in the Oberhalbstein area (Giess, 1994).

In modern times, no commercial mining has taken place at the nephrite jade occurrences in the Oberhalbstein area. This was probably due to the dispersed distribution of the material through the serpentinite and the apparent lack of a single mass of sufficient dimensions to warrant mining operations or to encourage deeper exploration beneath the ground surface. Consequently, output has been limited to fossicking for loose material on the ground surface and knapping of small pieces from outcrops. These fragments are suitable only for mineral specimens *(Figure 8)*. Another consideration is quality, which appears generally low for most gemmological purposes.

Conclusions

The Val Faller nephrite occurrences formed within the contact alteration zones associated with serpentinites in the Oberhalbstein ophiolite complex of Mesozoic age. The nephrite jade is categorised as an ortho-nephrite and occurs mainly in narrow patches and irregular pods. Colour is predominantly greyish green (10G 5/2), texture ranges from fine- to coarse-grained and surface lustre is typically vitreous.

Although surface indications of nephrite are widely scattered throughout the serpentinites in the Oberhalbstein area, the occurrences generally appear small in size and poor in quality. No commercial production is recorded but the region remains highly regarded as a significant nephrite jade province for historical, mineralogical and geological reasons.

Acknowledgements

We are much indebted to Russell J. Beck for helpful discussions and to Angela Hughes for assistance in preparing the diagrams.

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Nephrite jade from Mastabia in Val Malenco, Italy

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Abstract: *At Mastabia in Val Malenco, northern Italy, a major deposit of nephrite jade was recently identified at the site of an abandoned talc mine. Geologically, the talc orebody comprises a series of steeply dipping lenses associated with a fault wedge of dolomitic marble and calc-silicate rocks of Triassic age. The nephrite jade is hosted within massive tremolitite in the central core of the talc orebody and the nephrite and tremolitite were both discarded as waste material during talc mining operations. Recovery of nephrite from the spoil heaps is now underway. Predominant colours of the nephrite jade are of uneven pale green and yellow-green hue. Grain size ranges from fine- to coarse-grained and accessory constituents include calcite, talc and opaque iron minerals. The nephrite jade is classified as para-nephrite in type and formed together with talc and tremolitite by intense hydrothermal alteration and decarbonation of dolomitic marble along shear zones related to thrust structures. The quantity of nephrite jade available remains uncertain but appears substantial. The nephrite is fashioned into a range of jewellery and ornamental pieces.*

Introduction

Recently, a major new source of nephrite jade in Europe was identified at Mastabia in Val Malenco, northern Italy (*Figure 1*). The discovery, announced in January 2002 at the Fourth Symposium of the Federation for European Education in Gemmology, stimulated widespread interest not only because of the considerable quantities of nephrite apparently available but also because of its unusual geological setting (de Michele *et al.*, 2002).

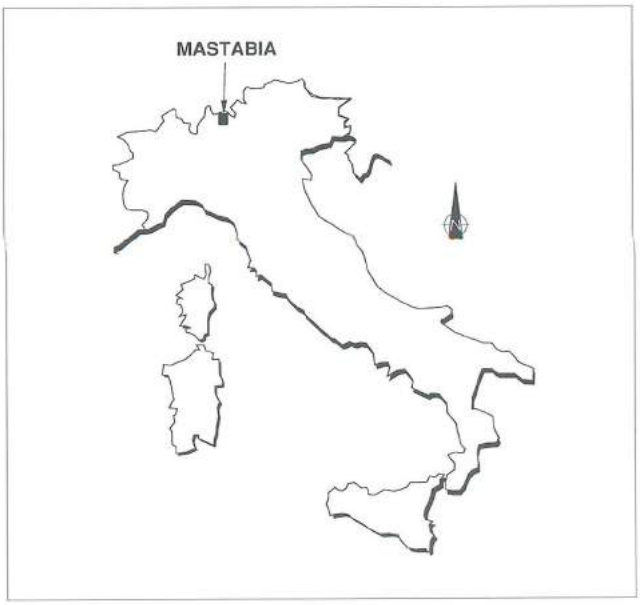

Figure 1: *Location of Mastabia in Val Malenco, northern Italy.*

Discovery of the nephrite jade is attributed to Pietro Nana of Sondrio who first noticed an attractive green stone in the discarded waste materials at an abandoned talc mine

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Figure 2: Photo of Pietro Nana (left) and Douglas Nichol with a typical block of Mastabia nephrite jade. Photo by Herbert Giess.

(*Figure 2*). The old mine lies near Mastabia, some 20 km north-north-west of the town of Sondrio, 4 km north-west of Torre di Santa Maria and 4 km south-west of Chiesa in Val Malenco. Here, the Italian Alps form steep terrain with spectacular and rugged mountains.

The writers visited Val Malenco during September 2003 as part of a wider study of nephrite jade in Europe. This paper provides a preliminary review and a description of the geological setting of the deposit of nephrite jade in Mastabia.

Geological setting

The geology of the Val Malenco district has been described in detail by Bonsignore *et al.* (1971) and the solid geology is outlined in a simplified form in *Figure 3*. The regional geology appears complex due to extensive tectonic disruptions associated with a stack of Alpine nappes (Penninic and Austroalpine nappe systems).

The Malenco Serpentinite is part of an ophiolite complex of Mesozoic age that forms the central feature of the district. The complex covers an area of some 200 km^2. It comprises a tectonic sheet around 2 km thick that dips at moderate angles eastwards and consists of serpentinized peridotite with minor relicts of lherzolite and harzburgite. Two other groups of igneous intrusions are present; the Fedoz Gabbro forms a series of irregular bodies emplaced during Permian time whereas the Bergell Granite, a pluton of mainly granodiorite and tonalite was intruded during Tertiary (Oligocene) time. The country rocks surrounding these igneous masses include pre-Mesozoic crystalline basement rocks (mainly schists and gneisses) together with dismembered blocks of Triassic carbonate strata.

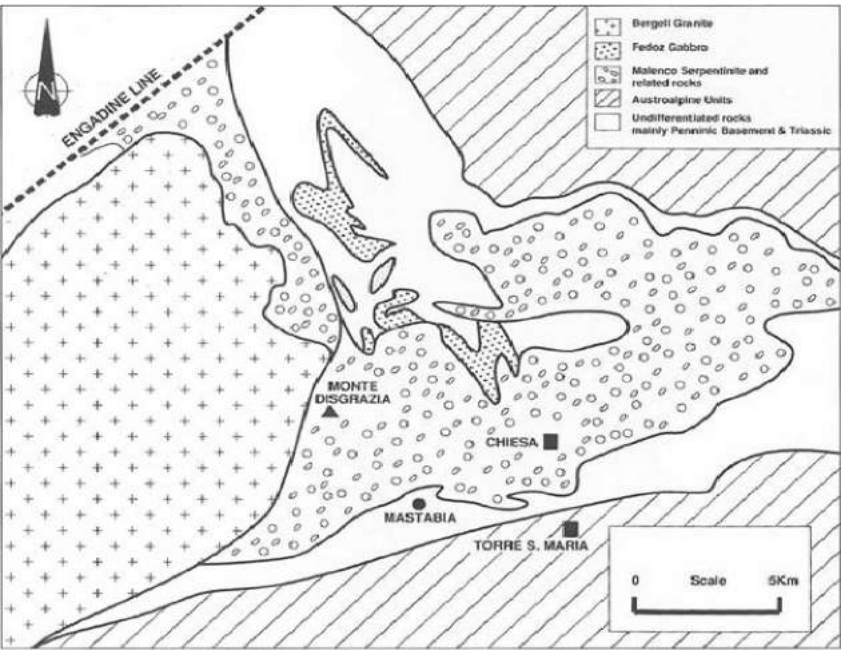

Figure 3: Simplified geological map of the Val Malenco district.

The Val Malenco district has a long history as a major mining centre for a wide variety of rocks and minerals. In relation to talc mining operations, at least 15 mine sites are recorded throughout the valley (Conti, 1956; Beaulieu,

1985). Almost invariably, they are situated either within the Malenco Serpentinite or in the dismembered blocks of Triassic carbonate rocks around its margins.

In the neighbourhood of Mastabia, the bedrocks occupy a narrow tectonic zone sandwiched between the massive Malenco Serpentinite to the north and Austroalpine strata to the south. The principal rocks around the old talc mine at Mastabia comprise tectonic slivers of schists and gneisses of the pre-Mesozoic crystalline basement together with fault wedges of Triassic dolomitic marble and calc-silicate rocks, all closely associated with the thrust-slide boundary between the Margna nappe and the Malenco Serpentinite.

Figure 4: Mastabia Talc Mine (circa 1965). View looking northwards. Mine entrance in centre left of picture (after Andreis 1970).

The Mastabia Talc Mine

The Mastabia Talc Mine is situated at elevation 2077 m above ordnance datum on the steep south-eastern mid-slopes of Monte Disgrazia and on a ridge between Valle Airale and Valle Giumellino.

From Chiesa in Val Malenco, access to the site is south-westwards for 1.5 km along the Primolo Road thence 6.5 km on a rough track via Alpe Lago to Alpe Mastabia. From here, a path leads north for some 600 m up to the mine entrance. The surrounding country is characterised by stony ground (*Figure 4*).

The early history of the mine remains uncertain but operations were apparently established around 1952 on an irregular talc orebody cropping out on the mountainside. Access to the orebody was gained by a series of adits into the hillside and extraction was carried out using conventional underground methods. The mined talc was brought to the surface by means of a number of galleries and tunnels and then transported down the steep mountainside by aerial cableway. It was then taken to a milling plant in the lower valley and processed primarily for use in the paper manufacturing industry. Mining operations ceased around 1985 due to an unacceptably high fibre content (acicular tremolite) in the talc product. When the mine closed, the adit entrances were barricaded.

According to Andreis (1970), the talc ore is predominantly massive with a waxy sheen and varies from white and pale green to greenish yellow in colour. It also contains a relatively high proportion of calcite as well as radial fibrous rosettes of tremolite.

Individual talc veins range up to about 10 m wide. However, massive tremolitite frequently forms prominent, tough and hard bands typically about 1 m wide in the middle of the lodes (*Figure 5*). Not surprisingly, these hard bands posed persistent problems during mining and so, wherever possible, they were avoided by the miners. Nonetheless, significant quantities were encountered during ore extraction and discarded to the waste heaps. In certain places, the tremolitite bands contain a core of moderately intense green fine-grained nephrite that graduates almost imperceptibly outwards into coarser-grained material of progressively paler tones. Not infrequently, the centre of the core is marked by a distinctive stripe up to 10 mm wide characterized by inclusions of opaque iron minerals.

Table I: Chemical composition of Mastabia nephrite and comparisons.

Identifier No.	1	2	3	4	5	6	7
Analysis (Wt.%)							
SiO_2	59.17	43.91	59.65	56.34	63.36	32.59	40.30
TiO_2	-	0.03	0.02	-	-	-	-
Al_2O_3	-	0.27	0.18	0.34	-	-	1.45
Fe_2O_3	-	0.26	0.16	0.71	-	0.72	5.80
MnO	-	0.01	0.04	0.12	-	-	0.11
MgO	24.81	18.34	23.74	22.59	31.89	18.64	39.90
CaO	13.80	26.51	12.44	14.92	-	23.35	1.20
Na_2O	-	0.52	-	0.19	-	0.10	-
K_2O	-	0.53	-	0.07	-	0.02	-
P_2O_5	-	0.01	0.07	-	-	-	-
LOI	2.22	8.05	3.00	4.20	4.75	22.56	10.50
Total	100.00	98.44	99.30	99.48	100.00	97.98	99.26
Trace elements (ppm)							
Co	-	11	<1	-	-	-	-
Cr	-	76	28	-	-	-	1100
Ni	-	124	2	-	-	-	2400

Identifier No.
1. Theoretical pure composition of tremolite - nephrite.
2. Nephrite jade from Mastabia (analysis by staff at the National Museum of Wales).
3. Nephrite jade from Mastabia (analysis by Alcontrol Geochem).
4. Nephrite jade from Mastabia (courtesy G. Liborio).
5. Theoretical pure composition of talc.
6. Talc ore from Mastabia (Andreis, 1970).
7. Malenco serpentinite from quarry Chiesa (Trommsdorff and Evans, 1972).

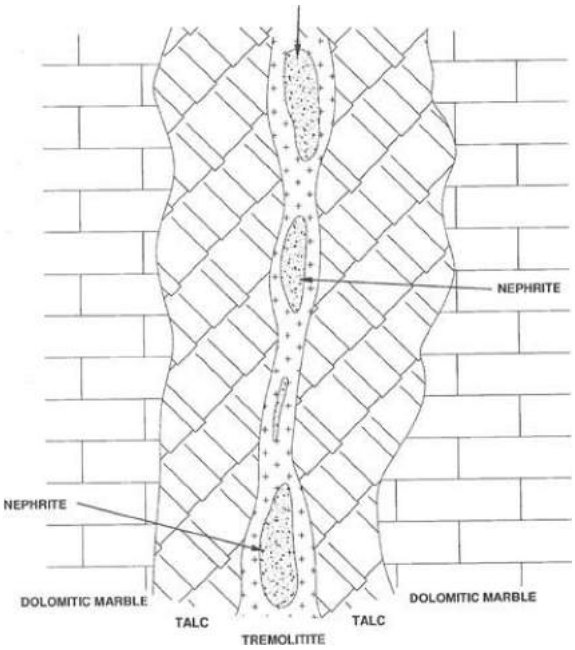

Figure 5: Schematic section illustrating rock relations at Mastabia Talc Mine (not to scale).

The nephrite jade is found exclusively within the massive tremolitite and the material discarded during talc mining operations is currently being salvaged for its nephrite content.

Nephrite jade

X-ray, chemical and petrographic examinations of representative samples of Mastabia nephrite have revealed that it consists of microcrystalline tremolite-actinolite which is intimately associated with minor but variable quantities of calcite, talc and pyrite. The principal impurity is calcite.

Mineralogically, nephrite is a monoclinic amphibole of variable chemical composition between the end members tremolite

Figure 6: Slab specimens of nephrite jade from Mastabia. Slab size approximately 10 mm wide. Foreground specimen contains inclusions of opaque iron minerals. Photo by Herbert Giess.

($Ca_2Mg_5Si_8O_{22}(OH)_2$) and ferroactinolite ($Ca_2Fe_5Si_8O_{22}(OH)_2$). The magnesium in tremolite is often partially replaced by iron.

However, Mastabia nephrite features very low iron contents, typically less than one percent, placing it closer in composition to the tremolite end member (*Table 1*).

Using the Munsell notation (Rock-Colour Chart Committee, 1980), the nephrite jade ranges from light greenish grey (5G8/1 & 5GY 8/1) through moderate yellow green (5GY 7/4) to greyish yellow green (5GY 7/2) but is predominantly moderate yellow green (5GY 7/4).

Localized zones contain an unusual variety of nephrite peppered with black flecks of opaque iron minerals, mainly pyrite (*Figure 6*).

Colours generally are patchy and uneven and surface lustre typically appears greasy and somewhat sheared. Variations in colour are ascribed to minor variations in iron content with higher Fe_2O_3 values producing greener hues and darker tones. Interestingly, Mastabia nephrite contains less than 100 ppm chromium, in marked contrast to other deposits elsewhere in the world with chromium contents of 1000 to 10000 ppm; chromium is responsible for imparting their emerald green colours (Nichol, 2000).

Texture controls the toughness and hence the durability of the gemstone as well as its polishing characteristics. Toughness is due to an interlocking mesh of fine fibre or needle like crystals which are commonly 0.1 to 5 μm in diameter and 20 to 150 μm long (*Figure 7*).

Variations in toughness depend upon the length and diameter of the fibres, and the size and orientation of the fibre bundles. The toughest nephrite has randomly oriented fibre bundles and a very fine grain size. The presence of foliation as aligned fibres or fibre bundles as well as coarse-grained tremolite reduces toughness.

Nephrite classification and origin

The nephrite jade at Mastabia is spatially associated with Triassic dolomitic marble and calc-silicate rocks of metasedimentary

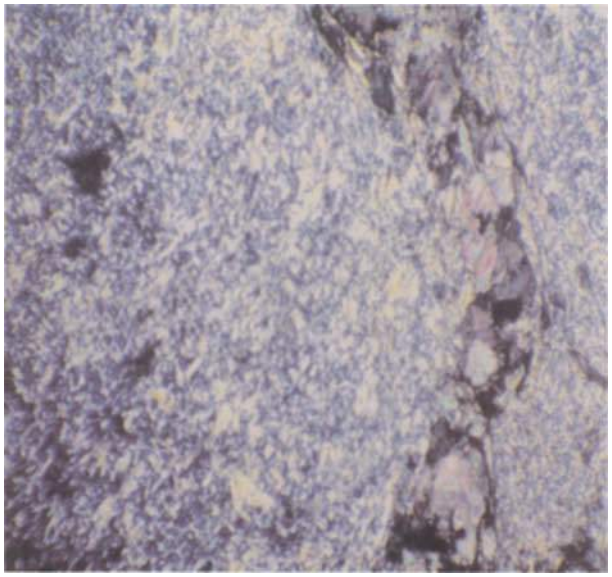

Figure 7: Photomicrograph of Mastabia nephrite under polarized light, with coarse grained vein of calcite on the right. Length of photo 1.1 mm. Photo by Dr Vincenzo de Michele.

Figure 8: Necklace fashioned from Mastabia nephrite jade. Photo by Pietro Nana.

derivation. Based on the field relationships between the nephrite bodies and the country rock together with the subdued chromium and nickel contents, the deposit is classed as para-nephrite in type (Nichol, 2000).

The origin of the Mastabia nephrite may be ascribed to metamorphism, metasomatism and decarbonation of impure dolomitic strata involving reactions of the form:

$$5CaMg(CO_3)_2 + 8SiO_2 + H_2O =$$
(dolomite) (silica)

$$Ca_2Mg_5Si_8O_{22}(OH)_2 + 3CaCO_3 + 7CO_2$$
(nephrite-tremolite) (calcite)

Generally, the mixed compositions and varied textures indicate intense fluid-rock reactions by hydrothermal solutions percolating within the shear zones.

It is also noteworthy that the geological features evident at Mastabia, as well as the close association of the nephrite with a talc orebody, appear remarkably similar to the geological environment reported by Dietrich and de Quervain (1968) for the Scortaseo nephrite jade deposit in south-east Switzerland. Indeed, the colour and general appearance of Mastabia nephrite also closely resemble Scortaseo nephrite.

Production practice

Output of Mastabia nephrite is still in the early stages of development and adequate stocks for immediate requirements are salvaged from mining wastes outside the talc mining adits.

Boulders of raw jade are transported from the mine site to Chiesa and Sondrio for sawing and grading according to colour and quality. Some jade is consigned to lapidiary workshops in China and Idar-Oberstein to be processed further into carved pieces and items of jewellery (*Figure 8*). Jade for hardstone carving is first trimmed with a diamond saw, carved using diamond tipped tools and then polished with diamond paste to achieve its characteristic final lustre (*Figure 9*). Sondrio provides the principal outlet for finished articles.

Conclusions

The Mastabia nephrite deposit formed in hydrothermally altered zones of intense deformation associated with a fault wedge of metamorphosed dolomitic marble and calc-silicate rocks. As well as nephrite jade, the alteration zone also contains talc and

tremolitite. The nephrite jade occurs as irregular pods exclusively within lenticular masses and bands of tremolitite in the central core of the talc orebody.

The material is categorised as a para-nephrite jade (Nichol, 2000). Colour is predominantly moderate yellow green (5GY 7/4), and texture ranges from fine- to coarse-grained microfibrous.

Much nephrite jade was originally extracted from the Mastabia Talc Mine in conjunction with tremolitite as waste material produced during talc mining operations. Substantial quantities of nephrite are understood to exist in the vicinity of the old workings but detailed geological investigations are required to provide quantitative assessments.

Lapidaries and artisans fashion the nephrite jade into a variety of jewellery pieces and ornamental hardstone carvings.

Figure 9: Ornamental carving fashioned from Mastabia nephrite jade. Size approximately 200 mm in height. Photo by Pietro Nana.

Acknowledgements

The authors are grateful to Pietro Nana for guidance during our visit to Val Malenco and also for providing Figures 8 and 9. We also thank Dr Vincenzo de Michele, Istituto Gemmologico Italiano for helpful advice and for providing Figure 7. Laboratory testing of specimens of Mastabia nephrite was carried out by the Department of Geology, National Museum of Wales, Cardiff and by Alcontrol Geochem, Chester. In addition, Professor Giuseppe Liborio, Department of Earth Sciences at University of Milan kindly provided one chemical analysis of Mastabia nephrite (Table I, Sample No 4).

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Stereoscopic effect in asterism and chatoyancy

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***Abstract**: The optical effect of a star displayed by rose quartz which appears to be located above the stone is described. An explanation of the phenomenon using ray diagrams is proposed. This analysis applies to all star and cat's-eye stones.*

Introduction

I recently purchased a star rose quartz sphere. At first there seemed to be nothing remarkable about it. True, it was big – 105 mm in diameter - and as is commonly the case, it was heavily fissured and had many growth features which made it non-transparent, so there was no diasterism. Although epiasterism was present, it appeared somewhat vague, but after continuous observation for about 20 seconds, to my amazement the star appeared to float about 40 mm above the surface of the ball! The effect was quite dramatic. Those who saw it tried to touch the star. I had not read about such a phenomenon, and determined to find out more.

Observations

One of the arms of the star, though it had a discontinuity, was brighter than the others and I concentrated on that. I noticed that, when I looked with my right eye, the arm appeared further to the left than it did when viewed with the left eye. This is shown in *Figure 1* taken with the camera in two positions having the same angle of view as the eyes at normal reading distance. *The conclusion is that the two rays cross above the stone*. The brain seeks to meld the two images of the arm into one, i.e. it causes the eyes to focus on the point where the rays cross and so a stereoscopic view is obtained. This is why the star appears to float in space. I then attempted to trace the light rays to the ball and from it to the eye. I arranged the ball such that the sun shone from directly behind me and the brightest arm of the star was vertical. In this position, the reflective needles in the quartz are perpendicular to my line of sight when looking with one eye down the line of the incident ray. I then ascertained the path of the incident and emergent rays as seen first from the position of the right eye and then from that of the left. (This is not easy, partly because of the fuzziness of the star.) *Figure 2* is the result of such an experiment.

It will be noticed that the emergent rays which reach the pupils appear to come from the sphere at points virtually coincident with

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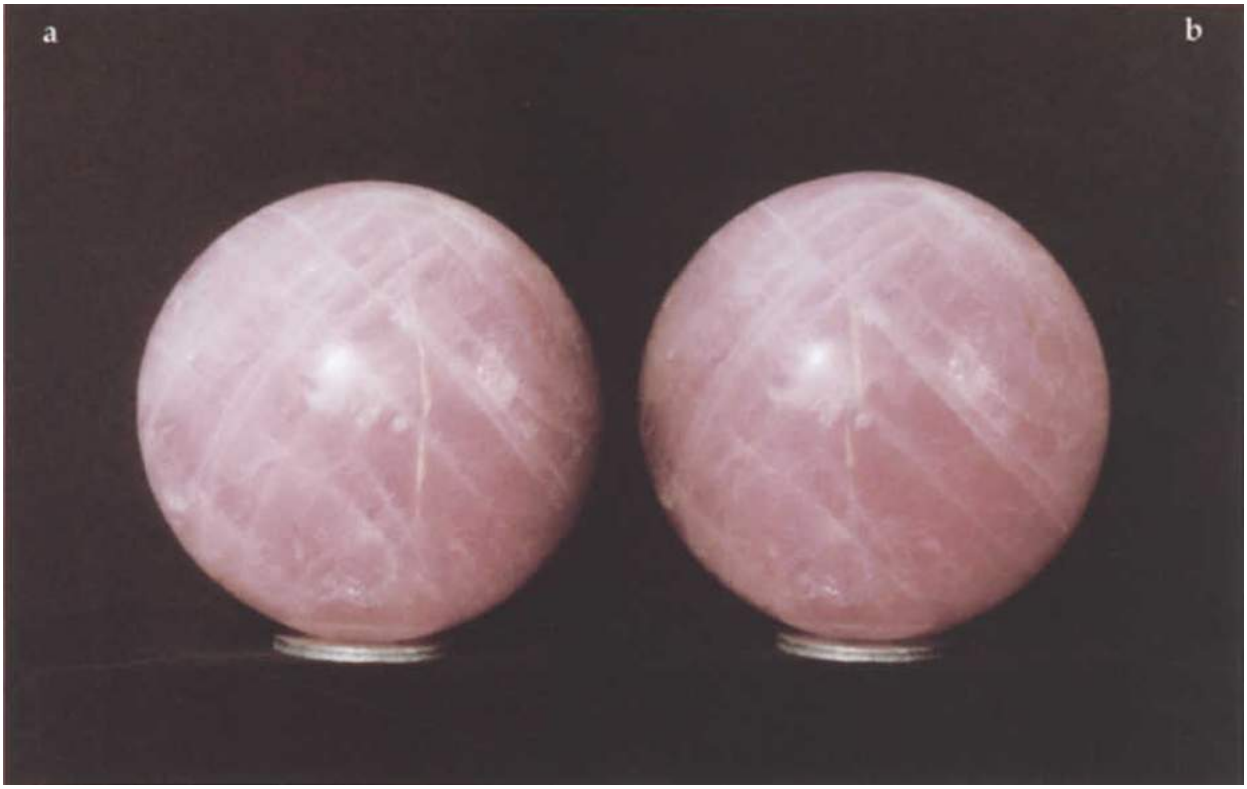

Figure 1: Star rose quartz sphere as seen by the left eye (a) and the right eye (b). The prominent arm of the star is vertical and just to the right of centre in (a), and to the left in (b).

In order to 'see' the sphere in *Figure 1* in three dimensions without the aid of a stereoscope:

1. Place the images flat on a desk or table;
2. Stand above the images with your eyes 50-60 cm above looking vertically down;
3. Allow your eyes to relax, like gazing into the distance. Your eyes momentarily defocus and images of the sphere float sideways; one image from the left and one from the right will coalesce and you should then focus on this image that lies at the centre of the three.
4. You should see this central image clearly and with a distinct depth to it, with the arm of the star appearing to be above the surface of the sphere.

the points of entry of the incident rays. The conclusion is that the light is reflected from needles very close to the surface. The rays converge about 45 mm above the sphere.

In order better to understand what is happening inside the sphere, I constructed a schematic diagram (*Figure 3*) in which the region of refraction and reflection is greatly enlarged. Starting with the observed angle of incidence and a (mean) refractive index of 1.55, the path of the ray can be calculated by the usual methods. The theoretical approach agrees very well with the results observed.

I am grateful to J R Fletcher of Nottingham for pointing out that the situation can be likened to a plano convex lens backed by a plane mirror. (Indeed if, instead of a mirror, one attaches a parallel array of polished wires one gets a reasonable cat's-eye! This is shown in *Figure 4*.) As the light passes twice through

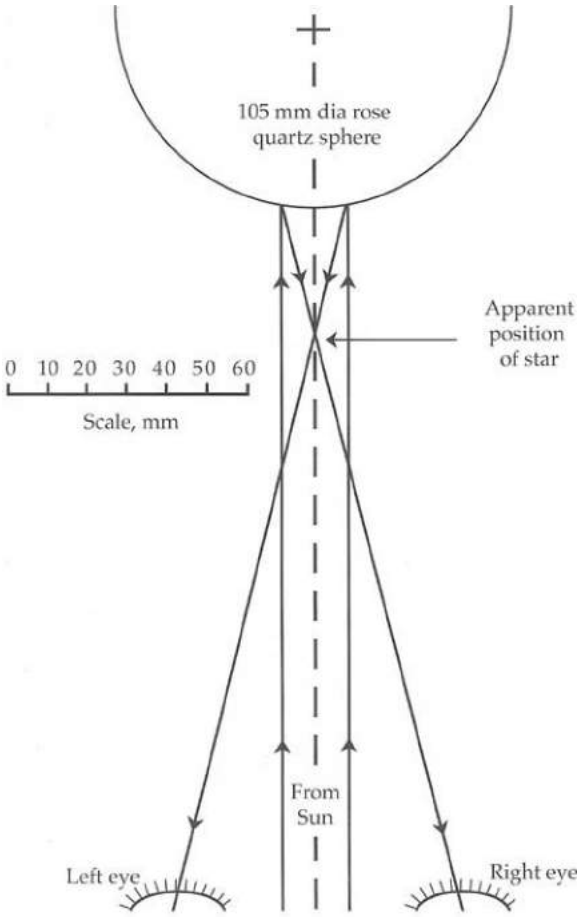

Figure 2: Schematic diagram of paths of the sun's rays to each eye.

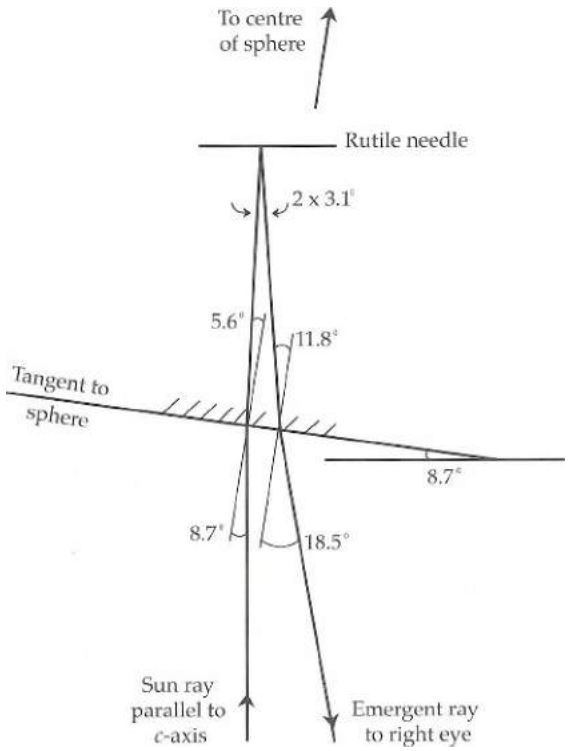

Figure 3: Schematic diagram of ray path. The angles are calculated for a 105 mm diameter sphere and for an inter-pupillary distance of 65 mm.

the lens, the effective focal length is halved (Fletcher, pers. comm.). The thin lens equation is $1/U + 1/V = 1/F = 2(N-1)/R$. Here, the source distance U is effectively infinite and its reciprocal zero. Consequently the image distance V is equal to the effective focal length F and so $V = R/2(N-1)$ where R is the lens radius and N the refractive index. Consequently, we would expect the image to be at a distance from the lens equal to 52.5 / 2(1.55-1) i.e. 47.7 mm. Within the accuracy of the assumptions and observations, this is in very good agreement with *Figure* 2.

Discussion

Although the above has been based on a particular example, the argument is quite general. It must, therefore, apply to all star stones and cat's-eyes that have ever been and ever will be.

Figure 4: Cat's-eye effect produced by pins taped to the flat underside of a plano-convex lens.

The only reference I have found to this phenomenon is in *Identification of Gemstones* by O'Donoghue and Joyner, page 72, who quote a GIA report (Mayerson, 2001) of blue cabochons having stars which appeared to float over the surface, and am surprised that this startling effect has not received more attention.

I have looked at smaller stars and cat's-eyes. In examples of moderate size the effect can be seen (though I had not noticed it before). In small stones the effect seems too small to attract attention. Tests, however, confirm that it is still there. In one respect, the fissures in rose quartz help by providing a background against which the stereoscopic effect is more obvious than in the case of stones with few visible inclusions, where the surface level is less obvious.

I conclude that the stereoscopic effect is of academic rather than practical interest but I hope that understanding of it extends the enjoyment to be had from gemmology. I only hope that it is not used by charlatans asking inflated prices for star rose quartz spheres 'containing a force field so powerful it projects the star outside the sphere'!

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Identification of an imitation of pearl by FTIR, EDXRF and SEM

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Abstract: *Pearl is an organic gem and its popularity is basically due to the beauty of its natural lustrous and iridescent surface. Most of the pearls in the market are now grown ('cultured') in farms containing thousands of molluscs. Each mollusc deposits a nacreous layer on an inserted bead of mother-of-pearl material. For superior quality pearls, it may take up to two years or more to harvest and the yield is usually low, and these factors account for their high price and the proliferation of pearl imitations. Pearl imitations which are developed in laboratories are not easily identified using conventional gemmological methods. In this investigation, the surface structures of the cultured pearls and its imitations were studied using a scanning electron microscope (SEM) at magnification of up to 2000×. Energy-dispersive X-ray fluorescence (EDXRF) and Fourier transform infrared (FTIR) spectroscopy were employed to study the chemical composition of the pearl layer and the bead for naturally-coloured cultured pearls, dyed cultured pearls and pearl imitations. EDXRF results show that the cultured pearls and their beads are basically* $CaCO_3$*, while the detection of only C and O in the pearl imitations indicates that they are consistent with a polymeric composition. The presence of Si, O, Na and Al in the bead of the pearl imitation is consistent with it being glass. In FTIR experiments, the absorption peaks of 700* cm^{-1}*, 713* cm^{-1}*, 862* cm^{-1} *and 1083* cm^{-1} *are observed in both naturally-coloured and dyed cultured pearls, which confirm that they are* $CaCO_3$ *with aragonite structure. However, the infrared spectra of pearl imitations are very different and are typical of polymers. In addition, studies on fluorescence using short and long wave ultraviolet radiation indicate that cultured pearls can be effectively distinguished from their imitations.*

Keywords: *Pearl Imitation, Pearls, FTIR, EDXRF, SEM*

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Introduction

Pearls are one of the more desirable gemstones in the world (Clark, 2000; Landman *et al.*, 2001). Unlike other gemstones, pearls are produced biologically by molluscs such as clam, oyster or snail. Molluscs form pearls naturally when an irritant affects their soft parts (Shirai, 1994). As a defence mechanism, the mollusc secretes a fluid to coat the irritant and layer upon layer of this nacreous coating is deposited on the irritant until a lustrous pearl is formed. These radiant layers of coating consist mainly of aragonite and conchiolin (Landman *et al.*, 2001; Shirai, 1981), the same substances deposited by the molluscs in building their shell. A cultured pearl undergoes a similar process of growth. The only difference is that the irritant is a surgically-implanted mother-of-pearl bead or a piece of shell (Wada, 1999). However, imitation pearls are produced very differently. In most cases, a glass bead is dipped into a solution made from fish scales, which then dries as a skin, (Landman *et al.*, 2001). This coating is thin and may eventually wear off. Recently, pearl imitations have been constructed of more recently developed materials to give good iridescent surface effects. These imitations can be easily mistaken for good-quality pearls as basic gemmological tests are not adequate for differentiating them.

Among recent studies on cultured pearls, the following are noteworthy. Studies of Chinese cultured pearls in relation to their production and colour-treatment using Raman spectroscopy have been made by Li and Chen (2001) and Li (2001). Formation and quality of pearls have been investigated and described in detail using optical and scanning electron microscope by Wada (1999). These structural studies are useful in understanding the formation of cultured pearls in molluscs. The history, production and yield of Australian pearls have been studied by Brown (2002), and the structure of non-nacreous pearls (Safar and Sturman, 1998) and Bangladeshi pearls (Kennedy, 2001) have also been described.

In the present investigations, studies on naturally-coloured and dyed cultured pearls and pearl imitations using accurate spectroscopic techniques as in Fourier transform infrared (FTIR) and energy-dispersive X-ray fluorescence (EDXRF) have been made. These techniques are useful for the identification of the chemical compositions of cultured pearls for comparison with these of pearl imitations. The usefulness of these techniques was discussed with examples by Hayashi (1999). Although some properties of pearl imitations were mentioned by Landman *et al.* (2001), accurate spectroscopic studies on them remain very limited. Furthermore, the pearl imitations abundant in the market show strong iridescence on their surfaces, and may not easily be distinguished by visual observation. Therefore, a systematic study of the chemical compositions using FTIR and EDXRF techniques of both cultured pearls and their imitations has been carried out. Surface structural studies have also been made using the scanning electron microscope (SEM) at magnifications up to 2000×, and fluorescence using short and long wave ultraviolet radiation has been observed. The results of these experiments show that pearl imitations can be differentiated effectively from cultured pearls.

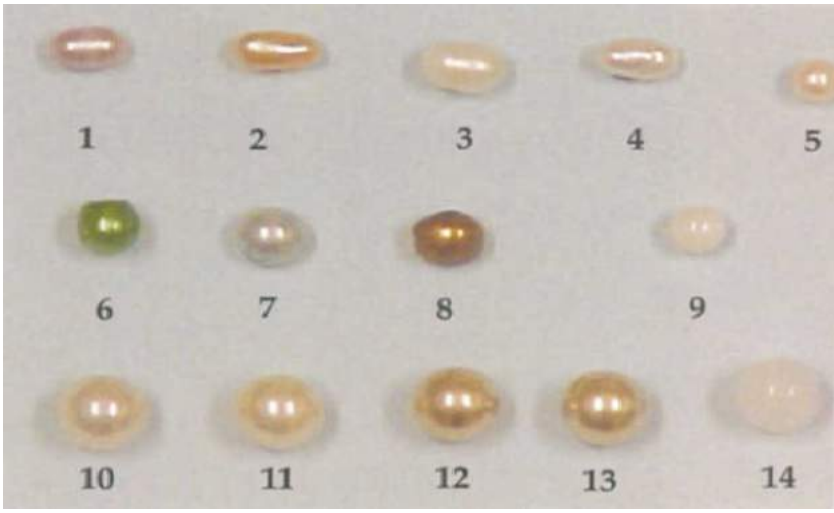

Figure 1: The photograph shows five samples of naturally-coloured cultured pearls (numbered 1 to 5, top row, from left to right); three samples of dyed cultured pearls and one sample of a cultured pearl bead (numbered 6 to 9, middle row, from left to right) and four samples of pearl imitations and one sample of a pearl imitation bead (numbered 10 to 14, bottom row, from left to right).

Table I: Gemmological and spectroscopic properties of naturally-coloured cultured pearls (samples 1 to 5), dyed cultured pearls (samples 6 to 8), cultured pearl bead (sample 9), pearl imitations (samples 10 to 13) and pearl imitation bead (sample 14).

Sample	Description and (SEM) observations	UV fluorescence short wave (254 nm)	UV fluorescence long wave (265 nm)	FTIR absorption peaks (cm^{-1})	EDXRF elemental peaks
Cultured pearls					
1	natural pink; baroque; layered, flaky surface	inert	weak blue	700, 713, 862, 1083, 1469, 1788, 2499, 2522, 2547, 2920	C, O, Ca
2	natural orange; baroque; layered, flaky surface	inert	inert	700, 713, 863, 1083, 1472, 1788, 2499, 2522, 2547, 2919	C, O, Ca
3	natural white; oval-shaped; layered, flaky surface	weak bluish white	very strong bluish white	700, 713, 862, 1083, 1467, 1788, 2500, 2522, 2547, 2918	C, O, Ca
4	natural white, strong iridescence; baroque; layered, flaky surface	weak bluish white	very strong bluish white	700, 713, 862, 1083, 1462, 1788, 2500, 2522, 2547, 2918	C, O, Ca
5	natural white; spherical; layered, flaky surface	weak bluish white	very strong bluish white	700, 713, 862, 1083, 1463, 1788, 2500, 2522, 2547, 2918	C, O, Ca
6	green-dyed; spherical; layered, contoured surface	inert	green	700, 713, 863, 1083, 1469, 1788, 2500, 2522, 2547, 2918	C, O, Ca
7	blue-dyed; spherical; layered, contoured surface	weak purple	very strong bluish white	700, 713, 862, 1083, 1469, 1788, 2500, 2522, 2546, 2917	C, O, Ca
8	gold-dyed; spherical; layered, contoured surface	inert	inert	700, 713, 861, 1083, 1469, 1788, 2499, 2522, 2547, 2918	C, O, Ca
9	bead for cultured pearls; spherical; layered, flaky surface	weak bluish white	strong bluish white	700, 713, 861, 1083, 1424, 1788, 2499, 2522, 2546, 2918	C, O, Ca
Imitation pearls					
10	cream-white; spherical; small cubic particles on surface	inert	weak dark purple	751, 840, 1068, 1161, 1280, 1376, 1654, 1732, 2554, 2929, 2964, 3466	C, O
11	cream-white; spherical; small cubic particles on surface	inert	weak dark purple	750, 840, 1067, 1161, 1280, 1375, 1654, 1732, 2553, 2929, 2964, 3468	C, O
12	gold; spherical; small cubic particles on surface; visible cracks and lines	inert	weak dark purple	752, 841, 1068, 1161, 1280, 1378, 1655, 1733, 2554, 2929, 2964, 3468	C, O
13	gold; spherical; small cubic particles on surface; visible cracks and lines	inert	weak dark purple	751, 840, 1067, 1161, 1281, 1376, 1654, 1732, 2553, 2929, 2963, 3469	C, O
14	bead for imitation pearls, cloudy grey; spherical	weak yellowish white	inert	3511, Highly opaque to IR	Si, O, Na, Al, Ca

Materials and experimental methods

Five samples of naturally-coloured cultured pearls (samples 1-5), three samples of dyed cultured pearls (samples 6-8), one sample of the beads used for a great number of cultured pearls (sample 9), four samples of pearl imitations (samples 10-13) and one sample of the beads used for pearl imitations (sample 14) were used in this investigation, as shown in *Figure 1*.

All samples of the naturally-coloured cultured, dyed cultured pearls, and their

beads (samples 1-9) were produced from a freshwater mollusc (*Hyriopsis cumingi* or *tritogonia*) in China (Li and Chen, 2001; Li, 2001). The pearl imitations and their bead (samples 10-14) are commercially available and have a Japanese brand-name. Scanning electron microscope (SEM) observations, ultraviolet fluorescence, Fourier transform infrared (FTIR) spectroscopy and energy-dispersive X-ray fluorescence (EDXRF) measurements were carried out on these samples and the results are summarized in *Table I*. Before every experiment, the surfaces of the cultured pearl samples were cleaned using ethanol solution in order to remove any contaminant derived from handling. However great care was taken with the pearl imitations and their surfaces were only very lightly cleaned with ethanol to prevent possible chemical reaction of the surface material with the solvent.

Ultraviolet (UV) fluorescence was the initial test carried out on all the samples. The UV lamp used is UVGL-58 (Mineralight, USA), with a short wave source of 254 nm and long wave of 365 nm. Cultured pearls normally have a weak whitish fluorescence under short wave and strong bluish white fluorescence under long wave (Matlins and Bonanno, 1997).

All the samples were tested using FTIR spectroscopy. The Perkin Elmer Instruments, Model Spectrum One - Fourier transform infrared spectrometer was used to record the spectra of all samples in the wavelength range of 400 cm^{-1} to 4000 cm^{-1}. The accuracy of the absorption peaks was ± 1 cm^{-1}. Since cultured pearl material is basically opaque to infrared radiation, a diluted sample of pearl in an infrared-transparent matrix of potassium bromide (KBr) is needed for detailed FTIR work. In preparating cultured pearl pellets for FTIR work, the samples were wiped clean with ethanol, and their surfaces were scraped to obtain some pearl material which was then ground to a fine powder, mixed with KBr, and pressed in a 2-tonne press to make flat circular pellets. These pellets are sufficiently translucent to allow collection of infrared transmission spectra and the recording of absorption peaks for identification of materials.

Following the FTIR work, EDXRF experiments and SEM observations were carried out using JEOLSM - 5600LV SEM/EDX microscopy with a working voltage of 20kV. Surface analysis by EDXRF was accomp-lished by bombarding a sample with high-energy electrons and detecting, and analysing the energy of the emitted X-rays (Potts, 1993). These electrons have penetrating power in a solid extending 1 to 5 µm depending on their energy and the nature of the substance. Since EDXRF is a surface-sensitive technique for chemical characterization of the surface of a solid, care is taken to ensure that the surfaces of the samples are clean. EDXRF helps to identify the elements present in the samples, while SEM observations reveal the surface structure of the samples. Both are useful in distinguishing cultured pearls from their imitations.

Results and Discussion

The results of short wave UV fluorescence, FTIR spectroscopy, EDXRF elemental analysis, and SEM surface observations are summarized in *Table I* for all 14 samples.

Ultraviolet (UV) fluorescence

For naturally-coloured cultured pearls (samples 1 to 5), there was no consistent distinction between fluorescence under UV in short and long wave. However, samples 3, 4 and 5 all being white cultured pearl, show very strong bluish white in the long-wave and weak bluish white in the short wave. In contrast, samples 1 and 2 do not show such strong fluorescence. The results of samples 3, 4 and 5 agree well with the observations given in Matlins and Bonanno (1997) which showed that cultured white pearls show weak white fluorescence in short wave and strong bluish white in the long wave. Similarly, the bead (sample 9) of the kind used in the cultured pearls shows weak white fluorescence in short wave and strong bluish white in the long wave. This indicates that the bead and the white cultured pearl could be of similar composition.

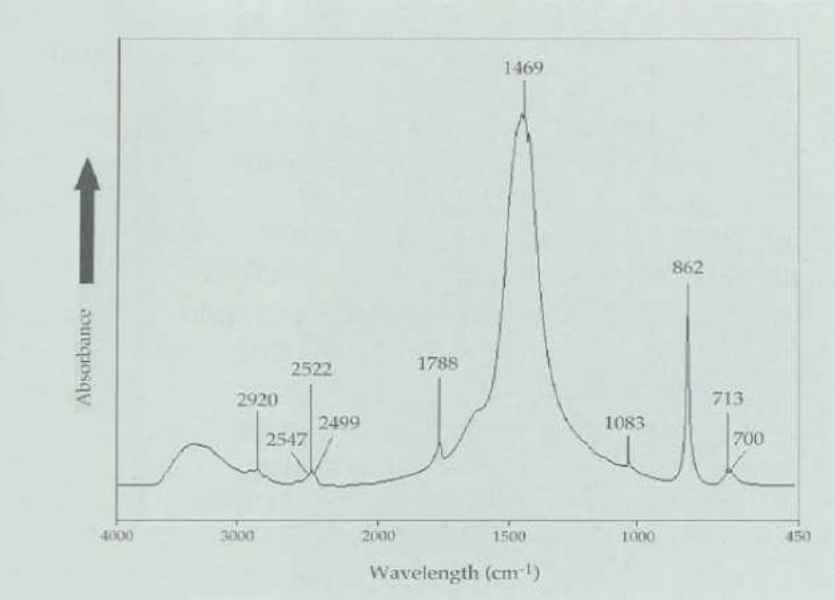

Figure 2: FTIR absorption spectrum typical of naturally-coloured and dyed cultured pearls (samples 1 to 8), and cultured pearl bead (sample 9).

For dyed cultured pearls (samples 6 to 8) there were no obvious trends in their UV fluorescence. Any fluorescent effects must depend on the presence of dye materials on the surface. The pearl imitations (samples 10 to 13) are inert in short wave and show weak dark purple fluorescence in long wave, whereas the bead used in the pearl imitations (sample 14) is inert in long wave and weak yellowish white in short wave. This shows that there is a clear difference in behaviour between the bead and its coating in the pearl imitation. Although fluorescence patterns are not conclusive enough for differentiation between cultured pearls and pearl imitations, the weak dark purple fluorescence in long wave shown by imitation pearls is a useful indicator.

Fourier transform infrared (FTIR) spectroscopy

All naturally-coloured and dyed cultured pearls (samples 1 to 8) and the bead used in cultured pearls (sample 9) have strong infrared absorption peaks at around 700 cm^{-1}, 713 cm^{-1}, 862 cm^{-1}, 1083 cm^{-1}, 1469 cm^{-1}, 1788 cm^{-1}, 2499 cm^{-1}, 2522 cm^{-1}, 2547 cm^{-1} and 2920 cm^{-1}. A typical FTIR spectrum is shown in *Figure* 2. These are typical infrared absorption peaks for calcium carbonate, $CaCO_3$ structure as given in Smith (1999). The peaks at 700 cm^{-1}, 713 cm^{-1}, 862 cm^{-1}, 1083 cm^{-1} show that $CaCO_3$ in the cultured pearls and pearl bead is of aragonite crystal structure, with a pattern similar to that shown by turtle eggshell (Baird and Soloman, 1979). The result shows that the pearl bead is made from the shell of a mollusc similar to that which produces the cultured pearls. Since the FTIR spectra of samples 1 to 8 give the same absorption peaks, it was not possible to use the FTIR method to differentiate naturally-coloured cultured pearls from the dyed ones. This agrees with the findings of Li (2001).

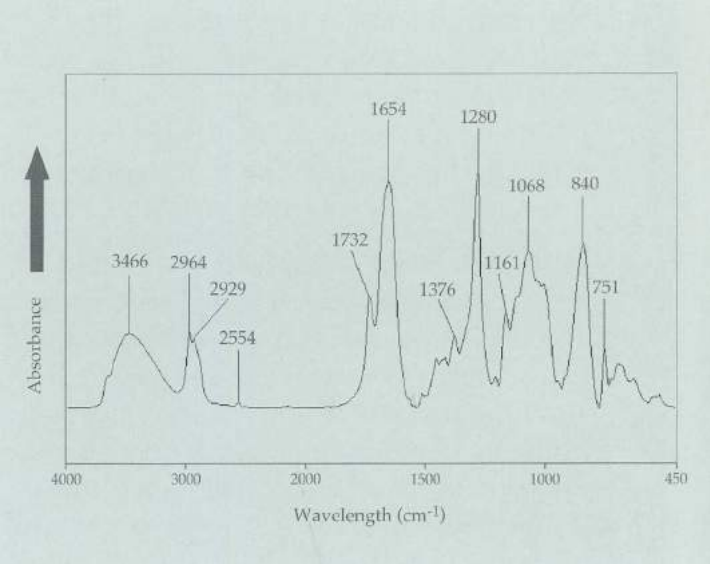

Figure 3: FTIR absorption spectrum typical of pearl imitations (samples 10 to 13).

The infrared spectra of pearl imitations (samples 10 to 13) and the bead used in pearl imitations (sample 14) are very different from those of cultured pearls. *Figure 3* shows the typical strong absorption peaks of pearl imitations at around 751 cm^{-1}, 840 cm^{-1}, 1068 cm^{-1}, 1161 cm^{-1}, 1280 cm^{-1}, 1376 cm^{-1}, 1654 cm^{-1}, 1732 cm^{-1}, 2554 cm^{-1}, 2929 cm^{-1}, 2964 cm^{-1} and 3466 cm^{-1}. These peaks indicate that pearl imitations are basically made up of polymeric material. In contrast to *Figure 2*, the absence of peaks due to $CaCO_3$ in *Figure 3*, especially that at 1469 cm^{-1}, clearly shows

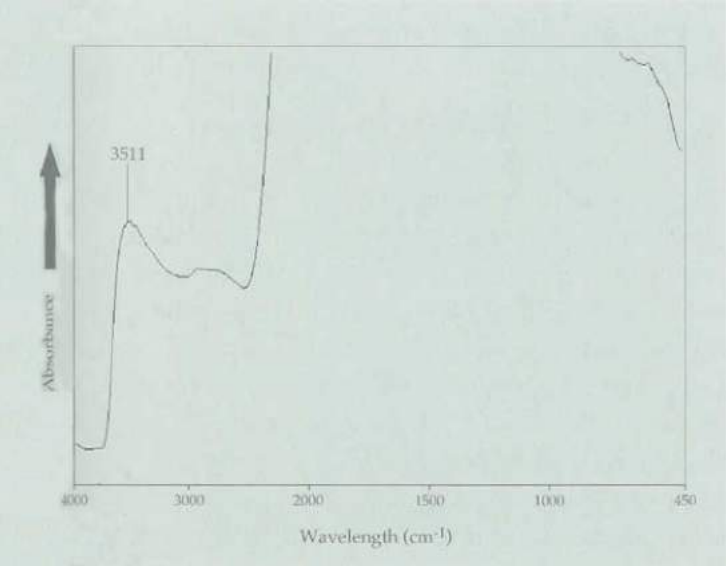

Figure 4: FTIR absorption spectrum typical of pearl imitation bead (sample 14).

that pearl material (nacre) is not used in imitations. In *Figure 3*, the peak at 3466 cm^{-1} is due to an O-H stretch, peaks at 2929 cm^{-1} and 2964 cm^{-1} are from C-H vibrations, strong peaks at 1654 cm^{-1} and 1732 cm^{-1} are due to C=O stretch, a strong peak at 1280 cm^{-1} is possibly due to a C-C-O asymmetric stretch in a phenol group, and the peak at 840 cm^{-1} is due to a C-C-O symmetric stretch (Smith, 1999 and Socrates, 1994). The presence of C, H and O atoms in these vibrations can be explained by the high polymeric content of pearl imitations. The bead for pearl imitations is opaque to infrared below 2500 cm^{-1} and has a broad peak at 3511 cm^{-1} as seen in *Figure 4*. This shows that the substance used in the bead is different from that used in cultured pearls.

The measurements of the various FTIR absorption peaks given in *Table 1* are useful and effective in differentiating naturally-coloured and dyed cultured pearls from their imitations. The beads used in cultured pearls and the pearl imitations are also different. One shortcoming of the method is that it does not enable distinction between the naturally-coloured and dyed cultured pearls. In addition, the technique is not sensitive enough to detect the low levels of dye used in the dyed pearls.

Energy dispersive X-ray fluorescence (EDXRF).

An EDXRF spectrum typical of naturally-coloured and dyed cultured pearls, is shown in *Figure 5*. The strong X-ray energy peaks of carbon, C $K\alpha_1$ at 0.277 keV; oxygen, O $K\alpha_1$ at 0.525 keV; calcium, Ca $K\alpha_1$ at 3.69 keV and Ca $K\alpha_2$ at 3.92 keV, and gold, Au M_β at 2.205 keV are present (see Blake, 1990). The spectrum recorded in the X-ray energy range of 0 to 9 keV can provide identification of all major elements with atomic number higher than boron, i.e. carbon and above, that are present on the surface of the pearls. The element hydrogen which is normally present in organic material as in pearl cannot be detected because of the small mass of hydrogen. EDXRF is a surface analysis technique with detection of elements to

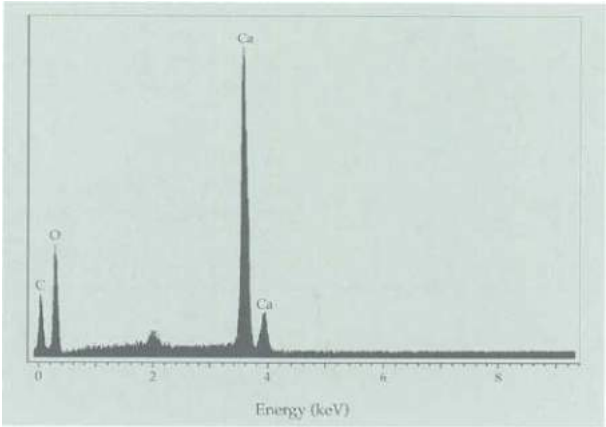

Figure 5: EDXRF spectrum typical of naturally-coloured and dyed cultured pearls (samples 1 to 8), and cultured pearl bead (sample 9).

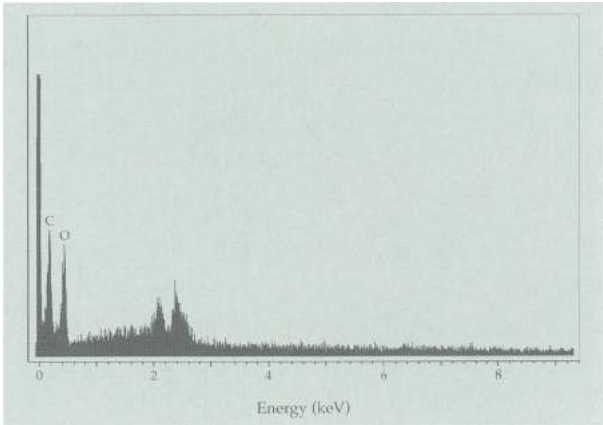

Figure 6: EDXRF spectrum typical of pearl imitations (samples 10-13).

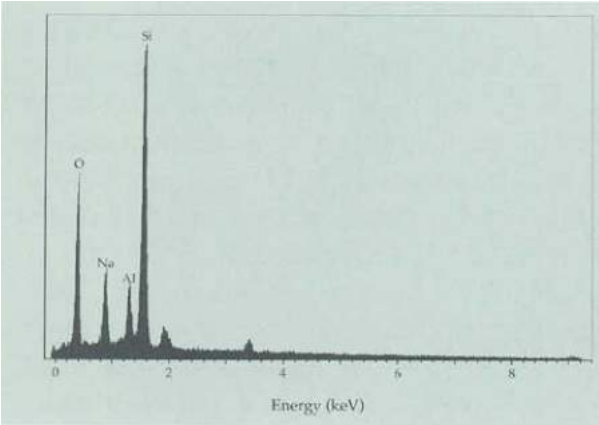

Figure 7: EDXRF spectrum typical of bead of pearl imitation (sample 14).

indistinguishable from those of samples 1-8 and is consistent with that of a mollusc shell.

The EDXRF spectrum typical of pearl imitations (samples 10-13) is shown in *Figure 6* and reveals the presence of C and O, and absence of Ca. The C and O peaks are consistent with the presence of polymers. Unfortunately, the EDXRF technique is unable to detect the lightest element, hydrogen which is an important component of polymers. The analysis of the bead (sample 14) used in pearl imitations is shown in *Figure 7* and indicates the presence of oxygen (O), silicon (Si), aluminium (Al) and sodium (Na). The energy

Figure 8: SEM micrograph typical of naturally coloured and of dyed cultured pearls (samples 1-8). Magnification 2000×.

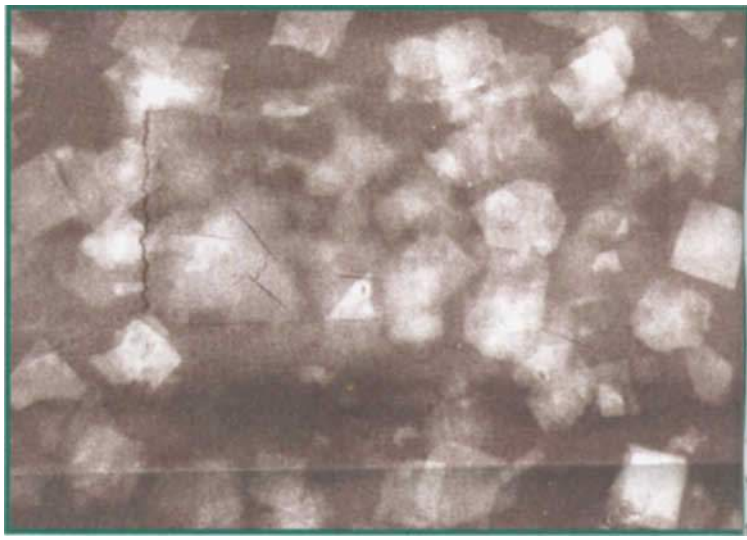

Figure 9: SEM micrograph typical of pearl imitations (samples 10 to 13). Magnification 2000×.

a depth of 5 μm, indicating that it may not be accurate for bulk studies. The gold peak comes from a thin layer of gold on the sample surface which is coated prior to the EDXRF scan to conduct away electrons from the electron beam and prevent a negative charge on the surface. The detection of Ca, C and O is consistent with the composition of cultured pearls, which is calcium carbonate, $CaCO_3$.

EDXRF spectra of dyed cultured pearls are similar to that in *Figure 5*. Elements other than Ca, C and O and Au are not found. This indicates that the dyes are not detectable by the EDXRF method. The EDXRF spectrum obtained from the cultured pearl bead is

pattern of the bead reveals that it cannot be $CaCO_3$. The high energy peaks of Si and O show that the bead is possibly made of glass as mentioned in Landman *et al.*, 2001. Further measurements on the bead give specific gravity as 2.2 and refractive index of 1.5, which are consistent with a glass material.

The elemental analysis of the samples using EDXRF provides useful information of the chemical composition of the surfaces of the samples. The detection of major elements can be used to distinguish cultured pearls from their imitations. The non-destructive

nature of EDXRF analysis is beneficial for pearls set in close-set jewellery.

Scanning Electron Microscopy (SEM)

All samples are coated with a very thin layer of gold to prevent surface charging during electron bombardment while viewing the SEM images.

The surfaces of naturally-coloured cultured pearls (samples 1-5), studied at magnifications up to 2000 times (*Figure 8*), consist of layered, contoured, and flake-like patterns. Similar patterns were observed on dyed cultured pearls (samples 6-8), and they are the top view of crystalline layers of calcium carbonate which were deposited gradually over time. The layers consist of aragonite platelets separated by conchiolin (Wada, 1999; Landman *et al.*, 2001). In contrast, the surface morphology of the pearl imitations (samples 10 to 13) is very different as shown in *Figure 9*. Small cubic particles of regular size are randomly distributed over the whole surface. These particles could be polymeric cubes in dense suspension in a matrix layer to cause the iridescence effect which imitates a natural pearl. The difference in the SEM observations is quite significant and could be useful for differentiating cultured pearls from their imitations.

For EDXRF and SEM experiments, all samples are coated with a very thin layer (a few nanometres) of gold using a vapour deposition method normally at a temperature of about 80°C in the chamber. For the smooth surfaces of pearls, the gold layer can be easily removed by wiping the surfaces with a soft texwipe dampened with distilled water. No resulting scratches were detected using a 10x loupe. For FTIR work, additional sample preparation is needed to make flat circular pellets. This takes about ten minutes for each sample preparation. The collection of a FTIR spectrum for a sample would take about five minutes. In EDXRF and SEM methods where the sample is placed in an evacuated chamber, each energy spectrum run or image focusing would take a total time of about 15 minutes, including pumping down time. The gold-coating process for these two methods is relatively simple and would take about ten minutes. For EDXRF and SEM measurements the experimental time is greatly reduced when a batch of 5 samples can be mounted on the same holder and studied in a single process run. Normally EDXRF and SEM measurements can be done on a sample concurrently using the same system. Generally, a conservative estimate of the total time required for each sample using all three tests: FTIR, EDXRF, and SEM is less than one an hour.

Conclusion

Basic gemmological tests such as optical spectroscopy and ultraviolet fluorescence are not sufficiently accurate for distinguishing cultured from imitation pearls. However, comparing their FTIR absorption peaks, pearl imitations can be distinguished from cultured pearls. In the present FTIR investigation, samples of pearl imitations on the market were found to be constructed of material consistent with a polymer. Also, on the basis of their FTIR absorption peaks, the cultured pearls consist of aragonite rather than calcite. Although the FTIR technique is reliable, it was destructive as a small amount of the cultured pearl or pearl imitation material had to be scraped from the surface to make circular pellets. In contrast, the EDXRF method is non-destructive, and the present investigations of cultured pearls, imitation pearls and the respective beads showed that accurate identification and differentiation of cultured pearls from pearl imitation are possible by determining which elements are present. Although it is not possible to distinguish naturally-coloured cultured and dyed cultured pearls using the FTIR and EDXRF techniques, imitation pearls could be reliably identified. Furthermore, the bead in the imitation pearls was found to be glass while that in cultured pearls was calcium carbonate. SEM micrographs of the surfaces of cultured pearls and pearl imitations are

significantly different and therefore useful for identification purposes. Hence judicious use of FTIR, EDXRF, and SEM techniques can lead to reliable identification of imitation pearls and cultured pearls.

Acknowledgement

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X-ray luminescence, a valuable test in pearl identification

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Abstract: *The increasing similarity of structures encountered in natural pearls and beadless freshwater cultured pearls requires one or more additional criteria for their differentiation. The majority of natural pearls are from saltwater oysters; in contrast, most beadless cultured pearls come from freshwater mussels. For some time it has been known that freshwater pearls produce luminescence under X-rays, whereas pearls grown in saltwater do not. The reason is because freshwater nacre contains traces of manganese. By using a sensitive camera this visible luminescence can be recorded and displayed on a monitor. The beads (from freshwater nacre) in Japanese saltwater cultured pearls (Akoya) also react to the X-ray excitation and may shine through the cultured overgrowths that are relatively thin. The method is used as an additional test and is not an alternative for X-radiograph images.*

Keywords: *freshwater nacre, Mn in aragonite, pearl identification, X-ray luminescence*

Pearl identification

Natural and beaded cultured pearls

In testing pearls, natural and cultured pearls are usually differentiated using X-ray shadow graphs (Lorenz and Schmetzer, 1986). X-ray shadowgraphs provide the most meaningful images to enable identification. Drill hole investigation by endoscope is now a historic method as needles for this technique are no longer available. A modern successor to the endoscope has been produced in a few prototypes (Atalay, 1994) and works with a red laser light. The proof for a bead in a cultured pearl is most efficiently detected by good radiography. With small beads and thick overgrowths, however, an X-ray shadowgraph will rarely show evidence of a bead. The Laue method is then a supplementary method when the presence of a nacre bead should be checked (Barnes, 1944). The method depends on interpreting the patterns obtained from unfiltered X-ray radiation directed on a bead consisting of well ordered layers of aragonite platelets (Barnes, 1944; Hänni, 1983). Six-spot patterns or four-spot patterns (Webster, 1994, p.547) may appear, depending on the direction of the ray with respect to the layers of an aragonite bead nucleus. Should the bead be of amorphous or unordered crystalline material, the

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pattern obtained would have no definite point structure, e.g. it may have a blurred halo or ring. A recent bead material manufactured form the giant clam shell (*Tridacna*), produces haloes on lauegrams when the X-ray beam is parallel to the growth layers. Perpendicular to the growth layers, clear four point patterns are visible. In any case, direct radiography (X-ray shadow method) is the preferred method to distinguish natural pearls from cultured pearls with a bead, either on fine-grained film or by digital imaging.

The growth structures of natural pearls as seen on X-radiographs have been known for many years; they reflect the individual growth development of each pearl (Alexander, 1939; Hänni, 2002). Characteristically there is an approximately round central body (formed by conchiolin-rich columnar calcite) coated by a more or less thick overgrowth of nacre formed by minute scales of tabular aragonite in concentric array. The X-radiographs of the aragonite coating can show concentric or bow-shaped lines.

Most natural pearls (all oriental pearls) derive from marine oysters, and the majority of beadless cultured pearls form in freshwater mussels. When there is no indication of a bead, a first separation of the two types can thus usually be made on the basis of whether nacre is saltwater or freshwater. A number of authors have already reported that freshwater nacre has an elevated concentration of manganese compared to saltwater nacre (Komatsu, 1987; Gutmannsbauer, 1992, 1994). Mn-doped calcium carbonate, including aragonite, possesses a characteristic luminescence when excited with X-rays or cathode rays (Waychunas, 1998). Freshwater nacre shows a characteristic fluorescence in whitish yellow (Lorenz and Schmetzer, 1985). In a recent publication Hänni *et al.* (2004) have demonstrated the usefulness of Mn-related X-ray luminescence in pearl identification.

Beadless cultured pearls

In the past the identification of beadless cultured pearls was straightforward because their radiography showed clear indications of their origin. The distinctive features on the film consist of a curved fine line or tangle of lines in the centre of the pearl, being the image of a complex central cavity, often empty or containing brown organic material. Note that the organic material is not the tissue transplant, as often reported. The tissue transplant grows into the pocket which is later the pearl sac, producing and containing the cultured pearl. However, these central features in older freshwater beadless cultured pearls are no longer as clear and large in the newer Chinese freshwater beadless cultured pearls. Smaller tissue parts are being transplanted and more years are allowed for the growth of the pearl. Because of the smaller graft the first pocket on whose surface the calcium carbonate is precipitated is also smaller. Any resulting cavity in the cultured pearl would be minute and would most probably be eliminated by the drilling process. Other growth features in the near-round to round Chinese freshwater cultured pearls may exist but are not always clearly visible in a random position of the pearl, although wavy growth lines or dividing lines have been shown by Scarratt *et al.* (2000). Beadless saltwater cultured pearls may show central cavities, too. Two cases may be discussed:

1. If the oyster has expelled the first bead, but the tissue graft still forms a pearl sac, a beadless cultured pearl can result. In the trade, beadless cultured saltwater pearls (South Sea and Tahiti) are often called 'Keshi'. There is no need and it is rather incorrect to call these products 'Keshi'. Originally Japanese Keshi cultured pearls were mantle pearls produced by accidental injury to the mantle of Akoya oysters. The term should definitely not be used for cultured pearls in gonad-grafted oysters.
2. If, after the first pearl crop, a second bead is inserted and the oyster expels it, the pearl sac, ready for further production, collapses, with nothing there to support it. Consequently, the shape of the second cultured pearl is very baroque, usually flattened. There is no need to call it 'Keshi' either, it is just a beadless cultured pearl. This kind of beadless Tahiti or South Sea cultured pearl is relatively simple to identify with an X-radiograph.

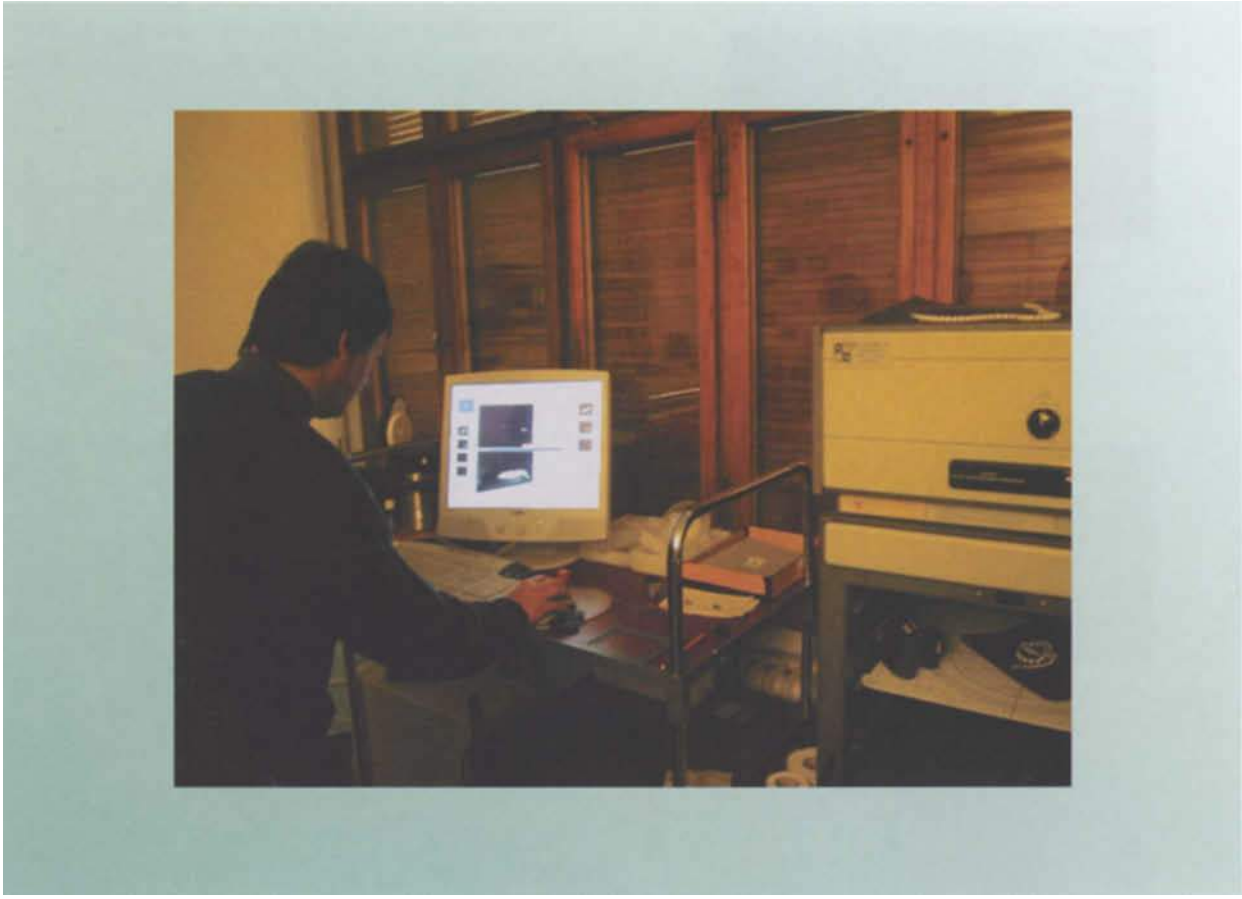

Figure 1: Working situation with X-ray apparatus, CCD camera and screen. A pearl necklace is ready in the X-ray chamber, the camera F-View II is visible. Photo H.A. Hänni © SSEF Swiss Gemmological Institute.

Investigation of the X-ray luminescence of nacre

For the observation of X-ray luminescence it could be sufficient to look at the objects in the dark when they are under X-ray excitation were it not for health and safety requirements. Since X-rays scatter and reflect off surfaces, it is absolutely necessary that the observer is protected from any of the rays which might reach the body. The excitation has thus to be made in a conventional X-ray cabinet, i.e. a conventional device for X-radiography with an observation window of lead glass. Safety is then guaranteed. The tungsten tube is operated at 95 kV and 4 mA. Instead of just looking at the effect, we propose here the use of a very sensitive digital camera system which records the luminescence pictures. The low intensity light emitted requires a special CCD camera and a computer programme (AnalySIS) which manages the recording. Preliminary experiments have proven the validity of the commercially available viewing system 'F-View II' by Soft Imaging Systems (*Figure 1*). The camera is equipped with a Peltier element that cools the detector. This provides low noise and the signals produce excellent pictures. The software allows easy control of the system and picture management (*Figure 2*). Since the camera is very sensitive to light, only low light is

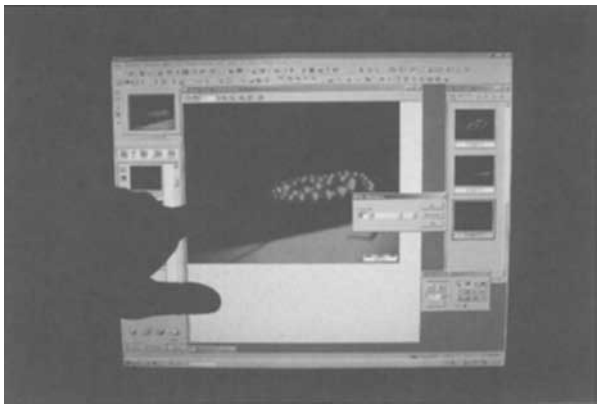

Figure 2: A pearl necklace, ready in the X-ray chamber, is pictured in room light and shown on the screen. The management and recording of images are done with a special programme. Photo H.A. Hänni © SSEF Swiss Gemmological Institute.

Figure 3: A strand of South Sea cultured pearls from Australia (right) and a strand of freshwater cultured pearls from China (left) in the weak room light supplied by a diode. Photo P. Giese © SSEF Swiss Gemmological Institute.

Figure 4: The same necklace as in Figure 3 *under X-ray excitation. The South Sea cultured pearls (from saltwater) do not show any luminescence while the freshwater cultured show clear luminescence. Photo P. Giese © SSEF Swiss Gemmological Institute.*

needed to provide the first reference picture, and a diode was chosen, already fixed in the sample room. A second picture of the pearls in the same position was then taken under X-rays. *Figures* 3 and 4 show a strand of Australian saltwater cultured pearls with thick overgrowths on the beads, next to a strand of beadless Chinese freshwater cultured pearls for comparison.

When Akoya cultured pearls are tested it becomes apparent that the bead which is made of shell grown in freshwater, also gives a luminescence reaction to the X-ray excitation. Depending on nacre thickness and the amount of organic material on each bead, different amounts of light may be registered (see *Figures* 5 and 6). The luminescence reaction may also be inhibited when pearls are dyed with dark colours or beaded cultured pearls have naturally pigmented overgrowths as e.g. from Tahiti or Mexico – although even in these examples, response can be variable.

No luminescence reaction appears with *Tridacna* (giant clam shell) beads, since this shell material grows in saltwater and does not contain the Mn which causes the luminescence.

Conclusions

X-rays cause weak luminescence in freshwater nacre or pearls. This effect is due to a weak concentration of manganese. Since nacre or pearls from saltwater are free of manganese, luminescence does not occur. The luminescence is only visible in the dark, either by the naked eye or with a sensitive CCD digital camera. This is an additional means of differentiation between freshwater and saltwater pearls and cultured pearls where X-ray features are not sufficient. Since Chinese freshwater cultured pearls are taking an increasing share of the market, possibilities of mixing them up with South Sea

Figure 5: An Akoya cultured pearl necklace (freshwater nacre beads with saltwater nacre overgrowth) in room light, ready in the X-ray apparatus for a luminescence picture. Photo P. Giese © SSEF Swiss Gemmological Institute.

Figure 6: The Akoya cultured pearl necklace shown in Figure 5 *recorded under X-ray radiation. Depending on the thicknesses of the overgrowths, a different luminescence is visible in different pearls, indicating that Mn is present in the beads. Photo P. Giese © SSEF Swiss Gemmological Institute.*

cultured pearls or with natural marine pearls are growing. Since pearl identification may be increasingly problematic, especially when only X-radiographs are considered, the observation of X-ray luminescence will be most useful for testing strands with a mixture of different types of pearls, and the attribution of pearls of a different type within a strand can be made with more confidence. The method is limited when nacre is rich in colouring pigment which generally suppresses the luminescence. This can occur with naturally coloured as well as with dyed pearls.

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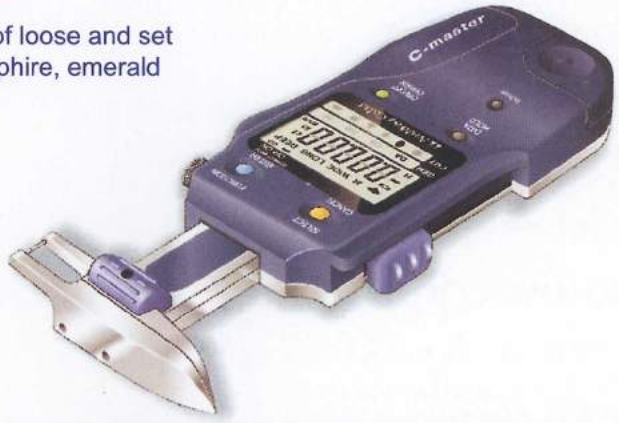

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The variation of RI with rotation of a doubly refractive gemstone on the refractometer hemicylinder

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Abstract: *The hemicylinder refractometer is used to determine the refractive index (RI) of faceted anisotropic gemstones as a function of crystal orientation. The technique is difficult due to large errors in measurement and uncertainty in the orientation of facets. The theoretical variation is investigated using analytical geometry to generate comprehensive parametric graphs of RI variation. These graphs are analysed systematically, providing methods with reference examples for determining the optic character of anisotropic gemstones.*

Keywords: *analytical geometry, double refraction, indicatrix section, optic orientation, refractive index variation*

Introduction

The refractive indices of a doubly refractive gemstone with RI < 1.8 can be determined by placing it in the centre of a refractometer hemicylinder with contact fluid (RI > 1.8) and recording the RI readings as it is rotated (see Hurlbut and Kammerling, 1991, 102, Fig. 7.26). The technique may be used on uniaxial and biaxial crystals regardless of optic sign. Readings are taken approximately every 15° or 30° as the stone is rotated on the hemicylinder through 180°. A graph of RI variation for such a gemstone may be obtained by plotting all sets of readings on a two-dimensional right-angled coordinate system, in which the vertical axis is the value of RI and the horizontal axis is the degree of rotating angle. Because of limits on the accuracy of measurement and difficulty in identifying the facet orientation of a gemstone, it is difficult to work out comprehensive and accurate graphs of RI variation for doubly refractive gemstones. This study, a theoretical model of the practical operational procedures, generates systematic graphs of RI variation using the analytical geometry method (*Figures* 3 and 4). By analysing these graphs, we can improve the study of the variation of RI with rotation of a gemstone on the refractometer hemicylinder. The following sections fulfil two purposes: they explain the actual technique of performing such measurements, and also show how the analytical geometry equations are solved in order to generate parametric graphs.

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The selections of initial orientation

The definition of the initial orientation

The initial orientation is the spatial relation between the gemstone's indicatrix and the surface of the refractometer hemicylinder; it is the position of the first measurement of RI before any rotation.

In order to indicate the orientation of a gemstone's indicatrix, we construct a three-dimensional right-angled system with Ox, Oy and Oz coordinates as follows *(Figure 1)*:

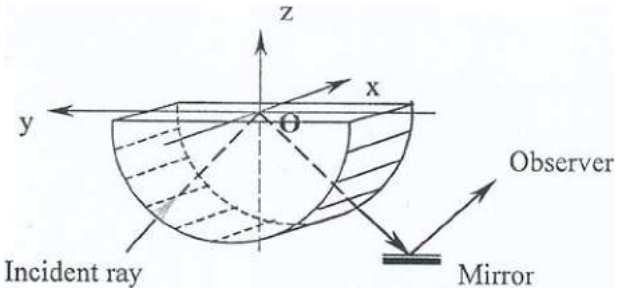

Figure 1: A schematic diagram to show the spatial relation of the coordinate system and the surface of the refractometer hemicylinder.

The coordinate plane xOy lies on the hemicylinder surface, and the following text relates to *Figure 1*. The origin O of the coordinates is located at the centre of the hemicylinder surface and represents the spot or position of total reflectance of the incident ray for angles greater than the critical angle. The Ox-axis is perpendicular to the long side of the rectangular hemicylinder surface, and points to the right of the observer. The Oy-axis is parallel to the long side and points forward from the observer and to the left of the reader. The Oz-axis is vertical and points upward.

After the relationship between the Oxyz coordinates and the refractometer hemicylinder has been established, the centre of the indicatrix of a gemstone placed on the refractometer can also be established to coincide with the origin of the Oxyz coordinates. With this in place, the initial orientation for a uniaxial gemstone can be determined by two angular measures: one between the vibration direction of the extraordinary ray and the Oy-axis *(Figure 2a)*, and the other between the plane NeOy (containing the Ne-semiaxis of indicatrix and the Oy-axis), and the coordinate plane xOy. These measures are respectively expressed by the symbols Ne^Oy and NeOy^xOy. The initial orientation for a biaxial gemstone is also determined by two angles. The first is between the vibration direction of the intermediate index (Nm) and the Oy-axis *(Figure 2b)*, and the other is between the vibration direction of the greatest index (Ng) and the Oz-axis. These measures are respectively expressed by the symbols Nm^Oy and Ng^Oz.

The selections of initial orientation

To illustrate the theory outlined in later sections, different initial orientations of a uniaxial gemstone have been selected and are

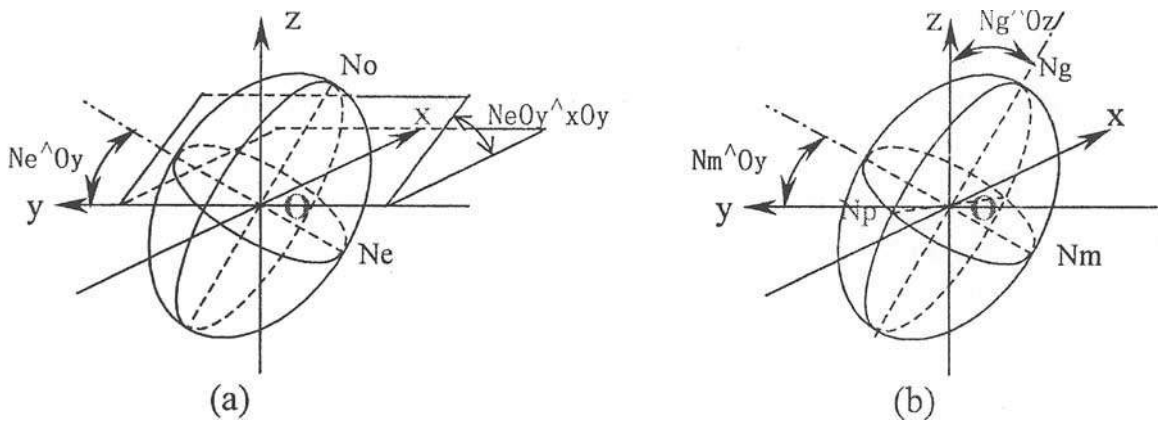

Figure 2: The relation of the indicatrix to the Oxyz coordinates in the initial orientation ((a) represents a uniaxial and (b) a biaxial gemstone).

listed in *Table I* ; these relate to *Figure 3*. Similarly, *Table II* contains selections of initial orientation for biaxial gemstones and these relate to *Figure 4*.

On rotation on a refractometer, biaxial gemstones produce more complex graphs than do uniaxial stones, so in this paper, more examples of different initial orientations of the former are listed and illustrated.

Figure 3: Graphs of RI variation of tourmaline as it is rotated on a refractometer hemicylinder. The vertical coordinate axis represents RI, and the horizontal axis represents the angle of rotation θ . Positions of initial orientation (A-00 etc.) are listed in Table I.

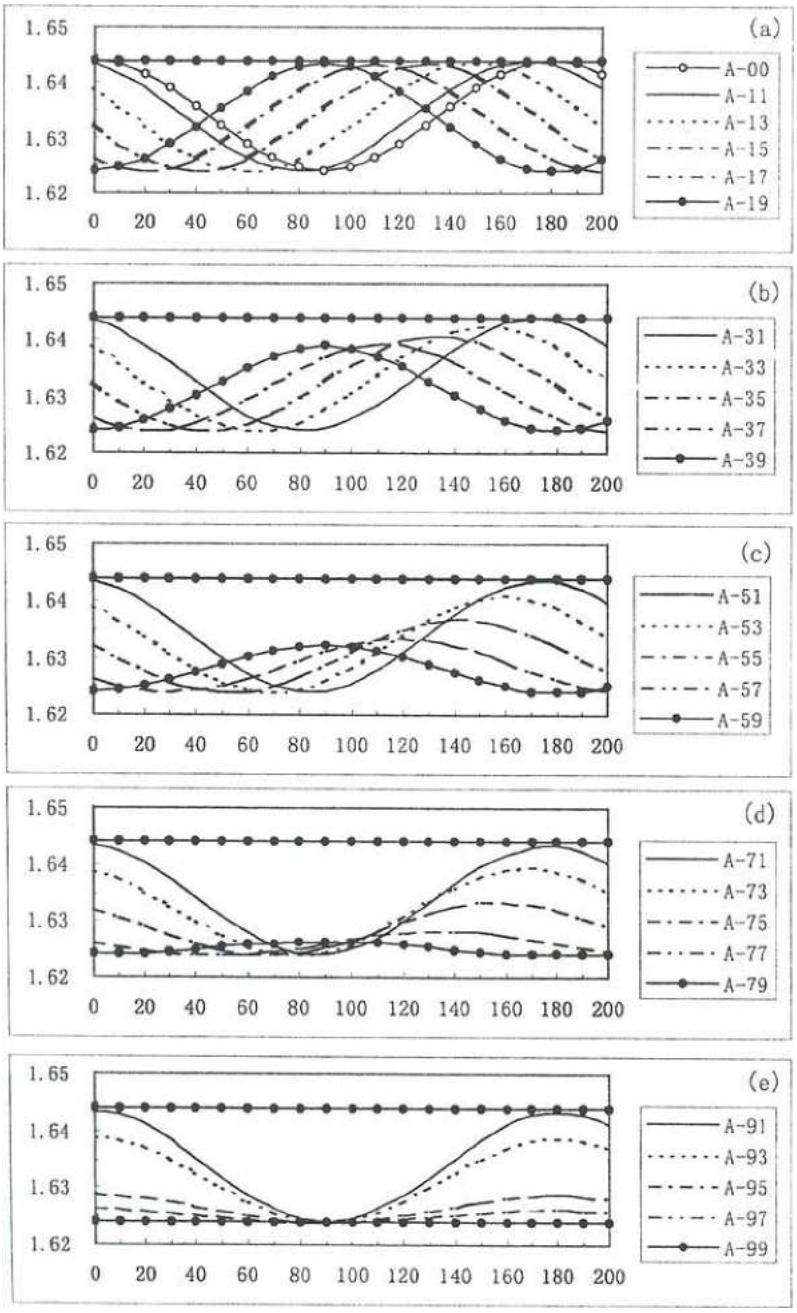

Table I: The selection of initial orientation for uniaxial gemstones.

Number	Ne^Oy	NeOy^xOy
A-00	00°	00°
A-11	10°	10°
A-13	30°	10°
A-15	50°	10°
A-17	70°	10°
A-19	90°	10°
A-31	10°	30°
A-33	30°	30°
A-35	50°	30°
A-37	70°	30°
A-39	90°	30°
A-51	10°	50°
A-53	30°	50°
A-55	50°	50°
A-57	70°	50°
A-59	90°	50°
A-71	10°	70°
A-73	30°	70°
A-75	50°	70°
A-77	70°	70°
A-79	90°	70°
A-91	10°	90°
A-93	30°	90°
A-95	50°	90°
A-97	70°	90°
A-99	90°	90°

Table II: The selection of initial orientation for biaxial gemstones.

Number	Nm^Oy	Ng^Oz	Number	Nm^Oy	Ng^Oz	Number	Nm^Oy	Ng^Oz	Number	Nm^Oy	Ng^Oz
B-00	00°	00°	B-25	50°	20°	B-50	00°	50°	B-75	50°	70°
B-01	10°	00°	B-26	60°	20°	B-51	10°	50°	B-76	60°	70°
B-02	20°	00°	B-27	70°	20°	B-52	20°	50°	B-77	70°	70°
B-03	30°	00°	B-28	80°	20°	B-53	30°	50°	B-78	80°	70°
B-04	40°	00°	B-29	90°	20°	B-54	40°	50°	B-79	90°	70°
B-05	50°	00°	B-30	00°	30°	B-55	50°	50°	B-80	00°	80°
B-06	60°	00°	B-31	10°	30°	B-56	60°	50°	B-81	10°	80°
B-07	70°	00°	B-32	20°	30°	B-57	70°	50°	B-82	20°	80°
B-08	80°	00°	B-33	30°	30°	B-58	80°	50°	B-83	30°	80°
B-09	90°	00°	B-34	40°	30°	B-59	90°	50°	B-84	40°	80°
B-10	00°	10°	B-35	50°	30°	B-60	00°	60°	B-85	50°	80°
B-11	10°	10°	B-36	60°	30°	B-61	10°	60°	B-86	60°	80°
B-12	20°	10°	B-37	70°	30°	B-62	20°	60°	B-87	70°	80°
B-13	30°	10°	B-38	80°	30°	B-63	30°	60°	B-88	80°	80°
B-14	40°	10°	B-39	90°	30°	B-64	40°	60°	B-89	90°	80°
B-15	50°	10°	B-40	00°	40°	B-65	50°	60°	B-90	00°	90°
B-16	60°	10°	B-41	10°	40°	B-66	60°	60°	B-91	10°	90°
B-17	70°	10°	B-42	20°	40°	B-67	70°	60°	B-92	20°	90°
B-18	80°	10°	B-43	30°	40°	B-68	80°	60°	B-93	30°	90°
B-19	90°	10°	B-44	40°	40°	B-69	90°	60°	B-94	40°	90°
B-20	00°	20°	B-45	50°	40°	B-70	00°	70°	B-95	50°	90°
B-21	10°	20°	B-46	60°	40°	B-71	10°	70°	B-96	60°	90°
B-22	20°	20°	B-47	70°	40°	B-72	20°	70°	B-97	70°	90°
B-23	30°	20°	B-48	80°	40°	B-73	30°	70°	B-98	80°	90°
B-24	40°	20°	B-49	90°	40°	B-74	40°	70°	B-99	90°	90°

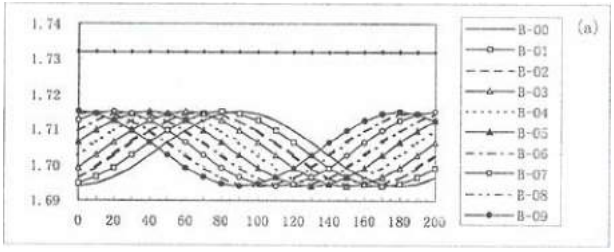

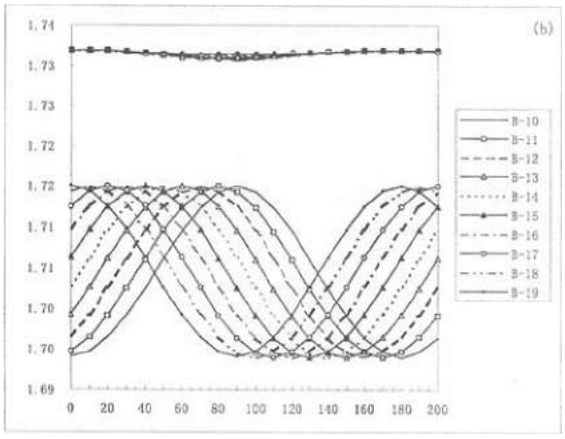

Figure 4: Graphs of RI variation of chrysolite as it is rotated on a refractometer hemicylinder. The vertical coordinate axis represents RI, and the horizontal axis represents the angle of rotation θ. Positions of initial orientation (B-00 etc.) are listed in Table II.

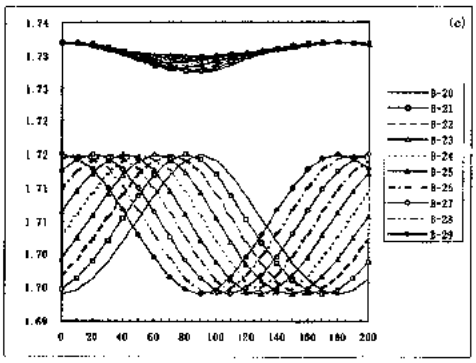
(c)
B-20
B-21
B-22
B-23
B-24
B-25
B-26
B-27
B-28
B-29

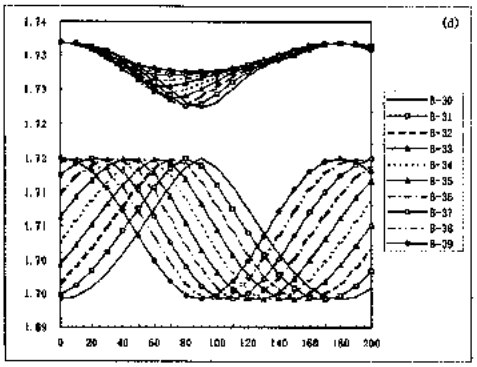
(d)
B-30
B-31
B-32
B-33
B-34
B-35
B-36
B-37
B-38
B-39

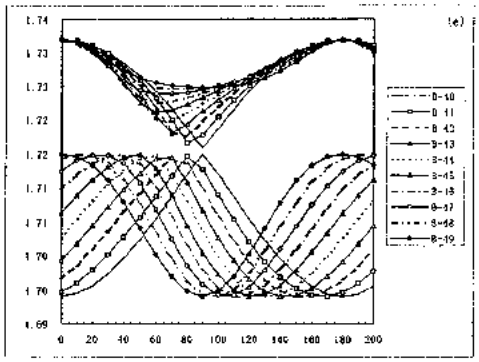
(e)
B-40
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B-45
B-46
B-47
B-48
B-49

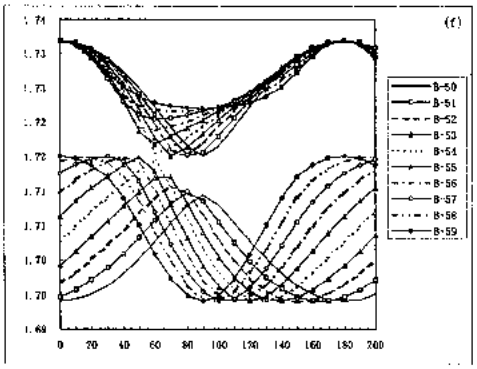
(f)
B-50
B-51
B-52
B-53
B-54
B-55
B-56
B-57
B-58
B-59

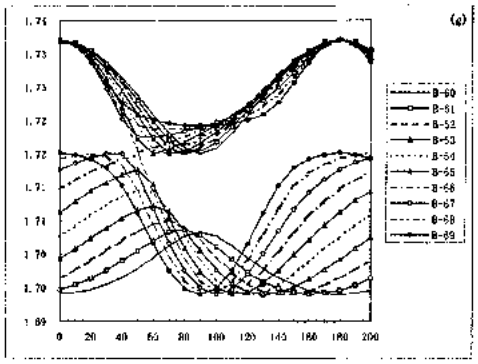
(g)
B-60
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B-68
B-69

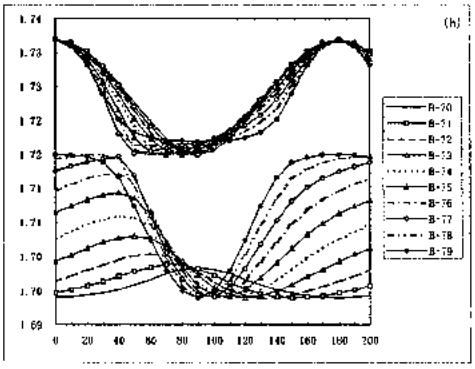
(h)
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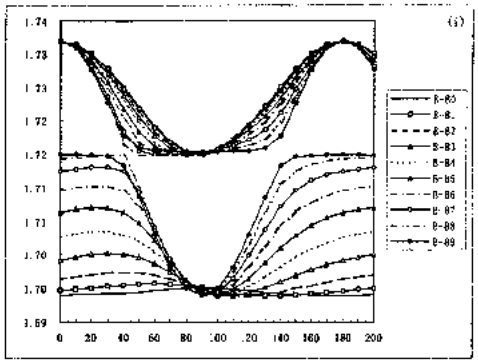
(i)
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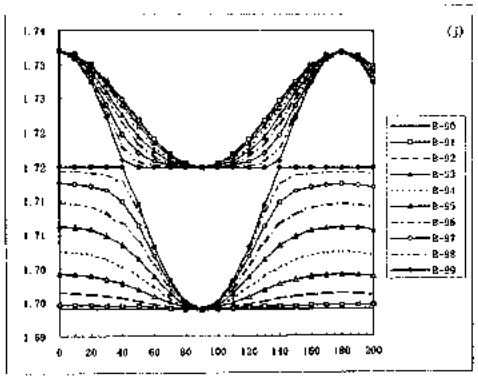
(j)
B-90
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B-92
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B-96
B-97
B-98
B-99

Construction of the graphs of RI variation by rotation of the gemstone

Just as RI variation can be plotted from practical measurements after an initial orientation is given, the RI values can be calculated using analytical geometry, with the process repeated for increments of 10° rotation of the gemstone, from 0° up to 200° on the hemicylinder (for the mathematical details, see Appendix). The angle of rotation of the gemstone on the hemicylinder is represented by the symbol θ, which is the angle of rotation around the Oz-axis from the initial orientation to the orientation in which the stone is being tested. To complete the parametric graph of RI variation for an initial orientation, plot all sets of the refractive indices and angles on a two-dimensional right-angle coordinate system, with the abscissa being the angle of rotation θ and the ordinate, the RI value.

Parametric graphs of tourmaline's RI variation are given in *Figure 3* as an example of a uniaxial crystal with negative optic sign. There are 26 parametric graphs corresponding with the initial orientations listed in *Table I* ; 25 consist of five sets of five graphs representing five values of NeOy^xOy(β_o), and one exceptional case, the graph A-00 is plotted on *Figure 3(a)*. For uniaxial crystals, the graph of RI variation for a positive crystal is the inverted image of that for a negative crystal in the same initial orientation, so this aspect of the investigation is complete.

Graphs of chrysolite's RI variation are listed in *Figure 4* as examples of a biaxial crystal. These correspond with the 100 initial orientations listed in *Table II* and consist of 10 groups, each group of graphs having the same angle Ng^Z (β_o).

Discussion

Each graph obtained from a uniaxial negative crystal consists of two lines *(see Figure 3)*: one is a straight line (i.e. the RI remains stationary) resulting from the ordinary ray and the other usually is a waveform curve resulting from the extraordinary ray (denoted by Ne', as opposed to Ne which is restricted to the one value furthest from No). They respectively represent the constancy of the RI No and the variation of Ne' as the stone is rotated on the hemicylinder. For the graphs of random initial orientations (i.e. the A-00 and A-99 graphs are excepted), the distance between the straight line No and the curve Ne' increases as the angle Ne^Oy increases, with the angle NeOy^xOy unchanged. Similarly, this distance increases as the angle NeOy^xOy increases, with the angle Ne^Oy unchanged. In a special initial orientation with the angles Ne^Oy = 90° and NeOy^xOy = 90° (i.e. the plane of vibration of Ne is vertical), both lines are straight in this graph (see A-99 in *Figure 3(e)*), and the higher and lower RIs respectively express the values No and Ne (the crystal is optically negative).

The graphs of a biaxial gemstone in initial orientations usually consist of two curves (*see Figure 4*). They respectively represent the variations of the RI Ng' and the RI Np' curves as the gemstone is rotated on the hemicylinder. For chrysolite, when the angle Ng^Oz is less than 40° (Ng^Oz = 0 is excepted), the minimum of the curve Ng' rises as the angle Nm^Oy increases (angle Ng^Oz unchanged), and the minimum falls as the angle Ng^Oz increases (angle Nm^Oy unchanged). When the angle Ng^Oz is more than 40°, the relation between the distance of the two curves and the angle Nm^Oy or Ng^Oz is more complex than when the angle is less than 40°. Under special initial orientations, such as the angle Ng^Oz = 0° and Nm^Oy =0° to 90° (i.e. the vibration plane of Ng is vertical), all parametric graphs have a straight line showing the refractive index Ng, and have similar curves (only their phase angles vary) showing the variations Np' for different angles Nm^Oy (see graphs B-00 to B-09 in *Figure 4 (a)*). Also in the special initial orientation Nm^Oy = 0° and Ng^Oz = 90° (i.e. the vibration plane Np is vertical), one line is straight showing the refractive index Np, the other is a curve showing the variation of Ng' (see B-90 in *Figure 4 (j)*). Again, in the case of

the angle Nm^Oy=90° and Ng^Oz=90° (i.e. the vibration plane of Nm is vertical), a straight line represents the refractive index Nm and the curve represents the variation of Ng′ or Np′ (see B-99 in *Figure 4 (j)*). A straight line on a plot for a biaxial gemstone can appear only with an initial orientation whereby one of the vibration planes of the three principal refractive indices is vertical.

Generally, the curve of RI variation of a doubly refractive gemstone is undulant with a period of 180°. In the RI variational graph of uniaxial gemstones, the curve Ne′ looks like a sine wave. Both the ascending and descending segments have the same gradient and length. In other words, the waveform of the curve Ne′ is symmetrical about the vertical line through the wave peak or wave trough. The principal refractive index Ne for uniaxial crystals is found from the highest points of the curve Ne′ of optically positive crystals or from the lowest point of optically negative crystals. Unlike uniaxial crystals, the curves Ng′ or Np′ of a biaxial gemstone in random orientation are not symmetrical about any vertical line. The gradient and length of an ascending segment are different from those of the descending segment. This results from the inequality of the three principal axes in the biaxial indicatrix. The principal refractive indices, Ng and Np in biaxial crystals, are respectively found from the highest point of the curve Ng′ and from the lowest point of the curve Np′.

The Nm value can be obtained only if one of the following three cases has occurred. Firstly the graph has been constructed using a special initial orientation (i.e. one of the vibration directions of the three principal indices is vertical). For instance, when the vibration of Ng is vertical, the value Nm is the maximum of the curve Np′ (see B-00 to B-09 in *Figure 4(a)*). And when the vibration of Np is vertical, the value Nm is the minimum of the curve Ng′ (B-90 in *Figure 4(j)*). When the vibration of Nm is vertical, the value Nm is expressed by the stationary RI in the graph (B-99 in *Figure 4 (j)*). Secondly the curves Ng′ and Np′ have a conjunct point. This point indicates the value of Nm. For example, the RI variational graphs of chrysolite have this point in the initial orientation about Nm^Oy = 60° and Ng^Oz =60° (B-66 in *Figure 4 (g)*). In the third case, the Nm is determined using two graphs: the maximum of the curve Np′ from one graph should coincide with the minimum of the curve Ng′ from another graph and indicate the value of Nm. Although it may be more difficult to obtain the value Nm than Ng or Np in practical measurement, the optic sign of a biaxial gemstone can be determined if the minimum of the curve Ng′ is lower than the middle value between Ng and Np, or the maximum of the curve Np′ is higher than the middle value (Read, 1990, p.98).

Conclusions

Parametric RI curves relative to rotations on a hemicylinder have been calculated for uniaxial and biaxial gemstones, and these have been used to illustrate the principles and problems associated with the practical technique of determining the refractive indices of gemstones. The curves can be used to guide smoothing of actual measurements, and improve procedures and accuracy of RI determinations. The complexities indicate how essential it is to try and orient at least one axis of the indicatrix parallel to the normal of the hemicylinder surface.

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We thank Dr Barron Larry, Geological Survey of Australia, and Dr Joe Xie, Department of Mineral Resources of Australia, very much for their helpful suggestions and advice concerning the paper.

Appendix

The analytical geometry method used to produce graphs of RI variation

The definition of the basic orientation and the spherical surface equations of the indicatrix.
In this paper, the **basic orientation** is estab-

lished so that the vibration direction of the principal index Ne coincides with the Oy-axis of the Oxyz coordinates for uniaxial crystals. The vibration directions of the principal indices Np, Nm and Ng of biaxial crystals coincide respectively with the Ox-axis, Oy-axis and Oz-axis. The equations for the spherical surfaces of a uniaxial indicatrix (eq.1) and of a biaxial indicatrix (eq.2) respectively are:

$$x^2 / No^2 + y^2 / Ne^2 + z^2 / No^2 = 1 \quad (1)$$

$$x^2 / Np^2 + y^2 / Nm^2 + z^2 / Ng^2 = 1 \quad (2)$$

The initial orientation and the spherical surface equation of the indicatrix

The definition of **initial orientation** is the same as that given in the text.

Initial orientations can be obtained from the basic orientation by the following means. First, rotate the gemstone's indicatrix clockwise by an angle θ_o on the coordinate plane xOy (i.e. round the Oz-axis). Then rotate the indicatrix clockwise by an angle β_o on the plane xOz (i.e. round the Oy-axis). For this case, the initial orientation of the gemstone is indicated by the pair of angles θ_o and β_o. This operation of clockwise rotation of the indicatrix is the same as the counter-clockwise rotations of the coordinates xOy and xOz in order by the angles θ_o and β_o. Note that the angle θ_o is the same as Ne^Oy for uniaxial and Nm^Oy for biaxial gemstones, whereas the angle β_o is same as NeOy^xOy for uniaxial and Ng^Oz for biaxial gemstones *(see Table I and Table II)*.

The position of a general point P on the surface of a gemstone's indicatrix, is identified by three coordinates (x,y,z) in the basic orientation. The coordinates of the same point have been changed after the rotation of the indicatrix by θ_o and β_o (here $\theta_o \neq 0$ and $\beta_o \neq 0$). If the point P in the initial orientation θ_o and β_o is identified by the coordinates (x_i, y_i, z_i), the following set of equations can express the relationship of the coordinates (x,y,z) to the coordinates (x_i, y_i, z_i).

$$x = x_i \cos\theta_o \cos\beta_o - y_i \sin\theta_o - z_i \cos\theta_o \sin\beta_o$$
$$y = x_i \sin\theta_o \cos\beta_o + y_i \cos\theta_o - z_i \sin\theta_o \sin\beta_o$$
$$z = x_i \sin\beta_o + z_i \cos\beta_o \quad (3)$$

Substituting in equations (1) and (2), the spherical surface equation of the uniaxial indicatrix becomes equation (4), and for the biaxial indicatrix it becomes equation (5):

$$[(x_i \cos\theta_o \cos\beta_o - y_i \sin\theta_o - z_i \cos\theta_o \sin\beta_o)^2 + (x_i \sin\beta_o + z_i \cos\beta_o)^2] / No^2 + (x_i \sin\theta_o \cos\beta_o + y_i \cos\theta_o - z_i \sin\theta_o \sin\beta_o)^2 / Ne^2 = 1 \quad (4)$$

$$(x_i \cos\theta_o \cos\beta_o - y_i \sin\theta_o - z_i \cos\theta_o \sin\beta_o)^2 / Np^2 + (x_i \sin\theta_o \cos\beta_o + y_i \cos\theta_o - z_i \sin\theta_o \sin\beta_o)^2 / Nm^2 + (x_i \sin\beta_o + z_i \cos\beta_o)^2 / Ng^2 = 1 \quad (5)$$

The elliptic equation of the indicatrix section on the xOz plane after rotation by an angle θ

Like the procedure used in practical measurement to generate RI values, after the initial orientation (θ_o, β_o) is given and the first RI values have been calculated, this procedure is continued as the gemstone's indicatrix is rotated in 10° increments on the xOy plane through to 200°.

As the indicatrix is rotated by an angle θ from the initial orientation (θ_o, β_o), the coordinates of the point P also change. If the coordinates of the point P in this orientation are expressed by (x_r, y_r, z_r), a set of three equations (Eq. (6)) can represent the relationship of (x, y, z) to (x_r, y_r, z_r).

$$x = (x_r \cos\theta - y_r \sin\theta) \cos\theta_o \cos\beta_o - (x_r \sin\theta + y_r \cos\theta) \sin\theta_o - z_r \cos\theta_o \sin\beta_o$$

$$y = (x_r \cos\theta - y_r \sin\theta) \sin\theta_o \cos\beta_o + (x_r \sin\theta + y_r \cos\theta) \cos\theta_o - z_r \sin\theta_o \sin\beta_o$$

$$z = (x_r \cos\theta - y_r \sin\theta) \sin\beta_o + z_r \cos\beta_o \quad (6)$$

In terms of optic principles and the defined basic orientation, as a beam of light passes from the hemicylinder into a gemstone the ray is refracted away from the normal. When the angle of incidence is at the critical angle, the refracted ray moves in the direction opposite to that of the Oy-axis as it is in *Figure 1* on the gemstone's surface, and its vibration direction is parallel to the coordinate plane xOz. This means that the gemstone's indicatrix section relative to this light lies on the plane xOz, and its elliptic equation can be obtained from the spherical surface

equation of the indicatrix by constraining $y_r = 0$. In this situation, the elliptic equation for the uniaxial indicatrix section is expressed as:

$$E_u z_r^2 + F_u x_r z_r + G_u x_r^2 = 1 \qquad (7)$$

where:

$E_u = [(\cos^2\beta_o + \cos^2\theta_o \sin^2\beta_o) / No^2 + \sin^2\theta_o \sin^2\beta_o / Ne^2]$

$F_u = 2\{(\cos\theta \sin\beta_o \cos\beta_o - (\cos\theta \cos\theta_o \cos\beta_o - \sin\theta \sin\theta_o) \cos\theta_o \sin\beta_o) / No^2 - (\cos\theta \sin\theta_o \cos\beta_o + \sin\theta \cos\theta_o) \sin\theta_o \sin\beta_o / Ne^2\}$

$G_u = [(\cos^2\theta \sin^2\beta_o + (\cos\theta \cos\theta_o \cos\beta_o - \sin\theta \sin\theta_o)^2) / No^2 + (\cos\theta \sin\theta_o \cos\beta_o + \sin\theta \cos\theta_o)^2 / Ne^2]$

For the biaxial indicatrix, the elliptic equations are:

$$E_b z_r^2 + F_b x_r z_r + G_b x_r^2 = 1 \qquad (8)$$

where:

$E_b = [\cos^2\beta_o / Ng^2 + \sin^2\theta_o \sin^2\beta_o / Nm^2 + \cos^2\theta_o \sin^2\beta_o / Np^2]$

$F_b = 2[\cos\theta \sin\beta_o \cos\beta_o / Ng^2 - (\cos\theta \sin\theta_o \cos\beta_o + \sin\theta \cos\theta_o) \sin\theta_o \sin\beta_o / Nm^2 - (\cos\theta \cos\theta_o \cos\beta_o - \sin\theta \sin\theta_o) \cos\theta_o \sin\beta_o / Np^2]$

$G_b = [\cos^2\theta \sin^2\beta_o / Ng^2 + (\cos\theta \sin\theta_o \cos\beta_o + \sin\theta \cos\theta_o)^2 / Nm^2 + (\cos\theta \cos\theta_o \cos\beta_o - \sin\theta \sin\theta_o)^2 / Np^2]$

Production of the graph of RI variation

Tourmaline is used as the example for a uniaxial gemstone, and the graph of its RI variation is produced as follows:

The initial orientation is given as $\theta_o = 30°$ $\beta_o = 70°$. After the stone is rotated by an angle $\theta = 50°$, the coefficients E_u, B_u and G_u of equation (Eq. (7)) can be calculated. The result is $E_u = 0.37202$, $F_u = -0.00666$ and $G_u = 0.37548$, generating the ellipse:

$$0.37202 z_r^2 - 0.00666 x_r z_r + 0.37548 x_r^2 = 1. \qquad (9)$$

On this ellipse, an adequate number of points at regular intervals are chosen, expressed by $p_k (k = 1,2,3, \ldots \ldots \ldots n)$. For each point p_k denoted by the coordinate pair (x_k, z_k), the values of the x_k and z_k must be derived from equations (9), for example by picking k values of x, and calculating k values of z.

The distance from point p_k to the centre of the ellipse (i.e. the origin of the Oxyz coordinates) is a radius of the ellipse, it can be obtained by equation $Op_k = |(x_k^2 + z_k^2)^{1/2}|$.

Distances from every point on the ellipse to the centre are calculated and then the longest and the shortest radius can be found. The two radii equal the two refractive indices of the stone in the orientation $\theta_o = 30°$, $\beta_o = 70°$, $\theta = 50°$. The sample calculations result respectively in No = 1.6440 and Ne′ = 1.6276.

Still under the initial orientation of $\theta_o = 30°$, $\beta_o = 70°$, by exchanging the rotation angle θ

Table III: The RI variation of tourmaline with an initial orientation of θo = 30°, βo = 70°.

Angle θ	00°	10°	20°	30°	40°	50°	60°
No	1.6440	1.6440	1.6440	1.6440	1.6440	1.6440	1.6440
Ne′	1.6389	1.6375	1.6353	1.6327	1.6301	1.6276	1.6256
Angle θ	70°	80°	90°	100°	110°	120°	130°
No	1.6440	1.6440	1.6440	1.6440	1.6440	1.6440	1.6440
Ne′	1.6244	1.6240	1.6246	1.6260	1.6281	1.6307	1.6334
Angle θ	140°	150°	160°	170°	180°	190°	200°
No	1.6440	1.6440	1.6440	1.6440	1.6440	1.6440	1.6440
Ne′	1.6359	1.6379	1.6392	1.6395	1.6389	1.6375	1.6353

and repeating the preceding operations, another pair of refractive indices can be obtained. By this means, all 21 pairs of RI can be calculated using the angles $\theta = 0°, 10°, 20°, 30° \ldots \ldots \ldots 200°$. The calculated data for the graph of RI variation of tourmaline under the initial orientation of $\theta_o = 30°$, $\beta_o = 70°$ are listed in *Table III*. The relevant graph is A-73 in *Figure 3(d)*.

In order to obtain other graphs with various initial orientations, start with various angle pairs θ_o and β_o *(see Table I)* and then calculate each longest and the shortest radius of the indicatrix section under every orientation θ_o, β_o and angle θ. Using this procedure, all the graphs of RI variation of tourmaline can be determined.

For a biaxial gemstone, a similar procedure for calculating the graphs of RI variation can be carried out using equation (8).

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Use of the polarizing filter on the refractometer

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Abstract: *Use of the refractometer is summarized and a new comprehensive method to obtain reliable refractive indices is described. A single table contains all possible combinations of RI data and should be kept with the gemmological refractometer for practical use by both beginners and expert gemmologists.*

Introduction

The refractometer is one of the most used instruments in gemmology. Unfortunately, very few gemmologists feel confident that they can properly interpret all of the data that can be observed. Most can accurately measure the range of refractive indices (RIs) but few can differentiate between uniaxial or biaxial (in special orientation) or determine the optic sign from observations on the shadow edges.

It is not because they were not willing to invest their time and effort. Interpretation of the observations on the refractometer is a part of many gemmology courses. The problem lies in the instructions for use of the refractometer – they are complex and are often difficult to understand. Many students learn just enough to pass an examination and later they do not apply the method fully in practice. In many practical identifications, determination of the range of the RIs is all that is needed. In some cases, however, proper interpretation of the observed data can save time and the cost of an additional test.

Previous methods

One of the best descriptions of the use of the refractometer is, also, one of the oldest. At the beginning of the 20th century Herbert Smith developed a modern refractometer. An excellent description of the use of the polarizing filter is found in Smith (1972). This method requires a good understanding of optical mineralogy theory and use of the indicatrix. At Smith's time many gemmologists were also excellent optical mineralogists and could easily follow his instructions.

Later, in the second half of the 20th century, gemmologists became more and more involved in the detection of synthetic materials and various enhancement or alteration processes. The techniques used did not require such a sound understanding of optical mineralogy theory. Consequently, some attempts to simplify refractometer use have produced complex, confusing and sometimes simply wrong instructions.

Present practice

It is very difficult to evaluate the present teaching of refractometer use. Many schools or institutions have their own course manuals (notes) and do not rely exclusively on the text books. The level of instruction varies a great deal.

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Table I: Optical properties which can be determined on the refractometer.

	Isotropic	Anisotropic			
		Uniaxial		Biaxial	
Crystal system	amorphous and cubic	tetragonal and hexagonal		orthorhombic, monoclinic and triclinic	
RIs	N	N_o N_e		N_z N_y N_x	
Optic sign		Positive $N_e > N_o$	Negative $N_o > N_e$	Positive N_y closer to N_x	Negative N_y closer to N_z
Optical angle				$2V_z = 0 - 90°$	$2V_x = 0 - 90°$
Maximum birefringence		$N_e - N_o$	$N_o - N_e$	$N_z - N_x$	

NB: Other symbols used include:
Uniaxial gems = $N_o = \omega$, $N_e = \varepsilon$; lower case n is also used.
Biaxial gems = $N_x = \alpha$, $N_y = \beta$, $N_z = \gamma$; $2V_z = 2V(+)$, $2V_x = 2V(-)$.

In fact, the only safe statement that can be made is that the use of the polarizing filter is a minor (and difficult) part of many courses and rarely used later. This should not be so. A new approach to the teaching of refractometer use is proposed whereby a student, a jeweller or an experienced gemmologist can become familiar with the new method in about an hour. This new graphical approach does not require an extensive background in optical mineralogy and very little needs to be memorized. All that is required for the practical use of the refractometer is presented in a single table.

With mastery of this procedure, a lot of time and effort can be saved, leaving more time for the ever increasing number of new methods needed for the identification of enhancements and alteration processes. Most of all, the confidence that they can use this basic instrument to its fullest, stays with gemmologists or jewellers for life.

New approach

The new approach comprises graphical presentation and step-by-step instructions in a single table. Every new method combines old and new ideas and experiences. Here, diagrams similar to those in Hurlbut and Kammerling (1991) are used in order to describe six basic patterns. However, the vertical scale is reversed so that it corresponds to the image seen in the refractometer (the highest value is at the bottom) as is shown in the diagrams by Read (1999).

The new approach is characterized by the following features:

1. There is no recording of the rotation angles and corresponding RIs, or plotting of this information on diagrams.
2. All possible combinations of optical data and the orientation of the gem table are presented in six patterns and the interpretation of each pattern is described separately.
3. A single table describes step-by-step interpretation of the observed data. Nothing needs to be memorized. A table kept next to the refractometer is all that is needed (the table is downloadable from the Gem-A website at www.gem-a.info).
4. The use of an optic angle diagram for biaxial gemstones makes determination of the optic sign very simple.

Review of optical properties determined on a refractometer

All of the optical properties that can be determined on a gemmological refractometer are listed in *Table I*. the term 'gemstone' in this context includes minerals and synthetic materials.

Isotropic gemstones

Isotropic gemstones crystallize in the cubic system or are amorphous (e.g. opal, glass). They show the same refractive index (RI) regardless of the direction of light rays moving through them. This produces a single and constant shadow edge during the rotation of the gemstone on the refractometer (*Table II*, Pattern I).

Anisotropic gemstones

In general, a light ray entering an anisotropic gemstone is divided into two rays that:

1. move at different speeds and have different RIs (birefringence);
2. are polarized and have vibration directions perpendicular to each other;
3. may have different absorption – resulting in different colours for each ray (pleochroism);
4. may move in slightly different directions – resulting in the doubling of images.

It is important to remember that there are exceptions to the above and when, for example, the light moves in special directions (called optic axes), it continues as a single ray.

The rotation of an anisotropic gemstone on the refractometer can bring it into a position where the light rays are moving in the direction of an optic axis. In this case, a single shadow edge is observed as in isotropic gemstones. However, further rotation brings into view two shadow edges – representing RIs of the two rays. This allows for the easy distinction between anisotropic and isotropic gemstones.

Anisotropic gemstones can have either one or two optic axes and on this basis are divided into two groups: uniaxial and biaxial.

Anisotropic uniaxial gemstones have one optic axis and crystallize in either the tetragonal or hexagonal crystal systems. One ray – called the ordinary ray – has a constant RI regardless of the direction of light through the gemstone and is designated N_o. During rotation of a uniaxial gemstone, one shadow edge remains constant, indicating the constant RI (N_o) of the ordinary ray.

In most orientations of a gem, the other shadow edge – representing the extraordinary ray – varies during the rotation. We refer to this shadow edge as variable and it is designated N_e. Uniaxial gemstones are characterized by two principal RIs N_o and N_e.

During the rotation, the variable shadow edge can show any RI - N_e' – between the two extremes of N_o and N_e. Patterns II, III and IV in *Table II* show the range of relationships between the shadow edges representing ordinary and extraordinary rays.

The RI of the ordinary ray (N_o) is read on the constant shadow edge. The RI of the extraordinary ray (N_e) is read on the variable shadow edge in the position where the constant and variable shadow edges are at maximum separation.

Two special cases (shown in patterns II and III) are more common than one might think, because many uniaxial gem crystals have prominent faces perpendicular or parallel to the optic axis. The table facet of a zircon is commonly cut perpendicular to the optic axis, while that of a tourmaline is commonly parallel – producing these special patterns II and III.

Anisotropic biaxial gemstones have two optic axes and crystallize in either the orthorhombic, monoclinic or triclinic crystal systems. They are defined by three principal RIs and three principal vibration directions, Z, Y and X. N_x is the smallest RI and is observed when light vibrates parallel to the principal vibration direction X, N_y is the intermediate RI for light vibrating parallel to the principal vibration direction Y, and N_z is the largest RI for light vibrating parallel to the principal vibration direction Z. It is important to note that N_y can be any value between N_z and N_x – generally it is not exactly halfway between the two.

RIs of the two rays formed in biaxial gemstones depend on the direction of light

through a gemstone. In general, when a biaxial gemstone is rotated on a refractometer, two variable shadow edges are observed (pattern VI). One ray has RI (N_x') that varies between N_x and N_y, and the other ray's index (N_z') varies between N_y and N_z. On rotation on the refractometer, the direction of light in the gemstone changes and so do the RIs (N_z' and N_x') of the two rays.

Special orientations of the optical elements and the gem table – when any of the principal vibration directions Z, Y and X is perpendicular to the gem table – are characterized by one constant and one variable shadow edge (patterns IV and V). As in uniaxial gemstones, these special orientations can be fairly common, because the principal vibration directions Z, Y and X are often perpendicular to the prominent faces chosen and fashioned as the table facet.

Determination of the optic sign

The optic sign depends on the relationship between the principal RIs (N_o/ N_e and N_z /N_y/N_x). In order to avoid complex descriptions of the behaviour of the shadow edges during the rotation of a gemstone - in this method, the principal RIs are determined first and then two simple rules are used to identify the optic sign.

Uniaxial gemstones: The optic sign of an anisotropic uniaxial gemstone is

Positive if $N_o < N_e$

Negative if $N_o > N_e$

Biaxial gemstones: The optic sign of an anisotropic biaxial gemstone is

Positive if N_y is closer to N_x

Negative if N_y is closer to N_z

The optic sign and angle between the optic axes depends on the three principal RIs (N_z /N_y/ N_x) and can be found using the Optic Angle Diagram in *Figure 1*. The use of the diagram is shown in the following example illustrated in *Figure 2*.

First, the three RIs of a gemstone were determined as:

$N_z = 1.625$

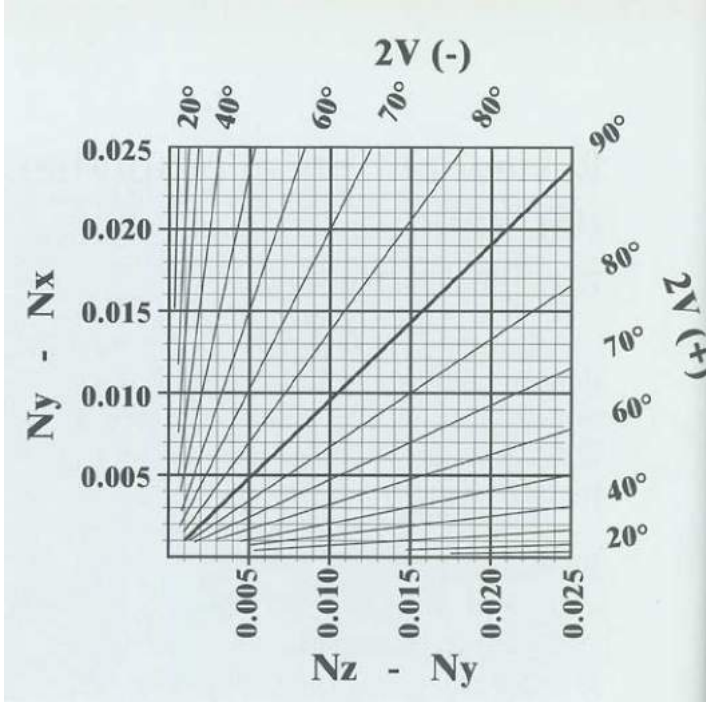

Figure 1: Diagram for determination of the optic sign and the optic angle of anisotropic biaxial gemstones.

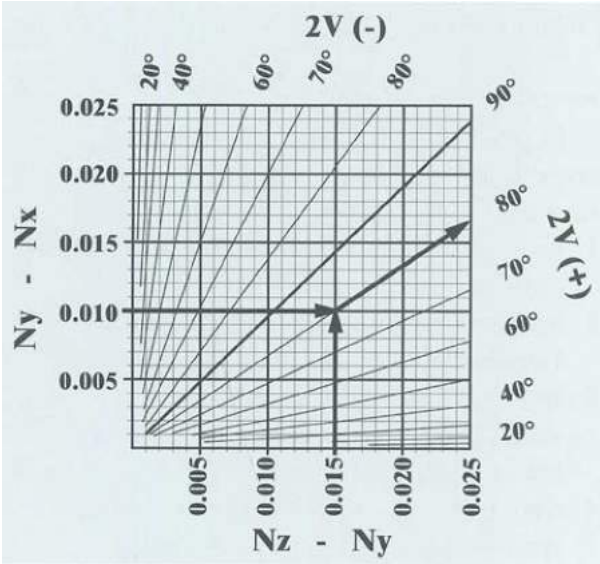

Figure 2: The optic angle diagram showing values plotted for $N_y - N_x$ and $N_z - N_y$ as discussed in the text.

$N_y = 1.610$

$N_x = 1.600$

Second, N_z - N_y and N_y - N_x were calcu lated as:

$N_z - N_y = 0.015$

$N_y - N_x = 0.010$

Third, these values were plotted on the Optic Angle Diagram and indicate that the gemstone is biaxial - positive with a 2V angle about 80°.

The Optic Angle Diagram can also be used to show how errors in the observed RIs can

have a significant bearing on determination of the optic sign.

The use of Table II

The determination of the optical properties of a gemstone on the refractometer is divided into several stages in this new approach. *Table II* summarizes the patterns obtainable from a refractometer, indicates which patterns yield further information with use of a polarizing filter, gives step-by-step instructions on how to obtain this information, and indicates the relevant orientation of the gem under measurement.

There are six possible pattern types, represented in six rows in *Table II*. The **Initial observation** column (column 2) charts the patterns of shadow edges obtainable if one rotates the gemstones through 180°. At this stage, the polarizing filter is not used.

For patterns I and II, the shadow edges are constant and the orientation of the gem when rotation is started is not significant, but for patterns III, IV and V, 0° on the pattern diagram indicates the point of maximum separation of the shadow edges. Pattern VI starts where the largest RI (N_z) is observed.

Patterns I, III and V yield the maximum optical information obtainable from the refractometer but patterns II, IV or VI, require detailed observations.

Detailed observation is done with the polarizing filter set into one of the two positions (north-south or east-west). The gemstone is first rotated to the position indicated by a red dot in *Table II* and the polarizing filter is set on the eye-piece. Identification is then based on the disappearance of a particular shadow edge.

A polarizing filter is supplied with most modern refractometers. Its vibration direction is indicated by a dot. If this dot is erased, a very simple procedure can be used to accurately determine the filter's vibration direction. A quartz crystal (with enough faces to indicate the crystallographic axis *c*) is set in the horizontal position on the refractometer table. The crystal is rotated in the position where the *c*-axis is perpendicular to the long axis of the refractometer. Two shadow edges are observed. The one with the RI of 1.544 represents the ordinary ray with its vibration direction being north-south. The polarizing filter is set on the eye-piece and rotated until this shadow edge (N = 1.544) disappears. The vibration direction of the polarizing filter is now exactly east-west (parallel to the refractometer table) and this direction should be marked on the polarizing filter. This test can be done with any uniaxial crystal where the *c*-axis and the shadow edge representing the ordinary ray can be identified.

Isotropic gemstones produce *pattern I* and this is characterized by a single shadow edge that stays constant during rotation. The rotation test is very important because, in particular positions, anisotropic gemstones can also show a single shadow edge (see patterns III and V).

Pattern II is a special case of a uniaxial gemstone where the optic axis is perpendicular to the gem table. The two shadow edges representing ordinary and extraordinary rays stay constant during rotation of the gem. The polarizing filter is used to identify the ordinary and extraordinary ray shadow edges in *Table II*.

Pattern III is the other special case where the optic axis of a uniaxial gemstone is parallel to the gem table. It is characterized by the variable shadow edge touching the constant shadow edge at one position during the rotation. The polarizing filter is not needed for determination of the optic sign. Read N_o on the constant shadow edge and read N_e on the variable shadow edge in the position where the two shadow edges are at maximum separation.

Pattern IV can be generated by both uniaxial and biaxial gemstones. In both cases we observe one constant shadow edge and one variable shadow edge which do not touch at any position of the gem during rotation.

The polarizing filter is used to determine whether the gemstone producing this pattern is uniaxial or biaxial. With the filter set in the north-south position on the eye-piece, if the constant shadow edge disappears the stone is

The use of the polarizing filter on the refractometer

PATTERN NUMBER	INITIAL OBSERVATION	POLARIZING FILTER	DETAILED OBSERVATION For observation with the POLARIZING FILTER rotate the gemstone in the position indicated by the RED dot. For determination of the REFRACTIVE INDEX rotate the gemstone in the position indicated by the GREEN dot.	ORIENTATION AND OPTICAL PROPERTIES	RESULTS
I	0° 90° 180° 1.500 1.600 1.700 Single CONSTANT shadow edge	Not used	**Detailed Observation not needed.** Make sure that the **SINGLE** Shadow edge stays **CONSTANT** during the rotation of the gemstone. 0° 90° 180° 1.500 1.600 1.700 N	Isotropic	Record N
II	0° 90° 180° 1.500 1.600 1.700 Two CONSTANT and PARALLEL shadow edges	Set in the North – South position NORTH SOUTH	1. Observation can be made in any position during the rotation of a gemstone. 2. Insert the polarizing filter. (Shadow edge of the ordinary ray (N_o) disappears.) 3. Read N_e on the shadow edge that stays visible. 4. Remove the polarizing filter. Read N_o on the shadow edge that is now visible. 0° 90° 180° 1.500 1.600 1.700 N_o N_e 0° 90° 180° 1.500 1.600 1.700 N_e N_o	**Uniaxial** Optic axis is perpendicular to the gem table Optic Axis	Record N_e, N_o Determine the **optic sign** Calculate the **maximum birefringence**
III	0° 90° 180° 1.500 1.600 1.700 Or 0° 90° 180° 1.500 1.600 1.700 One CONSTANT and one VARIABLE shadow edge **TOUCHING**	Not used	**Detailed Observation not needed.** 1. Read N_o on the constant shadow edge. 2. Read N_e on the variable shadow edge **when two shadow edges are separated the most.** (as shown by the green dots). 0° 90° 180° 1.500 1.600 1.700 N_o N_e 0° 90° 180° 1.500 1.600 1.700 N_e N_o	**Uniaxial** Optic axis is parallel to the gem table Optic Axis	
IV	0° 90° 180° 1.500 1.600 1.700 Or	Set in the North – South position NORTH SOUTH	1. Rotate gemstone in the position indicated by the red dot (where shadow edges are the closest). 2. Insert the polarizing filter **Observe which shadow edge disappears.** CONSTANT shadow edge DISAPPEARS 0° 90° 180° 1.500 1.600 1.700 N_o N_e 0° 90° 180° 1.500 1.600 1.700 N_e N_o	**Uniaxial** Random orienation Optic Axis	

IV	One CONSTANT and one VARIABLE shadow edge **NOT TOUCHING**		**Observe which shadow edge disappears.** Identify gemstone as uniaxial or biaxial. 3. Remove the polarizing filter. Read principal refractive indices in positions shown by green dots. VARIABLE shadow edge **DISAPPEARS**	**Biaxial** Z perpendicular to the gem table; X perpendicular to the gem table	Record N_z, N_y and N_x. Calculate the **maximum birefringence**. Use 2V diagram to determine the 1. **optic sign** 2. **optic angle (2V)**
V	One CONSTANT and one VARIABLE shadow edge **INTERSECTING**	Not used	**Detailed Observation not needed.** Read N_z, N_y and N_x as indicated by green dots	**Biaxial** Y perpendicular to the gem table	
VI	Two VARIABLE shadow edges **NOT TOUCHING**	Set in the East – West position	N_z AND N_x ARE DETERMINED AS THE LARGEST AND THE SMALLEST REFRACTIVE INDEX OBSERVED DURING THE ROTATION. N_y CAN BE READ EITHER ON THE UPPER OR ON THE LOWER SHADOW EDGE. *Each shadow edge must be observed separately to determine N_y.* Rotate gemstone in the position A indicated by the red dot. Insert the polarizing filter in the East-West position. If the shadow edge containing N_x disappears - read N_y and N_z on the other shadow edge. *If the shadow edge containing N_x does not disappear, test the other shadow edge.* Rotate gemstone in the position B indicated by the red dot. Insert the polarizing filter in the East-West position. If the shadow edge containing N_z disappears - read N_y and N_x on the other shadow edge.	**Biaxial** Random Orientation	

Table II: Patterns of shadow edges and use of polarizing filter to determine the optical properties of gems. (The Table may be downloaded from the Gem-A website at www.gem-a.info.)

uniaxial; if the variable shadow edge disappears it is biaxial.

Uniaxial in random orientation - where the optic axis is inclined at an angle to the gem table which is not 0° or 90°. The gemstone is rotated to the position of maximum separation of the two shadow edges and N_e is determined (with polarizing filter removed). N_o is read on the constant shadow edge.

Biaxial in special orientations – where the principal vibration directions X or Z are perpendicular to the gem table. N_y is read on the variable shadow edge when the two shadow edges are as close as possible. If the two shadow edges are almost touching it may be difficult to read N_y accurately, so the polarizing filter should be placed over the eyepiece and rotated until the constant shadow edge disappears; this should make it easier to measure N_y. N_z and N_x are read in the position where the constant and variable shadow edges are at maximum separation (with polarizing filter removed).

Pattern V represents the third special case of the biaxial gemstone - where the principal vibration direction Y is perpendicular to the gem table. The polarizing filter is not used. N_y is read on the constant shadow edge and N_z and N_x on the variable shadow edge in the positions where the two shadow edges are at maximum separation.

Pattern VI is the general case of a biaxial gemstone – where none of the principal vibration directions X, Y or Z is perpendicular to the gem table. It is characterized by two variable shadow edges. N_y is read on only one of them, and the polarizing filter must be used to identify which shadow edge contains N_y.

Each shadow edge must be observed in the separate position indicated in *Table II*. For the shadow edge showing N_x, this is a position with the highest RI reading. For the shadow edge showing N_z, this is the position with the lowest RI reading. To obtain the value of N_y and determine the optic sign of the gemstone, place the polarizing filter on the eyepiece in the east-west orientation and follow the procedure in *Table II*.

Sometimes bringing the gemstone to the required maximum or minimum position may be difficult if the shadow edge moves little during the rotation (shows almost the same RI). In such cases a rotation of the polarizing filter 10-15° off the proper position may help. If not, possible readings of N_y from both the N_x and N_z shadow edges must be considered in assessing which is the best value to use when attempting to identify the stone.

Conclusions

The refractometer is one of the most used gemmological tools. Its use including observation with the polarizing filter is a part of many courses and study programmes. However, many instructions concerning the filter are descriptive with very few drawings, making them complex and sometimes confusing for students. The new approach enables one to learn the use of the polarizing filter on the refractometer in a fraction of the time needed previously. This leaves more time for the study of the new techniques and methods used in identification of alteration or enhancement processes.

Any jeweller or gemmologist can become familiar with the use of the polarizing filter in about one hour. After that, *Table II* kept next to the refractometer will give them the confidence that they can properly interpret any observation made on the refractometer.

A set of standards representing the six patterns can easily be prepared. These could be combined with a set of drawings on CD showing vibration directions and RIs during the rotation.

Acknowledgement

I wish to thank my colleague Malcolm Beck for the critical reading of the manuscript.

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Note: Table II may be downloaded From the Gem-A website at www.gem-a.info

Letter to the editor

Computational science

I would like to draw the attention of the gemmological community to a very significant article: Computational Science Demands a New Paradigm. *Physics Today*, **58**(1), 35-41, Jan. 2005, by D.E. Post and L.G. Votta (both prominent computation experts).

There have been a number of studies reported in the gemmological literature on the computation of the effect of cut on the appearance of diamonds. I do not give references since these are well known and I wish to indicate neither approval nor criticism, either directly or indirectly, of any of these. However, I had thought that with my background in technical and computational matters I would be able to evaluate the 'models' used in such reports, yet a perusal of the cited article (dealing predominantly with physics and engineering) convinces me that only the original workers can both verify and validate such calculations.

In the words of the cited article: "... much computational science is still troublingly immature ... Verification and validation ... are crucial ... If a code is unverified, any agreement between its results and experimental data is likely to be fortuitous ... experiments [to validate a code] ... can often be relatively simple and inexpensive."

Any such computation involves a 'model' or 'code' (i.e. the specific computational instructions), including the assumptions made (here the nature of the illumination used, importance of body vs edge colours, which factors to include, which to ignore, etc.), and the range of parameters used (e.g. the angular range of the illumination, amount of obscuration by the head, the range of cutting angles, etc.).

I cannot repeat the details of this lengthy article, but the essential points made are these: To produce valid results, any approach must have all the steps used in the computation verified, i.e. demonstrated that there are no errors (typically about seven faults per 1000 lines of Fortran, according to the article), and then validated, that is shown to give the appropriate results. This last should be done not by confirming known results (see the above quotation), but by predicting new results and then showing agreement with actual experimental reality, i.e. observations.

The important point is also made that predictions should be limited only to the ranges of parameters over which results have been verified, since it has often happened that computations will give incorrect results outside of these ranges.

I apologize for not giving more details (which would be excessively lengthy and at least partially outside my sphere of competence), but I believe that anyone interested in this field needs to acquaint themselves with these rather complex concepts.

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Abstracts

Diamonds

[About signs of mechanical and chemical effects upon diamond crystals from the Urals deposits.]

V.N. ANFILOGOV (iminchf@ilmeny.ac.ru), *Proceedings of the Russian Mineralogical Society*, **133**(3), 2004, 105-8 (Russian with English abstract).

The complex morphology of diamond crystals is reviewed from the point of view of its application to location of their primary source. Dislocations on the surface of the crystals cannot be explained by mechanical distortion; they appear during growth due to internal defects. The occurrence in the Urals placer deposits of rounded diamonds cannot be explained by rolling in surf conditions. It is suggested that the primary source of diamonds in the Urals is in kimberlites near the placer deposits. The predominance of rounded dodecahedra among the Urals diamonds may be related to the composition of the host rocks intruded by the kimberlites. R.A.H.

In the pink: Argyle's diamond gift to Australia.

A. BEVAN AND P. DOWNES, *Australian Gemmologist*, **22**(4), 2004, 150-5, 4 illus.

The Argyle AK1 diamond mine in the East Kimberley region of Western Australia produces around 30 million carats of diamonds per year. Although this represents about a quarter of the world's current total production, only about 5% of the diamonds recovered from the AK1 pipe are of gem quality, with a further 70% classified as near-gem. These diamonds range in colour from white (colourless) through champagne and cognac (yellow to brown) to the rare pink stones, the latter comprising less than 0.1% of the total diamond extraction in Australia. In a gift to the nation, Argyle Diamonds have donated several hundred pink diamonds (including four pink octahedrons) to the mineralogical collection of the Western Australian Museum, Perth. For comparison, the collection also includes two colourless diamonds and two champagne coloured diamonds. Part of the sponsorship agreement between Argyle Diamonds and the Museum is that the stones be placed on permanent display and that other institutions throughout Australia may apply to the Museum to borrow material for temporary exhibition. P.G.R.

Characterisation of carbonado used as a gem.

K. DECORTE, Y. KERREMANS, B. NOUWEN AND J. VAN ROYEN, *Gemmologie. Z.Dt.Gemmol.Ges.*, **53**(1), 2004, 5-22 16 photographs, 2 tables, 5 diagrams, bibl.

Carbonado is a polycrystalline diamond composed of a large number of very small diamond crystal grains, randomly orientated. The pores between these crystals can be filled with different minerals – therefore carbonado cannot be considered pure diamond. It is never transparent and usually black. It often has a low SG around 3.52. Twenty–one rough carbonados were modelled and partially polished for use as gem material using laser processing techniques. Density, composition, colour and some aspects of morphology were studied. Morphological analysis differentiated between two categories of carbonado; the first consists of only one dominant grain size, while the second comprised larger diamond crystals embedded in a fine grained diamond matrix. Sr, Pb, Fe and Y were found in most samples. Optical luminescence spectra showed diamond lattice defects mainly due to radiation. The studied stones contain significant concentrations of isolated nitrogen atoms. E.S.

The modern De Beers and the significant changes to the diamond pipeline over the past decade - A literature review.

J. MORRIS, *Australian Gemmologist*, **22**(3), 2004, 112-24, 11 illus.

This paper covers the long history of De Beers who once controlled 90% of the world's rough diamond supply and was able to regulate the quantity of diamonds on the market at any one time. Comparison is made between the original diamond 'pipeline', the new 'supplier of choice' model and the possible final shape of the latter model. An abridged version of the restructured 2002 De Beers ownership 'family tree' is also included. Competition with companies such as BHP Billiton's Aurias Diamonds in Canada, and Rio Tinto's diamonds in Australia is also discussed as are Conflict diamonds and the Kimberley Process. P.G.R.

Diamonds in Russia – A literature review.

F. PAYETTE, *Australian Gemmologist*, **22**(3), 2004, 99-111, 10 illus. 6 tables.

This paper was presented by the author as the research part of the Australian Gemmological Association's Diploma of Diamond Technology course. It covers the geology of occurrence, the history of discoveries, the exploration and recovery techniques, the type of goods, and their marketing in Russia. Among the illustrations are views of five of the principal Russian diamond mines and a selection of typical Yakutian rough diamonds. A list of famous Russian diamonds is included. P.G.R.

Diamonds: time capsule from the Siberian mantle.

L.A. TAYLOR AND M. ANAND, *Chemie der Erde: Geochemistry*, **64**(1), 2004, 1-74.

In this invited review, the authors report their systematic studies on diamondiferous eclogite xenoliths from

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Siberia. The steps in investigating these are: (1) high-resolution computed X-ray tomography of the xenoliths to give 3D images that relate the minerals of the xenolith to their diamonds, (2) detailed dissection of the entire xenolith to reveal the diamonds inside followed by characterization of the setting of the diamonds within their enclosing minerals, and (3) extraction of diamonds from the xenolith to facilitate further investigation of the diamonds and their inclusions. In this last step, it is important to record carefully the nature and relative positions of the inclusions in the diamonds to maximize the number of inclusions that can be exposed simultaneously on one polished surface. In this modus operandi, CL imaging together with FTIR aggregation and C/N isotopic analyses are performed on polished diamond surfaces to reveal their internal growth zones and the spatial relationship of the mineral inclusions to these zones. Such multiple lines of evidence obtained in this way indicate the ultimate crustal origin for the majority of mantle eclogites. Similar pieces of evidence, particularly from $\delta^{13}O$ in P-type diamonds and $\delta^{18}O$ in peridotitic garnets lead to the suggestion that at least some of the mantle peridotites, including diamondiferous ones, as well as inclusions in P-type diamonds, may have a crustal protolith as well. R.A.H.

X-ray fingerprinting routine for cut diamonds.

R. DIEHL AND N. HERRES, *Gems & Gemology*, **40**(1), 2004, 40-57.

X-ray topography is a non-destructive technique that permits the visualization of internal defects in the crystal lattice of a gemstone, especially diamond, which is highly transparent to X-rays. This technique yields a unique 'fingerprint' that is not altered by gem cutting or by treatments such as irradiation and annealing. Using the table facet as a point of reference, the sample is crystallographically oriented in a unique but reproducible way in front of the X-ray source so that only one topograph is necessary for fingerprinting. Should the diamond be recovered after loss or theft, even after recutting or exposure to some forms of treatment, another topograph generated with the same routine could be used to confirm its identity unequivocally. R.A.H.

Diamants bruns: classification et origine de la couleur.

T. HAINSCHWANG, *Revue de Gemmologie*, **150**, 2004, 13-17.

The origin of the brown colour in diamond is examined with a question-and-answer dialogue. M.O'D.

A foundation for grading the overall cut quality of round brilliant diamonds.

M.L. JOHNSON, B. GREEN, T. BLODGETT, K. CINO, R.H. GEURTS, A.M. GILBERTSON, T.S. HEMPHILL, J.M. KING, L. KORNYLAK, I.M. REINITZ AND J.E. SHIGLEY, *Gems & Gemology*, **40**(3), 2004, 202-28.

Observations by the authors and detailed discussions with diamond manufacturers, dealers, retailers and potential customers confirmed that, in addition to brightness and fire, additional factors contribute to the appearance of a cut diamond, and that factors in addition to face-up appearance are important in assessing the quality of a diamond's cut. With the trade interaction as a starting point, the authors (1) tested the brightness and fire metrics to find the best fit with human observations, (2) identified and quantified factors in addition to brightness and fire that contribute to face-up appearance, (3) developed a standard viewing environment that mimics common trade environments, (4) created the basis for a comprehensive diamond cut grading system and (5) began development of reference software to predict the overall cut grade of a particular diamond. The GIA cut grading system described here includes the components of brightness, fire, scintillation, polish and symmetry, as well as weight and durability concerns, into a single overall grade for cut quality for standard round brilliants. Photographic examples of five categories are displayed in a double-page fold out. R.A.H.

Lab notes.

T. MOSES, I. REINITZ, S.F. MCCLURE AND M.L. JOHNSON (EDS), *Gems & Gemology*, **40**(3), 2004, 240-51.

Notes are included on the Cullinan blue diamond necklace containing several rare type IIb blue diamonds, a 11.60 ct diamond crystal with strong blue colour due to laboratory irradiation, a natural grey to blue diamond owing its colour to a scattering of light from clouds of pin-point inclusions (the Tyndall effect) and cuprian tourmalines from Mozambique exhibiting a colour change from purple in fluorescent light to grey-bluish green in incandescent light. R.A.H

Raman spectroscopy of diamond and doped diamond.

S. PRAWER (s.prawer@unimelb.edu.au) AND R.J. NEMANICH, *Philosophical Transactions of the Royal Society, Section A*, **362**(1824), 2004, 2537-65.

Raman spectroscopy (RS) is an essential non-destructive technique in research on diamonds and chemical vapour-deposited diamond films. Thus the typical Raman spectrum excited by a visible laser (1000 to 2000 cm^{-1} region) contains information on the phase purity and crystalline perfection of the diamond sample, while surface-enhanced RS shows new and unexpected structures on diamond surfaces, and the Raman spectrum can be used to map stress and strain in crystallites on the μm scale, remotely monitor the surface *T* of diamond and to monitor defects, annealing and electrical doping. The latest developments in Raman techniques are reviewed, and applications of RS in diamond science are described, including the measurement of phase purity and crystalline perfection, phonon confinement effects for finite crystal domains, non-contact measurement of *T*, annealing and defects, and doping with, e.g. boron, S, P or Li. The Raman spectrum is sensitive to the interaction of dopants with the electronic continuum, and it is the carrier concentration rather than the dopant concentration to which the RS is most sensitive. R.A.H.

Gems and Minerals

Elemental analysis of Australian amorphous banded opals by laser-ablation ICP-MS.

L.D. BROWN (Leslie.Brown@uts.edu.au), A.S. RAY AND P.S. THOMAS, *Neues Jahrbuch für Mineralogie, Monatshefte*, **9**, 2004, 411-24.

Several banded Australian opal-AG samples were found to contain darker-coloured black or grey bands adjacent to lighter-coloured white or clear bands. A study of the distribution of trace elements between these bands showed that darker-coloured bands contained significantly higher contents of transition elements (Ti, Co, V, Ni, C, Zn and Y) and REE (La, Ce) than lighter-coloured bands. A solution depletion model, involving the charge neutralization of silica colloids by highly charged transition metal cations, is proposed to explain these results.Irrespective of the origin of the opal, the distribution of the trace elements for the white, translucent and play-of-colour opal bands was shown to be similar, consistent with the proposed model. R.A.H.

Sapphire in basalt fake.
T. COLDHAM, *Australian Gemmologist*, **22**(4), 2004, 171, 1 illus.

While visiting the basaltic sapphire fields of Shandong, China, over a decade ago, the author picked up a piece of basalt containing a corundum xenocryst. Unfortunately his Chinese host then confiscated the find. However, in 2004 a similar specimen was seen by the author in Tucson and was purchased by him for US$80.00. The following day about ten similar specimens were on sale at US$10.00 each. Using a penknife and loupe soon revealed a line of black gritty glue around the sapphire crystals proving these cheaper samples to be fakes. A further inspection of the purchased US$80.00 specimen proved this also was a fake although more cleverly concealed than the cheaper versions! P.G.R.

The Kasumigaura pearl™.
B. DILLENBURGER, *Australian Gemmologist*, **22**(4), 2004, 156-61, 7 illus.

The Kasumigaura pearl™ is a natural coloured bead-nucleated slightly off-round freshwater pearl that is cultivated in and around Japan's second largest lake, Lake Kasumigaura. Historically the Japanese culture of freshwater pearls can be traced back to the thirteenth century, although the culture of commercial quantities of pearls first began in the late nineteenth century in Lake Biwa, Japan's largest lake. However, the increasing level of pollution in Lake Biwa led to a rapid decline in the production of the freshwater Biwa pearl. The paper describes how the Biwa pearl culture was eventually relocated to Lake Kasumigaura and refined by years of research using hybrids of Japanese and Chinese freshwater mussels. Details are included on the identification characteristics of these relatively rare and expensive cultured pearls. P.G.R

Aplicações de microscopia eletrônica de varredura (MEV) e sistema de energia dispersive (EDS) no estudo de Gemas: exemplos brasileiros.
L. DA C. DUARTE (laurend-uarte@bol.com.br), P.L. JUCHEM, G.M. PULTZ, T.M.M. BRUM, N. CHODOR, A. LICCARDO, A.C. FISCHER AND R.B. ACAUAN, *Pesquisas (1st Geociências, Univ. Fed. De Rio Grande do Sul. Brazil)*, **30**(2), 2003, 3-15.

SEM and EDS results in a study of Brazilian gemstones are presented. Emerald from Campos Verdes, in the State of Goiás, contains inclusions of talc, dolomite, chromite, pyrite, magnetite, etc.; sylvite crystals were identified by SEM/EDS. These salt inclusions suggest the percolation of K-bearing fluids during crystallization. These Campos Verdes emeralds are richer in Cr^{3+} in the outer green zones than in the inner colourless zones, i.e. Cr^{3+} acts as a chromophore. Amethyst from Rio Grande do Sul State contains needle-like inclusions of goethite (rather than cacoxenite and rutile, as suggested by others). Pyrolusite and hollandite were identified in agate and quartz geodes. In corundum from Barra Velha (Santa Caterina) application of SEM/EDS showed that the silk effect is due to inclusions of diaspore. The asterism in this corundum is ascribed to empty needle-like channels, rather than to rutile. In corundum from various localities in Minas Gerais, rounded inclusions of zircon are common: others have sillimanite and/or kyanite inclusions, suggesting a metamorphic origin. R.A.H.

A recent observation of corundum-spinel-sapphire assemblage at Kaltota in Balagoda region, Sri Lanka, and its significance as a cabochoning material.
M.D.P.L. FRANCIS AND H. MATSUEDA, *Gemmologie. Z.Dt.Gemmol.Ges.*, **53**(1), 2004, 43-52, 2 maps, 3 diagrams, bibl.

Most of the gems found in Sri Lanka are alluvial. The Balangoda region houses all types of in situ corundum deposits. This paper describes one such in situ deposit and how the material could be used in cabochon production. As the corundum is embedded in weathered soft rock, sometimes well exposed, it can be easily mined. Sapphirine is also found in this region but is rare. E.S.

Relationship between nanostructure and optical absorption in fibrous pink opals from Mexico and Peru.
E. FRITSCH (Fritsch@cnrs-imn.fr), E. GAILLOU, M. OSTROUMOV, B. RONDEAU, B. DEVOUARD AND A. BARREAU, *European Journal of Mineralogy*, **16**(5), 2004, 743-52.

Translucent pink opals from Mexico (Mapimi and Michoacan states) and Peru (Acari area, near Arequipa) are opal-CT, containing 10-40 % paly gorskite, as demonstrated by XRD, IR and specific gravity measurements. They have an unusual nanostructure, with bunches of fibres 20-30 nm in minimum diameter, related to the fibrous nature of the palygorskite crystals, as seen by electron microscopy. A complex absorption centred at about 500 nm is the cause of the pink colour. It is suggested that the absorption is due to quinine fossil products associated with the phyllosilicate fibres. The Raman spectrum of monoclinic palygorskite is deduced from that of its mixture with opal. The opal-CT – palygorskite – quinine association is a geological marker for a specific environment, presumable a fossil lake environment in a volcanic region. R.A.H.

Pezzottaite – a new mineral.
H.A. HÄNNI AND M.S. KRZEMNICKI, *Gemmologie. Z.Dt.Gemmol.Ges.*, **53**(1), 2004, 3-4, 1 photo, 1 diagram.

The caesium-rich morganites described in *Gemmologie, Z.Dt.Gemm.Ges.*, **52**, 2003 have been identified as a new mineral by the International Mineralogical Association (IMA) in Sept. 2003. The new name is pezzottaite. The material comes from Afghanistan and Madagascar and is closely related to pink beryl. E.S.

A necessary test in pearl identification.
H.A. HÄNNI, *Gemmologie. Z.Dt. Gemmol.Ges.*, **53**(1), 2004, 39-42, 4 photographs, bibl.

Because their structures are very similar, an additional test is required to distinguish between natural and non-nucleated freshwater cultured pearls. The majority of natural pearls come from saltwater oysters, while most beadless cultured pearls are grown in freshwater mussels. Freshwater pearls produce luminescence under X-rays, because their nacre contains more magnesium. This visible luminescence can be recorded by a sensitive camera. Beads from freshwater nacre in Japanese saltwater pearls also react on X-ray excitation and show through the usually thin layers. This method offers an additional test for the detection of freshwater pearls and is not an alternative for X-ray shadow pictures. E.S.

Origine du jade jadeite.
G.E. HARLOW, *Revue de gemmology*, **150**, 2004, 7-11.

General survey of jadeite with a question-and-answer dialogue. M.O'D.

On the distinction between natural and artificially coloured chalcedony/agate.
U. HENN, *Gemmologie. Z.Dt.Gemmol.Ges.*, **53**, 2003, 23-32, 14 photographs, 3 tables, 2 diagrams, bibl.

Natural chalcedony is found in a wide spectrum of colours, but it can easily be dyed because of its porosity. This technique has been known for 2000 years and the traditional methods developed during the nineteenth century need not be specifically declared. However, recent guide lines of nomenclature include the declaration of all treatment techniques and therefore methods of distinguishing between natural and artificially coloured chalcedony/agates must be used, whether by microscope or spectroscope. E.S.

Rhodochrosite-Vorkommen in Peru.
J. HYRSL AND Z. ROSALES, *Mineralien Welt*, **16**(1), 2005, 54-61.

Rhodochrosite is described from Peruvian locations of Pachapaqui, Raura, Hauron, Milpo, Atacocha and Manuelita. Local geology and mineralization is discussed. M.O'D.

Neue Fluorite aus Namibias Nordwesten.
S. JAHN, *Mineralien Welt*, **16**(1), 2005, 50-3.

Pale pink and green transparent to translucent fluorite is described from a site about 25 km north-west of Uis (Otjionamewa), Namibia. M.O'D.

An interesting Australian abalone pearl.
S.M.B. KELLY AND G. BROWN, *Australian Gemmologist*, **21**(12), 2003, Geoff Tombs Memorial Issue (Part 2), 498-501, 8 illus., 2 maps.

A large crescent-shaped abalone pearl was recovered from a black lip or rubra abalone that was fished from the waters off Clay Head in northern New South Wales. Details are included of this rare pearl's gemmological characteristics. P.G.R.

Cultured pearls from the Gulf of California, Mexico.
L. KIEFERT, D. MCLAURIN MORENO, E. ARIZMENDI, H.A. HÄNNI AND S. ELEN, *Gems & Gemology*, **40**(1), 2004, 26-38.

An overview is given of the history of natural and cultured pearls from Mexico and describes the production of commercial quantities of mabe as well as bead-nucleated full-round cultured pearls from the indigenous pearl oyster *Pteria sterna*. These cultured pearls have a brown or grey to dark grey body colour, with various interference colours caused by the stacking of platy aragonite crystals and organic matter. They show a red fluorescence to long-wave UV radiation. R.A.H.

A new deposit of gem quality colour-change diaspore from Möng Hsu, Myanmar.
U.HLA KYI AND KYAW KHAING WIN, *Australian Gemmologist*, **22**(4), 2004, 169-70, 5 illus., 2 tables.

Gem quality strongly pleochroic diaspore crystals displaying a distinct colour change were first found during the authors' field trip to the Möng Hsu gem field in the Shan State, Myanmar, during November 2003. The 20 crystals collected by the authors ranged in colour from pale green to pale purple and purplish-red. Tabulated results and illustrations show the pleochroic and colour change effects under varying conditions of illumination and crystallographic orientation. P.G.R.

Gem News International.
B.M. LAURS (Ed.), *Gems & Gemology*, **40**(2), 2004, 170-81.

Items mentioned include a large (6.2 cm tall) transparent crystal of yellow scapolite from northern Mozambique, specimens from the Cryo-Genic mine near Warren Springs, California, including beryl, pink tourmaline and metallic grey inclusions of pääkkönite in quartz, some cleverly assembled imitations of tanzanite in matrix and a natural tanzanite crystal (4.0 × 2.2 × 1.4 cm) associated with calcite, diopside and graphite. R.A.H.

Gem News International.
B.M. LAURS (ED.) (blaurs@gia.edu), *Gems & Gemology*, **40**(3), 2004, 252-69.

Items noted include an untreated type Ib diamond exhibiting green transmission luminescence and H2 absorption, gem amphiboles (richterite from Afghanistan, vivid green pargasite [coloured by V] from Pakistan and yellowish-brown pargasite and colourless edenite from Myanmar), a green gem beryl (more than 1 kg in weight) from Luumäki in Finland, cuttable rhodonite from Brazil, a range of orange-red spessartines from Afghanistan, green to blue gem tourmalines from Congo and dyed cultured pearls fading on exposure to heat in a parked car. R.A.H.

Gemstones in Vietnam.
P.V. LONG, G. GIULIANI, V. GARNIER AND D. OHNENSTETTER, *Australian Gemmologist*, **22**(4), 2004, 162-8, 12 illus.

Vietnamese research in geology indicated a high potential for the recovery of gemstones in both north and south Vietnam. In the late 1980s, placer deposits of ruby were uncovered by farmers during routine agricultural activities. Following this major discovery of high quality ruby in the Luc Yen and Yen Bai areas of northern Vietnam, gemstone sources were found in many other locations and culminated in 1988 with the setting up by the government of Vinagemco, a state-owned company for the investigation, mining, processing and trading of gem materials in Vietnam. This paper provides an overview of gemstone localities in Vietnam with special reference to ruby and sapphire. P.G.R.

Red grossular from the Sierra de Cruces, Coahuila, Mexico.
V.W. LUETH AND R. JONES, *Mineralogical record*, **36**(6), 2003, 73-95.

Pink to red crystals of grossular were first discovered in 1974 in the area of Lake Jaco, Coahuila, Mexico where well-formed dodecahedral specimens were found in association with good quality crystals of mustard-yellow vesuvianite. Details of the occurrence and geology are given, with short descriptions of other minerals found in the area. There is a sketch map and a short list of references. M.O'D.

Gem News International.
B.M. LAURS (ED.), *Gems & Gemology*, **40**(1), 2004, 66-86.

Items include an update on demantoid and cat's-eye demantoid from Iran, pink to pink-orange spinel from a new locality in Tanzania, fine crystals (to 1.5 cm) of tsavorite and green grossular from Merelani, Tanzania, and commercially produced highly saturated green-yellow diamonds that appear greener in daylight than in incandescent light. R.A.H.

Amethyst from Four Peaks, Arizona.
J. LOWELL AND J.I. KOIVULA, *Gems & Gemology*, **40**(3), 2004, 230-8.

For more than a century, the Four

Peaks mine in Maricopa County, Arizona, has produced gem-quality amethyst from crystal-lined or crystal-filled cavities in fractures in a brecciated quartzite. Crystals from this deposit exhibit a range of purple colours, uneven colour zoning and variable transparency, presenting challenges for obtaining a steady supply of material suitable for faceting. The faceted material may display fluid inclusions, tiny reddish-brown flakes of hematite, growth zoning and Brazil-law twinning, all of which provide visual clues for the distinction of Four Peaks amethyst from synthetic material. Recovery of amethyst at this locality continues on a limited basis. R.A.H.

Diamond Geezer.

J. McCall, *Geoscientist*, **14**(3), 2004, 10-11.

Short review of the history of diamond recovery in India. M.O'D.

Lab Notes.

T.M. Moses, I. Reinitz, S.F. McClure and M.L. Johnson (Eds), *Gems & Gemology*, **40**(1), 2004, 58-65.

Notes are given on a natural faint pink 20.24 ct type IIa diamond with numerous green radiation stains, two yellow synthetic diamonds (the metallic inclusions in one of which caused it to be attracted to a magnet), a 78.35 ct green herderite, and four translucent purple beads of spurrite. R.A.H.

Lab Notes.

T.M. Moses, I. Reinitz, S.F. McClure and M.L. Johnson (Eds), *Gems & Gemology*, **40**(2), 2004, 162-9.

Notes are included on cat's-eye demantoid garnet, a high refractive index (> 1.81) glass sold as peridot, a synthetic 8.85 ct sapphire with an unusual yellowish-green body colour resembling emerald, and a natural 8.88 ct orange-red spinel containing M-shaped etch tubes. R.A.H.

Gem treatment disclosures and U.S. law.

T.W. Overton, *Gems & Gemology*, **40**(2), 2004,106-27.

In recent years, the obligation to disclose fully all gem treatments has changed in the U.S.A. from a mere ethical responsibility to a legal one. The U.S. Federal Trade Commission guides for the gem and jewellery trade now require the disclosure of any treatment of a gem material that substantially affects its value. In addition, all state deceptive practice regulations in the U.S. require that vendors do not mislead customers as to the treatment status of gems they sell. Vendors should also be aware that insufficient disclosure can subject them to substantial civil liability for fraud by non-disclosure. Several case studies are outlined and suggestions for avoiding legal problems are made. R.A.H.

Alabandin (MnS) a new inclusion mineral in colourless chrysoberyl from Sri Lanka.

J. Ponahlo, F. Brandstaetter and T.T. Tran, *Gemmologie. Z.Dt.Gemmol.Ges.*, **53**, 2004, 33-7, 6 photographs, 2 tables, 1 graph, bibl.

A relatively large alabandite inclusion of about 670 μ was found in a rough colourless chrysoberyl from Sri Lanka. The method of examination is described. E.S.

Chemical composition and mineralogical properties of a pink tourmaline from pegmatites around Rajgarh, Ajmer District, Rajasthan, India.

L.A.K. Rao, S.R. Ali and P. Singh, *Australian Gemmologist*, **22**(4), 2004, 146-9, 1 illus., 1 map, 3 tables.

Pink tourmaline (rubellite) was extracted from a pegmatite body 1.5 km south of the village of Rajgarh in Ajmer District. Details are given of the mineral's gemmological properties and chemical constituents. The chemical data reveal that the Rajgarh tourmaline is characterized by unusually high concentrations of boron, manganese and ferric iron. P.G.R.

Opals from Slovakia ('Hungarian' opals): a re-assessment of the conditions of formation.

B. Rondeau (brondeau@mnhn.fr), E. Fritsch, M. Guiraud and C. Renac, *European Journal of Mineralogy*, **16**(5), 2004, 789-99.

Slovakian opals found in an andesitic host-rock in the Dubnik area, near Košice (part of Hungary until the end of World War I) are believed to have formed by water circulation during a tectonic event. Their physical properties were investigated by XRD, Raman spectra (main peak at 437 cm^{-1}) and scanning electron microscope (large silica spheres 125-270 nm in diameter). Surprisingly, these are properties of opals usually found in sedimentary deposits rather than those found in opals of volcanic rocks. Some preliminary results of a study of their oxygen isotopes indicate a high $\delta^{18}O$ for Slovakian and Australian opals (31 ‰), consistent with temperatures of formation less than 45°C; in contrast, Mexican opal-CT shows a lower $\delta^{18}O$ of 13 ‰ consistent with formation at a higher temperature, possibly as high as 190°C. R.A.H.

The origin of the color of pearls in iridescence from nano-composite structures of the nacre.

M.R. Snow (snow.mike@saugov.sa.gov.su), A. Ping, P. Self, D. Losic and J. Shapter, *American Mineralogist*, **89**(10), 2004, 1353-8.

The variety of body colours shown by South Sea pearls is in part due to a newly recognized structure of the nacre, the edge-band structure, which gives rise to interference colours characteristic of the width. With the pearl oyster, *Pinctada maxima*, the colours include a range of silver tones, creams, yellow and gold in various degrees of colour saturation. The authors have established that the primary body colour of *P.maxima* pearls arises from the interference of light within the binding regions of the aragonite tiles. The tile faces terminate in a fissured nano-composite structure with an organic matrix within the margin of the aragonite tiles. This edge-band structure gives rise to an optical film formed of organic matrix in aragonite. TEM images show that the edge-band structure increases in width from 74 nm in a silver pearl to 80 nm in a cream pearl, and to 90 nm in a gold pearl. These are first-order Newton's colours which, when mixed with the specular reflection of the nacre and modified by any pigmentation present, give the body colour of the pearl. The more common non-metallic whiter pearls can be accounted for by disorder of this structure leading to unsaturation of the colour. R.A.H.

TPR, EPR and UV-Vis studies of Ni(II) speciation in chrysoprase.

Z. Sojka, S. Witkowski, W. Zabinski, K. Dyrek and E. Bisinska, *Neues Jahrbuch für Mineralogie, Monatshefte*, 2004(1), **2004**, 11-25.

TPR (temperature programmed reduction), epr (electron paramagnetic resonance) together with UV-visible

methods were used to study the status of nickel ions in chrysoprase from three localities (Szylary, Lower Silesia, Poland [apple-green with Ni 1.71 wt.%], Marlborough Creek, Australia [emerald-green with Ni 0.98 wt.%] and an unknown African locality [dark-green with Ni 4.38 wt.%]). The speciation of Ni into 2:1 highly dispersed phyllosilicates (similar to Ni-talc and Ni-lizardite) and extra-framework species grafted onto the surface of chalcedony was demonstrated. Both kinds of Ni exhibit a distorted octahedral coordination giving rise to a broad e.p.r. spectrum with g=2.17 and three characteristic d-d bands that can be parameterised with 10Dq = 8897 cm^{-1} and B = 953 cm^{-1}. Dedydration of the samples influences significantly the coordination sphere of the extra-framework Ni ions, indicating that water molecules are directly involved as supplementary ligands.

R.A.H.

Spectroscopic and related evidence on the colouring and constitution of New Zealand jade.

C.J. WILKINS, W.C. TENNANT, B.E. WILLIAMSON AND C.A. MCCAMMON, *American Mineralogist*, **88**(8-9), 2003, 1336-44.

IR, optical absorption spectroscopy and Mössbauer spectroscopy were used to investigate the colour of jade [nephrite] from the South Island of New Zealand. Mössbauer spectra gave the distribution of Fe^{2+} and Fe^{3+} at the cation sites and also show how the Fe^{3+}/Fe^{2+} ratio increases due to oxidative weathering. The development of the attractive flecking in gem-quality jade is due to agglomerations of colloidally dispersed magnetite or chromite that can also lead to the formation of black spots. Darker samples are generally high in total iron, although not all lightly coloured samples are low in iron. Weathering in the climatic conditions may give either a brown, hydrated iron oxide or a whitish outer rind if the acidity is high enough to remove the oxide; in either case the nephrite matrix is unaltered. Two quite rare variations were found and ascribed to (1) incomplete nephrite formation in samples developed in association with an unusual ultramafic protolithology and (2) the formation of chromian margarite giving rise to a bluish green (pseudo) jade. EPMA results are given.

R.A.H.

Instruments and Techniques

LIBS: A spark of inspiration in gemmological analytical instrumentation.

T. THEMELIS, *Australian Gemmologist*, **22**(4), 2004, 138-45, 9 illus., 1 table.

LIBS (laser induced breakdown spectroscopy) or LASS (laser ablation spark spectroscopy) is a form of optical emission spectroscopy used primarily for qualitative analysis of elemental compositions. This paper describes a preliminary study of the use of LIBS for the detection of elements in gemstones. The technique provides a method of detecting the low concentrations of Be, Li, B and other elements used in some heat treatments of corundum and which are not detectable by other more conventional analytical instruments. More than 70 natural specimens of chrysoberyl, beryl, corundum heat-treated with beryllium, corundum heated with flux and beryllium, and corundum heat-treated with lithium were tested using the LIBS method. In this preliminary evaluation Be, Li and B were detected but had an error tolerance of around 20%. Although further development of this new method is expected to reduce the error tolerance, the author suggests that the slightly destructive LIBS technique may limit its use to rough specimens.

P.G.R.

Synthetics and Simulants

The 3543 cm^{-1} infrared absorption band I natural and synthetic amethyst and its value in identification.

V.S. BALITSKY (balvad@iem.ac.ru), D.V. BALITSKY, G.V. BONDARENKO AND O.V. BALITSKAYA, *Gems & Gemology*, **40**(2), 2004,146-61.

The proper use and limitations of IR spectroscopy for identifying natural vs. synthetic amethyst of various types have been studied, focusing on the 3800-3000 cm^{-1} region. The presence of absorption bands at approximately 3680, 3664 and 3630 cm^{-1} unambiguously proves a synthetic origin, but only for samples grown in near-neutral NH_4F solutions. Conversely, there are no unambiguous diagnostic features in the IR spectra of the more commercially significant synthetic amethyst grown in alkaline K_2CO_3 solutions. Nevertheless, previous investigators have found potential diagnostic value in absorption bands at ~ 3595 and 3543 cm^{-1}. The 3595 cm^{-1} band is found in the spectra of synthetic amethyst, it also is frequently absent from those of natural amethyst. The 3543 cm^{-1} band is found in most synthetic amethysts grown in alkaline solutions but this band also is sometimes present in natural amethyst, so it provides only tentative evidence of synthetic origin. The unambiguous identification of natural vs. synthetic amethyst must be based on a combined examination of the IR spectra, internal growth structures (including twinning) and inclusions.

R.A.H.

Diamond simulants – A literature review.

P. CARTWRIGHT, *Australian Gemmologist*, **22**(3), 2004, 125-31, 3 illus., 1 table.

The review contains a brief history of the manufacture of diamond simulants. This is followed by lists of the properties of diamond simulants. An indication of how these simulants can be distinguished from diamond is covered under the headings 'The unique properties of diamond' and 'The separation of diamond'. This is followed by a table of diamond simulant properties (which, for completeness, would have benefited from the inclusion of the several colourless natural diamond simulants). A footnote warns of the existence of a new diamond simulant – synthetic moissanite coated with a thin film of synthetic (CVD) diamond.

P.G.R.

Identification of synthetic diamond grown using chemical vapour deposition (CVD).

P.M. MARTINEAU, S.C. LAWSON, A.J. TAYLOR, S.J. QUINN, D.J. EVANS AND M.J. CROWDER, *Gems & Gemology*, **40**(1), 2004, 2-25.

Studies carried out at the DTC Research Centre in Berkshire have shown that single-crystal CVD synthetic diamond is clearly distinguishable from natural diamond. The history of the development of the CVD process, the different kinds of CVD synthetic diamond and the properties that differentiate them from natural diamond are outlined. Absorption, photoluminescence and cathodoluminescence spectra of CVD synthetic diamonds show a range of different impurity-related features not seen in natural diamond. Photoluminescence imaging is also useful in identifying CVD synthetic diamond, and X-ray topography may give supportive evidence.

R.A.H.

Lab-grown colored diamonds from Chatham Created Gems.
J.E. SHIGLEY, S.F. MCCLURE, C.M. BREEDING, A.H.-T. SHEN AND S.M. MUHLMEISTER, *Gems & Gemology*, **40**(2), 2004, 128-45.

Synthetic yellow, blue, green and pink diamonds from a new source are now being sold by Chatham Created Gems of San Francisco. Some of this new material displays hues and weaker saturations that more closely resemble natural diamonds than most of the synthetic diamonds recently encountered, which typically had very intense colours. These as-grown and treated type I and type II synthetic diamonds, produced by a high-pressure/high-temperature process, have many distinctive visual and spectroscopic features that serve to distinguish them from natural diamonds. These features include geometric patterns of colour zoning and luminescence, metallic inclusions, and bands seen in the visible and photoluminescence spectra; examples are illustrated. R.A.H.

[About mechanism of the fibrous structure appearing in cubic diamond crystals.]
V. M. SONIN, D. G. BAGRYANTSEV, A.I. CHEPUROV AND J.-M. DEREPPE, *Proceedings of the Russian Mineralogical Society*, **132**(2), 2003, 95-8 (Russian with English abstract).

The growth of diamond crystals at high *P* in the Fe-Ni-C system was studied in terms of a *T* decrease of ~1-2°/sec. A phenomenon has been detected of octahedral crystals re-facing via the transformation of numerous tiny cubic sub-individuals on their faces. Data show that this is possibly the formation mechanism of natural cubic diamond crystals with a fibrous structure. This is based on the growth of cubic sub-individuals parallel to one another in the {111} direction with the formation of subparallel fibres. Because of this phenomenon, sectors of cubic growth become enlarged while the octahedral growth sectors are declining; the main cause of this change in the growth mechanism is the sharp increase of supersaturation in the crystallization media provided by the falling *T*. R.A.H.

Abstractors

R.A. Howie	R.A.H.	M. O'Donoghue	M.O'D.	P.G. Read	P.G.R.	E. Stern	E.S.

Book Reviews

Achat + Jaspis.
Various authors, 2004. Kuratorium der Stiftung Deutsches Edelsteinmuseum, Idar-Oberstein, Germany. Edition des Deutschen Edelsteinmuseums. Bd 7. pp 88, illus. in colour. Map in colour loosely inserted. Hardcover ISBN 3 932515 42 0. €19.00.

The contributing authors of this beautiful tour d'horizon of the agate and jasper world are Professor Dr Hermann Bank, Rudolf Dröschel and Rainer Hoffmann-Rothe. Each opening from pages 49 to 88 shows magnificent examples of sliced and polished specimens with dimensions given. The standard of photography is the highest I have seen, certainly for this material. The location is given for each specimen depicted - all are from the Idar-Oberstein region.

Preceding the illustrated section are notes, some with English summaries, on some of the notable localities whose history is summarized. The map, not being bound in, can be used in a variety of circumstances. M.O'D.

Rio Grande do Sul, Brasilien. Landschaften - Menschen - Edle Steine.
R. BALZER, 2003. Reinhard Balzer [Eichendorfstrasse 7, D-35039], Marburg, Germany. pp 234, illus. in colour. Hardcover ISBN 3 88293 136 1. DM 58.00.

Just over half the book is devoted to a survey of the gemstones found in the Brazilian state of Rio Grande do Sul, their mining and fashioning. The remainder deals with folk-lore, agriculture and history. Most of the items described and illustrated are varieties of quartz and the link between Rio Grande do Sul and Idar-Oberstein is discussed. Both text and presentation are unusual (square format) and attractive. The photographs are excellent, in particular those of agate, and there is a useful bibliography. M.O'D.

Mana Pounamu. New Zealand jade
R.J. BECK and M. MASON, 2002. Reed Books, Auckland, New Zealand. pp 180, illus. in colour. Softcover ISBN 0 7900 0863 7. NZ$29.00.

An attractive and authoritative book describing the many varieties of nephrite found and worked in New Zealand. The senior author, a gemmologist, also has experience of jade carving and this topic is covered in some detail in the second part of the book. Early chapters describe New Zealand nephrite locations, the material recovered from them and the uses to which fashioned jade has been put by the Maoris. Colour photographs occupy a central section and the artefacts selected for reproduction are both beautiful and well presented. Diagrams and black-and-white photographs in the text show details of occurrences and fashioning. The type chosen lends itself to easy reading and the double spacing and the graceful font selected are pleasing to the eye.

An extensive bibliography includes many local sources which will not appear elsewhere and there are numerous references in the text to nephrite locations in other countries. This is an excellent study at a very low price. Most jade literature is in languages other than English and this book is especially welcome on this account. M.O'D.

Seeing the light.
R.H. CARTIER, 2004. [The author: no place of publication given] pp 324. Softcover ISBN 0 9735316 1 4. No price given.

The title will ensure that the book may be ordered by a large number of readers with (religious) evangelical tastes but this is an original book and, yes, the subtitle (Understanding optics without the mathematics) does introduce the text more or less accurately, though mathematics of a kind is necessarily implicit throughout and finally throws off its cloak in the Appendices.

By 'optics' the author means 'optics as applied to gem testing' and he very thoroughly explores virtually all the optical phenomena that the gemmologist is likely to come across. He succeeds quite well though a word-by-word examination of the text would be necessary to pinpoint heresy if it exists. Several observations I chose at random were accurately described in some cases linked to related ones with which the gemmologist may not be so familiar; I found this stimulating and useful. There could perhaps be more diagrams but if this is a self-published book the selection and obtaining of text illustrations would easily take up a great deal of time and expense. This is a book that can be consulted at random; the style is easy and the typescript good to read.

A minor criticism is the absence of a place of publication and a price, though the book can no doubt be ordered through its ISBN. The serious student will find much of interest and, yes, I have read (some of) it in bed. M.O'D.

Edle Steine vom Dach der Welt.
Various authors, 2003. Christian Weise Verlag, Munich, Germany. pp 96, illus. in colour. Softcover ISBN 3 921 65662 1 [ISSN 0945 8492] *extraLapis* no 14. €28.40.

As beautifully illustrated and as well written as the other numbers in this excellent series [now appearing in English], the present number describes the gem minerals of Afghanistan and Pakistan (the title can be translated as Gemstones from the roof of the world). As always the different sections follow one another without a break and an extensive bibliography concludes the survey. As this reviewer is familiar with some at least of the gem mines of Pakistan it was interesting to read that pargasite of appropriate colour is being

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called 'Hunza emerald' and that the list of Pakistan gem species has grown to include fine green transparent zoisite and fine orange scheelite. M.O'D.

Minerales de Bolivia.
O. KEMPF, S. TAWACKOLI and W.H. PAAR, 2003. The authors (Casilla 1283), La Paz, Bolivia. pp xix, 121, xvi, illus. in colour. Softcover ISBN 99905 0 417 2. €48.00.

A useful account in chemical order of the mineral species found in Bolivia, with small but adequate illustrations. Several species of more or less gem quality are included; tourmaline and the transparent quartzes; ametrine (given the alternative name bolivianite but not illustrated) and phosphophyllite (a very fine specimen illustrated) are among them. Several previous studies of Bolivian minerals by Ahlfeld have been published and they are listed, with other useful books, in the 38-item bibliography. There is a useful glossary. Perhaps the binding will need care over years of heavy reading. While the standard of photography and reproduction is moderate, the book is none the less welcome. M.O'D.

Fleischer's glossary of mineral species (9th edn).
J.A. MANDARINO and M.E. BACK, 2004. The Mineralogical Record, Tucson, U.S.A. pp xiv, 309. Softcover, ring-back, US$26.00.

The previous edition, published in 1999, contained 183 pages and the present edition 309. This represents a considerable increase in descriptions since the present edition now lacks the section on mineral groups, which took up 41 pages last time. Around 250 new species have appeared in the major journals and deletions (of discredited species) have been few.

The mineral groups section, revised, will appear in a future issue of *The Mineralogical Record*. Where species are group members their membership is indicated in their entry here, together with the now customary citations to *American Mineralogist* and other journals: a list of those consulted runs to six pages. As usual, each description gives composition, crystal system, main occurrence, series and group membership where relevant. The ring-back binding has served me well with constant use over the previous editions.

This text is essential for the collector as well as the professional mineralogist and its very low price gives little reason for neglect. M.O'D.

Diamond handbook; how to look at diamonds and avoid rip-offs.
R. NEWMAN, 2005. International Jewelry Publications, Los Angeles, U.S.A. pp 186, illustrated in black-and-white. Softcover ISBN 0 929975 36 7. US$ 18.95.

Yet again it is left to Renée Newman to provide the gem world with a guide which manages to give the trade reader virtually all the essential information needed to buy and sell diamonds: even if there were no HPHT treated diamonds or synthetic diamonds the problems of the ages have not gone away and are just as pressing as they ever were. The book is an advance of the same author's *Diamond ring buying guide* (6th edn, 2002).

The text covers everything the buyer needs to know, with useful comments on lighting and first-class black and white images that show up features better than those in colour. At all relevant points the author gives an up-to-date list of references.

I found several sections particularly interesting; no other text in current circulation discusses re-cutting and its possible effects and the author's discussion of the new topic of branded diamonds conveniently brings together a number of examples of particular cuts peculiar to different firms. I was pleased to see that the Old Mine cut is regaining popularity and that some diamonds have been re-cut in that style from their original cut (probably those giving spread rather than maximum dispersion).

Brief and useful notes describe the present position of synthetic gem diamond and treated diamond. Rip-offs are soberly described and sensation avoided. This is a must for anyone buying, testing or valuing a polished diamond and for students in many fields. I greatly welcome it. M.O'D.

China.
B. OTTENS, 2004. Christian Weise Verlag, Munich, Germany. pp 195, illustrated in colour. Softcover ISBN 3 921656 64 8 ISSN 0945-8492. *ExtraLapis* 26/27. €35.60.

This double issue of the elegant and informative series *ExtraLapis* is one of the first recent attempts to survey the more spectacular minerals (including gemstones) so far discovered in China. As always all of the openings show at least two fine photographs and there is a 38-item bibliography of European-language works only but including maps. Naturally we hope for the now customary English translation to appear before long.

Though a section on gem materials begins on page 138, previous sections also include gem and ornamental species. Beryl, amethyst, tourmaline, turquoise, peridot, diamond, corundum and diopside, together with remarks on jadeite and nephrite come in the gemstones section though sphalerite and fluorite, described elsewhere, might very well have found a place here. Some locations are given in a table arranged in (romanized) alphabetical order of location but I should imagine that not all species described are included. Chinese characters for some species are also given in a table. Gemmologists and mineral collectors should subscribe to this series and, maybe, to the main journal, *Lapis*. M.O'D.

Faszination Turmalin.
P. RUSTEMEYER, 2003. Spektrum Akademischer Verlag, Heidelberg, Germany. pp x, 309, illus. in colour. Hardcover. ISBN 3 8274 1424 5. €99.95.

The book is certainly designed to catch the eye and tourmaline serves this purpose admirably. This is the second book on tourmaline to have come from Germany in the past few years and though it is not on the same physical scale as Benesch (1990), one of the largest books on a single gemstone, the general conception is similar. Photographs in colour appear on the recto of every page and are faced either with text, diagrams or additional photographs. The reader is left in no doubt that tourmaline can often be sectioned to give beautiful and intriguing patterns.

Readers should be advised that this is not a study of fashioned stones but only of crystals, their symmetry and some of their inclusions as displayed by tourmaline. In this context this is a beautiful book. There is a useful bibliography and an index. M.O'D.

Crystals, growth, morphology and perfection.
I. SUNAGAWA, 2005. Cambridge University Press, Cambridge. pp xii, 295. Hardcover ISBN 0 521 84189 5. £55.00.

Compared with the late nineteenth and early twentieth centuries, the output of books on this type of crystallographic survey has declined. This may be due to either to the attainment of near-perfect methods of structural investigation or to the assumed establishment of required crystallographic data resources making another review superfluous. This being said, the reader is recommended to be within reach of

Professor Sunagawa's *Handbook of crystal growth* (1995) and *Morphology of crystals* (1988). The present text has been translated from the original Japanese.

However, here is an entirely up-to-date treatment of the crystalline state with many references to current investigative methods, well printed and illustrated and with chapter references rather that a bibliography. Professor Sunagawa is known for his interest in gemstones: gem- and ornamental-quality mineral crystals are frequently cited and illustrated.

The text begins with a statement of the fundamental concepts of the crystalline state. Some history of work carried out as far back as the seventeenth century is given before the establishment of the terms form and habit is reviewed. Succeeding chapters deal with growth, heat and mass transfer, spirals, twinning and etching. By chapter 10 the author has chosen four examples of mineral crystals to be examined in detail, rock crystal and agate, pyrite and calcite.

Following an intervening examination of crystal growth in pegmatites Sunagawa returns to individual species, with hematite, pholgopite and the development of the trapiche effect in emerald and ruby. Final chapters discuss the formation of muscovite by regional metamorphism, crystal growth in living bodies and crystals formed through excretion processes. Appendixes illustrate Miller indices, Bravais lattices and the seven crystal systems.

This is an excellent overview of the crystalline state and can be recommended to all students of mineralogy and to gemmologists who wish to pursue the subject beyond the artificial limits of the diploma curriculum.

M.O'D.

Suomen Gemmologinen Seurary.

Gemmologia/Jalokivet, Helsinki, 1991. pp 114, illustrated in colour. Softcover ISSN 1458-4646. Price on application.

Notes on gem species, including organic and synthetic materials with notes of methods of testing, assembled apparently from an unidentified serial but very well produced and attractively illustrated. M.O'D.

Tourmaline: a gemstone spectrum.

Lapis International LLC, East Hampton, Conn., USA, 2002. pp 106, illus. in colour. Softcover ISBN 0 971 5371 2 7. *extraLapis English 3*. Price on application.

Published independently from but in collaboration with the journal *Lapis*, the *extraLapis* series translated into English has at the time of writing covered emeralds (issue 2) and calcite (4). The texts are literal translations of the German versions [reviewed in the *Journal passim*] and the illustrations are equally excellent. M.O'D.

Lapin korukivet.

R. VARTIAINEN, 2001. [The author] Tampere. pp 80, illustrated in colour. Hardcover ISBN 952 91 3410 X. Price on application to risto.vartiainen@pp.inet/fi

Attractive and well prepared survey of the gem and ornamental minerals of Finland whose comparatively large area (for a European country) has produced a number of fine specimens whose locations are selectively given both in the text and on maps occupying pp 77-80.

A useful bibliography introduces many Finnish papers and monographs rather than the same old titles served to readers by many small guides. Probably since publication, diamond has been found in eastern Finland. M.O'D.

Minerals, their constitution and origin.

H-R. WENK, AND A. BULAKH. 2004. Cambridge University Press, Cambridge. pp xxii, 646 illustrated in colour. Softcover ISBN 0 521 52958 1. £35.00.

It is some years since a comprehensive introduction to minerals at the undergraduate to graduate level was published and the present text is welcome for this reason and for its coverage of the geological processes which produce minerals. Chapters in the first section cover the chemical elements, crystal structures and morphology and crystal growth. In the second section comes the physical investigation of minerals, the third and fourth sections dealing with mineral varieties and the mineral-forming process and with the formation of mineral groups.

Section five deals with applied mineralogy, including a chapter on gemstones. Several appendices deal with cleavage, hardness and other basic phenomena. Each chapter includes 'test your knowledge': students are asked for the causes of colour of emeralds, rubies and sapphires, along with other reasonable questions.

Colour photographs, forming a section near the centre of the book, are of good quality and include a number of gem and ornamental materials. While each chapter has its own list of references, additional items can be found in the seven-page bibliography. Readers need not stop with the gemstone chapter - later ones are equally valuable. At the price this text is worth buying.

M.O'D.

Magic of minerals and rocks.

D.J. WIERSMA, 2004. Springer, Berlin, Germany. pp 160, illus. in colour. Hardcover ISBN 3 540 21053 9. £25.00.

Large format well-produced book in which full-page photographs illustrate features of rocks and minerals considered aesthetically pleasing by the compiler-photographer. There is a very short introductory text and individual sections (which include gems, crystal, geode, texture, deformation among others) also have short lead-ins. The gem section includes mostly agates but the pictures are very fine. This reasonably-priced book would make an ideal present. M.O'D.

Proceedings of the Gemmological Association and Gem Testing Laboratory of Great Britain and Notices

Presentation of Awards

The Presentation of Awards gained in the 2004 examinations was held at Goldsmiths' Hall in the City of London on Monday 1 November. Alan Jobbins, President of the Association, presided and welcomed those present, particularly those from as far away as Canada, China, India, Indonesia, Japan, Myanmar and the U.S.A., as well as the Netherlands and Ireland.

The President introduced Ian Mercer, Gem-A's Director of Education, who presented the awards and gave the address (see below). A vote of thanks to Ian Mercer was given by Professor Alan Collins, Chairman of the Council of the Association.

A reception attended by over 200 members, students and their guests, was held following the ceremony.

Gem-A President Alan Jobbins (right) welcomes students to the Presentation and introduces Gem-A Director of Education, Ian Mercer, at the Presentation of Awards ceremony. Photo: Lewis Photos Ltd.

Ian Mercer's address

As Gem-A Director of Education, I am very glad to have this opportunity to talk to our Diploma graduates and prize winners here tonight. I would like to review just one or two of the many and various reasons for taking on this study. You and I both are pleased and relieved that you have been so successful. So, why might you have needed to put yourself through all this hard work? First, I think back to why I did the same, getting on for forty years ago now. It was because of our new President, Alan Jobbins, that I got into gemmology; and eventually that led to me being here, talking to you. I was starting out in a geological career and Alan was the curator of gems and minerals in the Geological Survey and Museum; he was also the Education Officer for the Survey and I went to him to seek advice to help me further into the world of minerals. He advised me that there were no pure mineralogy courses, but how about taking a gemmology course. I said, 'what's gemmology?', and that was the start of my everlasting learning curve in gems and ornamental materials. Actually, I sat my exams in this very Hall, with the sun streaming through those stained-glass windows introducing all sorts of selective absorption effects to my practical observations. But much more importantly, why and how did formal gem education get started first in Britain almost 100 years ago? This is relevant to why you needed to get your training right now.

At the start of the 20th century the British jewellery trade requested a gem training response to some serious changes in the gem trade. For example, Professor Verneuil was

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First Hirsh Foundation Award goes to graduate from China

Guilin Institute of Technology student Jiang Huijing led the world in gemmology examination success this year. Jiang, of Zhuhai City in Guangdong province, China, was awarded the new Hirsh Award and the Anderson Medal for her top marks in the Foundation Certificate examination in January 2004 and also the Anderson-Bank Prize for highest marks for a non-trade candidate in the June Diploma examination. Jiang Huijing, who travelled to London for the presentation of her awards, is pictured left receiving her Diploma from Ian Mercer, Gem-A's Director of Education. "Among more than 1000 exam candidates in over 50 centres world wide," said Ian, "Jiang has demonstrated her ability to achieve the real-life aims of our courses. I wish her every success."
Photo: Lewis Photos Ltd.

creating challenges when his synthetic ruby was rapidly becoming commercial through 1904 to 1908. The world's first trade diploma course and exam for the Diploma in Gemmology were developed from that time, and the course notes were first produced 92 years ago (we have updated them since, by the way!). The world's first home-study gem course started in 1921 and was later taken up by a man called R. M. Shipley who took his exam in London in 1929. He returned to the U.S.A. and started up the GIA using his hard-won knowledge – so you can see that our Diploma comes in pretty handy for some purposes. By 1925, cultured pearls had become commercially successful enough to prompt the trade into starting up the world's first gem testing laboratory, headed for many years by the great Basil Anderson, who also became chief examiner for the FGA Diploma. Anderson occasionally lectured after retirement in 1966: I was lucky enough to receive occasional tuition from both Anderson and Robert Webster in 1968. The Association and the Gem Testing Lab, long in close cooperation, joined forces officially as one organization in 1990 and, together, now run under the trade name 'Gem-A', as you know. And that was the year that I started working for the Association, although I had been a home-study tutor for some years.

Now let us think about a basic educational aspect and its relationship with the jewellery trade: what I call *'Observation and real-life gemmology'*. Gem education with qualification really got started with those changes and scares in the trade nearly 100 years ago. Now there are changes and scares by the shovel-full in the gem industry. Really, these should be seen as challenges. They lead to opportunity. I believe the gem and jewellery industry is set to change more drastically than ever. Consequently, there must be continual development in gem and diamond education and exam requirements. In practice, in real-life, there can be a dilemma between (i) the need for fast, observation-based decision-making in buying gems and gem-set jewellery, and (ii) the need for a second opinion, or an appraisal or lab report. Let us recognize the fact that a great number of our purchases are relatively quick decisions relying on our eyes alone. The decision to spend time and money on further information is based greatly on

Christie's Prize for Gemmology

Anu Manchanda of Bearwood, West Midlands, receiving the Christie's Prize for the best jewellery trade candidate of the year in the Gemmology Diploma examinations.Photo: Lewis Photos Ltd.

your experience. But without knowledge, and without good observation practice based on that knowledge, experience is pretty well degraded or even rather useless for safe trading or buying. 'Real-life', therefore, also involves knowing when and why you might need to get a further opinion or lab help. This has to be based on thorough training, so that you know the limits, both yours and those intrinsic to the gem itself. The problem is usually one of making time to build that practical foundation – time to take a course of training and then time to carry on learning through reading, conferences and seminars, short courses and the gathering of experience based on your training.

So what is the relevance of gem education in the jewellery industry? There is a difference between the *breadth* of learning and the *depth* of learning in any subject. In a practical subject like gemmology, the depth of detail can be great. However, most of the trade generally needs less depth than is contained in Webster's big textbook, for instance. Yet there are instances where trade knowledge needs to be deep enough to understand the great detail in what lies behind a problem such as gem origins: what are the criteria, why is it prone to differing interpretations, and what is really meant by the term 'Kashmir' when applied to a sapphire, for instance? These are questions which depend upon a deeper knowledge but they are essentially trade questions. It is true to say that the depth of information in the two Gem-A Diploma courses is tailored to the requirements of those in the trade who need to become *practically confident*. That is a key point. How *broad* an approach to gems does the jewellery trade need? For instance, the Gem-A Diplomas are broad in concept. This means that the training covers a wide spectrum of subjects including rough materials, crystallinity, great attention to the use of the eye in observation for a real-life approach both in gemmology and gem diamond studies, as well as a thorough understanding of testing techniques. Why? Because all of these aspects are required for the different areas of trade activity – retail jewellery, lapidary, diamond manufacture, jewellery design, mining and extraction, grading and valuation, antiques trading and auctioneering, to name just a few.

Now, as part of my experience and fascination with the subject, I would like to consider the relevance of the word *'real'* when applied to gems. As many of you might remember, even so long after your exam, synthetic sapphire is chemically the same as natural sapphire. Therefore, it is *real* sapphire, although it is produced artificially rather than naturally. So, why might most of the jewellery-buying public not think of synthetic sapphire as 'real'? This word 'real' is not generally useful for gem materials because it means different things in different contexts.

However, the jewellery-buying public could be helped to become more aware of the interesting possibilities and varieties in natural, imitation, synthetic and treated gem materials, so that they may start to decide for themselves the relative values, fitness for use or fascination, of these various gem materials in jewellery and ornaments. Gem-A's educational activities are directed towards the consumer as well as the gem and jewellery industry. About half of our students are not in the gem-related trades, although a proportion of these eventually join the trade. Education can then be provided by the trade itself in the form of informed advice, and that advice can be based on a sufficiently deep and practical knowledge provided by our courses, which in turn helps both the customer and the trade itself. For example, we know why a one-carat natural sapphire containing several healed fractures and other inclusions may be considered to be more valuable than a relatively clean one-carat synthetic sapphire of the same colour. Some customers would consider the more cloudy natural sapphire to be the more desirable object than the synthetic, whereas others may go for the perfection of the synthetic sapphire knowing that it is a man-made product. It is, after all, *'real'* sapphire, isn't it? So which really is more valuable? Is it a trade decision, a consumer decision or an educator's decision? In this instance maybe you could vote for the public. They make the final decision, after all. But how could you possibly advise or inform the consumer if you have little or no knowledge of gemmology?

So there is another key point: transfer that awareness to the buying public, with a confident use of gemmological expertise, backed by sufficiently wide-based training, to a great enough depth, and based on realistic observation techniques, and you can increase business. Synthetic, treated or imitation gems can then be allowed to sell themselves, and they can be used to sell-on to the untreated natural gems in jewellery: the so-called 'real thing'. That is my message in this fast-changing gem world, and it is these changes that will make more opportunity, so long as the good training and observational awareness are there to begin with, and so long as the consumer is enabled to be well aware. If *you* are the consumer then, with your training, you have already armed yourself with a good amount of personal consumer protection. Please continue to use this with full observational practice, please continue to use your eyes, your hand-lens and proper lighting, using every opportunity to notice what your training has enabled you to notice. And, after telling you all that, I advise you when buying not to believe anything written on the packet or anything anyone tells you (not even me) until you have looked for yourself and come to your own conclusion.

In order to produce that opportunity for you to gain the Association's Diplomas in all

The Deeks Diamond Prize

Emma McMillan of Dalkeith, Mid Lothian, receiving the Deeks Diamond Prize for the best candidate of the year in the Gem Diamond examinations. Photo: Lewis Photos Ltd.

our centres around the world, we have in the Gem-A education office a team of just a few very able people. I gladly take this opportunity to give them my personal and everlasting thanks, not least to Brenda Hunt, Lucy Dean and Hayley Smith for these three have worked to run the course and examination administration by sheer dedication and attention to detail. Lorne Stather is my development team, researcher and manager, for all the course materials and exams. I am not forgetting our Board of Examiners who are central to the existence of Gem-A; working in close cooperation with the education office, they are a group of experts who are dedicated and truly have your interests at heart. Please also remember that Gem-A exists as a membership association and that we vitally depend upon your continued support as qualified gemmologists by maintaining your membership, so that you can retain those coveted letters after your name, FGA or DGA.

Congratulations, all of you FGAs and DGAs!

Members' Meetings

Annual General Meeting

The 2004 Annual General Meeting was held on 14 September at 27 Greville Street, London EC1N 8TN (see report below). The AGM was followed by an illustrated talk entitled 'The rubies of Malawi: hidden gems of Africa' by David Hargreaves.

Gem-A Conference 2004

The Gem-A Annual Conference was held on Sunday 31 October at Kempton Park Racecourse, Sunbury-on-Thames, Middlesex. Keynote speaker was Tom Chatham of Chatham Created Gems Inc.

Conference events included a private viewing of the Crown Jewels with Crown Jeweller David Thomas, a champagne reception at antique dealers Wartski with a talk by Geoffrey Munn, and a visit to the Museum of London where groups had the opportunity to handle and examine items from the Cheapside Hoard of Elizabethan and Jacobean gems and jewellery.

A full report of the Conference was published in the December 2004 issue of *Gem & Jewellery News*.

Exhibition tour

A tour of the exhibition 'Hungary's Heritage: Princely treasures from the Esterházy Collection' at Somerset House was held on 10 November.

Gem Discovery Club Specialist evenings

On the first Tuesday of each month Club members have the opportunity to examine items from the collections of gem and mineral specialists. The November guest was Tom Chatham, keynote speaker at the Gem-A Conference, who brought along samples of synthetic diamond. Marcus McCallum provided a selection of items from his personal collection in December, Roy Huddlestone with a collection of doublets in February, Alan Jobbins was the March specialist with gems and crystals from over half a century of collecting and Marcia Lanyon brought along a collection of beads for the April Club evening. Reports of the specialist evenings are given in *Gems & Jewellery*.

The Gem Discovery Club meets every Tuesday from 6:00 to 8:00 p.m. at the Gem-A headquarters in Greville Street. For further details contact Mary Burland on 020 7404 3334, email mary.burland@gem-a.info.

Midlands Branch

Regular branch meetings were held at the Earth Sciences Building, University of Birmingham, Edgbaston. On 29 October Alan Jobbins gave a talk entitled 'Gems of the seven continents', on 28 January Dr Jeff Harris spoke on 'Diamonds from crust to core', on 25 February 'European jewellery from Elizabeth I to Elizabeth Taylor' was the subject of John Benjamin's talk and on 1 April David Callaghan gave a talk entitled 'Gems by candlelight'. The annual Bring and Buy and Team Quiz event was held at the Earth Sciences Building on 26 November.

Continued on p. 368

Gem-A Awards

Gem-A examinations were held worldwide in January 2005. In the Examinations in Gemmology, 125 candidates sat the Diploma Examination of whom 65 qualified including one with Distinction and eight with Merit, and 154 sat for the Foundation Examination, of whom 108 qualified. In the Gem Diamond Examination 90 candidates sat of whom 46 qualified, including five with Distinction and six with Merit. The names of the successful candidates are listed below:

EXAMINATIONS IN GEMMOLOGY

Gemmology Diploma

Qualified with Distinction

Smithie, Sheila Barron, Boston, Mass., U.S.A.

Qualified with Merit

Berden, Angela C.M., Balham, London
Braham, Adrian D., Reigate, Surrey
Huck, Perry, Stanford-in-the-Vale, Oxfordshire
Leadbeater, Craig, Dulwich, London
Liu Rongjun, Yujishan, Wuhan, Hubei, P.R. China
Pinckernelle, Kathia, London
Shwe Li, Yangon, Myanmar
Wagner, Olivier, Hammersmith, London

Qualified

Alcock, Kate, Byford, Hereford and Worcester
Alliston, Erika, Hammersmith, London
Bae Hyo Jun, Daegu, Korea
Chaiyawat, Yuanchan, Bangkok,Thailand
Chan Wai Fong, Hong Kong
Chen Manli, Guangzhou, P.R. China
Cheng Wai Ping, New Territories, Hong Kong
Cheung Yiu Hung, Kowloon, Hong Kong
Chiu Shu-Fen, Taipei, Taiwan, R.O. China
Chung Yim Ling, Mandy, Kowloon, Hong Kong
Clement, Jenny, London
Ding Hua Yu, Toronto, Ontario, Canada
Eun Ok Joo, Gyunggi-Do, Korea
Fleming, John James, Kelso, Roxburghshire
Gemmill, Tanya Charlotte, London
Ho Hay Mo, John, Yangon, Myanmar
Jung Hae Sook, Gyungbuk, Korea
Kilby Hunt, Judith, London
Klimek, Karina Sophia, Truro, Cornwall
Lam Shun Kwong, New Territories, Hong Kong
Li Fangwei, Wuhan, Hubei, P.R. China
Li Man, Wuhan, Hubei, P.R. China
Liang Liming, Guilin, Guangxi, P.R. China
Lin Shu-Zhen, Taipei, Taiwan, R.O. China
Liu Haimei, Guilin, Guangxi, P.R. China
Liu Xianyu, Guilin, Guangxi, P.R. China
Ma Yaw Lan Hsiung, Ruth, Hong Kong
Mai Zhi Qiang, Zhongshan, Guangzhou, P.R. China
Maranhao, Priscilla Petra, London
Naw Htar Phyu, Yangon, Myanmar
Pan Han, Guilin, Guangxi, P.R. China
Phisuthikul, Piyamaporn, Bangkok, Thailand
Ren Chunhua, Wuhan, Hubei, P.R. China
Rowley, Elaine, London
Ruan Qingfeng, Guilin, Guangxi, P.R. China
Scragg, Claire Patricia, Great Missenden, Buckinghamshire
Skaraas, Sonia C., London
Sue-a-Quan, Dona Marie, Yangon, Myanmar
Taylor, Richard E., Carlsbad, California, U.S.A.
Thomson, Alison, Ealing, London
Tripathi, Pooja, Jaipur, Rajasthan, India
Tsiknakis, Avgerinos, Athens, Greece
Vasant Gala, Rahul, Plaistow, London
Veitch, Tara MacNeil, Greenwich, London
Webb, Stephen Charles, Nelson, New Zealand
Wreford, David, London
Xie Shanshan, Guilin, Guangxi, P.R. China
Yaddanapudi, Pratima, Dagenham, Essex
Yang Hanyuan, Guilin, Guangxi, P.R. China
Yang Hao, Wuhan, Hubei, P.R. China
Yang Ping, Guilin, Guangxi, P.R. China
Ying Weigui, Wuhan, Hubei, P.R. China

Gem-A Awards

You Hongwen, Wuhan, Hubei, P.R. China
Yu Binxing, Wuhan, Hubei, P.R. China
Zhong, Lihong, Zhongshan, Guangzhou, P.R. China
Zhu Jia, Shanghai, P.R. China

Gemmology Foundation Certificate

Qualified

Axelson, Louise, Helsinborg,Sweden
Badrov, Irena, London
Bae Hyo Jun, Daegu, Korea,
Bang, Moo Geun, Daegu, Korea
Basnayake, Charmi K., Kandy, Sri Lanka
Bendikssen, Bjorn, Lannavaara, Sweden
Bickerstaff, Alastair, Newport, Shropshire
Brand, Juliette, Geneva, Switzerland
Buteyko, Tamara, London
Cai Hui Hua, Shanghai, P.R. China
Chan Mei Fong, Frances, Kowloon, Hong Kong
Chan Suk Wah, Shirley, Kowloon, Hong Kong
Chang Chi Wei, Taichung, Taiwan, R.O. China
Chang Chin Feng, Taichung, Taiwan, R.O. China
Cheng Chui Shan, Kowloon, Hong Kong
Cheng Qi , Shanghai, P.R. China
Cheung Ching Chung, Hong Kong
Cheung Pui Ying, Kowloon, Hong Kong
Chiu Fong Ting, Hong Kong
Chong Joon Yau, Singapore
Darell, Rikard, Lannavaara, Sweden
Dunn, William A., Los Angeles, California, U.S.A.
Fletcher, Robin, Reading, Berkshire
Fossurier, Anne, Montreal,Quebec, Canada
Fung Wing Yee, Hong Kong
Geng Yan, Shanghai, P.R. China
Gordon, Richard, Woodford Green, Essex
Harn Boh-Sheng, Taipei, Taiwan, R.O. China
Hattersley, Mark, Northwood, Middlesex
Hay Man Than Htaik, Yangon, Myanmar
Ho Siu Ming, Hong Kong
Hong Xiao Bin, Shanghai, P.R. China
Hsu Chia Jung, Taichung, Taiwan, R.O. China
Hwang Il Sik, Geoje, Korea
Ip Lai Kwan, New Territories, Hong Kong
Jang Wei-Jen, Taipei, Taiwan, R.O. China
Jensen, Annalisa, Esher, Surrey
Jiang Jie, Guilin, Guangxi, P.R. China
Johansson, Maria, Hoganas, Sweden
Jung Hae Sook, Gyungbuk, Korea
Kalayar Pyi Wai Shan, Yangon, Myanmar
Kau Yuk Ming, Eddie, Tuen Mun, Hong Kong
Kent, Paul Allen, Aarwangen, Switzerland
Khin Zar Thwe, Yangon, Myanmar
Kim Ji Won, Seoul, Korea
Kim Su Young, Gyungbuk, Korea
Kim Su Hyun, Dalseo-Gu, Korea
Latham, Elizabeth, Wallingford, Oxfordshire
Lau Ka Yan, Kowloon, Hong Kong
Lau Moon Lan, Stanley, Hong Kong
Lee Su Jin, Gwangju, Korea
Lee Wai Yee, New Territories, Hong Kong
Leung Kim Ping, Vicky, New Territories, Hong Kong
Li Na, Guilin, Guangxi, P.R. China
Lin Cen, Shanghai, P.R. China
Lin Jie, Guilin, Guangxi, P.R. China
Low San, Chatham, Kent
Lu Yi, Guilin, Guangxi, P.R. China
Lundgren, Tobias, Stockholm, Sweden
Lv Feng, Shanghai, P.R. China
Lyons, Melinda, Holywell, Clwyd
Ma Jun, Shanghai, P.R. China
Maass, Nora V.S., London
Mak Kim You Keung, New Territories, Hong Kong
Mao Yuanjiong, Guilin, Guangxi, P.R. China
Me Kyaw Khine, May, Yangon, Myanmar
Moe Seint Seint Lin, Yangon, Myanmar
Ong Chin Siang, Gary, Singapore
Osman, Abdirahman Adam, Cardiff, S. Glamorgan
Ottman, David Andrew, Carmichael, California, U.S.A.
Overton, Thomas William, Carlsbad, California, U.S.A.
Park Jae Young, Busan, Korea
Peng Conghui, Guilin, Guangxi, P.R. China
Perez, Christina, Citrus Heights, California,

Gem-A Awards

U.S.A.
Po Pui Chun, Tuen Mun, Hong Kong
Potter, Madeline, Ingrave, Brentwood, Essex
Prince, Ronald Fisher, Richmond, Surrey
Rentsch, Jean-Marc, Zurich, Switzerland
Riley, Deborah Mary, Discovery Bay, Hong Kong
Ringhiser, Barbara G., Lake Worth, Florida, U.S.A.
Shah, Nilay, Hatfield, Hertfordshire
Shen Mengxi, Guilin, Guangxi, P.R. China
Shin Chan Sik, Ulsan, Korea
Siu Pui Ka, Kowloon, Hong Kong
Song Ji Sun, Daegu, Korea
Soubiraa, Guillaume, London
Stewart, Sharon, Abbots Langley, Hertfordshire
Su Yi Win, Yangon, Myanmar
Susawee, Namrawee, Bangkok, Thailand
Tam Tung Lee, Toni, New Territories, Hong Kong
Tessari, Claudio, Ora, Italy
Thawornmongkolkij, Monruedee, Bangkok, Thailand
Traill, Lillian, Ladbroke Grove, London
Tyler, Clare J., Den Bosch, The Netherlands
Wacyk, Carri Tara, Antibes, France
Wadhwa, Pritam, Harrow, Middlesex
Wells, John, Bickerstaffe, Lancashire
Wong Yi Tat, Eddy, Kowloon, Hong Kong
Wong Lai Mun, Phyllis, New Territories, Hong Kong
Wong Ching Man, Ruby, New Territories, Hong Kong
Wong Wai Ming, New Territories, Hong Kong
Wright, Nathaniel Thomas, Peoria, Illinois, U.S.A.
Yeun, Dae Huem, Gyunggi-do, Korea
Yeung Ka Yee, Anthea, Kowloon, Hong Kong
Yeung, Angela, North Point, Hong Kong
Yip Siu Ling, New Territories, Hong Kong
Yuen-Ng Wai Kwan, Chrisdy, Hong Kong
Zhang Yonghua, Guilin, Guangxi, P.R. China

GEM DIAMOND EXAMINATION

Qualified with Distinction
Ko Cheuk Wah, Kowloon, Hong Kong
Leadbeater, Craig, Dulwich, London
Lindwall, Torbjorn, Lannavaara, Sweden
Wong Tung Wing, Kowloon, Hong Kong
Wong Yuen Leung, Kowloon, Hong Kong

Qualified with Merit
Berden, Angela C.M., Balham, London
Chawla, Jaspreet Kaur, London
Ho Sze Man, Helen, New Territories, Hong Kong
Kuo Yan Ki, Yannis, North Point, Hong Kong
Ng Wing Kwan, New Territories, Hong Kong
Terry, Dennis, Petts Wood, Kent

Qualified
Assouad, Carole Nathalie, Edgbaston, Birmingham, West Midlands
Chan Chi Wai, Hong Kong
Chan Kaman, Carmen, Hong Kong
Chan Siu Ping, Kowloon, Hong Kong
Chang Cheng Hsien, Taipei, Taiwan, R.O. China,
Chong Chanthasone, Kowloon, Hong Kong
Chuang Chang Chen, Taipei, Taiwan, R.O. China
Deprez, Guillaume, London
Fong Tik Kwan, Kowloon, Hong Kong
Haralabopoulos, Irene Rania, Athens, Greece
Ho Cham Wa, Kowloon, Hong Kong
Huddy, William Rupert Hugh, Holcombe, Somerset
Hui Ngai Yin, Kowloon, Hong Kong
Ip Tan Ching, Kowloon, Hong Kong
Kashaka, Jean-Claude M., Surbiton, Surrey
Katembwe, J. Christian, Rainham, Kent
Kiilu, Kyalo, Mayfield, East Sussex
Kuo Chi-Cheng, Taipei, Taiwan, R.O. China
Leung Kam Ping, Hong Kong
Liao Dan, Wuhan, Hubei, P.R. China
Lin Shu-Zhen, Taipei, Taiwan, R.O. China

Gem-A Awards

Lo Sunny, Kowloon, Hong Kong
Lu, Lu, Morden, Surrey
Mahmood, Zahid, Aston, Birmingham, West Midlands
Morgan, Jacqueline, Chalfont St. Peter, Buckinghamshire
Rudomino-Dusiacki, Patrick, London
Towers, Jill C., St Heliers, Auckland, New Zealand
Wan Ching Man, Kowloon, Hong Kong
Wenham, Diana L., North Harrow, Middlesex
Wong Tai-Wai, Kowloon, Hong Kong
Wong Yan Yan, Amy, Kowloon Bay, Hong Kong
Wong Pui Ying, Helena, Tsuen Wan, Hong Kong
Wreford, David, London
Yin Zhen, Beijing, P.R. China
Zhang Yun Tao, Beijing, P. R. China

EXAMINATIONS IN GEMMOLOGY

The following candidates qualified in the June 2004 examinations but their results were not released in time for publication in the October 2004 issue of *The Journal:*

Gemmology Diploma
Qualified with Merit
Lin Bing, Toronto, Ontario, Canada

Qualified
Hellenbrand, Yosef Joe, Thornhill, Ontario, Canada
Hogan, Anne, North Vancouver, British Columbia, Canada
Sheikh, Afia, Scarborough, Ontario, Canada
Thurner, John Robert, Burlington, Ontario, Canada

Continued from p. 364

On 4 December at Barnt Green branch members enjoyed the 52nd Anniversary Dinner.

A one-day branch conference was held on 13 March at Barnt Green with the theme 'Man-made diamonds and their identification'. A report of the conference will appear in the June issue of *Gems & Jewellery.*

North West Branch

On 17 November at Church House, Liverpool, the Branch AGM was held when Deanna Brady, Ray Rimmer and Eileen Franks were re-elected Chairman, Secretary and Treasurer respectively. The AGM was followed by a social evening. This was the last branch event at the Church House venue; future meetings will be held at YHA Liverpool International, 25 Tabley Street, Liverpool 1.

Scottish Branch

A programme of talks was held at the British Geological Survey, Murchison House, West Mains Road, Edinburgh: on 16 November Brian Jackson spoke on the 'Gemstones of Pakistan', on 18 January Liz Goring was the speaker on the subject 'Suffragette jewellery', Dr Jeff Harris followed on 22 February with a talk entitled 'Diamonds – a research perspective' and Alan Hodgkinson on 15 March on 'Tucson and all that's new'.

Annual General Meeting

The 2004 Annual General Meeting of Gem-A was held on 14 September at 27 Greville Street, London EC1N 8TN. Lawrence Hudson chaired the meeting and welcomed those present. The Annual Report and Accounts were approved.

The Council had nominated E. Alan Jobbins for the office of President for the term 2004-2006 and the nomination was carried. Alan Jobbins thanked the outgoing President, Professor Alan Collins, for his support of the Association during his four years in the office of President.

Terry Davidson and Michael O'Donoghue were re-elected and Sheila Burgoyne, Professor Alan Collins, Sally Everitt, Alan Jobbins and Peter Wates elected to the Council.

Ian Thomson retired in rotation from the Council and was not seeking re-election.

Dr Tony Allnutt and Brian Jackson were re-elected to serve on the Members' Audit Committee. As Sheila Burgoyne, Sally Everitt and Peter Wates had been elected to the Council, they were no longer eligible to serve on the Members' Audit Committee, and therefore had retired from that Committee. Hazlems Fenton were re-appointed auditors.

Membership

Between 1 November 2004 and 31 March 2005 the Council approved the election to membership of the following:

Fellowship and Diamond Membership (FGA DGA)

Hanlon, Adrienne K., Ingol, Preston, Lancashire, 2001/2004
Manolia, Evgenia, Zografou, Greece, 2004/2004
Marsh, Claire, Stourbridge, West Midlands, 2004/2003
Wong Mei Wai, May, Kowloon, Hong Kong, 1995/1996

Fellowship (FGA)

Blanksma, Eelco, Arnhem, The Netherlands, 2004
Drijver, Joyce Marie-Louise, Utrecht, The Netherlands, 2004
Duan, Tiju, Beijing, P.R. China, 2002
Gaskin, Clare K., London, 2004
Gerber, Doris Christine, Zurich, Switzerland, 2004

Donations

The Council is most grateful to the following for their donations. Donation levels are Circle of Benefactors (£5000 and above), Diamond (£1000 to £4999), Ruby (£500 to £999), Emerald (£250 to £499), Sapphire (£100 to £249) and Pearl (£25 to £99).

The following join those donors listed in previous issues of *The Journal:*

Emerald Donation
Terry Davidson, FGA, London

Sapphire Donations
Eisuke Ashida FGA, Kyoto City, Kyoto, Japan
Torbjorn Lindwall FGA, Lannavaara, Sweden
Paul R. Milton, Liverpool, Merseyside
Robert L. Rosenblatt, FGA, Salt Lake City, Utah, U.S.A.

Pearl Donations
Burton A. Burnstein, Los Angeles, California, U.S.A.
Dennis Durham, Kingston upon Hull, East Yorkshire
Siu-Kam Fan FGA DGA, Kowloon, Hong Kong
Gwyn Green FGA DGA, Barnt Green, Hereford and Worcester
Bede Johnson, Lewes, East Sussex
Ernest R. Mindry FGA, Chesham, Buckinghamshire
Moe Moe Shwe FGA, Singapore
Sara Naudi FGA, London
Gabriella Parkes DGA, London
Elaine Rowley, London
Iamze Salukvadze FGA DGA, Dubai, United Arab Emirates
David John Sayer FGA DGA, Wells, Somerset
Sunny K. Tsui FGA, Melbourne, Victoria, Australia
Nancy Warshow FGA DGA, Nairobi, Kenya
Glady Yan Wah Lau FGA, Hong Kong
Zeng Chun Guang BSc MSc FGA, Singapore

Gifts

The Council is most grateful to the following for their gifts for research and teaching purposes:

Tom Chatham, San Francisco, California, U.S.A., for four Chatham Created diamonds (yellow, pink, blue and colourless).

Roland N. Clarkson FGA DGA RJ Dip FRNS, Chessington, Surrey, for a Rayner Diamond Tester.

Peter R Dwyer-Hickey FGA DGA, South Croydon, Surrey, for eight cut diamonds.

Gwyn Green FGA DGA, Barnt Green, Hereford and Worcester, for an assortment of fashioned gemstones.

Brendan Haddock FGA DGA, Edinburgh, for three beryl crystals from Scotland.

Melanie A Medniuk FGA DGA, Witham, Essex, for two spodumene beads.

Jonathan Mehdi, London, for a quartz crystal with internal clusters of dark star-shaped inclusions (hollandite) from Madagascar.

Renée Newman GG, International Jewelry Publications, Los Angeles, California, U.S.A., for two books, the *Diamond Handbook* and the *Diamond Buying Guide*.

One Plus One Gems, Sheffield, South Yorkshire, for a pyrope/almandine garnet crystal, a sample of rock crystal with 'oily' inclusions (donated as 'Herkimer diamond'), and three faceted specimens, a spodumene (29.87 ct), a citrine (8.11 ct) and a zircon (14.85 ct).

Bob Springall, Woodside Park, London, for a large selection of cut and rough natural and synthetic gemstones as well as two table-top display cases, a Chelsea colour filter, a spectroscope, a calcite dichroscope with stand, a Chromoscope and a Jewellers' Eye reflectance meter.

Ian Thomson FGA, Thomson Gems, London, for two octagonal cut samples of green YAG, an Inamori synthetic alexandrite and an Inamori synthetic emerald.

Eric Van Valkenburg, High Pressure Diamond Optics Inc., Tucson, Arizona, U.S.A., for two carbon vapour deposition wafers (CVD).

Margot Willing FGAA DipDT, Claremont, Western Australia, for a piece of chrome chalcedony 'chloro-opalite' (Newman, W.A.), a piece of iron ore (Pilbara, W.A.), and an oval cabochon of 'tiger iron' (Ord Range, W.A.).

Gray, Mathew Neil, Lismore, New South Wales, Australia, 2004
Hemlin, Colette, Anjou, Quebec, Canada, 2004
Hogan, Anne P., N. Vancouver, British Columbia, Canada, 2004
Kuo, Chi-Cheng, Taipei, Taiwan, R.O.China, 2003
Leung Pui Fong, Helen, Hong Kong, 1984
Lovelock, Justina Elizabeth, London, 2004
Lyons, Annabel Helen, London, 2004
Pai, Vishnunarayan, Ernakulam, India, 2004
Peeters-Van Namen, Irene Françoise, Warmond, The Netherlands, 2004
Pumpang, Sureeporn, Bangkok, Thailand, 2004
Ravaoarimalala, Voahanginirina F., Antanimora, Madagascar, 2004
Scott, John R.J., Vancouver, British Columbia, Canada, 2004
Sheikh, Afia, Scarborough, Ontario, Canada, 2003
Singh, Amrinder Pal, Dehli, India, 2004
Stanyer, Natasha, Lewes, East Sussex, 2004

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Chang Wing Chi, Vivian, Kowloon, Hong Kong, 2004
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Macrae, Margaret, Isle of Lewis, Scotland, 2002

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Southam, Karen Lesley, Oldbury, West Midlands, 2004
Watling, David Robert Stuart, Sidcup, Kent, 2004
Wells, John, Ormskirk, Lancashire, 2004
Yeung Wing Chuen, Benny, New Territories, Hong Kong, 2004
Yiu, Ka Wah, Kowloon, Hong Kong, 2004

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Taylor, Vivien, Burnham, Buckinghamshire
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Villepigue, Debórah A., Manhasset, New York, U.S.A.
Webster, Eric T., West Chiltington, West Sussex
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Wilding, Mark, St Helens, Merseyside

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Michael Gardner Antiques, New Bond Street, London W1
Hirsh London, Hatton Garden, London, EC1N 8AH
J. W. Weldon, Clarendon Street, Dublin 2, Ireland

Transfers

Transfer from Associate Membership to Fellowship (FGA)

Inoue, Koichi, Osaka, Japan

Obituary

Huang Fengming 1965-2004

Huang Fengming studied and achieved her masters degree in the Department of Economic Geology in the China University of Geosciences in Wuhan and became an Associate Professor in the Gemmological Institute of China (CUG) within the university, working with the CUG for six years and teaching gemmology. The CUG was established through the work of Professor Chen Zhonghui as the first Gem-A Allied Teaching Centre in mainland China. Huang was a close academic associate of Professor Chen and she became an invaluable assistant with the detailed work for Gem-A and particularly for its crucial translation work under Professor Chen's exacting guidance. Huang, who had published two papers for *The Journal of Gemmology*, was studying for her gemmology doctorate when, after a protracted illness, she sadly died at the time of the International Gemmological Conference in September. She is remembered as a hard-working, respected and friendly colleague who is sadly missed.

Li Liping

A.H.G. Armstrong FGA (D.1951), Bridge of Allan, Stirling, died recently.

The Revd S. B. Nikon Cooper FGA DGA (D.1965), Walpole St Peter, Cambridgeshire, died on 11 October 2004. Nikon was a Gem-A correspondence course tutor for a record 35 years, retiring from the position in 2002. He was one of a team of three tutors with Keith Mitchell and Vera Hinton when he was appointed in 1967.

Walter Crombie FGA (D.1948), St Johns Wood, London, died on 23 October 2004.

Professor Dr Edward J. Gübelin FGA (D.1946 with Distinction), Lucerne, Switzerland, died on 15 March 2005. A tribute to Professor Gübelin is given on p. 257.

Neville Seymour Haile FGA (D.1972), Oxford, died in June 2004.

J. van Loo FGA (D.1951 with Distinction), Ra Epse, The Netherlands, died recently.

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18 May	**North West Branch:** Mineralization of fossils. Wendy Simkiss
15 June	**North West Branch:** 1960 and all that. David Callaghan
15 June	**North East Branch:** The Chinese pearl revolution with John Carter
18 June	**Midlands Branch:** Summer Supper Party
12 July	**Gem Discovery Club Specialist evening:** Branko Deljanin
21 September	**North West Branch:** Some you win, some you lose! Stephen Whittaker
30 September	**Midlands Branch:** Cultured pearls - evaluation workshop. Michael Houghton
19 October	**North West Branch:** Gems of life. Maggie Campbell Pedersen
26 to 28 October	**London:** Three-day Rough Diamond Assessment Course
28 October	**Midlands Branch:** Identification of gem materials using a micro scope. Gwyn Green
31 October	**Presentation of Awards**

contact details

When using e-mail, please give Gem-A as the subject:

London:	Mary Burland on 020 7404 3334; e-mail mary.burland@gem-a.info
Midlands Branch:	Gwyn Green on 0121 445 5359; e-mail gwyn.green@usa.net
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North West Branch:	Deanna Brady 0151 648 4266
Scottish Branch:	Catriona McInnes on 0131 667 2199; e-mail scotgem@blueyonder.co.uk
South East Branch:	Colin Winter on 01372 360290; e-mail info@ga-seb.org
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Guide to the preparation of typescripts for publication in *The Journal of Gemmology*

The Editor is glad to consider original articles shedding new light on subjects of gemmological interest for publication in *The Journal*. Articles are not normally accepted which have already been published elsewhere in English, and an article is accepted only on the understanding that (1) full information as to any previous publication (whether in English or another language) has been given, (2) it is not under consideration for publication elsewhere and (3) it will not be published elsewhere without the consent of the Editor.

Typescripts Two copies of all papers should be submitted on A4 paper (or USA equivalent) to the Editor. Typescripts should be double spaced with margins of at least 25 mm. They should be set out in the manner of recent issues of *The Journal* and in conformity with the information set out below. Papers may be of any length, but long papers of more than 10 000 words (unless capable of division into parts or of exceptional importance) are unlikely to be acceptable, whereas a short paper of 400-500 words may achieve early publication.

The abstract, references, notes, captions and tables should be typed double spaced on separate sheets.

Title page The title should be as brief as is consistent with clear indication of the content of the paper. It should be followed by the names (with initials) of the authors and by their addresses.

Abstract A short abstract of 50-100 words is required.

Key Words Up to six key words indicating the subject matter of the article should be supplied.

Headings In all headings only the first letter and proper names are capitalized.

A This is a first level heading

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First and second level headings are in bold and are ranged left on a separate line.

Third level headings are in italics and are indented within the first line of text.

Illustrations High resolution digital files, for both colour and black-and-white images, at 300 dpi TIFF or JPEG, and at an optimum size, can be submitted on CD or by email. Vector files (EPS) should, if possible, include fonts. Match proofs are essential when submitting digital files as they represent the colour balance approved by the author(s).

Transparencies, photographs and high quality printouts can also be submitted. It is recommended that authors retain copies of all illustrations because of the risk of loss or damage either during the printing process or in transit.

Diagrams must be of a professional quality and prepared in dense black ink on a good quality surface. Original illustrations will not be returned unless specifically requested.

All illustrations (maps, diagrams and pictures) are numbered consecutively with Arabic numerals and labelled Figure 1, Figure 2, etc. All illustrations are referred to as 'Figures'.

Tables Must be typed double spaced, using few horizontal rules and no vertical rules. They are numbered consecutively with Roman numerals (Table IV, etc.). Titles should be concise, but as independently informative as possible. The approximate position of the Table in the text should be marked in the margin of the typescript.

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(1) The Harvard system in which authors' names (no initials) and dates (and specific pages, only in the case of quotations) are given in the main body of the text, (e.g. Collins, 2001, 341). References are listed alphabetically at the end of the paper under the heading References.

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Papers Collins, A.T., 2001. The colour of diamond and how it may be changed. *J.Gemm.*, **27**(6), 341-59

Books Balfour, I., 2000. *Famous diamonds.* 4th edn. Christie's, London. p. 200

Abbreviations for titles of periodicals are those sanctioned by the *World List of scientific periodicals* 4th edn. The place of publication should always be given when books are referred to.

The Journal of
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January/April 2005

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Cover Picture: In honour of Professor Dr Edward J Gübelin – 1913-2005

Reflecting an adventurous life, this 10 mm spray of acicular tourmaline crystals protogenetically embellished with microcrystals of quartz rests for eternity encased in rock crystal, a true symbol of beauty in nature. Sample personally collected in 1987 by Edward J Gübelin and John I.Koivula at the Golconda Mine in Minas Gerais, Brazil, during a field excursion at the XXI International Gemmological Conference. Polarized light with compensator. Photomicrograph by John I.Koivula, courtesy of microWorld of Gems.
(See tribute to Professor Dr Edward Gübelin, p.257)

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A venture into the interior of natural diamond: genetic information and implications for the gem industry

Part I: The main types of internal growth structures

G.P. Bulanova[1], A.V. Varshavsky[2] and V.A. Kotegov[3]

1. *Earth Sciences, University of Bristol, Wills Memorial Building, Queens Rd., Bristol BS8 1RG, UK*
2. *Teaneck, New Jersey 07666, U.S.A.*
3. *The Institute of Geology of Diamonds and Precious Metals, 39 Lenin Av., Yakutsk 677891, Russia*

Abstract: *Natural diamonds are rarely homogeneous. Crystals contain evidence of complicated histories of growth, changes of habit, chemistry, stages of growth and resorption. To extract genetic information recorded during diamond formation they should be studied by modern methods of microanalysis in polished plates. The best way to polish diamond to reveal internal zonation is described and the interpretation of different types of internal morphology of diamonds from cathodoluminescence imagery is given. Knowledge of the internal structures of diamonds is not only useful for scientific observations, but also allows a better determination of their likely behaviour during the cutting and polishing processes. This gives an opportunity for more economic use of individual stones during gem production.*

Keywords: *cathodoluminescence, diamond, gem industry, internal structure, polished plates*

Introduction

The internal inhomogeneity of diamond monocrystals revealed first by Raman and Rendal (1944), has continued to be the subject of intensive study (Seal, 1962; Tolansky, 1966; Varshavsky, 1968; Moore and Lang, 1972; Lang, 1979, and many others). The early workers studied whole stones in their research using such optical properties of diamond as anomalous birefringence (ABR), photoluminescence (PL) and X-ray topography, or more rarely studied diamond sections and plates by etching. Genshaft *et al*. (1977) and Beskrovanov (1992) for example investigated the growth history of Yakutian diamonds by photoluminescence microtopography of polished plates. Although destructive to diamond, the method of using polished

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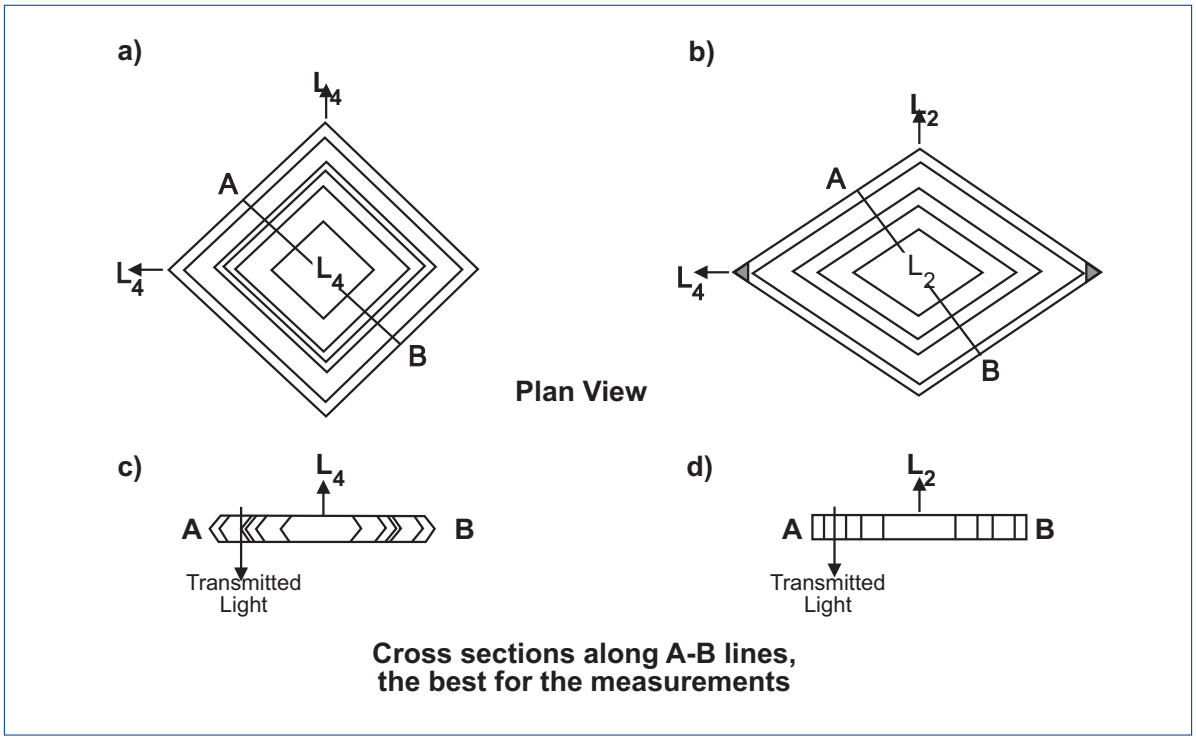

Figure 1: *Central plates of diamond polished along the cubic (a) and dodecahedral (b) planes. Configuration of octahedral zones are revealed inside cross sections of both types of plates (c and d). The octahedral zones in the cubic plate are inclined for transmitted light (a, c), but are parallel inside the dodecahedral plate (b, d).*

plates provides the opportunity to study a whole population, including opaque stones, coated, frosted, resorbed and sculptured crystals. Cathodoluminescence (CL) imaging of diamond plates and sections coupled with quantitative measurements of homogeneous growth zones by infrared spectra (FTIR) are powerful methods to constrain the history of diamond growth and to relate it to nitrogen content and aggregation state (Milledge *et al.* 1995 and many others). Also, in the context of diamond internal structure, isotope composition related to *in situ* syngenetic inclusions is being used more widely (Bulanova *et al.*, 1993, 2002; Harte *et al.*, 1999).

In spite of the increasing number of such studies around the world (e.g. Zedgenizov *et al.*, 1999; Kaminsky and Khachatryan, 2004; Appleyard *et al.*, 2004; Schulze *et al.*, 2004; Taylor and Anand, 2004), there is a lack of published information about the best crystallographic directions for diamond cutting, the methodologies for preparation of diamond plates and interpretation of CL–images of different types of internal structures. The aim of this paper is to share our knowledge and experience of (a) diamond sawing and polishing, (b) the study of the internal morphology of diamonds and (c) establishing constraints in diamond growth history. In pursuing the first objective some practical observations of diamond behaviour have been noted, which could be of benefit to the gem cutting industry.

Diamonds used in these studies are from the Yakutian Kimberlite pipes at Mir, 23rd Party Congress, Udachnaya and Aikhal. They are of commercial size (2-5 mm), of gem quality and mainly of octahedral morphology. Octahedral diamonds are the most important for study because dodecahedral stones, also widely used by the gem industry, are almost always formed by resorption of octahedra, so their internal structure also shows octahedral zoning. Stones with cubic habit and fibrous structure are not used in the gem industry, but coated diamonds can be used if the fibrous coat is thin enough and the internal octahedral part of the stone is of sufficient size for cutting as a gem.

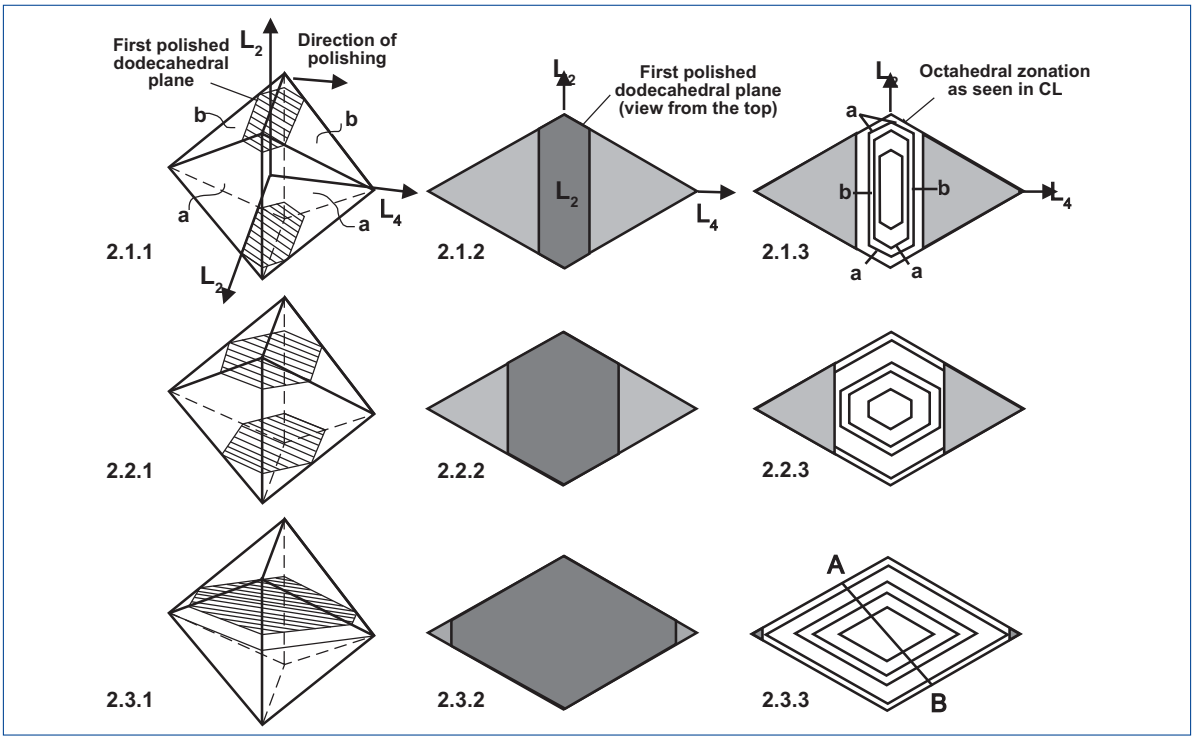

Figure 2: *Models of an octahedral diamond and the resulting octahedral zonation revealed during gradual progressive polishing along the dodecahedral plane. For the practical convenience of understanding the process of polishing using a horizontally positioned polishing wheel, a non-standard crystallographic orientation of diamond crystal is shown where the L_2 axis is vertical. (The standard orientation would be L_4 vertical).*
Figure 2.1.1: *The first stage of polishing showing the configuration of vertical octahedral zones (belt 'a' faces and zones) and those inclined at 35° (the interfacial angle between octahedron and dodecahedron) to the surface of polishing (belt 'b');*
Figure 2.1.2: *The first polished plane;*
Figure 2.1.3: *Configuration of octahedral zones on the CL image.*
Figures 2.2.1 - 2.2.3: *The same after the intermediate stage of polishing.*
Figures 2.3.1 - 2.3.3: *The same after a final polishing producing the diamond central plate. The best line of profile for the measurement is shown by the line AB on 2.3.3.*

Diamond sawing and polishing

The crystalline structure of diamond possesses two 'soft' directions, the cubic and dodecahedral, for relatively easy cutting and polishing. In the gem industry, the cubic direction is the most economical, so the first plates made from diamonds for scientific studies were sawn and polished along (100) planes (Lang, 1979). Cut and polished dodecahedral surfaces for scientific research were first used in Russia by Bulanova *et al.* (1979) and Beskrovanov (1986, 1992). *Figures 1a* and *b* exhibit a sketch of these two types of central diamond plates. The cross sections through the plates (*Figures 1c* and *d*) illustrate that for any plate polished along the cubic plane transmitted light would cross complex and inhomogeneous zones. In contrast, a plate polished along the dodecahedral plane, allows transmission of light along homogeneous zones. From the geometry of zones inside the plates it follows that the dodecahedral plane is preferable for the study of diamond's internal structure and the measurement of IR and other optical properties.

Most single natural diamonds grow as polyhedral crystals by octahedral growth layers (Sunagawa, 1984), and an example is shown in *Figure 2*. Let us consider a first configuration of octahedral zones on the plate surface if an octahedral diamond is polished along the dodecahedral plane. In this situation, the set of four octahedral faces (marked as 'a' on *Figure 2.1*) are vertically

parallel to the L_2 axis of the diamond, and are normal (perpendicular) to the dodecahedral plane of polishing. The other four octahedral faces (two of which are shown as 'b' on *Figure 2.1*) are inclined to the plane of polishing and need to be completely removed by polishing to expose the set 'a' of octahedral zones shown in *Figures 2.3.1* and *2.3.3*. If such polishing is made from both sides of the crystal (*Figure 2.2*), even a relatively thick plate could be used for studying the rim and intermediate parts of a diamond using the exposed set of 'a' zones. In a central plate <1 mm thick (*Figure 2.3*), the dynamics of diamond development, comprising the history of growth, evolution of habit, change of PL and CL-colours and distribution of optical defects (by FTIR and PL microspectroscopy), can all be studied.

The term 'central' used here does not refer to the geometric centre, but describes the real diamond growth nucleus. These two positions very seldom coincide. The position of nucleation (the genetic centre) can be identified by ABR-imaging of the crystal before and during polishing. In many cases a single inclusion or group of microinclusions are located in it, being seeds or catalysts for diamond nucleation and subsequent growth (Varshavsky, 1968; Bulanova *et al.*, 1979). Dislocation bundles commonly start from these central inclusions and radiate perpendicular to the growing octahedral zones. These may be observed by ABR-imaging, and further assist in the identification of the diamond genetic centre. Additionally, PL–imaging reveals the differences of colours between growth zones in the diamond and therefore also provides useful information. Thus, both PL– and ABR–images should be used as an aid in exposing the central growth zone.

Small octahedral diamonds (1-2 mm) can be directly polished from both sides until the central plate is complete. Ideally the two planes of the diamond plate should be parallel for FTIR measurements, but a small angle between them does not prevent one obtaining satisfactory results. Sections markedly inclined to the dodecahedral planes are not good for FTIR and can also give false information on CL images, so the correct orientation for polishing is very important. For other well-shaped crystals such as dodecahedra and cubes, polishing is also relatively easy. For complex morphologies and resorbed stones, the crystallographic orientation of etching pits and sculptures of growth and resorption on diamond surfaces are useful for finding the correct orientation for polishing.

Large diamonds (>2.5 mm) should be sawn into two parts, either mechanically or by laser. The cut should be made at just a small distance from the growth centre so that the diamond central zones can be easily exposed by subsequent polishing.

Many diamonds have complicated types of internal morphology, where a change of habit took place or mixed mechanism of growth has occurred (*Figure 3*). It is understood that for such crystals, only the central section will display the correct sequences of growth events. For more complex internal structures such as multicentred crystals, it is important to have a series of sawn and polished diamond sections and plates for scientific study.

CL-imagery of different types of structures of diamonds

General information about the physical mechanisms of CL emission, principles of CL-SEM technique and their application are well described by Sapharin and Obyden (1988). One of the limitations of CL imagery is that it forms only a detailed image of an object's surface to a depth of 1-5 microns. Therefore when using CL for study of diamond growth structures it is important to have a central section of the crystal because CL provides only a virtual two-dimensional image. PL- and ABR-imaging should be used simultaneously with CL studies as they will show a three dimensional image of the internal structure of a diamond and enable a more accurate interpretation of growth zones.

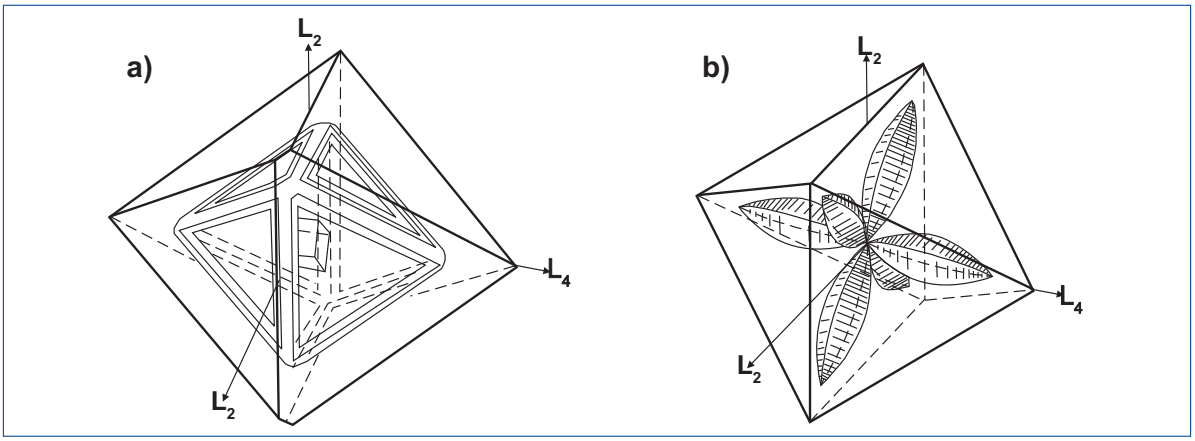

Figure 3: *Models of complex diamond internal morphology:*
a. Cube ⊠ rough layered octahedron ⊠ flat octahedron.
b. Cubo-octahedron ⊠ octahedron (the earliest cubo-octahedron is formed by a combination of six cubic growth lobes and octahedral zones between them. Selective absorption of nitrogen impurities by octahedral zones slows down their growth rate, thus resulting in the final shape of a pure octahedron.).

Let us consider how CL images of the main internal structures appear in octahedral diamonds polished along a dodecahedral plane.

1. Simple octahedral zonation

After polishing diamond to a small depth, the octahedral zonation will appear as a hexagonal shape (*Figure 2.1.3*). The belt 'a' of octahedral faces with related zones is orthogonal to the dodecahedral plane of polishing and the four 'b' faces and zones are inclined to it. Correspondingly, the four 'a' zones are the only ones in a position to display the true growth boundaries and any peculiarities in growth micro-structures. The 'b' set of growth boundaries are inclined octahedral zones projected onto the polished surface as lines parallel to the cubic planes (*Figure 2.1.3*), and these may be mistaken for cubic zones. CL imaging of the deeper sections of the crystal will show increases in the lengths of the 'a' sets of octahedral zones (*Figure 2.2.3*) which are the most important for study. After reaching the growth centre of the crystal, the overlying 'b' octahedral zones will have been removed, the 'a' set of octahedral zones will be completely exposed and CL and ABR images of simple octahedral zoning in central diamond plates will display a parallelogram shape (*Figure 2.3.3*). The best direction for measurements of optical properties is also shown on *Figure 2.3.3*.

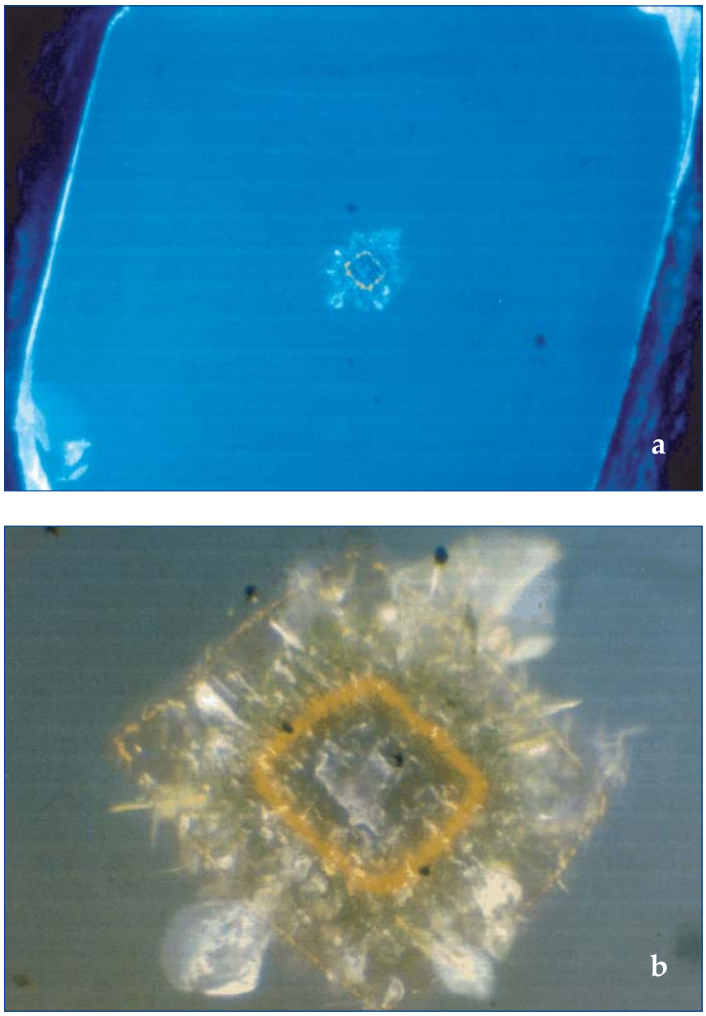

Figure 4: *Evolution of diamond habit: cube ⊠ octahedron. CL image of plate sawn on (110) plane of diamond 670 from the Mir pipe; width of crystal 3.5 mm.*
a. View of the whole plate.
b. Central cubic zone.

2. Complex zonation.

Bulanova (1995) described the five main types of core → rim changes in the internal morphology of diamond and these are:

Cube → octahedron;
Cubo-octahedron → octahedron;
Cube → rough layered octahedron or rounded → flat octahedron;
Uncertain (Rounded) → rough layered octahedron → flat octahedron;
Multicentred → rounded or agate-like → octahedron.

An example of a CL image of cube → octahedron type diamond zonation is shown in *Figure 4*. The size of the core cubic zone is always so small that only in the central section is it possible to have a true image of the change of diamond growth habit. The CL image of the other side of the diamond plate should show whether all central zones are exposed on this surface and whether they are of sufficient size for FTIR measurements (Mendelssohn and Milledge, 1995). If the zones on the two sides do not match then FTIR would give spectra for mixed zones which are difficult to interpret.

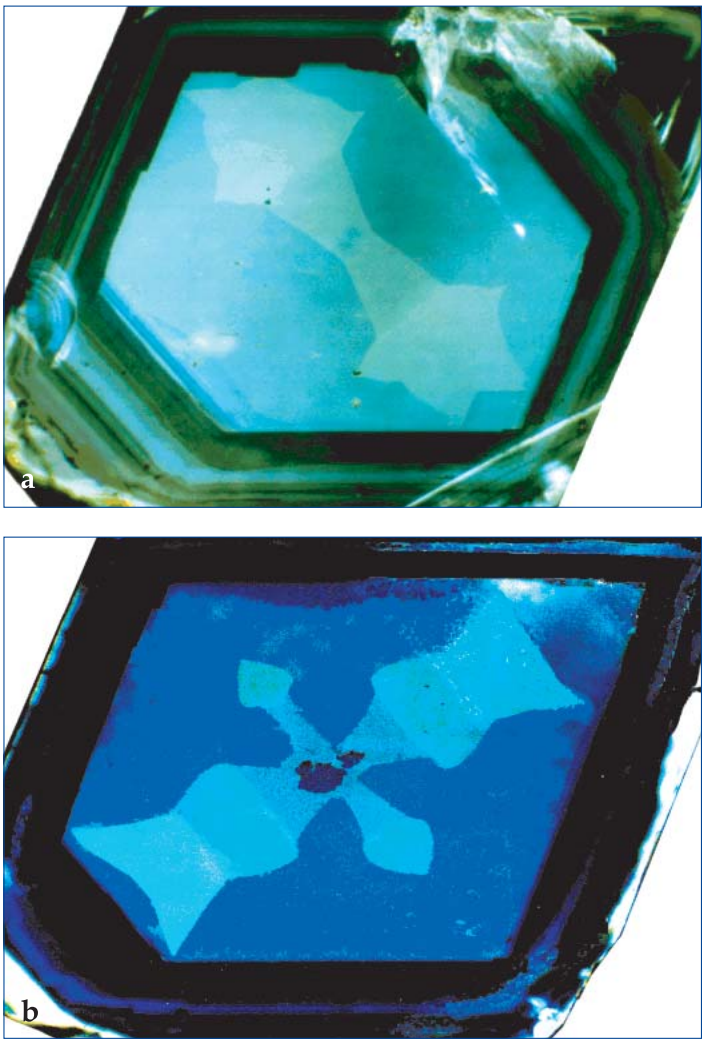

Figure 5: *Change of diamond morphology: cubo-octahedron (mixed growth) octahedron (tangential growth). CL image of plate sawn on (110) plane of diamond 1137 from Mir pipe, width 2.5 mm.*
a. Off-centre side of the plate.
b. Central plane of the plate.

The ideal model of a cubo-octahedron → octahedron internal diamond zonation (which gives rise to the so-called central cross structure) is shown in *Figure 3b*. *Figure 5a* shows that the off-central section along (110) of such a mixed structure will display cubic sectors only along the short diagonal of the plate (shown by the faint yellow CL colour), surrounded by larger areas of octahedral growth zones (shown by light blue CL). In the central section (*Figure 5b*), the two other cubic lobes of the cubo-octahedron appear and are in the best position for FTIR measurements. The earliest stage of growth for such sectorial diamonds takes place by mixed mechanisms of tangential and unfaceted, hummocky growth followed by a faceted tangential one. When any changes of habit and mechanism of growth have taken place in the cubic growth sectors, unusual microstructures may be observed. Usually, these are located in the areas at the tops of the 'b'- sets of octahedral zones (see *Figure 5* and Bulanova *et al.*, 2002).

The evolution of diamond internal morphology for the cube →rough layered octahedron or rounded → flat octahedron development is illustrated well in Bulanova (1995). The second stage of rough layered octahedral or even rounded zonation is most unusual and can be difficult to interpret. Such rounded almost undefined shape can also occur in initial growth zones.

In the case of such roughly layered octahedral, almost rounded shapes, unusual structures appear on CL images of the off-centre sections. For example, the CL images shown in *Figure 6a, b* display an off-centre zonal structure very difficult to explain,

but if polished to the diamond centre (see *Figure 6c*), the pattern becomes much clearer. The real internal growth structure is one which evolves thus: rounded → intergrowths-1 → intergrowths-2 → rounded → cubo-octahedron → rough layered octahedron → flat octahedron. In the first off-centre diamond CL image made on the level of the intermediate, rough-layered octahedral zones (*Figure 6a, b*), the tops of the octahedrons are not single, but appear to consist of many points. Also, the edges are not single, but are composed of many narrow vicinal faces, which are close to the position of a dodecahedron or trigonal-tris-octahedron. The off-centre section also gives a visual impression that in the areas where octahedral points and edges exist, the latest zones are intruded into the earliest zones, as found in rim to core 'druse' formation (*Figure 6b*). This artefact disappears in the central section of the crystal (*Figure 6c*). Thus we believe that the mechanism of diamond growth from the periphery to the centre of a crystal proposed by Zezin *et al*. (1992) is not real and can be explained by the reasons and mechanisms outlined above.

A multicentred type of diamond zoning is shown in *Figure 7*. In an early stage of the diamond polishing a rounded zonal structure was observed in the centre of which an inclusion of calcite was located (*Figure 7a*). In spite of the visual impression that it might be a centre of nucleation, the real centres of growth are still deeper within the diamond. CL images of the three plates made from this diamond provide a three dimensional tomographic picture of its internal morphology. The reconstructed history

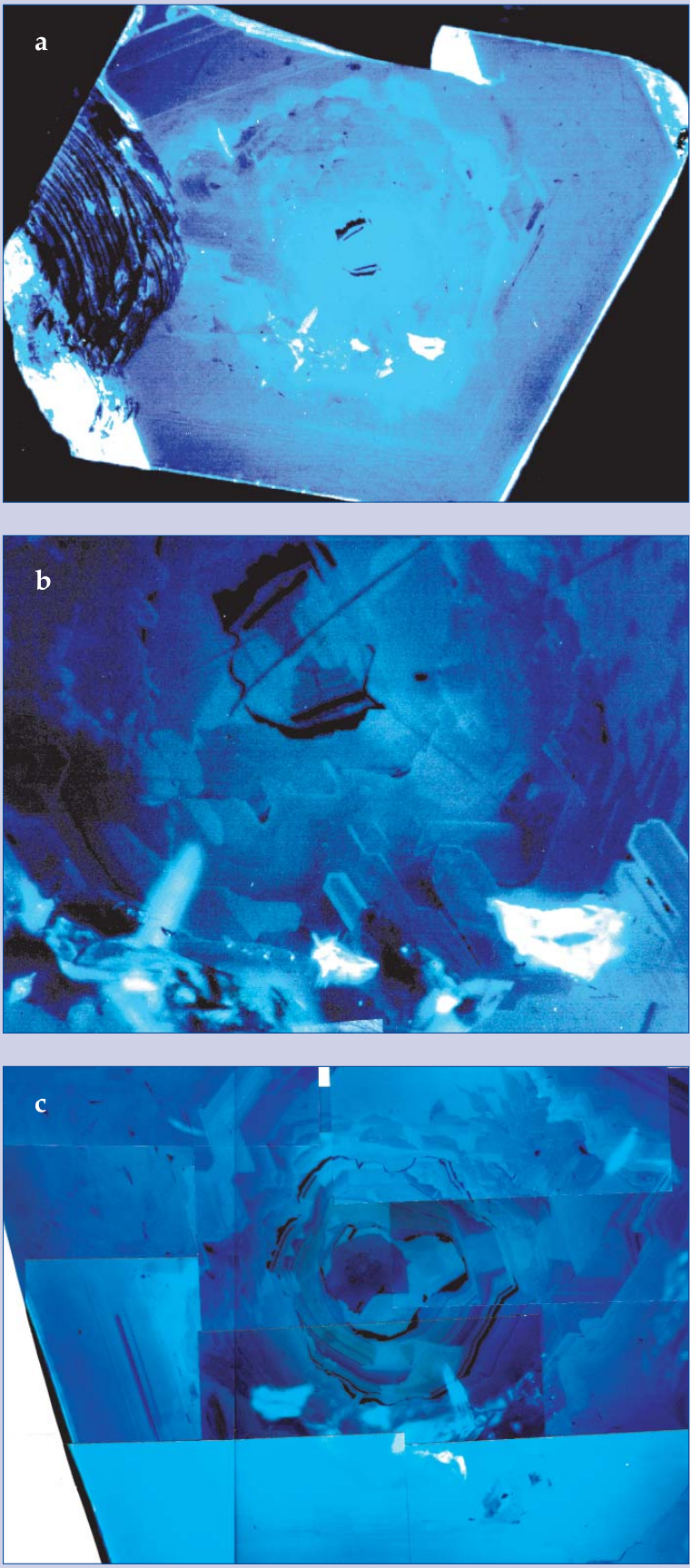

Figure 6: *Complex type of diamond internal morphology: rounded → intergrowths-1 → intergrowths-2 → rounded → cubo-octahedron → rough layered octahedron → flat octahedron. CL image of plate sawn on (110) plane of eclogitic diamond 4173 from the 23rd Party Congress pipe; width 4.5 mm.*

a. The off-centre section shows rough layered octahedral zonation in this intermediate part of the diamond giving a false visual impression that in the areas of octahedron points and edges the latest zones are intruded into earlier zones.

b. Detailed view of the middle of the off-centre plate.

c. True zonation revealed in the central plate.

of the diamond therefore is: two regrown broken diamonds → rounded oscillatory zones → rough layered octahedral. The revealed internal morphology provides an explanation for the external shape of this diamond, which was elongated along one of the L_2 axes. The diamond external morphology was inherited from and controlled by the elongated oscillatory intermediate zones which overgrew the two diamond seeds, located at some distance from each other (*Figure 7b*) Some specific microstructures again developed in the areas of the octahedral points (*Figure 7b*) during a period of habit change from rounded to octahedral, the growth mechanism going from hummocky to tangential.

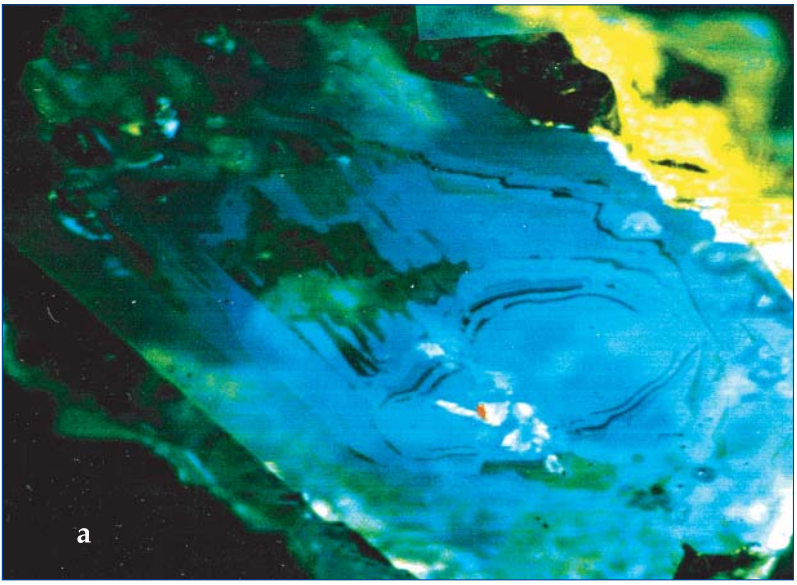

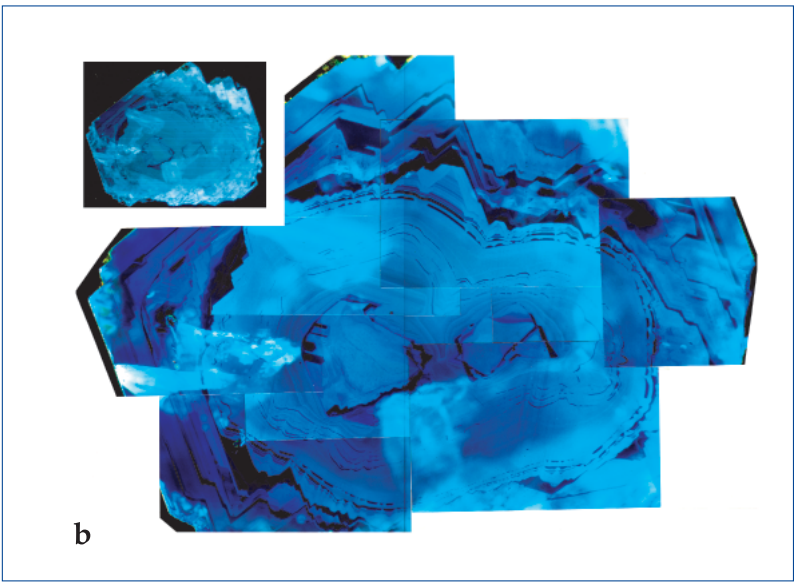

Figure 7: *The internal structure of a multicentred type of diamond. The CL image is of a plate sawn on the (110) plane of eclogitic diamond 1584 from the Mir pipe; width 5 mm.*
a. An off-centre diamond section showing rounded internal zoning and an inclusion of calcite, showing red CL, is located in what, falsely, has the appearance of a growth 'centre'.
b. A plate across the central part of the diamond displaying zonation: two regrown broken crystals/aggregate → rounded oscillatory zones → rough layered octahedron. Both seeds of broken crystals/aggregate are surrounded by a narrow type II diamond zone (dark in CL), filling in also the four deep channels of etching in the left side of the largest one.

From the above description it follows that only central plates polished along the dodecahedral planes of diamonds indicate true sequences of growth events and allow constraints to be placed on the evolution of diamond crystal shapes. CL images of such central plates can be used as the maps for further *in situ* studies such as FTIR, isotope measurements, stratigraphic location of inclusions, the study of their chemical composition, their age and their isotope composition. Additional important genetic information from CL images includes areas of plastic and brittle deformations, radiation damage, fractures and the presence of fresh or re-healed cracks.

Implications for the gem industry

Ideal, isometric, sharp-edged, regular crystals of natural diamonds, called 'glassies' in the trade, are rare. Most rough diamonds contain different defects, irregularities and stresses, such as internal twinning, aggregates, plastic and brittle deformation. These cause local hard directions inside stones which give problems for cutters and polishers who therefore need to study the diamond in preparation for their work. The use of optical polarizing microscopes and ultraviolet (PL) microscopes in these preliminary studies would enhance recognition of such defects. Even if a diamond looks perfect in ordinary light, investigation with ABR and PL will highlight the type of internal structure and location

of growth centre or centres, thus allowing a better understanding of how to cut the stones in a more economic way.

For example, our results show that it is important that two- or multi-centred crystals should be recognized prior to deciding the best diamond cut and polishing. The external shape of such stones may be distorted in the sense of being elongated along one crystallographic axis. The best cuts for such diamonds would be either between the different growth centres, or with both seeds left in the largest part of the stone. Cutting directly through one of the growth centres would not be recommended because multiple cracks would be generated from the seed area into the diamond-host.

Black micro-inclusion seeds in the central diamond growth zones very often contain gas or fluid phases. When the 'hidden' pressure associated with such phases is released by exposure of these inclusions on the surface during polishing, mini-explosions take place followed by a dramatic increase of cracks in the diamond-host. To escape this negative effect, the groups of central micro-inclusions should either be left inside the stone or completely polished away.

Conclusions

1. The (110) plane of central plates of diamonds is the best for the study of their internal structures and history of growth using CL images and FTIR measurements.
2. Because CL imagery provides almost a two-dimensional picture of an object's surface, all three methods (ABR, PL, and CL) should be combined for study of the internal structure of diamonds, complementing one another to locate the true central section of a diamond.
3. During the interpretation of microstructures in inclined sections or thick plates of diamonds care should be exercised to ensure that the real sequence of growth events and conditions are determined.
4. In diamond plates polished parallel to (110) planes, zones near the points of octahedra (cubic directions), may exhibit unusual textures and prompt misleading interpretations of growth histories.
5. The rough layered octahedral and rounded shapes of internal zones can produce other peculiar artefacts on CL images, but these will disappear after polishing down to the growth centre of the crystals.
6. When interpreting CL images of diamond plates and sections, the third dimension and the possibility of non-isometrically shaped internal zones should always be kept in mind.
7. Study of internal structure of natural diamonds using ABR and PL is useful for the gem industry. It will highlight potential difficulties for cutting and polishing of individual stones and will allow it to be done in the most economic way.

Acknowledgements

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Most of the CL images involved in this work were obtained in the Department of Earth Sciences at University College London in collaboration with Dr J. Milledge and her colleagues over the years, with the technical assistance of P.A. Woods. The CL data were combined with mid-infrared microspectroscopy, usually by making measurements at intervals along traverses of the plates, and these results will be discussed in the second part of this paper.

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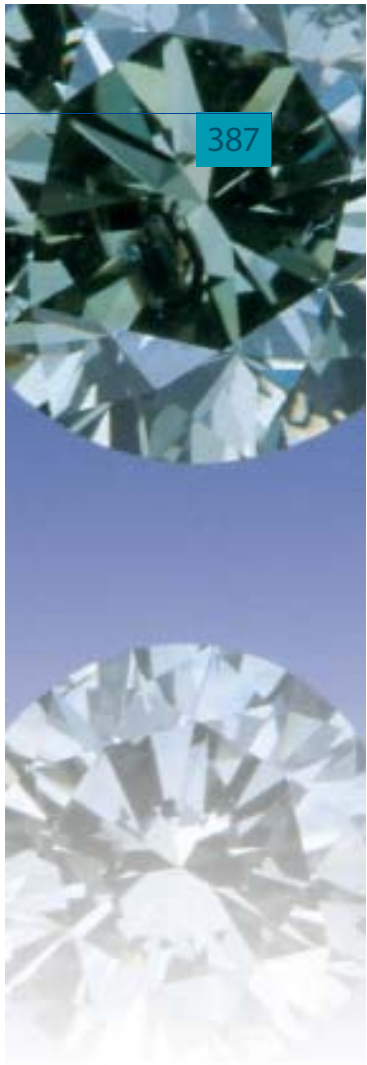

As-grown, green synthetic diamonds

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Abstract: *Green synthetic diamonds showing no evidence of irradiation or other laboratory treatment were examined to determine the nature of the coloration. The occurrence of distinct yellow and blue internal growth zones as well as absorption spectra indicating the presence of both isolated nitrogen and boron strongly suggest that the green colour is a result of the intergrowth of boron- and nitrogen-rich sectors. Variations in the boron/nitrogen concentration ratio during synthesis can produce as-grown diamond colours ranging from dark blue to green to yellow.*

Keywords: *boron, Chatham, colour origin, mixed growth, nitrogen, synthetic diamond*

Introduction

Natural gem diamonds displaying a green bodycolour are rare, and hence are highly valued in the marketplace (Genis, 2003). Artificial irradiation treatments are commonly applied to many types of natural and synthetic diamonds to induce green coloration (e.g., Collins, 1982; Vins, 2002). High-pressure, high-temperature (HPHT) treatment of type Ia diamonds has also produced attractive yellowish-green colours (Reinitz *et al*., 2000). Although some visible clues may be present, separation of natural from treated-colour green diamonds is often difficult for gemmological laboratories because the effects of laboratory irradiation and heating are very similar to processes in the Earth that generate green coloration. Consequently, green diamonds that can be proven to be of natural colour are quite rare.

As an alternative to treated colour natural diamonds, producers of gem-quality synthetic diamonds offer as-grown (i.e. untreated) yellow and blue laboratory-created diamonds (pink synthetic diamonds have periodically been presented as untreated, but at this time, all known synthetic pinks are treated colours) (Moses *et al*., 1993; Shigley *et al*., 2004). Green coloration is not common in synthetic diamonds and, when present, has usually been the result of post-growth irradiation. Rarely, elevated concentrations of Ni impurities have also been thought to be a cause of green coloration (Kanda, 1999). However, Chatham Created Gems of San Francisco, California, has recently made available a new kind of as-grown, green synthetic diamond that shows neither abnormal Ni content, nor any indication of irradiation or other post-growth treatment. We present gemmological and spectroscopic data from these synthetic diamonds illustrating the cause of this green coloration.

Materials and methods

A recent examination of 129 synthetic diamonds (Shigley *et al*., 2004) loaned to the Gemological Institute of America (GIA) by Chatham Created Gems included 16 samples that show a face-up green colour

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Figure 1: *The green synthetic diamonds provided by Chatham Created Gems range from green to bluish-, greyish- and yellowish-green hues. These two representative round brilliants weigh 0.19 – 0.34 ct. Photo by Maha Tannous Calderon, copyright GIA.*

(*Figure 1*). These synthetic diamonds are the focus of this study. The colours consisted of pure green, as well as bluish-, greyish- and yellowish-green hues. Note, however, that GIA does not issue colour reports for synthetic diamonds. Thirteen of the samples had been faceted into round brilliants weighing 0.16 – 0.41 ct. The other three were 0.79 – 1.06 ct uncut crystals.

Details of the gemmological features, reactions to ultraviolet radiation, chemical analysis, and photoluminescence spectra for all colours of the Chatham synthetic diamonds examined (including green) are presented in Shigley *et al*., 2004. The absorption spectra presented herein were collected in the mid-infrared range (6000-400 cm^{-1}; 1 cm^{-1} resolution) at room temperature using a Thermo-Nicolet Nexus 670 Fourier-transform infrared spectrometer and in the ultraviolet-visible-near infrared range (250-850 nm; 0.1 nm sampling interval) at liquid nitrogen temperature (~77 K) using a Thermo-Spectronic Unicam UV500 spectrophotometer at GIA in Carlsbad, CA.

Results and discussion

The 16 green synthetic diamonds fall into two distinct groups. Eight (including all three crystals) are type IIa and clearly show absorption features indicative of radiation damage (*Figure 2, A* and *B*) (see Collins, 1982) whereas the other eight lack these distinct spectroscopic features (*Figures 2C* and *D*). Exposure of diamond to radiation produces general radiation (GR) absorption features at the red and blue ends of the electromagnetic spectrum. The combination of the GR features and typical diamond absorption produces a green bodycolour. Irradiation treatment of natural and synthetic diamonds to artificially induce a green coloration is not unusual; therefore, this study will focus on the eight green diamonds showing no indication of treatment.

The untreated samples exhibit mid-infrared absorption spectra with detectable concentrations of both boron (2803 and 2457 cm^{-1} peaks) and isolated nitrogen (indicated by 1344 cm^{-1} peak) impurities (*Figure 2C*) (Zaitsev, 2001). In natural diamonds, B and N rarely occur together in a single crystal

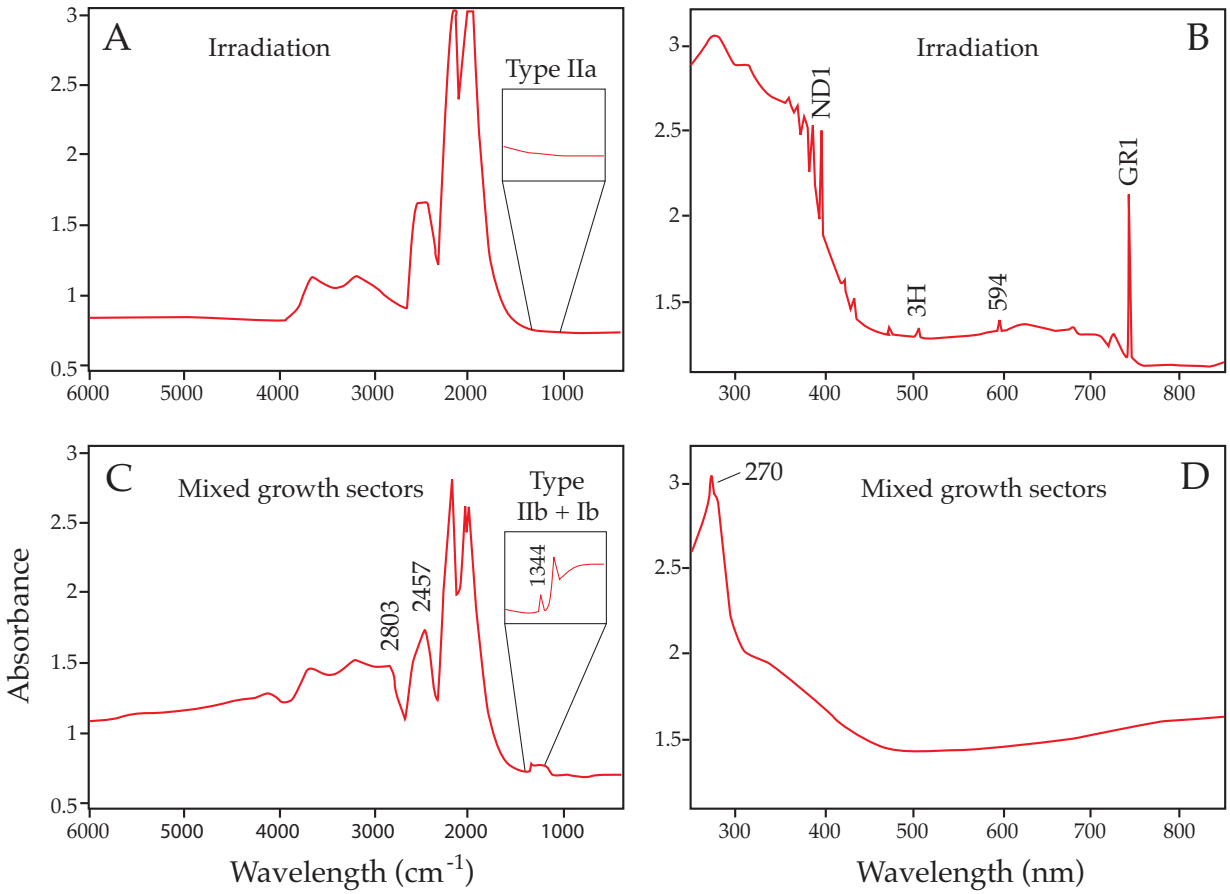

Figure 2: *Mid-infrared (A,C) and UV-visible-NIR (B,D) absorption spectra for two types of green synthetic diamonds.* A-B. *Type IIa synthetic diamonds that exhibit features clearly due to irradiation (GR1 at 741 nm, ND1 at 393 nm, 3H at 503 nm, and 594 nm line; Zaitsev, 2001).* C-D. *Synthetic diamonds with mixed IIb and Ib growth zones show evidence for both boron (see 2457 and 2803 cm^{-1} peaks in* C, *and increase in absorption toward 850 nm in* D) *and isolated nitrogen (see 1344 cm^{-1} peak in* C *and 270 nm peak in* D). *The peaks indicating irradiation are not present in these mixed type synthetic diamonds. Spectra redrawn from original data.*

in measurable quantities (Rooney *et al*., 1993; Hainschwang and Katrusha, 2003). The presence of both impurities implies a mixed type of IIb + Ib for these green synthetic diamonds.

Absorption in the ultraviolet-visible-near infrared range reveals three distinct features: a broad absorption band decreasing from 850 nm to ~600 nm, a smaller increase in absorption from ~400 nm to ~300 nm, and a distinct, rounded peak centred at ~270 nm (*Figure 2D*). The broad band at 850-600 nm is due to boron and produces the blue colour that is typical of IIb diamonds. The peak at ~270 nm indicates the presence of isolated nitrogen. In the absence of other colour centres, strong absorption due to isolated

Figure 3: *Colour zoning in untreated 0.16 ct green synthetic diamond immersed in water. Distinct yellow and blue zones correspond to particular cuboctahedral growth sectors and indicate nitrogen- and boron-rich regions (Welbourn* et al.*, 1996). Combination of these coloured sectors makes the diamond appear green. Photo by J.E. Shigley, copyright GIA.*

nitrogen at wavelengths less than ~500 nm produces the deep yellow seen in 'canary' diamonds (Collins, 1982; Zaitsev, 2001). The band at 400-300 nm is probably related to nitrogen as well. The combination of these absorption features results in a transmission 'window' from ~600 nm to 450 nm that produces the face-up green coloration.

Colour zoning, visible when the synthetic diamonds are immersed in water to reduce surface reflections, supports the spectroscopic evidence (*Figure 3*). Distinct yellow and blue zones were observed to correspond with particular internal growth sectors in the green synthetic diamonds.

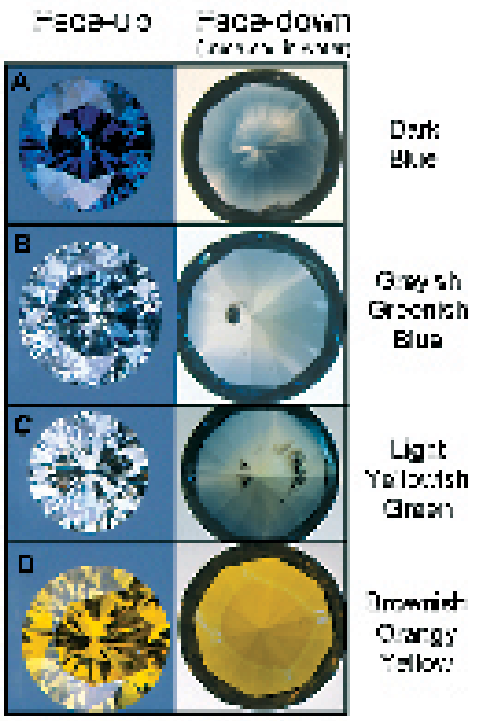

Figure 4: *Face-up and face-down views of dark blue, lighter blue, green and yellow as-grown synthetic diamonds. Colour zoning in the face-down view is easier to see by immersion in water. A. (0.27 ct). A fully saturated overall blue colour consists of dark blue and colourless zones. B. (0.31 ct) Less saturated blues exhibit blue and very pale yellow zones. C. (0.16 ct). Light green diamonds show distinct blue and yellow regions. D. (0.60 ct).Deep yellow samples consist of yellow and colourless growth sectors. Dark spots are metallic flux inclusions. Photos by Maha Tannous Calderon and J.E. Shigley, copyright GIA.*

The yellow zones, which are presumably rich in isolated nitrogen, correspond to {110} dodecahedral and {100} cubic growth sectors, whereas the blue zones, which are enriched in boron, comprise the {111} octahedral growth zones (Welbourn *et al.*, 1996). Synthetic diamonds grown by the HPHT temperature gradient technique commonly exhibit mixed cuboctahedral crystal forms with enrichments of either nitrogen or boron along specific growth planes (Strong and Wentorf, 1991; Scarratt *et al.*, 1996; Welbourn *et al.*, 1996). In general, both impurities are preferentially incorporated into octahedral growth sectors followed by cubic and/or dodecahedral sectors in synthetic diamond. In the case of these green samples, elevated concentrations of boron (relative to nitrogen) resulted in boron-dominated, blue octahedral growth sectors. Smaller concentrations of isolated nitrogen were taken up by the cubic and dodecahedral sectors. Although, the occurrence of both nitrogen and boron at concentrations necessary to generate yellow and blue growth sectors has been reported in synthetic diamonds (Shigley *et al.*, 1992; Rooney *et al.*, 1993; Hainschwang and Katrusha, 2003), mixed colour zones of strong enough intensity to give the faceted sample a face-up green coloration are unique. This mechanism of causing green by mixing yellow and blue growth sectors indicates that the samples represent as-grown, untreated synthetic diamonds.

In order to fully understand the nature of the mixed colour zoning and resultant green, we examined blue and yellow synthetic diamonds with face-up hues similar to those observed in the individual growth sectors. Just like the green synthetic diamonds, the yellows and blues appear to represent as-grown colours with no evidence for post-growth treatment. The blue diamonds range from dark blue to lighter hues including greyish or greenish blue. The darker blue hues represent IIb diamonds with relatively high boron content and mixed blue (IIb) and colourless (IIa) zones (*Figures 4A, 5A, 6A*). Lighter blue samples contain elevated boron concentrations, but, like the green synthetic

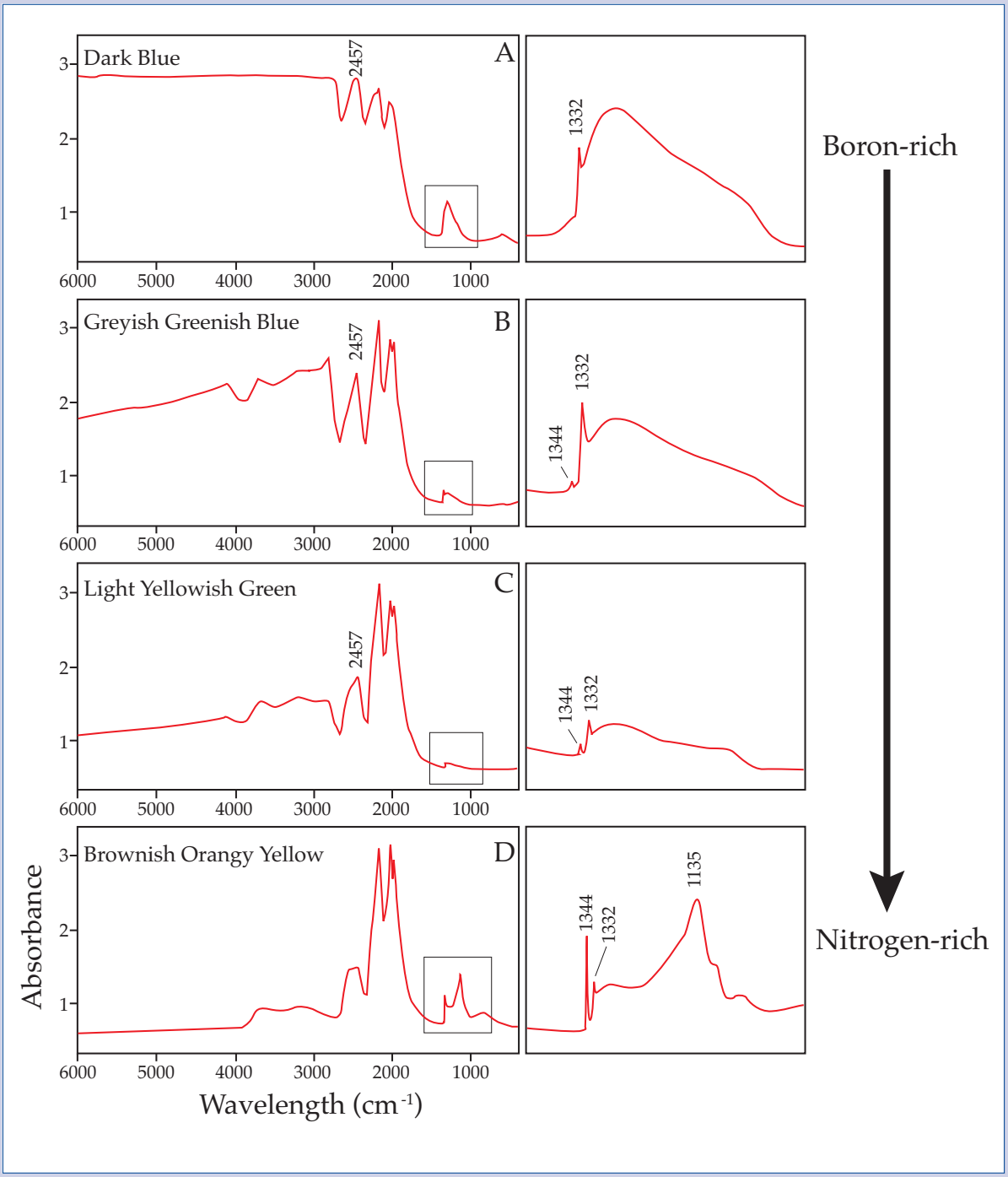

Figure 5: *Mid-infrared absorption spectra for the blue, light blue, green and yellow synthetic diamonds shown in* Figure 4. *The one phonon diamond region has been expanded in the column on the right to better show features due to nitrogen impurities.* A. *Dark blue diamonds contain high boron (2457 and 2803 cm^{-1} peaks) and little to no evidence for nitrogen.* B. *Greyish-greenish blue colour is associated with lower boron concentrations and small amounts of isolated nitrogen (1344 cm^{-1} peak).* C. *The yellowish-green diamond contains even less boron and more isolated nitrogen.* D. *The deep yellow colour is produced by significant isolated nitrogen and the absence of boron. Sample sizes were similar and are given in Figure 4. Spectra redrawn from original data.*

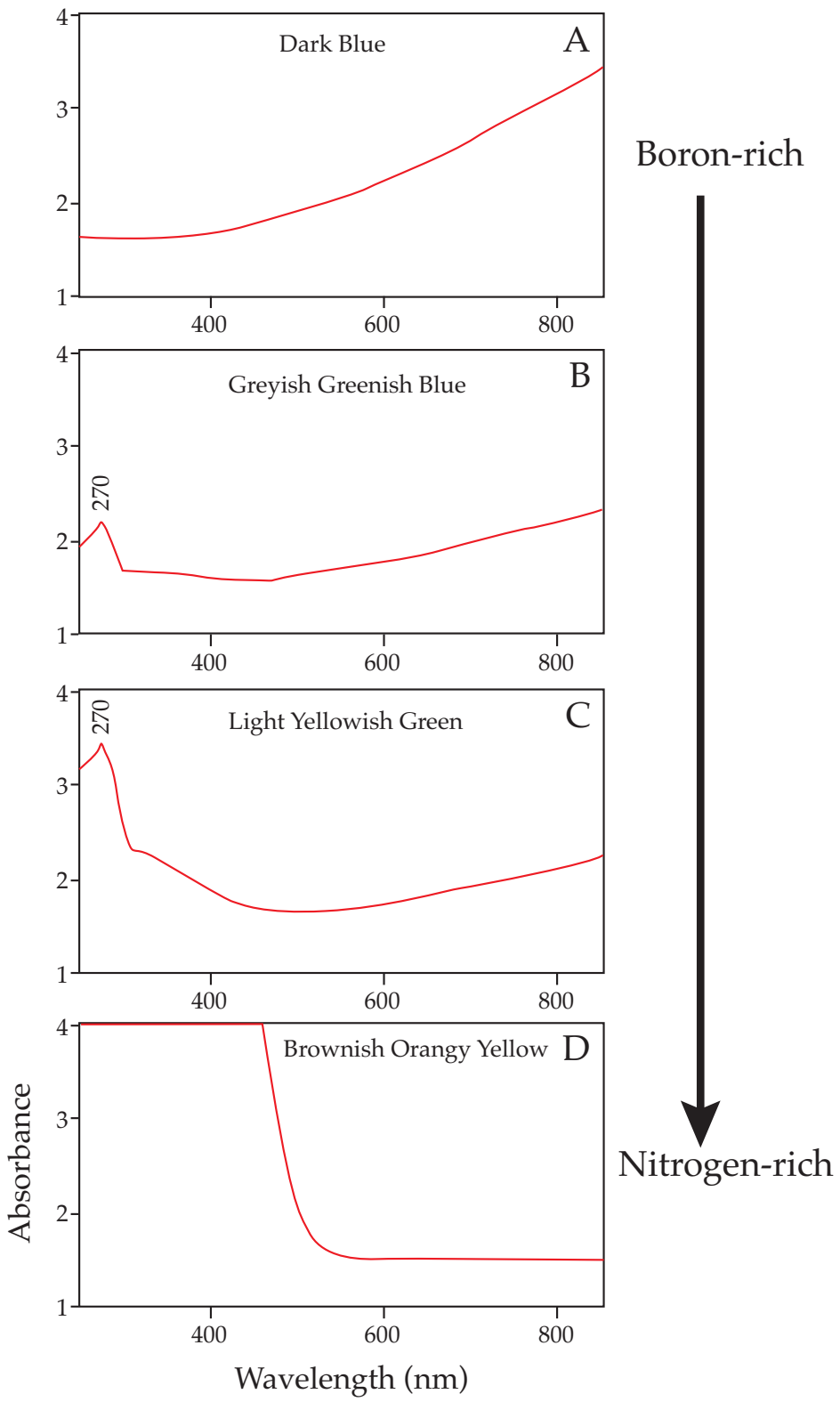

Figure 6: *Ultraviolet-visible-NIR absorption features for the synthetic diamonds in Figures* 4 *and* 5. A. *The dark blue diamond exhibits broadly increasing absorption toward 850 nm that produces a blue transmission window typical of IIb diamonds.* B. *A less saturated blue diamond shows less intense IIb absorption and a small broad peak due to isolated nitrogen at 270 nm, resulting in a greenish-blue colour.* C. *Increases in isolated nitrogen and decreases in boron shift the transmission window toward longer wavelengths and a yellowish green colour.* D. *Intense absorption due to isolated nitrogen and the absence of IIb absorption produces a deep yellow synthetic type Ib diamond. Sample sizes were similar and are given in Figure 4. Spectra redrawn from original data.*

diamonds, also show the 1344 cm^{-1} and 270 nm peaks indicating isolated nitrogen (*Figures 5B, 6B*). Growth sectors alternate between blue and very pale yellow, combining to give the faceted samples a light blue or greenish-blue face-up colour (*Figure 4B*). The yellow synthetic diamonds range from greenish-yellow to brownish orangy yellow and are type Ib with relatively high concentrations of isolated nitrogen (*Figures 4D, 5D, 6D*). The yellows exhibit mixed colour zoning with distinct deep yellow (Ib) and colourless (IIa) sectors.

The sequence of Chatham synthetic diamonds shown in *Figure 4, A-D*, illustrates the variation in colour from dark blue, to greyish greenish blue, to yellowish green, to deep yellow. Correspondingly, changes in colour zone combinations from blue-colourless to blue-very pale yellow to blue-yellow to yellow-colourless accompany the changes in face-up hue. Mid-infrared absorption spectra indicate that decreasing blue coloration is accompanied by decreases in B concentration (as noted from the intensity of the 2457 cm^{-1} peak) and increases in the amount of isolated N present (1344 cm^{-1} peak) (*Figure 5, A-D*). In response to changing B and N contents, absorption in the visible spectral range produces transmission windows that shift from ~400 – 500 nm (producing dark blue) to ~450 – 550 nm (greyish-greenish-blue) to ~500 – 600 nm (light yellowish-green) to ~550 – 700 nm (deep brownish-orangy yellow) (*Figure 6, A-D*).

The wide range of blue to green to yellow synthetic diamonds that are available for study exhibit a smooth gradation in boron/nitrogen ratios, suggesting that the intermixing of blue and yellow growth sectors is not caused by simple temperature fluctuations, but instead is a controlled process involving variations in the addition of impurities to the growth chambers. Although the conditions employed during synthesis of these diamonds have not been revealed, it is evident from the spectroscopic characteristics that changes in the relative concentration ratio of boron to 'nitrogen getters' (elements that remove ambient nitrogen from the growth environment to control the concentration of available nitrogen; Rooney *et al*., 1993; Zaitsev, 2001) can have profound effects on the colour of newly-grown synthetic diamonds. A precise control of the mixtures of these impurities during growth can result in green colours without the use of irradiation or post-growth heating.

Conclusions

Of the synthetic green diamonds made available to us for study by Chatham Created Gems, half of them represent a new kind of green coloration that has not been previously described in detail. The colour is caused by a mixture of boron-rich, blue growth sectors and nitrogen-rich yellow sectors. Absorptions due to boron and isolated nitrogen produce a transmission window in the yellow-green region of the visible spectrum resulting in a face-up green appearance. No evidence of irradiation or post-growth heating was detected and the derivation of green solely from mixed growth zones of blue and yellow indicates that the colours are as-grown. Simple variations in the boron/nitrogen ratios in the growth chamber can produce gem-quality synthetic diamonds ranging from dark blue to green to deep yellow.

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Iridescent colours of the abalone shell (Haliotis glabra)

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Abstract: *Shells and pearls of some molluscs are popular ornaments primarily due to the beauty of their natural iridescent colours. Strong iridescent colours are very evident on the polished shell of the mollusc* Haliotis glabra, *commonly known as abalone. A scanning electron microscope (SEM) was used to determine the origin of these colours, and the surface of the abalone was found to have a fine-scale diffraction grating structure of 2 µm groove width. From the diffraction patterns that were obtained using He-Ne and Nd: YAG lasers illuminating the shell, the groove density of the grating structure was derived. Good agreement was found between the groove density derived by diffraction experiments and that measured directly using the SEM. The strong iridescent colours of the shell are caused by diffraction which is the result of high groove density on the surface. The crystalline structure of the nacreous layers of the shell was studied using Fourier transform infrared spectroscopy (FTIR), and peaks at 700 cm^{-1}, 713 cm^{-1}, 862 cm^{-1} and 1083 cm^{-1} confirmed that the crystalline structure of the nacre of the shell isbasically aragonite.*

Keywords: *aragonite, FTIR,* Haliotis glabra, *iridescence, SEM, shell structure*

Introduction

The iridescent effect of colours or 'orient' caused interference or diffraction from surface microstructures is a well-known phenomenon in plants, insects, the feathers of birds and seashells (Lee, 1997; Brink and Lee, 1998; Brink *et al*., 1995; Tada *et al*., 1998; Brink and Lee, 1999; Parker, 2000; Weiner *et al*., 2000). Iridescent colours in seashells and pearls are usually attributed to a diffraction effect caused by an evenly grooved surface structure similar to that of a diffraction grating (Liu *et al*., 1999; Nassau, 2001). Moreover interference of light in multiple-layered microstructure just below the surface can also result in iridescent colours (Nassau, 2001; Brink *et al*., 2002) and studies on pearls have shown that iridescence is caused by both diffraction and interference (Nassau, 2001). Nevertheless, diffraction and interference studies on the iridescent colours of abalone shell are still limited, although recently, X-ray diffraction studies were carried out on the microstructure of the shell of the red abalone (*Haliotis rufescens*) by DiMasi and Sarikaya (2004).

In this work, we studied a polished shell of the mollusc *Haliotis glabra*, commonly known as abalone, which showed very strong iridescent colours (*Figure 1*). This iridescent effect is even stronger than that observed for pearls and mother-of-pearl materials. The colours of the abalone shell under white light vary with changes in the angle of observation.

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Figure 1: *The iridescent colours of a polished shell of the mollusc* Haliotis glabra *(abalone).*

Materials and experimental methods

The polished shell of a mollusc *Haliotis glabra*, indigenous to the seas around the Philippine islands was used in this investigation and is shown in *Figure 1*. Patches of colours of pink and blue-green are seen throughout the smooth polished surface. The surface of the whole abalone shell is polished with a diamond polishing compound to a final grade of 0.25 µm and then washed in ethanol to remove any traces of polishing residue. This method is similar to that of Brink *et al.*, 2002.

A He-Ne laser (λ = 632.8 nm) and a Nd:YAG laser (λ = 532 nm) were used to investigate the diffraction effect of the shell. A schematic diagram of the principal features of the laser diffraction experiment is shown in *Figure 2*. The laser beam was incident directly on the shell and the reflected beam (which is also diffracted) was captured on a screen. Measurements of the fringe separation x in the diffraction pattern were carried out on a white screen to an accuracy of ± 1 mm.

Scanning electron microscope (SEM) observations were carried out to study the microstructure of the shell sample. Before every experiment, the surface of the shell was cleaned using ethanol in order to remove any contaminant derived from handling. Samples of about 5 mm x 5 mm area were cut from the shell and examined up to magnifications of 7000x. Before the SEM experiments the samples were coated with a thin layer of gold to disperse the electrons and prevent charge build-up which would adversely affect the resolution of the micrograph. SEM work was carried out using a JEOL JSM – 5600LV SEM/EDX microscope with a working voltage of 20 kV.

To investigate the crystalline structure of the nacreous layers of the shell, a Perkin Elmer (Model Spectrum One) Fourier transform infrared (FTIR) spectrometer was used to record the spectra of the shell in the wavenumber range 450 to 4000 cm^{-1}. The accuracy of the absorption peaks was ± 1 cm^{-1}. Since pure shell material is opaque to most infrared radiation, a diluted sample in an infrared-transparent matrix of potassium bromide (KBr) is needed for FTIR work. The

shell material was ground to a fine powder, mixed with KBr, and compacted in a 10-tonne press to make flat circular pellets. These pellets are translucent and allow infrared light to pass through and be absorbed. The infrared transmission spectra were recorded to give absorption peaks for identification.

Results and discussion

In the diffraction experiments using the lasers, the incident laser beam is oriented at right angles to the shell surface giving a spot size of about 3 mm on the shell. The reflected beam shows a diffraction pattern on a screen with several orders of bright fringes or spots (*Figure 2*). The typical diffraction patterns of three bright spots are shown in *Figure 3*(*a*) and (*b*) for He-Ne and Nd:YAG lasers respectively. Higher orders of the diffraction fringes or spots are too weak to be observed. The phenomenon of diffraction patterns formed by the interference of reflected light rays at different angles from the fine grating structure of a surface is well established and described by Wilson and Buffa (1997). The bright fringes are not sharp since the groove microstructures are somewhat uneven across the surface, in contrast to the regularity of a compact disc.

In *Figure 3*(*a*) and (*b*) the 3 bright spots in the diffraction patterns of both lasers show that the fringe separation x for each pattern is quite uniform. The groove width

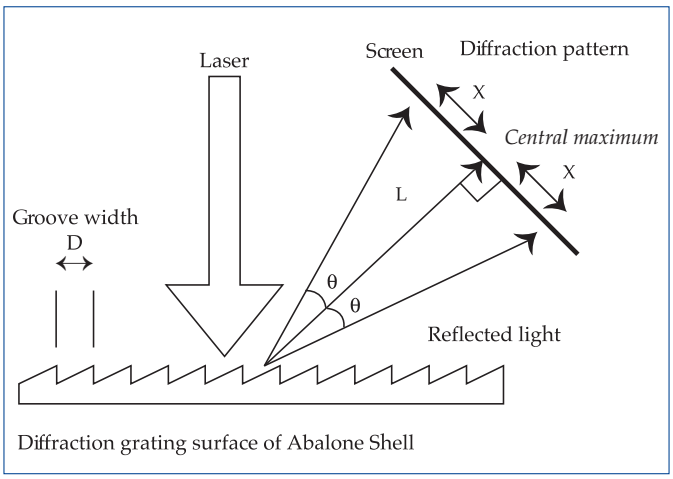

Figure 2: *A schematic diagram of the laser diffraction experimental set-up.*

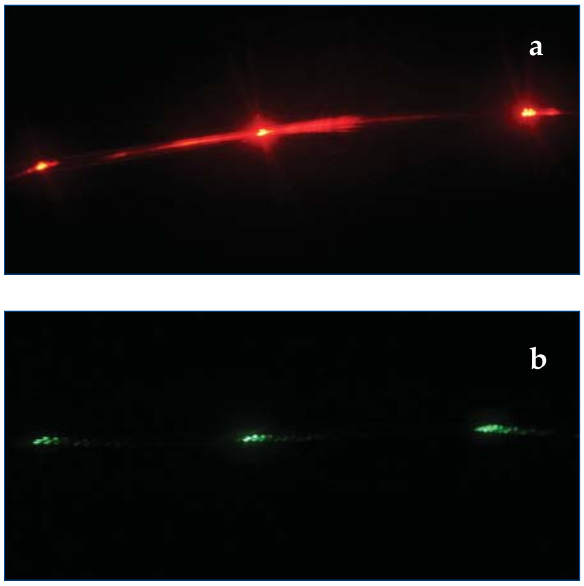

Figure 3: *A typical laser diffraction pattern produced by the shell observed up to the first order (n = 1).*
(a) *He-Ne laser diffraction pattern (λ = 632.8 μm),*
(b) *Nd:YAG laser diffraction pattern (λ = 532 μm).*

d of the grating can be calculated using the diffraction formula: $d = n\lambda/\sin\theta$ (Wilson and Buffa, 1997) where n is the order of the bright fringe, λ is the wavelength of light and θ is the angle of deviation as shown in *Figure 2*. Only the first order ($n = 1$) bright fringe at either side of the central maximum can be observed and used for calculations (*Figure 3*). The angle θ can be derived from the calculation of $\tan\theta = x/L$ where L is the distance from the point of incidence of laser light at the shell to the screen at the central maximum, as shown in *Figure 2*. In the diffraction experiments the measurements of groove width d were repeated at 5 different areas of the shell. For the He-Ne laser (λ = 632.8 nm) diffraction experiment, L is 14.3 cm, the bright fringe separation x ranges from 4.7 to 5.0 cm, and the mean value of groove width d is found to be 1.97 ± 0.05 μm. Similar experiments using Nd: YAG laser (λ = 532 nm) of L = 13.7 cm and x ranging from 3.6 to 4.6 cm give the mean value of groove width d to be 1.88 ± 0.05 μm. Using an overall average of 1.93 ± 0.05 μm for the groove width, a groove density of 518 ± 13 grooves/mm for the grating structure of the shell surface has been derived. These results show that the strong iridescent colours of

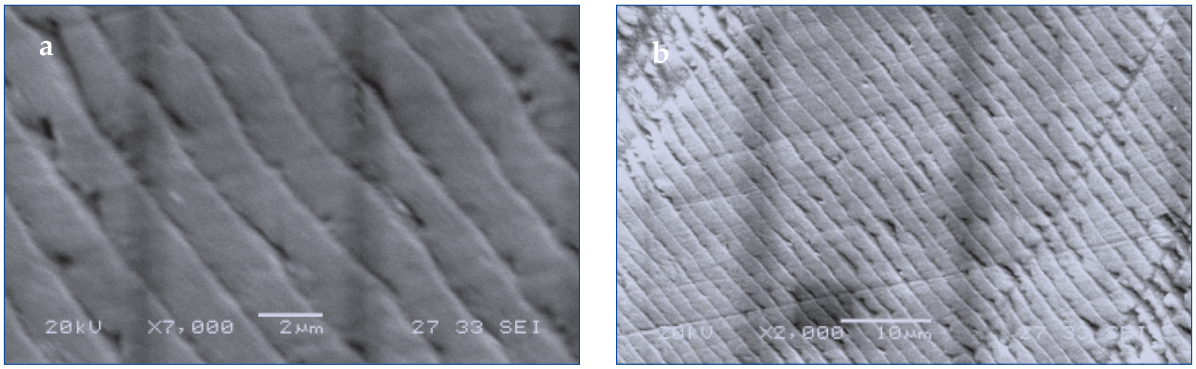

Figure 4: *SEM micrographs showing typical groove structures on the shell surface. (a) Fine closely-spaced grooves of about 2 μm width, at magnification of 7000x (b) Fine closely-spaced grooves of about 2 μm width at magnification of 2000x.*

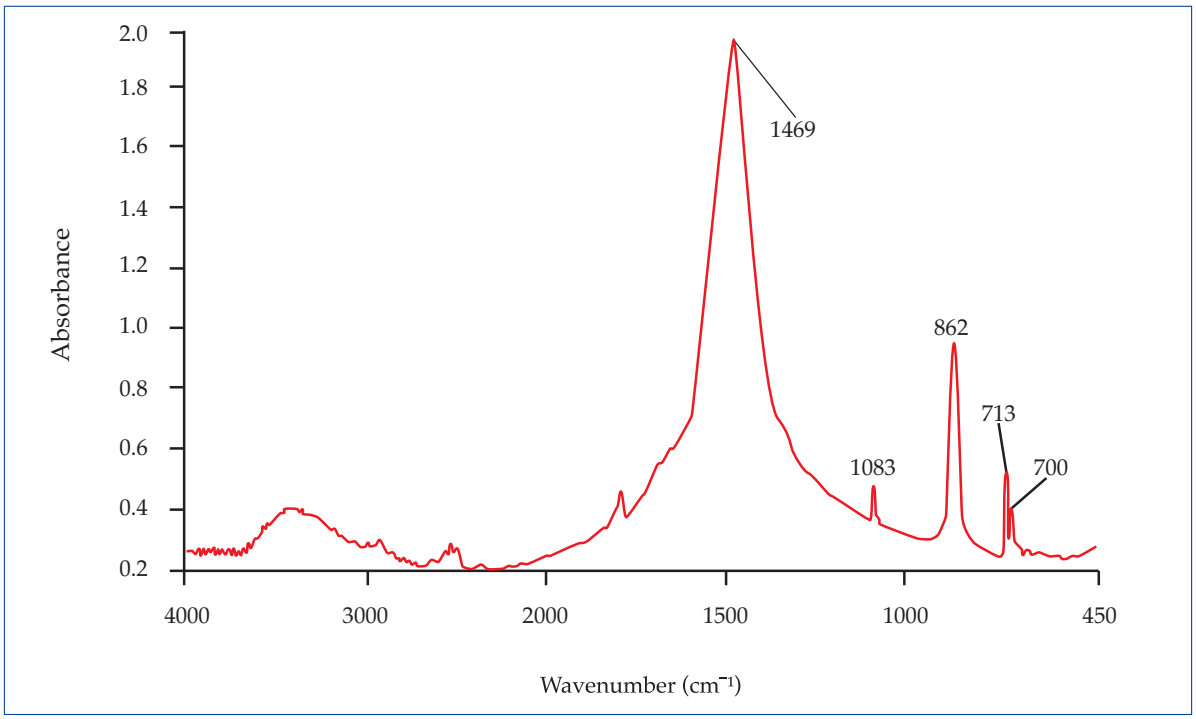

Figure 5: *The FTIR spectrum of the nacreous layer of shell. Peaks at 700 and 713 cm $^{-1}$ (from carbon-oxygen bond in-plane bending) and 862 cm^{-1} (out-of-plane bending) are characteristic of aragonite.*

abalone can be correlated with this high groove density. A high groove density or low groove width which results in large deviation angle θ usually causes the iridescent colours to be strong. This is because a large θ allows the colours to be well separated, resulting in better observation of several distinct colours. In a previous investigation, iridescent colours of lower strength on the shell of *Pinctada margaritifera* were observed with a groove width of 3.38 μm and groove density of 296 grooves/mm (Liu *et al.*, 1999).

The microstructure of the various parts of the surface of the shell was also investigated using the SEM. *Figure 4*(*a*) shows the typical groove structure of about 2 μm width at 7000x magnification. The pattern is found to be uniform over a larger area as shown in *Figure 4*(*b*) (magnification 2000x). Closer examination gives a value of 2.0 ± 0.2 μm for the groove width with an estimated uncertainty of 10%. This results in a groove density of 500 ± 50 grooves/mm which is in good agreement with the value of 518 ± 13 derived from the laser diffraction experiments. The results indicate that the laser diffraction method can be used to derive the groove density of the fine grating

structure of a shell with a conservative estimate of uncertainty of about 10%. Furthermore, both investigations strengthen the concept that the iridescent colours are caused by the fine reflection grating structure of the abalone shell. This is very similar to the strong iridescent colours seen on the surface of a compact disc (Wilson and Buffa, 1997).

A Fourier transform infrared (FTIR) spectrum typical of the nacreous layers of the shell is shown in *Figure 5*. The absorption peaks at 700 cm^{-1}, 713 cm^{-1}, 862 cm^{-1}, 1083 cm^{-1} show that $CaCO_3$ in the nacreous layers of the shell has a structure that is basically aragonite (see Smith, 1999; and Baird and Soloman, 1979). Specifically, aragonite contains carbon-oxygen bonds which bend in-plane giving absorption peaks at 700 and 713 cm^{-1}, and bend out-of-plane giving a peak at 862 cm^{-1}. The largest absorption peak at 1469 cm^{-1} is typically observed for all crystalline forms of $CaCO_3$. The peak is attributed to the carbon-oxygen stretching vibration in the molecule.

The infrared spectroscopy results are consistent with the SEM observations that the calcium carbonate layers are composed of aragonite, and are similar to the layers found in pearl (Landman *et al*., 2001; Wada, 1999). A grating structure of pearl similar to that of the abalone in this investigation has also been observed by Landman *et al.* (2001).

Conclusion

The polished shell of the abalone *Haliotis glabra* shows very strong iridescent colours, mostly pink and blue-green. The cause of the strong iridescent colours was studied by examining the microstructure of the surface of the shell using SEM and diffraction laser energy. Regular 2-µm grooves were observed over a large area of the shell, and the laser diffraction experiments indicate that this grooved density (about 518 grooves/mm) can generate strong iridescent colours. The infrared absorption peaks using FTIR spectroscopy confirm the aragonite structure of the nacreous layers of the shell.

Acknowledgement

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Diffraction Enhanced Imaging: a new X-ray method for detecting internal pearl structures

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Abstract: *The X-ray based Diffraction Enhanced Imaging method (DEI) has been applied to examination of pearls of different origin. DEI images – especially of large pearls – indicate internal growth features more clearly than the usual X-radiographs and show structures which could not be made visible with conventional methods. The DEI method furthermore offers a tool for the separation of larger tissue-nucleated cultured pearls from natural freshwater pearls if conventional X-ray methods fail.*

Keywords: *cultured pearl, diffraction, pearl structure, pearl testing, radiograph, X-ray*

Introduction

Still the most sophisticated and reliable way to identify the nature of pearls is an examination by using various X-ray techniques. The combination of X-radiography, X-ray diffraction and X-ray luminescence can identify pearls in almost all cases (Kennedy, 1998; Schlüter and Rätsch, 1999).

X-ray diffraction, which produces indicative Laue patterns of a pearl's interior, always reveals the shell bead in bead-nucleated cultured pearls.

A radiograph shows internal pearl structures because the inorganic components (aragonite, calcite) are less radiolucent than their organic component (conchiolin). Due to the different absorption strengths of X-rays by these components a radiograph reflects internal growth structure in different grades of shading.

With the interpretation of such X-ray images it is usually possible to distinguish natural pearls from tissue-nucleated cultured pearls like those from Asian freshwaters or from marine sources, and of course from bead-nucleated cultured pearls as well.

Finally X-ray luminescence separates fluorescent freshwater from non-fluorescent marine pearls, regardless of their natural or cultured origin.

With the appearance of large high-quality tissue-nucleated freshwater cultured pearls on the markets a new problem arises. Tissue nucleated pearls have irregularly shaped centres composed of conchiolin, a conchiolin-

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aragonite mixture or tiny cavities initially caused by the implanted epithelial cells. However, in many pearls and especially in those of larger size, the fine central growth irregularity, which proves a pearl to be tissue-nucleated, can no longer be detected by conventional X-radiography. The large outer pearl body, which has grown like a natural pearl, around the tiny irregularity in the centre of the pearl conceals the fine differences in the X-ray absorption evoked by those irregularities, so that they are no longer visible on X-ray radiographs.

Actually, if a bead-nucleus is not detectable and no structures of tissue-nucleation are visible, a differentiation between natural marine pearls (oriental pearls) and tissue-nucleated cultured freshwater pearls can be done by a test of their X-ray luminescence. But such an investigation gives no documented proof for the origin of the pearl. There is still the possibility that the pearl under examination – if X-ray luminescence is visible – is a natural freshwater pearl.

Our team now has applied the Diffraction Enhanced Imaging method (DEI) to pearl examination. Pearls of different origin have been tested with this method and compared with results from different well known X-ray methods like conventional and digital radiography or computed tomography. Our studies, carried out at Hamburger Synchrotronstrahlungslabor (HASYLAB) at Deutsches Elecktronen-Synchrotron (DESY), Hamburg, Germany, and European Synchrotron Radiation Facility (ESRF), Grenoble, France, show that detection limits for internal pearl structures and the resolution of the features with the DEI method are far superior to the results obtained from X-ray methods for pearl examination used to date.

Principles of DEI

For the new imaging method under development monochromatic radiation in the X-ray range is essential, and this

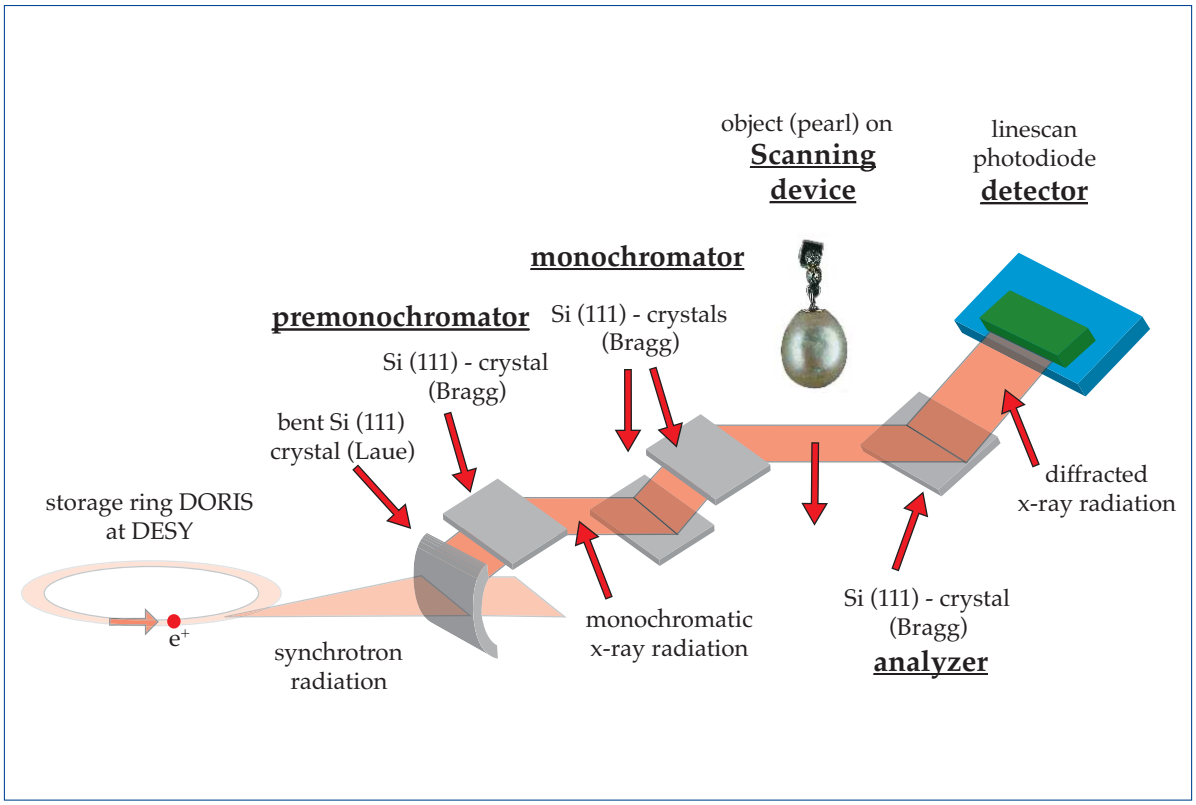

Figure 1: *Schematic diagram of the experimental set-up. The incoming radiation is made monochromatic by perfect silicon crystals. This beam illuminates the pearl on the scanning device and is analysed with the analyser silicon crystals.*

can be provided with sufficient intensity from synchrotron radiation. Synchrotron radiation with a spectrum from visible light wavelengths to hard X-rays is produced in particle storage rings, as for example the Doppel-Ring-Speicher (DORIS) at DESY. Synchrotron radiation is several orders of magnitude more intense than X-ray radiation from conventional X-ray tubes and has a very small divergence (opening angle). With the help of perfect silicon crystals, beam energies between 15keV and 60keV can be selected. Following Bragg's law, radiation (X-rays) with a certain energy is selected. This leads to a monochromatic X-ray beam with a bandwidth of about 10eV.

The principle of the DEI method (Chapman *et al.*, 1997) is based on the separation of scattered from non-scattered X-rays behind the imaged object. The small angle of scattering of the monochromatic X-ray beams in a sample is due to refraction at the boundaries of two materials with different refractive index. Therefore, the separation between the direct and the refracted part of the beam allows an extreme enhancement of contrast in the images at the edges between the materials and thus enables distinction between different materials.

How results are obtained from the equipment

The DEI system at HASYLAB (*Figure 1*) consists of a tunable premonochromator with two silicon crystals and a second double crystal monochromator for precise selection of the energy. The 1 mm high and 5 cm wide beam illuminates the sample which is mounted on a vertically moving stage. Behind this scanning device the silicon analyzer crystal is installed, which separates the scattered and non-scattered beams. Finally, either a line detector with 25 µm pixel size or a CCD-camera with 5 µm pixel size records the images.

The angle dependence of the intensity of the X-rays within the accepted energy band

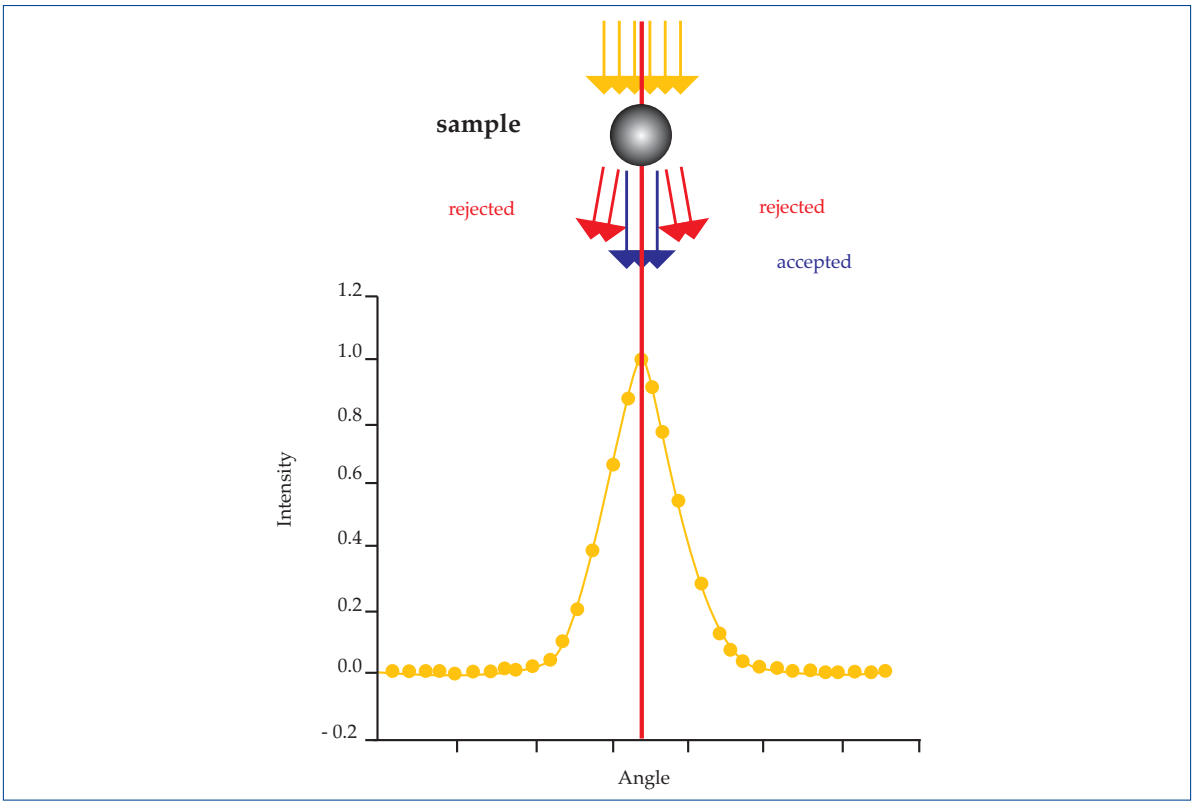

Figure 2a: *The rocking curve of the analyser crystal in the monochromatic beam. The image is taken at the maximum intensity position.*

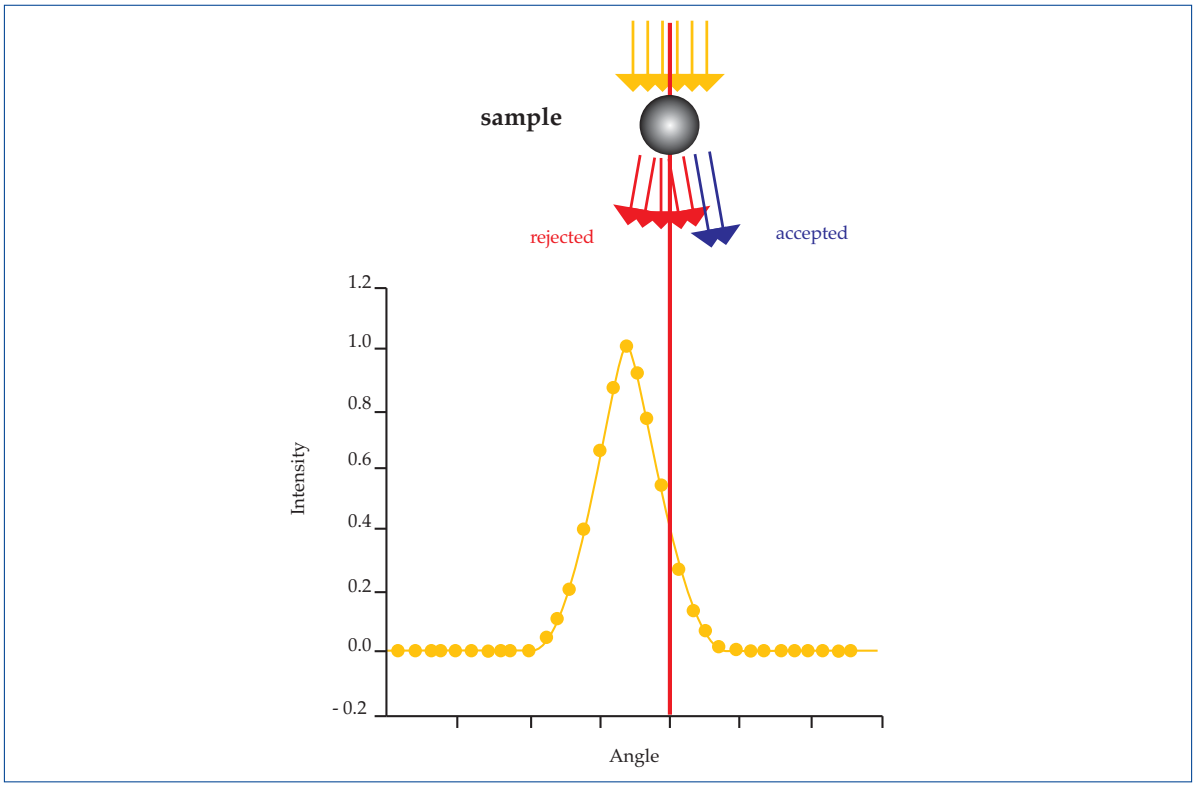

Figure 2b: *Analyzer crystal at the high angle side of the rocking curve. Radiation scattered in a certain direction is enhanced or suppressed, respectively.*

selected by a crystal is described by the so-called 'rocking curve' (*Figure 2*). The analyzer crystal is used to scan over the rocking curve of the monochromator crystal by changing its angle of incidence. If the angles of the two crystals exactly match (*Figure 2a*), then the X-rays which are scattered from the object are rejected. The resulting images are called 'top images'. If the angles of the two crystals are slightly detuned, the non-scattered beam is at the 'shoulder' of the monochromator's rocking curve (*Figure 2b*). Then the non-scattered X-rays are diminished, whereby the scattered part leads to a higher and a lower intensity, respectively, depending on the scattering direction, due to the slope of the rocking curve. In the latter set-up of the system the analyzer crystal is tuned first to the high angle side and then to the low angle side of the rocking curve (*Figure 2b*) and gives two shoulder images. A mathematical algorithm using both shoulder images delivers the 'refraction image' which clearly shows the boundaries of two materials with different refraction indices.

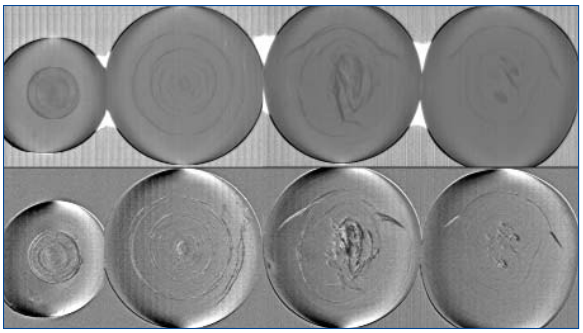

Figure 3: *Comparison of two natural (left) and two tissue-nucleated freshwater pearls (right). The top row shows the 'top images' (as described in Figure 2a), whereby an unsharp-masking algorithm was applied, and the bottom row shows the 'refraction images'. The natural pearls reveal well-known concentric growth patterns whereas the two tissue-nucleated freshwater pearls show both concentric patterns which are less regular and major central growth irregularities.*

Examination of different pearl types

Top and refraction images of two natural pearls produced with the DEI system clearly show concentric growth patterns as expected, but in a much more accentuated manner

than shown by conventional X-radiographs (*Figure 3*). In addition to concentric growth lines, circular central structures are visible in the DEI images of the natural pearls. They correspond to circular central shadows, which often can be observed in X-radiographs of natural pearls, and are due to conchiolin-rich centres.

Figure 4: *Oval (left) and drop-shaped (right) black, bead-nucleated cultured pearls from the Tuamotu Islands, French Polynesia: The 'refraction images' show the nuclei with outer nacreous layers. The 'refraction image' of the oval pearl in addition shows the laminated structure of the shell bead. The image of the drop-shaped pearl indicates gaps between the shell bead and the outer nacreous layer.*

Bead-nucleated cultured pearls (*Figure 4*) clearly show the nucleus with outer nacreous layer as well as gaps between the shell bead and the nacreous layer. Rarely seen in conventional X-ray radiographs, one of the 'refraction images' in *Figure 4* also indicates the laminated structure of the shell bead.

DEI images of tissue-nucleated cultured freshwater pearls reveal concentric growth lines in their outer parts around variform anomalies at or near the centre of the pearl (*Figures 3* and *5*), caused by organic-rich domains and/or tiny cavities. These structures correspond with the dark irregular shaped central features on X-radiographs of pearls of this type. They are indicative of tissue-nucleated growth and are the result of the initial behaviour and decay of the implanted tissue.

DEI images of tissue-nucleated marine pearls from NW-Australia, often referred to

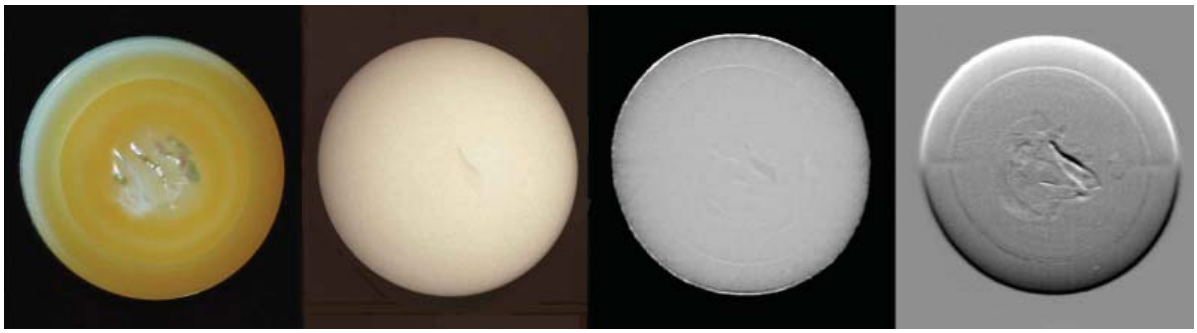

Figure 5: *The images of a Chinese tissue-nucleated cultured freshwater pearl show (from left to right): the original pearl cut in half after examination to reveal its interior (Photo by K.-C. Lyncker); a conventional X-radiograph; a 'top image' using the DEI method; and a 'refraction image' using the DEI method. Compared to the conventional X-radiograph, the central growth irregularity and growth lines visible from the DEI images are clearer.*

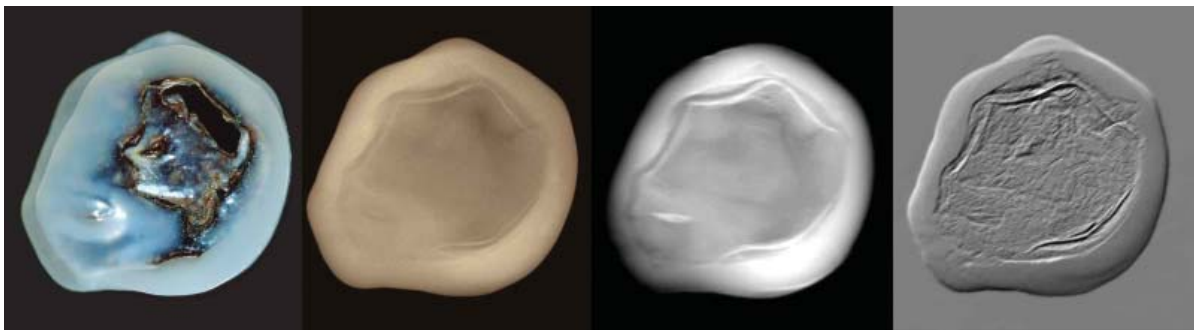

Figure 6a: *This tissue-nucleated cultured marine pearl ('keshi') from Australian waters has a central cavity lined with pale brown organic material followed by a thin nacreous layer. Beginning with a fine open gap this sequence repeats itself towards the outer nacreous layer. The images show (from left to right): the original pearl sectioned after examination to reveal its interior (Photo by K.-C. Lyncker); a conventional X-radiograph; a 'top image' using the DEI method; and a 'refraction image' using the DEI method.*

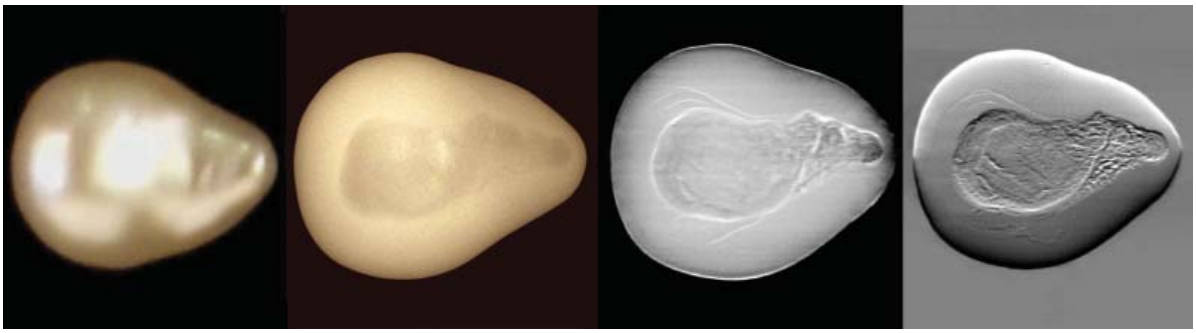

Figure 6b: *These images of another tissue-nucleated cultured marine pearl from Australia show (from left to right): the original pearl (Photo by M. Müller), a conventional X-radiograph, a 'top image' and a'refraction image' using the DEI method for comparison.*

as 'South Sea keshis', presented very detailed structures (*Figure 6a* and *b*). To verify the structures visible in the DEI images, parts of one were removed to reveal its interior (*Figure 6a*). This pearl disclosed a large central cavity lined with pale brown organic material, followed by a thin nacreous layer. Beginning with a fine open gap this sequence repeats itself towards the outer nacreous layer. The internal structures of this 'keshi pearl' are most clearly portrayed within the DEI refraction image, demonstrating the potential of the DEI method to reveal even the finest growth structures.

Conclusions

The DEI method applied to pearls can reveal internal pearl structures formerly not visible using conventional X-ray methods. However, although the high specifications of the equipment mean that this method is too expensive for routine pearl testing, it nevertheless offers the opportunity to perfectly document internal pearl structures. Thus it is useful for scientific purposes and for large pearls whose value depends on determining their origin as tissue-nucleated pearls or as natural freshwater pearls.

Acknowledgements

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A microscopy-based screening system to identify natural and treated sapphires in the yellow to reddish-orange colour range

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Abstract: *Features visible under a microscope of untreated, heat-treated and beryllium-diffusion-treated yellow, orange and reddish-orange sapphires, including padparadschas, are presented. A microscopy-based screening system for recognition and distinction of untreated, heat-treated and diffusion-treated sapphires combines structural features such as growth structures, colour zoning and inhomogeneous colour distribution patterns with the visual appearance of inclusions. Spectra and chemical compositions may be added to these microscopic characteristics and applied to an evaluation of samples of unknown origin and unknown treatment history. These properties combine to form a type of locality-specific data set, and are considered in the light of present knowledge about treatment techniques. The screening system allows the recognition of most untreated or heat-treated samples from Sri Lanka and Montana, U.S.A., and their distinction from beryllium-diffusion-treated samples from Sri Lanka, Montana, U.S.A., Ilakaka, Madagascar, and Songea, Tanzania.*

Keywords: *absorption spectroscopy, beryllium diffusion, colour zoning, growth structures, heat-treatment, inclusions, padparadscha, sapphire, screening system, trace-element chemistry*

In a previous paper (Schmetzer and Schwarz, 2004) we summarised the knowledge of causes of colour in untreated, heat-treated and diffusion-treated orange and pinkish-orange sapphires *(Figure 1a, b, c, d)*. The present paper deals with methods for the recognition of beryllium-diffusion-treated sapphires in the yellow, orange or reddish-orange colour range and for distinction` of these sapphires from different types of untreated or heat-treated samples. The paper consists of three parts:

Part I: Introduction; Materials and methods; Alteration of inclusions
Part II: Growth structures; Colour zoning and inclusions; Chromium and iron contents; Spectra of sapphires from Sri Lanka, Montana, Ilakaka and Songea
Part III: A microscopy-based screening system; Case studies; Conclusions

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PART I
Introduction

Orange sapphires 'enhanced' by beryllium diffusion treatment at elevated temperatures appeared on the market at the end of 2001 (see, e.g., McClure *et al.*, 2002). According to trace-element analyses, the new type of treated sapphires, especially samples from Songea, Tanzania, and Ilakaka, Madagascar, contained elevated beryllium concentrations, with the highest amounts of beryllium detected in the rims of the stones. It was suggested that Thai treaters first used this new heat treatment process on stones which did not respond to heat treatment with any colour improvement, e.g. purplish to purple Songea or Ilakaka material, which was not transformed to bright ruby or pink sapphire.

However, for proof that a sample has undergone beryllium diffusion, direct determination of beryllium content in the 5 to 40 ppm range in corundum is necessary using SIMS (McClure *et al.*, 2002; Wang and Green, 2002; Emmett *et al.*, 2003) or LA-ICP-MS (Peretti and Günther, 2002; Hänni, 2002; Hänni and Pettke, 2002; Fritsch *et al.*, 2003; Peretti *et al.*, 2003; Pisutha-Arnond *et al.*, 2003, 2004a). Both methods require highly sophisticated instrumentation and are extremely costly; thus, they are not useful as routine techniques for the examination of larger quantities of sapphires, or for small stones.

To overcome these problems, it was recently announced that LIBS might be useful as a somewhat cheaper routine method for quantitative beryllium determination in corundum (Hänni *et al.*, 2004; Krzemnicki *et al.*, 2004; Themelis, 2004). LIBS is a technique applied to a great number of analytical problems (see, e.g., Singh *et al.*, 1998) and has already been applied successfully for beryllium determination (Radziemski and Cremers, 1985). Nevertheless, its cost still means that this method will be limited to laboratories.

Consequently, the distinction of treated and untreated samples *(Figure 1a, b, c, d)* and the definitive detection of any type of treatment by use of traditional gemmological methods, e.g. by microscopic examination, is still one of the major challenges for a gemmologist.

According to Emmett *et al.* (2003), at that time there were only two reliable criteria

Abbreviations used in this article for equipment

EDXRF	Energy-dispersive X-ray fluorescence
LA-ICP-MS	Laser ablation-inductively coupled plasma-mass spectroscopy
LIBS	Laser-induced breakdown spectroscopy
SIMS	Secondary ion mass spectroscopy

Figure 1a: *Untreated padparadschas from Sri Lanka, range of samples from 4.51 to 9.05 ct. Photo by M. Glas.*

Figure 1b: *Different types of orange or reddish-orange sapphires from Sri Lanka; untreated chromium-bearing sample (left), heat-treated chromium-bearing sample (centre) and heat-treated chromium-free sample (right); range of samples from 1.45 to 2.17 ct. Photo by M. Glas.*

Figure 1c: *Beryllium-diffusion-treated chromium-free sapphires from Sri Lanka; range of samples from 0.78 to 1.66 ct. Photo by M. Glas.*

Figure 1d: *Beryllium-diffusion-treated sapphires from Ilakaka, Madagascar; range of samples from 1.10 to 1.47 ct. Photo by M. Glas.*

for the recognition of diffusion-treated and untreated sapphires:

- untreated sapphires are only recognisable if there is definite proof of the presence of undistorted inclusions. Samples which show inclusions in the 'natural' state, i.e. neither altered nor decomposed nor partly molten mineral inclusions, constitute such proof;
- beryllium-diffusion-treated sapphires may show surface-conformal colour zoning with varying penetration depth into the faceted stone. This feature is common in many sapphires produced in the early months and years of beryllium treatment.

Nowadays, however, diffusion-treated sapphires from Thailand, occasionally even labelled 'deep diffusion treatment' (*Figure 2a, b, c, d)*, are less likely to possess this feature.

One must also guard against natural material, sometimes with complex colour zoning (*Figure 3a, b*; see also Hänni and Pettke, 2002) which has been occasionally mistaken for a rim caused by diffusion treatment.

Some microscopic inclusion features have been used as 'highly indicative evidence' for beryllium diffusion treatment (Emmett *et al.*, 2003). However, because of the often similar appearance of altered inclusions in simply heat-treated and diffusion-treated sapphires (*see Box A*), a distinction between these two types of material based on microscopic observations is not easy.

According to Notari *et al.* (2003), the observation of orange or red homogeneous or inhomogeneous luminescence may also be useful in detecting beryllium-diffusion-

Figure 2a: *Diffusion-treated originally pink or purplish-pink sapphire of 1.44 ct originating from Ilakaka, Madagascar; this sample was labelled 'deep diffusion treated' in Thailand. Photo by M. Glas.*

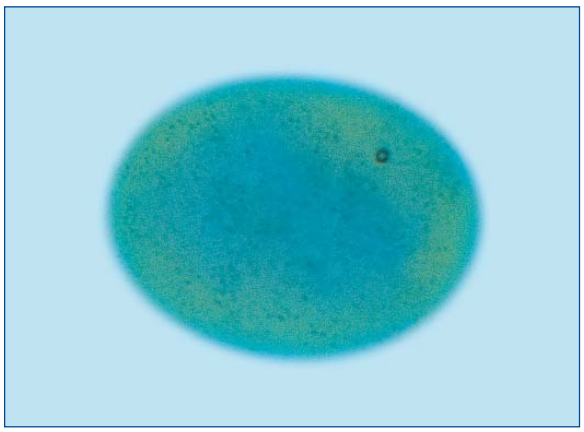

Figure 2b: *Occasionally a distinct colour boundary between core and rim is still visible in immersion in beryllium-diffusion-treated sapphires as seen in the sample pictured in* Figure 2a. *In many stones, however, this boundary is not visible. Photo by K. Schmetzer.*

Figure 2c: *Diffusion-treated originally pink or purplish-pink sapphire of 1.29 ct originating from Ilakaka, Madagascar. Photo by M. Glas.*

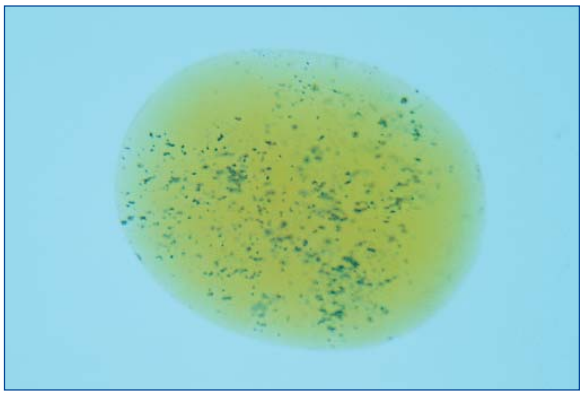

Figure 2d: *In the sample pictured in Figure 2c, no distinct colour zoning between rim and core is visible; only numerous tiny inclusions are seen. In the past, the diagnostic rim/core boundary was best seen in beryllium-diffusion-treated Ilakaka sapphires, simply because these gemstones do not show any growth pattern and colour zoning in the untreated state. Photo by K. Schmetzer.*

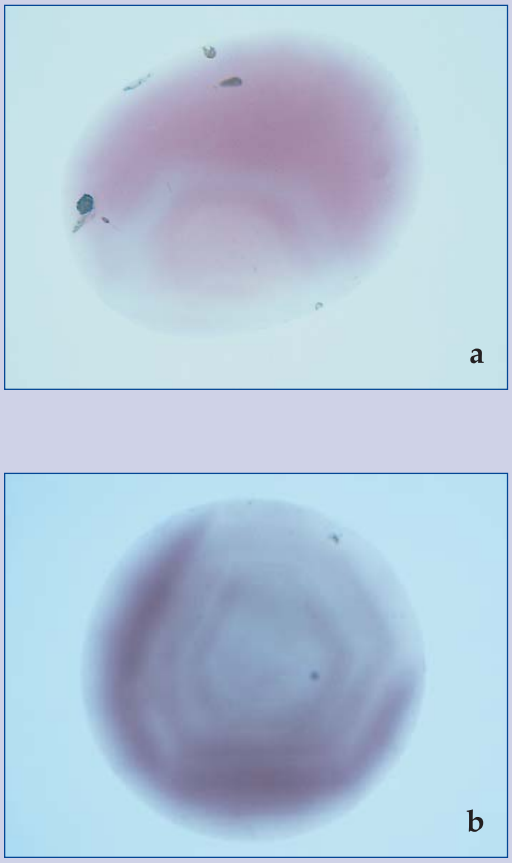

Figure 3: *Even in immersion, the colour zoning of untreated Songea rubies and sapphires (a) may closely resemble the pattern observed for diffusion-treated material (b) from the same locality; sample (a) 0.54 ct, sample (b) 0.75 ct. Photos by K. Schmetzer.*

treated sapphires. However, red fluorescence caused by chromium could mask any orange fluorescence caused by beryllium, and a special red colour filter, the observation of luminescence under immersion, or luminescence spectroscopy may be needed to make a final decision.

Only limited information has been presented about colour zoning other than describing the rim/core boundary which is related to the diffusion range and/or the depth of colour change in the diffusion-treated samples. In addition, a comparison of beryllium-diffusion-treated samples according to the locality of origin of the untreated material with untreated padparadscha from Sri Lanka and simple heat-treated sapphires in the same colour range (i.e. treated without Be-diffusion) has not been addressed in detail. At present, the known heat-treated orange or reddish-orange sapphires are mainly from Sri Lanka and Montana, U.S.A. (Notari, 1996, 1997; Emmett and Douthit, 1993).

The aim of the present paper is to fill – at least partly – this gap and to assess whether a screening technique for the distinction of treated and untreated samples in the ruby – yellow sapphire colour series, is a practical possibility with traditional microscopic methods. In addition, we have tried to evaluate a combination of these with gemmological laboratory techniques such as absorption spectroscopy or trace-element analysis. The aim is to find specific properties or a combination of features which would avoid costly quantitative determination of beryllium contents, and allow at least

some sapphires, including smaller stones, to be identifed as untreated, heat-treated or diffusion-treated sapphires.

The techniques applied in the present research are traditional microscopic techniques and – more or less – the methods that are used for origin determination of sapphires by laboratories, i.e. determination of microscopic properties (growth structures and colour zoning, inclusions) with and without immersion liquids, absorption spectroscopy in the visible and ultraviolet range, and – in some instances – determination of colour-causing trace-elements such as Ti, V, Cr, and Fe by EDXRF spectroscopy. In other words: the present study was performed to evaluate whether the number of samples that can be determined as untreated, heat-treated or beryllium-diffusion-treated can be increased by combining locality information with present knowledge about properties of these different categories of samples.

As with origin determination of sapphire, which depends on a sufficient number of samples with characteristic properties related to a specific natural source, it was always expected that even a combination of techniques could fail to identify the treatment status if insufficient samples possessed significant features. This situation is comparable with that of high-pressure high-temperature (HPHT) treated diamonds, some of which have properties which overlap with those of untreated type IIa natural diamonds (see, e.g., Fisher and Spits, 2000; Collins 2001). The screening technique presented here for beryllium-diffusion-treated sapphires is comparable to the screening technique for HPHT-treated diamonds as developed by De Beers (Lawson, 2002).

Materials and methods

For this study 279 sapphires were added to the research material (349 sapphires) used earlier (see Schmetzer and Schwarz, 2004). Most new samples originated from or belonged to four additional groups of samples, i.e. diffusion-treated sapphires from Sri Lanka, and untreated, heat-treated and diffusion-treated corundums from Montana, U.S.A. In total, we examined 628 corundum samples for this research project; an overview is given in *Table I.*

All samples were highly transparent, gem-quality rubies or sapphires, ranging from about 0.10 ct to 9 ct in weight, obtained from the trade, mostly in Europe and Thailand, from private collections, or from colleagues in gemmological laboratories. Three lots of diffusion-treated samples were specially prepared from rough of known origin, from Sri Lanka and Montana. Most samples were faceted gemstones, but we also examined some rough specimens (mainly from Montana) and numerous slices polished on both sides; the latter were prepared mostly from corundum lots which were specially diffusion-treated for us (see *Table I*).

Untreated lots of Montana sapphires, mostly in the yellowish-green, bluish-green or blue colour range and a few very pale pink sapphires, were available from two major localities which have been commercially mined in the past, i.e. from the Rock Creek and Missouri river deposits. Two lots of heat-treated samples in the orange to reddish-orange colour range were submitted from private collections and from the trade. The known history of these lots excluded any treatment by diffusion.

To complete the study and to investigate any possible overlap between heat-treated and diffusion-treated material from Sri Lanka and Montana, one of the authors (DS) obtained one parcel of diffusion-treated yellow Sri Lankan material in the Thai trade. An additional lot of Sri Lankan geuda material which had become colourless after ordinary heat treatment was diffusion-treated by J. Emmett. The technique applied is described in detail by Emmett *et al.* (2003). Because some Montana sapphires can be heat-treated to orange or reddish-orange, two lots of originally yellowish-green, bluish-green or blue Montana sapphires were diffusion-treated by J. Emmett and submitted for this research project.

The colour distribution of all samples was studied by immersion in methylene iodide, simply placing the samples on a diffused-light box in a Petri dish. Although the colour

Table I: Sources, colours, treatment history and causes of colour of corundums used in this study.

Locality	Colour	Type (number of samples examined)	Absorption bands	
			Dominant	Sub-ordinate
Sri Lanka	yellow	untreated (16)	thermally unstable colour centres	Fe^{3+}
	yellow, yellowish-orange or orange	heat-treated (67)	thermally stable colour centres	Fe^{3+}
	yellow, yellowish-orange or orange	diffusion-treated (43)	thermally stable colour centres	Fe^{3+}
	yellowish-orange, orange, pinkish-orange, reddish-orange	untreated (46)	thermally unstable colour centres, Cr^{3+}	Fe^{3+} Fe^{2+}/Ti^{4+}
	orange, pinkish-orange, reddish-orange	heat-treated (18)	thermally stable colour centres, Cr^{3+}	Fe^{3+}
Montana, U.S.A.	yellowish-green, bluish-green, blue, rarely pink	untreated (100)	Fe^{3+} Fe^{2+}/Ti^{4+}	Cr^{3+}
	orange to pinkish-orange or reddish-orange, brownish-orange	heat-treated (20)	thermally stable colour centres, Cr^{3+}, some also Fe^{3+}	Fe^{3+}
	yellow, yellowish-orange, orange	diffusion-treated (85)	thermally stable colour centres, Fe^{3+},	Cr^{3+}
Ilakaka, Madagascar	pink, purplish-pink, purple, purplish-violet, violet	untreated (75)	Cr^{3+} Fe^{2+}/Ti^{4+}	Fe^{3+}
	yellowish-pink, yellowish-orange, brownish-orange, orange brown, yellowish-brown	untreated (14)	Cr^{3+} Fe^{3+}	
	pink, slightly purplish-pink	heat-treated (10)	Cr^{3+}	Fe^{3+} Fe^{2+}/Ti^{4+}
	brownish-orange	heat-treated (1)	thermally stable colour centres, Cr^{3+}	Fe^{3+}
	yellowish-orange, orange, pinkish-orange, orangey-red, reddish-orange, brownish-orange	diffusion-treated (49)	thermally stable colour centres, Cr^{3+}, some also Fe^{3+}	Fe^{3+}
Songea, Tanzania	colourless to red or pink, purplish-red, purple, violet[a]	untreated (22)	Cr^{3+} Fe^{2+}/Ti^{4+}	Fe^{3+}
	colourless to red or pink, purplish-red[a]	heat-treated (10)	Cr^{3+}	Fe^{3+} Fe^{2+}/Ti^{4+}
	colourless to yellowish-orange, orange, or reddish-orange[a]	diffusion-treated (52)	thermally stable colour centres, Cr^{3+}	Fe^{3+}

[a] *some are colour-zoned with a colourless core and an intensely coloured rim*

distribution within the samples can be seen with the naked eye, examination with a loupe (10 x) or with a microscope at low magnification (10 x to 20 x) gives better results. Exact determinations of growth structures and colour zoning related to growth patterns were performed with a horizontal immersion microscope using a special sample holder with two rotation axes and specially designed eye-pieces (Schmetzer, 1986; Kiefert and Schmetzer, 1991; see also Smith, 1996). One could also use a vertical microscope with a sample holder which allows rotation and orientation of the sapphire in an immersion cell or a Petri dish.

Inclusions were studied using different microscopes and lighting conditions both with and without immersion liquid. A few

inclusions were identified by laser Raman microspectrometry using a Renishaw Raman microprobe or by X-ray powder diffraction. From other unpublished research projects describing untreated Ilakaka or Songea material (see *Table I*), some samples with inclusions already identified by Raman microprobe were available for comparison.

Trace-element contents of 182 samples were analysed by EDXRF spectroscopy. These analyses were performed with a Tracor Northern Spectrace 5000 system, using a program specially developed for trace element geochemistry of corundum. The samples for chemical analyses (Sri Lanka 36, Madagascar 84, Tanzania 42, U.S.A. 20) were selected to cover the full range of colours seen in untreated, heat-treated and diffusion-treated material from all four sources, although with this technique one is unable to detect the presence of light elements such as beryllium.

Trace-element contents and distribution in two colour-zoned diffusion-treated samples were investigated using LA-ICP-MS.

Absorption spectra of all samples were recorded in the UV-visible-NIR range with both a Leitz-Unicam SP 800 UV-Vis spectrophotometer and a Perkin-Elmer Lambda 19 spectrophotometer. Polarised or non-polarised spectra were recorded according to the orientation of faceted gemstones, rough crystals or simply polished slices.

BOX A: Alteration of inclusions upon heat treatment and diffusion treatment of corundum

Because low oxygen pressure inhibits development of the orange colour centre, Be-diffusion treatment of sapphires is generally performed in oxidizing atmospheres (Emmett *et al.*, 2003). In the 1990s, special furnaces with Kanthal Super 1900 molybdenum disilicide heating elements allowed heat treatment of corundum for longer periods at temperatures up to 1820 C in an oxygen-bearing environment. Special designs allowed treatment up to this temperature under pressures between 5 and 100 atmospheres, especially to reduce the times necessary to develop the desired colour change (*Figure 4*). With Zircothal (yttrium-stabilised zirconium oxide) heating elements, heat treatment of corundum in oxidising atmospheres at temperatures up to 2000 C can be performed. Furnaces of the types mentioned above, i.e. with both types of heating elements with or without high pressure design, have been available in Thailand since before 1995 (H. Linn, pers. com., 2002, 2003). These furnaces were used for several years for 'simple' or 'normal' heat treatment of ruby and sapphire before Be-diffusion treatment started commercially, probably in 2001 (see Coldham, 2002). Other furnaces used for commercial heat treatment of corundum at temperatures up to at least 1850 C are fired by gas (T. Häger, pers. com., 2003).

Figure 4: *High temperature furnace 'ruby star' that allows commercial treatment of corundum in oxidising environment at temperatures up to 1820°C and pressures up to 100 bars; courtesy of Linn High Therm GmbH, Eschenfelden, Germany.*

Dissolution of rutile needles or larger crystals and diffusion of titanium within the corundum lattice takes place above 1550 C. Thus, the observation of residues of rutile needles or diffusion haloes around rutile crystals only indicates heat treatment above about 1550 C. Most silicate inclusions and apatite (see Adolfsson *et al.*, 1999) decompose or melt at temperatures below 1500 C, but zircon, monazite and xenotime commonly survive. Melting temperatures of 1995 C for xenotime and between 2045 and 2072 C for natural and synthetic

monazite-type compounds have been determined (Hikichi and Nomura, 1987; Hikichi *et al.*, 1998) close to that of corundum. Furthermore, monazite is considered as an extremely heat-resistant material and stable with aluminium oxide under high temperatures, at least up to 1750 C (Morgan and Marshall, 1995; Morgan *et al.*, 1995; Hay and Boakye, 2001; Zhang and Guan, 2003). A similar high temperature stability with aluminium oxide is also expected for xenotime (Kuo and Kriven, 1995). Thus, inclusions of these minerals can survive heat treatment of sapphires and rubies at elevated temperatures. This indicates that even samples heated up to 1750 or 1800 C can contain monazite or xenotime inclusions which are neither melted nor otherwise decomposed by the treatment process.

Zircon crystals are also common inclusions in sapphires and may be used as indicators for high temperature treatment. As inclusions in corundum, pure zircons are stable up to about 1685 C. This temperature may decrease somewhat for impure natural zircons which are variable in chemical composition. Zircon is decomposed to tetragonal ZrO_2 and cristobalite above this temperature (Butterman and Forster, 1967). Melts in the system Al_2O_3-ZrO_2-SiO_2 coexisting with crystalline ZrO_2 indicate a heat treatment temperature above 1750 C (Rankin and Edwards, 2003). Consequently, the decomposition of zircon and other inclusions and the production of melt upon heat treatment (see also Emmett *et al.*, 2003) occur in the temperature range used for heat treatment of corundum before Be-diffusion treatment started commercially.

The papers published since the first recognition of Be-diffusion-treated sapphires on the market have presented details on the appearance of various types of inclusions that changed dramatically according to the high temperatures applied in the treatment (*Figure 5a, b*). Although there are comments by a number of authors that Be-diffusion treatment is performed at higher temperatures than 'normal' heat treatment in the range of 1600 to 1750 C (see, e.g., Emmett *et al.*, 2003) it has already been successfully performed at temperatures between 1625 and 1775 C by Themelis (2003), personal comments from others suggest that heat treatment was performed in the past at temperatures up to and even above 1800 C. The average maximum temperatures used in the beryllium diffusion process may be somewhat higher than those used for 'normal' heat treatment in the past, i.e. without adding colour-causing trace-elements to diffuse into the corundum lattice. But, because there is an almost complete overlap of temperature ranges used in both processes, no single microscopic inclusion feature described so far can be used to determine whether a sapphire is diffusion-treated or simply heat-treated.

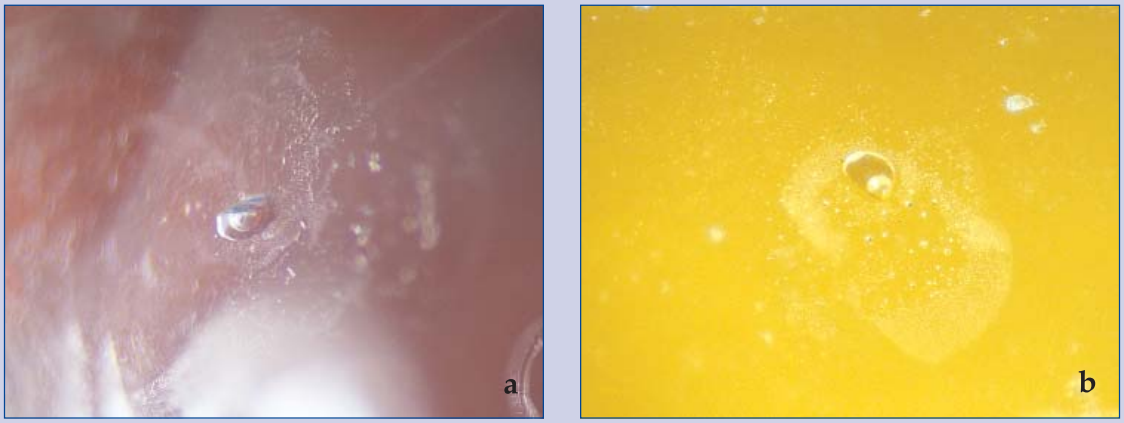

Figure 5: *Because the temperature ranges of the two forms of treatment can overlap, the inclusion features observed in heat-treated and diffusion-treated sapphires (here a sort of bubble surrounded by transparent solid material) may closely resemble each other as seen in a heat-treated pinkish-orange Montana sapphire (a) and in a diffusion-treated yellowish-orange Montana sapphire (b). 50x. Photos by L. Kiefert.*

PART II
Growth structures

General remarks

In the past, growth zoning has been found to be extremely helpful in establishing the locality of origin of rubies and sapphires. As will be shown below, growth structures combined with colour zoning can provide key identification features for the recognition of untreated, heat-treated and diffusion-treated sapphires.

Growth structures in the form of series of parallel growth lines may or may not be combined with colour zoning. All parts of a faceted sapphire which are related to one series of parallel growth lines are called growth sectors. Upon heat treatment, specific colours are generally developed only in some growth sectors of a crystal, e.g. in rhombohedral *r* sectors, or with different intensities in different growth sectors, e.g. in rhombohedral *r* and in dipyramidal *n* sectors. Diffusion treatment may be superimposed on colour zoning and cause dramatic changes, but growth zoning, i.e. the specific growth pattern of a crystal, is not affected by heat or diffusion treatment. Thus, the common growth patterns of the sapphires are described for first untreated, then 'normally' heat-treated and finally Be-diffusion-treated samples.

Sri Lanka

Rough padparadscha crystals from Sri Lanka are normally elongated along the *c*-axis with barrel-shaped to dipyramidal habit (see, e.g., Crowningshield, 1983). The hexagonal dipyramids of this material frequently show growth striations with an orientation perpendicular to the *c*-axis.

The microscopic examination in immersion shows the presence of growth lines parallel to the basal pinacoid *c* {0001}, parallel to different second-order hexagonal dipyramids such as *z* $\{22\bar{4}1\}$, *w* $\{11\bar{2}1\}$, and *n* $\{22\bar{4}3\}$ and parallel to the positive rhombohedron *r* $\{10\bar{1}1\}$. In examining faceted stones, checking three orientations of the sapphire under the microscope, should allow us to reconstruct the external morphology of the rough crystal (*Figure 6*).

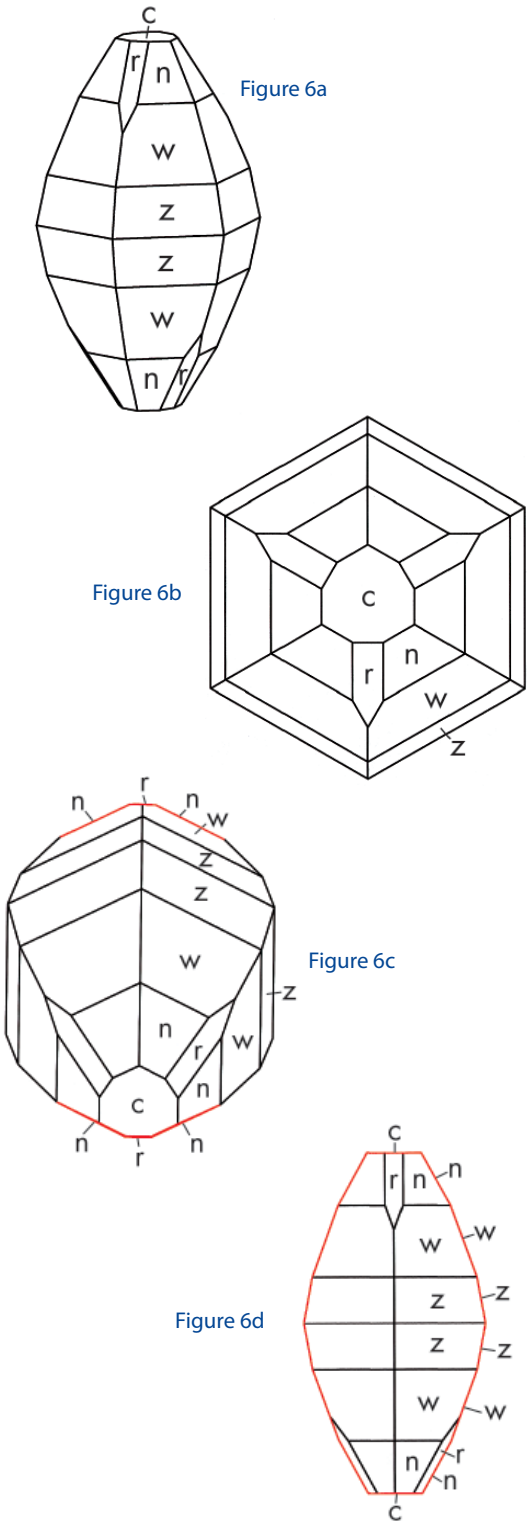

Figure 6: *Typical habit of padparadscha from Sri Lanka consisting of the basal pinacoid* c, *different hexagonal dipyramids* z, w, *and* n *and the positive rhombohedron* r; *(a) clinographic projection,(b) view parallel to the* c*-axis, (c) view at an angle inclined at about 30° to the* c*-axis, (d) view perpendicular to the* c*-axis. The traces of crystal faces which are parallel to the direction of view and, thus, can be seen in the microscope are indicated in red in* Figures b, c *and* d.

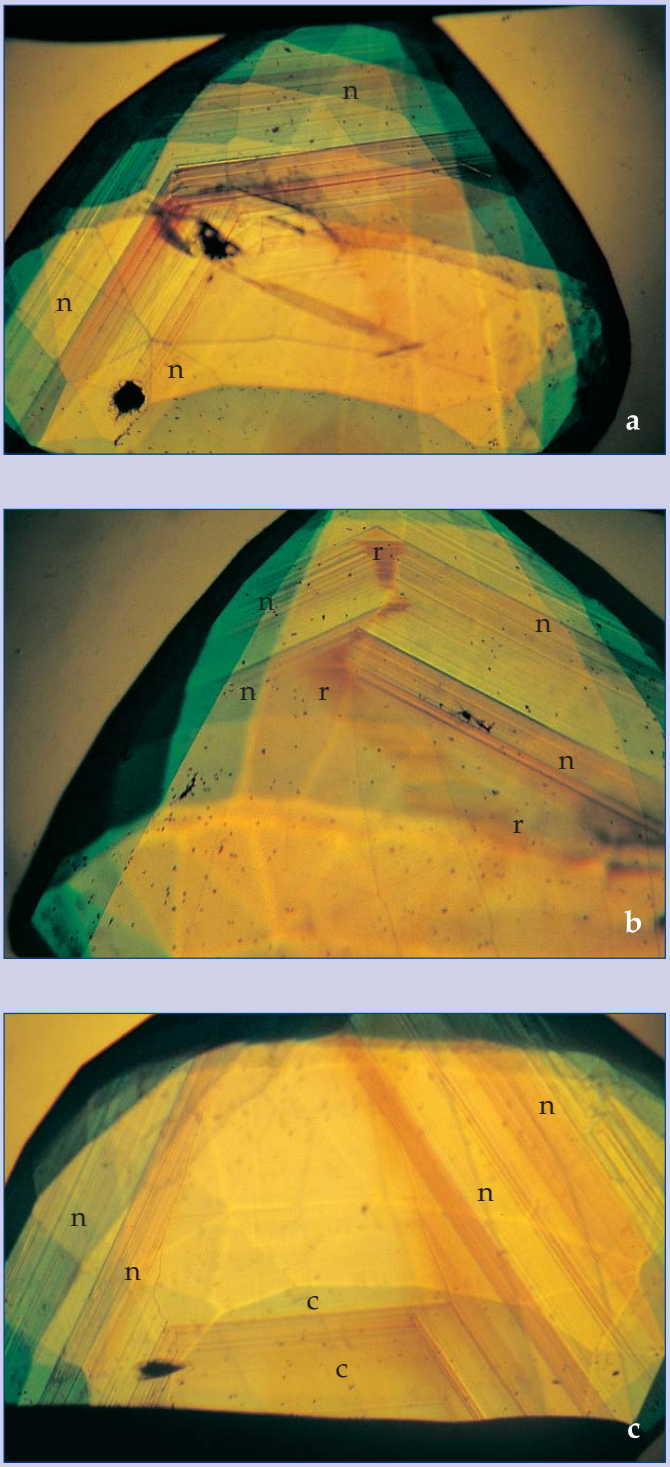

Figure 7: *Growth pattern and colour zoning in a heat-treated padparadscha from Sri Lanka: (a) view inclined at about 30° to the* c*-axis, two hexagonal dipyramids* n *are visible, (b) view inclined at about 30° to the* c*-axis, two hexagonal dipyramids* n *and the rhombohedron* r *are visible, (c) view perpendicular to the* c*-axis, two hexagonal dipyramids* n *and the basal pinacoid* c *are visible. 40*x*. Photos by K. Schmetzer.*

The first orientation is a view parallel to the *c*-axis. In Sri Lankan padparadschas, normally no prism crystal faces are developed or visible (*see overleaf*) and, thus, there are no sharp growth lines in this direction. In a view with an inclination approximately 30 to the *c*-axis (*Figure 7a, b*), normally a growth pattern consisting of two *n* faces or of two *n* faces in combination with *r* is present. In a view perpendicular to the *c*-axis, there is either a pattern consisting of the basal pinacoid *c* in combination with one or several hexagonal dipyramids *z*, *w* or *n*, where *n* is normally dominant (*Figure 7c*). After rotation of the crystal through 30 about the *c*-axis, a pattern consisting of basal *c* and rhombohedral *r* faces (*Figure 8*) should be visible. This growth pattern should completely reflect the external morphology of a rough crystal.

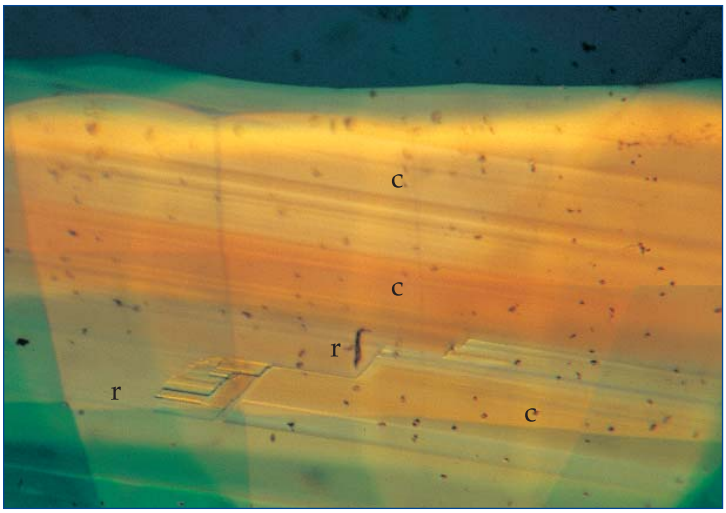

Figure 8: *Growth pattern and colour zoning in a heat-treated padparadscha from Sri Lanka; view perpendicular to the* c*-axis, the rhombohedron* r *and the basal pinacoid* c *are visible. 50*x*. Photo by K. Schmetzer.*

There are additional microscopic growth features in some crystals from Sri Lanka which are not completely understood at present. One feature is characterised by a fine structure which can be described as a mosaic-like pattern of oscillating growth lines on an extremely small scale (*Figures 9, 10*). These growth lines are parallel to different hexagonal dipyramids, mostly *n*, to the basal pinacoid and to the prism *a* $\{11\bar{2}0\}$, which is not developed macroscopically.

Because Sri Lankan sapphires are generally elongate (*see Figure 6*), faceted stones

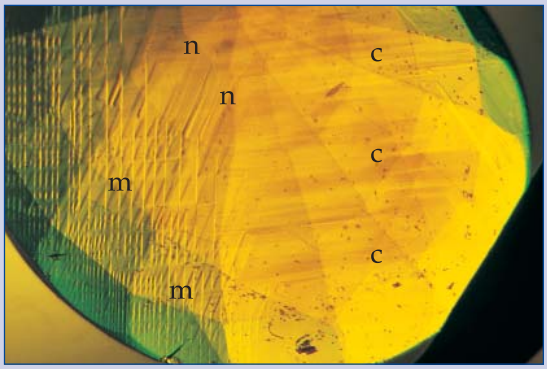

Figure 9: *Growth pattern and colour zoning in a heat-treated yellowish-orange chromium-free sapphire from Sri Lanka; view perpendicular to the* c*-axis, the hexagonal dipyramid* n *and the basal pinacoid* c *are visible, a large area showing a mosaic-like growth pattern* m *is also present. 50x. Photo by K. Schmetzer.*

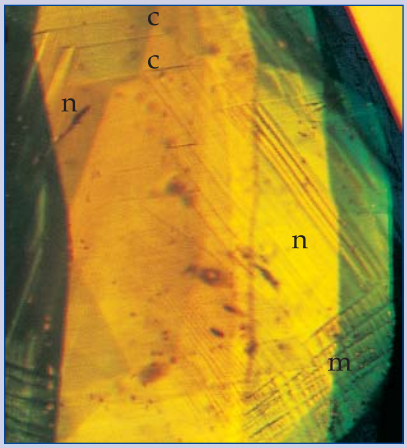

Figure 10: *Growth pattern and colour zoning in an untreated padparadscha from Sri Lanka; view perpendicular to the* c*-axis, two hexagonal dipyramids* n *and the basal pinacoid* c *are seen, an area showing a mosaic-like growth pattern* m *is also present. 50x. Photo by K. Schmetzer.*

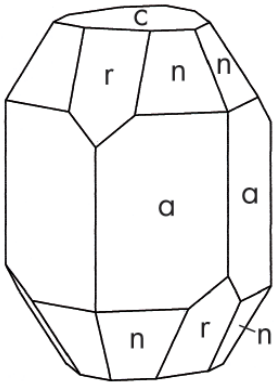

Figure 11a

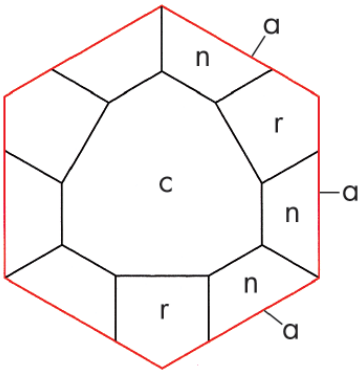

Figure 11b

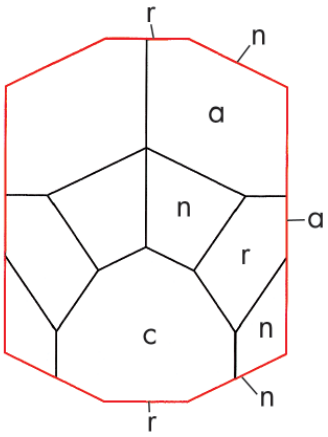

Figure 11c

Figure 11: *Typical habit of sapphire from Montana consisting of the basal pinacoid* c*, the hexagonal prism* a*, the hexagonal dipyramid* n *and the positive rhombohedron* r*; (a) clinographic projection, (b) view parallel to the* c*-axis, (c) view at an angle inclined about 30° to the* c*-axis, (d) view perpendicular to the* c*-axis, (e) view perpendicular to the* c*-axis;* Figures d *and* e *are related by a rotation of 30° about the* c*-axis. The traces of crystal faces which are parallel to the direction of view and, thus, can be seen in the microscope are indicated in red in* Figures b, c, d *and* e.

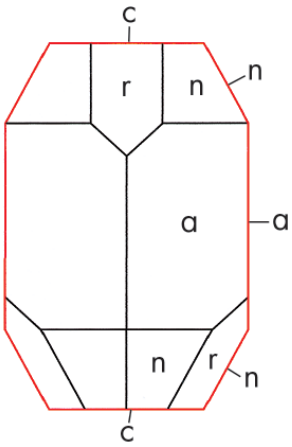

Figure 11d

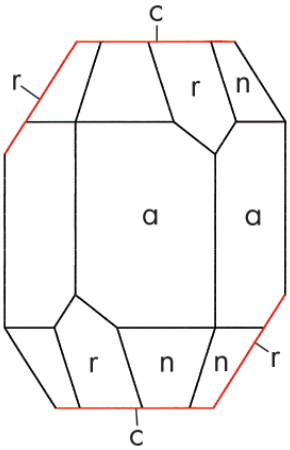

Figure 11e

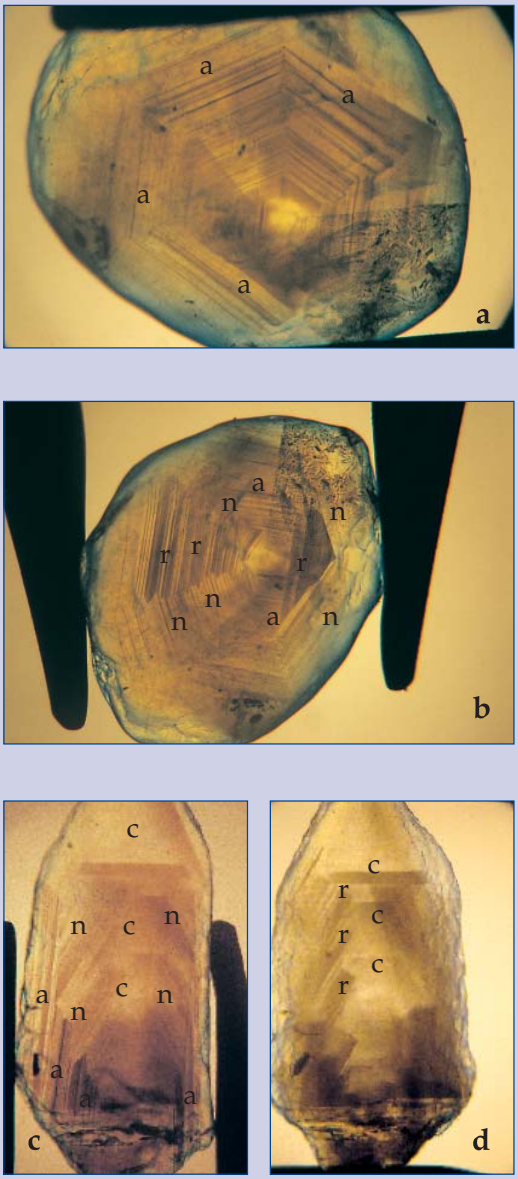

Figure 12: *Growth pattern and colour zoning in an untreated greenish-blue sapphire from Montana; (a) view parallel to the* c*-axis, six hexagonal prism faces* a *are visible, (b) view inclined at about 30° to the* c*-axis, two hexagonal prism faces* a*, four hexagonal dipyramids* n *and two rhombohedra* r *are visible, (c) view perpendicular to the* c*-axis, the basal pinacoid* c*, two hexagonal prism faces* a *and four hexagonal dipyramids* n *are visible, (d) view perpendicular to the* c*-axis, the basal pinacoid* c *and the positive rhombohedron* r *are visible;* Figures c *and* d *are related by a rotation of 30° about the* c*-axis. 40x. Photos by K. Schmetzer.*

rarely show a complete growth pattern, i.e. one which indicates both ends of the crystal. In general, a faceted gemstone contains only the faces related to one end of a crystal, e.g. one basal pinacoid and one series of hexagonal dipyramids.

Montana

The growth patterns in Montana sapphires mainly from the Rock Creek and the Missouri river deposits (*Figure 11*), are quite different from those seen in Sri Lankan material. The dominant forms present are the basal pinacoid *c* {0001}, the hexagonal prism *a* $\{11\bar{2}0\}$, the positive rhombohedron *r* $\{10\bar{1}1\}$ and the hexagonal dipyramid *n* $\{22\bar{4}3\}$. Due to large variation in the size of the hexagonal prism compared to the basal pinacoid *c*, there is a large habit range from tabular to more or less equidimensional to prismatic, of which the prismatic crystals are more common.

To determine the complete external morphology of a crystal, the three typical orientations as described above for Sri Lankan crystals should be examined. In a view parallel to the *c*-axis, Montana sapphires show growth lines parallel to the hexagonal prism *a* (*Figure 12a*). In a view with an inclination approximately 30 to the *c*-axis, in samples with prismatic habit, there is a growth pattern consisting of two *a* prism faces in combination with two hexagonal dipyramids *n* and one rhombohedral *r* face. In samples with more equidimensional habit, both ends of a crystal may be represented. This complex growth pattern (*Figure 12b*) consists of two prism faces *a* in combination with four hexagonal dipyramids *n* and two rhombohedral *r* faces. In a view perpendicular to the *c*-axis, there is a pattern consisting of the basal pinacoid in combination with the prism *a* and the hexagonal dipyramid *n* (*Figure 12c*). After rotation of the crystal through 30 about the *c*-axis, a pattern consisting of basal *c* and rhombohedral *r* faces (*Figure 12d*) should be visible.

Another characteristic of many Montana sapphires is that growth planes are outlined by different concentrations of small particles resembling mineral dust.

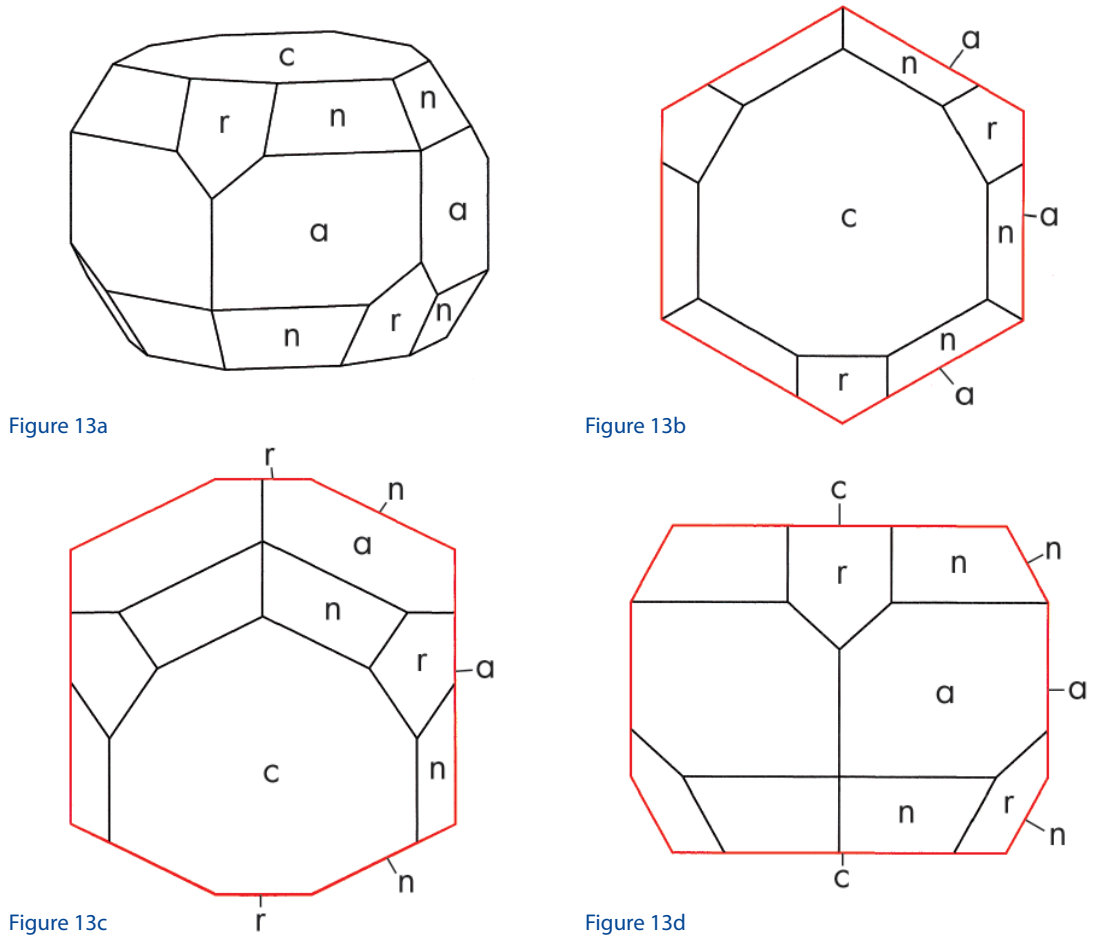

Figure 13: *Typical habit of ruby from Songea consisting of the basal pinacoid* c, *the hexagonal prism* a, *the hexagonal dipyramid* n *and the positive rhombohedron* r; *(a) clinographic projection, (b) view parallel to the* c*-axis, (c) view at an angle inclined at about 30° to the* c*-axis, (d) view perpendicular to the* c*-axis. The traces of crystal faces which are parallel to the direction of view and, thus, can be seen in the microscope are indicated in red in* Figures b, c *and* d.

Ilakaka

In some samples, inclusions are concentrated along specific growth planes of the basal pinacoid *c* and the hexagonal prism *a*, and under the microscope, this feature is seen as parallel lines of tiny inclusions tracing these faces. But most Ilakaka sapphires are free of visible growth planes.

Songea

The growth patterns in Songea sapphires and rubies (*Figure 13*) are closely similar to those seen in Montana material. Our samples would be described as having short prismatic, almost equidimensional habits. The dominant faces are the basal pinacoid *c* {0001} and the hexagonal prism *a* $\{11\bar{2}0\}$. Also present are faces parallel to the hexagonal dipyramid *n* $\{22\bar{4}3\}$ and the positive rhombohedron *r* $\{10\bar{1}1\}$.

The patterns visible under the microscope in different orientations (*Figure 14*) are almost identical to those of Montana sapphires. So in a view of a short prismatic crystal perpendicular to the *c*-axis, the patterns of both crystal ends are generally visible. At an inclination of about 30 to *c*, two prism *a* faces with two *n* and one *r* face related to the upper half of the crystal in combination with two *n* and one *r* face related to the lower half of the crystal are visible.

It is worth mentioning that for most Montana sapphires with prismatic habit, in the view at 30 to the *c*-axis only one half of the growth line orientations are visible, while in Songea sapphires and rubies, the faces related to the terminations at both ends of the crystals are generally present.

Colour zoning and inclusions

General remarks

Colour zoning may be very complex, but is extremely helpful for diagnosing untreated, heat-treated or Be-diffusion-treated sapphires. Colour zoning may occur between different growth sectors of a crystal, e.g. between dipyramidal *n* and rhombohedral *r* sectors, and along parallel growth planes within the same growth sector. *Figure 15* shows colour zoning in a heat-treated padparadscha from Sri Lanka with different orientations of the sample (the same sapphire is pictured at high magnification in *Figure 7*). In general, a combination of both techniques is recommended in order to obtain the full information from a sample. Occasionally, the use of a blue light filter is also helpful to recognise extremely weak colour variation in different growth zones, e.g. in untreated Sri Lankan material.

All types of colour zoning are a function of different trace-element distribution in different areas of a crystal. This zoning of colour-causing trace-elements is present before heat or diffusion treatment, and different reactions and changes may be caused according to the treatment applied. Colour zoning in different growth sectors or in different areas of the same growth sector may gradually increase or decrease without sharp growth boundaries.

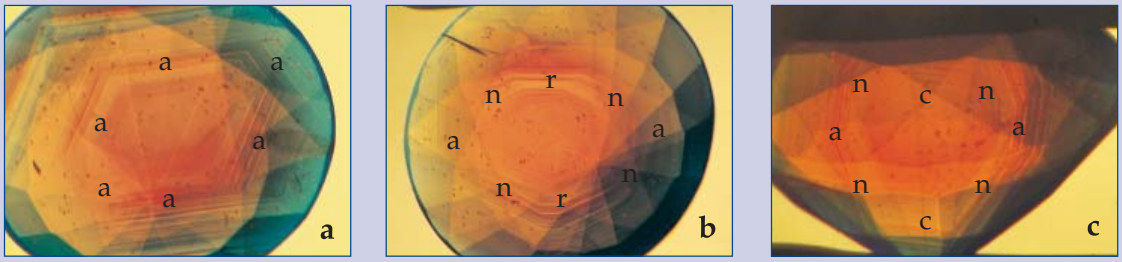

Figure 14: *Growth pattern and colour zoning in a diffusion-treated reddish-orange sapphire from Songea; (a) view parallel to the* c*-axis, six hexagonal prism faces* a *are visible, (b) view inclined at about 30° to the* c*-axis, two hexagonal prism faces* a*, four hexagonal dipyramids* n *and two rhombohedra* r *are visible, (c) view perpendicular to the* c*-axis, the basal pinacoid* c*, two hexagonal prism faces* a *and four hexagonal dipyramids* n *are visible. 50*x*. Photos by K. Schmetzer.*

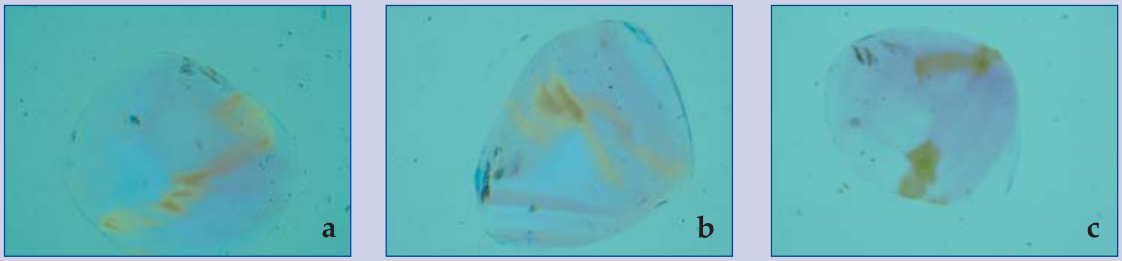

Figure 15: *Colour zoning associated with growth zoning in a heat-treated padparadscha from Sri Lanka of 3.20 ct in different orientations, but without exactly orientating the sapphire according to specific growth structures present. Size of the sample 7.1* x *7.9 mm. Photos by K. Schmetzer (see the same sapphire at high magnification in* Figure 7*).*

Growth zoning, on the other hand, may have sharp boundaries and differently coloured sectors will also be sharply divided.

Some types of colour zoning in corundum are not changed by heat or diffusion treatment, e.g. that caused by chromium. Other types of colour zoning may be superimposed on an already existing colour pattern by heat or diffusion treatment.

When orange colour centres are developed by heat treatment it is generally in particular growth sectors, e.g. in rhombohedral growth sectors of Sri Lankan sapphires. By diffusion treatment, an orange rim may be developed in suitable raw material, in the right temperature and treatment conditions. In the present study, about half of the diffusion-treated samples from Ilakaka had an orange rim in contrast to its presence in only a few sapphires from Songea. This may be explained as follows: there is a general lack of colour zoning in untreated sapphires from Madagascar, and so the newly developed rim contrasts clearly with the homogeneous body colour. On the other hand, an intense rim and an almost colourless core is common in natural rubies and sapphires from Songea, and any superimposed colour developed by diffusion treatment, following, at least partly, the outline of the rim, would be less clearly apparent.

Heat-treated Ilakaka sapphires were pink or slightly purplish-pink, and heat-treated Songea sapphires were colourless to red or pink (colour-zoned) or purplish-red (see *Table I*). In most sapphires from these localities, no orange colour centres are developed by simple heat treatment and, consequently, the colour of heat-treated samples is not in the reddish-orange to yellow colour range. Therefore, heat-treated Ilakaka and Songea sapphires are not described in detail in this paper, although one stone, a heat-treated slightly brownish-orange Ilakaka sapphire with orange colour centres, is described below in *Box B* as an example of an unusual stone.

Most heat-treated orange and yellowish-orange sapphires examined in this study, contain the decomposition products of zircon and other mineral inclusions such as apatite in Ilakaka stones or various silicates in Songea sapphires. Some also contain two-phase inclusions of what appears to be glass with a bubble. However, much less common were completely molten inclusions with melt that escaped into discoid fractures (see *Figures K10 – K12*), features to be described later for diffusion-treated sapphires.

Consequently, the average maximum temperature for heat-treated samples seen at present in the trade may have been lower (possibly in the range of 50 to 100 C) than the temperatures applied in most Be-diffusion treatment. It should be born in mind that the heat-treated sapphires seen in the trade are sometimes kept in company stock for years and that, for this study, heat-treated yellow, yellowish-orange and orange Sri Lankan material less than two years old was not used in order to avoid mixing simply heat-treated and diffusion-treated samples.

Thus, the visual appearance of inclusions in a sapphire is not a sufficient indicator for diffusion treatment and should only be used with colour zoning, chemical and spectroscopic properties to determine whether Be-diffusion treatment has been performed.

Sri Lanka

Untreated

Untreated padparadscha and padparadscha-like sapphires (*Figure 16*) in general show various types of colour zoning. In immersion liquid, at low magnification without a special orientation of the samples, colour zoning may be observed within different growth sectors or within different areas of the same growth sector

Figure 16: *Untreated padparadschas from Sri Lanka, range of samples from 1.80 to 3.12 ct. Photo by M. Glas.*

(*Figures A1 – A3*). The different colours may be a lighter and a more intense orange, yellow and orange, pink and orange, yellow, pink and orange, or even bluish-violet or purple and orange in different combinations. Using immersion and with exact orientation of the samples (*Figures A4 – A7*), one can conclude that the colour zoning is confined to growth planes. Mosaic-like growth structures may also be related to colour zoning (*Figure 10, A8, A9*).

The inclusions in untreated Sri Lankan padparadschas in this study are broadly similar to those in most Sri Lankan sapphires (*Figures A10 – A12*). These include zircon crystals, occasionally with tension cracks, negative crystals, tiny rutile needles, other unidentified mineral inclusions, and cavities filled with fluid and multiphase inclusions (see Koivula, 1986), some with diaspore needles (see Schmetzer and Medenbach, 1988). Multiphase inclusions may also contain graphite and rutile, gaseous and liquid CO_2 and diaspore needles (Notari, 1996; see also De Maesschalck and Oen, 1989; Francis *et al.*, 2003). These multiphase inclusions are commonly tabular negative crystals oriented parallel to the basal pinacoid of the corundum crystal. Further mineral inclusions determined by the Raman microprobe in padparadscha from Sri Lanka are apatite and mica (Notari, 1996).

Heat-treated

In chromium-free orangey-yellow or yellowish-orange heat-treated material from Sri Lanka (*Figure 18*) and in chromium-bearing reddish-orange or brownish orange samples (*Figure 17*), a strong colour zoning associated with growth-zoning is normally present (*Figures 7 – 9, 15, B1 – B3, C1 – C3*). Chromium-bearing samples may contain a distinct chromium zoning confined to specific growth sectors. Orange colour centres are normally developed to different concentrations in different growth sectors of a crystal, and are generally more abundant in *r* sectors. Thus, it is evident that the orange colour is, in general, only caused by the coloration of specific growth sectors, and complex structures may be observed when both types of colour zoning are present. In general, colour zoning in heat-treated samples, e.g. between orange brown *r* and adjacent pink *n* growth sectors, is much stronger than in untreated padparadschas. In chromium-free samples (*Figures C4 – C6*), colour zoning consisting of very light yellow (almost colourless) and very intense orange or brownish-orange areas is common. In chromium-bearing samples (*Figures B4 – B9*), the colour zoning may be pink and light orange or pink and intense orange or orange brown. This colour zoning is commonly also associated with sharp growth boundaries. Due to the heat treatment, no blue or purplish-blue sectors are present in this type of padparadscha. Mosaic-like growth structures connected with colour zoning are common in both types of heat-treated sapphire (*Figures C7 – C9*).

Heat-treated sapphires in the range yellow to reddish-orange (i.e. without and with

Figure 17: *Heat-treated, chromium-bearing padparadschas from Sri Lanka, range of samples from 0.94 to 1.45 ct. Photo by M. Glas.*

Figure 18: *Heat-treated, chromium-free yellow and yellowish-orange sapphires from Sri Lanka, range of samples from 1.31 to 2.17 ct. Photo by M. Glas.*

Figures A1 to A12: *Colour and inclusion features of untreated chromium-bearing padparadschas from Sri Lanka*

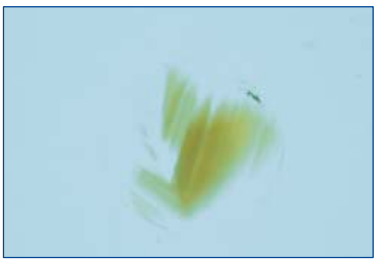

Figure A1: *I, 2.9* x *3.0 mm*

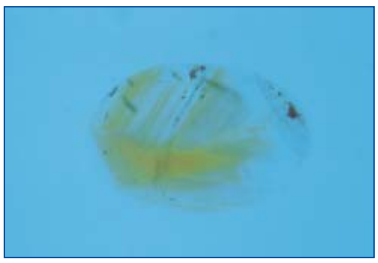

Figure A2: *I, 3.1* x *4.6 mm*

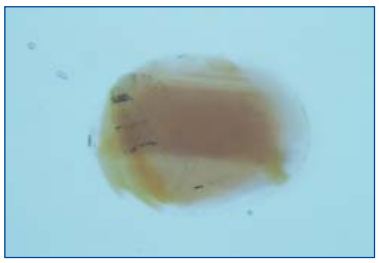

Figure A3: *I, 3.7* x *4.9 mm*

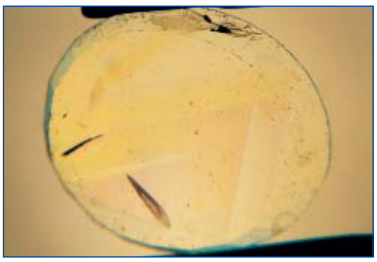

Figure A4: *I, 6.8* x *7.9 mm*

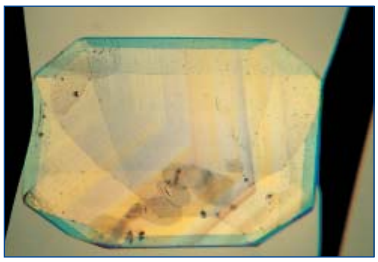

Figure A5: *I, 8.0* x *11.0 mm*

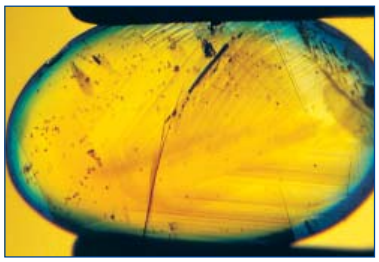

Figure A6: *I, 3.1* x *4.6 mm*

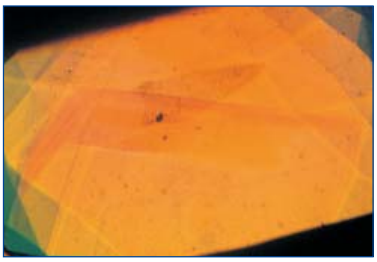

Figure A7: *I, 50* x

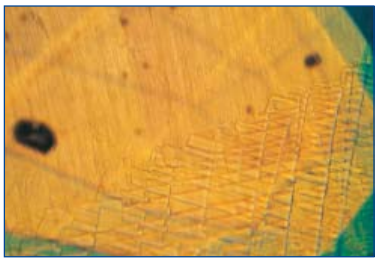

Figure A8: *I, 50* x

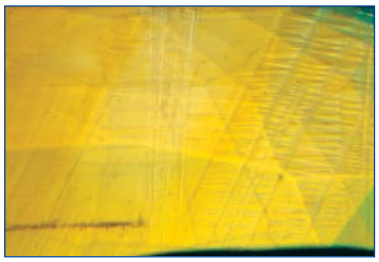

Figure A9: *I, 50* x

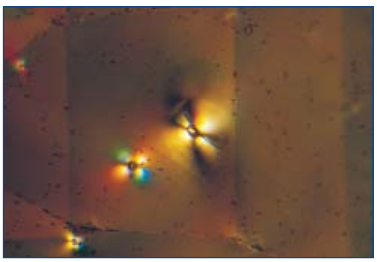

Figure A10: *I, # pol 80* x

Figure A11: *100* x

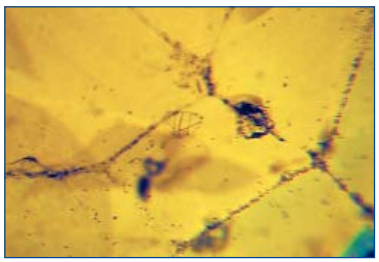

Figure A12: *I, 70* x

At low magnification in un-oriented samples, colour zoning may be observed within different growth sectors or within different areas of the same growth sector (A1 – A3). With exact orientation (A4 – A9) the colour zoning can be correlated with growth planes of the sapphire crystal.

Inclusions typical of Sri Lankan sapphires are zircon crystals, occasionally with tension cracks (A10), negative crystals, tiny rutile needles, and cavities filled with fluid and multiphase inclusions (A11, A12). The multiphase inclusions are commonly in the form of tabular negative crystals with an orientation parallel to the basal pinacoid.

A1 – 3: Growth and colour zoning at low magnification. A4 – 7: Growth and colour zoning of oriented stones. A8 – 9: Mosaic-like growth structure and colour zoning. A10: Zircons with tension cracks. A11: Two-phase inclusion (diaspore and liquid). A12: Three-phase inclusion (diaspore, liquid and gas bubble). Pictures 1-10 and 12 by K Schmetzer, 11 by L. Kiefert.

nb: I = immersion, # pol. = crossed polarisers

Cr) commonly contain thermally altered inclusions, especially mineral inclusions with stress fractures (*Figures B10 – B12, C10 – C12*). In some samples, these stress fractures or stress haloes are oriented parallel to the basal pinacoid. Some samples also contain decomposed mineral inclusions similar in appearance to the various forms of altered inclusions found in Be-diffusion-treated sapphires from Ilakaka and Songea. In particular, former diaspore needles, now decomposed, are common in negative crystals in a matrix of what appears now to be glass or polycrystalline material with a bubble. Inclusions of completely molten material, with part of the melt flowing into fractures and fissures (similar to the typical inclusion features of Be-diffusion-treated sapphires) are present but not common.

Beryllium-diffusion-treated

Except for the two stones described below, the Be-diffusion-treated Sri Lankan sapphires (*Figure 19*) show no distinct colour zoning. In a light box in immersion liquid, the stones are an almost homogeneous yellow to yellowish-orange. The alternating very light (almost colourless) and very intense colour bands normally seen in heat-treated material (see *Figures C1 – C3*) are absent.

Figure 19: *Beryllium-diffusion-treated, chromium-free yellow and yellowish-orange sapphires from Sri Lanka, range of samples from 1.17 to 2.15 ct. Photo by M. Glas.*

With exact orientation of diffusion-treated samples under an immersion microscope, the characteristic growth patterns of Sri Lankan material including the mosaic-like growth structures are commonly visible (*Figures D1 – D3*). In 41 of 42 samples no distinct colour zoning related to growth structures was visible. In some samples the homogeneous yellow gives way to an extremely weak zoning of alternating light and slightly more intense yellow areas. This extremely weak colour zoning is quite distinct from the strongly contrasting light yellow, almost colourless areas alternating with intense yellow, or yellowish-brown or yellowish-orange areas of heat-treated samples (see *Figures C4 – C9*).

One diffusion-treated yellow Sri Lankan sapphire showed a pattern of transparent yellow alternating with translucent zones which contained a high concentration of undissolved fine particles (*Figure D4*); such particles are common in untreated Sri Lankan geuda materials.

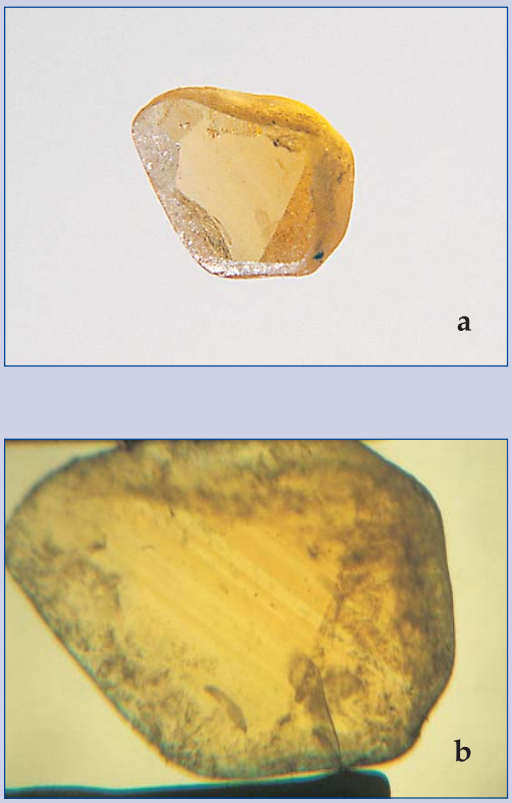

Figure 20: *Colour-zoned beryllium-diffusion-treated Sri Lankan geuda sapphire in ordinary light (a) and in the immersion microscope with a view along rhombohedral growth planes (b). Size of the sample 4.5 x 5.2 mm. Photos by K. Schmetzer*

Figures B1 to B12: *Colour and inclusion features of heat-treated chromium-bearing padparadschas from Sri Lanka*

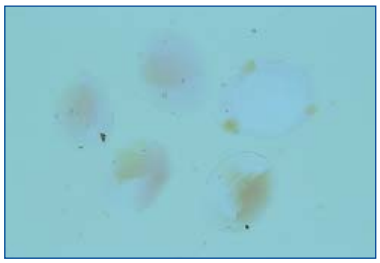

Figure B1: *I, 0.83 to 2.23 ct*

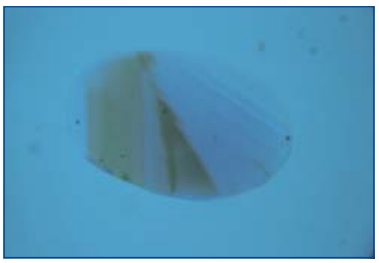

Figure B2: *I, 5.1* x *6.8 mm*

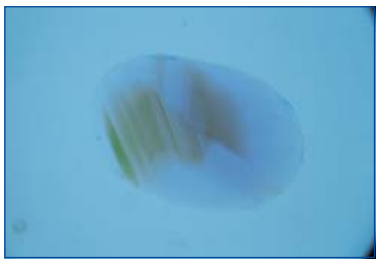

Figure B3: *I, 5.1* x *6.8 mm*

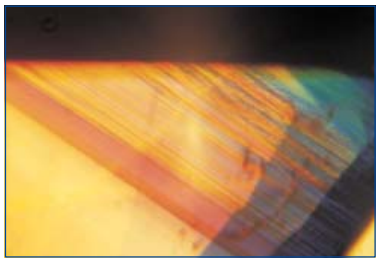

Figure B4: *I, 60* x

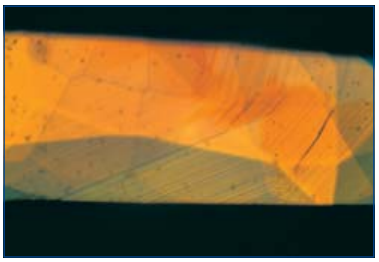

Figure B5: *I, 50* x

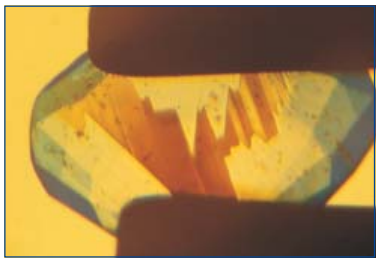

Figure B6: *I, 50* x

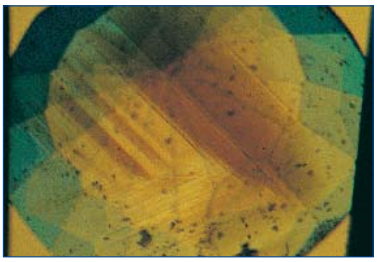

Figure B7: *I, 60* x

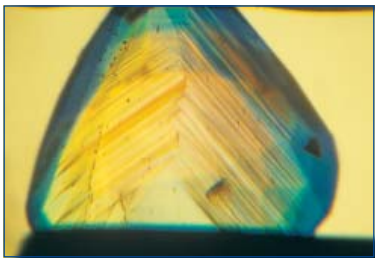

Figure B8: *I, 50* x

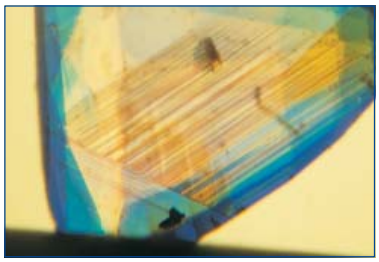

Figure B9: *I, 50* x

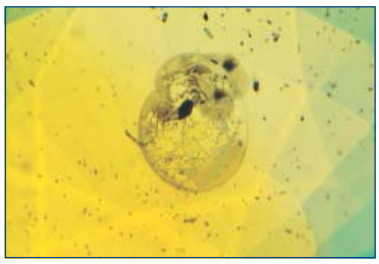

Figure B10: *I, 60* x

Figure B11: *50* x

Figure B12: *100* x

In heat-treated sapphires from Sri Lanka, a strong colour zoning associated with growth zoning is normally present (B1 – B3). In addition to colour zoning due to varying chromium content (B4, B5), orange colour centres can be developed to different degrees within different growth sectors of a crystal, especially in r *sectors (B6 – B9).*

Heat-treated padparadscha sapphires commonly contain thermally altered mineral inclusions, with stress fractures (B10) and decomposed mineral inclusions (B11, B12).

B1 – 3: Growth and colour zoning at low magnification. B4 – 9: Growth and colour zoning of oriented samples. B10 – 12: Thermally altered inclusions. Pictures 1 by M. Glas, 2 – 10 by K. Schmetzer, 11-12 by L. Kiefert.

nb: I = immersion

Two sapphires with unusual properties deserve separate description:

- The first stone (*Figure 20a*) was diffusion-treated by J. Emmett and shows a weak colour zoning after proper orientation in the immersion microscope (*Figure 20b*). The coloration of the sapphire consists of somewhat lighter and more intense yellowish-orange zones parallel to rhombohedral growth planes. This sapphire is the only one of our samples with optical properties intermediate between heat-treated and diffusion-treated samples. Trace-element distribution in this sample was obtained using LA-ICP-MS. A scan perpendicular to the colour zoning across a polished surface of the sapphire consisting of six analysis points revealed only small variation in the iron and titanium concentrations, but distinct variation of both magnesium and chromium. Thus, the differently coloured growth zones contain variable concentrations of these two colour-related trace-elements. A more detailed interpretation is beyond the scope of the present paper.

Figure 21a: *Colour-zoned beryllium-diffusion-treated yellow sapphire of 0.97 ct (right) compared to an ordinary diffusion-treated Sri Lanka sample of 1.16 ct with homogeneous colour distribution (left). Photo by M. Glas.*

- The second colour-zoned yellow sapphire (*Figure 21a*) was found in a mixed lot of diffusion-treated samples originating – according to their properties – either from Songea or from Ilakaka. The exact treatment history of this lot treated in Thailand is unknown. This particular sapphire has a growth pattern associated with colour zoning and shows colour concentrations in rhombohedral *r* growth sectors (*Figure 21b, c*), features typical of heat-treated Sri Lankan material. Trace element contents by LA-ICP-MS were obtained at two analysis points on the table of the faceted stone. These showed distinct variation of the magnesium concentration, but almost constant values for titanium, chromium, and iron. Although the most intense yellow sectors of the sample were not exposed on the table of the stone and, thus, were not analysed, we may conclude that the colour zoning of the sample is related to distinct magnesium zoning in different growth sectors.

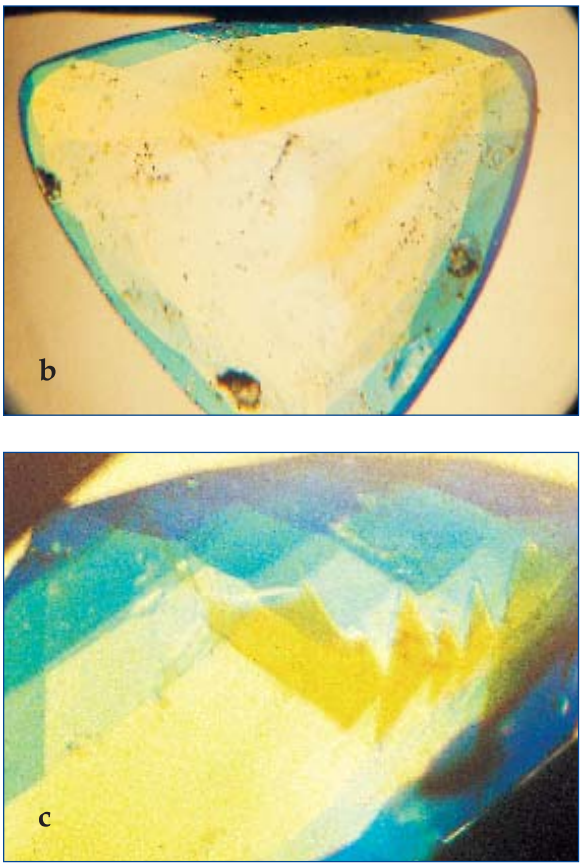

Figure 21b, c: *Colour zoning in beryllium-diffusion-treated yellow sapphire (right sample in* Figure 21a*); the coloration of the sample is almost exclusively related to very intense yellow rhombohedral growth zones. (b) 40x, (c) 60x. Photos by K. Schmetzer.*

The diffusion-treated yellow and yellowish-orange sapphires from Sri Lanka were, in general, extremely clean samples and showed only a few inclusions. Most of these were of decomposed minerals, some with stress fractures (*Figure D5*). Others were of two-phase inclusions consisting of glass or polycrystalline material with a bubble

Figures C1 to C12: *Colour and inclusion features of heat-treated chromium-free yellow amd yellowish-orange sapphires from Sri Lanka*

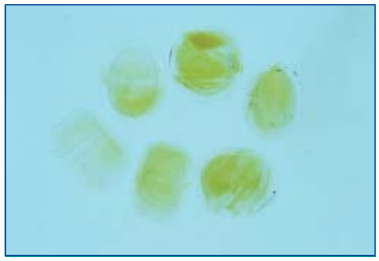

Figure C1: *I, 0.74 to 0.95 ct*

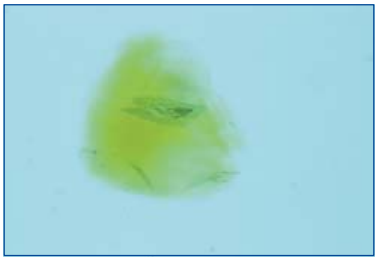

Figure C2: *I, 5.5* x *6.0 mm*

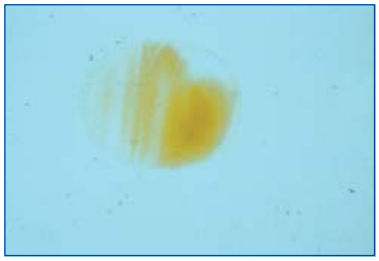

Figure C3: *I, 4.9* x *6.1 mm*

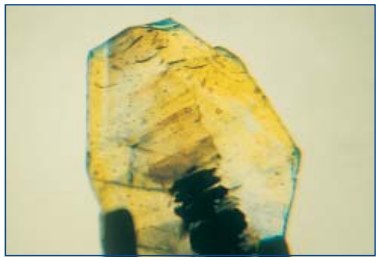

Figure C4: *I, 30* x

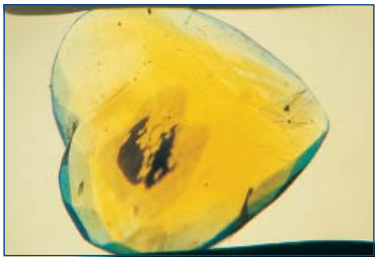

Figure C5: *I, 40* x

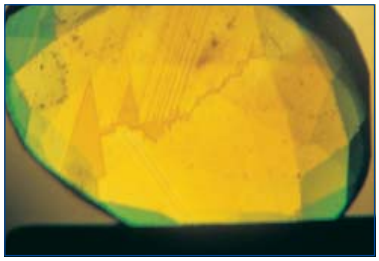

Figure C6: *I, 40* x

Figure C7: *I, 50* x

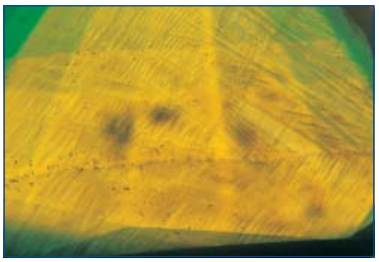

Figure C8: *I, 50* x

Figure C9: *I, 50* x

Figure C10: *I, 50* x

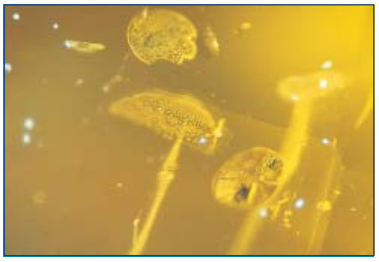

Figure C11: *50* x

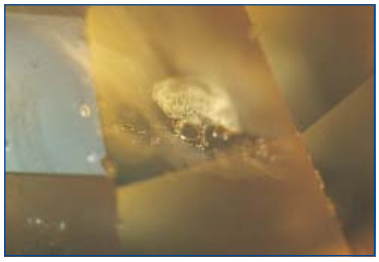

Figure C12: *50* x

In heat-treated chromium-free sapphires from Sri Lanka, a strong colour zoning is associated with growth zoning (C1 – C3). Colour centres are normally developed to different degrees within different growth sectors of a crystal, especially in r *sectors (C4 – C6). In general, colour zoning in heat-treated samples, e.g. between orange brown* r *and adjacent pink* n *growth sectors, is much stronger than in untreated yellow sapphires.*

Many heat-treated yellow and yellowish-orange, chromium-free sapphires contain thermally altered inclusions (C10 – C12), especially mineral inclusions with stress fractures, some oriented parallel to the basal pinacoid.

C1 – 3: Growth and colour zoning at low magnification. C4 – 6: Growth and colour zoning of oriented sapphires. C7 – 9: Mosaic-like growth structure and colour zoning. C10 – 12: Thermally altered inclusions. Pictures 1 by M. Glas, 2 – 9 by K. Schmetzer, 10 – 12 by L. Kiefert.

nb: I = immersion

(*Figure D6*). No characteristic inclusion feature that would easily allow a distinction between simply heat-treated and diffusion-treated Sri Lankan sapphires was found.

Montana

Untreated

Colour zoning in untreated yellowish-green, bluish-green or blue Montana sapphires (*Figure 22*) is extremely weak if present at all. Concentrations of small particles along internal growth faces is the commonest feature (*Figures 12, E1*).

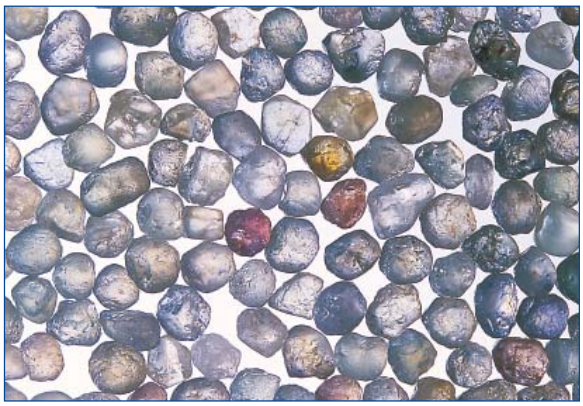

Figure 22: *Untreated yellowish-green to bluish-green or blue, with a few pink sapphires from Rock Creek, Montana; samples are about 4 to 6 mm across. Photo by M. Glas.*

The Rock Creek and Missouri river sapphires show only minor differences in their inclusion populations. Some samples contain isolated or intersecting twin lamellae with boehmite particles along the twin boundary. Small particles ('mineral dust') are common in various concentrations emphasising the growth patterns (*Figure E1*). Rutile crystals and other mineral inclusions are also present (*Figures E2, E3*). The most characteristic inclusion feature of the Montana sapphires that we examined were mineral inclusions surrounded by fluid discs oriented in planes parallel to the basal pinacoid.

Heat-treated

In contrast to untreated stones, heat-treated orange to reddish- or brownish-orange sapphires (*Figure 23*), show extreme and characteristic colour zoning. The colour of most samples consists of a more or less uniform light pink or brownish-pink on which is superimposed a strong orange developed only in specific growth sectors (*Figures F1, F2*). In most samples, the strong orange zoning is related to growth zones of the basal pinacoid, and the zones are terminated by basal *c* and rhombohedral *r* faces (*Figures F3 – F5*). This specific colour zoning is characteristic of heat-treated orange and pinkish-, reddish- or brownish-orange Montana sapphires, and was not found in untreated or heat-treated padparadschas from Sri Lanka nor in sapphires from Ilakaka and Songea. Less common in heat-treated Montana sapphires was colour zoning parallel to the hexagonal dipyramid *n* and/or parallel to the rhombohedron *r*.

Figure 23: *Heat-treated chromium-bearing Montana sapphires, range of samples from 0.41 to 0.85 ct. Photo by M. Glas.*

In a few heat-treated samples, the small particles outlining the growth planes survived the treatment. The most characteristic features are altered – decomposed or molten – mineral inclusions, which commonly form glass-like, somewhat rounded bodies with small bubbles (*Figures 5a, F6*). In many stones, this pattern is combined with stress fractures and haloes. The original mineral inclusions with fluid rosettes parallel to the basal plane are also decomposed and reveal discoid-like stress haloes after heat treatment.

Beryllium-diffusion-treated

The diffusion-treated Montana sapphires are yellow to orange, uniformly coloured, with no colour zoning related to growth zoning (*Figure 24*).

Figures D1 to D6: *Colour and inclusion features of beryllium-diffusion-treated chromium-free yellow amd yellowish-orange sapphires from Sri Lanka*

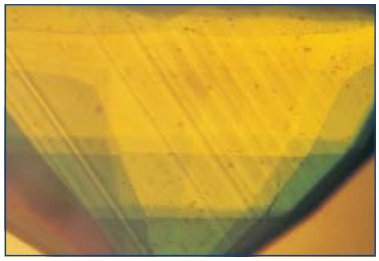

Figure D1: *I, 50* x

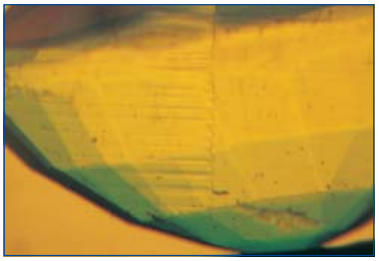

Figure D2: *I, 50* x

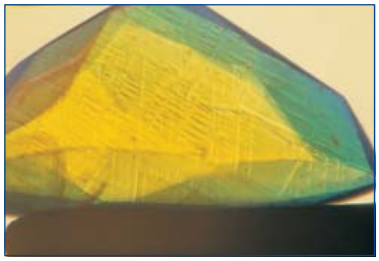

Figure D3: *I, 60* x

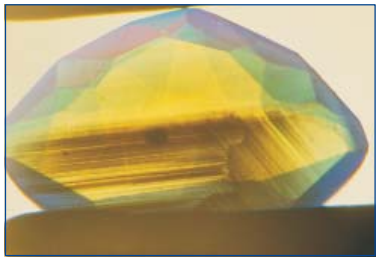

Figure D4: *I, 50* x

Figure D5: *50* x

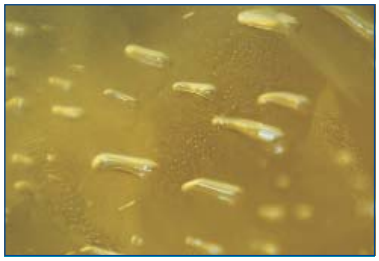

Figure D6: *100* x

Yellow diffusion-treated sapphires from Sri Lanka show no distinct colour zoning. In most orientations a sapphire will appear almost homogeneous yellow to yellowish-orange, but with an exact orientation the characteristic growth patterns of Sri Lankan sapphire, including the mosaic-like growth structures, are commonly visible (D1 – D3).

Some diffusion-treated yellow Sri Lankan sapphires contain zones of alternating transparent yellow and translucent areas (D4), the latter with undissolved fine particles. Decomposed mineral inclusions (D5), and two-phase inclusions with a bubble (D6) are present.

D1 – 2: Growth zoning in oriented samples. D3: Mosaic-like growth structure. D4: Growth zones of hexagonal dipyramids with undissolved particles. D5 – 6: Thermally altered inclusions. Pictures 1 – 4 by K. Schmetzer, 5 – 6 by L. Kiefert.

nb: I = immersion

Figures E1 to E3: *Growth and inclusion features of untreated yellowish-green to bluish-green or blue, rarely pink, sapphires from Montana*

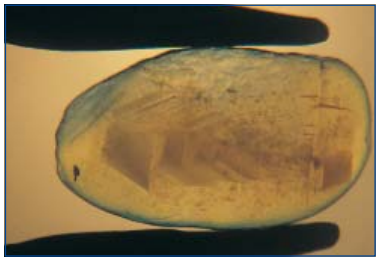

Figure E1: *I, 40* x

Figure E2: *100* x

Figure E3: *50* x

E1: Growth zoning of oriented sample, the c*-axis runs horizontally. E2: Rutile and small unidentified particles. E3: Mineral inclusions. Pictures 1 by K. Schmetzer, 2 – 3 by L. Kiefert.*

nb: I = immersion

Figure 24: *Beryllium-diffusion-treated, chromium-free yellow and yellowish-orange sapphires from Rock Creek, Montana; samples are about 4 to 6 mm across. Photo by M. Glas.*

The most characteristic inclusion pattern (*Figures 5b, G3 – G6*) consists of thermally decomposed and at least partly molten mineral inclusions, frequently in the form of two-phase inclusions with stress haloes and altered discoid-like rosettes. This is similar to the pattern for heat-treated Montana sapphires, the only difference being that rutile inclusions have distinctive diffusion haloes (*Figures G1, G2*); these resemble those in Songea sapphires.

Ilakaka

Untreated

In untreated pink to violet or orange brown Ilakaka sapphires (*Figure 25*), colour zoning with or without a particular growth pattern has not been found. Parallel lines of inclusions concentrated along crystal faces (*Figure H1*) are present in some stones. (For heat-treated Ilakaka sapphires, see 'General remarks' and discussion of difficult stones below).

Figure 25: *Untreated sapphires from Ilakaka, Madagascar; range of samples from 0.56 to 1.38 ct. Photo by M. Glas.*

Many Ilakaka sapphires show twin lamellae parallel to the positive rhombohedron, the most common form of twinning in corundum. If there are several series of intersecting twin lamellae, boehmite particles (polycrystalline material) are present along the twin boundaries. In some gemmological texts, these inclusions are referred to as 'boehmite needles'. Most Ilakaka sapphires contain numerous tiny mineral inclusions (*Figures H2 – H5*) such as apatite, zircon, monazite and xenotime (identified using the Raman microprobe). These tiny mineral inclusions commonly form irregular clusters. There are a few other mineral inclusions which are slightly larger (*Figure H6*).

Figure 26: *Beryllium-diffusion-treated sapphires from Ilakaka, Madagascar; range of samples from 0.99 to 1.82 ct. Photo by M. Glas.*

Beryllium-diffusion-treated

In diffusion-treated material (*Figure 26*), a colour boundary between the rim and the core of the faceted sapphire is commonly seen at low magnification (*Figures 2, I1 – I3*), but is not present in every stone. Any colour caused by the diffusion treatment is superimposed on the original homogeneous colour, and the depth of any colour change varies according to the trace-elements present and to the treatment conditions. If a sapphire has significant iron and chromium contents, the rim may be orange and the core may be pink (at lower iron concentrations), but other combinations may also be observed. Since there is a lack of visible growth patterns in

Figures F1 to F6: *Colour and inclusion features of heat-treated chromium-bearing sapphires from Montana*

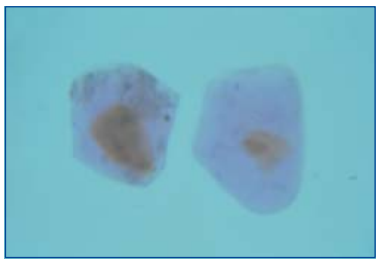

Figure F1: *I, 0.77 and 1.01 ct*

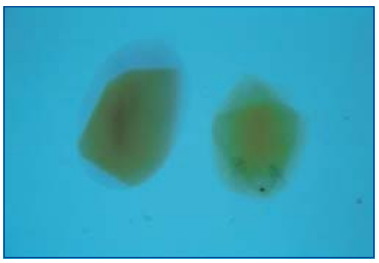

Figure F2: *I, 0.41 and 0.56 ct*

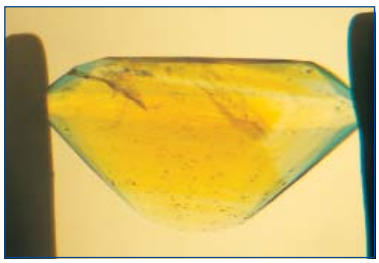

Figure F3: *I, 40* x

Figure F4: *I, 40* x

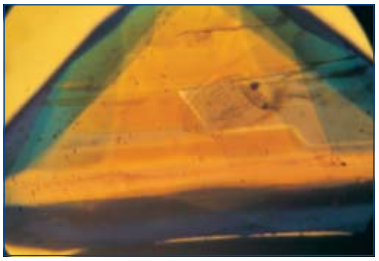

Figure F5: *I, 60* x

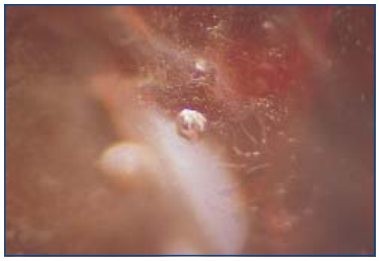

Figure F6: *I, 100* x

Strong orange is developed only in specific growth sectors of the sapphire crystals (F1, F2). The areas with strong orange coloration are terminated by basal c *and rhombohedral* r *faces (F3 – F5).*

F1 – 2: Growth and colour zoning at low magnification. F3 – 5: Growth and colour zoning of oriented samples. F6: Thermally altered inclusions. Pictures 1 – 5 by K. Schmetzer, 6 by L. Kiefert.

nb: I = immersion

Figures G1 to G6: *Colour and inclusion features of beryllium-diffusion-treated chromium-free yellow and yellowish-orange sapphires from Montana*

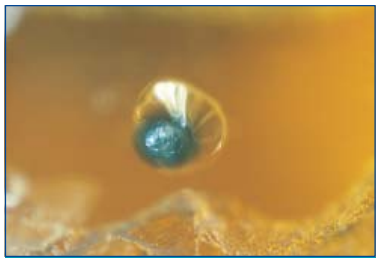

Figure G1: *50* x

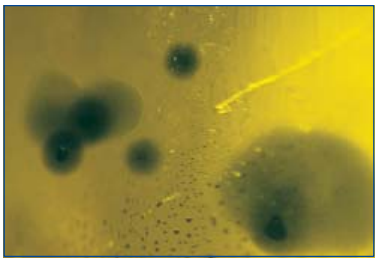

Figure G2: *50* x

Figure G3: *100* x

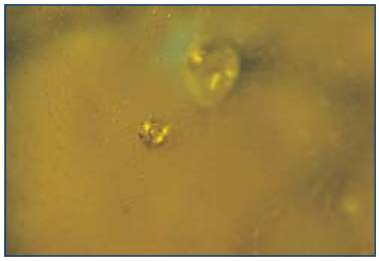

Figure G4: *100* x

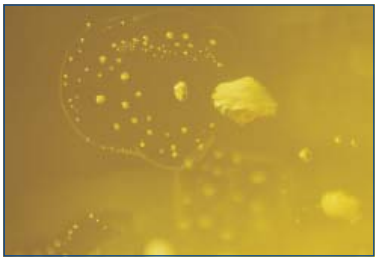

Figure G5: *100* x

Figure G6: *100* x

G1: Thermally altered rutile crystal with tension crack and diffusion halo. G2: Rutile crystals with diffusion haloes. G3-G6: Thermally altered inclusions. Pictures 1-6 by L. Kiefert.

Figures H1 to H6: *Colour and inclusion features of untreated chromium-bearing sapphires from Ilakaka.*

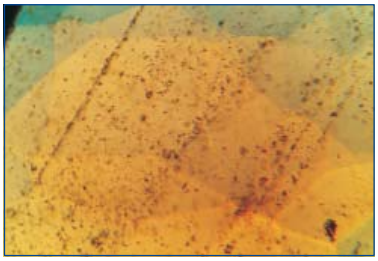

Figure H1: *I, 50* x

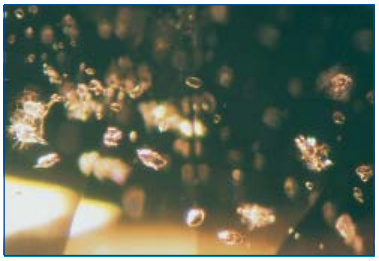

Figure H2: *70* x

Figure H3: *100* x

Figure H4: *100* x

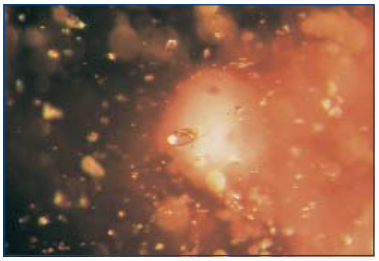

Figure H5: *100* x

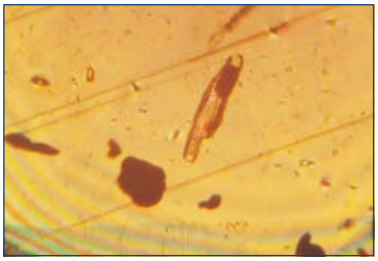

Figure H6: *I, 80* x

H1: Parallel lines of inclusions. H2: Zircon inclusions. H3: Zircon inclusions. H4: Zircon inclusions with monazite. H5: Zircon inclusions with xenotime. H6: Mineral inclusion and 'boehmite needles'. Pictures 1 and 6 by K. Schmetzer, 2 and 5 by E. Gübelin, 3 and 4 by L. Kiefert.

nb: I = immersion

untreated material, there is a corresponding absence of structural pattern or colour zoning in treated sapphires, even at high magnification.

On the surfaces of some samples and in some repolished stones, polycrystalline material formed during the diffusion process was present (*Figures I4, I5*). This material was determined by X-ray powder diffraction as corundum. In some samples fractures were filled with residual matter from the flux in which the diffusion process was performed.

Other inclusions consist of decomposed apatite and zircon crystals and/or molten and decomposed zircons (*Figures I6 – I11*). Stress fractures or haloes formed around the original crystals may be unoriented, or they may be parallel to the basal pinacoid. The altered mineral inclusions may be non-transparent, but transparent inclusions with a bubble are also present. If molten material were present, it migrated into stress fractures and haloes where it formed multiphase inclusions of glass with bubbles and/or other solid components.

Along twin planes, decomposed boehmite grains were transformed into polycrystalline corundum (*Figure I12*). New corundum was formed in an orientation different to that of the host, related to twin lamellae in some samples, but also occurring in untwinned stones.

Songea

Untreated

Untreated mostly purplish- or brownish-red Songea rubies (*Figure 27*) typically show great variation in colour zoning. Many have a colourless core and a red or purplish-red rim (*Figures 3a, J1*) and this is consistent with increasing chromium concentration from the core to the rim of a crystal (see Hänni and Pettke, 2002). This change in colour is in most crystals gradual without sharp boundaries and within particular growth sectors. In a few crystals however, sharp boundaries between different growth sectors were present, and even sharp curved boundaries resembling swirl-like colour zoning in rubies from Mogok, Myanmar, were observed.

Figures I1 to I12: *Colour and inclusion features of beryllium-diffusion-treated chromium-bearing sapphires from Ilakaka.*

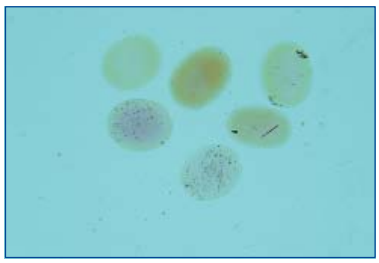

Figure I1: *I, 0.34 to 0.53 ct*

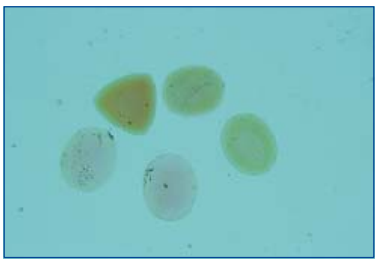

Figure I2: *I, 0.38 to 0.57 ct*

Figure I3: *I, 0.38 ct*

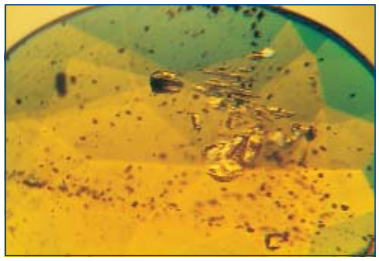

Figure I4: *I, 40* x

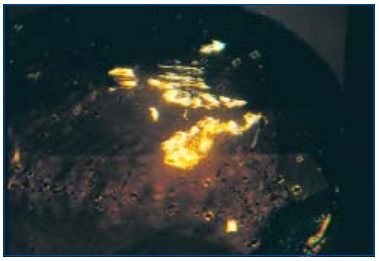

Figure I5: *I, 40* x *# pol.*

Figure I6: *100* x

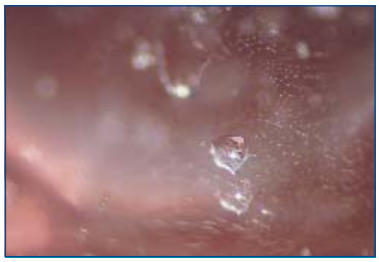

Figure I7: *100* x

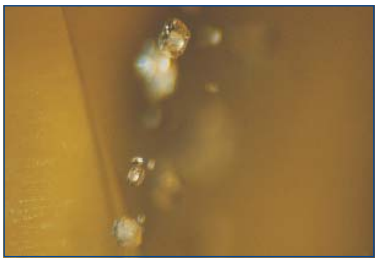

Figure I8: *100* x

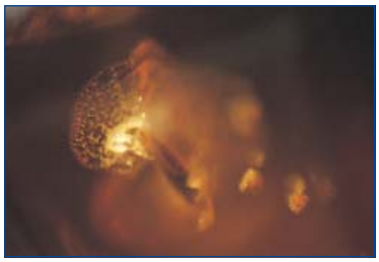

Figure I9: *100* x

Figure I10: *100* x

Figure I11: *100* x

Figure I12: *100* x

A colour boundary between the rim and the core of the faceted sapphire is commonly visible at low magnification (I1 – I3). Due to the iron and chromium contents, the rim may be orange and the core may be pink, but there can be other colour combinations. Growth patterns are absent in untreated material, and no characteristic pattern or colour zoning is visible at high magnification.

On the surface of some samples, polycrystalline corundum formed during the diffusion process remains (I4, I5). Ilakaka material commonly contains decomposed apatite and zircon crystals and/or molten and decomposed zircons (I6 – I11).

I1 – 3: Growth and colour zoning at low magnification. I4 – I5: Polycrystalline corundum on surface. I6 – I11: Thermally altered inclusions. I12: Thermally altered 'boehmite needle'. Pictures 1 – 2 by M. Glas, 3 – 5 by K. Schmetzer, 6 – 12 by L. Kiefert.

nb: I = immersion, # pol. = crossed polarisers

Figures J1 to J6: *Colour and inclusion features of untreated chromium-bearing sapphires from Songea.*

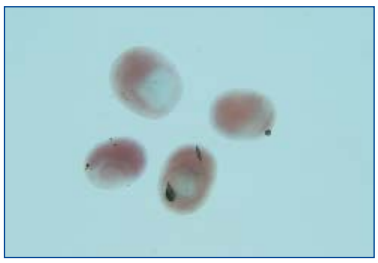

Figure J1: *I, 0.52 to 0.85 ct*

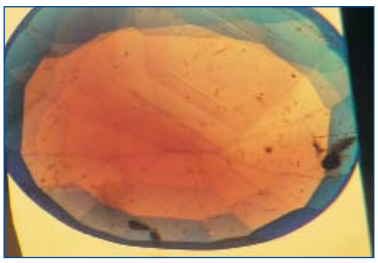

Figure J2: *40* x

Figure J3: *100* x

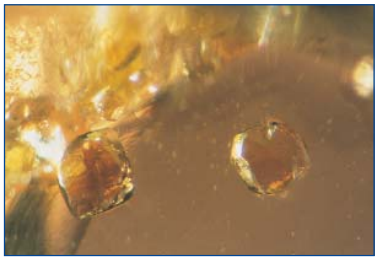

Figure J4: *65* x

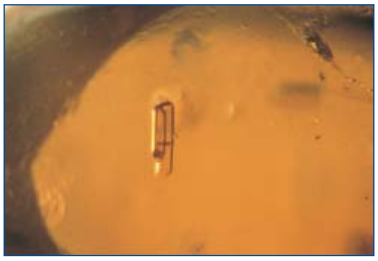

Figure J5: *65* x

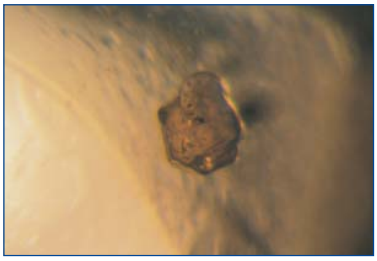

Figure J6: *100* x

Many Songea rubies contain a colourless core and a more intense red or purplish-red rim (J1).

The inclusions consist of zircon crystals, black to red rutile crystals (J3) and rutile in the form of oriented, short needles, together with apatite, phlogopite mica, olivine, garnet (J4), epidote (J5) and monazite (J6).

J1: Growth and colour zoning at low magnification. J2: Growth and colour zoning of oriented sample. J3: Rutile crystals. J4: Garnet crystals. J5: Epidote crystal. J6: Monazite crystal. Pictures 1 by M. Glas, 2 by K. Schmetzer, 3 by L. Kiefert, 4 – 6 by E. Gübelin.

nb: I = immersion

Some sapphires contained a growth pattern with basal, prism, dipyramidal and rhombohedral faces, a few without distinct colour zoning, but more with the growth pattern combined with a more or less intense variation of colour (*Figure J2*). Some crystals contain several light and more intense colour zones from the rim to core. To make the visual impression even more complex, the different types of colour and growth zoning may be observed within one Songea sample. (For heat-treated Songea material see 'General remarks'.)

Figure 27: *Untreated purplish-red rubies from Songea, Tanzania; range of samples from 0.69 to 0.95 ct. Photo by M. Glas*

Many purple or red Songea corundums contain zircon crystals, rutile, both as black to red larger crystals and as oriented short needles (*Figure J3*), and tiny, unidentified grains. Rutile was identified using Raman spectroscopy, as were the rarer inclusions of apatite, phlogopite, monazite, garnet, epidote and olivine (see *Figures J4–J6*, and Schwarz, 2001). The presence of garnet, epidote and olivine indicate an unusual geological origin for the Songea corundums. Negative crystals are rare.

Beryllium-diffusion-treated

In diffusion-treated Songea rubies and sapphires (*Figure 28*), further complexity can result if an orange rim or an orange zone of

Figures K1 to K12: *Colour and inclusion features of beryllium-diffusion-treated chromium-bearing sapphires from Songea.*

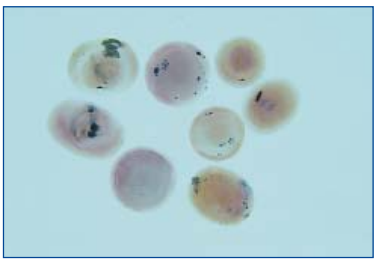

Figure K1: *I, 0.32 to 0.75 ct*

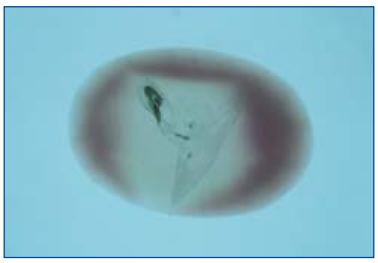

Figure K2: *I, 0.50 ct*

Figure K3: *I, 0.62 ct*

Figure K4: *I, 0.27 ct*

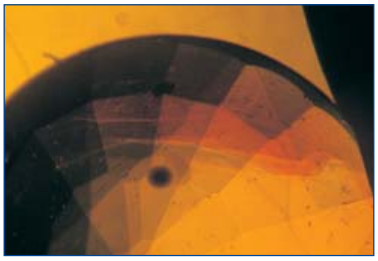

Figure K5: *I, 50* x

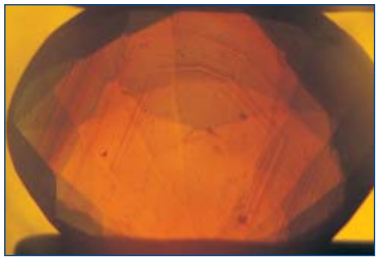

Figure K6: *I, 50* x

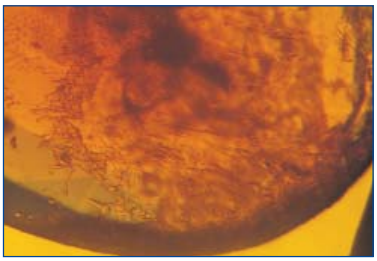

Figure K7: *I, 60* x

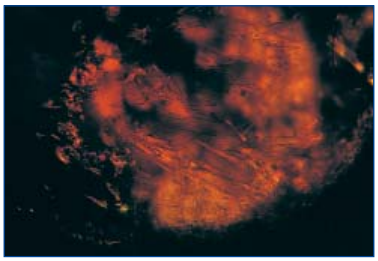

Figure K8: *I, 60* x *# pol.*

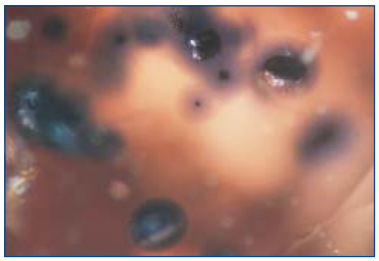

Figure K9: *50* x

Figure K10: *100* x

Figure K11: *100* x

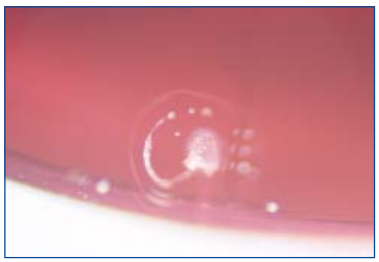

Figure K12: *100* x

Growth and colour zoning may be very complex, especially if an orange rim or an orange zone of greater depth is superimposed on chromium-related growth and colour zoning (K1 – K6).

Newly-grown polycrystalline corundum is present on the surfaces of some treated samples from Songea (K7, K8). Around the larger rutile crystals, bluish-violet diffusion haloes may be formed (K9).

K1-4: Growth and colour zoning at low magnification. K5-6: Growth and colour zoning of oriented samples. K7-8: Polycrystalline corundum on surface. K9: Rutile crystals with diffusion haloes. K10-12: Thermally altered inclusions. Pictures 1 by M. Glas, 2-8 by K. Schmetzer, 9-12 by L. Kiefert.

nb: I = immersion, # pol. = crossed polarisers

greater depth is superimposed on existing growth and colour zoning (*Figures 3b, 14, K1 – K4*). The most easily recognisable treated Songea stone is one with a red or purplish-red rim that became orange by diffusion treatment, still with a more or less colourless core. If the colour zoning before treatment, however, was already complex, a simple rim to core zoning may not be recognisable. This situation is not changed at higher magnification (*Figures K5, K6*). The overall colour impression given by a treated stone comprises the average of the coloured rim, the colourless core and the intensity of orange colour centres formed at some depth within the crystal.

Figure 28: *Beryllium-diffusion-treated sapphire of 0.94 ct from Songea. Photo by M. Glas.*

As described for Ilakaka material, newly-grown polycrystalline corundum is present on the surface of some treated samples from Songea (*Figures K7, K8*). Around the larger rutile crystals, bluish-violet diffusion haloes were formed during the diffusion treatment process (*Figure K9*). In stones where the diffusion halo was in contact with internal melt from mineral inclusions, bluish-violet flow structures were formed.

Treated Songea stones are also characterised by various forms of decomposed and/or molten mineral inclusions (*Figures K10 – K12*) and many have stress fractures and haloes with various forms of melt and spherical bubbles. The visual appearance of these inclusions is similar to that observed for altered mineral inclusions in treated Ilakaka samples but, on average, inclusions were less abundant and some Songea sapphires were clean. In some samples partly healed fissures and fractures that were occasionally filled with foreign material, probably flux, are present.

Chromium and iron contents of the sapphires

Table II contains data published by Schmetzer and Schwarz (2004, p.160) enhanced by results from 20 new samples from Montana and 10 from Sri Lanka. A graphical representation of the analytical results is shown in *Figure 29*.

Since the distribution of trace-elements from all four sources was not related to whether the samples were untreated, heat-treated or diffusion-treated, these categories are not specified in *Table II* and *Figure 29*.

It is evident from *Figure 29* that the Cr-Fe population fields for Sri Lanka and Madagascar samples, for Madagascar and Montana, and for Madagascar and Tanzania partly overlap. In some areas without overlap, a distinction between different localities would be indicated on the basis of these chemical contents. In other areas, the data may indicate that localities are highly improbable, e.g. there are no Songea sapphires with low iron contents or there are no Sri Lanka stones with high iron. Using other trace elements or trace element ratios, the overlaps between samples from different sources as seen in the iron-chromium variation diagram of *Figure 29* could be further reduced (for 'chemical fingerprinting' of sapphires compare, e.g., Sutherland *et al.*, 1998; Schwarz and Schmetzer, 2001; Saminpanya *et al.*, 2003; Rankin *et al.*, 2003).

Spectra of sapphires from Sri Lanka, Montana, Ilakaka and Songea

Causes of colour and spectroscopic features of different types of sapphires are summarised in *Table I* and a visual summary linking origins, compositions and treatments is presented in *Figure 30*. A more detailed discussion about various types of colour centres in sapphire and the possible

Table II: *Chromium and iron contents of untreated, heat-treated and diffusion-treated Sri Lankan padparadschas and yellowish-orange sapphires, and of untreated and treated rubies and sapphires from Montana, Madagascar, and Tanzania*

Wt.%	Sri Lanka (36 samples)	Montana (20 samples)	Ilakaka (84 samples)	Songea (42 samples)
Cr_2O_3	bdl. – 0.11	bdl. – 0.07[a] 0.01 – 0.07[b]	0.02 – 0.21[c] 0.06 – 0.15[d]	0.11 – 0.53
Fe_2O_3	0.03 – 0.25	0.53 – 1.15[a] 0.25 – 0.26[b]	0.05 – 1.95[c] 2.64 – 3.20[d]	1.04 – 1.80

bdl. = below detection limit
[a] *18 heat-treated and diffusion-treated samples*
[b] *2 heat-treated orange or pinkish-orange samples*
[c] *80 untreated and diffusion-treated samples in different colours*
[d] *4 untreated samples with orange brown or yellowish-brown colour*

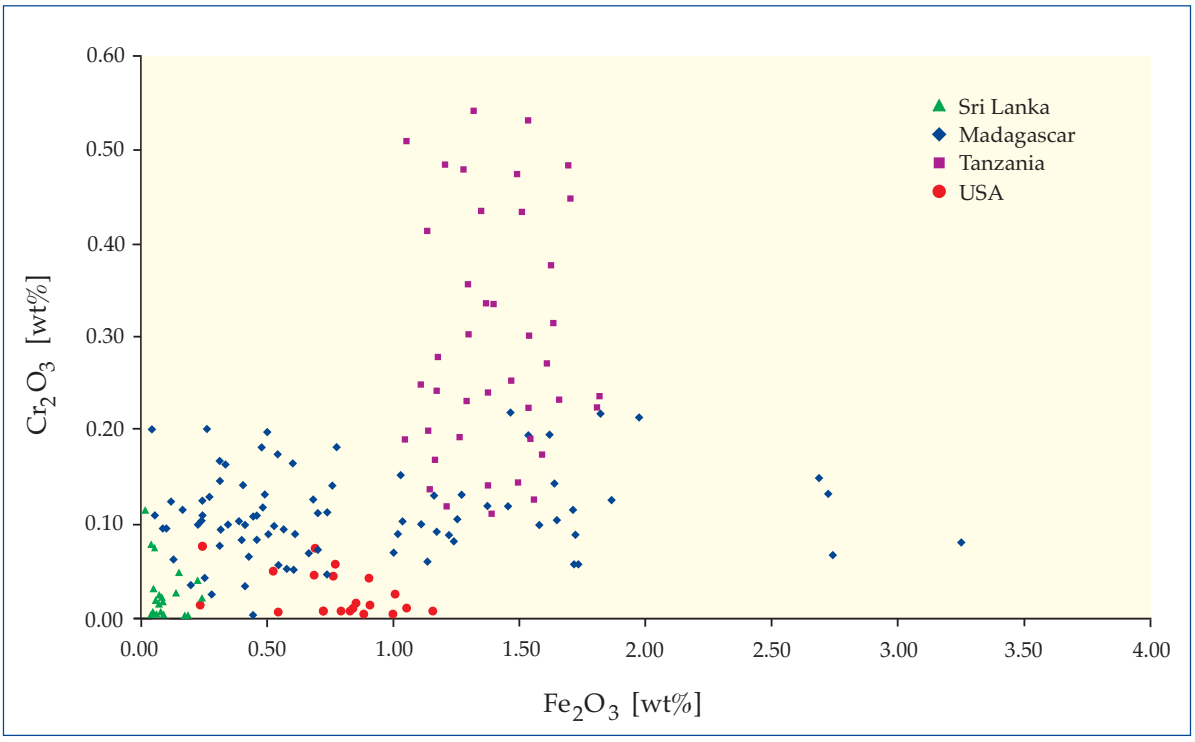

Figure 29: *Graphical representation of iron and chromium contents of 182 sapphires from Sri Lanka, U.S.A., Madagascar and Tanzania by EDXRF; for further characterisation of samples see* Table I. *It is evident that some population fields for samples from different occurrences partly overlap.*

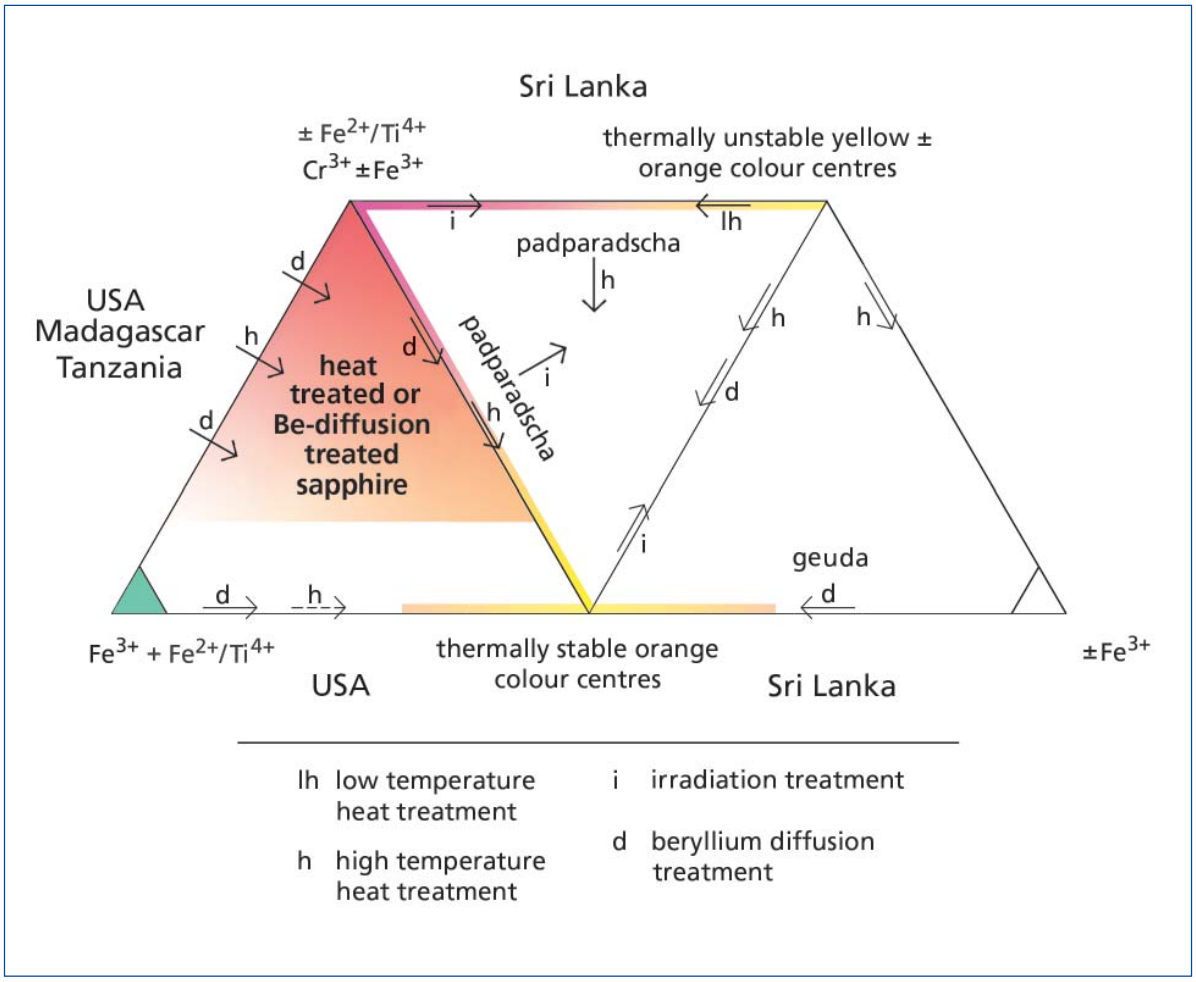

Figure 30: *This schematic diagram summarises the causes of colour in untreated, heat-treated and diffusion-treated sapphires in the yellow to red colour range from Sri Lanka, U.S.A., Madagascar and Tanzania; approximate directions of the shift of colour by heat treatment, diffusion treatment and irradiation are indicated with arrows. A dashed arrow indicates the colour change of chromium-free Montana sapphires by high temperature heat treatment (not explained in detail in this paper).*

Thermally unstable 'yellow' and/or 'orange' colour centres are present in untreated padparadscha and yellow sapphires from Sri Lanka, thermally stable 'orange' colour centres are developed by simple heat treatment or by diffusion treatment in sapphires from different localities. These thermally stable 'orange' colour centres add to the main causes of colour that are present before treatment, i.e. iron and chromium. The wide variety of colours in untreated and treated samples is due to large variation in chromium and/or iron contents and to the intensity of thermally unstable or thermally stable colour centres in untreated samples or after heat or diffusion treatment.

assignments of absorption bands in the visible and ultraviolet range is given by Schmetzer and Schwarz (2004) and the references cited therein.

- In general, there are five main colour-causing components of absorption spectra to consider for untreated, heat-treated and beryllium-diffusion-treated sapphires.
- The absorption bands of two of these components, namely Cr^{3+} and Fe^{3+}, are – in general – not changed in intensity by various types of treatment.
- The absorption bands assigned to Fe^{2+}/Ti^{4+} pairs (related to a blue sapphire component) in contrast, are present mainly in untreated samples, e.g. in specific growth zones of some Sri Lanka padparadschas, in untreated purple to violet sapphires from Songea and Ilakaka and in bluish-green and blue Montana sapphires. This blue sapphire component is reduced in intensity by heat treatment in an oxidizing atmosphere and was not present in our diffusion-treated samples.
- Thermally unstable yellow and/or orange colour centres are only present in untreated Sri Lanka sapphires, the absorption bands of these colour centres are removed by low

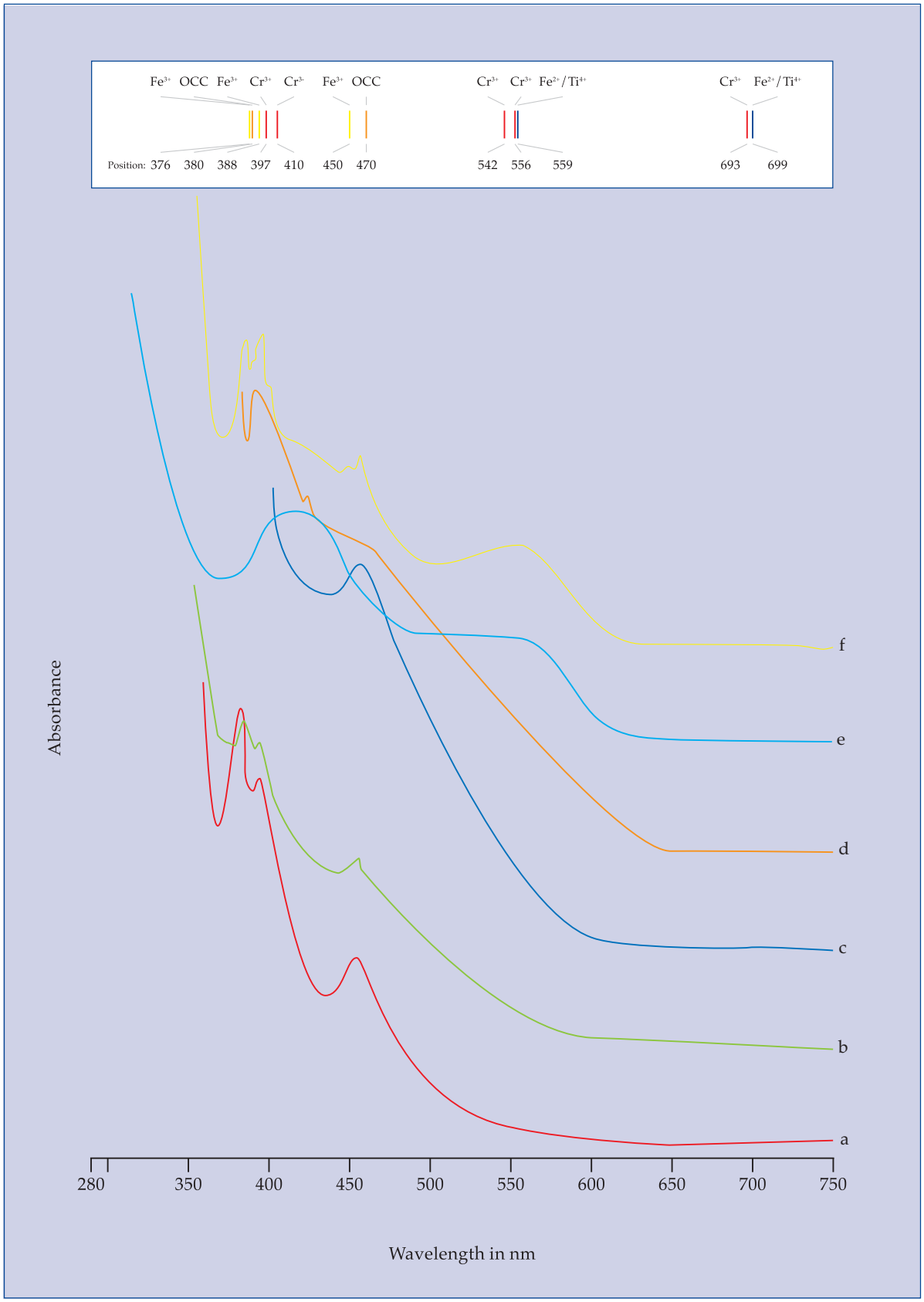

Figure 31: *Absorption spectra of heat-treated and beryllium-diffusion-treated sapphires from Montana, in the yellow to brownish-orange colour range: (a) diffusion-treated yellow sapphire, (b) diffusion-treated yellowish-orange sapphire, (c) diffusion-treated orange sapphire, (d) heat-treated orange sapphire, (e) heat-treated pinkish-orange sapphire, (f) heat-treated brownish-orange sapphire. The positions and assignments of absorption maxima are indicated at the top of the Figure; spectra (b) to (e) are vertically displaced for clarity.*

temperature heat treatment up to about 600 C.

- Thermally stable orange colour centres are produced by high temperature heat treatment or by high temperature diffusion treatment. Both types of treatment applied to natural sapphires with Fe and Cr produce identical absorption features.

The following discussion augments the spectroscopy described by Schmetzer and Schwarz (2004, p.162 *et seq*.).

For the group of diffusion-treated yellow, yellowish-orange or orange (chromium-free) sapphires from Sri Lanka (not covered by our previous paper), the spectra are more or less identical with those of simply heat-treated Sri Lankan sapphires of the same colour range.

For untreated, diffusion-treated and heat-treated sapphires from Montana which were also not discussed in our previous paper, the following results are summarised:

The absorption spectra of untreated Montana sapphires in the yellowish-green, bluish-green and blue colour range are characterised by strong absorption bands of Fe^{3+}, on which are superimposed Fe^{2+}/Ti^{4+} absorption bands (blue) of varying intensity. With increasing intensity of the blue sapphire component, the coloration shifts from yellowish-green to bluish-green or blue. Diffusion treatment of such stones produces yellow, yellowish-orange or orange colours. Their absorption spectra are characterised by strong absorption bands of Fe^{3+} and by absorption caused by orange colour centres (*Figure 31*). With increasing intensity of these orange colour centres, the colour of the samples is shifted from yellow to orange. Absorption bands of the blue sapphire component were completely removed by the beryllium diffusion treatment.

Absorption spectra of simply heat-treated orange, pinkish-orange, reddish-orange or brownish-orange Montana sapphires (*Figure 31*) are a combination of bands due to chromium and orange colour centres. Samples with colour centres dominant are orange, while samples with more intense chromium bands are pinkish- or reddish-orange. Sapphires with additional strong iron absorption bands are brownish orange. As described by Emmett and Douthit (1993), padparadscha-like colours are produced by oxidising heat treatment of originally pink Montana sapphires. This colour change is caused by the development of orange colour centres by heat treatment. Similar absorption spectra have been obtained from high temperature heat-treated sapphires from Sri Lanka.

The diagram (*Figure 30*) summarises the reaction to various treatments of untreated, heat-treated and beryllium-diffusion-treated sapphires from all four localities. Thermally unstable 'yellow' and/or 'orange' colour centres in Sri Lankan sapphires are removed by low temperature heat treatment. High temperature heat treatment causes the development of thermally stable 'orange' colour centres in sapphires from Sri Lanka and Montana. By beryllium diffusion treatment, similar or identical 'orange' thermally stable colour centres are developed in samples from all four countries.

PART III
A microscopy-based screening system

It is evident that without a detailed knowledge of diagnostic features of the types of treated and untreated sapphires on the international market, a gemmological examination would be incomplete and inconclusive. Furthermore, one needs that knowledge to decide whether a quantitative and costly beryllium determination is justified.

This costly option should be avoided if possible by determining gemmological properties which can indicate a locality of origin as well as any possible treatment. To assist this process and add to the microscopic properties such as inclusion features already described by different authors, we propose growth pattern, colour zoning and colour distribution pattern, observed at low and high magnifications, as key features for identification.

Figure 32 summarises the identification procedure. Any gemmologist equipped with a horizontal immersion microscope or with a more simple immersion cell which can be

added to a vertical microscope can use this flow diagram starting at steps a, b, and c. For those gemmologists unused to immersion microscopy, some training would be necessary to determine correctly the growth pattern and colour zoning of a faceted sapphire. Having done that, it would be helpful to compare this pattern with characteristic examples shown in this paper.

In order to identify untreated, heat-treated or beryllium-diffusion-treated yellow, orange, pinkish-orange or reddish-orange sapphires, one needs to know the nature of any growth patterns and colour zoning (in immersion by low and high magnification) and to identify any inclusions that might be in a 'natural' state or that might be altered. In many cases, the results of these visual observations can lead to a conclusive result.

If, however, the data are inconclusive, the gemmologist should go to steps d and e which are nowadays available as routine procedures in gemmological laboratories. The measurement of an absorption spectrum in the visible and UV and the determination of trace-element contents might be helpful, especially for the assessment of locality-specific features and possible treatment history of a sample. The additional information from spectroscopic and chemical examination may confirm preliminary results of microscopic examination or they can, in other cases, definitely exclude some possibilities of origin or treatment.

If absorption spectroscopy and trace-element chemistry (steps d and e) cannot be done or if they – in combination with steps a, b and c – do not lead to a possible identification of the sample, a direct determination of the beryllium content is necessary (step f).

Even if the data from steps *a*, *b*, and *c* do not lead to a precise result, regarding the treatment history of a sapphire with unknown origin, they may help determine the category to which a sapphire belongs and which types or groups of samples can be excluded. If, for example, we consider a sapphire with inclusions altered by high temperature treatment and with a growth pattern typical of a Songea stone, Sri Lankan and Montana origins would be ruled out for the stone, but the possibilities of high temperature or

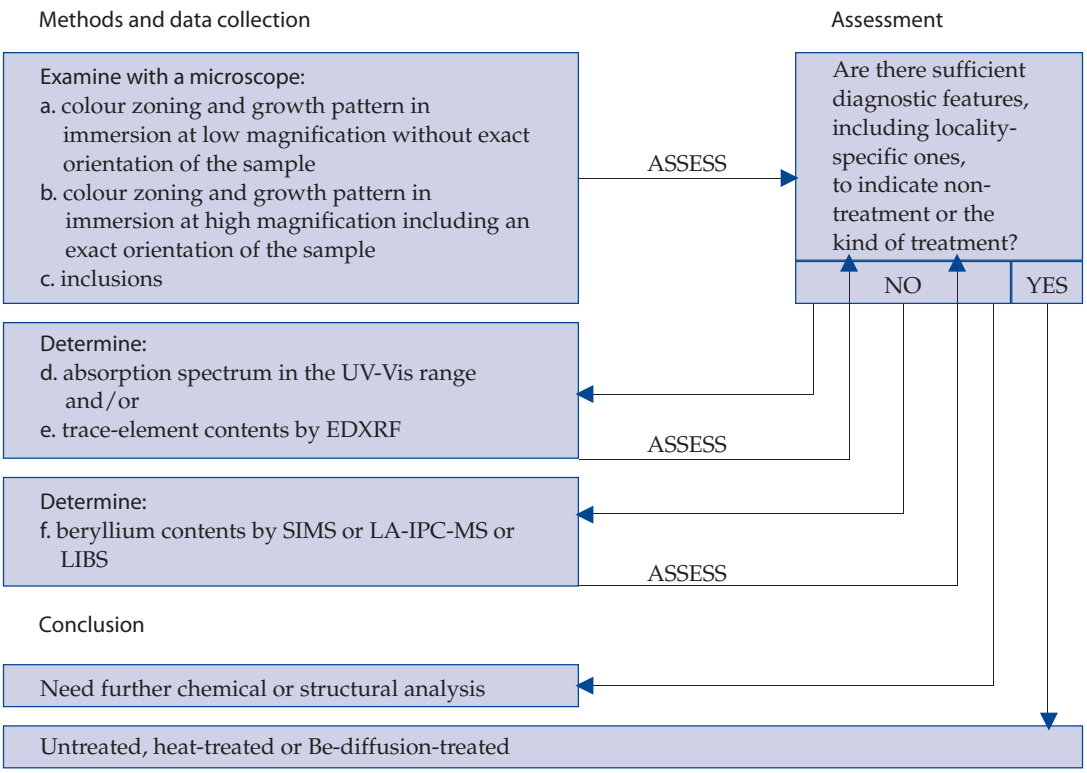

Figure 32: *Summary of the suggested screening process for sapphires.*

Be-diffusion treatment remain. It would then be for the client to decide if a quantitative beryllium determination is desirable.

Using the diagnostic features outlined above and other characteristic properties for each locality, it is – in general – possible to recognise a great percentage of orange to reddish-orange sapphires (padparadschas) from Sri Lanka as untreated or heat-treated, and to confirm their locality of origin. In most sapphires of this type, the colour is distributed in such way that there should be no confusion with beryllium-diffusion-treated sapphires from the localities examined. This applies also for heat-treated orange, reddish-orange or brownish-orange Montana sapphires.

Diffusion-treated sapphires, on the other hand, which do not show a characteristic strongly-coloured rim, may also be recognised by the lack of any typical colour zoning (in the case of Ilakaka and Sri Lanka material) or by a characteristic growth pattern associated with a typical colour zoning (typical of Songea sapphires as described in the example below).

Neither untreated nor heat-treated orange or reddish-orange sapphires from Sri Lanka or Montana, nor untreated brownish-orange sapphires from Ilakaka, show a combination of the identification features mentioned below for this particular orange Songea sapphire and, consequently, this sample is identifiable as diffusion-treated sapphire because neither untreated nor heat-treated samples from any natural source show this combination of diagnostic features. A similar general assignment to the specific category of diffusion-treated sapphires is also possible

Example: Beryllium-diffusion-treated orange sapphire from Songea

A 1.42 ct orange sapphire submitted from Bangkok for examination (*Figure 33a*) gave the following results:

a. *Immersion at low magnification:* Colour zoning light orange/intense orange is related to growth zoning (*Figure 33b*).

b. *Immersion at high magnification:* A complex growth pattern consisting of the basal pinacoid *c* combined with rhombohedral *r* $\{10\bar{1}1\}$ and dipyramidal n $\{22\bar{4}3\}$ faces (*Figure 33c*). The *c* growth sectors are more strongly coloured than *r* and *n* sectors.

c. *Inclusions:* No mineral inclusions useful in indicating if any treatment were present.

d. *Chemistry:* Fe_2O_3 1.26 wt.%, Cr_2O_3 0.05 wt.%

e. *Spectroscopy:* Intense iron and chromium absorption bands on which are superimposed an intense 470 nm absorption band caused by orange colour centres (*Figure 34a*).

Discussion: The growth pattern and iron content are typical for sapphires from Songea. The chromium content is smaller than that determined for our red to orange red samples, but untreated yellowish-green to greenish-blue and blue samples from Songea with lower chromium contents are known (Schwarz and Schmetzer, unpublished). These samples commonly have an almost colourless core and a more intensely coloured rim.

The colour zoning with a more intense centre related to a basal growth sector and a less intense rim related to rhombohedral and bipyramidal growth sectors is consistent with the use of this type of material for diffusion treatment. A lighter colour is produced in the rim, because part of the beryllium is needed to compensate titanium in the originally blue or greenish-blue part of the sample, which is not necessary in the originally colourless core. The spectrum shows an intense absorption band at 470 nm which is not obtained by simple heat treatment and confirms this result.

In summary, sapphires heat-treated only with no Be-diffusion, with this combination of properties, are not known, so this is a Be-diffusion-treated sapphire.

for orange Ilakaka sapphires which lack any growth and colour zoning but most of which contain typical altered inclusion clusters. It is also possible to identify diffusion-treated samples from Sri Lanka which contain altered inclusions and a typical mosaic-like growth pattern in the absence of any colour zoning. Again, untreated material from Sri Lanka should show no altered inclusions and heat-treated samples from Sri Lanka or Montana should reveal a distinct colour zoning.

As expected at the beginning of this study, there were insufficient diagnostic properties in some samples to determine their treatment history or origin. These few samples were almost free of inclusions and without any growth and colour zoning. Such samples, found in lots from any locality, and within categories of treated and untreated material, would need to be tested for beryllium for a final identification.

All heat-treated yellow sapphires from Sri Lanka showed a clear colour zoning with intense yellow or orangey-yellow and near-colourless alternating zones. Of the diffusion-treated sapphires from Sri Lanka, all but one were homogeneously coloured. This exception had weak colour zoning with light and medium yellow areas which are related to variable Cr and Mg contents. So although the microscopic screening system works for most yellow to orange Cr-free sapphires from Sri Lanka, the gemmologist should be particularly careful with weakly colour-zoned stones.

The most problematic sample examined was an intensely colour-zoned, diffusion-treated yellow sapphire, possibly of Sri Lankan origin and without an exactly known treatment history. Distinct magnesium zoning was indicated by LA-ICP-MS examination. It is obvious that samples that would have become yellow (and colour-zoned) by simple high temperature heat treatment, could also become yellow (and colour-zoned) by beryllium diffusion treatment if trace-element contents were appropriate. This may explain the colour zoning in this particular sample. Again, the gemmologist should critically review all the evidence a stone can offer.

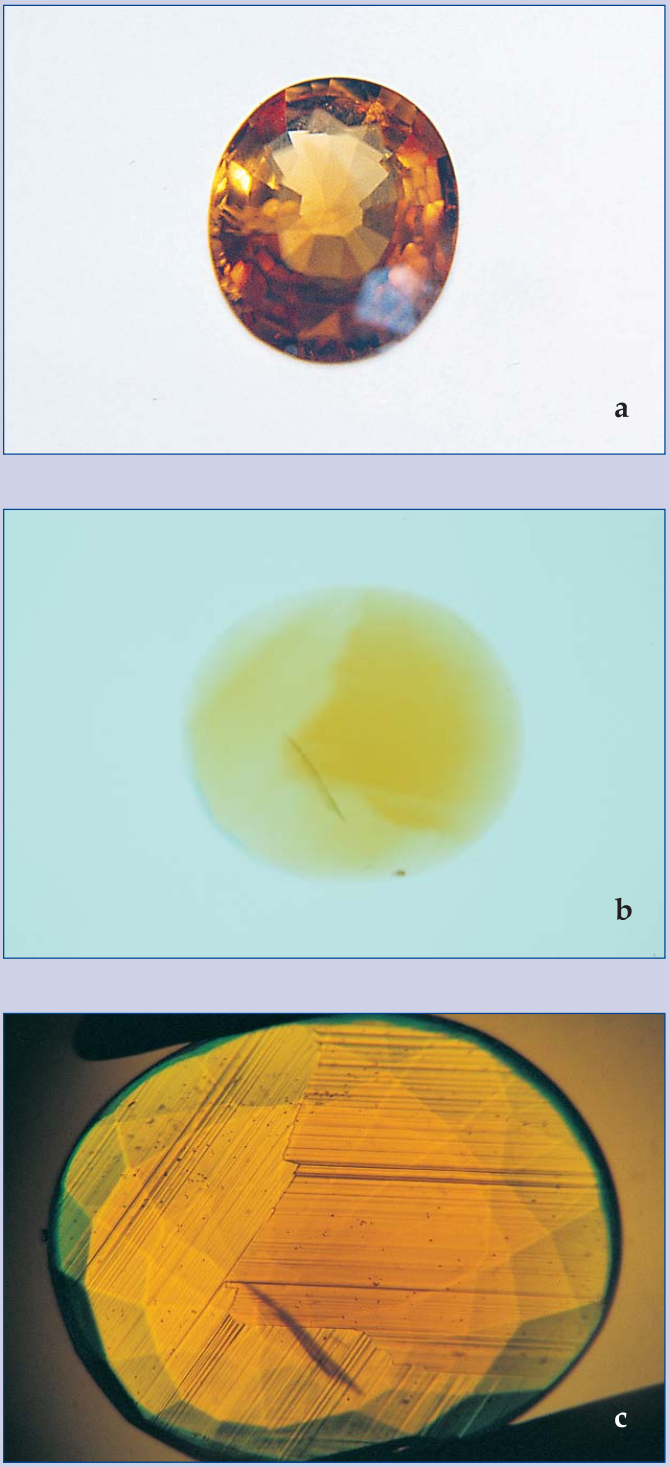

Figure 33: *(a) Beryllium-diffusion-treated reddish-orange sapphire of 1.42 ct from Songea. Photo by M. Glas; (b) Colour zoning in this sapphire is visible in immersion at low magnification; differently coloured growth sectors are visible. Photo by K. Schmetzer; (c) Colour zoning in this sapphire in immersion at high magnification; differently coloured basal* c *(darker) and dipyramidal* n *(lighter) growth sectors are visible. I, 40*x*. Photo by K. Schmetzer.*

Box B: Two case studies using the proposed system

For untreated light yellow, greenish-yellow, yellowish-green, greenish-blue or blue sapphires with multiple colour zones and using the experimental results described previously by Emmett *et al*. (2003) and Pisutha-Arnond *et al*. (2004 a, b), a blue coloration can be removed or lightened and a yellow coloration can be produced in originally blue areas of a sapphire by diffusion treatment. According to the mechanism of colour change as far as it is understood at present (see also Schmetzer and Schwarz, 2004) we can expect, after beryllium diffusion treatment, a more intense yellow or yellowish-orange coloration in the sapphire zones with lower titanium concentration compared to those with higher titanium. In colour-zoned sapphires with high iron concentrations, e.g. in sapphires of basaltic origin, these areas are frequently (in the untreated state) yellow, yellowish-green or light blue, in contrast to greenish-blue or more intense blue areas with higher titanium concentrations. Diffusion treatment of basaltic sapphires with extreme chemical zoning, can result in sapphires with very intense orange and blue zones, a feature not yet observed in untreated sapphires or in ones that had been simply heat-treated.

For the interpretation of the absorption spectra presented, the reader should compare the data given in our previous paper (Schmetzer and Schwarz, 2004); for an overview of absorption spectra of various types of untreated and heat-treated yellow to yellowish-orange sapphires the reader should also refer to Schmetzer *et al*. (1983).

Case study 1: Beryllium diffusion-treated yellow to yellowish-orange sapphires from Antsiranana, Madagascar

Beryllium diffusion-treated sapphires from Antsiranana province, northern Madagascar (and also from other basaltic sources) are now released in quantity from Bangkok on to the international market (see Atichat, 2004). Untreated and heat-treated material from this source was described in detail by Schwarz et al. (2000). We examined three diffusion-treated intense yellow to yellowish-orange sapphires (*Figure 35a*) with the following results:

a. Immersion at low magnification: One sample showed a weak colour zoning and two samples showed a more intense colour zoning related to growth structures (*Figure 35b*).
b. Immersion at high magnification: The three samples showed growth structures parallel to the basal pinacoid *c* (0001) and parallel to the hexagonal dipyramid *z* $\{22\bar{4}1\}$ (*Figure 35c*), the colour zoning was confined to *z* growth sectors.
c. Inclusions: The three samples did not contain any mineral inclusions useful to indicate a possible heat or diffusion treatment.
d. Chemistry: Fe_2O_3 1.50, 1.66, and 1.90 wt.% for the three samples, Cr_2O_3 was below the detection limit in each stone.
e. Spectroscopy: Each sample showed intense iron absorption bands, the 470 nm absorption of orange colour centres was also present (*Figure 34b*).

Discussion: From the Antsiranana province, many untreated basaltic sapphires are colour-zoned with yellow, greenish-blue and blue areas. This colour zoning is always confined to growth structures, with, e.g. the basal pinacoid *c* and the hexagonal dipyramid *z* as dominant growth planes. The possibility to improve samples of this nature by simple heat treatment into sapphires with the more 'marketable' homogeneous colours is limited (Schmetzer and Schwarz, unpublished research). Iron values are in the range observed for our three samples, chromium contents are also below detection limit (see Schwarz *et al*., 2000). The growth and colour zoning

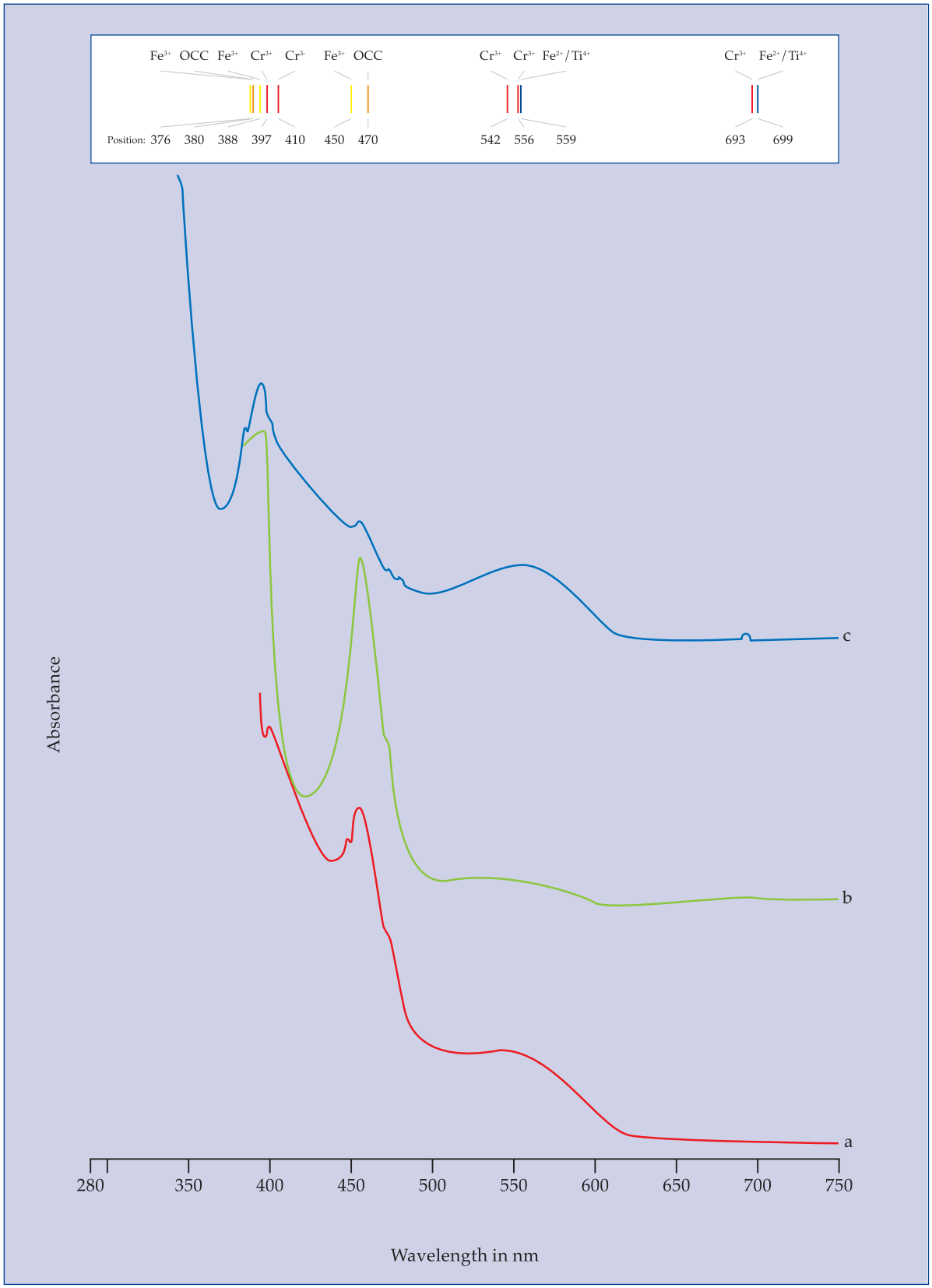

Figure 34: *Absorption spectra of heat-treated and beryllium-diffusion-treated sapphires: (a) beryllium-diffusion-treated reddish-orange sapphire of 1.42 ct from Songea; the spectrum shows the absorption bands of Fe^{3+}, Cr^{3+} and orange colour centres; (b) beryllium-diffusion-treated yellow sapphire from Antsiranana province, Madagascar; the spectrum shows the absorption bands of Fe^{3+} and orange colour centres; (c) heat-treated brownish-orange sapphire from Ilakaka, Madagascar; the spectrum shows the absorption bands of Cr^{3+}, Fe^{3+} and orange colour centres. The positions and assignments of absorption maxima are indicated at the top of the Figure; spectra (b) and (c) are vertically displaced for clarity.*

patterns of the three samples are related to those of the untreated sapphires. A more intense yellow is produced in originally yellow zones with lower titanium contents and a less intense yellow is produced in originally greenish-yellow to greenish-blue or blue areas. This is consistent with Be compensating for Ti as discussed above.

In summary: Sapphires with this combination of properties are unknown in the untreated or simply heat-treated categories.

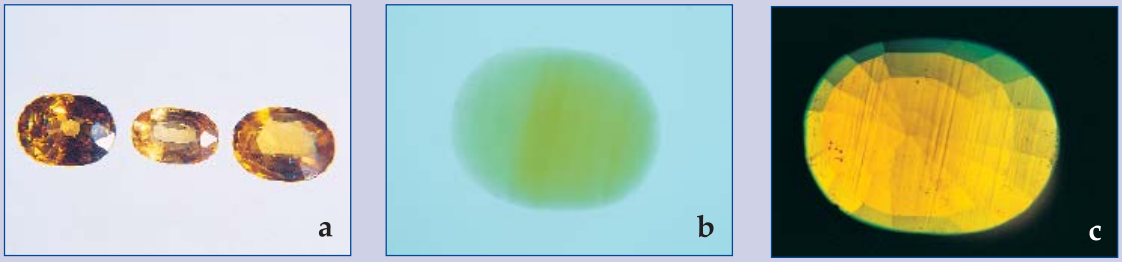

Figure 35: *(a) Beryllium-diffusion-treated yellow sapphires from Antsiranana province, Madagascar; range of samples from 2.01 to 2.86 ct. Photo by M. Glas; (b) Colour zoning in the yellow sapphire of 2.86 ct in immersion at low magnification; differently coloured growth sectors are visible. Photo by K. Schmetzer; (c) Colour zoning associated with dipyramidal z growth planes in the yellow sapphire of 2.86 ct in immersion at higher magnification. I, 25x. Photo by K. Schmetzer.*

Case study 2: Heat-treated orange sapphire from Madagascar

During this study we also received a slightly brownish-orange sample of 2.56 ct described as heat-treated Madagascar 'padparadscha' (*Figure 36a*). The owner was unable to provide a history for the stone. The following properties were determined:

a. Immersion at low magnification: the orange colour of the sample is related to an irregularly shaped core of the sapphire (*Figure 36b*), but not to the rim.
b. Immersion at high magnification: No specific sharp growth lines or colour zoning seen.
c. Inclusions: Numerous tiny mineral inclusions were present, and some showed thermal decomposition and alteration (*Figure 36c*) but there was no sign of any melt in fractures and fissures.
d. Chemistry: Trace-elements not determined.
e. Spectroscopy: Absorption bands of chromium and iron (*Figure 34c*) with superimposed bands from orange colour centres.

Discussion: The inclusion features are consistent with those in heat- or diffusion-treated sapphires from Ilakaka, and the alteration indicates temperatures of treatment in the range of about 1700 to 1750 C. Although this absorption spectrum is common in diffusion-treated Ilakaka sapphires, it alone is not sufficient to indicate diffusion treatment. The presence of colour zoning related to an irregularly shaped core indicates that orange colour centres were developed upon treatment only in the core of the sapphire, but not in the rim. Beryllium diffusion treatment would have created colour in the rim, and so this pale rim allows – in combination with the other properties mentioned – characterisation of the sample as heat-treated brownish-orange Ilakaka sapphire.

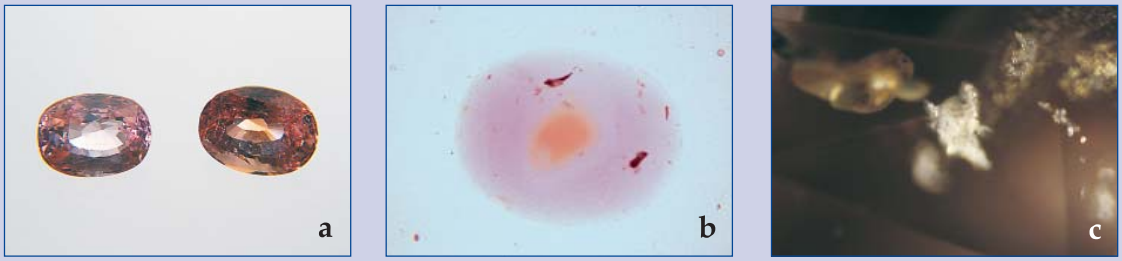

Figure 36: *(a) Heat-treated padparadscha from Sri Lanka of 2.23 ct (left) and heat-treated slightly brownish-orange sapphire from Ilakaka, Madagascar of 2.56 ct (right). Photo by M. Glas; (b) colour zoning in brownish-orange sapphire of 2.56 ct; the core of the sample shows a higher colour concentration compared to the much lighter rim, the orange coloration of the sapphire is related to the core. The sapphire measures 7.0 x 9.0 mm. Photo by K. Schmetzer; (c) brownish-orange sapphire of 2.56 ct with decomposed inclusions, most probably zircons. 50x. Photo by L. Kiefert.*

Conclusions

The microscopy-based screening system presented here is mainly based on a combination of structural microscopic properties such as growth pattern, colour zoning and distribution, and inclusion features. The addition of chemical and spectroscopic properties as characteristic, origin-related features may be helpful in indicating possible beryllium diffusion treatment. Nevertheless, it should be recognised that although the system is based on a comprehensive sample of sapphires on the market, there could still be some from other, unsampled localities which are commercially treated.

That said, the combination of characteristics used to date enables the recognition of most untreated and heat-treated Sri Lanka padparadschas, heat-treated Montana sapphires and beryllium-diffusion-treated materials. For a small percentage of diffusion-treated orange sapphires, a lack of characteristic inclusions should prompt further analysis.

The key for successful screening of lots of samples of unknown origin and unknown treatment history will always be to compare their features with those of treated and untreated samples from a specific locality. Without this specific combination of characteristic features related to locality, i.e. considering sapphires only in three groups, namely 'untreated', 'heat-treated' and 'diffusion-treated' as in the past, much information is overlooked. If one can use locality-related information, the percentage of samples which can be recognised in a normally equipped gemmological laboratory as untreated, heat-treated or diffusion-treated would rise significantly; this in turn would reduce the need for Be analysis.

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Growth of hexagonal bipyramidal ruby crystals by the evaporation of molybdenum trioxide flux

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Abstract: *Ruby crystals with hexagonal bipyramidal shape have been grown by the evaporation of MoO_3 flux isothermally. Red transparent crystals up to 1.8 mm in length and 1.7 mm in width were obtained, their sizes depending on the solute concentration and the holding temperature. Their form was a double six-sided pyramid bounded by twelve well-developed $\{11\bar{2}3\}$ faces of isosceles triangle shape. The habit of ruby crystals grown by this isothermal method of MoO_3 flux evaporation is quite different from the habits of ruby crystals grown by slow-cooling or temperature-gradient.*

Keywords: *flux growth, hexagonal bipyramid, molybdenum trioxide, synthetic ruby*

Introduction

Ruby (Al_2O_3:Cr) is one of the most attractive of red gemstones and belongs to the rhombohedral system.[1] Chemically, ruby is mainly composed of aluminium oxide (Al_2O_3), and the crystalline form found in nature is called corundum. Alumina is a general name for all forms of aluminium oxide, while corundum refers only to the crystalline material. Pure corundum is colourless and in gem deposits, may be called 'white sapphire'. On the other hand, ruby is aluminium oxide doped with chromium, and the chromium is responsible for the characteristic red colour. Therefore, although ruby can be thought of as 'red sapphire', its name was used long before the similarities of its characteristics with those of sapphire were realised and made public. Many crystal growth techniques, including Verneuil, Czochralski, hydrothermal, vapour phase and flux[2-11] have been utilized successfully to synthesize ruby single crystals. Among these techniques, the flux growth is very convenient and can produce ruby crystals at temperatures well below the melting point of the solute. Furthermore, the most important advantage is that the grown crystals have an idiomorphic or euhedral habit.

Flux growth procedures can be categorized into slow-cooling, flux-evaporation and temperature-gradient by the difference in the driving force of crystallization. Many researches have been reported on the slow-cooling growth of ruby crystals using

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systems of lead compounds, PbF_2[4,8] PbO-B_2O_3[6,9] and PbO-PbF_2[5,7], as solvents. However, lead compounds are not safe to store and handle because of their toxicity. In addition, it is very difficult to separate grown crystals from these fluxes. Most ruby crystals grown from these fluxes are thin hexagonal plates with well-developed {0001} faces.[4-9] In flux growth using the temperature-gradient method, Na_3AlF_6 and Na_3AlF_6-Li_3AlF_6 were employed as solvents.[10,11] The grown crystals displayed faces in the forms {0001}, {22$\bar{4}$3} and {10$\bar{1}$1}. However, except for Oishi *et al.*[2], no study has been reported on the MoO_3 flux-evaporation of ruby crystals.

In carrying out flux growth of ruby crystals, there is an obvious necessity for less dangerous flux materials. In the case of flux-evaporation, molybdate system fluxes are much less dangerous than lead compounds and are, therefore, good candidates as alternatives. Recent work in growth of gem crystals using systems of molybdate fluxes[12-15] has led to a recent conclusion that hexagonal bipyramidal ruby crystals can be synthesized from molybdenum trioxide flux. In this paper, we report on the growth of hexagonal ruby crystals from a MoO_3 flux at a growth temperature much less than the melting point of ruby. Additionally, the morphology and size of the resulting crystals are discussed in terms of growth conditions, such as solute concentration and growth temperature.

2. Experimental method

Ruby crystals were grown by flux-evaporation (an isothermal technique) from mixtures of reagent grade Al_2O_3 and Cr_2O_3 using MoO_3 as flux. The typical growth conditions are shown in *Table I*. The solute (0.430-2.200 g) and flux (27.881-29.572 g) powders were weighed out, mixed together and put into platinum crucibles (36 mm diameter x 40 mm height) with loosely sealed lids. The crucibles were heated at a rate of about 45 C per hour to 1000, 1050, 1100 or 1200 C and held at this temperature for 5 h. Subsequently, the crucibles were taken out from the furnace and rapidly cooled at room temperature. The crystal products were separated from the remaining flux in warm water. The morphology of grown crystals was observed by optical microscope (Keyence, VH-Z450+VH-7000C) and a confocal laser scanning microscope (Leica, TCSNT). The structure and chemical composition of the grown crystals were studied by X-ray diffraction (XRD, Rigaku, RINT-1500) and electron probe microanalysis (EPMA, JEOL, JXA-8900R). The length (*L*, parallel to the *c*-axis) and width (*W*, perpendicular to the *c*-axis) of the ruby crystals were measured and their average length (L_{av}) and width (W_{av}) were calculated for each growth run.

Table I: *Growth conditions of the ruby crystals*

Run No.	Solute			Flux	Holding temperature / C
	Content (mol%)	Al_2O_3 /g	Cr_2O_3 /g	MoO_3 /g	
1	2	0.428	0.002	29.572	1100
2	4	0.860	0.004	29.140	1100
3	5	1.078	0.005	28.922	1100
4	6	1.298	0.007	28.702	1100
5	7	1.519	0.008	28.481	1100
6	8	1.741	0.009	28.259	1100
7	10	2.189	0.011	27.811	1100
8	7	1.519	0.008	28.481	1000
9	7	1.519	0.008	28.481	1050
10	7	1.519	0.008	28.481	1200

3. Results and discussion

3.1 Growth of ruby crystals

Bipyramidal ruby crystals, up to 1.8 mm *L* x 1.7 mm *W* in size, were isothermally grown from the MoO_3 flux (*Table I*; runs 1-5, 9 and 10). *Figure 1* shows the typical grown crystals of ruby. The crystals were red and transparent. After 5 hours holding at 1100 and 1200 C the flux evaporation ratios of all runs were higher than 98 mass%.

In order to examine the effect of solute content on crystal averages (L_{av} and W_{av}), the growth experiments (runs 1-7) were attempted with a constant holding temperature of 1100 C and various solute contents. The L_{av} and W_{av} are plotted against solute content in *Figure 2*. Relatively large crystals of L_{av} = 1.2 mm and W_{av} = 1.0 mm

Figure 1: *Ruby crystals grown from MoO_3 flux.*

were grown from flux with 7 mol% of solute (run 5). The number of crystals was 798 and the yield was 91.5 mass %. The average mass of the crystals was 1.8 x 10^{-3} g. The crystal size decreased drastically with decreasing solute content. When the solute amount was 2 mol%, 1564 small crystals (0.384 g) of L_{av} = 0.6 mm and W_{av} = 0.5 mm were grown. The average mass of the crystals was 2.46 x 10^{-4} g. On the other hand, a countless number of crystallites was produced in runs 6 and 7, which contain higher than 8 mol% of solute.

The relationship between the holding temperature and the loss of flux or the

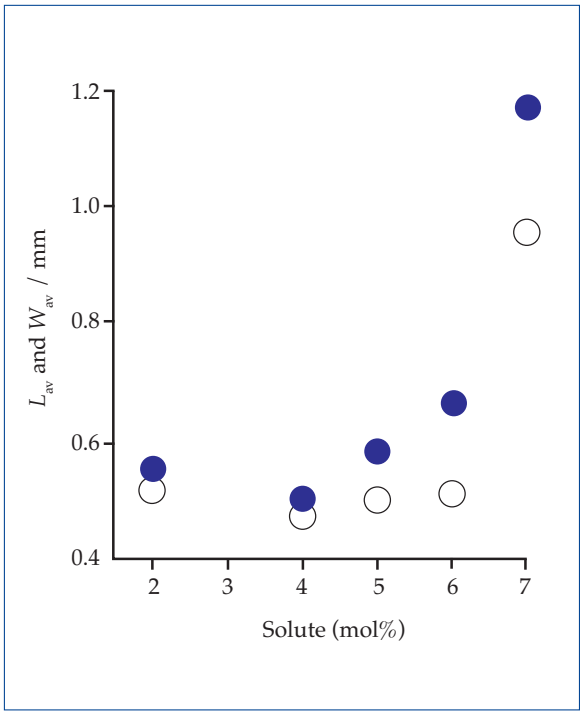

Figure 2: *Variation of average length (L_{av} closed circles) and width (W_{av} open circles) values of ruby crystals grown with solute concentration (runs 1-5).*

averages of the grown crystals are studied. The solute amount was fixed at 7 mol% (runs 8-10). At 1000 C the evaporation loss was about 40 mass%, thereafter linearly increasing with holding temperature and reaching about 99.5 mass% at higher than 1100 C. The crystal sizes were dependent on evaporation loss with a limit in crystal size (L_{av} ~ 1.1 – 1.2 mm) being reached when the mass loss exceeded 99%. In run 8 at 1000 C, the grown crystals were not large and bipyramidal, but very small crystallites because of a much smaller evaporation loss (about 40 mass%). However, it is possible that bipyramidal crystals could be grown by increasing the holding time at this same temperature. From these results, the optimum holding temperature for growth of large crystals was determined to be higher than 1100 C.

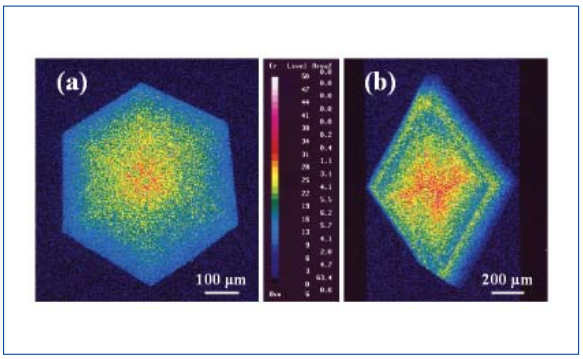

Figure 3: *Electron probe microanalysis data showing the distribution of chromium in the faces cut (a) perpendicular and (b) parallel to the c-axis.*

3.2 Evaluation of ruby crystals

The grown crystals exhibit the red colour typical of ruby and measure up to 1.2 mm (L_{av}) x 1.0 mm (W_{av}). The XRD pattern of pulverized crystallites was identical to that of α-Al_2O_3.[1] The variations in the concentration of the major constituents in the grown crystals were investigated by means of EPMA. Aluminium and oxygen are distributed almost homogeneously in the crystals. The EPMA data showing the distribution of chromium in the grown crystals are shown in *Figure 3*. *Figures 3a* and *3b* indicate the chromium distributed in sections cut perpendicular and parallel to the *c*-axis, respectively. The chromium was

preferentially incorporated in the centre of the crystals (*Figure 3a*), while a small growth zone of increased chromium is visible in the outer parts of the crystal in longitudinal section (*Figure 3b*). In addition, the chromium was equally distributed in all directions so the characteristic red colour appeared isotropic. Molybdenum from the flux and platinum from the crucible were not detected.

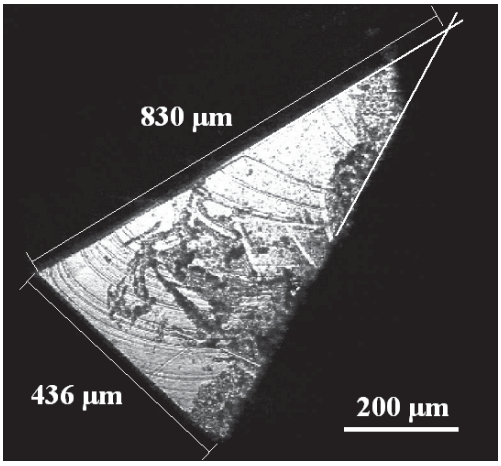

Figure 4: *Confocal laser scanning micrograph showing $(11\bar{2}3)$ face of the hexagonal bipyramidal ruby crystal.*

In order to determine the Miller indices of the crystal faces, the obtained crystals were investigated by XRD without pulverizing them. In the XRD result, only one diffraction line was detected at 2θ=43.35 , and assigned to the $(11\bar{2}3)$ plane. Furthermore, the Miller indices of the triangular faces were also calculated from their shape. The confocal laser scanning micrograph (CLSM) image of the triangle face is shown in *Figure 4*. We defined the parameter *R* to be the side ratio of the triangle face, i.e *R* = (length of a longer side) / (length of a shorter side). The *R* value obtained from the CLSM image is approximately 1.90. This value is very close to the theoretical value, 1.87, of $\{11\bar{2}3\}$ faces, based on lattice constants α=4.759 and *c*=12.991 Å in a hexagonal setting.[1] If the bipyramidal crystals were bounded by $\{22\bar{4}3\}$ faces, the theoretical *R* value would be 3.31 which is very different from the observed 1.90. In addition, the measured interfacial angles, that is $(11\bar{2}3)$ ^ $(11\bar{2}\bar{3})$ and $(11\bar{2}3)$ ^ $(2\bar{1}\bar{1}3)$ are, respectively, about 57 ± 1 and 52 ±1, which are essentially the same as the theoretical values of 57.57 and 51.98 .

As mentioned above, most ruby crystals synthesized from a system of lead compound fluxes are of thin hexagonal platelike habit with well-developed {0001} faces.[4-9] In contrast, the ruby crystals grown from the MoO_3 flux have a characteristic and unusual habit. *Figure 5* shows a typical grown ruby crystal and a schematic drawing of the crystal form consisting of $\{11\bar{2}3\}$ faces. As clearly seen in the optical image, the ruby crystal grown from MoO_3 flux is a hexagonal bipyramid which consists of twelve well-developed $\{11\bar{2}3\}$ faces. The faces are isosceles triangles and their surfaces appear to be comparatively smooth (*Figure 5*). $\{11\bar{2}3\}$ faces seem not to develop in platy ruby crystals grown by the slow-cooling or temperature-gradient methods. However, in MoO_3 flux, the $\{11\bar{2}3\}$ faces of ruby may adsorb molybdate ions more easily than other faces such as {0001}, $\{10\bar{1}1\}$ and $\{22\bar{4}3\}$, and so the growth of the $\{11\bar{2}3\}$ faces becomes dominant. However, it is not known why molybdate ions selectively adsorb on the $\{11\bar{2}3\}$ faces.

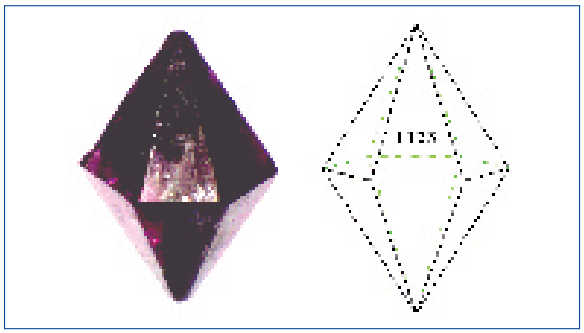

Figure 5: *Typical ruby crystal and a schematic drawing of a crystal bounded by the $(11\bar{2}3)$ faces.*

4. Conclusions

Hexagonal bipyramidal ruby crystals, exhibiting the typical red colour, have been successfully grown by a flux-evaporation technique. To fabricate this unusual form of ruby with MoO_3 as a flux is of primary importance. The grown crystals are bounded by well-developed $\{11\bar{2}3\}$ faces and can be up to 1.8 mm x 1.7 mm in size. The crystal sizes are dependent on the evaporation losses

of the flux which are related to the holding temperature and the solute amount. Since this flux growth process can be conducted at a low temperature far below the melting temperature of Al_2O_3, the technique will be favourable for the fabrication of not only bulk ruby crystals but also other corundum crystals, such as white, blue, yellow, pink and green sapphire. Furthermore, various surfaces such as Al_2O_3 materials (plate, ball, tube, etc.) and crystal substrates (sapphire, ruby, etc.) can be coated with a corundum crystal layer using epitaxial growth from a MoO_3 flux.

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Sapphire diffusion treatment and the behaviour of iron and titanium

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Abstract: *Using the parameters of thickness of diffusion layer and the conditions under which diffusion was carried out in a sample of blue sapphire from Thailand, the diffusion coefficients of iron (D_{Fe}) and titanium (D_{Ti}), the colouring ions, have been calculated. The results indicate that the diffusion coefficient of Ti^{4+} is 6.57×10^{-9} cm^2s^{-1} and that of Fe^{2+} is 1.62×10^{-9} cm^2s^{-1}. The factors affecting D_{Ti} and D_{Fe} are discussed.*

Keywords: *diffusion coefficient, diffusion treatment, Fick's law of diffusion, sapphire*

1. Introduction

The theoretical foundation of a sapphire's colour treatment lies in the diffusion process of a colouring element or elements into the gemstone. At a high temperature, colouring ions infiltrate into the surface layer of a gemstone through its crystal defects, enhancing its colour appearance. The technique of treating near-colourless sapphire to a deep blue only affected the global gemstone market towards the end of the 1980s.[1-2] After more than ten years' experimenting and perfecting, the craft has been greatly developed. But mainly for financial reasons, systematic study has not been comprehensive and most treatments are empirical, proceeding by trial and error. Consequently, developed theory is inadequate for communication. So it is hard to forecast the dependability and the precise effect that this colour-altering craft will have on any one batch of gemstones.[3] It is both theoretically and practically relevant to discuss the technique and mechanism of sapphire diffusion treatment, because the microscopic mechanism controls the macroscopic effect. Further, researching the diffusion coefficient of colouring ions, and guiding the experiment and production by theory, can improve the dependability of this craft and reduce the waste of gemstone resources.

2. Preparation of sapphires for diffusion treatment

First, near-colourless sapphires are washed in acid and classified, and those with blemishes or cracks making them unfit for diffusion treatment are rejected. Then, the rest are cut into semi-manufactured stones; these stones are not polished at this point.

The samples are then put into an alumina crucible with the chemical reagent containing Fe^{2+} and Ti^{4+} and slowly heated to 1800~1900 C in an oil fired furnace. After 72

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hours at this temperature they are allowed to cool down along with the furnace.

The sapphire diffusion treatment experiment was carried out in the laboratory of the Thailand Jewelry and Gem Company. There are numerous pits on the surfaces of the samples treated in this way and their colour is deep blue. For determining the thickness of the diffusion layer and the concentration distribution of the colouring ions (Fe^{2+}, Ti^{4+}), a 0.8 mm-thick slice was cut from the centre following the direction of the long axis (see *Figure 1*). From numerous measurements, the diffusion layer is of similar thickness all the way round the stone apart from the girdle, where it is thicker, ranging from 0.34-0.38 mm.

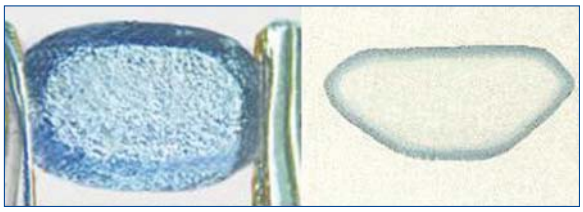

Figure 1: *Sapphire with a blue layer, 0.34 - 0.38 mm thick, around the surface caused by diffusion of iron and titanium.*

3. Fick's law of diffusion

In 1855, Adolf Fick published a paper entitled 'Uber Diffusion' in which he described the molecular diffusion process and derived his law. The law has direct relevance in understanding the diffusion treatment of sapphire. Fick's first law of diffusion states that the mass of a solute crossing a unit area per unit time in a given direction is proportional to the gradient of solute concentration in that direction.

$$J = -D\frac{d\rho}{dx} \qquad (1)$$

Where:

J = the flux of the diffusing species, $gcm^{-2}s^{-1}$

D = diffusivity or diffusion coefficient = the proportionality constant, cm^2s^{-1}

ρ = the mass concentration of diffusing solute, gcm^{-3}

x = distance; $\frac{d\rho}{dx}$ is the concentration gradient.

The negative sign means that the flow (flux) is in the direction opposite to that in which ρ increases.

Fick's first law of diffusion is only applicable for steady-state diffusion (the diffusion flux doesn't change with time). But the process of sapphire diffusion treatment is a process of non-steady-state diffusion, where the diffusion flux and the concentrations vary with time (t). Non-steady-state diffusion is governed by Fick's second law.

$$\frac{\partial\rho}{\partial t} = D\frac{\partial^2\rho}{\partial x^2} \qquad (2)$$

The solution of the diffusion equations is given in the Appendix.

4. The meaning of the diffusion coefficients of Fe^{2+} (D_{Fe}) and Ti^{4+} (D_{Ti}) in sapphire diffusion treatment

4.1. D_{Fe} and D_{Ti}

The research results concerning the cause of the blue colour in sapphire are well established, and are attributed to charge transfer between Fe^{2+} and Ti^{4+}. Therefore, the treatment to alter the colour of sapphire to blue is always related to the diffusion of Fe^{2+}, Ti^{4+}. To understand this diffusion, it is first necessary to know the diffusion coefficients of Fe^{2+} and Ti^{4+} in sapphire (D_{Fe}, D_{Ti}). The important factors affecting diffusion coefficient are types of crystal defect, form of diffusion , characters of ions, mass concentration and diffusion temperature. Consequently, from the ion diffusion coefficient, the possibility of ion diffusion, the velocity of diffusion and the thickness of the diffusion layer under some particular time condition can be deduced. To determine and analyze the diffusion coefficients of Fe^{2+}, Ti^{4+} in blue sapphire, the concentration distributions of Fe^{2+} , Ti^{4+} in the diffusion layer were analysed and determined by electron probe microanalysis (EPMA) using

Table I: *Sapphire compositions in the diffusion layer*

Analysis number	1	2	3	4	5	6	7	8	9	10	11
Distance *x* from surface of sapphire in mm	0	0.05	0.10	0.15	0.20	0.25	0.30	0.35	0.40	0.45	0.50
Wt.%											
Al_2O_3	96.04	96.78	97.83	98.57	98.52	98.76	98.54	98.63	98.76	98.82	98.76
MgO	0.23	0.45	0.35	0.26	0.33	0.35	0.43	0.37	0.31	0.30	0.33
Na_2O	0.06	0.02	0.03	0.01	0.03	0.05	0.07	0.03	0.02	0.04	0.05
K_2O	0.06	0.03	0.03	0.04	0.05	0.03	0.03	0.03	0.01	0.02	0.03
FeO	1.65	0.97	0.50	0.26	0.15	0.10	0.06	0.03	0.01	0.01	0.01
TiO_2	1.39	0.88	0.54	0.34	0.22	0.15	0.10	0.06	0.02	0.02	0.01
Cr_2O_3	0.02	0.03	0.02	0.03	0.05	0.04	0.04	0.03	0.04	0.04	0.05
V_2O_5	0.01	0.01	0	0	0.01	0	0.01	0	0.01	0.01	0.01
SiO_2	0.31	0.26	0.22	0.24	0.32	0.32	0.30	0.28	0.29	0.30	0.32
Total	99.77	99.43	99.52	99.75	99.68	99.80	99.58	99.46	99.47	99.56	99.57

NB: Total iron reported as FeO

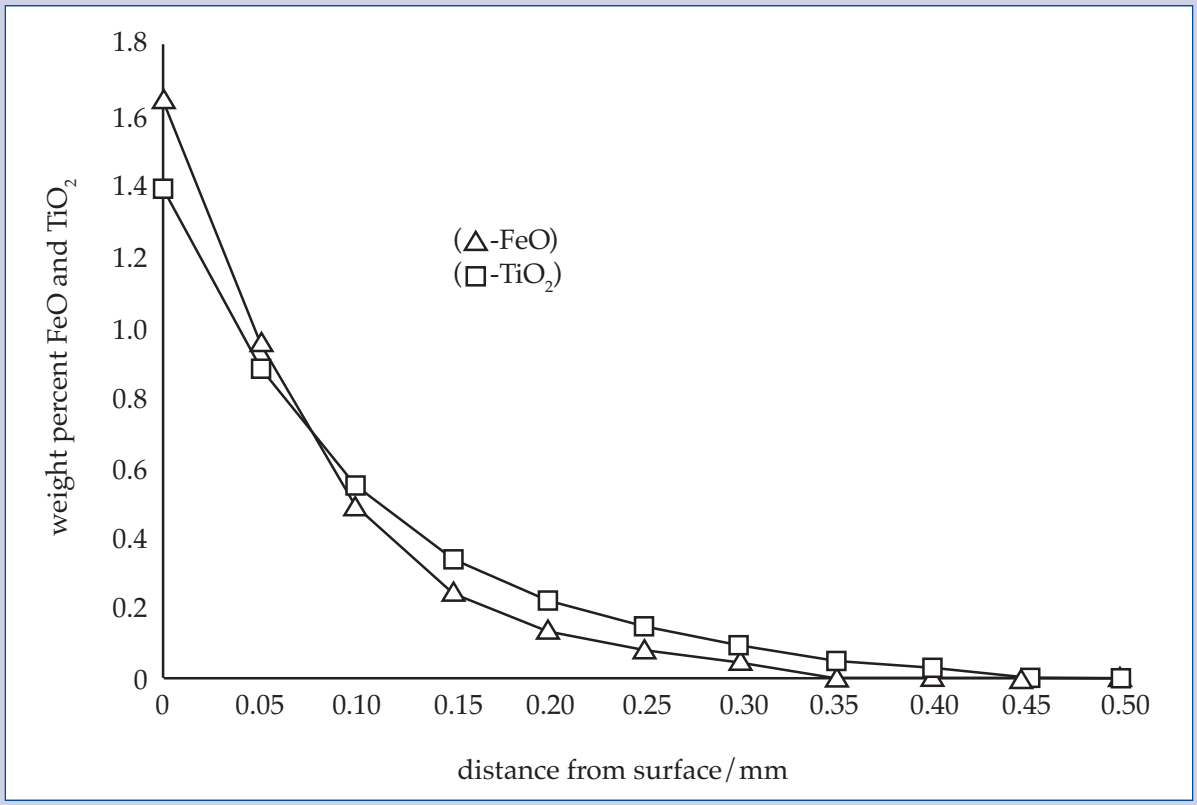

Figure 2: *Graph showing variation of weight percent FeO and TiO_2 due to diffusion with distances from sapphire surface.*

a JEOL JXA840A. The results are shown in *Table I* and *Figure 2*.

Putting the original concentrations of Fe^{2+} and Ti^{4+} in the reagent (ρ_1), the original concentrations of Fe^{2+} and Ti^{4+} in the blue sapphire (ρ_2), the maximum diffusion distance (x) and the concentrations of Fe^{2+} and Ti^{4+} at the point (ρ_{Fe}, ρ_{Ti}) at different times into equation (4) (see Appendix), we can calculate the diffusion coefficients of Fe^{2+} and Ti^{4+} (D_{Fe}, D_{Ti}). Some values are shown in *Table II*.

The data in *Table II* indicate that D_{Fe} and D_{Ti} decrease slowly with diffusion treatment time but are basically, under a fixed temperature, relatively steady. The diffusion constants D_{Ti} 6.57 10^{-9} cm^2s^{-1} and D_{Fe} 1.62 10^{-9} cm^2s^{-1} indicate

that Ti diffuses about 4 times faster than Fe.

4.2. The factors affecting the diffusion coefficients of Fe^{2+} and Ti^{4+}

4.2.1. Diffusion treatment temperature

The temperature at which blue sapphire undergoes diffusion treatment plays an important role in the effects on the diffusion coefficients of colouring ions. From $D = D_0 e^{-Q/RT}$ we can deduce that the diffusion coefficient increases exponentially with the rise of temperature. Thus, the quantity of the ions meeting the transition energy condition and the vacancies increase acutely when the temperature rises. So the diffusion treatment of blue sapphire is always carried out under a high temperature. The higher the temperature, the larger the diffusion coefficient, and the thicker is the diffusion layer. But too high a temperature would cause eroded pits on the surface of the sapphire, or even make the crystal melt.

4.2.2. Crystal defects in a gemstone

Various defects often exist in crystals of blue sapphire. These crystal defects have a large effect on the diffusion coefficient. The more crystal defects there are, the larger the quantity of vacancies in the crystal. This is favourable to a higher diffusion coefficient of a displacement ion. The main process in sapphire diffusion treatment is the displacement of Fe^{2+} , Ti^{4+} and Al^{3+}. Typically, diffusion in sapphire belongs to displacement ion diffusion, and the diffusion coefficient is closely related to the number of vacancies. If there is an edge dislocation in a crystal, Fe^{2+} and Ti^{4+} can diffuse quickly into the crystal's surface along what is in effect a pipeline to replace Al^{3+}. Its activation energy of diffusion in this situation is only about half of that in the crystal lattice. At crystal surfaces and grain boundaries the atomic patterns are relatively irregular. Compared with the atoms inside a crystal, they are at a higher energy state and the extra activation energy needed to make them diffuse is relatively small. As a result, the diffusion of atoms at a crystal surface or grain boundary is faster. These conclusions are consistent with the results of diffusion treatment — the diffusion layer near the girdle of blue sapphire is thicker than for example on the table facet, and also D_{Fe} and D_{Ti} appear to decrease as t increases (*Table II*).

Table II: *Diffusion coefficients of Fe and Ti measured after different treatment times.*

Diffusion treatment time: hours	D_{Fe} x 10^{-9} cm^2s^{-1}	D_{Ti} x 10^{-9} cm^2s^{-1}
36	1.82	7.05
48	1.73	6.55
72	1.31	6.10
Average	1.62	6.57

4.2.3. Ion radius and coordination number

An ion's diffusion activation energy is affected by factors such as its size, its affinity with other elements, its charge and coordination number. If the sizes of ions are similar, any distortion in a crystal lattice caused by diffusion is relatively small, so the activation energy needed for diffusion is also small, while the diffusion coefficient is relatively large. For example, when the coordination number is 6, the radii of Fe^{2+}, Fe^{3+} and Ti^{4+} are respectively 0.77, 0.65 and 0.61 Å. While the radius of Ti^{4+} is close to that of Al^{3+}, the radii of Fe^{2+} and Fe^{3+} are larger than the radius of Al^{3+} by 45.3% and 22.6% respectively. Consequently, the displacement diffusion of iron ions would cause relatively large distortion in the crystal lattice of blue sapphire. Thus the capacity of Fe to diffuse in sapphire is weaker than that of Ti^{4+} (see *Table II*).

4.3. The meaning of ion diffusion coefficients in sapphire diffusion treatment

The diffusion coefficient of colouring ions plays an important leading role in the process of sapphire diffusion treatment. Because of the differences in the character of Fe^{2+} and Ti^{4+} ions (ion radius, coordination number, affinity with other elements, charge and valence state), their diffusion coefficients in blue sapphire are quite different. Diffusion treatment of sapphire may be either colour-intensifying or colour-lightening. For example, treaters in Thailand have turned

near-colourless sapphires into attractive blue sapphire by diffusion treatment. At one time, because of the high concentration of iron in the blue sapphire of Shandong, its colour was too 'heavy', i.e. dark blue or even blue-black. For improving the quality of Shandong blue sapphire, the concentration of iron ions needed to be reduced, and colour-lightening diffusion treatment was carried out.

In the process of colour-intensifying diffusion treatment of blue sapphire, it is important to control the difference of Fe^{2+} and Ti^{4+} ions concentration in the diffusion reagent and to adjust the ratio of the colouring ions concentration in blue sapphire. In colour-lightening diffusion treatment, we should take account of the loss of Ti^{4+} due to its relatively large diffusion coefficient, compensating with a supply of Ti^{4+} if necessary to achieve the correct ratio of Fe^{2+} and Ti^{4+} for blue sapphire. Much Shandong blue sapphire yields an unattractive grey in the process of colour-lightening diffusion treatment, and the reason is loss of Ti^{4+}.

5. Conclusions

1. Fick's law is important in understanding the process of sapphire diffusion treatment. The diffusion coefficient of a colouring ion can reflect the diffusion ability of ions and diffusion velocity in general. We can also obtain the thickness of the diffusion layer at different temperatures and times using the diffusion coefficient.
2. The diffusion coefficients of the iron and titanium ions are quite different and $D_{Ti} > D_{Fe}$ by a factor of about four.
3. There are many factors affecting the diffusion coefficient. When the coordination number is 6, the radius of Ti^{4+} and that of Al^{3+} are relatively close. This is one of the main reasons why the diffusion coefficient of Ti^{4+} is relatively large.
4. Using the diffusion coefficients of colouring ions, we can monitor the technique of sapphire diffusion treatment effectively, advance the dependability of sapphire diffusion treatment and reduce the waste of gemstone resources.

Appendix. Solution of the diffusion equation

By specifying the boundary conditions in the process of sapphire diffusion treatment and considering the error function, we can solve the diffusion equation. Referring to the situation of the colour-altering technique, we combined the reagent containing the colouring ions (A) with the sapphire to establish the diffusion couple (*Figure 3*).

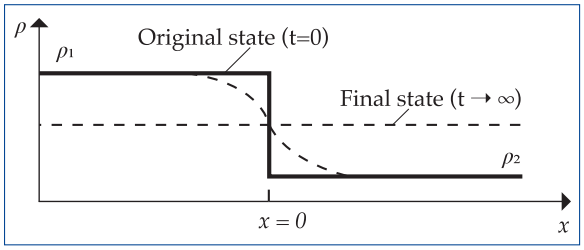

Figure 3: *Model of the solute concentration distribution.*

The solute (colouring ions) concentration in A is ρ_1, while that in B is ρ_2, and $\rho_1 > \rho_2$. When the diffusion couple is heated to a stable temperature, the solute will diffuse under the concentration gradient. The dashed line in *Figure 2* shows the distribution function of solute (ρ) concentration in the direction of x at different times (t) in the diffusion couple. The sapphire diffusion layer is very thin, so as a result, the diffusion components A and B can be assumed to be very large in comparison. So we can also assume that the end-member compositions of the diffusion couple remain unaffected by diffusion. Then the boundary conditions can be derived as follows:

For $t = 0$, $\rho = \rho_2$, at $x > 0$;
For $t = 0$, $\rho = \rho_1$, at $x < 0$;
For $x \to \infty$, $\rho = \rho_2$
For $x \to -\infty$, $\rho = \rho_1$

Through integration, we can then use the Grube-Jedele solution of Fick's second law of diffusion.

$$\rho = \frac{\rho^1 + \rho^2}{2} + \frac{(\rho_1 + \rho_2)}{\sqrt{\pi}} \int_0^{\beta} e^{-\beta 2}\, d\beta \qquad (3)$$

Where, $\frac{2}{\sqrt{\pi}} \int_0^{\beta} e^{-\beta 2}\, d\beta$ is the defined error

function $erf(\beta)$. This yields equation (4)

$$\rho = \frac{\rho^1 + \rho^2}{2} + \frac{(\rho_2 - \rho_1)}{2} \; erf\left[\frac{x}{2\sqrt{Dt}}\right] \qquad (4)$$

However, because $\rho_1 >>> \rho_2$, equation 4 can be written as:

$$\rho = \frac{1}{2}\rho_1 \left[1 - erf\left(\frac{x}{2\sqrt{Dt}}\right)\right]$$

and the appearance of this equation can be improved using the complementary error function to yield:

$$\rho = \frac{1}{2}\rho_1 erfc\left(\frac{x}{2\sqrt{Dt}}\right)$$

Equation (4) shows the solute concentration distribution in the direction of x at different times in the diffusion couple. The diffusion coefficient D is a function of temperature defined as:

$D = D_0 e^{-Q/RT}$

Where:

D_0 = frequency factor,

Q = activation energy of diffusion, $Jmol^{-1}$,

R = gas constant, $Jmol^{-1}. K^{-1}$,

T = absolute temperature, K.

Therefore, equation (4) states the function relationship of temperature, time, thickness of diffusion layer and solute concentration in the process of sapphire diffusion treatment. Through it we can analyze and guide the colour-altering technique theoretically to understand and anticipate the effect of sapphire diffusion treatment.

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Two remarkable taaffeite crystals from Sri Lanka

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Abstract: *Two slightly waterworn taaffeite crystals from Sri Lanka are described. A greyish violet crystal of 2.35 ct with bipyramidal habit exhibits two opposing basal pedions, three different hexagonal pyramids and one hexagonal prism as crystal forms. The morphology of a 0.73 ct chromium-bearing crystal with pyramidal habit is characterized by one pedion and one hexagonal pyramid. Gemmological, chemical and spectroscopic properties of the samples are in the range known for iron- and for iron- and chromium-bearing taaffeites from Sri Lanka.*

Introduction

Since the discovery of the first taaffeite as a cut gemstone in 1945, faceted taaffeites of gem quality have come predominantly from Sri Lanka, with only a few rare stones reported to come from Myanmar and Tanzania. The first 11.23 ct rough waterworn taaffeite crystal from Sri Lanka was described briefly by Saul and Poirot (1984), who mentioned two opposing basal pedions, pyramidal and prismatic faces.

In a more detailed study of five taaffeite crystals from Sri Lanka including the 11.23 ct sample of the John Saul collection, Kampf (1991) determined the crystal faces of the more or less waterworn crystals by means of a contact goniometer. Only one less waterworn crystal permitted reflected light goniometry. According to Kampf (1991), all crystals were described as pale to deep greyish purple and exhibit at least one basal pedion (0001) and two hexagonal pyramids $\{11\bar{2}4\}$ and $\{11\bar{2}2\}$. Additional hexagonal pyramids $\{11\bar{2}\bar{4}\}$ and $\{11\bar{2}\bar{2}\}$ and one hexagonal prism $\{10\bar{1}0\}$ were present in some crystals. Only the John Saul sample was truly bipyramidal with two opposing (0001) and $(000\bar{1})$ pedions. The morphology is consistent with the crystal class of taaffeite (C_{6v} – 6mm).

Chromium-bearing taaffeites are purple, purplish red or red and considered as extremely rare gemstones. The first stone discovered led to some confusion about naming the different minerals of the taaffeite group (see Schmetzer 1983 a, b), and a detailed mineralogical and gemmological description of seven faceted and one rough chromium-bearing samples was published by Schmetzer *et al.* (2000). The rough stone examined in that study was a crystal fragment which showed the pedion (0001) in combination with two pyramids $(\bar{1}123)$ and $\overline{(1123)}$. The eight taaffeites revealed chromium contents from 0.10 to 0.33 wt.% Cr_2O_3 and iron contents in the range of 1.37 to 2.59 wt.% FeO.

The two rough taaffeite crystals of 2.35

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Figure 1a, b: *This crystal of 2.35 ct and measuring 6.8 x 7.2 x 5.8 mm, is taaffeite with a bipyramidal habit and two opposing basal pedions; it is slightly waterworn. Photos: M. Burford.*

Figure 2: *This crystal of 0.73 ct and measuring 4.0 x 5.3 x 4.4 mm is a chromium-bearing taaffeite with pyramidal habit. It is slightly waterworn, and in this picture is resting on a polished window with the crystallographic c-axis near vertical or north-south. Photo: M. Burford.*

and 0.73 ct to be described in this paper were purchased in 2004 and 2002 by one of the authors (MB) in Sri Lanka. The 2.35 ct greyish violet sample (*Figure 1a, b*) is only slightly waterworn and allowed the determination of the complete morphology of another taaffeite crystal. The 0.73 ct red crystal (*Figure 2*) is the second red (chromium-bearing) taaffeite crystal known to the authors.

Materials and methods

The 2.35 ct taaffeite crystal was bought by one of the authors in Ratnapura and was said to come from this area. The 0.73 ct sample was sold by a Sri Lankan gem merchant with the information that the taaffeite was unearthed in a gem pit in the Kuruwita area, Ratnapura district.

The morphology of both samples was determined using an immersion microscope and a combination of techniques for the identification of crystal faces by measurement of specific angles which was described in detail by Kiefert and Schmetzer (1991). For the two taaffeites described in this paper, the accuracy of the measurement of different angles for the determination of crystal faces is estimated to be ± 2 . This accuracy was sufficient for an unequivocal determination of the morphology of the two stones. Standard microscopic techniques were used to examine internal features under different lighting conditions, both with and without immersion liquids.

The samples were identified and confirmed as taaffeites by Raman microspectrometry using a Renishaw 1000 system. Polarized UV-Vis (300 800 nm) absorption spectra were recorded for both samples using a Cary 500 Scan spectrophotometer.

The 2.35 ct violet crystal was preserved as recovered from a gem pit in Sri Lanka, and contrary to common practice in this country, no polished window had been fashioned to determine refractive indices. It was decided not to polish a window on this unique crystal, so although we could determine specific gravity, neither refractive indices by standard gemmological techniques nor quantitative chemical analysis by electron

microprobe could be carried out.

The 0.73 ct red crystal was obtained from the gem trade in Sri Lanka already with a polished window (to measure refractive indices). Standard gemmological methods were used to determine refractive indices (RI), optic character and specific gravity (SG). In addition, we analysed its solid inclusions by laser Raman microspectrometry using the Renishaw 1000 system mentioned above. To further characterize the sample, a Cameca Camebax SX 50 electron microprobe was used to obtain 8 point analyses from a traverse across the polished window of the gemstone.

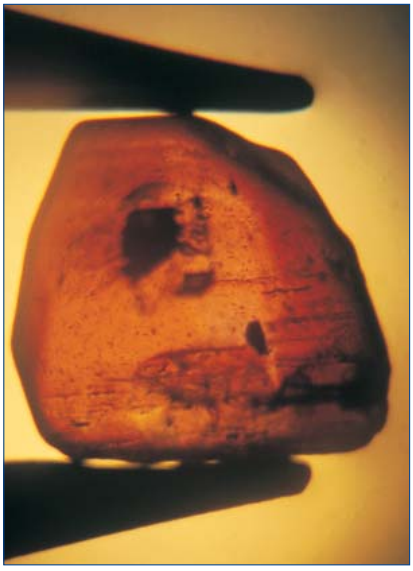

Figure 3: *In this orientation, the taaffeite crystal shows two opposing basal pedions as well as three different hexagonal pyramids, the angles between different crystal faces can be determined using the microscope. Immersion, height of the crystal 5.8 mm. Photo: K. Schmetzer.*

Results

I. Greyish violet taaffeite crystal of 2.35 ct

Morphology

The taaffeite is a completely preserved crystal (*Figure 1*) which exhibits opposing basal pedions, (0001) and $(000\bar{1})$ of different size. Three hexagonal pyramids $\{11\bar{2}3\}$, $\{11\bar{2}2\}$ and $\{11\bar{2}\bar{2}\}$ were determined (*Figure 3*), with $\{11\bar{2}2\}$ being dominant and the remaining two pyramids $\{11\bar{2}3\}$ and $\{11\bar{2}\bar{2}\}$ being somewhat smaller. The hexagonal pyramid $\{11\bar{2}4\}$, which was frequently mentioned by Kampf (1991), is not present in our sample. Subordinate $\{10\bar{1}0\}$ prism faces are also present. An idealized clinographic drawing of the taaffeite crystal is pictured in *Figure 4a*, which is consistent with the visual appearance of the sample in the same orientation (*Figure 4b*).

Gemmological properties and identification

The specific gravity of the crystal was determined as 3.63. Pleochroism was not observed; the sample is inert to both long- and short-wave UV radiation. The Raman spectrum of the specimen is more or less identical with literature data of taaffeites (Kiefert and Schmetzer, 1998;

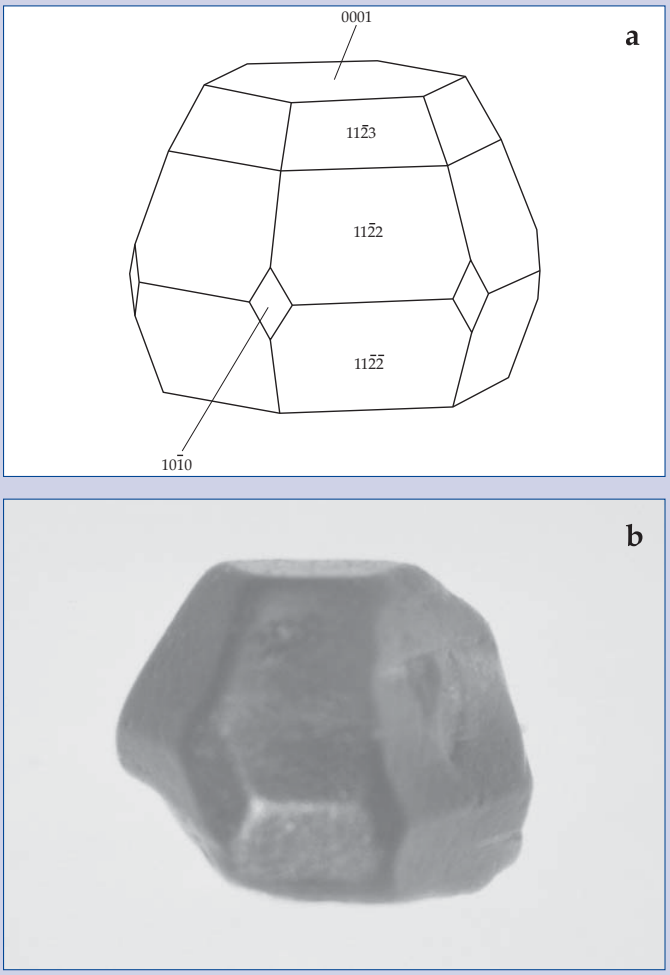

Figure 4: *(a) Idealized drawing of the 2.35 ct greyish purple taaffeite crystal (clinographic projection); the sample exhibits two basal pedions (0001) and $(000\bar{1})$ [below, not visible] as well as three different hexagonal pyramids $\{11\bar{2}3\}$, $\{11\bar{2}2\}$, $\{11\bar{2}\bar{2}\}$ and one hexagonal prism $\{10\bar{1}0\}$ as crystal forms; (b) photo with the sample in the same orientation. Photo: K. Schmetzer.*

Schmetzer *et al.*, 2005).

Features observed with the microscope

Under the gemmological microscope, a few mineral inclusions similar in appearance to apatites determined in other taaffeite samples were observed. The taaffeite crystal also contained several large healed fractures with liquid and two-phase (solid and liquid) inclusions similar to some already described (see Schmetzer *et al.*, 2000).

Spectroscopic properties

Absorption spectra in the UV – Vis range are identical with those of violet to greyish violet iron-bearing taaffeites from Sri Lanka as described by Schmetzer (1983b) and Schmetzer *et al.* (2000). This spectrum pattern is very similar to that of iron-bearing spinel, where the absorption maxima are predominantly assigned to ferrous iron, Fe^{2+}.

II. Red taaffeite crystal of 0.73 ct

Morphology

The crystal (*Figure 2*) is terminated by a pedion (0001) and the hexagonal pyramid {1122}. No other hexagonal pyramids are present. At the opposite end to the pyramids and parallel to its basal face the (originally broken?) sample is terminated by a polished face (*Figure 5*).

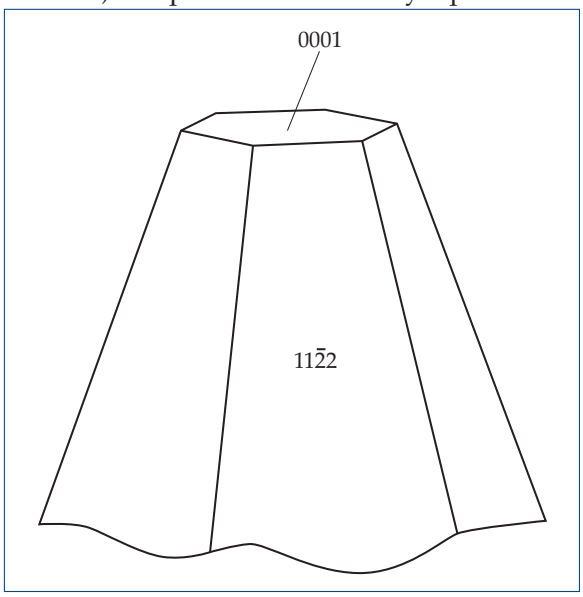

Figure 5: *Idealized drawing of the 0.73 ct chromium-bearing taaffeite crystal (clinographic projection); the sample exhibits one basal pedion (0001) and one hexagonal pyramid {11$\bar{2}$2} as crystal forms.*

Gemmological properties and identification

The colour of the transparent taaffeite is red with a slight purplish tint; pleochroism is light pinkish red parallel to the *c*-axis and somewhat more intense purplish red perpendicular to the *c*-axis. The stone is uniaxial negative and showed clear RI readings with n_o 1.723, n_e 1.719. The SG was determined as 3.63. The sample was inert to both long- and short-wave UV radiation. The Raman spectrum of the specimen is consistent with published data for taaffeites (Kiefert and Schmetzer, 1998; Schmetzer *et al.*, 2005).

Features observed with the microscope

Using the gemmological microscope, with different lighting conditions, with and without immersion, numerous mineral inclusions were observed, and these were identified as apatites and zircons by laser Raman microspectrometry. The crystal also contains a small healed fracture with two-phase (solid and liquid) inclusions.

Chemical composition

The results of electron microprobe analysis are presented in *Table I*. No distinct chemical zoning was observed in a traverse across the polished window of the sample. In addition to the major components of taaffeite, Al_2O_3 and MgO, the crystal contains major percentages of iron as well as minor amounts of zinc and chromium. Smaller traces of other transition metals, e.g. manganese, are also present. Cation proportions calculated for 16 oxygens per formula unit (*Table I*) are in good agreement with the theoretical formula of taaffeite, which requires 8 trivalent cations (Al, Cr, V) and 3 bivalent cations (Mg, Fe, Zn, Mn) per formula unit.

Spectroscopic properties

Absorption spectra in the UV – Vis range are identical with those of chromium-bearing taaffeites from Sri Lanka as described in detail by Schmetzer *et al.* (2000). The dominant chromium absorption band is found in the 550 nm range. The

Table I: *Gemmological properties and chemical composition of a red taaffeite crystal from Sri Lanka*

Gemmological properties

Weight (ct)	0.73	RI n_o n_e	1.723 1.719
Size diameter (mm) height (mm)	4.0 x 5.3 4.4	Birefringence	-0.004
Colour	Red with a slight purplish tint	Pleochroism ‖c ⊥c	Light pinkish red Intense purplish red
Specific gravity	3.63	Inclusions[a]	Apatites, zircons

Chemical composition

Microprobe analysis[b] (wt. %)		Cation proportions based on 16 oxygens (assuming Be = 1.000	
Al_2O_3	71.67	Al	8.009
V_2O_3	0.01	V	0.001
Cr_2O_3	0.11	Cr	0.008
TiO_2	0.01	Ti	0.001
		Sum	8.019
MgO	19.51	Mg	2.757
FeO[c]	2.46	Fe	0.199
ZnO	0.22	Zn	0.015
MnO	0.05	Mn	0.004
		Sum	2.975
BeO[d]	4.39	Be	1.000
Sum	98.47		

a. Determined by Raman microspectrometry.
b. Average of 8 point analyses using a Cameca electron microprobe.
c. Total iron as FeO.
d. Since beryllium is not detectable by microprobe analysis the BeO figure has been calculated for 1 BeO per formula unit; for the theoretical composition of taaffeite ($BeMg_3Al_8O_{16}$) an amount of 4.52 wt.% BeO is required.

different intensity of this band parallel and perpendicular to the *c*-axis is also responsible for the pleochroism of the taaffeite crystal.

Discussion and conclusions

Both specimens described are rare examples of only slightly waterworn taaffeite crystals. The 2.35 ct greyish violet crystal is complete with two opposing pedion faces. In addition, three hexagonal pyramids and a hexagonal prism are present as macroscopically recognizable crystal forms. The 0.73 ct red crystal is only the second chromium-bearing rough taaffeite known to the authors. In both crystals, the hexagonal prism {1122} is the dominant crystal form present. The hexagonal prism {1124} which was mentioned as the dominant crystal form of taaffeite crystals from Sri Lanka by Kampf (1991) is not present in these two crystals.

These morphological results confirm the crystal class of taaffeite as C_{6v} – 6 mm.

Gemmological, spectroscopic and chemical properties of both taaffeites are within the ranges already determined for gem quality taaffeites from Sri Lanka and described by Schmetzer (1983 a, b) and Schmetzer *et al*. (2000).

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Nephrite jade from Scortaseo, Switzerland

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Abstract: *At Scortaseo in the eastern Swiss Alps, two lenses of nephrite jade occur within the central core of a talc orebody associated with metamorphosed dolomitic limestone of Triassic age. Although mining operations were initiated for exploitation of talc, several thousand tonnes of nephrite were also extracted as a by-product. Predominant colours of the nephrite jade are of uneven pale green and grey-green hue. Grain size ranges from fine- to medium-grained and subordinate constituents include calcite and talc. In addition to massive nephrite jade, a major part of the deposit includes a distinctive variety of mixed nephrite-calcite rock termed 'Swiss jade'. It consists of pea-like spherules of nephrite set in a matrix of calcite. The nephrite jade is classified as para-nephrite in type and formed together with talc by intense hydrothermal alteration of dolomitic marble along shear zones. The quantity of nephrite jade available remains uncertain but appears substantial. Recent production involves recovery of material previously discarded during talc mining operations. The nephrite jade is fashioned into costume jewellery at a local workshop nearby at Poschiavo.*

Keywords: *bead, carving, nephrite, serpentinite, spherule, Swiss jade, talc*

Introduction

The nephrite jade deposit at Scortaseo is generally acknowledged as the largest and most significant in Europe. It has been worked for over fifty years for the manufacture of costume jewellery, hardstone carvings and ornamental pieces.

Scortaseo is located 30 km southeast of St Moritz and 4 km south-southwest of Poschiavo in southeast Switzerland (*Figure 1*). From just south of the village of Poschiavo, access to the site is southwestwards along the Selva road, thence by track towards Alpe Vartegna and the Canciano Pass. Here, the eastern Swiss Alps form steep terrain with spectacular and rugged mountains.

The writers carried out a field visit to Scortaseo as part of a wider study of nephrite jade in Europe. This paper provides a brief review and a description of the geological setting of the deposit of nephrite jade at Scortaseo.

Historical background

Mining operations at Scortaseo commenced around 1950 for talc, which was produced to supply nearby Italian paper factories. The discovery of the nephrite jade is attributed to Mr J. Olinto, a local resident, who collected attractive pieces of rock from the discarded spoil materials from the talc mine. He termed one unusual specimen 'Forellenstein' (trout stone) because of the unusual spotted pattern evident on broken surfaces. This was subsequently identified as nephrite jade at the federal technical university (ETH) in Zürich.

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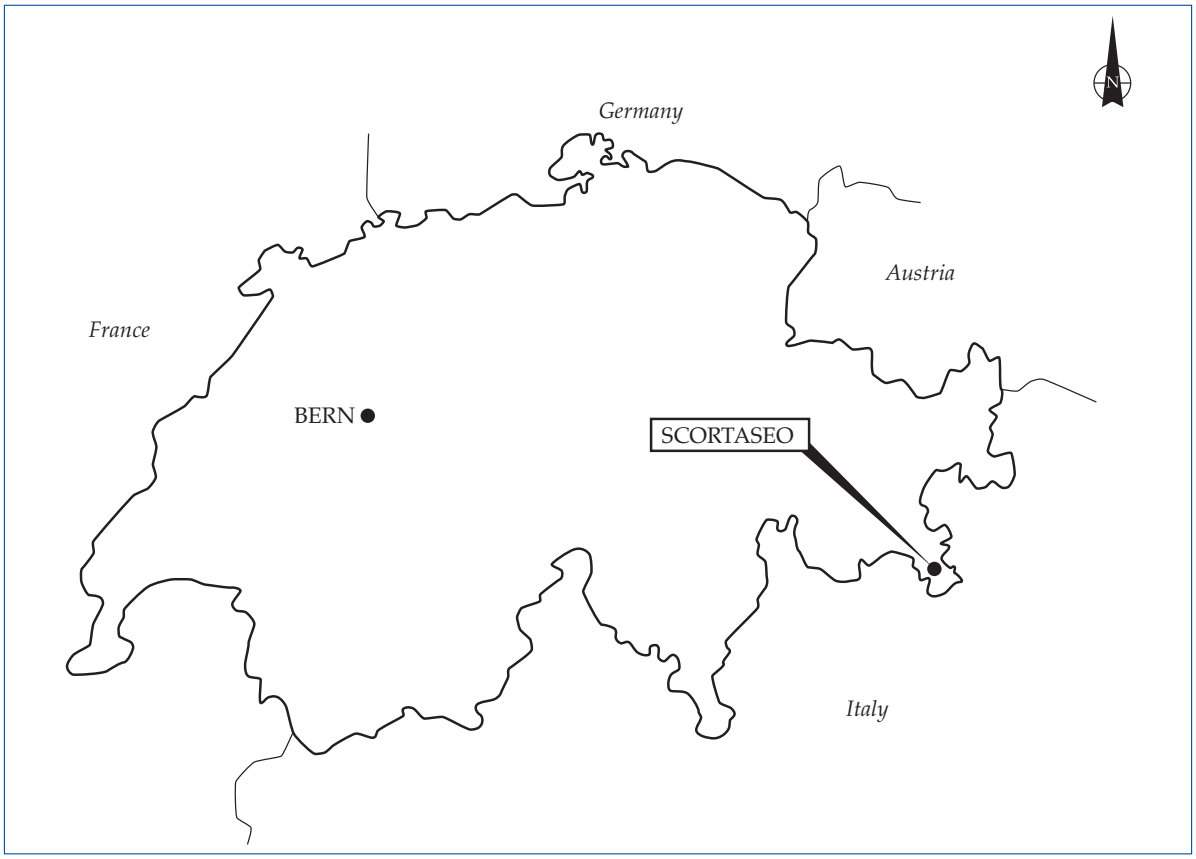

Figure 1: *Location of Scortaseo in southeastern Switzerland.*

Shortly after discovery, a substantial quantity of nephrite jade was produced. According to Jaffé (1986), annual production reached 1500 tonnes of nephrite-bearing rock, some of which was shipped to lapidary workshops in Idar-Oberstein, the German centre for hardstone processing. During the early 1960s, Schweizer Heimatwerk, an organisation promoting Swiss handicrafts, encouraged processing of the nephrite as a cottage industry in the local region (Gross, 1963). They achieved considerable success, marketing a wide range of items including necklaces, cabochons, cufflinks, small cups and dishes. However, by 1993 talc mining operations were discontinued because of the danger of rockfalls and so output of nephrite jade became limited to the residual stockpiles.

More recently, operations at the site have restarted for the production of construction aggregate by reusing the waste rock from the old spoil heaps. The crushed stone (which includes nephrite jade) is used locally for road-making material.

Geological setting

The regional geology of the Scortaseo district appears complex due to extensive tectonic disruptions associated with a stack of Alpine nappes (Penninic and Austroalpine nappe systems). The solid geology is outlined in simplified form in *Figure* 2.

In the neighbourhood of Scortaseo, the principal rock type consists of metamorphosed dolomitic limestone of Triassic age. It overlies basement rocks (mainly augen gneiss) of the upper-penninic Margna nappe with a tectonic boundary separating the two rock types. These bedrocks occupy a complex shear zone between the Malenco serpentinite and ophiolite complex to the west and Austroalpine strata to the east. The structural inlier of dolomitic limestone is thought to be a large block caught up in the shear zone.

The nephrite jade occurs as lenses within the central core of two talc orebodies. The lensoid masses measure around 100 m long by 2-5 m wide and at least 30 m

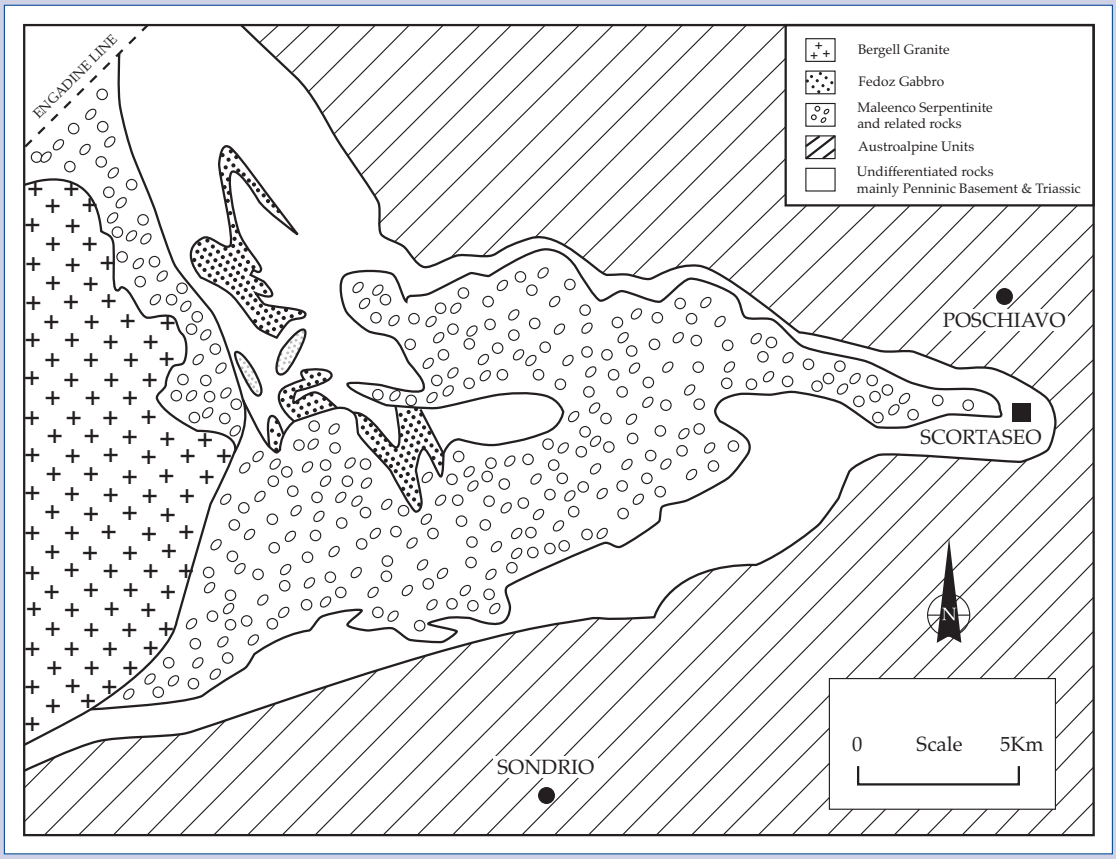

Figure 2: *Simplified geological map of the Scortaseo district.*

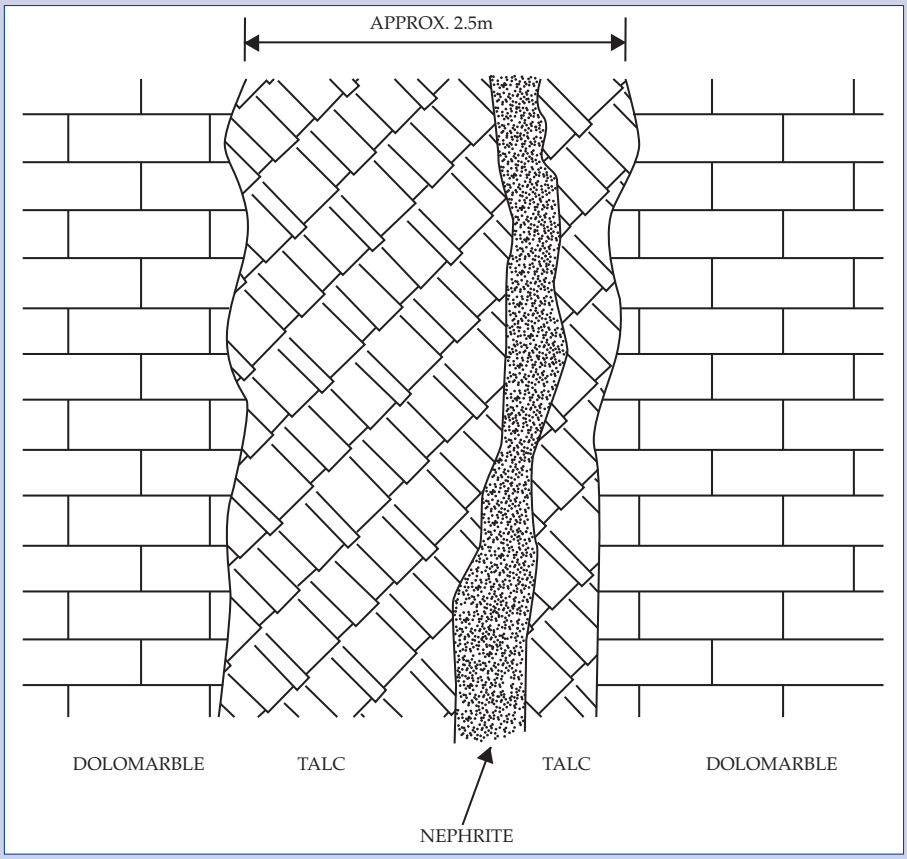

Figure 3: *Schematic section illustrating rock relations at Scortaseo.*

deep. One orebody is enclosed in dolomitic marbles (*Figure 3*) and the other follows the tectonic boundary between dolomarble and muscovite-chlorite gneiss.

Figure 4: *Workings area, Scortaseo. View westwards towards main quarry faces.*

Figure 5: *Workings area, Scortaseo. View northeastwards over platform of spoil material.*

The Scortaseo workings

Dietrich and De Quervain (1968) and Giess (1994) have described the mining site at Scortaseo in detail. The area of workings extends over about 2.5 ha on a steep hillside (*Figures 4 and 5*). Initially, opencast quarrying methods were used to extract the talc and nephrite orebodies and later, adits were driven into the hillside and mining proceeded using underground methods. Today, the extraction area comprises a series of benches and several working platforms formed using waste rock. The openings to the underground workings are inaccessible.

The principal rocks exposed in the quarry are bedded units of dolomitic marble. The dolomarble is fine-grained and ranges from grey and white to pale brown in colour. Minor interbeds of calcite-marble and quartzite are also present, the whole having been affected by mild metamorphism.

Nephrite jade

Massive nephrite jade (*Figure 6*) consists of microcrystalline tremolite-actinolite with a finely felted texture which is intimately associated with minor but variable quantities of calcite and talc.

Using the Munsell notation (Rock-Colour Chart Committee, 1980), the nephrite jade ranges from very pale green (10G 8/2) through greyish yellow green (5GY 7/2) and greyish green (10GY 5/2) to light greenish grey (5G 8/1) and light grey (N7) but is predominantly greyish yellow green (5GY 7/2). Generally, the colours appear somewhat patchy and uneven but clearer coloured areas are quite translucent.

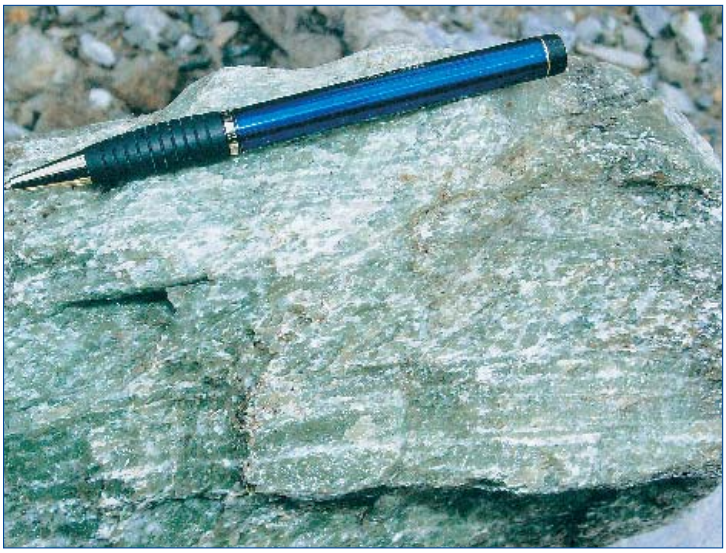

Figure 6: *A typical specimen of massive nephrite jade from Scortaseo. Approx. 200 mm across.*

Swiss jade

A major part of the deposit comprises a distinctive variety of nephrite rock, termed 'Swiss jade', that consists of a nephrite-talc-calcite assemblage with pea-sized spherules and globules of pure nephrite surrounded by talc margins and a calcite cement (*Figure 7*). As far as can be determined, this particular variety of nephrite rock appears unique to Scortaseo. It occurs in close association with massive nephrite jade within the central core of both talc orebodies.

Figure 7: *A typical specimen of 'Swiss jade' from Scortaseo showing spherules and globules of nephrite set in a matrix of calcite. Approx. 200 mm by 100 mm*

The unusual aggregations of nephrite constitute 70-90 % of the rock. They vary from spherical to lens-shaped grains and range in size from 1 to 10 mm in diameter. Certain bands contain only large spherules, others contain only small ones and a few have a mixture of large and small. Cross-cutting veinlets of nephrite are also present.

Typically, the spherules of nephrite are greyish yellow green (5GY 7/2) in colour and the calcite matrix varies between light greenish grey (5GY 8/1) and white (N9). Small amounts of talc form a thin rim or coating around some nephrite spherules.

The formation of the spherules of nephrite appears enigmatic and the origin of the texture is difficult to explain. Conceivably, it may be a relict sedimentary texture inherited from pelletal grains in the original carbonate strata. However, a more likely explanation involves the immiscibility relations between nephrite and calcite and vigorous fluid circulation during metasomatism. The cross-cutting veins of nephrite indicate its formation in at least two generations, so some is most likely to be metasomatic.

Nephrite classification and origin

According to Dietrich and de Quervain (1968), the nephrite jade and associated talc lodes at Scortaseo formed through the metasomatism of dolomitic marbles by the introduction of silicic acid solutions. Based on the field relationships between the nephrite bodies and the metasedimentary dolomarble, the deposits are classed as para-nephrite in type (Nichol, 2000).

It is also noteworthy that the geological features evident at Scortaseo, as well as the close association of the nephrite with a talc orebody, appear remarkably similar to the geological environment reported by Nichol and Giess (2005) for the Mastabia nephrite jade deposit in northern Italy. Indeed, the colour and general appearance of Scortaseo nephrite also appear similar to Mastabia nephrite.

Production practice

The number of small producers of finished items is difficult to ascertain but one significant workshop with a gallery and a shop exists in the village of Poschiavo. It fashions various types of jewellery and specialises in necklaces (*Figures 8 and 9*).

Figure 8: *Necklaces fashioned in nephrite jade from Scortaseo.*

Figure 9: *Beads fashioned in nephrite jade from Scortaseo.*

Conclusions

At Scortaseo in Switzerland, nephrite jade formed in hydrothermally altered zones of intense deformation associated with metamorphosed dolomitic limestone and calc-silicate rocks. The nephrite jade occurs as lenses within the central core of two talc orebodies. In addition to pure, massive nephrite a distinctive variety of mixed nephrite-calcite rock termed 'Swiss jade' constitutes a major part of the deposit. It consists of pea-like spherules and globules of nephrite set in a matrix of calcite.

The rock is categorised as a para-nephrite jade. Colour is predominantly greyish yellow green (5GY 7/2) and texture ranges from fine- to medium-grained microfibrous.

The nephrite jade was originally extracted as waste materials generated during talc mining operations. Substantial quantities of nephrite probably exist in the vicinity of the old workings and in the associated spoil heaps.

Lapidaries and artisans have fashioned the nephrite jade into a wide variety of ornamental hardstone carvings and jewellery pieces.

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Crossed filters revisited

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Abstract: *The crossed filters technique, introduced to gemmologists by Basil Anderson, has not found extensive use due, in part, to the cumbersome excitation filter he used. The commercialisation of new solid state sources, and ready availability of a variety of coloured glasses now makes possible simple and inexpensive means for practice of this fluorescence method.*

Keywords: *crossed filters, chrome-bearing gems, fluorescence, gem testing*

"These instruments and appliances to be of any practical value must be simple and substantial, as cheap as possible, and such that determinations made with their aid can be as well performed by the working jeweller as by a trained mineralogist."
Max Bauer (1904, p.561), writing about instruments for identification of gems.

Introduction

The crossed filters technique in gemmology, was first introduced in 1953 by Basil Anderson in a paper in the *Gemmologist* and later included in the sixth edition of his text *Gem Testing* (Anderson, 1959). The technique is well known to British gemmologists, but appears to be underutilised. In part, this reflects the bulky filter that Anderson used with his light source, a glass Florence flask filled with about 1 litre of copper sulphate solution. More recent mention of the technique in reference works offers little more help, repeating Anderson's filter choices or simply calling for a blue and a red filter (Harding, 1994; Hughes, 1997) giving no specifics. Hughes (1997) does state: "There is no better technique of observing fluorescence in ruby---", with which the authors agree. This paper looks at the history of the method, and offers practical and low cost means for implementing the technique which the gemmologist can easily accomplish.

As implemented in the past, the crossed filters technique principally provided a means of testing for chromium present within several gem materials. It is based on fluorescence due to the chromium ion (Cr^{3+}) present in gems such as ruby, emerald, spinel and alexandrite. The fluorescence is excited not only by ultraviolet light, but also by wavelengths in the visible region. Hoover and Theisen (1993) published excitation-emission spectra for a number of chromium-bearing gems with excitation in the range of 270 to 600 nm. Their results show that the predominant chrome excitation occurs in a blue band and a green-yellow band; the blue centred near 440 nm, and the broader green band centred at or below 600 nm. A central minimum is around 480 nm. Details vary among the various gem species and individual gems. As might be expected the excitation bands correspond approximately to the absorption bands seen in the spectroscope. Ruby shows a much broader excitation band than emerald for example. Their data also show a band in the UV from about 260 to 360 nm which is not very effective at exciting fluorescence.

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Iron quenching increases the wavelength at which fluorescence starts at the UV-violet excitation end. The effect of iron on emission spectra is mostly in an overall reduction in the strength of emission. For emeralds examined, a change of 2 orders of magnitude is seen, and for ruby about 1 order. These data are important in selection of a light source and excitation filter for detection of chromium in gems. The data suggest the optimum source should be broad and extend at least to the orange.

To determine the optimum viewing (emission) filter, the fluorescence spectra of chrome-bearing gems need examination. Most gemmologists are familiar with the 693-694 nm doublet in ruby, and the 'organ pipe' lines of red spinel, principally at 675, and 686 nm. Data from Hoover and Theisen (1993) show that very little emission due to chromium occurs at wavelengths shorter than 650 nm, but that much occurs well into the near-infrared, between 700 and 800 nm. In fact many of these gems have their emission peaks, and most of their emission, in the near infrared. Chrome tourmaline, chrome diopside, chrome grossular, and emerald are examples. Thus, the ideal viewing filter would have a very sharp cutoff near 650 nm, passing the longer wavelengths.

The problem for the practising gemmologist is whether he/she can find practical, inexpensive, light sources and colour filters to implement the technique. This paper presents several possibilities, but the basic requirements given above permit anyone to improve or to modify the details as new sources and filters become available.

A short history

Although the crossed filters technique for use in gemmology is due to Anderson, it was first used many years ago by Sir G.G. Stokes (1819 1903) for determination of very weak fluorescing materials. A dense cobalt glass combined with a thin signal green glass was used as an excitation filter, or a solution of ammoniacal copper sulphate. A yellow glass, or solution of potassium dichromate (yellow) was used for the viewing filter (Wood, 1934). Anderson (1959) mentions Stokes's work, and the possibility of filters similar to those that Stokes used for gemmological work. However, he substituted a simple copper sulphate solution for the blue filter, and, because only red fluorescence is involved with chrome gems, a red gelatine filter was used for viewing. This red gelatine filter was commonly used in photo processing at that time. With good filters the effect is quite pronounced.

Anderson describes it as "like glowing coals against a dead-black background- a sight so beautiful that it still delights the author after years of repetition." (Anderson,1959, p.168). He notes that it was first used as a lecture demonstration, but goes on to say that he found it so sensitive and useful in gem testing that it was constantly in use in the London laboratory. Anderson (1959), and Harding (1994) provide explanations of the use of fluorescence in gem testing, and for which gems crossed filters are most useful.

Another fluorescent effect described by Wood (1934) is important in practice of the crossed filters technique, but not normally mentioned. Fluorescence is principally a surface phenomenon, because the excitation light incident on the surface is absorbed to give the fluorescence. Wood presents an elegant experiment showing that the observed intensity of fluorescence is found to be many times brighter if viewed in a direction perpendicular to the surface, than if viewed through the material. The intensity difference can be greater than thirty times. The implication for the gemmologist would be in general to face the table of a gem towards the blue/UV source so as to present the greatest surface area of the stone to excitation light. Then he/she should view the fluorescence looking towards the girdle, as indicated in *Figure 1*. This also minimises the small amount of direct light that might get through the crossed filters, from transmission through the stone or by reflection from facets. With practice or common use, one will come to recognise the difference between the fluorescence, and light due to

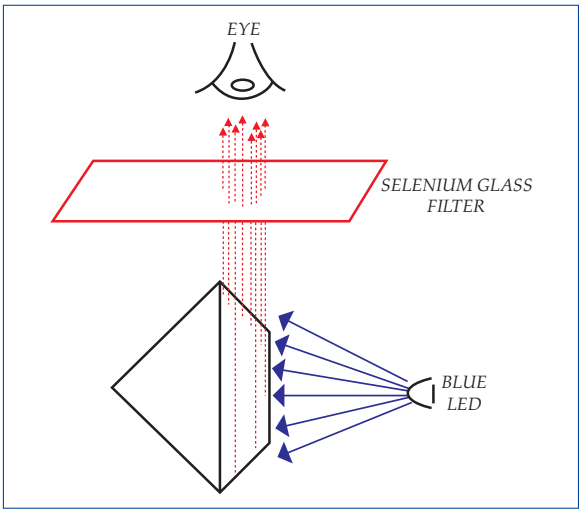

Figure 1: *Schematic diagram showing optimum illumination and viewing orientation for examination of a weakly fluorescing gem.*

simple reflection from facets. For strongly fluorescing gems there will be little need for orientation. It should also be noted that fluorescence from some solids is polarised. This can be seen in ruby by observing the change in the fluorescing image while rotating a polaroid plate during observation of the gem.

Modern sources and filter materials

Technology has given today's gemmologist a much wider range of light sources and advanced filter materials than Anderson had in his day, opening the possibility that simpler and perhaps less expensive components might be used for implementing a crossed-filters inspection unit. The authors are continuing to look at a number of possibilities with the prime motivation to keep costs low. For this reason, modern interference filters which can be tailored to almost any pass/block range have not been examined in detail, because they would make for rather expensive equipment. The focus was on keeping cost low enough for any gemmologist to be able to get materials and set up a simple viewing unit.

With the popularity of hobby stained glass work, a wide variety of coloured glass is now available everywhere. This was an obvious source for filter material. Two common glasses available to the hobbyist are blue cobalt and red selenium glasses (*Figure 2(a)*), whose spectra are given in Gem-A's introductory course, since they are used in glass simulants. The selenium glass with only a pass band in the red cutting at 630 nm makes a good viewing filter if an appropriate source-excitation filter combination can be found. *Figure 2(b)* shows the transmission spectra of selenium, cobalt and a green glass used by the authors. All spectra shown were obtained with an Oceans Optics S-2000 spectrometer and software running on a personal computer. Light from the cobalt glass has some red components that would pass the selenium glass, so a means of limiting this is needed. A green glass, similar to Stokes's signal green, was found at a local stained glass shop, and this was found to cut some of the red that passed the cobalt glass (*Figure 2*). This also passed more light in the green where greater fluorescence should occur. Other green to violet glasses were also tested.

The coloured glasses were all 2.5 mm thick, and had no patterning so that one could read print through a sheet. A single pane of selenium glass for viewing, and one and two thicknesses of the cobalt and green glasses were tested for minimum transmission using an incandescent source. The bulb filament could be seen in all cases, but other light was not evident. In use, the double pane cobalt filter appeared to give the best viewing when testing with a synthetic ruby. This appears to give adequate results for a simple crossed-filters apparatus, and is quite simple and inexpensive.

Also tested was a fluorescent light source using cool white bulbs which produced little light at wavelengths longer than 650 nm. This source, with two panes of the cobalt or green filters, produced better results than with an incandescent source. The cobalt glass is better than the green, producing an essentially black background against which the ruby appears as Anderson described it, "a glowing coal". Thus, the crossed filters technique can easily be implemented by any

gemmologist for a few dollars. Comparison illumination spectra for an incandescent, a cool white fluorescent source, and a white Light Emitting Diode (LED) source, all with the cobalt glass filter are shown in *Figure 3*. The disadvantage of an incandescent source used with a cobalt glass filter is seen by the relatively large amount of red light present in such an excitation source.

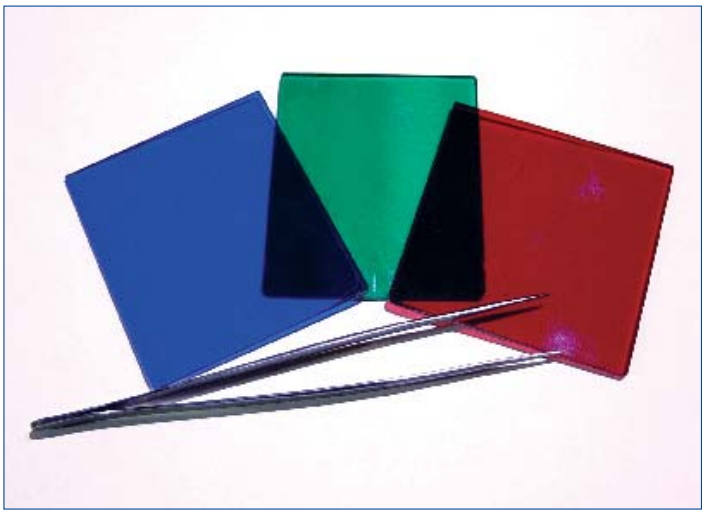

Figure 2a: *Photograph of the glass filters used in this investigation with gem tweezers for scale.*

The applicability of solid-state sources was also investigated. Recently available are LED sources in various colours including a bright blue and green, sold as miniature flashlights (torches), in addition to white LED torches. The blue produces little emission in the red, and from *Figure 3* is very near to the excitation provided by a white LED and cobalt glass excitation filter. All these LED sources are quite intense, and inexpensive. We also tested a three-element LED white source, using one pane of cobalt glass for an excitation filter (*Figure 3*), and found this excellent as well. The high brightness of the LED sources gives increased fluorescence from a gem. While a 'white' LED source may be used effectively with a cobalt glass filter the authors strongly recommend that the blue LED discussed below be used due to the simplicity of not needing a separate excitation filter.

Various blue LED units and one green unit have also been tried by the authors and appear very similar in effectiveness. Tests were made with these sources, and with no source filter on synthetic ruby. The results

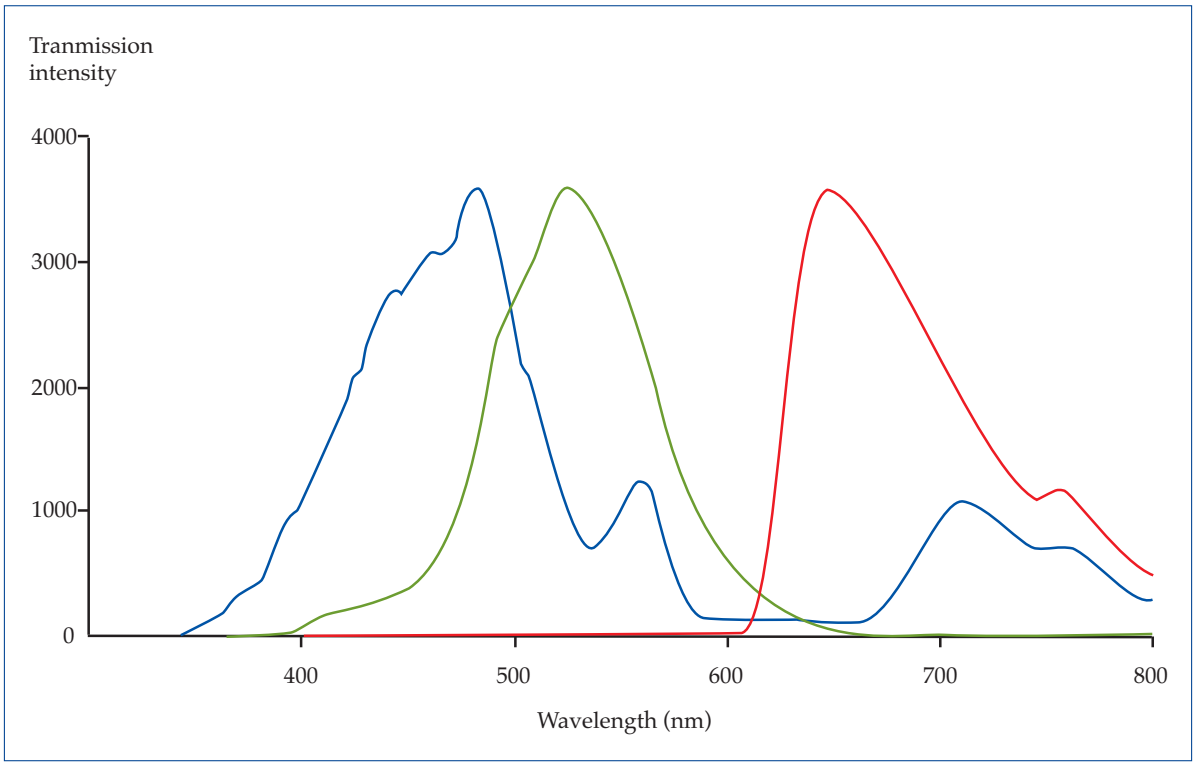

Figure 2b: *Transmission spectra of green (green curve), cobalt (blue curve) and selenium (red curve) glasses taken with an incandescent source.*

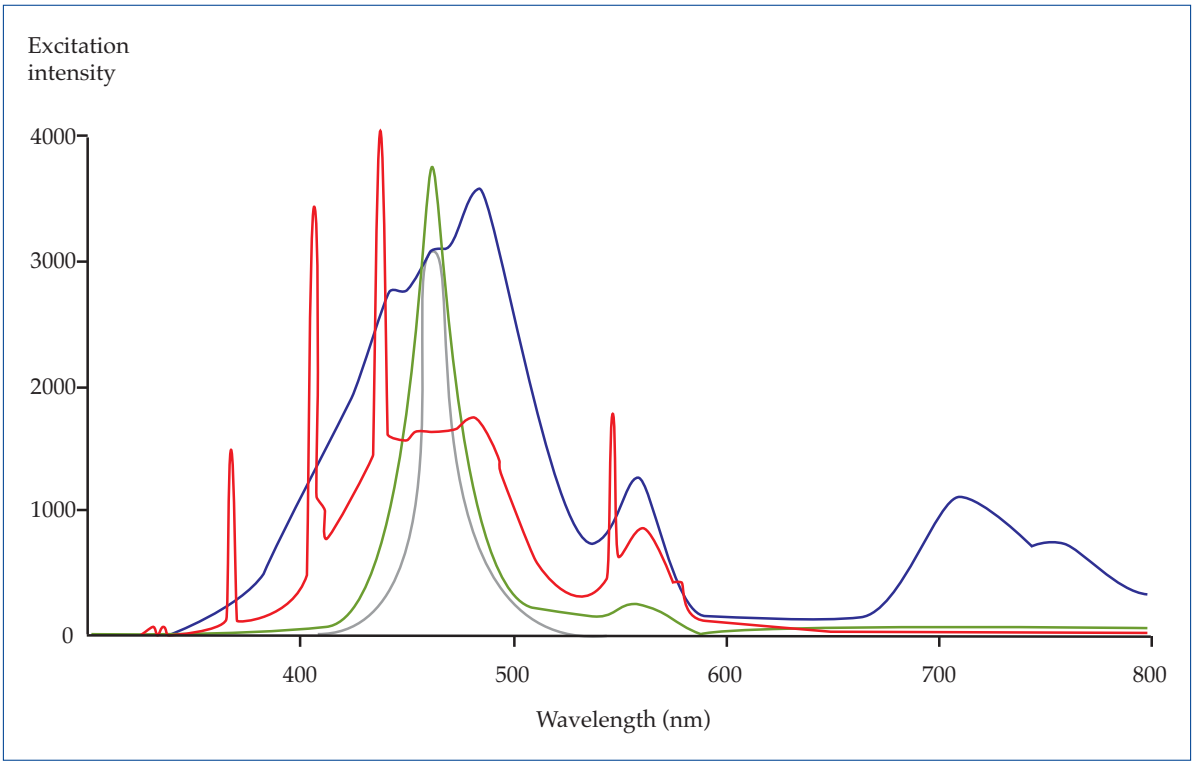

Figure 3: *Excitation spectra for a cobalt glass filter with incandescent (blue curve), fluorescent (red curve) and white LED (green curve) sources, and a blue LED (black curve) source.*

were truly amazing when the source was within a centimetre of the stone, which appeared almost alive (*Figure 4*). For ruby and red spinel the green source gave stronger fluorescence, as would be expected from the results of Hoover and Theisen (1993). However, there was too much transmission in the red for it to be considered as effective for weakly fluorescing gems. The authors will continue to investigate green sources, but for this paper will concentrate on the blue LED source. Readers are encouraged to experiment further.

For simplicity of use, effectiveness and cost (under $10) the blue LED source and single pane of selenium glass are recommended as the most practical, and best, way to implement the crossed filters technique. The equipment will fit in a shirt pocket or purse, and one is ready to test anywhere, especially when buying in the field, where it would be easy to test a parcel of stones quite rapidly.

Note should be made of the potential for extending the utility of the technique to those chrome-bearing gems fluorescing

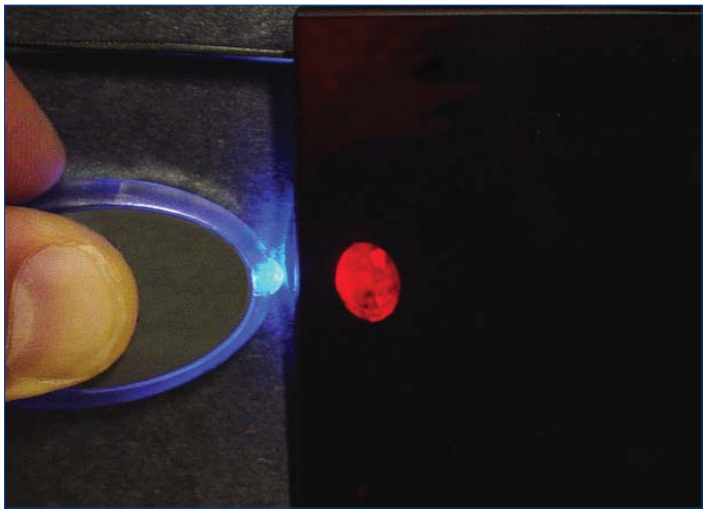

Figure 4: *Photograph of a synthetic ruby fluorescing using the crossed filters technique. Excitation with a blue LED source, and viewed with a selenium glass viewing filter. The selenium filter only covers the ruby.*

at wavelengths in the near infrared range, longer than 700 nm (emerald, jadeite, kyanite, chrome tourmaline, chrome diopside, chrome grossular, and probably others) by the use of infrared sensors, such as night vision devices, or cameras. Viewing should extend to 800 nm for best results. Harding (1994) notes

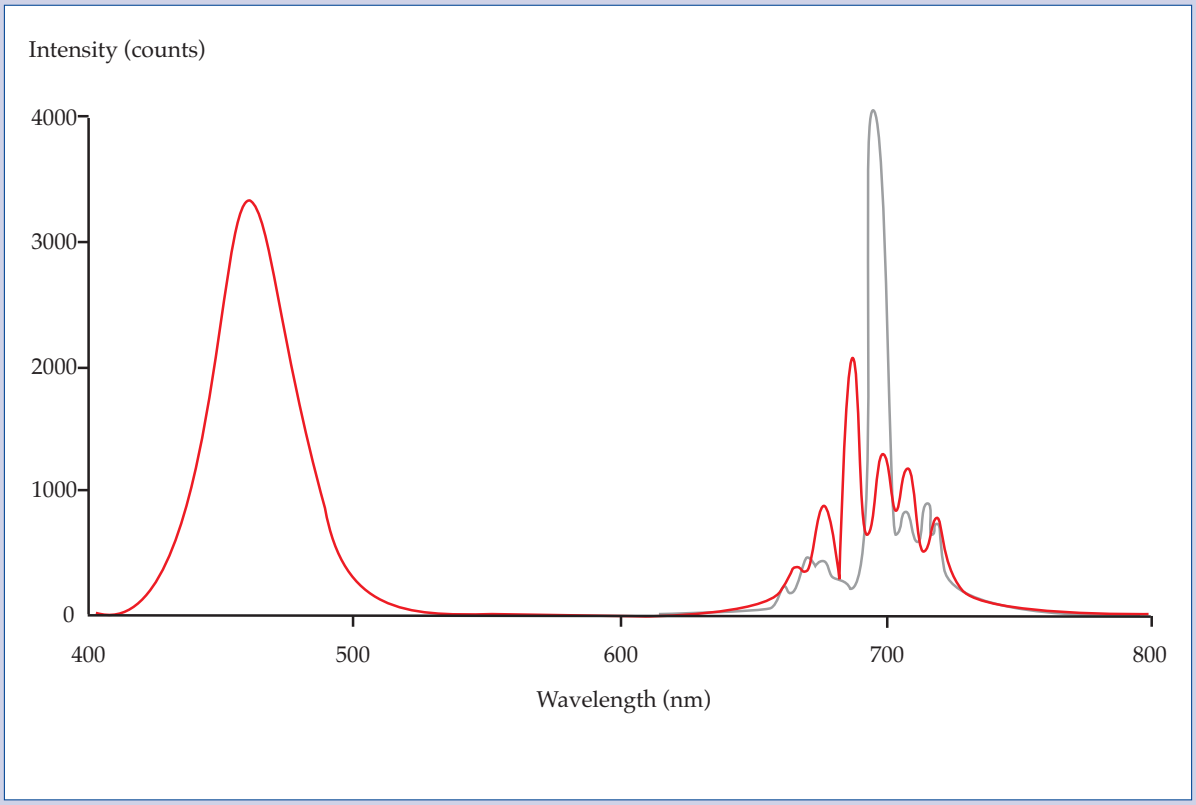

Figure 5: *Emission spectra of ruby (blue curve) and red spinel (red curve) from Myanmar using a blue LED for excitation. In the case of the spinel (red curve) the excitation curve of the blue LED has been superposed on the spinel emission, and shows as the prominent band between 400 and 500 nm.*

that Mitchell used a photographic infrared filter in place of the conventional red viewing filter, but evidently his eye was the sensor. His vision range would have been limited to a very narrow band near 700 nm, but Mitchell does note that synthetic emeralds were much more brilliant than natural stones with this combination. The fluorescent emission spectra of ruby and red spinel from Myanmar are shown in *Figure 5*, and for Sri Lankan sinhalite, mottled Myanmar jadeite jade, and Colombian emerald in *Figure 6*. The latter especially show that much emission occurs at wavelengths longer than 700 nm, and is a convincing illustration of the potential for examination of this region.

Comments on practical application

Gems that fluoresce strongly can be viewed in a normally lit room by limiting the amount of extraneous light entering the test region. For some gems the fluorescence is evident even without a selenium glass viewing filter. However, for best results crossed-filters testing should be done in a darkened room, eyes dark-adapted, and with the gems to be tested placed on dead black paper. This is essential for very weakly fluorescing gems such as sinhalite which, the authors discovered, may be separated from peridot in this simple manner. An added advantage of using visible light for excitation is that common glass lenses may be used to focus the blue or green light to a small intense spot if needed.

The authors have not done extensive testing either on large quantities of gems, or on gems from numerous sources. The applications for crossed filters given by Anderson (1959) and Harding (1994) are in general confirmed by our testing. However, the reader should remember that the excitation wavelengths we used are somewhat different than those produced by an incandescent source and a copper sulphate filter, so emissions may differ as

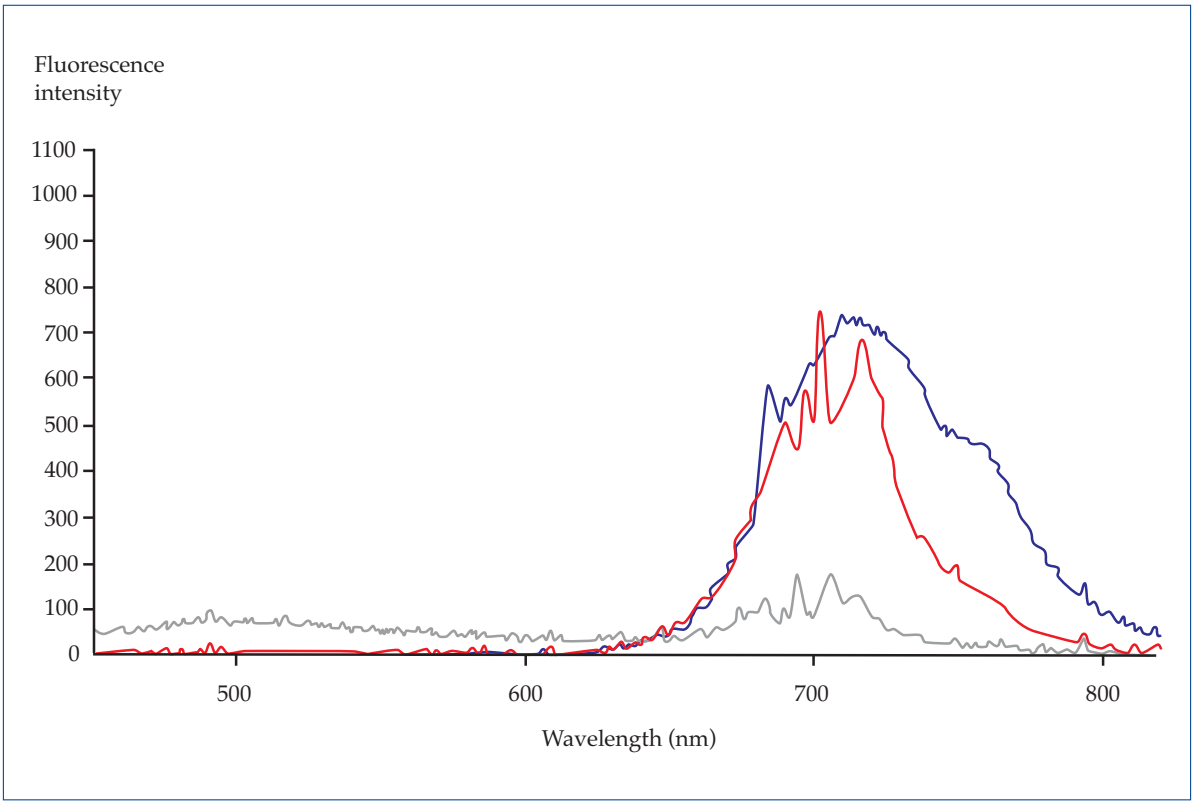

Figure 6: *Emission spectra of Colombian emerald (blue curve), Myanmar jadeite jade (red curve) and Sri Lankan sinhalite (black curve) using a blue LED for excitation.*

well. This corresponds to the differences Harding (1994) cautions about between different ultraviolet sources and illustrates in his figure 36.10. Harding also comments that comparison of luminescent response between two or three different illuminants can greatly increase the value of fluorescence in diagnostic testing. Having a simple means for crossed-filter testing adds another dimension to discrimination by traditional ultraviolet excitation methods. The authors have noted that in general the longer the wavelength of excitation light used the stronger the emission. Results reported below are from preliminary testing using a blue torch. Much additional testing is needed before the full capability of this variation on crossed-filters is known.

Results using a blue source

Looking at chromium-bearing gems, it is clear that there is a large variation in the strength of fluorescence of natural stones of one type, even from one source. In the following we will summarise what we have observed from limited observations.

All rubies observed fluoresce, the strongest being synthetic stones and natural rubies from Myanmar. Thai stones give a weak to moderate response, as expected from their iron contents. The strong emission at 694 nm is visible as the dominant emission in *Figure 5*.

Sapphires for the most part don't respond, although some light-coloured stones, light blue, pink, yellow or colourless, of varied provenance give a moderate to good response.

Red, and some lilac to purple spinels show good to poor responses. Myanmar stones fluoresce strongly. *Figure 5* shows that the 'organ pipe' lines of red spinel extend well beyond 700 nm.

Chrysoberyl is inert except for alexandrite although this varies according to source. From Minas Gerais, Brazil and India, alexandrites respond well to a blue light, in contrast to no response for the deep coloured cabochon material from Carnaiba, Bahia, Brazil.

Natural emeralds from different sources also show different responses, ranging from a strong response from Colombian stones to no response from Carnaiba, Brazil stones; this is generally similar to Anderson's observations. The good response of Colombian stones may reflect the generally low iron content in comparison with emeralds from other localities (Schwarz, 1987). However, concentration of chromium also determines the intensity of fluorescence and Colombian stones show higher average chrome contents than stones from deposits other than Brazil. This question needs further examination. Because almost all of emerald's fluorescence is in the infrared (*Figure 6*), we suspect that part of the variability in reported visual response is due to differences in human vision, and to differences in excitation spectra.

Jadeite jade from Myanmar was quite variable, ranging from a good response to no response. Mottled green/white cabochons may show red fluorescence with little correlation to visual colour patterning. *Figure 6* shows that the two principal emission peaks are on the high-wavelength side of 700 nm.

Examination of topaz showed that chrome-bearing varieties do fluoresce red, and give a much stronger response to the blue light than they do to LWUV. Brown, colourless, and blue varieties from volcanic or pegmatitic sources were found not to fluoresce. Many samples from the Ouro Preto district, Brazil, do react, with the strongest response from those having pinkish tones in white light, while light coloured to pure yellow stones show very weak to no response. The rare pink topaz from Brumado, Brazil, gives a strong response, as does the amber to pink topaz from Ghundao Hill, Pakistan. This probably reflects low iron contents coupled with significant chrome contents. Surprisingly, the pale yellow Schneckenstein topaz of Germany gave a moderate response from two samples tested. This substantiated the reports of crimson and pale violet topaz from the deposit reported many years ago by Feuchtwanger and Streeter, as mentioned by Hoover (1992).

Demantoid, and tsavorite garnets both gave no visible response – understandable because their emissions are weak and too far into the near infrared to be seen.

Because the blue torch/selenium glass combination was so effective for many common chrome-bearing gems, it was tested on a large variety of other stones. The results show that some other UV-fluorescing gems also fluoresce by crossed-filters examination.

Some surprises were found when comparing responses to LWUV and the blue LED crossed-filter technique. Diamonds give different responses to LWUV and to blue excitation. Diamonds that fluoresce blue-white under LWUV show varying strengths of orange to red fluorescence under blue light without a viewing filter, and red with the filter of course. Diamonds fluorescing yellow to whitish-yellow under LWUV, show a varying strength orange without the viewing filter, and red with the filter. In some stones the fluorescence is stronger under blue excitation than under LWUV. In the above tests with diamonds, it was found that a yellow viewing filter such as Stokes used, is a better detector of any response and colour differences due to the better match between the emitted light spectrum and the pass band of the yellow filter.

Other stones tested that fluoresced include: anorthite, Alaska, very weak; light coloured apatites, weak, but blue and green ones gave no response; calcite, some fluorescent varieties good; brown fluorite, Clay Center Ohio, strong, others no; colour-change garnet, Madagascar, fair; kyanite, Nepal, and Brazil, weak; scheelite, weak; sinhalite, Sri Lanka, very weak; sphalerite, weak; spodumene, weak to moderate, with no apparent relation to colour; tugtupite, good.

Of the organic gems, amber, ivory, and red coral all gave fair to good responses. The real surprise was the sinhalite which is considered to be non-fluorescing (Henn, 1994). Although the response is extremely weak, tests on three samples have shown that it can be differentiated from peridot if care is taken with the crossed-filters technique. *Figure 6* shows the emission spectrum of one

of the examined sinhalites, suggesting that chromium is present.

Summary

The red selenium glass and blue LED are simple and easy to use. The authors believe that the sources and filters described in this paper provide an important advance in application of the crossed-filters technology because it can be easily implemented by the average gemmologist at very little cost. However, with technology advancing at a rapid pace it would not be surprising if even better sources and/or filters become available in the near future. The information given in this paper should be sufficient for any gemmologist to easily determine which future technical advancements he/she might be able to adapt to the method.

The authors expect that this simple procedure will aid gemmologists in separation and discrimination between a number of gems. However, development and effectiveness of the technique will depend on testing sufficient quantities of stones, looking for differences to assist in distinguishing between synthetics and natural stones, and in distinguishing provenance. We feel that it should supplement conventional UV fluorescence testing. Also, with potential to exploit in the deep red region, it is possible that infrared-sensitive (digital) cameras could extend the limited range of the human eye.

Acknowledgements

The authors thank G. Pearson, Melbourne, Australia, for many stimulating discussions on spectral responses of gemstones, from which the impetus to pursue this study was derived, and the Stone Group Labs for the use of their spectrophotometers.

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Letters to the Editor

Asterism and chatoyancy

Further to the recent paper on asterism and chatoyancy[1], as far as I have been able to ascertain, the credit for being the first to draw attention (in 1981) to the position of the image in asterism must go to A. Wüthrich and M. Weibel[2]. They quote, as I did, the standard optics formula for the position of the real image formed when light passes through a plano-convex lens backed by a mirror. They consider, however, that the fundamental process in asterism is the scattering of light by thin cylinders, rather than reflection.

A.R. Moon and M.R. Phillips[3,4] point out that, in sapphire, the inclusions are flat strips, not cylinders, and further that the scattering model does not account for the observed fact that sharper stars result when the inclusions are long, rather than short. They say that a mechanism which does fit these observations is Fraunhofer diffraction. Babinet's Principle is cited to allow the opaque strips to be considered as if they were slits of the same dimensions. The authors agree with Wüthrich and Weibel about the position of the image.

So, although my paper turns out not to be the first to draw attention to the position of the image in chatoyancy and asterism, I hope it will have served a useful purpose in repeating this information, which seems not to have had the attention it deserves.

Harold Killingback FGA
Oakham, Leicestershire

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Use of the polarising filter on the refractometer

I was sorry to find that B.D. Sturman, author of the article 'The use of the polarising filter on the refractometer' (*Journal of Gemmology*, 2005, 29, 5/6) has not acknowledged two published works on this subject[1,2]. Contrary to the claim in the abstract, the stated method suitable for gemmologists unfamiliar with the indicatrix to use a polarising filter with the refractometer is, I feel, not strictly a 'new comprehensive method'. What Sturman is offering is an original table and his own approach to a known method.

However, in this table there is a minor error in that if instructions in pattern number I were followed, a person could fail to correctly diagnose a constant RI of 1.597 as a rhodochrosite with optic axis perpendicular to the facet because for this pattern a polarizing filter is not used. For those who find his diagrammatic representations easier to consider than the other approaches referred to above, I recommend a correction in 'pattern number I' with this polarising filter reference changed from 'not used' to read instead 'rotated, no blink confirms isotropism; for blink use pattern II or IV, presuming one shadow over the limit'.

Richard Cartier
Toronto, Ontario, Canada

1. Hodgkinson, A., 1992. Simple advanced refractometer technique: determining optic sign. *Canadian Gemmologist*, XIII(4), 114-17
2. Cartier, R.H., 2004. *Seeing the light, understanding optics without the mathematics.* Published by the author. ISBN 0-9735316-1-4, pp 234-44

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Response from B.D. Sturman

In the article I took special care to use terms such as 'new approach' and 'graphical presentation' when referring to the set of instructions in the Table, and I describe in detail what is new and what was taken from the selected published works. The term 'new comprehensive method' in the abstract was chosen by the editor; I am sorry I missed it during the proof-reading.

I do not believe that the instructions in the Table should be changed so that the polarising filter *must be used every time* a single shadow edge is observed. This would be the required procedure in order to avoid problems with rhodochrosite identification. (The gemstone must be cut in a very special orientation - the gem table is *exactly* perpendicular to the optic axis). Read, 1999[1] (see the reference in the article) provides examples of other gemstones on page 89 (smithsonite and painite) that may cause similar problems. This problem will be dealt with in a separate note that will be given in an article (in preparation) with a description of other possible problems, for example, biaxial gemstones with small 2V – producing patterns similar to uniaxial gemstones.

Determination of the optic sign in biaxial gemstones (when ß is determined) is not as useful as determination of 2V (for example in identification of sinhalite or peridot). It does not require additional time if the optic angle diagram is kept next to the refractometer.

There are several reasons why references mentioned in Cartier's letter were not listed in my article. The Hodgkinson article[2] was not mentioned because my article was not intended as an overview of the methods presented in the literature; its main thrust was to describe a new approach and a new graphical presentation. I have great respect for Alan Hodgkinson and his work, but his article in the *Canadian Gemmologist* was not needed for the description of the new approach.

On the other hand, Cartier's book[3] was not mentioned for very different reasons. The *Canadian Gemmologist*, Autumn 2005, contains a review of the book which is very negative. The reviewer listed many confusing or incorrect statements in the book and readers should be aware of these.

However, I decided not to quote the book for another reason. In his two articles on doubling[4,5] and one article on the optic axes[6] in *The Journal of Gemmology*, Cartier gives many confusing and incorrect statements. The best example is Cartier's description of birefringence as a "property of the medium" and double refraction as "the action of light as it enters the medium". It does not have any practical use and can only result in confusion. Every optical property is determined by observing the interactions of light and a gemstone – all optical properties are properties of the medium. This is a fact that has been accepted for hundreds of years and stays the same no matter how much we discuss "the use of the plural, the singular and contractions maintain the same conceptions throughout to avoid optics theory confusion," or that "Refraction, double refraction, birefringence and refringence should have continuity of concept between the singular and the plural." (The quotes are from Cartier's articles). I do not want to use a book as a reference if I find it confusing and I do not believe that readers would be well served by referring them to it.

Darko Sturman
Curator Emeritus, Royal Ontario Museum

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Abstracts

Diamond

Colombian diamonds.

T. Chavez-Gil and F.H. Romera-Ordoñez. *Gemmologie. Z. Dt. Gemmol. Ges.*, 53(2/3), 2004, 67-78, 10 photographs, 2 maps, 2 graphs, bibl.

The alluvial diamonds were found in gravel deposits in the south-eastern part of Colombia in the Alba Rosa stream in the Eastern Cordilleras, near the border with Venezuela and Brazil. The origin of the deposits is assumed to be in the Roraima series of Precambrian rocks, which in Venezuela, Brazil and Guyana are in parts diamond bearing. All examined material showed certain etch and corrosion markings which was taken to be proof of transportation in some corrosive medium, i.e. kimberlite or lamproite magma. In the gravel concentrate various heavy minerals were present, such as pyrope, almandine, ilmenite and some traces of olivine. The occurrence of these diamonds is rare. 100 diamonds were studied, mostly between 1 and 3 mm in diameter, but some up to 5 mm have been found. E.S.

Coated pink diamond -- a cautionary tale.

D.J.F. Evans, D. Fisher and C.J. Kelly. *Gems & Gemology*, 41(1), 2005, 36-41.

The examination of a cut 0.85 ct purple-pink diamond, reputed to have been HPHT treated, determined that this diamond, probably pale yellow originally, had been coated to change its colour. A microscopic examination revealed evidence of a coating only on the pavilion faces. This coating may have been calcium fluoride with a gold impurity added either to generate the absorption responsible for the pink colour or to assist as a nucleating agent for the calcium fluoride film. R.A.H.

Diamond mining project Panna: an overview.

A.K. Gupta and R.K. Garg. *Indian gemmologist*, 13(1/2), 2005, 13-8.

The Panna diamond area is situated in the north of Madhya Pradesh at the junction of the Bundelkhand and the Vindhyan regions. Details are given of the occurrence with notes on its history from its discovery in 1827 through its various upgrades up to the present. Mining is entirely mechanised; 28% of the crystals recovered are of gem quality, 38% are off-coloured and 34% dark brown or industrial quality. M.O'D.

Gem news international.

B.M. Laurs (Ed.) (blaurs@gia.edu). *Gems & Gemology*, 40(4), 2004, 334-57.

Items noted included a 1.33 ct orange-yellow natural diamond with an estimated 30-50 ppm of Ni. R.A.H.

The diamond pipeline – A literature review.

H.H. Lim. *Australian Gemmologist*, 22(6), 2005, 244-52, 4 Illus., I table.

The traditional diamond pipeline which traces the passage of rough diamonds from the mine to the market has been modified by the changes that have taken place in the diamond industry since De Beers was privatised and its business strategy was revised. The review includes brief descriptions of the history of diamond trading, prospecting, mining and recovery, the Central Selling Organisation (its role and its renaming as the new DTC), sorting and valuing, the Sights, cutting and polishing, diamond clubs and bourses, jewellery manufacturers and the retail market. P.G.R.

Global occurrences of primary host rocks of diamonds.

T. Marathe. *Indian Gemmologist*, 13(1/2), 2005, 50-3.

The geology of some of the world's major diamond deposits is discussed with particular reference to Indian sites. M.O'D.

Lab notes.

T.M. Moses, I. Reinitz, S . F. McClure and M.L. Johnson (Eds). *Gems & Gemology*, 40(4), 2004, 323-33.

Notes are given on a yellow-luminescent 2.03 ct 'hopper' diamond and a 0.12 ct Fancy Intense purplish pink natural diamond showing apparent magnetism (due to iron-bearing residue in surface cavities) R.A.H.

Lab notes.

T.M. Moses and S.F. McClure (Eds). *Gems & Gemology*, 41(1), 2005, 42-50.

Notes are given on HPHT-treated type IIa yellow diamond and on an inhomogeneous yellow type Ia Cape diamond. R.A.H.

Evolution of the Indian diamond industry.

J. Panjikar and K.T. Ramchandran. *Indian Gemmologist*, 13(1/2), 2005, 27-38.

The beginning of diamond production in India is believed to go back 3500 years. Geographical and geological details are given for the northern, southern and eastern groups of mines. Two maps pinpoint the main areas. M.O'D.

Kalimantan diamond.

Tay Thye Sun, P. Wathanakul, W. Atichat, Ling Heng Moh, Lee Kien Kem and R. Hermento. *Australian Gemmologist*, 22(5), 2005, 186-95, 9 illus., 1 map, 1 table.

Diamond occurs in commercial quantities in the Indonesian state of Kalimantan which is part of the island of Borneo. These diamonds are found mainly in West, Central and Southeast Kalimantan. They are of fine quality and are recovered in a range of fancy colours such as blue, pink and canary-yellow. The authors visited the diamond mines in the Banjarmasin-Martapura area of Southeast Kalimantan in March 2002 to study mining and trading activities. They purchased 14 diamond specimens for further study, and this paper contains a description of the morphology, surface and spectroscopic features of these diamonds. P.G.R.

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Treated-color pink-to-red diamonds from Lucent Diamonds Inc.

W. Wang, C.P. Smith, M.S. Hall, C.M. Breeding and T.M. Moses. *Gems & Gemology*, 41(1), 2005, 6-19.

Naturally-coloured diamonds in the pink-to-red range are among the most exotic and expensive gemstones. Lucent Diamonds of Denver has developed a new treatment process for natural type 1a diamonds that produces colours ranging from pink-purple through red to orangy brown, using a multi-step process that involves HPHT annealing, irradiation and low-pressure annealing at relatively lower temperatures. The stones that achieve a predominant pink-to-red or purple colour are marketed as 'Imperial Red Diamonds'. The gemmological properties and characteristic spectra for 41 of these diamonds are described. They can be readily identified by distinctive colour zoning, internal graphitisation and surface etching, and reactions to long- and short-wave UV radiation. The colour is caused by the absorption of the (N-V)- centre, with further influence from other centres; the IR absorption spectra are presented. R.A.H.

Gems and Minerals

A miscellany of organics – part 3.

G. Brown. *Australian Gemmologist*, 22(6), 2005, 264-8, 15 Illus.

This is a further compilation of laboratory reports that cover a range of identification problems associated with organic gem materials. Included are Berber beads, dyed paua shell, 'rattler' pearl beads, and lacquerware. P.G.R

Gemstone treatments – are they stable?

G. Choudhary and C. Golecha. *Indian Gemmologist*, 13(1/2), 2005, 54-7.

Common gemstone treatments are listed with examples and notes on stability. M.O'D.

The diamondiferous peridot (olivine) – garnet deposit of Shavryn Tsaram, Central Mongolia, with special reference to its placer deposits.

H.G. Dill, S. Khishigsuren, Yo. Majigsuren, J. Bulgamaa, O. Hongor and W. Hofmeister. *Gemmologie. Z. Dt. Gemmol. Ges.*, 53(2/3), 2004, 87-104, 14 photographs, 1 graph, 2 tables, 4 diagrams, bibl.

The deposit is located in the Khangai mountains of central Mongolia. Extensive hotspot volcanism occurred in the Mongolian plateau during the Tertiary and Quaternary periods, resulting in mainly alkaline basanites and olivine basalts, the host rock of the gemstones. Mainly garnets, olivine and sanidine were mined in opencast mines from the placer deposits during the mid-seventies and manufactured in Ulaanbaatar. Diamonds were found as a rare constituent. Gems and some heavy minerals may lead the geologists to the source rock of the gemstones. Reworking the gemstones in a secondary deposit may help refine gemstone quality. E.S.

Les gisements de rubis du Pakistan et du Viêt-nam.

V. Garnier, G. Guiliani, D. Ohnenstetter, Allah Bakhsh Kauser and Hoang Quang Vinh. *Revue de gemmologie AFC*, 151, 2005, 6-12.

The relationship of marble-hosted ruby deposits in both Pakistan and Vietnam to major tectonic structures is discussed with particular reference to the colliding Indian and Eurasian plates. The deposits were formed in the Cenozoic during the Himalayan orogenesis. The occurrence of ruby is restricted to impure marble horizons enriched in detrital minerals. M.O'D.

Les isotopes de l'oxygène: un traceur de l'origine gèologique des rubis et saphirs.

G. Giuliani, A. Fallick, V. Garnier, C. France-Lonord, D. Ohnenstetter and D. Schwarz. *Revue de gemmologie AFC*, 152, 2005, 9-11.

Study of the two principal isotopes of oxygen, 18O and 16O can provide evidence of the origin of some rubies and sapphires. M.O'D.

Rubellite and other gemstones from Momeik township, Northern Shan State, Myanmar.

U.T. Hlaing and A.K. Win. *Australian Gemmologist*, 22(5), 2005, 215-8, 6 illus., 2 maps.

Colourful tourmalines, including pink rubellite, are found in the vicinity of Molo village in the Momeik township of Shan State. The tourmaline crystals are associated with pegmatites that intrude peridotite, and occur either as single euhedral crystals or as mushroom-shaped aggregates and botryoidal masses. The paper describes the properties of the gems and their associated minerals which include quartz, orthoclase feldspar, beryl, petalite and hambergite. P.G.R.

The creation of a magnificent suite of peridot jewelry: from the Himalayas to Fifth Avenue.

R.E. Kane (finegemsint@msn.com). *Gems & Gemology*, 40(4), 2004, 288-302.

The ultimate value of a gemstone suite lies not only in the cost and quality of the materials themselves, but also in the selection of the rough, the quality of the faceting and the intricacy of the setting in a well-designed and well-manufactured suite of jewellery. This article describes in detail the whole process from the mine in the Sapat Valley region of Pakistan to the manufacture of the necklace, bracelet, ring and ear-rings. Eight kg (40 000 ct) of peridot rough eventually yielded a precisely matched suite of 54 gems ranging from 3.57 to 18.30 ct for a total weight of 350.40 ct. R.A.H.

Gem news international.

B.M. Laurs (Ed.) (blaurs@gia.edu). *Gems & Gemology*, 40(4), 2004, 334-57.

Items noted include 0.68 and 1.59 ct faceted yellow-orange clinohumites from the Pamir Mountains, Tadjikistan, jeremejevite from Madagascar, deep blue sapphires from southern Baffin Island, and a rare transparent 7.16 ct orange-red triplite from Pakistan. R.A.H.

Gem news international.

B.M. Laurs (Ed.) (blaurs@gia.edu). *Gems & Gemology*, 41(1), 2005, 52-73.

Cut specimens of aquamarine from Nigeria have a saturated blue colour (ε 1.582, ω 1.589, SG 2.76); a new deposit in western Xinjiang Province, China, is yielding rough and cut emeralds. The Santa Barbara mine near Parelhas, Rio Grande do Norte State, Brazil, is producing iolite from pods in narrow quartz veins. Mention is also made of a cut 1.11 ct pink pezzottaite reportedly from Afghanistan (ε 1.598, ω 1.605, SG.2.97;

EPMA shows Cs 10.18 and 12.56 wt %). A 5.0 mm inclusion of pezzottaite in quartz from the Sakavalana pegmatite in Madagascar is also described. A 10.53 ct gem-quality diamond is reported from a core sample of kimberlite from the Fort à la Corne diamond project in central Saskatchewan. R.A.H.

Les corindons à changement de couleur.

L. Massi. *Revue de gemmologie AFC*, 152, 2005, 16-19.

Many corundum specimens display a change of colour when examined under different types of light source. Details of the relevant absorption spectra are given. M.O'D.

Gemmologie Aktuell.

C.C. Milisenda. *Gemmologie. Z. Dt. Gemmol. Ges.*, 53(2/3), 2004, 63-6, 6 photographs.

A colourless chrysoberyl weighing 0.68 ct was found amongst sapphires from Mogok, Myanmar (Burma). It was easily identified as a natural chrysoberyl. In some opal mosaic triplets which were examined, the opal fragments were embedded in black glass and proved to be synthetic. The term is misleading because 'mosaic opal' can also describe natural precious opal showing a colour play with a mosaic type pattern. Some mounted and unmounted faceted stones were identified as dyed natural corundum, the stones are translucent grey with yellow, blue, green and also red tints and had been filled with artificial blue or red dye. A necklace made of 15 mm round turquoise blue beads from Asia was examined and found to be a dyed carbonate. The surface had a grainy appearance and the colour was more intense in veins and fissures. E.S.

Lab notes.

T.M. Moses, I. Reinitz, S.F. McClure and M.L. Johnson (Eds). *Gems & Gemology*, 40(4), 2004, 323-33.

Notes are give on a 4.45 ct transparent orange-brown iolite, a 22.77 ct greyish purple pearl from a natural saltwater mussel, and strands of drop-shaped 'golden' South Sea cultured pearls shown to have been colour-treated. R.A.H.

Lab notes.

T.M. Moses and S.F. McClure (Eds). *Gems & Gemology*, 41(1), 2005, 42-50.

A 'night glowing pearl' pearl was found to be a sphere of a talc-serpentine rock with a phosphorescent coating. Cut specimens represented as 'pink fire quartz' from Minas Gerais, Brazil, were found to contain inclusions of covellite showing bright pink iridescence. R.A.H.

Gemstones of Chattisgargh – an overview.

S. Pandey. *Indian Gemmologist*, 13(1/2), 2005, 85-6.

Diamond, alexandrite, ruby, sapphire, kornerupine, beryl, garnet and rock crystal are described from the Chattisgargh area of Raipur, India. M.O'D.

Gem deposits of Rajasthan.

S. Pareek. *Indian Gemmologist*, 13(1/2), 2005, 79-84.

Emerald, almandine garnet, dark green epidote, yellow chrysoberyl, variously-coloured tourmaline, amethyst, aquamarine, topaz, green apatite, variously-coloured fluorite, kyanite and andalusite, all with some gem potential are reported and described from Rajasthan. M.O'D.

A review of gemstone belts of eastern and southern India and guidelines for the search of gemstone deposits.

S.K. Sarkar and A.I. Guru. *Indian Gemmologist*, 13(1/2), 2005, 41-9.

The majority of gemstones found in India originate from the states of Andhra Pradesh and Orissa in the east and Tamil Nadu in the south. Geological conditions are described; main centres are listed and there is a useful short bibliography. M.O'D.

Flux filled corundums and their identification.

A. Sharma. *Indian Gemmologist*, 13(1/2), 2005, 39-40.

Hints on the identification of lead glass-filled rubies. M.O'D.

La moule perlière d'Europe: margaritifera (M.) margaritifera (L.1758).

E. Strack. *Revue de gemmologie AFC*, 151, 2005, 17-23.

Survey of the occurrence of European freshwater mussel-hosted pearls with examples of their use. M.O'D.

Opale aus Java.

H. Sujatmiko, H.C. Einfalt and U. Henn. *Gemmologie. Z. Dt. Gemmol. Ges.*, 53(2/3), 105-12, 14 illus., bibl.

Opal has been mined since the 1970s in the western part of Java from a strongly altered pumice layer in a late Tertiary volcano-clastic sequence. There are about one hundred miners working in small underground mines during the dry season from May to September under contract with lease holders. The opal varies from common opal to hyaline, fire opal, white and black precious opal with dominantly red, orange and green colours. Rough and pre-shaped opal pieces are sold, mainly by the lease holders, mostly to traders from Jakarta, Bandung, Yogyakarta and Bali; only a small amount is sold on the international market. E.S.

Opals from Java.

H. Sujatmiko, H.C. Einfalt and U. Henn. *Australian Gemmologist*, 22(6), 2005, 14 Illus., 1 map.

An English version of the article published in *Gemmologie. Z Dt. Gemmol., Ges.* (see above). P.G.R.

Trapiche of Myanmar.

K.K. Win. *Australian Gemmologist*, 22(6), 2005, 269-70, 2 Illus.

Myanmar is the locality of a range of trapiche gemstones that display a distinctive spoke-like star. The author illustrates a selection of these unusual stones, and suggests that these originate due to specific colouring elements, to the presence of other mineral inclusions, and to intergrowth of the same material. P.G.R.

Pearl resources of China.

Zhang Hui and Zhang Beili. *Australian Gemmologist*, 22(5), 2005, 196-209, 40 illus., 5 tables.

China has a long history of both natural pearl harvesting and pearl cultivation, the latter being invented and developed by the Chinese people early in the 13th century. However, pearl cultivation was not a large scale industry until the middle of the 20th century. Seawater pearl cultivation takes place in the Guangdong, Guangxi and Hainan provinces, and fresh-water cultivation localities are in Zhejiang and Jiangsu provinces. The Zhuji pearl market in Zhejiang and the Weitang pearl market in Jiangsu also play key

roles in the global marketing of Chinese freshwater pearls. The paper describes and illustrates the varieties of seawater and fresh-water Chinese cultured pearls and includes the National Standards used for grading and appraising of the pearls. P.G.R.

Instruments and Techniques

Professional Gem Light 3.

R. Beattie and T. Linton. *Australian Gemmologist*, 22(5), 2005, 210-4, 4 illus.

The Professional Gem Light 3 is an advanced laboratory hand lens lighting system. The compact lighting unit is mounted on a flexible arm and uses daylight-type (5500 degrees K) light sources to provide the three essential lighting systems for gemstone analysis; high intensity dark-field illumination, diffused and direct bright-field illumination, and very high intensity incident illumination. The authors describe the various features of the unit when used to examine gemstones and jewellery in conjunction with a hand lens, a combination which exploits the ease of use of the 10 lens as opposed to the more restricted use of a microscope. P.G.R.

Ein neues Instrument für die analytische Gemmologie: LIBS.

H.A. Hänni, M.S. Krzemnicki, L. Kiefert, and J.P. Chalain, *Gemmologie. Z. Dt. Gemmol. Ges.*, 53(2/3), 2004, 79-86, 3 photographs, I diagram, a graph, bibl.

The identification of Be-diffused corundum showed that it is essential for a gem laboratory to be able to analyse even low traces of chemicals in gemstones. The Be detection was made possible by micro mass spectrometry a costly process possibly outside the means of most gem laboratories. The new method is based on laser induced optical emission spectroscopy. Laser induced breakdown spectroscopy (LIBS) can be successfully used to identify Be-diffused corundum. A focused pulse of a Nd:YAG laser transforms some micrograms of the sample into plasma. The light emission is diffracted and recorded by a multi-channel analyzer. The line spectrum can be used for qualitative and quantitative analysis. Almost all chemical elements are detectable and it allows chemical fingerprinting of the gem material. The new method is slightly destructive as a tiny spot remains after the laser shot. E.S.

A new method for detecting Be diffusion-treated sapphires: laser-induced breakdown spectroscopy (LIBS).

M.S. Krzemnicki, H.A. Hänni and R.A. Walters. *Gems & Gemology*, 40(4),2004, 314-22.

The first application of laser-induced breakdown spectroscopy (LIBS) to gemmology is described. Until now, the detection of Be-diffused sapphire and ruby has been based on LA-ICP-MS or SIMS techniques, neither of which is readily available to most laboratories. In the study reported here, LIBS is used to detect Be in corundum at very low concentrations (down to ~2 ppm). This technique is a reliable tool for identifying Be diffusion-treated sapphires, and is affordable for most commercial gemmological laboratories. As with other laser-based techniques, LIBS may cause slight damage to a gemstone, but this can be minimised by choosing appropriate instrument parameters. R.A.H.

Une nouvelle méthode pour la détection des corindons traits par diffusion du beryllium: Laser-Induced Breakdown Spectroscopy (LIBS).

M.S. Krzemnicki, H.A. Hänni, R.A. Walters and J.-P. Chalain. *Revue de gemmologie AFC*, 152, 2005, 13-5.

The technique of Laser-Induced Breakdown Spectroscopy (LIBS) has been used for the detection of beryllium-diffused corundum. M.O'D.

Krüss refractometer – ER 6010.

T. Linton, R. Beatie and K. Hughes (GAA Instrument Evaluation Committee). *Australian Gemmologist*, 22(6), 2005, 260-2, 2 Illus.

The Krüss ER 6010 German-made refractometer contains a glass hemisphere 'table' which gives it the ability to measure refractive indices at wavelengths used for the determination of dispersion. The instrument has a scale calibrated in RI units of 0.01 covering the range of 1.30 – 1.83. Calibration of this scale can be adjusted over the limits of ± 0.002. The refractometer is supplied with a twin high-intensity yellow LED light source (with a bandwidth of 50nm) which plugs into the refractometer's rear port and is powered from a 240-volt plug pack. A compact student version of the instrument, model ER 6040, is also available. An evaluation of the refractometer's performance is included in the report. P.G.R.

Identification des corindons chauffés avec addition de verre au plomb.

V. Pardieu. *Revue de gemmologie AFC*, 152, 2005, 20-2.

Methods of detection of lead glass-filled corundum specimens are given. M.O'D.

Use and misuse of optical mineralogy constants in gemmology.

D.B. Sturman. *Australian Gemmologist*, 22(6), 2005, 234-43, 5 Illus., 3 graphs.

The author provides examples where the direct transfer of optical data from mineralogy to gemmology can cause misunderstanding. One example of such a transfer results in the calculated dispersion coefficient being an unreliable indicator of the actual amount of visible 'fire' produced by a faceted gemstone (although the coefficient may still be a useful identification constant for that gemstone). In a second example, the rules for the determination of birefringence cannot be applied to the 'doubling' of images as these are different optical properties. Factors contributing to doubling are described and diagrams are provided for a fast and reliable estimate of the doubling effect in gemstones. P.G.R.

Synthetics and Simulants

CVD diamonds; the biggest achievement in the diamond synthesizing.

A. Jain. *Indian gemmologist*, 13(1/2), 2005, 22-6.

Brief details of diamonds grown by chemical vapour deposition are

given with notes on identification. M.O'D.

Tanzanite v/s forsterite.

P.R. Jhaveri. *Indian Gemmologist*, 13(1/2), 2005, 68-70.

The usefulness of a synthetic forsterite as a tanzanite stimulant is discussed with notes on identification. The trade name Tanzanion has been suggested. M.O'D.

An updated chart on the characteristics of HPHT-grown synthetic diamonds.

J.E. Shigley, C.M. Breeding and A. H.-T. Shen. *Gems & Gemology*, 40(4), 2004, 303-13.

A new chart is presented, supplementing an earlier one published in 1995, which summarises the features of both as-grown ('non-modified') and treated ('modified') synthetic diamonds currently in the gem market (i.e. those grown by the high-pressure/high-temperature technique). It includes photographs of visual features, information about visible-range absorption spectra and illustrations of growth-structure patterns as revealed by ultraviolet fluorescence imaging. The chart is designed to help gemmologists to recognise the greater variety of laboratory-created diamonds that might be encountered today. R.A.H.

For further information on many of the topics referred to, consult *Mineralogical Abstracts.*

Abstractors

R.A. Howie R.A.H. M. O'Donoghue M.O'D. P.G. Read P.G.R. E. Stern E.S.

Book Reviews

Diamonds. The world's most dazzling exhibition, 8 July 2005 – 26 February 2006

Natural History Museum, 2005. Natural History Museum, London. pp 60, illus. in colour. Softcover. ISBN 0 565 09201 4. £7.00.

This short but very attractive catalogue is published to accompany an exhibition of diamonds held at the Natural History Museum, London. It is worthy of the exhibition which includes many famous diamonds, with some items of jewellery and some of the early attempts at diamond synthesis as well as current synthetic diamonds. The catalogue illustrates many of the exhibits and includes in the text a summary of the properties and history of diamond. Recent growth techniques are also described. This is a useful short study of diamond and would make a good introduction for study at any level. M.O'D.

Edle Steine vom Dach der Welt.

Various authors, 2003. Christian Weise Verlag, Munich, Germany. pp 96, illus. in colour. Softcover. ISBN 3 921 65662 1 [ISSN 0945 8492] extraLapis no 14. €28.40

As beautifully illustrated and as well written as the other numbers in this excellent series [now appearing in English], the present number describes the gem materials of Afghanistan and Pakistan (the title can be translated as Gemstones from the roof of the world). As always the different sections follow one another without a break and an extensive bibliography concludes the survey. As the reviewer is familiar with some at least of the gem mines of Pakistan it was interesting to read that pargasite of appropriate colour is being called 'Hunza emerald' and that the list of Pakistan gem species has grown to include fine green transparent zoisite and fine orange scheelite. M.O'D.

Bernstein-Fenster in die Urzeit.

M.J. Kobbert, 2005. Planet Poster Editions Göttingen. pp 224, Illustrated in colour, Hardcover. ISBN 3 933922 25 X. €19.80

Well-presented and attractively illustrated study of insect inclusions in amber with fairly short captions and brief introductions to the families represented. There is a short bibliography of works from 1951 and some advice on specimen investigation using the microscope. The price is very reasonable and the quality of reproduction good. This will be a useful addition to the still scarce literature on amber. M.O'D.

The National Gem Collection, Smithsonian Institution.

J.E. Post with photographs by Chip Clark, 2005. Harry N. Abrams, Inc., New York. pp 144, landscape format, paperback, illus. in colour. ISBN 0-8109-2758-6. £14.95.

Paperback edition of the original hardback edition published in 1997 and reviewed in the Journal, 26(5), 338-9. The selection from the more than 10 000 gems and jewellery pieces in the Smithsonian Institution's collection is a constant reminder of the qualities to which collectors and those in the gem trade aspire. The text opens up the topic for anyone with an interest in gems and at this price, is a good starting point for study. R.R.H.

Gemmology (3rd edn).

P.G. Read, 2005. Elsevier Butterworth-Heinemann, Oxford. pp 307, paperback. ISBN 0 7506 6449 5. £24.99.

This is the 3rd edition of a book providing a comprehensive introduction to the theory and practice of gemmology.

It begins with a straightforward summary of chemistry and geology, and an explanation of the physical properties of gemstones. Gemmological instruments and their uses are covered interestingly and in depth, before an account of synthetic and treated gemstones, and the methods used by gemmologists to recognise them. Styles and methods of gem cutting are described and illustrated, and a chapter on gem identification includes recommendations for a testing procedure which should be helpful to readers who are unfamiliar with the art.

Appendices describe natural and artificial materials, covering a wider range than the Gemmology Diploma syllabus. Lists and tables of gemstone properties, units of measurements and chemical elements provide useful reference sources. Advice given on examination techniques will be useful to gemmology students.

It is unfortunate that the usefulness of photographs is limited by the quality of reproduction. Some anomalies might be eliminated, e.g., is a spectroscope prism diagram, a ray of light passing from light into air appears to 'bend' towards the normal. Not all dyed green jadeite looks pink through the Chelsea Filter.

Notwithstanding these criticisms, the book contains a wealth of information which make it a useful reference work. It should be especially useful to Gem-A Gemmology Foundation Certificate and Diploma students. Additionally it is moderately priced, compact and relatively lightweight; an unusual and desirable combination of features for a textbook. P.D.

Dictionary of gems and gemology.

M. Manutchehr-Danai, 2005. Second revised and extended edition. Springer, Berlin. pp 879, Hardcover. ISBN 3 540 23970 7. £154.

This is a baffling book as the nature of the projected readership is unclear. It is of no use at all to professional gemmologists or practitioners of any other science as there are too many mistakes, whimsicalities, hundreds of names which have never been generally used, pointless translations of phrases into a number of languages and uncertain grasp of the wide area into which the compiler has expanded 'gemmology'.

This is a pity as the book is very well produced with good page layout, typeface and diagrams. It lies open very easily and were it not for the inaccuracies would almost be worth the very high price. Examples of some unfortunately-worded entries (easy to find) include 'green tourmaline-a green variety of tourmaline; hessonite garnet-another term for cinnamon stone; nitrogen oxide-NO3, impurity in emerald lost one electron probaly [sic] by irradiation to form color centers as seen in Maxixe-type beryl'.

As with many entries the reader can see what the compiler is attempting to say and with knowledge sufficient to spot the traps the reader can enjoy leafing through the book; unfortunately this does not benefit the beginner or visitor from the geological or mineralogical disciplines.

The (unpaginated) preliminary matter includes the compiler's thanks to a team of advisers: gemmologists will decide the value of such advice. I remember the first edition which was as equally plagued by similar or the same faults as this one - this is a great opportunity missed. M.O'D.

Faszination Turmalin.

P. Rustemeyer, 2003. Specktrum Akademischer Verlag., Heidelberg, Germany. pp 309, illus. in colour. Hardcover. ISBN 3 8274 1424 5. € 99.95

The book is certainly designed to catch the eye and tourmaline serves this purpose admirably. This is the second book on tourmaline to have come from Germany in the past few years and though it is not on the same physical scale as Benesch (1990-one of the largest books on a single gemstone) the general conception is similar. Photographs in colour appear on the recto of every page and are faced either with text, diagrams or additional photographs. The reader is left in no doubt that tourmaline can often be sectioned to give beautiful and intriguing patterns.

Readers should be advised that this is not a study of fashioned stones but only of crystals, their symmetry and some of their inclusions as displayed by tourmaline. In this context this a beautiful book. There is a useful bibliography and an index. M.O'D.

Tourmaline: a gemstone spectrum.

Lapis International LLC, East Hampton, Conn., USA. pp 106, illus. in colour. Softcover ISBN 0 971 5371 2 7. extraLapis English no.3. Price on application.

Published independently from but in collaboration with the journal Lapis the extraLapis series translated into English has at the time of writing covered emeralds (issue 2) and calcite (4). The texts are literal translations of the German versions [reviewed in The Journal passim] and the illustrations are equally excellent. M.O'D.

Mineralfundorte und ihre Minerale in Deutschland.

A. Wittern, 2005. E. Schweizerbart'sche Verlagsbuchandlung, Stuttgart. pp vii 288, Softcover. ISBN 3 510 65213 4. €22.80

The welcome second edition of a good friend to German mineral hunters, this book is a guide for intending visitors to sites of interest in Germany. The text shows clearly shows where the sites are and how to reach them. There is an extensive bibliography but no colour photographs apart from the azurite/malachite on the cover. The price is very reasonable and the addition of colour pictures (which are easily accessed from other sources) would have inflated it. M.O'D.

Laboratory created diamonds.

S. Woodring and B. Deljanin. 2005. EGL USA [New York]. pp. 39, illus. in colour. Softcover. £12.50

Short but informative guide to the growth, production and identification of HPHT and CVD-grown diamonds, with numerous photographs and diagrams incorporated within the text. This is an ideal short guide to an area in which developments are outpacing information sources and is to be welcomed. M.O'D.

Proceedings of the Gemmological Association and Gem Testing Laboratory of Great Britain and Notices

Photo Competition

The 2005 Photo Competition on the theme 'Rare Treasures' attracted a large number of entries of very high quality, illustrating rare gems, rare inclusions, rare jewels and rare phenomena.

First Prize

The first prize was awarded to Luella Dykhuis FGA DGA, Tucson, Arizona, U.S.A. *'Lepidocrocite inclusions in Quartz'*.

Second and Third Prize

The second and third prizes were both awarded to Zeng Chunguang FGA of Singapore, for his entries *'Hematite inclusions in Sunstone'* (second prize) and *'Trapiche emeralds'* (third prize).

We are pleased to announce that the prizes were sponsored by Harley UK, and the Association is most grateful to them for their generosity. The winning entries will be exhibited at the Gem-A Conference to be held on 30 October.

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Gem-A Awards

Gem-A Examinations were held worldwide in June 2005. In the Examinations in Gemmology 195 candidates sat for the Diploma Examination of whom 101 qualified, including three with Distinction and 14 with Merit. In the Foundation Gemmology Examination, 236 candidates sat of whom 174 qualified. In the Gem Diamond Examination 102 candidates sat of whom 60 qualified, including seven with Distinction and nine with Merit.

The Anderson Bank Prize for the best non-trade candidate of the year in the Diploma in Gemmology Examination was awarded to Chaman Golecha of Chennia, India.

The Christie's Prize for Gemmology for the best candidate of the year in the Diploma Examination who derives his or her main income from activities essentially connected with the jewellery trade has been awarded to Sheila Barron Smithie of Boston, Massachusetts, U.S.A.

The Anderson Medal for the candidate who submitted the best set of answers in the Foundation Certificate examination which, in the opinion of the Examiners, are of sufficiently high standard, and the Hirsh Foundation Award for the best candidate of the year in the Foundation Certificate Examination have been awarded to Nicola K. Sherriff of Verdun, Quebec, Canada.

The Deeks Diamond Prize for the best candidate of the year in the Gem Diamond Diploma examination has been awarded to Torbjorn Lindwall of Lannavaara, Sweden.

The Tully and Bruton Medals were not awarded.

EXAMINATIONS IN GEMMOLOGY

Gemmology Diploma

Qualified with Distinction

Dong Qingqing, Wuhan, Hubei, P.R. China
Golecha, Chaman, Chennai, India
Mao Yuanjiong, Guilin, Guangxi, P.R. China

Qualified with Merit

Bayoumi-Stefanovic, Nevin, London
Cai HuiHua, Shanghai, P.R. China
Chawla, Jaspreet Kaur, London
Fellows, Andrew Simon, Aldridge, West Midlands
Lee Tin Wan, New Territories, Hong Kong
Li Dan, Wuhan, Hubei, P.R. China
Li Na, Guilin, Guangxi, P.R. China
Lv Feng, Shanghai, P.R. China
Miyazaki, Satoshi, Toyonaka City, Osaka, Japan
Rajaobelina, Tsialiva, Antananarivo, Madagascar
Rajnikant Manisha, Antananarivo, Madagascar
Raoelison, Ivan Ludovic, Antananarivo, Madagascar
Torres, Eric, Antanarivo, Madagascar
Zhang Yonghua, Guilin, Guangxi, P.R. China

Qualified

Ahren, Anna Ekstrom, Tyreso, Sweden
Anderson, Judith S., Manchester, New Hampshire, U.S.A.
Andrianarimanana, Maminirina, Antananarivo, Madagascar
Andrianoelison, Hery Miadana, Antananarivo, Madagascar
Bardehle, Petra, Munich, Germany
Bergman, Marit, Johanneshov, Sweden
Brohi, Nosheen, Wanstead, London
Chan Pak Lin, Tsuen Wan, Hong Kong
Chan Fung Ping, Kowloon, Hong Kong
Chen Jie, Wuhan, Hubei, P.R. China
Cheng Qi, Shanghai, P.R. China
Cheung Ching Chung, Hong Kong
Chong Joon Yau, Singapore
Davis, Shelley, Toronto, Ontario, Canada
Dinapandresena, Hardi, Antananarivo, Madagascar
Eeckhout, Tiphaine, Thomery, France
Fossurier, Anne, Montreal, Quebec, Canada

Gem-A Awards

Geng Yan, Shanghai, P.R. China
Gillman, Scott, Sudbury, Massachusetts, U.S.A.
Glass, Krista-Leigh Fay, Stratford, Ontario, Canada
Godfrey, Kay, Halstead, Essex
Gu Jun, Singapore
Hok Yee Po, Kowloon, Hong Kong
Hong Xiao Bin, Shanghai, P.R. China
Ip, Renée, Thornhill, Toronto, Ontario, Canada
Janssen, Marjo, Voorschoten, The Netherlands
Kandalepa, Theophano, Athens, Greece
Kiamos, George K., Maroussi, Athens, Greece
Kim, Yoonjin, Bucheon City, South Korea
Kim, Su Hyun, Jincheon-Dong, Dalseo-Gu, Korea
Konstantopoulos, Konstantinos, Athens, Greece
Kwan-Kai-Lion, Antananarivo, Madagascar
Lawton, Sarah, Enderby, Leicestershire
Lee Lai Ha, New Territories, Hong Kong
Leondaraki, Marialena, Athens, Greece
Leung Chi Fai, Hong Kong
Li, Kehan, Enfield, Middlesex
Li On Kei, Sai Kung, Hong Kong
Li Po Man, North Point, Hong Kong
Liang Mai, Haidian District, Beijing, P.R. China
Lin Jie, Guilin, Guangxi, P.R. China
Lina S.W. Cheng, New Territories, Hong Kong
Lo Chun Kin, James, Tin Shui Wai, Hong Kong
Lu Shan, Tokyo, Japan
Lu Yi, Guilin, Guangxi, P.R. China
Ma Qin, Shanghai, P.R. China
McKercher, Jennifer A., Toronto, Ontario, Canada
Natsuka, Masaki, Toyonaka City, Osaka, Japan
Ng Yee Kar, Carolina, Chai Wan, Hong Kong
O'Dwyer, Michael, Wicklow Town, Co. Wicklow, Ireland
Omotedani, Hiroki, Matsudo City, Chiba, Japan
Paterson, Vanessa Ann, Arnold, Nottinghamshire
Pearson, Heather, Belper, Derbyshire
Pelletier, Lise, Montreal, Quebec, Canada
Peng Conghui, Guilin, Guangxi, P.R. China
Philogene, Stephanie, Montreal, Quebec, Canada
Rakotoarison Ony, Dominique, Antananarivo, Madagascar
Rakotoson, Eric, Antananarivo, Madagascar
Rasoanaivo, Sylvie Annick, Antananarivo, Madagascar
Razafimahefa, Hery Tiana Albert, Antananarivo, Madagascar
Sakonuma, Tomoko, Osaka City, Osaka, Japan
Sanders, Jacqueline, Yardley Gobion, Northamptonshire
Sardjono, Grace W., New Territories, Hong Kong
Satis, Amrita, Antananarivo, Madagascar
Saull, Elanor Nico, Stourbridge, West Midlands
Segi, Naoko, Nagoya City, Aichi Pref., Japan
Sun Dan, Wuhan, Hubei, P.R. China
Susawee, Namrawee, Bangkok, Thailand
Tammilehto, Eero, Helsinki, Finland
Taylor, Daniel, Leeds, West Yorkshire
Teng, Terry, West Hampstead, London
Thawornmongkolkij, Monruedee, Patumwan, Bangkok, Thailand
Wada, Natsuko, Takarazuka City, Hyogo Pref., Japan
Wang Sen, Wuhan, Hubei, P.R. China
Wong Yi Tat, Eddy, Kowloon, Hong Kong
Wong Ching Man, Ruby, New Territories, Hong Kong
Wong Oi Chun, New Territories, Hong Kong
Xiao Mai. Wuhan, Hubei. P.R. China
Yang Xinlei, Wuhan, Hubei, P.R. China

Gem-A Awards

Yin Yu, Guilin, Guangxi, P.R. China
Yu Dongsheng, Wuhan, Hubei, P.R. China
Yuki Chiu Wai Yu, Sheung Shui, Hong Kong
Zee Gar Bo, Michelle, Kowloon, Hong Kong
Zhang Guangrui, Wuhan, Hubei, P.R. China

Gemmology Foundation Certificate

Qualified

Abduriyim, Ahmadjan, Tokyo, Japan
Almroth, Kerstin Maria, Umea, Sweden
Alyawer, Najwa, Wimbledon, London
Anderson, James Ian, Hythe, Hampshire
Andrianarimanana, Maminirina, Antananarivo, Madagascar
Andrianoelison, Hery Miadana, Antananarivo, Madagascar
Au Chui Yee, Homantin, Hong Kong
Au Yeung Shun Wai, Aberdeen, Hong Kong
Bailey, J. Laurel, Citrus Heights, California, U.S.A
Bakken, Linda L., Trysil, Norway
Bedhavar, V. Subash Chandra, Tamilnadu, India
Bell, Lucy Kate, Kimberley, Nottinghamshire
Bello, Mohammed I., London
Benestam, Cissela, Bromma, Sweden
Bowers, Sally F., Fulham, London
Buchanan-Jardine, Katie, London
Bugge, Remy, Fredrikstad, Norway
Cao Yue, Shanghai, P.R. China
Caplin, Marco, Lachine, Quebec, Canada
Cen Qicong, Guilin, Guangxi, P.R. China
Chan Kwai Chu, Kowloon, Hong Kong
Chan Lai Fong, New Territories, Hong Kong
Chang Bo Youn, Daejon, Korea
Chen Xinxing, Guilin, Guangxi, P.R. China
Cheng Pei-Ling, Taipei, Taiwan, R.O. China
Cheng Yiu Pong, Chai Wan, Hong Kong
Che-Sheung, Joanna, Kowloon, Hong Kong
Chester, Mark, St Helens, Merseyside
Cheung Man Yi, Kowloon, Hong Kong
Cheung Ka Yan, Michiele, Ap Lei Chau, Hong Kong
Chin Yin Man, Kylie, Yangon, Myanmar
Chitou, Aurelie Gisele Boasse, Antananarivo, Madagascar
Chow Wai Lam, New Territories, Hong Kong
Chui Yee Man, New Territories, Hong Kong
Chung Yee Man, Stella, Kowloon, Hong Kong
Chung Yiu-Keung, Kowloon, Hong Kong
Clark, Jan, Charlton, London
Cutler, Leticia, Smethwick, West Midlands
Danjo, Keiji, Kofu City, Yamanashi Pref., Japan
Deeley, Philippa H., Etchingham, East Sussex
Denney, Brian Shane, Jacksonville, Illinois, U.S.A
Dinapandresena, Hardi, Antananarivo, Madagascar
El-Kassir, Mariam, Acton, London
Ellison, Armelle Inez, Bisley, Surrey
Emond, Jacinthe, Laval, Quebec, Canada
Farrukh, Nayir Khan, Bordesley Green, West Midlands
French, Catherine B., Loomis, California, U.S.A.
Fu Kim Man, New Territories, Hong Kong
Galbraith, Stuart Mark, Lansdown, Gloucestershire
Geormae, Emmanuel, Athens, Greece
Glover, Claire, Sunningdale, Berkshire
Goncalves Coelho, Ana Cristina, Antananarivo, Madagascar
Ha Lai, Kowloon, Hong Kong
Hall, Ian, Hatton, Warwickshire
Harrington, Olga, London
Harris, Nigel, Blindcrake, Cumbria
Hartley, Pauline, Woodkirk, West Yorkshire
Hastings, Carrie, Chico, California, U.S.A.
Razafimahefa, Hery Tiana Albert, Antananarivo, Madagascar
Heywood, Natalie Louise, Enfield, Middlesex
Hu Yuan, Guilin, Guangxi, P.R. China

Gem-A Awards

Huang Mingcai, Guilin, Guangxi, P.R. China
Hui Yuen Wah, Kowloon, Hong Kong
Humphrey, Brian, Fulham, London
Ito, Yukiyo, Shinagawa, Tokyo, Japan
Jeong Hye Jeong, Gwangju, Korea
Johnston, Nanette, Granite Bay, California, U.S.A.
Jones, Gary Ronald, Dudley, West Midlands
Ju Tian, Guilin, Guangxi, P.R. China
Kettle, Georgina Elizabeth, Solihull, West Midlands
Khan, Qaisra Maaria, London
Khine Shwe Wah, Yangon, Myanmar
Kidachi, Masanobu, Sagamihara City, Kanagawa Pref., Japan
Komvokis, Vasilis, Budapest, Hungary
Koustoumpardi, Theo, Athens, Greece
Kwan-Kai-Lion, Antananarivo, Madagascar
Kwok Mei Yee, Sindy, Aberdeen, Hong Kong
Lai Hung Tak, Kowloon, Hong Kong
Lam Mei Hei, Cally, New Territories, Hong Kong
Lam Siu Kuen, Kowloon, Hong Kong
Lam Lai Wah, Tsuen Wan, Hong Kong
Lam Suk Fan, Silvia, Taikoo Shing, Hong Kong
Lau Ngai Sheung, Kowloon, Hong Kong
Lau May Kwan, Kowloon, Hong Kong
Lau Pui Sze, Kowloon, Hong Kong
Lau Pui Ting, Kowloon, Hong Kong
Lau Yuen Yee, Simmy, Kowloon, Hong Kong
Lee Jeong Min, Daegu, Korea
Lee Chi Kin, Kenneth, North Point, Hong Kong
Lei Jin, Shanghai, P.R. China
Lesetedi Kelebogile, Billsley, West Midlands
Leung Shiu Lok, Taipo, Hong Kong
Leung Nga Yee, Hong Kong
Li Suet Lin, Happy Valley, Hong Kong
Lin Lang-Dong, Taipei, Taiwan, R.O. China
Liu Pui Man, Jasmine, Kowloon, Hong Kong
Liu Xi, Guilin, Guangxi, P.R. China
Liu Yao-Wen, Taipei, Taiwan, R.O. China
Liu You-Ching, Taipei, Taiwan, R.O. China
Liu Yu Chen, Taipei, Taiwan, R.O. China
Liu Zuodong, Guilin, Guangxi, P.R. China
Lo Nga Lai, Vicky, Kowloon, Hong Kong
Lou Haowei, Orpington, Kent
Lounina, Ekaterina, Birmingham, West Midlands
Ma Jun, Guilin, Guangxi, P.R. China
Ma Siu Ling, Sally, Kowloon, Hong Kong
Mak Hoi Chuen, Jeff, Kowloon, Hong Kong
Mak Bing Lan, New Territories, Hong Kong
Maniraho, Mireille, Gatineau, Quebec, Canada
Maske, Sandra Jay, Citrus Heights, California, U.S.A.
McVeigh, Thomas G., Victoria, British Columbia, Canada
McWhirter, Hannah Maeve, Bury St Edmunds, Suffolk
Meyer, Constance Marie, Montreal, Quebec, Canada
Meyrick, Daisy, London
Murray, Helen Claire, Four Oaks, West Midlands
Murtough, Isabel, Derby, Derbyshire
Myat Zaw, Yangon, Myanmar
Naing Sein, Yangon, Myanmar
Newall, Myron, Citrus Heights, California, U.S.A.
Ng, Emma, London
Ng Sum Yi, Kowloon, Hong Kong
Ngai Mei Ching, Bonny, Kowloon, Hong Kong
Ngala, Kalambayi Dadou, Forest Gate, London
Okuyama, Muneyuki, Kofu City, Yamanashi, Japan
Pang Kin Hung, Kowloon, Hong Kong
Panidis, Ioli, Elefsina, Greece
Pau Khan Lian, Yangon, Myanmar
Philogene, Stephanie, Montreal, Quebec, Canada
Price, David, Colchester, Essex

Gem-A Awards

Qin Ting, Guilin, Guangxi, P.R. China
Rajaobelina, Tsialiva, Antananarivo, Madagascar
Rajnikant, Manisha, Antananarivo, Madagascar
Rakotoarison, Ony Dominique, Antananarivo, Madagascar
Raneke, Anna Maria, Stockholm, Sweden
Ranjatoelina, Domoina, Antanimora Tana, Madagascar
Raoelison, Ivan Ludovic, Antananarivo, Madagascar
Rasoanaivo, Sylvie Annick, Antananarivo, Madagascar
Salava, Franky, Antananarivo, Madagascar
Satis, Amrita, Antananarivo, Madagascar
Shah, Chandni, Mumbai, India
Sherriff, Nicola, Verdun, Quebec, Canada
Sim Ooi Kok, Kingston-upon-Thames, Surrey
Slovak, Kate, Leicester, Leicestershire
Son Hwa Jung, Gangwon-Do, Korea
Su Yi-Hsuan, Taipei, Taiwan, R.O. China
Szymanska, Zofia, London
Thi Thi Han, Yangon. Myanmar
Torres, Eric, Antanarivo, Madagascar
Tran, Mark Hung, Elk Grove, California, U.S.A.
Tsai Chung-Yao, Taipei. Taiwan, R.O. China
Tsui Wing Sze, New Territories, Hong Kong
van Bruggen, Hemriette, Lunteren, The Netherlands
Wahlstrom, Bengt Christer, Halmstad, Sweden
Watson, John Richard, Berkhamsted, Hertfordshire
Watts, Clare, Beckenham, Kent
Westlake, Ingrid, London
White, Susan, Bushey, Hertfordshire
Wong Po Yi, New Territories, Hong Kong
Wong Yu Lap, Hong Kong
Wong Yuen Kwan, Annie, North Point, Hong Kong
Wong Man Yee, Ada, Kowloon. Hong Kong
Wong Mars, New Territories, Hong Kong
Wong Ka Yee, Kowloon, Hong Kong
Wong Lai Mi, Tseung Kwan, Hong Kong
Wong Man Tung, Kowloon, Hong Kong
Woo Mei Woon, Shirley, New Territories, Hong Kong
Wu Wing Yi, Kowloon, Hong Kong
Xu Hui, Shanghai, P.R. China
Yau Siu-Yin, Kowloon, Hong Kong
Yeung Tsz Ming, New Territories, Hong Kong
Yip Tak Wing, Shatin, Hong Kong
Yiu Ka Wah, Kowloon, Hong Kong
Zeng Linghan, Guilin, Guangxi, P.R. China
Zhuang Lingyan, Guilin, Guangxi, P.R. China

GEM DIAMOND DIPLOMA EXAMINATION

Qualified with Distinction

Clarkson, Mia, Salisbury, Wiltshire
Fong Yan, William, Kowloon, Hong Kong
Lounina, Ekaterina, Birmingham, West Midlands
Lovelock, Justina Elizabeth, London
McCrabbe, Julie Alice, Hackney, London
Pereira Anisha, Edgbaston, West Midlands
Van der Molen, Wouter Nicolaas, Zwolle, The Netherlands

Qualified with Merit

Andrews, Kitiya, Kings Norton, West Midlands
Glasgow, Sarah Alexandra, London
Glover, Claire, Sunningdale, Berkshire
Humphreys, Emma Louise, Preston Brockhurst, Shropshire
Lee Ka Wai, Shatin, Hong Kong
Qian Ying, Helen, Yuen Long, Hong Kong
Scragg, Claire Patricia, Great Missenden, Buckinghamshire
Wong Wai Lok, Kowloon, Hong Kong
Yuen Kim Kam, New Territories, Hong Kong

Qualified

Bains, Neelam, Great Barr, Birmingham

Gem-A Awards

Baker, David, Bath, Avon
Besic, Senka, Frederiksberg, Denmark
Bryan, Holly Eve, Dalkey, Co. Dublin, Ireland
Carnegie, Susan, Giffnock, Glasgow, Scotland
Chan Mei, Kowloon, Hong Kong
Davis, Samantha Angela, Bearwood, West Midlands
Galbraith, Stuart Mark, Lansdown, Gloucestershire
Gordon, Richard, London
Head, Jemima, Wilsden, West Yorkshire
Kathris, Ioannis, Holargos, Greece
Klimek, Karina Sophia, Truro, Cornwall
Konstantinidou, Maria, Petroypoli, Athens, Greece
Kwok Yuk Kuen, Kowloon, Hong Kong
Lam Shun Kwong. New Territories, Hong Kong
Lampson, Ming, London
Lancaster, David, Hemel Hempstead, Hertfordshire
Lee Fung Mei, Kowloon, Hong Kong
Lee Oi Yan, Christine, New Territories, Hong Kong
Leondaraki, Marialena, Syntagma, Athens, Greece
Leung Oi Yee, Louisa, Hong Kong
Li Xiaolu, Wuhan, Hubei, P.R. China
Man Lili, Wuhan, Hubei, P.R. China
Man Ying, Wuhan, Hubei, P.R. China
Ota, Shinya, Yamanashiken, Japan
Palmares, Richard P., Sale, Cheshire
Papadopoulos, Ioannis, Neapoli, Thesaloniki, Greece
Peers, Sofia L.R., Leamington Spa, Warwickshire
Powar, Krishna, Smethwick, West Midlands
Seto Yee Man, Yvonne, New Territories, Hong Kong
Shah, Chandni, Mumbai, India
Shen Bin, Wuhan, Hubei, P.R. China
Slovak, Kate, Leciester, Leicestershire
Tam Sze Yan, New Territories, Hong Kong
Tam Chun Yu, Kowloon, Hong Kong
Tsang Yuen King, New Territories, Hong Kong
Warner, Simon, Amersham, Buckinghamshire
Welton-Cook, Elsa, West Kensington, London
Wong Yui Kwan, Kowloon, Hong Kong
Yamout, Sabah Ibrahim, Leeds, West Yorkshire
Yeung Tsz Ming, New Territories, Hong Kong
Yeung Yan Chu, Rosanna, Kowloon, Hong Kong
Yip Ching Yi, Corinna, Tai Koo Shing, Hong Kong
Yu Xidan, Wuhan, Hubei, P.R. China

Charity status

The Council of the Association is pleased to announce that the Association became a Registered Charity on 19 May 2005, registered charity no. 1109555. Charity status will greatly help the Association to expand and develop the services offered to members. One advantage is that it will be possible to claim back tax on eligible UK donations and subscriptions. Using Gift Aid means that for every pound received, the Association can claim an extra 28 pence from the Inland Revenue, so £10 could be turned into £12.80 just as long as donations are made through Gift Aid. UK members will be requested to complete and return Gift Aid declaration forms, to be circulated with the 2006 subscription notices, to enable them to participate in the scheme.

Members' Meetings

Gem Discovery Club

Specialist Evenings

Once a month Club members have the opportunity to examine items from the collections of gem and mineral specialists.

Gifts and Donations

The Association is most grateful to the following for their gifts for research and teaching purposes:

Maria Alferova, Geology Department, Moscow State University, for a selection of green grossular garnet crystals.

Leonardo Carrazone, SETT Stones, São José do Rio Preto-SP, Brazil, for a prasiolite crystal.

Tom Cushman, Sun Valley, Idaho, U.S.A., for a collection of crystals and cut stones including pieces of copal resin with insect inclusions, corundum, feldspar cabochons including two sunstones, grossular garnet, quartz cabochons one with dark star-shaped inclusions and four with blue flecked inclusions, and three faceted pezzottaites.

James P.M. Day FGA, Tunbridge Wells, Kent, for a donation to the appeal for funds (Pearl Donation).

De Beers, Johannesburg, South Africa, for three large samples of kimberlite, each with a polished face, from the Monastery, Uintjiesberg and Voorspoed mines in South Africa.

Harold Killingback FGA, Oakham, Leicestershire, for the rose quartz sphere (105 mm diameter) that was featured in his article 'Stereoscopic effect in asterism and chatoyancy' published in The Journal of Gemmology, 2005, 29(5/6), 312.

Marcia Lanyon FGA, London for parcels of faceted sapphires of various cuts and sizes.

Michele Marci, Rome, Italy, for quartz cabochons from Brazil, one with covellite and the other with gilalite inclusions.

Francesco Mazzero, GemOA sarl, Paris, France, for two Ethiopian opals.

Jason Williams FGA DGA, G.F. Williams & Co. Ltd., London, for a selection of iolite cabochons, carved amethyst leaves, synthetic Verneuil stones and paste.

Rogério Zucoloto Luz, Minas Gerais, Brazil, for specimens of mica and quartz with vivianite crystals.

Bequest

The Association has received notification that it is to benefit from the estate of the late Revd S.B. Nikon Cooper FGA DGA. Although final figures are yet to be announced, the bequest is to be in excess of £45,000.

Nikon, who died on 11 October 2004, was a Gem-A correspondence course tutor for a record 35 years, retiring from the position in 2002. He was one of a team of three tutors with Keith Mitchell and Vera Hinton when he was appointed in 1967.

The Council is most grateful to the Revd Cooper for his lifelong support of the Association and for his generous bequest.

The May guest was Cecilia Pople who gave a short slide show of some of the interesting items from her personal jewel box, some of which she brought along for Club members to examine. In June Branko Deljanin, Director of Canadian Operations at the European Gemmological Laboratories (EGL) in Toronto and a Gem-A Tutor, gave a presentation on synthetic and treated diamonds including the latest KM micro-laser treatments. This was followed by a hands-on session when Club members could examine a variety of treated stones. David Davis brought along a selection of fine and rare specimens from his own collection for examination in July, severely testing the gemmological knowledge of Club members! Natural and imitation organic gemstones was the subject for the August meeting with Maggie Campbell Pedersen. Many of the items she provided for examination were examples of fakes currently circulating on the market. In October Harold Killingback's theme was asterism and chatoyancy, and

among the samples he brought along was the star rose quartz sphere as featured in his article 'Stereoscopic effect in asterism and chatoyancy' (*The Journal of Gemmology*, 2005, 29, 5/6).

London

A presentation was given on 15 April at the Gem-A London headquarters by Maria Alferova of the Moscow State University entitled 'Chrome-bearing green garnets'. Maria, who was visiting London en route for Scotland where she was speaking at the Scottish Branch Conference, has carried out extensive fieldwork in Russia and is currently specializing in chromium-bearing gem garnets. A report of her talk was published in *Gems & Jewellery*, June 2005.

Midlands Branch

Branch meetings held at the Earth Sciences Building, University of Birmingham, Edgbaston, included a demonstration of identification of gem materials using the microscope by Gwyn Green on 29 April and a cultured pearl evaluation workshop with Michael Houghton of Phoenix Far East Pearls Ltd on 30 September. The Branch's popular Summer Supper Party was held on 18 June.

North East Branch

On 13 April John Harris brought along a selection of specimens with prominent absorption spectra for a hands-on session on the observation, calibration and recording of gemstone spectra. 'The Chinese Pearl Revolution' was the title of John Carter's presentation on 15 June. A renowned authority on pearls, John spoke about the impact the Chinese production is having on the established trade. On 14 September Gem-A President Alan Jobbins gave a colourful pictorial presentation describing a wide range of the animal and vegetable materials which have been used for adornment over the centuries. All meetings were held at the offices of Evans of Leeds Ltd, Millshaw.

North West Branch

Regular Branch meetings were held at the new venue, the YHA Liverpool International, 25 Tabley Street, Liverpool 1. Eric Emms spoke on diamond treatments on 20 April, followed by a presentation by Wendy Simkiss on 18 May on the mineralization of fossils. On 15 June David Callaghan gave a review on twentieth-century styles, fashions and eminent designers in his talk entitled '1960 and all that'. 'Some you win, some you lose' was the title of auctioneer Stephen Whittaker's talk on 21 September. Stephen, of Fellows & Sons, Birmingham, gave Branch members the opportunity to handle auction pieces and – with his expert guidance – to value them accurately.

Scottish Branch

The Tenth Annual Scottish Branch Conference was held in Perth from 29 April to 2 May. The keynote speaker was Shane McClure, Director of the GIA West Coast Laboratory, who gave two presentations reporting on recent research and interesting and unusual stones seen at the Laboratory. A full report of the Conference was published in *Gems & Jewellery*, June 2005.

South East Branch

On 17 April a 'Jem Jumble' – a jumble sale event of gem miscellany – was held at the Gem-A headquarters in Greville Street. An illustrated lecture on amber and fakes was given by organics expert Maggie Campbell Pedersen on 26 June.

South West Branch

An afternoon of talks and hands-on sessions entitled 'Between a Rock and a Hard Place' was held at the Bath Royal Literary and Scientific Institution in Bath. Henry Meadows spoke on Blue John, followed by Richard Slater and Liz Latham on agates and other hard stones. 'Do you know if the stone you're looking at is a diamond?' was the question asked by Doug Garrod on 31 July during his afternoon presentation on synthetic, simulated and treated diamonds.

Membership

Between 1 April and 30 September 2005 the Council approved the election to

membership of the following:

Fellowship and Diamond Membership (FGA DGA)

Abrahams, Roy Henry, Ruislip, Middlesex, 1985/1987
Cheung Yiu Hung, Kowloon, Hong Kong, 2005
Lin Shu-Zhen, Taipei, Taiwan, R.O. China, 2005
Wackan, Susan Kirsten, London, 1985/1986
Williams, Benja-min Jacob, Blockley, Gloucestershire, 2003/2004

Fellowship (FGA)

Abel, Arlan, Minneapolis, Minnesota, U.S.A., 1991
Agrawal, Puru, New Delhi, India, 2004
Alcock, Kate, Hereford, Hereford and Worcester, 2005
Alliston, Erika A., London, 2005
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Errata

In *The Journal of Gemmology*, 2005, **29** (5/6), p.318, in Table I., for 'long wave 265 nm' read 'long wave 365 nm'

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Cover Picture: Lepidocrocite inclusions in quartz.
Photography by Luella Dykhuis FGA DGA, Tucson, Arizona, U.S.A.

First Prize in the 2005 Photographic Competition (see p.490).

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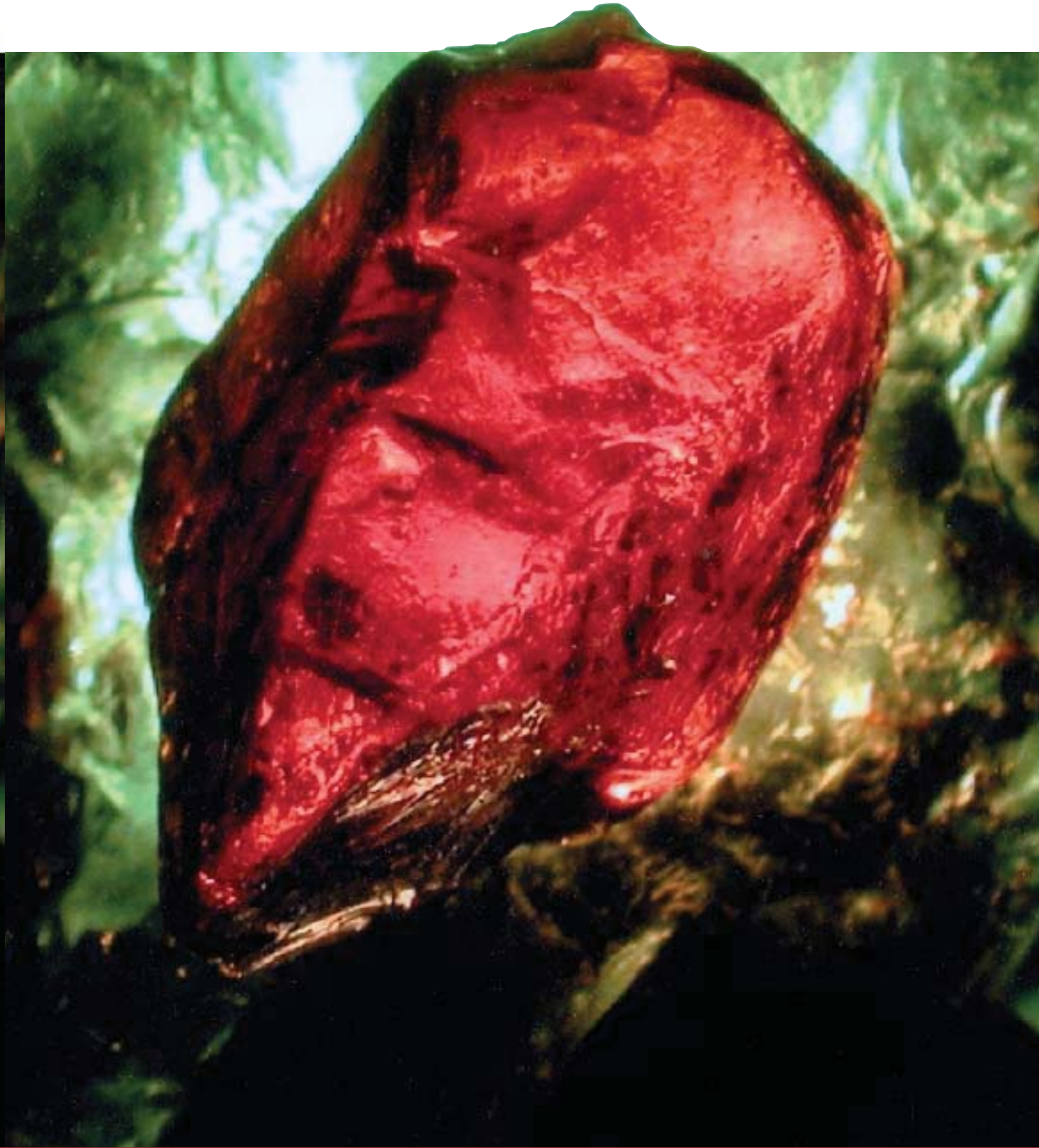

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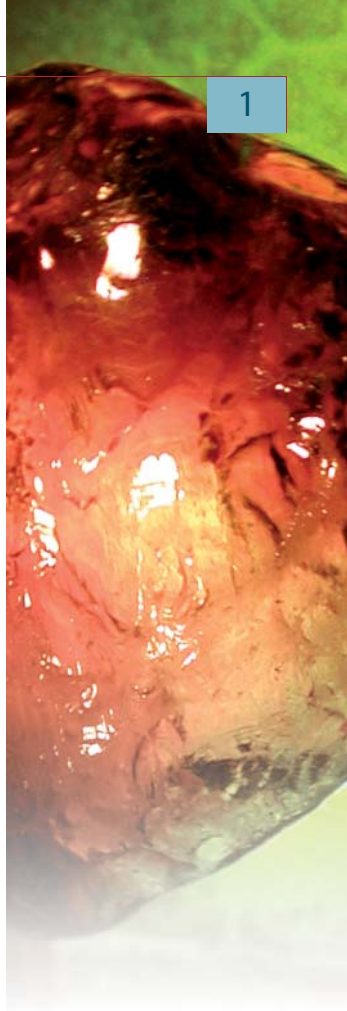

The Usambara effect and its interaction with other colour change phenomena

Asbjørn Halvorsen

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Abstract: *The Usambara effect, colour change with change in path length of light through a material, is found to interact with the alexandrite effect, colour change with change in spectral distribution of light. This article provides insight into the interaction between the Usambara effect and other colour change phenomena. In colour change studies of the past more focus has been placed on the alexandrite effect, but old studies also show awareness of the Usambara effect. This contribution provides a review of previous work and updating of earlier interpretation of this effect in the light of new observations. Epidote and kornerupine are introduced as new colour change minerals, and the Usambara effect is discussed in synthetic alexandrite and chlorophyll.*

Keywords: *absorption-modified dispersion, alexandrite effect, concentration effect, fluorescence, thermochromy, Usambara effect*

Introduction

"Let us rather recognise that even relatively simple observations can still provide us with unexpected and awe-inspiring phenomena."

This statement by Dr Kurt Nassau in the preface to the 2001 edition of *Physics and Chemistry of Color* referred to the Usambara effect and some other new discoveries. The Usambara effect is named after the verdant Usambara Mountains, south of the Umba area in Tanzania, and was introduced by Halvorsen and Jensen (1997a,b). They had studied a peculiar colour change from green to red in chromiferous tourmaline from Nchongo in the Umba area (*Figure 1*) and concluded that this depended primarily on the path length of light through the stone, modified by type of illumination and varying with pleochroic directions. This effect seemed to be hardly known to gemmologists. Nassau responded to the article by Halvorsen and Jensen (1997a) with a Letter to the Editor (Nassau, 1997). He advised that this effect was well known in the field of organic dyes and expressed his surprise that it had not been observed previously in minerals. Further, he expressed expectation that now, when attention had been drawn to these effects, they would very likely also be

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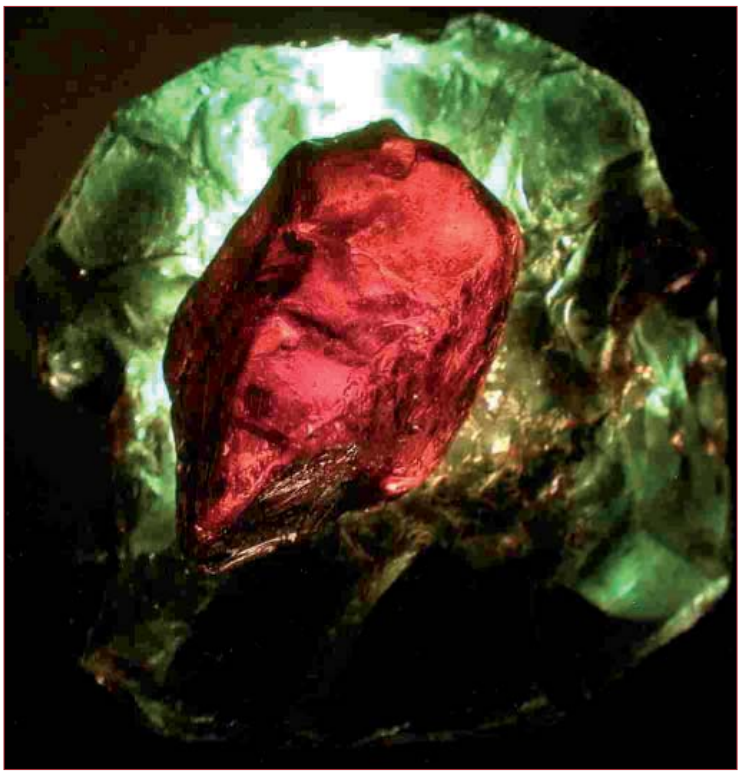

Figure 1: *A green UE tourmaline turns red when placed on top of another green UE tourmaline.*

observed in other minerals. In a colorimetric study of the same tourmalines, Liu *et al.* (1999a) suggested that the Usambara effect is a complex phenomenon, including effects of both path length and type of illumination.

The optical behaviour of the Nchongo tourmalines is extreme. After having studied a cut stone from this locality, Nassau (*pers. comm.*, 2002) commented: "I cannot think of any other stone that would show such clear-cut contrasting colours." This colour change behaviour is also found in some other minerals and man-made materials, e.g. plastics (Nassau, 2001). Most striking is maybe the similarity with colour change found in chlorophyll – the main colorant in nature.

The aim of this paper is to place the Usambara effect in the wider context of other colour change phenomena and to update understanding of it by description and discussion of new observations. Much of this is based on a detailed study of Nchongo tourmaline, but first there is a review of previous investigations of colour change phenomena.

Colour change phenomena in minerals – previous investigations

Colour change effects are reversible effects where radical changes in colour (hue) of a mineral are observed as result of environmental changes. A common attribute for most colour change minerals is transmission spectra with two pronounced transmission peaks, i.e. dichromatic spectra. In this study, the following causes of colour change are discussed:

- Change in spectral composition of light – *alexandrite effect*
- Change in path length of light through a material – *Usambara effect*
- Change in temperature – *thermochromy*
- Change in the direction of light in relation to the optic axes of an anisotropic mineral – *pleochroism*
- Change in concentration of light absorbing impurities – *concentration effect*

Throughout this paper UE is used as abbreviation for *Usambara effect* and AE for *alexandrite effect*.

Alexandrite effect (AE)

Gem minerals changing colour between daylight and incandescent light have been known and appreciated for centuries. Such colour change was first observed in a mineral found in the emerald mines at Tokowaia in the Urals (Wörth, 1842; Kokscharow, 1861). According to Gübelin and Schmetzer (1982) and other recent authors, alexandrite was discovered in 1830. Of the older authors, only Wörth (1842) seems to inform on when this happened: the mineral was first found in the Tokowaia mines in 1833. This was claimed to have happened on the birthday of Alexander Nikolajewitsch, later Tsar Alexander II, and the Finnish explorer and mineralogist Nils Nordenskiöld suggested that the new mineral be named *alexandrite*. The colours were described as emerald green in daylight and reddish violet in candlelight which were linked by Nordenskiöld to the red and green Russian military colours.

The name *alexandrite* was also used by Wörth, who examined the new mineral in St Petersburg in 1833 and found it to be chrysoberyl, a beryllium aluminium oxide (Wörth 1842: Kokscharow, 1861). Kokscharow gave Gustav Rose the credit for the first comprehensive crystallographic description of alexandrite (i.e. chrysoberyl). Rose (1842) described in detail the mineral deposits in the Urals. In an emerald green chrysoberyl he found dichroism to be influenced by type of light: in transmitted light a hyacinth colour was observed in one direction in the crystal. This colour was seen only in strong sunlight or candlelight, not in normal daylight. Wörth (1842) described observations done in overcast daylight: green colour in one direction and red perpendicular to this. He found that by changing the proportions of green and red in the light, the colour of the mineral changed. When illuminated by candle light or by a low sun, the red rays dominated the green rays and the observed colour was red. Both Rose and Wörth concluded that the chrysoberyl was coloured by chromium oxide. Chemical analyses by Awdejew (1842) showed a chromium oxide content of 0.36%.

Another mineral known for colour change (in addition to strong pleochroism) is tourmaline. Bank and Henn (1988) reported change from green in daylight to brownish red or red in artificial light in tourmalines from Tanzania, and although their searches for previous examples of tourmalines with the AE had proved fruitless, such tourmalines from the Urals had been described a century earlier by Cossa and Arzruni (1883). This tourmaline was found in chrome-iron deposits near Sysert, south of Yekaterinburg, associated with emerald, uvarovite, demantoid and a new mineral, chrome mica. The detailed description includes results of chemical, crystallographic and optical analyses. In daylight, prismatic crystals of tourmaline were yellowish brown when illuminated parallel to the optic axis and blue green perpendicular to this. In incandescent light the colours were orange reddish brown to ruby red and weak green, respectively. Cossa and Arzruni suggested that the new tourmaline variety was a perfect counterpart to alexandrite; they also claimed that previously only alexandrite was known for such colour change. Gustav Rose had donated samples of Ural chromian tourmaline to the Museum of Natural History in Berlin in 1829, but did not observe the colour change behaviour in these. The relevant passage of Cossa and Arzruni (1883), translated from German, is:

"Two minerals that have been unknown till now deserve attention: a beautiful emerald green chrome mica and a deep green chrome tourmaline. The latter was certainly seen, collected and described by G. Rose, but the true nature of this remained however hidden for this sharp observer. Prof. Websky recognised at the first glance that this mineral contained chrome. This was also confirmed by the observation of the beautiful dichroism, till now only known for alexandrite, and the pronounced partial transparency for certain parts of the spectrum. This property was especially clear by use of lamp light; these red rays were transmitted nearly unimpaired in the tourmaline, which appeared intense ruby-red."

The British Museum also received a sample of the Ural chromian tourmaline from Arzruni. Dunn (1977) examined this sample, a dravite with a Cr_2O_3 content of 5.96%, but did not comment on any colour change behaviour.

According to Gübelin and Schmetzer (1982), White *et al.* (1967) introduced the term *alexandrite effect.* This denotation had, however, already been used by Neuhaus (1960), who presented typical absorption spectra for several chromium-containing minerals, all with two absorption maxima, and classified them (*Figure 2*) as:

- Red group, with absorption maximum I at <~540 to ~570 nm and maximum II at <~390 to <~415 nm, mainly *oxides*.
- Green group, with maximum I at >~580 to >~650 nm and maximum II at >~420 to >~460 nm, mainly *silicates*.
- Transition group, including AE minerals, with maxima in general located between the maxima of the red and green groups.

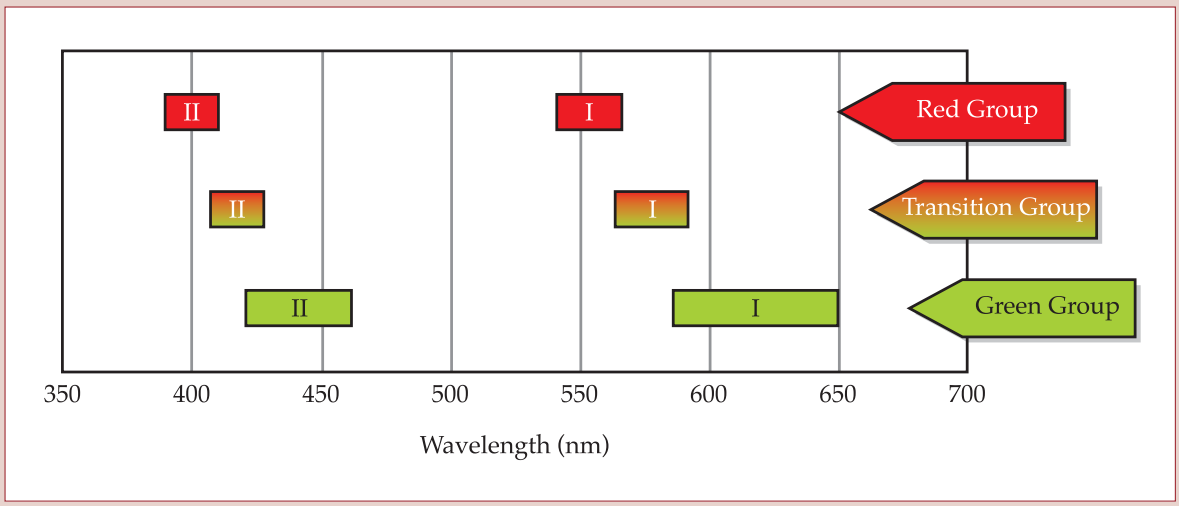

Figure 2: *Chromium-containing minerals classified as three spectral groups according to Neuhaus (1960), with location of absorption maxima I and II for the three groups.*

In 1970 Crowningshield reported a rare garnet from Tanzania, which was found to be an isomorphous mixture of pyrope and spessartine, and appeared blue-green in daylight and purple-red in incandescent light. However, garnets with green to red colour change were not as rare as Crowningshield suggested, as similar garnets had been found in the Czech Republic (Fiala, 1965) and Norway (Carstens, 1973).

In a study of colour change in man-made crystalline chromium compounds, White *et al*. (1967) found the AE in ruby with 20 wt% Cr_2O_3, appearing pink in incandescent light and green in daylight. Schmetzer *et al*. (1980) described the AE in chrysoberyl, garnet, corundum and fluorite. Bank and Henn (1988) mentioned that such colour change was also known in alexandrite, garnet, corundum, spinel, zircon, fluorite, kyanite and diaspore. Bernstein (1982) described the AE in monazite from North Carolina, showing yellow-orange in daylight, reddish-orange in incandescent light and pale green in fluorescent light. He also listed other AE minerals, including coquimbite in addition to those listed by Bank and Henn (1988).

Liu *et al*. (1994, 191) described the AE as "change in colour appearance with differences in lighting" and stated that they had observed approximately 40 gem minerals displaying this behaviour. They introduced four categories of colour change that all met a requirement of at least 20 calculated absolute hue-angle change between different light sources in the CIELAB colour space. This concept was further elaborated by Liu *et al*. (1999b).

Usambara effect (UE)

Chrysoberyl and tourmaline

Early awareness of the UE is found in the descriptions by Haidinger (1849) and Kokscharow (1861) of Ural chrysoberyl. Haidinger observed the trichroic colours using a dichroscope loupe. In daylight, variations of green were observed, and under lamplight he described colour 1 (lightest tone) as orange-yellow, colour 2 (darkest tone) as emerald green and colour 3 (medium tone) as reddish violet. A remarkable observation was that the latter colour was dichromatic, i.e. having two colour maxima. In thin sections colour 3 was green with an addition of violet, and in thick sections reddish violet. Haidinger recorded the strange phenomenon of colour 2 also being green in lamplight, i.e. not influenced by change in illumination, but being dominated by the red with a lighter tone (see Discussions with Dr Kurt Nassau below). Also Cossa and Arzruni (1883) seemed to observe the UE. Their main concern in regard to colour change in the Ural tourmaline was change in pleochroic colours with type of illumination. They also described how the

pleochroic colours varied from thin to thick sections of the mineral, with reference to code numbers in Radde's International Colour Scale. Regrettably it has not been possible to trace illustrations or explanations for these colour codes.

The early researchers apparently had a good understanding of the factors affecting colour change in minerals, and of the interaction between these. Wörth (1842) concluded that chromium oxide was the colouring agent in alexandrite. He had found that a solution of chromium in hydrochloric acid or in sulphuric acid transmitted both green and red rays and had demonstrated for other researchers how the colour in crystallised bodies (presumably laboratory-grown crystals) coloured by chromium, was affected by pleochroism. According to Wörth, Nordenskiöld later found the same properties in the Ural chrysoberyl. Wörth also reported in detail how the pleochroic colours are influenced by type of illumination.

In a paper on colouring in minerals, Kennard and Howell (1941, 407) used the term 'polychromatism' with reference to "the fact that the hue and saturation of the colour, in isotropic as well as anisotropic materials, are dependent on both the concentration of the absorbing substance and the depth or thickness of the medium traversed." As an example of a strongly polychromatic mineral, they mentioned ferric oxide (hematite), with hues ranging from yellow through red to nearly black. They did not mention colour change caused by change in illumination. Polychromatism was the term used by Webster (1994) to describe green to red colour change in chrome alum solutions, caused by either increase in concentration or sample thickness. Haidinger (1849) and Kokscharow (1861) also used this denotation for a UE type of colour change in alexandrite.

Webster (1961) described tourmalines from the Gerevi Hills, Tanzania, which appeared red under a Chelsea colour filter. In a thorough description of the optical behaviour and physical properties of this mineral, he used the term '*dichromatism*' to describe the property such that in transmitted light, thinner sections of a dark stone appeared green and thicker sections red. The depth of the red seen through a Chelsea filter, as well as the strength of dichroism, varied in proportion with the depth of the green. In a dark green stone, the thinner sections showed strong dichroism in light and dark green colours, while thicker sections showed light and dark red dichroic colours. Under a SW UV lamp the tourmaline showed mustard yellow fluorescence and under high intensity light a dim red glow. Webster did not comment on the influence of type of illumination on the colour change in these tourmalines. In 1997 Halvorsen and Jensen were not familiar with Webster's observations, but their observations (*op. cit.*, 1997a) were very similar. Based on spectral analyses, and in agreement with chemical analyses by Basset (1955), Webster concluded that the vanadium content exceeded that of chromium, and that the vanadium content in dark stones was higher than in light stones. Basset did not describe colour change in the tourmaline. This is understandable in view of the apparently poor quality of sample material, as indicated in his description. Bank and Henn (1988) referred to Webster (1961), but did not mention any colour change as a result of changes in path length. Also Crowningshield (1967) found that some very small Tanzanian chromian tourmaline samples appeared bright red under the Chelsea colour filter. On the basis of an absorption spectrum he inferred the presence of chromium. Crowningshield also did not observe any colour change, but his stones were very small. In a detailed description of many gem minerals from the Umba valley, Zwaan (1974) described a sample of emerald-green tourmaline from the Umba mine showing red in transmitted incandescent light but did not further explore the phenomenon. How can this pronounced colour change behaviour have avoided further focus in recent publications on gemstones from this region? UE tourmalines also occur in the John Saul ruby mine, Taita-Taveta District, Kenya (Simonet, 2000) which is located just north of the Umba area of Tanzania, about 95 km NNW of Nchongo. Emerald-green tourmalines with similar colour change behaviour have also been found in Madagascar (M.S. Krzemnicki, *pers. comm.*, 2004).

Garnet

Fiala (1965) described change from green in daylight to red-violet in incandescent light in pyropes from peridotites in the Ceské Stredehori Mountains, close to Trebenice in the Czech Republic. The green colour in daylight was seen especially in small fragments – an observation indicating presence of the UE. C. Simonet (*pers. comm.*, 2000) observed the UE in garnets from Taita Hills, Kenya. He found that this type of colour change was much stronger in garnets than in tourmalines from this area, especially in daylight, and that many stones showed both AE and UE. In the trade, gem dealers he had met described the UE in many stones as dichroism and talked about dichroism in garnets.

Manson and Stockton (1984, 200) studied a selection of garnets exhibiting colour change between incandescent light and daylight equivalent illumination and observed that: "While all the stones show some change in colour between incandescent and daylight or fluorescent illumination, most also display a different colour when light is passed through the stone, as compared to internally reflected light from the same source." They referred to the latter as colour shift and suggested: "Colour shift does not occur with a change in illumination, but rather with the relative amounts of light (from a single source of illumination) that a viewer observes either (1) passed through the stone or (2) internally reflected by a gemstone. The former reveals the stone's body colour, the latter requires the viewer and illuminant to be on the same side of the gem, so that the internal reflections (which represent the reflected colour) may be observed."

The observations by Manson and Stockton are similar to observations concerning UE tourmalines and are discussed below.

Concentration effect

Colour change with change in concentration of light-absorbing impurities is covered by the denotation *'polychromatism'* (Kennard and Howell, 1941). In his study of pyropes, Fiala (1965) found that the colour changed from orange-red to violet with Cr_2O_3 content increasing from 1.15% to 6.54%. Pyrope garnets showing an AE had previously been described from peridotites found on the island of Otterøy, close to Molde, Norway, changing from violet in daylight to wine red in incandescent light (Hysingjord, 1967 and 1971). Then, Carstens (1973) found that a more chromium-rich pyrope from the same location changed from blue-green in daylight to wine-red in incandescent light. This pyrope had a Cr_2O_3 content of 6.22%, while the one with colour change from violet to wine red had 3.72%. Carstens analysed absorption spectra for the green chromium-rich pyrope and a red chromium-poor pyrope (1.50% Cr_2O_3), finding a pronounced shift towards the red end of the spectrum for the two absorption peaks, as well as for the minimum between these, with increased Cr_2O_3 content. He concluded that the change from green to red in these garnets, being essentially solid solutions of pyrope, almandine and uvarovite, occurred at about 6-7% Cr_2O_3. Orgel (1957) reported a similar colour change in laboratory-grown rubies which remained red with up to 8% Cr_2O_3, turning progressively more and more green with increasing Cr_2O_3 content. This effect was also described by Thilo *et al.* (1955) and by Nassau (2001).

Thermochromy

This colour change phenomenon is related to crystallographic lattice distortions caused by change in temperature. Kenngott (1867) described colour change to green by heating of red corundum from Sri Lanka, and reversion to red by cooling. Thermochromy in corundum and spinel has been thoroughly discussed by Weigel (1923) on the basis of detailed spectral analyses and he found that the colour change in ruby was influenced by pleochroism. Thilo *et al.* (1955) concluded that the colour change with temperature in ruby is momentary and strictly reversible. They studied the colour behaviour of samples of synthetic corundum with variation in chromium content and measured the *grey*

point temperatures, at which a grey colour was observed on the transition between red and green. The lower the chromium content, the higher was the *grey point* temperature. With a Cr_2O_3 content of 5%, the *grey point* temperature for ruby was found to be of the order of 600 C. They also found that the *grey point* changed with type of light. At room temperature corundum with 17% Cr_2O_3 was grey in daylight and red in incandescent light. These findings were analysed by Orgel (1957) who described this optical behaviour of ruby as anomalous. Based on experimental data on chromium-containing solids, Poole (1964) suggested that thermochromy is a general property of solids containing Cr^{3+} ions. He assumed thermochromy to be present in chromium-containing minerals, including ruby, emerald, uvarovite, fuchsite and chrome diopside. Carstens (1973) found that his red pyrope with 1.50% Cr_2O_3 turned green when heated to about 200 C, while a violet pyrope with 3.72% Cr_2O_3 turned green at about 150 C. Neuhaus (1960) described thermochromy in chrome alum solutions.

The Usambara effect

Basic idea

Characteristic for UE is colour change as response to change in the light transmission path length. A green UE tourmaline may turn red in transmitted light when placed on top of another green UE tourmaline (*Figure 1*). When light is transmitted through a coloured mineral, certain frequencies are absorbed and the remaining frequencies combine to give the mineral its colour. Change in path length of transmitted light will affect the spectral power distribution. An increased path length will result in a general increase in absorption. The Lambert law, $I_{(z)} = I_0 * \exp(-a*z)$, defines the degree of absorption for a given path length z, where I_0 is the intensity of light entering the material, and $I_{(z)}$ is the intensity of the light after passing through a thickness z of material with absorption coefficient a. If the intensity of light is reduced to half on passing through material with thickness z, an increase in material thickness (or path length) to 2z will reduce the intensity of transmitted light to a fourth. A crucial condition in regard to the UE is that the increase in absorption is higher for the higher frequencies than for the lower. With increased path length, the intensity of the red transmission is increased relative to the intensity of the green, and thereby the balance between the green and red transmissions is shifted towards red, a shift that can be observed as relatively sudden. The sensitivity of the human eye is highest in the green sector, for wavelengths between 500 and 510 nm (Kuehni, 1997), so if light transmitted through a mineral has transmission peaks of the same intensity in the green and red, the mineral will appear green. With a minor change towards red in the balance between the transmissions in the green and red, a mineral might still appear green, but if there is sufficient increase in red transmission, a sudden change to red may be observed (Poole, 1964).

Discussions with Dr Kurt Nassau

Extensive discussions between Nassau and the author covered various aspects of the UE and, concerning its definition, Nassau (*pers. comm.*, 1998) suggested:

"It is necessary here to distinguish between a colour change that involves a change in hue (or dominant wavelength or chromatic colour, etc.) and one that does not do so. The term Usambara effect is obviously intended to apply only to a change involving hue. Most materials will change colour without a change in hue when either the concentration of a light-absorbing impurity or the light path length is increased. If there is a change in the field (crystal or ligand), then the hue will change with the concentration, but not with the path length. Only when at least one transmission band extends significantly out of the visible region, as at the red end of the spectrum with your tourmaline, will there be a change of hue with either concentration or path length. It seems to me that only under these conditions should the former be termed "concentration dichroism" in dyes or the concentration effect

of colour-producing impurities in minerals. Similarly, only the latter should be termed the Usambara effect."

In a discussion about causes for observed colour changes in UE tourmaline, Nassau (*pers. comm.*, 2000) commented:

"One interesting question which your discussion has raised in my mind is why it is so rare to see more than one of the pleochroic colours from a gemstone (without turning it or using a polariser): andalusite with both reddish and greenish colours is exceptional – some alexandrite also shows this effect, but less strongly, some zoisite with yellow flashes in the green, and green to almost black in tourmaline (not exactly a colour change). Even then, why do only some pleochroic materials show only some of their colours on being turned (without a polariser)? Ruby shows both its colours, but iolite shows only two of its three colours. I believe that I now know the answer: the reason lies in the fact that the ordinary ray colour is seen in all orientations. If the o rdinary ray colour is intense and saturated, it will then hide the other colours in those orientations where one would expect to see them."

This explanation is consistent with that given by Wörth (1842) and by Haidinger (1849) for their observations concerning alexandrite.

New observations, investigations and interpretations

The observations described below relate to UE tourmalines from Nchongo, unless otherwise specified. They are grouped according to the cause (tentative or proven) for the observed phenomena: *colour change due to change in path length of transmitted light*, *thermochromy*, *dispersion* and *visible-light-induced fluorescence*. Discussion and suggested explanations follow the observations.

Spectral analyses were carried out by K.A. Solhaug, Agricultural University of Norway, Ås, using an Ocean Optics SD 2000 spectrometer (*Figures 3, 10, 15 and 17*) and L.O. Björn, Lund University, Sweden, using an Optronics 754 spectroradiometer (*Figure 7*). Electron microprobe analyses were carried out by C.J. Stanley at the Natural History Museum, London, using a Cameca SX50. Fluorescence was measured by J. Kihle, Institute of Energy Technology, Oslo, Norway, using a customised Olympus BX-61 microscope at 10x magnification, fibre-optically connected to a modified Edinburgh Analytical Instrument CD900 excitation/emission spectrometer, excitation wavelength set to 405 nm.

Gemmological instruments utilised by the author include a Krüss refractometer, OPL dichroscope, dichromatic colour filters: Chelsea filter with transmissions in the deep red and in the yellow-green (570 nm). Hanneman Aqua filter with transmissions in deep red and in blue-green (490 nm). Fibre optic lamps had 20W and 150W tungsten halogen light sources. A Nikon Coolpix 990 camera was used to record images.

Change in path length of transmitted light

Observations

I a The colour of a green UE tourmaline, illuminated from behind, shifts towards red when studied through green or blue UE sheets of plastic. The same happens when the tourmaline is studied through solutions of certain types of green and blue dyes for colouring Easter eggs.

I b A certain orange-yellow sapphire placed on top of a green UE tourmaline turns deep red in transmitted light.

I c Normally a green UE tourmaline appears red when studied through a Chelsea colour filter, and an even stronger red through a Hanneman Aqua filter. In a pale green UE tourmaline, the colour of a thicker part of the stone may turn red under a Chelsea filter, but not the thinner parts. The same effect is seen in tsavorites from Kalalani, Umba area, which show more red in the thicker than in the thinner parts when studied through a Chelsea filter.

I d An emerald green kornerupine crystal from Nchongo, Umba area, shows a peculiar pleochroism.

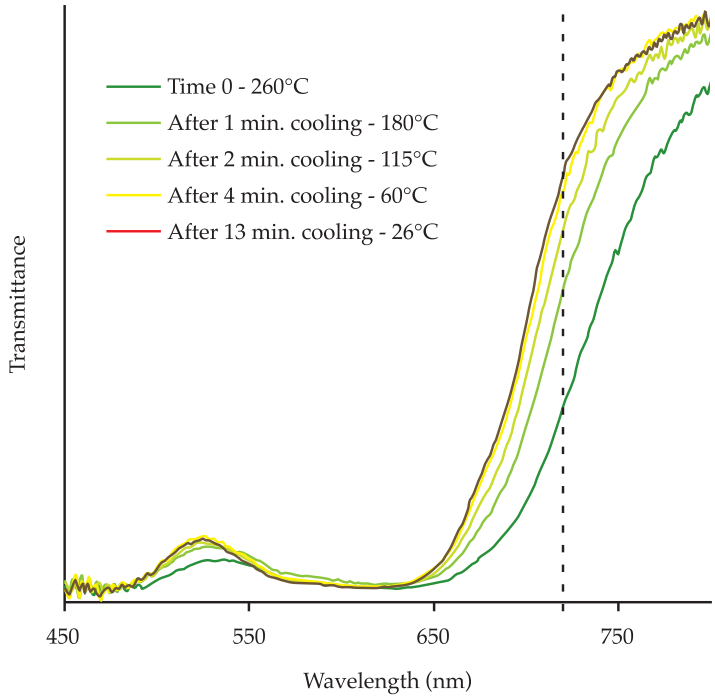

Figure 3: *Effect of temperature on UE demonstrated by spectral transmittance curves. A UE tourmaline was heated and the recording done during cooling at the shown time intervals. The largest difference in spectral transmittance intensity is at about 720 nm, shown by the dotted line.*

Discussion

Dichromatic colour filters (e.g. Chelsea filter) have a colour changing effect similar to the UE. The colour change observed when a green tourmaline is placed on top of another green tourmaline is the same as that seen when one of the stones is replaced with a Chelsea filter. Placing the orange-yellow sapphire on top of a green UE tourmaline also results in relative increase in intensity of the combined red transmission due to superposition, with colour change to red.

Thermochromy

Observations

II When a UE tourmaline is moderately heated to about 250-300 C the red colour disappears and then reappears when the stone is cooled down. The return of the red colour is not spontaneous, but is seen first in the thickest part of the stone, then in the thinner parts. By measuring the temperature when the stone was cooling, its influence on colour could be observed at least down to 120-130 C. Also the red colour attributed to absorption-modified dispersion (see below) disappears when the stone is heated.

Discussion

This test was done after reading Carstens' (1973) descriptions of thermochromy in garnets with change in colour at 150 C. Observation II indicated that even lower temperatures than 150 could affect the colours involved in the UE in tourmaline. Spectral analyses were then done at different temperatures. To avoid influence of pleochroism and of change in light path length, all measurements had to be done without moving the sample. A heated stone was placed on the spectrophotometer and measurements conducted while the stone was cooling. With the available instrument set-up, measurement of temperature in the stone was not possible simultaneously with the transmittance recording. By repeating heating of the sample and then measuring the decreasing temperatures at the same time intervals as the spectra had been recorded, the corresponding temperatures could be estimated. These temperatures are linked to the spectra in *Figure 3*, and indicate the approximate range for this test. The change in spectral transmittance intensity is highest at the highest temperatures, but even down towards room temperature a

slight change can be observed. The largest change is indicated by a dotted line at about 720 nm. *Figure 4* shows the change in intensity at 720 nm with temperature change. It follows that temperature changes experienced under natural climatic conditions may affect the UE colour change in some stones.

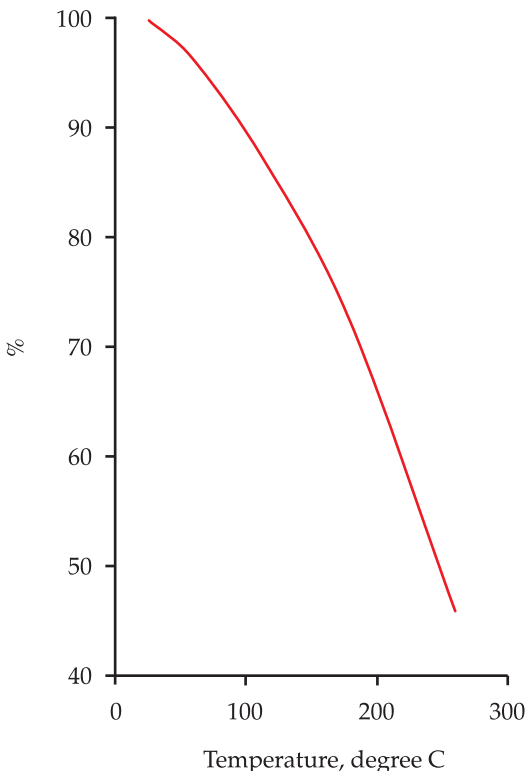

Figure 4: *Change in spectral transmittance intensity at 720 nm in green tourmaline with temperature change. Intensity at 26 C set as 100%.*

Absorption-modified dispersion (AMD)

Observations

III a Light reflected from faceted UE tourmalines may contain red and green flashes, and the quantitative distribution of these colours will depend on size of the stone, colour saturation and illumination (*Figure 5*). Larger stones will show a higher proportion of red than small stones, but the red hue in a small stone seems identical to the red hue in a large stone cut from the same crystal. Red flashes have been observed in faceted stones down to 0.2 ct. Study of such flashes under a loupe shows that the colour changes from strong red, often seen as a sharp band, at one end of a facet, through a central yellow transition zone, to a strong green band at the opposite end. The green hue in this *spectrum* may be a purer green than the transmittance colour. Such *dichromatic fire* may also be seen in other gem minerals with transmission spectra characterised by two transmission bands (dichromatic minerals). Examples are alexandrite, tanzanite, colour-change sapphires and tsavorite. Careful study of reflections in facets in rubies from the Umba area not only revealed the deep red colour, but also a thin, blue band close to the edge of a facet. In blue sapphires from Umba, thin red bands were observed, and the same feature was seen in the facets of deep blue spinel.

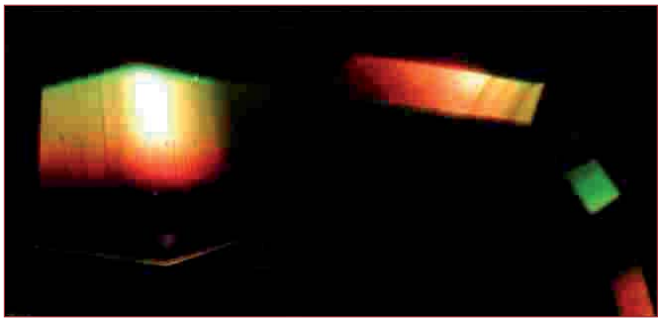

Figure 5: *Dispersion colours in facets of 18 ct UE tourmaline.*

III b In prismatic tourmaline crystals, viewed in the direction of the *c*-axis and illuminated from behind, a red colour may be seen along the crystal faces, while the central part of the crystal is green, see *Figure 6*. C. Simonet (*pers. comm.*, 2001) observed the same in tourmaline crystals from Taita Hills, Kenya. He did an electron microprobe traverse across the crystal to check the possibility that the red colour was caused by compositional zoning such as chromium variation, but such zoning was not found.

Figure 6: *Red colour along contour of UE tourmaline crystal when viewed along c-axis and illuminated from behind. Photo by J. Kihle.*

III c A strong red colour may be observed at surface irregularities, such as edges and weathering grooves on rough stones and the roughly ground girdles of faceted stones. Red colour may also be seen associated with inclusions.

III d Viewing a light bulb through the table of sizable faceted UE tourmalines held close to the eye reveals a pronounced red-green spectrum which consists of a sharp green band following the contour of one side of the bulb and a sharp red band along the contour of the opposite side. No distinct colours are seen in between. The green and the red bands have more or less the same width. If the stone is rotated, the green and the red bands shift towards each other and when the bulb is viewed parallel to the table the two bands appear next to each other. Crowningshield and Ellison (1951) introduced the Eyeball method for determination of optical properties and described spectral observations in various gemstones. In incandescent light the red in alexandrite was very strong and the blue-green was almost halved by a broad absorption band. In daylight, the red was very weak while the blue-green was strong. In a UE tourmaline, the widths of red and green bands change somewhat with type of light, but possibly not as much as in alexandrite. The Eyeball method was described for faceted stones, but in UE tourmaline, spectral images can also be seen in rough stones and cabochons. Further, the light source does not need to be well defined: for example, looking at a variably-lit landscape through a faceted tourmaline held close to the eye reveals numerous spectral images related to light and dark points in the landscape. Also when a stone is moved away from the eye, the spectral images of a light source can be seen as red and green flashes in the stone.

III e If a fibre-optic light is placed against the backsurface of a flat plate of UE tourmaline, a partial or full red rim may be seen at the edge of the circular fibre bundle. A full red circle seems to be dependent on a certain thickness of the stone, while a partly red, partly green circle is produced by stones of less thickness. Similar observations can be made when viewing the fibre optic light through a Chelsea filter, a chlorophyll solution, or through certain green or blue dyes.

III f A remarkable observation was made when studying a flat, rough, deep green UE tourmaline. With the fibre optic light placed behind the stone in the direction of the short axis, the stone showed a deep green hue. With the light placed on the same side as the observer, an object such as a pencil held behind the stone could show a deep red hue, especially along the edges.

Discussion

Although dispersion has not traditionally been considered to be connected with change in the body colour of a mineral, it is still important in connection with the UE. A major part of the red flashes in a faceted

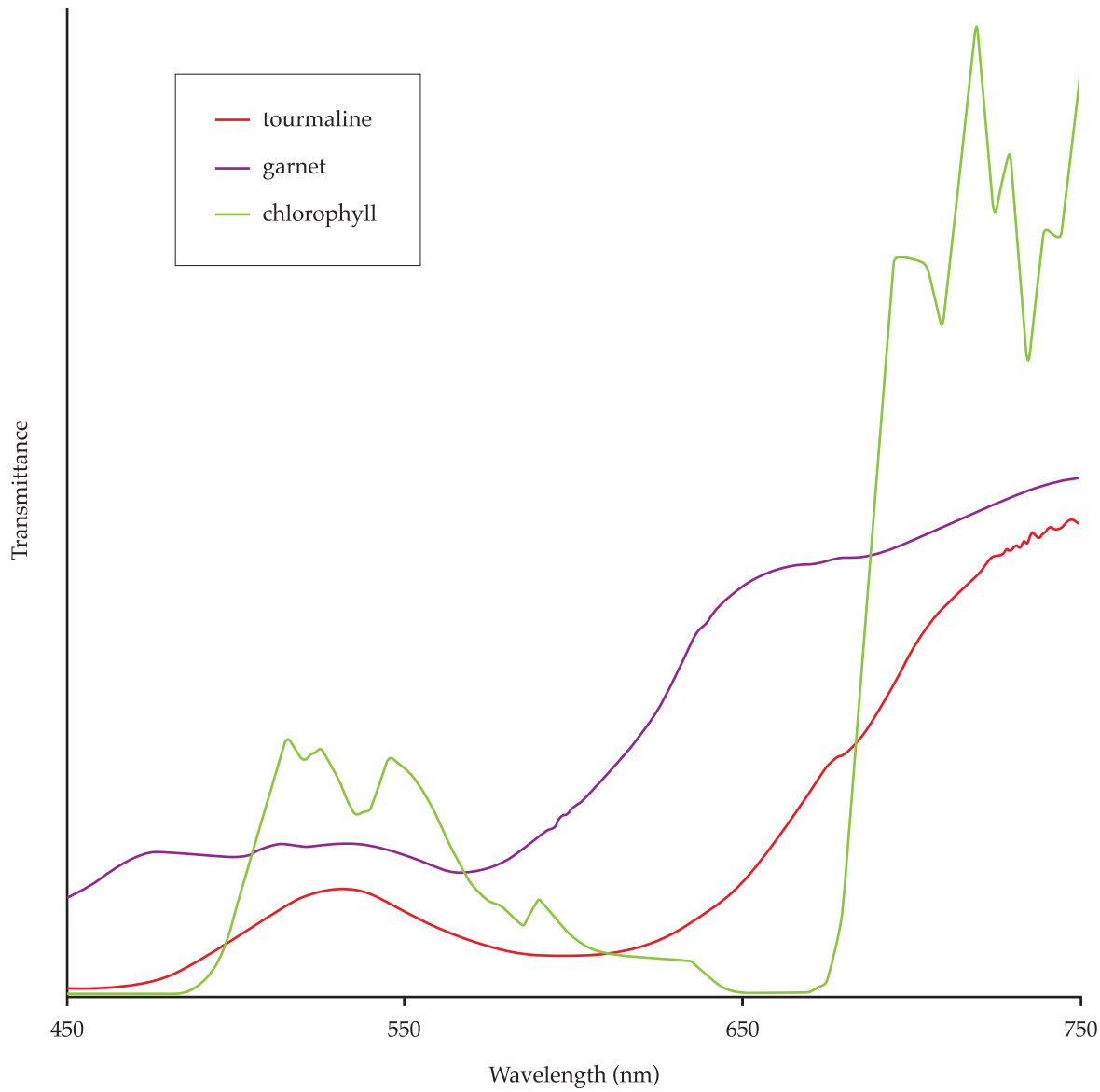

Figure 7: *Transmission spectra for UE tourmaline (red), chlorophyll solution (green) and 'colour shift garnets' (purple) (garnet spectrum based on Manson and Stockton, 1984, Figure 4).*

green UE tourmaline is apparently caused by dispersion. Dispersion in gemstones is described as *fire* and is most clearly observed in colourless or pale-coloured gems with strong dispersion. In more intensely coloured stones dispersion is normally masked. It is here postulated that minerals with dichromatic transmission spectra are exceptions and that these may show a conspicuous *dichromatic fire*, an apparently neglected quality criterion for gemstones. In minerals with dichromatic absorption spectra the appearance of dispersion seems to be different from what is normally seen in coloured gems. A UE tourmaline has normally strong colour saturation and weak dispersion. Is it still possible that dispersion can be the cause of the colour change phenomena described above? It is possible that parts of the dispersion spectrum are being absorbed. In a colourless stone with no absorption, dispersion separates all the colours of the visible spectrum and is seen as *polychromatic fire*. In a coloured stone with one dominant transmission frequency, all the colours separated by dispersion are being inhibited, except for the transmitted colour, resulting in *monochromatic fire*. In a coloured stone with a transmission spectrum characterised by two colours of more or less

the same intensity, a *dichromatic fire* may be seen. Transmission bands may act as *windows* for dispersion colours of corresponding frequencies. Red dispersion rays escape through a red transmission window, and similarly green dispersion rays through a green transmission window. Any other dispersion colours are trapped by absorption.

Manson and Stockton (1984) suggested that the *colour shift* in their garnets required an absorption spectrum similar to that which produces the Alexandrite type of colour change, see *Figure 7*. They found the AE not to be the dominating effect and the colour shift was observed in transmitted light or by internal reflections. Is it possible that the *colour shift* observed in transmitted light was an effect of light path length (UE)? By colorimetric analyses of Manson and Stockton's absorption spectra, L.O. Björn (*pers. comm.*, 2004) has linked the change in colour with change in path length. The *colour shift* in reflected light was probably due both to UE and AMD.

AMD may take place also in UE materials with sample thickness too small to give a UE colour change. This prioritised appearance of AMD in relation to the UE can be seen in UE tourmalines, but is even better shown by the green and blue dyes showing the UE.

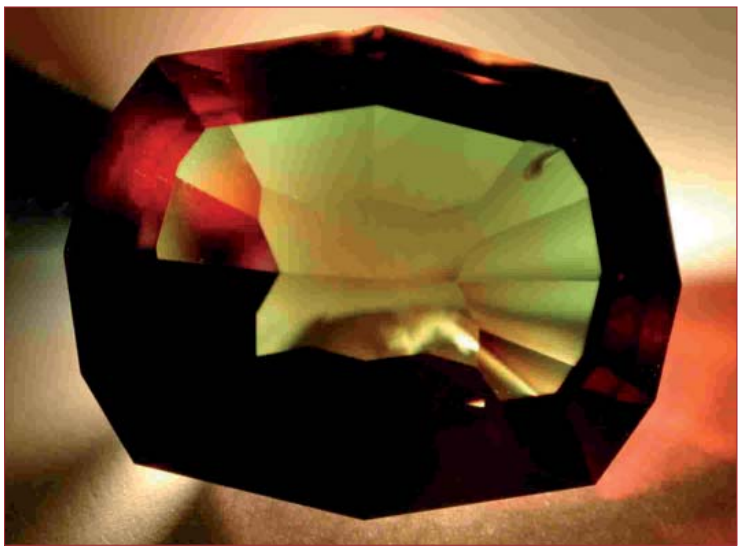

Figure 8: *Red fluorescence caused by fibre optic light at upper left corner of 18 ct UE tourmaline.*

Fluorescence induced by visible light

Observations

IV a When fibre-optic light is placed against the surface of a UE tourmaline more than about 8mm long, a red, elliptical ray can be seen (*Figure 8*). The red ray extinguishes at a depth of 4 – 6 mm, and is somewhat chalky, different from the clear red caused by the UE.

IV b A green UE tourmaline turns red when illuminated with high-intensity violet light (405 nm), see *Figure 9*.

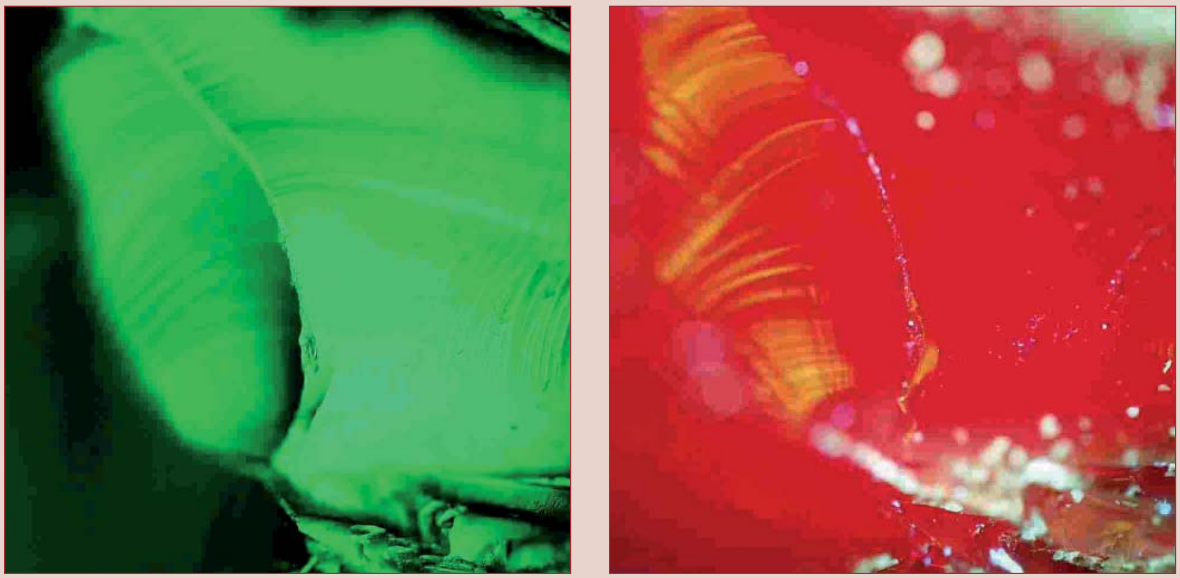

Figure 9: *Colour change due to fluorescence: (a) green when illuminated with white light, and (b) red with 405 nm monochromatic light. 400x magnification. Photo by J. Kihle.*

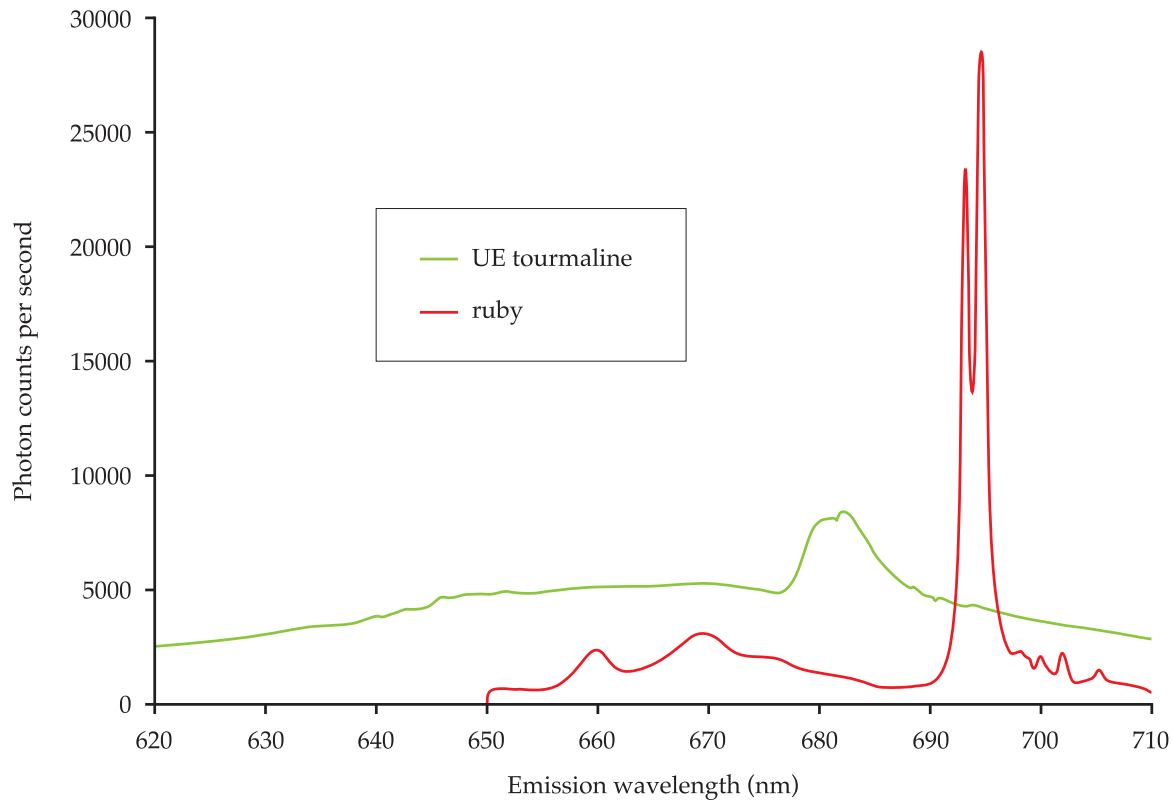

Figure 10: *Fluorescence spectra for UE tourmaline (green) from Nchongo, Tanzania and for ruby (red trace) from Froland, Norway, using excitation of 405 nm.*

Discussion

In a fluorescence study of some UE tourmalines J. Kihle (*pers. comm.*, 2002) found a red luminescence when the tourmaline was excited by light in the violet part of the visible spectrum. The strongest luminescence was obtained with an excitation wavelength of around 405 nm, with a pronounced luminescence intensity peak at 682 nm, see *Figure 10* where it may be compared with a fluorescence spectrum for ruby. When excited by 405 nm light, the luminescence intensity from the tourmaline is about 30% of that from the ruby.

The elliptical shape of the red luminescence ray obtained from green UE tourmalines using fibre-optic light, is probably caused by reduction in light intensity by absorption. Beyond a distance of 8-12 mm from the light source, the intensity is probably too low for inducing fluorescence. Increasing the intensity of the light is found to result in a deeper luminescence penetration.

Chemistry and colour in UE tourmalines

Halvorsen and Jensen (1997a) described the tourmalines in their study as calcium-bearing dravites and two analysed samples had 0.34 and 0.22 wt% Cr_2O_3 and about 0.05 wt% V_2O_5. In various studies of tourmalines from East Africa, a topic for discussion has been the relative contents of Cr and V in green tourmalines and whether they should all be called chrome tourmalines. Schmetzer and Bank (1979) concluded that green tourmalines from East Africa are mainly coloured by vanadium and should be named *vanadium tourmalines*, but Simonet (2000) reported higher chromium than vanadium contents for three out of four green tourmalines from the Taita-Taveta District, Kenya. For the present study, the contents of Cr_2O_3, V_2O_5 and FeO in a selection of cut UE tourmalines from Nchongo were analysed at the Natural History Museum, London, and the results are given in *Table I*. Corresponding transmission spectra are shown in *Figure 11*. Samples 2073 and 2045 with relatively high V_2O_5 – content

Table I: *Contents of Cr_2O_3, V_2O_5 and FeO in cut green UE tourmalines from Nchongo, Tanzania, based on electron microprobe analyses.*

Sample[a]			Chromophores wt%[b]		Colour			Refractive indices		
No.	Weight ct	Cr_2O_3	V_2O_5	FeO	Hue, fluorescent light	Saturation[a]	Response to Chelsea filter	nω	nε	Δn
2073	0.8	0.19	0.72	bdl	Bluish green	Very high	Mod. – strong	1.641	1.621	0.020
2045	1.0	0.15	0.75	bdl	Bluish green	Very high	Mod. – strong			
2030	1.4	0.24	bdl	bdl	Bluish green	High	Mod.	1.643	1.624	0.019
2060	2.45	0.12	0.14	bdl	Olive green	Medium	Mod.	1.643	1.622	0.021
2063	4.1	0.19	bdl	bdl	Green	Medium	Mod.	1.645	1.629	0.016
2062	1.5	0.15	bdl	bdl	Green	Medium	Mod.	1.645	1.634	0.011
2078	1.15	0.08	bdl	0.16	Green	Medium – low	Weak	1.639	1.620	0.019
2034	0.55	bdl	bdl	bdl	Green	Very low	Very weak	1.643	1.637	0.006

N.B. a. Samples listed according to colour saturation: high to low, visually assessed.
b. Wt.% semi-quantitative from uncoated specimens, normalised to 3.5 wt.% H_20 and 10 wt.% B_2O_3; detection limits about 0.01 wt.%; bdl = below detection limit. Cameca SX50 electron microprobe, analyst: CJ Stanley.

(0.72 and 0.75 wt%), have a pleasant bluish-green hue, but are too dark for use as gems. Their spectra show a more distinct and broader absorption in the yellow-orange, compared to the other spectra. Sample 2078, with a measurable FeO content, shows a pure green colour. Apparently, red flashes in the light-coloured stones are caused by AMD and not by UE.

UE in plants

In nature, green is the dominant colour and chlorophyll the main colorant. Pigments in green plants are chlorophylls a and b with transmissions in green and red (*Figure 7*), similar to the transmissions in the UE tourmaline, and anthocyanins with transmission in red (*see Appendix*). The UE in different depths of chlorophyll solution in acetone are shown in *Figure 12*. A thin layer of this in a beaker is green in transmitted light. When the layer thickness is increased, the colour turns red. In addition to UE, AMD and visible light induced fluorescence in chlorophyll solution can also be observed.

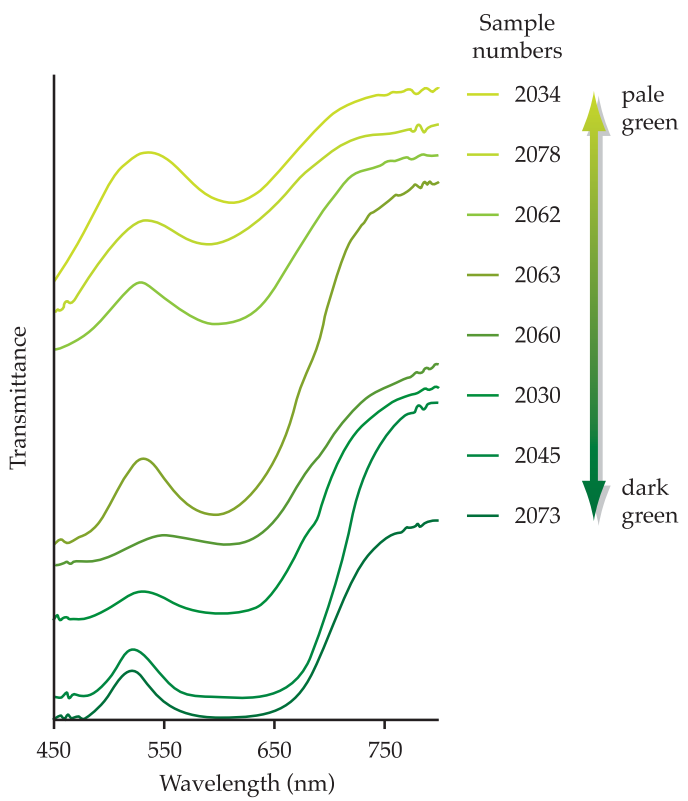

Figure 11: *Transmission spectra for the eight UE tourmalines listed in Table I.*

Figure 12: *UE colour change in chlorophyll solution. a) green with liquid thickness 5 mm. b) red with liquid thickness 15 mm.*

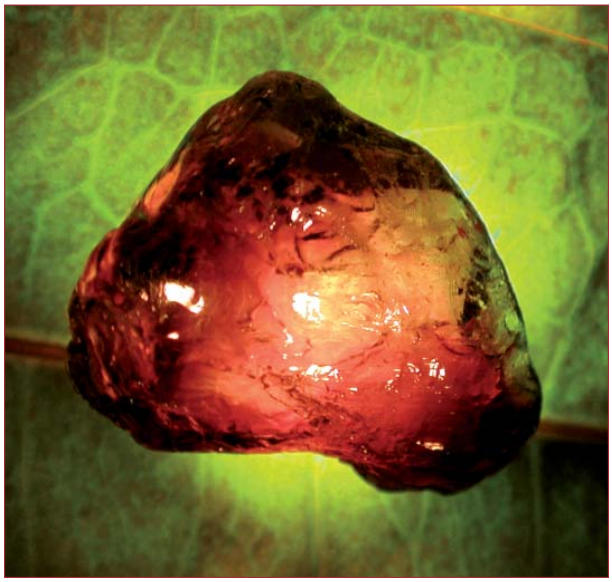

Figure 13: *A deep green UE tourmaline appears red when placed on top of two or three leaves and illuminated from below.*

Fluorescence spectra obtained with 405 nm excitation wavelength showed fluorescence peaks at 671 nm for the chlorophyll solution (cf. 682 nm for the UE tourmaline) with fluorescence intensity close to eight times as high for the chlorophyll.

A green UE tourmaline crystal may also turn red when illuminated by high-intensity light through two or three green leaves (*Figure 13*) which act as a colour filter, increasing the relative intensity of red.

UE in other minerals

Kornerupine

Kornerupine is a borosilicate with orthorhombic crystal symmetry. An emerald-green kornerupine crystal from Nchongo, Umba area, shows a peculiar pleochroism. Refractive indices are $n\gamma = 1.681$ and $n\alpha = 1.671$ and electron microprobe analysis showed a Cr_2O_3 content of 0.24-0.28 wt%. When viewed along the *c*-axis, the crystal apparently shows both UE and AE types of colour change. In incandescent light, green is seen in the short section of the crystal and brownish red in the longest section (*Figure 14*). Observation of both green and red colours along the *c*-axis could possibly be explained as result of change in light ray direction and influence of the strong pleochroism. The red seen in the *c*-direction is however strengthened when the kornerupine is placed on top of a UE tourmaline, a feature interpreted as presence of UE in the kornerupine. Under the dichroscope the kornerupine shows variations between bluish green and red perpendicular to the *c*-axis and variations of red along the *c*-axis. The colour observations are related to the vibration directions as follows: green in α direction, two shades of red in β and γ directions. In fluorescent light,

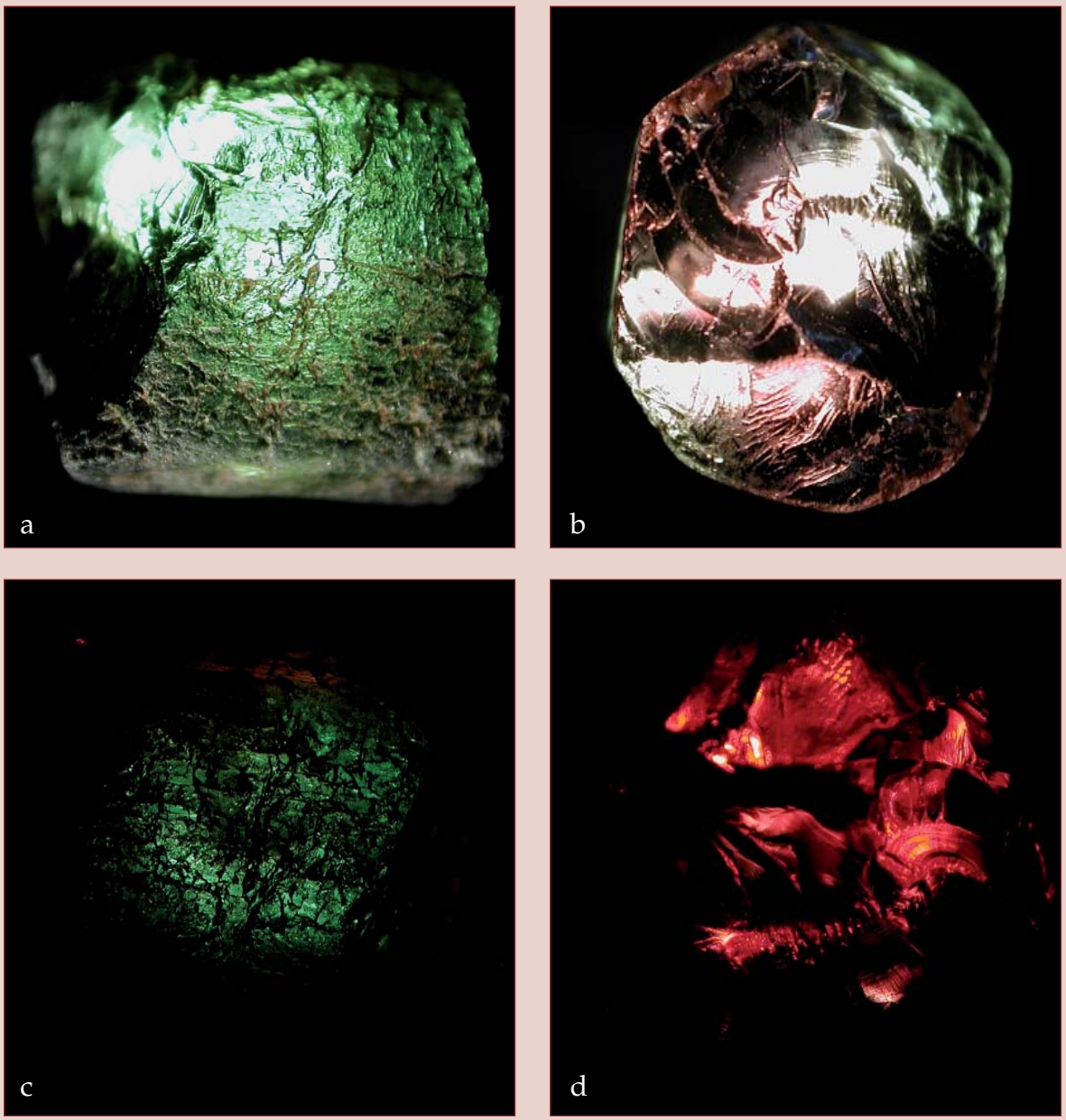

Figure 14: *Pleochroism in kornerupine crystals from Nchongo. Length along the* c*-axis varies from 6.5 mm to 11 mm. (a) Seen perpendicular to* c*-axis in transmitted incandescent light; (b) parallel to the* c*-axis; (c and d) same lighting, but with use of Hanneman Aqua filter.*

the red colour is absent. Under a Hanneman Aqua filter, the red intensifies but the bluish green at right angles becomes an even darker pure green. With moderate heating the red colour disappears (thermochromy). AMD can also be observed. The transmission spectra in *Figure 15* are not considered as dichromatic spectra, but they demonstrate the distinct pleochroism of this crystal, with strong transmission in the green when measured perpendicular to the *c*-axis and strong transmission in the red parallel to the *c*-axis.

Epidote

Epidote from Tanganyika Massagati, a remote area north of Mahenge, Tanzania, changes colour from green to brownish red with increasing thickness (*Figure 16*). The red is intensified by a Chelsea filter. This colour change is also influenced by type of illumination. The transmission spectrum of this epidote (*Figure 17*) is dichromatic and resembles the UE tourmaline spectrum, with the green transmission at a slightly higher

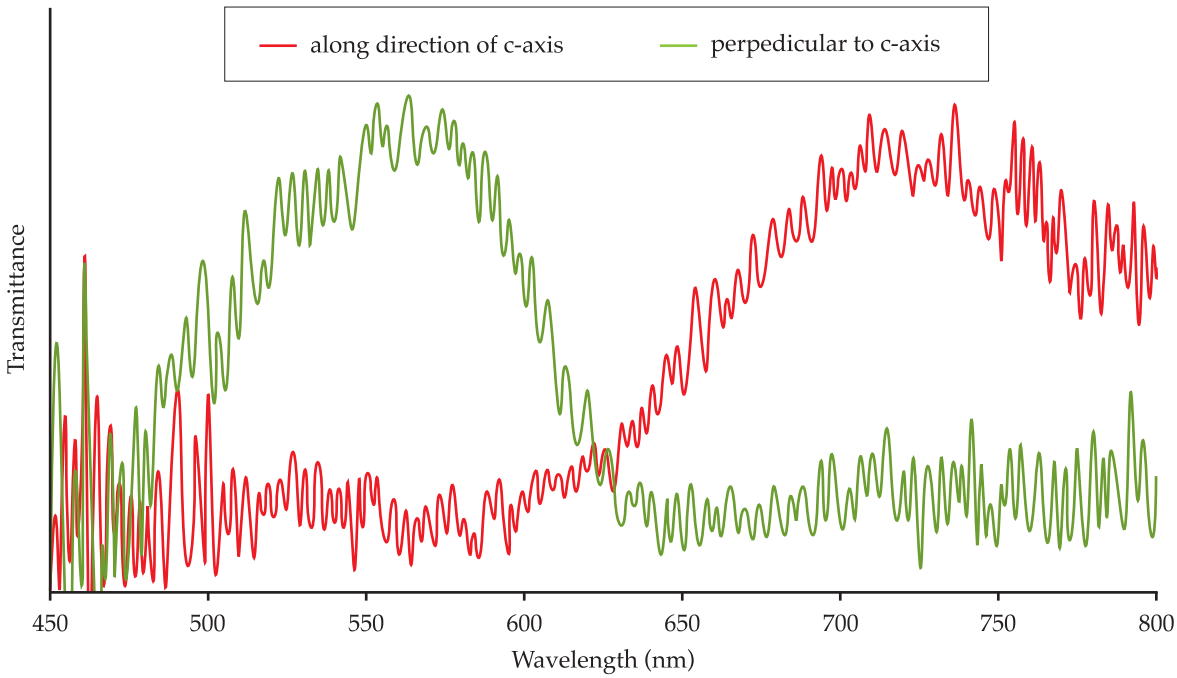

Figure 15: *Transmission spectra for kornerupine from Nchongo, Umba area, along the direction of (red) and perpendicular to (green) the c-axis.*

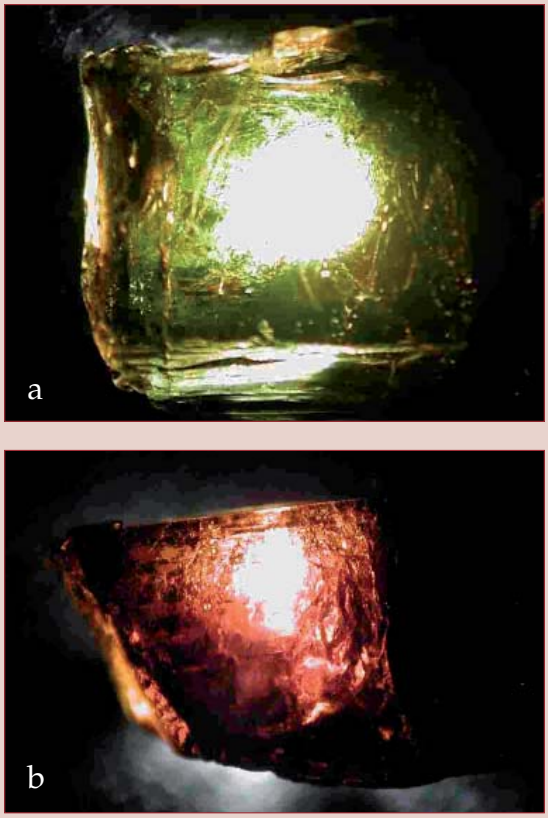

Figure 16: *UE in epidote crystal fragments from Tanganyika Massagati. (a) Green with 4 mm thickness. (b) Brownish red with 8 mm thickness. In (a) AMD is visible as tiny red spots at irregularities. Both (a) and (b) are viewed into a 001 cleavage face.*

wavelength. This spectrum was obtained from a {001} cleavage fragment, with light travelling in the XZ plane, perpendicular to the Y axis. No detectable chromium or vanadium was found by electron microprobe analyses; its refractive indices are $n\gamma=1.765$ and $n\alpha=1.732$.

Alexandrite

Alexandrite is not only appreciated as a gemstone. Synthetic alexandrite is also important as tunable solid-state laser material. Three rods of such alexandrite with lengths 70-80 mm were obtained from Northrop Grumman Space Technology. The Cr contents of the rods were 0.076% (light colour), 0.123% (medium colour) and 0.308% (dark colour). All rods show deep red along the long axis, both in incandescent light and in daylight. However, a 10 mm thick slice cut from the medium-coloured rod appeared greenish blue viewed along the length (*Figure 18*). In the long rod of medium colour, variations between dark, greyish rose and red along the long axis, and along the same axis in the 10 mm piece, variations between greyish yellow and greenish blue are visible under the dichroscope.

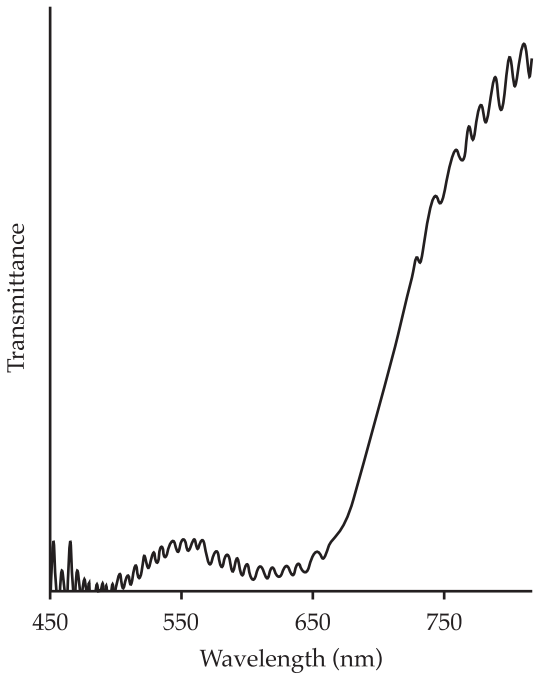

Figure 17: *Transmission spectrum for epidote from Tanganyika Massagati.*

Prediction of UE colour change by colorimetric analyses

The author of a recent book on colorimetric studies in the field of biology (Björn, 2002) has developed an interesting method for prediction of UE colour change by analyses of transmission spectra using computer programmes which can be downloaded from the internet (L.O. Björn, *pers. comm.*, 2004). A description of this method may be requested from the present author. The materials studied include chlorophyll, UE tourmaline, alexandrite and colour change garnet, see *Figure 7*. The predicted colour changes correspond well with the observed colour changes, particularly the change from green to red with increase in path length for UE tourmaline and for alexandrite. This method for UE colour change prediction can be extended to AE colour change by considering the spectral distribution of illumination.

Concluding remarks

Based mainly on observations and analyses of the Nchongo tourmalines, this study has provided insight into the complex colour phenomena in minerals with spectra characterised by two colour maxima (dichromatic minerals). In addition to AE and UE, the phenomena of thermochromy, visible-light-induced fluorescence and absorption-modified dispersion (AMD) have been described and discussed. AMD is a tentative explanation for certain colour phenomena in dichromatic materials and needs further verification. Colour change behaviour is also described for the minerals epidote and kornerupine. As a curiosity, the colour change behaviour of chlorophyll is briefly described and the use of green leaves as a colour filter, which can change the colour of UE tourmaline, is shown.

The study has also provided insight into the interaction between the various colour phenomena. It is concluded that the AE is affected by the UE and they may both interact with other described colour phenomena. Haidinger (1849) and Cossa and Arzruni (1883)

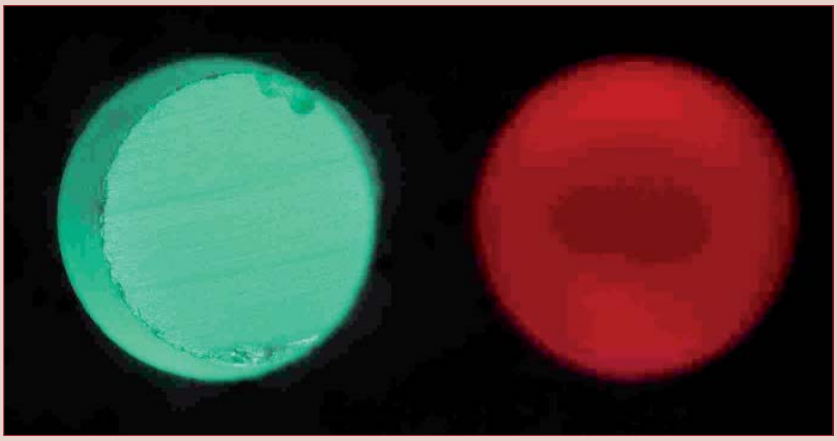

Figure 18: *UE colour change in rods of alexandrite with 0.123% Cr. Using daylight, the 10 mm-long rod is blue, and the 40 mm long rod is red. The red is blurred, probably because the highest optical density is towards the far end of the rod and out of focus.*

described interaction between AE and UE. The observation by Fiala (1965) of green colour in small pyrope fragments indicates the same. Haidinger (1849), Kokscharow (1861), Cossa and Arzruni (1883), and Farrel and Newnham (1965) described interaction between AE and pleochroism, by different degrees of colour change along the different optic axes. In the kornerupine described in this paper, AE was found in only one direction. C. Simonet (*pers. comm.*, 2000) observed this feature in kyanite from Kenya. Haidinger (1849) noted that one of the trichroic colours in alexandrite was not affected by whether the source was daylight or incandescent light. Weigel (1923), Thilo *et al*. (1955), Orgel (1957) and Carstens (1973) described interaction between AE, concentration effect and thermochromy. The above observations indicate interaction between thermochromy and UE, as well as AMD and pleochroism. Neuhaus (1960) suggested that AE colour change observations should be conducted at a constant temperature, and that observations of thermochromy should be carried out with constant spectral distribution of light. This study shows that understanding the interaction between the various colour change phenomena is essential for understanding the features of any one stone. In particular, the influence of UE should be considered in studies of AE. Colour change in minerals is complex and its understanding requires a holistic approach.

Acknowledgements

I wish to thank Kurt Nassau, Cedrik Simonet, Brenda Jensen and Lars Olof Björn for valuable discussions, and Brenda also made useful comments about the structure and content of this paper. Ulf Kapborg is thanked for providing the alexandrite rods from Northrop Grumman Space Technology, USA. Multiconsult, Norway is thanked for financial support and Chris Stanley, Lars Olof Björn, Knut Asbjørn Solhaug and Jan Kihle provided analyses relating to the colour change experiments. Thanks also to Ada Eckhoff and other librarians for their persistence in the search for old publications.

Appendix

UE in plants

When the leaves open in the spring some trees look reddish, as anthocyanins may be the dominating pigments in the early phase of the leaves, before the chlorophylls become dominant and green is the observed colour. In the autumn a spectacular colour change may take place, with the green leaves turning yellow or red. The green chlorophyll then decreases to reveal the red, orange or red of the remaining anthocyanins. Chlorophyll is the main factor in photosynthesis, using the energy of sunlight for production of oxygen. Chlorophyll absorbs light in the violet-blue and in the orange-red and transmits in the green and red. Light absorption leads to formation of excited chlorophyll. This returns to the ground state by dissipation of energy through the photochemical process, conversion into heat and emission of fluorescence in the red. Chlorophyll is not only important for photosynthesis, but also as a communication device for trees and plants. Plants have a sort of *colour vision*, by being able to *sense* the frequencies of the light surrounding them (L.O. Björn, pers. comm., 2004). When light is transmitted through a canopy of vegetation, selective absorption takes place. A plant can *sense* the ratio between short-wave (about 660 nm) and long-wave red light (about 730 nm) and be aware of any competing plants or trees and thereby adapt to its neighbourhood.

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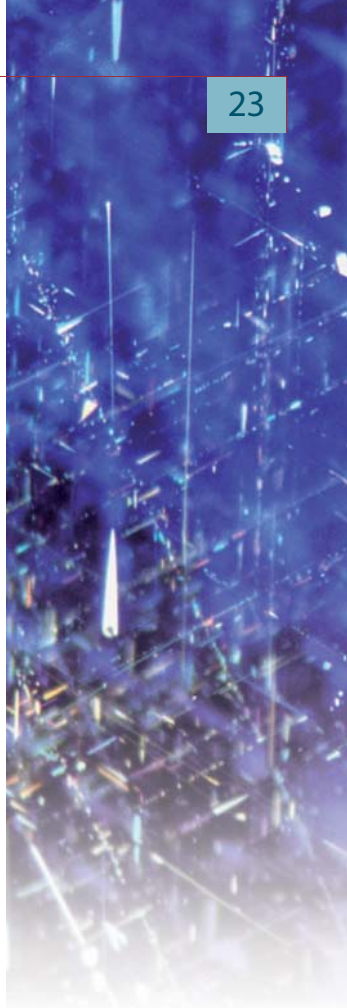

Determination of the origin of blue sapphire using Laser Ablation Inductively Coupled Plasma Mass Spectrometry (LA-ICP-MS)

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Abstract: *Non-basalt-related and basalt-related sapphires can be distinguished on the basis of their trace element contents (sometimes called a chemical fingerprint), as determined with energy-dispersive X-ray fluorescence analysis. When using the oxide weight percent ratios of Cr_2O_3/Ga_2O_3 versus Fe_2O_3/TiO_2 these trace elements show two discrete populations. However, for blue sapphires originating from non-basalt-related deposits in the Isalo area of Madagascar, from Ratnapura, Sri Lanka and from Mogok, Myanmar, a nearly complete overlap is observed whereas the overlap for basalt-related sapphires from Bo Phloi, Kanchanaburi, Thailand, New South Wales, Australia, and ChangLe, Shandong, China, is less significant. LA-ICP-MS was applied to obtain ppm and ppb-level data for 'ultra-trace elements' such as Zn, Sn, Ba, Ta and Pb. The results clearly show that they differ for blue sapphires from the sources investigated. The combination of trace element and 'ultra-trace element' contents offers the potential for providing useful criteria in identifying the geographical origins of sapphires and other gemstones.*

Keywords: *chemical finger print, geographical origin determination, laser ablation-inductively coupled plasma mass spectrometry (LA-ICP-MS), trace and ultra-trace element, untreated sapphire.*

Introduction

Although determination of geographical origin of a gemstone is justified, in common with seeking the origin of other precious and rare objects, it should be regarded primarily as an opinion issued by a laboratory or gemmologist. It is commonly difficult to provide reliable evidence for such opinions. They can either be well-based on detailed analytical data for each gemstone, on databanks and literature references, or they can be less well-based and range from unreliable and unprofessional guesses to plain wishful thinking. Nevertheless, origin information about a gemstone can have

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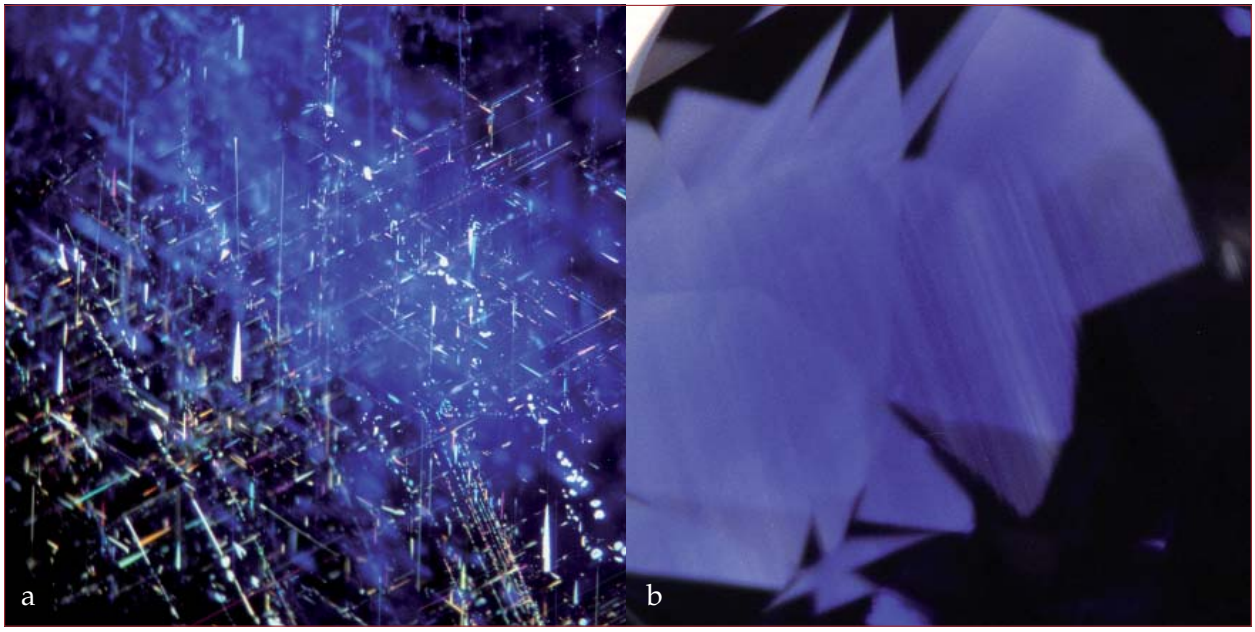

Figure 1: *Rutile needles forming 'silk' (a), and colour zoning (b) are present in many Isalo sapphires.*

historic and even archaeological importance, and for some jewellers it is a major factor in their daily trading. New analytical methods continuously have to be investigated for increased reliability of origin identification. The present paper describes such an effort.

Originally, the determination of sapphire origins focused on observation of internal features (Hughes, 1997) with later developments based on optical absorption spectrometry and chemical trace element analysis by X-ray fluorescence. With these methods, determination of geological occurrence, that is distinction between basalt-related origin (e.g. from Australia, China or Thailand) and non-basalt-related origin (e.g. from Sri Lanka, Myanmar or Madagascar) is now straightforward. However, distinction of sapphire origins in different countries but with a similar geological mode of occurrence – such as between Thailand and Australia, or between Madagascar, Sri Lanka and Myanmar – are much more difficult. When newly discovered blue sapphires from Madagascar came onto the gem market in the late 1990s, distinction between these and the more traditional sources in Sri Lanka and Myanmar often caused problems in the gem trade.

Recently, high-quality natural blue faceted sapphires from a new deposit at Isalo in the Ilakaka area of south-west Madagascar have become a commoner item in gem laboratories for determination of their geographical origin than sapphires from Sri Lanka and Myanmar.

The Isalo sapphires come from secondary deposits associated with high-grade metamorphic and meta-sedimentary sources and have internal features similar to those in blue sapphires from Sri Lanka and Myanmar. Inclusions such as rutile needles, zircon with tension cracks, healed fissures and colour zoning are commonly seen in specimens from the Isalo area (*Figure 1*), but 'fingerprint' fluid inclusions (healed fissures) typical of Sri Lankan sapphires (*Figure 2*) have not been found.

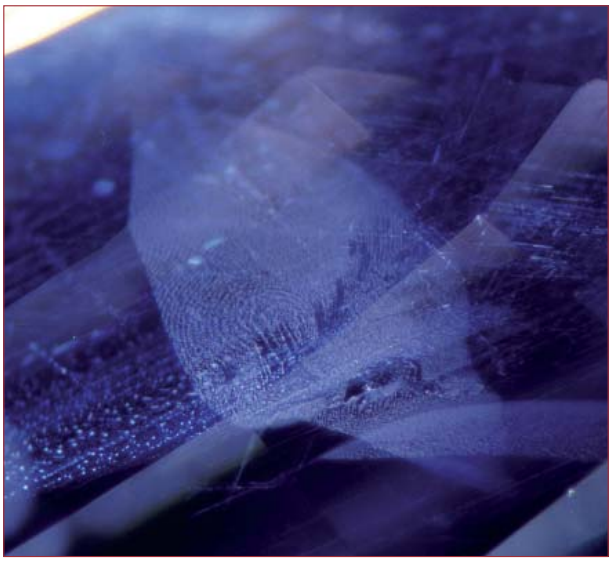

Figure 2: *Fluid inclusion resembling a 'fingerprint' in sapphire from Sri Lanka.*

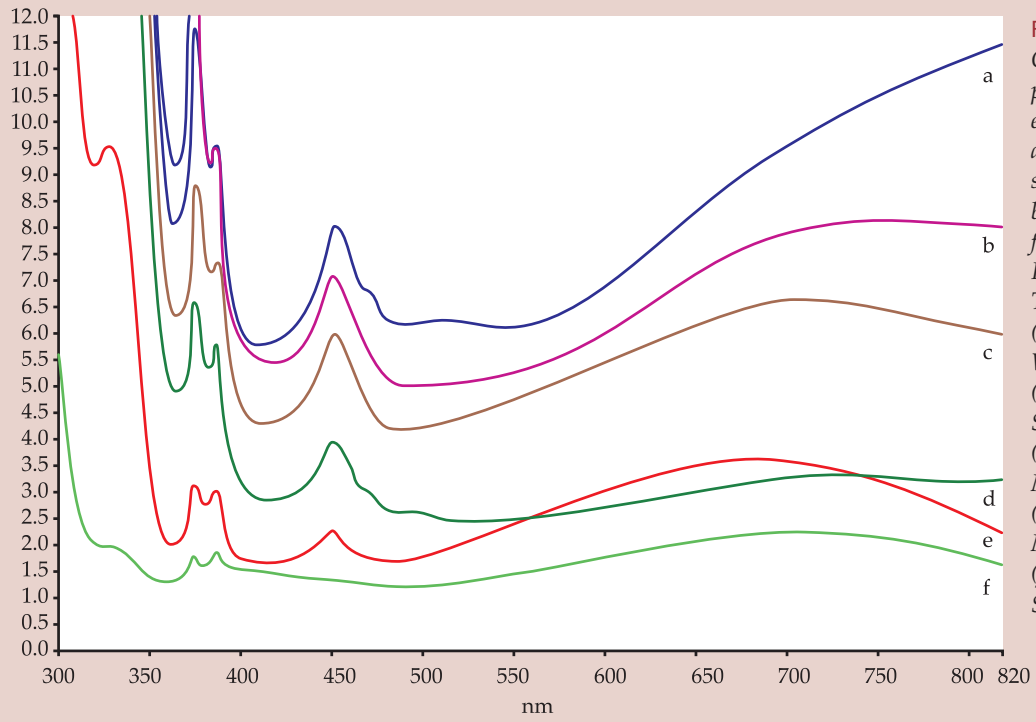

Figure 3: *Overlay of polarized e-ray UV-Vis absorption spectra of natural blue sapphires from: (a) Kanchanaburi, Thailand (b) New South Wales, Australia (c) ChangLe, Shandong, China (d) Isalo, Ilakaka, Madagascar (e) Mogok, Myanmar (f) Ratnapura, Sri Lanka.*

The absorption spectra of Isalo blue sapphires are dominated by a broad pleochroic band between 500 and 800 nm with an e-ray absorption peak near 700 nm (due to charge transfer Fe^{2+}/Ti^{4+}), and a typical spectrum showing bands at 450 nm and 388 nm, a weak band at 377 nm and a band at 328 nm (all due to iron) with total absorption starting at about 300 nm, are shown in *Figure 3*. The polarised e-ray absorption spectrum of Isalo sapphire is different from the e-ray spectra of Sri Lankan and Myanmar sapphires.

Blue sapphires from Isalo can generally be distinguished from Sri Lankan and Mogok sapphires on the basis of colour, inclusions and absorption spectra. The aim of this study is to provide more compositional data and criteria from laser ablation (LA) and inductively coupled plasma mass spectrometry (ICP-MS) methods to be able to distinguish between these sapphires with more confidence. The compositional data are also compared to those of sapphires from the Bo Phloi district of Kanchanaburi, Thailand, from New South Wales, Australia, and from the ChangLe district of Shandong, China.

The sources of sapphires in Madagascar, Sri Lanka and Myanmar

Recent finds of significant quantities of gems in Madagascar, comparable to Sri Lanka and Myanmar, have had an important effect upon world gemstone supplies. The first finds of gem-quality blue sapphire were in the metamorphic skarns at Andranondambo, southern Madagascar, and mining started at the beginning of 1990 (Schwarz *et al.*, 1996) (*Figure 4*). Subsequently, dark blue sapphires associated with basaltic tuffs were found in the Diego Suarez area at the north end of the island and then a new large-scale secondary deposit containing sapphires of a range of colours was discovered in the Isalo/Ilakaka area of southwest Madagascar (Schmetzer, 1999). This deposit lies south of Isalo National Park and extends to Sakahara town; it contains high-saturation blue, pink and other colours of sapphires in large quantities, all deposited in a sedimentary basin. The primary geological source of these sapphires is not yet known, but sapphire placers

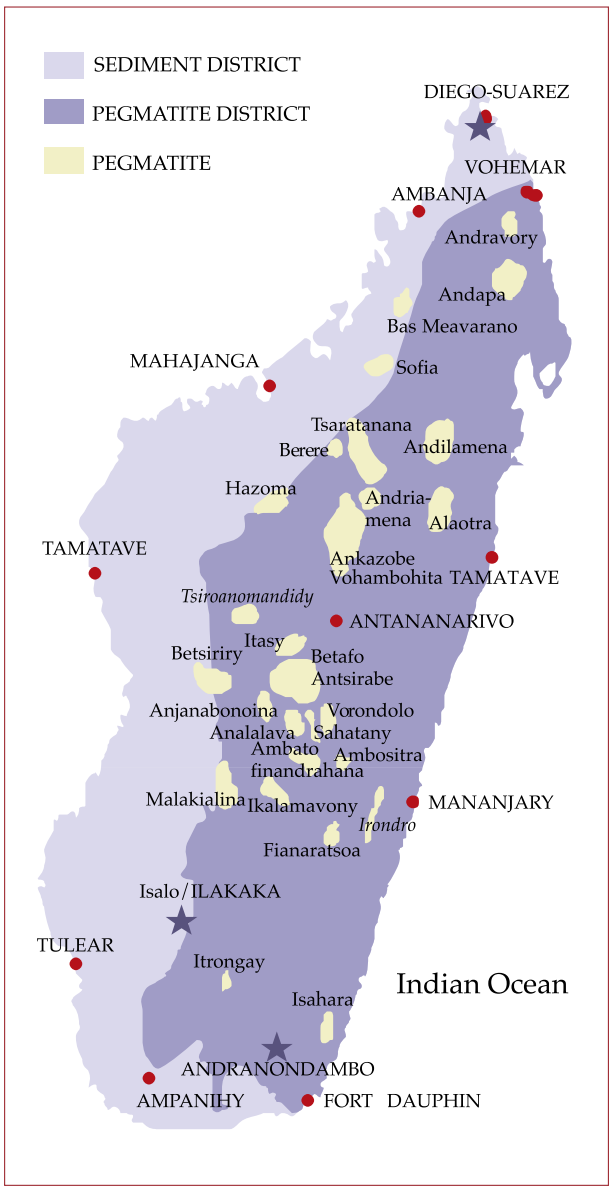

Figure 4: *Map of Madagascar showing the corundum-producing areas of Isalo, Ilakaka, Andranondambo and Diego Suarez, and the broad regions where sedimentary or pegmatitic rocks predominate (modified after Pezzotta, 2001).*

have probably originated from coarse-grained lenses and sedimentary strata of Permian and Mesozoic-age greywackes that themselves derived from possibly diverse sources of earlier metamorphic and pneumatolytic rocks and pegmatites.

In Sri Lanka, most of the main corundum deposits lie on the Highland, Vijayan and southwest groups of Precambrian metamorphic rocks (Cooray, 1967; Zoysa, 1981; Zwaan, 1982) (*Figure 5*). Colourless and sky blue to deep blue sapphires with habits of spindle-shaped hexagonal

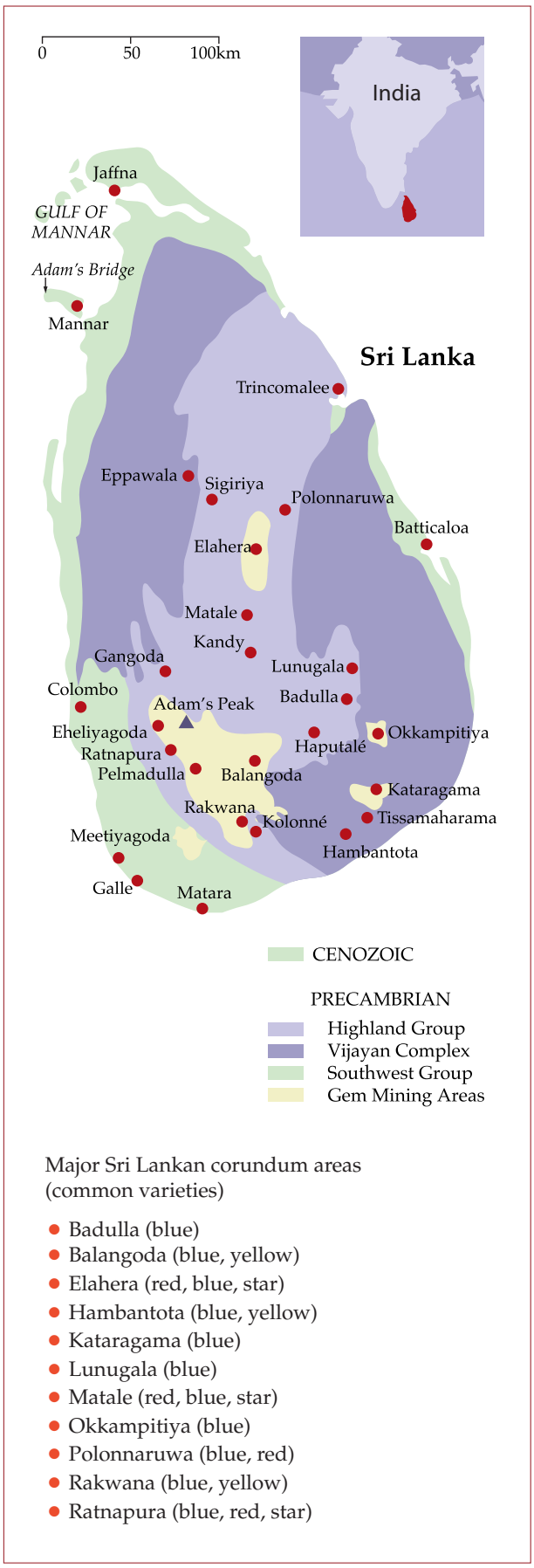

Figure 5: *Map of Sri Lanka showing the major gem-producing fields (modified after Zwaan, 1982).*

bipyramids and flattened prisms with dominant pinacoid faces are mainly mined from secondary alluvial gravels, thought to be derived from a range of metasedimentary rocks including calc-silicates, marbles, quartzites, pelitic gneiss, khondalite and metamorphic rocks of igneous parentage, especially charnockites (orthopyroxene-bearing granites). Only a few dark opaque sapphires have been found *in situ*, and these have been in pegmatites and gneisses. Mining is carried out in the Ratnapura, Elahera and Pelmadulla areas. The granulites and upper amphibolite metamorphic rocks derived from igneous rocks of the Vijayan and southwest groups are devoid of gems (Mathavan *et al*., 2000).

Although rubies are the best-known gems from Myanmar, some of the world's finest blue sapphires have also come from the Mogok area (*Figure 6*). Sapphires from this area are tabular with pinacoid faces

Figure 6: *Map of gem localities of Myanmar and Southeast Asia (modified after Hughes, 1997).*

and probably originated in pegmatites, nepheline-corundum syenites and biotite gneisses, in contrast to the rubies which formed in contact- and regional-metamorphosed crystalline limestone (Hughes, 1997). Both sapphires and rubies occur in intimate association in virtually all alluvial deposits throughout the Mogok area, but the sapphires are found in quantity at only a few localities, particularly 13 km west of Mogok, near Kathe (Halford-Watkins, 1935).

Although many Myanma blue sapphires show a more saturated blue than Sri Lankan sapphires, some are paler and do resemble those from Sri Lanka. Also, colours overlap with Madagascan sapphires and separation on this basis alone is not possible.

Gem mineral analysis methods

Standard methods of gem testing are increasingly being augmented by UV-visible-IR spectroscopy to analyse spectra, X-ray fluorescence (XRF) to obtain composition, and the electron probe micro-analyser (EPMA) to obtain detailed composition. Even these methods however may not lead to conclusive results and more sensitive analytical techniques are being developed. In mineral research samples are commonly dissolved by acid or are flux-melted using alkalis and brought into solution before they are analysed by Inductively Coupled Plasma-Atomic Emission Spectrometry (ICP-AES) or by Inductively Coupled Plasma-Mass Spectrometry (ICP-MS). Bringing the sample into solution, however, is both time-consuming and destructive. For analysis of small variations in composition EPMA with an element-mapping function can be used, but this method is also time-consuming in that the specimen has to be in an evacuated chamber and sensitivity to some elements is limited.

For gems, it is important to minimise any damage to a specimen under investigation, so Laser Ablation-Inductively Coupled Plasma-Mass Spectrometry (LA-ICP-MS), which can be used to analyse a solid sample in a very localized area with high sensitivity, offers new possibilities of obtaining trace element and ultra-trace element compositions of a gem mineral.

What is LA-ICP-MS?

LA-ICP-MS is a method of quantitatively and qualitatively analysing constituents of a sample by detecting a number of elements which have been evaporated from a tiny point on its surface. This is done by means of irradiation of the sample by a high-energy laser beam on its surface and the elements released are then ionised by high-frequency power which generates a plasma. The elements in the plasma can then be rapidly detected in minute amounts at the parts per billion (ppb) to parts per million (ppm) levels from atomic number 2, He (helium) upwards. A sample chamber does not need to be evacuated to carry out this analysis, and precise targeting of a specific area is possible with a narrow laser beam and a CCD camera. Measurements can be done on clean, rough or polished samples when using the fourth harmonic (266 nm) and the fifth harmonic (213 nm) of the tunable Nd-YAG (neodymium-doped yttrium aluminium garnet) laser or when using an excimer laser (193 nm). However, in order to obtain an acceptable result, one must allow that a minimum area on the gemstone of 100 μm^2 will suffer some damage. Guilong and Gunther (2001) were the first to use this method in seeking the origins of sapphires (*Figure 7a-b*).

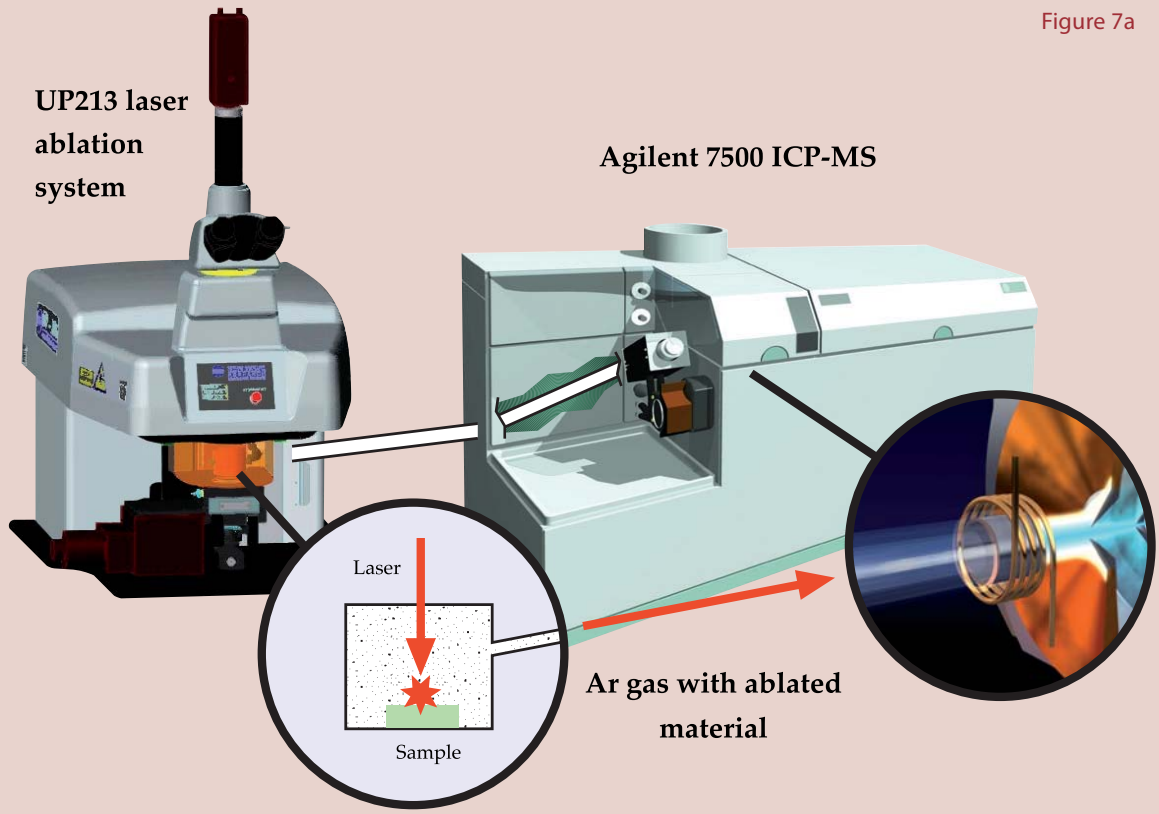

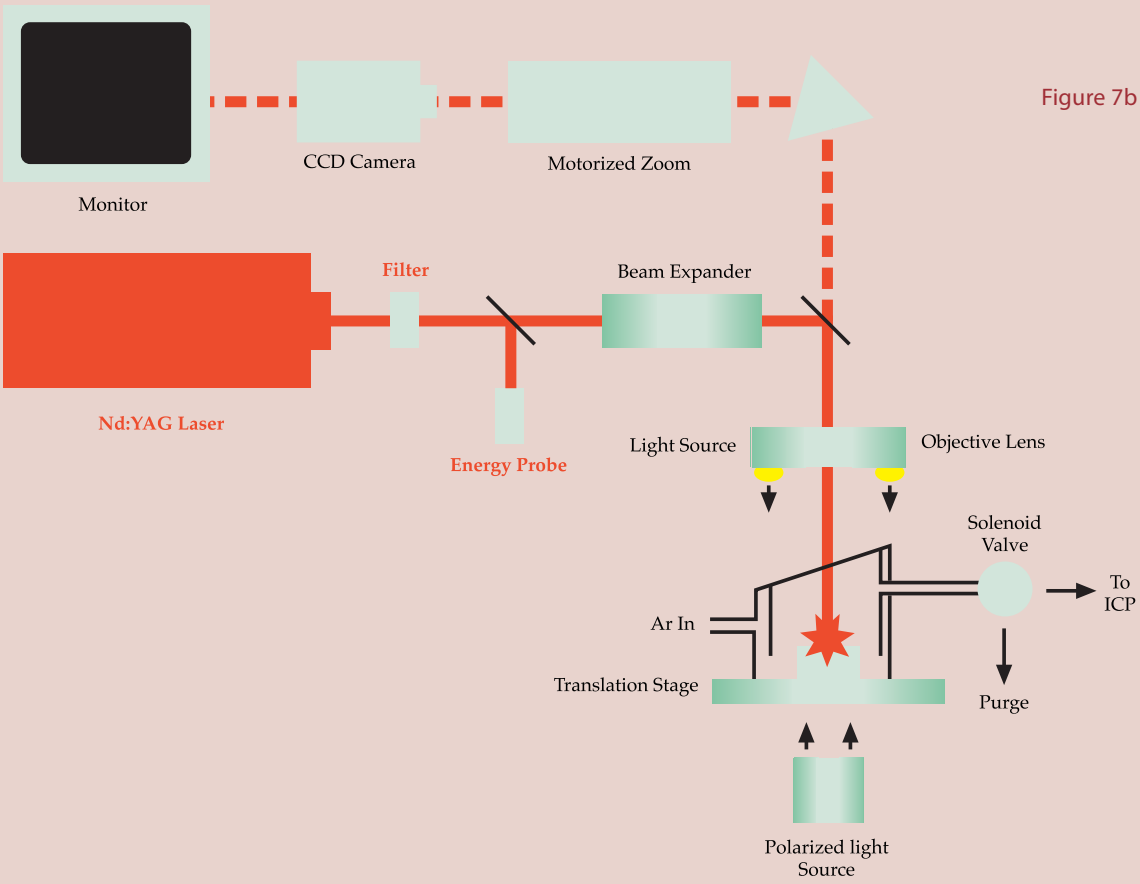

Figure 7(a-b): *Schematic diagrams showing the main elements of the Nd:YAG laser ablation system for ICP-MS*

Figure 8: *The LA-ICP-Mass Spectrometry system in the GAAJ Laboratory in Tokyo.*

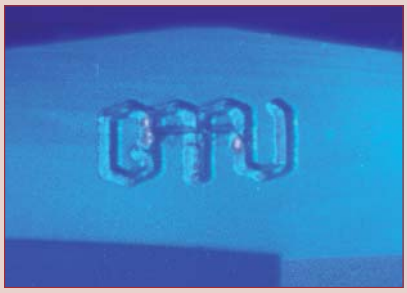

Figure 9: *Laser logo mark of 'GAAJ' on the girdle of a blue sapphire in dark field illumination. The size of the mark is 80x 230 µm with a laser line width of 16 µm and depth of 4~7 µm.*

Measurements and samples

The Merchantek UP-213A/F made by New Wave Research and the model 7500a made by Agilent were used for the laser ablation system and for ICP-MS respectively (*Figures 7 and 8*). A concentration conversion factor on each element was made in this study to calculate its content because using calibration curves is less reliable. A standard sample multi-element glass NIST612 and internal standard of pure Al_2O_3 were used to calculate a concentration conversion factor, and this was used to convert the raw data obtained from the actual sample to quantitative values. After a laser analysis a trace of damage is left on the stone surface. However, this disadvantage was converted to an advantage by using the laser to generate sufficient material for analysis and at the same time inscribing the 'GAAJ' logo on the girdle; presence of the logo also proves that the test has been carried out (*Figure 9*). The width of the laser line is 16 µm, and the size of the mark is 80x230 µm with a depth of 4~7 µm; it can barely be seen under a 10x loupe and resembles the inscription currently performed on diamonds. Conditions used are indicated in *Table I*. Each stone was subjected to laser ablation for 25 second periods in three runs, and ICP-MS data acquired for 40 second periods.

Table I: *The settings and conditions used during LA-ICP-MS analysis*

New Wave Reasearch UV-213 A/F	Laser ablation parameters	Agilent	Plasma parameters
Wave length	213 nm	RF power	1500w
Pulse frequency	10Hz	Auxiliary gas flow rate	Ar 1.22ml/min and He 0.50ml/min
Laser energy	0.032mJ	ICP torch	Fassel torch 1.5mm id silica injector
Ablation pattern	'GAAJ' logo mark 16 µm wide line	Spray chamber	Water cooled
Scan speed	20 µm/sec	Sampler cone	Nickel. 1.1mm diameter
Laser warm up	5 sec	Skimmer core	Nickel. 0.8mm diameter
		Sampling depth	7mm
		Mass number	m/z=2 to 260
		Integration time	0.01 sec per point

Figure 10: *Blue sapphires (left to right and top to bottom: Madagascar, Sri Lanka, Myanmar, Thailand, Australia, China); all stones have natural colours and have not been heat-treated.*

The sapphires analysed include 35 from Isalo, Madagascar, 30 from Ratnapura, Sri Lanka, and 15 from Mogok, Myanmar, all of which were non-heated-treated sapphires and came from non-basalt-related origins (*Figure 10*). Also, non-heat-treated sapphires from basalt-related origins in other localities such as Bo Phloi, Kanchanaburi, Thailand (6 stones), New South Wales, Australia (6 stones) and ChangLe, Shandong province, China (5 stones) were collected *in situ* from the mines. Details of the samples are given in *Table II*.

Descriptions of the different concentration ranges of the elements are as follows: ultra-trace elements $\leqq$ 100 ppm < trace elements $\leqq$ 10000 ppm (1%) < minor elements $\leqq$ 100000 ppm (10%) < major elements $\leqq$ 100%.

Table II: *Details of sapphire samples from major gem-producing countries*

Locality	Isalo, Ilakaka Madagascar	Ratnapura, Sri Lanka	Mogok, Myanmar	Bo Phloi, Kanchanaburi, Thailand	New South Wales, Australia	ChangLe, Shandong, China
Sample numbers	MD001-020 to M9-001-015	D027-502	B328-342	TH032-037	NS001-006	C125-127
Total of samples analysed	35	30	15	6	6	5
Colour	deep blue-light blue	blue-light blue	blue-light blue	dark blue-blue	dark blue-greenish blue	dark blue
Shape	mixed cut and cabochon	mixed cut	mixed cut	mixed cut	mixed cut	mixed cut
Weight (ct)	0.401-6.365	0.410-4.735	0.364-6.820	1.234-3.408	2.548-4.001	4.057-5.273
Fluorescence LW-UV	inert-weak red	inert-weak red	inert	inert	inert	inert
Fluorescence SW-UV	inert-very weak red	inert-very weak red	inert	inert	inert	inert

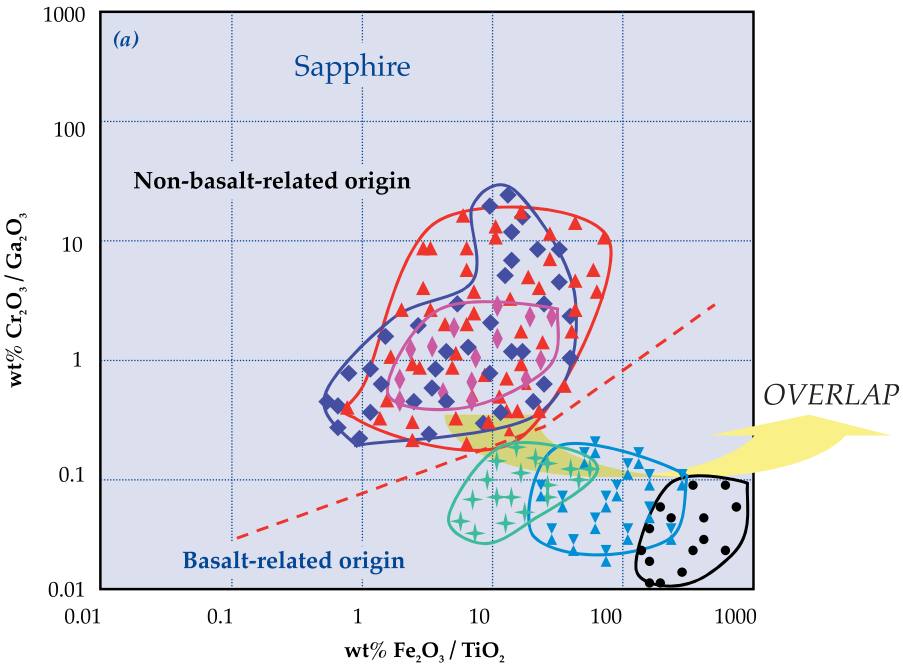

(a) **Non-basalt-related Sapphire**
- Isalo/Ilakaka, Madagascar
- Ratnapura, Sri Lanka
- Mogok, Myanmar

Basalt-related Sapphire
- Bo Phloi/Kanchanaburi, Thailand
- New South Wales, Australia
- ChangLe/Shandong, China

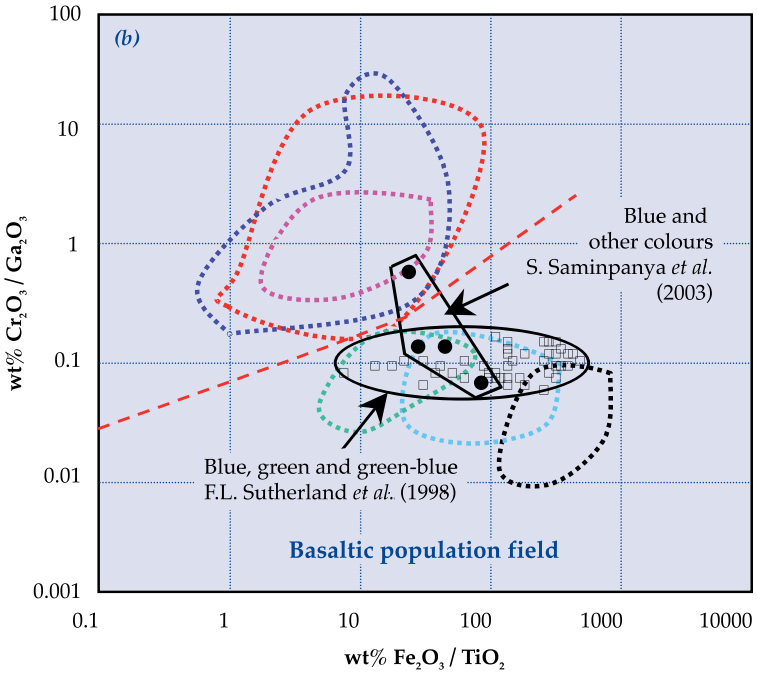

(b) **Comparison 'Basaltic' type Sapphires**
- Kanchanaburi, Thailand
- New South Wales, Australia

Figure 11: (a) *Cr_2O_3/Ga_2O_3 versus Fe_2O_3/TiO_2 ratios of blue sapphires from major gem-producing countries of the world. Group I consists of non-basalt-related sapphires with higher Cr and low Fe, Ti and Ga contents; Group II consists of basalt-related sapphires with high Ti, Fe, Ga and low Cr contents.*
(b) *Outlines of the fields detailed in (a) with sapphire data published by Sutherland et al. (1998) and Saminpanya et al. (2003) for comparison.*

Results

LA-ICP-MS determinations of seventeen trace elements (^{23}Na, ^{24}Mg, ^{39}K, ^{47}Ti, ^{51}V, ^{53}Cr, ^{55}Mn, ^{57}Fe, ^{60}Ni, ^{63}Cu, ^{66}Zn, ^{69}Ga, ^{93}Nb, ^{118}Sn, ^{137}Ba, ^{181}Ta and ^{208}Pb have been carried out on the 97 blue sapphires listed in *Table II* and the element contents in ppm are shown in *Table III* in order of atomic weight.

Results for Cr, Ga, Fe and Ti are plotted as oxide ratios in *Figure 11* to enable comparison with recent published work by Sutherland *et al*. (1998) and Saminpanya *et al*. (2003). Some of these previously reported data (from Bo Phloi; Kanchanaburi, Thailand, and New South Wales, Australia) are shown as black-bordered fields in *Figure 11b*.

By means of this diagram, two major groups of sapphires could be distinguished: the light to deep coloured non-basalt-related sapphires and the deep to dark coloured basalt-related sapphires (*Figure 11a*). The points representing non-basalt-related sapphires from Madagascar, Sri Lanka and Myanmar lie in fields that completely overlap each other and so these chemical criteria cannot be used to separate sapphires from these three localities.

These trace element contents in basalt-related sapphires from three localities (Kanchanaburi, New South Wales and Shandong) in the second group lie in fields with less overlap. In comparison with previous data for similar localities (*Figure 11b*), our new data show a slightly wider range of Cr_2O_3 for New South Wales greenish-blue to dark blue sapphires and a wider range of Fe_2O_3/TiO_2 ratios in blue and dark blue Kanchanaburi sapphires.

For non-basalt-related sapphires, the above diagram is of no help in distinguishing Isalo, Ratnapura and Mogok sapphires. However, differences between sapphires from these three localities were first found in some of their ultra-trace element contents: specifically in Zn, Sn, Ba, Ta and Pb. The differences are summarized in *Table IV*.

Table III: *Trace and ultra-trace element contents in parts per million of sapphires from major gem-producing countries obtained using LA-ICP-MS.*

Locality		Madagascar	Sri Lanka	Myanmar	Thailand	Australia	China
Number		MD001-020 to M9-001-015	D027-502	B328-342	Th032-037	NS001-006	C125-127
Element	Na	bdl	bdl-55	14-49	bdl	bdl	bdl
	Mg	7-140	12.210	19-21	3-22	6-12	2-8
	K	bdl	bdl-7	bdl-4	bdl	bdl-5	bdl
	Ti	28-590	18-300	29-240	62-980	84-630	120-1200
	V	0.7-12	2-13	3-5	2-5	5-10	27-45
	Cr	2-66	3-120	4-31	0.3-0.6	0.7-7	<0.1-6
	Mn	<0.7	<0.7	<0.4	<0.4	<0.3-3	<0.3-9
	Fe	89-1160	180-1140	1030-1630	910-3670	1940-4660	1680-7230
	Ni	<0.4	<2	0.8-3	<0.2	<0.3	<0.2
	Cu	<0.2	<0.3	0.3-0.5	<0.5	<0.4	0.6-1
	Zn	bdl	bdl	1-15	bdl	bdl	bdl
	Ga	7-66	7-40	8-43	44-1000	55-130	88-190
	Nb	bdl	bdl	<0.2	bdl	bdl	bdl
	Sn	0.2-21	<2	0.5-2	<0.4	<0.3	<0.3
	Ba	bdl	bdl	0.1-2	bdl	bdl	bdl
	Ta	0.5-2	bdl	bdl	bdl	<0.1	bdl
	Pb	bdl	bdl	0.2-2	bdl	bdl	bdl

Note: '<' sign and 'bdl' are below the detection limit.

Table IV: *Summary of distinctive element contents in sapphires.*

Locality	Non-basalt-related origin	Detection limit ppm
Isalo, Ilakaka Madagascar	High Sn, high Ta, high Ga contents no Zn, no Ba, no Pb	Sn<0.1 Ta<0.01 Ga<0.5 Zn<1.01 Ba<0.05 Pb<0.13
Ratnapura Sri Lanka	no Zn, no Ba, no Ta, no Nb, no Pb low Sn (two samples)	Nb<0.01
Mogok Myanmar	Zn, Ba, Pb, and low Sn, Nb contents no Ta	
Locality	**Basalt-related origin**	**Detection limit ppm**
Bo Phloi, Kanchanaburi, Thailand	High Mg, low V contents	Mg<0.35 V<0.14
New South Wales, Australia	Low V contents	
ChangLe, Shandong, China	High V, high Cu, high Mn contents	Cu<0.21 Mn<0.40

Discussion

The Fe, Ti, Cr and Ga contents of sapphires obtained using LA-ICP-MS confirm the grouping of non-basalt-related and basalt-related sapphires when plotted on Cr_2O_3/Ga_2O_3 vs. Fe_2O_3/TiO_2 diagrams and reported by different workers.

The relative abundance of Ti, Fe and Ga in basalt-related corundums worldwide has been related or linked to plutonic crystallisation from a melt (Levinson and Cook, 1994) or alkaline Si-and Al-rich melts, either evolved from basaltic magma (Irving, 1986; Coenraads *et al*., 1990) or derived from the melting of amphibolitised mantle (Sutherland, 1996; Sutherland *et al*., 1998).

Isalo sapphires contain significant quantities of Ti, Fe, Ga and two elements closely related to granite, Sn and Ta. These sapphires were found in gem placer deposits in coarse-grained rocks of Permian and Mesozoic greywackes, which are considered to have been derived from metamorphic, pegmatitic and pneumatolytic rocks, reflecting a complex geological environment. But the presence of Sn and Ta suggests that the sapphires formed close to syenites or granites (see Aspen *et al*., 1990 and Möller *et al*., 1989). Saminpanya *et al*. (2003) also mentioned the presence of significant contents of the granitophile elements Ta, Nb and Sn in non-basalt-related Laos sapphires which originated from the Ban Huai Sai area. In contrast, the Ratnapura sapphires are notable for the absence of Zn, Ba, Pb, Ta and Nb with only two samples containing Sn above the detection limit. These sapphires have been mined from secondary deposits derived from various sources including the metasedimentary rocks: calc-silicates, marbles and pelitic gneisses, and metamorphic rocks of igneous parentage, particularly charnockites (orthopyroxene-bearing granites) (Cooray, 1994).

Mogok sapphires contain different quantities of Zn, Nb, Sn, Ba and Pb, the absence of Ta distinguishing them from Isalo sapphires. These contents suggest that Mogok sapphires were associated with nepheline-corundum syenite or syenitic gneiss which had been metasomatised by a felsic magma. A similar process was postulated for some Thai sapphires by Saminpanya *et al*. (2003) who explained that corundum-bearing syenitic gneiss was formed from Precambrian paragneiss through metasomatism by felsic or carbonatitic liquids at deep levels beneath Thailand.

The basalt-related blue and dark coloured sapphires from Bo Phloi, Kanchanaburi, New South Wales and ChangLe, Shandong, contain significant Ti, Fe and Ga. The ChangLe sapphires had the highest V contents of all the sapphires tested in this study. Generally, sapphires found in basaltic terrains are considered to have been carried to the Earth's surface by rapidly rising alkali basalt magmas and tuffs (Coenraads *et al*., 1990; Guo *et al*., 1992; Levinson and Cook, 1994). Experiments indicate that corundum crystals cannot be grown directly from melts of basaltic composition, and formation of corundum in a metamorphic environment is accepted by most researchers, although precise details are still unclear.

Chemical analysis is very important in the identification of gemstones. At present, the XRF method is entirely non-destructive and, in this respect, is more generally acceptable than LA-ICP-MS analysis, but its disadvantage is its limited sensitivity. This study has shown that trace and ultra-trace element analysis using LA-ICP-MS can be very useful for origin determination of gemstones. It can also be effective in detecting diffusion treatment and in identifying different parts of pearls. Trace and ultra-trace elements can show considerable variation across the surface of a sample, and to obtain a true picture, LA-ICP-MS analyses should be carried out around the girdle and on a number of facets. This study represents an initial stage in compiling trace element data which are useful in the gem trade and more data from more samples from more localities should now be collected.

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Rubies with lead glass fracture fillings

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Abstract: *Recently, a large number of relatively large faceted rubies showing an unusual inclusion pattern have appeared in the gem market. A detailed examination showed that the stones have been treated with a lead-bearing glass of high RI to improve the clarity. Under magnification, flash effects and bubble-like inclusions were visible and enabled straightforward detection of stones with this new type of modification. X-ray images (radiographs) also show evidence of fracture filling and lead can be detected by using X-ray fluorescence analyses. At present the majority of the stones tested have been from an occurrence at Andilamena in north-eastern Madagascar. However, the treatment can be applied to all types of fractured corundums.*

Keywords: *clarity enhancement, identification, Pb-glass, ruby*

Introduction

In recent months unusually large numbers of faceted, transparent to translucent rubies showing an unusual inclusion pattern have appeared in the gem market. The results of inquiries indicated that the majority of the stones originated from Madagascar.

A first Lab-Alert relating to these stones issued by the Research Laboratory of the Gemmological Association of All Japan (GAAJ) on 15 March 2004 described a lead-glass impregnated ruby with a weight of 13.22 ct. This was followed by short notes published by colleagues from the USA (e.g. AGTA-GTC Lab, 2004; Rockwell and Breeding, 2004). A first detailed description of the treatment process was published by Pardieu (2005) on the AIGS website.

Since then we have examined approximately 150 stones weighing between 2.5 and 20 ct (*Figure 1*). After having tested the first stones in March 2004, we confirmed that their fractures and cavities had been filled with a lead-based glass to improve the clarity and informed the client about the result. The client then confirmed that the stones had been treated in Thailand and offered for sale with the suffix 'New Treatment' (in Thai: 'Paw Mai').

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Figure 1: *Faceted rubies from Madagascar with lead glass fracture fillings (weight between 4.03 and 12.58 ct).*

Precursor material

Rubies rich in fissures and with a sufficient saturation of colour are the most suitable samples for treatment (*Figure 2*). At present most of such stones originate from a secondary deposit at Andilamena in north-eastern Madagascar. The occurrence was discovered in 2000 and is located in the Toamasina Province, about 50 km north of Lake Alaotra. Material from the mine is available by kilogram and includes cm-sized, partly rounded with tabular, prismatic or, rarely, rhombohedral crystal habits, and distinct striations on the basal and prism faces. From a geological point of view the corundum occurrences of northern Madagascar are related to late Mesozoic basalt flows in which both sapphires and rubies occur as xenocrysts. In addition to the Andilamena stones, heavily fractured rubies from Tanzania (Morogoro), Kenya and a star ruby from Madagascar (*Figure 3*) have been treated with Pb-glass and there may be similar rubies from other sources on the market.

Figure 2: *Ruby crystals from Madagascar with a saturated colour and numerous cracks. Their appearance can be significantly improved with a high RI glass.*

Figure 3: *Star ruby with lead glass fracture fillings from Madagascar (weight: 4.48 ct)*

Treatment process

The treatment is a multi-step process involving simple heating and the use of different lead rich compounds to fill the fissures and cavities of the stones (Pardieu, 2005; Themelis, 2005, *pers. comm.*).

First, the stones are preformed in order to remove the matrix and any other impurities that could affect the treatment. Then the stones are washed with hydrofluoric acid (75% HF). In the first stage of the heating process in an electrical furnace at temperatures between 900° and 1400°C, additional impurities are removed from the fissures. This temperature range may not affect any rutile inclusions present. Next the stones are heated with various chemical additives.

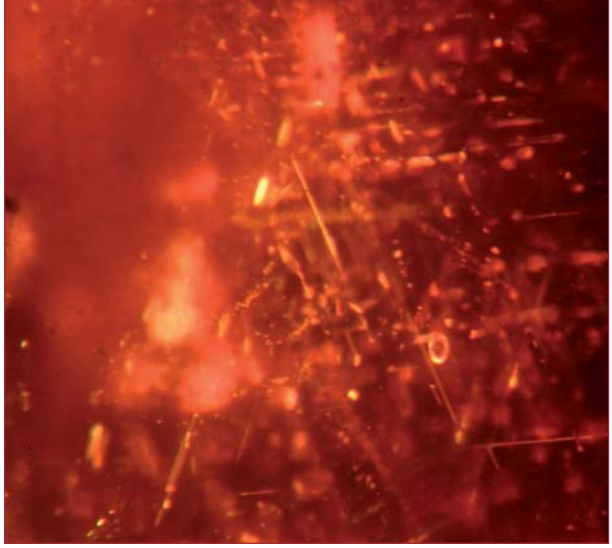

Figure 4: *The presence of oriented unaltered rutile needles suggests that the rubies have not been treated at high temperatures (immersion, reflected light, field of view 3 mm).*

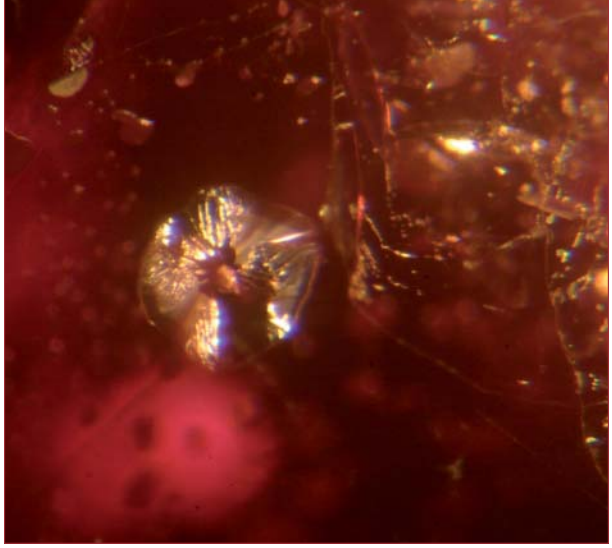

Figure 5: *Mineral inclusions surrounded by discoidal tension cracks are indications of thermal enhancement (immersion, reflected light, field of view 2 mm).*

Several chemical components may be used and various compositions are currently being tested. At present the composition is mainly a mixture of silica and lead but a number of other components such as sodium, potassium, calcium, tungsten, germanium and in particular metal-halides may be added to the powder and enter the glass composition as well. The composition of high refractive index glass and the process of filling fractures in minerals are published in European patent Application No. 1069087A1 (2001). It describes a glass composition having an RI of more than 1.75 and includes at least two metal-oxides or hydroxides (e.g. PbO and Bi_2O_3), one metal-halide or oxyhalide (e.g. PbF_2 or $PbCl_2$) and a glass-forming and stabilising component (e.g. SiO_2). The resulting glasses are colourless but can be coloured by adding small amounts of chromophores such as Cr_2O_3, Fe_2O_3, or others.

The stones are embedded in the powder along with some oil and placed in a crucible. The powder will melt in a furnace open to the atmosphere at temperatures between 850° and 1100°C and form a glass of high liquidity which enters microcavities in the stones and enhances their clarity.

The second heating process can be repeated several times until the best appearance can be obtained. Then the stones are faceted and polished. Some stones may be heated again with chemicals probably to make sure all microcavities are filled; this in turn means that the stones can take a better polish and their lustre is improved.

Identification criteria

If the term 'new treatment' is mentioned in the context of the corundum gem trade then, automatically, beryllium-diffusion comes to mind, a treatment in which the specimens are subjected to a high temperature. However, some samples in our batch of 150 showed crystallographically oriented and unaltered rutile inclusions (*Figure 4*), a feature which generally is viewed as an indication that a stone was not subjected to high temperatures. However, other stones contained mineral inclusions surrounded by tension cracks (*Figure 5*) which are typically found in stones that have been thermally enhanced, but not necessarily at very high temperature.

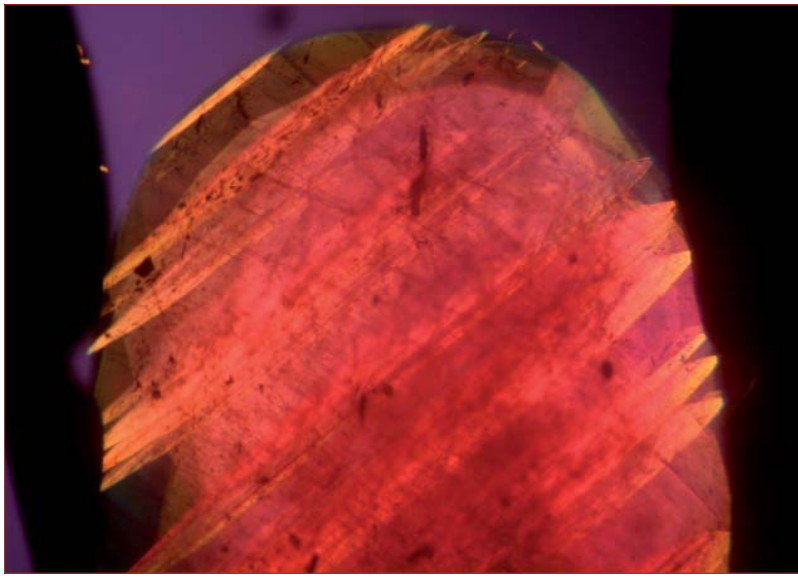

Figure 6: *Lamellar twinning and boehmite tubes are commonly observed in rubies from East Africa (immersion, crossed polars, field of view 4 mm).*

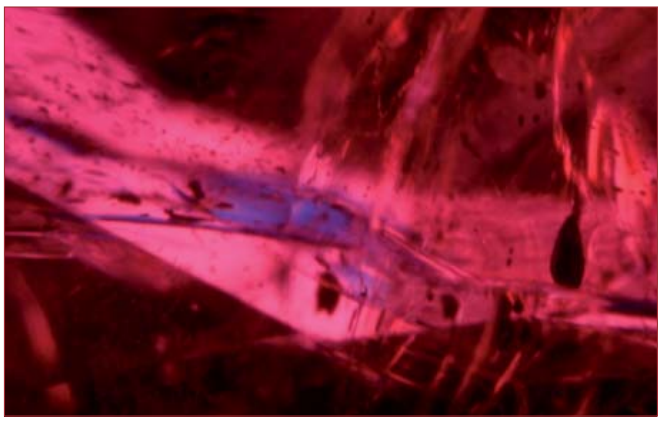

Figure 7: *Blue flash effect in a fracture-filled ruby from Madagascar (dark field illumination).*

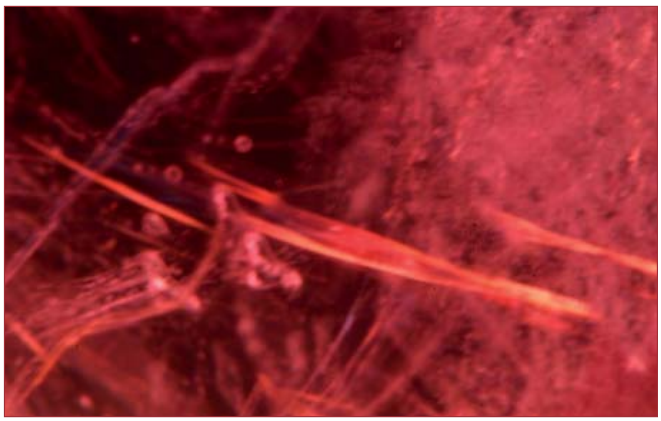

Figure 8: *Orange flash effect in a fracture-filled ruby from Madagascar (dark field illumination).*

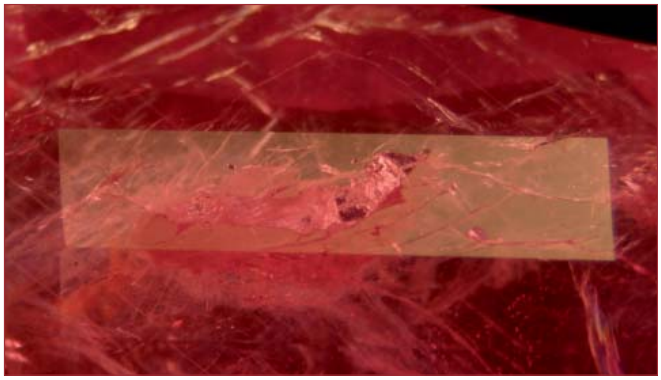

Figure 9: *Open fracture in a clarity-enhanced ruby from Madagascar (dark field illumination).*

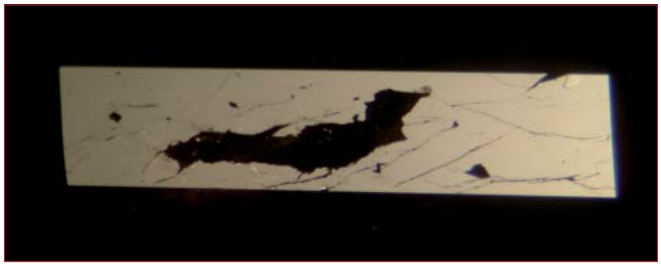

Figure 10: *The same open fracture when viewed in reflected light.*

Depending on their composition Pb-based glasses may have a melting point below 600°C (Themelis, 1992; Pfaender, 1997) a temperature that will not affect rutile inclusions but may affect minerals with a significantly lower melting point than rutile.

Most of the stones examined had an inclusion pattern typical of East African rubies including those from Madagascar. They showed a distinct twinning (*Figure 6)*, and contained boehmite tubes and rutile needles in addition to other birefringent mineral inclusions and dust-like particles. The identification of the treatment process is quite straightforward for a trained gemmologist, especially for those familiar with the process used by the Israeli companies Yehuda and Koss to enhance the clarity of diamonds. Such treated stones first appeared in the mid 1980s and are known as 'Yehuda diamonds' and 'Koss-diamonds' in the trade. The presence of a high RI glass within the microcavities can be detected in both diamonds and rubies by the 'flash-effect'. In dark field illumination the glass-filled cavities will show blue to purple or orange colour flashes, that can best be seen when viewed parallel to the fissures (*Figures 7 and 8*). Fractures which contain foreign glassy substances of lower refractive indices such as the flux-assisted healed fissures of rubies from Mong Hsu in Myanmar, do not produce these flashes.

Washing the stones in HF after final cutting will dissolve the surface-reaching glass and leave behind open cavities (*Figures 9* and *10*).

Flat bubble-like inclusions also form a characteristic and diagnostic inclusion pattern (*Figure 11*) and larger fracture-filled areas are more visible in immersion (*Figure 12*).

X-ray images and X-ray-fluorescence analyses (EDXRF) can also confirm the presence of Pb-bearing glass. Because of the lead content the glass is less transparent to X-rays than the ruby host and as a result the filled areas appear darker on an X-ray image (*Figure 13*). *Figure 14 a*, *b* and *c* shows EDXRF spectra taken from fillings in the fractures of three different stones and all indicate the presence of lead.

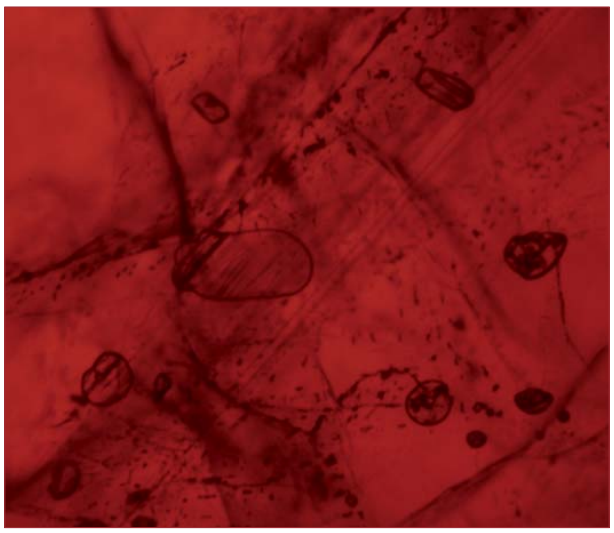

Figure 11: *Flat, bubble-like inclusions are a typical feature of lead glass fracture fillings in rubies (immersion, transmitted light, field of view approx. 1 mm).*

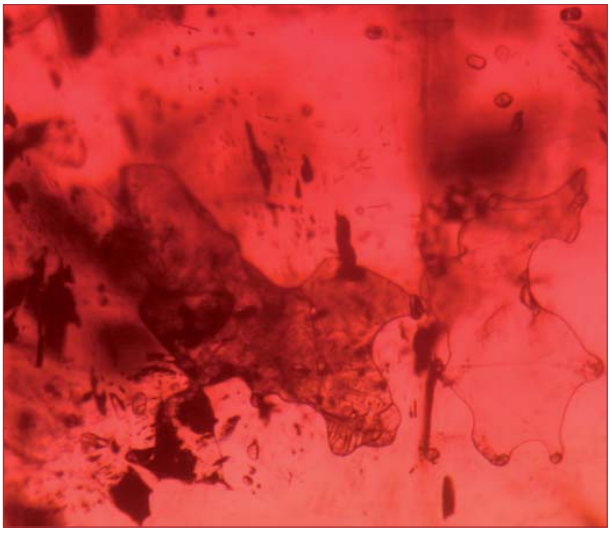

Figure 12: *Larger filled fracture in a ruby from Madagascar (immersion, transmitted light, field of view approx. 2 mm).*

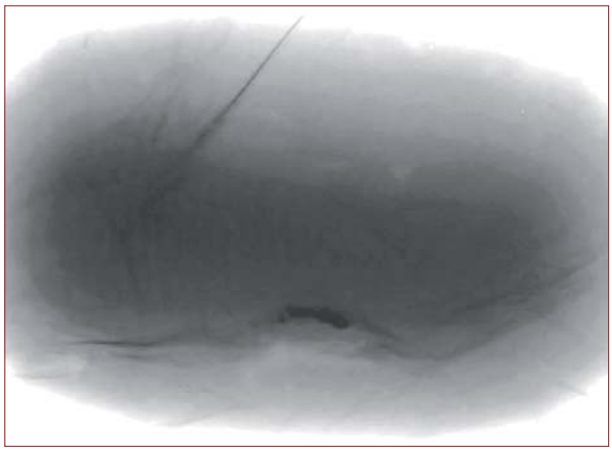

Figure 13: *Lead glass is less transparent to X-rays and, therefore, filled fractures appear darker on images than the corundum host.*

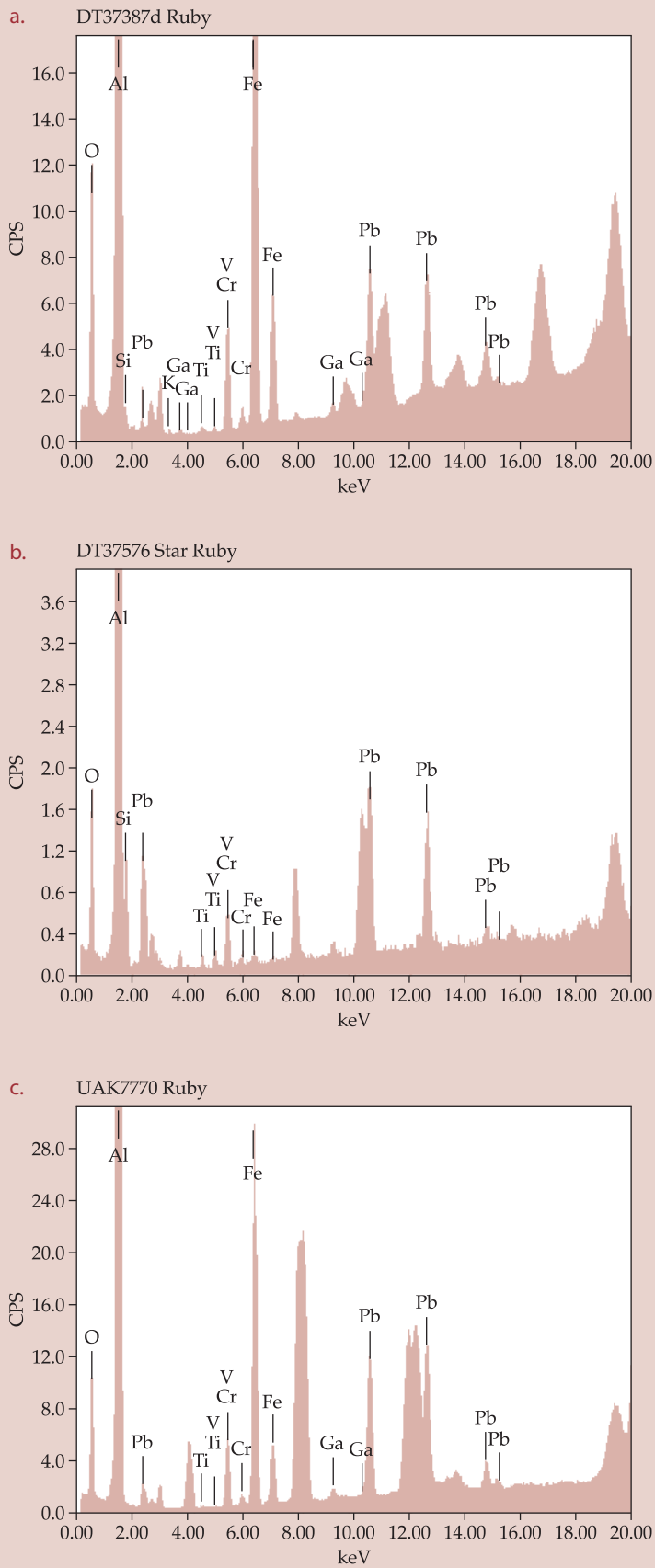

Figure 14a-c: *X-ray fluorescence spectra indicating the elements present in glass filling fractures in three rubies. The presence of lead (Pb) is confirmed.*

Conclusion

The filling of fractures in rubies with glass-like substances has been known for many years.

In the past the fractures were healed predominantly with a flux-based melt (borax) and the temperature used was relatively high (≥1200°C), which commonly altered the inclusion pattern significantly (e.g. notably by reshaping or dissolving any rutile needles) and thus was indicative of the heating process.

In contrast, the lead-bearing melt can be induced into fissures at significantly lower temperatures (≤1000°C) and, as a result, the inclusion pattern at first sight may not necessarily indicate that the stones have been heated.

However, the new treatment process of filling fractures in rubies by using a glass of distinctly higher refractive index than that produced by the borax fluxes and one that is almost the same as that of corundum significantly increases a stone's clarity. Therefore, this clarity enhancement needs to be specifically mentioned in any gemstone report of such a stone.

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A note on a pearl attached to the interior of Crassostrea virginica (Gmelin, 1791) (an edible oyster, common names, American or Eastern oyster)

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Abstract: This report describes an egg-shaped non-nacreous pearl attached to the interior of a Crassostrea virginica (Gmelin, 1791) (in the position of the adductor scar); the State shell of Connecticut, Mississippi and Virginia, commonly known as the American or Eastern oyster. The pearl is said to have been discovered when the owner opened (shucked) an oyster for eating. The pearl is hollow and together with the shell has a gross weight of 28.204 grams. The pearl measures approximately 13.00 x 10.88 mm. The mollusc, UV/visible and Raman spectra, and microradiography results are described.

Keywords: Crassostrea virginica, *Eastern oyster, mollusc, Raman spectra, USA*

Introduction

When envisioning the growth of a pearl within an oyster, it is the nacre-producing pearl oysters of the family *Pteriidae* that generally come to mind. These winged or pearl oysters include *Pteria penguin, Pinctada radiata, Pinctada maxima* (gold-lipped pearl oyster) *Pinctada margaritifera* (black-lipped pearl oyster), *Pinctada fucata* and numerous others (Anonymous, 2004).

The family *Ostreidae* is composed of edible oysters and is most commonly known throughout the world as a popular source of seafood. The shell is porcellanous (non-nacreous) and the pearls produced from these edible oysters generally have little beyond curiosity value (Anonymous, 2005). This report describes one such interesting non-nacreous pearl attached to the interior of *Crassostrea virginica* (Gmelin, 1791) (*Figure 1* and *Table I*) in the position of the adductor muscle scar (Carriker, 1996).

Crassostrea virginica, the American or Eastern oyster, is native to the Western Atlantic coast of North America from the Gulf of St. Lawrence in Canadian waters southward around Florida (Anonymous, 2003), and all along the Gulf of Mexico, the Caribbean and the coasts of Venezuela, Brazil

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Figure 1: *The pearl featured in this report is attached to the interior of* Crassostrea virginica *(Gmelin, 1791) in the position of the adductor scar (photo Elizabeth Schrader © GIA).*

and Argentina. It is common in estuaries and coastal areas of reduced salinity, and has been introduced along the Pacific coast in California and Washington, also in Hawaii, Australia, England, Japan and possibly other areas, but generally has not become established in most of these localities. The species still occurs naturally in some areas as extensive reefs on hard to firm bottoms; it is very important commercially and is widely cultivated in many areas (Carriker and Gaffney 1996; Wallace, 2001).

The shell is made up of two valves, the upper one flat and the lower convex, with variable outlines and a rough outer surface. The oyster spends most of its life attached with a sticky substance to various shells, rocks, and roots. Initial attachment is by a slender, near-transparent byssus thread.

Table I: *Taxonomic Hierarchy*

Kingdom	*Animalia*
Phylum	*Mollusca*
Class	*Bivalvia*
Order	*Ostreoida*
Family	*Ostreidae*
Genus	*Crassostrea*
Species	*Crassostrea virginica*

This is followed by adhesion of the left valve to the substrate with a tanned protein similar to that of the periostracum. Both the thread and the adhesive are produced by the byssal gland.

After the oyster becomes sessile (permanently attached), it is invariably attacked by oyster drills, starfish and other enemies. The American, Eastern (or common) oyster reaches a length of 2 to 6 inches (5-15 cm). These oysters are harvested in artificial beds on both coasts of the United States: on the Atlantic especially in the regions of the Delaware and Chesapeake bays and in the waters off Long Island, and in the Gulf Coast off Louisiana; in the Pacific off the state of Washington. Prepared beds are usually seeded with veligers or young sessile oysters called spats. In warm waters they mature in 1½ years; in cooler waters the period of growth is about 4 to 5 years. They are usually transplanted several times before harvest to enhance their food supply and stimulate growth.

Pearls in edible oysters are not unknown, examples similar to the one described herein are on view in the pearl exhibit in the American Museum of Natural History, New York (specimen number 268828) (*Figure 2*) and described on the AMNH website (Anonymous, 2005). However, the pearl described herein seems to be unusually large and elegantly shaped. As with the AMNH examples this pearl is attached in the area of the adductor scar.

Figure 2: *A specimen of* Crassostrea virginica *(Gmelin, 1791) containing a pearl in the position of the adductor scar. On view in the pearl exhibit in the American Museum of Natural History, New York. Photograph by Denis Finnin © AMNH.*

A natural pearl from Crassostrea virginica

Materials and methods

Analytical techniques employed included: microscopy using gemmological microscopes at magnifications ranging from 15 to 60 x; UV/visible spectra were recorded in reflectance mode using a Zeiss MCS 500/501 spectrometer over the range between 250 and 800 nm; Raman data were obtained using the Renishaw Raman system 1000 spectrometer incorporating a 514 nm argon ion laser; microradiographs were produced using a Faxitron X-ray unit at 90 kV and 3 ma.

Results

Appearance and chemical composition

This pearl is egg-shaped with an uneven and mottled surface. It is attached in the area of the adductor scar to the inside of the shell of an Eastern (edible) oyster and like the shell is non-nacreous.

While the subject of the chemical composition of pigments in all types of oyster shells (and the pearls they produce) is of great interest to the gemmologist, this area of gemmological investigation is far from being fully characterised. However, for *Crassostrea virginica* there are significant published data for gemmologists to note. According to Stenzel (1971) "Oysters living in warm and tropical regions have darker, more vivid, more varied and more extensive colorations than those living in cooler climates. The inner surfaces of the valves of northern populations of *Crassostrea virginica* living north of Cape Cod, for example, are characterized by whitish to grayish yellow colors, and adductor muscle scars are grayish-red purple to very dusky red purple. The inner valve surfaces of the same species living in the northern part of the Gulf of Mexico possess large areas of light brown to grayish purple and only a few patches of whitish color. Their adductor muscle scars have approximately the same colors. It is therefore generally possible to distinguish by pigmentation individuals from at least the extremes of their range". Also, "Carriker *et al.* (1982) observed that strongly pigmented areas on the surface of the right valve of *Crassostrea virginica* grown in controlled laboratory conditions contained low concentrations of magnesium, aluminum, silicon, and titanium" (Carriker, 1996).

Structure

In examining 'collectable' items, regardless of value, one has to be aware of possible 'fakes'. In this instance apart from confirming the pearl's authenticity, one of the other concerns might be whether or not the 'item' had been 'created' by adhering the pearl artificially to the shell.

During a careful microscopic examination of this pearl no indications of it being a manufactured product were observed; no layered (banded) shell-like structures were observed in the pearl and no artificial adhesion to the shell. The structures observed on parts of the surface of the pearl and the shell's internal surfaces resemble those seen in some other non-nacreous shells and pearls (e.g. *Mercenaria mercenaria*); having a slightly rippled appearance.

Figure 3: *Non-nacreous pearl attached to the interior of* Crassostrea virginica *in the position of the adductor scar (photo Elizabeth Schrader © GIA).*

Figure 4: *Non-nacreous pearl attached to the interior of* Crassostrea virginica *in the position of the adductor scar (photo Elizabeth Schrader © GIA).*

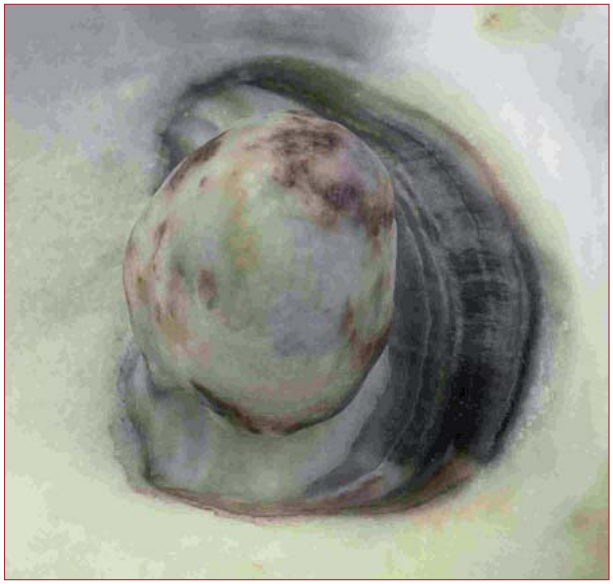

Figure 5: *Non-nacreous pearl attached to the interior of* Crassostrea virginica *in the position of the adductor scar (photo Elizabeth Schrader © GIA).*

The purple area in the region of the adductor scar was unusually translucent, and a close examination of this area and the pearl prompted an image in the mind's eye of "an iceberg (the pearl) floating in a purple translucent sea". Also 'floating' atop the purple area are a small number of calcitic globules (*Figures 3, 4* and *5*).

A detailed account of the shell microstructure is set out by Carriker (1996). Raman data presented later which indicates that calcite rather than aragonite is the main component of the examined pearl and shell, confirms the comments of Carriker and Palmer (1979) quoted by Carriker (1996): *"From homogeneous aragonitic prodissoconch II valves, the shell metamorphoses abruptly beyond the metamorphic line to prismatic calcite (externally) and foliated calcite (internally). The reason for the sharp transition in shell mineralogy from aragonite to calcite, while islands of aragonite remain in muscle scars and residual fibers in the ligament, is unclear."*

Microradiography

While being the most powerful technique in the arsenal of the gemmologist when distinguishing natural from cultured pearls, microradiography relies upon the differences in X-ray absorbance between the alternating crystalline and organic layers that are generally present within a nacreous pearl (natural or cultured) (Kennedy, 1998; Akamatsu *et al*., 2001) but these differences are not necessarily obvious in non-nacreous pearls. Non-nacreous pearls tend to have a structure that consists of dense closely packed crystal arrays without large amounts of organic material being present. Therefore in general, non-nacreous pearls are opaque to X-rays and only occasionally show the presence of organic material by microradiography. Fortunately the pearl in this *Crassostrea virginica* shell revealed considerable information about its growth history despite being encumbered also by the shell.

The microradiographs are shown in *Figures 6* and *7* and reveal that the pearl is not only egg-like in its external form, but also show clearly that it is egg-like internally

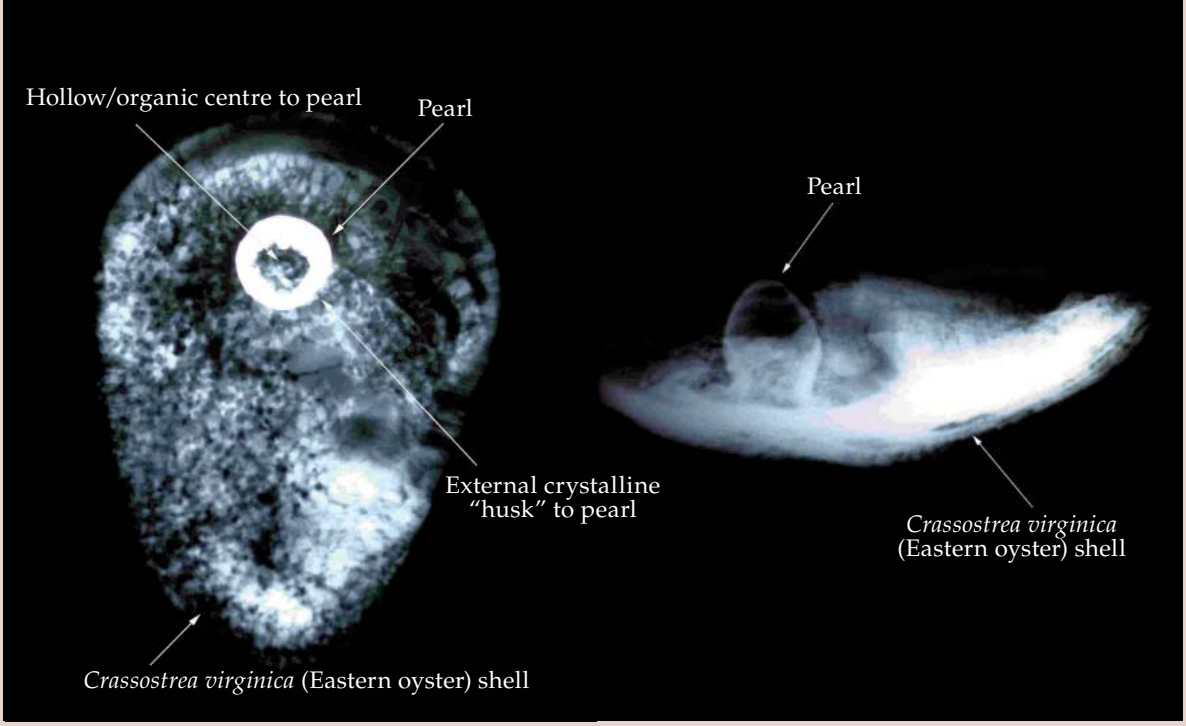

Figure 6: *Microradiographs showing the* Crassostrea virginica *shell and pearl from above (left) and in profile (right). The shell and pearl structures are indicated by the annotations. Photo reproduction by Elizabeth Schrader © GIA.*

Figure 7: *A close-up view of the microradiograph in Figure 6 concentrating on the pearl alone and revealing an organic core. Photo reproduction by Elizabeth Schrader © GIA.*

– being composed of a relatively thin 'shell' of calcium carbonate (calcite) surrounding a large organic core. These microradiographs indicate that if the pearl were to be removed from the shell there would be a high likelihood of damage. Also, from its position in the shell and its organic core, it is very likely that during growth the pearl encased at least a portion of the adductor muscle.

Raman and UV/visible spectra

Raman spectra (Kiefert *et al*., 2001) were collected from the purple portions only of the pearl. All spots examined produced similar spectra with peaks located at 311, 501, 666, 914 941, 1029, 1145, 1308, and 1574 cm^{-1} (*Figure 8*).

These peaks are currently unassigned. Other peaks located at 1088, 711 and 279 cm^{-1} which we can attribute to calcite (Traub *et al*., 1999, Li and Chen, 2001; Huang *et al*., 2003, Kiefert *et al*., 2004) were also noted. The spectrum for this pearl differs from those recorded for the non-nacreous pearls produced by *Strombus gigas* (the conch pearl) and the *Melo* volutes (the melo pearl) where peaks attributable to carotenoids are invariably present if these pearls are coloured, and where it is the peaks normal for aragonite (rather than calcite) at 1085 and 703 cm^{-1} that dominate. However, the presence of calcite rather that aragonite compares well with the spectra produced by the scallop pearl from *Nodipecten* (*Lyropecten*) *subnodosus* (Scarratt and Hänni, 2004).

The Raman spectrum of the pearl was compared with the Raman spectrum produced from the white area on the interior of the *Crassostrea virginica* shell to which it is attached (*Figure 9*). The white area produced a Raman spectrum typical of aragonite with peaks at 703 and 1085 cm^{-1} that were

Pearl in *Crassostrea virginica* – purple area

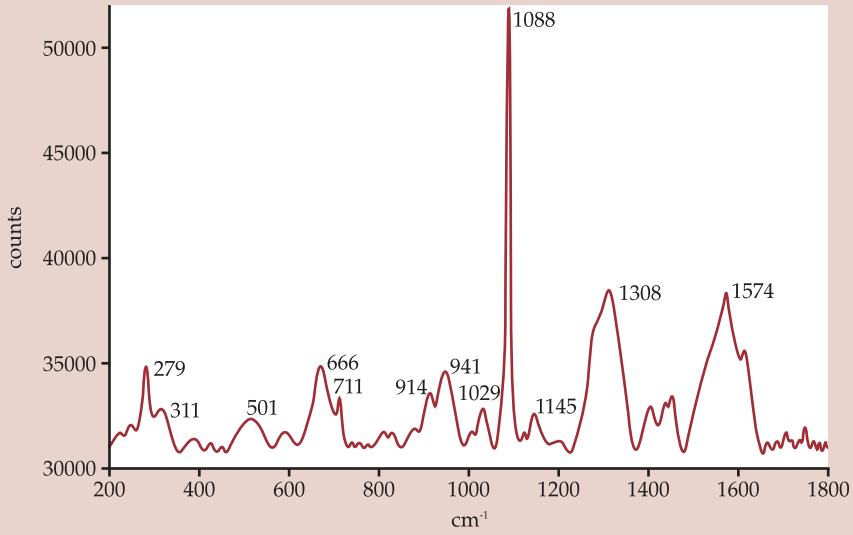

Figure 8: *The Raman spectrum recorded for a purple area on the pearl adhering to the* Crassostrea virginica *shell. Characteristic peaks associated with calcite are recorded at 279, 711 and 1088 cm^{-1} the other peaks are unassigned.*

Pearl in *Crassostrea virginica* – white area

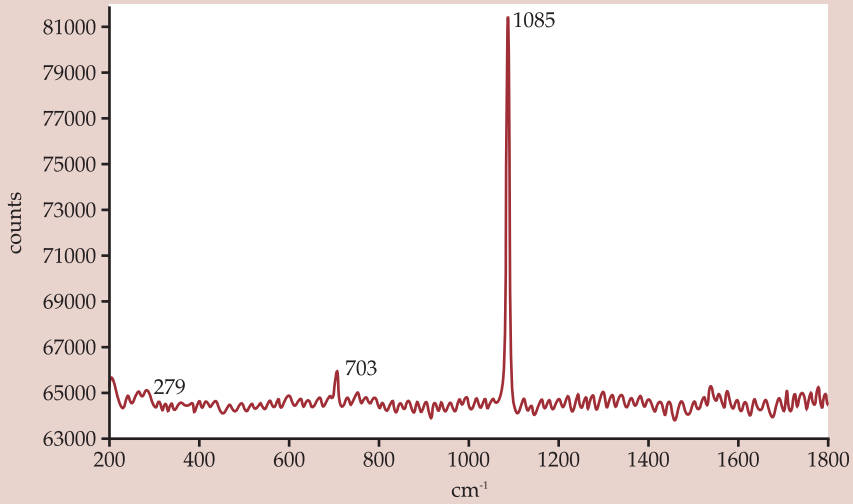

Figure 9: *The Raman spectrum recorded for a white area on the inside of the pearl containing* Crassostrea virginica *shell described in this report. Peaks characteristic of aragonite at 1085, 703 and 279 cm^{-1} are recorded.*

Purple area in *Crassostrea virginica* shell

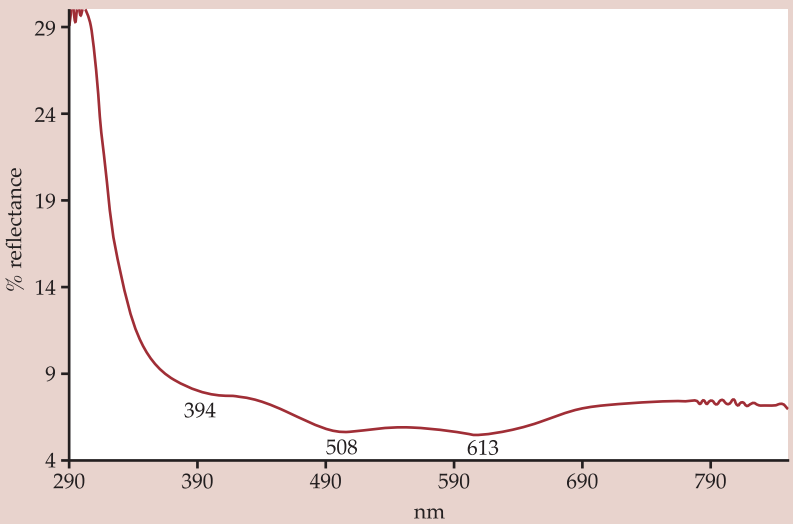

Figure 10: *The UV/visible spectrum recorded for a purple area on the pearl within the adductor scar of the* Crassostrea virginica *shell. Broad low reflectance features were noted centred at 394, 508 and 613 nm.*

unaccompanied by any unassigned peaks present in the purple areas of the pearl itself.

UV/visible spectra were recorded in reflectance mode for the purple area within the adductor scar on the interior of the *Crassostrea virginica* shell (*Figure 10*). Broad low reflectance features are centred at 394, 508 and 613 nm.

Discussion

While pearls from *Crassostrea virginica* have previously been reported, the examination of this pearl has for the first time recorded the Raman and UV/visible spectra for the shell and pearl. Radiographs have also revealed that the pearl has a large organic core and that its position within the shell indicates that the pearl has encased at least a portion of the adductor muscle. Clearly, unless great care is taken, damage to the pearl might occur if an attempt were made to remove it from the shell. Although such pearls may be regarded merely as interesting or curious and great conversational pieces, their investigation and recording allows those who are fascinated by the products of molluscs to understand the full range of the pearl family.

Acknowledgements

Several individuals were generous with their time and expertise during the preparation of this paper. Firstly the owner Anthony Dellagrotta, took the trouble to inform Antoinette Matlins of the existence of this item and Ms Matlins generously passed the information on to the authors. Both individuals took time from their busy schedules to bring it to New York City for examination. It is to Elizabeth Schrader of GIA that the authors owe the excellent macro photography. To Dr Lore Kiefert (Laboratory Director at AGTA-GTC) the authors are indebted for allowing the use of the Zeiss MCS spectrometer for the recording of UV/visible spectra. To Kathleen Moore the authors are greatly indebted for providing the image of the two examples in the AMNH pearl exhibit. Finally the authors are indebted to those authors and editors responsible for the particularly lucid work: The Eastern Oyster: *Crassostrea Virginica* (Kennedy, V. S., *et al*., 1996), a truly excellent reference text about the fascinating world of this mollusc.

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A short review of the use of 'keshi' as a term to describe pearls

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Abstract: *The original term 'keshi' describes tiny mantle pearls that developed without a tissue transplant during the production of Akoya cultured pearls. The term is now often used for gonad-grown cultured pearls that have formed from mantle tissue grafts under conditions where a bead has been rejected. A discussion of the term 'keshi' in its original and recent application is given. The formation of original and recent keshi cultured pearls is explained, with radiographs and cross sections of recent keshis. Current pearl trade use of the term is discussed. An alternative term to keshi – a beadless cultured pearl – is proposed. Recent Chinese freshwater cultured pearls with beads and the potential increase in numbers of beadless cultured pearls are discussed.*

Keywords: *beadless cultured pearls, bead rejection, Keshi cultured pearl, Keshi pearls*

Introduction

In earlier gemmological literature the term 'keshi' was traditionally used for small, near-round nacreous pearls deriving from Akoya shells that have undergone operations for producing beaded cultured pearls (Henn, 2001; Strack, 2001). The keshi pearls are characterised as unexpected by-products or even natural pearls (Webster, 1983, p. 538) and enjoy thus a close-to-natural identity. In the CIBJO nomenclature rules (CIBJO, 1998), the term 'keshi' appears under cultured pearls. We have noted that over approximately the last ten years, the term 'keshi' has increasingly often been used for pearls which do not come from the Akoya oyster (*Figure 1*) and are significantly larger. In fact today the name 'keshi pearl' is applied to a great number of large, well-shaped to off-shaped South Sea and Tahiti cultured pearls. This article reviews the background of

Figure 1: *Beadless cultured Tahiti pearl – a so-called keshi – mounted as a pendant, with its radiograph showing a large irregular cavity (dark area). Length of the pearl 22 mm. Photo © H.A.Hänni, SSEF.*

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this new application of an old term to recent production of cultured pearls and discusses gemmological terminology and trade usage.

Comments on how Japanese keshis formed

An early description of the term 'keshi' in the western gemmological literature can be found in Taburiaux (1983, 1985). Keshi pearls have been found sporadically in Japanese Akoya shells during harvesting the beaded cultured pearls, and they are usually around 2 mm or smaller (*Figure 2*).

Figure 2: *Keshi pearls from Japanese Akoya production. The smaller ones are mantle pearls which grew as a reaction to damage at the edge of the shell and in the mantle epithelium incurred during handling. The small size is consistent with the short period of time between the operation and the harvesting. The oblong and bigger ones are gonad grown, as a consequence of a lost bead. Length of the gauge is 1 cm. Photo © H.A.Hänni, SSEF.*

It is interesting that these original keshi pearls were found in the mantle tissue, and not in the gonads that had received the mantle tissue transplant. They therefore cannot owe their formation directly to the transplanted epithelium. That they are always small has to be related to the age of the shell, or more correctly, with the length of time between the handling of the shells and harvesting of the crop. The following thoughts are deduced from the author's own observations and reflections and are presented without having consulted the extensive professional literature in Japanese; should any of the ideas be similar, apologies are offered.

The formation of a natural pearl is in most cases the consequence of an injury to the external mantle tissue (Gübelin, 1946; Hänni, 2002). The subsequent healing of that injury may lead to the formation of a cyst, i.e. a pearl sac lined with external mantle tissue. Further production of calcium carbonate leads to the concretion, which may consist of or be coated with nacre, i.e. the pearl. Very small natural pearls are sometimes called poppy seed pearls (Landmann *et al.*, 2001, p 61). They are in fact the natural counterpart to the original keshis in *Pinctada martensii*, the classical Japanese oyster for beaded cultured pearls.

To explain a keshi pearl in the mantle, we should therefore look for an injury which dates back a sufficient number of years to account for the size of the small pearl encountered at the harvest of the Akoya cultured pearls. Since the growth period for Akoya cultured pearls is approximately one year to get a relatively thin nacre overgrowth on the bead, we can thus assume that the injury occurred during the handling of the shells from the sea to the operation table and back again to the sea. The very thin and fragile edge of the shell may have received a blow or have been damaged. The subsequent healing of such involuntary damage may well be the start of what is to become the so-called keshi pearl. In the short time between the operation (when the injury happened) and the harvest, a 2 mm pearl is perfectly well imaginable. When the keshis are retrieved from the shells during harvesting of the Akoyas, other concretions are also collected that have grown from tissue grafts that have accidentally lost the bead (*Figure 2*). Such formations include gonad-grown concretions that occur from tissue grafts that have lost the bead. They are small, randomly shaped, beadless cultured pearls, also of a size consistent with the short period of growth allowed for the Akoya process (i.e. operating on a mature *Pinctada martensii* oyster to produce beaded cultured pearls and harvesting them after a few months).

Requirements for the formation of a cultured pearl

Over about the past hundred years, the growth of (cultured) pearls that do not adhere to the shell has been stimulated by the transfer of a small piece of mantle tissue (mantle epithelium) from a sacrificed donor oyster into the body of a living oyster. The sites in the body where the grafts of tissue are most successful are the mantle or the gonad (the reproductive organ). The mantle tissue is the organ which lines and builds the shells, while the gonad is situated deep in the shell. To carry out the operation, the living oyster shell is opened about one centimetre and the tissue transplant is inserted with or without a bead.

In order to produce a cultured pearl, a small number of technical conditions must be selected (some of these options are independent from each other):

- one may work with freshwater or seawater oysters
- the cultured pearl may grow in the mantle or in the gonad, i.e. the tissue can be transplanted into the mantle or into the gonad
- the cultured pearl may or may not have a bead
- the donor oyster and receiver oyster may or may not be of the same species.

Should one decide to have mantle-grown cultured pearls, the first operation would include only the tissue transplant – the young oysters have a mantle that is too thin to house a bead – and their first (or only) product will be a beadless CP. With time both the pearl sacs and the shell rim grow larger so that the CPs virtually slide into the shell.

Should one decide to have gonad-grown cultured pearls, one has the choice to add a bead (beading) to the mantle tissue transplant (grafting). To start the formation of a CP, the grafting is indispensable but the beading is optional. In many circumstances, using one or both of these terms presents a much clearer picture than using the term 'nucleation' where either could be meant.

Understanding the formation of the product

Over the past several years large pearls that carry the name 'keshi' have become more common in trade fairs, in advertisements and in jewellery shops. They come mainly from cultured pearl (CP) farms using *Pinctada maxima* and *Pinctada margaritifera* shells, i.e. from salt-water oysters. Although the formation of small by-products in these shells, as in the Japanese Akoya, is possible, these so-called 'keshis' differ in size and mostly also in shape from the original. Commonly these large 'keshis' are found in the gonad tissue, and not in the mantle of the shell (Clinton Schenberg, *pers comm.*, 1998; Dora Fourcade, *pers. comm.* 2003; Andy Müller, *pers. comm.*, 2005).

'Keshi' pearls from Australia, Tahiti or from the Philippines, are completely different from the keshi pearls as found in the Akoya oyster. Through the study of X-ray pictures of such so-called keshi pearls we can distinguish two types among them. Type 1 has a growth characteristic which is very similar to that of a beadless CP, such as the freshwater CPs from China. The shape is round to oval and a trace of a relatively small cavity is visible in the centre (Hänni, 2002). Most type 2 pearls have a flattened baroque shape with a distinct central cavity visible on the X-ray picture. The similar appearance of the central cavities in pearls of both types to central cavities in beadless freshwater CPs offers an explanation for their formation. The following comments are based on our observations and follow discussions with cultured pearl specialists D. Fourcade in 2003, A. Müller in 2002 and C. Schenberg in 1998.

Type 1: In the course of the production of beaded cultured pearls, it may happen that the oyster rejects the bead nucleus, although the tissue transplant is already grafted into the gonads. The mantle tissue will thus form a pearl sac and secrete calcium carbonate from its inner surface, and in this way produce a beadless cultured pearl. Because the piece of mantle tissue was placed into the gonad, this cultured pearl will grow in the gonad and later be harvested from there. Such formations are well known from all oysters that are commonly used for bead-cultured pearl production such as *Pinctada maxima* and *Pinctada margaritifera* (South Sea and Tahiti) (*Figure 3*).

Figure 3: *South Sea* Pinctada maxima *(left) and Tahiti* Pinctada margaritifera *(right) beadless cultured pearls as grown after rejection of the bead after the first operation (tissue transplant and bead implant). Largest pearl is about. 8 mm long. Photo © H.A.Hänni, SSEF.*

Type 2: After a first CP with bead is harvested from one of the above-mentioned shells the already-present pearl sac is ready to take a second bead (second nucleation). Such a second bead nucleus is of the size of the previously harvested pearl and is placed in its former position. Since the inner surface of the pearl sac is still productive and will continue to precipitate nacre, the second bead will soon be covered with an overgrowth. There is thus no need for a second grafting or tissue transplant. Often, however, the bead is rejected from the pearl sac immediately after its introduction. The pearl sac then collapses since it is unsupported by a bead, but on its surface nacre is still being produced, forming a flattened to baroque shaped beadless CP. After the normal growth period, this product is harvested with the other CPs of the 'second generation' (*Figure 4*).

We can assume that beadless CPs may be formed in the gonads of operated shells when the first or second introduction of a bead is unsuccessful. In both situations, the formation is caused by the mantle tissue formerly transplanted (grafted) into the gonads. In a cross section through beadless CPs from saltwater oysters the structure is clearly visible. In type 1 the central cavity is small and more equidistant from the pearl's surface. In type 2 the surface continues to precipitate calcium carbonate, forming a

Figure 4: *South Sea* Pinctada maxima *(left) and Tahiti* Pinctada margaritifera *(right) beadless cultured pearls as grown after rejection of the second bead (after collection of first cultured pearl and second bead implant). Larger pearl is about 15 mm long and 4.5 mm thick. Photo © H.A.Hänni, SSEF.*

Figure 5: *Cross sections through four beadless South Sea cultured pearls. The pearl at the upper left is from a first crop (after rejection of the first bead) and the other three pearls are from a second crop (after rejection of the second bead) where larger pearl sacs had collapsed. Length of the pearl on the lower left is 18 mm. Photo © H.A.Hänni, SSEF.*

crust around a collapsed sac and leaving an irregular and perhaps large gap in the centre, as seen in *Figure 5*. In *Table I* the different beadless cultured pearls and their origin and trade terminology are listed.

Identification of beadless cultured pearls

The identification of beadless cultured pearls is most readily done with X-ray shadow pictures, i.e. radiographs. The method is described in a number of books and professional papers (e.g. Hänni, 1997; Scarratt *et al*., 2000). However, distinction of natural pearls from beadless cultured pearls is not always easy. Usually the beadless cultured pearls are characterised by a mark on the radiograph indicating a relatively significant central cavity and a number of growth bands with slight undulations. Those beadless cultured pearls that are currently called 'keshi' (*Figure 4*) show quite significant central cavities as seen in the X-ray pictures in *Figure 6*. Beadless cultured pearls do not reveal the directional characteristics shown by CPs with nacre beads, so the Laue diffraction method (Hänni, 1983) is not useful. A separation between saltwater and freshwater beadless cultured pearls can be done by X-ray luminescence on the basis of the Mn content (Hänni *et al*., 2005).

Table I: *Identification and trade terms for beadless cultured pearls.*

Shell type	Trade name	Identification
Pinctada martensii (Akoya)	keshi	beadless cultured pearl
Pinctada maxima	South Sea keshi	beadless cultured pearl
Pinctada margaritifera	Tahiti keshi	beadless cultured pearl
Cristaria plicata	freshwater pearl	beadless cultured pearl
Hyriopsis cumingi	freshwater pearl	beadless cultured pearl

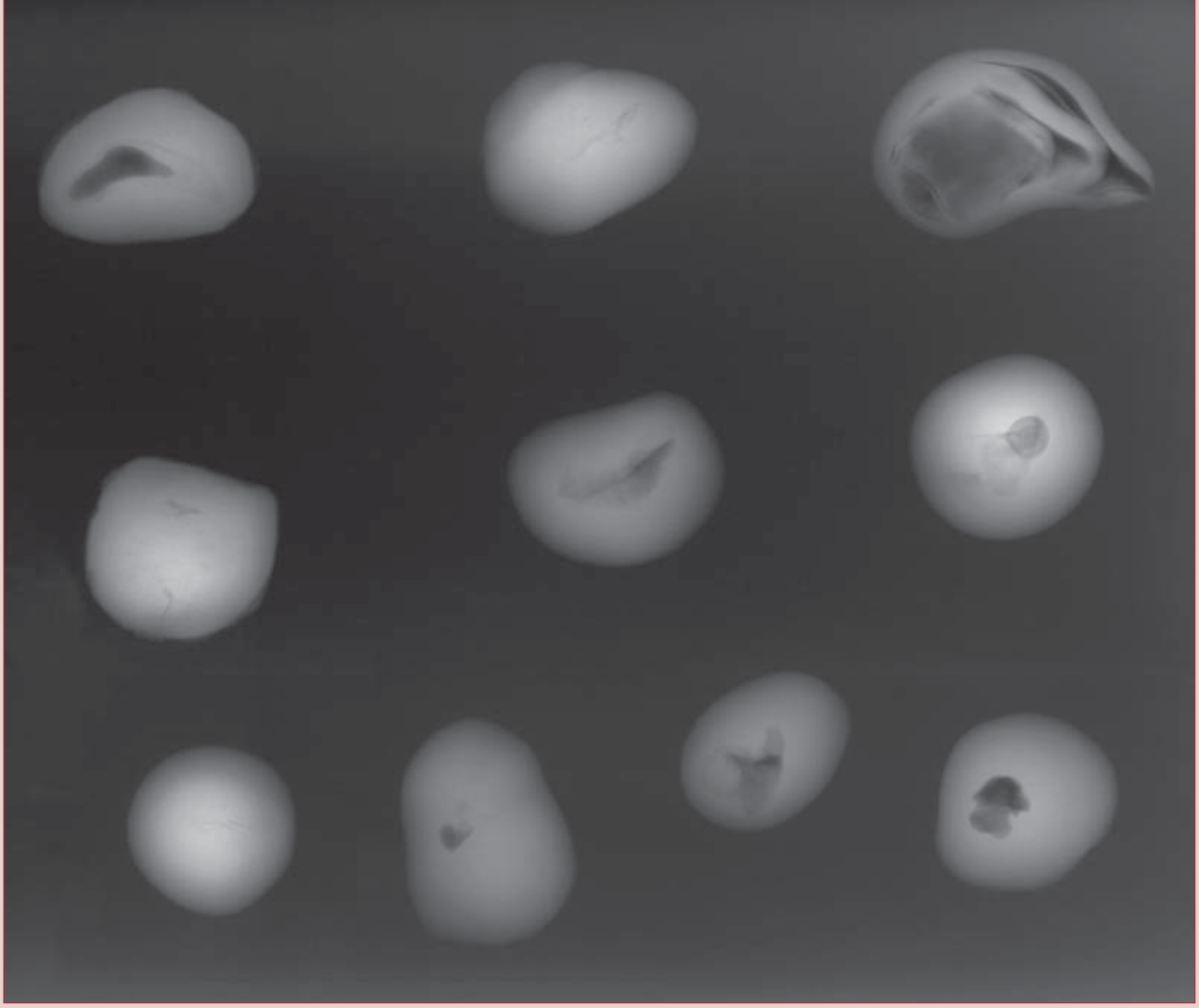

Figure 6: *X-radiograph of a number of beadless South Sea cultured pearls called 'keshi' in the trade. Central cavities are visible in most pearls and show typical appearance. Photo © H.A.Hänni, SSEF.*

Discussion of the recent use of the term 'keshi'

We have seen that the original application of the term 'keshi' is related to an injured rim of the shell in the mantle area. Original keshi pearls are thus 'mantle pearls', and not 'gonad pearls'. The more recent application of the term 'keshi' is related to concretions caused by mantle tissue transplants (grafts) into the gonads. However, the feeling in the pearl trade has always been more favourable to the term 'keshi' as such pearls were considered somehow to be more natural than straight cultured pearls. Such feeling and pressure from pearl traders led to the International Confederation of Jewellery, Silverware, Diamonds, Pearls and Gemstones (CIBJO) agreeing to the term 'keshi' for use in describing a seawater cultured pearl without a nucleus (CIBJO, 1999). Descriptions in popular text books on pearls may introduce the same meaning of the expression that "something went wrong in the process of culturing pearl" (Matlins, 1999). In the same book it is made clear that the keshi is considered "not a natural pearl".

Although those in the pearl trade may call the 'gonad pearls' keshis, it is very questionable if it is scientifically helpful to equate these with the accidentally produced original keshi pearls. Their position in the gonads, the use of voluntarily grafted mantle tissue and their size are three major features of difference. So, while the keshis may strictly be by-products, since the producer wanted a fully round large beaded pearl rather than a baroque one, they cannot be considered as natural accidents since the tissue was transplanted into the gonads voluntarily. These 'gonad pearls' are

definitely cultured pearls since they derive from the tissue transplant. The author thinks that the terms 'beadless cultured pearl' or 'baroque beadless cultured pearl' would be acceptable names, which is furthermore correct in its statement, and that such pearls should not be called keshi pearls.

There is considerable danger in widening the term 'keshi' to include beadless CPs. Chinese production now consists largely of beadless (freshwater) CPs. Would the Tahiti and South Sea cultured pearl producers want the Chinese producers to market their pearls as keshis, merely because they are beadless? In one sense, the Chinese producers could even argue that their products grow in the mantle, just as the original keshis do. With the forthcoming production of beaded freshwater CPs from freshwater shells in China, we must also expect greater numbers of beadless CPs after bead rejection. The new production of large beaded CPs from the Chinese mussels is achieved by introducing a bead after the harvest of the first large beadless pearl (*Figure 7*). By this process the mussels can produce a second CP after only a short time, but one which is beaded. Since the mantle production of CPs can yield over 40 pearls in one mussel, intentionally flat beadless CPs can be produced simply by not inserting a bead into the empty pearl sacs. And inevitably, the number of flat beadless CPs resulting from rejection of the bead will also rise (*Figure 8*).

While studying a catalogue from a jewellery auction in Geneva in 1989, the author noticed the term 'keshi' in the description for a seven-strand pearl necklace, although an accompanying gemmological test report identified the pearls as natural. It seems that the cataloguer had chosen the term 'keshi' to refer to the slightly baroque shape of the pearls. So, although the term was used a long time ago, in this context it is potentially misleading; with this article the author would like to restore a clear meaning to the term 'keshi' so that trade and consumers do know what they can expect when it is applied.

Figure 7: *Round freshwater beaded cultured pearls from China. These are grown as a second product in the mantle after the first (beadless) pearl has been collected. By inserting a bead into the pearl sac, a second large and round CP can be harvested shortly after the first crop. Photo © H.A. Hänni, SSEF.*

Figure 8: *The flat beadless freshwater cultured pearls. They represent pearls that have grown as a second product in the mantle after the first (beadless) pearl has been collected. Any bead that may have been inserted has been rejected, so there is no support for the pearl sac and it collapses into a flattened shape, which in turn leads to the flattened pearls. Photo © H. A. Hänni, SSEF.*

Conclusion

The term 'keshi' as applied originally to small mantle pearls from the Japanese Akoya cultured pearl production is now used widely for cultured pearls from Tahiti and the South Seas. While the original product can be considered as an unintended by-product,

the pearls that are called keshi today in the market are large beadless cultured pearls. They are produced in the gonad and most are formed after a bead has been expelled after an unsuccessful implant. Although the term is approved in the trade, it is questionable whether these pearls should be named keshis. A term such as 'beadless cultured pearls' would explain more precisely what they really are.

Acknowledgements

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Editor's note: The nomenclatures surrounding gem materials are continuously being discussed and updated by CIBJO and other organisations. We believe it important to encourage debate and comment in this Journal, but the views expressed are those of the author concerned.

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A new type of Tairus hydrothermally-grown synthetic emerald, coloured by vanadium and copper

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Abstract: *Gemmological, chemical and spectroscopic properties of a new type of hydrothermally-grown synthetic emerald produced commercially by the Tairus company in Novosibirsk, Russia, are described. The results of chemical and spectroscopic examination in the UV-Vis range indicate that the samples are coloured by a combination of vanadium and copper; chromium contents are negligible. Infrared spectra show the presence of different types of water molecules and/or hydroxyl ions. Two major types of isomorphic replacement are present, octahedral substitution of aluminium by vanadium and tetrahedral substitution of silicon by aluminium with charge compensation by lithium on channel sites. Distinction of this new type of synthetic emerald from natural emerald can be made on the basis of distinct growth features visible through the microscope, and chemical and/or spectroscopic features may also be helpful.*

Keywords: *content of Cr, Cu, V; gemmological properties; IR spectra; synthetic emerald; Tairus; UV-Vis spectra*

Introduction

Since 1989, the year of its foundation, the Tairus company has become one of the world's largest producers of synthetic gem materials, mainly differently coloured varieties of the corundum and beryl families. Tairus is a Joint Venture between the Russian Academy of Sciences (Siberian Branch) of Novosibirsk and Tairus (Thailand) Co. Ltd of Bangkok.

In the past, a number of different types of synthetic emerald have been grown hydrothermally by Tairus. Emeralds coloured by a combination of chromium, iron, nickel and copper were produced by Tairus and elsewhere in Russia (see Granadchikova *et al.*, 1983; Schmetzer, 1988) in steel autoclaves without noble metal liners, and synthetic emeralds

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coloured mainly by chromium were grown in autoclaves with noble metal insets or with teflon coating. A product which was marketed as 'internally clean' synthetic emerald was grown using specially oriented seed crystals (Koivula *et al*., 1996; Schmetzer, 1996). With this special orientation of the seed, the Russian researchers tried to avoid the formation of easily detectable growth features.

In 2001, the Tairus company purchased Biron's growth technology (intellectual know-how and technical equipment) from Australia which was developed to produce synthetic emeralds whose colour is due to almost equal amounts of chromium and vanadium – in an attempt to resemble Colombian emeralds as closely as possible. After an intermediate production period in Thailand 2002, Biron type synthetic emerald is now produced by Tairus in Russia (W. Barshai, *pers. comm.* 2004).

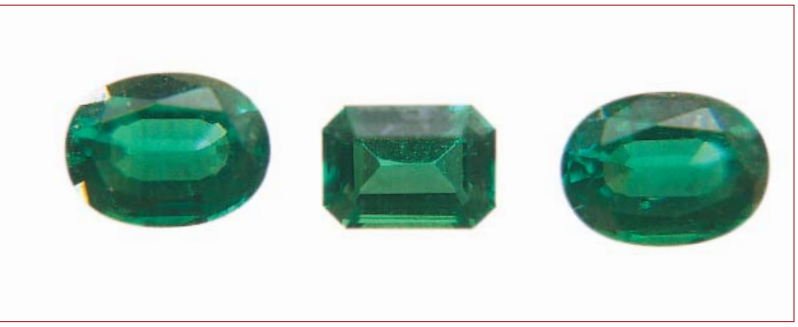

Figure 1: *Faceted samples of the new type of Tairus hydrothermally-grown synthetic emerald coloured by vanadium and copper; samples from 0.91 ct (centre, 5.0 × 7.0 mm) to 1.17 ct (right, 6.1 × 8.1 mm). Photo by M. Glas.*

In 2004, a new type of synthetic emerald (*Figure 1*) was introduced by Tairus to the international market as 'Colombian Color Emerald'. The new development in synthetic emerald growth is attributed to Dr Dimitry Fursenko and his team, who worked on this project since 1999 and which culminated in September 2004 when the first rough crystals were cut (see http://www.tairus.com/). It is the purpose of the present paper to characterise this new type of hydrothermally-grown variety of synthetic beryl.

Crystal growth

The following section was produced using the information given and the photos submitted by the Russian scientists involved in the production of the new type of synthetic emerald in the laboratories of Tairus in Novosibirsk. Fursenko and his team are pictured in *Figure 2a*, and all research and development as well as commercial production is performed in the Tairus building in Novosibirsk (*Figure 2b*).

Figure 2a: *The technology for the growth of the new type of synthetic emerald has been developed by Dr. Dimitry Fursenko (centre) and his team, Dr. Victor Thomas (right) and Ivan Fursenko (left). Courtesy of D. Fursenko.*
Figure 2b: *The commercial production as well as the scientific research is performed in the Tairus building in Novosibirsk, Russia. Courtesy of D. Fursenko.*

Figure 3 a, b: *The commercial production of the new type of Tairus synthetic emerald is performed in steel autoclaves with noble metal lining; height of the autoclaves about 50 cm, external diameter about 9 cm. Courtesy of D. Fursenko.*

Materials and methods

For this study, we examined ten hydrothermally-grown synthetic emeralds of the new type (*Figure 6*), which were purchased by one of the authors (DS) at Tairus, Bangkok, in 2004. They comprised four faceted stones (0.91 to 1.64 ct) and six platy rough crystals (2.86 to 10.70 ct). The rough crystals (thickness between 4 and 5 mm) had been sawn by the producer along the boundary of the seed and the grown emerald, in this way removing all residual parts of the seed plate. We were informed that our samples represent the commercial production after the final development of the growth technique.

Commercial growth is performed in steel autoclaves (*Figure 3 a, b*) with a working chamber of 250 to 300 ml. A transparent model for demonstration (*Figure 4a*) shows the arrangement of seed plates and nutrient (*Figure 4b*). Colourless or very pale green natural beryl from the Ural mountains (cracked and purified) is used as the initial charge for crystal growth. The beryl nutrient, colour-causing dopants and components of the mineraliser (not shown) are placed into the lower part of the working chamber. Typical sizes of seed plates located in the upper part of the autoclave are 80 18 mm. Crystals are grown at a temperature near 600 C and a pressure near 1.5 kbar. The temperature gradient in the autoclave is in the range of 50 to 100 C. With these growth parameters, a growth rate of 0.3 mm per day is obtained. Typically, a synthetic emerald crystal (*Figure 5*) measures 80 18 14 mm, indicating a growth period of about 20 days.

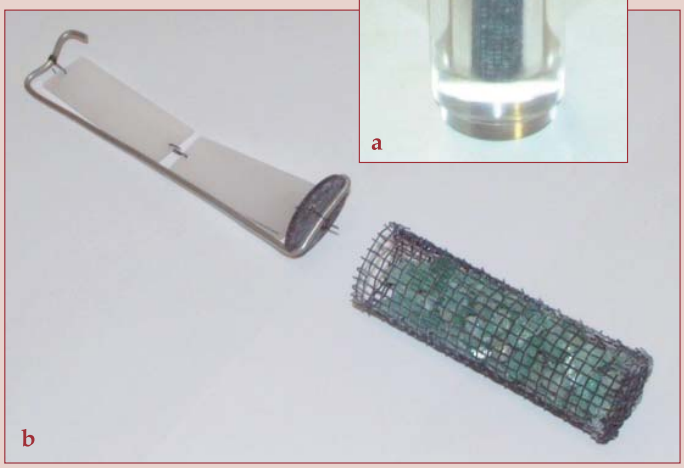

Figure 4 a, b: *A transparent autoclave model is used to demonstrate the arrangement of nutrient (below) and seed plates; components of colour-causing dopants and mineralizers are placed at the bottom of the autoclave (not shown). Courtesy of D. Fursenko.*

Figure 5: *A typical synthetic emerald crystal measures about 80 × 18 × 14 mm. Courtesy of D. Fursenko.*

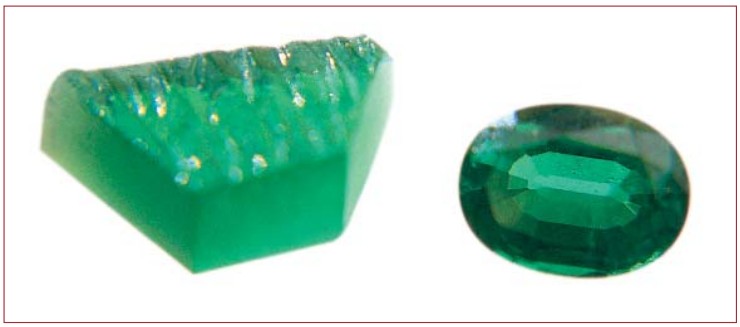

Figure 6: *Faceted and rough samples of the new type of Tairus hydrothermally-grown synthetic emerald coloured by vanadium and copper; rough crystal plate of 3.23 ct (12.7 × 6.6 mm), faceted stone of 1.16 ct (6.1 × 8.1 mm). Photo by M. Glas.*

Standard gemmological methods were used to determine refractive indices (RI), optical character, specific gravity (SG) and fluorescence under long- and short-wave ultraviolet (UV) radiation. Standard microscopic techniques were used to examine the internal features under different lighting conditions, both with and without immersion liquids. The orientation of growth planes and colour zoning was performed with a horizontal (immersion) microscope with a specially designed sample holder and specially designed eye pieces (to measure angles).

For chemical characterisation, we first submitted all ten samples for qualitative energy-dispersive X-ray fluorescence (EDXRF) analysis using a Tracor Northern Spectrace 5000 system. Quantitative chemical data for the four faceted samples were determined by electron microprobe using a Cameca Camebax SX 50 instrument. Traverses with 10 point analyses each were performed across the table facets of the four faceted gemstones. To obtain quantitative data for water and light elements (lithium and beryllium), slices were cut from two rough crystal plates and the powder obtained from these slices was used for wet chemical analyses. Lithium and beryllium contents were determined by atomic absorption spectroscopy (AAS), and the water content of the sample was analysed by Karl-Fischer titration.

Polarized UV-Vis absorption spectra (280 to 800 nm) from all ten samples were recorded with a Perkin Elmer Lambda 19 spectrophotometer. For the two samples for which the best orientation was obtainable (according to the determination of the optic axis by an immersion microscope combined with the results of UV-Vis spectroscopy), we also measured polarized absorption spectra in the near infrared (800 to 2500 nm; 12500 to 4000 cm^{-1}) with the Perkin-Elmer Lambda 19. Infrared spectroscopy in the mid-infrared range (4000 to 400 cm^{-1}) was performed using two different methods. For an overview of the complete range, a limited amount of powder was scraped from two rough samples for the preparation of KBr pressed pellets. For the measurement of polarized spectra in the mid-infrared, thin slices were sawn from two rough crystal plates with appropriate orientation (determined from immersion microscopy). These thin slices were polished to a thickness of about 0.3 mm to enable polarized measurement in the 4000 to 2000 cm^{-1} range (below 2000 cm^{-1} the thickness of these slices did not allow any reliable measurements). Both types of mid-infrared spectra were recorded using a Perkin Elmer FT-IR 1725X infrared spectrometer.

Solid particles on the rough surfaces of two synthetic-emerald crystals were analysed using an electron microprobe. For the identification of similar-appearing inclusions in one rough sample, this crystal was cut and polished in several steps until one of these inclusions was sufficiently exposed at the surface to enable an examination by electron microprobe and optical microscopy.

Results

Visual appearance and gemmological properties

All rough crystals had uneven, undulating surfaces parallel to the sawn plane (*Figure 7*), i.e. parallel to the original surface of the seed. This step-like surface consists of numerous faces of polycentrically growing synthetic emerald subindividuals. When examined with the unaided eye, all samples showed an intense, homogeneous, slightly bluish green colouration without any prominent colour zoning. The variation of colour within our ten samples was limited, indicating that these products came from an established production line.

Standard gemmological properties (*Table I*) show only small variation, and overlap those of natural emeralds from various localities, especially those of low alkali-bearing stones from Colombia. They are in the range commonly observed also for low iron-bearing or iron-free hydrothermally-grown synthetic emeralds.

Table I. *Gemmological properties of V-Cu-bearing Tairus synthetic emeralds*

Colour	Homogeneous, very slightly bluish green
Pleochroism	Parallel c: bluish green Perpendicular c: yellowish green
RI	n_o 1.576 – 1.578 n_e 1.570 – 1.571
Birefringence	0.006 – 0.007
SG	2.68 – 2.69
UV fluorescence	Short wave: inert Long wave: inert

Chemical composition and formula

The results of qualitative X-ray fluorescence analysis indicate that there are no major differences between rough crystal plates and faceted synthetic emeralds.

Figure 7: *Rough crystal plate of 7.52 ct the new type of Tairus hydrothermally-grown synthetic emerald coloured by vanadium and copper showing an uneven, undulating surface formed by numerous faces of subindividuals of synthetic emerald; size of plate about 16.5 × 7.5 mm, weight 7.52 ct. Photo by M. Glas.*

The results of microprobe analyses of four faceted samples are presented in *Table II*. In addition to the major components of beryl, Al_2O_3 and SiO_2, there are distinct amounts of vanadium and smaller percentages of chromium and copper. Traces of other transition metals and alkali elements are also present, while caesium, chlorine and fluorine were below the detection limit of the electron microprobe. Only a small variation within the three colour-causing trace elements, vanadium, chromium, and copper, was detected on traverses across the table facets of the cut synthetic emeralds (*Table III*).

Wet chemical analyses of powdered material from two samples showed the presence of distinct amounts of water and minor amounts of lithium (*Table II*). The values of Li_2O, BeO and H_2O did not show significant variation between the duplicate samples, so average values were used for the calculation of cation proportions and the crystal chemical formula, based on 36 oxygens, according to the general formula $Be_6Al_4Si_{12}O_{36}$ (see Deer *et al*., 1986).

Isomorphic replacement of Be, Al, and Si in the beryl structure has been discussed in numerous papers, and summaries are given by Shatskiy *et al*. (1981), Aurisicchio *et al*. (1988), Lebedev *et al*. (1988), and Sherriff *et al*. (1991). According to these authors, beryls are subdivided into two groups, one with predominant octahedral aluminium substitution and the other with predominant tetrahedral beryllium substitution.

Table II: *Chemical composition of V-Cu-bearing Tairus synthetic emeralds*

Microprobe analyses (average of 10 points on each emerald)				
Wt.%	A	B	C	D
SiO_2	64.91	64.62	63.81	64.45
TiO_2	0.01	0.01	0.01	0.01
Al_2O_3	18.22	18.03	18.11	18.30
V_2O_3	1.14	1.33	1.34	1.36
Cr_2O_3	0.03	0.04	0.04	0.04
Fe_2O_3*	0.01	0.03	0.01	0.01
MnO	0.01	0.01	0.01	0.02
NiO	0.01	0.02	0.01	0.01
MgO	0.01	0.01	0.01	0.01
CuO	0.13	0.10	0.09	0.12
Na_2O	0.02	0.02	0.03	0.02
K_2O	0.01	0.02	0.02	0.02
Cs_2O	bdl	bdl	bdl	bdl
F	bdl	bdl	bdl	bdl
Cl	bdl	bdl	bdl	bdl
Wet chemical analyses (average of two powder samples)				
Li_2O	0.26	0.26	0.26	0.26
BeO	13.50	13.50	13.50	13.50
H_2O	1.48	1.48	1.48	1.48
Sum microprobe and wet chemical analyses	99.74	99.49	98.74	99.60

*Total iron as Fe_2O_3. bdl = below detection limit

Number of ions based on 36 oxygens (excluding H_2O)				
Specimen	A	B	C	D
Si	11.888	11.875	11.816	11.834
Ti	0.002	0.002	0.002	0.001
Al	3.932	3.905	3.952	3.960
V	0.167	0.196	0.200	0.201
Cr	0.004	0.007	0.006	0.006
Fe	0.002	0.004	0.002	0.002
Mn	0.002	0.003	0.002	0.003
Ni	0.002	0.003	0.001	0.001
Mg	0.002	0.002	0.003	0.002
Sum Al octahedron	4.113	4.122	4.168	4.176
Cu	0.017	0.014	0.013	0.016
Be	5.941	5.960	6.006	5.955
Sum Be tetrahedron	5.956	5.974	6.019	5.971
Li	0.190	0.191	0.192	0.191
Na	0.005	0.008	0.009	0.007
K	0.003	0.005	0.005	0.005
Sum alkalies	0.198	0.204	0.206	0.203
H_2O	0.901	0.904	0.911	0.903

Average formula: $(Be_{5.96}Cu_{0.02}Li_{0.02})_6{}^{tet}(Al_{3.79}V_{0.21})_4{}^{oct}(Si_{11.85}Al_{0.15})_{12}{}^{tet}O_{36}(Li_{0.18}H_2O_{0.91})^{channel}$

Table III: Chemical variation of colour-causing trace elements in V-Cu-bearing Tairus synthetic emeralds

Microprobe analyses (ranges of 10 point analyses each, data in wt.%)				
Specimen	A	B	C	D
V_2O_3	1.09 - 1.21	1.24 – 1.41	1.30 – 1.40	1.30 – 1.43
Cr_2O_3	0.01 - 0.05	0.02 – 0.08	0.02 – 0.06	0.02 – 0.07
CuO	0.09 – 0.17	0.07 – 0.014	0.06 – 0.14	0.07 – 0.15

In octahedral sites in beryl, aluminium can be replaced by trivalent transition metals such as chromium, vanadium, and iron. Heterovalent isomorphic substitution is characterised by replacement of aluminium by divalent transition metals such as iron, manganese or by magnesium. For charge balance, alkalies enter channel sites of the beryl lattice and these substitutions can be summarised as follows:

Al^{3+}(octahedral) → Me^{3+}(octahedral) with Me^{3+} = V, Cr, Fe or

Al^{3+}(octahedral) → Me^{2+}(octahedral) + Me^{1+}(channel) with Me^{2+} = Mg, Fe, Mn and Me^{1+} = Li, Na, K, Cs

In tetrahedral sites, beryllium can be replaced by divalent transition metals such as iron or copper. Heterovalent isomorphic substitution is characterised by replacement of beryllium by lithium. For charge balance, alkalies enter channel sites of the beryl lattice:

Be^{2+}(tetrahedral) → Me^{2+}(tetrahedral) with Me^{2+} = Fe, Cu or

Be^{2+}(tetrahedral) → Li^{1+}(tetrahedral) + Me^{1+}(channel) with Me^{1+} = Li, Na, K, Cs

In the new type of Tairus synthetic emeralds, the major colour-causing trace elements are vanadium, chromium and copper, replacing aluminium on octahedral and beryllium on tetrahedral sites according to the following scheme (see spectroscopic properties and cause of colour):

Al^{3+}(octahedral) → V^{3+}(octahedral)

Al^{3+}(octahedral) → Cr^{3+}(octahedral)

Be^{2+}(tetrahedral) → Cu^{2+}(tetrahedral)

The results of chemical analyses show also a limited heterovalent isomorphic replacement of beryllium by lithium, because the sum of Be + Cu (sum Be tetrahedron in *Table II*) is slightly smaller than the theoretical value of 6 apfu (atoms per formula unit). For charge balance, lithium also enters channel sites of the synthetic beryls:

Be^{2+}(tetrahedral) → Li^{1+}(tetrahedral) + Li^{1+}(channel)

In addition, the traces of bivalent magnesium, iron or manganese on aluminium sites need charge compensation according to the following scheme:

Al^{3+}(octahedral) → Me^{2+}(octahedral) + Li^{1+}(channel) with Me^{2+} = Mg, Fe, Mn

The analyses of the Tairus synthetic emeralds also show a small but distinct silicon deficiency (Si apfu smaller than 12) and some excess aluminium (sum Al octahedron in *Table II* larger than 4 apfu). An isomorphic replacement of Al and Si has been discussed in several papers (see, for example, Shatskiy *et al.*, 1981; Schmetzer and Bernhardt, 1994). Considering the different possibilities discussed and the necessity of charge balance, the following coupled isomorphic replacement scheme is consistent with analytical data:

Si^{4+} (tetrahedral) → Al^{3+}(tetrahedral) + Li^{1+}(channel)

Lithium has a complex function:

a) it replaces beryllium in tetrahedral sites and
b) it enters channel sites as charge compensator
   - b1) for bivalent magnesium, iron or manganese on aluminium sites,
   - b2) for lithium on beryllium sites and
   - b3) for aluminium on silicon sites, which is the major fraction of the three.

The amount of lithium determined experimentally is in good agreement with this complex function.

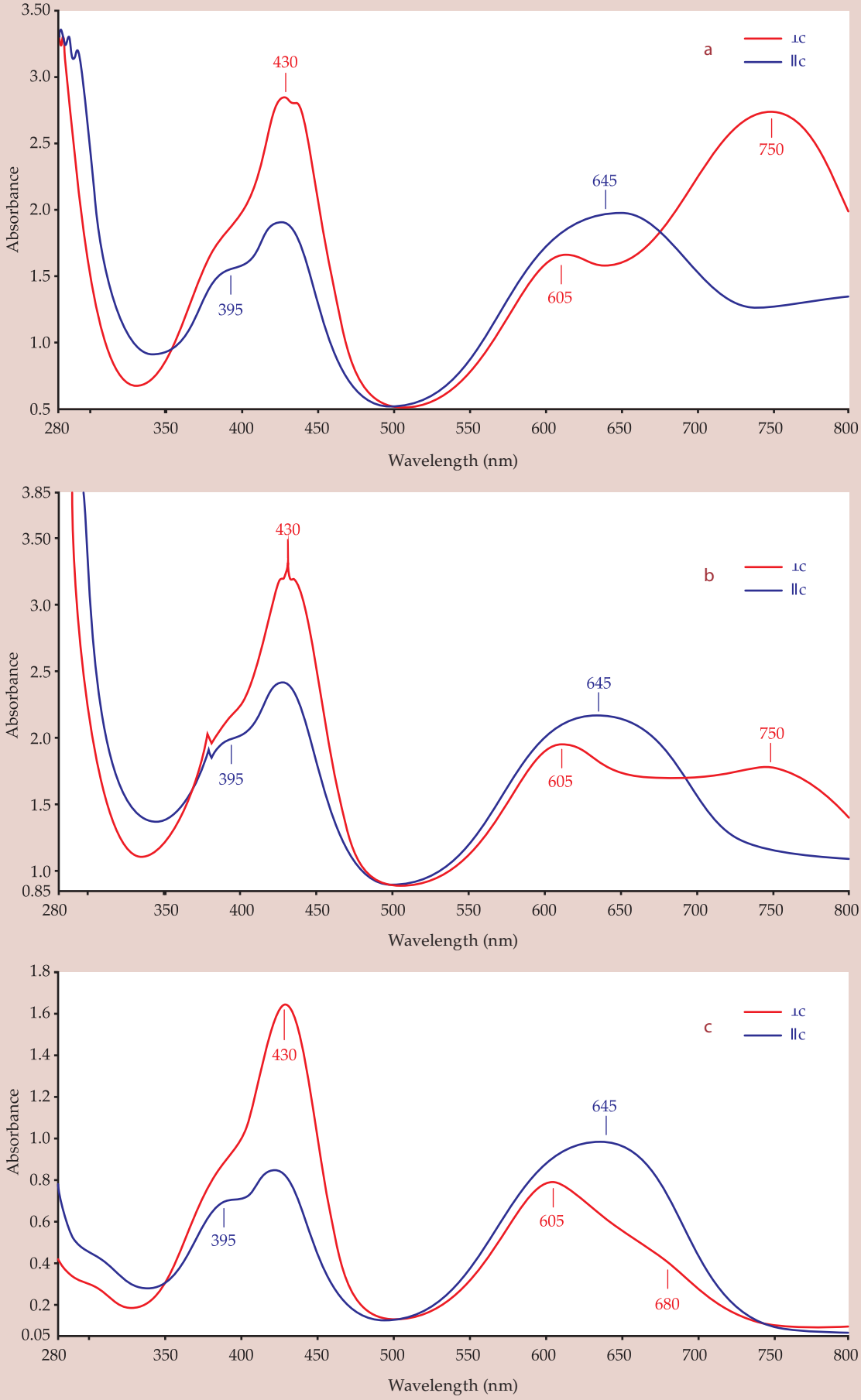

Figure 8: *Polarized absorption spectra of two samples of the new type of Tairus hydrothermally-grown synthetic emerald coloured by vanadium and copper (a,b) compared with the spectra of a vanadium-bearing hydrothermally-grown Biron synthetic emerald (c).*

Table IV: *Spectral features related to transition metals in Tairus synthetic emerald*

Absorption maximum (nm)	Polarisation E	Assignment
1180	⊥c	Cu^{2+} on tetrahedral Be^{2+} sites
920	‖c	
750	⊥c	
680 sh	⊥c *	Vanadium (?)
645	‖c	V^{3+} on octahedral Al^{3+} sites
605	⊥c	
430	⊥c >‖c	
395	‖c >⊥c	

sh = shoulder
* hidden by the Cu^{2+} band at 750 nm

As a result, the average crystal chemical formula for the four samples is calculated as given in *Table II*. The dominant isomorphic substitution in our Tairus synthetic emeralds is a replacement of aluminium by vanadium on octahedral sites. A heterovalent substitution of silicon by aluminium on tetrahedral sites with charge compensation by lithium on channel sites is also present.

Spectroscopic features of transition metals in beryl and cause of colour

Absorption spectra of samples of the new type of Tairus synthetic emerald (*Figure 8 a,b*) show numerous broad absorption bands in the UV-Vis-NIR range (*Table IV*). For an assignment of these absorption maxima, we have to consider the results of chemical analyses which indicate that the only significant colour-causing transition metals are vanadium and copper.

The position of absorption maxima at 1180, 920 and 750 nm is consistent with the spectra of copper-bearing hydrothermally-grown synthetic beryls (Solntsev *et al.*, 1976; Solntsev, 1981 a,b; Lebedev *et al.*, 1983, 1986; Rodionov *et al.*, 1987) and, consequently, these three broad absorption bands are assigned to Cu^{2+} on tetrahedral beryllium sites.

Absorption spectra of natural vanadium- and iron-bearing beryls from Brazil and Kenya (Wood and Nassau, 1968; Schmetzer, 1978, 1982) are similar, but not completely identical to absorption spectra of hydrothermally-grown synthetic vanadium- and iron-bearing or to synthetic vanadium-bearing, iron-free beryls (Beckwith and Troup, 1973; Solntsev, 1981 a,b; Lebedev *et al.*, 1983, 1986). The differences in the 350 to 450 nm range are partly understandable by an overlap of the absorption bands due to vanadium and those due to iron, mostly in natural samples. Differences in the 600 to 700 nm range, on the other hand, are not completely understood at present.

If we focus only on the vanadium-related absorption bands of the spectra of the new type of Tairus synthetic emerald, these are identical with the spectra of vanadium-doped beryl crystals grown through gas-transport reactions (Rodionov *et al.*, 1987) as well as with the spectra of a vanadium-bearing, chromium- and iron-free sample grown by the Biron company in Australia for research purposes (*Figure 8c*; note: samples of the commercial production of Biron normally contained similar amounts of both, chromium and vanadium, see, for example, analyses by Mashkovtsev and Smirnov, 2004).

Comparing the pure vanadium spectrum of the Biron sample, it is evident that our spectra of the Tairus synthetic emerald samples are due to a superimposition of a 'pure' vanadium and a 'pure' copper spectrum. Thus, the absorption bands at 645, 605, 430 and 395 nm (*Table IV*) are assigned to V^{3+} on octahedral aluminium sites. The assignment of an additional shoulder at 680 nm (see *Figure 8c*), which is seen in the spectra of various natural and synthetic vanadium-bearing samples (Wood and Nassau, 1968; Beckwith and Troup, 1973; Schmetzer, 1978, 1982; Rodionov *et al.*, 1987) is rather uncertain. This shoulder might be due to vanadium cations which are not in the trivalent state.

Compared to vanadium, the relative amounts of chromium are small. Under these circumstances, the absorption bands of chromium are hidden by the much stronger absorption bands of vanadium (see Schmetzer, 1978, 1982; Schwarz and Schmetzer, 2002).

The bluish-green colour of the new Tairus samples is consistent with a combination of the yellowish-green colouration of a vanadium-bearing synthetic beryl sample and the blue colour of a copper-bearing hydrothermally-grown beryl (*Figure 9*). It is evident, that the colour of the pure vanadium-bearing yellowish-green sample is shifted to the desired bluish-green 'emerald' colour by the influence of the copper dopant of the synthetic beryl.

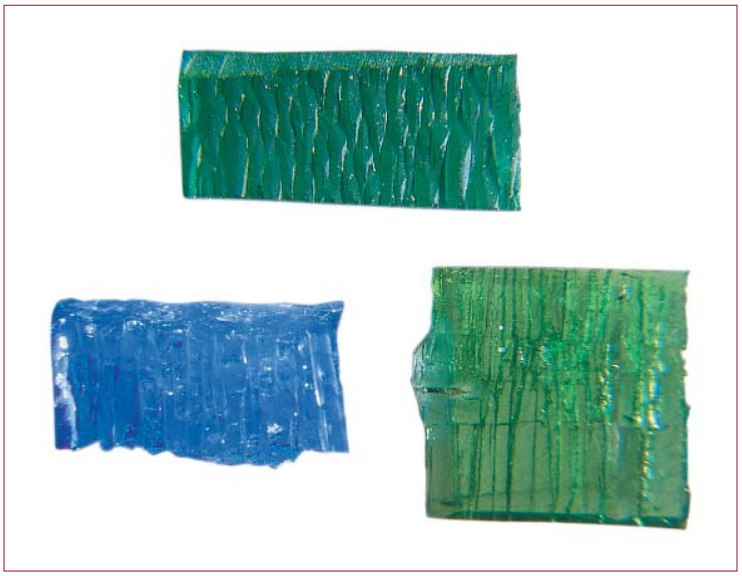

Figure 9: *The slightly bluish green coloration of the new type of Tairus synthetic emerald (top, 7.52 ct, 16.5 × 7.5 mm) is caused by superimposition of the light blue colouration of a synthetic copper-bearing beryl (below left) and the yellowish-green colouration of a synthetic vanadium-bearing beryl (below right); the copper- and vanadium-doped samples are Russian research samples obtained by one of the authors in the early 1990s. Photo by M. Glas.*

Infrared spectroscopy

Mid-infrared range (from 4000 to 400 cm^{-1})

The spectra of the KBr pellets prepared with the emerald powder (*Figure 10*) show two absorption bands at 3697 and 3595 cm^{-1}. These spectra are consistent with infrared powder spectra of chromium-, iron-, nickel- and copper-bearing Russian hydrothermally-grown synthetic emeralds as described by Schmetzer (1988; see also the references cited therein). This general type of spectrum is identical for both lithium- and sodium-bearing synthetic beryl crystals (Shatskiy *et al.*, 1981; Vladimirova *et al.*, 1987).

In the mid-infrared the fundamental vibrations of molecules in the channels of the beryl structure as well as lattice vibrations are present. In our samples, no absorption bands related to chlorine (in the 2500 to 3100 cm^{-1} range, Schmetzer *et al.*, 1997; Mashkovtsev and Solntsev, 2002; Mashkovtsev and Smirnov, 2004), to ammonium (in the 2500 to 3300 cm^{-1} range, Mashkovtsev and Solntsev, 2002; Mashkovtsev and Smirnov, 2004; Mashkovtsev *et al.*, 2004) or to CO_2 (at 2360 cm^{-1}, Wood and Nassau, 1967, 1968; Charoy *et al.*, 1996; Mashkovtsev and Smirnov, 2004) were observed.

Polarized spectra (*Figure 11*) show two strong absorption bands at 3695 and 3596 cm^{-1} and one weaker band at 3505 cm^{-1} (polarization parallel to *c*) as well as two doublets at 3684, 3675 cm^{-1} and 3605, 3593 cm^{-1}, a broad band at 3873 cm^{-1} and two weak bands at 3558 and 3505 cm^{-1} (polarization perpendicular to *c*). These spectra are identical with the spectra of chromium-, iron-, nickel- and copper-bearing Russian hydrothermally-grown synthetic emeralds grown for research purposes (Mashkovtsev and Lebedev, 1993) and with chromium-, iron-, nickel- and copper-bearing hydrothermally-grown synthetic emeralds of commercial Tairus production (Mashkovtsev and Solntsev, 2002; Mashkovtsev and Smirnov, 2004).

Using polarized infrared absorption spectra of alkali-bearing natural and alkali-free synthetic beryls and emeralds, two types of water molecules were characterized in channel sites of the beryl structure (Flanigen *et al.*, 1967; Wood and Nassau, 1967, 1968; Aines and Rossman, 1984). Type-I water molecules have their two-fold symmetry axis perpendicular to the *c*-axis of the beryl crystal and are not adjacent to alkali ions. Type-II water molecules have their two-fold symmetry axis parallel to the *c*-axis of the beryl crystal and are adjacent to alkali ions. Furthermore, comparing intensity ratios of the three main water absorption bands in the 3500 cm^{-1} to 3800 cm^{-1} range, it was concluded that one or more additional types of water

or hydroxyl group are present in beryl (Schmetzer, 1989; Schmetzer and Kiefert, 1990).

Subsequently, this general statement was confirmed by numerous researchers, but different assignments of various absorption bands in natural and synthetic alkali-bearing beryl and emerald samples have been given (Mashkovtsev and Lebedev, 1993; Aurisicchio *et al.*, 1994; Charoy *et al.*, 1996; Mathew *et al.*, 1997; Mashkovtsev and Solntsev, 2002; Mashkovtsev and Smirnov, 2004; Mashkovtsev *et al.*, 2004). In most cases, the doublets in the 3670 and in the 3600 cm^{-1} range are considered as overlaps of two different types of water maxima or as overlaps of water and hydroxyl bands.

In summary, we can conclude that the mid-infrared spectra of the new type of lithium-bearing hydrothermally-grown Tairus synthetic emeralds are due to three different types of water molecules or to two different types of water molecules and hydroxyl ions. The spectra are identical with those of older hydrothermally-grown synthetic beryls and emeralds (research samples and early commercial production) as well as with the spectra of previously produced types of synthetic emeralds grown by Tairus in Novosibirsk.

Near-infrared range (from 800 to 2500 nm; i.e. from 12500 to 4000 cm^{-1})

In the near-infrared numerous relatively broad to small absorption bands (*Figure 12*) are present in our samples. The two broad bands at 1180 and 920 nm have already been assigned to Cu^{2+} replacing Be^{2+} on tetrahedral lattice sites (see above).

In the spectrum with polarization E parallel *c* we observed absorption maxima at 1150, 1400, 1413, 1468, 1768, 1897, 2152 and 2460 nm; in the spectrum with E perpendicular to *c*, the absorption bands were found at 1366, 1410, 1420, 1430, 1835, 1898, 1961 and 2207 nm. Using the references cited above, all absorption bands are assigned to overtone and combination frequencies of both types of water and hydroxyl groups.

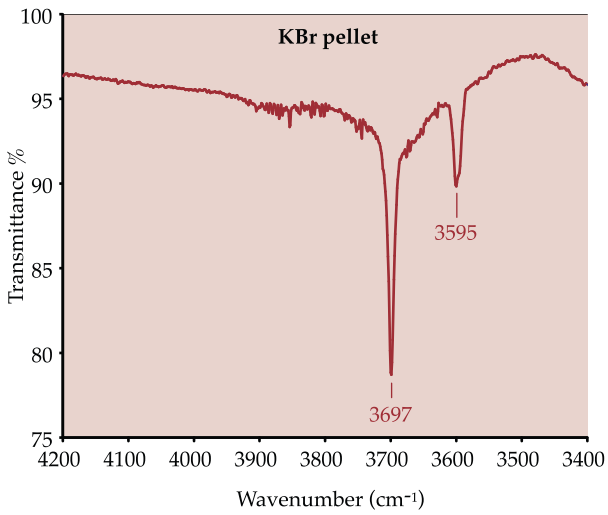

Figure 10: *Mid-infrared absorption spectra of synthetic emerald powder (KBr pellet technique) in the range of fundamental water vibrations show two dominant absorption bands at 3697 and 3595 cm^{-1} which were assigned to two different types of water molecules in the beryl structure.*

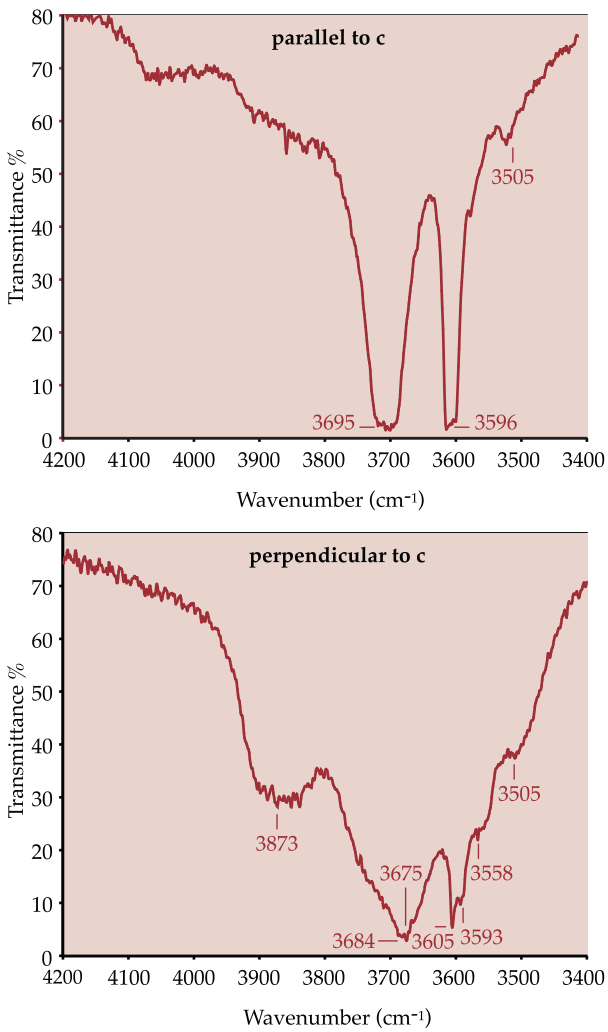

Figure 11: *Polarized absorption spectra of a 0.3 mm thick oriented crystal plate in the mid-infrared range showing numerous absorption bands of different types of water molecules and/or hydroxyl ions.*

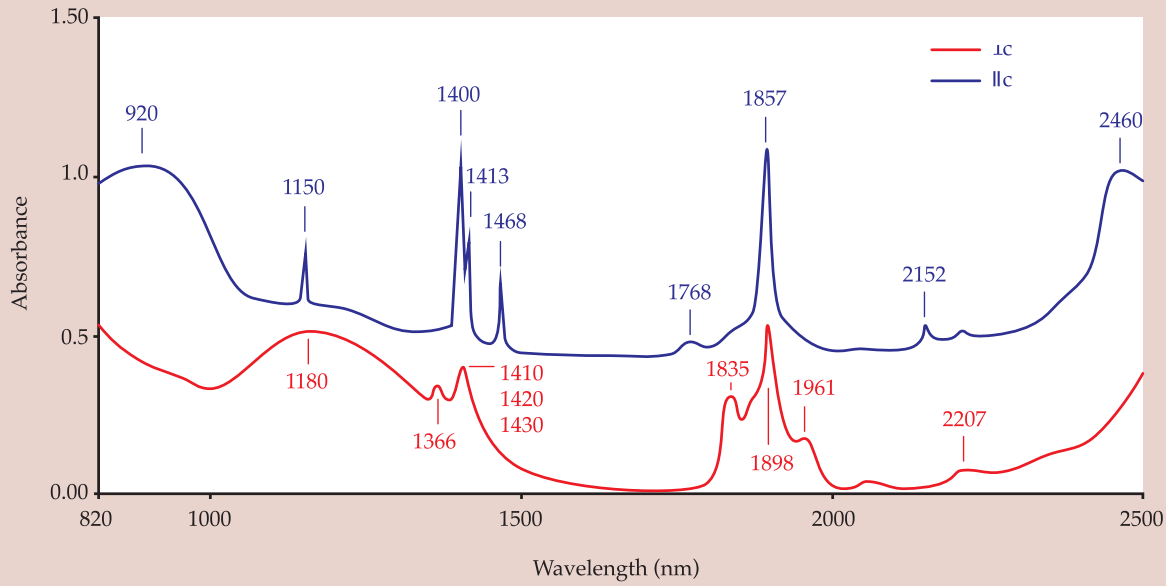

Figure 12: *Polarized absorption spectra in the near infrared showing two broad absorption bands due to copper at 1180 and 920 nm and numerous absorption bands of different types of water molecules and/or hydroxyl ions; the upper spectrum is vertically displaced for clarity.*

Microscopic characteristics

Structural properties

Neither rough nor faceted samples of the new type of Tairus hydrothermally-grown synthetic emerald showed residues of seed plates. All samples, however, contain step-like growth lines related to a weak colour zoning (*Figure 13*). In the rough samples, the sizes of the numerous steps within the growth lines increased from the sawn plane, which was next to the seed plate, towards the distant as-grown surface of the synthetic emerald crystal (*Figure 14*).

In both the rough and faceted samples, the angle between the step-like growth planes and the *c*-axis (representing the angle between seed plate and *c*-axis) was found to lie in a limited range between 28 and 30 . These results indicate that the synthetic emeralds were grown with seed plates cut with an angle to the *c*-axis slightly smaller than the characteristic angle of about 30 -32 which was for a long time used in growing synthetic emeralds in Russia (Schmetzer, 1988, 1996).

Almost perpendicular to the step-like growth lines, subgrain boundaries which are irregular and with a variety of orientations are present (*Figure 13, 14*). In one direction oblique to the step-like growth planes,

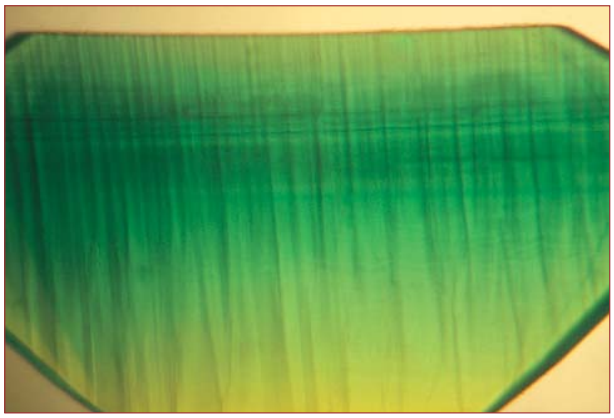

Figure 13: *Faceted Tairus hydrothermally-grown synthetic emerald coloured by vanadium and copper; with step-like growth lines and colour zoning, and irregular subgrain boundaries almost perpendicular to the growth and colour zoning. Immersion, 40×. Photo by K. Schmetzer.*

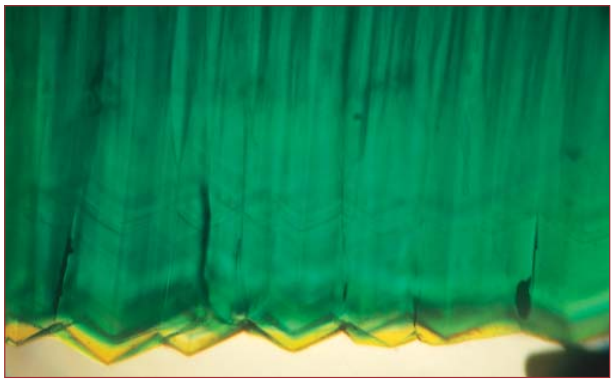

Figure 14: *Rough crystal plate with step-like growth lines and colour zoning, irregular subgrain boundaries almost perpendicular to the growth and colour zoning. Immersion, 40×. Photo by K. Schmetzer.*

Figure 15: *Faceted Tairus synthetic emerald showing block structure between subparallel oriented subindividuals. Immersion, 60×. Photo by K. Schmetzer.*

a characteristic block structure between subparallel oriented subindividuals is present (*Figure 15*). These microscopic features are characteristic for synthetic beryl and synthetic emerald, which is grown hydrothermally from seed plates cut oblique to the *c*-axis of the beryl crystal and non-parallel to possible natural faces of beryl (Klyakhin *et al*., 1981; Granadchikova *et al*., 1983; Lebedev and Askhabov, 1984; Lebedev *et al*., 1986; Schmetzer, 1988).

Inclusions

Most of our Tairus synthetic emeralds were extremely clean. In one crystal and on the surface of two rough synthetic emerald plates, there are tiny opaque crystals or lamellae with a metallic lustre (*Figure 16a*). The solids on the surface of the rough crystal plates were identified using the electron microprobe as native copper. For the identification of the solid inclusions within a synthetic emerald plate, the sample was cut and polished until an octahedral crystal with metallic appearance (*Figure 16b*) was exposed at the surface; this inclusion was also identified as native copper. Only a few synthetic emerald samples contain small feathers consisting of liquid and two-phase inclusions.

Discussion

The ten samples of the new synthetic hydrothermally-grown beryl variety marketed by Tairus as 'Colombian Color Emerald' examined in the present study, reveal only small variability in their gemmological, chemical and spectroscopic properties. These data indicate – as announced by the producer – that our research material comprised samples of a commercial product grown by a finally developed technical process (see crystal growth).

According to the orientation of step-like growth structures and colour zoning, the orientation of the seed (about 28 -30 inclined to the *c*-axis) is only slightly different from the 'traditional' orientation used in Russia for commercial crystal growth of various types of synthetic emerald (about 30 -32). A more

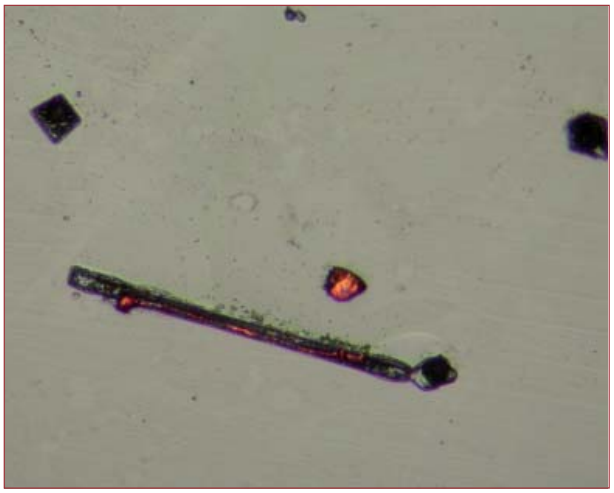

Figure 16a: *On the surface of two Tairus hydrothermally-grown synthetic emerald plates we observed several crystals or lamellae of metallic copper. Reflected light, size of the lamella about 300 µm. Photo by H.-J. Bernhardt.*

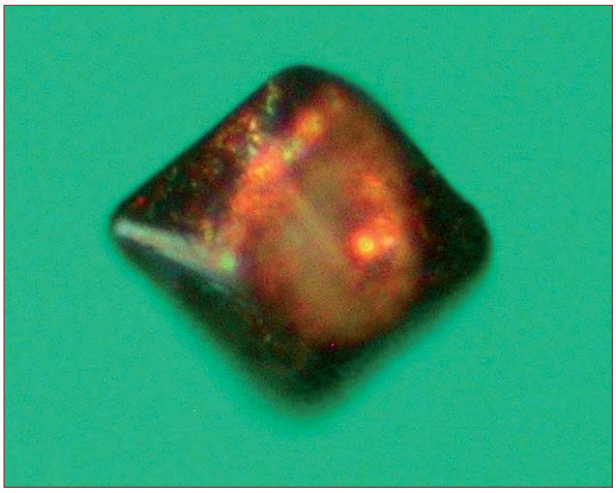

Figure 16b: *This octahedral copper crystal inclusion in a Tairus synthetic emerald was exposed at the surface after cutting and polishing of the sample. Reflected light, diameter of the crystal about 55 µm. Photo by H.-J. Bernhardt.*

Figure 17: *Different types of hydrothermally-grown synthetic emeralds; upper line left: Biron (Australia) synthetic emerald coloured by chromium and vanadium (1.49 ct, 7.9 × 6.4 mm), centre: Russian synthetic emerald coloured by chromium (grown in an autoclave with noble metal liner), right: Russian synthetic emerald coloured by chromium, iron, copper, and nickel (grown in an autoclave without noble metal liner); lower line: two samples of the new type grown by Tairus coloured by vanadium and copper. Photo by M. Glas.*

significant difference and the new scientific development in Novosibirsk is the formation and establishment of a growth medium in which both colour-causing trace elements, vanadium and copper, are incorporated in the required concentration as well as in the required valence state (mainly as V^{3+} and Cu^{2+}) into the beryl lattice. This suggests careful control of oxygen partial pressure in the autoclave, but, towards the end of the growth period, the partial pressure may change and enable the formation of native copper crystals both as inclusions and on the surfaces of crystals.

Gemmological properties of the material are in the range commonly observed for natural and hydrothermally-grown synthetic emeralds. Chemical and spectroscopic properties indicate that the synthetic beryls are coloured by a combination of vanadium and copper; chromium, which may derive from the natural colourless or slightly green beryl from the Ural mountains used as nutrient, is a very minor component. Infrared spectroscopy shows the presence of various types of water molecules and hydroxyl groups, partly related to lithium in channel sites in the beryl structure.

Although experimental samples coloured by vanadium (yellowish green) or by copper (light blue) have been known for several decades, the new product is the first example of a synthetic bluish green 'emerald colour' synthetic beryl whose colour is caused by a combination of vanadium and copper, i.e. without any significant influence of chromium. The desired 'Colombian type' colouration of the new material closely matches the colour of other hydrothermally-grown synthetic emeralds on the market, for example synthetic emeralds coloured by:
a) chromium,
b) vanadium and chromium, or
c) a combination of chromium, iron, copper and nickel (*Figure 17*).

The causes of colour and the definition of variously coloured natural and synthetic green beryls as 'emerald' was recently discussed by Schwarz and Schmetzer (2002). Considering that a practical definition of the term 'emerald' should include all materials accepted in general by the trade as emerald

without any need of a quantitative, time consuming chemical analysis (for example of chromium and/or vanadium contents in Colombian emeralds which show a great variability of chromium to vanadium ratios), the following suggestion was made: "Emeralds are yellowish green, green or bluish green, natural or synthetic beryls, which reveal distinct chromium and/or vanadium absorption bands in the red and blue-violet ranges of their absorption spectra." Using this practical suggestion, the new material from Tairus is designated as synthetic emerald. The colour of the material underlines this designation, even if no distinct amounts of chromium are present in the synthetic beryls.

The distinguishing of the new type of Tairus synthetic emeralds from other emeralds can be carried out by microscopic examination on the basis of typical growth features such as step-like growth lines confined to colour zoning, irregular subgrain boundaries, and block structures between subparallel oriented subindividuals. In certain circumstances, spectroscopic and/or chemical data might also be helpful.

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The identification value of the 2293 cm^{-1} infrared absorption band in natural and hydrothermal synthetic emeralds

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Abstract: *Where ordinary gemmological tests fail to reveal the identity of a gemstone Fourier-Transform Infrared Spectroscopy (FTIR) can often provide the answer. Ways of distinguishing natural from synthetic emeralds of various types have been concentrated in the spectral region between 2240-2400 cm^{-1}, where many more- or less-strong absorptions are observed. Amongst these, the presence of a small absorption near 2293 cm^{-1} has been utilized by many authors to indicate a natural emerald since this absorption had not been found in synthetics.*

However, now a Russian Tairus hydrothermal synthetic emerald has been found which shows the 2293 cm^{-1} absorption, so this feature can no longer be used to prove a natural origin.

Keywords: *gem-testing, IR spectroscopy, synthetic emerald*

Introduction

Recently, the author was preparing a lecture on beryl and while dealing with emeralds, natural and synthetics, expected to describe a straightforward example of an FT-IR separation between a natural Gachalá (Colombia) emerald and a synthetic hydrothermal Tairus emerald. However, a synthetic Russian Tairus hydrothermal emerald of 2.01 ct (*Figure 1*) from my collection showed the 2293 cm^{-1} absorption not normally seen in hydrothermal synthetic emeralds (Stockton, 1987; Koivula *et al.*, 1996; Zecchini and Maitrallet, 1998).

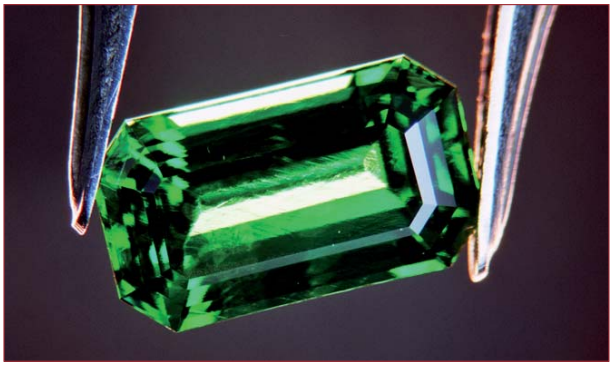

Figure 1: *Hydrothermal synthetic emerald grown by Tairus in 1996. It is emerald cut, weighs 2.01 ct, shows apparent turbidity and has an infrared absorption band at 2293 cm^{-1}.*

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Gemmological properties

The emerald-cut transparent synthetic Russian Tairus hydrothermal emerald, measured with a Mitutoyo micrometer, was 9.60 5.60 mm with a depth of 5.12 mm. The weight on a Mettler PL 300C carat scale was 2.01 ct.

The refractive index (RI) determinations were carried out using a Rayner Dialdex refractometer and monochromatic sodium light. The indices obtained from the table facet were ω = 1.582, ε = 1.575, giving a birefringence of 0.007, with optic sign negative. The uniaxial interference figure, obtained using a glass sphere between crossed polars, indicated that the *c*-axis was nearly parallel to the table facet and slightly inclined to the short axis (width) of the table. These characteristics overlap those reported for natural emeralds (Anderson, 1980; Nassau, 1980; Sinkankas, 1981; Kane and Liddicoat, 1985; Webster, 1994).

Under a calcite dichroscope, with fibre optic illumination, a strong dichroism in yellowish green (ω ray) to bluish green (ε ray) was observed through the table facet. This is consistent with the behaviour of other natural and hydrothermal synthetic emeralds reported in the literature.

The absorption spectrum observed through the pavilion, in daylight conditions with a Beck spectroscope, revealed a typical absorption spectrum for emerald (either natural or synthetic) with bands at 400-460, 580-600, 640, 670 and 680-700 nm.

The stone was examined with a Multispec combined LW/SW ultraviolet unit and as with many natural emeralds and other synthetic hydrothermal emeralds from other sources, remained inert to SW (254 nm) and LW (365 nm).

The specific gravity (SG) was obtained by hydrostatic weighing in distilled water using a Mettler PL 300C carat scale, and the stone was found to have a value of 2.70; this was

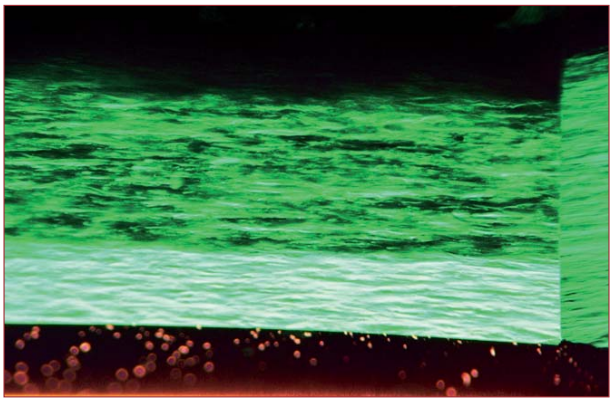

Figure 2: *Turbidity is very apparent in hydrothermal emeralds, and particularly in a probable Russian sample, of 2.62 carats (dark-field illumination 15x).*

Figure 4: *Characteristic chevron pattern is clearly visible in the 2.01 ct emerald cut hydrothermal Russian synthetic emerald (dark-field illumination 25x).*

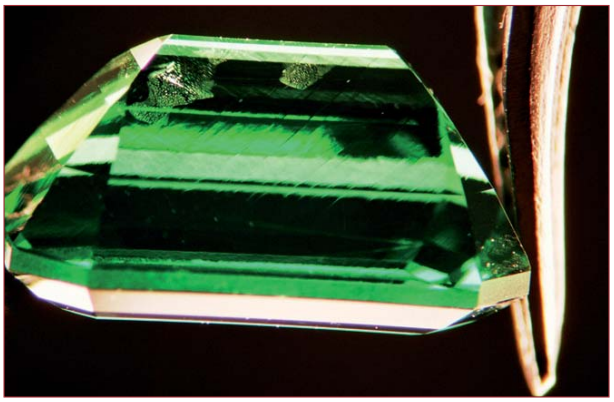

Figure 3: *Strong parallel growth pattern was readily observed under the microscope in the 2.01 carat emerald cut hydrothermal Russian synthetic emerald. Also note the 'fingerprints' lying near the culet (dark-field illumination 10x).*

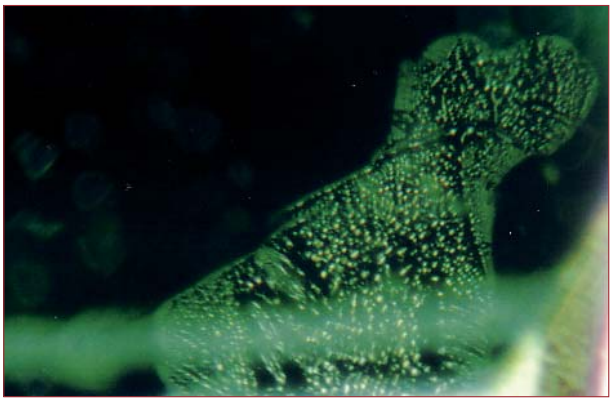

Figure 5: *Very few 'fingerprints' consisting of tiny two-phase inclusions, were observed under the microscope in the 2.01 ct emerald cut hydrothermal Russian synthetic emerald (dark-field illumination 20x).*

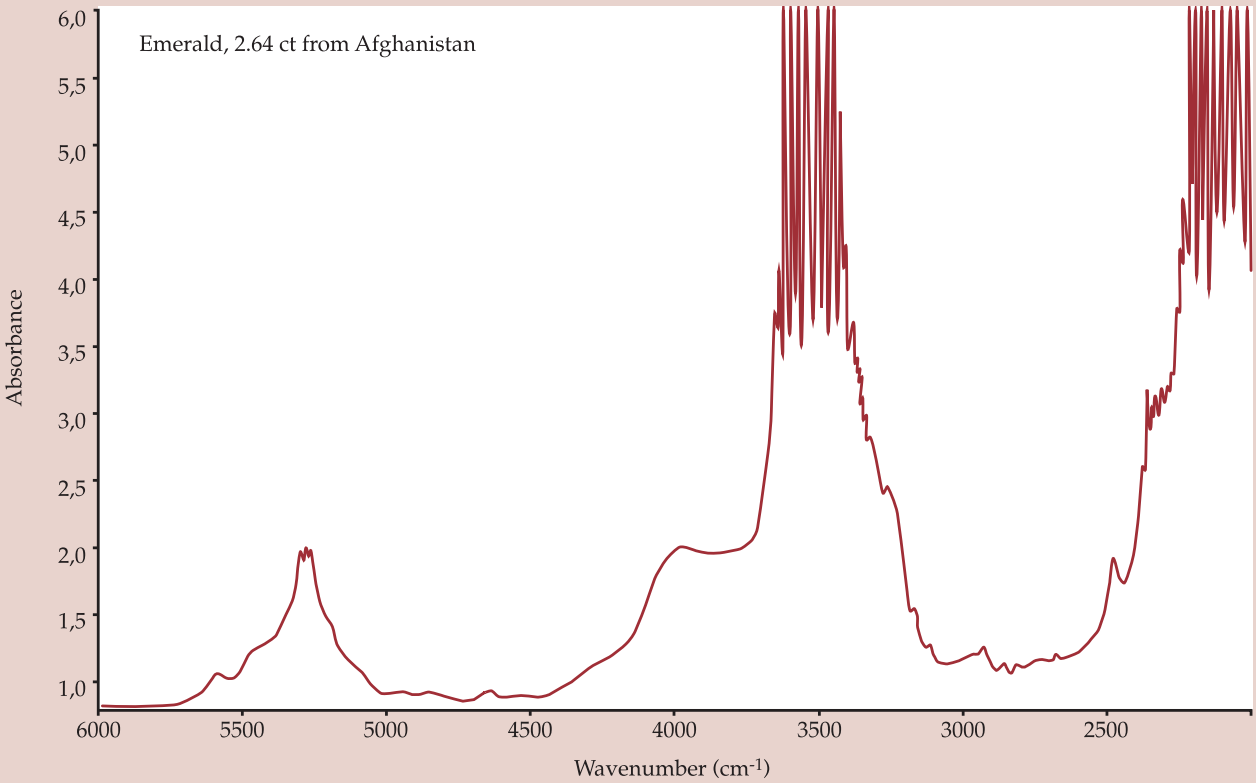

Figure 6a: *Infrared spectrum characteristic for most natural emeralds, here recorded from a 2.64 ct emerald from Afghanistan.*

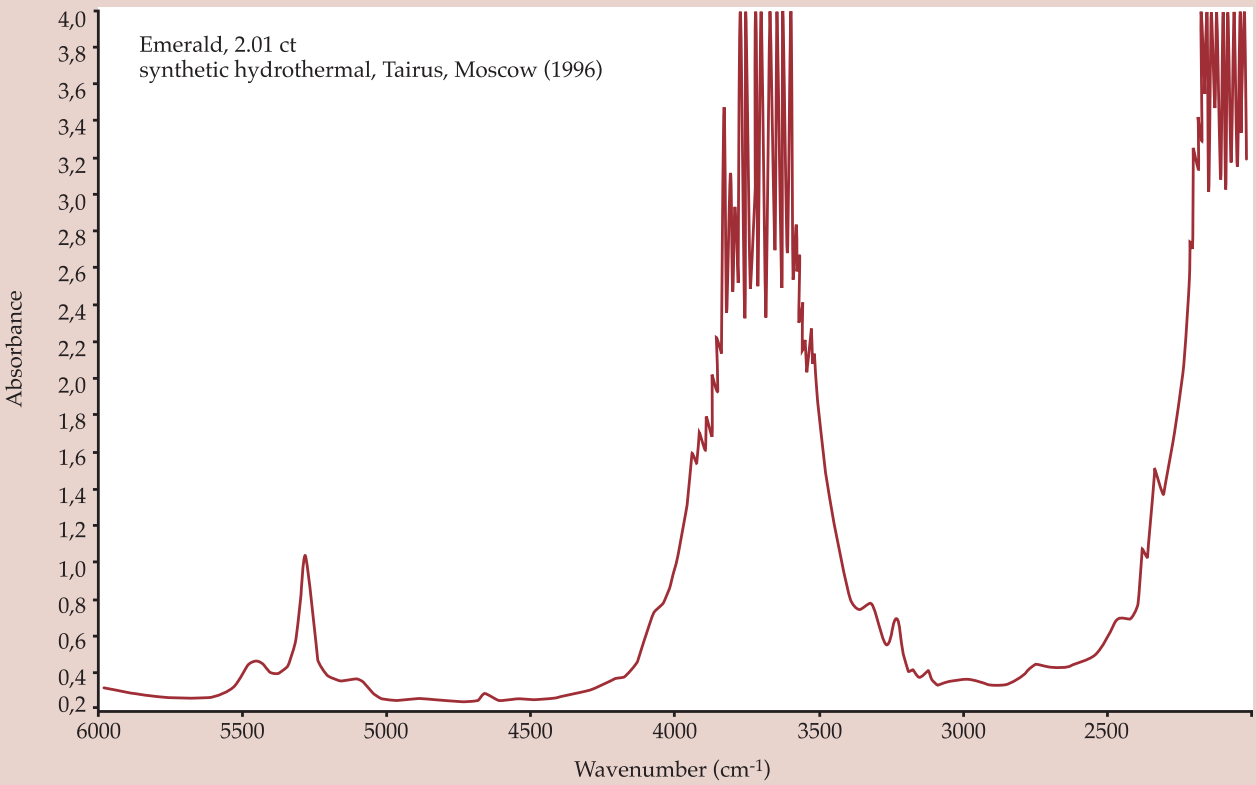

Figure 6b: *Infrared spectrum typical of hydrothermal synthetic emeralds shown by a Tairus emerald of 1996.*

confirmed when the stone sank slowly in the 2.67 heavy liquid. These values overlap those of natural emeralds and hydrothermal synthetic emeralds from other sources.

Under a Bausch & Lomb Mark V Gemolite binocular microscope using dark field illumination or overhead lighting as appropriate, no foreign inclusions were observed, but as in all the hydrothermal synthetic beryls (aquamarines and emeralds) examined by the author, the stone showed strong turbidity similar to that in another stone shown in *Figure 2*, with a distinct series of parallel growth planes (*Figure 3*), a characteristic chevron-like growth pattern (*Figure 4*) and some beautiful fingerprint-like patterns, one notably consisting of tiny two-phase inclusions resembling a dog's face (*Figure 5*) in the culet region of the stone. These characteristics are not found in natural emeralds, but are in line with those mentioned for hydrothermal Russian synthetic emeralds (Schmetzer, 1996; Koivula *et al.*, 1996; see also Schmetzer *et al.*, 1997).

Infrared spectroscopy

Infrared absorption spectra (FTIR) were obtained using a Fourier-Transform Nicolet Magna-IR ESP System 560 spectrometer.

Typical spectra for natural emeralds show strong absorptions around 2000-2300 cm^{-1}, a series of peaks between 2300-3300 cm^{-1} (their number and magnitude vary according to the crystallographic orientation of the stone tested), strong absorptions in the mid-infrared (due to their water content) around 3400-4000 cm^{-1}, series of peaks between 4100-5000 cm^{-1}, and intense absorption around 5000-5500 cm^{-1}, again due to water content.

This last absorption around 5000-5500 cm^{-1} often gives some clue as to whether the emerald is natural or hydrothermal synthetic. Indeed, independent of their geographical origin, the great majority of natural emeralds show a more or less triangular-shaped absorption band around 5000-5500 cm^{-1} (*Figures 6a* and *8*).

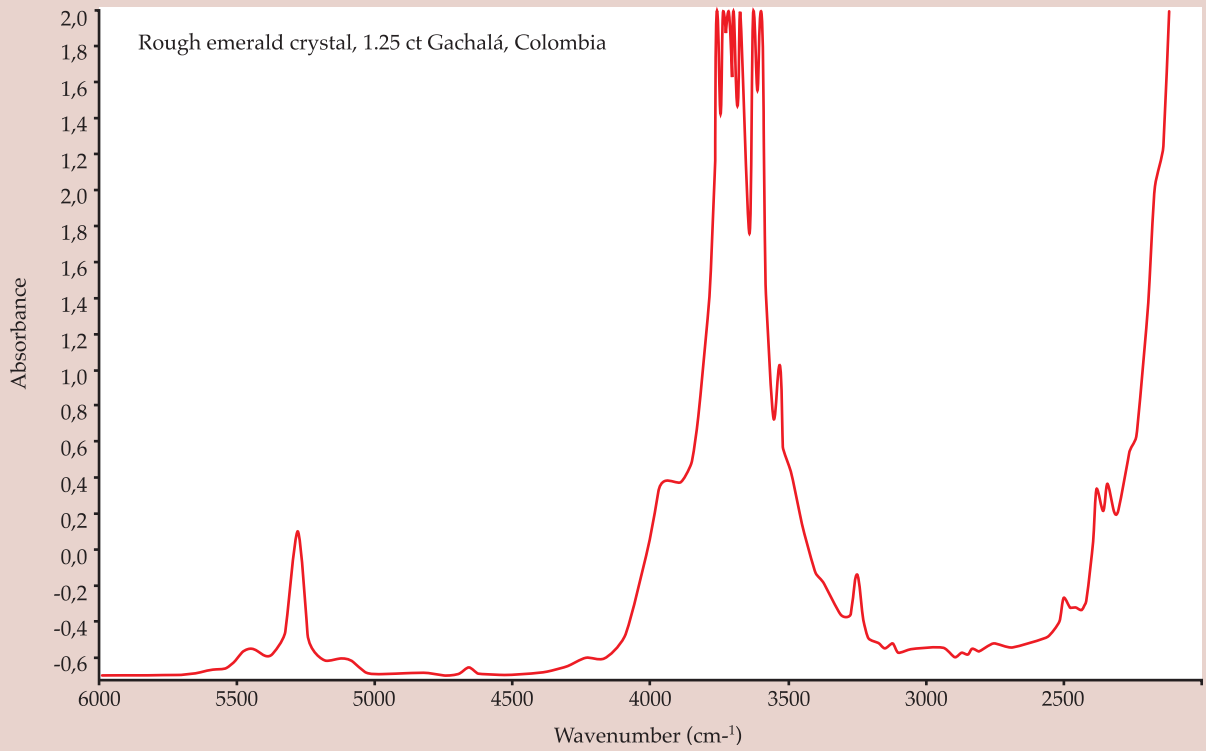

Figure 7: *Very similar infrared spectrum to the one displayed by hydrothermal synthetic emeralds, here observed in a natural emerald from Gachalá (Colombia).*

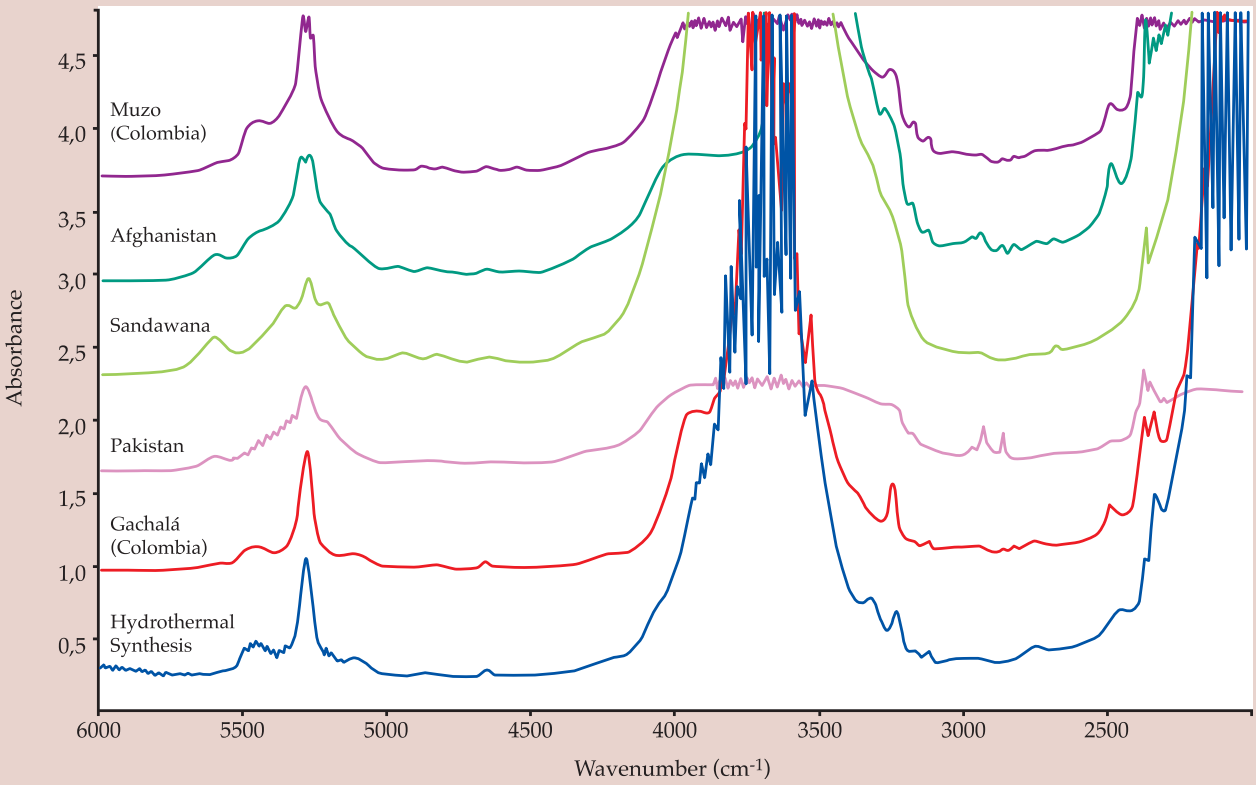

Figure 8: *Typical infrared absorption bands in natural emeralds from different sources compared with the one shown by the Russian hydrothermal synthetic emerald of 2.01 ct. Note the similar aspect of the absorption band near 5000-5500 cm^{-1} for both Gachalá (Colombia) emeralds and the hydrothermal synthetic emerald.*

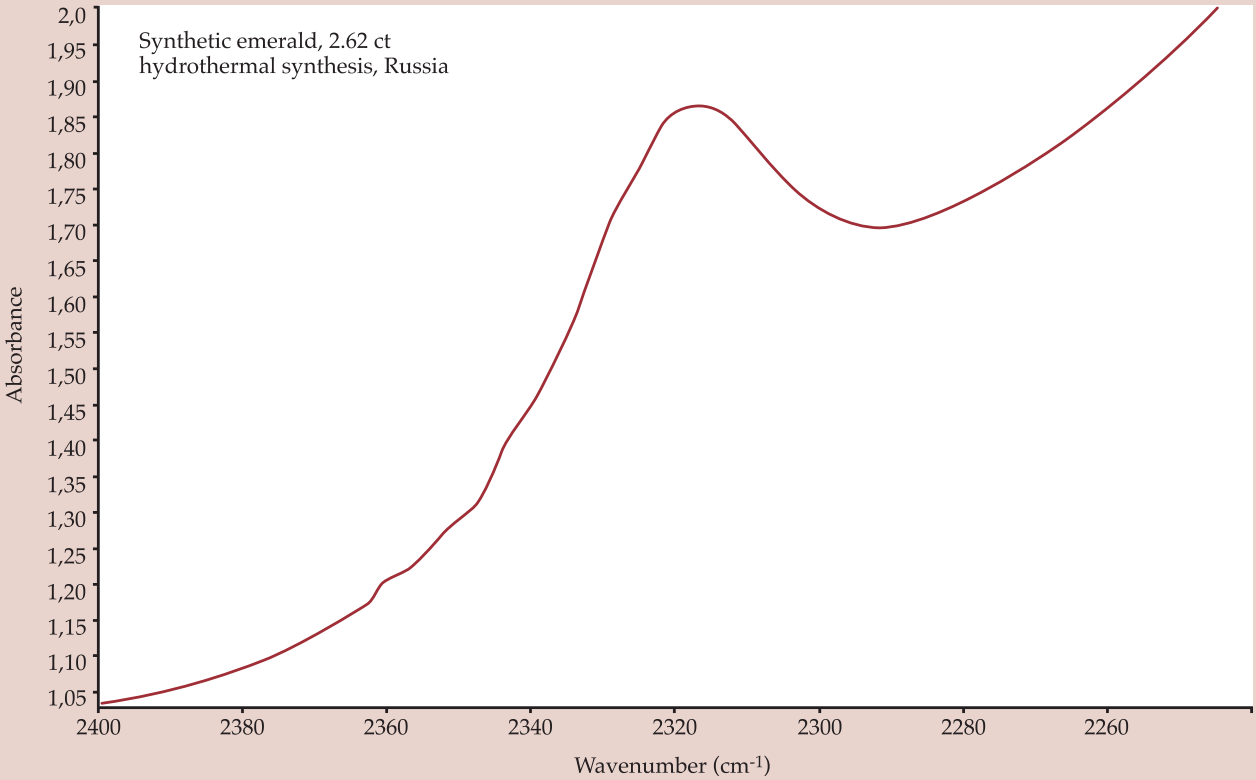

Figure 9: *Many synthetic hydrothermal emeralds can be separated from Gachalá (Colombia) emeralds when they do not show the 2293 cm^{-1} absorption band.*

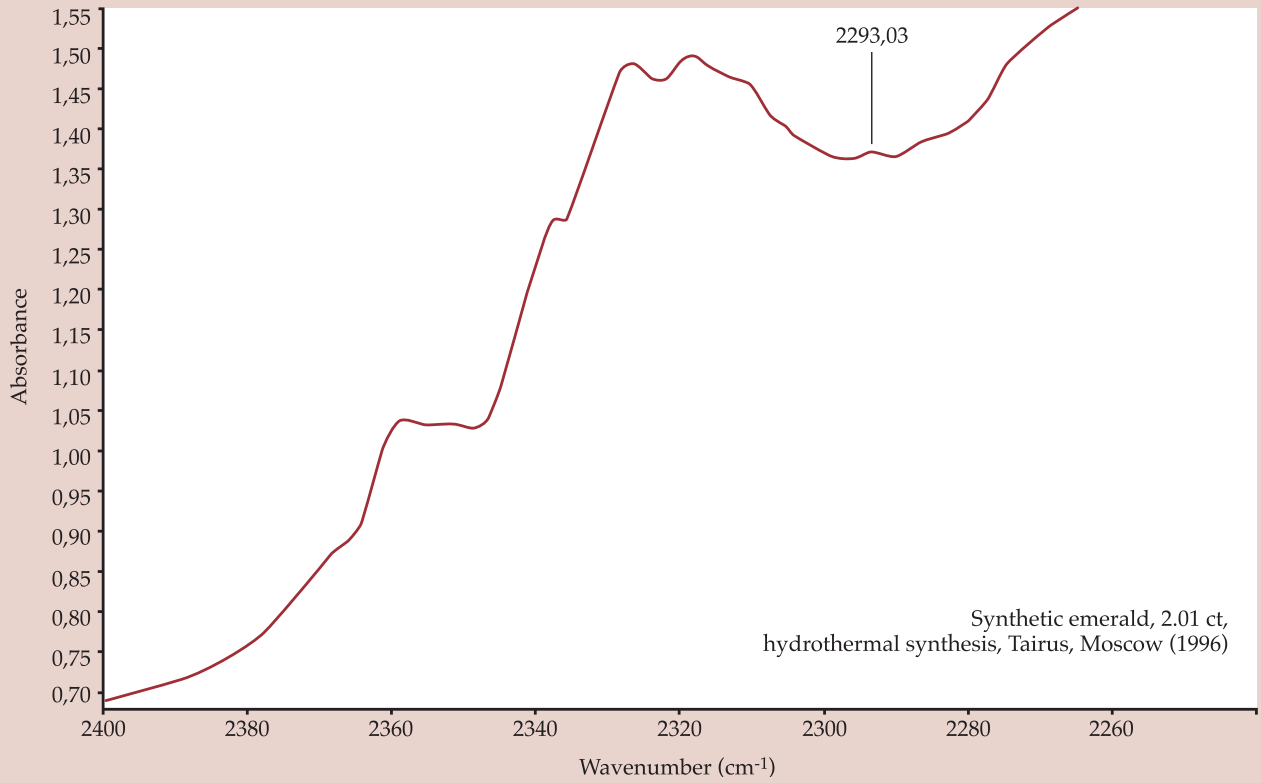

Figure 10a: *The 2.01 ct synthetic Russian Tairus hydrothermal emerald exhibiting a 2293 cm^{-1} absorption band which is also present in natural emeralds.*

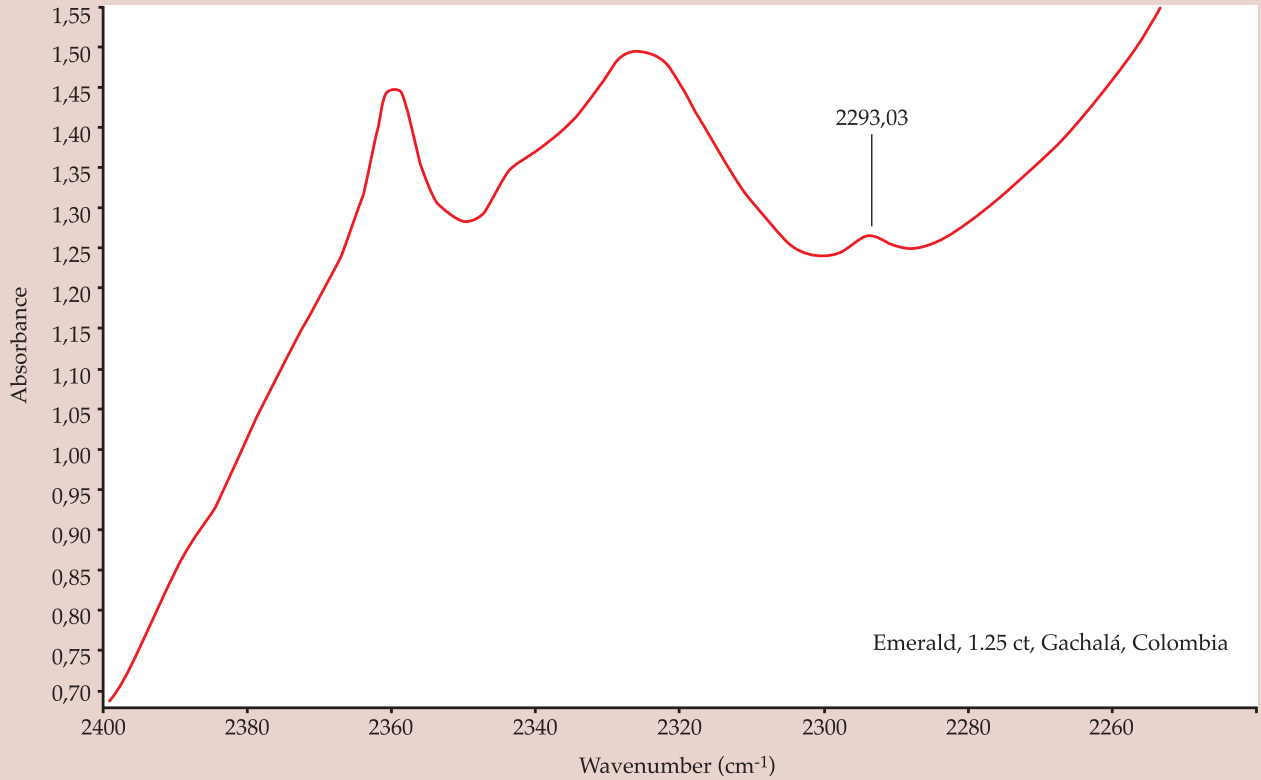

Figure 10b: *Emeralds from Gachalá (Colombia) show the 2293 cm^{-1} absorption band.*

Hydrothermal synthetic emeralds often show similar absorption spectra to the one described for natural emeralds, but instead of a triangular-shaped absorption band around 5000-5500 cm^{-1}, the main peak is found between two round absorptions (*Figures 6b* and *8*).

Unfortunately, natural emeralds from Gachalá (Colombia) show very similar spectra (*Figures 7 and 8*), and therefore cannot be separated on this basis from their hydrothermal synthetic sisters.

Hitherto, hydrothermal synthetic emeralds have been indicated by the absence of a peak at 2293 cm^{-1} (*Figure 9*). So it was a surprise when the 2.01 ct synthetic Tairus hydrothermal emerald, like the natural emeralds, displayed the peak at 2293 cm^{-1} (*Figure 10*).

Finally, the presence of two minute peaks at 4052 cm^{-1} and 4375 cm^{-1} (*Figure 11*) indicate that this stone is synthetic as they have not been found in natural emeralds (Fritsch, *pers. comm.*, 2005).

Conclusion

On one hand, the standard gemmological properties, such as refractive index (RI), dichroism, absorption spectrum, UV fluorescence and specific gravity, confirm that the stone is emerald, but they are of no help in distinguishing natural from synthetic.

On the other hand, the strong turbidity, the characteristic chevron-like growth pattern, and the shapes of the 'fingerprint' inclusions, indicate a synthetic hydrothermal emerald.

So, although infrared spectroscopy was unnecessary to separate this synthetic hydrothermal emerald from its natural counterparts, it confirmed that the minute peaks at 4052 cm^{-1} and 4375 cm^{-1} were significant indicators of origin and cast doubt on using the presence or absence of the 2293 cm^{-1} peak to say that an emerald is natural or synthetic respectively.

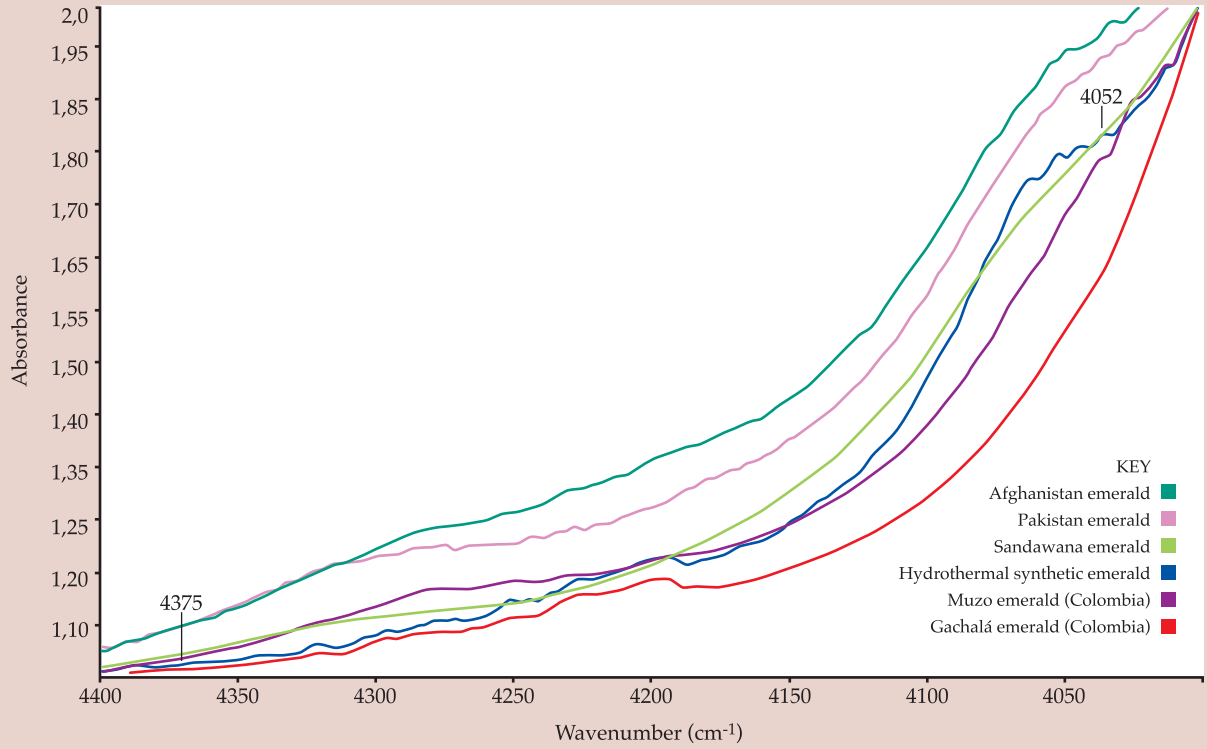

Figure 11: *Natural emeralds can be distinguished from hydrothermal synthetics by the absence of the 4052 cm^{-1} and 4375 cm^{-1} absorption bands.*

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Surface coating of gemstones, especially topaz – a review of recent patent literature

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Abstract: *Different methods of surface coating of gem materials are reviewed with respect to various patent documents published recently. In addition to the longer known techniques of simple sputtering and dye-coating, two different types of coating processes are used: first, heat treatment of a faceted gem in contact with a transition metal-bearing powder, and secondly deposition of a coating on the facets of a sample and subsequent heat treatment of the coated stone. The reaction mechanisms, nomenclature and recognition of treated stones are discussed.*

Introduction

Various types of surface-treated topaz have been seen in the gem market and described by different authors (see, for example, Millington, 2005). One major treatment process, producing pink, orange and red coloration, was characterized as a simple coating of the faceted stone with an easily removable dye layer. In contrast, a cobalt-bearing layer on another type of treated green, blue-green and blue topaz was more resistant to a simple scratching test (see, for example, Johnson and Koivula, 1998; Underwood and Hughes, 1999). Due to the lack of technical information describing the exact production processes, there was speculation about a possible 'diffusion' mechanism of this coloured layer into the surface of faceted colourless topaz samples (McClure and Smith, 2000). Schmetzer (2001) cited the first technical information from patent documents about the production process of green, blue-green, and blue surface-treated topaz as published in the international patent application WO 98/48944 A1 and in the American patent US 5,888,918, both by R. Pollak (documents 3 and 4 in *Table I*). According to these descriptions, the faceted topaz samples are heat treated within a finely divided powder of cobalt metal or cobalt oxide.

Such or similar treated stones have even found their way not only onto the markets of gem consuming but also into the trade of gem producing countries such as Nigeria (see, for example, Krzemnicki, 2002; *Figure 1*) and, in the opinion of the present author, understanding the technical procedure of treatment mechanisms is essential for correct nomenclature of treated gems. In addition, detailed knowledge of treatment processes is one of the key features for the recognition of treated samples and for their distinction from untreated gem materials. Thus, the present review briefly summarises the contents of different patents related to surface treatment of gem materials, and especially of topaz.

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Table I: *Patent documents describing surface treatment of gem materials, especially topaz**

Document/patent family**	No.	Issued	Inventor/applicant	First step of treatment	Coating/diffusion material	Colours (examples)	Remarks
WO 96/06961 A1 US 6,197,428 B1	1 2	7.3.1996 6.3.2001	Rogers/Deposition Sciences, CA, USA	Chemical vapour deposition or sputtering or others	Various oxides or plastics	Golden orange in transmission and blue in reflection or green in transmission and silvery pink in reflection	Alternating layers with high and low refractive indices creating an interference filter
WO 98/48944 A1 US 5,888,918 US 6,376,031 B1 US 2002/0174682 A1 EP 1 017 504 B1 DE 698 17 380 T2	3 4 5 6 7 8	5.11.1998 30.3.1999 23.4.2002 28.11.2002 20.8.2003 24.6.2004	Pollak/Pollak, Encinitas, CA, USA	Contact heat treatment with powder	Cobalt metal or cobalt oxide, optional: additional metals or metal oxides	Blue, blue-green, green-blue, green	Additional heat treatment after coating is possible
US 5,853,826	9	26.12.1998	Starcke *et al.*/Azotic Coating Technology, Rochester, Minn., USA	Sputtering or chemical vapour deposition or physical vapour deposition or others	Thin coating of the pavilion of a stone with one or several thin layers, especially Ti, TiO_2, Zr, ZrO_2, also other metals, metal oxides, nitrides, sulfides and carbon	Green to violet (at different angles)	Various reflection and interference phenomena are observed when viewed at different angles of observation
EP 0 888 730 A1 US 5,981,003 US 6,146,723	10 11 12	7.1.1999 9.11.1999 14.11.2000	Arends/Fitness Innovations & Technologies, Chester, N.J., USA	Adhering coloured ink to the surface, drying	Transparent ink including a dye	Red, blue, green, yellow	Removable coating
BR 2000-1034 A	13	27.11.2001	Soares Sabioni *et al.*/Soares Sabioni, Ouro Preto, Minas Gerais, Brazil	Contact heat treatment with powder	Mixtures of topaz powder and metal powder or metal oxide powder or metal salt powder	Blue (cobalt)	a. Preparation of mixture of powder b. heat treatment of mixture c. diffusion by contact heat treatment with powder; repeated treatment with different metals is possible

Document/patent family**	No.	Issued	Inventor/applicant	First step of treatment	Coating/diffusion material	Colours (examples)	Remarks
BR 2000-2321 A	14	30.4.2002	Soares Sabioni and Mendonça Ferreira/Soares Sabioni, Ouro Preto, Minas Gerais, Brazil	Vacuum sputtering	Transition metal	Yellow to reddish orange (iron)	a. deposition of transition metal coating to crown or pavilion b. heat treatment of coated stone
US 2002/0128145 A1 US 6,635,309 B2	15 16	12.9.2002 21.10.2003	Pollak/Pollak, Encinitas, CA, USA	Contact heat treatment with powder	Copper metal or copper oxide, optional: additional metals or metal oxides	Yellow to red	Iron can produce similar colours; additional heat treatment after coating is possible
US 2003/0008077 A1 EP 1 394 293 A1 US 6,872,422 B2	17 18 19	9.1.2003 3.3.2004 29.3.2005	Gupta and Goyal/Gupta and Goyal, Jaipur, Rajasthan, India	Chemical vapour deposition or physical vapour deposition or others	Metals, metal oxides, metallic compounds, alloys	Blue, green (cobalt); yellow, reddish yellow, orange, pinkish yellow (iron); green (chromium); blue (cobalt and chromium); blue to green (cobalt and nickel); imperial (iron and chromium and nickel)	a. deposition of coating to the faceted stone b. heat treatment of coated stone
DE 102 15 141 A1	20	16.10.2003	Anonymous/Meelis, Idar-Oberstein, Germany	Spraying	Iron oxide	Yellow-orange	a. deposition of coating to the faceted stone b. heat treatment of coated stone
RU 2 215 454 C1	21	10.11.2003	Balitsky *et al.*/Institute of Experimental Mineralogy RAS, Chernogolovka, Moscow district, Russia	Sputtering	Iron	Yellow to yellow-orange or orange	a. deposition of coating to the faceted stone b. heat treatment of coated stone
RU 2 215 455 C1	22	10.11.2003	Balitsky and Balitskaya/ Institute of Experimental Mineralogy RAS, Chernogolovka, Moscow district, Russia	Contact heat treatment with powder	Cobalt oxides and zinc oxide	Dark blue	Cobalt of various valence states
US 2004/0083759 A1	23	6.5.2004	Starcke *et al.*, Rochester, Minn., USA	Sputtering or chemical vapour deposition or others	Any dielectric material, e.g. oxide, nitride, carbide, sulphide, with dopant	Yellow (titania and vanadium oxide); blue (silica and cobalt oxide)	Additional heat treatment after coating is possible or necessary

* patent documents are sorted in patent families (i.e., groups of patent documents with similar contents related to the same inventor or applicant, frequently based on the same priority application); patent families are presented chronologically according to the first member of a patent family published

** Abbreviations: BR Brazil; DE Germany; EP Europe; RU Russia; US United States of America; WO World Intellectual Property Organization

Figure 1: *This surface-coated topaz is coloured by a thin iron-bearing layer on the pavilion of the stone; similar stones have been offered to gem dealers in Nigeria as natural topaz. The stone measures 10.1 × 8.0 mm, weight 2.95 ct. Photo by M. Krzemnicki, SSEF, Basel.*

Review of the patent literature

A number of different patent documents have been published describing various techniques of surface enhancement of gem materials, which relate to the formation of surface coloration of natural and synthetic gemstones, especially topaz, quartz and sapphire. A general overview is given in *Table I*. The review covers documents published in the period 1996 to 2005.

Three patent documents describe simple coating technologies without specific heat treatment. In the US patent by Starcke *et al.* (document 9), a thin coating of a metal, metal oxide, nitride, sulphide or carbon is deposited on the pavilion of a faceted gem. Different colours are seen at different angles of observation, a feature which is caused by various reflection and interference phenomena. A more complex coating process is applied by Rogers (documents 1, 2). An optical interference coating is made of alternating layers of materials with relatively high refractive indices and relatively low refractive indices. The refractive indices and thickness of the alternating layers are chosen so that at least part of visible light incident on the gemstone is reflected. In this way, the coating creates an optical interference filter. Different colours are observed in transmission and reflection as well as at different angles of observation. Stones with the features described in these patents (*Figure 2*) have been seen on the market with various trade names such as 'aqua aura' for surface-coated topaz and quartz or 'tavalite' for surface-coated cubic zirconia (Kammerling and Koivula, 1992; Johnson and Koivula, 1996 a,b).

Figure 2: *These two 'fire topazes' are surface-coated with thin metallic layers deposited on the pavilion or the crown facets. Such stones may appear under different trade names. Various optical reflection, transmission and interference phenomena cause different coloration (from green to violet) when the samples are viewed at different angles. The stones are 9.2 × 7.0 mm, weights 2.27 and 2.21 ct. Photo by M. Glas.*

Figure 3: *The colour of this surface-coated pink topaz is due to an easily removable dye. The stone is 18.0 ×13.0 mm and weighs 15.17 ct. Photo by M. Glas.*

A coating of transparent ink including a red, blue, green or yellow dye and which is removable has been described by Arends (documents 10-12). The permanent ink is made from n-propanol, n-butanol and

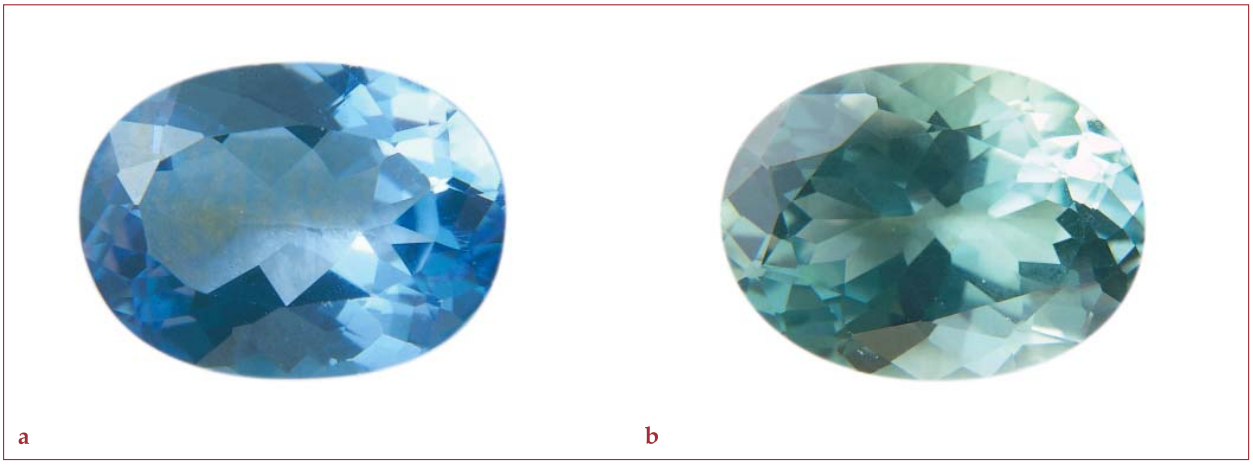

Figure 4 a, b: *The colour of these surface-coated blue and green topazes is caused by cobalt-bearing layers with cobalt in different valence states. The stones are 16.2 × 12.0 mm (blue) and 20.2 × 15.2 mm, weights 10.57 and 21.84 ct. Photo by M. Glas.*

diacetone alcohol and is adhered to the facets of the gemstone, for example cubic zirconia or white sapphire. The coating is easily removable in isopropyl alcohol. Nowadays, pink dye-coated topazes are not uncommon on the market (*Figure 3*).

Two major techniques are used for a more permanent surface coating of mostly colourless, natural and synthetic gem materials, especially for topaz, quartz and sapphire. The first technique is based on heat treatment of faceted gem materials in a transition metal-bearing powder (see documents 3-8, 13, 15, 16 and 22). The colour-causing transition metal may be present as metal or metal oxide. The transition metals used by Pollak are cobalt for blue, blue-green or green colours (*Figure 4 a, b*) and copper for yellow to red colours (documents 3-8, 15, 16). Using this technology, Pollak also mentioned that iron surface treatment produces colours comparable to copper (documents 15, 16). Furthermore, Pollak reported that various additional metals or metal oxides can be added to the cobalt- or copper-bearing powder used for treatment (documents 3-8, 15, 16). The colour of the material obtained by these processes can be changed by subsequent heat treatment of the coated gem material in different atmospheres without further contact with a metal- or metal oxide-bearing powder (documents 3-8, 15, 16). In this subsequent step of treatment, a shift of blue-green topaz colouration to a more pure blue or the development of a red hue in yellow surface-treated topaz is achievable.

A special mixture of cobalt oxides and zinc oxide has been used by Balitsky and Balitskaya (document 22). For this type of contact heat treatment with powder, the powdered material used to surround the faceted gem during heat treatment can also contain fine grained material of the same gem mineral. In a Brazilian patent by Soares Sabioni *et al.* (document 13), the inventors used a mixture of powdered topaz with a powder of a metal or a metal oxide or a metal salt, which was heat treated in a first step before placing faceted topaz in this pre-heated powder for a second step of heat treatment. Repeated heat treatment is possible in powders containing various metals, in this way creating a succession of differently doped layers on the surface of the treated samples.

The second major technique requires two steps of treatment, (a) the deposition of a coating on the faceted stone and (b) heat treatment of the coated gem (documents 14, 17-19, 20, 21, 23). The coating of the gem may be carried out by vacuum sputtering, chemical vapour deposition, physical vapour deposition, spraying, or other techniques.

The coat may consist of metals, metal oxides, metallic compounds or alloys. As described by Gupta and Goyal (documents 17-19), a wide variety of colours is obtainable after subsequent heat treatment of the coated

material, such as blue to green (cobalt or cobalt and chromium or cobalt and nickel), green (chromium), yellow to orange (iron; see *Figure 1*). The appearance of 'Imperial' topaz is obtainable by a combination of iron, chromium and nickel. The colour of the sample can be controlled using different treatment conditions. For topaz with cobalt-bearing surface layers, heat treatment in air in a temperature range from 900 to 1000 C produces a green coloration, while under heat treatment in a temperature range of 950 to 1050 C a blue/green colour is obtained. Heat treatment in nitrogen or in a reducing environment, on the other hand, results in a blue coloration of the surface-coated topaz.

Another type of colour reaction within the surface layer is described by Starcke *et al.* (document 23). For topaz with a very light grey surface coating consisting of titania and vanadium oxide, a yellow body colour was obtained after heat treatment at 450 C. In another topaz with a colourless surface layer consisting of silica and cobalt oxide, a light blue colour was developed after heat treatment at 450 C.

Reaction mechanism

For both major techniques mentioned above, exact details of the chemical reactions are, in general, not disclosed. For both methods, 'diffusion into the outer surface' as well as 'chemical bonding to the surface' are claimed as reaction mechanisms (documents 3-8, 15, 16, 17-19). 'Diffusion into the outer surface' of a faceted gemstone indicates the production of a coloured zone or layer without a distinct interface, for example the diffusion of cobalt atoms into the crystal structure of topaz. 'Chemical bonding to the surface' of a faceted gemstone indicates the production of a coloured zone or layer with a distinct interface between the surface coating and the underlying gemstone.

According to the descriptions in the Brazilian patents of Soares Sabioni and co-authors (documents 13, 14), some transition metals such as cobalt are diffused into the surface of the treated topaz. Consequently, both techniques – i.e. contact heat treatment with a metal-bearing powder and heat treatment of a surface deposited metal-bearing layer – result in a diffusion reaction between a cobalt-bearing layer or powder with the topaz crystal and the formation of a cobalt-bearing zone on the outer surface of the topaz crystal. Consequently, the treated sample might consist of an outer layer of a cobalt-bearing material deposited on to the surface and an inner layer in which cobalt is diffused into the topaz crystal structure. The exact composition and the crystalline and/or amorphous phases present within the surface layer or surface layers may vary according to treatment conditions and are unknown at present (see Underwood and Hughes, 1999). A detailed examination of the outer layers of variably treated gem materials, for example by a combination of X-ray powder diffraction with an electron microscope or with the electron microprobe, is necessary to clarify this point.

It is mentioned that other compounds than cobalt such as iron oxide diffuse less easily into the topaz crystal structure. For such compounds, contact heat-treatment with a metal-bearing powder is less effective and, consequently, iron-bearing layers are first deposited on the surface of topaz for subsequent heat treatment if, for example, a yellow to orange or reddish-orange coloration is desired (see documents 14, 17-19, 20, 21). After heat treatment, the iron-bearing layer is not easily removable from the topaz surface. As described in some documents cited, the iron-bearing layer or atoms of this layer are 'bonded' to the topaz surface. This description reflects the more or less stable formation of a topaz-iron oxide composite surface layer.

A special mechanism is claimed by Starcke *et al.* (document 23). These authors describe heat treatment of the surface-coated gemstone without any diffusion from the surface coating into the gemstone. This is due to heat treatment "at an elevated temperature below that at which there occurs substantial diffusion of material from the coating into the gemstone". The temperatures applied, however, are up to 1150 C and, consequently, in a temperature range in which other authors describe diffusion.

Figure 5: *These two pink topazes are dye-coated on the pavilion facets of the samples. Different colour intensities are observed when viewed through the colourless crown and through the dyed pavilion. The stones are 18.0 × 13.0 mm and 15.8 × 12.0 mm, weights 15.17 and 10.59 ct. Photo by M. Glas.*

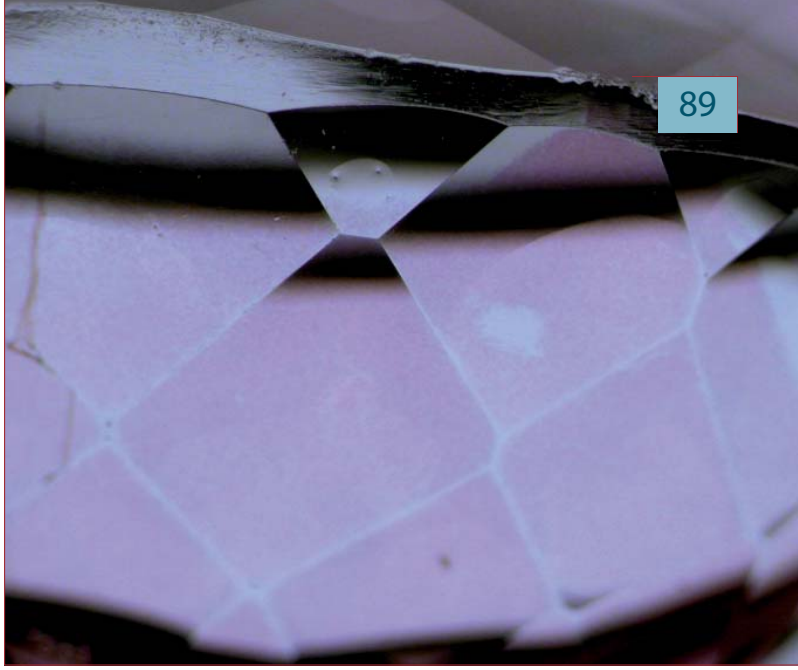

Figure 6: *This dye-coated pink sapphire shows small colourless patches on pavilion facets. Magnification 30x. Photo by J.-P. Chalain, SSEF, Basel.*

Detection of treatment

According to the various treatment techniques applied for surface coating of topaz and other gem materials, the criteria for the detection of treated material may vary (see also Millington, 2005). Thin metallic coatings causing interference and other optical effects (*Figure 2*) are not found on faceted examples of natural untreated stones. In coated stones different colours may be observed when the stones are viewed from different directions. For a number of samples such as some pink topazes examined recently (*Figure 3*), which are dye-coated on pavilion facets, the colour intensity observed through the colourless table will differ from that on the pavilion (*Figure 5*). Surface-coated samples of this type show colourless spots or small colourless patches on facets (*Figure 6*) or along facet junctions.

For a number of samples produced by contact heat treatment with powder or by heat treatment of a metal-bearing layer (*Figures 1, 4 a, b*), an irregular or somewhat spotty colour distribution on coated facets or facet junctions can also be observed. There are also frequent references in the literature to small colourless areas, also described as colourless chips within the coating (see, for example, Johnson and Koivula, 1998; Underwood and Hughes, 1999; McClure and Smith, 2000; Krzemnicki, 2002).

Nomenclature and conclusion

In summary, various mechanisms are described for different treatment techniques. The properties of the resulting type of coating are due to the actual process applied, but are also dependent on the main transition metal or group of transition metals, for example cobalt, iron or copper, used for coating. The different minerals such as quartz, topaz or corundum, subjected to a particular transition metal and treatment technique, may well show different reactions. Consequently, when naming a stone whose treatment history is not known, only a reference to the general technique applied should be made. All techniques described above are processes of surface-coating and, consequently, a description of a stone that has undergone any of these as 'surface-coated' reflects the applied treatment technique and distinguishes these gem materials from irradiated or simply heat-treated gemstones.

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Gem minerals from the Saranovskoye chromite deposit, western Urals

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Abstract: *Gem-quality minerals, including uvarovite, Cr-grossular and Cr-titanite, associated with the Saranovskoye chromite deposit, northern Urals, are described. The geology and mineralogy of the deposit indicates its formation following a well-known cycle of low-grade metamorphic processes and hydrothermal activity.*

Keywords: *'alexandrite' effect, Cr-amesite, Cr-grossular, Cr-titanite, low grade metamorphism cycle, uvarovite*

Introduction

Many gem-quality minerals and ornamental stones are formed in rocks which have undergone low grades of metamorphism. These include agates, datolite, natrolite and prehnite in the zeolite facies of metamorphism; powellite, jasper, xonotlite, grossular and hydrogrossular (including Transvaal 'jade'), andradite, diopside, vesuvianite (including californite), amethyst, titanite (sphene) in the prehnite-pumpellyite facies of metamorphism; and demantoid in the pumpellyite-actinolite facies (Spiridonov, 1998). The temperatures and pressures of formation of the different facies are: zeolite facies 150-290°C, 0.5-4kb; and prehnite-pumpellyite facies 250-330°C, 1.5-7kb (Coombs *et al.*, 1959; Cho *et al.*, 1986; Philpotts, 1990; Frey and Robinson, 1999; Spiridonov *et al.*, 2000). Due to the fluid-dominant character of the low-grade metamorphism (Fyfe *et al.*, 1981), the rocks at the Saranovskoye chromite deposit contain alpine-type veins (Vertushkov and Kobyashev, 1975) with emerald-green uvarovite crystals (Hess, 1832; Ivanov, 1997), Cr-titanite (Ivanov, 1979), violet Cr-amesite (Zimin, 1939) and ruby-red Cr-diaspore – 'saranite' (Fersman, 1954).

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Materials and methods

All of the samples in this study were collected from the mine by T.G. Fattykhov over a 30 year period and, over the last 10 years, by E.M. Spiridonov. This systematic collection is representative of the full range of levels at the deposit, from the lower horizons at a depth of 300 m to the surface.

Optical and electron microscopy methods were used to investigate and distinguish minerals and document their optical and internal features. More than 200 samples were analysed using electron microprobe analysis (EMPA) and scanning electron microscope with energy-dispersive X-ray spectrometer (SEM-EDS). Analyses were performed on different colour zones, mineral assemblages and mineral inclusions. X-ray diffraction (XRD) was used to determine mixed-layered minerals and pumpellyite group minerals. For gem-quality minerals, standard gemmological instrumentation was used to record optical character, pleochroism, colour (using standards in GemSet based on Munsell colour theory), optical transmission spectra and reaction to ultraviolet radiation (365 nm long-wave, 254 nm short-wave). Specific gravity was determined by hydrostatic weighing. The description of OH-bearing garnets is based on the nomenclature of Passaglia and Rinaldi (1983) and chlorite group minerals are named after Strunz (2002) and, where refinements were needed, after Hey (1954).

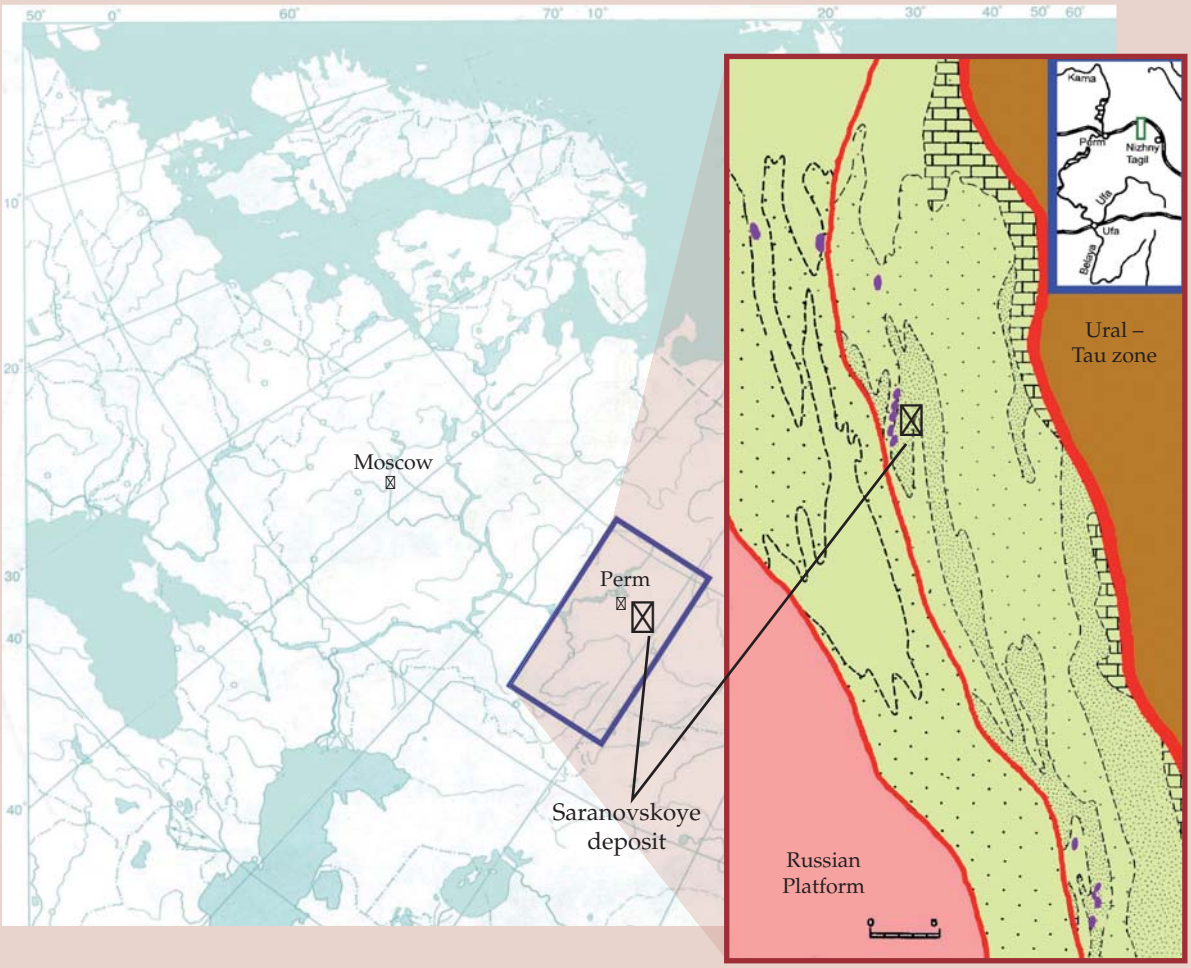

Figure 1: *Geographical and geological position of the Saranovsky chromitiferous belt.*

Geology

The Saranovskoye chromite mine is located in the Perm' region, 98 miles NW from Perm' city, on the north-western slopes of the Urals *(Figure 1)*, and at the time of writing (2005) is the only industrial chromite mine in Russia. From its opening in 1889, it was mined open-cast, but now extraction is mainly from underground.

The ore is recovered from up to 30 chromitite horizons, 0.5-14 m thick, located in Precambrian dunites and harzburgites (olivine-pyroxene rocks) of the Saranovsky massif. These ultrabasic rocks are crossed by gabbro and gabbro-dolerite bodies and a number of dolerite and picrite dykes *(Figure 2)* (Ivanov, 1997). The gabbro-dolerites contain stratified sulphide blebs and measurement of the details of their stratification allowed reconstruction of the original flat bedding of the chromitiferous dunite-harzburgite massif.

Since their formation, the ultrabasic rocks have, together with siliceous and carbonate rocks, been folded and metamorphosed in

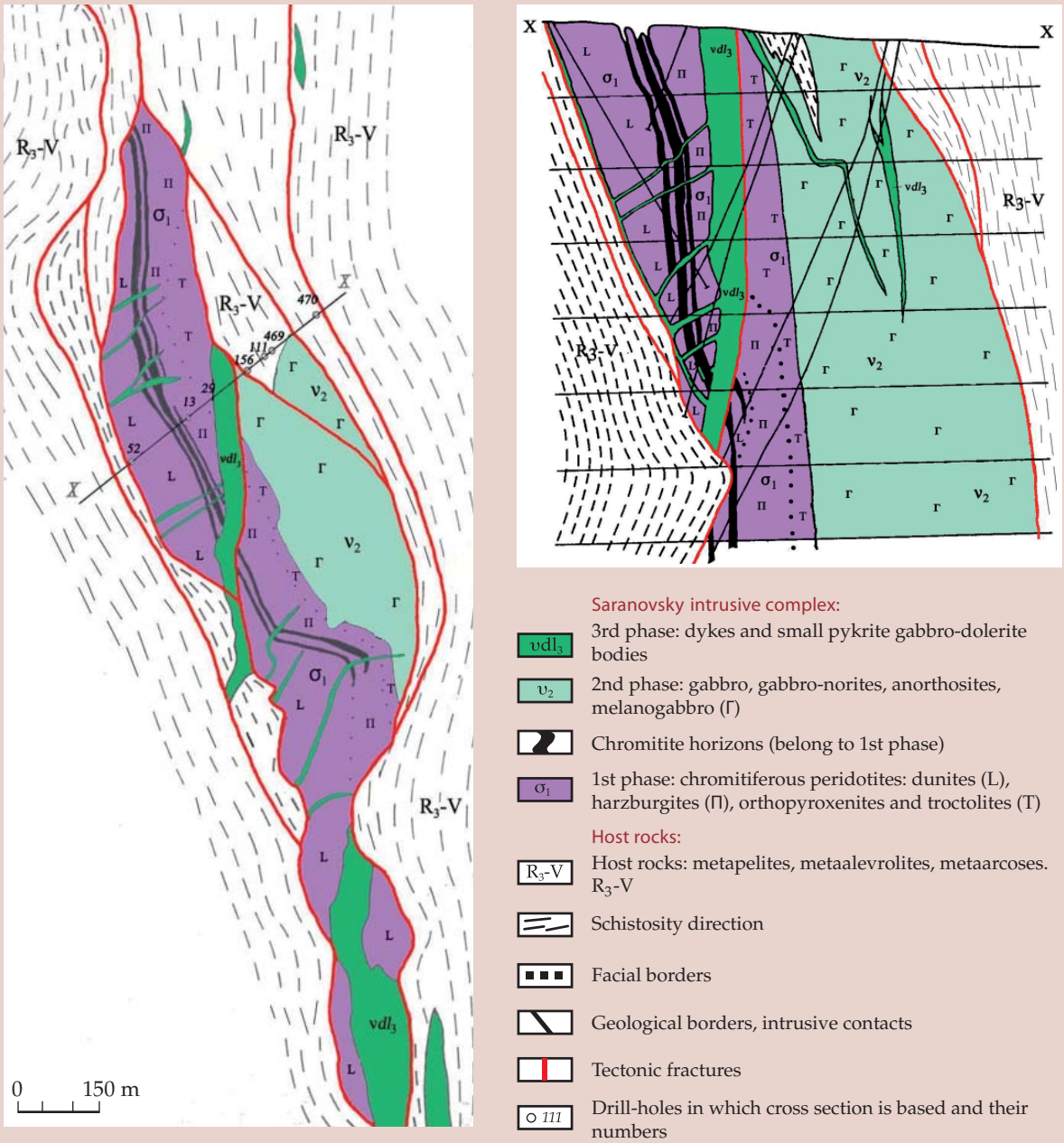

Figure 2: *Geological sketch and cross-section of the Saranovskoye chromite deposit, after E.M. Spiridonov. R_3-V represents sequences of metamorphosed clays, silts and sands. X-X in the section is about 400 m.*

Paleozoic time and many units are near-vertical. They have also been overthrust by crystal blocks of considerable thickness which caused local high pressure-low temperature metamorphism. This mixture comprises the Saranovsky massif and lies on the western slopes of the Ural Mountains. Surrounding the massif, at the edge of the Russian platform, are many varieties of siliceous schists, some of which contain pyrite.

The low grade metamorphism

Minerals of the pumpellyite group and diaspore are widely developed in all the rocks associated with the Saranovskoye chromite deposit and it may be concluded that the grade of metamorphism did not exceed that of the prehnite-pumpellyite facies. The following stages of the low-grade metamorphism have been established:

- First stage – zeolite facies to prehnite-pumpellyite facies of moderate pressure;
- Second stage – prehnite-pumpellyite facies of high pressure (330-340°C and 6-6.5 kb, based on the epidote-pumpellyite thermobarometer of T.Arai (Tiriumi and Arai, 1989);
- Third stage – prehnite-pumpellyite facies of higher pressure;
- Fourth stage – prehnite-pumpellyite facies of moderate pressure (~3 kb);
- Fifth stage – zeolite facies.

In general, this trend corresponds to the standard 'Perchuk's loop' (Perchuk, 1983).

The intensity of this low grade metamorphism is extremely uneven. Magnesiochromite in the original ultrabasic rocks was first locally replaced by chromite and then by ferrian chromite and chromian magnetite, which were later replaced by Cr-containing gem minerals *(Figure 3)*. Cr-containing gem minerals form crusts on the sides of carbonate alpine-type veins. Uvarovite and Cr-grossular were formed as a result of the second stage of metamorphism; at the third stage, Cr-amesite and Cr-diaspore (both with an alexandrite effect) were formed and gem-quality Cr-titanite formed at both the third and fourth stages. Cr-grossular, Cr-amesite, Cr-diaspore and Cr-titanite usually occur near the metachromitite-metabasic rock contact.

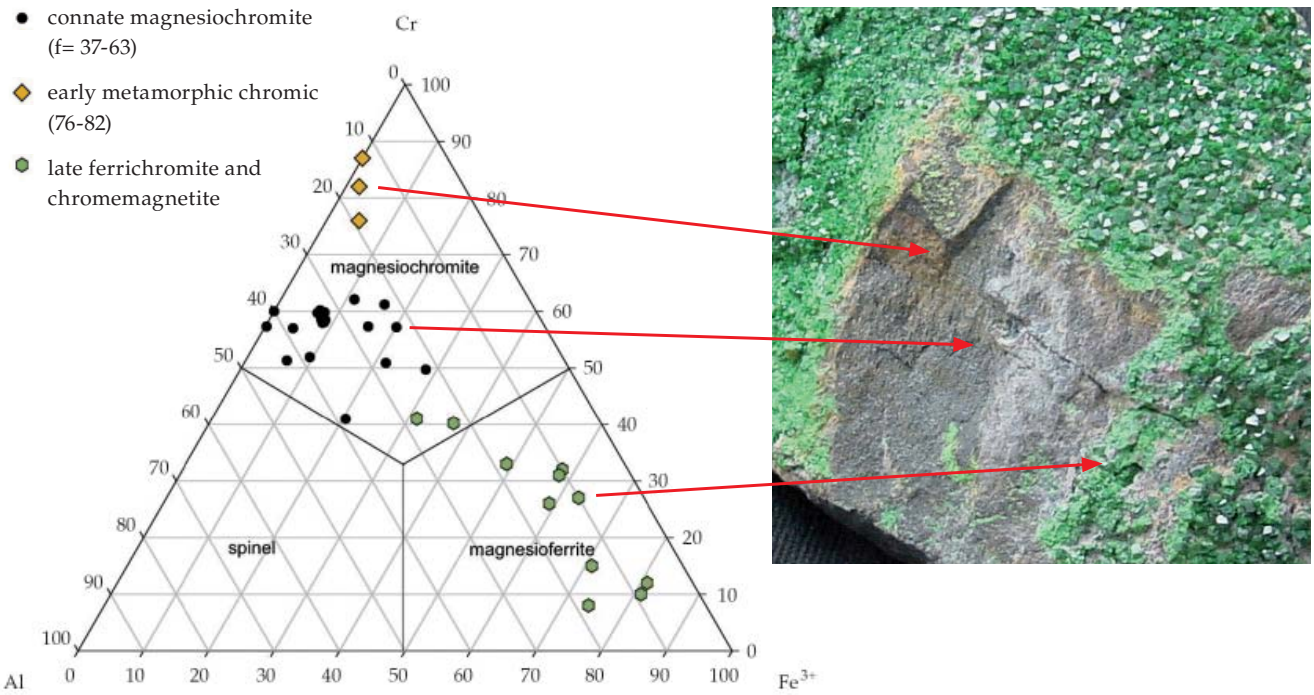

Figure 3: *Successive replacement of magnesiochromite by chromite and uvarovite is indicated by the crust of green uvarovite crystals and the analyses of opaque minerals in the grey ultrabasic rock. Image size 8 cm. Photo by M.S. Alferova.*

First stage

Lizardite is widespread in meta-ultrabasic rocks of the first stage. It may also be found as separate relic nests among brucite-antigorite serpentinites of the second stage.

Second stage – the main, 'green' stage

Here brucite-antigorite and antigorite serpentinites, metachromitites, metagabbro, metasediments, including rodingites are widespread. Among these there are many alpine-type veins which contain parallel-columnar aggregates of crystals, among which are the following associations:

- quartz (opaque crystals or clear rock crystal up to 13 cm long) ± albite ± ankerite ± calcite ± stilpnomelane (enriched in Ba) ± fengite (among metasediments);
- carbonate + epidote-clinozoisite ± ferroan chlorite ('corundophilite' and 'ripidolite' according to Hey (1954)) ± albite ± magnetite ± titanite (or rutile) ± Fe-Cu sulphides (among metabasic rocks);
- antigorite ± carbonate + brucite ± magnetite (among metaultrabasic rocks);
- calcite or dolomite + green clinochlore ('corundophilite' of Hey (1954)), including 3-11 wt.% Cr_2O_3, + titanite ± Cr-containing garnet (grossular, hydrogrossular, uvarovite) ± Cr-pumpellyite (up to shuiskite – Ivanov *et al.*, 1981), and among metachromitites, calcite + Cr-chlorite + Cr-fengite (fuchsite).

Chromium-containing derivatives from metabasic rocks

Fine-grained aggregates of optically anisotropic Cr-garnet have almost completely replaced metachromitites near contacts of chromitites and basic dykes in some zones of crushing and mylonitisation and along glide planes *(Figures 4, 5)*. They form continuous crusts, groups of crystals on metachromitites, commonly with chromian clinochlore ('corundophilite' of Hey (1954)), opaque Cr-titanite *(Figure 6)*, shuiskite, Cr-pumpellyite and apatite. Gem-quality uvarovite and Cr-grossular of a deep emerald-green colour are minerals which developed relatively late in the second stage. They form transparent rhombic dodecahedra up to 12 mm across. The green garnets lie in the composition range covered by the end-members grossular,

Figure 4: *Tectonic glide plane in metachromitite (a), and uvarovite overgrown by late calcite crystals (b). Sample sizes: left – 15 cm, right – 7 cm. Photos by M.S. Alferova.*

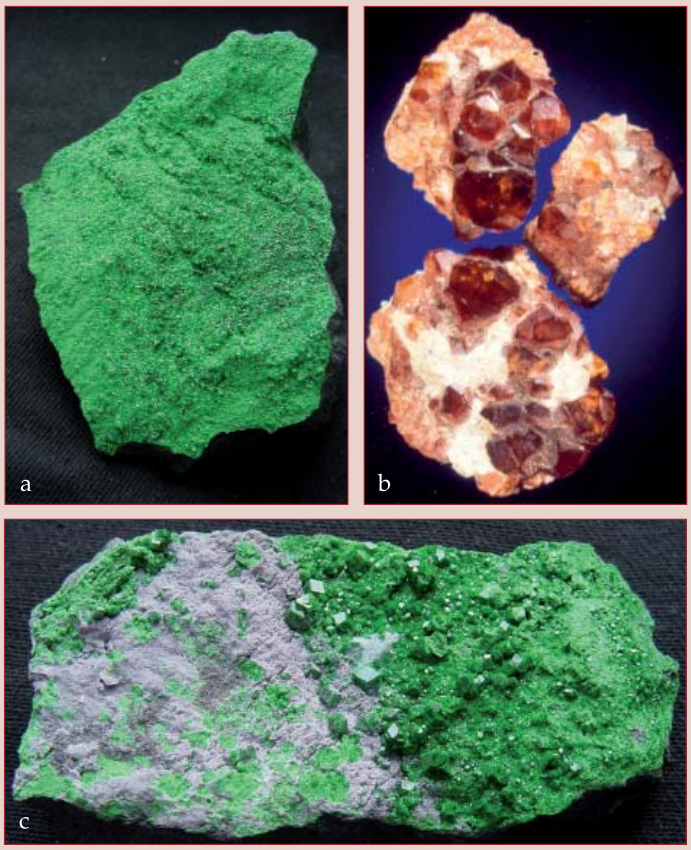

Figure 5: *Continuous uvarovite aggregate (20 cm) (a); red grossular crystals (largest crystal 25 mm) with albite (b); uvarovite crystals up to 7 mm across (c). Photos by M.S. Alferova.*

Figure 6: *Transparent uvarovite (green) associated with opaque Cr-titanite (pale-green) and Cr-clinochlore ('corundophilite') (silver-grey). Specimen 6 cm across. Photo by M.S. Alferova.*

andradite and uvarovite and representative analyses are shown in *Table I*. They contain 17-92% of uvarovite end-member, up to 2 wt.% TiO_2, ~0.5 wt.% Fe_2O_3 and traces of Zn, Ni, V, Cu, Mg and Mn. In the marginal parts of the Saranovsky massif uvarovite is often associated with quartz which forms overgrowths on the rhombic-dodecahedral crystal edges. At that time the Saranovsky massif was probably an 'open' system with Si available from hydrothermal fluids. Uvarovite and Cr-grossular show fine oscillatory zoning similar to that described in Cr-garnets from rodingites by Mogessie and Rammlmair (1994).

Cr-titanite of this second stage occurs in euhedral opaque pale-green crystals and contains 0.3-1 wt. % Cr_2O_3 and up to 0.5% Al; heterovalent isomorphism Ti + O ↔ Al, Cr + OH is typical as noted by Hammer *et al.* (1996).

Chrome-free derivatives from metabasic rocks and metasediments

Some fracture zones through the rodingites contain grossular (hessonite) in cherry-red to orange crystals up to 35 mm across *(Figure 5)*. The grossular contains iron with 4-17% of the andradite end-member, up to 3 wt.% TiO_2 and up to 0.1 wt.% Cr_2O_3. Transparent crystals of quartz (up to 15 cm) and albite (up to 3 cm) commonly occur in the metasediments.

At the end of the second stage CO_2 fugacity

Table I: *Chemical compositions of uvarovite (1-3), Al-uvarovite (4-5), Cr-grossular (6), Fe-grossular (7-9) from the Saranovskoye chromite deposit*

wt. %	1	2	3	4	5	6	7	8	9
SiO_2	34.13	35.69	36.46	36.22	36.56	36.37	39.22	39.27	39.30
TiO_2	1.53	0.69	0.77	0.22	0.36	0.72	0.22	0.14	0.19
Al_2O_3	1.13	3.47	5.07	7.55	7.94	10.09	19.41	18.26	18.31
Fe_2O_3	0.58	0.29	b.d.	1.23	0.29	2.01	3.37	4.70	4.69
V_2O_3	0.35	b.d.	0.13	b.d.	b.d.	0.45	b.d.	b.d.	b.d.
Cr_2O_3	26.13	24.03	22.57	18.87	18.49	13.92	0.07	0.20	b.d.
FeO	n.d.	n.d.	0.56	n.d.	n.d.	n.d.	2.87	1.87	2.62
MnO	b.d.	b.d.	b.d.	0.05	0.10	0.31	2.56	2.82	2.08
MgO	0.08	0.03	0.05	0.06	b.d.	0.15	0.10	0.11	traces
CaO	33.46	33.18	33.97	33.79	34.22	33.62	32.26	32.70	32.87
ZnO	n.d.	n.d.	n.d.	n.d.	n.d.	0.35	0.15	b.d.	0.35
NiO	b.d.	b.d.	b.d.	b.d.	b.d.	b.d.	traces	0.24	b.d.
Total	97.39	97.38	99.58	97.99	97.96	97.99	100.23	100.31	100.41

Analyst I.M. Kulikova, using a Camebax SX50 electron microprobe
b.d. = below detection
n.d. = not determined

increased, as titanite became unstable and was replaced by rutile (Philpotts, 1990). Rutile forms prismatic crystals up to 40 x 6 x 6 mm and needle-like crystals up to 120 x 0.5 x 0.5 mm; it also occurs as felt-like aggregates.

Third stage – 'violet' stage

Mineralization was predated by another phase of movement and crushing. Typical of the third stage are silica-deficient minerals such as amesite, perovskite, diaspore, Cr-hydrogarnet and brucite. Thus, at this stage the Saranovsky massif appears to have been a relatively closed system, not open to Si-bearing fluids.

The main mineral of that stage is violet-lilac Cr-bearing (1-4 wt.% Cr_2O_3) amesite showing a pearly lustre and a strong alexandrite effect (*Figure 7*; see *Table II*, 1-2). Cr-amesite is developed in metamorphic-hydrothermal calcite veins in contact with metachromitites. Many of the Cr-amesite crystals are polychromatic, the bases of the

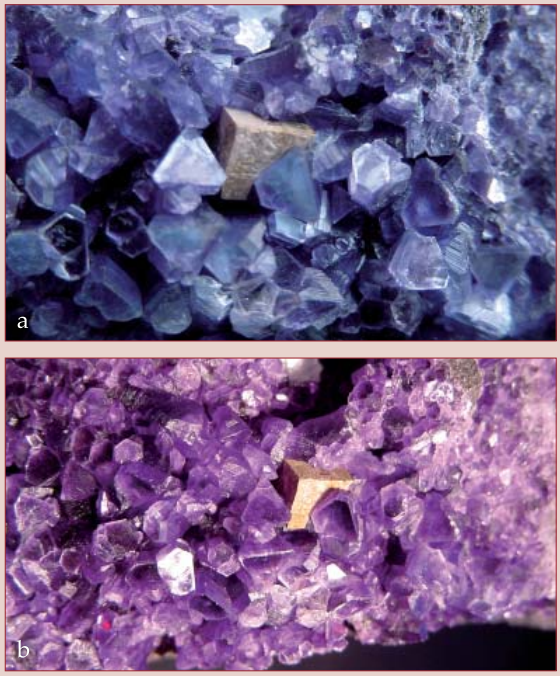

Figure 7: *Cr-amesite showing a strong 'alexandrite' effect. (a) in daylight, (b) in electric (tungsten) light. Perovskite cubic crystal edge size 5 mm. Photo by M.S. Alferova.*

Table II: *Chemical compositions of Cr-amesite (1-2), Cr-diaspore (3-5), titanite (6-7) and Cr-clinochlore ('kammererite') (8-9)*

wt.%	1	2	3	4	5	6	7	8	9
SiO_2	20.00	21.37	n.d.	n.d.	n.d.	30.41	30.50	30.13	33.58
Nb_2O_5	n.d.	n.d.	n.d.	n.d.	n.d.	0.14	0.19	n.d.	n.d.
TiO_2	b.d.	b.d.	0.35	0.19	0.33	38.56	38.96	b.d.	b.d.
Al_2O_3	33.88	34.81	78.69	77.95	77.28	0.02	0.28	14.15	11.61
Cr_2O_3	0.87	1.88	3.71	4.42	5.49	0.98	0.86	8.97	4.66
Fe_2O_3	n.d.	n.d.	0.11	0.15	0.13	n.d.	n.d.	n.d.	n.d.
V_2O_3	0.03	b.d.	0.52	0.18	0.19	0.54	0.45	0.13	0.11
FeO	0.70	0.89	b.d.	b.d.	b.d.	0.40	0.12	0.87	2.39
MnO	0.01	b.d.	n.d.	n.d.	n.d.	0.05	0.06	0.12	traces
MgO	26.34	27.52	n.d.	n.d.	n.d.	b.d.	0.01	33.15	35.02
CaO	n.d.	n.d.	n.d.	n.d.	n.d.	28.06	28.30	n.d.	n.d.
NiO	0.31	0.79	n.d.	n.d.	n.d.	b.d.	b.d.	b.d.	b.d.
F	0.07	b.d.	n.d.	n.d.	n.d.	0.25	0.21	n.d.	n.d.
Cl	n.d.	n.d.	n.d.	n.d.	n.d.	traces	b.d.	n.d.	n.d.
H_2O*	n.d.	n.d.	n.d.	n.d.	n.d.	0.09	0.06	n.d.	n.d.
Total	82.21	87.26	83.38	82.89	83.42	99.50	100.00	87.52	87.37

Analyst N.N. Kononkova, using a Camebax SX50 electron microprobe; H_2O* – calculated
b.d. = below detection
n.d. = not determined

Figure 8: *Cr-diaspore of lavender and lilac colours together with Cr-amesite (greyish-violet) and hydrogrossular (pale-green). Specimen 8 cm across. Photo by M.S. Alferova.*

Figure 9: *Gem-quality Cr-titanite crystal (green) associated with Cr-amesite (grey) and calcite (white). Titanite is 9 mm across. Photo by M.S. Alferova.*

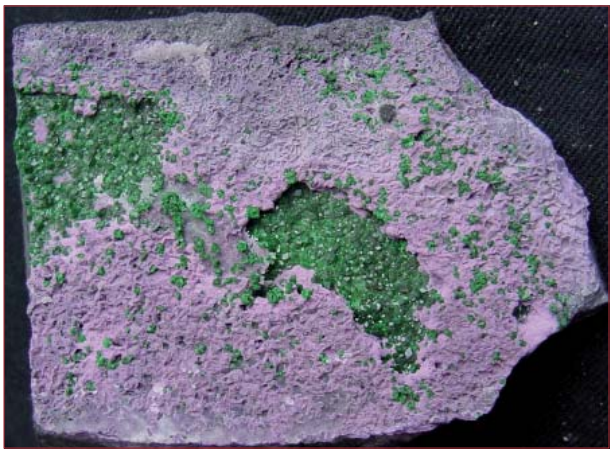

Figure 10: *Lilac chromian clinochlore ('kammererite') with uvarovite. Specimen size 17 cm. Photo by M.S. Alferova.*

pillar-like crystals being enriched in Cr and of a deep lilac colour, but upwards towards the carbonates the colour pales as the Cr content decreases, eventually becoming colourless. Amesite crystals with low Cr content are typically split vermicular crystals.

In the contact zones of metachromitites and metabasites, plates of lavender, lilac or red Cr-diaspore *(Figure 8)* together with Cr-amesite and Cr-hibschite are commonly developed. The plate sizes are up to 8 cm across. Diaspore contains up to 5 wt.% Cr_2O_3 (see *Table II*, 3-5), and shows an alexandrite effect.

Cr-titanite is the latest gem-quality mineral of this stage *(Figure 9)*. It forms as pseudomorphs after perovskite, overgrowths on columnar Cr-amesite crystals or on chromitites along calcite vein contacts. In these veins Cr-titanite forms translucent deep-green tabular crystals of up to 35 22 14 mm in size. In cavities of dissolution it forms intergrowths with tabular Cr-amesite crystals and also forms transparent crystals which may be almost isometric, tabular or variously twinned. Sizes are up to 45 25 3 mm exhibiting superb emerald-greens of varying intensity to light-green, often with a golden tint. Cr-titanite is biaxial and shows strong pleochroism from apple-green (across {100}) to olive-green (along {100}). Gem-quality crystals contain 0.7-1.0 wt.% Cr_2O_3 and up to 0.25 wt.% F, with traces of Al, Fe, Mg, V, Zn, Ni, Cu and Cl (see *Table II*, 6-7); a typical formula is $(Mg_{0,01}Fe_{0,02}Ca_{0,97})_{1,00}(Ti_{0,90}Al_{0.04}Cr_{0,02})_{0,96}[Si_{1,02}O_4][O_{0,88}(OH)_{0,12}]_{1,00}$.

Fourth stage – 'pink' stage

This is a stage of lower temperatures and pressures, characterised by yellowish-green lizardite which occur as pockets, bands or blocks, replacing antigorite serpentinites. In peridotites and chromitites aluminian magnesiochromite is extensively replaced by chromian magnetite, which in turn is replaced by brightly coloured red and pink-lilac chromian clinochlore ('kammererite' of Hey (1954)) *(Figure 10)*. In the clinochlore structure Cr fills both octahedral and

tetrahedral positions giving rise to its colour (Lapham, 1958). Chemically, chromian clinochlore from the Saranovsky massif contains between 6 and 14 wt.% Cr_2O_3 (see *Table II*, 8-9). Areas of chromian clinochlore crusts on metachromitites may be up to several square metres, and not infrequently there are overgrowths of calcite, small plates of apatite and Cr-titanite crystals.

The most significant products of the fourth stage are perfect Cr-titanite twins *(Figure 11)*. They are emerald green and are of various habits from blade-like (1-3 mm thick) to plate-like (in fractions of a millimetre). The crystals and twins are found in cavities of dissolution and late calcite veins.

Later fourth stage minerals include ilmenite and redledgeite; these are products of titanite replacement. Ilmenite forms flattened crystals up to 7 mm across, but is not pure – rather it is an almost equal mixture of the Mg, Mn and Fe end-members geikielite, pyrophanite and ilmenite. The most interesting mineral in alpine-type veins is redledgeite ($BaCr_2Ti_6O_6 \cdot H_2O$), which derives its Cr, Ti and Ba from metachromitites, metabasites and metasediments respectively.

At the end of the fourth stage CO_2 fugacity increased and titanite was replaced further by polycrystalline aggregates of quartz, calcite and anatase ($CaTiSiO_5 + CO_2 \rightarrow CaCO_3 + SiO_2 + TiO_2$) which kept the habit of the titanite and formed pseudomorphs. Polycrystalline pseudomorphs of kassite $CaTi_2O_4(OH)_2$ were also formed. Ilmenite is replaced by needle-like intergrowths of rutile or polycrystalline aggregates of anatase. Where titanite and ilmenite have been completely replaced, the result is commonly a Cr-clinochlore crust with many small flattened light-brown anatase crystals.

Fifth stage

The lowest-temperature products of low-grade metamorphism are developed in separate blocks, strips and pockets among earlier rocks and minerals, extensively replacing them. Antigorite and lizardite in

Figure 11: *Perfect Cr-titanite twins (up to 14 mm across) (green) and calcite crystals (white) on a matrix of Cr-clinochlore (pale-grey). Photo by M.S. Alferova.*

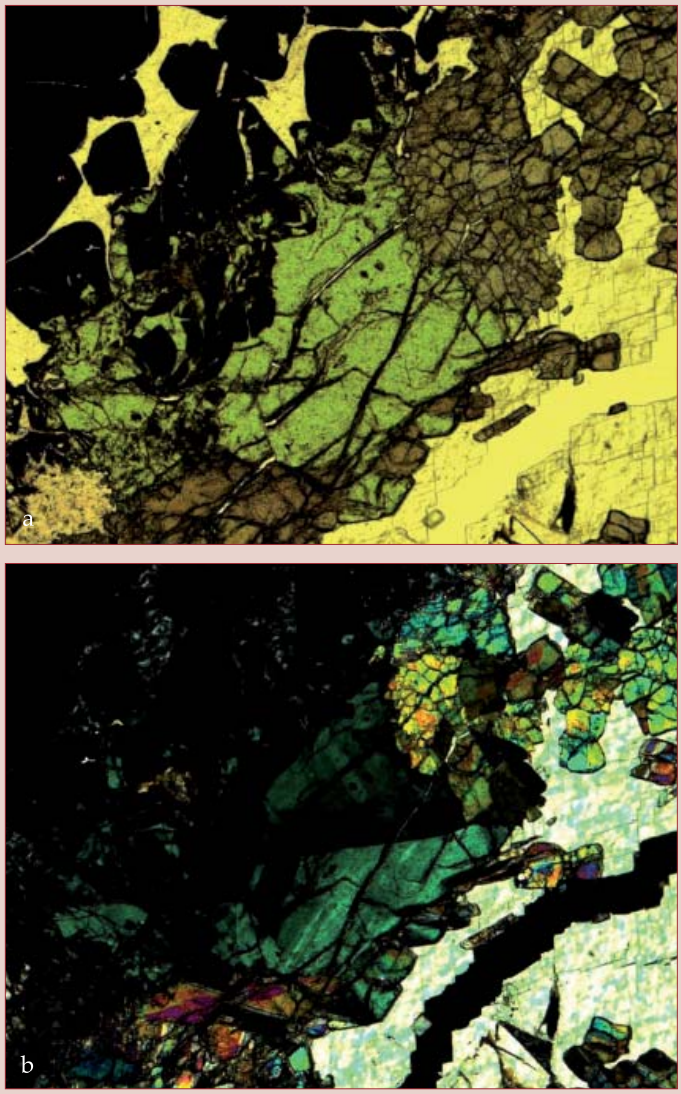

Figure 12: *(a) Thin section of uvarovite (green) and shuiskite (brown) in plane-polarized light. (b) In cross-polarized light, the garnet shows transmission in the lower part indicating anisotropy. Thin section 9 mm across.*

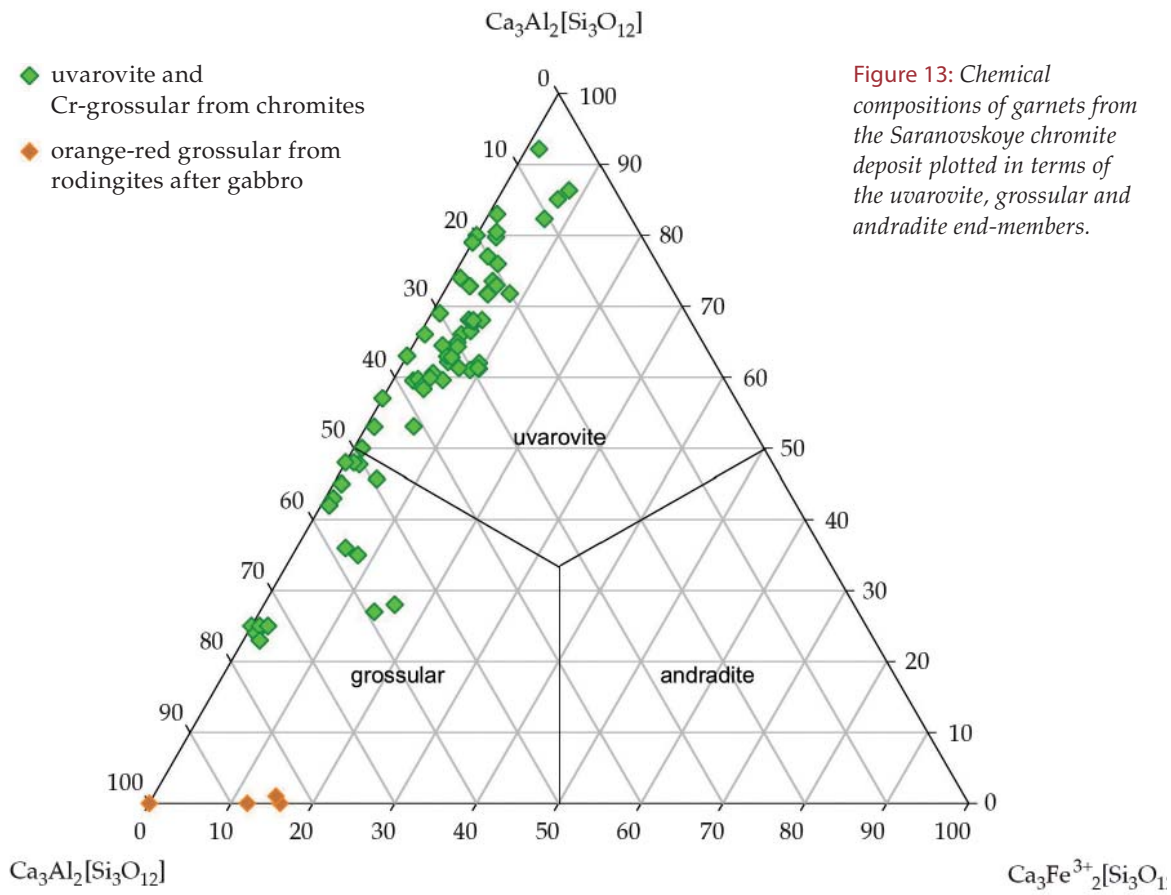

Figure 13: *Chemical compositions of garnets from the Saranovskoye chromite deposit plotted in terms of the uvarovite, grossular and andradite end-members.*

serpentinites are replaced by fine-grained hydrotalcite, and chromite may be replaced by pink and pink-violet stichtite. Granular calcite aggregates may be dissolved and replaced by calcite crystals up to 40 cm long either singly or in groups and associated with the calcite in places are sulphides, clay minerals and pale-green titanite.

Gem minerals

Uvarovite and Cr-grossular. The rough crystals are predominantly rhombic dodecahedra, up to 8-12 mm across, show no evidence of dissolution on their surfaces and commonly form crusts of intergrown crystals on chromitite surfaces. Many garnet crystals are transparent and range from a 'pure' green uvarovite (G6/4, G7/4, G5/5 using the Munsell notation) to pale-green Cr-grossular (G5/3). Some show strong oscillatory colour and optical zoning in thin section and others display optical anisotropy *(Figure 12)*; this is due to ordering of Al and Cr in the structure (Ivanova *et al.*, 1998). Representative analyses of garnets from the Saranovskoye deposit are given in *Table I*, and more are plotted in *Figure 13* to indicate the range for green garnets which may contain from 17% up to 92% of the uvarovite end-member. These Urals garnets have refractive indices of 1.740-1.870 (Anderson, 1996), birefringence up to 0.008, (measured using Michel-Levy interference colour chart for thin sections), a specific gravity range of 3.41-3.65 and show no reaction to ultraviolet radiation. Normally transparent uvarovite crystals do not contain inclusions but many semi-transparent crystals contain relic chromite, fluid inclusions and cracks. Uvarovite is generally too small for cutting as individual stones, but small sparkling mats of uncut crystal aggregates on matrix are often set in jewellery. Larger pieces grace the collections of many museums.

Fe-grossular (hessonite) forms tetragon-trioctahedral (trapezohedral) crystals up to 35 mm across. Crystals are transparent, from

Figure 14: *Gem Cr-titanite flat twin. Photo by M.S. Alferova.*

cherry-red (O5/3, yO4/5) to orange (oY5/5, Y5/5, Oy4/5) *(Figure 5b)* and, although rare, are readily used for cutting. *Table I*, columns 7-9, contain representative compositions.

Cr-titanite is the gem symbol of the Saranovskoye deposit *(Figure 14)*. Typical habits show {100}, {001}, {111}, {102} and {110} faces, with twinning on (100). Gem-quality crystals and many twins are transparent, variously green (slyG8/3 to slyG6/3), and with strong pleochroism *(Figure 15)*. Typical compositions are given in *Table II*, columns 6-7, and no zoning was found. The green colour is due to the chromium content of up to 0.98 wt.%; vanadium (up to 0.54 wt.%) probably contributes a bluish tint to the green colour. The chromophore pair Fe^{2+}-Fe^{3+} is absent. Gem-quality Cr-titanite contains fluorine up to 0.25 wt.% in contrast to earlier Cr-titanite which is opaque and fluorine-free. Refractive indices of gem Cr-titanite exceed 1.8 and range from 1.900 to 2.034, dispersion 0.022-0.035 (Anderson, 1996), specific gravity 3.52 ± 0.02; no reaction to ultraviolet radiation was seen. Inclusions are represented by amesite, chlorite, clinochlore and fluid inclusions. Due to its relatively low hardness (5-5.5 on the Mohs scale) Cr-titanite is seldom used in jewellery, but its brilliance is comparable with the best demantoid.

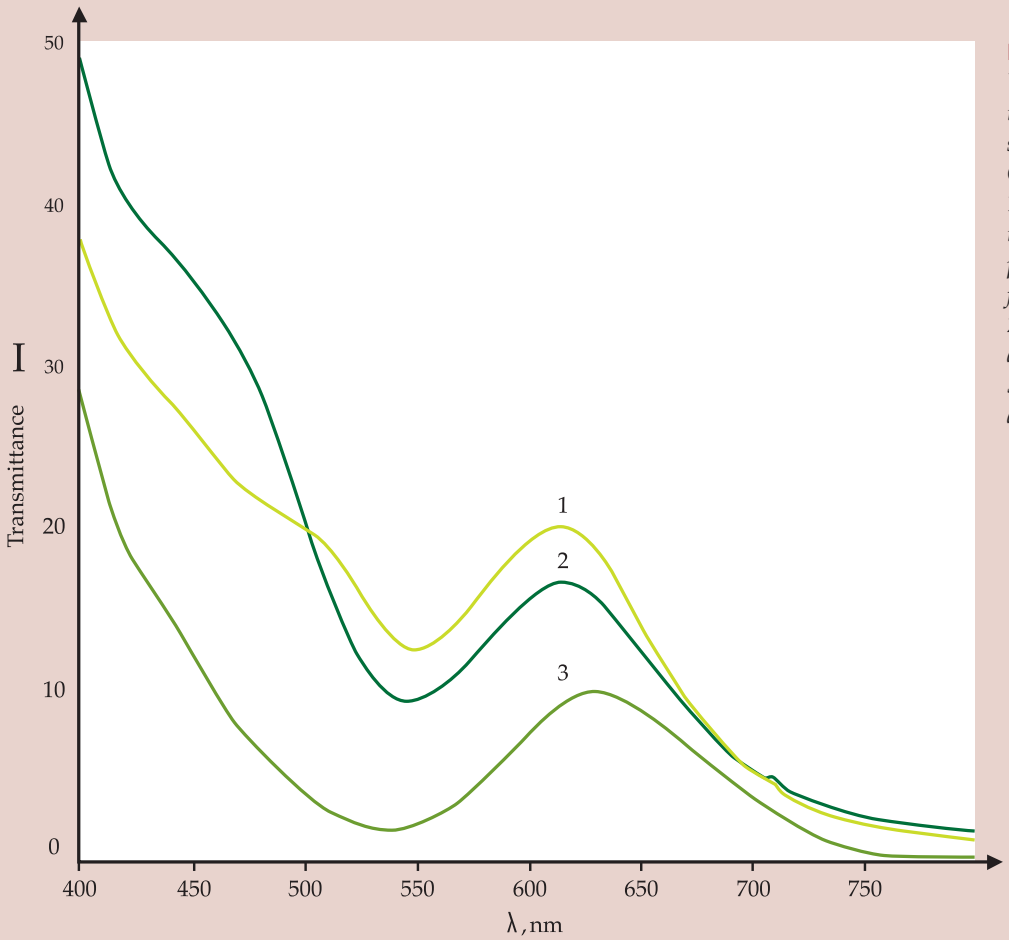

Figure 15: *Visible range transmission spectra of gem Cr-titanite: 1 – across (100), the composition plane in flat twins, 2 – along (100) and across (111), 3 – along (100) and across (102).*

Conclusion

In the Saranovskoye chromite deposit there is a wide range of Cr-rich minerals, many of which have potential as gems and ornamental stones. Such diversity was generated by a low-grade metamorphism cycle which caused the chromium to become mobile and enter such minerals as uvarovite, Cr-titanite, shuiskite, amesite and diaspore. Some areas in and around the massif contain no chromium but nevertheless yield cherry grossular, rock crystal and jewellery-grade albite.

Acknowledgements

Oleg K. Ivanov is gratefully thanked for assistance, I.M. Kulikova and N.N. Kononkova for providing microprobe analyses, and A.V. Vasil'ev for providing optical spectra. We thank B. Jackson for revision of the translated text. The study was supported by RFBR grant (04-05-64152).

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Letters to the Editor

Iridescent colours of the abalone shell

The recent paper by T.L. Tan, D. Wong and P. Lee *(The Journal of Gemmology,* 29(7/8), 395-9) addresses the long-standing question of whether the iridescence of abalone and other shells may be due to diffraction from any evenly grooved two-dimensional, surface structure, a compact disk being a common example, or related to the well known multi-layered aragonite/conchiolin, three-dimensional, microstructure below the surface. Iridescence due to repeating internal structures is exemplified by polysynthetically twinned labradorite or precious opal, familiar to all gemmologists.

The research of Tan, Wong and Lee clearly demonstrates that a grating structure is present on the surface of the abalone they studied, as shown both by the diffraction given by the lasers and by the SEM illustrations. They then conclude that the iridescence is due to this grating structure. They certainly provide sufficient evidence that the iridescence may be due to diffraction from the surface structure. However, we do not believe that they provided conclusive evidence for diffraction as a cause of the abalone iridescence.

Consider the layered nature of the shell, alternating regularly between the harder aragonite tiles and the softer conchiolin. When the shell is polished we would expect that the conchiolin would undercut forming a rippled surface much as jade develops an 'orange peel' surface, and some banded agates reveal their bands by small undulations in the polished surface. Thus, it is not surprising to see the surface of the layered shell develop a grating-like structure when cut and polished. This appears to be what Tan, Wong and Lee have shown. With the presence of both a layered microstructure below the surface and a grating structure at the surface, it remains to be demonstrated to what extent each of the optical structures may contribute to the observed iridescence.

Nassau (2001) in his discussion of biological coloration notes that the identification of structural colours can be difficult. He also states (p. 318): "Many of the imputed biological diffraction grating colours have been shown on detailed study to originate in thin film interference; *observation of a periodic grating structure is quite insufficient as evidence"* (emphasis ours). Yet this is the only evidence presented by Tan, Wong and Lee. Nassau (2001, p. 318) cites an example of butterfly wings where a grating can be observed under the microscope, but the naked eye only sees the iridescence due to thin-film interference. He also gives various ways to distinguish between colours based on interference or diffraction and most readers can easily test any shell material they may have by some of his criteria. The simplest is to observe the iridescent colours going between a direct light source such as an incandescent bulb indoors, to a very diffuse light source, such as outdoors on an overcast day. Your readers can compare a compact disk, a labradorite and opal cabochon, and a shell sample; in diffuse light iridescence due to a surface grating becomes very weak, while that due to internal layered structures remains strong. When we perform this test on a variety of shells the iridescence remains strong in diffuse light. Such observations lead us to conclude that internal layering as opposed to surface diffraction is the primary, but not necessarily the only, cause of iridescence in many shells.

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Snow and Pring (2005) in their study of abalone attribute the colour to Bragg diffraction in the layered structure of the nacre. Additionally, they show by sputter coating the abalone surface with gold, which would preserve a surface grating, that the iridescence was mostly lost. Clearly showing that surface effects didn't contribute to the colour. Similar methods should be done on the abalone studied by Tan, Wong and Lee.

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Response from Dr T.L. Tan

The valuable comments and suggestions of D. B. Hoover and B. Williams are truly appreciated, and have prompted me and my co-authors to carry out further studies on the iridescent colours on the shell. These are discussed below.

Internal microscopic structure of the abalone shell by SEM

The structure of the abalone shell below its surface is examined at 3000x magnification using a scanning electron microscope (SEM). The micrograph of a cross-section of the shell reveals a regularly layered microstructure composed of nacreous aragonite platelets, separated by a thin layer of conchiolin. The thin conchiolin layers are not as obvious as the thicker aragonite layers. Preliminary measurements of the aragonite layers at various cross-sections of the shell give the thickness of the layer to be about 1.0 µm. Further measurements of the thickness of the layers will be accurately made and analysed.

Iridescent colours caused by Bragg diffraction in the layered structure

Due to the layered structure of the aragonite nacre, multilayer interference has been considered to be a possible cause of iridescence (Nassau, 2001). Furthermore, the stacks of identical layers can form a three-dimensional diffraction grating which can cause iridescent colours, in accordance with Bragg's law (Nassau, 2001). As mentioned by Hoover and Williams, Snow and Pring (2005) had explained the blue-green iridescent colours in the abalone (Haliotis *iris*) shell using Bragg diffraction. In this abalone species, the thickness of the aragonite layer is 0.25 to 0.39 µm. They also studied two other species of abalone. The Bragg equation $n\gamma = 2ud\sin\theta$ was used. We will attempt to explain the iridescent colours of the abalone (Haliotis *glabra*) shell of this work using the Bragg equation. Further experimental studies on the colours of the shell at various diffraction angles will be needed to better understand the mechanism of Bragg diffraction in the layered structure of the shell of this abalone species.

Contribution to iridescent colours by diffraction from surface grating structure

To understand the possibility of iridescent colours arising by surface diffraction from the grating structure of the shell, we will be coating a thin layer of gold using the sputtering method as done by Snow and Pring (2005), and as suggested by Hoover and Williams. The opaque gold layer would preserve the surface grating structure and prevent transmission of colours from the layered structure below the surface. However, gold has a strong yellow tint which may mask the iridescent colours. We will explore the use of platinum as a coating material.

Discussion

Hoover and Williams suggested that we look at the intensity of iridescent colours on the shell as it is moved from direct light to diffused light, and this experiment was conducted on a few abalone shell samples. We found that the iridescent colours remain unchanged under both types of light in agreement with that observed by Hoover and Williams. This shows that the internal layered structure contributes partly or significantly to the iridescent colours on this shell. In a study on abalone shell, Snow and Pring (2005) attributed the colours primarily to Bragg diffraction in the layered structure of the nacre. On the other hand, Liu, Shigley and Hurwit (1999) investigated the colours on the shell of the black-lipped

oyster and concluded that strong iridescent colours on the shell were caused mainly by surface diffraction from the regular reflection grating structure of the shell. It is obvious that the surface grating structure was the result of fine polishing of the shell which has an internal layered structure. Therefore the question of whether the iridescence shown by abalone shell or other shells may be caused by surface diffraction and/or multilayered Bragg diffraction or interference remains to be investigated.

We fully agree with the suggestion of Hoover and Williams to further investigate the contribution of diffraction and/or interference due to the internal layered structure to the iridescent colours of abalone shell. We will be working on this and will report the results of investigations in the near future.

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Abstracts

Diamonds

[The mutual relation between the angle and direction of the incident ray on the crown main facet and of the radiation ray from the facing crown main facet.]

M. Kato. *Journal of Gemmological Society of Japan*, 23(1-4), 2002, 22-5, 3 *figs (in Japanese with English abstract)*.

This is the fifth paper concerning mathematical analyses of optical paths through a cut stone. In this paper, the mutual relation of the facing crown main facets are developed from the analyses given in previous papers. First, relating to the optical path inside a stone, a fancy crown angle is estimated from incident orientation, crown angle and radiant side. Then the incident ray and emerging ray are drawn from several refraction angles. Two figures are presented to show the radiant angle calculated factors against incident orientation. I.S.

Characterization and grading of natural-color yellow diamonds.

J.M. King, J.E. Shigley, T.H. Gelb, S.S. Guhin, M. Hall and W. Wang. *Gems & Gemology*, 41(2), 2005, 88-115.

The analysis of data collected over a five-year period on more than 24,000 natural-colour yellow diamonds is reported, including colour-grade, type of cut, clarity grade, weight, UV fluorescence and UV-visible and IR spectra. Among natural-colour diamonds, those with a yellow hue are some of the most abundant, although they are much less common than the colourless to light yellow diamonds associated with the GIA's D-to-Z colour grading scale. Since the yellow colour is a continuation of the gradation of colour associated with this scale, there can be misconceptions about the colour grading which involves appearance, as well as other characteristics of yellow diamonds. The grading and appearance aspects are discussed to clarify these differences. Five sub-groups of type I yellow diamonds are also identified, which (with some overlap) are characterized by representative spectra and colour appearances. R.A.H.

Lab Notes.

T.M. Moses and S.F. McClure (Eds). *Gems & Gemology*, 41(2), 2005, 16475.

Notes are given on a natural fancy dark pink-brown type Ib diamond with an unusually high nitrogen content. R.A.H.

Lab notes.

T.M. Moses and S.F. McClure (Eds). *Gems & Gemology*, 41(3), 2005, 256-63.

Notes are included on dyed rough diamond crystals, two strongly coloured natural type IIb blue cut diamonds which showed strong red phosphorescence after exposure to short-wave UV radiation in DiamondView, and a greenish-blue 19.66 ct cut stone of yttrium zirconium oxide resembling a high-quality zircon. R.A.H.

Diamonds from the Udachnaya pipe, Yakutia.

V. Rolandi, A. Brajkovic, I. Adamo and M. Landonio. *Australian Gemmologist*, 22(9), 2006, 387-97, 15 illus, 1 map.

This study of ten rough diamonds from the Udachnaya mine in the Sakha Republic of Yakutia includes descriptions of their morphology, surface and internal features, FTIR absorption spectra and CL topography. The diamond specimens ranged in weight from 0.066 to 0.622 ct and were greyish-yellow to brownish orange-yellow in colour. The paper contains a description of the geological setting of the Siberian platform and details the exploration of Siberian diamond deposits initiated by Professor V. Sobolev. In 1937 Sobolev predicted that diamonds might be found in the Siberian cratonic area after comparing the Siberian geological conditions to those of the Karoo formation in South Africa. P.G.R.

Diamants cubiques ou presque cubiques: definitions utiles sur la morphologie.

B. Rondeau, E. Fritsch, M. Moore and J.F. Sirakian. *Revue de Gemmologie AFG*, 153, 2005, 13-16.

Review of cubic or near-cubic diamond crystals with observations on their morphology. M.O'D.

A review of political and economic forces shaping today's diamond industry.

L. Shor. *Gems & Gemology*, 41(3), 2005, 202-33.

During the past 15 years, political and economic forces have converged to transform radically the structure of the diamond industry worldwide. Upheavals in the former Soviet Union and several African nations – as well as the development of new sources such as in Australia and Canada – led to restructuring of the rough diamond market. This in turn created new competitive pressure at the wholesale and retail levels, including a movement to establish new diamond cuts and diamonds as branded items. At the same time, technological advances enabled the faster, more efficient manufacturing of rough diamonds, created new treatments and fostered the introduction of economically viable gem-quality synthetic stones. While demand for diamond jewellery remains strong in the United States, which accounts for nearly 50% of world consumption, new markets such as India and China are likely to spearhead continued growth. New social and governmental initiatives have affected how the entire industry conducts business. R.A.H.

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Gems and Minerals

Amber-like fossil resin from North Queensland, Australia.

D.M. Colchester, G. Webb and P. Emseis. *Australian Gemmologist*, 22(9), 2006, 378-85, 8 illus, 1 table.

Although Australia is practically devoid of fossil resin occurrences, recently pieces of amber-like fossil resin have been found on remote beaches near Cape Weymouth on the east coast of Cape York Peninsula in north Queensland. The Cape Weymouth specimens, which range in colour from clear pale yellow to almost opaque dark brown, were examined for their appearance and inclusions. They were then subjected to standard gemmological tests to discriminate between amber and copal resin. The fossil resins were found to be stable to semi-stable and therefore suitable for gemmological purposes, while the insect inclusions were considered to be of scientific importance. The specimens were also checked using FTIR spectroscopy and their spectra were found to be broadly similar to that of kauri gum (a copal resin) and to Baltic amber but were sufficiently different in the finer detail to have their own distinctive signature. The paper includes a classification of names applied to fossil resins and Anderson and Crelling's fossil resin classification. P.G.R.

The Devonshire mineral collection at Chatsworth House.

M.P. Cooper. *Mineralogical record*, 36, 2005, 239-72.

Specimens of gem and ornamental quality minerals form part of the Devonshire collection at Chatsworth House, Derbyshire, England. The paper describes the progress and successful completion of a cataloguing and conservation programme. M.O'D.

Gemmologisch-lagerstättenkundliche Untersuchungen an Türkisen aus magmatischen und sedimentären Kupfererzvorkommen.

H.G. Dill and U. Henn. *Gemmologie. Z. Dt. Gemmol. Ges.*, 54, 2005, 85-96, 20 photographs, bibl.

Turquoise is a copper aluminium phosphate with a wide range of other elements, either in the unit cell, or as inclusions. Cu-Al phosphates are found in either the top layer of phosphate bearing sedimentary rocks or in Cu bearing metal deposits of magmatic origin. The present investigations did not discover any significant differences among the trace elements and minor inclusions which could be related to their parent rock. High resolution techniques have shown that the separation of elements of turquoise from its trace elements may have occurred when late stage fluids percolated through the matrix mineral. E.S.

Emeralds from the Panjshir Valley (Afghanistan).

J. Fijal, W. Heflik, L. Natkaniec-Nowak and A. Szczepaniak. *Gemmologie. Z. Dt. Gemmol. Ges.*, 53(4), 2004, 127-42, 8 photographs, 5 diagrams, 3 tables, bibl.

The emerald crystals examined came from the Panjshir valley in Afghanistan, probably from the southern mines. The mines are situated at 3-4000 m above sea level and are the highest emerald mines in the world. They are accessible by dirt tracks. The mining is intermittent, unsystematic and of limited range. The mines consist of systems of tunnels and small shafts opened in hard marbles using explosives. Afghan emeralds vary from dark to light green, the latter with various tints from yellow to blue. They were examined by microscopy and by chemical, X-ray and infrared spectroscopic analyses. The authors concluded that the emeralds from Panjshir valley were most probably the result of metasomatic alterations associated with regional metamorphism initiated by tectonic changes. E.S.

Prächtige Bilder jaspise von der Morrison Ranch in Oregon.

H. Gamma. *Mineralien Welt*, 16(6), 2005, 66-72.

Ornamental quality jasper is described from the Morrison Ranch in the Owyhee River Canyon, Oregon, U.S.A. M.O'D.

Gemmologische Kurzinformationen. Tansania- Mondstein: Albit (Peristerit) mit blauem Flächenschimmer.

U. Henn. *Gemmologie. Z. Dt. Gemmol. Ges.*, 54(2/3), 2005, 114-7, 4 photographs, 1 table, bibl.

Since mid 2004 transparent adularescent feldspars from Tanzania have been offered on the market. Physical and chemical properties are given. The blue adularescence is due to Tyndall scattering. Under the microscope the moonstones show white, parallel needle-like inclusions. E.S.

Gemmologische Kurzinformationen. Gemmologische Untersuchungen an Korunden aus Pakistan.

U. Henn and C.C. Milisenda. *Gemmologie. Z. Dt. Gemmol. Ges.*, 54(2/3), 2005, 111-4, 8 photographs, bibl.

The article describes properties of pink to pink-red and pink-blue bi-coloured corundum from recent finds in Kohistan and the Neelum valley in Pakistan. The pinks show a Cr spectrum, while the blue parts show the Fe^3 and Fe^2 Ti^4 spectrum. RI, birefringence and SG are in the normal corundum range. Healing cracks and lamellar twinning are typical internal features. Additionally there are rutile needles arranged in the form of star shapes. E.S.

Türkis – Eigenschaften und Vorkommen, Imitationen und künstliche Eigenschaftsveränderungen.

U. Henn and C.C. Milisenda. *Gemmologie. Z. Dt. Gemmol. Ges.*, 54(2/3), 2005, 97-110, 11 photographs, 1 table, 6 graphs, bibl.

Turquoise is one of the oldest known gemstones. It has been known by this name since about 1550 because it was mainly traded via Turkey. It is mostly found in porous aggregates. Chemical and physical properties are given. The oldest occurrence was Egypt, where it was known 5000 years ago. 2000 years ago it was found in Iran, other finds are in South West U.S.A., Mexico, Hubei province in China, Uzbekistan, Kazakstan and the Umba valley in Tanzania.

Because of its high porosity it is often impregnated with various organic substances, enhancing the colour and allowing a better polish. Reconstructed turquoise is constructed from small pieces which are powdered and pressed into blocks with or without matrix. It is imitated by a number of different minerals such as ceruleite, or by dyed minerals. Identification of opaque gemstones is difficult, infrared spectroscopy is a useful tool. E.S.

The identification of impregnated nephrite.

L. Jianjun. *Australian Gemmologist*, 22(7), 2005, 310-17, 9 illus., 2 maps, 2 tables.

Among all the jades revered by the Chinese, white nephrite from the Hetian County in China's Xinjiang province is considered to be the top grade and the most popular. Unfortunately this white Hetian nephrite is becoming worked out and is being replaced with less costly white nephrite from Russia and the Qinghai province in China. Recently this alternative material, bleached (to remove iron oxide stains) and impregnated (with epoxy resin) to imitate the Hetian white nephrite, has appeared on the market. Research by the author has suggested that the best way that these treated nephrites can be positively identified is by the use of the infrared spectrometer; the paper describes this method. P.G.R.

The adverse impact of scatter on the tone of Shandong sapphire.

L. Jianjun. *Australian Gemmologist*, 22(9), 2006, 408-11, 3 illus.

Theoretical analysis of the results from the photometry and colorimetry of sapphires from Shandong in the Peoples Republic of China has shown that the large number of micro-inclusions present in these gems have a scattering effect on any light incident on the stones. Attempts to enhance the colour of the Shandong sapphires by heat treatment is only effective in 10% of the material as the heating creates additional stress fractures and increases the scattering effect. P.G.R.

A gemological pioneer: Dr Edward J. Gübelin.

R.E. Kane (*finegemsintl@msn.com*), E.W. Boehm, S.D. Overlin, D.M. Dirlam, J.I. Koivula and C.P. Smith. *Gems & Gemology*, 41(4), 2005, 298-327.

This paper gives a detailed account of the work of the late Dr Gübelin (1913-2005) of Switzerland who, during a career that spanned more than 65 years, built a monumental reputation as a gemmologist. He wrote extensively on nearly all aspects of gemmology and produced more than 250 articles and 13 major books. He established the first systematic classification of inclusions in natural gem materials and demonstrated the importance of these internal features in determining not only the identity of the gemstone but also its country of origin. This account is accompanied by 29 photographs (including one with Basil Anderson) reflecting various aspects of his work. R.A.H.

[Natural amethysts from Caxarai mine, exhibiting infra-red absorption at 3543 cm^{-1}.]

H. Kitawaki. *Journal of Gemmological Society of Japan*, 23(1-4), 2002, 16-21, 10 figs (in Japanese with English abstract).

The IR peak at 3543 cm^{-1} has been used as a diagnostic peak to discriminate synthetic from natural amethysts with synthetic amethyst showing the peak, whereas the natural stones do not. This paper reports the occurrence of natural amethyst which shows this peak. The amethysts occur possibly in a pegmatite at Caxarai mine, Rondonia State, Brazil, 130 km north of Porto Velho, the state capital. The amethysts show characteristically different features from those occurring in geodes in basalt lava flows. Their *z* $\{01\bar{1}1\}$ growth sectors show a deeper amethyst colour and sharper growth zoning than *r* $\{10\bar{1}1\}$ growth sectors. This is opposite to the ordinarily observed characteristics in natural amethysts from hitherto known localities. The amethysts sometimes show strongly bluish pleochroism. Brazil twinning associated with Dauphine twinning and showing conical forms, often encountered in synthetic amethyst, is a pattern also present in some Caxarai specimens. I.S.

[Light interference phenomena observed in pearls with pale and dark colour and the measurement.]

H. Komatsu, C. Susuki, and S. Ogura. *Journal of Gemmological Society of Japan*, 23(1-4), 2002, 5-15, 28 figs (in Japanese with English abstract).

The beauty of pearls comes from 'teri', a Japanese term to express the combined effect of lustre and interference colours seen in pearls. 'Teri' is not a simple equivalent to lustre, but appears due to light interference from the textures of pearls. Thus, pearls of different colours exhibit different 'teri'. 'Teri' exhibited by pale pearls such as Akoya pearls, appears phenomenologically opposite to that exhibited by dark pearls such as kurocho. Based on theoretical analysis of 'teri', optical methods combined with computer evaluation are designed to quantitatively evaluate the 'teri' of pearls in the series of dark and pale coloured pearls. I.S.

[A note on the relationship between the origin of "teri" and nacreous layer structure.]

H. Komatsu, and J. Yazaki. *Journal of Gemmological Society of Japan*, 24, 2004, 24-8, 12 figs (in Japanese with English abstract).

The thickness of single aragonite layers and regularity in their stacking in both dark and pale coloured pearls have been measured by SEM observations and the results are correlated with the brightness of 'teri', the surface interference seen when a pearl is radiated by direct light from above. It was shown that the colour relates to the thickness and the brightness to the regularity of the aragonite layers. It was also shown that organic mechanisms in the environment surrounding the pearl sac control the thickness and regularity of these layers. I.S.

[Interference of light in upper and lower hemisphere of a pearl. An "Aurora" effect.]

H. Komatsu and C. Suzuki. *Journal of Gemmological Society of Japan*, 24(1-4), 2004, 29-37, 27 figs (in Japanese with English abstract).

The origin and mechanism of the 'Aurora' effect, an interference

colour appearing on the lower half of a pearl sphere when it is irradiated by diffused light from below, is analysed and related to 'teri', an interference phenomenon appearing on the upper surface when it is illuminated from above. An apparatus called an Aurora Viewer was constructed, and the interference colour is quantitatively measured from the centre to the periphery of a sphere for dark and pale coloured pearls. It was shown that there is a qualitative correlation between the 'Aurora effect' and 'teri'. I.S.

The pegmatic gem deposits of Molo (Momeik) and Sakhan-gyi (Mogok).

U.H. Kyi, T. Themelis and U.K. Thu. *Australian Gemmologist*, 22(7), 2005, 303-9, 11 illus., 2 maps, 5 tables.

Molo is situated in a remote area 51 km north-east of Momeik in Myanmar's Shan State. Its alluvial sediments are a new source of many rare gemstones and minerals (such as phenakite, petalite, hambergite, Cs-rich morganite and pollucite) as are the pegmatite dykes that are intruded into the peridotite country rock. The pegmatite deposit at Sakhan-gyi is located 16 km west of Mogok (in Mandalay Division) and for more than 100 years has been the main source in Myanmar of aquamarine, goshenite, topaz, quartz and danburite. The paper discusses these two pegmatite deposits and concludes that by their intrusive nature and mineral assemblages they are not contemporary. P.G.R.

A new deposit of jeremejevite from the Mogok stone tract, Myanmar.

U.H. Kyi and U.K. Thu. *Australian Gemmologist*, 22(9), 2006, 402-405, 6 illus., 3 tables.

Although purchased by the authors in Mogok as quartz and beryl specimens, these colourless and light yellow terminated prismatic crystals were found to be jeremejevite, one of the world's rarest gemstones. The paper lists the constants of jeremejevite and provides the confirmatory XRD and EDX-RF identification data for this material. It is possible that further discoveries of gem quality jeremejevite in the Mogok stone tract could make it a gemstone of interest to gemmologists and gem collectors. P.G.R.

Gem news international.

B.M. Laurs (Ed.) (*blaurs@gia.edu*). *Gems & Gemology*, 41(2), 2005, 176-87.

Items mentioned include pyrope-almandine from Ethiopia, inclusions of orange spessartine in Bolivian obsidian, a brownish-yellow synthetic sapphire from Jaipur, and a natural 8.01 ct faceted ruby with lead glass-filled fractures and other glass-filled rubies making their appearance from laboratories in the Middle East. R.A.H.

Gem news international.

B.M. Laurs (Ed.) (*blaurs@gia.edu*). *Gems & Gemology*, 41(3), 2005, 264-79.

Items mentioned include a fuchsite-corundum-alkali feldspar rock from near Serra de Jacobina in northern Bahia, Brazil; pinkish-orange to purple sapphires from a new locality in the Kurur area of Tamil Nadu, India; a tenebrescent scapolite from Afghanistan, changing from colourless to blue on exposure to UV radiation; a quartz cabochon from Paraiba, Brazil, containing blue clusters of gilalite fibres; and a fibrolite (sillimanite) dyed and impregnated to imitate ruby. R.A.H.

Gem news international.

B.M. Laurs (Ed.) (*blaurs@gia.edu*). *Gems & Gemology*, 41(4), 2005, 350-69.

Details are given of a blueschist (blue glaucophane, green omphacite and red garnet) from the lower Aosta Valley of the Western Italian Alps which takes a good polish and is sold as an ornamental material and cut into cabochons. Other items include a 68.55 ct bright greenish-yellow grossular from East Africa, green orthoclase from Vietnam, a nearly transparent bright green feldspar from Mogok and bright orange-red cut stones of plagioclase from Tibet. A new discovery of the rare mineral painite in situ at Thurein-taung and at the Wetloo mine near Mogok is reported, which has yielded more than 167 faceted stones (0.05–0.30 and rarely to 2 ct). R.A.H.

Jaspisvarietäten aus dem Eibenstocker Granit, Sachsen.

U. Lehmann. *Lapis*, 30(11), 2005, 34-40.

Ornamental deep red jasper is described from granite at Eibenstock, Saxony, Germany. M.O'D.

Chinese cinnabar.

G. Liu. *The Mineralogical record*, 36, 2005, 69-80.

Cinnabar is more likely to turn up in the mineral cabinet than as an ornament despite its magnificent red colour and its translucency, but fashioned specimens are known. The main mining districts are identified and described. M.O'D.

Le traitement des corindons du béryllium: une mise au point.

S.F. McClure. *Revue de gemmologie AFG*, 153, 2005, 4-7.

Summary in French, with adaptations and additional photographs, of a paper first published in *Gems & Gemology*, 38(3), 2002, 255-6. M.O'D.

Gemmologie Aktuell.

C.C. Milisenda. *Gemmologie. Z. Dt. Gemmol. Ges.*, 53(4), 2004, 123-6.

The author describes briefly a transparent, yellowish-green tremolite-actinolite from Pakistan and some pink to red spinels from Tanzania weighing approx. 0.3 g each. There is also a description of a colour-change (blue to purple-violet) sapphire from the Luc Yen region of Vietnam weighing 2.21 ct and a 27.60 ct star sapphire from Laos; the asterism was caused by healing cracks and orientated dust-like mineral inclusions. From Tanzania a glass was offered as tanzanite. Another glass with an RI of 1.81 was offered as peridot. E.S.

"Paraiba-Turmaline" aus Quintos de Baixo, Rio Grande do Norte, Brasilien.

C.C. Milisenda. *Gemmologie. Z. Dt. Gemmol. Ges.*, 54(2/3), 1005, 73-84. 1 map, 9 photographs, 2 tables, 1 graph, bibl.,

Paraiba tourmalines occur in pegmatities near the village of Soa in the Paraiba state and in two other sites in the neighbouring Rio Grande do Norte state. One of those is the Quintos de Baixo mine, about 45 km northeast of Sao Jose de Batalha. Originally this produced commercial beryls and they were joined by tourmalines in 1996. Twelve samples were analysed by electron microprobe. They showed typical elbaite composition with the copper and manganese being the most

important trace elements responsible for the bright blue to green colours. E.S.

Gemmologie Aktuell.

C.C. Milisenda. *Gemmologie. Z.Dt. Gemmol.Ges.*, 54(2/3), 2005, 63-72, 16 photographs.

A new source of cuprian tourmalines has been discovered near Alto Ligonha in Mozambique. The stones weighed between 1 and 6 ct each and showed the characteristic absorption bands for copper and manganese. A translucent brownish-yellow chrysoberyl cat's-eye from Sri Lanka weighing 8.65 ct yielded SG 3.772 and RI 1.75. It showed parallel orientated tubes as well as short, needle-like inclusions orientated in a second direction. Both these inclusions are responsible for the asterism. Nine red, violet and purple stones from Rakwana in Sri Lanka were examined. They are star spinels and weighed between 1.91 and 4.95 ct. Eight showed a six-rayed star, while one exhibited a four-rayed star. A faceted, cushion-shaped sapphire from Madagascar weighing 2.19 ct showed all the usual properties, but was found to be colour-changing from green in daylight to reddish-brown in incandescent light. Under the microscope the stone showed numerous small zircon crystals. The absorption spectrum showed iron, chromium and vanadium. Other stones reported on included colour-change garnets from Madagascar. The stones changed from bluish-green in daylight to reddish-violet in incandescent light. RI 1.765, SG 3.9. Amethyst-coloured and colourless quartz from an occurrence near Karoor in southern India contained numerous hematite inclusions. Olive to brownish-green kornerupine cat's-eyes from Sri Lanka were examined as were some translucent blue rough anhydrite from Peru, RI 1.575, SG 2.93, hardness 3.5. There is also a report on a new find of aquamarines from Sao Jose de Safira in Valadares, Minas Gerais, Brazil. Spodumene from Pakistan has been offered in the trade. One of the hiddenites weighing 9.19 ct showed an intense green colour which was shown to have been produced by irradiation; the colour, however, faded on exposure to light, becoming pale pink. If kept in the dark the colour seemed more constant. A lot of faceted red stones which had been purchased in Afghanistan as rubies were identified as dyed sillimanite (fibrolite). The red colour was concentrated in cracks and pores between individual fibres. E.S.

Hydrophanopal aus Indonesien.

C.C. Milisenda and M. Wild. *Gemmologie. Z. Dt. Gemmol. Ges.*, 53(4), 2004, 169-72, 5 photographs, bibl.

Hydrophane opals are porous and with increased absorption of liquids show increased diaphaneity and colour play. The examined samples came from Java and weighed between 0.96 and 12.05 ct. They were black, greyish-brown, brown to orange, some showing attractive play of colours. When immersed in water, they increased between 2 and 25% in weight. One opaque to translucent specimen weighing 0.96 ct, brownish-orange, showed a vivid play of colour; immersion in water caused the play of colour to disappear and the weight to increase to 1.24 ct. When taken out of water the colours disappeared and the stone became opaque, however after a few minutes, the play of colours returned; the stone then weighed 1.15 ct, eventually reducing to 1.00 ct with attractive colour play. E.S.

Inclusions in transparent gem rhodonite from Broken Hill, New South Wales, Australia.

P.W. Millsteed, T.P. Mernagh, V. Otieno-Aliego and D.C. Creagh. *Gems & Gemology*, 41(3), 2005, 246-54.

Solid, vapour and fluid inclusions in transparent rhodonite crystals from Broken Hill have been identified by Raman spectroscopy and gemmological/petrographic techniques. Among the solid inclusion are sphalerite, galena, quartz and fluorite. The rhodonite also contains hollow needle-like tubes and negative rhodonite crystals. Three-phase inclusions were found to contain a saline liquid, a gaseous mixture of N_2 and CH_4, and ilmenite crystals. R.A.H.

What's new in minerals.

T.P. Moore. *Mineralogical Record*, 36, 2005, 285-301.

Among unusual and potentially gem-quality specimens reported from mineral shows are a crystal of väyrynenite, red-orange, near transparent, from Shengus, Gilgit District, Northern Areas, Pakistan, and red-orange transparent to translucent triplite, 1 cm, from Alchuri, Shigar Valley, Baltistan, Pakistan. A chrome-green hiddenite crystal of 6.7 cm is described and illustrated from Hiddenite, NC, U.S.A. Other ornamental gem-quality crystals from the United States include aquamarine crystals from Mount Antero, Chaffee County, Colorado. M.O'D.

Lab Notes.

T.M. Moses and S.F. McClure (Eds). *Gems & Gemology*, 41(2), 2005, 16475.

Notes are given on a yellowish-orange magnesioaxinite from Tanzania and Cu-bearing (CuO up to 0.09 wt %) colour-change tourmaline from Mozambique. R.A.H.

Lab notes.

T.M. Moses and S.F. McClure (Eds). *Gems & Gemology*, 41(4), 2005, 340-8.

Notes given included a diaspore 'vein' in a 3.96 ct natural sapphire. R.A.H.

Chinese fluorite.

B. Ottens. *The Mineralogical Record*, 2005, 36, 59-68.

Fine ornamental and gem-quality Chinese fluorite has been known for many years. Locations and examples are described; most specimens are reported to be oiled. M.O'D.

Tongbei.

B. Ottens. *The Mineralogical record*, 2005, 36, 35-43.

Fine crystals of spessartine and smoky quartz are described from granite outcrops in Fujian Province, China. Tongbei is the local centre. M.O'D.

Xueboading.

B. Ottens. *The Mineralogical record*, 2005, 36, 45-57.

Fine orange scheelite and aquamarine are among minerals found in the Mount Xueboading area of Sichuan Province, China. M.O'D.

Mining in China.

B. Ottens. *The Mineralogical record*, 2005, 36, 4-11.

Brief account of discoveries and personalities concerned with mining in China during the past 300 years. M.O'D.

Gemstone resources in China.

C.M. Ou Yang. *Australian Gemmologist*, 22(8), 2005, 349-59, 18 illus., 6 maps, 2 tables.

The People's Republic of China is a large country that has a very complex geological structure. Its ancient land mass is host to vast, largely untapped, reserves of gemstones. The author describes and illustrates the occurrences and localities of a range of gemstones which are relatively common in China. These include diamond, sapphire, ruby, emerald, aquamarine, tourmaline, quartz, garnet, peridot, nephrite and bowenite. P.G.R

Use of IR-spectroscopy and diffraction to discriminate between natural, synthetic and treated turquoise, and its imitations.

A. Pavese, L. Prosperi and M. Dapiaggi. *Australian Gemmologist*, 22(8), 2005, 366-71, 3 illus., 4 tables.

A total of 94 samples of natural, synthetic, treated and imitation turquoise samples were analysed by infrared spectroscopy in the non-destructive reflectance mode. Treated turquoise specimens were also studied in the IR transmission mode. With some of the imitations it was necessary to resolve ambiguities by the use of non-destructive X-ray diffraction. P.G.R.

Un nouvel outil géochimique de reconnaissance des saphirs bleus basaltiques et métamorphiques: le rapport Ga/Mg .

J-J. Peucat, P. Ruffault, E. Fritsch, C. Simonet, M. Bouhnik-le-Coz and B. Lasnier. *Revue de gemmologie AFG*, 153, 2005, 9-12.

Basaltic blue sapphires may be distinguished from their metamorphic counterparts by a study of their respective Ga/Mg ratio. Two types of sapphire are distinguished; specimens from syenites and alkali basalts, with a Ga/Mg ratio and sapphires from metamorphic hosts or plumasites where the ratio is lower. M.O'D.

New finds of sapphire placer deposits on Nosy-Be, Madagascar.

R. Ramdohr and C.C. Milisenda. *Gemmologie. Z. Dt. Gemmol. Ges.*, 53(4), 2004, 143-58, 14 photographs, 1 map, 4 diagrams, bibl.

There are many corundum occurrences in northern Madagascar. Late Mesozoic basaltic extrusions have transported many xenocrysts, now to be found in various placer deposits. A new deposit is Nosy-Be and this is compared with occurrences on the Ambato peninsula and at Ambilobe, both north-east Madagascar. Sapphires are mainly found in the alluvium of small creeks. Searching and exploitation is largely by local villagers, who mine selected creek beds. The size of the deposits does not warrant large scale mining. The bulk of the material found is opaque corundum, some of which can be enhanced by heat treatment. E.S.

Gem corals – classification and spectroscopic features.

V. Rolandi, A. Brajkovic, I. Adamo, R. Bocchio and M. Landonio. *Australian Gemmologist*, 22(7), 2005, 285-97, 12 illus., 2 tables.

Until the beginning of the eighteenth century the origin of coral was unknown, and it was not until 1723 that G.A. Peyssonel demonstrated that corals are formed from the skeletons of marine animals. This paper analyses several gem corals belonging to the classes Hydrozoa and Anthozoa of the phylum Cnidaria. Identification of gem-quality corals requires a sequence of scientific investigations including the study of surface structures, the distribution of colour and the determination of physical data. Both FTIR- and Raman-spectroscopy have been shown to be useful tools for analyzing the mineral phases (calcite or aragonite) and the chromophore composition of each coral. With the use of both methods the characterization of genera and species of Cnidaria that have gem potential have been shown to be possible. P.G.R.

Kosmochlor and chromian jadeite aggregates from the Myanmar jadeitite area.

G.H. Shi (*shiguanghai@263.net.cn*), B. Stöckhert and W.Y. Cui. *Mineralogical Magazine*, 69(6), 2005, 1059-75.

Four distinct textures and related compositions of kosmochlor and chromian jadeite are described from rocks in the Myanmar jadeitite area. One of these four textures involves recrystallized fine-grained aggregates in deformed jadeite. The concomitant redistribution of chromium from chromite into kosmochlor, chromian jadeite and finally jadeite with < 1 wt % Cr_2O_3, together with the high transparency related to the fine-grained microstructure, produces the gemmologically important green jadeite. R.A.H.

[Investigation of corundum heat treated by a new technique.]

J. Shida, H. Kitawaki and A. Ahmadjan. *Journal of Gemmological Society of Japan*, 24(1-4), 2004, 13-23, 12 figs, 3 tables (in Japanese with English abstract).

To clarify what sort of treatment is applied to produce sapphire showing intense orange-pink hue, which has recently appeared in the gem market, various characterization techniques are applied to suspect stones. In addition to ordinary gem testing methods, internal and surface features were investigated by laser tomography and SEM, element distributions in stones were determined by EDXRF, SIMS, LA ICP, XPS, etc. In the new technique, only those sapphires coloured pink by initial heat treatment are subjected to a second heat treatment together with chrysoberyl in aluminium crucibles. It was confirmed that the main cause of the observed colour change is diffusion of Be inwards from the surface. I.S.

Mt. Mica: a renaissance in Maine's gem tourmaline production.

W.B. Simmons, B.M. Laurs, A.U. Falster, J I. Koivula and K. L. Webber. *Gems & Gemology*, 41(2), 2005, 150-63.

The Mt. Mica area in south-western Maine has been mined for tourmaline and other pegmatite gems since the 1820s, with most of the tourmaline production occurring during the late 1880s to the 1910s, with only occasional finds made from

the 1960s to the 1990s. Since May 2004, however, a new mining venture has produced gem- and specimen-quality tourmaline in a variety of colours. The faceted stones typically are yellowish green to greenish blue, although pink and bi- or tri-coloured stones have been cut. Their gemmological properties are typical for gem tourmaline. Microprobe analyses show that the tourmaline mined from pockets at Mt. Mica predominantly fell in the elbaite field, but minor amounts of schorl, foitite and rossmanite also occur. R.A.H.

Klare Bergkristalle aus dem Norden Islands.

H. Steen. *Lapis*, 30(11), 2005, 30-34.

Well-formed clear quartz crystals and accompanying minerals are described from deposits in northern Iceland. M.O'D.

From the laboratory.

Tay Thye Sun. *Australian Gemmologist*, 22(9), 2006, 406/7, 6 illus.

The author reports on two unusual items of gemmological interest that were submitted for testing to his Far East Gemological Laboratory in Singapore. The first of these consisted of two octahedral 'diamond' crystals purchased by a client in Madagascar. Standard gemmological tests proved that one of these crystals was topaz and the other was colourless cubic zirconium oxide. The CZ diamond imitation was the more convincing but lacked trigons on its octahedral faces. The second item was a 3.76 ct Burmese ruby whose surface-reaching fractures and cavities were filled with a waxy substance. FTIR spectroscopy identified wax peaks at 2923 and 2855 cm^{-1}. Subsequently the author examined a 14 ct natural ruby which was also wax-filled in a similar way. P.G.R.

Glass filled rubies: clarity-enhanced rubies with glass-forming additives.

T. Themelis. *Australian Gemmologist*, 22(8), 2005, 360-5, 10 illus., 1 table.

The successful filling of surface-reaching fractures in diamonds was first reported in 1982 by Israeli diamond cutter Zvi Yehuda. At the time the exact nature of the filler was unknown and the process was often used following laser drilling. By1990 several firms had started providing this service to the diamond industry. In 2004 a series of experiments were performed at the author's gem treatment laboratory in Bangkok using rubies at relatively low to mid range temperatures of 900-1300 C. Details of the process used are given including the selection of the starting material, the preparation of the rubies prior to treatment, selection of additives and the selection of heating parameters. Characteristic identifying features are given and the paper concludes with some cautionary words on the process, a warning on potential health hazards and a note on the need for disclosure at every level of gem merchandising. P.G.R.

Unverhofft kommt oft: Amethyst aus dem mattital, Wallis.

P. Winkler. *Lapis*, 30(10), 2005, 69.

Crystals of amethyst are described from the Mättital, Valais, Switzerland. M.O'D.

Emeralds from the Kafubu area, Zambia.

J.C. Zwaan, A.V. Seifert, S. Vrana, B.M. Laurs, B. Anckar, W.B. Simmons, A.U. Falster, W.J. Lustenhouwer, S. Muhlmeister, J.I. Koivula and H. Garcia-Guillerminet. *Gems & Gemology*, 41(2), 2005, 116-48.

After Colombia, Zambia is considered as the world's second most important source of emeralds (by value). Most of the emeralds are being mined from large open pit operations in the Kagern, Grizzly and Chantete concessions, near the Kafubu River in the Ndola Rural Restricted Area. The economic emerald mineralization is confined almost entirely to phlogopite reaction zones adjacent to Be-bearing quartz-tourmaline veins that have metasomatically altered Cr-bearing metabasite host rocks. The Zambian emeralds have relatively high refractive indices (n_e 1.591, n_o 1.599), high birefringence (0.006–0.009) and specific gravity (2.71–2.78), with inclusions typically consisting of partially healed fissures, as well as actinolite, phlogopite, dravite, fluorapatite, magnetite and hematite. Electron microprobe analyses indicate moderate amounts of Cr, Mg and Na, moderate-to-high Fe and relatively high Cs and Li. Their physical properties, microscopic characteristics and chemical compositions should in many cases allow the Zambian emeralds to be distinguished from those from other commercially important localities. R.A.H.

Instruments and Techniques

Practical application for measuring gemstone dispersion on the refractometer.

T. Linton. *Australian Gemmologist*, 22(8), 2005, 330-44, 4 illus., 3 tables.

Two previous papers by D.B. Hoover and T. Linton were published on this subject in the *Australian Gemmologist*, 20(12), 2000, and 21(4), 2001). These earlier papers are summarized and then the author describes the use of a refractometer employing a hemisphere or hemicylinder prism (such as the Eickhorst SR/XS) in order to achieve the necessary accuracy of readings. Because the gemmological standard reference wavelengths chosen to measure dispersion (Fraunhofer lines B at 686.7 nm and G at 430.8 nm) are close to the limits of human vision, it is recommended that the narrower range of C (656.3 nm) to F (486.1 nm) is used and the results extrapolated out to the B and G lines. However as the relationship between refractive index and wavelength is non-linear and produces a curve when plotted, this curve must first be linearized (i.e. converted into a straight line). Although measurement, linearization and extrapolation of refractive index data can be accomplished by the gemmologist using the methods described in the paper, the author proposes that the process is simplified by accepting the C-F interval as the standard for gemmology as it is in other scientific disciplines. This short cut eliminates the need for linearization and only involves the determination of three or four refractive indices at appropriate wavelengths.

Dispersion is not presently considered as a viable and accurate identification criterion and extrapolation of apparent C-

F dispersion readings to the B-G wavelengths is a complex and time consuming process. In addition, a single number cannot fully represent the dispersion of a birefringent gemstone. The author suggests that the data contained in the paper's final table be considered as a basis for the future use of C-F dispersion figures as an aid to gemstone identification. P.G.R.

Krüss PO11 proportion ocular and stone holder.

T. Linton, R. Beattie and K. Hughes, *Australian Gemmologist*, 22(9), 2006, 398-401, 9 illus.

This well-illustrated report by the GAA Instrument Evaluation Committee examines the Krüss PO11 device for measuring a diamond's proportions and facet angles when used in conjunction with a standard zoom microscope fitted with sub-stage illumination. The 30 mm proportion-measuring ocular is fitted into the microscope's eyepiece tube, and a spring-loaded stone holder enables the diamond to be manipulated over the projected image of the ocular. The ocular contains a calibrated profile of a Tolkowsky brilliant cut diamond which allows the measurement and comparison of cut proportions for total height, crown height, pavilion depth, table size, girdle thickness, and eccentricity of culet, table and girdle shape to be accurately determined. P.G.R.

Synthetics and Simulants

Characterization of the new Malossi hydrothermal synthetic emerald.

I. Adamo (*ilaria.adamo@unimi.it*), A. Pavese, L. Prosperi, V. Diella, M. Merlini, M. Gemmi and D. Aj . *Gems & Gemology*, 41(4), 2005, 328-38.

A report is presented of a new production of hydrothermal synthetic emeralds, grown in the Czech Republic with Italian technology, and marketed with the trade name Malossi synthetic emerald. Details of an investigation of several crystals (1–141 ct) by microprobe and UV-Vis-NIR and IR spectroscopy are given, together with a comparison of this material with natural and synthetic emeralds (the latter grown by the flux and hydrothermal techniques). These studies reveal that Malossi hydrothermal synthetic emerald can be identified on the basis of microscopic features and chemical composition, along with the mid-infrared spectrum. Chromium was the only chromophore found in the Malossi samples. R.A.H.

Prospects for large single crystal CVD diamonds.

S. S. Ho, C. S. Van, Z. Liu, H. K. Mao and R. J. Hemley. *Industrial Diamond Review*, 1/2006, 28-32.

A description is given of chemical vapour deposition (CVD) techniques for fabricating large single-crystal diamond at very high growth rates (up to > 100 J-lm/h). Single crystals more than 1 cm in thickness and weighing more than 10 ct can now be produced with a range of optical and mechanical properties for different applications. This diamond can be tailored to possess high fracture toughness, and high-pressure/high-temperature annealing can increase its hardness significantly. The size of the diamonds can be further enlarged by successive growth on different faces. The process has been optimized to produce diamond with improved optical properties in the ultraviolet to infrared range, opening prospects for new technological and scientific applications. Illustrations are given of a 5 ct single-crystal CVD diamond (without seed), 12 mm high and 6.7 mm diameter, cut from a 10 ct block using a computer-controlled YAG laser system, and of a 0.2 ct brilliant cut diamond produced from a 1 ct block. R.A.H.

Lab notes.

T.M. Moses and S.F. McClure (Eds). *Gems & Gemology*, 41(4), 2005, 340-8.

Notes are given for yellow cut stones of cubic zirconia imitating irradiated and annealed Cape diamonds, and small (0.11–0.16 ct) bright orange-yellow synthetic diamonds presenting a challenge for their identification with standard gemmological techniques alone. R.A.H.

Crystallographic and spectroscopic analyses of synthetic moissanite.

C. Rinaudo. *Gemmologie. Z. Dt. Gemmol. Ges.*, 53(4), 2004, 159-68, 8 photographs, 9 diagrams, I table, bibl.

Synthetic moissanite (SiC) varying in colour from near colourless to almost black were examined under microscope, by Raman spectroscopy and X-ray transmission topography with synchrotron radiation. All near-colourless samples proved to be single crystals, while the dark samples were composed of at least two polytypes. E.S.

Experimental CVD synthetic diamonds from LIMHP-CNRS, France.

W. Wang, A. Tallaire, M.S. Hall, T.M. Moses, J. Archard, R.S. Sussmann and A. Gicquel. *Gems & Gemology*, 41(3), 2005, 234-44.

The gemmological and spectroscopic features of six synthetic type IIa diamonds grown in the Laboratoire d'Ingénierie des Matériaux et des Hautes Pressions (LIMHP) at the Centre National de la Recherche Scientifique in Paris are reported, and their diagnostic features are compared to those of diamonds produced by chemical vapour deposition (CVD). Three of the six samples were nitrogen doped, whereas the other three were classified as high purity. A number of characteristics diagnostic of CVD synthetic diamonds were present in the nitrogen-doped crystals, despite an absence of defect-related absorption features in the infrared region. The identification of the high-purity samples was more complicated, but it was still possible based on features in their photoluminescence spectra, their distinctive birefringence and characteristic luminescence images. R.A.H.

Abstractors

R.A. Howie R.A.H. M. O'Donoghue M.O'D. P.G. Read P.G.R. E. Stern E.S. I. Sunagawa I.S.

Book Reviews

Photoatlas of Inclusions in Gemstones. Volume 2.

E.J. Gübelin and J. I. Koivula, 2005. Opinio Verlag, Basel. 829 pp, over 2200 colour plates. Hardcover. ISBN 3-03999-029-2. £160.00.

This rigorous volume builds on the original *Photoatlas of Inclusions in Gemstones*, enhances its usefulness and extends the original work by incorporating new information and developments that have occurred in the field of micro gemmology since 1986.

The first thing that strikes you about this book is its size. It has a whopping 829 pages (containing 2167 inclusion images) compared with the 532 pages in Volume 1 that has become the standard reference book in the field of inclusions and micro features in gemstones. The price ($260 plus tax where appropriate) may seem steep but you get a huge amount for your money. The quality of production is excellent and the images, virtually all of which have not previously been published, are often of exceptional beauty. Anyone who has attempted photomicroscopy will feel humbled by the outstanding quality of the images which are a testament to the skill, knowledge and patience of the authors.

The basic premise of the study of microscopic features in gemstones is that similar processes will result in a range of similar features in gems of the same species. So whether these processes are geological, treatment or synthesis, significant information is stored within the gems that aid in their identification and separation.

Although the volume is portrayed as a voyage of discovery and exploration into the world of inclusions in natural gemstones, their treatments, imitations and synthetics it keeps a firm hold on the importance of the basic premise and does not lose sight of the fact that this is primarily an image reference library albeit aesthetically pleasing for all that.

The *Introductory Section* contains useful abbreviations and definitions of the types of inclusions. Whilst illumination and magnification abbreviations accompany each image, regrettably, but understandably because of the inherent difficulty in unequivocally assigning a type to inclusions, little information on this latter aspect accompanies the images. This latter aspect is more than compensated for by expansive descriptive captions on the nature of the inclusions that facilitate 'typing' of inclusions by the reader.

Section two, the *Thematic Section*, has a clear and instructive piece on photomicroscopy methods. It is accompanied by examples of the results achieved by the various techniques. Particularly revealing are images of the same field of view photographed using different techniques, lending truth to the saying that a picture can be worth a thousand words. Inclusion analysis with accompanying photomicrographs is also included in this section. Whilst this is especially useful for those with access to specialist analytical instruments it is nevertheless helpful in painting the picture of the gamut of analytical options available and the results they produce. Inclusions within inclusions (with accompanying photomicrographs) complete this section and serve to remind us of the complex geological history of many gemstones. It is an area of investigation that is largely untapped due to present technology limitations.

Section three, *Characteristics of Inclusions*, devotes 172 pages to the diagnostic features of inclusions, colours, morphology, fluid inclusions and their geological correlation. Having these in a separate section serves to focus on the salient features used in characterisation and the degree to which they are diagnostic. This new method of presentation may initially be undervalued until readers learn to familiarise themselves with its benefits before diving into the gem specific section.

The 'meat' of Volume 2 is in section four; *Inclusions in Gems of Commercial Importance*. There are 526 pages containing 1597 images; almost the same number of pages as in the whole of Volume 1: The species and varieties covered are amber, beryl, chalcedony, chrysoberyl, feldspar, garnet, opal, peridot, quartz, spinel, topaz, tourmaline, zircon and zoisite. Each is preceded by a few pages of supporting text that addresses to a greater or lesser degree as befits the gemstone the petrogenesis, mineral genesis and paragenesis, treatments, colour, structures, synthetic versions and simulants, locality sources, and not least the nature of the inclusions. The gem specific sections are subdivided. Natural gems come first and a printed subheading indicates the beginning of treated and/or synthetic gems. This is not consistent for all gem specific sections but as the latter comes at the end of each section this aids navigation. Considerably more images of lab grown, manufactured and treated stones are included compared with the same gemstone in Volume 1. This attests to the extensive developments and improvements in these fields. Additional reading references are also given. If the reader is wondering what has happened to new information on diamond, emerald, ruby and sapphire these are covered in the as yet unpublished Volume 3.

The conclusion serves to re-emphasize the power, versatility, usefulness and cost effectiveness of microscopy in gemmology and urges gemmologists to re-establish their microscopy skills and consequently keep their gemmological knowledge alive. Microscopy, they argue, stimulates the thought process more so than relying on 'black box' generated answers provided by modern analytical equipment.

Indexes are important. The reader needs to find things quickly. Lack

of an index was a major weakness of the *Internal World of Gemstones.* A purposeful sampling of the index found it to be accurate and with breadth. There were some very minor terminology differences arising from nationality differences in the use of descriptive terms for example *zebra stripes* in amethyst when the term *tiger stripes* is used in the UK but these were readily overcome.

Truly this superb volume is the consummate companion to a properly equipped gemmological microscope and every gemmologist should have both. B.J.

Artificial Gemstones.

M. O'Donoghue, 2005. NAG Press, London. pp 294, illus. in colour. Hardcover. ISBN 0 7198 0311 X. £30.00.

After a brief introduction, the book's opening chapter, entitled 'The structure and development of crystals', takes the reader through basic crystallography to the fascinating world of crystal growth, a subject which over the years has become the author's speciality. The main production techniques of flame-fusion, flux growth and hydrothermal methods of gemstones synthesis are then outlined and typical examples grown by these methods are described.

The following chapter covers enhancement treatments and includes dyeing, bleaching, coating, impregnation, heating, diffusion, irradiation and even sputtering. Detection of many of these processes is by the use of the microscope to examine both the surface and interior of the treated gem. Gem testing instruments are briefly covered in the next chapter and this is followed by one containing advice on the photographing of inclusions.

The bulk of the book contains information-packed chapters on synthetic versions and simulants of each of the major gem species, beginning with diamond and including corundum, beryl, opal, quartz, chrysoberyl and spinel. A valuable addition to several of these chapters is 'Notes from the literature' which provides up-to-date information on recent or significant developments abstracted from current reports.

'Artificial gemstones' is profusely illustrated with 75 half-page size colour microphotographs illustrating typical inclusions. Many of these photographs, complete with their captions, come from the collection of the late Professor Dr Eduard Gübelin. A useful list of all the illustrations, with their captions and page numbers appears at the front of the book and enables them to be linked to the appropriate text when using the presence of inclusions to distinguish between artificial and natural materials.

The book concludes with a useful bibliography as an aid to further research into the principles and practice of crystal growth. P.G.R.

Comparative study of gem minerals, beryl and corundum, from various Indian occurrences.

J. Panjikar, 2004. Pangem Publishers, Pune, India. pp xii, 119, illustrated in colour. Hardcover. ISBN 81 901 22208. Price on application.

The literature of Indian gem materials is far from profuse and this opportune book, developed from a PhD thesis submitted by the author to the University of Bombay [Mumbai] is one of the few recent accounts of features by which Indian corundum and beryl may be recognized. Beryl varieties covered are emerald and blue beryl, corundum varieties are ruby and blue sapphire. The two minerals and their varieties are described by state; thus beryl is described from locations in Jammu and Kashmir, Rajasthan, Orissa, Andhra Pradesh and Gujarat, and corundum from Jammu and Kashmir, Orissa, Andhra Pradesh, Karnataka, Tamil Nadu and Kerala.

In each case the geology of the deposits is briefly described with notes on physical and optical properties. Inclusions are examined and analysed where possible by the electron microprobe. Many inclusion features are illustrated in colour and the quality of the photographs is good (use of the red compensator was found useful; magnifications are most commonly 50 and 100 .

The whole book is a fine example of mineralogical research and its already high quality is enhanced by a ten-page bibliography in which only serious studies are cited. Tables are plentiful and there are maps of the states in which deposits of corundum and beryl are reported. M.O'D.

Pearls.

E. Strack, 2006. Ruehle-Diebener Verlag, Stuttgart, Germany. pp 707, 658 illustrations, mainly photographs and maps. Hard cover and dust cover. £75.00.

This is the English translation of the German edition published in 2001. It is beautifully produced with many photographs and explanatory maps. The book is divided into two parts, one dealing with natural pearls, the other with cultured pearls. Each of the many chapters is accompanied by an extensive bibliography.

In the natural pearl section, the process of pearl formation is explained in detail and the geographic occurrences and characteristics, molluscs, *pinctada,* freshwater and various other sources described. There is also an interesting chapter on large and famous pearls and pearl objects. An introduction to the natural pearl market and the evaluation of pearls is given. The historical chapter on natural pearls covers the role of pearls in antiquity to the present time.

The part of the book dealing with cultured pearls starts with an historical overview and has detailed chapters on pearls from Japan, Korea and China. The freshwater cultured pearls from Japan, Lake Biwa and Lake Kasumigaura and the freshwater cultured pearls from China are described, as well as those from North America and the South Seas. White South Sea pearls are compared with black South Sea pearls (Tahitian) and the varied sources described. Mabe pearls are produced in many countries as are cultured pearls from gastropods.

Amongst the most useful chapters are those dealing with fakes and imitations, testing methods, artificial coloration, and care and maintenance.

There are a number of indices to facilitate finding specific subjects. It is a most comprehensive reference book, the photographs are well chosen and readers will find much to interest them. The book will make a most useful and attractive addition to any library, especially one belonging to a gemmologist, gem laboratory or pearl enthusiast. E.S.

Proceedings of the Gemmological Association and Gem Testing Laboratory of Great Britain and Notices

Presentation of Awards

The Presentation of Awards gained in the 2005 examinations was held at Goldsmiths' Hall in the City of London on Monday 31 October. Alan Jobbins, President of the Association, presided and welcomed those present, particularly successful candidates attending from as far away as Australia, Canada, Hong Kong, India, Korea, Madagascar, New Zealand and the U.S.A., as well as Denmark, France, Greece, the Netherlands, Sweden and Switzerland.

The President introduced John I. Koivula, Chief Gemmologist at the American Gem Trade Association's Gemological Testing Center (AGTA-GTC) in Carlsbad, California, who presented the Diplomas and prizes. Following the presentations, John Koivula gave his address. John encouraged the students to continue their education: "This is just the starting point for those receiving their diplomas today" he said. "I hope that everyone finds something in gemmology that excites them, as I did with inclusions." He stressed the need to protect the word 'natural', and emphasized that great care should be taken to identify treated stones. John said: "You are gemmologists now and you have your reputation as gemmologists to uphold."

A vote of thanks to John Koivula was given by Dr Jack Ogden, Chief Executive of the Gemmological Association.

A reception attended by over 200 members, students and their guests, was held following the ceremony.

The 2005 prize winners (from left): Nicola Sherriff from Verdun, Quebec, Canada, winner of the Anderson Medal and the Hirsh Foundation Award; Sheila Smithie from Boston, Massachusetts, U.S.A. winner of the Christie's Prize for Gemmology; Chaman Golecha from Chennai, India, winner of the Anderson Bank Prize; and Torbjorn Lindwall from Lannavaara, Sweden, winner of the Deeks Diamond Prize.

Guest speaker John Koivula gives his address. Photo: Lewis Photos Ltd.

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Gem-A Awards

Gem-A examinations were held worldwide in January 2006. In the Examinations in Gemmology, 137 candidates sat the Diploma Examination of whom 61 qualified including one with Distinction and 12 with Merit, and 204 sat for the Foundation Examination, of whom 150 qualified. In the Gem Diamond Examination 91 candidates sat of whom 42 qualified, including four with Distinction and six with Merit. The names of the successful candidates are listed below:

EXAMINATIONS IN GEMMOLOGY

Gemmology Diploma

Qualified with Distinction

Zhu Hanli, Shanghai, P.R. China

Qualified with Merit

Cen Qicong, Guilin, Guangxi, P.R. China
Challani, D. Mohit, Chennai, India
Chandhok, Simran Kaur, New Delhi, India
Emond, Jacinthe, Laval, Quebec, Canada
Hu Yuan, Guilin, Guangxi, P.R. China
Jensen, Annalisa Tintern, Esher, Surrey
Lai Suk Kwan, Eleanor, Kowloon, Hong Kong
Lam Kwok Man, May, West Smithfield, London
Lam Kwok Yee, Monica, West Smithfield, London
Sun Xiaolei, Beijing, P.R. China
Xu Hui, Shanghai, P.R. China
Zhang Xiaopu, Wuhan, Hubei, P.R. China

Qualified

Al-Hadad, Raed Mustafa, Montreal Quebec, Canada
Badrov, Irena, London
Chan Mei Fong, Frances, Kowloon, Hong Kong
Chaudry, Mohamed Ashraf, Wardle, Rochdale, Lancashire
Chen Cheng Tang, Taipei, Taiwan, R.O. China
Chen Xinxing, Guilin, Guangxi, P.R. China
Chitou, Aurelie Gisele, Antananarivo, Madagascar
Chu Hon Chung, New Territories, Hong Kong
Costin, Charlotte, Horsham, West Sussex
Darell, Rikard, Uppsala, Sweden
Eastwood-Barzdo, Elizabeth, Dully, Switzerland
Edwards, Catherine, Salisbury, Wiltshire
Fan Jing, Beijing, P.R. China
Flower, Caro, Brinton, Melton Constable, Norfolk
Goncalves Coelho, Ana Cristina, Antananarivo, Madagascar
Guo Yu, Wuhan, Hubei, P.R. China
Huang Mingcai, Guilin, Guangxi, P.R. China
Jang Wei-Jen, Taipei, Taiwan, R.O. China
Jiang Lihua, Wuhan, P.R. China
Kwok Men Yee, New Territories, Hong Kong
Leung Ka Lok, Kowloon, Hong Kong
Leung Kam Ping, Sai Kung, Hong Kong
Li Mengjie, Guilin, Guangxi, P.R. China
Lin Lang-Dong, Taipei, Taiwan, R.O. China
Liu Xi, Guilin, Guangxi, P.R. China
Liu Zuodong, Guilin, Guangxi, P.R. China
Luo Yueping, Beijing, P.R. China
Ma Jun, Guilin, Guangxi, P.R. China
Meyer, Constance Marie, Paris, France
Michaels, Sarah A., Virginia Beach, Virginia, U.S.A.
Ong Chin Siang, Gary, Singapore
Peers, Sofia L. R., London
Qin Ting, Guilin, Guangxi, P.R. China
Rana, Ashka Sureshkumar, A'bad, Gujarat, India
Ranjatoelina, Domoina, Antananarivo, Madagascar
Scott, Craig John, West Meon, Petersfield, Hampshire
Shen Bin, Wuhan, Hubei, P.R.China
Shen Mengxi, Guilin, Guangxi, P.R. China
Soderholm, Kathryn Ashe, Dulles, Virginia, U.S.A

Gem-A Awards

Tessari, Claudio, Ora, Italy
Tsang Kwai Ying, Yau Yat Tsuen, Hong Kong
Tu Yu-Chieh, Taipei, Taiwan, R.O. China
Wang Ying, Wuhan, Hubei, P.R. China
Xu Ning, Beijing, P.R. China
Ye Xiaohong, Beijing, P.R. China
Yee Yee Mon, Yangon, Myanmar
Zeng Linghan, Guilin, Guangxi, P.R. China
Zhuang Lingyan, Guilin, Guangxi, P.R. China

Gemmology Foundation Certificate

Qualified

Adler, Stevan, New York, U.S.A.
Al-Hadad, Raed Mustafa, Montreal, Quebec, Canada
Andriambelo, Andry Rainier, Antananarivo, Madagascar
Andrianamoizana, Claudia, Antananarivo, Madagascar
Andriasamy, Francine Gisele, Antananarivo, Madagascar
Asvine Tsakou, Kawindre, Antananarivo, Madagascar
Ayeb, Kaled, Montpellier, France
Bae Hong Ryul, Seoul, R.O. Korea
Barbour, Alexandra, Dorchester, Dorset
Bieri, Willy, Escoltzmatt, Switzerland
Brooks, Candy, Catcott, Bridgwater, Somerset
Chan Wai See, Lavinia, Guangzhou, P.R. China
Chan Po Ling, Kowloon, Hong Kong
Chan Wing Sze, Herleva, Kowloon, Hong Kong
Chandhok, Simran Kaur, New Delhi, India
Chang Mei-Yen, Karen, Taipei, Taiwan, P.R. China
Chau Shan Yuen, Wan Chai, Hong Kong
Chen Ying-Chen, Taipei, Taiwan, R.O. China
Chen Hsiuchuan, Taipei, Taiwan, R.O. China
Chen Shioulin, Taipei, Taiwan, R.O. China
Chen Hsiang Ling, Taichung, Taiwan, R.O. China
Chen Li, Guilin, Guangxi, P.R. China
Chester, Mel, St. Denys, Southampton, Hampshire
Cheung Hoi Man, Shau Kei Wan, Hong Kong
Chok, Georges, Paris, France
Chow Man Yee, Tai Hang, Hong Kong
Chu Man Tsz, Sylvia, Chai Wan, Hong Kong
Coppin, Daisy, Corsham, Wiltshire
De La Tullaye, Remi, Fublaines, France
Faugeroux, Valerie, La Gardelle, France
Flower, Caro, Brinton, Melton Constable, Norfolk
Forsberg, Erika, Lannavaara, Sweden
Frei, Thomas, Pratteln, Switzerland
Garbis, Angela, Koukaki, Athens, Greece
Green, Anthony, Westcliff-on-Sea, Essex
Grimal, Marie, Marseille, France
Haaja, Pasi Janne, Helsinki, Finland
Han Fen, Shanghai, P.R. China
Hartley, Daisy, Ilkley, West Yorkshire
Higginson, Matthew J., Cassington, Oxfordshire
Hilde Lam Nga Sheung, North Point, Hong Kong
Hnin Lwin Aye, Yangon, Myanmar
Ho Tak Kwong, Kowloon, Hong Kong
Hon Wai Ching, Kowloon, Hong Kong
Hossenlopp, Patricia, Chene – Bougeries, Switzerland
Huang Hui Wen, Taichung, Taiwan, R.O. China
Hui Ngai Yin, North Point, Hong Kong
Hwang, Sang Un, Goryung, R.O. Korea
Iabrazzo, Richard, Cannes, France
Jiang Jingxia, Shanghai, P.R. China
Kallioniemi, Mari, Helsinki, Finland
Kao, Chen, Taipei, Taiwan, R.O. China
Kasumu, Maambwa S., Finchley, London
Kearney, Sonny Michael, Kimberley, Nottingham
Kim Hyo Sook, Gyoungbuk-Do, R.O. Korea
Kim, Ji A, Daegu, R.O. Korea
Kim, Mi Hyun, Seoul, R.O. Korea
Ko, Cheuk Wah, Quarry Bay, Hong Kong
Krska, Gemma, Durban, South Africa

Gem-A Awards

Kuhn, Barbara, Duebendorf, Switzerland
Kweon Ji Eun, Daegu, R.O. Korea
Kwok Sau Ying, Tuen Mun, Hong Kong
Kwon Sae Ra, Seoul, R.O. Korea
Kyaw Kyaw, Yangon, Myanmar
Lam Wai Han, Kowloon, Hong Kong
Larsson, Jacqueline, Hammersmith, London
Larsson, Niclas, Lannavaara, Sweden
Lee Hui Min, Taipei, Taiwan, R.O. China
Lee Kit Kau, Fanling, Hong Kong
Leung Hang Fai, Henry, Kowloon, Hong Kong
Li Liu Fen, Guangzhou, P.R. China
Li Mei, Guilin, Guangxi, P.R. China
Lin Jui-Yi, Taipei, Taiwan, R.O. China
Lin Chia Hui, Taipei, Taiwan, R.O. China
Lo Pui Yin, Shirley, Tai Po, Hong Kong
Lorentzen, Roy Roger, Tromsoe, Norway
Manassero, Robert, Simiane, France
Meninno, Marco, London
Naartijarvi, Eva, Kiruna, Sweden
Nam Yong Ju, Seoul, R.O. Korea
Netsah, Maayane, Finsbury Park, London
Ng Ka Kit, New Territories, Hong Kong
Ng Kim Ling, Kowloon, Hong Kong
Ni Ziqian, Guilin, Guangxi, P.R. China
Or Wing Chee, Stella, Kowloon, Hong Kong
Ovaskainen, Sami, Helsinki, Finland
Pan Pai, Guilin, Guangxi, P.R. China
Pang Yufei, Guilin, Guangxi, P.R. China
Park Mi Young, Seoul, R.O. Korea
Piha, Saara, Espoo, Finland
Piirto, Irmeli, Espoo, Finland
Poon Mei Ling, Hong Kong
Pyrro, Riku, Kirkkonummi, Finland
Quint, Camilla, London
Rakotobe, Alice Hortense, Antananarivo, Madagascar
Rakotomanantsoa, Miguel, Antananarivo, Madagascar
Ranaivoson, Hantarinoro, Antananarivo, Madagascar
Randrianantoandro, Minoarisoa Michelle, Antananarivo, Madagascar
Rasatranabo Razakarivony, Aina Anthony, Antananarivo, Madagascar
Razafimahafaly, Fanjamalala Blandine, Antananarivo, Madagascar
Razafimahatratra, Tojoniaina Harintsoa, Antananarivo, Madagascar
Razafindrasolo, Toky Ny Aina, Antananarivo, Madagascar
Retsin d' Ambroise, Laura, Paris, France
Rodman, Anna, Lund, Sweden
Rudomino-Dusiacki, Patrick, London
Shan Luk, Kowloon, Hong Kong
Shi Huayan, Shanghai, P.R. China
Shukla, Satyendra Kumar, Gujarat, India
Sourendre Shah, Rupal, Antananarivo, Madagascar
Spagnoletti Zeuli, Lavinia, London
Stidwill, Thuong, Upper Tooting, London
Stockwell, Hilary, Brussels, Belgium
Sun Yuan, Guilin, Guangxi, P.R. China
Sundell, Andreas, Lannavaara, Sweden
Suokko, Teija, Tampere, Finland
Tam Shuk Man, Tai Po, Hong Kong
Tang Kit Yee, Tsing Yi, Hong Kong
Teh Hong Kee, Penang, Malaysia
Thanadtamakul, Pakamon, Nonthaburi, Thailand
Thomas, Estelle Melissa, Surbiton, Surrey
Tikkunen, Anni, Lahti, Finland
Tsui Wan Kam, Barbara, Hong Kong
Vasquez, Alejandra, London
Villeneuve, Jeanne, Paris, France
Wang Ling, Guilin, Guangxi, P.R. China
Wang Wei, Guilin, Guangxi, P.R. China
Wat Wing Suet, Tsim Sha Tsui, Hong Kong
Wen Chia-Ling, Taipei, Taiwan, R.O. China
Withey, Alison, Encinitas, California, U.S.A.
Wong Man Yat, Kowloon, Hong Kong
Wong Kit Man, Angela, Tin Shui Wai, Hong Kong
Wong Man Yuen, Daniel, Hong Kong
Wong Tung Wing, Hong Kong
Woo Jung, Daegu, R.O. Korea
Wu Chung-Kang, Taipei, Taiwan, R.O. China
Wu Shih-Han, Taipei, Taiwan, R.O. China

Gem-A Awards

Yang Hsu-Chiao, Taipei, Taiwan, R.O. China
Yang Tak Him, Tsuen Wan, Hong Kong
Ye Mengqian, Guilin, Guangxi, P.R. China
Yoon Jung Mi, Daegu, R.O. Korea
Yu Heyu, Guilin, Guangxi, P.R. China
Yun Soo Min, Gimhae, R.O. Korea
Yung Pan, Kowloon, Hong Kong
Zhang Chao, Guilin, Guangxi, P.R. China
Zhang Wei, Shanghai, R.O. China
Zhou Huijuan, Guilin, Guangxi, P.R. China
Zhou Ye, Guilin, Guangxi, P.R. China
Zhu Hanli, Shanghai, P.R. China
Zhu Cheng, Guilin, Guangxi, P.R. China
Zou Jin, Guilin, Guangxi, P.R. China

GEM DIAMOND EXAMINATION

Qualified with Distinction

Huck. Perry, London
Lau Man Yu, Kowloon, Hong Kong
Michaels, Sarah A., Virginia Beach, Virginia, U.S.A
Wong Man Yee, Kowloon, Hong Kong

Qualified with Merit

Cai Yitao, Wuhan, Hubei, P.R. China
Ho Ching Yee, New Territories, Hong Kong
Lai Siu Kwong, New Territories, Hong Kong
Lam Kwok Yee, Monica, West Smithfield, London
Lo Wing See, Kowloon, Hong Kong
Ng Ka Kit, New Territories, Hong Kong

Qualified

Chan Hing Yip, Kowloon, Hong Kong
Chen Chih-Wei, Taichung City, Taiwan, R.O. China
Chen Jianhua, Kowloon, Hong Kong
Chow Po Ling, Sai Ying Pun, Hong Kong
Chu Kong Ting, New Territories, Hong Kong
Chuk Yim Ming, Kowloon, Hong Kong
Chung Tsz Bun, Kowloon, Hong Kong
Freeman, Derek, Hove, East Sussex
Gits, Hugo, Knokke, Belgium
Howells, Robert, Abergavenny, Monmouthshire
Jiang Huan, Wuhan, Hubei, P.R. China
Jiang Yi, Beijing, P.R. China
Kapos, Thomas, Voula, Athens, Greece
Kong, Jason, Kowloon, Hong Kong
Kuchard, Monika, London
Lai Sau Han, Winnie, Hong Kong
Lam Kwok Man, May, West Smithfield, London
Lam Lai Wah, Tsuen Wan, Hong Kong
Lau Ho, Kowloon, Hong Kong
Leung Man Yee, New Territories, Hong Kong
Ma Yaw Lan Hsiung, Ruth, Hong Kong
McHugh, Trudi, Eastleigh, Hampshire
Mo Ying Lin, Marilyn, Kowloon, Hong Kong
Pang Shing Kwan. New Territories, Hong Kong
Papapavlou, Despina-Maria, Christoforos, Rhodes, Greece
Parsonson, Chloe Celine, London
Rahn, Adelle, Pewsham, Chippenham, Wiltshire
Tsang Wa, New Territories, Hong Kong
Wallbank, Julie Samantha, Lichfield, Staffordshire
Webster, Eric T., West Chiltington, West Sussex
Wong Kin Ching, New Territories, Hong Kong
Wong Yu Lap, Hong Kong
Zhang Niaoniao, Wuhan, Hubei, P.R. China

Members' Meetings

Gem Discovery Club

Specialist Evenings

Once a month Club members have the opportunity to examine items from the collections of gem and minerals specialists.

The November guest was Gem-A Conference keynote speaker John Koivula, who divulged some of his latest research on the inclusions in gemstones, particularly that on the detection of heat-treated corundum. In December David Hargreaves, owner and operator of the Chimwadzulu ruby mine in Malawi, spoke to Club members about the formation and mining of rubies and sapphires, the treatment of the stones, current production issues affecting the market today and price trends. Members had the opportunity to examine the many samples that David had brought along. Maria Alferova of the Moscow State University was the February specialist, when she gave an illustrated talk on her recent gem fieldtrip to Transbaikalia. 'Nature v. jewellers' was the title of Harry Levy's presentation to Club members in March, when he discussed what jewellers could and could not do with gemstones.

Annual General Meeting

The 2005 Annual General Meeting was held on 11 October at 27 Greville Street, London EC1N 8TN (see report p. 122). The AGM was followed by an illustrated talk by Vivian Watson entitled 'A walk in the garden', when Vivian took a stroll through the history of the jewellery trade in Hatton Garden. After the talk, members attended an informal dinner at the Abbaye Belgian Restaurant, Charterhouse Street, celebrating the 80th anniversary of the founding of the Gem Testing Laboratory.

Gem-A Conference

The 2005 Gem-A Conference, a celebration of the life and work of the late Professor Dr Edward Gübelin, was held on Sunday 30 October at the Renaissance London Heathrow Hotel. The theme, 'The Inside Story: the inclusions in gemstones', recognized Professors Gübelin's lifetime study of inclusions in gemstones. The speakers at the event were John I. Koivula (keynote), Edward Boehm, Professor Henry Hänni, Dr Daniel Nyfeler, Stephen Kennedy and Professor Andy Rankin.

A programme of events arranged to coincide with the Conference included a Private Viewing of the Crown Jewels with Crown Jeweller David Thomas and a guided tour of the Diamonds exhibition at the Natural History Museum.

A full report of the Conference was published in the December 2005 issue of *Gems & Jewellery.*

Midlands Branch

At the Branch AGM held at the Earth Sciences Building, University of Birmingham, Edgbaston, on 27 January, Gwyn Green retired as Chairman. Branch President David Larcher thanked Gwyn for her enthusiasm and hard work during the ten years she had held the office. Elizabeth Gosling and Stephen Alabaster were re-elected Secretary and Treasurer respectively. Paul Phillips was later elected as Chairman of the Branch. The AGM was followed by a Bring and Buy Sale and Team Quiz. Other Branch meetings held at the Earth Sciences Building included a demonstration on the identification of gem materials using a microscope by Gwyn Green on 28 October, 'A history of buttons' by Jenny Swindells on 25 November, 'Horological Jewelling' by John Moorhouse on 24 February, and 'Chasing rainbows by observing gemstone spectra' by John Harris on 31 March.

The 53rd Anniversary Branch Dinner, held at Barnt Green, again proved to be a very popular and successful event. On 19 March a one-day Loupe and Lamp event was held at Barnt Green. Working in pairs, participants had to identify 60 stones using only a 10x lens and a hand torch or lamp. This was followed by a presentation by Gwyn Green pointing out the relevant identifying features for each stone.

North East Branch

In September 2005 Neil Rose retired as Branch Chairman and Mark Houghton and

Sara North were appointed jointly to the position.

Branch meetings held at the Ramada Jarvis Hotel, Wetherby, included 'Cartier, the King of Jewellers' by Terry Davidson on 3 November, and 'Spectroscopy for Gemmology Students', a hands-on event with Colin Winter on 22 March.

North West Branch

On 19 October Maggie Campbell Pedersen gave a talk on organic gemstones entitled 'Gems of Life'. The Branch AGM was held on Wednesday 16 November when Deanna Brady, Ray Rimmer and Eileen Franks were re-elected Chairman, Secretary and Treasurer respectively. These meetings were held at YHA Liverpool International, Wapping, Liverpool 1.

A special event was held on 15 February to celebrate the 30th anniversary of the Branch, held at Liverpool Cathedral. Following a reception, Maria Alferova of the Moscow State University gave a presentation on the Gems of Russia.

Scottish Branch

Regular meetings have been held at the British Geological Survey, Murchison House, West Mains Road, Edinburgh. Dr Bruce Cairncross spoke on the gem deposits of southern Africa on 24 August. On 27 September Maggie Campbell Pedersen gave a talk entitled 'Gems of Life', describing organic gems and how imitation and treated specimens may be identified. Terry Davidson gave a presentation entitled 'Cartier: the 20th century' on 24 October. On 7 November Basil Dunlop spoke about the cultural history as well as the natural history of Cairngorm gemstones.

A buffet, followed by a Bring and Buy Sale and a Quiz, were held at the Bruntsfield Hotel, Edinburgh, on 18 January.

On 21 February at the British Geological Survey Roger Key gave an illustrated talk on the hunt for diamonds in Mozambique, where he had been working to assess the gemstones deposits, and also showed slides from his exploratory mapping visit to Madagascar. Alan Jobbins gave a talk entitled 'A gemmological journey from the Alps to Vesuvius' on 14 March.

South East Branch

The Branch AGM was held on 18 December at the Gem-A headquarters in Greville Street, London EC1, followed by a talk by Dr Frances Wall entitled 'Diamonds and the deep carbon cycle'.

Annual General Meeting

The 2005 Annual General Meeting was held at the Gem-A headquarters at 27 Greville Street, London EC1N, on 11 October. Professor Alan Collins chaired the meeting and welcomed those present. The Annual Report and Accounts were approved.

Terry Davidson and Evelyne Stern were re-elected and Marcus McCallum elected to the Council. Lawrence Hudson retired in rotation from the Council and was not seeking re-election. The Chairman reported that Dr Roger Harding and Ian Mercer had resigned from the Council in November 2004, and Jeffrey Monnickendam and Vivian Watson had resigned in June and May 2005 respectively.

Peter Dwyer-Hickey and John Greatwood were re-elected and Jim Collingridge, Gwyn Green and David Lancaster elected to the Members' Audit Committee. The Chairman reported that Lawrence Music and Dr Jamie Nelson had resigned from the Members' Audit Committee in April 2005. Hazlems Fenton were re-appointed auditors.

Membership

Between 1 October 2005 and 31 March 2006 the Council approved the election to membership of the following:

Fellowship and Diamond Membership (FGA DGA)

Lee Fung Mei, Kowloon, Hong Kong, 2004/05
Leondaraki, Marialena, Athens, 2005
Taylor, Daniel, Leeds, West Yorkshire, 2004/05

Donations

The Council of the Association is most grateful to the following for their donations. Donation levels are Circle of Benefactors (£5000 and above), Diamond (£1000 to £4999), Ruby (£500 to £999), Emerald (£250 to £499), Sapphire (£100 to £249) and Pearl (£25 to £99).

Emerald Donation:

Terry Davidson, FGA, Coln St Aldwyn, Gloucestershire

Sapphire Donations

Dr Genevieve Davies, London
Torbjorn Lindwall FGA DGA, Lannavaara, Sweden
Robert L. Rosenblatt FGA, Salt Lake City, Utah, U.S.A.
Elaine Rowley FGA, London

Pearl Donations

Burton A. Burnstein, Los Angeles, California, U.S.A.

Dennis Durham, Kingston upon Hull, East Yorkshire

Victoria Forbes FGA DGA, Portadown, Northern Ireland

Gwyn Green FGA DGA, Barnt Green, Hereford and Worcester

Yvonne Holton FGA DGA, Edinburgh, Scotland

Bede Johnson, Lewes, East Sussex

Marcia Lanyon FGA, London

Sandra Lear FGA, Rothbury, Morpeth, Northumberland

Masao Kaneko FGA, Tokyo, Japan

Paul R. Milton FGA, Liverpool
Ernest R. Mindry FGA, Chesham, Buckinghamshire

Sara Naudi FGA, London

Gabriella Parkes DGA, London

David J. Sayer FGA DGA, Wells, Somerset

Moe Moe Shwe FGA, Singapore

Karen Tulo FGA, Ludwigshafen, Germany

Anne Van der Meulen FGA DGA, Chicago, Illinois, U.S.A.

Nancy Warshow FGA DGA, Nairobi, Kenya

Keith P. Whitehouse BSc(Hons) FGA DGA, Stafford

Wong Ching Man, Happy Valley, Hong Kong, 2004
Zebrak, Tracy, London, 1981/82

Fellowship (FGA)

Chaiyawat, Yuanchan, Bangkok, Thailand, 2005
Chan Pak Lin, Tsuen Wan, Hong Kong, 2005
Chan Pik Kwan, Cecilia, New Territories, Hong Kong, 1982
Chan Wai Fong, Wah Fu Estate, Hong Kong, 2005
Cheung Ching Chung, Aberdeen, Hong Kong, 2005
Davidge, Elizabeth Anne, Eastbourne, West Sussex, 1998
Davis, Shelley, Toronto, Ontario, Canada, 2005
Dupuis, Ronald J.R., Toronto, Ontario, Canada, 1979
Eguchi, Yumi, Fukuoka-City, Fukuoka-Pref., Japan, 2003
Fellows, Andrew Simon, Aldridge, West Midlands, 2005
Fossurier, Anne, Montreal, Quebec, Canada, 2005
Gillman, Scott, Sudbury, Massachusetts, U.S.A., 2005
Glass, Krista-Leigh, Stratford, Ontario, Canada, 2005
Golecha, Chaman, Chennai, India, 2005
Hoso, Sadayuki, Fujuoka-City, Fukuoka Pref., Japan, 1992
Ip Wai Yin, Renée, Toronto, Ontario, Canada, 2005

Janssen, Marjo, Voorschoten, The Netherlands, 2005
Kandalepa, Theophano, Patissia, Greece, 2005
Kwan, Kai Lion, Tananarive, Madagascar, 2005
Kwok Mei Yee, Sindy, Ap Lei Chau, Hong Kong, 2005
Lawton, Sarah, Enderby, Leicestershire, 2005
Lee Lai Ha, New Territories, Hong Kong, 2005
Lee Tin Wan, Shatin, Hong Kong, 2005
Leung Chi Fai, Hong Kong, 2005
Li Chi Man, Tin Hau, Hong Kong, 1992
Li Po Man, North Point, Hong Kong, 2005
McKercher, Jennifer, Toronto, Ontario, Canada, 2005
Pang Shing Kwan, New Territories, Hong Kong, 2004
Qingfeng, Ruan, Guilin, Guangxi, China, 2005
Rakotoson, Eric, Antanimora, Madagascar, 2005
Raoelison, Ivan Ludovic, Antanimora, Madagascar, 2005
Rasoanaivo, Annick Sylvie, Antananarivo, Madagascar, 2005
Ryu, Keiko, Hamamatsu-City, Japan, 1974
Salmi, Tarja, Sodankylä, Finland, 1991
Sanders, Jacqueline, Towcester, Northamptonshire, 2005
Shapshak, Leon, Highlands North, South Africa, 1952
Susawee, Namrawee, Bangkok, Thailand, 2005
Tammilehto, Eero Juhani, Helsinki, Finland, 2005
Thawornmongkolkij, Monruedee, Bangkok, Thailand, 2005
Wong Cheng Shin Wan, Lina, Tai Po Kau, Hong Kong, 2005
Wong Ching-Man, Ruby, New Territories, Hong Kong, 2005
Yokote, Hideki, Maubaru-City, Fukuoka-Pref., Japan, 1993
Yoshimoto, Misako, Fukutu-City, Fukuoka-Pref., Japan, 1988
Zee Gar Bo, Michelle, Kowloon, Hong Kong, 2005
Zoeter, Johannes Simon, Bergen op Zoom, The Netherlands, 1990

Diamond Membership (DGA)

Baker, David Mark, Bath, Somerset, 2005
Chan Chi Wai, Hong Kong, 2005
Clarkson, Mia Helen, London, 2005
Davis, Samantha Angela, Bearwood, Warley, West Midlands, 2005
Fong Yan, William, Tai Po, Hong Kong, 2005
Head, Jemima Elizabeth, Bingley, West Yorkshire, 2005
Kathris, Ioannis, Holargos, Greece, 2005
Ko Cheuk Wah, Quarry Bay, Hong Kong, 2005
Kwan Ka Lun, Karen, Wanchai, Hong Kong, 2004
Lee Ka Wai, Shatin, Hong Kong, 2005
Lee Oi-Yan, Christine, Tai Po, Hong Kong, 2005
Powar, Krishna, Smethwick, Birmingham, West Midlands, 2005
Terry, Dennis, Petts Wood, Kent, 2005
Tsang Yuen King, New Territories, Hong Kong, 2005
Warner, Simon, Tring, Hertfordshire, 2005
Wong Wai-Lok, Calvin, Kowloon, Hong Kong, 2005
Yamout, Sabah, Leeds, West Yorkshire, 2005
Yeung Tsz Ming, New Territories, Hong Kong, 2005

Associate Membership

Akaishi, Hitomi, Hannou City, Saitama Pref, Japan
Akiyama, Claire Nozomi, Woodbury Down Estate, London
Al-Othaim, Abrar, Acton, London
Annetts, Deborah, London
Aung Than, Hay Mar, London
Azzopardi, Malcolm, St Julians, Malta
Bhartiya, Saurabh, Hendon, London
Brimming, Julie Anne, Bristol, Avon
Bundu, Bukl´elo, London
Buttle, Nicholas James, Bexhill-On-Sea, Sussex
Cahalon, Maureen, Ballinasloe, County Galway, Ireland
Chau Kit Ying, Lily, Hong Kong
Chen Chih-Wei, London
Cho, Jungmin, London
Craig, Roselind, London
Craig, Veronica, Hindhead, Surrey
Dhillon, Mandeep, Smethwick, West Midlands
Diallo, Abdoulaye, London
Edwards, Catherine, Salisbury, Wiltshire
El-Kassir, Mariam, Acton, London
Flower, Caro, Melton Constable, Norfolk
Frost, Richard Henry John, Rochester, Kent
Fukuoka, Shinobu, Osaka City, Osaka, Japan
Fukuoka, Y., Toyonaka City, Osaka, Japan
Hassey, Lauren, Putney, London

Gifts

The Association is most grateful to the following for their gifts for research and teaching purposes:

Marino and Beatriz Aragon, San Pedro, California, U.S.A., for rough and polished Colombian copal specimens.

Luella Woods Dykhuis FGA DGA, Tucson, Arizona, U.S.A., for parcels of tumbled peridot beads from Mahana Bay, Hawaii, and faceted amethysts, samples of opal in matrix from Spencer, Idaho, U.S.A., and Mount St. Helens glass (made from the ash from St Helens), a ruby in matrix from India, a brass bead decorated with blue bird feathers, a Tahiti pearl, a rough pink smithsonite and a fibrous serpentine cabochon.

Gwyn Green FGA DGA, Barnt Green, Hereford and Worcester, for 400 faceted quartzes.

John Hay Mo Ho FGA, Hong Kong, for two painite crystals.

Dr Donald B. Hoover FGA, Springfield, Missouri, U.S.A., for topaz crystals.

Padam Jain, RMC Gems HK Co., Kowloon, Hong Kong, for two faceted glass stones displaying colour change.

Dr Joachim Lindblom PhD FGA, Turku, Finland, for a copy of his book Mineralogical studies on luminescence in diamond, quartz and corundum.

Jonathan Mehdi, London, for a cushion-shape faceted quartz with a purple-blue fluorite inclusion.

Ngwe Lin Htun, Gemmological Science Centre, Yangon, Myanmar, for two painite crystals.

Christien Oldbury, Salisbury, Wiltshire, for a tagua nut.

Eric Van Valkenburg, Tucson, Arizona, U.S.A., for a painite crystal.

Jason Williams FGA DGA, G.F. Williams & Co. Ltd., London, for a selection of gemstones.

Hiroko Wilson, Hong Kong, for a collection of gemmological instruments

Huen Lai-Kei, Sheree, Richmond, British Columbia, Canada
Jamieson, Katie Jane, London
Jatia, Vijaykumar, Mumbai, India
Kaneda, Mitaka, Minato-ku, Tokyo, Japan
Kasumu, Maambwa, Whitechapel, London
Khan, Amjad, Harrow, London
Knowles-Cutler, Laura, Westerham, Kent
Kobayashi, Taisuke, Arakawa-ku, Tokyo, Japan
Komachi, Ryusuke, Kyoto City, Kyoto, Japan
Kuchard, Monika, London
Lam Kwok-Yee, Monica, West Smithfield, London
Lam Kwok-Man, May, West Smithfield, London
Latham, Elizabeth, Wallingford, Oxfordshire
Lau, Tim, London
Mathurata, Kaneel, London
Matsuura, Miho, Yokohama City, Kanagawa Pref., Japan
Michaels, Sarah, London
Mistry, Mahesh, Leicester
Miyamoto, Kazuhiko, Osaka City, Osaka, Japan
Moroz, Magdalena, Richmond, Surrey
Naito, Ayako, Taito-ku, Tokyo, Japan
Nagao, Saeko, Kooriyama City, Fukushima Pref, Japan
Nakagawa, Yumi, Kitakatsuragi-gun, Nara Pref, Japan
Nakamura, Takatsugu, Osaka City, Osaka, Japan
Nakanishi, Nobuo, Ikeda City, Osaka, Japan
Nishizawa, Kazumi, Ibaraki City, Osaka, Japan
Obayashi, Koko, Setagaya-ku, Tokyo, Japan
O'Doherty, Brigid Isobel, Belfast, Northern Ireland

Okabe, Yuichi, Kawasaki City, Kanagawa Pref., Japan
Parkinson, David, Hackney, London
Preston, Paula, Blackheath, London
Reeves, Victor, Leicester
Ringhiser, Barbara, Lake Worth, Florida, U.S.A.
Ross, Lynne, Harrow, Middlesex
Russell, Elaine, Dundee, Scotland
Saito, Rieko, Numazu City, Shizuoka Pref., Japan
Sarginson, Jane, London
Sawamura, Tsukasa, Toshima-ku, Tokyo, Japan
Schonboschler, Christiané, London
Scott, Craig John, West Meon, Hampshire
Shimizu, Maki, Oyama City, Tochigi Pref., Japan
Shpartova, Irina, London
Soderholm, Kathryn Ashe, London
Swaenen, Marcel, Brasschaat, Belgium
Tai, Wai, London
Tanaka, Makiko, Tokorozawa City, Saitama Pref., Japan
Tanikawa, Masatoshi, Hino City, Tokyo, Japan
Thiebaut, Ivane, London
Uchiyama, Mio, Ichikawa City, Chiba Pref., Japan
Ueda, Miwa, Matsue City, Shimane Pref., Japan
Ushioda, Motofusa, Suginami-ku, Tokyo, Japan
Usujima, Chika, Machida City, Tokyo, Japan
Vafaei, Khatereh, North York, Ontario, Canada
Warren, Cherry Elizabeth, Stokenchurch, Buckinghamshire
Wenbo, Han, Ji Nan, Shandong, P.R. China
Yamada, Masashi, Toshima-ku, Tokyo, Japan

Laboratory Membership

Gem Road Ltd, London, W14 0RT

Transfers

Diamond Membership (DGA) to Fellowship and Diamond Membership (FGA DGA)

Chawla, Jaspreet Kaur, London, 2005
Godfrey, Kay, Halstead, Essex, 2005
Kiamos, George K., Maroussi, Athens, Greece, 2005
Konstantopoulos, Konstantinos, Athens, Greece, 2005
O'Dwyer, Michael, Johnswell Road, Kilkenny, Ireland, 2005
Pearson, Heather, Belper, Derbyshire, 2005

Fellowship (FGA) to Fellowship and Diamond Membership (FGA DGA)

Klimek, Karina S., Truro, Cornwall, 2005
Lancaster, David, Hemel Hempstead, Hertfordshire, 2005
Lovelock, Justina E., London, 2005
Scragg, Claire P., Little Kingshill, Buckinghamshire, 2005
Van der Molen, Wouter N., Zwolle, The Netherlands, 2005

Associate Membership to Fellowship (FGA)

Ahren, Anna Ekstrom, Tyreso, Sweden, 2005
Anderson, Judith S., Manchester, New Hampshire, U.S.A., 2005
Bardehle, Petra, Munich, Germany, 2005
Bayoumi-Stefanovic, Nevin, London, 2005
Gillman, Scott, Sudbury, Massachusetts, U.S.A., 2005
Kim, Yoonjin, Bucheon City, South Korea, 2005
Leondaraki, Marialena, Syntagma, Athens, Greece, 2005
Li, Kehan, Enfield, Middlesex, 2005
Lu, Shan, Nerima-ku,Tokyo, Japan, 2005
Miyazaki, Satoshi, Toyonaka City, Osaka, Japan, 2005
Natsuka, Masaki, Toyonaka City, Osaka, Japan, 2005
Omotedani, Hiroki, Matsudo City, Chiba, Japan, 2005

Associate Membership to Diamond Membership (DGA)

Lampson, Ming, London, 2005
Ota, Shinya, Yamanashiken, Japan, 2005
Palmares, Richard P., Sale, Cheshire, 2005
Yamout, Sabah Ibrahim, Leeds, West Yorkshire, 2005
Yeung Tsz Ming, New Territories, Hong Kong, 2005

Obituary

Leslie Fitzgerald

We announce with deep regret the death of Leslie Fitzgerald FGA (D.1983), Woking, Surrey, at the age of 83. Leslie first came to the jewellery trade in 1947 working in both the manufacturing and retail sections of the industry. In 1979 he joined the Gemmological Association and National Association of Goldsmiths as Education Secretary, responsible for the administration of courses and examinations until his retirement in 1990. He lectured at the College for the Distributive Trades and also taught gemmology in Harrow. NAG tutor, Eddie Stanley, who worked closely with Leslie for many years, writes: "Leslie was a practising Christian and indeed one of the first joining members of the Christian Jewellers Association. He quiet belief system directly affected how he treated all who came into contact with him, his judgement was sound. His tutoring was carried out from a dedication to serve the trade by passing on his knowledge and understanding of trade matters. There are many in the jewellery trade today who have good reason to be thankful for the life and input from Leslie."

It is with deep regret that we announce the death on 7 April of R. Keith Mitchell FGA (Tully Medallist 1934), a Vice President of the Association.

A full obituary will be published in the next issue of *The Journal*.

Anita Axell FGA (D.1988), Stockholm, Sweden, died recently.

Reginald Bridges FGA DGA (D.1951), Chigwell, Essex, died in June 2005.

Deborah J. Cloke FGA (D.1983), Sevenoaks, Kent, died suddenly on 5 May 2005.

Matthew C.M. Faulds BSc, FGA (D.1972), Keswick, Cumbria, died in 2005.

George A. McNair FGA (D.1983), Jesmond, Newcastle-upon-Tyne, died in September 2005.

Thomas Primavesi FGA (D.1963), Pointre Claire, Quebec, Canada, died in September 2005.

John Weatherill FGA (D.1957), Cardiff, died in September 2005

Forthcoming Events

Tuesday 16 May	London: Private viewing of Fabergé and the Russian Jewellers at Wartski (fully booked)
Tuesday 13 June	Scottish Branch: Gems of Russia, from Karelia to Transbaikal. BRIAN JACKSON
Saturday 17 June	Midlands Branch: Summer supper party
Wednesday 21 June	North West: A review of the garnet family. BRIAN JACKSON
Tuesday 27 June	London: AGM followed by a talks and a private viewing of Sotheby's June sale 'Jewels: Antique, Period and Contemporary'
Thursday 13 July	North East Branch: The Naughty Nineties. BRIAN DUNN
Wednesday 19 July`	North West Branch: Thoughts from 'a broad' – a trip around the world of coloured gemstones. TRACEY JUKES
Tuesday 12 September	Scottish Branch: A history of gemmology through the literature. NIGEL ISRAEL
Wednesday 20 September	North West Branch: Colour enhancement of diamond and how it may be detected. PROFESSOR ALAN COLLINS
Wednesday 18 October	North West Branch: Some gemmological and lapidary diversions. DOUG MORGAN
Tuesday 24 October	Scottish Branch: All the colours of diamond. MARTIN VAINER
Sunday 5 November	Gem-A Annual Conference
Monday 6 November	Presentation of Awards and Graduation Ceremony

Contact details

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North West Branch:	Deanna Brady 0151 648 4266 or Ray Rimmer on 0151 525 6066 rr001c8559@blueyonder.co.uk
Scottish Branch:	Catriona McInnes on 0131 667 2199; e-mail scotgem@blueyonder.co.uk
South West Branch:	Richard Slater on 01635 553572; e-mail rslater@dnfa.com

Gem-A Website

For up-to-the-minute information on Gem-A events visit our website on www.gem-a.info

Guide to the preparation of typescripts for publication in The Journal of Gemmology

The Editor is glad to consider original articles shedding new light on subjects of gemmological interest for publication in The Journal. Articles are not normally accepted which have already been published elsewhere in English, and an article is accepted only on the understanding that (1) full information as to any previous publication (whether in English or another language) has been given, (2) it is not under consideration for publication elsewhere and (3) it will not be published elsewhere without the consent of the Editor.

Typescripts Two copies of all papers should be submitted on A4 paper (or USA equivalent) to the Editor. Typescripts should be doubled spaced with margins of at least 25mm. They should be set out in the manner of recent issues of The Journal and in conformity with the information set out below. Papers may be of any length, but long papers of more than 10 000 words (unless capable of division into parts or of exceptional importance) are unlikely to be acceptable, whereas a short paper of 400-500 words may achieve early publication.

The abstract, references, notes, captions and tables should be typed double spaced on separate sheets.

Title page The title should be as brief as is consistent with clear indication of the content of the paper. It should be followed by the names (with initials) of the authors and by their addresses.

Abstract A short abstract of 50-100 words is required.

Key Words Up to six key words indicating the subject matter of the article should be supplied.

Headings In all headings only the first letter and proper names are capitalized.

A This is a first level heading

B This is a second level heading

First and second level headings are ranged left on a separate line.

Third level headings are in italics and are indented within the first line of the text.

Illustrations High resolution digital files, for both colour and black-and-white images, at 300 dpi TIFF or JPEG, and at an optimum size, can be submitted on CD or via email. Vector files (EPS) should, if possible, include fonts. Match proofs are essential when submitting digital files as they represent the colour balance approved by the author(s).

Transparencies, photographs and high quality printouts can also be submitted. It is recommended that authors retain copies of all illustrations because of the risk of loss or damage either during the printing process or in transit.

Diagrams must be of a professional quality and prepared in dense black ink on a good quality surface. Original illustrations will not be returned unless specifically requested.

All illustrations (maps, diagrams and pictures) are numbered consecutively with Arabic numerals and labelled Figure 1, Figure 2, etc. All illustrations are referred to as 'Figures'.

Tables Must be typed double spaced, using few horizontal rules and no vertical rules. They are numbered consecutively with Roman numerals (Table IV, etc.). Titles should be concise, but as independently informative as possible. The approximate position of the Table in the text should be marked in the margin of the typescript.

Notes and References Authors may choose one of two systems:

(1) The Harvard system in which the authors' names (no initials) and dates (and specific pages, only in the case of quotations) are given in the main body of the text, (e.g. Collins, 2001,341). References are listed alphabetically at the end of the paper under the heading References.

(2) The system in which superscript numbers are inserted in the text (e.g. ... to which Collins refers.[3]) and referred to in numerical order at the end of the paper under the heading Notes. Informational notes must be restricted to the minimum; usually the material can be incorporated in the text. If absolutely necessary both systems may be used.

References in both systems should be set out as follows, with double spacing for all lines.

Papers Collins, A.T., 2001. The colour of diamond and how it may be changed. J.Gemm., 27(6), 341-59

Books Balfour, I., 2000. Famous diamonds. 4th edn. Christie's, London. p.200

Abbreviations for titles of periodicals are those sanctioned by the World List of scientific periodicals 4th edn. The place of publication should always be given when books are referred to.

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Cover Picture: A green Usambara effect (UE) tourmaline turns red when placed on top of another green UE tourmaline.
(See The Usambara effect and its interaction with other colour change phenomena, p.1)

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The Gemmological Association and Gem Testing Laboratory of Great Britain

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Ronald Keith Mitchell FGA 1912 -2006

A tribute by Christopher Cavey FGA

I was extremely sad to receive the news that Keith had passed away, as this was not only a personal loss for me, but a great loss for the entire gemmological world. Keith was a remarkable man as well as being a truly exceptional gemmologist, and after he retired from dealing in gems on a daily basis, he never lost interest and continued to read and write about gems whenever he could.

Keith started his career in the silver buying department of Mappin & Webb Ltd in 1928 at the age of 16. He was already interested in gemstones and was waiting for an opportunity to open up for him in the jewellery department, which he joined in 1933. Whilst he was in this employ he started his gemmological studies enrolling at Chelsea Polytechnic. He studied very hard and spent his lunch hours carefully perusing the gem collections in the Geological Museum which was then located in Jermyn Street, just off Piccadilly in London's West End. In 1934 he sat the Diploma in Gemmology Examination; this was to prove a tough year in the gem exams as there was considerable competition but, despite coming up against Robert Webster, it was Keith who won the day and gained the most prestigious prize in gemmology - the B.J. Tully Memorial Medal.

As the winner of the Tully Medal Keith was immediately elected to the Gemmological Association's council, which he served faithfully until his calling up into the Royal Corps of Signals during the early years of World War II. He was posted to Singapore and it was not long afterwards that the Japanese invaded and he found himself a Prisoner of War. A number of his fellow POWs were taken to Thailand to build the infamous Burmese railroad, but Keith was taken to mainland Japan, where he and his fellow inmates were forced to labour making steel for the Japanese war effort, surviving on the poorest of diets for some three and a half years. It has to be said that anyone who can survive such conditions for such a period has indeed to be quite exceptional, and Keith was that in many ways.

After the war he returned to London and took up work with jewellers A & E Davis, situated in Piccadilly in the West End of London. In 1947 he became a tutor at Chelsea polytechnic assisting Thorold Jones who ran the classes in those days, and in 1948 was re-elected to the Council of the Gemmological Association.

In 1950 he took on the task of running the first year correspondence courses for the GA as an Instructor. Only one year later he took over the second year as well, and he ran them single-handed for some years until eventually Vera Hinton took over some of the first-year students.

Keith was a very decent and proper man and expected very high standards from those who worked with him, and of those he was teaching, He expected his students to work hard and continued to give private tuition right up until his retirement. He used

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to send out material to his students and ask for their observations. When he received these he would then give them a copy of his own observations on the same materials, so they could see just what they had missed!

He was the sole author of the correspondence courses used by the GA from the 1950s to 1983.

In the early 1960s,, Keith needed a change and more independence, so struck out on his own dealing in gems, mineral specimens and jewellery. He took over an office in Halton House just round the corner from Hatton Garden in Holborn. During that time he handled many gems from A C D Pain in Burma and formed close relationships with a number of dealers in Sri Lanka. He acquired the Taaffe collection along with the first ever specimen of taaffeite, which was the 'type specimen' for this species. He left this on loan to the Natural History Museum in London. He was a regular contributor to gemmological journals, not only in England but also in Australia, and made many original observations on a number of gem species.

He invented the 'Mitchell' spectroscope stand and was a major contributor to items coming into the London Gem Testing Laboratory. He was a close friend of Basil Anderson, Robert Webster and Alec Farn, and enjoyed an affable relationship with Alan Jobbins and Pat Statham at the Geological Museum in London. He worked with Charles Mathews, the famous lapidaries in Hatton Garden, and was instrumental in the cutting of some very rare gem species for the first time. He handled a large part of the E H Rutland collection upon his untimely death in 1976, and was one of the very few gemmologists in London who regularly handled very rare gem species.

He continued to run the correspondence courses for the GA until 1969 when he was diagnosed with a heart condition. This made him re-consider his overall workload but he continued to trade in gems on a daily basis until his retirement in 1979.

Despite his retirement Keith continued to work on gems and carried on publishing gemmological papers and he finally went on to publish over 40 papers in all. He also performed a great service to thousands of gemmologists with his masterly use of the English language in abstracting papers from other publications; his vast experience of a wide range of gems supported many an enlightening and penetrating supplement to an abstract.

For some time, he had also been working on the memoirs of his wartime experiences. After some searching he managed to find a publisher, although much to his disappointment the size of his book was cut in half before going to press. He did at least have some satisfaction in knowing that a part of his story had at last been told.

Keith revised Basil Anderson's and James Payne's work *The Spectroscope and Gemmology*, adding extra chapters and diagrams.

He privately published sets of slides (each one an original photograph shot by his own hand) showing crystal habits and symmetry together with an explanatory booklet which was retailed by the GA. These were available for a number of years, to assist students of gemmology with their understanding of crystals. Keith was also a good photographer and pioneered a number of techniques for photographing gem materials in daylight and down the microscope.

He was made Vice President of the GA in 1984 and remained in this office until his death on 7 April 2006 at the age of 94.

Keith had lost his loving wife of many years some time ago, but thankfully is survived by his two sons, two grandchildren and a great granddaughter.

For those of us that knew him well he was a great friend with an extraordinary sense of humanity and humour. I believe him to have been a truly great gemmologist and the pertinence and wisdom expressed in his publications should ensure that he is remembered as one of the founding fathers of British gemmology in the twentieth Century.

The role of Be, Mg, Fe and Ti in causing colour in corundum

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Abstract: *New beryllium-diffusion experiments on pure synthetic and iron-doped synthetic sapphire samples and on natural blue sapphires were undertaken to fully understand how colour is affected by Fe, Ti, Mg and Be in corundum. LA-ICP-MS analyses were carried out on sections through and on the treated surfaces of the sapphires. The results have confirmed that the divalent Be acts essentially in the same way as that of Mg, i.e. as a stabilizer of colour centres.*

Keywords: *beryllium diffusion, blue sapphire, colour centres, heat treatment, LA-ICP-MS analysis, yellow sapphire*

Introduction

Although corundum diffusion-treated with beryllium (Be) has been discussed recently by a number of authors including McClure *et al*. (2002), Peretti and Günther (2002), Peretti *et al*. (2003), Hänni (2002), Hänni and Pettke (2002), Emmett *et al*. (2003), Fritsch *et al*. (2003), Themelis (2003), Pisutha-Arnond *et al*. (2003 and 2004) and Schmetzer and Schwarz (2004, 2005), the role of Be in corundum has not yet been fully understood. Pisutha-Arnond *et al*. (2004) presented studies on UV-Vis-spectroscopy and trace-element chemistry of irradiated and Be-treated synthetic and natural colourless sapphires, yellow and orangey yellow Be-treated natural sapphires and some Be-treated natural blue sapphires, and established that the majority of Be-treated sapphires showed indications of Be diffusion into the corundum lattice from an external source. The chemical analyses obtained by laser ablation inductively coupled plasma mass spectrometry (LA-ICP-MS) consistently showed that there were excess contents of (Be+Mg) over Ti in all of the yellow sapphires which were coloured by stable defect centres. The oxidation and reduction heating experiments also showed that oxidizing conditions were an important factor in the formation of stable colour centres. So, currently it is believed that after combining Mg and Be with any Ti present to form colourless $MgTiO_3$ and/or

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$BeTiO_3$ clusters, any excess of (Be+Mg), in combination with iron and the heat treatment in an oxidizing atmosphere can produce stable yellow colour centres in yellow Be-treated natural sapphires.

In the previous study, Pisutha-Arnond *et al*. (2004) assumed the divalent Be could have the same effect in the corundum structure as Mg. However, Mg and many other trace elements are usually present in natural corundum and this makes it difficult to understand the direct relationship of Be and Fe in any natural sapphire treated with Be. Hence in order to prove such an assumption it was necessary

Materials and methods

In order to test whether Be has a comparable effect to Mg in producing brown coloration in an otherwise pure synthetic sapphire (i.e. Be in the Al_2O_3 system), a comparison experiment was performed on a piece of synthetic colourless 'watch glass' sapphire with high purity (THSCS01). The piece was cut in half, and one half was heat-treated with ground chrysoberyl in a crucible while the other half was heated in another crucible without chrysoberyl in an electric furnace. Each crucible was held at 1750°C (measured by a thermocouple in which a certain degree of temperature gradient was unavoidable) for 30 hours in an oxidizing atmosphere. After the treatment, both halves of the 'watch glass' were lightly polished, cleaned and their trace element contents determined using LA-ICP-MS at the GEMOC Key Centre, Department of Earth and Planetary Sciences, Maquarie University, Sydney, Australia. The UV-Vis spectrum of the chrysoberyl-treated half was also recorded.

To further confirm that Fe needs to be present to form yellow (rather than brown) defect centres an Fe-doped sapphire was synthesized by a flame-fusion technique, irradiated with X-rays for 30 minutes using a Rh-tube at 60 kV and 53 mA, and then shortly after, subjected to a fading test. The fading was carried out for one hour at a distance of 3 cm from a 100W light bulb. The sample was subsequently heated in a crucible with ground chrysoberyl at 1780°C for 50 hours in an oxidizing atmosphere. This Be-treated sample was then subjected to the fading test again. The sample was photographed and at each step of the experiments, UV-Vis spectra were recorded with E perpendicular to the *c*-axis (o-ray), except where noted otherwise. The sample was then cut in half, lightly polished, cleaned and analysed for trace element contents across the cut surface using LA-ICP-MS.

Additionally, two simply heat-treated natural blue sapphires and one natural blue sapphire Be-treated under unknown conditions were obtained from Thai stone heaters. The samples were cut in half and the cut surface was lightly polished and cleaned. Their trace element contents were obtained using LA-ICP-MS at five positions namely: Rim1, Mid-Point1, Core, Mid-Point2 and Rim2 to yield a profile of analyses.

Detailed descriptions of LA-ICP-MS instrumentation, analytical and calibration procedures are similar to those given by Norman *et al*. (1996). The UV laser ablation microprobe (a New Wave Research 266 nm Nd:YAG) is coupled to an Agilent 7500 ICP-MS. All analyses were done with a pulse rate of 5 Hz and a beam energy of approximately 0.5 mJ per pulse, producing a spatial resolution of 30-50 micrometres in diameter on the samples. Quantitative results for 9 trace elements (Be, Na, Mg, Ti, V, Cr, Mn, Fe and Ga) were obtained through calibration of relative element sensitivities using the internal standards NIST-610 multi-element glass and pure Al_2O_3, and the external standard BCR2G basaltic glass. The detection limits vary from analysis to analysis and are typically less than 1 ppm for Be, V, Ga; less than 4 ppm for Mg, Ti, Mn; less than 13 ppm for Cr; less than 40 ppm for Na and less than 80 ppm for Fe. The results significant in this study are presented in diagrams and detailed numerical results can be obtained from the senior author.

to carry out more Be-diffusion experiments with pure synthetic and Fe-doped synthetic sapphires without the influence of Mg and other trace elements. In addition, more LA-ICP-MS analyses needed to be carried out on natural blue sapphires both untreated and treated with Be to test the assumption of similarity of Be and Mg.

In order to understand the Be-diffusion process and its mechanism, the role of trace elements and the cause of stable yellow colour centres are reviewed briefly. The role or interaction of Mg, Ti and Fe in creating stable yellow colour centres or blue colours is well understood (Häger, 1992, 1993, 1996, 2001; Emmett and Douthit, 1993). The divalent Mg and tetravalent Ti form colourless $MgTiO_3$ (geikielite) clusters, and after formation of these clusters, any excess Mg could combine with Fe in an oxidizing atmosphere to produce colour-active defect centres or stable yellow colour centres. However, in corundums with rather low Fe content such as Mg-doped synthetic stones, stable brown or brownish violet colour centres, rather than yellow, are produced (Wang *et al*., 1983; Häger, 1996, 2001). The Mg seems to act as a stabilizer of the defect centre. On the other hand, if there is an excess of Ti after the calculation of $MgTiO_3$, the excess Ti in combination with Fe could form colour-active $FeTiO_3$ clusters under both reducing and oxidizing conditions. These clusters create Fe^{2+}/Ti^{4+} inter-valence charge transfer absorption bands near 578 and 735 nm which are responsible for the blue coloration of sapphire (Townsend, 1968; Ferguson and Fielding, 1972; Häger, 1992, 1996, 2001; Emmett and Douthit, 1993).

Results

Simple heat-treatment and beryllium-diffusion treatment of a pure synthetic colourless sapphire

After simple heat treatment (i.e. heat treatment that is not accompanied by other minerals or chemicals), the pure synthetic sapphire (THSCS01) remained colourless but it turned brown after Be diffusion treatment (*Figure 1*). Trace element analyses of the colourless half show that the original material is relatively pure with only traces of Ti (< 4ppm) and Na (< 200 ppm). The brown half contains about 10 ppm by weight of Be, that is, about 20 atom mole ppm of Be has diffused into the corundum lattice,

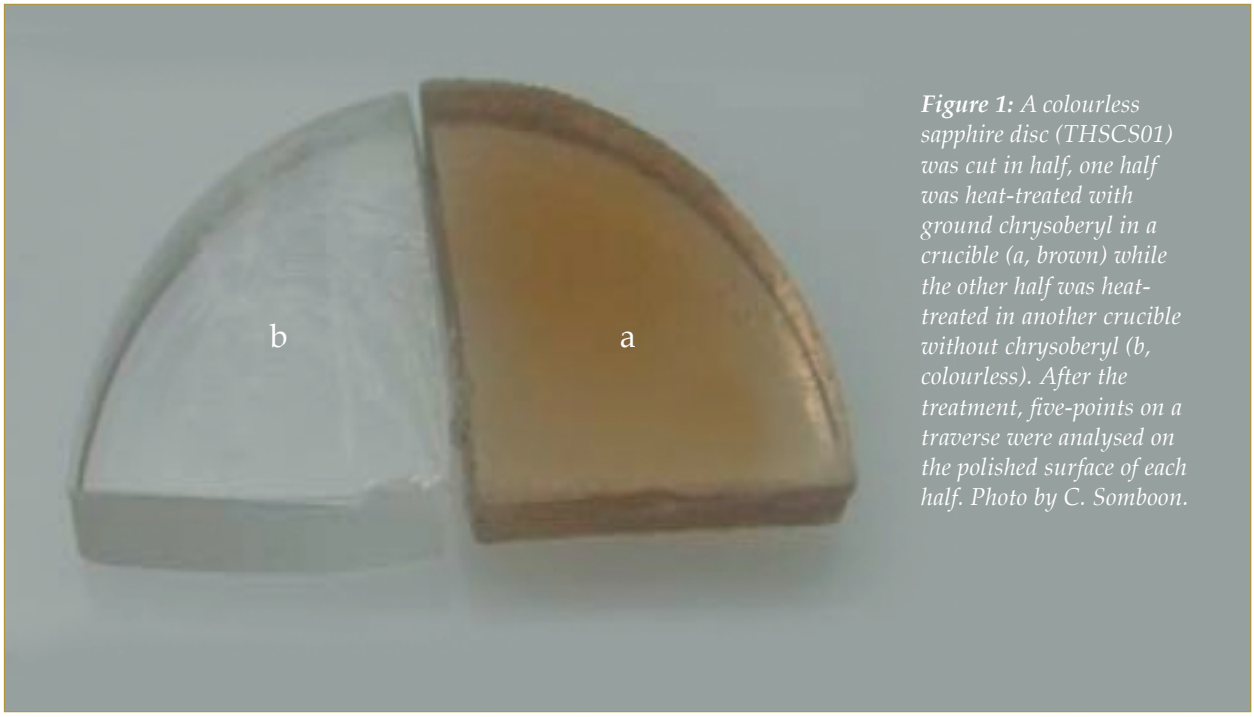

Figure 1: *A colourless sapphire disc (THSCS01) was cut in half, one half was heat-treated with ground chrysoberyl in a crucible (a, brown) while the other half was heat-treated in another crucible without chrysoberyl (b, colourless). After the treatment, five-points on a traverse were analysed on the polished surface of each half. Photo by C. Somboon.*

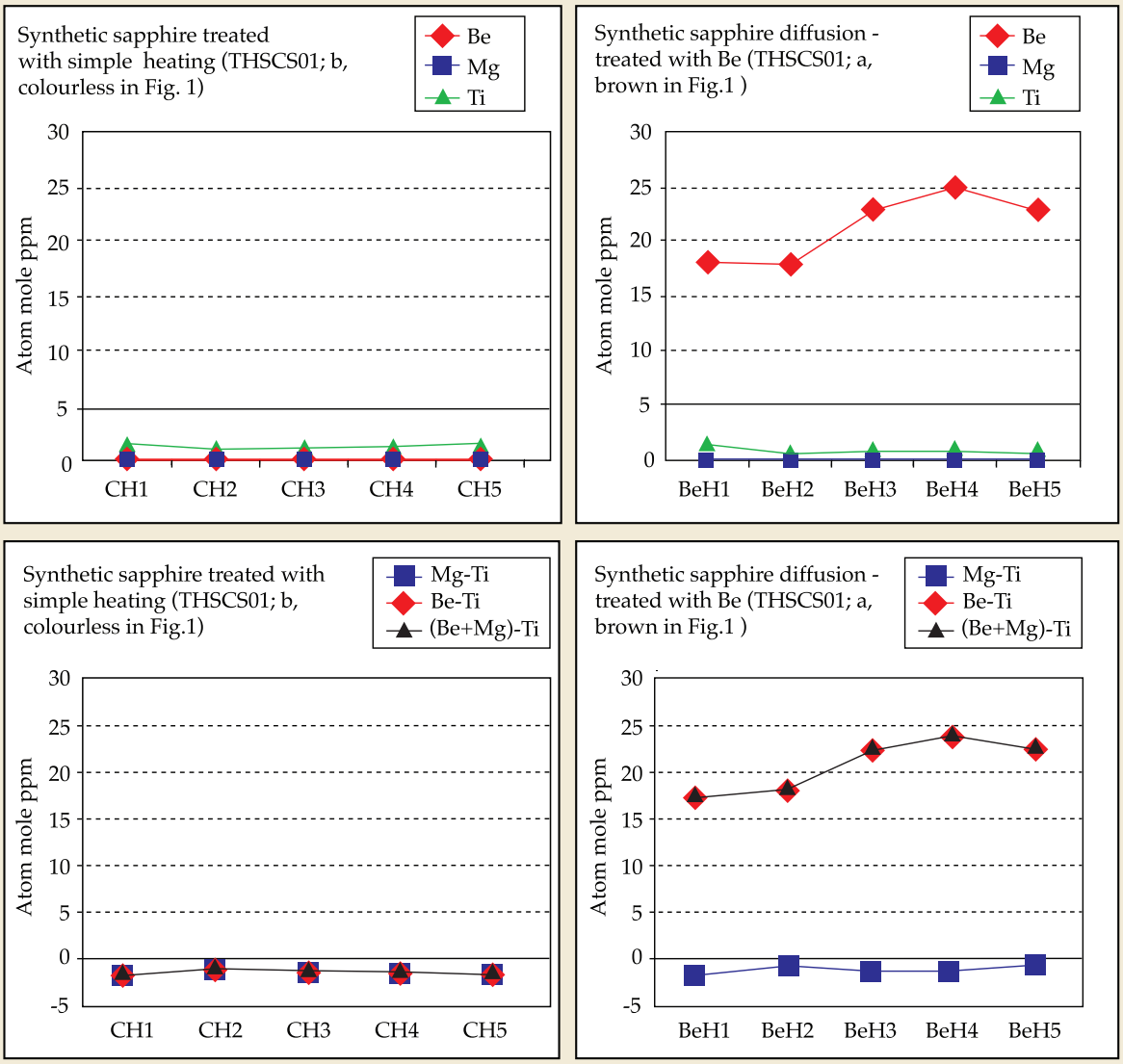

Figure 2: Be, Mg and Ti contents at the surfaces of the simply heat treated (CH numbers) and chrysoberyl-treated (BeH numbers) sections of the sapphire disc (THSCS01) shown in Figure 1. The right-hand diagrams illustrate the positive values of (Be – Ti) in the Be-treated half and Mg points are included in view of discussion later in the paper.

while the presence of any of the other eight trace elements is negligible (*Figure 2*). The UV-Vis spectrum of the Be-treated brown half shows exactly the same pattern as that of the flame-fusion grown sapphire (PKSCS01) treated under unknown conditions by a Thai heat-treater (*Figure 3*) with a broad absorption band centred at around 420 nm.

Treatments of an iron-doped synthetic sapphire

An Fe-doped synthetic sapphire was colourless before treatment (*Figure 4a*) and contained abundant gas bubbles typical of flame-fusion grown material (*Figures 4* and *5*). The sample became yellow after irradiation treatment (*Figure 4b*) and its UV-Vis spectrum shows a continuous increase in absorption towards shorter wavelengths with a shoulder at about 450 nm (*Figure 6*). After a fading test, this sample became colourless (*Figure 4c*) but it turned yellow again after treatment with Be and this colour was stable after a fading test (*Figure 4d*).

The UV-Vis spectrum of the sample treated with Be shows exactly the same pattern as that of the sample irradiated with X-rays (*Figure 6*), and these spectra are also similar to that of a Sri Lankan yellow sapphire coloured by stable defect centres and to

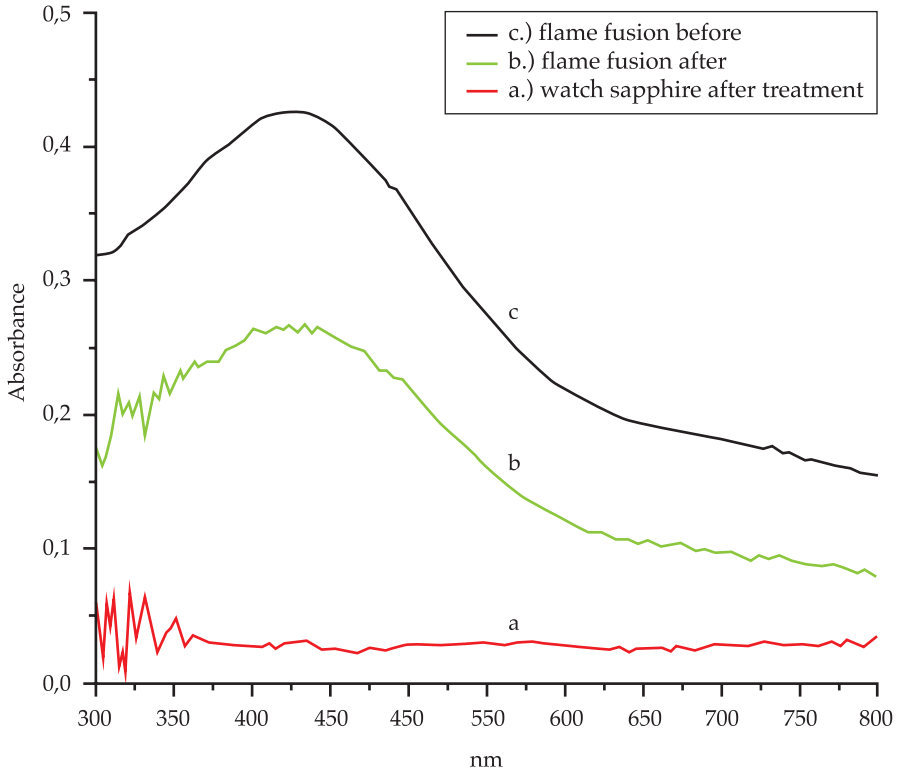

Figure 3: UV-Vis spectra of the flame-fusion-grown sapphire (PKSCS01) before treatment (a, colourless) and after Be-treatment under unknown conditions by a Thai heater (b, brown). Spectrum c was recorded from the brown half (THSCS01) treated with Be in our own experiment, and is the same as that of sample WG02 described by Pisutha-Arnond et al. *(2004).*

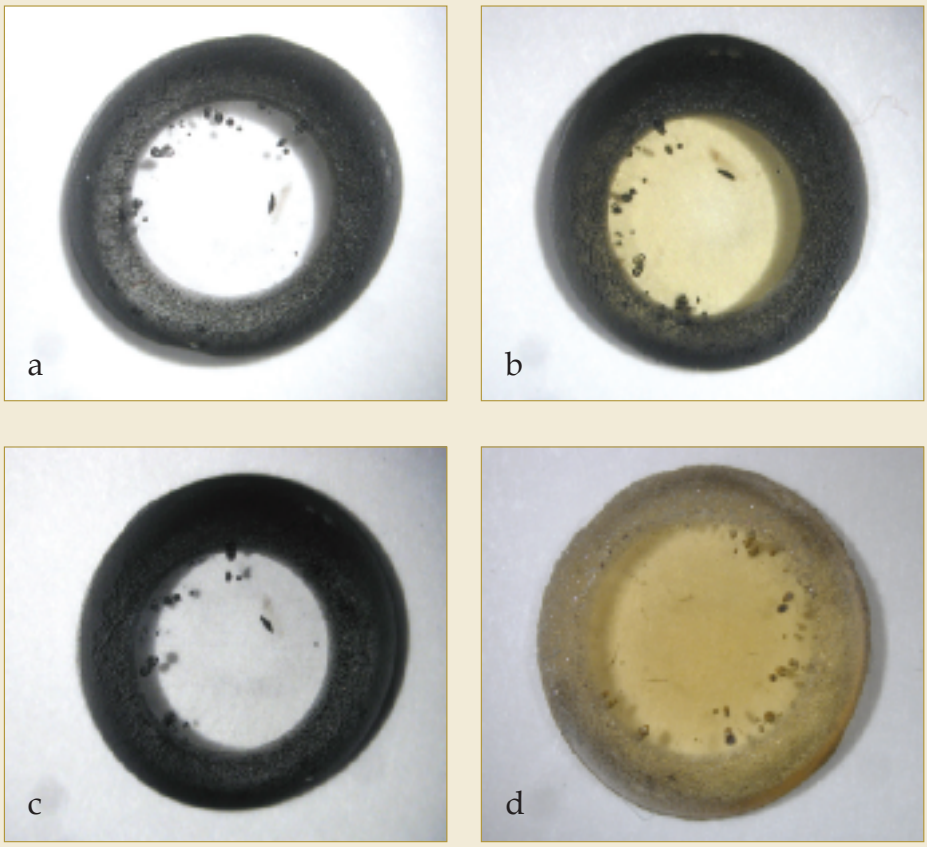

Figure 4: Photographs of an Fe-doped colourless flame-fusion sapphire before treatment (a), yellow after X-ray irradiation treatment (b), colourless after a fading test (c), and yellow again after Be-treatment (d). The final colour was stable under the fading test. Photos by T. Häger.

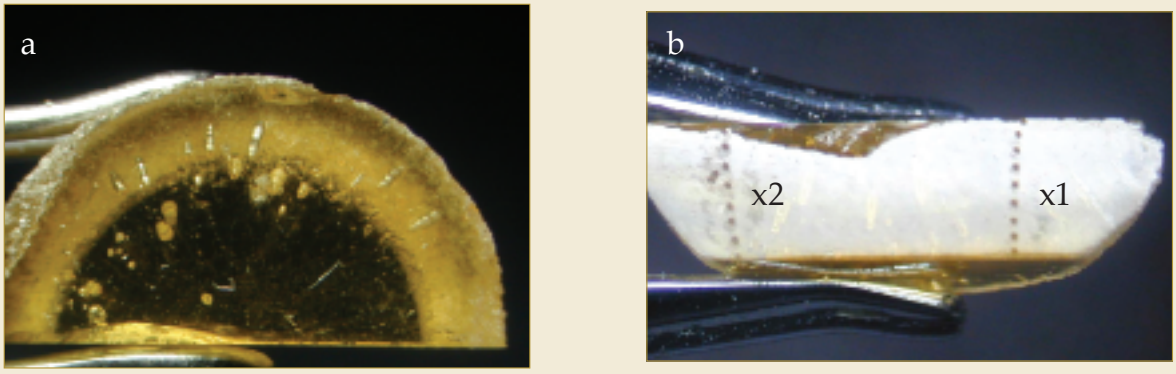

Figure 5: The Fe-doped sapphire described in Figure 4, treated with Be and cut in half (a), with details of abundant gas bubbles. In (b) are shown the positions of two traverses (X1 and X2) on the cut surface where analyses were obtained using LA-ICP-MS. Photos by C. Somboon.

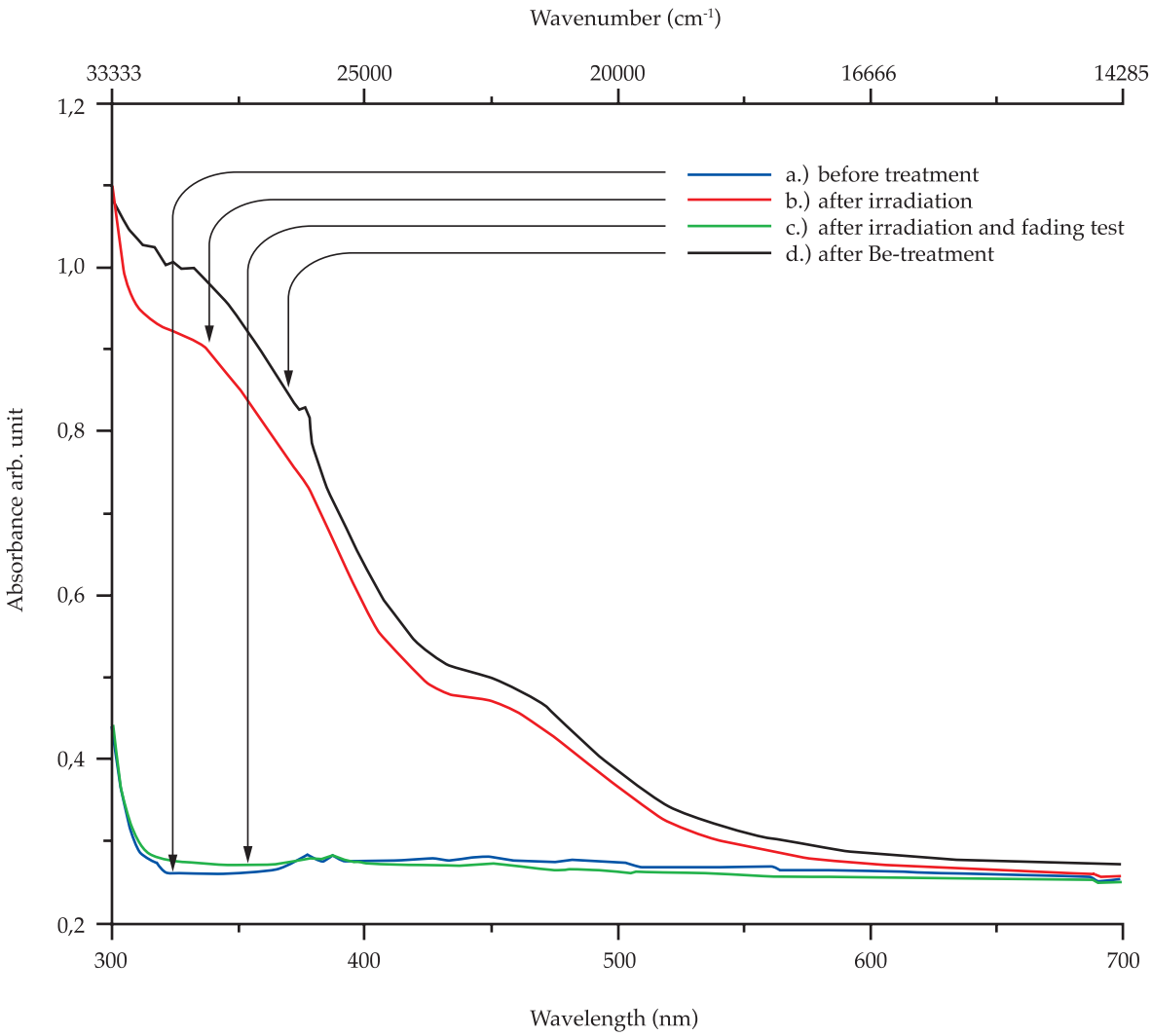

Figure 6: UV-Vis spectra of the Fe-doped flame-fusion-grown sapphire before treatment (a), after X-ray irradiation treatment (b), after a fading test (c), and after Be-treatment (d). All spectra were measured with E perpendicular to the c-axis (o-ray).

that of a synthetic sapphire doubly-doped with Mg and Fe (*Figure 7*). The trace element analyses confirm that significant contents of Be and Fe (about 25-30 atom mole ppm of Be and 50-60 atom mole ppm of Fe) are present in this sample after Be treatment while the other trace element contents are negligible (*Figure 8*). Hence it is clear that colour in the sample can be attributed solely to Be+Fe with no influence from other trace elements.

Heat-treated natural blue sapphires

As expected the two simply heat-treated natural blue sapphires, one from Australia (AUS1) and the other from an unknown source, are homogeneous in colour throughout (*Figures 9* and *11*). The five point profile analyses across the cut surfaces reveal no detectable Be (below 1 ppm detection limit) (*Figures 10* and *12*), but show significant Fe and Ti with trace amounts of Mg. At all the analysed points Ti exceeds Mg+Be.

Be-treated natural blue sapphire

A 2.28 ct rectangular cut blue-green sapphire (BG1) reportedly from Bang Kacha (Chanthaburi, Thailand) was heat-treated with Be under unknown conditions by a Thai stone heater. After treatment the sample clearly showed a thin surface-related yellow rim surrounding a blue core with complex zoning (*Figure 13a*). The sapphire was cut

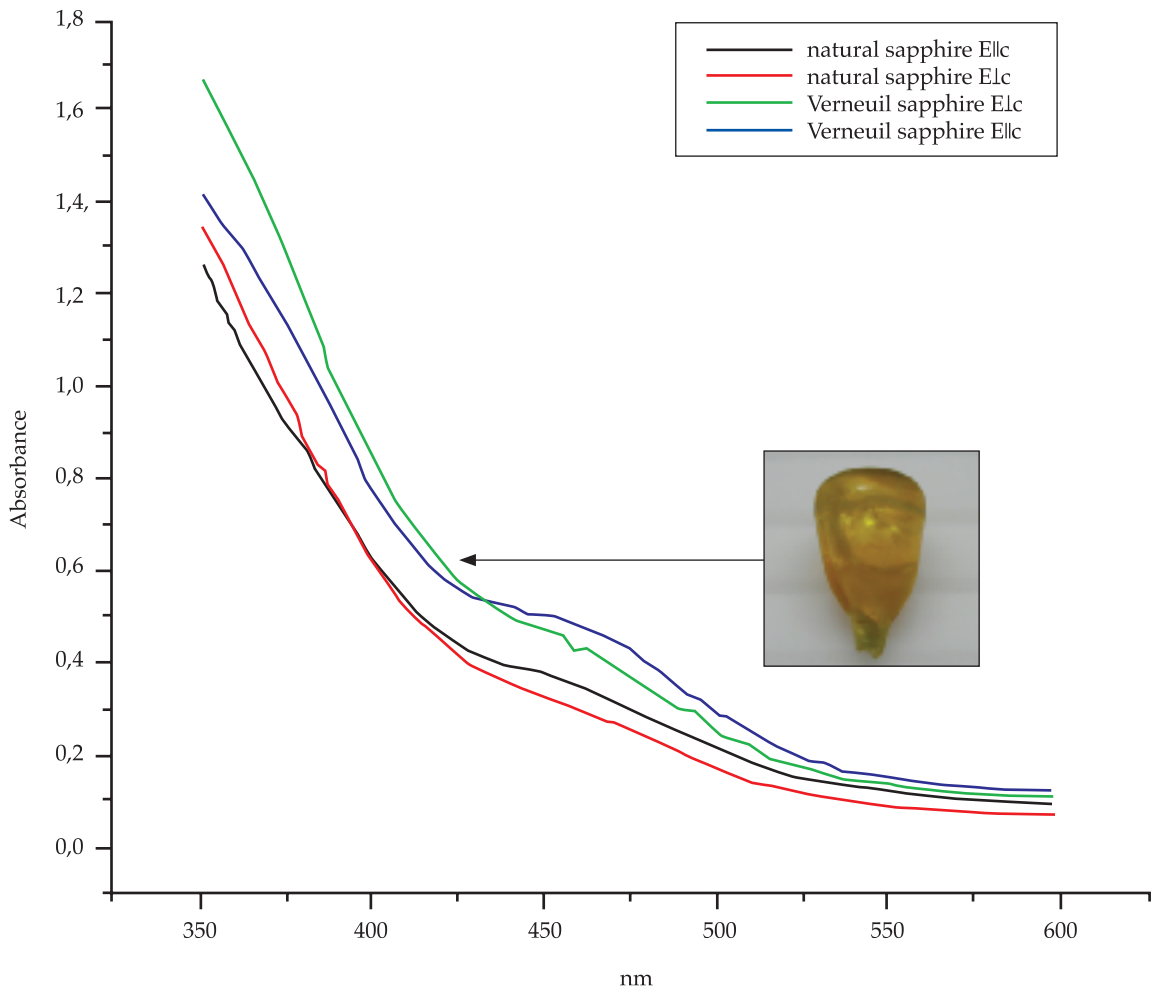

Figure 7: UV-Vis spectra of a natural Sri Lankan yellow sapphire coloured by stable defect centres (red and black curves) with the spectra of a synthetic flame-fusion-grown sapphire doped with 50 ppm Mg and 50 ppm Fe (green and blue) for comparison (Häger, 2001).

into two and the blue core of one piece can be seen in *Figures 13b* and *c*. The LA-ICP-MS profile analysis shows negligible Be (< 1 ppm) in the core and elevated Be content towards the yellow rims (*Figure 14*). All the analysed points in the blue core show an excess of Ti over total Mg+Be content. At the points near each rim, at the blue-yellow boundary, the analyses do show elevated Be contents but the Ti contents still exceed the sum of Be+Mg (*Figure 14*). However, at all the points analysed on the outer surface of the stone, which are definitely on the yellow rim (*Figure 15*), there is an excess of Be+Mg over Ti (*Figure 16*). Additionally, all analyses indicate a rather high Fe content which is typical of sapphire from a basaltic source.

Discussion

The experiments described above on pure synthetic sapphire with and without Be diffusion indicate that the brown coloration is due to the presence of Be. The Be-diffusion treatment in an oxidizing atmosphere did produce stable brown colour centres similar to those found earlier in the synthetic sapphire doped with Mg. However they

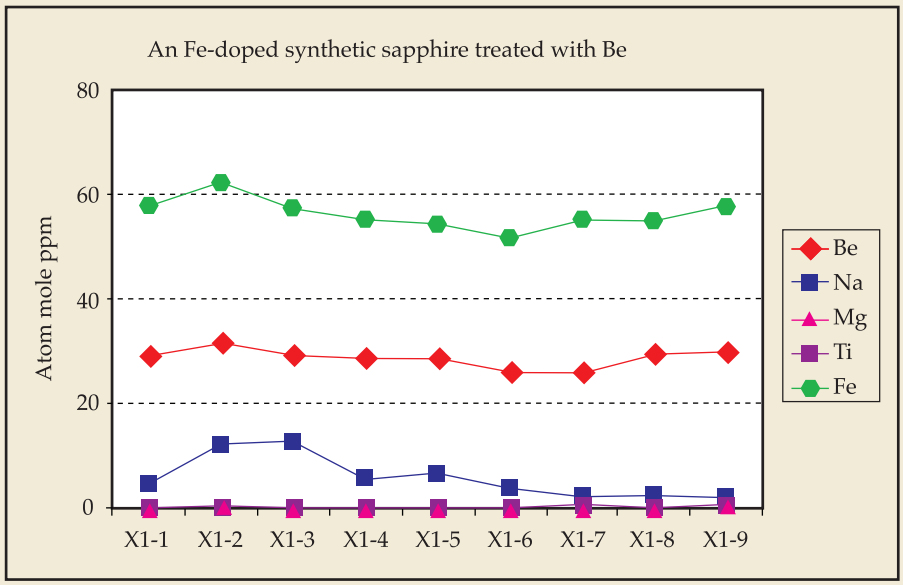

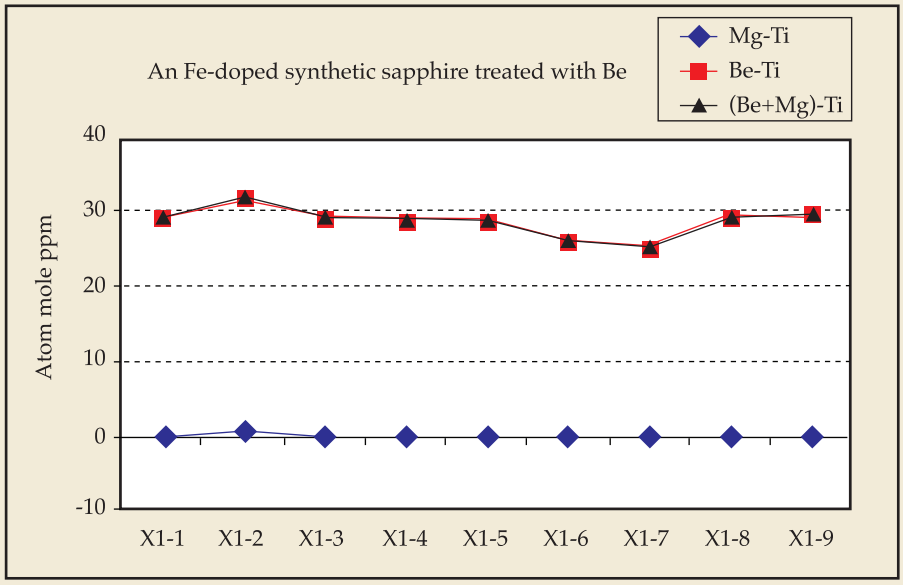

Figure 8: Trace element content along the traverse X1 of the Fe-doped synthetic sapphire treated with Be. The Fe and Be contents are constantly high across the cut surface; Mg and Ti contents are at or below the limits of detection.

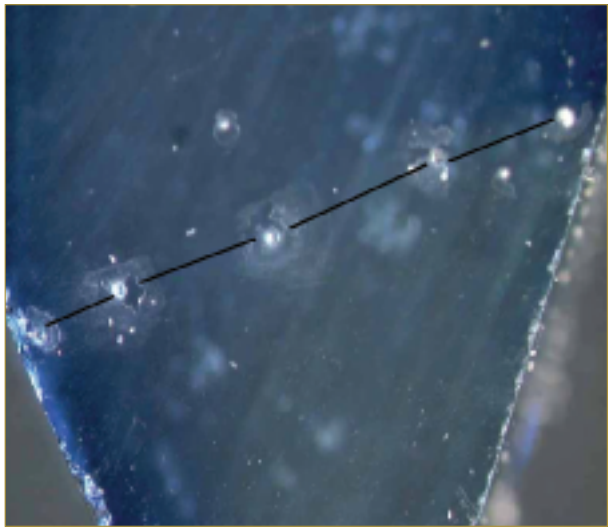

Figure 9: A natural blue sapphire (DIF1), reportedly simply heat-treated, was cut in half and the five points shown where LA-ICP-MS analyses were made (see Figure 10). Photo by P. Lomthong

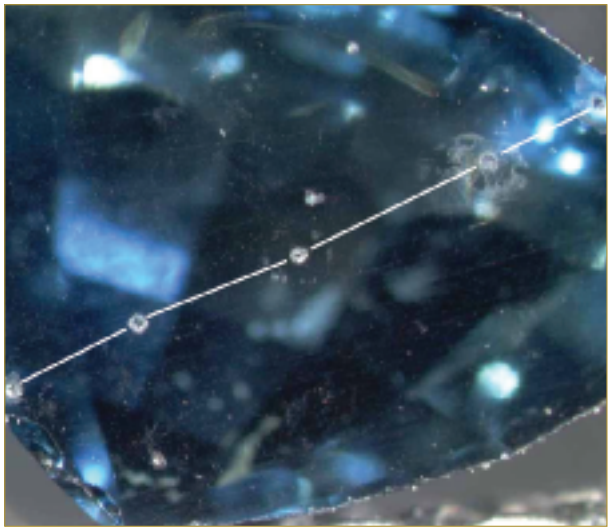

Figure 11: Cut section of an Australian blue sapphire (AUS1) reportedly simply heat-treated. LA-ICP-MS analyses were carried out at the five points marked and data for Be, Mg and Ti shown in Figure 12. Photo by P. Lomthong.

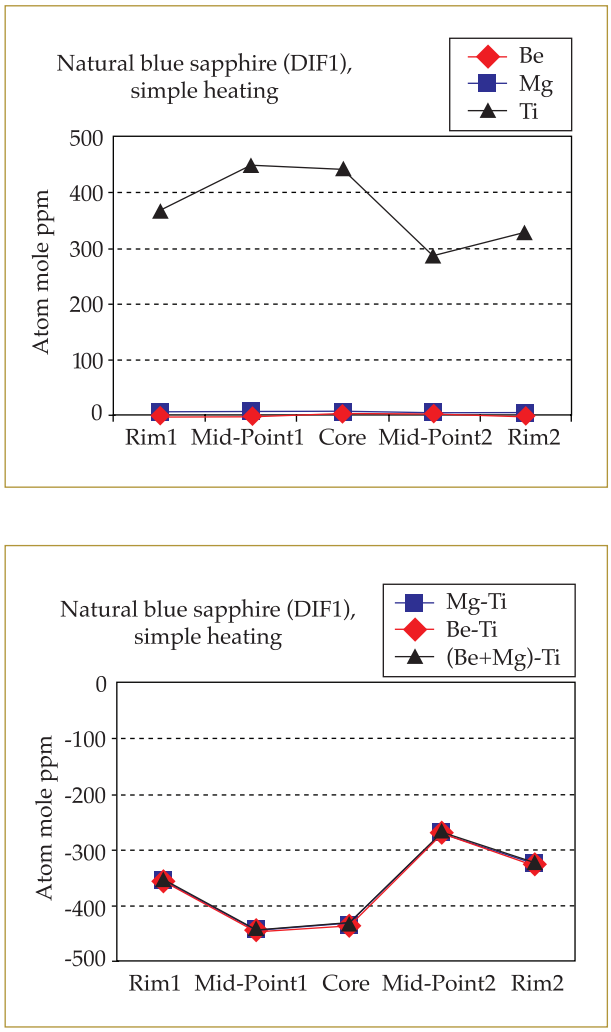

Figure 10: Plots of trace element content variation across the cut surface of the heat-treated blue sapphire (DIFI) shown in Figure 9. The anlyses show negligible contents of Be, Mg and Ti > Mg at all points analysed.

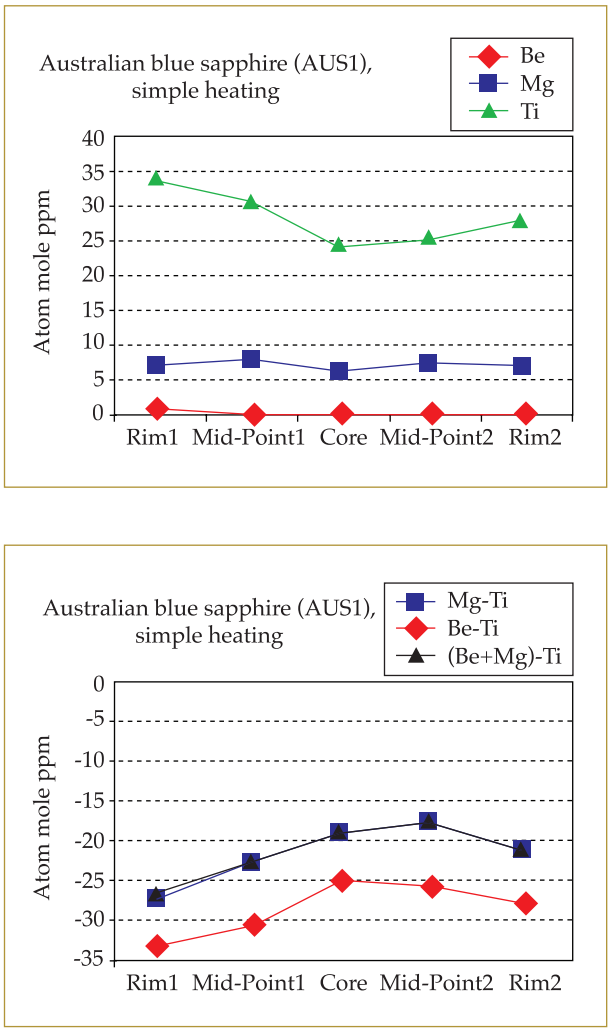

Figure 12: Contents of Be, Mg and Ti across the cut surface of the Australian blue sapphire (AUS1) shown in Figure 11. The analyses show negligible contents of Be, and Ti > Mg at all five points analysed.

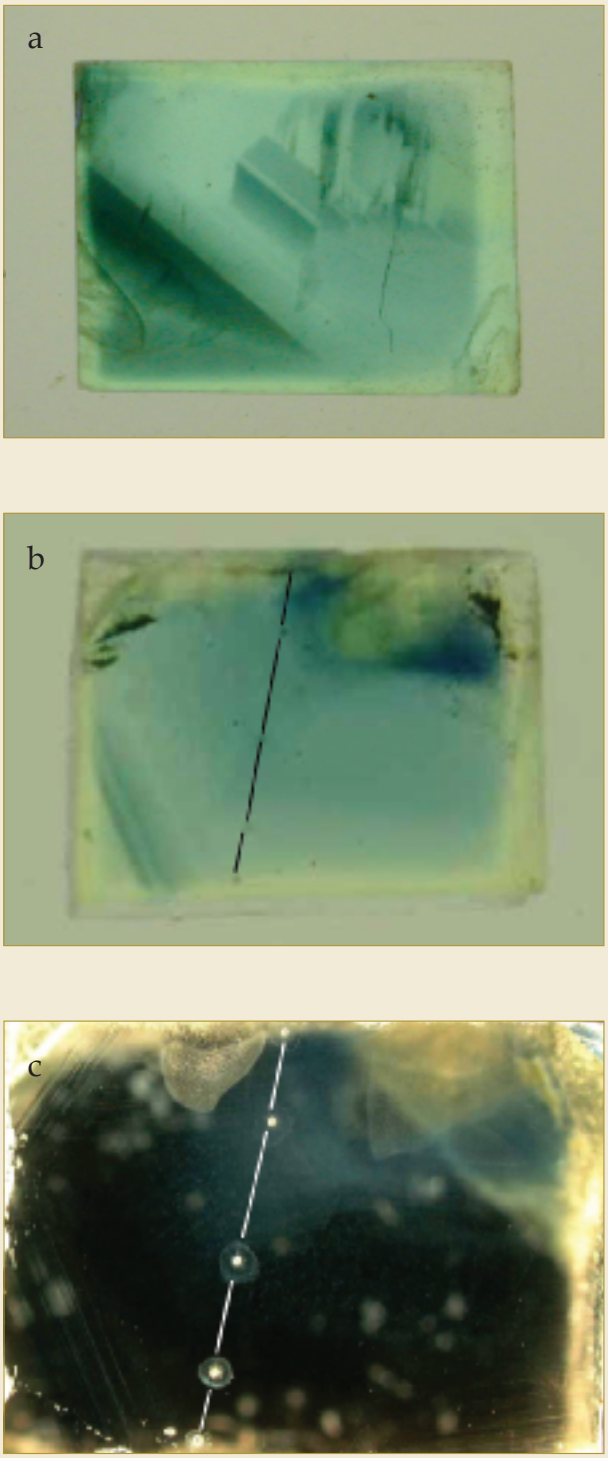

Figure 13: A rectangular block of a natural blue-green sapphire (BGI), heat-treated with Be by a Thai heater, showing a thin surface-related yellow rim surrounding the complex-zoned blue core (a, in immersion liquid). After the treatment the sample was cut in half (b, in immersion; c, in air) and analyses were made at five points across the cut surface using LA-ICP-MS. Two points on both rims are very close to the yellow zone (rim) while three points in the middle are definitely in the blue core. Photos by C. Somboon.

produce different absorption spectra with the main peak centred at around 420 nm for the Be-diffusion-treated sample and at around 450 nm for the Mg-doped sample (see Pisutha-Arnond *et al.*, 2004, Figure 28).

The experiments on the synthetic sapphire doped with Fe and afterwards diffusion-treated with Be indicate that the combination of Be+Fe in the Al_2O_3 system behaves in the same way as Mg+Fe. That is, when divalent Be in combination with Fe in the Al_2O_3 structure is heat-treated in an oxidizing atmosphere stable yellow colour centres are produced that are similar to those in synthetic sapphire double-doped with Fe and Mg. The spectrum produced by sapphire doped with Be+Fe or Mg+Fe might therefore be attributed to 'metal^{2+}+Fe-related stable colour centres' while that produced solely by irradiation of Fe-doped sapphire could be referred to 'Fe-related unstable colour centres'.

In the natural blue sapphire subjected to normal heat-treatment described above (*Figures 9* to *12*), all the analysed points show Ti > Mg+Be. After calculation of $MgTiO_3$ and $BeTiO_3$ clusters, the excess Ti could form colour-active $FeTiO_3$ clusters or Fe-Ti intervalence charge transfer, which caused blue coloration of the stones.

In the Be-treated natural blue sapphire, all the analysed points in the blue core show an excess of Ti over Mg+Be content (i.e. after the calculation of $MgTiO_3$ and $BeTiO_3$ clusters). At the boundary of the blue core and the yellow rim there are elevated Be contents but the Ti contents still exceed the sum of Be+Mg (*Figure 14*). The excess Ti could therefore form colour-active $FeTiO_3$ clusters which cause blue coloration in the core area.

In contrast, at all the points analysed on the outer surface or rim of the stone (*Figure 15*) there is an excess of Be+Mg over Ti (*Figure 16*) and the colour is yellow. All the analysed points also indicate the presence of Fe which suggests that the excess of Be+Mg in combination with Fe in an oxidizing atmosphere have led to the formation of stable yellow colour centres. The blue sapphire (BG1) shown in *Figures 13* to *16*

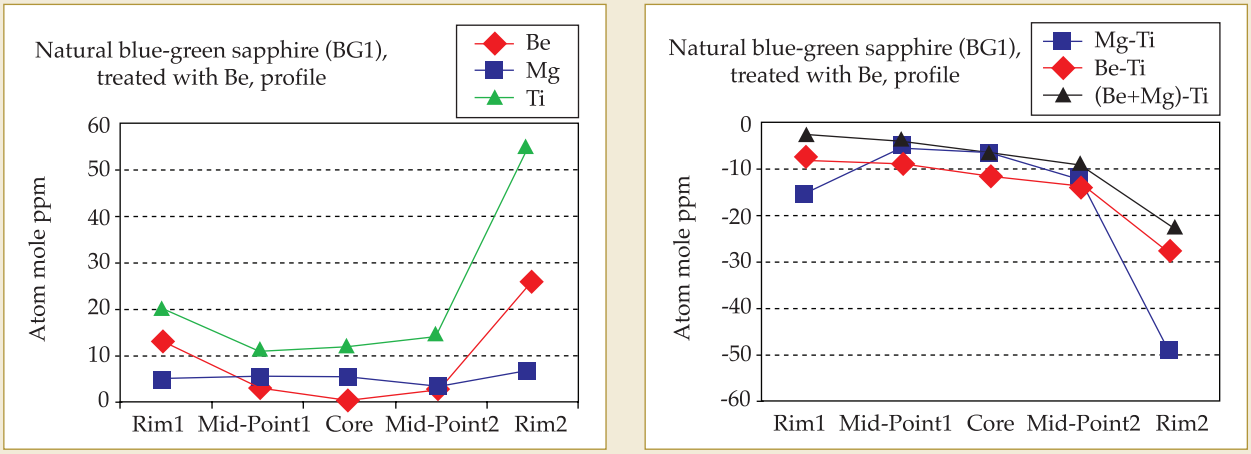

Figure 14: Contents of Be, Mg and Ti at five points across the cut surface of the Be-treated blue-green sapphire (BG1)shown in Figure 13 (b and *c). The Be contents are high at the rims and decrease toward the core. The analyses show Ti> (Be+Mg) in all the analysed points which are within the blue area.*

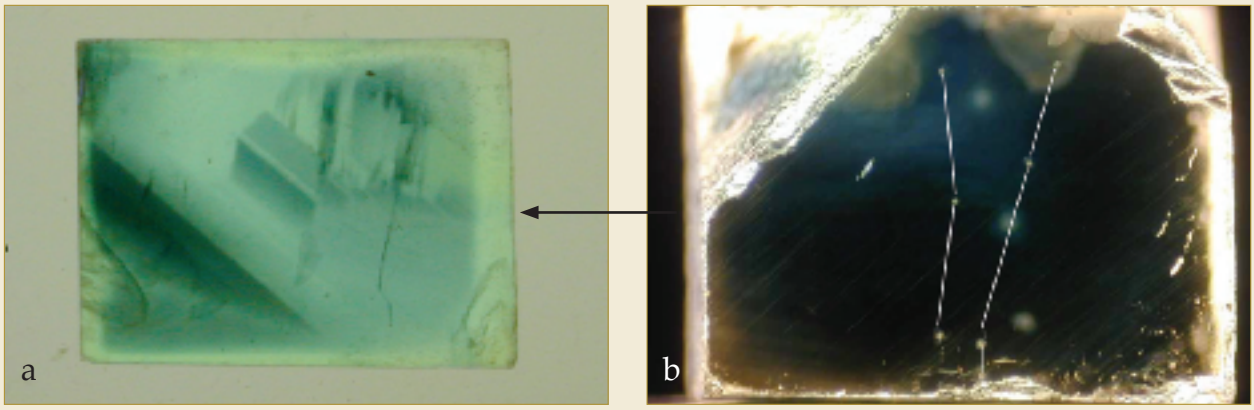

Figure 15: (a) Rectangular block of Be-treated natural blue-green sapphire (BG1) shown in Figure 13(a). (b) is a view of the right face of (a), looking in the direction of the arrow and shows the locations of the seven analyses by LA-ICP-MS, all at the yellow surface of the Be-treated sapphire. Photos by C. Somboon.

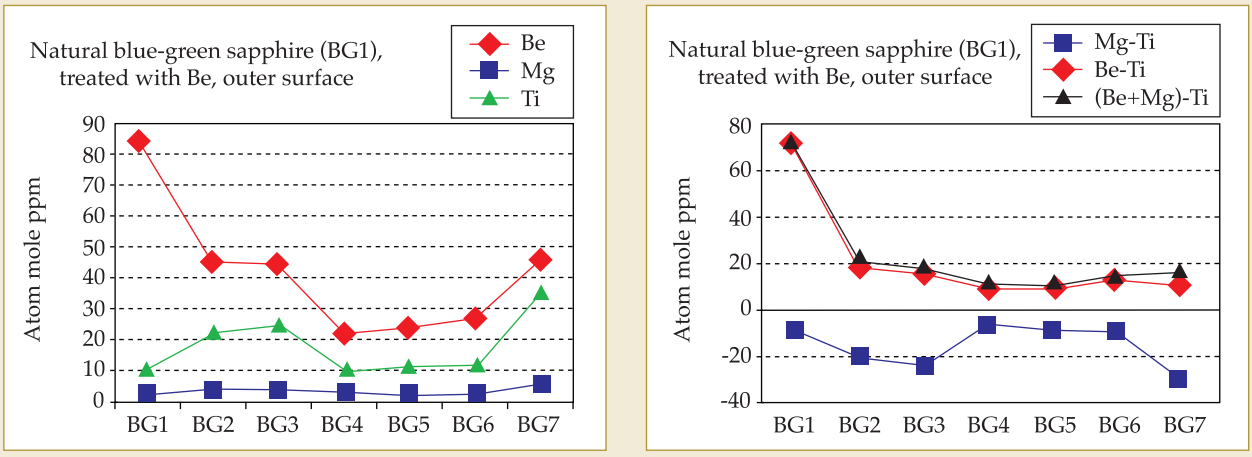

Figure 16: Be, Mg and Ti contents at seven points on the outer surface of the Be-treated blue-green sapphire (BG1) shown in Figure 15. The analyses show variable contents of Be and Ti but Be content is generally high. So (Be+Mg) exceeds Ti at all points in the yellow rim and when plotted, the profile is clearly distinct from the profile of (Mg-Ti) points below the zero line.

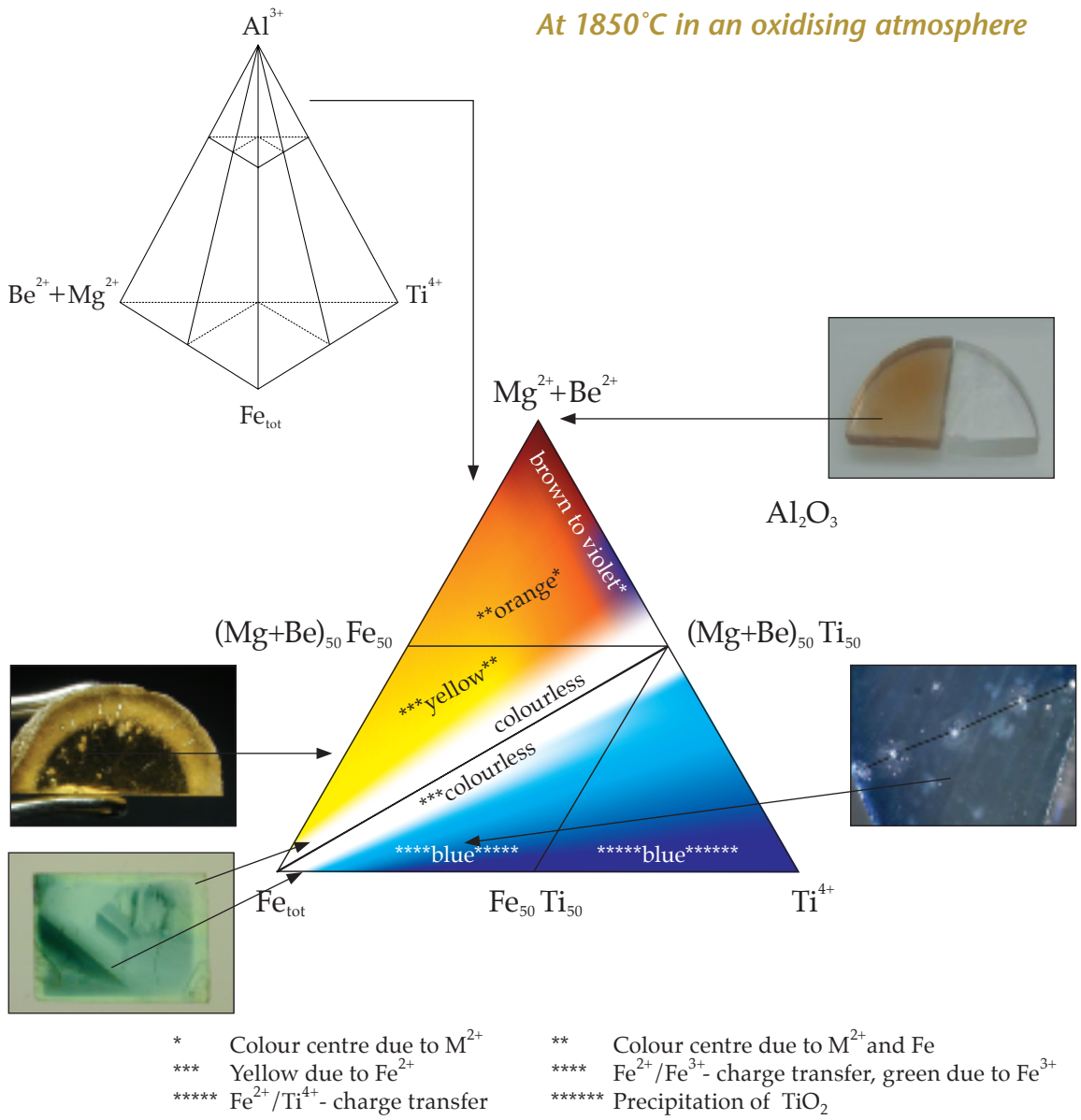

Figure 17: Approximate compositions of some treated sapphires discussed in this paper plotted on the triangular diagram proposed by Häger (1996). This model relates the colours in sapphires to their trace element content in an oxidizing atmosphere. Fe_{tot} Means Fe^{2+}+Fe^{3+} and the field relates to the proportions of trace elements in a corundum host.

is another stone in which Ti exceeds the Mg content at all the analysed points. These data confirm that simple heat-treatment is unlikely to change a blue sapphire to yellow. But if the blue sapphire is subjected to diffusion of Be it is possible to increase the (Be+Mg) /Ti ratio and turn the rim yellow when the ratio exceeds 1.

Conclusion

If the results presented above are combined with those of Pisutha-Arnond *et al.* (2004), it can be concluded that Be and Mg act in a very similar way in the 'pure' Al_2O_3 system although in the UV-Vis spectrum they produce absorption peaks at different wavelengths. In the Al_2O_3 system doped with Fe, addition of Be and Mg produces essentially similar results, as they do when the system also contains Ti. Thus, it is now valid to add Be into the Mg corner in the triangular diagram model proposed by Häger (1996 and 2001; see also Schmetzer and Schwarz, 2004). In so doing we can plot the approximate compositions of some treated

stones in the diagram as shown in *Figure 17*. The colours of these treated stones fit the model reasonably well.

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The authors wish to thank Prof. Sakda Siripant, the former Director of the GIT, for continuous support of this study, and Prof. W. Hofmeister from the Institute of Gemstone Research, University of Mainz for his support also. Furthermore we would like to thank the staff of the GIT Lab for their assistance: Mr Thanong Leelawatanasuk, Miss Chaniya Somboon, Miss Somruedee Sakkaravej, Miss Thitintharee Pavaro; and the research staff at Kasetsart University: Miss Pantaree Lomthong and Miss Sermrak Ingavanija.
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A new find of sapphire placer deposits on Nosy-Bé, Madagascar

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Abstract: *The north of Madagascar is rich in corundum occurrences. Late Mesozoic basaltic extrusions have brought with them many corundum xenocrysts, which can be found now in various types of placer deposits. A new deposit on Nosy-Bé is described and compared with the occurrences on the Ambato peninsula and at Ambilobe, NE Madagascar. Sapphires are found mainly in the alluvium of small creeks. Searching and exploration is largely done by local villagers, who mine selectively in creek beds. Although up to 20 ct/m^3 are found, the size of the deposit does not appear to suffice for a large scale mining operation. The bulk of the corundum recovered is opaque. A minority of stones can be enhanced by heat treatment. Their gemmological characteristics correspond to those found in sapphires from basaltic-type deposits.*

Keywords: *corundum, gemmological characteristics, geology, Madagascar, placer deposits*

Introduction

Madagascar is well known for its many gemstone deposits. There are countless occurrences of virtually all types of gemstone, with the exception of diamonds. In the past ten years much sapphire has been found in the NE of Madagascar (*Figure 1*). The recent discoveries of sapphires in the region between Ambilobe and Antsiranana, the former Diego Suarez have been described by Superchi *et al*. (1997) and Schwarz *et al*. (2000). There, sapphires are found in karsts of the Ankarana limestones. At the centre of the mining activity, which sprung up in the last six years, are the villages Andranonakoho and Ambondromifehy, some 38 and 43 km, respectively, NE of Ambilobe.

The source of the sapphires has been identified as the basalts of the Massif d' Ambre. They are of Pliocene or Quaternary age. These basalts brought with them corundum, some of which is of gem-quality. With erosion of the basalts, the sapphires were transported by streams and eventually accumulated in fractures in the underlying limestone (*Figure 2*). Extraction and recovery of the gemstones in this environment is rather strenuous and quite dangerous for the miners (*Figures 3* and *4*).

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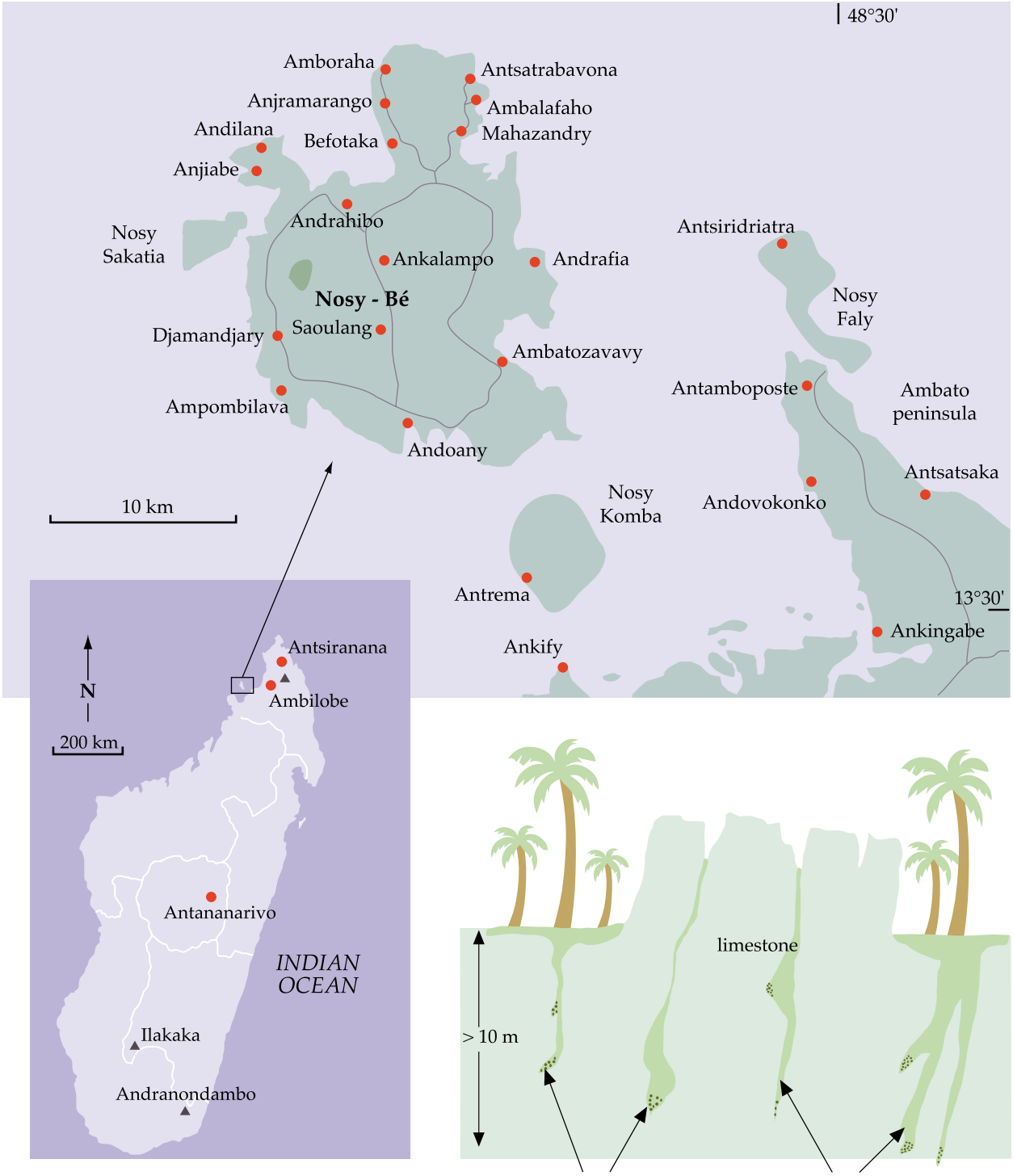

Figure 1: Simplified geographical map of northern Madagascar showing the sample localities at Befotaka on Nosy-Bé island and Andovokonko on Ambato peninsula. The inset shows the well-known sapphire occurrences in the North between Ambilobe and Antsiranana (Ambondromifehy) and in the South at Ilakaka and Andranondambo.

Figure 2: Simplified cross-section, showing the accumulation of sapphires in limestone karst, NE of Ambilobe, northern Madagascar. Weathering and rain water dissolve limestone along joints and cracks; this enlarges them and they are then filled with detrital minerals and soils.

Recent discoveries of sapphires and zircons on the Ambato peninsula and on Nosy-Bé demonstrate the widespread occurrence of these precious stones in traps and placers and have enabled a fuller understanding of their formation. The following description deals largely with the deposit on northern Nosy-Bé with some comments on the occurrences at Andovokonko, Ambato peninsula.

Figure 3: *A miner showing loam containing sapphire, recovered from karst cavities.*

Figure 5: *Crater lakes, northern Nosy-Bé.*

Figure 4: *Women and children wash the sapphires from the loam.*

Figure 6: *Sedimentary layers of basaltic tuff and lapilli.*

Regional geology

Basement rocks, probably ranging from Archaean to Proterozoic in age, are quite common in Madagascar, but have not been encountered on the northern part of Nosy-Bé. There the rock succession begins with Lias sediments, largely sandstones, intercalated with argillites and marls. These sediments have been intruded by syenites and microgranites. During this process, the sediments have been folded and deformed and now dip 35° to 55° to the N or to the S, and generally strike 70° to 90°.

On top of the sediments, a sequence of mafic lavas and tuffs of basanitic and phono-tephritic composition yield K – Ar ages of 7.32 Ma and 10.15 Ma, respectively (Melluso and Morra, 2000). These ages, however, do not match with geological field observations. The sequence of lavas and tuffs (with many lapilli) found on Nosy-Bé is generally loose, uncompacted and very vulnerable to erosion, as can be seen in the landforms around the crater lakes shown in *Figure 5*. Such loosely packed material erodes rapidly in a tropical climate with heavy rainfall (*Figure 6*). It is possible that these volcanic rocks are not older that 0.1 Ma.

Mineral assemblages

The commonest heavy minerals are iron oxides and minor ilmenite, with zircon and sapphire, and these are concentrated in parts of the river beds. The iron oxides consist of very fine grains and form 'black sands'; they are noticeable in the washing pan as 'tails' only, while the precious minerals are usually of millimetre size and larger. Much of the corundum is up to 5 mm across but some specimens can reach 30 mm in diameter. Zircons and sapphires are generally angular to subangular with little evidence of rounding, indicating short transport distances. Sapphire comprises >40% of the recovered stones and should be described as 'coloured corundum' since it is usually fractured, more or less opaque and not of gem-quality.

Some olivine has also been found, and could readily be mistaken for green sapphire, if not examined carefully. Zircons are described as opaque hyacinth (*Figure 7*) and are not of commercial interest.

Figure 7: Group of zircon hyacinth crystals between two groups of differently coloured sapphires.

Characteristics of the sapphires

The sapphires may be blue, blue-violet, greenish-blue, greenish-yellow or yellow and, as such, represent a characteristic basaltic-type sapphire suite, comparable to those from Australia, Nigeria, Thailand, Laos and Cambodia. Sutherland *et al*. (1998) referred to them as 'BGY (blue-green-yellow) sapphire'. Although most rough material is corroded, some long-prismatic, six-sided, barrel-shaped crystals have also been found. Most of the stones showed a distinct colour-zoning, some with bicoloured (blue-yellow) and others with tricoloured (blue, green-yellow, yellow) patterns.

Refractive indices and specific gravities fall within the known ranges for the mineral species corundum. n_o varies between 1.760 and 1.765 and n_e between 1.768 and 1.773 with a maximum birefringence of 0.008. The SGs, determined with a hydrostatic balance, range from 3.98 to 4.03. The sapphires were inert under both long and short wave UV.

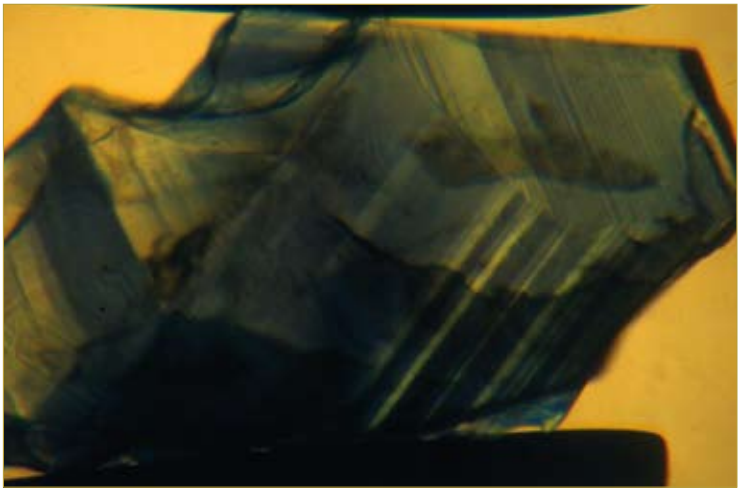

Figure 8: Intense colour zoning and growth structure form a typical inclusion pattern in the sapphires from northern Madagascar. Immersion, transmitted light, field of view 3 mm.

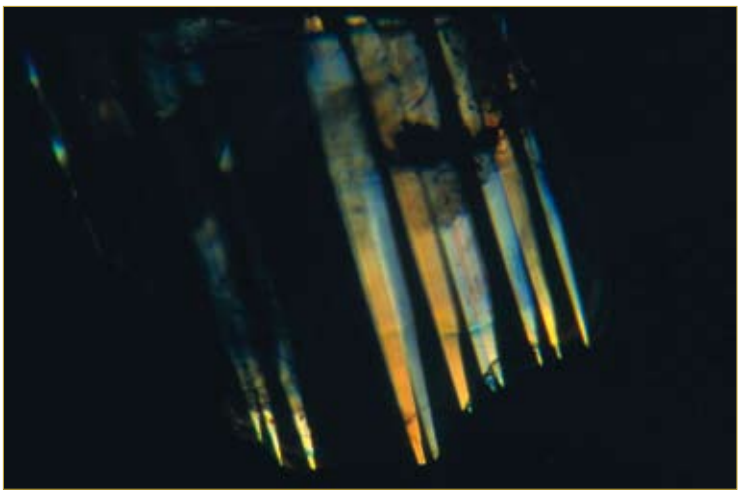

Figure 9: Distinct twinning lamellae in a sapphire from northern Madagascar. Immersion, transmitted light, crossed polars, field of view 2 mm.

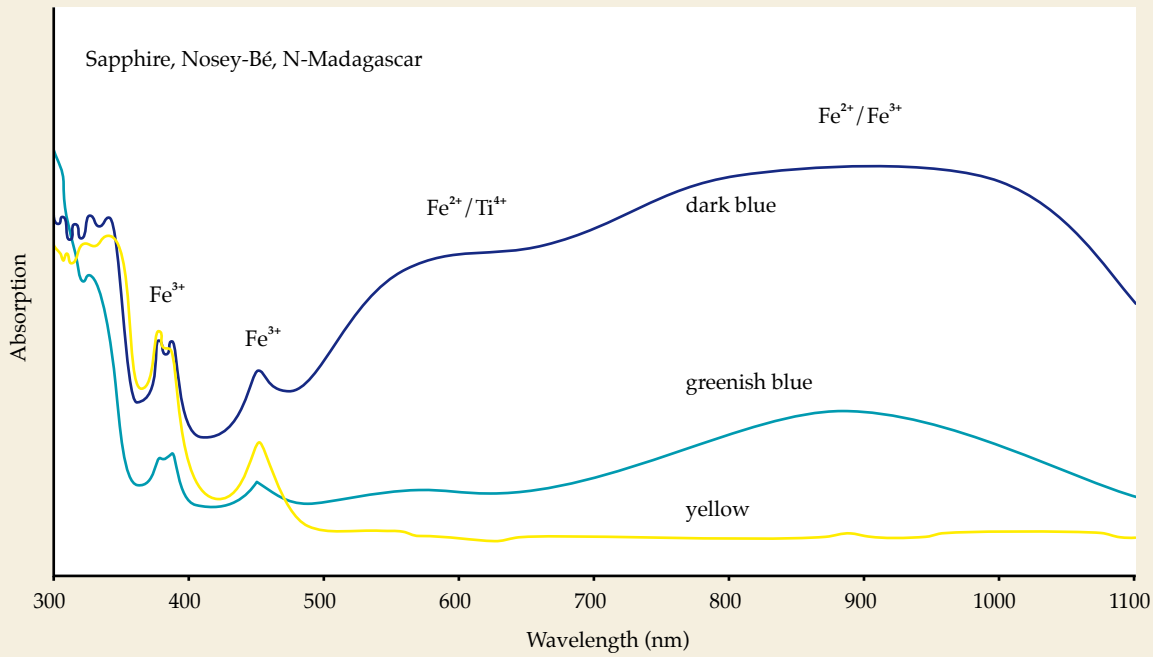

Figure 10: Non-polarized UV/VIS/NIR-spectra of three typical colours of sapphire from Nosy-Bé, northern Madagascar.

The most characteristic inclusion pattern is a distinct growth- and colour-zoning (*Figure 8*), which in most stones is visible with the naked eye. Twinning lamellae are also commonly present (*Figure 9*). In addition, healing planes and minute birefringent mineral inclusions have also been found. The absorption spectra of the samples investigated are typical of basaltic-type corundum (*Figure 10*). Irrespective of the colour, all spectra show distinct absorption bands due to trivalent iron at 376, 388 and 450 nm. The blue and greenish-blue specimens show an additional Fe^{2+}/Ti^{4+} charge-transfer band at 580 nm and a Fe^{2+}/Fe^{3+} charge-transfer band with a maximum near 850 nm, which is characteristic for basaltic-type sapphires. These spectra are comparable to those found in sapphires from other occurrences in northern Madagascar and distinct from the metamorphic-type sapphires from the southern part of the island (cf. Milisenda *et al.*, 2001).

Genesis of the placer deposits

At Nosy-Bé, the classical process of the formation of placer deposits can be observed: erosion, alluvial transport and early deposition of heavy minerals. The primary occurrence of corundum in a host rock has not yet been found, but there is no doubt that it was brought to the surface with alkaline basalts, which themselves originate from the Earth's mantle. According to Sutherland and Schwarz (2001) corundums associated with basalts crystallized in a syenitic melt within metasomatised mantle at formation temperatures estimated to be around 1000°C. Melluso and Morra (2000) calculated a depth of the sapphire source of 60 to 80 km.

The basalt at Nosy-Bé has been largely eroded, similar to the basalt associated with the sapphire deposits near Ambilobe, in the Antsiranana Province of northern Madagascar. In late Tertiary (?) or Quaternary times, the fractured and porous basalt flows and tuffs on Nosy-Bé had been eroded rapidly during severe rains and subsequent floods. The heavy mineral fraction of the washed-out material was transported towards the sea but deposited at the foot of the hills and on the alluvial plains as soon as the speed of the rivers slowed down. The heavy mineral assemblages are found in thin layers, irregularly distributed within coarse-grained sand and pebble horizons as well

as directly above the basement rocks. There are indications that some of the placers have been reworked.

The deposit at Befotaka started quite recently and is still in the formation process; the small river near the village is transporting debris towards the sea, forming a mini-delta which is gradually expanding. During severe floods, heavy minerals are transported further than normal and deposited near the expanding shore line. We thus have the situation that placers are found at the foot of the hills, under several metres of loamy overburden and in the deeply carved river bed, while at the shore line traces of heavy minerals are noticed at the surface, because the lighter fraction is washed out to the sea.

On Ambato Peninsula sapphires have accumulated on uneven basalt surfaces (*Figures 11* and *12*).

Prospecting procedure

Like so many discoveries of ore deposits and mineral occurrences the sapphire strikes at Befotaka and Ambato Peninsula are not the result of systematic prospecting but rather of diggings by local inhabitants, presumably stimulated by other finds on the main island of Madagascar (*Figures 12* and *13*).

On Nosy-Bé, people working in rice paddies at the little river at Befotaka noticed some glittery stones, which they gave to experienced dealers for assessment. Quickly the potential of the area was recognized and random mining began. Sapphires and zircons were recovered from the river bed and small shafts were sunk in the river bank (*Figure 14*). The work soon yielded several kilograms of precious stones and word of the find spread.

One of the authors (RR) was then approached by the local dignitaries to study the area, assess the potential and give advice on exploitation of the deposit.

After some field studies an opinion had to be formed about the geological setting of the occurrence. The area is covered by thick vegetation, particularly in the valleys, and lack of funds precluded clearing of undergrowth, gridding, trenching and shaft-sinking, so the

Figure 11: Andovokonko, Ambato Peninsula. Searching for sapphires on the basalt surface with calcrete crust. Nosy-Bé is in the background.

Figure 12: Ambato Peninsula Woman prising loose sapphire on basalt surface in tidal flats.

Figure 13: Searching for sapphires under granite boulders

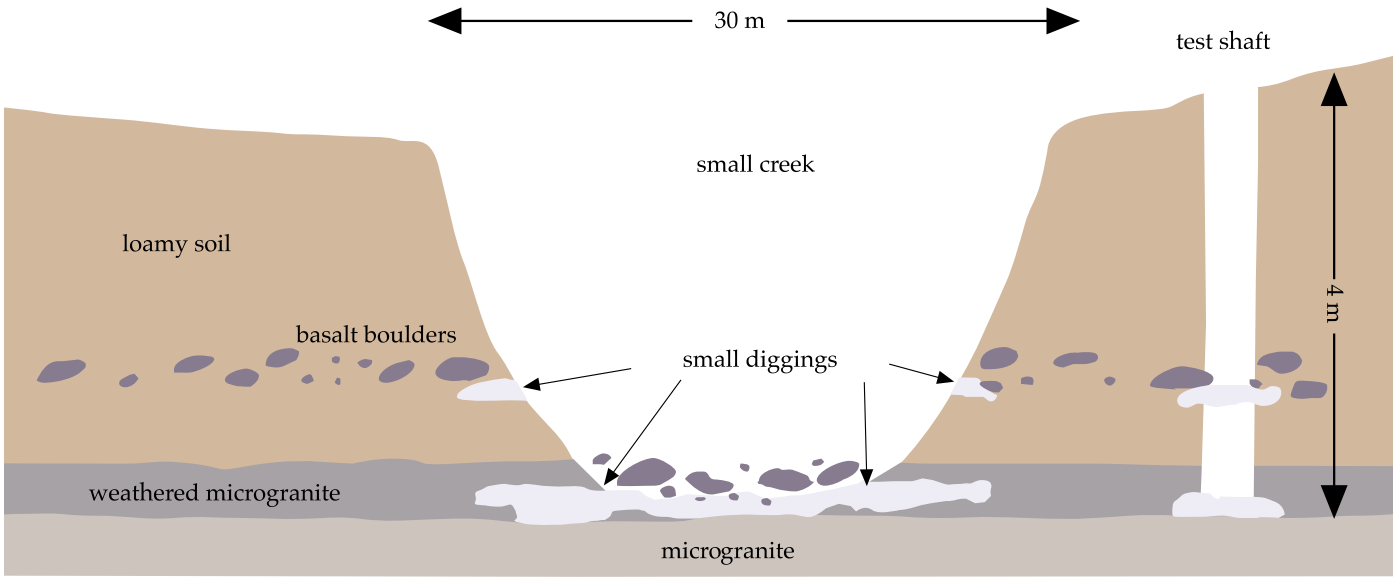

Figure 14: Cross-section of creek bed with workings for sapphire.

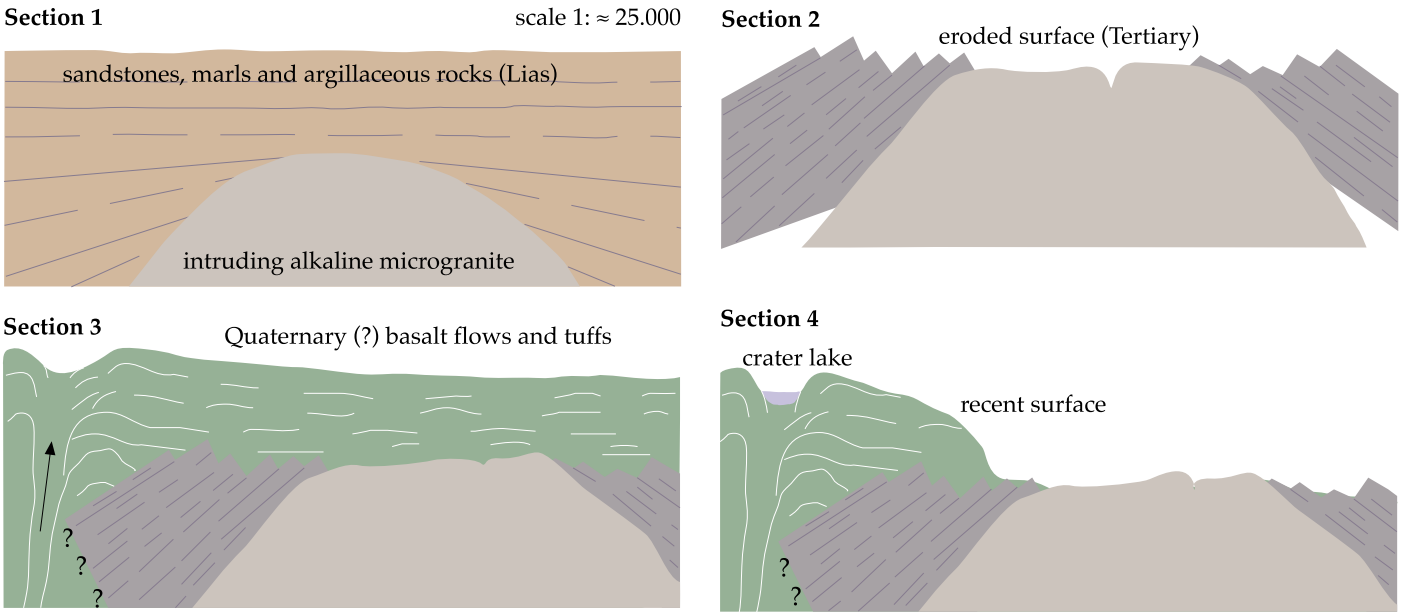

Figure 15: Sequence of cross-sections explaining the probable geological history of northern Nosy-Bé, with Section 4 representing the present day.

entire area of some 5 × 5 km was covered on foot. This gave an adequate understanding of the geology and mineral occurrences.

The 'core' of the peninsula is a (micro-) granitic batholith, overlain by Liassic sandstone, argillaceous sandstone and Tertiary to Quaternary (?) basalts (*Figure 15*). Systematic sampling of stream sediments and panning for heavy metals was done in the creeks. Corundum and zircon were found only in a few places and could not be traced to any source rock. These two minerals were also found on strongly weathered surfaces of the granite. Both minerals can also be found trapped under boulders in a clay matrix directly above the granite (*Figure 16*). The Lias sediments are steeply dipping and form small cliffs,

Figure 16: Befotaka, Nosy-Bé. Sapphire-bearing horizon above the granite.

Figure 17: Steeply dipping Lias sediments.

and they were searched for corundum and zircon, but only the heavy iron oxides were found (*Figure 17*). Based on these observations, work concentrated on the search for sapphires in the zone above the granite and on the eroded basalt platforms at sea level. This approach proved successful. In this rough terrain with its rather steep morphology, only a few river valleys and the coastal plains have potential, and although precious stones were found quite frequently, only at one place near Befotaka, were they in significant quantities. Apparently only there was the basalt large enough for the river to do its work and concentrate sufficient stones to form a commercially viable deposit. In other areas the basalt cover might have been thinner or poorer in corundum or perhaps the valuable stones have simply been washed away. The conclusion is that commercially interesting zones are largely confined to the alluvium of one small river (*Figure 18*). Further, quantitative evaluation of the deposit must be done with suitable equipment such as a backhoe for trenching and submersible pumps for water drainage.

Commercial aspects

The prospecting for sapphires in the vicinity of Befotaka has confirmed the existence of recent placer deposits concentrated in a layer above the granite bedrock. The extent and grade of the deposits have not been assessed in the usual terms of 'certain, probable, possible' because a professional valuation would require systematic trenching, bulk sampling, sorting of sapphires and additional tests on the reaction of the stones to thermal enhancement. However, a start has been made which enables us to make the following comments regarding commercial aspects.

Samples taken randomly from the placers have contained sapphires in concentrations up to 20 ct/m^3 with stone sizes up to 15 ct. In contrast, the loamy overburden yielded <3 ct/m^3. The pisolithic gravel C – horizon above the weathered granite surface has intermediate concentrations and probably contains >10 ct/m^3.

The creek bed sand and gravel, similar in its composition to the horizon struck in the few test pits, gave comparable results. Small sapphires appeared to be randomly distributed, while larger specimens (>0.5 ct) and good quality pieces are found directly at the uneven surface of the bedrock. There the precious stones and other heavy minerals accumulate in small traps such as crevices in the bedrock and underneath boulders. The local miners are

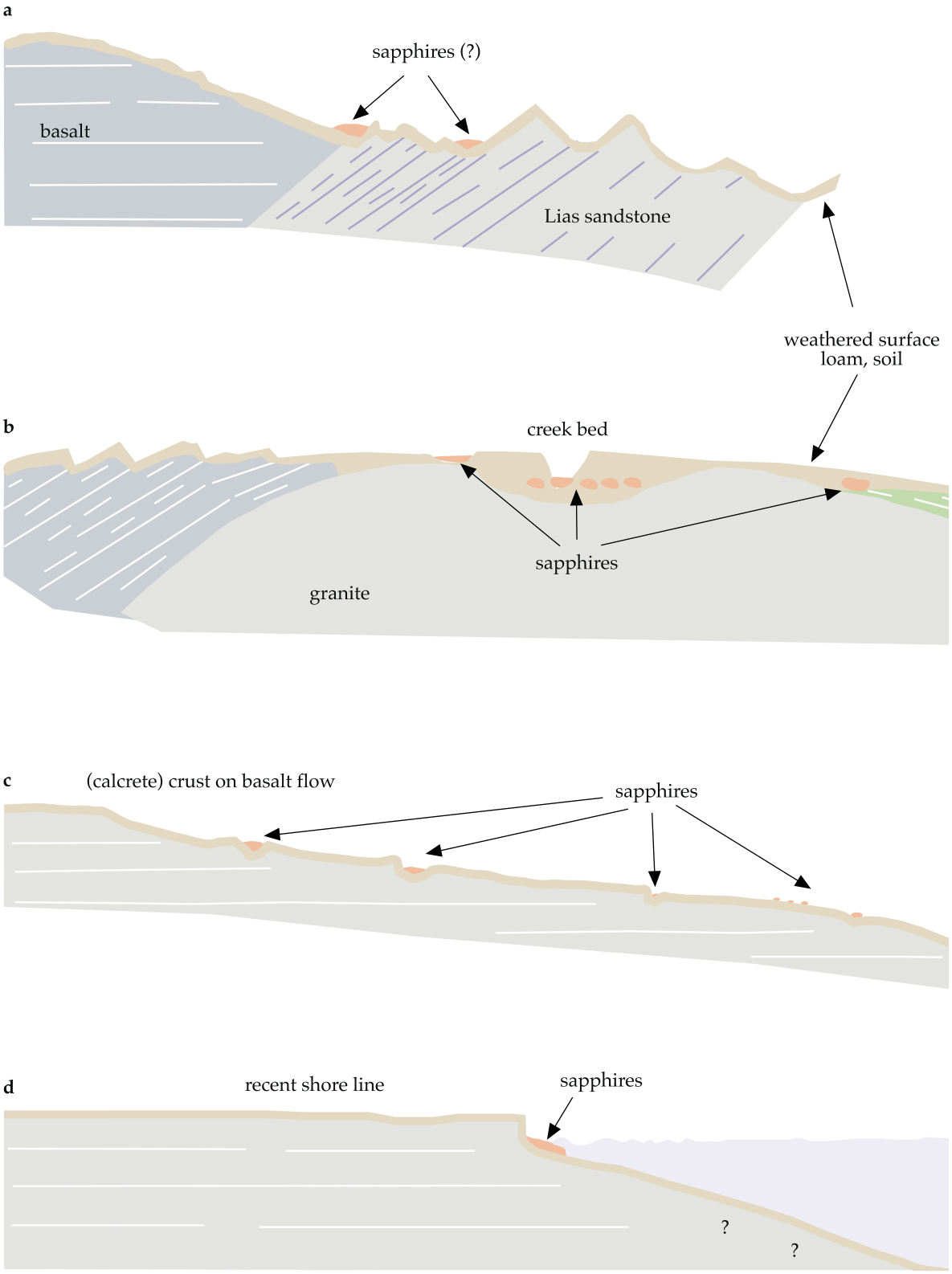

Figure 18: Schematic cross-section, showing traps and placers containing sapphires (a+b: Befotaka, Nosy-Bé, c+d: Andovokonko, Ambato peninsula).

aware of this and carefully search the creek bed for those traps, often using simple tools to prise stones from the ground. In a commercial mining operation this would be done by water jets (*Figure 19*).

The recovered corundum ranges from opaque or dark to beautiful blue and transparent. If the sapphire population is comparable to that at Ambilobe, Antsiranana Province, we can assume that to be marketable, some 90% of translucent samples require thermal enhancement. Samples with a grey, milky appearance and containing a certain amount of Ti in the form of rutile needles are best suited for this treatment. After treatment at around 1800° C under reducing conditions they should show a good sapphire blue.

To obtain more realistic figures for recovery costs it is recommended to use ct/m^2 surface rather than ct/m^3 of placer deposit. If one assumes a recovery of 20 ct/m^2, of which 8 ct (40%) can only be used for cabochons, this leaves 12 ct (60%) to be sapphire of good quality; such a proportion would justify heating to enhance their value. Of this, some 5 ct of faceted stones could be cut.

The crucial question of market value of course depends on the market, which varies, but one could estimate, based on recent experience, that the production of untreated rough stones directly from the mine should bring > 25 US$ per m^2 of mined surface.

All these are assumptions and no large or medium scale mining should be started without a proper feasibility study, based on accurate figures for reserves, grade, quality of stones, and market prices. In spite of this, a mining company has recently commenced work in the area, and one hopes that lessons learned from previous gemstone booms and sudden collapses are not ignored. As quickly as new mining centres can spring up, so can they vanish. Once surface deposits have been exploited and/or mining below the water table is required, the migrating miners move on…and with them the dealers. Left behind are ghost towns (*Figures 20* and *21*), a testament to a short-term view of local resources and, perhaps, a stimulant to thoughts of more long-term development.

Figure 19: Example of medium-sized mining and treatment operation (near Ilakaka, S Madagascar).

Figure 20: Huts for buying and selling of rich sapphire lots are quickly set up…

Figure 21: …and equally as quickly abandoned.

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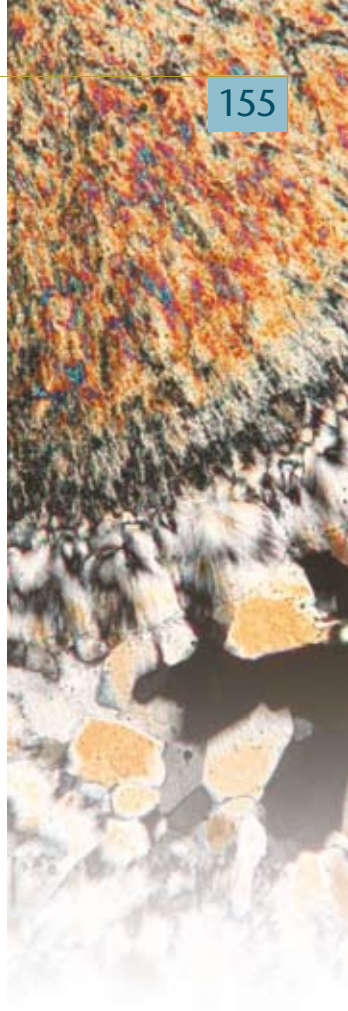

Chrysocolla quartz from the Bacan Archipelago, South Halmahera Regency, North Maluku Province, Indonesia

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Abstract: *Chrysocolla quartz from South Halmahera occurs in a series of basaltic pillow lavas as veins and small pods. A brief account is given of the geology, mining procedure and current processing facilities, supplemented by information on gemmological characteristics, mineralogical composition and internal textural pattern. The chrysocolla quartz is cut as cabochons which range in colour from sky blue to bluish green, uniform or mottled in appearance due to the proportion of chrysocolla and the intergrowth pattern with quartz and chalcedony. Apart from common opaque spots of native copper and cuprite and very little malachite, additional coloured minerals are present in the bluish green variety, of which dioptase (?) and ajoite (?) are indicated by optical and qualitative chemical data, respectively. Chrysocolla in this material seems to be largely non-crystalline because of few and very weak reflections in X-ray diffraction recordings. Some genetic aspects of the mineralization are discussed.*

Keywords: *chrysocolla quartz, petrographic texture, secondary copper minerals, small scale mining, Tertiary volcanic rocks*

Introduction

For several years, blue to greenish gemstone material has been known from the North Maluku Province, Indonesia, under the name of 'Bacan stone'. This refers to its source on the island of Bacan, situated in South Halmahera, about 2400 km east of Jakarta (*Figure 1*). In fact, the gem material originates from the island of Kasiruta, to the northwest of Bacan island (spelt Batjan in some atlases). It occurs as chrysocolla-bearing quartz veins and small pods in volcanic rocks. Polished cabochons from this material are of very pleasing colours (*Figure 2*), and some of them resemble turquoise or chrysoprase.

Small scale mining commenced in 1988, and currently the material attracts interest from Taiwanese, South Korean and Indonesian buyers. The local government

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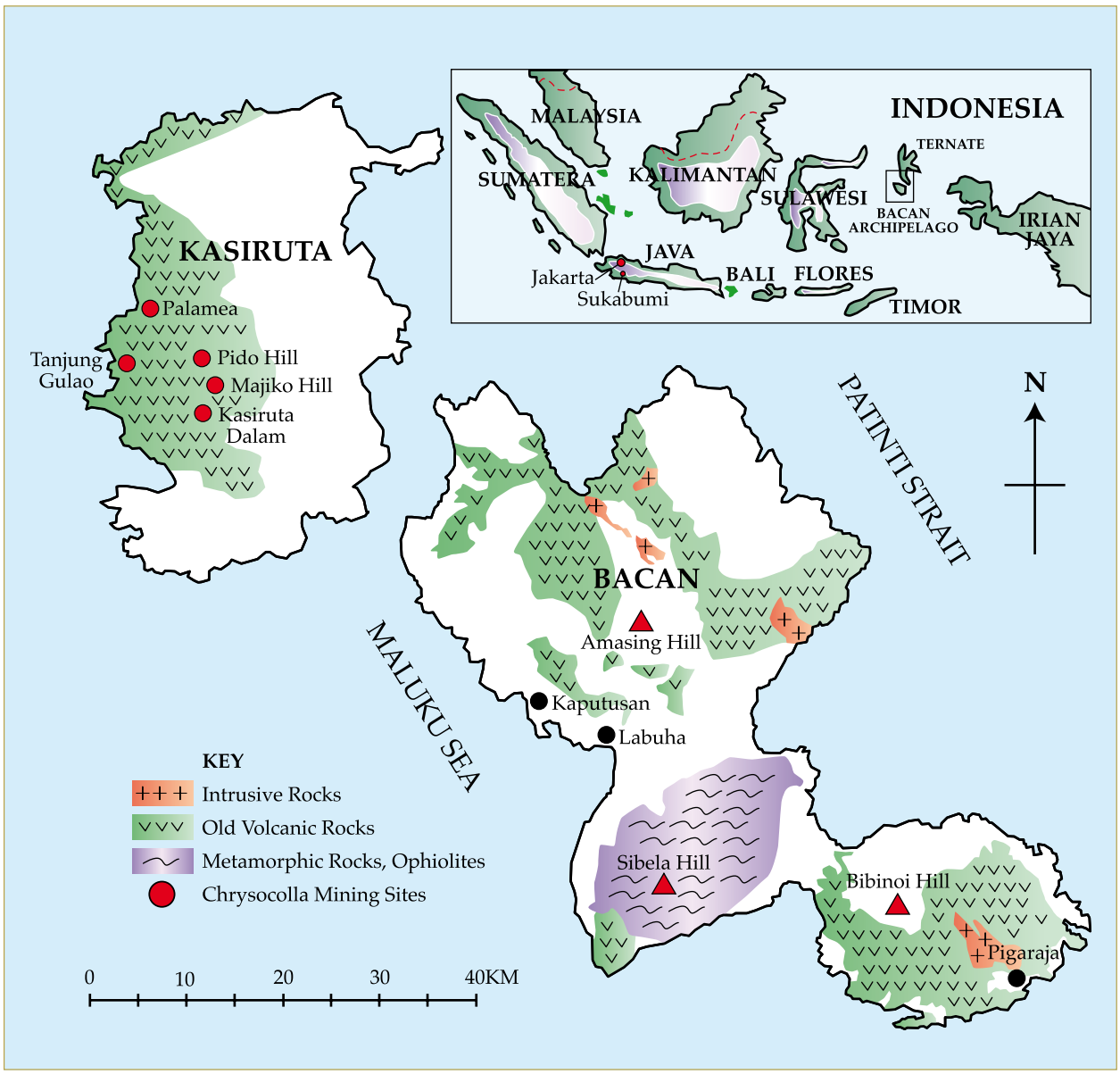

Figure 1: Bacan archipelago is situated southwest of the island of Halmahera. The map shows the extent of the 'Older Volcanics' (the host rocks to the chrysocolla quartz) on the islands of Bacan and Kasiruta, the porphyry intrusions and the metamorphic and ophiolitic basement. Sediments and 'Younger' and 'Recent Volcanics' as well as structural elements have been omitted from the map.

supports efforts to develop further the already existing small local gem cutting industry.

Geology

The geology of the Bacan archipelago (Hall *et al.*, 1988; Sukamto *et al.*, 1981; Yasin, 1980) is dominated by volcanic rocks of three island arcs, developed successively since the Early Tertiary, in a complex tectonic setting due to the collision of the Philippine Sea Plate (to which the Bacan Archipelago and the island of Halmahera belong) to the East and the Molucca Sea Plate to the West, forming the Molucca Sea Collision Zone (Hall *et al.*, 1995; Hall, 2000). The oldest non-metamorphic rocks of this area are the 'Older volcanic rocks' of the Philippine Sea Plate Arc volcanism, a series of basaltic pillow lavas of island arc chemistry, and volcanic breccias with local intercalations of foraminiferal limestones with an upper Oligocene age which occur on Bacan and Kasiruta islands (*Figure 1*). They are followed by 'Older sediments' composed of dominantly clastic rocks (mudstones and volcanoclastic turbidites), and reef limestones on top of this

sequence. The 'Younger Volcanic rocks' of the Neogene Halmahera Arc are composed mainly of volcanic breccias of andesitic to basaltic composition, stratigraphically followed by 'Younger sediments' possibly of a Late Tertiary to Early Quaternary age, and the youngest (up to Recent) volcanic rocks of the Present Halmahera Arc as cinder cones and tuff-volcanoes of andesitic composition. Uplifting of the Bacan archipelago during plate collisions followed by erosion has exposed the oldest rocks of this area which are ophiolitic rocks (crystalline schists and mafic to ultramafic rocks) of Jurassic age (Hall *et al.*, 1995) at Sibela Hill in the centre of Bacan.

During the Middle Miocene, the Oligocene to Miocene sequences were locally intruded by porphyritic rocks of granodioritic, dioritic and tonalitic composition with a little Cu/Au mineralization (Silitonga *et al.*, 1981), with malachite, chrysocolla, tenorite and limonite in the exposed oxide zone, and covelline and chalcosine in the core samples drilled from the cementation zone (Rammlmair *et al.*, 1985). A disseminated Cu-Ag-Au mineralization in green pillow lavas of the 'Older volcanic rocks' has been reported from the central Kasiruta island (Djaswadi *et al.*, 1990).

Figure 2: Cabochons made from Bacan stone range in colour from pale blue to a deeper blue green. Each weighs between 8 and 12 ct.

Gemstone deposits on Kasiruta island

Chrysocolla quartz together with multicoloured chalcedony is presently mined at five localities on Kasiruta island (*Figure 1*). All mining sites are situated in the pillow lavas of Oligocene age, forming the 'Older volcanic rocks'. The lavas are dark grey to near-black volcanic rocks of basalt composition with white plagioclase laths up

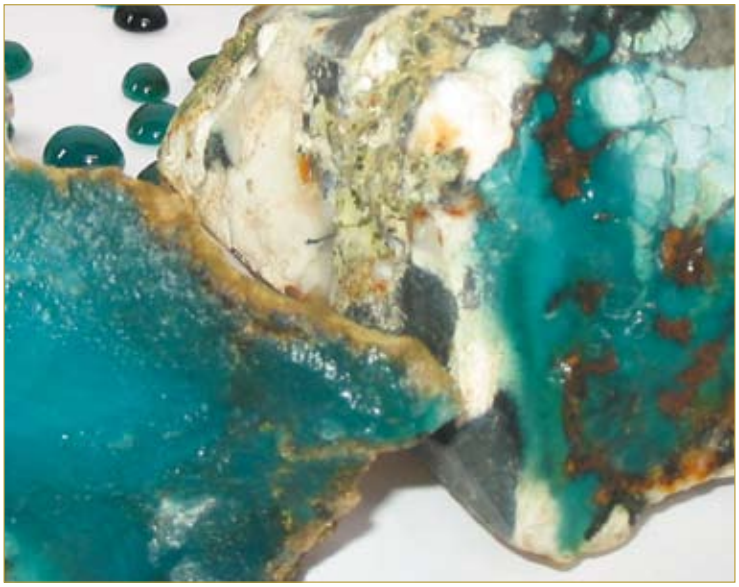

Figure 3: The massive chrysocolla quartz rock sample on the right weighs about 1.5 kg and was mined from vein type mineralization on Kasiruta island. The deep greenish blue stone on the left is a high quality material slice of about 300 g.

to a few millimetres long in a dense, partially glassy matrix which contains abundant microcrysts of plagioclase and clinopyroxene. Microfractures are filled with pale green palagonite as an alteration product.

The mineralization is either of *vein type*, filling fractures, fissures or joints as massive concentrations of chrysocolla and quartz (*Figure 3*), or of the *crust type*. The *vein type* crosscuts volcanic breccia and pillow lavas. Veins vary in width between a few centimetres and 30 cm, with a length of up to 10 m, and seem to be related to extension joint systems (common at Pido and Majiko hills). The *crust type* is irregular in shape, forming small pods and showing features of impregnation. It is common at the contact of

and in spaces between pillows (as at Tanjung Gulao, *Figure 4*).

Mining

Chrysocolla mining in the area was started on a very small scale in 1988 by a few groups of local miners. This so-called 'Bacan Stone' is said to have become more generally known when about 500 kg of gem-quality material was collected during a mineral assessment programme by an Indonesian exploration company and appeared on the market in Sukabumi, West Java, the centre of the gemstone industry in Indonesia. As a result, the demand for and extraction of 'Bacan stone' have increased significantly, especially since 2004.

In November 2004, 24 groups of miners consisting of three to seven persons each were involved in mining activities on Kasiruta (Sujatmiko, 2004). The main mining area was on Majiko Hill with 17 groups

Figure 4: A volcanic breccia between pillows is impregnated and cemented with chrysocolla quartz of crust type mineralization (locality: Tanjung Gulao). Gem-quality material has already been extracted from the dark cavity at the upper left.

actively working the *vein type* mineralization. None had a mining permit and there was neither guidance in extraction nor supervision by the local Government.

Mining commences where surface indications of chrysocolla are found (*Figure 5*). The *vein type* deposits are preferred as the mineralization pattern is more regular than in the more disseminated *crust type*. Hand-dug shafts with a very narrow opening

Figure 5: Small scale surface mining at Pido Hill exposes the pillow lava structure (irregular oval holes).

are sunk to a depth of 5 to 10 m, following the mineralized zone. The equipment used is very simple and includes shovel, pick, hammer and crowbar. The impact of mining on the environment at these places is usually restricted to the immediate surroundings of the small shafts and involves clearing of the vegetation, some soil removal and dumping of waste rock.

The general pattern is that each group stays at the mining site for about a week before taking a rest for a few days. During a period of three months each group collects between 20 kg to 200 kg of chrysocolla quartz, which will also contain some associated multicoloured chalcedony. Miners are mostly active in the period between the planting (September) and the harvesting (January-February) seasons. However, especially with the recent increase of prices for good quality chrysocolla quartz from Kasiruta, mining continues on a smaller scale throughout the whole year.

Home industry and gem trade

There are about ten gem cutting facilities in Labuha, the capital of South Halmahera regency, where local craftsmen process mainly the translucent chrysocolla quartz

varieties, but make little use of other gemmy material like chalcedony or coloured jasper ('picture stone'). The equipment consists mainly of grooved carborundum wheels for shaping and grinding but there have been recent government moves to introduce new machinery. Since no polishing powders are available, polishing is done with dry bamboo sticks, where the silica in the bamboo fibres gives a very good polish (*Figure 6*). Most of the chrysocolla quartz is cut as oval cabochons in the range of 6 to 20 ct, although some are heart shaped. Until recently, the only public market was a gem shop at the airport of Ternate, the capital of North Maluku province, where the cabochons were sold to visitors at prices between US$ 30 and 100 per piece of 10 to 15 ct, about 5 to 10 times the amount paid to the craftsmen in Labuha (US $5 to 20). The main selling of cut stones and also of gem rough has shifted now to Sukabumi and Jakarta in West Java and Surabaya in East Java.

Figure 6: A local craftsman at Labuha, Bacan island, uses simple machinery for shaping and grinding of cabochons. Polishing with dry bamboo gives a very smooth surface to the stones.

Increasingly, most of the rough gem material is sold directly at the mining site to buyers from Indonesia, South Korea, Japan and Taiwan. Prices in 2005 ranged from several tens up to two hundred US$ per kg and stand currently at about US$ 500 per kg for first grade quality. It is therefore increasingly difficult for local craftsmen to have access to gem-quality rough material at affordable prices.

Figure 7: The photograph shows the range of chrysocolla quartz rough material and cabochons investigated in this study. Although strongly coloured homogeneous material is favoured for cabochons (IC 4-7), inhomogeneous material of variable colours (IC 1, 3) can still be used for cutting of ornamental pieces. The white dotted, black pieces (IC 2) are from the volcanic host rock.

Material for examination

The gem material from the Kasiruta localities supplied for gemmological, mineralogical and chemical examination consisted of six cabochons and the remains after their cutting (*Figure 7*). The rough material is variable in mineralogical composition and colour even on a centimetre scale, requiring careful selection of pieces to be cut for even-coloured stones (*Figures 2* and *8*). On the other hand, its variation (*Figure 7*) does allow for production of stones with an ornamental character. The properties of the six cabochons are summarized in *Table I.*

Colour

The cabochons range in colour from green-blue with a moderate colour saturation through lighter colours to a dark bluish green. The blue stones are described as chrysocolla, whereas the green stones (*Figure 8*) are sold as 'chrysoprase'. In many stones, the colour is fairly homogeneous on top of the cabochon, but appears somewhat mottled in others due to clearly visible intergrowths with colourless quartz (*Figure 9*). A few small black spots are copper ore minerals. The cutter usually tries

Sample no.	Weight (carat)	Colour	Surface appearance	SG	Fluorescence under long- and short-wave UV
IC 4	4.8	Green blue, moderate saturation	Uniform in colour and texture, a few opaque spots	2.34	Weakly dark blue
IC 5	5.0	Green blue/turquoise, low saturation	Mottled appearance due to intergrowth with quartz	2.50	Light blue white Rough: dark blue to violet,chalcedony part bluish white
IC 6a	3.5	Bluish green, moderate saturation	Dto., small agate lined vug on lower surface	2.33	No fluorescence
IC 6b	4.2	Bluish green, strong saturation	Fairly uniform in colour, globules of blue mineral in green matrix visible with handlens	2.47	No fluorescence Rough: blue fluorescence in light blue green parts
IC 7a	3.1	Greenish blue, moderate saturation	Mottled appearance due to intergrowth with quartz, change to greenish at edge	2.38	Blue white Rough: bluish white in chalcedony parts
IC 7b	11	Greenish blue, strong saturation	Fairly uniform colour, few opaque spots, white lower surface and edge	2.44	Blue white, white lower surface with bluish white fluorescence

Table I: Summary of some properties of chrysocolla quartz cabochons and rough material from Kasiruta, North Maluku, Indonesia

Figure 8: Many chrysocolla quartz cabochons appear distinctly green and are sold locally as chrysoprase. The large cabochon weighs 21 ct, the others around 11 ct each.

Figure 9: The base of a blue green cabochon (cabochon IC 6a) appears mottled due to globules of chrysocolla in colourless quartz. A small vug is lined by pale brown chalcedony and the centre filled with quartz. Length of bar: 1 mm.

Figure 10: Immersed in water and magnified, the inhomogeneous nature of this cabochon is visible, with blue chrysocolla globules in a darker green matrix. Some black grains of ore are visible on the right, and an air bubble is visible in the vug on the left. Cabochon IC 6b, length of bar: 1 mm.

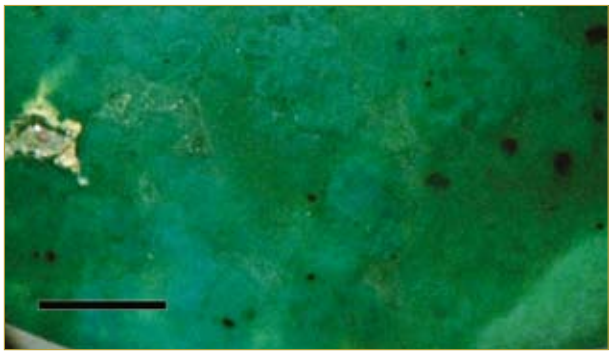

to place any patchy or inhomogeneous colour areas on the base or towards the edges of the cabochon.

Viewed with handlens or binocular microscope, even the seemingly homogeneously coloured cabochons may display a heterogeneous appearance/ composition. This is due to the presence of colourless quartz and opaque minerals as well as to the uneven distribution of mineral aggregates of various intensity of blue and green colours (*Figure 10*), even more evident in thin sections cut from this material. Of the examined cabochons, only IC 4 had a perfectly homogenous surface save for several small spots of ore minerals, similar to the one in *Figure 11*.

Specific gravity

The specific gravity of the cabochons ranges from 2.34 to 2.50, reflecting the variable mixtures of quartz and chrysocolla. The highest value (2.50) outside the chryscolla range is due to a very high proportion of quartz (with its higher SG of 2.65) and chalcedony (2.58 to 2.63); this cabochon is also the faintest in colour due to the rather small amount of chrysocolla.

Hardness and refractive index

Hardness and refractive index have not been determined in a systematic way due to the heterogeneous nature of the material, but tests on some stones indicate that even the seemingly purest chrysocolla sample (cabochon IC 4) has a hardness higher than 6 due to the quartz content. Viewed with oblique incident light, the polished surface exhibits small depressions due to the hardness differences of chrysocolla and quartz. Because all investigated cabochons consist of intimate intergrowth of various minerals, no reliable measurements of the refractive index are available.

Fluorescence

Chrysocolla is not known do exhibit fluorescence under UV-light (Eppler, 1984). However, both the cabochons and the rough material exhibit variable fluorescence under long- and short-wave UV light. Details are given in *Table I*. Chalcedonic parts of the rough material and the bleached (white) base of one cabochon display a light bluish white, and the fluorescence in the samples is most likely due to their chalcedony content, perhaps modified by the presence of coloured minerals which may affect colour perception.

Durability

Mechanically, the hardness of six of the stones protects them fairly well against wear. However, they are more vulnerable to chemical attack: dilute hydrochloric acid decolorized the surface rapidly to a white 'chrysocolla', and even weak acids like citric acid, common in many household cleaning solutions, bleached the surface colour perceptibly with development of a yellowish tone after 15 min of contact with a commercial cleaning solution. This reaction revealed the inhomogeneous mineralogical composition more clearly by developing different shades of colour. Thus, prolonged exposure to these solutions will seriously affect the colour of the chrysocolla quartz.

Figure 11: This fairly homogeneously coloured cabochon (similar to IC 4) is typical of the blue end of the colour range of Bacan stones. Weight: about 20 ct.

Surface and internal textures

When magnified, many polished cabochons show intricate patterns of water-clear quartz surrounding bluish white globular and irregularly shaped aggregates which can be interconnected with each other and even form chain-like textures. The base of one of the cabochons (IC 5) is a good example of this intergrowth pattern (*Figure 12*). Because

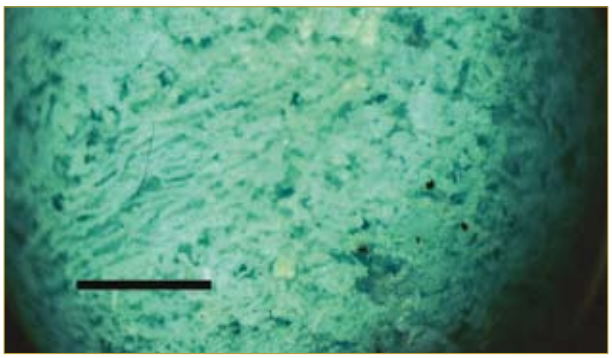

Figure 12: The rather poor quality of cabochon IC 5 on its base shows the intricate intergrowth of chrysocolla (blue green) and quartz (dark). Cabochon immersed in water, length of bar: 1 mm.

the quartz is transparent, the colour of the chrysocolla aggregates below the surface is reflected through the surrounding quartz, giving an overall blue or green colour to the stones.

A surface may be interrupted by the presence of very small vugs with fillings resembling agate and a lining of white or pale yellow chalcedony towards the massive material (*Figure 9*); some vugs also have small perfect quartz crystals protruding into free space.

Mineralogical composition

In chrysocolla quartz or chrysocolla chalcedony, the chrysocolla occurs finely dispersed within, impregnated by or encrusted by silica material. This has higher mechanical durability than pure chrysocolla and is much more suitable for use as a gem. However, when used as a trade name chrysocolla quartz or chrysocolla chalcedony often applies to quartz-chalcedony rocks coloured by widely dispersed and minute secondary Cu minerals which may include not only chrysocolla *sensu stricto*, but also a range of similar secondary Cu-silicates and Cu-sulphates such as ajoite, plancheite, shattuckite, brochantite and antlerite (see Johnson *et al.*, 1995). The trade name has also been used for any massive, globular, glassy, blue to green copper-bearing silicate mixture of minerals which has not been identified.

The true mineral chrysocolla forms layers and globules of fibrous aggregates, commonly in a radiating pattern, with the fibres not exceeding a length of 5 mm. It is a hydrous copper silicate with the formula $(Cu, Al)_2H_2Si_2O_5(OH)_4.nH_2O$, where the water content is variable and Cu can be substituted partially by Mn (Throop and Buseck, 1971), Fe and Al (Anthony *et al.*, 1995; Van Osterwyck-Gastuche, 1970). Up to 5.9 wt.% Al_2O_3 and up to 5.7 wt.% Fe_2O_3 have been reported from chrysocolla (Gaines *et al.*, 1997). Such substitutions and the presence of minerals such as (hydr)oxides of Fe, Mn and Cu can result in variable colours from pale blues and greens to black (Anthony *et al.*, 1995; Eppler, 1984; Gaines *et al.*, 1997; Webster, 1994).

Pure chrysocolla is birefringent with RIs of 1.57 - 1.60 (Gaines *et al.*, 1997), but the gem materials labelled chrysocolla generally have RIs around 1.50, indicating that they are mixtures perhaps including other copper silicates, chalcedony and opaline silica. The gem materials also have variable hardness (Mohs 2-4) and specific gravity of 2.0 - 2.4 (Klein, 2002).

The mineralogical composition of six samples typical of the gem material from Kasiruta has been examined qualitatively by X-ray diffraction (using a Siemens D 500 diffractometer, Cu KÅ radiation at 1.5405 Å, (delta lambda 0.0038 Å), a graphite monochromator, speed 0.5°/min as standard parameters between 5.0 and 65.0° 2θ) and by microscopic observations in thin section of the rough gem material from which the cabochons had been cut.

X-ray diffraction results

The diffractograms of the cabochon material all indicate quartz as the main crystalline phase. The bluish green cabochon IC 6a contains additionally a major amount of chalcedony, a deduction confirmed in thin section, and three very small peaks indicate the silica variety mogánite (Graetsch, 1994).

Non-quartz peaks are rare and very weak. In two samples, one or two reflections coincide with the main reflections of chrysocolla (Anthony *et al.*, 1997) at 1.48 and 2.90 Å d-spacings, but the other reflections

are not visible. Chrysocolla is a hydrogel or gelatinous precipitate (Klein, 2002; Webster, 1994). It is therefore commonly of low structural order, and much chrysocolla has been found to be highly disordered to non-crystalline, which explains the weak or missing reflections in XRD recordings. A few very small peaks at d = 1.509 Å (from cuprite?), 2.082 Å (from native copper?) and others of unknown origin confirm the microscopic observation of the presence of additional mineral phases.

The XRD-data of a separated vividly blue, fibrous part from the rough material from which IC 6 was cut, selected to be as free from quartz as possible, confirm the poor crystalline order of the sample material. The diffractogram (*Figure 13*) shows a rapid increase of the background level, which forms then an elevated plateau (to the end of the recorded diffraction angle), typical of material in a highly disordered state. This plateau is overtopped by quartz peaks and three very weak and indistinct peaks at d = 1.48, 2.89 and 1.60 Å, coinciding with the stronger reflections of chrysocolla, and two reflections at low angles with d = 8.5 and 16.5 Å, which are close to published d-values for chrysocolla at 7.9 and 17.9 Å (Anthony *et al.*, 1997).

Thin section observation

In thin sections (plane polarized light), some chrysocolla aggregates in the samples from Bacan are pale green but most show variable intensities of brown, either in the core or at the rim of zoned globules (*Figure 14*). Such colour variation may be explained by different Cu-, Mn- or Fe-contents, but this needs verification.

The textural pattern is variable. Chrysocolla as very fine grained fibres can be intimately intergrown with quartz (samples IC 4 and IC 5) in compact masses or forming a network of small globules

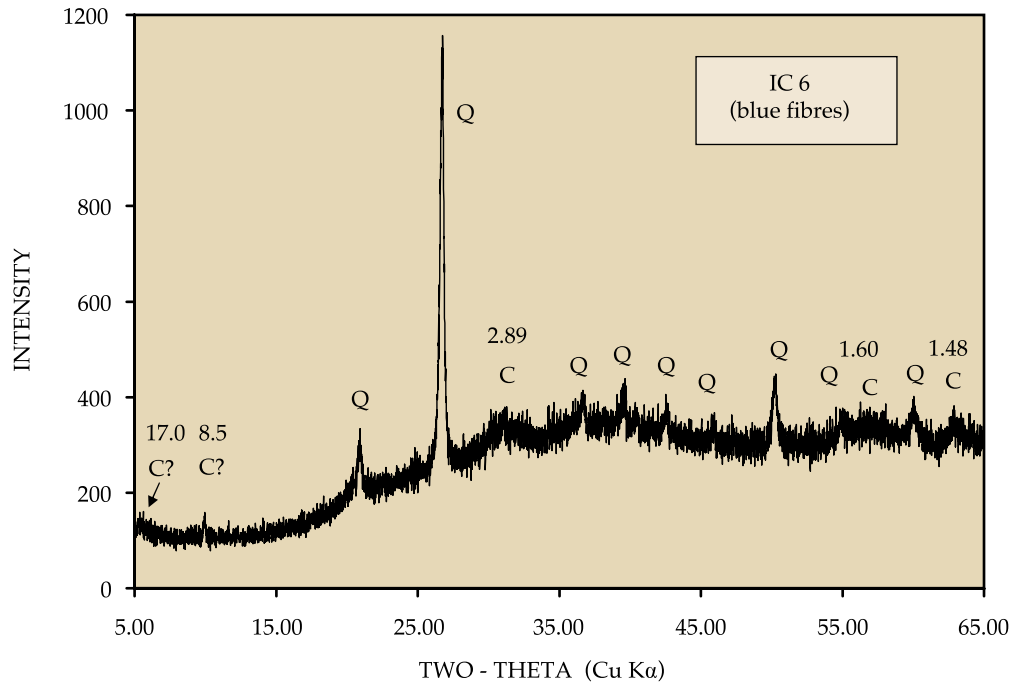

Figure 13: The X-ray diffraction recording obtained from a blue, fibrous part of rough gem material (sample IC 6) shows a markedly elevated background reading between 2θ angles of 20° and 65°, the distinctly visible peaks of quartz (Q) and a few and very low, broad peaks of chrysocolla (C). (The broad peak at d = 1.60 interferes with a very weak reflection of quartz). The elevated background and the few and indistinct chrysocolla peaks indicate a highly disordered structural state of the chrysocolla. Numbers above symbols are d-values of chrysocolla peaks.
(Two Theta values are converted to d-values by the Bragg equation: $n\lambda = 2d \sin 2\theta$, with n = 1,2,3,..; λ = wavelength of the applied radiation (in Å); d = distance between two parallel planes of the crystal lattice (in Å); θ = angle of reflection of the X-ray beam on the sample surface.)

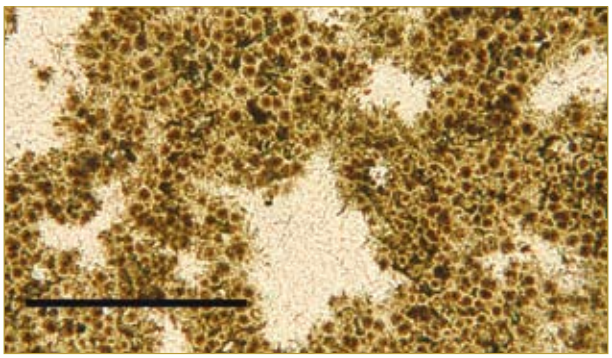

Figure 14: Aggregates of small chrysocolla globules form a network whose gaps are filled with quartz. Sample IC 5, thin section, plane polarized light, length of bar: 1 mm.

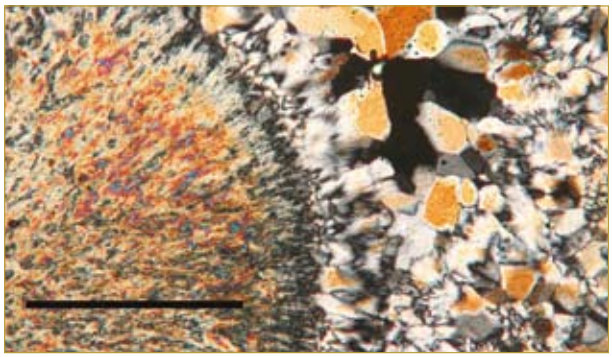

Figure 15: A sphere of radiating chrysocolla fibres is rimmed by a thin layer of chalcedony, followed by coarser grained quartz. Sample IC 6, thin section, crossed polarizers, length of bar: 1 mm.

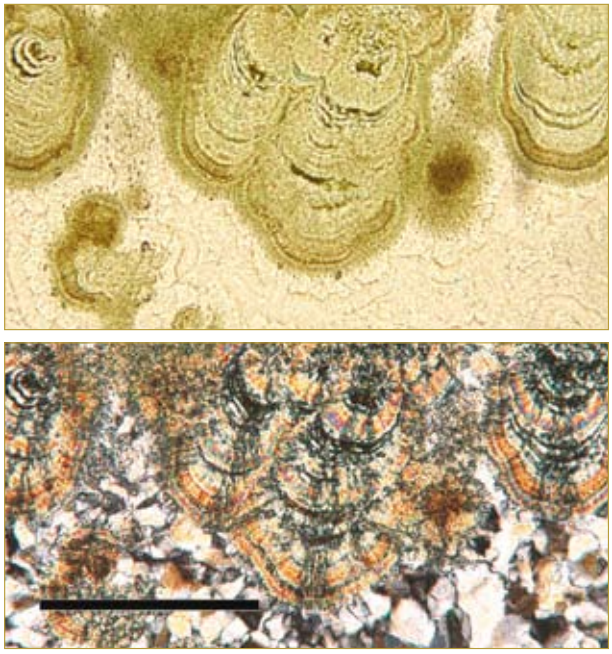

Figure 16: Thin section of IC 6 displaying the colloform banding of globules of chrysocolla with small interlayers of chalcedony and the later growth of quartz in several layers around the chrysocolla-chalcedony aggregate (upper photograph). The lower photograph, taken in cross polarized light, shows the radiating habit of the chrysocolla fibres. Length of bar: 1 mm.

(*Figure 14*). Another textural type consists of large globules of radiating chrysocolla fibres, rimmed by a thin zone of chalcedony (*Figure 15*). A third type, prominent in IC 6 and 7, forms botryoidal aggregates of several chrysocolla layers of variable thickness, with quartz/chalcedony interlayers. Here, each chrysocolla layer consists of outwardly radiating fibre bundles and may be near-colourless or coloured in variable intensities of brown and green (*Figure 16*). Small quartz aggregates act as the nucleation centres for these semi-spherical colloform aggregates, as do copper minerals.

According to thin section observation, coloured mineral species in addition to chrysocolla are present in the Bacan material. Small 'islands' of vividly emerald to grass green and roughly colloform aggregates set in a colourless to white matrix are composed of malachite and have been found in all samples in trace amounts. Though malachite is generally a common mineral in the oxide zone of copper sulphide mineralization, it is rare in the examined material from Kasiruta.

The greenish-blue material (IC 4 and 5) consists mostly of chrysocolla with only a few specks of malachite as colouring mineral, whereas the bluish-green material (cabochons IC 6a and b) has at least two additional coloured minerals: the botryoidal chrysocolla aggregates are surrounded by a compact layer composed of a grainy mineral in tiny rectangular crystals (*Figure 17*). Its blue green colour (the cause for the overall colour of these cabochons), refractive index distinctly higher than that of quartz, high birefringence and straight extinction under crossed polarisers indicate that it is probably dioptase. Additionally, a grey-green mineral phase in small compact, embayed grains with a blue tinge in oblique incident light, which occurs also in sample IC 7, remains to be identified.

Quartz occurs in three varieties: firstly as fibrous chalcedony, forming clusters of small rosettes in quartz-rich parts, often as a thin zone of outwardly radiating fibres around chrysocolla globules (*Figure 15*), and occasionally with agate banding in

vuggy parts. Secondly, it forms a mosaic of microcrystalline quartz with increasing grain size towards the centre of the quartz-filled areas between the chrysocolla-quartz aggregates. Thirdly, quartz occurs rarely as well shaped tiny crystals in small cavities.

The layering of successive quartz crystallization (without chrysocolla intergrowth) resembles the botryoidal aggregates of chrysocolla (*Figure 16*, upper photograph), and occurs both as the outer layers around chrysocolla-quartz bodies and as separate, quartz-chalcedony colloform spheres. The remaining space between the spheres is filled by coarser quartz grains. The amount of this layered and gap-filling quartz determines the degree of reduction of the overall colour intensity and is the cause of a mottled appearance when present in higher concentrations, as in cabochon IC 5, where it is estimated to make up about 60 % by volume.

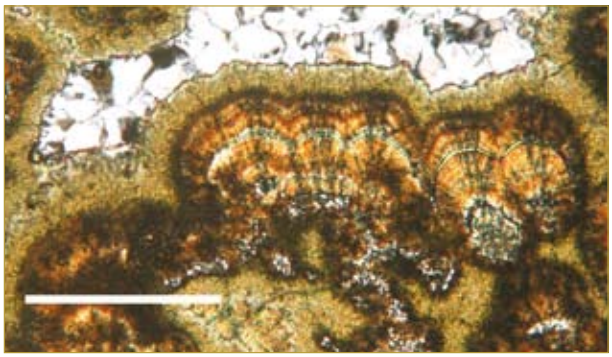

Figure 17: Botryoidal aggregates of chrysocolla and chalcedony are surrounded beyond the outer dark brown layer of chrysocolla by a dense, grainy zone of an unidentified green mineral (dioptase?) in the blue green sample IC 6. Thin section, crossed polarizers, length of bar: 1 mm.

Copper ore minerals, all of secondary origin, are abundant in the rough gem material and are also present in very small amounts as dark spots in the cabochons. In addition to the (rare) malachite, cuprite (Cu_2O) is common as small xenomorphic grains or as grain aggregates and has been identified on the basis of its reflectance, the abundant red internal reflections and the characteristic tiny inclusions of native copper. Where coarser grained, it is dark red and commonly surrounded by another ore mineral, probably tenorite (CuO), a common associate in chrysocolla quartz. Native copper occurs also as fillings of microfractures.

Where abundant, the ore minerals change the overall colour of the gem material to near-black with a bluish tint. They are also present as regular, chain-like linings in the banded patterns of chalcedony and as nucleation centres for chrysocolla-quartz globules (*Figure 18*).

Clusters of a needle-shaped or bladed ore mineral, opaque in thin section but dark brown in thin blades, have been observed in material of sample IC 4. It has been found only in the weathered crust of rough gem material where the stone has lost its green or blue colour. It surrounds sub-spherical microcrystalline quartz aggregates, probably the remnants of the original chrysocolla-quartz globules, and is very likely derived from Fe-rich chrysocolla, the Fe being released during weathering and recrystallizing as an oxyhydroxide. Qualitative XRF analytical data support this interpretation.

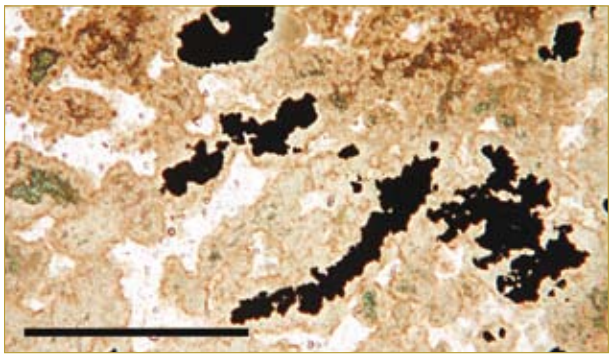

Figure 18: Cuprite and native copper (black) and malachite (green) act as nuclei for chrysocolla (pinkish brown) crystallization in sample IC 3. Quartz (colourless) fills the space between the chrysocolla aggregates. Thin section, plane polarized light, length of bar: 1 mm.

Information from chemical data

Preliminary qualitative analyses have been carried out on the six cabochons using a wavelength dispersive X-ray fluorescence machine (Tracor Spectrace 5000) with a Rh-tube run at 50 KV and 0.35 mA and an Al-filter. All samples contain some Fe and Mn

and traces of Ca and Ti. Potassium is clearly present in the cabochons IC 6a and IC 6b. Other metals have not been detected (Al may be present, but was undetectable due to the use of an Al-filter). A few conclusions can be drawn from these data.

The potassium in samples IC 6a and IC 6b indicates probably the bluish green mineral ajoite ($(K,Na)Cu_7AlSi_9O_{24}.nH_2O$) as another mineral causing (together with the supposed dioptase) the more green colour of these cabochons.

The name 'chrysoprase' for the beautiful greenish translucent gem material from Kasiruta is misleading as Ni has not been detected in the examined cabochons. From the geological point of view, the association with basaltic volcanics and the Cu-dominated mineralization makes it unlikely for chrysoprase to occur in this environment.

Concerning other blue and green secondary minerals, neither phosphates (e.g.turquoise) nor sulphates (e.g. antlerite) are present because neither P nor S have been detected in the samples.

The highest copper counts were obtained from the blue cabochon IC 4 which indicates a high chrysocolla content as expected from its colour saturation and low amount of quartz.

Since no other Fe, Mn-bearing minerals have been observed in thin sections of (unweathered) rough gem material, the small amounts of Fe and Mn detected are interpreted as minor contents of the chrysocolla

Genetic aspect and conclusions

Genetically, chrysocolla is an alteration product in the oxidation zone of a copper sulphide mineralization, with quartz-chalcedony as a common co-precipitate in intimate intergrowth. This chrysocolla quartz may be accompanied by a variety of other secondary Cu-minerals, such as malachite, tenorite, ajoite, plancheite, dioptase and cuprite, which are usually not identified in the gem material as they are of lesser interest to the gem trade. The gem material from Bacan exemplifies this variability by showing at least four different blue to green minerals of which only chrysocolla and malachite have so far been positively identified. The proportion of quartz-chalcedony to chrysocolla and its distribution as fine intergrowth with the coloured minerals or as clusters and patches affects the overall colour saturation and textural appearance of the Bacan gems.

Textural evidence points to a certain sequence of mineral precipitates during the process of supergene alteration of the primary mineralization which is related to the progressive oxidation of sulphides and dissolution of primary mineral species. A generalized sequence involves the following steps, probably replacing the primary texture or being superimposed onto its relics:

- crystallization of cuprite, native copper, malachite and tenorite from Cu-bearing aqueous solutions, derived from the oxidation and dissolution of primary or secondary Cu-sulphides,
- change in precipitation from Cu-oxides and Cu-carbonate to Cu-silicates: chrysocolla-quartz intergrowths or botryoidal, layered chrysocolla-chalcedony sequences from still Cu-bearing, but strongly siliceous aqueous solutions or gels due to dissolution of primary quartz during an advanced process of mineral dissolution, crystallize around nucleation centres of the secondary Cu-minerals,
- growth of a rim of chalcedony or microcrystalline quartz around chrysocolla aggregates from a Cu-depleted siliceous solution or gel, or of other Cu-silicates like dioptase (?) or ajoite (?) as in the bluish green material if Cu is still present in the gel/solution.

The later precipitates are:

- quartz or chalcedony in separate globular aggregates with radiating patterns which may be partially contemporary with the crystallization of the outer quartz-chalcedony layers around chrysocolla-quartz aggregates, followed by
- coarser grained quartz without systematic orientation of the crystals (this

quartz type, however, may be a relic of the primary texture) and rarely, by

- late chalcedony or quartz crystals in vugs.

This sequence reflects the comparatively easy and early oxidation and dissolution of the Cu-sulphides, followed by a rapid decrease of Cu supply with time to the zone of secondary mineral precipitation, and the development of siliceous, increasingly Cu-depleted solutions or gels due to dissolution of primary quartz during prolonged near-surface weathering or in the zone of fluctuating groundwater levels (Cuadra C., P. and Rojas S., G., 2001).

The chrysocolla quartz and other secondary copper minerals on Kasiruta island owe their formation to mineralization processes during Tertiary magmatic activities. The primary mineralization in the volcanic rocks may have been a porphyry-related epigenetic Cu mineralization of Middle Miocene age already known in the Bacan archipelago (Djaswadi *et al*., 1990; Rammlmair *et al*., 1985), or a small and locally occurring syngenetic Cu mineralization in the Oligocene pillow basalt lavas, or both. The small occurrences of the *crust type* chrysocolla between pillows are a strong indication for the latter type of primary mineralization, whereas the *vein type* chrysocolla could be derived from porphyry. In terms of prospecting for further occurrences, if the chrysocolla were derived from a porphyry, one would expect new finds to be in the vicinity of known occurrences, but if it originated in the pillow lavas, it could show a wide and unsystematic distribution, also of low volume at each occurrence. In view of the widespread occurrence of the Older Volcanics both on Kasiruta and on Bacan island (where no chrysocolla quartz mineralization is yet known), the potential of gem-quality rough material might be considerable.

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Crowning glory: the identification of gems on the head reliquary of St Eustace from the Basle Cathedral Treasury

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Abstract: *The gems on a thirteenth-century reliquary of St Eustace have been examined non-destructively using Raman microspectroscopy with a horizontal laser attachment and X-ray fluorescence spectrometry. Nine of the gems are composed of varieties of quartz (rock crystal, chalcedony, amethyst and carnelian), two of aragonite (pearl and mother of pearl), one of obsidian and six of synthetic glass. The compositions of five glass stones suggest that they represent re-used Roman glass, while the intaglio on the obsidian and a drill hole in the pearl also suggest the re-use of old material. One glass stone has a medieval glass composition.*

Keywords: *gems, glass, medieval, Raman microspectroscopy, reliquary, X-ray fluorescence spectrometry*

Introduction

The head reliquary of St Eustace (British Museum M & ME 1850,11-27,1) is a container for holy relics, dating to the early thirteenth century (see *Figure 1*). It has two parts, one carved out of wood in the shape of a man's head in which unlabelled fragments of a skull thought to be that of St Eustace were kept with various other labelled relics; the other, a metal covering of silver gilt which is decorated with a diadem encrusted with gems. The metal covering was made some time after the wooden head, possibly to enrich this holy artefact. The reliquary was originally kept in the treasury of Basle Cathedral and was acquired by *The British Museum* in 1850 (Cherry, 2001; Husband and Chapuis, 2001). Many ornate holy relics dating from the early eleventh through to the sixteenth centuries AD formed the treasury at Basle Cathedral. The collection was subsequently split up when the Canton of Basle was divided in 1833 (Hänni *et al.*, 1998; Reiche *et al.*, 2004). The city of Basle

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Figure 1: Photograph of the head reliquary of St Eustace. The reliquary is 33.5 cm high

Figure 2: Part of an engraving of the conversion of St Eustace to Christianity by Albrecht Dürer, AD 1501. A print is in the British Museum (1868-8-22-183)

kept part and the rest of the collection was auctioned off in 1836 to various museums in Berlin, London, New York, Paris, St Petersburg, Vienna and Zurich (Hänni *et al.*, 1998; Reiche *et al.*, 2004).

According to legend, Eustace was a general under the Roman Emperor Trajan who reigned from AD 98 to 117. He converted to Christianity while out hunting on Good Friday, after seeing a vision of a stag with a luminous crucifix between its antlers (see *Figure 2*) (described in approximately 1260 by de Voragine, 1993 translation). Some time later, after a victorious battle, he refused to participate in the thanksgiving to the Roman gods, and was burnt to death with his wife and two sons inside a bronze bull. After three days the family was removed from the bull, and their dead bodies were found to be miraculously undamaged.

Sixteen gems are set around the diadem of the head reliquary of St Eustace, all equally spaced. In addition, two of 20 original gems set on the top corners of the base pedestal survive. A study of the stones on the head reliquary of St Eustace had previously been carried out in the Research Laboratory of the British Museum in 1957 using traditional gemmological methods. This examination left a number of issues unresolved and it became apparent, during the preparation of a recent catalogue that several of the identifications were questionable, and a re-examination was therefore undertaken.

Analytical methods

The gems are set into the diadem and base pedestal in closed-back settings, and it was not permitted to remove them for examination using standard gemmological methods. Instead the gems were examined using a 10× loupe, then investigated using Raman microspectroscopy. For other studies using this method to identify ancient gems, see Smith and Robin (1997), Calligaro *et al.* (2002), Clark and van der Weerd (2004), Smith (2005) and Kiefert *et al.* (2005). Selected stones and all those identified as paste, were then examined using air-path X-ray fluorescence spectrometry (XRF). These are non-destructive methods which allowed the identification of the stones *in situ*. The surface of each gem was wiped with a clean soft cloth prior to analysis to remove any contamination due to handling.

Horizontal Raman microspectroscopy

The Raman microspectroscope in the Department of Conservation, Documentation and Science at the British Museum is a Dilor LabRam Infinity model equipped with a Nd: YAG green laser at 532 nm and a near-infrared diode laser at 784 nm. It has a conventional microscope stage and objectives as well as an open-beam horizontal microscope attachment. As the head reliquary is too large to permit examination under a conventional Raman microspectroscope, the horizontal beam attachment was used with a ×50 long working distance objective (see *Figure 3*). In this way the Raman microspectroscope was used to analyse the gems while they were still in the diadem and base pedestal. The gem to be analysed was positioned directly in front of the laser beam, for count times between 5 and 20 seconds for 6 accumulations. The maximum power of the lasers used was 4 mW. It was possible to identify each of the gems from its Raman spectrum, by comparison with an internal British Museum database of reference Raman spectra of gems. These British Museum internal reference gems were analysed using both the green and near infrared lasers, and their identifications were confirmed using standard gemmological techniques

Figure 3: The British Museum Raman microspectroscope with an open-beam horizontal microscope attachment showing how spectra were obtained from the gems on the head reliquary of St Eustace. A close-up image of part of the diadem is visible in the screen on the right.

and X-ray diffraction. These internal reference Raman spectra are consistent with other published gemstone spectra (Pinet *et al.*, 1992; Huang, 1999). The accuracy of the Raman peak positions in measuring and assigning them is +/- 2 cm^{-1}.

X-ray fluorescence spectrometry

In situ XRF analysis of the surfaces of the unprepared gems was carried out in air, using a molybdenum X-ray tube operated at 35 kV and 0.4 mA. Spectra were accumulated for 500 seconds and count rates were typically 500 per second. XRF was used to identify the types of glass (paste) gems. The glass compositions were calculated by comparison with the spectra of Corning Museum standard glasses (Brill, 1999). There are a number of limitations to this method. Important light elements in glass such as sodium, aluminium and magnesium cannot be detected, while the error on silicon is high. In addition, the geometry of the analysis cannot be well controlled, and surface analysis of glass is likely to have included some corroded material. For these reasons, the analyses are, at best, approximations of the true composition of the glasses, and are considered semi-quantitative. However, even semi-quantitative data are very useful in that the compositional ranges of early glasses were quite restricted, and the XRF analyses allow the glass gemstones to be placed in specific compositional categories which have certain cultural affiliations.

Gems

The head reliquary of St Eustace contains a variety of gems, including colourless, white, purple, orange, black, grey, red and blue stones. Most of the stones are cabochons which are common in medieval reliquaries (Clark, 1986), but four have facets: one is a dark orange rectangular table cut stone, one is a white opaque gem with a table facet, one is an intaglio of a hippocamp, while another resembles a nicolo with an intaglio fish motif. All the gems are mounted in closed-back rub-over settings, and for this study have been numbered Gem 1-18, starting with the milky white gem at the front of the diadem and moving sequentially round the head as indicated in *Figure 4*. Gems 17 and 18 are on the base pedestal.

In the following sections the results are collated and summarized under species headings and compared with the results of the previous (1957) study in *Table I*. Some of the gemstone identifications corroborate the earlier identifications, but some have been revised. In particular, the number of gems that are identified as glass (paste) is greater than was previously recognized. The other gems include rock crystal (quartz), amethyst, carnelian, chalcedony, obsidian, mother-of-pearl and pearl. Furthermore, XRF analysis has allowed identification of the glass types used.

Rock crystal

There is just one rock crystal (quartz) gemstone on the head reliquary: Gem 10, an oval cabochon. It is colourless, transparent and contains few inclusions. The main peak on the Raman spectrum occurs at *c.* 463 cm^{-1} with subsidiary peaks at *c.* 206 cm^{-1} and *c.* 353 cm^{-1} (see *Figure 5a*). This spectrum matches the reference spectrum for quartz.

Amethyst

There are two amethysts set in the diadem, Gem 2 and Gem 5, which are located on the true left of the head. Gem 2 is a square cabochon and Gem 5 is a rectangular cabochon. They are purple and appear slightly cloudy, both containing feathers (healed fractures) (see *Figure 6a*). Both gems gave similar Raman spectra with the main peak at *c.* 464 cm^{-1}, and other peaks at *c.* 207 cm^{-1}, *c.* 354 cm^{-1}, *c.* 401 cm^{-1} and *c.* 807 cm^{-1} (see *Figure 5b*). The reference spectrum for quartz matches the spectra obtained from these gems, and as they are purple in colour they are identified as amethyst.

Table I: Gems in the head reliquary of St Eustace.

Gem No.	Colour	1957 identification	Present identification
1	milky white	chalcedony	pale blue-grey chalcedony
2	purple	amethyst	amethyst
3	orange-brown	paste	orange-brown soda-lime-silica glass – Roman glass
4	black intaglio	black jasper	obsidian
5	purple	amethyst	amethyst
6	white opaque	mother-of-pearl	mother-of-pearl (aragonite)
7	red	paste	red potash-lime-silica glass – medieval glass
8	milky white	chalcedony	pale blue-grey chalcedony
9	colourless with blue backing	paste	colourless soda-lime-silica glass – Roman glass
10	colourless	crystal	rock crystal
11	grey cloudy	chalcedony	pale blue-grey chalcedony
12	orange	agate or onyx	carnelian
13	grey milky	chalcedony	pale blue-grey chalcedony
14	top opaque pale blue-grey, base dark brown	nicolo or paste	soda-lime-silica glass imitation of nicolo – Roman glass
15	grey	pearl	baroque pearl bead (aragonite)
16	orange	sard	carnelian
17	pale blue	crystal	pale blue soda-lime-silica glass – Roman glass
18	pale blue	crystal	pale blue soda-lime-silica glass – Roman glass

Carnelian

There are two gems identified as carnelian in the diadem, Gem 12 and Gem 16. Gem 12 is an orange oval cabochon and Gem 16 is a dark orange rectangular table cut stone, and both are translucent (see *Figure 6b*). The Raman spectra of these two gems are very similar and match the British Museum reference spectrum for microcrystalline quartz. Both show main peaks at *c.* 463 cm^{-1} with a subsidiary peak at *c.* 501 cm^{-1} which is the characteristic peak for moganite, a silica polymorph which commonly occurs in microcrystalline quartz (Kingma and Hemley, 1994). The other peaks occur at *c.* 207 cm^{-1} and *c.* 354 cm^{-1}. As these gems are orange in colour and are very fine grained, they are identified as carnelian.

Chalcedony

Four gems in the diadem have been identified as pale blue-grey chalcedony: Gems 1, 8 and 13 are all oval cabochons while

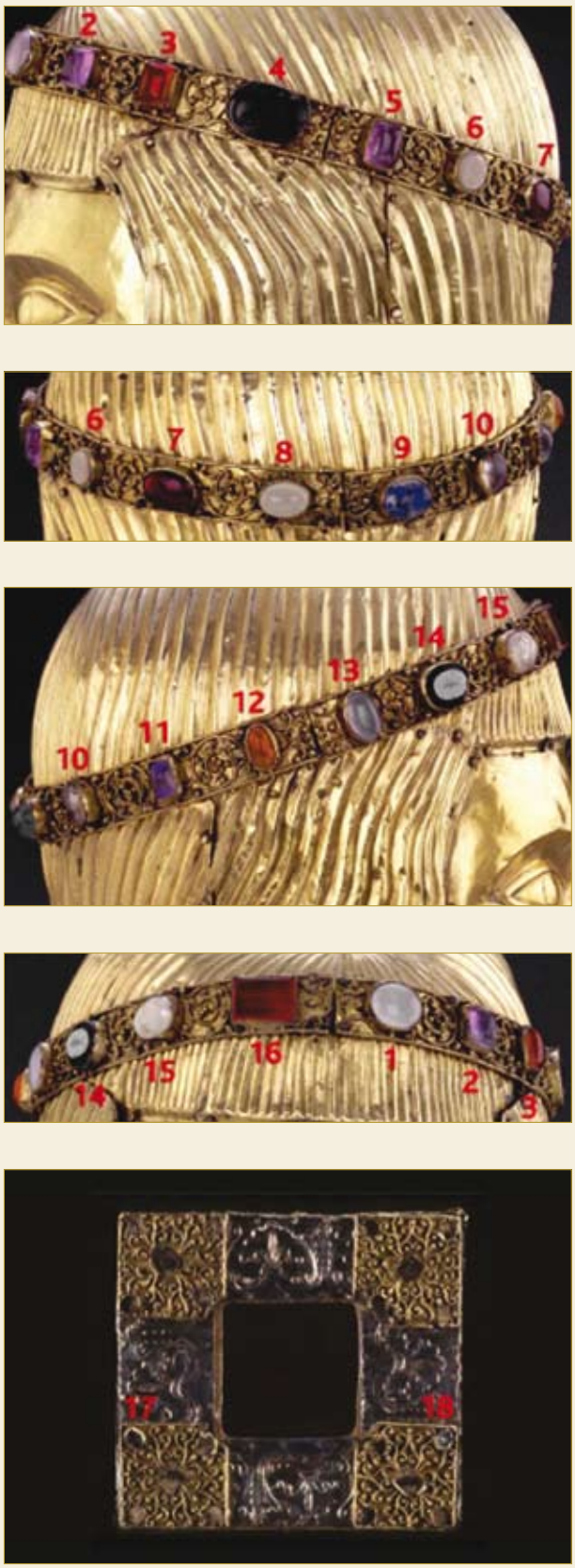

Figure 4: The gems in the diadem and base pedestal of the head reliquary of St Eustace. The gem numbers correspond to those in Table I.

Gem 11 is a square cabochon. They generally have a milky or cloudy translucent appearance (see *Figure 6c*). The Raman spectra for all these gems are similar. They all have their main peaks at *c.* 463 cm^{-1} with a subsidiary peak at *c.* 501 cm^{-1}, the characteristic peak for moganite (see Carnelian above) and other peaks at *c.* 207 cm^{-1} and *c.* 354 cm^{-1}. As these gems are translucent and have a very fine grained texture, they are identified as pale blue grey chalcedony.

Baroque pearl

A large baroque pearl bead complete with a drill hole has been set into the front of the diadem, Gem 15 (see Figure 6d). The Raman spectrum for this pearl has its main peak at c. 1085 cm^{-1} with minor peaks at c. 207 cm^{-1} and c. 704 cm^{-1}, a combination which matches that of reference Raman spectra for aragonite (see Figure 5c) and which confirms that it is a pearl. Calcite can be discounted as its main peak positions lie at 1089 cm^{-1}, 713 cm^{-1}, 284 cm^{-1} and 155 cm^{-1} (Williams, 1995). This large pearl contains a drill hole which is unnecessary in its closed setting in the diadem and which suggests that the pearl may originally have been worn as a bead or on a string. Its setting into the diadem is possibly an example of the re-use of a gem from antiquity.

Mother-of-pearl

There is just one gem fashioned from mother-of-pearl and that is Gem 6. It is round with a table facet and has lost most of its iridescent nacreous layer. The Raman spectrum for this gemstone matches the reference spectrum for aragonite with peaks at *c.* 1085 cm^{-1} and *c.* 705 cm^{-1} (see *Figure 5d*) and this together with the iridescent layer confirms identification of this gem as mother-of-pearl.

Synthetic glass (paste): compositional categories

A number of the gems in the diadem and those from the base pedestal of the head reliquary were found to be made of synthetic glass or paste. Most of these glasses did not give Raman bands significantly above background, probably due to surface alteration and contamination effects.

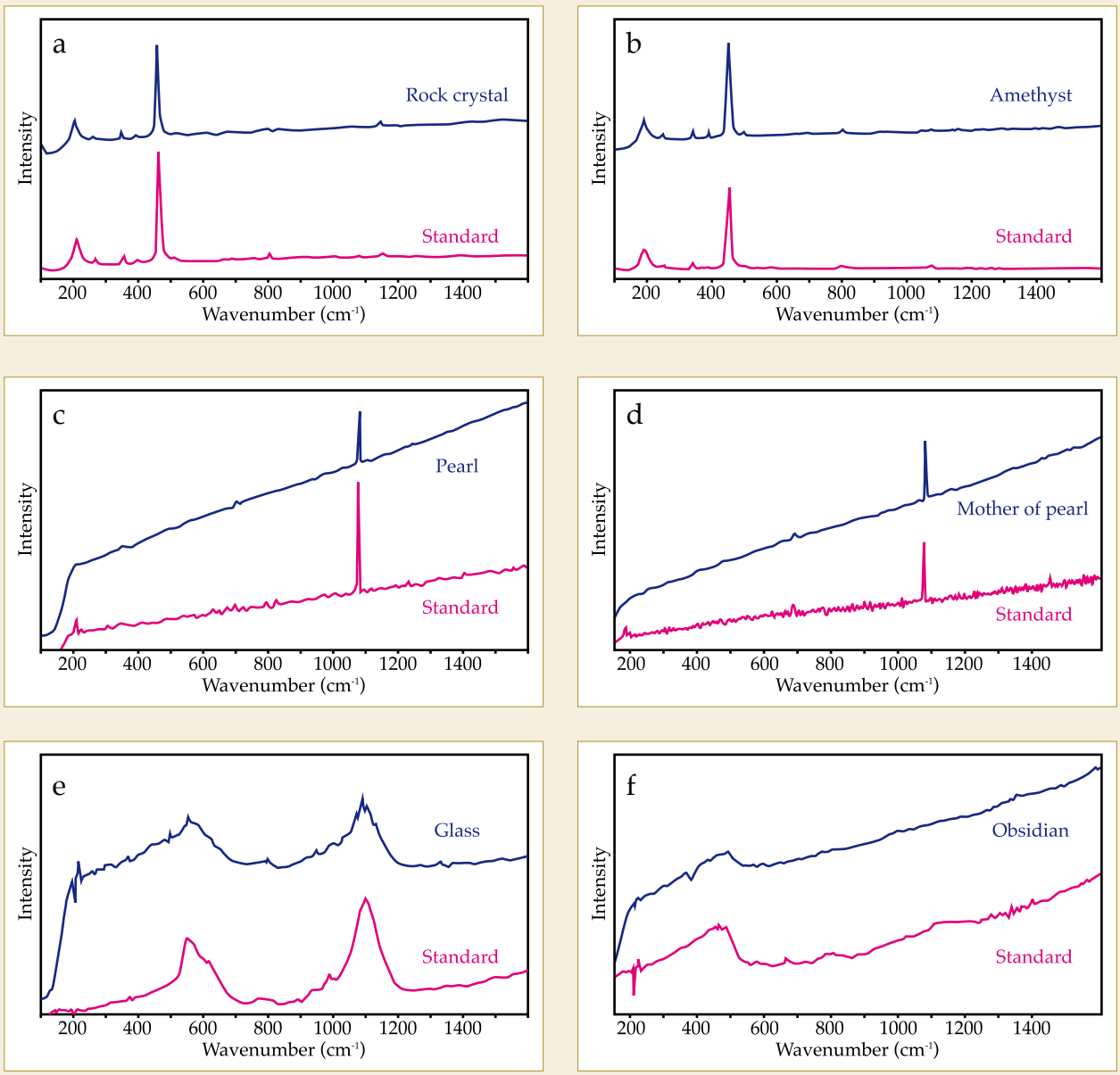

Figure 5: Raman spectra of some of the gems on the head reliquary of St Eustace using the Nd:YAG green laser (532 nm):
a) Raman spectra of Gem 10 rock crystal (blue) and the British Museum reference sample for quartz (pink).
b) Raman spectra of Gem 2 amethyst (blue) and the British Museum reference sample for quartz (pink).
c) Raman spectra of Gem 15 baroque pearl (blue) and the British Museum reference sample for pearl (pink).
d) Raman spectra of Gem 6 mother-of-pearl (blue) and the British Museum reference sample for aragonite (pink).
e) Raman spectra of Gem 3 orange-brown glass (blue) and the British Museum reference sample for glass (pink).
f) Raman spectra of Gem 4 obsidian (blue) and the British Museum reference sample for Obsidian (pink)

However, the orange-brown glass (Gem 3) gave a spectrum with two broad peaks, one at *c.* 559 cm^{-1} and the other at *c.* 1087 cm^{-1} with the green laser, which coincide with the bands for a glass reference sample (see *Figure 5e*) and correspond to the Si-O bending and stretching modes respectively (see Columban *et al.*, 2003).

Of the six synthetic glasses identified and analysed by XRF, five (Gems 3, 9, 14, 17 and 18) showed lime (CaO) contents of the order of 10% with very small amounts of potash (K_2O *c.*1%). The moderate lime and low potash contents of these glasses mean that they are almost certainly soda-lime-silica glasses (Bowman and Freestone, 1997). Sayre and Smith (1961) recognized two types of soda-lime-silica glass to be prevalent in the pre-industrial world, one with low potash and magnesia (ie. below about 1.5 % each), and the other with higher concentrations of these components. Recent work has confirmed this basic subdivision

Figure 6: Photographs of some of the gems on the head reliquary of St Eustace:

a) Amethyst (Gem 5) showing feathers.
b) Carnelian (Gem 16).
c) Pale blue-grey chalcedony (Gem 1).
d) Baroque pearl (Gem 15) with the end of a drill hole just visible at the right-hand side. The drill hole has no purpose in this setting and indicates a previous use for the pearl.
e) Orange-brown transparent glass (Gem 3) showing bubbles characteristic of glass.
f) Glass nicolo simulant with a fish motif (Gem 14). Surface-reaching bubbles can be seen in the opaque pale grey table.
g) Colourless glass with opaque blue glass(?) globules forming a backing (Gem 9).
h) Obsidian (Gem 4) with a hippocamp intaglio on the table.

which is attributed to the use of different types of soda as raw material (Henderson, 1985; Wedepohl, 1997; Freestone and Gorin-Rosen, 1999). The high lime/potash ratios of the present glasses strongly suggest that they are all of the low-potash, low-magnesia category and they are considered to have been made using a naturally-occurring evaporitic source of soda, such as that found in the Wadi Natrun, Egypt.

In contrast, the glass Gem 7 has a quite different composition, with high concentrations of both potash and lime, around 20%. This type of potash-lime-silica glass was produced using the ashes of beech trees and ferns as sources of alkali, and is commonly termed 'woodash glass' or 'forest glass' (Henderson, 1985; Wedepohl, 1997).

Orange-brown transparent glass: Represented as the square cabochon, Gem 3, contains swirls and bubbles typical of glass (see *Figure 6e*). It is a soda-lime-silica type glass, containing around 1% iron oxide and a minor amount of manganese oxide which are the colourants. Also present is antimony in the order of 1% antimony oxide (see *Figure 7a*), which was used as a decolourant in the production of ancient glass (Sayre, 1963).

Red transparent glass: Gem 7 is a transparent red glass oval cabochon containing large bubbles, and is the sole representative of potash-lime-silica or woodash glass, typical of glasses made in medieval times. It contains low amounts of iron (tenths of a percent) but around 0.2% copper (see *Figure 7b*), which

might be just enough to precipitate copper crystallites, giving rise to a copper ruby glass. Alternatively (and more likely), the red tone may be due to the manganese oxide (*c.* 0.5%) in the glass.

Pale blue-grey opaque and dark brown glass: It was originally unclear if Gem 14, with an opaque dark brown pavilion and an opaque pale blue-grey crown with a fish motif carved into the table, was a nicolo or a paste imitation (see *Figure 6f*). However, bubbles are visible in both parts of the stone and these are indicative of synthetic glass. The pavilion of Gem 14 proved to be a soda-lime-silica glass coloured brown by *c.* 2-3% manganese oxide; also approximately 1% of antimony oxide is present, which makes it opaque. The crown is opacified by a relatively high concentration of antimony oxide (*c.* 5-10%), probably present as calcium antimonate (see for example Freestone, 1991). The pale-blue-grey coloration appears to be due to the presence of small quantities of cobalt and copper in solution (approximately 0.1% each),

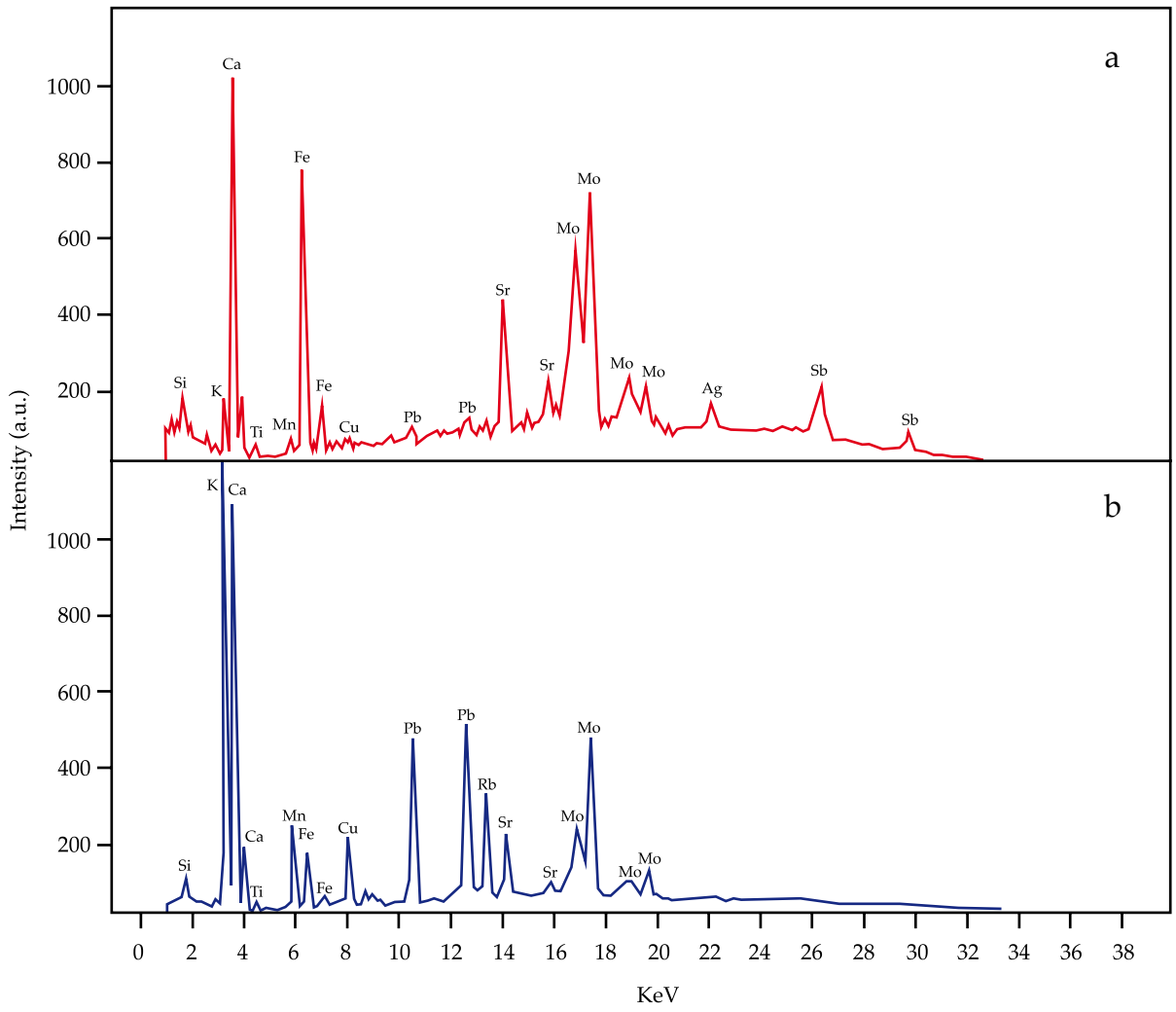

Figure 7: X-ray fluorescence (XRF) spectra showing qualitative elemental composition of synthetic glasses (paste). The main elemental peaks are labelled by chemical symbol. The molybdenum peak (Mo) on each spectrum is derived from the X-ray target used.

a) XRF spectrum of the orange-brown transparent glass (Gem 3). This glass is a silica glass with a high lime (Ca) to potash (K) ratio, high iron (Fe) content and low manganese (Mn) content. It is a Roman glass. The small silver (Ag) peak is probably due to contamination from the silver gilt mount.
b) XRF spectrum of the red transparent glass (Gem 7). This glass is a typical medieval glass with a high potash (K) content. It is a potash lime silica glass.

perhaps modified by the presence of *c*.5-10% lead oxide.

Colourless glass with blue backing and pale blue transparent glasses: Three oval cabochons, Gem 9 on the diadem, and the smaller Gems 17 and 18 set on the top of the base pedestal, are of pale blue, transparent, soda-lime-silica glass. Gem 9 is made from a colourless glass, bubble-rich, with rounded blue globules of what look like an ultramarine blue-coloured opaque ?glass at the base of the stone (see *Figure 6g*). Gems 17 and 18 were originally identified as crystal but their compositions and Raman spectra indicate that they are glass. Apart from the presence of a small amount of copper (*c.* 0.1%) which is insufficient to cause a strong coloration, in Gem 18 there appeared to be no deliberately added blue colourant (copper, cobalt). Instead, these glasses appear to owe their weak blue coloration to ferrous iron (c.f. Brill, 1988), which was incorporated incidentally as a component of the sand when the glass was originally made. Antimony, commonly added to ancient glass as a decolourant, is present in Gem 9, while all three glasses contain tenths of a percent of manganese, the typical decolourant of soda-lime-silica glass from the Roman period on.

Obsidian

An opaque black oval wheel-cut intaglio with a hippocamp (sea-horse) on the table facet (Gem 4), originally identified as jasper, proved to be glass (see *Figure 6h*). However, it gave a Raman spectrum unlike those of the other glasses, with a small broad band visible at *c.* 487 cm^{-1} using the green laser (see *Figure 5f*). XRF results indicated the presence of iron, potassium and low levels of calcium (*c.* 2% CaO); the low level of calcium and the fact that it is subordinate to potassium (*c.* 5%) suggests that this stone is probably the natural volcanic glass, obsidian.

Discussion

Nine of the 18 gems were identified as a varieties of quartz (including rock crystal, amethyst, carnelian and chalcedony), six were identified as glass paste, two were organic gems (baroque pearl and mother-of-pearl) and one was obsidian.

The procurement of gems in the medieval period has been discussed by Stratford (1993: 22). He notes the high value attributed to rock crystal, as well as the passion for Antique cameos and intaglios, which were recycled in large numbers. Only one of the gems on the Basle Head is of rock crystal, and this may be taken as a reflection of the rarity of, or demand for, this material. Rock crystal does not appear to have been mined systematically and specifically in Europe before the nineteenth century and this stone may represent a chance European find (as a by-product of metal mining or in a river bed), a material imported from the East, or a re-ground Roman stone (Stratford, 1993: 22). Rock crystal sources include the Alps, Cyprus, Egypt, Hungary, Kharga Oasis, Spain and Turkey (Ogden, 1982). The obsidian intaglio (Gem 4) is likely to be a recycled Roman object, given its subject-matter and its composition; obsidian was not widely used in the medieval period, and the most accessible sources were in the Mediterranean region. The pearl bead clearly represents re-use of a gem that was originally part of another object, although its antiquity is uncertain. It is well-known that pearls were very popular during the Roman period (Clark, 1986), and it may well be possible that the pearl bead here is recycled Roman, in keeping with the re-use of Antique gems in this period. Pearls were seen as 'symbols of regeneration' in Christian iconography and were frequently used to adorn the crowns of sovereigns in Europe (Clark, 1986). The origins of the other natural stones are unclear; they might have been recently mined and traded items, or ground down from Antique (Roman) materials. The re-use of Roman gems for the Basle treasury reliquaries is possible as there was a Roman city in Basle and another close by, located on important trade routes. There are other examples of the re-use of Antique and other gems in medieval objects (e.g. Gray, 1989; Hänni *et al.*, 1998; Kiefert *et al.*, 2005). Gems

decorating reliquaries were probably chosen for their symbolic qualities of beauty, value, rarity and religious significance (Clark, 1986).

More informative as to origin are the glass stones, which were frequently used in the medieval period as gems (Bimson and Freestone, 2000; Dandridge, 2002), particularly in reliquaries and other sacred objects (Merrifield, 1849). The low-potash, soda-lime-compositions of the majority are at variance with the composition of northern European medieval glass which was typically a potash-lime-silica variety. There is a wide consensus that soda-lime-silica glasses of the low-potash type are likely to have gone out of production by the tenth century (Freestone and Gorin-Rosen, 1999; Henderson, 2002; Whitehouse, 2002). These factors, coupled with the common presence of antimony, indicate a Roman affinity for most of the glasses, and probably indicate the re-use of old Roman glass. The nicolo simulant, for example, is likely to represent a Roman cased (layered) cameo glass; analysis has shown that the pale overlays of these glasses were commonly opacified with calcium antimonate, accompanied by an elevated lead content (Freestone, 1990). Indeed, closely similar synthetic nicolos, with similarly rather crudely engraved intaglios, were widely used in the Roman finger rings (Johns, 1996). The re-use of Roman glass on this scale is not surprising. Writing early in the twelfth century, Theophilus in his book *De Diversis Artibus* tells us that glass mosaic tesserae from old Roman buildings were used to enamel metalwork (Hawthorne and Smith, 1963). Analysis of twelfth-century enamels confirms this statement (Freestone, 1992, 1993). Written some time before the twelfth century, Eraclius describes in his book *De Coloribus et Artibus Romanorum* how Roman glass was used to mould glass gems (Merrifield, 1849). An exception in the present case is the red cabochon, Gem 7, which appears to represent a contemporary medieval glass. Interestingly, the red glasses of the enamelwork of the Mosan region (the valleys of the Meuse and the Rhine in what is now Belgium and the Rhineland) are also exceptional in a similar way, in that while all of the other colours appear to be re-used Roman glasses, the reds (in the case of the enamels, opaque rather than translucent reds) are clearly medieval (Freestone, 1993). The reasons for this are not completely clear but may relate to the relative rarity of red glass in general and translucent red glass in particular, in the ancient world. It was very difficult to produce, and we now know that it requires the presence of extreme reducing conditions in the glass for copper red or very oxidizing conditions for manganese red. Once the medieval glass workers had learned how to produce red glass on a large scale for ecclesiastical 'stained' glass windows, it is likely to have become widely available.

Comparisons with previous analyses of gems in medieval reliquary treasures

Raman microspectroscopy has also been used to analyse the gems adorning other objects from the Basle Cathedral Treasury, the Reliquary cross and the Dorothy monstrance, both believed to have been manufactured around 1440 (Hänni *et al.*, 1998). Hänni *et al.* (1998) identified rock crystal, amethyst, smoky quartz, citrine, quartz-topped doublets, turquoise and glass (paste) in the Reliquary cross, and rock crystal, amethyst, black chalcedony, carnelian, agate, quartz-topped doublets, glass doublet, peridot, sapphire, garnet, spinel and glass (paste) in the Dorothy monstrance. A carnelian intaglio of a goat and an agate cameo of a woman's head, both set in the Dorothy monstrance, suggested to Hänni *et al.* (1998) the re-use of either Greek or Roman engraved gems, a common practice in the medieval era. The other possibility they mooted was that they were made at the same time as the objects in which they are found, coinciding with a resurgence of interest in engraved gems in the fifteenth century. Raman spectral analysis of the gems in the cross of the church of St Clara and the Agnus Dei monstrance, also part of the Basle Cathedral Treasury, by Kiefert *et al.* (2005) identified sapphires. Both objects contain sapphires with drill holes. In the first, an oval

cabochon sapphire was observed to have a drill hole from end to end along its length, and in the second a light blue sapphire had two drill holes. This again illustrates the re-use of gems in medieval reliquaries.

Reiche *et al.*'s (2004) non-destructive analysis of the gems in the early eleventh-century reliquary Heinrich's cross, also part of the Basle Cathedral Treasury, was made using a mobile Raman microscope. They identified most of the gems as glass paste or varieties of quartz (including rock crystal, amethyst, carnelian and chalcedony), but also found some garnets (almandine, spessartine and almandine-spessartine varieties), sapphires and rubies. It is interesting to note the relatively high use of varieties of quartz and synthetic glass on reliquaries from the Basle Cathedral Treasury (see *Table II*). Unfortunately, the glass paste compositions were not further investigated by either Hänni *et al.* (1998) or Reiche *et al.* (2004), so no detailed comparisons can be made with the glass gems on the head reliquary of St Eustace. However, using XRF and open-architecture X-ray diffraction, Dandridge (2002) did identify the compositions of the glass used for gems in the late twelfth-century Romanesque reliquary cross from Limoges, France, as being consistent with both Roman glass and Romanesque enamels. He also identified rock crystal in the cross.

The identifications of the gems set in the reliquary objects relate only to those currently in place, which may or may not be original, as also noted by Reiche *et al.* (2004). There is no way of knowing if some or all of the gems on the reliquary head of St Eustace have been replaced since it was made.

Conclusions

The use of the Raman microspectroscope with a horizontal laser attachment, in combination with X-ray fluorescence spectrometry and a 10× loupe, has allowed the identification of the full range of stones adorning the head reliquary of St Eustace. It has been possible to correct a number of the earlier identifications and in some cases update the terminology used. In particular, glass or paste is seen to be much more abundant in the assemblage. Furthermore, the use of X-ray fluorescence analysis, coupled with a modern understanding of the chemistry of early glass, has allowed the identification of the majority of glass stones as re-used Roman glass. There is also good evidence that several of the natural gems (obsidian, pearl) were re-used, probably Antique. Thus the present investigation emphasizes the extent to which the re-use of old materials to decorate metalwork was embedded in the practices of the medieval goldsmith. Recent research suggests that the re-use of old Roman glass tailed off in the thirteenth century (Biron *et al.*, 1996). However, a fetish for Roman intaglios and engraved stones continued through to relatively modern times, and it was only with their removal from circulation into public museums and private collections of antiquities that the processes of re-use, reworking or incorporation into new objects were reduced on any significant scale.

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Table II: Proportions of gem varieties in reliquaries from the Basle Cathedral Treasury.

Gemstone type	Head reliquary of St Eustace	Hänni *et al.* (1998)	Reiche *et al.* (2004)
Quartz varieties	50%	40%	22%
Glass (paste)	33%	30%	46%
Other gemstone varieties	17%	30%	32%
Total number of gems	18	47	68

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The orientation and symmetry of light spots and asterism in rose quartz spheres from Madagascar

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Abstract: *The orientation of light spots on the surface of four asteriated rose quartz spheres from Madagascar is described. The up to 50 different light spots form similar patterns on all samples examined with respect to their orientation, but are somewhat different according to their relative intensity. They are represented by the poles of six groups of symmetry equivalent quartz crystal forms, related to prismatic, rhombohedral and basal crystal faces. The phenomenal light spots are caused by reflection at plane phase boundaries with an orientation parallel to crystal faces of the rose quartz host and are due to inclusions of tiny minerals or negative crystals and/or oriented reflecting plane fluid cavities or mineral platelets.*

Introduction

Phenomenal quartzes are known from various localities. Specimens with needle-like inclusions orientated parallel to one direction are known as quartz cat's-eyes. Asteriated quartzes or rose quartzes with six-rayed stars reveal three groups of needle-like inclusions orientated in a plane perpendicular to the *c*-axis. Rarely twelve-rayed stars are seen which show six groups of needles in the same plane. Multi-star quartzes revealing numerous stars on the surface of cabochons or complete spheres come mainly from Sri Lanka. The multi-star network is due to numerous intersecting light bands which are caused by various groups of needle-like inclusions (Kumaratilake, 1997; Schmetzer and Glas, 2003).

Occasionally, asteriated rose quartzes reveal – in addition to the three ordinary light bands forming the six-rayed star – several more or less sharp light spots. Such additional light spots have already been described by Goldschmidt and Brauns (1911) and by Kalkowsky (1915) in rose quartz spheres from Brazil and Madagascar as 'Lichtknoten' (light knots). This optical phenomenon has rarely been mentioned in gemmological textbooks (see for example Bauer and Schlossmacher, 1932).

On asteriated rose quartz spheres or cabochons seen on various occasions at mineral or gem shows, the authors have also observed such additional light spots, mainly in material from Brazil or

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Madagascar. The present study, however, started when we received two extraordinary rose quartz spheres, weighing 421 and 159 grams, diameters about 6.7 and 4.9 cm. The specimens originated from Madagascar and were submitted by the Swiss gem merchant A. Leuenberger to the SSEF Swiss Gemmological Institute, Basel, Switzerland. Leuenberger had noticed that in addition to their ordinary six-rayed asterism, the rose quartz spheres showed numerous light spots distributed over the complete surface, a phenomenon that he had not seen in any of the numerous spheres he had cut or seen in the past.

Stimulated by the initiative of Mr Leuenberger, the authors examined a large number of asteriated and non-asteriated rose quartz spheres that were offered by several Malagasy dealers at the Munich mineral fair. Most of these samples showed only the ordinary six-rayed star of asteriated quartz *(Figure 1)*. However, we were able to select two additional spheres of 138 and 113 grams in weight, diameters 4.6 and 4.3 cm, respectively, for the present study, which showed the optical phenomenon mentioned above. Rose quartz is found in many localities on the island of Madagascar and at all of these is of pegmatitic origin (Pezzotta, 2001). Such pegmatitic origin has also been reported for Brazilian asteriated and non-asteriated rose quartz by Cassedanne and Roditi (1991).

Visual appearance and macroscopic observation

All four rose quartz spheres showed a similar phenomenal pattern consisting of a complete six- or twelve-rayed star and additional light spots. The central star in spheres A,C and D (see a summary of observed light effects in *Table 1*) revealed three intersecting light bands and was not very strong (*Figures 2a, 4, 5a*). In B, three additional, even weaker light bands were present forming, together with the three somewhat more intense light bands, a twelve-rayed central star (*Figure 3a*). The intersection points of these stars are called north and south poles of the spheres.

In all four spheres, it was possible to follow the six arms of the star (in B to follow the six stronger arms of the twelve-rayed star) from the north to the south poles of the spheres. Turning the spheres to follow these light bands along the arms of the star, i.e. from the first intersection point (north pole) to the second intersection point (south pole), five additional light spots are located on each of these light bands (*Figures 2b, 3b*). From the positions of these light spots, i.e. from the pole distances of the different spots on the arms of the star, it is obvious that these light spots form symmetry equivalent groups (designated groups 1,3 and 4 in *Table 1, column 1*). The light spots designated as group 1 were located at a distance of 90° to the poles of the spheres, i.e. at the equator of all samples (*Figure 2b*). The light poles of groups 3 and 4 were on the upper and lower hemispheres of the rose quartz spheres (*Figure 3b*). It was also observed that the patterns of spots observed on the upper and lower half of the spheres are identical with respect to pole distances and intensities. A schematic drawing of all the patterns of light bands and light spots observed on the four spheres is given in *Figure 6*.

Figure 1: *Ordinary six-rayed asterism in a rose quartz from Madagascar. This sphere weighs 81 grams and measures 3.9 cm in diameter; the light spot left of the intersection point of the six arms of the star is the reflection of the fibre optic spot light used for illumination.*

Table 1: Phenomenal light effects in four rose quartz spheres from Madagascar.

Sphere						A	B	C	D
Weight [grams]						138	113	159	421
Diameter [cm]						4.6	4.3	4.9	6.7
Central star						six-rayed	twelve-rayed	six-rayed	six-rayed
Other light bands									$[0\bar{1}11]$
Group of faces	**Designation of faces**	**Symbol**	**Miller indices (hkil)**	**Angle of light spots versus c-axis**	**Number of symmetry equivalent crystal faces and light spots**	**Intensity of light spots, relation to the central star***			
1	hexagonal prism	m	$(10\bar{1}0)$	90°	6	strong	strong	moderate	strong
2	trigonal prism	*a* *a′*	$(11\bar{2}0)$ $(2\bar{1}\bar{1}0)$	90°	3 3	weak	moderate	n.o.	weak
3	rhombohedron	*r* *z*	$(10\bar{1}1)$ $(01\bar{1}1)$	51.8°	2x3 2x3	strong	strong	moderate	strong
4	rhombohedron	π π′	$(10\bar{1}2)$ $(01\bar{1}2)$	32.4°	2x3 2x3	weak	moderate	moderate	weak
5	trigonal dipyramid	*s* *s′*	$(11\bar{2}1)$ $(2\bar{1}\bar{1}1)$	65.6°	2x3 2x3	moderate	strong	moderate	moderate
6	basal pinacoid	*c*	(0001)	0°	2x1	moderate	strong	strong	moderate

* Light spots related to the arms of the central six- or twelve-rayed star are indicated in blue, light spots not related to the central star are indicated in red. n.o. = not observed.

Following the arms of the central stars from the north pole to the south pole, on spheres A and D (see again *Figure 6*), the sequences of light spots on the arms of the star showed the following intensities: a first spot of low intensity (group 4), three subsequent light spots of high intensity (belonging to group 3, to group 1 and again to group 3) and another light spot of low intensity (again group 4). As already mentioned, the middle light spot of high intensity (group 1) was located exactly half way between the north and south poles of the sphere, i.e. at its equator. In spheres B and C, the same sequence and position of light spots belonging to groups 1, 3 and 4 was observed, although with different relative intensities (*Table 1*).

Rotating spheres A and D to view their virtual equators, the six intense light spots (group 1) on the six arms of each star were clearly visible. In addition, six more light spots of lower intensity (group 2) were observed, equidistant from the light spots on the arms of the six-rayed star. Consequently, a total of 12 light spots (six of higher intensity on the arms, group 1, and six of the lower intensity, group 2) were located at the equator of the sphere. Finally, between each light spot of low intensity at the equator and the north

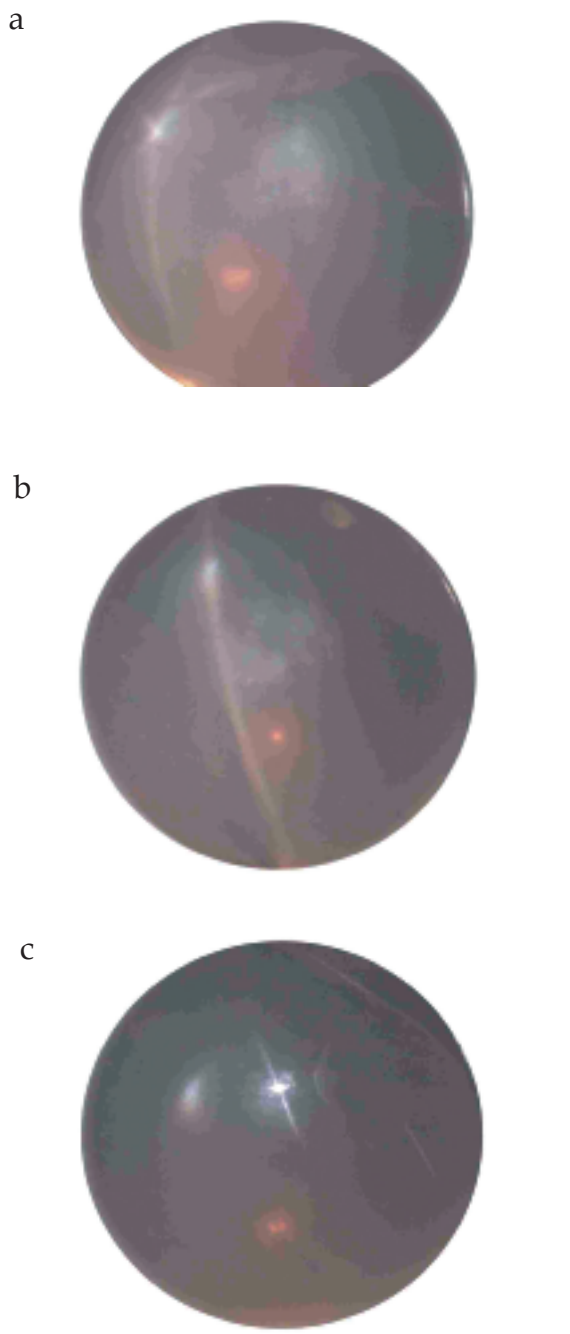

Figure 2: Rose quartz sphere from Madagascar showing six-rayed asterism and numerous light spots on its surface; (a) six-rayed central star with a light spot at the intersection point of the arms of the star, (b) light spot located on one of the arms of the six-rayed star at the equator of the sphere, the light spot is related to the pole m; (c) light spot located between the equator and one of the poles of the central star, but not on one of the arms of the star, the light spot above left is related to the pole s; the light spot above right is the reflection of the fibre optic spot light used for illumination. This sphere (sample A) weighs 138 grams and measures 4.6 cm in diameter.

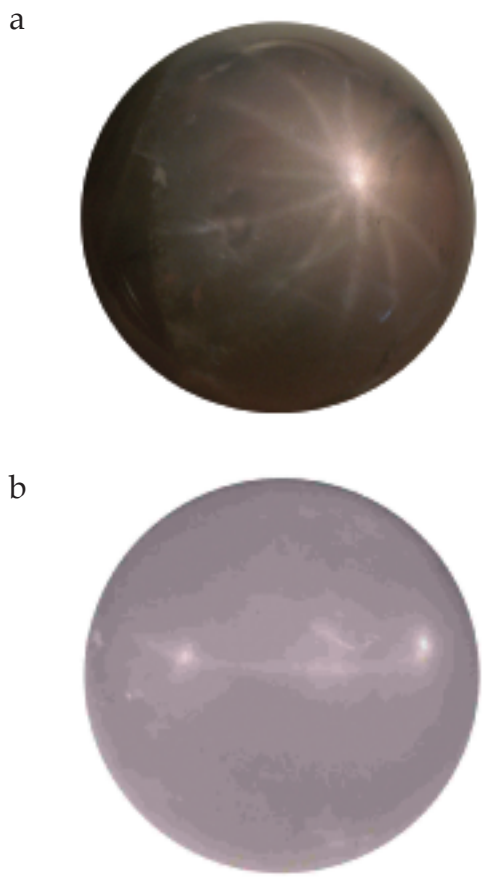

Figure 3: Rose quartz sphere (sample B) showing twelve-rayed asterism and numerous light spots on its surface; (a) twelve-rayed central star with a light spot at the intersection point of the arms of the star, (b) two light spots located on one of the arms of the twelve-rayed star between the equator and one of the poles of the central star, the light spots are related to the poles r and π. This sphere weighs 113 grams and measures 4.3 cm in diameter.

and south poles of the sphere, one additional light spot of moderate intensity is present (*Figures 2c, 5c*). These symmetry equivalent light spots are designated as group 5.

In spheres B and C, in addition to the different relative intensities of the light spots belonging to groups 1, 3 and 4, the following differences were observed. In B, the light spots belonging to groups 2 and 5 were stronger in intensity than in A and D. They lie on the additional six light bands of the twelve-rayed central star (see *Figure 3a*). In sphere C, there was no evidence for 6 light spots of low intensity at the equator (group 2). The 12 light spots between the arms of the star (group 5),

Figure 4: Rose quartz sphere (sample C) showing six-rayed asterism with a light spot at the intersection point of the arms of the star; the light spot at the right is the reflection of the fibre optic spot light used for illumination. This sphere weighs 158 grams and measures 4.9 cm in diameter.

however, were present (see again *Table 1*).

In all four spheres, additional light spots are present at the intersection points of the central star, i.e. at the north and south poles of the spheres (*Figures 2a, 3a, 4* and *5a*). They are of different sizes and intensities but this variation cannot be explained by intersection of the arms of the six- or twelve-rayed stars alone.

Sphere D contains distinct light bands forming the arms of the six-rayed central star, and additional light bands of low intensity (see *Figure 5b*), but it was extremely difficult to follow these light bands over the surface of the complete sphere. However, they appear to form a network between at least some of the light spots described above. The other three spheres, did not appear to show any similar networks of light bands.

Crystallographic orientation of light spots

Using the stereographic projection, a quick overview of the number and position of the various groups of light spots in relation to the six- or twelve-rayed central star is obtainable (*Figure 6*). In total, 48 light spots belonging to five groups (6 + 6 + 12 + 12 + 12 spots of groups 1 to 5) were observed (*Table 1*). If we add the two spots at the north and south pole (group 6), the sphere shows 50 light spots distributed over its surface. It is evident that the positions of the spots at the equator (two groups with 6 spots each) are identical with the poles of the hexagonal prism *m* (group 1) as well as with the trigonal prisms *a* and *a′* (group 2) of quartz. The light spots at the intersection points of the central stars represent the position of the basal pinacoid *c*.

With this basic information, the angles between the remaining light spots which are not located at the equator of the sphere (three groups of 12 spots each) and the poles of the spheres were estimated. Using these data, the positions of the spots were found to be identical with the positions of the poles of four different rhombohedra, *r*, *z*, *π* and *π′* (groups 3 and 4), and two trigonal dipyramids *s* and *s′* (group 5). In summary, the positions of all 50 light spots observed on the surface of the sphere are represented by the pole positions of six groups of symmetry equivalent quartz crystal forms, namely basal pinacoid, prism, rhombohedron and dipyramid. Consequently, the oriented light spots are represented by the pole positions of known quartz crystal faces.

Crystallographic orientation of additional light bands

On the surface of sphere D, several light bands of low intensity were observed forming a special type of network. Although these weak reflections did not form complete light bands over the surface of the sphere, one network of six symmetry equivalent light bands was clearly established. Following one of these light bands from the equator at a light spot belonging to a pole of a trigonal prism (*a* or *a′*), this light band connects one light spot belonging to the pole of a first rhombohedron (*r* or *z*) with a light spot belonging to the pole of a second rhombohedron (*π* and *π′*) and a light spot belonging to the pole of a third rhombohedron (again *r* or *z*), running through the equator at a second prism (*a* or *a′* ; see *Figure 6D*). These light bands are inclined to the *c*-axis and are represented by the crystallographic zone symbol [0111]. The angle of these six light bands to the *c*-axis is calculated as 32.4°. Consequently, the needle

axis of elongated particles forming these light bands is inclined at an angle of 57.6° to the *c*-axis.

Two of this group of six equivalent light bands intersect at each rhombohedral light spot belonging to a pole of group 3 (*r* or *z*) (*Figure 5b*). Combined with one light band of the central star, each rhombohedral light spot related to poles of group 3 also becomes the centre of a weak six-rayed star. In addition, the light spots belonging to poles of groups 2 and 4 become centres of weak four-rayed stars (see *Figure 6*).

Other groups of symmetry equivalent light bands (caused by additional groups of needle-like inclusions in different orientation) may also be present, but their intensity was too low to determine any orientation.

Microscopic observation

Without destroying the rose quartz spheres we were able to observe at high magnification extremely thin needles in all samples, especially by means of fibre optic illumination. These sets of needles are responsible for the six- or twelve-rayed asterism and for the additional light bands of sphere D. Such thin needles are commonly described as oriented rutile needles in quartz host crystals.

In C, we found numerous extremely small reflecting particles in all orientations of the sphere, in which distinct light spots were seen on the surface. However, we were unable to resolve the individual particles and to determine if they were mineral inclusions or negative crystals. We were also unable to determine if individual particles reflect only in one orientation of the host crystal or if individual particles were related to several reflections and light spots.

In D, reflecting particles were present that were large enough to be resolved with the gemmological microscope. In detail, we observed a dense pattern of oriented reflecting plane faces, some hexagonally or trigonally outlined and commonly elongated parallel to a particular crystallographic direction (*Figure 7a, b*). This specific pattern of reflecting, mostly elongated plane faces was seen in each of the numerous orientations of the sphere in which a

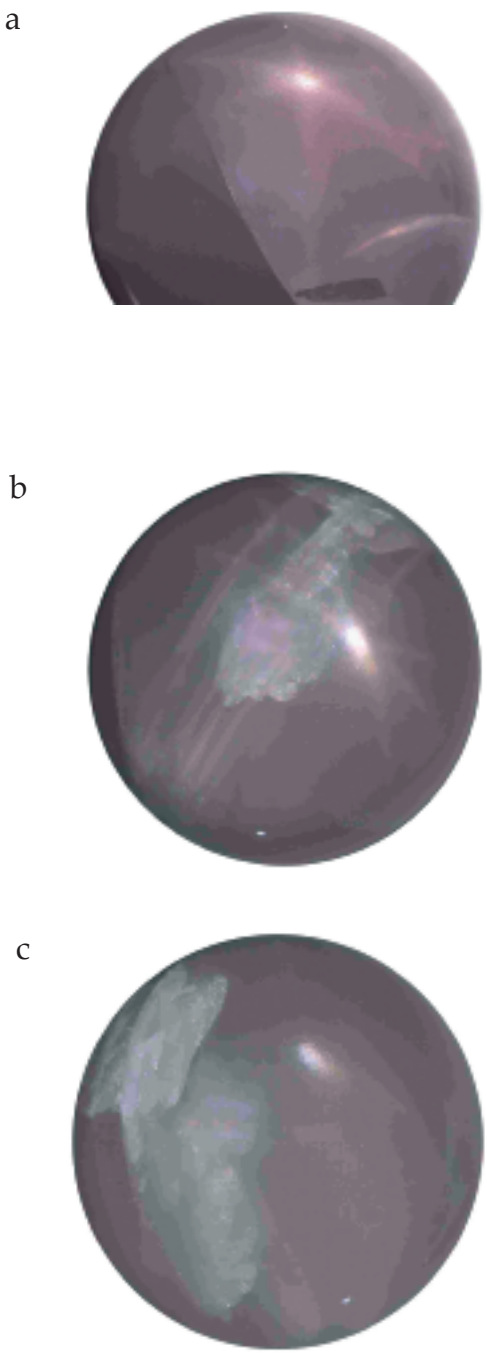

Figure 5: Rose quartz sphere (sample D) showing six-rayed asterism, numerous light spots and light bands on its surface; (a) six-rayed central star with a light spot at the intersection point of the arms of the star, (b) light spot located at the intersection point of one of the arms of a six-rayed star with two additional weak light bands, the light spot is related to the pole r; (c) light spot located between the equator and one of the poles of the central star, but not on one of the arms of the star, the light spot is related to the pole s. This sphere weighs 421 grams and measures 6.7 cm in diameter.

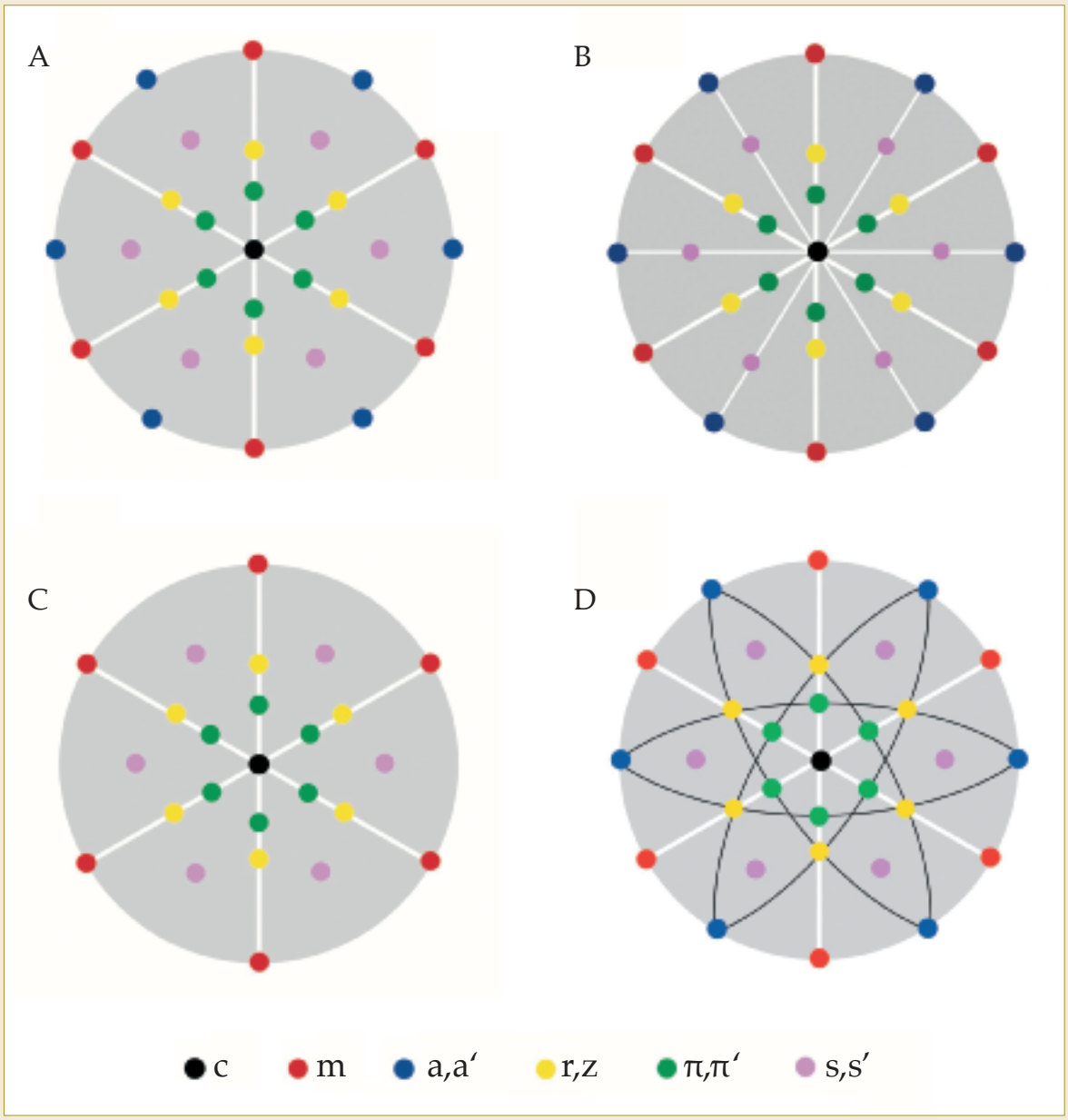

Figure 6: Stereographic projection of light poles on the surfaces of rose quartz spheres (samples A,B,C and D) from Madagascar and their orientation relative to the light bands of the central six- or twelve-rayed stars (only the upper hemispheres of the projection spheres are drawn). The light spots are related to several groups of symmetry equivalent poles of quartz crystal faces. In sample D, additional light bands perpendicular to [0$\bar{1}$11] form four- and six-rayed stars at the positions of rhombohedral and prismatic light spots. Symbols at the bottom represent Groups 1-6 of faces detailed in Table 1.

somewhat larger light spot (compared to C with the extremely small particles) was seen on the surface. Due to microscopic examination it is, however, not clear if these reflecting plane faces represent solid or fluid-containing thin platelets or if they represent the surfaces of larger solid or fluid inclusions (mineral inclusions or fluid-filled negative crystals).

An investigation of the larger inclusions in sphere D by micro-Raman spectroscopy did not lead to any conclusive results. We obtained only the spectrum of the quartz host but no additional lines which could help to further identify the inclusions.

Spheres A and B contain both reflecting small particles and the somewhat larger plane faces that are present in C and D respectively. In A and B, however, the

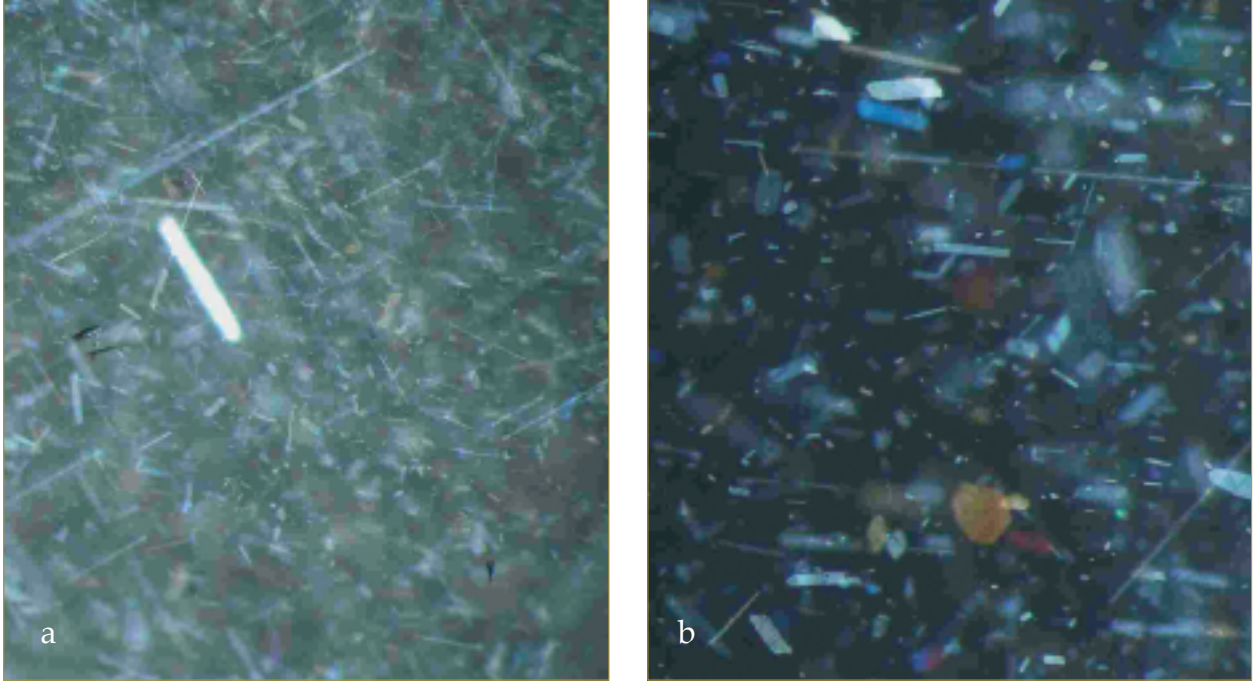

Figure 7: Numerous reflecting plane faces, some hexagonally or trigonally outlined and mostly elongated parallel to a specific crystallographic direction were seen in sample D in each orientation of the sphere in which light spots were seen on its surface; (a) magnified 40 ×, (b) magnified 80 × (photo 7b by H. A. Hänni).

reflecting plane faces are smaller. At present we are unable to decide if we have one distinct type of inclusion with different sizes or if we really have two different types of inclusion present in the rose quartz spheres – in addition to the series of extremely thin needles which are assumed to cause the light bands of the more or less intense six- or twelve-rayed stars.

Further research is needed to identify all types of inclusion in rose quartz spheres showing asterism and additional light spots. This could be done with oriented thin sections (cut from similar phenomenal spheres) using a combination of microscopy, electron microscopy, electron diffraction, micro-Raman spectroscopy and electron microprobe analysis. This is a complex problem which was beyond the resources of the present study.

Discussion

The above orientations of light spots related to crystal faces of rose quartz spheres were determined at the beginning of the twentieth century by Goldschmidt and Brauns (1911) and Kalkowsky (1915), and they further indicated that the light forming the light spots is reflected from the faces of negative crystals within the rose quartz host or from series of oriented light-reflecting platelets of unknown nature. From our study of spheres A, B, C and D, it is evident that the different light spots are caused by reflected light originating from phase boundaries or planes which are orientated parallel to six different forms of symmetrically equivalent quartz crystal faces. In contrast, Maier (1943) suggested that the light spots in rose quartz originate from intersecting light bands, even if there are no intersecting light bands or no light bands at all are visible.

In seeking the reasons to explain our observations on four rose quartz spheres from Madagascar, especially

- the intensities of light spots related to light bands of the central stars,
- the intensity of isolated light spots not related to light bands of the central stars and
- the microscopic proof of light reflecting particles and/or platelets of different size.

The suggestion of Maier (1943) seems unrealistic. In particular, there is an absence of any distinct light spots (poles) at the intersections of light bands as described in detail for quartzes from Sri Lanka (Schmetzer and Glas, 2003) and this makes it unlikely that intense light spots could be caused by two or three intersecting, but invisible light bands. Consequently, the idea that the observed light spots (related to the poles of quartz crystal faces) are caused by

reflection of light from plane faces of negative crystals and/or oriented mineral platelets within the rose quartz single crystal is more likely. This schematic model is consistent with the visual observation of the numbers and positions of all light spots. The dominant orientations of the reflecting faces are parallel to the dominant faces of quartz, e.g. parallel to the hexagonal prism *m* as well as the rhombohedra *r* and *z*, and produce the brightest spots. Light spots of lower intensity represent subordinate faces of quartz, i.e. the rhombohedra π and π' as well as the trigonal prisms *a* and *a'*.

However, the nature of the inclusions responsible for the light spots is not clear so far. It is evident that reflected light indicates phase boundaries between the host rose quartz crystal and additional solid or liquid phases. The solid phases might be mineral inclusions or mineral platelets. The liquid phases might be fluid-filled platelets or negative crystals outlined by the number of quartz crystal forms mentioned above. It is also not clear if there is any connection with the fibrous nanoinclusions of dumortierite (?), which were determined recently in rose quartzes originating from different deposits all over the world (see Goreva *et al*., 2001).

The different intensities of light spots on the surface of different spheres could be caused by either liquid or solid inclusions. Different concentrations of the light reflecting faces of negative crystals would result in different concentrations of light reflecting mineral platelets in different rose quartz host crystals. The different sizes of the observed light spots might be due to different sizes of light-reflecting phase boundaries.

The rose quartz spheres contain also one or two groups of needle-like inclusions with an orientation perpendicular to the *c*-axis of the host crystals. These rutile (?) needles are responsible for the central six- or twelve-rayed stars of the samples. The larger sphere D contains at least one additional group of needle-like inclusions inclined to the *c*-axis, thus forming the six additional light bands which are, consequently, also inclined to the *c*-axis.

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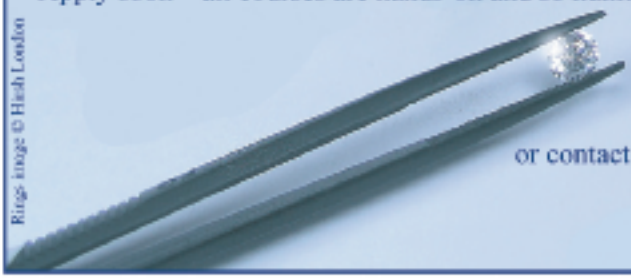

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Identification of the horse origin of teeth used to make the Japanese 'kakuten' using DNA analysis

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Abstract: *'Kakuten' is a kind of 'ojime', an ornamental craft product of the Edo era in Japan. There are worldwide collectors of this item owing to its magical and exotic motif and refined craftsmanship. 'Kakuten' has also attracted the particular interest of collectors because its material has been believed to consist of the red crown of the Japanese crane. Recently, the texture and composition of the 'kakuten' were investigated under high magnification and by microarea Fourier transform infrared spectroscopy, and it was clarified that the 'kakuten' is made from the tooth of a grass-eating animal. In the present study, the species of the animal has been identified using analysis of the DNA sequence of mitochondrial cytochrome b gene (CYTB) including the species-specific region. Nucleotide sequence data indicate that the 'kakuten' is very similar to and has a close phylogenetic relationship to a horse; thus, we conclude that 'kakuten' artefacts are fashioned from the teeth of a horse.*

Key words: *horse cytochrome b, kakuten, nucleotide sequence, ojime, species identification*

Introduction

'Netsuke' and 'ojime' are small ornamental craft products of the Edo era and have been regarded as Japanese magical jewels by collectors[1]. 'Ojime' is used to tighten the connecting strings between a cylindrical container of a khsier (a tobacco pipe) and a

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pouch for shredded tobacco leaves (*Figures 1a,b* and *c*), or between a 'netsuke' and an 'inroh' (*Figures 1d* and *e*). An ornamental ring containing many 'kakuten' is shown in *Figure 1f*. These items have attracted worldwide interest owing to their exotic motifs and delicate craftsmanship. Among the various products, 'kakuten', a kind of 'ojime', has been highly praised not only for being a magical ornament but also for its interesting origin. The literal translation for 'kakuten' is a head (red crown) of a Japanese crane and the word 'ho-ten' or 'ho-ting' used instead of 'kakuten' in the old literature means a casque of an extinct bird, the helmeted hornbill [2]. However, gemmological tests of specific gravity and refractive index gave different results for the material of 'kakuten' and that of these birds. It is thus interesting to clarify the origin of this craft product, and identification of its material may allow us to continue the tradition of its manufacture.

For the identification of the origin of 'kakuten', Sunagawa *et al.* [3,4] investigated its texture under high magnification and its composition by microarea Fourier transform infrared spectroscopy (FTIR), and concluded that 'kakuten' is made from the tooth of

Figure 1: Photographs of 'kakuten' artefacts inserted between a cylindrical container for tobacco pipe and a pouch of shredded tobacco leaves (a, b and c), on a woven rope between 'netsuke' and 'inroh' (d and e, a rear view), and in f, 91 pieces of 'kakuten' tied in a ring. The sizes of 'kakuten' are: 2.0 cm in a, 1.9 cm in d, 1.9 cm in e and in the range 1.8-3.0 cm in f.

a grass-eating animal [3]. This observation revealed valuable gemmological information because ornamental objects made from the teeth of animals are very rare. However, the animal species could not be identified in their study. On the basis of their conclusion that 'kakuten' is made from a part of an animal tooth, several further biological studies were possible, and one appropriate one to determine the animal species was deoxyribonucleic acid (DNA) analysis.

The sequence variation of the mitochondrial cytochrome b gene (*CYTB*) has been widely studied as it provides a powerful basis to resolve phylogenetic relationships in a wide range of animal species and is often used to identify species of animals in forensic investigations (e.g., Hsieh *et al.*[5]). Therefore, one should be able to determine the animal species from which the materials of 'kakuten' originate using phylogenetic data on the basis of *CYTB* variation. In this study, we have carried out a nucleotide sequencing analysis for *CYTB* from 'kakuten' samples by polymerase chain reaction (PCR). Furthermore, by comparing the nucleotide sequences of *CYTB* between 'kakuten' and other animals, the origin of 'kakuten' artefacts has been clarified.

Materials and methods

Two 'kakuten' samples, 'kakuten' -1 and 'kakuten' -2, were analysed in the present study, 'kakuten' -1 being the sample used in our previous studies [3, 4]. To extract total DNA, 1 g of the 'kakuten' was milled to a fine powder and suspended with 20 ml of 0.5 M EDTA (pH 8.0) for five days for decalcification. The DNAs from decalcified samples were extracted using a DNA extraction kit and NucleoSpin DNA Trace (Macherey-Nagel, Dueren, Germany) following the supplier's protocol, and the DNA was eluted in 100 μl of sterile water. Additionally, total DNAs (20 ng/μl) were isolated from horse (thoroughbred) and cattle (Holstein) blood samples using an automated DNA extractor (MagExtractor System MFX-2000, Toyobo, Osaka, Japan), and were also used for comparison in the present analysis.

Terminology used in DNA studies

Polymerase Chain Reaction (PCR):

PCR is a molecular biological technique for amplifying a specific DNA fragment with a pair of primers. The purified PCR products can be used for sequencing.

Base pair (bp):

A unit of length for the double-strand DNA fragments. Each DNA nucleotide is composed of a base (adenine, A; thymine, T; guanine, G; or cytosine, C), a phosphate molecule, and a sugar molecule (deoxyribose).

Bootstrap analysis:

Statistical technique to evaluate the reliability of each node in a phylogenetic tree. High bootstrap values support the validity of the clustering.

To obtain the nucleotide fragments of *CYTB* from the extracted DNAs, we designed an available primer pair by referring the *CYTB* sequence data of the horse (accession number, AY584828), cattle (V00654), elephant (AJ224821) and camel (X56281) from GenBank (http://www.ncbi.nlm.nih.gov/GenBank). The primer sequences were as follows: forward, 5'TCAGCAATTCCCTACATCGGCAC3'; and reverse, 5' CGGAATATTATGCTTCGTTG3'. PCR amplification of the *CYTB* fragment of 503 base pairs (bp) (nucleotide position, nt, 451-953) was performed in a total volume of 15 μl of the following mixture: 2 μl of DNA solution, 15 pmol of each primer, 2.5 mM $MgCl_2$, 0.33 mM dNTPs, 1.5 μl of 10× reaction buffer (Applied Biosystems, Foster City, CA, U.S.A.) and 1.5 U of AmpliTaq Gold (Applied Biosytems). Thermal reactions were carried out using a GeneAmp PCR System 9700 (Applied Biosystems) with initial denaturation at 95°C for 10 min, followed by 33 cycles of 94°C for 30 secs, 55°C for 1 min and 72°C for 30 sec and a final step at 72°C for 10 min. To check whether the fragments were amplified, PCR products were subjected to electrophoresis using a 2.0% agarose gel. Direct sequencing of PCR products purified using GFX™ PCR DNA and Gel Band Purification kits (Amersham Biosciences, Piscataway, NJ, U.S.A.) was performed on both strands using BigDyeTerminator Cycle Sequencing kit (Applied Biosystems). The sequencing products were loaded in to an automated DNA sequencer ABI PRISM 3100 (Applied Biosystems). A sequence of 460 bp (nt 474-933) was determined using a sequencing analysis software (Applied Biosystems).

The sequence data from the 'kakuten', horse and cattle DNAs were compared with those of six animal species, namely, the horse, cattle, elephant, camel, pig (Z50107) and mouse (V00711) species, taken from GenBank using multiple sequence alignment in GENETYX-Mac software package programme Ver 11.0 (Software Development, Tokyo, Japan), and a neighbour-joining tree was constructed with nucleotide variation on the basis of these sequencing data.

Results and discussion

Figure 2 shows the electrophoretic patterns of PCR-amplified fragments obtained from the 'kakuten', horse and cattle DNAs. Single bands were observed for each sample and each PCR product showed the expected band 503 bp. On the other hand, there were no bands for the PCR blanks. These results indicate that *CYTB* fragments can be amplified successfully without producing artefacts or cross-contamination during the PCR.

Nucleotide sequence data of 460 bp were obtained from these PCR products. These sequences are shown in *Figure 3* with the sequences of the six animal species from GenBank. The horse and cattle DNA sequences obtained from our measurements were completely identical to the horse (AY584828) and cattle (V00654) data in GenBank, respectively. Both the 'kakuten' -1 and 'kakuten' -2 sequences had notable homology (71.7 -79.1%) with the cattle, elephant, camel, pig, and mouse sequences in GenBank. A sequence homology of more than 99% was found between the 'kakuten' and the horse sequences. 'Kakuten' -1 and 'kakuten' -2 sequences had homologies of 99.57% (458/460) and 99.78% (459/460) to the horse data, respectively. Two nucleotide

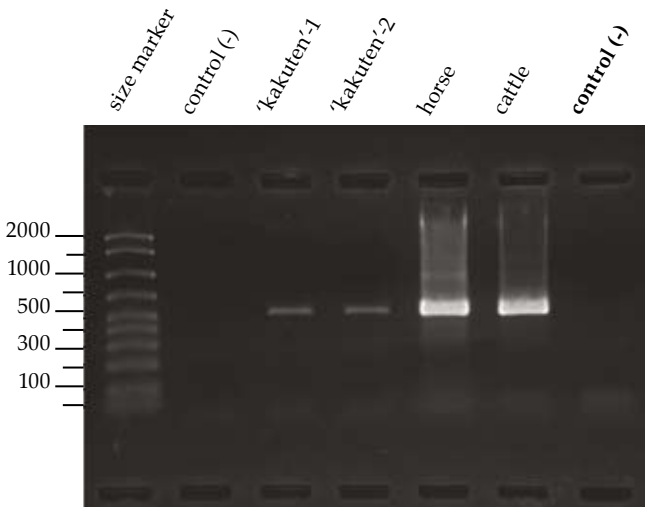

Figure 2: Electrophoretic patterns of PCR-amplified fragments from 'kakuten', horse and cattle DNAs. The molecular sizes (50-2000 bp) are indicated on the left side. PCR blank, control (-), is the amplified product using sterile water as a template.

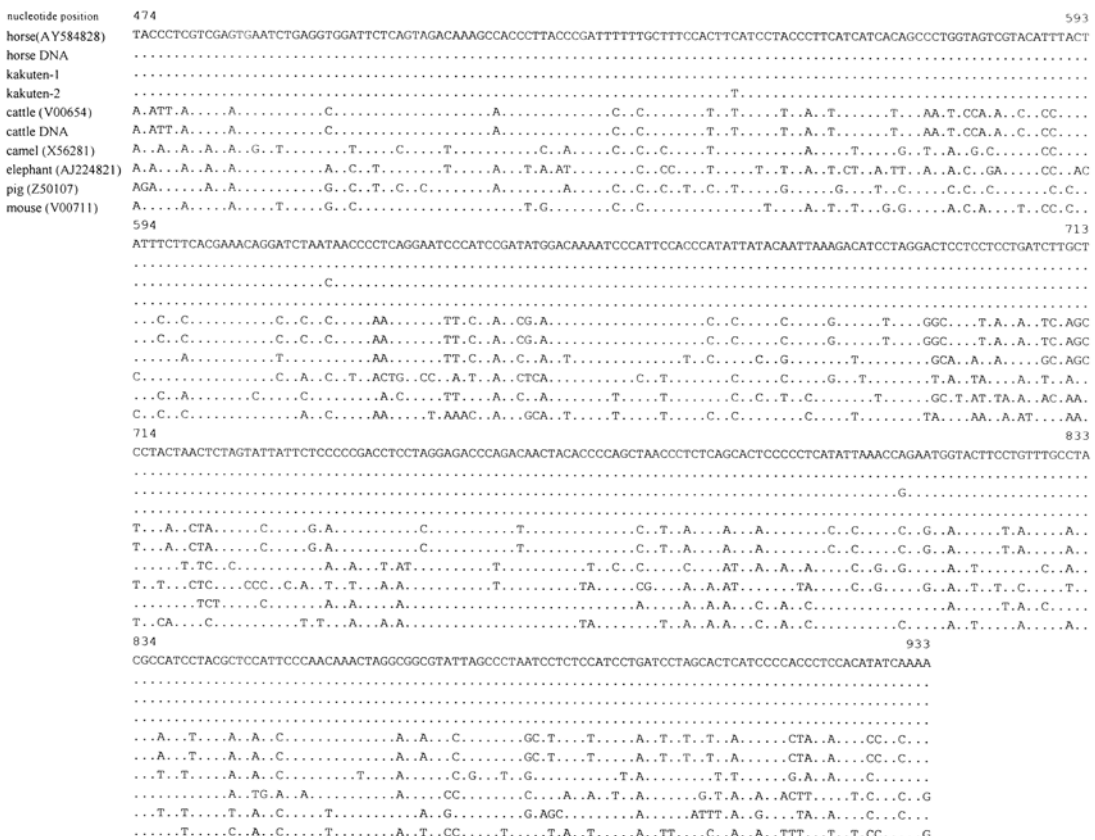

Figure 3: Comparison of partial sequences of CYTB (460 bp) among 'kakuten', horse and cattle DNAs, and those of six animals from GenBank. Dots indicate concordance with the sequence of the horse (AY584828).

substitutions (C↔T at nt 618 and G↔A at nt 810) were observed between the 'kakuten' -1 and horse sequences and one nucleotide substitution (T↔C at nt 549) was observed between the 'kakuten' -2 and horse sequences. Since they were synonymous ('silent') substitutions, no differences are predicted between the primary structures of cytochrome b of the 'kakuten' and the horse. Moreover, it was found that the data of 'kakuten' -1 was completely identical to another *CYTB* sequence of the horse, D32190, in GenBank. From these data, it was considered that the observed variation between the 'kakuten' and horse sequences was due to a difference within the same species. In addition, 'kakuten' -1 and 'kakuten' -2 can be classified into the horse group and they are clearly distinct from other animal groups in the phylogenetic tree constructed using the sequences of the 'kakuten', horse, and cattle DNAs and those of the six animals mentioned above (*Figure 4*). Since this region of the horse CYTB sequence (AY584828) has homology of 71.4% with that of the Japanese crane sequence (U27550) (not shown), it is unlikely that the 'kakuten' is fashioned from crane material.

The 'kakuten' has been used for producing near-spherical shapes of 'ojime' (*Figures 1a, c, d* and *e*). The 'haori' is a traditional jacket of Japanese men and can be tied with silk strings attached with 'kakuten' ornaments. The larger 'kakuten' with globular shapes up to 30mm in diameter have also been hung as side weights for a 'kakejiku' (a Japanese painting decorated in the corners, a 'tokonoma' of a Japanese guest room). However, because the molar tooth of the adult horse (thoroughbred) measured in this investigation was only 19-21 mm x 30-32 mm, it is probable that some 'kakuten' artifacts are composed of more than one piece of molar glued together.

In conclusion, it is clear that on the basis of DNA analysis of the species-specific *CYTB* sequence, the material from which 'kakuten' originates is the horse, in particular, the tooth of the horse. This result also means that 'kakuten' ornaments may be manufactured today using material similar to that used in the Edo period.

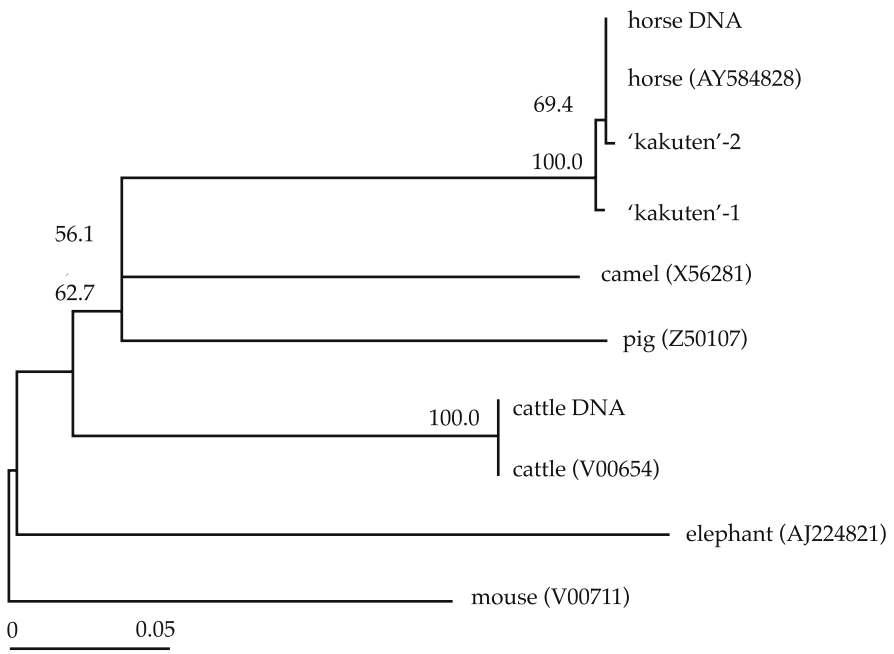

Figure 4: Phylogenetic tree of 'kakuten', horse and cattle DNAs, and those of six animals from GenBank, constructed by neighbour-joining method. The numbers on the nodes are percentages of bootstrap values based on 1,000 replications indicating the statistical confidence for each cluster of the tree (see Box). Scale bars represent the nucleotide substitution rate per site.

Acknowledgements

We thank Mr Takashi Nagamine for the donation of a piece of 'kakuten', Mr Tei-ichiroh Motoyama for lending photographs of three sets of 'kiseru-zutu' (tobacco pipe and its container), Dr Mitsuko Masui (the director of Yokohama Zoorasis, Yokohama) for her inspiring suggestion, Dr Sugako Aramaki (Laboratory of Racing Chemistry) for her kind commissioning of this research, and Dr Ichiro Sunagawa for his critical reading of this manuscript.

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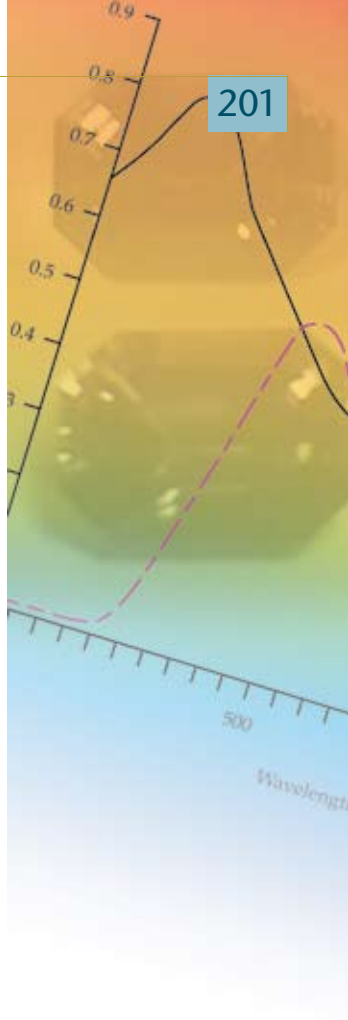

A colorimetric study of a tourmaline from Mozambique which shows a reverse alexandrite effect

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Abstract: *A tourmaline from northern Mozambique shows a reverse alexandrite effect. It appears a greenish-blue colour under incandescent light and purple under daylight. An advanced colorimetric study confirmed the reverse colour change of the tourmaline between incandescent light and daylight. The traditional alexandrite effect theory attributes the colour change to two transmission bands in the visible wavelength range, but the colours observed in the Mozambique tourmaline do not correspond to the transmission bands. The reverse alexandrite nature of the Mozambique tourmaline also cannot be explained by the traditional theory. A new alexandrite effect theory attributes the colour change to a combination of chromatic adaptations and colour responses of the human visual system to the incoming visible light from the gemstone under different light sources.*

Keywords*: alexandrite effect, colour change, hue angle, tourmaline*

Introduction

Alexandrite effect gemstones normally display warm colours, such as orange and purple, under incandescent light, and cool colours, such as blue and green, under daylight. Traditionally, this alexandrite effect has been explained by two transmittance bands in the visible wavelength range of its spectrum (Gübelin and Schmetzer, 1982). Recently one author (B.A.F.) obtained a 5.68 ct colour-change tourmaline from Moiane, northern Mozambique, which shows a greenish-blue colour under incandescent light, and purple under daylight. This colour change is a reverse alexandrite effect (Wentzell 2004; Wentzell *et al*., 2005).

Liu *et al.* (1994, 1995, 1999) used an advanced colorimetric method to study the alexandrite effect of many gemstones in detail. They found that not only gemstones with two prominent spectral transmittance bands, essential for the traditional alexandrite effect theory, but also other gemstones with

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multi-bands and step bands demonstrated the alexandrite effect. Generalizing on these findings led to proposing a new theory to account for the alexandrite effect. This consists of a combination of chromatic adaptations of the human visual system to different light sources, and the vision system response to the spectral distribution reflected by the colour change gemstones when they are illuminated by the different light sources.

Figure 1: The 5.68 ct tourmaline from Mozambique under incandescent light (a) and under daylight (b).

Based on a study of the appearance change of Munsell chips under different light sources (Helson *et al.*, 1952) and their alexandrite effect experiments with all available alexandrite effect samples, Liu *et al.* (1994) determined that a 20° absolute hue-angle in the CIELAB colour space is the 'empirical' criterion for judging the alexandrite effect, since all the hue-angle changes of the colour chips are smaller than 20° and all the hue angle changes of alexandrite effect gemstones are greater than 20°. If a gemstone shows a hue-angle change more then 20°, it would qualify as displaying the alexandrite effect. If the hue-angle is smaller than 20°, a small hue shift may be observed, but it would not be recognized by colour memory.

Four categories of colour change can be distinguished among alexandrite effect gemstones according to the pair of illuminants used (Liu *et al.*, 1994). The type 1 alexandrite effect gemstones change colour between daylight and incandescent as well as fluorescent daylight and incandescent light, but do not change colour between daylight and fluorescent daylight. Alexandrite is a typical type 1 colour change gemstone. The type 2 alexandrite effect gemstones change colour between daylight and fluorescent daylight as well as fluorescent daylight and incandescent light, but not between daylight and incandescent light. Colour change glass is a typical type 2 colour change material. Type 3 alexandrite effect gemstones change colour between the three pairs of light sources. Some colour change sapphires are typical type 3 colour change gemstones. Type 4 alexandrite effect gemstones only change colour between fluorescent, daylight and incandescent light. Some garnets are typical type 4 colour change gemstones.

In this study, we use the colorimetric method (see Liu *et al.*, 1999) to measure spectral transmittance and to calculate the colorimetric data. Liu's theory (1994) will be used to offer an explanation for the reverse nature of the alexandrite effect demonstrated by the tourmaline reported on here.

Material

The tourmaline used for this study is a 5.68 ct emerald-cut stone (11.63 × 8.67 × 7.48 mm). Its colour is greenish-blue (see *Figure 1a*) under incandescent light and purple (*Figure 1b*) under daylight. This colour change is a reverse alexandrite effect. A 'normal' alexandrite effect would appear purple under incandescent light and bluish green under daylight. This tourmaline is the first gemstone to demonstrate the reverse alexandrite effect and, at the time of writing (May 2006), is unique.

An Ocean Optics USB-2000 spectrometer with an integrating sphere was used to measure the spectral transmittance of the tourmaline with the light beam perpendicular to the table facet.

Table I: Colour changes of the tourmaline.

Observed hue			Calculated hue-angle		
Incandescent	**Daylight**	**Fluorescent daylight**	**A**	**D65**	**F7**
greenish blue	purple	purple	225	315	314

Note: Metamerism index MIv is the CIE standard method of assessing the spectral quality of daylight simulators in the visible wavelength range. Metamerism index MIv of a daylight simulator must be B or better for colour grading of gemstones.

Results

The transmittance spectrum (*Figure 2*) of the tourmaline shows two transmittance bands in the visible wavelength range. One is centred at about 430 nm and the other at about 570 nm.

The transmittance spectrum of alexandrite is shown in *Figure 2* (dotted line) for comparison. Alexandrite has a transmittance band centred at about 490 nm, and another at a longer wavelength that extends from 570 nm into the near infrared range. It is clear that the two transmittance bands of the tourmaline are positioned at significantly shorter wavelengths than those of the alexandrite.

Table I shows the calculated colorimetric data from the transmittance spectrum of the tourmaline under CIE standard illuminants

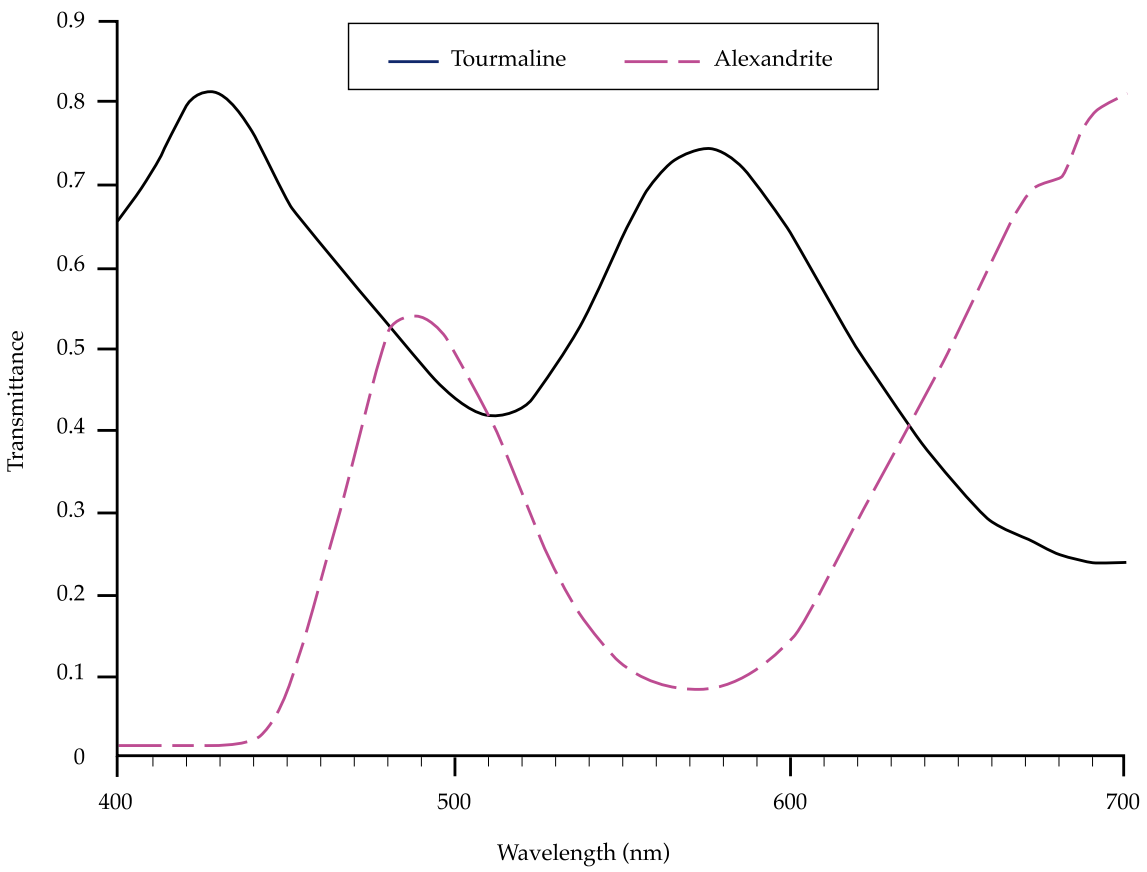

Figure 2: Transmittance spectra of Mozambique tourmaline and of alexandrite.

A, D65 and F7, and the observed hues are under an incandescent light with a colour temperature at about 2856 K, a D65 daylight simulator at about 6500 K with a metamerism index MIv A in the visible wavelength range, and a fluorescent daylight lamp with a colour temperature at about 6500 K.

Discussion

The CIELAB colour space is a near-uniform colour space, and any hue-angle represents the hue of a colour (see, for example, Liu *et al.*, 1999). *Figure 3* shows the hue-angle changes of the tourmaline in the CIELAB colour space. The calculated hues of the tourmaline under the three CIE standard illuminants A, D65, and F7 agree with the observed hue under the three corresponding light sources: an incandescent light, a D65 daylight simulator, and a 6500 K fluorescent lamp. The hue-angle of 225° under CIE standard illuminant A represents a greenish blue hue, and the observed hue is greenish blue under incandescent light. The hue-angle of 315° under CIE standard illuminant D65 represents a purple hue, and the observed hue is purple. The hue-angle of 314° under F7 fluorescent daylight lamp at 6500 K is also a purple hue, and the observed hue is the same purple.

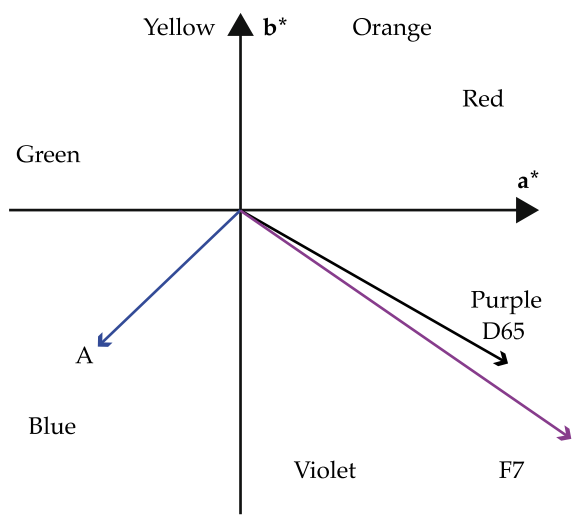

Figure 3: Hue-angle changes of the tourmaline in the CIELAB colour space.

The hue-angle change in the CIELAB colour space is used to evaluate the degree of the alexandrite effect. All colours may change to some degree between different light sources but unless the hue angle change exceeds 20°, such shifts do not qualify as an alexandrite effect. All purple colours, for example, show significant colour shifts between incandescent light and daylight, but not sufficient to produce an alexandrite effect. The strength of the alexandrite effect is classified into four categories as shown in *Table II.*

The observed hue change of the tourmaline between CIE standard illuminants A and D65 is 90°, and the calculated hue-angle change between A and D65 is 89°, thus the tourmaline is an alexandrite effect gemstone in the alexandrite effect category of 'strong'.

Based on the classification of the alexandrite effect proposed by Liu *et al.* (1994), the tourmaline shows a type 1 colour change, i.e. it changes colour between daylight and incandescent light and between fluorescent daylight and incandescent, but shows no change between daylight and fluorescent daylight.

Both colour observations and colorimetric calculations confirm that the tourmaline displays a reverse alexandrite effect. The reverse alexandrite effect of the tourmaline cannot be explained by the traditional theory. According to the traditional theory, this tourmaline should appear a warm colour with long wavelengths dominant under incandescent light, and a cool colour with short dominant wavelengths under daylight. From *Figure 2*, it is apparent that the tourmaline should show a yellow-orange colour under incandescent light (long

Table II: The categories of alexandrite effect.

Hue-angle change	Category
20° - 45°	moderate
45° - 90°	intense
90° - 135°	strong
135° - 180°	very strong

wavelength transmittance band is centred at about 580 nm) and blue under daylight (short wavelength band is centred at about 430 nm). In fact, it appears purple under daylight and greenish blue under incandescent light. Thus, the reverse colour change of the tourmaline demonstrates that the traditional theory of the alexandrite effect is inadequate.

The theory proposed by Liu *et al.* (1994) argues that the alexandrite effect is caused by a combination of both chromatic adaptation and the visual system responses to the spectral distribution of the light from an alexandrite effect gemstone under different light sources. The principles of colour perception dictate that the visual system will adapt to illumination with incandescent light by becoming less sensitive to the long wavelength range of red and orange. Likewise the visual system will adapt to illumination with sunlight by becoming a little less sensitive to the short wavelength range and slightly more sensitive to the longer wavelengths. These chromatic adaptations are not dependent on the object illuminated.

When this tourmaline is viewed under an incandescent light several effects occur to produce its observed colour of greenish blue. The chromatic adaptation reduces the human visual system's sensitivity to the long wavelength range of orange and red. The tourmaline's relatively low transmittance of the long wavelength range, that can be seen in *Figure* 2, further reduces the visual system's perception of the orange and red hues. The high spectral transmittance of the tourmaline, in the short wavelength band centred on about 430 nm combines with the previous effects to produce a greenish-blue colour. The tourmaline's high spectral transmittance centred about 570 nm contributes a little green to complete the tourmaline's observed colour of greenish-blue under incandescent light.

When the tourmaline is viewed under daylight several effects occur to produce its observed colour of purple. The chromatic adaptation will reduce but not eliminate the contribution from the high spectral transmittance band centred on 430 nm to the tourmaline's colour. Also, chromatic adaptation will increase the long wavelength contribution to the tourmaline's colour, despite the tourmaline's relatively low transmittance of the long wavelength range. The contributions of the 430 nm and the 570 nm transmittance bands combine to produce a purple colour.

Colour constancy is a very fundamental colour vision phenomenon. In the wider field of colour science in general, the alexandrite effect, which is a non-colour-constancy phenomenon, is very unusual. Traditional explanations relied heavily on the two transmittance bands in alexandrite's visible spectrum, but newer theories were put forward by Liu *et al.* (1994) to explain anomalies. The discovery of this tourmaline from Mozamibque with its particular colour behaviour has meant more difficulties for the traditional theory, but support for the theories of Liu *et al.* (1994).

Conclusions

At the time of writing, all the alexandrite effect gemstones which have been previously studied have shown colour changes from warm hues under incandescent light to cool hues under daylight. The tourmaline is the first gemstone found that shows a reverse alexandrite effect from greenish blue under incandescent light to purple under daylight. Our advanced colorimetric study of the tourmaline confirms this reverse alexandrite effect. The colour change behaviour (alexandrite effect) of the tourmaline is type 1, and its hue change category is strong at about 90° between the CIE standard illuminants A and D65.

The reverse alexandrite effect of the studied tourmaline cannot be explained by traditional theory of the alexandrite effect, but it does provide more evidence for Liu's explanation. The alexandrite effect is a non-colour-constancy phenomenon caused by a combination of chromatic adaptations to the different light sources and vision system responses to the spectral distribution of the light emitted by the alexandrite effect gemstones illuminated by the corresponding light sources.

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Fuchsite quartzite as an imitation of emerald

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Abstract: *Ten parcels of pre-shaped green stones were identified mostly as emerald, but some were fuchsite quartzite. Both emerald and quartzite stones had been treated with a filling substance to improve their clarity, identified as paraffin oil. Since the fuchsite quartzite has a deeper green colour than usual for this rock, it is possible that the impregnating oil was also green.*

Keywords: *Emerald, fissure fillers, infrared spectroscopy, oil treatment, quartzite, Raman spectroscopy*

Introduction

Rough and cut gemstones have been used in the last few years in Brazil as a guarantee for public and private debts. To increase the security of this kind of transaction, certificates describing such stones are commonly sought from the Gemological Laboratory (LABOGEM) at the Universidade Federal do Rio Grande do Sul (UFRGS).

Ten parcels of pre-shaped green stones, declared as emerald by the owner, were examined at LABOGEM for certification. Standard mineralogical investigations indicated that most stones were indeed emerald, but there were some stones with slightly different characteristics from emerald. These stones were identified as fuchsite quartzite, and this paper summarizes its properties to enable recognition of material that is probably traded as emerald in the gemstone market.

Both emerald and fuchsite quartzite stones in the parcels were impregnated with a filling substance, whose residue was noticed inside the plastic package and which was also greasy to the touch. This treatment probably increased both colour and clarity in the fuchsite quartzite, because its green hue is closer to emerald than expected for this rock. So, the fuchsite quartzite and emerald look similar at first glance in the parcels. However, when looked at in more detail, emerald and quartzite do show differences due to their internal textures. These differences are reported in detail below.

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Analytical procedures

Standard mineralogical and gemmological tests, petrographical examination and electron microscopy with energy-dispersive analysis (SEM-EDS) were performed to characterize the emeralds and their imitations. Some advanced investigation techniques were used to identify the filling substance, including infrared and Raman spectroscopy. The analyses were performed at LABOGEM, at the Physics Institute and the Electron Microscopy Centre, all at the Federal University (UFRGS) in Porto Alegre.

Mineral data were obtained with a *Schneider* 10x hand lens, dichroscope, polariscope and gemmological microscope, an *Olympus* stereomicroscope, a *Topcon* refractometer and a *Leitz* petrographic microscope. Specific gravity (SG) was determined with an A200CT *Marte* hydrostatic balance to a precision of 0.001 g, in distilled water at room temperature. *Krüss* ultraviolet lamps of short and long wavelengths were used in order to observe fluorescence.

Petrographic analysis of the quartzite stones was done with the permission of the owner. The aim of quartzite petrography was to obtain a complete description of the mineralogy and textures of this rock to determine its provenance.

A *Jeol JSM 5800* SEM with an energy dispersive system (EDS) for semi-quantitative chemical analyses was used to identify minerals in the quartzite. The samples were coated with a thin layer of carbon to prevent charge build-up. Fourier Transformation Infrared (FTIR) transmission analyses were performed using a *Bomem* (*Hartmann & Braun*) spectrometer in the Attenuated Total Reflectance (ATR) mode, in the range 2500 to 3400 cm^{-1}. Micro-Raman spectroscopy was performed on emeralds and quartzite samples using a *Jobin Yvon HR 320* monochromator system equipped with a CCD detector and a He-Ne laser beam (632.8 nm) coupled with an *Olympus* microscope, in the range 400 to 2500 cm^{-1}.

Results and discussion

Ten parcels of pre-shaped stones weighing approximately 200 g each were submitted to authenticity tests. The shapes of the stones include oval, rectangular, marquise, pear, triangular, rounded and free-form, ranging between 7 and 30 mm in size.

Two groups of stones were distinguished on the basis of general characteristics. The larger group was composed of opaque to translucent stones, with light-green, greyish-green and yellowish-green colours; irregular colour distribution and colour zoning were observed. A weak dichroism was observed in some translucent stones, with twin colours varying from yellowish green to bluish green. Some stones contain grey to black surface inclusions, identified as biotite and matrix rock fragments. These preliminary mineralogical observations indicate emerald of low gem quality.

The smaller group of stones was characterized by a strikingly homogeneous green, which was quite distinct from the colours of the emeralds, even to the naked eye (*Figure 1*). This material did not exhibit inclusions and dichroism was absent.

Under a long wavelength ultraviolet lamp, emerald showed a dark red or a yellowish-green glow, while the unknown material was inert (*Table I*). Observed under magnification, this unknown material showed wavy bands with slightly different green hues, in patterns different from the colour zoning seen in emerald, and its structure was granular, resembling a crystalline aggregate. Under the polariscope, this material remains light during 360° rotation, which is typical of aggregates. With combined transmitted and incident light, it was possible to see granular quartz crystals and platy mica crystals. Euhedral to subhedral pyrite and orange-red subhedral crystals, probably corundum, were also identified.

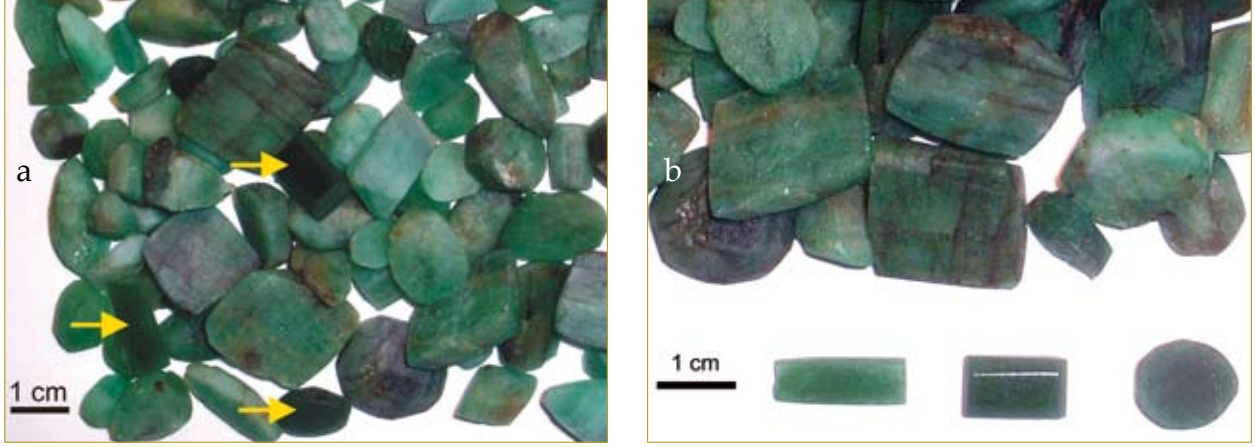

Figure 1: One parcel of pre-shaped green stones. (a) Some quartzite stones (arrowed) among emeralds. (b) A detailed view of three homogeneous green quartzites are shown at the bottom below rather poor quality emeralds with irregular colour distribution and grey to black inclusions.

The refractive indices (RI), despite the difficulty related to the polycrystalline structure, were approximately $N_o = 1.540$ and $N_e = 1.550$ (*Table I*), characteristic of quartz. However, the SG of this material was higher than that of quartz but similar to the analysed emerald.

Microscopic observation of thin sections confirmed that the unknown material was quartzite (*Figure 2*) with the following composition and textures:

- anhedral quartz with wavy extinction in a granoblastic texture;
- oriented light-green mica crystals with weak pleochroism, in a lepidoblastic texture;
- euhedral to subhedral opaque crystals, previously identified as pyrite using a stereomicroscope;
- euhedral to subhedral corundum;
- reddish-brown patches of iron oxides (Bard, 1985; Klein and Hurlbut, 1993).

SEM/EDS analyses of the mica crystals revealed the presence of Cr (*Figure 3*) which is consistent with their green colour and indicates their identification as fuchsite (Kerr, 1959; Klein and Hurlbut, 1993). The pyrite and corundum identifications were confirmed by SEM/EDS analyses and some small zircon crystals, about 40 µm long, were also found.

Table I: Some standard properties of the analysed emerald and quartzite stones.

Properties	Analysed materials	
	Emerald	Fuchsite quartzite
colours	light-green, greyish green, yellowish green	green
colour distribution	irregular distribution; parallel zoning	wavy bands
transparency	opaque to translucent	translucent
dichroism	weak; from yellowish green to bluish green	absent
SG	2.65 – 2.70	2.67
360° rotation on polariscope	four dark and light positions	constant transmission, remains light
RI	1.570-1.583	1.540-1.550
fluorescence under UV light	dark red and yellowish green	inert
internal features	inclusions of biotite and matrix rock fragments	grain boundaries of quartz and flakes of fuchsite mica

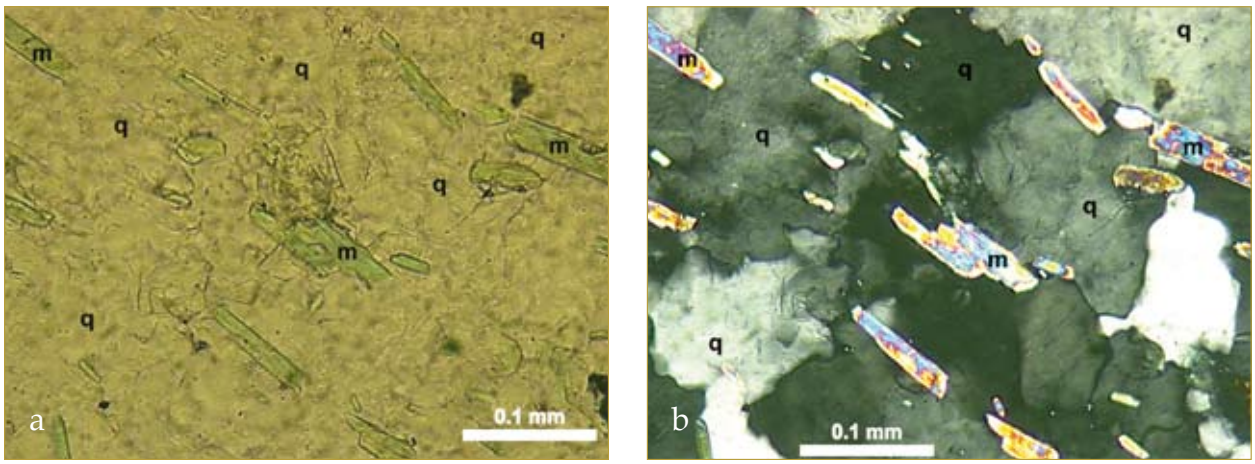

Figure 2: A thin section of fuchsite quartzite observed under a petrographic microscope in ordinary illumination (a) and using crossed polars (b), showing granoblastic quartz (q) with wavy extinction and light-green Cr-muscovite (fuchsite) crystals (m) in a lepidoblastic texture.

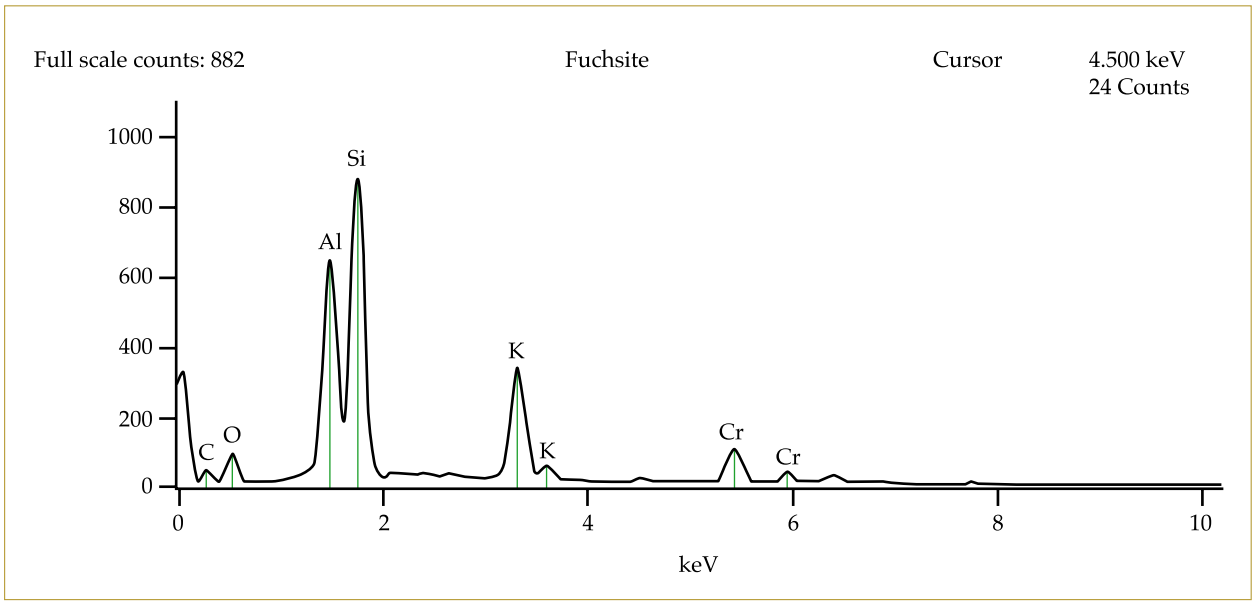

Figure 3: Spectrum showing the presence of the major elements of muscovite (K, Al, Si) and a small but significant content of Cr which is the cause of the green colour and the reason for the varietal name fuchsite. Carbon content is due to coating applied to the specimen to disperse electrical charge.

Fillers were not detected either in emerald fissures or in pores in the quartzite, under magnification or using UV light (see Johnson *et al.*, 1999 and Kiefert *et al.*, 1999). This is probably because the stones were not treated under vacuum to introduce the filling substance into fissures or pores, and is consistent with the fact that Brazilian dealers of rough and pre-shaped emerald only wet the emerald surface with the treatment substances. Sometimes these substances may be heated to reduce their viscosity so that they flow into surface fissures more easily than at room temperature. However, this treatment improves the clarity only at the surface of the stones and further treatment may be done after the stones have been cut.

Raman spectra were obtained from both emerald and fuchsite quartzite samples but Cr content in both caused considerable fluorescence. Backgrounds were so high that no peaks could clearly be attributed to fillers even between 1200-1700 cm^{-1}, the better region to characterize filling substances according to Kiefert *et al.* (1999). However, there is a clear peak at 467 cm^{-1} in the fuchsite quartzite stones due to the quartz content (*Figure 4*).

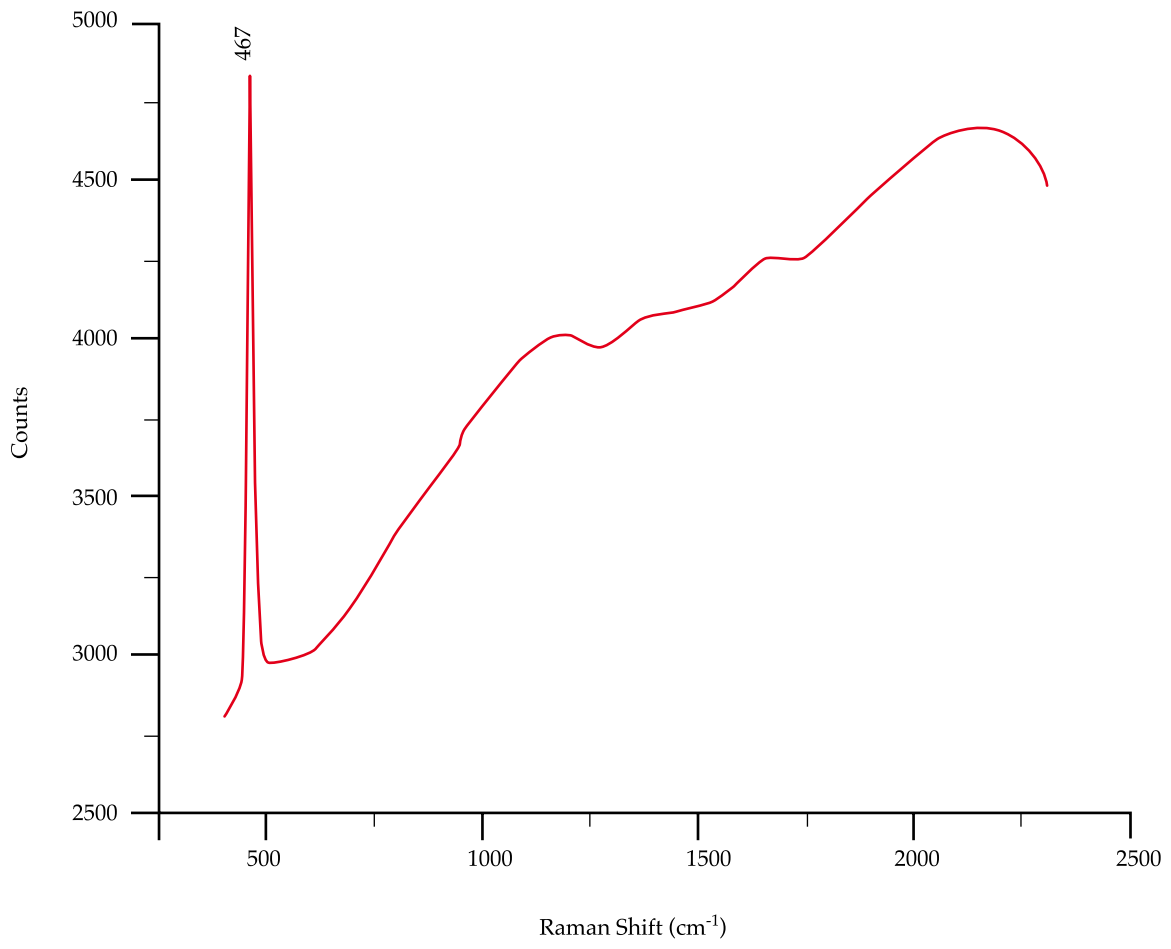

Figure 4: A Raman spectrum of the quartzite, with strong fluorescence from 500-2500 cm^{-1}, due to Cr content in fuchsite crystals. The peak observed at 467 cm^{-1} is due to quartz (Nyquist et al., *1997;* Handbook of minerals Raman spectra*).*

FTIR spectra obtained from emeralds and quartzites in the ATR mode proved to be the best method of identifying any impregnating substances in the analysed stones. FTIR spectra of oils and artificial resins show that the main absorption bands lie in the 2800 to 3000 cm^{-1} range, corresponding to C-H vibration bonds present in many organic compounds; bands between 3000 and 3100 cm^{-1} are only present in the spectra of resins (Kiefert *et al.*, 1999). In this work, FTIR spectra from several samples of emerald and quartzite showed absorption bands in the 2600 to 3000 cm^{-1} range. In addition to the characteristic absorption bands of emerald and quartzite, both stones consistently showed absorption bands in the range 2600 to 3000 cm^{-1}. *Figure 5* shows two representative spectra from the quartzite (A and B), and one representative spectrum of emerald (*Figure 5 C*), where two main absorption bands can be observed at approximately 2850 cm^{-1} and 2920 cm^{-1}, with a shoulder at ± 2953 cm^{-1}. These peaks are also present in universal oil (*Figure 5 D*) at 2854 cm^{-1} and 2925 cm^{-1}, with a shoulder at 2955 cm^{-1} and agree with data shown by Kiefert *et al.* (1999). A comparison with the FTIR spectra for

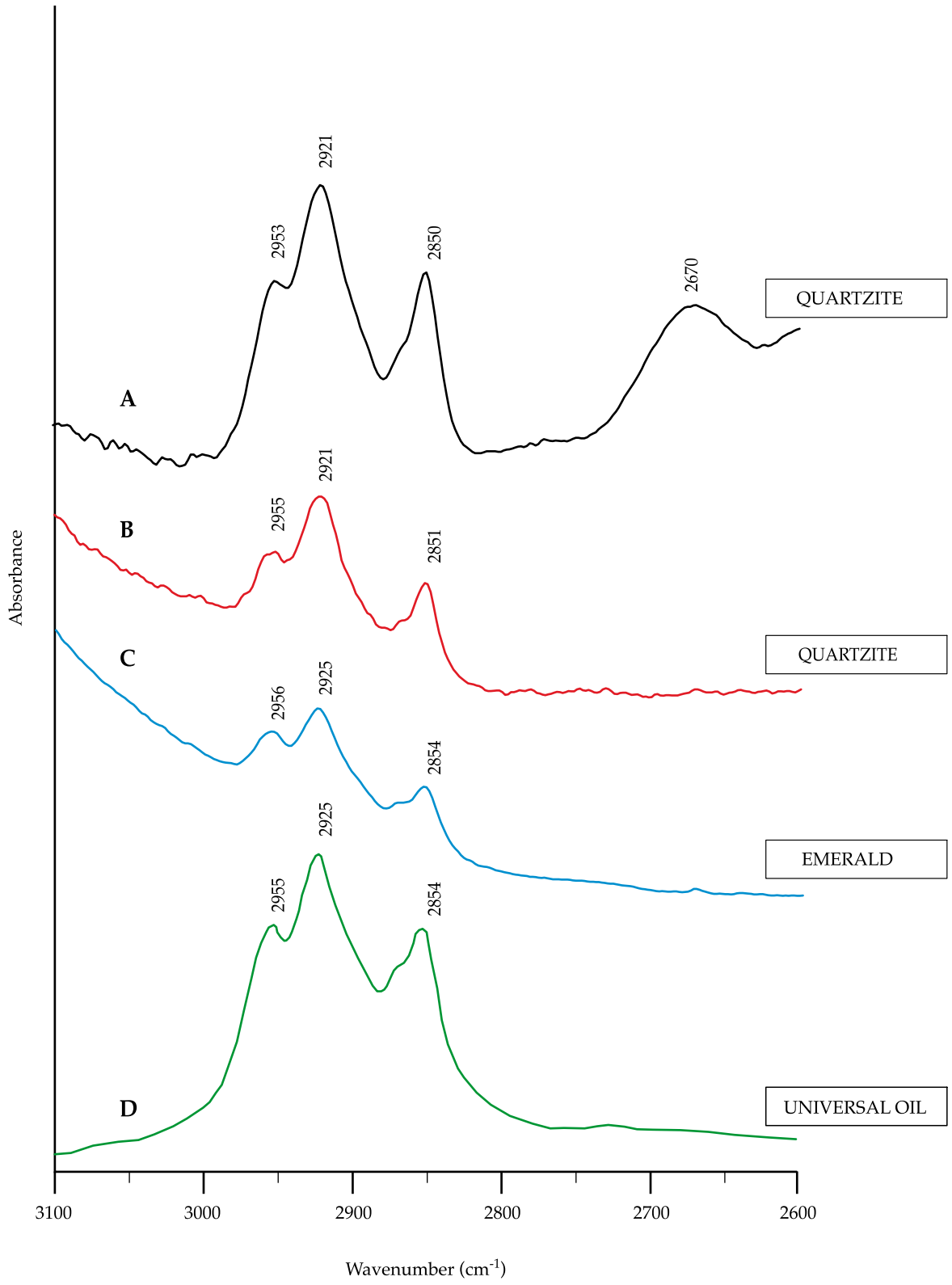

Figure 5: FTIR spectra of two fuchsite quartzite stones (A and B), one emerald (C) and of universal oil (D) as described by Kiefert et al. *(1999), in the range 3100-2600 cm^{-1}. The comparison of these four spectra show that absorption bands are very similar in the 2850-2956 cm^{-1} area, indicating that universal oil could be the filling substance used in emerald and in quartzite. The absorption band in A at 2670 cm^{-1}, was observed in only one quartzite sample (A).*

filling substances presented by Johnson *et al*. (1999) shows a similarity between these results and the 'group B' filling substances, as shown in *Figure 6*. This group is represented by substances like paraffin oil and wax, Joban oil and HXTAL resin. The results obtained in the present research are most closely matched by the spectrum of paraffin oil. According to Gardner *et al*. (1978) and Kiefert *et al*. (1999), paraffin oil and universal oil are the same substance and Budavari *et al*. (1996) describes the name 'Nujol' as one of the trade marks used for this product. The broad absorbance peak observed in the quartzite spectrum at 2670 cm^{-1} in *Figure 5 A*, is reported neither by Kiefert *et al*. (1999) nor by Johnson *et al*. (1999) for paraffin oil. However, there are small peaks in this region for paraffin wax, as shown in Figure 6 B, spectrum h. An absorbance band with a wave number near this value (2670 cm^{-1}) was reported by Scholl (1983) for paraffin oil and this band was obtained also from a Nujol drop, made and distributed in Brazil by Schering-Plough Chemical Industry.

Conclusions

The precise identification of emerald as well as the identification of any filling substances is very important in order to avoid damage to consumer confidence. Basic gemmological tests can provide information sufficient to distinguish emerald from its imitations, but to obtain data on any treatments or filling substances it is necessary to use advanced techniques like SEM/EDS, Raman and FTIR spectroscopy (Farmer, 1974; Gadsen, 1975; McMillan and Hofmeister, 1988; Johnson, *et al*., 1999).

Fracture filling is commonly used to enhance the clarity and even the colour of emeralds. Impregnation with different types of oil and resins has been used for decades and is accepted in the trade nowadays. However, major coloured stone trade organizations recommend that such gemstone treatment should be disclosed with details of the products used for this treatment (Levy, 1997; Johnson *et al*., 1999; Kiefert *et al*., 1999). In the stone parcels described in the present study, both emeralds and quartzites were submitted to treatment and as a result, looked very similar at first glance. FTIR spectra show that the filling substance used

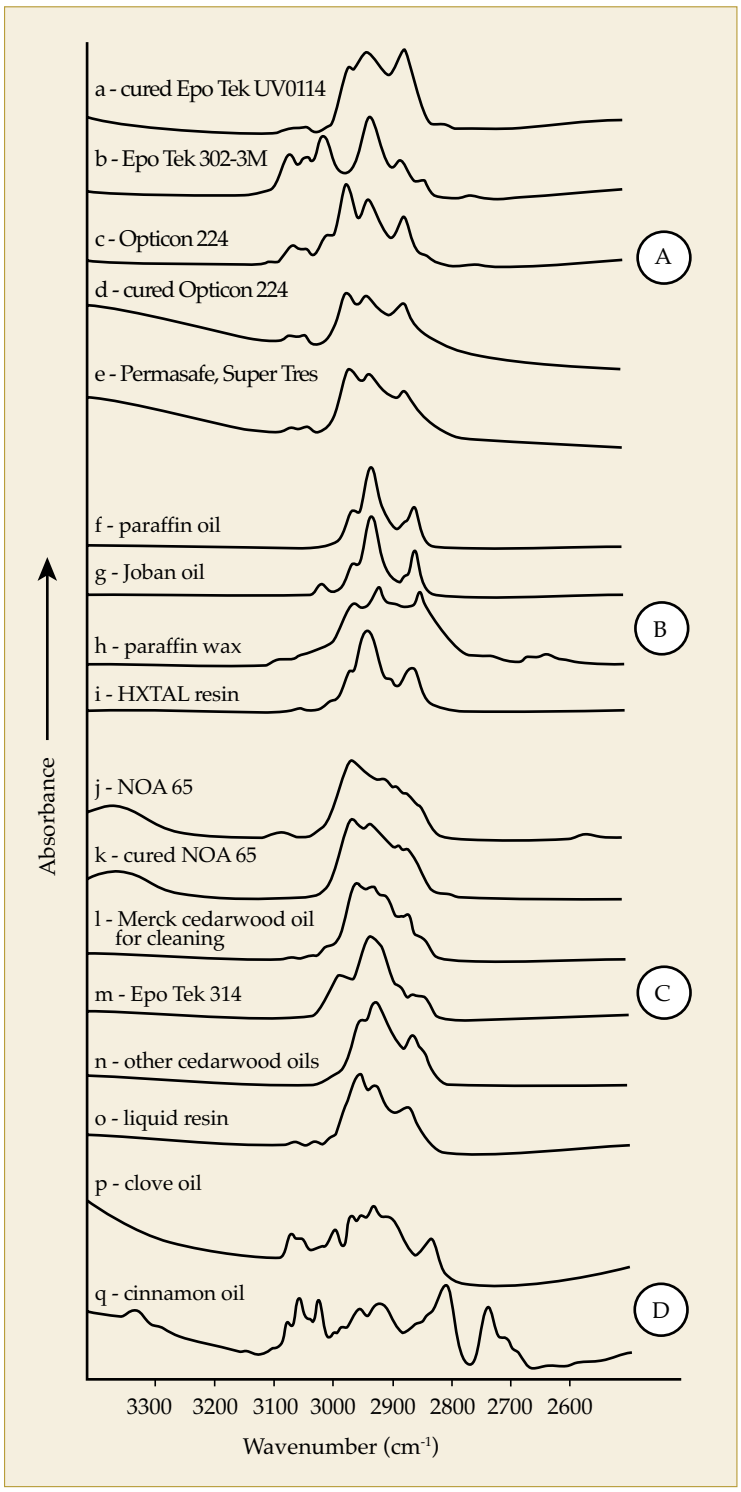

Figure 6: Infrared spectra of 17 filling substances arranged in four groups based on their spectra in the range 3400-2500 cm^{-1}, according to Johnson et al. *(1999). The infrared spectra from emerald and quartzite obtained in this research are most similar to group B.*

was either paraffin oil or something very similar. Paraffin is also known as universal oil which is colourless and on the market in Brazil with the trade mark Nujol; it is commonly used by local gemstone dealers to improve clarity in emerald. However, on closer inspection, the quartzite showed a deeper green than would be expected if only the green fuchsite were causing the colour and, according to Ringsrud (1983), colourless fillers can improve the colour appearance of an emerald. The oily residue on the plastic packages containing the stones was colourless, but it is possible that some green substance was added to the Nujol used to treat the quartzite. According to Polli (2001), oils with green dyes are commonly used in countries like India and Brazil to impregnate gemstones such as quartz or beryl in order to obtain emerald imitations.

As yet the presence of any green dye has not been detected using FTIR, and it is possible that Joban oil, which is moderately green and has a paraffin-like spectrum, was used rather than Nujol or pure paraffin.

Mixing of the treated fuchsite-quartzite cut stones with emerald in gem parcels is a threat to consumer confidence, but the degree of occurrence and how serious this fraud is has not yet been determined. The work will continue in seeking the origins of the quartzite and treatments.

Acknowledgement

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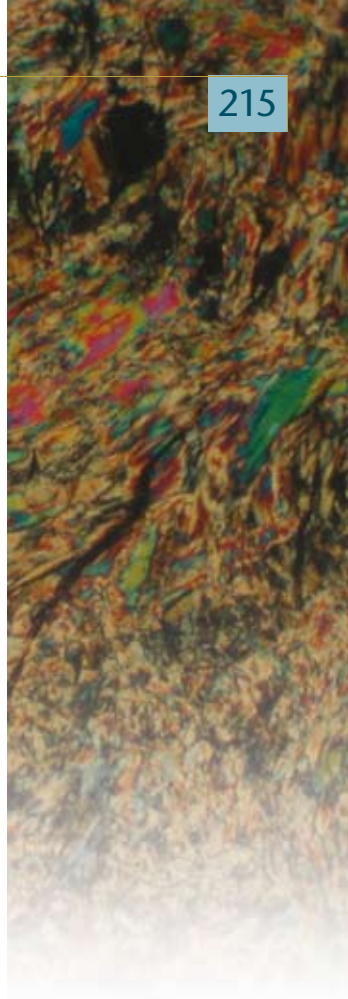

Characterization of omphacite jade from the Po valley, Piedmont, Italy

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Abstract: *A dark green jade has been discovered recently in secondary alluvial deposits which are widespread in the Po valley, between Cuneo and Turin (Piedmont, Italy). Traditional gemmological tests have been combined with advanced analytical techniques (X-ray powder diffraction, chemical composition determination, absorption and photoluminescence spectroscopy) and thin section examinations to provide full characterization of this material and reveal that it is mainly composed of omphacite pyroxene.*

Keywords: *chemical composition, gem testing, jade, omphacite, PL spectroscopy, UV-Vis-IR spectroscopy*

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Introduction

Jade has a rich history dating back thousands of years, due to its use as a precious and enchanting gemstone (see, for example, Hughes *et al*., 2000). A dark green jade has been discovered recently by Franco Manavella and Franco Salusso as pebbles in secondary alluvial deposits in the Po valley (Piedmont, north Italy). This material is suitable for cutting into small cabochons or slabs. Other deposits have been discovered in nearby areas, and a geological map of recoveries is being compiled. However, a full characterization of this dark green jade and its correct mineralogical composition have still to be established. The present study aims to provide a detailed description of this dark green jade from the Po valley, so as to (i) determine whether it consists of a single mineral phase or of an assemblage, (ii) establish its relationship to a given family of minerals and (iii) provide a set of features to enable distinction of this Po valley jade from other jades. Interest in the dark green jade in question is also motivated by paleo-ethnological implications, as this jade has been mined and used since prehistoric times by local populations to manufacture a variety of articles (D'Amico *et al*., 1995).

Materials and methods

The dark green jade from the alluvial deposits of the Po valley has been characterized on the basis of the observations gathered from a suite of eight samples (see *Figure 1*), kindly provided by Carlo Mora.

Seven of the eight specimens (nos. 1, 2, 3, 4, 5, 6, 7) are cabochon-cut with (i) either an oval or a drop shape (five of these have a hollow inside so as to improve the colour transparency), (ii) weight ranging from 0.93 to 3.67 ct and (iii) size within 10.5-17.7 × 6.1-12.1 × 1.2-2.6 mm; the only rough sample studied (specimen A) weighs 6.31 ct, with dimensions of 14.3 × 11.4 × 2.1 mm.

All samples were first investigated by traditional gemmological methods, to determine their optical and physical properties. Polished thin sections were obtained from specimens 1 and A, and investigated in transmitted light mode by means of a traditional microscope and using a Cambridge Stereoscan 360 scanning electron microscope (SEM). The SEM is equipped with an Oxford Isis 300 energy dispersive spectrometer (EDS), and this enabled study of exsolution textures and compositional zoning in the same thin sections.

X-ray powder diffraction measurements were then carried out on two specimens (1 and A), to determine the mineralogical composition of the dark green jade. Data collections were performed at normal temperature and pressure by means of a Panalytical X'Pert-PRO MPD X'Celerator X-ray powder diffractometer, using CuKα radiation (λ=1.518 Å) and a beam of 40 kV, 40 mA. X-ray powder diffraction patterns were collected over 5-117° 2θ, with steps of 0.008° 2θ, a counting time of 25 sec/step and NBS-Si as an internal calibrant. This has enabled the lattice parameters to be calculated by the Rietveld method using the GSAS software package (Larson and Von Dreele, 2000) to treat the experimental 2θ-profiles.

The chemical composition of the dark green jade has been quantitatively determined using an Applied Research Laboratories electron microprobe fitted with five wavelength dispersive spectrometers (WDS) and a Tracor Northern energy dispersive spectrometer (EDS) (accelerating voltage of 15 kV; sample current on brass of 15 nA; counting time of 20 sec on peaks and 5 sec on backgrounds). Natural kaersutite (for Na, Mg, Al, Si, K, Ca, Ti, Fe), rhodonite (for Mn) and chromite (for Cr) have been used as standards; the results have been corrected for matrix effects using a conventional PAP routine of the SAMx series of

programs. Proportional formulae and Fe^{2+}/Fe^{3+} partitioning have been calculated on the basis of the method described in Cawthorn and Collerson (1974). Measurements have been carried out on two thin sections, obtained from specimens 1 and A.

The following equipment was used for spectroscopic investigations:

(i) a Nicolet NEXUS FTIR spectrometer, operating both in transmission mode (the beam passing through a sample, for all the specimens, and through pellets composed of a blend with a 1:100 sample to KBr ratio, for specimens 1 and A, only) and in reflectance mode [by means of a diffuse reflectance accessory (DRIFT); all samples were studied], to investigate the 4000-400 cm^{-1} infrared range, with a resolution of 4 cm^{-1};

(ii) a UNICAM UV-Vis 500 spectrometer, operating in reflectance mode, equipped with an integrating-sphere and tungsten and deuterium lamps, to study the 190-900 nm ultraviolet-visible-near infrared range;

(iii) a custom-made instrument equipped with frequency-doubled Nd:YAG laser (λ=532 nm, Casix CDPL-1100T), a monochromator (Jobin Yvon HR640) with reciprocal dispersion of 24 Å/mm and a photomultiplier tube (Hamamatsu R6357), to record photo-luminescence (PL) spectra at room temperature for three samples (nos. 1, 2 and 3).

Particular attention has been paid to spectroscopic techniques because they provide non-destructive analytical methods, except for the IR-measurements in transmission mode using KBr compressed pellets.

Gemmological properties

The gemmological features of the dark green jade from the Po valley are shown in *Table I*. All samples are translucent with a dark green hue. They exhibit refractive indices and specific gravities ranging over 1.67-1.68 and 3.35-3.36, respectively. These values are slightly higher than those common for jadeite jade (R. 1.65-1.66; SG 3.32-3.33), from different geographic localities (Hargett, 1990; Fritsch *et al*., 1992; Htein and Naing, 1995; Ou Yang and Li Hansheng, 1999; Ou Yang and Qi, 2001). The specimens are inert under short- and long-wave UV radiation, appear dark green under a Chelsea colour filter and have a hardness of 6½ on the Mohs scale. Gemmological microscopy observations reveal the cabochons to have a microcrystalline to a porphyroblastic texture with black and green veins and spots, fractures , and some prismatic, transparent and colourless crystals..

Figure 1: Six of the eight omphacite jades (0.93-3.67 ct and 6.1-17.7 mm) from the Po valley, examined in this study. Photo by Ilaria Adamo.

In agreement with Hargett (1990); Ou Yang *et al*. (2003) and Harlow *et al*. (2004), the results of the gemmological testing of the jade from the Po valley suggest an omphacite-like composition. Omphacite jade has recently grown in importance in the gems market [see for instance the inky black omphacite jade from Hong Kong and China (Ou Yang *et al*., 2003) and the blue omphacite from Japan and Guatemala (Harlow, 2003; Harlow *et al*., 2004)] and this has boosted much interest in the dark green jade from the Po valley as a gemmological material.

Thin sections examination

Thin section observations using a traditional petrographic microscope and a scanning electron microscope show a randomly

Table I: Gemmological properties of omphacite jade from the Po valley, Piedmont (Italy).

Colour	dark green
Transparency	translucent
RI*	1.67-1.68
SG	3.35-3.36
UV fluorescence	short-wave: inert long-wave: inert
Chelsea colour filter	dark green
Mohs hardness	6½
Microscopic features	microcrystalline texture; black and green veins and spots; fractures; prismatic, transparent and colourless crystals

* By the distant vision method

oriented microcrystalline to a porphyroblastic texture *(Figure 2)*, composed almost totally of omphacite. SEM-EDS measurements reveal some compositional zoning, or micro exsolution within the omphacite grains (*Figure 3*). The lighter areas (20-80 μm across) contain relatively more Ca, Mg and Fe than the darker areas which are richer in Na and Al. This suggests that lighter patches have more of the diopside-hedenbergite end-members while the darker areas (30-100 μm size) are closer to pure jadeite.

X-ray powder diffraction

An X-ray powder diffraction pattern of the jade from the Po valley (*Figure 4*) indicates that it consists of a single phase consistent with an Fe-bearing omphacite, in agreement with the results from gemmological analysis. The very small angular step used in the scan and the modest instrumental contribution (the Full Width at Half Maximum of LaB6 over the whole angular range explored is never larger than 0.02° 2θ) means that the presence of any other phases would have been recorded. During the refinement, the cell parameter of the internal standard was kept fixed in order to correctly evaluate the zero-point correction of the goniometer. The refined cell parameters of the dark-green jade [a = 9.5791(3), b = 8.7588(2), c = 5.2554(3) Å, $\alpha = \gamma = 90°$ and $\beta = 106.918(2)°$ with monoclinic cell setting and C2/c space group] are typical of omphacite [Edgar *et al.*, 1969; Ogniben, 1968; Deer *et al.*, 1978; Rossi *et al.*, 1983; see, in particular, Camara *et al.* (1998) who report a detailed study of a large suite of Fe-rich omphacite samples].

Chemical composition

The results of chemical analyses of jade specimens 1 and A are summarized in *Table II* and indicate an omphacitic composition, in agreement with previous observations. The valence state of iron has been investigated and on the basis of crystal-chemical considerations and relying on the model of Cawthorn and Collerson (1974) both Fe^{3+} and Fe^{2+} are present, in keeping with the compositions of omphacite samples reported by Deer *et al.* (1978). The Fe^{3+} / Fe^{2+} ratio of >1 is consistent with the high Na-content, which is commonly accompanied by relatively high ferric iron. The chromium contents

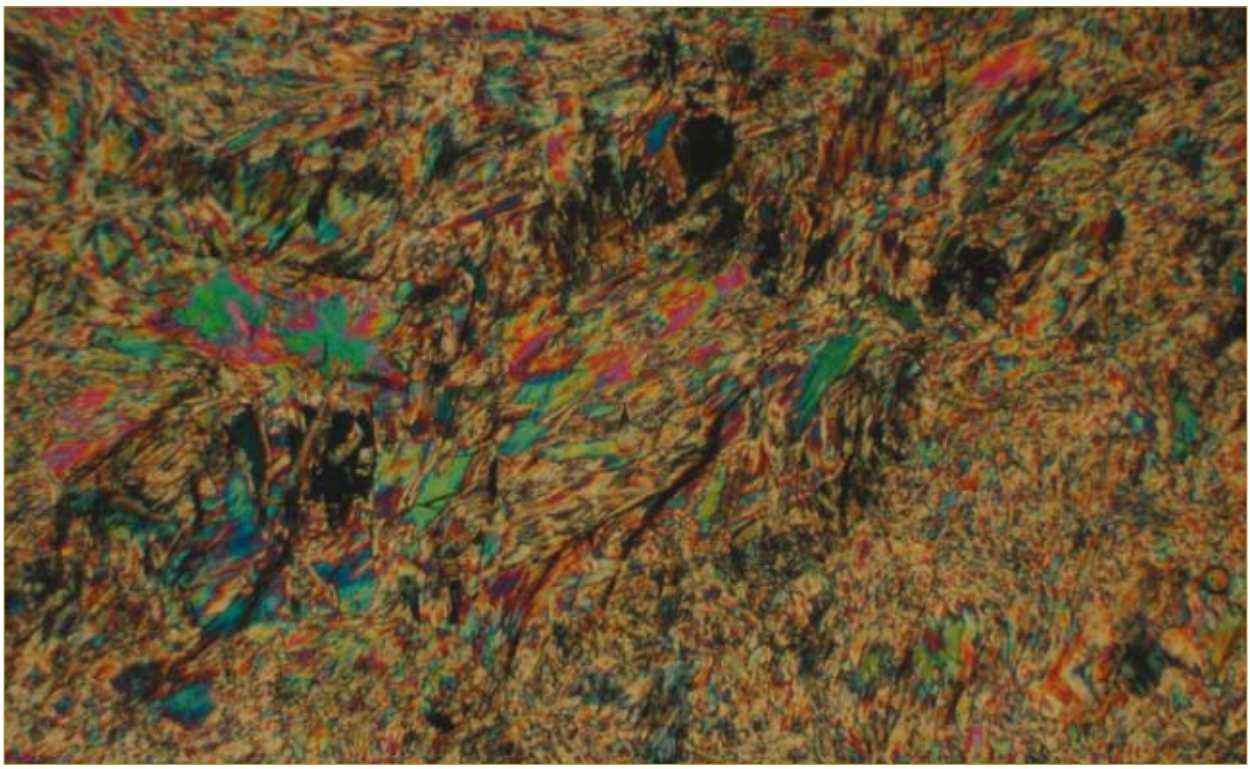

Figure 2: Thin section of omphacite jade (specimen 1) from the Po valley, showing a porphyroblastic texture. Cross polarized light; magnification 9x. Photo by Illaria Adamo.

Figure 3: Back-scattered electron image of omphacite jade from the Po valley. The darker areas are richer in jadeite while the paler areas have higher contents of diopside-hedenbergite. Photo by Agostino Rizzi.

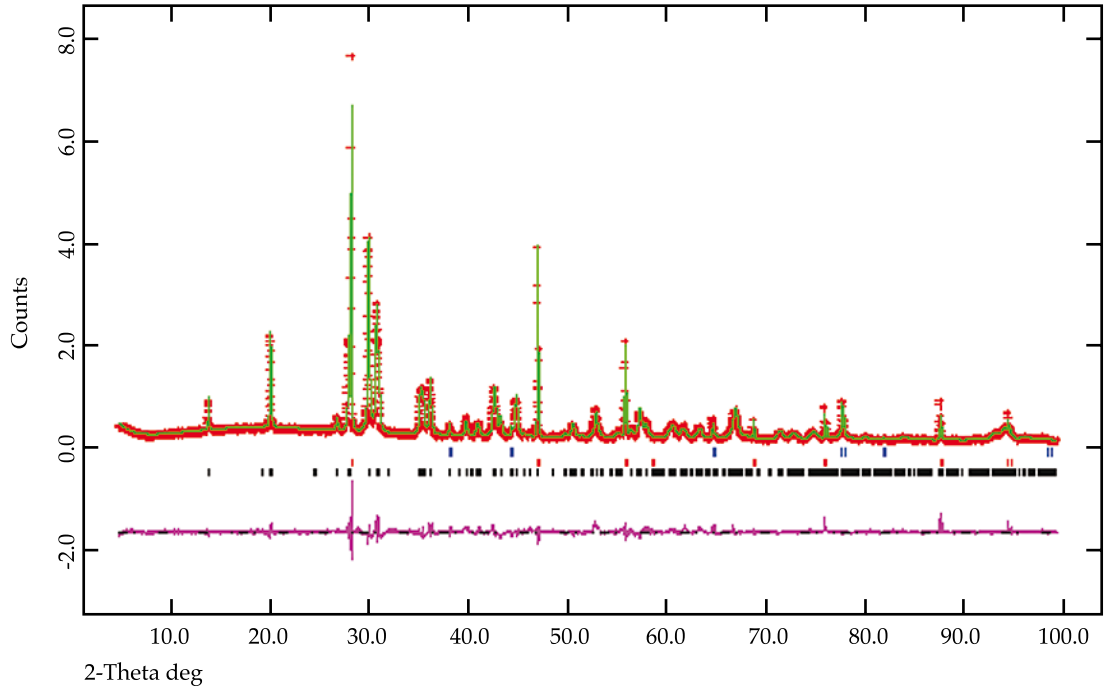

Figure 4: Rietveld refinement of the X-ray powder diffraction pattern (5 -100° 2θ-angle range) of the omphacite jade from the Po valley. The lower pattern represents the residuals between calculated and experimental curves.

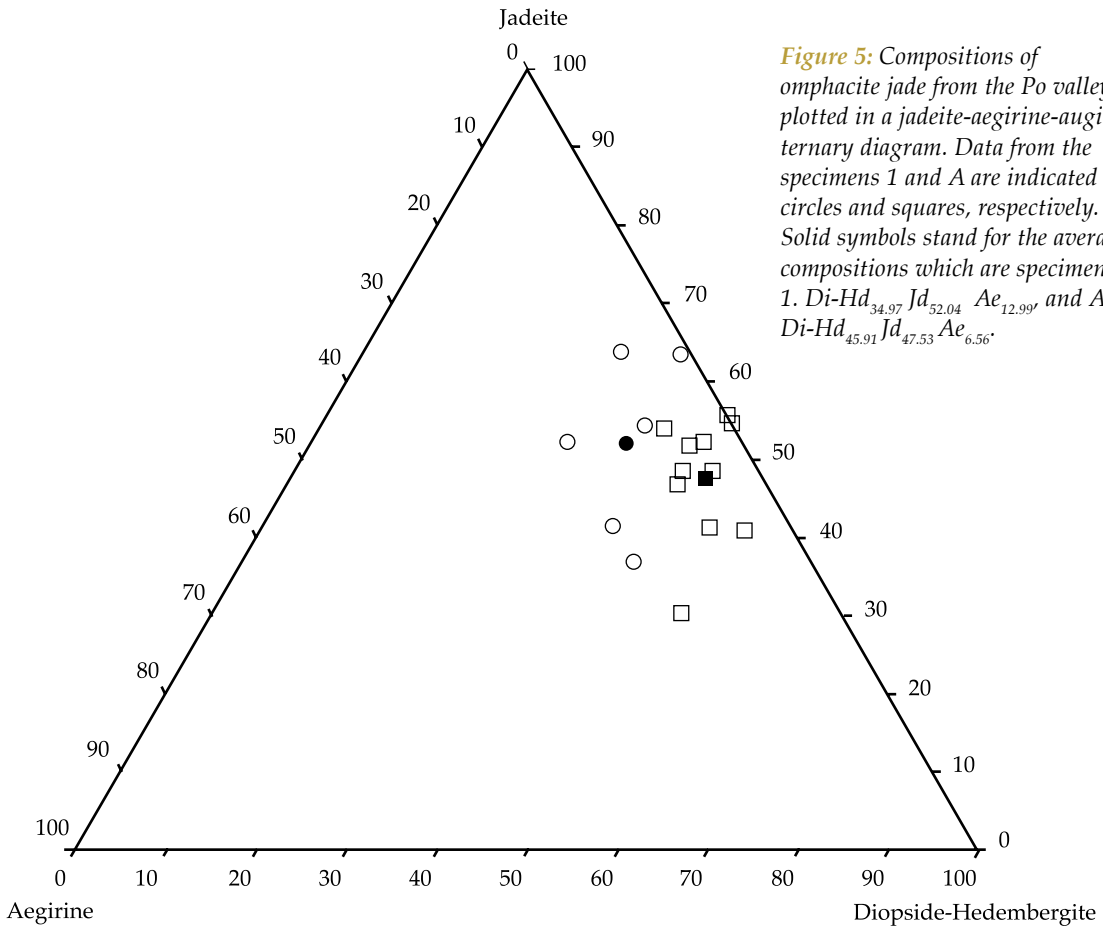

Figure 5: Compositions of omphacite jade from the Po valley, plotted in a jadeite-aegirine-augite ternary diagram. Data from the specimens 1 and A are indicated by circles and squares, respectively. Solid symbols stand for the average compositions which are specimen 1. Di-Hd$_{34.97}$ Jd$_{52.04}$ Ae$_{12.99}$, and A. Di-Hd$_{45.91}$ Jd$_{47.53}$ Ae$_{6.56}$.

Table II: Chemical composition of omphacite jade from the Po valley.

Oxide (wt.%)	Specimen 1 (mean of 6 analysis points)	Specimen A (mean of 12 analysis points)	Cations calculated on the basis of six oxygens		
			Element	Specimen 1	Specimen A
SiO_2	55.86	55.44	Si	1.965	1.965
TiO_2	0.22	0.14	Ti	0.006	0.004
Al_2O_3	13.23	11.96	Al	0.549	0.500
Cr_2O_3	0.17	0.29	Cr	0.005	0.008
Fe_2O_3	5.17	2.60	Fe^{3+}	0.137	0.069
FeO	1.14	1.38	Fe^{2+}	0.034	0.041
MnO	0.13	0.12	Mn	0.004	0.004
MgO	6.38	8.37	Mg	0.335	0.442
CaO	8.27	11.22	Ca	0.312	0.426
Na_2O	9.94	8.29	Na	0.678	0.570
K_2O	0.01	*	K	-	-
			Na/(Na + Ca)	0.685	0.572
Total	100.52	99.81	Al/(Al + Fe^{3+})	0.800	0.879

* Below detection limit (0.01 wt.%)

(average 0.23 wt.%; 0.007 atoms per formula unit) are probably responsible for the very attractive green colour (Rossman, 1980). These conclusions are substantiated by spectroscopic observations, discussed in the next section.

The results in *Table II* agree with the omphacite compositional field (Morimoto, 1988) defined by the Na/(Na + Ca) and Al/(Al + Fe^{3+}) ratios, lying within $0.2 \leq Na / (Na + Ca) \leq 0.8$ and $Al /(Al + Fe^{3+}) > 0.5$ (see also: Clark and Papike, 1968; Deer *et al.*, 1978; Ou Yang *et al.*, 2003). The chemical composition of omphacite is expressed through its formula unit, *i.e.* $(Ca,Na)(Mg,Fe^{2+},Fe^{3+},Al)(Si_2O_6)$ and, being a solid solution of the pyroxene group, can be formulated in terms of the four end-members: $CaMgSi_2O_6$ (diopside, Di), $CaFe^{2+}Si_2O_6$ (hedenbergite, Hd), $NaAlSi_2O_6$ (jadeite, Jd) and $NaFe^{3+}Si_2O_6$ (aegirine or acmite, Ae) In *Figure 5* the measured compositions of jade from the Po valley are displayed on a ternary diagram as a function of Di-Hd, Jd and Ae. The analysis points exhibit some scatter, which suggests some degree of chemical inhomogeneity or microscopic zoning.

Mn and Ti are present in quantities comparable to Cr and provide a full compositional characterization of the omphacite jade from the Po valley.

Spectroscopic features

Infrared spectroscopy

A typical omphacite-like mid-infrared spectrum over the 1500-400 cm^{-1} range obtained in transmission mode from our jade samples (KBr-pellet method) is shown in *Figure 6*, along with that of pure jadeite for comparison (see also the results of Ou Yang *et al.*, 2003, on inky black omphacite jade). Both transmission and reflectance IR patterns are characterized by a broad band at about 3530 cm^{-1} (*Figure 7*), due to OH incorporated in the pyroxene structure and this is consistent with recent studies (see, for example, Skogby *et al.*, 1990;

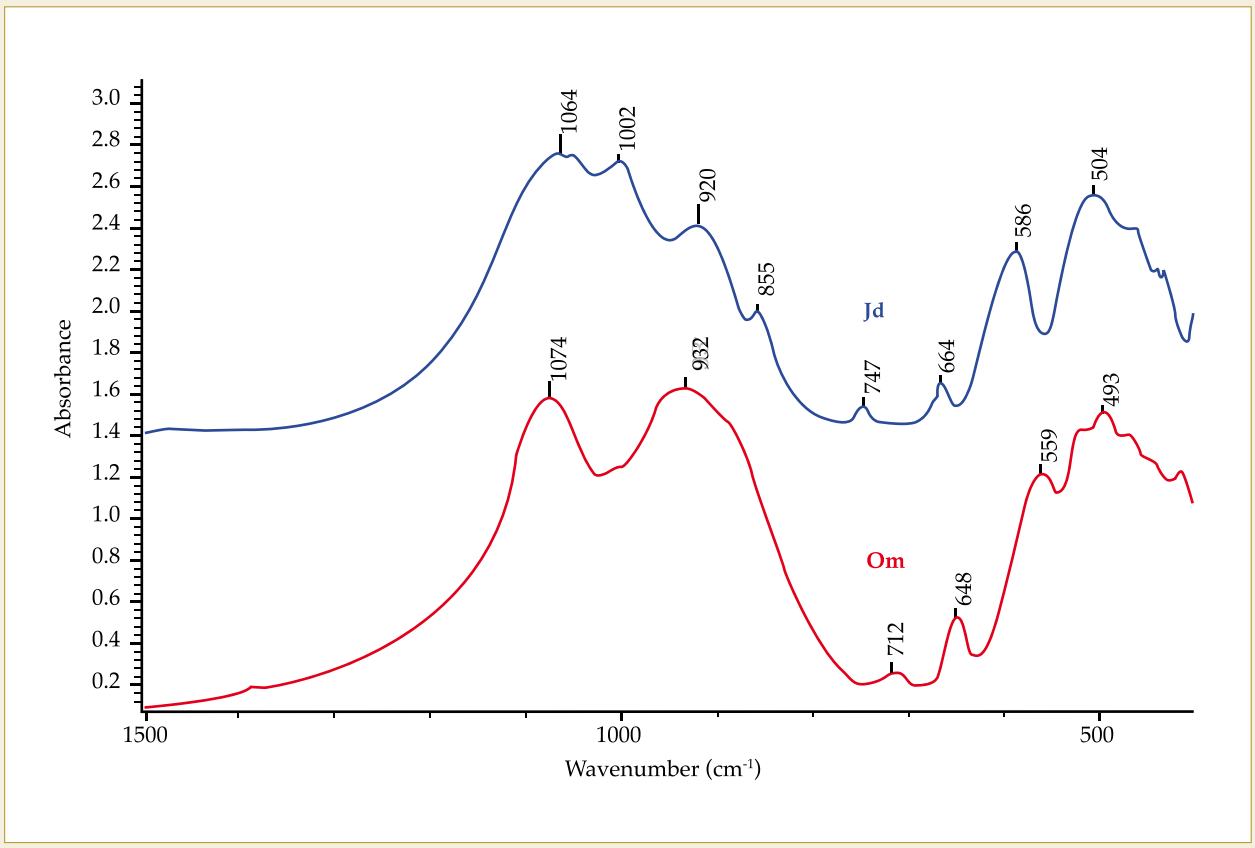

Figure 6: Infrared spectrum (1500-400 cm^{-1}) in transmission mode (KBr-pellet technique) of omphacite jade (Om), compared with a typical spectrum of jadeite jade (Jd). The spectra are offset for clarity.

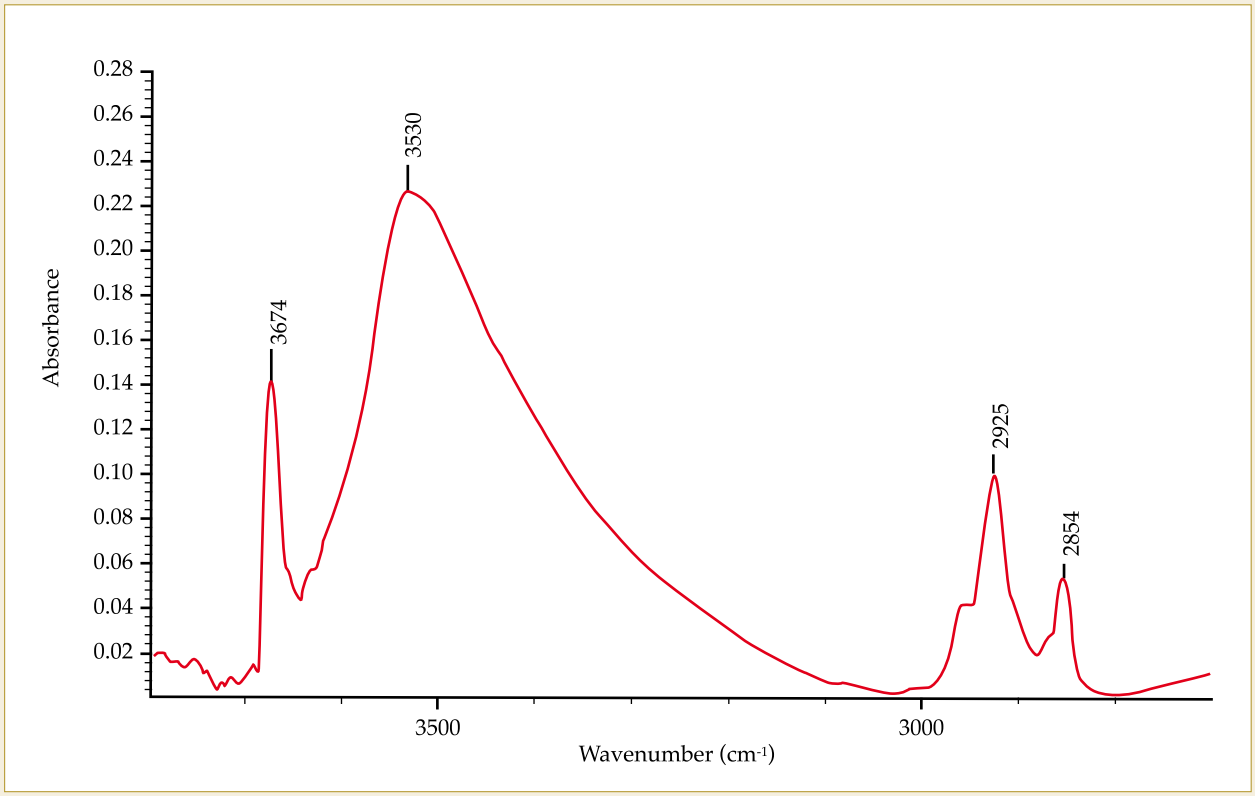

Figure 7: Infrared spectrum (3800-2700 cm^{-1}) in transmission mode (obtained with the beam passing through the sample) of the omphacite jade. Peaks attributed to hydroxyl groups (3674 and 3530 cm^{-1}) and residues of organic matter (2925 and 2854 cm^{-1}) are visible.

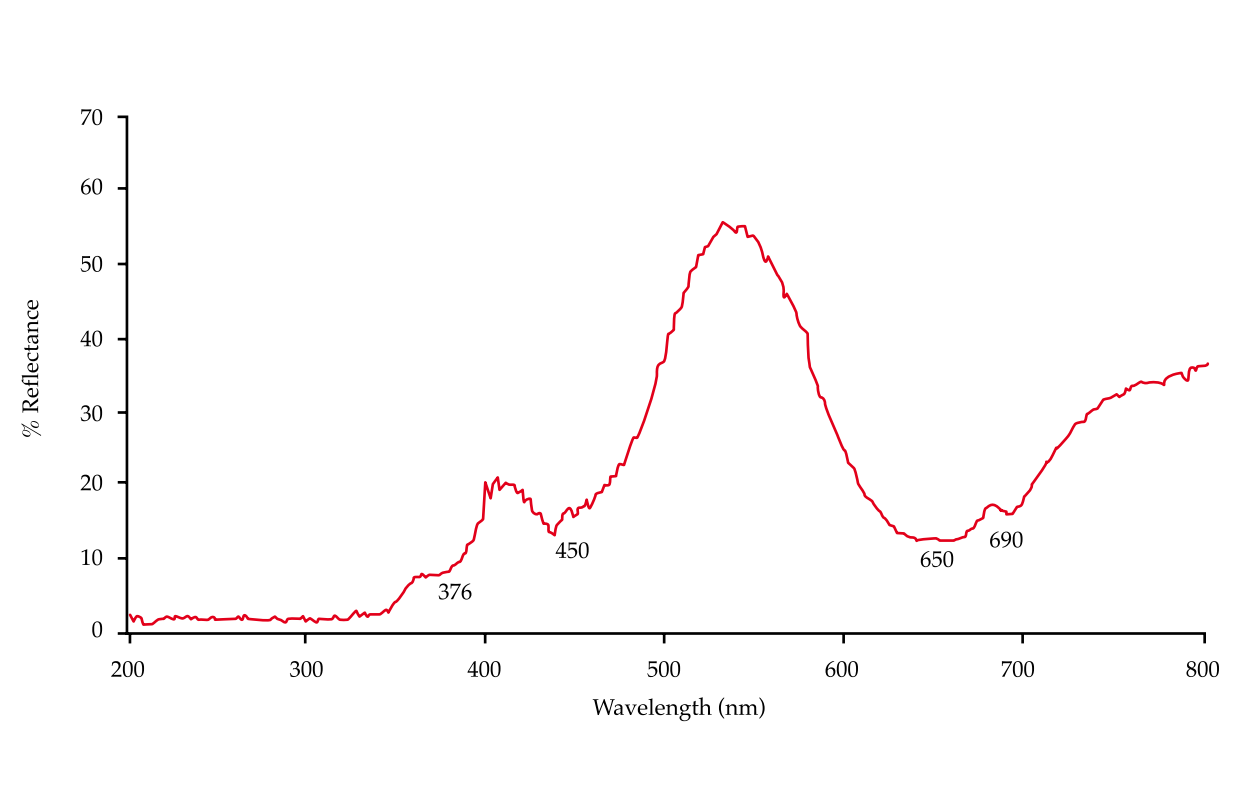

Figure 8: Reflectance spectrum in the range 200-800 nm of omphacite jade (specimen 1) from the Po valley. Broad absorption bands near 450 nm and 650 nm and a narrow band at 690 nm are typical of Cr^{3+}.

Katayama and Nakashima, 2003; Koch-Müller *et al.*, 2004). Some spectroscopic features due to the hydroxyl group can also be related to the occurrence of inclusions in omphacite jade, such as a sharp band at 3674 cm^{-1}, clearly observable in both transmission and reflectance IR spectra (see again *Figure 7*), and attributable to thin sub-microscopic amphibole (probably tremolite) lamellae (Ingrin *et al.*, 1989; Skogby *et al.*, 1990; Hawthorne *et al.*, 2000, Ishida *et al.*, 2002; Jenkins *et al.*, 2003; Koch-Müller *et al.*, 2004). The presence of pyroxene-amphibole intergrowths, due to alteration processes is common in omphacite (Veblen and Buseck, 1981; Skogby *et al.*, 1990; Koch-Müller *et al.*, 2004) and can readily be detected by IR spectroscopy.

Weak absorption peaks near 2920 cm^{-1} and 2850 cm^{-1} in both transmission and reflectance mode (see *Figure 7*) are probably due to residues of organic material used after polishing to improve the shine of the jade (Fritsch *et al.*, 1992; Tan *et al.*, 1995; Quek and Tan, 1997, 1998).

Ultraviolet-visible-near infrared spectroscopy

A non-polarized spectrum over the ultraviolet-visible energy range (200-800 nm) of omphacite jade from the Po valley is displayed in *Figure 8*. Consistent with the microprobe analyses, the spectrum exhibits features typical of Cr^{3+}, i.e. two broad absorption bands at 450 and 650 nm, with a narrow band at 690 nm, that are located either side of the transmission window near 530 nm (Khomenko and Platonov, 1985; Rossman, 1980, 1988; Burns, 1993; Harlow *et al.*, 2004). The absorption peaks at 376 nm and 438 nm due to Fe^{3+} are barely detectable because of Cr^{3+} absorption (see Rossman, 1974, 1980, 1988; Khomenko and Platonov, 1985; Burns, 1993; Harlow, 2003; Harlow *et al.*, 2004) and this confirms that the dark green hue is due mainly to Cr^{3+}.

Photoluminescence spectroscopy

The photoluminescence (PL) spectrum over the 550-850 nm energy range (*Figure 9*) contains a band or a shoulder at about 690 nm and confirms the presence of Cr^{3+}.

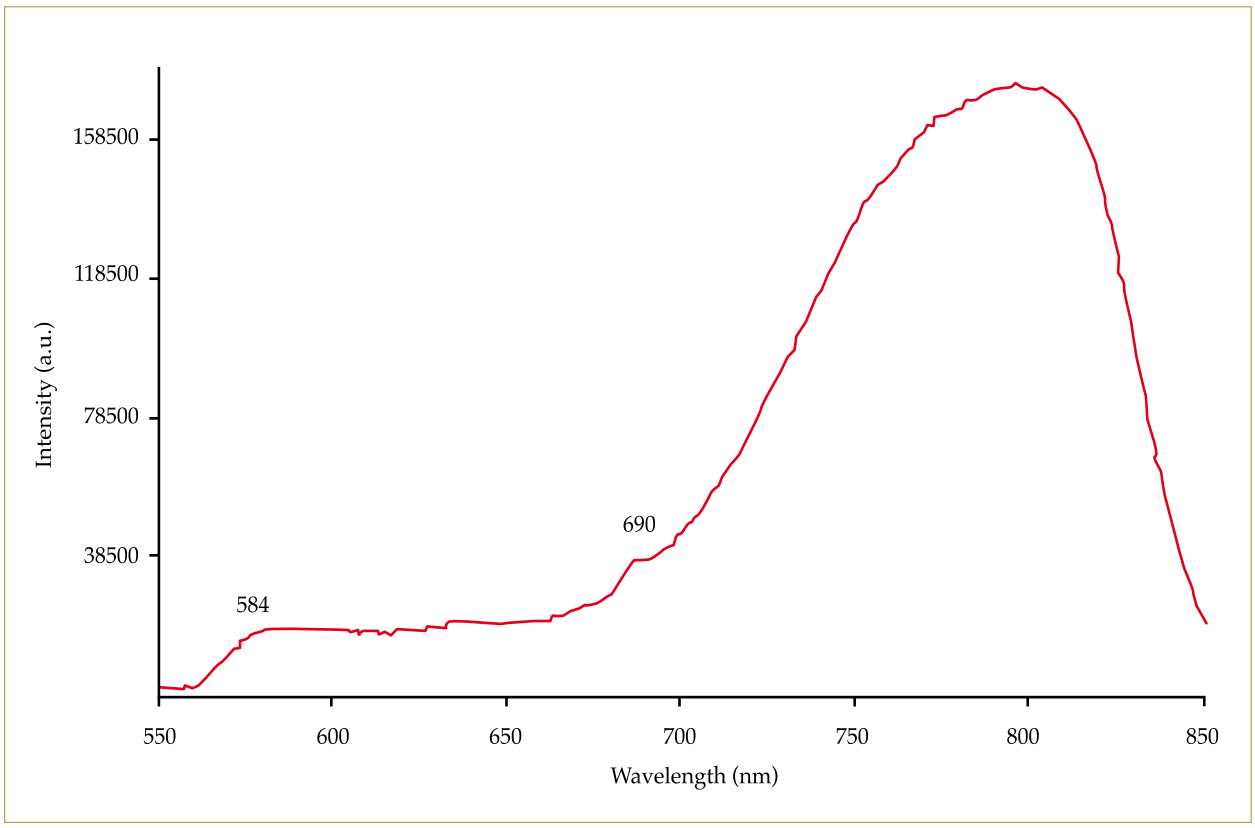

Figure 9: Photoluminescence spectrum over the 550-850 nm range of the omphacite jade (specimen 1) from the Po valley. Note the peak/shoulder at about 690 nm, due to Cr^{3+}; the emission band at 584 nm, related to Mn^{2+}; and the wide photoluminescence band on the longer wavelength side (centred about 800 nm) attributed to Fe^{3+}.

A wide emission band at 584 nm (see again *Figure 9*) is attributed to Mn^{2+} (Tarashchan, 1978; Walker, 1985; Blasse and Grabmaier, 1994; Zharikov and Smirnov, 1997), while Fe^{3+} is probably responsible for the broad PL band at longer wavelengths. However, for iron, determination of the band maximum is hindered by the decrease of sensitivity of the photo-multiplier passing from the visible to the infrared energy region. The attribution of this band to Fe^{3+} is further supported by the PL spectrum recorded with a germanium detector (Walker and Glynn, 1992; Carbonin *et al.*, 2005), which also brings to light a series of narrow lines at high wavelength, related to Fe^{2+} (Walker and Glynn, 1992).

Distinctive features of the dark-green jade from the Po valley

The omphacite jade from the Po valley may be readily distinguished from jadeite jades and from their simulants by means of traditional gemmological testing, in particular by determining their RI (1.67-1.68) and SG (3.35-3.36).

Determination of the Fe^{3+}, Fe^{2+}, Ti^{4+}, Cr^{3+} and Mn^{2+} contents by chemical analyses, UV-Vis and PL spectroscopy, and of the possible presence of hydroxyl groups and residues of organic matter applied after polishing using IR spectra, should be carried out to characterize this dark green jade from the Po valley.

Conclusions

On the basis of the results from gemmological testing and advanced analytical methods, the dark green jade from secondary alluvial deposits in the Po valley (Piedmont, Italy) consists mainly of omphacite pyroxene with some micro exsolution and some compositional zoning. The dark green colour is mainly attributable to trivalent Cr, which is present along with comparable amounts of Mn and Ti. The luminescent properties of the

dark-green jade of the Po valley are related to Mn^{2+}, Fe^{2+}, Fe^{3+} and Cr^{3+}. Promotion and distribution of this material on the Italian gemstone market are planned for the near future.

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Dyed polymer-impregnated jadeite jade: identification by light-induced autofluorescence spectroscopy

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Abstract: *Dyed polymer-impregnated jadeite jade is collectively known as grade B+C jade, while grade A jadeite jade is natural and untreated. In this work, autofluorescence spectra in the visible light range from 400 to 700 nm have been measured for six samples of grade A jade and six samples of grade B+C jades, and strong autofluorescence in the green-blue region (450-550 nm with maxima near 505-520 nm) was observed in the spectra of all samples of grade B+C jade. In contrast, weak autofluorescence was found throughout the whole visible region for all grade A jade samples and the method is thus effective in differentiating grade B+C jade from grade A jade. The strong green-blue autofluorescence in grade B+C jades can be explained by the presence of dyes and polymers used to treat them. Infrared spectra of all jade samples were recorded to confirm the grades and the presence of polymers in grade B+C jades. Autofluorescence spectroscopy has been found useful for identifying dyed polymer-impregnated jade particularly where it is thick or completely enclosed in jewellery mounts.*

Keywords: *autofluorescence spectroscopy, jade grades B and C, jadeite jade, treated jade*

Introduction

Nephrite jade has been prized in China for thousands of years, yet some of the finest jade is jadeite which has been a part of the Chinese culture only since the late eighteenth century, when the mines in what is today north-central Myanmar were opened (Schumann, 1997). The most desirable jadeite is natural, untreated and of fine colour, but of course, supply is limited, and many jadeite jades in the market today, especially since the 1980s have been treated to improve their aesthetic attraction, hence the importance of grading (Fritsch *et al.*, 1992; Hurwit, 1989). Jadeite jades (basically $NaAlSi_2O_6$) are generally classified according to their treatment process under three broad grades, A, B and C. The grading scheme we refer to in this paper with categories A, B and C,

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relates to the treatment of a jade item and not to how beautiful or ugly an item may be. Grade A jadeite jade is natural and untreated. Its surface is usually waxed with beeswax to improve lustre after polishing (Quek and Tan, 1997). Grade B jadeite jade is bleached, and polymer-impregnated jade (Fritsch *et al*., 1992; Fritsch, 1994). The polymer resin not only covers the open fractures but also significantly improves its transparency and colour by covering the jadeite with a hard and clear plastic-like coating. Grade B+C jadeite jade is subjected to a combination of treatment such as bleaching, dyeing and staining, and polymer-impregnation (Liddicoat, 1971; Wu, 2001). Webster (1994, pp 685-6) mentioned that greyish-white jadeite can be stained to an 'imperial jade' colour by the use of a combination of organic yellow and blue dyes. Also, white jadeite is stained to a strong mauve colour which is deeper in hue than any natural mauve or 'lavender' jadeite.

Fritsch and McClure (1993) mentioned that more sensitive detection methods are critical for differentiating between the different grades of jadeites as the skill of doctoring of jadeite by impregnation of polymers improves. This distinction of jade grades has become an intense area of interest for both gemstone dealers and gemmologists. Since natural jadeite jade (grade A) has been difficult to locate in the market, gemmologists have used sophisticated methods of studying these jades to determine what type of treatment it may have undergone. Polymer-impregnation and use of dyes in jades will no doubt cause a definitive change in some physical and chemical properties although some basic tests are unreliable, such as refractive index measurement, visible absorption spectrum using the hand-held spectroscope, and ultraviolet luminescence (Fritsch *et al*. 1992), or even, inconclusive, like specific gravity (Quek and Tan, 1997). Infrared spectroscopy was successfully used to distinguish grade B from grade A jade (Fritsch *et al*., 1992). Other sophisticated techniques in identifying grade B jades such as X-ray photoelectron spectroscopy (Tan *et al*., 1995; Quek and Tan, 1998); infrared fibre-optic probe (Gao and Zhang, 1998); and diffuse reflectance infrared Fourier transform (DRIFT) spectroscopy (Quek and Tan, 1997) have also been reported.

In this work, light-induced autofluorescence spectroscopy is used for the first time to obtain conclusive evidence of dye and polymer impregnation in grade B+C jadeite jade and thereby provide a useful means of distinguishing it from grade A jade. However, this technique cannot at present be used to detect dyed jadeite. The autofluorescence technique is already well established in studies on biological tissues (Chang *et al*., 2002), and dental research (Amaechi and Higham, 2002; Pretty *et al*., 2004). Furthermore, luminescence or fluorescence spectroscopy (Rendell, 1987), as it is generally known, has been used to study minerals and materials (Gaft *et al*., 2005), paintings (Wainwright, 1989), and gemstones (Hoover and Theisen, 1993; Harding, 1994; Moroz *et al*., 1998).

Materials and experimental methods

Six samples of natural untreated jadeite jade (grade A jade) are shown in *Figure 1*. They are light to dark green with white patches and contain fine fissures on their polished surfaces. Six samples of polished dyed polymer-impregnated jadeite jade (grade B+C jade) are shown in *Figure 2*; these are light to dark green. Four of the samples are carved into symbolic animals, while two are parts of different bangles. All twelve samples originated from Myanmar (formerly Burma). The samples were thoroughly rinsed in propanol immediately before all measurements and blow-dried to remove any organic contaminant on their surfaces due to handling.

Refractive index values were obtained for all samples using the spot method on a gemmological refractometer. The samples have a surface polish which is good enough

Figure 1: Six natural untreated jadeite jades, grade A, used in this study. The dimensions of the cabochon are about 2 cm × 1.5 cm.

Figure 2: Six treated jadeite jades, grades B+C, used in this study. The dimensions of the jade at the centre of the bottom row are 4.5 cm × 1 cm.

for reliable measurements. Specific gravity measurements were made using the hydrostatic weighing method (Klein, 2002, pp 33-5). An electronic balance with sensitivity of 0.01 g was used to determine the weights of the samples.

In the transmission Fourier transform infrared (FTIR) spectroscopic work, a Perkin-Elmer Spectrum One spectrometer with a resolution of 2 cm^{-1} in the useful wavenumber range of 2000 to 4000 cm^{-1}, was used to record the spectra of all samples. The infrared measurements are non-destructive. Taking into account the spectrometric resolution of 2 cm^{-1}, and other possible errors in the experiments, the position (in cm^{-1}) of an absorption peak is accurate to ± 3 cm^{-1}.

All the jade samples were further tested using the light-induced autofluorescence spectroscopic technique with the Shimadzu RF-5301PC spectrofluorophotometer. A typical schematic diagram of the configuration of the spectrofluorophotometer is shown in *Figure 3*. This instrument is used to irradiate a sample with excitation light and measure the fluorescence emitted from the irradiated sample for qualitative or quantitative analysis. The excitation of a molecule due to absorption of light energy to a high-energy state and the subsequent fall to a lower energy level results in emission of (fluorescent) light that has a wavelength longer than that of the incident light (Rendell, 1987; Schulman,1985). The excitation light wavelength of 405 nm was selected using an excitation monochromator placed next to the 150W xenon discharge lamp. This excitation wavelength has been used in studies on organic substances (Guilbault, 1990) and stimulates fluorescence in the visible region of 405-700 nm. The emission monochromator selectively receives fluorescence emitted from the sample and its photomultiplier tube measures the intensity of the fluorescence. The term autofluorescence describes materials which fluoresce by themselves

Figure 3: Schematic diagram of the light-induced autofluorescence spectrofluorophotometer system.

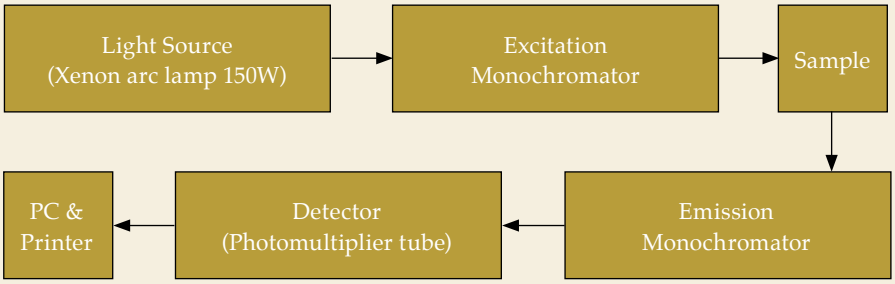

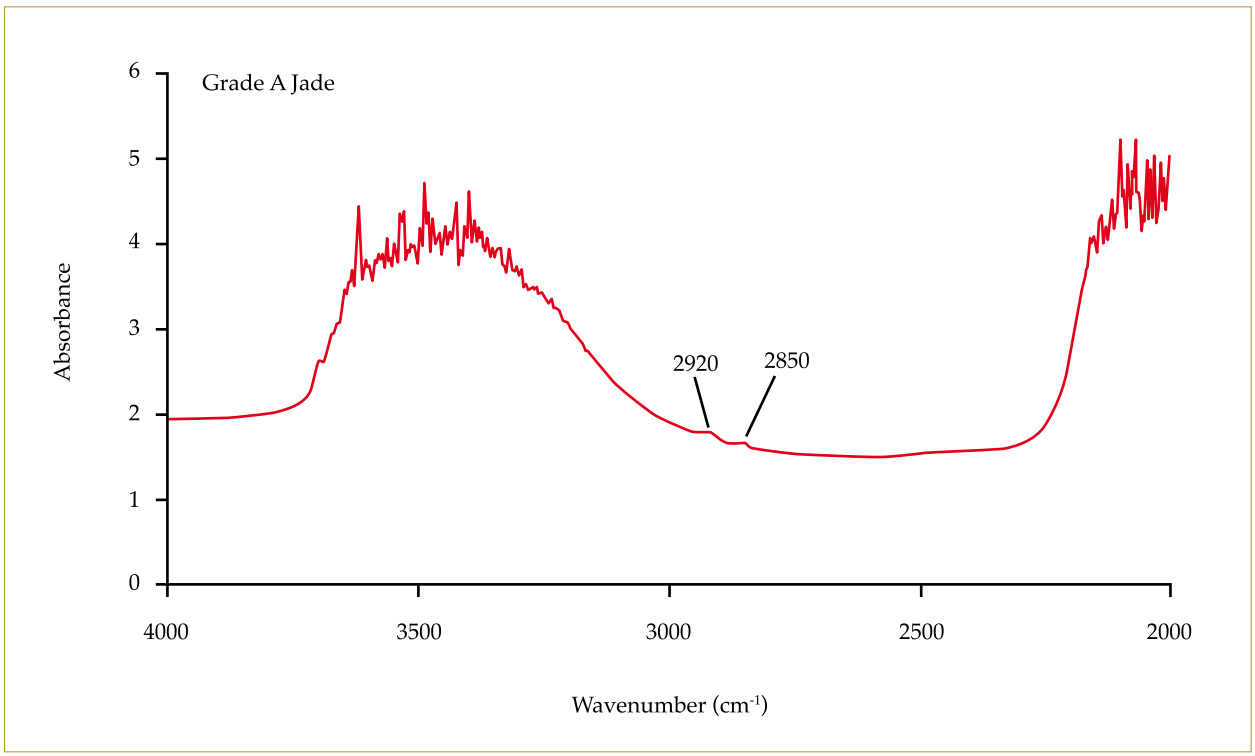

Figure 4: Typical Fourier transform infrared (FTIR) absorption spectrum of grade A jadeite jades. The infrared peaks due to wax on the jade samples are at 2850 cm^{-1} and 2920 cm^{-1}.

without the introduction of fluorescent reagents. Autofluorescence spectra of intensity versus wavelength in the 400-700 nm region were measured in all 12 jade samples.

Results and discussion

The refractive index measurements for all six grade A jades gave a mean of 1.66 ± 0.01, while for all six grade B+C jades, a mean of 1.65 ± 0.01 was obtained. Within experimental error, there is no significant difference between these refractive index measurements. These measurements agree with the typical value of 1.65-1.66 for jadeite jade (Fritsch *et al*., 1992), and the value of 1.652-1.688 given in Schumann (1997).

Specific gravity (SG) measurements of grade A jades were found to be in the range of 3.30 to 3.36, giving a mean of 3.32 ± 0.02. Measurements of grade B+C jades lay in a wider range of 3.09 to 3.26, with a mean of 3.18 ± 0.08. These measurements agree well with 3.04 to 3.27 for grade B jades, measured by Fritsch *et al*. (1992). Although it may appear from the present measurements that SG can be used to differentiate grade A from grade B+C jade, Fritsch *et al*. (1992) reported that some bleached and polymer-impregnated jades sank in 3.32 SG liquid, their behaviour depending on the type of polymers used in impregnation.

In the Fourier transform infrared (FTIR) transmission studies, the jade samples were virtually opaque to infrared radiation in the 400-2000 cm^{-1} region, and therefore the useful region of study was restricted to 2000-4000 cm^{-1}. *Figure 4* shows the typical spectrum of grade A jades. Weak infrared absorption peaks at 2850 cm^{-1} and 2920 cm^{-1} indicate the presence of small quantities of wax used in buffing the jade surface and not in impregnation (Fritsch *et al*., 1992; Quek and Tan, 1997, 1998). For grade B+C jades, strong infrared absorption was typically found in the 2880-3060 cm^{-1} region, as shown in *Figure 5*. The strong peaks at 2880, 2930, 2970, 3040 and 3060 cm^{-1} indicate a high concentration of C-H bonds, found in organic materials including polymers. Polymers such as epoxy resin and polystyrene have been commonly used for impregnation (Fritsch *et al*., 1992; Quek and Tan, 1998), and strong infrared absorption of similar pattern has been found in this region. The infrared absorption in the 2880-3060 cm^{-1}

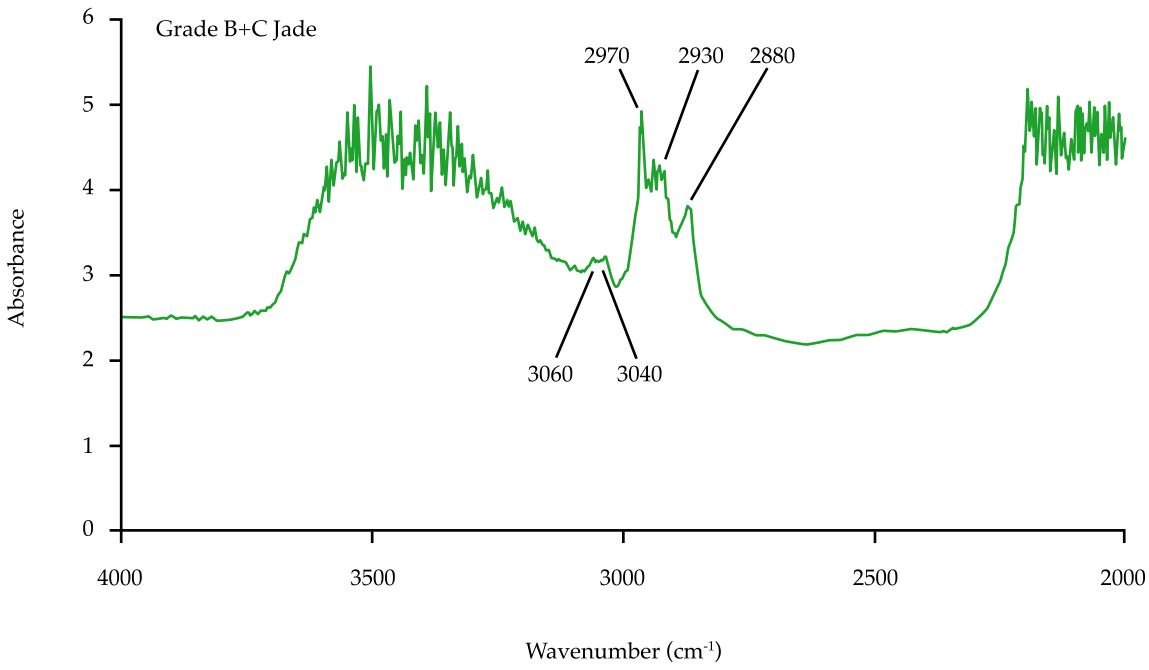

Figure 5: Typical Fourier transform infrared (FTIR) absorption spectrum of grade B+C jadeite jades. The infrared peaks due to an organic substance in the jade samples are at 2880 cm^{-1}, 2930 cm^{-1}, 2970 cm^{-1}, 3040 cm^{-1}, and 3060 cm^{-1}.

region can also be the result of the presence of organic substances used in dyes in grade B+C jades. Organic dyes used in staining jades have been reported, and one example concerned two organic dyes, one yellow and the other blue, which were combined to turn a greyish-white jadeite into an 'imperial jade' colour (Webster, 1994). Dyed and/or polymer-impregnated jades have been in the jade market for quite some time (Liddicoat, 1971; Fritsch *et al*., 1992; Schumann, 1997; Wu, 2001).

The two typical autofluorescence spectra of grade A and grade B+C jades in the 400-700 nm wavelength region are shown *Figures 6* and *7*. The spectra effectively cover the whole visible light region. All six grade A jade samples show weak fluorescence of relatively uniform intensity up to five arbitrary units in the 400-600 nm region, which decreases to zero at 650 nm. This means that there is minimum fluorescence in the yellow–orange-red region. As a whole, this would result in a relatively blue fluorescence. The broad gradual peaks found in the 450-500 nm region may further add to the overall weak blue fluorescence in grade A jade. However, Schumann (1997) reported that in pale green natural jadeites, very weak fluorescence of 'whitish glimmer' was observed. The weak blue fluorescence observed in grade A jades could be due to the presence of wax in small quantity, as organic substances such as wax and polymers tend to fluoresce in the blue region (Fritsch *et al*., 1992). The weak fluorescence could also be caused by trace transition metals (iron and chromium) present in jades (Nassau, 2001).

From the autofluorescence spectra typical of all six grade B+C jades shown in *Figures 6* and *7*, it can be observed that strong fluorescence of about 40 to 55 arbitrary units, occurred in the 450-550 nm wavelength region when excited by violet-ultraviolet light of 405 nm. This is a factor of about ten times more than that of grade A jades in the same region. With strong fluorescent peaks occurring in the range of 505 nm to 520 nm, and near zero fluorescence in the 600-700 nm region, the dominant colour in grade B+C jades is green-blue. The strong fluorescence in the 450-550 nm region could be explained by the presence of organic compounds found in organic dyes and polymers used in the treatment of grade B+C jades. Organic compounds such as those used in polymer-impregnation of jadeites were found to have bluish white to yellowish green, or chalky blue fluorescence (which covers the 400-600 nm region) when subjected to long-wave ultraviolet radiation (Fritsch *et al*., 1992; Quek and Tan,

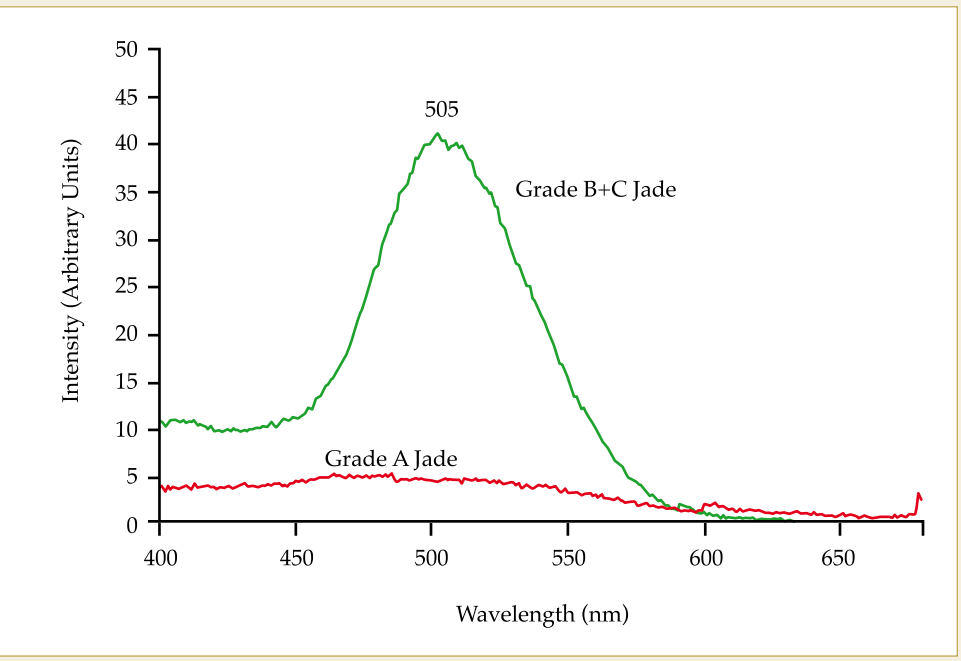

Figure 6: Typical light-induced autofluorescence spectra of grade A and grade B+C jadeite jades. The spectral peak for grade B+C jadeite jades is at 505 nm.

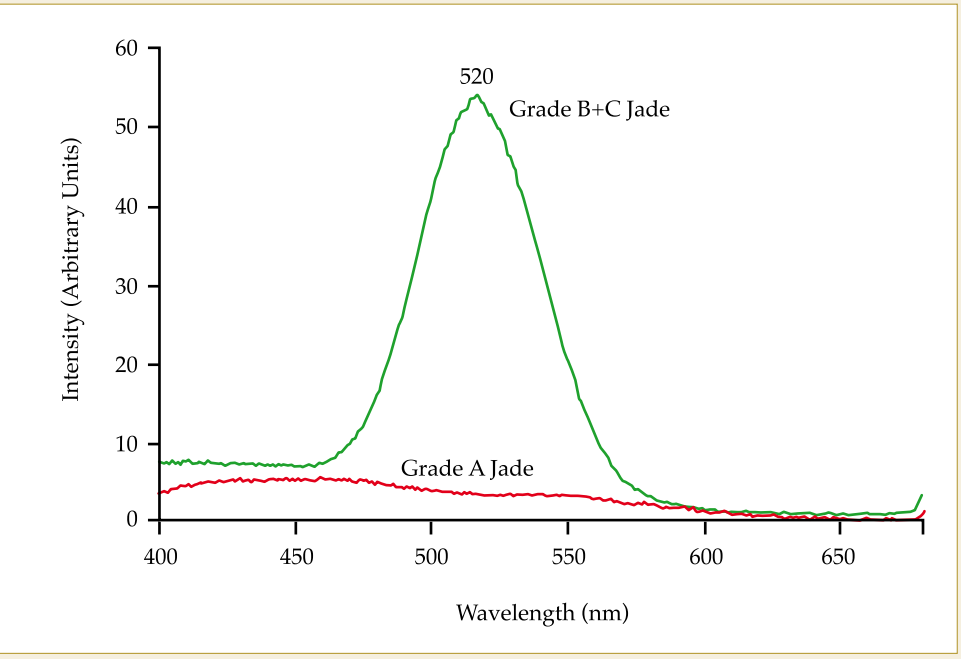

Figure 7: Typical light-induced autofluorescence spectra of grade A jade (no obvious peak) and grade B+C jade (peak at 520 nm).

1997, 1998). Strong green-blue fluorescence in the 450-600 nm region was typically observed in limestone samples containing bitumen, by Wang *et al.* (1997), who found that bitumen was the cause of this fluorescence. Organic dyes such as the 'coumarin dye' were excited to fluoresce in the 500-580 nm region by violet light and ultraviolet radiation, as reported in Nassau (2001). An extensive list of types of organic dyes and their fluorescence bands are provided in Guilbault (1990). All the organic dyes were found to fluoresce strongly in the 450-650 nm region. Results from this autofluorescence spectroscopic work show that the strong fluorescence in the 450-550 nm region in all grade B+C jade samples caused by organic dyes and polymers in them can be used to differentiate them from grade A jades. However, this method cannot at present be used to detect grade C jade (dyed jade).

Conclusion

Dyed polymer-impregnated jadeite jade known in the gem trade as grade B+C jade cannot be differentiated from the natural untreated (grade A) jadeite jade using refractive index measurements. Specific gravity measurements do show that our samples of grade B+C jades have slightly lower values than those of grade A jades. However, the specific gravity readings are not significantly different and are highly dependent on the concentration and type of materials used to treat these jades. So such differences are not a reliable guide to identity. In this work, light-induced autofluorescence spectroscopy has been found to be effective in differentiating grade B+C jade from grade A jade. Strong autofluorescence in the green-blue (450-550 nm) region was observed in the spectra of all samples of grade B+C jade. In contrast, weak autofluorescence of about 10 times less that of grade B+C jade, was found throughout the whole visible region for all grade A jade samples. The strong green-blue autofluorescence in grade B+C jades is attributed to the presence of organic dyes and polymers used in their treatment. Fourier

transform infrared (FTIR) spectra of all jade samples were recorded to confirm the presence of organic substances in grade B+C jades. The use of autofluorescence spectroscopy which is a non-destructive surface technique, for identifying dyed polymer-impregnated jadeite jade from natural jadeite jade is found to be effective and accurate. It is particularly useful for thick jade samples on which transmission infrared measurements are impossible, and for jade close-mounted in jewellery.

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Abstracts

Diamonds

A gemological study of a collection of chameleon diamonds.

T. Hainschwang, D. Simic, E. Fritsch, B. Deljanin, S. Woodring and N. DelRe. *American Journal of Science*, **41**(1), 2005, 20-35.

A report is given of a unique collection of 39 cut chameleon diamonds, ranging from 0.9 to 1.93 ct, which exhibited temporary changes in colour when heated to ~ 150°C, and, for some, after prolonged storage in the dark (i.e. thermochromic and photochromic colour changes, respectively). Most changed from olive green to brownish yellow or yellow, but some changed from light yellow to a more intense greenish yellow; the first group are typical of the 'Classic' chameleons, whereas the purely thermochromic change shown by the second group was the 'Reverse'. These two groups showed different spectroscopic and UV fluorescence characteristics, but all show strong long-lasting phosphorescence after short-wave UV excitation. Using this combination of reaction to UV radiation and spectroscopic properties, a gemmologist can separate chameleon from other green diamonds without recourse to heat. R.A.H.

Lab Notes.

T.H. Moses and S.F. McClure (Eds). *Gems & Gemology*, **42**(2), 2006, 160-8.

Items noted include extensive circular brown or green radiation stains on two cut diamonds, an intense pink colour of three diamonds as a result of a surface coating and a 1.03 ct cut diamond containing several blue inclusions that proved to be sapphire. R.A.H.

The Cullinan diamond centennial: a history and gemological analysis of Cullinans I and II.

K. Scarratt (ken.scarratt@gia.edu) and R. Shor. *Gems & Gemology*, **42**(2), 2006, 120-32.

The year 2005 marked the centenary of the discovery of the largest gem diamond ever found: the 3106 ct Cullinan. Eight decades after it was mined, at the Premier mine (renamed the Cullinan mine for its centenary in 2003), 25 km east of Pretoria, South Africa, a team of British gemmologists conducted the first modern examination of the two largest diamonds cut from the rough, the 530 ct Cullinan I and the 317 ct Cullinan II, which have been part of the British Crown Jewels since their presentation to King Edward VII in 1908. This article traces the history of this diamond and presents the full details of the examination and grading of these two approximately D-colour, potentially flawless, historic diamonds. This examination took place in the vault below the Waterloo Barracks in the Tower of London. Photographs are presented of both stones dismounted from their settings, and details not given in the earlier two-volume set *The Crown Jewels: the History of the Coronation Regalia in the Jewel House of the Tower of London* [M.A. 99M/1248] include the UV spectra confirming that these stones are type II diamonds, and their colour grading. R.A.H.

High-pressure-high-temperature treatment of gem diamonds.

J.E. Shigley (jshigley@gia.edu). *Elements**, **1**(2), 2005, 101-4.

The annealing of gem-quality diamonds at very high pressures (> 5 GPa) and temperatures (> ~ 1800°C) can produce significant changes in their colour. Treatment under these high pressure high temperature (HPHT) conditions affects certain optically active defects and their absorptions in the visible spectrum. In the jewellery industry, laboratory-treated diamonds are valued much less than those of natural colour. Polished diamonds are carefully examined at gemmological laboratories to determine the 'origin of the colour' as part of an overall assessment of their quality. Currently, the recognition of HPHT-treated diamonds involves the determination of various visual properties (such as colour and features seen under magnification), as well as characterization by several spectroscopic techniques. HPHT-treated diamonds were introduced into the jewellery trade in the late 1990s, and despite progress in their recognition, their identification remains a challenge. While some detection methodologies have been established, the large number of diamonds requiring testing with sophisticated scientific instruments poses a logistical problem for gemmological laboratories. R.A.H.

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Synchrotron micro-X-ray fluorescence analysis of natural diamonds: first steps identification of mineral inclusions *in-situ*.

H. Sitepu, M.G. Kopylova (mkopylov@eos.ubc.ca), D.H. Quirt, J.N. Cutler and T.G. Kotzer. *American Mineralogist*, **90** (11-12), 2005, 1740-7.

Synchrotron micro-X-ray fluorescence analytical data yielded the first high-resolution maps of Ti, Cr, Fe, Ni, Cu and Zn for natural diamond grains, along with quantitative μSXRF analyses of select chemical elements in exposed kimberlite indicator mineral

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grains. The distinction of diamond inclusions inside the natural diamond host, both visible and invisible using optical transmitted-light microscopy, can be mapped using synchrotron μXRF analysis. Overall, the relative abundances of chemical elements determined by μSXRF elemental analyses are broadly similar to their expected ratios in the mineral and therefore can be used to identify inclusions in diamonds *in-situ*. Accurate estimates are given by synchrotron μXRF analysis of Cr of exposed polished minerals when calibrated using the concentration of Fe as a standard; corresponding Cr *K*-edge μXANES analyses on selected inclusions yield unique information about the formal oxidation state and local coordination of Cr. R.A.H.

Diamond cut grading: unintended consequences and solutions.

S. Sivovolenko, G. Holloway, Y. Shelementiev and J. Mistry. *Australian Gemmologist*, **22**(10), 2006, 447-54, 12 figs.

The threats to creative and innovative diamond cutting by diamond grading labs who now grade the cut quality of stones are explored. L.J.

Gems and Minerals

"Paraíba"-type copper-bearing tourmaline from Brazil, Nigeria and Mozambique: chemical fingerprinting by LA-ICP-MS.

A. Abduriyim (ahmadjan@gaaj.zenhokyo.co.jp), H. Kitawaki, M. Furuya and D. Schwartz. *Gems & Gemology*, **42**(1), 2006, 4-21.

Gem-quality bright blue to green 'Paraíba'-type Cu-bearing tourmaline is now known from deposits in Nigeria and Mozambique, in addition to three commercial localities in Brazil. The Nigerian and Mozambique tourmalines show saturated blue-to-green colours and cannot be distinguished from the Brazilian material by standard gemmological tests or on the basis of semi-quantitative chemical data obtained by EDXRF. However, quantitative chemical data from laser ablation-ICP-MS show that tourmalines from the three countries can be differentiated by plotting (Ga + Pb) vs. (Cu + Mn), the Pb/Be ratio vs. (Cu + Mn) and Mg-Zn-Pb. Analytical results are tabulated together with physical properties for six variously coloured samples from Brazil and for five each from Nigeria and Mozambique. In general, the Nigerian tourmalines contain greater amounts of Ga, Ge and Pb, whereas the Brazilian stones have more Mg, Zn and Sb. The new Cu-bearing tourmalines from Mozambique show enriched contents of Sc, Ga, Pb and Bi, but lacked Mg. All are elbaites. R.A.H.

Problems that may be encountered when identifying gemstones in antique jewellery: some practical tips.

R. Bauer. *Australian Gemmologist*, **22**(10), 2006, 455-59, 11 images.

The identification of various gemstone types used in antique jewellery are discussed. The use of the 10x lens is advocated, together with other simple techniques. Examples used include discriminating rose-cut diamonds from rose-cut zircons, synthetic doublets, imitation pearls, turquoise, coral, opal doublets, amber and diamonds with old style cuts. L.J.

Pseudomorphesen und Polyederbildungen im Amethystgang von Wiesenbad, Sachsen.

W. Beck and T. Treffurth. *Lapis*, **31**(5), 2006, 22-3.

Pseudomorphism is discussed with special reference to amethyst from Wiesenbad, Saxony, Germany. M.O'D.

Torrington and its gemstones.

H. Bracewell. *Australian Gemmologist*, **22**(11), 2006, 479-84, 1 map, 17 figs.

This paper describes the location and geology of Torrington, an old tin mining village in New South Wales. The geology comprises a granite plateau which is richly mineralized, including deposits of tin, tungsten, quartz, topaz and emerald. The history of the mining activity at Torrington from the late nineteenth century to the present day is described. L.J.

Vulcanite or gutta-percha that is the question.

G. Brown. *Australian Gemmologist*, **22**(10), 2006, 460-5, 10 figs, 1 table.

A description of the physical and chemical properties of vulcanite and gutta-percha, both long chain polymers made from sap-like exudates or latex is given. A history of these two synthetic gem materials is detailed, and their use in jewellery from the mid century is discussed. The features used to discriminate between vulcanite and gutta-percha are specified, together with a recommended testing sequence. L.J.

The Devonshire mineral collection of Chatsworth House: an 18th century survivor and its restoration.

M.P. Cooper. *Mineralogical Record*, **36**(3), 2005, 239-72.

A fascinating account is given of the reassembly, restoration and recataloguing of this mineral collection assembled nearly 200 years ago. Details are included of the 'Duke's Emerald' from Muzo, Colombia; this weights 1383.95 ct, is a terminated prism 5 cm in diameter and was for long renowned as the largest and finest uncut emerald in existence. It is a superb deep green, but although it is perfectly transparent in places, it is heavily flawed in others. A colour photograph is presented. R.A.H.

Occurrence of *in-situ* corundum in Kegalle District, Sri Lanka.

T.S. Dharmaratne, R. Chandrajith and S. Weerawarnakula. *Gemmologie. Z. Dt. Gemmol. Ges.*, **54**(1), 2005, 21-34. 3 maps, 8 photographs, 1 table, bibl. (English with German abstract.)

Recently discovered *in-situ* corundum occurrences in two

locations are described; they are known as Ballapana and Galapitamada in the Kegalle district, Sri Lanka. The *in-situ* corundum mineralization in the area occurs in structurally controlled biotite gneiss rocks. The corundum-bearing rocks of Ballapana are variably weathered and lateritized. The texture of the gneiss suggests a reaction between biotite and sillimanite that has produced corundum and K-feldspar. The corundum crystals from Galapitamada contain higher amounts of Fe_2O_3 compared to other locations. E.S.

Geologie und Petrographie des Saphir- und Rubinvorkommens van Chimwadzulu Hill, (W-Malawi).

H.G. Dill. *Gemmologie. Z. Dt. Gemmol. Ges.*, **54**(1), 2005, 7-20. 1 map, 16 photographs, 1 table, bibl. (German with English abstract.)

Corundums are widely found in the Proterozoic belt extending over Eastern Africa from Kenya, to Tanzania and Malawi into Madagascar. The Chimwadzulu Hill deposit is in the Kirk range in Malawi and forms part of the corundum belt together with deposits near the north of Lake Malawi and in the Mwanza district in the south of the country. A great variety of gem and sub-gem corundum crystals is concentrated in an eluvial placer deposit and is intermittently mined in open cast operations on the Kirk plateau. Hydration and desilication of basic igneous rocks abundant in anorthite led to Al-enriched minerals like corundum and zoisite. Amphibolites enriched with zoisite and garnet are taken as an 'ore guide' to the primary corundum mineralization. E.S.

Petrographische und gemmologische Untersuchungen der Chalcedon-Lagerstätte Finishi Village in den Stormberg-Vulkaniten (Malawi).

H.G. Dill and U. Henn. *Gemmologie. Z. Dt. Gemmol. Ges.*, **55**(1/2), 2006, 25-38. 1 map, 25 photographs, 1 graph, bibl. (German with English abstract.)

In south west Malawi along the border with Mozambique, large areas are covered with layers of tholeiitic basalts intruded by doleritic dykes and sills. This igneous activity climaxes during the lower Jurassic and its igneous rocks were attributed to the Stormberg series. High contents of Fe and Cr in the basaltic magma led to the formation of spinels such as magnetite and chrome picotite. Later the igneous rocks were subjected to auto-hydrothermal alteration resulting in calcite and chalcedony filled amygdules in the basalt cavities along subhorizontal joints and druses in the breccia zones. The blue chalcedony from Malawi is found in either geodes or clefts and shows thinly layered interbedding of blue chalcedony and milky quartz in some cases with rock crystal and calcite. RI, birefringence and density are typical of chalcedony. The blue colour is caused by the Tyndall effect (selective reflection of the light by sub-microscopic particles and/or pores). E.S.

Sérandit aus Aris, Namibia.

H.V. Ellingsen. *Mineralien Welt*, **17**(3), 2006, 51.

Sérandite is briefly reported from Aris, Namibia. M.O'D.

Gold, opal und Wein-Mineraliensammeln im Zemplen- und Slanske-Gebirge in Ungarn und der Slowakei.

D. Grolig. *Mineralien Welt*, **17**(3), 2006, 52-62.

General account, with maps, of gold and opal-bearing sites in Hungary and Slovakia. M.O'D.

The characterisation of tortoise shell and its imitations.

T. Hainschwang (thomas.hainschwang@gia.edu) and L. Leggio. *Gems & Gemology*, **42**(1), 2006, 36-52.

Tortoiseshell reached the height of its popularity as an ornamental gem material during the 18th, 19th and early 20th centuries, but the advent of plastic imitations and new laws protecting sea turtles have led to a drastic reduction in the amounts of tortoise shell in the market. Proper identification is important and this paper summarizes the gemmological properties of tortoiseshell and its imitations, including the results of several spectroscopic tests; transmission and specular reflectance infrared spectroscopy were found to be of particular value. R.A.H.

Keshi Perlen – ein erklärungsbedürftiger Begriff.

H.A. Hänni. *Gemmologie. Z. Dt. Gemmol. Ges.*, **55**(1/2), 2006, 39-50. 8 photographs, 1 table, bibl. (German with English abstract.)

The original term 'Keshi pearls' describes tiny mantle pearls which have developed without tissue transplant during the production of Akoya cultured pearls. The term is now frequently used for gonad-grown cultured pearls which have formed from the mantle tissue grafts after a bead has been rejected. The correct term for these should be 'beadless cultured pearls'. Bead rejection may occur in gonad-grown as well as mantle-grown cultured pearls, in freshwater as well as seawater. Recent examination of Chinese freshwater cultured pearls with beads suggest that they have been formed in mantle pearl sacs which have previously produced beadless pearls. The non-beading or bead rejection of such mantle pearl sacs may lead to large flattened baroque beadless cultured pearls. E.S.

Gemmologische Kurzinformationen. Skapolith-Katzenaugen aus Indien.

H. Henn. *Gemmologie. Z. Dt. Gemmol. Ges.*, **54(1)**, 2005, 55-8. 4 photographs, 1 table, bibl. (German with English abstract.)

Scapolite cat's-eyes from India show brownish-orange to yellow-brown to brown as well as grey colours. RI = 1.559-1.579, DR 0.020, density 2.74-2.75. The brownish-orange and yellow-brown hues are due to hematite inclusions. Browns and greys are caused by dark crystal inclusions, and the cat's-eye effect is caused by parallel oriented dark crystal needles. E.S.

Gemmologische Kurzinformationen. Roter, klar durchsichtiger Andesin aus dem Kongo.

U. Henn. *Gemmologie. Z. Dt. Gemmol. Ges.*, **54**(1), 2005, 53-55. 4 photographs, 1 graph, bibl.

The red transparent andesine feldspar from the Congo showed RIs of 1.554-1.562, DR 0.008, SG 2.69. Tiny inclusions with metallic lustre and lamellar twinning were observed. E.S.

Chatoyance und Asterismus bei Feldspat aus Tansania.

U. Henn, C.C. Milisenda and T. Häger. *Gemmologie. Z. Dt. Gemmol. Ges.*, **54**(1), 2005, 43-46. 5 photographs, 1 table, 1 graph, bibl. (German with English abstract.)

Yellow-brown aventurescent feldspar cat's-eyes and star feldspars from Tanzania were shown to be alkali feldpsars with distinct perthitic structure. Chatoyancy and asterism were caused by oriented needle-shaped hematite inclusions. E.S.

U. Henn and C.C. Milisenda. *Gemmologie. Z. Dt. Gemmol. Ges.*, 54(4), 2005, 121-202.

This is an issue completely devoted to the treatment of gemstones. It is subdivided into treatment methods and resulting changes of their properties, with an introduction by Th. Lind on the nomenclature of and trade in treated gem material. Lind discusses the laws governing declaration of treatment, and the general rule to classify gems as natural, enhanced or treated.

Methoden der künstlichen Eigenschaftsveränderungen bei Edelsteinen, setting out methods of artificial alteration of the properties of gemstones, occupies pp. 127-34, with 4 photographs, 1 graph and a bibliography. Heat treatment can produce changes in the colour and colour intensity, improve transparency, but might result in fissures. Various types of heat treatment are discussed. The authors then describe diffusion treatment and irradiation, bleaching, impregnation with colourless organic substances and fracture filling with glass as well as dyeing. The surface of a stone can be covered by deposition of a thin film; foiling has been known for 2000 years, but engraved foils can also produce asterism or chatoyancy.

Edelsteine und ihre künstlichen Eigenschaftsveränderungen on pp 135-202, with 2 tables and 74 photographs, presents gems and the artificial alteration of their properties in alphabetical order. For each gem, there are descriptions of the treatments available, the results produced, possible identification accompanied by photographs and bibliography for the more important stones from agate to zoisite and 'Zugperle' (cultured pearl). It is a very comprehensive summary, as much as is possible within 70 pages. E.S.

Steckbrief Spinel.

R. Hochleitner and S. Weiss. *Lapis*, **31**(11), 2006, 8-11.

Update of spinel finds with mineralogical data. M.O'D.

Smaragde selbstgessamelt: die Fundstelle Minnesund in Norwegen.

P. Imfeld and S. Weiss. *Lapis*, **31**(5), 2006, 32-5.

Emerald is described from Minnesund, Norway. The local geology and mineralization are noted. Some specimens were found during panning for gold. M.O'D.

Herkunftsbestimmung von Süsswasserzuchtperlen mit Laser Ablations ICP-MS.

D.E. Jacob, U. Wehrmeister, T. Häger and W. Hofmeister. *Gemmologie. Z. Dt. Gemmol. Ges.*, **55**(1/2), 2006, 51-8. 1 map, 9 photographs, 1 table, 1 graph, bibl. (German with English abstract.)

It has become increasingly difficult to differentiate between freshwater cultured pearls from Lake Kasimigaura in Japan and those coming from China. The authors present a new objective method to determine origin using trace elements in the composition of the pearls. Tiny holes (10 μm maximum) are drilled by laser close to the drill hole of the pearl. The method is practically non-intrusive and requires minimum sample preparation. The measured Ba/Sr ratios clearly distinguish Kasimigaura cultured pearls by their low values from the higher and more variable Ba/Sr values of the Chinese freshwater pearls. E.S.

Neue 'Holzopale' vom Wintermühlenhof im Siebengebirge.

E. Klein, F. Höhle and H. Lorenz. *Mineralien Welt*, **17**(4), 2006, 38-42.

Common opal known locally as 'wood opal' and occurring in white through yellow to brown is described from the Wintermühlenhof area of the Siebengebirge, Germany. M.O'D.

Haüyn, Titanit und Apatit aus Niedermendig.

H.-J. Kolzem. *Lapis*, **30**(3), 2005, 25-7.

Gem quality crystals of blue transparent hauyne, pink apatite and yellow-brown titanite are described from the Niedermendig area of the Eifel, Germany. M.O'D.

Gem News International.

B.M. Laurs (Ed.) (blaurs@gia.edu). *Gems & Gemology*, **42**(1), 2006, 62-80.

Items noted at the 2006 Tucson show include a 62.81 ct tsavorite from Tanzania, a fine-grained muscovite ~ 7 cm across (EPMA given) represented as rose quartz, a series of cut stones of greenish-yellow sillimanite from India and yellowish-brown cut titanites (up to 6.21 ct) from Pakistan. Mention is also made of a 2.2 ct step-cut vayrynenite from northern Pakistan and a convincing moonstone doublet consisting of a grey labradorite base with a glass top. R.A.H.

Gem News International.

B.M. Laurs (Ed.) (blaurs@gia.edu). *Gems & Gemology*, **42**(2), 2006, 169-88.

Mention is made of a 9.50 ct faceted euclase with an intense greenish-blue colour, a 10 ct faceted fluorite exhibiting a distinct colour change from blue in daylight or fluorescent light to purple in incandescent light, and jeremejevite from Sri Lanka and Myanmar. Details are given also of cabochons and faceted stones of yellowish green to yellow prehnite from the Northern Territory, Australia, and from Mali, and of a cabochon (14.97 ct) and faceted stone (3.70 ct) of triploidite from China (probably the tin-polymetallic sulphide deposits near Dachang, Guangxi). R.A.H.

Die Achate aus dem Rhyolith vom Rehberg bei Sailauf im Spessart.

J. Lorenz. *Lapis*, **31**(6), 2006, 13-20.

Good-quality ornamental agates are described from rhyolites at Rehberg near Sailauf, Spessart, Germany, some specimens showing a green fluorescence. Associated minerals are noted. M.O'D.

Identification and durability of lead glass-filled rubies.

S.F. McClure, C.P. Smith, W. Wang and M. Hall. *Gems & Gemology*, **42**(1), 2006, 22-34.

Since 2004, large quantities of rubies which have had numerous fractures filled with high lead-content glass, making them appear very transparent, have been reaching international markets. This dramatic treatment is not difficult to identify with a standard gemmological microscope, since it shows flash effect, gas bubbles, etc. Locating filled cavities in reflected light, however, is more challenging, as the surface lustre of the filler is close to that of the ruby. The filling material appears to be very effective in reducing the appearance of fractures, and is fairly resistant to heat exposure during jewellery repair procedures, but does react readily with household solvents. R.A.H.

Elephant pearls true or false?

B. Mann. *Australian Gemmologist*, **22**(11), 2006, 503-7, 9 figures, 1 table.

Elephant pearls are spherical calcified concretions of dentine that come from the soft tissue of growing tusks of mammoths and modern elephants. Ten suspected elephant pearls were investigated and found to come from the molar teeth of Asiatic elephants that have been fashioned by man. The elephant pearls were tested by standard gemmological methods and X-radiography. Evidence of surface working was found on all the pearls, and six had been dyed (red, blue and purple). The history of elephant pearls is given. L.J.

Almandin und Andalusit von Neualbenreuth, Bayern.

S. Meier. *Lapis*, **30**(3), 2005, 31-4.

Almandine crystals of apparently gem or ornamental quality are described from Neualbenreuth, Bavaria, Germany where they occur in a mica schist. Crystals of andalusite in quartz are described from the same area. M.O'D.

[Colorimetry of coloured gemstones: Comparative study of the colorimeter with the visual colour sensation of gemstones.]

K. Miki and Y. Takahashi. *Journal of Gemmological Society of Japan*, **24**(1-4), 2004, 3-12, 7 figs, 5 tables. (in Japanese with English abstract).

By a combination of a set of LEE filters and multi-colorimeter measurements, statistical data on how personal visual sensitivity varies depending on the colours of gemstones have been processed. It was found that small differences are more easily detected in some colours than in others. The green and pale colours of yellow, orange, pink, blue and violet are easier to distinguish than dark colours of red, blue and bluish violet. The results show that general colour sensation fits in with perceived colour of gemstones. Faceted gemstones display several colours due to the presence of many facets, and a range of bright and more shadowy colours. Detailed colour sensations from such stones were analysed by visual tests of three colour differences. It was demonstrated that most human colour sensation recognises the medium bright colour as the defining colour of such faceted gemstones. I.S.

Aquamarine aus neuen Vorkommen in Brasilien.

C.C. Milisenda and H. Bank. *Gemmologie. Z. Dt. Gemmol. Ges.*, **54**(1), 2005, 47-51. 6 photographs, bibl. (German with English abstract.)

The new occurrence is situated at Padre Paraiso, about 80 km north of Teofilo Otoni in the state of Minas Gerais in Brazil. It produces large transparent crystals weighing up to 80 kg. Faceted specimens are pastel-coloured greenish blue and may exceed 100 ct. Intense blue aquamarines have been found near the famous Santa Maria de Itabira deposit at Tatu; faceted stones range from 1 to 10 ct. A third new find is near Jacutinga, 60 km south of Pocos de Caldas and 10 km east of the border of the Sao Paulo state. Faceted specimens are small, seldom more than 3 ct, but show an intense blue colour rarely seen in small aquamarines. E.S.

Neues Vorkommen kupferführender Turmaline in Mosambik.

C.C. Milisenda, Y. Horikawa, K. Emori, R. Miranda, F.H. Bank and U. Henn. *Gemmologie. Z. Dt. Gemmol. Ges.*, **55**(1/2), 2006, 5-24, 30 photographs, 1 table, 4 graphs, bibl. (German with English abstract.)

A new occurrence in the region of Alto Ligonha in the north of Mozambique produces purple to violet, pink, blue, violet-blue, green-blue, yellow-green and green tourmalines, the colour being caused by trace elements of manganese and/or copper, comparable with the Paraíba tourmalines from Brazil. Purple-violet and violet-blue stones can be heat treated to result in a turquoise blue colour. The chemical composition indicates that it is the lithian tourmaline elbaite. The lively blue and green tourmalines have been very successful on the gem market and have led to the discussion as to whether the name 'Paraíba touramalines' should refer to their origin or composition. E.S.

Rubin emit bleihaltigen Gläsern gefüllt.

C.C. Milisenda, Y. Horikawa and U. Henn. *Gemmologie. Z. Dt. Gemmol. Ges.*, **54**(1), 2005, 35-42. 12 photographs, 3 graphs, bibl. (German with English abstract.)

The filling of fractures in rubies with glass has been known for a long time. These glass substances usually had borax as a basis. As these treatments are undertaken at a temperature of 1500°C, the original fracture is altered and the treatment can easily be verified. The new filling material used is a lead-containing glass with a higher RI which can be applied at a lower temperature (1000°C), so the original fissure is not altered too much. Magnification reveals characteristics such as flash

effect and bubble-like inclusions. At present the majority of such treated stones come from Andilamena (north central Madagascar). This treatment can be applied to all corundums. E.S.

Gemmologische Kurzinformationen. Gelb-grüne, facettierte Sillimanite aus Orissa (Indien).

C.C. Milisenda and M. Wild. *Gemmologie. Z. Dt. Gemmol. Ges.*, **55**(1/2), 2006, 59-61. 4 photographs, bibl. (German with English abstract.)

Transparent yellow-green to green-yellowish sillimanites come from a new find in Orissa. The faceted stones resemble chrysoberyl and weigh between 2.85 and 10.63 ct with RIs of 1.658-1.681, DR 0.020-0.021 and SG of 3.26. The absorption spectra showed lines at 460, 440, 412 and 360, which can be attributed to trivalent iron. Microscopic examination showed parallel orientated, fibrous mineral inclusions and parallel orientated needle-like inclusions and hollow tubes. E.S.

Lab Notes.

T.M. Moses and S.F. McClure (Eds). *Gems & Gemology*, **42**(1), 2006, 54-61.

Notes are given on a diamond with 'fingerprint' inclusions (common in rubies and sapphires, but extremely rare in diamonds) and a pink diamond with etch channels at the intersection of glide planes. Two of the emerald crystals in a mineral specimen 'assembled' from genuine Colombian material were found to show internal descriptions in Arabic; the crystals apparently had been core drilled from the bottom and a rolled up piece of paper inserted into the drill holes which were then filled with a resin. R.A.H.

Kolonne bei Embilipitya auf Sri Lanka-eine interessante Fundstelle für Olivin, Hornblende und Spinelle.

H.D. Müller and S. Jahn. *Mineralien Welt*, **17**(4), 2006, 44-51.

Finds of olivine, hornblende and spinel are described from the Embilipitya area of Sri Lanka. Other species mentioned include schorl and allanite. Some of the olivine appears to be of gem quality. M.O'D.

Smaragd 2004, Anatas 2005: Kristallfestival im Habachtal.

H. Neutkins. *Lapis*, **31**(6), 2006, 26.

Recently-discovered and attractive specimen-quality emerald crystals are described from the Habachtal, Austria. M.O'D.

Das Smaragd-Vorkommen von Byrud (Eidsvoll) in Süd-Norwegen.

F.S. Nordrum and G. Raade. *Mineralien Welt*, **17**(4), 2006, 52-64.

Emerald crystals, some of gem quality, are described from the southern Norwegian deposit at Byrud (Eidsvoll). The local geology and other species found are also described. M.O'D.

Mineral and melt inclusions in sapphires as an indicator of conditions of their formation and origin (Primorsky region of the Russian Far East).

V. Pakhomova, B. Zalishchak, V. Tishkina, M. Lapina and N. Karmanov. *Australian Gemmologist*, **22**(11), 2006, 508-11, 3 figs.

The authors have studied the sapphires from the Nezametnoye corundum deposit in Russia to investigate the physico-chemical conditions of corundum formation. They studied the mineral and primary melt inclusions that are syngenetic with the corundum using XRF, thin section petrography and electron microprobe analysis. From the mineral and melt inclusion data, they suggest that corundum crystallized from a quartz-syenite melt within a temperature range from 780° to 820°C, and pressure range from 1.7 to 3 kbar, involving both magmatic and metasomatic processes. These results contradict previous theories that the Nezametnoye corundum formed in alkali basalts. L.J.

Spessartin- und Dioptas Mineralisationen im Kaokoland, Namibia.

A. Palfi. *Mineralien Welt*, **16**(4), 2005, 49-61.

Spessartine and diopside mineralization is described from Kaokoland in north-west Namibia. Some of the fine transparent orange spessartine crystals have been faceted. A mineral list is given. M.O'D.

Characteristic spectral features of iron as a gemstone chromophore.

G. Pearson. *Australian Gemmologist*, **22**(10), 2006, 430-46, 35 figs, 1 table.

UV-Visible spectrophotometry has been used to determine the absorption spectra of gemstones that contain iron including sapphire, beryl, chrysoberyl, spinel and peridot. The spectra determined differed from those found in the gemmological literature. A single absorption band found between 400-460 nm was present in all, as was a pair of absorption bands in the UV region between 360-390 nm, not visible with a gemmological spectroscope. L.J.

The variation of gemmological properties and chemical composition of gem-quality taaffeites and musgravites from Sri Lanka.

K. Schmetzer, L. Kiefert, H-J. Bernhardt and M. Burford. *Australian Gemmologist*, **22**(11), 2006, 485-92, 8 figs, 2 tables.

The physical and chemical properties of three taaffeites and one musgravite from Sri Lanka are described. They are beryllium-magnesium-aluminium oxides. The gems were analysed using standard gemmological methods, non-polarized UV-VIS spectrometry, Raman microspectroscopy and electron microprobe. The greyish violet colour of the taaffeites is ascribed to iron and the purple-red colour of one taaffeite to traces of chromium and moderate iron levels. The variations in chemical composition result in variations in the gemmological properties. However there are overlaps in the gemmological properties of the taaffeites and musgravites. L.J.

Ein 'Lapis' aus den Jahre 1903.

H.-P. Schröder. *Lapis*, **31**(11), 2006, 13-16.

Describes and illustrates Rudolf Zimmermann, Monatsschrift Mineralien-Geseins-und Petrefakantensammler. Some colour plates from the original are reproduced. M.O'D.

A guide to mineral localities in China.

B. Smith, C. Smith, G. Liu and B. Ottens. *The Mineralogical record*, 2005, **36**, 87-101.

The guide is arranged in alphabetical order of location and includes type (mining district, mine, etc), geographical coordinates, province and type of mineral. A number of species yielding gem-quality specimens are included. A country map is provided. M.O'D.

My other collection.

B. Sneyd. *Australian Gemmologist*, **22**(10), 2006, 466-9, 16 figs.

Various types of postcards illustrating aspects of gemstones and gemmology collected by the author are described. L.J.

Ammolith-ein opalisiererender Muschelmarmor aus dem Karwendelgebirge, Tirol.

M. Strasser. *Lapis*, **31**(11), 2006, 37-40.

A fossilized ammonite with an opal-like play-of-colour is described from the Karwendelgebirge, Tirol, Austria. The trade name ammolite has been used for ornamental quality material. M.O'D.

Gemstone mining and exploration in Australia.

F.L. Sutherland. *Australian Gemmologist*, **22**(11), 2006, 496-502, 2 maps, 6 figs.

An overview of the significant gem deposits in Australia that are currently being worked, including precious opal, diamond, sapphire, nephrite, chrysoprase, agate, silicified ornamental materials and pearls. 2005 saw the start of new ruby mining in Eastern Australia, and recent finds of amber have been found in the Cape York Peninsula.

L.J.

A SIMS study of the transitional elemental distribution between bands in banded Australian sedimentary opal from the Lightning Ridge locality.

P.S. Thomas (paulthomas@uts.edu.au), L.D. Brown, A.S. Ray and K.E. Prince. *Neues Jahrbuch for Mineralogie Abhandlungen*, **182**(2), 2006, 193-9.

The distribution of trace elements in banded Australian sedimentary opal from the Lightning Ridge region was investigated with secondary ion mass spectrometry (SIMS) using both spot and spatial analysis by stepping incrementally across the sample in line-scan mode. The opal was found to be fairly homogeneous within bands, but it showed a relatively sharp change in trace element contents at the interface between bands for such elements as Ti, V, Co, Cu, Zn and Y. A number of elements (Na, Mg, Al, K, Ca, Mn and Fe), however, did not vary significantly between bands, which is taken to suggest that the adjacent bands in the opals were formed at the same time. These observations are consistent with earlier reported laser ablation ICP-MS results, and support the solution depletion sedimentation model proposed as the mechanism for band formation in banded opal. R.A.H

Old opal fields revisited at Coober Pedy.

I.J. Townsend. *Australian Gemmologist*, **22**(11), 2006, 475-8, 5 figs, 3 maps.

A South Australian Government financed initiative to subsidize drilling projects to locate new opal fields at Coober Pedy was begun in 2004. As a result new opal bearing deposits have been located. In addition High Resolution Resistivity has been tested on known opal bearing areas at Coober Pedy with good results. L.J.

The effects of heat treatment on zircon inclusions in Madagascar sapphires.

W. Wang (wuyi.wang@gia.edu), K. Scarratt, J.L. Emmett, C.M. Breeding and T.R. Douthit. *Gems & Gemology*, **42**(2), 2006, 134-50.

A study of zircon inclusions in gem-quality sapphires showed that progressive decomposition and chemical reactions between zircon and the host sapphire occurred at 1400-1850°C. In unheated sapphires, transparent zircon inclusions displayed slightly elongated forms and clear interfaces with their corundum host; most were confined within the host at relatively high pressures (up to 27 kbar), and showed evidence of natural radiation-related damage metamictization. Subsolidus reactions of some zircon inclusions started at as low as 1400°C, as shown by the formation of baddeleyite (ZrO_2) and a SiO_2-rich phase. Differences in the degree of pre-existing radiation damage are the most likely cause for the decomposition reactions at such relatively low temperatures. Melting of zircon and dissolution of the surrounding sapphire occurred in all samples at 1600°C and above. From these observations, a systematic sequence of both modification and destruction of zircon inclusions with increasing temperature was compiled. This may be useful as a gemmological aid in determining whether a zircon-bearing ruby or sapphire has been heated and to provide an estimate of the heating temperature. R.A.H.

Gemmology, geology and origin of the Sanawana emerald deposits, Zimbabwe.

J.C. Zwaan. *Scripta Geologica*, **131**, 2006, 212.

The emeralds from the Sandawana deposits, Zimbabwe, have relatively high refractive indices (ε 1.584 – 1.587, ω1.590 – 1.594) and specific gravity (2.74 – 2.77), with evenly distributed colour ranging from medium to dark green and with yellowish- to bluish-green dichroism. They contain inclusions of actinolite and cummingtonite needles and long prismatic laths of albite and apatite, as well as phlogopite, calcite, dolomite, quartz and ilmenorutile; partially healed fissures are also seen. Electron microprobe analyses were performed on four gem-quality, medium to dark green rough emeralds and one light green emerald extracted on pegmatite, all from the Zeus mine. Probe analyses are also reported for 23 amphibole inclusions and for 20 other inclusions; trace element contents of 22 emeralds were also measured. These emeralds have relatively high contents of Cr, Na, Mg, Li and Cs, and are readily distinguished from emeralds from most other localities by traditional gem-testing techniques. These emerald deposits occur at the contacts between the Mweza greenstones and REE-bearing granitic pegmatites emplaced during a main 2600 Ma deformation event at the southern end of the Zimbabwe craton. Late-stage Na rich 'solution-melt' containing F, P,

Li, Be and Cr caused albitization and phlogopitization in the greenstone wall-rock. Synkinematic growth of phlogopite was accompanied by emerald, fluoropatite, holmquistite and chromian ilmenorutile, indicating Na-K metasomatism in the emerald-bearing shear zone. Further data on emeralds and associated minerals and the mining methods employed are included in the main text, along with illustrations, diagrams and electron micrographs. R.A.H.

Instruments and Techniques

Applications of laser ablation-inductively coupled plasma-mass spectrometry (LAICP-MS) to gemology.

A. Abduriyim (ahmadjan@gaaj-zenhokyo.co.jp) and H. Kitawaki. *Gems & Gemology*, **42**(2), 2006, 98-118.

The authors have applied the minimally destructive LA-ICP-MS technique to gemmology to take advantage of its high spatial resolution, rapid and direct analysis of gemstones (whether loose or mounted), and precise measurement of a wide range of elements – even in ultra-trace amounts. The principles of LA-ICP-MS are summarized and the application of this technique to the detection of Be diffusion treatment in corundum and the identification of the geographic origins of emeralds. The method is significantly less expensive than secondary ion mass spectrometry (SIMS) and more sensitive than laser-induced breakdown spectroscopy (LIBS), which is the least costly of these three techniques. R.A.H.

Test case for the refractometer – olivine or sinhalite?

A Hodgkinson. *Australian Gemmologist*, **22**(11), 2006, 493-5, 9 figs, 1 table.

Brown iron-rich olivine is similar in appearance to sinhalite. The refractometer can, with care, be used to differentiate brown olivine from sinhalite by detecting the position of beta which is nearer to gamma in sinhalite. Magnetism can be used to detect the more magnetic olivine. Absorption spectra are useful in some instances, as is the use of thermal conductivity and crossed filters. L.J.

Re-surfacing a refractometer prism.

T. Linton. *Australian Gemmologist*, **22**(10), 2006, 470-1, 2 figs.

The potential effects of repolishing a refractometer prism are detailed, including inaccurate readings of RI. L.J.

Faceting transparent rhodonite from Broken Hill, New South Wales, Australia.

P.W. Millsteed (paulmilsteed@hotmail.com). *Gems & Gemology*, **42**(2), 2006, 151-8.

Because of its perfect cleavage and brittle nature, rhodonite is notoriously difficult to facet. A technique has been developed through experiments on eight crystals from the North mine at Broken Hill, via a systematic structural, crystallographic and optical analysis and the use of a non-conventional faceting approach – the 'greasy lap'. This method uses a mixture of petroleum jelly and diamond grit to charge a non-embedded lap, allowing the diamond grit to 'roll free' during the lapping process. R.A.H.

Synthetics and Simulants

A study on the identification of turquoise by FTIR.

Y-C. Kim. *Journal of the Korean Crystal Growth and Crystal Technology*, **14**(6), 2004, 272-6 (Korean with English abstract).

Natural turquoise can be distinguished easily from its common substitutes using infrared spectroscopy in the range 2000~450 cm-1, especially by features in the mid-infrared. Gilson turquoise exhibits a significantly smoother pattern when compared with natural turquoise, due to a different state of aggregation. Infrared spectra of natural, treated synthetic and imitation turquoise (gibbsite, calcite) are shown and compared. I.S.

Prospects for large single crystal CVD diamonds.

S.S. Ho, C.S. Van, Z. Liu, H.K. Mao and R.J. Hemley. *Industrial Diamond Review*, **66**, 2006, 28-32.

A description is given of chemical vapour deposition (CVD) techniques for fabricating large single-crystal diamond at very high growth rates (up to > 100 J-lm/h). Single crystals more than 1 cm in thickness and weighing more than 10 ct can now be produced with a range of optical and mechanical properties for different applications. This diamond can be tailored to possess high fracture toughness, and high-pressure/high-temperature annealing can increase its hardness significantly. The size of the diamonds can be further enlarged by successive growth on different faces. The process has been optimized to produce diamond with improved optical properties in the ultraviolet to infrared range, opening prospects for new technological and scientific applications. Illustrations are given of a 5 ct single-crystal CVD diamond (without seed), 12 mm high and 6.7 mm diameter, cut from a 10 ct block using a computer-controlled YAG laser system, and of a 0.2 ct brilliant cut diamond produced from a 1 ct block. R.A.H.

Abstractors

R.A. Howie R.A.H. L. Joyner L.J. M. O'Donoghue M.O'D. E. Stern E.S. I . Sunagawa

Book Reviews

Gems of Sri Lanka (6th revised edn).

D.H. Ariyaratna, 2006. Ariyaratna, London. 177 pp, illus. in colour. Softcover. ISBN 955-95494-4-8. £14.95.

This sixth edition describes gem prospecting and mining, and the polishing and trading of Sri Lankan gemstones. There are introductory chapters on gem varieties and identification, but the style is generally non-technical, with appendices including a glossary of Sri Lankan terminology and tables of gemmological data.

It is an interesting book which contains a great deal of local information, together with sound advice for non-professional gem buyers. The quality of reproduction of some photographs could have been improved, and more useful proof reading would have been beneficial. Some technical details are open to criticism. It is implied, for example, that all emerald appears reddish through the Chelsea Colour Filter, and some birefringence values given in the tables are open to criticism. Overall, however, the book gives an interesting account of Sri Lankan methods of gem recovery, production and trading, and should appeal to those who are interested in the industry, especially if they intend to visit the country. P.J.E.D.

Mineralogical studies on luminescence in diamond, quartz and corundum.

J. Lindblom, 2005. Turun Yliopisto, Turku, Finland. (Annales Universitatis Turkuensis. Sarja-Ser. All, tom.183.)

A collection of papers by Lindblom and other authors. The texts are of considerable interest to gemmologists. The titles, following a general introduction, are: Differentiation of natural and synthetic quality diamonds by luminescence properties; Luminescence study of defects in synthetic as-grown and HPHT diamonds compared to natural diamonds; Details of intense light-green luminescence in quartz; Luminescence of thermally enhanced and beryllium-diffused rubies. Each paper has its own list of references and some illustrations are in colour. M.O'D.

Gems (6th edn).

M. O'Donoghue (Ed.), 2006. Elsevier: Butterworth/Heinemann, Oxford. xxx + 874 pp. ISBN 0-75-065856-8 (hardback). £90.00.

This new edition has been considerably updated and expanded since the fifth edition (1994). Michael O'Donoghue is both the editor and principal contributor, having been responsible for seventeen of the thirty-one chapters. In Part I, there are two useful introductory chapters, the first by Roger Harding being on the geological sources of gems, introducing the three main categories of rocks and the processes that formed them, before touching on the ages of gems, gem regions and gem recovery methods. This chapter ends with a useful note on the word 'origin' in certificates of authenticity: 'geological source' or 'geographical locality' may be preferable. The second chapter is by Ian Mercer on crystalline gem materials, introducing the crystal systems, the varying sizes of atoms and the concepts of habit, polymorphism, twinning, etch marks and the importance of directional properties (while avoiding the complications of face indices).

Part II deals mainly with individual gem species opening with two chapters on diamond, the first covering a general survey of diamond from the various regions of the world, before describing the effects on it of light and other radiation, and the appearance in the market of synthetic moissanite and other simulants. The second diamond chapter is by Alan Collins, and starts by reminding us that, on average, approximately 1 tonne of rock from a diamond mine must be processed to yield each carat of diamond–and even then less than 25 per cent is of gem quality. The methods used to produce synthetic diamonds are fully described, including chemical vapour deposition, and the origin of colour in diamond is fully explored, with details of colour enhancement by high-pressure-high-temperature annealing and a discussion on the colour change process. The chapter on ruby and sapphire takes full account of modern developments, with useful details on absorption spectra, and on the importance of Cr, V, Fe and Ti in the coloration of these gem minerals; the various methods of synthesis and simulation are described. The beryl chapter deals mainly with emerald, noting that Cr must be present if a green beryl is named as emerald, whereas green beryl coloured by vanadium should be termed green beryl. This section is followed by descriptions of chrysoberyl and alexandrite, spinel, topaz, tourmaline, the garnet family (with a sub-section on nomenclature), feldspars, zircon, peridot, quartz, opal, turquoise, lapis lazuli and jade. The remaining chapters deal with less common species (I found it odd to see cavansite described as resembling turquoise), natural glasses, simulants, synthetic gemstones, composite stones, plastics and pearls, and with the various cuts of gemstones and methods of value enhancement. There are appendices listing birthstones, a glossary of unusual and often misleading names, and a list of famous diamonds. This book builds on the foundations laid by previous editions, but gives a lot of space to the occurrences and localities of some of the species, e.g. topaz and feldspar. It is well illustrated with line diagrams and black-and-white photographs, together with an inset of 31 colour plates. It is unfortunate, however, that many of the captions for the numerous photographs illustrating the first chapter were apparently written in the expectation of them appearing in colour, making the references to interference colours, red garnets, green mica and pale brown glass, somewhat superfluous. In addition, the caption for Figure 1.7 is entirely wrong (it should be that of Figure 1.8a) and Figure 1.8b is a repeat of Figure 1.24 but with an inappropriate caption. R.A.H.

The Smale Collection: beauty in natural crystals.

S. Smale, 2006. Lithographie Inc., East Hampton, Connecticut. 204 pp, illus. in colour. Hardcover, ISBN: 9780971537187. €40.00.

Opening this magnificent book, I was reassured that the soul of the great mineral/crystal album was only sleeping and not moribund. This is exactly what the title and subtitle indicates – one man's collection (or a part of it) showing the pieces closest to his heart. The front cover with two crystals depicted introduces the fortunate reader to some of the finest photographs I have seen in handling most of the major gem and mineral books published for the past 40 years. Many of the photographs are of gem minerals: each caption gives the specimen size, where found and provenance. There is a short bibliography.

The author and noted photographer Jeff Scovil are to be congratulated on a most inspiring production. M.O'D.

Gemstones. Understanding – Identifying – Buying.

K. Wallis, 2006. Antique Collectors' Club, Woodbridge, Suffolk. 127 pp, illus. in colour. Hardcover. ISBN 1-85149-494-4. £15.95.

Gemstones is an ideal reference book for the gem collector, hobbyist and student gemmologist, its profuse high quality colour illustrations also enabling the identification by comparison of a range of gem materials. Written for the layperson as an introduction to the fascinating world of gemstones and jewellery, the first few pages of *Gemstones* lists the qualities which go to make up a desirable gem. These pages also contain explanations of some of the more technical gemmology terms together with descriptions of basic low-cost instruments for the identification of stones, both subjects of special interest to the author.

The history, myths and legends associated with gemstones are then covered before the book launches into its first major section, 'Precious stones', which deals with diamond, emerald, ruby and sapphire. The following section entitled 'The gemstones' includes a selection of the less well known inorganic stones ranging from andalusite to zircon. A third section 'Organic gems' features amber, ammolite, coral, horn, ivory, jet, pearl and shell. Samples of these gemstones and gem-mounted jewellery are illustrated in colour in all three sections, and this part of the book concludes with 'A selection of minor gemstones' which lists both rare and collectors' stones.

Practical cautionary advice is given in 'Buying gemstones', a section which includes information on the current types of enhancement treatments, on synthetics and simulants, and on gemstone collection. This is followed by notes on the metals and hallmarks used in jewellery mounts. The book continues with 'Gemstones around the world' which gives further useful advice on where to buy and what to avoid in various parts of the world. A final section 'Gems on the internet' warns of risks in buying loose stones and gem-set jewellery from unfamiliar websites. However, several useful and informative sites are listed in this section.

Printed on good quality paper, which further enhances the colour illustrations, the book concludes with a useful set of appendices (Glossary; Rainbow of colours; Specific gravity and refractive index of gemstones; Translations – gem names in English, French, German, Italian and Spanish; Tanzanite values; Diamond values; Comparative gem values; Further reading). P.G.R.

Khibiny.

V. Yakovenchuk, G. Ivanyuk, Y. Pakhomovsky and Y. Men'shikov, 2005. Laplandia Minerals Ltd in association with the Mineralogical Society of Great Britain and Ireland, Apatity and London. 466 pp, illus. in colour. ISBN 5-900395-48-0. €149.00.

This is one of the welcome surveys of a celebrated mineral area with which gemmologists with an interest in the wider world of minerals should be aware and ready to learn from. In any case, the profuse colour photographs, bibliography and well laid out text should be an example to those attempting similar depth of coverage of other classic deposits.

Khibiny is the largest nepheline syenite intrusion on Earth and more than 470 mineral species have been found there – around 88 for the first time. Gemmologists quite fairly will want to know about minerals with ornamental potential; while some blue sapphire crystals are illustrated, Khibiny is not a classic gemstone source. None the less, some species may one day turn up in a state appropriate for fashioning. I noted that sérandite, already known as most beautiful (and rare) crystals from Mt St. Hilaire, Quebec, is also reported from Khibiny, though as an inadequately characterized mineral or species of doubtful report.

The micromounter will have a more fruitful visit (if such are possible) encountering attractive crystals of rhodochrosite, eudialyte, cancrinite, villiaumite and mangan-neptunite.

The text is arranged in traditional chemical order and follows a description of the main mineral localities. Photographs give the size of the specimen depicted and the individual mineral descriptions, and the bibliography occupies 15 A4-sized pages.

For this reviewer, the best feature of the book was the opportunity to see examples of species known (if remembered) from reports of new mineral species (often from Russia and vicinity) in the less illustrated journals. M.O'D.

Proceedings of the Gemmological Association and Gem Testing Laboratory of Great Britain and Notices

Gem-A Awards

Gem-A Examinations were held worldwide in June 2006. In the Examinations in Gemmology 221 candidates sat for the Diploma Examination of whom 119 qualified, including six with Distinction and 30 with Merit. In the Foundation Gemmology Examination, 227 candidates sat of whom 174 qualified. In the Gem Diamond Examination 67 candidates sat of whom 33 qualified, including two with Distinction and six with Merit.

The Tully Medal for the candidate who submits the best set of answers in the Gemmology Diploma examination which, in the opinion of the Examiners, are of sufficiently high standard, was awarded to Dr Catherine Appleyard of Lewes, East Sussex. Dr Appleyard was also awarded the Anderson Bank Prize for the best non-trade candidate of the year in the Diploma in Gemmology examination.

The Christie's Prize for Gemmology for the best candidate of the year in the Diploma examination who derives her main income from activities essentially connected with the jewellery trade, has been awarded to Nicola Sherriff of Verdun, Quebec, Canada.

The Anderson Medal for the candidate who submitted the best set of answers in the Foundation Certificate examination which, in the opinion of the Examiners, are of sufficiently high standard, was awarded to Kay Harris of Penang, Malaysia.

The Hirsh Foundation Award for the best candidate of the year in the Foundation Certificate Examination was awarded to two candidates, Kay Harris of Penang, Malaysia, and Simon Dowden of Chadds Ford, Pennsylvania, U.S.A.

The Deeks Diamond Prize for the best candidate of the year in the Diploma in Gem Diamond examinations was awarded to Perry Huck of Harare, Zimbabwe.

The Bruton Medal was not awarded.

EXAMINATIONS IN GEMMOLOGY

Gemmology Diploma

Qualified with Distinction

Appleyard, Catherine, Lewes, East Sussex
Sherriff, Nicola, Verdun, Quebec, Canada
Wang Ling, Guilin, Guangxi, P.R. China
Wang Yu, Wuhan, Hubei, P.R. China
Westlake, Ingrid, Chamonix, France
Yu Heyu, Guilin, Guangxi, P.R. China

Qualified with Merit

Bell, Lucy Kate, Stirchley, Birmingham, West Midlands
Bergeron, Elise, Montreal, Quebec, Canada
Borg, David, Paola, Malta
Carrel, Leigh, Preston, Lancashire

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Gem-A Awards

Chan Wing Sze, Herleva, Kowloon, Hong Kong
Chen, Ying Chen, Taipei, Taiwan, R.O. China
Chui Yee Man, Tseung Kwan O, New Territories, Hong Kong
Han Keng Siew, Aloysius, Singapore
Huen Lai-Kei, Sheree, Richmond, British Columbia, Canada
Hui Wan Man, Kowloon, Hong Kong
Jiang Junjie, Wuhan, Hubei, P.R. China
Khan-Farrukh, Nayer, Washwood Heath, West Midlands
Larsson, Carl Niclas, Öregrund, Sweden
Larsson, Jacqueline, Amsterdam, The Netherlands
Lin, Jui-Yi, Taipei, Taiwan, R.O. China
Luzuriaga Alvarez, Martha Gladys, Laval, Quebec, Canada
Ma Yuli, Wuhan, Hubei, P.R. China
Mak Kim Yiu Keung, Ma On Shan, New Territories, Hong Kong
Matoba, Akiko, Nara City, Nara Pref., Japan
Murray, Helen Claire, Sutton Coldfield, West Midlands
Ni Ziqian, Guilin, Guangxi, P.R. China
Okuyama, Muneyuki, Kohoku-ku, Yokohama, Japan
Randrianantoandro, Minoarisoa Michelle, Ampandrianomby, Antananarivo, Madagascar
Razakarivony, Aina Anthony, Ampandrianomby, Antananarivo, Madagascar
Retsin d' Ambroise, Laura, Paris, France
Slovak, Kate, Leicester
Sun Yuan, Guilin, Guangxi, P.R. China
Surawy, Laura Katherine, London,
Yiu Ka Wah, Tokwawan, Kowloon, Hong Kong
Zhou Huijuan, Guilin, Guangxi, P.R. China

Qualified

Akiyama, Claire Nozomi, Saitama-Ken, Japan
Anderson, Nicola M., Edinburgh, Scotland
Bellec, Marion, Ergue-Gaberic, France
Butt, Andrew, Toronto, Ontario, Canada
Callaway, Heather, Stone, Staffordshire
Chan Lai Fong, Tuen Mun, New Territories, Hong Kong
Chandra, V. Subash, Krishnagiri, Tamil Nadu, India
Chang Mei-Yen, Karen, Taipei, Taiwan, R.O. China
Chen Shioulin, Taipei, Taiwan, R.O. China
Chen Li, Guilin, Guangxi, P.R. China
Cheung Man Yi, Kowloon, Hong Kong
Chiu Fong Ting, Tuen Mun, Hong Kong
Chow Wai Lam, Fan Ling, New Territories, Hong Kong
Coene, Helena, Brussels, Belgium
Danjo, Keiji, Kofu City, Yamanashi Pref., Japan
Deeley, Philippa, Etchingham, East Sussex
Dunn, Andrew Charles, Reading, Berkshire
Dunn, William A., Los Angeles, California, U.S.A.
Ellison, Armelle, Woking, Surrey
Forsberg, Erika, Bandhagen, Sweden
Furuya, Satoshi, Bunkyo-ku, Tokyo, Japan
Gauci, Karen Elizabeth, Burnaby, British Columbia, Canada
Geormas, Emmanuel, Byron, Greece
Gogna, Sanjeev, Una, Himachal Pradesh, India
Gouros, Arte, Coulsdon, Surrey
Hartley, Pauline, Woodkirk, West Yorkshire
Hayashi, Kinya, Tokushima City, Tokushima Pref., Japan
Haythornthwaite-Shock, Lucy, Mangotsfield, Bristol, Avon
Heywood, Natalie Louise, Enfield, Middlesex
Hu Kaifan, Wuhan, Hubei, P.R. China
Jiang Jingxia, Shanghai, P.R. China
Jones, Gary, Dudley, West Midlands
Jones, Jason Matthew, Beverley, East Yorkshire
Kidachi, Masanobu, Sagamihara City, Kanagawa Pref., Japan
Ko Hoi Fu, Shamshui Po, Kowloon, Hong Kong

Gem-A Awards

Kronis, Tamara Lynne, Toronto, Ontario, Canada
Kweon, Ji Eun, Suseong-Gu, Daegu, Korea
Kwok Mei Yee, Sindy, Ap Lei Chau, Aberdeen, Hong Kong
Lam Mei Hei, Cally, Shatin, New Territories, Hong Kong
Lam Siu Kuen, Hazel, Tseung Kwan O, Kowloon, Hong Kong
Latham, Elizabeth, Wallingford, Oxfordshire
Lee, Marian, Taipei, Taiwan, P.R. China
Leung Shiu Lok, Sam, Taipo, Hong Kong
Leung Shun Lok, Kowloon Bay, Hong Kong
Li Ling, Wuhan, Hubei, P.R. China
Li Mei, Guilin, Guangxi, P.R. China
Liao Dan, Wuhan, Hubei, P.R. China
Lin Wenyan, Wuhan, Hubei, P.R. China
Liu, Hongmei, Toronto, Ontario, Canada
Low, H. San, Chatham, Kent
Luo Xuan, Wuhan, Hubei, P.R. China
Meng Wenxiang, Shanghai, P.R. China
Morsink, Cornelis E., Stirling, Ontario, Canada
Nagao, Saeko, Kooriyama City, Fukushima Pref., Japan
Ogata, Etsuko, Osaka, Japan
Okano, Makoto, Iwatsuki City, Saitama Pref., Japan
Pan Pai, Guilin, Guangxi, P.R. China
Pang Yufei, Guilin, Guangxi, P.R. China
Parkes, Gabriella, London
Peng Daoming, Wuhan, Hubei, P.R. China
Razafindrasolo, Toky Ny Aina, Ampandrianomby, Antananarivo, Madagascar
Ren Chan, Wuhan, Hubei, P.R. China
Robichaud, Emilie Gould, London
Singh, Priti, Jaipur, India
Sourendre, Shah Rupal, Ampandrianomby, Antananarivo, Madagascar
Tam Tin Sang, Daniel, Richmond, British Columbia, Canada
Tanaka, Yumi, Toyonaka City, Osaka, Japan
Tang Yin Tung, Chai Wan, Hong Kong
Thiebaut, Ivane, London
Tonkin, Claire Louise, Stratford, London
Tsoi Mei Yu, Fanling, New Territories, Hong Kong
Tsui Wing Sze, Yuen Long, New Territories, Hong Kong
Van Spaendonk, Ann, Kalmthout, Belgium
Wang Wei, Guilin, Guangxi, P.R. China
Wang Yuchao, Wuhan, Hubei, P.R. China
Widmer, Danielle Helene, Mississauga, Ontario, Canada
Wong Mars, Ma On Shan, New Territories, Hong Kong
Wong Yuen Kwan, Annie, North Point, Hong Kong
Xue Lilin, Wuhan, Hubei, P.R. China
Xue Xiaoxin, Wuhan, Hubei, P.R. China
Ye Mengqian, Guilin, Guangxi, P.R. China
Zhu Cheng, Guilin, Guangxi, P.R. China
Zou Jin, Guilin, Guangxi, P.R. China

Gemmology Foundation Certificate

Qualified

Ahn, Su Jin, Seoul, Korea
Amicone, Maria, La Salle, Quebec, Canada
Aung Myo Oo, Kamayut Township, Yangon, Myanmar
Baker, David Mark, Bath, Somerset
Bellec, Marion, Ergue-Gaberic, France
Booth, Eveline Violet, London
Bove, Bertrand, Vitry Sur Seine, France
Bracey, Anne Christine, Birmingham, West Midlands
Caulton, David, Dore, Sheffield, South Yorkshire
Cederholm, Jenny, Stockholm, Sweden
Chan Kai Chi, Seeheim-Jugenheim, Germany
Chan Che Min, Tsuen Wan, Hong Kong
Chan Tak Kit, Emily, Kowloon, Hong Kong
Chan Tsz Yan, Yuen Long, New Territories, Hong Kong
Chan Wing Kwok, Hong Kong
Chan Yuet Ngai, Taikoo Shing, Hong Kong
Chau Kit Ying, Lily, San Francisco, California, U.S.A.

Gem-A Awards

Chen Cui, Guilin, Guangxi, P.R. China
Cheung, Nelly, Tai Koo Shing, Hong Kong
Cheung Chi Shing, Peter, Lam Tin, Kowloon, Hong Kong
Cheung Ching Ping, Candy, Tseung Kwan O, Kowloon, Hong Kong
Chien Lien Chin, Taichung, Taiwan, R.O. China
Chin Suet Ying, Kwai Chung, New Territories, Hong Kong
Cho, Hee Jeong, Anyang-Si, Gyunggi-Do, Korea
Choi, Jae Jin, Seoul, Korea
Chu Kong Ting, Hong Kong
Chu Shuk Man, Carmen, Shatin, New Territories, Hong Kong
Chung Man Yin, Phoenix, Tuen Mun, Hong Kong
Clark, Denise A., London
Claydon, Louise, Morden, Surrey
Conway, Mark, Northampton
Corser, Elizabeth, Wellington, Shropshire
Cote, Gaetan, St. Lambert, Quebec, Canada
Craddock, Natalie, Bridport, Dorset
Cui, Xianzhong, London
de Josselin de Jong, Joris, Amsterdam, The Netherlands
Dowden, Simon, Chadds Ford, Pennsylvania, U.S.A.
Doyle, Helen Anne, Weymouth, Dorset
Driscoll, Brian John, New York, U.S.A.
Drummond, Jean, Farnham, Surrey
Ferneyhough, Ella, Henley-in-Arden, Warwickshire
Fletcher, Alison Jane, Birmingham, West Midlands
Fontaine, Clotilde, Versaille, France
Freidericos, Nikitas, Athens, Greece
Fung Kei Yan, Apleichau, Hong Kong
Gosden, Paul Jeremy, London
Gourlet, Agnes, Chartres, France
Guter, Danielle, Solna, Sweden
Halabi-Lenvenyte, Urte, London
Harris, Kay, Penang, Malaysia
Hassey, Lauren Adriana, London
Heit, Liesbeth, London
Henderson, Rheanan, Edinburgh, Scotland
Holley, Deborah, Trowbridge, Wiltshire
Horn, Chandra Leah, Montreal, Quebec, Canada
Hsiao, Pei Ying, Taichung, Taiwan, R.O. China
Hu, Helen, London
Huang, Lei, Smethwick, Staffordshire
Huang Ching-Ping, Shanghai, P.R. China
Hudson, Joanne, Victoria Falls, Zimbabwe
Hui Man Kwong, Kwai Chung, New Territories, Hong Kong
Hui Wing Hing, Kowloon, Hong Kong
Jeavons, James, Geebung, Queensland, Australia
Johnson, Belinda, Birmingham, West Midlands
Joshi, Sumit D., Pune, Maharashtra, India
Katayama, Shinko, Colombo, Sri Lanka
Khaing, Htite Htite, Ahlone Township, Yangon, Myanmar
Kim, Hyoung Suk, Seoul, Korea
Kim, Seul Gi, Gwangju, Korea
Kim, Ji Eun, Chungbuk-Do, Korea
Kobayashi, Taisuke, Tokyo, Japan
Kong Yang, Guilin, Guangxi, P.R. China
Koundouraki, Evagelia, Athens, Greece
Lam Shu Wing, Kwun Tong, Hong Kong
Lee Joo Yeon, Daegu, Korea
Lee Min Sook, Seoul, Korea
Lee Cheuk Ming, Kowloon, Hong Kong
Lee Oi Yan, Christine, Tai Po, New Territories, Hong Kong
Leung Kee Yun, Tin Shui Wai, New Territories, Hong Kong
Li Kam Tim, Quarry Bay, Hong Kong
Li Qianhe, Guilin, Guangxi, P.R. China
Lilley, Samantha, Fyfton, Leicestershire
Lim, Joon Suk, Seoul, Korea
Lin, Chun Hsien, Taipei, Taiwan, R.O.C.
Liu Mei-Chun, Bianca, Fanling, New Territories, Hong Kong
Liu Zijian, Guilin, Guangxi, P.R. China

Gem-A Awards

Lo, Sunny, Kowloon, Hong Kong
Lui Chi Kong, Matthew, Shatin, New Territories, Hong Kong
Luzuriaga Alvarez, Martha Gladys, Laval, Quebec, Canada
Ma Tsz Kwan, Hong Kong
McFadden, Robin, Birmingham, West Midlands
Machefert, Jean-Michel, Cormeilles En Parisis, France
Mahesh M. Babu, Palai, Kottayam, Kerala, India
Mansell, Melanie, Plymouth, Devon
Mareso, Daniele, Brockley, London
Matsuura, Miho, Yokohama City, Kanagawa Pref., Japan
Menekodathu Remanan, Amarnath, Surat, Gujarat, India
Meng Wenxiang, Shanghai, P.R. China
Miller, Me'Shell, North Highlands, California, U.S.A.
Mok Chiu Fai, Kwai Chung, New Territories, Hong Kong
Mok So Yiu, Tsuen Wan, Hong Kong
Naito, Ayako, Tokyo, Japan
Nakagawa, Yumi, Kitakatsuragi-gun, Nara Pref., Japan
Nakanishi, Nobuo, Ikeda City, Osaka, Japan
Ng Sheung Kan, Quarry Bay, Hong Kong
Nicolson, Louise, London
O'Connor, Darla Jo, Citrus Heights, California, U.S.A.
Okabe, Yuichi, Kawasaki City, Kanagawa Pref., Japan
Parhi, Chinmayee, Surat, India
Park, Hyun Jin, Daegu, Korea
Park, Ji Min, Daegu, Korea
Peng Chih Pin, Taipei, Taiwan, R.O. China
Preston, Paula, London
Prickett, Sydney James, Brisbane, Queensland, Australia
Puniani, Geeta, Surat, Gujarat, India
Qin Xue, Shanghai, P.R. China
Rafferty, Frank, Ambrieres-Les-Vallees, France
Raimundo Da Silva, Aldina, Verdun, Quebec, Canada
Raj, Kara, Ampandrianomby, Antananarivo, Madagascar
Rajak, Mohamad Zakaria Bin Abdol, Yangon, Myanmar
Rakotobe, Vanessa, Ampandrianomby, Antananarivo, Madagascar
Rebmann, Olivier, Geneva, Switzerland
Rodjanagosol, Anothai, Bangkok, Thailand
Rutanatumsri, Kunthida, Bangkok, Thailand
Said, Ibrahim, Grangetown, Cardiff, Wales
Sakata, Yuko, Kanazawa City, Ishikawa Pref., Japan
Sawamura, Tsukasa, Tokyo, Japan
Sek Kam Yin, Kwun Tong, Kowloon, Hong Kong
Shah, Arti, South Harrow, Middlesex
Shah Bhavin Kirtikumar, Surat, India
She Pak Yu, New Territories, Hong Kong
Shi, Huadan, Shanghai, P.R. China
Shimizu, Maki, Oyama City, Tochigi Pref., Japan
Singh, Priti, Jaipur, India
Smith, Laura Sian, Reading, Berkshire
Sritunayothin, Pattra, Bangkok, Thailand
Stevens, Janet Connors, Bellevue, Washington, U.S.A.
Stevens, Laura Ann, Bewdley, Worcestershire
Tai Ai Hwa, Taipei, Taiwan, R.O. China
Tanvangi, Pragya, Surat, India
Tarner, Charles B., Sacramento, California, U.S.A.
Tidd, Lauren, Churchdown, Gloucester
To Wing See, Tuen Mun, Hong Kong
Tong Sen Yue, Sandy, Central, Hong Kong
Tsang, Fiona T.Y., Aberdeen, Hong Kong
Uchiyama, Mio, Ichikawa City, Chiba Pref., Japan
Veenhoven, Taletta, Amsterdam, The Netherlands
Wang Hao, Guilin, Guangxi, P.R. China
Wang Qi, Guilin, Guangxi, P.R. China
Wang Wenqi, Guilin, Guangxi, P.R. China

Gem-A Awards

Watson, Jennifer, Sutton Coldfield, West Midlands
Webster, Penny A., Creston, California, U.S.A
Wen, Wen Chi, Taichung, Taiwan, R.O. China
Wilkinson, June, Warmington, Peterborough, Northamptonshire
Wong Chi Kin, Mid-Levels, Hong Kong
Wong Ho Ming, Kowloon, Hong Kong
Wong Kin Ching, Tai Po, New Territories, Hong Kong
Wong Ling Ling, Tseung Kwan O, New Territories, Hong Kong
Wootton, Sophie Louise, London
Wright, Peter, Chaddesley Corbett, Worcestershire
Wu Zhao Min, Kowloon, Hong Kong
Xie Yi, Shanghai, P.R. China
Yadanar Lwin, Sanchung, Myanmar
Yamada, Masashi, Tokyo, Japan
Yang Chung Mei, Judy, Tsing Yi, New Territories, Hong Kong
Yau Wai Yee, Kowloon, Hong Kong
Yen Kwan, Humphrey, Central, Hong Kong
Yoon, Yoo Jin, Daegu, Korea
You Jia, Shanghai, P.R. China
Yun Mao, Shanghai, P.R. China
Zhang Jinying, Guilin, Guangxi, P.R. China
Zhao Lisha, Guilin, Guangxi, P.R. China
Zhuo Jun Xu, Shanghai, P.R. China

GEM DIAMOND EXAMINATION

Qualified with Distinction
Braham, Adrian David, Reigate, Surrey
Li, Kehan, Enfield, Middlesex

Qualified with Merit
Chown, Philip, Sevenoaks, Kent
Chiu Wai Yu, Yuki, Sheung Shui, New Territories, Hong Kong
Goodwille, Zoe, Battersea, London
Gregory, Kerry Honor, St Mellons, Cardiff, Wales
McKellar, John, Hereford
Wong Lai Yin, Kowloon, Hong Kong

Qualified
Belsham, Lesley, Great Dunmow, Essex
Branting, Andreas, London
Chan Wai Fong, Wah Fu Estate, Hong Kong
Fellows, Andrew Simon, Walsall, West Midlands
Fong Po Yi, Kowloon, Hong Kong
Garcia, Victoria, Sydenham, London
Haythornthwaite-Shock, Lucy, Mangotsfield, Bristol, Avon
Hui Ming Yan, Ray, Tseung Kwan O, New Territories, Hong Kong
Hui Tsz Yin, Kowloon, Hong Kong
Jezova, Olesia, London
Keung Wing Fun, Kowloon, Hong Kong
Lee Wah Ho, Yuen Long, Hong Kong
Leung Hang-Fai, Henry, Kowloon, Hong Kong
Marlow, Joseph Stephen, Sutton Coldfield, West Midlands
Qin Si, Wuhan, Hubei, P.R. China
Rice, Danielle, Halsham, East Yorkshire
Sheehy, Matthew James, Burnham, Berkshire
Tulo, Karen, Ludwigshafen, Germany
Wang Ligeng, Wuhan, Hubei, P.R. China
Watson, Jennifer, Sutton Coldfield, West Midlands
Webb, Stephen Charles, Nelson, New Zealand
Williams, John, London
Wong Ka Lai, Kowloon, Hong Kong
Wong Lai Wa Lever, Kowloon, Hong Kong
Wong Yuen Ching, Winnie, Kowloon, Hong Kong

Members' Meetings

London

A private viewing of the exhibition 'Fabergé and the Russian Jewellers' was held at Wartski's, Grafton Street, London W1, on 16 May.

On 11 October a group visit to the exhibition 'Bejewelled by Tiffany' at the Gilbert Collection, Somerset House, London SW1, was arranged, preceded by a lecture by the exhibition's curator Clare Phillips.

The 2006 Annual General Meeting was held on 27 June at Sotheby's, New Bond Street, London W1 (see report p.251). The AGM was followed by a Private Viewing of Sotheby's June sale 'Jewels: Antique, Period and Contemporary'. Joanna Hardy, Daniela Mascetti and Alexandra Rhodes of Sotheby's Jewellery Department spoke about selected items from the sale.

Gem Discovery Club Specialist Evenings

The Gem Club meets every Tuesday evening at the Gem-A London headquarters when Club members have the opportunity to examine a wide variety of stones.

Once a month gem and mineral specialists bring along items from their own collections; short introductory talks are followed by hands-on sessions under the guidance of the guest specialist. The April guest was Jason Williams of G.F. Williams & Co., of Hatton Garden, who gave a presentation on the cutting of synthetic gemstones in Southern China. In May Dr Jack Ogden took a look at the history of spurious and treated gemstones from ancient Egypt and Western Asia, through Roman imitations to heat treatment of corundum in sixteenth-century Ceylon, in his presentation 'Fooling some people for much of time: 5000 years of gem deception'. In his 'Cameo performance' in June, jewellery dealer Richard Digby spoke about the materials commonly used for cameos and intaglios, and factors likely to affect value. Maggie Campbell Pedersen was the July specialist, giving information on amber and how to identify fakes. In September jewellery valuer Rosamond Clayton gave a presentation on jade, describing the various treatments and simulants, and assessing the quality for the purpose of valuation. Club members were able to examine a collection of rare gemstones in October, brought along by Michael O'Donoghue.

Midlands Branch

Branch meetings held at the Earth Sciences Building, University of Birmingham, Edgbaston, included a talk on 31 March by John Harris entitled 'Chasing rainbows by observing spectra', 'Arts and Crafts jewellery' by Antiques Roadshow expert Keith Baker on 29 September, and on 27 October a talk on tourmaline by Dr Michael Krzemnicki, director of education at SSEF, Switzerland. The annual summer supper party was held at Barnt Green on 17 June.

North East Branch

On 20 April David Callaghan spoke on cameos and intaglios and on 13 July Brian Dunn gave a talk entitled 'The Naughty Nineties'. Both meetings were held at the Ramada Jarvis Hotel, Wetherby.

North West Branch

Regular Branch meetings have been held at the YHA Liverpool International, Livepool 1. On 19 April Melanie Francis spoke on trends at the 2006 Tucson Gem and Mineral Fair, on 21 June Brian Jackson reviewed the garnet family, on 19 July Tracey Jukes took members for a trip around the world of coloured gemstones with a talk entitled 'Thoughts from 'a broad'', and on 20 September Gem-A Chairman Professor Alan Collins spoke on colour enhancement in diamond and how it may be detected.

Scottish Branch

The Annual Scottish Branch Conference was held at the Lovat Hotel, Perth, from 28 April to 1 May. Speakers included Dr Karl Schmetzer (keynote), Richard Digby, Alan Hodgkinson, Helen Molesworth, Dr Mark Newton and Thom Underwood. A variety of workshops and demonstrations were held on the Sunday afternoon and the

Conference concluded with a field trip on the Monday to Lochan na Lairige. (A report on the Conference was published in *Gems & Jewellery*, May 2006.)

Scottish Branch meetings moved to the new venue of Napier University, Craiglockhart Campus, Edinburgh, in June. On 13 June Brian Jackson gave a talk entitled 'Gemmological wanderings in Russia'. This was followed on 22 August by 'Gem pegmatites of Southern California' by Jesse Fisher, on 12 September with 'A history of gemmology via the literature' by Nigel Israel' and on 24 October with 'All colours of diamond' by Martin Vainer.

South East Branch

A 'Jem Jumble', a bring-and-buy sale, was held at the Gem-A headquarters on 29 October.

South West Branch

Meetings held at the Bath Royal Literary Scientific Institution, Bath, included a presentation on 23 April by Stephen Kennedy on recent developments in the UK coloured stone trade and on 8 October 'The colours of gemstones and how we see them' by Doug Garrod.

Annual General Meeting

The 2006 Annual General Meeting was held at Sotheby's, New Bond Street, London W1, on 27 June. Professor Alan Collins chaired the meeting and welcomed members. The Annual Report and Accounts were approved. E. Alan Jobbins was re-elected as President of the Association for the term 2006-2008. Alan Collins, E Alan Jobbins and Michael O'Donoghue retired from the Council in rotation and, being eligible, Alan Collins and Michael O'Donoghue were re-elected. Alan Jobbins did not seek re-election to the Council. Tony Allnutt and Peter Dwyer Hickey retired in rotation from the Members' Audit Committee and being eligible were re-elected to the Committee. Hazlems Fenton were re-appointed as auditors for the year.

Following the business part of the evening, attendees were generously entertained with wine at a private view of the 'Jewels: Antiques, Period and Contemporary'. The Association is very grateful to Sotheby's for hosting the evening, and particularly to the Directors and staff in the jewellery department for their hospitality and for the fascinating talks about some highlights of the jewellery on show.

Membership

Between 1 April and 31 October 2006, the Council approved the election to membership of the following:

Fellowship and Diamond Membership (FGA DGA)

Brohi, Nosheen, London, 2005
Callaway, Heather, Stone, Staffordshire, 2006
Suraway, Laura Katherine, London, 2006
Tsui, Tommy, Kowloon, Hong Kong, 1997

Fellowship (FGA)

Al-Hadad, Raed, Abu Dhabi, United Arab Emirates, 2006
Anderson, Nicola M., Edinburgh, Scotland, 2000
Bell, Lucy Kate, Stirchley, West Midlands, 2006
Butt, Andrew, Toronto, Ontario, Canada, 2006
Carrel, Leigh, Preston, Lancashire, 2006
Challani, Mohit, Chennai, India, 2006
Chan, Mei Fong, Kowloon, Hong Kong, 2006
Chandhok, Simran, New Delhi, India, 2006
Chaudry, Mohamed Ashraf, Rochdale, Lancashire, 2006
Costin, Charlotte, Horsham, West Sussex, 2006
Deeley, Philippa, Etchingham, East Sussex, 2006
Dunn, William A., Los Angeles, California, U.S.A., 2006
Eastwood-Barzado, Elizabeth, Dully, Switzerland, 2006
Emond, Jacinthe, Laval, Quebec, Canada, 2006
Guasrella, Rita, Vetulonia, Italy, 1996
Jones, Gary, Dudley, West Midlands, 2006
Jones, Jason Matthew, Beverley, East Yorkshire, 2006
Lam, Hazel, Kowloon, Hong Kong, 2006

Lam Mei Hei, Cally, Shatin, Hong Kong, 2006
Leung Shiu Lok, Sam, Taipo, Hong Kong, 2006
Leung, Shun Lok, Kowloon, Hong Kong, 2006
Lin, Lang-Dong, Taipei, Taiwan, R.O. China, 2006
Liu, Hongmei, Toronto, Canada, 2006
Low, H. San, Chatham, Kent, 2006
Morsink, Cornelius E., Stirling, Ontario, Canada, 2006
Murray, Helen Claire, Sutton Coldfield, West Midlands, 2006
Ong Chin Sing, Singapore, 2006
Philogene, Stephanie, Cachan, France, 2005
Rakotoarison, Dominique, Antananarivo, Madagascar, 2005
Rana, Aska, Ahmedabad, India, 2006
Tsang Kwai Ying, Kowloon, Hong Kong, 2006
Wessels, Jurie Hendrik Wyand, London, 2004
Zhu, Healy, Yiwu City, P.R. China, 2005

Diamond Membership (DGA)

Loaker, Alistair, Stevenage, Hertfordshire, 2002
Marlow, Joseph Stephen, Sutton Coldfield, West Midlands, 2006
Garcia Grandal, Victoria, London, 2006
Ng Ka Kit, New Territories, Hong Kong, 2006
Papapavlou, Despina-Maria, Christoforos, Greece, 2006
Parsonson, Chloe, London, 1996
Rice, Danielle, Halsham, East Yorkshire, 2006
Williams, Michael, London, 2006
Wong Yu Lap, Angel, Shatin, Hong Kong, 2006
Yeung Ka Yee, Anthea, Pok Fu Lam, Hong Kong, 2004

Associate Membership

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Obituary

Rodney F. Collyer FGA (D.1953), Rubery, Birmingham, West Midlands, died in March 2005.

Margaret Irwin FGA (D. 1971), Mickle Trafford, Cheshire, died on 5 April 2006.

Errata

On p. 91, author address number 2, for 'Saranovy' read 'Saranovsky'

On p. 93, Figure 2, key, for 'pykrite' read 'picrite'; for 'metaarcoses' red 'meta-arkoses'; for 'Facial' read 'Facies'

On p. 94, Figure 3, top left, for 'chromic' read 'chromite'

On p. 100, Figure 13, the formula for uvarovite should read $Ca_3Cr_2(Si_3O_{12})$

On p. 109, the first U.H. Kyi abstract, for 'pegmatic' read 'pegmatitic'

On p. 127, first column, line 18, for 'He quiet belief …' read 'His quiet belief …'

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Tuesday 12 December	**London:** Gem Discovery Club Specialist Evening – Diaspore. CIGDEM LULE-WHIPP
Tuesday 23 January 2007	**Scottish Branch:** Stone setting workshop. DAVID WEBSTER
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Tuesday 27 February	**Scottish Branch:** Notes from the Gem Testing Laboratory. STEPHEN KENNEDY
Sunday 18 March	**Midlands Branch:** Loupe and lamp training day
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The Editor is glad to consider original articles shedding new light on subjects of gemmological interest for publication in *The Journal.* Articles are not normally accepted which have already been published elsewhere in English, and an article is accepted only on the understanding that (1) full information as to any previous publication (whether in English or another language) has been given, (2) it is not under consideration for publication elsewhere and (3) it will not be published elsewhere without the consent of the Editor.

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Abbreviations for titles of periodicals are those sanctioned by the *World List of scientific periodicals* 4th edn. The place of publication should always be given when books are referred to.

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(See Crowning glory: the identification of gems on the head reliquary of St Eustace from the Basle Cathedral Treasury, p.169)

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Formation of large synthetic zincite (ZnO) crystals during production of zinc white

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Abstract: *Remarkable zincite crystals have formed as a by-product of zinc white production in Olawa Foundry, Poland. Some are of gem quality and have been faceted. Small primary crystals formed by reaction of zinc vapour with carbon dioxide from fuel burning gases leaking through faults in a diaphragm of a retort furnace. Some of these have undergone carbon monoxide-promoted and zinc vapour-assisted sublimation to form large secondary crystals. Many of these crystals are brightly coloured and transparent, and have been found up to 2 kg in weight. Most of the crystals are fluorescent in ultraviolet light.*

Keywords: *chemical assisted sublimation, crystal growth, zinc oxide, zincite*

Introduction

Zincite is a relatively rare natural oxide of zinc, with the ideal formula ZnO. The world's largest deposit of zincite is near Franklin and Ogdensburg, Sussex County, New Jersey, USA. The district is famous for its wide range of more than 250 minerals, including crystals of rare fluorescent species (Palache, 1935; Bancroft, 1984). Zincite occurs here mainly as a massive material or as small granules with other major zinc-bearing minerals such as willemite and franklinite, embedded in a white crystalline limestone.

† Sadly John W. Nowak died on 16 April 2007. An obituary notice is given on p. 355.

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Zincite crystals are quite rare and generally tend to be small. The world's best crystals, transparent and several cm in length, are known only from Buckwheat mine, on Mine Hill close to Franklin. Only a few natural gem-quality zincite crystals, displaying a magnificent deep red colour have been cut. One example weighing 20.06 ct is on exhibit in the National Gem Collection at the Smithsonian Institution in Washington D.C. and others are in the American Museum of Natural History in New York City (Sinkankas, 1959).

Not surprisingly, the appearance in the early 1980s of very large transparent and brightly coloured zincite crystals at major mineralogical shows created considerable interest. This rare and exciting cutting material was attractive mainly to lapidary enthusiasts, and many have been faceted (Kammerling and Johnson, 1995) (*Figure 1*). Despite their aesthetic beauty, this zincite was far less appealing to conservative mineral collectors because its synthetic origin was unmistakeable. From the scientific point of view an intriguing issue was the question of the conditions in which such spectacular zincite crystals could grow.

Figure 1: *Faceted zincite crystal. Photograph by R.S.W. Braithwaite.*

The increasing demand for this synthetic zincite had been largely fulfilled for a time, but now the material is only available from dealers' old stocks. The mineralogical and gemmological communities had not been aware of the provenance of these zincite crystals (Crowningshield, 1985; Kammerling and Johnson, 1995) until information became available on the Internet. In this article we establish that the distinctive and exquisite zincite crystals which appeared in Europe and in the U.S.A. during the period 1980–2004 originated from the Olawa Foundry SA near Wroclaw in Poland. We also describe the major features of zinc white production technology that unexpectedly caused the formation of these large zincite crystals as an accidental by-product, and present unique photographs documenting this phenomenon.

Crystalline ZnO is a wide band-gap semiconductor for various high-tech applications. Especially promising is the use of ZnO crystals to produce blue lasers for digital video-disc systems and data storage, emitter devices in the blue and ultraviolet region, and piezoelectronic devices (Nause *et al.*, 1999). Currently very few technologies can deliver centimetre-sized ZnO mono-crystals; one is based on hydrothermal growth (Kortunova and Lyutin, 1995; Suscavage *et al.*, 1999), another on chemical vapour transport (CVT) (Noritake *et al.*, 1991a,b; Fujitzu *et al.*, 1993; Mycielski *et al.*, 2004), and the most promising one, based on pressurized melting (Nause *et al.*, 1999), has the potential to produce low-cost ZnO wafers up to 100 mm in diameter. All the listed technologies require quite sophisticated processing equipment. In contrast, Olawa's simple furnace has delivered transparent ZnO crystals weighing up to 2 kg. Evidently, in this case the mechanism of crystal growth and vapour transport was highly effective. However, the plant was not designed to produce structurally uniform ZnO crystals, so unfortunately these crystals do not meet the requirements for electronic material.

Zinc white production at the Olawa Foundry SA, Poland

Zinc white is an important industrial product for numerous applications. Most is consumed in the rubber, dye, ceramic and pharmaceutical industries. Of the several production technologies described in the literature (Bailar, 1973; Kirk and Othmer, 1970), Olawa Foundry SA produces zinc white as a powder according to the so-called French method, by vaporizing pure zinc and burning it in air. The process is conducted in a single retort furnace of modified and patented construction (Jasinski *et al.*, 1987; Igielski *et al.*, 1988). A cross-section of the furnace is shown diagrammatically in *Figure 2*.

The furnace consists of two sections, the upper being the combustion chamber (3) and the lower the vaporizing chamber (2). Heating gas is burned in the combustion chamber, creating temperatures up to 1400-1500 C. The combustion chamber is separated from the vaporizing chamber by a ceramic diaphragm (1), conducting heat so that the metallic zinc (2a) placed in the lower section is heated by radiation, melted and vaporized. The zinc vapour is overheated to ~ 950 C and leaves the furnace through the burner opening (6) into the oxidation chamber (4), where in contact with wet air it forms zinc white powder, which is then collected.

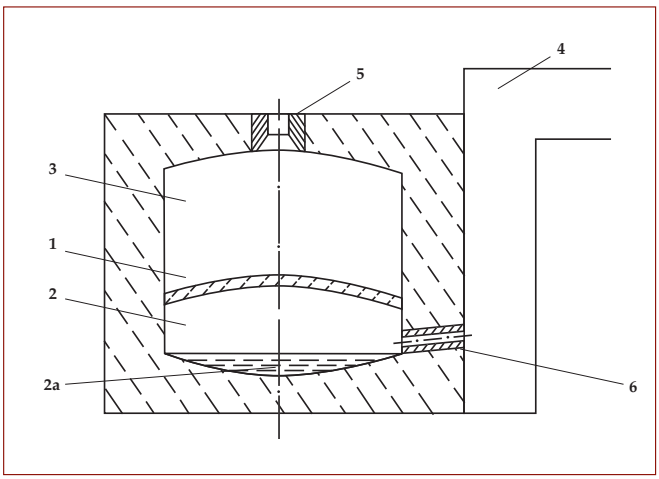

Figure 2: *Cross-section of a single retort furnace for zinc white production at Olawa (Jasinski et al., 1987): (1) ceramic diaphragm; (2) vaporizing chamber; (2a) metallic zinc melt; (3) combustion chamber; (4) zinc vapour oxidizing chamber; (5) gas burner; (6) zinc vapour burner.*

Initial exploitation of the plant exposed several minor technical difficulties, which have gradually been eliminated. The most serious problem was a slow increase in heating gas consumption per tonne production of zinc white. A periodic shutdown of the plant revealed that the top of the vaporizing chamber, against the lower part of the diaphragm, was virtually covered by hundreds of kilograms of small to giant colourful zincite crystals and many crystals had fallen to the bottom (*Figure 3*).

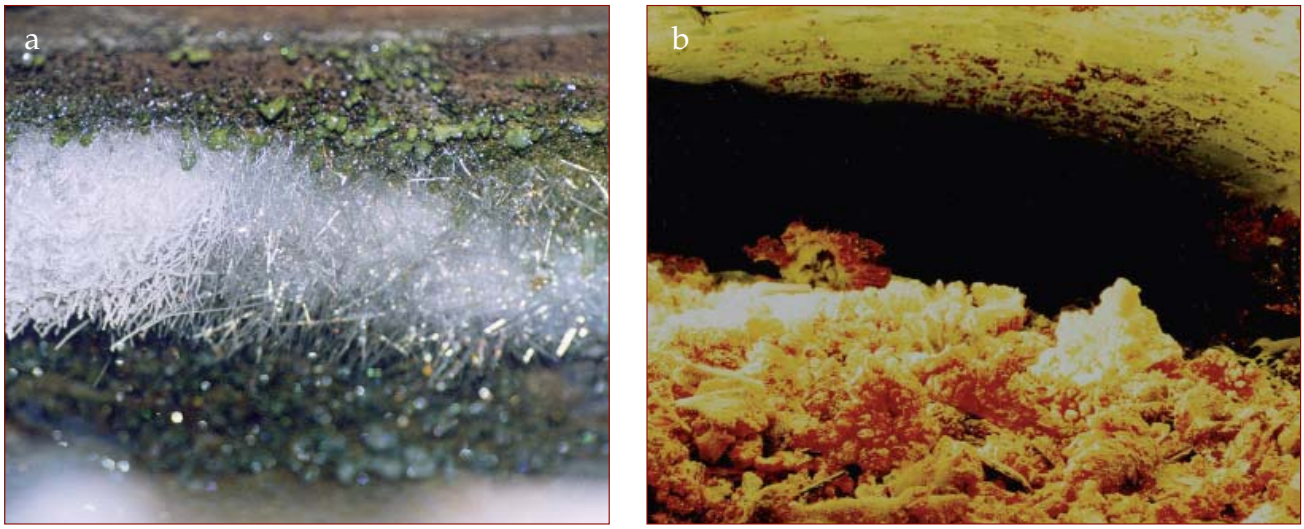

Figure 3: *Zincite crystals in vaporizing chamber: (a) on roof of chamber; (b) fallen crystals on floor of chamber. Photographs by R. Jaslan.*

As far as we know, other zinc white producers have not reported such a technological anomaly. From the very beginning the reason for the unexpected formation of zincite crystals was attributed to an unpredicted micro-porosity of the diaphragm. In order to improve the diaphragm there was a serious effort to select appropriate heat resistant ceramic materials, cements and seals, and apply an innovative construction technology.

After considerable experimentation, rewarding results have been achieved. At the maintenance shutdown of the furnace in 2002 no crystalline material was found, but some residual remains after zinc evaporation, such as for example an Fe-Al alloy, were found in addition to the usual ashes. Uninterrupted furnace runs have since been extended from four to six months to one full year and by February 2005 to over two years.

Mechanism of the zincite crystal formation

The correct production process for zinc white in a single retort furnace should not create macro-crystals of zinc oxide. The necessary condition for the formation of crystals in the vaporizing chamber was the presence of micro-flaws in the defective ceramic diaphragm. As a result the fumes from the combustion chamber could slowly penetrate the vaporizing chamber. The fumes contain nitrogen, carbon dioxide and possibly some remaining oxygen in addition to other minor components. Contact of the zinc vapour with these fumes caused a rapid generation of apparently primary zincite crystals in an oxidizing atmosphere according to the following reactions:

(1) $Zn(g) + CO_2 \rightleftharpoons ZnO(s) + CO$

(2) $Zn(g) + \frac{1}{2}O_2 \quad ZnO(s)$

Distinctive zones of crystal formations on the diaphragm 'matrix' show variable local extension and peculiar spatial formations. The zones closest to the diaphragm display small needles of complex morphology (*Figure 3a*). The more distant zones show considerably larger secondary crystals displaying a habit typical of many synthetic zincite crystals (*Figures 3b* and *6*) as illustrated in the *Atlas der Krystallformen* (Goldschmidt, 1913) and many show dissolution or growth features. The following factors should be taken into account in considering the nature of the driving force involved in the sublimation:

- A high vertical temperature gradient reaching 350–400 C between the molten zinc at 907 C (bottom of the vaporizing chamber) and the diaphragm at 1250 C. This gradient was not constant and likely to vary over the diaphragm surface.
- ZnO crystals were formed on the lower diaphragm surface, and on the side walls of the vaporizing chamber.
- With a high, unstable vertical gradient of zinc vapour concentration, there could be horizontal transfer of zinc vapour.

Interestingly, the precise mechanism of ZnO(s) sublimation is not well known. Generally, the process is slow *in vacuo* at high temperatures (>1500 C). However, a number of additives, such as wet hydrogen, argon or chlorine can act as sublimation activators, which dramatically increase the sublimation rate at temperatures as low as ~1000 C (Triboulet *et al*., 1991). This mechanism is called 'chemical assisted sublimation' or 'chemical vapour transport' and has been used in the laboratory synthesis of transparent ZnO mono-crystals (Noritake *et al*., 1991a,b; Fujitzu *et al*., 1993; Isshiki *et al*., 2005b).

Reversible reaction (1) shows that gaseous zinc and solid zinc oxide can act in

association with a third key reactant, carbon dioxide (Bailar, 1973; Yu *et al*., 2005). Consequently, equation (1) is important for an explanation of zincite crystal growth. From left to right, equation (1) describes ZnO crystal formation inside the vaporizing chamber. Initially, fast-rate stage needles of primary ZnO crystals were formed in an oxidizing micro-atmosphere containing concentrated CO_2 close to open cracks. The temperature of these crystals was nearly equal to the temperature of the diaphragm. In the reverse direction equation (1) actually describes the mechanism of carbon monoxide promoted sublimation of ZnO(s). This mechanism can be described in terms of a cycle (*Figure 4*).

CO released in the initial oxidation (equation 1) reacted with a crystal surface of ZnO(s) (A); the Zn(g/s) and CO_2 generated were flushed out from the crystal surface by a stream of Zn(g) (B). As a result, a diluted mixture of ZnO(g) and CO in flowing Zn(g) was formed instantly (C), this interacting with already formed ZnO(s) (D). One mole of CO can dissolve many molar equivalents of ZnO(s) because CO is regenerated during the oxidation reaction (C). The reductive mixture [ZnO(g) + CO + Zn(g)] formed the atmosphere of the upper part of the vaporizing chamber. This mixture was responsible for ZnO crystal growth, erosion, dissolution, habit changes, colouring and transport. Direct formation of ZnO(g) by sublimation of ZnO(s) under the sole influence of Zn(g) (reaction d) is doubtful, and unlikely at ambient pressure (Triboulet *et al*., 1991).

Centres of sublimation and growth were randomly distributed over the diaphragm surface. They were subject to rearrangement in response to changes in heat transfer and concentration of [ZnO(g) + CO + Zn(g)] as well as a reaction to opening and closing of cracks.

Methane from the fuel gas would also be a very strong sublimation promoter if present in larger than trace amounts in the fumes entering the vaporizing chamber. The oxidation of methane by ZnO (equation 3) has recently been found very useful for producing metallic zinc and synthesis gas ($CO + 2H_2$) (Jamshidi *et al*., 2005).

(3) $ZnO(s) + CH_4 = Zn(g) + CO + 2H_2$

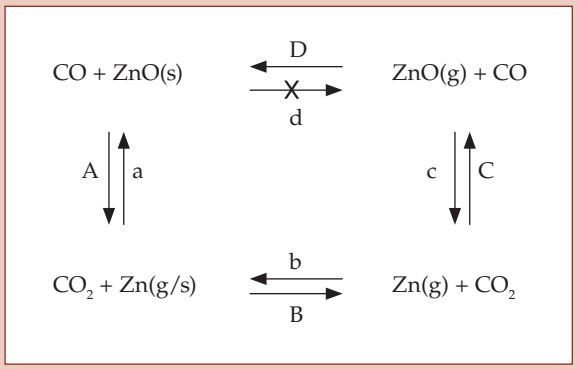

Figure 4: Reaction cycle involved in the formation of the zincite crystals. ZnO(s) = surface of ZnO crystal; ZnO(g) = vapour of ZnO in Zn(g) solvent; Zn(g/s) = Zn atom adsorbed on ZnO(s); Zn(g) = Zn vapour. A = degradation of ZnO(s) surface under the influence of CO; B = desorption of Zn(g) from ZnO(s) surface by Zn(g) vapour; C = oxidation of Zn(g) by CO_2 to generate ZnO(g); D = growth of ZnO(s) crystal from ZnO(g) vapour; a, b, c, d = reverse reactions respectively of A, B, C, D.

A recent patent briefly describes the synthesis of high-purity high quality ZnO crystals using CO and CO_2 as vapour transport agents, providing strong experimental support for our postulated sublimation mechanism (Isshiki *et al*., 2005b).

Tons of zinc vapour run continuously through the plant every day. The transporting potential of this solvent at the top of the chamber was apparently adequate to keep increasing masses of zincite in constant transport.

Coloration

Natural zincite crystals from Franklin display reds of variable intensity and hue (Sinkankas, 1959). The colour of these crystals is caused by the presence of Mn^{2+} ions in tetrahedral sites and is additionally influenced by some Fe^{3+} content (Bates *et al*., 1966). ZnO crystals grown hydrothermally in the presence of Mn^{2+} ions especially for jewellery purposes are red-orange (Kuz'mina *et al*., 1991); those contaminated with iron are amber-coloured (Laudise *et al*., 1960), and others are green as a result of incorporation of unknown impurities or lattice defects (Suscavage *et al*., 1999).

Zincites from Olawa are free from colouring elements such as iron or manganese (Kammerling and Johnson, 1995) as even if traces of these elements were present in the raw zinc, which is of high purity, they would not co-evaporate with the zinc and would stay in the melting tank. Under laboratory conditions, when zinc oxide is heated in zinc vapour, additional neutral zinc atoms diffuse to octahedral interstices in the crystal lattice (Mohanty and Azaroff, 1961; Greenwood, 1968; Isshiki *et al*., 2005a; Lott *et al*., 2005). These n-type doped crystals are brightly coloured, just like the material from Olawa, and darker crystals are the most conductive. The hue and intensity of the colour largely depends on the concentration of the extra zinc atoms in the crystal lattice, but the physical mechanism of coloration remains to be elucidated (Kotera and Yonemura, 1992; Erhart *et al*., 2005).

A striking feature of the zincites from Olawa is their high transparency and rather uniform colour distribution. We postulate that a sublimation process of ZnO(s) inside the furnace was CO promoted and Zn(g) assisted. As a consequence, the growing secondary crystals were easily doped by a Zn(g) incorporation mechanism. Variation in growth conditions resulted in some gradual colour changes, typically observed in the [0001] direction, e.g. yellow to pale yellow or colourless, green to colourless and red to yellow. Long lasting ageing at the high temperatures involved caused diffusive redistribution of doping centres. Presumably, the presence of lattice defects conjugated to electron donors such as neutral zinc atoms are responsible for colour development.

Description of the zincite crystals from Olawa

Zincite crystals are hexagonal, of wurtzite structure, space group $P6_3mc$, with a = 3.250 Å, c = 5.207 Å; Z = 2. Refractive indices are high, with ω = 2.013, ε = 2.029; birefringence = 0.016; optically uniaxial, positive. Mohs hardness = 4.5 – 5; specific gravity = 5.67 (Bailar, 1973). Their gemmological properties have been described in detail by Kammerling and Johnson (1995) and readers are referred to their Table II for a concise summary.

The zincite crystals from Olawa display enormous diversity in size, habit and colour. They can be divided into two genetically different subgroups.

1. Primary crystals formed by oxidation of Zn(g) by CO_2 from furnace fumes (oxidizing environment)

These are small, from sub-millimetre to 5–8 mm, rarely larger. Thin needles with sharp edges and smooth faces are common, but frequently signs of dissolution over the full crystal length are present. Crystal tips are sharp or pinhead-like, with tiny pyramidal terminations (*Figure 5a*). Exceptional short needles terminated by {0001} plates of dendritic snowflake-like crystals have been found, as well as beautiful crystal aggregates (*Figure 5a* and *b*). These are formed by tiny needles growing in striking order perpendicularly on prismatic or pyramidal faces of larger needles, to form many patterns resembling flowers, brushes, combs or firs. The crystals are predominantly colourless, pale yellow or green, rarely intensely yellow to reddish yellow.

Analogous zincite crystals of complicated morphology but of nanometre size, obtained by a vapour transport process have been extensively studied by Yu *et al*. (2005).

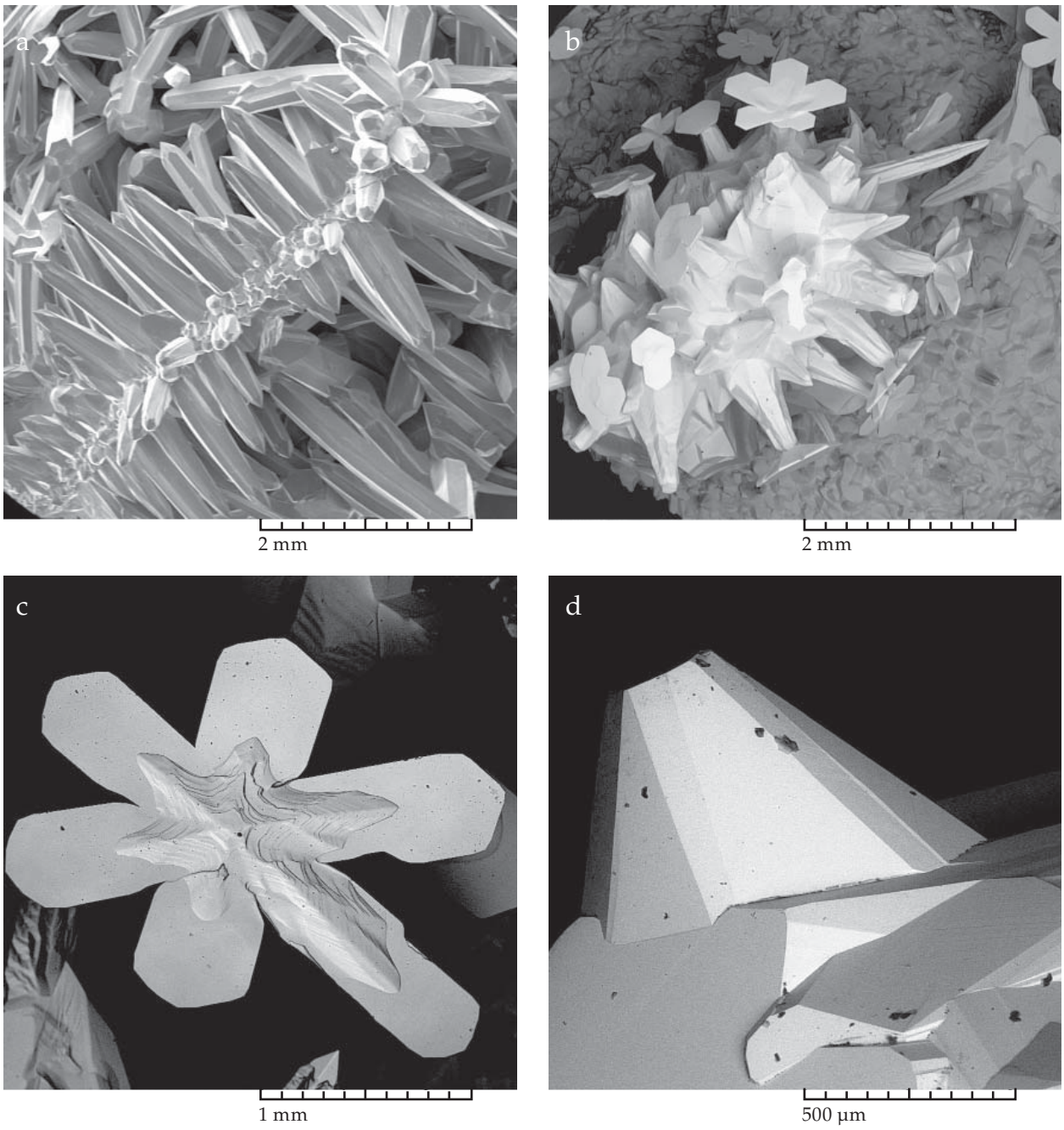

Figure 5: SEM photographs of primary zincite crystals: (a–b) crystal clusters; (c–d) single crystals. Photographs by K. Polanski. Vega © Tescan.

2. Secondary crystals formed from ZnO(g) vapours by CO-promoted transformation of ZnO(s) in the presence of Zn(g) (reductive environment)

Secondary zincite crystals form complex groups, commonly on relict primary zincites, and are usually much larger, commonly reaching 10–12 cm in length and 1 cm in diameter. Gigantic transparent crystals 10–15 cm in length, 5–6 cm in diameter and weighing up to 2 kg have been found and a cluster is shown in *Figure 6*. The larger secondary zincites show a strong tendency to grow along the [0001] direction, and possess a typical hexagonal prismatic habit with diverse pyramidal terminations (*Figure 7*). Complex pyramidal crystals showing pronounced hemimorphism with the {0001} face are commonly observed. Most of the larger secondary zincite crystals display dissolution or growth features on somewhat rounded surfaces and edges.

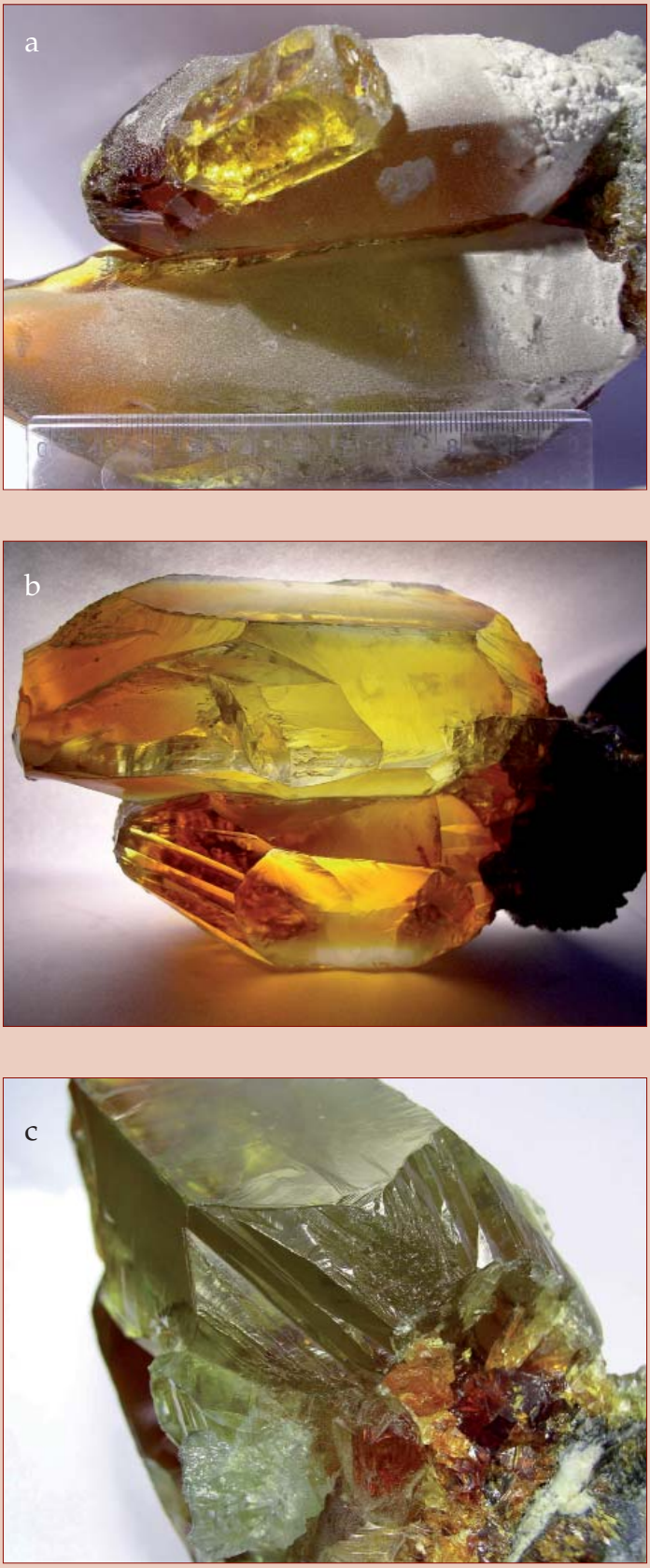

Figure 6: Giant zincite crystal cluster weighing 3.5 kg from the collection of A. Ignaciak: (a) front view; (b) back view; (c) view from underneath. Photographs by M. Krystek.

Most secondary zincite crystals are transparent and are usually intensely coloured in shades of red, orange, yellow, green or brown. Their colour intensity varies from pale to deep and saturated. Colour distribution in the larger crystals is rather uniform, gradual or sectoral colour changes being uncommon. Yellow tones are clearly detectable in green and red crystals. Small, thick prismatic near-colourless crystals of almost blue-white hue were also observed; their lack of coloration is intriguing, and these crystals may be primary in genesis, being formed slowly in an oxidizing atmosphere in which doping was inhibited. The laboratory preparation of large colourless single crystals of ultra-pure zinc oxide by controlled oxidizing of zinc vapour at elevated temperature was described by Bailar (1973).

Fluorescence

Most of the crystals display fluorescence under ultraviolet illumination (Kammerling and Johnson, 1995), typically of a yellowish green to white (*Figure 8*). The darker orange crystals are mostly inert under short-wave (254 nm) and variably fluorescent under long-wave (365 nm) or LED UV illumination; paler crystals of all colours, especially those growing on the orange crystals are usually strongly fluorescent. The small complex primary spiky crystals with snowflake-like overgrowths fluoresce pale yellow in short-wave UV, with bright green patches in their base areas, and are brighter under LED UV, the 'snowflakes' and branches being brightest. Natural very pale yellowish prismatic zincite crystals formed from volcanic vapours in Kamchatka show a strong, very similar fluorescence (e.g. specimen 01-68 in R.S.W. Braithwaite collection).

Inclusions

A number of crystals were examined microscopically for the presence of inclusions. Many appeared to be free from obvious inclusions, but others contained wispy dark bands, fissures, glossy spherules or dull oval-shaped bodies (*Figure 9*). These complement the three examples illustrated by Kammerling and Johnson (1995).

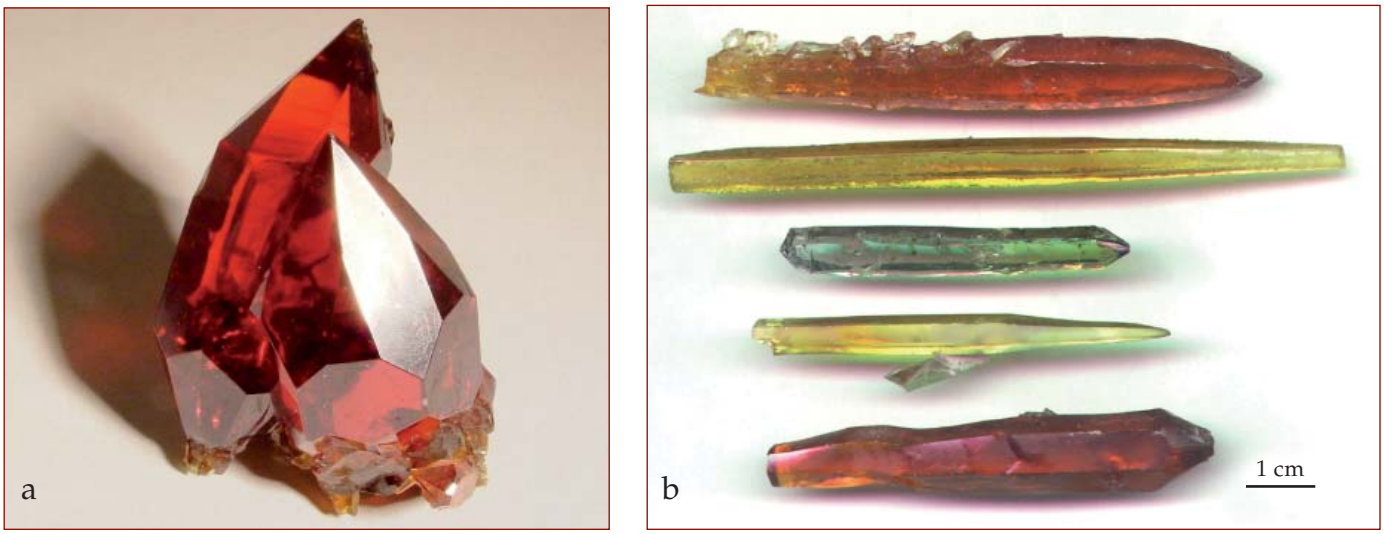

Figure 7: Secondary zincite crystals: (a) two red 5 cm crystals from the collection of A. Miziolek, photograph by M. Krystek; (b) selection of long crystals from the collection of R.S.W. Braithwaite; photograph by R.S.W. Braithwaite.

Conclusions

Olawa's zinc-white production furnace has produced remarkable synthetic ZnO crystals, some in quantities and forms unlike any previously reported. We conclude that the formation of large ZnO crystals as a by-product has resulted from a defective porosity of a ceramic diaphragm in the furnace. In consequence, carbon dioxide from burning fuel gas penetrated cracks and oxidized zinc vapour to form small primary zincite crystals. These crystals underwent carbon monoxide-promoted, zinc vapour-assisted sublimation to form large secondary zincite crystals, some of gem quality.

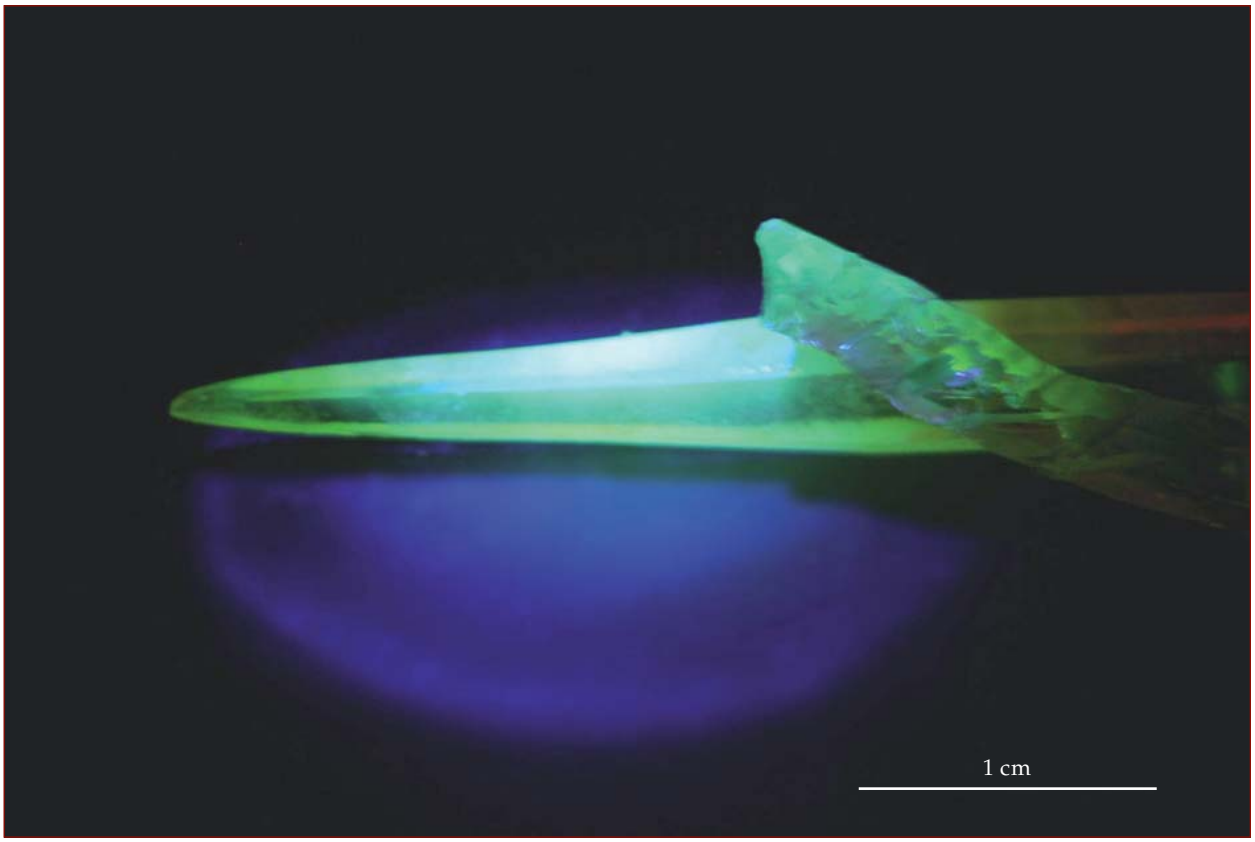

Figure 8: Zincite crystal fluorescing under LED-UV illumination. Photograph by R.S.W. Braithwaite.

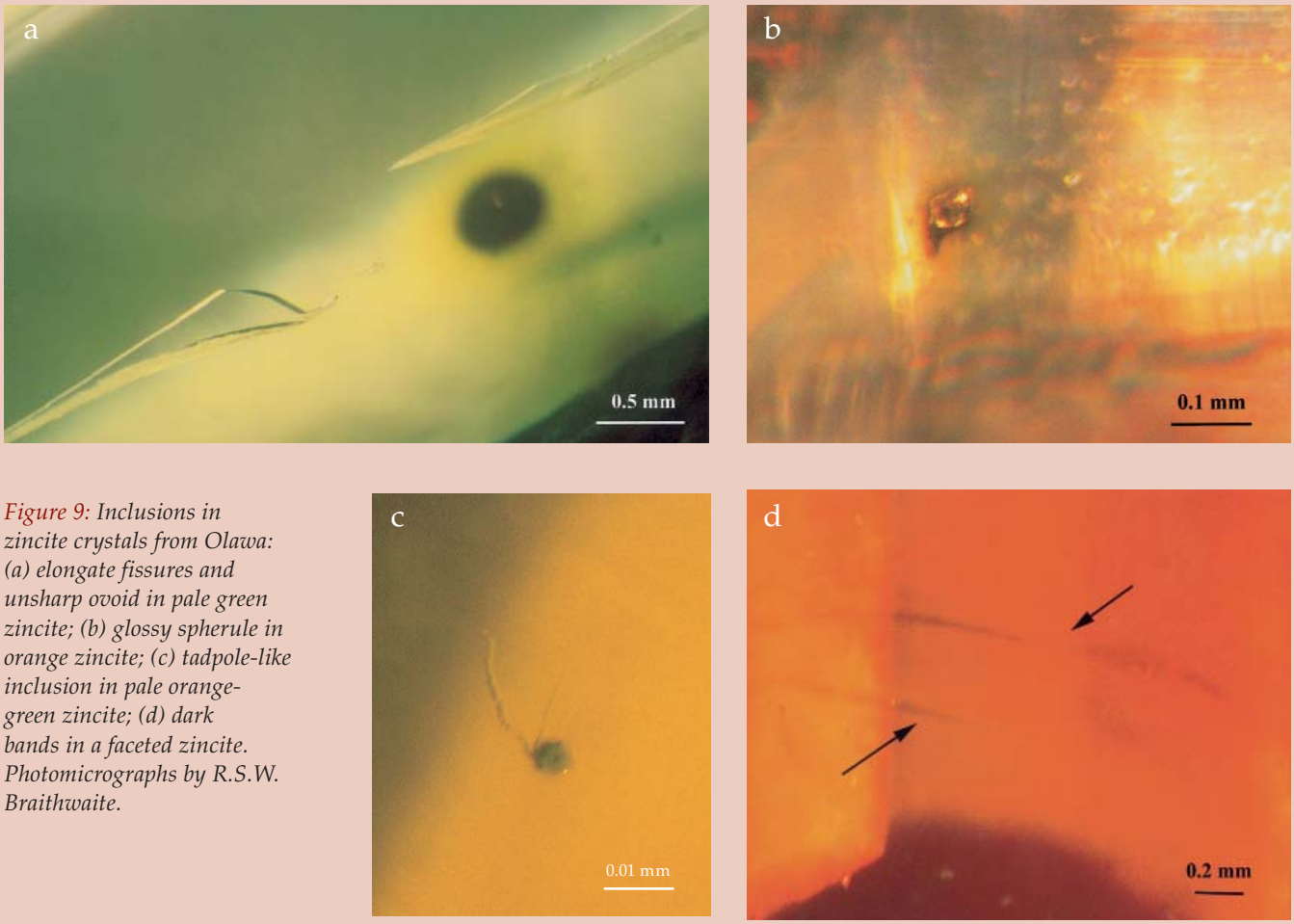

Figure 9: Inclusions in zincite crystals from Olawa: (a) elongate fissures and unsharp ovoid in pale green zincite; (b) glossy spherule in orange zincite; (c) tadpole-like inclusion in pale orange-green zincite; (d) dark bands in a faceted zincite. Photomicrographs by R.S.W. Braithwaite.

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Colour zoning in heat-treated yellow to yellowish-orange Montana sapphires

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Abstract: *Heat-treated sapphires in the yellow to yellowish-orange colour range originating from Montana, U.S.A., were examined in order to determine if the growth patterns and colour zoning which are present after the heat treatment process are helpful for the distinction of this material from beryllium-diffusion-treated sapphires.*
The investigations were performed in immersion on a diffused-light box at low magnification and with a horizontal immersion microscope at higher magnification.

The orange colour centres which are responsible for the intense yellow to yellowish-orange coloration of the samples are predominantly developed in intensely coloured basal growth sectors which are surrounded by rhombohedral and dipyramidal sectors with much lighter yellow coloration. This characteristic pattern of growth structures and colour zoning is useful for locality determinations as well as for a distinction from beryllium-diffusion-treated sapphires in the yellow to orange colour range.

Introduction

Untreated sapphires from the Rock Creek deposit in Montana, U.S.A., are light blue, bluish green, greenish blue, yellowish green, yellow or pink with low saturation. Due to this low colour saturation, only a small percentage of the untreated rough can be used for jewellery purposes. Consequently, the material is heat treated to develop more intense blue or yellow colours. A detailed description of heat treatment processes performed in reducing or oxidizing atmospheres was published by Emmett and Douthit (1993), who also discussed the causes of colour in heat-treated and untreated material.

Light yellow untreated or heat-treated Montana sapphires are coloured by minor amounts of iron. Upon heat treatment in an oxidizing atmosphere, an intense yellow coloration is developed in the central part of a certain percentage of the sapphire crystals, which is caused by magnesium-related colour centres. Consequently, a more intense yellow to yellowish-orange coloration is observed in such heat-treated sapphires. If the colour centres are developed by heat treatment in

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the rarer chromium-bearing sapphires from Montana, a pinkish-orange to reddish-orange 'padparadscha' coloration is obtained. The colour zoning of both types of heat-treated Montana sapphires is readily visible in rough stones, but is more difficult to observe in faceted stones (see the examples given by Emmett and Douthit, 1993). A similar colour centre to that observed in Montana sapphires was described in heat-treated yellow, orange or reddish-orange sapphires from Sri Lanka by Schmetzer *et al*. (1983).

Since the appearance of large quantities of beryllium-diffusion-treated sapphires in the yellow to reddish-orange colour range at the end of 2001 (McClure *et al*., 2002), the application of various microscopic criteria for a distinction of beryllium-diffusion-treated from simply heat-treated sapphires has been discussed by various authors, and a detailed summary is given by Emmett *et al.* (2003) and Schmetzer and Schwarz (2005). The high temperatures applied in 'normal' heat treatment and beryllium diffusion procedures mean that decomposed or even melted mineral inclusions can be caused by both processes with similar visible results. Thus, no single microscopic inclusion feature described so far can be used to determine whether a sapphire is diffusion-treated or simply heat-treated.

A direct beryllium determination as proof of beryllium diffusion treatment can be done by laser ablation-inductively coupled plasma-mass spectroscopy (LA-ICP-MS), secondary ion mass spectroscopy (SIMS) or laser-induced breakdown spectroscopy (LIBS). Although some of the major gemmological laboratories have established at least one of these techniques directly in their premises or have access to such analytical instruments, e.g. at university or other research laboratories, the situation in Bangkok (which may reflect the trade in general) was characterized by A. Peretti in June 2006 as follows:

"As we test beryllium-treated corundum by LIBS everyday in Bangkok, we have learned that smaller heated yellow sapphires goods are generally mixed with beryllium-treated yellow sapphires goods. The dealers (that I have spoken to) have mostly given up on the 'beryllium-treated' versus 'non-beryllium-treated' small sapphire issue, because the costs of testing exceed the costs of the materials. Beryllium-treated corundums are most likely widespread, particularly in the smaller goods. Larger coloured sapphires, however, are more carefully handled (so far my opinion). Therefore, beryllium-treatment seems to establish itself in the smaller goods within the general term of 'heat-treatment'".

Consequently, a quick screening test for possible beryllium diffusion treatment, especially for larger lots of small sized samples, is still highly desirable and necessary.

Due to the development of colour centres by heat treatment only in specific growth sectors of sapphire crystals, the examination of growth patterns in combination with colour zoning was used for a distinction of untreated, heat-treated and beryllium-diffusion-treated sapphires from specific localities, especially for a recognition of simply heat-treated yellow or pinkish-orange to reddish-orange (padparadscha) sapphires from Sri Lanka (Schmetzer and Schwarz, 2005). Growth patterns in combination with colour zoning were also used for a characterization of heat-treated, chromium-bearing sapphires from Montana in the orange to pinkish-orange or reddish-orange colour range. Chromium-free, beryllium-diffusion-treated Montana sapphires with a homogeneous yellow, yellowish-orange or orange coloration were also studied, but no detailed investigation is available for chromium-free or almost chromium-free, heat-treated samples from Montana in the yellow to yellowish-orange colour range. Therefore, the present study was undertaken to determine whether the characteristic growth pattern and colour zoning found in chromium-bearing sapphires from Montana applies also for chromium-free samples; that is, to find out if a microscopic examination is also helpful for a recognition of this type of material and its distinction from homogeneously coloured beryllium-diffusion-treated samples in the same colour range.

Figure 1: *Faceted round Montana sapphires, diameters from 5.2 to 5.4 mm, weights from 0.60 to 0.80 ct.*

Figure 2: *Heavily waterworn sapphire crystals from Montana, sizes from about 3 to 5 mm, weights from 0.33 to 0.72 ct.*

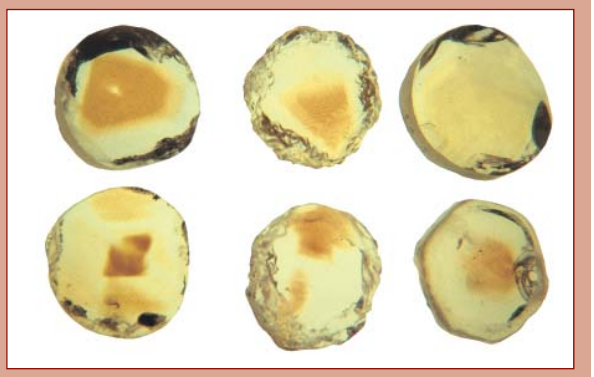

Figure 3: *Slices of rough waterworn sapphire crystals from Montana, polished on both sides, diameters from about 5 to 6 mm, weights from 0.58 to 1.08 ct.*

Most of these heat-treated samples shown in figures 1, 2 and 3 show a characteristic colour zoning with intensely coloured yellow, yellowish-orange or brownish-yellow zones surrounded by somewhat lighter yellow areas.

Materials and methods

Untreated lots of Montana sapphires from two major localities, i.e. from the Rock Creek and Missouri river deposits, were studied and reported on by Schmetzer and Schwarz (2005). The results of these examinations, especially the morphology and growth pattern of untreated material, will be cited shortly thereafter (for details of these occurrences, especially for information about history of the sapphire production and colour ranges of the sapphires, see Hughes (1997) and Kane (2003); the origin of the sapphire deposits was recently discussed by Berg and Dahy (2002)).

For the present study we examined three lots of heat-treated Montana samples:

a. 32 faceted round sapphires, diameters from 5.2 to 5.4 mm, weights in the range of 0.60 to 0.80 ct (*Figure 1*);

b. 40 rough heavily waterworn sapphire crystals, sizes from about 3 to 5 mm, weighing from 0.33 to 0.72 ct (*Figure 2*); and

c. 11 slices of rough waterworn sapphire crystals, polished on both sides, diameters from about 5 to 6 mm, weighing from 0.58 to 1.08 ct (*Figure 3*).

Lots (a) and (b) came from the stock of Fine Gems International, Helena, Montana; lot (c) was from the research and teaching collection of one of the authors (DS). All three lots have known treatment histories, and no beryllium diffusion was performed on any of the samples. Lots (a) and (b) consisted predominantly of Rock Creek sapphires, but some may come from the Missouri river deposit. Lot (c) was said to contain only Rock Creek samples.

A few of our samples have a very light yellow homogeneous body colour, but most show more intense yellow, orange or brownish-orange zones (*Figures 1* to *3*). These zones are easily visible in polished slices or in the rough material, but were more difficult to observe in some faceted stones.

The colour distribution in all samples was studied by immersing the stones in methylene iodide, simply placing them on a diffused-light box in a Petri dish. Although

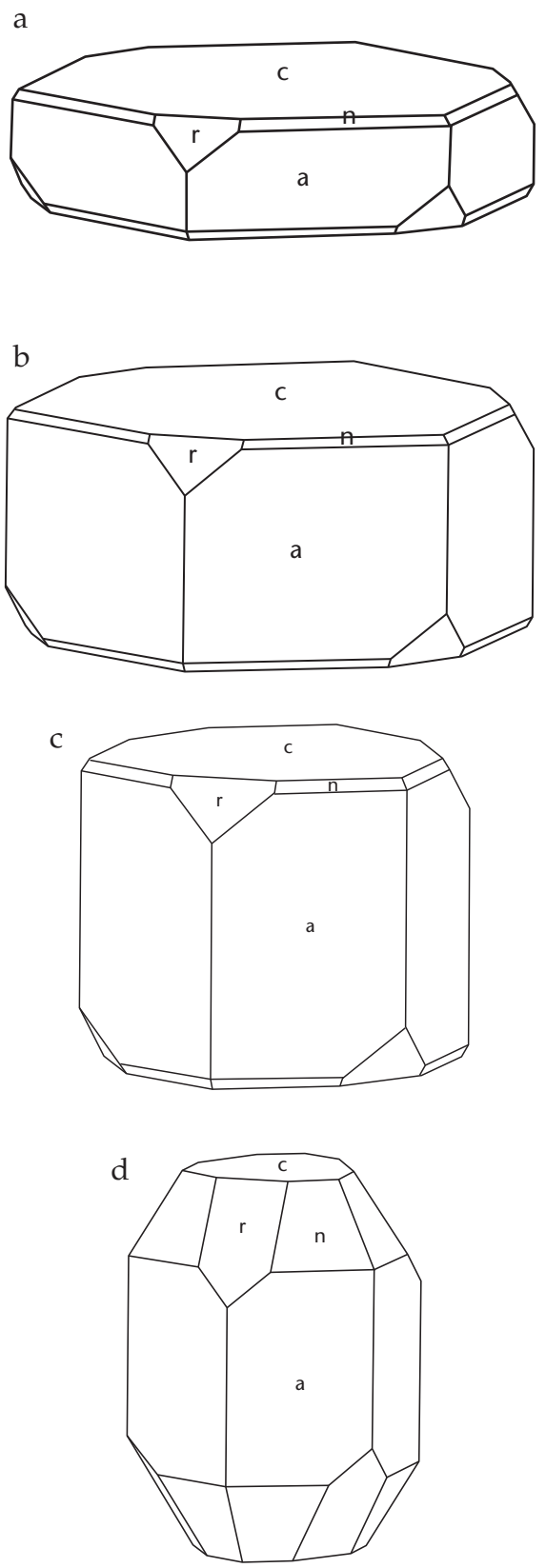

Figure 4a to d: *Typical habits of sapphire crystals from Montana, U.S.A., consisting of the basal pinacoid* c, *the hexagonal prism* a, *the hexagonal dipyramid* n *and the positive rhombohedron* r; *different habits are due to wide variation in the size ratios of* a *and* c.

the colour distribution within each stone can be seen with the unaided eye, examination with a loupe (10×) or with a microscope at low magnification (10× to 20×) provides better results. Exact determination of growth structures and colour zoning related to growth patterns was performed with a horizontal immersion microscope using a special sample holder with two rotation axes and specially designed eye-pieces.

Trace and minor element contents of 40 samples were obtained using EDXRF spectroscopy. The analyses were performed with a Tracor Northern Spectrace 5000 system, using a program specially developed for trace element geochemistry of corundum. Non-polarized absorption spectra of 20 samples were recorded using a Perkin-Elmer Lambda 19 spectrophotometer.

Results

Morphology and growth patterns of untreated Montana sapphires

The habits of Montana sapphires from both the Rock Creek and Missouri river deposits, are predominantly formed by the hexagonal prism *a* $\{11\bar{2}0\}$ and the basal pinacoid *c* {0001}, with subordinate rhombohedral *r* $\{10\bar{1}1\}$ and dipyramidal *n* $\{22\bar{4}3\}$ faces. Due to large variations in the relative size of the hexagonal prism *a* compared to the basal pinacoid *c*, there is a large habit variation between tabular, thick tabular, equidimensional and prismatic (*Figure 4*).

In the immersion microscope, growth patterns consisting of the four crystal forms mentioned above are visible. In a view perpendicular to the *c*-axis, there is either a pattern consisting of the basal pinacoid *c* in combination with the hexagonal dipyramid *n* and the prism *a* (*Figure 5a*) or a pattern consisting of the basal pinacoid *c* in combination with the rhombohedron *r* (*Figure 5b*). The two characteristic views are related to each other by a rotation of 30 about the *c*-axis (for further details refer to Schmetzer and Schwarz (2005)).

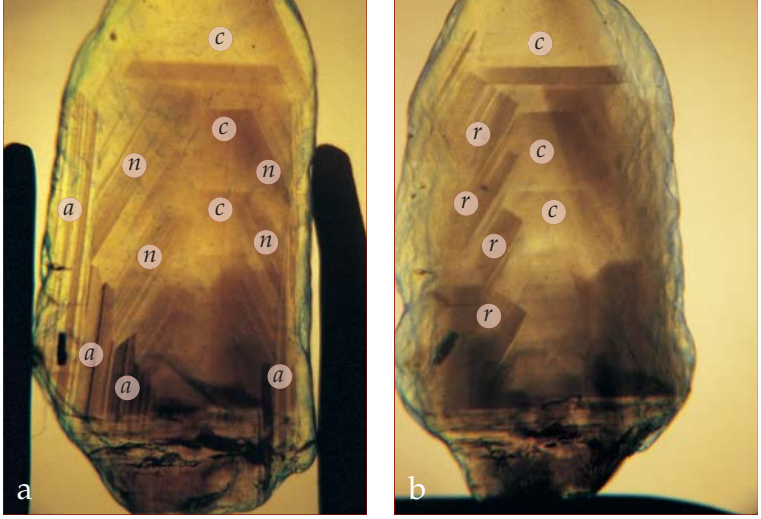

Figure 5a,b: *Growth pattern and colour zoning in an untreated greenish-blue sapphire from Montana, U.S.A. a) View perpendicular to the* c*-axis, the basal pinacoid* c*, two hexagonal prism faces* a *and two hexagonal dipyramids* n *are visible. b) View perpendicular to the* c*-axis, the basal pinacoid* c *and the positive rhombohedron* r *are visible; Figures a) and b) are related by* a *rotation of 30° about the* c*-axis.*

Chemical and spectroscopic properties and causes of colour

X-ray fluorescence analysis showed a large variation of iron contents between 0.19 and 0.94 wt.% Fe_2O_3. Although the chromium contents of 22 sapphires were below the detection limit of the analytical method (0.005 wt.% Cr_2O_3), 18 contained minor amounts of chromium (between 0.005 and 0.013 wt.% Cr_2O_3). The chromium versus iron distribution of the 40 analysed research samples is plotted in *Figure 6* and compared with chromium and iron contents in padparadscha-type heat-treated Montana sapphires studied previously (Schmetzer and Schwarz, 2005).

The spectroscopic properties of our sapphires (*Figure 7*) are consistent with the chemical data. All spectra showed the dominant iron-related absorption bands at 450, 388 and 376 nm. In a few samples with a homogeneous light yellow coloration, no additional absorption bands were observed.

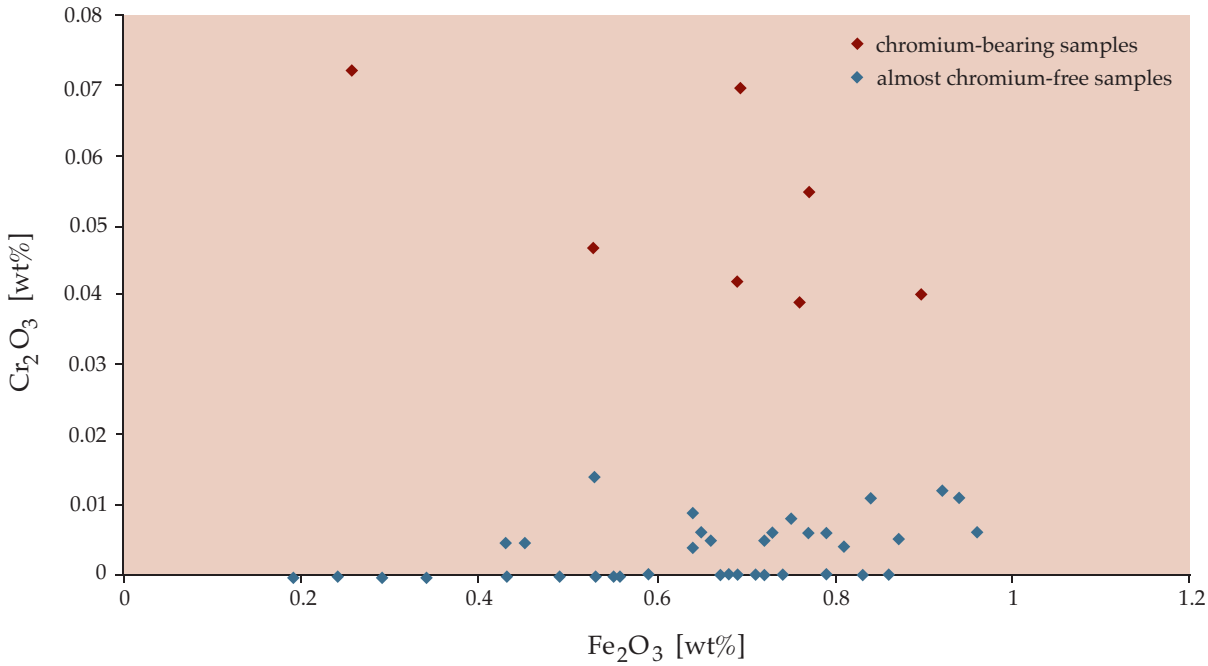

Figure 6: *Graphic representation of iron and chromium contents as determined for 40 heat-treated yellow to yellowish-orange sapphires from Montana, U.S.A., by energy-dispersive X-ray fluorescence spectroscopy (EDXRF); iron contents vary widely between 0.19 and 0.94 wt.% Fe_2O_3, chromium contents of the sapphires are very low (18 samples) or below the detection limit of the instrument (22 samples, <0.005 wt.% Cr_2O_3; because of identical iron values, the points of three samples overlap). The iron and chromium contents of seven chromium-bearing orange to reddish-orange heat-treated Montana sapphires (Schmetzer and Schwarz, 2005) are given for comparison.*

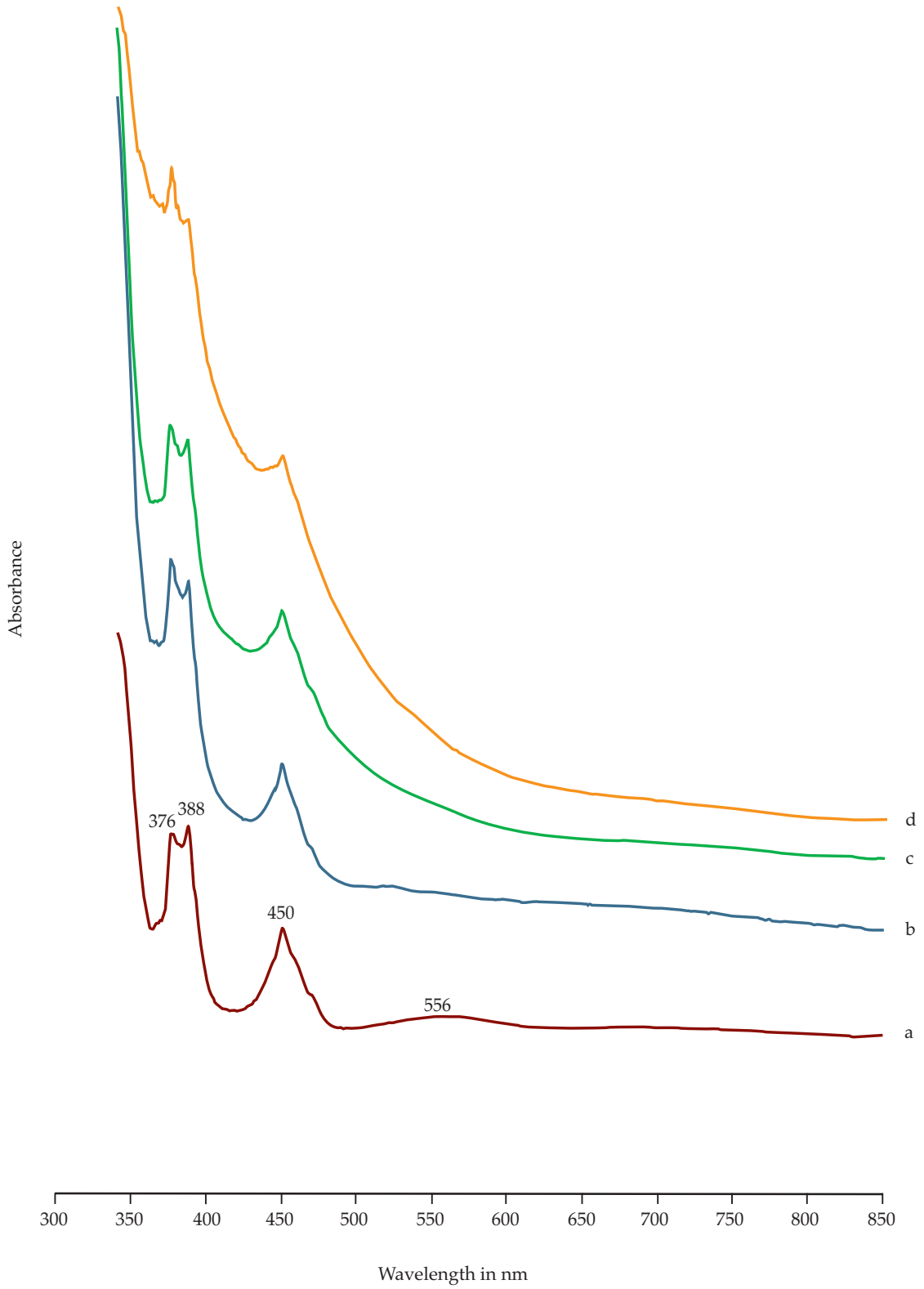

Figure 7: *Absorption spectra of heat-treated sapphires from Montana, U.S.A. in the yellow, yellowish-orange or brownish-yellow colour range; all samples show the characteristic absorption spectrum of iron-bearing sapphires with dominant absorption maxima at 450, 388 and 376 nm. In sample (a) with homogeneous yellow body colour, a small absorption band of chromium at about 556 nm is also visible (chromium contents of this sample 0.005 wt.% Cr_2O_3), but no orange colour centres were developed by heat treatment. Spectra (b) to (d) indicate that increasing numbers of orange colour centres were developed by the heat treatment process, which are macroscopically seen as intensely coloured yellow, yellowish-orange or yellowish brown growth sectors within the surrounding lighter yellow areas. Thus, in (b) to (d), the iron-related absorption spectrum is superimposed on that of the orange colour centres; spectra (b) to (d) are vertically displaced for clarity.*

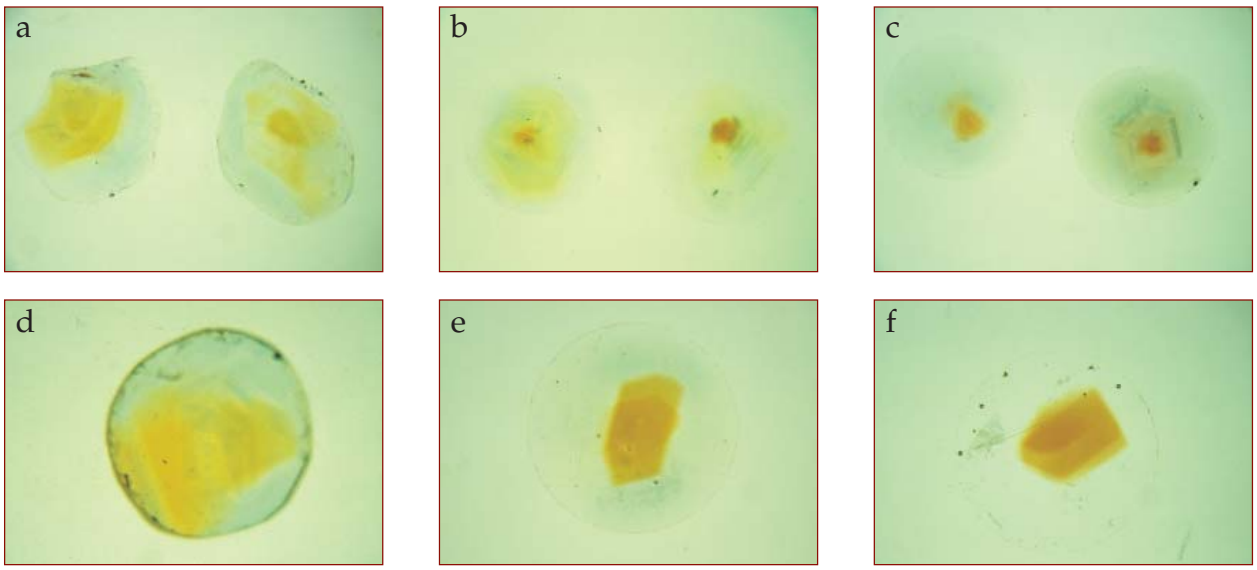

Figure 8 (a) to (f): *In heat-treated Montana sapphires, orange colour centres are developed predominantly in central areas which are related to basal growth sectors; in a view approximately parallel to the* c*-axis of each sample, central darker areas are visible, mostly with a distinct fine structure. In the surrounding lighter yellow areas, small zones with residual blue colour zoning are present in some stones, an original colour not completely removed by the heat treatment process. Immersion, sizes of samples about 4 to 5 mm.*

All samples that showed – in addition to the light yellow homogeneous body colour – at least one more or less intense orange to brownish-orange growth sector, also showed a continuously increasing absorption from the visible to the ultraviolet region, which is superimposed on the iron absorption bands. This absorption is related to thermally stable orange colour centres which are developed by heat treatment. Due to the high intensity of the iron-related absorption band at 450 nm, an additional absorption of this orange colour centre which was expected at about 470 nm was not seen. No chromium absorption bands were observed in most of our spectra compared to the spectra pictured by Schmetzer and Schwarz (2005) for Montana sapphires with higher chromium contents (in the range of 0.040 to 0.073 wt.% Cr_2O_3). Only a few of our yellow sapphires showed a weak chromium absorption band at 556 nm; such samples have chromium contents near 0.01 wt.% Cr_2O_3.

Consequently, the colour of light yellow sapphires which do not have any intensely coloured yellow to orange growth sectors is solely due to their iron contents. If orange colour centres were developed by heat treatment, the absorption related to these colour centres would be superimposed on the iron-related absorption spectrum and affect the resulting colour. These data and interpretations are consistent with the results given in the paper of Emmett and Douthit (1993) and with the recent papers of Emmett *et al*. (2003) and Schmetzer and Schwarz (2004, 2005).

Growth pattern and colour zoning

Even in random orientation, most of the rough or faceted sapphires in this study, in immersion show the presence of intense yellow, orange, or brownish-orange zones when immersed in liquid. In many samples, we observed a dark central core surrounded by lighter yellow parts of the sapphire crystals (*Figures 8* and *9*). In addition to distinct fine structures, which are present in most of the intense yellow to orange or brownish-orange cores, the darker areas may also be composed of several distinguishable parts. In the central zone or in these central darker growth sectors, the orange colour centres are developed by the heat treatment process, whereas in the surrounding areas, only a light yellow iron-related coloration is visible. In the rims of some heat-treated sapphires, the original blue or greyish-blue

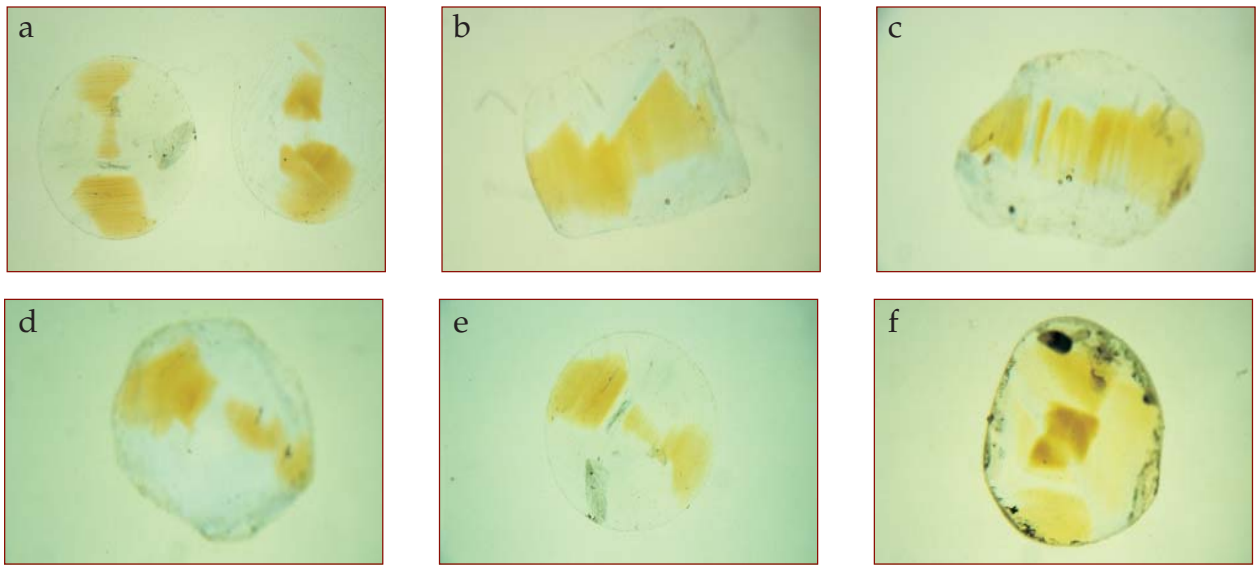

Figure 9 (a) to (f): *In heat-treated Montana sapphires, orange colour centres are developed predominantly in central areas which are related to basal growth sectors; in a view approximately perpendicular to the* c*-axis of each sample, elongated darker areas are visible in the centres of the stones, mostly with a distinct fine structure due to varying diameters of the darker basal growth sectors along the* c*-axis. Immersion, sizes of samples about 4 to 6 mm.*

coloration was not completely removed by the heat treatment process and a residual blue remains.

With different orientations of the rough and faceted sapphires, the outlines of the core or the darker central zones change. If the samples are examined in a direction approximately parallel to the *c*-axis of the sapphire crystal, a dark, more or less compact central core may be observed in most stones (*Figure 8*). In an orientation approximately perpendicular to the *c*-axis, a more or less elongated darker central part (*Figure 9*) is visible. The diameters of these darker centres are very variable along the *c*-axis and in some stones, the darker core is discontinuous consisting of several parts separated by lighter yellow growth zones.

With a more exact orientation of the sapphires in the immersion microscope, the measurements indicate that the growth structures and colour zoning are closely comparable to the growth pattern of untreated samples (see *Figures 5 a,b*). In heat-treated sapphires, the darker cores, in which the orange colour centres were developed by the heat treatment process, consist of basal growth sectors with diameters that change along the *c*-axis. These darker basal growth zones show sharp boundaries to rhombohedral *r* and dipyramidal *n* growth sectors (*Figure 10*). Growth striations (i.e. growth planes) are also visible within the outer (lighter yellow) *r, n* and *a* growth sectors, but these growth striations are not combined with an intense colour zoning. This pattern of growth and colour zoning, i.e. the intensely coloured basal growth sectors confined either by lighter yellow dipyramidal *n* growth sectors (*Figure 11*) or by lighter yellow rhombohedral *r* growth sectors (*Figure 12*), is typical for the locality, and also indicates that heat treatment only, in the absence of beryllium, was performed.

Discussion

The results of the present study represent another example for the applicability of growth patterns and colour zoning as a focal point of a microscopy-based screening system to distinguish heat-treated and beryllium-diffusion-treated sapphires in the yellow to reddish-orange colour range. We can summarize, that heat-treated yellow, yellowish-orange or orange (chromium-free to almost chromium-free) Montana sapphires show characteristic growth patterns consisting of basal, rhombohedral, dipyramidal and prismatic growth zones.

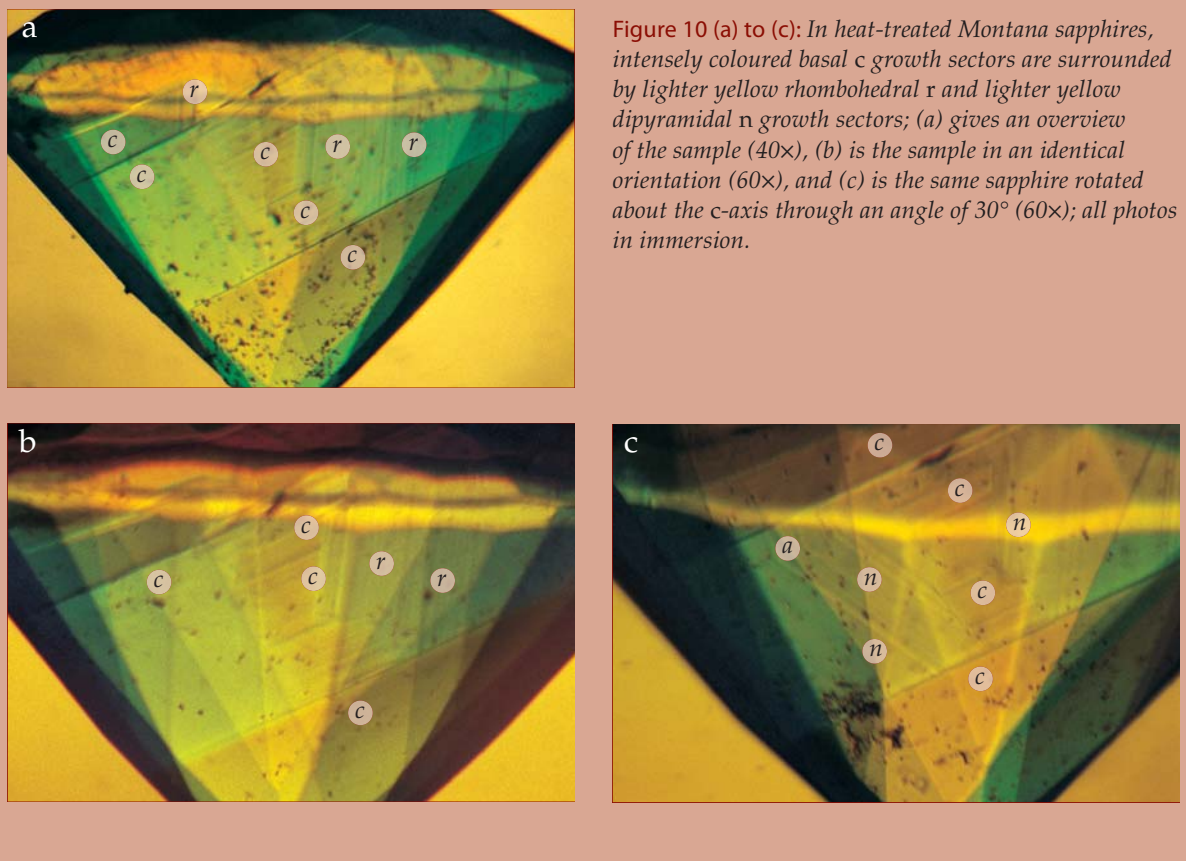

Figure 10 (a) to (c): *In heat-treated Montana sapphires, intensely coloured basal* c *growth sectors are surrounded by lighter yellow rhombohedral* r *and lighter yellow dipyramidal* n *growth sectors; (a) gives an overview of the sample (40×), (b) is the sample in an identical orientation (60×), and (c) is the same sapphire rotated about the* c*-axis through an angle of 30° (60×); all photos in immersion.*

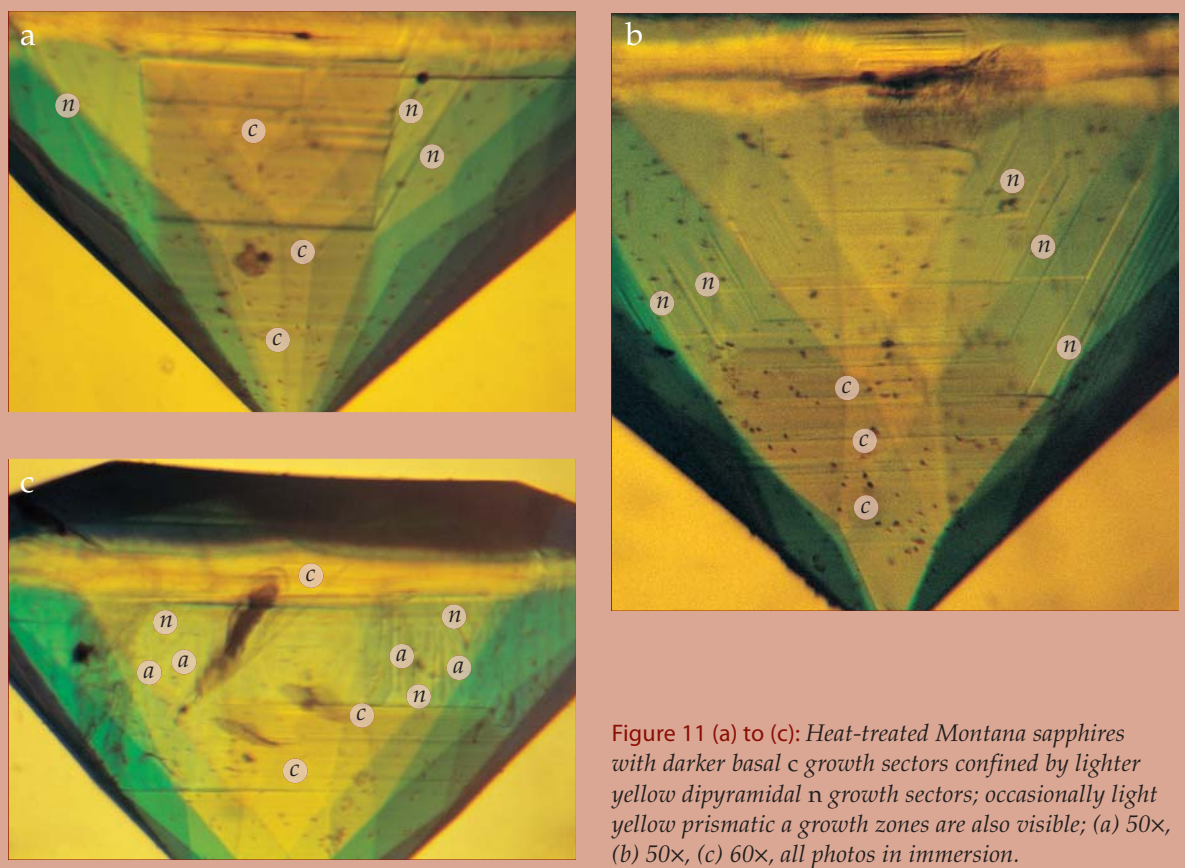

Figure 11 (a) to (c): *Heat-treated Montana sapphires with darker basal* c *growth sectors confined by lighter yellow dipyramidal* n *growth sectors; occasionally light yellow prismatic a growth zones are also visible; (a) 50×, (b) 50×, (c) 60×, all photos in immersion.*

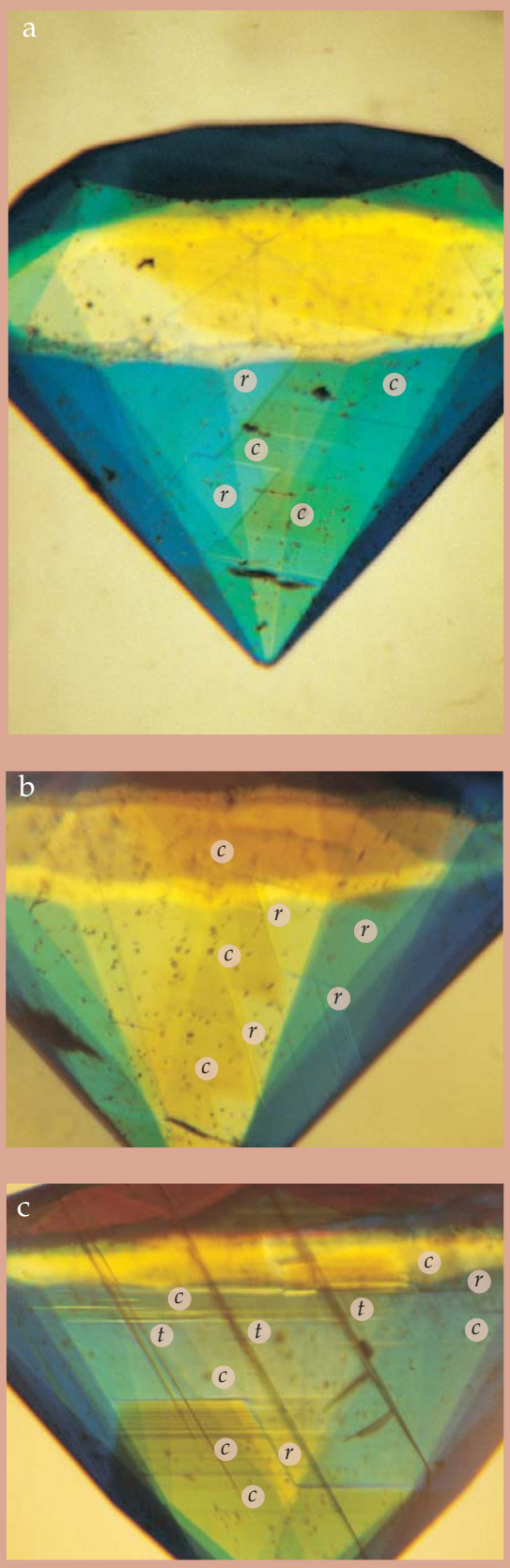

Figure 12 (a) to (c): *Heat-treated Montana sapphires with darker basal* c *growth sectors confined by lighter yellow rhombohedral* r *growth sectors; occasionally twin planes* t *parallel to the rhombohedral faces are also visible; (a) 30×, (b) 60×, (c) 50×, all photos in immersion.*

These internal growth patterns are consistent with the morphology of the untreated rough sapphire crystals. It is evident that the characteristic features described may be observed also in relatively small samples (between 0.3 and 1.1 ct) and, thus, the applicability of the method for the distinction of lots of smaller yellow to yellowish-orange sapphires is clearly demonstrated.

Darker growth zones, in which the orange colour centres are developed by heat treatment, are related to basal growth sectors with sharp boundaries to lighter yellow rhombohedral or dipyramidal growth zones. This is a characteristic pattern of growth zoning combined with an extreme colour zoning, which is typical for the locality. A similar pattern was found in heat-treated chromium-bearing Montana sapphires with a padparadscha-like reddish-orange or pinkish-orange colour. In these sapphires, orange colour centres are also developed in basal growth sectors only, but these samples contain elevated amounts of chromium (Schmetzer and Schwarz, 2005).

In beryllium-diffusion-treated Montana sapphires, in contrast, a homogeneous yellow to yellowish-orange coloration is developed throughout the entire stone (Schmetzer and Schwarz, 2005). Consequently, the observation of the characteristic growth patterns and colour zoning described in this paper are extremely useful for locality determinations and are conclusive for the separation of heat-treated and diffusion-treated sapphires.

Acknowledgements

The authors are grateful to Robert E. Kane of Fine Gems International, Helena, Montana, U.S.A., for the loan of faceted and rough Montana sapphires for this research project.

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Cape Breton ruby, a new Canadian gemstone discovery, Cape Breton Island, Nova Scotia

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Abstract: *Ruby was discovered near Frenchvale, Cape Breton, Nova Scotia, in mid-August 2004, in a geological context closely resembling that in the Hunza Valley, Kashmir. Although only relatively low grade stones from this newest Canadian gemstone locality have been recovered so far, the terrain holds promise of quality ruby. The potential for future discoveries in Atlantic Canada are excellent*

Keywords: *marble, Nova Scotia, Precambrian, ruby, skarn*

Introduction

The Frenchvale area in the Boisdale Hills, southeastern Cape Breton Island, contributed carbonate flux to the steel mills of Sydney, Nova Scotia, over several decades. Here, as elsewhere in the extensive Precambrian terrain of Cape Breton, exploration has long been carried out sporadically for metalliferous deposits of lead, zinc and copper, and more recently for precious metals. Then in mid-August 2004, during the course of a mineral exploration programme, ruby corundum was serendipitously discovered in the environs of a disused quarry at Frenchvale, Cape Breton county.

The village of Frenchvale is located about 18 km west southwest of Sydney (*Figure 1*).

The Frenchvale quarry is a boomerang-shaped excavation 0.63 km long east-west, and 0.33 km north-south, located about 0.7 km northwest of the village (*Figure 2*). Readily accessed by a network of secondary roads in the area, the quarry is situated in the midst of the Boisdale Hills, a beautiful, gently rolling terrain intersected by streams and dotted with lakes.

History

During the 1960s Mosher Limestone Ltd., through its affiliate Scotia Limestone Ltd., supplied 'purifying stone', namely limestone and dolomite, the main natural fluxes in

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steel making, to the Sydney Steel works. Iron ore feedstock, not available locally, arrived in Sydney by ship from mines in Newfoundland and Labrador.

Geology

Sir William Dawson made first mention of geological associations in the area in his classic *Acadian Geology* (1855, p. 322) and Weeks (1954) provides an overview of the results of early geological studies.

The results of subsequent work (Barr and Setter, 1986; Hill, 1987, 1989; Barr and Raeside, 1989; Raeside, 1989; Raeside and Barr, 1990) on the Precambrian geology of Cape Breton has led to the reallocation to other units, of some rocks previously assigned to the George River Group (Raeside, 1989), considered the oldest rocks in the region. For example, the migmatite within a gneiss complex at Lime Hill on North Mountain, southwestern Cape Breton, contains "... minor spinel- and corundum-bearing neosomes..." (Raeside, 1989). This earliest discovery of corundum on the island is in a unit within the Bras d'Or terrane viewed by Raeside and Barr (1990) as distinct from the George River Group *(Figure 1).* For the purpose of this report, however, the term is retained in order to highlight areas of particular interest in the exploration for Cape Breton rubies. The focus here is on a small window of the George River Group, centred in the Boisdale Hills, a locality which Milligan (1970) considered as the type. This report is based on over four months geological mapping and sampling, and a follow-up drilling programme as part of an on-going mineral exploration programme within a 4000 Ha claim block in the Boisdale Hills held by Mount Cameron Minerals Inc. (MCMI). Mineral collecting is prohibited in this claim block without the permission of MCMI.

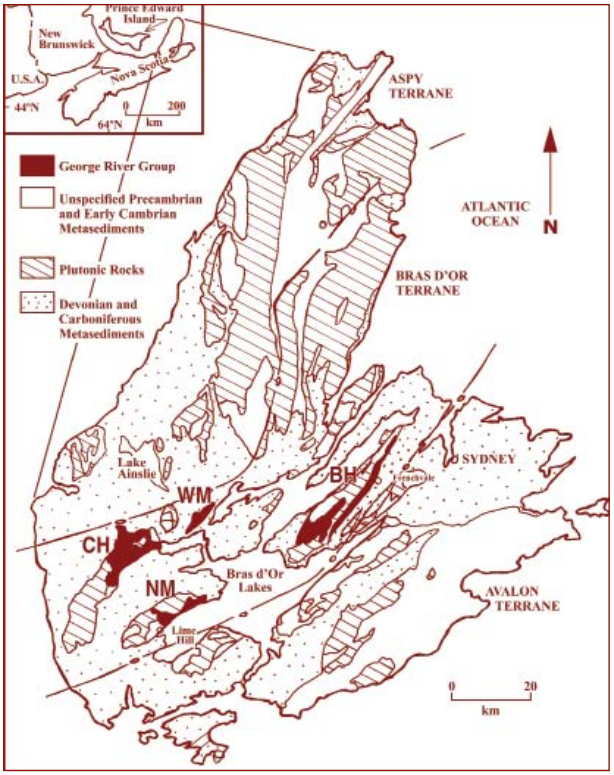

Figure 1: *Sketch map shows the extent of Precambrian metasedimentary rocks on Cape Breton Island; main occurrences of George River Group rocks (BH - Boisdale Hills, NM - North Mountain, CH - Creignish Hills, WM - Whycocomagh Mountain) are restricted to the Bras d' Or tectonostratigraphic terrane (modified from Raeside, 1989).*

Although no type section has been formally proposed for the George River Group, the term has been loosely applied to many interbedded carbonate and clastic and minor volcanic rocks of variable metamorphic grade on Cape Breton Island. As noted above, the informal type locality is the Boisdale Hills, where a Late Precambrian sequence of schists, gneisses and siliceous dolomitic marbles has been regionally metamorphosed to upper amphibolite facies. These rocks are intruded by predominantly late stage shallow level hybrid igneous dykes and sills ranging from granite through hornblende diorite to diabase. Ratio of metasediments to intrusives is estimated at 3 : 1.

Results of radiometric age determinations reported by White *et al*. (1994) identify the intrusive igneous rocks from the northern Boisdale Hills as late Cambrian to early Ordovician. In the environs of Frenchvale quarry, upper amphibolite grade metamorphism is represented by the presence of two-mica schist, garnetiferous (grossular-andradite, so-called 'grandite')-sillimanite-andalusite gneiss, and in metacarbonates in the quarry itself, by the presence of corundum and a suite of calc-silicate minerals. Both fault-bounded and intrusive contacts with

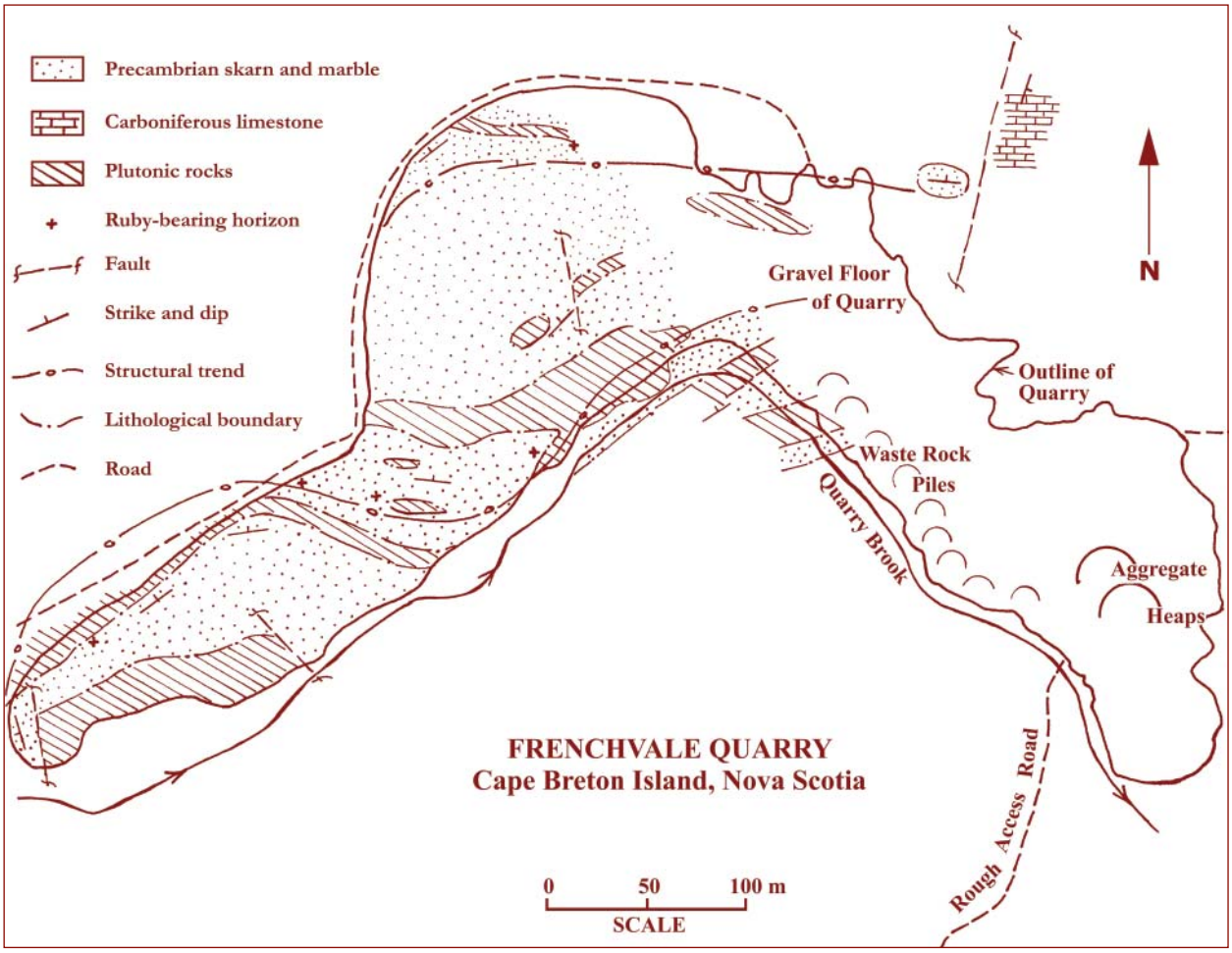

Figure 2: *Geological sketch map of Frenchvale quarry, situated 0.7 km northwest of the village of Frenchvale, and approximately 18.7 km west southwest of Sydney, Cape Breton Island, Nova Scotia.*

Figure 3: *Discovery specimen (untrimmed) of prismatic (1.2 cm diameter) ruby in skarn from the northeast wall of Frenchvale quarry. Photograph by D. Mossman.*

country rock metasediments are encountered in the area. The largest fault occurs near the east end of the quarry and separates Carboniferous limestones from the more ancient skarns of the quarry *(Figure 2).*

Lower grade (in part retrograde) metamorphism is evident in chloritization, development of talc, widespread silicification and serpentinization, and the presence of exsolved aluminium hydroxides in corundum (Schmetzer, 1987). Overall the metasediments have been made over into skarn, or more specifically 'skarnoid rocks', a term describing relatively fine-grained, iron-poor, calc-silicate rocks which reflect the compositional control of the original sediment (Einaudi *et al.*, 1981). Skarns and skarnoid

Table I: *Minerals from the George River Group, Frenchvale and environs, Cape Breton Island (this study; Chatterjee, 1977; Hill, 1989)*

Andalusite	Orthoclase
Antigorite	Pargasite
Apatite	Phlogopite
Biotite	Plagioclase (peristerite and anorthite)`
Calcite	Prehnite
Chalcopyrite	Pyrite
Chlorite	Pyrrhotite
Cordierite	Quartz
Corundum	Scapolite
Diopside	Serpentine
Dolomite	Sillimanite
Epidote	Sphalerite
Forsterite	Sphene
Garnet ('grandite')	Spinel
Goethite	Talc
Graphite	Titanite (sphene)
Hematite	Tremolite-actinolite
Magnetite	Vesuvianite
Marcasite	Wollastonite
Monticellite	Zoisite
Muscovite (including var. fuchsite)	

rocks develop in response to either localized contact metamorphism adjacent to an igneous intrusion, or regional metamorphism whereby mineral changes in the rocks occur over an extensive area. The latter hypothesis is believed to apply to the ruby occurrences at Frenchvale (*Figure 3*). Unlike classic skarns, however, the Frenchvale metacarbonates are not dominated by garnet and pyroxene.

Mineralogy

Many minerals, including some relatively exotic species, have been identified (Chatterjee, 1977; Hill, 1989) in the George River Group metasediments (*Table I*). Dolomite and to a much lesser extent, calcite, are of course major components of the purest marbles; fine-grained, disseminated flake graphite is virtually ubiquitous. Calc-silicate minerals, for the most part coarse-grained, are widely developed especially in what were originally impure limestones/marbles but which have undergone a measure of silicification. In these, a relict banding and sporadic stylolitization suggest the original stratification, and wollastonite, scapolite and vesuvianite are common.

Metamorphic mineral assemblages are characteristic of upper amphibolite grade facies (Chatterjee, 1977). Forsterite (usually heavily serpentinized), diopside, and tremolite are widespread in the metacarbonates. Spinel has likewise been reported (Chatterjee, in Milligan, 1970) though not seen by the writers. In gneiss, sillimanite and andalusite can accompany phlogopite and/or biotite, muscovite and plagioclase, attesting to a former high temperature, low pressure

regime. Various minerals, including sulphides, quartz, calcite, talc, serpentine, scheelite and tourmaline (schorl) are common in the vicinity of shear zones which provided the channels for a relatively late stage non-focused flow of mineralizing fluids.

Retrograde metamorphic minerals are locally conspicuous, a good illustration being green chromian-muscovite (fuchsite), which commonly envelopes corundum crystals. As a result of weathering, goethite, magnesite, and kaolin are locally abundant. Among sulphides, pyrrhotite, pyrite and marcasite are of widespread occurrence, with chalcopyrite least evident.

Cape Breton ruby

Here, we follow Hughes' (1997, p. 401) carefully considered recommendation that "... all corundums of a red colour, regardless of its depth or intensity should be termed rubies, just as was done prior to the 20th century." Cape Breton ruby was first recognized in mid-August 2004 as pea-sized crystals more or less enveloped by fuchsite along the northeastern rim of the Frenchvale quarry. Outcrops of ruby-bearing rock were subsequently identified at several other locations in the quarry and environs.

Corundum at Frenchvale ranges from white to dark grey, but rose, purple, red-violet and various shades of lavender are the most prevalent (*Figures 4* and *5*). More than one colour can occur at any given locality; several very small blue crystalline portions within red corundum have been recovered. The term 'oriental amethyst' has been suggested for the purple variety. However, the true nature of corundum being now well understood (Hughes, 1997), use of such a misleading term serves little purpose.

Figure 4: *A Cape Breton ruby (~ 1 ct) cut by Hans Durstling and set in a gold ring by Donald Baird. Photograph by D. Mossman.*

Comparing the colours of faceted Cape Breton ruby under various light sources reveals weak change of colour effects, with tungsten light producing the strongest rose red. Refractive indices of rose red crystals at the discovery site give $n_e = 1.766$, $n_o = 1.776$, values characteristic of the middle of the field for the mineral.

Typically, the crystals have a 'fat' rather than flat habit. However, tabular to blocky hexagonal prisms are common as are various pinacoid combinations with well-developed rhombohedron faces. Flattened bladed crystals are less common. On fold limbs, ruby crystals tend to be oriented parallel to the foliation of the enclosing rock, having been deformed at the same time as the enclosing rock.

Cape Breton ruby shows rhombohedral parting and prominent basal parting, the former giving nearly cubic angles. Only one imperfectly developed set of needle-like rutile inclusions has been observed, although prismatic rutile crystals (to 0.5 mm dia), and less often pyrite, occur around the rims of ruby crystals at some localities. Exsolved diaspore and/or boehmite are present (John Emmett, pers. comm., 2004) and doubtless contribute to the opacity/translucency of the stones. Heat treatment carried out under oxidizing conditions for 12 hours at 980 C and more, result in a colour change to bright pink, but at the cost of complete opacity.

Deformation was a late stage geological event. Indications are that some Cape Breton rubies initially formed as a progressive stage of amphibolite facies metamorphism. Then, a second generation crystallized as a consequence of retrograde metamorphism. A third mode of occurrence of corundum at Frenchvale is its presence in several small

granitic pegmatites, and this suggests that the mineral may also have been locally produced under conditions of partial anatexis at the peak of metamorphism by the breakdown of muscovite to corundum, K-feldspar and water.

During an extensive shallow drilling programme undertaken by MCMI in late 2004, true stratigraphic thicknesses of 15 m or more of ruby-bearing skarn were intersected immediately north and west of the Frenchvale quarry. Results of drilling confirm that ruby crystallized at specific horizons in the metamorphic sequence at Frenchvale – in some instances remote from intrusive rocks. Further, oblique, non-faulted contacts between ruby-containing horizons and granodiorite supply additional evidence in support of the concept that regional metamorphism and not contact metamorphism played the major role in ruby genesis. This finding has important implications for further exploration in the region, because together with the presence of corundum in the gneiss complex at North Mountain (Lime Hill), it means that rubies may be found in the George River Group whether igneous intrusions are present or not.

Comparison with ruby from the Hunza Valley

The corundum-muscovite association common at several ruby localities in Frenchvale, along with other principal characteristics of the deposit, highlights the remarkable resemblance to the Hunza, Kashmir, occurrences (Okrusch *et al.*, 1976, Hughes, 1997; Hammer, 2004). Evidently, at the old Hunza mines much of the material recovered was cracked and had more value as specimens than as rough, although some was suitable for producing cabochons or carvings. This contrasts with the much higher quality material presently being recovered from modern workings a few kilometres distant (Syed M. Shah, pers. comm., 2005). Cape Breton ruby shares the following geological and gemmological characteristics with ruby from Hunza:

1. Primary deposits consist of a siliceous corundum-bearing marble enclosed in gneisses and mica schist;
2. Colour, red to deep purple, violet to purple, some blue; most crystals are opaque to translucent;
3. Stones show a strong chromium spectrum;
4. Crystal habits are generally prisms, rhombohedra or bi-pyramids with development of pinacoid faces;
5. Strong fluorescence in red to orange-red; long wavelength UV response stronger than short wavelength;
6. Cavities and negative crystals are common inclusions;
7. Some crystals are coated with a thin waxy 'veneer' of translucent white mica and talc;
8. Corundum forms intercalations within garnetiferous mica schists and biotite-plagioclase gneisses, which are cut by pegmatites and aplite dykes;
9. A green scaly mineral closely associated with ruby is muscovite which contains traces of Cr (and V) (O'Donoghue, 1988, p. 164).

Conclusions

Cape Breton ruby is an exciting new gemstone find in Atlantic Canada. Aside from a few detrital grains of ruby found in British Columbia, and rumours of gem quality sapphire in the Northwest Territories and the Yukon, Ontario, is usually said to have Canada's most important corundum deposits, especially sapphire from several counties, albeit in small quantities as gems (Hughes, 1997). There is also an exciting new find of ruby from Baffin Island (Brad Wilson, pers. comm., 2006), certainly one of the more challenging gemmological exploration frontiers.

In Precambrian times, western Scotland and eastern Canada were probably very close, and Cartwright *et al.* (1985) have documented an area in Lewisian gneiss near Stoer, northern Scotland, of (pink) corundum associated with staurolite in a chromian muscovite matrix, although the Scottish gneiss is Archean and considerably older than the Late Precambrian

Figure 5: *Pendant of Cape Breton ruby set in silver; fashioned by Hans Durstling. Photograph by F. Isenor.*

metamorphic sequences in Cape Breton.

Although faceted Cape Breton rubies are not at present of the finest quality, they are attractive and may eventually support a vigorous local market in jewellery. Collectors, too, will find mineral specimens of interest. Prospects for future field discoveries in Atlantic Canada are excellent, especially if, as Raeside and Barr (1989) postulate, units equivalent to the Bras d'Or terrane exist in southern New Brunswick and in Newfoundland. Certainly on Cape Breton Island, lithologies traditionally considered to belong to the George River Group deserve close attention, especially the stream and glacial gravel deposits. It will be worthwhile also to bear in mind the analogy with Hunza, Kashmir, an area in which newer prospects within kilometres of old workings are currently producing high quality rubies and sapphires.

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Better refractometer results with the Bright Line technique

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Abstract: *Grazing incidence illumination of gemstones on the gemmologist's refractometer is now little used, but offers some significant advantages. The authors review the history of such use, give detailed explanations of how it is accomplished, and provide suggestions for its application to practical problems. There are three principal applications of grazing incidence illumination that can aid the gemmologist in practical discrimination between gems. One is in easier and better determination of the refractive index, or indices for birefringent stones. The second is in estimation of relative dispersion, and the third is in being able to observe polarized absorption spectra of gems.*

Keywords: *bright line technique; grazing incidence; polarized spectra; refractive index; refractometer*

Introduction

"It is a wise precaution in a doubtful case to study the effect when the stone is illuminated from above and not below."

G. F. Herbert Smith (1940, 31) in discussing use of the refractometer.

Many gemmologists may not be aware of the 'bright line' technique (Anderson, 1959) for obtaining refractive index (RI) readings with the common, critical angle refractometer or if aware, do not make use of it. This is not surprising due to the limited discussion of the technique in modern gemmological texts and the design of many modern instruments, which can make it awkward to properly position the light source. The authors have taken a new look at the 'bright line' method, which is an old variation of stone illumination, and have found that it has distinct advantages that are not currently utilized. This paper examines the technique and explains how to get more from your standard gemmological refractometer.

History

Most readers will be familiar with the workings of the standard gemmologist's critical angle refractometer, where light enters a dense glass prism from behind and below, and is reflected at the glass/gem interface, so that a shadow edge defines the critical angle of reflection on a scale within the instrument. In using the 'bright

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Figure 1: *A critical angle refractometer with the light shield removed and illuminated for grazing incidence using a torch.*

Figure 2: *Modern style refractometer with small LED light directed at grazing incidence.*

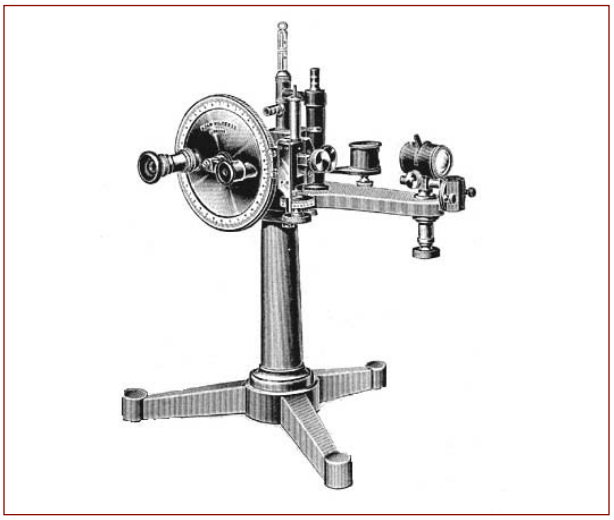

Figure 3: *Pulfrich refractometer, catalog scan taken from Arthur H. Thomas Co.* Laboratory Apparatus and Reagents. *Philadelphia (1921).*

line' technique, the normal light port of the instrument is not used, and light enters the gem directly, so that some of the light is at grazing incidence to the glass/gem interface (*Figures 1* and *2*). With this technique, the light and dark parts of the refractometer scale are reversed, and importantly, a very bright spectrum is seen at the boundary, hence the term 'bright line'. The authors believe that the dramatic difference in the appearance of the readings between the two illumination methods, shown in *Figure 8*, has not been adequately noted in the literature. Traditional illumination with white light produces a diffuse shadow edge with hints of blue on the low side and red on the high side, but monochromatic light or a polarizing filter can make the reading more distinct. Grazing incidence produces one or two very bright, clear spectra that show the absorption spectrum of the gem. In pleochroic stones, the differing spectra can be observed side by side. This means of comparison is a valuable educational and identification tool. Anderson (1959, 1980) indicates that C. J. Payne used this method when it was difficult to obtain readings by traditional means. The light hood of the instrument was removed and Anderson (1959, 33) says that the light was "… so adjusted as to provide light at grazing incidence on the stone …". No other lighting details are given. He goes on to note that it may be necessary to rotate the stone to see the effect clearly, again without further explanation.

G. F. Herbert Smith, the father of the gemmologist's refractometer, was certainly aware of the utility of grazing incidence illumination, as shown by the quotation given at the introduction above. His 1913 text *Gemstones* does not include instruction on grazing incidence illumination, but by his 9th edition (1940) he includes it. Smith even shows a photograph of a Zeiss pocket refractometer designed for jewellers, that provides for illumination to either the glass hemisphere or the stone. A schematic drawing of this instrument is shown by Diniz Gonsalves (1949), clearly showing that an adjustable mirror is moved to provide

either type of illumination and indicating that the grazing illumination is directed along the plane of the prism/gem interface. Diniz Gonsalves notes that it is one of the instruments most often used by the experts.

Critical angle refractometers used in other industries may use either type of illumination. The Pulfrich refractometer (*Figure 3*), designed for grazing incident light, provides much needed information on the use and limitations of such refractometers. A sketch of the principal optics of this instrument when measuring a solid is shown in *Figure 4*. In order to obtain good results, the material being tested must have an optically flat surface (for example, a polished facet surface) with an adjacent surface intersecting at a clean, 90-degree angle (Cooper, 1946). These two factors are critical in obtaining accurate results with the instrument. Light entering the solid at grazing incidence will exit into the dense glass at the critical angle. Light entering the solid at angles less than grazing will be refracted into the dense glass at angles less than the critical angle, lightening the lower part of the refractive index scale. In other respects it is the same as a gemmologist's refractometer. This explains the reversal of the dark and light parts of the scale.

The technique is mentioned in the 3rd edition of Webster's *Gems* (1975), but was dropped by the 5th edition (1994). Webster (1975) emphasizes that the technique is sometimes useful for those difficult cases when an RI cannot be obtained by normal means, adding that best results are for trap-cut [rectangular step-cut] gems, without explanation. He makes another comment regarding colour fringes seen when using white light for RI determinations in the traditional manner that will be important for our story later. Webster (1975, 627) says: "The sharpness or otherwise of the coloured fringe of the shadow edge in white light will give some idea of the dispersive power of the stone … and this may give useful confirmatory information." This technique gives a strong indication of relative dispersion, not easily available by other

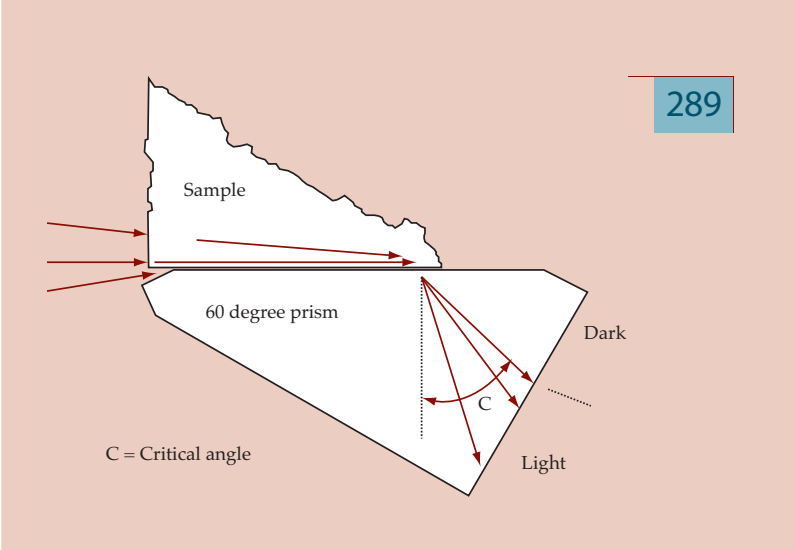

Figure 4: *Sketch of the light path in the sample and prism of a Pulfrich refractometer when solids are measured.*

testing methods. Hoover and Linton (2000, 2001), and Linton (2005) are the only authors we know of who have recently made much use of the 'bright line' technique, as noted in their papers on dispersion measurement. There are few other references to the technique in the current literature, other than Liddicoat (1989), who makes passing mention of it. Liddicoat states that the light source should be directed from above and behind the stone, not mentioning grazing incidence. We shall address this aspect later. Liddicoat (1989) notes the reversal of the bright and dim parts of the scale, and further states that the spectrum when using the bright line scheme is predominantly red, as opposed to the blue-green seen in normal operation.

The authors suspect that the principal reasons for the lack of interest in the 'bright line' technique are the lack of instruction in its use and the redesign of most modern instruments, limiting the size of light source that can be used to obtain grazing incidence. Many gemmologists may have tried it but have become discouraged in their attempts to get proper lighting. Understanding the illumination requirements permits one to adjust the measuring technique so that, with practice, useful measurements can be quickly and easily obtained.

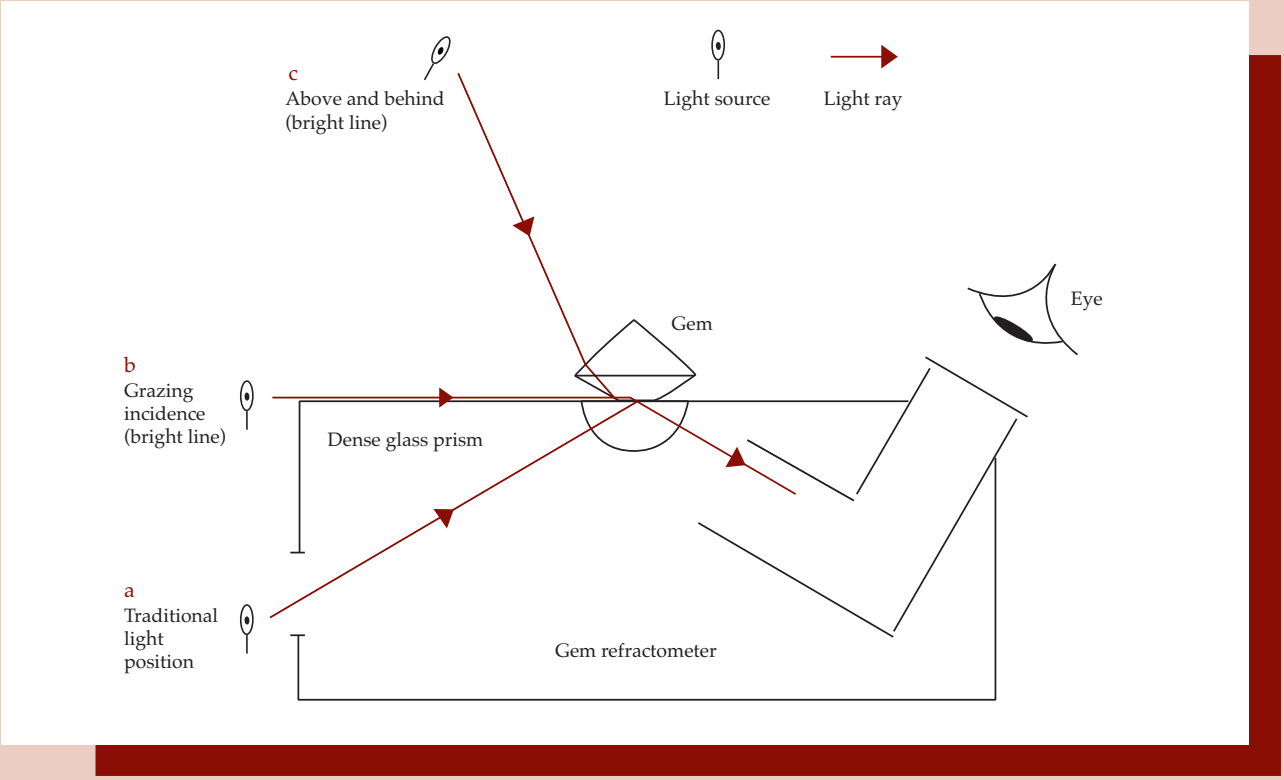

Figure 5: *Diagram of a refractometer showing the positions a, b and c of a light source for traditional illumination, and for grazing incidence.*

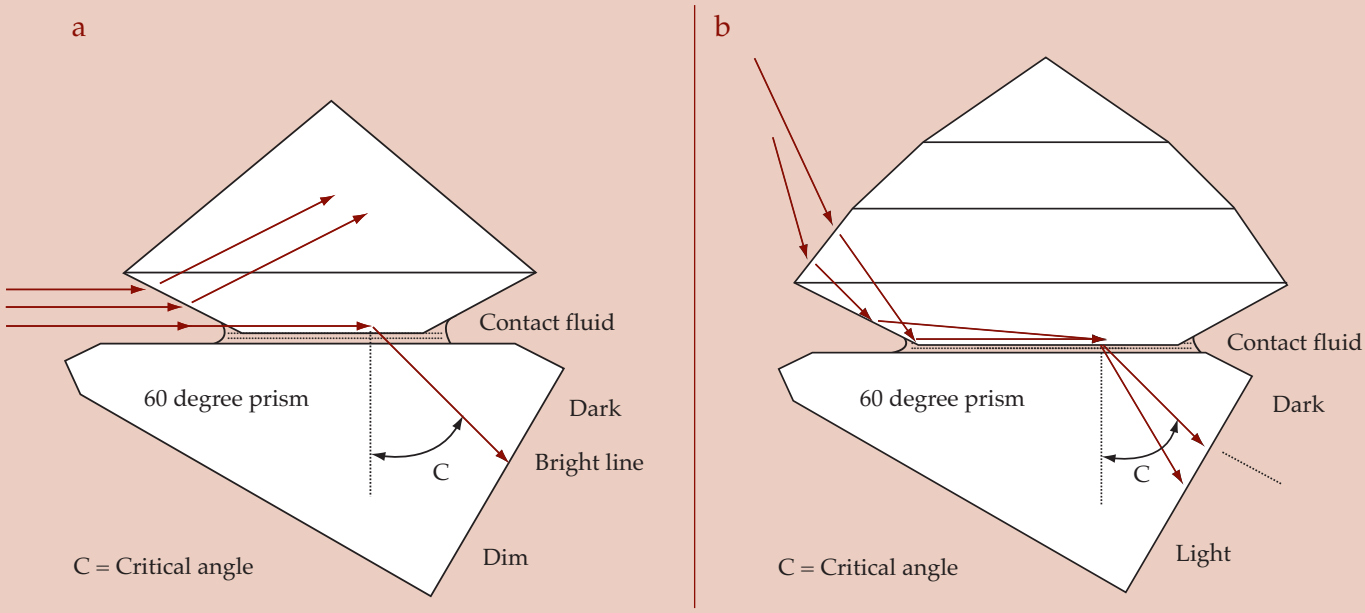

Figure 6: *Sketch of the light paths in the prism of a gemmologist's refractometer when grazing incidence is used. In position (a) light is directed in the plane of the prism surface. In position (b), light is directed into a pavilion facet from above and behind.*

Obtaining grazing illumination

The review above shows that for the 'bright line' technique to be practised; a simple, reversible alteration to the standard gemmologists' refractometer is required to allow for grazing incidence mode (*Figure 1*). The light shield must be removed. The Eickhorst refractometers have easily removable light shields, making them ideal for practicing the technique. Alternatively, a small light source can be used, as in *Figure 2*. We prefer to remove the cover. *Figure 5* shows a conventional refractometer with the dense glass prism, and a 90-degree telescope with scale for viewing the critical angle. Three possible positions (a, b and c) for the light source are also indicated. In this diagram the plane of the paper is the optical plane of the instrument. Position a is the traditional mode of illumination from below. Position b may be easier to obtain with the light shield removed (*Figures 1* and *2*). Position c will vary depending on the RI and facet angles of the stone under test.

Figure 6 shows details of two ways in which grazing light may be introduced into a gem placed table-down on a refractometer with the light shield removed. *Figure 6a* shows a light beam travelling at grazing incidence along the instrument path, and parallel to the gem/prism interface. The thickness of the contact fluid layer is exaggerated in this figure for clarity, and we only consider the facets adjacent to the table. This mimics the light path in the Pulfrich instrument, except that when using a faceted gem, having the adjacent facet at 90 degrees to the table is generally not possible, nor is it necessary. The adjacent facet must still be oriented at 90 degrees to the plane of the refractometer, as shown in the diagram (*Figure 7*). Within a small range, the light can also be oriented at 90 degrees to any facet adjacent to the table, as long as the light path still roughly follows the light path of the refractometer. This explains Anderson's statement that a stone may have to be rotated in order to obtain a reading, and Webster's comment on trap-cut stones being best. Certainly, rectangular step cut stones are best for learning the technique. Light directly entering crown facets will refract light away from grazing incidence (*Figure 6a*). Light entering the contact fluid film between the gemstone and the instrument table will be refracted at the critical angle of the fluid, or upward into the stone, and lost (not shown). It is only if there is a sufficient bead of contact liquid on the adjacent crown facet (*Figure 6a*) that light at grazing incidence will be able to enter the stone. Therefore, it is key that one should use sufficient RI fluid so that a small bead of fluid forms at the facet edge. A consequence of using the small 'window' of liquid rather than a facet at 90 degrees is that the lower part of the refractometer scale will not be so brightly lit as with a 90 degree face due to the lower quality of light at appropriate angles entering the gem. The scale in this case remains quite dark, with only the one (or two if birefringent) bright spectrum clearly seen; a shadow edge(s) will be seen if monochromatic light is used.

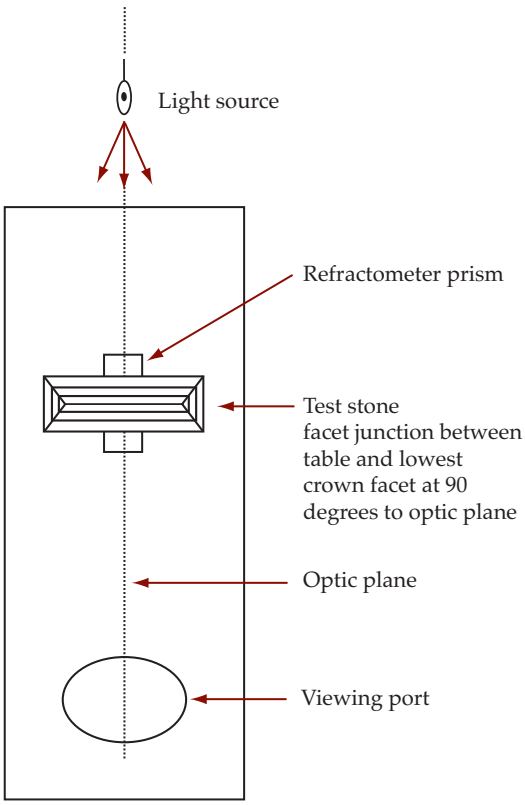

Figure 7: *Diagram of a refractometer showing the placement of a gem with respect to the optic plane of the refractometer.*

Figure 6b shows another method of getting light into a faceted gem at grazing incidence. By holding the light source above and slightly behind the stone, the light entering the pavilion is internally reflected off of a crown facet at its intersection with the table. The optimum position of the light source will vary depending on the RI and facet angles of the stone. With normal faceting angles, as in most stones, the reflection within the gem at the crown facet will be at or above the critical angle providing good light intensity at grazing incidence. Placing the stone so that the facet junction between the table and crown facet is perpendicular to the optical plane of the refractometer remains crucial. Tracing this light path back within the stone and out, one sees that generally the light source should be above the stone, and away from the viewer. This explains Liddicoat's suggestion (op. cit.) that the source be "from above and behind".

It is most important to note that there are a number of possible light paths which may produce line or spectral images on the scale at other than the critical angle. These false readings can cause some confusion to the novice, but are simple to detect. Smith (1940) gives us the clue; one should check the gem with illumination from both above and below (traditional refractometer testing). If illumination is correct, then shadow edges and spectra will be at the same positions. Continue to adjust the light position until the readings match and are consistent. What none of the quoted writers has said is that when using white light and traditional illumination, both the boundary and the spectrum seen at the boundary are very weak, while with grazing illumination the spectrum is bright and well defined (*Figure 8*).

This aspect will turn out to be a major asset, especially in cases where it is difficult to get clear readings by the traditional method. In these cases, the 'bright line' technique is ideal for confirming both R.I. and birefringence. This supports what C. J. Payne found many years ago. Two bright spectra would be seen for a birefringent gem. Pleochroic stones may show two slightly different spectra due to the variation in absorbance along different polarization directions. If one uses monochromatic illumination, then for grazing incidence the 'shadow edge' is not really a shadow edge, but one sees the edge defined by a very bright sharp spectral line that marks the RI for that wavelength, against a generally dark background. In essence one has a prism spectroscope with a birefringent prism. It is these bright, sharp lines that make it much easier to read the scale of the instrument at any particular colour.

Making a measurement

At first the user may have difficulty obtaining clear readings by grazing illumination, but practice will quickly bring proficiency. Unfortunately, it is not entirely without problems. Poorly cut stones and included stones will give significant problems, scattering or distorting the light beam in its passage through the stone. Such defects prevent greater application of the technique. Mounted stones have obvious limitations in orientation, but many will still yield good results with bright line if an RI reading is possible. It is suggested that the beginner

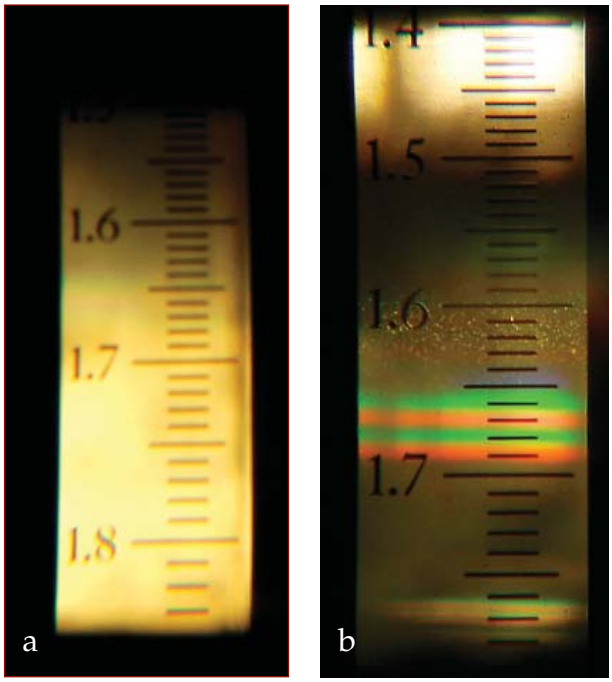

Figure 8: *Refractometer readings for a peridot when illuminated by white light with (a) traditional illumination, and with (b) grazing illumination.*

start with a well-cut, clean, rectangular step-cut quartz and use white light. For some refractometers, it will be helpful to remove the top cover. Use a light source that is easily moved so comparisons can be made quickly between the a, b and c illumination positions shown in *Figure 5*. A small key-chain white LED source is ideal.

Remember to use sufficient contact liquid, and to orient the stone so that one of the facet junctions with the table will be perpendicular to the refractometer axis. This is illustrated in *Figure 7*, which shows a step-cut stone on a refractometer. *Figure 9* illustrates the direction that the optic plane of the refractometer should take with respect to three different cuts. With a stone on the refractometer, find the shadow edge using traditional illumination methods. Look carefully and you will find a very faint spectrum at the shadow edge. With your head held in this viewing position, take your light source and raise it slowly to shine on the stone in the b position shown in *Figure 5*. As the light is raised, a very bright spectrum should suddenly appear in the same position as the shadow edge under traditional illumination. Note that there may be additional spectra at other positions on the scale. These are to be ignored. Practise until you can easily find the bright spectrum. Next, raise the source to be above the stone in the c position of *Figure 5*, and move it up and down to find the bright spectrum from light reflecting within the stone. If you have difficulty, practise with other clean, well-cut stones.

Various light sources can be used with this technique, and a small LED light is one example, as shown in *Figure 2*. If using white LED, it is important to note that it is not a true, full-spectrum light; and while it will produce accurate RI readings, the spectrum may not be accurate enough for positive identifications. Today's well-stocked lab should have several white and monochromatic LED lights. Yellow LEDs are ideal for traditional RI readings when a monochromatic filter is not available. It should be obvious how much brighter and sharper the readings are with grazing incidence. If the room is very dimly lit, the refractometer scale may be difficult to read; it will help to introduce some diffuse light into the rear light port in order to light the scale. Once seen, the bright line effect is quite impressive. But remember, poorly cut and/or included stones can give poor results.

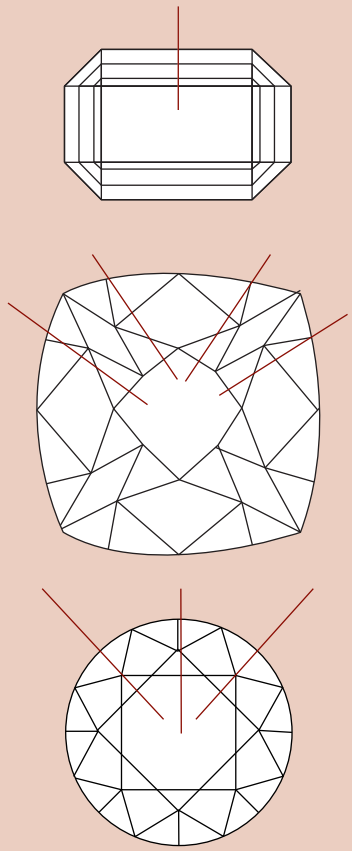

Figure 9: *Diagrams of emerald-, cushion- and brilliant-cut gems, showing the orientation of the gem facets to the light path /optical plane of the refractometer (as in* Figure 7*) for grazing illumination.*

Summary of steps to obtain a bright line reading

1. Obtain RI reading through traditional lighting method (*Figure 5*, position a).
2. Remove light cover from refractometer (*Figure 1*). (Optional)
3. Apply sufficient RI fluid to create a small bead along table/facet edge interface (*Figure 6*).
4. Align a facet (chosen facet must be adjacent to the table) at ninety degrees to light path/optic plane (*Figures 7* and *9*).
5. Direct light along grazing incidence (*Figure 5*, position b).
6. Observe bright line spectrum (*Figure 8*).
7. Direct light from above and behind (*Figure 5*, position c).
8. Confirm reading by comparison with position a (*Figure 5*, position a and b).

Utilization of grazing incidence

There are three key areas where grazing incidence will be of benefit to gemmologists in facilitating gem identification. The first is in better and easier reading of refractive index or indices, for birefringent stones. The second is in estimation of dispersion, and lastly as a simple prism spectroscope.

Refractive index or indices measurements

Gemmologists will occasionally come across a specimen that gives vague or unclear readings on the refractometer by traditional methods. The 'bright line' technique is ideal for obtaining RI measurements on such stones, as grazing incidence gives much better definition of the shadow edge(s). Even for clear and simple RI measurements, the authors recommend that Smith's (1940) advice be heeded, and that both illumination techniques be used whenever possible. It is quick and simple, and provides much greater confidence.

Orienting a stone for maximum birefringence readings may be difficult due to the requirement that the facet through which the light enters the stone must be at 90-degrees to the light path, limiting the number of positions for gem. Accurate birefringence readings should be taken using traditional illumination, and then confirmed with bright line technique if the facets allow. Displacing the light source slightly to one side or the other when using bright line (*Figure 5* positions b and c) can still provide good readings within a given range, depending on the facet arrangement.

Dispersion estimation

If a white light source is used for grazing incidence a clear, bright spectrum should be visible, including its absorption features. Because these spectral colours may cover a wide span on the refractometer scale, it might be tempting to assume this would provide a good measure of dispersion, by simply taking the difference in readings at either end. This is not the case. The spread of the spectrum across the scale is an apparent dispersion, not a true dispersion; and its width is inversely proportional to the dispersion of the gem. If the refractometer reading indicates a large apparent dispersion, then that gemstone will have a low actual dispersion. For example quartz will show a wide, spread spectrum across the refractometer scale, whereas a spinel will show a narrower spectrum. Imitation gems of glass typically have high dispersions and show relatively low apparent dispersion on the refractometer. These glass imitations have become more sophisticated and more prevalent in the market, with their optical and physical properties often overlapping with known natural materials. While intense colours may mask the observed dispersion, the apparent dispersion in the bright line method can be a strong indicator of their true nature.

The amount of apparent dispersion a gem may show depends on the type of refractometer, prism or hemisphere, and the nature of the dense glass used (see Hoover and Linton, 2000, 2001 for details). In order to qualitatively estimate dispersion, one needs to become familiar with an instrument by checking known materials and standards representing a range of dispersion. Once familiar, then relative dispersions may be estimated, based on the width in RI units of the colour spectrum relative to known gems.

It should be emphasized that the above discussion concerns relative dispersion. True dispersion is difficult to measure, but Hoover and Linton (2000, 2001) have given details of the problem using a critical angle refractometer; they show that it is only practical for those instruments with a hemispherical or hemicylindrical dense glass element.

In general, dispersion follows closely the refractive index of a material, so is not expected to be a simple means of discrimination except for glasses and liquids, which tend to have higher dispersions than crystalline solids. Care also needs to be taken if estimates are made from the spectrum produced from white light: absorptions in the gem at the red or blue end of the spectrum may make the apparent dispersion appear less than it really is (e.g. selenium glass).

Absorption spectra definition

When trying the 'bright line' technique with a ruby and white light, it will become immediately apparent that the coloured fringe shows the absorption spectrum of the ruby, and appears similar to that seen using the 'Visual Optics' method (Hodgkinson, 1995). Other strongly absorbing gems also show typical spectra, e.g. almandine; emerald; gold, cobalt, and selenium glass imitations; and cobalt coloured synthetic spinels. Thus, for some stones, the spectroscope may be avoided simply by resorting to grazing incidence illumination. We believe this significantly adds to the importance of the refractometer as a determinative instrument for gemmologists.

Another advantage is that for anisotropic gems, both polarized spectra are visible at the same time, a feature not previously available to most gemmologists. This can yield additional information, which may help to identify a gem such as alexandrite or tourmaline. The polarized spectra of anisotropic gems commonly overlap, especially in those with relatively low birefringence and/or dispersion, so that use of a polarizing filter may be needed to clearly separate them. The difference in absorption spectra of strongly pleochroic stones can be observed and easily compared. Of course, it helps if the stone is oriented for maximum birefringence, although this may not be possible if facet geometry is unfavourable. As with traditional RI measurement, if the *c*-axis is perpendicular to the facet under test, only one spectrum will be seen. With ruby the difference in the red end of the spectrum is easily seen by the shift from red to orange-red. With green and blue tourmaline the distinct differences in absorption along the ordinary and extraordinary rays across the entire spectrum can be seen. The spectrum of the ordinary ray in most tourmalines will be much weaker than that of the extraordinary ray. Distinct differences in the polarized spectra of properly oriented dark emeralds may also be seen by this method. In alexandrite, distinct differences in the spectra of each ray are visible and easily compared, side-by-side. The low-index ray passes much of the yellow, while the high index ray has an absorption in the yellow easily seen by its absence. Liddicoat (1989) shows examples of such polarized spectra.

Although the spectra produced by grazing incidence illumination are quite clear, minor or very narrow absorption lines may not be easily visible, especially at the blue end. The width or spread of the spectrum will also be an inverse function of the gem's dispersion. For the serious gemmologist, a simple addition can be used to spread the spectrum a little. If a small 45-90 degree prism is made of low dispersion glass (or better fluorite which has very low dispersion) then the apparent dispersion will cover a range of about 0.05 units on the refractometer. The prism is placed on the refractometer, similar to that for a Pulfrich refractometer as illustrated in *Figure 4*. It can then act as a 'poor man's' spectroscope, but without the capacity to produce polarized spectra. Light simply has to be introduced to the vertical end of the prism after passing through a gem whose spectrum is to be observed.

Summary

The authors believe that use of the long-neglected 'bright line' technique to measure refractive indices can be a significant aid to gemmologists. This tool can significantly increase the confidence in measurements of refractive indices, especially for difficult cases. Further, it may assist in identifying glass or paste by providing estimates of relative dispersion, or provide polarized absorption spectra without resorting to other instrumentation. The authors suggest that students of gemmology should also be exposed to the technique, as an aid in learning how to measure refractive indices, and for better understanding of refractometers. Renewed use of the 'bright line' method will hopefully inspire more equipment manufacturers to build refractometers that enable easier implementation of this valuable technique.

Acknowledgements

We extend thanks to Bear Williams of Stone Group Labs for the use of their photographic and gemmological equipment, and to an anonymous reviewer for their valuable suggestions.

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The effect of heat treatment on colour, quality and inclusions of aquamarine from China

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Abstract: *Aquamarine from Altai, Siukiang, China, is heat treated from yellowish green to blue to make it more attractive for the gem market. Treatment is carried out at 480-500°C and results in both colour change and changes to the inclusions. The nature of these changes is illustrated and the appearance of tiny black inclusions is attributed to carbon which resulted from reduction of original fluids in the inclusions.*

Keywords: *aquamarine, China, heat treatment, inclusions*

Introduction

Gem quality aquamarine comes from many countries but the main sources are Brazil, Russia, China and Pakistan. Of these, Brazil produces the finest stones. In China, aquamarine can be found in the provinces of Sinkiang, Mongolia, Hunan, Yunnan and Hainan, and the quantity and quality range from Altai, Sinkiang is especially large. However, much of the rough is not of gem quality – it has a pale colour and may be extensively fractured (Wang, 1999). With increasing demands for aquamarine in the gem market, the supply of natural high-quality stones has declined and consequently prices have risen.

One way to address this problem is to improve the colour of originally pale-coloured rough and since this can be achieved to some extent by heat treatment, this technique has become very important for the Chinese gem industry (He *et al.*, 1995). This has consequences for both the home and export markets.

This account reports the results of heat treatment applied to aquamarine from Altai, Sinkiang, and especially its effects on the inclusions.

Materials, equipment and methods

The samples of aquamarine from Altai, Sinkiang, include randomly shaped lumps and step-cut faceted stones (*Figure 1*) in the

Figure 1: *Aquamarine crystals and cut stones from Altai, Sinkiang, typical of those studied for this report.*

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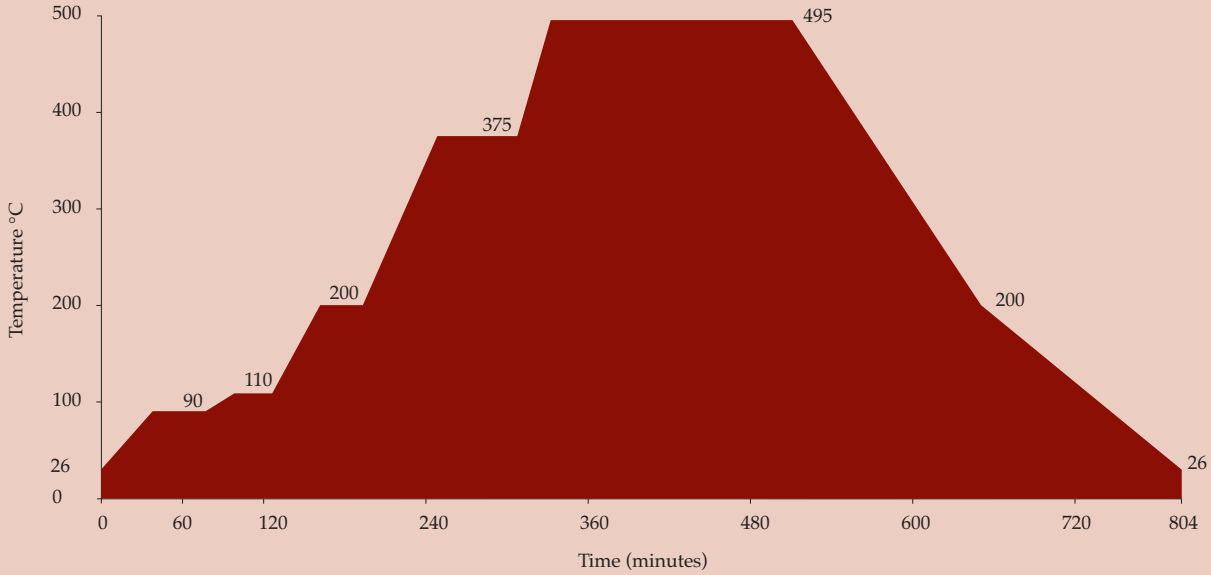

Figure 2: *Chinese aquamarines are heated to 495°C at 3°C/min. in the stages shown. They are held at 90°C for 60 min., at 110° and 200° for 30 min. each, at 375° for 60 min. and at 495° for 180 mins.*

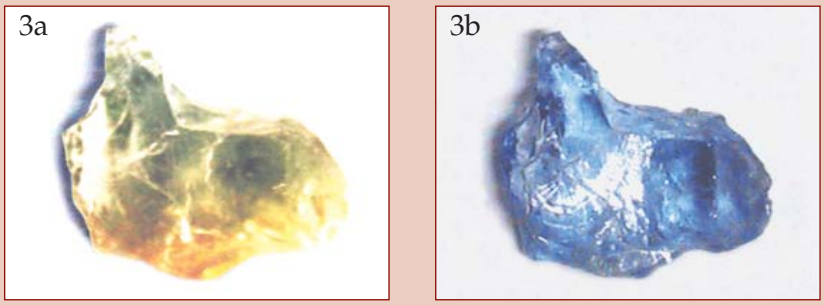

Figure 3: *Untreated aquamarine (a) and heat-treated crystal showing the colour change from yellow-green to blue.*

weight range of 10-15 ct (natural rough) and size range 4 x 6 to 6 x 9 mm (faceted). The natural colour is blue-green.

To heat the stones, a Resistance Furnace (SG2-3-12, made in China) using up to 3kW and delivering temperatures up to 1200 C, was used. Compositions of the stones and their inclusions were determined by coating them with gold and using a Philips scanning electron microscope (SEM model type EL30ESENTMP) fitted with an EDAX energy dispersive spectrometer.

The procedure for heating the aquamarine was as follows:

- aquamarines were mixed with hollow alumina granules and placed in an alumina pot;
- the pot with its load was placed in the furnace and slowly heated in a reducing atmosphere to 480-500 C;
- the load was held at this temperature for three hours and then the temperature was slowly reduced to room temperature.

Great care is needed in increasing and decreasing the temperature slowly to minimize any cracking from vapour pressures in the inclusions. Heating rate up to 495 C and down to 200 C is 3 C/min. and is slower from 200 C to room temperature. The whole cycle is shown in *Figure 2*.

Results

An example of the colour change in aquamarine caused by the procedure described above is shown in *Figure 3*. The colour in *Figure 3b* is considered much more attractive in the gem market. In order to understand further the changes caused by heat treatment, inclusions were studied in detail under the gemmological microscope. Most Altai aquamarines contain cavities which are tube-shaped (many together look like rain), negative crystals or are of irregular shape, and

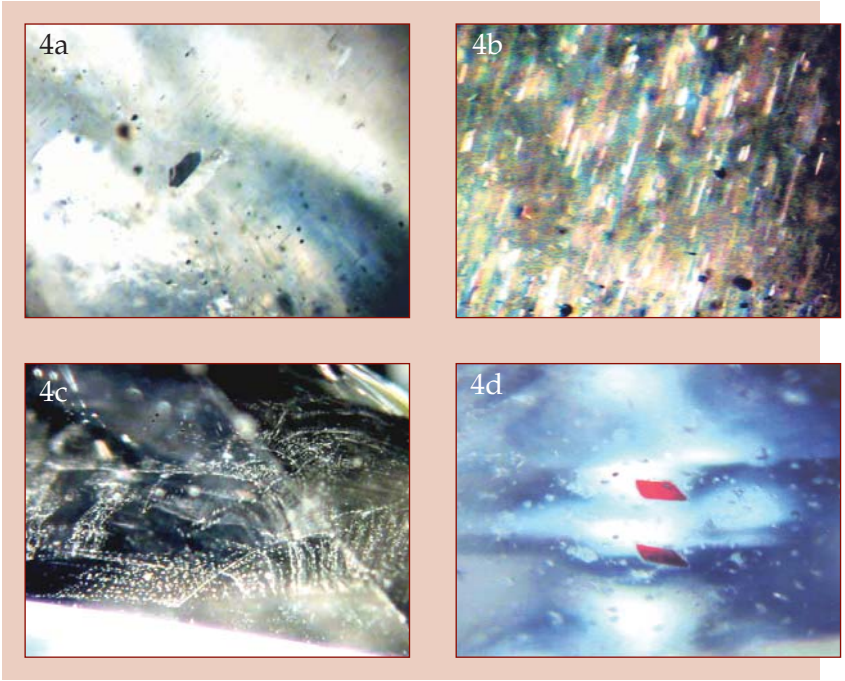

Figure 4: *Inclusions in natural untreated aquamarine: (a) crystal with clear curved face; (b) tube inclusions, 'rain'; (c) curved plane with abundant liquid-filled inclusions, 'fingerprints'; (d) crystal inclusion with clear straight boundaries.*

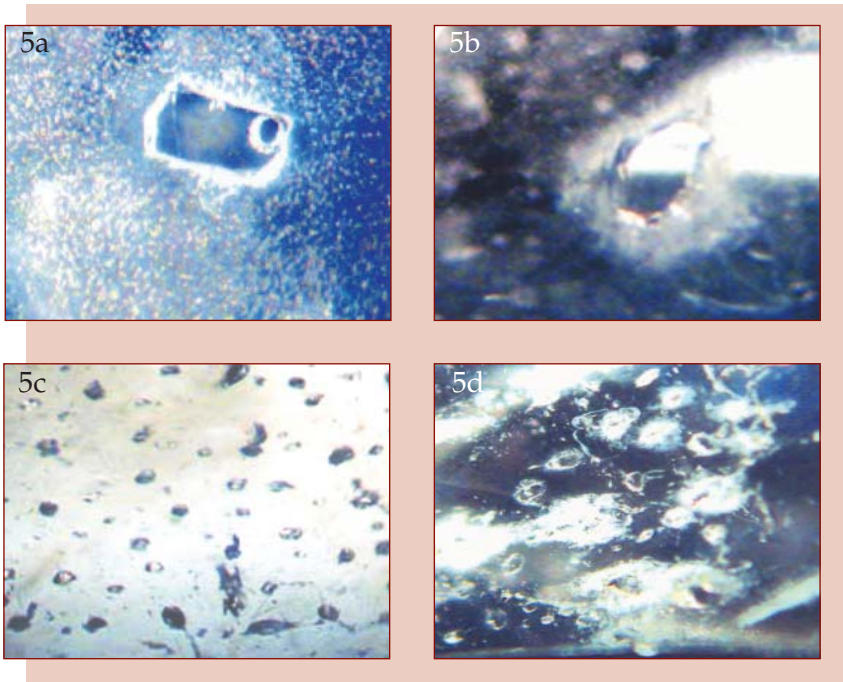

Figure 5: *The changes visible in inclusions after heat treatment: (a) negative crystal with two-phases, liquid and gas, clearly defined; (b) after heat treatment the cavity has changed shape, is empty and the surrounding host crystal is 'frothy' with local shattering; (c) two-phase inclusions in a 'fingerprint'; (d) disc-shaped fractures around the inclusions in (c) after heat treatment*

these may contain liquid, gas or both; some stones contain also tiny cavities in an overall fingerprint pattern (*Figure 4*). Solid inclusions (*Figure 4d*) have typically clean and distinct margins in natural untreated aquamarines.

Heat treatment changes most inclusions quite significantly. Examples are shown in *Figure 5* where a negative crystal cavity containing liquid and a round bubble of gas (a) transforms on treatment to an irregular cavity surrounded by a 'frothy' zone where escape of the volatiles has affected the host crystal (b). Changes of a similar nature affect the tiny cavities in a 'fingerprint' (*Figures 5c* and *d*) where disc-shaped fractures are formed around the original liquid-filled cavities and these resemble poached eggs.

More irregular zones of alteration may form around other inclusions (*Figure 6*).

If the heat treatment is not strictly controlled or if the aquamarine contains too many liquid-filled inclusions, an excessive number of fractures may be formed. Commonly these are disc-shaped, parallel to

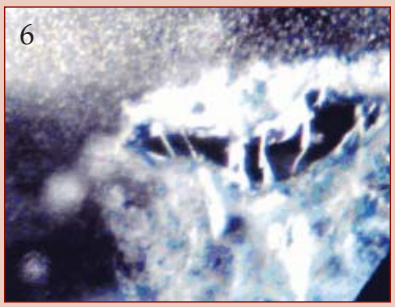

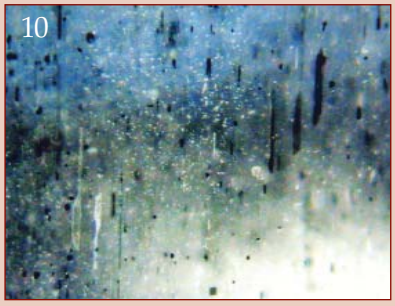

.Figure 6: *Cloudiness or frothiness around a cavity formed by heat treatment of an aquamarine.*

Figure 7: *Disc-shaped fractures penetrated by tube inclusions in close-up (a) and in a cut aquamarine (b).*

Figure 8: *Some disc-shaped fractures display iridescence.*

Figure 9: *Typical cracks formed in aquamarine when it is heated too quickly.*

Figure 10: *Tube inclusions showing black carbon deposits after heat treatment.*

the basal pinacoid {0001} and perpendicular to the *c*-axis (*Figure 7*) and some show iridescence on their surfaces (*Figure 8*). Where the discs are penetrated by tube inclusions, they resemble lotus leaves on a stalk. Rapid heating may lead to abundant tiny fractures creating very much reduced transparency in the stones (*Figures 9* and *10*).

After heat treatment in a reducing atmosphere, most colourless inclusions showed spider-like structures (*Figure 11*) or black spots on inclusion surfaces which resembled smog. The most likely explanation for this phenomenon is that the liquid in the inclusions was CO_2 and not water, and that the treatment reduced it to carbon which was deposited on the inclusion walls. Microprobe analysis of the black substance indicates the main component as carbon and supports this interpretation (*Figure 12*).

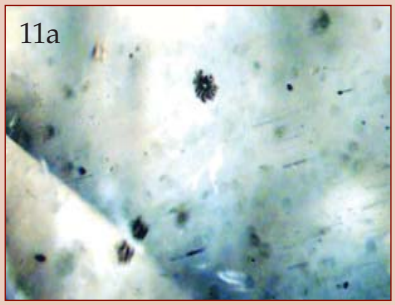

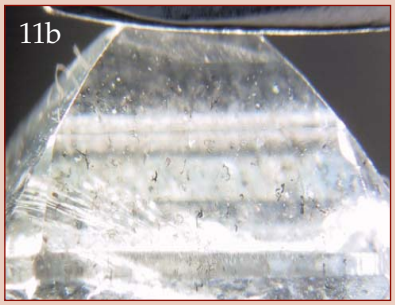

Figure 11: *Spider-like inclusions are probably black carbon deposits in disc fractures after heat treatment (a). A combination of fractures and black carbon makes a treated aquamarine look as if it contains 'smog'.*

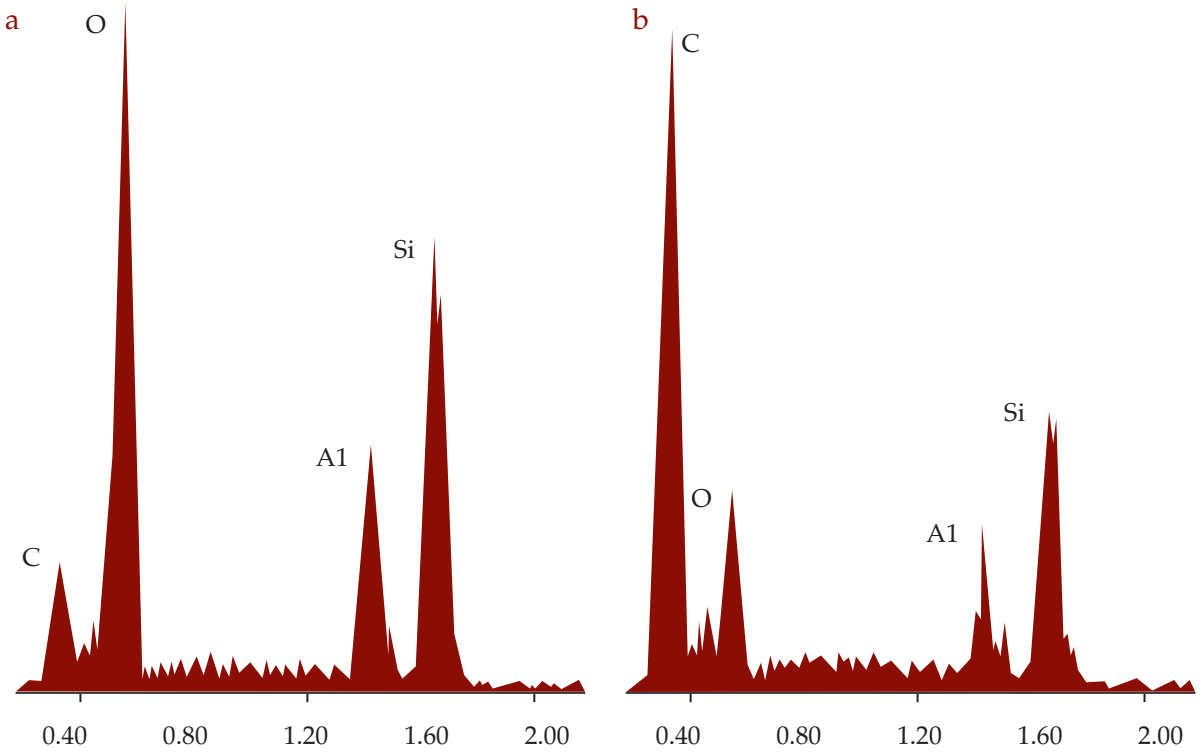

Figure 12: *Spectra showing the major elements in aquamarine (except for Be) in (a), and the relatively high carbon peak from a black spot on a fracture caused by heat treatment (b).*

Conclusions

a Heat treatment of Altai aquamarine produced the best results when rough or cut stones were slowly heated to 480-500 C, held at that temperature for 3 hours and slowly cooled.

b Heat treatment altered the characteristics of inclusions such that natural and treated stones can readily be distinguished.

c Inclusions with spidery structures or dark spots have resulted from the reduction of their contents of carbon-bearing fluids during heat treatment.

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A remarkably large clinohumite

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Abstract: *Recently a remarkably large clinohumite weighing 9.45 ct was identified at the Gem Testing Laboratory, Jaipur, India. This bright brownish-orange specimen of clinohumite was said to be from the Pamir Mountains, Tajikistan. Clinohumite, a rare magnesium silicate, is a monoclinic member of the humite group of minerals and is usually found in weights below three carats. This study reviews the gemmological properties, internal features and IR spectrum of the specimen. The colour, its remarkable size and the observed magnification features proved it a collectors' gem.*

Keywords: *clinohumite, gemmological properties, IR analysis, magnification features*

Introduction

Most commonly found only as small grains, large clinohumite crystals are rare and sought by collectors; some are fashioned into bright yellow-orange gemstones. Though the mineral has been known for a long time, gemmy crystals have been available in the international market only for the past two decades or so. Gem-quality clinohumite is known to occur in two important localities — the Pamir Mountains (at Kukh-i-lal, Sumdzin and Changin), in Tajikistan in association with spinel and in the Taymyr region (Basin of Kotui River) in Siberia (O'Donoghue, 2006, p.400; Henn *et al*., 2001; Laurs and Quinn, 2004). Another find of clinohumite has been reported in association with spinel in Mahenge, Tanzania (Hyrsl, 2001). Recently, a large brownish-orange clinohumite was submitted for identification at the Gem Testing Laboratory, Jaipur.

Specimen description

The specimen (*Figure 1*) is an oval mixed cut measuring 15.13 10.41 7.78 mm and weighing 9.45 ct. It is transparent and has a bright brownish-orange colour resembling some hessonite and spessartine garnets. The stone is slightly included with eye-visible inclusions (again *Figure 1*) and was reported to be from Tajikistan.

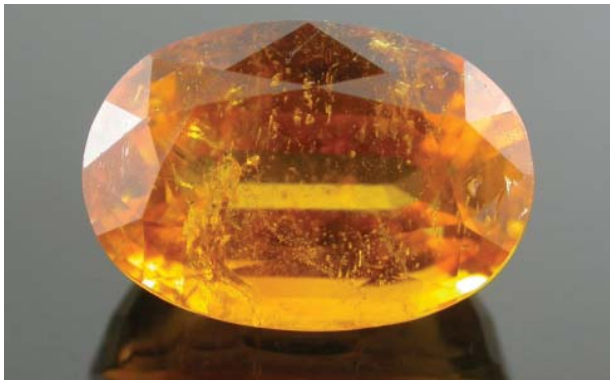

Figure 1: *Brownish-orange clinohumite of 9.45 ct. Photo by G. Choudhary.*

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Gemmological properties

Using traditional gemmological equipment, the stone's properties were determined and are summarized in *Table I*. Refractive index (RI) and birefringence are consistent with the values mentioned in literature (O'Donoghue, 2006; Henn *et al*., 2001; Laurs and Quinn, 2004; Arem, 1987, p.113-14). The specimen exhibited a strong pleochroism with yellow, orange and brownish yellow being the three hues, and under the short wave ultraviolet light (SWUV) it displayed strong orange-yellow fluorescence with a surface-related greenish-yellow chalkiness (*Figure 2*). The surface-related chalkiness under SWUV reminded us of the fluorescence commonly associated with brown glass coloured by uranium.

Internal features

Inclusions and other features were observed in the stone under immersion using both vertical and horizontal type microscopes.

Table I: *Gemmological properties of a clinohumite weighing 9.45 ct*

Colour	Brownish orange
Diaphaneity	Transparent
RI	1.646 - 1.670
Birefringence	0.024
Optic character/ sign	Anisotropic, biaxial positive
Pleochroism	Strong trichroism: yellow, orange and brownish yellow
SG	3.21
Visible spectrum	Complete absorption of wavelengths shorter than 430 nm
SWUV	Strong orange-yellow with surface greenish- yellow chalkiness
LWUV	Inert
Chelsea colour filter	No change to body colour

Growth-related features

The specimen exhibits dominant zones in one direction throughout most of the stone, but there is an angular pattern at the narrow end. The overall complex pattern of the growth zoning is probably an indication of the shape of the original crystal. Colour zoning is coincident with the growth zoning only in patches (*Figure 3*).

Swirl-like features

Swirl-like structures are present almost throughout the stone and these may indicate the outlines of intergrown individual crystals (*Figure 4*). Swirl features are commonly present in glasses and may occur in some natural gemstones, such as Mogok ruby. To our knowledge, such inclusions have not been reported in clinohumite.

Reflective planes

The specimen exhibited flat, parallel and highly reflective planes (*Figure 5*) at an inclination to the dominant growth zones. These may represent incipient cleavage although clinohumite cleavage is reported as poor.

Fluid inclusions

Feathers: The stone contains fluid inclusions in various structures, the most obvious of which are the 'feathers' or 'fingerprints' (*Figure 6*). These have the appearance of fine hair and show high reflection strongly resembling the inclusions common in tourmaline which have been described as 'trichites'. At higher magnification two phase inclusions within the trichites may be visible.

Oriented multiphase inclusions: Many multiphase (mainly two-phase but some also with black crystals) inclusions were observed in certain parts of the stone. They are contained in long, tubes with a slightly corroded appearance which are oriented in a single direction. The nature of the inclusions can be complex (*Figure 7*) and some reminded us of those seen in kunzite.

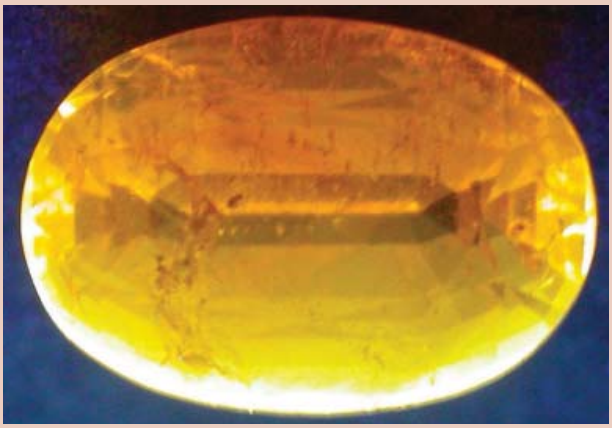

Figure 2: *Strong yellow-orange fluorescence of the clinohumite under SWUV radiation; also note the surface-related greenish-yellow chalkiness. Photo by G. Choudhary.*

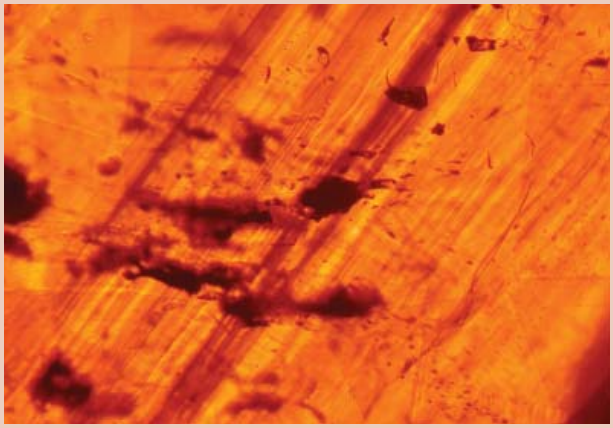

Figure 3: *Strong colour zoning is visible along the dominant growth zones; in some parts of the stone it gave a patchy effect. Diffused; magnified 30×. Photo by C. Golecha.*

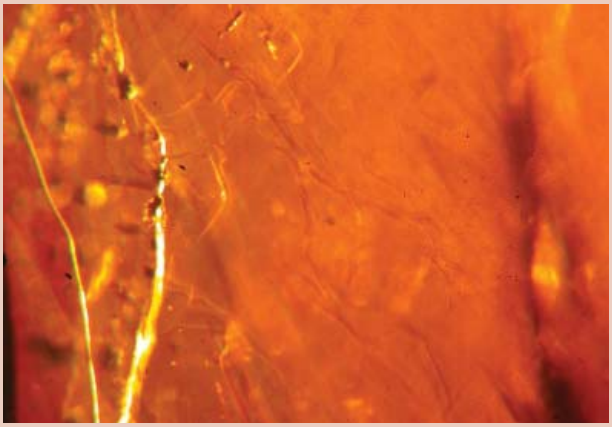

Figure 4: *Swirl like patterns resembling those in some glasses; magnified 35×. Photo by G. Choudhary.*

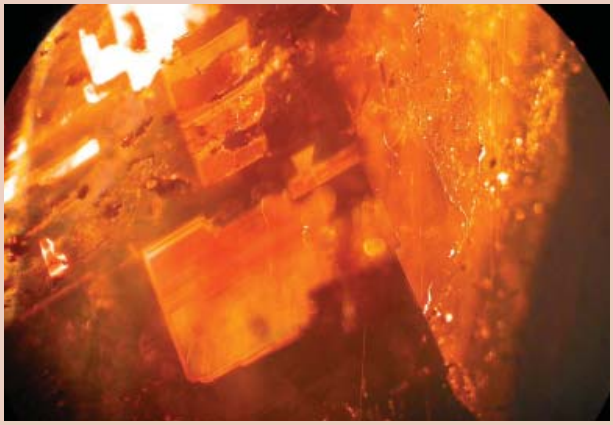

Figure 5: *Highly reflective, flat, one directional planes of weakness were observed. Note the fine tube like inclusions vertically oriented on the right side. Crossed polars; magnified 25×. Photo by M.B. Vyas.*

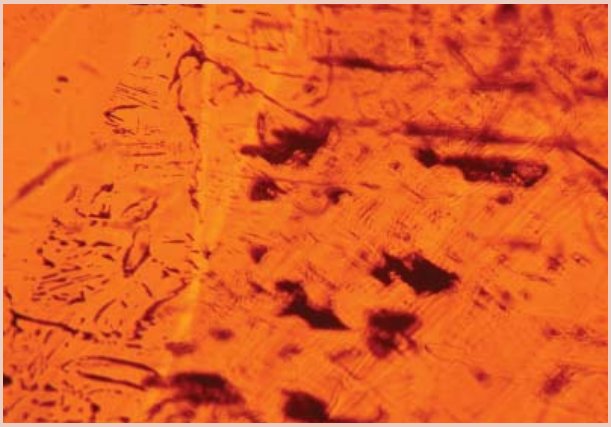

Figure 6: *The clinohumite is host to many types of fluid inclusions, most striking of which are inclusions resembling the 'trichites' seen in tourmaline. Magnified 35×. Photo by C. Golecha.*

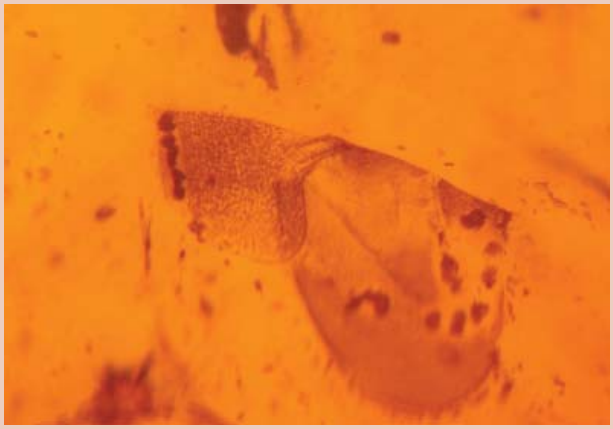

Figure 7: *Fluid inclusions are also present in the form of 'fingerprints' with a hazy or folded appearance. Diffused light; immersion; magnified 35×. Photo by C. Golecha.*

Figure 8: *Infrared spectrum of the clinohumite.*

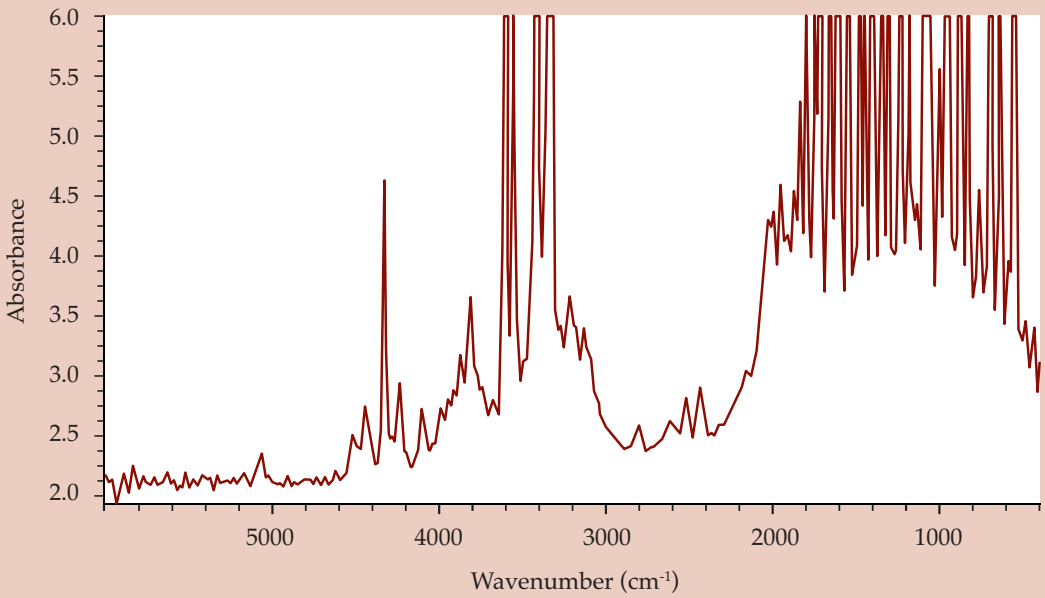

Infrared spectrum

An infrared spectrum was obtained using a Fourier Transform Infrared Spectroscopy (FTIR) Avatar Nicolet 360 ESP model. The range recorded was 400 to 6000 cm^{-1} (*Figure 8*) and the spectrum showed complete absorption between 400 and 2000 cm^{-1} with numerous peaks between 2400 and 4500 cm^{-1}. The authors were unable to obtain a standard infrared spectrum of clinohumite for comparison so this spectrum is presented as a basis for further work.

Discussion

The 9.45 ct specimen described is a rare example of a large gem-quality clinohumite. More and more stones are making their way to the gem trade in Jaipur from neighbouring countries such as Pakistan and Afghanistan, a fact reflected in the increase in the stones received for identification at the Gem Testing Laboratory in Jaipur. This specimen was submitted to us by a gem merchant with the information that it had been recovered from the spinel mines in the Pamir Mountains and had been transported through Afghanistan. However, the dealer had no idea that it was clinohumite, a gem that was new to him.

Acknowledgement

The authors are grateful to Mustaqeem Khan for bringing the gem to their notice.

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Gem-quality garnets: correlations between gemmological properties, chemical composition and infrared spectroscopy

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Abstract: *A suite of 19 natural gem-quality garnets has been investigated to determine the correlations between those measurable quantities which are effective in their identification. The results reveal that IR spectroscopy, along with gemmological and chemical analyses, can provide sufficient data to enable positive characterization of garnet gemstones. In particular, the IR active bands over the 1150-800 and 650-450 cm^{-1} ranges allow a discrimination between pyralspite and ugrandite series. Furthermore, pyrope, spessartine and andradite garnets exhibit such mid-infrared patterns that are potentially useful in their identification.*

Keywords: *chemical composition, garnet, gem testing, infrared spectroscopy*

Introduction

The garnet group, or family, hosts a variety of minerals which have often aroused significant interest as gemmological materials for their chromatic and morphological properties (see, for instance, the overview by Stockton and Manson, 1985).

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Analytical methods

We have examined 19 faceted gem-quality natural samples (from 0.20 to 6.84 ct) of different garnet species (*Figure 1*); 17 are transparent and two are opaque (the latter are hydrogrossular garnets). The localities of our specimens are listed in *Table Ia* and *b*.

All the samples have been investigated using standard gemmological methods to determine colour, refractive indices (by means of a Kruss refractometer, using methylene iodide as a contact liquid), specific gravity and absorption lines over the visible energy range, using a hand spectroscope.

The chemical compositions of the samples have been determined in a non-destructive way using an Applied Research Laboratories electron microprobe equipped with five wavelength dispersive spectrometers (WDS) and a Tracor Northern energy dispersive spectrometer (EDS), using an accelerating voltage of 15 kV, a sample current on brass of 15 nA, and counting time of 20 sec on peaks and 5 sec on backgrounds. Natural kaersutite (for Si, Fe, Ti, Al, Mg and Na), chromite (for Cr), rhodonite (for Mn) and pure V have been employed as standards. For determining iron in almandine garnets (samples 2 and 3), natural fayalite was chosen as a standard instead of kaersutite. Ca contents in *pyralspite* and *ugrandite* were determined using standard kaersutite and standard diopside, respectively. V*K*α and Ti*K*β-radiations give rise to a well-known interference which has been corrected by an appropriate re-scaling. By normalizing analyses to 12 oxygens and 8 cations, ferric iron contents have been calculated using the method of Droop (1987). The matrix effects have been accounted for through a conventional PAP routine of the SAMx series of programs.

Mid-infrared (4000-400 cm^{-1}) spectroscopic investigations have been carried out on all the samples, using a Nicolet NEXUS FTIR spectrophotometer, and results recorded in both reflection and transmission mode. Infrared spectra in reflectance mode, of interest for jewellery applications because it is non-destructive, were recorded using a diffuse reflectance accessory (DRIFT); four spectra at a resolution of 4 cm^{-1} were recorded from each randomly oriented specimen. Further IR-measurements in transmittance mode at a resolution of 4 cm^{-1} have been carried out using KBr compressed pellets with a sample to KBr weight ratio of 1:100, to provide support to the interpretation of the IR-data collected in reflectance mode.

Figure 1: *The 19 faceted garnet samples (from 0.20 to 6.84 ct) investigated in the present study (left: ten pyralspite garnets; right: nine ugrandite garnets) Pictures by Loredana Sangiovanni (IGI).*

As silicates with a general formula $X_3Y_2Si_3O_{12}$ (where X corresponds to Mg^{2+}, Fe^{2+}, Mn^{2+} or Ca^{2+}, and Y to Al^{3+}, Fe^{3+}, Ti^{4+}, Cr^{3+}, or V^{3+}), almost all natural garnets are solid solutions between two or more end-members of the group. Most garnets belong to two series known as *pyralspite* (pyrope-almandine-spessartine; Y = Al^{3+} and X = Mg^{2+}, Fe^{2+}, and Mn^{2+}, respectively) and *ugrandite* (uvarovite-grossular-andradite; X = Ca^{2+} and Y = Cr^{3+}, Al^{3+}, and Fe^{3+}, respectively). A comprehensive survey of the chemistry and the structure of the garnet group is provided by Deer *et al*. (1997).

Notwithstanding the relevant role that garnets play as gemstones, relatively few studies have been published which relate the gemmological, chemical and spectroscopic features of garnets to enable one to precisely attribute a given specimen to the appropriate series, species and/or variety [the term variety in this context has been defined by Stockton and Manson (1985)].

In the present paper, we combine the results obtained from a suite of gem-quality garnets from some different localities by techniques ranging from traditional gemmological tests to 'modern' spectroscopic approaches (IR-spectroscopy) and advanced chemical determination methods (electron probe micro-analysis), with the aim to:

(i) discover any correlations between gemmological properties, chemical composition and IR vibrational frequencies;

(ii) increase the general knowledge of gemmologically relevant features of garnet gemstones;

(iii) provide a detailed set of spectroscopic and chemical data to help link macroscopic observations to microscopic properties, enabling precise identification.

In such a context, our work joins that of Stockton and Manson (1985) and adds data from the infrared spectra obtained from a range of garnets. Hereafter we adopt the gemmological nomenclature according to Stockton and Manson (1985), complemented by that of Johnson *et al*. (1995), so that one classifies garnet gemstones into nine species (pyrope, almandine, pyrope-almandine, spessartine, almandine-spessartine, pyrope-spessartine, grossular, andradite and grossular-andradite) and eight varieties (chrome pyrope, rhodolite, malaya, colour-change, tsavorite, hessonite, demantoid and topazolite).

Gemmological properties

The gemmological properties of the garnets, the colour, refractive index, specific gravity and spectral absorption lines, are summarized in *Table Ia* and *b* (see pages 314-317). Such properties are the foundation of precise identification of the species and/or variety of a given garnet gemstone.

Chemical composition

The quantitative chemical analyses of the 19 faceted garnets are summarized in Table *Ia* and *b*. The molar composition in terms of end members enables a positive attribution of a specimen to a given garnet series/species/variety to be made. The results are consistent with those obtained from gemmological testing, though they do provide a significantly more detailed characterization.

The compositions of garnets lying in the *pyralspite* range (see *Table Ia* and *Figure 2*), namely pyrope (variety chrome pyrope), almandine, pyrope-almandine (variety rhodolite), spessartine and almandine-spessartine are consistent with those in the literature (Deer *et al*., 1997; Eeckhout *et al*., 2002). The pyrope-spessartine variety known by some in the gem trade as 'malaya garnet' contains 52.75 mol.% pyrope, 33.65 mol.% spessartine, 6.10 mol.% grossular and 7.50 mol.% almandine (sample 9), which is consistent with results reported by Schmetzer *et al*. (2001), and shows just small contents of Cr^{3+} and V^{3+}. The chromatic behaviour of the colour-change pyrope-spessartine (sample 10) from green in day/fluorescent light to purple in incandescent light, is attributable to a relatively high combined V_2O_3 + Cr_2O_3 content of 1.58 wt. %; this is a diagnostic feature of such gemstones with respect to the other pyrope-spessartine garnets (Manson and Stockton,

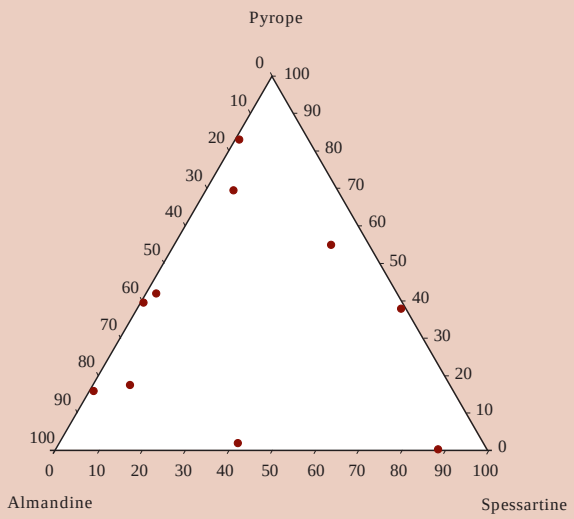

Figure 2: *Pyrope-almandine-spessartine triangular plot of the ten samples belonging to the pyralspite series. For details see Table Ia.*

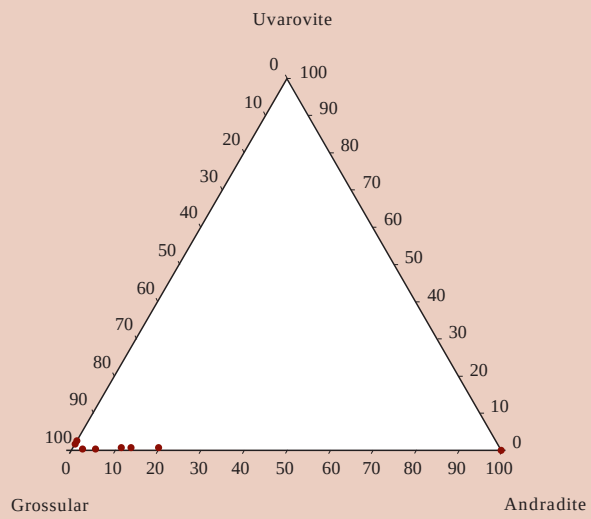

Figure 3: *Uvarovite-grossular-andradite triangular plot of the nine samples belonging to the ugrandite series. For details see Table Ib.*

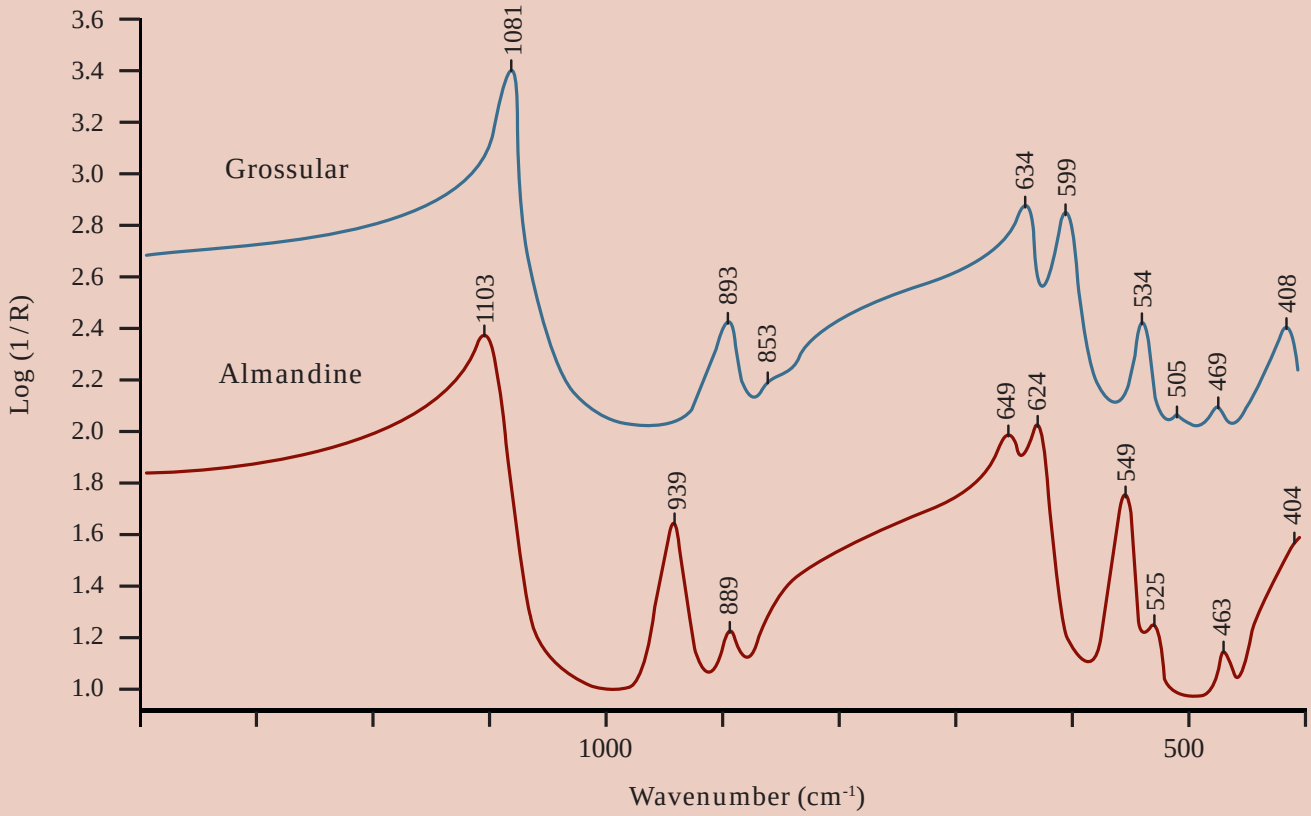

Figure 4: *Mid-infrared spectra (1400-400 cm^{-1}) in reflectance mode for two garnets (almandine and grossular) representative of the pyralspite and ugrandite series.*

1984; Schmetzer and Bernhardt, 1999; Krzemnicki *et al*., 2001).

Five samples in the *ugrandite* series (see *Table Ib* and *Figure 3*) have compositions typical of grossular (Deer *et al*., 1997). The tsavorite varieties are distinguishable from pure grossular on the basis of their significant V_2O_3 and lesser Cr_2O_3 contents, causing a green hue (Kane *et al*., 1990; Mercier *et al*., 1997). The grossular variety known as hessonite contains sufficient Fe^{3+} to cause the orange-yellow colour (Kanis and Redmann, 1994; Phillips and Talantsev, 1996). Our andradite sample 16 is greenish yellow, due to its ferric iron content, and has less than 0.02 wt % of Cr^{3+} (Deer *et al*., 1997; Phillips and Talantsev, 1996). The grossular-andradite, from Mali, has a composition similar to that reported by Johnson *et al*. (1995) and its colour is entirely due to its content of Fe^{3+}.

Infrared spectroscopy

Infrared spectroscopy is sensitive to the composition of a gemstone, as vibrational frequencies are dependent on the nature of the cations involved (Tarte and Deliens, 1973).

The observed infrared bands and frequencies in the 1400-400 cm^{-1} range for all the garnets examined here are listed in *Table II* and *Table III* (see pages 318 and 319), obtained using the diffuse reflectance and transmittance modes respectively. Infrared reflectance patterns in the mid-infrared energy range of two specimens representative of the *pyralspite* and *ugrandite* series [almandine (sample 3) and grossular (sample 11), respectively] are shown in *Figure 4*, by way of example.

With reference to the data collected in reflectance mode (*Table II*), all the spectra are characterized over the 1150-800 cm^{-1} range by three strong absorption bands assigned to the ν3-asymmetric stretching mode of the SiO_4 tetrahedron in the garnet structure (Hofmeister and Chopelas, 1991; Hofmeister *et al*., 1996). The *pyralspite* frequencies range from 1094 to 1125 (mean 1111); from 924 to 945 (mean 938); from 876 to 892 (mean 886) cm^{-1} which are distinct from the *ugrandite* frequencies which range from 1044 to 1082 (mean 1075); from 867 to 897 (mean 891); and from 825 to 853 (mean 849) cm^{-1}, as shown in *Figure 5*. Such frequencies are related to the unit cell edge *a* of the garnet structure (Launer, 1952; Moore and White, 1971; Tarte and Deliens, 1973; Hofmeister *et al*., 1996; Chaplin *et al*., 1998) and allow one to immediately say whether a garnet lies in the *pyralspite* or *ugrandite* series (mean *a* 11.535 and 11.968 Å, respectively; see Deer *et al*., 1997). By comparison with other *pyralspite* and *ugrandite* garnets investigated, our spessartine and andradite samples show lower frequencies of the three bands in question (see for details *Table II* and *Figure 5*).

Similar conclusions are achieved by inspecting patterns in transmission mode over the same energy range, apart from some differences revealed in terms of active bands (four instead of three) and of their related positions (compare *Table II* with *Table III*; for a survey on infrared transmittance bands see also: Moore and White, 1971; Tarte and Deliens, 1973; Hofmeister *et al*., 1996; Chaplin *et al*., 1998).

Over the 650-450 cm^{-1} range, absorbance peaks recorded in reflectance mode are ascribable to the ν2-symmetric and ν4-asymmetric bending modes of the SiO_4 tetrahedra (see *Table II*, *Table III* and *Figure 6*). In *ugrandites* such frequencies (in cm^{-1}) range from 595 to 639 (mean 630), from 549 to 606 (mean 594), from 492 to 535 (mean 529), and from 467 to 506 (mean 499), and are at lower values than in *pyralspite*s which range from 644 to 650 (mean 648), from 612 to 639 (mean 627), from 543 to 559 (mean 552), and from 522 to 528 (mean 525), thus providing a useful marker for discrimination between the two series (Moore and White, 1971; Tarte and Deliens, 1973; Hofmeister and Chopelas, 1991; Hofmeister *et al*., 1996; Chaplin *et al*., 1998). At these frequencies, as for the higher frequencies (cf. *Figures 5* and *6*), our spessartine shows lower values than other *pyralspite* garnets and our andradite likewise shows lower values than other *ugrandite* garnets. Pyrope gives IR-patterns with a single band at 639 cm^{-1} (*Table II*,

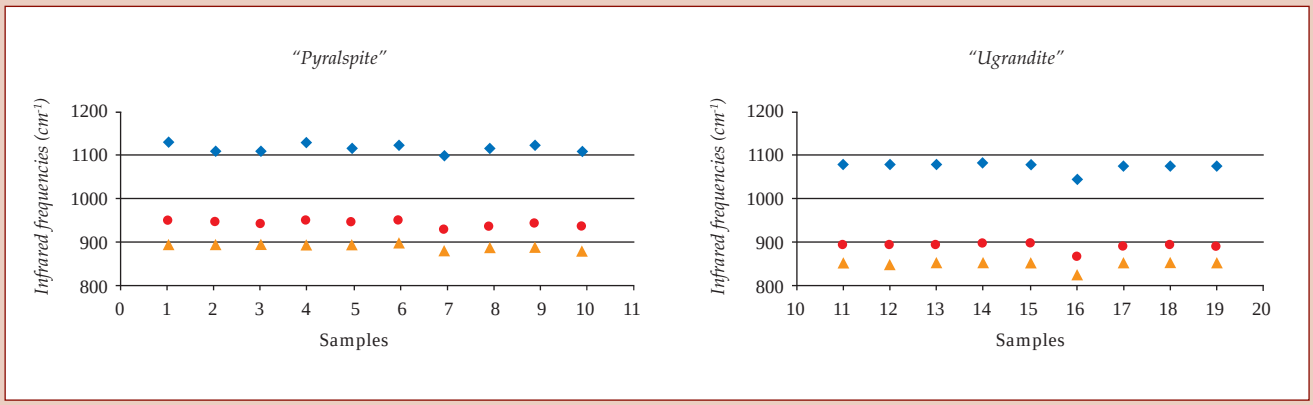

Figure 5: *Frequencies of the IR bands, measured in reflectance mode, over the 1150-800 cm^{-1} range for the pyralspite and ugrandite series. Triangles, circles and diamonds correspond to the different IR vibrational frequencies (see also Table II).*

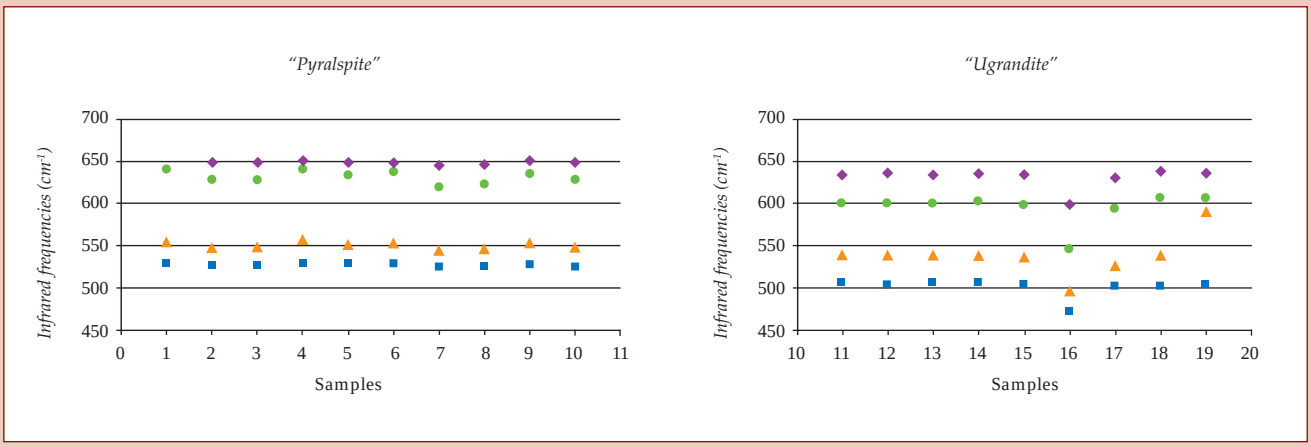

Figure 6: *Frequencies of the IR bands, measured in reflectance mode, over the 650-450 cm^{-1} range for the pyralspite and ugrandite series. Again squares, triangles, circles and diamonds correspond to the different IR vibrational frequencies (see also Table II).*

col. 1) compared with the two shown by almandine at 624 and 648 cm^{-1}, which is consistent with the results of Moore and White (1971) and Tarte and Deliens (1973). By comparison with other *ugrandite* garnets, andradite has only a single peak at 423 or 436 cm^{-1}, in reflectance and transmittance mode, respectively, instead of two.

Lastly, both pink and green hydrogrossular garnets (samples 18 and 19) give IR transmission spectra exhibiting H_2O absorption bands, particularly prominent about 3620 and 3600 cm^{-1}, in keeping with the hydrogarnet substitution, i.e. $[SiO_4] \leftrightarrow [H_4O_4]$; a broad absorption band at about 3350-3400 cm^{-1} is assigned to non-structural adsorbed H_2O (Rossman and Aines, 1991; Amthauer and Rossman, 1998).

Conclusion

Although every garnet gemstone exhibits a unique set of gemmological characteristics defining its identity (colour, refractive index, specific gravity and visible spectral features, observed through a hand spectroscope), mid-infrared spectroscopy and electron micro-analytic methods yield

additional useful information. Electron microprobe analyses can enable specification of series, species and variety, providing a full compositional characterization. IR-spectroscopy in reflectance mode proves to be an effective auxiliary diagnostic tool. The positions of the IR absorption bands in the 1150-800 and 650-450 cm^{-1} ranges allow an immediate discrimination between the *pyralspite* and *ugrandite* families. Moreover, pyrope, spessartine and andradite garnets possess such IR-patterns that are potentially useful in their identification.

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Table Ia: Physical and chemical properties of pyralspite garnets

Properties	Samples[a]									
	1	2	3	4	5	6	7	8	9	10
	Pyrope var. chrome pyrope	Almandine	Almandine	Pyrope-almandine var. rhodolite	Pyrope-almandine var. rhodolite	Pyrope-almandine var. rhodolite	Spessartine	Almandine-spessartine	Pyrope-spessartine var. malaya	Pyrope-spessartine var. colour-change
Colour	red	purplish red	purplish red	red-purple	red-purple	red-purple	orange	orange-red	yellowish orange	green (daylight) purple (incandescent light)
Refractive index[b]	1.741	>1.79	>1.79	1.750	1.778	1.778	>1.79	>1.79	1.754	1.775
Specific gravity	3.68	4.19	4.14	3.81	3.96	3.98	4.13	4.27	3.83	4.00
Spectral absorption features (hand spectroscope)	a 445 nm cutoff; a weak band at 505 nm; a broad band at 564 nm; and a pair of thin bands at 684 and 670 nm	bands at 423, 438, 460, 505, 520, 573, 610 nm; a band at 690 nm	bands at 423, 438, 460, 505, 520, 573, 610 nm; a band at 690 nm	bands at 423, 438, 460, 504, 524, 574, 614 nm; a band at 691 nm	bands at 423, 438, 460, 505, 520, 573, 610 nm; a band at 690 nm	bands at 423, 438, 460, 505, 524, 575, 610 nm; a band at 690 nm	three bands at 410, 421 and 430 nm forming a cutoff at about 435 nm; bands at 460, 480, 520 nm; a weak band at 573 nm	a 435 nm cutoff; bands at 460, 480, 504 and 573 nm	three bands at 410, 421 and 430 nm forming a cutoff at about 435 nm; bands at 462, 480, 504, 520, 573 nm	three bands at 410, 421 and 430 nm forming a cutoff at about 435 nm; bands at 460, 480, 504, 520; a broad band at 573 nm
Oxide (wt.%)[c]										
SiO_2	40.81	35.42	38.10	40.68	39.47	40.61	36.30	35.47	40.73	39.23
TiO_2	0.21	0.02	0.01	0.02	0.04	0.01	0.13	0.03	0.03	0.08
Al_2O_3	23.07	21.58	20.65	23.05	21.63	21.56	20.64	20.63	23.23	21.67
Cr_2O_3	01.41	0.02	0.03	0.05	0.04	0.01	bdl[d]	0.01	0.01	0.36
Fe_2O_3	03.00	03.52	-	1.86	0.18	-	0.19	02.14	0.06	-
FeO	07.03	34.32	33.20	11.23	24.36	27.36	05.23	24.08	03.53	0.51
MnO	0.34	0.47	3.47	3.09	1.04	0.33	37.28	16.75	15.99	24.18
MgO	20.49	03.68	4.47	18.11	10.83	10.53	0.01	0.44	14.23	8.71
CaO	03.81	0.76	0.57	1.52	1.86	0.47	0.33	0.26	02.34	3.56
Na_2O	0.04	0.01	0.01	0.01	0.01	0.02	0.02	0.06	0.02	0.03
K_2O	0.01	bdl	bdl	0.01	0.03	0.01	bdl	bdl	0.01	0.02
V_2O_3	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	0.01	1.22
Total	100.22	99.80	100.51	99.63	99.49	100.91	100.13	99.87	100.20	99.57

Numbers of ions on the basis of 12 oxygens										
Si	2.904	2.864	3.034	2.960	3.019	3.081	2.987	2.931	3.001	3.007
Ti	0.011	0.001	0.001	0.001	0.002	0.001	0.008	0.002	0.002	0.005
Al	1.935	2.056	1.938	1.976	1.950	1.928	2.002	2.009	2.016	1.958
Cr	0.079	0.001	0.002	0.003	0.002	0.001	-	0.001	0.001	0.022
Fe^{3+}	0.161	0.214	-	0.102	0.011	-	0.012	0.133	0.003	-
Fe^{2+}	0.418	2.320	2.211	0.683	1.558	1.736	0.360	1.664	0.218	0.033
Mn	0.021	0.032	0.234	0.190	0.067	0.021	2.598	1.173	0.998	1.570
Mg	2.174	0.444	0.531	1.964	1.235	1.191	0.001	0.054	1.563	0.995
Ca	0.291	0.066	0.049	0.119	0.152	0.038	0.029	0.023	0.184	0.293
Na	0.006	0.002	0.002	0.001	0.002	0.003	0.003	0.001	0.003	0.004
K	0.001	-	-	0.001	0.003	0.001	-	-	0.001	0.002
V	-	-	-	-	-	-	-	-	0.001	0.075
Mol.% end members										
Grossular	-	-	1.50	-	4.41	1.25	0.38	-	6.10	5.42
Almandine	14.40	81.10	73.11	23.11	51.72	58.14	12.04	57.10	7.50	1.14
Pyrope	74.90	15.50	17.55	66.44	41.00	39.90	0.04	1.90	52.75	34.42
Spessartine	0.70	1.10	7.74	6.44	2.24	0.71	86.94	40.20	33.65	54.32
Andradite	8.30	2.30	-	4.01	0.53	-	0.60	0.80	-	-
Uvarovite	1.70	-	0.10	-	0.10	-	-	-	-	1.05
Goldmanite	-	-	-	-	-	-	-	-	-	3.65

[a] The localities of garnets are Arizona, India, Sri Lanka, Sri lanka, Sri Lanka, Namibia, Sri Lanka, Tanzania, Tanzania for 1, 3, 4, 5, 6, 7, 8, 9, 10 samples, respectively. The source of sample 2 is unknown.
[b] As observed through a Kruss refractometer.
[c] The number of averaged points are 10, 3, 5, 6, 4, 3, 3, 5, 4, 3 for 1, 2, 3, 4, 5, 6, 7, 8, 9, 10 samples, respectively.
[d] bdl=below detection limit (0.01 wt.%)

Table Ib: Physical and chemical properties of ugrandite garnets

Properties	Samples[a]								
	11	12	13	14	15	16	17	18	19
	Grossular	Grossular var. tsavorite	Grossular var. tsavorite	Grossular var. hessonite	Grossular var. hessonite	Andradite	Grossular-andradite	Hydro grossular	Hydro grossular
Colour	yellow	green	green	yellowish orange	yellowish orange	greenish yellow	greenish yellow	pink	green
Refractive index[b]	1.738	1.741	1.743	1.742	1.754	>1.79	1.766	1.72[c]	1.73[c]
Specific gravity	3.59	3.62	3.65	3.66	3.65	3.88	3.66	3.03	3.54
Spectral absorption features (hand spectroscope)	none	none	none	bands at 407 and 430 nm	bands at 407 and 430 nm	none	band at 440 nm	none	none
Oxide (wt.%)[d]									
SiO_2	39.49	39.43	39.13	38.48	39.13	34.87	38.59	36.87	38.64
TiO_2	0.52	0.39	0.43	0.02	0.20	0.05	0.56	0.01	0.06
Al_2O_3	21.31	19.61	20.39	20.64	18.34	0.10	17.38	20.89	20.05
Cr_2O_3	0.02	0.34	0.18	bdl[e]	0.01	0.02	0.05	0.01	0.41
Fe_2O_3	1.80	0.02	-	4.18	4.96	31.30	6.52	0.67	1.15
FeO	-	-	0.01	-	-	0.02	-	-	-
MnO	0.35	0.75	1.19	0.09	0.32	0.02	0.09	0.93	0.24
MgO	0.37	0.58	0.50	0.01	0.06	0.17	0.74	0.03	0.01
CaO	36.49	36.80	35.24	36.96	37.80	33.02	36.04	37.59	37.50
Na_2O	0.03	0.02	bdl	bdl	0.01	bdl	0.02	0.01	bdl
K_2O	0.02	0.01	bdl	bdl	0.01	bdl	0.01	0.01	0.01
V_2O_3	bdl	1.14	1.48	bdl	bdl	bdl	bdl	bdl	bdl
Total	100.40	99.09	98.55	100.38	100.86	99.57	100.00	97.02	98.07

Numbers of ions on the basis of 12 oxygens									
Si	2.969	3.016	3.002	2.914	2.983	2.968	2.960	2.802	2.982
Ti	0.029	0.023	0.025	0.001	0.011	0.003	0.032	0.001	0.004
Al	1.889	1.768	1.843	1.842	1.647	0.010	1.571	1.871	1.823
Cr	0.001	0.021	0.011	-	0.001	0.001	0.003	0.001	0.025
Fe^{3+}	0.102	0.000	-	0.238	0.284	2.004	0.377	0.038	0.067
Fe^{2+}	-	-	0.000	-	-	0.002	-	-	-
Mn	0.022	0.049	0.077	0.006	0.021	0.001	0.006	0.060	0.016
Mg	0.042	0.067	0.057	0.001	0.006	0.021	0.085	0.003	0.002
Ca	2.940	3.016	2.897	2.998	3.087	3.010	2.962	3.060	3.101
Na	0.004	0.002	-	-	0.001	-	0.003	0.002	-
K	0.002	0.001	-	-	0.001	-	0.001	0.001	0.001
V	-	0.070	0.091	-	-	-	-	-	-
Mol.% end members									
Grossular	92.75	91.48	90.40	87.90	84.50	-	77.92	95.75[f]	94.61[f]
Almandine	-	-	0.01	-	-	0.06	-	-	-
Pyrope	1.40	2.12	1.90	-	0.20	0.70	2.80	0.10	0.05
Spessartine	0.70	1.55	2.54	0.20	0.66	0.04	0.20	1.91	0.51
Andradite	5.10	0.05	-	11.90	14.62	99.20	18.98	2.24	3.51
Uvarovite	0.05	1.09	0.54	-	0.02	-	0.10	-	1.32
Goldmanite	-	3.71	4.61	-	-	-	-	-	-

[a] The localities of garnets are Tanzania, Tanzania, Sri Lanka, Sri Lanka, Italy, Mali, South Africa, South Africa for 12, 13, 14, 15, 16, 17, 18, 19 samples, respectively. The source of sample 11 is unknown.

[b] As observed through a Kruss refractometer.

[c] By the distant vision method.

[d] The number of averaged points are 8, 3, 4, 7, 4, 5, 5, 4, 3 for 11, 12, 13, 14, 15, 16, 17, 18, 19 samples, respectively.

[e] bdl=below detection limit (0.01 wt.%).

[f] Consisted of mol. % grossular and hydrogrossular, for samples 18 and 19.

Table II: Infrared reflectance band frequencies (in cm^{-1}) for all garnets in study

Pyralspite									
1	2	3	4	5	6	7	8	9	10
Pyrope var. chrome pyrope	Almandine	Almandine	Pyrope-almandine var. rhodolite	Pyrope-almandine var. rhodolite	Pyrope-almandine var. rhodolite	Spessartine	Almandine-spessartine	Pyrope-spessartine var. malaya	Pyrope-spessartine var. colour-change
1125	1102	1103	1125	1112	1116	1094	1109	1118	1104
944	940	939	945	941	944	924	932	938	930
888	891	889	890	889	892	876	883	884	877
-	648	649	650	649	649	644	646	650	648
639	624	624	639	631	634	612	616	633	622
558	548	549	559	553	555	543	545	556	549
527	524	525	528	526	527	522	522	525	523
471	463	463	471	467	466	459	460	469	464
406	404	404	404	405	404	404	404	405	404

Ugrandite								
11	12	13	14	15	16	17	18	19
Grossular	Grossular var. tsavorite	Grossular var. tsavorite	Grossular var. hessonite	Grossular var. hessonite	Andradite	Grossular-andradite	Hydrogrossular	Hydrogrossular
1081	1080	1081	1082	1079	1044	1075	1075	1077
893	893	893	897	897	867	891	893	891
853	850	852	853	853	825	853	851	851
634	635	633	636	633	595	630	639	635
599	600	599	601	597	549	593	606	605
534	535	534	535	532	492	528	534	533
505	505	506	506	503	467	500	500	502
469	469	469	472	468	423	465	470	470
408	410	410	413	411	-	408	410	407

Table III: Infrared transmittance band frequencies (in cm^{-1}) for all garnets in study

Pyralspite									
1	2	3	4	5	6	7	8	9	10
Pyrope var. chrome pyrope	Almandine	Almandine	Pyrope-almandine var. rhodolite	Pyrope-almandine var. rhodolite	Pyrope-almandine var. rhodolite	Spessartine	Almandine-spessartine	Pyrope-spessartine var. malaya	Pyrope-spessartine var. colour-change
995	996	996	998	995	998	975	998	993	984
970	966	966	971	968	971	950	959	965	955
901	902	901	903	901	905	888	895	897	889
872	874	876	874	876	876	863	869	870	863
-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-
-	638	638	643	643	643	631	634	648	638
577	571	570	577	573	576	562	566	573	567
530	527	527	533	529	531	522	524	526	525
482	477	476	482	479	481	471	473	480	477
460	452	453	460	457	456	449	450	458	452

Ugrandite								
11	12	13	14	15	16	17	18	19
Grossular	Grossular var. tsavorite	Grossular var. tsavorite	Grossular var. hessonite	Grossular var. hessonite	Andradite	Grossular-andradite	Hydrogrossular	Hydrogrossular
951	951	951	951	951	929	950	950	951
915	914	915	916	913	886	911	916	914
861	860	861	861	859	831	856	860	859
843	842	843	843	841	811	838	843	843
-	-	760	-	-	-	759	-	-
-	-	668	-	-	-	-	681	676
619	620	619	619	617	589	615	616	617
545	544	544	545	541	510	539	546	544
505	506	505	503	502	479	500	504	505
476	474	475	476	473	436	469	476	476
453	450	453	452	450	-	444	448	454

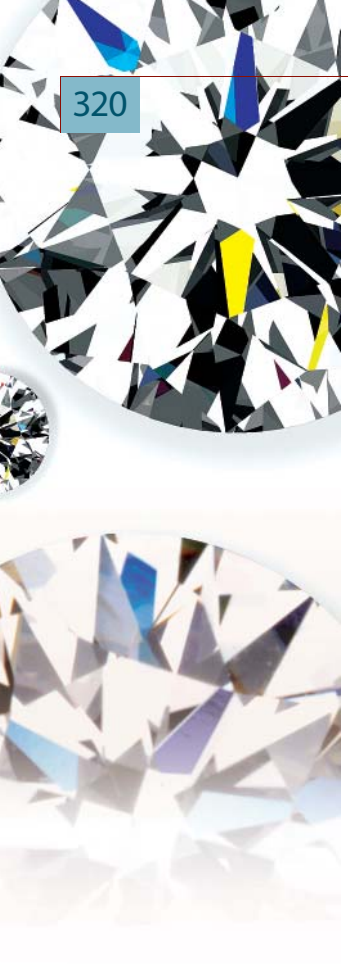

Accordance in round brilliant diamond cutting

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Abstract: *Over more than 150 years, those involved in the diamond industry have worked to establish the ideal angles and proportions to cut the facets of the Standard Round Brilliant (SRB) diamond in order to produce the 'Ideal' gem. This paper reviews milestones in that work and demonstrates that the solutions by major contributors to this endeavour have surprising commonalities. These common aspects are in accord with the research and investigation of the author as well as the knowledge of diamond cutters and the teaching of diamond cutting institutions.*

Keywords: *cut grading, diamond, round brilliant*

Introduction

The 57-facet Standard Round Brilliant cut (SRB) has evolved over several hundred years. Its finest cut quality has historically been called 'Ideal'. Many consider the Ideal Round Brilliant style of cut superior because its cut quality (called its 'make') brings out the best in diamond beauty, brilliance, fire and sparkle. The quality of these attributes of diamond beauty is referred to as the diamond's 'optical performance' or its 'light performance' (Cowing, 2005).

Diamonds in a range of cut proportions that are seen by diamond cutters and many other experienced observers as having greatest beauty possess the best combination of brilliance, in both its aspects of brightness and contrast, fire, and scintillation (sparkle with movement) (Cowing, 2005). This is the essence of the 'Ideal Round Brilliant'.

Today, consumers in increasing numbers are looking for diamonds with the best possible beauty, i.e. the best light performance. They look to jewellery retailers for proof of perfection of cut. In turn, the jewellers often look to the diamond grading laboratories or gemmologist-appraisers for assistance in providing consumers with confirmation of the quality of their diamond's make.

The laboratories of the Gemological Institute of America (GIA) and the American Gem Society (AGS) appear to be divided as to the finest or ideal make in the round brilliant diamond. The AGS believes "Tolkowsky was right" (Bates, 2004) and that the angles and proportions within a narrow range of the Tolkowsky Ideal have the best optical performance. The GIA has found: "There is no one set of proportions that yields the most beautiful diamond" (Boyajian, 2004). Instead, there are many different proportion sets that are seen as top performers. "The long-held view that expanding deviations from a fixed arbitrary set of proportion

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values produces diamonds with increasingly poorer appearances is simply not valid" (Boyajian, 2004).

GIA's grade or measure of make has five levels. The highest is 'Excellent'. The range of angles and proportions that attain the GIA 'Excellent' grade is larger than that of the AGS 'Ideal 0' grade. Although there are significant differences, the 'Excellent' grade is best compared to the top two grades of the 11 grade AGS system, each comprising the top approximately 20% of the grades in both systems.

Several diamond cutting houses and retailers, some grading laboratories, and some gemmologists and researchers including the author, set the bar for the best make higher in some respects than either GIA or AGS. In a sense you could say that they answer to a higher authority. For this investigator, that authority comes from a "direct assessment" of the diamond's optical performance in typical illumination circumstances (Cowing, 2005).

Consider the commonalities

The question is how to reconcile the differing viewpoints. The answer is found by considering aspects that these different viewpoints have in common. I find that there are more aspects of agreement among the cut grading systems than disagreement. To discover the best round brilliant diamond make, let's look at the aspects in common between the grading systems of all these groups rather than their differences.

The round brilliant cut sweet spot

If you play or watch golf or tennis, no doubt you will have heard about the 'sweet spot'. This is the area near the middle of a club or racket where the ball is struck with maximum control and speed. Striking the ball within the sweet spot causes it to respond with the best, most consistent performance.

There is also a 'sweet spot' in terms of cutting angles and proportions for peak diamond performance. The range of this sweet spot encompasses pavilion and crown angles long associated with the 'Ideal' cut. In this sense, the range of angles and proportions said by GIA and AGS to give the best brilliance, fire and sparkle, are their respective sweet spots. When the cutter fashions the diamond with sufficient craftsmanship to obtain a diamond within the sweet spot range, the diamond responds with the best light performance and beauty.

In tennis the best athletes use a racket with the largest sweet spot and aim to hit its centre. In diamond design, the evolution of the 'Ideal' round brilliant has led cutters very close to the centres of the sweet spot of both grading systems. Today's cutters aim close to the centre of the round brilliant's sweet spot when they want to ensure the best light performance and beauty.

Seven parameters are used today to define the round brilliant cut. (Standard 'indexing' or placement of each facet is assumed). These seven parameters are the pavilion main angle, the crown main angle, the table size, the length of the pavilion halves (lower girdle facets), the length of the star facets, the girdle thickness and the culet size. What is most remarkable is the finding of close agreement in the locations of the centres of each group's sweet spot in all seven of these parameter dimensions. As an aid in discussing these parameters, here are descriptions and illustrations of the anatomy of a round brilliant.

Anatomy of the 57-facet round brilliant cut

The round brilliant cut has two key parts, the top and the bottom known as the crown and pavilion. The diamond's crown and pavilion are joined together at the girdle, where the diamond is at its maximum width.

The Crown

Most of the brilliance, fire and sparkle reflected to our eyes from within the finest round brilliant cut diamonds comes from light that entered the diamond through its

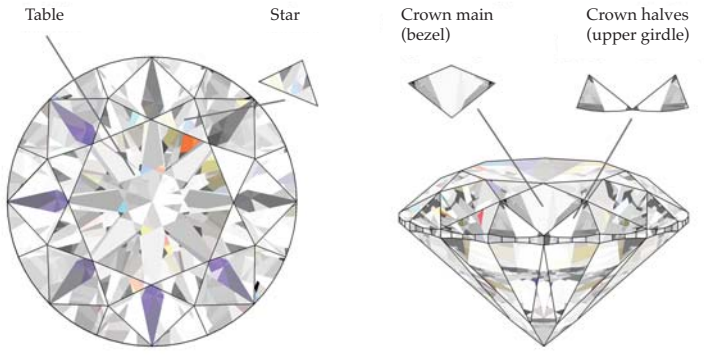

Figure 1: *Names of the crown facets shown in face-up and perspective views.*

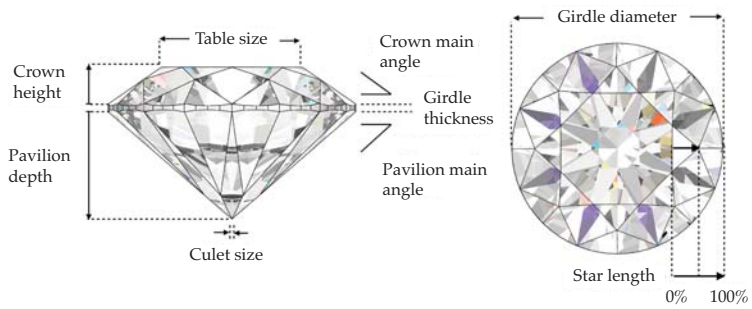

Figure 2: *Angles and proportions of the standard round brilliant cut. Note that table size is measured from corner to corner as labelled in the side view where the crown main facets are on edge.*

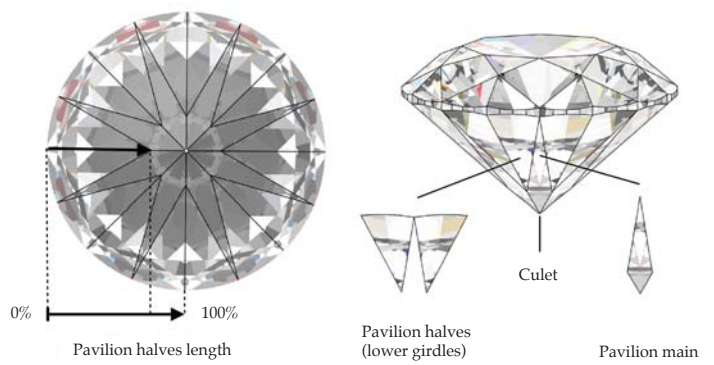

Figure 3: *Pavilion facets from bottom and perspective views.*

top section, the crown (see *Figure 1*).

The largest facet, which is centred on the crown, is the octagon-shaped table. Eight triangle-shaped facets called stars surround it. Next are the eight kite-shaped facets called crown mains or bezels. The sixteen crown halves follow the mains. These are also called upper girdle facets, because one of their three sides forms the upper outline of the girdle.

The parameters that uniquely define the crown of the standard round brilliant are shown in *Figure 2*. They are the crown main angle, the table size, the angle of the crown halves and the star angle. An alternative to listing the angle of the crown halves and the angle of the stars is to specify the star length percentage. The star length determines the angles of the stars and halves in the context of a specific crown main angle and table size.

The pavilion

Below the girdle is the pavilion, which is the principal light-reflecting portion of the round brilliant (*Figure 3*).

The pavilion is comprised of 16 pie-shaped pavilion halves, also called lower girdle facets. Eight pavilion main facets intersect the pavilion halves. A small, octagon shaped, 58th facet may be present at the tip of the pavilion. This point, where the eight pavilion mains come together, is the culet, and this 58th facet is called the culet facet.

All the brilliance, fire and sparkle our eyes see emerging from within the round brilliant through its crown is reflected from either the pavilion mains or the lower halves. Changes in the sizes and angles of the pavilion mains and halves have the greatest effect on the diamond's beauty and optical performance.

The girdle

The girdle is the thin section whose surface forms the diamond's perimeter. It joins the crown and pavilion. The upper and lower girdle facets, commonly called the halves, form the girdle's scalloped boundaries. The girdle itself may be polished or unpolished. Today it is generally faceted, as shown in *Figures 1, 2* and *3*.

Facet alignment

In the round brilliant cut, the crown and pavilion halves are aligned across the girdle. The tail of the crown main, kite-shaped facet lines up directly across the girdle from the sharp point of the pavilion main facet.

Tolkowsky's theory and Morse's Ideal angles

In the 1860s, Henry D. Morse, founder of the first successful American diamond cutting firm, discovered the centre of the diamond's sweet spot in two of the most important of the seven parameters. These are the pavilion main angle and the crown main angle. This was the greatest single stride in the evolution of what today is known as the 'Ideal'. A half-century later, the engineer and diamond cutter, Marcel Tolkowsky (1919) validated these angles theoretically using arguments based on both mathematics and physics.

Since that time, the term 'Ideal Cut' has come to be associated with the angles and proportions of Tolkowsky's theoretical determination. These are a pavilion main angle of 40.75 , a crown main angle of 34.5 and a 53% table. However, this definition of the 'Ideal' is incomplete because it addresses only 17 of the 57 important facets defining the round brilliant cut diamond, and the range of the theoretical sweet spot for pavilion angle, crown angle, and table size is not addressed.

Because of the historical overemphasis on Tolkowsky's theoretical angles of 40.75 and 34.5 in association with 'Ideal', it is important to know that the five diamonds that Tolkowsky listed in his book as examples of maximally brilliant diamonds, had pavilion angles from 40 to 41 , and crown angles from 33 to 35 . These figures provide an implicit sweet spot range. Additionally, Tolkowsky notes in his book that American writers credit Henry D. Morse with first cutting for "maximum brilliancy". The angles that Morse first discovered that were said by writers like Frank B. Wade (1916) and Herbert Whitlock (1917) to yield an 'ideal brilliant' had a range that centred on a 41 pavilion and a 35 crown.

The centre of the range of Ideal

Frank Wade was an American diamond expert who greatly influenced the thinking about the 'Ideal' cut. He said of Morse's angles: "Within the limits of one or two degrees there is little variation in brilliancy." This accords with today's consensus that there is a range of appropriate angles and proportions producing the best optical performance and beauty. This article calls that range the diamond cutting sweet spot. Differences of opinion are principally in the extent of variation in angles and proportions from those of Morse and Tolkowsky that retain the finest brilliance, fire and sparkle.

It is worth looking at those variations and the centre of the round brilliant cut diamond's sweet spot for not only the crown and pavilion main angles, but all seven of the parameters that define the important facets making up the round brilliant cut.

Comparing the centres of the sweet spots

We compare the GIA's 'Excellent' range of crown and pavilion main angles in their 5 grade system and the top two grades in the AGS's 11 grade system, because both comprise approximately the top 20% of each laboratory's grading system. Because of the interaction and interrelationship between the diamond's parameters, they must be considered in relation to each other. This is why both GIA and AGS provide charts for each table size showing the range of crown and pavilion main angle combinations that comprise each grade.

Centre of the sweet spot for the table

Figure 4 shows, for each table size, the number of combinations of crown and pavilion main angles that may attain the top grade in GIA's and AGS's grading systems.

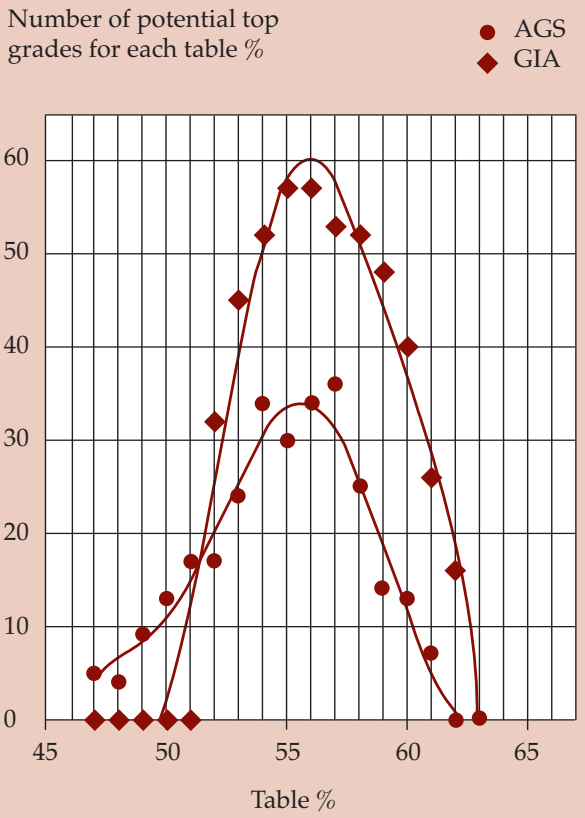

Figure 4: *Number of combinations of crown and pavilion main angles for each table percentage that may attain the top cut grade.*

A visual assessment of the peak area of each of these curves indicates that the centre of the sweet spot of the table size is closest to 56% in both grading systems. These two curves indicate that table sizes within 2% to 3% of the sweet spot centre of 56% contain a majority of the best combinations of crown and pavilion main angles.

Sweet-spot centre for the crown and pavilion angles

Let us analyze the combinations of crown and pavilion main angles that receive the top grades in each system for a 56% table. The centres of the GIA and AGS sweet spots are compared with the Morse and Tolkowsky 'Ideal' angle combinations in *Figures 5, 6* and *7*.

The sweet spot of potential 'Excellent' combinations of crown and pavilion angles is outlined in red in *Figure 5*. It has as its centre, indicated by the red spot, a pavilion main angle of 41.2 and a crown main angle of 34.0 . Shown in cyan and green are the Tolkowsky angle combination of 40.75 and 34.5 and the Morse angle combination of 41 and 35 .

GIA 'axis of Excellent'

Also shown in *Figure 5* is the negative slope of approximately -4.5 to 1 (red line) that is the axis of the sweet-spot for crown and pavilion angle, the 'axis of Excellent' (The major axis of an ellipse fit to the 'Excellent' sweet spot would have this approximate slope.) Although the GIA 'axis of Excellent' is shown as a line, it is not necessary to be on that line in order to attain the 'Excellent' grade. The slope of this line indicates that a change in pavilion angle from either Morse's or Tolkowsky's angles is best compensated by a 4.5 times change in crown angle in the opposite direction. Notice that Morse's angles are closest to that line. Tolkowsky's angles are in the 'Excellent' range and only slightly shallower by 0.25 in pavilion angle and 0.5 in crown angle.

Figure 6 is the corresponding AGS cut grade estimation chart for a 56% table. The sweet spot of potential AGS 0 and 1

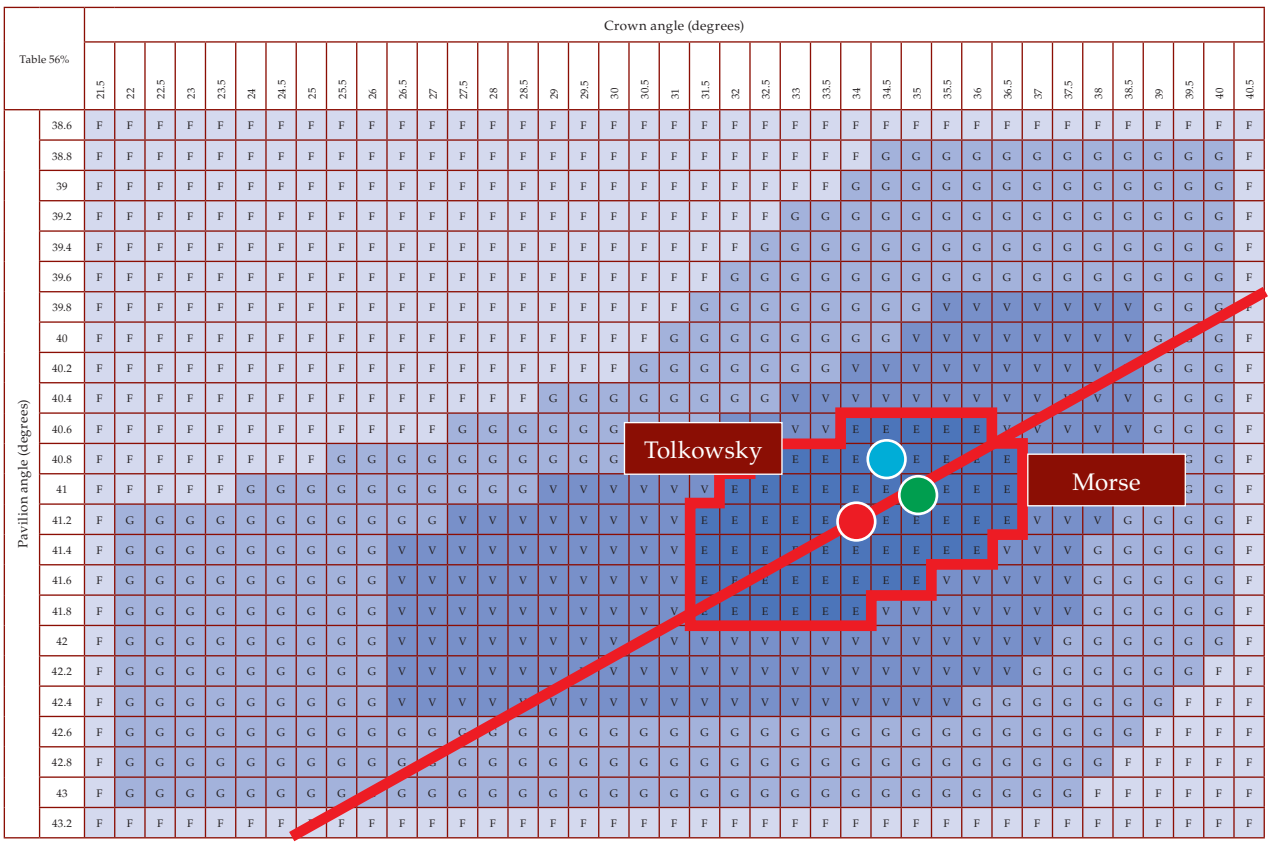

Figure 5: *GIA cut grade estimation for a 56% table. The 'sweet-spot' of potential 'Excellent' combinations of crown and pavilion angles is outlined in red. It has as its centre a pavilion main angle of 41.2° and a crown main angle of 34.0° (red spot) compared to the Tolkowsky angles of 40.75° and 34.5° (cyan spot) and the Morse angles of 41° and 35° (green spot).*

combinations of crown and pavilion angles is outlined in blue. It has as its centre, shown with the blue dot, a pavilion main angle of 41.1 and a crown main angle of 33.75

Remarkably, this centre of the sweet-spot for the top 20% of the AGS cut grades has the same pavilion angle within a tenth of a degree and a crown angle that is within a quarter degree of the corresponding centre of GIA's 'Excellent' grade.

AGS 'axis of Ideal'

The axis of best angle combinations for the AGS 0 and 1, the 'axis of Ideal', also has about the same -4.5 to 1 negative slope as the GIA's 'axis of Excellent'. Tolkowsky's angles fall nearest this axis of best angle combinations. Morse's angles of 41 and 35 are just slightly steeper in crown angle and slightly deeper in pavilion angle. Notice that this range of AGS Ideal 0 and 1 grades, although having a similar slope as the GIA 'axis of Excellent', is much narrower. It excludes Morse's Ideal angle combinations from the top two grades. Clarification on this point was obtained from AGS (P. Yantzer, pers. comm.) He indicated that the AGS charts are guidelines for the cutters, and the range of AGS 'Ideal 0' is somewhat wider than is shown by their charts. For example, Morse's 'Ideal' angles of 41 and 35 in proper combination with the other five parameters do attain the AGS 'Ideal 0' grade. This is in spite of the chart's indication that the combination of 41 and 35 is an AGS 2.

Figure 7 is a combined comparison of the AGS 'Ideal 0 and 1' sweet spot with that of the GIA 'Excellent' showing their overlap and the close agreement of the sweet spot centres. So based upon the charts of both GIA and AGS, we observe that the target centre of the sweet-spot of the best round brilliant cut is Morse's 41 for pavilion angle and closer to Tolkowsky's crown angle of

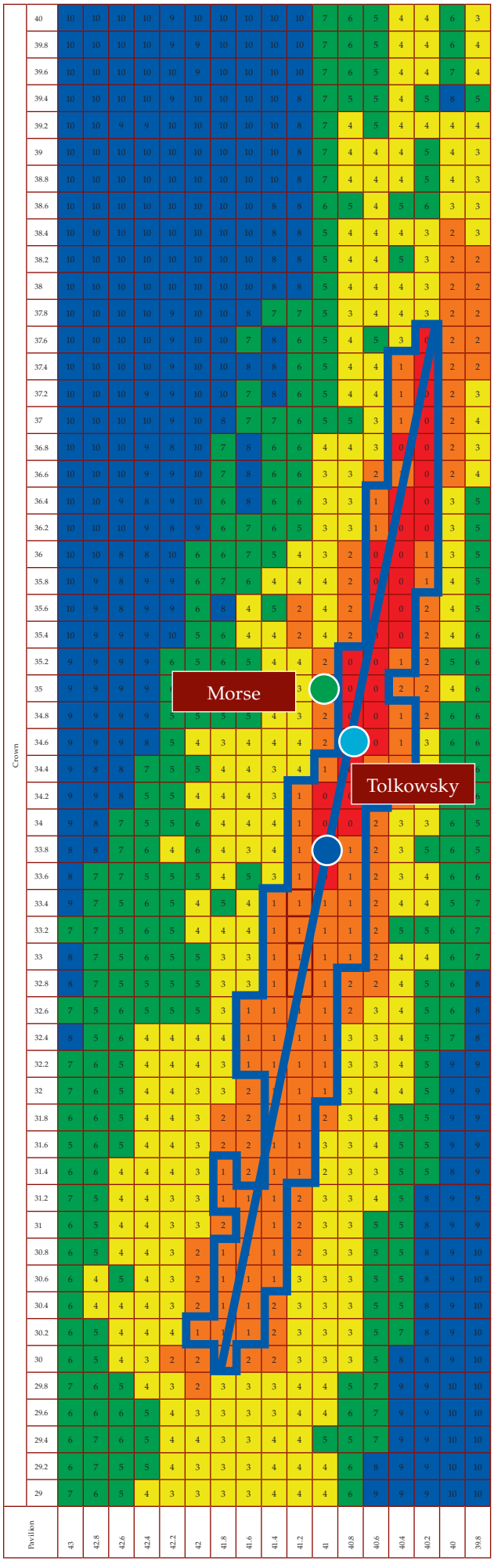

Figure 6: *AGS cut grade estimation for a 56% table. The 'sweet-spot' of potential AGS 0 and 1 combinations of crown and pavilion angles is outlined in blue. It has as its centre a pavilion main angle of 41.1° and a crown main angle of 33.75° compared to the Tolkowsky angles of 40.75° and 34.5° and the Morse angles of 41° and 35°.*

34.5 at 34 . Both 41 and 34 are very close to both the angles of Morse and Tolkowsky. In proper combination with the other five parameters, this sweet-spot centre of 41 and 34 along with the angle combinations of Morse and Tolkowsky all have ideal optical performance and beauty.

This sweet spot centre accords well with this investigator's findings based upon his direct assessment of the diamond's optical performance in typical illumination circumstances. The sweet spot centre of 41 and 34 is also in accordance with the teaching of diamond cutters and diamond cutting institutions. For example, from the 1970s the Institute for Technical Training in Antwerp, Belgium, taught angle combinations of 41 and 34 - 34.2 (pers. comm., D. Verbiest). In the same time frame, but a continent away in Johannesburg, South Africa, the Katz Diamond Cutting Factory was teaching its apprentices to cut the 'Ideal' round brilliant to a 41 pavilion main angle and 33 to 35 crown main angle (pers. comm., P. Van Emmenis).

What about the centre of the sweet spot for each of the other 4 of the 7 parameters defining the round brilliant?

The importance of the length of the pavilion halves

There is general agreement that it is the interrelationship of all the individual proportions that determine the diamond's performance and beauty. However, the diamond's light performance is most sensitive to changes in the pavilion main angle, the crown main angle and the length of the pavilion halves (lower girdle facets.) We can explore the range of the pavilion

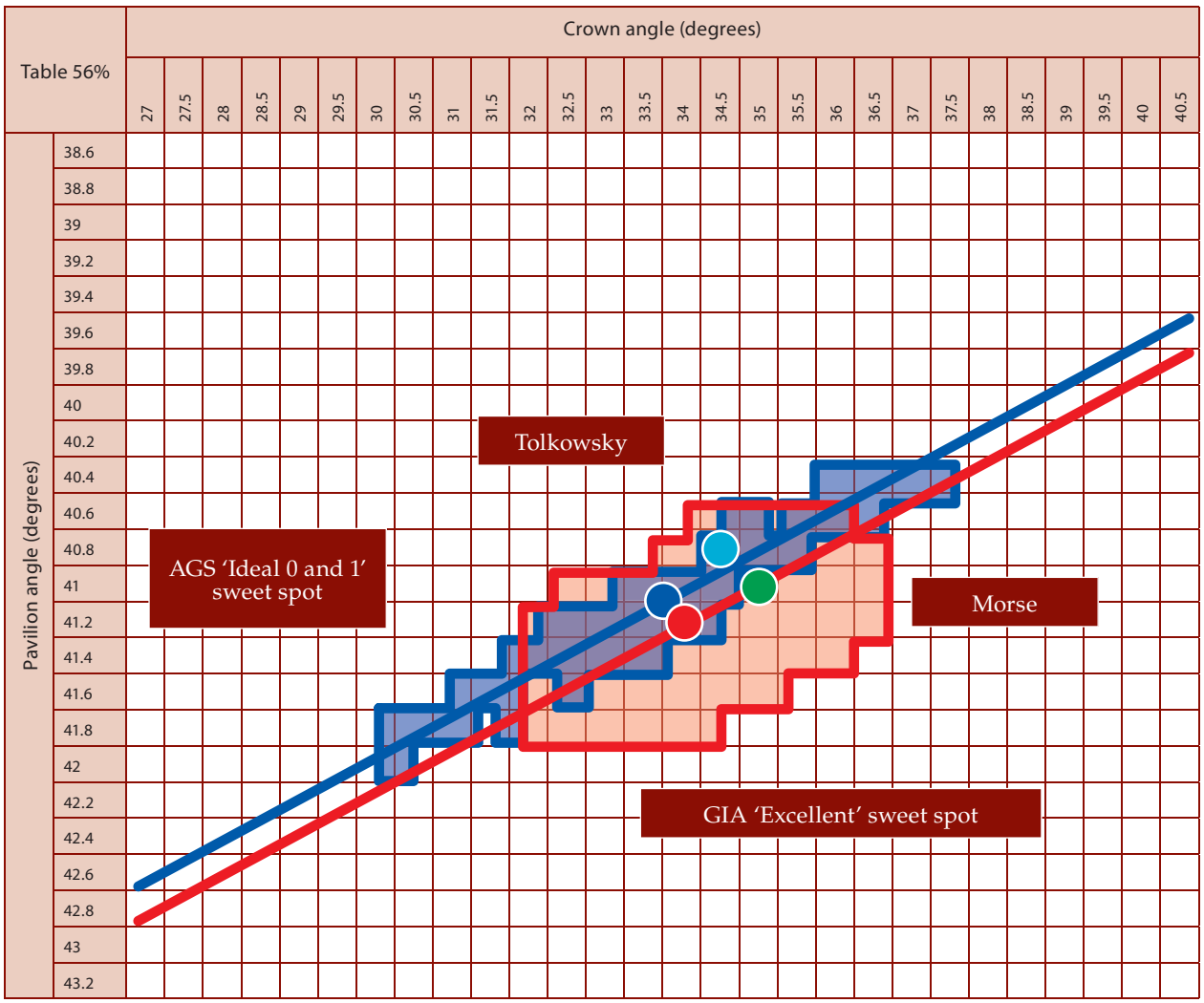

Figure 7: *A comparison of the AGS 'Ideal 0 and 1' (blue) sweet spot with that of the GIA 'Excellent' (red) showing their overlap and the close agreement of the sweet spot centres.*

halves and the other parameters in the context of the sweet spot centres of the table size, crown angle and pavilion angle.

In the early nineteenth century and before, most of the area of the pavilion was occupied by the main facets, which dominated the diamond's reflection pattern. As can be observed today in 58 facet, triple-cut diamonds from that era, the halves were small compared to those of the modern round brilliant. (Triple cut is the term from the nineteenth century for the early 58 facet brilliant cut (Tillander, 1995) that today is popularly referred to as an Old European Cut (Gaal, 1977).) At that time the pavilion halves extended less than half the way to the culet. In contrast, Tolkowsky indicated in his book in 1919 that the high-class brilliant had lower halves two degrees steeper than the pavilion mains. This resulted in a length of the lower halves of about 60%, which was a significant increase in the length and size of the halves from those earlier times.

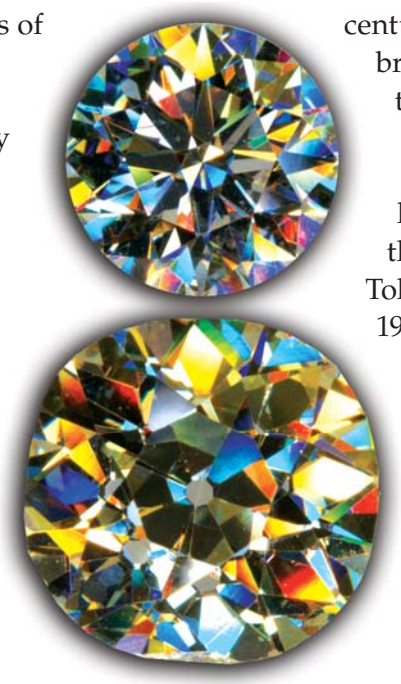

Figure 8: *Modern 'Ideal' round brilliant cut (1.00 ct) and early triple-cut (2.38 ct) under the same 'fire friendly' illumination.*

During the twentieth century, the pavilion halves were further increased in length with consequent increase in their area and influence on the diamond's beauty. The motivation for this increase in the length of the halves was the increased amount of sparkle or scintillation brought about by larger halves. However, a consequence of the increase in the halves in order to favour scintillation was a decrease in the size of the main facets. This brought an accompanying reduction in the desirable properties of large flash sparkle and fire that result from larger mains. This large flash fire and sparkle was a fundamental aspect of the appeal of the early round brilliant from the times of Morse and Tolkowsky.

Figure 8 shows a 2.38 ct early triple-cut diamond with shorter pavilion halves compared to a 1 ct, 'Ideal' round brilliant with approximately 77% lower halves. Both were photographed in the same 'fire friendly', high contrast, spot illumination. This is lighting favourable to the display of fire. Both are impressive demonstrations of the diamond's fire resulting from white light dispersed into colours of the spectrum. However, larger flashes of fire, due principally to larger mains, are apparent in the early triple-cut compared to the more numerous but smaller flashes of fire in the 'Ideal' cut.

In illumination that is more favourable to brilliance and sparkle, such as that in a typical jewellery store, the comparison between diamonds with shorter and longer pavilion halves reveals a similar contrast in their light performance. That contrast is between the large flashes of brilliance, fire and sparkle due to the larger mains of the early 'Ideal' cut and a greater amount of smaller sparkle and fire due to the larger halves and thinner mains of the modern 'Ideal' cut. To further demonstrate this contrast, a modern 'Ideal' cut was simulated (*Figure 10*) with proportions similar to those of the 'Ideal' cut photographed and shown in *Figure 9*. (Comparison of the actual photograph to the computer simulation of the diamond demonstrates the photo-realism and utility of today's computer imaging technology.) Changing just the length of the lower halves of the diamond in *Figure 10* to the 60% of Tolkowsky's time, causes the diamond's mosaic pattern of reflections to return to the large flash brilliance and fire in *Figure 11* that characterized the beauty and appeal of the older brilliant cuts. At the same time, we can appreciate in the modern 'Ideal'

Figure 10: *Computer image of a similar 'Ideal' cut diamond in typical viewing and illumination circumstances. The simulated diamond is inset at a smaller magnification to enable comparison at closer to actual size.*

Figure 9: *Photograph of an 'Ideal' cut diamond in typical viewing and illumination circumstances.*

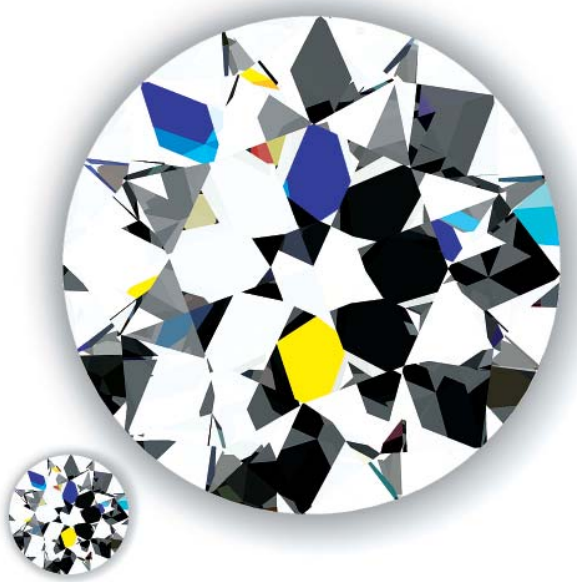

Figure 11: *Computer image of the identical 'Ideal' cut diamond except for a 60% length of the lower halves. The simulated diamond is inset at a smaller magnification to enable comparison at closer to actual size.*

the retention of large flashes along with more numerous smaller flashes of sparkle and fire evident in *Figures 9* and *10*.

This comparison of optical performance and the previous one in *Figure 8* support the observation that an attractive balance between the areas occupied by the mains and halves is necessary for these two central reasons.

A number of individuals, diamond manufacturers, and this investigator agree that the best balance between the area of the main reflections and the area of the halves is obtained with a 75% to 80% length of the pavilion halves. This is the sweet spot range of lower half length that retains the large flash sparkle and fire and at the same time provides a greater amount of scintillation. The range of possible GIA 'Excellent' lower girdle facet lengths is 70% to 85%. Both ranges have the same 77.5% as the centre of the sweet spot of lower half length.

Agreement on the parameters of girdle and culet size

Of the seven parameters, those of girdle thickness and culet size have the least influence on the brilliant cut's light performance. There is general agreement regarding these two parameters. The noticeably large culets of the past have been determined to detract from diamond beauty. Because it is parallel to the table, a large culet facet appears like a lifeless, dark 'window' in the diamond's centre. This can be seen in the early triple-cut in *Figure 8*. The culet facet has been minimized or eliminated in the modern round brilliant. The girdle thickness is kept thin to medium for two reasons. Any less thickness increases the vulnerability to chipping, and any greater thickness causes the diamond's apparent size (which the trade calls 'spread') to appear noticeably smaller than would be expected for its weight.

Sweet spot centre of the star length

That leaves just the star length as the remaining parameter to consider. In the context of the table size and crown main angle, the star length determines the angles of the star facets and the crown halves or upper girdle facets. Although having less impact on diamond beauty than the pavilion mains and pavilion halves, the angles of the crown halves and stars do influence the diamond's light performance. Star lengths of 45% to 65% have the potential to receive a GIA 'Excellent' cut grade. This makes 55% the centre of the GIA sweet spot for star length. This accords with the findings of this investigator and the practice of many of today's cutters of the modern 'Ideal' cut. We find that the best optical performance is obtained with a star facet length between 50% and 60%, centred at the same 55%.

Summary of the seven-parameter sweet spot centre

For a round brilliant cut diamond, the finest or ideal beauty is attained in the narrow range of parameters that in this paper is called the sweet spot. This is the range of angles and proportions historically called 'Ideal',

where the round brilliant cut exhibits the best distribution of brilliance (in both its aspects of brightness and contrast), fire and sparkle in typical real world illumination circumstances. Essential to this concept of 'Ideal' is the balance of the properties of reflections from the pavilion main facets and the pavilion halves (the lower girdle facets.)

Considering the GIA and AGS sweet-spot parameter centres and the knowledge gained from his own research, the author concludes that the seven-dimension, sweet-spot centre for the 'Ideal' round brilliant is as follows:

Listed in order of parameter importance:

1. Pavilion main angle = 41
2. Length of pavilion halves = 77%
3. Crown main angle = 34
4. Table size = 56%
5. Star Length = 55%
6. Girdle size = thin to medium
7. Culet size = small to none

These proportions accord with the author's knowledge of the parameters that yield the essence of ideal beauty in the standard round brilliant. That understanding is based upon direct assessment of the diamond's optical performance in typical real world illumination circumstances. There remain many important differences among the various grading systems, but we can all agree upon the centre of the 'Ideal' cut diamond's sweet-spot.

A conclusion reported by Cowing (2000) was that diamond cutters were correct in their adherence to close to a 41° pavilion angle. This angle is the most critical of the diamond's parameters. Further research by the author into all seven of the parameters that define the round brilliant has validated the accomplishments and progress of diamond cutters from the times of Morse and Tolkowsky until today. They would likely approve of today's 'Ideal' round brilliant, which evolved from their key contributions to the art and science of diamond fashioning.

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The causes of colour variation in Kashan synthetic rubies and pink sapphires

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Abstract: *The trace element patterns of Kashan synthetic rubies and pink sapphires reveal two colour-causing transition metal elements, chromium and titanium, which are present in ranges of concentrations up to 0.23 wt.% TiO_2 and up to 0.62 wt.% Cr_2O_3. UV-visible absorption spectra consist of the absorption bands of Cr^{3+} on which the absorption bands of Ti^{3+} are superimposed. The titanium component of the spectra predominantly removes the purplish tint of the ordinary ruby colour and thus the saturated red or even orangey red coloration of the synthetic Kashan corundum material is developed. By heat treatment in air, titanium is oxidized from Ti^{3+} to Ti^{4+} and the influence of titanium on the ruby colour is removed.*

Keywords: *Heat treatment, Kashan, synthetic ruby, trace elements, visible-range spectra.*

Introduction

Reference samples of natural and synthetic gem materials are frequently used in gemmological laboratories. In general, the properties of natural reference samples of known origin or the features of synthetic reference samples of a known producer are compared with properties of samples of unknown origin which are submitted for examination. In other cases, analytical instruments are calibrated using reference samples with known properties, e.g. of known chemical composition. During a re-examination of the properties of a large suite of Kashan synthetic rubies, the authors have observed some chemical and spectroscopic properties related to the causes of colour within these samples which have only briefly been mentioned in the gemmological literature. In particular, the causes of colour and the correlation of trace element contents with spectroscopic properties in Kashan synthetic rubies have not been described and understood in detail.

Kashan synthetic rubies were produced by Ardon Associates in Austin, Texas, U.S.A., from the end of the 1960s to the mid-1980s with a short renaissance in the mid-1990s (Nassau, 1990; Laughter, 1994; Kammerling *et al.*, 1995; Hughes, 1997). The synthetic rubies are flux-grown from a cryolite-bearing melt (Gübelin, 1983; Henn and Schrader, 1985; Schmetzer 1986 a,b). Compared to various natural and synthetic rubies, some of the Kashan crystals contain unusually high

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titanium in the range of 0.04 to 0.17 wt.% TiO_2 (Kuhlmann, 1983; Muhlmeister *et al.*, 1998) with high titanium contents reported especially for pink samples (Gübelin, 1983). These relatively high amounts of titanium are, most probably, related to an unusual pleochroism observed in part of the Kashan material with an extraordinarily strong yellowish red or orange parallel to the *c*-axis (Gübelin, 1983; Hughes, 1997). From the examination of absorption spectra it is known that some Kashan synthetic rubies reveal an absorption band due to Ti^{3+} in addition to the ordinary Cr^{3+} absorption spectrum (Schmetzer, 1986 b, p.102). This titanium-related absorption band reduces the violet to purplish tint of chromium on its own in many 'ordinary' rubies or pink sapphires (see Box).

Materials and methods

For the present study, the authors examined 70 Kashan synthetic rubies in the range of 0.14 to 3.05 ct in weight, originating from the reference and teaching collection of one of the authors (DS) and from other reference collections. The samples (*Figure 1*) show clear ranges in colour from purplish pink to pink and orangey pink, and from purplish red to red and orangey red. In general, those samples with a less intense violet or purplish tone tended to resemble 'Thai rubies', and those with a somewhat more intense violet to purplish hue tended to resemble 'Burmese rubies'. All 70 stones showed a small shift of colour between daylight and incandescent light.

Figure 1: *Six Kashan synthetic rubies and pink sapphires showing a wide range of colour representative of our research material. Weight of samples from 0.96 to 1.60 ct, the sample at the lower left weighs 1.05 ct and measures 5 × 7 mm. Photo by H.A. Hänni.*

Trace or minor element contents of all 70 samples were obtained using EDXRF spectroscopy. The analyses were performed with a Tracor Northern Spectrace 5000 system, using a programme specially developed for trace element geochemistry of corundum. The detection limit for these minor elements was in the range of 0.005 wt.%; consequently below detection limit (bdl) indicates a concentration below 0.005 wt.%.

Polarized UV-Vis absorption spectra of 15 samples with different trace element contents, especially with different titanium concentrations, were recorded with a Perkin-Elmer Lambda 19 spectrophotometer after orientation of the optic axis of each sample with the aid of an immersion microscope. Heat treatment of four samples with high titanium contents was performed in air at 1750 C over a period of 170 h, and then their polarized absorption spectra were recorded again.

Results

Chemical properties

On visual inspection, the synthetic rubies show a continuous range of colour (*Figure 1*) and cannot be subdivided into groups with specific colours. This visual impression is confirmed by their chemical compositions. EDXRF spectroscopy shows that two major colour-causing trace elements, namely chromium and titanium, are present with chromium contents between 0.09 and 0.62 wt.% Cr_2O_3 and titanium contents from bdl

According to a general practice in the gem trade, we are using the terms 'ruby' and 'pink sapphire' for chromium-bearing synthetic corundum. However, we would like to mention that there is no clear boundary between the two varieties due to a continuous range of chromium contents within the Kashan material.

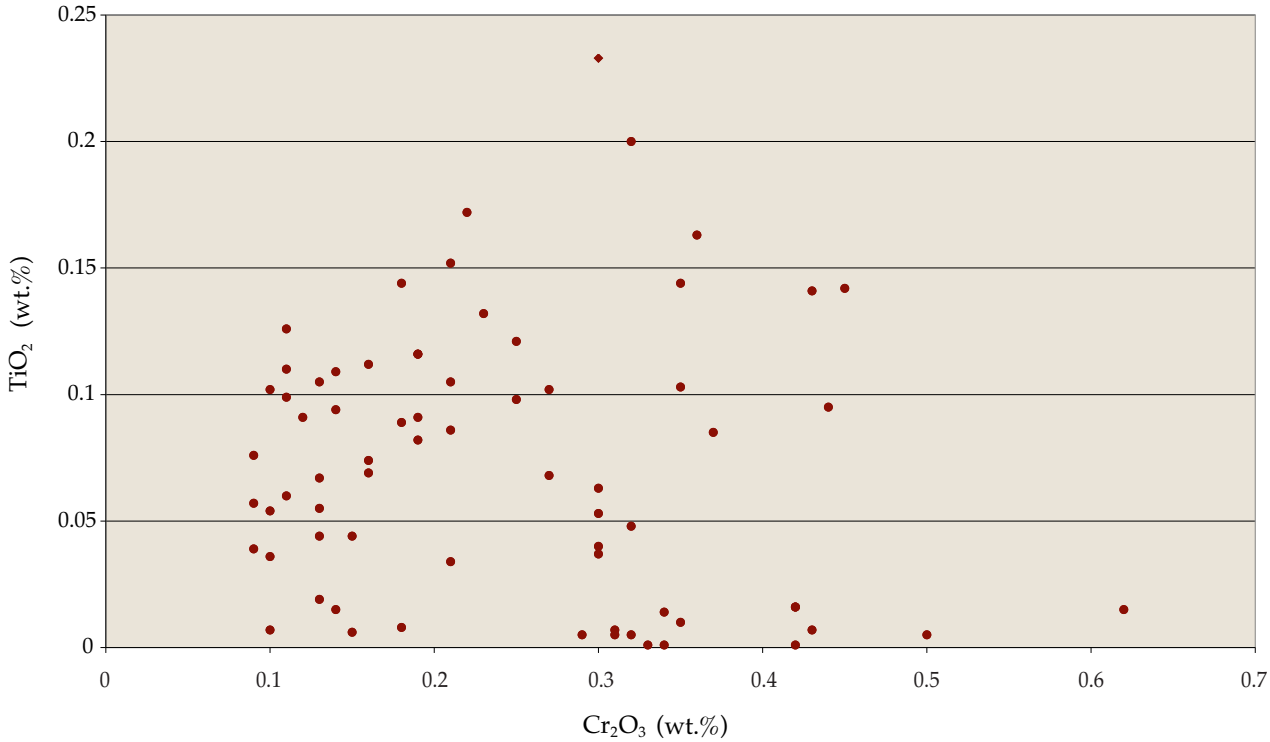

Figure 2: *Graphic representation of chromium and titanium contents as determined for 70 Kashan synthetic rubies and pink sapphires by energy-dispersive X-ray fluorescence spectroscopy (EDXRF); the chromium contents vary widely between 0.09 and 0.62 wt.% Cr_2O_3, and the titanium contents of the sapphires also show a wide variation from the detection limit of the instrument up to 0.23 wt.% TiO_2. No special clusters or concentration of samples around specific points in the diagram are evident.*

to 0.23 wt.% TiO_2. A correlation diagram of Cr_2O_3 versus TiO_2 contents (*Figure 2*) indicates a continuous range of trace element data for chromium and titanium with no clustering or concentration of data around specific points in the diagram. Consequently, these data do not indicate a limited number of specific colour types but a continuous range of coloration or variation in colour.

Other trace element values were relatively low: iron contents from bdl to 0.03 wt.% Fe_2O_3 and vanadium contents between 0.005 and 0.03 wt.% V_2O_3 were detected, no gallium contents above the detection limit of the instrument were found, as expected for Kashan synthetic corundums. These data indicate that only chromium and titanium have to be considered as colour-causing trace elements in Kashan synthetic rubies.

Spectroscopic properties

All absorption spectra of different samples with various chromium and titanium contents (*Figure 3*) reveal the absorption bands of Cr^{3+} on octahedral

Table I: *Spectroscopic properties of Kashan synthetic rubies and pink sapphires.*

Colour cause	Absorption maximum (nm) and polarization relative to the **c**-axis	Intensity of absorption bands
Ti^{3+}	493 ‖c and ⊥c	‖c > ⊥c
	542 (shoulder) ‖c and ⊥c	‖c > ⊥c
Cr^{3+}	556 ⊥c; 542 ‖c	⊥c > ‖c
	410 ⊥c; 397 ‖c	‖c > ⊥c

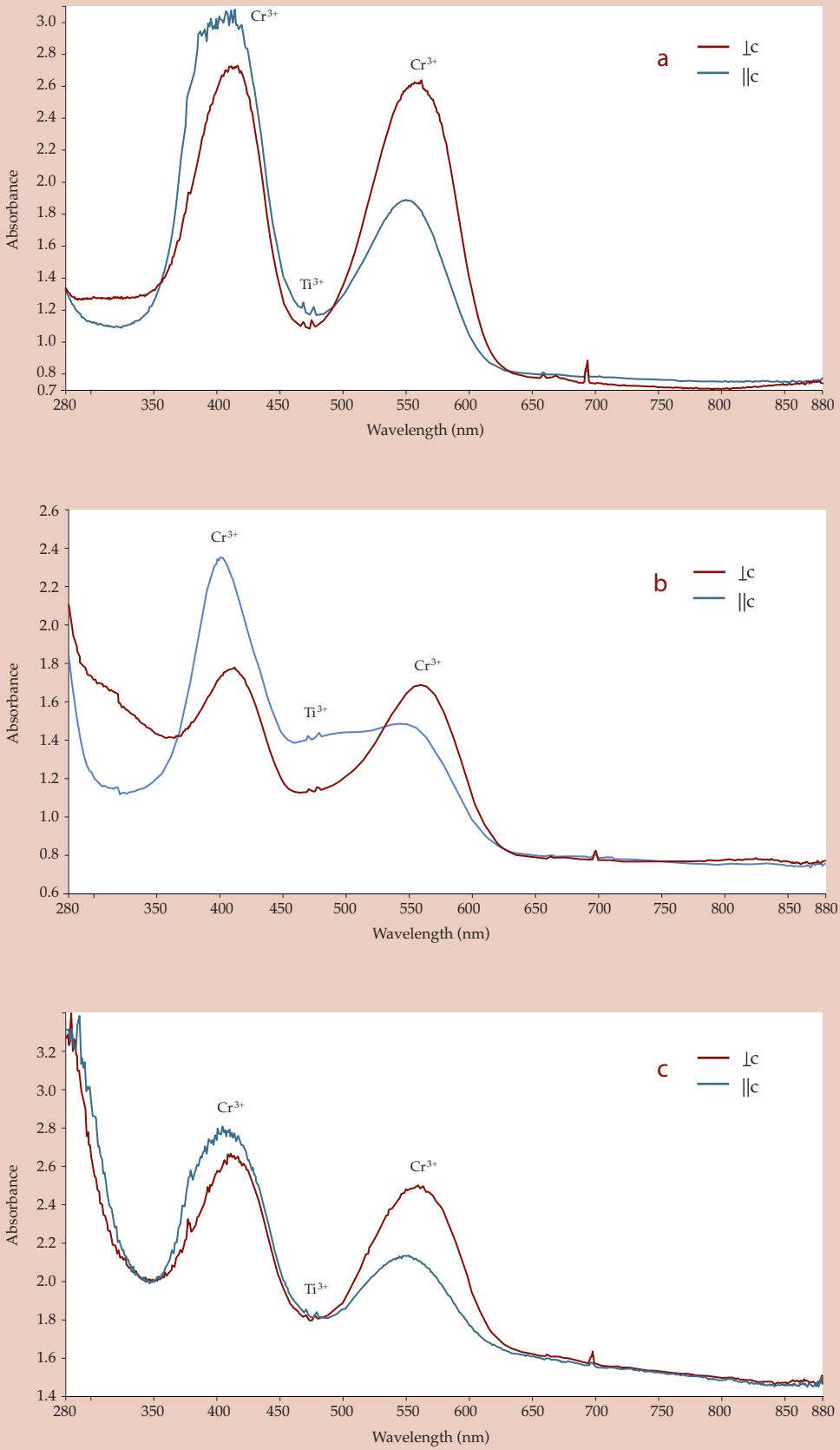

Figure 3: *Polarized UV-visible absorption spectra of two samples of Kashan synthetic rubies coloured by chromium and titanium; (a) sample I with trace element contents of 0.04 wt.% TiO_2 and 0.42 wt.% Cr_2O_3, (b) sample II with trace element contents of 0.15 wt.% TiO_2 and 0.21 wt.% Cr_2O_3, (c) spectrum of sample II after heat treatment in an oxidizing environment. The spectra represent samples with relatively low (spectrum a) and relatively high (spectrum b) titanium contents, in spectrum (c) the influence of titanium in spectrum (b) is removed after oxidation of Ti^{3+} to Ti^{4+}.*

Figure 4: *Heat-treated Kashan synthetic ruby of 1.57 ct (left) with trace element contents of 0.15 wt.% TiO_2 and 0.21 wt.% Cr_2O_3 (spectrum see* Figure 3c*) compared to an untreated sample of 1.29 ct with similar trace element contents of 0.14 wt.% TiO_2 and 0.18 wt.% Cr_2O_3. The heat treated sample measures 6 × 8 mm. Photo by H.A. Hänni.*

aluminium sites of the corundum structure (*Table I*). This well known chromium spectrum of ruby or pink sapphire is accompanied by two absorption bands of Ti^{3+}, a strong band with a maximum at 493 nm and a somewhat less intense shoulder at 542 nm. Both the band and the shoulder due to Ti^{3+} are more intense in spectra taken with polarization parallel to the *c*-axis than in spectra perpendicular to the *c*-axis (McClure, 1962; Moulton, 1986; Wong *et al*., 1995; see again *Table I*).

In the UV-Vis absorption spectra of samples that were heat treated in an oxidizing environment, the absorption bands of Ti^{3+} were completely removed (*Figure 3*). This is consistent with oxidation of Ti^{3+} to Ti^{4+}, because Ti^{4+} does not show any absorption bands in the visible range. A similar reaction has already been described for titanium-bearing synthetic corundum after annealing in an oxidizing environment by Moskvin *et al*. (1980). The remaining peaks in spectra of our annealed samples consisted only of Cr^{3+} bands which were not affected by the heat treatment process. The colour of these Kashan synthetic rubies changed from orangey pink or orangey red before heat treatment to purplish pink or purplish red after heat treatment (*Figure 4*).

It is worth mentioning that a reverse process can occur by heat treatment of synthetic titanium-bearing sapphire in a reducing atmosphere, in which Ti^{4+} is transformed to Ti^{3+} and the colour of the samples is intensified (Moskvin *et al*., 1980; Johnson *et al*., 1995).

Cause of colour and pleochroism

As indicated by chemical and spectroscopic properties of the samples, we have to consider a combination of two colour-causing trace elements to explain the colour of Kashan synthetic rubies. Synthetic sapphires doped with Ti^{3+} alone show a pink coloration (see, e.g., Johnson *et al*., 1995) and the purplish red colour of synthetic chromium-doped Verneuil rubies is known to all gemmologists. To understand the influence of titanium on the colour of chromium-bearing corundum, the position of the Ti^{3+} absorption maximum becomes important; this is located just between the two strong chromium absorption bands

Figure 5: *Kashan synthetic rubies and pink sapphires arranged in groups with different trace element contents; the chromium contents are indicated below the samples (in wt.% Cr_2O_3) , the titanium contents are indicated left of the samples (in wt.% TiO_2). Lower line: samples with purplish pink to purplish-red coloration and titanium contents in the range of 0.01 to 0.02 wt.% TiO_2. Second line: samples with slightly purplish-pink to slightly purplish-red coloration and titanium contents in the range of 0.03 to 0.05 wt.% TiO_2. Third line: samples with pink to red coloration and titanium contents in the range of 0.06 to 0.09 wt.% TiO_2. Upper line: samples with orangey-pink to orangey-red coloration and titanium contents in the range of 0.10 to 0.14 wt.% TiO_2. The chromium contents of the samples within each of the four colour lines increases from left to right (compare also* Figure 2 *and* Table II*).*

In general, the colour intensity from light pink to intense red is correlated with increasing chromium contents; with increasing titanium contents, the purplish to violet hue of the samples is reduced. Weight of samples from 0.96 to 3.05 ct, the sample at the lower left weighs 2.01 ct and measures 6 × 8 mm. Photo by H.A. Hänni.

Table II: Schematic overview of colour and pleochroism of Kashan synthetic rubies and pink sapphires.

Approximate titanium contents (range, wt.% TiO_2)	Overall body colour	Colour relative to the *c*-axis	
		‖c	⊥c
0.10 – 0.14	*Very intense* orangey pink to orangey red	*Very intense* reddish yellow	*Intense* pink to red
0.06 – 0.09	*Intense* pink to red	*Intense* pinkish yellow to orange	*Moderate* pinkish red to purplish red
0.03 – 0.05	*Moderate* Slightly purplish pink to slightly purplish red	*Moderate* pinkish yellow to orange	*Not affected* purplish pink to purplish red
0.01 – 0.02	*Not affected* purplish pink to purplish red	*Not affected* yellowish pink to yellowish red	*Not affected* purplish pink to purplish red

NB: The words in italics indicate the influence of each range of titanium content on the colour and pleochroism compared to titanium-poor or titanium-free rubies or pink sapphires.

in the visible range. We also have to consider that the intensity of the titanium absorption bands is much stronger in the spectrum parallel to the *c*-axis than in that perpendicular to the *c*-axis.

The visual impression of the overall body colour as well as the pleochroism of Kashan synthetic rubies and pink sapphires are summarized in *Table II* and correlated with approximate titanium contents of the samples; representative samples are pictured in *Figure 5*. However, it should be emphasized, that the coloration of each sample is a function of its trace element contents, in these stones, mainly of chromium and titanium. Due to the varying intensity of chromium and titanium absorption bands in the spectra parallel and perpendicular to the *c*-axis, the impression of the colour of a faceted stone is also influenced by the orientation of the table facet relative to this axis.

If only small amounts of titanium (in the range of 0.01 to 0.02 wt.% TiO_2) are present, the 'ordinary' colour of ruby or pink sapphire is little or not affected. With increasing titanium contents, the colour is affected in both directions of the pleochroism of uniaxial corundum, i.e. parallel and perpendicular to the *c*-axis. Due to the different intensity of the titanium absorption in both directions, relatively small amounts of titanium (in the range of 0.03 to 0.05 wt.% TiO_2) are sufficient to change the colour parallel to c, whereas higher titanium contents (in the range of 0.06 to 0.09 wt.% TiO_2) are needed to affect the visual impression of the colour perpendicular to c.

In general, the colour parallel to the *c*-axis becomes less red and more yellowish and the colour perpendicular to the *c*-axis becomes less violet and more pure red or pink (*Table II*). Thus, the colour parallel to the *c*-axis is shifted from yellowish red to reddish yellow and the colour perpendicular to the *c*-axis is changed from purplish pink or purplish red to a more pure pink or red

without any violet or purplish colour tone. The body colour of the samples is changed from purplish pink or purplish red to orangey pink or orangey red (*Figure 5*, *Table II*).

In heat-treated samples with complete oxidation of titanium from Ti^{3+} to Ti^{4+}, the 'ordinary' chromium pleochroism of ruby or pink sapphire is observed and the stones are purplish red (see again *Figure 4*).

Discussion

The synthetic rubies and pink sapphires examined were obtained during a period of several years by one author (DS). Thus, it may be concluded that they are a mixture of the Kashan production from several years, and cover at least a major range of the production of Ardon Associates in the 1970s and 1980s. It is obvious that the producer clearly recognized the influence of titanium and consequently used this trace element as dopant to produce rubies and pink sapphires with a saturated red coloration, i.e. by removing the purplish tint of purely chromium-doped synthetic corundum.

As comparable trace element contents or absorption spectra have not been described for rubies from any natural source or for synthetic stones from any other producer, these chemical and spectral features might be useful for recognising Kashan synthetic rubies or pink sapphires and distinguishing them from natural gems.

Acknowledgement

The authors are grateful to Dr T. Häger, University of Mainz, Germany, for performing the heat treatment of some Kashan samples.

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Abstracts

Diamond

Ein Schadenfall besonderer Art.

H.A. Hänni. *Gemmologie. Z. Dt. Gemmol. Ges.*, 55(3/4), 2006, 105-10. 3 photographs, 2 tables, bibli.

The origin of a crater-like pit in a cut diamond is explained as a consequence of a laser shot mistakenly directed into the stone during a repair of the setting. The laser transformed a little of the diamond into graphite, the increase of volume blasted a portion of the stone away and created the damage. E.S.

The Arkansas Diamond rush continues.

J. Houran. *The Mineralogical Record*, 37, 2005, 505-10.

Several major diamond crystals are reported from the Crater of Diamonds State Park, Arkansas, U.S.A. A Centennial book on the area and its diamonds is promised. M.O'D.

Diamond from the Los Coquitos area, Bolivar State, Venezuela.

F.V. Kaminsky (felixvkaminsky@cs.com), O.D. Zakharchenko, G.K. Khachatryan, W.L. Griffin and D.M. DeR. Channer. *The Canadian Mineralogist*, 44(2), 2006, 323-40.

A set of 77 diamond crystals (average weight 30 mg) from the Los Coquitos placer deposit on the Guaniamo River, Venezuela, have been examined comprehensively and compared with diamonds from the Quebrada Grande kimberlite sills and placer deposits, both ~ 50 km SE. The Los Coquitos diamonds are similar in general, but differ in having a higher proportion of octahedral crystals and a slightly higher total nitrogen content of 719 ppm. The $\delta^{13}C$ values of the Los Coquitos diamonds vary from +0.4 to -20.5 ‰. The garnet inclusions in the Los Coquitos diamonds are lower in Ca, the pyroxenes have a wider compositional range and olivine has a lower Fo content compared to inclusions in the Quebrada Grande suite, and the Los Coquitos diamonds show a greater depletion in LREE. It is considered that the Los Coquitos diamonds were derived, at least in part, from an undiscovered kimberlite source sampled from a different section of the subcontinental lithospheric mantle. R.A.H.

The impact of internal whitish and reflective graining on the clarity grading of D-to-Z color diamonds at the GIA Laboratory .

J.M. King, T.M. Moses and W. Wang. *Gems & Gemology*, 42(4), 2006, 206-20.

Unlike many other characteristics that affect the clarity grade of diamonds, determination of the impact of 'whitish' graining and 'reflective' graining as bands, lines or planes in extended areas through a range of motion requires analysis that goes beyond visibility at 10x magnification. The importance of this observation is underlined by such graining often being the only characteristic present in large, high-clarity, high-colour diamonds. The history of the reporting of such graining by the GIA Laboratory is reviewed, the causes of the different types of graining most commonly encountered are considered, and the methodology and critical assessment that GIA graders use to determine the impact of such graining on the clarity of the diamond are examined. R.A.H

Gem News.

B.M. Laurs (Ed.). *Gems & Gemology*, 42(4), 2006, 268-92.

Notes included an update is given on diamond trading in Sierra Leone. R.A.H.

Lab Notes.

T.M. Moses and S.F. McClure (Eds). *Gems and Gemology*, 42(4), 2006, 260-7.

A note is given of a fancy deep pink 0.84 ct diamond which became deep orange-pink after exposure to UV radiation, this colour persisting for about two weeks. R.A.H.

[Spectroscopic studies on irradiation-enhanced fancy colour diamonds.]

J.C.C. Yuan, M.-S. Peng and Y.-F. Meng. *Kuangwu Yanshi (Journal of Mineralogy and Petrology)*, 25(3), 2005, 47-51. (Chinese with English abstract.)

Spectroscopic techniques ranging from FTIR, UV-visible-near infrared absorption, photoluminescence and Raman spectroscopy were used to study 10 natural diamonds with fancy colour induced by radiation. These diamonds are classified on their FTIR characteristics. Their visible absorption and low-temperature photoluminescence spectra indicate that there are a number of colour-centre peaks attributable to point defects. In addition to the N3 absorption peak, peaks at 595 and 637 nm are also observed. The colour-centre peaks at 575, 595 and 637 nm in the low-temperature photo-induced luminescence spectra, in combination with the H_1b

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colour centre at 4929 cm^{-1} and the H_1c colour centre at 5156 cm^{-1} in the near infrared spectra, are not only reliable indicators for green diamonds having been irradiated, but are also an important characteristic of other colours in diamonds treated by irradiation. R.A.H.

Gems and Minerals

Andradit wom Pizzo Crampiolo, Grampelhorn.

C. Albertini and S. Graeser. *Lapis*, 31(5), 2006, 28-31.

Non-gem andradite is described from Pizzo Crampiolo in the border area of Switzerland (Valais) with Italy. M.O'D.

Fluorite; novo ed eccezionale ritrovamento al Chumar Bakhoor, in Pakistan.

R. Appiani. *Rivista Mineralogica Italiana*, 30, 2006, 250-3.

Fluorite crystals of considerable size (around 12 cm) and predominantly pink to red are reported from a pegmatite at Chumar Bakhoor (5520 m) in the Hispar Valley, Pakistan. Some material appears to be of ornamental quality. M.O'D.

Alchuri, Shigar Valley, Northern Areas Pakistan.

D. Blauwet. *The Mineralogical Record*, 37, 2005, 513-40.

Minerals recently reported and with possible ornamental potential are described: fine green titanite, clinozoisite, Cr-diopside, zoisite and orthoclase. Exceptional crystals of red to orange väyrynenite are especially noteworthy; the source is probably the Braldu river valley. The Namlook mine in this valley has also produced fine translucent to transparent red crystals of triplite. M.O'D.

The Jackson's Crossroads amethyst deposit, Wilkes County, Georgia.

R.L. Bowling, R. Moore and T. Ledford. *The Mineralogical Record*, 36, 2005, 479-86.

Fine gem-quality amethyst crystals were discovered in 1988 in east-central Georgia, U.S.A. The host rock appears from investigations to be either a metadacite or a slightly metamorphosed granite. Amethyst crystals are found in a variety of pocket-types and are described as highly lustrous royal purple. A faceted specimen shown weighed 48.35 ct. M.O'D.

Die Chromlagerstätte Sarany im Ural.

V. Burlakov and V.V. Avdonin. *Lapis*, 31(10), 2006, 53-60.

The geology and mineralization of the Sarany area in the Russian Urals are described. A list of minerals is given. Some chromian titanite is of ornamental quality M.O'D.

Erongo Mountains, Namibia.

B. Cairncross. *The Mineralogical Record*, 37, 2005, 361-470.

Species of possible gem quality are described from the Erongo Mountains, Namibia. They include light blue jeremejevite, aquamarine, fluorite, orthoclase and topaz. M.O'D.

Leopard opal: play-of-color opal in vesicular basalt from Zimapán, Hidalgo State, Mexico.

R.R. Coenraads (coenraads01@optus.net.com.au) and A.R. Zenil. *Gems & Gemology*, 42(4), 2006, 236-46.

So-called 'leopard opal' consists of vesicular basalt impregnated with play-of-colour opal, and is known only from Zimapán, Hidalgo State, Mexico. Its occurrence is due to an abundance of silica derived from the chemical breakdown of overlaying layers of volcanic ash, the permeability of the underlying basalt and the presence in the basalt of pores of an aesthetically pleasing size. The even distribution and small size of the opal-filled vesicles makes for an attractive rock when cut or carved and polished. Veinlets and irregular masses of opal showing various body-colours (red, white and colourless to pale blue) have also been deposited along joints and fractures within the basalt. This opal deposit, which may have been worked in pre-Columbian times, has been explored recently only by a number of test pits, leaving a potential for future development R.A.H.

Die Mineraliensammlungen des Australian Museum, Sydney.

I. Graham, R. Pogson and G. Webb. *Lapis*, 31(2), 2006, 33-7.

The mineral collections of the Australian Museum, Sydney are generally described with some features highlighted. M.O'D.

Claro, Südschweiz: Aquamarin und seltene Titanmineralien aus Pegmatitdrusen.

R. Guerra and S. Weiss. *Lapis*, 31(12), 2006, 20-5.

Aquamarine of apparently near gem-quality is described from Claro, southern Switzerland. The beryl is accompanied in a pegmatite by uncommon titanium minerals. These and other minerals can be found in a descriptive list. M.O'D

The cause of iridescence in rainbow andradite from Nara, Japan.

T. Hainschwang (thainschwang@yahoo.com) and F. Notari. *Gems & Gemology*, 42(4), 2006, 248-58.

'Rainbow' andradite from the Yoshina area, Nara Prefecture, Japan, occurs as relatively small orange-brown crystals showing iridescence in almost the entire spectral range. It is an almost pure andradite. Two different types of lamellar structures appear to be responsible for the iridescence. These structures cause predominantly thin-film interference and probably diffraction of light. The terms of interference and diffraction are discussed and correlated to the iridescence observed in these garnets R.A.H.

Pre-Columbian jadeite axes from Antigua, West Indies: description and possible sources.

G.E. Harlow (gharlow@amnh.org), A.R. Murphy, D.J. Hozjan, C.N. de Mille and A.A. Levinson.

The Canadian Mineralogist, 44(2), 2006, 305-21.

Excavation of workshop sites on Antigua uncovered jade axe forms and associated fragments, all of which are jadeite jade (jadeitite). This Antigua site dates as the Saladoid period (~ AD 250-500). Ten of these jade artefacts were examined mineralogically and petrographically. For six of them, the mineral assemblage includes jadeite, omphacite, albite, a white-tan mica, zoisite/clinozoisite and titanite; allanite was found in the cores of zoisite in two jades, and glaucophane and lawsonite were each seen in a single sample. EPMA results are reported. Quartz is found as a secondary matrix phase around corroded grains of jadeite and as inclusions in omphacite. Possible sources include Guatemala. R.A.H.

Pencil garnet from the Haramosh Mountains, near Gilgit, Pakistan.

F.C. Hawthorne and W.W. Pinch. *The Mineralogical Record*, 36, 2005, 525-7.

Almandine with a very high spessartine content is described from the area of the Haramosh mountains in the northern areas of Pakistan near Gilgit. Crystals appear to show a first-order hexagonal prism terminated by a second-order hexagonal pyramid. None the less their identity is confirmed by electron probe microanalysis. Full details of the forms are given. M.O'D.

Blauer, pinkfarbiger und hellgrüner Opal aus Peru.

U. Henn. *Gemmologie. Z. Dt. Gemmol. Ges.*, 55(3/4), 2006, 111-8. 11 photographs, 3 graphs, bibl.

Greenish-blue and blue opals from Peru have been on the market for thirty years, usually known as Andean opals. Today there are also pink opals available, the colour resembling angel-skin corals. E.S.

Korallen im Edelstein – und Schmuckhandel.

U. Henn. *Gemmologie. Z. Dt. Gemmol. Ges.*, 55(3/4), 2006, 77-104. 41 photographs, 4 tables, bibl. (German with English abstract.)

After pearls, corals come second in the organic jewellery trade. This article deals with the description of different coral species, their characteristics, treatments and imitations. The Mediterranean *corallium rubrum* is red to orange and was predominant until the nineteenth century, when Japan became the centre of the industry. The Japanese variety is dark red to salmon in colour, the Taiwanese dark red to white-pink. The white coral Shiro is found between Japan and the Philippines. The Hawaiian bamboo soft red coral is white to brownish and generally dyed red. The Indo-Pacific blue corals are commonly dyed and impregnated. Black corals can be bleached to a golden colour and are often impregnated to improve their lustre. True Hawaiian gold corals (narella) have a typical dimpled structure and can also be impregnated. Stone corals, such as tiger or apple coral, are less important in the trade. White porous stone corals can be dyed red to pink as well as blue. Today there are large amounts of red, pink and blue reconstructed corals on the market. They consist of powdered coral fragments bound with coloured resin. There are many types of imitations on the market: glass, porcelain, plastics, dyed chalcedony or agate, dyed mother-of-pearl and ceramics like the 'synthetic coral' by Gilson or Kyocera. E.S.

"Regenbogen-Mondstein" aus Indien.

U. Henn. *Gemmologie, Z. Dt. Gemmol. Ges.*, 55(3/4), 2006, 133-5. 4 photographs.

Colourless to milky-white, transparent to semi-transparent feldspar is offered in the trade as rainbow-moonstone; the stones show adularescence and labradorescence. The physical properties are as for andesine feldspar. Typical inclusion patterns of labradorescent plagioclase feldspar, esp. polysynthetic twinning lamellae and cleavage cracks can be seen under the microscope. E.S.

The Honourable George Knox, 1765-1827, Parliamentarian and Mineral Collector. His collections in Trinity College, Dublin, Ireland

P.N.W. Jackson. *The Mineralogical Record*, 37, 2005, 543-51.

An aquamarine of fine colour and measuring 5.1 cm is among the geological collections of Trinity College, Dublin. A number of items were formerly in the collection of George Knox. M.O'D.

Die schönen Feldspat-Kristalle aus Namibia.

S. Jahn. *Mineralien Welt*, 17(6), 2006, 66-72.

Amethyst, green fluorite, goethite and quartz in association with potassium feldspar are described from the Erongo area of Namibia. M.O'D.

Neu: grüne Fluorit von Riemvasmaak, Northern Cape, Südafrika.

S. Jahn and J. Steinbinder. *Mineralien Welt*, 17(6), 2006, 62-5.

Fine green fluorite crystals are described from Riemvasmaak, Northern Cape, South Africa. Some crystals are found as octahedra. M.O'D.

Achate aus Patagonien.

P.Jeckel. *Lapis*, 30(10), 2005, 29-33.

Agate specimens of good ornamental quality are described from the Esquel region of Patagonia, Argentina. M.O'D.

Die Jagd nach den 'Puma-Achaten' in Argentinien.

P. Jeckel. *Mineralien Welt*, 16(4), 2005, 68-70.

'Puma-agate' is described from Mendoza Province of Argentina, close to the border with Chile. The occurrence is similar to some in Germany. M.O'D.

[A study on the identification of turquoise by FT-IR.]

Y-C. Kim. *Journal of the Korean Crystal Growth and Crystal Technology*, 14(6), 2004, 272-6. (Korean with English abstract.)

Natural turquoise can be distinguished easily from its common substitutes using infrared spectroscopy in the range 2000~450 cm^{-1}, especially by features in the mid-infrared. Gilson turquoise exhibits a significantly smoother pattern when compared with natural turquoise, due to a different state of aggregation. Infrared spectra of natural, treated, synthetic and imitation turquoise (gibbsite, calcite) are shown and compared. I.S.

Gem News.

B.M. Laurs (Ed.). *Gems & Gemology*, 42(4), 2006, 268-92.

Details are provided of a 2.9 cm prismatic crystal of bicoloured beryl from the Erongo Mts, Namibia, with a sharp division between bluish-green and brownish-orange parts. From Brazil, a vein of milky white quartz is described with yellow-orange areas which are marketed as 'sunset' quartz. R.A.H.

Collecting cavansite in the Wagholi quarry complex, Pune, Maharashtra, India.

M.F. Makki. *The Mineralogical Record*, 36, 2005, 507-12.

Fine specimens of the vivid blue hydrated silicate of calcium and vanadium, cavansite, are described from a quarry complex at Pune, Maharashtra, India. Specimens occur in small vugs and irregular cavities beneath overlying compact basalt and many need careful handling and reinforcement. M.O'D.

Gemmologie Aktuell.

C.C. Milisenda. *Gemmologie, Z. Dt. Gemmol. Ges.*, 55(3/4), 2006, 73-6. 2 photographs.

In the last few months large amounts of diffusion-treated sapphire cabochons have come on the market. The identification of cabochons is more difficult than of faceted stones as the coloured coating is not so obvious. However, these stones showed also a distinct blue coloration within hollow tubes and surface fissures. There are also a large number of fancy coloured – mostly orange and yellow – sapphires on the market which have been diffusion-treated with beryllium. The amount of beryllium intensifies the yellow. It is also possible to remove or brighten blue colour. There are often unusual, circular inclusions in these stones; however, tests showed that these inclusions can be called characteristic for high-temperature treatment, but not diagnostic for beryllium diffusion. Some pink beads were sold as pink opal, but proved to be dyed marble; when tested with hydrochloric acid, there was strong effervescence and infra-red spectroscopy confirmed the presence of carbonates. E.S.

Alpine 'iron roses'.

T. Moore. *The Mineralogical Record*, 36, 2005, 491-503.

Fine brilliant hematite crystals are described from Alpine-type clefts in various localities, the name 'iron roses' having long been used for suitably shaped aggregate examples. Ilmenite occasionally occurs in similar shapes. M.O'D.

What's new in minerals.

T. Moore. *The Mineralogical Record*, 36, 2005, 285-301.

Among apparent gem-quality specimens displayed at the 2005 Tucson Gem and Mineral Show were a crystal of väyrynenite from the Shengus area, Gilgit district, Northern Areas, Pakistan: this appeared a transparent to translucent reddish-orange in the photograph. Also described were two deep blue aquamarine crystals from Mount Amero, Chaffee county, Colorado, U.S.A. M.O'D.

Lab Notes.

T.M. Moses and S.F. McClure (Eds). *Gems and Gemology*, 42(4), 2006, 260-7.

Notes are given of a 5.82 ct, transparent, green round-brilliant-cut demantoid, of exceptional colour and size, reportedly from Russia; a 3.96 ct cut poudretteite; and a 0.68 ct modified lozenge step cut pyroxmangite. R.A.H.

Die Vervendung von Röntgenstrahlen in der Achatforschung.

T. Moxon. *Mineralien Welt*, 16(4), 2005, 71-2.

X-rays have been used in the investigation of agate structure in a study carried out at the University of Cambridge. M.O'D.

[The colour enhancement of natural ruby produced from Mong Hsu.]

C-W. Park and P-C. Kim. *Journal of the Korean Crystal Growth and Crystal Technology*, 14(6), 2004, 290-7. (Korean with English abstract.)

A natural rough ruby from Mong Hsu containing colour patches ranging from blue to nearly black was heat treated to investigate colour enhancement. The optimum conditions to produce an overall clear red were found to be temperatures of 1400-1600 C, and duration of 12 hours in an oxygen atmosphere. EPMA analyses indicated that part of the blue or black colour patches are due to charge transfer between Fe^{2+} and Ti^{4+}. The contents of Fe^{2+} or Fe^{3+} and Ti^{4+} were reduced by heat treatment. Due to recrystallization of TiO_2, silk was formed on the surface of the ruby when heat treated for 12 hours at 1700 C. I.S.

The minerals of the Hunting Hill quarry, Rockville, Maryland.

F.J. Parker. *The Mineralogical Record*, 36, 2005, 435-46.

Specimens of red grossular garnet and green diopside are described from the Hunting Hill quarry, Rockville, Maryland, U.S.A. Some grossular has been faceted. A descriptive mineral list is provided. M.O'D.

What's new in minerals?

J. Polityka. *The Mineralogical Record*, 37, 2005, 573-82.

Minerals of possible gem interest noted at recent shows include red tourmaline in divergent clusters from the Minh Tien pegmatite, Luc Yen, Yen Bei Province, Vietnam; proustite crystals from Chanarcillo, Chile, and fine blue euclase from near Ouro Preto, Minas Gerais, Brazil. M.O'D.

Luc Yen: neue Edelstein-Turmaline aus einem Pegmatit in Nordvietnam.

P. Russo and F. Escaut. *Lapis*, 31(6), 2006, 49-51.

Gem-quality red liddicoatite tourmaline is described from the Luc Yen pegmatite in North Vietnam. M.O'D.

Achate von der Teufelsrutsch.

H-P. Schröder. *Lapis*, 31(5), 2006, 38-42.

Ornamental agates are described from the Teufelsrutsch, between Nack and Wendelsheim, Rhineland, Germany. M.O'D.

Das Laacher See-Gebiet. Feuer, Eis und edle Steine.

W. Schüller. *Lapis*, 31(10), 2006, 13-26.

Minerals, some of ornamental quality, are described from the area of the Laacher See, Germany. M.O'D.

Blau-Quarz aus Minas Gerais, Brasilien.

R. Schultz-Güttler. *Gemmologie, Z. Dt. Gemmol. Ges.*, 55(3/4), 2006, 135-6. 1 photograph.

The amethyst mine of Montezuma in the northern part of the Brazilian state of Minas Gerais produces amethyst which can be modified to green by thermal treatment, the so-called prasiolite. Recent treatment with gamma rays produced a surprisingly blue colour. The pleochroism was strong; reddish along the *c*-axis and reddish-blue perpendicular to the *c*-axis. E.S.

Fifty-nine treasure hunts in Minas Gerais, 1969-2005. (Memoirs of a Collector, part 1.)

G. Steiger. *The Mineralogical Record*, 36, 2005, 531-49.

The author has visited, and describes specimens from, 59 different locations in Minas Gerais, Brazil. Tourmaline of gem quality features in this part. M.O'D.

Raman- und fluoreszenz-spektroskopische Eigenschaften von Zirkon-Einschlüssen in chrom-haltigen Korunden aus Ilakaka und deren Veränderung durch Hitzebehandlung.

B. Wanthanachaisaeng, T. Häger, W. Hofmeister and L. Nasdala. *Gemmologie, Z. Dt. Gemmol, Ges.*, 55(3/4), 2006, 119-32. 11 photographs, 7 graphs, bibl.

The samples came from the Ilakaka-Sakahara region in the south-west of Madagascar. Under the microscope zircon inclusions change their appearance above 1400 C. The authors used a heat treatment which allowed changes to be observed at 1000 C; this treatment varies not only the temperature, but also the duration of the treatment and heating and cooling rates. Remnant pressures acting on the zircon inclusions varied from 1 to 5 kbar — significantly lower than previously described pressures of up to 27 kbars.E.S

Identification of 'chocolate pearls' treated by Ballerina Pearl Co.

W. Wang (wyul.wang@gia.edu), K. Scarratt, A. Hyatt, A.H.T. Shen and M. Hall. *Gems & Gemology*, 42(4), 2006, 222-35.

Treated cultured pearls with a chocolate coloration have entered the market from several sources. Gemmological, spectroscopic and chemical analyses have been performed on both untreated and treated cultured pearls to provide a better understanding of the 'chocolate' treatment process used by one company and to determine how these products can be identified. It seems likely that the organic components in black cultured pearls were partially bleached to create the brown colour; no foreign colouring agent was detected. Cultured pearls so treated can be identified on the basis of their unusual coloration, characteristic fluorescence, UV-Vis-NIR reflectance and Raman spectra, and trace-element composition (Pb5-26 ppm). R.A.H.

The Mineralogical Record label archive.

W.E. Wilson. *The Mineralogical Record*, 36, 2005, 450-7.

Gemmologists who are also mineral collectors need to know that the *Mineralogical Record* has collected and preserved more than 6000 examples of specimen labels from many dealerships and other collections world-wide. It is believed to be the largest such collection outside major museums. M.O'D.

W.A. Thompson. A half century of collecting and dealing in minerals.

W.E. Wilson. T*he Mineralogical Record*, 37, 2005, 555-66.

Among the specimens in the Thompson collection are fine purple zoisite crystals, wulfenite and vanadinite, some of gem quality M.O'D.

Instruments and Techniques

A study on the identification of ruby and garnet by optical method.

J-H. Hwang and J-K. Choi. *Journal of the Korean Crystal Growth and Crystal Technology*, 15(5), 2005, 182-7.

A new colour filter, called the Hwang Ji Ho filter has been prepared, which enables one to distinguish ruby from other red gemstones. Through this filter, ruby appears blue, whereas red garnet is dark red. Other red stones such as spinel and tourmaline also appear dark red. I.S.

A Raman investigation of the amblygonite-montebrasite series.

B. Rondeau (rondeau@mnhm.fr), E. Fritsch, P. Lefevre, M. Guiraud, A.M. Fransolet and Y. Lulzac. *The Canadian Mineralogist*, 44(5), 2006, 1109-17.

Nine rough minerals and seven faceted gemstones of the amblygonite-montebrasite series were analysed by Raman spectroscopy, XRD, IR and gemmological properties (density and refractive indices); the Raman signal appears to be a good indicator of the F content. Three peaks evolve significantly as the F content increases: from 599 to 604, from 1056 to 1066 and from 3379 to 3348 cm^{-1}. Also, the FWMH (full width at half maximum) of the peak around 3370 cm^{-1} increases from 11 to 57 cm^{-1} as F content increases. All the faceted gemstones analysed were found to consist of montebrasite rather than amblygonite as claimed by the gem traders. R.A.H.

Synthetics and Simulants

Experimental study on diamond dissolution in kimberlitic and lamproitic melts at 1300-1420°C and 1 GPa with controlled oxygen partial pressure.

Y. Kozai and M. Arima (arima@ed.ynu.ac.jp). *American Mineralogist*, 90(11-12), 2005, 1759-66.

Experiments were carried out in the graphite stability field to evaluate the dissolution processes of diamond crystals in kimberlitic and lamproitic magmas. Dissolution agents used include an aphanitic kimberlite from Wesselton mine, South Africa, and a lamproite from Mount North, West Kimberley, Australia. With increasing run duration, diamond morphology changed from a sharp octahedron

through a combination of octahedral and tetrahexahedroidal forms to spherical tetrahexahedroidal forms with rounded faces. Negatively oriented trigons formed on the octahedral {111} face. As the degree of diamond dissolution increased, the trigons changed from smaller shallow types to larger deep types. The dissolution rate in the kimberlite solvent at 1300 C was 0.12 mm/h under the HM buffer, 0.0034 mm/h under the MW buffer and 0.0017 mm/h under the WI buffer, whereas at 1420 C it was 0.014 mm/h under the WI buffer. In the lamproitic solvent, the dissolution rate was 0.0024 mm/h at 1420 C for the WI buffer. The data indicate that diamond dissolves in silicate melts as carbonate ions through an oxidizing reaction. The degree of dissolution depends greatly on temperature, oxidation state and the compositional dependence of CO_2 solubility in the melts. R.A.H.

Luminescence study of defects in synthetic as-grown and HPHT diamonds compared to natural diamonds.

J. Lindblom (joachim.lindblom@utu.fi), J. Hölsa, H. Papunen and J. Häkkänen. *American Mineralogist*, 90(2-3), 2005, 428-40.

Optically active defects in as-grown, high-pressure-high-temperature (HPHT), boron-doped, and synthetic diamonds (SD) grown with a nitrogen-getter, as well as in natural diamonds (ND), were characterized by absorption and luminescence spectroscopies using different excitation sources. The laser-excited photoluminescence (PL) spectra of SDs show numerous sharp lines characteristic for Ni-related centres, whereas NDs yield mainly broad PL bands. Under UV and electron beam excitation, the yellow synthetic diamonds display green luminescence patterns along octahedral directions. The UV-excited PL spectra of the yellow SDs show a green band associated with Ni-related optical species. NDs display broad bands centred at ~ 450 nm that are related to complex nitrogen-related aggregates formed in the mantle over a long period of geological time. The CL spectra of SDs reveal many Ni-related and simple nitrogen-vacancy defects. All synthetic diamonds were found to show luminescence from Ni-related defects centred at ~ 480 and 530 nm at room temperature and 77K, respectively, and a sharp luminescence band at 694 nm due to a Cr^{3+} impurity in corundum inclusions. R.A.H.

Diamond formation in metal-cabonate interactions.

J. Siebert (julieri.siebert@lmcp.jussieu.fr), F. Guyot and V. Malaverge. *Earth & Planetary Science Letters*, 229(3-4), 2005, 205-16.

Reduced silicon alloyed with Fe metal has been shown to react chemically with $FeCO_{3\ siderite}$ at pressures of 10-25 GPa and temperatures of 700-1800 C according to: $2\ FeCO_{3\ siderite} + 3\ Si_{\ in\ metal} = 2Fe_{\ in\ metal} + 3\ SiO_{2\ stishovite} + 2\ C_{diamond}$. Since no carbon seeds were introduced, the only source of C for diamond formation was the carbonate phase. This observation provides a mechanism for diamond formation, possibly relevant to the early Earth. Thermodynamic modelling of these reactions shows that the stishovite/silicon oxygen fugacity buffer is far more reducing than the carbonate/diamond equilibrium; this is taken to imply that in Earth mantle conditions no silicon-bearing metal can exist with carbonates. The formation of diamond by reactions between carbonates and highly reducing metal phases containing significant amounts of silicon might have been expected to have occurred in the early Earth by the mixing of oxidized and reduced accretion components at pressures and temperatures greater than 10 GPa and 1700 C. R.A.H.

The nature of Ti-rich inclusions responsible for asterism in Verneuil-grown corundum.

C. Viti (vitic@unisi.it) and M. Ferrari. *European Journal of Mineralogy*, 18(6), 2006, 823-34.

Verneuil-grown star corundum with variable zoning and colouring (ruby and sapphire) host three sets of acicular inclusions at 120 . The inclusions are up to 20-30 µm long and 0.1-0.4 µm wide. Their cross-sections match the visible-light wavelength and explain the optical diffraction responsible for sharp six-arm stars in cabochon gemstones. The inclusions are elongated parallel to corundum $\{10\bar{1}1\}$ faces and are polysynthetically twinned on $\{10\bar{1}1\}$. Electron diffraction and high resolution TEM show that the inclusions are almost isostructural with the corundum matrix, even if slightly distorted to a monoclinic lattice with *a* 5.00, *b* 4.63, *c* 13.08 Å, γ 118 . Nanochemical data point to a TiO_2 stoichiometry, thus indicating the occurrence of Ti^{4+} cations, coupled with vacancies, within the distorted corundum-like structure (with only half of the octahedral sites occupied). Close to the apical terminations of the TiO_2 needles, local stoichiometry is consistent with the presence of Ti^{2+} cations, formed by redox disproportionation during post-growth thermal annealing. R.A.H.

Crystal morphology and feature of the diamond films by DC arc discharge.

X.-H. Zhang, L. Wang (wangling@cdut.edu.cn), J.-P. Long, S.-H. Chang and J.-G. Zhou. *Kuangwu Yanshi (Journal of Mineralogy and Petrology)*, 25(3), 2005, 100-4. (Chinese with English abstract.)

Polycrystalline films of diamond with surface morphology with {100} and {111} faces were synthesized on an abraded tungsten carbide tool from a gas mixture of methane and hydrogen using DC arc discharge CVD. The morphology of the diamond film was examined by scanning electron microscopy. With increasing concentration of carbon gas, the morphology of the film of diamond changed from {111} to {100} and the diamond particle shape varied from octahedral to cubic. A lot of twin-like particles and ballast-like particles also exist in the diamond film. R.A.H.

Abstractors

R.A. Howie R.A.H. M. O'Donoghue M.O'D. E. Stern E.S. I. Sunagawa I.S.

Book Reviews

Minerals and Their Localities (2nd updated edn).

J.H. Bernard and J. Hyrsl, 2006. Granit, Prague. 823 pp, illus. in colour. ISBN 80-7296-054-7. 98.

This very large book presents virtually all established mineral species in alphabetical order with a high proportion of examples illustrated in colour. This has given at least two photographs in each opening and often more. Data given for each species includes name, chemical composition and group membership, physical properties including crystal system and space group. Mode of occurrence and major localities complete each entry.

A number of appendices presents: the richest localities of the world; references; alphabetical list of mineral localities; brief biographies of the authors and a final appendix describing, with all the properties cited in the main text, recently published minerals.

This is a major achievement and the authors are to be congratulated; no doubt there are occasional slips/typos but a careful selection of entries failed to throw up any examples. The typeface is well chosen, bearing in mind that the print size has to be small. The binding appears to be secure. The standard of reproduction is also excellent, again bearing in mind that the photographs have to be small. Anyone with a serious interest in minerals should buy this most reasonably-priced book. M.O'D.

Symmetrielehre der Kristallographie. Modelle der 32 Kristalklassen zum Selbstbau.

R. Borchardt and S. Turowski, 1999. Oldenbourg, Munich. ISBN 978-3-486-24648-3. 29.80.

Attractively produced and printed guide to making models of the 32 crystal classes. Many readers may prefer to keep the book whole or at least copy the drawings. M.O'D.

Russian Gemstones Encyclopedia.

V.V. Bukanov, 2006. Granit, St. Petersburg. 472 pp. ISBN 80-7296-053-9. 79

The presentation and some of the photographs are similar to (and sometimes the same as) those in the excellent Bernard and Hyrsl *'Minerals and their localities'* (2006), reviewed above. The page formats and the typeface are virtually identical (this is not a criticism as they are both excellent). The reader may ask whether or not the texts (where appropriate) are identical – they are not. The author has managed to incorporate a large number of gem species while acknowledging the scarcity of gem varieties of some of the species covered.

Entries are in general by alphabetical name of species: members of mineral groups are not always where the reader might expect to find them but this is a problem with any encyclopedic work. The author provides an alphabetical list of mineral names to make the problem less of a hindrance.

Appendixes deal with unique diamonds (giving date of discovery and covering world-wide deposits not just Russian ones), unique specimens of ruby and sapphire, beryl varieties, quartz and gold nuggets. There is a respectable list of references.

The book with its small but attractive colour photographs is pleasing to look at though this reviewer would appreciate knowing where he is on any given page: though running heads are intrusive they would have been useful here. In addition it would have been good to have more detail about Russian deposits but this would have necessitated a much larger work.

I would strongly recommend an early purchase for this book and for Bernard and Hyrsl. Both books are printed in the Czech Republic but can be obtained most easily from Weise Verlag, Orleansstr 69, 81667 Munich, Germany. M.O'D.

A Journey with Colour. A History of South Australian Opal, 1840-2005.

L. Cram, 2006. Len Cram, Lightning Ridge. 368pp, illus. in colour. Hard cover. ISBN 0-9585414. Approx. £77.

The third and final volume of Len Cram's superbly illustrated survey of Australian opal deals with the opal fields of South Australia. As in the previous two volumes the standard of colour photography and reproduction reaches ever-new heights and it is safe to say that these are among the very finest illustrated gemstone books ever printed. As before there is a great deal of history as well as accounts of mining and of the opals themselves. South Australian opal fields include both Andamooka and Coober Pedy, the latter being described for the years 1961-2005 and Andamooka from 1930-2005. The two fields occupy pages 15 to 298 of the book, which gives some idea of their importance. Other fields described include Mintabie and Stuart Creek.

The reader will feel that he has really met some of the larger-than-life characters whose doings, legal and

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illegal, are described in Len Cram's easy-to-read prose.

The 'Special Collector's' edition, hardbound, is the version to go for and it may not be long before copies become unobtainable. M.O'D.

Feldspat.

[Contributions by various authors], 2006. Weise, Munich. 97 pp, illus. in colour. *(ExtraLapis* 30*)*. 17.80.

The complicated feldspar mineral group is most attractively illustrated in this excellent series – if precedent is followed an English-language version should appear in due course. As always the colour photographs are beautiful – the authors appear to favour microcline – and the text authoritative. The absence of red Oregon sunstone from the illustrations is my only, minor, criticism. M.O'D.

Jade.

C. Lam Shiu Ling, 2005. Lead On Publishing Co., Hong Kong. Illus. in colour. ISBN 962-86332-5-2. $380.

Attractively produced and informative guide to jadeite and nephrite jade. The text shares each page with colour photographs of jade varieties, some in mounts and with maps. The possible multiplicity of fanciful names is restricted and the reader can assume that nomenclature is up-to-date. Chinese characters are illustrated here and there (perhaps rather small for this reviewer's eyes). Details of fashioning and marketing are informative and useful as are the descriptions and illustrations of simulants and treatments.

The photographs, while certainly adequate, do not always show the best colour quality although most greens get away with it; there is a useful bibliography with one or two surprising omissions (Laufer, Ou Yang) but as a whole the book comes off very well and can be recommended to readers at any level. M.O'D.

[Catalogue of an] Exhibition held at Somerset House, London, 2 November 2002 – 26 January 2003.

J.A. Rosenthal, 2002. Art Books International, London. In slip case and with presentation bag. £200.00.

This is one of the most beautiful jewellery books that I have ever seen and also one of the largest and heaviest; the presentation bag is most welcome. The book illustrates and briefly describes 397 pieces, in almost all cases devoting a whole opening to each piece. Captions describe the stones used, with a few words on the design but the text has been kept economical to allow maximum space for the magnificent photographs – some of these have been enlarged to form front and back end-papers. The reader is encouraged (by the reviewer) to look at the pictures with the aid of a torch in a darkened room when the stones appear to be in relief. M.O'D.

Minerals of the Carpathians.

S. Szakall (Ed.), 2002. Granit, Prague. ISBN 80-7296-014-8. 59.

This publisher appears to be relatively new, at least in the mineral and gemstone field and the present book compares with others I have recently reviewed. The Carpathians spread into several countries; the Czech Republic, Hungary, Poland, Romania, Slovakia and Ukraine and the book describes deposits and individual species from all of them. As I have come to expect, the standard of presentation is high with an easily read typeface, small but excellent colour photographs and a wealth of appendices and maps in the text. There are species and locality indexes and a particularly valuable section describes the mineral museums in the area covered.

While the major gem minerals are generally absent from the area there are many species keenly sought by collectors. Fine green crystals of cuprite, groups of amethyst crystals (some with rhodochrosite), fire opal, chrysocolla and almandine catch the eye.

Organic substances are included and a section at the rear of the book presents idealized crystal diagrams, with notations, of some of the featured minerals. Photographs of the directors of the museums are welcome and there is an excellent bibliography, arranged by individual countries; this is useful as some entries are presented in the appropriate vernacular of the countries covered. M.O'D.

Surselva: Kristalle, Klüfte, Cavacristallas.

M.Wachtler (Ed.), 2006. Weise, Munich. 99 pp, illus. in colour. *(ExtraLapis* 31*)*. 17.80

Though this beautifully-illustrated survey of the geology, mineralization and species to be found in the general area of Disentis, Graubünden (Grisons), Switzerland, deals primarily with species too small for ornamental use, some are remarkable for their colour and form: a deep pink fluorite, variously-coloured rutile and rock crystal are notable. This series is essential for the serious collector.

M.O'D.

Gemstones of Sri Lanka. Rarely Encountered Gemstones of Sri Lanka.

G. Zoysa, 2006. Speed Mark, Colombo, Sri Lanka. Illus. in colour. US$7.00 (US$10 laminated).

Two comprehensive charts, one displaying the major commercial gemstones and the other the rare gem varieties which have been recovered from the gem deposits of Sri Lanka.

R.R.H.

The Journal of Gemmology Celebrates 60 years

The year 2007 marks the 60th anniversary of The Journal of Gemmology, the official journal of the Gemmological Association of Great Britain when it was incorporated under the Companies Act in 1947.

Printed in black-and-white with a grey cover, the 1947 Journal looked very different from the publication produced today.

Contributors to the first volume included names familiar to us all – B.W. Anderson, Prof. Edward Gübelin, R. Keith Mitchell and Robert Webster. In his editorial in the January 1947 issue, the then President of the Association, Dr G.F. Herbert Smith, concluded by saying: "The Association goes from strength to strength; it is a privilege which I greatly value to have been connected with the movement from the very start, and I hope that it may be my good fortune to aid its progress still further." He would have been justly proud to know the strength of the Association today, with a Journal that remains a leader in its field.

1947...

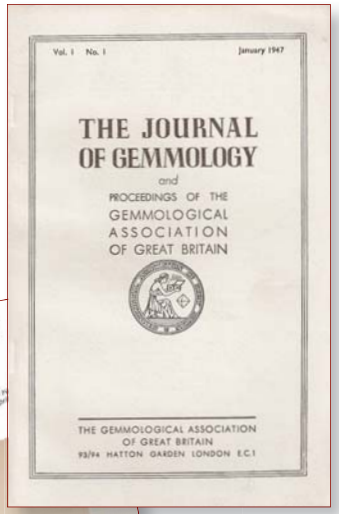

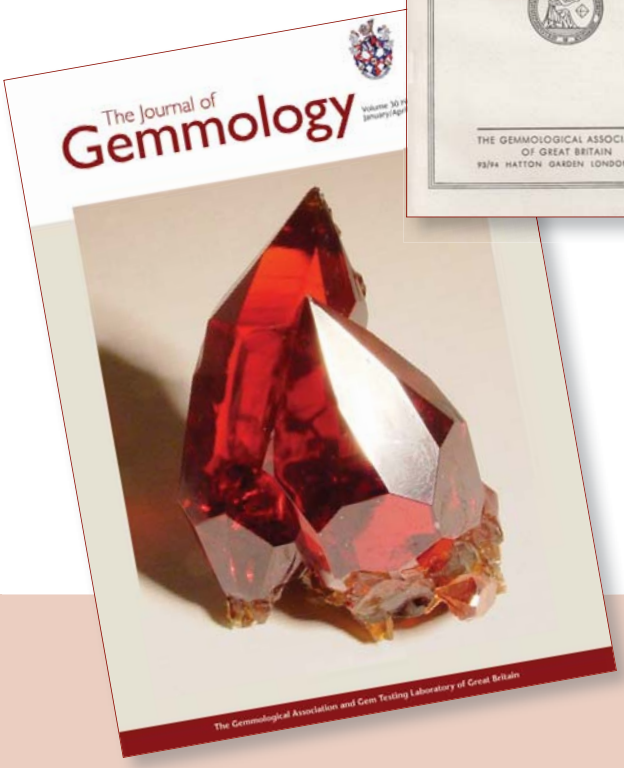

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Gem-A Conference theme

The first two articles of the January 1947 issue of the Journal were 'All pearls are not what they seem!' by Dr A.E. Alexander and 'Jade picture' by Elsie Ruff. To mark the anniversary of *The Journal of Gemmology*, the 2007 Gem-A Conference will focus on the subjects of these two articles with the theme 'Gems of the Orient'.

So join us at the Gem-A Conference to celebrate the first sixty years of The Journal of Gemmology.

Gem-A Conference 2007 GEMS OF THE ORIENT

Sunday 28 October -The Renaissance Heathrow Hotel

Presentations by an international panel of speakers will cover pearls from their history to the pearl market today, and the latest developments in jade.
Further details of the Conference will be published in the June issue of Gems & Jewellery.

Proceedings of the Gemmological Association and Gem Testing Laboratory of Great Britain and Notices

Conference and Presentation of Awards

The 2006 Gem-A Conference was held on Sunday 5 November at the Renaissance London Heathrow Hotel. Speakers at the event were Dr Ahmadjan Abduriyim, Victoria Finlay, Doug Garrod, Grenville Millington, Dr Jack Ogden, Dr Jayshree Panjikar and Benjamin Zucker. A programme of events was arranged to coincide with the Conference, including a private viewing and guided tour of the Crown Jewels with Crown Jeweller David Thomas, and a private viewing of the exhibition 'Bejewelled by Tiffany, 1837-1987' at the Gilbert Collection, Somerset House.

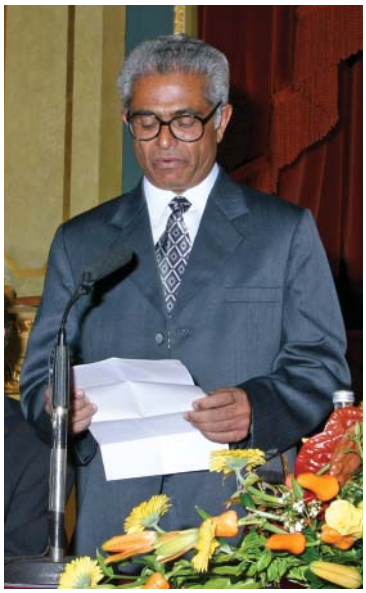

K.T. Ramchandran giving his address at the Presentation of Awards.

On Monday 6 November the Presentation of Awards gained in the 2006 Gem-A examinations was held at Goldsmiths' Hall in the City of London. Gem-A Chairman, Professor Alan Collins, presided, and K.T. Ramchandran, Executive Director of the Gemmological Institute of India, presented the awards. In his address, Mr Ramchandran emphasized the importance of education in the jewellery trade and the need for Gem-A graduates to act ethically and to continue to gain knowledge of the subject.

The presentation was followed by a reception for over 200 graduates and their guests.

Reports of both the Conference and Presentation of Awards were published in *Gems & Jewellery*, 2006, 15(5).

R. Keith Mitchell Award

A new award, the R. Keith Mitchell Award for Excellence in the Field of Gemmological Spectroscopy, has been created in honour of Vice President R. Keith Mitchell who died in April 2006*. The first presentation of this award took place at the Presentation of Awards held at Goldsmiths' Hall on Monday 6 November 2006.

The award was presented to Colin Winter for his publication, lecturing and teaching that had done so much to spread the understanding of the importance of the hand-held spectroscope in gemmology.

*A tribute to Keith Mitchell was published in *The Journal of Gemmology*, 2006, 30(3/4), p.129.

From left: R. Keith Mitchell Award winner Colin Winter, with Keith Mitchell's sons Anthony and Graham at the Presentation of Awards ceremony at Goldsmiths' Hall.

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Gem-A Awards

Gem-A examinations were held in October 2006 and January 2007. In the Examinations in Gemmology 177 candidates sat for the Diploma Examination of whom 90 qualified, including seven with Distinction and 15 with Merit. In the Foundation Gemmology Examination, 154 candidates sat of whom 92 qualified. In the Gem Diamond Examination 46 candidates sat of whom 29 qualified, including four with Distinction and three with Merit. The names of the successful candidates are listed below.

EXAMINATIONS IN GEMMOLOGY

Gemmology Diploma

Qualified with Distinction

Dong Jin, Beijing, P.R. China
Frei, Thomas, Pratteln, Switzerland
Liu Tung-Wen, Taipei, Taiwan, R.O. China
Mahesh M. Babu, Kottayam, Kerala, India
Sinagra, Monika, Shanghai, P.R. China
Xu Baoqin, Wuhan, Hubei, P.R. China
Yan Xi, Wuhan, Hubei, P.R. China

Qualified with Merit

Barbour, Alexandra Frances, Dorchester, Dorset
Chang Qing, Beijing, P.R. China
Chen Yingying, Wuhan, Hubei, P.R. China
Gao Chujun, Wuhan, Hubei, P.R. China
Gourlet, Agnes, Chartres, France
Hug, Samuel, Gosport, Hampshire
Kaneyasu, Yoshimasa, Okayama-ken, Japan
Learmonth, Bryony, Stafford, Staffordshire
Mak Hoi Chuen, Jeff, Kowloon, Hong Kong
Newall, Myron, Colorado Springs, Colorado, U.S.A.
Peng Hui, Wuhan, Hubei, P.R. China
Peng Juan, Wuhan, Hubei, P.R. China
Puniani, Geeta, Surat, Gujarat, India
Wong Tung Wing, Shau Kei Wan, Hong Kong
Zhang Mengfei, Beijing, P.R. China

Qualified

Amicone, Maria, La Salle, Quebec, Canada
Andriasamy, Gisele, Paris, France
Bowers, Sally Faye, Fulham, London
Caplin, Marco, Lachine, Quebec, Canada
Chen Hsiu-Chuan, Taipei, Taiwan, R.O. China
Chen Cui, Guangxi, P.R. China
Chen Xi, Beijing, P.R. China
Cheng Chong Chuen, New Territories, Hong Kong
Cheung Ka Yan, Michiele, Ap Lei Chau, Hong Kong
Chung Yee Man, Stella, Kowloon, Hong Kong
Cote, Gaetan, St. Lambert, Quebec, Canada
Cui Lei, Beijing, P.R. China
Elles, Sarah Louise Jean, London,
Han Fen, Shanghai, P.R. China
Horn, Chandra Leah, Montreal, Quebec, Canada
Hossenlopp, Patricia, Chene-Bougeries, Switzerland
Hui Yuen Wah, Kowloon, Hong Kong
Kao Chen Li-Chen, Taipei, Taiwan, R.O. China
Katayama, Shinko, Colombo, Sri Lanka
Kemprud, Tanya D., Revelstoke, British Columbia, Canada
Khan, Ehtesham Ullah, Peshawar, Pakistan
Kim, Ji A, Nam-Gu, Daegu, Korea
Ko Cheuk Wah, Robin, Quarry Bay, Hong Kong
Kong Yang, Guangxi, P.R. China
Kwok Sau Ying, New Territories, Hong Kong
Kwok Yuk Kuen, Kowloon, Hong Kong
Lau Kwan, May, Kowloon, Hong Kong
Lee, Ju Yeon, Daegu, Korea
Lee Wai Kwok, Simon, Kowloon, Hong Kong
Lefebvre, Alburt, Brampton, Ontario, Canada
Li Suet Lin, Happy Valley, Hong Kong
Li Hu, Wuhan, Hubei, P.R. China
Li Qiang, Wuhan, Hubei, P.R. China

Gem-A Awards

Li Qianhe, Guangxi, P.R. China
Lin Chia Hui, Taipei, Taiwan, R.O. China
Liu Shuhan, Wuhan, Hubei, P.R. China
Luo Haiyan, Beijing, P.R. China
Lwin, Min, Yangon, Myanmar
Menekodathu Remanan, Amarnath, Surat, Gujarat, India
Micatkova, Lubica, London
Nam, Yong Ju, Seoul, Korea
Ng Sum Yi, Jordan, Kowloon, Hong Kong
Ngai Sheung Lau, Kowloon, Hong Kong
Oldbury, Christien, Poole, Dorset
Panidi, Lydia, Elefsina, Greece
Parhi, Chinmayee, Surat, India
Park, Ji Min, Daegu, Korea
Rajbanshi, Niren Man, South Ealing, London
Sherin, Saira, Peshawar, Pakistan
Sit Yat Sing, Shatin, Hong Kong
Thanattamkul, Pakamon, Nonthaburi, Thailand
Tian Cheng, Beijing, P.R. China
Tong Sen Yue, Sandy, Central, Hong Kong
Traill, Lillian, London
Tyler, Clare J., Den Bosch, The Netherlands
Wacyk, Carrein Tara, London
Wang Qi, Guangxi, P.R. China
Wat Wing Suet, Kowloon, Hong Kong
Watson, John Richard, Berkhamsted, Hertfordshire
Wong Yu Lap, Angel, Sha Tin Centre, Hong Kong
Wu Shih-Han, Taipei, Taiwan, R.O. China
Xie Yi, Shanghai, P.R. China
Zeng Fanrong, Wuhan, Hubei, P.R. China
Zhong Dan, Beijing, P.R. China
Zhou Chuanjie, Wuhan, Hubei, P.R. China
Zhou Yanfei, Wuhan, Hubei, P. R. China
Zong, Yue, Guangzhou, P.R.China
Zotta, Elisa, Parma, Italy

Gemmology Foundation Certificate

Qualified

Barker, Holly J., Johannesburg, South Africa
Chan Tat Hang, New Territories, Hong Kong
Chauhan, Rakesh, Chandigarh, India
Chen, Yu-Chen, Taipei, Taiwan, R.O. China
Cheng Yuan, Guangxi, P.R. China
Cheung Pui Shan, Alicia, New Territories, Hong Kong
Chiu Chun-Chieh, Taipei, Taiwan, R.O. China
Chokshi, Sheel Deepak, Vadodara, Gujarat, India
Chrismas, Jacqueline, Godalming, Surrey,
Cole, Natalie Rachel, Stone, Staffordshire
Daudin, Mathieu, Paris, France
De Alwis Dissanayake, Manoja Dilsiri, Colombo, Sri Lanka
De Barros, Valere, Maron, France
De Gaetano, Antonella, Genova, Italy
Ding, Hui, Surbiton, Surrey
Dong Haiyang, Guangxi, P.R. China
Drai, Stephanie, Clamart, France
Dufour, Gaspard, Chens Sur Laman, France
Efthymiadis, Avraam, Parga, Greece
Elles, Sarah Louise Jean, London
Faktor, Joanna, London
Feng, Jingling, Shanghai, P.R. China
Garcia-Agu, Cecile, Mouans-Sartoux, France
Gill, Julia Mary, Dudley, West Midlands
Goldman, Lucy, London
Griffiths, Neil Robert, Bromsgrove, Worcestershire
Guo Qian, Guangxi, P.R. China
Hailan Liu, Shanghai, P.R. China
Harris-MacNeil, Joanna, London
Ho Ching Yee, New Territories, Hong Kong
Ho Yue Yau, Tsuen Wan, Hong Kong
Hug, Samuel, Alverstoke, Gosport, Hampshire
Iozzino, Vittorio, Busalla, Genova, Italy
Jain, Aarti, Surat, Gujarat, India
Jayasuriya, Hasantha Udara Prem, Kandy, Sri Lanka
Jeong, Yu Joo, Korea
Jezova, Olesia, London
Kaneyasu, Yoshimasa, Okayama-ken, Japan
Learmonth, Bryony, Stafford, Staffordshire
Kathris, Ioannis, Holargos, Greece
Khan, Ehtesham Ullah, Peshawar, Pakistan
Khan, Nuzhat, London
Kiilu, Kyalo, Oldbury, West Midlands
Kim, Min Yeong, Ulsan-Si, Korea

Gem-A Awards

Kim, Dong Hui, Daegu, Korea
Lai Tsz Wing, Aberdeen, Hong Kong
Lam Ying Kit, Hong Kong
Lau Man Yee, Chai Wan, Hong Kong
Lau Tsui Wah, Kowloon Tong, Hong Kong
Lee Ka Wai, Shatin, Hong Kong
Lee Seung Hee, Daegu, Korea
Lee Suk Wa, Ma Wan, Hong Kong
Lee Young Hee, Gyongsangbuk-Do, Korea
Lee Chi-Ju, Taipei, Taiwan, R.O. China
Li Po Shan, John, Central, Hong Kong
Liao, Tsai Chun, Taipei, Taiwan, R.O. China
Lin Li, Guangxi, P.R. China
Lin Wanchun, Guangxi, P.R. China
Lin Yu Chi, Taipei, Taiwan, R.O. China
Ling Xiaoqing, Shanghai, P.R. China
LiuTung-Wen, Taipei, Taiwan, R.O. China
Longini, Giovanni, Parma, Italy
Loo Shun Yee, Andrew, Kwai Chung, Hong Kong
Lui Ching Yi, Maggie, Hong Kong
Lung, Wan-Hui, Taipei, Taiwan, R.O. China
Maclellan, Kirstin, London
Mathieu, Clare Cecilia, London
Micatkova, Lubica, London
Mo Zurong, Guangxi, P.R. China
Monogyios, John, Athens, Greece
Nicolson, Anulak, Bangkok, Thailand
Park, Sun Young, Gyonggi-Do, Korea
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Wu, Shih-Han, Taipei, Taiwan, R.O. China
Zee Gar Bo, Michelle, Kowloon, Hong Kong

Members' Meetings

London

A private viewing of a sale which included the works of Andrew Grima was held on 5 December at Bonhams Auctioneers, New Bond Street, London W1.

Gem Discovery Club Specialist Evenings

The Gem Club meets every Tuesday evening at the Gem-A London headquarters when Club members have the opportunity to examine a wide variety of stones, and once a month a guest gem or mineral specialist is invited to give a presentation.

The November guest was Jason Williams of gem dealers G.F. Williams & Co. of Hatton Garden, who demonstrated some of the skills needed to be a successful gem dealer. Members were given a series of activities to test their skills, including counting stones at speed, sorting by value, matching stones for colour, shape and weight, and folding stone papers. Cigdem Lule Whipp, the December specialist, gave a presentation on gem-quality diaspore. Club members were able to examine diaspore samples she had collected in Turkey. Freeform gem carving was Memory Stather's subject at the February specialist evening. In her presentation Memory described the process from the choosing of materials to the finished item, with the aid of a display of finished objects as well as raw materials, sketches and tools. In March Jack Ogden gave a presentation entitled 'Base Practices – The Decorative Etching of Gemstones in Antiquity' describing the use of the decorative etching of gem materials, especially carnelian, in Roman and earlier times. Jack brought along samples for members to examine.

Midlands Branch

The Branch AGM was held on 26 January 2007 at the Earth Sciences Building, University of Birmingham, Edgbaston, at which Paul Phillips, Elizabeth Gosling and Stephen Alabaster were re-elected Chairman, Secretary and Treasurer respectively. The AGM was followed by a Bring and Buy Sale and a Team Quiz. Other events held at the Earth Sciences Building included a talk on 24 November 2006 by Peggy Hayden entitled 'Nineteenth century jet and other black jewellery', the Branch AGM, Bring and Buy and Team Quiz on 26 January 2007, a presentation entitled 'From paste to diamonds: shedding light on colourless gems' by Gwyn Green on 23 February, and 'The cravat pin, an almost forgotten item of jewellery', by James Gosling on 30 March. Events held at Barnt Green included an Instrument Training Day on 26 November and a Loupe and Lamp Training Day on 18 March, as well as the 54th Anniversary Branch Dinner on 9 December.

North East Branch

On 1 November 2006 Brian Jackson gave a talk on 'Gem collecting in Russia' and on 14 March 2007 Alan Hodgkinson

Gifts

The Association is most grateful to the following for their gifts for research and teaching purposes:

Luella Woods Dykhuis FGA DGA, Tucson, Arizona, U.S.A., for rough specimens of Montana sapphire, tourmaline, Mexican topaz and quartz, and faceted amethyst, garnet and peridot. She also donated a large faceted quartz with lepidocrocite inclusions as featured on the cover of The Journal of Gemmology, 2006, 29(7/8).

Dennis Heyden, St. Louis, Missouri, U.S.A., for a purple jade carving of an owl.

John W. Nowak CEng FRAeS FGA, Bexley, Kent, for a large selection of faceted stones and crystals.

Pierre Salerno FCGmA, Luynes, France, for samples of ruby rough and a piece of rhodonite and garnet 'raisin bread', both from Greece.

Pierre Vuillet a Ciles FGA, Villards d'Heria, France, for three cream coloured quahog pearls.

Jason Williams FGA DGA, London, for a selection of faceted stones

gave a presentation entitled 'Stretching the refractometer'. Both meetings were held at the Ramada Jarvis Hotel, Wetherby.

North West Branch

On 15 November 2006 at the YHA Liverpool International, Liverpool 1, the Branch AGM was held at which Deanna Brady was elected Chairman and Secretary of the Branch.

Scottish Branch

Scottish Branch meetings included an opal workshop by Alan Hodgkinson on 27 November 2006 and Notes from the Gem Testing Laboratory by Stephen Kennedy on 27 February 2007, both held at the Napier University, Craiglockhart Campus, Colinton Road, Edinburgh. A Stone Setting Workshop by David Webster was held on 23 January at North Glasgow College. On 20 March, Brian Jackson spoke on the history of Scottish agates at Murchison House, West Mains Road, Edinburgh.

South East Branch

The Branch AGM was held on 25 February at the Gem-A London Headquarters at which Peter Wates was elected Chairman, Elizabeth Davidge Secretary and Lawrence Hudson re-elected Treasurer. The AGM was followed by a talk by David Lancaster entitled 'Cataloguing and Preparing a Sale of Antique Jewellery'.

Membership

Between November 2006 and March 2007, the Council approved the election to membership of the following:

Fellowship and Diamond membership (FGA DGA)

Andrews, Kitiya, Birmingham, West Midlands. 1996/2005
Slovak, Kate, Leicester, Leicestershire. 2005/2006
Ward, Louisa, London. 1996/1998

Fellowship (FGA)

Bellec, Marion, Ergue-Gaberic, France. 2006
Bergeron, Elise, Montreal, Quebec, Canada. 2006
Cardew, Charles Julian, Penzance, Cornwall. 1982
Chan Wing Sze, Herleva, Kowloon, Hong Kong. 2006

Forsberg, Erika, Stockholm, Sweden. 2006
Goncalves Coelho, Ana Christina, Johannesburg, South Africa. 2006
Hartley, Pauline, Dewsbury, West Yorkshire. 2006
Holmes, Lissa, London. 2003
Kronis, Lynne, Toronto, Ontario, Canada. 2006
Offord, Nigel, Romsey, Hampshire. 1987
Tantisiriohaiboom, Yenrudee, Ho Chi Minh City, Vietnam. 2002
Turner, John, Burlington, Ontario, Canada. 2004
Win, Mai Mu Mu, Yangon, Myanmar. 1995
Xue Xiaoxin, Wuhan, Hubei, P.R.China. 2006

Diamond membership (DGA)

Lo Wing See, Hong Kong. 2006
Mchugh, Trudi, Eastleigh, Hampshire. 2006
Wong Kwun Tong, Lever, Hong Kong 2006

Associate membership

Abey, Sara, London,
Aderhold, Bryan, Ridgewood, New Jersey, U.S.A.
Allen Amanda, Northampton, Northamptonshire
Allsop, Jenny, Hythe, Kent
Amorena, Juan, Pamplona, Spain
Arlabosse, Jean-Marie, Cagnes s/Mer, France
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Franklin, Dale, London
Franks, Jill, London
Fukaya, Keiko, Tokyo, Japan
Gordon, Pippa, London
Greenwood, Debbie, London
Griffiths, Sara, London
Halliday, Jilly, London
Han, Jie, London
Hara, Kiyo, Nishimuro-gun, Wakayama Pref., Japan
Hawkins, Silas, London
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Hirayama, Chieri, Osaka City, Japan
Hu, Xiao Yu, London
Huang Chiao-Ying, London
Huybrechts, Thomas, Salisbury, Wiltshire
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Ito, Takako, Tokyo, Japan
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Kamharn, Pranom, London
Kanatsu, Takeshi, Matsue City, Shimane Pref., Japan
Keenan, Alison, London
Kishi, Tomoo, Himeji City, Hyogo Pref., Japan
Klein-Bernhardt, Ute, Wausau, Wisconsin, U.S.A.
Kobayashi, Nobue, Kofu City, Yamanashi Pref., Japan
Lacosta, Patricia, London
Little, Anne, Holmfirth, West Yorkshire
Mahoud Al-Musallam, Zainab, Kuwait
Manabe, Go, Tokyo, Japan
Marmont, Joan, London
Martin, Helen, Liverpool, Lancashire
Mashiko, Fumiko, Yachiyo City, Chiba Pref., Japan
Mori, Hirokazu, Osaka City, Japan
Nishimura, Fumiko, Kofu City, Yamanashi Pref., Japan
Novak, Daniel, Amarillo, Texas, U.S.A.
Ohara, Youhei, Nagaokakyo City, Kyoto, Japan
Oike, Akane, Tokyo, Japan
Oliver, Wendy, Aberystwyth, Ceredigion
Quintin-Baxendale, Brian, Ruislip Manor, Middlesex
Roberts, Julia, London
Ross, Antonia, Fleet, Hampshire
Sekine, Shunji, Tokyo, Japan
Smith, Gary, Montoursville, Pennsylvania, U.S.A.

Donations

The Council of the Association is most grateful to the following for their donations. Donation levels are Diamond (£1000 to £4999), Ruby (£500 to £999), Emerald (£250 to £499), Sapphire £100 to £249) and Pearl (£24 to £99)

Sapphire Donations

Torbjorn Lindwall FGA DGA, Lannavaara, Sweden
Robert L. Rosenblatt FGA, Salt Lake City, Utah, U.S.A.

Pearl Donations

Raed Mustafa Al-Hadad FGA, Abu Dhabi, United Arab Emirates
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Tsuruta, Miho, Onga-gun, Fukuoka Pref., Japan
Ueda, Kenji, Osaka City, Japan
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Vasdekis, Lukas, Athens, Greece
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Wakita, Youko, Osaka City, Japan
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Watanabe, Yoshiko, Minamitsuru-gun, Yamanashi Pref., Japan
Williams, Anne-Marie, Amersham, Buckinghamshire
Yamada, Mayumi, Kobe City, Hyogo Pref., Japan
Yamaguchi, Yuko, Gerrards Cross, Buckinghamshire
Yoshida, Ayana, Tokyo, Japan
Zebrowski-Jensen, Catherine, Pena Bianca, New Mexico, U.S.A.

Laboratory Membership

P. Fisher Ltd, London
Graus Antiques, London

Obituary

It is with deep regret that we announce the death on 17 April of David Kent FGA (D. 1948), a Vice President of the Association since 1992. A full obituary will be published in the next issue of *The Journal*.

Hsieh Juan Ku-Wei FGA (D.1997), Taipei, Taiwan, died in November 2006.
Joan M. Hull FGA, Leighton Buzzard, Bedfordshire, died on 3 January 2007.

George M.A. McChlery MA CA FGA (D.1962), Glasgow, died on 26 December 2006.

John W. Nowak CEng FRAeS FGA (D.1974), Bexley, Kent, died on 16 April 2007.

Pekka J. Parikka FGA (D. 1989), Helsinki, Finland, died in August 2006.

Philip Riley FGA (D.1960 with Distinction), Kimpton, Hitchin, Hertfordshire, died in August 2006. Philip had served on the Council of the Gemmological Association of Great Britain for many years and was Vice Chairman of the Association from 1965-1970.

Peter A. Waters FGA DGA, Aldcliffe, Lancaster, died on 11 December 2006. Peter was awarded the Tully Medal in 1962 and had been a Gem-A correspondence course tutor for many years.

Errata

Vol. 30(3/4), p.147: in the last paragraph n_o and n_e have been transposed and the sentence should read: "n_e varies between 1.760 and 1.765 and n_o remains stationary between 1.768 and 1.773 …"

Vol. 30(3/4), p.236, column 3, Gemmologische Kurzinformationen; the author should be U. Henn not H. Henn

In Vol. 30(3/4), p.252 in the list of elected Fellows, Ong Chin Sing should read Ong Chin Siang

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Forthcoming Events

Gem-A Annual General Meeting

The Gem-A AGM is to be held on Monday 18 June at 6:00 p.m.
at the National Liberal Club, Whitehall Place, London SW1A 2HE.

Tuesday 1 May	Gem Discovery Club Specialist Evening. Gemstones in 18th century Portuguese jewellery. RUI GALOPIM DE CARVALHO
Friday 4 to Monday 7 May	Scottish Branch Annual Conference: Keynote speaker: PROFESSOR EMMANUEL FRITSCH
Saturday 12 May	South East Branch. Viewing of a private collection of African gems and minerals.
Thursday 17 May	North West Branch. Lord Derby – 15th Earl of Derby's agate collection. WENDY SIMKISS
Thursday 24 May	North East Branch. Coloured stone market. TRACEY JUKES
Tuesday 5 June	Gem Discovery Club Specialist Evening. The development of the Lennix synthetic emerald. ROY HUDDLESTONE
Saturday 16 June	Midlands Branch. Summer Supper Party
Thursday 21 June	North West Branch. Opals. ALAN HODGKINSON
Sunday 23 September	Hong Kong Dinner and Graduation Ceremony. To be held at The Salisbury, Kowloon, Hong Kong
Sunday 28 October	Gem-A Annual Conference. Gems of the Orient
Monday 29 October	Presentation of Awards and Graduation Ceremony.

Contact details

When using e-mail, please give Gem-A as the subject:

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North West Branch:	Deanna Brady on 0151 648 4266
Scottish Branch:	Catriona McInnes on 0131 667 2199; e-mail scotgem@blueyonder.co.uk
South East Branch:	Peter Wates; email peter_at_GASEB@yahoo.co.uk
South West Branch:	Richard Slater on 01635 553572; e-mail rslater@dnfa.com

Gem-A Website

For up-to-the-minute information on Gem-A events visit our website on www.gem-a.info

Guide to the preparation of typescripts for publication in The Journal of Gemmology

The Editor is glad to consider original articles shedding new light on subjects of gemmological interest for publication in The Journal. Articles are not normally accepted which have already been published elsewhere in English, and an article is accepted only on the understanding that (1) full information as to any previous publication (whether in English or another language) has been given, (2) it is not under consideration for publication elsewhere and (3) it will not be published elsewhere without the consent of the Editor.

Typescripts Two copies of all papers should be submitted on A4 paper (or USA equivalent) to the Editor. Typescripts should be doubled spaced with margins of at least 25mm. They should be set out in the manner of recent issues of The Journal and in conformity with the information set out below. Papers may be of any length, but long papers of more than 10 000 words (unless capable of division into parts or of exceptional importance) are unlikely to be acceptable, whereas a short paper of 400-500 words may achieve early publication.

The abstract, references, notes, captions and tables should be typed double spaced on separate sheets.

Title page The title should be as brief as is consistent with clear indication of the content of the paper. It should be followed by the names (with initials) of the authors and by their addresses.

Abstract A short abstract of 50-100 words is required.

Key Words Up to six key words indicating the subject matter of the article should be supplied.

Headings In all headings only the first letter and proper names are capitalized.

A This is a first level heading

B This is a second level heading

First and second level headings are ranged left on a separate line.

Third level headings are in italics and are indented within the first line of the text.

Illustrations High resolution digital files, for both colour and black-and-white images, at 300 dpi TIFF or JPEG, and at an optimum size, can be submitted on CD or via email. Vector files (EPS) should, if possible, include fonts. Match proofs are essential when submitting digital files as they represent the colour balance approved by the author(s).

Transparencies, photographs and high quality printouts can also be submitted. It is recommended that authors retain copies of all illustrations because of the risk of loss or damage either during the printing process or in transit.

Diagrams must be of a professional quality and prepared in dense black ink on a good quality surface. Original illustrations will not be returned unless specifically requested.

All illustrations (maps, diagrams and pictures) are numbered consecutively with Arabic numerals and labelled Figure 1, Figure 2, etc. All illustrations are referred to as 'Figures'.

Tables Must be typed double spaced, using few horizontal rules and no vertical rules. They are numbered consecutively with Roman numerals (Table IV, etc.). Titles should be concise, but as independently informative as possible. The approximate position of the Table in the text should be marked in the margin of the typescript.

Notes and References Authors may choose one of two systems:

(1) The Harvard system in which the authors' names (no initials) and dates (and specific pages, only in the case of quotations) are given in the main body of the text, (e.g. Collins, 2001,341). References are listed alphabetically at the end of the paper under the heading References.

(2) The system in which superscript numbers are inserted in the text (e.g. ... to which Collins refers.[3]) and referred to in numerical order at the end of the paper under the heading Notes. Informational notes must be restricted to the minimum; usually the material can be incorporated in the text. If absolutely necessary both systems may be used.

References in both systems should be set out as follows, with double spacing for all lines.

Papers Collins, A.T., 2001. The colour of diamond and how it may be changed. J.Gemm., 27(6), 341-59

Books Balfour, I., 2000. Famous diamonds. 4th edn. Christie's, London. p.200

Abbreviations for titles of periodicals are those sanctioned by the World List of scientific periodicals 4th edn. The place of publication should always be given when books are referred to.

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Cover Picture: Two red synthetic zincite crystals. Photograph by M. Krystek.
(See Formation of large synthetic zincite (ZnO) crystals during production of zinc white, p.257)

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The Gemmological Association of Great Britain

The Gemmological Association of Great Britain

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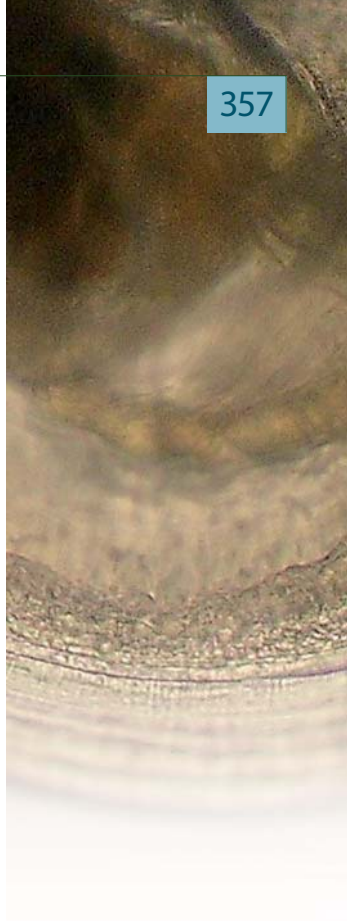

A description of pearl farming with Pinctada maxima in South East Asia

Professor H.A. Hänni
SSEF Swiss Gemmological Institute, Basel, Switzerland

Abstract: *This reports on a modern pearl farm in South East Asia which uses* Pinctada maxima *oysters. Marine biologists and geneticists supervise the pearling process. Culturing oysters from fertilized eggs has generally replaced wild oyster collection. In hatcheries larvae and spat are reared under scientifically controlled conditions. After around two years the oysters are about 12 cm in size and ready for the operation. Careful selection of donor oysters for the tissue graft and of host oysters to grow the pearls ensures optimum conditions for pearl formation. Excellent environmental conditions are sought to grow pearls of superior quality. High standards of working hygiene, X-ray checks and regular and frequent cleaning of the oysters and the holding nets are further steps to ensure high quality. Almost four years from the hatching of the larvae, the oysters are ready for a first pearl harvest. Most of the oysters are not re-beaded, and their muscle flesh is processed as seafood and the shells utilized for their nacre. The pearls are graded for quality and marketed mainly in Australia.*

Keywords: *pearl culturing process, pearl farming,* Pinctada maxima*, South Sea cultured pearls*

Introduction

In February 2006 the author had the opportunity to visit a pearl farm belonging to North Bali Pearls in Penyabangan, which is part of PT Cendana Indopearls, a company in the Atlas South Sea Pearls (Australia) group (*Figure 1*). In December 2006 a second trip was undertaken, this time to the West Papua area, for purposes of familiarization with the main pearl farming centre there. In both places, the author was afforded facilities at a state-of-the-art pearl farm to study the preparatory work that results eventually in the prized South Sea cultured pearls. The volume of scientific, technical and financial investment that has to go into a modern pearl farm is very impressive. The shares of these pearl forms are bought and sold on the stock exchange, and the success or otherwise of a harvest has a direct bearing on the share price.

The literature on oysters and cultured pearls is voluminous, and only a small selection can be listed here. On the biology of the *Pinctada maxima* oyster, see Dix, 1973 and Lowenstam and Weiner, 1989. On the farming of pearl oysters, see Jobbins and Scarratt, 1990; James, 1991; Müller, 1997. The microstructure of pearls is dealt with in Wise, 1970; Gauthier and Ajaques, 1989; Gutmannsbauer, 1993; Gutmannsbauer and Hänni, 1994. On issues of nomenclature, CIBJO, 1997, 2006,

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Figure 1: *The pearl farm in North Bali, an aquacultural business with an ultra-modern approach to oyster production and pearl culturing in Penyabangan. Photo © H.A. Hänni.*

and Hänni, 2006a,b, are useful. For general information on pearls, see Hänni, 1995 and 1997; Schoeffel, 1996; Matlins, 1999; Hänni, 2001; Strack, 2006. Methods of identifying pearls are covered in Wada, 1981; Komatsu, 1987; Lorenz and Schmetzer, 1985.

Oysters used in cultured pearl production serve one of two distinct purposes. Some are used as mantle tissue donors, while others serve as host animals for the cultured pearls. Both halves of an oyster's shell have a layer of soft skin. This tissue, known as mantle tissue (or mantle epithelium), lines the whole shell and has produced both wings of the oyster.

A tiny piece of the outer surface of this mantle tissue is essential for transference of the nacre-forming ability to a different site for the purpose of growing a cultured pearl. The body of an oyster selected as a host animal has two sites where the transplanted mantle tissue can be accepted and will form a cultured pearl. One is the host's mantle tissue and the other is its gonad (reproductive organ). Pearls may be referred to accordingly as mantle-grown or gonad-grown. Located deep within the oyster shell, the gonad affords the room for one or two beads to be implanted in order to produce one or two beaded cultured pearls. In general, cultured pearls with beads will be the familiar saltwater-grown Akoya, South Sea and Tahiti varieties.

Cultured pearls without a bead usually derive from transplanted mantle tissue placed in the mantle of freshwater mussels, producing well-known varieties such as the Biwa or Chinese freshwater cultured pearls. Thus cultured pearls are always formed by the transfer of mantle tissue, regardless of whether the graft is into freshwater mussels or saltwater oysters, and regardless of the presence or absence of a bead. *Figure 2* provides an overview, illustrating sectioned cultured pearls of all types.

Pearl farmers who use *Pinctada maxima*,

Figure 2: *Cross-sections through different kinds of cultured pearls. Upper part: beadless pearls, e.g. South Sea 'keshi', Chinese freshwater cultured pearls. Lower part: cultured pearls with beads, e.g. Akoya, Tahiti and South Sea, and freshwater. Photo © H.A. Hänni.*

the large silver or gold lipped oyster (South Sea pearl oyster), insert a bead of nacre along with the mantle tissue (Japanese term: *saibo*). This is the practice followed at the farm in North Bali. Some of the grafted oysters expel this bead; however, the mantle tissue remains and forms a pouch inside which it produces a beadless cultured pearl, a variety marketed as a keshi cultured pearl (Hänni, 2006). But the great majority will retain the bead, form a pearl-sac round it and envelop the bead and deposit a good thick layer of nacre. This results in the classical South Sea cultured pearl.

Back in the 1960s, trading in cultured pearls was centred on Broome and Darwin in north-western Australia. Problems persisted over a long period in the rearing of oysters artificially from fertilized eggs, and therefore the animals required were harvested from the seabed by divers. They were then grafted and transported to warmer waters. As the harvesting of wild oysters in Australia is subject to quota, the production of cultured pearls is correspondingly limited.

The pearl farm in North Bali

The North Bali pearl farm is linked to other pearl farms in West Papua (Irian Jaya, Indonesia). The brief account provided here will indicate the complexity of modern production processes for cultured pearls with bead, and will refer for comparison to the production of beadless freshwater pearls. Thus, for example, a pearl oyster will produce a single cultured pearl, while as many as fifty may develop simultaneously inside freshwater mussels. The formation of beadless freshwater cultured pearls, however, may take several years when larger sizes are required.

In North Bali (Penyabangan) the author visited a farm which rears young oysters from fertilized eggs in a breeding facility. Carefully selected individuals are used to found a line of vigorous, handsome oysters, and the broodstock and subsequent generations will remain under genetic monitoring by scientists. With a view to minimizing disease and parasite infestation, the initial breeding and rearing stages take place in filtered seawater. The fertilized eggs and larvae are given the best possible conditions in which to grow into baby oysters (*Figure 3*).
The purified water is enriched by food in the form of specially cultivated micro algae. Once the juveniles reach a certain size, they lodge on special jute strings and continue to grow. At one month old they are transferred to ordinary seawater adjacent to the farm premises. By now they have grown to 1.5 or 2 mm in size. One net frame will accommodate up to 500 juvenile animals, and the hatchery as a whole has a population of several millions of larvae. Of these, about 20 per cent survive the transition from larva to oyster. When the young pearl oysters are 10 mm across, they are separated, and each tiny shell is re-housed in a net frame with

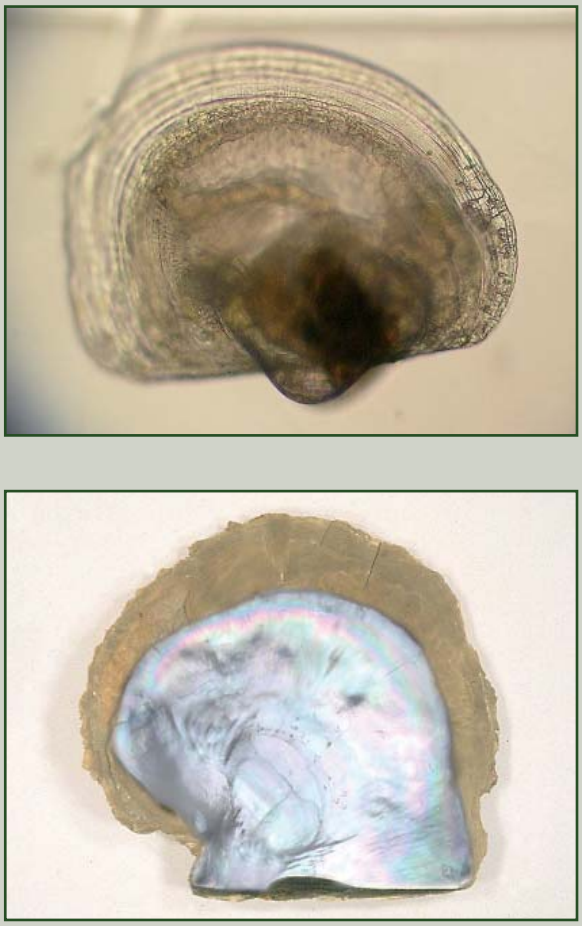

Figure 3: *A three-week-old* Pinctada maxima *oyster 2 mm across, photographed through the microscope, and a five-year-old shell half of the same species (18 cm). Photo © H.A. Hänni.*

64 others. These nets are suspended from horizontal longlines so that they hang at a depth of between 5 and 10 metres below the sea surface. From the shore the distinctive spherical black buoys supporting the hundreds of metres of line are clearly visible. The main activities involved in this phase of pearl oyster farming are regular removal of algae and also fouling organisms from nets and shells and monitoring of the growth rate of operated shells that have received their bead using X-rays (*Figure 4*). The work is carried out partly from ships or on shore.

The whole process of pearl formation could take place in Bali, but with a view to improving product quality, the North Bali Pearls management chose to ship most of the juvenile oysters at about eighteen months old to West Papua for depositing the nacre. In generous-sized ship-borne seawater tanks (*Figure 5*), as many as 40,000 *Pinctada maxima* at a time are freighted to clean waters remote from all civilization, and here they have almost two years to benefit from the ideal local growing conditions.

Figure 4: *X-ray monitoring after a cleaning process shows whether the bead has been retained in the oyster. Photo © H.A. Hänni*

Figure 5: *Workers handling nets with oysters ready for the tanks in the ship which will take them to Alyui Bay in West Papua (Irian Jaya). Photo © H.A. Hänni*

The ship takes a week to reach West Papua, the Indonesian part of New Guinea, also known as Irian Jaya. Ideal conditions are found in the Alyui Bay area (approximately 0 12'S, 130 14'E) where the coves between the islets are sheltered, and the water contains suitable minerals and plankton at the right temperature around 27 C.

The pearl farm in West Papua

The Alyui Bay base is not accessible overland but can be reached by sea from Sorong, a journey of 12 hours. Berthing facilities, office premises, production sheds, workshops, canteen and staff quarters are all on the shoreline and back directly onto jungle. The diving base essential for coping with the many and varied underwater tasks is also located by the pier. The company's board of management is Australian, the technical staff Indonesian. The pearling operations base and surrounding bays are under military guard as a precaution against theft of oysters.

Preparing the oysters for grafting

On reaching approximately 11-12 cm in size, the oysters undergo the surgery which enables production of the cultured pearls. They have to be conditioned for this operation, either by sinking the nets to the seafloor for 4-6 weeks or by covering

the nets for 4 weeks with fabric which has 1mm diameter holes. Either way the oysters are prevented from feeding and thus from producing gametes, which would cause problems during the surgical procedure (Taylor and Knauer, 2002). The food withdrawal slows down bodily processes and ensures empty gonads.

The operating table

The author's earlier visits to other pearl farms – in China, Australia and French Polynesia – had invariably made for extremely interesting observations with regard to work routines, technical provision and equipment. In contrast to some working conditions seen elsewhere by the author, the graft surgery conditions at PT Cendana Indopearls and Atlas South Sea Pearls in Indonesia (Bali and Irian Jaya) proved exemplary. The two most important innovations, in the author's assessment, have been the self-rinsing operating table with integral oyster-clamp and the cold-light fibre-optic lighting for the surgical procedures (*Figure 6*). The work-surface is continuously swilled clean by filtered seawater, and a spray device washes the instruments automatically as they are returned to their holders. The lighting used – from either a low-voltage lamp or a light pipe – affords the transplant technician a clear view of the operation site deep inside the barely opened oyster. This contrasts with some other farms visited in the past where the entire production shed had been lit by a small number of fluorescent tubes high in the ceiling.

Donor oysters and host oysters

The next step is to select which oysters will be tissue donors and which will be those that host the cultured pearls. Tissue donors provide pieces of mantle tissue for the graft. They must have nacre of the desired quality in terms of colour, lustre and 'orient' (iridescence). Young oysters are opened so that the quality of their nacre can be assessed.

Figure 6: *A clean workplace with good lighting for the operation site, hygienic surroundings and an instrument rack which is rinsed continuously characterizes the high standards at Atlas South Sea Pearls farms. Photo © H.A. Hänni*

Figure 7: *Two strips cut from the mantle tissue of a donor oyster are divided into tissue grafts (*saibo*) for transplantation. Photo © H.A. Hänni*

If the mantle tissue has grown on silvery, highly iridescent shell surfaces, the oyster is selected for tissue donation.

The remainder become potential host oysters which need to be large, vigorous specimens capable of providing optimal nurture for the transplant (Knauer and Taylor, 2002).

The mantle tissue graft

During subsequent preparation of the tissue pieces it is important not to lose track of which side had lain next to the shell, as only this outer mantle tissue is capable of secreting nacre. Two strips are cut out with scissors from the mantle tissue on each half of the shell and then cut into tiny grafting pieces (*Figure 7*). One tissue-donor oyster sacrificed for this purpose will yield about 30 *saibo*, each approximately 2.5 x 2.5 mm square. Next, these slivers of flesh containing

the complete genetic programme for the production of nacre are implanted one at a time in host oysters by a grafting technician. To make the transplant readily visible in the body of the oyster and ensure accurate positioning, the practice in many farms is to stain it red with eosin.

The bead

In Alyui, as also elsewhere, beads for the cultured pearls are derived from mussel-shell beads cut and shaped from thick-walled Pigtoe river mussels (Strack, 2006). These beads have a more or less parallel-layered structure. Even though the *Pinctada maxima* at Alyui deposit good thick coatings over the bead, care is taken to use beads that are white in colour. In Tahiti, where *Pinctada margaritifera* oysters produce dark-hued shells, it is possible to use nuclei that may be pale brown. Where snow-white beads are particularly important is for Akoya pearls, which have characteristically thin coatings. Here any brownish marbling of the beads would show conspicuously through the deposited nacre. The synthetic 'Bironite' type beads (Snow, 1999) and those made from the shell of the giant mussel *Tridacna maxima*, are not used at Alyui. The traditional Pigtoe beads are usually coated with the antibiotic tetracyclin as a prophylactic measure against disease and implant rejection.

The operation

The selected host oysters will still be young (11-12 cm), so the implanted beads must not exceed about 5.8-7.6 mm in diameter. Host oysters have to be vigorous, fast-growing specimens. Their own nacre does not need to be particularly fine, as the cultured pearl will acquire the quality characteristics introduced by the transplanted donor grafted tissue. The thickness of the deposit and the rate of growth, however, depend principally on the nurture, i.e. on the host oyster. Once the host has been slightly opened and secured in the operation clamp, the grafting technician makes a precisely performed incision in the gonad. The antibiotic-treated beads are then inserted and the tissue transplants added (*Figure 8*).

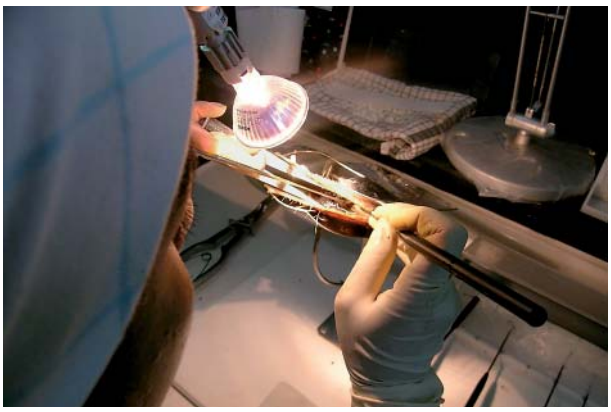

Figure 8: *A technician introduces a bead and a tissue graft into the gonad of a* Pinctada maxima. *On the excellently equipped workstation further tissue grafts and shell beads are waiting for transplantation. Photo © H.A. Hänni.*

The donor mantle tissue is accepted by the host oyster's gonad tissue, grows on in its new environment, and receives blood and minerals via the circulatory system.

The growth phase

Following the operation, the oyster is returned to seawater and allowed some time to recover. During this time, the mantle tissue graft in the gonad begins to fuse into its surroundings and also increases in size, growing concentrically around the bead and forming a closed sac. On its inner side, it gradually begins to secrete calcium carbonate in the form of aragonite platelets: the bead is acquiring its coating of mother-of-pearl. These thin aragonite platelets are what gives mother-of-pearl its unique characteristic orient.

Further checks carried out alongside routine cleaning permit the monitoring of growth and removal of casualties. Oysters that have rejected their bead are not re-seeded: they produce beadless cultured pearls, as the pearl-sac that has been formed fills up without a bead (Hänni, 2006). Oysters identified as bead-rejectors by X-ray are kept around three years in the water in order to produce substantial beadless cultured pearls, so-called South Sea keshi pearls.

It is during this growth phase that the quality of the cultured pearl will be determined. A number of factors are decisive. One important factor is the genetic makeup of the oyster concerned. This determines

its vigour and its growth rate. A second set of factors are the environmental conditions during the growth phase: light, available food, water temperature and salinity, etc. Other factors again are of human origin: hygiene during surgery, selection and condition of the transplant, and keeping feeding conditions at an optimum by regular net-cleaning (*Figure 9*).

When allowance is made for the condition of the mantle tissue, the formation of the pearl-sac follows a more or less routine course. Cleanly cut edges to the epithelium wound amply guarantee the formation of a fully functional pearl-sac. However, frayed edges will give rise to unsightly scar tissue which cannot produce problem-free nacre. Irregular shapes, dimples or rings may result.

As a rule, oysters that have undergone surgery at Alyui Bay will remain in the water for at least 18 months, sufficient time for an impressively thick coating of nacre to be secreted over the bead. Interestingly, pearl size is subject to major variation even when the maturing period inside the oyster is the same. Individual oysters will have nurtured their pearl-sacs to varying degrees, reflecting differences in their respective physical resources. 'Lazy' tissue or insufficient nourishment from the host will result in pearls that are smaller than those produced when all parts of the system have been working at their optimum. Where a nacre deposition period 'pregnancy' lasting nearly two years is involved, differences in the products from individual pearl-sacs will be more conspicuous than they would in thinly coated cultured pearls that have had only a short maturing period.

Figure 9: *Frequent cleaning with water jets and by hand is necessary to keep the nets and oyster shells free of parasitic animals and plants. A large number of boats are at work every day servicing the longlines. Photo © H.A. Hänni*

The harvest

The quality of day-to-day nacre deposition is affected by environmental influences, water temperature in particular. The shape of the cultured pearl is broadly speaking the product of the accumulated layers surrounding the bead. Irregularities may perpetuate themselves and lead to non-rounded shapes. However, surface characteristics such as colour, sheen and lustre are largely the outcome of the deposition of material over the few weeks preceding the harvest. Nacre formed at cooler temperatures is known to be made up of thinner platelets, which means that as nacre it is of finer quality. That in turn suggests that harvesting should take place just after a period during which thin platelets were being formed. Accordingly, the harvest proper is preceded by a number of oysters opened as small sample harvests. These give insight into the general condition and quality of the nacre formed up to that point. When the pearl is to be removed, the slightly opened oyster is held firmly in the clamp. A precisely executed incision opens up the gonad, and the cultured pearl can be lifted out with a specially designed tool (*Figure 10*). It is striking that a harvest of cultured pearls of uniform age yields a wide range of sizes and some variations in shape. Beadless (bead rejected) keshi pearls of the first generation are identified early on by X-ray checks when the shells undergo routine cleaning. These shells are separated and stay in separate nets, being allowed to grow for 12 months longer than the beaded cultured pearls in order to attain a marketable size. *Figure 11* shows a number of cultured pearls, all of the same age, from a sample harvest. However, the colours do not vary greatly, most of these pearls having either a clean silvery white colour or a gold tone. Half-tones are uncommon, as are pearls with constrictions (so-called 'circled' pearls).

Figure 10: *Removal of a cultured pearl from the gonad of a* Pinctada maxima. *The white part in the shell (to the left) is the powerful adductor muscle. Photo © H.A.Hänni.*

Figure 11: *A small trial harvest provides data on the present quality of the pearl surfaces. The picture shows a bead (yellow, width 6.5 mm) in comparison with pearls produced after 18 months in the shell. The mean diameter is about 12.5 mm. Photo © H.A.Hänni.*

Only those oysters that have formed top-quality pearls are beaded a second time; large beads are now used as the quality of the nacre that can be obtained diminishes as the pearl-sac grows older.

At Alyui Bay, the annual harvest in 2007 took place February. Most of the oysters were not re-beaded. Pearls from a first-harvest oyster range in size from 9 to 16 mm, with frequency peaking at 10 to 12 mm diameter (*Figure 12*). Pearls from re-beaded oysters yielded diameters of from 12 to 20 mm, with maximum frequency at 14 - 16 mm. Atlas South Sea Pearls open approximately 240,000 oysters annually. Oysters identified through X-ray monitoring during cleaning as having lost the implanted bead (10%) have been separated from the main population at an earlier stage. These oysters will have formed

Figure 12*: These beaded South Sea cultured pearls from Alyui Bay, West Papua (Irian Jaya) were harvested in February 2007. The diameters vary between 9 and 16 mm. Photo © H.A.Hänni.*

a beadless cultured pearl or keshi in their pearl-sac, and are allowed to grow for three years. About 15,000 keshi cultured pearls are produced annually in this way; they range from 5-15 mm in diameter with a mean of 8-9 mm.

About 90 per cent of the cultured pearls produced at Alyui Bay are put on the market in Australia, through the Pearlautore International Company. Eighty per cent are offered for purchase as loose pearls. The others, after being drilled through and graded for size, are traded as strings, along with pearls from other farms, and bought up in lots by wholesalers. A small number of pearls from the harvest go into jewellery manufactured in Atlas South Sea Pearls' own boutiques in Bali.

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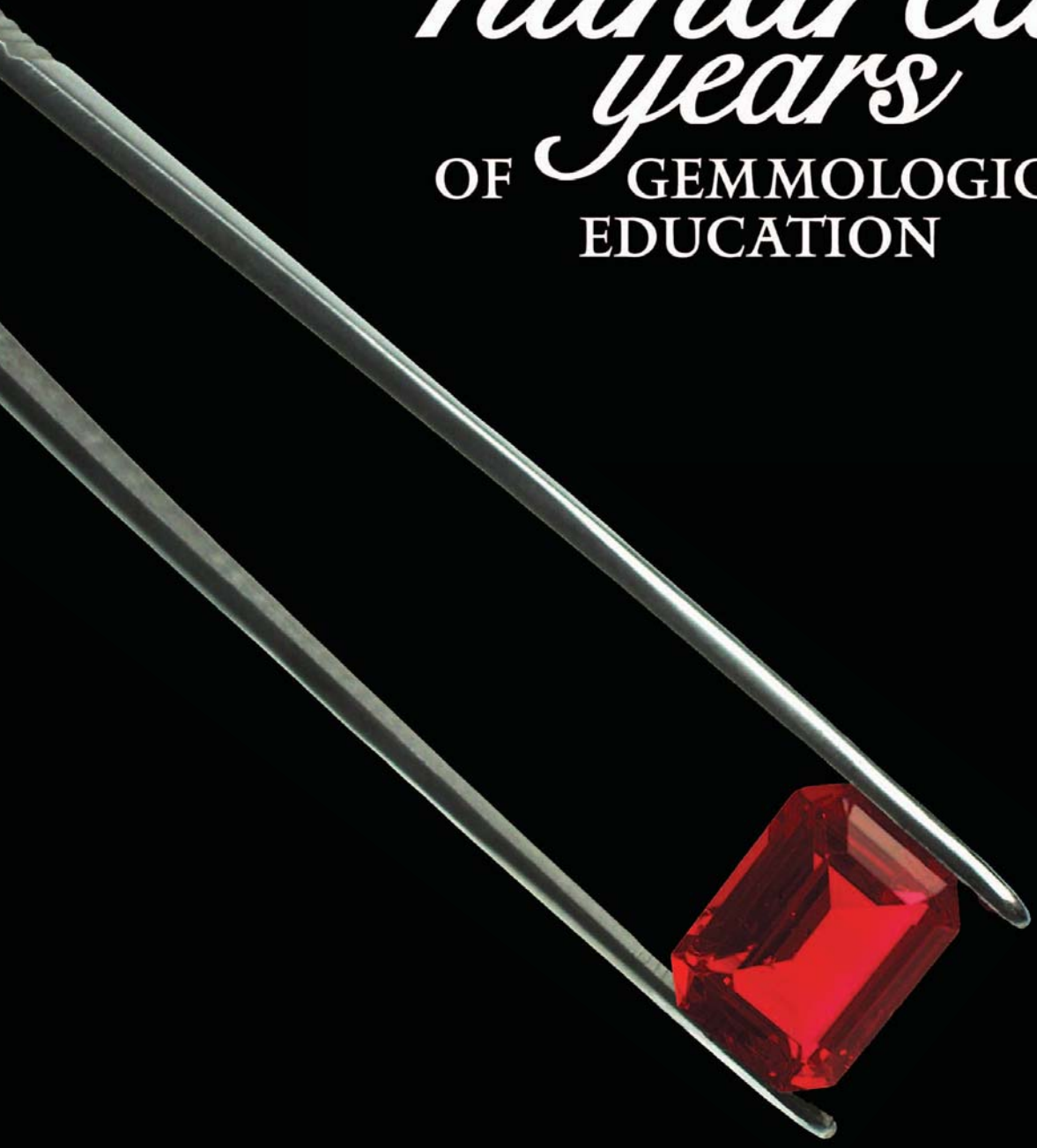

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Gem-quality taaffeites and musgravites from Africa

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Abstract: *Gemmological, microscopic, chemical and spectroscopic properties of a parcel of 30 taaffeites and ten musgravites of African origin, most probably all from Tunduru, Tanzania, are presented. The faceted gemstones were identified by a combination of laser Raman microspectroscopy, quantitative electron microprobe analyses and LA-ICP mass spectroscopy. The variation of gemmological properties such as specific gravity and refractive indices is correlated with transition metal contents of the samples. Absorption bands in the UV-Vis range are assigned to iron in different valence states. Typical inclusions are primary apatite and magnesite crystals and healed feathers consisting of cavities that contain fluids and tiny secondary magnesite crystals. Gemmological and microscopic properties of these African stones are compared with characteristic features of taaffeites and musgravites from Sri Lanka. Most gem-quality taaffeites and musgravites from Sri Lanka and Africa originate from magnesian skarns or from calc-silicate rocks of metasomatic origin.*

Introduction

The taaffeite group consists of three independent mineral species, taaffeite, musgravite and pehrmanite (Armbruster, 2002). That the formulae and crystal structures of taaffeite and musgravite are distinct was established in the 1980s (Schmetzer, 1983 a,b; Nuber and Schmetzer, 1983). Only taaffeite and musgravite are known in gem quality, especially from Sri Lanka. Taaffeite, $BeMg_3Al_8O_{16}$, is a rare collector's stone, and musgravite, $BeMg_2Al_6O_{12}$, is considered as one of the rarest gem species known to date (McClure, 2001).

Since the 1980s, faceted taaffeites have continued to appear in parcels of cut and rough stones from Sri Lanka. Additionally, a gem-quality taaffeite from Myanmar has been reported by Spengler (1983) and recently, several samples from the Tunduru area in Tanzania have been described (anonymous, 1996; Burford, 1998). The first faceted musgravites, probably from Sri Lanka, were identified by Demartin *et al*. (1993).

Although the chemical formulae for the two Be-Mg-Al-oxides, taaffeite and musgravite, are no longer in dispute, the special physical and

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chemical properties of chromium-, iron- and zinc-bearing, gem-quality taaffeites from Sri Lanka have come to light only within the last decade revealing more detailed knowledge of these gem materials (Schmetzer *et al*., 2000, 2005 a,b). The first quantitative chemical analyses of gem-quality musgravites from Sri Lanka were also reported recently (Schmetzer *et al*., 2005 c,d).

Taaffeites from Sri Lanka, in general, contain minor amounts of transition metals, especially iron and zinc, and in red to purplish red or intense purple specimens traces of chromium are also present. Some samples with extraordinarily high values of refractive indices (RI) and specific gravity (SG) contain extremely high zinc and/or iron values up to 8.87 wt.% ZnO and up to 5.62 wt.% FeO. Quantitative chemical analyses of gem-quality musgravites from Sri Lanka mostly revealed minor percentages of iron and zinc, but one sample contained a high amount of iron (4.91 wt.% FeO). Gemmological properties of taaffeites and musgravites such as SG and RI were found to be correlated with trace element contents of individual samples (Schmetzer, 2005; Schmetzer *et al*., 2006). In both minerals, taaffeite and musgravite, zinc and iron predominantly replace magnesium in the crystal structure.

In contrast to the detailed knowledge of the gemmological, physical and chemical properties of gem-quality taaffeites and musgravites from Sri Lanka established so far (see references cited above), only one chemical analysis of a gem taaffeite from Myanmar is known to the authors (Schmetzer *et al*., 2000), and quantitative chemical data of material from Tanzania are unknown.

Due to the similar chemical composition and crystal structure of taaffeite and musgravite, the gemmological properties of these independent species overlap. Consequently, for an unequivocal determination of faceted gems of this group a combination of special physical techniques such as X-ray diffraction and/or quantitative chemical analysis and/or micro-Raman spectroscopy is needed (Kiefert and Schmetzer, 1998). Because all specimens from Tunduru have so far been determined only by traditional gemmological methods, it is not known whether the samples described from Tanzania as taaffeites (anonymous, 1996; Burford, 1998) also contained some musgravites.

Consequently, the authors accepted the generous offer of W. Spaltenstein of Multi Colour Gems, Chantaburi, Thailand, to lend us 40 faceted specimens of taaffeite or musgravite of African origin for detailed gemmological, chemical and spectroscopic examination.

Materials and methods

The present study is based on 40 faceted stones ranging in weight from 0.35 to 3.97 ct (*Figures 1* and *2*). The rough gem material used for cutting these stones originated from the Tunduru mining area in Tanzania and consisted of mixed parcels containing the various gem species recovered in that particular area (see, for example, Johnson and Koivula, 1996, 1997; Henn and Milisenda, 1997, Burford, 1998). After cutting large lots of heavily water-worn rough pebbles in Thailand, the different gem materials found within the mixed parcels were sorted and taaffeites or musgravites were selected by gemmological methods, especially by the determination of optical properties.

In the cutting and sorting processes in Thailand, material from Tunduru is commonly mixed with imported rough from Ilakaka, Madagascar. However, at the time of writing (March 2007) gems of the taaffeite group have neither been reported from Ilakaka (see, for example, Schmetzer, 2000; Milisenda *et al*., 2001) nor identified in the laboratory of the Institut de Gemmologie de Madagascar in Antananarivo (T. Ramerison, pers. comm., 2006). Therefore, we assume that at least the majority of specimens examined in this study originate from Tanzania although we cannot completely exclude the possibility that a few stones could come from Madagascar. We are sure that none of the stones comes from Sri Lanka or Myanmar.

Standard gemmological methods were

used to determine the RI, optical character, SG and fluorescence under long- and short-wave ultraviolet radiation for all samples. Standard microscopic techniques were used to examine internal features of the stones under different lighting conditions, both with and without immersion liquids.

Subsequently we examined all 40 samples by laser Raman microspectroscopy using a Renishaw 1000 system equipped with a 514 nm argon laser. For each Raman spectum, 20 scans (10 seconds/scan) were accumulated. As a result, the lot could be subdivided into 30 taaffeites and 10 musgravites (for the distinction of taaffeites and musgravites using Raman spectra see Kiefert and Schmetzer, 1998). In addition, we analysed the solid inclusions of the samples using the laser Raman system mentioned.

To further characterize the samples we selected 15 taaffeites and all 10 musgravites for chemical analysis. To determine the quantitative chemical composition a Cameca Camebax SX 50 electron microprobe was used to obtain 10 point analyses from traverses across the table facets of all 25 gemstones. For the examination of beryllium contents (which cannot be determined by electron microprobe) and further trace element analysis we selected two taaffeites and three musgravites for laser ablation-inductively coupled plasma-mass spectroscopy (LA-ICP-MS) using a pulsed Excimer ArF laser with a characteristic wavelength of 193 nm, combined with special optics to homogenize the energy distribution across the laser beam combined with the Perkin Elmer ELAN 6100 ICPMS quadrupole instrument. Non-polarized UV-Vis (300-800 nm) absorption spectra were recorded using a Cary 500 Scan spectrophotometer.

Results

Identification of mineral species

The physical properties and chemical compositions of ten taaffeite and ten musgravite samples from Africa are summarized in *Tables I* and *II*. The data for the remaining 20 taaffeites more or less duplicated the properties of the taaffeites given in the table and would not supply any additional information of significance. The identification of our samples by laser Raman microspectroscopy as described by Kiefert and Schmetzer (1998) and recently by Okano *et al.* (2006) was conclusive for most but not all of the faceted taaffeites and musgravites. All specimens showed a high to extremely high background fluorescence in their Raman spectra, and in some this was sufficient to swamp the critical lines for the minerals and prevent unequivocal identification. With a combination of quantitative chemical analysis by electron microprobe and Raman microspectroscopy, however, all 30 taaffeites and ten musgravites were identified.

Figure 1: *These three violet, bluish grey and light purple taaffeites show the variation of colour seen in samples from Africa. The violet sample of 2.68 ct measures 9.0 mm in width.*

Figure 2: *The 10 studied musgravites from Africa show a wide range of colour from intense purple and light purple to violetish grey, bluish grey and bluish greenish grey. The largest sample of 3.97 ct measures 8.2 × 11.6 mm.*

Visual appearance and gemmological properties

The colours of the taaffeites vary between light purple, purplish violet, violet, greyish violet, bluish violet, greyish blue and bluish grey *(Figure 1)*. The musgravites show a similar colour variation, except that one is an intense purple and two have a bluish greenish grey colour *(Figure 2)*. Pleochroism in all stones is very weak or absent. All taaffeites and musgravites are inert to long- and short-wave ultraviolet radiation.

RIs and SGs of the taaffeites vary between 1.719 and 1.729 for ω and 1.715 and 1.723 for ε, and between 3.60 and 3.69 for SG. The musgravites have almost identical values in the same range, but with a smaller variation: their RIs vary between 1.719 and 1.725 for ω and between 1.715 and 1.720 for ε, and their SGs between 3.61 and 3.64. Thus, both groups of samples show overlapping ranges for these diagnostic gemmological properties. Consequently, for an unequivocal determination of a faceted gem of this mineral group a combination of sophisticated techniques such as X-ray diffraction (powder or single crystal techniques) and/or quantitative chemical analysis (for example, by electron microprobe) and/or micro-Raman spectroscopy is needed.

Microscopic observations

In some of the *taaffeites* we were able to identify rounded apatite grains or magnesite crystals. These closely resemble the internal features seen in taaffeites from Sri Lanka (see, for example, Schmetzer *et al.*, 2000, 2005a,b, 2006).

In the *musgravites* we identified several small, somewhat rounded apatite crystals *(Figures 3* and *4)*, and a few larger magnesite inclusions, some of which are located in the centre of a rosette of tiny fluid (?) particles *(Figure 5)*. Healed fractures usually consisting of numerous small negative crystals with multiphase fillings are also present *(Figures 6* and *7)*. With Raman analysis, it was confirmed that the birefringent crystals within these cavities are also small magnesites. In one sample we observed a cluster of brownish tabular crystals (*Figure 8*), and the Raman spectrum indicated that it was probably mica. In another musgravite we observed a tiny black crystal surrounded by a tension crack, but the Raman spectrum could not be matched with that of a known mineral.

None of the examined taaffeites or musgravites revealed significant growth patterns or colour zoning. Also many were either completely free of or had inclusions that were too small for laser Raman microspectroscopy.

In summary, there was neither any characteristic inclusion that could be used for a distinction of taaffeites from musgravites, nor was any characteristic internal feature observed that would enable separation of African taaffeites and musgravites from stones originating from Sri Lanka.

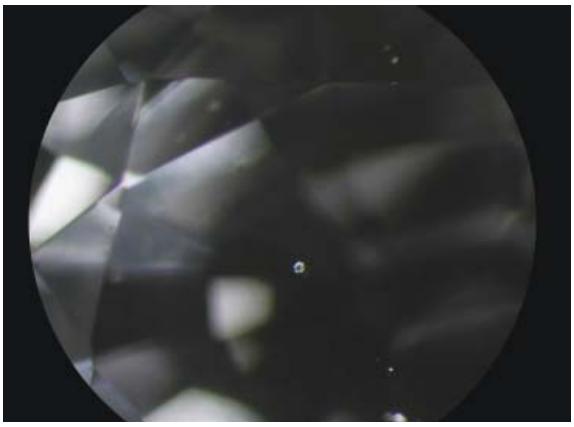

Figure 3: *Small somewhat rounded crystals of apatite are typical inclusions in musgravites from Africa. Magnified 20×.*

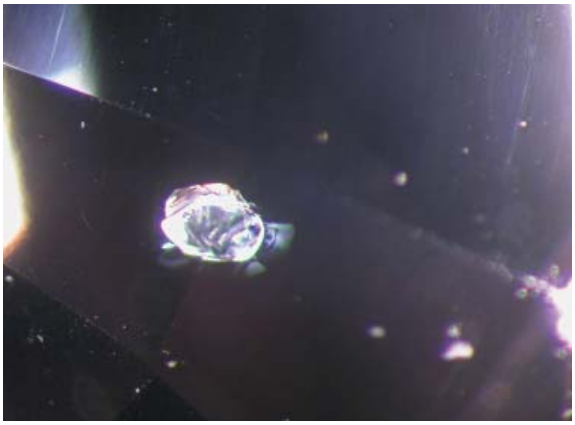

Figure 4: *Rounded apatite inclusion in musgravite from Africa, magnified 80×.*

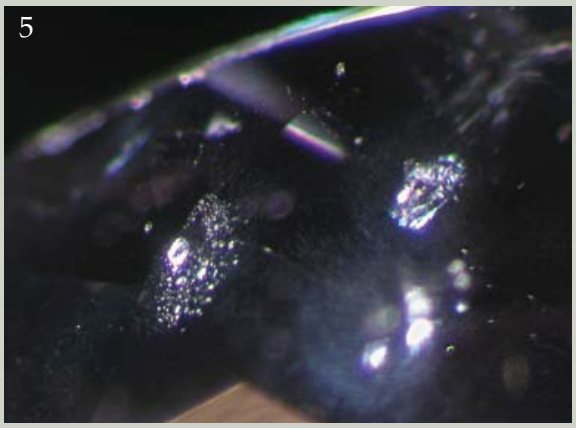

Figure 5: *Primary magnesite crystals occasionally with fluid (?) rosettes are also characteristic for musgravites from Africa. Magnified 70×.*

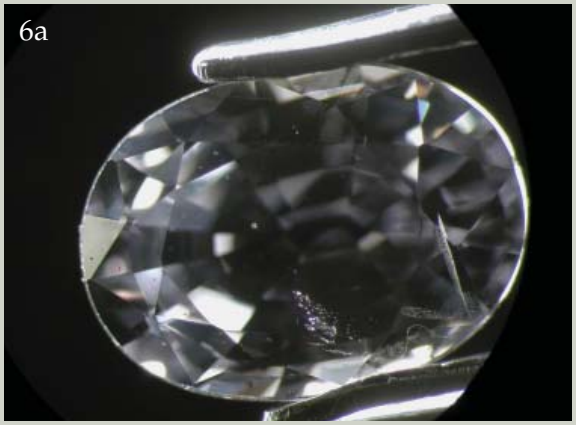

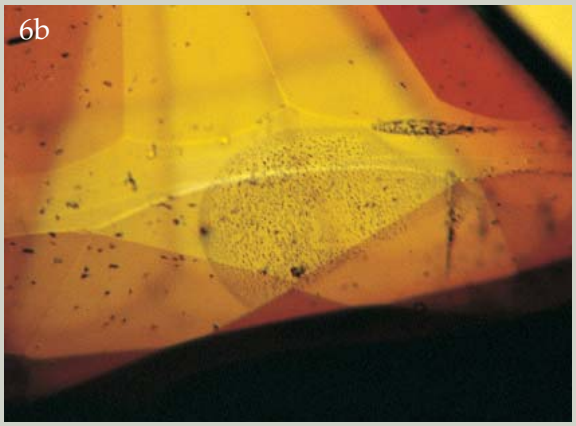

Figure 6: *Healed feathers consisting of small cavities with multiphase filling (fluid with tiny magnesite crystals) are common in musgravites from Africa. (a) overview, the stone measures 5.5 × 7.5 mm; (b) in immersion, only tiny particles are common; (c) with crossed polarizers, the birefringent crystals are clearly visible. (b) and (c) magnified 70×.*

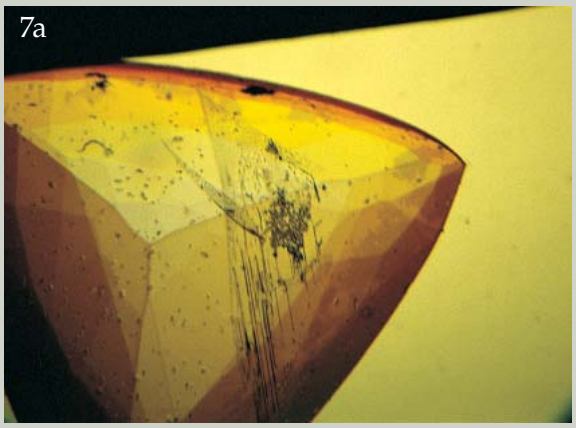

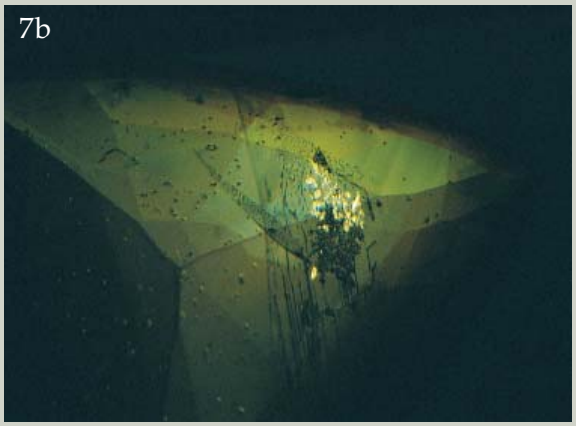

Figure 7: *Musgravite with a healed fracture with two-phase filling (fluid and solid). The fluid channels are clearly visible in plane polarized light in immersion (a) and the birefingent crystals become visible using crossed polarizers (b). Magnified 70×.*

Figure 8: *A cluster of brownish yellow platelets, probably mica, is an inclusion in a musgravite from Africa. Magnified 80×.*

Table I: *Physical properties and chemical compositions of taaffeites from Africa.*

Physical properties

Specimen	A	B	C	D	E	F	G	H	I	J
Weight (ct)	1.10	0.90	2.30	0.63	1.42	1.47	0.35	0.53	0.48	3.51
SG	3.60	3.61	3.60	3.62	3.61	3.63	3.64	3.64	3.66	3.69
RI ω	1.719	1.719	1.719	1.721	1.722	1.723	1.725	1.725	1.726	1.729
ε	1.715	1.715	1.715	1.717	1.718	1.719	1.720	1.720	1.721	1.723
Birefringence	0.004	0.004	0.004	0.004	0.004	0.004	0.005	0.005	0.005	0.006

Chemical composition (microprobe analysis, average of 10 analysis points each, wt.%)

Al_2O_3	73.56	73.41	73.63	73.39	73.28	72.98	73.01	72.52	72.52	71.89
V_2O_3	bdl	0.01	bdl	0.01	bdl	0.01	bdl	bdl	0.01	bdl
Cr_2O_3	0.01	0.01	0.01	bdl	0.01	0.02	0.01	0.01	0.01	0.01
TiO_2	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
MgO	21.16	20.98	20.91	20.67	20.41	20.01	19.99	19.68	19.09	18.19
FeO[a]	0.31	0.53	0.67	1.08	1.70	2.33	2.45	2.79	0.86	1.03
ZnO	0.17	0.17	0.12	0.11	0.15	0.08	0.08	0.04	3.34	4.78
MnO	0.01	0.02	0.02	0.02	0.03	0.04	0.05	0.05	0.05	0.02
BeO[b]	4.50	4.49	4.50	4.48	4.48	4.47	4.47	4.44	4.44	4.40
Sum	99.73	99.63	99.87	99.77	100.07	99.95	100.07	99.54	100.33	100.33
sum of transition metal contents (wt.%)[c]	0.51	0.75	0.83	1.23	1.90	2.49	2.60	2.90	4.26	5.85

Cation proportions based on 16 oxygens

Al	8.027	8.027	8.033	8.030	8.019	8.017	8.014	8.013	8.016	8.011
V	-	0.001	-	0.001	-	0.001	-	-	0.001	-
Cr	0.001	0.001	0.001	-	0.001	0.001	0.001	0.001	0.001	0.001
Ti	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Sum trivalent cations	8.029	8.030	8.035	8.032	8.021	8.020	8.016	8.015	8.019	8.013
Mg	2.920	2.902	2.886	2.860	2.825	2.781	2.775	2.751	2.670	2.565
Fe	0.025	0.041	0.052	0.084	0.132	0.182	0.191	0.219	0.068	0.081
Zn	0.011	0.012	0.008	0.008	0.010	0.005	0.005	0.003	0.231	0.334
Mn	0.001	0.001	0.001	0.001	0.002	0.003	0.004	0.004	0.004	0.001
Sum divalent cations	2.957	2.956	2.947	2.953	2.969	2.971	2.975	2.977	2.973	2.981
Be[d]	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000

bdl = below detection limit.

[a] Total iron as FeO. [b]Since beryllium is not detectable by microprobe analysis, the BeO content has been calculated for 1 Be per formula unit; for the theoretical composition of taaffeite ($BeMg_3Al_8O_{16}$) an amount of 4.52 wt.% BeO is required. [c]Calculated as (V_2O_3 + Cr_2O_3 + TiO_2 + FeO + ZnO + MnO). [d]Calculated on the basis of 16 oxygens assuming Be = 1.000.

Table II: *Physical properties and chemical compositions of musgravites from Africa.*

Physical properties

Specimen	A	B	C	D	E	F	G	H	I	J
Weight (ct)	1.18	0.44	3.97	0.36	0.46	0.61	0.35	0.86	0.65	0.60
SG	3.61	3.61	3.62	3.61	3.62	3.62	3.62	3.62	3.63	3.64
RI ω	1.719	1.720	1.721	1.721	1.722	1.722	1.722	1.723	1.724	1.725
ε	1.715	1.716	1.717	1.717	1.718	1.718	1.718	1.719	1.719	1.720
Birefringence	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.005	0.005

Chemical composition (microprobe analysis, average of 10 analysis points each, wt.%)

Al_2O_3	73.98	74.30	74.32	73.96	74.00	73.75	73.78	74.05	73.63	73.19
V_2O_3	bdl	0.01	bdl	bdl	bdl	bdl	0.01	bdl	0.01	bdl
Cr_2O_3	0.01	0.08	0.01	bdl	0.01	0.01	0.01	0.01	0.01	0.01
TiO_2	bdl	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
MgO	18.99	18.90	18.58	18.45	18.57	18.36	18.32	18.69	18.19	17.99
FeO[a]	0.61	1.09	1.20	1.23	1.45	1.59	1.56	1.51	1.84	2.00
ZnO	0.12	0.06	0.11	0.14	0.15	0.04	0.18	0.36	0.18	0.10
MnO	0.02	0.02	0.06	0.05	0.02	0.03	0.04	0.06	0.12	0.09
BeO[b]	6.04	6.08	6.06	6.03	6.05	6.02	6.03	6.07	6.02	5.98
Sum	99.77	100.56	100.35	99.87	100.26	99.81	99.94	100.76	100.01	99.37
sum of transition metal contents (wt.%)[c]	0.76	1.26	1.39	1.43	1.64	1.68	1.81	1.95	2.17	2.21

Cation proportions based on 12 oxygens

Al	6.004	5.997	6.013	6.013	6.001	6.007	6.007	5.986	6.002	6.003
V	-	0.001	-	-	-	-	-	-	0.001	-
Cr	0.001	0.004	0.001	-	0.001	0.001	0.001	0.001	0.001	0.001
Ti	-	0.001	0.001	0.001	0.001	0.001	0.001	0.001	-	0.001
Sum trivalent cations	6.005	6.003	6.015	6.014	6.003	6.009	6.009	5.988	6.004	6.005
Mg	1.950	1.930	1.901	1.898	1.905	1.891	1.886	1.911	1.875	1.866
Fe	0.035	0.063	0.069	0.071	0.083	0.092	0.090	0.087	0.106	0.117
Zn	0.006	0.003	0.006	0.007	0.008	0.002	0.009	0.018	0.009	0.005
Mn	0.001	0.001	0.003	0.003	0.001	0.002	0.002	0.003	0.007	0.005
Sum divalent cations	1.992	1.997	1.979	1.979	1.997	1.987	1.987	2.019	1.997	1.993
Be[d]	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000

bdl = below detection limit.
[a]Total iron as FeO. [b]Since beryllium is not detectable by microprobe analysis, the BeO content has been calculated for 1 Be per formula unit; for the theoretical composition of musgravite ($BeMg_2Al_6O_{12}$) an amount of 6.08 wt.% BeO is required. [c]Calculated as (V_2O_3 + Cr_2O_3 + TiO_2 + FeO + ZnO + MnO).
[d]Calculated on the basis of 12 oxygens assuming Be = 1.000.

Table III: *Trace element contents in taaffeites and musgravites from Africa.*

Specimen	Taaffeite A	Taaffeite G	Musgravite A	Musgravite H	Musgravite I
Weight (ct)	1.10	0.35	1.18	0.86	0.65
Li	22	3	8	7	127
B	50	24	346	688	220
Ga	610	172	296	259	107
Sn	9	1	11	2	23

N.B. LA-ICP mass spectrometry was used. Results are in ppm and are means of three analysis points for each stone.

Chemical composition

The results of electron microprobe analysis are presented in *Tables I* and *II*. No distinct chemical zoning was observed in the traverses across the table facets of the samples. In addition to the principal components of taaffeite and musgravite, Al_2O_3, MgO and BeO (which is not detectable directly by electron microprobe), the samples contain distinct amounts of iron and zinc. The ranges of iron contents in both minerals (from 0.31 to 2.79 wt.% FeO in taaffeites and from 0.61 to 2.00 wt.% FeO in musgravites) are broadly similar.

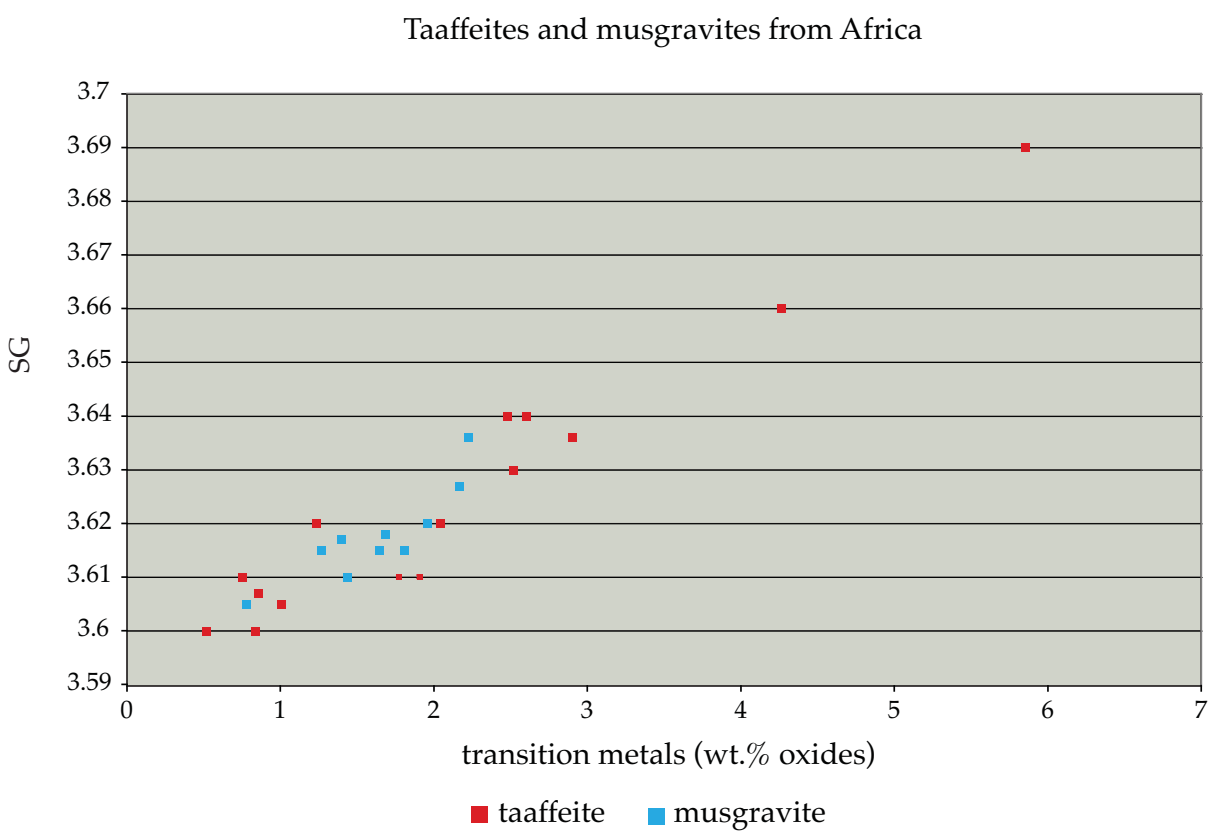

Figure 9a: *A correlation of the sum of transition metal contents with SG indicates the influence of chemical composition on gemmological properties of taaffeite and musgravite samples from Africa (for data see* Tables I *and* II*). 'Normal' samples have transition metal contents of up to 2.90 wt.%; two zinc-rich taaffeites with trace element contents of 4.26 and 5.85 wt.% are shown on the right of the diagram; the overlap of physical properties for samples of both minerals with similar transition metal contents is evident.*

There is, however, a distinct difference in the variation of zinc contents: the range observed for taaffeites is from 0.04 to 4.78 wt.% ZnO and for musgravites only from 0.04 to 0.36 wt.% ZnO. In one sample only (musgravite B) was there a significant chromium content of 0.08 wt.% Cr_2O_3. In addition, there are smaller traces of other transition metals present such as titanium and manganese.

Further trace element analyses for two taaffeites and three musgravites are given in *Table III*. Apart from the main constituents Be, Mg and Al, distinct contents of lithium, boron, gallium and tin were found. Na, Si, P, Ti, V, Cr, Mn, Fe, Co, Ni and Zn were also found as minor to trace elements in these samples, but at or below the detection limit were K, Ca, Sc, Ge, Rb, Sr, Y, Zr, Nb, Cs, La, Ce, Dy, Lu, Hf, Ta, W, Pb, Bi, Th and U. The taaffeites A and G show distinctly lower concentrations of boron than the three musgravites (samples A, H and I), but the other trace elements show overlapping concentration ranges.

The main difference in chemical composition between taeffeite and musgravite is their different beryllium contents, and since these cannot be measured by electron microprobe, the difference was proven directly by mass spectroscopy. Using the analytical results obtained for taaffeite A measured with this technique as an internal standard for the theoretical beryllium content of taaffeite (4.52 wt.% BeO), the value for taaffeite G was calculated to 4.51 wt.% BeO, and the analytical data for the three musgravites A, H and I gave BeO values of 6.03, 5.98 and 5.97 wt.%. These data confirm the generally accepted formulae for both mineral species, which requires an amount of 4.52 wt.% BeO for pure taaffeite (without iron and zinc contents) and an amount

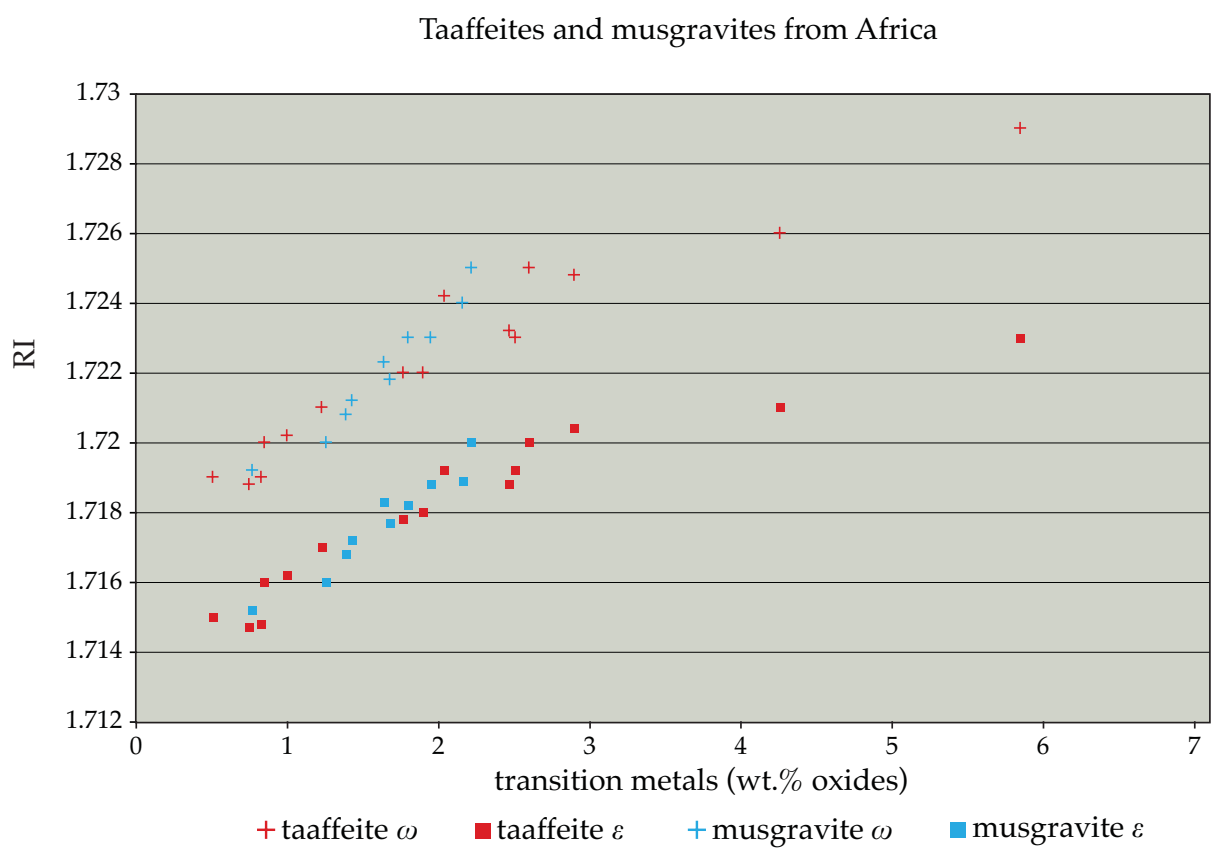

Figure 9b: *A correlation of the sum of transition metal contents with RIs ω and ε indicates the influence of chemical composition on gemmological properties of taaffeite and musgravite samples from Africa (for data see* Table I *and* II*). 'Normal' samples have transition metal contents up to 2.90 wt.%; two zinc-rich taaffeites with trace element contents of 4.26 and 5.85 wt.% are shown on the right of the diagram; the overlap of physical properties for samples of both minerals with similar transition metal contents is evident.*

of 6.08 wt.% BeO for pure musgravite (without iron and zinc contents).

The chemical compositions calculated according to the chemical formula of taaffeite for 16 oxygen atoms and 1 beryllium atom per formula unit is close to ideal cation proportions *(Table I).* The sum of trivalent cations is close to the theoretical value of 8.000 and the sum of bivalent cations is close to the ideal value of 3.000. These data indicate that only a small fraction of total iron may be present as Fe^{3+} with the majority of iron replacing magnesium as Fe^{2+}. The same applies for musgravite *(Table II):* the sum of trivalent cations is close to the theoretical value of 6.000 and the sum of bivalent cations is close to the ideal value of 2.000.

From this study, there is no evidence of any intermediate phase with a composition and formula between the two established mineral species, taaffeite and musgravite. The range of chemical composition shown by the 25 samples analysed in the present study is smaller than the range reported by Okano *et al.* (2006) for taaffeite and musgravite samples from Sri Lanka although this is based on semi-quantitative EDXRF analyses.

SGs and RIs of taaffeites and musgravites from Africa are compared with their individual sums of transition metal contents (V_2O_3 + Cr_2O_3 + TiO_2 + FeO + ZnO + MnO) in *Figures 9a* and *b*. In addition to iron, there is a strong correlation between higher zinc contents and increase in RI and SG of both species (Schmetzer *et al.,* 2000, 2006; Schmetzer 2005).

Spectroscopic properties and cause of colour

UV-Visible absorption spectra of the light purple, violet, greyish violet, greyish blue and bluish grey African taaffeite samples are similar to the spectra of iron-bearing taaffeites from Sri Lanka as already described by Schmetzer (1983b) and Schmetzer *et al.* (2005a), with the most prominent absorption bands at 629, 581, 557, 472, 458, 385 and 370 nm.

These absorption bands, mostly of low to moderate intensity, are assigned to iron, mostly to Fe^{2+} in tetrahedral coordination, with only the usually low-intensity 629 nm band, assigned to an Fe^{2+}/Fe^{3+} intervalence charge transfer absorption.

The spectra of the light purple, violet and greyish violet musgravites described in this paper *(Figure 10)* show the same absorption maxima and intensity relations for different absorption bands *(Figure 10,* sample H). The spectrum of the intense purple chromium-bearing stone shows a distinct absorption maximum at 557 nm which is assigned to an overlap of the iron-related absorption band at 557 nm with a chromium absorption located in the same spectral range *(Figure 10,* sample B). Chromium-bearing taaffeites from Sri Lanka with a similar absorption maximum at about 550 nm due to chromium have already been described by Schmetzer *et al.* (2000, 2006).

The absorption spectra of bluish grey or greyish blue African musgravites are similar to those of violet samples. Most absorption bands are of low to moderate intensity, but the 629 nm absorption band is more intense *(Figure 10,* sample F). The two bluish greenish grey musgravites (chemical properties see *Table II,* samples I and J) show the same type of spectrum although the 629 nm absorption band is even stronger and there is an additional maximum at 600 nm *(Figure 10,* sample I). Very similar spectra (Schmetzer, unpublished data) with an intense 629 nm absorption have been observed in two yellowish greenish grey and blue-green musgravites from Sri Lanka described recently (Schmetzer *et al.*, 2005d).

This kind of spectrum with an intense 629 nm absorption has so far not been found in taaffeites. In bluish green spinels from Sri Lanka, however, a similar absorption feature has already been described (Schmetzer *et al.*, 1989), where a similar intense absorption band at 645 nm was assigned to an Fe^{2+}/Fe^{3+} intervalence charge transfer absorption. The same cause could also explain the 629 nm absorption band in musgravite, where in addition to ferrous iron (Fe^{2+}), it also contains low concentrations of ferric iron (Fe^{3+}).

A more detailed interpretation of colours, absorption spectra and especially a more complete discussion of the assignment of absorption bands is beyond the scope of the present article.

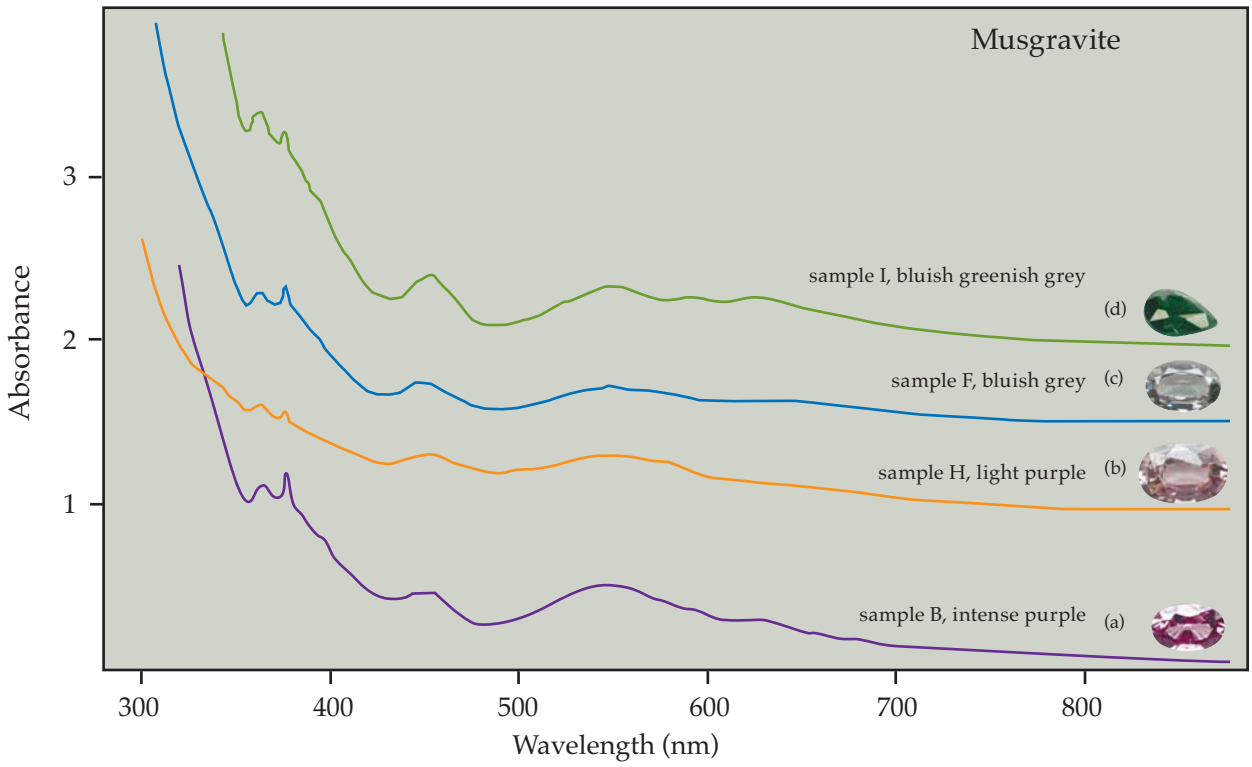

Figure 10: *Absorption spectra of iron- and chromium-bearing musgravites from Africa; from bottom to top: (a) iron- and chromium-bearing musgravite, sample B of* Table II, *intense purple; (b) iron-bearing musgravite, sample H, light purple; (c) iron-bearing musgravite, sample F, bluish grey; (d) iron-bearing musgravite, sample I, bluish greenish grey. The most characteristic iron-related absorption maxima are located at 629, 600, 581, 557, 472, 458, 385 and 370 nm; a chromium absorption band in spectrum (a) is located at about 550 nm; spectra of samples H, F, and I are vertically displaced for clarity. Sample H measures 4.9 x 7.1 mm.*

Discussion

Properties of taaffeites and musgravites from Africa

The taaffeites and musgravites from Africa are characterized by low to moderate iron contents. Two taaffeite samples only show distinct zinc contents of 3.34 and 4.78 wt.% ZnO, but no zinc-rich musgravites have been found. Only one musgravite showed unusual chromium contents of 0.08 wt.% Cr_2O_3.

The variations of RIs and SGs within taaffeites and musgravites are related to their contents of transition metals, i.e. these physical properties mainly increase with increasing iron and zinc contents (see again *Tables I* and *II*, *Figures 9a* and *b*). However, African taaffeites and musgravites with relatively low transition metal contents have overlapping ranges for these diagnostic gemmological properties. In addition, no significant inclusions or spectroscopic properties have been found which could be usefully combined with standard gemmological methods for a quick distinction of taaffeites from musgravites. Only the bluish greenish grey musgravites show a specific colour and related spectroscopic absorption features which have, so far, not been observed in taaffeites.

Consequently, for an unequivocal determination of faceted gems of the taaffeite group originating from Africa, a combination of sophisticated techniques such as X-ray diffraction (powder or single crystal techniques) and/or quantitative chemical analysis (for example by electron microprobe or LA-ICP-MS) and/or Raman microspectroscopy is needed. This fact is already common knowledge for stones from Sri Lanka.

Comparison of properties of taaffeites and musgravites from Africa and Sri Lanka

The gemmological, chemical and spectroscopic properties of most gem materials belonging to the taaffeite group from both Africa and Sri Lanka have so far shown no significant differences. Apart from some extraordinary taaffeites with extremely high iron and zinc contents reported from Sri Lanka (Schmetzer, 2005; Schmetzer *et al.*, 2006), the properties of normal taaffeites and musgravites from both sources overlap, especially their SGs and RIs (*Table IV*, *Figures 11a* and *b*). At present, gem-quality musgravites with high zinc contents are unknown from both occurrences. So far, all samples from both sources with a bluish greenish grey, yellowish-green or blue-green colour and an intense 629 nm absorption band have been identified as musgravites. Gem-quality taaffeites with that particular colour are unknown to the authors.

Considering the musgravite from Sri Lanka with lamellar spinel inclusions (Schmetzer *et al.*, 2005c) as a unique stone, taaffeites and musgravites from both sources show some common inclusions such as somewhat rounded apatite grains, isolated magnesite crystals and healed fractures consisting of negative crystals with multiphase fillings (magnesite and fluid). Other inclusions such as feldspar, graphite and mica have been reported only in a few stones and cannot be considered as characteristic for one mineral species or one locality. The only

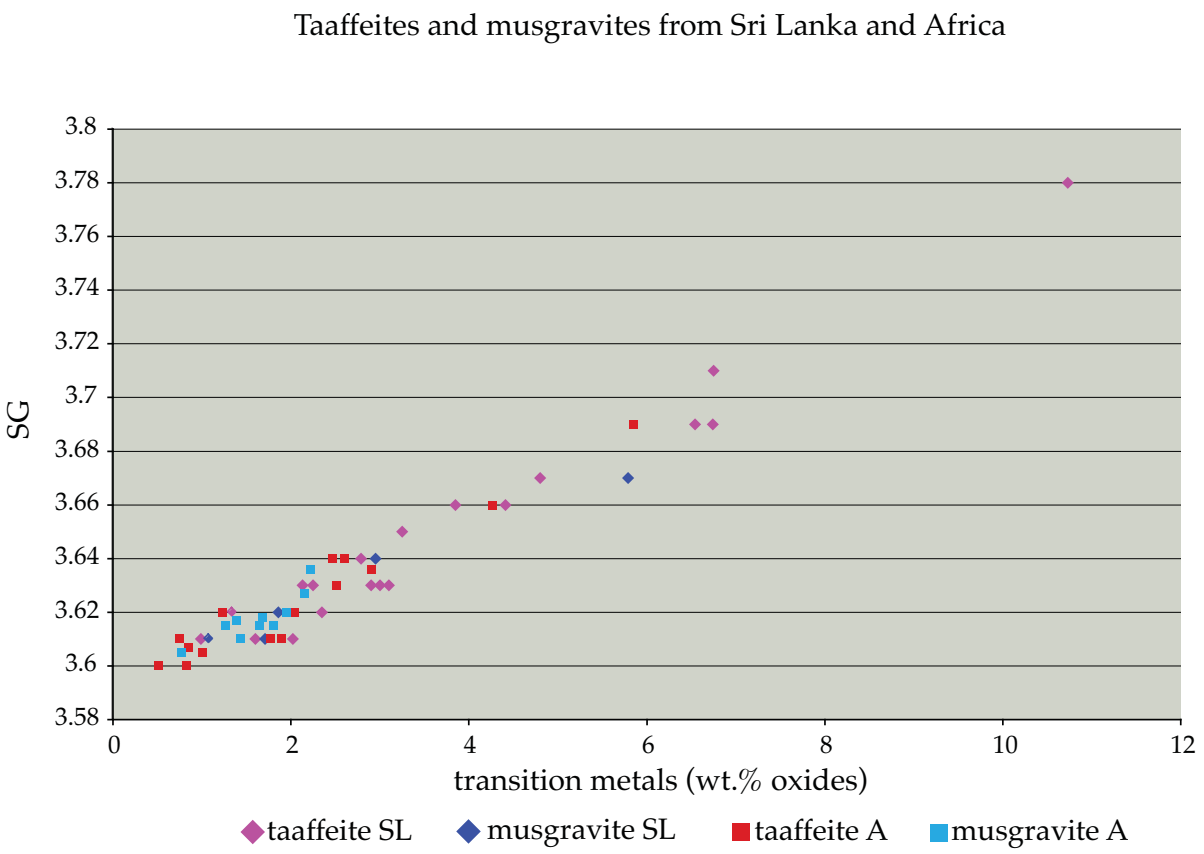

Figure 11a: *A correlation of the sum of transition metal contents with SG indicates the influence of chemical composition on gemmological properties of taaffeite and musgravite samples from Africa (data see* Tables I *and* II*) and Sri Lanka (data see* Table IV*). 'Normal' samples have transition metal contents up to 3.25 wt.%; zinc- and iron-rich specimens have transition metal contents between 3.85 and 10.73 wt.%. The overlap of physical properties for samples of both minerals from both sources with similar transition metal contents is evident. A = Africa, SL = Sri Lanka.*

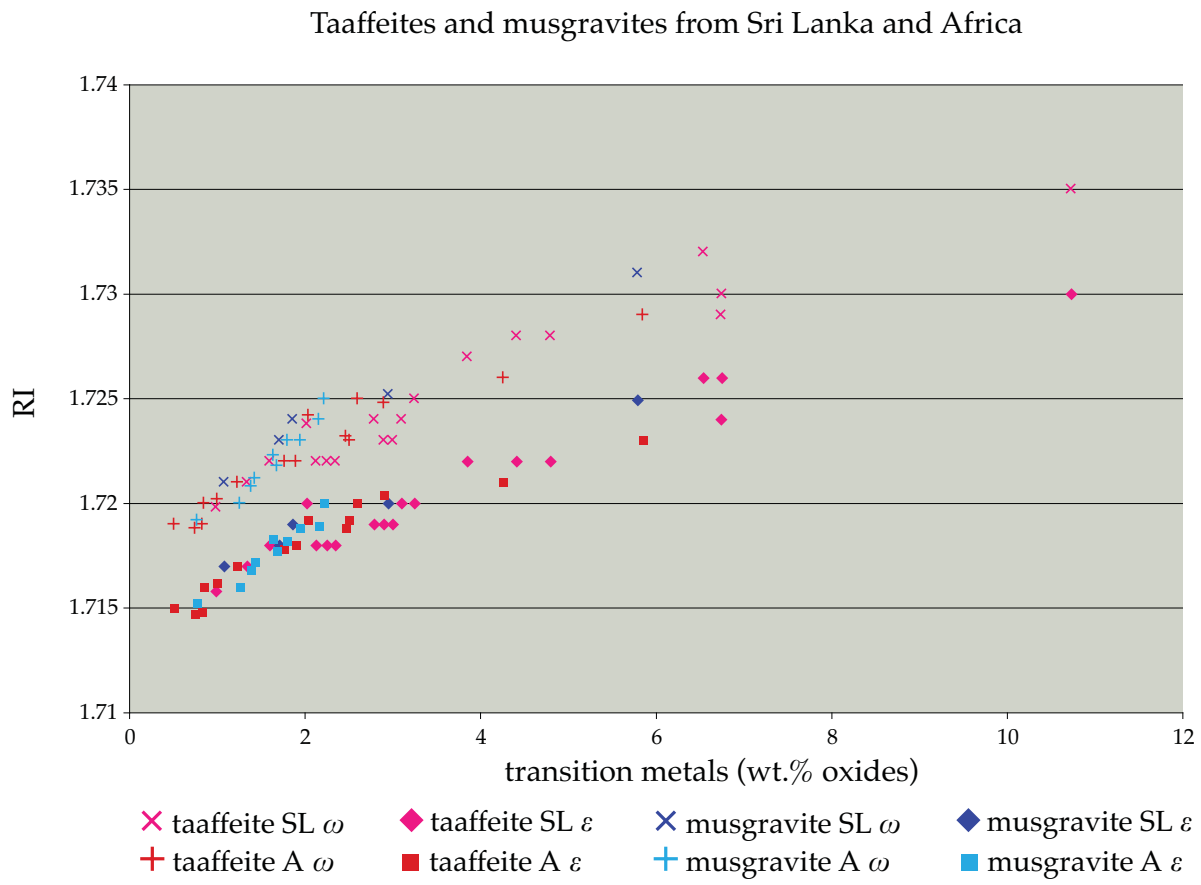

Figure 11b: *A correlation of the sum of transition metal contents with RIs* ω and ε *indicates the influence of chemical composition on gemmological properties of taaffeite and musgravite samples from Africa (data see* Tables I *and* II*) and Sri Lanka (data see* Table IV*). 'Normal' samples have transition metal contents up to 3.25 wt.%; zinc- and iron-rich specimens have transition metal contents between 3.85 and 10.73 wt.%. The overlap of physical properties for samples of both minerals from both sources with similar transition metal contents is evident. A = Africa, SL = Sri Lanka.*

inclusions which are relatively common in both taaffeite and musgravite from Sri Lanka are numerous tiny zircons with tension cracks; these have not so far been found in any of the African stones.

Origin of taaffeites and musgravites from Africa and Sri Lanka

General overviews of taaffeite and musgravite occurrences in different host rocks have been given by Grew (2002), Aleksandrov and Senin (2002) and Schmetzer *et al.* (2005d). Phase relationships in the BeO-MgO-Al_2O_3 system, especially of the pseudobinary system chrysoberyl ($BeAl_2O_4$) - spinel ($MgAl_2O_4$), are given by Franz and Morteani (2002). Both minerals are found in various environments, but typical host rocks are magnesian skarns and calc-silicates of metasomatic origin. Up to now only one primary source for taaffeite group minerals is known from Sri Lanka. The material from Bakamuna is described by Fernando and Hofmeister (2000) as taaffeite, but their chemical data (electron microprobe analysis) are a closer fit to musgravite. The material was found in the metasomatic contact zone of a marble with a high-grade metamorphic pelitic gneiss.

The presence of primary magnesite crystals and tiny magnesites in healed feathers within taaffeites and musgravites from Sri Lanka, suggests that their origin may lie in a magnesian skarn or metasomatic calc-silicate host rock (Schmetzer *et al.*, 2005d). A similar

Table IV: *Range of physical properties and chemical compositions of gem-quality taaffeites and musgravites from Sri Lanka[a] and Africa[b].*

Physical properties

		'Normal' taaffeites Sri Lanka	Iron- and zinc-rich taaffeites Sri Lanka	'Normal' musgravites Sri Lanka	Iron-rich musgravite Sri Lanka	'Normal' taaffeites Africa	Zinc-rich taaffeites Africa	'Normal' musgravites Africa
SG		3.61 – 3.65	3.66 - 3.78	3.61 - 3.64	3.67	3.60 - 3.64	3.66 - 3.69	3.61 - 3.61
RI	ω	1.720 – 1.725	1.727 – 1.735	1.721 – 1.725	1.731	1.719 – 1.725	1.726 – 1.729	1.719 – 1.725
	ε	1.716 – 1.720	1.722 – 1.730	1.717 – 1.720	1.725	1.715 – 1.720	1.721 – 1.723	1.715 – 1.720

Chemical composition (wt.%)

Cr_2O_3	0.01 – 0.21	0.01 – 0.15	0.01 – 0.02	0.01	0.01 – 0.02	0.01	0.01 – 0.08
FeO[c]	0.80 – 2.59	1.40 – 5.62	0.90 – 2.50	4.91	0.31 – 2.79	0.86 – 1.03	0.61 – 2.00
ZnO	0.05 – 1.18	0.07 – 8.87	0.04 – 0.43	0.70	0.04 – 0.17	3.34 – 4.78	0.04 – 0.36
Sum of transition metal contents[d]	0.99 – 3.25	3.85 – 10.73	1.05 – 2.99	5.79	0.51 – 2.90	4.26 – 5.85	0.77 – 2.22

Structural properties and inclusions

	Sri Lanka	Africa
Common	apatites, magnesite crystals, healed feathers with multiphase fillings (fluid and magnesite), zircons with tension cracks	apatites, magnesite crystals, healed feathers with multiphase fillings (fluid and magnesite)
Rare	growth structures and colour zoning, spinel lamellae, graphite, feldspar, mica	mica, black grain with tension cracks

[a]All data from: Schmetzer and Bank (1985), Bank and Henn (1989), Schmetzer *et al.* (2000), Schmetzer *et al.* (2005 a,b,c,d, 2006).
[b]This paper. [c]Total iron calculated as FeO. [d]Calculated as (Ga_2O_3 + V_2O_3 + Cr_2O_3 + TiO_2 + FeO + ZnO + MnO).

metasomatic origin has already been suggested for Sri Lankan taaffeite by Kampf (1991). A primary source of taaffeite or musgravite in Tanzania is unknown. The similarity of the inclusion patterns of these gem materials from Sri Lanka and Africa, especially the presence of primary magnesite crystals and magnesite as a component of multiphase inclusions in healed feathers, however suggests similar geological conditions in their formation.

Acknowledgements

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Some observations on the composition and origin of opals from Java

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Abstract: *The precious opal from Rangkasbitung, Banten Province in West Java occurs in a decomposed tuff layer as a component of the paragenesis montmorillonite – zeolite (clinoptilolite) – opal which formed in an open fresh water system at low temperatures. White, water, brown and black precious opals and non-precious opals from this area have been investigated by various methods. The gemmological characteristics are described. Internal features consist of flow texture, microcrystalline granular quartz/chalcedony, and inclusions of zeolites. Several opals show indications of stress (micro-fractures, glide planes, deformed fields of play-of-colour) which is discussed as a possible reason for the poor stability of some Indonesian opals during processing and wear.*

Though all opals are optically isotropic, X-ray diffraction data indicate that three structural types are present: opal-A, opal-CT and a structurally intermediate opal-'C'. All opals are composed basically of small granules (nanograins) of 30 to 50 nm diameter. Spherical, regularly arranged aggregates of these granules are visible only in opal-A samples, whereas opal-CT and opal-'C' types appear relatively non-structured. Hydrofluoric acid-etched samples render visible in a SEM a very regular pattern of spheres of about 290 nm diameter in opal-A, but similar treatment of opal-'C' showed complete dissolution of spheres leaving a framework of pore cement. HF treatment of opal-CT left a massive cement and a hardly visible regular arrangement of only a few non-spherical voids.

Analyses of the main elements in five representative opals indicate a wide range of concentrations for Al (4200-10100 ppm), Ti (3-5700 ppm), Ca (1480-6370 ppm), Na (700-2450 ppm) and K (390-1630 ppm) as the main impurities. Iron (6-403 ppm) is relatively low and is unlikely as the sole cause of dark brown and black body colours. Major trace elements of tens of ppm are Ba, Zr, Y and Rb. With the exception of unusual high values of Ti, Ca and Mg in one opal and the low Ba content, the chemistry does not provide a direct genetic link to the tuffaceous host rock.

Keywords: *composition, deformation, inclusions, Indonesian opal, LA-ICP-MS, structure, XRD*

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Introduction

Precious opals of mainly brown to black body colour are produced in West Java/Indonesia, about 150 km southwest of Jakarta near the town of Rangkasbitung in the Banten province, by small scale miners (Lambert and Brown, 1994; Sujatmiko *et al*., 2004). The opals occur as irregularly-shaped nodules up to a few centimetres in diameter in a zone of decomposed tuff, up to 2 m thick, in the Pliocene Genteng Formation, a 700 m thick volcaniclastic sequence of tuff, pumice, breccia, claystone, conglomerates and polymict sandstones. The opal-bearing zone consists of clay (montmorillonite with minor kaolin), partially devitrified tuff particles, abundant small, water-clear plagioclase crystals of andesine composition, a few xenolithic rock fragments, and opal. Similar occurrences of precious brown opal in volcaniclastic sediments (welded tuffs) have been reported from Ethiopia (Johnson *et al*., 1996) and Somaliland (Kinnaird and Jackson, 2000; Kinnaird, 2002).

Since the physical properties of these opals are not well documented in the gemmological literature, the results of the investigation on several opal varieties from this location are reported here.

Gemmological characteristics

Body colour

Of the eleven precious opals, three are water-opals of colourless, water-white appearance (*Figure 1a*); three are so-called 'tea-opals' (Lambert and Brown, 1994) with a light brown to dark brown body colour (*Figure 2*); and one has an apparent grey body colour, caused by abundant thin white lines on the surface in a light brown and slightly

Sample material and methods of investigation

Thirteen opal samples with variable body colour were available for investigation using a binocular, polarizing microscope, X-ray diffraction, laser ablation ICPMS and a scanning electron microscope. Cutting and polishing of eight stones had been discontinued because of their low quality - they had opaque areas without play-of-colour, inclusions, small fractures or had been damaged during cutting. The weight of the cabochons ranged from 0.8 to 6.5 ct. Three samples consisted of rough gem material with a weight between 3.3 and 9.0 ct.

A stereo microscope with a maximum magnification of 45x was used for study of the opals in air and immersed in water, and under transmitted and oblique incident light. Thin sections of eight opals were examined using a standard polarizing microscope.

For viewing the samples under short- and long-wave UV light, a viewing cabinet was used.

Twelve samples were examined by XRD with a Siemens D500 diffractometer, Cu Kα radiation at 1.5405 Å, (delta lambda 0.0038 Å) and a graphite monochromator. Measurements were taken between 15.0 and 40.0 2θ at a scanning speed of 0.5 /min (standard parameter), followed by measurements on 7 samples with a low scanning speed of 0.06 /min between 18 and 27 2θ using corundum as internal standard.

Untreated and HF-etched surfaces of seven opals were investigated by SEM using a LEO 1530 GEMINI scanning electron microscope at 10 kV and a 5 nanometre Pt-coating of the samples.

Five opal samples with body colours ranging from water clear to brown and black were investigated for main and trace elements by laser ablation ICPMS using a New Wave Research UP 213 laser ablation unit and an Agilent 7500ce ICPMS with Ar as carrier gas, Si as internal standard (determined with microprobe) and NIST 610 as external standard. Each sample was measured at three sample points.

Figure 1: *Examples of opals from Indonesia with different body colours.* 1a: *This transparent water opal (IO 12, 4 ct) shows play-of-colour in comparatively large patches of red, blue and green.* 1b: *The apparent grey body colour of this turbid light brown 'tea-opal' (IO 8, 1.5 ct) is caused by traces of multiple parallel planar features which dissect the colour fields in two main directions (only one set is clearly visible). The fracture on the left side marks the direction of the second set. These are interpreted as latent microfractures.* 1c: *This typical black opal (IO 3, 2 ct) with red, green and blue play-of-colour developed surface fractures when exposed to strong heat from a 500 W photo lamp.* 1d: *This is a good example of spot-like red and green colour fields in a black opal (IO 2, 3.5 ct) which needs strong illumination to show its full colours.*

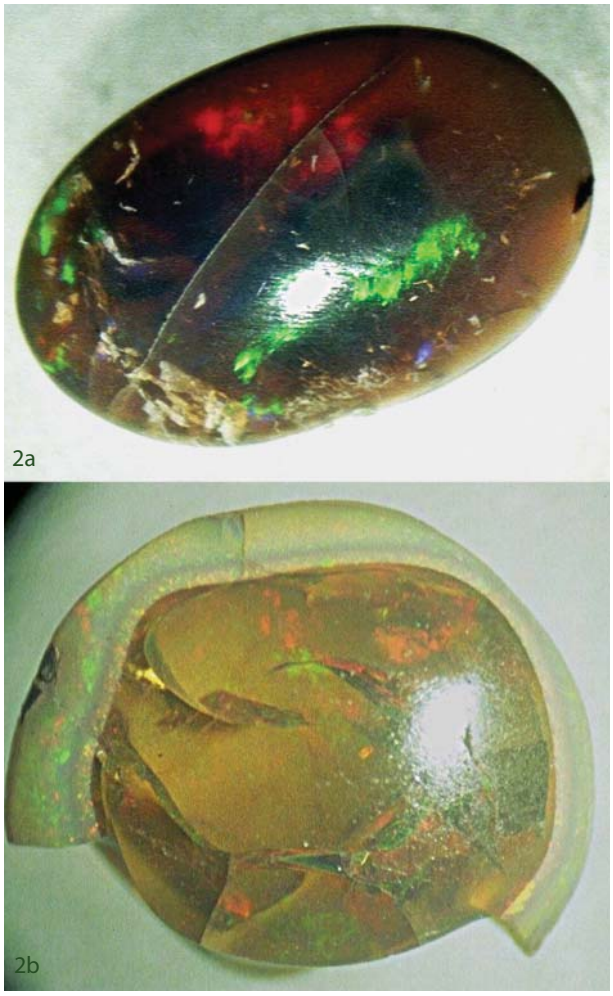

Figure 2: *'Tea opals' from Indonesia;* 2a: *The slightly translucent dark brown specimen IO 5 of 1.5 ct contains abundant white flaky inclusions, possibly the zeolite mordenite.* 2b: *A core of brown opal is surrounded by pin-fire white opal in this sample (IO 15, 1.5 ct) and is interpreted as two stages of crystallization. The pattern could be explained if one imagines replacement of a plant root (cross section), where firstly the 'tea opal' fills the inner part and then the white opal only develops after the outer more resistant layer of the root has decomposed.*

turbid groundmass (*Figure 1b*). The body colours of another three opals are black to the unaided eye (*Figures 1c* and *1d*), but when viewed under strong illumination at thin edges their body colour is a very deep brown. One white opal was also studied.

Of the two non-precious opals, one is pale yellow brown, while the other is dark brown with a reddish tinge, similar to fire-opal though of a not very attractive colour.

Diaphaneity

Of the three water opals, one is absolutely water-clear and the others are slightly turbid, though still transparent. The brown opals ('tea-opals') are translucent when light-coloured but only transmit light at their edges in the darker stones. The white and the three black opals are opaque. Of the non-precious opals, the pale yellow opal is nearly transparent, while the dark brown is only slightly translucent.

Play-of-colour

The play-of-colour is dominated by red, orange and green in most of the investigated samples, a common feature in Indonesian opals (Sujatmiko *et al.*, 2004). However, a close inspection with hand lens/binocular microscope and a stronger illumination also reveals the presence of subordinate patches of very deep blue. A similar preference for major reds and greens with minor royal blue patches has been reported from chocolate brown opals from Somaliland (Kinnaird, 2002). The play-of-colour is not always developed

throughout a cabochon: two brown opals had clearly visible colour fields next to areas of apparently non-precious opal. Strong illumination is needed for black opals to show their full play-of-colour. In the two non-precious opals, a very faint, spot-like play-of-colour appeared fleetingly when strong illumination was moved along their sides.

The fields or patches with play-of-colour are usually small (<1-2 mm, but in a few samples up to 5 mm), and a typical spot-like pattern is shown in *Figures 1c* and *d*. Their shape ranges from polygonal to somewhat elongated, commonly with serrated or blurred boundaries. The white opal has very small, densely packed colour fields, which give a sparkling impression ('pin fire') in red and blue. In cross-section, these colour fields are columnar and arranged in a parallel array perpendicular to the original surface of the rough gem. A dominantly green 'pin fire' is present in a white opal rim around a core of 'tea opal' in an unusual two-colour cabochon (*Figure 2b*).

Pseudo-birefringence

With the exception of one 'tea-opal' with faint play-of-colour, and the two non-precious opals, the other 5 opals examined in thin section (water opal, 'tea-opal' and black opal) showed pseudo-birefringence under crossed polarizers in strong blues to

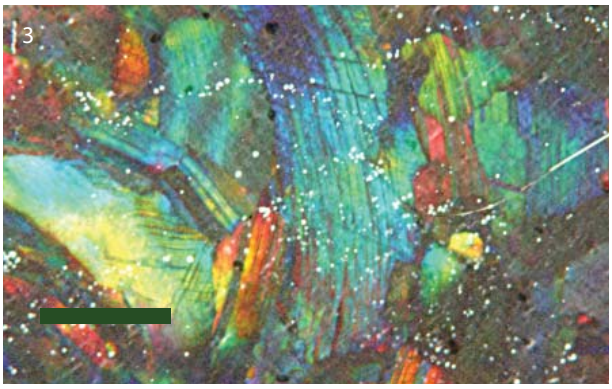

Figure 3: *Colour fields in this opal sample (IO 1) viewed under crossed nicols contain abundant dark lines from stacking faults and glide planes. Colour bands are slightly curvilinear which may indicate deformation due to external stress. Note also the variable and often small size of colour fields. (White spots are due to sample preparation). Thin section micrograph, length of bar: 0.5 mm.*

Figure 4: *Fields with play-of-colour (viewed as pseudo-birefringence colours) in this water opal (IO 9) are extremely elongated probably as a result of deformation. Thin section, crossed polarizers, length of bar: 0.5 mm.*

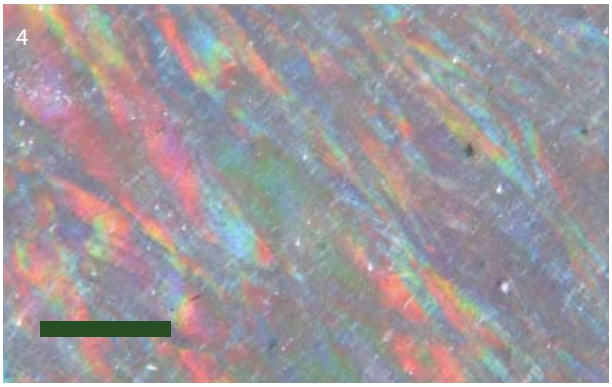

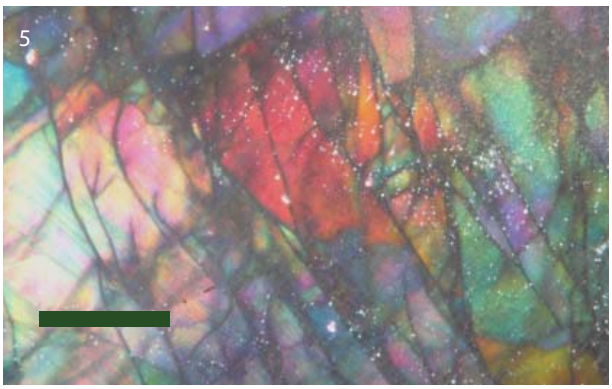

Figure 5: *Pseudo-birefringence in this dark brown opal (IO 1) reveals abundant cross cutting dark lines as traces of microfractures in three sets. (White spots are from thin section preparation). Thin section, crossed polarizers, length of bar: 0.5 mm.*

Figure 6: *The colour fields in this black opal (IO 6) are dissected and offset by three sets of microfractures, although the opal as a whole is still coherent. The light area in the lower right corner is a photographically overexposed aggregate of clinoptilolite with pale brown discoloration and a thin zone of microcrystalline quartz (?) at the contact with the opal. (Opal is broken off from the thin section in the angular grey area in the lower part of the picture). Thin section, crossed polarizers, length of bar: 0.5 mm.*

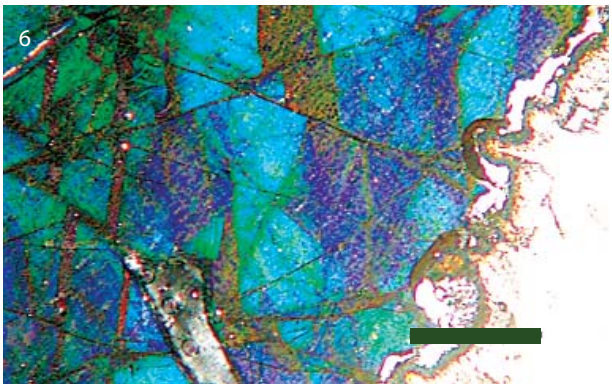

blue-greens, yellows and, less commonly, in reds. Dark striations inside the individual colour fields are caused by stacking faults (Graetsch, 1994) and probably also by glide planes and are common in several samples (*Figure 3*). A slight bending of these lamellae is present in the stone shown in *Figure 3* and the colour fields in the water opal shown in *Figure 4* indicate strong shearing. Abundant microfractures in two to three sets are visible in two samples under crossed polarizers, but this feature is hardly discernible or invisible in plane polarized light (*Figure 5*). In one sample, a displacement of fractured parts of colour fields is present (*Figure 6*).

Specific gravity and refractive index

The specific gravity (SG) range of 1.98 to 2.06 and the refractive index (RI) range of 1.435 to 1.468 of these stones have been reported by Sujatmiko *et al*. (2004). The SG values are in the normal range for opals (1.98 to 2.20 according to Webster, 1994) as are the RI values (1.44 to 1.46; Webster, 1994) with the exception of the somewhat high value of 1.468. The colourless or paler coloured opals have the lower SG and RI values.

Fluorescence

Although fluorescence in opal has been described in Webster (1994) as white to pale blue, pale brown or green with most black opal being inert, no conspicuous fluorescence under short or long wave UV light has been observed in most of the samples from Indonesia. The exceptions are in one water opal and in the white opal, which both gave a weak pale blue fluorescence under short and long wave UV light. Both are opal-A according to XRD results.

Reaction to heat

Illumination with a 500W photo lamp at a distance of 30 cm for a few minutes resulted in a network of cracks (crazing) on the surface of a black opal (*Figure 1c*).

Similarly, fractures developed in thin section material during prolonged microscopic work due to heating from the light source.

Hydrophane opal

The 'pin fire' white opal rim of the 'eye' cabochon shown in *Figure 2b* consists of hydrophane opal; this shows unusual behaviour of *losing* its play-of-colour when immersed in water, and regaining it on drying. The same effect was also observed in an off-white part of a flow-textured opal (see below). Similar observations on opal from Indonesia have been reported previously by Milisenda and Wild (2004) and Koivula and Tannous (2001). In both cases, the RIs of the white schlieren and of the white opal are slightly lower than the brown opal, perhaps caused by higher water content.

Internal features

Rock and mineral inclusions

Only three opals (the two non-precious opals and one water opal) are free of any inclusions and other internal features as described below. Strongly decomposed pale yellow-brown soft tuff particles and plagioclase crystals are associated with the rough opal and may occur as inclusions. Precious opal matter fills the microfractures in the tuff particles.

A massive aggregate of platelets arranged in parallel (*Figure 6*) in a black opal-CT has the optical characteristics of a zeolite (with a birefringence of about 0.006, and an RI higher than opal but lower than the araldite resin (1.62)) and a hardness much lower than quartz. Its XRD data are identical with clinoptilolite ($(Na, K, Ca)_{2-3}Al_3(Al, Si)_2Si_{13}O_{36}.12H_2O$). At its contact with the opal, the aggregate is embayed and rimmed by a pale brown zone and a thin band of what appears to be microcrystalline quartz. A similar zone surrounds the tuff inclusions at their contacts with opal.

Small, distorted, fibrous and colourless aggregates are abundant in another 'tea-opal' (*Figure 2a*) and according to their fibrous nature and optical data, are probably composed of another zeolite, possibly mordenite.

Twisted tube-like features of unknown nature are present in this opal, similar to

Table I: *XRD data of twelve samples of Indonesian opals (IO), with comparisons.*

Sample No.	Body colour	Type	4.10 Å peak1	I_{max}	FWHM $\Delta°2h$ CuKα	4.3 Å peak	2.50 Å I_{max}	FWHM $\Delta°2h$ CuKα
IO 1	dark brown	opal-CT	4.113/4.103	795	1.247	+	130	0.764
IO 7	brown	opal-CT	4.101/4.107	795	0.876	+	102	0.592
IO 11	colourless	pal-CT	4.107	750	0.801	+	130	0.630
IO 12	colourless	opal-CT	4.115/4.113	730	1.146	+	132	0.778
Herdian.[2] Graetsch		opal-CT opal-CT			0.54-0.75 0.68-1.11			
IO 6	black	opal-'C'	4.100	570	1.212	–	67	0.857
IO 3	black	opal-'C'	4.115/4.107	600	1.318	–	62	0.859
IO 4	brown	opal-'C'	4.101/4.101	790	1.128	–	92	0.928
IO 8	pale brown	opal-'C'	4.094	750	1.123	–	97	1.248
IO 13	brown[3]	opal-'C'	4.118	560	1.289	–	52	0.973
IO 14	pale yellow[3]	opal-'C'	4.114/4.109	550	1.467	–	49	1.467
Herdian.[2] Graetsch		opal-C opal-C			0.15-0.25 0.09-0.95			
IO 9	colourless	opal-A_G	broad peak			–	–	
IO 10	white	opal-A_G	broad peak			–	–	

N.B.

1. First measurement at 0.5 /min; second measurement at 0.06 /min and internal standard
2. Comparisons are quoted from the works of Herdianita et al. (2000) and Graetsch et al. (1994). Note the higher values of FWHM for opal-'C' compared with opal-C, and also a tendency for higher FWHM values in opal-CT in Indonesian samples.
3. Non-precious opal.

those in brown opals from Ethiopia (Johnson *et al*., 1996) and in a fire opal from Opal Butte, Oregon, USA (Holzhey, 1997). In the Indonesian opal, these tubes start at the interface of the tuff inclusion or of the massive zeolite layer, and protrude into the opal.

Two opals (opal-CT) contain tiny spherulites of chalcedony. They are probably not inclusions incorporated during growth/deposition of the opal but may be re-crystallization products of the opal during its ageing.

Flow texture

Irregularly shaped volumes which are pale brown to off-white, milky-turbid and opaque were found in six opals (white, black and brown opal). These have flow textures similar to those described by Johnson *et al*. (1996) in Ethiopian brown opals, and even have cell-like features as shown in their figure 14. In one opal, the off-white part is distinguished in thin section from the surrounding brown (near-colourless in section) opal by patches of brown discoloration and a slightly lower RI. Interestingly, play-of-colour, pseudo-birefringence and the patchy brown tinge vanished in a few seconds when the thin section was immersed in water, and then reappeared during drying, thus behaving like an inverse hydrophane, in contrast to the surrounding opal which was not affected optically.

Structure of opals

In thin sections, non-precious opals are isotropic under crossed polarizers but pseudo-birefringence is shown by precious opals. Initially, this would suggest that they are non-crystalline opals, but, based on their diffraction patterns, three structurally different types can be distinguished (*Table I*) and examination under the scanning electron microscope indicates that they also have different nanostructures.

X-ray diffraction results

Four precious opals (two water opals, a brown and a black opal) have the opal-CT structure, i.e. an opal with an extensive stacking disorder of cristobalite and tridymite units (see IO 1, 7, 11 and 12 in *Table I*). They are characterized in their diffractogram by a well developed 4.10 Å-peak with a small spread between 4.101 Å and 4.118 Å, combined with the characteristic shoulder at 4.3 Å (caused by extensive stacking disorder due to intercalated structural elements of tridymite and low-cristobalite), and a small peak at 2.50 Å (*Figure 7*). The main peak is rather broad at FWHM (full width at half-maximum height of peak) compared with data for opal-CT (e.g. Graetsch *et al*., 1994; Herdianita *et al*., 2000), which indicates small crystallite sizes in the Indonesian samples. Variations among the opal-CT samples of the intensity of the shoulder on the main peak, and the slight shift of its maximum indicate variable proportions of tridymite domains and therefore various degrees of structural order.

Flörke *et al*. (1991) distinguished between opal-CT_{LS} with a fibrous-parabolic texture under the polarizing microscope ('LS' for the length-slow optical character of the fibres) and opal-CT_M ('M' for a massy, almost isotropic character due to random orientation of the crystallites and their structural disorder). Since the four Indonesian samples do not show any fibrous texture under the polarizing microscope, they belong to the opal-CT_M type.

Opals IO 3, 4, 6 and 8 and non-precious opals IO 13 and 14, have X-ray patterns different from the four discussed above in that there is no 4.3 Å peak as a shoulder to the main peak (*Figure 8*). Though the diffraction pattern resembles opal-C (an opal of disordered low-cristobalite with minor evidence of tridymite stacking and superstructure reflections of low-cristobalite; Graetsch, 1994), the maximum of the main diffraction line is on the tridymite side (between 4.10 and 4.11 Å) rather than on the cristobalite side (4.04 Å), and there are no superstructure reflections of low-cristobalite visible (H. Graetsch, pers. comm.). These differences support the notation opal-'C'. The pattern is similar to the one for high-cristobalite which, however, is not stable below about 270 C. Compared with the opal-CT data, the intensity of the peak at 4.10 Å tends to be smaller and the FWHM is generally broader. The latter feature contrasts especially with data from real opal-C (*Table I*), where the FWHM is much smaller (narrower) because of a better structural order (Graetsch *et al*., 1994). The difference in the FWHM between opal-CT and opal-'C' is even stronger in the 2.50 Å peak and proves a very small crystallite size in the opal-'C' samples. Probably, SiO_4 tetrahedrons are arranged in short range order similar to that of cristobalite, but long range order is not present. Structurally, these opals could be intermediate between amorphous SiO_2 and cristobalite (H. Graetsch, pers. comm.). A slight asymmetry in the main peak of two opal-'C' samples towards the 4.3 Å shoulder hints at the presence of some tridymite domains and a transition to opal-CT.

The remaining two opals (the white opal IO 10 and a slightly turbid water opal IO 9) are X-ray amorphous: the diffractogram shows only a characteristic broad hump (*Figure 9*) between 15 and 30 2θ Cu Kα with a maximum at around 22.5 2θ Cu Kα (equivalent to a d-spacing of about 3.95 Å and therefore slightly different from the main peak of opal-CT) and no additional peaks. These samples are of opal-A type, or more precisely, of opal-AG type (G for gel-like, after the classification by Flörke *et al*., 1991).

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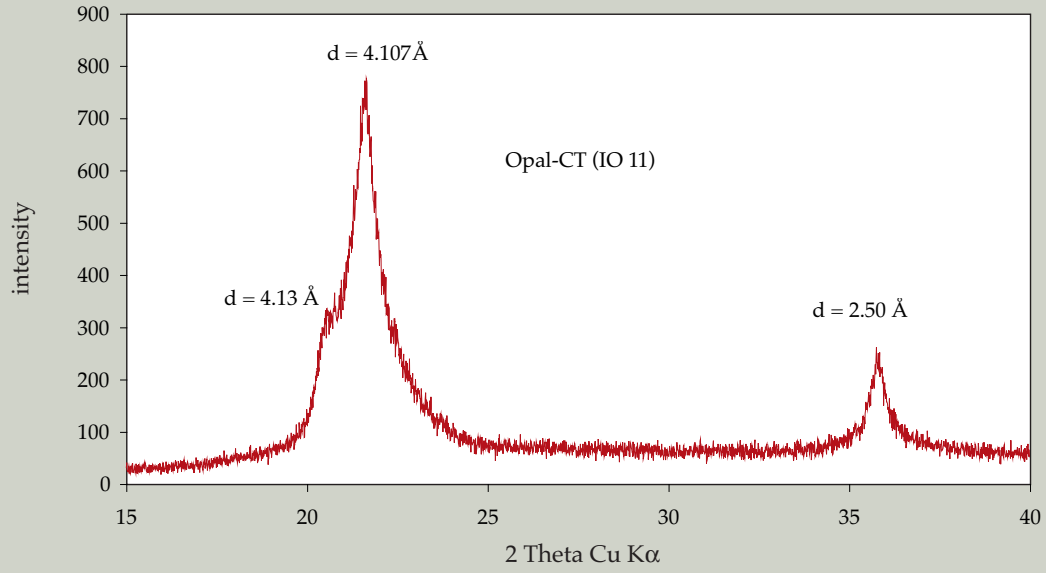

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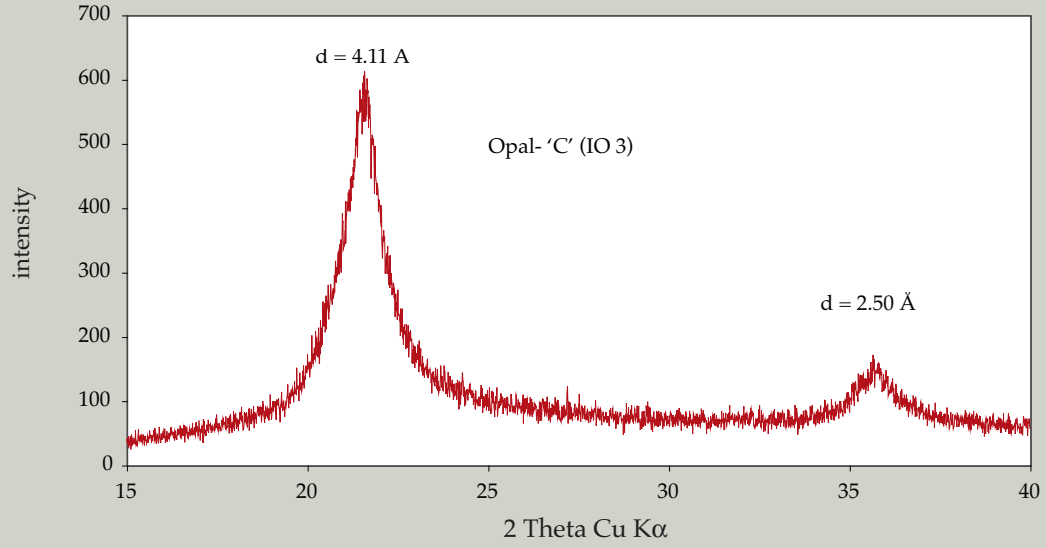

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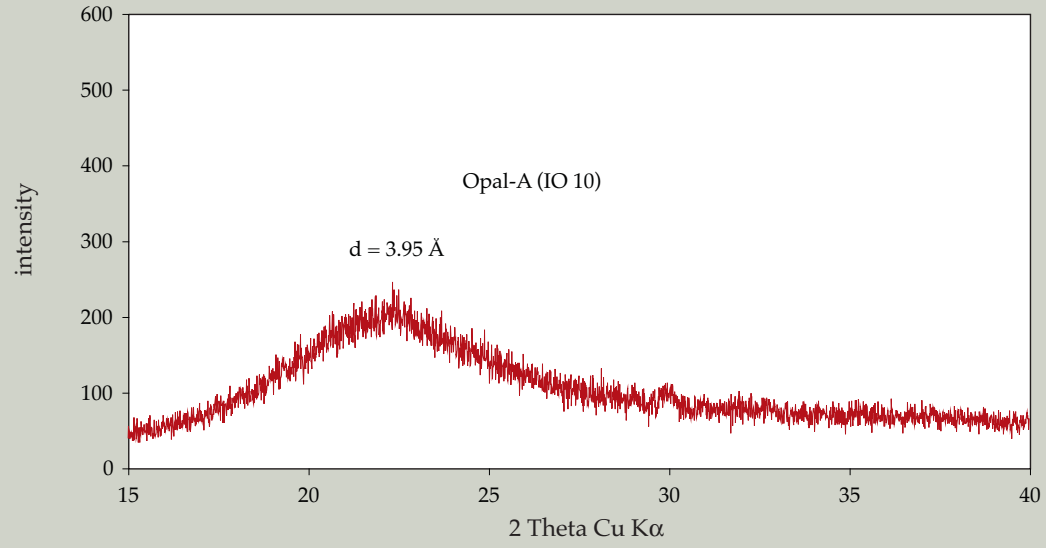

Figure 7: *The diffractogram of this opal-CT (water opal IO 11) displays a 'shoulder' at 4.13 Å next to the main peak (at 4.107 Å) which indicates domains of tridymite. Note the sharpness of the peak at 2.50 Å which results from better structural order than is present in opal-'C' (see* Figure 8*).*

Figure 8: *The diffractogram of opal-'C' (IO 3) shows a lower structural order than that of opal-CT: there is no shoulder at 4.13 Å on the main peak (which means an absence of tridymite domains) and the two reflections are broader than in opal-CT diffractograms.*

Figure 9: *This diffractogram of opal IO 10 shows the single and very broad reflection, characteristic for opal-A, around a d-value of 3.95 Å.*

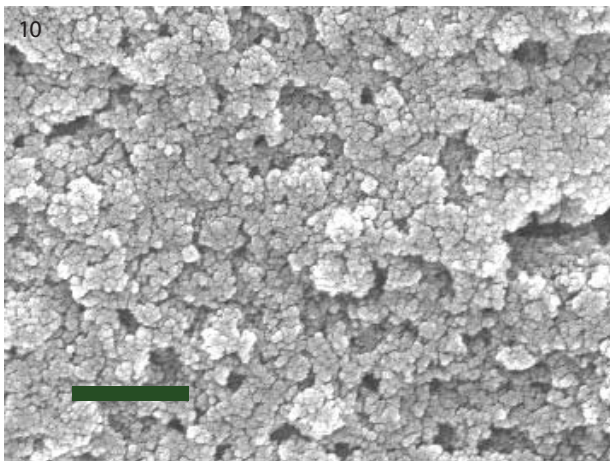

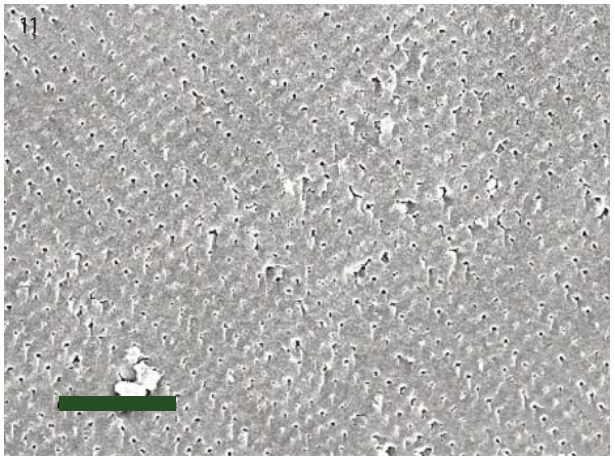

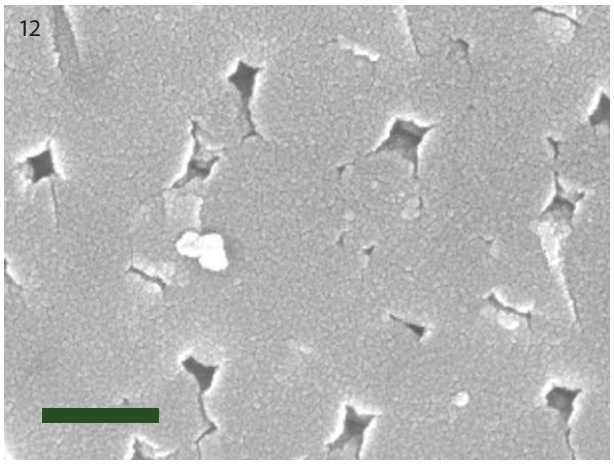

Figure.10: *This SEM image of sample IO 12, an opal-CT, shows the small particles (nanograins) making up the opals made visible by etching with hydrofluoric acid . Length of bar: 0.1 µm or 100 nm.*

Figure 11: *SEM image of opal-A (IO 9) showing the cuspate pore spaces marking the regular arrangement of spheres. Length of bar: 2 µm.*

Figure 12: *An enlarged part of the micrograph (Figure 11) reveals the densely packed spheres. Each sphere is composed of small granules (nanograins) of 30-50 nm in random packing. SEM image, length of bar: 300 nm.*

SEM investigation

Seven opals consisting of precious opal-A, -'C' and -CT and non-precious opal examined in a scanning electron microscope were all found to consist of a dense packing of small sub-rounded granules (nanograins) of 30 to 50 nm diameter (*Figure 10*) which themselves can be composed of a few still smaller particles. This grain-size is similar to that of the 50 nm diameter granules in fire opal from Mexico and the 10 to 40 nm in fire opal from Ethiopia and other localities (Fritsch *et al*., 1999, 2002). Thin platelets which form lepispheres in some opal-CT, for example as described by Flörke *et al*., (1975, 1991) and by Gaillou *et al*. (2006b), have not been found in Indonesian opal, whether or not acid-etched.

Whereas the granules in opal-'C', opal-CT and the non-precious opal do not show a systematic pattern, they appear fairly regularly arranged in the two opal-A samples into spherical aggregates. The white opal (IO 10) displays a weakly visible linear arrangement of spheres with a diameter of around 400 nm and very little pore space, and the water opal (IO 9) exhibits a well-developed array of small cusp-shaped, slightly distorted voids between densely packed and slightly deformed spheres of 320 to 410 nm diameter (*Figure 11*), with a frequency maximum at 360 to 380 nm. The large sizes and the variation in diameters may be due to the overgrowth of initially perfect spherical aggregates by additional nanograin deposition, indistinguishable from the nanograins in the spheres, into the voids between the spheres, but the pattern may be explained alternatively by strong compaction of large spheres. The remaining pore space is estimated from SEM micrographs at << 10 % only. Each sphere is composed of the above mentioned small granules without a visible regular internal arrangement (*Figure 12*), and their size is distinctly larger than in Australian precious opals where it is about 140 to 250 nm (Fritsch *et al*., 2002).

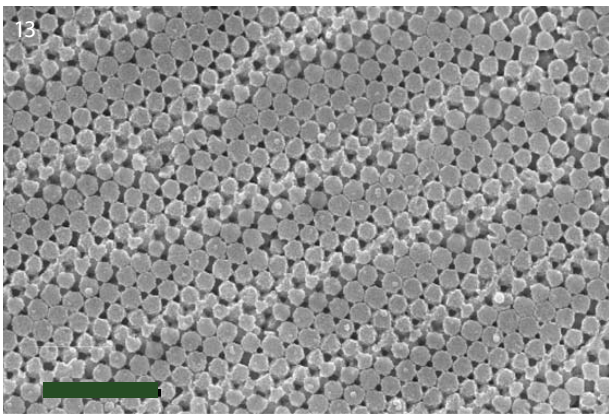

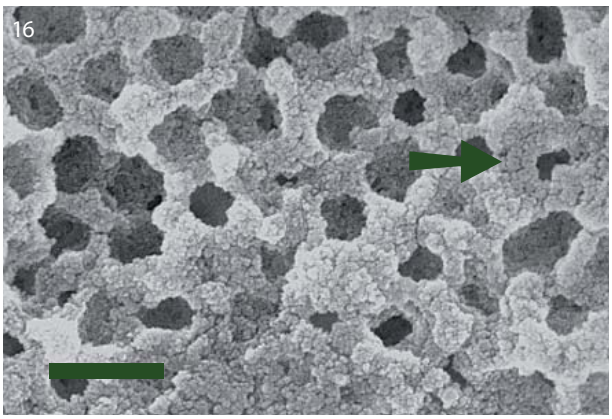

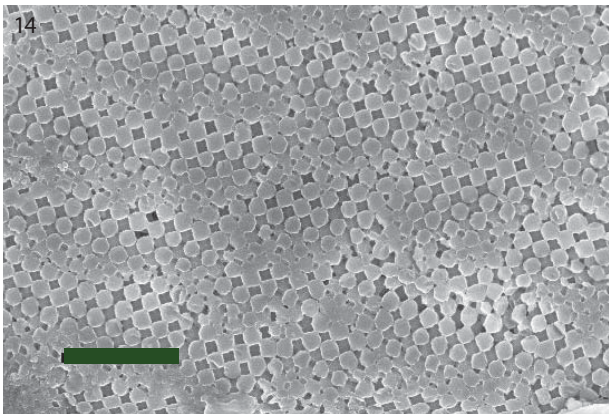

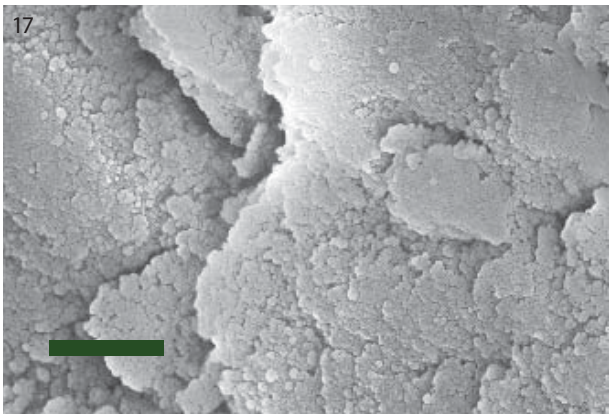

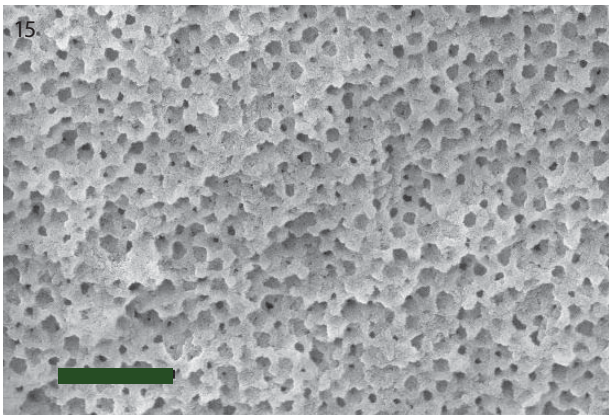

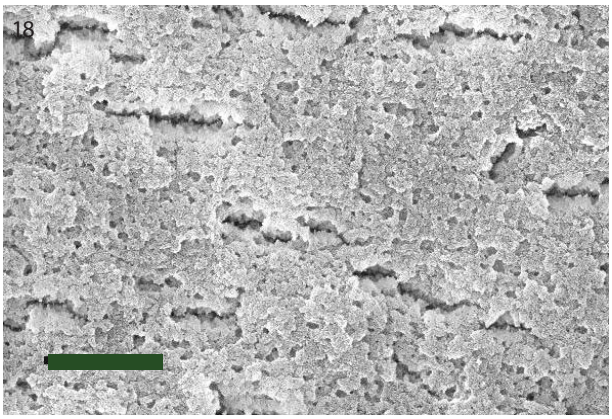

Figure 13: After etching with hydrofluoric acid, the regular internal structure of the opal-A sample (IO 9) becomes clearly visible as hexagonal close packed spheres (with a diameter of about 290 nm). Zones of square packed spheres mark subtle off-sets in the linear arrangement (stacking faults). The surface of the sample cuts obliquely through successive layers of spheres at a low angle, causing a periodic change in the size of the cross-sections of spheres on rows in a NW-SE direction. SEM micrograph, length of bar: 2 µm.

Figure 14: The regular arrangement of the spheres appears in some areas in square packing instead of the more common hexagonal close packing. Opal-A (IO 9), HF-etched. SEM micrograph, length of bar: 2 µm.

Figure 15: After HF-etching, opal-'C' (IO 3) shows a framework composed of small particles around sub-spherical holes. The holes represent former spheres and their systematic arrangement in rows is still visible despite a three-dimensional etching which exposes deeper (offset) layers. SEM micrograph, length of bar: 2 µm.

Figure 16: At higher magnification than in Figure 15, the nanograins of the framework cement are visible. These are usually without regular arrangement, but may show rarely a two-layer concentric shell around the dissolved sphere (right side of photo). Length of bar: 0.5 µm.

Figure 17: Planar, layer-like features in this HF-etched opal-CT (IO 1) are interpreted as stress-induced glide planes. SEM micrograph, length of bar: 2 µm.

Figure 18: This opal-CT (IO 12) is strongly cemented, original spheres are obscured and only indicated by unsystematically exposed, irregularly shaped holes. HF-etched specimen, SEM micrograph, length of bar: 2 µm.

Microstructures become much more visible after treatment of the opal surface with 10% hydrofluoric acid for 30 seconds (Fritsch *et al*. 2002). After etching, the water opal-A (IO 9) displayed a very regular arrangement of spheres, dominantly hexagonal close-packed (*Figure 13*) with patches of more open pattern with spheres occupying the corners of quadrangles (square-packed) shown in *Figure 14*. The etching was rather strong since the diameter of the spheres was reduced to about 290 nm at which point they were just in contact with surrounding spheres. Scanning over the sample revealed some areas of more or less equal-sized spheres showing no pattern of regular packing, and these coincide with the patches devoid of play-of-colour.

In contrast to the opal-A sample, the two investigated opal-'C' samples (a black precious (IO 3) and the brown non-precious opal (IO 13)) reacted to the HF treatment with dissolution of the cores (about 270 to 320 nm in diameter after dissolution) rather than the rims (*Figure 15*), leaving an acid-attacked framework of silica cement which is composed of randomly packed (rarely concentrically arranged) small granules or nanograins (*Figure 16*). In the non-precious opal, the etching behaviour was similar and the spherical holes also had fairly equal dimensions, but except over very short distances, were not systematically arranged. Fritsch *et al*. (2002) attribute the difference in solubility to probably better crystallized silica particles of the cement.

Of the two opal-CT samples, the dark brown opal IO 1 displayed a layered structure of flakes consisting of tiny granules in a dense, unsystematic arrangement (*Figure 17*). A weakly regular pattern of small holes in the massive cement is visible in the second opal-CT (water opal, IO 12) though not easily discernible due to variable intensity of etching (*Figure 18*).

The interesting questions concerning coagulation of the nanograins and why 'spheres' of certain sizes are formed can probably only be explained in terms of the physico-chemical processes operating in silica sols and gels, and are beyond the scope of this paper.

Chemical composition

Most opals are nearly pure SiO_2 with the total of other element concentrations (mainly Al, K, Na, Ca, Fe and not including H_2O) reaching approximately 1 to 2 weight % only. The total of these element oxides in five analysed Indonesian samples (*Table II*) ranges between 1.4 % and 3.7 % with a large variability in concentration ratios. In general, the element concentrations decrease in the order Al, Ca, Na, K, (Ti, Fe, Mg, Mn). The grey opal IO 8 has an unusually high Ti content (4900 ppm or 0.82 % TiO_2) and relatively high Ca, Mg and Fe which might reflect derivation from a tuffaceous host rock. Of the analysed trace elements, Rb, Sr, Zr and Ba may be dominant in different stones to the extent of several 10s of ppm. Other trace elements with concentrations above 1 ppm are Cr and Cs in all five opals, and V, Co, Ni and Nb in three of them.

Discussion and conclusions

One can draw several conclusions concerning genetic aspects and characteristics of the Indonesian opals from this short study.

The restricted occurrence of the opals as isolated nodules in a layer of clay-rich tuff, which extends laterally for several square km (Sujatmiko *et al*., 2004), points strongly to a direct genetic link to the host rock through an alteration process which decomposed the tuff particles. This is supported by the presence of zeolites (alkali-clinoptilolite, probably also mordenite) as inclusions in the opal or adhering to its surface. Both minerals have formed therefore under the same conditions. In the absence of metamorphic minerals from burial metamorphism or of external heat sources, the appropriate model for zeolite formation from a silicic tuff is an open system under fresh water conditions (Hay and Sheppard, 1981). Percolating ground water reacts with the glassy tuff particles to form montmorillonite (and opal, if a strong oversaturation in silica is already attained in this zone). In a somewhat deeper zone or

Table II: *Chemical compositions of five opals with different body colours from Indonesia.*

ppm	IO 1 dark brown	IO 3 black	IO 8 grey	IO 12 colourless	IO 13 brown
Si	440608	435233	430278	420929	420929
Al	5930 5660-6320	5936 5661-6219	9497 8846-10020	5445 5291-5639	4277 4248-4316
Ti	792 783-799	1029 1006-1053	4934 4543-5603	3.7 3.45-4.0	78 77.4-80.3
Fe	73 71.8-73.1	100 96.2-101.4	362 334.8-402.5	6.6 6.0-6.9	25 23.7-24.7
Mn	48 47.4-48.3	52 51.6-52.2	38 37.9-38.5	11 11.2-11.3	23 22.8-23.5
Mg	49 46.7-41.0	35 28.5-39.8	439 419.5-551.0	27 25.6-26.6	23 23.2-23.3
Ca	2640 2585-2767	2557 2520-2623	5952 5573-6361	1853 1844-1861	1489 1488-1490
Na	1273 1235-1299	2200 2122-2296	766 704-814	1782 1669-1888	2362 2317-2422
K	1184 1108-1276	599 552-658	939 895-996	1555 1480-1629	397 396-399
Total 1	96.2%	95.4%	95.8%	91.8%	91.5%
Total 2	1.9%	2.3%	3.7%	1.7%	1.4%
B	0.298-0.49	0.3-0.44	31.48-32.71	0.255-0.31	0.185-0.22
V	1.246-1.286	2.576-3.01	5.58-6.76	0.0043-0.01	0.23-0.251
Cr	2.083-2.4	2.78-4.01	3.71-4.77	1.2-1.558	1.22-1.19
Co	2.97-3.22	8.09-9.01	4.31-4.62	0.0155-0.0246	0.26-0.31
Ni	1.87-2.25	1.7-1.82	3.57-5.01	0.44-0.88	0.33-0.38
Rb	17.92-20.58	8.55-9.69	19.87-21.68	27.29-29.5	6.69-6.85
Sr	6.55-7.41	9.59-10.4	22.54-23.34	4.05-4.38	3.94-3.98
Y	30-30.32	30.54-32	31.55-34.53	0.0419-0.0456	7.98-8.67
Zr	11.26-11.67	25.92-28.94	51.06-55.52	2.55-2.82	8.14-8.72
Nb	1.763-1.852	2.04-2.144	9.8-10.77	0.0048-0.0059	0.154-0.163
Cs	2.18-3.03	1.87-2.009	3.65-4.15	5.52-5.86	1.632-1.701
Ba	14.57-15.09	58.11-60.65	40.54-43.11	8.51-9.19	12.73-13.48

N.B. Values obtained using LA-ICPMS; main elements are means of three sample points and minimum and maximum values are also given; ranges only are given for trace elements. Total 1 is the value for all oxides except water and Total 2 is the total of oxides minus silica and water.

under prolonged reaction between water and glassy tuff particles, its ionic strength and pH value increase with increasing amounts of dissolved Na^+, K^+, Ca^{2+} and $H_2SiO_4^{2-}$, from which zeolites (and opal) can precipitate with or without an intermediate gel stage, to form an assemblage of montmorillonite, opal and zeolite. Clinoptilolite and mordenite are the first zeolites to occur in such a system. The clinoptilolite in the Indonesian opal indicates a maximum temperature of opal formation of < 55 C (the upper stability of alkali-clinoptilolite; Hay, 1981) or, if the zeolite is Ca-rich, somewhat higher (up to about 90 C in case of a Ca-clinoptilolite).

Because of its wide range of element

concentrations and the lack of constant element ratios, the chemical composition of the five analysed opals does not seem to reflect directly the composition of the volcanic host rock from which they are derived. Variable degrees of tuff decomposition, locally and in time, with variable release of element concentrations into the groundwater can be expected during the process of silica precipitation as well as an effect of locally different composition of the tuff layer. The low Ba content (below 110 ppm) may be a direct indication of a volcanogenic as opposed to a sediment-hosted origin (Gaillou *et al*., 2006a), whereas the main element composition is well within the range of sediment-hosted opals, such as those from various Australian opal fields (Brown *et al*., 2004). Though the data base is still rather small, Indonesian opals show no signs of having a particularly distinctive composition.

The colour spectrum in a precious opal is a function of its refractive indices, the angle of incidence of light and, critically, the size of its silica spheres: the larger the diameter, the longer the wavelength of the diffracted light (e.g. Rossman, 1994; Sanders, 1968). The comparatively large size of the spheres in the Indonesian samples explains the dominance of red to green colours in these opals. According to calculations and a diagram by Wollaert *et al*. (1990), a minimum sphere diameter of about 260 nm is necessary to display red colours at a minimum angle of incident light (in addition to colours of shorter wavelength at larger angles), which is well satisfied by these samples. The main condition for the formation of larger spheres may be a comparatively low density of nucleation points in the silica sol which allows for larger masses of silica particles to agglomerate on each site compared with opals of dominantly blue play-of-colour.

For opal without play-of-colour, Rossman (1994) lists heterometric spheres, their random packing, their non spherical shape and complete filling of voids by silica cement as reasons for the absence of play-of-colour. In the one SEM-investigated non-precious Indonesian opal, the poorly ordered packing of equal-sized spheres is responsible for the absence of play-of-colour. Concerning the role of voids, their presence is not essential in producing play-of-colour (see Fritsch *et al*., 1999, 2002) and this is confirmed by the precious opal-CT and opal-'C' samples, which have no visible open voids in SEM micrographs. Rather, diffraction is caused by differences in refractive index between (hidden or visible) spheres and the silica between the spheres.

The body colour of precious and common opals has been a point of debate. Although many have thought that the iron and manganese contents can explain the colour of fire opals and of brown opals, Fritsch *et al*. (1999, 2002) have pointed strongly to mineral inclusions rather than elements in an ionic state and list examples of mineral inclusions as colouring agents in opal from various occurrences. They relate the colour of brown opals to nano-sized Fe-components (supposedly Fe-oxides or Fe oxy-hydroxides of 10-20 to 100-200 nm size) which they found in TEM images and by Raman spectroscopy, and the black zones in opals to traces of manganese. Similarly, Johnson *et al*. (1996) have reported iron pigmentation and tiny minerals (supposedly pyrite and iron oxide) in flow textured brown opals from Ethiopia. Gaillou *et al*. (2006 a) found higher Fe-contents correlated with increasing intensity of colour from yellow to brown (between 3000 and 13000 ppm in very dark brown opals; Gaillou, pers. comm.). However, Fe and Mn contents in the analysed Indonesian samples are very low (up to 362 and 53 ppm, respectively) and are therefore not expected to have a dominant effect on the body colour. Brown *et al*. (2004) found no systematic differences in Fe or Mn which could be related to dark and light coloured zones of banded Australian opal but there were significantly higher contents of other trace elements in the darker coloured bands. It is interesting in this respect, that the water-white precious opal IO 12 has lower concentrations of the transition elements Fe, Ti, V, Ni and Co by one to four orders of magnitude compared with the opals with brown to black body colour whereas the concentrations of the main elements Al, Na, K, Ca and Mg is well within the range shown by the other opals.

For black (non-precious) opal in silicic volcaniclastic sediments from Honduras, Banerjee and Wenzel (1999) relate the body colour to organic carbon compounds (probably porphyrins) which they confirmed using FTIR and UV-Vis measurements. This is a speculative but possible explanation for the black body colour in Indonesian opals: the origin of carbon could be either organic matter from the sediment layers in the Genteng Formation above the opal-bearing horizon or from more recent, decomposed plant roots which penetrated the tuff layer.

Opal from Indonesia often develops fractures during polishing or after it has been worn for some time. One cause for this poor stability lies in hidden, latent micro-fractures (*Figure 5*), which have been observed in thin sections of brown and black opal (see also Sujatmiko *et al.*, 2004). There are also indications in the fields of play-of-colour, that several opals underwent some stress during their formation as indicated by glide planes, bent colour lamellae (*Figure 3*), crosscutting microfractures through several colour fields with a displacement of fragments against each other in a still coherent opal-CT mass (*Figure 6*), and a sub-parallel arrangement of elongated colour fields (*Figure 4*) in one opal-A cabochon which is interpreted as the result of shearing or squeezing. The deep linear or polygonal etching in HF-treated opal-CT, visible in SEM micrographs, may be also the result of mechanical weakness along micro fractures or stress-induced glide planes which allow for a more rapid and deeper acid attack.

Because there is no indication of tectonic impact on the host rock, a possible alternative cause of stress could have been increasing load of the overlying sediments brought about by the decomposition of tuff particles which weakens the internal stability of the tuff layer and results in its compaction and the deformation or collapse of cavities. Hence, opal in these voids will be deformed to various degrees, depending on the strength of the acting force and the rigidity of the opal. It seems possible that the observed flow texture also developed during this process: the layers of lighter and darker coloured bands which may have formed initially through undisturbed sedimentation of a coagulating silica sol (as proposed by Brown *et al.*, 2004), could have been disturbed by internal flow as a reaction to compressive forces.

The conversion of initially amorphous opal matter (opal-A) to opal-CT/opal-C and finally to quartz has been known from early investigations of diagenetic processes in silica (e.g. Jones and Segnit, 1971; Kano, 1983), and has been more recently described as an ageing process of silica in sinters from hydrothermal fields in New Zealand (Herdianita *et al.*, 2000). This process involves time since deposition, temperature changes, the chemical environment and the presence of other minerals as factors in these structural changes. In the Indonesian opal occurrence, opal-A, a structurally intermediate opal-'C', opal-CT and microcrystalline quartz/chalcedony are present in the same horizon. Therefore a multi-stage or a continuous process of opal formation over a prolonged period seems likely. More than one stage of opal formation is also indicated by the rim of white opal with a sharp contact against a core of 'tea opal' (*Figure 2b*, IO 15). According to this model, ageing has transformed the earliest precipitated opal-A into opal-CT, opal-'C' as a younger precipitate is in a transitional stage of transformation to opal-CT, and opal-A is the most recently formed of the three structural types.

However, Gaillou *et al*. (2006 b) state, that this ageing process is restricted to diatomite and sinter opal during their diagenesis and propose that the structural differences between opal-A and opal-CT are a primary feature from the silica precipitation stage and are due to variable growth rates and silica concentrations in the gel. They postulate that spheres in opal-CT are composed of nanograin aggregates as platelets or lepispheres which are not visible on freshly broken surfaces and are completely dissolved by HF-etching, therefore not directly detectable. This markedly different structure compared with opal-A would probably prohibit a transformation of opal-A to opal-CT unless future research indicates the possibility of a rearrangement of the randomly oriented nanograins of opal-A into the platelets of opal-CT during ageing of gem opal.

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Vaterite in freshwater cultured pearls from China and Japan

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Abstract: *Japanese and Chinese beaded and non-beaded cultured freshwater pearls of good quality were investigated with Raman spectroscopy and LA-ICP-MS. In 50% of the investigated non-beaded samples vaterite was identified by Raman spectrometry in polished cross-sections near the centre of the pearl as well as in small blemishes on the pearl surfaces. Continuous growth structures transect both vaterite and aragonite areas. Sodium and strontium concentrations are significantly lower in vaterite areas whereas the Mg concentration is up to two orders of magnitude higher and ratios of these elements allow distinction of the two phases using LA-ICP-MS. With the findings that vaterite is relatively common in the centres of high-quality freshwater cultured pearls and is the reason for lack of orient on some pearl surfaces, it is necessary to fully understand how it forms in order to optimize the quality of such pearls.*

Keywords: *aragonite, freshwater cultured pearls,* Hyriopsis, *LA-ICP-MS, Raman spectroscopy, trace elements, vaterite*

Introduction

Shells and pearls of molluscs are products of biomineralization, i.e. crystals formed by living organisms. The epithelial cells of the mollusc's mantle are responsible for the formation both of the shell (e.g. Addadi *et al*., 2006) and of pearls. They are composite materials composed of calcium carbonate crystals embedded in an organic matrix in a structure that is often referred to as a 'bricks and mortar' structure (e.g. Huang *et al*., 2004; Watabe, 1965; Snow *et al*., 2004). The organic matrix provides the framework in which the crystals form (e.g. Addadi *et al*., 2006) and contains macromolecules that have been found to play a key function in controlling the crystal growth process and the polymorph switch from calcite to aragonite during shell growth (Belcher *et al*., 1996; Sudo *et al*., 1997; Levi *et al*., 1998; Thompson *et al*., 2000; Feng *et al*., 2000; Addadi *et al*., 2006). In addition to the calcium carbonate polymorphs aragonite, calcite and vaterite, molluscs are able to produce amorphous calcium carbonate (ACC) which is believed to represent a precursor-product in the process of crystalline $CaCO_3$ formation in some organisms (Addadi *et al*., 2003, 2006; Beniash *et al*., 1999). The nacre of

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mollusc shells and pearls has been subject to numerous investigations to understand both its unique structural properties and the principles underlying the biomineralization processes (e.g. Watabe, 1965; Feng *et al*., 1999; Hou and Feng, 2003; Snow *et al*., 2004; Addadi *et al*., 2006). The mollusc's shell and pearls are both produced by epithelial tissue, and this is why it is used in pearl culturing (see next section). The continuous growth of a pearl can be clearly observed under the microscope by concentric rings of alternating fine dark organic material and thicker rings of calcium carbonate (e.g. Strack, 2001), as well as by rings of different colour intensity. Pearls are produced by a number of mollusc species in nature. The inner part of a marine pearl commonly consists of prismatic crystals of calcite and the outer layer of nacre is made up of aragonite platelets (e.g. Watabe, 1965), which are flat polygonal crystals with their *c*-axes perpendicular to the layer plane (e.g. Watabe, 1965; Song *et al*., 2003; Snow *et al*., 2004). Freshwater cultured pearls, however, have been shown to consist mostly of aragonite, with calcite only rarely reported. Instead, vaterite, a metastable $CaCO_3$ polymorph, has been found recently in the upper layers and at the surface of lacklustre freshwater cultured pearls (Ma and Dai, 2001; Ma and Lee, 2006; Qiao *et al*., 2006, Qiao and Feng, 2007).

The organisms secreting calcium carbonate control which polymorph is produced (Falini *et al*., 1996; Feng *et al*., 2000) and in some cases a switch from one polymorph to another has been observed (Thompson *et al*., 2000). However, although the aragonite calcite interface in molluscs and pearls has been investigated intensively (Belcher *et al*., 1996; Thompson *et al*., 2000; Dalbeck *et al*., 2006), very little is known about the vaterite - aragonite switch. Here, we present a systematic account of the occurrence of vaterite in good quality pearls from the mollusc genus *Hyriopsis* and show that vaterite is not restricted to lacklustre pearls and, thus, may represent an important factor in influencing the quality of pearls.

Freshwater cultured pearls

In general, freshwater pearls can be cultured with or without bead nuclei. In both cases it is necessary to implant a piece of epithelial tissue either in the gonad (usually with nucleus) or in the mantle tissue of the mussel. This tiny piece of tissue has the key function to stimulate the formation of a pearl sac (Landman *et al*., 2001). The newly formed pocket is lined by epithelial cells and becomes a biologically isolated compartment. Subsequently, the cells secrete the pearl material within this compartment, using a part of the implanted tissue as template. As the implanted cells are also responsible for the colour of the pearl, the section of the donor mussel's mantle epithelium from which the graft is taken is very important.

Chinese freshwater cultured pearls

A large number of rivers, lakes, waterways and natural and artificial ponds are available for pearl culturing in the southern, central and eastern regions of China (approximately 167000 km^2 (Strack, 2001)). Mussels most commonly used to culture freshwater pearls are *Hyriopsis cumingii* (also called the 'Triangle mussel' due to its shape). The tissue for implantation is usually taken from the mantle epithelium of a donor freshwater mussel of the same genus (Akamatsu *et al*., 2001). Earlier techniques used a 2 x 2 mm piece of mantle tissue cut from a two- to three-year-old mussel inserted into the mantle lobe. Nowadays larger pieces of mantle tissue of *c*. one-year-old mussels are used. The tissue of younger mussels is thinner and can be rolled more tightly before insertion (Akamatsu *et al*., 2001) yielding better round shapes of the pearls.

Freshwater cultured pearls in Japan: Lake Biwa and Lake Kasumigaura

Lake Biwa, the largest of Japan's lakes is situated on Honshu Island, 500 km west of Tokyo, close to Kyoto. The lake obtained its name from its form (a Biwa is a four-

stringed lute). Pearl culturing at Lake Biwa started in about 1914 (Landman *et al*., 2001), although the exact freshwater pearl mussel used originally is not known for certain. In the early 1920s, however, *Hyriopsis schlegeli*, MARTENS 1861 was already in use and the changeover from bead nucleation to beadless nucleation happened only ten years later. In Japan the Biwa pearl mussel is called 'Ikecho gai' because its form is similar to a butterfly (Ikecho, jap. butterfly and gai, jap. mussel). As a consequence of continuous environmental problems pearl culturing in Lake Biwa abruptly decreased in the early 1990s. Today, *Hyriopsis schlegeli* is nearly extinct at Lake Biwa. Only in small satellite lakes and ponds has pearl culturing survived. Pearl cultures there use a hybrid mussel species obtained by cross-breeding some of the remaining *Hyriopsis schlegeli* with their Chinese relative *Hyriopsis cumingii* (*Figure 1*). In February 2006 two of the authors (UW and DEJ) visited the pearl farms at Lake Biwa which produce high quality pearls, examples of which are shown in *Figure 2*.

Lake Kasumigaura, located approximately 60 km to the northeast of Tokyo, is Japan's second largest lake. The name 'Kasumigaura' includes the main river Nishiura and also the lakes Kitaura and Sotonasakaura and their connecting water courses. The first freshwater cultured pearls from Lake Kasumigaura were marketed in Europe around the mid-1990s. Already the first harvests yielded almost round pearls up to 20 mm in diameter. This meant that the pearls were comparable with the cultured pearls from the South Seas and Tahiti, both in size and in terms of price. Until the 1990s, not many details about pearl culturing companies in the region were available, but it can be assumed that pearls from harvests in the region were marketed together with pearls from Lake Biwa. Most Kasumigaura pearls contain bead nuclei made from American freshwater nacreous shell. A conspicuous feature of the bead is that it is drilled through to allow optimal handling during implantation into the mussel. Mr K. Yanase, one of the three farmers at Lake

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Figure 1: *Pearl mussel from Lake Biwa (pearl culturer: K. Kawabata), a cross-breed of the Japanese Biwa pearl mussel* Hyriopsis schlegeli *with its Chinese relative* Hyriopsis cumingii.

Figure 2: *Freshwater cultured pearls of high quality from Lake Biwa. Mr Kawabata cultivates his pearls in the area of Omnihachiman City at the southern end of Lake Biwa.*

Figure 3: *Freshwater cultured pearls with bead nucleus from Lake Kasumigaura (pearl culturer K. Yanase). Photo: B. Dillenburger*

Kasumigaura who was visited by two of the authors (UW and DEJ) in February 2006, uses nuclei with diameters of 8 mm, 8.5 mm and 9 mm. The pearl farms of Mr K. Yanase are situated behind a dam in the southern region of the lake, in the connecting branches of the rivers and in artificial ponds that are fed with lake water. In each mussel only one pearl is cultured. The range of colour is broad and includes white, apricot, rosé, pink, mauve and violet tones. In a few pearls, their body tone may have an additional green, bronze or golden overtone, generally with a metallic lustre (*Figure 3*).

Material and experimental methods

Chinese freshwater cultured pearls without bead nucleus (*Hyriopsis cumingii*) of a wide colour range were bought from different pearl-dealers in Germany to obtain examples from different locations and which had been harvested at different times. Japanese freshwater cultured pearls of *Hyriopsis schlegeli* crossed with *Hyriopsis cumingii* from Lake Kasumigaura (bead-nucleated samples) and Lake Biwa (bead-nucleated and samples without beads) were obtained directly from the farmers.

Fifty pearl samples were chosen from over 200 and Raman spectra were obtained from their surfaces. Twelve (eleven from China, one from Lake Biwa) of these fifty samples (see *Figure 4*) were cut in half with a diamond-plated saw and polished with diamond paste on a copper plate to study the cross-sections by Raman spectroscopy.

Raman spectroscopy is a non-destructive method that allows clear identification of the different $CaCO_3$ polymorphs. For comparison, Raman spectra of inorganic aragonite, calcite and vaterite from the mineral collection of the Department of Geosciences, Johannes Gutenberg-University, Mainz were obtained (*Figure 5*).

The structures and Raman spectra of aragonite and calcite are well documented (e.g. Gabrielli *et al*., 2000; Anderson, 1996; Behrens *et al*., 1995; Urmos *et al*., 1991; Griffith, 1974; White, 1974). In contrast, the corresponding information for vaterite is still a matter of discussion. In the Raman spectrum of aragonite, three so-called internal modes (ν_1, ν_3 and ν_4) are Raman active and are reported to appear near 1085 cm^{-1} (ν_1) for the most intense band, near 1465 cm^{-1} (ν_3) and a doublet between 701 cm^{-1} and 705 cm^{-1} (ν_4). For

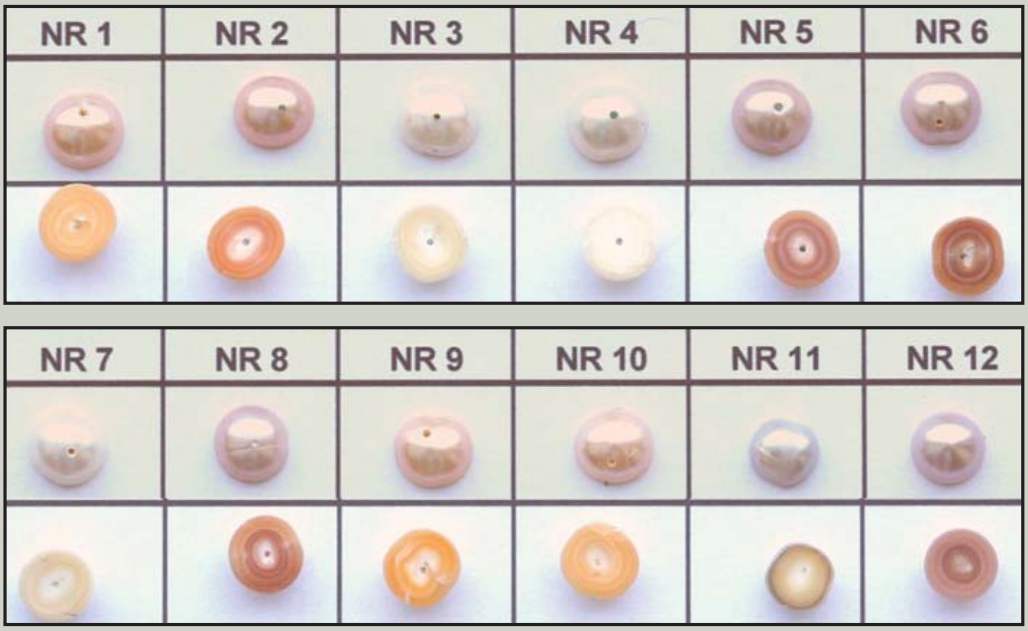

Figure 4: *Cross-sections of the beadless freshwater cultured pearls used in this study. Pearl numbers 1-10 and 12 are from China and number 11 is from Lake Biwa, Japan. All are between 7 and 9 mm in diameter.*

calcite the internal modes are given with 1086 cm^{-1} (ν_1) for the most intense band, near 1434 cm^{-1} (ν_3) and in the region of 711 cm^{-1} (ν_4). The Raman spectrum of vaterite shows a splitting of the most intense ν_1 band between 1074 cm^{-1} and 1090 cm^{-1}, and also a splitting of the ν_3 and ν_4 bands. Peak maxima are summarized in *Table I*.

While Gabrielli *et al*. (2000) observed two bands of the ν_1 vibration of vaterite, Gauldie *et al*. (1997) reported three bands. Behrens *et al*. (1995) attributed this spectral signal to a doublet at 1074 cm^{-1} and 1090 cm^{-1}, also referring to a third peak at 1080 cm^{-1} which was interpreted as a calcite impurity.

All Raman spectra were recorded at room temperature using a Horiba Jobin Yvon LabRAM HR spectrometer equipped with a Si-based CCD-detector (Peltier-cooled), an integrated Olympus BX41 optical microscope and an x-y-stage automatically controlled by software and a joystick. A 50x long-distance objective (numerical aperture 0.55) was selected. The reflected light and the Rayleigh light were reduced using the respective notch filters. The 514.5 nm line of an Ar^+-ion laser and the 632.8 nm He-Ne laser line were used for excitation. A grating with 1800 grooves per mm and a slit width of 100 µm were chosen and the laser power was 10 mW. Data acquisition and spectra treatment were carried out with the commercially available program LabSpec v4.02 (Jobin Yvon Horiba). For single point measurements, spectra were recorded twice. Peak analysis was performed with an Origin-lab® 7.5 professional software package. The peaks were fitted as the composition of either single or overlapping Lorentz curves.

For the mapping technique, a certain area of the cross section of the pearl was defined (for example 8.15 x 8.15 mm in the maps presented in *Figure 8*). Every 40 µm in x and y directions a spectrum was recorded twice for two seconds. Therefore the resulting numbers of spectra were *c*. 200 x 200 = 40000. With the LabSpec software the backgrounds of all 40000 spectra were subtracted and all spectra were decomposed into the respective subspectra with the implemented curve fitting procedure. The resulting intensity of every peak was converted to a colour code. Therefore, every pixel in the Raman-map represents one spectrum and every colour a certain intensity which, in turn, equals a certain amount of the respective phase. With this technique it is very easy to show clearly the distribution of the phases.

Trace elements in different $CaCO_3$ polymorphs were measured using LA ICP-MS (Laser Ablation Inductively Coupled Plasma Mass Spectrometry). This method uses a laser microscope as sampling device connected to an inductively coupled plasma-mass-spectrometer (ICP-MS) and material ablated by the laser from a specimen is swept directly into the mass spectrometer for analysis by a stream of argon or helium gas (Fryer *et al*., 1995). The instrument used in this study consists of a New Wave Research UP213 combined with an Agilent 7500ce quadrupole ICP-MS. The 213 nm wavelength (fifth harmonic wavelength of the Nd:YAG crystal) has the advantage over the older systems using 266 nm (fourth harmonic wavelength) that its absorbance in light-coloured or transparent material (e.g. aragonite, corundum, etc.) is higher, which is favourable for ablation and signal stability. In this way, up to *c*. 30 chemical trace elements (present in concentrations of less than 1 wt. %) can be determined simultaneously with minimal erosion on the specimen surface. Laser craters drilled in this way at our laboratory are typically 0.1 mm and can be further reduced to 0.05 mm (*Figure 10*). One analysis takes around 120 seconds on average, during which time-resolved signals for background (60 sec) and sample-signal (60 sec) are detected. The time-resolved detection of the signal also allows identification of material differences in the specimen (e.g. chemical zonation) which may either be natural or be caused by chemical treatment of pearls. Detection limits are generally significantly below one ppm (0.0001 wt.%). In this study, the laser was pulsed with 0.3 mJ per pulse at a frequency of 10 Hz. Laser spot sizes were 0.1 mm and argon was used as carrier gas. Data reduction was carried out using the commercially available software "Glitter" with ^{43}Ca as the internal and NIST SRM 612 glass as the external standards. All analyses were duplicated. In the case of high-quality samples, Raman investigations were carried out before laser ablation on the same spot.

Table I: *Raman peak maxima in cm^{-1} of the different $CaCO_3$ polymorphs*

$CaCO_3$-polymorph	reference	ν_1 symmetric stretching (CO_3^{2-})	ν_3 asymmetric stretching (CO_3^{2-})	ν_4 in-plane bending (CO_3^{2-})
Calcite	Bischoff *et al.*, 1985	1085 (2.5)	1434 (2.0)	711 (3.6)
	Rutt & Nicola, 1974	1085	1435	711
	Urmos *et al.*, 1991	1085 (2.5)		711 (4.5)
Aragonite	White, 1974	1087	1464 1466	703
	Urmos *et al.*, 1991	1085 (2.1)	1462 (6.0)	701, 705
	Gabrielli *et al.*, 2000	1085	1460, 1570	701, 705
	Urmos *et al.*, 1991	1085 (2.2)	1462 (6.5)	701, 705
Vaterite	Gabrielli *et al.*, 2000	1074 1090	1445, 1485 1550, 1595	668, 682, 740, 750
	Gauldie *et al.*, 1997	1074 1081 1090		685, 740, 744, 751
	Behrens *et al.*, 1995	1074 1090		740, 750

Results

Identification of $CaCO_3$ polymorphs

To distinguish aragonite and calcite from vaterite, the most intense band ν_1 (symmetric stretching) and the ν_4 (in- plane bending) signals in the Raman spectra of the three carbonate polymorphs can be used (*Table I* and *Figure 5*). In the Raman spectrum of synthetic vaterite (*Figure 5*) and in the vaterite areas of the freshwater cultured pearls a triplet at 1074 cm^{-1}, 1080 cm^{-1} and 1091 cm^{-1} for the ν_1 (CO_3^{2-}) signal is clearly visible. Raman signals in this wavenumber area for three pearl samples are shown in *Figure 6*. If calcite impurities were present, peaks in the ν_3 - and ν_4 - region would also have to be present, but were not found in our samples: this does not support the findings of Gabrielli *et al.* (2000). Our results clearly indicate that the observed Raman band at 1080 cm^{-1} should be attributed to vaterite and not to calcite impurities in vaterite (*Figure 6*, spectrum c). Nevertheless, vaterite areas in the pearls sometimes contain varying amounts of aragonite which was detected as an additional peak at 1085 cm^{-1} within the triplet of the ν_1 of vaterite (*Figure 6*, spectrum a). Depending on the amount of aragonite in the vaterite-aragonite mixture, this signal occurs as a shoulder (*Figure 6*, spectrum b) or as a separate peak (*Figure 6*, spectrum a) between the 1080 and 1091 cm^{-1} peaks of vaterite. The split of the ν_4 Raman band at 701 cm^{-1} and 705 cm^{-1} clearly indicates that this impurity is aragonite (*Table I* and *Figure 5*). In our samples the ν_4 Raman band of vaterite (*Figure 7*) gives rise to five peaks. Gauldie *et al.* (1997), Gabrielli *et al.* (2000) and Behrens *et al.* (1995) all reported fewer peaks for this Raman band (*Table I*), but the four peaks (685 cm^{-1}, 740 cm^{-1} , 744 cm^{-1} , and 751 cm^{-1}) observed by Gauldie *et al.* (1997), identified in fish earstones of the coho salmon, so-called otoliths, are in good agreement with four of our observed peaks (685 cm^{-1}, 739 cm^{-1}, 744 cm^{-1} , and 752 cm^{-1}). Gabrielli *et al.* (2000) also reported a peak with low intensity at 669 cm^{-1} but these authors did not detect the peak at 744 cm^{-1}, so, to the best of our knowledge, this is the first report to specify all five peaks for the ν_4 Raman band of vaterite.

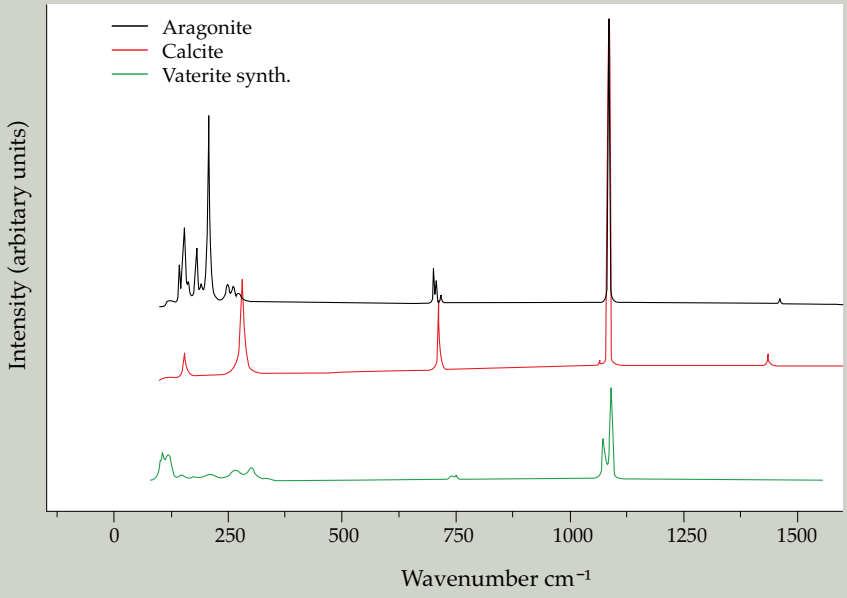

Figure 5: *Raman spectra of aragonite (black), calcite (red) and synthetic vaterite (green). Spectra were obtained from minerals in the collection of the Department of Geosciences, Johannes Gutenberg-University, Mainz. The spectra are vertically displaced for clarity.*

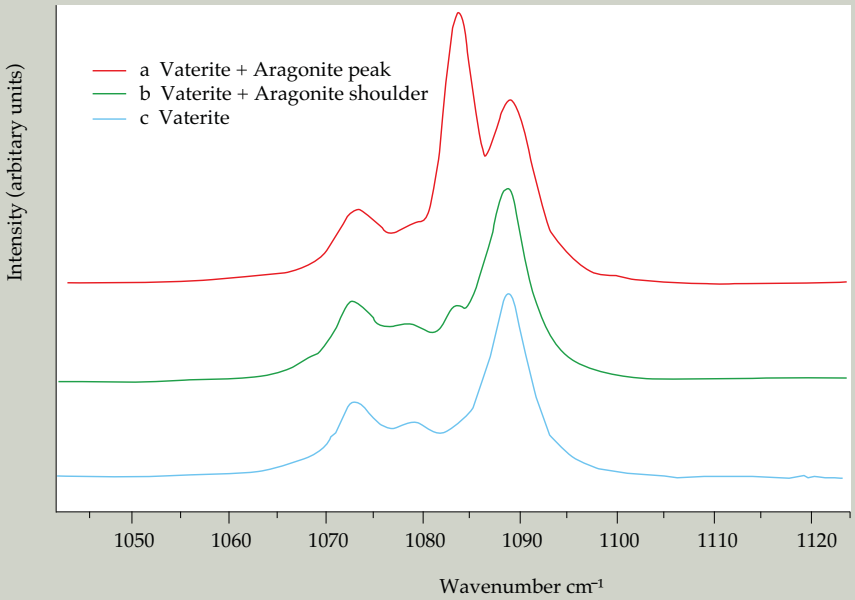

Figure 6: *Raman spectra of the pearl samples 4 (spectrum a), 11 (spectrum b) and 12 (spectrum c) show the triplet at 1074, 1080 and 1091 cm^{-1} of the ν_1 (CO_3^{2-}) Raman signal of vaterite clearly. A peak at 1085 cm^{-1} in spectrum a and a shoulder at this position in spectrum b indicate the presence of aragonite.*

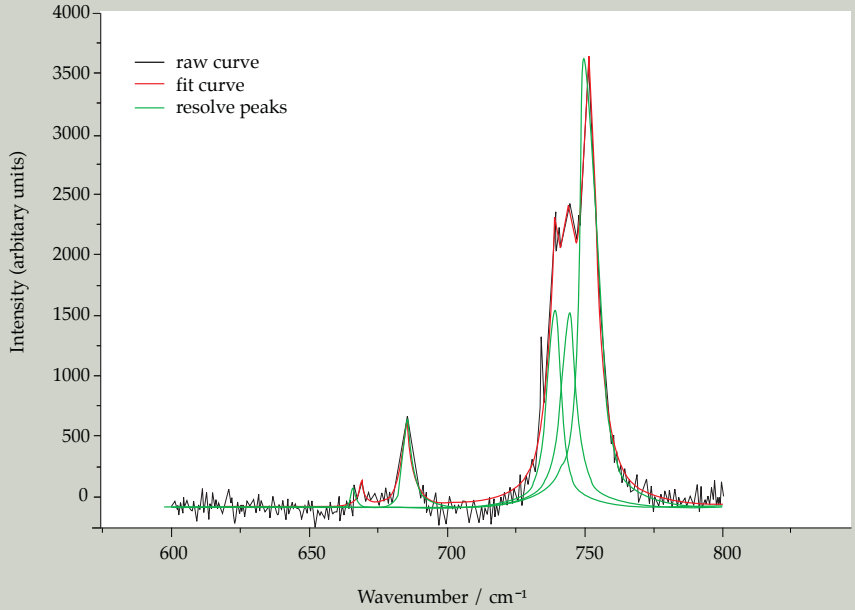

Figure 7: *Raman spectrum showing ν_4 (CO_3^{2-}) for the vaterite area in sample 12. The compound spectrum has been clearly resolved into five peaks at 669 cm^{-1}, 685 cm^{-1}, 739 cm^{-1}, 744 cm^{-1} and 752 cm^{-1} indicated by the green traces (see also* Table I*).*

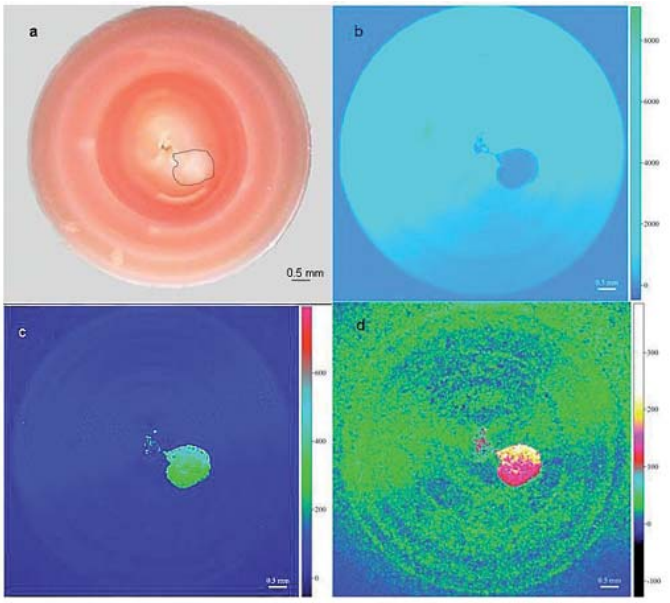

Figure 8: (a) *During cultivation, growth rings of different colours were formed in this Chinese freshwater cultured pearl (sample 12); the near-white vaterite area is outlined with a dotted line. Raman maps of this cross section are shown* (b, c *and* d). *The Raman map in* (b) *shows intensity variation at 1085 cm*$^{-1}$. *In the dark blue area in the centre of the pearl only low intensities were measured, whereas the turquoise areas clearly show aragonite intensities (i.e. high intensities for wavenumber 1085). Two Raman maps of vaterite peaks at 1091 cm*$^{-1}$ *and 1074 cm*$^{-1}$ (c *and* d *respectively) show high intensities in the roundish zone close to the centre and indicate that it consists of vaterite.*

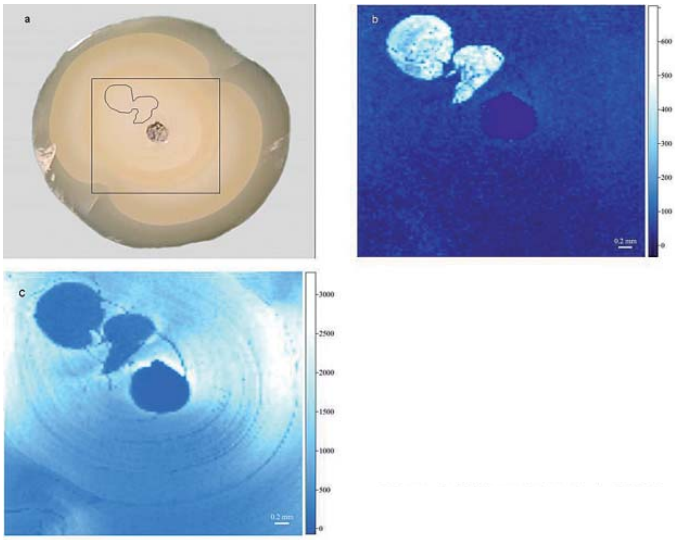

Figure 9: (a) *Polished cross-section of sample 4 (from China); the irregular shape of the vaterite area is outlined in black. The rectangular area was mapped by Raman spectroscopy and* (b) *shows the intensities at 1091 cm*$^{-1}$, *with the bright area indicating vaterite.* (c) *The pearl at 1085 cm*$^{-1}$; *the bright area indicates that it mostly consists of aragonite.*

Raman spectra from the surface of the freshwater cultured pearls exclusively showed the typical Raman shifts for aragonite. However, after sectioning of the pearls, vaterite areas could be identified by the Raman mapping technique in the inner parts of six samples, whose surfaces were previously found to consist of aragonite only.

Cross sections of two pearls typical of our sample are shown in *Figures 8a* and *9a* and their Raman maps are shown in *Figures 8b*, *c*, *d*, and *Figures 9b*, *c* respectively.

Within the Raman map pictured in *Figure 8b* the roundish area in the centre of the pearl shows low intensity responses at 1085 cm^{-1}, implying that this part consists neither of calcite nor of aragonite. The analysis of the complete Raman dataset shows that the major part of the pearl cross-section outside the roundish area close to the pearl's centre consists of aragonite (turquoise coloured area in *Figure 8b*). In *Figure 8c* the intensities at 1091 cm^{-1} - the most intense band of vaterite (*Table I*) are plotted, clearly indicating that this region (light green) consists of vaterite; this conclusion is supported by the map of intensities at 1074 cm^{-1} shown in *Figure 8d*.

Similarly, a Raman map of the intensities at 1091 cm^{-1} in the cross section of sample Nr. 4 (*Figure 9b*) shows an irregular area of high intensities indicating vaterite close to the centre of the pearl. The map in *Figure 9c* shows high intensities at 1085 cm^{-1} outside the vaterite area indicating aragonite.

In addition to its presence near the centres of good quality pearls, vaterite was also detected in small surface blemishes in a Kasumigaura pearl (*Figure 10*). This pearl is of high lustre, but shows a number of small pits on the surface that are pure white and lack the lustre of the surrounding pearl surface. Raman spectra clearly indicated that the white areas consisted of vaterite.

Ma and Lee (2006) reported on vaterite, aragonite and calcite in lustreless freshwater cultured pearls, and concluded that vaterite was rare or absent in high quality pearls, implying that if vaterite is present, it is one factor reducing the quality of pearls. Contrary to Ma and Lee (2006) our

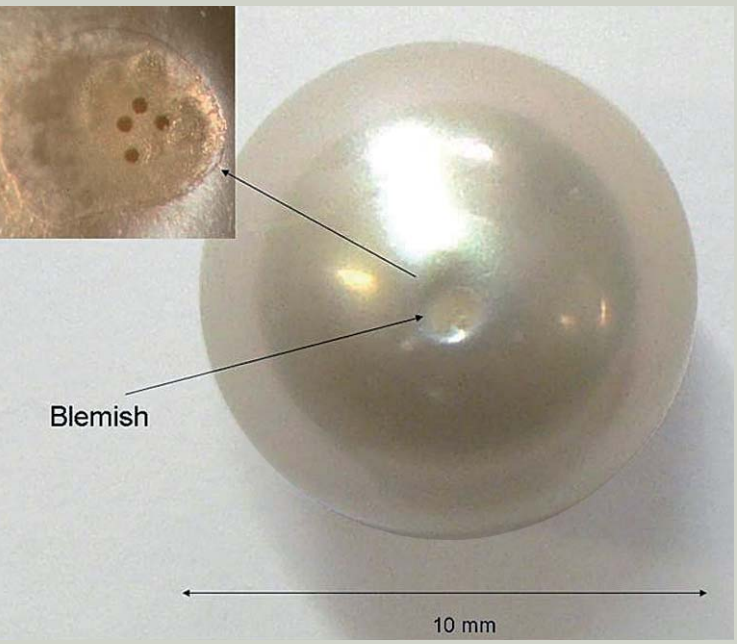

Figure 10: *Cultured Kasumigaura pearl of good quality with a little spot in which vaterite was determined by Raman investigations; laser ablation analyses were carried out after the Raman work and resulted in four tiny laser craters shown in the magnified inset.*

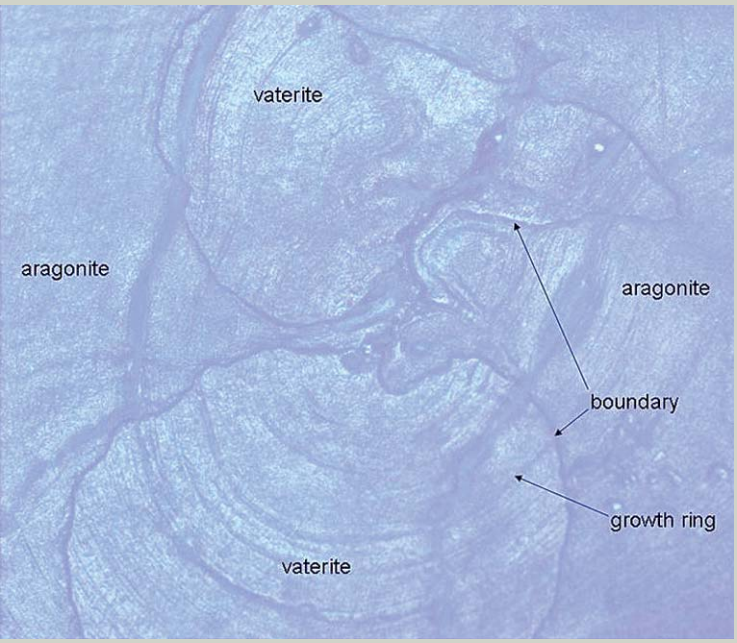

Figure 11: *Image of the inner part of the cross-section of pearl sample 4 (see* Figure 9*). The surface was etched and dyed with Mutvei's solution (Schoene* et al.*, 2000), which colours the pearl with different intensity depending on organic content. Thus, the boundaries between the vaterite and aragonite areas (arrows) and the growth rings which cross these boundaries without deviation are clearly visible.*

investigations show no evidence for the presence of calcite which is supported by the reports of Qiao *et al*. (2006).

Our results support the view that vaterite in the near-surface parts of the pearl (sub-surficial to surficial) is a major influence on quality. Additionally this study shows that vaterite is a common phase inside freshwater cultured pearls, both from China and Japan, and that these tiny regions are independent of vaterite occurrences at the surface of the pearl. In high-quality pearls, any vaterite is situated near the centre of the pearl and in close vicinity to the remnants of the tissue implant.

Microscopic observations

Under a binocular microscope, concentric growth rings of different colours in the sectioned samples are clearly visible whereas the vaterite areas are consistently and homogeneously of light colouring (nearly white), irrespective of the actual colour of the pearl. In *Figure 8a* the vaterite area (marked with dotted lines) is light coloured in contrast to the pink colour of the pearl, whereas in *Figure 9a* the vaterite area is not so distinct in an off-white sample. The morphology of any vaterite areas in the centre of a pearl varies from specimen to specimen, but it is almost always of a rounded shape and situated near the centre of the pearl (see *Figures 8*, *9* and *11*). To further study the micro-structure of the vaterite zones, cross-sections were treated with Mutvei's solution (Schoene *et al*., 2005). This etching method gently dissolves the calcium carbonate with acetic acid, while the organic matrix is stabilized with glutaraldehyde, and Alcian Blue colours the pearl with different intensity that highlights the organic regions (*Figure 11*). Under the microscope, the etched surfaces show a more intense blue at the boundaries between the different $CaCO_3$ polymorphs, implying that organic material is concentrated there. This chemical treatment also emphasizes organic growth rings and indicates that they traverse vaterite and aragonite areas alike.

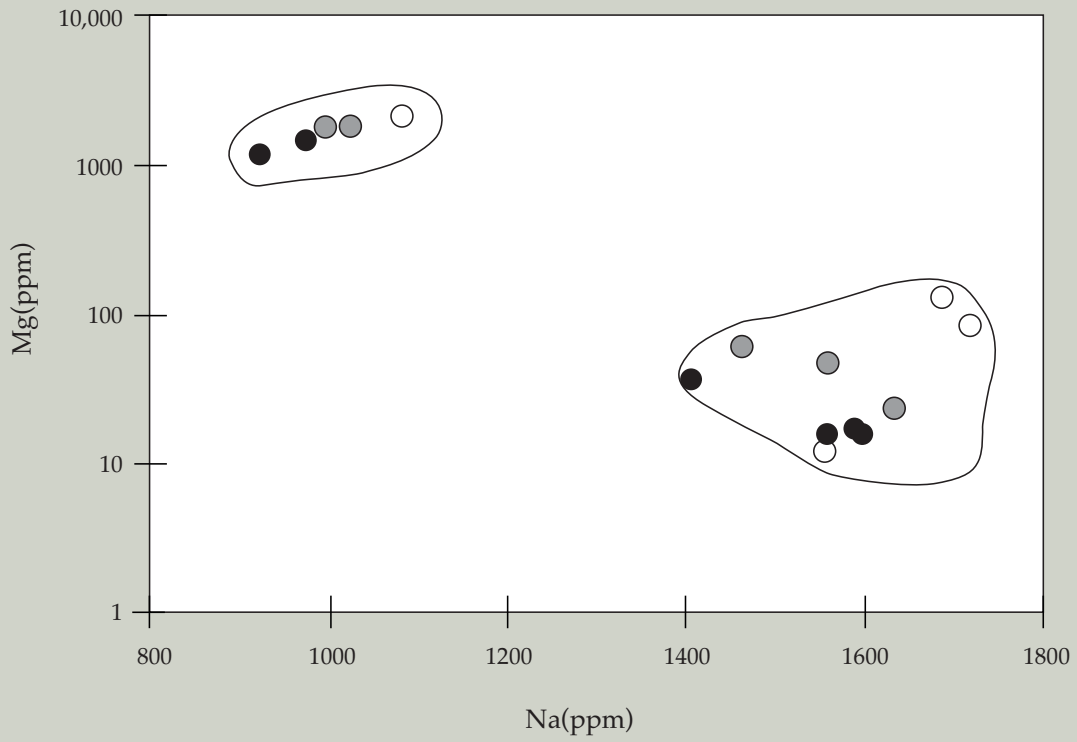

Figure 12: *A plot of Mg vs. Na concentrations (in ppm) from vaterite-bearing areas (left field) and aragonite-bearing areas (right field) in pearl samples 4 (solid symbols), 7 (open symbols) and 12 (grey symbols), indicates a Na/Mg ratio of 0.47 – 0.71 for vaterite and between 12 and 161 for aragonite.*

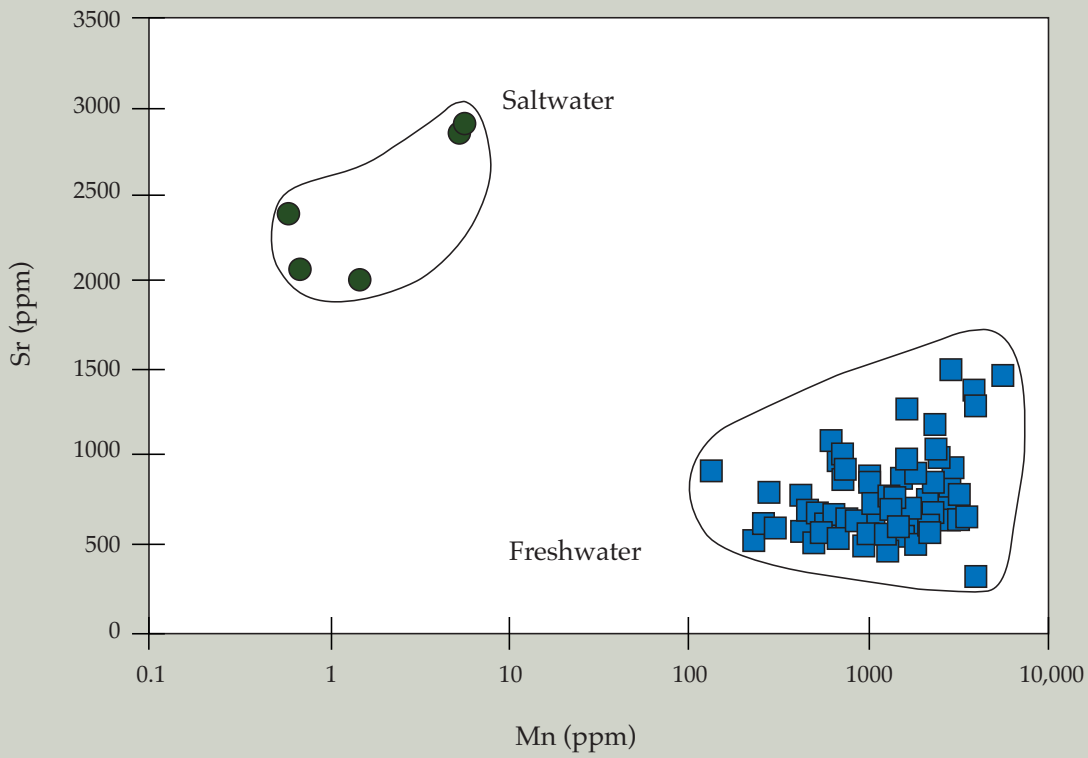

Figure 13: *A plot of strontium vs. manganese concentrations (in ppm) shows that this can be used to clearly distinguish between freshwater pearls and those grown in seawater.*

Chemical composition of vaterite and aragonite

In situ measurements of vaterite and aragonite areas by LA-ICP-MS show that magnesium concentrations are significantly higher in the vaterite (1121 – 2286 ppm) than in the aragonite areas (10.6 –140 ppm) (*Figure 12*).

Additionally, sodium and strontium concentrations are distinctly higher in the aragonite - (1409 – 1718 ppm and 323 – 923 ppm, respectively) than in vaterite-bearing areas (923 - 1083 ppm and 215 – 256 ppm, respectively). Thus, the measured Na/Mg ratios clearly distinguish vaterite (0.47-0.71) from aragonite (12-161). These results are supported by studies on vaterite and aragonite in fish otoliths. The concentrations of Mg in these biominerals were reported to be 30-fold higher in vaterite than in aragonite, whereas the concentrations of Sr were 10-fold higher in aragonite than in vaterite (e.g. Melancon *et al*., 2005). Brown and Severin (1999) examined the elemental distribution in otoliths of inconnu (*Stenodus leucichthys*) and identified regions depleted in Sr and Na. Further analyses of these regions revealed the presence of vaterite. The findings of Tomás and Geffen (2003), too, show lower sodium and strontium concentrations in the vaterite than in the aragonite areas of fish otoliths, whereas the concentrations of manganese are reported to be higher in the vaterite areas. In our study the Mn concentrations reveal no diagnostic difference between aragonite and vaterite implying that any difference due to structural or organic influence is disguised by the influence of water salinity on the Mn concentration in pearls (*Figure 13*; Jacob *et al*., 2006c).

In contrast to Melancon *et al*. (2005), who observed 20 fold higher Ba concentrations in aragonite than in vaterite, the Ba concentration in the aragonite areas (67 - 229 ppm) in our study show no significant difference from the Ba concentration in the vaterite areas (41 -283 ppm).

Discussion

Addadi *et al*. (2006) proposed that the nacre deposition process of molluscs occurs in a sequence of stages. The first stage is assembly of the organic matrix – the framework in which the minerals form. At the second stage, amorphous calcium carbonate (ACC) is deposited in this framework. In the following step the nucleation of individual aragonite crystals at the expense of the transient ACC phase takes place. It is possible that vaterite is also produced from ACC, either as a metastable precursor of aragonite (e.g. Hasse *et al*., 2000) or as an endproduct equivalent to aragonite. However, the mechanism of vaterite production *in vivo* has not been studied in detail. In their study, Marxen *et al*. (2003) discuss these questions and conclude that the transformation from ACC proceeds directly to aragonite without forming vaterite as a transient phase, which was supported by Hasse *et al*. (2000) in a study on snail shells.

Our observations indicate that aragonite and vaterite may grow simultaneously in the same growth ring but in different areas (*Figure 11*), corresponding well with the findings of Melancon *et al*. (2005), who reported on simultaneous growth of vaterite and aragonite in otoliths of lake trout. But textural evidence is still lacking to enable us to decide between two possible hypotheses: either vaterite acts as a precursor to the formation of aragonite but is stabilized by organic materials before this can take place, or vaterite and aragonite grow simultaneously.

While the crystal structure of vaterite is still a matter of discussion (see Kamhi, 1963; Meyer, 1969; Lippman, 1973) the detection of three peaks for ν_1 at 1074, 1080 and 1091 cm^{-1} (*Figure 6*) and the five components for ν_4 (e.g. in sample 12, *Figure 7*) in our study indicate that vaterite is hexagonal. This symmetry was proposed by Lippmann (1973) (see also Gabrielli *et al*., 2000), and was based on the high temperature modification of $YbBO_3$ (Bradley *et al*., 1966). Lippman (*op. cit*.) that in this crystal structure, substitution of strontium for calcium is less probable than in orthorhombic aragonite (Brown and Severin,

1999). This is supported in our study where Sr concentrations are significantly higher in aragonite than in vaterite. The lower concentration of Na in vaterite suggests that the crystal structure may restrict incorporation of ions larger than Ca (see Brown and Severin, 1999). But the substitution of smaller cations for Ca in vaterite is in good agreement with the significantly higher Mg concentrations in the vaterite areas. Noethig-Laslo and Brecevic (1998) have shown that the Mg^{2+} ion fits well into the vaterite structure, and Jiao *et al*. (2006) found that when Mg is present in adequate concentrations it is known to exert an important effect on aragonite precipitation.

Although the different elemental concentrations in aragonite and vaterite can be related to crystal structures, they may be overprinted by regional differences in trace element contents of the waters in which the pearl mussels were cultured. Firstly, Jacob *et al*. (2006c) showed that a clear distinction between freshwater cultured pearls from China and those from Lake Kasumigaura could be made on the basis of the Ba concentrations in the pearls. Secondly, Sr and Mn concentrations can vary according to the water salinity (see Banerjee and Rager, 2001; Banerjee and Habermann, 2000; Secor *et al*., 1995). And thirdly, some biological factors influence both elemental distribution and polymorph formation.
In vitro studies of molluscs have suggested that specific proteins and macromolecules have the ability to control growth and nucleation of the different polymorphs (see Belcher *et al*., 1996; Falini *et al*., 1996; Thompson *et al*., 2000; Gottliv *et al*., 2003; Matsushiro *et al*., 2003; Matsushiro and Miyashita, 2004).

Although the subject of study for a number of years now, the causes and the mechanisms for producing aragonite or vaterite in pearls have not yet been fully understood. However, most authors agree that the organic matrix plays a key role in controlling which $CaCO_3$ polymorph is formed: Qiao *et al*. (2006) consider that the controlling factors are some special soluble proteins; Ma and Lee (2006) assumed that organic material controls polymorph formation and stabilizes vaterite in pearls. One possible reason for the occurrence of vaterite in shell given by Hasse *et al*. (2000) is that it may simply be the sign of a disturbed mineralization process. This is consistent with the assumption that some vaterite formation in fish otoliths can be attributed to stress in the animal (Melancon *et al*., 2005; Brown and Severin, 1999). Sweeting *et al*. (2004) suggested that environmental stress may play an important role for the occurrence of vaterite in otoliths of coho salmons. Massou *et al*. (2004) also proposed that the main causes for interruptions in growth of fish otoliths can be attributed to external stress which still leaves the actual biochemical mechanisms that lead to vaterite formation largely unknown. Clearly, more detailed biochemical work is needed to reveal the underlying causes.

Conclusion

In this study we have shown that vaterite not only occurs at the surface, but also in the interior parts of freshwater cultured pearls from *Hyriopsis cumingii* and *Hyriopsis cumingii* hybridized with *Hyriopsis schlegeli*, independent of their quality, colour, cultivation method and provenance. To the best of our knowledge, this is the first time that vaterite has been identified in Japanese freshwater cultured pearls. Polished cross-sections revealed vaterite in 50% of the studied pearls. Thus, mineralization of vaterite is a common phenomenon in pearls from *Hyriopsis* mussels, but has not yet been observed in pearls from other mussel species. Strontium and sodium concentrations are significantly lower in vaterite compared with adjacent aragonite whereas the Mg concentration is up to two orders of magnitude higher. These large differences in Mg/Na ratios allow identification of these two polymorphs even without Raman spectroscopy.

The occurrence of the vaterite close to the centres of many pearls and commonly close to the remains of organic material derived possibly from implanted tissue, implies that vaterite has a significant role in the biomineralization process.

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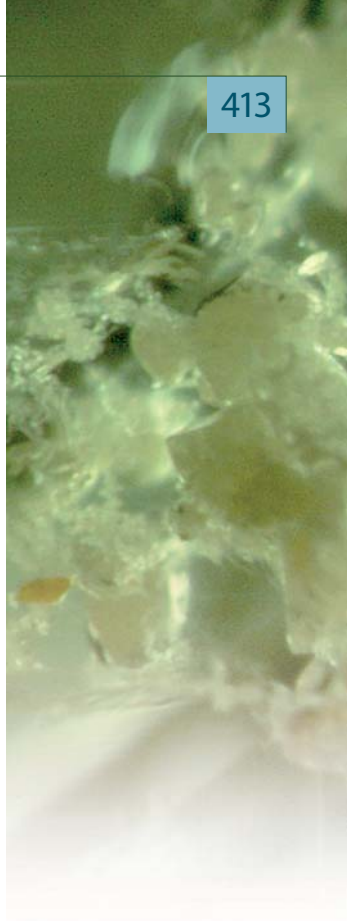

Vanadium-bearing gem-quality tourmalines from Madagascar

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Abstract: *Gemmological, microscopic, chemical and spectroscopic properties of green, vanadium-bearing gem-quality tourmalines from southern Madagascar are presented. The samples are iron- and lithium-free and are designated as calcic aluminous dravites. They reveal a small compositional variability for sodium, calcium, magnesium and aluminium. Positive correlations between Na and Al and between Ca and Mg are present, always with Al>6 atoms per formula unit and Mg<3 atoms per formula unit.*

Vanadium is the main transition metal present with smaller amounts of chromium and these cause the green coloration. Absorption bands in the UV-Vis range are assigned to V^{3+} on octahedral aluminium sites.

Mineral inclusions in the tourmalines were characterized by laser Raman microspectroscopy and quantitative microprobe analyses. The commonest are bytownite plagioclases, but quartzes and zircons are also present as well as cavities and healed fractures containing liquid and two-phase fillings (liquid/gas). Non-homogeneous irregularly shaped grains consist of a mixture of hydrous aluminium silicates and iron hydroxides.

The tourmalines from Madagascar are compared with iron-free or almost iron-free gem-quality tourmalines, mainly from East Africa. Correlation diagrams of Na, Ca, Mg and Al show two different population fields, a) with Al>6 and Mg<3 atoms per formula unit (aluminous dravites) and b) with Al<6 and Mg>3 atoms per formula unit (uvites). The main isomorphic replacement within this solid solution series occurs between the tourmaline end-members oxy-dravite, $Na(Mg_2Al)Al_6(BO_3)_3Si_6O_{18}(OH)_3O$, and uvite, $CaMg_3(MgAl_5)(BO_3)_3Si_6O_{18}(OH)_4$, and is represented by the substitutional scheme $Na^+ + 2Al^{3+} + O^{2-} \leftrightarrow Ca^{2+} + 2Mg^{2+} + (OH)^-$.

Keywords: *calcic aluminous dravite, electron microprobe analysis, isomorphic series, vanadian tourmaline, UV-visible absorption spectra*

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Introduction

Recently, a parcel of rough crystals and crystal fragments of a green mineral (*Figure 1*) were purchased as garnets from a German dealer in a local gem market in Madagascar. The transparent material of gem quality was indicated to originate from a new locality in southern Madagascar close to the occurrence of green, vanadium-bearing grossular (tsavorite) in the Gogogogo – Bekily area (see Mercier *et al*., 1997). According to their crystal shape, their pleochroism and their optical properties (measured on rough crystal faces), the crystals were quickly identified as tourmaline.

Numerous tourmaline occurrences are known in Madagascar and the island is famous for multi-coloured and colour-zoned tourmalines, mostly elbaite and liddicoatite (Pezzotta, 2001; Dirlam *et al*., 2002). A more detailed examination of the parcel of our tourmalines indicated that they are vanadium-bearing dravites, and since vanadium-bearing dravites of gem quality are, according to the knowledge of the present authors, not described in detail from Madagascar, the present study was undertaken to evaluate the properties of this new tourmaline material in detail.

Figure 1: *Rough crystal fragments and faceted vanadium-bearing tourmalines from southern Madagascar. The crystal showing striations on a prism face (lower right) measures about 8 x 13 mm; the faceted triangular stone weighs 0.23 ct and measures 4.2 x 4.1 mm.*

Vanadian tourmalines (dravites and uvites) from East Africa (Kenya and Tanzania) have been known in the gem trade since the end of the 1970s, and this light to intense green gem material has frequently been misnamed 'chromium-tourmaline' in the trade (see Schmetzer *et al*., 1979; Schmetzer and Bank, 1979; Keller, 1992; Simonet, 2006). Just recently, vanadium-bearing gem-quality uvites from Zambia with a special trapiche inclusion pattern have been described by Hainschwang *et al*. (2007).

Materials and methods

From the original lot purchased in Madagascar containing several hundred tourmalines, about 30 rough crystal fragments were available for the present study. The larger part of the lot was faceted for commercial purposes and about 40 tourmalines were obtained from this part after cutting (*Figure 2*). Furthermore, a parcel of about 20 rough or sawn impure tourmaline fragments which had been rejected during the faceting process were available.

Standard gemmological methods were used to determine the refractive indices (RI), optical character, specific gravity (SG) and fluorescence under long- and short-wave ultraviolet radiation of 20 faceted stones. Standard microscopic techniques were used to examine the internal features under different lighting conditions for all rough, sawn and faceted samples, both with and without immersion liquids.

To determine the chemical composition of the tourmalines, we selected five samples for microprobe analysis using a Cameca Camebax SX 50 electron microprobe. For each tourmaline, we obtained 10 point analyses from traverses across the samples. To obtain qualitative data for water and lithium, two rough crystal fragments were powdered for wet chemical analysis. Lithium was determined by atomic absorption spectroscopy (AAS) and the water content was analysed by Karl-Fischer titration.

For the examination of boron contents (which, like lithium and water, cannot be determined routinely by electron microprobe)

and for trace element analysis we selected two faceted tourmalines for laser ablation-inductively coupled plasma-mass spectroscopy (LA-ICP-MS) using a pulsed Excimer ArF laser with a characteristic wavelength of 193 nm and special optics to homogenize the energy distribution across the laser beam combined with the Perkin Elmer ELAN 6100 ICPMS quadrupole instrument. As indicated above, further trace element analyses, e.g. for lithium, were also performed by mass spectroscopy.

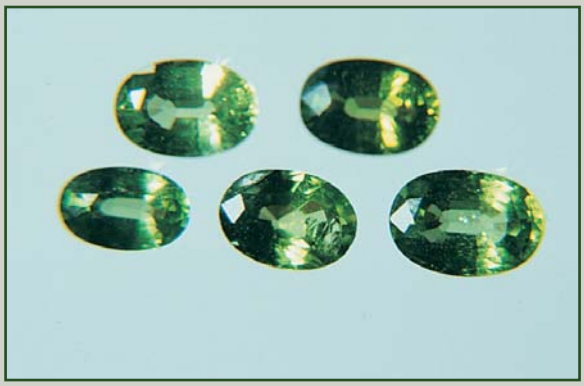

Figure 2: *Faceted vanadium-bearing tourmalines from southern Madagascar. Weights of samples between 0.33 ct and 0.60 ct, the largest tourmaline (lower right) measures 4.4 x 6.5 mm.*

Polarized UV-Vis-NIR (300-880 nm) absorption spectra were recorded for seven rough or faceted samples using a Perkin-Elmer Lambda 19 spectrophotometer. Unit cell dimensions were determined for one of the crystals analysed by electron microprobe using an automatic four-circle single crystal diffractometer and refined with powder data using $CuK_{\alpha 1}$ radiation with Si as internal standard.

To identify the inclusions present in the tourmalines, we examined 15 faceted samples by laser Raman microspectroscopy using a Renishaw 1000 system. In addition, we selected 12 heavily included crystal fragments which had been rejected for faceting. From these 12 tourmalines polished thin sections of 20-25 µm thickness were prepared to enable microscopic examination and quantitative microprobe analyses of mineral inclusions, and to carry out Raman microspectroscopy of selected inclusions which had already been measured by electron microprobe.

Results

Visual appearance and gemmological properties

The tourmaline crystals available for the present study mostly were irregular fragments without any crystal faces. Only a few samples showed prism faces, occasionally with striations parallel to the *c*-axis (*Figure 1*). All rough and faceted samples were homogeneously green without any distinct colour zoning (*Figures 1* and *2*).

Gemmological properties are summarized in *Table I*. Only small variations of refractive indices and specific gravity were observed. The pleochroism of all samples is distinct with a yellowish green coloration parallel to the *c*-axis and a more intense, slightly bluish green perpendicular to *c*. In short-wave ultraviolet light a weak to medium greenish yellow, slightly chalky fluorescence is present, but all samples are inert in long-wave UV.

Chemical composition

Chemical properties of five analysed samples are summarized in *Table II*. No compositional zoning of significance was detected within the single tourmaline crystals. All samples are sodium-, calcium- and magnesium-bearing aluminium tourmalines. Lithium is present only in trace amounts (average 0.004 wt.% Li_2O), and iron and manganese contents were at the detection limit of the electron microprobe. Distinct amounts of vanadium and chromium are present, with vanadium content always exceeding that of chromium.

The five tourmaline crystals examined by electron microprobe showed variation in their sodium, calcium, magnesium and aluminium contents. The compositional variability between different elements and especially a correlation between specific cations is, however, elucidated in more detail after calculation of the numbers of atoms per formula unit (apfu) according to the generally accepted structural formula of tourmaline on

Table I: *Physical and gemmological properties of V-bearing tourmalines from Madagascar.*

Colour	Green
Pleochroism parallel *c* perpendicular *c*	Yellowish green Bluish green
Refractive indices ω ε	1.638 – 1.640 1.618 – 1.620
Birefringence	0.020
Specific gravity	3.04 – 3.05
Unit cell dimensions[1] a_o (Å) c_o (Å)	15.9215 (1) 7.1867 (1)
Spectroscopic properties (nm) Absorption maxima ‖c Absorption maxima ⊥ c Intensity relations	 599, 441 610, 418, 370 (shoulder) 610 > 599 ; 441 > 418
UV fluorescence: short-wave long-wave	Weak to medium greenish yellow, slightly chalky Inert
Commonly-observed inclusions	Quartz, plagioclase (bytownite), zircon, solid multiphase inclusions consisting at least of hydrous aluminium silicates and iron hydroxides, cavities and healed fractures containing liquid and two-phase inclusions (liquid and gas)
Rarely-observed inclusions	Rutile, graphite, xenotime

[1] Refined powder data determined for sample D.

the basis of 31 anions (*Table II*).

According to the standard formula of magnesium-bearing aluminous tourmalines, $(Na,Ca,\square)(Mg,Al)_3(Mg,Al)_6(BO_3)_3Si_6O_{18}(O,OH,F)_4$, where the symbol □ represents a vacancy in the structure, we have to consider site occupancies of five cation-polyhedra, i.e. for Na,Ca,□ = X-site, Mg,Al = Y-site, Mg,Al = Z-site, B, and Si (see Tourmaline structure box). Various natural tourmalines with magnesium-aluminium disorder have been described, for which both cations, Al and Mg, are distributed within the two relevant octahedral Y- and Z-sites (Hawthorne *et al.*, 1993; Pieczka, 1999; Bloodaxe *et al.*, 1999; Da Fonseca-Zang *et al.*, 2001; Ertl *et al.*, 2003; Pertlik *et al.*, 2003; Marschall *et al.*, 2004; Novak *et al.*, 2004). This is more or less common and not an exceptional case (Grice and Ercit, 1993). For an exact determination of order/disorder and site occupancies of Mg and Al of our tourmaline crystals, which cannot be derived from analytical data, a crystal structure refinement would be necessary, but this is beyond the scope of the present paper. Thus, for simplicity of discussion of site populations in our samples, in which the amount of aluminium always exceeds 6 atoms per formula unit (Al > 6 apfu), we only consider the sums of magnesium and aluminium (Al + Mg) on the octahedrally coordinated Y- and Z-sites.

For all our samples, the sum of aluminium in Y- and Z-sites is >6 and the sum of magnesium in Y- and Z-sites is <3, with Al + Mg ~ 9, i.e. close to the theoretical value. The silicon tetrahedron is occupied mostly with Si but also a small almost constant substitution of about 0.1 atoms Al for Si is present. This feature has already been reported from vanadium-bearing gem-quality tourmalines from East Africa (MacDonald and Hawthorne, 1995), and is also common for iron-bearing members of the schorl-dravite series (Grice and Ercit, 1993). The boron content is almost equal to the theoretical value of 3, which indicates that no tetrahedral boron on Si-sites is present.

Table II: *Chemical composition of V-bearing tourmalines from Madagascar.*

Microprobe analyses (average of 10 point analyses each, wt.%)

Specimen	A	B	C	D	E
SiO_2	36.64	36.36	36.41	36.21	36.11
TiO_2	0.49	0.53	0.58	0.58	0.60
B_2O_3[1]	10.67	10.67	10.67	10.67	10.67
Al_2O_3	34.18	33.55	33.48	33.23	33.09
V_2O_3	0.17	0.19	0.19	0.19	0.20
Cr_2O_3	0.04	0.11	0.07	0.03	0.06
FeO[2]	0.01	0.02	0.01	0.02	0.01
MnO	0.01	0.02	0.01	0.01	0.02
MgO	10.63	10.75	10.96	10.99	10.96
CaO	1.58	1.75	1.93	2.36	2.43
Na_2O	1.56	1.49	1.48	1.37	1.36
K_2O	0.05	0.06	0.06	0.05	0.05
Li_2O[3]	0.00	0.00	0.00	0.00	0.00
F	0.48	0.50	0.51	0.40	0.38
H_2O[4]	3.00	3.00	3.00	3.00	3.00
-O=F	-0.20	-0.21	-0.21	-0.17	-0.16
Total	99.31	98.79	99.15	98.94	98.78

[1]Average analyses of two samples by LA-ICP-MS. [2]Total iron as FeO.
[3]Average analyses of two samples by wet chemical methods, LA-ICP-MS gave 0.004 Li_2O. [4]Average analyses of two samples by wet chemical methods.

Number of ions based on 31 (O, OH, F)

Specimen	A	B	C	D	E
Si	5.910	5.901	5.893	5.881	5.877
Al	0.090	0.099	0.107	0.119	0.123
Sum T site	6.000	6.000	6.000	6.000	6.000
B	2.970	2.988	2.980	2.990	2.997
Al	5.914	5.896	5.896	5.901	5.892
Ti	0.059	0.065	0.071	0.071	0.074
V	0.022	0.024	0.025	0.024	0.026
Cr	0.005	0.015	0.008	0.004	0.008
Sum Z site	6.000	6.000	6.000	6.000	6.000
Mg	2.557	2.600	2.645	2.661	2.658
Fe	0.002	0.003	0.002	0.002	0.001
Mn	0.002	0.003	0.003	0.002	0.003
Li	0.003	0.003	0.003	0.003	0.003
Al	0.493	0.421	0.384	0.340	0.333
Sum Y site	3.057	3.030	3.037	3.008	2.998
Na	0.487	0.468	0.465	0.433	0.429
K	0.010	0.012	0.012	0.010	0.011
Ca	0.273	0.305	0.335	0.411	0.424
Sum X site	0.770	0.785	0.812	0.854	0.864
OH	3.228	3.247	3.239	3.250	3.258
F	0.246	0.257	0.261	0.207	0.194

Approximate formula: $(Na_{0.4}Ca_{0.4}\square_{0.2})(Mg_{2.6}Al_{0.4})Al_6(BO_3)_3(Si_{5.9}Al_{0.1})O_{18}(OH_{3.25}F_{0.25}O_{0.5})$

Tourmaline structure

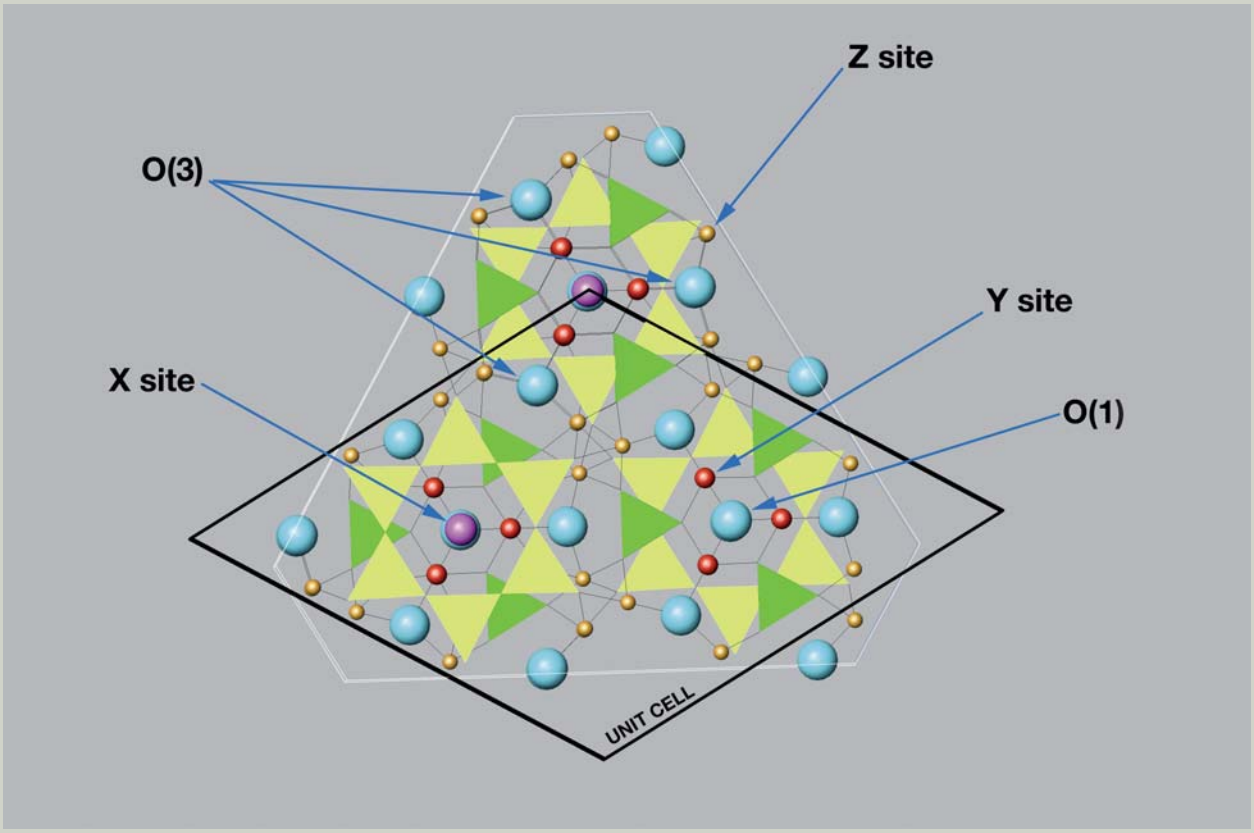

Tourmaline structure projected parallel to the (0001) plane; yellow: (SiO_4)-tetrahedra, green: planar (BO_3)-groups, purple: X-sites, red: Y-sites, orange: Z-sites, blue: V-and W-sites (representing O(3)- and O(1)-sites). From Simmons (2002), reproduced by permission of Litographie, LLC, East Hampton, CT, USA.

To understand the different schemes of isomorphic replacement within the oxydravite, dravite and uvite solid solution series discussed in this paper, it is helpful to consider the tourmaline structure in detail. A general summary is given in various textbooks and monographs (see, e.g., Dietrich, 1985; Deer *et al.*, 1986; Klein, 2002; Simmons, 2002).

The tourmaline structure (see above) consists of (Si_6O_{18})-rings of six edge-sharing (SiO_4)-tetrahedra, which are linked to planar (BO_3)-groups. These structural elements of silicon- and boron-polyhedra are linked to each other by different cations on X-, Y- and Z-sites of the tourmaline structure.

The X-site is coordinated by nine anions and the Y- and Z-sites are octahedrally coordinated. The Y-octahedron is somewhat larger than the Z-octahedron. In the present case, the X-site contains Na, Ca or vacancies, and the Y- and Z-sites are occupied by Mg and Al.

The formula unit of tourmaline contains 31 anions which are located at eight different lattice sites at the corners of the different coordination polyhedra of the tourmaline framework. Six of these eight different lattice sites contain only oxygen, and only two of these eight sites, designated O(1) and O(3), can also contain hydroxyl-groups and fluorine, (OH) and F.

The O(3)-sites, which are also designated as V-sites, can only contain oxygen and hydroxyl-groups, and the O(1)-sites, which are also designated W-sites, can contain oxygen, hydroxyl-groups and fluorine.

This is typical for members of the schorl-dravite series (see, e.g., Grice and Ercit, 1993; Bloodaxe *et al*., 1999). At the X-site, the sums of Na and Ca are consistently below the ideal maximum value of 1, which means that vacancies are present at this site.

As already mentioned, the main compositional variables in the five tourmalines are Na, Ca, Mg and Al.

For the X-site a negative correlation is found between the site occupancies of sodium and calcium (*Figure 3a*), and for the (Y+Z)-sites, a negative correlation is found between the site occupancies of magnesium and aluminium (*Figure 3b*). Comparing the site populations of cations between X and (Y+Z) polyhedra, positive correlations are observed between magnesium and calcium and between aluminium and sodium (*Figures 3c,d*), and there are negative correlations between magnesium and sodium and between aluminium and calcium. Vacancies on the X-site show a positive correlation with Al-contents and a negative correlation with Mg-contents (*Figures 3d* and *c*). These data indicate a coupled isomorphic replacement of four cations on X- and (Y+Z)-sites (*Figure 3e*) according to the scheme

$$(Na^{1+}+Al^{3+}) \leftrightarrow (Ca^{2+}+Mg^{2+}).$$

This heterovalent substitution scheme is similar to the known isomorphic replacement

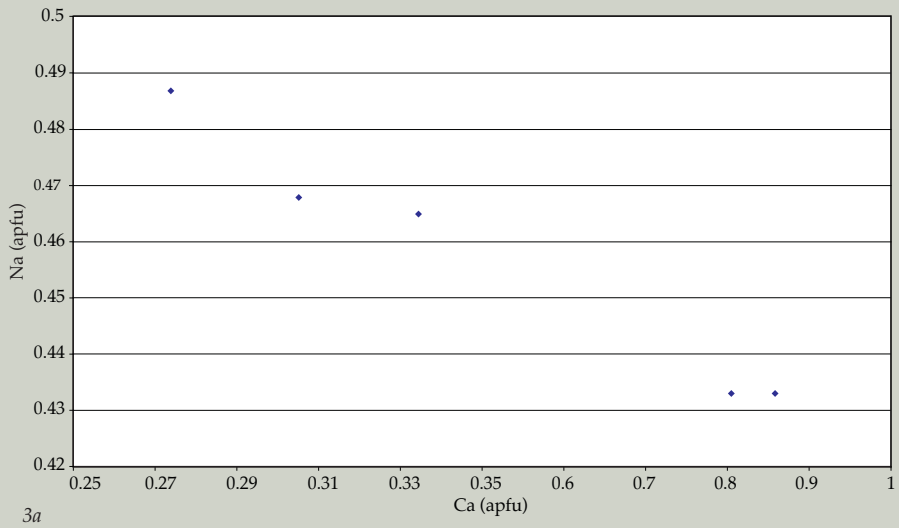

3a

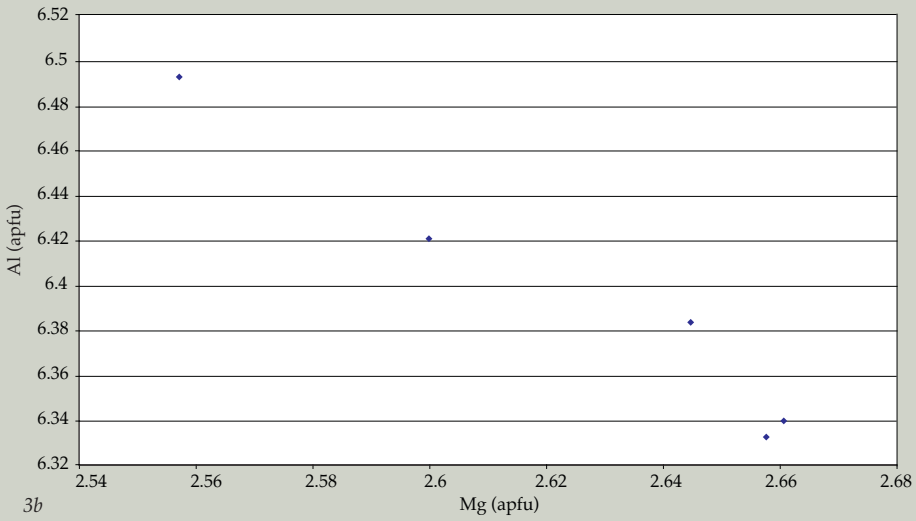

3b

Figure 3: *Correlation diagrams of site populations of various major components in X-, Y- and Z-sites of vanadium-bearing tourmalines from southern Madagascar.*

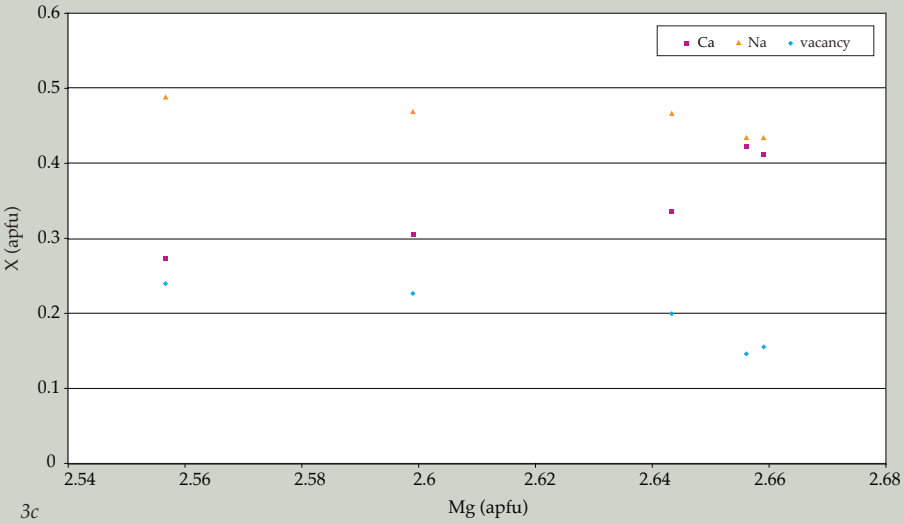
Ca
Na
vacancy
X (apfu)
Mg (apfu)
0
0.1
0.2
0.3
0.4
0.5
0.6
2.54
2.56
2.58
2.6
2.62
2.64
2.66
2.68

3c

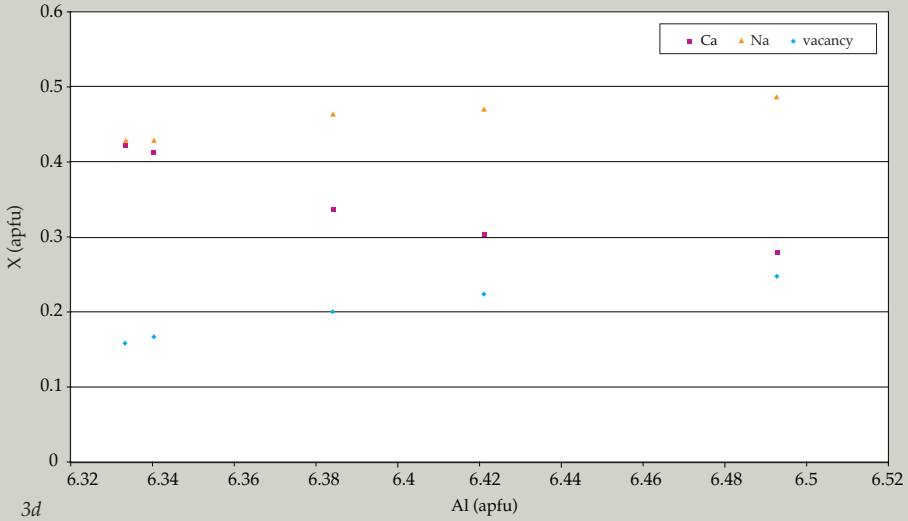
Ca
Na
vacancy
X (apfu)
Al (apfu)
0
0.1
0.2
0.3
0.4
0.5
0.6
6.32
6.34
6.36
6.38
6.4
6.42
6.44
6.46
6.48
6.5
6.52

3d

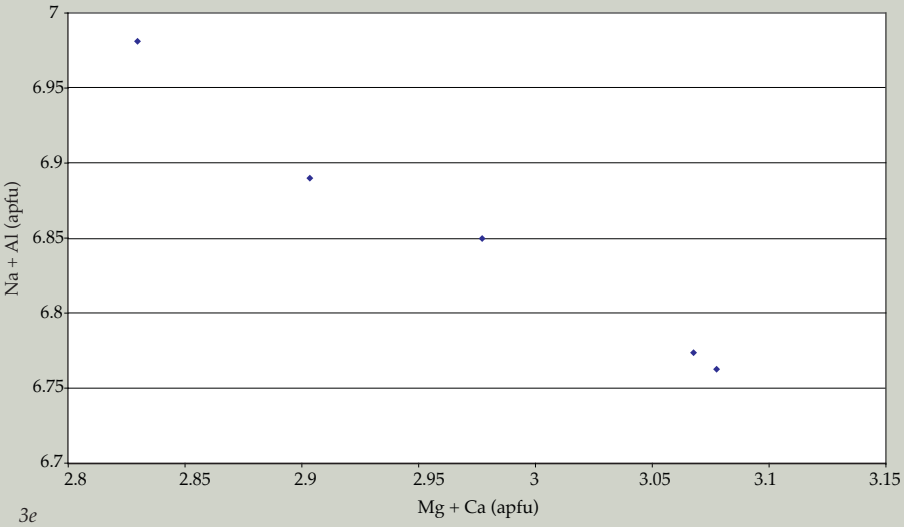
Na + Al (apfu)
Mg + Ca (apfu)
6.7
6.75
6.8
6.85
6.9
6.95
7
2.8
2.85
2.9
2.95
3
3.05
3.1
3.15

3e

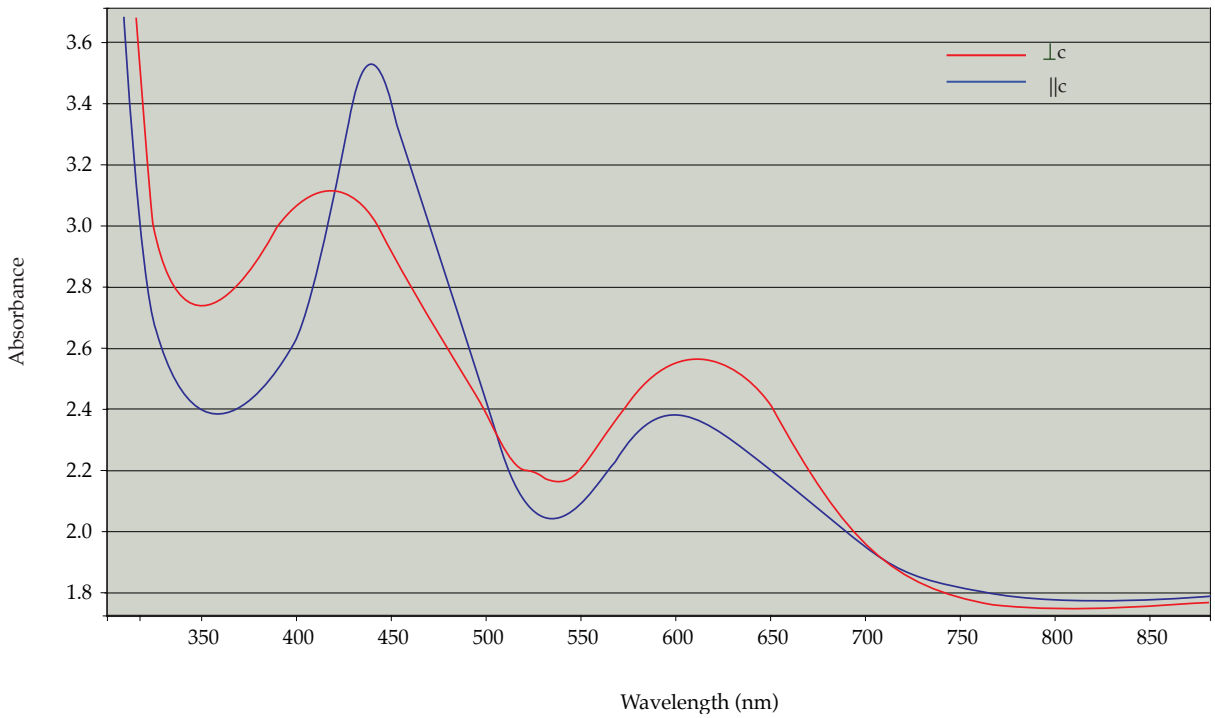

Figure 4: *Polarized UV-visible absorption spectrum of a vanadium-bearing, iron-free tourmaline from southern Madagascar.*

within the dravite – uvite solid solution series (for further details see Discussion and *Table V*).

An approximate, somewhat simplified formula (where traces of transition metals are omitted) for an average composition for the five analysed tourmaline crystals from Madagascar reads:

$$(Na_{0.4}Ca_{0.4}\square_{0.2})(Mg_{2.6}Al_{0.4})Al_6(BO_3)_3(Si_{5.9}Al_{0.1})O_{18}(OH_{3.25}F_{0.25}O_{0.5})$$

Spectroscopic properties and cause of colour

The absorption spectrum of the green vanadium-bearing tourmalines from Madagascar consists of two strong absorption bands with maxima at 599 and 441 nm in the spectrum parallel to *c* and maxima at 610 and 418 nm in the spectrum perpendicular to *c* (*Figure 4*). In some samples in addition to these major absorption bands, an additional shoulder is seen at 370 nm in the spectrum perpendicular to *c* (not shown in *Figure 4*).

This type of spectrum is consistent with the data reported in the literature for vanadium-bearing tourmaline from East Africa (Schmetzer, 1978, 1982); the stronger absorption bands were assigned to V^{3+} on octahedrally coordinated aluminium-sites (Z-sites) of the tourmaline structure.

The absorption bands of chromium in dravite occur at 588 and 417 nm, which are in the same spectral range as those of vanadium (Manning, 1969; Schmetzer, 1978; Nuber and Schmetzer, 1979; Halvorsen and Jensen, 1997; Simonet, 2000) and, thus, the two superimposed absorptions cannot be separated. Consequently, the colour of the green dravites from Madagascar is caused mainly by trivalent vanadium on aluminium sites, with some enhancement from the traces of chromium.

Features seen with the microscope, identification of inclusions

The tourmaline samples from Madagascar contain numerous, mostly irregularly shaped solid inclusions (*Figure 5*) as well as cavities with liquid and two-phase inclusions (liquid/gas). These two-phase inclusions were homogenized under microscopic illumination, i.e. the gas bubble disappeared after a slight increase of temperature. On cooling to room temperature, the gas bubbles reappeared and the inclusions were again two-phase. This type of reaction is characteristic for two-phase inclusions consisting of liquid and gaseous CO_2.

Table III: *Chemical composition of plagioclase inclusions in V-bearing tourmalines from Madagascar (data of samples A and C represent bytownite grains with high and low albite/anorthite contents, respectively; data of sample B represent a grain of intermediate composition).*

Microprobe analyses (wt.%)				Number of ions based on 8 O			
Inclusion	A	B	C	Inclusion	A	B	C
Na_2O	3.17	2.72	2.04	Na	0.283	0.242	0.183
K_2O	0.13	0.11	0.06	K	0.008	0.006	0.004
CaO	14.48	15.35	16.80	Ca	0.715	0.757	0.830
Al_2O_3	30.99	32.13	32.95	Al	1.683	1.743	1.790
SiO_2	49.98	48.92	47.59	Si	2.303	2.251	2.195
Total	98.75	99.23	99.44	Total	4.992	4.999	5.002

Table IV: *Chemical composition of fine-grained multiphase inclusions in V-bearing tourmalines from Madagascar (ranges, wt.%).*

	Hydrous aluminium silicates	Hydrous iron aluminium silicates[3]	Iron hydroxides
No. of analyses	4	5	5
SiO_2	46.34 – 60.03	43.96 – 63.73	1.38 – 2.81
TiO_2	0.01 – 0.07	0.02 – 0.04	0.09 – 0.19
Al_2O_3	26.21 – 35.95	9.21 – 23.06	2.67 – 3.20
Fe_2O_3[1]			76.39 – 77.21
FeO[2]	0.54 – 2.18	7.24 – 16.32	
MnO	0.01 – 0.11	0.01 – 0.16	0.02 – 0.10
MgO	0.29 – 0.72	1.35 – 3.58	0.30 – 0.37
CaO	0.09 – 0.40	0.28 – 0.78	0.33 – 0.47
Na_2O	0.09 – 0.41	0.16 – 0.29	0.10 – 0.15
K_2O	0.08 – 0.32	0.87 – 1.75	0.03 – 0.05

[1]Total iron as Fe_2O_3. [2]Total iron as FeO.
[3]Possibly a mixture of hydrous aluminium silicates and iron hydroxides.

For the identification of solid inclusions, Raman microspectroscopy of inclusions in faceted gems was combined with optical microscopy of polished thin sections and electron microprobe analyses of solids localized in these thin sections. In addition to optical microscopy in reflected and transmitted light, numerous back-scattered electron (BSE) images were obtained using the electron microprobe to evaluate homogeneity within included solids. This technique is very sensitive to compositional variations between the tourmaline host and its inclusions, and especially to compositional variations within non-homogeneous mineral grains. In addition, mineral grains in thin sections analysed by electron microprobe were also submitted to Raman microspectroscopy.

As a result, we were able to identify several minerals present as crystals with specific external forms or as single irregularly shaped mineral grains. In addition, non-homogenous inclusions consisting of several mineral phases within a single grain were also recorded.

a. *Single mineral phases (Figures 5-8).* Irregularly shaped plagioclase grains and euhedral quartz crystals are common inclusions. Numerous zircon crystals were also observed, frequently in close contact

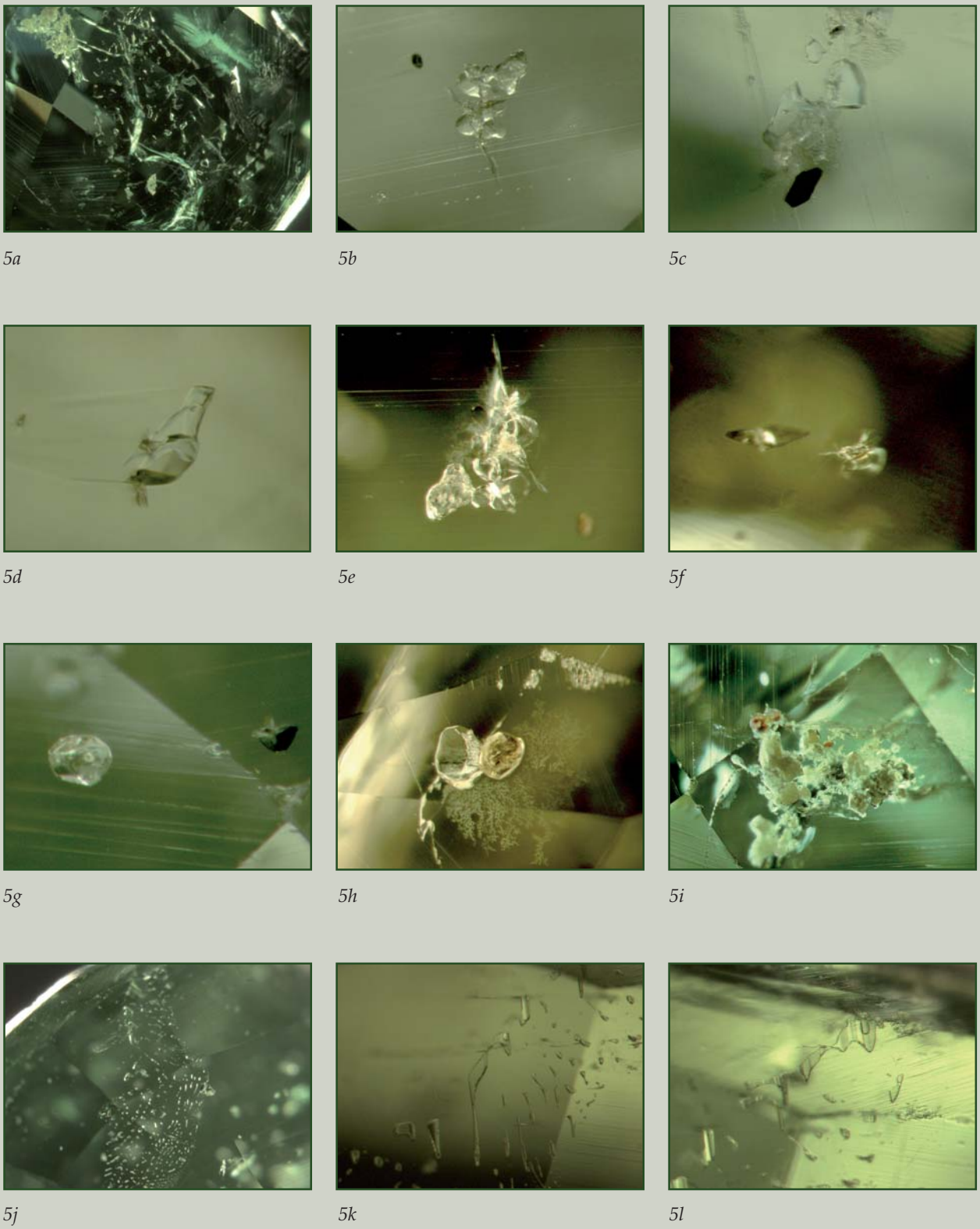

Figure 5: *Inclusion patterns of vanadium-bearing tourmalines from Madagascar as seen with the gemmological microscope:* (a) *general overview with aggregate of irregularly shaped, non-homogeneous grains consisting of hydrous aluminium silicates and iron hydroxides (upper left), cavities with liquid and two-phase (liquid and gas) filling, 80×;* (b) *aggregate of irregularly shaped plagioclases, 40×;* (c) *aggregate of irregularly shaped plagioclases and black graphite platelet, 80×;* (d) *irregularly shaped plagioclase, 80×;* (e) *aggregate with quartzes, plagioclase and zircons with tension cracks, 60×;* (f) *euhedral zircon crystals with tension cracks, 80×;* (g) *euhedral quartz crystal (left) and black graphite (right), 80×;* (h) *quartz and xenotime (right), 80×;* (i) *aggregate of irregularly shaped, non-homogeneous grains consisting of hydrous aluminium silicates and iron hydroxides, 80×;* (j) *cavities with liquid and two-phase (liquid and gas) filling, 60×;* (k) *cavities with liquid and two-phase (liquid and gas) filling, 80×;* (l) *cavities with liquid and two-phase (liquid and gas) filling, 80×.*

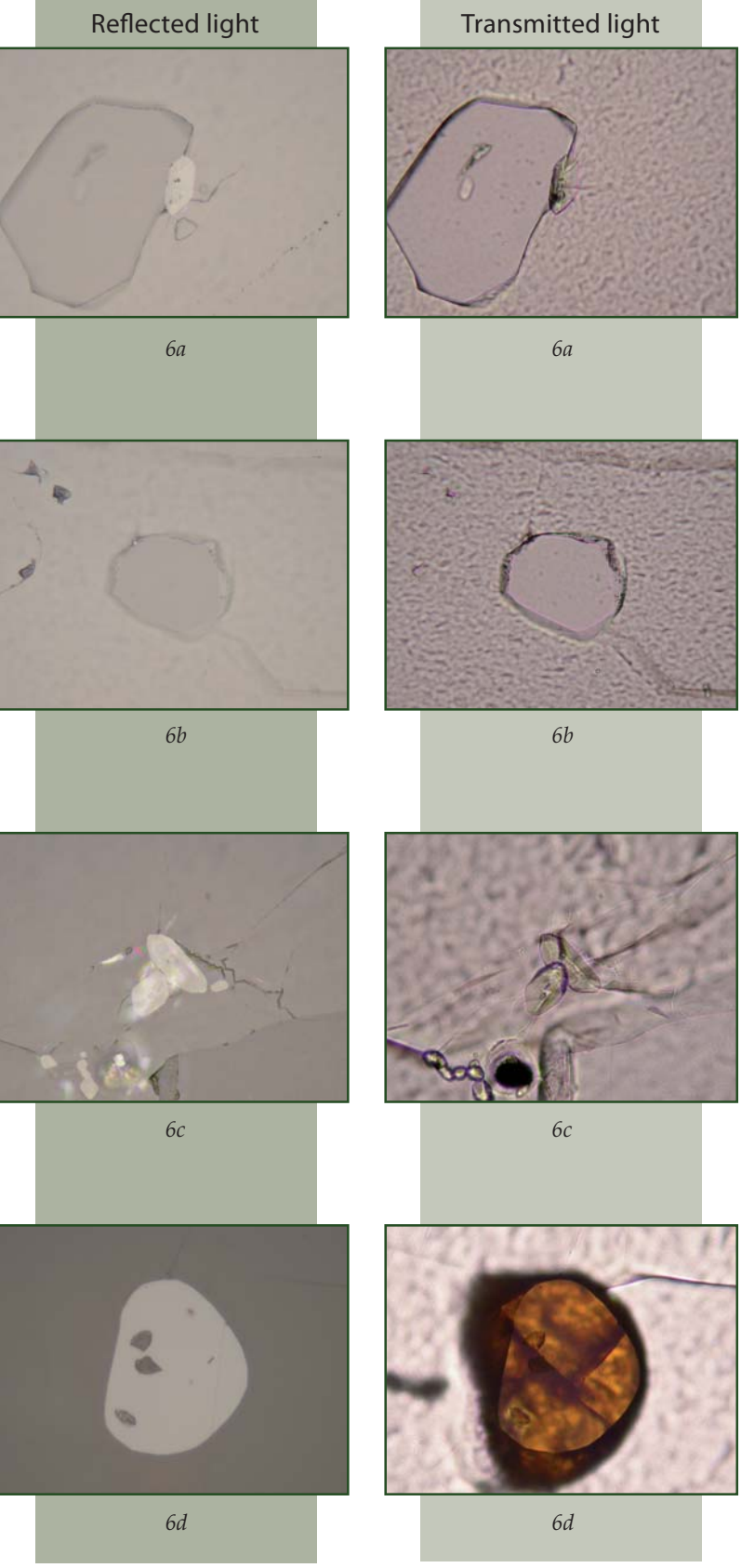

Figure 6: *Mineral inclusions in vanadium-bearing tourmalines from Madagascar as observed in polished thin sections in reflected (left column) and transmitted light (right column): (a) plagioclase and zircon, width of photo 0.35 mm; (b) quartz, width of photo 0.15 mm; (c) zircons, width of photo 0.15 mm; (d) rutile, width of photo 0.15 mm.*

with plagioclase or quartz grains. Less common are black graphite platelets, rutile and xenotime.

Quantitative analyses of 22 plagioclase grains in seven tourmaline host crystals were obtained and some representative analyses are given in *Table III*. All plagioclases represent a continuous compositional range from albite$_{28.4\%}$ anorthite$_{71.6\%}$ to albite$_{18.1\%}$anorthite$_{81.9\%}$, i.e. all analysed plagioclase grains are in the compositional range of bytownite.

b. *Non-homogeneous inclusions (Figures 5* and *9).* Fine-grained admixtures of several minerals are present in off-white to pale yellow, irregularly shaped grains in many tourmalines. In thin sections, they are visible as intensely intergrown colourless to off-white and reddish-brown phases (*Figure 9*), but were too small to identify unambiguously.

Quantitative microprobe analyses of several small to extremely small particles (*Table IV)* indicated that they are:

- hydrous Al-silicates, most probably clay minerals such as kaolinite (off-white to colourless component) and
- Fe-hydroxides with smaller amounts of Al and Si, most probably limonitic iron hydroxides (reddish-brown component)

Several grains or phases contain iron, aluminium, and silicon as major components, with smaller amounts of magnesium and potassium (*Table IV*). However, we were unable, even by a combination of quantitative electron microprobe analyses and Raman spectroscopy of the same grains to clarify if these inclusions represent

- hydrous Fe-Al-silicates which are admixtures of the two phases specified above, namely hydrous Al-silicates and Fe-hydroxides, or
- hydrous Fe-Al-silicates which are separate mineral species.

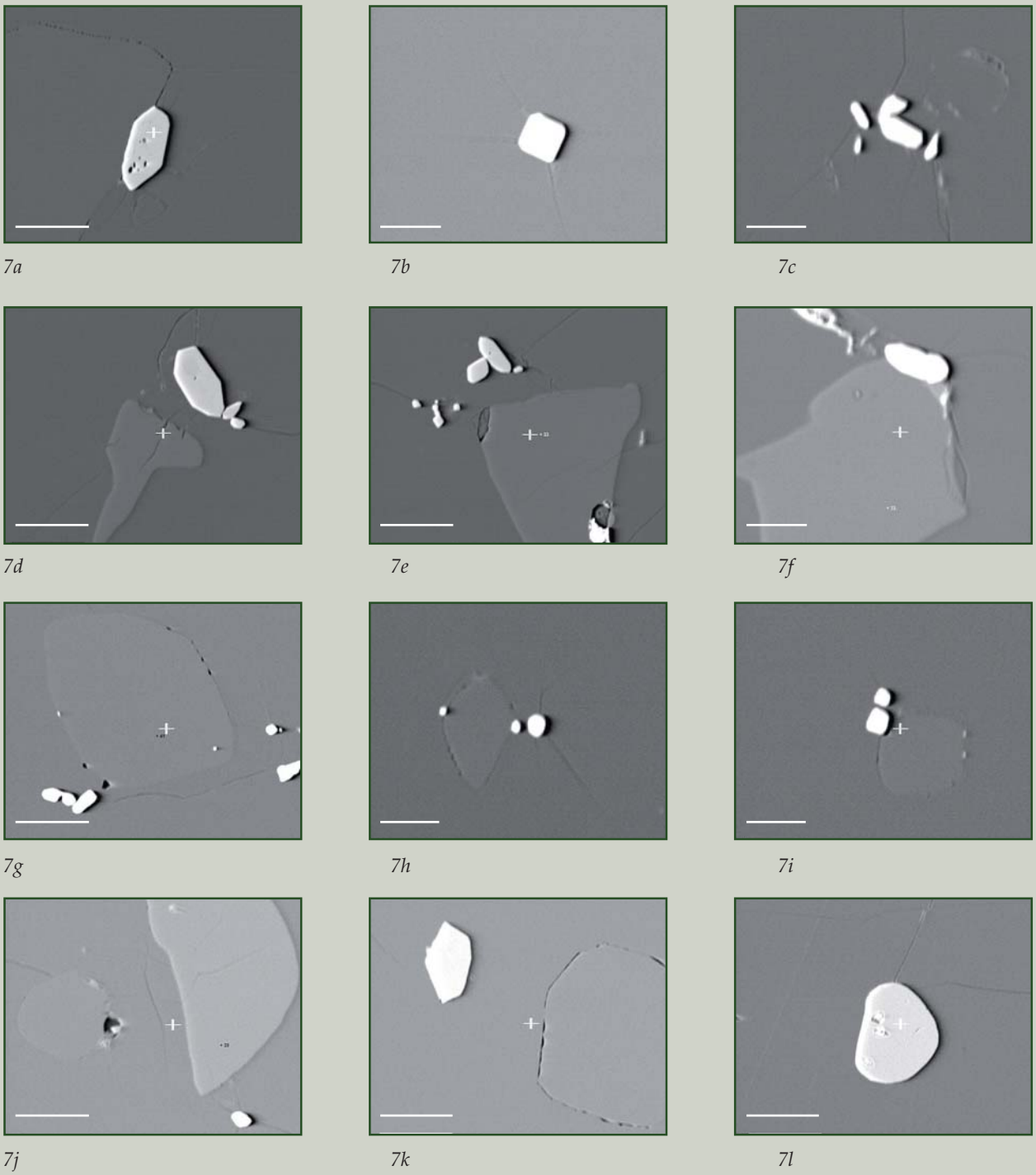

Figure 7: *Back-scattered electron (BSE) images of mineral inclusions in vanadium-bearing tourmalines from Madagascar as observed in polished thin sections: (upper row) zircons; (second row) plagioclases and zircons; (third row) quartzes and zircons; (lower row) plagioclase, quartz and zircon (left), quartz and rutile (centre), rutile (right). Zircons and rutiles show bright electron images. The bars at the bottom left of the images represent 50 µm in a, d, e, g, j, k and l, and 20 µm in b, c, f, h and i.*

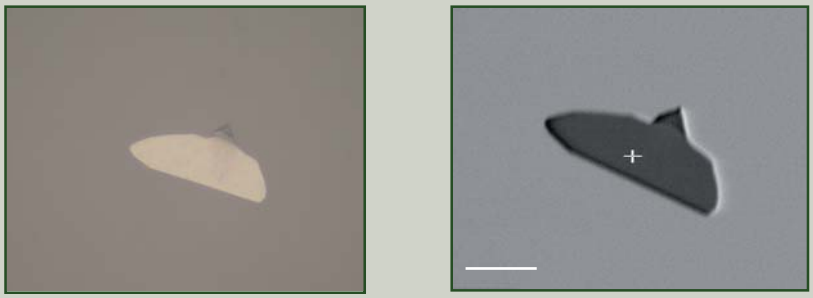

Figure 8: *Inclusion of graphite (bright) in reflected light (a, width of photo 0.15 mm) and back-scattered electron (BSE) image of graphite (dark) (b, the bar at the bottom left of the image represents 20 µm) in vanadium-bearing tourmaline from Madagascar.*

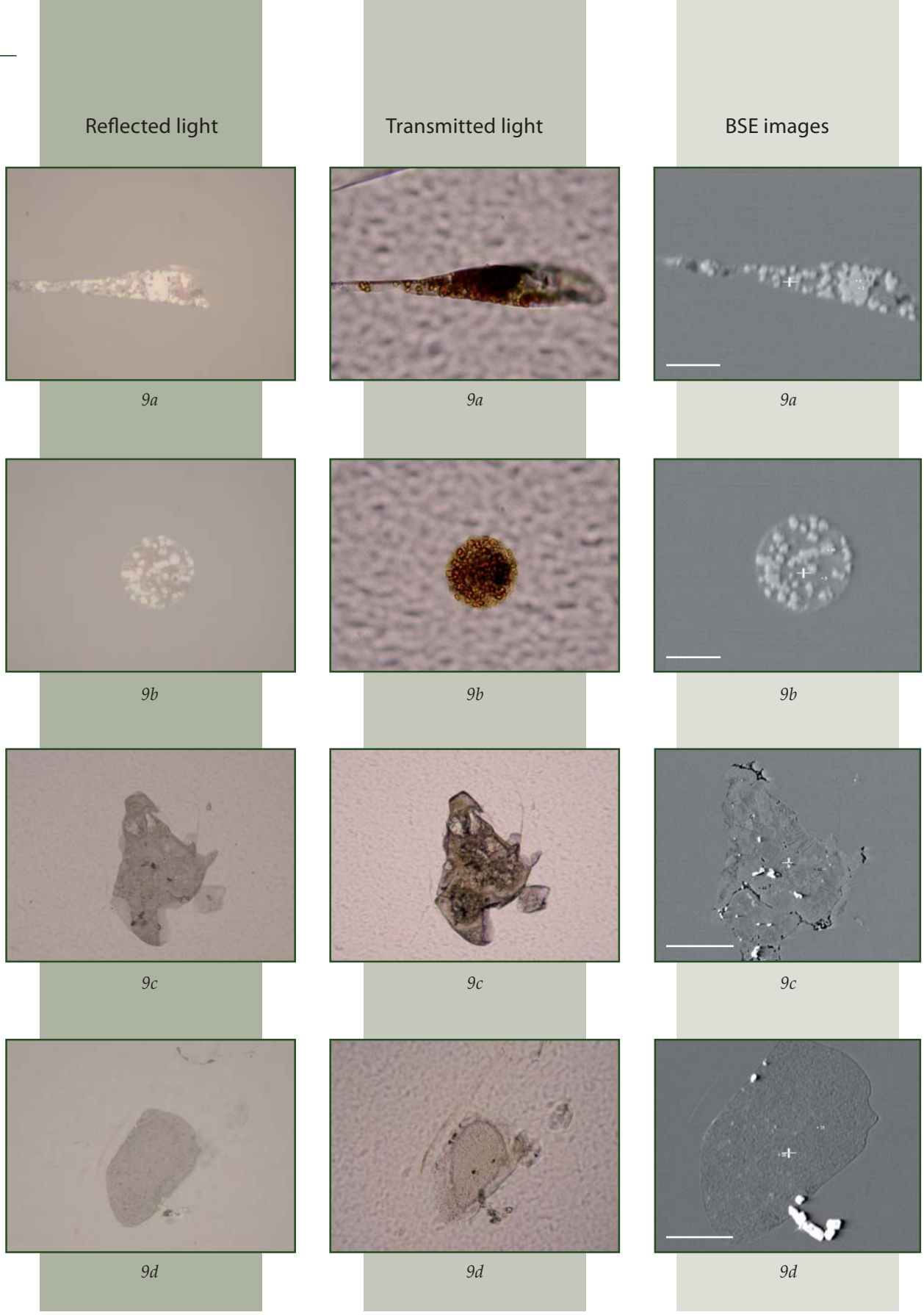

Figure 9: *Non-homogeneous mineral grains in vanadium-bearing tourmalines from Madagascar as observed in polished thin sections in reflected (left), in transmitted light (middle) and as back-scattered electron (BSE) images of the same grains (right). In the two grains pictured in 9a and 9b, iron hydroxides are dominant and hydrous aluminium silicates are subordinate mineral phases (width of all four photos 0.15 mm, the bars at the bottom left of the BSE images represent 20 µm). In the two grains pictured in 9c and 9d, hydrous aluminium silicates are dominant and iron hydroxides are subordinate mineral phases (width of all four photos 0.35 mm, the bars at the bottom left of the BSE images represent 100 µm in 9c and 50 µm in 9d).*

Table V: *Properties of some magnesium-bearing gem quality tourmalines from East Africa and Madagascar.*

Locality	Analysed samples	Colour	V_2O_3 (wt.%)	Cr_2O_3 (wt.%)	FeO[a] (wt.%)	Al (apfu)	Mg (apfu)	Designation
Landanai, Tanzania[1]	3	pale green to intense green	0.14 – 0.30	nd	nd	<6	>3	uvite
Gerevi Hills, Tanzania[1]	3	pale brown or green	0.11 – 0.36	nd	nd to 0.10	>6	<3	calcic aluminous dravite
Umba Valley, Tanzania[1]	1	green	0.44	0.15	nd	>6	<3	calcic aluminous dravite
Kwale District, Kenya[1]	4	green to intense green	1.78-4.03	nd to 0.55	nd	>6	<3	calcic aluminous dravite
Tsavo Park, Kenya[1]	1	green	0.08	0.53	0.02	>6	<3	calcic aluminous dravite
Lualenyi, Kenya[1]	1	brownish green	0.37	nd	0.17	>6	<3	calcic aluminous dravite
Voi-Taveta area, Kenya[2]	4	yellow	nd	nd	nd	>6	<3	calcic aluminous dravite
Lelatema (?), Tanzania[3]	2	green	0.04 – 0.06	0.36 – 0.64	nd	>6	<3	calcic aluminous dravite
East Africa[4]	9	pale green to intense green	0.18 – 1.54	0.03 – 0.17	nd	<6	>3	uvite
Umba Valley, Tanzania[5]	2	green	0.05	0.22 – 0.34	nd to 0.06	>6	<3	calcic aluminous dravite
Yellow Mine, Taita-Taveta District, Kenya[6]	4	yellow, green, blue green	nd to 0.03	0.01 – 0.43	nd to 0.03	>6 6	<3 3	calcic aluminous dravite calcic dravite
John Saul Mine, Taita-Taveta District, Kenya[6]	2	yellow green, yellow pink	0.01 – 0.14	0.06 – 0.09	0.07 – 0.92	>6	<3	calcic aluminous dravite
Mukongonyi, Taita-Taveta District, Kenya[6]	1	yellow brown	0.01	0.06	0.17	>6	<3	calcic aluminous dravite
Kavungu Mine, Jivunda, Zambia[7]	2	green	0.28 – 0.35	0.06 – 0.15	nd – 0.01	<6	>3	uvite
Southern Madagascar[8]	5	green	0.17 – 0.20	0.03 – 0.11	0. 01 – 0.02	>6	<3	calcic aluminous dravite

[a] Total iron as FeO. apfu = atoms per formula unit. nd = not detected.
[1] Schmetzer *et al*. (1979). [2] Hänni *et al*. (1981). [3] Bank and Henn (1988). [4] MacDonald and Hawthorne (1995).
[5] Halvorsen and Jensen (1997). [6] Simonet (2000). [7] Hainschwang *et al*. (2007). [8] this paper.

Discussion

Properties of magnesium-bearing tourmalines from East Africa, Zambia and Madagascar

Magnesium-bearing gem-quality tourmalines have been described from different localities in East Africa and recently also from Zambia (see *Table V*). On the basis of colour-causing trace elements, we can divide such tourmalines into three groups:

a. those samples with vanadium concentrations up to 4.03 wt.% V_2O_3, with distinctly smaller or no chromium content. According to our analytical results, the gem material from Madagascar belongs to this group.
b. a second group of localities supplied tourmalines with higher chromium than vanadium contents. The highest chromium content reported to date has been 0.64 wt.% Cr_2O_3.
The colour intensity of any tourmaline

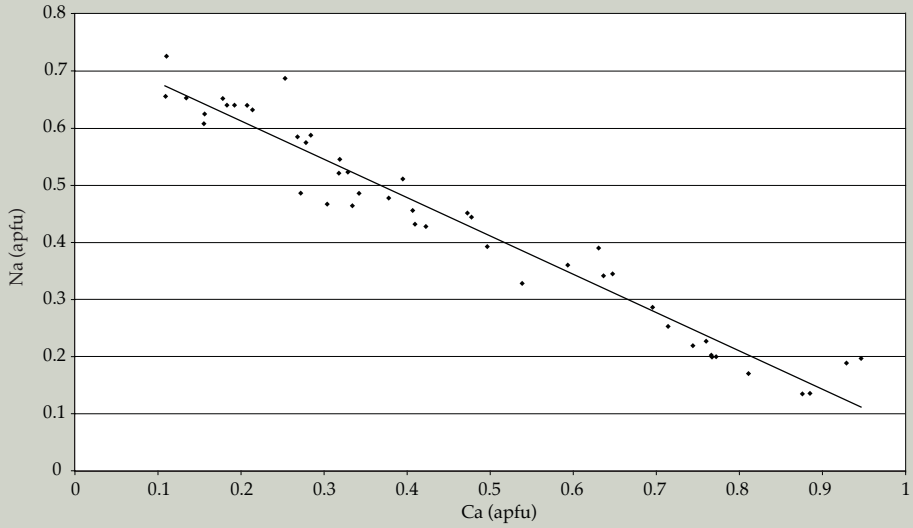

10a

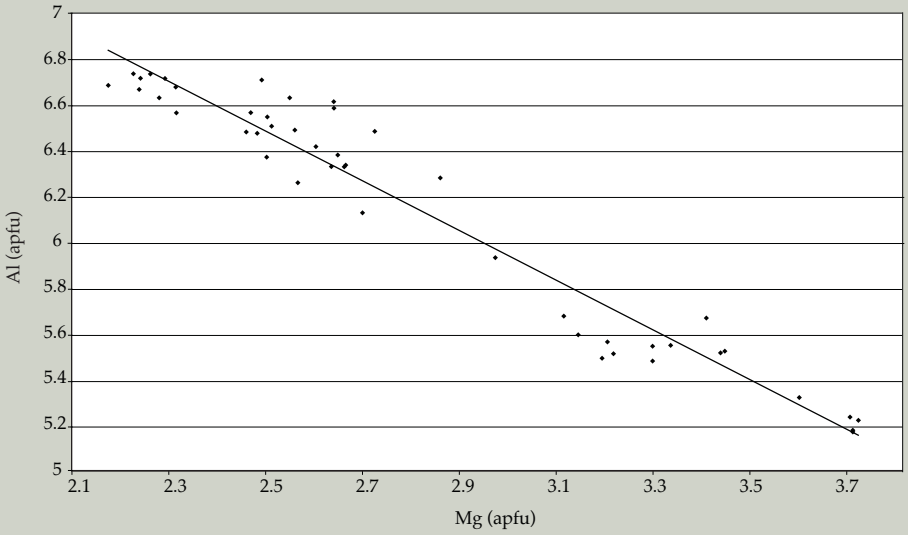

10b

Figure 10: *Correlation diagrams of site populations of various major components in X-, Y- and Z-sites of magnesium-bearing gem quality tourmalines from East Africa, Zambia and southern Madagascar; the diagrams are based on 37 analyses of tourmalines from East Africa, four analyses of tourmalines from Zambia and five analyses of tourmalines from southern Madagascar.*

10c

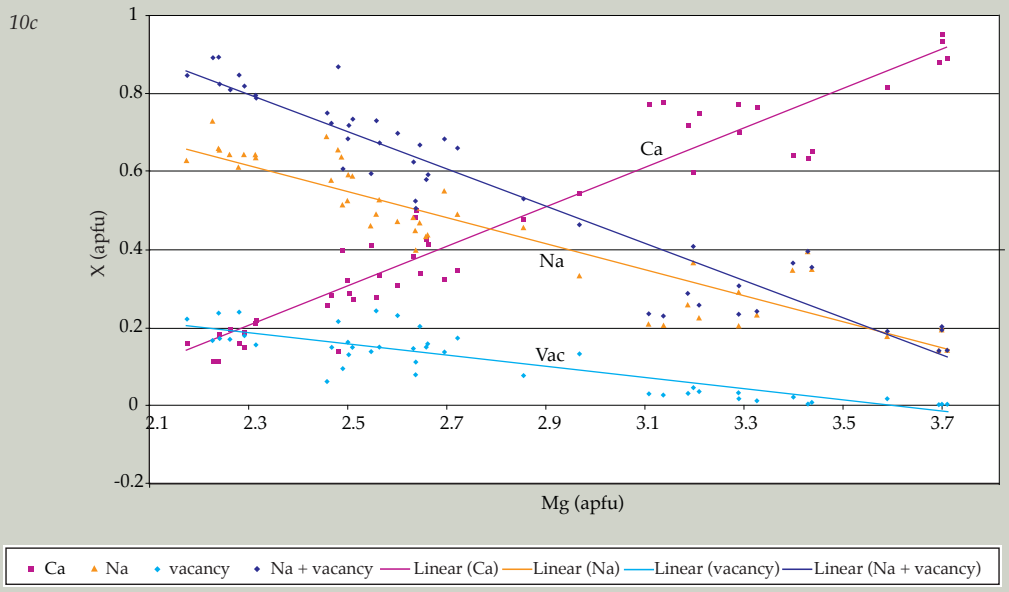
X (apfu)
Mg (apfu)
Ca
Na
Vac
Ca
Na
vacancy
Na + vacancy
Linear (Ca)
Linear (Na)
Linear (vacancy)
Linear (Na + vacancy)

10d

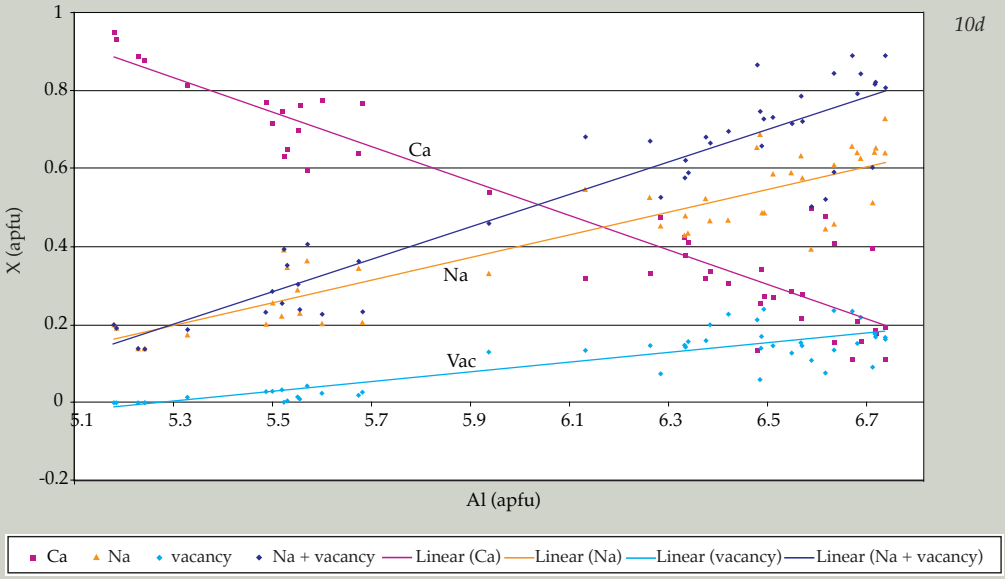
X (apfu)
Al (apfu)
Ca
Na
Vac
Ca
Na
vacancy
Na + vacancy
Linear (Ca)
Linear (Na)
Linear (vacancy)
Linear (Na + vacancy)

10e

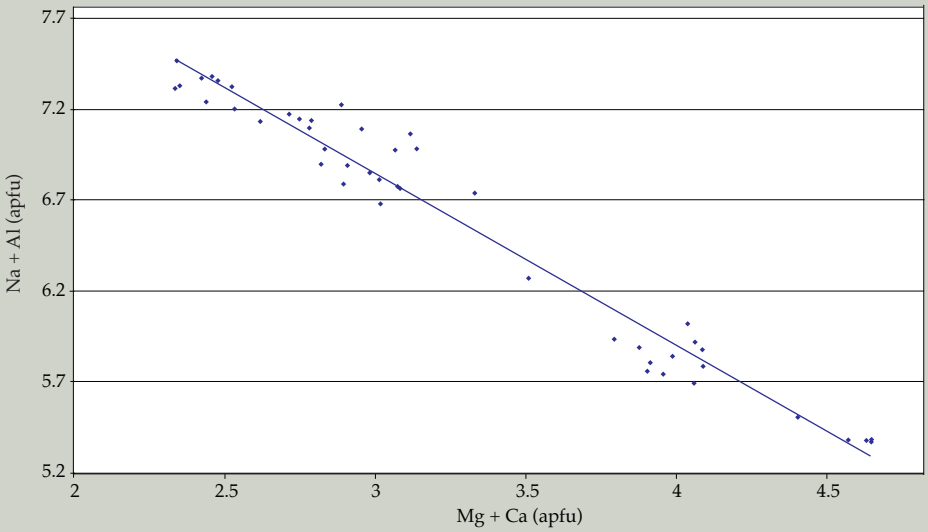
Na + Al (apfu)
Mg + Ca (apfu)

from either group is directly related to its vanadium or chromium contents.

c. In those tourmalines with vanadium or chromium and additional small iron and/or titanium contents, brownish green or brown colours may also be observed. Tourmalines with small iron and/or titanium contents, but without vanadium or chromium, are yellow, yellowish brown or brown.

The samples of all three groups with different coloration mentioned above, i.e. with V>Cr or with Cr>V or with Fe and/or Ti (without V or Cr), are sodium- and calcium-bearing, magnesium-rich aluminium tourmalines.

All these magnesium-bearing tourmalines show variation in their Na, Ca, Mg and Al contents and correlation diagrams have been plotted for the five samples from Madagascar, 37 analysed tourmalines from various literature references in East Africa and four samples from Zambia (see again *Table V*). In *Figure 10a*, there is a clear negative correlation between the site occupancies of sodium and calcium (X-site), and for the (Y+Z)-sites, there is also a negative correlation between the site occupancies of magnesium and aluminium (*Figure 10b*). Comparing the site populations of cations between X and (Y+Z) polyhedra, there are positive correlations between magnesium and calcium and between aluminium and sodium (*Figure 10 c,d*), and negative correlations between magnesium and sodium and between aluminium and calcium (*Figure 10 c,d*). Vacancies on the X-site show a positive correlation with Al-contents and a negative correlation with Mg-contents (*Figure 10 c,d*). These trends are also observed if we compare the sum of sodium and vacancies (Na + vacancy) with magnesium, calcium and aluminium (*Figure 10 c,d*). All these data indicate a coupled replacement of sodium or (sodium + vacancies) and aluminium by calcium and magnesium (*Figure 10e*).

This substitution is heterovalent and is the same as the known isomorphic replacement within the dravite $NaMg_3Al_6(BO_3)_3Si_6O_{18}(OH)_4$ – uvite $CaMg_3(MgAl_5)(BO_3)_3Si_6O_{18}(OH)_4$ solid solution series, which is represented by the scheme $(Na^{1+}+Al^{3+}) \leftrightarrow (Ca^{2+}+Mg^{2+})$.

The magnesium-bearing calcic tourmalines can be subdivided into two population fields. A first subgroup with Al<6 and Mg>3 apfu (atoms per formula unit), is consistent with the traditionally accepted composition and formula of uvite. A second subgroup consists of tourmalines, also with distinct calcium contents, but with Al>6 and Mg<3 apfu. The material from Madagascar belongs to this second subgroup, the samples of which can be designated as calcic aluminous dravites. Only one calcium-bearing sample (from the Yellow Mine, Kenya) had Mg-contents of 3 as well as Al-contents of 6 apfu and can be designated as calcic dravite. So far, no calcium-free dravites have been analysed from the different localities in East Africa, Zambia and Madagascar (see again *Table V*), neither within the bright green, vanadium- or chromium-bearing, nor within the yellow to brown, low-iron gem tourmalines. Vacancies on X-sites are more abundant in the group with Al>6 (aluminous dravites) than in the group with Al<6 (uvites) where they are fewer or almost negligible.

According to Henry and Guidotti (1985), tourmalines of the two subgroups mentioned above originate from two different types of host rocks:

a. tourmalines with Al<6 and Mg>3 apfu (uvites) originate from metacarbonates and meta-pyroxenites
b. tourmalines with Al>6 and Mg<3 (aluminous dravites) mainly originate from low-Ca meta-ultramafics and Cr,V-rich metasediments, but they also come from metapelites and metapsammites which may or may not coexist with an Al-saturating phase.

The different genetic origins of tourmalines of the two subgroups may well be the cause of their differences in composition.

Comparing the chemical compositions of gem-quality magnesium-bearing tourmalines from East Africa, Zambia and Madagascar with the formulae of different tourmaline end-members as proposed by Hawthorne and Henry (1999), we only have to consider the formulae and isomorphic replacement schemes of lithium- and iron-free members of the rather complex tourmaline solid solution series (*Table VI*). For a more detailed

Table VI: *Formulae of iron- and lithium-free tourmaline end-members and isomorphic replacement schemes.*

Formulae of tourmaline end-members[1]

Name (see box)	X-site	Y-site	Z-site	T	B	V	W
Dravite	Na	Mg_3	Al_6	Si_6O_{18}	$(BO_3)_3$	$(OH)_3$	(OH)
Oxy-dravite*	Na	Mg_2Al	Al_6	Si_6O_{18}	$(BO_3)_3$	$(OH)_3$	O
Olenite	Na	Al_3	Al_6	Si_6O_{18}	$(BO_3)_3$	O_3	(OH)
Uvite	Ca	Mg_3	$MgAl_5$	Si_6O_{18}	$(BO_3)_3$	$(OH)_3$	(OH)
Oxy-uvite*	Ca	Mg_3	Al_6	Si_6O_{18}	$(BO_3)_3$	$(OH)_3$	O
Calcic magnesium-foitite*	$Ca_{0.5}\,\square_{0.5}$	Mg_3	Al_6	Si_6O_{18}	$(BO_3)_3$	$(OH)_3$	(OH)
Magnesium-foitite*	$\square$	Mg_2Al	Al_6	Si_6O_{18}	$(BO_3)_3$	$(OH)_3$	(OH)

Isomorphic replacement schemes[1]

End-member	Dominant replacement scheme	End-member
Oxy-dravite*	$Al^{3+} + O^{2-} \leftrightarrow Mg^{2+} + (OH)^-$	Dravite
Oxy-uvite*	$Al^{3+} + O^{2-} \leftrightarrow Mg^{2+} + (OH)^-$	Uvite
Olenite	$Al^{3+} + O^{2-} \leftrightarrow Mg^{2+} + (OH)^-$	Dravite
Dravite	$Na^+ + Al^{3+} \leftrightarrow Ca^{2+} + Mg^{2+}$	Uvite
Oxy-dravite*	$Na^+ + Al^{3+} \leftrightarrow Ca^{2+} + Mg^{2+}$	Oxy-uvite*
Dravite	$Na^+ + (OH)^- \leftrightarrow Ca^{2+} + O^{2-}$	Oxy-uvite*
Dravite	$Na^+ \leftrightarrow 0.5\,Ca^{2+} + 0.5\,\square$	Calcic magnesium-foitite*
Oxy-dravite*	$Na^+ + O^{2-} \leftrightarrow \square + (OH)^-$	Magnesium-foitite*

* Hypothetical end-members. [1]The symbol $\square$ represents vacancies on X-sites.

discussion of possible Na,Ca substitution schemes in iron-bearing aluminium tourmalines, the reader is referred to the papers of Burt (1989), Henry and Dutrow (1990), Hawthorne (1996) as well as Hawthorne and Henry (1999).

It is evident that the tourmalines from East Africa, Zambia and southern Madagascar are sodium-calcium aluminium-magnesium tourmalines with the number of aluminium atoms per formula unit between 7 and 5 [7>Al(apfu)>5] and the number of magnesium atoms per formula unit between 2 and 4 [2<Mg(apfu)<4] . Sodium and calcium, on the other hand, both vary between 1 and 0 apfu. This is the known compositional range for Mg-bearing tourmalines, samples with Mg <2 apfu (compositional miscibility gap between oxy-dravite and olenite) or with Mg>4 apfu are extremely rare or unknown (see, e.g., Dunn, 1977; Dunn *et al*., 1977; Foit and Rosenberg, 1979). Consequently, the tourmalines are members of a solid solution series between the end-members oxy-dravite, $Na(Mg_2Al)Al_6(BO_3)_3Si_6O_{18}(OH)_3O$, and uvite, $CaMg_3(MgAl_5)(BO_3)_3Si_6O_{18}(OH)_4$. It is important to underline, that within the two end-members of this series, 1 Na apfu is replaced by 1 Ca apfu, and, in addition, 2 Al apfu are replaced by 2 Mg apfu. Charge balance within this series is maintained by dehydroxylation.

For this solid solution series the isomorphic replacement scheme does not correspond to any common replacement schemes between dravite and other magnesium-bearing tourmaline end-members given in *Table VI*. However, by a combination of the schemes oxy-dravite – dravite (identical with oxy-uvite – uvite): $Al^{3+} + O^{2-} \leftrightarrow Mg^{2+} + (OH)^-$ and dravite – uvite (identical with oxy-dravite – oxy-uvite): $Na^+ + Al^{3+} \leftrightarrow Ca^{2+} + Mg^{2+}$ we can derive an isomorphic replacement scheme between the

end-members oxy-dravite – uvite as follows:

$Na^{+} + 2Al^{3+} + O^{2-} \leftrightarrow Ca^{2+} + 2Mg^{2+} + (OH)^{-}$.

This scheme is dominant for the tourmaline solid solution series oxy-dravite – uvite and represents the compositional variability observed for the gem material from East Africa, Zambia and southern Madagascar.

In detail, to explain the average composition of our samples from Madagascar, $(Na_{0.4}Ca_{0.4}\square_{0.2})(Mg_{2.6}Al_{0.4})Al_6(BO_3)_3(Si_{5.9}Al_{0.1})O_{18}(OH_{3.25}F_{0.25}O_{0.5})$ and starting from a tourmaline end-member with oxy-dravite composition, the first substitution is in the oxy-dravite – uvite series: 0.3Na + 0.6Al + 0.3O → 0.3Ca + 0.6Mg + 0.3(OH) (*Table VI*, lower box, rows 5 and 2).

To derive the vacancies in the X-site, we have to add two further substitutions, which are formally represented by the series dravite – calcic magnesium-foitite and oxy-dravite – magnesium-foitite (*Table VI*, lower box, rows 7 and 8), which for the Madagascar tourmalines translates to:

0.2Na → 0.1Ca + 0.1□

and 0.1Na + 0.1 O → 0.1□ + 0.1(OH)

where the symbol □ indicates vacancies on X-sites. These three substitutions sum as follows:

0.6Na + 0.6Al + 0.4O → 0.4Ca + 0.2□ + 0.6Mg + 0.4(OH)

To complete the explanation of the composition of the Madagascar tourmalines, we have to consider the replacement of a small fraction of silicon by aluminium according to: $Si^{4+} + O^{2-} \rightarrow Al^{3+} + (OH)^{-}$, in the present case 0.1Si + 0.1O → 0.1Al + 0.1(OH).

Summary

The green gem-quality tourmalines from southern Madagascar are calcic aluminous dravites with limited compositional variability consisting mainly of coupled isomorphic replacement between (Na,Al) and (Ca,Mg), and vacancies on X-sites. The tourmalines are essentially iron- and lithium-free, but contain small amounts of vanadium and chromium, with $V_2O_3 > Cr_2O_3$ which is the cause of the green coloration.

Common solid inclusions are plagioclase (with a compositional variability within the bytownite field), quartz and zircon.

Irregularly shaped grains consist of a mixture of at least two minerals, namely hydrous aluminium silicates and iron hydroxide. We were unable to confirm whether more mineral phases – perhaps hydrous iron aluminium silicates – may be present within this admixture. Isolated cavities and healed fractures containing liquid and two-phase inclusions (liquid and gas) are also common.

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Clarification of measurement of the RIs of biaxial gemstones on the refractometer

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Abstract: *All possible refractometer observations on biaxial gemstones can be represented by four patterns shown in diagrams where RIs are plotted on the vertical axis and rotation angles on the horizontal axis. New understanding of the behaviour of biaxial gemstones on the refractometer is based on calculated movements of shadow edges for many different orientations of the optical elements and the gem table or a gem facet.*

Keywords: *biaxial gemstones, gem identification, refractive index calculations, refractometer*

Introduction

The refractometer is one of the oldest and the most reliable gemmological instruments and it is still the central instrument of many gemmologists. Modern refractometers are an improvement over older instruments as they have better optics and a larger scale that allows more precise readings, but the most important improvement is the availability of monochromatic light in small, battery-operated units that can be taken anywhere.

The great majority of gem identifications are based on determination of the minimum and the maximum refractive indices (RIs) that can be easily and accurately determined on any gemstone with well polished facets regardless of its optical orientation. Additional tests or procedures in identification are required only for those gemstones that show an overlap in their RIs with other gemstones. In these cases, a determination of the optic character or the optic sign is needed and this may be accomplished with the help of the polarizing filter.

However, many gemmologists have been reluctant to learn and apply this method, and many alternative methods based on observations without using the polarizing filter have been proposed and are described in gemmological textbooks and teaching manuals. These methods could not be comprehensively tested because of the limited understanding of the behaviour of biaxial gemstones on the refractometer and some of them may be incomplete, confusing or may even lead to incorrect identifications.

There is no reason for this problem to continue. Today we can use two different

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methods to predict observations on any gemstone regardless of the orientation of its optical elements relative to the gem table or any other facet. Every statement and every procedure new or old can be tested.

In 1942 Burbage and Anderson used an algebraic method to calculate RIs and the movements of the shadow edges on a topaz whose optical elements were in a particular orientation to the gem table. Recently, computer-based calculations were made for many different orientations of a chrysolite in *The Journal of Gemmology* by Xinhua Song *et al*., 2005.

In the same issue of *The Journal of Gemmology*, Sturman (2005) used a different method to test procedures for use of the polarizing filter in identifications using the refractometer. A brief overview of this graphic method, based on the use of the stereographic projections, is presented in the Appendix.

In this article, all possible observations on biaxial gemstones on the refractometer are discussed. Diagrams are used to represent observations on the refractometer during the rotation of a gemstone, with rotation angles plotted on the horizontal axis and the corresponding RIs on the vertical axis. In routine work, it is not necessary to record rotation angles and RIs, or to construct diagrams. Any observation on the refractometer can be related to a pattern presented on a diagram if three simple rules are followed:

1. Observe whether the shadow edges are constant (do not change during the rotation) or variable (show different RIs – i.e. move up and down).
2. Observe if they touch (get together) during the rotation – a single shadow edge is observed at a time.
3. Always rotate a gemstone in a clockwise direction and:
   a. where two variable shadow edges are visible, start the observation where the maximum RI (γ) is observed, or
   b. where a constant and a variable shadow edge are visible, start the observation where shadow edges are separated the most.

Review of optical properties of biaxial gemstones related to identifications on the refractometer

Identification of a gemstone on the refractometer is a very different process from the identification of a mineral grain on the polarizing microscope. Terms and concepts such as indicatrix, acute or obtuse bisectrix, the normal to the optic axes plane or positions of the principal vibration directions are very important for mineralogists. In contrast, they are of no importance to gemmologists using the refractometer for identification.

All that a gemmologist really needs to know is the following simple rule. In general, light is divided into two rays as it moves through an anisotropic (uniaxial or biaxial) gemstone. These two rays:

- are polarized and have different vibration directions – detected using a polariscope
- have different RIs – observed on the refractometer
- may have different absorption (colours) – detected using a dichroscope
- may move in slightly different directions – observed as image doubling with a lens, microscope or even with the naked eye.

The phrase 'in general' is used to indicate that there are exceptions to this rule; when light moves in special directions called the optic axes, it is not divided into two rays and continues to move in the same way as it would through an isotropic gemstone. In any other direction, two rays are formed and their properties (vibration directions, RIs, colours or the slight difference in directions in which they move) depend on the direction of light passing through a gemstone.

In order to understand the behaviour of light in biaxial gemstones, RIs for every possible direction should be examined and then represented in some informative way. Mineralogists use the indicatrix, where RIs are plotted on the vibration directions of light rays. It is extremely useful to mineralogists working on the polarizing microscope but is

of very limited use to gemmologists working with the refractometer.

In this article, RIs are related to directions of light rays through a gemstone – directions that constantly change during the rotation of a gemstone on the refractometer. Studies of the behaviour of light moving in many different directions show that biaxial gemstones have three characteristic RIs – principal RIs α, β and γ. Principal RI α has the lowest value, γ has the highest and β is an intermediate RI between the two. In most directions, as light is split into two rays, the observed RIs of the two rays are not the minimum and maximum but something in between and are marked as α' (a ray with the lower RI) and γ' (a ray with the higher RI). Studies showed another important fact; α' is always between α and β, and γ' is always between γ and β. Therefore, β is an equally important characteristic constant as the minimum and maximum RIs (α and γ).

Figure 1 shows two gemstones (sinhalite and peridot) with exactly the same minimum and maximum RIs; α=1.668 and γ=1.707. However, there is an essential difference in the way the light travels through sinhalite and peridot. In both gemstones, in general, two rays are formed but in sinhalite, the ray with the lower RI (α') is always between 1.668 and 1.698 and the other ray, γ' is always between 1.698 and 1.707. In peridot, α' is always between 1.668 and 1.688 and the other ray γ' is always between 1.688 and 1.707. In sinhalite β=1.698 and in peridot β=1.688 (see *a* and *b* in *Figure 1*).

Peridot and sinhalite may show the same minimum and maximum RIs but there is an essential difference in the value of the principal RI β that can be used in identification.

Observations on the refractometer

In general, when a biaxial gemstone is set on the refractometer and is rotated, then different directions of light passing through a gemstone are examined and different RIs are observed. However, we do not observe every possible direction of light travelling through a gemstone but only directions that are parallel to the gem table or a facet. A rotation of 180° is all that is needed to bring every direction in the gem table (or a facet) to coincide with the elongation axis of the refractometer (direction of light through the refractometer).

In general, two rays formed in a biaxial gemstone are seen as two shadow edges in the refractometer eyepiece. As a gemstone is rotated and directions of light are changed, the positions of the shadow edges may also change; as seen in the eyepiece, they may move up or down, they may stay constant, or they may diverge, converge or even join together.

These movements of the shadow edges – the behaviour of the biaxial gemstones on the refractometer during the rotation of the gem through 180° – depend on the orientation of the optical elements and the gem table or a facet. Only a limited number of directions may be observed (directions parallel to the gem table) and, therefore, limited movements of the shadow edges are seen. The observations presented in *Figure 1* are seldom seen in practice. It requires a very special position of the optical elements and the gem table. This is the only orientation where the full movements of both shadow edges can be seen; from α to β on the α' shadow edge and from γ to β on the γ' shadow edge.

- In biaxial gemstones with other orientations of the gem table and optical elements, the full movement (from α to β and from γ to β) may be seen on only one shadow edge; the movement of the other shadow edge is limited.

All possible orientations of the optical elements of biaxial gemstones and the gem table can produce many possible observations, but all observations can be described by the patterns shown in *Figures 1, 2, 3* and *4*.

These patterns can be further divided into two groups:

1. Patterns with two variable shadow edges – moving up and down during the rotation.
   a. Two variable shadow edges – touching
   b. Two variable shadow edges – not touching, and
2. Patterns where one shadow edge is

constant – showing the same reading during the rotation of the gem.
a. A constant and a variable shadow edge – intersecting in two points
b. A constant and a variable shadow edge – not touching.

Two variable shadow edges – touching (Figure 1)

The patterns shown in *Figure 1* were discussed above. Two variable shadow edges meet at one point during the rotation and a single shadow edge is seen only at this point. This single shadow edge gives the reading of the principal RI β. Unfortunately, the pattern shown in *Figure 1* is seldom seen in practical work. It is observed only on gemstones that have a very special orientation of the gem table (or a facet) and the optical elements. Determination of α and γ is straightforward; α is the minimum reading on the α' shadow edge and γ is the maximum reading on the γ' shadow edge. Principal RIs α and γ are generally observed at different rotation positions.

Two variable shadow edges – not touching (Figure 2)

This is the most common pattern of observation on biaxial gemstones (*Figure 2*). The lowest and highest RI readings for a gem can always be found when testing any flat polished

a. Sinhalite

α=*1.668* α'=*1.668 – 1.698* β=*1.698*
γ=*1.707* γ'=*1.698 – 1.707*

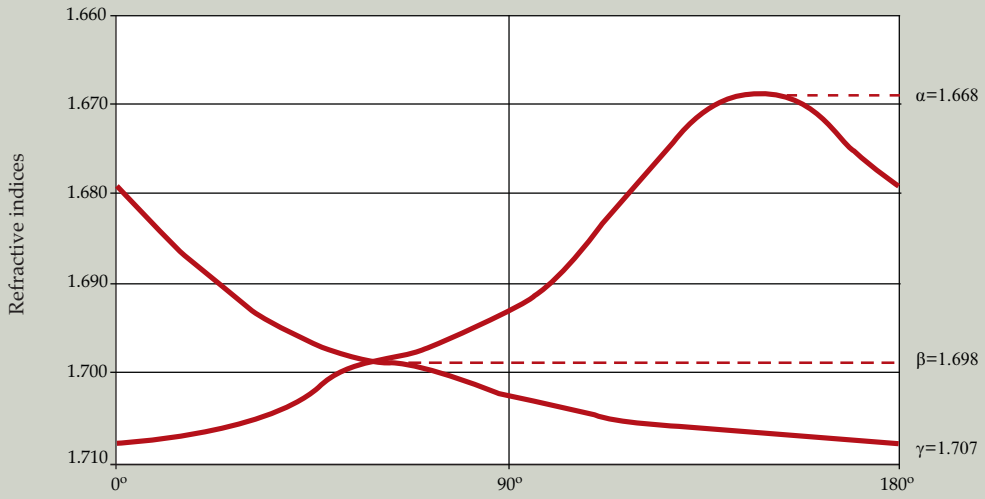

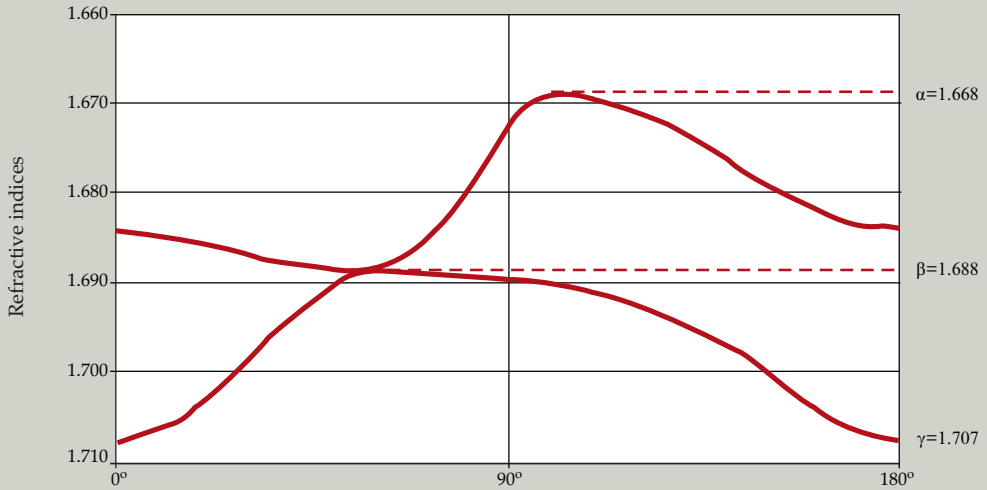

b. Peridot

α=*1.668* α'=*1.668 – 1.688* β=*1.688*
γ=*1.707* γ'=*1.688 – 1.707*

Figure 1: *Patterns of RI variation with rotation of biaxial gemstones on a refractometer: two variable shadow edges – touching. Two shadow edges (α' and γ') meet in one rotation position where a single shadow is seen, giving the value of the principal RI β.*

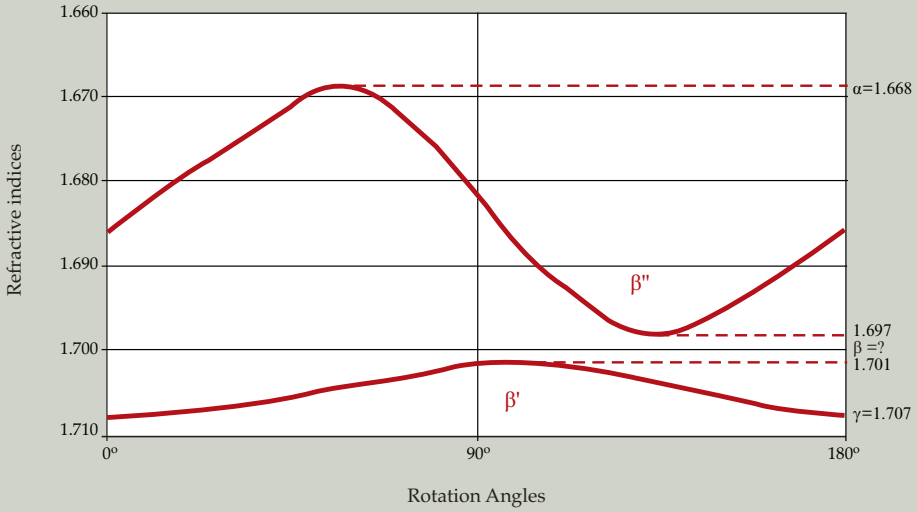

a. *Two possible* β *readings should be recorded as:*

From γ'	*From* α'
γ=*1.707*	α=*1.668*
β'=*1.701*	β"=*1.697*

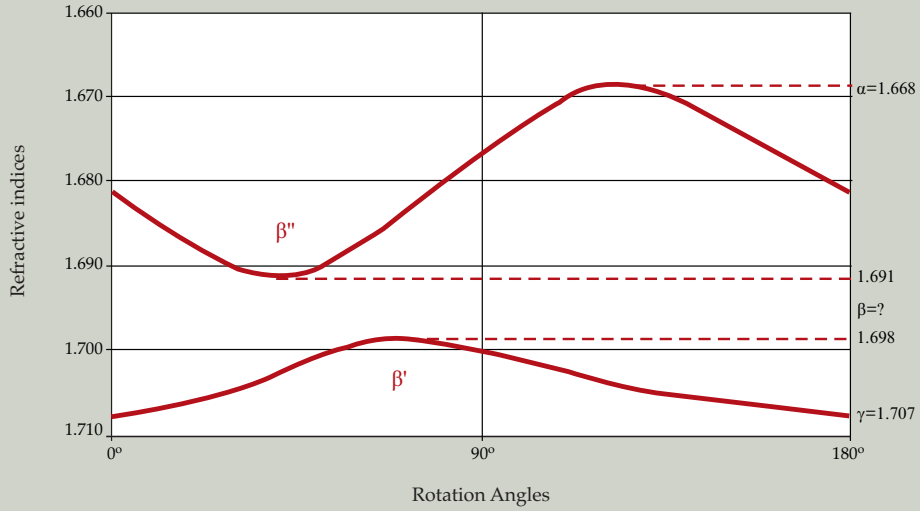

b. *Two possible* β *readings should be recorded as:*

From γ'	*From* α'
γ=*1.707*	α= *1.668*
β'=*1.698*	β"= *1.691*

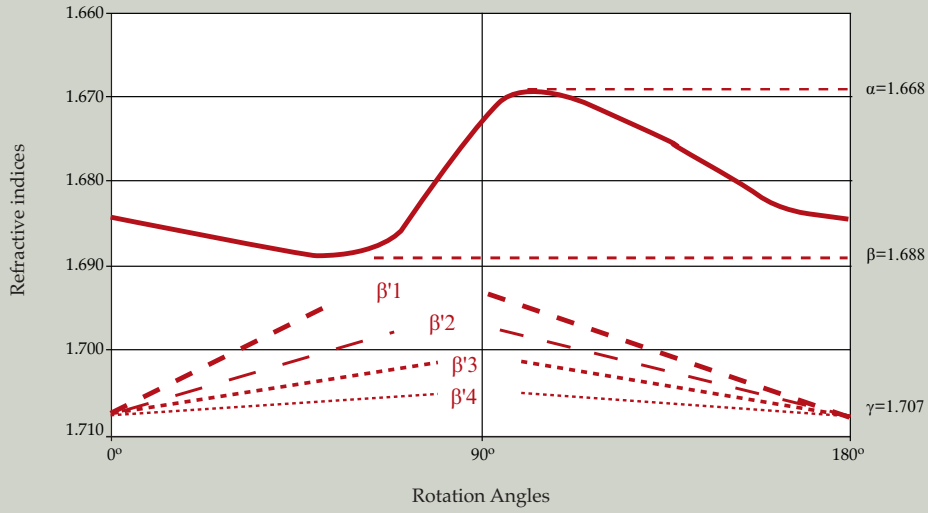

c. *Shadow edge* α' *moves all the way from* α *to* β.
Shadow edge γ' *may show many possible* β' *readings – they depend on the orientation of the gem table and optical elements.*

Figure 2: *Two variable shadow edges – not touching.*

surface on a gem. Thus, α is the minimum reading on the α' shadow edge and γ is the maximum reading on the γ' shadow edge. Principal RIs α and γ are generally observed at different rotation positions.

- While one shadow edge always moves from the minimum or maximum RI to β, the movement of the other shadow edge is limited – it does not move all the way to β.

Therefore, there are two positions observed during the rotation that may give the value of β (*Figure 2a* and *2b*):

- the lowest reading on γ' and
- the highest reading on α'.

A polarizing filter or additional procedures must be used to decide which β is correct and identify the true β.

It is important to remember that one shadow edge (either α' or γ') will always move to β – the true β – but that the value of false β seen on the other shadow edge depends on the orientation of the gem table (or facet) and the optical elements. In *Figure 2c* the pattern is shown where the α' shadow edge moves from α to β. The movement of the γ' shadow edge is limited and can change direction at any value. Several possible β' positions (β'1, β'2, etc) are shown to illustrate some of the many possible observations on gemstones with different orientations of the gem table and the optical elements.

The text comments in *a* and *b* of *Figure 2* show a simple way of keeping a record of observations that can be used later in interpretation of data – if needed. There is no need to construct a diagram, or to record rotation angles and corresponding readings of the RIs etc. All that is needed are four readings in rotation positions that can easily be identified. The main advantage of this method is that the original observation is easily repeated after a few hours or after several years – by the same observer or by a new one.

The γ' shadow edge is observed first and the maximum RI γ is recorded. This is the starting point of any future observation. The gemstone is then rotated and the γ' shadow edge is observed until the position of β' (the minimum reading on γ') is found and recorded. After this, the gemstone is rotated back to the starting position and then the α' shadow edge is observed. As a gemstone is rotated (always clockwise, for consistency) the readings on the α' shadow edge may either increase or decrease. *Figure 2a* shows an example where readings on α' first decrease to α (the lowest reading on the α' shadow edge) and then the readings increase to β'' (the highest reading on the α' shadow edge). In other gemstones with different orientations of the optical elements and the gem table (e.g. in *Figure 2b*), the readings on the α' shadow edge may first increase to β'' and then decrease to α.

A constant and a variable shadow edge – intersecting at two positions (Figure 3)

The pattern in *Figure 3a* is characterized by one shadow edge that gives a constant reading during the rotation. The other shadow edge is variable and moves up and down between the maximum RI γ and the minimum RI α. During the rotation of a gemstone on the refractometer, the distance between the constant and the variable shadow edges gets smaller and smaller until they meet in two rotation positions and only a single shadow edge is observed. These rotation positions give the value of β; α and γ are recorded as the minimum and the maximum RIs. The pattern shown in *Figure 3a* is rarely observed because it requires a very special orientation.

Much more commonly observed are patterns on gemstones where the alignment of the optical elements and the gem table (or a facet) is at a small angle to the special orientation of *Figure 3a*. *Figure 3b* shows such a pattern. It is still possible to get a close estimate of β because both shadow edges move to almost the same reading, but not at the same stage of the rotation. Although β' and β'' seem to be the same, they are not, but the difference is too small to be seen on the refractometer scale. This pattern is easily recognized as being similar to that in *Figure 3a*. Either one or the other shadow edge stays constant at the β reading during a long period of the rotation but when it moves it may be sudden and fast. Care must be taken to make sure that the minimum and the maximum RIs (α and γ) are accurately determined because of possible fast

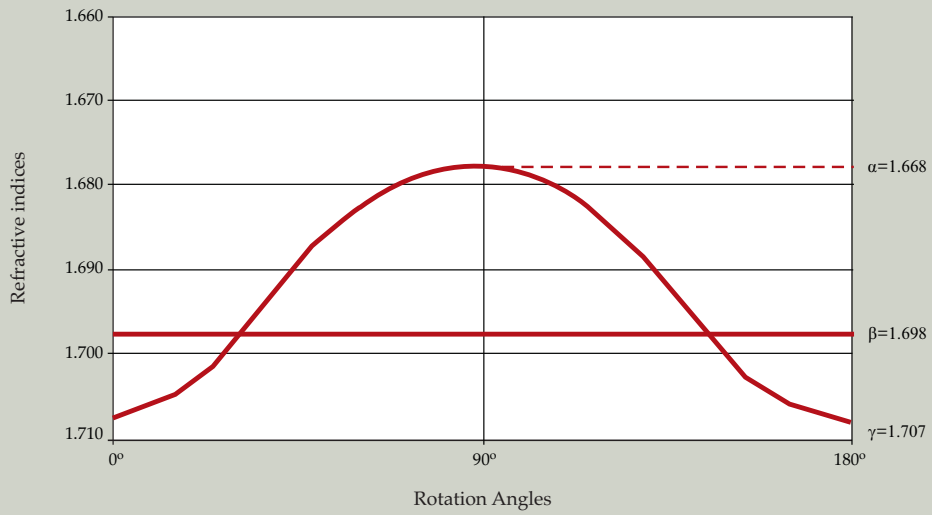

a. *A rarely observed pattern in biaxial gemstones, only seen when the principal vibration direction Y is precisely perpendicular to the gem table. During rotation of 180°, one shadow edge stays constant – giving β. At two rotation positions, the constant and the variable shadow edges join together – making a single shadow edge.*

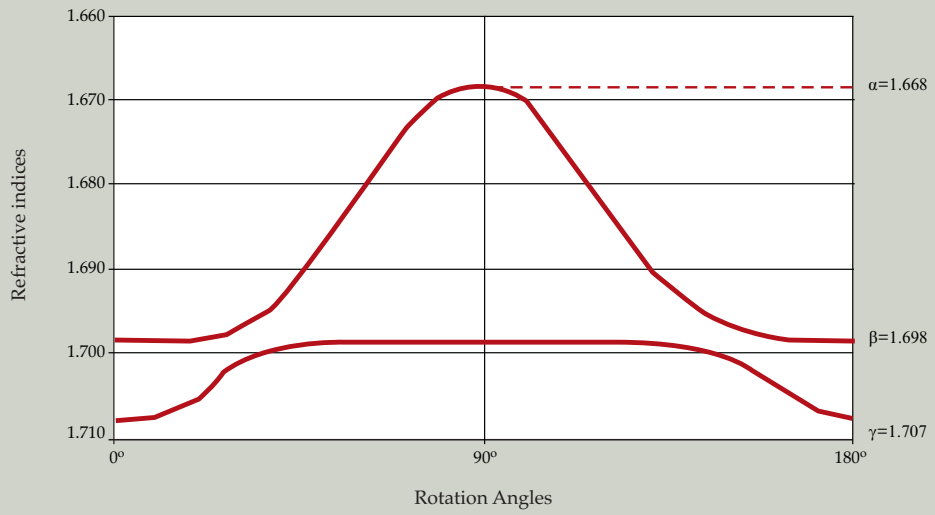

b. *This pattern is produced when the principal vibration direction Y is not quite perpendicular to the gem table. Two variable shadow edges stay separated at all times during rotation. On determining β, make sure that both shadow edges move to the same value. If not, go to c.*

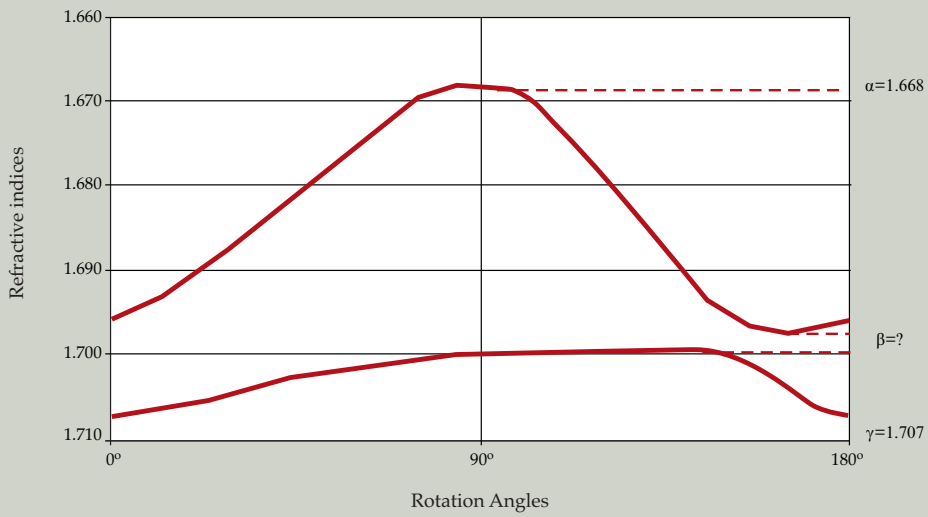

c. *When both shadow edges do not move to the same β, the polarizing filter must be used to identify the true β.*

Figure 3: *A variable and a constant shadow edge intersecting; and a variable and near-constant shadow edges almost touching.*

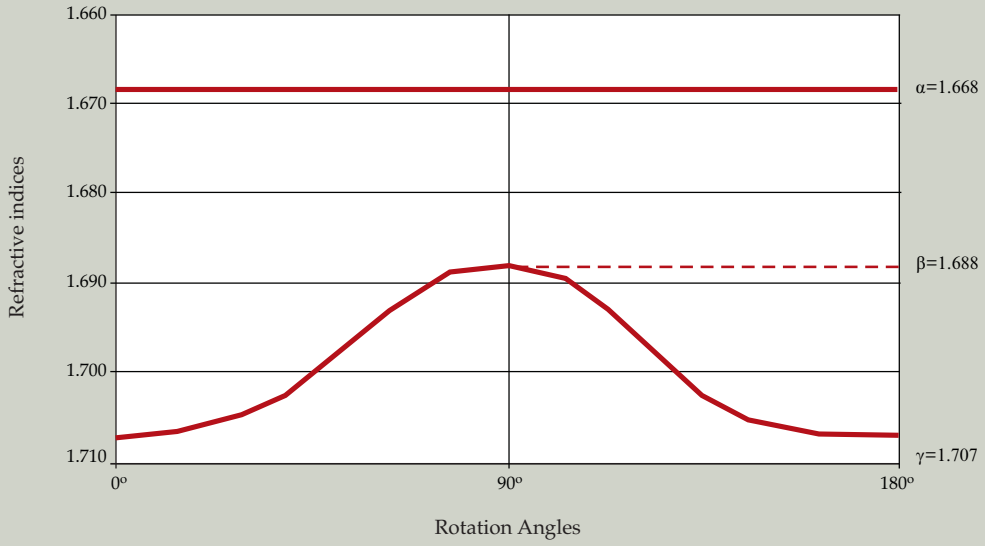

a. *A biaxial gemstone (peridot) in a special orientation of the gem table and optical elements.* α *is determined on the constant shadow edge and* β *and* γ *are determined on the variable shadow edge.*

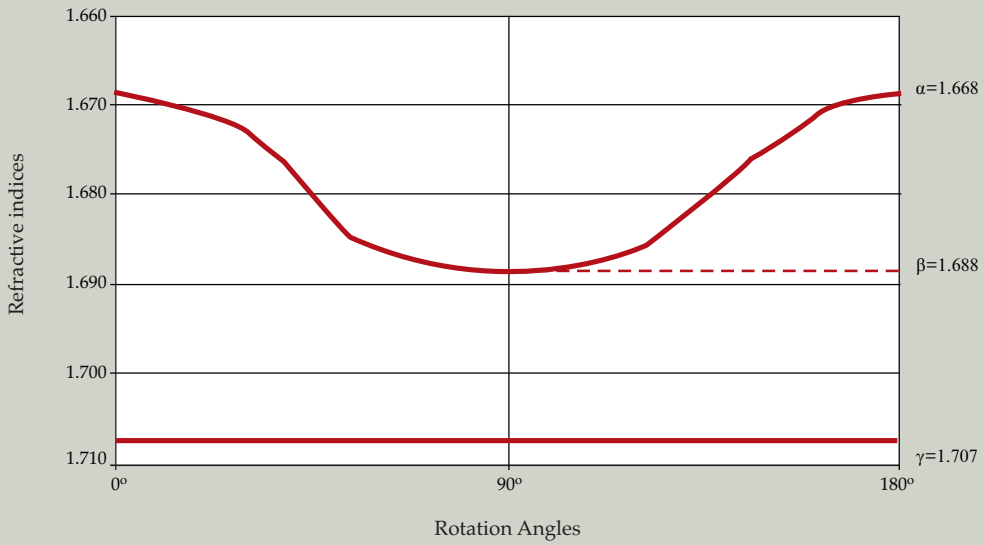

b. *A biaxial gemstone (peridot) in another special orientation of the gem table and optical elements.* γ *is determined on the constant shadow edge and* α *and* β *are determined on the variable shadow edge.*

Figure 4: *A constant and a variable shadow edge – not touching.*

movements of the shadow edges at the rotation positions where α and γ are determined.

Figure 3c shows a pattern where neither shadow edge moves to the same reading. The rotation patterns still show extensive ranges where either one or the other shadow edge stays close to the β reading but the polarizing filter or other procedures must be used to identify the true β.

A constant and a variable shadow edge – not touching (Figure 4)

The patterns shown in *Figures 4a* and *4b* can be observed both on uniaxial and on biaxial gemstones in special orientations of the optical elements and gem table. Either α or γ stays as a constant shadow edge during the rotation.

In *Figure 4a* the principal RI α is seen as a constant shadow edge while the variable shadow edge γ' moves from maximum separation at γ to β. In *Figure 4b* the principal RI γ is seen as a constant shadow edge, while the variable shadow edge moves from α to β.

- It is important to remember that other tests must be used to determine whether a gemstone is uniaxial or biaxial.

However, once a stone is identified as biaxial, its three principal RIs (α, β, γ) can easily be determined.

Conclusions

All possible movements of shadow edges observed on biaxial gemstones during rotation on the refractometer can be described by four sets of patterns shown in *Figures 1, 2, 3* and *4*. On some patterns the three principal RIs (α, β, γ), the optic character and the optic sign, can easily be determined; on other patterns additional tests are needed or the polarizing filter must be used.

- Determination of α and γ is straightforward – they are the minimum and the maximum RIs present in all patterns.
- Determination of β is straightforward in some patterns – see *Figure 1* and *Figure 3*.
- In rotation patterns like those in *Figure 4*, the polarizing filter must be used to identify the stone as uniaxial or biaxial. However, once it is identified as biaxial, all three RIs (α, β, γ) can be read directly during the rotation.
- In the most common pattern *(Figure 2)*, additional tests must be made or the polarizing filter must be used, in order to identify the true β.

The great majority of observations on biaxial gemstones are variations of a pattern described in *Figure 2* – two variable shadow edges not touching. The other patterns in *Figures 1, 3* and *4* require special orientations of the optical elements and the gem table (or a facet) and are only rarely observed. The reason that they are observed at all is that gem cutters sometimes use a large crystal face as the gem table. In many orthorhombic or monoclinic gemstones for example, optical elements are in special orientations with the large faces and these show the features explained in *Figures 1, 3* and *4*.

Acknowledgement

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Appendix

Calculation of the RIs of biaxial gemstones during rotation on the refractometer

First step

Determination of the vibration directions (x' and z') for selected positions during the rotation of a gemstone on the refractometer. Stereographic projection (with the plane of the projection set parallel to the gem table) and the modified Biot-Fresnel construction were used.

Second step

Determination of the positions of a particular vibration direction (x' or z') in relation to the principal vibration directions X, Y and Z. In order to make these measurements simpler, the stereographic projection was rotated so that principal vibration directions were in the standard position (Z vertical and X horizontal with phi=0°) and angles phi and rho were measured for each particular vibration direction (x' or z').

Third step

Equation of the indicatrix given in many textbooks (for example, Bloss: Optical Crystallography (1961), p.155, equation 9-2) was used to calculate RI for each vibration direction (x' or z'). These calculated RIs and the rotation angles were then plotted on diagrams in order to show movement patterns of the shadow edges.

Determination of the optic axial angle in biaxial gemstones and its use in gemmology

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Abstract: *From the very beginning of the use of the refractometer in identification of gemstones, gemmologists faced two problems:*

- *how to differentiate between biaxial gemstones with similar or overlapping RIs*
- *how to distinguish a uniaxial and a biaxial stone in an orientation which produced one variable and one constant shadow edge.*

The use of the polarizing filter to solve these problems can be avoided in many cases by the use of the optic axial angle method. The most important feature of this method is that it is reliable. Also, whether or not the method can be applied is quick to determine.

Determination of an optic axial angle can be made on a simple diagram and the list of biaxial gemstones and their optic axial angles are shown. Determination of the optic axial angle requires the same data as determination of the optic sign but it is a much more discriminatory constant for use in identification of biaxial gemstones.

Keywords: *biaxial gemstones, optic axial angle diagram*

Introduction

Optical mineralogy has played a very important role in the development of our understanding of earth processes and earth materials. From the mid-nineteenth to the mid-twentieth century, many methods were developed and various accessories designed for the study of minerals and rocks with the polarizing microscope. A large amount of data on the optical properties of minerals was collected and used, not only to identify minerals in rocks but also to determine their chemical composition and structural state, thus giving important clues on the conditions under which rocks were formed and about the geological forces that affected them.

Optical gemmology uses many of the concepts, methods and data on the optical properties of minerals in the study of gems. There are, however, some concepts in optical mineralogy that have not been properly applied in gemmology. One such concept is the use of the optic axial angle in identification of biaxial gemstones.

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The main reason for this is that very different procedures are used for its determination: in gemmology it is done on the refractometer, whereas in mineralogy the polarizing microscope is used.

The optic sign (positive or negative) and the optic axial angle (the angle between the optic axes) are very important constants in identification of biaxial mineral grains with the polarizing microscope. They are observed with a special lens on the polarizing microscope producing conoscopic light and these constants (optic sign and optic axial angle) are fully independent from other determinations. A mineralogist may make an error in estimates of refractive indices (RIs) or birefringence of some mineral grain but this does not in any way affect the determination of the optic sign and the optic axial angle.

The optic sign and the optic axial angle of biaxial gemstones are determined in a very different way in gemmology. They are calculated from the principal RIs α, β and γ, which are determined on the refractometer.

The rule for the optic sign is very simple:

$\beta-\alpha < \gamma-\beta$ - optic sign is positive

$\beta-\alpha > \gamma-\beta$ - optic sign is negative

Equally simple is determination of the optic axial angle on the diagram in *Figure 1* from differences β-α and γ-β.

Any error in the determination of the principal RIs (α, β and γ) can lead to a wrong determination of the optic sign or the optic axial angle and consequently to the incorrect identification of a gemstone.

Determination and the use of the optic angle in gemmology

Determination of the optic axial angle, the angle between the optic axes in biaxial gemstones, can be made quite straightforward, and requires similar data to those needed to determine the optic sign. All three RIs, α, β and γ, are determined on the refractometer and the differences β-α and γ-β are calculated and plotted on the optic axial angle diagram in *Figure 1*. An example of use of the diagram and the list of biaxial gemstones and their optic axial angles are also shown in this figure. The construction of the diagram is described in Appendix I.

The difference between the use of the optic sign and the optic axial angle can best be explained by a simple example. The optic sign divides gemstones into two groups, positive and negative, in the same way as, for example, gemstones can be divided into colourless and coloured. The optic axial angle divides biaxial gemstones into many small groups in the same way as the information on colour can be used to divide coloured gemstones into many smaller and well defined groups (blue, red, yellow, etc). Therefore, the use of the optic axial angle in gemmology is potentially of greater help in identification of gemstones on the refractometer.

Such use can be applied in three different sets of circumstances:

1. to differentiate between biaxial gemstones with overlapping RIs – if β can be observed directly (*Figure 2*);
2. to differentiate between biaxial gemstones with overlapping RIs – if two solutions for β are possible (*Figure 3*),
3. to differentiate between a uniaxial gemstone and a biaxial gemstone (with special orientation of the gem table and the optical elements) (*Figure 4*).

In the discussion, diagrams are used to show the movements of the shadow edges during the rotation of a gemstone on the refractometer (*Figures 2, 3* and *4*). The rotation angles are plotted on the horizontal axis of a diagram and the corresponding RIs on the vertical axis. Diagrams are also used to indicate rotation positions where α, β and γ are determined. In the routine work, there is no need to record and plot the rotation angles and corresponding RIs every 30° or 60° in order to make diagrams. All that is required is to recognize the special rotation positions at which α, β and γ can be determined and this can be mastered in a few minutes by comparing diagrams with observations on a particular gemstone.

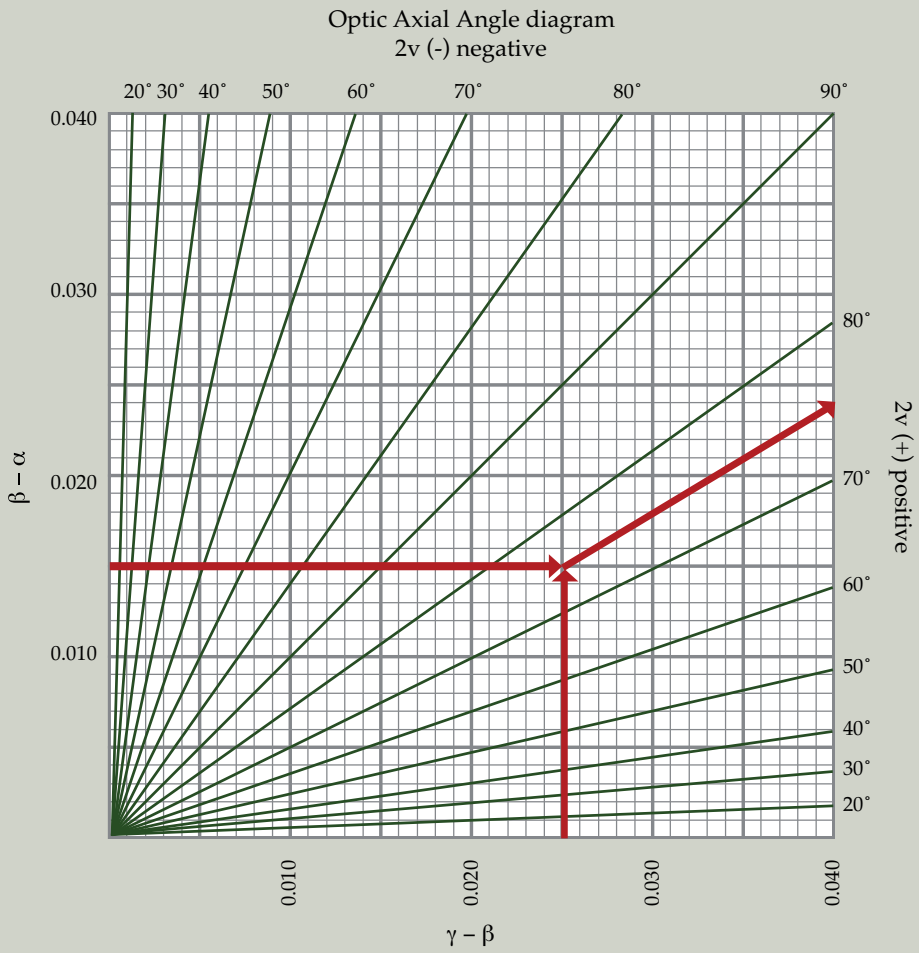

Figure 1: *Optic axial angle diagram with plotted example of gemstone with α 1.600, β 1.615, γ 1.640; so β - α = 0.015, γ - β = 0.025 and 2V is + 75°. List of biaxial gemstones with their optic axial angle and sign.*

Biaxial Gemstones

Name	2V (sign)	
Actinolite	80 -85	(-)
Albite	~90	
Amblygonite	70 -85	(+)
Andalusite	~90	
Aragonite	20	(-)
Augelite	50	(+)
Axinite	65 -85	(-)
Baryte	40	(+)
Beryllonite	70	(-)
Boracite	80 -90	(+)
Brazilianite	70 -75	(+)
Chrysoberyl	30 -70	(+)
Colemanite	55	(+)
Danburite	~90	
Datolite	75	(-)
Diaspore	85	(+)
Diopside	55 -60	(+)
Enstatite	45 -90	(+)
Epidote	~90	
Euclase	50	(+)

Name	2V (sign)	
Grandidierite	30	(-)
Hambergite	~90	
Herderite	70	(-)
Iolite	40 -90	(-)
Kornerupine	5 -50	(-)
Kyanite	80	(-)
Labradorite	~90	
Lazulite	65 -70	(-)
Legrandite	35 -50	(+)
Natrolite	60 -65	(+)
Orthoclase/Sanidine	20 -90	(-)
Peridot	~90	
Petalite	~90	
Rhodonite	60 -70	(+)
Sillimanite	20 -30	(+)
Sinhalite	55	(-)
Spodumene	50 -70	(+)
Tanzanite	40	(+)
Topaz	45 -70	(+)
Zoisite	30 -50	(+)

1. Biaxial gemstones with overlapping RIs – if β can be read directly

Figure 2 shows examples where all three principal RIs of a biaxial gemstone can be read directly during the rotation of that gemstone. Principal RI α is the smallest value on the diagram, γ is the largest and β is indicated in two different ways:

- For gemstones A and C in *Figure 2*, the principal RI β is read in the position where two variable shadow edges meet – a single shadow edge is observed.
- For gemstone B in *Figure 2,* the principal RI β is indicated by the value reached by both shadow edges. The shadow edges may or may not meet. However, on rotation, first one shadow edge and then the other move to the same reading giving β.

Three possible patterns of observations on peridot or sinhalite gemstones are presented in the *Figure 2*. RIs observed on gemstones A, B and C were used to determine three optic axial angles (2V) on the optic axial angle diagram in *Figure 1* and these are compared to the optic axial angles on the list. All three gemstones have RIs and birefringence in agreement with both peridot and sinhalite. However, the calculated optic axial angles make identification fast and reliable:

Gemstone A with 2V (-) = 88° indicates peridot
Gemstone B with 2V (-) = 88° indicates peridot
Gemstone C with 2V (-) = 53° indicates sinhalite

Many biaxial gemstones on the list in *Figure 1* show a range of values of optic axial angles rather than a single value. For example, the optic axial angle observed on actinolite gemstones can lie between 80° and 85° (depending upon its precise composition) with a negative optic sign. In some gemstones this range is in the 2V = 90° area and their optic sign can be either positive or negative. A small error in determination of the RIs of ±0.001 could easily therefore indicate an erroneous optic sign. For this reason, in dealing with a gem with an optic angle close to 90° it is better that gemmologists do not describe it as positive or negative, but say that it has an optic angle of '2V about 90°'.

Apart from measurement error, there can be real variation in the optic axial angle of some gemstones and the reason for this is the same as for the variation in their RIs. Their chemical composition can vary as two or more elements can replace each other and this, in turn, is reflected in the variation of optical properties. For example, variation in the Mg to Fe ratio in peridot crystals from different localities is reflected in variation of the maximum RI γ from 1.670 to about 1.720 (a difference of 0.050). The corresponding change in optic axial angle is about 15° (from 2V (+) = 80° to 2V (-) = 85°, shown as 2V ~ 90 on the list in *Figure 1*).

In the examples given in *Figure* 2, use of the optic axial angle gives fast, simple and reliable identifications of gemstones such as peridot or sinhalite. The same result can be obtained by simply using values of α, β and γ for peridot and sinhalite. However, values of β are seldom given in gemmological literature. Furthermore, many gemstones do not have a single value of β but show the range of values, similarly to ranges for α and γ. For any particular set of α and γ values, a corresponding β value must be given. This may involve a time consuming and, sometimes, fruitless search through the literature.

All this is avoided with the use of the optic axial angle in identification of gemstones. *Figure 1* gives everything needed for practical use: list of gemstones with their optic axial angles and a diagram for determination of optic axial angles from α, β and γ.

The special patterns of movements of shadow edges shown in *Figure 2* are unfortunately seldom observed in practice (see Sturman (2007) in this issue). RI β can be read directly only on gemstones with a favourable orientation of the gem table (or a facet) and its optic elements. Much more commonly encountered are the patterns shown in *Figure 3*, where two variable shadow edges remain separated during the rotation. This leads to two possible readings of the principal RI β.

2. Biaxial gemstones with overlapping RIs – if two solutions for β are possible

Identification of a peridot and sinhalite on the refractometer is an example given in many textbooks and its use is continued in this section.

Figure 3 shows observations on peridot or sinhalite gemstones where two variable

Gemstone A

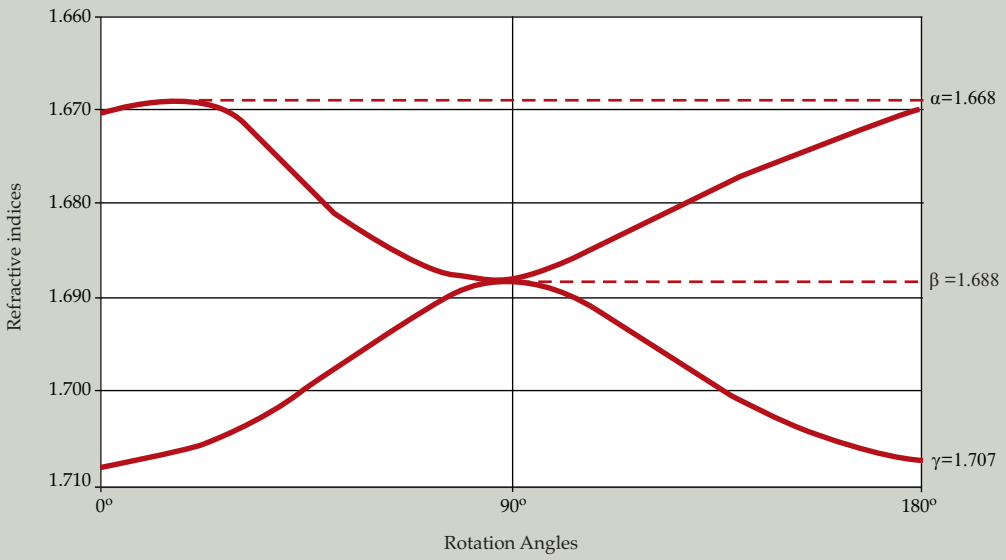

β - α = 0.020
γ - β = 0.019

optic axial angle
2V (-) = 88

Gemstone B

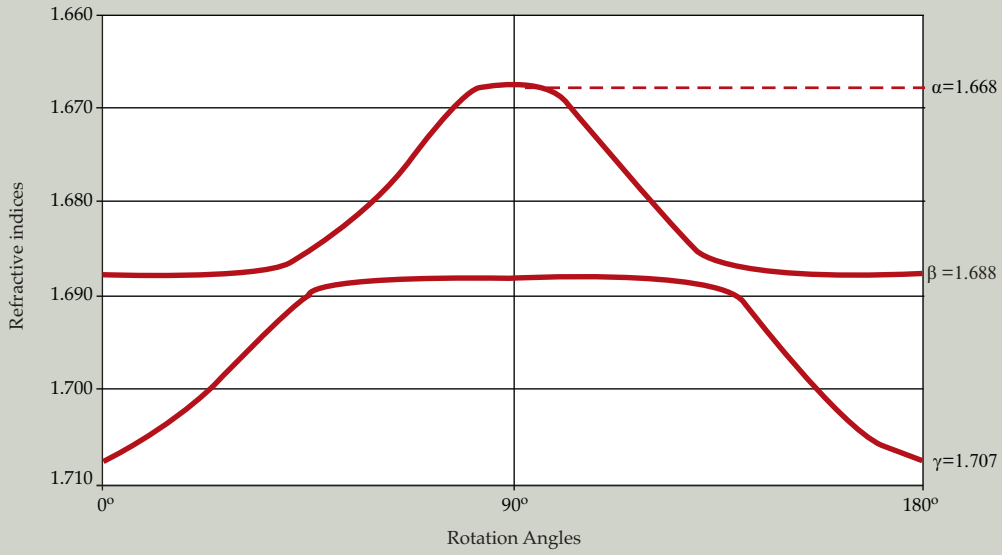

β - α = 0.020
γ - β = 0.019

optic axial angle
2V (-) = 88

Gemstone C

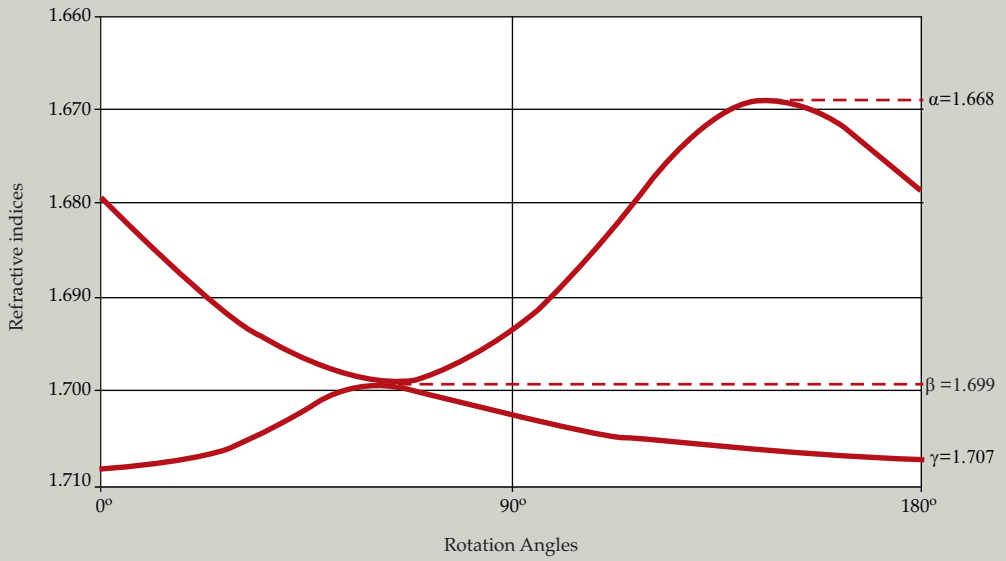

β - α = 0.031
γ - β = 0.008

optic axial angle
2V (-) = 53

Figure 2: *Diagrams showing relations of RIs with rotation angles on the refractometer in gemstones where β can be read directly. Examples of the derivation of the optic axial angle and its sign are given for three stones.*

Gemstone D

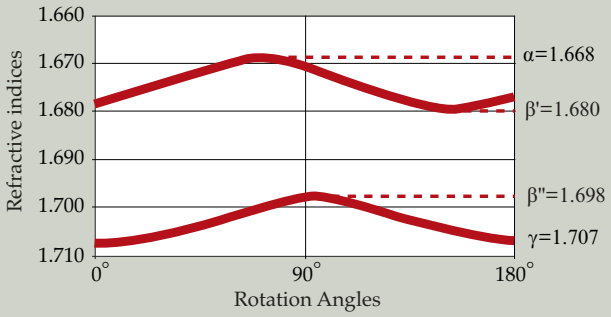

Solution I	Solution II
α = 1.668	α = 1.668
β" = 1.698	β' = 1.680
γ = 1.707	γ = 1.707
β" - α = 0.030	β' - α = 0.012
γ - β" = 0.009	γ - β' = 0.027
Optic axial angle 2V" (-) = 57	Optic axial angle 2V' (+) = 68
May be sinhalite	Cannot be peridot
Indicates sinhalite	

Gemstone E

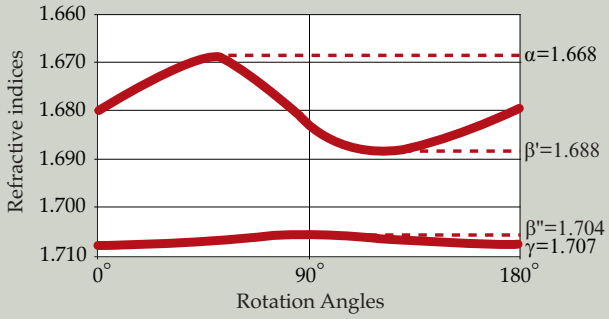

Solution I	Solution II
α = 1.668	α = 1.668
β' = 1.688	β" = 1.704
γ = 1.707	γ = 1.707
β' - α = 0.020	β"- α = 0.036
γ - β' = 0.019	γ - β" = 0.003
Optic axial angle 2V' (-) = 88	Optic axial angle 2V" (-) = 32
May be peridot	Cannot be sinhalite
Indicates peridot	

Gemstone F

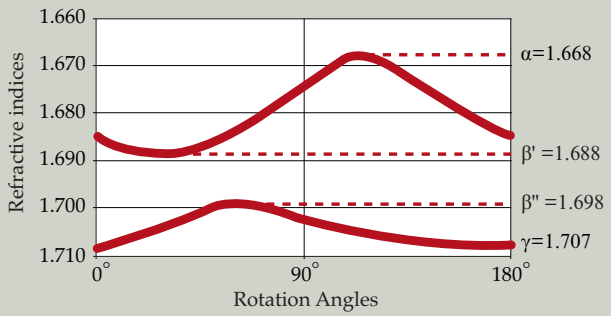

Solution I	Solution II
α = 1.668	α = 1.668
β' = 1.688	β" = 1.698
γ = 1.707	γ = 1.707
β'- α = 0.020	β"- α = 0.030
γ - β' = 0.019	γ - β" = 0.009
Optic axial angle 2V' (-) = 88	Optic axial angle 2V" (-) = 57
May be peridot	May be sinhalite
May be either peridot or sinhalite	

Figure 3: *Diagrams showing the relation of RIs with rotation angles on the refractometer in gemstones where the true value of β is not immediately apparent. Each variable shadow edge has one rotation position where a possible β can be observed, denoted by β' and β". Two possible optic axial angles 2V' and 2V" can be derived from β' and β" and these are compared with a standard list to reach a conclusion as indicated in examples D, E and F.*

shadow edges do not meet or reach the same reading. Each shadow edge has a position where a possible β can be observed. It is

- the highest reading on the shadow edge containing α and
- the lowest reading on the shadow edge containing γ.

Only one is the true β, the other is a false β. Instead of using the polarizing filter to identify the true β, the problem can be solved by determination of the optic axial angle for both possible β readings. One of these two optic axial angles must be in agreement with a particular gemstone. If it is not, then it cannot be this particular gemstone.

The procedure is as follows: during rotation of a gemstone to identify α and γ, both readings for possible β are also recorded. Then, both possible βs are used to determine the corresponding optic axial angles – there is no need at this stage to determine which is the true β and which is false. The role of the possible error in determination of the RIs is discussed in Appendix II.

The use of the optic axial angle in identification of biaxial gemstones with two possible β readings is best explained by examples shown in *Figure 3*. Observations on three gemstones, D, E and F, gave RIs and birefringence that agree with both sinhalite and peridot. Then determinations of the optic axial angles of D and E made their identification very simple, fast and reliable. But the movements of the shadow edges on the third gemstone (F) are consistent for either peridot or sinhalite. In this case, it is impossible to use this procedure in identification. The criteria are straightforward:

- If one optic axial angle agrees with sinhalite and the other does not agree with peridot then we have a reliable identification – the results indicate sinhalite (*Figure 3*, gemstone D).
- Similarly, if one optic axial angle agrees with peridot and the other does not agree with sinhalite then, again, we have a reliable identification – the results indicate peridot (gemstone E).
- However, if one agrees with peridot and the other agrees with sinhalite (gemstone F) then identification based on the use of the optic axial angle is not possible, because this particular pattern of movements of shadow edges can be observed on both sinhalite and peridot.

3. Identification of a gemstone as uniaxial or biaxial (in special orientations)

It is possible that a uniaxial and a biaxial gemstone may have similar RIs and give identical patterns when rotated on the refractometer. For example, observations on gemstone G in *Figure 4* gave the following data:

One variable and one constant shadow edge, not touching, with

RI maximum = 1.642 – observed on the constant shadow edge, and

RI minimum = 1.620 – observed on the variable shadow edge in the position where shadow edges are at maximum separation.

This pattern (a variable and a constant shadow edge) could be observed on a uniaxial gemstone (tourmaline) or on a biaxial gemstone (actinolite) with a special orientation of the gem table.

The solution to this problem is to interpret the observed data on the basis of two different assumptions; first, as if the gemstone were uniaxial and then as if it were biaxial. In uniaxial gemstones the shape (dip) of the variable shadow edge depends on the angle between the gem table (or a facet) and the optic axis. It depends on the cutter's choice of the gem table and it can be anything between the two extremes of

- two constant and parallel shadow edges and
- a constant and a variable shadow edge that meet.

A similar pattern (a constant and a variable shadow edge) can be observed on biaxial gemstones with special orientation of the gem table and optic elements. However, the shape (dip) of the variable shadow edge in biaxial gemstones depends on the value of β. If the dip of the variable shadow edge does not give the reading of β of actinolite, then this pattern cannot be produced by actinolite. Instead of the search for β values through the literature, a simple determination of the optic axial angle is all that is needed.

If the calculated optic axial angle does not agree with the values listed in *Figure 1* for a particular gemstone, then it cannot be this gemstone. Gemstone G in *Figure 4* is firmly indicated as tourmaline because the calculated optic axial angle is clearly outside the range for actinolite. Observed data on Gemstone G rule out the possibility that it may be actinolite.

In some situations the observed data may be in agreement with actinolite and with tourmaline, such as those for gemstone H in *Figure 4*. In this case, the method does not provide a solution and the polarizing filter must be used.

The role of the possible error in determination of the RIs is discussed in Appendix II.

Conclusion

The optic axial angle is a very useful constant in identification of biaxial gemstones on the refractometer. It requires the same observations as determination of the optic sign but it is much more useful. It is especially valuable in the following situations:

- in identification of biaxial gemstones with RIs which overlap those of other gem species,
- in differentiating between uniaxial and biaxial gemstones in special orientations.

These problems can be solved with the use of the polarizing filter. However, many gemmologists are reluctant to use it and many procedures without the use of the polarizing filter have been described in textbooks and teaching manuals. They may be very simple or very complex, but many of them have, unfortunately, one thing in common – they can lead to an incorrect identification.

The optic axial angle method described in this article is an alternative to these procedures. It offers simple, fast and very reliable solutions to two problems mentioned above. It cannot be applied in every situation but the observer knows right away if it can, or cannot, be used.

The optic axial angle method is a step between the initial observation (minimum and maximum RIs) and detailed observations with the polarizing filter (Sturman, 2005). It is not used every time a gemstone is set on the refractometer but only when needed. *Figures 1, 2, 3* and *4* contain all the guidance needed for confident and reliable use of the method. If anyone decides to use the method years after reading the article, all that is required is a quick look at the figures – hopefully kept close to the refractometer.

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I wish to thank Duncan Parker for help in preparation of this manuscript and many useful discussions. Comments by the reviewers greatly improved the manuscript.

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Sturman, B.D., 2005. Use of the polarizing filter on the refractometer. *J. Gemm.*, 29(5/6), 341-8

Sturman, B.D., 2007. Clarification of measurment of the RIs of biaxial gemstones on the refractometer. *J. Gemm.*, 30(7/8), 434-42

Appendix I

Optic axial angle diagram

The optic axial angle – the angle between the optic axes of biaxial gemstones - depends on the principal RIs α, β and γ according to the equation I-1. There are several diagrams that can be used in order to avoid the complex calculations. One such diagram is shown in the article on the use of the polarizing filter by Sturman (2005). It is not very complex but it may be made even simpler by the use of the approximate equation I – 2. This equation was used to prepare a simple optic axial angle diagram shown in *Figure 1* in this article.

$$\tan 2V_z = \frac{1/\alpha^2 - 1/\beta^2}{1/\beta^2 - 1/\gamma^2} \qquad \text{Equation I-1}$$

$$\tan 2V_z = \frac{\beta - \alpha}{\gamma - \beta} \qquad \text{Equation I-2}$$

The error introduced by the use of the approximate equation and the simpler diagram is much smaller than the error of (±0.001 or 0.002) that can be expected in the readings of the RIs in the routine work with the refractometer. Therefore, the optic axial angle diagram in *Figure 1* can be safely used in most routine determinations of the optic

Gemstone G
If uniaxial:

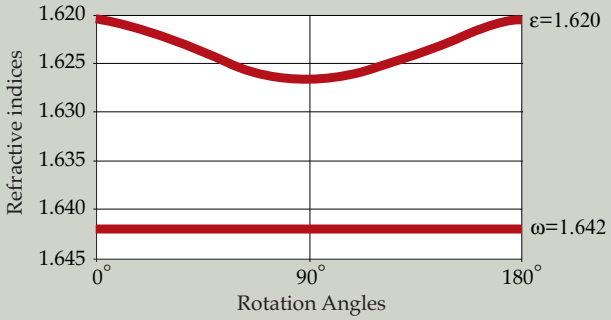

Gemstone G
If biaxial:

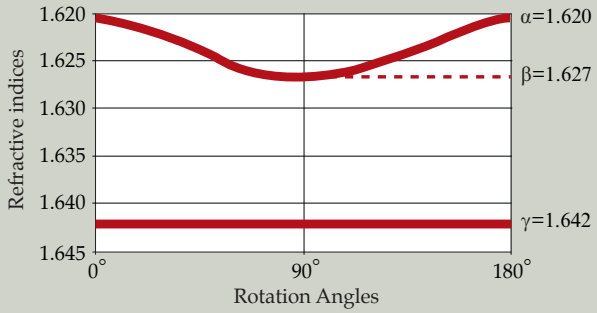

Solution I	Solution II
ε = 1.620	β - α = 0.007
ω = 1.642	γ - β = 0.015
Optic sign (-)	2V (+) = 70
RIs, birefringence and optic sign all agree with tourmaline	Optic axial angle does not agree with actinolite
Cannot be actinolite - indicates tourmaline	

Gemstone H
If uniaxial:

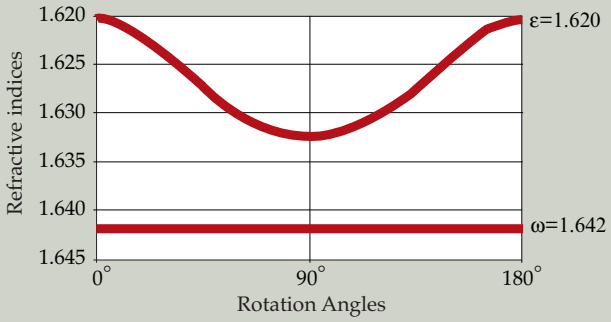

Gemstone H
If biaxial:

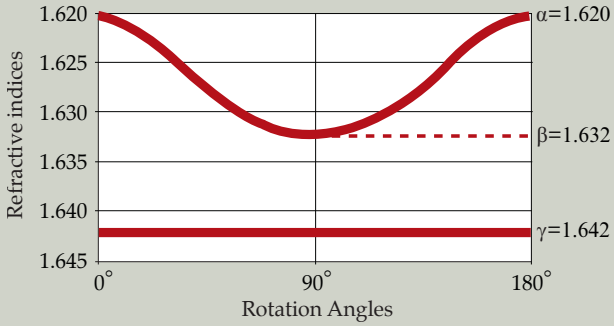

Solution I	Solution II
ε = 1.620	β - α = 0.012
ω = 1.642	γ - β = 0.010
Optic sign (-)	2V (-) = 84
RIs, birefringence and optic sign all agree with tourmaline	Optic axial angle agrees with actinolite
Can be either actinolite or tourmaline	

Figure 4: *Diagrams showing relations of RIs with rotation angles on the refractometer in gemstones where one shadow edge is constant. In uniaxial gemstones, the shape of the variable shadow edge (the dip of the variable line during the rotation) depends on the cutter's choice of the gem table. The variable line may be horizontal, almost horizontal, dip all the way to a constant line or it can come to any position in between – it depends only on the choice of the gem table. In biaxial gemstones – where shadow edges of either α or γ stay constant during the rotation), the dip of the variable line depends on the value of β. In gemstone G, the RIs and birefringence indicate that it can be tourmaline or actinolite, but the shadow edges patterns and calculation of the optic axial angle (2V) rule out actinolite. In gemstone H, the calculated optic axial angle agrees with actinolite - it may be either actinolite or tourmaline.*

axial angles.

Most gemstones have partial birefringences (β-α and γ-β) smaller than 0.040 and for them the optic axial angle can easily be determined on the diagram. For the very few gemstones with larger birefringence, the use of the diagram is also simple; both partial birefringences are divided by the same number (2, 3, etc) until they are smaller than 0.040 and the optic axial angle is then found on the simplified diagram. It must be mentioned, however, that in this case, the error caused by the use of the simplified diagram may be larger than 1° or 2°.

Appendix II

The effect of a possible error in determination of the RIs.

A possible error in determination of the RIs depends very much on the clarity with which shadow edges are seen. This in turn depends on many factors such as the quality of the polish of facets, quality of the monochromatic light, construction and the optics of the refractometer, etc. It is impossible to give a general set of values that can be applied to every observation.

The safest test for any observation is to make several repeated readings of the RIs. This would indicate the possible errors and give the extreme values that must be used in the interpretation of the results. In a great majority of observations this is not required because results will clearly indicate one way or the other. However, in borderline cases, a simple and fast test may be used to avoid repeated measurements. We named it a 'β +/- 0.002' test.

Figure 5 gives an example of the use of this test. Gemstone I gave a pattern (a constant and a variable shadow edge) that can be observed on uniaxial and biaxial gemstones. Maximum RI, minimum RI and birefringence indicate that it may be tourmaline or actinolite. The solution as biaxial gave an optic axial angle of 2V (+) = 86° – it is close to but not in the actinolite range given in *Figure 1*. The 'β +/- 0.002 test' (addition or subtraction of 0.002 from the observed β) gives two additional β values that can be used in calculations of the optic axial angles. One of these calculated optic axial angles (2V (-) = 84°) is within the range of actinolite. Therefore, the optic axial angle method does not give an identification in this case; Gemstone I can be either tourmaline or actinolite. Other procedures must be used in identification.

It must be pointed out that the safest procedure is to determine the possible error in measurements of the RIs for every determination. It is also important that an observer accepts the fact that in some situations the optic axial angle method cannot give a reliable result. Even more important is the fact that an observer at all times knows whether or not the method can be used.

Gemstone I

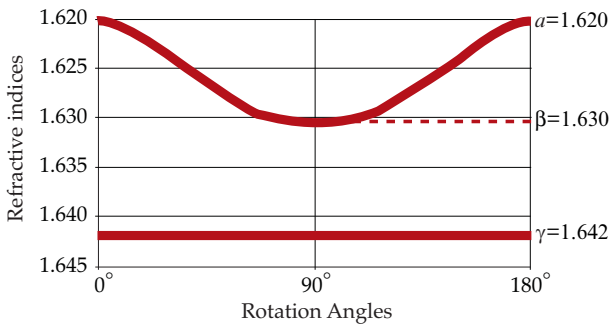

Solution as biaxial:	New solution based on the β +/- 0.002 Test	
β = 1.630	β = 1.632	β = 1.628
β - α = 0.010	β - α = 0.012	β - α = 0.008
γ - β = 0.012	γ - β = 0.010	γ - β = 0.014
2V (+) = 86	2V (-) = 84	2V (+) = 75
Cannot be Actinolite	May be Actinolite	Cannot be Actinolite

Figure 5: *The use of the β +/- 0.002 test. The observed β=1.630 gives 2V (+) = 86° - not in the range of 2V (-) = 80°-85° for actinolite (see list on* Figure 1*). The test (addition or subtraction of 0.002 to or from the observed β) gives two more values to be used in calculation of the optic axial angles. One of these gives the optic axial angle of 2V (-) = 84°- it is within the range given for actinolite. Therefore, the observed pattern can be expected on actinolite crystals with the usual error in determination of the RIs.*

Letter to the Editor

'Bright Line Technique' examples

In their article 'Better refractometer results with the Bright Line technique' (*The Journal of Gemmology*, 2007, 30(5/6), 287-96), Don Hoover and Cara Williams provided a most useful coverage of the refractometer by looking at the history of these unorthodox methods of illumination and explaining the resultant enhanced shadow edge phenomena.

I would like to expand a little on the information contained in their article.

A typical setup (*Figure 1a*) uses a fibre optic light source which is easily bent into variable positions for overhead lighting. Without further modification, the white light produces spectral shadow formations *(Figure 1b)*. Practice is required to distinguish the conclusive shadow information from the rogue shadows which are likely to form. The colour shadow in the 1.50 region is such a rogue. With a polarizer in position over the eyepiece, the quartz ordinary ray registers its universal RI 1.544.

Figure 1a.

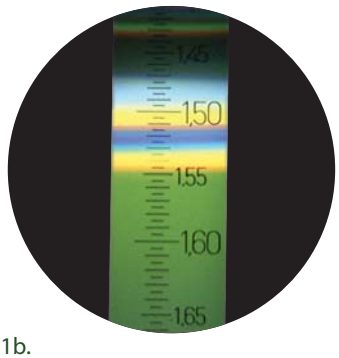

Figure 1b.

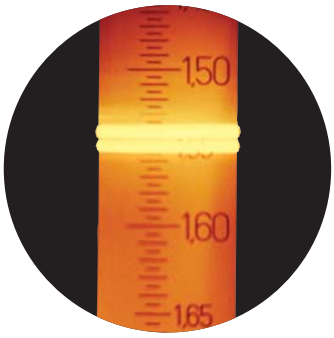

Figure 2b.

Figure 2a.

With a yellow filter held over the end of the fibre optic *(Figure 2a)*, the information is much clearer.

In this instance, there is no polarizer, and the two quartz shadow edges are seen simultaneously: 1.544, 1.553 (*Figure 2b*).

In their summary, the authors state: "This tool can significantly increase the confidence in measurement of refractive indices, especially for difficult cases." Small gemstones are a case in point, where there is no shadow formation by conventional illumination, as was the case with some 1.5 mm flux-grown synthetic emeralds *(Figure 3a)*.

In such an instance, apart from ensuring that initially the prism and gem are clean, a pencil-end is a useful accessory to gently press the stone into a full surface contact with the refractometer prism.

Figure 3a.

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This is preferable with small stones, as to use an index finger would certainly result in refractometer liquid contacting the skin.

If there is still no shadow formation *(Figure 3b)*, introduce a fibre optic light above but also behind the stone. The optimum position can soon be found by manoeuvring the light until a horizontal bright line forms on the scale.

With practice, the observer learns how to interpret the RI reading to three places of decimals. Here the extraordinary ray registers at 1.560 *(Figure 3c)*, lower than that of any natural emerald, and in conjunction with the polarizer and rotation of the stone, the birefringence can be measured. Note how, with the top lighting method, the shadow column is inverted to spread down the scale.

Figure 3b.

Figure 3c.

An interesting refractometer behaviour was obtained with a painite *(Figure 4a)*. Such a gemstone was regarded with gemmological awe only a few years ago. Today there are painites in their thousands, principally from Myanmar. In appearance, they have a colour reminiscent of a red garnet. Such is the value of these previously rare gems, that £100

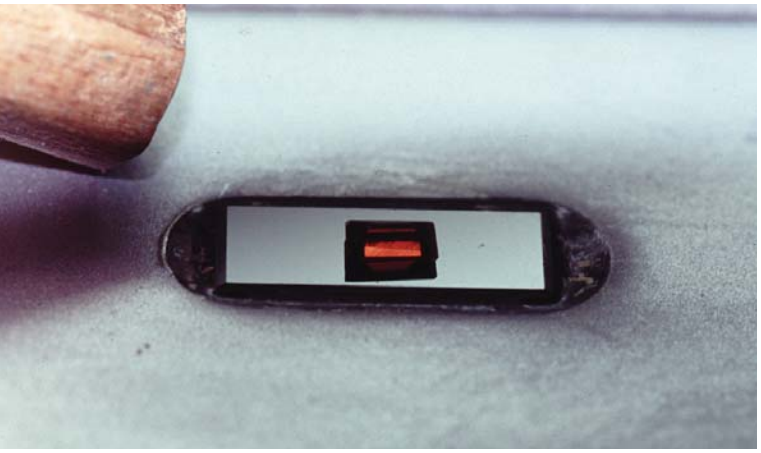

Figure 4a.

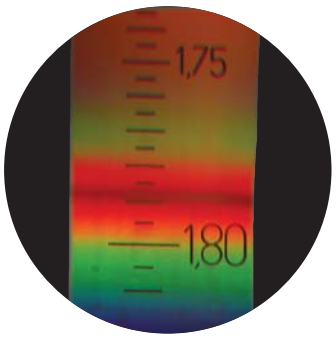

Figure 4b.

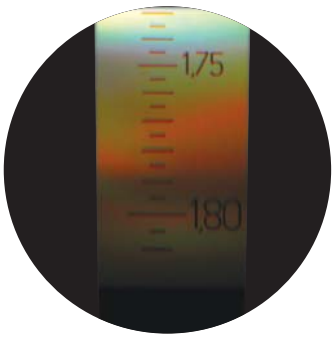

Figure 4c.

for a 2.5 x 2 mm gem requires that they be positively identified, and distinguished from a similar looking garnet which would have little or no value.

What is intriguing about the painite is that its two RIs span that of the contact liquid (RI 1.81), the extraordinary ray approximately RI 1.787 (*Figure 4b*) and the 'unseen' ordinary ray (Webster (1994, p.356): RI 1.8159). By rotation of the polarizer, the ordinary ray retains a total shadow column across the liquid boundary (*Figure 4c*).

Some idea of the ord-ray RI measurement can be gained by a loupe estimation of the facet doubling (Webster (op. cit.): birefringence 0.029), and adding on the estimated figure to the extraordinary ray RI 1.787.

The writer originally stumbled on this inverted lighting technique as an aid to the distant vision (spot) method for dealing with cabochon gems (Hodgkinson, 1988).

Subsequent experimentation revealed the interesting area of top light illumination for awkward faceted gems.

However, the Hoover/Williams article has laid bare the whole area, and must surely lead to a new dimension of interest in the humble refractometer.

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Reference

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Webster, R., 1994. *Gems.* 5th edn. Ed. P.G. Read. Butterworth-Heinemann Ltd., Oxford

Abstracts

Diamonds

Global rough diamond production since 1870.

A.J.A. Bramse (archonespl@iinet.net.au). *Gems & Gemology*, 43(2), 2007, 98-119.

A compilation and analysis of data for the global production of rough diamonds (both by weight and by value) is presented, covering 27 countries, 24 major diamond mines and eight advanced projects. Production from Africa was dominant until the middle of the twentieth century. Not until the 1960s did production from non-African sources (first the Soviet Union, then Australia and now Canada) become important. Distinctions between carat weight and value affect relative importance significantly. The total global production from antiquity to 2005 is estimated at 4.5 billion carats valued at US$ 300 billion, with an average value per carat of $ 67. For the 1870-2005 period, South Africa ranks first in value and fourth in carat weight; Botswana ranks second in value and fifth in carat weight. Global production for 2001-2005 was approximately 840 million carats with a total value of $ 55 billion, for an average value of $ 65 per carat; for this period, USSR/Russia ranks first in weight and second in value, but Botswana is first in value and third in weight, just behind Australia. R.A.H.

The evolution of diamond morphology in the process of dissolution: experimental data.

A.F. Khokhryakov and Y.N. Pal'yanov (palyanov@uiggm.nsc.ru). *American Mineralogist*, 92(5-6), 2007, 909-17.

Experiments on the dissolution of octahedral, pseudo-dodecahedral and cubic natural diamond crystals in water-containing carbonate and silicate systems in high-*P*, high-*T* conditions in the diamond stability field are reported. The dissolution agents used included $CaCO_3$, $CaMg(CO_3)_2$. $CaMgSi_2O_6$ and kimberlite from the Udachnaya pipe, Yakutia, with the addition of distilled water. The experimental data show that diamonds change their morphology from octahedra, dodecahedra and cubes to tetrahexahedroids when the weight loss is 20-25%, to a cube when the loss is 50% and a pseudo-dodecahedron transforms into a tetrahexahedroid when the weight loss is as low as 10%. A comparison of crystal morphology surface features and goniometric data for diamond dissolution forms produced in water-bearing systems with rounded natural diamonds showed their complete identity. A scheme has been constructed for morphological evolution of natural diamond crystals during their dissolution. R.A.H.

Argyle in Western Australia, the world's richest diamondiferous pipe: its past and future.

V. Lorenz. *Gemmologie. Z. Dt. Gemmol. Ges.*, 2007, 56(1-2), 35-38.

First discovered in 1976 in the Ellendale area by the Kalumburu Joint Venture and its successor the Ashton Joint Venture, Argyle proved to be the richest pipe. The pipe is heavily deformed both horizontally and vertically, about 2 km long with a diameter varying between 10 and 500 m. Contents vary between 1 ct/t to 5 ct/t. Originally only about 5% were considered gem quality, but this has somewhat improved due to marketing of brown stones. With the whole pipe being extensively mined, it was expected that it would have to be closed by 2007/08, but life has now been extended for about another eight years. Only two of the Ellendale lamproite pipes are now being worked. E.S.

The south Tien Shan belt of diamondiferous alkaline basic rocks.

V.S. Lutkov and A.R. Faiziev. *Doklady Earth Sciences*, 413(2), 2007, 192-4.

Diamond crystals in the southern Tien Shan can be divided into three types: (1) fragments of transparent and translucent, colourless and grey, isotropic octahedral; (2) irregular grains composed of intergrowths of white and grey, transparent and translucent, octahedral faces; (3) light yellow and yellow grains of cubic crystals and combination of plane-faced cubes and octahedra. The western sector of the southern Tien Shan includes unique kimberlite pipes and dykes of K-silicate rocks and carbonatites. Major element and trace element analyses are presented for nine samples of Lower Mesozoic alkaline basic rocks. These rocks are characterized by the coexistence of two heterogeneous mineral associations. High contents of magnetite (3-15 kg/t) are associated with native metals, moissanite and diamonds. The concentrates of some large samples contain as much as 150-200 yellow-green diamond octahedra (0.05-0.2 mm in size). A.M.C.

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Branded diamonds: their advantages and limitation: a literature review.

A. Lynch. *Australian Gemmologist*, 22(12), 2006, 542-55.

This paper discusses the marketing processes involved in branding diamonds, drawing on literature from mass psychology, market research and targeted marketing. The author considers how marketing techniques have been applied by diamond companies such as De Beers, Argyle Diamonds and BHP/Billiton (Ektai and Canadia brands). L.J.

Lab notes.

T.M. Moses and S.F. McClure (Eds). *Gems & Gemology*, 43(1), 2007, 47-55.

Notes are given on blue diamonds showing multiple phosphorescence colours, a known HPHT annealed yellow-orange diamond with a strong 480 nm absorption band, a 3.14 ct black diamond coloured by very dense clouds of micro-inclusions, and a vivid yellow 1.35 ct synthetic diamond apparently grown at a relatively high temperature of ~ 1700 C. R.A.H.

Maintaining consumer confidence in detecting synthetic and treated diamonds.

S. Quinn. *Gemmologie. Z. Dt. Gemmol. Ges.*, 2007, 56(1-2), 43-6.

The DTC is maintaining confidence by identifying synthetic and treated diamonds, and assessing their gemmological properties and their impact. Synthetic diamonds on the market are comparatively easy to detect. Techniques like HPHT treatment and multiple treatments including irradiation require more advanced instruments and knowledge. The main categories of concern are type I and fancy-coloured diamonds. E.S.

Serenity coated colored diamonds: detection and durability.

A.H. Shen (andy.shen@gia.edu), W. Wang, M.S. Hall, S. Novak, S.F. McClure, J.E. Shigley and T.M. Moses. *Gems & Gemology*, 43(1), 2007, 16-34.

The gemmological, spectroscopic and chemical properties of diamonds treated using the new 'Serenity Technologies' coating technique for inducing various 'fancy' colours are reported. This technique produces colours that include intense blue, green, yellow and orange to pink to purple-pink. The presence of a coating can be ascertained with magnification by observation of an interference-related coloured film (often with a bronze tint), scratches and colourless and/or dark areas on the surface of pavilion facets. Confirmation of the treatment can be provided by UV-Vis absorption spectra and chemical analysis. The latter has also revealed that the coating is a SiO_2 film doped with Au and/or Ag for blue, pink and yellow coloration, or with a surface film of Fe_2O_3 for orange. The colours produced by this treatment are stable to some standard jewellery repair and cleaning procedures, but they are not considered permanent. R.A.H.

The journey of light = freedom of expression.

G. Tolkowski. *Gemmologie. Z. Dt. Gemmol. Ges.*, 2007, 56(1-2), 65-6.

Expression, art, adornment equal beauty – this is carried by the journey of light. E.S.

[Zoning in diamonds from 'Mir' kimberlite pipe: FTIR data.]

E.A. Vasilyev and S.V. Sofroneev. *Proceedings of the Russian Mineralogical Society*, 136(1), 2007, 90-101. (Russian with English abstract.)

A study of plates prepared from diamonds of the 'Mir' kimberlite pipe by FTIR microspectroscopy showed that the formation of B1 defects occurred at annealing during crystal growth, but that the B2 centres were formed mainly after growth had been terminated. It is shown that development of the B2 defects in natural diamonds is a secondary process related to the aggregation of admixture nitrogen; that process had the kinetics of the decomposition of an oversaturated solid solution. There are thus possibilities for the determination of the temperature and duration of growth of natural diamonds. R.A.H.

Gems and Minerals

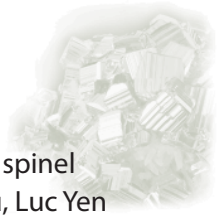

The sapphire and spinel deposit of An Phu, Luc Yen mining district, Yen Bai province, Vietnam.

D. Blauwet. *The Mineralogical Record*, 37, 2006, 224-38.

Account of a journey made to the Luc Yen mining district of Vietnam and of the ruby and spinel occurrences at the An Phu mine near the village of An Phu. Specimens recovered are described. M.O'D.

Gem corals: X-ray diffraction, solid state NMR, elemental analysis.

R. Bocchio, S. Bracco, A. Brajkovic, A. Comotti and V. Rolandi. *Australian Gemmologist*, 22(12), 2006, 524-32.

The crystallographic features and chemical composition of gem quality corals have been investigated by X-ray diffraction, NMR and laser ablation inductively coupled plasma mass spectrometry. The Octocorallia corals were found to be mainly calcitic while the Hexacorallia were mainly aragonitic in composition. Mg and Sr were considered to be the best discriminating elements, with the trace elements displaying much overlap between the two coral types. The calcitic corals have higher amounts of Mg while the aragonitic corals have more Sr. L.J.

[Mineralogy of fossil resins of Northern Eurasia.]

M.A. Bogdasarov. *Proceedings of the Russian Mineralogical Society*, 135(6), 2006, 66-78. (Russian with English abstract.)

An investigation is reported on the diagnostic properties and genesis of fossil resins from the Cretaceous, Tertiary and Quaternary sediments of N Eurasia on the basis of their physical and chemical characteristics, including their morphology, size, mass, density, optics, mechanical and thermal properties, elementary chemical compositions, etc. The constitution of amorphous organic minerals with a polymeric structure including fossil resins allows the use of IR spectrometry, e.p.r., DTA at

low heating rates, X-ray structural analysis, chemical analysis, emission spectrometry, etc. A summary of results from an investigation of the amber-bearing provinces of Baltic-Dnieper, N. Siberia and the Far East shows that resins of the Baltic-Dnieper province can be determined as amber (succinite). The amber-like resins of the N Siberian and Far Eastern provinces are mainly represented by the resins retinite and gedanite, too fragile to have any value in jewellery. Widespread viscous fossil resins on the Sakhalin coast, Far Eastern province, are rumanite and have a high potential for use. R.A.H.

Crocoite and associated minerals from Tasmania.

R.S. Bottrill, P.A. Williams, S. Dohnt, S. Sorrell and N.R. Kemp. *Australian Journal of Mineralogy,* 12, 2006, 59-90.

Magnificent crystals of orange crocoite from Tasmania are described and illustrated. Many are collector or even gem-quality. Associated minerals and geological details are given for all Tasmanian locations. M.O'D.

Stichtite from western Tasmania.

R.S. Bottrill (rbottill@mrt.tas.gov.au) and I.T. Graham. *Australian Journal of Mineralogy*, 12(2), 2006, 101-7.

The Dundas area of western Tasmania is the type locality for stichtite. This colourful but uncommon mineral (a magnesium-chromium hydroxycarbonate) is most plentiful on Stichtite Hill, near the Adelaide and Red Lead silver-lead-crocoite mines; several other localities are listed, all near Dundas. The host rocks are serpentinized dunite. The stichtite is pale pink to deep purple, fine grained and commonly contains disseminated chromite grains. It is hosted in massive, yellowish green to dark green serpentinite, yielding the material for attractive ornamental carvings. R.A.H

Blue and pink opals from Acari, Peru.

A. Brakovic, V. Rolandi, P. Vignola and R. Grizzetti. *Australian Gemmologist*, 23(1), 2007, 3-15.

Opals from Peru have been analysed by optical microscopy, X-ray powder diffraction, SEM-EDXA, Raman microscopy, FTIR (ATR) and ESR spectra and the results presented. The opals showed no play of colour. XRD detected cristobalite and tridymite in both varieties classifying them as opal-CT, as well as small amounts of chalcedony. Copper was found to be the colourant in the blue opals, and carotenoids, quinones and/or Fe(III) centres in the pink opals. The genesis of these opals has been attributed to volcanism and volcanic events. L.J.

Another imitation elephant pearl.

G. Brown. *Australian Gemmologist*, 22(12), 2006, 556-7.

Objects described as 'elephant pearls' or 'bamboo pearls' purchased in Angkor Wat, Cambodia have been examined and shown to be made from compact mammalian cortical bone. Traces of the bone structure are evident, such as Haversian and Volkmanns canals. L.J.

Madagascar tourmalines: new data and new localities.

E. Castaman, A. Donini, E. Gambini, A. Marzola, E. Pesota and M. Superchi. *Gemmologie. Z. Dt. Gemmol. Ges.,* 2007, 56(1-2), 61-4.

Multi-coloured tourmalines have been found in the pegmatites of Tsarafara (Sahatany area), in Andranomanelatra and in Ampanivan; these pegmatitic dykes are characterized by boron enrichment and concentrations of rare elements. Raman spectra were obtained. E.S.

Thermal treatment of Brazilian beryls.

G. de Oliveira Polli and H.M.P. Roeser. *Gemmologie. Z. Dt. Gemmol. Ges.,* 2007, 56(1-2), 47-50.

Commercially, thermal treatment is used mainly for blue and green aquamarines, morganite and heliodor to improve and modify their natural colour. This can usually be achieved by heating the stone for 1-2 hours at temperatures varying between 350–900 C. Ninety percent of aquamarines and morganites on the market are heat treated. For this research 383 yellow, blue, colourless, pink and green beryls from 19 Brazilian localities were used. Colour introduction by diffusion treatment could not be applied to colourless beryls as this mineral does not support the high temperatures and long exposure times necessary, but it was possible to produce a surface covering with a stable colour. E.S.

Eurominerallexpo.

[Various authors.] *Rivista Mineralogica Italiana,* 31, 2007, 32-9.

Among gem-quality mineral specimens on display at Eurominerallexpo, Torino, 6-8 October 2006, were trapiche emerald from Colombia, opal from Betroka, Madagascar, ruby from Luc Yen, Yan Bai province, Vietnam, danburite from Betafo, Madagascar (a yellow faceted stone of 13.28 ct), deep pink to red fluorite from Chumar Bakhoor, Pakistan, and an emerald crystal of 6.5 cm from Dafdar, Toshgorgan, Xinjiang, China. M.O'D.

Continuity and change in Chinese freshwater pearl culture.

D. Fiske (dfiske@gia.edu) and J. Shepherd. *Gems & Gemology*, 43(2), 2007, 138-45.

Most Chinese freshwater cultured pearls are produced by implanting tissue pieces in the mantle of *Hyriopsis cumingii* mussels. In the late 1990s *H. schlegelii* mussels were imported from Japan and were cross-bred with native *H. cumengii* mussels. Using the two pure species and the hybrid, Chinese farmers now produce tissue-implantation-only cultured pearls and have developed a method termed coin-bead/spherical-bead nucleation. This method has yielded significant quantities of jewellery-quality baroque shapes and lesser quantities of jewellery-quality rounds and near-rounds. R.A.H.

The changes in the Japanese jewellery market.

M. Furuya. *Gemmologie. Z. Dt. Gemmol. Ges.,* 2007, 56(1-2), 21-22.

The history of Japanese jewellery is about 2000 years old as shown by beads found in ancient tombs, but as a fashion industry it was not until 1970 that fine gold jewellery was first made. The fine jewellery industry

now accounts for many billions, and there is a growing market for wholesalers, retailers, mail orders and import of less expensive jewellery from China and India. E.S.

Trapiche tourmaline from Zambia.

T. Hainschwang (thainschwang@yahoo.com), F. Notari and B. Anckar. *Gems & Gemology*, 43(1), 2007, 36-46.

Well-formed crystals of green tourmaline from NW Zambia show a growth pattern reminiscent of trapiche emeralds when sliced perpendicular to the *c*-axis, and were originally encountered in parcels sold in Zambia as emeralds. The trapiche appearance may have originated from skeletal growth, the pattern being formed from a black carbonaceous substance (mostly graphite) partly filling growth tubes concentrated in three areas: (1) along the three edges of the trigonal pyramids, (2) at the interface between the trigonal pyramids and the prism faces and (3) between individual growth sectors of the prism. Spectroscopic and chemical analyses indicate that the tourmaline is uvite coloured green by a vanadium-related mechanism. Electron microprobe analyses are given for the green central region and the black trapiche ray for two slices of this trapiche tourmaline. R.A.H.

Recent developments in pearl testing.

H.A. Hänni. *Gemmologie. Z. Dt. Gemmol. Ges.*, 2007, 56(1-2), 23-4.

Trade rules require correct designation of natural, cultured and imitation pearls, the distinction of natural pearls from beaded or beadless cultured pearls being a major task in the gemmological lab. Identification of treatment is also required. X-ray shadow pictures are still used for first identification, ED-XRF analysis separates freshwater from saltwater products. Pearls stained black with silver nitrate can be detected; coating and polishing can be detected by SEM. X-ray luminescence differentiates between freshwater and seawater pearls based on manganese content. Raman spectroscopy can show up organic dyes. UV-VIS-NIR can identify some natural and treated colours. So-called 'chocolate' pearls are controversial as they may be bleached or stained. The latest technique is LA-ICPMS which can discriminate pearls on the basis of multi-element trace analysis. E.S.

Gemstone deposits in Vietnam and China.

W. Hofmeister. *Gemmologie. Z. Dt. Gemmol. Ges.*, 2007, 56(1-2), 25-28.

Due to overall tectonic regimes in the south-east Asia region, some geological settings in Vietnam and China have appropriate high pressure and temperature histories for gemstone formation. Ruby and sapphire are deposited in typical metamorphic and pseudo-magmatic environments. Rubies are found in the Day Nun-Con Voi region in the province Yen Bai in Northern Vietnam. Pseudo-magmatic sapphire occurs from Dac Lac in central Vietnam and Changle, Shandong Province, eastern China, showing the typical crystallographic, chemical and gemmological features of magmatic sapphires. Slightly changing chemistry of the rocks can produce gem spinels, sometimes being accompanied by emerald-green amphibole minerals. Gneissic rocks can produce good quality star rubies and sapphires. Around the city of Malipo, Yannan province in China and Ha Giang Province in Vietnam, there are granitic to granodioritic rocks cut by pegmatite veins, which give rise to the occurrence of beryl. The emerald colour is produced by small amounts of chromium and larger amounts of vanadium. E.S.

Identifying Japanese freshwater cultured pearls from Lake Kasumigaura.

D.E. Jacob, U. Wehrmeister, T. Häger and W. Hofmeister. *Australian Gemmologist*, 22(12), 2006, 539-41.

Laser ablation inductively coupled plasma mass spectrometry is used to show that Japanese Kasumigaura pearls have lower Ba/Sr and Ga/Sr ratios than Chinese pearls which have much higher and more variable ratios. L.J.

Durability testing of filled emeralds.

M.L. Johnson. *Gems & Gemology*, 43(2), 2007, 120-37.

Detailed reports are given of the treatment of 128 emeralds with nine emerald fillers (Araldite 6010, cedarwood oil, paraffin oil, unhardened and surface-hardened Opticon, a mixture of cedarwood oil and Canada Balsam, surface-hardened Norland Optical Adhesive 65, and the solid fillers Gematrat and Permasave). The emeralds were then exposed (along with 14 unfilled emeralds) to common conditions of wear and cleaning. After some six years, the emeralds were subjected to one of the following tests of durability: exposure to long-wave UV radiation, mild heat and incandescent light in a display case, five chill-thaw cycles, a desiccation environment, ultrasonic cleaning, cleaning with steam or mild chemical solvents. Changes were seen in 35% of the filled emeralds after the mild exposure tests; those with liquid fillers were especially susceptible. The desiccation environment made fissures visible in most emeralds. Hard fillers damaged their host emeralds by expanding cracks during durability testing, and chill-thaw cycling extended cracks in both filled and unfilled emeralds. Emeralds with liquid fillers were the most susceptible to changes in appearance due to ultrasonic cleaning. These results are discussed and some observations are made on the effectiveness of different fillers. A possible script for use by a jeweller to warn clients about filled emeralds and their maintenance and care is provided. R.A.H.

Emerald and alexandrite from the Malysheva Mine, Ural Mountains, Russia.

L. Kiefert. *Gemmologie. Z. Dt. Gemmol. Ges.*, 2007, 56(1-2), 29-30.

The first emeralds were found in 1831 in the Urals near the Takovaya river, 90 km north of Ekaterinburg. Today the emeralds come from the Malysheva mine in the old Takovaya river region. The mine also produced a small quantity of alexandrites. E.S.

Recent micro-observations of inclusions and related structures in gems.

J.I. Koivula. *Gemmologie. Z. Dt. Gemmol. Ges.*, 2007, 56(1-2), 31-4.

Identification of inclusions in gemstones is a very specialized skill. Destructive analysis is to be discouraged and the inclusion might add to the host gem by its rarity or beauty. Sometimes inclusions are exposed by breakage or during cutting, which makes identification easier. Gem materials used for research have usually been rejected by the trade. Modern microscopic techniques and current technologies may facilitate discovering and identifying new inclusions. E.S.

Gem news international 2007.

B. Laurs (Ed.) (blaurs@gia.edu). *Gems & Gemology*, 43(1), 2007, 56-80.

Items noted include a cat's-eye leifite from Mont Saint-Hilaire; play-of-colour opal from Piaui, Brazil; yellow prehnite from the Merelani tanzanite mine, Tanzania; green variscite with orange-brown veining containing tiny inclusions of native gold from central Western Australia; fine spodumene, morganite and tourmaline from weathered pegmatite at Tsarafara, Madagscar; small pink crystals of pezzottaite from Myanmar; and large cabochons and rough nodules of turquoise from a copper mine in Sonora, Mexico. R.A.H.

The origin of color in 'fire' obsidian.

C. Ma (chi@gps.caltech.edu), G.R. Rossman and J.A. Miller. *The Canadian Mineralogist*, 45(3), 2007, 551-7.

A variety of obsidian from Glass Buttes, Oregon, known as 'fire' obsidian for its thin layers showing various colours, was investigated with field-emission SEM, EPMA, electron back-scatter diffraction and optical spectroscopy methods. The thin layers, 300-700 nm thick, give rise to brilliant colours in reflection and mainly consist of concentrated nanometric crystals of magnetite. The colour is caused by thin-film optical interference, in which the thin layers have a higher calculated index of refraction ($1.496 < n < 1.519$) than that of the host glass (n 1.481). R.A.H.

What's new in minerals.

T. Moore. *The Mineralogical Record*, 38(3), 2007, 211-32.

Among gem minerals exhibited at the 2007 Tucson Gem and Mineral Show were aquamarine from the Shigar Valley, Northern Areas, Pakistan, and a turquoise pseudomorph after apatite from the La Caridad mine, Nacozari de Garcia, Sonora, Mexico. Chrome-green spodumene (hiddenite) has been recovered from a pocket at the Adams Farm, Alexander County, North Carolina, U.S.A. M.O'D.

The significance of new cuts in the 21st century.

B. Munsteiner. *Gemmologie. Z. Dt. Gemmol. Ges.*, 2007, 56(1-2), 39-40.

Facet cutting was developed by Ludwig von Berquem in 1476. From the 1960s there has been significant development of new gem cuts and these are discussed. E.S.

The Xianghuapu mines, Chenzhou Prefecture, Hunan Province, China.

B. Ottens. *The Mineralogical Record*, 38(1), 2007, 55-63.

Green crystals of fluorite are described from working quarries at Xianghuapu, Chenzhou Prefecture, Hunan Province, China. Crystals are found as cubes or as combinations of the cube and octahedron. Some material believed to be from these mines and offered for sale in the past may have been colour-enhanced by artificial irradiation. M.O'D.

Adventure rough stones – on the way to the mines.

E. Petsch. *Gemmologie. Z. Dt. Gemmol. Ges.*, 2007, 56(1-2), 41-42.

The author relates stories of early and present mining in far corners of the earth mainly by pioneers from Idar-Oberstein. E.S.

What's new in minerals.

J. Polityka. *The Mineralogical Record*, 37, 2006, 73-87.

Among gem-quality mineral specimens observed at the Springfield show of 2005 were deep red chondrodite from Badakhshan, Afghanistan, and a painite crystal of 6 mm from Mogok, Myanmar. M.O'D.

Marble-type ruby deposits.

D. Schwarz and D. Ohnenstetter. *Gemmologie. Z. Dt. Gemmol. Ges.*, 2007, 56(1-2), 51-2.

Marble hosted ruby deposits in central and south-east Asia, in the Urals in Russia and in Tanzania are the most important sources of gem-quality rubies. In Asia these deposits are located from Afghanistan to Vietnam. They are spatially related to major tectonic structures. Rubies from marble-hosted deposits show specific features compared with those found in other hosts. E.S.

Seventy-five years German Gemmological Association.

Gemmologie. Z. Dt. Gemmol. Ges., 2007, 56(1-2), 3-16.

Short overview of the history, development and present state of the German Gemmological Association which was founded by G.O. Wild in the Idar Gewerbehalle (trade hall), where a local gemmological exhibition had been housed since 1897. Wild was born in Idar, but had lived some time in the U.S.A., where he had come into contact with G.F. Kunz. In 1935 the association had 300 members and started training courses. After the war a Gemstone Research Institute was founded under the leadership of Prof. K. Schlossmacher. In 1953 the first exams were held and the first *Zeitschrift* was published, which is now in its 56th volume. Hans Caesar, Xaver Saller and Prof. H. Bank have been Presidents, a post filled at present by Dr Th. Lind. The Association works closely with various German universities and relevant international organizations. More than 30,000 have taken part in their educational programmes. E.S.

Observations on new coated gemstones.

J.E. Shigley. *Gemmologie. Z. Dt. Gemmol. Ges.*, 2007, 56(1-2), 53-6.

Historically inks, tints, dyes, paints and varnishes have been applied to surfaces of gemstones to improve, enhance or hide the underlying colour. Today many treatments are applied, such as irradiation, HPHT annealing or chemical diffusion. Multiple coatings may be applied. Commercial companies are advertising

improvements to diamond, corundum, topaz, beryl, opal, apatite, spinel, zoisite and possibly others. Coloured coatings are intended to enhance, hide or change the underlying body colour, while colourless coatings are intended to improve durability by sealing the surfaces of CZs or synthetic corundums. One coating substance is diamond-like carbon (DLC), an amorphous carbonaceous material with some physical properties similar to diamond. These coating materials present certain challenges to the jewellery trade, such as what are they, how thick are they, do they compromise identification, how durable are they and how much should the trade be concerned by them. E.S.

'New beryllium diffusion treatment' proves to be natural corundum surface-coated with cobalt.

C.P. Smith. *Gemmologie. Z. Dt. Gemmol. Ges.*, 2007, 56(1-2), 57-60.

Over the past year vivid blue sapphires have been on the market in Bangkok and New York; they were said to be produced in Chanthaburi, Thailand, by a 'new' beryllium treatment. The colour resembles Paraiba tourmaline. They were found to be natural corundum, surface-treated with cobalt, and were easily identified by their mottled surface and absorption spectrum of three bands at 550, 585 and 625. E.S.

Pink-to-red coral: a guide to determining origin of color.

C.P. Smith (chsmith@aglgemlab.com), S.F. McClure, S. Eaton-Magaña and D.M. Kondo. *Gems & Gemology*, 43(1), 2007, 4-15.

Due to a variety of environmental and legal factors, the supply of high-quality, natural-colour coral in the pink-to-red range has dramatically decreased in recent years and the quantity of dyed coral on the market has increased. From a study of more than 1000 natural- and treated-colour samples, the authors summarize the procedures that are useful in the identification of colour origin of pink-to-red coral. A variety of techniques, including magnification, exposure to acetone and Raman analysis, can determine if the colour of a piece of such coral is dyed. Although both magnification and the use of acetone have limitations, Raman spectroscopy can establish conclusively whether the specimen contains carotene and that the colour is natural. R.A.H.

Tormaline policrome in Vietnam.

F. Tamagnini. *Rivista Mineralogica Italiana*, 31, 2007, 104-7.

Deposits of multi-coloured tourmaline are described from Vietnam. Pink appears to be the predominating colour and some crystals appear to be of gem quality. M.O'D

From the Laboratory.

Tay Thye Sun. *Australian Gemmologist*, 23(1), 2007, 16-21.

This report includes comments on: a composite stone-plastic moulding of a Buddha statue; an imitation coconut pearl; a rare star ruby with red rays; B-Jade with blue surface sheen; a citrine displaying blue-green flashes; a large treated blue topaz for investment; a ruby paperweight; and an unusual Sri Lankan sapphire. L.J..

Ikons, classics and contemporary masterpieces of mineralogy.

W.A. Thompson. A supplement to *The Mineralogical Record*, 2007. The Mineralogical Record, Tucson, 192 pp.

About 175 beautiful mineral specimens are shown full-page in colour with facing descriptions and notes on mineral collecting. Though many specimens are of gem quality the crystals are unlikely to be fashioned. The photographs are well up to the *Record's* standard of excellence. M.O'D.

Gem corundums from Nan Khun-Nam Yuen, north-eastern Thailand.

P. Wathanakul, W. Atichat, V. Pisutha-Arnond, C. Sutthirat and D. Schwarz. *Gemmologie. Z. Dt. Gemmol. Ges.*, 2007, 56(1-2), 67-70.

The Nam Khun-Nam Yuen gem field is located in the Ubonratchathani province, in the north-east of Thailand bordering Cambodia. Blue-green-yellow sapphires and minor rubies have been found and the corundum population is bi-modal. Basaltic rocks are nearby. The stones are generally free from inclusions. Fine rutile needles and tiny zircons are rare, but secondary iron stains are common. Colour zoning is typical. Some light green-yellow sapphires with high transparency can be heat-treated to greenish-yellow or yellow under appropriate heating conditions. E.S.

Gallery reviews: Mineral museums update.

J.S. White. *The Mineralogical Record*, 37(4), 2006, 323-9.

Among the museums surveyed are the Natural History Museum, London, the Royal Museum, Edinburgh, the National Museum of Natural History, Smithsonian Institution, Washington DC, U.S.A., and the Royal Ontario Museum, Toronto, Canada. M.O'D.

Red wulfenite from the Kuruktag Mountains, Xinjiang Uygur, China.

W.E. Wilson and M.J. Origlieri. *The Mineralogical Record*, 38(1), 2007, 67-71.

Red crystals of wulfenite, some undoubtedly of ornamental quality, are described from a manganese deposit 300 kmx from the city of Hami and about 500 km from the Mongolian border, Xingjiang Uygur Autonomous Region, China. Crystals up to 4 cm on edge are reported. M.O'D.

Contrasts in gem corundum characteristics, eastern Australian basaltic fields: trace elements, fluid/melt inclusions and oxygen isotopes.

K. Zhaw (Khin.Zaw@utas.edu.au), F.L. Sutherland, F. Dellapasqua, C.G. Ryan, T.-F. Yui, P.T. Mernagh and D. Duncan. *Mineralogical Magazine*, 70(6), 2006, 669-87.

Corundum xenocrysts from alkaline basalt fields differ in their characteristics and hence in their lithospheric origins. Detailed comparisons are made between sapphires from Weldborough,

NE Tasmania, and those from Barrington, New South Wales. The Tasmanian sapphires are magmatic (high Ga, av. 200 ppm), and dominated by Fe (av. 3300 ppm) and variable Ti (av. 400 ppm) as chromophores. They contain Cl, Fe, Ga, Ti and CO_2-rich fluid inclusions and yield □^{18}O values (5.1 to 6.2 ‰) of mantle range. Geochronology on coexisting zircons suggests several sources (from 200 to 47 Ma) disrupted by basaltic metls (47 ± 0.6 Ma). Gem corundums from Barrington, NSW, also include magmatic sapphires (Ga av. 170 ppm, □^{18}O 4.6 to 5.8 ‰), but have more Fe (av. 9000 ppm) and less Ti (av. 300 ppm) as chromophores. Zircon dating suggests that gem formation was preceded and overlapped by Cainozoic basaltic melt generation (59–4 Ma). In contrast, a metamorphic sapphire-ruby suite (low Ga, av. 30 ppm) incorporates more Cr into the chromophores (up to 2250 ppm). Fluid inclusions are CO_2-poor, but melt inclusions suggest some alkaline melt interaction. The □^{18}O values (5.1 to 6.2 ‰) overlap magmatic sapphire values. The formation of rubies may be attributed to interactions at contact zones (*T* 780–940 C) between earlier Permian ultramafic bodies and later alkaline fluid activity. R.A.H.

Models of emerald formation: a new perspective.

J.C. Zwaan. *Gemmologie. Z. Dt. Gemmol. Ges.*, 2007, 56(1-2), 71-4.

The classic model of emerald formation assumes that emeralds found in schist-type deposits are formed by interaction between invading pegmatitic magmas/fluids and pre-existing mafic rock. Colombian emeralds are an exception, hosted by an early Cretaceous black shale limestone; the young Eocene deposits are not related to pegmatites or magmatic fluids. Morteani proposes that these deposits were formed by syn- to post-tectonic reactions during low-grade regional metamorphism. Giuliani, working with schist-like deposits, concluded that emeralds might be formed unconnected with pegmatites, or might be formed near pegmatites but were not formed as a result of single-stage contact metamorphism. The formation of the Sandawana emeralds however cannot be disconnected from magmatic activity. Evidence shows that no single theory can be applied to the formation of schist-type deposits. E.S.

Instruments and Techniques

Measurement of refractive indices with the Gemmeter™: a critical evaluation.

L. Cosnier. *Australian Gemmologist*, 22(12), 2006, 533-8.

Based on infrared reflectivity this new refractometer, which covers a low to high RI range, is shown to be reliable. However comparison with a conventional refractometer shows that the Gemmeter can obtain readings for high RI gems but is less precise for stones with lower RIs. L.J.

A forecast of important techniques in the coming decade.

E. Fritsch. *Gemmologie. Z. Dt. Gemmol. Ges.*, 2007, 56(1-2), 17-20.

The author stresses the continued need for careful observation using 'classical' gemmological methods. Methods which will probably be expanded include UV visible and infrared absorption, Raman scattering and X-ray fluorescence. The emission spectrum is used to help to detect HPHT-treated diamonds; the use of excitation spectra and time resolving luminescence is likely in future to be applied for the separation of natural from treated material. Trace element analysis is certain to be extended and isotopic studies look promising as they are now nearly non-destructive, with SIMS and other ion probes. They have been applied successfully using ^{18}O to determine origin of emeralds. The future gemmologist may not come from the ranks of the earth sciences, but from chemistry and physics. E.S.

Krüss HA10 Hearts and Arrows Loupe.

GAA Instrument Evaluation Committee Report. *Australian Gemmologist*, 23(1), 2007, 29-31.

Krüss Optronics present a simple and easy-to-use instrument that effectively displays the quality of cut found in Tolkowski cut diamonds. L.J.

Synthetics and Simulants

[Inclusions of metal-solvent and color in B-containing monocrystals of artificial diamond.]

A.I. Chepurov, E.I. Zhimulev, I.I. Fedorov and V.M. Sonin. *Proceedings of the Russian Mineralogical Society*, 135(6), 2006, 97-101. (Russian with English abstract.)

Single crystals of type IIb synthetic diamonds, from 0.1 to 2 ct, have been grown with cubo-octahedral habit together with minor faces {110}, {311} and {511}. These crystals are various shades of blue or dark blue depending on the amounts of B in the system; a characteristic feature is a sectorial structure expressed in a non-uniform distribution of colour. Metal inclusions with faceted isometric, lamellar extended inclusions, non-faceted inclusions and microinclusions have been found; they correspond in chemical composition with that of the metal solvent. The IR spectrum of these boron-bearing diamond crystals is presented together with figures showing the dependence of the *a* cell parameter of metallic inclusions on the iron content of the Fe-Ni alloy. R.A.H.

Abstractors

A.M. Clark - A.M.C. R.A. Howie - R.A.H. L. Joyner - L.J.
M. O'Donoghue - M.O'D. E. Stern - E.S

Book Reviews

Pinzgau - Tal der Kristalle und des grünen Feuers.

E. Burgrgsteiner and M. Wachtler, 2007. extraLapis No. 32. Weise, Munich. Pp 99, illus. in colour. ISSN 09458493. Price on application.

Review of the geology, mineralization and mineral species of the Pinzgau area, Salzburg, Austria. Ornamental-quality pink fluorite and fine green titanite (sphene) are among the species likely to be of interest to gemmologists. As always with this series, the standard of production and reproduction of photographs are of the highest order. M.O'D.

Robbing the Sparry Garniture. A 200-Year History of the British Mineral Dealers.

M.P. Cooper, 2007. The Mineralogical Record, Tucson, AZ. 358 pp. Softcover. [No ISBN]. US$49.00.

This is an amazing effort and without doubt has saved, probably at the eleventh hour, a great deal of information that could so easily have been lost. The book is much more than an alphabetical list of dealers (there are far more that might be assumed): Mick Cooper gives us details of their catalogues and illustrates, on many pages, their labels (the content and even the printing style of these often give a clue to the dates when particular specimens are first recovered). Some contemporary dealers have been photographed and reproductions of earlier photographs are plentiful.

While gemmologists will find a number of references to dealers who sold ornamental pieces, they will also enjoy reading about the practitioners of a profession that may appear submerged to many who are more familiar with fashioned artefacts.

The work is a great service to the earth sciences. M.O'D.

Tables of gemstones identification.

R. Dedeyne and I. Quintens, 2007. Glirico (glirico@gemmologie.be), Gent. Pp 309. Hardcover ISBN 9789078768012. Price on application.

Following a brief introduction in which some terms are explained, the remainder of the book presents numerical tables of major constants. There is no central index so, unless the reader already roughly knows whereabouts in the tables the desired species can be found, use of the book is likely to be wasteful of time. As always with tables, the authors have been faced with the question of nomenclature so that obsolete names have crept in as well as the usual fanciful and tedious names for quartz varieties and many others. There are 17 books listed in the bibliography where the GIA's centre of operations is stated to be Los Angeles and *Australian Gemmologist* is named as *Australian Gemmology*. This carelessness is typical of the whole book and the authors have been less than well-served by their advisers. It cannot be recommended (surely this type of book is now obsolete?); a pity because the production is good and the front cover the book's best feature. M.O'D.

Geology of Gem Deposits (short Course Series Volume 37).

L.A. Groat (Ed.) (lgroat@eos.ubc.ca). Mineralogical Association of Canada, Quebec. 288 pp plus 24 colour plates. ISBN 978-0-921294-37-5. US$ 50.00.

Gem deposits are rare because in general the conditions that promote their formation are unusual, and thus worthy of scientific study. Modern geological and analytical techniques have now been applied to gem occurrences in Canada and elsewhere, leading to radical alteration of models and understanding. This volume looks at gemstones from a geological perspective and reviews in ten chapters current concepts on the origins of diamond, ruby, sapphire, emerald and other coloured gems. R.A.H.

Opal, the Phenomenal Gemstone.

Various authors, 2007. extraLapis, English No 10. Lithographie, LLC, East Hampton, CT. 108 pp. ISBN 978 0 970908 0 9. Price on application.

This latest monograph in the welcome extraLapis series carries papers on various aspects of opal, including: Science, history and lore (noted dealers Si and Ann Frazier, who also contributed an opal glossary of terms), Play-of-colour in opal (Max Weibel) , Composite opal (Karl Fischer), Synthetic, colour-enhanced and imitation opal (Michael O' Donoghue), Ethiopia to Indonesia, a sampling of lesser-known opal localities (Gloria Stabler), and Opal

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from Mexico (Jürgen Schütz). There is an excellent list of references and a map of world opal localities.

As we have come to expect from this series (and its German counterpart) the colour pictures are beautiful. M.O'D

The World of Fluorescent Minerals.

S. Schneider, 2006. Schiffer Publishing, Atglen, PA. pp 192, illus. in colour. Softcover. ISBN 0 7643 2544 2. US$29.95.

All books on fluorescent minerals need to be fully illustrated in colour and in many examples definition seems to have suffered in the transition, between photograph and reproduction. This very attractive book is an exception; it could serve as a general illustrated guide to minerals even without the fluorescence effects. As well as the photographs there are useful hints for the collector and both dimensions and weights are given for the specimens depicted.

In most cases the same specimen is shown in both LW and SW UV: the arrangement is by country of origin and there is a short list of dealers holding stocks of or specializing in fluorescent minerals: all are in the United States. There is a short bibliography and a list of names and addresses of special interest groups in the United States.

This is an excellent book and most attractively produced. M.O'D.

Namibia, Minerals and Localities. 2nd edn.

L. Von Bezing, R. Bode and S. Jahn, 2007. Bode, Haltern. pp 856, illus. throughout in colour. €111.00.

While the weight of the book may be the first feature to strike the reader, an examination of every opening will quickly indicate that this is one of the world's greatest mineral books, worthily continuing the German tradition of excellence in both text and illustration. In every way this is a splendid book; authoritative text by authors and consultants and some of the most beautiful mineral photographs I have yet seen.

Of course if you are aiming to select a single country which contains the most spectacular mineral specimens, Namibia is one of the best to choose. Gem-quality minerals (tourmaline – it has its own 'Tourmaline gallery') and many others can be found among the photographs. Some of the less common minerals are much better collected for their crystals than for fashioning – look up cuprite, smithsonite, malachite and wulfenite.

The first part of the book describes the history of mineral prospecting and mining in Namibia. Tsumeb, as expected, is comprehensively treated, but there are also the Erongo mountains, the Rössing mountains, the Onganja mine and its copper deposits and, naturally, the pegmatites in the central areas and the story of Luderitz and the diamonds.

This section is followed by an encyclopaedic treatment of the minerals; there are no appendices but the references cover pages 834-38.

This is a breathtaking book; apart from the specimens many photographs give the reader some idea of the country in general. Forget the (reasonable) expense and the weight and buy the book. M.O'D.

New titles from Gem-A

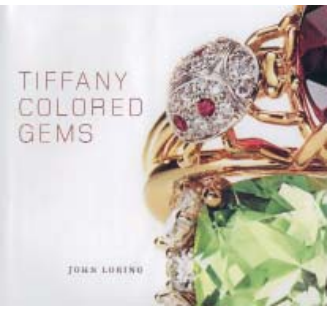

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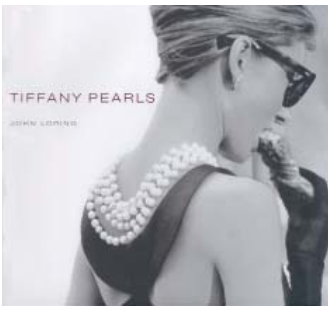

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John Loring, 2006
Abrams, New York
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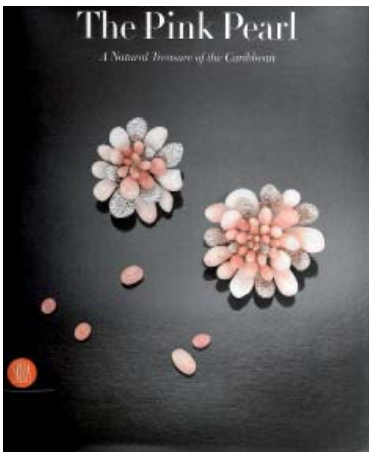

The Pink Pearl - A Natural Treasure of the Caribbean*
Text by David Federman, adapted by Hubert Bari, 2007
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Proceedings of the Gemmological Association of Great Britain and Notices

Gem-A Conference and Graduation Ceremony

The 2007 Gem-A Conference was held on Sunday 28 October at the Renaissance London Heathrow Hotel. The theme of the Conference was 'Gems of the Orient: Pearls and Jade', and speakers included Shigeru Akamatsu, George Bosshart, Prof. Dr Henry A. Hanni, Roger Keverne, Chiu Mei Ou Yang, Gaiti Rabbani, Kenneth Scarratt and Elisabeth Strack. A programme of events was arranged to coincide with the Conference, including a private viewing of the Crown Jewels at the Tower of London, visits to the School of Earth Sciences, Kingston University, to view and learn about the equipment used to research gems and minerals, and a Gem Discovery Club specialist evening.

On Monday 29 October the Graduation Ceremony and Presentation of Awards gained in the 2007 examinations was held at Goldsmiths' Hall in the City of London. Chairman of the Gem-A Council, Prof. Alan T. Collins, presided, and David Thomas, Crown Jeweller from 1991 to July 2007, presented the awards.

Ms Chiu Mei Ou Yang of Hong Kong was awarded an Honorary Lifetime Membership in recognition of her substantial contribution to the world of gemmology and to the Association. The award was presented by Gem-A President Alan Jobbins.

The address was given by David Thomas, who stressed to the graduates the importance of their education for the trade and the necessity for continual learning throughout their careers. He concluded by saying; "You can all achieve your dream by dedication, continual learning and belief in yourself. I urge you all to continue your education in this fascinating and historic trade."

The ceremony was followed by a reception for nearly 300 graduates and guests.

Reports of both the Conference and the Graduation Ceremony will be published in the December 2007 issue of *Gems & Jewellery.*

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Gem-A Awards

Gem-A Examinations were held worldwide in June 2007. In the Examinations in Gemmology 230 candidates sat for the Diploma Examination of whom 139 qualified, including eight with Distinction and fifteen with Merit. In the Foundation Gemmology Examination, 220 candidates sat of whom 153 qualified. In the Gem Diamond Examination 80 candidates sat of whom 49 qualified, including six with Distinction and seven with Merit.

The Tully Medal is awarded to the candidate who submits the best set of answers in the Gemmology Diploma examination which, in the opinion of the Examiners, are of sufficiently high standard. This year, most unusually, two Tully Medals were awarded. Sophie Louise Wootton of London was awarded the Tully Medal as well as Christie's Prize for Gemmology for the best candidate of the year in the Diploma Examination who derives their main income from activities essentially connected with the jewellery trade. Taisuke Kobayashi of Tokyo, Japan, also received the Tully Medal in addition to the Anderson Bank Prize for the best non-trade candidate of the year in the Diploma in Gemmology.

The Foundation Certificate in Gemmology examination awards, the Anderson Medal for the candidate who submitted the best set of answers which, in the opinion of the Examiners, were of sufficiently high standard, and the Hirsh Foundation Award for the best candidate of the year, were awarded to Holly J. Barker of Johannesburg, South Africa.

The Gem Diamond Diploma examination awards, the Bruton Medal for the candidate who submitted the best set of answers which, in the opinion of the Examiners, were of sufficiently high standard, and the Deeks Diamond Prize for the best candidate of the year, were both awarded to Peter Alexander Jansch of Englefield Green, Surrey. This year the Gem-A Council awarded a special prize for the best set of theory papers in the Gem Diamond Diploma examination, Distinction category. This was awarded to Gregory Peter Hall of Brighton, East Sussex.

The names of the successful candidates are listed below:

EXAMINATIONS IN GEMMOLOGY

Gemmology Diploma

Qualified with Distinction

Guo Xiao Lei, Wuhan, Hubei, P.R. China
Jiang Xin, Wuhan, Hubei, P.R. China
Kobayashi, Taisuke, Tokyo, Japan
Raoult, Francoise, Étables-sur-Mer, France
Sawamura, Tsukasa, Tokyo, Japan
Sekine, Shunji, Tokyo, Japan
Tang Zi Wei, Wuhan, Hubei, P.R. China
Wootton, Sophie Louise, London

Qualified with Merit

Bryl Gaudet, Lou-Pierre, Montreal, Quebec, Canada
Cheng Yuan, Guilin, Guangxi, P.R. China
Cui Xianzhong, London
Di Dongshuang, Wuhan, Hubei, P.R. China
Haokip, Seikholen, Imphal, Manipur, India
Hu, Helen, London
Jain, Apeksha, New Delhi, India
James, Bronwynne, St Albans, Hertfordshire
Li Xiao Lin, Wuhan, Hubei, P.R. China
Machefert, Jean-Michel, Cormeilles-en-Parisis, France
Mo Zurong, Guilin, Guangxi, P.R. China
Sahabunyakul, Saran, Bangkok, Thailand
Smith, Laura Sian, Oxford
Wang Qin, Guilin, Guangxi, P.R. China
Xing Yingying, Wuhan, Hubei, P.R. China

Gem-A Awards

Qualified

Abduriyim, Ahmadjan, Taito-ku, Tokyo, Japan
Adler, Stevan, New York, U.S.A.
Andrianaina Rado, Antananarivo, Madagascar
Avender, Breanne Valeda, Burnaby, British Columbia, Canada
Bove, Bertrand, Vitry-sur-Seine, France
Cao Li Fei, Wuhan, Hubei, P.R. China
Caulton, David, Dore, Sheffield
Chan Che Min, Tsuen Wan, Hong Kong
Chang Hsiao Huei, Westmount, Quebec, Canada
Chauhan, Rakesh, Chandigarh, India
Cheung, Nelly, Tai Koo Shing, Hong Kong
Cheung Ching Ping, Candy, Tseung Kwan, Kowloon, Hong Kong
Chiu Chun-Chieh, Taipei, Taiwan, R.O. China
Corser, Elizabeth, Wellington, Shropshire
Craddock, Natalie, Bridport, Dorset
Cutler, Leticia, Birmingham, West Midlands
Daudin, Mathieu, Paris, France
De Barros, Valere, Maron, France
de Siran de Cavanac, Bérengère, Toulon, France
Dereszewska, Basia, London
Dighton, Anna Louise, Saffron Walden, Essex
Dong Haiyang, Guilin, Guangxi, P.R. China
Doyle, Helen, London
Drummond, Jean, Farnham, Surrey
Faugeroux, Valerie, Lagardelle-sur-Lèze, France
Feng Jing Ling, Shanghai, P.R. China
Ferneyhough, Ella Jane, Birmingham, West Midlands
Fong Yan, William, Tai Po, Hong Kong
Fu Xin, Haidian District, Beijing, P.R. China
Fujii, Yasuhisa, Sinagawa-ku, Tokyo, Japan
Galbraith, Stuart, Bourton-on-the-Water, Gloucestershire
Grimal, Marie, Marseille, France
Guo Qian, Guilin, Guangxi, P.R. China
Han Jie, Coventry, West Midlands
Harrington, Olga, Zurich, Switzerland
Heit, Liesbeth, London
Hsu Chia Jung, Taichung, Taiwan, R.O. China
Hu Xiao Yu, London
Hui Wing Hing, Kowloon, Hong Kong
Iwamoto, Akiko, London
Jin Yan Nan, Wuhan, Hubei, P.R. China
Kim Dong Hui, Daegu, South Korea
Kim Ji Eun, Chungbuk-Do, South Korea
Koundouraki, Evagelia, Athens, Greece
Lam Nga Sheung Hilde, Kowloon, Hong Kong
Lau Tsui Wah, Kowloon Tong, Hong Kong
Lee Cheuk Ming, Kowloon, Hong Kong
Leong Weng Fock, Cedric, Antananarivo, Madagascar
Li Hua, Wuhan, Hubei, P.R. China
Li Zhi, Wuhan, Hubei, P.R. China
Liao Tsai Chun, Taipei, Taiwan, R.O. China
Lilley, Samantha, London
Lin Chun Hsien, Taipei, Taiwan, R.O. China
Lin Li, Guilin, Guangxi, P.R. China
Lin Wanchun, Guilin, Guangxi, P.R. China
Ling Xiao Qing, Shanghai, P.R. China
Liu Zijian, Guilin, Guangxi, P.R. China
Lo, Sunny, Kowloon, Hong Kong
Lo Pui Yin, Shirley, Tai Po, Hong Kong
Lung Wan-Hui, Taipei, Taiwan, R.O. China
Luzuriaga Alvarez, Hugo Vicente, Montreal, Quebec, Canada
McWhirter, Hannah Maeve, Bury St Edmunds, Suffolk
Miller, Me'Shell, North Highlands, California, U.S.A.
Mitchell, Jonathan D., Midland, Texas, U.S.A.
Miyamoto, Kazuhiko, Osaka City, Osaka, Japan
Mok So Yiu, Tsuen Wan, Hong Kong
Munoz-Vasquez, Alejandra C., London
Naing, Sein, Lanmadaw Township, Yangon, Myanmar
Naito, Ayako, Tokyo, Japan
Nakagawa, Yumi, Kitakatsuragi-gun, Nara Pref., Japan
Narudeesombat, Nalin, Bangkok, Thailand
Palmares, Richard P., Sale, Cheshire
Perks, Helen Elizabeth, Telford, Shropshire
Piha, Saara, Helsinki, Finland
Powar, Krishna, Smethwick, West Midlands
Prak, Sam, Toronto, Ontario, Canada
Ranaivoson Hantarinoro, Antananarivo,

Gem-A Awards

Madagascar
Randriamialisoa Tody Harilala, Antananarivo, Madagascar
Ren Lei, Haidian District, Beijing, P.R. China
Rodman, Anna, Sweden
Rossi, Hélène, Besançon, France
Saejoo, Sakrapee, Bangkok, Thailand
Sarraf, Kundan, Lalitpur, Nepal
Shen Jiani, Guilin, Guangxi, P.R. China
Spagnoletti Zeuli, Lavinia, London
Stevenson, Laura Jacqueline, North Vancouver, British Columbia, Canada
Suokko, Teija, Tampere, Finland
Tai Ai-Hwa, Taipei, Taiwan, R.O. China
Takahata, Yoshichika, Takamatsu City, Japan
Tang Jiahui, Guilin, Guangxi, P.R. China
Tanvangi, Pragya, Surat, India
Uchiyama, Mio, Ichikawa City, Chiba Pref., Japan
von Schantz, Casimir, Helsinki, Finland
Voulgaris, Apollon, Mykonos, Greece
Wang Haiyuan, Haidian District, Beijing, P.R.China
Wang Wenqi, Guilin, Guangxi, P.R. China
Wang Yi Xian, Wuhan, Hubei, P.R. China
Watson, Jennifer, Sutton Coldfield, West Midlands
Win, Mo Mo, Yankin Township, Yangon, Myanmar
Wong, Winnie, Tsimshatsui, Kowloon, Hong Kong
Wong Lai Mi, Tseung Kwan O, Hong Kong
Wong Yin Kwan Angela, Tin Shui Wai, New Territories, Hong Kong
Wu, Benson, Oakville, Ontario, Canada
Wu Chiayu, Taipei, Taiwan, R.O. China
Wu Wing Yi, Kowloon, Hong Kong
Yamada, Masashi, Tokyo, Japan
Yamaguchi, Yuko, Osaka, Japan
Yang Jui Lin, Taipei, Taiwan, R.O. China
Yau Wai Yee, Kowloon, Hong Kong
Yeung, Anthea Ka Yee, Hong Kong
Yip Tak Wing, Shatin, Hong Kong
Zhang Duo, Wuhan, Hubei, P.R. China
Zhang Yanyan, Haidian District, Beijing, P.R.China
Zhao Lisha, Guilin, Guangxi, P.R. China
Zheng Lulu, Wuhan, Hubei, P.R. China
ZhuoJun Xu, Shanghai, P.R. China

Gemmology Foundation Certificate

Qualified

Abey, Sara, London
Anastasopoulou, Georgia, Greece
Andersson, Lina, Sundbyberg, Sweden
Andersson, Joel, Lannavaara, Sweden
Andrianaina Rado, Antananarivo, Madagascar
Astrand, Frida, Malmo, Sweden
Au, Anita Suet Ki, Tsimshatsui, Kowloon, Hong Kong
Austen, Katelyn Scarlet, Oldbury, West Midlands
Aye Su Nandar Htay, Yangon, Myanmar
Beer, Robyn M., Rocklin, California, U.S.A.
Bigford, Julie Claire, Malvern Wells, Worcestershire
Brian, Jeremy, Marseille, France
Brichet, Leonore, Vernouillet, France
Bryl Gaudet, Lou-Pierre, Montreal, Quebec, Canada
Burton, Lola Clare, Bournemouth, Dorset
Cane, Deborah, Birmingham, West Midlands
Chan Hing Yip, Ken, Kowloon, Hong Kong
Chan Ka Man, Carmen, Lantau Island, Hong Kong
Chan Wai Sze, Shatin, New Territories, Hong Kong
Chan Yuk Ying, Tsimshatsui, Kowloon, Hong Kong
Chang Hsiao Huei, Westmount, Quebec, Canada
Chapman, Dominic Richard James, Caterham, Surrey
Cheung Fai Har, Candy, Yuen Long, Hong Kong
Cheung Suk Wan, Shatin, New Territories, Hong Kong
Chie, Christine, Heng Fa Chuen, Chai Wan, Hong Kong
Chitty, Warne William, Aspen, Colorado, U.S.A.
Chow Siu Fung, Tsimshatsui, Kowloon, Hong Kong

Gem-A Awards

Chu Fung Yee, Tsimshatsui, Kowloon, Hong Kong
Chung Tsz Bun, Kowloon, Hong Kong
Day, Helen Laura, Wolverhampton, Staffordshire
de Siran de Cavanac, Berengere, Toulon, France
Dereszewska, Basia, London
Dighton, Anna Louise, Saffron Walden, Essex
Duval, Julie, London
Evans, Natalie, London
Evans, Charles I., London
Giertta, Maria, London
Gilli, Claude, Les Pennes Mirabeau, France
Gunnarsson, Camilla, Lannavaara, Sweden
Guy, Nicholas M., Fremington, North Devon
Hall, Christopher Robert, Wednesbury, West Midlands
Hampton, Kate, Mazesycoed, Pontypridd, Wales
Hamren, Elisabeth, Ostersund, Sweden
Han Jie, Coventry, West Midlands
Hansson, Maria, Eslou, Sweden
Harker, Catherine Anne, Birmingham, West Midlands
Hou Xukui, Guilin, Guangxi, P.R. China
Hsu Juiwen, Taiwan, R.O. China
Hu Xiao Yu, London
Hui Yuet Ming, Kowloon, Hong Kong
Huijbrechts, Thomas N., Salisbury, Wiltshire
Iwamoto, Akiko, London
James, Bronwynne, St Albans, Hertfordshire
Jay Wang San, Katherine, Hong Kong
Jeong Eun Ah, Kofu City, Yamanashi Pref., Japan
Kambale, Sonia, Surat, Gujarat, India
Kankkunen, Markus, Tervalmpi, Finland
Kanwar, Kerensa Janet, Renfrew, Scotland
Karkouli, Elpida, Drossia, Greece
Keung Wing Fun, Kowloon, Hong Kong
Kim, Eun Jeong, Gyungnam-Do, South Korea
Kim, Richard, Citrus Heights, California, U.S.A.
Kim, Deok Hyeon, Nam-Gu, Daegu, South Korea
Knutsen, Annmari Ellilia, Oslo, Norway
Kobayashi, Nobue, Taito-ku, Tokyo, Japan
Kok, Hans, DJ Ysselstein, The Netherlands
Kuchard, Monika, London
Kui Nui Reema, Yeong Long, Hong Kong
Lai Siu Kwong, New Territories, Hong Kong
Lam Pui Ling, Shau Kei Wan, Hong Kong
Lam Sau Kwan, Hong Kong
Larsson, Ylva, Lannavaara, Sweden
Lau Ho, Kowloon, Hong Kong
Lee, Sinnie, Kowloon Tong, Hong Kong
Lee Ka Ho, Vincent, Kowloon, Hong Kong
Leong Weng Fock, Cedric, Antananarivo, Madagascar
Leung Ka Yee, Ainsley, Sheung Shui, New Territories, Hong Kong
Li Jingna, Guilin, Guangxi, P.R. China,
Liang Rong, Guilin, Guangxi, P.R. China
Lofberg, Anders, Lannavaara, Sweden
Luzuriaga Alvarez, Hugo Vicente, Montreal, Quebec, Canada
Ma, Hoi Shan, Kowloon, Hong Kong
McWhirter, Euan, London
Man Sai Wing, Kwun Tong, Hong Kong
Marsh, Lynn, Farringdon, Tyne and Wear
Martins Molgard, Silvia, Colombo, Sri Lanka
Mi Zhiwei, Guilin, Guangxi, P.R. China
Mo Ying Lin Marilyn, Kowloon, Hong Kong
Mogridge, Emma Denise, Cornworthy, Devon
Mu Yujing, Shanghai, P.R. China
Narudeesombat, Nalin, Bangkok, Thailand
Ng Wai Hing, Tsuen Wan, New Territories, Hong Kong
Nichol, Camilla, York
O'Hagan, David, Sutton Coldfield, West Midlands
Owen-Jones, Joy, Birmingham, West Midlands
Pan, Ya-Fen, Taiwan, R.O. China
Papapavlou, Despina-Maria, Rhodes, Greece
Park, Seon Hyun, Buk-Gu, Daegu, Korea
Partner, Robert, Cropston, Leicestershire
Patel, Jayeshkumar Ramajibhai, Surat, India
Poon Wing Yan, Tin Shui Wai, New Territories, Hong Kong
Pughe, Marianne, Corbridge, Northumberland
Randriamialisoa Eva Harilala, Antananarivo, Madagascar

Gem-A Awards

Ranorosoa Nadine, Antananarivo, Madagascar
Raoult, Francoise, Étables-sur-Mer, France
Razanadimby, Lalanirina, Antananarivo, Madagascar
Ross, Antonia, Fleet, Hampshire
Rossi, Hélène, Besançon, France
Rufus, Simon, London
Saejoo, Sakrapee, Bangkok, Thailand
Sawyer, Jennifer, Hungerford, Berkshire
Sellors, James, Birmingham, West Midlands
Shah, Krupa, Nairobi, Kenya
Shah, Roshni M., Nairobi, Kenya
Shaw, Heather, Barnsley, Yorkshire
Shum Yau Kuen, Charlotte, Kowloon, Hong Kong
Siegan-Smith, Breige, London
Siriwardena, H.H.D.A.L., Raddolugama, Sri Lanka
Smith, Mark, Richmond, Surrey
So Hoi Ling Beta, New Territories, Hong Kong
Sonoda, Yasuko, Kofu City, Yamanashi Pref., Japan
Spencer, Jason, Birmingham, West Midlands
Tang Jiahui, Guilin, Guangxi, P.R. China
Tang Kai Chung, Yuen Long, New Territories, Hong Kong
Thein Thein Win, Yangon, Myanmar
Toca, Mayte, Antananarivo, Madagascar
Tsuruta, Miho, Onga-gun, Fukuoka Pref., Japan
Ueda, Kenji, Osaka City, Japan
Valerio Sa, Helena, Montreal, Quebec, Canada
van Beek, Ellen, Schoonhoven CB, The Netherlands
Vigneron, Charlotte, Boulogne-Billancourt, France
Vlemmix, J.M.A, Ravenstein AD, The Netherlands
Voyiatzi, Niki, London
Wakabayashi, Takuji, Tokyo, Japan
Wan, Hsiang Hsin, Taipei, Taiwan, R.O. China
Wang, Yinjie, Shanghai, China
Wang Ling, Shanghai, China
Ward, Simon Francis, Leigh-on-Sea, Essex
Watanabe, Yoshiko, Minamitsuru-gun, Yamanashi Pref., Japan
Wong Wing Sze, Hong Kong
Xu Hui, Guilin, Guangxi, P.R. China
Yamada, Mayumi, Kobe City, Hyogo Pref., Japan
Yamaguchi, Yuko, Osaka, Japan
Yeung Siu Sing, Antony, Kowloon, Hong Kong
Yoon, Hee Sung, Seoul, South Korea
Yoshida, Ayana, Tokyo, Japan
Yu, Young Il, Ansan-Si, Gyeongg-Do, Korea
Yu Kwai Sang, Tsuen Wan, New Territories, Hong Kong
Yu Xiubing, Shanghai, P.R. China
Zaleszczyk, Alicja, Birmingham, West Midlands
Zetterblom, Ulrika, Lannavaara, Sweden
Zhang Minghui, Guilin, Guangxi, P.R. China
Zhuang, Zhiyuan, Shanghai, P.R. China

GEM DIAMOND EXAMINATION

Gem Diamond Diploma

Qualified with Distinction

Bell, Lucy Kate, Stirchley, Birmingham, West Midlands
Deeley, Philippa, Etchingham, East Sussex
Jansch, Peter Alexander, Englefield Green, Surrey
Khan Farrukh, Nayer, Washwood Heath, West Midlands
Murray, Helen Claire, Sutton Coldfield, West Midlands
Robichaud, Emilie Gould, London

Qualified with Merit

Beer, Jasmin, Birmingham, West Midlands
Chan Wing Sze, Herleva, Kowloon, Hong Kong
Dong Wei, Wuhan, Hubei, P.R. China
Harker, Catherine Anne, Birmingham, West Midlands
Low, San, Chatham, Kent
Westlake, Ingrid, Chamonix, France
Zhao Xi, Wuhan, Hubei, P.R. China

Gem-A Awards

Qualified

Au Wing Ki, Astor, Happy Valley, Hong Kong
Austen, Katelyn Scarlet, Oldbury, West Midlands
Bao Li, Chaoyangmenwai, Beijing, P.R. China
Boubker, Layla, Hatfield, Hertfordshire
Chan Che-Sheung, Joanna, Hong Kong
Chan Kin Chung, San Po Kong, Kowloon, Hong Kong
Chin Suet Ying, Kwai Chung, New Territories, Hong Kong
Chiu Fong Ting, Siu Hang Tsuen, New Territories, Hong Kong
Dorudi, Roya, London
Geormas, Emmanuel, Byron, Greece
Harman, Bronwen, Reading, Berkshire
Ho Yue Yau, Tsuen Wan, Hong Kong
Jenkinson, Glenn W., Telford, Shropshire
Jones, Gary, Dudley, West Midlands
Jordan, Steven L., Biggleswade, Bedfordshire
Khaing, Hnin Hnin, London
Ko Yum Sum, Iris, Kowloon, Hong Kong
Lam Shun, Kowloon, Hong Kong
Leno, Petra, Newbury, Berkshire
Leza, Marianna, Ano Glyfada, Greece
Lwin, Pwint Phue, London
Martins, Miki, Burnaby, British Columbia, Canada
Ng Yuk Yu, Shatin, New Territories, Hong Kong
Rice, James, Hull, East Yorkshire
Symes, Evelyn R., Bath, Somerset
Tam Tin Sang, Daniel, Kowloon, Hong Kong
Thomas, David John, Milton Keynes, Buckinghamshire
Wang Gang, Feng Tai District, Beijing, P.R. China
Wang Jiazheng, Wuhan, Hubei, P.R. China
Wang Min, Wuhan, Hubei, P.R. China
Wilson, Naomi, Birmingham, West Midlands
Woolley, Claire Corinna, Cradley Heath, West Midlands
Xie Junjun, Wuhan, Hubei, P.R. China
Xu Hui, Fengtal District, Beijing, P.R. China
Yang Lei, Wuhan, Hubei, P.R. China
Zhao Hang, Wuhan, Hubei, P.R. China

Members' Meetings

London

Annual General Meeting

The Annual General Meeting was held at the National Liberal Club, Whitehall Place, London SW1, on 18 June. Professor Alan Collins chaired the meeting and welcomed members. The Annual Report and Accounts were approved. Sheila Burgoyne and Sally Everitt retired from the Council in rotation and being eligible Sally Everitt was re-elected to the Council. Sheila Burgoyne did not seek re-election. James Riley and Jason Williams had been appointed to serve on the Council since the 2006 AGM and both were elected. Brian Jackson and Gwyn Green retired in rotation from the Members' Audit Committee and, being eligible, were re-elected to the Committee. Hazlems Fenton were re-appointed as auditors for the year.

A special resolution was put to the meeting that the name of the Association be changed to 'The Gemmological Association of Great Britain'. After discussion the name change was put to the vote and was agreed by a large majority.

A presentation by John I Koivula of the GIA, Carlsbad, entitled 'The latest views of the MicroWorld' followed the AGM, a report of which appeared in the August 2007 issue of *Gems & Jewellery*.

Seaman Schepps (1881-1972): America's Court Jeweller

A guided tour of the Seaman Schepps exhibition at the Gilbert Gallery, Somerset House, was held on the afternoon of 18 June, planned to coincide with the Gem-A AGM and talk by John Koivula. The guided tour highlighted the key works of Seaman Schepps, his background, and the historical and social context of his work, as well as the innovative materials he used, unusual settings and originality of designs.

Gem Discovery Club Specialist Evenings

The Gem Club meets every Tuesday evening at the Gem-A London headquarters when Club members have the opportunity to examine a wide variety of stones, and once a month a guest gem or mineral specialist is invited to give a presentation.

The guest in April was Marcus McCallum who talked about stone beads, the recent market explosion, the new stones and cuts coming onto the market, and the methods of treatment. Rui Galopim de Carvalho of Sintra, Portugal, in the UK to speak at the Gem-A Scottish Branch Conference, was the May guest. He gave a presentation on the gemstones used in seventeenth- and eighteenth-century Portuguese jewellery. At the June specialist evening, Club members learnt about the history and characteristics of Lennix synthetic emeralds from guest Roy Huddlestone. Plenty of time was allowed for the participants to examine the large selection of the synthetics that Roy had brought along. The July guest, gem dealer Jason Williams, gave a brief talk on the values and value factors of gemstones before challenging Club members to estimate relative values of a large number of cut and polished gemstones. In August Harry Levy gave an up-date on the treated and synthetic diamonds circulating on the market today. The September specialists, Peter Rome and John Taylor of Charles Mathews (Lapidaries), gave an insight into the art of fine gem cutting by hand. In October, Harold Killingback's subject was asterism in quartz when he demonstrated how light from a laser is affected by the regular array of inclusions in a sphere of star rose quartz. At the Gem Club held at the end of October to coincide with the Gem-A Annual Conference, Jack Ogden gave a presentation entitled 'A Lust for Lustre: 2500 years of the pearl trade from Alexander's armies to the Gem Testing Laboratory'. Jack brought along a selection of pearls for participants to examine.

Midlands Branch

Branch meetings held at the Earth Sciences Building, University of Birmingham, included a presentation on 27 April by Heather McPherson when she asked the question: 'Could you be a valuer?', a talk by Richard Digby on 28 September on 'Cameos and intaglios', and on 26 October organics expert Maggie Campbell Pedersen on 'Gems from life'. The Branch's Summer Supper Party was held on 16 June at Barnt Green.

North East Branch

On 24 May at the Ramada Jarvis Hotel, Wetherby, gem dealer Tracey Jukes spoke on the coloured stone market and on 13 September at the same venue the gems and gem industry of Sri Lanka was the subject of Don Ariyaratna's presentation.

North West Branch

Branch meetings held at YHA Liverpool International, Wapping, Liverpool 1, included on 19 April 'Questions and Answers', a talk by Ian Williams who runs a workshop making hand-made jewellery;

On 17 May Wendy Simkiss spoke on the agate collection of the 15th Earl of Derby, and on 21 June Alan Hodgkinson gave a presentation on opals. The branch AGM was held at YHA Liverpool International when Deanna Brady was re-elected Chairman and Secretary of the Branch.

Scottish Branch

The Scottish Branch Conference was held at the Lovat Hotel, Perth, from 4 to 7 May. Speakers included Dr Emmanuel Fritsch (keynote), Dr David Fisher, Rui Galopim de Carvalho, Henrietta Lidchi and Maggie Campbell Pedersen. As in previous years, the Sunday afternoon was devoted to displays, demonstrations and workshops, and the conference concluded on the Monday with a field trip to 'Ruby Bay' at Elie to hunt for pyrope garnets. (A full report of the event was published in the June 2007 issue of *Gems & Jewellery*.)

Meeting held at the British Geological Survey, Murchison House, West Mains Road, Edinburgh, included a talk by Richard Gardner of Michiko Pearls on 18 June entitled 'The pearl trade today' and on 16 October gem dealer Tracey Jukes spoke on 'Coloured gemstone valuation in the 21st century'. On 11 September the Branch held a joint meeting with the Scottish Mineral and Lapidary Club at their premises in Leith when Memory Stather gave a presentation on gem carving.

Membership

Between 1 April and 31 October 2007, the Council approved the election to membership of the following:

Fellowship and Diamond Membership (FGA DGA)

Cheung Ching Ping, Candy, Tseung Kwan, Kowloon, Hong Kong. 2004/2007
Bill, David Nigel, Burntwood, Staffordshire. 1980/1981
Davis, Jonathan Vincent, Harrow, Middlesex. 1978/1979
Geormas, Emmanuel, Byron, Greece. 2006/2007
Kahn Farrukh, Nayer, Birmingham, West Midlands. 2006/2007

Fellowship (FGA)

Adler, Stevan, New York, U.S.A. 2007
Amicone, Maria, Quebec, Canada. 2007
Avender, Breanne Valeda, Burnaby, British Columbia, Canada. 2007
Balter, Jonathan, London. 1992
Barbour, Alexandra Frances, Dorchester, Dorset. 2007
Barker, Holly, Johannesburg, South Africa. 2007
Caulton, David, Dore, Sheffield, Yorkshire. 2007
Chang, Hsiao Huei, Westmount, Quebec, Canada. 2007
Chung, Stella Yee Man, Hong Kong. 2007
Corser, Elizabeth, Wellington, Shropshire. 2007
Cropp, Alastair, Milton, Queensland, Australia. 1999
Decourteney, Chris, Poole, Dorset. 2007
de Siran de Cavanac, Bérengère, Toulon, France. 2007
Doyle, Helen, London. 2007
Ellor, Lucy, Farnham, Surrey. 1992
Ferneyhough, Ella, Birmingham, West Midlands. 2007
Frei, Thomas, Pratteln, Switzerland. 2007
Gourlet, Agnes, Paris, France. 2007
Heit, Liesbeth, London. 2007
Hui Yuen-Wah, Hong Kong. 2007
Katayama, Shinko, Colombo, Sri Lanka. 2007
Kemprud, Tanya, Revelstoke, British Columbia, Canada. 2007
Lau, Tsui Wah, Kowloon City, Hong Kong. 2007
Lee, Cheuk Ming, Hong Kong. 2007
Lefebvre, Alburt, Brampton, Ontario, Canada. 2007
Lilley, Samantha, London. 2007
Lo Pui Yin, Shirley, Hong Kong. 2007
Machefert, Jean-Michel, Cormeilles-en-Parisis, France. 2007
Mak Hoi Chuen, Jeff, Hong Kong. 2007
Mak, Kim, Hong Kong. 2006
Manarkattu, Mahesh, Palai, India. 2007
McWhirter, Hannah Maeve, Bury St Edmunds, Suffolk. 2007
Miller, Me'Shell, North Highlands, California, U.S.A. 2007
Mok So Yiu, Tsuen Wan, Hong Kong. 2007
Piha, Saara, Helsinki, Finland. 2007
Rodman, Anna, Lund, Sweden. 2007
Sane, Dipal, Mumbai, India. 1989
Sinagra, Monika, Shanghai, P.R. China. 2007
Suokko, Teija, Tampere, Finland. 2007
Tip Tak Wing, Shatin, Hong Kong. 2007
To Ka Ho, Hong Kong. 1982
Voulgaris, Apollo, Mykonos, Greece. 2007
Wacyk, Carrein Tara, Castelnaudary, France. 2007
Watson, John Richard, Berkhamsted, Hertfordshire. 2007
Wootton, Sophie Louise, London. 2007
Zheng, Zizi, Rochester, New York, U.S.A. 1998
Zotta, Elisa, London. 2007

Diamond Membership (DGA)

Au, Astor Wing Ki, Happy Valley, Hong Kong. 2007
Chung Ka Yee, Anita, Hong Kong. 2007
Freidericos, Nikitas, Athens, Greece. 2007
Harker, Catherine, Birmingham, West Midlands. 2007
Jenkinson, Glenn, Telford, Shropshire. 2007
Kennedy, Martin, Belfast, Northern Ireland. 2007
Lee, Sinnie, Hong Kong. 2007
Leung, Vincent, Toronto, Ontario, Canada. 2007
Netsah, Maayane, Nairobi, Kenya. 2007
Ng Yuk Yu, Shatin, New Territories, Hong Kong. 2007
Ngwe, Ohnmar, London. 2007
Woolley, Claire Corinna, West Midlands. 2007

Associate Membership

Allen, Anne, Dorchester, Dorset
Amrit, Paveet, Northolt, Middlesex
Aung, May Thu, London

Baghdadi, Abeer, Jeddah, Saudi Arabia
Boyle, Katrine, Coatbridge, Lanarkshire
Bright, David, The Hague, The Netherlands
Cable, Kenneth, London
Cane, Mary, London
Carson, Elaine, Hillsborough, Northern Ireland
Carter, Anne Margaret, Wantage, Oxfordshire
Chan Tat Hang, Hong Kong
Chau Lok Yeun Amy, Hong Kong
Chen, Anny, Taipei, Taiwan, R.O. China
Cobley, Samuel Ryan, Forfar, Angus, Scotland
Diamond, Marcia, London
Dolland, Steven, London
Dr Higgins, Maureen, Edinburgh, Scotland
Ewington, Craig, London
Featherstone, Hazel, London
Gits, Pasquinel, Knokke, Belgium
Godden, Angela, Weston, Hertfordshire
Hall, Michael, London
Hamilton, Hunter Ian, Redditch, Worcestershire
Harris, Timothy, Rye, East Sussex
Hoeu, Samnang, London
Hope, Lorraine, London
Hui, Hau Kan, Feltham, Middlesex
Islam, Rezaul, Swansea, Glamorgan, Wales
Kaye, Elaine, Sturminster Newton, Dorset
Khan, Jewell, London
Kumarasinhe, Peter, Crowthorne, Berkshire
Kyaw Thu Min, Yangon, Myanmar
Lau Ka Yan, Hong Kong
Lee Suk Wa, Hong Kong
Lefevre, Andre Francis, Maia, Portugal
Lin Chun-yen, London
Liou Shin-Ling, Egham, Surrey
Lu, Sisi, London
Luk Wai Ho, Hong Kong
Mahdi, Mehiden, London
Manarkattum, Mahesh, Kottayam, India
Manasse, Daniele, Rome, Italy
Maxfield, Melanie, Milverton, Somerset
Mayne, Edwina, London
Meintjes, Vanessa, Hove, East Sussex
Micatkova, Michaela, London
Miller, Susan Catherine, Atlanta, Georgia, U.S.A.
Nasser, Fidaa, Wilrijk, Belgium
Nicolson, Anulak, Bangkok, Thailand
Pask, Amelia, Blenheim, New Zealand
Patel, Indira, London
Patel, Kamlesh Pravinbhat, Ahmedabad, India
Pennino, Monica, Henham, Essex
Qulunbe, Bashe, London
Rasche, Elizabeth, London
Sahabunyakul, Saran, Bangkok, Thailand
Sampieri, Karen, New York, U.S.A.
Santer, Kurt, St Brelade, Jersey, Channel Islands
Shen, Huanqun, Shanghai, P.R. China
Siingwa, Chrispin, Luton, Bedfordshire
Taylor-Warren, Sevenoaks, Kent
Tereszczuk, Stasia-Mae, Little Horwood, Buckinghamshire
Tidey, Alan John, East Farleigh, Kent
Trummer, Eugene, Haywards Heath, West Sussex
Trummer, Joanna, Haywards Heath, West Sussex
Tyler, Linda, Wokingham, Berkshire
Underwood, Antonia, London
Van-Beer, Dreda, Dover, Kent
Vieira, Armindo, London
Waterhouse, Bente, Edenbridge, Kent
Woo, Ka Yin, Hong Kong
Yang Yiwei, London

Transfers

From Fellowship (FGA) to Fellowship and Diamond Membership (FGA DGA)

Bell, Lucy Kate, Birmingham, West Midlands
Blatherwick, Clare, Edinburgh, Scotland
Chan Wing Sze Herleva, Kowloon, Hong Kong
Chan, Mei Fong, Hong Kong
Deeley, Philippa, Etchingham, East Sussex
Dr Lin, Lang-Dong, Taipei, Taiwan
Fisher, Fiona, Jane, Dublin, Ireland
Flower, Caro, Melton Constable, Norfolk
Harman, Bronwen, Reading, Berkshire
Jones, Gary, Dudley, West Midlands
Jordan, Steven, Biggleswade, Bedfordshire
Khan-Farrukh, Birmingham, West Midlands
Larsson, Jacqueline, Amsterdam, The Netherlands
Low, San, Chatham, Kent
Murray, Helen Claire, Sutton Coldfield, West Midlands
North, Sarah, York, North Yorkshire
Robichaud, Emilie Gould, London
Symes, Evelyn R, London
Westlake, Ingrid, Chamonix, France
Zee, Gar Bo Michelle, Hong Kong

From Diamond Membership (DGA) to Fellowship and Diamond Membership (FGA DGA)

Fong Yan, William, Tai Po, Hong Kong
Ko, Cheuk Wah Robin, Hong Kong
Koundouraki, Evagelia, Athens, Greece
Palmares, Richard P, Sale, Cheshire
Perks, Helen Eliazabeth, Telford, Shropshire
Powar, Krishna, Smethwick, West Midlands
Wat, Wing Suet, Hong Kong
Wong Tung Wing, Hong Kong
Wong Yu Lap, Angel, Sha Tin Centre, Hong Kong
Yeung, Anthea Ka, Yee, Hong Kong

From Associate Membership to Fellowship (FGA)

Bowers, Sally Faye, London.
Dereszewska, Basia, London
Dighton, Anna Louise, Saffron Walden, Essex
Drummond, Jean, Farnham, Surrey
Elles, Sarah Louise Jean, London
Fujii, Tasuhisa, Tokyo, Japan
Han, Jie, Coventry, West Midlands
Hu, Xiao, Yu, London
Hug, Samuel, Gosport, Hampshire
Iwamoto, Akiko, London
James, Bronwynne, St Albans, Hertfordshire
Kaneyasu, Yoshimasa, Okayama-Ken, Japan
Khan, Ehtesham, Ullah, Peshawar, Pakistan
Kobayashi, Taisuke, Tokyo, Japan
Learmonth, Bryony, Stafford, Staffordshire
Micatkova, Lubica, London
Mitchell, Jonathan, Midland, Texas, U.S.A.
Miyamoto, Kazuhiko, Osaka, Japan
Naito, Ayako, Tokyo, Japan
Nakagawa, Yumi, Kitakatsuragi-gun, Nara Pref., Japan
Rajbanshi, Niren Man, London
Sahabunyakul, Saran, Bangkok, Thailand
Sawamura, Tsukasa, Tokyo, Japan
Sekine, Shunji, Tokyo, Japan
Sherin, Saira, Peshawar, Pakistan
Takahata, Yoshichicka, Takamatsu City, Japan
Uchiyama, Mio, Japan
von Schantz, Casimir, Helsinki, Finland
Yamada, Masashi, Tokyo, Japan
Yamaguchi, Yuko, Osaka, Japan

Associate Membership to Diamond Membership (DGA)

Bland, Clare, London
Hall, Gregory Peter, Brighton, East Sussex
Li Zhen, London

Subscriptions 2008

It has been agreed that the membership subscription rates will remain unchanged for 2008 at £72.50 for UK members, £80.00 for those in Europe and £85.00 for overseas. Existing Fellows, Diamond and Associate members will be entitled to a £5.00 discount for subscriptions renewed by 31 January 2008.

Gifts

The Association is most grateful to the following for their gifts for research and teaching purposes:

Eisuke Ashida FGA, Kyoto City, Japan, for a monetary donation

Mrs W. Buckingham, Chorleywood, Hertfordshire, for a collection of books in memory of the late William Buckingham FGA

Maggie Campbell Pedersen FGA, London, for a piece of Baltic amber

John Ho Hay Mo FGA, Hong Kong, for a piece of rough johachidolite

Dost Muhammed Khan, Peshawar, Pakistan, for a selection of crystals

Ehtesham Ullah Khan FGA, Peshawar, Pakistan, for a selection of crystals

Nicki Sherriff FGA, Verdun, Quebec, Canada, for two diopside crystals

Thomson Gems, London, for a selection of gemstones

Donations to the 100 Club and Educational Sponsorship will be listed in the next issue of The Journal.

One hundred years of Gemmological Education

In 2008 Gem-A will be celebrating One Hundred Years of Gemmological Education. To ensure that we remain the provider of the highest status gem education through our second century, we have ambitious plans for the expansion and increased accessibility of Gem-A courses worldwide.

This can only be achieved with the support of our Fellows and Members. Our target is one hundred donations of a minimum of £1000 (US$2000) by September 2008.

As a member of the 100 Club, you will play an important role in helping us to achieve our charitable aims. As a patron, you will be honoured with:

- a 100 Club certificate
- an invitation to the Gem Centenary Dinner
- your name on a plaque in the London Headquarters of Gem-A, in our Centenary publication and on our website.

Your contribution will help us to:

- Develop our gem courses and make them more widely available
- Upgrade our in-house facilities for students
- Establish our website as a primary focus for gemmological education and gem information
- Establish a scholarship fund
- Encourage the study of gemmology worldwide through articles and the media
- Make gem education more accessible in developing countries
- Improve ethical and environmental awareness in the gem trade
- Reinstate the Research Diploma for Fellows
- Support for continuous gemmological learning in the gem trade.

Payments may be spread over one year (minimum £83.33 or US$167 per month). Companies and those wishing to make larger contributions or to support specific initiatives, should go to www.gem-a.com/information/noticeBoard.php or contact Olga Gonzalez on +44 (0)20 7404 3334, email olga@gem-a.com.

One hundred years of Gemmological Education 1908 2008

Obituary

David George Kent FGA
1915 – 2007

A tribute by E. Alan Jobbins

David was born in London in 1915, left school at 14 and went to work for Becks, a firm of jewellers in London's Tottenham Court Road, where he stayed for three years. Having gained experience he move to Bravingtons, a large jewellers near King's Cross Station, and spent the rest of his working life there, retiring as a director.

In 1940 he was called up to serve in the Army and joined the Royal Signals Regiment. He spent several years in India as a staff Sergeant responsible for the maintenance of radio communication equipment – which was to serve him well in later life. He was posted to Africa and Germany, and on demobilization decided to learn more of the German language as a follow-up from his final posting. He checked for available courses in *Floodlight* – an educational booklet issued by the then London County Council. Immediately before the entry for 'German' came 'Gemmology'; the subject caught his eye and he was hooked – he never looked back. He studied at Chelsea Polytechnic and in 1948 qualified in the Gemmology Diploma examinations – the same year as Robert Crowningshield, who later became a vice president of the GIA laboratory.

He joined the post-diploma class run by Basil Anderson (the first Director of the London Gem Laboratory) soon after he qualified and this is where I first met him in the early 1950s. He remained a regular attendee until he was in his late 80s. He was a practical examiner for the Gemmology Diploma examination for many years.

David was a very practical man and, helped by his army experience with many types of instruments, was able to devise various ingenious attachments to microscopes and spectroscopes which made observations much easier. In 1993 he was elected a Vice President of the Gemmological Association in recognition of his contribution to the jewellery industry and his considerable help to the Association.

He built up a large collection of gemstones and generously presented his fine suite of colourless stones to Gem-A, other groups of gemstones going to the Victoria and Albert Museum along with historical runs of gemmological journals. He was a great traveller and enjoyed excursions run by Eric Bruton, the celebrated author of *Diamonds*, to gem deposits in Brazil, China, Russia and Thailand. He had gemmological friends around the world, even as far a field as Australia and New Zealand.

The other love of David's life was his bicycle which he only gave up in his 80s. He cycled hundreds of miles around England to visit relatives and gemmological friends. One incident he particularly remembered was a journey to Somerset to see farming friends when he was booked by a country policeman for holding on to a slow moving lorry going uphill. He was rather miffed at this since it was 2 am and he had travelled at night to avoid the traffic and the summer heat. He cycled to work from the suburbs through traffic to central London every day until he retired.

David remained a bachelor all his life. He had few close relatives, his parents and sister having died many years ago. He was like a brother to Mimi, a distant relative, and they shared many years of their retirement together in their sixteenth-floor apartment with magnificent views over the whole of London.

Although not a regular church-goer, David held a very Christian attitude to life and was always ready to help others – particularly young people entering into the jewellery trade. He was a lovely man and great fun to be with, especially when sharing his favourite tipple – a glass of port.

William Charles Buckingham FGA
1921 – 2007

William Buckingham (known in the trade as Billy Buck) started his career in the gem trade in 1937 at the age of sixteen with Jade Dragon Ltd, later to become George Lindley & Co. Ltd. Both he and Mr Lindley served their country gallantly in the Second World War, and rejoined the company after hostilities ceased. Like the late David Kent (see previous page), William attended gemmology classes at the Chelsea Polytechnic and was awarded his Gemmology Diploma in 1948. He took control of and continued running one of the most successful gemstone businesses in London's Hatton Garden after George Lindley died.

William Buckingham served on the Council of the Gemmological Association from 1952 until 1967. In 1988 he very generously donated his fine collection of zircons to the Gemmological Association to mark his retiral after fifty years from George Lindley & Co. He also offered an award to newly-qualified Fellows of the Association who carried out research on the zircons to determine any variation in properties of samples from different localities. Research carried out by the FGAs in the Edinburgh Gemmological Group and their findings were published in *The Journal of Gemmology*, 1993, 23(7), p.387.

William, a proud Normandy veteran, was honoured in death by the draping of his coffin with the Union flag appropriately decked with his campaign medals and flanked by a guard of honour at the Service of Thanksgiving.

Leonard A. Baker

Stanley George Hill FGA
1911 – 2007

Stanley (Stan) Hill was born in Birmingham where he served an apprenticeship as a silversmith. In 1936 was appointed lecturer in metalwork at the Liverpool School of Art. He retired in 1976 but his career as a craftsman and designer continued for many more years. Stan was one of the founders in 1960 of the Bluecoat Display Centre in Liverpool. He had a studio at Bluecoat where he worked regularly until he was nearly 90, hand-crafting jewellery and silverware pieces in a very wearable simple geometrical form.

Stan's interest in geology and gemmology developed in the 1950s and he qualified in the Gemmology Diploma Examinations in 1958. It was the sheer beauty and variety of gemstones that sustained his interest and his creativity in jewellery design.

A staunch member of the North West Branch of the Gemmological Association, Stan would offer help, advice and support to the chairman and the committee. He attended practically every meeting, listening intently to each speaker, and even though some of us thought he had fallen asleep he still managed to ask the most relevant questions. His wish to share his knowledge and enthusiasm for gemstones extended to meetings at his home, where he encouraged everyone to pore over his collection.

Stan's beloved wife Betty died in 2005, but he coped with her loss with great courage. He died peacefully at Arrowe Park Hospital after a short illness.

Richard Hill and Sue Horder (nee Hill)

John L. Pyke FGA
1910 – 2007

John Pyke began his career in the jewellery trade with an apprenticeship at Baker's Jewel Casket in Wigan in 1926. He completed his training in 1931, after graduating with a Distinction in the Gemmology Diploma Examinations. Because of the Depression, the family firm, William Pyke & Sons, founded by his grandfather, could not afford to employ him, but he obtained the position of workshop manager at Coombe Co. Ltd in Rangoon. While in Burma he took the opportunity to travel extensively around the country buying gemstones.

He returned home in 1938 and married Joan the following year, just before war broke out. He volunteered for Wingate's forces, but the army sent him to the Middle East where he was twice mentioned in despatches.

When he was demobbed in 1945 he devoted his considerable energies to rebuilding William

Pyke & Sons, which by that time had no money and very little stock. He ran the company until 1977, but remained Chairman until his death.

He was Chairman of the National Association of Goldsmiths from 1963 to 1968 and later President. During his chairmanship he was greatly involved in the UK's involvement in CIBJO.

John Pyke was a qualified gemmologist with a deep appreciation of all gemstones. He was one of the founder members of the North West Branch of the Gemmological Association which was formed in 1975, later becoming the Branch patron. Said Deanna Brady, Chairman of the North West Branch: "John Pyke often entertained our members with anecdotes about his travels throughout Burma, bringing along his collection of gemstones for all to handle. He was always there, offering continual support to our committee."

John S. Pyke

Prof Akira Chikayama FGA (D.1966), Tokyo, Japan, died on 24 September 2007 at the age of 85.

William Fleming Ferguson FGA (D.1956), Balloch, Strathclyde, Scotland, died in 2007.

Masashi Furuya FGA (D.1976), Yamanashi-ken, Japan, died on 23 October 2007 at the age of 59.

It is with deep regret that we announce the sudden death of Professor Chen Zhonghui of Beijing, P.R. of China, on 6 November 2007. Professor Chen was an Honorary Fellow of the Association and was the examination co-ordinator for China. A full obituary will be published in the next issue of *The Journal*.

Gem-A Events 2008

Saturday 26 and Sunday 27 January	The Materials and Techniques of Ancient Egyptian Jewellery. A special seminar to coincide with the Tutankhamun Exhibition in London. Tutor: JACK OGDEN
Friday 25 January	Midlands Branch. Branch AGM, Bring and Buy, and Team Quiz.
Monday 25 February	Scottish Branch. Techniques of Chinese Jade Carving and the Mughal Terrapin. MARGARET SAX
Friday 29 February	Midlands Branch. Birmingham Silver and the History of the Assay Office. DR SALLY BAGGOTT
Sunday 16 March	Midlands Branch. Practical training day: the use of the microscope.
Tuesday 1 April	Scottish Branch. It's all in the cut. JAMES RILEY
Friday 4 April	Midlands Branch. Fabergé and his workmasters. STEPHEN DALE
Friday 25 April	Midlands Branch. Corundum – natural, treated and synthetic. DOUG GARROD
Friday 2 to Monday 5 May	Scottish Branch Conference, Queen's Hotel, Perth. Speakers will include: George Rossman (keynote), David Callaghan, Alan Hodgkinson, Elisabeth Strack and Stephen Whittaker.
Saturday 25 to Monday 27 October	Special Centenary Conference and Graduation Ceremony.

Contact details

When using e-mail, please give Gem-A as the subject:

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North East Branch:	Mark Houghton on 01904 639761; email sara_e_north@hotmail.com
North West Branch:	Deanna Brady on 0151 648 4266
Scottish Branch:	Catriona McInnes on 0131 667 2199; email scotgem@blueyonder.co.uk
South East Branch:	Veronica Wetten on 020 8577 9074; email veronica@wetten.co.uk
South West Branch:	Richard Slater on 07810 097408; email richard@fellows.co.uk

Gem-A website

For up-to-the-minute information on Gem-A events visit our website at www.gem-a.com

Guide to the preparation of typescripts for publication in The Journal of Gemmology

The Editor is glad to consider original articles shedding new light on subjects of gemmological interest for publication in The Journal. Articles are not normally accepted which have already been published elsewhere in English, and an article is accepted only on the understanding that (1) full information as to any previous publication (whether in English or another language) has been given, (2) it is not under consideration for publication elsewhere and (3) it will not be published elsewhere without the consent of the Editor.

Typescripts Two copies of all papers should be submitted on A4 paper (or USA equivalent) to the Editor. Typescripts should be doubled spaced with margins of at least 25mm. They should be set out in the manner of recent issues of The Journal and in conformity with the information set out below. Papers may be of any length, but long papers of more than 10 000 words (unless capable of division into parts or of exceptional importance) are unlikely to be acceptable, whereas a short paper of 400-500 words may achieve early publication.

The abstract, references, notes, captions and tables should be typed double spaced on separate sheets.

Title page The title should be as brief as is consistent with clear indication of the content of the paper. It should be followed by the names (with initials) of the authors and by their addresses.

Abstract A short abstract of 50-100 words is required.

Key Words Up to six key words indicating the subject matter of the article should be supplied.

Headings In all headings only the first letter and proper names are capitalized.

A This is a first level heading

B This is a second level heading

First and second level headings are ranged left on a separate line.

Third level headings are in italics and are indented within the first line of the text.

Illustrations High resolution digital files, for both colour and black-and-white images, at 300 dpi TIFF or JPEG, and at an optimum size, can be submitted on CD or via email. Vector files (EPS) should, if possible, include fonts. Match proofs are essential when submitting digital files as they represent the colour balance approved by the author(s).

Transparencies, photographs and high quality printouts can also be submitted. It is recommended that authors retain copies of all illustrations because of the risk of loss or damage either during the printing process or in transit.

Diagrams must be of a professional quality and prepared in dense black ink on a good quality surface. Original illustrations will not be returned unless specifically requested.

All illustrations (maps, diagrams and pictures) are numbered consecutively with Arabic numerals and labelled Figure 1, Figure 2, etc. All illustrations are referred to as 'Figures'.

Tables Must be typed double spaced, using few horizontal rules and no vertical rules. They are numbered consecutively with Roman numerals (Table IV, etc.). Titles should be concise, but as independently informative as possible. The approximate position of the Table in the text should be marked in the margin of the typescript.

Notes and References Authors may choose one of two systems:

(1) The Harvard system in which the authors' names (no initials) and dates (and specific pages, only in the case of quotations) are given in the main body of the text, (e.g. Collins, 2001,341). References are listed alphabetically at the end of the paper under the heading References.

(2) The system in which superscript numbers are inserted in the text (e.g. ... to which Collins refers.[3]) and referred to in numerical order at the end of the paper under the heading Notes. Informational notes must be restricted to the minimum; usually the material can be incorporated in the text. If absolutely necessary both systems may be used.

References in both systems should be set out as follows, with double spacing for all lines.

Papers Collins, A.T., 2001. The colour of diamond and how it may be changed. J.Gemm., 27(6), 341-59

Books Balfour, I., 2000. Famous diamonds. 4th edn. Christie's, London. 200pp

Abbreviations for titles of periodicals are those sanctioned by the World List of scientific periodicals 4th edn. The place of publication should always be given when books are referred to.

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Cover Picture: Inclusion pattern in a vanadium-bearing tourmaline from Madagascar.
(See Vanadium-bearing gem-quality tourmalines from Madagascar, p.413)

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Thortveitite – a new gemstone

R. Chapman, I.F. Mercer, A.H. Rankin and J. Spratt

Abstract: A water-worn pebble of good clarity purchased in Bangkok started the quest that identified this as gem-quality thortveitite, a scandium yttrium silicate. A faceted stone and a cleavage fragment, both from the original pebble, have been tested. Results from standard gemmological tests on the faceted stone did not match those from any known gemstone. The stone and fragment were subsequently identified as high-scandium thortveitite. The unusual chemistry indicates a possible synthetic origin; however, a natural origin is suggested by the presence of three-phase inclusions in a planar array (feather) within the faceted stone.
Keywords: electron microprobe, Raman spectroscopy, scandium, thortveitite, three-phase inclusions

Introduction

A specimen of purple gem-quality material was purchased in Bangkok in a mixed parcel of rough of stated African origin. It was not possible to establish the geographic source of this rough prior or subsequent to its acquisition in 2004.

When purchased, the specimen was a water-worn pebble that showed no discernible crystal form. It had a mid-purple colour which varied with distinct pleochroism. A 12.3 mm × 9.1 mm × 8.95 mm faceted gemstone of 10.01 ct was cut from the pebble. Standard gemmological tests on this faceted stone gave results which did not match published data of any known gemstone. Prior to cutting, the rough was accidentally dropped on concrete and a fragment cleaved from its side. This small cleavage fragment was eventually used for initial electron microprobe analysis and Raman spectroscopy. Subsequently the faceted stone and the cleavage fragment were subjected to further testing. The material was identified as thortveitite, but with a composition richer in scandium than shown in a range of published analyses of the mineral thortveitite. Mineral specimens of thortveitite are normally small (up to a few millimetres), often acicular, variously coloured, occasionally transparent but more often opaque to translucent. This unusual high-scandium material has gem potential and the results of our investigation are presented as a reference point in the event of discovery of further rough or cut gem-quality stones. This in turn might enable further research to establish its origin.

Figure 1: Double refraction and small cleavages in facet edges viewed through the crown facets of the thortveitite. © R. Chapman.

Standard gemmological tests and observations

The gemmological properties determined using standard gemmological tests and observation on the faceted stone are set out in *Table I*.

Figure 1 illustrates the back facet edges of the faceted material, looking through the table facet. There is a series of small cleavage nicks along pavilion facet junctions that give the appearance of blurred facet edges. A similar phenomenon is seen with some cut spodumene.

Laboratory tests and observations

The cleavage fragment of thortveitite was split into two and each was analysed by electron microprobe at the Natural History Museum, London. The analyses were obtained using wavelength dispersive X-ray spectrometry (WDX) on a Cameca SX50 electron microprobe. The conditions used were 15kV (accelerating voltage) 15nA (probe current) with a 10 µm spot size. The data shown in *Table II* are the average of 10 analyses of the cleavage fragment (five from each of the two separated samples). Weight % Oxide values shown as <dt were determined but were below the instrumental detection limit.

The material was identified as thortveitite, $(Sc,Y)_2Si_2O_7$. This specimen is

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Figure 2: Appearance of the faceted thortveitite in daylight (left) and incandescent light (right).

rich in scandium but contains almost no yttrium.

A comparison with recently published electron microprobe data on natural thortveitite from various localities worldwide is shown in *Table III*. From this, it is apparent that the silica and alumina contents for the studied sample lie within the known range, but that the yttrium content (0.1wt% Y_2O_3) is at least an order of magnitude lower. The scandium content (52.9% Sc_2O_3) is significantly higher than those previously reported. Other notable differences include a lower Fe_2O_3 content and, with the exception of one sample from Baveno, Italy, a lower Yb_2O_3 content. Other REEs are below the detection limit of the instrument used.

Laser Raman microspectroscopy was carried out at the School of Earth

Table I: Gemmological properties of the faceted thortveitite.

Colour	Purplish blue of moderate saturation in daylight *(Figure 2a)*; purple of intense saturation in incandescent light *(Figure 2b)*. Face-up colour in daylight with Gem Dialogue: 70% grey, 20% purple (B2P). No evidence of colour zoning was readily visible
Visual appearance	High vitreous lustre with pronounced pleochroism. Distinct pleochroic colours of: violet, blue and straw-yellow *(Figure 3)*.
Clarity	Good clarity with a colourless fine linear inclusion *(Figure 4)*.
Hardness	When cutting the gemstone, this mineral appeared to have comparable hardness with quartz. It polished easily and well. A Mohs' hardness estimate was not obtained.
Cleavage	A small cleavage 'nick' in the table *(Figure 5)* indicated the presence of cleavage in at least two directions.
Specific gravity	3.48
Refractive indices	$\alpha = 1.753$ $\beta = 1.793$ $\gamma = 1.809$
Birefringence	0.056 The extent of observed DR is illustrated in *Figure 6*.
Optic sign	Biaxial negative
Absorption spectrum	Two very fine lines in the green at around 535 nm plus a band in the deep blue at 425 nm.
UV luminescence	None observed under either long-wave or short-wave UV light.
Inclusions	Across the centre of the photomicrograph *(Figure 4)* some lens-shaped lighter patches have the appearance of twinning patterns. In one corner there is a planar feather containing a cloud of small inclusions *(Figure 8)*. There is also another small, irregular group of similar inclusions. A prominent colourless linear inclusion *(Figure 3)* extends from the planar feather across the stone. It is seen to be discontinuous under 30× magnification, with a 'string of pearls' appearance, and is surrounded along its length by a very sparse 'halo' of extremely small inclusions which appears to have dispersed from the linear inclusion.

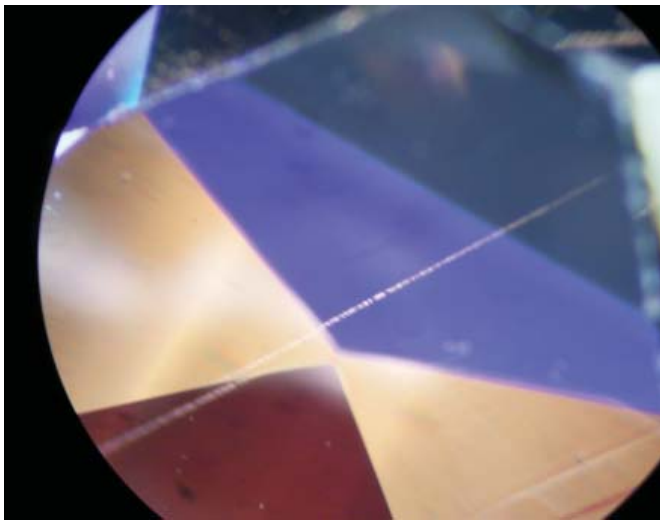

Figure 3: Distinct pleochroism displayed by the faceted thortveitite. A colourless linear inclusion is prominent across the centre of the picture.

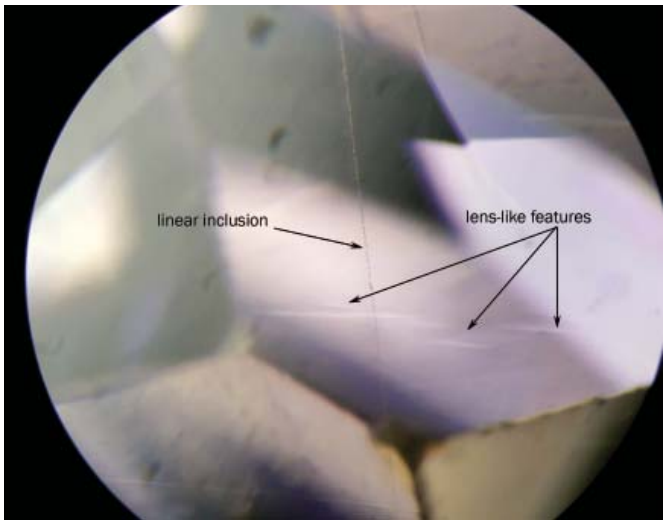

Figure 4: Linear inclusion and lens-like features in the faceted thortveitite.

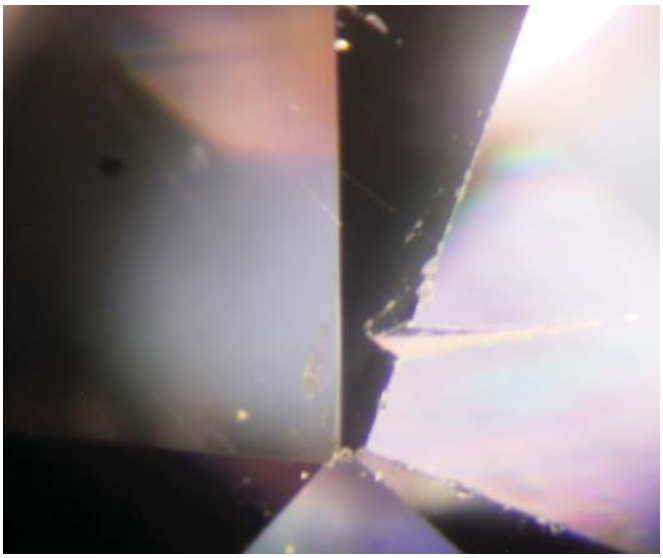

Figure 5: Presence of at least two directions of cleavage illustrated by the presence of this small cleavage nick on the edge of the table of the faceted thortveitite.

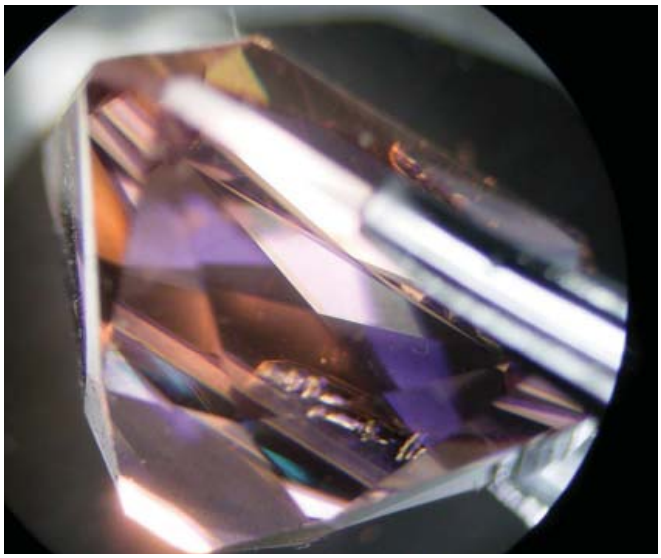

Figure 6: The distinct double refraction effect seen through the faceted thortveitite.

Sciences, Kingston University, UK, on the uncut surface of part of the small, cleaved, elongate crystal fragment (*c.* 0.3 mm × 2 mm) using a Renishaw RM1000 Raman Spectrometer equipped with a CCD detector and a 633 nm He-Ne ion laser. The system was operated in confocal mode with the laser focused on or below the surface of the sample through a 50× objective lens of an Olympus petrological microscope. Under these conditions the Raman analysis was restricted to an area of less than *c.* 30 μm^2. Spectra were recorded over the frequency range 180 to 1500 cm^{-1} and a time interval of

Table II: Composition of thortveitite obtained by electron microprobe analysis.

Oxide	Wt% oxide	No of ions based on 14 oxygens	Detection limit (wt%)	Standard deviation
SiO_2	45.09	3.931	0.03	0.67
Al_2O_3	0.23	0.023	0.02	0.02
Sc_2O_3	52.90	4.019	0.05	0.26
Y_2O_3	0.10	0.005	0.07	0.04
Yb_2O_3	0.12	0.003	0.10	0.03
Fe_2O_3	0.63	0.046	0.06	0.06
Totals	**99.07**	**8.028**		

NB: Na, Mg, K, Ca, V, Ti, Mn, Sr, La, Ce, Dy, Ho, Er, Tm, Lu, Th and U were sought but below the limit of detection (<dt)

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30 seconds. The system was calibrated using the single Raman peak positions of pure crystalline silicon and diamond at 521 and 1330 cm^{-1} respectively. Analyses were carried out in triplicate to ensure that random effects from cosmic rays or electrical surges could be discounted. All peak positions reported here are believed to be accurate to within ± 1 cm^{-1}.

The Raman spectrum *(Figure 7)* of the thortveitite crystal fragment shows a prominent peak at 441 cm^{-1} and a number of other well-defined and broader minor peaks in the range up to 945 cm^{-1} *(Table IV)*. As illustrated in *Table IV*, the peak positions are in very good agreement with those reported by Brethau-Raynal *et al.* (1979) for a pulverized single crystal of pure synthetic thortveitite ($Sc_2Si_2O_7$). Further Raman analysis of the faceted sample confirmed the results for thortveitite. The absence of peaks at 435 and 392 cm^{-1} in our spectra can be explained by crystal orientation effects whereas in pulverized samples a complete range of orientations of crystal faces are exposed to the laser beam compared with only specific orientations in single crystals; this was demonstrated by Brethau-Raynal *et al.* (1979) on orientated crystals of synthetic $Yb_2Si_2O_7$ which also possesses the thortveitite structure. The Raman spectra for this thortveitite specimen are significantly different to those reported by Ross (1971), probably due to the use of impure material in these earlier studies as discussed by Brethau-Raynal *et al.* (1979). The Raman spectrum reported in the Renishaw Mineral Library Database is also markedly different, probably due to sample misidentification.

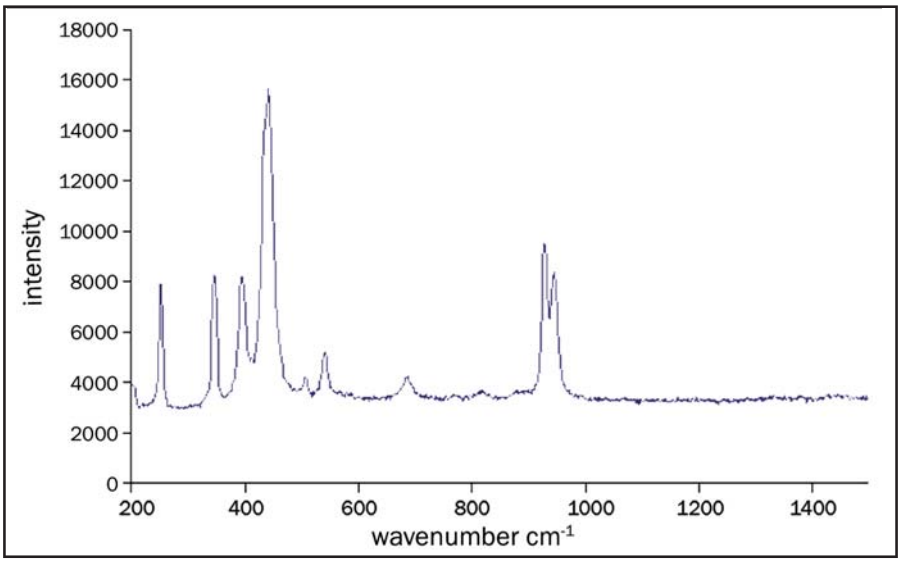

Figure 7: Raman spectrum of thortveitite.

The very small inclusions in the feather in the faceted stone (see *Figures 8* to *11*) contain three-phase (L+V+S) hydrothermal-type inclusions with a gas bubble, brine and probable halite (cubic NaCl) daughter mineral. The NaCl could not be confirmed as this mineral is Raman inactive and the H_2O band at *c.* 3500 cm^{-1} is obscured by strong fluorescence above *c.* 2800 cm^{-1}. With their high relative relief, these small inclusions are likely to be

Table III: Selected major element contents of thortveitite from various localities compared with the gem thortveitite.

Locality	Norway[1]				Madagascar[1]	USA[2]	USSR[3]	Italy[4]		This study
	Iveland 1	Setesdalen 2	Evje 3	Evje 4	Benfanamo? 5	Montana 6	Kola 7	Baveno 8	Cuasso al Monte 9	Locality unknown 10
SiO_2	37.59	40.44	41.29	41.9	44.63	44.6	46.2	44.4	45.19	45.09
Al_2O_3	0.61	0.90	0.88	0.96	1.05	0.81	n.d	1.1	0.07	0.23
Sc_2O_3	25.01	32.83	37.13	40.41	47.81	44.60	48.9	43.4	44.01	52.90
Y_2O_3	17.73	8.67	8.41	5.79	2.31	2.28	1.9	1.9	2.59	0.10
Yb_2O_3	7.01	2.58	4.52	3.33	0.18	0.41	0.7	0.1	0.74	0.12
Fe_2O_3	2.06	3.11	1.68	1.39	1.39	1.48	1.6	1.5	2.89	0.63

1. Bianchi *et al.*, 1988
2. Foord *et al.*, 1993
3. Vloshin *et al.*, 1991 (cited in Gramaccioli, 2000)
4. Gramaccioli *et al.*, 2000

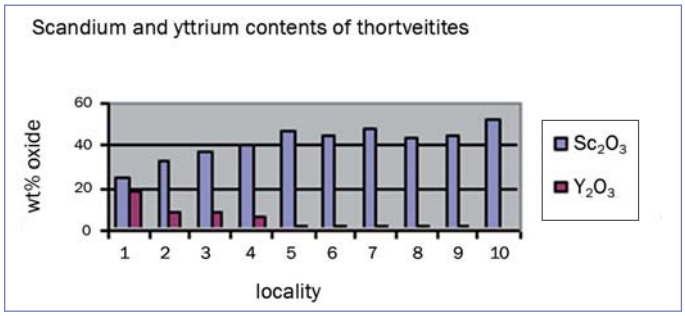

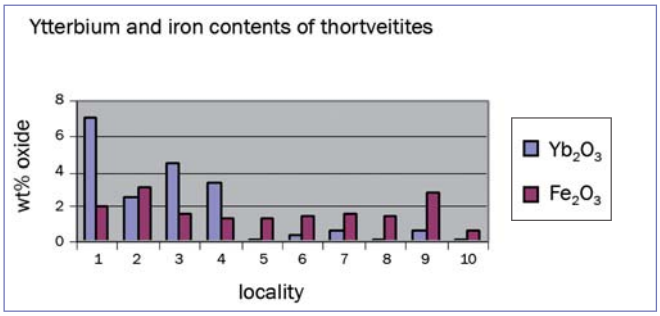

hydrothermal rather than quenched flux or melt inclusions. They are similar to those commonly observed in beryl and topaz crystals from granitic environments. There are possible decrepitation haloes around the rounded inclusions (one is outlined in *Figure 9*) due perhaps to subsequent heating, whether natural or during artificial heat treatment. The indications are that the material has a natural origin grown from, or affected by, moderate temperature, high salinity hydrothermal fluids.

Discussion

These results indicate that the material is thortveitite. Natural thortveitite, a monoclinic scandium yttrium sorosilicate with the chemical formula $(Sc,Y)_2Si_2O_7$, occurs in granitic pegmatites and is named after the Norwegian engineer Olaus Thortveit. It is a primary source of commercial scandium.

However, the low Fe, Y and REE content and very high scandium content of the studied sample could indicate that this is a laboratory-grown rather than a naturally-occurring specimen. Brethau-Raynal *et al.* (1979) have reviewed the various techniques previously used for the laboratory synthesis of thortveitite structure silicates (including the pure thortveitite end-member $Sc_2Si_2O_7$). Although most previous methods produced only small or impure samples, however, the 'floating zone' technique employed by these authors, involving heating of the starting materials in a platinum crucible to ~ 1800°C, produced clear single crystals up to 2–3 cm long and 5 mm in diameter.

Table IV: Major and minor Raman peak positions and intensities of the studied thortveitite crystal compared with peak positions reported by Brethau-Raynal et al. *(1979) for a pulverized sample of a pure synthetic crystal of thortveitite ($Sc_2Si_2O_7$)*

Peak position (cm^{-1}) This study	Peak position (cm^{-1}) Synthetic thortveitite*	Relative intensity This study	Shape This study
956	949	medium	sharp
929	932	medium	sharp
687	688	weak	broad
545	543	weak to medium	sharp
507	510	weak	broad
441	445 and 435**	strong	sharp
395	397 and 392**	medium	sharp
346	347	medium	sharp
251	253	medium	sharp
203	203	weak	sharp
192	194	weak	broad

* Brethau-Raynal *et al.* (1979)

** Not apparent from spectra recorded in the present study

Relevant factors in considering the origin of the studied stone may be summarized thus:

- This gemstone was originally purchased as a water-worn pebble. Of course, this could be simulated in a tumbler but, given the lack of a developed gemstone market for this material, could this be a chance appearance?
- If material of this size, colour and clarity is indeed synthetic, then more may have entered the market. If it has in fact been manufactured specifically for the gem market, it could be expected that further synthetic specimens are likely to have come to light during the past four years or more.
- The chemistry reveals a fairly pure scandium end-member material, which suggests possible synthesis.
- The inclusions are not particularly characteristic of synthetic material but they do indicate a likely hydrothermal origin. Published information on synthesis of thortveitite is currently confined to non-hydrothermal methods.
- Recent geological fieldwork results suggests that scandium minerals are more widespread than has hitherto been inferred (Gramaccioli *et al.,* 2000).

Figure 8: Plane of fluid inclusions within the cut stone.

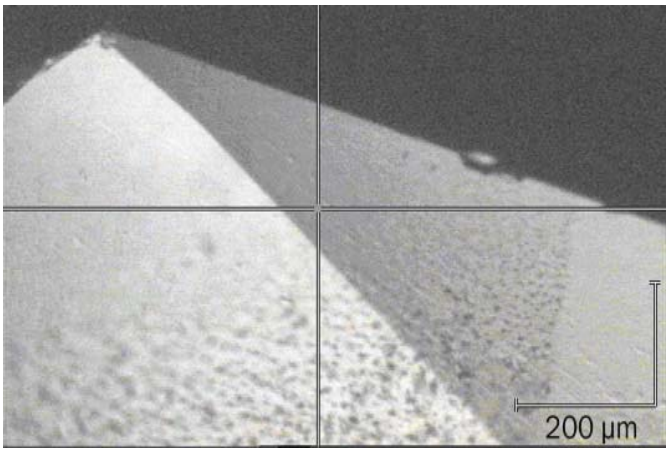

Figure 9: Rounded three-phase fluid inclusions surrounded by possible decrepitation aureoles of smaller inclusions (one is outlined).

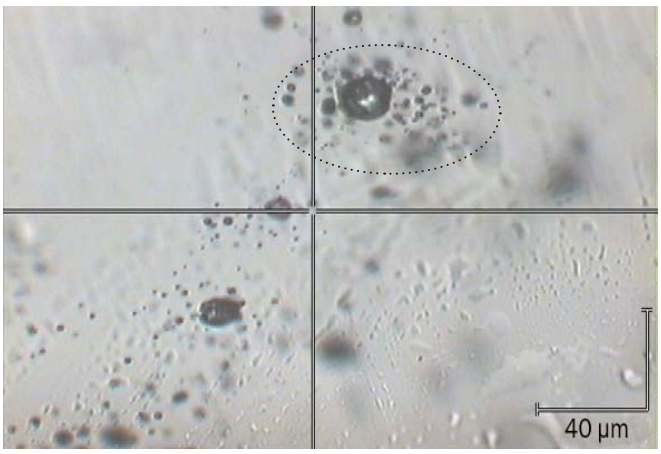

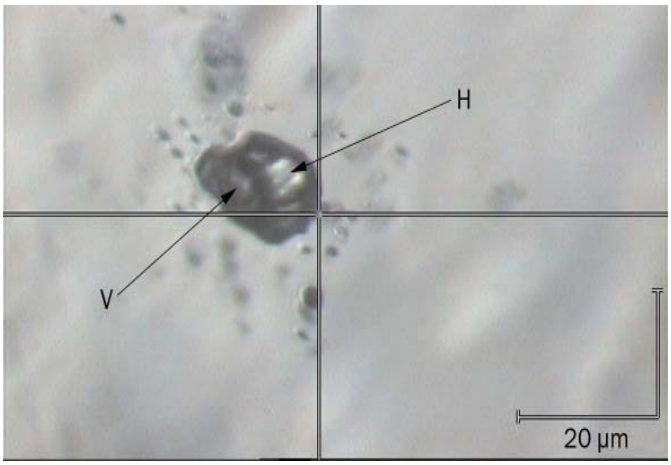

Figure 10: Close-up of rounded three-phase fluid inclusion with vapour bubble (V) and cubic daughter mineral believed to be halite (H).

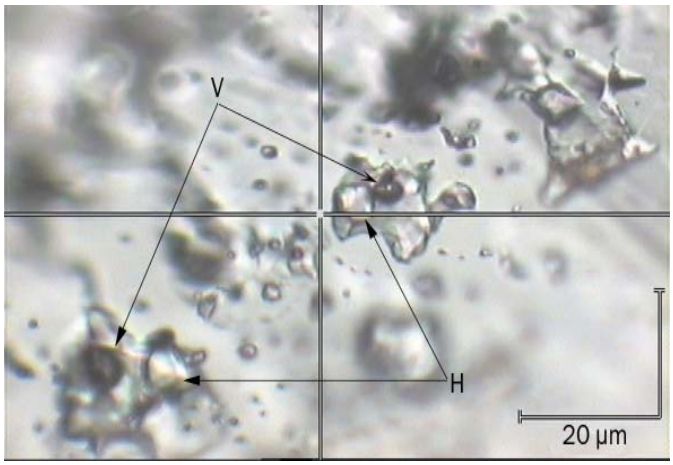

Figure 11: Group of irregular three-phase fluid inclusions with vapour bubbles (V), halite cubes (H) and an aqueous brine.

Conclusion

As the original pebble from which the test specimens derive was relatively large, reasonably clean and of unknown occurrence, initially it was considered that it may be an artificial, synthetic gemstone product. Chemical analysis which revealed a high scandium and low yttrium content appeared to substantiate this. Further observation, however, suggests the possibility that it is of natural mineral origin. Either way, the material appears to have been subjected to moderate heating, either by natural or by human agency. Given the size and clarity of the original rough specimen of thortveitite, it is suspected that more of this material may be in circulation but that specimens remain as yet unidentified. We hope that this article will prompt a search for more rough or cut specimens of gem-quality thortveitite which would enable observation and analysis to establish further useful data and maybe its origin.

Acknowledgements

The assistance of the late Grahame Brown, a leading Australian gemmologist and great supporter of international gem education, has been much appreciated. We also thank Peter Tandy of the Department of Mineralogy, Natural History Museum, London, for his assistance.

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Surface treatment of gemstones, especially topaz – an update of recent patent literature

Dr Karl Schmetzer

Abstract: This review provides an overview of numerous patent documents that have been published recently and describe various coating technologies for gem materials. Parts of the documents focus on the deposition of one single or several specifically structured or composed layers in order to obtain the desired colour and the desired optical effects or wear resistance. Contact heat treatment of faceted stones with solid transition metal-bearing plates as well as heat treatment of layers deposited on the surfaces of the gemstones, are also reported. Chemical data of one sample of iron-coated topaz provide a first insight into the reaction mechanism within the outer diffusion layer.

Introduction

The quantity of surface-treated gem materials, especially topaz, seen in the market *(Figure 1)* is increasing. This is, at least partly, due to problems in the United States of America related to the Nuclear Regulatory Commission (NRC) rules regarding the import and distribution of irradiated blue topaz by non-licensed companies. Surface-coated topaz of various colours might, at least partly, fill the enormous demand for this relatively cheap product. Much more valuable are various other surface-treated gemstones such as coated pink diamonds; because of their value, there is a greater need to identify any treatment of such stones.

Numerous patents dealing with different types of surface treatment or surface enhancement of gemstones, especially topaz, have been reviewed and summarized by Schmetzer (2006). Four different basic technologies were reported:
(a) coating with differently coloured dyes;
(b) coating by chemical vapour deposition, physical vapour deposition or sputtering without specific heat treatment;
(c) contact heat treatment with transition metal-bearing powder;
(d) deposition of a coating to the faceted stone and subsequent heat treatment.

While methods (a) and (b) produce surface coatings which are easily (at least partly) removable or scratched by normal wear of the faceted stones, techniques (c) and (d) claim a more permanent surface coating. Although 'diffusion into the outer surface' and 'chemical bonding to

Figure 1 (above and below): Surface-coated topaz specimens treated by various techniques to obtain different colours are available nowadays from various producers. The red cushion-cut stone above weighs 1.08 ct and measures 6.1 × 6.1 × 3.9 mm; the blue square-cut stone in the upper row below weighs 5.39 ct and measures 6.1 × 6.0 mm. Photos by L. Kiefert, AGTA Gemological Testing Center, New York, USA.

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the surface' are described as a reaction mechanism occurring in techniques (c) and (d) which are related to heat treatment, the exact reaction mechanism or mechanisms are not known in detail. This is due to the lack of experimental data describing the chemical and/or physical properties of the surface coating layer or layers. First results have been obtained by Befi *et al.* (2006) and Kiefert *et al.* (2007), who mainly examined the chemical composition of the layer or layers nearest to the surface by X-ray fluorescence analysis (EDXRF).

Since publication of the review by Schmetzer (2006) which covered the period from about 1996 to 2005, new patent documents have been obtained and a general overview is given in *Table I*.

Detailed knowledge of possible treatment processes is essential for the recognition of treated gemstones in the laboratory, a task which becomes more and more complex for the gemmologist (see, for example, Shen *et al.*, 2007). It is a matter of speculation as to how relevant some of the matters discussed in the patents will be in the future to gemmologists, but to have outlines of such topics and to have points of reference for possible future work is, I believe, important. In addition, it should be mentioned that *Table I* summarizes only patents which are specifically related to and applied for the enhancement of gem materials and not to general surface treatments of various substances.

Some light is also shed on the importance of patents dealing with surface enhancement of gem materials if we consider the numerous law suits that occurred in the United States due to patent infringement of US patent 5,853,826 by Starcke *et al.,* issued 29 December 1998 and assigned to Azotic Coating Technology (document 3). Following the reactions of some of the companies involved, a re-examination of this patent was initiated and carried out by the United States Patent and Trademark Office (see the related re-examination communication, issued 7 May 2007). This process led to amended claims (especially to an amended claim 1) which were published in the related 'Ex Parte Re-examination Certificate' (document 4).

A. Deposition of a coating without specific heat treatment

Deposition of a coating including a wear-resistant material

A technique for the increase of wear resistance of a coloured coating is described by Neogi and Neogi (documents 17 and 18). In general, an integrated coating consisting of a colour-imparting agent and an abrasion-resistant agent is deposited on the surface of a faceted gemstone. Precursors of this technique have already been described by Nassau *et al.* (documents 1 and 2), who mentioned a diamond coating to improve and provide a harder surface on faceted moissanite that resists scratching and abrasion and by Wright (document 8), who described the coating of various gemstones by diamond-like-carbon.

In the patent applications of Neogi and Neogi (documents 17 and 18), two major embodiments are described. In one variant, the colour-imparting agent and the abrasion resistant agent are deposited in a single step within one layer. In an alternative embodiment, the colour-imparting agent is deposited in a first layer and the abrasion-resistant agent is deposited subsequently in a second layer. The colour-imparting agent may provide the perception of colour via interference phenomena or via absorption phenomena in the visible range. As examples, metals or semiconductors such as Au, Pt, Cr, Fe, Si, Ge, Bi, Ni, Co, Ta, Er, Mn, Mg, Al, Zr, Ti, Se and Be are mentioned. Furthermore, various coatings consisting of oxides, nitrides and alloys are applied. Abrasion wear resistance may be provided by integrating any of the materials such as diamond-like carbon, chemical-vapour-deposited diamond, alumina, polymer-based materials, nitrides or carbonitrides. The main example given of coated gemstones is topaz, but ruby, sapphire and emerald are also discussed.

Sub-surface implantation methods are also described by Neogi and Neogi in documents 17 and 18 as additional possible methods to improve the appearances of gemstones. Colour can be imparted to diamonds and other gemstones via implantation of impurities using a gas cluster ion beam apparatus. Subsequent to this first step of treatment, an abrasion-resistant layer with or without an additional colour component can then be deposited on the surface of the faceted stone.

Deposition of a coating causing optical phenomena

A special dichroic effect is produced by a coating consisting of alternating transparent layers containing metallic and/or ceramic particles. This method is described by Gaillard Allemand in documents 15 and 16 and uses various reflection and interference phenomena. The layers are made from, for example silica, titania or magnesium fluoride and metallic chromium. A final reflecting metallic layer is deposited on these alternating layers, which may consist of titanium or chromium.

Deposition of a coating and formation of a diffractive optical element

Another method for the enhancement of the optical appearance of gem materials, especially for the enhancement of fire, is described by Maltezos *et al.* (documents 20 and 21). For this purpose a diffractive optical element comprising a diffraction grating is formed on one or more facets of the stone. The formation of these diffractive optical structures to enhance dispersion or fire of a gemstone, for example diamond, is performed by the deposition of that particular structure on the surface or by etching the optical structure into the surface of the gemstone. One particular technique for the formation of distinct patterns of diffractive elements is the deposition of subsequent mask and resist layers in combination with lithographic techniques involving various etching steps. In addition to diamond, cubic zirconia, zircon, moissanite, topaz, rutile, strontium titanate, spinel, yttrium aluminium garnet and gadolinium gallium garnet are mentioned as examples.

B. Deposition of a coating with specific heat treatment

Contact heat treatment with transition metal-bearing solids

Another group of patent publications by Rauch and Würtenberger (documents 5 to 7) describes the contact heat treatment of faceted gem materials with transition metal-bearing solids. In contrast to previous descriptions, the gem materials are not heated in transition metal-bearing powders, but in contact with a solid plate of metal or metal oxide, where, for example cobalt oxide, iron oxide or vanadium oxide form a substantial constituent of the plate. The plate has recesses in the shapes of the pavilions of the stones. The faceted gemstones, for example, corundum or topaz, are simply placed on the plate and heated for several hours in oxidizing or reducing atmospheres. The process is designed to avoid damage to the gemstones during the heat treatment process.

Deposition of a coating to the faceted stone and subsequent heat treatment

Two groups of patent documents describe the coloration of gem materials by the deposition of colour-causing coating on the facets of the gemstones consisting of one or two layers or thin films and subsequent heat treatment.

Documents 9 to 14 by Starcke *et al.* contain descriptions of methods where heat treatment is performed preferably at temperatures below that at which substantial diffusion occurs from the coating into the gemstone. Examples are quartz, topaz and beryl. The coating applied preferably consists of two components, a carrier and a colour-causing dopant. The carrier may be any dielectric material, for example, any metal oxide, metal nitride, metal carbide, metal sulphide or metal boride, but not a pure metal or alloy. The dopant may be a metal, alloy, oxide, nitride, boride, or another compound which is highly absorptive in the visible range. To obtain homogeneous and uniform body colours, annealing temperatures between 300 and 1150°C are given. For example, topaz can be heated at a temperature of 450°C for about one hour. It is also mentioned that the coating on the pavilion is of maximum thickness adjacent to the culet and becomes thinner with increasing distance from the culet. This type of variable layer thickness is said to improve the coloration of the gemstone.

In a recently published patent application, Yelon *et al.* (document 19) have described how to obtain a uniform colour using a coating and subsequent heat treatment technology. The coating is applied in a reactor by means of a precursor consisting of an organometallic compound, especially a metal carbonyl, or another metallic source, for example an oxide of Al, Mg or Si doped with a metal. After the deposition step the coating is typically black or metallic. If necessary, a change of colour is performed by heating in a temperature range of about 250 to 550°C in an oxidizing atmosphere. A colour change is accomplished due to the change of the valence state of the metal in the coating. Topaz, quartz, ruby, emerald, and sapphire are given as examples. Adhesion of the coating is strengthened because part of the coating material forms a diffusive layer with the gemstone substrate; topaz is given as an example.

Analytical data from this type of reaction or diffusion zone are presented by Yelon *et al.* (see again document 19). The compositional details were obtained by Auger electron spectroscopy and are given with topaz as core or substrate and iron carbonyl, $Fe(CO)_5$, as precursor compound. The surface-related reaction or diffusion zone *(Figure 2)* consists of two sublayers. The outer sublayer with a thickness of about 50 nm contains distinct but relatively low amounts of Al and Si (from the topaz), as well as high concentrations of iron but no fluorine. In a subsequent area, between 50 and 100 nm, the iron content decreases and the silica and alumina contents increase. It is not disclosed whether the 0–100 nm zone is in a crystalline or amorphous state. More than 100 nm from the surface, the analyses indicate that the topaz is unaffected by any diffusion. These interesting analytical results indicate that a diffusion or solid state reaction zone is formed by the heat treatment process. Its two sublayers both consist of the elements of the topaz (from the core) and iron (from the deposited metallic layer).

It is assumed that the indicated content of Fe of between 2 and 5 wt.% at 100–400 nm from the surface are iron background values attributable to the analytical technique. This is because diffusion of iron into the topaz structure to produce an almost flat profile for 300 nm is very unlikely. The data from this example therefore indicate some content of iron in the 50 nm-thick outer layer and decreasing iron contents in the 50 nm-thick inner diffusion layer, but do not support the presence of any diffused iron deeper in the crystal.

Discussion

The patent documents reviewed in this paper and summarized in *Table I* reflect two different basic technologies.

The first group of documents contains methods for the deposition of various thin layers or films on the surfaces of faceted stones without additional heat treatment. In documents 3 and 4 by Starcke *et al.,* 15 and 16 by Gaillard Allemend, and 20 and 21 by Maltezos *et al.,* various optical reflection and interference phenomena are used to improve the optical properties (fire) of the gemstones or to create a specific visual impression. Documents 1 and 2 by Nassau *et al.* as well as documents 8 by Wright, and 17 and 18 by Neogi and Neogi, describe the improvement of hardness and wear resistance of the gem material itself or of the colour-causing coating or layer deposited on the surface of the gemstones. An example of this kind of material is diamond-coated synthetic moissanite which has already appeared on the gem market (Hammer and Schmetzer, 2000), and can provide misleading readings on moissanite testers.

A second group of patent publications describes techniques for the deposition of a coating accompanied by a specific heat treatment process. Documents 5 to 7 by Rauch and Würtenberger describe a

*Table I: Patent documents describing surface treatment of gem materials, especially topaz**

Document/patent family**	No.	Issued	Inventor/applicant	Type of surface treatment	Coating/diffusion material	Colours (examples)	Remarks
WO 98/21386 A1 US 5,882,786	1 2	22.5.1998 16.3.1999	Nassau *et al.*/ C3, Morrisville, NC, USA	Chemical vapour deposition or physical vapour deposition	Diamond	Colours according to the dopant of the core	Coating of moissanite
US 5,853,826 US 5,853,826 C1	3 4	26.12.1998 11.9.2007	Starcke *et al.*/ Azotic Coating Technology, Rochester, MN, USA	Sputtering or chemical vapour deposition or others	Thin coating of the pavilion of a stone with one or several thin layers, especially Ti, TiO_2, Zr, ZrO_2, also other metals, metal oxides, nitrides, sulphides and carbon	Green to violet (at different angles)	Various reflection and interference phenomena are observed when viewed at different angles of observation
US 2003/0124299 A1 AT 411 464 B US 7,033,640 B2	5 6 7	3.7.2003 26.1.2004 25.4.2006	Rauch and Würtenberger/ D. Swarovski & Co., Wattens, Austria	Contact heat treatment with a solid plate	Metals or metal oxides	Blue (cobalt oxide); yellow (vanadium oxide)	Diffusion directly from the solid plate or through an additional diffusion layer between the gemstone and the solid plate
US 2003/0224167 A1	8	4.12.2003	Wright, Kirkland, WA, USA	Conventional DLC application process	Diamond-like-carbon		Improvement of optical properties and wear resistance
US 2004/0083759 A1 US 6,997,014 B2 US 2006/0068106 A1 US 2006/0065016 A1 US 7,137,275 B2 US 2007/0157666 A1	9 10 11 12 13 14	6.5.2004 14.2.2006 30.3.2006 30.3.2006 21.11.2006 12.7.2007	Starcke *et al.*/ Azotic Coating Technology, Rochester, MN, USA	Sputtering or chemical vapour deposition or others	Thin coating of the pavilion of a stone with one or several thin layers of any dielectric material, e.g. oxide, nitride, carbide, sulphide, which consists of or contains a dopant that is highly absorptive in part of the visible area	Yellow (titania and vanadium oxide); blue (silica and cobalt oxide)	Additional heat treatment after coating is possible or necessary, but below a temperature at which diffusion from the coating into the gemstone occurs; different thickness of the coating on the pavilion with varying distance from the culet
EP 1 674 431 A1 WO 2006/070137 A1	15 16	28.6.2006 6.7.2006	Gaillard Allemand/ Baccarat, Glonville, France	Various known sputtering techniques	Successive transparent layers containing metallic and/ or ceramic particles with a final reflecting opaque metal layer		A decorative dichroic visual effect is produced

	US 2006/0182883 A1 WO 2006/089080 A2	17 18	17.8.2006 24.8.2006	Neogi and Neogi/ Temecula, CA, USA	Deposition of a colour-causing material and a wear-resistant material concurrently or in two steps	Integrated coating consisting of a colour imparting agent (metal, semiconductor, oxide, nitride, alloy) and an abrasion wear-resistant agent (diamond-like carbon, CVD diamond, alumina, polymer-based materials, nitrides, carbonitrides)	Amber with secondary green effects (an integrated layer of a diamond film with chromium oxide on topaz); yellow (a diamond-like-carbon layer with Si on topaz); light green, gold and amber shades (varying levels of gold with diamond-like carbon)	The colour may be caused by bulk absorption or via interference; colour improvement by sub-surface implantation techniques and other methods are also mentioned
	US 2007/0110924 A1	19	17.5.2007	Yelon *et al.*, Columbia, MO, USA	Chemical vapour deposition or physical vapour deposition	Organometallic compound or a metal-bearing compound as precursor for the deposition of a metallic layer	Different colours are obtainable by various precursors such as amber [$Fe(CO)_5$]; dark blue or green blue [$Co_2(CO)_8$]; orange [$Mn_2(CO)10$]; violet [$Ti(C_3H_7O)_4$]; red [Al_2O_3 doped with Cr)	If necessary, heat treatment of the stone with the deposited metallic layer, formation of an intermediate layer consisting of Al and Si (from the topaz core) and the metal, e.g. iron, of the precursor layer
	WO 2007/067696 A1 US 2007/0157667 A1	20 21	14.6. 2007 12.7.2007	Maltezos *et al.*, Fort Salonga, NY, USA	Formation of a diffractive optical element on the surface of the gemstone by deposition of a mask layer and a resist layer, lithography of the resist layer and subsequent etching	The mask layer may consist of titanium, aluminium, platinum, chromium, silicon dioxide or silicon nitride; the resist layer will depend on the lithography process and may consist of polymethylmethacrylate		The natural fire of the gemstone is increased

Deposition of a coating including a wear-resistant material without specific heat treatment

Deposition of a coating causing optical phenomena without specific heat treatment

Contact heat treatment with transition metal-bearing solids

Deposition of a coating and subsequent heat treatment

* patent documents are sorted in patent families (i.e. groups of patent documents with similar contents related to the same inventor or applicant, frequently based on the same priority application); patent families are presented chronologically according to the first member of a patent family published

** Abbreviations: AT Austria; EP Europe; US United States of America; WO World Intellectual Property Organization

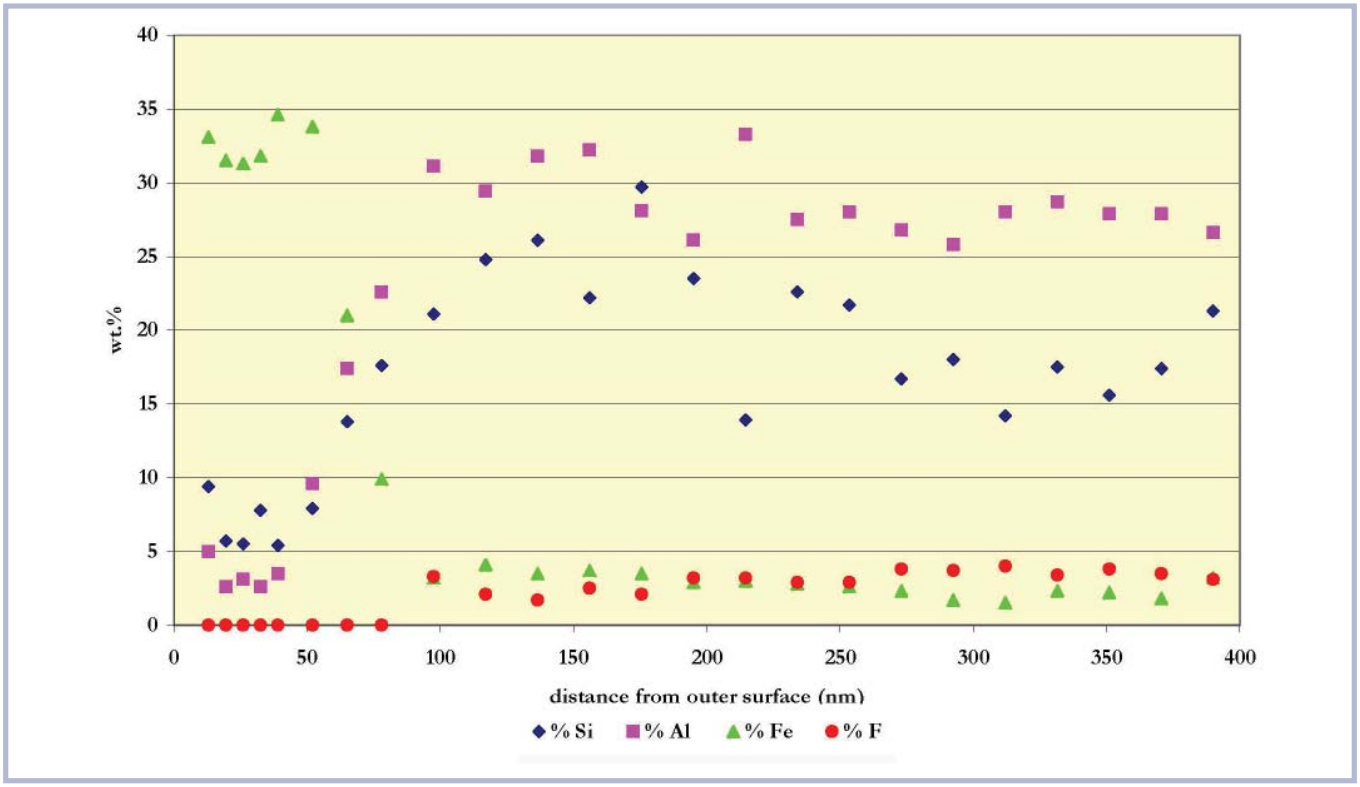

Figure 2: Chemical zoning within the reaction and/or diffusion layer of surface-coated and subsequently heat-treated topaz. The chemical data (obtained by Auger electron spectroscopy) were taken from the patent application of Yelon et al. (US 2007/0110924 A1, document 19); the two outer analysis points closest to the surface were omitted because they contained artefacts of sample preparation. The diagram reveals an outer reaction zone with high iron contents (from the coating) and small but distinct aluminium and silicon values (originating from the topaz core); within an intermediate zone between this outer layer and the topaz core, an intermediate layer is observed in which the iron contents gradually decrease and the aluminium and silicon contents gradually increase.

new variant of the contact heat treatment technology using a solid transition metal-bearing plate as source for the colour-causing agent. For this technology previously only transition metal-bearing powders were used. Another group of patent publications consisting of documents 9 to 14 by Starcke *et al.* and of document 19 by Yelon *et al.* describes improvements of the known two-step technology consisting of a deposition of a metal-containing layer on the surface of the gem material and subsequent heat treatment to improve or change the stability as well as the visual appearance to the coating.

Apart from surface-coated moissanite and diamond, the author is unaware of which, if any, of these various technologies has already been implemented and is in commercial production for release of such treated materials on to the market. From the descriptions given in the documents reviewed, it is very difficult to give any evaluation about the optical quality and wear resistance of the various coatings described for a number of gem materials. But it is most probable that at least some of the technologies referred to in this paper will be applied to gem materials in the future. Consequently the recognition of these various types of treatments will be a significant focus of research for gemmological laboratories in the future.

Most interestingly, the analytical data from the margin of a topaz specimen coated with iron carbonyl (Yelon *et al.*, document 19) provides a first insight into its chemical composition and formation as a reaction to heat treatment.

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Gem-A Centenary Conference and The 2nd European Gemmological Symposium

Saturday 25 — Sunday 26 October 2008

The Hilton London Kensington

Gem-A is proud to be hosting this year's European Gemmological Symposium in conjunction with our centenary celebrations. This dynamic two-day conference will highlight both the history of gemmology and the jewellery trade, and will discuss tips and new technologies that are relevant to today's gemmologists. Our gathering of international speakers and members promises to make this an historic event.

Day 1: The Foundations of Gemmology

There will be a range of papers reviewing the history of gemmology from many perspectives, including the history of diamonds, Portuguese gems, the history of inclusions, the life of George Frederick Kunz and the gems in the Swedish Crown Jewels. *Speakers:* Sandra Brauns, Rui Galopim de Carvalho, Al Gilbertson, John Koivula, Yvonne Markowitz and Jack Ogden.

Day 2: Practical Gemmology in the Modern World

Papers will discuss the practical use of gemmological instruments which are significant to gemmologists today and the analysis of certain gem materials, as well as new developments and discoveries. *Speakers:* Emmanuel Fritsch, Henry Hänni, Ulrich Henn, Alan Hodgkinson, Michael Krzemnicki, Duncan Parker and Brad Wilson.

Conference Dinner/Dance

A Conference Dinner/Dance will be held at the Hilton London Kensington on the Saturday evening.

Conference Events

Monday, 27 October

8:45 to 10:00	Private viewing of The William and Judith Bollinger Jewellery Gallery at the Victoria and Albert Museum, South Kensington, with an introduction by Richard Edgecumbe. £15.00 + VAT.
14:00 to 16:30	New Approach to the Teaching and the Use of the Refractometer. A practical session with demonstrations by Darko Sturman and Duncan Parker. £20.00 + VAT.
18:30 to 21:00	Graduation Ceremony at Goldsmiths' Hall in the City of London. The ceremony wil be followed by a reception. £10.00 + VAT.

Tuesday 28 October

10:00 to 16:30	Precious Metal Clay Workshop with Helen O'Neill of the PMC Studio. £40.00 + VAT.
16:45 to 18:00	Private viewing of the Crown Jewels with a guided tour by David Thomas. £40.00 + VAT.

Fees and booking details

The fee for the Conference, to include lunch, is £135.00 plus VAT for one day, or £255.00 plus VAT for two days. An early-bird discount of £10.00 per day may be deducted by those booking by 31 August. Tickets for the Dinner/Dance are £35.00 plus VAT.

For full details of the event, how to register and how book a room at the Hilton, visit our website at www.gem-a.com or contact Olga Gonzalez at Olga.Gonzalez@gem-a.com or tel: +44 (0)20 7404 3334. Details of sponsorship are available on request.

Photo: Kunzite and spodumene crystals © L Kuehn

Visualization of the internal structures of cultured pearls by computerized X-ray microtomography

U. Wehrmeister, H. Goetz, D.E. Jacob, A. Soldati, W. Xu, H. Duschner and W. Hofmeister

Abstract: Computerized three-dimensional X-ray microtomography is capable of revealing the internal structure and some of the material properties of pearls at high resolution, and is thus a more useful tool in pearl testing than conventional X-ray radiography. Differences in transparency to X-rays (radiodensities) can be detected and speed up the process of locating different $CaCO_3$-polymorphs in the pearl. When combined with micro-Raman spectroscopy, vaterite-containing areas can be identified.

Keywords: aragonite, cultured pearls, microtomography, pearl testing, Raman spectroscopy, vaterite

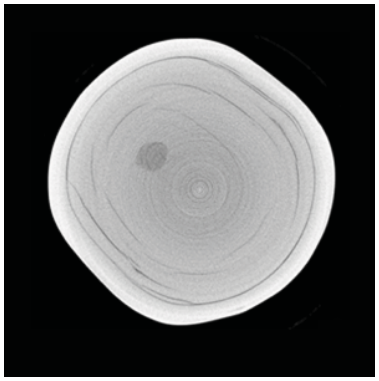

Introduction

Pearls are produced in nature by a number of mollusc species and man has taken advantage of this ability to develop cultured pearls. These can be divided into two groups: beaded (containing a bead nucleus manufactured from shell material) and non-beaded cultured pearls, both from marine and freshwater environments. The inner part of marine pearls commonly consists of prismatic crystals of calcite and the outer layer, the nacre layer, is made up of aragonite platelets (e.g. Watabe, 1965; Gutmannsbauer and Hänni, 1994; Song *et al.,* 2003; Snow *et al.*, 2004). Freshwater cultured pearls, however, have been shown to consist mainly of aragonite, whereas calcite has been reported only rarely. Instead, vaterite, a metastable $CaCO_3$ polymorph can be found in these pearls (Ma and Dai, 2001; Wehrmeister *et al.*, 2007; Qiao *et al.*, 2006). All $CaCO_3$ polymorphs are embedded in an organic matrix in a structure that is often referred to as a 'bricks and mortar' structure (e.g. Huang *et al.*, 2004; Snow *et al.*, 2004).

The differentiation of keshi cultured pearls (saltwater beadless cultured pearls) and natural seawater pearls as well as the distinction of natural freshwater pearls from beadless freshwater cultured pearls has become increasingly difficult since some of their characteristic radiographic features overlap (Lorenz and Schmetzer, 1986; Schlüter *et al.*, 2005; Hänni, 2006). In general, natural pearls show well-defined concentric growth patterns (Wada, 1998), while most beadless cultured pearls reveal less regular growth structures often accompanied by central cavities (in the case of keshi pearls, see Hänni (2006)) and central growth irregularities (in the case of beadless freshwater pearls, see Akamatsu *et al.* (2001)). However, in some cases, these differences are not well enough developed to differentiate between cultured and natural pearls on the basis of conventional X-ray radiography.

Here, we present computerized three-dimensional (3D) X-ray microtomograms combined with Raman spectra of beadless freshwater cultured pearls from Japan and China. Compared to conventional radiograms 3D-computerized X-ray microtomography reveals the internal structure of pearl at high resolution (less than 100 µm).

The occurrence of the metastable $CaCO_3$ polymorph vaterite in freshwater cultured pearls has been reported earlier in freshwater cultured pearls of low quality (Ma and Dai, 2001; Qiao *et al.*, 2007). However, by combining computerized X-ray microtomography and Raman spectroscopy, it has been shown that the occurrence of vaterite is not confined to so-called lacklustre pearls, but can also be detected in the inner parts of high quality cultured pearls, often closely associated with the remains of the tissue graft (Wehrmeister *et al.*, 2007).

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Materials and experimental methods

Table I gives a summary of the pearls used in this study: two non-beaded freshwater cultured pearls, one from China (A) and one from Lake Biwa (B), and two cultured pearls with beads (one freshwater cultured pearl from Lake Biwa (C) and a marine South Sea cultured pearl (D)). The Chinese sample and the South Sea cultured pearl were bought from different pearl-dealers whereas the Japanese pearls were obtained directly from the farmers. Only sample D was drilled. Samples A and B were cut in half with a diamond-plated saw and polished with diamond paste on a copper plate. Raman maps were obtained from both cross-sections to identify vaterite and aragonite. Tomograms of the two pearl halves (A and B) and of the whole samples C and D were acquired directly by computerized X-ray microtomography without further pre-treatment.

X-ray micro computer tomography

All computerized X-ray microtomography measurements were carried out by a SCANCO µCT-40 instrument (Scanco Medical AG, Bassersdorf CH) at the Medical Faculty, Johannes Gutenberg-University of Mainz. The cone-beam computerized micro tomograph scanner is equipped with a microfocus X-ray source of 5 or 7 µm spot size and 30-70 kV (160 µA) acceleration voltages. Depending on the sample size, a nominal isotropic resolution of 6–72 µm is achievable.

Most of the samples were mechanically fixed in a special sample holder for the measurements. To get the highest possible contrast between the pearl's soft tissue and the intrinsic different inorganic phases, 2000 per 360° X-ray transmission images (2048 × 2048 pixel) were taken by averaging each 10 single X-ray radiographs at the same position x, y, z with an acquisition time of 300 ms. To minimize artefacts when calculating the tomograms, the charge coupled device (CCD) detector geometry (2048 × 256) limits the amount of slices per rotation to 2 mm in height. So, for example, pearls with a diameter of 16 mm require more than 16,000 X-ray radiographs to reconstruct the 2000 slices of 8 µm thickness with the cone-beam method which leads to total acquisition time of 13.7 hrs per sample. All measurements and reconstructions were carried out in real time by the computer system fitted with 4 RISC processors (2 × 24 GB RAM) of the new HP Itanium type controlled by a 64-bit VMS operating system.

The physical CT image contains the values for the Linear Attenuation Coefficients µ [1/cm] at each voxel (volume pixel) which depend on the energies of the incoming X-ray photons and the material properties. The calculated µ-values are converted into a 2-byte number (-32768 to 32767) internally and visualized as 12-bit greyscale pictures.

Computerized microtomography is particularly optimized for application in the field of medicine. In this connection it is of great interest to correlate the Linear Attenuation Coefficient with definite tissue or bone density in order to detect deviations from healthy biomaterial. Sir G.N. Hounsfield invented a scale, which is a linear transformation of the measurement of the Linear Attenuation Coefficient in a new scale. This scale is denoted in Hounsfield units (HU). The radiodensity of water (at standard pressure and temperature) is determined with zero HU, whereas bones have a numerical value of 400 HU and up. For an average bone density a value of 500HU is given.

Raman spectra

The Raman spectra were recorded at room temperature using an Horiba Jobin Yvon LabRAM HR 800 spectrometer equipped with a Si-based CCD-detector (Peltier-cooled) and an integrated Olympus BX41 optical microscope. A 50x objective (numerical aperture 0.55) was used. The Rayleigh radiation was blocked using notch filters. The scattered light was diffracted by a grating with 1800 grooves/mm. The 514.5 nm line of an Ar^+-ion laser and the 632.8 nm Helium-Neon laser line were used for excitation, and laser power was 10mW. Data acquisition and spectra treatment were carried out with the commercially available program LabSpec v4.02 (Jobin Yvon Horiba). For single point measurements, spectra were recorded twice.

By using the Raman mapping technique the spatial distribution of different $CaCO_3$ polymorphs could be identified. For the Raman mapping of a pearl cross section a certain area was defined (for example 8.15 x 8.15 mm in the maps presented in *Figures 4F* and *5F*) and every 40 µm in x and y directions a spectrum was recorded twice for two seconds using a motorized and software-controlled x-y stage. The 40 µm step was selected to optimize the time acquisition for the resolution of the Raman maps. The resulting intensity of every peak was converted to a colour code. The Raman maps in *Figures 4F* and *5F* show the intensity variations at 1090 ± 1 cm^{-1} – the most intense band of vaterite. Thus, every pixel in these maps represents a single spectrum and every shade of grey a certain intensity.

Modern data acquisition software for Raman spectroscopy allows the necessary calculations for further data evaluation. In this project the analysis was performed with an Origin-lab® 7.5G professional software package. After background subtraction, a calculation of the full width at half maximum as well as a calculation of the position and intensity of the maxima are done by fitting a calculated curve to the measured spectrum. The peaks were fitted as the composition of either single or overlapping Lorentz curves.

Table I: Details of cultured pearls examined in this study.

Sample	Pearl description	Presence or absence of bead	Provenance
A	freshwater cultured pearl *c.* 8 mm diameter cut in halves	beadless	China
B	freshwater cultured pearl *c.* 8.55 mm diameter cut in halves	beadless	Japan – Lake Biwa
C	freshwater cultured pearl *c.* 11 mm max. diameter	drilled bead nucleus	Japan – Lake Biwa
D	saltwater cultured pearl, drilled *c.* 12 mm max. diameter	bead nucleus	South Sea

Analytical methods for pearl investigation

Because the determination of the nature of a pearl these days can be increasingly difficult, in some specimens it is only the combination of different methods that can lead to a successful identification. Pearls from a freshwater environment, for example, typically contain orders of magnitude higher contents of Mn than those from a marine environment (Gutmannsbauer and Hänni, 1994; Habermann *et al.*, 2001). These high Mn-concentrations can be detected by trace element analysis (e.g. by Laser Ablation ICP-MS, Jacob *et al.*, 2006a, b) or by X-ray luminescence methods (Banerjee and Habermann, 2000; Banerjee and Rager, 2001) and can be used to clearly differentiate between freshwater and marine pearls. In a pearl where the determination of its provenance is in question, good results can be achieved by quasi-non-destructive trace element measurements by Laser Ablation ICP-MS (Jacob *et al.*, 2006a,b), whereas spectroscopic methods (IR and Raman spectroscopy) are used to identify the modifications of $CaCO_3$ in pearls (e.g. Barnard and de Waal, 2006; Urmos *et al.*, 1991; Hedegaard *et al.*, 2005; Wehrmeister *et al.*, 2007) and have been found to be useful in identifying the origin of pearl colour (e.g. Li and Chen, 2001; Karampelas *et al.*, 2006). Lastly, both naturally coloured Tahiti cultured pearls and naturally coloured freshwater cultured pearls can be distinguished from their artificially dyed counterparts by Raman spectroscopy (e.g. Li and Chen, 2001; Karampelas *et al.*, 2006).

For the differentiation of natural from cultured pearls the best methods are different radiographic investigations (Lorenz and Schmetzer, 1986). These are often carried out with radiograms (X-ray shadow pictures; see *Figure 1*) that enable one to visualize the internal structures of a pearl and can show the presence of a manufactured nucleus. The recorded images are two-dimensional, while the structures occur at varying depths within the pearl. Therefore several radiograms are normally taken to get sufficient information about the internal growth structures. However, the identification is not always easy, because some radiographic features are common to both beadless cultured and natural pearls (Akamatsu *et al.*; 2001; Hänni, 2006; Lorenz and Schmetzer, 1986; Schlüter *et al.*, 2005). The development and availability of tabletop X-ray tomograms offers a rather new and improved method for pearl testing, because of their much higher resolution and three-dimensional capacities compared to conventional radiograms.

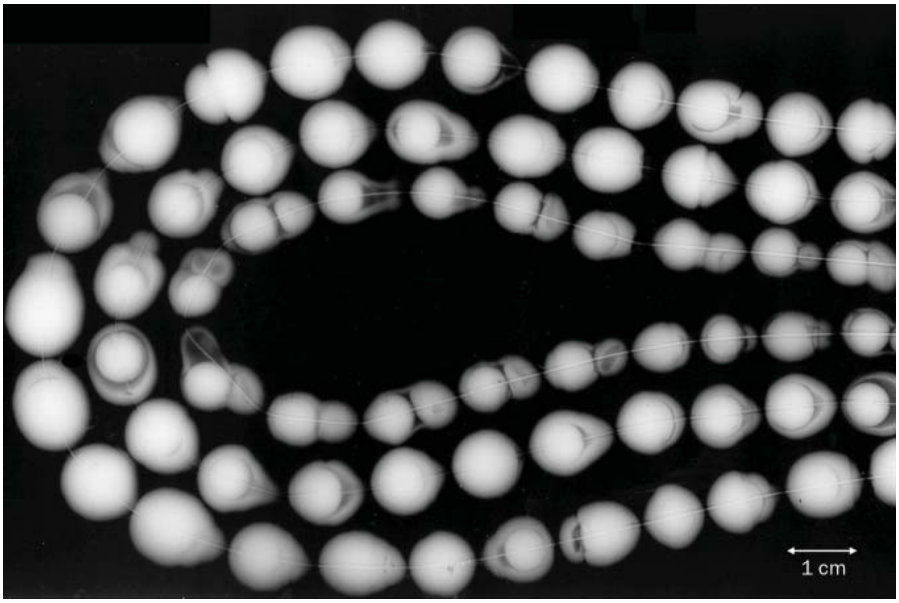

Figure 1: X-ray shadow image (radiogram) of South Sea cultured pearls. The internal structures and the bead nuclei are visible in most pearls, albeit with little structural detail.

Results and discussion

Pearls are composite materials, consisting of $CaCO_3$ platelets with an organic interlayer. These two substances differ in radiodensity (i.e. the transparency towards X-rays) which is the basis of a good visualization by microtomograms. The identification of different mineral phases and organic material is achieved by different grey values in the tomogram.

Structures easily visualized by micro-tomograms are the beads in pearl C (Lake Biwa, Japan) and in pearl D (South Sea), both in two-dimensional sections *(Figures 2 c-f* and *Figure 3 c-f)* and in 3D visualizations *(Figures 2a, b* and *Figure 3 a, b)*. The bead nucleus in pearl C *(Figure 2)* is drilled, whereas the whole pearl is not drilled. Because of their special

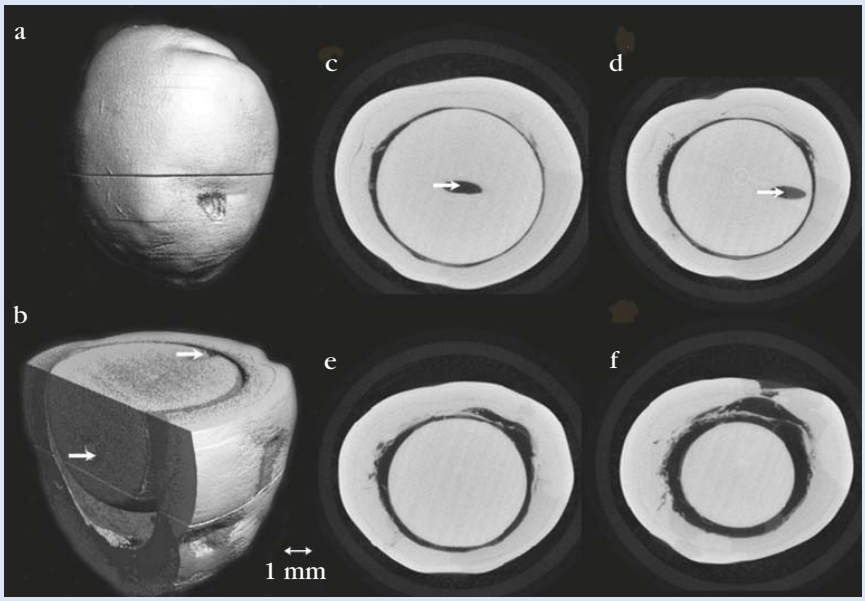

Figure 2: Radiograms of a freshwater beaded cultured pearl from Lake Biwa (pearl C). Images a and b show the 3D shape of the pearl and sections through the bead. In b the drill hole through the bead (the pearl is not drilled) is marked with white arrows as it is in the two-dimensional sections c and d. Drilled beads are part of the special implanting procedure used by the pearl farmers at Lake Biwa and Lake Kasumigaura. Contrast in the tomograms is optimized to detect any variation in the carbonate phases, so detail is lost in the area between the bead and the nacre layers that is rich in organic material and thus appears black.

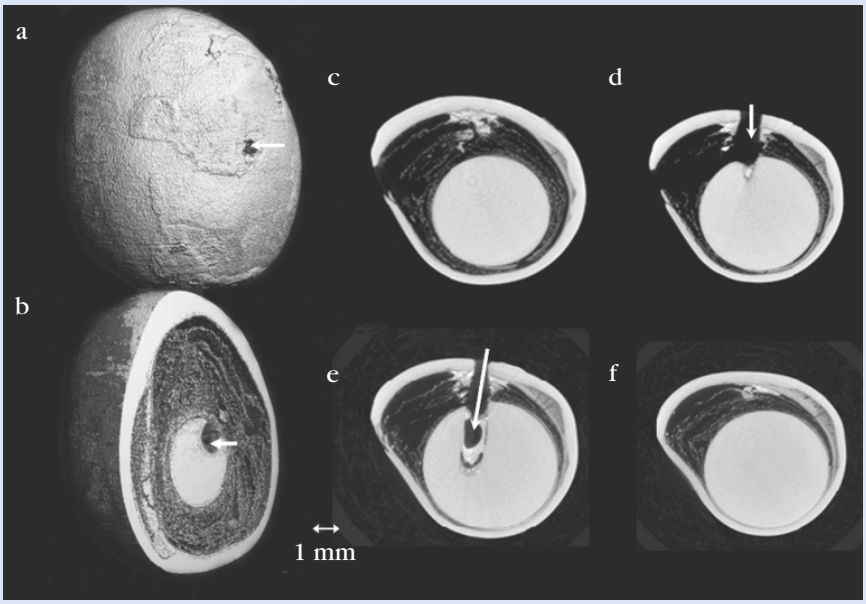

Figure 3: Three- (a and b) and two-dimensional (c–f) images of a drilled South Sea cultured pearl (pearl D).
The drill hole is marked with white arrows. In the two-dimensional, as well as in the 3D section and tomograms c-f, the bead and the cavity between it and the nacre coating are clearly visible. The organic material (darker shades of grey) has grown in a distinct layer around the bead, whereas between these organic layers no material can be detected (black). Any faint concentric rings in c-f are artefacts of the tomography.

implanting method, the pearl farmers K. Yanase (Lake Kasumigaura) and M. Sakai (Lake Biwa) use these drilled nuclei. The drilling of the nuclei is also often (but not always) detectable in X-ray radiograms that have much lower resolution than the tomograms. Freshwater cultured pearls from China contain either no bead or one made of freshwater shell-material that has not been drilled. Thus, beaded cultured pearls can be differentiated on the basis of presence or absence of a drill hole in their X-ray image and attributed to a Japanese source or otherwise. However, development of new implantation methods in China may very well require drilled nuclei in the future, requiring different or additional methods (e.g. Jacob *et al.*; 2006a,b).

Tomograms of a South Sea cultured pearl (pearl D) (see *Table I* and *Figure 3*) show the nucleus and the outer nacreous layer in great detail, as well as the gap between both. The dimensions of the gap are very variable, which can easily be seen in *Figures 3b–f*. The organic material has grown in a distinct layer around the nucleus. The empty space between the layers of organic material can be clearly discerned. Before this pearl was drilled, the gap could have been filled with a liquid. It is also clear that the thickness of the nacre layer can vary considerably.

The sizes of South Sea cultured pearls are in the range of 7 mm to 25 mm and their nacre thicknesses range from *c.* 1.5 mm to 4 mm, whereas baroque or oval shaped pearls can reach lengths of up to 40 mm (Strack, 2006). An X-ray shadow picture of South Sea cultured pearls of both baroque and round shapes is shown in *Figure 1*. The round bead nucleus and the nacre layer can be seen clearly in most of the pearls, but the X-ray radiograph fails to show any difference between the deposits of organic material and cavities.

None of the known X-ray radiographic methods is able to show any differences between the carbonate polymorphs, vaterite, calcite and aragonite areas and thereby indicate where they may be present. For example, in a radiograph only organic material, cavities, fissures and drill holes can be visualized in a calcium

carbonate matrix, and the X-rays cannot 'see' which polymorph might be present. The different shades of grey shown by the pearls in *Figure 1,* which can be identified as bead and nacre, both consist of aragonite and their intensities depend on the thicknesses of carbonate traversed by the X-rays. In the radiographs shown in *Figures 2* and *3* no difference in the shade of grey between bead and nacre (both identified as aragonite by Raman spectroscopy) is visible.

In order to test the potential of the microtomography method to distinguish between the polymorphs vaterite and aragonite, two sectioned freshwater cultured pearls (pearl A, *Figure 4* and pearl B, *Figure 5*) with vaterite sectors were analyzed. The two-dimensional X-ray microtomograms at various levels (*a, b, c and d* in *Figures 4* and *5*) within the pearls clearly indicate the internal structure. Irregular organic layers show the heterogeneity of the growth structure and are clearly unlike those of natural pearls (Gutmannsbauer and Hänni, 1994; Wada, 1998; Strack, 2006). The surfaces of the polished cross sections *(Figures 4e* and *5e)* show small cavities close to the centres of the pearls and to the vaterite regions — these cavities are also typical of beadless cultured freshwater pearls. The Raman spectral peak at 1090 ± 1 cm^{-1} is indicative of vaterite (Wehrmeister *et al.*, 2007) and mapping the incidence of this peak across a surface indicates the spatial distribution of vaterite. Raman intensity maps of cross sections of pearls A and B are presented in *Figures 4f* and *5f*. Raman spectra outside the vaterite areas have different intensities of the Raman shift at 1085 cm^{-1} and peaks at 701 and 705 cm^{-1}, showing that the vaterite is surrounded by aragonite (Urmos *et al.*, 1991). The boundaries between aragonite and vaterite areas are sharp and clearly visible in the Raman maps. *Figures 4a* and *5d* are two-dimensional microtomograms taken slightly below the surfaces depicted in *4e* and *5e* and show small but significant contrasts in grey-values which indicate the different polymorphs; these may be compared with the Raman maps. The difference in density between

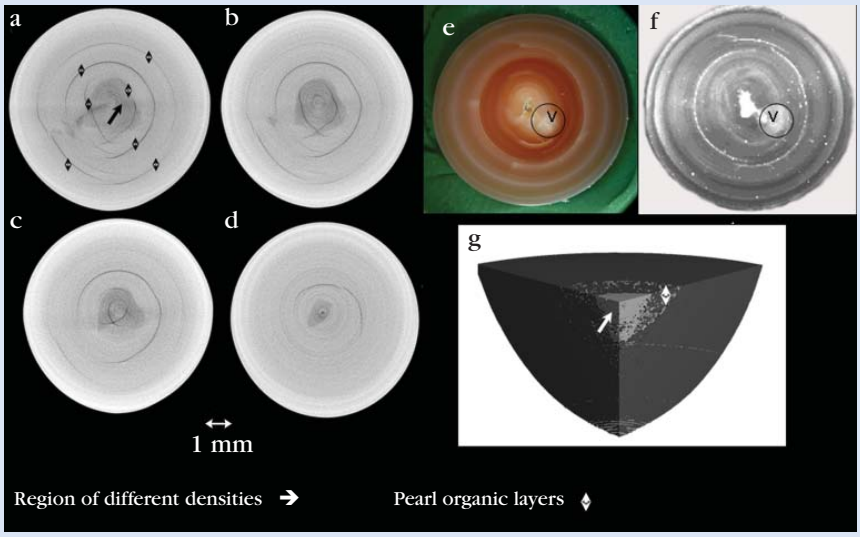

Figure 4: a-d show two-dimensional X-ray microtomograms of a sectioned freshwater cultured pearl (pearl A). These tomograms at various levels within the pearl (with a showing the highest level – 0.5 mm under the sectioned surface and d the lowest level) clearly reveal the internal structure. In 4a the darker coloured region of lower density within the pearl is marked with an arrow, whereas the organic layers are denoted with double arrows. Faintly visible concentric rings in a-d are artefacts of the tomography. In the sectioned pearl 3D image, g, the area of different density is lighter grey and marked with a white arrow; the organic layers are marked with white double arrows.
4e is a photograph of the polished cross-section of pearl A, and next to it (f) is a Raman intensity map of this surface at 1090 ± 1 cm^{-1}, a characteristic band for vaterite. Thus, using Raman spectroscopy, vaterite could be identified in the light grey area close to the centre of the pearl (denoted with V).

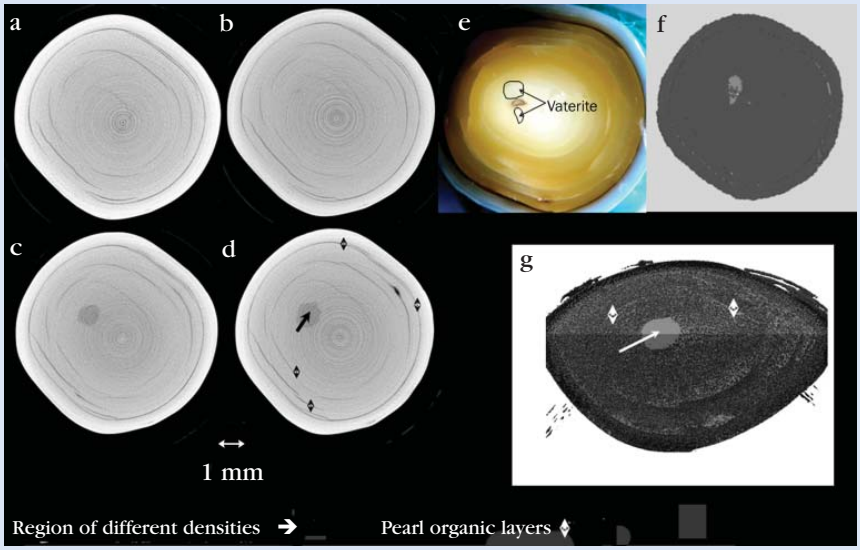

Figure 5: a–d show two-dimensional tomograms at various levels (a is the lowest and d is the level 0.5 mm under the surface) within freshwater cultured pearl B (Table I). Symbols as in Figure 4.
In the 3D image of the sectioned pearl, g, the areas of different densities are visible as different grey levels. Photograph e is a polished section of pearl B and two areas of vaterite are indicated. The Raman intensity map f at 1090 ± 1 cm^{-1} clearly indicates vaterite regions (pale grey) near the centre of the pearl.

inorganic aragonite and vaterite (0.39 gcm^{-3}) is sufficient to allow a distinction between these two phases based on their characteristic radiodensities. However, in pearls, these carbonate phases are both intimately mixed with organic material (e.g. Addadi *et al.*, 2006) thus changing their densities. It has often been argued that vaterite in biominerals is stabilized by organic material (e.g. Hasse *et al.*, 2000; Jacob *et al.* 2007) and in vitro studies indeed show higher concentrations of organic molecules in vaterite than in aragonite (Falini *et al.* 1998, 2000). Because organic molecules are low in density, a higher content of organics in vaterite will therefore preferentially reduce the vaterite density (2.54 gcm^{-3}) compared to that of the heavier aragonite (2.93 gcm^{-3}). A higher content of organic material in vaterite will therefore enhance the density difference between aragonite and vaterite and, in turn, the difference in radiodensity and contrast of the microtomograms.

However, this correlation may not be so straightforward and a detailed examination of the areas in the microtomograms indicates that they do not perfectly coincide with those identified as vaterite by Raman mapping. The vaterite areas identified by Raman mapping are smaller than the areas of different radiodensity resolved by the microtomograms. Furthermore, Raman spectroscopy shows that the transition between vaterite and aragonite occurs abruptly (within 2 µm, Wehrmeister *et al.*, 2007), indicating that the differences between the tomograms and the Raman maps are not likely to have been caused by variable mixtures of vaterite and aragonite. Instead, it is possible that a higher content of organic material in the general vaterite-containing region could be the cause of the different outlines.

This then suggests that the microtomography method is capable of identifying areas of higher organic to carbonate ratios, whereas the presence of vaterite has to be ascertained by Raman spectroscopy.

Conclusions

The identification of pearls is increasingly difficult and in some cases only the combination of different methods leads to a successful identification. Computerized X-ray microtomography enables resolution of structures on the micrometre scale, one or two orders of magnitude better than traditional X-ray radiograms. The inner structure and organic growth lines of pearls can be observed; cavities and hollows can be clearly differentiated from deposits of organic material due to their different grey scale in the tomograms, and features of bead nuclei distinguished. In addition, vaterite-containing areas within aragonite in two pearls have been identified on the basis of different intensities of grey in two- and three-dimensional tomograms. This contrast in the grey levels may, in part, be caused (and thereby emphasized) by higher concentrations of organic molecules in the vaterite-containing area rather than being solely due to the difference between the densities of aragonite and vaterite. The method is a fast and non-destructive method to identify the location of any vaterite in a pearl before Raman spectroscopy is used to map its exact distribution. However, microtomography is a most useful tool for scientific purposes and in testing highly valuable pearls, it can yield definitive structural information.

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Specular reflectance infrared spectroscopy – a review and update of a little exploited method for gem identification

Thomas Hainschwang and Franck Notari

Abstract: Specular reflectance FTIR (Fourier Transform Infrared) spectroscopy is a relatively little-exploited but very efficient technique to identify minerals and other materials that possess a somewhat reflective surface. In the past years the Gemlab and GemTechLab laboratories have used and refined the method for gemmological purposes and developed an extensive database of specular reflectance infrared spectra of minerals, gemstone imitations, organic materials and synthetic gem materials. This paper explains the method, introduces the spectrometer and accessories used and highlights the practical applications and advantages of specular reflectance FTIR spectroscopy in gemmology.
Keywords: intrinsic absorptions, spectral database, specular reflectance FTIR spectroscopy, vibrational spectroscopy

Introduction

Vibrational spectroscopy is very important for gemmological analysis and has been increasingly used in laboratories over the last few decades. The two methods included in the term vibrational spectroscopy are Raman and infrared spectroscopy (Schrader, 1995). Both are based on the interaction of light waves with vibrating molecules or crystal lattices. Raman spectroscopy detects bands due to inelastic scattering of laser light (thus monochromatic light) by vibrating molecules and crystal structure. Upon scattering, Raman bands are detected slightly shifted towards wavelengths of lower energy (higher wavelength, lower wavenumber) (Stokes shift) and with much weaker intensity to higher energy (lower wavelength, higher wavenumber) (Anti-Stokes shift). In infrared spectroscopy the vibrational energy of molecules changes upon absorption of infrared radiation, thus vibrational transitions are detected; in order to be infrared active, a molecule needs to possess a permanent dipole moment (Schrader, 1995).

Infrared and Raman spectroscopy are methods very commonly employed in analytical laboratories (Kiefert *et al.*, 1999). The best-known method of analysing samples with an infrared spectrometer is transmitting the infrared beam directly through the sample and observing the resulting absorption bands (King *et al.*, 2004). The intrinsic absorption bands of most materials (found in the mid infrared from ~ 2000–400, rarely to 200 cm^{-1}) however, are very intense, and cannot be resolved unless samples are thin enough (by polishing into thin films), or powdered and mixed with potassium bromide (KBr) and then pressed into pellets for analysis (Martin *et al.*, 1989). When investigating the infrared spectra of gemstones, however, sectioning or powdering are generally not possible and transmission spectra are performed without special preparation. Although the nature, shape and volume of a gem may allow some latitude, one can generally only observe the near to mid-infrared domain from around 7500 to about 2000 cm^{-1} with a standard Fourier Transform Infrared (FTIR) spectrometer. The features in this domain practically all relate to trace contents or impurities in samples, such as water in beryl (see for example Adamo *et al.*, 2005), and are only of limited use for identifying materials.

A very effective solution for this problem is to use specular reflectance

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Materials and methods

For building the Gemlab–Gemtechlab specular reflectance FTIR spectral database and for the research conducted for this paper, a PerkinElmer Spectrum BXll FTIR spectrometer and a Nicolet Nexus FTIR spectrometer, each one equipped with a DTGS (Deuteriated Triglycin Sulphate) detector, were used. One to 100 scans were carried out at room temperature and spectra recorded with a resolution of 4 cm^{-1}. Higher resolutions up to 1 cm^{-1} were also investigated, but found not to be worth the extra time involved since all reflectance bands are far larger than 4 cm^{-1}; the narrowest reflectance band found was 8 cm^{-1} at full width half maximum (FWHM). A PerkinElmer fixed angle specular reflectance accessory and a modified Spectra Tech diffuse reflectance accessory were used to record the specular reflectance infrared spectra *(Figure 1)*. In the PerkinElmer fixed angle accessory the sample is placed with any smooth or near-smooth face on a disc with a central hole to hold the stone which fits into the sample stage *(Figure 1a)*. Small samples need to be fixed with Blu Tack in the centre of the disc. In the Spectra Tech accessory the mirror usually used as 'sample stage' needs to be removed and the stone placed with Blu Tack on the pedestal instead of the mirror; thus the selected sample surface is used instead of the mirror to reflect the infrared beam *(Figure 1b)*. Since both accessories have their advantages and disadvantages, for practical purposes it is good to have both on hand. The fixed angle specular reflectance accessory is low in cost and extremely simple to use; large objects can be analyzed and the time of sample preparation and spectral analysis is very short, since no adjustments whatsoever are necessary. For curved faces, matte surfaces and extremely small facets the accessory is not ideal, although in most instances an interpretable result can be obtained. The best results are obtained from faceted gemstones of 0.10 ct and larger, the larger the reflecting facet the better.

The modified diffuse reflectance accessory is ideal for the analysis of samples with curved and or matte surfaces, but its disadvantages are: the analysis of large stones is not possible due to limited space in the sample chamber, the time of sample preparation is longer, they have to be fixed with Blu Tack, and spectral analysis is more time consuming since the signal strength must be adjusted manually. Therefore the only applications where this more expensive accessory is useful are those rare cases where no acceptable result can be obtained from the fixed angle specular reflectance accessory. Due to the geometry of the diffuse reflectance accessory, very small surfaces and surfaces with little reflectivity can be effectively analyzed.

In order to identify materials automatically, a search database consisting of the spectra of more than 600 mineral species has been built by the Gemlab and Gemtechlab laboratories. The samples used to record the spectra for this database were all selected from the Gemtechlab and Gemlab laboratory reference collections; the stones in these collections have all been precisely identified by various techniques such as chemical analysis, X-ray diffraction, Raman spectrometry, etc. All spectra were recorded in reflectance mode in a range of 4000–400 cm^{-1} with a resolution of 4 cm^{-1} and normalized to 100% at the wavelength of the most intense reflectance peak. The automatic search database was set up using the Omnic software by Thermo Nicolet, with which recorded spectra can be identified automatically, indicating the match in percent of the sample spectrum with reference spectra.

Due to the intensities of the reflectance bands, atmospheric artefacts can in practice be ignored and thus background spectra do not need to be repeated for gem identification purposes. Another advantage of these band intensities is that for most samples, only a few scans are sufficient to achieve a good signal-to-noise ratio; when a stone has flat facets, then no more than one sample scan is necessary.

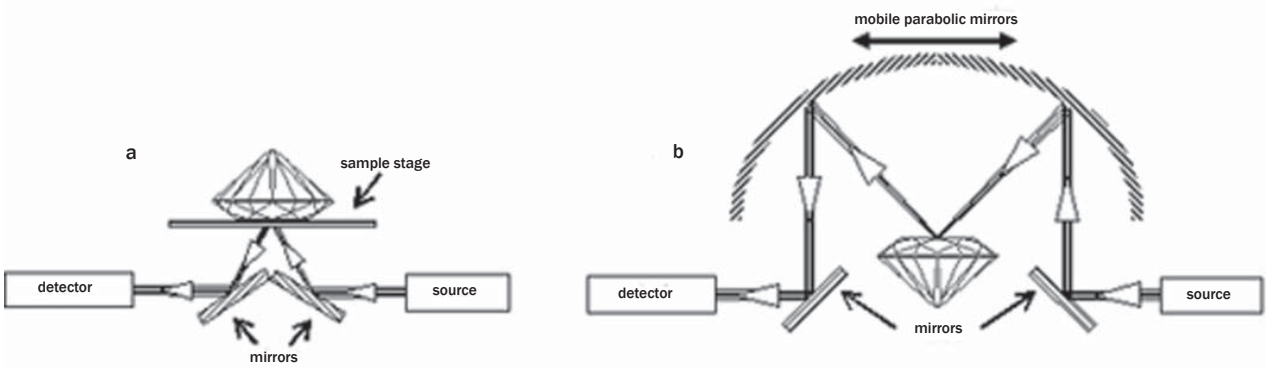

Figure 1: The design and function of the two accessories used to record specular reflectance infrared spectra: (a) fixed angle specular reflectance accessory, (b) modified diffuse reflectance accessory.

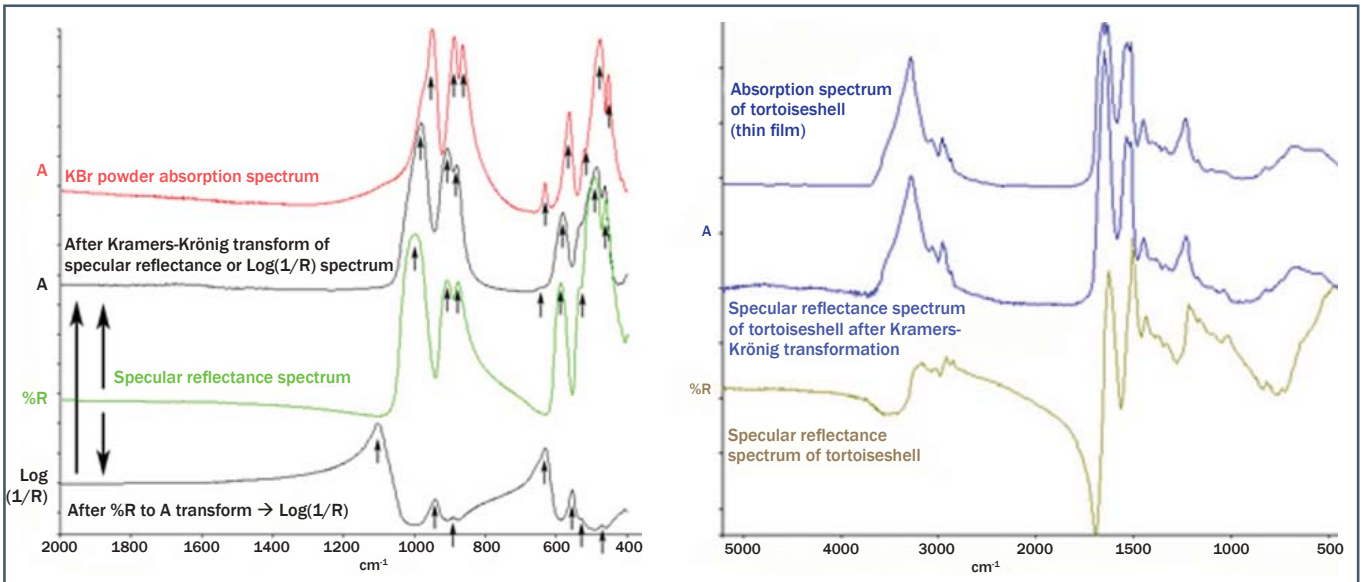

Figure 2: Comparison of specular reflectance versus true absorption spectra for an almandine garnet (left) and for tortoise shell (right, from Hainschwang and Leggio, 2006). The two examples are used to demonstrate the effect of the Kramers-Krönig transform: in the case of tortoiseshell the result is a perfect match with the true absorption spectrum, while in the almandine garnet the transform only had a slight effect on the reflectance spectrum; after the transformation the spectrum still was not a perfect match with the true absorption spectrum. In the garnet graph the bottom trace shows what happens upon %R to A transformation and consequent indexation of the 'absorptions'. Such transformation does not make much sense when determining a mineral from a reflectance spectrum since the unmodified reflectance peaks are much closer to a real absorption spectrum; upon application of the Kramers-Krönig transform to this Log(1/R) spectrum, the resulting spectrum will be the same as the one resulting from the application of the Kramers-Krönig transform to the specular reflectance spectrum. The examples garnet and organic material were chosen for demonstration because of their isotropy.

FTIR spectroscopy: this is a powerful vibrational analysis method to determine intrinsic structural vibrations of materials without destructive sample preparation; the beam is not transmitted through a sample, but reflected off the surface (White, 1974; Martin *et al.*, 1989; Coates, 2000; King *et al.*, 2004). With a comprehensive collection of reference spectra this method allows one to identify all minerals and imitations, most organics, and, in certain cases, even synthetics after only a few seconds analysis time (Martin *et al.*, 1989). The spectral information alone allows identification of the mineralogical group in most instances. Additionally, complexity of a crystal structure and presence of structural OH groups can be determined.

The Gemlab and Gemtechlab gemmological laboratories have refined this method for gemmological applications and have created an extensive database of reference specular reflectance FTIR spectra since 2001.

Characteristics and interpretation of specular reflectance spectra

Specular reflectance spectra resemble true absorption spectra to different degrees. In some gemstones, reflectance bands correspond closely to absorption bands, but in other cases, especially in organic materials, they appear strongly distorted due to abnormal dispersion *(Figure 2)*. This distortion can in most cases be corrected by the application of the Kramers-Krönig transform, which is used to transform specular reflectance spectra into true absorption spectra *(Figure 2)*. However, the applicability of this transform needs to be verified for each material because although the modified spectra of some stones are perfect matches with their true absorption spectra, for others the results are not an improvement on the original reflectance trace *(Figure 2)*. For identification purposes it is thus best to keep the spectra unmodified. So, for most minerals (and consequently for gemstones) the reflectance spectra can practically be regarded and interpreted in the same way as absorption spectra; the most prominent exception is diamond, because diamond is purely covalent and thus does not exhibit distinct FTIR reflectance peaks. For the general case of gemstones, where only infrared light reflected from a mirror-like surface reaches the detector, only structural peaks can be detected. In those minerals where the infrared beam can also be reflected from internal surfaces (such as in foliated minerals like mica), absorptions due to impurities may also be seen in the spectra. These features will then appear as they do in transmittance spectra, that is, they will appear in the opposite direction to that of reflectance peaks caused by structural vibrations. It has been noted in some recent publications that authors have recorded specular reflectance spectra of polished gemstones and shown them upside down, with a Y-scale indexed with 'Log(1/R)'; this happens when a spectrum recorded in reflectance mode is

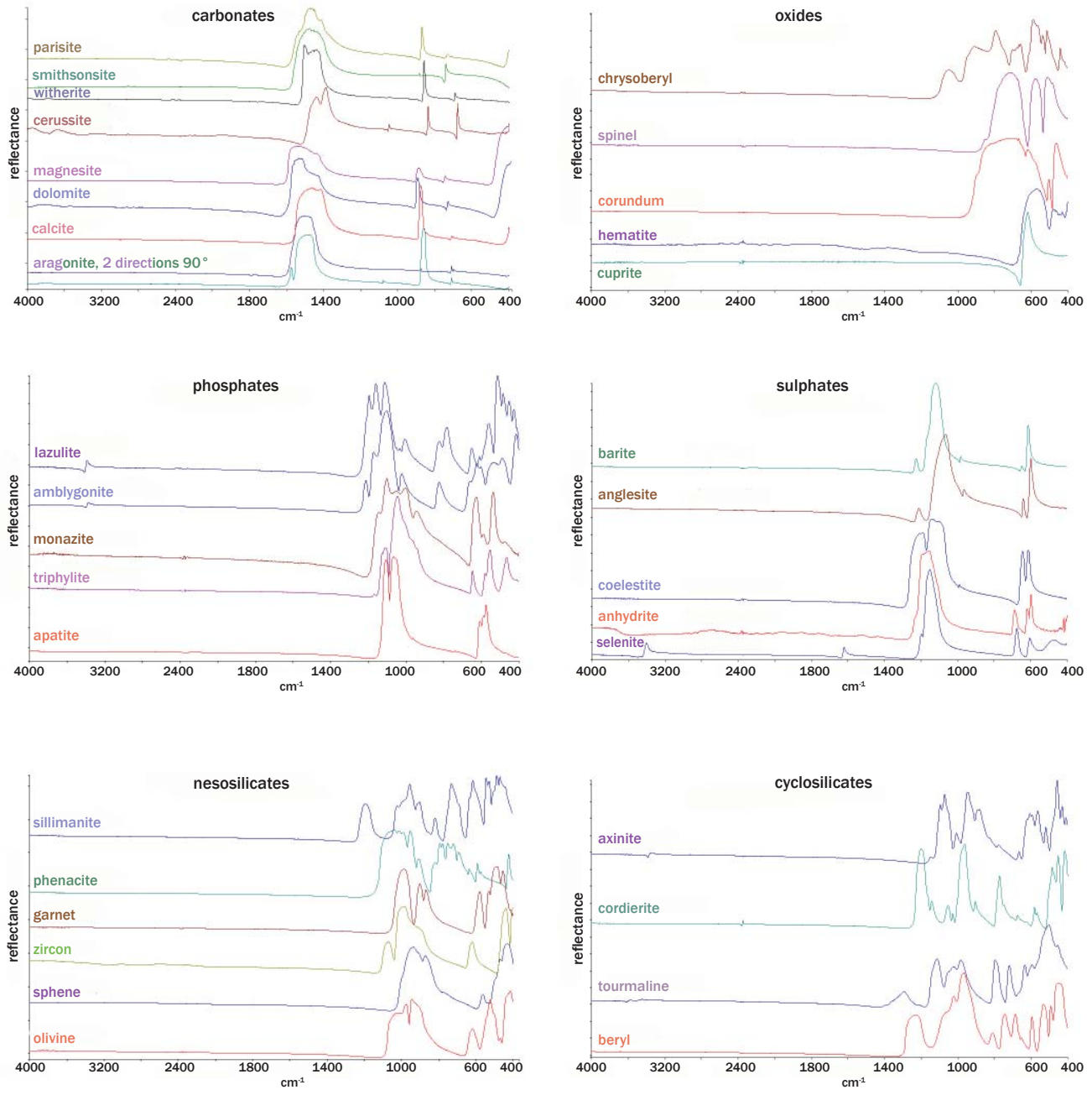

Figure 3: A selection of specular reflectance FTIR spectra of various arbitrarily oriented gemstones and minerals arranged according to their mineralogical groups.

transformed by a spectrometer program into absorbance, without using the Kramers-Krönig transform. The unusual shape of such transformed spectra and indexing the apparent 'absorption peaks' leads to much confusion and appears not to make much sense for the purpose of gem identification, since the unmodified reflectance spectra are much closer to a real absorption spectrum (*Figure 2,* left graph).

The bands detected in specular reflectance FTIR spectroscopy are very intense and only the peaks due to major compositional components of a material are detected, i.e. vibrations directly associated with the chemical formula of a substance. Because of this sensitivity to chemical composition and to the molecular coordination such a spectrum can be regarded as the fingerprint of a material. From the particular shape of a curve and the presence or absence of certain vibrations, a specular reflectance FTIR spectrum can usually be attributed to a mineralogical group. In *Figure 3* the spectra of gem minerals belonging to some of the more important mineralogical groups are shown and the differences between the groups are quite evident.

In gemstones with a simple structure, such as many of the carbonate and the sulphate minerals, the main vibrations

Box A: Notes on spectroscopic terms

- **%Transmittance (%T)**: the ratio, expressed in percent, of the intensity of the light transmitted through a sample to the intensity of light striking a sample, i.e. intensity of emerging light divided by intensity of incident light, × 100.
- **Absorbance**: inversely and logarithmically related to transmittance by the formula A = log(100/%T).
- **%Reflectance (%R)**: the ratio, expressed in percent, of the amount of radiation reflected from a sample surface to the amount of radiation reflected from a standard surface, usually an infrared mirror.
- **Kramers-Krönig transform (KKT)**: transform used to transform specular reflectance spectra into absorption spectra; it is based on the relations between refraction and absorption of electromagnetic waves in a substance.
- **Vibrations in molecules or ions**:
  External vibrations (lattice vibrations/lattice modes) [~600 to 80 cm^{-1}]:
  Translations (T_x, T_y, T_z) and Rotations (R_x, R_y, R_z)
  Internal vibrations (Internal modes) [~ 3800 to 400 cm^{-1}]:
  ν_1 = symmetric stretch (Raman) ν_2 = out of plane bend (b) (IR)
  ν_3 = asymmetric stretch (s) (IR+Raman) ν_4 = in plane bend (IR+Raman)
  Number of vibrations in a non-linear molecule or ion with n atoms = 3n-6 internal vibrations;
  Number of vibrations in a linear molecule or ion with n atoms = 3n-5 internal vibrations.
  Both linear and non-linear molecules or ions possess 6 external vibrations, 3 rotary and 3 translatory.
  Detailed explanations and definitions of terms for vibrational spectroscopy can be found in the Glossary of Terms used in Vibrational Spectroscopy (Bertie, 2002).

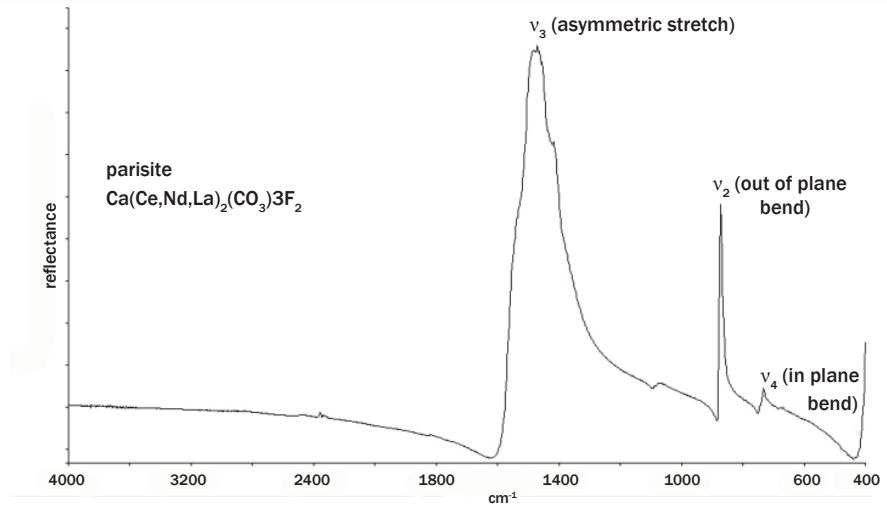

Figure 4: The attributions of the principal reflectance peaks to the corresponding molecular vibrations of the carbonate ion CO_3^{-2} in the specular reflectance spectrum of the rare carbonate parisite.

(ν_2, ν_3, ν_4) of the molecular group can be directly attributed. For example the carbonate ion CO_3^{-2} in different carbonate minerals (for example calcite, aragonite and dolomite) has its main vibrations at the following positions: ν_2 → 850 – 900 cm^{-1} – ν_3 → 1400 – 1600 cm^{-1} – ν_4 → 680 – 770 cm^{-1} *(Figure 4)* (see, for example, White 1974). For more complex minerals like many of the silicates attribution is more complex and is beyond the scope of this paper.

In anisotropic gem materials (i.e. in all minerals except the ones belonging to the cubic crystal system plus aggregates [for example jadeite, chalcedony, nephrite] 'Mineraloids' [for example obsidian, tektites, opal] and organic materials [for example tortoiseshell, amber, bone]) the orientation of the samples in the specular reflectance accessory can have visible effects on the reflectance spectra due to the anisotropy. Anisotropic materials not only show distinct orientation-dependent variations in the UV and visible part of the electromagnetic spectrum, but also in the infrared region. The spectra of the α, β and γ rays of tanzanite recorded using an infrared polarizer between the infrared beam and the specular reflectance accessory are shown in *Figure 5;* the distinct differences between the individual rays are evident. The effects of this anisotropy are far less distinct without use of a polarizer. Although sample orientation alone will cause certain variations, only in a few materials will they be significant enough to potentially affect the efficiency of the automatic search function. Such minerals with different spectra in different directions therefore need to be recorded in various orientations and several reference spectra saved. In the great majority of gem materials the variations due to anisotropy do not affect the efficiency of the automatic search function, since it is usually only the intensities of the individual peaks that vary, not their positions or wavenumbers.

Practical applications of specular reflectance FTIR spectroscopy

This method has some major applications in gem identification. The specular reflectance spectra are generally characteristic for one single gem species. Therefore, when the matching reference spectra are in a database, any material can be rapidly identified by a technician or gemmologist trained to use the FTIR instrument and the spectrometer software; this is also true for diamond, since all diamond-imitations show reflectance peaks while diamond does not.

Also, even in the absence of a matching reference spectrum, an experienced

spectroscopist can obtain extensive clues towards identifying a material by relating the major peaks of a spectrum to a mineralogical group and assessing its complexity. Since the method is very sensitive to compositional changes, synthetic gemstones can be differentiated from their natural counterparts when they are not a perfect structural match; so substances like synthetic turquoise, flame fusion synthetic spinel and most synthetic alexandrite can be identified rapidly. The sensitivity to compositional changes even permits in most cases the determination of gems in complex solid solution series such as the garnet group. If properly identified end-member garnets are in the database, at least the major components in a gem garnet under test can be identified *(Figure 6)*.

In many items submitted to laboratories for identification, gemstones are mounted in jewellery and identification by standard gemmological methods or even by many advanced methods like UV-Vis-NIR can be very challenging, time consuming or even impossible. The method described here is the ideal solution for identifying all materials used as gems, and even very small stones in heavy mountings can be identified. Additionally the specular reflectance data can be saved and, together with other gemmological data, used as formal proof in the event of any dispute.

Another application is the identification of very small surface-reaching inclusions in gemstones and grains within rocks; surfaces with a diameter as small as 0.5 mm were sufficient to yield critical data using the modified diffuse reflectance accessory, even when they were curved or matte. Using the fixed angle accessory approximately double the surface diameter was necessary to get good data and surfaces had to be more or less flat and smooth. To avoid interference from the surrounding material on the spot being analysed, Blu Tack was used as a screen because it does not produce artefacts in this analytical method, in contrast to transmittance spectroscopic analysis.

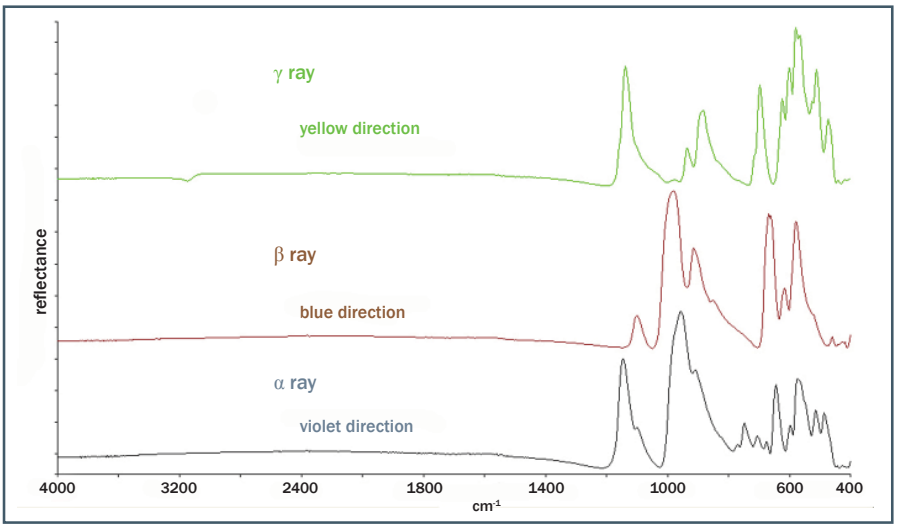

Figure 5: The polarized specular reflectance spectra of the α, β and γ rays of tanzanite. The spectra show very distinct differences due to extreme anisotropy. Arbitrarily oriented tanzanite would result in a spectrum of a combination of the three traces, showing most peaks and varying intensities. The spectra are cut off at 450 cm^{-1} since the infrared polarizing filter used did not transmit below this wavenumber. The colour annotations were added to each trace to show how each ray relates to the pleochroic colours of tanzanite.

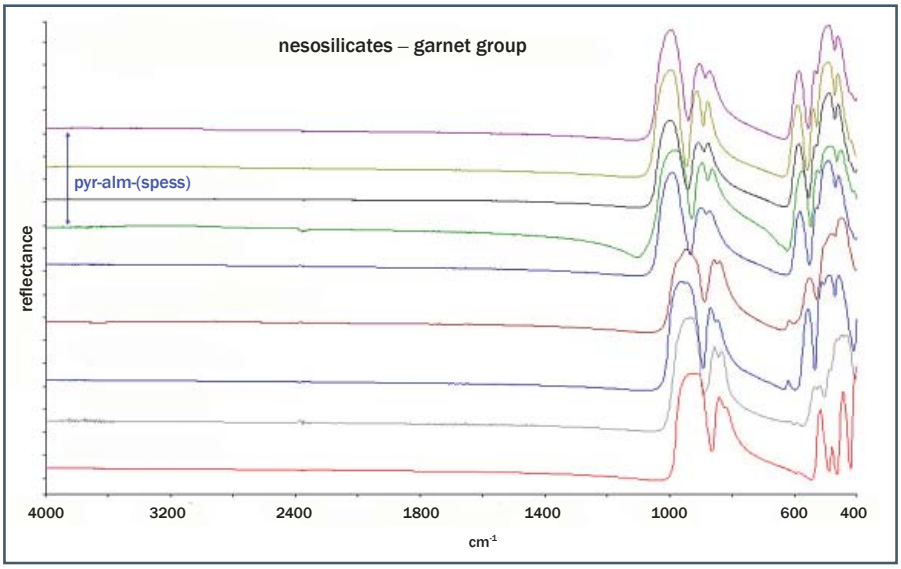

Figure 6: The garnet group shows extensive isomorphous replacement between molecules of almost all of its species. The major components of non-end member garnets can be identified by specular reflectance infrared spectroscopy.

Although all these tasks can also be achieved by Raman spectroscopy, the Raman systems used in gemmological laboratories are generally very costly compared to an infrared spectrometer and to maintain their financial viability, they are normally occupied by tasks other than gem identification. Due to the high intensities of reflectance bands and due to the large FWHM of all bands it is not necessary to use a research-grade FTIR spectrometer for gem identification – a low cost FTIR system with a maximum resolution of 4 cm^{-1} is more than sufficient.

A very important point in day-by-day work is that the time needed for gem identification with this spectroscopic method can be short. Assuming the spectroscopy software is open and the

search database ready, by using the fixed angle accessory an experienced operator can take approximately one minute to identify a stone conclusively; this includes sample preparation and data storage. Of course, one should not forget that rapid microscopic observation is always necessary in order to avoid misidentifications of, for example, assembled stones such as doublets or triplets.

Concluding remarks

The advantages of the spectroscopic method of specular reflectance FTIR analysis for gem identification purpose have been presented in this paper. These include high accuracy of gem identification and very short analysis time. Even though the specular reflectance spectra vary somewhat in appearance from true absorption spectra, they are similar enough to obtain most of the information that can be obtained from KBr powder absorption spectra. Compared to the only other spectroscopic method capable of very rapid and precise gem determination — Raman spectroscopy — the instruments necessary for specular reflectance FTIR spectroscopy are relatively low-cost and robust. While the method presented in this paper is limited to the identification of gem materials, the spectrometer used with other accessories has many more applications such as diamond type and treatment determination, determination of foreign substances such as glass, resin and oil in gemstones and is thus an important tool for gemmological laboratories.

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Afghan beryl varieties

Lucyna Natkaniec-Nowak

Abstract: Colour varieties of Afghan beryls from pegmatites at Ghursalak in Konar Province (aquamarine, morganite) and from the Panjshir Valley (emerald) have been investigated. The aquamarine, composition with SiO_2 (65.75 wt.%), Al_2O_3 (17.87 wt.%) and BeO (12.29 wt.%) is similar to that of many other aquamarines, and the low concentration of alkalis as well as relatively high amounts of Li_2O (0.34 wt.%) all indicate the gemstone to be normal beryl with limited isomorphous substitution in octahedral and tetrahedral sites. The calculated unit cell parameters (i.e. a = 9.2221 Å, c = 9.1990 Å, c/a = 0.9975), optical characteristics (i.e. ω = 1.576, ε = 1.571; Δ = 0.005) and the IR spectra of aquamarine with characteristic bands at 1206 and 963 cm^{-1} are typical of normal beryl. Emerald with contents of SiO_2 (64.50 wt.%), Al_2O_3 (15.19 wt.%) and BeO (12.73 wt.%) and significant amounts of alkalis (i.e. $Na_2O+K_2O+Li_2O$ = 2.1 wt.%) is alkali-rich octahedral beryl. This attribution is also indicated by the unit-cell parameters (i.e. a = 9.2399 Å, c = 9.1984 Å, c/a = 0.9955) and optical characterization (i.e. ω = 1.580, ε = 1.574; Δ = 0.006). Morganite with SiO_2 (64.16 wt.%), Al_2O_3 (17.91 wt.%) and BeO (11.81 wt.%) has the highest total alkali content ($Na_2O+K_2O+Li_2O$ = 3.51 wt.%) and is assigned to alkali-rich (Na-K-Li) tetrahedral beryl. The IR spectra of morganite (additional band at ***c.*** 1060 cm^{-1}, no shifts of 1215, 970 cm^{-1} towards lower wave numbers) together with calculated unit-cell parameters (i.e. a = 9.2198 Å, c = 9.2314 Å, c/a = 1.0012) and optical characteristics (i.e. ω = 1.580, ε = 1.574; Δ = 0.006) are all typical for a tetrahedral beryl. The Afghan beryls formed within granitic, beryl-muscovite pegmatites in hydrothermal conditions.

Keywords: aquamarine, emerald, morganite, NE Afghanistan

Introduction

The mountainous country of Afghanistan has been known for ages as a source of valuable mineral resources: gold, silver, lead, zinc, iron, antimony, copper, manganese, nickel, tin, sulphur, gypsum, salt, coal, oil as well as various precious stones, among which two of the most prominent are colour varieties of beryl, emerald and aquamarine. Exceptionally beautiful gem-quality beryls provide the slowly developing Afghan market with foreign currency.

Among the many papers dealing with Afghan beryls, especially emeralds and aquamarines, of special interest are those by Bariand and Poullen, 1978; Bowersox, 1985; Aurisicchio *et al.*, 1988; Bowersox *et al.*, 1991; Jones, 1991; Seal *et al.*, 1991; Bowersox and Chamberlin, 1995; Forestier and Piat, 1998; Bowersox *et al.*, 2000; Sachanbinski and Sobczak, 2001; Vapnik and Moroz, 2001; Hänni and Krzemnicki, 2003; Sachanbinski *et al.*, 2003; Fijał *et al.*, 2004.

The occurrence of beryls in Afghanistan

Beryl-bearing pegmatites occur in the NE part of Afghanistan, mainly in the provinces of Badakhshan, Laghman, Konar, Kapisa and Nangarhar (Chmyriov *et al.*, 1973; Rossovskiy *et al.*, 1976; Bowersox and Chamberlin, 1995; Hausel, 2006). The top quality aquamarines and morganites are mined in the Nilaw, Mawi and Kurghal regions of Laghman Province from cavities in pegmatite veins *(Figure 1)*.

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Materials and methods

Beryl samples from pegmatites of Ghursalak (Konar Province) and Panjshir Valley in NE Afghanistan were provided by Mr Jacek Szczerba. Investigations of nine colour varieties of beryl were carried out at the laboratories of the Department of Mineralogy, Petrography and Geochemistry, Faculty of Geology, Geophysics and Environment Protection, AGH University of Science and Technology in Cracow, Poland. They included hand specimen observations, optical investigation with a standard polarizing microscope in transmitted light, chemical, X-ray (XRD) and infrared spectroscopic (IR) analyses as well as special gemmological determinations.

Standard optical examinations were carried out with an Olympus BX 51 polarizing microscope. XRD analyses were done with a Philips X-Pert PW 1729 diffractometer in the range 5-75° 2Θ, applying CuKα radiation, a graphite monochromator, voltage 35 kV, lamp current 30 mA. Unit-cell parameters were calculated using the least squares method applying the DHN-PDF programme. A pure Si powder was used as an internal standard. IR spectra for selected beryl powdered samples were recorded with a BIO-RAD model FTS 1665 spectrometer in the range 400-4000 cm^{-1}. Determinations of chemical elements in three samples (aquamarine, emerald and morganite) were made. Main components, i.e. SiO_2, BeO, Al_2O_3, CaO, Li_2O, V_2O_3, were determined by inductively coupled plasma-atomic emission spectrometry (ICP-AES). The analyses were made using a PLASMA 40 Perkin Elmer spectrometer. Rb_2O and Cr_2O_3 were measured by inductively coupled plasma mass spectrometry (ICP-MS), using an Elan 6100 Perkin Elmer spectrometer. Other components, i.e. Fe_2O_3, MgO, CuO, MnO, K_2O, Na_2O, were determined by instrumental neutron activation analysis (INAA). The investigations were carried out with a 2 MW Pool Type reactor and a CANBERRA detector. The gemmological determinations of internal features, optical characteristics and luminescence were carried out using Schneider equipment.

The famous deposits of emerald occur in the Panjshir Valley (Kapisa Province).

The Nilaw-Kolum Pegmatite Field (35°12' N and 70°21' E) is one of the major regions producing gems in Afghanistan (Bariand and Poullen, 1978; Wolfart and Wittekindt, 1980; Orris and Bliss, 2002). Besides gem-quality beryl crystals, the pegmatites also contain albitized microcline, black tourmaline, lepidolite, multicolour tourmaline, kunzite (pink spodumene), columbite, manganotantalite, tantalite, cassiterite and others. According to Fuchs *et al.* (1974), beryl reserves of the pegmatites were estimated in the hundreds of tons.

The Mawi pegmatite (35°12' N and 70°20' E), occurring east of Nilaw near the Kolum river, hosts morganite accompanied mainly by kunzite and tourmaline and rarely by gem-quality aquamarine (Hausel, 2006). These morganites enriched in Cs are pink, pinkish-orange or orange (Hänni and Krzemnicki, 2003). They are usually up to 6 cm in length, prismatic and non-transparent.

South of Nilaw and Mawi, in the Kurghal deposit (35°04' N and 70°18' E), near the Alingar river, rare beryl crystals are accompanied by oligoclase, microcline, black tourmaline and muscovite, but it is most famous for extraordinary transparent green tourmalines.

The Ghursalak (Gursalak) Pegmatite Field in Konar Province (about 34°57' N and 70°43' to 70°44' E) has yielded beryl but it remains less well known than Mawi and Kurghal (Schumann, 1997; Hausel, 2006).

The emerald mines in the Panjshir Valley, located on the eastern side of the

Table I: Characteristics of aquamarine from the Ghursalak Pegmatite, Konar Province, NE Afghanistan.

Sample No.	Linear dimensions [length × width × height] (cm)	Weight (g)	Specific gravity SG	RI and birefringence	Characteristics of the crystal	Remarks
A1	2.5 × 2.0 × 2.7	22.02	2.68	ω = 1.576 ε = 1.571 Δ = 0.005	Pale blue with weak growth-zoning, translucent (many flaws and cracks)	Selected for detailed investigations
A2	2.2 × 1.6 × 2.2	14.80	2.80	ω = 1.575 ε = 1.571 Δ = 0.004	Blue with a green hue, translucent, numerous internal flaws and cracks filled with brown material	SEM and Raman investigations indicate brown material is probably clay minerals + Fe-compounds or bituminous substance
A3	1.7 × 1.5 × 2.6	9.62	2.72	ω = 1.578 ε = 1.573 Δ = 0.005	Euhedral crystal, pale blue, growth zones and tiny, 2-phase gas-liquid inclusions, transparent, locally translucent	Gem of high quality, *Figure 3.*

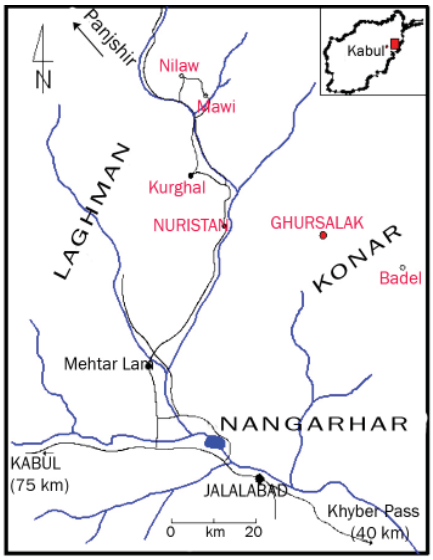

Figure 1: Locality map of beryl deposits in the NE provinces of Afghanistan (after Bariand and Poullen, 1978).

river at altitudes between 2690 and 3800 m, cover an area of 16 km^2 (Neilson and Cannon, 1977; Bowersox, 1985; Bowersox *et al.*, 1991; Orris and Bliss, 2002; Schwarz and Giuliani, 2002). The beryls occur sporadically in quartz-ankerite-pyrite veins. The pyrite can be used as an indication of the emerald mineralization. In general, the Panjshir Valley emeralds are dark green *(Figure 2)*, similar in colour to the fine emeralds found at the Muzo mine in Colombia (Kazmi and Snee, 1989; Sabot *et al.*, 2001) and sporadically over 15 mm in length. They are larger and cleaner than those found in the Swat and Gilgit regions of Pakistan (Gübelin, 1982; Kazmi *et al.*, 1985).

Since the 1970s most Afghan emeralds have been mined in the Bismal area (35°28' N and 69°49' E; 2690 m above sea level) in Kapisa Province, i.e. Bismal — Rewat and Ringe i Mukeni — Zara Kel (www.fieldgemology.com). Other emerald mining areas of less economic significance are in Konar Province, i.e. the Badel mine (34°50' N and 70°56' E) and in the Sorobi District near the Jagdalak ruby mine, as well as in the Laghman Province (Various authors, 2002).

Mineralogical and gemmological characteristics of Afghan beryls

Aquamarine

Three gem-quality samples of aquamarine (A1, A2, A3) from the Ghursalak deposit were studied *(Table I)*. The crystals are a delicate pale blue or blue with a green tint and a weak vitreous lustre. Different parts of the crystals are transparent or translucent according to the absence or presence of growth zones densely distributed parallel to the crystallographic *c*-axis, fissures or other defects. No mineral inclusions were found. However, tiny, 2-phase (gas and liquid) inclusions are present and visible in the zoned beryl A3.

Aquamarine A1 was selected for detailed investigation *(Figure 3)*. It is a perfect hexagonal prism, and its unit cell parameters are: a = 9.2221 Å, c = 9.1990 Å, c/a = 0.9975, which are consistent with published values (Aurisicchio *et al.*, 1988; Andersson, 2006). According to Gaines *et al.* (1997), the measured values of the RIs (ω = 1.576, ε = 1.571) and birefringence Δ = 0.005 are characteristic of low-alkali aquamarines. This aquamarine is inert under short- and long-wave ultraviolet (SW and LW UV) light.

The composition of aquamarine A1 is given in *Table II,* and on this basis, its structural formula is:

Figure 2: Emerald crystals from the Panjshir Valley, NE Afghanistan; collection J. Szczerba; Photo: S. Konopacki.

$$(Be_{2.65}Li_{0.12})(Al_{1.79}Fe^{3+}_{0.03}Ca_{0.03}Mg_{0.02})$$
$$(Si_{5.90}Al_{0.10})O_{18}\ (Na_{0.06}K_{0.01})\cdot 0.52(H_2O)$$

The relatively high contents of Al_2O_3 (17.87 wt.%) and BeO (12.29 wt.%) show that the aquamarine is a normal beryl with limited isomorphic replacements in both octahedral and tetrahedral sites. Here, the octahedral sites are occupied mainly by Al, Fe^{3+}, Ca and Mg. According to Aurisicchio *et al.* (1988), if Na + K > Mg then the total Li substitutes for Be in the tetrahedral sites, while Na and K are located in structural channels. Since Na_2O + K_2O < 0.5 wt.%, this aquamarine can be considered a low-alkali beryl (Černy, 1975). The Rb/K ratio is 0.08 and such a low value is also characteristic of beryls with low contents of alkali ions. Minor amounts of Mn, Rb, V and Cr are present as trace components.

A concentration of 0.37 wt.% Fe_2O_3 indicates that this element is responsible for aquamarine colour. In comparison to beryls from other localities in the world, the Fe-content is rather low, which is consistent with a pegmatitic origin (Chukhrov, 1963).

Table II: Chemical compositions of three Afghan beryls.

Oxide (wt.%)	A1 Aquamarine	E1 Emerald	M1 Morganite
SiO_2	65.75	64.50	64.16
Al_2O_3	17.87	15.19	17.91
Fe_2O_3	0.37	0.70	0.26
CaO	0.31	0.89	0.25
MgO	0.18	1.37	0.015
MnO	0.02	0.045	0.02
K_2O	0.11	0.27	0.44
Na_2O	0.34	1.15	1.61
Li_2O	0.34	0.68	1.46
Rb_2O	0.019	0.065	0.031
BeO	12.29	12.73	11.81
V_2O_3	0.013	0.093	0.004
Cr_2O_3	0.028	0.219	0.028
CuO	0.022	0.10	0.021
H_2O^+ (at 900°C)	1.75	2.08	1.89
Total	**99.412**	**100.082**	**99.909**
number of oxygens	18	18	18
Si	5.900	5.786	5.771
Al [IV] Al [VI]	0.100 1.790	0.214 1.392	0.229 1.670
Fe^{3+}	0.025	0.047	0.017
Ca	0.030	0.086	0.024
Mg	0.024	0.183	0.002
Mn	0.002	0.003	0.002
K	0.013	0.031	0.051
Na	0.059	0.201	0.281
Li	0.123	0.246	0.529
Rb	0.001	0.003	0.002
Be	2.649	2.744	2.552
V	0.001	0.006	–
Cr	0.002	0.015	0.002
Cu	0.002	0.007	0.002

Emerald

Three gem-quality emeralds from the Panjshir Valley were selected for study *(Table III)*. They are from light to dark green with yellow or blue tints and a weak vitreous lustre. They contain numerous inclusions of different kinds, and some cracks and fissures are filled with a brown substance, probably containing bituminous matter.

Selected for detailed investigation, emerald E1 is a prismatic crystal *(Figure 4)*. The crystal is dichroic in blue-green for the extraordinary ray and yellow-green for the ordinary ray. It is inert in both LW and SW UV light which is probably a result of its iron content, a feature in Afghan emeralds reported for example by Fijał *et al.* (2004). It is known that even small amounts of this element annihilate fluorescence of emeralds (Gaines, 1976).Its unit-cell parameters are: a = 9.2399 Å, c = 9.1984 Å, c/a = 0.9955, and the X-ray diffraction reflections are: 8.04(100); 4.62(35); 4.00(30); 3.27(96); 2.88 (91); 2.53 (20) Å.

The composition of emerald E1 is given in *Table II,* and on this basis, its structural formula is:

$$(Be_{2.74}Li_{0.25}\ Na_{0.01})$$
$$(Al_{1.39}Fe^{3+}_{0.05}Ca_{0.09}Mg_{0.18}Cr_{0.02}V_{0.01}Cu_{0.01})$$
$$(Si_{5.79}Al_{0.21}O_{18}(Na_{0.19}K_{0.03})\cdot 0.62(H_2O)$$

In comparison to the other investigated beryls, the emerald has the lowest content of Al, but has higher Fe, Ca, and Mg. The BeO content of 12.73 wt.%, is lower than the 'ideal' content 13.96 wt.%, but this is characteristic of emeralds from granitic beryl-muscovite, Ta-Be or Li-Be pegmatites (Zasiedatielev, 1970). This also indicates some substitution of Be in the tetrahedral (BeO_4) sites: firstly because Na + K > Mg, Li could substitute for Be, and secondly because the ratio H_2O/Na_2O < 2, Na could also substitute for Be. The remaining Na together with K occurs in structural channel sites. Rb_2O and MnO are present in traces only. The minor content of CuO probably indicates Cu compounds occurring as inclusions in the emerald crystal.

Figure 3: Aquamarine (A3) from the Ghursalak Pegmatite, Konar Province, NE Afghanistan; collection J. Szczerba; Photo: S. Konopacki.

Cr, V and subordinately Fe are, generally, chromophores responsible for the colour of emeralds (Nassau and Jackson, 1970; Taylor, 1977; Sinkankas, 1981; Spiesser and Fritsch, 1998; Various authors, 2005). In comparison with emeralds from other world occurrences, the Afghan emeralds show relatively high Cr_2O_3 content (0.219 wt.%), but are below the majority of Colombian stones (Muzo emeralds have around 0.29 wt.% Cr_2O_3 and 0.21 wt.% V_2O_3, vide Fijał *et al.*, 2004).

Noticeably high in the emerald E1 is the MgO concentration (1.37 wt.%), which is characteristic of beryls from pegmatites intruding ultrabasic and basic rocks. This is consistent also with the presence of significant amounts of CaO (0.89 wt.%).

According to Černy (1975), the emerald analysed can be classified as alkali-rich beryl with contents of Na_2O (1.15 wt.%), Li_2O (0.68 wt.%) and K_2O (0.27 wt.%); $Na_2O + K_2O$ = 1.42 wt.% makes up 67% of total alkalis with Na and Li noticeably prevailing over K (Ginsburg, 1955; Černy, 1975; Seal *et al.*, 1991).

Morganite

The details of investigations on three morganites from the Ghursalak mines are given in *Table IV*. The crystals are pale to dark pink and have a weak vitreous lustre. Due to their numerous internal defects the gems are translucent and non-transparent. Additionally, gas-filled cavities and 2-phase liquid-gas inclusions lie in zones parallel to the crystallographic *c*-axis, and fine, dark, solid inclusions – probably biotite flakes are also present. Under SW and LW UV light the crystals are pale violet.

The unit-cell parameters of morganite M1 are: a = 9.2198 Å, c = 9.2314 Å; c/a = 1.0012.

The results of chemical analysis of the morganite *(Table II)* were used to calculate its structural formula:

$$(Be_{2.55}Li_{0.45})(Al_{1.67}Fe^{3+}_{0.02}Ca_{0.02})(Si_{5.77}Al_{0.23})O_{18}(Na_{0.28}K_{0.05}Li_{0.08})\cdot 0.57(H_2O)$$

Morganite M1 has the lowest Be and highest Li contents of the three analyses and one may conclude that some Li has substituted for Be in the tetrahedral sites, which is typical of tetrahedral beryls *(t-beryls)* (Kurazkovskaya *et al.*, 1987). The channel sites are occupied by Na, K and the remaining amounts of Li. Trace elements include Mg, Mn, Rb, V, Cr and Cu. The low content of MnO (0.02 wt.%) and the Fe/Mn ratio of 8.5 could indicate a significant role for Fe as a colouring agent in this crystal.

Infrared spectroscopic investigations

IR spectra of the three beryls, i.e. aquamarine A1, emerald E1 and morganite M1, are presented in *Figure 5*. Bands in the range 1400-400 cm^{-1} can be attributed to Si-O, Be-O and Al-O stretching and bending vibrations. The Si-O asymmetric stretching vibrations appear at

Figure 4: Emerald (E1) from the Panjshir Valley, NE Afghanistan; collection J. Szczerba; Photo: S. Konopacki.

1200-900 cm^{-1} (Wood and Nassau, 1968; Aurisicchio *et al.*, 1994; Moroz *et al.*, 1999). Absorption maxima in this region were recorded at 1206, 1087, 1019, 963 cm^{-1} (aquamarine), 1163, 1060, 957 cm^{-1} (morganite), 1198, 1061, 1017 and 957 cm^{-1} (emerald). In the standard infrared absorption spectrum of beryl without any isomorphous substitution, the absorption maxima appear about 1215 and 970 cm^{-1} (Pliusnina, 1964; Sitarz *et al.*, 1997). Hence, for the coloured beryls in this study, the positions of these bands are at lower wave numbers. In detail, the band at 960 cm^{-1} is split into two maxima at 963 and 957 cm^{-1} and this can be explained by deformation of the silicate ring. The band at 1019/1017 cm^{-1} occurring in aquamarine and emerald, was not recorded for the morganite crystal.

The bands at 809-807, 747-744 and 682-680 cm^{-1} result from the Be-O stretching vibrations. In the absorption spectra of all beryl varieties there are bands at 653-649 and 593-590 cm^{-1}, characteristic of ring structures. The bands at 443-439 cm^{-1} are associated with the O-Si-O bending vibrations, whereas the bands at 525-519 and 499-493 cm^{-1} correspond to the Al-O vibrations in octahedral coordination.

The presence of the H_2O molecules of type II, i.e. those coordinated by the alkali cations (mainly Na and Li) and O-H groups, is indicated by the bands at 3596-3595 cm^{-1} (stretching vibrations) and 1637-1624 cm^{-1} (bending vibrations) (Sinkankas and Read, 1986; Wood and Nassau, 1967, 1968).

In the spectra of aquamarine and emerald there are two bands in the range 2900-2800 cm^{-1} attributed to the ν(C-H) stretching vibrations. This indicates the presence of organic matter, probably bituminous within structural channels of the beryls.

Summary and conclusions

Three beryl varieties of different colours, i.e. aquamarine, emerald and morganite have been investigated applying mineralogical and gemmological methods. Numerous internal and external defects negatively affect the

Table III: Characteristics of emeralds from the Panjshir Valley, Kapisa Province, NE Afghanistan.

Sample No.	Linear dimensions [length × width × height] (mm)	Weight (g)	SG	RI and birefringence	Characteristics of the crystal	Remarks
E1	9 × 4.5× 4	0.24	2.67	ω = 1.582 ε = 1.576 Δ = 0.006	Prismatic crystal, dark green, zoned, weak vitreous lustre, transparent to translucent (visible small cracks); high-quality gem	Selected for detailed investigations *Figure 4*
E2	10 × 3 × 2.5	0.19	2.68	ω = 1.585 ε = 1.576 Δ = 0.009	Prismatic crystal, dark green with a light yellow shade, weak vitreous lustre, transparent to translucent; small external cracks; high-quality gem	
E3	10 × 4.5 × 6	0.40	2.70	ω = 1.588 ε = 1.580 Δ = 0.008	Hexagonal prism, zonal, green with a blue shade; weak vitreous lustre, translucent, numerous liquid and 2-phase (liquid-gaseous) inclusions observed in structural channels, tiny, elongated solid inclusions (?) and brownish substance, probably composed of bituminous matter, cracks	

Table IV: Characteristics of morganites from the Ghursalak Pegmatite, Konar Province, NE Afghanistan.

Sample No.	Linear dimensions [length × width × height] (cm)	Weight (g)	(SG)	RI and birefringence	Characteristics of the crystal	Remarks
M1	2.3 × 1.8 × 2.5	20.05	2.74	ω = 1.590 ε = 1.582 Δ = 0.008	Pale pink with weak vitreous lustre, translucent, many flaws and cracks	Selected for detailed investigations
M2	2.8 × 2.9 × 3.8	25.83	2.68	ω = 1.598 ε = 1.588 Δ = 0.010	Pink, translucent, numerous internal flaws and cracks	
M3	2.8 × 2.0 × 4.5	26.88	2.76	ω = 1.602 ε = 1.594 Δ = 0.008	Deep pink, translucent, numerous internal cracks and liquid-gas inclusions	Gem of low quality

degree of transparency of these gem-quality minerals. This is especially true for the emerald in which many cracks, growth lines, gaseous and 2-phase gas-liquid inclusions, solid inclusions (for example organic compounds) have been recognized.

The chemical analyses revealed that the beryl varieties differ in their contents of Al_2O_3 and BeO. In emerald, the low Al_2O_3 combined with a high Rb_2O/K_2O ratio (0.24) suggest that it can be classified as an octahedral beryl *(o-beryl)*. The lowest BeO content occurs in the morganite (11.81 wt.%) and is typical of tetrahedral beryls *(t-beryls)*. Its low concentration indicates a probable derivation from granitic, beryl-muscovite pegmatites (Zasiedatielev, 1970; Černy, 2002).

Aquamarine was classified as a normal beryl with limited replacements in octahedral and tetrahedral sites, since its Al_2O_3 (17.87 wt.%) and BeO (12.29 wt.%) contents correspond quite well with the literature data for normal beryls, for example 17.0–19.5 wt.% Al_2O_3 and 12.3–14.0 wt.% BeO (Bakakin *et al.*, 1970; Kurazkovskaya *et al.*, 1987).

On the basis of their total alkali contents, aquamarine is classified as a low-alkali beryl, while emerald is a Li-Na beryl (Li>Na>K). The highest concentration of alkalis was reported in morganite and this is a Li-Na-K beryl.

From the relatively high contents of Li and H_2O^+ in all the beryls as well as their lower concentrations of BeO and Fe_2O_3, it can be stated that Afghan beryls crystallized within beryl-muscovite pegmatites under conditions characteristic of pneumatolytic and hydrothermal stages. Moreover, the emerald-bearing pegmatites probably intruded basic or ultrabasic rocks, as the emerald shows considerable amounts of MgO (1.37 wt.%) and CaO (0.89 wt.%). The occurrence nearby of Eocene, basic and ultrabasic rocks is consistent with this suggestion (Fijał *et al.*, 2004). Afghan emeralds probably formed at temperatures between 220 and 350°C (see Cheilletz *et al.*, 1994). Such a temperature range indicates that the emeralds crystallized at a late or final stage of pegmatite formation (Chukhrov, 1963). Li as well as Rb, Mn, V and Cu occurring as traces in the beryls accumulate in residual magmatic melts under hydrothermal conditions (Hawthorne and Černy, 1977). Considerable amounts of H_2O^+ in structural sites are also typical of beryls derived from granitic, beryl-muscovite pegmatites (Taylor *et al.*, 1992).

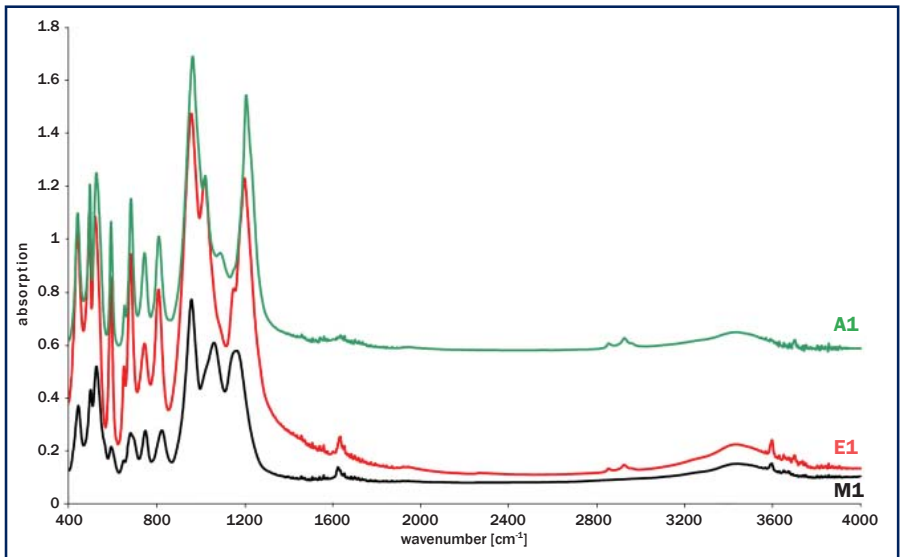

Figure 5: IR spectra of aquamarine A1, emerald E1 and morganite M1.

The chemical data are supported by the IR spectra *(Figure 5)*. Main bands in the range of 1200-950 cm^{-1} are diagnostic in distinguishing the three types of beryls according to the classification of Aurisicchio *et al.* (1994). The bands at 1206 and 963 cm^{-1}, recorded for aquamarine A1, occur at similar wave numbers as bands of standard beryl without isomorphous substitution, hence the mineral investigated belongs to the normal beryl group with limited substitution in tetrahedral and octahedral sites. In the spectrum of morganite M1 there is a band at 1060 cm^{-1} typical of tetrahedral beryls. The position of the band at 1017 cm^{-1} and the presence of an additional band at 1161 cm^{-1}, recorded for emerald E1 are characteristic of octahedral beryls. For both, morganite and emerald, the maxima at 1215 and 970 cm^{-1} were shifted towards lower wave numbers.

The unit-cell parameters, i.e. *a, c* and *c/a,* obtained in this investigation correspond well with published parameters. According to the lattice parameter classification of Andersson (2006), aquamarine has been assigned to the normal type, morganite to the tetrahedral type and emerald to the octahedral type beryls. The highest value for *a* is diagnostic for octahedral beryls, enriched in Fe^{3+}, Fe^{2+} and Mg^{2+}. Alkali-rich members of the beryl group, i.e. tetrahedral types, have the highest *c*, which is mainly caused by the presence of Li^+ in the tetrahedral sites.

Until recently Afghanistan has not been a major gem-mineral producer for the world market. However, gem-quality beryl, lapis lazuli, corundum, spodumene, garnet and tourmaline have been recorded from this country since Egyptian, Greek and Roman times. At present the production and supply of good-quality Afghan gemstones is growing, and many examples of superb material can be seen in gem markets worldwide. Gem mining plays an important role in the present-day economy of Afghanistan, and the search for new gemstone deposits continues in the mountainous regions of Afghanistan.

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The positions of light spots on rose quartz star spheres

Harold Killingback

Abstract: An explanation is offered of the apparent difference between the positions of light spots on a star rose quartz sphere as seen in a photograph of the actual sphere, compared with a photo of a table tennis ball marked with the orientations of these spots.

Keywords: asterism, rose quartz

Introduction

Schmetzer and Krzemnicki (2006) describe various configurations of light spots which can be seen on some examples of star rose quartz spheres. These spots are mostly on the rays of light forming the asterism, but occasionally they can also be observed between the rays. The authors concluded that the cause is the reflection of light from minute plane surfaces orientated in accordance with the crystal structure of quartz. It could not be determined whether these plane surfaces were negative crystals or platelets but, for simplicity, I shall here refer to them as platelets. The important point is that the reflections are from plane surfaces, unlike the needle-like inclusions which give rise to the continuous arcs of asterism in quartz. The authors illustrated the geometrical positions of light spots and arcs by means of stereographic projections.

Their paper encouraged me to look more closely at examples in my own collection which also show light spots, and to mark a table tennis ball with a three dimensional map based on the relevant stereographic projection.

Figure 1: Rose quartz sphere showing two light spots on a ray of epiasterism.

Observations

An example of a rose quartz sphere having light spots is shown in *Figure 1*. This picture shows two of the 20 light spots which can be seen as the sphere is rotated. My preliminary measurements of the angles were sufficient to confirm that, when viewed normal to the surface of the sphere and with the light source behind one, the patches of light are in those angular positions in which the most strongly defined spots occurred in the examples described by Schmetzer and Krzemniki (2006). They are all on arcs of

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asterism and comprise:-

- two at the centres of the six-ray stars, at each 'pole' (associated with the basal planes)
- 12 at 51.8° from the *c*-axis, there being six above and six below the 'equator', (associated with the rhombohedron faces)
- six at 90° from the *c*-axis, i.e. on the 'equator' (associated with the hexagonal prism)

I could not see any other light spots in my example.

I marked a table tennis ball *(Figure 2)* so as to show the rays and the light spots, as an alternative to, and based on, the stereographic projection. It was at once apparent that there was a material difference in appearance between the photo of the actual sphere and that of the model of the same object. In the photo of the real thing *(Figure 1),* two light spots are visible. One of them is related to a rhombohedral face angle and the other to a prism face. The sphere is orientated so that the spots are more or less equally spaced from the centre of the view. Measured on the photo, the distance between the spots is some 76% of the sphere's diameter.

In the picture of the model one can, in contrast, see nine light spots. The gap between the two spots corresponding to those in *(Figure 1)* is here only some 33% of the sphere's diameter.

Photographs of the Earth from space look, except for cloud cover, like the terrestrial globe in the schoolroom. So why do not my two photos look similar? I now propose an explanation of this apparent discrepancy.

Discussion

Figure 3 shows a cross section of the rose quartz sphere in the plane of one of the three circular azimuthal arcs of asterism. It is tilted so that RO, the normal to a rhombohedral face direction, and PO, the normal to a prism face direction, are equispaced about a horizontal line SO. This is the orientation of the sphere in *Figure 1.* CO is the *c*-axis. Angle COR is 51.8° and angle COP is 90°. So angle ROP is 38.2° and angle ROS is half this, i.e. 19.1°. Points C, R and P are some of those marked on the table tennis ball. The distance RP relative to the diameter of the sphere is sin 19.1, i.e. about 33%, as drawn on the model.

Throughout the sphere there are countless minute platelets, which act like two-sided mirrors. As, in this example, there are 20 spots, there must be ten orientations of platelets. Four of the orientations are perpendicular to the cross section in the illustration, as are the needle-shaped crystals which give rise to the great circle of asterism which corresponds to the circle drawn here. To avoid overcrowding the drawing, I have not included the radius vector at 51.8° from the 'south' pole, nor any details on the 'west' side. I have shown a representation of each of the other three families of platelets as short lines at right angles to CO, RO and PO, but of course there are platelets having the other orientations also.

Now consider the situation of an observer looking along SO, again with the light behind him. For simplicity, assume both source and observer are a long way from the sphere so that incident rays and reflected rays that reach the observer can be taken to be parallel to SO. Light rays along SO are normal to the surface of the sphere so will not be refracted, but they will not return to the observer from inside the sphere because none of the ten platelet face angles is normal to SO.

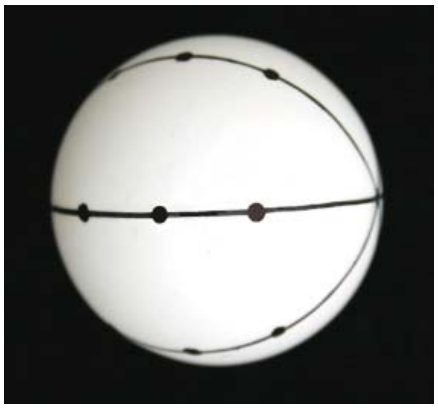

Figure 2: Table tennis ball marked with the positions of asterism and light spots.

Point P corresponds to the position of a light spot direction on the table tennis ball. A ray striking the sphere near P would meet the sphere obliquely so it would be refracted. It might meet a platelet orientated in any one of the ten directions, but none will result in light reaching the observer. As an example, one ray path showing reflection from a plate normal to PO is drawn on the diagram. By symmetry, the same is true for a ray reaching the sphere in the region of R, corresponding to another dot on the table tennis ball; it will not return to the observer either. So the appearance cannot be like that of the table tennis ball shown in *Figure 2.*

Now consider two incident rays of light which strike the sphere at Q and Q' respectively. Let the incident angle in each case be Θ. After refraction on entering

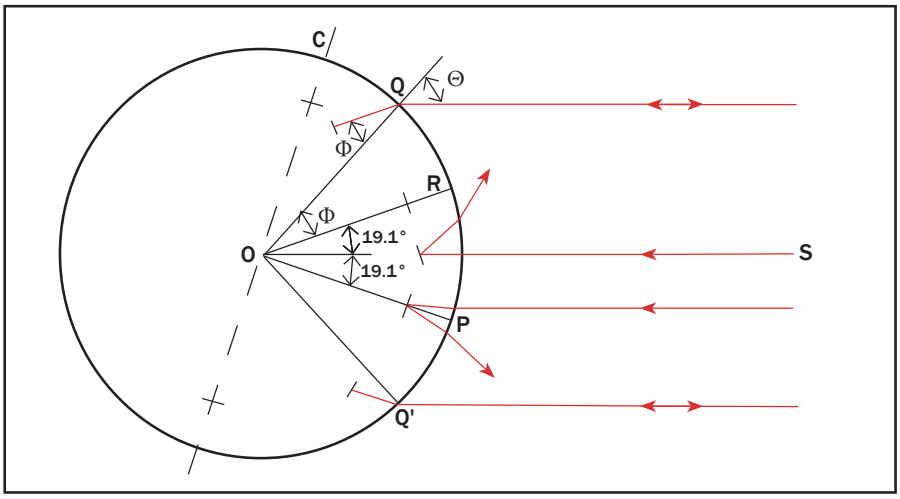

Figure 3: Ray diagram for the formation of light spots.

the sphere, the angle becomes Φ, say. Suppose I have so chosen the spacing of the rays at Q and Q' that the refracted rays are parallel to RO and PO respectively. Then there will be platelets on the paths of the rays which are at right angles to these paths. Light which meets such reflective surfaces will retrace its route and bright spots will be seen by the observer when looking at points Q and Q'. This resembles what we see when looking at the actual sphere, as shown in *Figure 1*.

We now can understand why the rose quartz sphere and the tennis ball look different, but we next need to calculate the positions of the points Q and Q'.

Because the refracted ray from Q is parallel to RO, angle QOR = Φ. Angle QOS is Θ, so

$$\Phi = \Theta - 19.1$$

and, taking a mean refractive index of 1.55,

$$\sin \Theta = 1.55 \sin \Phi.$$

From these two equations, it can be shown that Θ = 47.5°, and Φ = 28.4°.

With the derived value for Θ, the distance QQ' is 74% of the diameter of the sphere.

This is only in moderately good agreement with the value 76% observed in *Figure 1*. It should be noted, however, that although the light source, the sun, was far away, the camera was quite close.

The closeness of the camera, needed to get a good size of image, means that, for accuracy, we should take account of at least two of three factors in order to obtain better agreement. Firstly, in the photograph, the apparent diameter of the sphere will be smaller than the true diameter (by the cosine of the angle between the horizontal axis and the line from the camera tangential to the sphere). This has the effect of increasing Φ slightly. Secondly, the refracted ray will no longer be normal to the platelet, and although the amount is small the effect is doubled by reflection. Consequently, the angle of incidence at the quartz/air interface will be a few degrees greater, even if we ignore the third factor, namely that the point of exit of the ray will be a little lower on the sphere so the angle of the normal to the surface at the point of exit will have changed. If the platelet is close to the surface we may be justified in ignoring this effect. Working back from the observed spacing of 76% for QQ', I calculate that the emerging ray will be sloping down by some 3.6°. Such a ray meets the axis about 379 mm from the sphere. This is near enough where the camera was.

So we now know why we should expect to see light dots apart by about 76% of the sphere's diameter when the viewpoint is about 38 cm from the sphere.

Conclusions

The apparent discrepancy between the views in *Figures 1* and *2* is explained by noting that they are showing different things:

- In *Figure 1*, the photo shows reflection from those platelets which, although not being observed along a radius vector, are in positions which allow the reflected and twice refracted ray to reach an observer who has the light behind him.
- In *Figure 2*, the marked-up table tennis ball is a map of all the various positions of radius vectors along which an observer could see a light spot if the source of illumination were behind him and shining along the vector.

I was led into expecting the table tennis ball to look like the actual sphere, in the way that a schoolroom globe looks like the earth, by mistakenly thinking of light spots as things, in the way that physical features are things, whether they are distinctive inclusions in the quartz or features on the surface of the earth. Light spots, however, are effects, not things. You cannot take a piece home with you any more than you can capture a rainbow.

Coda

Is the marked-up table tennis ball useful? I believe it does give an accurate and helpful indication of the pattern of asterism and light spots, provided its message is properly understood. So, bearing in mind the difference between the representations in *Figures 1* and *2*, it is helpful to view the table tennis ball through a hole in a piece of card or plastic in contact with the ball, such a hole limiting the outlined area of the ball by being about 17 mm in diameter. In this way the viewer is not confused by parts of the pattern which would not be seen from the viewpoint in question. The ball can, of course, be rotated behind the card to display other aspects of the pattern. In *Figure 4,* the distance between the two light spots is the same in relation to the diameter of the hole as it is in *Figure 1* to the diameter of the sphere, so the impression given is reasonably accurate.

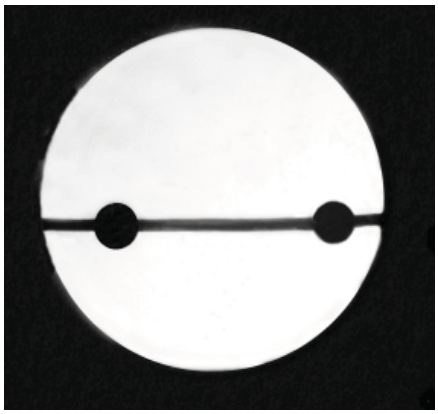

Figure 4: Table tennis ball with mask.

Acknowledgement

I am grateful to Dr Karl Schmetzer for the inspiration provided by his paper and for his helpful comments during the preparation of this note.

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Identification of taaffeite and musgravite using a non-destructive single-crystal X-ray diffraction technique with an EDXRF instrument

Ahmadjan Abduriyim, Taisuke Kobayashi and Chihiro Fukuda

Abstract: The rare gems taaffeite and musgravite have lately become more popular among collectors. Due to their similar chemical compositions and crystal structures, their main gemmological properties overlap and so sophisticated measurement techniques such as quantitative chemical analysis, Raman spectroscopy or X-ray powder or single crystal diffraction are needed for their identification. This study describes an EDXRF instrument used as single-crystal X-ray diffraction apparatus and the technique to identify taaffeite and musgravite in a relatively conclusive procedure. A special rotating and tilting stage has been constructed to non-destructively determine the differences in diffraction pattern based on the different symmetries (trigonal and hexagonal), unit cell dimensions and space groups of taaffeite and musgravite.

Keywords: EDXRF, musgravite, non-destructive gem test, rotating and tilting stage, single crystal XRD, taaffeite, Wulff net

Introduction

Taaffeite and musgravite from Sri Lanka, Myanmar and Tanzania are rare gemstones that are popular among collectors *(Figure 1)*. Gem-quality taaffeite and musgravite are both transparent, commonly with red, purple, blue, violet, grey or very dark colours. Taaffeite ($BeMg_3Al_8O_{16}$) shows a wider range of colours (which are due to high amounts of chromium and iron) than musgravite ($BeMg_2Al_6O_{12}$) which has only been found as purplish grey, greenish grey, greyish blue, and dark stones to date. These two mineral species, belonging to the same mineral group taaffeite, have very similar chemical compositions and crystal structures and their gemmological properties are so similar that they cannot be distinguished using standard gemmological identification tests. Several

Figure 1: Purple taaffeite (2.25 ct) and greyish-green musgravite (0.86 ct) from Sri Lanka are mounted in a pendant and ring respectively. These gems are popular among rare stone collectors. Courtesy of Midori Jewellery, Tokyo; Photo by Masaaki Kobayashi.

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Identification of taaffeite and musgravite

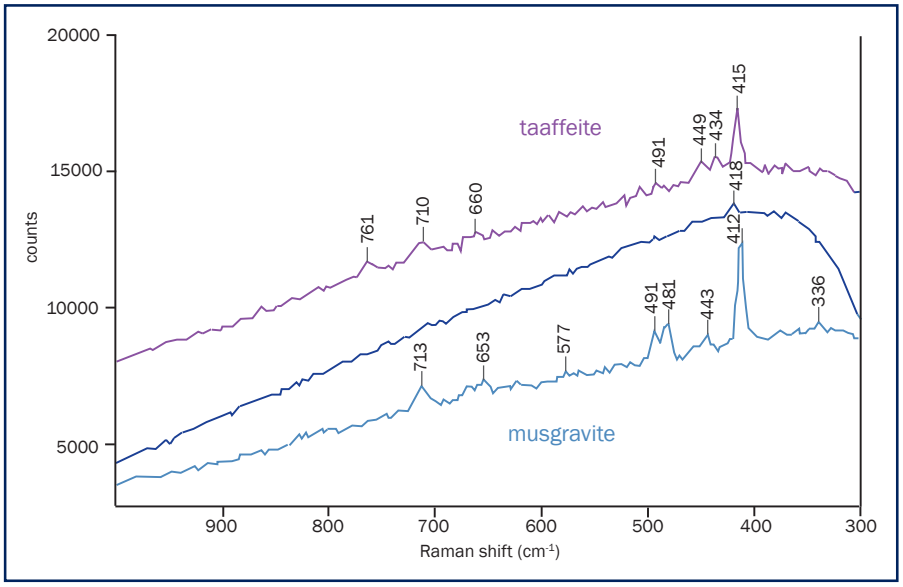

Figure 2: The Raman spectra of taaffeite and musgravite from Sri Lanka, obtained using 514 nm laser excitation. There is a strong Raman peak for taaffeite at 415 cm^{-1}, moderate peaks at 434 and 449 cm^{-1} and several weak peaks in the region of 600-800 cm^{-1} (660, 710 and 761 cm^{-1}). In the musgravite sample, the 412 cm^{-1} peak is the strongest, and several moderate and weak peaks were detected at 336, 443, 481, 491, 653 and 713 cm^{-1}. However, if a sample has an extremely high continuous background fluorescence (central spectrum) it may show only a very weak peak at 418 cm^{-1}, and peaks in the region 440-800 cm^{-1} may be indistinct and of little help in identification.

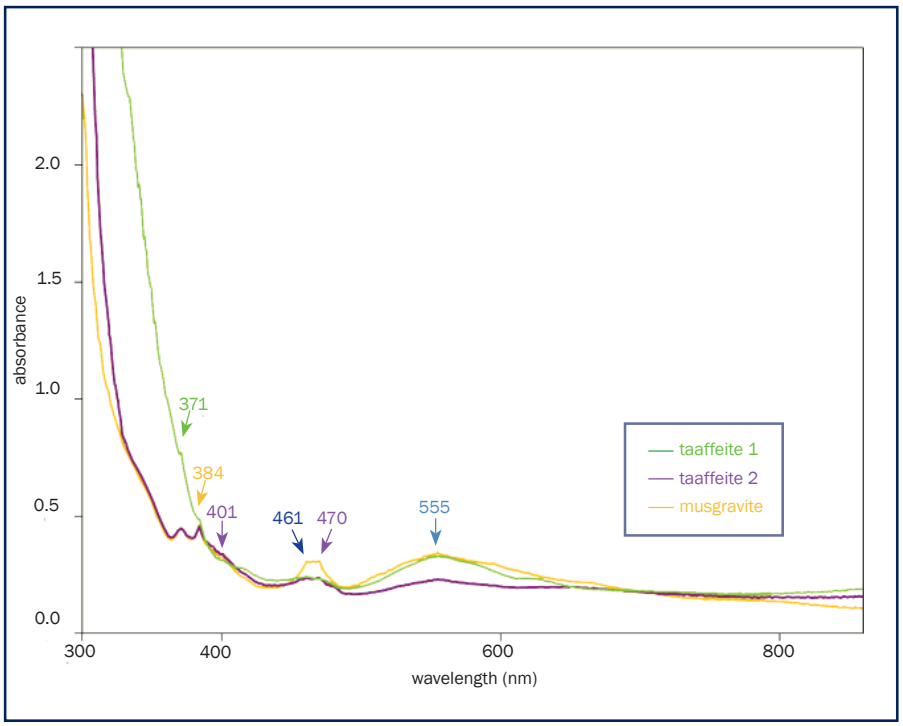

Figure 3: The UV-Vis-NIR spectral features of taaffeite are similar to those of musgravite. A broad absorption band centred at 555 nm and five other absorption peaks at 371, 384, 401, 461 and 470 nm are present. The intensity of the peak at 371 nm may be somewhat weaker in taaffeite than in musgravite, but in a few taaffeites this peak is strong, so it is not a reliable distinguishing feature.

techniques with high resolution and accuracy such as X-ray single crystal and powder diffraction, chemical quantitative analysis by electron probe microanalysis (EPMA) and Raman spectroscopy are effective in distinguishing these two minerals (Schmetzer *et al.*, 2000, 2005a,b, 2006, 2007; Kiefert and Schmetzer, 1998). In petrology and mineralogy the X-ray diffraction method is used as the most effective means to identify minerals. However, this involves taking small powder samples for testing which means losing some of the gem. Non-destructive Raman spectroscopy can be highly effective in distinguishing the two minerals, but some stones generate such a high continuous fluorescence background *(Figure 2)* that a useful Raman spectrum may not be detected. In the UV-visible absorption spectrum, absorption peaks at 371, 384, 401, 461, 470 and 555 nm are present in both minerals, and any differences are not consistent enough to be reliable distinguishing features *(Figure 3)*. Semi-quantitative analysis using an energy-dispersive X-ray fluorescence (EDXRF) spectrometer can yield the elemental ratios, and if one sums the trivalent elements (Al_2O_3+V_2O_3+Cr_2O_3+Ga_2O_3) and divalent elements (MgO+CaO+MnO+FeO+ZnO) *(Figure 4)* (Okano *et al.*, 2006), and assumes that the sum of molecular proportions (XO+X_2O_3=100%), the totals for a stone should either fall near 42.86% XO for taaffeite or 40% for musgravite. However, semi-quantitative EDXRF analysis resolution is not always of sufficiently high level to detect the light elements. A Si-semiconductor detector (SSD) should provide relative standard deviations (RSD) of light elements, especially Mg of less than 1.0 wt% and if it does not, further sophisticated measurements are required to obtain satisfactory data.

Consequently, in this study we tested the possibility of distinction between taaffeite and musgravite by analysing the distribution of their X-ray diffraction patterns obtained using an EDXRF analysis instrument. Many gemmological laboratories have such an instrument and

to adapt this for diffraction work would avoid having to obtain an X-ray generator and Laue back reflection camera.

The main use of an EDXRF instrument is to obtain compositions from X-ray fluorescence analysis, but when analyzing a single crystal, diffracted X-rays that meet the diffraction conditions for particular lattice planes and interplanar spacings are also produced and can be diagnostic for particular species. Therefore, to use this property and develop an easy method to separate taaffeite from musgravite relatively quickly, we have installed a special sample stage on the EDXRF instrument that can be used to rotate a sample through 360° under an incident X-ray beam and also tilt it ± 20 degrees. This enables one to obtain a suitable crystal orientation for diffraction by adjusting the stage holding the gem sample. (See also the report at the annual meeting of the Gemmological Society of Japan 2007 by Abduriyim *et al.* (2007a,b,c).)

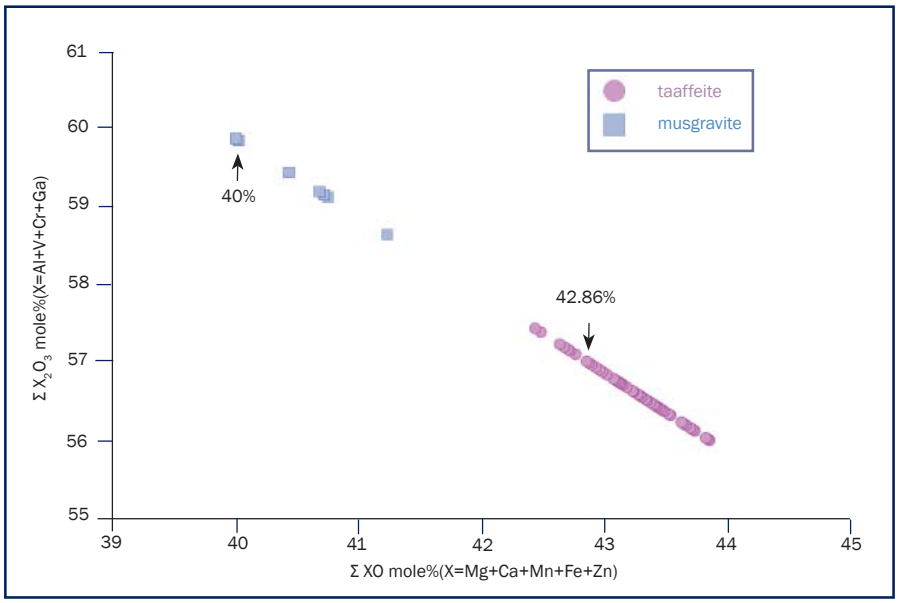

Figure 4: Comparison of the total molecular ratios of trivalent oxides X_2O_3 (Al_2O_3+V_2O_3+Cr_2O_3+Ga_2O_3) and divalent oxides XO (MgO+CaO+MnO+FeO+ZnO) in taaffeite and musgravite obtained using EDXRF analysis. The theoretical value of XO for taaffeite is 42.86% and for musgravite it is 40%. There is a clear separation of taaffeite and musgravite values with taaffeite showing the higher divalent values, and musgravite the higher totals of trivalent oxides.

Understanding the non-destructive single-crystal X-ray diffraction technique using an EDXRF instrument

Principle

This application of X-ray diffraction using an EDXRF instrument is based on the principle of Laue back-reflection. In the conventional Laue method which uses film, a 'symmetrical' image made by a group of X-rays diffracted by a crystal will be projected on the X-ray film when continuous X-rays enter the crystal which is in a fixed orientation. At this time, the lattice constants (unit cell parameters) and Miller indices of crystal lattice planes that correspond to each spot projected on the film cannot be estimated by collating information only from symmetry of the sample. In our method, this limitation or functional restriction of the Laue method can be dealt with by examining the energy dispersive X-ray spectrum of the sample. If orientation of a known sample crystal with known unit cell dimensions and space group can be precisely set, a relation between the crystal lattice planes and emitted X-rays that result from optimum diffraction conditions can be estimated by calculation.

In an EDXRF spectrum of a crystalline sample, diffracted X-rays originating from lattice planes of the crystal will be detected as well as characteristic X-rays resulting from its chemical constituents. The energy distribution of the diffracted X-ray peaks is not constant because they vary according to the orientation of the crystal. To determine whether any peaks in an X-ray fluorescence spectrum can be attributed to diffraction, several spectra obtained from random settings of the crystal should be compared. After removing the peaks that have common energy values and relative intensity ratios in the spectra, i.e. the peaks of the characteristic X-rays, any remaining peaks with different energy values and intensities are a result of diffraction by the crystal structure. Although both taaffeite and musgravite are optically uniaxial and have hexagonal lattices, they have different unit cell dimensions and different symmetries (hexagonal and trigonal) resulting from different space groups and crystal structures. In this study, we exploit the differences in spectra of diffracted X-rays from the crystal lattice planes, which result from the two minerals even though they are in the same crystallographic orientation, in order to distinguish between them. The quickest and most effective method is to compare the diffraction peaks of the $\{h0\bar{h}l\}$ $\{0k\bar{k}l\}$ lattice planes (see 'Analysis process' below and *Figure 9a,b*).

Firstly, assuming that the orientation of the stone is with its *c*-axis parallel to the X-ray beam and that the incident X-rays can be directed parallel to the *c*-axis, the position of diffraction peaks in the energy dispersive spectrum can be calculated. In the crystal systems of taaffeite and musgravite, the lattice constants and space groups are as follows:

Taaffeite:
a=5.684Å c=18.332Å space group: $P6_3mc$

Musgravite:
a=5.675 Å c=41.096 Å space group: $R\bar{3}m$

The spacing of lattice planes in hexagonal lattices can be calculated by the following formula using the Miller index (hkil) and appropriate lattice constants a and c:

Materials and methods

Figure 5: Nine taaffeites and three musgravites from Sri Lanka display a range of colours, with red, purple, violet, grey and black taaffeite on the left side (top, 0.20–0.64 ct, bottom, 0.74-2.83 ct), and purple, grey and black musgravite (a smaller colour range) on the right (0.34–4.50 ct). Courtesy of Magical Stone Lab; Photos by Masaaki Kobayashi.

To identify taaffeite and musgravite and to understand the new non-destructive X-ray diffraction analysis technique, a total of 85 faceted gems have been examined in this study. They were supplied by a merchant from the Magical Stone Lab, Tokyo, Japan, who informed us that these stones were purchased in Sri Lanka, but that their source(s) were unknown. The range of weights of the stones is 0.20 to 4.50 ct; the colour of the taaffeites ranges from red, dark red, purplish red, purple, intense or dark purplish violet, and dark greyish violet to dark grey, and in musgravite the colours are purple grey, greyish violet, bluish grey, greyish green, brownish grey and black (see *Figure 5*). The refractive indices of all samples were checked and then they were examined to obtain their compositions using EDXRF, their Raman spectra and finally their structure using destructive X-ray powder diffraction techniques. Only 11 of the 85 stones were musgravite.

To obtain diffracted X-rays that meet the diffraction conditions of certain lattice planes of taaffeite and musgravite, a new goniometric sample stage was developed and fitted to a JEOL EDXRF spectrometer JSX-3600 (see *Figure 6*). From the stones investigated, one representative sample of taaffeite (T-001) and one musgravite (M-10) were selected to explain how this new non-destructive single-crystal X-ray diffraction technique is used. For X-ray diffraction analysis, polychromatic white X-rays of molybdenum (Mo) wavelength 0.07 nm were used; the beam passed through a 100 μm φ collimator, 30 kV voltage was applied for acceleration, and 200–300 second periods were set for data collection. All X-ray fluorescence lines and numbers of Laue back-reflection peaks were detected in air and under vacuum at ~ 0.01 Pascal.

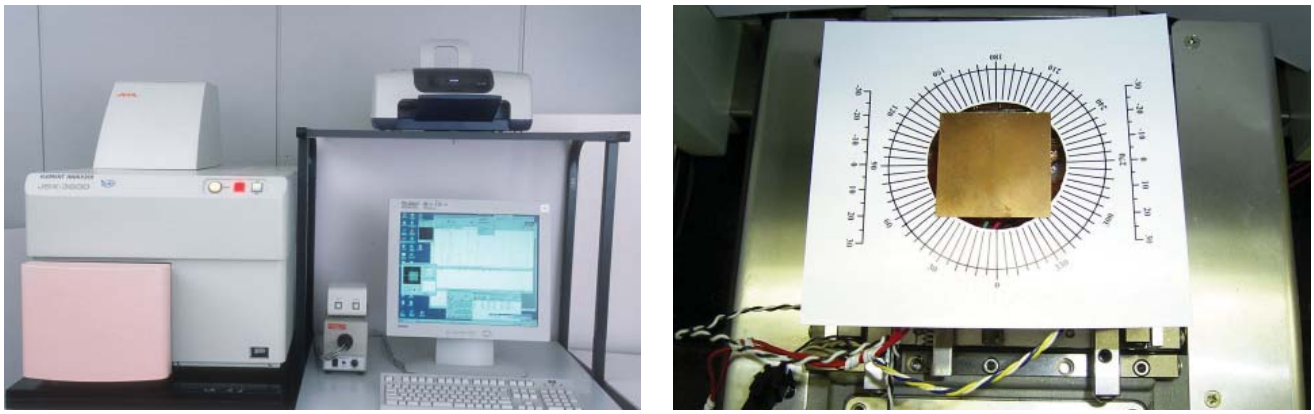

Figure 6: A JEOL energy dispersive X-ray fluorescence (EDXRF) spectrometer JSX-3600 used in this study is shown on the left. On the right is a close-up view of the newly developed goniometric sample stage for attachment to an EDXRF JSX-3600. A rotating stage with rotation angle (ω) is mounted on the X-Y scanning stage, and a tilting stage with tilting angle (τ) is placed on the rotation stage. The tilting stage can be inclined ± 20°. Each stage is labelled with a graduated scale underneath and is powered by a stepping motor. Photo by Masaaki Kobayashi (left) and A. Abduriyim (right).

Identification of taaffeite and musgravite

$$\frac{1}{d_{hkil}^2} = \left(\frac{4}{3} \times \frac{h^2+hk+k^2}{a^2}\right) + \frac{l^2}{c^2} \qquad (1)$$

where d is the distance in Å between adjacent (hkil) planes. The wavelength of the X-rays that meet the diffraction conditions can be found by Bragg's law:

$$n\lambda = 2d_{hkil} \sin\theta \qquad (2)$$

where λ is the wavelength of the X-rays, and θ is the Bragg angle. From the angular relationship between the incident X-rays and the fixed detector in the EDXRF instrument (45°, see *Figure 7*), the possibilities of obtaining diffracted X-rays are limited to a Bragg angle of:

$$\theta \approx (180°-45°)/2=67.5° \qquad (3)$$

The energy values of diffracted X-ray peaks that are expected to be seen in an EDXRF spectrum can be directly obtained from the X-ray wavelength. The values of energy and wavelength are in inverse proportion and can be estimated roughly from the following formula:

$$E(eV) \approx 12.4/\lambda\ (Å) \qquad (4)$$

The energy range of X-rays used in data verification in this study was set under 16 keV. This is because the characteristic X-rays of Mo that are used as the anticathode for X-ray generation lie in the range over 16 keV in our EDXRF instrument. The diffracted X-ray peaks produced in this energy range overlap the characteristic X-ray spectrum of Mo and make their verification more difficult.

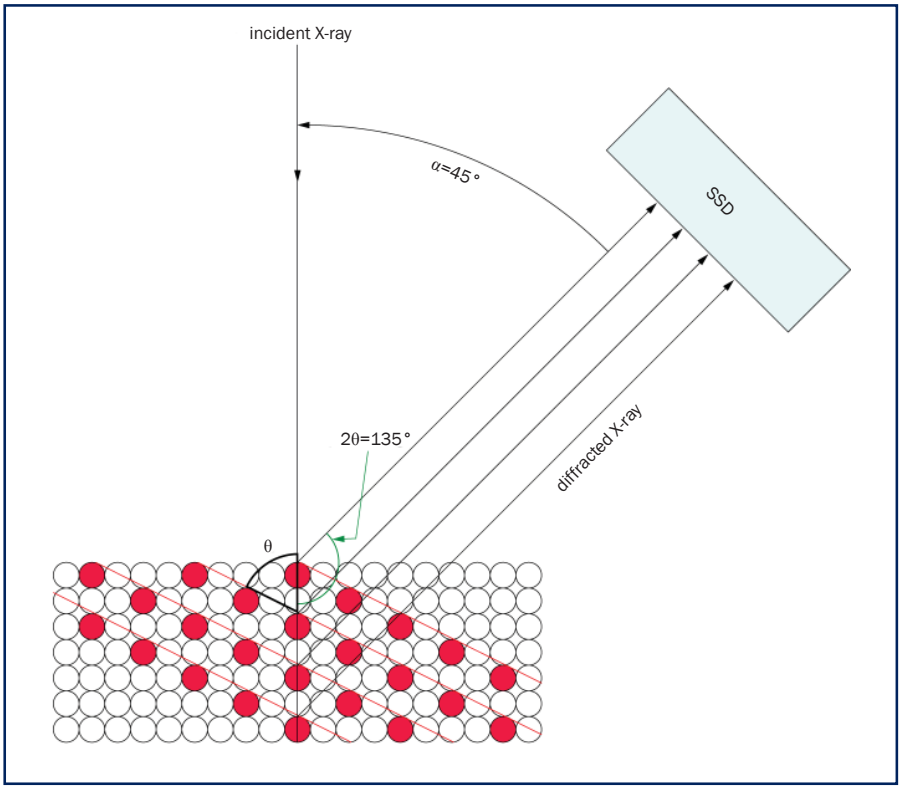

*Figure 7: The schematic diagram shows the angular relationship of the incident X-rays and the detector in our instrument, and the X-ray diffraction effect. Atomic planes of a crystal cause an incident beam of X-rays (if its wavelength is approximately the magnitude of the interatomic distance) to interfere with one another as they leave the crystal. At certain angles the X-rays diffracted from a set of planes are in phase, complementing each other and producing peaks of intensity on film or recorder. Diffraction occurs when Bragg's law is satisfied; this is calculated as 2d sinθ=nλ, where **d** is the distance between the planes in the atomic lattice, **θ** is the angle between the incident X-ray beam and the atom planes, **λ** is the wavelength of the X-rays, and **n** is an integer. The atom positions coloured red lie in planes which generate the diffracted X-rays. The angle 2θ is the angle between the primary (transmitted) X-ray beam and the diffracted beam; the angle α is the angle between the incident X-ray beam and the fixed detector, and is 180°-2θ.*

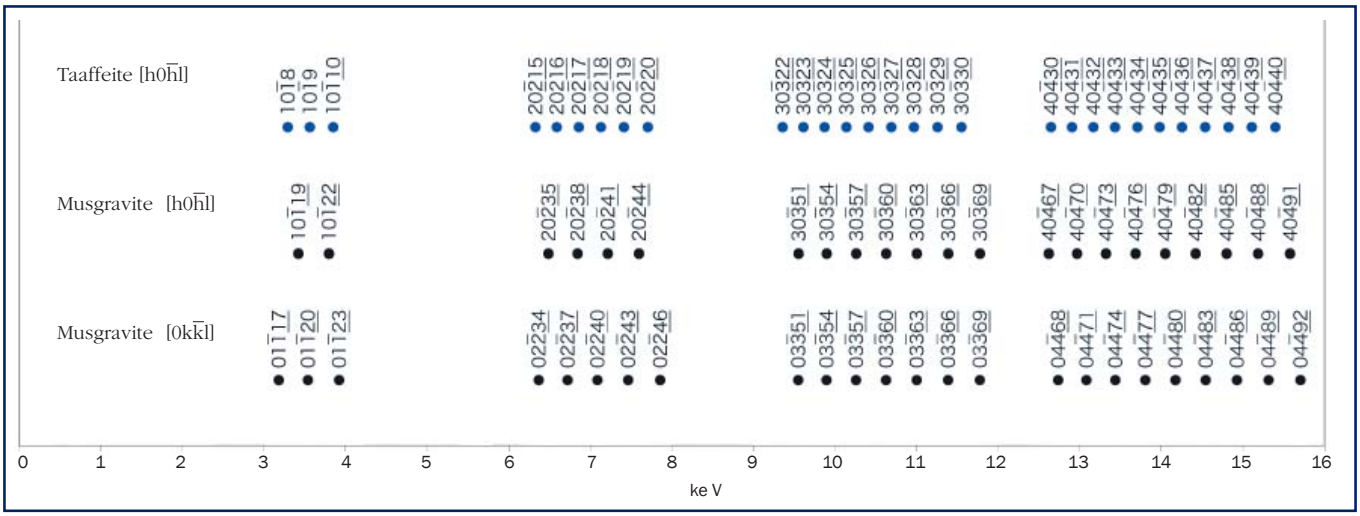

Figure 8: The energy values of peaks attributable to diffracted rather than fluorescent X-rays in an EDXRF spectrum when continuous X-rays are directed parallel to the c-axis of taaffeite and musgravite. The calculations from formulae (1) to (4) indicated that in both crystals, their diffraction spectra almost overlap in the energy ranges 3~4, 6.5~8, 9.5~11 and 12~14 keV. The peaks {h0$\bar{h}$ l} and {0k$\bar{k}$l} for musgravite are different, but for taaffeite they are the same. Estimation of the Miller index of a diffraction peak is only possible when orientation of the crystal is accurately set on the sample stage of the instrument.

Identification of taaffeite and musgravite

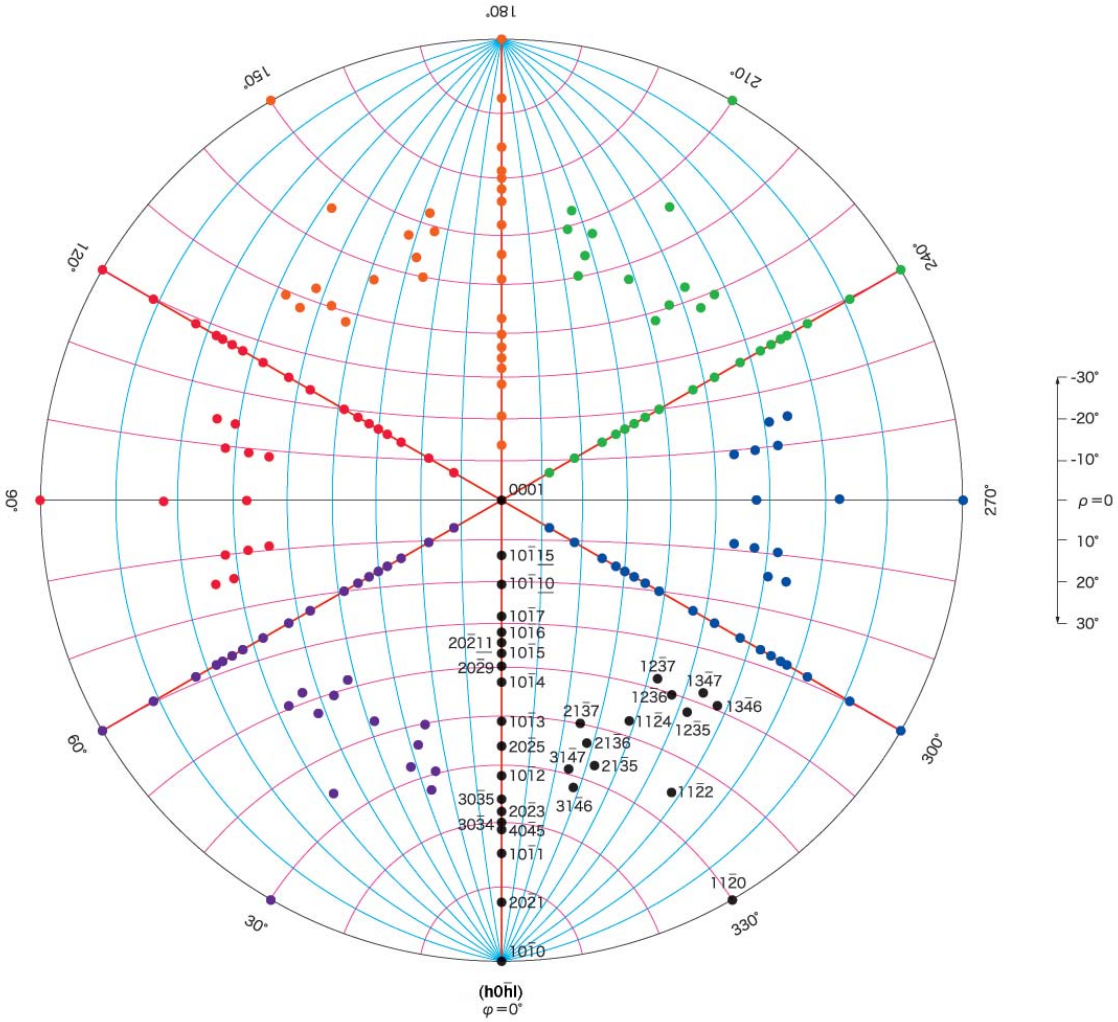

Figure 9a: The (0001) lattice plane standard pole of hexagonal taaffeite is indicated on a Wulff stereographic projection net. The Miller indices of taaffeite are labelled in black when the stage is set at ω=0°; on rotation each 60°, the Miller indices are labelled in the sequence violet, red, orange, green and blue.

The calculations from (1) to (4) above have shown that the energy ranges of both taaffeite and musgravite in which diffraction spectra will appear almost overlap in the regions 3~4, 6.5~8, 9.5~11 and 12~14 keV *(Figure 8)*. This is because both minerals have very similar values of the lattice constant a. In addition, their values of c are relatively large (although quite different) compared to common minerals. Therefore, the diffraction spectrum distribution of each mineral will be seen as a group of small peaks in a limited energy range, and this causes trouble in estimating a Miller index of the diffraction peaks. It is important to ensure that a crystal or stone is orientated precisely on the sample stage, or estimation of the Miller index of the diffraction peaks will be impossible.

The space group of taaffeite allows diffracted X-rays to be generated from lattice planes {h0$\bar{h}$l} and {0k$\bar{k}$l} under any conditions because the extinction rule does not apply. In contrast, the extinction rule does apply to musgravite and diffracted X-rays can be generated only when conditions –h+1=3n or k+1=3n are satisfied in lattice planes {h0$\bar{k}$l} and {0k$\bar{h}$l}. As a result, crystal lattice planes that have the spacing between {h0$\bar{h}$l} and {0k$\bar{k}$l} suitable for diffraction appear every 60° during rotation round the *c*-axis in taaffeite, while they only appear every 120° in musgravite. In other words, the {h0$\bar{h}$l} and {0k$\bar{k}$l} patterns are identical for taaffeite but different for musgravite. This is the most important feature to distinguish these two minerals.

Since the position of an incident X-ray beam, a sample face and an X-ray detector is almost fixed in a basic commercial EDXRF, it is most unlikely that a crystal at the X-ray irradiation spot will be in optimum orientation for diffraction. To prepare for this study, one author (A.A.) consulted a former study (Shimobayashi and Kitamura, 1998, 1999a,b and 2002), and improved our EDXRF JSX-3600 instrument by fitting a special stage to enable precise orientation of a crystal and obtain Miller indices. This special sample stage is placed on the X-Y movement stage on which a sample can be rotated through 360° about an axis parallel to the incident X-ray beam (ω-stage), and allows an inclination of up to 20°

Identification of taaffeite and musgravite

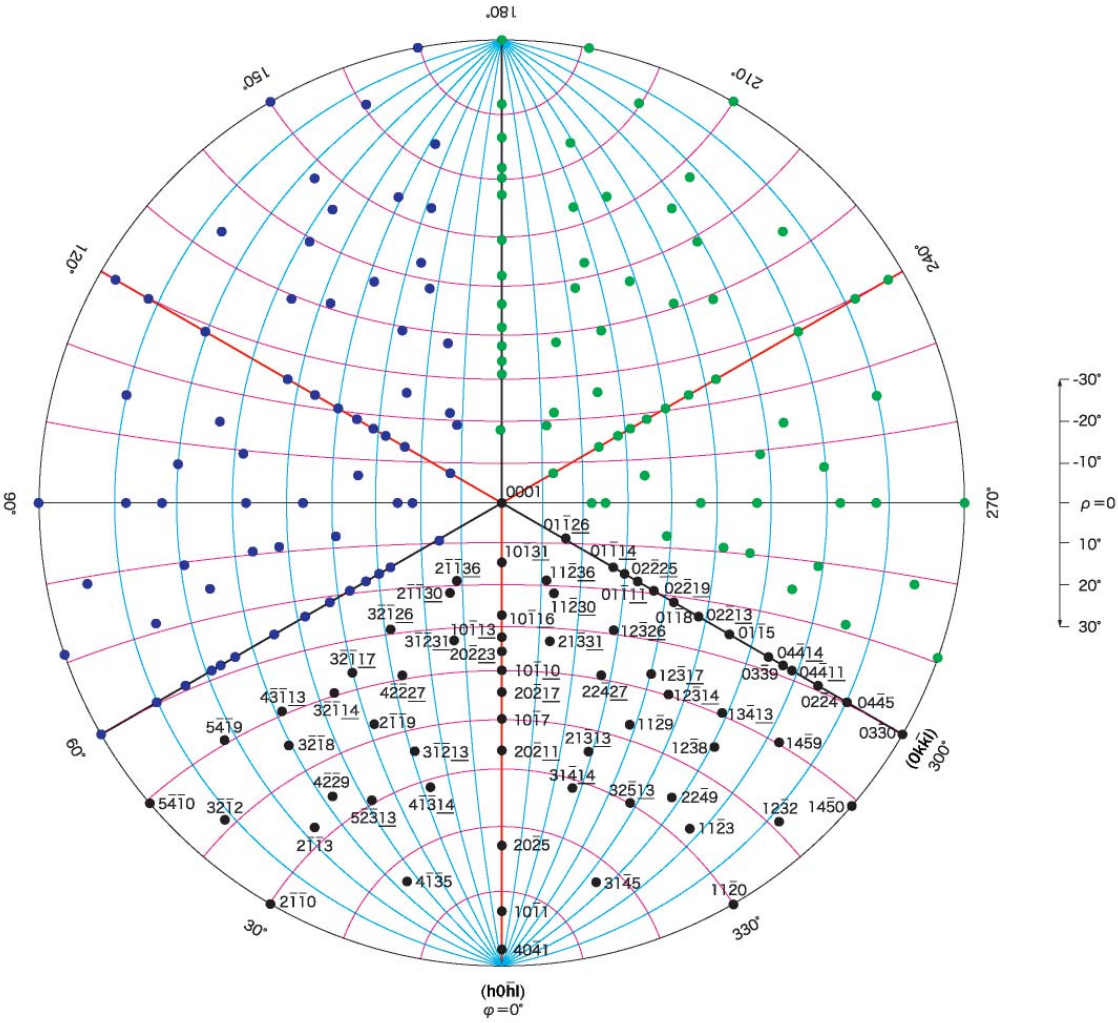

Figure 9b: The (0001) lattice plane standard pole of trigonal musgravite is indicated on a Wulff stereographic projection net. The Miller indices of musgravite are labelled black at 0° and on rotation, blue at 120° and green at 240°. φ is the rotation angle on the Wulff net; ρ is the tilting angle to the X-axis of the scanning stage.

(τ-stage). Each of these two sophisticated stages is powered by a motor, and the measurement and operation are done by a controller (see again *Figure 6b*).

Analysis process

1. The taaffeite or musgravite under investigation should be set with its optic axis, or *c*-axis, perpendicular to the sample stage of the EDXRF instrument, so that continuous X-rays can travel along the *c*-axis direction. The optic axis can be found by rotation of the stone between crossed polarizing filters with a converging lens until an interference figure of concentric rings with a black cross isogyre is found.
2. A convenient way to find the crystal orientation of taaffeite and musgravite is to plot the Miller indices of lattice planes in each crystal on a Wulff stereographic projection net *(Figure 9a,b)*. The sample rotation stage (ω-stage) is placed to correspond to the φ-axis of the Wulff net, and the tilting stage (τ-stage) is set to the ρ-axis. (φ is the rotation angle on a large circle; ρ is the interfacial angle (h0h̄l) ∧(0001)). Miller indices of taaffeite are recorded in black at ω=0° on the stage, in pink at 60°, red at 120°, yellow at 180°, green at 240° and blue at 300°. For the Miller indices of musgravite, each is set up at 120° intervals and marked with black, blue or green. Then, measurements are taken with a constant setting ρ=0° on the Wulff net and a variable φ (this means that the sample is rotated without being tilted). Throughout this spectrum measurement, confirm that the diffraction spectra are within the energy range that has been calculated (see above). Set the angle at which that spectrum appears at 0 degree, and measure the spectra after every 60° rotation of the sample stage, then the spectra can be observed as a group of diffraction peaks in the same energy range. These are the diffracted X-ray spectra of the crystal lattice planes with Miller indices {h0h̄l} and {0kk̄l}.

Results

The oval mixed-cut violet sample T-001 and greyish violet M-10 were each

Identification of taaffeite and musgravite

Figure 10: The taaffeite T-001 of 1.72 ct on the left, and musgravite M-10 of 0.65 ct on the right, were analysed by EDXRF JSX-3600 for this study. Photos by Masaaki Kobayashi.

set on the goniometric sample stage without any coating preparation *(Figure 10)*. The optic axis of each stone was identified and set parallel to the direction of the incident X-ray beam. The surface of each stone was placed at the standard working distance (WD) of 1 mm from the bottom of X-ray beam window. The sample stage is then rotated from ω=0° to 360° gradually without any tilting (τ= 0°), and the diffracted X-ray spectra of the crystal lattice plane obtained as shown below.

In each diffraction spectrum of taaffeite at the successive setting angles of ω=0°, 60°, 120°, 180°, 240° and 300°, each pattern of diffraction peaks (h0$\bar{h}$l) and (0k$\bar{k}$l) occurs at an almost identical energy position *(Figure 11)*. This indicates that taaffeite possesses six-fold (hexagonal) symmetry about its *c*-axis.

On the other hand, the peak positions in the diffraction spectra of musgravite showed a slight difference between the first group of ω=0°,120° and 240° reflections and the second group of ω=60°, 180° and 300° *(Figure 12a,b)*. The results for the group ω=0°,120° and 240°, and for the group ω=60°, 180° and 300°, are detailed in the caption for *Figure 12*. These indicate that musgravite possesses three-fold (trigonal) symmetry about its *c*-axis.

From the above, it is clear that peak energy positions in the diffraction spectra of taaffeite and musgravite differ, and so, therefore, do the Miller indices of the lattice planes that cause these differences. All the Miller indices detected in this orientation lie between 20.4° and 26.4° away from the optic axis of the crystal (that is, lattice plane {0001}) (see *Figure 13a,b*).

For further verification, additional diffraction spectra of {h0$\bar{h}$l} and {0k$\bar{k}$l} were obtained from X-rays entering along a direction other than parallel to the *c*-axis, in the following way. The sample stage was tilted while the rotating stage was set at the angle at which spectra appeared in the first measurement (ω=0° and 60°). Then, X-rays entered under conditions of different tilt angles τ and spectra were measured. In other words, φ on the Wulff net was kept constant while ρ was varied, and this was continued until diffraction peaks appeared on a spectrum. When the τ-stage was tilted at about +9° several different diffraction peaks were detected in taaffeite and musgravite respectively *(Figures 14* and *15)*. When the τ-stage was tilted in the opposite way, at -9°, again different diffraction peaks were detected in taaffeite and musgravite *(Figures 16* and *17)*.

The energy positions of a series of these diffraction peaks were obtained and showed no overlap, and so the derived Miller indices were proved to indicate different lattice planes in the two minerals.

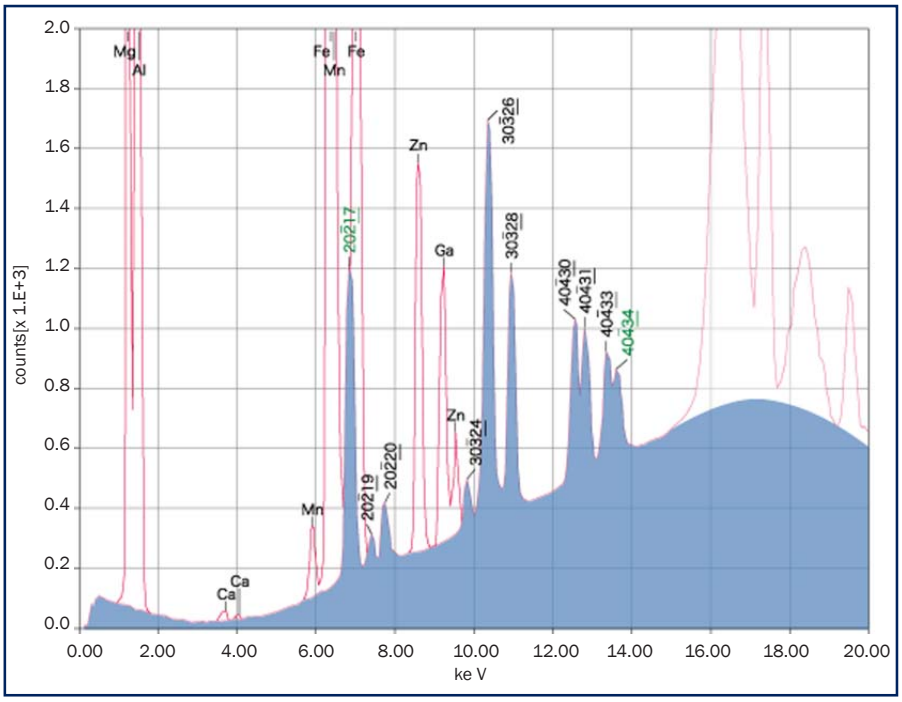

Figure 11: An energy dispersive X-ray spectrum with fluorescence peaks and diffraction peaks from lattice planes in taaffeite T-001. The diffracted X-ray peaks indicate Miller indices of (20$\bar{2}$17), (20$\bar{2}$19), (20$\bar{2}$20), (30$\bar{3}$24), (30$\bar{3}$26), (30$\bar{3}$28), (40$\bar{4}$30), (40$\bar{4}$31), (40$\bar{4}$33) and (40$\bar{4}$34) and were obtained at stage settings of ω= 0° and φ=0°. (20$\bar{2}$17) and (40$\bar{4}$34) is a doublet diffraction peak of (20$\bar{2}$17) which is indicated green.

Therefore, distinction between taaffeite and musgravite was successful using this method.

Summary

The chemical compositions of taaffeite and musgravite are very similar, and the differences in quantitative values of Be and Mg between the two are slight. Sophisticated analysis such as EPMA is required for accurate determinations. EDXRF analysis may help to separate these two minerals but the method is not sufficiently accurate for light elements, especially magnesium.

Taaffeite and musgravite also appear to have similar crystal structures but their lattice constants and space groups are different. Raman spectroscopy can be used to distinguish taaffeite from musgravite in gemmological laboratory testing, but some stones may be too fluorescent to provide useful Raman spectra. In such cases, one could resort to destructive, X-ray powder diffraction (using a few micrograms of sample from the gemstone's girdle). In this study, we have focused on this difficulty and have attempted to solve it in a non-destructive way by using a single crystal X-ray diffraction method. This exploits the differences in the crystal lattice planes between taaffeite and musgravite. While irradiating a sample with a continuous X-ray beam in a standard EDXRF instrument, both fluorescent X-rays and diffracted X-rays can be produced but since the X-ray detector is fixed in this instrument, accurate detection of diffracted X-rays from a certain lattice plane is very restricted. Therefore, our research group devised a special rotating and tilting stage to increase the detection capability and enable measurement of a range of crystal lattice planes. In this procedure, to run an effective analysis method, several processes should be confirmed during the operation. Firstly, take 2 or 3 spectra to place the *c*-axis exactly parallel to the X-ray beam. In this step, we have to rotate the sample every 2 or 3 degrees gradually within 30 degree ranges to get diffracted X-ray peaks during the analysis. Then measure the same diffraction spectra in

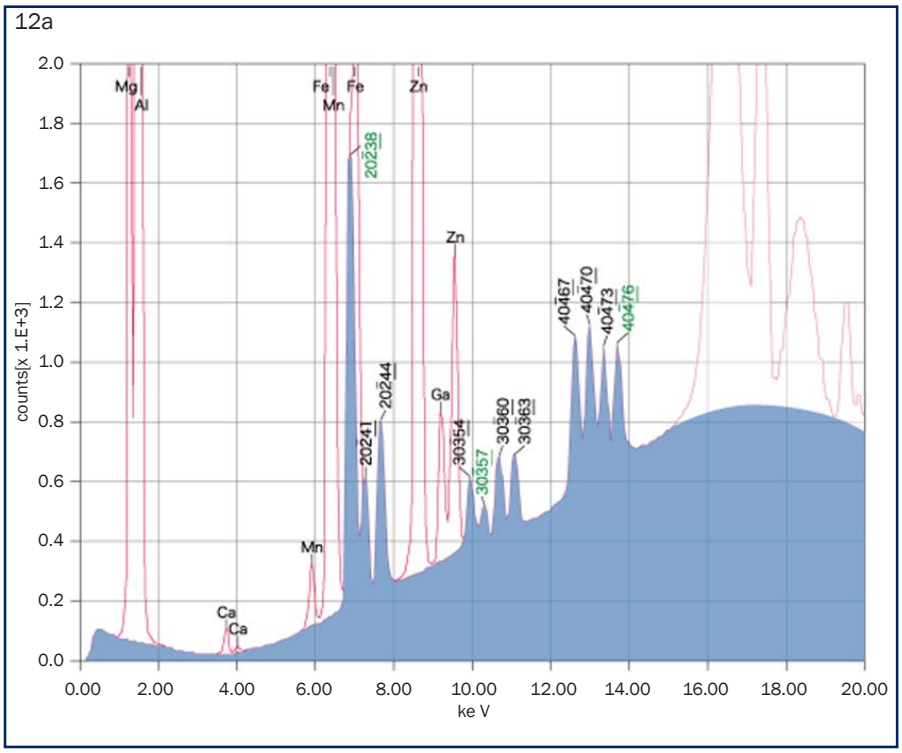

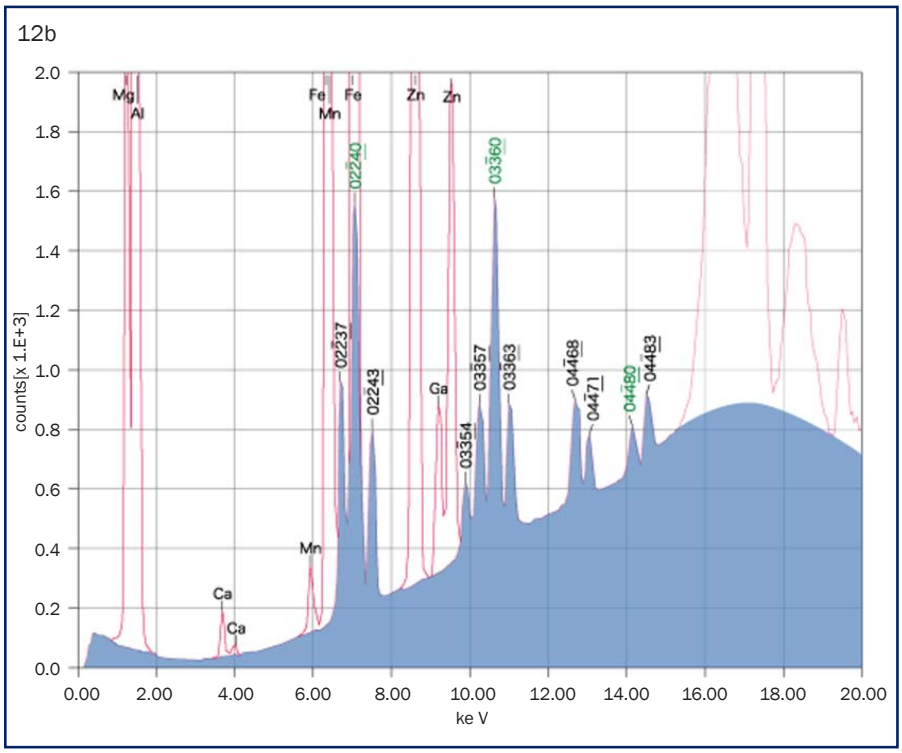

Figure 12: An energy dispersive X-ray spectrum with fluorescence peaks and diffraction peaks from lattice planes in musgravite M-10. (a) Diffraction peaks from lattice planes indicate Miller indices $(20\bar{2}\underline{38})$, $(20\bar{2}\underline{41})$, $(20\bar{2}\underline{44})$, $(30\bar{3}\underline{54})$, $(30\bar{3}\underline{57})$, $(30\bar{3}\underline{60})$, $(30\bar{3}\underline{63})$, $(40\bar{4}\underline{67})$, $(40\bar{4}\underline{70})$, $(40\bar{4}\underline{73})$ and $(40\bar{4}\underline{76})$ with stage settings of $\omega = 0°$, $\tau = 0°$. The peaks $(20\bar{2}\underline{38})$, $(30\bar{3}\underline{57})$ and $(40\bar{4}\underline{76})$ comprise the triplet diffraction peak of $(10\bar{1}\underline{19})$, and are marked in green. (b) $(02\bar{2}\underline{37})$, $(02\bar{2}\underline{40})$, $(02\bar{2}\underline{43})$, $(03\bar{3}\underline{54})$, $(03\bar{3}\underline{57})$, $(03\bar{3}\underline{60})$, $(03\bar{3}\underline{63})$, $(04\bar{4}\underline{68})$, $(04\bar{4}\underline{71})$, $(04\bar{4}\underline{80})$ and $(40\bar{4}\underline{83})$ Miller indices are detected at stage settings of $\omega = 60°$, $\tau = 0°$. The peaks $(02\bar{2}\underline{40})$, $(03\bar{3}\underline{60})$ and $(04\bar{4}\underline{80})$ comprise the triplet diffraction peak of $(01\bar{1}\underline{20})$, and are marked in green.

Identification of taaffeite and musgravite

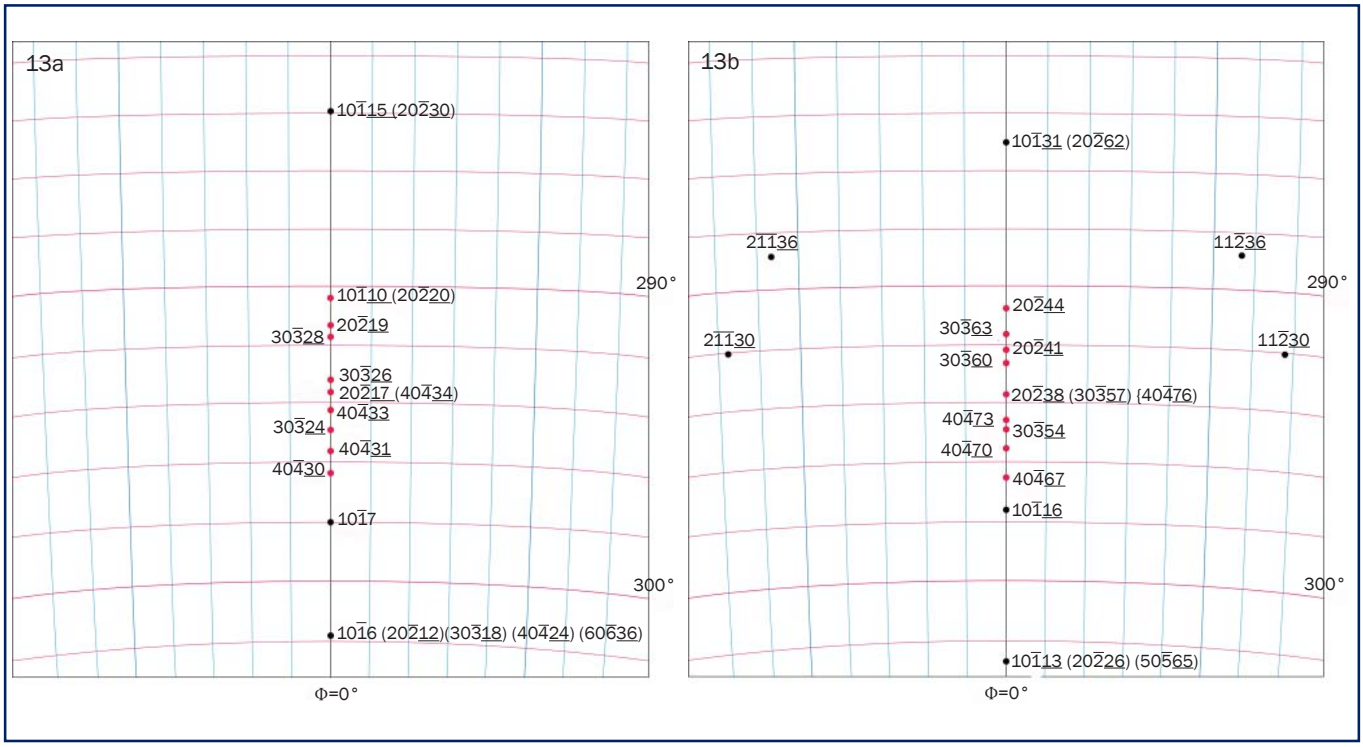

Figure 13: (a) The lattice planes with Miller indices (20$\bar{2}$17), (20$\bar{2}$19), (20$\bar{2}$20), (30$\bar{3}$24), (30$\bar{3}$26), (30$\bar{3}$28), (40$\bar{4}$30), (40$\bar{4}$31), (40$\bar{4}$33) and (40$\bar{4}$34) are indicated for taaffeite T-001 on a section of the Wulff net magnified near 290-300° in the central part of Figure 9a. (b) Miller indices (20$\bar{2}$38), (20$\bar{2}$41), (20$\bar{2}$44), (30$\bar{3}$54), (30$\bar{3}$57), (30$\bar{3}$60), (30$\bar{3}$63), (40$\bar{4}$67), (40$\bar{4}$70), (40$\bar{4}$73) and (40$\bar{4}$76) of musgravite M-10 plotted on an enlarged section of the Wulff net. The interfacial angles between these Miller indices and the standard pole [0001] indicate that φ=0° and that ρ has a range of 20.4° to 26.4°. The ρ angles just fall within the diffraction range detectable by the Si-semiconductor detector.

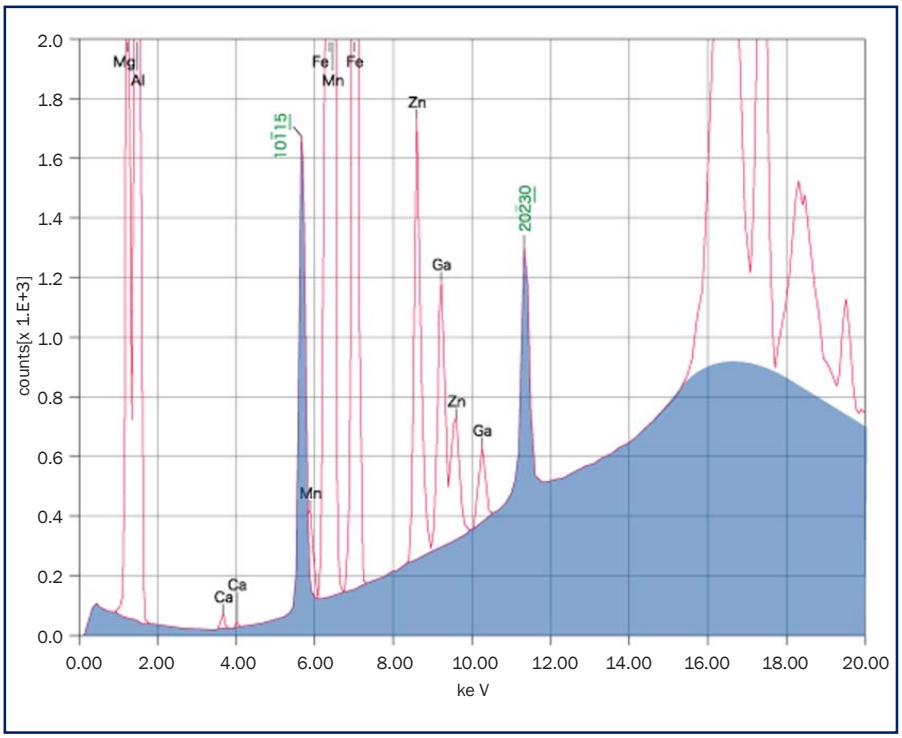

Figure 14: With the stage settings of ω= 0°, τ=+9°, the diffraction doublet peak indicating Miller indices of (10$\bar{1}$15) and (20$\bar{2}$30) of taaffeite T-001 was obtained and is marked green.

the same energy range on rotation of the sample every 60 or 120 degrees. If these diffraction peaks are initially not visible, further tilt is necessary by steps of 2 degrees and rotating again until they are. Second, set the diffraction peaks for the 0 degree position. Finally, rotate and then tilt if you want to further confirm. This process should take less than one hour. As a result, accurate distinction between taaffeite and musgravite is possible by determining their symmetry, which is 6-fold in taaffeite and 3-fold in musgravite. Most importantly for gems, the method is non-destructive.

Identification of taaffeite and musgravite

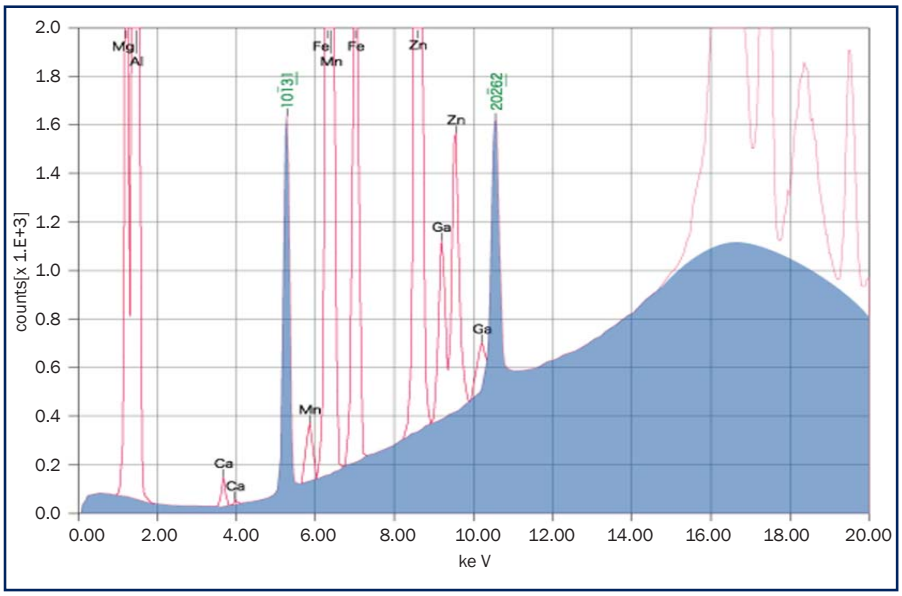

Figure 15: With musgravite at stage settings of ω= 0°, τ=+9°, the diffraction doublet peak indicating Miller indices of $(10\bar{1}31)$ and $(20\bar{2}62)$ was obtained and marked in green. These are clearly different from the taaffeite peaks shown in Figure 14.

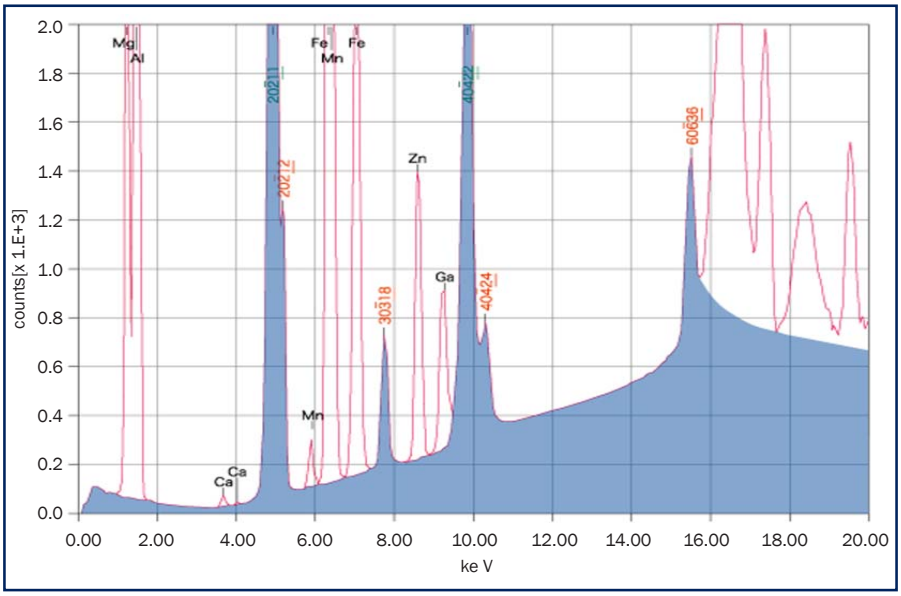

Figure 16: Diffraction X-ray peaks of taaffeite planes $(20\bar{2}11)$, $(20\bar{2}12)$, $(30\bar{3}18)$, $(40\bar{4}22)$, $(40\bar{4}24)$ and $(60\bar{6}36)$ were obtained with stage settings of ω= 0° and τ=-9°. The peaks $(20\bar{2}12)$, $(30\bar{3}18)$, $(40\bar{4}24)$ and $(60\bar{6}36)$ comprise the quadruple diffraction peak of $(10\bar{1}6)$; the peaks $(20\bar{2}11)$ and $(40\bar{4}22)$ comprise the doublet diffraction peak of $(20\bar{2}11)$.

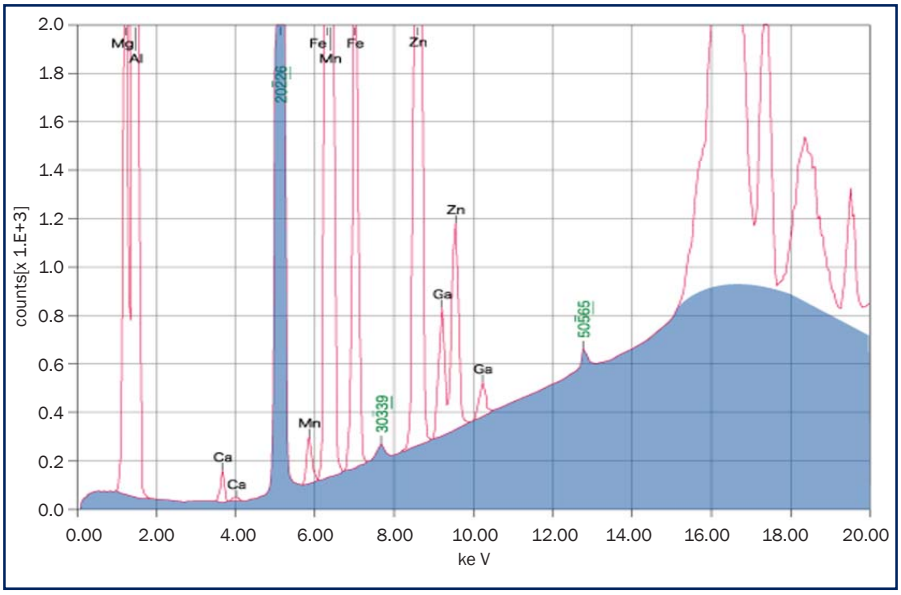

Figure 17: Diffraction X-ray peaks of musgravite planes $(20\bar{2}26)$, $(30\bar{3}39)$ and $(50\bar{5}65)$ were obtained with stage settings of ω= 0° and τ=-9°. These three peaks comprise the triplet diffraction peak of $(10\bar{1}13)$; the low intensities of $(10\bar{1}13)$ and $(40\bar{4}52)$ means that they may not be distinguishable from the peaks due to fluorescence.

Acknowledgements

The authors are grateful to Dr Norimasa Shimobayashi (Kyoto University, Kyoto) for EDXRF stage construction, technical information and sample analysis advice, all of which made this non-destructive single-crystal X-ray diffraction study possible. We are also grateful to Dr Karl Schmetzer for discussion and critical comments, which helped improve the manuscript. Special thanks are due to Midori Jewellery for providing photographs of jewellery and to our sample supplier, the Magical Stone Lab. Finally, we thank our research colleagues Hiroshi Kitawaki FGA and Makoto Okano FGA at GAAJ for assistance with this work.

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Abstracts

Diamonds

Fluorescence spectra of colored diamonds using a rapid, mobile spectrometer.

S. Eaton-Magaña, J.E. Post, P.J. Heaney, R.A. Walters, C.M. Breeding and J.E. Butler. *Gems & Gemology,* **43**(4), 2007, 332-51.

A study is reported on numerous coloured diamonds from the Aurora Butterfly of Peace and other collections, using a new type of fluorescence spectrometer whose advantages include high portability, low cost and rapid collection times; for comparison, 10 irradiated diamonds were also studied. With only two exceptions, the natural colour diamonds could be separated into three categories (on the basis of the peak wavelength and the fluorescence spectra) that generally corresponded with their body colours: 1) ~ 450 and ~ 490 nm recorded mainly for pink, yellow and fancy white diamonds, 2) ~ 525 nm mainly for green-yellow or yellow-green and brown diamonds and 3) ~ 550 nm mainly for orange, grey-green (including chameleon) and type 1a blue-grey or grey-blue diamonds. A spectrum that is anomalous for the diamond's body colour may indicate that it has been treated; in some cases fluorescence spectroscopy can help to determine diamond type. R.A.H.

An examination of the Napoleon diamond necklace.

E. Gaillou and J.E. Post. *Gems & Gemology,* **43**(4), 2007, 352-7.

The intriguing history of the Napoleon necklace given by Napoleon Bonaparte in 1811 to his empress Marie Louise involves both royals and con artists (and one individual who was both), and it was ultimately donated to the Smithsonian Institution in 1962. IR absorption analysis of 101 stones in the necklace revealed that a high proportion of the larger diamonds are the relatively rare type IIa; most of the smaller stones are type IaAB. The luminescence behaviour of these diamonds to UV exposure correlates with their diamond type. R.A.H.

Lab notes.

T.M. Moses and S.F. McClure (Eds). *Gems & Gemology,* **43**(4), 2007, 358-65.

Notes are given on a 1.84 ct bright orange spessartine with dark blue-green inclusions of apatite, a 1.01 ct cut diamond with inclusions of garnet and omphacite, a natural black diamond with oriented etch channels and a 1.80 ct diamond cut in the shape of a fish. R.A.H.

A history of diamond treatments.

T.W. Overton and J.E. Shigley. *Gems & Gemology*, **44**(1), 2008, 32-53.

Although various forms of surface coatings intended to alter the colour of diamonds have long been in use, the modern era features more permanent colour alterations through irradiation and high pressure/high temperature annealing and improvements in apparent clarity with lead-based glass filling. Modern gemmologists are faced with a broad spectrum of colour and clarity treatments ranging from the simple to the highly sophisticated, and from the easily detected to the highly elusive. The history, characteristics and identification of known diamond treatments are reviewed. R.A.H.

Natural-color purple diamonds from Siberia.

S.V. Titkov, J.E. Shigley, C.M. Breeding, R.M. Mineeva, N.G. Zudin and A.M. Sergeev. *Gems & Gemology*, **44**(1), 2008, 56-64.

Twelve natural-colour purplish-pink to grey-purple diamond crystals from the Mir kimberlite field, Siberia, and seven round brilliants faceted from these crystals, were studied visually and by using UV-Vis-NIR, IR and photoluminescence spectroscopy. Aspects of their colour and the various structural defects in these purple diamonds are due to their post-growth plastic deformation in the earth. All the samples exhibited prominent parallel planar lamellae along which the purple colour is concentrated. R.A.H.

Natural type Ia diamond with green-yellow color due to Ni-related defects.

W. Wang, M. Hall and C.M. Breeding. *Gems & Gemology,* **43**(3), 2007, 240-3.

Commonly seen in HPHT-grown synthetic diamonds with a green component, Ni-related defects have now been found in a type Ia natural diamond with a strong green component. The 1.75 ct fancy green-yellow diamond shows a strong peak at 1332 cm^{-1} in the IR absorption spectrum, strong absorption from the 1.40 eV centre and the associated ~ 685 nm band in the Vis-NIR spectrum and very strong emissions from Ni-related defects in the photoluminescence spectra – all of which indicate that nickel is the primary cause of the green colour. R.A.H.

[Morphology of diamonds from kimberlite pipes of Catoca field (Angola).]

V.N. Zinohenko. *Proceedings of the Russian Mineralogical Society,* **136**(6), 2007, 91-102. (Russian with English abstract.)

The morphology of more than 3200 diamond crystals from kimberlite pipes of the Catoca field in the Lunda diamond-bearing province of NE Angola, has been studied in detail, Diamond crystals from different pipes in this field have distinguishing peculiarities in their morphology and in their physical-

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mineralogical properties. Octahedral forms predominate in crystals from the Catoca and Kamitogo pipes, which are considered to be indicative of conditions more favourable for diamond growth and preservation, in comparison with diamonds from the Kakele pipe, where rhombododecahedra are the commonest forms. These morphological and other mineralogical peculiarities of diamond crystals may be used to appraise the diamond-bearing potential of their primary source in NE Angola. R.A.H.

***European Journal of Mineralogy*, 20(3), 2008.**

This special issue devoted entirely to diamonds is in honour of Vladimir S. Sobolev who first suggested that diamonds might be found in the rocks of the northern Siberian platform. He followed this up with the use of indicator minerals such as Cr-rich pyrope to locate kimberlite which led to the discovery of the famous Mir pipe and to several hundred kimberlite pipes in Yakutia. Nikolai V. Sobolev is the eldest son of V.S. Sobolev. The issue contains a total of ten papers, five of which are abstracted below.

Nanometre-sized mineral and fluid inclusions in cloudy Siberian diamonds: new insights on diamond formation.

A.M. Logvinova, R. Wirth, E.N. Fedorova and N.V. Sobolev. *European Journal of Mineralogy*, **20**(3), 2008, 317-31.

Nm-sized isolated inclusions have been studied in four cloudy octahedral diamonds from the internationalnaya and one for the Yubileynaya mines, Yakutia. TEM, AEM, EELS and HREM were applied as well as line scan and elemental mapping of the samples. All the crystals exhibit an octahedral habit with opaque central cuboid cores with numerous nano-inclusions (between 30 and 800 nm). They are composed of multi-phase assemblages which include silicates, oxides, carbonates, brines (KCl) and fluid bubbles. Distinguishable crystalline phases include: a crystalline high-Mg silicate, dolomite, Ba-Sr carbonate, phlogopite, ilmenite, ferropericlase, apatite, magnetite, K-Fe sulphides (djerfisherite ?) and kyanite. Carbonates were identified in TEM foils from all the diamonds, studied, and show a general enrichment in incompatible elements such as Sr and Ba. Some elemental variations may be explained by fractional crystallization of fluid/melt or mixing of fluids with different compositions. R.A.H.

Diamond potential of metamorphic rocks in the Kokchetav Massif, northern Kazakhstan.

V.A. Pechnikov and F.V. Kaminsky. *European Journal of Mineralogy*, **20**(3), 2008, 395-413.

There are two known diamondiferous bodies in Kazakhstan, the Kundy-Kol deposit and the Barchi-Kol occurrence; both are located in the western part of a metamorphic belt outcropping in the centre of the Kokchetav Massif. This metamorphic belt is interpreted as a mega-mélange that comprises structural units underlain by HP and UHP rocks. Diamondiferous UHP rocks in the Hundy-Kol deposit form a narrow (~ 1 km thick) band; they comprise less than 1% of the total UHP rock volume. Garnet-biotite gneiss makes up about 80% of the diamondiferous zone. A certain regularity is discernible in the spatial distribution of the diamonds, linear diamond-rich zones alternate with barren ones. The diamond grade ranges from several carats per ton (cpt) to several hundreds of cpt. Different morphological varieties of diamonds include octahedral, cubes, cubo-octahedral forms, skeletal and spheroidal crystals. A wide range of $\delta^{13}C$ (–8.9 to –27 ‰) and $\delta^{15}N$(+5.3 to +25 ‰ values have been measured. Diamonds from different rock types differ in their isotopic patterns: those from gneiss have 'lighter' isotopic compositions relative to those of pyroxene-carbonate and garnet-pyroxene rocks. Graphite, coesite, clinopyroxene, rutile, titanite, kyanite, K-feldspar, biotite, phengite, phlogopite, quartz, albite, apatite, chlorite and carbonates are minerals forming intergrowths with diamonds; the most frequent being graphite + diamond. It is concluded that a model of crustal fluid-metasomatic formation of diamonds in metamorphic rocks best reflects the observations. This model presumes that the formative process occurred at relatively low temperature and pressure within an open disequilibrium catalytic system; it does not exclude an UHP episode in the geological history of the metamorphic rocks. R.A.H.

Monitoring diamond crystal growth, a combined experimental and SIMS study.

V.N. Reutsky, B. Harte, Y.M. Borzdov and Y.N. Palyanov. *European Journal of Mineralogy,* **20**(3), 2008, 365-74.

Detailed ion microprobe measurements were made on two synthetic diamond crystals grown by the metal catalyst technique under identical *P-T* conditions of 1450°C and 5.5 GPa, but with different source nitrogen abundances. Measurements of the C and N isotope compositions and nitrogen abundances were made in traverses across the crystal sectors, which included cubic and octahedral sectors of both relatively rapid and relatively slow growth. In both crystals an early growth phase dominated by falling $\delta^{13}C$ and rising N is followed by an extensive growth phase with moderately constant $\delta^{13}C$ and gradually descending N. This change in $\delta^{13}C$ has been modelled numerically; the stabilization is achieved once a steady state is attained and diamond grows with the same $\delta^{13}C$ composition as the graphite source. The decreasing N values appear to be a product of Rayleigh fractionation. The nitrogen isotope compositions show major differences of ~ 30 ‰ between octahedral and cubic sectors, possibly representing a consistent difference in N isotope adhesion between the two faces. R.A.H.

Olivine inclusions in Siberian diamonds: high-precision approach to minor elements.

N.V. Sobolev, A.M. Logvinova, D.A. Zedgenizov, N.P. Pokhilenko, D.V. Kuzmin and A.V. Sobolev. *European Journal of Mineralogy*, **20**(3), 2008, 305-15.

At depths in the continental lithospheric mantle exceeding 120–150

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km there are two types of geological environment which support diamond formation. They are ultramafic or peridotitic (U-type) and eclogitic (E-type) environments, as shown by minerals found as inclusions in diamonds and which make up xenoliths of diamondiferous peridotites and eclogites in kimberlites. In primary diamond-bearing kimberlite and lamproite rocks the ratio of diamonds from these two geological environments varies widely between localities. U-type diamonds predominate, however, in the great majority of diamond occurrences worldwide. Olivine is the most typical inclusion in U-type diamonds, along with enstatite, pyrope and chromite in harzburgitic or dunitic assemblages. More than 260 olivine inclusions from major Siberian mines were studied and compared with olivine from diamonds of the Snap Lake dyke system in Canada. Olivine composition in eight xenoliths of diamondiferous peridotites from Udachnaya pipe representing the rarest mantle samples, were also re-examined. Inclusions were analysed for major and minor elements by electron microprobe to obtain high-precision and accuracy, especially for Ni, Ca, Mn, Cr, Co and Al. Minor element abundances in most of the olivines vary in the following ranges: (wt %): NiO 0.320–0.408, CaO 0.005–0.045, MnO 0.079–0.131, Cr_2O_3 0.013–0.115, Co 0.009–0.022 and Al_2O_3 0.007–0.039. About 70% of the olivines were very low in CaO, reflecting a relatively low equilibration temperature of the lherzolitic paragenesis, or lack of clinopyroxene associated with olivine. R.A.H.

Diamondiferous xenoliths from crystal subduction: garnet oxygen isotopes from the Nyurbinskaya pipe, Yakutia.

Z.V Spetsius, L.A. Taylor, J.W. Valley, M.T. Deangelis, M. Spicuzza, A.S. Ivanov and V.I. Banzeruk. *European Journal of Mineralogy,* **20**(3), 2008, 375-85.

The newly developed Nyurbinskaya kimberlite pipe in Yakutia has yielded an unprecedented array of xenoliths, each containing diamonds. Some 121 of these xenoliths were studied and garnets were separated from the different types of xenoliths, including mostly eclogites, but also some pyroxenites and peridotites. The $\delta^{18}O$ ratios of most of the peridotitic garnet samples lie within the range of the average mantle, except for one with a $\delta^{18}O$ value of 6.57 ‰. Garnets from pyroxenites (websterites) in general have $\delta^{18}O$ values above 6.0 ‰, with two samples as high as 7.3 and 8.50, and only two samples as low as 5.9 and 6.0 ‰. Eclogitic garnets have a $\delta^{18}O$ range of 4.7 to 9.7 ‰, with > 80% about 6 ‰. These new garnet oxygen-isotope ratios are not only evidence for subduction of oceanic crust, but also evidence for a major involvement of the upper, low-temperature metasomatized portion of the crustal section. R.A.H.

Gems and Minerals

The Minh Tien tourmaline mine, Luc Yen mining district, Yenbai Province, Vietnam.

D. Blauwet. *Mineralogical record,* **38**, 2007, 443-52.

Account of a visit to the Minh Tien mine in Yenbai Province, Vietnam. The recovery of specimen-quality tourmaline crystals is described. M.O'D.

A study of nail-head spicule inclusions in natural gemstones.

G. Choudhary and C. Golecha. *Gems & Gemology,* **43**(3), 2007, 228-35.

Nail-head spicules are inclusions that have traditionally been associated with hydrothermal synthetic quartz and emerald. They are caused primarily by rapid growth conditions and disturbances during crystallization of their host. These or similar-looking inclusions, however, have also been found in natural emerald and sapphire. A yellow sapphire, spinel, diamond and quartz have also been found with inclusions that strongly resemble them. Nail-head spicules remain a notable feature of rapid and disturbed growth, but their presence does not confirm a stone's natural or synthetic origin without further examination. R.A.H.

Mineralogical and geochemical characterization of the 'bituminous' agates from Nowy Kościół (Lower Silesia, Poland).

M. Dumanska-Slowik, L. Natkaniec-Nowak, M.J. Kotarba, M. Sikorska, J.A. Rzymelka, A. Loboda and A. Gawel. *Neues Jahrbuch für Mineralogie Abhandlungen,* **184**(3), 2008, 255-68.

The agates from Nowy Kościół, Lower Silesia, exhibit mainly horizontally stratified structures often developed as typical multiradial stars. These agates are mainly spherical with diameters of 2 to 40–70 cm; most are brownish red, 'honey-black' or red. The dark colour of their banding is mainly caused by Fe-compounds, REE-bearing minerals, Zn sulphides and organic matter. The content of organic matter is relatively low (0.15 wt %) but is dispersed within the silica matrix. It forms thin laminae or irregularly shaped drops or lenses. Asphaltenes are the dominant bitumen (56 %), with the remainder varying between 10 % aromatic hydrocarbons, 16 % resins and 18 % saturated hydrocarbons. Stable carbon isotope ($\delta^{13}C$) analysis (saturated hydrocarbons -28.9 ‰, aromatic hydrocarbons -28.3 ‰, resins -28.6 ‰, asphaltenes -28.3 ‰, whole organic matter -25.9 ‰) revealed its algal or mixed algal/humic origin. R.A.H.

Copper-bearing tourmalines from new deposits in Paraíba State, Brazil.

M. Furuya. *Gems & Gemology,* **43**(3), 2007, 236-9.

Two newly discovered pegmatites with Cu-bearing tourmaline are described, not far from the original locality of Mina da Batalha. The Glorious mine has produced a limited amount of gem-quality material with a composition similar to the blue tourmaline from the Mina da Batalha, but the second mine has not yet produced any gem-quality tourmaline. Violet material from the Glorious mine becomes blue on heat treatment, producing faceted stones of 0.15–0.34 ct. R.A.H.

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Amethystfund aus dem Zemplen-Gebirge.

D. Grolit. *Mineralien Welt,* **29**(1), 2008, 55-61.

Amethyst of possible ornamental quality is described from Zemplén, Hungary, where it has been found with clinoptilolite. M.O'D.

Perlenzucht mit Pinctada maxima in Süost-Asien – ein Beispiel.

H.A. Hänni. *Gemmologie. Z. Dt. Gemmol. Ges.,* **56**(3/4), 2007, 83-96. 13 photographs, bibl. (German with English abstract.)

This is an update on modern farming methods used in south east Asia, mainly in north Bali and West Papua, under the supervision of marine biologists and geneticists from the James Cook University. Culturing oysters from fertilized eggs has replaced wild oyster collection. The larvae and spat are developed in hatcheries under scientifically controlled conditions. It takes two years for the oyster to grow to about 12 cm and be ready for the operation. Donor oysters for tissue graft and host oysters are carefully controlled with regular cleaning and X-ray checks. The first harvesting begins when the oyster is four years old. Most of the oysters are not re-seeded; their muscles are processed as seafood and the shells used as nacre. The pearls are processed, quality graded and marketed in Australia. E.S.

Gemmologische Kurzinformationen. Imitation für Feuerachat.

U. Henn. *Gemmologie. Z. Dt. Gemmol. Ges.,* **56**(3/4), 2007, 127-9, 5 photographs. (German with English abstract.)

A fire agate necklace offered in the trade was shown to be agate with thermally induced fractures. Milky-white zones were found alongside these fractures due to dehydration. The typical botryoidal structure of fire agate was also missing. E.S.

Gem news international.

B.M. Laurs (Ed.). *Gems & Gemology,* **43**(3), 2007, 252-74.

News is given of the development of a large diamond mine in the Fort a Corne kimberlite field some 60 km E of Prince Albert, Saskatchewan; exploration drilling and processing has already led to the recovery of 10,251 diamond crystals (~ 1270 ct) from 40,000 tonnes of kimberlite. Other items include an unusual colour-zoned axinite from Pakistan, with distinctly more Ti and Mn in the blue zone than in the light brown zone, Cr-V-bearing kyanite from Madagascar (with La-ICP-MS analyses of trace elements in kyanite from four countries) and a Cr-V-bearing light yellow-green spodumene from Afghanistan. R.A.H.

Gem news international.

B.M. Laurs. Lab notes. *Gems & Gemology,* **43**(4), 2007, 366-91.

Items mentioned include the soaring prices obtained at auction for coloured diamonds or flawless colourless cut diamonds, the marine diamond deposits in Namibia, magnesioaxinite and ferro-axinite from Tanzania (EPMA results given), yellow-green clinohumite and yellow chondrodite from Tanzania (with EPMA), sinhalites (1.35–3.20 ct) from Mogok, Myanmar, variously coloured Cu-bearing tourmalines from Mozambique and Nigeria, and new Russian synthetic beryl simulating 'Paraíba' Cu-bearing tourmaline. R.A.H.

Gem news international.

B.M. Laurs (Ed.). *Gems & Gemology,* **44**(1), 2008, 74-94.

Descriptions are given of an unusually large 76.27 ct cut titanite showing a vibrant display of dispersion, a 59.58 ct jeremejevite from Madagascar and an orange spessartine from Loliondo, Tanzania. Mention is made also of faceted blue afghanite and greenish-blue hauyne, both from Badakshan, Afghanistan, and a piece of light blue rough manganaxinite with MnO 6.9 wt % and with V_2O_3 ~ 0.1 wt % as the chromophore. R.A.H.

Yellow Mn-rich tourmaline from the Canary mining area, Zambia.

B.M. Laurs, W.B. Simmons, G.R. Rossman, E.A. Fritz, J.I. Koivula, B. Anckar and A. U. Falster. *Gems & Gemology,* **43**(4), 2007, 314-31.

Yellow gem-quality elbaite has been quarried in the Canary mining area of Zambia since 1993, both from pegmatites and eluvial/alluvial deposits, in colours ranging from yellow-green to yellow to orange and brown. Much of the orange-to-brown material is heated to attain a 'golden' or 'canary' yellow colour. The tourmaline is Mn-rich (up to 9.18 wt % MnO; EPMA results are given for 11 samples: ε 1.623–1.625, ω 1.645–1.649; SG 3.11–3.17) and contains traces of Ti and little or no Fe. Its distinctive composition is probably the result of the crystallization of abundant schorl from an unusual B-rich, Li-poor pegmatite magma, which depleted Fe while conserving Mn until the late-stage crystallization of gem pockets. R.A.H.

Copper-bearing (Paraíba-type) tourmaline from Mozambique.

B. Laurs, J.C. Zwaan, C.M. Breeding, W.B. Simmons, D. Beaton, K.F. Rijsdijk, R. Befi and A.U. Falster. *Gems & Gemology,* **44**(1), 2008, 4-30.

Cu-bearing tourmaline is found in alluvial pebbles beneath about 5 m of overburden, on the eastern side of the Alto Ligonha pegmatite district, Mozambique. They occur in a wide range of colours, typically pink to purple, violet to blue and blue to green or yellowish-green. Heat treatment of all but the green to yellowish-green stones produces Paraíba-like blue-to-green hues by reducing the absorption at ~ 520 nm caused by the presence of Mn^{3+}. The gemmological properties are typical of those for Cu-bearing tourmaline; the most common inclusions are partially healed fractures and elongate hollow tubes. Electron microprobe analyses are given; the stones have relatively low Cu contents and very low amounts of Fe and Ti. R.A.H.

Zirkone aus dem Reichsforst im Fichtelgebirge.

S. Meier and S. Weiss. *Lapis,* **32**(12) 2007, 20-8, 33-4.

Gem-quality transparent to translucent pink to reddish zircon is described from the Reichsforst in the Fichtelgebirge, Bavaria, Germany. M.O'D.

Abstracts (continued)

Notes from the DSEF gem lab.

C.C. Milisenda. *Gemmologie. Z. Dt. Gemmol. Ges.,* **56**(3/4), 2007, 79-82, 6 photographs.

A new Brazilian occurrence of gem-quality emeralds has been found near the town of Lages in the state of Rio Grande do Norte. Fifty specimens weighing between 0.3 and 10 ct were examined. They had standard physical properties. Mica formed the most characteristic inclusion, but there were also two- and, very rarely, three-phase inclusions. Healing cracks, hollow tubes, growth and colour zoning were observed.

A transparent faceted colourless stone with blue inclusions, purchased in Brazil, was shown to be rock crystal with gilalite inclusions. This material has been known since 2003 and comes from a deposit in Paraíba. Some yellow-green faceted stones weighing 7–10 ct had several absorption lines between 500 and 750 nm. These are typical features of Maxixe-type beryls which owe their colour to artificial irradiation. A specimen of 14.7 ct offered as scapolite cat's-eye had an RI 1.58 and SG 2.72. It showed strong dichroism and its infrared spectrum indicated it to be beryl. Its absorption spectrum showed the characteristic bands of irradiated Maxixe-type beryl. An octagonal faceted stone of 12.19 ct offered as bicoloured tourmaline had an RI 1.543-1.552, and thus was shown to be quartz. It was found to be a triplet consisting of colourless quartz and colourless beryl connected by a bicoloured green and pink adhesive binding. E.S.

Lab Notes.

T.M. Moses and S.F. McClure (Eds). *Gems & Gemology,* **43**(3), 2007, 244-51.

Items noted include an unusually large (201.18 ct) cat's-eye aquamarine, an unsuccessful attempt at diamond deception (in which an HPHT-treated diamond had been purposely cut and inscribed to match a previous GIA report of a diamond with a natural origin of colour), an intense blue 8.54 ct kyanite initially mistaken for sapphire and a large (67.94 ct) crystal of phenakite masquerading as a diamond. R.A.H.

Lab notes.

T.M. Moses and S.F. McClure (Eds). *Gems & Gemology,* **44**(1), 2008, 66-73.

Items noted include a square-cut 5.29 ct fancy brownish greenish yellow diamond which had experienced multiple growth/dissolution stages during its formation, the first CVD synthetic diamond submitted for grading, and an orange zircon which contained a melted inclusion indicating that the zircon had been subjected to an unusually high-temperature heat treatment possibly when mixed in with corundum subjected to such heat treatment. R.A.H.

Spodumenes from Nuristan, Afghanistan.

L. Natkaniec-Nowak. *Australian Gemmologist,* **23**(2), 2007, 51-7, 8 figures, 3 tables, 1 map.

Chemical analysis, Mössbauer spectroscopy and X-ray diffraction were used to investigate coloured spodumenes from the Nilaw mine. The authors found that Fe and trivalent Cr were responsible for the colour of green-yellow spodumene. A mixture of Mn, Fe and possibly Cr is thought to produce the violet-pink colour of kunzite. The spodumenes are found associated with the alkaline igneous rocks being products of post-magmatic pegmatitic-pneumatolytic processes. L.J.

Sealant impregnated rubies.

G.M. Pearson. *Australian Gemmologist,* **23**(2), 2007, 58-61, 14 figures.

Natural rubies are suggested to be impregnated with lead glass based on their appearance in transmission X-radiographs. L.J.

The formation of precious opal: clues from the opalization of bone.

B. Pewkliang, A. Pring and J. Brugger. *The Canadian Mineralogist,* **46**(1), 2008, 139-49.

The composition and microstructure of opalized saurian bones (Plesiosaur) from Andamooka, South Australia,have been analysed and compared to saurian bones that have been partially replaced by magnesian calcite from the same geological formation, N. of Coober Pedy, South Australia. Powder XRD shows that they are essentially pure SiO_2 (88.59–92.69 wt %), with minor Al_2O_3 (2.02–4.04 wt %) and H_2O (3.36–4.23 wt %). No traces of biogenic apatite remain after opalization. The opal is depleted in all trace elements relative to Post-Archaean Australian Shale composite (PAAS). During the formation of the opal, the coarser details of the bone miscrostructure have been preserved down to the level of the individual osteons (~ 100 µm), but the central canals and boundary area have been enlarged and filled with chalcedony, which postdates opal formation. These chemical and microstructural features are consistent with the opalization process being a secondary replacement after partial replacement of the bone by magnesian calcite, and also with the opal forming first as a gel in the small cavities left by the osteons, and the individual opal spheres growing as they settle within the gel. Changes in the viscosity of the gel provide a ready explanation for the occurrence of colour and potch banding in opals. The indication that opalization is a secondary process after calcification in the Australian opal fields is consistent with a Tertiary age of formation. R.A.H.

Dobova, die klassische Lokalität des Dravit.

A. Recnik, A. Hinterlechner-Ravnik and G. Niedermayr. *Mineralien Welt,* **29**(1), 2008, 48-53.

Well-formed dravite crystals are described from the Dobova area of Slovenia. M.O'D.

Lipovka: German Vein oder Vein for Germans?

M. Sehrig. *Lapis,* **33**(4), 2008, 29-34.

Pegmatite in the 'German Vein' in the geological park at Lipovka, central Urals, Russia, has produced specimens of pink tourmaline and chrysoberyl. M.O'D.

From single source to global free market: the transformation of the cultured pearl industry.

Abstracts

R. Shor. *Gems & Gemology,* **43**(3), 2007, 200-26.

Over the past fifteen years a combination of market forces, environmental events and scientific research has radically changed the cultured pearl industry from a single commodity dominated by one producer to a highly diverse industry operating throughout the Pacific region. The new products, consistent quality and broader marketing programmes in turn led major designers and retailers in the west to take a much greater interest in cultured pearls. During this period, consumer interest has expanded from the traditional small and medium white round Japanese akoya cultured pearl to the larger South Sea and Tahitian products, and to previously unfashionable shapes and colours. R.A.H.

Mineralogical investigations of dentine from African elephant, Siberian mammoth, hippopotamus, walrus and sperm whale tusks.

T. Sito, L. Natkaniec-Nowak, M. Pawlikowshi and M. Dumanska-Slowik. *Gemmologie. Z. Dt. Gemmol. Ges.,* **56**(3/4), 2007, 117-26, 14 photographs, 17 diagrams, bibl.

The tusks/teeth from African elephants, Siberian mammoth, hippopotamus, walrus and sperm whale were macro-and microscopically examined, including both the mineral matrix (dahllite) and the organic component (collagen). The thickness of single collagen fibres, bunches of fibres and the size of the nutritious channel were measured. The characteristics of the dentine should be helpful in the identification of zoological discoveries in archaeological sites. E.S.

Infrared spectroscopic study of modern and ancient ivory from sites at Jinsha and Sanxingdui, China.

L. Wang, H. Fan, J. Liu, H. Dan, Q Ye and M. Deng. *Mineralogical Magazine,* **71**(5), 2007, 509-18.

Anicent ivory from the Chengdu Jinsha and Guanghan Sanxingdui sites in China has been buried for several thousand years. These ancient ivory samples have been compared with modern ivory, using IR spectroscopy in the 400–4000 cm^{-1} range. By combining these results with XRF analytical data, the crystallinity and crystal chemistry of the apatite component as well as the structural characteristics of the ivory have been compared. The ancient ivory consists almost entirely of hydroxyl-carbonate apatite. Compared with modern ivory, the PO_4^{3-} and CO_3^{2-} bands are stronger, the PO_4RF values are obviously greater and an extra OH^- band at 3569 cm^{-1} is observed. These results imply that there is a greater degree of apatite crystallinity in the ancient apatite and that there has been incorporation and recrystallization of CO_3^{2-} in the apatite during burial. Positive correlations are found between the apatite crystallinity, CO_3^{2-} and OH^- ion contents and burial time. The organic matter in ancient ivory has been lost or decomposed, which may be the main reason for ancient ivory being easily dewatered and readily friable after being unearthed. R.A.H.

Vaterit in Süßwasser-Zuchtperlen aus China und Japan.

U. Wehrmeister, D.E. Jacob, A.L. Soldati, T. Häger and W. Hofmeister. *Gemmologie. Z. Dt. Gemmol. Ges.,* **56**(3/4), 2007, 97-116, 13 photographs, 5 graphs, 1 table, bibl. (German with English abstract.)

Japanese and Chinese tissue and bead nucleated cultured freshwater pearls of good quality were investigated with Raman spectroscopy and LA-ICP-MS. In 50% of the investigated tissue-nucleated samples vaterite could be identified near the centre of the cultured pearls as well as in little blemishes on the surface. Continuous growth structures transect both vaterite and aragonite areas. Sodium and strontium are significantly lower in vaterite areas while Mg is significantly higher. The high amount of good quality cultured pearls implies that the formation of vaterite during growth may be a major factor affecting the quality of freshwater cultured pearls. E.S.

Tourmaline from the Minh Tien pegmatite, Luc Yen mining district, Yenbai Province, Vietnam.

W.E. Wilson. *Mineralogical Record,* **38,** 2007, 453-7.

Tourmaline from the Minh Tien pegmatite in Yenbai Province, Vietnam, has occurred in divergent clusters from pink to raspberry-red to yellow green and yellow-orange. Discussion continues on the composition which may be elbaite, rossmanite or liddicoatite. M.O'D.

The 100-year history of the benitoite gem mine.

W.E. Wilson. *The Mineralogical Record,* **39**(1), 2008, 13-42.

The history, working and production of the Dallas benitoite gem mine, San Benito County, California, are described with notes on some of the personalities who were instrumental in establishing the recovery of gem-quality benitoite. It would appear from this account that the mine is now opened occasionally for rockhound access rather than for the regular production of gem-quality material. M.O'D.

American mineral treasures.

W.E. Wilson. *The Mineralogical Record,* **39**, 2008, 171-222.

Overview of a near-50 case mineral display featuring fine and often rare American mineral specimens, many of ornamental quality, displayed at the 2008 Tucson Gem and Mineral Show. Brief descriptive notes include present ownership. M.O'D.

Instruments and Techniques

AGIL refractometer with LED light source.

T. Linton and R. Beattie. *Australian Gemmologist,* **23**(2), 2007, 62-63, 2 figures.

A moderately priced critical angle refractometer with light source produced by the Asian Gemmological Institute and Laboratory (AGIL) in Hong Kong is reviewed. The authors conclude that this is a quality instrument with a clear and easy to read scale. It provided accurate results when tested. L.J.

Abstracts

Synthetics and Simulants

Latest generation CVD-grown synthetic diamonds from Apollo Diamond Inc.

W. Wang, M.S. Hall, K.S. Moe, J. Tower and T.M. Moses. *Gems & Gemology,* **43**(4), 2007, 294-312.

Gemmological and spectroscopic properties of 43 chemical vapour deposition (CVD) synthetic diamonds (0.14–1.20 ct) from Apollo Diamond Inc. of Boston, Massachusetts, have been examined to characterize this latest generation (2006-2007) of their products. Relative to those examined in 2003, the new samples showed considerably improved size, colour and clarity. In addition to colourless and near-colourless material, fancy orange-to-pink colours are now produced. These high-quality CVD-grown diamonds are comparable in colour and clarity to natural diamonds; they can be identified by the use of a combination of gemmological and spectroscopic properties. R.A.H.

Abstractors

R.A. Howie – R.A.H. L. Joyner – L.J. M. O'Donoghue – M.O'D. E. Stern – E.S.

Letters

Tables of Gemstone Identification

A letter from R. Dedeyne, I. Quintens and J. Hyršl expressing concern about the review of their book Tables of Gemstone Identification (*Journal of Gemmology*, **30**(7/8), 2007, 463), was forwarded to me with a request for a second opinion.

After a very brief introduction together with a list of the abbreviations used, this book is basically a series of tables, of which the more important are those listing refractive index, opaque and translucent stones, density, spectra and an alphabetical index with supplementary data. Once a reader has gained familiarity with the abbreviations used, these tables are seen to contain a wealth of information. The problem of dealing with a mineral species with widely varying compositions is tackled by giving it several entries. This contributes to the length of some of the tables (the density table extends over a daunting 115 pages with, for example, baddeleyite getting 43 entries and hyperstene [sic] at least 30). It is also unfortunate that a few odd names such as hematine (sintered iron) and rock names (anyolite, nuumite, unakite, verdite) crop up: not many, but they inevitably appear several times in the refractive index and density tables. There are also brief tables showing the relationship between refractive index and density of glasses, minerals of the garnet group and on the isotropic and anisotropic imitations of diamond. The tables end with short lists of books and journals dealing specifically with gem minerals and gemmology.

Books dealing with tabulated determinative features of minerals and gemstones are popular with readers. The test here will be whether the main tables presented are found to be suitable for identifying unknown gemstones despite their length and the complexities of multiple entries. The work is thus rather massive for bench use, but the price seems eminently reasonable.

Professor R.A. Howie
Matlock, Derbyshire

Proceedings of the Gemmological Association of Great Britain and Notices

Conference and Graduation Ceremony

The 2007 Gem-A Conference was held at the Renaissance London Heathrow Hotel on Sunday 28 October. Speaking on the theme 'Gems of the Orient – Pearls and Jade' were Shigeru Akamatsu, Japan, George Bosshart, Switzerland, Professor Henry A. Hänni, Switzerland, Roger Keverne, London, Mimi Ou Yang Chiu Mei, Hong Kong, Kenneth Scarratt, Thailand, and Elisabeth Strack, Germany.

A programme of events and workshops was arranged to coincide with the Conference including a private viewing of the Crown Jewels with David Thomas, and group visits to the School of Earth Sciences, Kingston University, to view and learn about the equipment used to research gems and minerals.

The Graduation Ceremony was held at Goldsmiths' Hall in the City of London on Monday 29 October. Gem-A Chairman Professor Alan Collins presided and David Thomas MVO, Crown Jeweller from 1991 to July 2007, presented the awards and diplomas. In his address David Thomas gave a brief résumé of his career in the jewellery trade and his role as Crown Jeweller. Stressing the importance of education to the trade, he told the graduates: "In these days of modern technology with so many of our ancient crafts and traditions disappearing, it is only by your dedication and studies that the trade will survive." The ceremony was followed by a reception for graduates, members and their guests.

A special award was made during the Graduation Ceremony of an Honorary Life Membership to Ms Mimi Ou Yang Chiu Mei, in recognition of her substantial contribution to the world of gemmology and to the Association. Ms Ou Yang is founder and director of the Hong Kong Gems Laboratory and the Hong Kong Institute of Gemmology, one of Gem-A's largest Allied Teaching Centres. She has conducted numerous studies on jadeite jade, lectures in gemmology and jdaeite, and has produced four books and numerous articles on the subject.

Reports of the Conference, the Graduation Ceremony and the award of the Honorary Life Membership were published in *Gems & Jewellery*, 2007, **16**(5), 8-14.

Gem-A President Alan Jobbins awarding Ms Mimi Ou Yang Chiu Mei with an Honorary Life Membership during the Graduation Ceremony. Photo courtesy of Lewis Photos Ltd.

Gem-A Awards

Gem-A examinations were held in October 2007 and January 2008. In the Examinations in Gemmology 156 candidates sat for the Diploma Examination of whom 72 qualified, including one with Distinction and nine with Merit. In the Foundation Gemmology Examination, 163 candidates sat of whom 120 qualified. In the Gem Diamond Examination 70 candidates sat of whom 34 qualified, including one with Distinction and one with Merit. The names of the successful candidates are listed below.

Examinations in Gemmology

Gemmology Diploma

Qualified with Distinction

Rasche, Elizabeth, London

Qualified with Merit

Hansson, Maria Charlotte, Lannavaara, Sweden
Kyaw Swar Htun, Yangon, Myanmar
Lau Pui Ting, Kowloon, Hong Kong
Li Jingna, Guilin, Guangzi, P.R. China
Qu Gang, Beijing, P.R. China
Underwood, Antonia Charlotte, London
Vignal, Patrick, Ampus, France
Wang Jian Xing, Wuhan, Hubei, P.R. China
Xu Chong, Wuhan, Hubei, P.R. China

Qualified

Baker, David Mark, Bath, Avon
Bieri, Willy Peter, Escholzmatt, Switzerland
Bracey, Anne Christine, Birmingham, West Midlands
Brichet, Leonore, Vernouillet, France
Chan Chi Wai, Wah Fu Estate, Hong Kong
Chan Wing Kwok, New Territories, Hong Kong
Chen, Sisi, Wuhan, Hubei, P.R. China
Cheung Chi Shing Peter, Lam Tin, Kowloon, Hong Kong
Cheung Pui Shan, Alicia, Tsuen Wan, New Territories, Hong Kong
Chien, Lien Chin, Taichung, Taiwan, R.O. China
Chitty, Warne William, Aspen, Colorado, U.S.A.
Chong, He, Wuhan, Hubei, P.R. China
De Alwis Dissanayake, M. D., Colombo, Sri Lanka
Ding Hui, Surbiton, Surrey
Dowden, Simon, Chadds Ford, Pennsylvania, U.S.A.
Driscoll, Brian John, New York, U.S.A.
Gerrard, Belinda Louise, Sydney, New South Wales, Australia
Gunnarsson, Camilla Elizabeth, Norrtälje, Sweden
Hon Wai Ching, Hung Hom, Hong Kong
Hou Xukui, Guilin, Guangxi, P.R. China
Hsu Juiwen, Taipei, Taiwan, R.O. China
Jeavons, James, Geebung, Queensland, Australia
Lai Sau Han, Winnie, Hong Kong
Lau Ka Yan, Hong Kong
Lau Yuen Yee, Simmy, Kowloon, Hong Kong
Lee Chi-Ju, Taipei, Taiwan, R.O. China
Li LiuFen, Guangzhou, P.R. China
Li Yan, Beijing, P.R. China
Liang Rong, Guilin, Guangxi, P.R. China
Lin Chun-Yen, Taipei, Taiwan, R.O. China
Lin Yu Chi, Taipei, R.O. China
Maclellan, Kiki, London
Mak, Bing Lan, Fanling, New Territories, Hong Kong
Meninno, Marco, London
Mi Zhiwei, Guilin, Guangxi, P.R. China
Mitchell, Andreas, London
Mu, Yujing, Shanghai, P.R. China
Netsah, Maayane, London
Overton, Thomas William, Carlsbad, California, U.S.A
Partridge, Jennifer Anne, Cambridge
Raguin, Odiane, Eguilles, France
Raimundo Da Silva, Aldina, Verdun, Quebec, Canada
Ringhiser, Barbara G., Lake Worth, Florida, U.S.A.
Russell, Marie, Worcester, Worcestershire
Sheng Ran, Beijing, P.R. China
Shpartova, Irina, London
Sikkema, Ariane, Almelo, The Netherlands
Strafti, Kalliopi-Maria, Athens, Greece
Tan Koon Oi, Beijing, P.R. China
Tsang Wai Ming, Causeway Bay, Hong Kong
Vigneron, Charlotte, Boulogne-Billancourt, France
Wan Moli, Guangzhou, P.R. China
Wang Yinjie, Shanghai, P.R. China
Wong Ling Ling, Tseung Kwan O, New Territories, Hong Kong
Wong Man Yuen, Daniel, Pokfulam, Hong Kong
Xia Qiang, Wuhan, Hubei, P.R. China
Xu Hui, Guilin, Guangxi, P.R. China
Yang Xi, Wuhan, Hubei, P.R. China
Yu Xiubing, Shanghai, P.R. China
Zhang Minghui, Guilin, Guangxi, P.R. China
Zhao Na, Beijing, P.R. China
Zheng Xin Zi, Wuhan, Hubei, P.R. China

Foundation Certificate in Gemmology

Qualified

Agarwal, Kamal Kishore, Jaipur, Rajasthan, India
Al-Saif, Manar, Wembley, Middlesex
Amrit, Paveet, Northolt, Middlesex
Ang, Pamela Co, Shanghai City, Shanghai, P.R. China
Araujo Cartwright-Jepson, Maria Claudia, London
Asplund, Jan Olof, Kiruna, Norrbotten, Sweden
Baek, Kyung Ha, Jeollabuk-do, Korea
Baethe, Vanessa, Saint-Maur-Des-Fosses, France
Berezovsky, Florence Paulette Marie, Zurich, Switzerland
Bhatia, Esha, Gujarat, India
Blagg, Natalie, London
Bondar, Ilona, London
Branting, Andreas, London
Cai Min, Guangxi, P.R. China
Carre, Stephanie, Rambouillet, France
Chan Kin Chung, San Po Kong, Kowloon, Hong Kong
Chang, Shao-Ling, Taipei, Taiwan, R.O. China
Cheng Ming Yee, Kristy, Kowloon, Hong Kong
Chong, Ronald R.K.K., Amstelveen, The Netherlands
Deng Jianrong, Guangzhou, P.R. China
Dionne, Jean-Sebastien, Ste-Catherine-Jacques-Cartier, Quebec, Canada
Duraffourg Valerie, Belle Fontaine, France
Empson, Laura, Knaresborough, North Yorkshire
Flaxman Johnson, Edmund, Windsor, Berkshire
Fontaine, Josee, St-Basile-le-Grand, Quebec, Canada
Freeman, Derek, Hove, East Sussex
Gao, Xiaohuan, Shanghai, P.R. China
Geahel, Annemarie Charles, Montreal, Quebec, Canada
Gonzalez, Olga M., London
Goubert David, Les Avignon, France
Gritsenko, Anastasia, London
Harson, Docteur Jean Claude, Porto Vecchio, Corsica
Hoeu, Atitmuni Samnang, Phnom Penh, Cambodia
Hong, Nabin, Shanghai, P.R. China
Honour, Kevin J., Yeading, Middlesex
Huang Jinming, Guangxi, P.R. China
Jakkawanvibul, Jirapit, Bangkok, Thailand
Jamieson, Pauline, Edinburgh
Jaugeat Blaise, Vanves, France
Ji Qiusong, Guangxi 541004, China
Joannou, Christina, Ilford, Essex
Khounchanh, Marisa, Pointe-Claire, Quebec, Canada
Kim, Min Ji, Busan, Korea
Kuo Jia-Wen, Taipei, Taiwan, R.O. China
Lapsiwala, Foram Pravin, Gujarat, India
Law King Man, Kennedy Town, Hong Kong
Lee, Yun Jung, Ulsan, Korea
Lee Suk Chong, Yan Tong, Hong Kong
Lee Wan Ho, New Territories, Hong Kong
Li, Zhuonan, Shanghai, P.R. China
Liang, Jie, Birmingham, West Midlands
Lin, Sheau Lan, Taipei, Taiwan, R.O. China
Lin, Chun-Yen, Taipei, Taiwan, R.O. China
Liu, Feng-I, Taipei, Taiwan, R.O. China
Liu, Huijing, Shanghai, P.R. China
Louy, Olivier, Montreal, Quebec, Canada
Loye, Edward R., Plymouth, Devon
Lu, Sisi, Richmond, British Columbia, Canada
Lu, JR-Yang, Taipei, Taiwan, R.O. China
Lundvall, Linn, Lannavaara, 98013, Sweden
Luo Han, Guangzhou, P. R. China
Lust, Nathalie, Les Pennes Mirabeau, France
Lyons, Louise, London
Manasse, Daniele, Rome, Italy
Manuelli, Piero, Genoa, Italy
Matsukawa, Kent, Gampaha, Sri Lanka
Mayne, Edwina L., London
Mergalet, Caroline, Villefranche Sur Mer, France
Mitchell, Andreas, London
Muhhamedjanova, Jelena, Tallinn, Estonia
Ng Fei Yeung, Kowloon, Hong Kong
Noronha Muthu, Mrs Sunita Karen, Gujarat, India
Nwe, May Moe, Yangon, Myanmar
O'Cock, Sabrina, London
Park, Jin Hui, Busanjin-Gu, Busan, Korea
Park, Hey Kyung, Daegu, Korea
Park, Jin Hee, Daegu, Korea
Peng, Hsiang Chieh, Taipei, Taiwan, R.O. China
Peyron Alain, Nice, France
Poore, Sarah, Worthing, West Sussex
Pwint Phyu Win, Yangon, Myanmar
Rasche, Elizabeth, London
Rousseville, Prisca, London
Samaratunge, Punyadevi, Horana, Sri Lanka
Seo, Sun Mi, Daejeon, Korea
Shah, Prachi Hirenbhai, Surat, India
Sharma, Anita, Haryana, India
Simonsson, Kim, Stockholm, Sweden
Skalwold, Elise Ann, Ithaca, New York, USA
Soh Lip Sim, Johor Bahru, Malaysia
Soh Shi Hong, Johor Bahru, Malaysia
Son, Hye Jin, Masan-Si, Gyongsangnam-do 631-862, Korea
Soumare, Myriam, Paris, France
Spauwen, Tim, Mechelen, The Netherlands
Tan Huay Sian, Michelle, Singapore
Tan Kiat Choo, June, Johor Bahru, Malaysia
Teng, Ying, Shanghai, P.R. China
Teng Yongqing, Guangxi, China
Thinn, Jessica Myint, London
Thomas, Jane, Skipton, North Yorkshire,
Tran-Vinh, Caroline, Issy-Les-Moulineaux, France
Underwood, Antonia Charlotte, London
Wang, Wenyi, Guangzhou, P. R. China
Wang Hongmei, Guangxi, P. R. China

Wang Hui, Guangxi, P. R. China
Wang Liling, Guangxi, P. R. China
Wang Zongyu, Guangxi, P. R. China
Watrelos, Celine, Paris, France
Weng Chuxin, Guangxi, P. R. China
Win, San San, Singapore
Wu Dehe, Dehe, Guangzhou, P. R. China
Ye Ying, Singapore
Yim, Hye Jung, Gypmgsamgnam-do, Korea
Yip Long Ching, New Territories, Hong Kong
Yow, Kitty, Island South, Hong Kong
Zavadnikova, Valeria, London
Zhang Jieqin, Guangxi, P. R. China
Zheng, Wenting, Shanghai, P. R. China
Zhong Xiangtao, Guangxi, P. R. China
Zhu, Ye, Shanghai, P. R. China

Gem Diamond Examination

Gem Diamond Diploma

Qualified with Distinction
Rowley, Elaine, London

Qualified with Merit
Vefa, Jale Aydin, Sidcup, Kent

Qualified
Chan Che Min, Tsuen Wan, Hong Kong
Chan Po Ling, Kowloon, Hong Kong
Chan, Oi-Yan, Kowloon, Hong Kong
Cheng Chong Chuen, Tsuen Wan, New Territories, Hong Kong
Dollond, Steven, London
Drummond, Jean, Farnham, Surrey
Ferneyhough, Ella Jane, Leamington Spa, Warwickshire
Ho Wing Yi, Kowloon, Hong Kong
Hui, Hau Kan, Feltham, Middlesex
Huijbrechts, Thomas N., Salisbury, Wiltshire
Ji, Shuming, Beijing, P.R. China
Kai, Li, Beijing, P.R. China
Kan Sau Mei, Abby, Kowloon, Hong Kong
Kearney, Sonny Michael, Kimberley, Nottinghamshire
Khaing, Win Win, Bahan Township, Yangon, Myanmar
Lam Lai Kam, Kowloon, Hong Kong
Lee, Kitty Wai Yin, Tuen Mun, New Territories, Hong Kong
Lin, Chun-Yen, Taipei, Taiwan
Monogyios, John, Athens, Greece
Ng, Che Keung, New Territories, Hong Kong
Shaw, Martin Mackenzie, Kowloon, Hong Kong
Shaw, Bianca Debbie Fung Yee, Kowloon, Hong Kong
Shen, Huanqun, Shanghai, P.R. China
Stefani, Helen, Athens, Greece
To Siu Lun, New Territories, Hong Kong
Tong Sen Yue, Sandy, Central, Hong Kong
Wang, Qian, Beijing, P.R. China
Wang Hongbin, Wuhan, Hubei, P.R. China
Wong Fung Ha, New Territories, Hong Kong
Wong Lai Pui, Tuen Mun, New Territories, Hong Kong
Wong Wing Suet, Kowloon, Hong Kong
Xing Yingying, Hubei, P.R. China

Members' Meetings

Gem Discovery Club Specialist Evenings

The Gem Club meets every Tuesday evening at the Gem-A London headquarters when Club members have the opportunity to examine a wide variety of stones, and once a month a guest gem or mineral specialist is invited to give a presentation.

The November guest speaker was Diane Flora who gave Club members an introduction to the AGS Diamond Grade Cutting System. The guest in January was Mohammed Jabir who gave a presentation entitled 'Pearls, a natural history', explaining the origin and history of pearls before describing the growing interest in natural pearls and the resulting increase in demand and prices. In February Helen O'Neill of PMC Studio Ltd gave a talk and demonstration on precious metal clay with particular reference to the *in situ* firing of natural gemstones. Haji Abdul Hajid Butt, former general manager of J & K Minerals, the Indian Government Agency responsible for the Kashmir sapphire mines, was the March specialist, who gave a talk about the Kashmir sapphire mines, their location, geology, potential and the problems of working at 16,000 feet! Gem Club members were treated to a second specialist evening in March, when Guy Clutterbuck gave a talk on Zambian emeralds and aquamarines. He buys substantial quantities of emerald and aquamarine at source in Zambia, in addition to investing in small-scale mining operations. The April guest speaker, Alexandra Russell-Stoneham, shared her knowledge on the Russian diamond market in her presentation 'From Yakutia with Love'. She had delved into the world of the Russian diamond market, tracing its history from the discovery of the first kimberlite pipe to the present day, whilst studying in St Petersburg. In May, Anton Vasiliev from the LAL Stone-cutting Company, Russia, presented a special report on the Russian emerald mines, followed by a presentation on his facet design software.

Many of the Gem Club presentations have been reported in *Gems & Jewellery*.

Midlands Branch

The Branch Annual General Meeting was held on 25 January 2008 at the Earth Sciences Building, University of Birmingham, at which Paul Phillips, Elizabeth Gosling and Stephen Alabaster were re-elected Chairman, Secretary and Treasurer respectively. The AGM was followed by a Team Quiz and a Bring and Buy Sale. Other events held at the Earth Sciences Building included a presentation by Gwyn Green on 30 November 2007 on the observations of bubbles as an aid to gem identification, a talk on 29 February 2008 entitled 'Birmingham silver and the history of the Assay office' by Dr Sally Baggott, Curator at the Birmingham Assay Office, and a presentation by Doug Garrod on natural, treated and synthetic corundum on 25 April. At a meeting on 18 November 2007 held at Barnt Green, Alan Hodgkinson gave a talk on opals and provided many interesting specimens to examine. The Branch's 55th Anniversary Dinner was held on 8 December, also at Barnt Green.

North East Branch

Meetings held at the Ramada Jarvis Hotel, Wetherby, included a talk by Don Ariyaratna on the gems and the gem industry of Sri Lanka on 13 September 2007 and 'It's all in the cut', a presentation by James Riley of Backes & Strauss on pricing held on 2 April 2008. Doug Garrod gave a talk on the colour in diamond on 1 May at the Pavilion Hotel, Fulford, York.

North West Branch

On 17 April organics expert Maggie Campbell Pedersen spoke on organics and their fakes. James Riley of Backes & Strauss gave a talk on diamonds on 15 May entitled 'It's all in the cut'. Both meetings were held at the YHA Liverpool International, Wapping, Liverpool.

Scottish Branch

The Scottish Branch Conference was held at the Queen's Hotel, Perth, from 2 to 5 May. Speakers included George Rossman (keynote), David Callaghan, Alan Hodgkinson, Brian Jackson, Harold Killingback, Elisabeth Strack, Anton Vasiliev and Stephen Whittaker. The Sunday afternoon was devoted to workshops and displays, and the Conference concluded on the Monday with a field trip to collect haggis rock and visit Lauriston House to view the Blue John collection. (A report of the Conference was published in June 2008 issue of *Gems & Jewellery*.)

On 26 November 2007 Branch members visited auctioneers Lyon & Turnbull for a preview of their Fine Jewellery and Silver Sale. Meetings held at the British Geological Survey, Edinburgh, included a talk by Tracy Jukes on 16 October 2007 on coloured gemstone valuation in the twentieth-first century; Louise Johnson gave a presentation entitled 'Samba, topaz, lemurs and sapphires' on 22 January 2008; and James Riley gave a talk entitled 'It's all in the cut', explaining how the cut of a diamond affects the price, on 1 April. On 25 February at Napier University, Edinburgh, Margaret Sax gave a talk on techniques of Chinese and Mughal jade carving.

South East Branch

The Branch Annual General Meeting was held on 27 March at the Grange Holborn Hotel, London WC1, when Veronica Wetten, Liz Taylor and Roderick Booth were elected Chairman, Secretary and Treasurer respectively. The AGM was followed by a lecture on jade by Alan Jobbins.

South West Branch

Branch meetings held at the Bath Royal Literary and Scientific Institution included a hands-on session on 8 October 2007 with Doug Garrod looking at the colours of gemstones and how we see them; a talk on Scottish gemstones by Brian Jackson on 24 February, and a talk and practical session with Gwyn Green entitled 'Is it a diamond?' on 18 May.

Membership

Between 1 November 2007 and 31 May 2008, the Council approved the election to membership of the following:

Fellowship (FGA)

Abduriyim, Ahmadjan, Japan. 2007
Bieri, Willy Peter, Escholzmatt, Switzerland. 2008
Bracey, Anne Christine, Birmingham, West Midlands. 2008
Bryl Gaudet, Lou-Pierre, Montreal, Quebec, Canada. 2007
Dowden, Simon, Chadds Ford, Pennsylvania, U.S.A. 2008
Gunnarsson, Camilla E., Norrtälje, Sweden. 2008
Hansson, Maria Charlotte, Lannavaara, Sweden. 2008
Hossenlopp, Patricia, Chene – Bougeries, Switzerland. 2007
Luzuriaga Alvarez, Hugo Vicente, Montreal, Quebec, Canada. 2007
Munoz-Vasquez, Alejandra, London, 2007
Naing, Soe Moe, Southall, Middlesex. 1999
Sarraf, Kundan, Kathmandu, Nepal. 2007
Sourendre Shah, Rupal, Antananarivo, Madagascar. 2006
Stevenson, Laura, North Vancouver, British Columbia, Canada. 2007
Tovey, Kevin, Newport, Gwent. 1987

Educational Sponsorship and the 100 Club

This year Gem-A is celebrating One Hundred Years of Gemmological Education. To ensure that we remain the provider of the highest status gem education through our second century, we have ambitious plans for the expansion and increased accessibility of Gem-A courses worldwide. This can only be achieved with the support of our Fellows and members, and the gem and jewellery trade.

To encourage donations, two new fundraising schemes have been introduced. The first is the 100 Club aimed at Fellows and members of the Association; a donation of a minimum of £1000 is required to join the Club. The second is Educational sponsorship. Gem and jewellery companies, trade organizations and all those who support gem education have been invited to become sponsors with a choice of three levels: Diamond Sponsorship (over £10,000), Ruby Sponsorship (£5000–£9999) and Pearl Sponsorship (£1000–£4999).

The Council of the Association is most grateful to the following who have already joined the 100 Club or become Educational Sponsors.

100 Club

Canadian Gemmological Association, North York, Ontario, Canada
Terry M.J. Davidson FGA, Coln St Aldwyn, Gloucestershire
David Gann Ltd, London
Gemological Institute of America, Carlsbad, California, U.S.A.
Dr Roger R. Harding FGA, Avebury, Wiltshire
Andrew F. Hinds FGA, London
Harold Killingback FGA, Oakham, Leicestershire
Shinko Katayama FGA, Colombo, Sri Lanka
Robert J. Maurer FGA DGA, Redhill, Surrey
Dr Jack M. Ogden FGA, London
James Riley, Knutsford, Cheshire
Scottish Branch of the Gemmological Association of Great Britain
Simon A. Stoodley FGA, Alton, Hampshire
Unni Trolle FGA DGA, Eslov, Sweden
John O. Vince FGA, West Adderbury, Oxfordshire

Educational Sponsorship

Ruby Sponsorship

The Accredited Gemologists Association, San Diego, California, U.S.A.

Pearl Sponsorship

Mohammed Idris Jabir, Kuala Lumpur, Malaysia
Sanaullah Khan, Peshawar, Pakistan
K.K. Sharma, Indian Diamond Institute, Surat, India
Benjamin Zucker, new York, U.S.A.

Diamond membership (DGA)

Austen, Katelyn, Birmingham, West Midlands. 2007
Martins, Miki, Burnaby, British Columbia, Canada. 2007
Thomas, David John, Milton Keynes, Buckinghamshire. 2007

Associate membership

Akerlund, Sophia, Lidingo, Sweden
Akinfenwa, Ayodeji, London
Astley, Mark, London
Awad, Elizabeth, Reading, Berkshire
Blake, Andrea, Chevy Chase, Maryland, U.S.A.
Chen Wei-Ting, London
Chitty, Warne, Aspen, Colorado, U.S.A.
Coppack, Flavia, London
Corbett, John, East Grinstead, West Sussex
Drayson, Marie Lule, London
Dungler, Pierre, Beziers, France
Duval, Pauline, France
Feldheim, Yinon, Israel
Florio, Daniela, London
Fowell, May, London
Franklin, Peter Nigel, Shenfield, Essex
Fujii, Hideo, Soka City, Saitama Pref., Japan
Gamley, Alistair, Hullbridge, Essex
Gandulfo, Veronica, Teofilo Otoni, Minas Gerais, Brazil
Gerrard, Edward Francis, Nealon, Western Australia, Australia
Glendening, Sarah Louise, Eastbourne, East Sussex
Gordon, Richard, Farningham, Kent
Hamston, Janet, Old Basing, Hampshire
Hara, Shintarou, Sasebo City, Nagasaki Pref., Japan
Hardy, Sarah, Middlesbrough, North Yorkshire
He Xiaoyu, London

Gifts and Donations

The Association is most grateful to the following for their gifts and donations for research and teaching purposes:

Haji Abdul Majid Butt, Kashmir, for a piece of Kashmir sapphire mine rock containing sapphire crystals
Maggie Campbell Pedersen FGA, London, for a selection of organic beads including natural, dyed and simulated coral, and carved bone, jet, opercula and spikey shells
Steven Collins FGA DGA, Letchworth, Hertfordshire, for a selection of pezzottaite cabochons
Branko Deljanin BSc FGA DGA, Vancouver, British Columbia, Canada, for a piece of rough diamond crystal weighing 0.69ct
Eric Emms BSc FGA DGA, London, for a two-pan balance
Alexey Eremen, Russian Colored Stone Company, Genesee, Colorado, U.S.A., for a piece of Russian chromian diopside
Chaman Golecha FGA, Chennai, India, for pieces of sapphire and ruby with a trapiche-like appearance
Mohammed Idris Jabir, Kuala Lumpur, Malaysia, for a selection of natural and cultured pearls, in memory of his father Mohammed Idris
Dominic Mok FGA DGA, Hong Kong, for a range of refractometers for Gem-A's examinations in Hong Kong and a box of yu hua shi (Chinese agate)
Paula Preston, London, for two boxes of yu hua shi (Chinese agate)
Sara Ritchie GG, Glen Ridge, New Jersey, U.S.A., for three pieces of operculum
Alexandros Sergoulopoulos FGA DGA, Athens, Greece, for four rough diamond crystals
Jason Williams FGA DGA, London, for a collection of natural and synthetic cut stones
Zhili Qiu FGA, Guangzhou, P.R. of China, for a selection of rough B jade

Montetary donations were gratefully received from:

Raed Al-Hadad FGA, Abu Dhabi, United Arab Emirates
Alexander Armati DGA, Sonning Common, Berkshire
Eisuke Ashida FGA, Kyoto, Japan
Petra C. Bardehle FGA, Holzhausen, Munsing, Germany
Bjorn Bendikssen, Sto, Norway
L.M. Bevers-Reinders.FGA, Rotterdam, The Netherlands
Burton A. Burnstein., Los Angeles, California, U.S.A.
Susan Deacon FGA, London
Dennis Durham., Kingston upon Hull, East Yorkshire
Gwyn Green FGA DGA, Birmingham, West Midlands
Masao Kaneko FGA, Tokyo, Japan
John C.A. Kulukundis FGA, London
Heli Kuulman FGA, Tallinn, Estonia
Sandra Lear FGA, Morpeth, Northumberland
Torbjorn Lindwall FGA DGA, Lannavaara, Sweden.
Caroline E. Maclachlan FGA DGA, Edinburgh, Scotland
Stefanos Mourtzanos FGA, Crete, Greece
Sara Naudi FGA, London
Edward Nealon, Booragoon, Western Australia, Australia
Robert L. Rosenblatt FGA, Salt Lake City, Utah, U.S.A.
Elaine Rowley FGA DGA, London
David J. Sayer FGA DGA, Wells, Somerset
Moe Moe Shwe FGA, Singapore
Monika Sinagra FGA, Shanghai, P.R. China
Elisabeth Strack GG FGA, Hamburg, Germany
Annaliese J.C. Stubbs DGA, London
Stasia-Mae Tereszczuk, Little Horwood, Buckinghamshire
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Transfers

Associate Membership to Fellowship and Diamond Membership (FGA DGA)

Lin Chun-Yen, Taipei, Taiwan, R.O. China. 2008

Fellowship to Fellowship and Diamond Membership (FGA DGA)

Drummond, Jean, Farnham, Surrey. 2008
Ferneyhough, Ella Jane, Leamington Spa, Warwickshire. 2008
Rowley, Elaine, London. 2008

Diamond Membership to Fellowship and Diamond Membership (FGA DGA)

Baker, David Mark, Bath, Avon. 2008
Chan Chi Wai, Wah Fu Estate, Hong Kong. 2008
Netsah, Maayane, London. 2008

Associate Membership to Fellowship (FGA)

Chitty, Warne W., Aspen, Colorado, U.S.A. 2008
Gerrard, Belinda Louise, Sydney, New South Wales, Australia. 2008
Jeavons, James, Geebung, Queensland, Australia. 2008
Mitchell, Andreas, London. 2008
Rasche, Elizabeth, London. 2008
Ringhiser, Barbara G., Lake Worth, Florida, U.S.A. 2008
Shpartova, Irina, London. 2998
Underwood, Antonia Charlotte, London. 2008

Associate Membership to Diamond Membership (DGA)

Dollond, Steven, London. 2008
Hui Hau Kan, Feltham, Middlesex. 2008
Huijbrechts, Thomas N., Salisbury, Wiltshire. 2008
Shen, Huanqun, Shanghai, P.R. China. 2008

Erratum

In *J. Gemm.,* 2007, **30**(7/8), p.450, right-hand column, in equations I-1 and I-2 the term should be $\tan^2 V_z$, not $\tan 2V_z$

Obituaries

Professor Chen Zhonghui 1935–2007

Professor Chen was born in Shanghai on 1 October 1935 and died on 6 November 2007 at the age of 73 (sadly, just before I was due to meet him in Beijing where he lived in the university district).

Chen trained as a geologist and studied the geology of coal in the Ukrainian Coalfield where he also learnt Russian. On his return he taught coal geology at the China University of Geosciences (CUG) in Beijing and wrote many articles on the economic geology of coal. In 1980 he rose to Principal in CUG and, at that time, he moved with part of the university to Wuhan on the Yangtze River (Chang Jiang) and soon afterwards was made Professor. Professor Chen established the first gemmological education in Mainland China, with the first Gem-A course starting in 1989. Thus he initiated the Association's excellent relations with so many people in the gem and jewellery industry in Mainland China, following the pioneering visits of E. Alan Jobbins (now President of the Association) and Dr Jamie B. Nelson who introduced the Association's curriculum and practical gem testing programme during the previous year. Their introduction to Professor Chen and his wife Professor Yan Weixuan, who had established the mineralogical museum at the university, came through their good friend Ms Mimi Ou Yang Chiu Mei, President of the Hong Kong Institute of Gemmology – a Gem-A Allied Teaching Centre. In order to achieve this historic start in 1989, Professor Chen sought and obtained funding from many sources throughout Mainland China and Taiwan, and through his efforts the Wuhan school became the first of our Allied Teaching Centres in Mainland China. He followed this with plans for a jewellery institute, established in 1992. He established the Association's Gem Diamond Diploma course in China in 1993 with funding from the chemical industry.

Throughout this time and afterwards through his retirement and up until his death, Chen Zhonghui was tireless in his translation work and in producing a translation glossary, course notes and handbooks. His huge effort to support the Association's examination system throughout China established and ensured its safety and integrity. He also produced the *Chinese-English Dictionary of Jewellery*, now in its third edition.

Chen was highly regarded in international gemmology; he set up the annual conference of the Gemmological Institute of China at the Wuhan campus and later elsewhere in China, attracting many important gemmologists from more than twenty countries, increasing China's relationships with international gemmology. In 1997, Chen and his wife were invited by the Association to visit London for Chen to present the Diplomas and

Professor Chen and his wife Professor Yan Weixuan during their visit to London in 1997.

Prizes at the annual Awards Ceremony at Goldsmiths' Hall, where he delivered a speech which brought the connections with the Far East that bit closer to the home of gemmological education. In 2004–5 Chen organized the 29th International Gemmological Congress in Wuhan which, after a year's delay brought about by the SARS outbreak, attracted gemmologists from more than thirty countries.

Through these past two decades, Chen remained in very close contact with me in my role as Director of Education and with the members of our team, some of whom he met during our periodic visits to China, and his welcome and ready discussions leave a legacy of continuity in our programme of work in China. Without his effort and support, it is hard to see how such good relations and success for the Association in China could have come about and continue in a way that enables us to develop further our close contact and our education and membership programmes.

For his great service to gemmology and gem education, Professor Chen was awarded an Honorary Fellowship of the Association in 1999, one of only four in the world at that time. His great care and his extremely high standards, his attention to detail, his readily-given advice and his warm sense of humour, are all attributes so valuable in someone who I am pleased to have known as a good friend as well as a truly valuable supporter of the Association and its education staff.

Ian Mercer

Grahame Brown
1935–2008

Grahame Brown, long-time Editor of the *Australian Gemmologist*, passed away on 15 January 2008, after a long battle with cancer.

Graham joined the Queensland division of the Gemmological Association of Australia (GAA) in 1973. His many achievements in the world of gemmology included the award in 1974 of the Australia Prize, having achieved the highest marks in Australia in the GAA Diploma of Gemmology examinations. He was elected a Fellow of the Gemmological Association of Great Britain in 1975, having qualified for his Diploma in Gemmology with Distinction. In 1978 he was awarded the first Research Diploma of the GAA for a thesis entitled 'Investigations into the structure and properties of precious corals'.

It would be hard to find a group of several gemmologists and gem materials authors and gem enthusiasts who together could begin to take the place of someone like Grahame. And he made his expertise available, worldwide, to gemmologists, enthusiasts and students. He gave great support to students of Gem-A and to its exam candidates, by giving student support, arranging exam facilities and taking great care of the detail and security of the Association's exam system. Grahame's talks in London demonstrated his straightforward approach to information and its sharing, opening further the discussion on the huge variety of organic gems or, as he correctly insisted for very logical reasons, 'gem materials of organic origin'.

My all-too-brief chats and discussions with Grahame, in London, in China and in his own home just last October, left me with a pleasant feeling that here is a bloke who's in touch and, crucially, one who kept in touch with the fullest use and enjoyment of the literature and the communicators in the world of gems. Grahame's passing is a huge loss to the international gem world.

Ian Mercer

William (Bill) F. Ferguson
1931–2007

Bill Ferguson FGA DGA (D. 1956), Balloch, Strathclyde, died following a short illness in 2007.

Bill served a five-year horological apprenticeship with John Hudson in Alexandria, Dunbartonshire, prior to his National Service from 1952–54. He was an Inspector for Westclox for one year before taking over the jewellery business of John Hudson. He started teaching part-time, but later took on a full-time position teaching gemmology and horology at Barmulloch College, Glasgow, leaving his wife May to run the shop during the week.

Bill won the admiration of countless students by his encouragement and compassionate concern to pass on all he knew.

Bill Ferguson is survived by his wife May and son Neil, who carries on the jewellery tradition in Rhode Island.

* * *

Robin Ian McKay FGA DGA (D.1957), Harmans Cross, Dorset, died on 5 December 2007.

Evelyn Sim FGA DGA (D.1990), Edinburgh, died in 2007.

Gem-A Events

Monday 30 June	**ANNUAL GENERAL MEETING** followed by **Surviving a Life Sentence at Christie's** by **David Warren**
Thursday 3 July	**GEM-A CENTENARY DINNER**
Wednesday 9 July	**GEM DISCOVERY CLUB** **Identification of Small, Colourless and Fancy Colour HPHT-grown and CVD-grown Diamonds** with **Branko Deljanin** of EGL Canada
Tuesday 16 September	**HONG KONG GRADUATION AND AWARDS DINNER** Venue: Royal Palace Chinese Restaurant, Kowloon (see p30 for further details)
Thursday 18 September	**NORTH WEST BRANCH** **Fakes and Forgeries in the Silver Markets** by **Andrew Spicer**
Friday 26 September	**MIDLANDS BRANCH** **Reflections on Gem Cutting** by **Doug Morgan**
Thursday 16 October	**NORTH WEST BRANCH** Branch AGM followed by **Gems in Archaeology** by **Jo Jones**
Thursday 23 October	**NORTH EAST BRANCH** **Identifcation of Colourless Gems in jewellery** by **Gwyn Green**
Saturday 25 and Sunday 26 October	**GEM-A CENTENARY CONFERENCE AND EUROPEAN GEMMOLOGICAL SYMPOSIUM** Venue: The Hilton London Kensington (see p.14 for further details)
Monday 27 October	**GRADUATION CEREMONY AND PRESENTATION OF AWARDS** Venue: Goldsmiths' Hall, Foster Lane, London EC2V 6BN
Friday 31 October	**MIDLANDS BRANCH** **British and European Hallmarking, Birmingham Silver and the Influence of Matthew Boulton** by **Dr Sally Baggott**
Friday 28 November	**MIDLANDS BRANCH** **Eighteenth-Century Jewellery: Buttons, Bows and Bones** by **John Benjamin**
Saturday 29 and Sunday 30 November	**MIDLANDS BRANCH** **Anniversary Dinner (Saturday) and Centenary Conference (Sunday)** Venue: Menzies Strathallan Hotel, Birmingham
Sunday 7 December	**NATURE'S TREASURE: MINERALS AND GEMS** A joint Gem-A/Mineralogical Society one-day seminar Venue: The Flett Theatre, Natural History Museum, London

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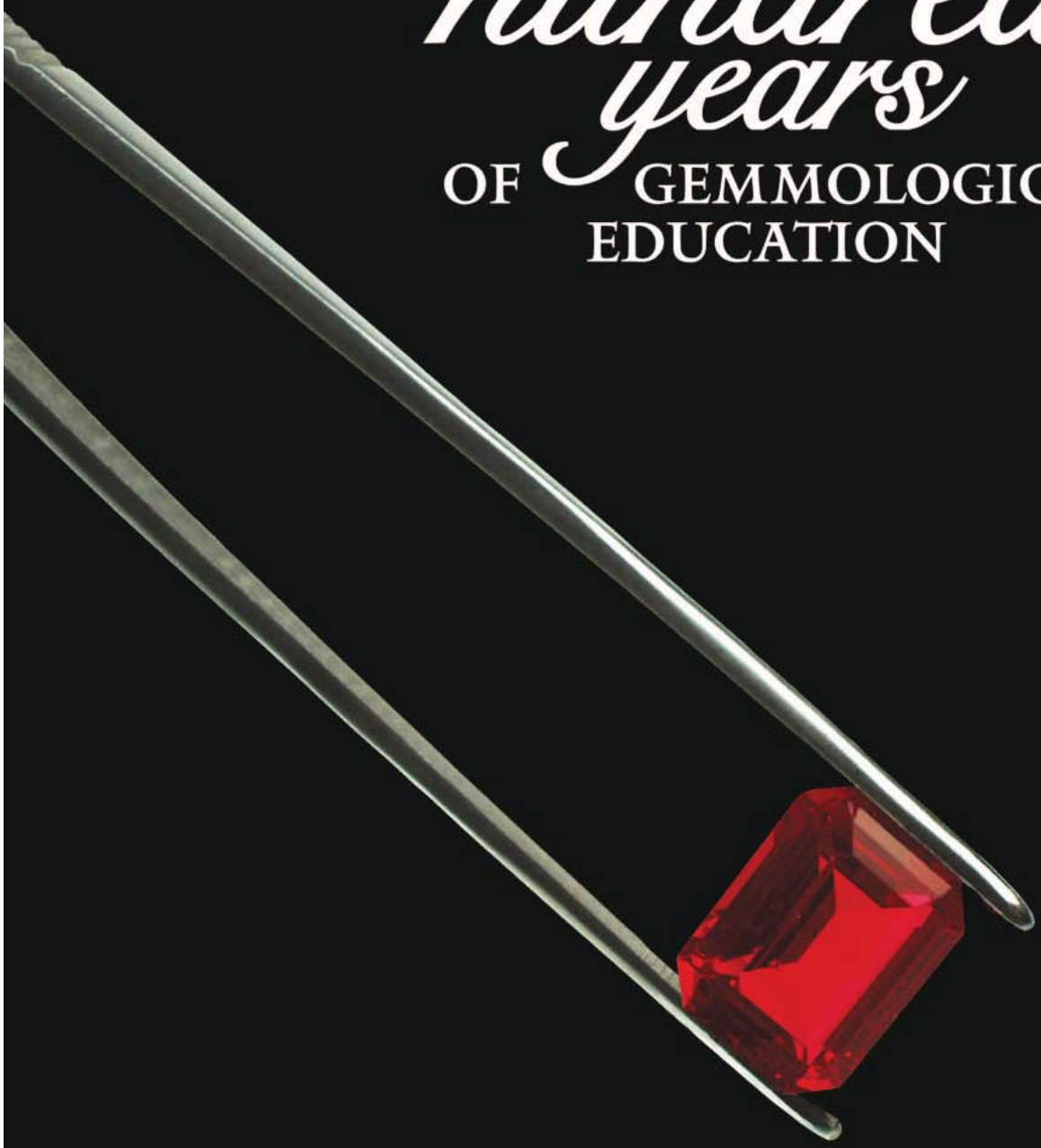

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Cover Picture: Faceted thortveitite in daylight (top) and incandescent light (lower right).
(See Thortveitite – a new gemstone, p. 1.)

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A fancy reddish brown diamond with new optical absorption features

Taijin Lu, Tatsuya Odaki, Kazuyoshi Yasunaga and Hajime Uesugi

Abstract: Red or near-red natural diamonds are extremely rare, and the possible origins of their colour are unclear. A weak absorption band at 776 nm in the visible range and a clear absorption band at 6169 cm^{-1} in the infrared region were detected in a near-red diamond, which could be factors in understanding the possible origin of this colour in natural diamonds.

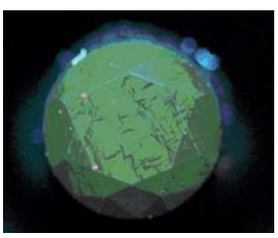

Keywords: diamond, spectroscopy, infrared, photoluminescence, UV-visible

Introduction

Although the popular image of diamond for centuries has been that of a colourless gem, it can be yellow, orange, blue, green, black, white, purple, pink and red, colours which are traditionally referred to as 'fancy' (see, e.g., Fritsch, 1998). Coloured diamonds contain impurities, such as nitrogen or boron, or structural defects, and are usually graded using a fancy-colours grading system (King *et al.*, 1994). In this system, the diamonds described as predominantly red are among the most intriguing and highly valued gems in the world, because of both the richness of their colour and their extreme rarity. As stated by the Gemological Institute of America (GIA), until 2002 only four fancy red diamonds from the public domain had been graded in the GIA Gem Laboratory (King and Shigley, 2003). The diamonds with near-red colours are usually graded using additional descriptive terms, such as fancy purple-pink, fancy reddish purple, etc. depending on the secondary hue, tone, and saturation. These fancy colour diamonds are also often well documented due to their high price and rarity (Kane, 1987). However, precisely because of this rarity, studies have been few and there is very little understanding of the possible origins of the red and near-red colours in natural diamonds. Recently, we have had an opportunity to examine a fancy reddish brown diamond, which is shown in *Figure 1*. Systematic non-destructive spectroscopic investigations under optimum measurement conditions have been carried out to record its optical absorption features and possibly relate them to the origin of its colour. UV-Visible-near infrared (UV-Vis-NIR) spectra were recorded with a Nihonfenko high-resolution spectrometer (Model Jasco V-670, 300 – 1000 nm, 0.5 nm resolution, deuterium-tungsten-halogen source) with our own designed optical fibre system which allows us to record the spectra at liquid nitrogen temperature with high resolution. Infrared absorption spectra were collected using both the Nihonfenko Jasco FT/IR-6100 and the FT/IR-660 plus Fourier-transform infrared (FTIR) spectrometers (6,000 – 400 cm^{-1}, and 11,000 – 7,000 cm^{-1}, 1 cm^{-1} resolution, up to 1024 scans, at room temperature). Raman and photoluminescence spectra were recorded using a Renishaw inVia Raman microscope (488 nm, 514.5 nm, and 632.8 nm laser sources, at liquid nitrogen temperature).

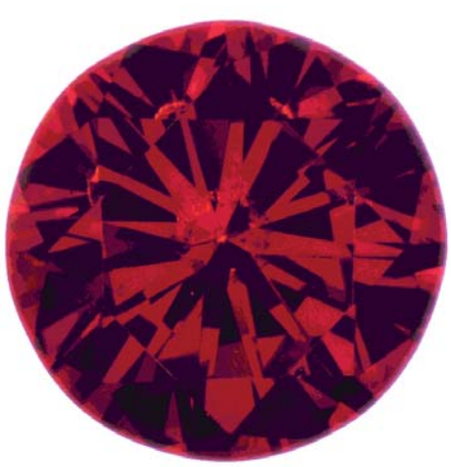

Figure 1: Fancy reddish brown diamond of 0.202 ct. Photo by H. Ito.

Results

The natural diamond of 0.202 ct, cut as a round brilliant, contains mineral inclusions easily visible in dark-field illumination under a gemmological microscope. After careful observation and comparison, the colour was graded as fancy reddish brown according to the GIA system, which is very close to red.

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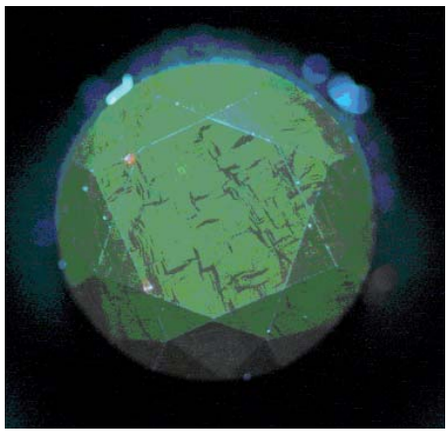

Figure 2: The reddish brown diamond showed green-yellow fluorescence when examined using the UV fluorescence imaging system of the DTC DiamondView. Growth features resembling script are visible in the image.

The stone was inert under both long-wave (365 nm) and short-wave (254 nm) UV lamps, but it displayed weak green-yellow fluorescence when examined in the DTC DiamondView imaging system *(Figure 2)*. A growth pattern consisting of short dark lines disposed at approximate right angles and resembling script is visible in the image. This probably represents agglutination of numerous tiny octahedral crystals in sub-parallel orientation at an early stage of the diamond's formation.

The UV-visible spectrum at room temperature is shown in *Figure 3(a)*. It shows complete absorption below 500 nm with a steep absorption curve to transmission near 700 nm. At liquid nitrogen temperature, a weak but clear absorption band at 776 nm was detected *(Figure 3b)*. Although a 776 nm band has been occasionally detected in photoluminescence spectra in natural blue diamond with red phosphorescence (Johnson and Moe, 2005), to the best of our knowledge, this is the first recorded observation of a band at this position in the UV-visible absorption spectrum of a natural diamond.

Details of the infrared absorption spectrum are shown in *Figure 4* and suggest that the diamond is mostly type Ib with minor IaA. The 1332, 1344, 1353, 1358, 1374 and 1387 cm^{-1} peaks are all nitrogen related (*Figure 4a,* and see Zaitsev, 2001). However, two weak absorption bands at 6169 cm^{-1} and 4702 cm^{-1} were detected in the 7000 – 4000 cm^{-1} range *(Figure 4b)*. The small 4702 cm^{-1} band has been reported by Fritsch *et al.* (1991), without attribution to its cause, but an extensive search of the literature has not yielded any mention of the 6169 cm^{-1} band which is clearly present in this diamond.

The Raman spectrum of the reddish brown diamond was recorded and contains the standard diamond peaks with no exceptional features. To further characterize the spectroscopic features of this diamond, photoluminescence (PL) spectra excited by an Ar-ion laser with both 488 nm and 514.5 nm wavelengths at liquid nitrogen temperature were recorded. A strong and broad emission band centred about 710 nm was detected. Sharp emission bands of 637 nm, 692 nm, 704 nm, 818 nm and 905 nm are superimposed on both sides of this broad band *(Figure 5)*. Under the Ar-ion laser, relatively strong red luminescence is visible even with the naked eye.

Discussion and summary

Pink to red (or purple) diamonds can be obtained from yellow to brown type Ib diamonds, whether natural or synthetic, when subjected to irradiation and annealing treatment (Collins, 1982). The colour is primarily due to a broad absorption band centred at 550 nm, and to the irradiation and annealing treatment-related absorption bands, such as GR1 (741 nm), N-V centres (575 nm, 637 nm), and the 595 nm band, which are usually detected using advanced spectroscopic techniques (Moses *et al.,* 1993). Since these absorption features are absent from the spectrum of the near-red diamond, its colour is probably natural. The weak 776 nm absorption band in the visible range and a clear 6169 cm^{-1} band in the infrared absorption spectrum are new absorption features in this diamond, but it must be stated that strongly coloured

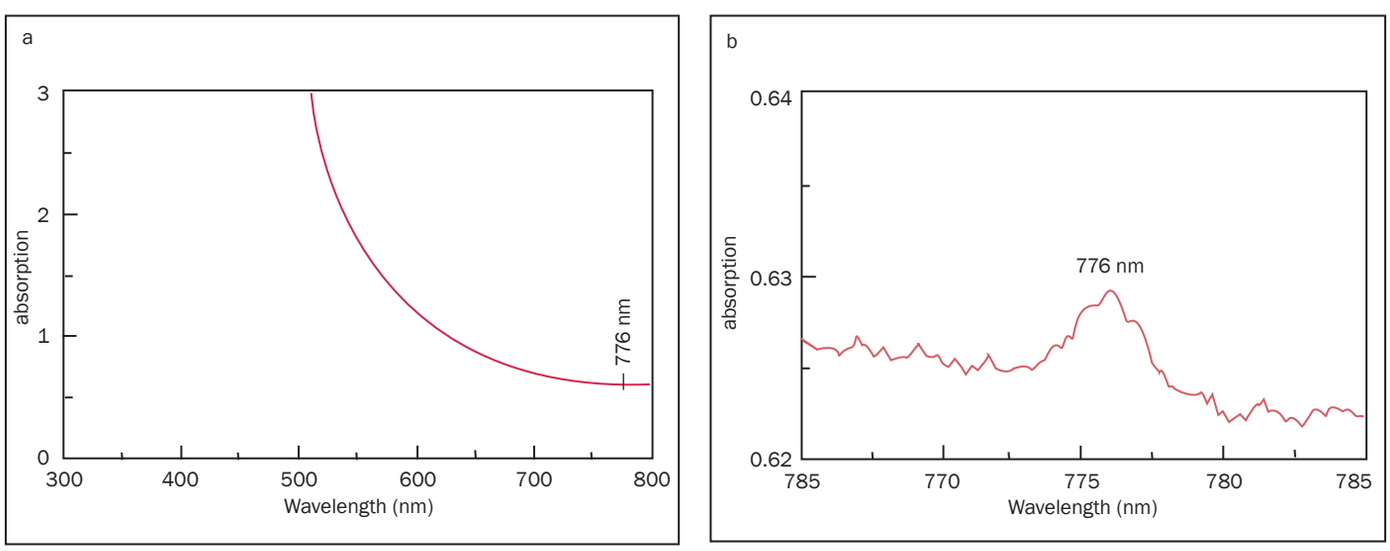

Figure 3: (a) Visible absorption spectrum of the reddish brown diamond at room temperature showing a steep absorption curve from 700 nm to complete absorption below about 500 nm. (b) A weak absorption band at 776 nm is present in the spectrum when the stone is cooled with liquid nitrogen.

natural diamonds often show previously undocumented spectroscopic features which may or may not turn out to have diagnostic value.

The infrared spectrum shows that the diamond is predominantly type Ib with absorption in the visible range caused by single nitrogen atoms in the diamond structure. However this absorption may be augmented by a band near 485 nm which occurs in diamonds showing a broad photoluminescence peak near 700 nm. Collins and Mohammed (1982) first drew attention to this band, although their diamonds exhibited yellow photoluminescence under long-wavelength UV whereas the reddish brown diamond was inert.

Although the cause of colour in this near-red diamond is not yet clear, the spectroscopic data could prove helpful when combined with data from similar stones in the future.

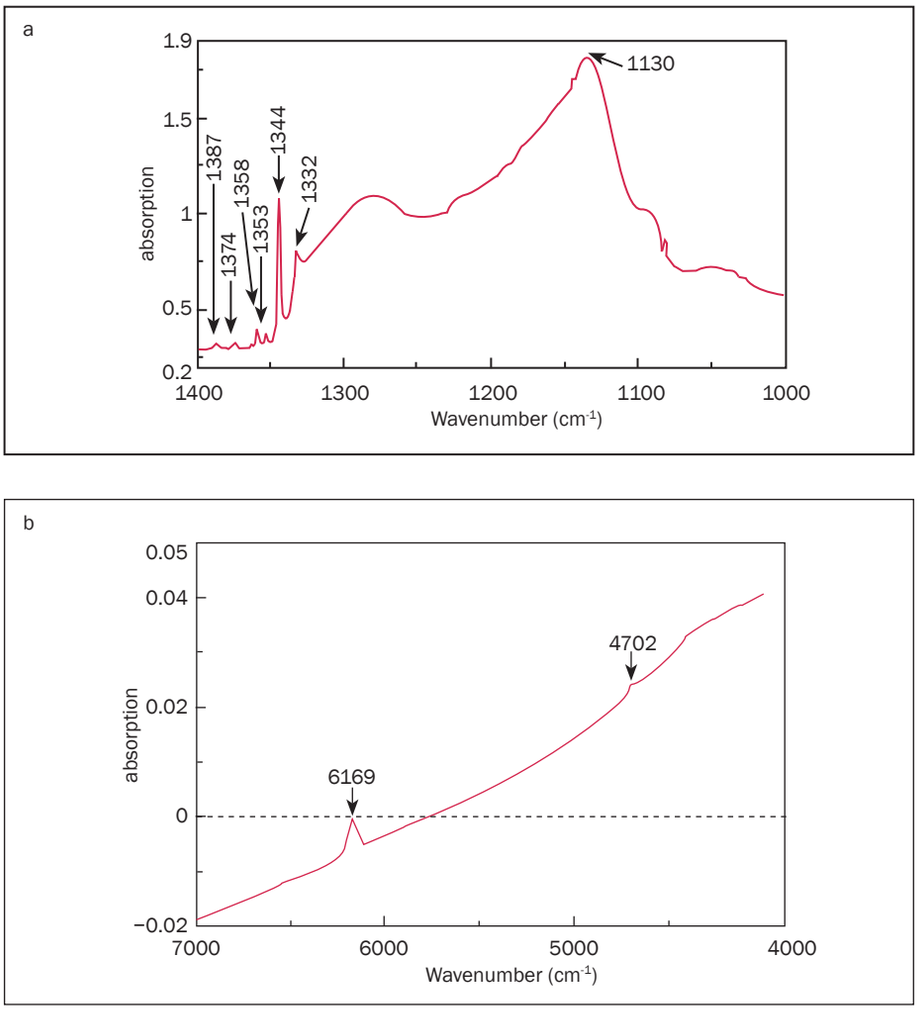

Figure 4: (a) The infrared absorption spectrum shows that the diamond is a type Ib with minor IaA. (b) There is a clear 6169 cm^{-1} absorption band and a small peak at 4702 cm^{-1} in the 7000–4000 cm^{-1} range.

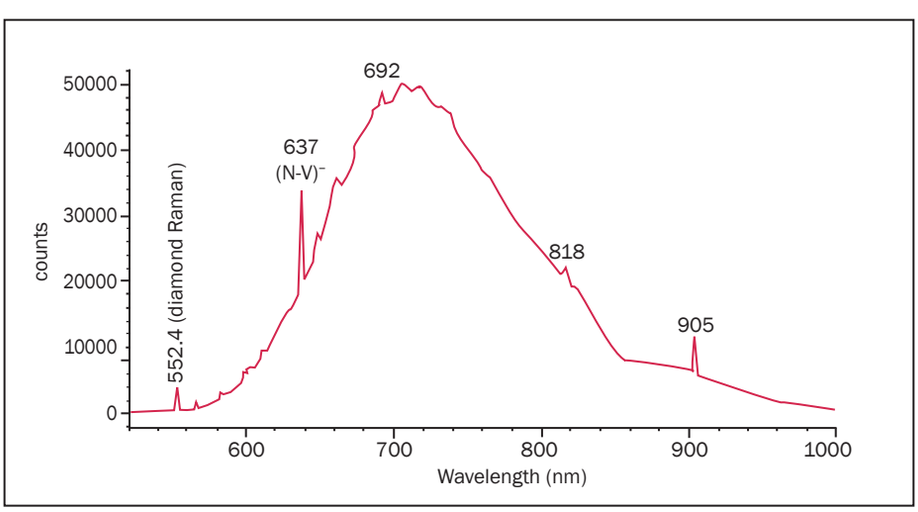

Figure 5: Photoluminescence spectrum of the reddish brown diamond showing a strong broad emission band centred around 710 nm. The spectrum is the result of excitation by an Ar-ion laser (514.5 nm) at liquid nitrogen temperature.

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The authors thank Dr Ichiro Sunagawa, emeritus professor of Tohoku University and Yoshiko Doi, AGT Gem Laboratory and GIA Japan for their valuable comments and support.

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A place for CZ masters in diamond colour grading

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Abstract: Over the last 20 years and despite recommendations to the contrary, many gemmologists and appraisers have gravitated to the use of cubic zirconia (CZ) master stone sets to assist in the colour grading of diamonds. This investigation revisits with new insight, diamond grading technique and methodology. It addresses the judicious use of CZ master stone sets to augment diamond masters that are smaller in size and number. Study results support the use of accurately graded, carat-size CZs in reducing the subjectivity of colour grading when only incomplete (every other grade) diamond master sets of small (under 0.4 ct) sizes are available.

Keywords: colour grading, cubic zirconia, CZ, diamond

Introduction

This investigation explores historical guidance in the use of diamond master stones, and offers a rationale for augmenting master stone sets of smaller and fewer diamonds with a full set of carat size CZ masters. The question addressed is: Can the acknowledged subjectivity of diamond colour grading be reduced by supplementing an incomplete set of smaller diamond master stones with a complete set of larger CZ masters? Along with two gemmologist-appraiser colleagues, the author also conducted and reports on a study of the accuracy of eight ten-stone sets of CZ master stones, four from each of two main manufacturers of these sets.

Findings are reported of studies in five areas related to diamond colour grading:

1. The historical development by the Gemological Institute of America (GIA) of a colour grading standard beginning with the GIA colour grading 'yardstick'.
2. Industry and GIA teaching of methods and recommendations for colour grading using GIA Diamond Masters, which reduce the subjectivity of colour grading.
3. The pros and cons in the use of CZ master stones in diamond colour grading.
4. A study of grading environments involving a multiplicity of lighting types resulting in additional recommendations for colour grading using CZ or diamond master stones.
5. An evaluation of CZ master stone sets from two main manufacturers.

GIA's development of a colour grading system

Accurate colour grading of diamonds has been and remains one of the difficult challenges facing dealers, laboratories, gemmologists and appraisers. As diamond prices continue to rise, so does the necessity for accurate colour determination. Today, a single colour grade difference in, for example, a 2 ct, VS1, round brilliant can mean over a 20% change in its value. A mistake in grading can have this sort of large impact on appraised value. With amounts like this in the balance, it is incumbent upon the graders of diamond colour to be as accurate as possible despite the myriad of confounding factors that add an industry-acknowledged degree of subjectivity to colour grading.

It is helpful to examine how the Gemological Institute of America (GIA) has addressed and answered the need for accurate and consistent colour grading. In 1941 the GIA introduced "a method of grading diamond colours against a standard in the form of a definitely set and constant scale, as incorporated in the new GIA Colorimeter. This is the first time a colour-grading 'yardstick' has been established." "Thus, the problem of the relative colour of the grades seems to have been largely solved for the jeweller who has a series of key stones (GIA Masters) graded on the 'yardstick'" (Shipley and Liddicoat, 1941). *Figure 1* is a representation of that numerical 'yardstick' and its relation to the GIA letter grades and to the master diamond grades. The letter grades, which correspond to the numerical grade ranges of the 'yardstick', were introduced by GIA in 1953. The D-Z letter grading system has become the 'lingua franca' of colour grading in the United States and largely worldwide, and GIA graded, master diamond sets have become the standard reference tool for

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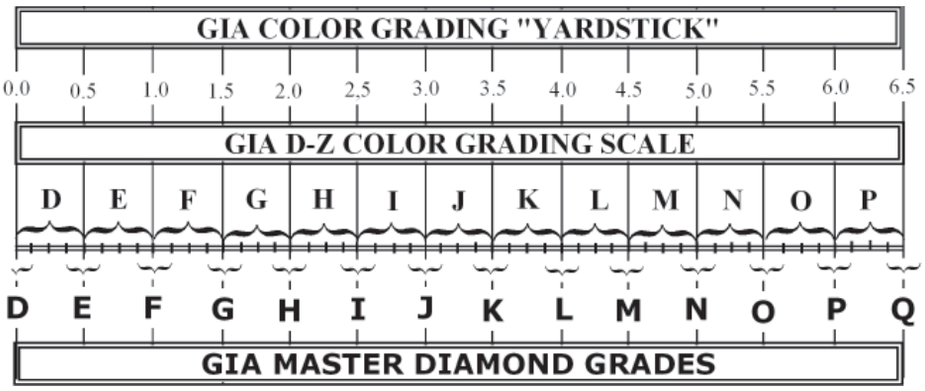

Figure 1: GIA 'yardstick', letter grades and GIA diamond master stone positions which define the letter grades.

diamond colour grading. The relationship between the letter grades, the numerical grades of the GIA 'yardstick', and the position and range of each master grade is shown in *Figure 1*. Notice the numerous brackets indicating the position and range of each grade relative to the GIA colour-grading 'yardstick'.

GIA master diamonds are graded with twice the accuracy of standard grading, so they in turn can be used for standard, whole-letter diamond grading. A master G, for example, is within a quarter grade range around the F/G border (1.5 ± 0.125), compared to the standard grade of G, which has a full grade range between the F/G border and the G/H border (1.5 to 1.999).

There is little to no argument with the view that a third carat or larger, complete set of GIA-graded master diamonds, like those shown in *Figure 2*, is the best tool for accurate colour grading. They are second-generation diamond master stones having been graded against the primary master stone set, which is often referred to as the 'master master' colour grading set at GIA (G. Roskin, pers. comm.)

In *Figure 2* is a complete diamond master stone set of nine, heavy-third carat, ideal cut, whole-grade master diamonds from E to L and N. Because of the expense of retaining diamonds of this size or larger for each colour grade, most small grading laboratories, gemmologist-appraisers and jewellers have purchased only a small number of quarter to third carat masters. Appraisers and laboratories certified by the American Gem Society (AGS) and the Accredited Gemmologist Association (AGA) are required to have at least five GIA-graded masters of a quarter carat or larger.

Prescription for accurate colour grading

A review of the guidelines for the use of GIA-graded diamond masters is important. These instructions help reduce subjectivity caused by the many variables that can affect colour grading. These guidelines are from the organizations, literature and grading manuals of GIA and AGS and from the experience of professional diamond graders.

1. Grading should be done in a lighting environment of diffuse, daylight-equivalent illumination free of coloured reflections from adjacent objects. This can be accomplished by using enclosures like those of the GIA DiamondLite and DiamondDock *(Figure 3)* or, as is often done, by using white-plastic diffusers over the light source and enclosing the diamond in a folded white card.
2. Clean the diamond to be graded and, if needed, also clean the master stones. Especially in the whiter colour grades, any dirt, particularly on the girdle, is liable to lower the apparent colour, possibly by as much as a grade or more.
3. To prevent distracting reflections and dispersion colours, use a dull, flat white background such as the several plastic trays from suppliers of gemmological equipment, the GIA DiamondLite or Diamond Dock trays or accordion-folded white paper or cardboard. A non-fluorescing background is prescribed, but observation of industry practice and personal experience indicates that either non-fluorescent material or common white paper containing a blue fluorescent dye work equally well, as long as they are flat white with no bluish tint under the illumination used in grading.

Figure 3: GIA Diamond Dock, photograph by Jonathan Weingarten

Figure 2: Complete set of GIA-graded diamond master stones from E through L and N.

Figure 4: Foreign buyers area, trading floor of the Israel Diamond Exchange, courtesy Israel Diamond Exchange

4. The GIA's prescription for the grading illumination is daylight equivalent light. In past years, GIA recommended and used in their grading the daylight fluorescent tubes of their DiamondLite. In addition to the DiamondLite, the GIA Diamond Course (GIA, 1994) stated: "Filtered, cool white, balanced fluorescent light is best." The term 'cool white' is associated with northern daylight, as 'warm white' is with incandescent light. Because warm white is roughly every colour temperature from 2000 K to 4000/4500 K, the range of cool white is lighting above 4500 K to the 6500 K of the standard daylight (D65) fluorescent tubes (pers. comm., R. Geurts). (Note that in fluorescent lighting cool colour temperatures begin at the 4100 K of the 'cool white' fluorescent.)

   Many gemmologists employ the small daylight fluorescent with white plastic diffuser attached to their GIA microscopes. Also in wide use by the trade is the eighteen-inch, daylight, 15-watt fluorescent tubes in a standard desk lamp. An example of their use can be seen in *Figure 4* which shows dealers on the trading floor of the Israel diamond exchange.

   Notice that in spite of the available daylight from the large area of North facing windows, and ceiling mounted fluorescents, those examining diamonds are employing the lighting from standard desk lamps.

   True daylight varies widely, but the 4200 K of a cool-white fluorescent to the 5500 K colour temperature of noon daylight, and up to the 6500 K of blue skylight are prescribed for diamond grading. Of this range of daylight colour temperatures, the 6500 K daylight fluorescent tube is a little too bluish-white for some, the author included, who find better colour discrimination under noon-daylight from a fluorescent tube in the 5000 K to 5500 K range. Examples are the 'full spectrum', tubes such as the Ott Light. Excellent colour discrimination can also be made in the 4200 K colour temperature of a cool white fluorescent. The principle is that the illumination, like a diamond's immediate surroundings, should be flat white without a blue or yellow tint. Additionally, all these fluorescent tubes and the ones in the GIA DiamondLite and DiamondDock emit a component of UV, which needs to be considered when grading diamonds that fluoresce from UV excitation, but that is a subject for another article.

5. Place the master stones table down with increasing colour left to right, as in *Figure 5,* in order to look into their pavilions in directions perpendicular to the pavilion facets or parallel to the girdle.

   On the basis of the tone/saturation of its colour, place the diamond being graded between the master stones closest to it. If it fits just above a G master stone, for example, (which the GIA graded to be within a quarter grade of the F/G boundary), the colour grade is F. If it fits just below the G master, the colour grade is G. This procedure assumes a master stone for every grade. Many sets are incomplete, and where there are missing colour masters, visual interpolation of the grade between the surrounding master diamonds is necessary, or the more difficult extrapolation of the grade is necessary if the diamond is outside the colour range of the masters.

Figure 5: Six CZ masters and one diamond (colours E-K) in the tray of the Diamond Dock, photograph by Jonathan Weingarten.

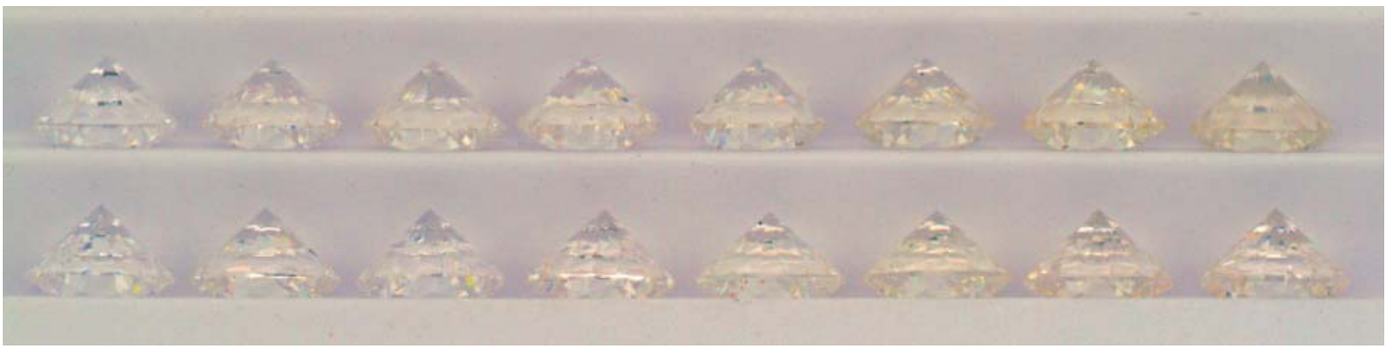

Figure 6: CZ master sets, colours E-L from manufacturer B (top row) and manufacturer A (bottom row).

6. To minimize confusion when comparing the unknown diamond's colour to the masters, these reference diamonds should be of similar well-made cut and proportions. They should be of Cape series, yellow hue, with no distracting inclusions, no more than faint fluorescence, and be similar in size with a minimum 0.25 ct weight. Master stones should not have thick and/or unpolished girdles, as these features can cause confusion. Unpolished girdles trap dirt and metal particles with handling, which can lower their perceived colour a grade or more.

This is the prescription for accurate colour grading using diamond masters. Attention to these instructions aids in reducing the subjectivity in diamond colour grading.

For and against CZ master stones for colour grading

With all the vigilance needed in the use of diamond colour master stones, what are the pros and cons in the use of CZs as masters?

A sidebar from GIA's Diamond Grading Course (GIA, 1994), titled "No CZ for D-Z" makes it clear that GIA writers and educators have advised against the use of CZs as master stones for colour grading. The reasons given are the different yellow hue, confusing reflections from CZ's greater dispersion, the difference in lustre, and the concern over CZ's colour stability. Any case made for the use of CZ masters has to address these concerns.

Large laboratories such as those of the GIA and the AGS have multiple sets of GIA-graded diamond master stones for colour grading. Small laboratories, such as the author's AGA Certified Gem Laboratory, and gemmologist- appraisers, who have obtained AGS's Independent Certified Gemmologist Appraiser (ICGA) designation, are required to grade with at least a five-diamond master set. However, many gemmologist-appraisers, the author included, feel it is necessary to use a complete set comprising each of the most important whole letter grades from E to L or lower.

A sample of 38 gemmologist-appraisers listing their colour grading equipment on the Internet revealed that 16 listed a combination of diamond and CZ master stones, seven listed only CZ, and 15 listed only diamond.

This small sample indicates that many gemmologist-appraisers have found a place for CZ in master stone sets. Many jewellers and others in the industry have employed CZ masters since they became available over 23 years ago. The appeal of CZ Masters is an economic one. Because of the poor economy of tying up large amounts of money in larger diamonds, most master stone sets consist of quarter to third carat sizes of four or more diamonds. Without a master diamond for each grade, visual interpolation or extrapolation is required, which increases the subjectivity of colour grading. In addition, disparity in size makes precise comparison of colour more difficult, and comparing the colour of a small quarter or third carat diamond master to a carat or greater size diamond requires considerable skill only obtained through practice and experience.

Both James Naughter GG FGA of A&A Gemological Laboratory (pers. comm.) and Howard Rubin GG of Gem Dialogue Systems (pers. comm.) relate that they can much more effectively arrive at a colour grade of a carat or greater size diamond using carat size CZ masters than by using the smaller and fewer stones of their diamond master sets. They and others find that a more accurate grade can be obtained with a 10 stone master set of carat size CZs than can be obtained with a small, incomplete set of diamond masters.

Al Gilbertson (pers. comm.), one of the two original AGS, ICGA appraisers with over thirty years experience, states that when on appraisal assignment outside the laboratory, he would take on the road with him a set of CZs that he had checked periodically for accuracy against his diamond master stone set. His diamond masters remained in his laboratory, while he risked only the loss of the relatively inexpensive CZ masters. He would compare his CZ masters once or twice a week against diamonds graded by GIA to develop familiarity and skill in their use. Gilbertson's point was not to shun the use of CZs, but to be practised in their use when the need arose. Periodic practice and checking of CZs raises proficiency in their use and would reveal any possible colour change.

The laboratory of David Atlas GG, President of D. Atlas & Co. Inc. (pers. comm.), employed several sets of CZ master stones in their colour grading and GIA-graded diamond master stones were used to check frequently for any colour change in the CZs.

Several diamond wholesale dealers known to the author use CZ master sets in their buying. The often-narrow margins in their wholesale transactions mean that

a one-grade mistake in colour grading can make the difference between profit and loss. Their success in the practical use of CZs in diamond buying and colour grading is testimony to the accuracy, and usefulness of their CZ masters.

For many, CZs have become a recognized and accepted tool in diamond colour grading. All these examples support the usefulness of CZ masters in the colour grading of diamonds.

Considerations specific to the use of CZ in colour grading

For those who currently use or who are contemplating using CZs for colour grading diamonds, there are a few factors to consider in addition to the guidelines listed for GIA diamond master stones.

Of foremost importance is having a CZ master stone set that is accurately graded against a full, reference GIA diamond master set. The CZs should correspond in tone and saturation and be close in hue to their diamond master set equivalents. The biggest problem is the accuracy and evenness of colour spacing of these master sets. After all, the GIA master diamonds are a 'second generation' having been graded against the 'master master primary set'. The CZ master sets are third generation stones incorporating possible accumulated (or cancelled) errors of two graders.

A revealing test of initial accuracy and evenness of spacing of a ten stone master set of either diamond or CZ is to mix them up, and by eye try to put them back in order of increasing colour. Assuming normal colour vision, if your placing results in the set being out of order, it is the set that is the problem.

In considering the hue differences between CZs used as masters and the yellow tints in type 1a, Cape series diamonds, these are small and not nearly as difficult as comparing the tone/saturation of a pale grey or pale brown diamond with the pale yellow, Cape series, master diamonds. The author and those interviewed for this article found little difficulty comparing the colour of yellow cape series diamonds to the yellow hue of CZ masters.

Addressing the concern for the colour stability of CZ, the experience of the author and of other owners and CZ-master manufacturers is that the type of CZ material used by the two main suppliers, one for over 22 years, has proved to be largely stable under normal care and use.

The differing absorption spectra of diamonds and CZ raises concern for possible colour shifts (called metameric failure) in different illumination environments. A way to avoid this possibility is by grading (and periodic checking and recalibrating against diamond masters) under lighting similar to illumination the manufacturer of the CZ set recommends and uses in his initial grading. Experiments by this investigator, grading in five different lighting environments, yielded the same colour grading determinations. This finding reduces the concern for possible colour shifts, as there was no apparent metameric failure. Relative to the diamond masters, no colour shifts of the CZs were observed.

Evaluation of CZ master stone sets

To provide a preliminary assessment of currently available CZ master stone sets, a number were obtained from several different vendors of gemmological equipment. All these suppliers carry CZ sets from either or both of two sources, designated A and B in this study. Purchased were eight, 10 stone sets, four from each manufacturer. The purpose was to evaluate the accuracy of the sets.

This investigator graded each set against a background of accordion-folded flat white paper with his complete diamond master set. To check for any possible colour shift in different lighting due to CZ's different absorption spectrum and varying small amounts of yellow fluorescence, the grading was done for each stone in five different lighting environments. These were a daylight fluorescent, a daylight fluorescent through a lexan plastic filter to remove UV, a cool white fluorescent, a 'full spectrum' fluorescent, and a white LED lamp.

Using all five lighting environments, the author found the same colour determination in each of these illuminations. This established that CZ's different absorption spectrum and varying amounts of fluorescence did not result in colour changes (metameric failure) large enough to cause additional error in colour grading.

Experimenting with these five different lighting environments resulted in the surprising finding that colour differences were more apparent and colour comparisons were more easily made in cool white and 'full spectrum' fluorescent lighting (colour temperatures from 4200 K to 5500 K). Colour differences of a grade or less were more difficult to see and evaluate in the slightly bluish-white daylight fluorescent and the LED lighting (colour temperatures 6500 K and above). This finding is interesting, because, on one hand, it is at odds with the widespread prescription for north daylight equivalent (6500 K) lighting (Bruton, 1978), while on the other hand, it supports GIA's Diamond Course (GIA, 1994) statement: "Filtered, cool white, balanced fluorescent light is best." The author suggests trying both to find a personal preference.

The B master sets contained the master stones D through L and N, while the A sets contained the stones E through N. The sets were evaluated as a 10 stone whole, and then re-scored for the more important eight grades E through L, shown in *Figure 6*, which both sets have in common.

The author graded all eight sets, and David Atlas and James Naughter graded four sets apiece, two from each manufacturer, and the results are given in *Table I*. It is important to acknowledge that the errors measured are a combination of errors in the manufacturers' gradings, differences between our three master stone sets, and any errors in grading by the three of us. The author had the advantage of a full set of diamond master colour grades, while James Naughter used a GIA and AGS graded five diamond master set, and David Atlas used a full set of CZs graded

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Table I: Results of grading by D. Atlas (DA), M. Cowing (MC) and J. Naughter (JN) of four A (A1-4) and four B (B1, 3, 5, 7) CZ master stone sets.

Set	Grader	D	E	F	G	H	I	J	K	L	M	N
A1	MC	-	Hi E	E/F	E	F/G	Hi I	Hi J	H/I	I(<J)	K	N
	DA	-	D	E	F	G	H	I	J	K	M	O/P
A2	MC	-	Hi D	D	E	F/G	F	H/I	Hi K	K	L	L/M
	JN	-	Hi D	D	Hi H	I	Hi J	K	Hi L	L	Lo L	M
A3	MC	-	D	Hi D	E	Hi F	Hi G	Hi I	K	Lo K	K	O
	DA	-	E	E	F	G	H/I	J	L/M	M	N	O/P
A4	MC	-	Hi D	Hi D	Hi F	Hi G	Hi G	K	K	Lo K	M	L/M
	JN	-	Hi D	Lo D	Lo E	Lo G	Hi H	J	K	Hi L	M	N/O
B1	MC	D	E	Hi F	G	Hi H	Hi I	Hi J	K	Hi L	-	N
	DA	D	E	F	F/G	H	I	J	K	L/M	-	O
B3	MC	D	E	E	F/G	G/H	H/I	Hi J	Hi K	Hi L	-	N
	DA	D	E	E	G	H	I	J	K	L/M	-	N/O
B5	MC	D	E	Hi F	Hi G	H	Hi I	Hi J	Hi K	K	-	M
	JN	Hi D	Hi E	Hi F	Hi G	Hi H	Hi I	Hi J	Hi K	Hi M	-	N
B7	MC	D	E	E/F	F/G	Hi H	Hi I	I	K	L	-	O
	JN	Hi D	Hi E	Lo E	F/G	Hi H	Hi I	Lo I	Lo K	M	-	N

against diamond masters and including a GIA H master diamond. On any given stone, our errors may increase or decrease the true manufacturer error adding uncertainty to this measure. However, the results, including the total average error in comparing the group of four sets from each manufacturer, do indicate a sufficiently accurate evaluation that shows the relative accuracy and consistency of the sets from each.

Two measures of error were used to evaluate the eight CZ master sets, the second being twice as demanding as the first. The first measure is normal colour grading, meaning the determination whether each CZ is within or at the top of its grade. This measure scores each CZ as either zero error if a stone is within or at the top of its stated grade or, if outside the grade, the number of grades it is off.

This first error measure, which determines how close the CZs were to their labelled grades, finds that the A sets have an average per stone error, over the most important eight grades, of 1.36 grades (scoring of author, MC) and 0.88 grades (scoring of David Atlas, DA and James Naughter, JN). In comparison, the B sets have an average per stone error of 0.09 grades (MC) and 0.13 grades (DA and JN).

The second and more critical error measure, which determines how close the CZs were to the diamond master stones they represent, finds that the A sets have an average per stone error over the most important 8 grades of 1.16 grades (MC) and 0.80 grades (DA and JN). In comparison, the B sets have an average per stone error of 0.19 grades (MC) and 0.38 grades (DA and JN).

On the basis of this survey therefore, the B sets are the more accurate. In addition to having higher accuracy, the B sets also have the more even spacing between the grades. Due to this even spacing, no two grades were too close and it was possible to scramble the B sets and, by eye, put them back in correct order.

Having said this, it is important to state that this survey was carried out on only a small sample of sets purchased in 2008,

Table II: Closeness of CZs to their labelled grades; errors measured in units and decimal points of one grade.

Set A					
Set	Grader	10 error ave.	Worst error in 10	8 error ave.	Worst error in 8
A1	MC	1.25	2.5	1.31	2.5
	DA	0.95	1.5	1	1
A2	MC	1.45	3	1.5	3
	JN	1	1	1	1
A3	MC	1.5	3	1.5	3
	DA	0.85	2	0.75	2
A4	MC	1.05	2	1.13	2
	JN	0.8	1.5	0.75	1.5
A#	MC	1.31	3	1.36	3
	DA & JN	0.9	2	0.88	2

Set B					
Set	Grader	10 error average	Worst error in 10	8 error average	Worst error in 8
B1	MC	0	0	0	0
	DA	0.1	1	0	0
B3	MC	0.1	1	0.13	1
	DA	0.1	1	0.13	1
B5	MC	0.2	1	0.13	1
	JN	0.1	1	0.13	1
B7	MC	0.2	1	0.13	1
	JN	0.2	1.	0.25	1
B#	MC	0.13	1	0.09	1
	DA & JN	0.13	1	0.13	1

N.B.: A# = average for all stones, or worst in all stones
B# = average for all stones, or worst in all stones.
DA denotes D. Atlas, MC denotes M. Cowing and JN denotes J. Naughter

Table III: Closeness of CZs to their equivalent diamond master stones; errors measured in units and decimal points of one grade.

A					
Set	Grader	10 error ave.	Worst error in 10	8 error ave.	Worst error in 8
A1	MC	1	2.5	1	2.5
	DA	0.65	2	0.5	0.5
A2	MC	1.05	2.5	1.13	2.5
	JN	1.2	1.5	1.25	1.5
A3	MC	1.28	2	1.23	2
	DA	0.95	2	0.75	2
A4	MC	1.18	2	1.29	2
	JN	0.71	1.5	0.7	1.2
A#	MC	1.13	2.5	1.16	2.5
	DA & JN	0.88	2	0.8	2

B					
Set	Grader	10 error average	Worst error in 10	8 error average	Worst error in 8
B1	MC	0.25	0.5	0.19	0.5
	DA	0.6	1.5	0.5	1
B3	MC	0.2	0.5	0.13	0.5
	DA	0.6	1	0.56	0.5
B5	MC	0.25	0.5	0.19	0.5
	JN	0.1	1	0.13	1
B7	MC	0.4	1.5	0.25	0.5
	JN	0.32	1.5	0.34	1.5
B#	MC	0.28	1.5	0.19	0.5
	DA & JN	0.41	1.5	0.38	1.5

N.B.: Symbols as in Table II.

whose dates of assembly are not known. It may be, for example, that the A and B sets were assembled at different times. The implications of this survey for sets in the future are not quantifiable by the author.

Conclusions

The main benefits of this study are in showing the practical use of accurately graded CZ master stone sets, and the factors and methodology in their proper use, demonstrating the importance of verifying the initial accuracy of the set, and making periodic checks against full, diamond master colour grading sets to ensure retention of that accuracy.

Interested gemmologist-appraisers are encouraged to explore for themselves why CZ masters have found a place in the colour grading of diamonds. This investigation finds that CZ masters have a contribution to make in reducing the subjectivity of diamond colour grading when, as is frequently the case, the available diamond masters are relatively small in number and/or size. The study findings and results also support the argument that an accurate and complete set of CZ masters can, by themselves, be effectively employed in diamond colour grading, if periodically checked for retention of that accuracy.

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The geological context of gems in the Velasco Pegmatitic District, Argentina

Fernando Guillermo Sardi

Abstract: The Velasco Pegmatitic District is located in the Velasco range, La Rioja province, northwestern Argentina. The Velasco range is made up of several granitic units of different petrography, magmatic evolution and age among which are the Huaco and Sanagasta granites. The pegmatites in the Velasco district have a spatial and genetic relationship with these granites and belong to the rare-element class, beryl type, beryl-columbite-phosphate subtype. The pegmatites are usually zoned and the K-feldspar zone is generally the most important for gem-quality beryl. Heliodor and aquamarine varieties are present and these crystals can be cut to yield products of attractive beauty. Other beryl crystals with poor transparency can be utilized for cabochons or tumble polished. Rock-crystal and rose-quartz are also present in some pegmatites from the Velasco district.

Keywords: aquamarine, gemstone, heliodor, pegmatite, rock crystal, rose quartz, Velasco range

Introduction

The Velasco range is located in the central region of La Rioja province, northwestern Argentina *(Figure 1)*. It is the largest mountainous unit of the geological province of the Sierras Pampeanas, which is characterized by large volumes of crystalline rocks of several origins and ages.

Beryl-bearing pegmatites are found in the Huaco Granite (Toselli *et al.*, 2000) and in the Sanagasta Granite (Grosse and Sardi, 2005). For this reason, each granite is considered a lithological guide to possible gem occurrences (Sardi, 2005). Both granites have mainly porphyroid textures, without signs of deformation. Their outcrops occupy much of the central-north and central-east zones of the Velasco batholith *(Figure 2)*. The Huaco Granite covers 620 km^2 and the Sanagasta Granite 240 km^2 (Grosse and Sardi, 2005), and the Huaco Granite contains more Be-pegmatites than does the Sanagasta Granite.

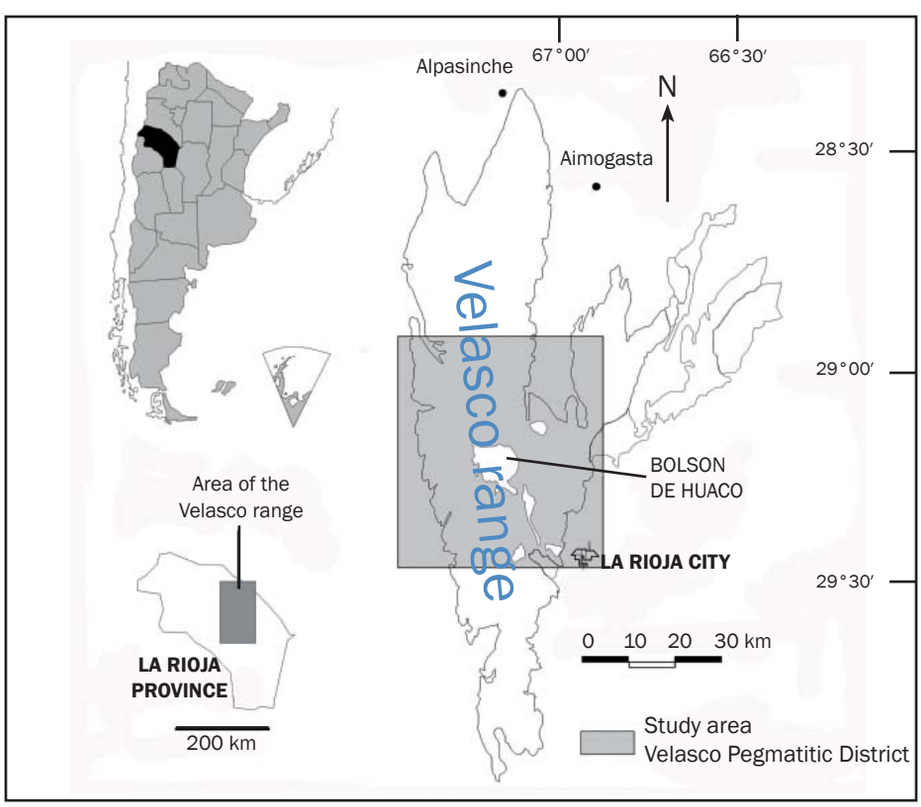

Figure 1: Location of the study area. On the right is the outline of the Velasco Range, and the indicated study area.

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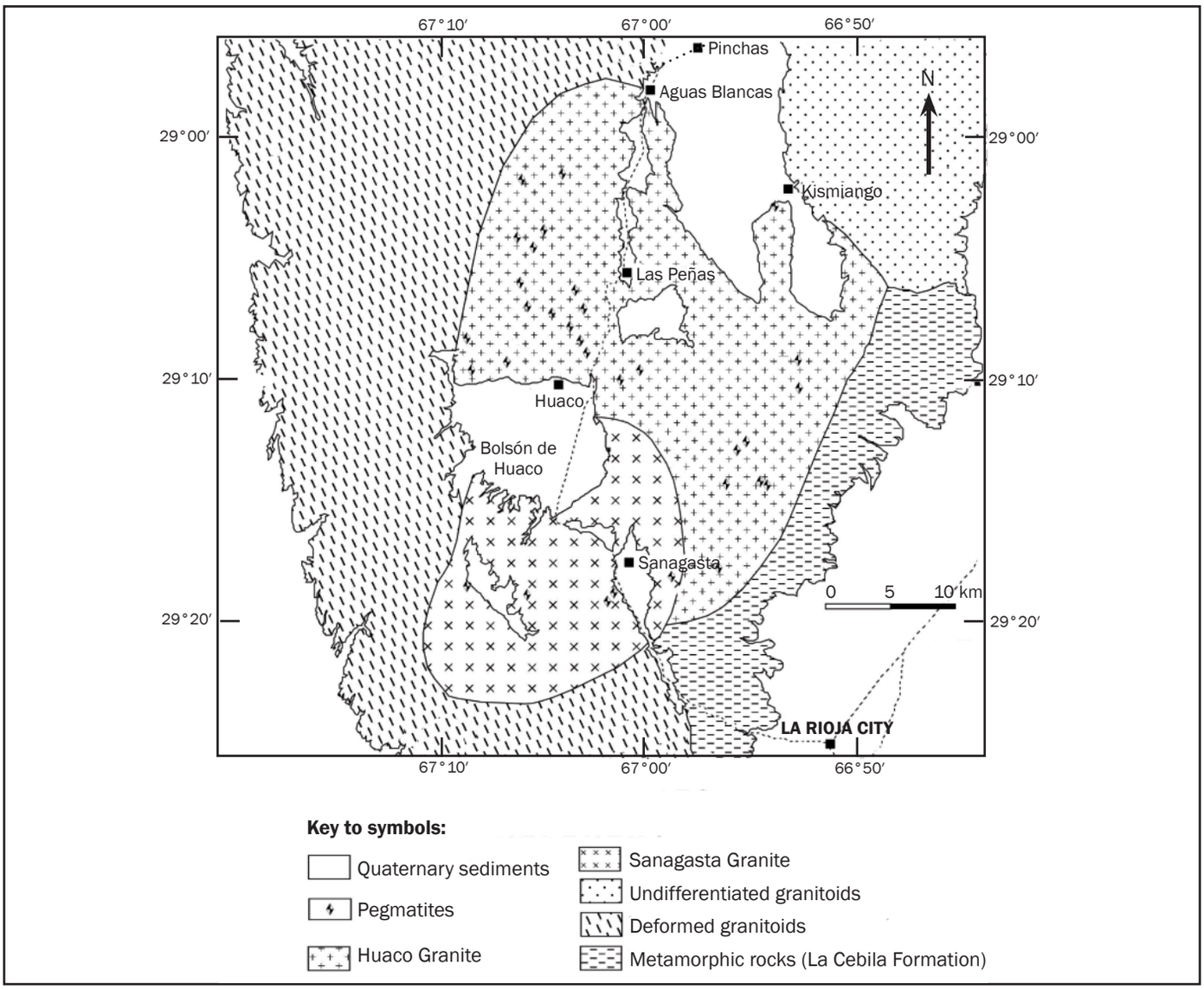

Figure 2: Simplified geological map of the Velasco Pegmatitic District. Modified from Sardi and Grosse (2005). Bolson de Huaco is an area which is a topographic depression covered with Quaternary sediments.

The pegmatites lie in the Velasco District of the Pampean Pegmatitic Province as defined by Galliski (1994). Herrera (1968), in a local classification, grouped the pegmatites from the Pampean Pegmatitic Province into four categories following a course of fractionation from 'type 1', barren pegmatites with oligoclase, to 'type 4', highly evolved with Li mineralization. In this case, the pegmatites from Velasco District correspond to the 'type 3' which is characterized, in general, by a simple zonal structure, by high diversity and abundance of accessory minerals, and by the appearance of a phase of substitution of potassium by sodium. Subsequently, they have been classified, according to Cerný (1991) as belonging to rare elements class; beryl type and beryl-columbite-phosphate subtype (Galliski, 1994; Sardi and Grosse, 2005).

The aim of this communication is to record some gem-quality minerals in the pegmatites. Most are beryl, and of lesser importance is quartz. Beryl is an accessory mineral in the Velasco pegmatites and has been extracted only sporadically and in an inconsistent manner during the last century. At the moment only gem-quality stones are being recovered. Mineralogical and gemmological studies of such deposits in the area are very scarce, and the data presented below are preliminary, and represent a beginning for more detailed research.

Geological setting

The Velasco range consists of a mixture of Palaeozoic granitic rocks of different origins and evolutions. Such rocks of I-type affiliation in the south and granitoids of S-type affiliation towards the centre and north of the range can clearly be distinguished (Toselli *et al.,* 2002, 2005; Bellos, 2005). In the south, the granitoids are granodioritic and tonalitic with hornblende and magnetite as accessory minerals, and per- and meta-aluminous tendencies in their compositions; while in the north, the rocks are shallow magmatic porphyroid granites with two micas, and with a per-aluminous character. The plutons in the centre and north of the

Velasco range comprise the Aimogasta Carboniferous Batholith (Toselli *et al.,* 2006) and they are intrusive into deformed orthogneisses of Ordovician age and also commonly into protomylonites and mylonites of Ordovician to Devonian age (Toselli *et al.,* 2006).

On the east flank of the Velasco range, the La Cebila Formation is represented by sporadic outcrops of meta-pelites and meta-psammites. These sediments are of Upper Precambrian – Lower Cambrian age (Aceñolaza *et al.,* 2000), and their metamorphic grade does not exceed greenschist facies. In the extreme north of the range, contact metamorphic rocks appear whose mineral association indicates nearby shallow-level granitic intrusions (Rossi *et al.,* 1997).

The Huaco (Toselli *et al.,* 2000) and Sanagasta (Grosse and Sardi, 2005) Granites make up the whole of the Aimogasta Carboniferous batholith. Petrographically, their main characteristic is a porphyroid texture with megacrysts of perthitic microcline, in some places making up to 50 % of the rock (Sardi *et al.,* 2002). These megacrysts are white in the Huaco and pink in the Sanagasta Granites. The Sanagasta granite's K-feldspar megacrysts are occasionally mantled by plagioclase generating a Rapakivi-like texture (Grosse and Sardi, 2005; Grosse *et al.,* 2008). Another difference is that the Sanagasta Granite has a higher biotite/muscovite ratio than the Huaco Granite. The matrix is essentially composed of quartz, microcline, plagioclase, biotite and muscovite. The geochemical studies made by Grosse *et al.* (2008) indicate the granites to be silica-rich, potassium-rich, ferroan and alkali-calcic to slightly calc-alkalic. U-Pb monazite age determinations on Huaco and Sanagasta Granites indicate Lower Carboniferous crystallization ages and the isotopic and geochemical studies indicate a mainly crustal source, possibly similar to the Ordovician peraluminous metagranitoids which are nearby (Grosse *et al.,* 2008).

Velasco District pegmatites

The Velasco District has numerous pegmatite bodies that are developed immediately north, east and south of Bolsón de Huaco (see explanation in the caption of *Figure 2*). The area of the Velasco Pegmatitic District is occupied by the Huaco and Sanagasta Granites and the Be-pegmatites have a spatial relation with them *(Figure 2)*. These bodies present more or less homogeneous characteristics as to their structures and mineral composition. According to Sardi *et al.* (2002), their contacts with the granitic host-rock are sharp.

The lengths of the pegmatites are no greater than 250 m and most consist of a marginal-external zone, an intermediate zone and core of quartz (Sardi, 2005). The marginal-external zone wraps around the coarse-grained minerals in the pegmatite. It is aplitic and/or equigranular fine- to medium-grained leucogranite and is composed of quartz, microcline, plagioclase, tourmaline, muscovite, biotite, apatite, and topaz (Sardi, 2005). The intermediate zone contains mainly quartz with microcline and/or plagioclase, with microcline being the more common; perthitic and graphic textures are also common. The accessory minerals in this zone are muscovite, scarce biotite, apatite, triplite, beryl and tourmaline (Sardi, 2005). Herrera (1971) and Ricci (1971) had already reported garnet, fluorite, columbite-tantalite and wolframite which can be added to this list. The core of the pegmatite is massive quartz, usually grey but some is pink. Here, the accessory minerals are very scarce: tourmaline, muscovite and beryl (Sardi, 2005).

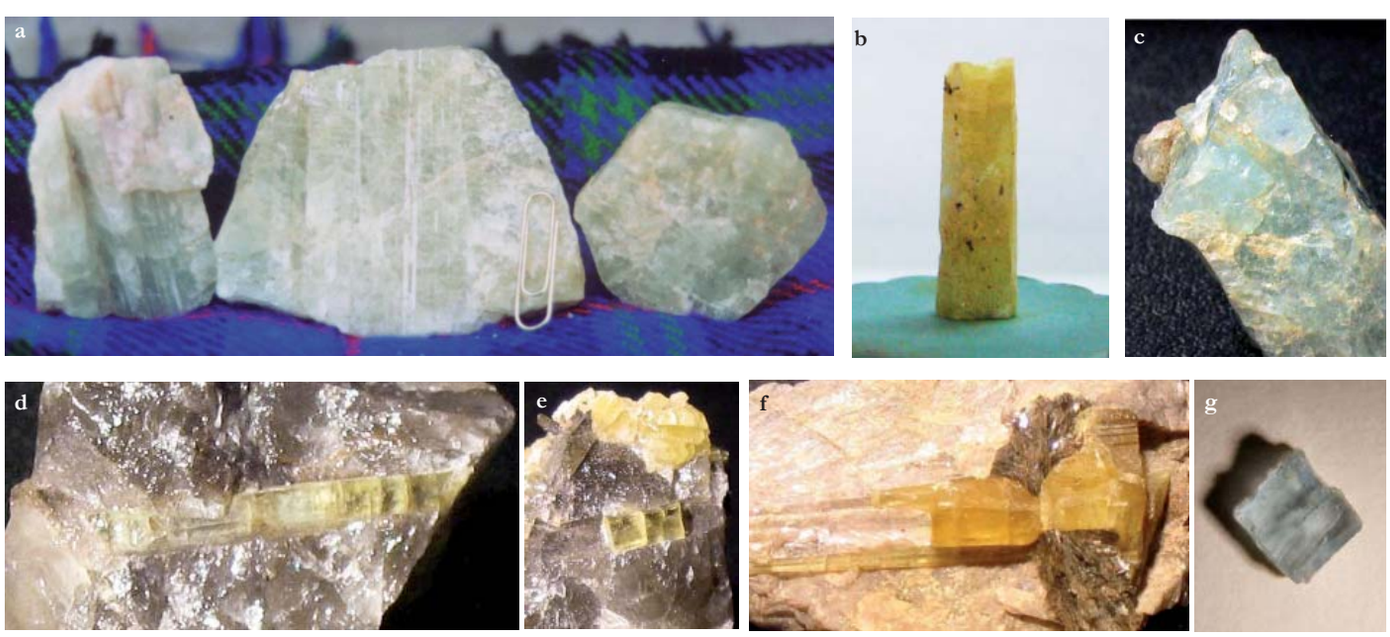

Figure 3: Beryl from the Velasco Pegmatitic District.
Milky beryl: (a) Green and pale green beryl; the left and centre fragments show striated faces, and in the one on the left a hexagonal contour is visible. Width of image 12.2 cm. (b) Idiomorphic yellow beryl. Width of image 3.2 cm. (c) Pale blue (turquoise colour) beryl – aquamarine. Width of image 0.6 cm.
Translucent and transparent beryl: (d and e) Heliodor varieties, associated with grey quartz. Width of images: 1.5 cm and 0.6 cm respectively); (f) Heliodor with feldspar and mica. Width of image: 1.7 cm. (g) Fragment of aquamarine. Width of image 1.8 cm.

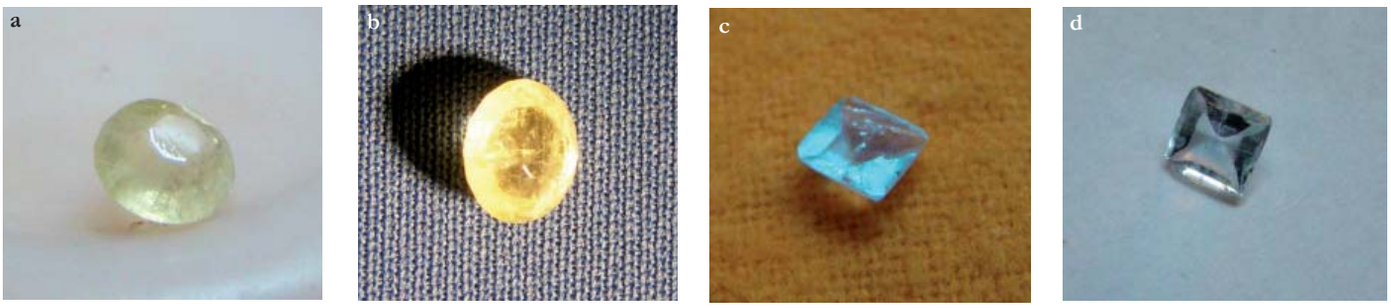

Figure 4: Faceted examples of heliodor and aquamarine. (a and b) Heliodor, 7 mm long, on different backgrounds and under different lights; weight 0.615 ct. (c and d) Aquamarine, 5 mm square, on different backgrounds and under different lights. Weight 1.279 ct.

Gemstones

Beryl

Beryl is generally concentrated in the intermediate zones associated with anhedral quartz, clusters of muscovite and K-feldspar (Sardi, 2005). Most beryls are green, yellow and pale blue *(Figures 3a, b and c)* but varieties of colourless beryl are very scarce and are associated mainly with quartz. The beryls are idiomorphic, and have vitreous lustre and conchoidal fracture. According to Sardi (2005), most are well-developed hexagonal prisms, some with vertically striated faces *(Figure 3a)*. The most common forms are first-order prisms and basal pinacoids, although some crystals appear wedge-shaped. The mineral size is variable. Transverse sections of the crystals measure up to 6 cm and the longest crystals are up to 12 cm. When the mineral is associated with muscovite, beryl is thin and long, but in association with grey quartz it is thicker. A poor cleavage can be present parallel to (0001). Only rarely does it have inclusions of other minerals such as tourmaline, quartz and muscovite.

The economic importance of beryl from the Velasco Pegmatitic District lies in its gem quality (Sardi, 2005). The yellow variety of beryl, heliodor, has total transparency, scarce fractures and is free of inclusions of other minerals *(Figures 3d, e and f)*; pale green and pale blue aquamarine *(Figure 3g)* reach lengths of about 3 cm. The almost total absence of fractures in heliodor and aquamarine can permit their cutting and polishing to give beautiful and attractive stones *(Figures 4a, b, c and d)*. Some gem-quality crystals of beryl may be so embedded in quartz that it is difficult to extract them without fracturing; these may be more desirable and valuable for mineral collectors as heliodor or aquamarine in matrix. Goshenite is very scarce and small in size relative to heliodor, and thus is less important.

Non-gem-quality crystals of beryl are of greater size and range from translucent or semi-translucent to milky. They have only minor commercial value, and some may be cabochon cut or polished by tumbling. Gem-quality crystals are considered to have originated in the later stages of cooling and crystallization of the pegmatitic cavity and may be secondary or recrystallized.

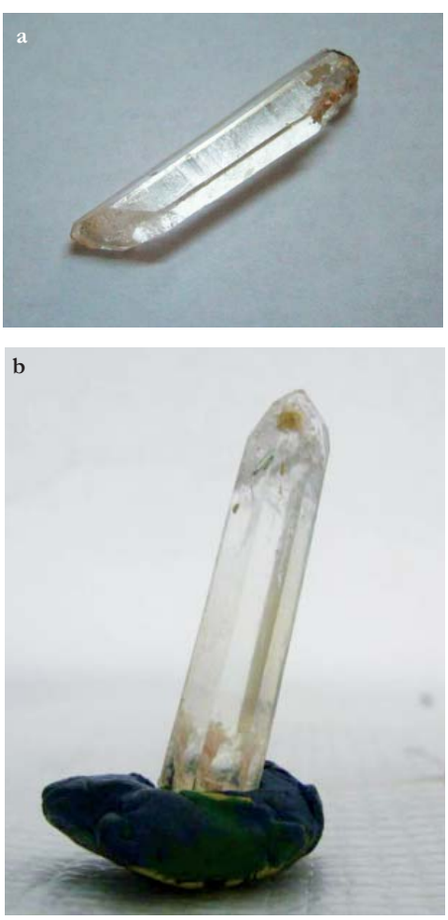

Figure 5: (a and b) Typical rock crystal, 42 mm long, on different backgrounds and under different lights; weight 4.2252 g; (c) A specimen of rose quartz, 96 mm high, with a rough top and polished sides.

Quartz

There is more than one generation of quartz in the pegmatites and the gem-quality quartz is considered to have been formed during the later pegmatitic (or hydrothermal) stage. The variety rock crystal has been found in the intermediate zone of the pegmatites in association with K-feldspar. It is colourless, entirely transparent, idiomorphic with hexagonal contours and without inclusions. Crystals reach 4.2 cm in length and 1 cm in width *(Figure 5a and b)*. Rose quartz has been

found in pegmatites in the Sanagasta Granite, generally forming part of the core-quartz of the pegmatites *(Figure 5c)*. It is coarsely crystalline and in some is very transparent and free of inclusions. The quartz gems are secondary in importance to the beryl.

Conclusions

At present, gem-quality beryl and quartz can be recovered from the pegmatites of the Velasco District (Argentina). Most of the gem beryl occurs in idiomorphic prisms of yellow, green or pale blue, in sizes up to 12 cm in length, and with different degrees of transparency. Some crystals of heliodor and aquamarine are large enough to have commercial value. The formation of the gems is attributed to crystallization in the late stages of pegmatitic evolution. Future studies, especially of a thermometric nature, could yield further insight into their origin. Gem-quality quartz in these pegmatites occurs as rock crystal and rose quartz.

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Magnetic susceptibility, a better approach to defining garnets

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Abstract: Using a new, non-destructive method of gem testing, magnetic susceptibility, the authors show how the major end-member composition of any garnet may be confidently predicted by plotting RI against measured susceptibility. On this diagram, eight end-member garnets are plotted, so that any measured garnet can be placed in an appropriate ternary area. This method shows how previous methods of identifying garnets — by their colour, RI and spectrum — are insufficient to accurately identify chemistry in the garnet group. Furthermore, it can be done with inexpensive equipment available to most gemmologists.

Keywords: garnet, gem testing, magnetic susceptibility, refractive index, specific gravity, UV-Visible spectra

Spessartite garnet. Photo by R. Weldon.

Introduction

Most gemmologists classify garnets based on their colour, refractive index (RI) and absorption spectrum[1,2,3,4,5,6,7]. As new sources and new gem varieties of garnet are discovered, and as our information on garnet chemistry increases, problems with the present gemmological classification become more apparent[8]. The practising gemmologist needs a better means for characterization of garnets to avoid such problems. In this article, the authors will show how any gemmologist can closely infer the major end-members composition of a garnet — without expensive or high-tech equipment.

Two of the authors introduced a new method of gem testing — magnetic susceptibility — in a recent paper[9]. Due to the presence of transition metals in many garnets, the garnet group provides an interesting range of stones to which this method can be applied. Our research further confirmed that far more accurate garnet composition can be revealed in this way than was previously possible with only conventional gemmological testing equipment. Few non-destructive tests can give a better idea of the chemistry. When the RI is plotted against magnetic susceptibility, a more complete picture of a garnet's chemistry can be made. While this new characterization technique raises questions about the current nomenclature and classification of gem garnets, we will stick to the chemistry and leave nomenclature and classification to future debate.

Most modern gemmological texts identify six garnet end-member species; the pyralspite group — pyrope, almandine and spessartine; and the ugrandite group — grossular, andradite and uvarovite[8,10,11]. A garnet species in its theoretical pure form is referred to as an end-member, however they have not been found pure in nature. Natural garnets are always a mix of several end-members, typically with three to five species of significant quantity[12]. The mineralogist recognizes fifteen garnet end-members — some of which exist only in theory[12]. In this article we will consider eight of them, adding knorringite and goldmanite to the more familiar six *(Table I)*. The mineralogist names any of the mixed garnets by the name of the dominant end-member[12]. Thus, although a pyrope may contain less than 50% of the pyrope molecule, it can still be the dominant component when more than two end-members are present, which is commonly the case.

Due to the difficulty of getting sufficient compositional information quickly and easily, gemmology has generally followed a different nomenclature, opting to define nine varieties of garnets: pyrope, pyrope-almandine, almandine, almandine-spessartine, spessartine, spessartine-pyrope, grossular, grossular-andradite, and andradite[5,6,7]. Uvarovite is normally not included as it has limited gem significance. To date, gemmologists have not come to an agreement on what value of RI should mark the separation between

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Table I: Properties and chemical formulae of the end-member garnets considered in this paper.

End-member	RI	SG (calc.)	Volume susceptibility (k) (calc.) × 10^{-4} SI	Chemistry
Pyrope	1.714	3.582	-0.225	$Mg_3Al_2Si_3O_{12}$
Almandine	1.829	4.315	40.7	$Fe_3Al_2Si_3O_{12}$
Spessartine	1.799	4.197	47.45---	$Mn_3Al_2Si_3O_{12}$
Grossular	1.734	3.594	-0.225	$Ca_3Al_2Si_3O_{12}$
Andradite	1.887	3.859	30.76	$Ca_3Fe_2Si_3O_{12}$
Uvarovite	1.865	3.850	12.9	$Ca_3Cr_2Si_3O_{12}$
Goldmanite	1.834	3.765	6.9	$Ca_3V_2Si_3O_{12}$
Knorringite	1.875	3.835	13.68	$Mg_3Cr_2Si_3O_{12}$

N.B. [12, 18]

these arbitrary boundaries in the garnet chemistry continuum[8]. Adding further to the confusion, gemmologists classify, mostly by colour, eight commonly-used trade names of these nine varieties; chrome pyrope, rhodolite, malaia, colour-change pyrope-spessartine, tsavorite, hessonite, topazolite, Mali and demantoid[5]. Note that these are their gemmological classes, not mineralogical classes. With trade names, it becomes yet more complicated, but no more accurate.

From our studies, we do not believe that gemmologists, relying only on RI, spectrum, and colour can reliably — or consistently — allocate the correct species or varietal name to a garnet being studied. Gemmological texts often imply, for example, that tsavorite, because it is coloured by vanadium and/or chromium, is allochromatic, when in fact it is a combination of garnet end-members that creates the colour. Very often there is a third (or even more) end-member present, that while less than 10% in quantity, can yet affect the RI and colour in such a way as to lead to a false conclusion by the traditional methods. Problems with the current state of affairs will become apparent later in this paper.

History

The mineralogical literature abounds with papers on the garnets[12]. Much of the information has limited relevance to gemmology in the classification and identification of gem garnets, as stones of gem quality comprise only a very small proportion of the whole, and gemmological identification methods must be non-destructive. In a series of articles on the garnets, Manson and Stockton [1,2,4] and Stockton and Manson[3,5] presented an in-depth study on 202 transparent, gem-quality garnets that is invaluable to gemmologists for presentation of the chemistry and physical properties of each of the studied garnets. In their final paper of the series[5] (p.215), they set the precedent for the garnet classifications currently in use.

Manson and Stockton obtained their accurate garnet chemistry analyses using microprobe equipment not available to the average gemmologist. It should be noted that while they measured the specific gravity (SG) of each gem, they do not use SG at all in characterizing gem garnets[5]. In fact, they state (p. 216): "Although we generally discourage the use of this property in gemmology, it nevertheless can provide some useful indications." We will see why they may have done this later on.

Mineralogists often use another method of quantitative measurement of garnet, — its unit cell length. This measurement of the length of one edge of the unit cell, from X-ray diffraction data, is not practical for the gemmologist. Sriramadas[13] has published eight ternary diagrams for the garnet group showing RIs and unit cell lengths on the triangles. Winchell[14] notes that ternary diagrams are mostly used to estimate composition from measured physical properties, but that generally there are too few properties to uniquely define the composition. Using the garnet group as an example, he shows how treating two physical properties as independent variables, one can plot the compositions, and yet another physical property on the same graph. In essence, one can put the information of the eight plots of Sriramadas, on one graph. Winchell[14] uses RI and cell length on the Y and X axes, and shows SG variation within each ternary diagram, which now becomes a general triangle. He recognizes, as others have, that SG is not a very reliable measurement for determining chemical composition.

The Manson and Stockton papers[1,2,3,4,5] note that virtually all gem garnets can be described by five end-members; namely, pyrope, almandine, spessartine, grossular, and andradite. Deer *et al.*[12] note that these five members usually make up more than 99% of any garnet's composition. This will be important in what follows. Stockton and Manson[5] also note that Cr^{+3}, V^{+3} and $Ti^{+3,+4}$, although important for colour in some garnets, can be treated as trace elements, and not as components of other end-member gem garnets, at least for this method of classification.

Johnson *et al.*[6] add another important contribution to gem garnet chemistry with a paper on the Mali grossular-andradite garnets. These gems are ugrandites with typical yellow-green stones averaging about 80% grossular, 18% andradite and 2% pyrope. It is important to note that these are typically strongly zoned; hence, their physical properties will vary as well as their colour across the zonation. In these Mali garnets, pyrope is typically 2 to 3% with almandine and spessartine much less. They noted that mineralogists may use physical properties such as unit cell length, RI and SG to determine garnet composition from end-member values, and tested how well their data served to match determined chemistry. They found that, for the Mali garnets, RI correlated well with the garnet chemistry, while there was poorer correlation with other physical properties, especially SG which was determined hydrostatically. It would be expected that since the Mali garnets are almost entirely grossular-andradite, only one property is needed to define the chemistry and RI would do this.

Adamo *et al.*[7] recently described correlations between physical properties and chemistry for 17 gem-quality garnets in both the ugrandite and pyralspite groups, and also examined IR spectral features to see what they may contribute to classification of the garnets. They concluded that IR spectra, in particular, permit discrimination between the pyralspite and ugrandite series. Their data generally agree with what was found by Manson and Stockton[1,2,3,4,5]. Three hessonites contained from 84.5 to 92.75% grossular with andradite the other major component at 5 to 14%. Pyralspite members were under 2.1%. The two tsavorites measured showed about 90% grossular, and 4% goldmanite (vanadium garnet). Of ten pyralspites measured, grossular contents ranged from 0 to 6.15%, the andradite component was generally under 1% but in one sample was 8.3%. Uvarovite reached 1.7% in a chrome-pyrope, and goldmanite 3.65% in a colour-change pyrope-spessartine. The chromium content of a garnet may be expressed as either uvarovite or knorringite, but since knorringite is stable only at very high pressures (greater than 70-100kbar)[12], the chrome in most gem garnets is probably better considered as part of the uvarovite end member. An important exception may be in some gem chrome pyrope.

Adamo *et al.*[7] used the same garnet nomenclature as Stockton and Manson[5] but added the variety grossular-andradite, based on the work of Johnson *et al.*[6]

It was in 1933 that Winchell divided the garnet group into two series composed each of three major garnet species — the ugrandite series (uvarovite, grossular, andradite), and the pyralspite series (pyrope, almandine, spessartine). These two mineralogical series do not appear to be as well known to gemmologists as they should be. Although complete solid solution between natural members of each series was believed possible, there appeared to be a compositional gap between them. Modern studies on the garnets have shown there to be more miscibility between the various garnet end-members than previously thought but the two series do show structural differences and most gem garnets appear to fall within or close to one series or the other.

Table II: Some paramagnetic ions, their valencies, effective magnetic moments, and the square of the moment, which is proportional to the magnetic attraction.

Ion	Magnetic moment (experimental)	Magnetic moment squared (relative attraction)
Transition elements:		
Fe^{3+}, Mn^{2+}	5.9	34.8
Fe^{2+}	5.4	29.2
Mn^{3+}, Cr^{2+}	4.9	24.0
Co^{2+}	4.8	23.0
Cr^{3+}, V^{2+}	3.8	14.4
Ni^{2+}	3.2	10.2
V^{3+}	2.8	7.84
Cu^{2+}	1.9	3.61
Ti^{3+}, V^{4+}	1.8	3.24
Rare-earth elements:		
Dysprosium Dy^{3+}	10.6	112.
Holmium Ho^{3+}	10.4	108.
Erbium Er^{3+}, terbium Tb^{3+}	9.5	90.
Gadolinium Gd^{3+}	8.0	64.
Thulium Tm^{3+}	7.3	53.
Ytterbium Yb^{3+}	4.5	20.
Neodymium Nd^{3+}, praseodymium Pr^{3+}	3.5	12.2
Europium Eu^{3+}	3.4	11.6
Cerium Ce^{3+}	2.4	5.7
Samarium Sm^{3+}	1.5	2.2

Magnetic measurements

Modern understanding of magnetism shows that it arises from the motion of electrons in atoms in the same way that an electrical current in a wire produces a magnetic field about the wire. Within the atom, electrons move in orbits about the nucleus and also spin. Both of these motions produce very small magnetic dipole fields, so the electrons act as very small permanent magnets within the atom. The magnetic property of any material is the resultant of the contributions of all of its atoms and how this reacts to an applied magnetic field. More on this complex subject can be obtained from Kittel[15], college physics texts, or the Internet.

We will be primarily concerned with magnetic susceptibility per unit volume, k, a bulk property of all materials, that can be directly measured. These materials can be classified in three distinct groups according to the sign and value of their magnetic susceptibility.

The orbiting electrons about an atom of any material, when in the presence of an applied field, will precess, presenting a weak opposing magnetic field. Precession is the wobble that a toy top makes when the spin axis is not in line with the vertical direction. If no other magnetic effects are present, these materials will be weakly repelled by a magnet, and k will be negative. Such materials are called diamagnetic. Most gems are diamagnetic.

In some atoms and molecules there is a net magnetization generally related to electron spin, but which in bulk is zero due to thermal motion of the atoms. However, when a field is applied they

can become oriented to give a small net positive susceptibility, overcoming the negative value due to diamagnetism. Such materials are called paramagnetic. The elements contributing to this type of magnetism, that are relevant to gemmology, are the transition and rare-earth elements. These elements, while best known for their colour causing properties, whether as major or trace components in many gems, also have paramagnetic properties.

As shown in *Table II,* the manganese- and iron-bearing gems will have the greatest paramagnetic susceptibilities, as the rare-earth content of most gems is small. Thus, magnetic testing will indicate the presence or quantity of these elements, just as absorption spectra show their presence by the absorption of light. Paramagnetic gems are of the most interest in gem characterization and identification by means of susceptibility measurements. The table shows the square of the measured effective ion moment, because this is directly proportional to susceptibility.

Ferromagnetic materials have much larger absolute susceptibilities than diamagnetic or paramagnetic materials due to a natural alignment of magnetic moments of the individual atoms. They are further distinguished by being made up of small individual magnetic domains in which the magnetization may not be the same as a neighbour. To the gemmologist, ferromagnetic minerals, such as magnetite, are of interest where they may be present as inclusions, but are generally of less importance than paramagnetic minerals.

In the past, non-laboratory gemmologists have had only two truly quantitative, physical tests available by which to characterize gemstones. These are refractive index (RI and related birefringence) and SG. Unfortunately, RI and SG are not very independent variables, as many years ago Gladstone and Dale (quoted in Larsen and Berman[16]) showed that the ratio of RI to SG is approximately a constant, (RI-1)/SG=k. Because of the Gladstone-Dale relationship, and the fact that accurate measurement of SG

Figure 1: Apparatus used to measure magnetic susceptibility in this study.

is generally difficult, mineralogists and gemmologists often marginalize the use of SG for characterization of their materials. This is clearly one of the reasons that Stockton and Manson[5] didn't make use of SG in their work.

By having a new, independent, quantitative physical property by which to characterize gems, the gemmologist now has much greater scope to characterize gemstones than before. Not only can we measure a gem's susceptibility, but we can also calculate what its susceptibility should be from its chemistry when known; or, with certain assumptions, calculate the quantity of a transition metal in a gemstone as shown by Hoover and Williams[9].

Making magnetic susceptibility measurements

The basic theory behind susceptibility measurements has been described in a previous article[9], where the magnetic attraction (pull) between a very small Neodymium-iron-boron (NdFeB – or NIB) magnet and the flat table of a cut gem was measured on an electronic scale. If the NIB magnet pole face is smaller in diameter than the gem's table, then the pull is a direct measure of the gem's susceptibility. We have used cylindrical magnets of ¼, 3/16, 1/8 and 1/16 inch diameters by ½ inch long. These N42 grade NIB magnets are available from K&J Magnetics Inc. (www.kjmagnetics.com). These are inexpensive, but very strong. We recommend following the manufacturers warnings regarding use. For the best precision, the largest magnet that fits within the stone's table should be used. For all measurements shown in this paper we used a 1/8 inch magnet, which allowed measurements on stones of one carat or larger. In order to convert this pull

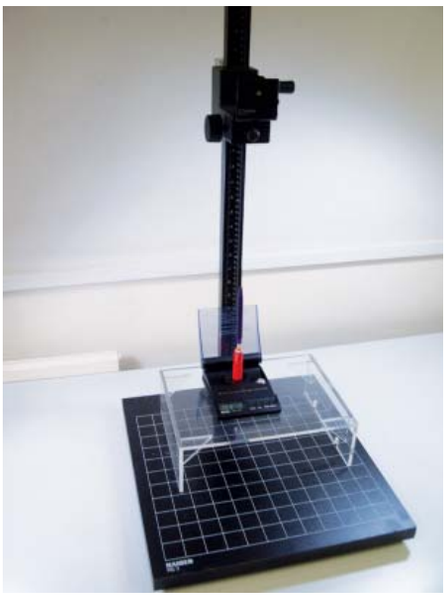

Figure 2 (above): An early prototype using a photo stand. While less precise than later set-ups, this arrangement proved useful for experimenting with the technique.

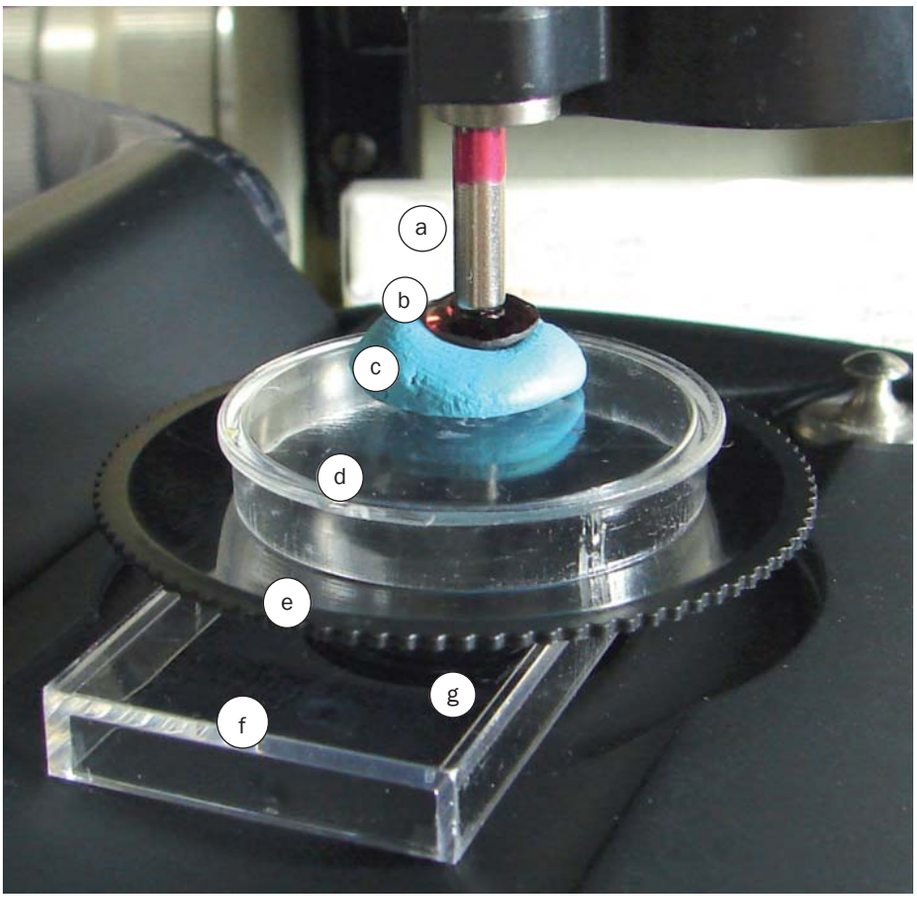

Figure 3 (right): Close-up of magnet and stone interface on scale. a) cylindrical NIB magnet; b) stone under test; c) Blu Tack ring support to hold the stone; d) non-magnetic stone support; e) scale measuring cup; f) bridge support – to avoid pressure on the scale while the stone table is made parallel to the magnet face; g) scale's active surface (underneath the bridge).

into a measure of the gem's susceptibility one need only measure a material of known and consistent susceptibility — a standard. A standard can be any paramagnetic material in which the paramagnetic element that causes the magnetic susceptibility is equally distributed and in consistent quantity. For our testing purposes, we used cobalt chloride ($CoCl_2.6H_2O$) with a pull of 0.855 ct (measured with one of our 1/8 inch (3.12 mm) magnets) and susceptibility of 9.87×10^{-4} SI units. The equation below shows the relationship to determine an unknown susceptibility from pull measurements.

Equation 1

$k = C \times \text{Pull}$

where Pull = measured pull of the test stone and

$$C = \frac{k \text{ (of standard)}}{\text{Pull (of standard)}}$$

As an example, a 3.10 ct pyralspite has a pull of 1.135 ct with the 1/8 inch magnet. Its susceptibility, $k = [9.87\times10^{-4}\text{SI} / .855 \text{ ct}] \times 1.135 \text{ ct} = 11.54\times10^{-4} \text{ SI/ct} \times 1.135 \text{ ct} = 13.10\times10^{-4}\text{SI}$.

The concept is very simple, but the measurement must be done with care and it takes some practice to become consistent. The equipment is shown in *Figures 1, 2* and *3*. The authors are continuing to investigate ways to improve the apparatus and technique, but believe that their present method is quite adequate for garnet characterization.

The current apparatus is a surplus biological microscope stand containing a fine focus mechanism, and an x-y translation stage for centring the gem table with the magnet face. In place of the microscope optics is a plastic fitting with a steel bolt at its centre, to which a cylindrical magnet of whatever size needed may be placed. This holds the magnet in a fixed, stable, and rigid position. The fine focus knob raises and lowers the microscope stage by micrometres, with a macro knob for larger adjustments.

For measuring the force of the magnetic attraction, a small digital scale was placed on the microscope stage. We used a GemOro PCT50 scale, but any similar scale that measures to 0.005 ct should work. The gem is placed on a non-magnetic pedestal, table up, and held in place with Blu Tack, then placed within the scale's measuring cup. A number of precautions need to be observed in order to obtain accurate and reproducible measurements. First, the magnet and gem table must be absolutely clean and free of all grease, dirt and dust. An antistatic brush will help prevent static electricity from affecting measurements, as well as aid in the removal of charged dust, especially in cold climates. One needs to regularly check the magnet pole surface, as these very strong magnets tend to acquire minute specks of magnetic particles, which must be removed before measuring.

Once these precautions are satisfied, it is critical to make the magnet pole surface and the gem's table exactly parallel. This is done by placing the gem within a bit of Blu Tack so that it is held in place along the girdle. A rigid bridge consisting of a 1/8 inch plastic sheet measuring 1 by 2 inches

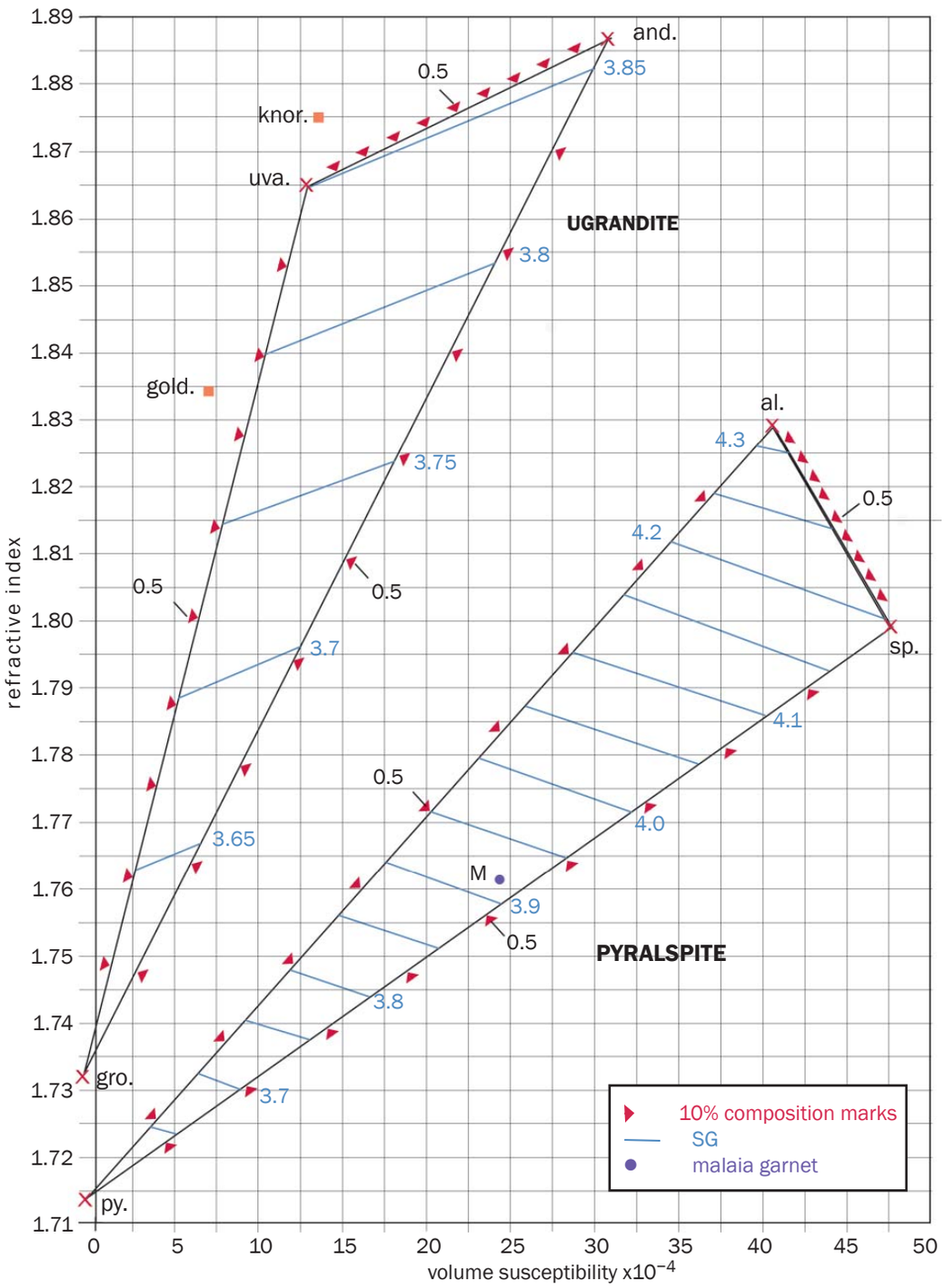

Figure 4: Plot of RI versus magnetic susceptibility for the garnet end-members pyrope, almandine, spessartine, grossular, andradite, uvarovite, goldmanite and knorringite. The pyralspite and ugrandite ternary triangles are shown with 10% triangles (red) shown along sides, and SG variations (blue) within each ternary. The purple data point (M) in the middle of the pyralspite ternary is that of a malaia garnet we measured.

is placed above the scale's recessed active surface and the measuring cup placed on this bridge. This then permits the magnet and gem table to be brought in contact and pressure put on the interface, so as to push the gem into the Blu Tack and align the two surfaces exactly parallel. With the bridge in place, the magnet is separated a millimetre or less from the gem table, and the surfaces viewed from two directions, at about 90 degrees difference, to be sure that they are parallel. Once the surfaces are parallel, the microscope stage is lowered, the bridge removed, and the measuring cup placed back on the scale. Again, check that the table and magnet face are parallel. In practice, we have had little problem in parallelism after the bridge is removed if care is taken. Next, the magnet and gem are separated by several centimetres, and the scale is turned on and tared. Then the microscope stage is gradually brought up to meet the magnet, and the maximum attraction measured. A magnetic attraction will show as a negative reading. Upon contact of the magnet with the gem, the scale reading will go in a positive direction. The maximum negative reading is the 'pull'. This number is then converted to k, using the formula (1).

A diamagnetic gem will give a very small positive measurement, due to the 'push' or repulsion of the stone by the magnet. For a 1/8-inch magnet, this will typically be about 0.02 ct.

As more individuals try their hand at such measurements there undoubtedly will be better methods developed for their implementation. At present, this method gives the best results for us.

Results

A ternary diagram, sometimes called a triangular plot, is a simple graphical tool to show chemical compositions in a three-component system. The diagram is an equilateral triangle where 100% of a component is plotted at each triangle point. Zero percent of that component would be at the opposite side and the centre point of the triangle would represent 33.3% of each. They are often used to determine garnet composition, and have been described and used in the papers by Manson and Stockton[1,2,3,4,5]. The pyralspite and ugrandite groups are examples, but if other garnet end-members are important in a garnet, additional diagrams are needed. For the five principal garnet end-members, grossular, andradite, pyrope, almandine and spessartine, ten ternary diagrams would be required to cover all possibilities for three major components[14]. Where four components are involved it becomes a bit more complex, but details can be found in Hutchison[17] (p.374 *et seq.*).

Because many physical properties of minerals have been shown to be approximately linear functions of the proportions of their components, the ternary diagrams can also show the variation of a physical property (P) with chemistry within the triangle[14,17], summarized in the following equation:

Equation 2

$$P=\Sigma\ p_i m_i = p_1 m_1 + p_2 m_2 + p_3 m_3 \ldots$$

where p_i = the property of the ith end-member such as RI, and m_i = the mole percent of that end-member in the composition.

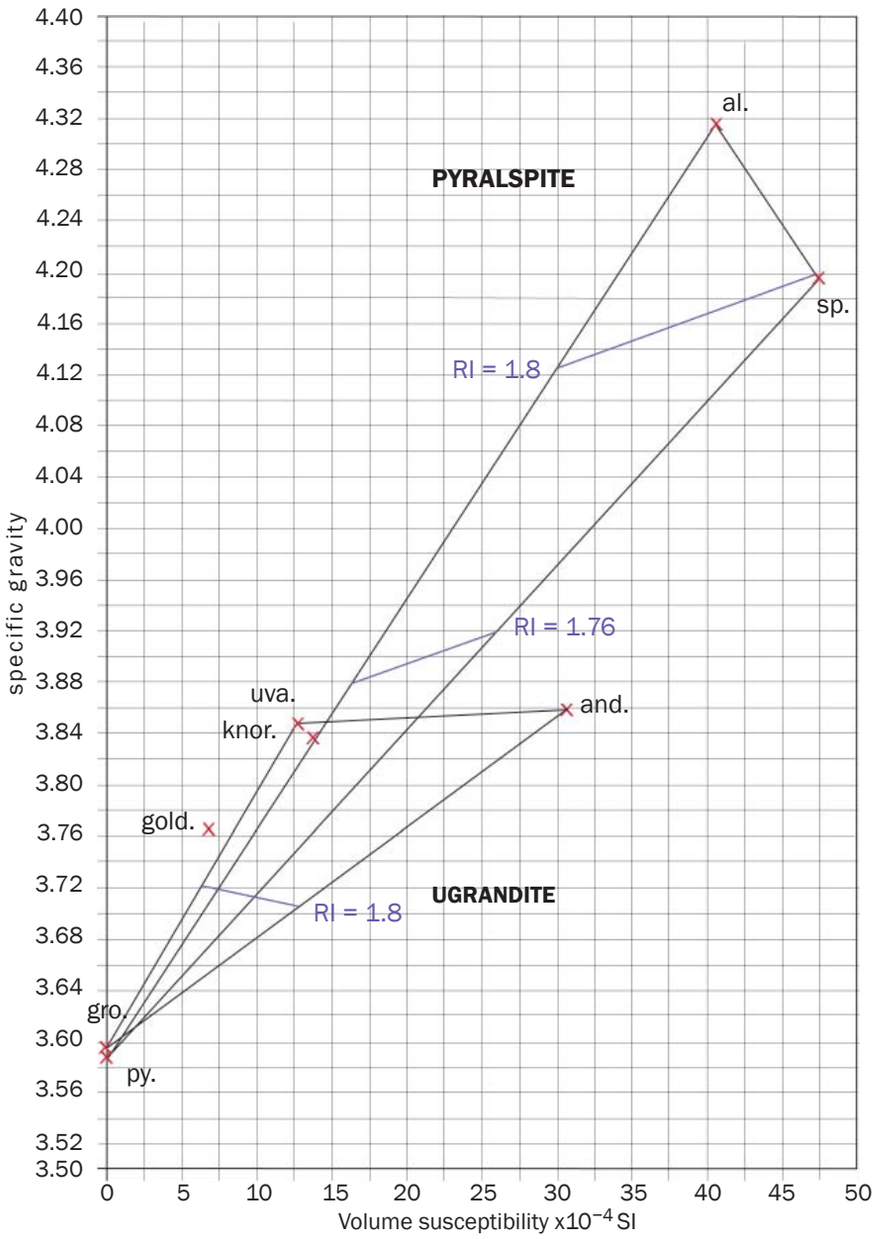

Figure 5: Plot of SG versus magnetic susceptibility for the garnet end-members pyrope, almandine, spessartine, grossular, andradite, uvarovite, goldmanite and knorringite. The pyralspite and ugrandite ternary triangles are shown with reddish purple lines indicating lines of constant RI.

Because we wish to distinguish between the various garnets, the statement by Deer *et al.*[12] (p.497) on the subject is worth reviewing: "Within the garnet group the various species are best distinguished by their RIs, SGs and cell edges in conjunction, if possible, with partial chemical data, e.g. for FeO or MnO. The entry of even small amounts of the uvarovite molecule to the ugrandite series imparts an emerald-green colour in hand specimen; chrome-pyrope is usually reddish but some show a green hue."

Because most gemmologists are not normally able to measure the cell edge dimension of a garnet, we will substitute the value of magnetic susceptibility for this, and plot RI against magnetic susceptibility. This provides information on the FeO and MnO that Winchell[14] called for.

Proposed new garnet characterization technique

In order to effectively use the plot in *Figures 4* and *5*, one needs to understand how the values of each end-member garnet are shown. The gemmological properties of RI and SG, for the eight

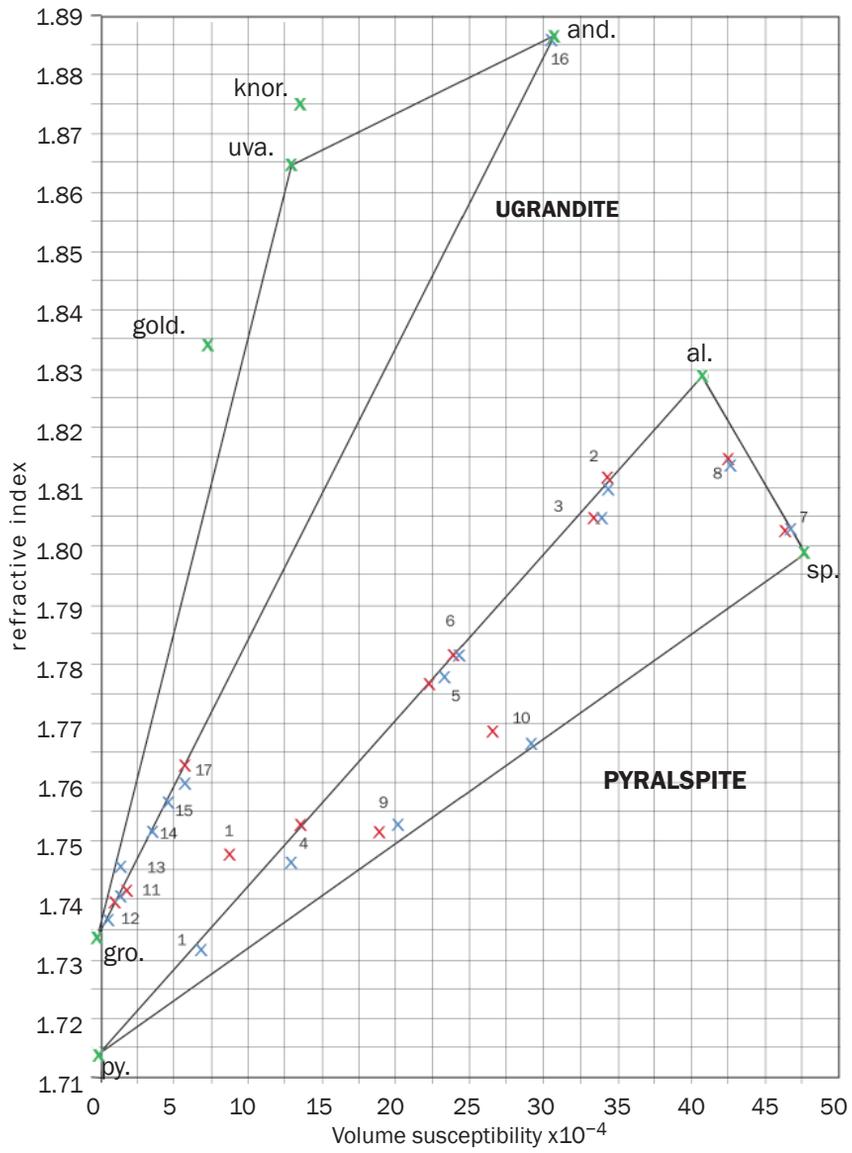

Figure 6: Plot of RI versus magnetic susceptibility for the garnet end-member data of Adamo et al.[7] *Red crosses are calculated for all end-members found, blue crosses are for the three main end-members of each series.*

end-member garnets we will consider, are taken from the mineralogical literature[12,18]. The values for their magnetic susceptibilities have been calculated based on 'ideal chemistry' as shown in *Table I* and mean measured moments from *Table II* by use of the Langevin equation[15].

Figure 4 illustrates the basic plot used, with RI on the Y-axis and magnetic susceptibility (k) on the X-axis. Of the eight principal garnet end-members plotted, the commonest six are joined to demonstrate the ternary diagrams. These are the pyralspite and ugrandite triangles (which are no longer equilateral) with the end-member abbreviations shown at each corner. Small red triangles along each side mark 10% intervals, with the 50% position labelled (0.5). Blue lines and numbers mark SG values, assuming only pyralspite or ugrandite components are present.

As can be seen in *Figure 4*, if one has a pyralspite garnet with no other garnet components, then it must plot within the pyralspite triangle, but if a measured garnet is within the triangle, how does one determine what its pyralspite composition is? Consider a malaia garnet that we measured with an RI of 1.762, and susceptibility of 24.1 × 10^{-4}SI. This is plotted in *Figure 4* as a purple spot (M). From its position in the triangle, it is apparent that this garnet is a pyrope-spessartine-almandine. First, one prints the illustration to a piece of paper so that lines can be drawn and measured. Additionally, this is available for downloading from one of the author's websites (www.stonegrouplabs.com go to 'Articles and Papers', then 'Garnet Chart'). The scale of the printout is irrelevant. From each apex of the pyralspite ternary, draw lines through the data point (the purple dot). Next, measure the length of the line between the pyrope apex to the opposite base, and the length between this base and the data point. When we did this, the measurements were 163 mm and 77.5 mm. The ratio 77.5/163 = 47.5 is the proportion of pyrope in the garnet. Doing this for the other components, we find 42% spessartine, and 11% almandine. These total 100.5% when added, showing minor graphical measurement error, but still a far more accurate idea of the components than would otherwise be known. This malaia garnet would be described as approximately $Py_{47}Sp_{42}Al_{11}$. The precision of all measurements is important to accurately define the chemistry. Based on our repeat measurements we estimate that RI should be within +/- .001 and susceptibility about +/- 1 × 10^{-4} SI. Thus, the error bars are of similar magnitude on the graphs for the scales used, suggesting that each property measurement contributes to a similar error in chemistry.

Note that it only requires values of RI and k to be able to specify the three pyralspite components. A value of the SG, if accurate, would be able to confirm the composition, or if accurate and not in agreement would indicate the presence of one or more additional end-members.

With this understanding, it should be clear that if we take the malaia garnet and add a little andradite, but keep the pyralspite components balanced, the data point would move up in RI, with very little change in susceptibility. Adding a little grossular would pull the point down and to the left. In this figure, for clarity we have shown only the two principal garnet ternary diagrams, but clearly one could draw in all the others. Other results presented below from pyropes and almandines plot within the grossular-

pyrope-almandine triangle, indicating that these garnets most likely contain a measurable grossular component.

These can be computed in a similar manner to pyralspites or ugrandites, by closing the lines for the relevant triangle — grossular, pyrope and almandine.

We want to emphasize that the only change that we are making to long-used mineralogical techniques[14] is the substitution of magnetic susceptibility for unit cell length.

Another way to present the RI, SG, and k data is shown in *Figure 5*, which has SG on the Y-axis and magnetic susceptibility on the X-axis, giving additional insights into property variations. *Figure 5* shows that there is an overlap between the pyralspite and ugrandite groups below an SG of 3.86. The violet lines in each group mark lines of constant RI. The diagram clearly shows there is complete separation between the two groups for indices above 1.80. This is particularly important for the identification of garnets whose RI is above 1.80, where most gemmologists cannot obtain measurements. Thus, SG can be substituted for RI using this new technique. As *Figure 5* shows, andradite, almandine and spessartine can be distinguished on the SG-susceptibility chart at the higher RIs.

Using *Figure 4* as the basic diagram and by taking published compositions from the literature, we can now calculate what their RIs, magnetic susceptibilities and SGs should be. This can be done using as many end-member components as we have values for. However, in using such chemical data, one needs to be aware of the problems of calculating end-member molecules from chemical analyses as noted by Deer *et al.*[12] Conversely, we can estimate what the compositions could be, based on the measured values of the properties, for each three-component system if we have two properties, or for four-component systems if we have values of RI, susceptibility and SG. In many cases, there will be more than one combination of end-members that can fit a given physical property set. It is up to the gemmologist to choose which possibility is most probable. We believe this new technique for indirect determination of garnet chemistry, permitting better characterization of the garnet group, is a major step forward in gemmology.

Table III: Comparison of measured and calculated properties of selected garnets from Adamo et al., *2007.*

Specimen number	Property	Measured	Calculated on basis of		Composition
			All end members	Three main end members	
1	RI	1.741	1.748	1.732	$Py_{75}Al_{14}Sp_{0.7}An_{8.3}Uv_{1.7}$
	SG	3.68	3.719	3.704	
	Susc. #		8.79	6.69	
2	RI	>1.79	1.812	1.81	$Py_{15}Al_{81}Sp_{1.1}An_{2.3}$
	SG	4.19	4.190	4.196	
	Susc. #		34.20	34.27	
7	RI	>1.79	1.803	1.803	$Py_{.04}Al_{12}Sp_{87}Gr_{0.4}An_{0.6}$
	SG	4.13	4.207	4.212	
	Susc. #		46.34	46.62	
10	RI	1.775	1.769	1.767	$Py_{34}Al_{1.1}Sp_{54}Gr_{5.4}Uv_{1.0}Go_{3.6}$
	SG	4.00	3.935	3.963	
	Susc. #		26.53	29.11	
11	RI	1.738	1.742	1.741	$Uv_{.05}Gr_{93}An_{5.1}Py_{1.4}Sp_{0.7}$
	SG	3.59	3.612	3.607	
	Susc. #		1.70	1.35	
12	RI	1.741	1.740	1.737	$Uv_{1.1}Gr_{91}An_{.05}Py_{2.1}Sp_{1.5}Go_{3.7}$
	S.G	3.62	3.612	3.600	
	Susc.		0.94	0.45	
16	RI	>1.79	1.886	1.886	$An_{99.2}Py_{0.7}Al_{0.06}Sp_{0.04}$
	SG	3.88	3.857	3.857	
	Susc.		30.55	30.56	
17	RI	1.766	1.763	1.760	$Uv_{0.1}Gr_{78}An_{19}Py_{2.8}Sp_{0.2}$
	S.G	3.66	3.645	3.680	
	Susc.		5.76	5.68	

NB: Calculation based on equation (2)
Magnetic susceptibility all × 10^{-4} SI

Determination of properties from chemistry

As an example of using compositions to determine properties, we have plotted on *Figure 6* RI and susceptibility data calculated for the pyrope and ugrandite garnets of Adamo *et al.*[7] using equation (2). Values in red are derived using all the end-member compositions given by Adamo *et al.*, while those in blue are for only the three main components of either the pyralspite or ugrandite subgroups, and normalized to 100%, much as Manson and Stockton[5] have done. The numbers on each data point correspond to those of Adamo *et al.*[7] The end-member garnets *(Table I)* are indicated by green crosses and labelled. The pairs of red and blue crosses, generally, are fairly close. In *Table III* is a selection comparing these calculated values against measured values given by Adamo *et al.* The analyses of the ten pyralspites showed seven end-members present, but no individual specimen with all seven. Four to six end-members were found between these pyralspites, with half needing only

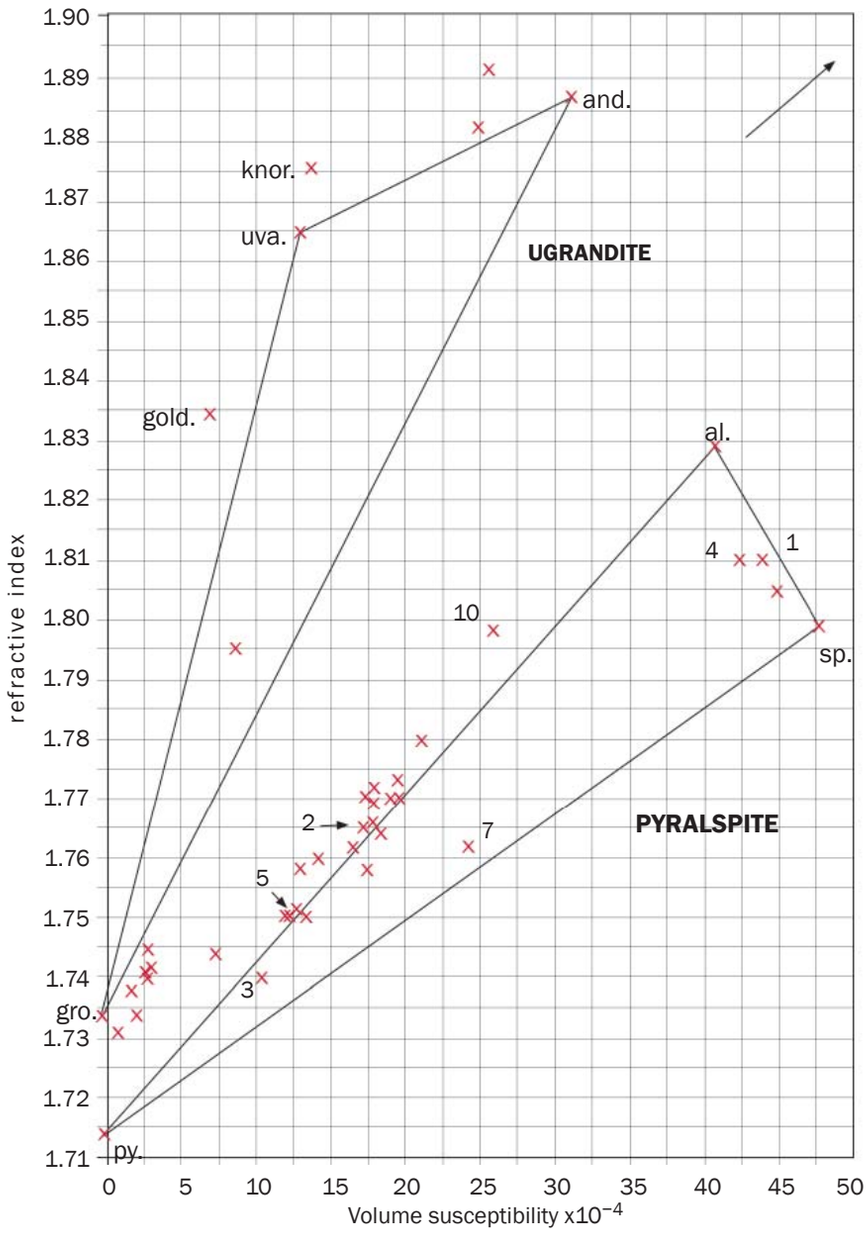

Figure 7: Plot of RI versus magnetic susceptibility for a series of garnets measured by the authors. The pyralspite and ugrandite ternary triangles are shown.

four end-members to describe them. Grossular and andradite were the largest non-pyralspite components found. The chrome pyrope, specimen 1 of Adamo's list *(Figure 6)*, shows the greatest divergence between values based on the pyralspite component (blue cross within the pyralspite ternary diagram) versus complete chemistry. This stone had 8.3% andradite, and 1.7% uvarovite mixed with pyrope, almandine and spessartine components. The shift in graph position is toward the uvarovite-andradite positions, as would be expected. The other specimens in this series, 2–10, had 2.3%, 1.6%, 4.01%, 5.04%, 1.25%, 0.98%, 0.8%, 6.1%, and 10% non-pyralspite components respectively.

In the ugrandite group specimens (*Table III* and *Figure 6*), the data show the grossular garnets stretched out on the grossular-andradite join up to about 20% andradite (specimen 17). This is a similar pattern to that found by Manson and Stockton[2]. Some of the red crosses do not show because of overlap with the blue ones. In *Table III* the measured and calculated property values of a selection of the ugrandites can be compared. One andradite (16) is essentially pure and this is typical, as most natural andradites are compositionally close to the end-member[12].

The distribution of points in *Figure 6* shows that for these gem garnets, measurements of the RI and susceptibility correlate with the chemical composition rather well, remembering that the red crosses represent the practical measurements. Chrome pyrope, the garnet with the widest spread between red and blue values (specimen 1), shows that it can't be well characterized as a pure pyralspite and that some additional component needs to be considered, such as andradite or uvarovite.

The data of Adamo *et al.,* although far fewer in number, illustrate what Manson and Stockton[1,2,4,] and Stockton and Manson[3,5] found: in general, gem andradite and grossular fall close to their respective end-members in the ugrandite ternary diagram; gem almandine and pyrope fall along the pyrope-almandine line with little spessartine present; and similarly for the almandine-spessartine group. The malaia (specimen 9) and colour-change (specimen 10) pyralspite garnets are mainly spessartine-pyrope with minor almandine. These values, we believe, are well correlated, including those for SG.

Estimation of chemistry from properties

For gemmologists, the most practical and quick means of determining the composition of a garnet is through magnetic susceptibility. We have measured the RI and susceptibility of 39 gem garnets from worldwide sources and the results are given in *Table IV* and *Figure 7*. Grossulars plot close to the end-member, as do the andradites. In the pyralspite group, most almandine-pyropes show little evidence of a spessartine component, and the almandine-spessartines show little pyrope. It is only the malaia garnets that have a strong mix of all three end-members. In *Figure 7* the RIs of stones below 1.79 were measured with a conventional, critical angle refractometer. Those with RI over 1.79 were measured with a deviation angle refractometer, built by one of the authors (D.H.), making use of a laser pointer light source. The accuracy of this device is estimated at +/-

Absorption spectra and chemistry

A thorough investigation of the use of absorption spectra to determine garnet species would require another paper; so to indicate the diagnostic limitations of this method, only a few features of the pyralspite series will be discussed. In the pyralspite garnets, it is the Mg^{2+}, Mn^{2+} and Fe^{2+} contents that determine the species. This gives us three choices when looking at a pyralspite spectrum, if, for the moment, trace elements are neglected, there is either an Fe^{2+} spectrum, a Mn^{2+} spectrum, or both. Stockton and Manson[5] rely on the presence of the 410 and 430 nm Mn lines to indicate if any Mn is present. Rossman[19] (p.218) notes: "Only the sharp 410 nm band is seen in the spectrum of many minerals with minor amounts of Mn^{2+} in the presence of greater quantities of Fe^{2+}." This raises the question of whether Mn lines in many garnets can be identified with the hand spectroscope, as these weak lines are commonly hidden in the obscurity of the blue end of the spectrum. Pearson[20] also discusses the poor sensitivity at each end of the visible spectrum of the human eye and its limitations for identification of absorption lines in the blue to violet when using a hand spectroscope.

Figures 8a and *8b* show pairs of similar spectra from garnets we have measured (specimens 1, 2 and 3, 4) in *Figure 7*. These transmission spectra were run on an Ocean Optics S2000 Spectrophotometer. The classic almandine absorption lines at about 505, 526 and 576 nm are present in all.

In *Figure 8a* the spectra of specimens 1 (spessartine) and 2 (pyrope) appear nearly identical. In the region between 400 and 500 nm, note that the 410 and 430 nm absorption lines used by gemmologists to identify Mn^{2+} (5) are not present. This was confirmed with the hand spectroscope, where only a cut-off at approximately 440 nm was observed. The 575 line was most apparent, the 505 was relatively strong, and the 526 line could be seen by only one of the authors. No characteristic manganese lines could be seen.

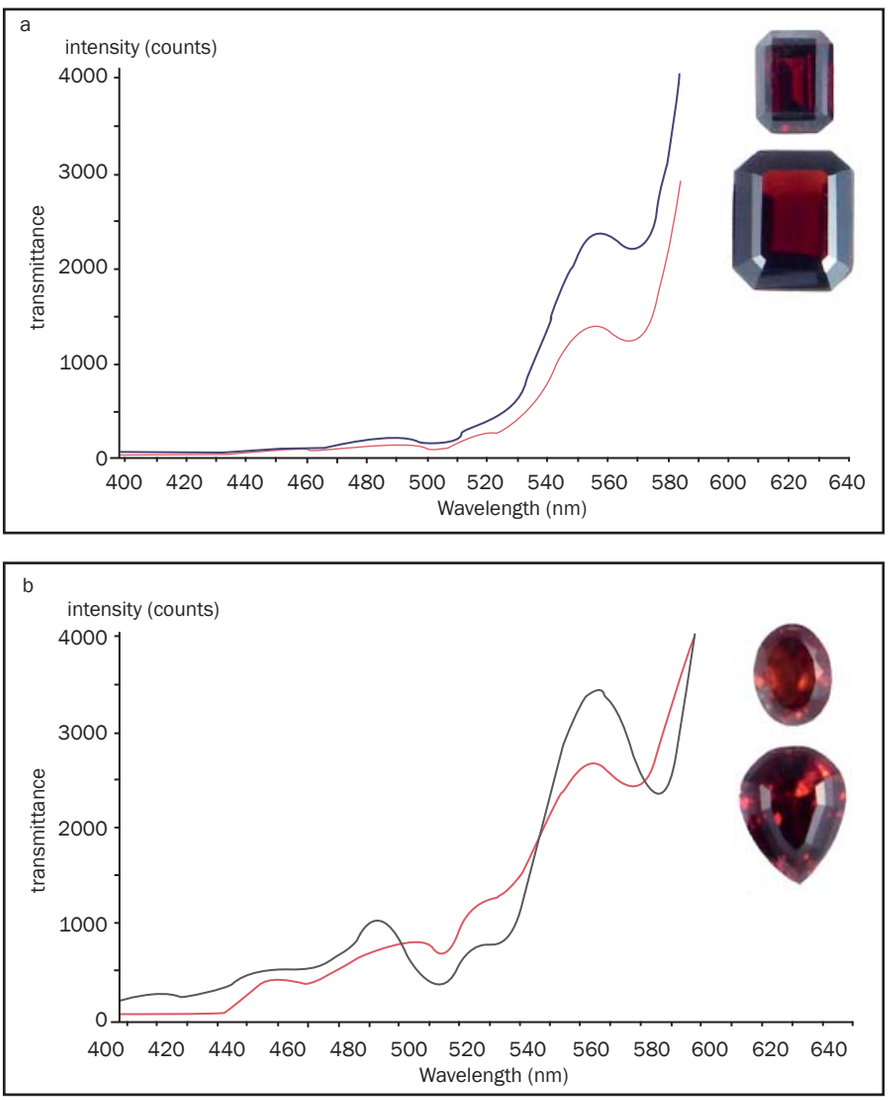

Figures 8a and b: Graphs of transmission spectra for the four pictured garnets, showing similarities between pyrope and spessartine spectra. a) Red line is a 2.24 ct spessartine (no. 1); black line is a 4.19 ct pyrope (no. 2); b) Red line is a 1.61 ct oval spessartine (no. 4); black line is a 4.73 ct pyrope (no. 3).

In *Figure 8b* there are some small differences in spectra of specimens 3 (pyrope) and 4 (spessartine), especially a shift in the two troughs (absorptions) near 575 nm between the two spectra. The almandine lines are clearly prominent. The cut-off in the blue is near 430 nm, with no evidence of manganese lines at either 410 or 430 nm. There is also a weak absorption near 460 nm, but this is not recognized as a strong Mn line. There are no Mn lines visible with the hand spectroscope. With the hand spectroscope, the authors observed only iron lines at 510 and 575, with a cut-off at approximately 430 for the 1.61 ct oval (red curve). The 526 line seen in *8b* could not be distinguished with the hand spectroscope. For the 4.74 ct pear shape, two authors observed a cut-off at 400 and 430 nm, strong lines at 575 nm, a good line at 505 nm, and a weak line at 526 nm. In each of these sets, one stone is near the almandine-spessartine boundary with little pyrope, and the other primarily pyrope *(Figure 7)*. Yet all stones have very similar colours.

Table IV: Magnetic susceptibility and other properties of the garnets measured in this study.

No.	Species or variety	Weight ct.	Locality	Colour	RI	k × 10^{-4}
1	spessartine	2.24	?	deep red	1.810	43.8
5	pyrope	3.42	Mozambique?	red	1.751	12.5
7	malaia	2.78	E. Africa	orange	1.762	24.1
10	almandine	2.57	India	deep red	1.798	25.8
14	tsavorite	2.54	E. Africa	medium bright green	1.731	0.69
15	demantoid	1.25	Russia	green	1.892	25.5
24	hessonite	3.73	Sri Lanka?	orange	1.741	2.54
25	'uvarovite'	17.97	Cab, S. Africa	fine deep green	1.795	8.53
28	rhodolite	1.55	Tocantins, Brazil	purple	1.77	17.2
29	rhodolite	7.75	unknown	purple-red	1.773	19.3

0.004 and because the laser wavelength is 680 nm, the RI values were corrected for dispersion.

From the data given in *Figure 7*, it is apparent that these garnets can easily be separated into pyralspite or ugrandite groups based on RI and susceptibility values. If there is any question, SG should assist, due to the large density gradient between the two groups (*Figures 4* and *5*). Of greater importance is the power this gives us in identifying the chemistry of a particular gem within the pyralspite or ugrandite groups. As an example, look at the garnet labelled 5 in *Figure 7*. This 3.42 ct stone is on the almandine-pyrope line, so can be specified as approximately $Py_{68}Al_{32}$ with an RI of 1.751 and susceptibility of 12.5 × 10^{-4}SI. Of course, a mix of other different garnet end-members could be devised to give the same physical properties, but this is the simplest. This stone was sold as a Mozambique spessartine many years ago, but our data indicate clearly that it is predominantly pyrope. In colour, it is close to the other three adjacent pyropes.

The malaia garnet labelled 7 is an example where three end-members are present (see also M in *Figure 4*). It is approximately $Py_{47}Sp_{42}Al_{11}$, compared to the malaia measured by Adamo *et al.*[7] (no. 9 in *Figure 6*), which was $Py_{52.7}Sp_{33.6}Al_{7.5}Gr_{6.1}$. The garnet labelled 10 was purchased as an Indian almandine, but it falls above the almandine-grossular join, so must have some andradite or chrome garnet component. A clue to its probable composition is provided by Deer *et al.*[12] in the composition of one Indian garnet from Madras, which is $Al_{61.4}Py_{30.8}An_{5.9}Sp_{1.4}Gr_{0.5}$. This composition gives a calculated RI of 1.796 and susceptibility of 27.4 × 10^{-4}, remarkably close to that of the measured Indian almandine (1.798, 25.8). If one calculates the composition from its position in the pyrope-almandine andradite ternary diagram, one obtains a composition of $Al_{62}Py_{30}An_{8}$. This, we believe, is a good example of what can be done with this new technique.

Discussion

By plotting pairs of RI and susceptibility values for garnets as shown in *Figure 4* and following, one can directly define a garnet's chemistry based on the composition of any three selected end-member molecules. Because it has been found that 99% of most garnet compositions can be described by a combination of the five common garnet end-members[5,12], the probable compositions of any tested garnet are quite restricted.

Additionally, by plotting RI and magnetic susceptibility, the pyralspite and ugrandite series' ternary triangles are quite separate and do not overlap[12,14]. Clearly, a stone lying in the pyralspite ternary area will have a limited amount of any ugrandite component that could be present in order to fit measured physical properties.

The measurements of 39 stones plotted in *Figure 7* reveal variations in gem garnet chemistry that were not obvious from previous gemmological work[5,6,7,10]. Looking at the pyrope to almandines near the line (join) between the pyrope and almandine end-members, it is clear that most of these have some measurable component from the ugrandite series garnets. This is evident by their plotting at higher RI values than the line along the join. If one looks at garnet chemistry given for example in Deer *et al.*[12] for pyrope, chrome-pyrope, and almandine, most analyses show a significant ugrandite component (or knorringite, in some stones) with one of these being the second largest component. This had been reported by Rouse[10], but not emphasized. Our data show that this is rather common in gem garnets, and needs to be considered when discussing variations in garnet properties.

Further research and testing of this new method is called for in order to confirm results from this method with measured chemistry on more stones. The current method is good for identifying the chemistry in terms of three end-members. To combine SG measurements with the current information will increase its complexity, but could more accurately define the chemistry in terms of four end-members. For example, grossular and spessartine components in a stone can balance each other out, hiding evidence of both, as has been observed in some rhodolites.

The authors have presented a means for quantitatively measuring the magnetic susceptibility of cut gemstones as an aid in characterizing their end-member chemistry. In fact, any rough material need only have one polished surface to enable testing by this method. The simplicity of the method makes it ideal for field-testing new finds of garnet.

It is recognized that trade and varietal names of garnet will continue to be used for commercial purposes. However, for gemmological purposes, we believe it would be better to describe the actual end-member chemistry of a garnet derived using this new method. The technique overcomes the present RI and SG limitations as garnet identification methods. Further, it will allow new varieties to be easily defined in the garnet continuum with less confusion about their composition.

Acknowledgements

The authors would like to thank colleagues in the trade, too numerous to name, for frank discussions of garnet characterization, identification and nomenclature. Particular thanks go to Sylvia Gumpesberger for her persistence in pushing us to examine, in a quantitative sense, what magnetic measurements might do to advance the science of gemmology. We wish to thank Grant Pearson for in-depth discussion of eye-visible gem spectra. We are also indebted to the late Professor N. Haralyi whose early magnetic work first caught our attention, and finally, our appreciation to an anonymous reviewer whose suggestions considerably improved the paper.

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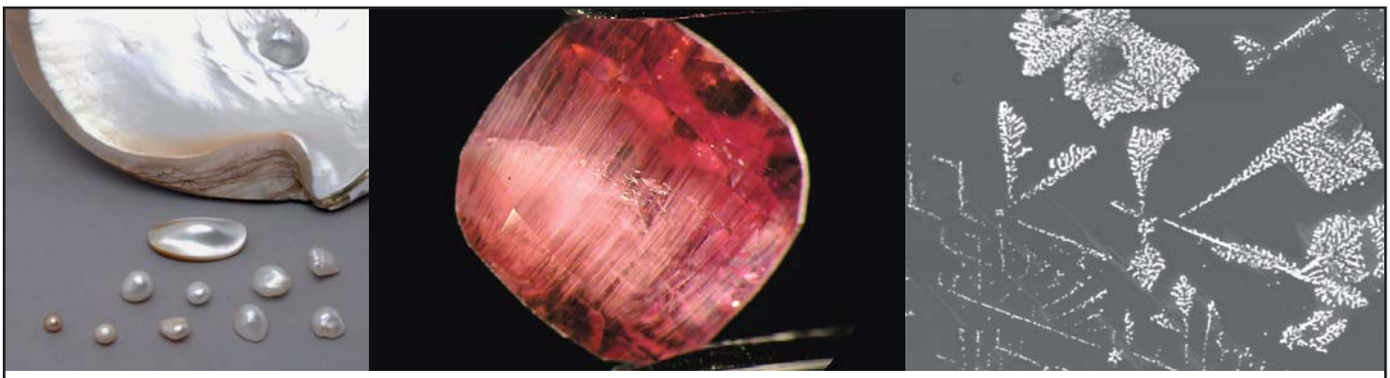

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The refraction of light by garnet depends on both composition and structure

David K. Teertstra

Abstract: The index of refraction *(n)*, used to identify minerals, depends on both composition and crystal structure. The method of optical analysis implies that a photon refracts by local interaction with individual ions. The index *n* is calculated exactly using a dependence of the specific refractivity of ions on the inter-ionic distances and angles of the crystal, and is influenced by bonds to surrounding ions up to half-a-unit-cell distant.

Keywords: crystal chemistry, crystal structure, garnet, index of refraction, optics, photon

Introduction

This paper deals with controversial aspects of light and its refraction in gems and minerals, and proposes a model to deal with them. In this model, for convenience, the particles have been called photons but it should be understood that these particles have some postulated properties that differ from those of the conventional photon of quantum theory. The photon is a probe of the crystal structure. The energy of the photon is constant; the photon remains intact and the wavelength is not reduced. The ions of each element have a specific electric structure and a characteristic contribution to the net index of refraction of the material. Accounting for the crystal structure, this new method of optical analysis also gives an accurate measure of composition.

What a gem looks like depends on its interaction with light, determined mainly by the processes of reflection, refraction and absorption. The optical properties of gems are essential to their identification. Measurements of refraction can be diagnostic, mainly because the index of refraction depends upon the composition and structure. Each measured index of refraction relates to a specific structure and state of cation order (Teertstra 2005, 2006). For a given structure-type (garnet is considered here, see *Table I*), a change of composition directly relates to a change in the optics, whereas for a fixed composition, polymorphs of minerals can be distinguished optically (e.g. kyanite, sillimanite, andalusite). That said, the relation between optical properties and composition has been precise only for pure binary or ternary series, as a theory relating optical properties to both composition and crystal structure is entirely absent.

A general theory, relating each compositional and structural state (as expressed by the structural formula of the mineral, e.g. $Mg_3Al_2Si_3O_{12}$ for pyrope) to the specific physical properties, has remained elusive. To make progress, one must understand both light and crystallography. Historically, for example, the evidence for X-rays as a high-energy form of light rather than a new type of particle was simultaneous with the evidence for the structure of minerals as ordered three-dimensional arrays of

Table I: Physical properties (n, a, D) of end-member silicate garnets.

Species	formula	n	a (nm)	$D_{calc.}$
Pyr – pyrope	$Mg_3Al_2Si_3O_{12}$	1.714	1.1459	3.5591
Alm – almandine	$Fe_3Al_2Si_3O_{12}$	1.830	1.1526	4.3184
Sps – spessartine	$Mn_3Al_2Si_3O_{12}$	1.800	1.1621	4.1902
Grs – grossular	$Ca_3Al_2Si_3O_{12}$	1.734	1.1851	3.5952
And – andradite	$Ca_3Fe^{+3}{}_2Si_3O_{12}$	1.889	1.2058	3.8507
Uvr – uvarovite	$Ca_3Cr_2Si_3O_{12}$	1.865	1.1996	3.8514
Gld – goldmanite	$Ca_3V_2Si_3O_{12}$	1.834	1.2070	3.7651

NB: *n* is refractive index; *a* is the unit cell edge; *D* is the density calculated from the unit cell.

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atoms. From the equations of Bragg and Laue, and by using the scattering factors of ions, both the structure and composition of a crystal can be determined. In thin-sheet diffraction, light is reflected only at specific angles if the wavelength of light is similar to the distance between planar layers of atoms. However, the same information can be determined using the refraction data of a group of minerals, but using the refractivity factors of ions.

Although the photoelectric effect (now a subset of the theory of atomic absorption, in which an atomic-electric transition from a low-energy orbital to a high-energy orbital accompanies the absorption of a photon by an individual atom) indicated to Einstein that light is a local particle of similar size to an electron, the only model of light currently available results from the plane-wave solution to the Maxwell equations for electricity and magnetism. The model of light as an electromagnetic wave requires the energy to be spread out along the wavelength as well as across the wavefront, in conflict with the physical evidence for a finite local particle of light. In the theory presented here, for example, each ion has a specific refractivity and the net index of refraction is explained only if light consists of photons that interact locally with each ion.

The wave theory of light requires a homogeneous (or average) index of refraction for materials, but the mineralogical data indicate that the index of refraction (n) increases as the density (D) increases, so $n \propto D$, or $n = KD$. Such changes of n and D are due to substitutional exchange mechanisms such as Mg <–> Fe that are common to many minerals. By considering that each ion in a dielectric crystal has a characteristic optical refractivity (by virtue of the number of and density of electrons), a characteristic radius (by virtue of the atomic-electric structure) and a characteristic atomic weight (by virtue of the number of protons and neutrons), the net values of n and D calculated as a simple sum of the ionic properties agrees rather well with measurement (see Mandarino 2007 for calculation of n from oxides).

The equation for ions in crystals is $n/D = \Sigma(k_i d_i)$, where k_i is the molar ionic refractivity and d_i is the fractional density (the weight of a number of ions i of atomic weight AW per unit-cell volume V is also the ion weight fraction). For a single ion, the refractivity is $s_i = k_i AW/An$, in nm^3, where An is Avogadro's number. The index of refraction is then a sum of the partial contributions of the refraction of each ion, with $n = \Sigma|n_i| = A_N \Sigma(s_i' |d_i|/AW)$. This modified Gladstone-Dale equation (Gladstone and Dale, 1864; Teertstra, 2005) is offensive to wave theorists who insist that light does not interact with individual atoms, but the fact remains that the wave theory is complex and difficult to use and produces distinctly inaccurate values of n (e.g. Rocquefelte *et al.,* 2004, 2006). And although the theory of light as an electromagnetic wave has had over a century of development, not a single worker in physics has been able to relate the optical properties of crystals to the structure using the theory. Also a modified theory of light may be required, as a working model of the photon does not currently exist.

From the wave theory of light to a proposed local photon

Early workers in optics such as Isaac Newton and Albert Einstein considered that the interactions of light with matter were best explained if light consists of a stream of local particles. However, as the interference patterns of light and of water waves appear similar, and as phenomena such as refraction are described by trigonometric functions, the earliest mathematical descriptions are of light as a sinusoidal wave. The relations between electricity and magnetism derived in 1864 by James Maxwell generated not only a simple formula for the speed of light, but also allowed a description of light as a plane-polarized electromagnetic wave. This wave contains a negative electric component that alternates further along in space with a positive electric component, while magnetic flux occurs perpendicular to the electric plane. As light can be described as an electromagnetic wave (Iksander, 1992), it must be acted on by the electric force to effect refraction, but this idea seems to be absent from physics.

For wave refraction, it is required that the wavelength of light is reduced on entering a denser medium (e.g. yellow light in air is effectively blue in water), but such a reduction of wavelength is non-observable and physically indeterminate. For a reduced wavelength, the quantum equation for energy ($E = hc/\lambda$ where h is Planck's constant, c is the speed of light and λ is wavelength) predicts an increased energy, but this is also indeterminate. The wave theory assumes that light may be redirected (reflected or refracted) at no energetic cost, so explanations for thermodynamics or for the motion of free ions toward a light source (e.g. ion trapping by lasers) are absent. There are also no fundamental explanations for diffraction or for atomic absorption or emission by single atoms. The current situation in physics is that separate sets of equations exist for waves and for particles, and the wave-like and particle-like aspects of light are considered complementary. The overall consensus is that one cannot use light to gather information about objects that are smaller than the wavelength of light, but a glance at the results in *Table II* indicates radii of refraction that are similar to atomic radii.

The main problem tackled here is that the wave theory of light has only poor relations to the refractive properties of materials. Although it was known to Maxwell that each pure material (e.g. diamond, sulphur) has a specific index of refraction (commonly determined using yellow light), and that index of refraction of a solution depends on the index of refraction of the end-member components (e.g. water and alcohol), functional electromagnetic equations could only be found by assuming an average index of refraction for materials. In wave theory, a uniform wave-front cannot be maintained if each ion has a unique index of refraction. If light is refracted by each ion, light must consist of particles.

The refraction of light by garnet depends on both composition and structure

From the wave theory of light, transmission through a gem occurs as the electric component of light induces an oscillation in the electrons of the material. Much of the refraction is thus attributed to the loosely-held valence electrons of the anions, as these are the most polarizable. However, calculations of index of refraction based on polarizability (in nm^3; e.g. the Lorentz-Lorenz equation; Jaffe 1988, Eggleton 1991, Iksander 1992) are poor because cations are also major contributors to the index of refraction.

The theory of electromagnetism also lacks connections to mass. It is known, however, that charge is maintained by reduction of rest mass when particles of opposite charge form electric bonds. The mass of hydrogen is less that the mass of the electron and proton alone (this is the binding energy $E = mc^2$), as mass is consumed to maintain charges of -1 for the electron and +1 for the proton. Applying such ideas to light, and requiring local mechanisms of propagation (by rejecting the mysterious process of action at a distance required for waves), a local decline in the electromagnetic energy of a photon requires an exchange with mass (*Figure 1*). For a local photon, the electromagnetic energy of a packet of light oscillates with mass, if the total energy is constrained to a finite region of space. Mass is zero for maximum electromagnetic energy and vice-versa, so the photon has wave properties only on trace over time. This reduction of symmetry from a plane wave requires an electric-charge monopole, alternating over time from positive to negative, with polar loops of dipole magnetic flux that are perpendicular to the electric-charge monopole *(Figure 1).*

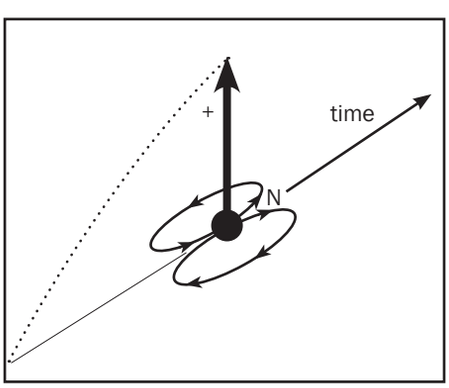

Figure 1. A model of a local photon. Over one-quarter of the wavelength, the electric-charge monopole increases from zero to a maximum value, in phase with dipole magnetic flux. The electromagnetic energy is conserved by exchange with transient mass; the mass is zero when the electric-charge monopole is at a maximum. The photon maintains constant speed and momentum and exhibits a sin2θ wave on trace over time.

Refraction occurs as this local photon is acted on by the electric charge about each ion. Refraction thus occurs by serial displacement of the photon about each ion in the crystal structure as the photon takes a roller-coaster ride through the gem. The index of refraction is due to an increased path length rather than a reduced wavelength. In this analysis, no new laws of physics are required although new principles are introduced, and a simple equation for photon refraction then indicates the composition and structure of the material.

A relation between optics, composition and crystal structure

From atomic theory, ions form from neutral elements by the gain or loss of electrons. The elements Mg and O react to form an ionic bond with Mg^{2+} and O^{2-} ions in an MgO molecule, as both ions gain an electric structure like that of an inert gas. The two positive charges of Mg^{2+} can be considered to extend with spherical symmetry from the surface of an inert-gas core of electrons (Ne). The two valence electrons of O^{2-} are held in orbital paths by the positive charge of the nuclear protons, but are also attracted to the Mg^{2+} cation.

In liquids and solids, the cations attract coordination polyhedra of anions and vice-versa. However, as ions of like charge repel one another, paths through the structure of a dielectric solid consist of alternating cations and anions. The regular grid-like arrangement of cations in crystals relates to near-equal forces of repulsion between cations, but the valence electrons of O^{2-} glue the structure together.

In the present theory of refraction, a single ion of Mg^{2+} can do work on a passing photon to change its direction. As the ion presents a spherical distribution of charge to a photon that is incoming from any direction, the characteristic refractivity of this free ion ($s_i = k_i AW/An$ in nm^3) is considered to represent the refractive volume of the ion.

The electric force F on a charge near the ion varies with distance d in proportion to $1/d^2$, but Coulomb's law (of $F \propto 1/d^2$) lacks subtlety. The ions Mg^{2+} and Fe^{2+} in MgO and FeO are considered identical because d is measured from the centre of charge (effectively the nucleus), but these ions have differences in electric structure that shield the charge of the nucleus to different degree. The ions differ in refractivity. The working solution used here is to consider refractivity due to ionic charge as Coulomb-like, with the s_i of an ion affecting other ions in proportion to $1/d^2$.

For the equation $n/D = \Sigma(k_i d_i)$ applied to a simple binary series such as (Mg,Fe)O, by knowing *n, D* and d_i from analysis, it is easy to find relative values of molar refractivity k_i for Mg^{2+}, Fe^{2+} and O^{2-} that exactly return the measured values of *n* and *D*. However, these values of k_i generate inexact values of *n* and *D* in other polymorphs of (Mg,Fe)O, probably due to differences in the structure-type (Eggleton, 1991).

One may also find relative values of k_i for Mg^{2+}, Fe^{2+}, Mn^{2+} and Ca^{2+} in garnet that give minimal differences between calculated and measured values of *n* and *D* for all samples in the quaternary space of the $(Mg,Fe,Mn,Ca)_3\ Al_2Si_3O_{12}$ solid solution, but these k_i values give inexact results when applied to the broader $(Mg,Fe,Mn,Ca)_3\ (Al,Fe^{3+},V,Cr)_2Si_3O_{12}$ solid solution, again probably due to differences in structure.

Workers in mineral optics have sought constant values for the molar refractivity of oxides (Mandarino, 2007), suggesting a characteristic electric structure for ions or molecules, but a general relation between optics, composition and structure must also account for birefringence. The effective refractivity of an ion has been shown to vary depending on the general structure-type (Eggleton, 1991) and on variation within a specific structure (Teertstra, 2005).

Table II: Values of refractivity (s_i), cut-off distance (dc), radius of refraction (R) and radius (r) of free ions.

Ion	s_i (nm^3)	dc (nm)	R (nm)	r (nm)	R/r
Mg^{2+}	0.02158	0.38	0.174	0.089	1.9
Fe^{2+}	0.03130	0.42	0.196	0.091	2.2
Mn^{2+}	0.03200	0.43	0.197	0.098	2.0
Ca^{2+}	0.03436	0.43	0.202	0.112	1.8
Al^{3+}	0.00168	0.30	0.074	0.053	1.4
Fe^{3+}	0.02680	0.58	0.186	0.065	2.9
V^{3+}	0.02170	0.60	0.173	0.064	2.7
Cr^{3+}	0.02130	0.64	0.172	0.062	2.8
Si^{4+}	0.01400	0.50	0.150	0.026	5.8
O^{2-}	0.02500	0.50	0.181	0.140	1.3

The structure factor

The idea of photon refraction by individual ions naturally arises because the volume of refraction of an ion is similar to the ionic volume (Shannon and Prewitt, 1969). Also of interest, *Table II* indicates that the refractivity of a free ion is a function of charge and radius.

The present theory uses visible-light refraction data and compares this to the X-ray data for thin-sheet diffraction. The density calculated from X-ray diffraction measurements is $D = \Sigma(a_i AW)/V An$, where a number of atoms a of type i and atomic weight AW (g/mol) occupy the unit-cell volume V (nm^3). From single-crystal structure refinement, the composition is determined by the scattering factors of the ions, and also by the inter-ionic distances if the scattering factors are similar (e.g. <Al-O> and <Si-O> distances in nm for Al-Si solid solution at a site). The density calculated by refraction, $D = n/\Sigma(k_i d_i)$, where $d_i = a_i AW/V = w_i$ (the ion weight fraction), must agree with the density calculated by diffraction; that is, the value k_i is a refractive factor analogous to the ionic X-ray scattering factor.

The refractivity of ions is explained entirely by classical electrostatic theory, as the charge of each ion acts on the photon by the Coulomb force. If the refractivity is proportional to the electric force, it must fall off as $1/d^2$. With the inter-ionic distances di known from the crystal structure (Novak and Gibbs, 1971), values for the ionic refractivity can proxy for the electric force. With reference to *Figures 2* and *3*, the explanation is as follows.

If the refractivity of a free (unbound) single ion of Mg^{2+} is, say, $s_i(Mg^{2+}) = 2$, and say $s_i(O^{2-}) = 6$, then the net refractivity of the MgO molecule will increase as the inter-ionic distance (di) decreases (once the ions are close enough to bond). This requires di < dc, where dc is a cut-off distance beyond which the refractivity of one ion does not measurably affect the refractivity of a distant neighbour. The inter-ionic distances di are taken from the structure data of Novak and Gibbs (1971), but one must iterate to find the dc values for each ion.

The ion O^{2-} places charge at Mg^{2+} a distance di away, and this increases the refractivity of Mg by $s_i'(Mg^{2+}) = s_i(Mg^{2+}) + s_i(O^{2-})(dc - di)^2$. A high estimated s_i of O^{2-} means that it places sufficient charge at Mg^{2+} to increase the refractivity of Mg^{2+} from 2 to an effective value of, say, $s_i'(Mg^{2+}) = 2.6$, but with a low refractivity of Mg^{2+}, the effective refractivity s_i' of O^{2-} in the Mg-O bond may be only 6.02. Now if a second ion of Mg bonds to the MgO molecule, it will further increase the effective refractivity of O^{2-} but will decrease the effective refractivity of Mg^{2+} (due to repulsion). But if the bond is stable, n (Mg-O-Mg) > n (Mg-O).

Now suppose that Fe partly substitutes into the Mg site. A fractional site

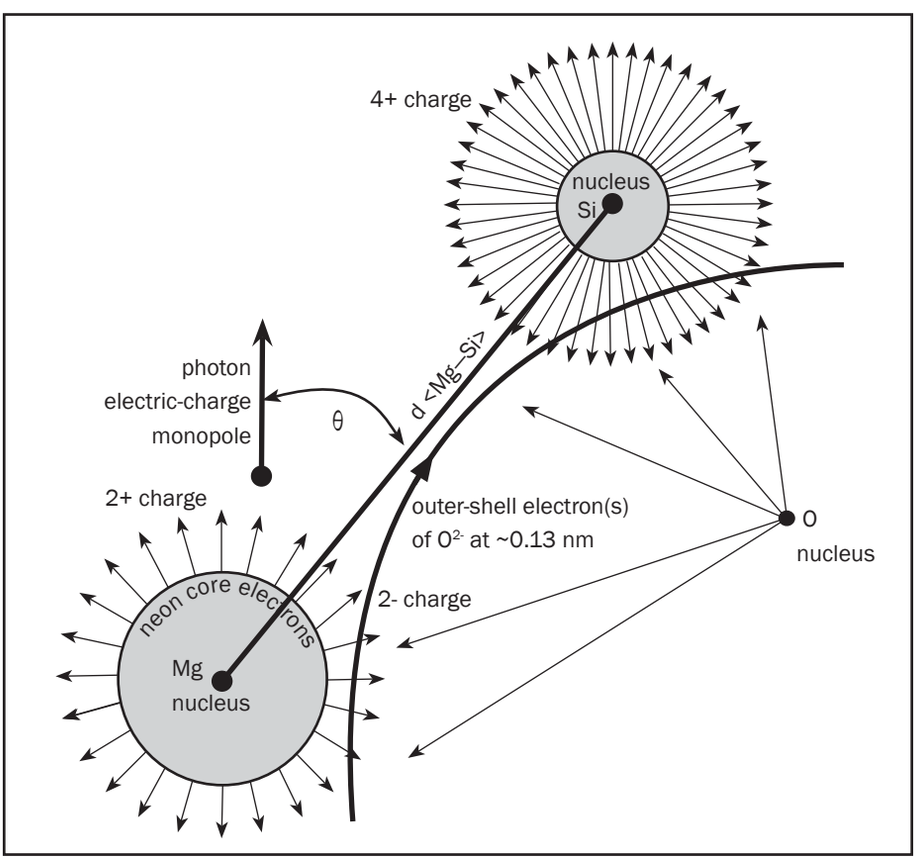

Figure 2. A generalized model of the relations between the polarization of light, the refractivity and identity of ions, and inter-ionic distances and angles. The model is applicable to aperiodic molecules, liquids and solids, and crystals. The force on a photon near an ion depends on the distances and angles to surrounding ions.

The refraction of light by garnet depends on both composition and structure

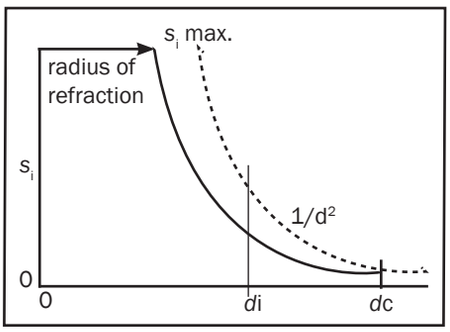

Figure 3. Ion refractivity s_i vs. cut-off distance dc. If a photon refracts at a specific level of energy at a radial distance from the nucleus, the charge beyond that radius of refraction falls off by $1/d^2$. An ion contributes a fraction of its refractivity s_i to a neighbour at di, also falling off as $1/d^2$. Beyond the cut-off distance dc, the ion does not contribute to the refractivity of a neighbour. Increasing the cut-off distance (from solid curve to dashed curve) is equivalent to increasing the radius of refraction; more charge is placed at di and the refractivity of the neighbouring ion is increased.

occupancy (*f*) is needed to account for the solid solution, such that Mg + Fe = 1 for full occupancy of the site. For example, the site may contain 20% Fe, giving *f*(Mg) = 0.8 and *f*(Fe) = 0.2 for the formula $(Mg_{0.8}Fe_{0.2})O$.

Experimentally, the electric vector of the photon is given a known direction by passing the light through a polarizing filter such as Polaroid. Attempts to describe the refraction of light through a crystal by reference to a plane wave of light were unsuccessful. If a local photon is considered, a single value for the refractivity of an ion occurs if the refraction of a photon is dominated by that ion over the time when the photon is near the ion. The refractivity is changed to minor degree by charge placed at the ion by surrounding ions. This additional force on the photon is at a maximum value for ions above and below the electric-charge monopole of the photon, and is zero for ions perpendicular to the proposed monopole. For garnet, it is convenient to calculate the angle θ by considering polarized light refracting along an a axis. The sum is taken for all ions in a sphere surrounding the site of interest; it is not with reference to a plane of polarization exhibited by a wave of light.

The general structure-factor for refraction is $C = \Sigma[\cos\theta\, fs_i(dc - di)^2]$, where *f* is the fractional site occupancy of ion i (accounting for solid solution), θ is the angle between an ion and the electric monopole of the photon (in this case parallel to the a axis of garnet), dc is the cut-off radius beyond which the refractivity of one ion does not affect the refractivity of another ion, and di is the inter-ionic distance. Knowing *n, D* and the inter-ionic distances for each composition, and calculating cosθ from the structure, there are only two variables for each ion, s_i and dc (*Table II*). However, these two variables are constrained to fall off as $1/d^2$ from free to bound cations and must explain the *n* and *D* values of all members of the solid solution. The system is thus highly constrained and strongly convergent on specific values of s_i and dc.

Note that the structure factor for refraction is different from the structure factor for diffraction. The physical phenomenon affecting refraction is the identity of an ion that is (for a time) dominating the local refraction of a photon; one must also account for the distance and angle to all ions surrounding this ion that alter its refractivity. By contrast, diffraction results from the sheet arrangement of ions in a crystal, and the specific identity of ions in a plane only influences the intensity of reflection. Any structure proposed to explain the refraction data need not be periodic (i.e. crystalline), thus allowing the photon as a probe of aperiodic materials including molecules, glass or liquids.

Table III: Site structure factors for end-member species of garnet.

Species	C_X	C_Y	C_Z
pyrope	0.00792	0.00877	0.01041
almandine	0.00757	0.00808	0.00938
spessartine	0.00732	0.00769	0.00891
grossular	0.00677	0.00592	0.00828
andradite	0.00373	0.00649	0.00535
goldmanite	0.00443	0.00654	0.00615
uvarovite	0.00296	0.00576	0.00453

With reference to the structural formula $X_3Y_2Z_3O_{12}$ of the anhydrous isotropic species of garnet, a photon undergoing local refraction about an ion in the X-site has a degree of refraction that is dominated by the X-cation, but the refractivity is influenced by all the surrounding ions (mainly by the nearest ions of oxygen, but also by the more distant X-, Y- and Z-site cations). The X-site contains large divalent cations in a distorted cube of coordinating oxygen anions. The Y-site contains trivalent cations in octahedral coordination, and the Z-site contains tetravalent cations in tetrahedral coordination. Each oxygen ion is coordinated by one Z-cation, one Y-cation and two X-cations (Novak and Gibbs, 1971).

For example, the structure factor for the X-site is the sum $C_X = C_{XO} - C_{XX} - C_{XY} - C_{XZ}$. For pyrope, $Mg_3Al_2Si_3O_{12}$, this is $C_X = \Sigma[\cos\theta\, fs_i(O^{2-})(dc - di)^2] - \Sigma[\cos\theta\, fs_i(Mg^{2+})(dc - di)^2] - \Sigma[\cos\theta\, fs_i(Al^{3+})(dc -$

Table IV: Values of molar refractivity (k_i) of ions in end-member silicate garnets.

Species	Mg^{2+}	Fe^{2+}	Mn^{2+}	Ca^{2+}	Al^{3+}	Fe^{3+}	V^{3+}	Cr^{3+}	Si^{4+}	O^{2-}
pyrope	0.7310	0.4223	0.4376	0.6349	0.2332	0.3511	0.3359	0.3220	0.5234	0.4383
almandine	0.7223	0.4181	0.4338	0.6298	0.2185	0.3535	0.3386	0.3229	0.5001	0.4529
spessartine	0.7156	0.4156	0.4310	0.6256	0.2092	0.3541	0.3359	0.3212	0.4904	0.4636
grossular	0.6980	0.4106	0.4259	0.6196	0.1687	0.3439	0.3218	0.3091	0.4790	0.4860
andradite	0.6205	0.3772	0.3916	0.5726	0.1816	0.3503	0.3282	0.3159	0.4250	0.5494
goldmanite	0.6180	0.3758	0.3905	0.5712	0.1863	0.3529	0.3309	0.3183	0.4231	0.5443
uvarovite	0.5890	0.3634	0.3779	0.5536	0.1653	0.3425	0.3199	0.3073	0.3930	0.5766

di)^2] -Σ[cosθ $fs_i(Si^{4+})(dc - di)^2$]. If $s_i(Mg^{2+})$ = 0.02158 and C_X = 0.00792 (*Table III*), the effective refractivity s_i' of Mg^{2+} in the X-site is 0.02950 nm^3 and $k_i(XMg^{2+})$ is 0.7310 cm^3/g (*Table IV*). The substitution of another X-cation for Mg increases the size of the unit cell and increases the <X-X>, <X-Y>, <X-Z> and <X-O> distances and the effective refractivity of Mg^{2+} decreases. With the refractivity contribution of an ion constrained to fall off as $s_i(dc - di)^2$, only the specific values of s_i and dc will return the measured values of *n* of *Table I*. The calculated values of *n* are not reported because the equation is sufficiently accurate to match the measured values of *n* for all species of garnet in the $(Mg,Fe,Mn,Ca)_3(Al,Fe^{3+},V,Cr)_2Si_3O_{12}$ solid solution.

The molar values of refractivity reported in the matrix of *Table IV* include the structure factors. From the structural formula and relative to end-member pyrope, the calculated unit-cell edge is *a* = 1.1459 + 0.0130667 Ca + 0.005400 Mn + 0.0022333 $^XFe^{2+}$ + 0.010350 $^YFe^{3+}$ + 0.010950 V + 0.007250 Cr nm, and *V* = a^3. For pyrope, the ionic weight fractions (or fractional densities) calculated from the formula $Mg_3Al_2Si_3O_{12}$ are 0.1809 Mg, 0.1339 Al, 0.2090 Si and 0.4762 O, Σ1. With eight formula units in the unit cell volume, the formula weight is 403.127 g/mol and the density is 3.5591 g/cm^3. The calculated index of refraction is *n* = *D*[(0.1809)(0.7310) + (0.1339)(0.2332) + (0.2090)(0.5234) + (0.4762)(0.4383)] = 1.714. For minor to trace quantities of Mn, Ca, $^XFe^{2+}$, $^YFe^{3+}$, V and Cr, one may use the k_i values for these ions in pyrope.

The k_i values of the ions vary depending on the identity of and the distance to the surrounding ions. From pyrope to almandine, for example, there is a linear change in $k(Mg^{2+})$; this is (0.7223-0.7310)/3 per $^XFe^{2+}$, and this is an additional (0.7223-0.6180)/2 per V for a hypothetical ferroan goldmanite. From the structural formula and relative to end-member pyrope, the calculated molar refractivity of Mg is $k(Mg^{2+})$ = 0.7310 - 0.011000 Ca + 0.0051333 Mn + 0.002900 $^XFe^{2+}$ + 0.055250 $^YFe^{3+}$ + 0.056500 V + 0.007100 Cr. The other k_i values may be calculated in a similar manner.

Accounting for changes in density, the resultant of the k_i matrix is an easy-to-use formula: *n* = 1.714 + 0.0066667 Ca + 0.0286667 Mn + 0.0386667 $^XFe^{2+}$ + 0.077500 $^YFe^{3+}$ + 0.05000 V + 0.065500 Cr. This formula was used to verify the values of n used in *Table I* (Teertstra, 2006) in that a linear best fit is attained between calculated and measured values of *n* for numerous compositions of garnet reported in the literature.

Practical implications

The optical properties of materials are essential to their identification. Each proposed structural formula implies a specific state of cation order and definite physical properties for gems and minerals. Using the values of s_i and dc in *Table I*, the physical properties of any proposed ionic structure may predicted (e.g. spinel, olivine, pyroxene, glass). The method of optical analysis is sensitive to light elements that cannot be analyzed by electron microprobe. Once values for the refractivity of ions are known, given a composition, the method can also be used to predict the structure.

If the index of refraction and the density or the unit-cell-volume are measured, the values of k_i may be used to determine the structural formula and hence the composition of a garnet sample. Convergence on the correct formula occurs as differences across the equality $n/\Sigma(k_i d_i) = \Sigma(a_i AW)/VAn$ are minimized.

If the composition is measured along with *n*, and the formula shows ΣX>3 and ΣY<2, then a recalculation of $^YFe^{3+}$ from $^XFe^{2+}$ may be verified by an improved agreement between calculated and measured values of *n*. The index of refraction is sensitive to the valence of an ion and to the order of cations in the structure.

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Ornamental variscite: A new gemstone resource from Western Australia

Margot Willing, Susan Stöcklmayer and Dr Martin Wells

Abstract: Variscite ($AlPO_4.2H_2O$) is an uncommon bluish-green mineral that has been used as an ornamental gemstone since the Neolithic Age. A new location of variscite has recently been investigated on Woodlands Station, Western Australia. The variscite from here occurs in a variety of aggregated habits within fine-grained Proterozoic siltstones and breccias. Rock surfaces have been found encrusted with microcrystals of variscite and wardite. Within the host rocks, associated minerals include metavariscite, crandallite, jarosite, quartz and grains of native gold. The gemmological properties of the Woodlands variscite are: RI range of 1.570 to 1.582, and SG from 2.49 to 2.55, and these are within the ranges of variscite from other world sources. X-ray diffraction analysis confirms the variscite to be of the 'Meßbach-type' in association with metavariscite, a dimorph of variscite. Using visible reflectance spectroscopy, trivalent chromium was verified as the main chromophore responsible for the colour. Minor vanadium is also present, probably in mixed oxidation states of +3 and +4.

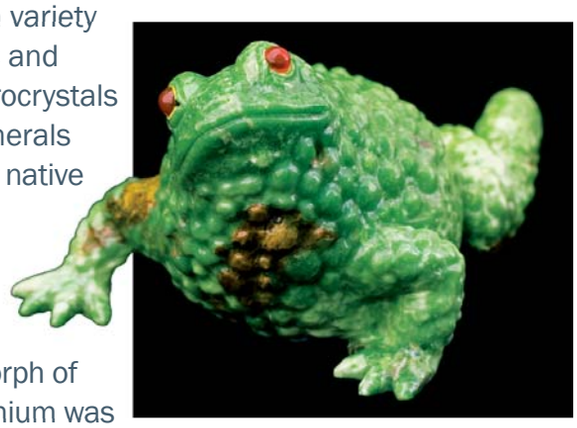

Keywords: Gold inclusions, 'Meßbach-type' variscite, metavariscite, trivalent chromium, Woodlands Station, Western Australia

Introduction

Ornamental variscite is bluish green in colour, fine grained and massive in habit. Its colour ranges from white, through light brown and bluish-green to yellowish-green. When used together with its matrix minerals and associated relict host rock, the resulting reticulated patterns are reminiscent of the variations in colour and textures shown by turquoise-in-matrix. Variscite has characteristics common with turquoise, the best-known ornamental phosphate gem mineral. They are recorded together in some worldwide localities and the mining history of both minerals dates to the Neolithic Age.

Variscite, a hydrated aluminium phosphate ($AlPO_4.2H_2O$), was first described in 1837, from a source in Germany where it occurred at Meßbach quarry, Altmannsgrün, near Plauen, Vogtland, formerly Variscia (Dana, 1892). This find was not a source of ornamental grade material. In Querre's words: "Lacroix, the famous French geologist, determined in 1896 the formula of variscite, official name of this mineral [$AlPO_4.2H_2O$]" (Querre *et al.,* 2007). Variscite also occurs as microcrystals that are recorded as colourless, green or red. The rare ferroan red variety occurs as encrustations on hematite at Iron Monarch quarry, Iron Knob in South Australia and at Boa Vista mine in Minas Gerais, Brazil (http://www.mindat.org/). Variscite forms at low temperature as a secondary mineral commonly associated with other hydrated minerals particularly its dimorph — metavariscite. It is found as veins and nodular encrustations within and on a variety of rock types. It may occur as a replacement mineral having developed *in situ* from phosphate-bearing fluids in association with fine-grained and clay-bearing aluminous rocks. It is also reported having formed at ambient temperature with other phosphate minerals within soils and on various substrates including serpentinite derived by chemical action from bird guano (Simpson, 1952).

History of early exploitation (4500–3000 BC) of variscite from the Iberian Peninsula is reported from recent archaeological work (Arribas *et al.,* 1970, Harrison *et al.,* 2001; Camprubi *et al.,* 2003; Dominguez-Bella, 2004), where evidence at some sites

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Figure 1a: Variscite seahorse on quartz base, height 20 cm. Carved by Robert Jüchem, Idar-Oberstein, Germany.
Figures 1b and 1c: Gold mounted pendant (30 mm diameter) and gold-mounted cufflinks (17 mm square), fashioned by Murray Thompson, Goldsmith, Brett Barker.

indicates workings continued to be mined into the Middle Ages. Variscite jewellery in the form of beads, necklaces and pendants is recorded from numerous Neolithic sites in Spain and Portugal, from burial sites in France (Forde, 1930) and, more recently, from rare Roman (AD 43–410) sites in England (Middleton, 2007).

Most of the ornamental variscite used in modern times for lapidary and jewellery purposes has originated from finds in the U.S.A., notably Utah. Deposits from here, first discovered in 1893, have been worked sporadically into the mid-twentieth century (Larsen, 1942; Dickerson, 1971). Clay Canyon in the Oquirrh Mountains, Fairfield County, Utah, has been the largest producer (Thomssen, 1991) with other occurrences including the Little Green Monster, and Utahlite Hill, Box Elder County and Amatrice Hill, Tooele County (Doelling, 1980). The state of Nevada has also been a source for gem variscite, with the Verde Web variscite mine in Lander County (Novak, 1982) being one recorded producer.

Variscite of blue green colour and translucent quality suited for ornamental purposes *(Figure 1)* is being mined from a new location at Woodlands Station in remote Western Australia (WA). Recent research has established that elemental gold occurs as inclusions within this variscite (Hancock, 2008). Although variscite is recorded from other locations within WA it has only been mined previously from Milgun Station, south east of this new find.

In this paper, the authors describe the properties of this new ornamental variscite, its geological occurrence and associated minerals.

Terminology

Minerals

Metavariscite: monoclinic; dimorph of variscite.

Strengite: orthorhombic; Fe $PO_4.2H_2O$, forms an isomorphous series with variscite; Fe^{3+} replacing Al^{3+}.

Variscite: orthorhombic; a member of a mineral series that includes arsenates and phosphates with the general formula $AXO_4.2H_2O$, where A = aluminium (Al^{3+}), iron (Fe^{3+}), chromium (Cr^{3+}) or indium (In^{3+}) and X may be arsenic (As) or phosphorus (P). Two polymorphic varieties of variscite exist: 'Meßbach' (VM) and 'Lucin' (VL) types, closely related, differing only in unit cell dimensions. Both terms are derived from their localities in Meßbach, Vogtland, Germany and Lucin (Utah, U.S.A.); see Clark (1993).

Historical mining and uses of variscite

Early to Middle Stone Age (c. 4500–2500 BC)

Exploitation of variscite as an ornamental material dates to prehistory. It was desirable, favoured for its intense green and blue-green colour. It was also of value as shown by the efforts made by Neolithic peoples to mine, fashion and trade it over hundreds of kilometres through parts of Europe. Recent archaeological work, notably at Can Tintorer in the Gavà Neolithic Mining Complex, about 20 km SW of Barcelona in NE Spain shows the early and deliberate exploitation and mining of variscite from 4000 BC over a period of 300-400 years (Harrison *et al.,* 2001). Veinlets and seams of variscite were worked from host rock slates via underground passages and galleries covering hundreds of metres, to depths of 40 m (Camprubi *et al.,* 2003). Beads and other items *(Figure 2a)* were fashioned in settlements nearby and exchanged across Spain and into the Pyrenees, distances up to 550 km.

Figure 2a: Variscite collar necklace found in a burial site inside the Neolithic mines of Gavà, Spain.

At Palazuelo de las Cuevas, Zamora, west of Can Tintorer, the mining of variscite also dates to the fourth millennium BC and beads from these two areas do not overlap in their trading. Variscite from here was also exploited in the later Roman period (Dominguez–Bella, 2004) and into the Middle Ages (Arribas, 1970). Similar mining and bead trading is known in parts of Portugal, where hundreds of beads have been discovered (Meireles, 1987).

Beads and pendants of variscite of various sorts and styles are also known and described from the Carnac region of north-western France, notably Neolithic tombs at Lannec-er Ro'h and Mané-er-Hroek, Morbihan, Brittany (Forde, 1930; Cassen, 1998). Recent trace element analyses of green beads and pendants from these burial sites indicate that the original source of the variscite is from the Iberian Peninsula (Querre *et al.,* 2007). An item of this collection, housed in the British Museum is a pendant fashioned from one piece of variscite and measuring 45 mm x 29.5 mm *(Figure 2b)*. The collection of ten beads displays various qualities of variscite, but overall the colours are intense, the beads well polished, the shapes varying between ovoid, discoidal and cylindrical with two showing several sets of bevels or facets, and all unornamented. The largest has a length of 21 mm. All are drilled through for suspending with large diameter holes, from 2 to 4 mm. These worked variscite articles have previously been described under the terms 'Callais' and 'Callainite' (Bauer, 1904), and it is possible that other archaeological finds of green ornamental materials may include variscite that has not yet been verified mineralogically.

Figure 2b: Variscite pendant and beads from burial sites in Mané-er-Hroëk, Brittany, France (4500-4000 BC). British Museum collection, with permission.

The Roman Period (AD 43–410)

Rare finds of variscite beads and jewellery are also known from the Roman era, and some examples from Britain are listed in *Table I*. In contrast to the large numbers of beads dated from the Stone Age period, those attributed to the Roman era are uncommon.

These rare archaeological finds demonstrate the importance and high esteem associated with owning variscite jewellery. The source of the variscite found in these Roman deposits has not been established with certainty.

Table I: Variscite artefacts found at archaeological sites in Britain; all Roman Period (AD 43-410).

Variscite artefacts	Archaeological sites	Reference
Fragment of a ring shank; carved in criss-cross design with serpents' head finial*	Gadebridge Park, Hemel Hempstead	Neal, D.S. (1974)
3 x beads; octagonal cross-sections	Balkerne Lane, Colchester	Crummy, N. (1983)
1 x bead; octagonal cross section	Tanner Row, York	Hooley, D. (1988)
1 x bead; faceted cuboid	Rougier Street, York	Hooley, D. (1988) Unpublished Ref. in Middleton *et al.* (2007)
7 x cylindrical green beads; mounted on an incomplete gold necklace	Grange Farm, Gillingham, Kent	Middleton *et al.* (2007)

** The first record of variscite identified from an archaeological site in Britain*

Common misnomers

- *Amatrice or amatrix:* a trade name, a coined term to describe variscite together with matrix material; also referred to as American matrix and variscite-quartz. Amatrice commonly includes wardite within its occurrence as concretionary masses.
- *Callais, callainite:* obsolete mineral names, originally terms describing turquoise and attributed to Pliny. These terms also have described non-specific green ornamental materials from ancient grave sites in Brittany. Both turquoise and variscite have been so described in archaeological studies and early mineral reference works.
- *Lucinite:* a trade name for variscite from near Lucin, Utah.
- *Utahlite:* a trade name for compact variscite nodules from Stransbury Mountains of Tooele County, Utah.
- *Variquoise:* a trade name describing combined variscite and turquoise rock
- *Verde web variscite:* a trade name for light blue and light green variscite with included black 'spider web' pattern matrix, from Lander County, Nevada. For more on variscite names, see Dietrich (2008).

Variscite from Western Australia

Variscite from the new occurrence in Western Australia was first shown in 2006 at the Arizona Mineral and Fossil Show in Tucson (Laurs *et al.,* 2007). The material is comparable to the highest quality that has been exploited worldwide with an intense bluish-green colour and translucent quality. Some of the material occurs with textural characteristics that make sculptural *objets d'art* attractive and recognizably different to variscite from elsewhere. The new deposit outcrops sporadically over a distance of several kilometres and has potential to be an important source of gem- and carving-quality material. Until these recent new finds, the only previous mining of variscite in Western Australia was on Milgun Station, located 67 km southeast of the 'Woodlands' deposit.

During a period from the early 1980s until 2001 several mining companies were active in the general area searching for gold and various base metals. Variscite was recorded in drill samples from several locations on Woodlands Station during this time. This historical information was later followed up and more recent detailed prospecting has established several areas where variscite occurs. The variscite described in this paper is from the first new discovery that was made in 2004.

Located within the 1:250 000 Western Australian Geological and Topographical map series Sheet SG 50 -3 (Mt Egerton), it is situated on Woodlands Station *(Figure 3)* within the Shire of Meekatharra, approximately 1000 km north of Perth and 95 km east south east of Mount Augustus. The most direct access is off the Mt Augustus/Woodlands road that intersects the Great Northern Highway a few kilometres north of Meekatharra.

Figure 3: Woodlands Station variscite deposit, Western Australia; view northwards from the mine site. Foreground shows mined ore.

Geological setting

All the new occurrences of variscite on Woodlands Station, as well as those from sources on Milgun Station, occur within sedimentary rocks that form part of the Mesoproterozoic Bangemall Supergroup, dated at 1000–1600 Ma. The most recent occurrences are from argillaceous sediments and silicified breccias of the upper Kiangi Creek Formation, part of the middle Edmund Group. The Kiangi Creek Formation comprises predominantly terrigenous sediments, especially arenites, and fine-grained brown and grey shales, and silt-, mud- and claystones, with minor horizons of cherts and dolomites including a stromatolite horizon. The original sediments were accumulated on a marine shelf, with restricted current circulation under hypersaline conditions (Muhling and Brakel, 1985).

Variscite occurs as conformable seams within brown siltstones and as cross-cutting veins and irregular zones within brecciated chert and silicified siltstone horizons. Quartz veining is commonly associated with variscite where the host rocks are brecciated.

Field occurrences

Occurrences of stratabound variscite have been traced in the host rocks along strike for approximately one kilometre and zones containing nodular and veinlet forms of variscite have been found over a larger area. The horizon containing the variscite veins varies between approximately 400 and 900 mm in thickness (D. Vaughan, pers. comm., 2008). Individual stratabound variscite seams range from a maximum width of ~55 mm to more common widths of <20 mm; seams also interconnect with one another via narrower veins *(Figure 4)*. In some veins variscite has a markedly fibrous nature occurring in cross-fibre orientation to the general bedding of the host rocks. Elsewhere, the host rocks have been brecciated and cross-cutting veins of variscite both traverse and enclose angular rock fragments. Veins may be less than 1 mm wide and connect with irregularly shaped zones several centimetres across; however only one open-cut has so far been progressed and all the material described is from this site. The open-cut is ~30-40 m in length and has been mined only during short periods in the wintertime, so far yielding several tonnes of material. At other times, the quarry site is temporarily covered with spoils material, and the variscite, as described here, was collected from loose samples at the ore heap, augmented with selected specimens donated by the mine owners.

Figure 4: At the mine site. Specimen boulder showing variscite veining.

Nature of the variscite

The variscite is varied in its nature and colour; that exploited for decorative and gemmological purposes is microcrystalline, intense green in colour and commonly microfibrous in habit. There is wide variation in occurrences of this fine grained variscite; from the seams already described that are fairly regular in width, to contorted and 'ptygma'-like veins with folds that pinch and swell *(Figure 5a)*. In other specimens variscite occurs as globular and botryoidal aggregations and, unusually, in tapered pod-like aggregations *(Figure 5b)*. Rare encrustations of microcrystals of colourless variscite *(Figure 5c)* and wardite *(Figure 5d)* were identified on rock surfaces and in fillings of small cavities.

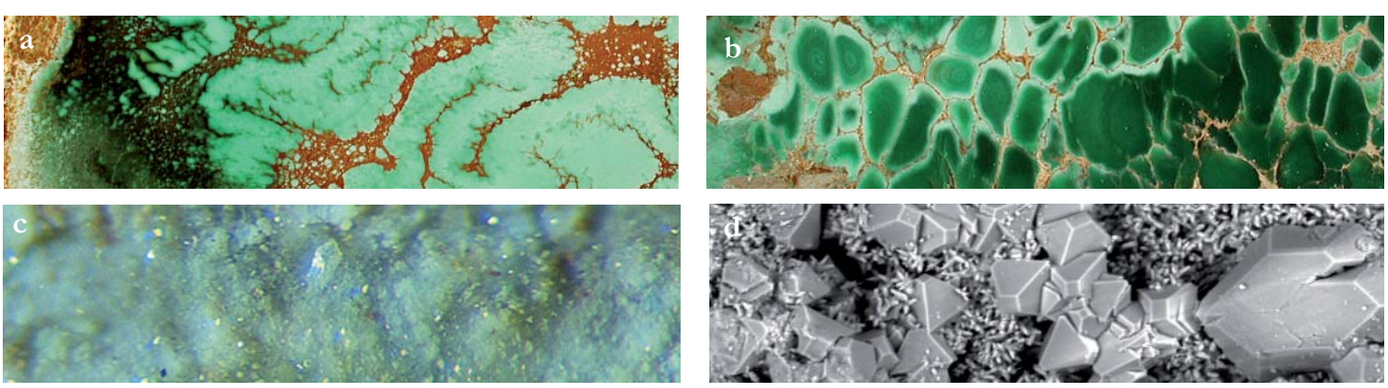

Figure 5: (a) Blue-green variscite-in-matrix showing 'ptygma'-like veining.
(b) Vein of pod-form variscite with brown rock matrix. Seam thickness ~35 mm.
(c) Rock surface — encrustations of secondary minerals; dominantly colourless variscite crystals. Centre: crystal of variscite (0.5 mm).
(d) SEM image showing wardite crystals as an encrustation on siltstone.

Material and methods

Samples of gem-quality variscite were cut using a 0.35 mm diameter diamond wire saw, and sections of four specimens V1, 4–6 are shown in *Figure 6a*. Standard gemmological methods were used on a selection of fashioned cabochons and carvings *(Figure 6b)* to determine refractive index (RI), specific gravity (SG) and luminescence. The absorption spectrum was captured with a digital camera attached to a monocular microscope which housed a diffraction grating spectroscope. Internal features were examined through a binocular microscope with oblique illumination.

Petrographic thin sections were prepared to view the relationship between country rock and the variscite mineralization through a standard petrological microscope. Further mineral identification work was assisted by RI oil-immersion techniques on grain crushes. Due to the very fine-grained nature of the minerals it was necessary to confirm all identification work with scanning electron microscope (SEM) and X-ray diffraction (XRD) techniques.

The XRD data were collected using a Philips X'Pert XRD fitted with a Cu tube (1.54056Å), automatic divergence slits, and diffracted beam graphite monochromator with the following settings: 2-theta range = 5–65°, step size = 0.03°, step time = 2s, divergence slit = 1 mm (fixed), receiving slit = 0.8 mm.

The Debye Scherrer X-ray powder (XRD) camera method was used to identify crystals occurring on rock surfaces.

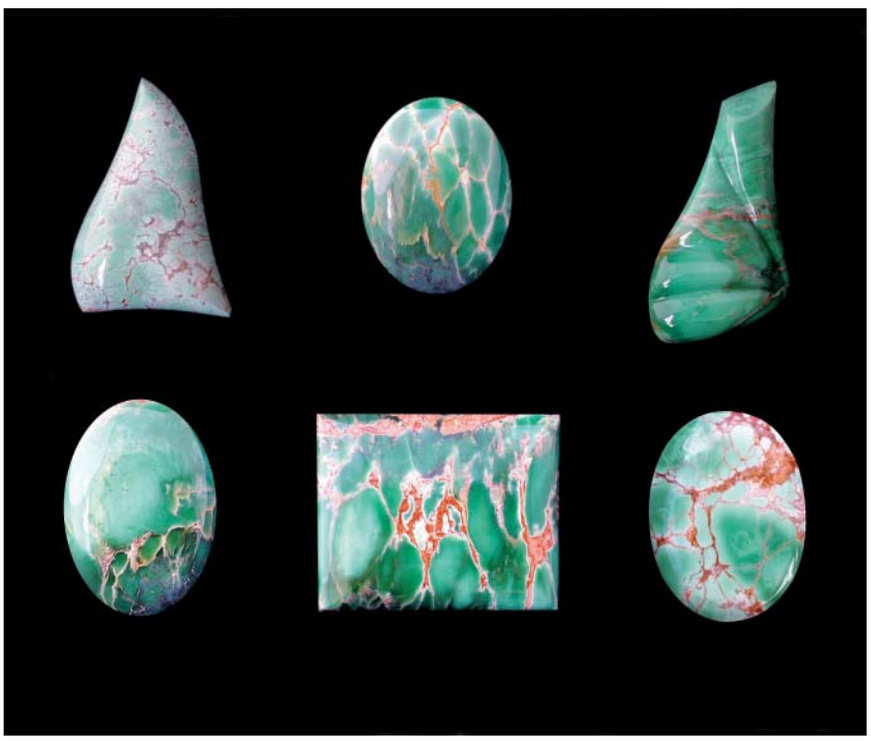

Figure 6b: A composite image of a selection of gem-quality 'Woodlands' variscite cabochons and carvings. Specimens top left and top right carved by Dalan Hargrave; oval and rectangular cabochons fashioned by Murray Thompson.

A Philips XL40 Controlled Pressure SEM fitted with an EDAX energy dispersive X-ray spectrometer (EDS) and a Robinson Back Scattered Electron (BSE) Detector, was used to identify gold and minerals associated with variscite.

X-ray fluorescence (XRF) for quantitative chemical analysis was performed on fused glass beads consisting of variscite mixed with lithium tetraborate and metaborate in the ratio 12:22 as flux. The beads were measured on a sequential PANalytical MagiX PRO XRF equipped with a 4.0 kW tube with fixed channels for Al and Si. Detection limits for most trace elements reported are ~10 ppm; major oxide report detection limits between 0.002% and 0.01%.

Reflectance spectra covered the visible to short-wave infrared wavelength range (400 to 2500 nm). Reflectance spectra of the unpolished and polished surface of each 20 mm square by 1–2 mm variscite slab were measured using an ASD Field Spec® Pro FR spectrometer (Analytical Spectral Devices, Boulder, U.S.A.), optimized and calibrated against a 100% reflectance Spectralon® white reference standard.

A mixed acid digest and the ICP-MS method of analysis was used for minor elements, the rare earths and Y, Th and U; Sc was analysed using ICP-optical emission spectroscopy.

V1 V4 V5 V6

Figure 6a: Sections of four variscite specimens — V1,V4, V5 and V6 — used in this study.

Results

Optical mineralogy and petrology

Host rocks

Variscite is hosted within siltstones, where it commonly occurs in conformable seams, and in brecciated zones, where it may be accompanied by quartz. The light brown siltstones *(Figure 7a)* are very finely banded but non-fissile and may be locally silicified. The texture is accentuated by streaks and microlamellae of reddish-brown iron oxides that also occur as euhedral castes, probably pseudomorphs after iron pyrite. Siltstones in contact with variscite contain a high proportion of secondary minerals; including variscite, quartz, crandallite and jarosite *(Figures 7b, 7c)*. Within brecciated zones, rock fragments are commonly silicified and are distinctly harder than the siltstones. Many fragments have an ultrafine 'chert-like' texture and may appear red-brown and clouded white in reflected light; some fragments are cherts, others are probably silicified siltstones *(Figure 7d)*. Due to their fine-grained nature (1 µ), their mineralogy could not be confirmed by optical methods.

Variscite and associated minerals

Variscite occurs in two distinct habits; equigranular *(Figure 7d)* and fibrous *(Figures 8b, 8c)*. Equigranular variscite with 'salt and pepper' 'chalcedonic-like' texture generally occurs within narrow veins and in zones bordering rock fragments within the brecciated zones. Fibrous variscite dominates in seam occurrences and characteristic reticulate patterns are developed in some places. These patterns have developed where bundles of variscite fibres, in elongate or pod-like forms, are closely packed with interstitial relict rock and brown-coloured matrix outlining their borders *(Figure 8a)*. Dimensions of pods vary; the longest measured 25 mm in the longest dimension. Pods often show variation in the green colour at their perimeters. Thin sections at greater magnification show the fibre patterns and concentric growth banding within individual pods *(Figures 8b, 8c)*. In longitudinal section pods show preferred fibre orientation and concentric banding *(Figure 8b)* with sweeping plumose extinction patterns when viewed between crossed polars. Variscite with these textures shows high translucency.

Especially well developed around pod borders is a distinctive pattern of polygonal brown patches *(Figure 8c)*. The pattern is clearly visible in plane polarized light (PPL) and is similar to a craquelure texture in the varnish of some old paintings and to that developed on the surfaces of septarian nodules. The texture may be the result of dehydration and shrinkage of pods, sometime after formation. Some pod borders are also lobed and finely fimbriated; these may

Figure 7a: Brown siltstone with stratabound variscite seam (20 mm thickness) in cross-fibre habit.

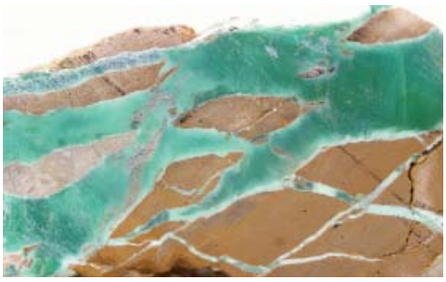

Figure 7b: Brown siltstone hosting veins of variscite and quartz lenses.

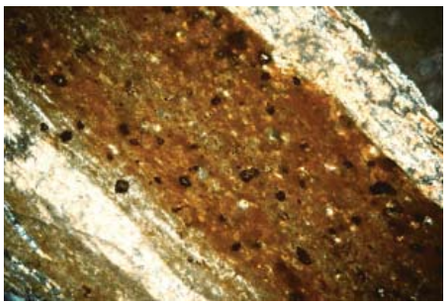

Figure 7c: Thin section of limonite-clouded siltstone, bordered by microlaminae of variscite and crandallite (colourless). The siltstone is speckled by granules of iron oxide-after-pyrite. Magnification 50x, cross polarized light.

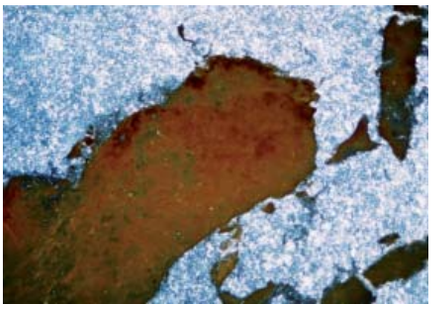

Figure 7d: Thin section of breccia showing oxidized and silicified siltstone fragments in a microcrystalline groundmass of variscite. Magnification 50x, cross polarized light.

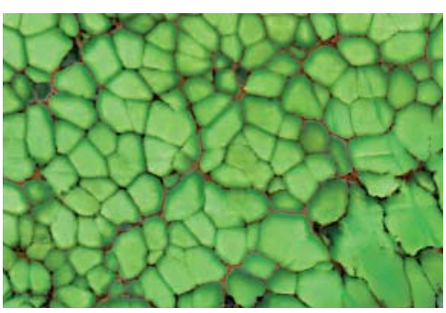

Figure 8a: Thin slice of variscite V6 viewed in transmitted light showing a reticulate pattern of variscite pods with interstitial matrix minerals. The variscite shows high translucency and green zones of different intensities are visible.

Figure 8b: Thin section of colloform variscite V5; fibres have aggregated to form elongated pods, with concentric growth patterns. Magnification 50x.

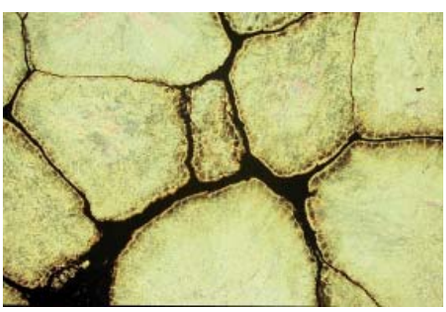

Figure 8c: Thin section of variscite V6 — transverse sections of pods, polygonal forms with reticulate pattern of interstitial remnant brown rock. Border zones of individual pods show desiccation textures. Magnified 50x.

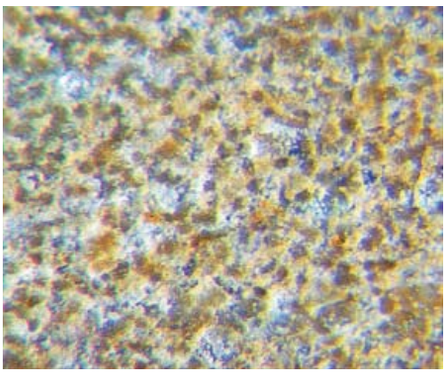

Figure 9a: The brown speckles on this host rock surface are crandallite.

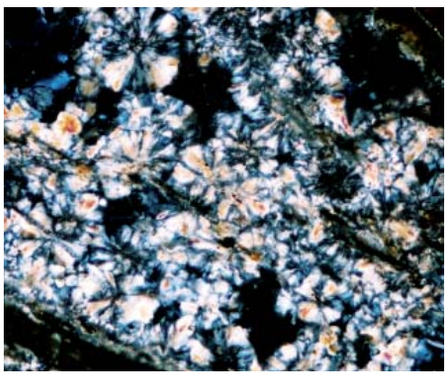

Figure 9b: Thin section showing crandallite microspheres in clouded siltstone. Magnification 50x, cross polarized light.

Table II: Summary of the gemmological properties of 'Woodlands' variscite

Colour	Light bluish-green
	Light to dark green
Diaphaneity	Opaque to translucent
Lustre	Waxy; takes a high polish
Hardness	~ 5
Fracture	Uneven
RI (range)	1.570 to 1.582
SG	2.49 to 2.55
UV fluorescence	Inert to both LW and SW
Chelsea colour filter	Grey to pale pink response
Absorption spectrum	Diffuse bands ~685 nm, 650 nm, 610 nm; absorption of the blue-violet
Microscopic features	Gold inclusions. Matrix: clay, quartz, iron oxides.

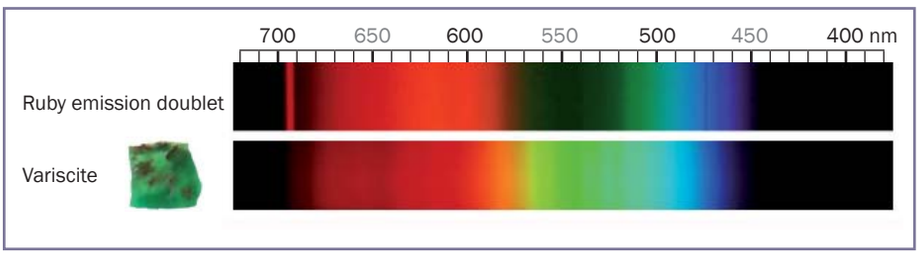

Figure 10: Absorption spectrum of variscite slab V4 ~2 mm thick, from a diffraction grating spectroscope, beneath a synthetic ruby spectrum showing its emission doublet as a calibration marker.

be deformational features caused by close packing and folding of the pods at the time of crystallization. The interstitial material between pods is dark coloured and interconnects, accentuating the reticulated overall pattern. It is optically semi-opaque and grey or brown in colour with red oxide grains. The presence of alunite, kaolinite and xenotime was confirmed using SEM; crandallite and quartz were identified as secondary fillings with layered growth banding; other substances could also be present.

Crandallite

Crandallite ($CaAl_3(PO_4)_2(OH)_5.H_2O$) occurs as a secondary mineral in fine bands (~2-3 mm) throughout some of the host rocks *(Figure 9a)*, especially common in those in contact with variscite. Grains display a range of habits: granules, fibrous sheaves and microspheroids ~25 µm in diameter *(Figure 9b)*. Crandallite in sheaf and spheroidal forms has commonly formed along open gashes and may show concentric growth and sweeping extinction patterns in thin section. In hand specimens some siltstones appear speckled due to the development of spherulitic crandallite.

Jarosite

Jarosite ($KFe_3(SO_4)_2(OH)_6$) is a minor component, occurring as encrustations on, and within, the siltstones as a late secondary mineral and is distinctly yellow or greenish yellow in colour. It is found in veinlets throughout rock fragments of the breccia as well as in fissures through zones of variscite. It occurs as lath-like grains and as fibrous fan-like sheaves. In thin section under crossed nicols it often displays anomalous interference colours of 'Berlin blue'

Quartz

Quartz is common in cross-cutting veins and lenses *(Figure 7b)* within the country rocks and brecciated horizons, and the associated variscite is often coarsely crystalline with hypidiomorphic granular textures. Well terminated quartz crystals occur in open veins and micro vugs where comb structures are also present.

Turquoise

Although not visible in specimens V1–V6, turquoise is reported occurring as thin conformable veins within the host rock (Nickel *et al.,* in press).

Gold

A rare and unique feature of the variscite is the occurrence of native gold as inclusions *(Figure 11a)*. In the group of specimens examined in this study, gold occurs in discrete grains, some as platelets, others as grains with spongy and pelletized surface textures. Grains range in diameter from 25 µ to 100 µ. Gold is most easily visible in the dark green variscite, although it is also reported to occur in massive and colloidal forms within the host rocks (Hancock, 2008). It occurs within the variscite as late syngenetic or epigenetic inclusions. The granules are reported to be of high purity containing no silver and may represent a

re-precipitation of primary gold that has been reported within the sedimentary sequences (Hancock, 2008).

Gemmological characteristics

Appearance

The selected cabochons and carvings fashioned from massive gem variscite *(Figure 6b),* exhibit light to intense green hues with some specimens showing a bluish-green. Most gem variscite is opaque, but portions of the dark green type show a marked degree of transparency. The brown matrix material provides the colour contrast in the characteristic web, cellular and reticulate patterns.

Optical and physical properties

The gemmological properties of the selected variscite cabochons and carvings are summarized in *Table II*. RIs, measured by the distant vision method on cabochons, range from 1.57 for the lighter material, to 1.58 for mid to darker green material. Small birefringence was evident on plane polished surfaces of translucent dark green variscite, and RI readings of 1.578 to 1.582, were recorded. The specific gravity of the variscite cabochons varies due to porosity and composition, from 2.49 to 2.55, the highest value being recorded from dark green material. The properties of this new 'Woodlands' variscite from Western Australia are within the ranges of published values in the gemmological literature (Webster, 1975).

The absorption spectrum of the predominantly translucent variscite V4 *(Figure 10)*, displays a Cr^{3+} spectrum with bands of diffuse absorption in the red at ~685 nm and ~650 nm, and an absorption cut-off below ~465 nm. A diffuse band at ~610 nm is unassigned. The Vis-NIR reflectance spectroscopy section gives a more detailed spectral analysis of the four variscite slabs (see below).

Inclusions

Microscopic examination of several polished specimens of gem quality variscite showed planes of yellowish-gold opaque inclusions *(Figure 11a)*. SEM-EDS analyses of surface-reaching inclusions confirmed their identity as elemental gold. SEM-EDS and XRD analyses of the brown matrix material, forming patterns within the variscite *(Figure 11b)*, confirm the presence of iron oxides, quartz, and traces of crandallite and alunite.

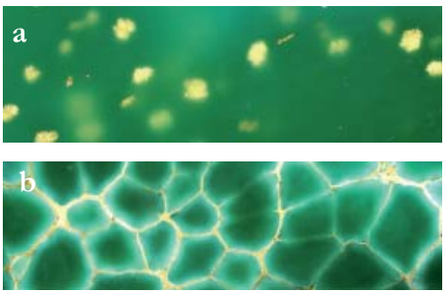

Figure 11: (a) Gold inclusions in variscite V6 between 30 and 100 µm across. Oblique illumination.
(b) Reticulate patterning of matrix material outlining variscite pods. Oblique illumination 7x.

Mineral identification

Two X-ray diffraction patterns of 'Woodlands' massive gem-quality variscite samples V1and V5 *(Figure 12)* indicate that the dominant phase is variscite. Both patterns match 25-18, International Centre for Diffraction Data (ICDD) database for the 'Meßbach-type' variety of variscite (Salvador and Fayos, 1972). Minor amounts of metavariscite (Kniep and Mootz, 1973) are present in variscite sample V5, and crandallite and alunite are present as traces.

Table III: Chemical composition of 'Woodlands' variscite.

Oxide/ Element	Wt. %			
	V1	V4	V5	V6
Al_2O_3	31.6	32.10	30.6	31.5
SiO_2	0.47	1.04	0.50	1.46
P_2O_5	45.3	45.9	44.4	45.7
TiO_2	0.14	0.31	0.40	0.29
Fe_2O_3	1.37	1.08	1.86	1.27
CaO	bdl	bdl	0.19	0.05
Na_2O	0.08	0.10	0.19	0.12
K_2O	0.13	0.02	0.06	0.02
V_2O_3	0.35	0.32	0.46	0.50
Cr_2O_3	0.09	0.21	0.18	0.16
PbO	bdl	bdl	0.08	bdl
SO_3	0.43	0.09	0.31	0.11
F	0.05	0.10	0.11	0.07
LOI*	21.90	18.50	21.90	17.20
-O=2F	- 0.02	- 0.04	- 0.05	- 0.03
Total	101.89	99.73	101.19	98.42

bdl: below detection limit
* The loss on ignition value (LOI at 1050°C) was used to calculate total water in the formula for V1, V4-6.

V1 $(Al_{0.96}Fe_{0.03}V_{0.01})\Sigma_{1.00}\ (P_{0.99}Si_{0.01}S_{0.01})\Sigma_{1.01}\ O_4.1.91\ H_2O$
V4 $(Al_{0.96}Fe_{0.02}V_{0.01}Ti_{0.01})\Sigma_{1.00}\ (P_{0.99}Si_{0.03})\Sigma_{1.02}\ O_4.1.6\ H_2O$
V5 $(Al_{0.94}Fe_{0.04}V_{0.01})\Sigma_{0.99}\ (P_{0.98}Si_{0.01}S_{0.01})\Sigma_{1.00}\ O_4.1.91\ H_2O$
V6 $(Al_{0.96}Fe_{0.03}V_{0.01})\Sigma_{1.00}\ (P_{1.00}Si_{0.04})\Sigma_{1.04}\ O_4.1.6\ H_2O$

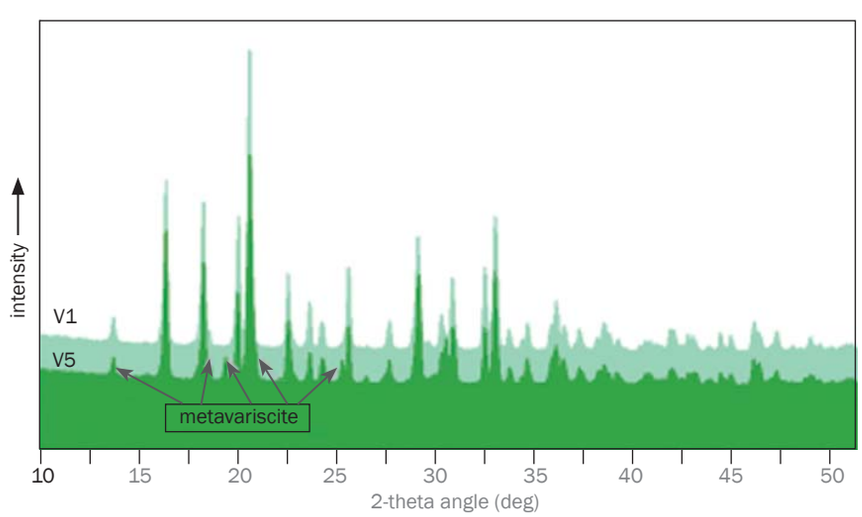

Figure 12: X-ray diffraction patterns of variscites V1 and V5. Patterns displaced vertically for clarity.

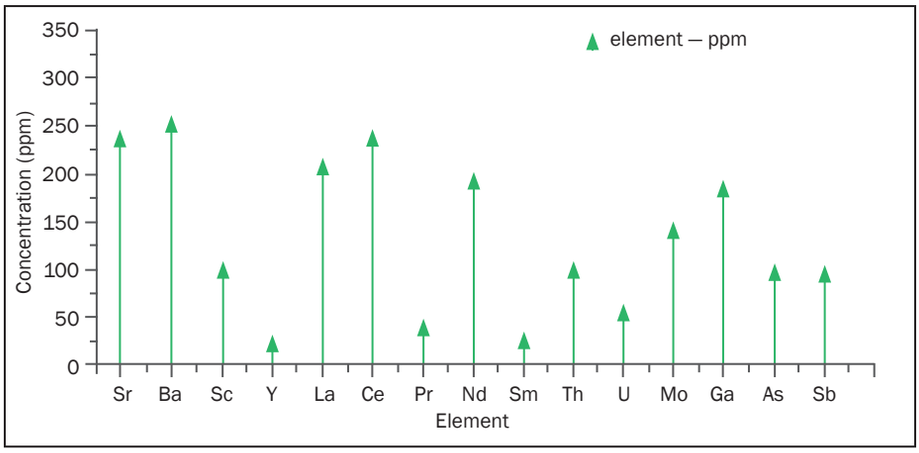

Figure 13: Minor element content of variscite V5.

Chemical composition

The ideal formula for variscite is $AlPO_4.2H_2O$. The results of quantitative x-ray fluorescence analyses of four gem grade 'Woodlands' variscite samples V1, V4-6 are summarized in *Table III*. In addition to the major detectable elements of Al, P and water in the ideal formula, minor amounts of Si, Ti, Fe, V, Cr and S are present. The elements Na, K and F are also present as traces. A separate analysis for the ferrous ion (Fe^{2+}) indicated that it was below the detection limit (bdl); consequently, all of the iron is assigned to the ferric (Fe^{3+}) state.

The vanadium and chromium contents of 'Woodlands' variscite *(Table III)* display a similar chemical fingerprint to the variscite deposits of El Bostal – Zamora (Spain) and Pannéce – Brittany (France), (Querre *et al.,* 2007, fig.1). The mean vanadium content of 2771 ppm and chromium content of 1094 ppm of the four 'Woodlands' variscites result in a vanadium to chromium ratio of 2.5:1, in comparison to ratios of 2.9:1 for El Bostal, and 2.2:1 for Pannéce.

The relatively high lead content of 750 ppm in variscite sample V5 *(Table III)* may signify selective enrichment of isotopes in the variscite and this specimen was also analysed using inductively coupled plasma mass spectrometry (ICP-MS). The results are summarized in *Figure 13* and show that the actinides, uranium (~50 ppm) and thorium (~100 ppm), are in high abundance, indicating the presence of active daughter nuclides and related gamma radioactivity, from the natural decays of U^{238} to Pb^{206}, U^{235} to Pb^{207} and from Th^{232} to Pb^{208} (Senior and Chadderton, 2007). This is consistent with the finding of anomalous radioactivity using a portable field scintillometer in the siltstone layer below seams of variscite (D.Vaughan, pers. comm., 2008).

Also of note is the scandium (Sc) content of 100 ppm, which equates to ~3oz per tonne and is similar to the variscite-Sc association in Utah. In 1942, several hundred pounds of variscite were found in the vicinity of the Utahlite mine, Utah, whilst the area was being prospected for scandium (Novak, 1982).

A sample of gem grade variscite analysed for elemental gold by neutron activation, contained 17.5 ppm gold.

Table IV: Absorption band centre wavelengths and band assignments in variscite.

Sample				Band assignment	Reference
V1	V4	V5	V6		
Band centre (nm)					
520	525	535	525	Transmission window	
-	-	-	424	Fe^{3+} ions	Calas *et al.,* 2005
-	451	-	-	Cr^{3+} v2 transition, $^4A_{2g}(F) \rightarrow {}^4T_{1g}(F)$	Calas *et al.,* 2005
631	630	629	631	Cr^{3+} v1 transition, $^4A_{2g}(F) \rightarrow {}^4T_{2g}(F)$	Calas *et al.,* 2005
655	656	656	655	Cr^{3+} spin forbidden transition, $^4A_{2g}(F) \rightarrow {}^2T_{1g}(G)$	Balan *et al.,* 2002 Calas *et al.,* 2005
690	690	690	690	Cr^{3+} spin forbidden transition, $^4A_{2g}(F) \rightarrow {}^2E_g(G)$	Balan *et al.,* 2002 Calas *et al.,* 2005
861	855	856?	857	Vanadyl, VO^{2+}, groups	Calas *et al.,* 2005
nd	886	888	887	Vanadyl, VO^{2+}, groups (?)	Calas *et al.,* 2005
1179	1177	1174	1175	OH overtone?	
1240	1239	1237	1239	V^{3+} spin forbidden transition, $^3T_{1g}(^3F) \rightarrow {}^1E_g(^1D), {}^1T_{2g}(^1D)$	Alda *et al.,* 2003
1281	1279	1280	1279	Unassigned	

NB: Band centre values are averaged from reflectance measurements for both the polished and unpolished surface of each variscite slab.
nd: not determined. The absorption band was too broad to accurately determine a centre position.

Vis-NIR reflectance spectroscopy

Colour properties: chromophores

Reflectance spectra for each unpolished surface of the four slabbed variscite samples V1, V4, V5 and V6 are presented in *(Figure 14a)*. The relatively greater overall reflectance ratio (albedo) of V1 is due to its opaque nature compared to the other variscite samples, which are near-translucent (i.e. gem-quality). The slabbed form allows transmission of some incident illumination with a corresponding reduction in the overall albedo, but the wavelengths of measured absorption bands are not affected.

The main absorption activity occurs in the visible to near-infrared wavelength range from 400 to ~1500 nm *(Figure 14b)*.

Absorption features in the shortwave infrared wavelength range, 1500 to 2500 nm, are generally weak, broad and poorly resolved. The broad band between 1460 and 1879 nm may be related to SO_4 groups of minor associated mineralogy (e.g., jarosite), whereas the sharp feature near 1430 nm can be assigned to OH vibration overtones of structural water within variscite. However, the main absorption activity occurs in the 400 to 1500 nm wavelength range, and it is this region that is the focus.

Wavelengths and band assignments of measured absorption features are listed in *Table IV*. The transmission window/maximum reflectance for variscite V1 is on the edge of the green at 520 nm, whereas transmission windows in samples V4–V6 shift towards the mid-green at ~528 nm. Two main absorption bands were detected at 520–750 nm (centre ~630 nm) and 750-1100 nm (centre ~865 nm); with the former band related to chromium and the latter feature due to vanadium. In octahedral co-ordination Cr^{3+} shows two absorption bands arising from the spin-allowed v1 and v2 transitions at 629 and 444 nm, respectively (Calas *et al.,* 2005). Whilst all measured variscite samples show a prominent Cr^{3+} spin-allowed v1 band, the v2 transition was not fully resolved in any of our variscite samples. Instrument noise at wavelengths <450 nm, together with the increasing absorption tail near 400 nm due to ligand-metal-charge-transfer (LMCT) from bands such as O-V in vanadyl and possibly O-Fe due to Fe^{3+} replacing Al in variscite, interfered and obscured the Cr^{3+} v2 transition at near-UV wavelengths.

The weak but sharp absorption features on the high wavelength side of the v1 transition at 655 nm and 689 nm (Figure 14b) are characteristic of Cr^{3+} in octahedral co-ordination (Calas *et al.,* 2005). Their detection confirms the presence of Cr^{3+}, rather than V, as the main chromophore in variscite (Calas *et al.,* 2005). Similarly, detection of these spin-forbidden transitions in spectra measured for dickite also confirmed the incorporation of Cr^{3+} within the structure of this clay mineral (Balan, *et al.,* 2002).

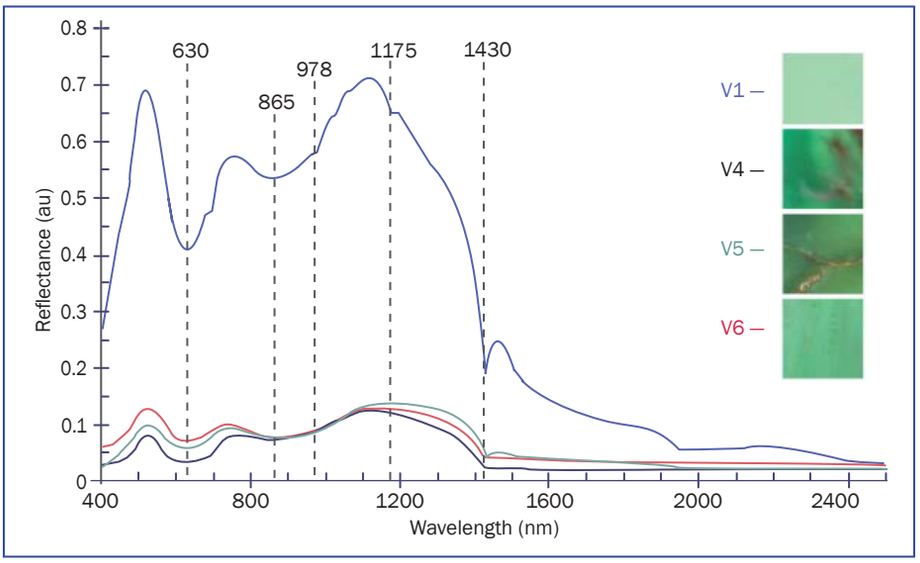

Figure 14a: Reflectance spectra for the unpolished surface of four slabbed variscite samples. The sharp features at approximately 978 and 1430 nm are overtones of OH vibrations from structural OH in variscite and are not listed in Table IV. Reflectance spectra have not been vertically offset.

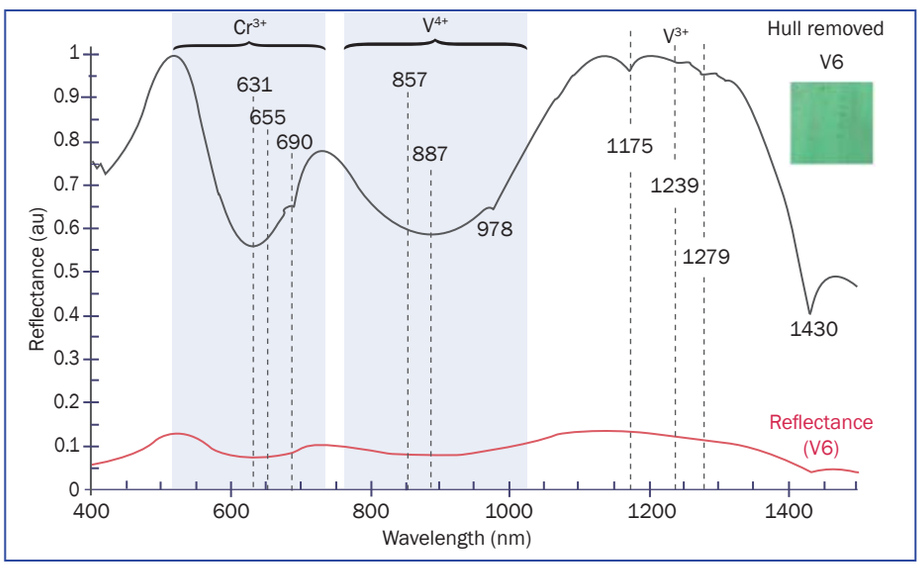

Figure 14b: Reflectance (red curve) and Hull removed spectra (black curve) for variscite V6, showing detail of absorption features in the 400 to 1500 nm wavelength range. The Hull removed spectra helps to emphasize small absorption features not easily resolved in the reflectance spectrum. Absorption features at 978 and 1430 nm are overtones of OH vibrations from structural OH in variscite and are not highlighted. The spectra have not been vertically offset.

The second main absorption band, centred at ~860 nm can be assigned to vanadyl, VO^{2+}, groups with V in the +4 oxidation state. Splitting of this band by an additional feature at 890 nm *(Table IV)* produced an asymmetric broadening to longer wavelengths. However, the smaller longer wavelength feature at 1240 nm, assigned to V^{3+} indicates that V in variscite may be in a mixed oxidation state. Vanadium can occur in either the +2, +3, +4 or +5 oxidation states, with transport of V^{4+} and V^{5+} in the fluid state being the most common (Schindler *et al.,* 2000). Recent optical absorption spectra recorded for variscite and metavariscite, detected only a very weak feature near 870 nm, which was interpreted by Calas (2005), supported by other data, as indicating little V^{4+} but substitution of PO_4 tetrahedra by V^{5+} as vanadate groups.

Figure 15: (a) Variscite carved in contemporary freeform style; height 11 cm. Carved by Dalan Hargrave, U.S.A.
(b) Chinese carving of variscite in traditional style; height 4.5 cm.

Discussion and summary

Variscite as an ornamental mineral is used in its microcrystalline and massive form and has adequate hardness for carved objects to take a good polish. Its attractive colour and appearance in complex textural patterns have contributed to its popularity *(Figures 15* and *16)*.

Although the exploitation of variscite has a long history, there have been few sources of ornamental quality material worldwide. Much of the variscite currently marketed is from stockpiled material from known and inactive occurrences principally from the states of Utah and Nevada, U.S.A. Some of this material has been collected on a casual basis from old workings, sites that are also visited by researchers and private mineral collectors. In contrast, non-gemmological low-grade variscite and microcrystals are not uncommon and are recorded from many countries.

Western Australia is now a source of ornamental quality material and deposits on the Woodlands sites have considerable economic potential. The deposits are situated within fine-grained dominantly argillaceous rocks of extensive occurrence, where gold is known to be present. The variscite occurs together with several minor minerals, notably crandallite, alunite, iron oxides and quartz; these minerals may be present within the ornamental grade material. Metavariscite was found to occur more commonly within pale coloured and partly altered variscite material. The presence of gold granules as co-genetic inclusions within the variscite is of great interest as a rare gemmological phenomenon and provides the prospects with added economic potential.

The variscite seams are generally <100 mm wide, limiting thickness of useable material and typical examples of carved, cut and polished variscite are illustrated. Larger objects can be worked from material using other directions and incorporating matrix material. The somewhat porous nature of variscite, due to its fibrous nature, may result in discoloration if in contact with certain liquids, and tests using refractive index oils, for example, resulted in yellowish staining.

The matrix material in the variscite with a reticulate pattern can be both friable and porous, and like turquoise, would need to be stabilized with wax or resins to avoid accidental damage and permanent

Figure 16: Variscite fish; dimensions 35 cm x 25 cm, ~4 kgs. Eyes fashioned from hessonite garnet. Carved by Robert Jüchem, Idar-Oberstein, Germany.

discoloration. Some cut material has been impregnated with cyanoacrylate, an acrylic resin, to stabilize the interstitial materials and obviate damage.

Reflectance spectra indicate that the chromium Cr^{3+} ion is the main chromophore responsible for the attractive green colour of 'Woodlands' variscite. Early indications show that variscite can incorporate vanadium (V) in a number of oxidation states. Reflectance spectroscopy may enable a quick assessment of V oxidation state(s) and this may provide an indicator of the conditions under which the formation of variscite occurred. X-ray adsorption spectroscopy (XAS) studies of the 'Woodlands' variscite are currently part of an investigation into the nature of and the potential relationship between gold mineralization and the oxidation state of V in variscite.

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Photo credits

Henri Oorjitham: 1a, 15a. Josep Bosch: 2a. Susan Stocklmayer: 1c, 2b, 3, 4, 7a, 7b, 8a. Margot Willing: 1b, 5a, 5b, 6b, 11a, 11b, 15b, 16. Ian Robertson: 5c, 8c, 9a. Ernest Nickel: 5d. Ian Pontifex: 7c, 7d, 8b, 9b. John Harris: V1, V4, V5, V6, 10.

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Visually distinguishing A-jadeite from B-jadeite

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Abstract: Jadeite grades A and B are described in the context of the Chinese gem trade. Visual distinction of the grades is described, illustrated and discussed in terms of surface lustre, distribution of colour, nature of inclusions, internal reflection of light, microfractures and features of the fashioning of various items. Development of these recognition skills is recommended but recourse to the laboratory should always be an option for difficult items.

Keywords: China, gem grading, jadeite, treated gems, visual skills

Introduction

The rapidly growing popularity of collectables has caused increasing interest in jadeite items, especially by ordinary Chinese citizens, and there is no reason to believe the enthusiasm will diminish in the future.

Determining the authenticity and values of jadeite items can be difficult problems. Their valuation involves many contentious issues but one of the most important is differentiating between A-jadeite, the natural and non-improved jade, and B-jadeite which is the clarity enhanced version of natural jadeite. This is especially important in commercial circumstances.

The ordinary dealer or collector is not generally familiar with professional gem identification instruments, and the absence of detailed technical knowledge about the production of B-jadeite, even amongst traders, means that evaluations made using basic instruments such as the magnifier may not be reliable. Being able to identify the different versions of jadeites simply by sight is, nevertheless, a highly desirable skill.

Definitions of A-jadeite and B-jadeite

The identifications of A-jadeite and of B-jadeite can only be undertaken when the precise definitions of these materials are understood. However, in China, there is no formal description in any Chinese National Standard and the distinction between them is yet to be established, especially for commercial use in this country.

It has been widely believed that A-jadeites have been only cut and polished without changing their appearance or durability, while B-jadeites have been acid treated and the developed cavities and pores have been filled with organic compounds (Fritsch *et al.,* 1992).

Organic compounds such as waxes, resins and epoxies can be difficult to identify when they have been applied as sealants and fillers. They are best detected and characterized using the infrared spectrometer but this instrument was not readily available in China until about 1996. Alternatively, a hot wire can be a useful preliminary means of detecting organic filling although it can be mildly destructive.

Jadeite carvers insist that a final sealing with wax is an essential completion step even for non-enhanced jadeite items. However, it is not really practical to attempt to distinguish between wax applied for polishing and that applied for filling cavities and pores produced by acid treatment. This resulted in wax-treatment for jadeites being listed as an enhancement in the 1996 edition of the Chinese National Standard (AQSIQ, 1996). In spite of this, it is currently widely accepted in the trade that such jadeite items treated with wax just for surface glazing can still be classed as A-jadeite, and therefore, the wax-filling does not need to be disclosed in sale notes or certificates.

Recently, it has been observed that some jadeite items had been excessively treated with wax or other sealants to well beyond that appropriate for finishing jadeite carvings. Gas bubbles are present in some of this material and can be seen with only the 10x loupe, sometimes even without a lens. Consequently, the 2003

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edition of the Chinese National Standard (AQSIQ, 2003) listed such impregnation with wax or sealant as the commercially-defining treatment for B-jadeite.

Heat can also be used to turn some iron-pigmented jadeite red, and in the Chinese National Standard this colour-changing heat-treatment is also considered to be an enhancement (AQSIQ, 2003). However, such thermally treated jadeite still is considered to qualify as A-jadeite in a commercial sense.

Therefore, the definition of A-jadeite which is accepted in the Chinese gem trade is as follows. Type A-jadeite is jadeite that has only been treated by carving, polishing, or surface-filling with just a little wax to finalize the lustre development; additionally, heating to develop red colours and surface treatment with a mildly-bleaching acid such as oxalic acid or waxberry acid (but without damaging the structural integrity of the stone) are also considered to still qualify as A-jadeite (waxberry acid is derived from the China waxmyrtle or China bayberry of the family Myricaceae).

The accepted definition of B-jadeite is as follows. Type B-jadeite includes jadeite items which have been leached by strong acid and the resulting pores and cavities then filled with sealant such as a polymer (Fritsch *et al.*, 1992) or with wax, the latter of course being less durable or permanent than a thermoset polymer like an epoxy resin.

C-jadeite is generally understood to mean dyed jadeite, but without impregnation of sealant. This is not discussed in this paper.

B-jadeite production

In order to appreciate some of the more subtle differences between A and B-jadeite, the production process of B-jadeite is outlined below. Starting material appropriate for treatment is selected. Its grain size and structure should be coarse and conspicuous so that strong acid will easily attack and erode the undesirable components in the jadeite. Suitable material is generally of lower grade which enables a greater profit margin and it often contains numerous black inclusions of various kinds. The material is sliced and roughly formed. The thickness of the slices should not be significantly greater than that of the intended roughly formed items such as bracelets, because the time required for the acid to penetrate and affect depths of more than about a centimetre is excessive, which is unsatisfactory and expensive. The items are then treated with a solution of a strong mineral acid and controlled heating may also be beneficial to accelerate the action. After sufficient time in acid treatment the items are washed at least twice in aqueous solutions of alkali to neutralize any residual acid and are then rinsed. A second treatment with a much weaker solution of acid is generally conducted followed by a wash with a weak alkali solution and a final rinse in water prior to drying in the open air. Thus, the product is porous and chalky. (If the operator wants to produce B+C jadeite, porous and chalky zones on the items are selectively treated by hand with solutions of various dyes of appropriate colours which are readily absorbed to produce simulated patterning and colours resembling that of better quality untreated natural jadeite.) Finally the items are dried and then submerged into a melted or liquid sealant such as resin or uncured polymer and the air remaining in the pores and cavities in the jade is pumped out under vacuum. Releasing the vacuum then allows the atmospheric pressure to force the sealant to impregnate the voids. If necessary, the material is then cooled and is ready for carving.

Key points to be considered in visually identifying A and B-jadeite

Some of the rather subjective factors which can be used to distinguish A-jadeite from B-jadeite are listed and are then discussed in more detail below. Integration of these considerations can then usually result in a moderately reliable assessment of whether the item can be categorized as A-jadeite or B-jadeite:

1. surface lustre or comparative reflectance differences
2. distribution of coloration on the surface
3. nature of the internal inclusion patterns
4. internal reflection of light resembling the adularescence of moonstone
5. presence of micro-fractures
6. size of the item and the quality and intricacy of the carving

Visually identifying jadeite as type A or B requires careful and thorough examination with attention to all of these points in order to avoid erroneous conclusions.

Discussion of the key points

1. Authenticating jadeites based on differences in surface reflectance or lustre

When viewed under a suitable light source, larger polished items with substantial curved or comparatively flat surfaces may provide detectable differences in reflectance of A-jadeite surfaces *(Figure 1)* compared with those of B-jadeite. The more reflective glazed surface with a brighter vitreous gloss of A-jadeite contrasts with that of the generally less-reflective polymer-impregnated B-jadeite.

Localized zones (or belts) of surface area may also show distinct variations in the natures of the reflective highlights between A- and B-jadeites such that they are really more a difference of brightness than of colour. Imagining the view of the jadeite to be just a black and white image can improve comparative assessments of the relative intensities of these localized reflections.

2. Surface 'colour levels'

If A-jadeites with high transparency and an even texture are viewed with strong light, (for example, direct sunlight), the surface will appear to develop a 'cold' colour tone *(Figure 2)*. This effect can also occur on A-jadeites with an intrinsically 'warm' colour such as a yellow through brown to a red (see *Figure 3*). The appearance is probably a subjective mental evaluation of the sharpness of

Figure 1: Example of vitreous reflection which is sharply defined and three light belts with sharp boundary on the back leg of the carving, characteristic of A-jadeite.

Figure 2: 'Cold' colour sharp reflections on the surface of a green A-jadeite carving.

Figure 5: An exquisite 'qiao se' effect, which describes the use of different colour zones in the A-jadeite to artistically demonstrate the uniqueness of the piece.

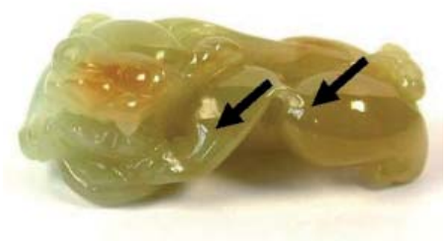

Figure 3: 'Cold' colour of well-defined reflections also observed on the surface of A-jadeite with a yellow-brown 'warm' body tone compared to the 'cool' green of the jadeite in Figure 2.

Figure 4: Clear colour boundaries and unaltered green core zones in partially weathered jadeite, characteristic of A-jadeite.

the reflected images rather than any real difference in true colour perception, analogous to the 'hard' and 'cold' crisp brilliance of a well-faceted white diamond compared to the more 'soft' and 'gentle' appearance of most of its less refractive simulants. This elevated level of 'cold' contrast generally appears only on the surface of A-jadeite, presumably because the lower refraction of most of the organic sealants and impregnation agents used for B-jadeite leads to its lower reflectivity. Even most lay people who are usually uninformed in the intricacies of jadeite treatments can appreciate this distinction without difficulty, so that when two different polished glossy objects without much difference in body colour, although with distinct differences in reflectivity are compared, impressions of different 'colour tones' of 'cold' colour and 'warm' colour are perceived.

Sections of strong cold colour reflections which glisten with slight movement of the light source or specimen can be observed at different locations on the surface of A-jadeite pieces, but these crisper 'cold' colour reflections are less common on B-jadeite items with their contents of sealants and fillers.

3. Inclusions

Natural inclusions in jadeites can include brown or various alternatively coloured substances, black minerals and 'catkin' pellets. The externally oxidized and differently coloured weathering shell surface of rough jadeites is a common epigenetic alteration, and its deliberate retention in jadeite carvings to provide aesthetic colour contrasts generally indicates A-jadeite. However, false or simulated 'weathering shells' may also be encountered. Genuine weathering shells exhibit intense colour gradations and clear boundaries between the oxidized zone and the less affected interior. A genuine weathering shell gives the impression that the oxidation colours have diffused from outside to inside, but a dyed imitation or false weathering shell gives a contrary impression. A genuine weathering shell of a brown oxidized zone encapsulating an unaltered green core is illustrated in *Figure 4*.

Modern technology is now quite capable of imitating the brown component that earlier was considered to be evidence of untreated A-jadeite so that its presence is now less useful for differentiating A- from B-jadeites. However, there may be other evidence that can indicate A-jadeite rather then B-jadeite, such as a very fine quality of the carving technique, as well as 'qiao se' (a feature indicating the skill in exploiting the irregular distribution of the best natural colour to the best effect in the available material as shown in *Figure 5*).

Black oxide inclusions mainly consist of chromite, magnetite or franklinite (a zinc, manganese and iron spinel), apparent as opaque black dots and speckles. These black oxide particles commonly accompany the jadeite's brilliant green, lavender or grey body colours which are developed by naturally incorporated transition metal ions such as those of chromium, manganese and

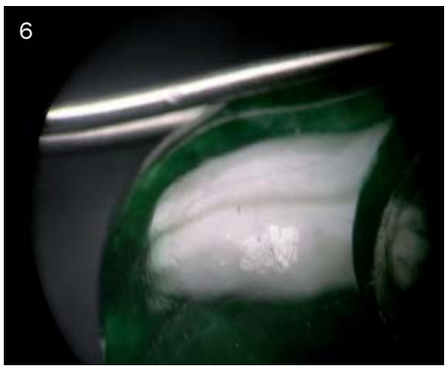

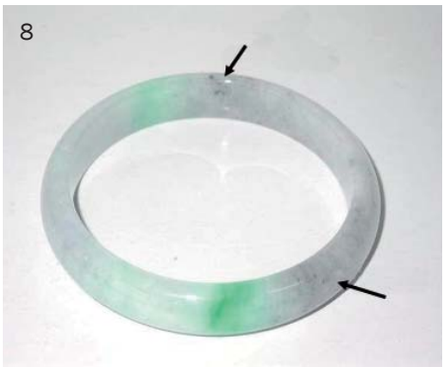

Figure 6: Reflective inclusion with metallic lustre exposed at the jadeite surface; diagnostic evidence of A-jadeite.
Figure 7: Black inclusion in a vivid green A-jadeite.
Figure 8: Black inclusion within a mottled grey and green jadeite, indicating that it is probably A-jadeite.
Figure 9: Greenish-blue epigenetic inclusion on a mesh-textured surface of an A-jadeite.
Figure 10: A-jadeite with greenish-blue inclusion when observed in transmitted light.

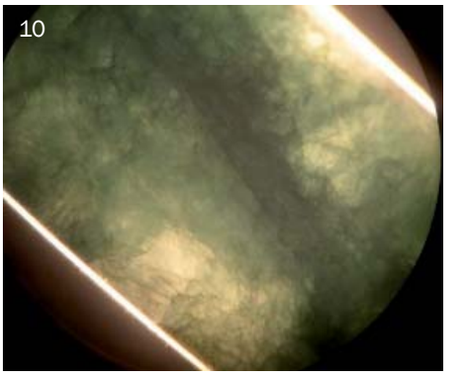

iron. Reflections produced by natural dark inclusions with a metallic lustre such as pyrite may indicate A-jadeite (see *Figures 6, 7* and *8*), but one should also be aware that small black particulate inclusions can equally be found in the B (and C) grades of jadeite. Sometime the man-made black spots in B- (and C-) jadeite will puzzle the dealer who thinks that they occur only in A-jadeite.

Surface characteristics caused by greenish-blue secondary inclusions (similar to dyed jadeite) in A-jadeite (as shown in *Figures 9* and *10*) can be similar to those in B-jadeite. Typically in A-jadeite, one usually sees brown epigenetic inclusions that are absent in dyed jadeite and, in terms of the Chinese jadeite trade, its appearance (as shown in *Figures 9* and *10*) is described as 'coarse ice dizi' ('dizi' being a description applied by Chinese jadeite specialists to specify texture of jadeites), which indicates a texture like granular ice. Compared with B-jadeite, A-jadeite can display orientation of crystal growth, partially radiated aggregates, and more often display longer prismatic crystals (as shown in *Figure 10*).

In A-jadeite with good 'shui tou' (transparency), there are commonly isolated centres of white cotton-like fibres which are roughly spherical as shown in *Figures 11* and *12*. They resemble the onset of flocculation in a solution, and such features can also be present in B-jadeite; however, in much B-jadeite polymer filling changes the appearance to tangled fibres or wisps as shown in *Figure 13*.

4. Internal behaviour of light resembling adularescence

The combination of reflection, refraction, scatter, interference and diffraction of light from many tiny crystal faces and fissures in jadeite commonly creates an effect resembling adularescence, commonly yellow.

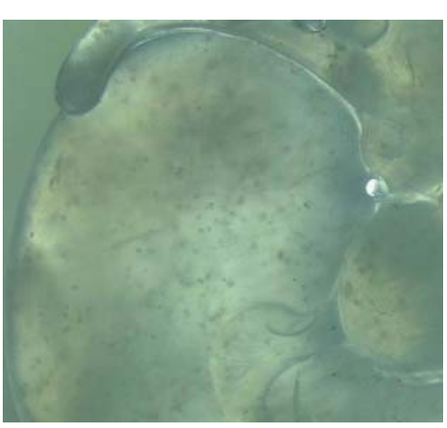

Figure 11: A-jadeite with roughly spherical separate centres of white cotton-like inclusions.

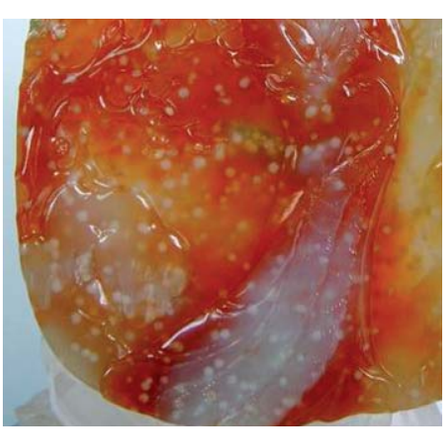

Figure 12: Isolated round cotton-like inclusion in A-jadeite.

Figure 13: Blurry irregular cotton-like inclusions in B-jadeite.

Figure 14: A-jadeite with good 'shui tou' showing yellow internal reflection.

A-jadeite has a distinctly 'cold' surface lustre but a 'warm' glow from internal reflected light, while B-jadeite does not have these features. Even on a blue background an A-jadeite with good 'shui tou' (transparency) shows a warm reflection from its interior in *Figures 14*, *15* and *16*.

In *Figure 15a* the halo around the Buddha's head shows a yellow glow typical of A-jadeite, while the B-jadeite in *Figure 15b* shows a white-blue tone in the halo. This latter effect is due to the treatment with polymer and some fluorescence.

It is worth noting the highly reflective area on the surface of the Buddha in

Figure 15: Two Buddha carvings. The halo around the head in (a) exhibits a yellow glow characteristic of A-jadeite, while the halo in (b) exhibits a white-blue reflection, characteristic of B-jadeite.

Figure 16: A yellow glow is visible in the beads in the upper part of the A-jadeite carving.

Figure 15a, which suggests that the surface is very smooth, in contrast to that of the piece shown in *Figure 15b* which has poor lustre and probably a coarse surface microstructure.

This internal reflection resembling adularescence is a significant identification feature for A-jadeites because even in some jadeites with poor transparency, there can be small regions of nice transparency and even texture which generate this phenomenon.

Such an effect is absent in B-jadeite as the polymer (whose refractive index is closer to jadeite than that of air in micro-space) effectively reduces the odds of reflection (on the crystal faces and micro-fissures faces) and scatter (among the micro-crystals) of the transmitted light. Additionally the polymer's fluorescence is often blue-white. So it shows white in B-jadeite (in *Figure 15b*).

5. Authenticating jadeites based on tiny fissures:

In A-jadeite, especially jadeite with poor 'shui tou', fissures between crystals (probably stress-induced) can often be seen (*Figures 17, 18* and *19*). In B-jadeite, the filling of the interior fissures with modern polymers makes them less apparent.

The jadeite ring in *Figure 17* has a texture resembling broken ice and, in addition, in the upper part, when one observes it in transmitted light, it appears yellowish because of the scattered

Figure 17: The tiny fissures in this A-jadeite create an appearance like broken ice.

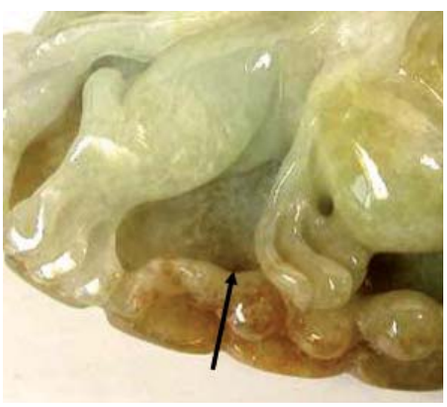

Figure 18: A-jadeite carving with a concave hollow in which fissures and crystal faces appear like broken ice.

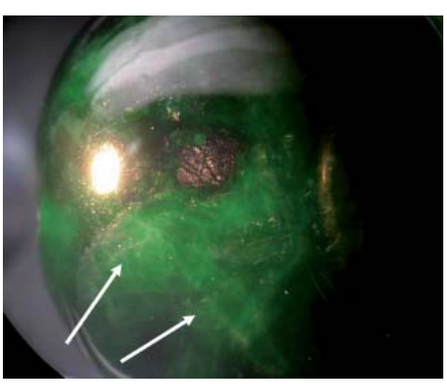

Figure 19: A-jadeite with white ridges, mid-left of picture, resulting from light reflected from linear fissures, characteristic of A-jadeite.

light (soft glow or effect resembling adularescence) which is also characteristic of A-jadeite.

In *Figure 19*, the colour of the fissures on the left is whiter than the body colour of the jadeite; the white fissures are the sign of A-jadeite. Towards the centre of

the picture, and below the black metallic inclusion, is an array of fissures in a sinuous zone which also indicates that the jadeite is A-grade. In B-jadeite interior fissures are commonly difficult to see and at the surface they appear as veins like earthworm traces. However, ageing B-jadeites may also develop fissures on exposure to hot light, especially the lights in showcases.

In the A-jadeite carving in *Figure 20*, on the right of the picture, the ear of the pixiu (a legendary animal which can bring good luck) appears white. This is because the colour of the pixiu body or the green grain (called the 'colour root' in China) is blocked by a noticeable fissure just under the ear. This effect would not show in B-jadeite because the colour would not be blocked; the colour of the 'colour root' would diffuse through the fissures, a phenomenon which Chinese experts call 'colour drifting'.

The 'colour root' and 'colour drifting' are thus important concepts in identifying A- and B-jadeite in China.

There are two types of 'colour root', one with boundaries and one without. Disappearance of the colour of a jadeite at a big fissure indicates an A-grade stone, while the disappearance of colour where texture remains unchanged indicates B-jadeite.

'Colour drifting' is dependent on the texture and grain of the jadeite, and while common in B-grade stones, is not restricted to them. Imagine compacted snowballs on which a drop of ink is applied. The ink will migrate along grain boundaries and the whole mass will assume some colour. In the terms of the Chinese gem trade, 'dizi (texture) eats colours' and 'colours glorify dizi'.

6. The factors of size and quality of carving

Jadeite articles can be subjectively divided on the basis of size into two main groups: those carvings more than 3 cm across (about the size of an egg) and the rings, pendants and other jewellery items less than 3 cm thick (*Figures 21* and *22*).

Pieces more than 3 cm across are usually not filled with polymer, but jadeite jewellery made from slices (such as bracelets, two-dimensional ornaments with thickness less than 2 cm) should be examined carefully. Most B-jadeite comes from sliced material.

The degree of intricacy and skill of the carvings serves as more important evidence in identifying jadeites than their basic shape. For example, the large beautifully carved brush pot shown in *Figure 23* has a diameter larger than 3 cm and is A-jadeite.

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Figure 20: One of the pixiu's ears appears white because there is a fissure immediately beneath it.
Figure 21: B-jadeite jade carving.
Figure 22: B- and C-jadeite jade bracelets and ring.
Figure 23: A-jadeite brush pot.
Figure 24: A-jadeite seal.
Figure 25: This jadeite with a sharp ridge is probably A-jadeite.

Figure 26: The points of these drop-shaped cabochons are a good indication of A-jadeite.

B-jadeite artefacts cannot be produced with very great intricacy of carving because their filling and sealing with polymers necessarily reduces their hardness. This restricts the shapes of B-jadeites to geometries without very sharp edges or points (*Figures 25* and *26*).

Conclusion

Mastering the skills described above would be of great benefit to dealers and ordinary consumers and is entirely possible with practice. However, because the visual skills still leave a margin for error in detecting frauds and such treatments as coating, reconstructing and dyeing, they should be used mainly for reference and only with caution at a commercial level. In some cases, turning to professionals in trade laboratories is the only way to reach accurate conclusions or get precise results.

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General Administration of Quality Supervision, Inspection and Quarantine of the People's Republic of China (AQSIQ), 2003. *National Standard of P.R. China: Gem-Nomenclature. (GB/T16552-2003),* Standards Press of China: Beijing, 10

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Abstracts

Diamonds

Elements de caracterisation des diamants naturels et synthétiques colorés.
E. Eric. *Revue de gemmologie AFG,* 162, 2007, 4-13.

Summary with illustrations of natural and synthetic coloured diamonds. M.O'D.

Diamond integrated quantum photonics.
A.D. Greentree, B.A. Fairchild, F.M. Hossain and S. Prawer. *Materials Today,* **11**(9), 2008, 22-31.

Survey of the uses of diamond in the quantum computer industry. Particular coverage is given to the operation of colour centres in diamond. M.O'D.

Explosive maar-diatreme volcanism in unconsolidated water-saturated sediments and its relevance for diamondiferous pipes.
V. Lorenz. *Gemmologie. Z. Dt. Gemmol. Ges.*, **57**(1/2), 2008, 41-60. 5 photographs, 1 diagram, 3 maps.

Three examples of maar-diatreme volcanoes formed in soft sediment are discussed: one in the Saar-Nahe basin in southern Germany, one carboniferous midland valley basin in Scotland and the middle proterozoic diamondiferous diatremes of the Halls Creek Mobile belt in East Kimberley, Western Australia. E.S.

Formation of Archaean continental lithosphere and its diamonds: the root of the problem.
D.G. Pearson and N. Wittig. *Journal of the Geological Society*, **165**(5), 2008, 895-914.

The paper examines the formation of diamonds in the early evolution of the Earth; it is suggested that the presence of diamonds included in Hadean zircons may suggest that deep continental material may have existed as early as 4.2 Ga ago. M.O'D.

The use of laser and X-ray scanning to create a model of the historic Koh-i-Noor diamond.
S.D. Sucher and D.P. Carriere. *Gems & Gemology,* **44**(2), 2008, 124-41.

For centuries, the Koh-i-Noor was one of the world's largest diamonds. It was recut in 1852 to an oval of 105.60 ct. Using one of the two plaster casts now in the Natural History Museum, London, the present authors have captured the surface topology of the original Koh-i-Noor through photography plus laser and X-ray scanning methods. A crystallographic analysis of the major facets determined the diamond's orientation within a 'perfect' diamond crystal, which was used to refute the theory that this diamond had been cut from the Great Mogul. Computer modelling established the orientation of the recut diamond within the historic version. All this information was then used to create an accurate replica from cubic zirconia, offering a good approximation of the brilliance and optics of the original stone. R.A.H.

Gems and Minerals

Crystallization of biogenic Ca-carbonate within organo-mineral micro-domains. Structure of the calcite prisms of the *Pelecypod Pinctada margaritifera* (Mollusca) at the submicron to nanometre ranges.
A. Baronnet, J.P. Cuif, Y. Dauphin, B. Farre and J. Nouet. *Mineralogical Magazine,* **72**(2), 2008, 617-26.

Atomic force microscopy (AFM) and transmission electron microscopy (TEM) were used to investigate the fine structure of the calcite prisms from the pearl-oyster shell *Pinctada margaritifera*. The AFM analysis shows that the prisms are made of densely packed circular micro-domains (in the 0.1 µm range) surrounded by a dense cortex. The TEM images and diffraction patterns allow the internal structure of the micro-domains to be described. Each of them is enriched in Ca-carbonate. Hosted in distinct regions of each prism, some are fully amorphous, and some others fully crystallized as subunits of a large calcite single crystal. At the border separating the two regions, micro-domains display a crystallized core and an amorphous rim. Such a border probably marks out an arrested crystallization front having propagated through a previously bio-controlled architecture of the piling of amorphous micro-domains. Compared to recent data concerning the stepping mode of growth of the calcite prisms and the resulting layered organization at the µm-scale, these results give unexpected views regarding the modalities of biocrystallization. R.A.H.

L'Ambre Dominicain.
A.B. Costa. *Revue de gemmologie AFG,* 162, 2007, 15-16.

Short note on amber from the Dominican Republic. M.O'D.

About mineral collection. (Part 1 of 5.)
R. Currier. *The Mineralogical Record,* **39**(4), 2008, 305-13.

First part of a survey of the profession and hobby of mineral collecting with particular relevance to the United States. M.O'D.

Abstracts (continued)

Coloring of topaz by coating and diffusion processes: an X-ray photoemission study of what happens beneath the surface.

H. Gabasch, F. Klauser, E. Bertel and T. Rauch. *Gems & Gemology,* **44**(2), 2008, 148-54.

Surface-treated topaz has become a viable alternative to topaz coloured by irradiation, but unlike irradiation which affects the entire stone, coloration by chemical modification is limited to the near-surface region. The treatment techniques are well established, but less is known about how the processes involved create the desired appearance. X-ray photoemission spectroscopy, combined with sputter depth profiling, has allowed the characterization of two fundamentally different colouring mechanisms for chemically treated topaz: coloured coatings and diffusion-induced coloration. R.A.H.

Les gisements de corindons gemmes de Madagascar.

G. Giuliani, D. Ohnenstetter, A. Fety, M. Rakotondrazafy, A.E. Fallick and others. *Revue de gemmologie AFC,* 159, 2007, 14-28.

The geology and mineralogy of gem-quality corundum locations in Madagascar are discussed. A bibliography and map are included. M.O'D.

Le peuple Thrace en Bulgarie et les mines du Laurium.

E. Gonthier. *Revue de Gemmology AFG,* 162, 2007, 17-22.

Notes on the ancient lead slags of Laurium, Greece, and the possible use of the minerals found there by the people of Thrace, present-day Bulgaria. M.O'D.

Quelques variétes d'ambre animal et d'ambre vegétal.

E. Gonthier. *Revue de Gemmology AFG,* 163, 2008, 11-17.

Summary of ambers or amber-like substances of animal and vegetable origin. M.O'D.

Einige Gedanken zu Jadeit-Jade.

H. Hänni. *Gemmologie. Z. Dt. Gemmol. Ges.,* **57**(1/2), 2008, 5-12, 5 photographs, 1 graph, bibl.

Jadeite is a polycrystalline gemstone, the transparency of which is greatly influenced by grain size and homogeneity. The grain boundaries are opened by weathering of the jade blocks in the river. Transparency can be improved by cleaning with acid and filling of the pores. In green jadeite there is sometimes an isomorphous replacement of Al by Cr. A mixed crystal series from jadeite to kosmochlor produces colourless to green to black material with increasing RI and SG values. A new standard for jadeite definition is being introduced in Hong Kong, accepting small amounts of kosmochlor and omphacite; however, the the values must not exceed SG over 3.4 and RI over 1.688. Materials within this field are called Fei Cui jade in China. E.S.

Les granats andradites-demantoides d'Iran: zonage de couleur et inclusions.

S. Karampelas, E. Gallou, E. Fritsch and M. Douman. *Revue de Gemmology AFC*, 2007, 107, 14-20.

A recently-discovered deposit of demantoid garnet is described from Iran. A content of more than 0.7% up to 1.2% of chromium oxide is required to give the green colour. Inclusions of fibrous calcite are reported and specimens show marked colour zoning. M.O'D.

Gem News International.

B.M. Laurs. *Gems & Gemology,* **44**(2), 2008, 164-90.

Brief descriptions are given of a 2.41 ct cut diamond with a brownish-orange inclusion (possibly eclogitic garnet), under the table showing a strong resemblance to a bird in flight, and of a colourless diamond showing strong phosphorescence. Also mentioned are an orange-red labradorite from China, an orange beryl from India, a rare faceted Cr-rich clinochlore from Turkey, an orange danburite from Tanzania, faceted lawsonite form Marin County, California, and a green Cr/V-bearing paragonite from northern Pakistan. Faceted peridot extracted from a pallasite and rubies and sapphires from a new locality in eluvial soil at Winza in central Tanzania are illustrated. R.A.H.

The Königskrone topaz mine, Schneckenstein, Saxony, Germany.

H. Leithner. *The Mineralogical Record,* **39**(5), 2008, 355-67.

Wine-yellow crystals of gem-quality topaz have been mined from the Ebenstock granite in the Vögtland area in Upper Saxony, Germany. It is possible that crystals from this area were used in many European-made items of jewellery. Figures from *Goldschmidt, Atlas der Kristalformen* (1922) are reproduced. M.O'D.

Coated tanzanite.

S.F. McClure and A.H. Shen. *Gems & Gemology,* **44**(2), 2008, 142-7.

The examination of 23 tanzanites coated by an apparently new technique revealed that the smaller (4–5 mm) stones could be identified as coated, based on a combination of the unusually intense colour and microscopic examination which revealed surface iridescence as well as wear of facet junctions (small areas where the coating had been abraded away). Two larger (3+ ct) stones did not show iridescence or wear (unless examined at high magnification), and were thus much more difficult to identify. XRF and LA-ICP-MS analyses showed the presence of Co, Zn, Sn and Pd in the coating. R.A.H.

Le Nigeria. Source de pierres de couleur.

J-C. Michelou. *Revue de Gemmology AFG,* 159, 2007, 30-41.

The gem-producing potential of Migeria is discussed with particular reference to beryl and corundum mineral deposits and their geology. Nigeria is compared with other African countries. M.O'D.

Le retour de l'émeraude.

J-C. Michelou. *Revue de Gemmology AFG,* 163, 2008, 4-6.

General survey of emerald and its provenance. M.O'D.

Lab Notes.

T.M. Moses and S.F. McClure (Eds). *Gems & Gemology,* **44**(2), 2008, 156-63.

Items noted include a gem-quality fancy brown CVD synthetic diamond with traces of boron, crystals of a bluish-green plagioclase coloured by copper, and a

Abstracts (continued)

blue cut sapphire with an unusually high content of light rare earth elements. R.A.H.

Der Zonarbau des Alexandrits von Novello Claims, Simbabwe.

M. Okrusch, H. Brätz and U. Schüssler. *Gemmologie. Z. Dt. Gemmol. Ges.,* **57**(1/2), 2008, 13-22. 3 photographs 1 graph, 2 tables.

The optically visible zonation of an alexandrite twin from the Novello claim was investigated by EMP and LA-ICP-MS analysis. The colouring elements of this stone were chromium and iron-titanium; zinc, gallium, vanadium and scandium were found, the quantity varying with zonal distribution. E.S.

Rhodochrosit aus dem Blei/Zink-bergwerk Wudong bei Liubao, Guangxi, China.

A. Ottens. *Lapis,* **33**(10), 2008, 53-6.

Rhodochrosite of ornmanetal quality is described from the Wudong lead/zinc mine, Guangxi, China. M.O'D.

Nouvelles des travaux sur le beryllium et les saphirs bleus.

V. Pardieu. *Revue de Gemmology AFG,* 163, 2008, 7-9.

Review of beryllium-treated blue sapphires with illustrations of characteristic inclusions. M.O'D.

Les tourmalines cuprifères du Nigeria et du Mozambique.

B. Rondeau and A. Delaunay. *Revue de Gemmology AFC,* 107, 2007, 8-13

Paraíba-type bright blue tourmalines owing their colour to copper are reported from Nigeria and from Mozambique. Divalent copper, the origin of the colour, gives a broad absorption band at 690 nm. Some green and purple tourmalines show a similar band. Some green specimens also show a strong absorption of the blue to the ultra-violet and this has been attributed to trivalent manganese. Heat treatment up to 600–700°C has no effect on the green colour while dark blue stones lighten. Purple stones become light blue or colourless. Locality information can be gained from the composition of trace elements. There may be confusion between blue specimens from Brazil and Mozambique as trace element compositions can overlap. M.O'D.

Characterization of emeralds from a historical deposit: Byrud (Eidsvoll), Norway.

B. Rondeau, E. Fritsch, J.-J. Peucat, F.S. Nordrum and L. Groat. *Gems & Gemology,* **44**(2), 2008, 108-22.

An emerald deposit, mainly in small pegmatites intruding alum shales, at Byrud, southern Norway, yielded significant amounts of crystals and gem rough in the late nineteenth and early twentieth centures. Complex multiphase inclusions in the emeralds consist of water, gaseous methane, halite, sylvite, calcite and a sulphide assemblage (pyrrhotite, galena and sphalerite); this sulphide assemblage makes the Byrud emeralds easy to distinguish from those from elsewhere. They also have a characteristic chemical composition, being coloured mostly by vanadium (up to 1 wt % V_2O_3) and contain low Mg and Ma (≤ 0.1 wt % oxide). EPMA and LA-ICP-MS results are given. The relative amounts of Fe, Mg, Cr, Rb and Cs appear to be diagnostic. IR absorption spectra show that they contain little water. R.A.H.

Gruene Quartze – Farbursachen und Behandlung.

R. Schultz-Guettler, U. Henn and C.C. Milisenda. *Gemmologie. Z. Dt. Gemmol. Ges.,* **57**(1/2), 2008, 61-72. 10 photographs, 4 graphs, bibl.

Recently larger amounts of green faceted quartz have been observed in the trade. Most of these owe their colour to artificial irradiation. The original material is a colourless to light yellow quartz from Rio Grande do Sul in Brazil. In contrast to green prasolites obtained by heat treating amethysts, the colour will fade in strong sunlight or in temperatures above 150°C. The samples investigated showed a broad band in the absorption spectrum with a max of 592–620 nm. Prasolites have a broad absorption spectrum around 720 nm. Separation of heat treated and irradiated specimens is also possible with the Chelsea colour filter when illuminated with incandescent light: prasolites appear green, irradiated specimens red. Synthetic quartz has also appeared in the trade; the absorption spectrum shows broad bands at 740 nm and 930 nm as well as a band at 510 nm. E.S.

La Mine de Williamson.

S. Scolie, M. Philippe and D. Sirakian. *Revue de Gemmology AFC,* 107, 2007, 21-5.

History and updated geological survey of the Williamson diamond mine at Mwadui, Tanzania. M.O'D.

Bei den Demantoid – Väschern von Poldnevaja im Ural.

M. Sehrig. *Lapis,* **33**(11), 2008, 32-5.

Illustrated description of a significant deposit of demantoid garnet in the Urals, Russia. M.O'D.

Structural characterization and chemical composition of aragonite and vaterite in freshwater cultured pearls.

A.L. Soldati, D. E. Jacob, U. Wehrmeister and W. Hofmeister. *Mineralogical Magazine,* **72**(2), 2008, 579-92.

Vaterite and aragonite polymorphs in freshwater cultured pearls from mussels of the genus Hyriopsis (Unionidae) were structurally and compositionally characterized by Raman spectroscopy, micro computer tomography, high resolution field emission SEM, and LA-ICP-MS. The appearance of vaterite in pearls is related to the initial stages of biomineralization, but vaterite can not be a precursor to aragonite. Vaterite is not related to a particular crystal habit and therefore does not have a structural functional in the pearls. Larger contents of elements typically bound to organic molecules, such as P and S in vaterite, as well as larger total organic contents in vaterite as opposed to aragonite in conjunction with larger concentrations of Mn^{2+} and Mg^{2+}, imply a stabilizing role of organic macromolecules and X^{2+} ions for biological vaterite. Distribution coefficients between aragonite and vaterite for provenance-independent elements, such as Mn and Mg (0.27 and 0.04, respectively) agree very well with those observed in fish otoliths. R.A.H.

Nucleated cultured pearls: what is there inside.

M. Superchi, E. Castaman, A. Donini, E. Gambini and A. Marzola. *Gemmologie. Z.*

Abstracts (continued)

Dt. Gemmol. Ges., **57**(1/2), 2008, 33-40. Illustrated in black-and-white and in colour, bibl.

Discussions about nucleated cultured pearls are generally related to the nacre: surface, treatment and thickness. Productions using nuclei obtained from materials other than mother-of-pearl (established by classical rules) have started and are on the market without any specific declaration. This report publishes the results of a diffraction (Laue) testing system applied to nucleated cultured pearls, which allows the distinction between nuclei obtained from mother-of-pearl, from shells having crossed lamellar structure or from a composite artificial material called 'bironite'. E.S.

Infrared spectroscopic study of modern and ancient ivory from sites at Jinsha and Sanxingdui, China.

L. Wang , H. Fan, J. Liu, H. Dan, Q. Ye and M. Deng. *Mineralogical Magazine,* **71**(5), 2007, 509-18.

Ancient ivory, buried for several thousands of years at the Chengdu Jinsha and Guanghan Sanxingdui sites in China, has been compared with modern ivory, using IR spectroscopy in the 4000–400 cm^{-1} range. By combining these results with XRF data, the authors determined the crystallinity and crystal chemistry of the apatite component, as well as the structural characteristics of the ivories. The ancient ivory consisted almost entirely of hydroxyl-carbonate apatite. Compared to modern ivory, the PO^{3-}_4 and CO^{2-}_3 bands were stronger, the νPO_4 IR bands were clearly greater, and an extra OH^- band at 3569 cm^{-1} was observed. These results imply that there is a greater degree of crystallinity in the ancient apatite, and that there has been incorporation and recrystallization of CO^{2-}_3 in the apatite during burial. Positive correlations were found between apatite crystallinity, CO^{2-}_3 and OH^- contents, and burial time. The loss of organic matter from the ancient ivory may be the main reason why it is easily dehydrated and readily friable after being unearthed. R.A.H.

Rhodonit.

S. Weiss. *Lapis*, **33**(11), 2008, 36.

Illustrated summary of gem- and ornamental-quality rhodonite with some important sites included. M.O'D.

Herbert P. Obodda.

J.S. White. *The Mineralogical Record,* **39**(4), 2008, 315-31.

Gem-quality vayrynenite from Pakistan is featured as one of the very many rare gem-quality crystals which have passed through the hands of noted American mineral and gem dealer Herb P. Obodda whose illustrated biography is given. M.O'D.

New primary gem occurrences in Sri Lanka.

J.C. Zwaan and E.G. Zoysa. *Gemmologie. Z. Dt. Gemmol. Ges.,* **57**(1/2), 2008, 23-32. 9 photographs, 2 maps, bibl.

Primary pegmatitic and metamorphic gem deposits of commercial interest have recently been discovered in Sri Lanka. In the Opanayaka district about 25 km south of Ratnapura aquamarines have been found in pegmatites. Small hexagonal light- to grey-blue corundum crystals, some with more rounded outlines, were found in the eastern corner of the highlands at Wellawaya and at Kamburipitiya reddish-orange hessonite was found, 5–10% of fine gem quality, 20–30% medium quality. Properties were found to be similar to those of gems found in the rich alluvial deposits of Sri Lanka. E.S.

Synthetics and Simulants

Single-crystal polarised-light FTIR study of an historical synthetic water-poor emerald.

F. Bellatreccia, G. Della Ventura, M. Piccinini and O. Grubessi. *Neues Jahrbuch für Mineralogie – Abhandlungen,* **185**(1), 2008, 11-16

Re-examination of an emerald synthesized by Hautefeuille and Perry (1888) using a flux method has shown it to be very close to the stoichiometric composition and homogeneous except for a significant variation in Cr_2O_3 content (1.45–2.59 ct %); trace amounts of Ti, Mg, Fe, Zn, Na, K and F were also noted. It has *a* 9.2264, *c* 9.1904 Å. Despite the synthetic conditions, FTIR spectra in the OH-stretching region show the presence of weak but significant H_2O vibrations. The polarized FTIR spectra collected with E c consist of a unique sharp and intense band at 3463 cm^{-1}, whereas the E c spectra consist of two minor bands at 3643 and 3587 cm^{-1}. These bands are assigned to the ν3 antisymmetric stretching and ν1 symmetric stretching modes of type II water in the structural channels, respectively. These water molecules are probably associated with Li impurities in the mineral due to the flux used for the synthesis. Using the molar absorption coefficient of Libowitzky and Rossman (see *American Mineralogist*, **82**(11-12), 1997, 1111-15), a water content of ~ 30 ppm is derived for this emerald. R.A.H.

Abstractors

R.A. Howie – R.A.H. M. O'Donoghue – M.O'D. E. Stern – E.S.

Book reviews

Fleischer's Glossary of Mineral Species.
M.E. Back and J.A. Mandarino, 2008. The Mineralogical Record, Tucson. pp xiv, 345. Price on application.

The tenth edition of this most useful and convenient classic quick reference book follows its predecessors in its alphabetical list of validated species with reference to the most important citation in English, primarily *American Mineralogist* and *Mineralogical Magazine*. Group membership is indicated where appropriate and the groups themselves, with their constituent species, are described at the end of the main text. In this section the descriptions of some groups are expanded: this is particularly useful where the amphiboles are described and here some references are made to important studies.

The list of journals from which data have been obtained is impressive and covers six pages; non-English works are included.

To make up a reliable and quick trio of books for reference, Fleischer should be joined by the five volumes of Anthony *et al. Handbook of Mineralogy* (1990–2003) and the full-colour Bernard and Hyrsl *Minerals and their Localities* (2006). Gemmological laboratories and teaching establishments without at least two of these three should not be attracting customers! M.O'D.

Fluorite der Welt. Afrika, Amerika, Asien, Europa. extraLapis No. 35.
2008. Weise, Munich, Germany. pp 103, illus. in colour. €17.80.

The highly desirable extraLapis series continues with a beautifully illustrated overview of some of the world's most notable ornamental fluorite deposits. It is to be hoped that other deposits, for example the Blue John location in Derbyshire, England, will feature in a later issue. This would be worth waiting for. M.O'D.

Photoatlas of Inclusions in Gemstones, Volume 3.
E.J. Gübelin and J.I. Koivula, 2008. Opinio Publishers, Basel, Switzerland. pp 672, illus. in colour. ISBN 3-03999-047-4 €250.00.

Rarely has a gemmology book been so eagerly awaited and this, the third volume in the series of inclusions in gemstones by Eduard Gübelin (deceased 2005) and John Koivula, is excellent and exceeds expectations.

Volume 1, published in 1986, soon became a standard reference in the field of gemmology but it was not until 2005 that the second volume, which provided greater depth and scope, was published. The major commercial gemstones, diamond, ruby, sapphire and emerald, not covered in volume two, are the mainstay of volume three.

The book covers exactly what it says in the title and more. The 672 pages contain 1796 images and it is indeed a huge reference library of images and the practising gemmologist would be all the poorer for its absence.

The quality of production is excellent and the images are often of exceptional beauty. Anyone who has attempted photomicroscopy will feel humbled by the outstanding quality of the images which are a testament to the skill, knowledge and patience of the authors. I could find only one image that had been published previously (exsolved rutile in ruby from East Africa – Volume 1) but the difference in captions indicates that this feature had been re-evaluated. Thus the resource of images is cumulative for all three volumes. In this respect the user would benefit from the production of a DVD with search facilities rather than thumbing through three volumes.

As frequently stated or alluded to in the book, the basic premise of the study of microscopic features in gemstones is that similar processes will result in a range of similar features in gems of the same species. So whether these processes are geological, treatments or synthesis, significant information is stored within the gems that aid in their identification and separation.

Whilst Volume 1 was portrayed as a voyage of discovery and exploration into the world of inclusions in natural gemstones, their treatments, imitations and synthetics, this volume builds on the geological and process correlation established in Volume 2. This is a major strength of Volume 3 where, within individual species and varieties (including their synthetic counterparts and simulants) not only are they brigaded into geological settings but within that grouping arranged by locality or, in the case of synthetics and simulants, by manufacturing process. At the beginning of each of these groupings there is text that briefly, but succinctly, covers the topics that the images illustrate. At the end of the primary text that prefaces each gem material there is a useful list of additional reading references. Helpful, informative and often expansive captions that include illumination and magnification data complement the impressive photographs that beautifully illustrate the diagnostic features. The authors also discuss and illustrate the very latest discoveries of mineral and fluid inclusions in gems.

There is a very brief Introductory Section that outlines the basic premise of the role that inclusions play in the identification of gemstones and their treatments.

Section two, Inclusions in Major Commercial Gems, takes up 457 pages

Book reviews (continued)

and is the meat of Volume 3. It begins with inclusions in diamonds. The opening text covering mineral inclusions, peridotitic inclusions, eclogitic inclusions, inclusions from the deep mantle, cloud formations, the age of natural diamonds, diamond treatment, synthetic diamonds and diamond substitutes, gives an insight into the range of images that follow.

The diamond part of the section is followed by inclusions in corundum. These are conveniently arranged so that inclusions in rubies and sapphires from analogous petrological and geological settings can be compared. Thus, for example, rubies from Luc Yen and Quy Chau – Vietnam, rubies from Mogok and Mong Hsu – Myanmar (Burma), rubies from the Ganesh Himal area – Nepal, rubies from Azad and Hunza – Pakistan and rubies from Jagdalek – Afghanistan are presented sequentially as they are examples of rubies found in marbles. Inclusions indicative of treatment follow those typically found in natural corundum. Treatments illustrated are diffusion, heating, fillings, coating, and oiling and dying. The synthetic corundum inclusions illustrate the processes of flame fusion (Verneuil), Czochralski pulling, floating zone and flux growth. The latter is further subdivided in the text by manufacturer: Chatham, Kashan, Ramaura, Knischka and Douros. Unspecified Russian hydrothermal growth, and the images are annotated accordingly.

The third part of this section covers emeralds arranged according to their genetic types, followed by inclusions indicative of treatment and lastly inclusions in synthetics. It is here that the authors, looking to the future, give examples of repair through re-growth; an aspect considered only theoretical where gem rubies and sapphires are concerned.

The third and final section deals with Inclusions in Rare and Unusual Gems. Arranged alphabetically the gems are andalusite, apatite, axinite, benitoite, calcite, cordierite, danburite, diopside, ekanite, enstatite, fluorite, glass, gypsum, kornerupine, pezzottaite, sapphirine, scapolite, sillimanite, sinhalite, spodumene and taaffeite. Introductory text prefaces each of these.

Criticism, none of which will materially affect the gemmological user, is confined to the pernickety such as application of current mineralogical nomenclature (e.g. tantalite – (Mn) as opposed to manganotantalite, and the use of names that no longer have IMA-approved species status (e.g. biotite; which it is now recommended be used for a series such as the biotite-phlogopite series). One very minor irritation could be the presentation of descriptions on one page that pertain to images on a subsequent page such that some pages have no captions: this occurs but rarely. It would be wrong to give criticism because of omissions for as the authors state this is not a gemmological text book or gem identification manual.

In conclusion, these highly respected authors have produced an exceptional book drawing on decades of meticulous optical microscopic examination, research and highly specialized photomicrography. The greatest challenge facing the gemmologist is the need to recognize and separate natural gems from synthetics and untreated stones from those that have been treated. In facing up to this challenge this current work is an invaluable asset given that the gemstone industry has increasingly grown to depend on the interpretation of inclusions.

Collectively the Photoatlas volumes make an outstanding contribution to the field of gemmology. B. J.

Gems & Gemology in Review: Treated Diamonds.

J.E. Shigley, 2008. GIA, Carlsbad, California. pp 301. ISBN: 978-0-87311-054-9. £49.50.

Chapters in this excellently-produced book are adapted from papers already published in *Gems & Gemology* and like other compilations in the series cover the latest findings in a single subject area. The review could hardly have come at a more critical moment for the diamond trade and will certainly be widely distributed and used.

The chart in the back pocket illustrates the diagnostic features of filled diamonds and most usefully includes features of unfilled diamonds which could be mistaken for fillings.

This book is not just recommended – it is essential. M.O'D.

Working with Gemstones. A Bench Jeweler's Guide.

A.A. Skuratowicz and J. Nash, 2008. MISA/ASM Press, Providence RI. pp 128. ISBN 09713495-4-1. Price on application.

Pleasantly illustrated in colour, the book aims to present the major gemstones to the working jeweller, manufacturer and designer with practical advice on mounting, heat resistance and a number of other features that will assist both the wearer and the buyer. The photographs are high quality and the book design attractive. M.O'D.

Phenomenal Gems.

F. and C. Ward, 2008. Gem Book Publications, Malibu, California. pp 64. ISBN-13 978-1-887651-12-7. £10.95.

An especially attractive newcomer to the Fred Ward Gem Book series, this book describes gemstones exhibiting chatoyancy, asterism, play-of-colour, iridescence and other optical features. As always, Fred Ward's pictures are unmatchable and the book is a must. M.O'D.

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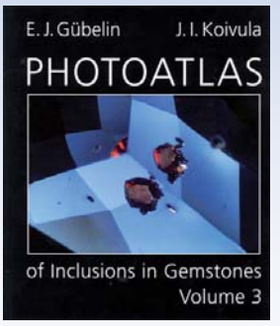

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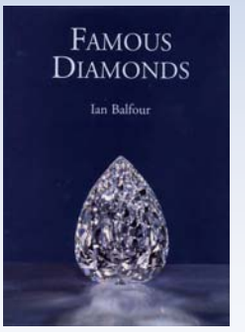

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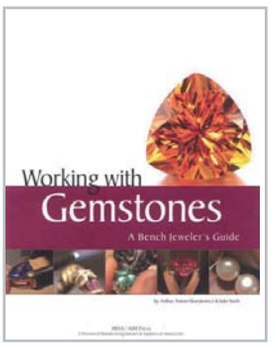

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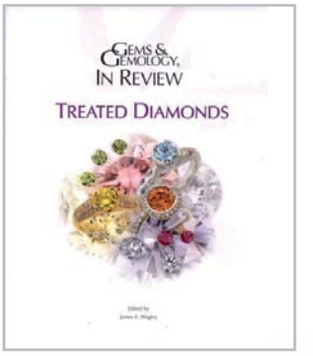

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Proceedings of the Gemmological Association of Great Britain and Notices

Educational Sponsorship

This year has been a resounding success for Gem-A, the effects of which have been felt globally by our students and members. As an educational charity, we are extremely grateful to our sponsors and supporters, who have helped us achieve many of our goals for 2008.

The 100 Club and the Educational Sponsorship initiatives were established in 2008 to invite members and supporters to donate a minimum of £1000 each, which would be used towards the expansion and updating of our courses worldwide. Thanks to our sponsors, The Gemmological Association of Great Britain has been able to create the new Foundation in Gemmology course notes which are now in use, containing up-to-date information and a new look. In addition, Gem-A has launched an online education resource centre for students which incorporates access to web-based assignments, a glossary of terms, past papers, student forums and a calendar of events. A member version of the site will be launched in 2009, so that members of Gem-A can also have access to online education resources. Our new Foundation in Gemmology Open Distance Learning course will provide students with a refractometer, twenty stones, a full gem testing kit, a gem reference guide and includes practical tuition within the UK. With all of these added benefits for our distance students, we are looking towards expanding internationally through our Open Distance Learning (ODL) Programme.

With the help of our sponsors, Gem-A has also launched a new website. With a clean look that is easy to navigate, prospective students are better able to find course information, and members and the trade are more easily able to find out about news and upcoming events. A members' area of the website will be launched in 2009, which will include exciting new features accessible to members-only, such as a searchable archives for *The Journal of Gemmology*.

Currently under development is a new short-term natural pearl course, leading to a certificate of completion, which will be taught in conjunction with the Dubai Pearl Exchange. The course will first be taught in Dubai in Autumn 2009, and is another step taken towards increasing worldwide accessibility of our courses.

Until we reach our target of 100 members for the 100 Club, the 100 Club initiative will continue. A plaque to commemorate those who have donated to the 100 Club will be placed in the lobby of the Gem-A headquarters. Educational Sponsorship is an on-going initiative, and we encourage 100 Club members and others dedicated to the Association to help us raise funds for 2009. As we enter the second century of gemmological education, our need for your help is still great. Next year we need funds to help us create course notes for a new Diploma in Gemmology course, set to begin in September 2009, as the follow-up to the new-style Foundation course. We are also looking to raise funds to purchase gem-testing equipment for our student teaching facilities, for research and for future supervised access for members. Donations in the form of gem testing equipment are also highly appreciated, and we would be delighted to receive a simple Raman, or a new UV/VIS spectrometer to have in-house for teaching.

For further information on sponsorship, or to see the list of sponsors on the web, visit http://www.gem-a.com/membership/sponsorship.aspx. If you would like to become a member of the 100 Club or become an Educational Sponsor for 2009, please email olga.gonzalez@gem-a.com.

Gem-A Awards

Gem-A Examinations were held worldwide in June 2008. In the Examinations in Gemmology 243 candidates sat for the Diploma Examination of whom 116 qualified, including 19 with Merit. In the Foundation in Gemmology Examination, 252 candidates sat of whom 176 qualified. In the Gem Diamond Examination 103 candidates sat of whom 50 qualified, including five with Distinction and five with Merit.

The **Christie's Prize for Gemmology** for the best candidate of the year in the Diploma Examination who derives their main income from activities essentially connected with the jewellery trade was awarded to **Antonia Ross** of Fleet, Hampshire.

The **Anderson Bank Prize** for the best non-trade candidate of the year in the Diploma in Gemmology examination was awarded to **Elizabeth Rasche** of London.

A new prize, the **Diploma Practical Prize** for excellence in the Diploma Practical Examination, was awarded for the first time, sponsored this year by Gwyn Green. The Diploma Practical Prize was awarded to **Antonia Underwood** of London.

In the Foundation Certificate in Gemmology examination, the **Anderson Medal** for the candidate who submitted the best set of answers which, in the opinion of the Examiners, were of sufficiently high standard, and the **Hirsh Foundation Award** for the best candidate of the year, were awarded to **Dr Pauline Jamieson** of Edinburgh.

The **Bruton Medal**, awarded for the best set of theory answer papers of the year in the Gem Diamond Diploma examination, was awarded to **Kundan Sarraf** from Kathmandu, Nepal. In addition to the medal, the winner received a copy of *Diamond Cuts in Historic Jewellery* by H. Tillander (donated by John Greatwood) and a Type II Diamond Spotter (donated by the SSEF Swiss Gemmological Institute, Basel).

The **Deeks Diamond Prize** for the best candidate of the year in The Gem Diamond Diploma examination, was awarded to **Jacqueline Larsson** of Amsterdam, The Netherlands.

The Tully Medal was not awarded.

The names of the successful candidates are listed below.

Gemmology Diploma

Qualified with Merit

Agarwal, Kamal Kishore, Jaipur, Rajasthan, India
Bai Feng, Beijing, P.R. China
Bigford, Julie Claire, Malvern Wells, Worcestershire
Gao Xiao Huan, Shanghai, P.R. China
Giertta, Maria, London
Harker, Catherine Anne, Birmingham, West Midlands
Huang Jinming, Guilin, Guangxi, P.R. China
Ji Qiusong, Guilin, Guangxi, P.R. China
Kui Nui, Reema, Yuen Long, Hong Kong
Lau Ho, Kowloon, Hong Kong
Lek Chin Kwang, Singapore
Luo Han, Guangzhou, P.R. China
Nwe, May Moe, Yangon, Myanmar
Peng, Hsiang Chieh, Taipei, Taiwan, R.O. China
Ross, Antonia, Fleet, Hampshire
Sharma, Anita, Haryana, India
Shaw, Heather Catherine, Barnsley, South Yorkshire
Skalwold, Elise Ann, Ithaca, New York, U.S.A.
Wu Dehe, Guangzhou, P.R. China

Qualified

Agu, Cecile, Le Cannet, France
Andersson, Joel, Umeå, Sweden
Au Chui Yee, Ada, Cascades, Homantin, Hong Kong
Baethe, Vanessa, Saint-Maur-Des-Fossés, France
Benson, Jillian Rose, Toronto, Ontario, Canada
Bhatia, Esha, Gujarat, India
Booth, Eveline Violet, Cheltenham, Gloucestershire
Brian, Jeremy, Marseille, France
Cai Qing, Wuhan, Hubei, P.R. China
Carre, Stephanie, Armées, France
Claydon, Louise, Morden, Surrey
Coppack, Flavia, London
Day, Helen Laura, Norwich, Norfolk
Dionne, Jean-Sebastien, Ste-Catherine-Jacques-Cartier, Quebec, Canada
Drai, Stephanie, Clamart, France
Dunn, Katherine Joanna, Toronto, Ontario, Canada
Fontaine, Josee, St-Basile-le-Grand, Quebec, Canada
Foran, Amelia Luetta, Toronto, Ontario, Canada
Freeman, Sarah, London
Gilli, Claude, Les Pennes Mirabeau, France

Goldman, Lucy, London
Hamren, Elisabeth, Ostersund, Sweden
Ho Siu Ming, Shaukiwan, Hong Kong
Hui Yuet Ming, Kowloon, Hong Kong
Jaugeat Blaise, Vanves, France
Kamoune Yannick, Ndemanga, Pierrefitte-sur-Seine, France
Keeffe, Veronica Cheryl, Oshawa, Ontario, Canada
Kim, Ji Eun, Busan, Korea
Kyaw Thu Min, Yangon, Myanmar
Lapsiwala, Foram Pravin, Gujarat, India
Larsson, Ylva, Vado, Sweden
Lee Hing Fan, New Territories, Hong Kong
Li Ying, Wuhan, Hubei, P.R. China
Liang, Jie, Birmingham, West Midlands
Liang Feng, Wuhan, Hubei, P.R. China
Liu, Huijing, Shanghai, P.R. China
Liu Yang, Wuhan, Hubei, P.R. China
Mao Li Hui, Wuhan, Hubei, P.R. China
Martins Molgard, Silvia, Colombo, Sri Lanka
Meraly, Afsana, Antananarivo, Madagascar
Mo, Zhuangguo, London
Ng Wai Hing, New Territories, Hong Kong
Nicolson, Louise Alexandra Patricia, London
Noronha Muthu, Sunita Karen, Gujarat, India
Pan Yang, Scarborough, Ontario, Canada
Pang Le, Wuhan, Hubei, P.R. China
Panicco, Fabio Michel, Antanavarivo, Madagascar
Perochon, Cyrielle, Castel-le-Lez, France
Piirto, Irmeli Anja Susanna, Espoo, Finland
Prendergast, Lorna, Great Missenden, Buckinghamshire
Pwint Phyu Win, Yangon, Myanmar
Pyrro, Riku Matti, Kirkkonummi, Finland
Qi Geng, Scarborough, Ontario, Canada
Qu Peng Cheng, Wuhan, Hubei, P.R. China
Rafferty, Frank, Ambrieres-les-Vallees, France
Ranorosoa, Nadine Joelle, Antananarivo, Madagascar
Razanadimby, Lalanirina, Antananarivo, Madagascar
Rufus, Simon, London
Samaratunge, Punyadevi, Horana, Sri Lanka
Shah, Prachi Hirenbhai, Surat, India
Siriwardena, Henarath H. D. Ajith Lal, Raddolugama, Sri Lanka
So Lai Yin, Shau Kei Wan, Hong Kong
Soh Shi Hong, Johor Bahru, Johor, Malaysia
Soumaré, Myriam, Paris, France
Spauwen, Timotheus A. P., Geleen, The Netherlands
Spencer, Jason, Birmingham, West Midlands
Tan Kiat Choo, June, Johor Bahru, Malaysia
Teng, Ying, Shanghai, P.R. China
Teng Yongqing, Guilin, Guangxi, P.R. China
Valerio Sa', Helena, Mississauga, Ontario, Canada
Valley, Aurelie, Amberieu-en-Bugey, France
Veenhoven, Taletta W., Amsterdam, The Netherlands
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Foundation in Gemmology

Qualified

Akmeemana, G.G.N., Kandy, Sri Lanka
Asakawa, Masako, Johetsu-City, Niigata, Japan
Ayabe, Hiroko, Nishinomiya City, Hyogo Pref., Japan
Bahadur, Seema, London
Bahri, Sebastien, Feucherolles, France
Beer, Jasmin, Birmingham, West Midlands
Bezant, Laura, Chelmsford, Essex
Boele, Georgette, Les Acacias, Switzerland
Bright, David, The Hague, The Netherlands
Brom, Jean-Baptiste, London
Brown, Claire E., Perth, Scotland
Brutsch, Sonia, Lucinges, France
Campbell-Jones, Amy V., Sheffield, South Yorkshire
Cao Juan, Shanghai, P.R. China
Cao Weifeng, Guilin, Guangxi, P.R. China
Cartier, Laurent E., Basel, Switzerland
Chang Cheng, Taipei, Taiwan, R.O. China
Chang Hsuan Ming, Taipei, Taiwan, R.O. China
Chatzipanagiotou, Ioannis Tzannis, Attiki, Greece
Chen Shaofeng, Guangzhou, P.R. China
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Cheng Wing Yan, New Territories, Hong Kong
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Gem Diamond Examinations

Gem Diamond Diploma

Qualified with Distinction
Gill, Julia Mary, Dudley, West Midlands
Larsson, Jacqueline, Amsterdam, The Netherlands
Sarraf, Kundan, Kathmandu, Nepal
Wootton, Sophie Louise, London
Yung Wai Lam, Hung Hom, Hong Kong

Qualified with Merit
Henning, Sarah Alexandra, Edgbaston, West Midlands
Naylor, Peter D., Birmingham, West Midlands
Russell, Marie, Worcester
Tidd, Lauren Elizabeth, Churchdown, Gloucester
Tsantoulas, Apostolos, Athens, Greece

Qualified
Bracey, Anne Christine, Birmingham, West Midlands
Chen Wenlong, Beijing, P.R. China
Chen Xi, Beijing, P.R. China
Corser, Elizabeth, Wellington, Shropshire
Craddock, Natalie, Bridport, Dorset
Cui, Xianzhong, London
Cui Xue, Wuhan, Hubei, P.R. China
de Fere, Susannah, London
Dessypri, Eleni, Athens, Greece
Ding, Hui, Surbiton, Surrey
Ewington, Craig A., London
Fraser, Brenna Heather, Kingston-upon-Thames, Surrey
Gallant, Victoria, London
Hsien Pui Ling, Tsuen Wan, Hong Kong
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Lam Cheuk Hei, Kowloon, Hong Kong
Lee Ching Wah, Shatin, Hong Kong
Lui Fong, New Territories, Hong Kong
Lung Mei Ting, May, Shatin, Hong Kong
Moroz, Magdalena, London
Noble, Frances, Wendover, Buckinghamshire

Nordgren, Pia Yu, Vallingby, Sweden
Rajbanshi, Niren Man, Kathmandu, Nepal
Richardson-Jefferies, Phillipa, London
Russell-Stoneham, Alexandra, London
Smith, Mark, Richmond, Surrey
Smith, Laura Sian, Oxford
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Tsoi Mei Yu, New Territories, Hong Kong
Vaughan, Angela, Limerick, Ireland
Vikatos, Ilias, Patras, Greece
Wan Bresson, Wuhan, Hubei, P.R. China
Watson, Sarah Louise, Rowley Regis, West Midlands
Wong Yin Tak, Tony, Kowloon, Hong Kong
Wratten, Nicholas William, Notting Hill, London
Yang, Yiwei, London
Yau Cho Kwan, Chai Wan, Hong Kong
Yip Wing Man Kennis, Kowloon, Hong Kong

Gem-A Events

Gem-A Centenary Conference and Second European Gemmological Symposium

During the weekend of 25 and 26 October at the Hilton London Kensington Hotel Gem-A hosted the Second European Gemmological Symposium in conjunction with our centenary celebrations. The dynamic two-day conference covered both the history of gemmology and the jewellery trade, and new techniques that are relevant to today's gemmologists. The speakers included Sandra Brauns, Rui Galopim de Carvalho, Emmanuel Fritsch, Al Gilbertson, Henry Hänni, Ulrich Henn, Alan Hodgkinson, John Koivula, Michael Krzemnicki, Yvonne Markowitz, Jack Ogden, Duncan Parker and Brad Wilson.

A programme of events arranged to coincide with the Conference held on Monday 27 and Tuesday 28 October included the Graduation Ceremony at Goldsmiths' Hall (see below), a guided tour of the Crown Jewels at the Tower of London with David Thomas, and a private viewing of the new William and Judith Bollinger Jewellery Gallery at the Victoria and Albert Museum. In addition two workshops were held, one on a new approach to the use of the refractometer with Darko Sturman and Duncan Parker, and the second on precious metal clay with Helen O'Neill. The final event was a Gem Discovery Club Specialist Evening when Antoinette Matlins demonstrated the value of small, simple gem testing tools (a report of this Specialist Evening is given on page 147).

A report of the Conference will be published in the December 2008 issue of *Gems & Jewellery*.

Graduation Ceremony

On Monday 27 October the Graduation Ceremony and Presentation of Awards was held at Goldsmiths' Hall in the City of London. Professor Alan Collins, Chairman of the Gem-A Council, presided and Gem-A President Professor Andy Rankin presented the awards.

Michael O'Donoghue and Terry Davidson who had retired from the Council during the year, were presented with certificates honouring their contribution to the work of the Association.

The Prize Winners at Goldsmiths' Hall (from left): Antonia Underwood (Diploma Practical Prize), Kundan Sarraf (the Bruton Medal), Elizabeth Rasche (Anderson Bank Prize), Jacqueline Larsson (the Deeks Diamond Prize), Dr Pauline Jamieson (the Anderson Medal and the Hirsh Foundation Award) and Antonia Ross (The Christie's Prize for Gemmology). Photo courtesy of Photoshot.

Conference Sponsors and Supporters:

The Association is most grateful to the following for their support:

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Marcia Lanyon Ltd, London
Maggie Campbell Pedersen FGA, London
dg3 Diversified Global Graphics Group for sponsoring the folders and delegate badge

We were particularly pleased to welcome a number of Fellows and Diamond members who had graduated in Gem-A examinations in past years. To mark the celebration of One Hundred Years of Gemmological Education, those who had been unable to be present at the Graduation Ceremony in the year in which they qualified, were invited to attend the 2008 event for the formal presentation of their Diplomas.

In his address Professor Rankin referred to the international status of our examinations saying to the graduates: "Your Gem-A qualifications are recognized throughout the world as the gold standard in training and education of professional gemmologists for the gem and jewellery industry. This recognition is in part due to long-standing traditions of excellence over 100 years, and in part due to the a hard work and commitment you have put into achieving your awards. You can be justifiably proud of your achievements which are being celebrated here today ."

Professor Rankin finished by again congratulating the graduates on their achievement and wishing them every success for the future.

The ceremony was followed by a reception for graduates and guests.

A report of the Graduation Ceremony will be published in the December issue of *Gems & Jewellery*.

Pearl evening at Christie's

On 29 September Christie's King Street kindly hosted a champagne reception and pearl evening for the benefit of Gem-A's educational initiatives. Presentations included 'Pearls: a perspective on size and value' by David Warren, Head of the Jewellery Department at Christie's Dubai, 'Pearl Fishing in Scotland' by Kenneth Scarratt, Director of Research at GIA (Thailand), and 'The Romance and History of Pearls' by Gem-A CEO Dr Jack Ogden.

A report of the event was published in the October issue of *Gems & Jewellery*.

Centenary Dinner

A dinner was held on 3 July at Goldsmiths' Hall in the City of London to celebrate one hundred years of gemmological education. The evening commenced with a champagne reception in the setting of the Goldsmiths' Company's exhibition 'Treasures of the English Church' followed by a livery-style dinner. Those attending included representatives of international gem laboratories and institutes, and members of the British gem trade auction houses. After dinner a speech was given by John Benjamin FGA DGA, valuer and jewellery consultant with considerable experience of the gem and auction trade both in the UK and overseas.

A report of the event was published in the August issue of *Gems & Jewellery*.

Centenary Dinner Sponsors

The Association is most grateful to the following for their support:

Major Sponsors

Venue: **The Goldsmiths' Company,** London
Champagne Reception: **SSEF, Swiss Gemmological Institute,** Basel, Switzerland
Table Gifts: **Fellows & Sons Auctioneers & Valuers,** Birmingham, West Midlands
Candlelit Chandeliers: **Hazlems Fenton,** Chartered Accountants, London
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Organic Gems, London
Zultanite Gems LLC, Fort Lauderdale, Florida, U.S.A.

Hong Kong Graduation and Awards Dinner

A special dinner and graduation ceremony was held in Hong Kong on 16 September at the Royal Palace Restaurant, Tsimshatsui, Kowloon, in celebration of One Hundred Years of Gemmological Education. The event was organized in conjunction with Gem-A's teaching centres in Hong Kong, the Asian Gemmological Institute and Laboratory Ltd (AGIL) and the Hong Kong Institute of Gemmology (HKIG). The guest speaker was Charles Chan, President of the Hong Kong Jewellery and Jade

Manufacturers' Association. Speeches were also given by Gem-A CEO Dr Jack Ogden, Prof. Mimi Ou Yang Chiu Mei of HKIG and Dominic W.K. Mok of AGIL.

A report of the event was published in the October issue of *Gems & Jewellery*.

Hong Kong Graduation and Awards Dinner Sponsors and Supporters

Gem-A is indebted to the many sponsors, donors and volunteers listed below who made the event possible.

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Feng Hsiu-Yun FGA DGA, Taiwan Earth Gemmological Inc. ATC, Taichung, Taiwan R.O. China

Sponsors

Dr Ellen Lau GG FGA, Hong Kong
Gemmological Association of All Japan, Tokyo, Japan

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Prof. Mimi Ou Yang Chiu Mei FGA, Hong Kong Institute of Gemmology, Hong Kong

Dinner Prize draws, Table Prizes and special donations

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Guest of Honour Charles Chan, President of the Hong Kong Jewellery and Jade Manufacturers' Association, speaking at the Hong Kong Graduation and Awards Dinner.

Nature's Treasures: Minerals and Gems

On 7 December at the Flett Lecture Theatre, Natural History Museum, London SW7, a seminar was held which had been arranged jointly between Gem-A, The Mineralogical Society and The Russell Society.

Short talks on a wide range of topics including diamonds, inclusions, ancient gems, agates, mineral luminescence, environmental aspects and many more were enjoyed by an audience of nearly 100.

After lunch, there were displays and demonstrations on various aspects of gems and minerals.

Members' Meetings

London

Annual General Meeting

The Gem-A Annual General Meeting was held at the National Liberal Club, Whitehall Place, London SW1, on 30 June. Professor Alan Collins chaired the meeting and welcomed members. The Annual Report and Accounts were approved. Professor Andrew Rankin was elected President for the period 2008-2010. Michael O'Donoghue

and Evelyne Stern retired from the Council in rotation and being eligible Evelyne Stern was re-elected to the Council. Michael O'Donoghue did not seek re-election. Jim Collingwood and John Greatwood retired from the Members' Audit Committee by rotation and being eligible John Greatwood was re-elected to the Committee. Jim Collingwood did not seek re-election. Hazlems Fenton were re-appointed as auditors for the year.

The AGM was followed by a presentation by David Warren, Jewellery Department head of Christie's London King Street and Dubai. He shared anecdotes and tales from his exciting 30 years of experience working with the firm. Having been based in London, Glasgow, Hong Kong and other areas, he specializes in developing the jewellery departments of different regions and had just completed his third successful sale for Christie's in Dubai.

Gem Discovery Club Specialist Evenings

The Gem Discovery Club meets every Tuesday evening at the Gem-A London headquarters when members have the opportunity to examine a wide variety of stones. Once a month, a guest specialist speaker is invited to give a presentation.

On 13 May the guest speaker was Dennis Allen, whose presentation focused on synthetic moissanite. Well known in the industry, Dennis Allen was a founder of Emagold UK and was appointed President of the group for three years. He was also Chairman of the BJA in the early 1990s. He is now an industry consultant, a role that includes acting as technical director for a diamond sight holder and an advisor for TPS for the jewellery section of the International Spring Fair. In his presentation, Dennis Allen gave a background to synthetic moissanite since its introduction ten years ago, and explained what moissanite is and how it was discovered. He then focused on the growth in self-purchasing and how this has repositioned synthetic moissanite, concluding with the current position on sales and growth in the UK and customer comments on the product.

On 9 July the guest speaker was Branko Deljanin, Director, EGL Canada, who gave a presentation on the Identification of Small, Colourless and Fancy Colour HPHT-grown and CVD-grown Diamonds. Branko discussed both standard and advanced gemmological methods, including microscopy, UV, FTIR spectroscopy, XRF chemistry and PL Imaging and also problems in identification of small laboratory diamonds, diamond screening and testing, grading, certification and the CIS Fluorescence system. At the beginning of the evening, the speaker signed copies of his new 85-page book *Laboratory-grown Diamonds: Information Guide for HPHT-grown and CVD-grown diamonds* (2nd edition).

On 28 October the specialist speaker was Antoinette Matlins, a respected gemmologist and well-known author and lecturer. Often seen on several television networks offering important consumer information, Antoinette devotes much of her work to education and consulting within the trade. Antoinette has an unusual ability to translate complex material into relevant, practical, and — most important — useful information, and she conducts product knowledge training for some of the most prestigious retailers and industry groups in the USA. Many gemmologists today overlook basic tools and techniques that can be important aids to gem identification and treatment detection; Antoinette's specialist evening was a fresh and invigorating look at the simple side of gemmology. Her hands-on presentation demonstrated the value of small, simple tools and gave the audience a new appreciation for their value in this high-tech world, whether checking for treatments, checking parcels for 'salting,' or guarding against HPHT enhanced diamonds. At the end of the evening, the speaker signed copies of her new book *Gem Identification Made Easy* (4th edn).

Two Gem Discovery Club Specialist Evenings were held in November. On 4 November the guest speaker was Thomas Dailing. With nearly 50 professional designing

Gifts and Donations to the Association

The Association is most grateful to the following for their gifts and donations for research and teaching purposes:

Chao-Ming Wu FGA DGA, Taipei, R.O. China, for a selection of polished jadeite slabs and rough sapphire crystals

John R. Fuhrbach FGA BSc GG, JONZ Fine Jewels, Las Cruces, USA, for a collection of rough and cut, natural and synthetic stones

Keecha Narayanamurthy FGA, Ipoh Perak, Malaysia, for a selection of rough black tourmaline and white topaz

C.W. Sellors Fine Jewellery, Ashbourne, Derbyshire, for a selection of cut gems

Prof. Weixuan Yan FGA DGA, Beijing, P.R. China, for a collection of 100 pieces of animal carvings, books and photos, in memory of Prof. Zhonghui Chen

The 100 Club (£1000)

Joerg Baudendistel, Obertshausen, Germany

Helen L. Plumb FGA DGA, Aberdeen, Scotland

awards, Thomas has become one of North America's most recognized jewellery designers. Thomas Dailing Designs are contemporary classics, delicately balanced with dramatic artistry and a strong sense of engineering. His creations typically showcase concave faceted gems by Richard Homer. By continually pioneering new techniques, Thomas Dailing brings his unique vision to the jewellery world. Thomas's presentation with images of his creations focused on his history and progression as a jewellery designer and on his interaction with the legendary gem cutter Richard Homer.

On 11 November was a meeting with challenges designed to assess the skills necessary for any successful stone dealer. There were many tests, such as parcel paper folding, gemstone weight estimation and valuing parcels of stones and during the evening participants had the opportunity to try their hand at 'being a dealer' themselves. The gem dealer and guest speaker was Jason Williams of G.F. Williams, London. Jason is on the Board of Trustees of Gem-A; in order to source the best stones for his stock Jason travels extensively, bargaining hard and exercising strict quality control, resulting in a fantastic range of coloured stones.

Midlands Branch

The Branch held their annual summer luncheon party on 16 June at Barnt Green. On 26 September a monthly meeting was held at the Earth Sciences Department, Birmingham University, Edgbaston, where Branch Vice Chairman Doug Morgan talked on the early development of gem cutting, the practical problems in dealing with various gem materials, modern equipment and methods for carrying out complex gem cutting as an art form.

On 31 October, also at the Earth Sciences Department, Dr Sally Baggott, Curator at the Birmingham Assay office, gave an illustrated talk on Birmingham Silver and the Influence of Matthew Boulton.

On 28 November John Benjamin, an independent jewellery valuer, historian and author, traced jewellery design from the grim iconography of 1700s memento mori to neo-classicism and the era of sentimental jewellery in the 1800s. Topics included how diamonds and gems were cut and set, pastes, cut steel, Berlin ironwork, romanticism and much more.

The Midlands Branch Anniversary Dinner and Centenary Conference were held on Saturday and Sunday, 29 and 30 November at Menzies Strathallan Hotel, Edgbaston. Speakers included Doug Garrod, Gwyn Green, Henry Hänni, Alan Jobbins, Shena Mason and Vanessa Paterson.

North East Branch

At a Branch meeting held on Thursday 23 October at the Ramada Jarvis Hotel, Wetherby, West Yorkshire, Gwyn Green, a Gem-A examiner and tutor, gave a presentation and a practical session on the identification of colourless gems in jewellery. Gwyn's presentation and practical session appealed not only to students and valuers but also to the working jeweller.

North West Branch

Meetings held at the YHA Liverpool International, off Wapping, Liverpool, included a practical evening on 19 June when participants had the opportunity to examine a variety of rubies (synthetic and treated), diamonds (glass infill, and laser treated) and sapphires (synthetics). On 18 September Andrew Spicer of Bonhams of Chester gave a talk entitled 'Fakes and Forgeries in the Silver Markets'.

At the Branch Annual General Meeting held on 16 October James Riley was elected Chairman, Secretary and Treasurer. The AGM was followed by a talk by Jo Jones, an archaeologist and expert witness, entitled 'Gem Archaeology'.

Scottish Branch

Monthly meetings held at the British Geological Survey, Edinburgh, included a presentation and practical session on 11 June on the identification of colourless stones in jewellery by Gwyn Green, a Gem-A examiner and tutor. On 17 September Andrew Ross, Principal Curator of Invertebrate Palaeontology and Palaeobotany at the National Museums Scotland, gave a presentation on his observations on amber stability and properties. Dr Cigdem Lule spoke on 16 October on the reasons why it is important to have an understanding of gemmology in the jewellery business, citing zultanite from Turkey as an example.

On 11 November jewellery appraiser and expert witness Peter Buckie gave a talk entitled 'The challenge of valuing one of the world's largest diamonds: appraiser's dream or nightmare?'; this highlighted a faceted diamond weighing over 200 carats, D-colour, internally flawless, with excellent symmetry and polish; that he had recently been asked to value.

A joint meeting with the Scottish Mineral and Lapidary Club was held on 23 October at the Club's headquarters in Maritime Lane, Edinburgh. The speaker was Brad Wilson, Vice President and Fellow of the Canadian Gemmological Association, who gave a presentation entitled 'Coloured gemstone discoveries in Canada'.

South East Branch

On 14 June members had the opportunity to view a collection of African gems and minerals, which were beautifully presented in a small private museum near Sevenoaks, Kent. Most of the specimens had been collected at source by our host over many years during the course of his work in Africa.

On 22 October at the Queen Elizabeth Room, Portland Place, London W1, Marcus McCallum gave a presentation entitled 'An Informal Chat with a Travelling Gem Dealer'. Marcus, a well known and respected gem dealer based in Hatton Garden, focused on how he got into the trade, how things have changed over the years and shared some interesting anecdotes. Participants had the opportunity to examine a variety of unusual specimens Marcus had brought along.

On 19 November members of the Branch had the opportunity to visit the new William and Judith Bollinger Jewellery Gallery at the Victoria and Albert Museum. The visit included an introduction to the gallery, which displayed more than 3500 pieces telling the story of European Jewellery during the last 800 years, by members of the curatorial team, Richard Edgcumbe, Jo Whalley and Clare Phillips.

South West Branch

Branch members were challenged by Jason Williams of G.F. Williams of London to 'Beat the Dealer' at a meeting held at BRLSI Building, Queen Square, Bath, on 9 November. This was an afternoon designed to assess the skills which are necessary for any successful stone dealer. Time is money to a stone dealer; the faster you are the more stones you can buy, sort and ultimately sell. However, you must also be accurate. Tests included spotting the rogue CZ in a parcel of diamonds, quickly and accurately sorting a matching set of stones from a parcel, parcel paper folding, gemstone weight estimation and valuing parcels of stones. He is on the Council of Gem-A and regularly speaks at branch meetings and London's Gem Club. In order to source the best stones for his stock Jason travels extensively, bargaining hard and exercising strict quality control. This results in a fantastic range of coloured stones, from small jobbing stones to exquisite neon Paraiba tourmaline, colour-changing alexandrite and lush green tsavorite. During the afternoon, participants had the opportunity to see a range of Jason's stones.

Membership

Between 1 June and 30 November 2008 the Council approved the election to members of the following:

Fellowship and Diamond Membership (FGA DGA)

Chiu Wai Yu Yuki, Sheung Shui, Hong Kong. 2005; 2006
Lai Sau Han, Winnie, Hong Kong. 2008, 2006
Peers, Sofia, London. 2005, 2006

Fellowship (FGA)

Agu, Cecile, Le Cannet, France. 2008
Baethe, Vanessa, The Hague, The Netherlands. 2008
Bigford, Julie Claire, Malvern Wells, Worcestershire.2008
Booth, Eveline, Cheltenham, Gloucestershire.2008
Chan Wing Kwok, Tai Po, Hong Kong. 2008
Chien Lien-Chin, Taichung City, Taiwan, R.O. China. 2008
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Ding Hui, Surbiton, Surrey. 2008
Driscoll, Brian John, New York, U.S.A. 2008
Dunn, Katherine Johanna, Toronto, Ontario, Canada. 2008
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Hamrén, Elisabeth, Ostersund, Sweden. 2008
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Hsu Chia Jung, Taichung City, Taiwan, R.O. China. 2007
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Jensen, Annalisa, London. 2006
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Cui, Xianzhong, London. 2008
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Sarraf, Kundan, Kathmandu, Nepal.2008
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Giertta, Maria, London. 2008

Mo, Zhuangguo, London. 2008
Prendergast, Lorna, Great Missenden, Buckinghamshire. 2008
Rafferty, Frank, Ambrieres-les-Vallees, France. 2008
Ross, Antonia, Fleet, Hampshire. 2008
Win, Thein Thein, Cricklewood, London. 2008
Woo Ka Yin, Kowloon Bay, Hong Kong. 2008

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Subscriptions 2009

It has been arranged that membership subscriptions will remain unchanged for 2009 at £72.50 for UK members, £80.00 for those in Europe and £85.00 for overseas.

The Journal of Gemmology

We are pleased to announce that as from 2009, The Journal will go online. We will be using a state-of-the-art interface for this, providing full search facilities. Access will be via our website and will require membership log-in. The articles will be peer reviewed as now and will be placed online as soon as they are ready.

All online Journal articles will have a detailed summary in our magazine *Gems & Jewellery,* explaining the interest, relevance and importance of the article, the science, if necessary, and, of course, pointing to the online article where the full text, charts, tables and so on will published. These summaries will be readable and interesting brief articles, not to be confused with the succinct abstracts that will continue to be provided online.

All the Journal articles placed online in 2009 will be also published in 'hard copy' as a single issue in similar format to the present Journal and sent to all paid-up Gem-A members as part of their 2009 subscription.

Editorship of the Journal

As the advertisement on this page shows, Gem-A is seeking a new editor for *The Journal*. Dr Roger Harding is retiring as editor of after 15 years. Roger was Director of Gemmology for the Gemmological Association from 1990 to 2003 and became Editor of *The Journal* in 1994. As Editor, Roger has worked tirelessly to keep *The Journal* to its renowned high standards, working closely with an international editorial panel and Mary Burland, the production editor.

His retirement comes at a time when *The Journal* is about to move online as an adjunct to the printed version and this change will provide new challenges and opportunities for the next editor.

The Council of the Gemmological Association are extremely grateful to Roger for all his hard work and dedication over the years, and take this opportunity to thank him and to wish him well for the future.

Gem-A is seeking a new

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for *The Journal of Gemmology*

The Gem-A Board is seeking an Honorary Editor for *The Journal of Gemmology*, to work from home with occasional meetings at Gem-A, London.

Responsibilities will include proactively soliciting suitable papers, managing peer review, copy editing, proof reading and working closely with the production editor.

Applicants, whose first language will be English, should be current Fellows of the Association and possess:

- a demonstrable high level of mineralogical and/or geological knowledge and understanding
- editing skills and editorial experience
- a suitable computer, broadband internet connection and a reasonable level of IT skills, including knowledge of Word and Adobe Acrobat.

The Editor will receive an honorarium and some expenses.

For further information contact Dr Jack Ogden at jack.ogden@gem-a.com.

Gem-A Events 2009

Wednesday 21 January	**SCOTTISH BRANCH** **An evening with gems with Alan Hodgkinson** *Venue:* British Geological Survey, Edinburgh
Friday 30 January	**MIDLANDS BRANCH** **Annual General Meeting followed by the annual Bring and Buy and Team Quiz** *Venue:* Earth Sciences Department, Birmingham University, Edgbaston
Friday 27 February	**MIDLANDS BRANCH** **The Cheapside Hoard by James Gosling** *Venue:* Earth Sciences Department, Birmingham University, Edgbaston
Sunday 15 March	**MIDLANDS BRANCH** **Practical Training Day: Identification of Gemstones Mounted in Jewellery** *Venue:* Barnt Green, Worcestershire
Wednesday 25 March	**SCOTTISH BRANCH** **Scottish Pearl Evening at Cairncross of Perth**
Friday 27 March	**MIDLANDS BRANCH** **An Exploration into the World of Pearls by Gwyn Green** *Venue:* Earth Sciences Department, Birmingham University, Edgbaston
Friday 24 April	**MIDLANDS BRANCH** **Cometh the Day, Cometh the Jewel by David Callaghan** *Venue:* Earth Sciences Department, Birmingham University, Edgbaston
Friday 1 to Monday 4 May	**SCOTTISH BRANCH CONFERENCE** *Venue:* The Queen's Hotel, Perth (Further details given on page 90)
Sunday 21 June	**MIDLANDS BRANCH** **Summer Luncheon Party**
Saturday 17 and Sunday 18 October	**GEM-A ANNUAL CONFERENCE** *Venue:* Hilton London Kensington
Monday 19 October	**GEM-A GRADUATION AND PRESENTATION OF AWARDS** *Venue:* Goldsmiths' Hall, Foster Lane, London EC2

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Cover Picture: Variscite set in 18ct yellow gold, containing Australian champagne, cognac and colourless diamonds, suspended from a diamond bead strand. Variscite fashioned by Murray Thompson; jewellery designed and crafted by Thomas Meihofer, Stacey Illman and Kristian Fraurud. Photo by Jurgen Lunsmann. (See Ornamental variscite: a new gemstone resource from Western Australia, page 111.)

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The Editor is glad to consider original articles shedding new light on subjects of gemmological interest for publication in *The Journal of Gemmology*. A Guide to the preparation of typescripts for publication in *The Journal* is given on our website, or contact the Production Editor at the Gemmological Association of Great Britain.

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A signature for nephrite jade using its strontium isotopic composition: some Pacific Rim examples

Dr Christopher J. Adams and Russell J. Beck FGA

Abstract: Geochronological and radiogenic isotope studies of nephrite jade are reviewed, with particular reference to its paragenesis and as an aid to identifying and characterizing various sources around the Pacific Rim. Detailed studies of nephrites within several 'fields' in New Zealand, which fall within distinct geological terranes and within metamorphic belts of differing ages, clearly demonstrate the inheritance of nephrite strontium isotope compositions from their host rocks during metamorphism and metasomatism. The applications and interpretations developed from this approach are also shown to hold for preliminary analyses of nephrite in other localities around the Pacific Rim, in New Caledonia, Australia, Taiwan, Russia and Canada.

Keywords: jade, nephrite, Rb-Sr age, strontium isotopes

Introduction

Jade is a gemstone associated with ultramafic rocks in ophiolite complexes and occasionally in metamorphosed dolomites (Harlow and Sorensen, 2005). It is an almost monomineralic rock, occurring as a tremolite-amphibole type, nephrite (or nephrite jade) or a pyroxene-type, jadeitite (or jadeite jade). Although rare, deposits of nephrite jade are present around the world and especially in countries of the Pacific Rim (New Zealand, Australia, New Caledonia, China, Korea, Japan, Russia (Siberia), USA (Alaska and California) and Canada (British Columbia)) (Figure 1). Almost every culture in these countries prized jade for its beauty and durability, and so it was frequently traded or carried between them, and into Pacific Ocean islands where jade most probably does not occur naturally. Not surprisingly, considerable interest exists among archaeologists and anthropologists in tracking jade artefacts from place to place and establishing their original source, using mineralogical or chemical characteristics. Unfortunately, such jade 'signatures' may not be completely distinctive, and here we discuss an alternative technique using radiogenic isotopic ratio patterns, as applied to nephrite jades from several Pacific Rim sources.

Characteristics of nephrite jade

Nephrite jade usually comprises >99% microcrystalline amphibole of the tremolite-actinolite series, with the highest quality types close to tremolite [$Ca_2(Mg,Fe)_5Si_8O_{22}(OH)_2$]. It is only moderately hard (6–6.5), but exceedingly tough, and this toughness arises from the development of an interwoven 'felted' fabric of the tremolite crystals. This toughness can vary slightly with direction of the felted fabric. The lustrous shades of green provide the great beauties of jade and, together with some mesoscopic markings (mm-scale), are the most memorable characteristic.

The specialist can easily recognize distinctive features in jades from different sources around the world, for example in terms of texture, colour and inclusions, but doubts may remain that such features are not entirely diagnostic (see a range of nephrites in *Figure 2*). Attempts to quantify these features more have included Mossbauer spectroscopy (Wilkins *et al.*, 2003), major element composition and trace element analysis (Nichol, 2000). All these approaches encounter the same problem that the principal jade component

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Figure 1: Nephrite jade occurrences in countries around the Pacific Ocean.

is a single, common mineral type with little scope for variation.

Almost invariably, tremolite-actinolites are stable under medium-grade (greenschist facies, 350–450°C) metamorphic conditions at which nephrite jade forms; predictably their major element compositions show little variation, either within a specific locality, or between unrelated localities around the world. Minor and trace element analyses of nephrite jades are potentially more discriminatory because they tend to highlight the chemical distinctiveness of their minor (<1%) mineral impurities, e.g. chromite, spinel, garnet, sulphide, chlorite and chromium-mica (fuchsite). Chromium in particular is widely variable in jade types, for example between ortho- and para-nephrites and jadeites (Nichol, 2000), but the trace element variability within, and amongst, several nephrite fields remains inadequately investigated. Since minor mineral components have potential for considerable variation at all scales, a purely trace element chemical 'signature' remains open to question.

Paragenesis of nephrite jades

Nephrite jades form by recrystallization of original rocks (protoliths) at low to moderate temperatures and pressures (extending from pumpellyite-actinolite to amphibolite facies), either during metamorphism (*in situ* as a closed system) or by metasomatic reaction (*in situ* as an open system), or, most commonly, by a combination of both. Most nephrites form at greenschist facies (350–450°C, 5–7 kbar) by metasomatic reaction at the boundary between two components:

(1) serpentinite, itself formed by hydrous alteration of ultramafic (e.g. dunite, harzburgite) and mafic (e.g. dolerite, gabbro) rocks, which contribute Fe, Mg and OH, and

(2) sedimentary rocks such as greywacke, sandstone and limestone (and in some places volcanic rocks such as basalt and andesite) which essentially contribute SiO_2, Al_2O_3 and Ca (see a typical example in *Figure 3*).

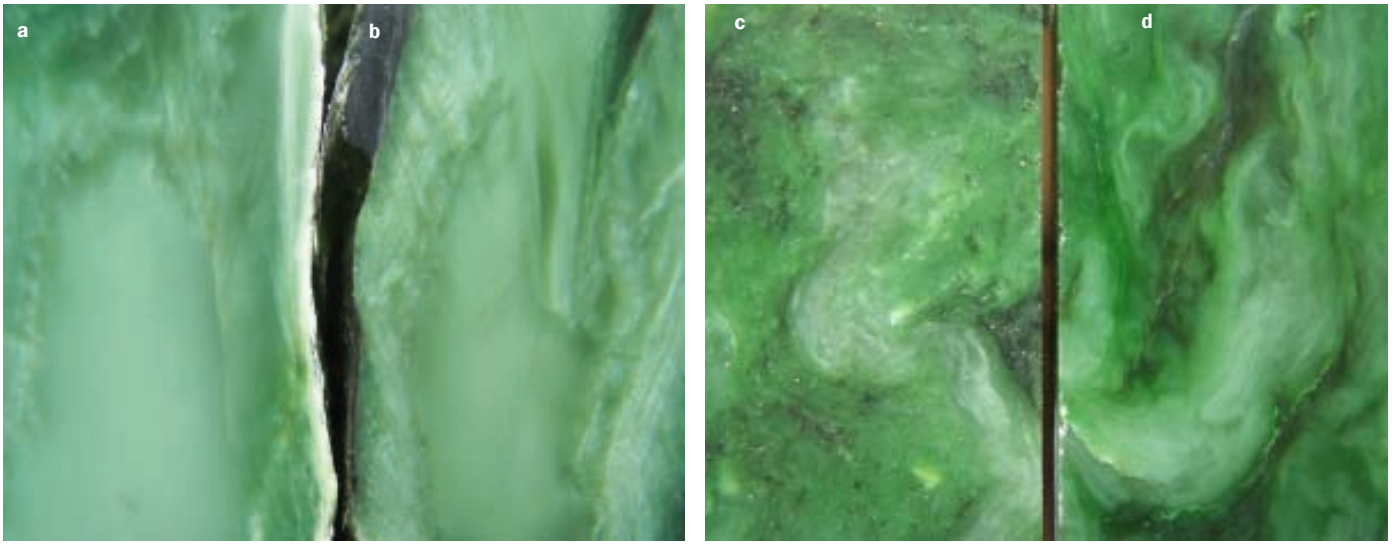

Figure 2: Nephrite jades of similar appearance from the Pacific Rim: (a) East Sayan Mountains, Siberia, Russia, (b) Olderog Creek, North Westland, New Zealand, both with particularly uniform textures; (c) South Westland, New Zealand; (d) Cassiar, British Columbia. These examples do contain microscopic inclusions which are sometimes an aid to source characterization, but they do not necessarily allow a unique distinction. Photos by R.J. Beck.

Metamorphic and metasomatic zones are readily mapped in the field and typical mineral assemblages are established across several geological periods (Coleman, 1966; Cooper and Reay, 1983). For example, in New Zealand, classic, low- to medium-grade metasedimentary successions (Permian to Cretaceous) are grouped into several tectonostratigraphic terranes of differing ancestry, some of which contain small (1–10 km scale) 'fields' of nephrite jade.

Each terrane may contain up to four main metamorphic events: Triassic, 250–240; Jurassic, 210–190; Cretaceous, 150–120; and Miocene, 10–5 Ma (Adams and Graham, 1996, 1997; Adams *et al.*, 1999; Adams and Maas, 2004).

For each terrane and metamorphic event, the ages show a gradual variation, approximately at the 100 m to km-scale, in which mineral ages are inversely related to their original metamorphic crystallization temperature (depth of burial) and the onset of their cooling in response to post-metamorphic uplift. Metamorphic ages within the nephrite fields are therefore site-specific and are to some extent predictable. This region thus provides an excellent starting-point from which to test whether the nephrite jades do properly inherit the age (and associated isotopic ancestry) of their host rocks.

Dating of nephrite jade

Widely used to determine metamorphic mineral ages, the potassium-argon (K-Ar) dating method and the related $^{40}Ar/^{39}Ar$ technique rely on the long-lived radioactive decay of isotope ^{40}K to a rare argon isotope ^{40}Ar. Whilst commonly applied to minerals with acceptable K contents >0.5%, such as micas, feldspars and hornblende, for jades with K contents <0.2% the methods usually do not give sufficiently precise ages to be useful.

The rubidium-strontium (Rb-Sr) dating method also relies on a radioactive decay with long half-life (*c.* 50.10^9 years), in this case ^{87}Rb to ^{87}Sr, and it can be applied to a wide range of Rb-bearing minerals (e.g. micas, feldspars) and rocks. The isotopic composition of strontium is thus variable because the minor isotope, ^{87}Sr, is radiogenic, i.e. it is formed by radioactive decay, whilst

Figure 3: Nephrite jade country in New Zealand, in the Dun Mountain-Maitai terrane, Livingstone Mountains, South Island. Serpentinite underlies the grass in the right foreground, the figure is standing on brown rubbly metasediments, and there is a pale nephrite lens between the figure and rucksack. The Rb-Sr isochron samples whose data are plotted in Figure 5 were collected from this outcrop. Photo by R.J. Beck.

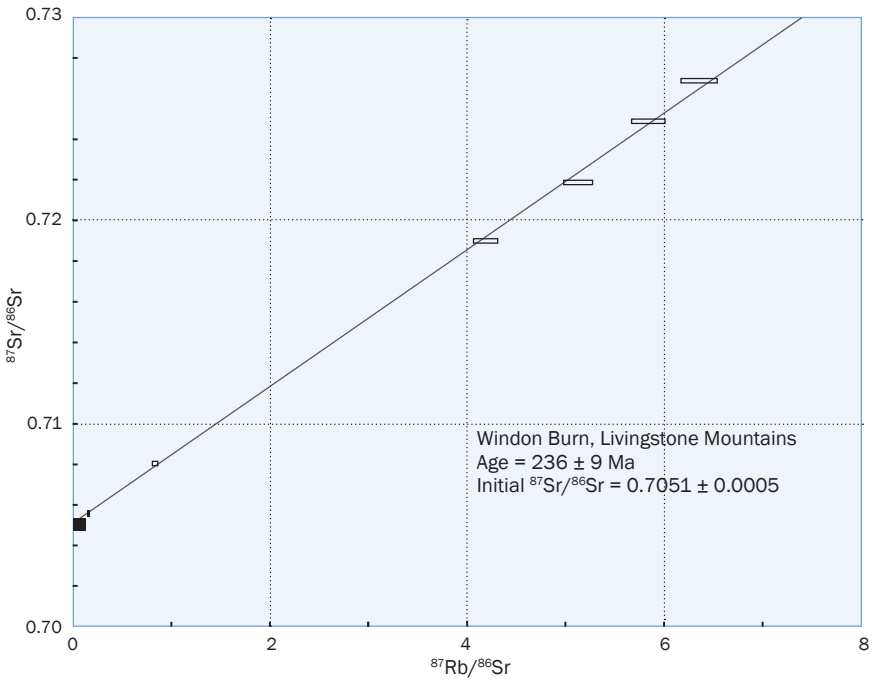

Figure 4: A Rb-Sr isochron diagram of several semi-schist samples (original protolith a graded bed of metasediments) from the outcrop pictured in Figure 3. The original rocks were size-graded sediments and their Sr isotope ratios are assumed to have been homogenized at the time of metamorphism. The analyses thus define an isochron line with slope proportional to the metamorphic age (t), and an intercept at zero $^{87}Rb/^{86}Sr$ as the initial $^{87}Sr/^{86}Sr$ ratio (i). A nephrite jade from this locality (solid square) lies very close to the initial $^{87}Sr/^{86}Sr$ ratio of 0.7051 indicated by the isochron.

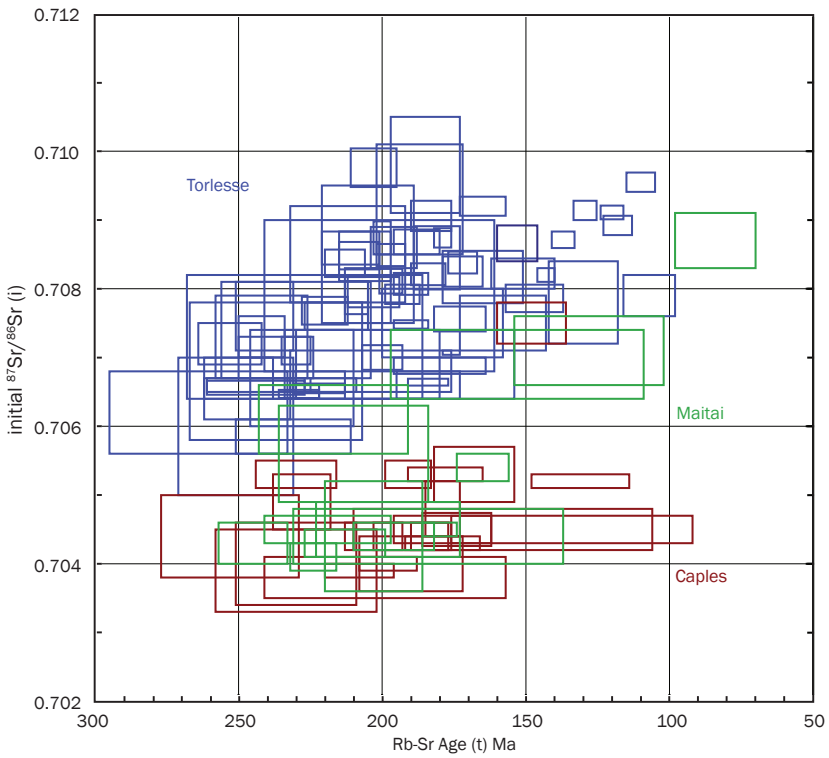

Figure 5: Rb-Sr metamorphic ages, and initial $^{87}Sr/^{86}Sr$ ratios at the time of metamorphism of metasediments from Torlesse (Rakaia) (blue line), Dun Mountain-Maitai (green line), and Caples (red line) terranes of New Zealand (data from Adams and Graham 1996, 1997; Adams et al., 1999, 2002; Adams and Maas, 2004).

its sister strontium isotopes, ^{88}Sr, ^{86}Sr and ^{84}Sr, are all stable. The abundance of ^{87}Sr will thus be higher (as a percentage of total Sr) in rocks and minerals that are old, and/or have high Rb concentrations. Since most minerals and rocks contain some Sr (and thus ^{87}Sr) at their time of formation, then both the age and initial ^{87}Sr present must be determined. This is done using an isochron method, which requires the analysis of several samples of the mineral being dated which have slightly different Rb and Sr contents, but are nonetheless assumed to be coeval and cogenetic. Upon this essential assumption, an isochron diagram *(Figure 4)* displays the analytical data as the isotopic ratios $^{87}Rb/^{86}Sr$ and $^{87}Sr/^{86}Sr$, whose array slope is proportional to the age (t) as Ma, and the $^{87}Sr/^{86}Sr$ intercept (i) is the initial Sr-isotopic ratio. Naturally, where there is little variation in Rb/Sr ratio of the samples, i.e. they are closely clustered on the isochron line, and/or where the Sr content is high relative to Rb, i.e the points are close to the intercept, then the resulting age determination will be imprecise. Both possibilities commonly occur with jade analyses. However, a compensatory benefit is that the initial Sr-isotopic ratios (i) can be determined with good precision, and it is this feature, which is related to jade ancestry, that can provide a characteristic signature. This is crucially important in New Zealand, where not only the ages (t) of metamorphic rocks vary in an orderly way, but their terrane ancestry also dictates distinctive ranges of initial $^{87}Sr/^{86}Sr$ (i) values. The combined terrane (t)-(i) data for metasedimentary rocks thus occupy specific terrane data-fields *(Figure 5)* and it would be expected that the nephrite jades formed within them would also follow this pattern.

Nephrite jade could inherit its Sr isotopic composition at the time of formation from either serpentinite or sedimentary rock components (see above). Component (1), serpentinite, is itself produced from protolith rocks of upper mantle origin. The Rb content of the upper mantle is low and fairly uniform, and thus its contribution of ^{87}Sr

over time has been low. Thus the isotopic composition of Sr within the mantle throughout Earth history has always been 'primitive' and it follows only a shallow evolution curve (as expressed by the ratio $^{87}Sr/^{86}Sr$) with time. Ultramafic and mafic rocks formed in this region, commonly with elevated Sr contents, 100–1000 ppm, thus inherit similarly primitive Sr isotopic compositions. However, when emplaced into newly-formed lower oceanic crust (e.g. as ophiolite complexes), the common associated process of hydration and serpentinization leads to major loss of Ca, and greatly decreased Sr contents, to 1–10 ppm.

In contrast, the sedimentary rocks of component (2) are overwhelmingly produced by the erosion of continental crust, itself a very complex mixture of igneous (e.g. granite), metamorphic (e.g. schist) and pre-existing sedimentary (e.g. greywacke) rocks. These have widely different ages, Sr contents e.g. 20–200 ppm, and isotopic compositions. Also typically they have Rb contents 50–100 ppm, which are an order of magnitude greater than mantle rocks. For these reasons the Sr isotopic composition of the continental crust, and the sedimentary rocks derived from it, are much more variable and 'evolved', and their $^{87}Sr/^{86}Sr$ ratios are higher (more radiogenic). The difference in Sr content between serpentinite (< 1ppm) and sedimentary rock (>100 ppm) components implies that any nephrite tremolite formed in a metasomatic reaction zone would acquire Sr overwhelmingly from the latter, and in doing so largely inherit its strontium isotopic composition. This is well illustrated in data from a New Zealand locality (see Box A).

Box A. Nephrite in South Island, New Zealand

At an isolated nephrite jade locality in a serpentinite melange of the Dun Mountain-Maitai terrane at Windon Burn, Livingstone Mountains, South Island, New Zealand (Adams *et al.*, 2007), a tectonic inclusion comprises dark grey, fine metagreywacke and metasiltstones which define a Rb-Sr isochron age, 236±9 Ma (Middle-Late Triassic), and initial $^{87}Sr/^{86}Sr$ 0.7051±0.0005 *(Figure 4)*. These data are characteristic of Late Permian, Maitai Group metasediments nearby to the west (Adams *et al.*, 2002). The metamorphism is coeval with a narrow (0.5 m) metasomatic reaction zone at the metasediment/serpentinite boundary, where lenses of nephrite jade have formed *(Figure 3)*. The nephrite at this locality has a present-day $^{87}Sr/^{86}Sr$ ratio 0.7057, and the initial $^{87}Sr/^{86}Sr$ ratio, calculated at 236 Ma, is 0.7056, coincident with that of the metasediments. Crucially, these data support a model for nephrite formation at a late stage. Its isotopic characteristics could not have been acquired during serpentinization, with its associated metasomatic release of Ca, and Sr of primitive Sr-isotopic composition (0.7032–0.7035), but rather *later* with the metamorphism/shearing that created the tremolite fabric.

Strontium isotopes in nephrite jade

New Zealand

Rb-Sr and $^{87}Sr/^{86}Sr$ (present-day) isotopic data for New Zealand nephrite jades, summarized from the detailed study of Adams *et al.*,(2007), are listed in Table I and subdivided into the three geological terrannes (Dun Mountain-Maitai, Caples and Torlesse) that contain nephrite fields (Beck, 2002). The great majority of these data are from *in situ* jade occurrences, and at many (but not all) of these localities, co-existing host-rock age/isotopic data could also be obtained. However, as discussed above, several limitations frequently preclude useful Rb-Sr nephrite and host-rock age measurements, but rather, since the Rb/Sr ratios are often very low (<0.1), the present-day $^{87}Sr/^{86}Sr$ ratios are sufficiently close to initial $^{87}Sr/^{86}Sr$ values to be calculated with good precision. In *Figure 6*, these data are shown in isochron diagram format, but with a logarithmic $^{87}Rb/^{86}Sr$ scale to reveal the fine-scale variation in the lower range of Rb/Sr ratios.

The nephrite data *(Figure 6)* clearly occupy three fields corresponding to their terrane hosts, and in those localities where independent age evidence is available

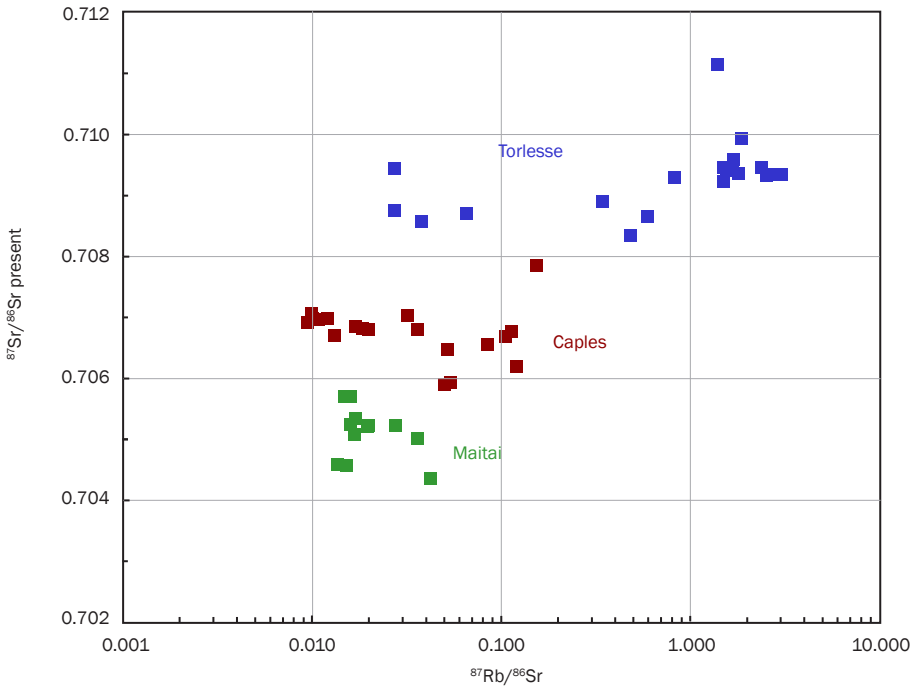

Figure 6: $^{87}Rb/^{86}Sr$ and present-day $^{87}Sr/^{86}Sr$ ratios of New Zealand nephrite jades from the Dun Mountain-Maitai, Caples and Torlesse terranes. Although the Rb/Sr ratios overlap, their $^{87}Sr/^{86}Sr$ ratios are distinct.

A signature for nephrite jade using its strontium isotopic composition: some Pacific Rim examples

Table I: Rb-Sr isotopic data for Pacific Rim nephrite jades.

Name	Sample type	Formation or location	Rb ppm	Sr ppm	Rb/Sr	$^{87}Rb/^{86}Sr$	$^{87}Sr/^{86}Sr$	e[1]	Metamorphic Age (Ma)[2,3]	$^{87}Sr/^{86}Sr$ initial	±	e[1]
NEW ZEALAND: DUN MOUNTAIN-MAITAI TERRANE												
BER1	neprite (not *in situ*)	Livingstone volcanics?	0.8	52.8	0.015	0.042	0.704366	± 0.000033				
WB	nephrite (not *in situ*)	Windon melange	0.2	38.9	0.005	0.015	0.705703	± 0.000027	236±9	0.70565	±	0.00003
WB1	nephrite (*in situ*)	Windon melange	0.2	41.4	0.006	0.016	0.705698	± 0.000027	236±9	0.70564	±	0.00003
LH-1	nephrite (not *in situ*)	Dun Mountain ophiolite	0.3	23.1	0.013	0.036	0.705017	± 0.000050	*236±9*	0.70490	±	0.00005
LH-2	nephrite (not *in situ*)	Dun Mountain ophiolite	0.3	26.0	0.010	0.028	0.705239	± 0.000028	*236±9*	0.70515	±	0.00003
LV1	nephrite (not *in situ*)	Windon melange	0.1	18.7	0.006	0.016	0.705240	± 0.000029	*236±9*	0.70519	±	0.00003
LV2	(multiple analyses, 10×10 mm slice)		0.2	26.3	0.007	0.020	0.705220	± 0.000024	*236±9*	0.70515	±	0.00002
LV3			0.2	30.5	0.006	0.017	0.705090	± 0.000026	*236±9*	0.70503	±	0.00003
LV4	(LV1-5)		0.1	22.2	0.006	0.017	0.705340	± 0.000029	*236±9*	0.70528	±	0.00003
LV5			0.1	20.7	0.007	0.020	0.705230	± 0.000028	*236±9*	0.70516	±	0.00003
NEW ZEALAND: CAPLES TERRANE												
ARC-1	nephrite (*in situ*)	Alpine schist	1.1	31.3	0.036	0.104	0.706689	± 0.000031				
SW-1	nephrite (not *in situ*)	not known	0.5	12.8	0.039	0.113	0.706765	± 0.000032				
O-1	nephrite (not *in situ*)	Greenstone melange	0.1	36.3	0.003	0.010	0.707050	± 0.000031	*170±18*	0.70703	±	0.00003
O-2	(multiple analyses, 10×10 mm slice)		0.1	26.2	0.003	0.009	0.706920	± 0.000034	*170±18*	0.70690	±	0.00003
O-3			0.1	33.6	0.003	0.010	0.706990	± 0.000032	*170±18*	0.70697	±	0.00003
O-4	(O1-5)		0.1	35.1	0.004	0.012	0.706990	± 0.000020	*170±18*	0.70696	±	0.00002
O-5			0.1	34.6	0.004	0.011	0.706970	± 0.000034	*170±18*	0.70694	±	0.00003
R1	nephrite (not *in situ*)	Greenstone melange	0.2	27.9	0.006	0.017	0.706850	± 0.000029	*168±11*	0.70681	±	0.00003
R2	(multiple analyses, 10x10 mm slice)		0.2	28.3	0.006	0.018	0.706820	± 0.000032	*168±11*	0.70678	±	0.00003
R3			0.3	28.1	0.011	0.032	0.707030	± 0.000035	*168±11*	0.70695	±	0.00004
R4	(R1-5)		0.1	32.2	0.005	0.013	0.706690	± 0.000026	*168±11*	0.70666	±	0.00003
R5			0.2	30.9	0.007	0.020	0.706800	± 0.000032	*168±11*	0.70675	±	0.00003
RB	nephrite (not *in situ*)	Greenstone melange	0.4	34.4	0.013	0.036	0.706807	± 0.000034	*168±11*	0.70672	±	0.00004
SB	nephrite (not *in situ*)	Greenstone melange	0.7	22.1	0.029	0.085	0.706550	± 0.000030	*168±11*	0.70635	±	0.00004
SC5	nephrite (*in situ*)		0.3	17.3	0.017	0.050	0.705908	± 0.000035	*168±11*	0.70579	±	0.00004
SC7	nephrite (*in situ*)		0.5	8.7	0.053	0.153	0.707857	± 0.000032	*168±11*	0.70749	±	0.00005
BB1	nephrite (*in situ*)		0.1	6.1	0.016	0.047	0.706116	± 0.000040	*150±10*	0.70600	±	0.00004
BB2	nephrite (*in situ*)	Patuki melange	0.1	7.5	0.019	0.054	0.705925	± 0.000100	*150±10*	0.70579	±	0.00010
EB-1	semi-nephrite[4] (*in situ*)	Croisilles melange	0.1	25.6	0.005	0.014	0.704576	± 0.000038	*206±10*	0.70453	±	0.00004
EB	semi-nephrite[4] (*in situ*)		0.1	22.9	0.005	0.015	0.704561	± 0.000029	*206±10*	0.70451	±	0.00003
OB-1	semi-nephrite[4] (*in situ*)	Croisilles melange	0.7	17.3	0.042	0.121	0.706196	± 0.000034	*206±10*	0.70575	±	0.00040
WR-1	semi-nephrite[4] (*in situ*)	Patuki melange	0.5	28.0	0.018	0.052	0.706468	± 0.000032	*160±2*	0.70635	±	0.00003
NEW ZEALAND: TORLESSE TERRANE												
J1	nephrite (not *in situ*)	Pounamu ultramafics	4.0	4.6	0.870	2.518	0.709330	± 0.000029	5.9±6.1	0.70960	±	0.00020
J2	(multiple analyses, 10×10 mm slice)		3.3	4.0	0.822	2.379	0.709460	± 0.000024	5.9±6.1	0.70960	±	0.00020
J3			2.0	3.9	0.519	1.502	0.709450	± 0.000030	5.9±6.1	0.70960	±	0.00020
J4	(J1-5)		4.5	4.3	1.042	3.014	0.709340	± 0.000037	5.9±6.1	0.70960	±	0.00020
J5			5.0	5.4	0.933	2.700	0.709340	± 0.000026	5.9±6.1	0.70960	±	0.00020

A signature for nephrite jade using its strontium isotopic composition: some Pacific Rim examples

Name	Sample type	Formation or location	Rb ppm	Sr ppm	Rb/Sr	$^{87}Rb/^{86}Sr$	$^{87}Sr/^{86}Sr$	e[1]	Metamorphic Age (Ma)[2,3]	$^{87}Sr/^{86}Sr$ initial	±	e[1]
NEW ZEALAND: TORLESSE TERRANE (continued)												
A1	nephrite (*in situ*)	Pounamu ultramafics	2.8	4.8	0.581	1.681	0.709420	± 0.000029	*5.9±6.1*	0.70928	±	0.00014
A2	(multiple analyses, 10×10 mm slice)		3.0	4.7	0.628	1.818	0.709360	± 0.000030	*5.9±6.1*	0.70921	±	0.00016
A3			3.2	4.9	0.645	1.868	0.709930	± 0.000070	*5.9±6.1*	0.70977	±	0.00017
A4	(A1-5)		2.7	4.6	0.587	1.698	0.709580	± 0.000028	*5.9±6.1*	0.70944	±	0.00015
A5			2.7	5.0	0.536	1.550	0.709410	± 0.000033	*5.9±6.1*	0.70928	±	0.00014
JC-1A	nephrite (not *in situ*)	Pounamu ultramafics	2.9	5.5	0.516	1.494	0.709220	± 0.000037	*5.9±6.1*	0.70910	±	0.00014
JC-1	nephrite (not *in situ*)	Pounamu ultramafics	2.6	5.3	0.481	1.392	0.711156	± 0.000039	*5.9±6.1*	0.71104	±	0.00013
JC-2	nephrite (not *in situ*)	Pounamu ultramafics	2.0	7.1	0.284	0.823	0.709297	± 0.000042	*5.9±6.1*	0.70923	±	0.00008
CR1	semi-nephrite (*in situ*)		0.2	1.4	0.119	0.343	0.708896	± 0.000063	*25±1*	0.70877	±	0.00006
MC-1	nephrite (*in situ*)	Alpine schist	0.2	20.1	0.009	0.027	0.709450	± 0.000040	*130±1*	0.70856	±	0.00004
MC-2	nephrite (*in situ*)	Alpine schist	0.3	27.6	0.009	0.027	0.708764	± 0.000032				
J33214C	semi-nephrite[4] (not *in situ*)	Diedrich Ck site B5	0.28	12.40	0.023	0.065	0.708700	± 0.000110				
J33211C	semi-nephrite[4] (not *in situ*)	Kokatahi R, site A4	2.26	11.03	0.205	0.593	0.708648	± 0.000037				
J33216C	semi-nephrite[4] (not *in situ*)	Toaroha R site A3	0.18	13.76	0.013	0.038	0.708575	± 0.000035				
J33217C	semi-nephrite[4] (not *in situ*)	Toaroha R site A3	2.77	16.59	0.167	0.483	0.708336	± 0.000038				
NEW CALEDONIA												
TIKX1	nephrite	Tiwaka River	0.11	13.90	0.008	0.023	0.704334	± 0.000029				
TIWX3	nephrite	Tiwaka River	0.10	15.36	0.007	0.019	0.704460	± 0.000028				
TIWX5	nephrite	Tiwaka River	0.25	67.50	0.004	0.011	0.705297	± 0.000028				
NCP	nephrite	Pombe	0.09	76.79	0.001	0.003	0.704864	± 0.000034				
IDO1	ouenite[5]	Île d'Ouen	0.27	138.40	0.002	0.006	0.705091	± 0.000044				
IDO2	ouenite[5]	Île d'Ouen	0.10	22.41	0.004	0.013	0.704530	± 0.000030				
IDO3	ouenite[5]	Île d'Ouen	0.17	79.89	0.002	0.006	0.704697	± 0.000030				
IDO5D	ouenite[5]	Île d'Ouen	0.28	165.50	0.002	0.005	0.705732	± 0.000027				
IDO5L	ouenite[5]	Île d'Ouen	0.14	214.90	0.001	0.002	0.705851	± 0.000029				
COWELL, SOUTH AUSTRALIA												
COW1	nephrite	Cowell	0.69	5.43	0.127	0.368	0.720347	± 0.000031				
COW10	nephrite	Cowell	6.63	5.03	1.318	3.833	0.760777	± 0.000045				
COW20	nephrite	Cowell	2.97	7.71	0.385	1.117	0.728423	± 0.000036				
COW30	nephrite	Cowell	1.35	19.10	0.071	0.205	0.718314	± 0.000031				
CA	nephrite	Cowell	2.40	7.45	0.322	0.934	0.734300	± 0.000033				
BRITISH COLUMBIA, CANADA												
BCC	nephrite	Cassiar	0.22	4.32	0.051	0.147	0.711785	± 0.000042				
TAIWAN												
TH	nephrite	Hualien mine	0.28	3.57	0.078	0.227	0.712853	± 0.000040				
SIBERIA, RUSSIA												
VR	nephrite	Vitim mine	0.50	4.11	0.122	0.352	0.711390	± 0.000031				
SR	nephrite	Sayan mts.	7.06	15.34	0.460	1.332	0.712467	± 0.000036				

NOTES
1. e: 1 standard error
2. Ages in normal type are measured at locality; those in italics are assumed ages from nearby localities
3. Decay constants: Steiger and Jäger (1977)
4. Semi-nephrite is a term used for a tremolite rock in which the felted fabric is only imperfectly developed; it is not as tough as true nephrite.
5. Ouenite is an informal name for a plagioclase-tremolite rock from Île d'Ouen, New Caledonia, locally termed 'jade', and will be described in a forthcoming paper by Beck and Grapes.

(see Adams *et al.*, 2007) to calculate the nephrite initial Sr-isotopic composition, then these fall within the data range of their host-rock terranes as shown in *Figure 5*.

The Torlesse terrane nephrites have the highest and greatest range of Rb/Sr ratios, a feature of the Torlesse terrane host-rock schists also. They principally form within a metamorphic zone (Alpine Schist) at 5–10 Ma, much younger than their other terrane counterparts, so that the radiogenic strontium corrections required for Sr-initial ratio determination are trivial. The high present-day $^{87}Sr/^{86}Sr$ ratios, 0.708-0.711 *(Figure 6)* of the Torlesse terrane nephrites are thus mainly a consequence of the high initial $^{87}Sr/^{86}Sr$ ratios (at time of metamorphism), 0.706–0.710, of their Torlesse Group metasediment host-rocks *(Figure 5)*.

Similarly, present-day $^{87}Sr/^{86}Sr$ ratios, 0.704–0.706, for Dun Mountain-Maitai terrane nephrites *(Figure 6)* fall within the initial $^{87}Sr/^{86}Sr$ range for Maitai Group metasediments *(Figure 5)*. In this case, although the metamorphic ages of the nephrites are much older, *c.* 220–250 Ma, the Rb/Sr ratios, and their range, are 1–2 orders of magnitude lower, and thus the radiogenic isotope correction to calculate the initial $^{87}Sr/^{86}Sr$ ratios (at time of metamorphism) remains minimal.

The Caples terrane nephrite present-day $^{87}Sr/^{86}Sr$ data (*c.* 0.706–0.707) occupy an intermediate position, between those of Dun Mountain-Maitai and Caples terranes *(Figure 6)*. Here, the metamorphic ages of most of the host Caples Group metasediments are in the range 140–180 Ma and, with $^{87}Rb/^{86}Sr$ ratios considerably higher than Dun Mountain-Maitai terrane examples, the calculated nephrite initial $^{87}Sr/^{86}Sr$ ratios are *c.* 0.705–0.706. These are significantly lower than present-day values, but just coinciding with uppermost values from the host rocks, *c.* 0.7055 *(Figure 5)*.

Pacific Rim nephrite jades

Preliminary studies have been made of nephrite jades from other countries around the Pacific Ocean (New Caledonia, Australia, Taiwan, Russia and Canada), and Rb-Sr and Sr-isotopic data are listed in *Table I*.

All sample collection, processing, analytical and data processing procedures were identical to those described by Adams *et al.*,(2007).

These nephrite jade localities *(Figure 1)* generally lie within Palaeozoic-Mesozoic mobile belts of the Pacific Rim, but the Australian dataset includes an unusual cratonic, Precambrian, nephrite jade deposit at Cowell, South Australia. Some of these nephrite occurrences are not *in situ,* and hence the original age of both serpentinite and sedimentary host-rock components, and their metamorphic ages, are uncertain. The $^{87}Rb/^{86}Sr$ and present-day $^{87}Sr/^{86}Sr$ isotopic data are shown in *Figure 7*, in the same format as the New Zealand data of *Figure 6*.

New Caledonia

Most nephrite jade deposits in New Caledonia are concentrated in the central, axial mountain ranges, in the Tiwaka River watershed and adjacent rivers that flow east to the Pacific Ocean. The area is dominated by low- to medium-grade metasediments (Central terrane, Triassic-Jurassic), with more local Permian ophiolites with serpentinite complexes (Koh terrane).

At two localities, crucial outcrops show the typical metasomatic reaction zone between serpentinite and fine metagreywackes, with small, 0.2 m lenses of nephrite jade within this zone. A Rb-Sr isochron of the host-rock metasediments yields a very imprecise age of 87±130 Ma, but the initial $^{87}Sr/^{86}Sr$ ratio of 0.7049±0.0006, is concordant with those of nephrites at this locality, 0.7043–0.7051. With Rb/Sr ratios in a slightly lower range of 0.005–0.05, New Caledonia nephrite data lie adjacent to, but slightly overlap, the least radiogenic nephrites from the Dun Mountain-Maitai terrane of New Zealand *(Figure 7)*.

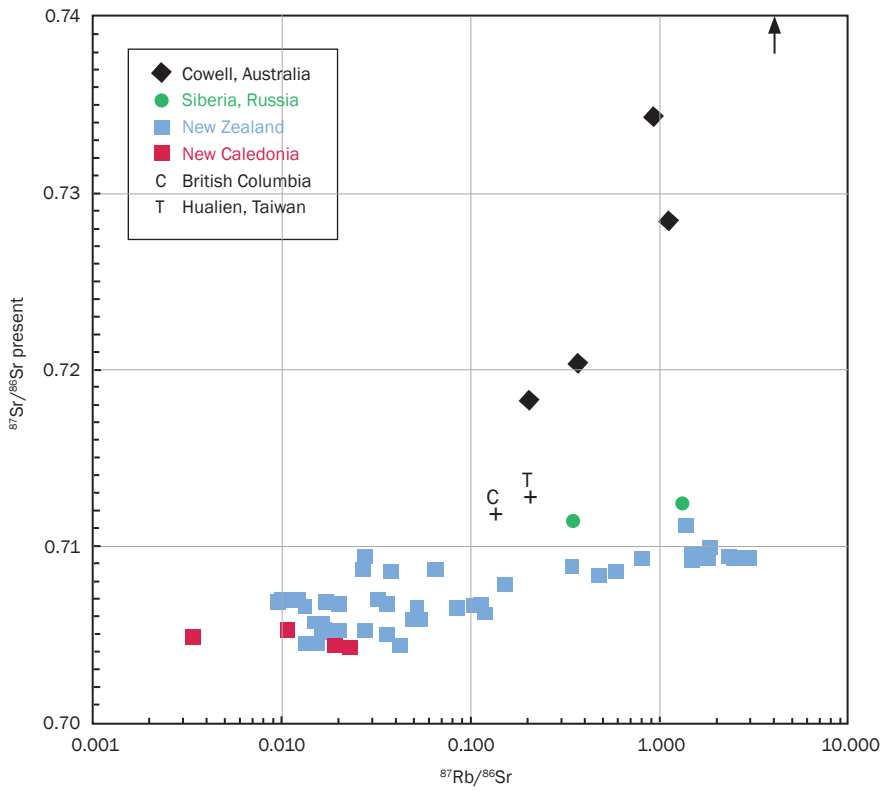

Figure 7: $^{87}Rb/^{86}Sr$ and present-day $^{87}Sr/^{86}Sr$ ratios of nephrite jades from the Pacific rim. Arrow indicates the position at the $^{87}Rb/^{86}Sr$ axis of a Cowell sample analysis that falls above the limit of the diagram. Symbol sizes are larger than the data-point error boxes at 95% confidence limits.

Cowell, South Australia

Nephrite jade occurs west of Cowell, South Australia, in an amphibolite facies metamorphic complex (Cleve Metamorphics) of late Palaeoproterozoic age, *c.* 1600–1700 Ma. A dark green-black jade forms massive (m-scale) lenses in metasomatic reaction zones between granite-gneisses and horizons of metasediment, metavolcanics, talc-schist, dolomitic marble and serpentine marble (Nichol, 1974, 1977). The nephrite jades *(Table I, Figure 7)* have distinctive, high present-day $^{87}Sr/^{86}Sr$ ratios of 0.720–0.760, presumably reflecting their Precambrian ancestry. Although the several samples come from four separate outcrops, the general slope of the Cowell data array *(Figure 7)* reflects an Rb-Sr isochron metamorphic age of *c.* 800 Ma (Neoproterozoic), much younger than elsewhere in the Cleve metamorphic complex, but still with distinctively high initial $^{87}Sr/^{86}Sr$ ratios of 0.715–0.720.

Taiwan

Nephrite jade is well known in Taiwan; it is found as boulders in several rivers on the east coast of the island, and formerly was mined in the Fengtien area, near the city of Hualien. The Fengtien *in situ* deposits lie within a 3 x 10 km area, where massive jade lenses (m-scale) and diopside-rock intervene between greenschist facies, graphitic mica-schists (Tananao Schist) and serpentinite, which together form part of a late Palaeozoic-Mesozoic basement metamorphic complex (Li-Ping Tan *et al.,* 1978). In *Figure 7* the isotopic data for a Fengtien nephrite jade fall between the Cowell and New Zealand data, and the high present-day $^{87}Sr/^{86}Sr$ ratio, 0.7128, suggests that the radiogenic strontium contribution to this nephrite would originate from relatively old host-rock metasediments. Unfortunately, their age is not known and an initial $^{87}Sr/^{86}Sr$ ratio cannot yet be calculated.

British Columbia, Canada

Numerous nephrite deposits occur along a NW–SE trending belt, 50 km wide, through central British Columbia (Leaming, 1978). All are associated with late Palaeozoic/early Mesozoic ophiolite complexes, and are concentrated in southern (Lillooet), central (Omineca) and northern (Cassiar) fields. Much of the nephrite is recovered from river and glacial deposits, but *in situ* deposits exist within the Late Devonian to Early Carboniferous Cache Creek Group (ophiolites, chert, argillite and volcanics), at Dease Lake and Cassiar. In *Figure 7*, a single nephrite analysis from Cassiar appears similar to that of nephrite from Taiwan, and their ages and calculated initial $^{87}Sr/^{86}Sr$ ratios are also similar.

Siberia, Russia

Two important nephrite jade fields occur in Siberia. In the Vitim River area nephrite forms at contacts of early Palaeozoic leucocratic granitoids with dolomitic marbles to form distinctive greenish-white jade (Sekerin and Sekerina, 1986a, 1986b; Sekerina, 1992; Suturin and Zamaletdinov, 1984). In the East Sayan mountains, there is a major nephrite deposit in Late Proterozoic (or possibly Cambrian) ultramafic complexes of the Ospinsk-Kitoy massif. The nephrite lies within metasomatic reaction zones between serpentinite and albitized gabbro and/or albitites (Kolensik, 1970; Prokhor 1991).

Again, the present-day Sr-isotopic ratios of the Siberian nephrites, 0.7113–0.7125 *(Figure 7)*, are similar to those in the nephrites from Taiwan and Canada, but the latter have significantly higher Rb/Sr ratios. Since the host-rocks in this region are probably early Palaeozoic or older, their contents of radiogenic strontium would be significant, and any calculated initial $^{87}Sr/^{86}Sr$ ratios substantially lower than these present-day values.

Conclusions

The New Zealand nephrite jade results *(Figure 6)* clearly show a strong association with the age and isotopic history of their host-rocks. The initial Sr-isotope signatures of each South Island jade field are diagnostic of its terrane and distinctive at least on a 1–10 km scale. At this level, they thus provide a trustworthy characteristic for identification of nephrite jade sources.

Our preliminary data for other jade provinces around the Pacific Rim appear equally distinctive *(Figure 7)*, with only slight overlap with the New Zealand datafields. Although all the samples are from (or very close to) *in situ* jade occurrences, in many localities the precise relationship to, and age of, the host rocks are unknown or ambiguous, and therefore the initial Sr-isotopic ratios cannot be calculated with precision. Work is now underway to obtain high-quality Rb-Sr isochron age data from host-rock horizons immediately adjacent to the Tiwaka (New Caledonia), Tamworth and Cowell (Australia), and Hualien (Taiwan) jade deposits to improve these Sr-isotope signatures, and to define real Sr-isotope datafields with accuracies similar to those of New Zealand. However, it is clear even from our preliminary New Caledonia nephrite data that the low Rb/Sr and initial $^{87}Sr/^{86}Sr$ ratios reflect the relatively young age (possible Late Jurassic) and juvenile sediment material (active volcanic arc) of their host-rocks. In contrast, the much older (Precambrian) and evolved ('continental') host-rocks at Cowell, South Australia, bequeath their distinctively higher radiogenic $^{87}Sr/^{86}Sr$ ratios on nephrite jade from this locality.

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Jaspilite — the gemstone of Ukraine

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Abstract: The Ukrainian jaspilites, occurring within Proterozoic sediments of the Krivoy Rog Basin, are an important raw material used in the national metallurgical industry. Some exhibit significant diversity of texture and colour and are suitable as decorative rocks. In a few, the reflective optical effects described as 'tiger's-eye' and 'falcon's-eye' are present. Quartz and iron-ore minerals (hematite, magnetite, goethite) are the main rock-forming minerals of the jaspilites, and carbonates (siderite, ankerite), amphiboles (cummingtonite, grünerite), feldspars and apatite are subordinate phases. In Ukraine, the decorative types of jaspilite are valuable for making fancy goods such as vases and clocks, artistic jewellery, and for the production of facing stone used especially for indoor design.

Keywords: jaspilite, shaping, texture, Ukrainian

Introduction

Jaspilites are iron- and silica-rich metamorphic rocks of volcanic or sedimentary origin, and only occur rarely in nature. Worldwide they appear within Precambrian complexes such as that in the Hamersley Basin in the northwest of Western Australia, Jasper Hill, Marquette Iron Range, Michigan, and Diamond Hill, Chittenden Co., Vermont, in the U.S.A., and the Krivoy Rog Basin, Dnepropetrovsk region, in Ukraine (Trendall, 1975; Morris, 1980; Baranov, 2006; www.mindat.org/min-26407.htm).

Ukrainian jaspilites are an important strategic raw material for the metallurgical industry in Krivoy Rog, Zaporozhe and Komsomolsk (see Dumanska-Slowik *et al.,* 2007). Also many decorative types can be distinguished among these rocks, so some can be used in slab form as facing stones on buildings, while others are fine enough for jewellery (Heflik *et al.,* 2008). The industrial classification of various jaspilite types was presented by Baranov (2006), and the Gemmological Centre of the National Mining University in Dnepropetrovsk (Ukraine) has promoted jaspilite as the prospective gemstone of Ukraine for some years. The aim of the latter is to show the natural beauty of these stones and their potential use in various contexts. However, the scope of this promotion has been limited since the majority of papers have been published in Ukrainian and Russian (e.g. Baranov, 2002, 2006; Baranov *et al.,* 2006; Heflik *et al.,* 2008).

Geological setting

Of 48 iron ore deposits in Ukraine, only 25 are currently being exploited. The Krivoy Rog iron-ore Basin is the main mining centre and its main geological features are shown in *Figure 1.* It is ca. 100 km long by 2–7 km wide and is elongate south–north. The Krivoy Rog Basin is situated between two large crustal blocks of different age: the Ingulsky block built of Lower Proterozoic granitoids and metamorphic rocks, and the Sredneprideprovsky block containing Archaean plagiogranites.

The Krivoy Rog Structure contains complexes from both these blocks which have been subjected to extensive and strong folding and faulting. The jaspilites occur within the Proterozoic sedimentary and volcanic rocks (2.5–1.8 Ga) which have been metamorphosed at greenschist and amphibolite facies conditions. The thicknesses of Fe-bearing rocks range from 0.3 to 3.5 km.

Decorative jaspilite varieties

Ukrainian jaspilites exhibit a wide range of textures and colours, mainly red with different tints from bright red to deep-brown, yellow, orange and blue, and some are grey with a metallic lustre. Based on colour, six categories have been distinguished:

- red-banded,
- orange-banded,
- yellow-banded,

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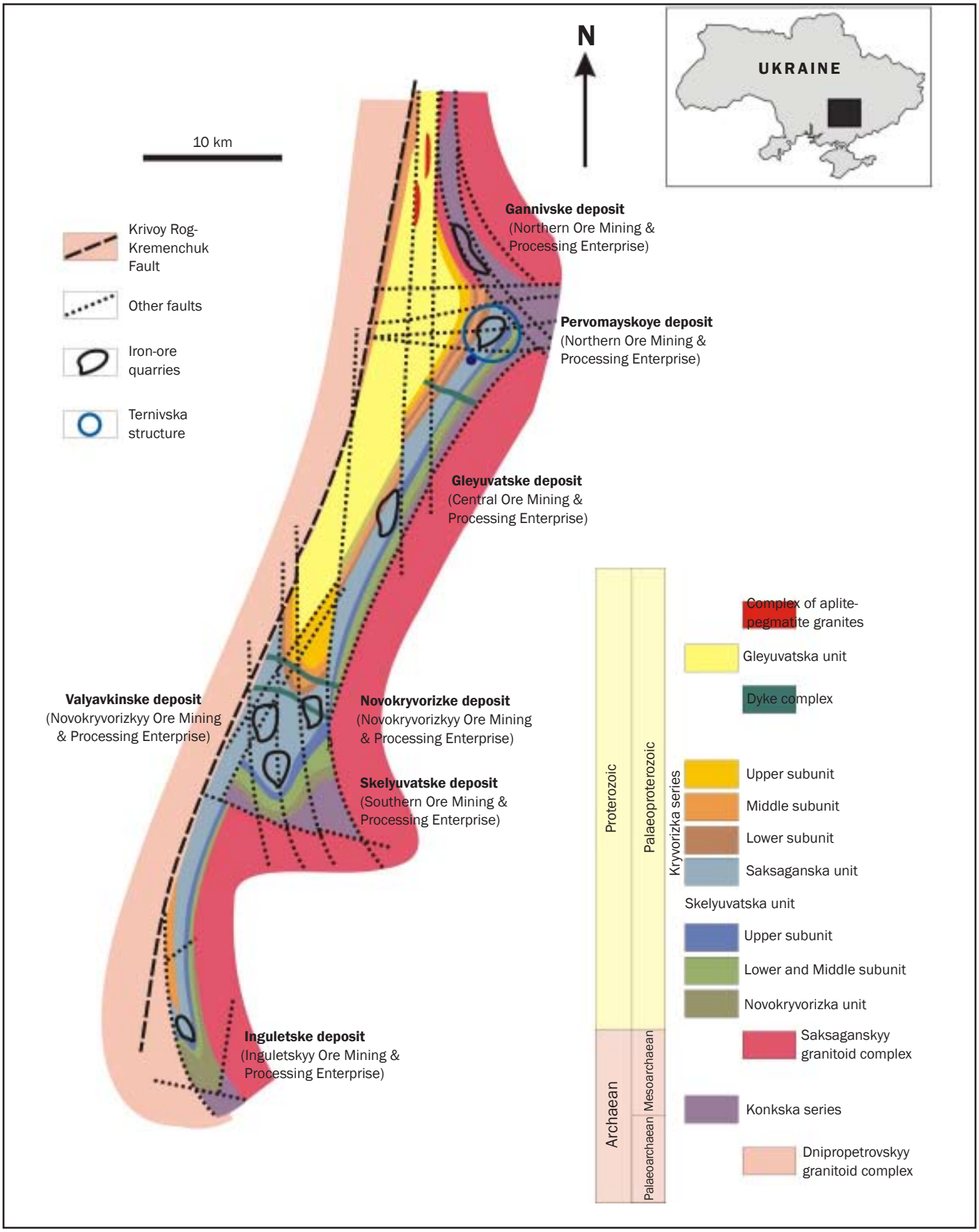

Figure 1: Schematic geological map of the Krivoy Rog Structure, Ukraine.

- yellow-banded with tiger's-eye,
- blue-banded with falcon's-eye and
- grey-banded.

In addition, the rich diversity of texture has enabled five groups to be distinguished and these are:

- parallel-striated
- wavy-striated
- intensely folded or crumpled on a small scale (plicated),
- breccia-like and
- landscape varieties.

The parallel-striated jaspilite's main features are straight parallel stripes of different colour, mineral composition and texture *(Figure 2)*. Wide- and thin-striated varieties can be distinguished, with even and uneven alternation of the layers. According to the location of the stripes, pieces can be cut to create textural pictures with bands parallel or at angles to the edges.

Wavy-striated jaspilite is defined by the presence of uneven wavy-like stripes *(Figure 3)*. Here again, wide- and thin-striated varieties can also occur. The textures may be clear or more diffuse with areas of boudinage or pinched, sausage-like structures. Generally, this variety is decorated by shallow cracks filled with magnetite and hematite of secondary origin.

The intensely folded or plicated variety is a kind of parallel-striated jaspilite and/or a wavy-striated type, which has been affected by strong deformation processes. This jaspilite contains traces of various dislocations, breaks and natural cracks filled with quartz, magnetite, hematite or iron-rich mica.

Breccia jaspilite (Figure 4) contains broken fragments, some of different composition, later cemented by siliceous or siliceous-carbonate material. The broken fragments differ not only in composition but also in their shape (rounded, acute-angled), size and colour (dark grey, light grey, brown red, red, bright red).

Landscape jaspilites are those types with inclusions and structures giving the appearance of scenic landscapes best seen in polished section *(Figure 5)*. The decorative appeal of this variety is determined by the contrast of various colours and healed natural cracks.

The main rock-forming minerals of the jaspilites are quartz, magnetite, hematite, siderite, chlorite, biotite and the amphibole grünerite. Significant amounts of aegirine and riebeckite also occur in jaspilites strongly altered during alkaline metasomatism. Hydrogoethite, albite, rhodesite, ankerite, pyrite, chalcopyrite and apatite appear as secondary

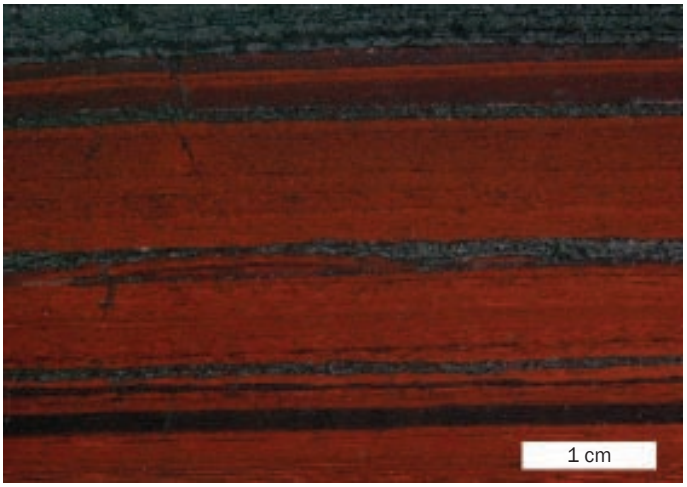

Figure 2: Red, parallel-striated jaspilite.

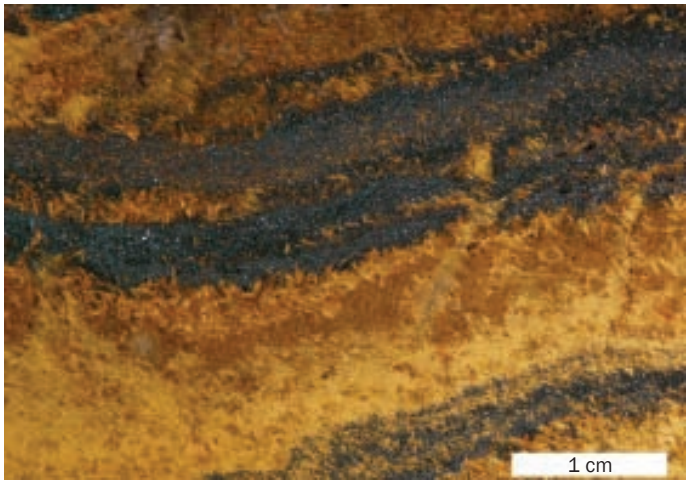

Figure 3: Yellow, wavy-striated jaspilite.

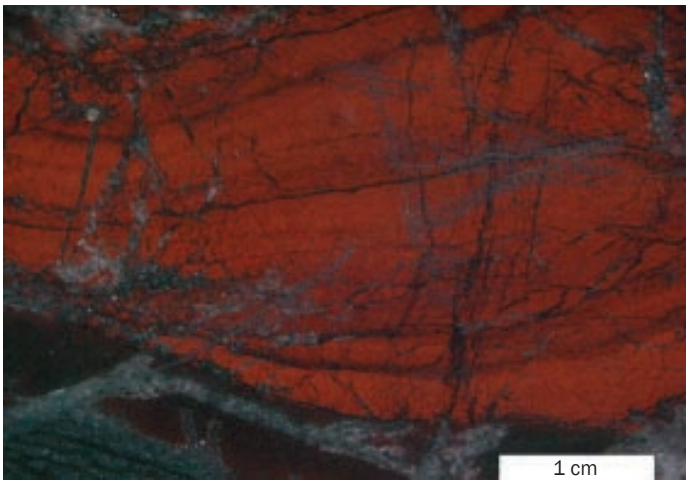

Figure 4: Red, breccia jaspilite.

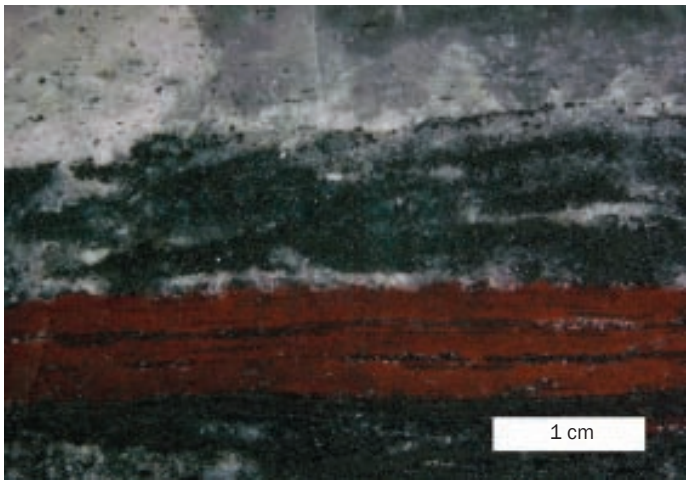

Figure 5: Red, landscape jaspilite.

and accessory mineral components (Dumanska-Slowik *et al.,* 2007). All the jaspilite varieties contain ≥ 15 wt.% Fe.

The rhythmically banded jaspilites consist of alternate laminae of silica (quartz, chalcedony), iron minerals (magnetite, hematite, siderite or goethite) and amphiboles. Typical red laminae caused by hematite in irregular aggregates are shown in *Figure 6.* Such parallel-striated jaspilites can have alternate red and grey laminae up to 12 cm in thickness. In detail, hematite is responsible for the red colour, and the interstices between the flakes are filled with fine-crystalline quartz and carbonates. The grey laminae consist of magnetite with an admixture of hematite and are commonly accompanied by carbonates (siderite), chlorite and quartz.

Although yellow-banded jaspilites are less common than the red varieties, they exhibit the same textural patterns on polished sections. They consist of golden-yellow and brown-grey laminae up to 12 cm in thickness. Amphiboles (cummingtonite subgroup), forming fibrous and lamellar crystals, are the main constituents of the yellow laminae *(Figure 7)* and the presence of these minerals causes the 'tiger's-eye' effect which is only noticeable in the yellow-bands *(Figure 8).* Also within the yellow laminae, aggregates of Fe-bearing minerals (hematite, goethite) and fine-crystalline quartz can be present (Heflik *et al.,* 2008). The brown-grey bands in the jaspilite may consist of:

1) thick layers of micro-crystalline quartz with a small admixture of hematite and goethite;
2) thin layers of medium-crystalline quartz (up to 75%) and ore-bearing minerals making up to 25% of the lamina volume; or
3) laminae enriched in Fe-bearing minerals (up to 90% of the volume) with quartz as an impurity up to 10%.

The latter layers are in contact with the golden-yellow regions of the jaspilite.

Bands in jaspilites that appear grey overall in detail consist of alternate thin black and grey laminae. The black laminae consist of quartz, hematite and goethite, with chlorites, carbonates (siderite or ankerite), feldspars and apatite as subordinate phases. Grey and grey-green veins up to several cm thick, which intersect the rocks, consist of fibrous crystals of amphiboles (mainly grünerite and subordinate cummingtonite) *(Figure 9).*

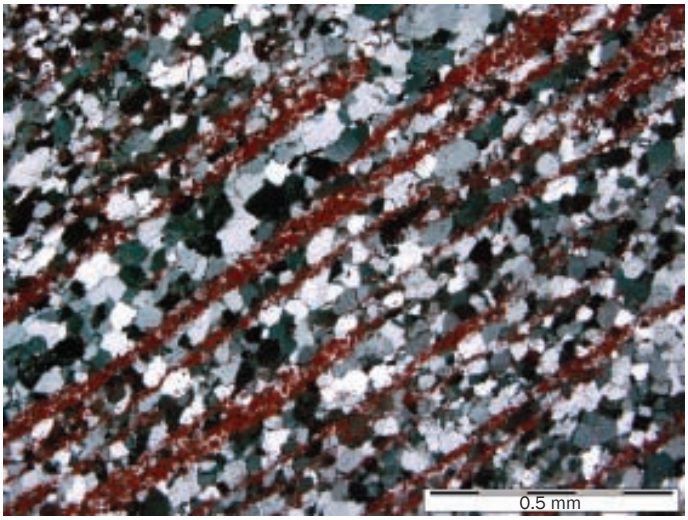

Figure 6: Red hematite in matrix of quartz; detail of texture in parallel-striated jaspilite. Thin section, cross-polarized light.

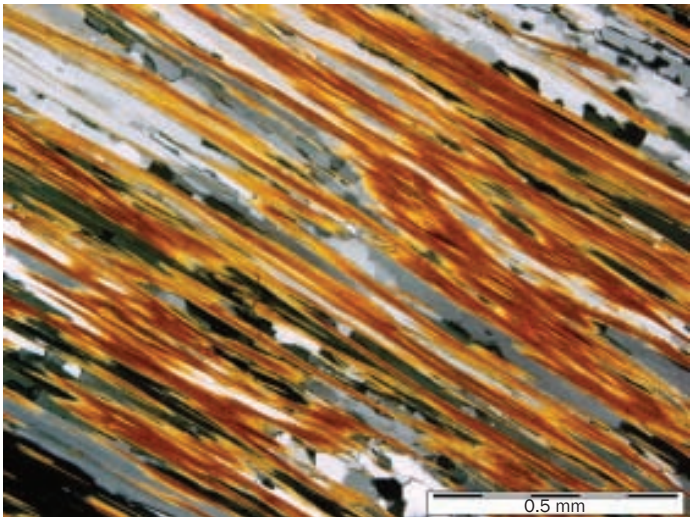

Figure 7: Fibrous crystals of amphibole in quartz matrix in parallel-striated yellow jaspilite. Thin section, cross polarized light.

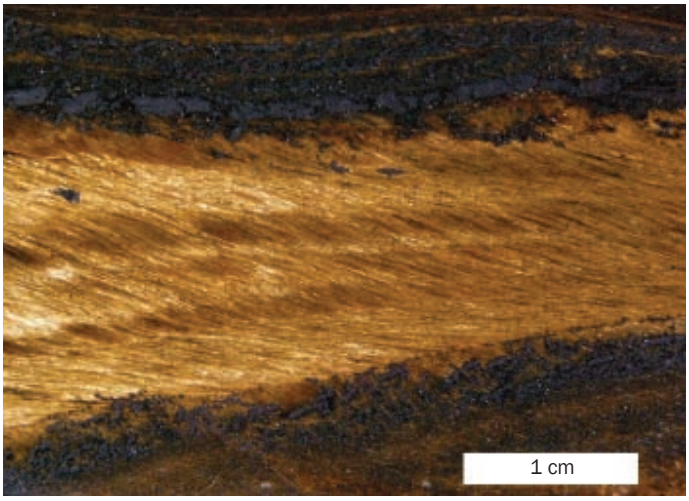

Figure 8: 'Tiger's-eye' effect in yellow, wavy-striated jaspilite.

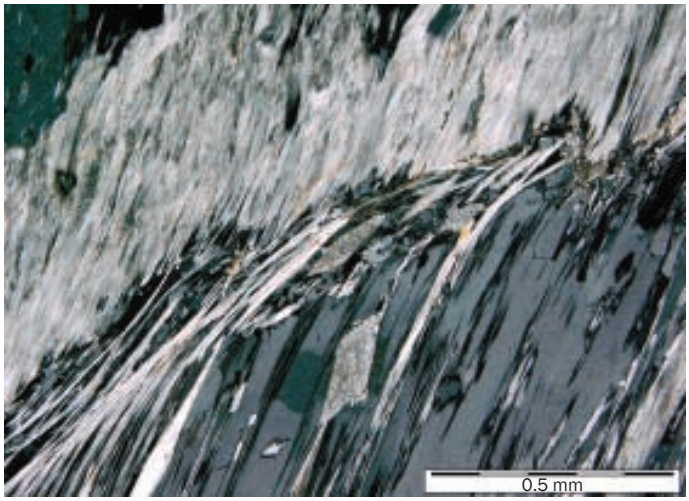

Figure 9: Fibrous crystals of amphiboles in grey jaspilite. Thin section, cross polarized light.

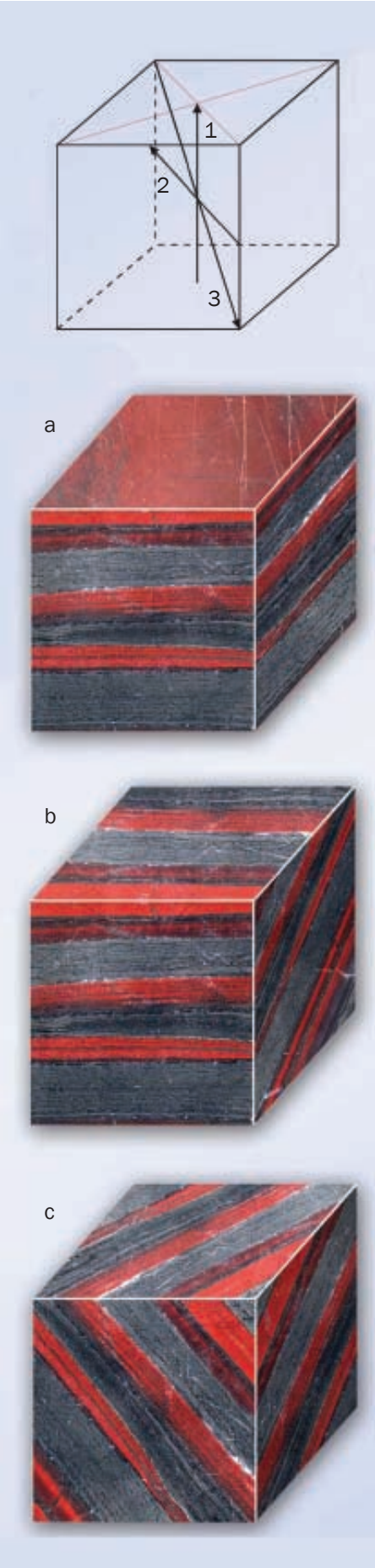

Figure 11: Examples of jaspilite fashioning according to the third principle of stone shaping. In an oval cabochon, it is possible to orientate striated jaspilite to get five different volumetric pictures.

The shaping and manufacture of jaspilite

Based on the study of jaspilite's decorative properties, three principles of shaping these stones have been established. They guide one in making the most of the textures and colours of the pieces of rough.

The first principle of shaping

The textural picture or pattern depends on the direction of cutting angle *(Figure 10)*.

The second principle of shaping

The textural picture depends on the size of the polished section of the jaspilite. If the surface is large enough, it may contain a mixture of jaspilite varieties.

The third principle of shaping.

The textural picture of the jaspilite depends on its shape. Thus, if one considers cutting striated jaspilite as a cube, it is possible to obtain three different volumetric pictures:

1. Two facets of the cube have a homogeneous picture and four are parallel-striated *(Figure 10)*.
2. Four facets show striation parallel to the edges of the cube and two facets are diagonal-striated.
3. All the facets of the cube exhibit the diagonal-striated picture.

Using striated jaspilite, it is possible to get seven different volumetric pictures out of a parallelepiped, five from a hexagonal prism, five from a tetrahedral pyramid, three from a cone, and three from a cylinder. In an oval cabochon one can reveal five different volumetric pictures of the jaspilite *(Figure 11)*. Examples of plicated and breccia patterns are shown in *Figure 12*.

Figure 10: Examples of jaspilite illustrating the third principle of stone shaping (a cube).
a. Two facets of the cube appear homogeneous for four have parallel bands.
b. Four facets have striation parallel to the edges of the cube and two have a diagonal pattern.
c. All facets have diagonal striations.

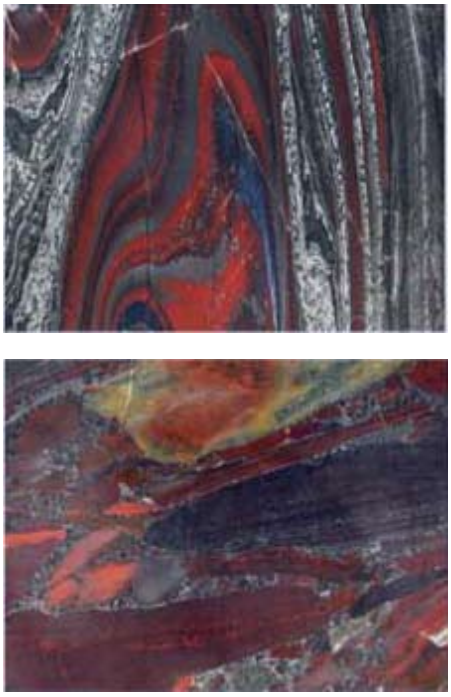

Figure 12: Typical patterns shown by pilcated (top) and breccia jaspilites.

Figure 13: (a) The cameo of Alexander the Great set in jaspilite, silver (made by Peter Baranov and Vladimir Konstantinov). (b) The cameo of Alexander Pole carved in jaspilite and set in silver on a jaspilite stand (designer Irina Buryak, made by Svyatoslav Nikitienko).

Figure 14: Vase 'Geyser' in jaspilite (made by Peter Baranov). Height 20 cm.

15: This box 'The Pearl of Seas' is made of jaspilite, labradorite and silver, and is gilded in places (designer Peter Baranov, made by Maxim Netecha and Vladimir Konstantinov). Length 14 cm.

The Ukrainian jaspilites provide excellent material for production of functional artistic goods. The two cameos and vase shown in *Figures 13* and *14* are examples of the popular art of glyptography.

Texturation is another technique often applied to jaspilite, in which the coloured parts are polished while the grey or uncoloured areas remain with a ground, matt finish. For special items, the jaspilite may be selectively gilded *(Figure 15)*.

Jaspilites can also be used to decorate the interiors of buildings. Some years ago, the idea of the 'Jaspilite Hall' was conceived, being inspired by the Malachite Hall of the Hermitage in St. Petersburg (Russia). Some artistic projects based on this idea, supported by the National Mining University and the Dnepropetrovsk Regional State Administration, have been developed (Baranov *et al.*, 2006).

It is well known that the attractiveness of such decor depends not only on the decorative properties of the stones, but also on the taste and skill employed in their use by the architect. The 'Jaspilite Hall' projects, including 'Cantata about a Gemstone', 'A Stone Flower', 'The Gothic' and 'The Knight Hall', combine these two factors. In 'The Gothic' project, the austere style matches and complements the sober colours of the Ukrainian jaspilites *(Figure 16)*.

Figure 16: A computer-generated model entitled 'The Gothic' shows a room decorated with jaspilite and depicts a figure to indicate a sense of scale. Project designer Jurij Kolokolov; computer drawer Vadim Karmanov.

Conclusion

The attractive decorative properties of Ukrainian jaspilite and the considerable reserves available promise well for the future of this material. A wide range of jaspilite items are already exhibited and sold at the 'World of gemstones' exhibition, held in Dnepropetrovsk every month, and there is potential to expand onto global markets.

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Ruby and sapphire from Marosely, Madagascar

Laurent E. Cartier

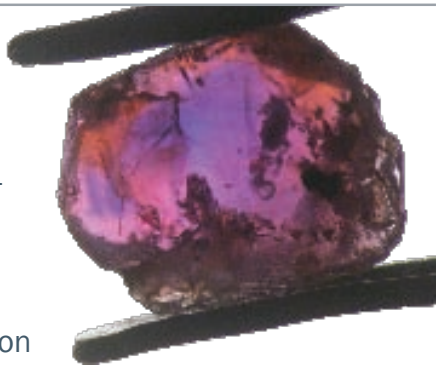

Abstract: The Marosely corundum deposit is eluvial and follows in a long line of corundum localities discovered in recent years in Madagascar. Colours range from red to blue, and stones are typically zoned, being purple overall. Thirty-five rough corundum samples of 0.1–2.0 ct in weight were selected for study, and the main aspects of this work focused on spectroscopic and chemical properties of the stones. FTIR spectra show the presence of 3160 cm^{-1} and 3309 cm^{-1} peaks in natural untreated corundums, and the relevance of these to the detection of heat treatment of corundum is discussed. LA-ICP-MS data concerning chromophores in colour-zoned samples are consistent with spectral data. Results for ultra-trace element concentrations proved less revealing, emphasizing the need for a combinatory approach with other analytical methods in advancing corundum origin determination efforts.

Keywords: corundum, FTIR spectra, LA-ICP-MS, Madagascar, origin determination, UV-visible spectra

Introduction

Since the discovery of Andranondambo in 1993, Madagascar has become an increasingly important source of gem corundum for the world market. The past decade and a half has brought about the discovery of a significant number of both large and small ruby and sapphire deposits (Kiefert *et al.,* 1996; Schwarz *et al.,* 1996; Pezzotta, 2001; Offant, 2005; Ralantoarison, 2006; Giuliani *et al.,* 2007). Considering that much of Madagascar has not yet been thoroughly explored, it is certain that in coming years many more deposits will be found to provide the world market with gem-quality ruby and sapphire (Schwarz *et al.,* 2000; Ramdohr and Milisenda, 2006). The diversity of Madagascar's geological environment and its different types and origins of corundum deposits (e.g. basaltic, skarn, metasomatic) presents certain challenges for origin determination of corundum. This paper offers a detailed examination of selected samples from a lesser-known corundum deposit at Marosely (Pezzotta, 2007; Cartier, 2008) and is part of a comprehensive study. The results from these natural untreated corundum samples should improve understanding about a range of current gemmological issues such as detection of heat treatment and origin determination.

Figure 1: Ruby and sapphire from Marosely, Madagascar. From left to right: violetish blue sapphire (0.363 ct), pink sapphire (0.164 ct), ruby (0.208 ct). Note these were not used as specimens for this study and serve merely to illustrate the variation in colour of material from the deposit.

The Marosely deposit is located in the Ranotsara region (near 47°E, 23°S) of south-central Madagascar and is eluvial. Most of the corundum crystals from this deposit are fragmental; no euhedral crystals have been found, and only a few specimens have crystal faces. Metamorphic corundum deposits have been reported in the region by

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Figure 2 Artisanal mining activity in the Marosely mining area, south Madagascar.

Offant (2005), Ralantoarison (2006) and Ralantoarison *et al.* (2006), but the high-metamorphic Marosely corundums have probably experienced considerable subsequent metasomatic alteration (Cartier 2008). *Figure 1* shows three cut stones typical of this deposit and *Figure 2* mining activity in the area.

Gemmological properties

Table I: Gemmological properties of Marosely corundum samples.

	Range	Mean
SG	3.96–4.05	3.99
RI ω	1.762–1.767	1.764
ε	1.769–1.775	1.772
ω – ε	(−0.007)–(−0.010)	−0.008

The recorded values of SG and RI for corundums from Marosely are shown in *Table I*. Their UV-fluorescence ranged as follows:

254 nm: none-weak (red)

366 nm: none-strong (red)

Nearly all stones are inert to short-wave UV radiation with only one showing weak red fluorescence; this is a Cr-rich sample (1b1). This is also the only stone to show strong fluorescence at 366 nm. Only a few stones show no reaction when exposed to 366 nm UV light. Generally speaking, the redder, Cr-richer and Fe-poorer the stone, the stronger it fluoresces (which is consistent with the known behaviour of Fe in corundum).

Internal characteristics

Mineral inclusions

A variety of solid mineral inclusions were found in the samples, the main ones being zircon, mica and rutile. Sillimanite, calcite, diaspore, feldspar (Ca-rich plagioclase, colourless) and spinel are also present in some samples. These solid inclusions were identified by means of the microscope and Raman microprobe. Negative crystals are also relatively common.

Typical zircon inclusions and their Raman shift peaks are shown in *Figures 3*, *4* and *5*. The differences in peak heights, evident in *Figure 3*, are due to anisotropy in the zircons but their positions correlate well with values reported in literature (e.g. Bruder, 1995; Ostertag, 1996; Waite, 2000).

Colour zoning

Most specimens show patchy colour zoning *(Figures 6* and *7)* and the boundaries between darker bluer colours and redder colours demark the zones of growth. Although not all stones show colour zoning, the rims of most crystals are redder and more Cr-rich than the centres.

Materials and methods

All samples used in this study were acquired at the mining site directly. Thirty-five samples representing a range of colours were selected, and on each two parallel faces were polished. The samples were examined microscopically and mineral inclusions identified using a Renishaw Raman microprobe. FTIR and UV-Vis absorption spectroscopy (using a Varian-Cary 500 spectrometer) and EDXRF measurements were carried out on all samples at the SSEF Swiss Gemmological Institute, and instrumental details are similar to those reported by Krzemnicki *et al.*,(2001) and Krzemnicki (2004). LA-ICP-MS data were obtained from equipment at the University of Berne using an ArF laser of wavelength 193 nm (see Pettke (2006) for more details). Semi-quantitative determination of the oxides in the corundum was obtained using a Tracor X-ray Spectrace 5000 EDXRF model.

Colour and spectroscopic properties

Marosely corundums range from purplish red (ruby colour) to blue, but the majority are a mixture of both colours, resulting in purple.

Typical UV-Vis absorption spectra for Marosely corundums are shown in *Figure 8*. The six spectra represent a gradual change from a blue sapphire colour to a ruby colour (1d3–1e4–1e1–2a1–2g1–2b1), which can be matched with the shifts in absorption and transmission bands. The 410 nm, 556 nm and 693 nm absorption peaks/bands are all due to Cr^{3+} content (Bosshart, 1981). The peak at 388 nm, which becomes less apparent with increasing Cr^{3+} concentrations, is due to the presence of Fe^{3+} (Kiefert, 1987) and this is near-undetectable in the sample with the lowest Fe/Cr ratio (2.014, 2b1).

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Broad absorption bands can be caused by more than one trace element. For example, in the region 550–565 nm, the 556 nm band of Cr^{3+} can be augmented by the band for Fe^{2+}/Ti^{4+}, usually found around 562 nm.

The doublet at 377 nm/388 nm becomes more pronounced with increasing Fe^{3+} concentration and correlates well with the increasing 450 nm peak. This 450 nm peak corresponds to Fe^{3+}/Fe^{3+} interactions, whereas the band at 562 nm in *Figure 8*, is caused by Fe^{2+}/Ti^{4+} inter-valence charge transfer (Schmetzer and Schwarz, 2004).

Colour is very much a product of the combinations of absorption and transmission bands and peaks. Any shift (e.g. 556 nm → 562 nm) of absorption bands in the unpolarized spectrum results in a change of perceived colour.

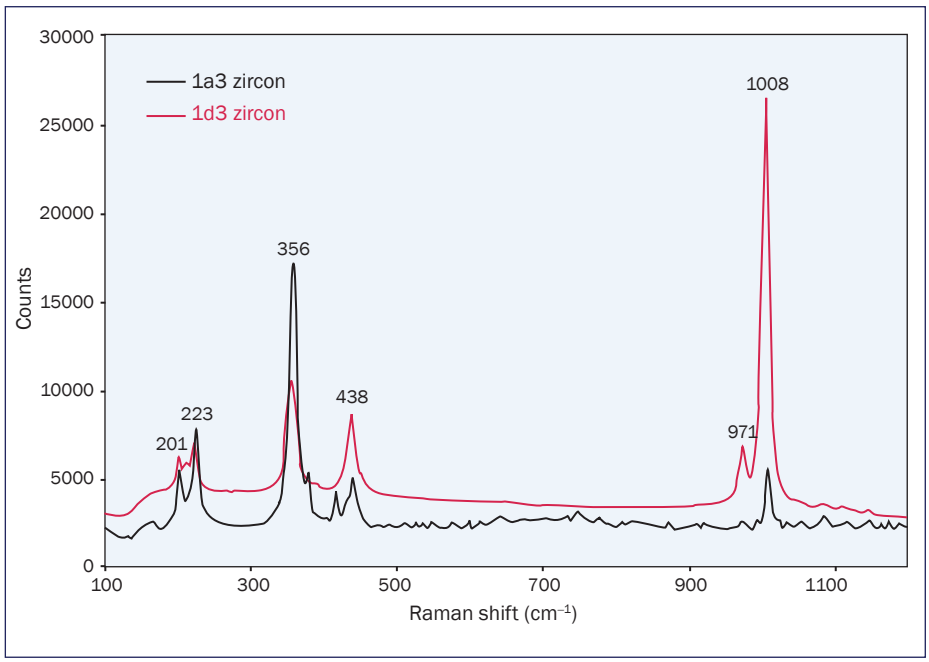

Figure 3: Raman spectra of zircon inclusions in samples 1a3 (blue sapphire) and 1d3 (light purple sapphire)

Figure 4: Zircon inclusion in sample 1d3. 20×

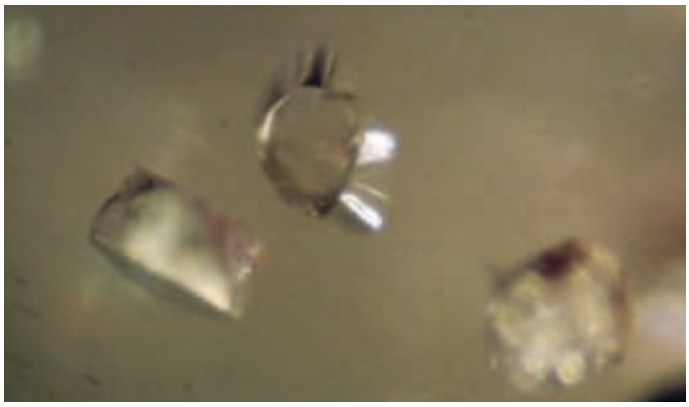

Figure 5: Zircon inclusion in sample 1a3. 20×

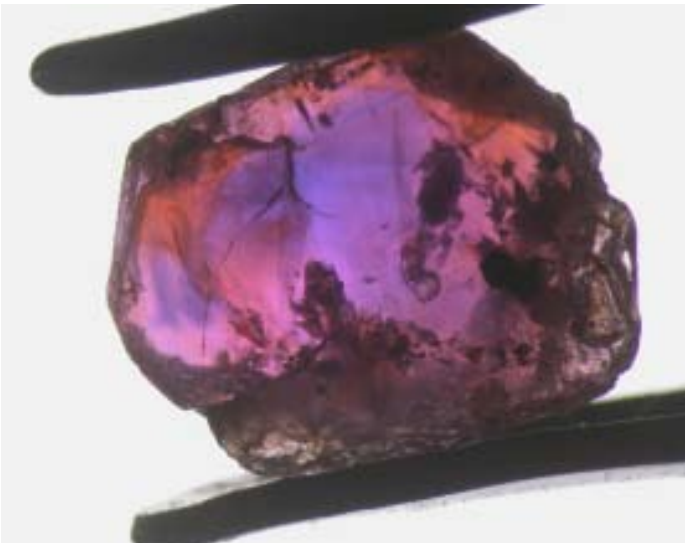

Figure 6: Sample 2c2 (0.663ct) from Marosely showing inhomogeneous or patchy colour zoning and important presence of inclusions. 10×

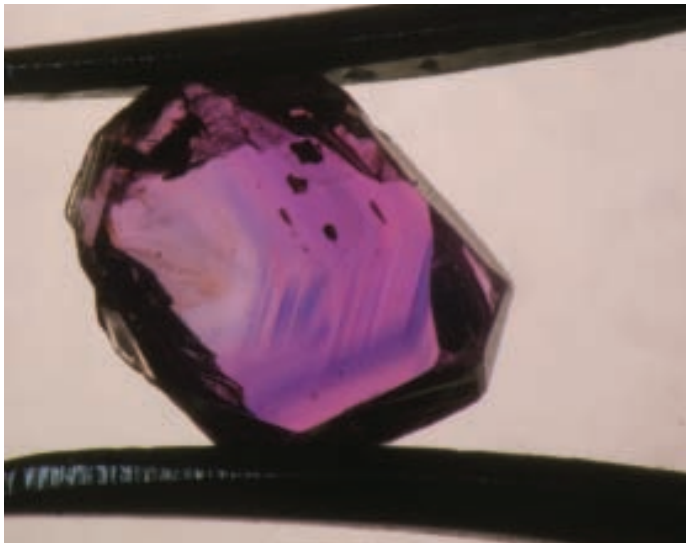

Figure 7: Specimen 2b3 (0.561 ct) showing straight bands of colour.

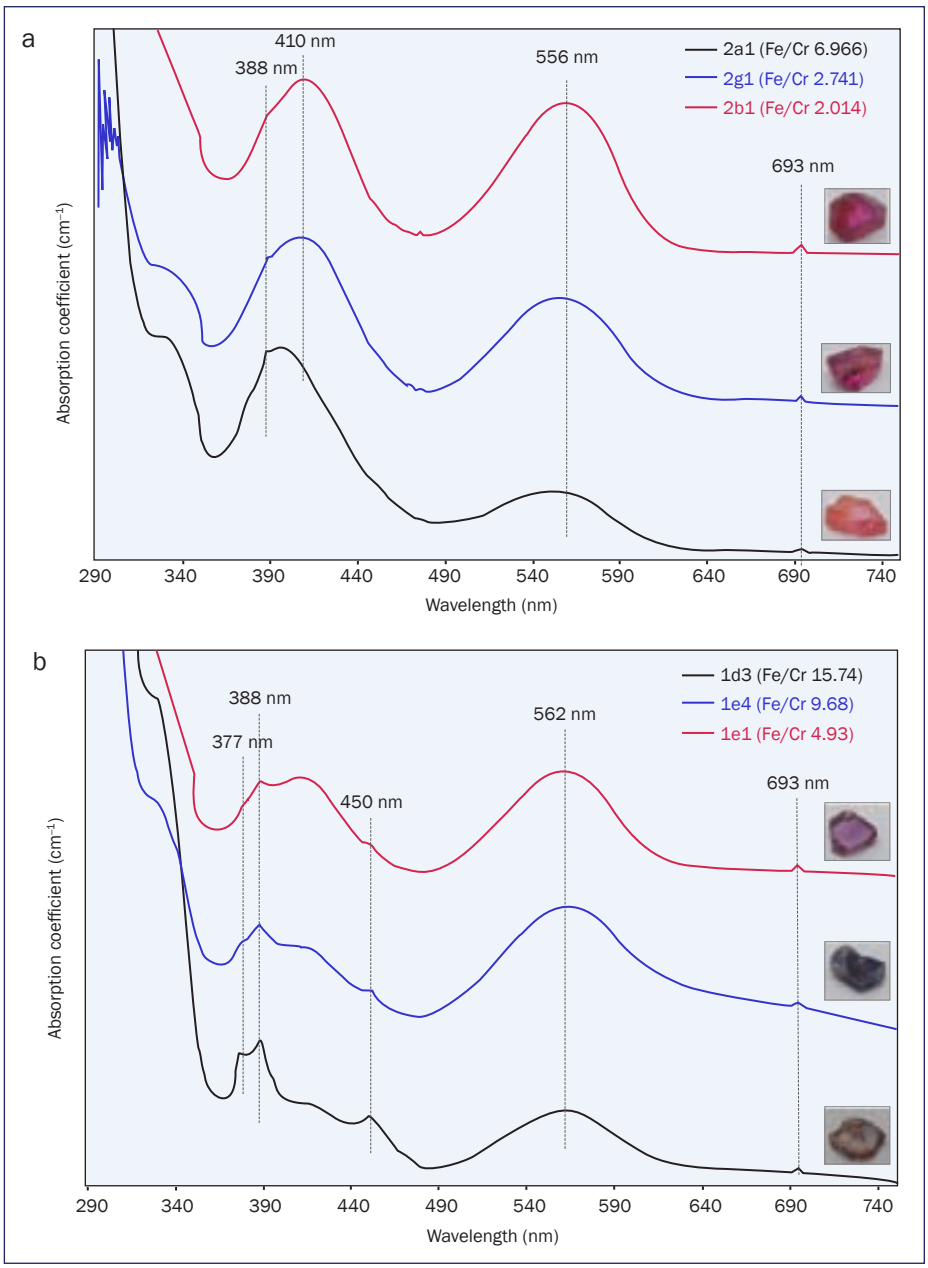

Figure 8a and b: Comparison of different UV-Vis absorption spectra of varyingly coloured Marosely corundum samples. The Fe/Cr ratios are indicated.

Pleochroism

In those stones in which pleochroism was observed, the ordinary ray (ω) colour was purplish red or bluish violet, whereas the extraordinary ray (ε) colour was mostly orangey red.

One sample (2a1) demonstrated considerable pleochroism. The ω colour was reddish pink, whilst that for the ε was orangey-pink (see *Figure 9*). The ordinary ray shows less absorption in the lower parts of the spectrum, but it is more absorbant above 410 nm and its 560 nm band features much more prominently than in the extraordinary ray. The shift in absorption peaks and bands (slightly to the right for ε) accounts for the pleochroism and the associated change in colour.

Infrared spectrometry

FTIR has in recent years gained more attention as a potentially useful method for detecting heat treatment of corundum, which is possibly identifiable by the presence of certain peaks (Smith, 1995; Perretti *et al.*, 1995; Balmer *et al.*, 2006; Beran and Rossman, 2006; AGTA, 2007).

All rough stones originally collected from the Marosely deposit and used within the context of this study have neither been heated nor treated. They have been simply cut and polished on two parallel sides. This excludes heat treatment as a possible cause of certain peaks discussed below. The possible influence of specimen orientation on spectral curves suggested by Smith (1995) and Volynets *et al.* (1972) was small or absent. All samples were measured in two directions (i.e. turned 90° for the second measurement), relative to the two parallel faces.

In *Figure 10*, FTIR spectra of pink and pale purple sapphires are shown. The peaks found at 2854 cm^{-1}, 2922 cm^{-1} and 2951 cm^{-1} correspond to oils and fats. This most probably corresponds to contamination from accidental handling or from the substance used for polishing the stones (Epoxide). CO_2 and H_2O bands can vary due to atmospheric fluctuations during and between each measurement and this is evident in the 2300–2600 cm^{-1} region when comparing *Figures 10* and *11*. A number of peaks were detected in the region 3600–3700 cm^{-1}. Some are triplets (3619 cm^{-1}, 3650 cm^{-1}, 3695 cm^{-1}), but more often pairs (3619 cm^{-1}, 3695 cm^{-1}) are present and probably indicate the presence of a type of mica or kaolinite (W. Balmer, pers. comm., 2007).

The frequency of occurrence of FTIR peaks in all samples is shown in *Table II*. The peak at or near 3080 cm^{-1} is not very common, indicating the scarcity of hydrous aluminium phases (see Smith *et al.*, 1995; Smith, 1995; Peretti *et al.*, 1995). However, neither diaspore nor boehmite

Table II: Frequency of FTIR peak occurrences in 35 Marosely corundums.

	3080 cm^{-1}	≈3160 cm^{-1}	3309 cm^{-1}	≈3390 cm^{-1}	3619 cm^{-1}	3650 cm^{-1}	3695 cm^{-1}
Number of samples presenting specific peak/band	5	7	27	6	14	5	13

could be clearly identified using Raman microprobe analysis.

Balmer *et al.* (2006) reported a peak at 3160 cm^{-1} in investigations on yellow sapphires, attributing this peak to goethite or an epidote group mineral. As neither could be identified in the seven samples using Raman microprobe analysis, the origin of this peak remains uncertain. Waite (2000) reported that the 3160 cm^{-1} peak was found in powder IR measurements from Tunduru, indicating that it is not due to surface contamination but a phase that is effectively present in corundum.

The peak at 3309 cm^{-1} was found in 27 of the 35 Marosely corundum specimens. Smith *et al.* (1995) believed this peak to be due to the breakdown of hydrous aluminium phases (i.e. diaspore, boehmite), but Balmer *et al.* (2006), in investigations on yellow sapphires, have argued that it may be caused by structurally bonded OH groups, in association with an excess of a certain trace element (see also Volynets *et al.*, 1972). Beran *et al.* (2006) also found that OH bands (e.g. 3309 cm^{-1}, 3160 cm^{-1}) were much more prominent in blue sapphires, hinting at OH associated with oxidation/reduction reactions involving iron. Tetravalent Ti may also play a role (Moon and Phillips, 1994). For the natural, untreated Marosely samples, there is no clear relation between the presence and size of a 3309 cm^{-1} peak and the colour of the crystal, and also its presence is not indicative of artificial heat treatment.

Other recorded peaks in the context of this study on thirty-five Marosely specimens were found at 2345 cm^{-1}, 2428 cm^{-1}, 2514 cm^{-1}, 2532 cm^{-1}, 2732 cm^{-1} and 3012 cm^{-1}.

Chemical composition

Semi-quantitative determinations of the oxides in Marosely corundums were obtained using EDXRF and the results are shown in *Table III*. Total iron is given as Fe_2O_3 since Fe^{2+} and Fe^{3+} cannot be differentiated using this method. Three samples (1b1, 1a5, 2f1) showed especially high Fe concentrations (0.5–0.8 wt%

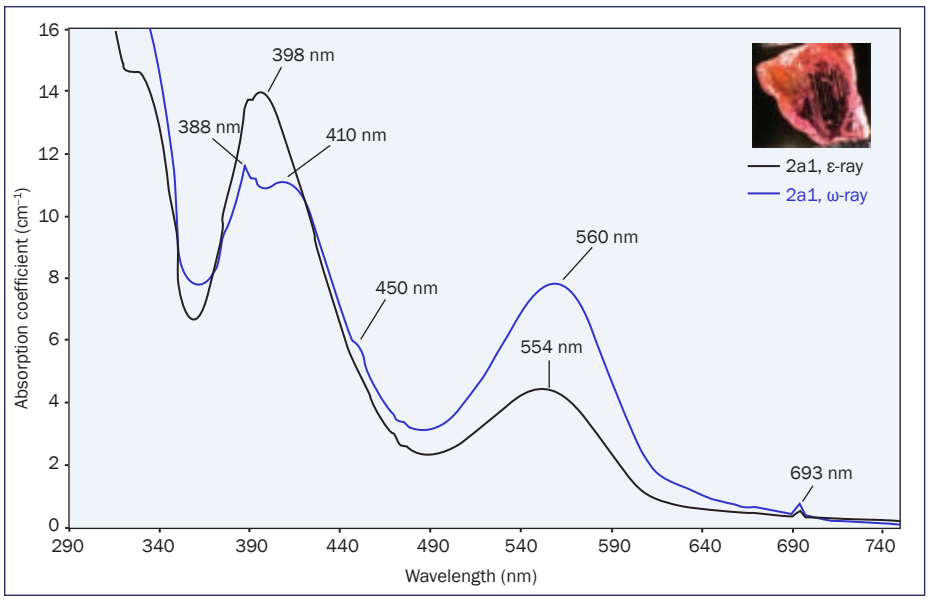

Figure 9: UV-Vis absorption spectra exemplifying pleochroism in sample 2a1.

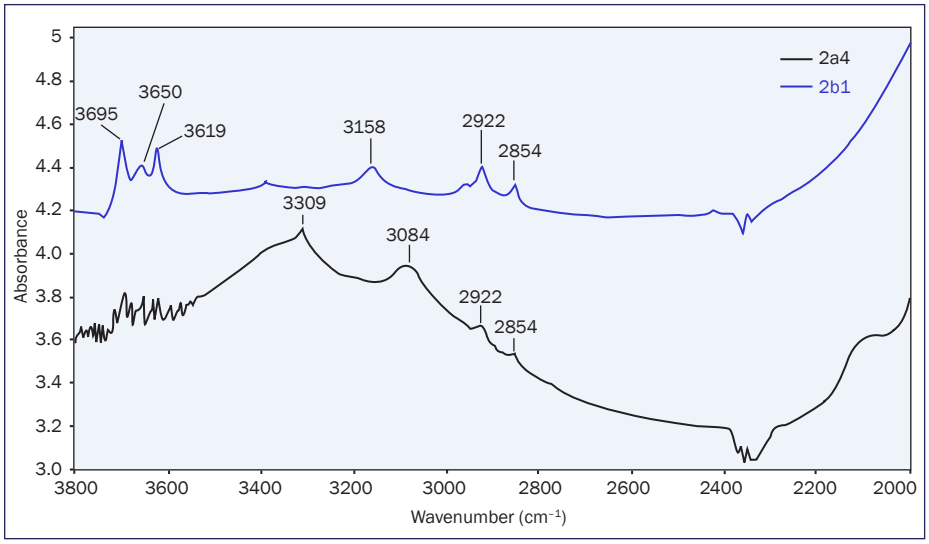

Figure 10: FTIR spectra of pink (2b1) and light purple (2a4) sapphires.

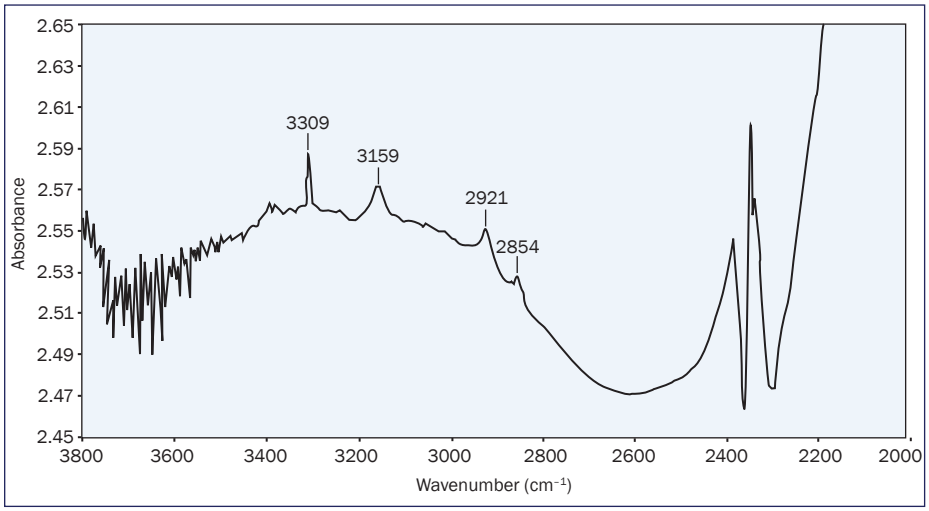

Figure 11: FTIR spectrum of a purple sapphire (2g3). 3159 cm^{-1} and 3309 cm^{-1} are clearly distinct peaks. The varying absorption character of the 2300–2400 cm^{-1} region is due to atmospheric fluctuations during measurements.

Table III: Compositional range and mean of 35 Marosely corundums determined using EDXRF.

	Concentration range (wt%)	Mean (wt%)	Mean error
Al_2O_3	98.3–99.9	99.39	±0.22
Fe_2O_3	0.086–0.822	0.29	±0.01
Cr_2O_3	0.022–0.19	0.08	±0.008
TiO_2	0.003–0.098	0.024	±0.002
V_2O_3	0–0.01	0.004	±0.0008
Ga_2O_3	0–0.006	0.003	±0.0003

Fe_2O_3). Chromium was the second most common trace element present, ranging from 0.022–0.19 wt%. It is highly influential in the coloration of corundum from this deposit. The mean concentration of TiO_2 is 0.024 wt%, with higher Ti concentrations generally corresponding to milkier and bluer stones.

The considerable variation of chemical components in different samples makes comparisons to other well-described deposits difficult. This variation is a reflection of the fact that most stones are chemical intermediates between ruby and sapphire.

Trace elements and LA-ICP-MS

The LA-ICP-MS equipment in Berne can be used to analyse areas only 160 µm in diameter, and thus obtain much more detailed data for elements present at trace or ultra-trace levels (Pettke, 2006) than one can using only EDXRF.

Seven corundum samples from Marosely were selected for closer examination. These varied in colour and in chemical composition. For each sample, at least three points were targeted and measured to ensure accuracy and reproducibility of results.

The stones were measured in two groups of samples:

- 1a2 (violetish blue corundum), 1a3 (blue corundum), 1d1 (light purple corundum)
- 1e2 (purple colour zoned corundum), 2a1 (pink corundum), 2a4 (violetish blue corundum), 2c1 (purple corundum)

and the results in parts per million (ppm) are shown in *Table IV*.

Recently, research has been conducted using LA-ICP-MS technology on a range of ultra-trace elements in the hope that quantitative results, measured with improving geochemical instrumentation, could deliver more insight into a stone's chemical history, and consequently facilitate origin determination (Hattendorf *et al.,* 2003; Saminpanya *et al.,* 2003; Rankin *et al.,* 2003; Abduriyim *et al.,* 2006). In the Marosely corundums, 40 elements were measured of which

Table IV: Trace element contents of seven Marosely corundums obtained using LA-ICP-MS analysis.

Sample	Group 1				Group 2				
	1a2	1a3	1d1	Standard rsd %	1e2	2a1	2a4	2c1	Standard rsd %
Colour	violetish blue	blue	pale purple		purple (colour-zoned)	pink	violetish blue	purple	
Be	bdl	0.137–0.151	bdl–0.113	0.90	bdl–0.133	bdl	0.097–0.126	bdl–0.029	1.80
Mg	19.42–51.08	106.3–111.4	36.13–61.22	0.70	23.28–26.17	32.87–45.78	150.3–160.7	33.65–53.44	2.10
K	4.03–6.05	0.888–3.06	2.91–7.47	3.70	0.739–2.92	5.37–7.05	5.40–5.89	2.59–7.89	2.50
Ti	40.83–73.00	175.6–184.2	53.07–219.3	0.60	34.13–484.6	23.34–28.01	254.5–263	52.42–74.75	1.10
V	12.77–16.93	23.48–23.95	24.06–33.08	0.50	17–34.5	18.28–20.08	33.3–33.4	21.74–22.02	0.70
Cr	365.8–466.2	232.2–246.4	844.1–1564	0.90	176.3–768.7	742.5–819	650–688.3	724.1–1028	0.80
Mn	0.101–0.124	0.116–0.155	0.108–0.132	0.80	0.078–0.124	0.155–0.163	0.201–0.209	0.101–0.186	0.40
Fe	2184–2285	1959–2037	2005–2778	2.20	1764–1889	1752–1898	3032–3117	1353–1415	2.20
Zn	2.41–3.37	1.92–2.54	4.25–10.92	1.10	1.13–2.18	2.91–3.79	3.94–8.38	2.95–8.88	4.60
Ga	30.58–34.84	80.41–81.90	30.05–36.67	0.50	42.10–59.52	52.24–54.17	56.21–60.89	19.62–21.03	0.40
Ge	0.106–0.116	0.127–0.172	0.084–0.179	0.60	0.169–0.99(*)	0.074–0.139	0.086–0.092	bdl–0.133	1.60
Nb	bdl– 0.011	0.002–0.008	0.006–0.228(*)	1.40	0.015–2.49 (*)	0.002–0.003	0.002–0.006	0.007–0.011	0.40
Sn	0.069–0.086	0.094–0.1	0.085–0.254	0.60	0.111–0.215	0.083–0.105	0.125–0.166	0.123–0.145	1.00
Ta	bdl	bdl	bdl	2.00	bdl–0.81(*)	bdl	bdl	0.003–0.006	1.60
Th	bdl	bdl	bdl–0.006	1.40	bdl–0.118(*)	0.001–0.006	bdl	0.002–0.005	1.00
U	bdl	0.002–0.043	bdl–0.006	0.70	bdl–0.006	0.001–0.004	0.001–0.003	0.008–0.051	1.20

NB: Ranges are in ppm over three or more spots. bdl corresponds to below detection limit. The error margin is expressed as relative standard deviation (rsd). (*): Denotes a maximum value which is too high and probably due to unidentified factors in the raw data.

a relevant 16 are listed in *Tables IV* and *V*. All elements apart from Fe and Cr were present at <1000 ppm. The chromophore element Cr ranges 232–1564 ppm. Titanium, is generally at lower concentrations, but reaches a maximum of 484 ppm in sample 1e2. Mg (19.4–161 ppm), K (0.74–7.9 ppm, most likely from inclusions in the crystal) and Zn (up to 10.9 ppm) concentrations are higher than the figures reported in the literature for other localities (e.g. Abduriyim *et al.*, 2006). There is no correlation between Mg concentration and crystal colour.

Of the only two measured actinides, thorium levels are very near the detection limit, but uranium is higher (maximum 0.051 ppm).

Example of colour and chemical zoning

All selected stones from Marosely range from red to blue, with most stones having an intermediate purple colour. This colour range is largely regulated by variations in Cr^{3+} and Ti^{4+} concentrations which can be demonstrated, using LA-ICP-MS technology, through point analysis in the different colour zones.

Three spots in sample 1e2 were ablated and measured (see *Figure 12*):

- 17sbc04 in a pale blue area
- 17sbc05 in a reddish purple area
- 17sbc06 in a dark blue area

The area around 17sbc06 is of a very dark blue colour and this correlated with the higher Ti values (484.6 ppm). The area around 17sbc 05 is of a reddish purple colour and also has the highest Cr values (768.7 ppm). Other element concentrations also showed variations and some may be due to micro-inclusions.

Discussion

The link between colour and the presence of specific chromophores has been confirmed using spectroscopy and chemical analysis. As Cr only exists as Cr^{3+} in corundum, and is not involved in intervalence charge transfer (IVCT) for coloration, the direct relationship between Cr^{3+} and red coloration is more evident and explicable than, for example, the

Table V: Trace element contents of three colour zones in sample 1e2 obtained using LA-ICP-MS analysis.

Spot	17sbc04	17sbc05	17sbc06	standard rsd %
Colour	pale blue	reddish purple	dark blue	
Be	bdl	0.086	0.133	1.80
Mg	26.17	24.49	23.28	2.10
K	0.739	2.71	2.92	2.50
Ti	64.57	34.13	484.6	1.10
V	17	34.5	26.08	0.70
Cr	594.6	768.7	176.3	0.80
Mn	0.124	0.116	0.078	0.40
Fe	1780	1889	1764	2.20
Zn	1.34	1.13	2.18	4.60
Ga	42.10	59.09	59.52	0.40
Ge	0.299	0.169	0.99 (*)	1.60
Nb	0.015	bdl	2.49 (*)	0.40
Sn	0.147	0.111	0.215	1.00
Ta	0.04	bdl	0.81 (*)	1.60
Th	bdl	bdl	0.118 (*)	1.00
U	0.006	bdl	0.005	1.20

NB: Concentrations in ppm. bdl corresponds to below detection limit. The error margin is expressed in relative standard deviation (rsd). (*): Denotes a maximum value, which is too high, and probably due to unidentified factors in the raw data.

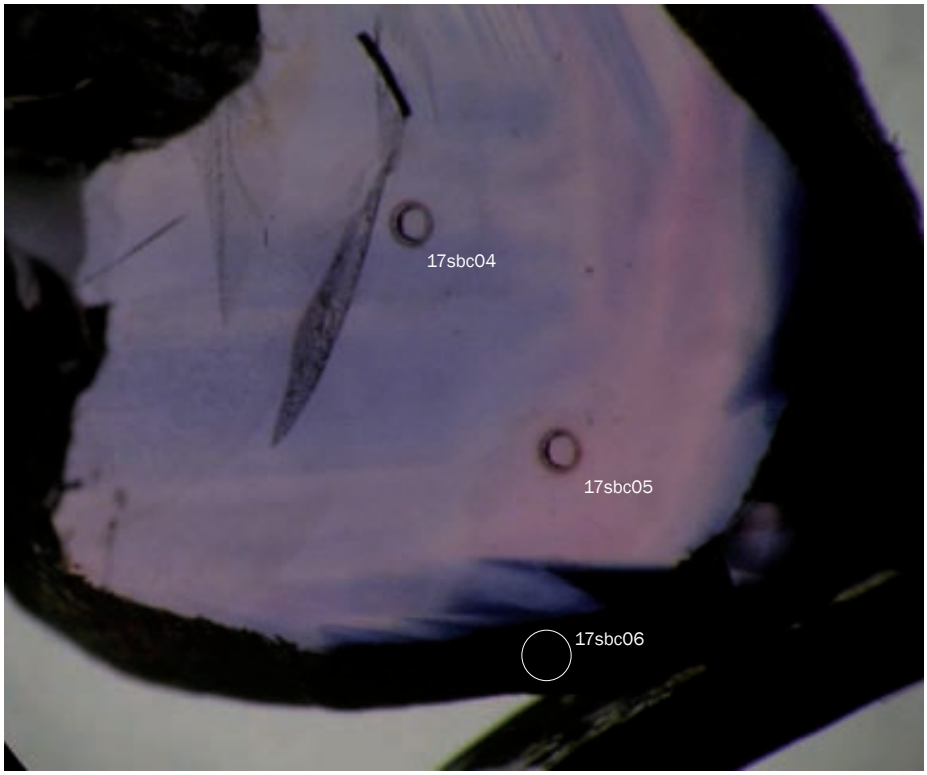

Figure 12: Magnified image of sample 1e2, showing three ablation craters caused by the laser during LA-ICP-MS measurements. The spots are about 0.16 mm across and barely visible to the naked eye.

concentration and role of Ti^{4+} or Fe^{2+}/Fe^{3+}. Generally, Cr and Ti regulate coloration. Fe is present in sufficient quantity and is not the limiting factor, whereas V showed only a very small effect on colour variations.

Apart from Al, Fe and Cr, all other elements in Marosely corundum are present at ultra-trace levels (i.e. <1000 ppm). The LA-ICP-MS method is very useful with the possibility of localized measurement of low quantities of elements. But further calibration and quantification of different deposit types and occurrences is still required to enlarge the dataset and fulfil the potential of LA-ICP-MS as a more potent tool in determining the origin of specific corundum samples.

Quantitative results for elements such as Fe, Cr, Ti, V and Ga have been plotted by many authors (Abduriyim *et al.,* 2006; Muhlmeister *et al.,* 1998; Sutherland *et al.,* 1998; Schwarz *et al.,* 2000) in order to illustrate and search for criteria to distinguish corundum of different origins, based on their chemistry. A commonly used diagram is a logarithmic plot of wt% values Cr_2O_3/Ga_2O_3 vs. Fe_2O_3/TiO_2. This approach has produced good results when attempting to discern two very different types of corundum; such as when comparing basaltic and non-basaltic sapphires. But considering that the Marosely deposit has been greatly altered by metasomatism and shows no great homogeneity with regard to the above-mentioned elements, this approach, as for many other deposits, is not effective.

The infrared spectral region between 3000 cm^{-1} and 4000 cm^{-1} shows absorption bands due to O-H bonds in the Marosely corundums. The nature of these is still widely debated and uncertain (Volynets *et al.,* 1972; Smith, 1995; Balmer *et al.,* 2006; AGTA, 2006; Beran *et al.,* 2006), but primarily, they are believed to be due to Al-hydroxide phases such as diaspore and boehmite. The three regions around 3160 cm^{-1}, 3309 cm^{-1} and 3600–3700 cm^{-1} are of most interest. The absence of a 3160 cm^{-1} peak does not imply heat treatment, since it is absent in 28 of the 35 untreated Marosely samples. The presence of a number of peaks in these stones (e.g. 3160 cm^{-1} and 3309 cm^{-1}) proves that these IR peaks can occur in natural corundum and step-wise heat treatment should be undertaken to understand their evolution and specific nature. The peaks found in some stones between 3600 and 3700 cm^{-1} are probably due to mica and/or kaolinite.

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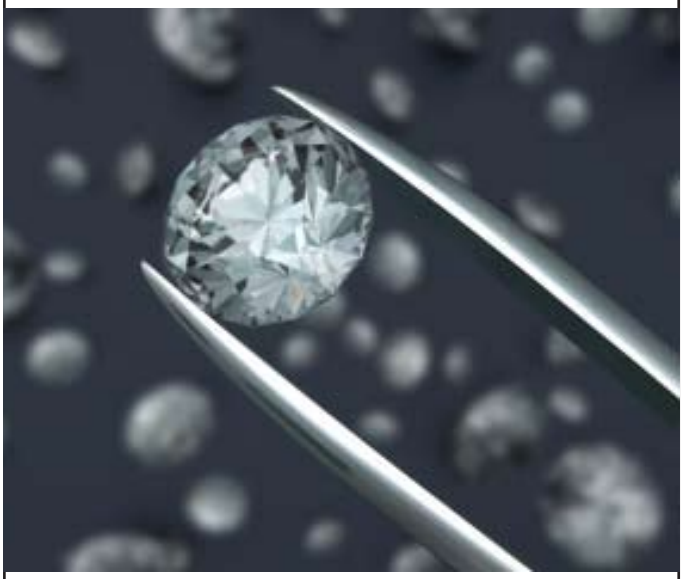

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Identification of dyed jadeite using visible reflection spectra

Yan Liu, Taijin Lu, Manjun Wang, Hua Chen, Meidong Shen, Jie Ke and Beili Zhang

Abstract: Burma jadeites are often dyed to improve their colour. Most dyed jadeites are identified using a microscope or a high resolution digital imaging system. However, when dye-related microscopic features are not clear, their visible reflection spectra can be used for identifying dyed jadeite rapidly and accurately. This visible spectral method can be used to identify both dyed-only jadeite (C type) and the dyed and impregnated jadeites (B+C type), which may otherwise be difficult to distinguish.

Introduction

Low-quality jadeites are often impregnated and/or dyed to improve their transparency and colour. Polymer-impregnated jadeite is classified as B type in the gem trade, and can be identified using FTIR spectroscopy (Fritsch *et al.*, 1992; Lu and Shigley, 2000).

Dyed jadeite is classified as C type, and is usually identified using visual imaging techniques with a microscope or a high resolution imaging system, since the dye is commonly visible in the pores or spaces between the inter-locking crystal fibres. Some dyed materials can be detected using X-ray fluorescence analysis. Hence, in most cases, 'C' jadeite can be easily identified by trained gemmologists. However, when high-quality colourless transparent jadeites with a fine-grained, compact and uniformly distributed texture of fibrous crystal are dyed, the characteristic microscopic features of the dyed jadeite may be unclear or hardly visible using traditional microscopy. Such pieces can be difficult to distinguish from jadeites of natural colour.

Natural green and lavender jadeites commonly display five characteristic spectral absorption lines in the visible wavelength range which are attributed to their Cr and Fe contents (see Webster, 1994; Nassau, 2001; Zhang, 2006). Although the absorption lines of some transparent jadeites can be recorded with a gemmological spectroscope (GIA, 1990; Zhang, 2006), they generally cannot be easily observed using a hand spectroscope.

Since the spectra of most jadeites cannot be measured using the commercially available visible spectrophotometers generally used in gemmological laboratories due to their size, shape, lack of transparency and other factors, we report here a method to identify dyed jadeite by measuring the visible reflection spectra using a TrueColor spectrometer with dual integrating spheres. By combining reflection spectra in the visible range with IR absorption spectra, dyed-only and impregnated and dyed jadeites can be accurately identified.

Measurement and samples

Although jadeites range from translucent to opaque, only a small proportion of jadeites are transparent enough to yield transmission spectra. But reflection spectra obtained from translucent or opaque stones can be measured both for colour grading by a colorimetric method and for the spectroscopic study of jadeites.

Reflection spectra of various jadeites were obtained using a new type of visible reflection spectrometer (TrueColor Spectrometer) developed by one author (Y.L.) for spectral measurement and colour grading of coloured diamonds and gemstones. This spectrometer has dual integrating spheres, one for providing illumination and spectral measurement and the other for hosting the sample, as shown in *Figure 1*. A collimating lens is installed in the measurement integrating sphere. The lens is focused on the aperture between the measurement and the sample integrating spheres. The reflected light from a measured jadeite with the transmitted light reflected back by the sample integrating sphere is collected by the lens, and then sent to the spectrometer by an optical fibre cable. A diffraction grating separates the light into a spectrum on a CCD array within the spectrometer. The computer receives the electronic signals generated by the CCD and converts them to a reflection spectrum, and then calculates colour and provides colour grades.

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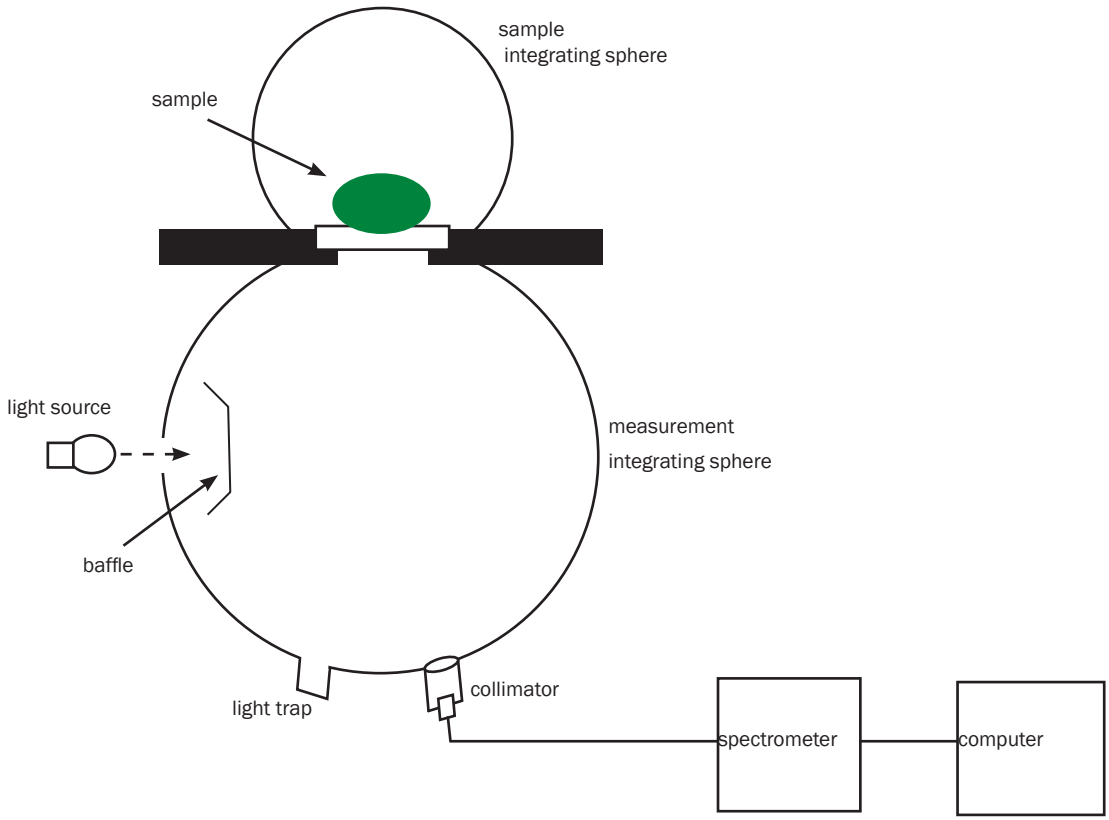

Figure 1: Schematic diagram of the TrueColor reflection spectrometer.

The sample integrating sphere provides an environment similar to that for visual observation of jadeite in the trade. If a jadeite is transparent, a portion of transmitted light is reflected back by the sample integrating sphere and enters the measurement process. Consequently, the reflection spectrum of a translucent jadeite is significantly higher than that measured without an integrating sphere. More importantly, for the transparent jadeites, the measured reflection spectrum is similar to that observed on a white background in the trade.

Figure 2: Three B+C type jadeite slabs typical of many hundreds examined.

Although the visible wavelength ranges only from 400 to 700 nm, the wavelength range of the spectrometer has been established at 380 to 760 nm to aim for more accurate colour measurement and grading. The extended wavelength range also makes it possible to measure the spectral features of gemstones and coloured diamonds in the 380 to 400 nm and 700 to 760 nm ranges for detailed study of such centres as GR1 at 741 nm in green diamonds.

Before taking a measurement, the spectrometer is calibrated by recording three spectra: that of a standard white tile, a standard black tile, and one without a tile. The procedure for measuring the reflection spectrum of jadeites is simple and quick: a jadeite is placed on the aperture between the measurement and sample integrating spheres, the sample integrating sphere is then fitted on the top, the measurement button on the screen of the computer is clicked, and a reflection spectrum will be collected and displayed on the screen. The whole measurement process takes about one

Figure 4: A carved Buddha pendant of B+C type jadeite.

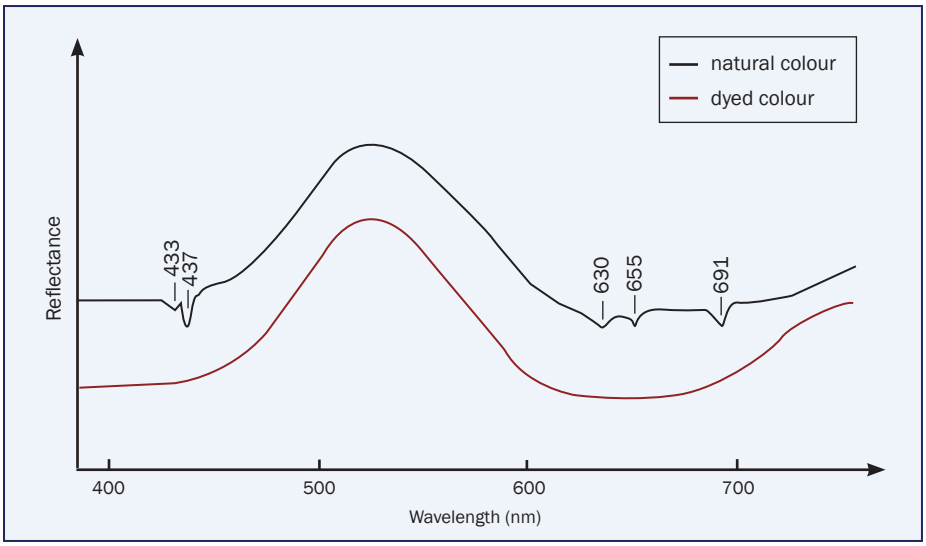

Figure 3: Reflection spectra of a typical natural green jadeite and a dyed green jadeite.

minute. For many (opaque) jadeites where only reflection is measured, the sample integrating sphere is not necessary, and any size of specimen can be measured as long as it can be put on the spectrometer.

Many hundreds of natural, impregnated, dyed-only, and impregnated and dyed jadeites have been examined. Most samples have been green, but a few were lavender. A natural colourless jadeite slice was measured as a reference spectrum. Several jadeite slabs of B+C type with different colours (obtained from a jadeite factory in Guangdong province, China) were examined in detail using non-destructive imaging and spectroscopic techniques at the National Gemstone Testing Center, China (see *Figure 2* for typical samples).

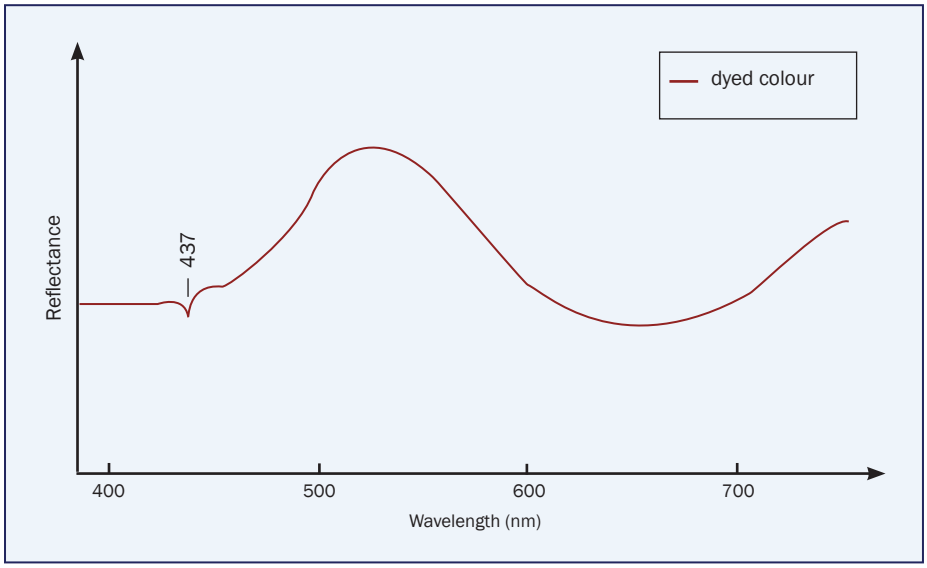

Figure 5: The reflection spectrum of a B+C type green jadeite with a weak 437 nm absorption line.

Results

Figure 3 shows typical reflection spectra in the visible wavelength range of naturally-coloured green jadeite and dyed green jadeite. That of the natural jadeite shows the characteristic absorption lines at 433 nm, 437 nm, 630 nm, 655 nm and 691 nm. The strengths of these five lines change significantly depending on the nature and saturation of the colour, but normally the 437 nm line is the strongest. The reflection spectra of many natural jadeites show only the absorption line at 437 nm, with the other four lines being very weak or invisible.

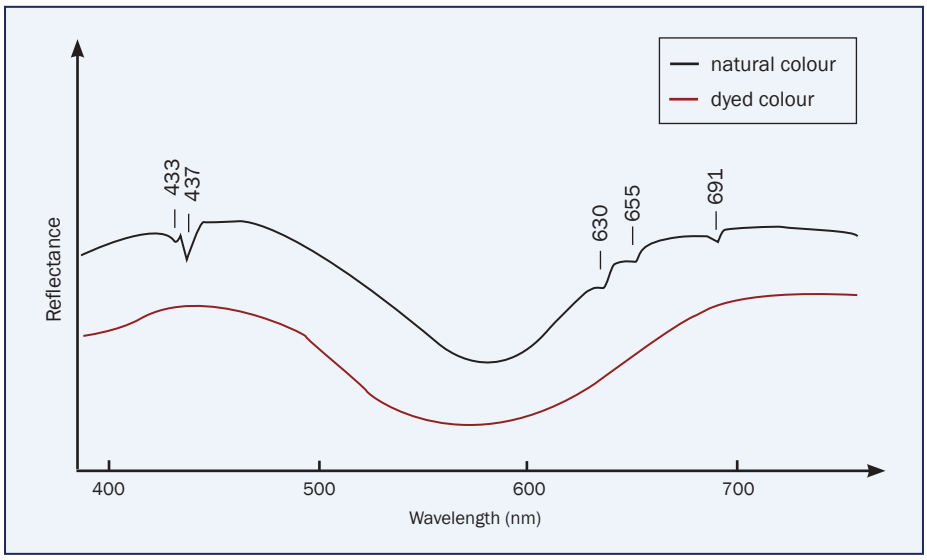

Figure 6: Reflection spectra of natural lavender jadeite and dyed lavender jadeite.

Although the reflection spectrum of dyed green jadeite does not have the five sharp absorption lines (see *Figure 3*), its basic shape is similar to that of the naturally coloured green jadeite, thus appearing similar in colour. Indeed, the two greens cannot be distinguished using only the naked eye.

Figure 4 shows a B+C type of green jadeite Buddha pendant, and its reflection spectrum is the same as the dotted line spectrum shown in *Figure 3*. This is typical of most B+C type green jadeites.

Although only a few of 'B+C' jadeites with an enhanced green colour due to dye treatment show a weak 437 nm absorption line *(Figure 5)*, almost all show a relatively strong and broad band at longer wavelengths near 680 nm. In other words, a weak 437 nm absorption line together with a broad absorption band and a long wavelength is a diagnostic feature of a B+C type jadeite. The long wavelength transmittance bands visible in *Figure 5* are probably the reason that such dyed jadeite appears red under the Chelsea Colour filter.

The spectrum of natural colourless jadeite lacks any sharp absorption lines, so when such material is dyed, it too may lack sharp absorption lines and appear similar to the dotted line spectrum in *Figure 3*.

The five characteristic absorption lines in the reflection spectra of naturally coloured green jadeites are also present in naturally coloured lavender jadeites (see *Figure 6*). The dotted line in *Figure 6* shows the typical spectrum with similar broad absorption bands but without the five sharp spectral lines.

Naturally coloured green jadeites from Burma typically show five absorption lines at 433 nm, 437 nm, 630 nm, 655 nm and 691 nm in their reflection spectra as shown in *Figure 3*.

In contrast, the reflection spectra of most dyed green jadeites do not show these five absorption lines and this absence is an indication that the measured jadeite has been dyed, particularly for those jadeites with vivid green colours. The reflection spectra of both dyed only (C type) and impregnated and dyed (B+C type) jadeites can be identified by this method. Since the 437 nm absorption line is the strongest of the five lines, it may be detected in some of the dyed vivid green jadeites, which suggests that the starting material was a low grade pale green jadeite. The reflection spectra of such dyed green jadeites also show a relatively strong broad absorption band above about 680 nm, which is related to the dye. The existence of both the weak 437 nm absorption line and this broad band at the longer wavelength in vivid green jadeites indicate that they are low saturation jadeites that have been dyed. In fact, any vivid green jadeite with only a weak 437 nm absorption line suggests that it has been dyed, since natural vivid green jadeites should show all five absorption lines.

Identification of some dyed-only green jadeites without clearly visual microscopic features can be a challenge using only traditional microscopic observation and FTIR techniques, but measurement of their reflection spectra by the TrueColor spectrometer with dual integrating spheres can provide a rapid and effective technique for their identification and distinction from natural jadeite.

The reflection spectra of naturally coloured lavender jadeites also show the five narrow absorption lines characteristic of green jadeite, whereas dyed lavender jadeites only show broad absorption bands in their reflection spectra.

Discussion and conclusions

Jadeites are translucent to opaque, and not sufficiently transparent for transmittance spectra to be routinely obtained by the kind of UV-Visible spectrophotometer used in most gemmological laboratories. To study the spectral properties and to measure the colours of jadeites, we have to measure the reflection spectra.

Acknowledgement

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Jadeite jade from Myanmar: its texture and gemmological implications

Guanghai Shi, Xia Wang, Bingbing Chu and Wenyuan Cui

Abstract: Jadeitites, rocks consisting predominantly of jadeite, are the source of the precious stone known as feitsui by the Chinese. Jadeitites vary greatly in transparency, compactness and toughness due to their diverse textures and microstructures. The authors consider these textures in two major groups: (i) primary and (ii) deformed and recrystallized. In the first group, the rocks are coarse-grained with mosaic, granitoid or radial textures and some crystals are chemically zoned; such rocks can be porous. In the second group are jadeitites of finer grain size, generally formed by metamorphism of the coarse-grained jadeitites, with textures showing variable preferred orientation of crystals, mechanical twinning, shear zones, development of sub-grains, serrated high-angle sutured grain boundaries, or a 'foam' pattern. Texture, compactness and colour variation has generated a large number of trade names. The most precious jadeite jades are described as 'icy' or 'glassy', which relates to the quality of their transparency. Studies of jadeite textures have gemmological applications both in identifying and grading rough material and in the design, fashioning and grading of manufactured articles. Geologically, textures provide evidence of the formation and metamorphism of the whole range of Myanma jadeitites and it is probable that these processes are linked to the major Sagaing strike-slip faults.

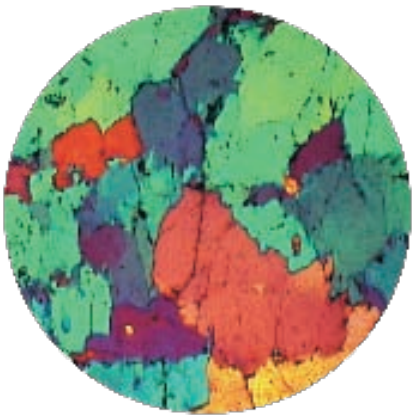

Keywords: classification, gem trade terminology, jadeite, metamorphic textures, Myanmar, petrography

Introduction

The jade which dominantly consists of jadeite crystal aggregates has over the years attracted several names in different countries. The Chinese call jade feitsui (or feicui), which means jadeite jade, with no implications as to its source (e.g., Ouyang, 2003). Westerners simply call it jadeite (e.g., Damour, 1881), which sometimes causes confusion, since jadeite is also the mineral name for sodium-aluminium silicates of the pyroxene group. The Burmese use the term Myanma jade to designate jadeite jade from the Jade Tract in Myanmar (e.g., Nyan Thin, 2002). According to current gemmological opinion in China, jade is defined as a natural polycrystalline aggregate with fine compact texture, high toughness, good lustre and a medium to high degree of translucency. Both feitsui and medium- to low-quality jadeite rock are, petrologically, jadeitite, composed mainly of jadeite and other sodic- and sodic-calcic clinopyroxenes such as omphacite and kosmochlor. Jadeitite is a high pressure metamorphic rock deposited from jadeitic fluids (Ouyang, 1984; Harlow and Olds, 1987; Hughes et al., 2000; Harlow and Sorensen, 2005; Shi et al., 2003, 2005a, 2008; Yi *et al.,* 2006). However, not all jadeitites have the qualities required of feitsui, because they may have coarse-grained textures which are variably porous and therefore lack the coherence which is desirable for carving materials. Jadeitite which has the qualities of precious jade is rarely found even in the best deposits in Myanmar.

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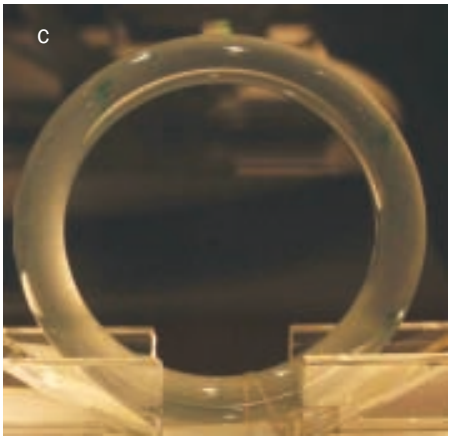

Figure 1: The glassy feitsui (green and colourless jadeite jades) from Myanmar. (a) A necklace of 15 exceptionally bright emerald green oval cabochons; (b) a ring with an imperial green oval cabochon; (c) a colourless bangle.

Having been mined for more than 300 years, the Myanma jadeite areas, called the Myanmar Jade Tract, still produce the emerald green imperial jadeite jade which is fashioned as cabochons for rings, bracelets, pendants and other jewellery pieces *(Figure 1)*, but on precious jadeite, research has so far been incomplete. Previous mineralogical and gemmological studies on jadeites have dealt with mineral and chemical compositions, fluid inclusions, and with which agents cause colour in jadeite (Gübelin, 1965a,b; Ouyang, 1984; Harder, 1995; Htein Win and Naing Aye Myo, 1994, 1995; Hughes *et al.,* 2000; Johnson and Harlow, 1999; Shi et al., 2003, 2005a, b, 2008). However, there has been little understanding about the primary textures of the Myanma jadeite materials, and much less about their deformed textures or microstructures, and the relationship of both kinds of texture to jade qualities. Also the process of transformation of coarse-grained to fine, compact jadeitite has not been explained. Although Ouyang (2000) and Shi et al.,(2004) have reported on some textures of Myanma jadeitites, the focus has been on their grain sizes, metasomatic textures and brittle deformation, without giving detailed descriptions of the deformed and recrystallized textures and gemmological applications. In this investigation, we present the primary and deformed textures of white jadeite materials (including icy to glassy jades) from Myanmar, attempt to establish correlations between textural features and jade qualities, and discuss the gemmological applications and implications.

Geological setting

Myanma jadeitites occur within the N–S striking Hpakan ophiolite complex which is about 50 km long and 5–10 km wide, situated in the east of the Indo-Myanmar Range and north of the Central Myanmar Basin. The ophiolites straddle a fault which is possibly a branch of the north Sagaing Fault *(Figure 2)*. Geographically, the Indo-Myanmar Range is flanked on the east by the Central Myanmar Basin, and the national border between Myanmar and India generally follows the high points of the Range. Geologically, along the eastern boundary of the Range is a line of discontinuous ophiolite and ophiolite-derived blocks. In this terrain accumulation and deformation of rocks have taken place within a zone where oceanic crust of the Indian plate has been subducted beneath the Burmese plate with intra-oceanic features (Shi *et al.,* 2009). Based on ages of zircon inclusions, this subduction and formation of some jadeite probably took place in Upper Jurassic times (Shi *et al.,* 2008). The Central Myanmar Basin (16ºN–25ºN, 94ºE–97ºE), consists of low land between the Indo-Myanmar Range and the China-Myanmar high land. The Sagaing fault is a major strike-slip dextral or right-lateral continental fault that extends over 1200 km and connects to the Andaman spreading centre at its southern end. It has been interpreted by some authors as a plate boundary between India and Indochina (LeDain *et al.,* 1984) and accommodated nearly 60 % of the relative

motion between the two plates. Two low-angle branch faults connect directly to the main fault at its northern end, and a sub-parallel fault to the west is also a location for jadeitites (Bertrand and Rangin, 2003; Morley, 2004).

The Hpakant ophiolite complex consists mainly of serpentinized peridotite, chromite-bearing peridotite, metagabbro and metabasalt. Also within the complex are jadeitite veins or blocks, usually separated by sodic- and sodic-calcic-amphibolites, some of which can contain the rare pyroxenes kosmochlor and omphacite (Ouyang, 1984; Harlow and Olds, 1987; Hughes *et al.,* 2000; Shi *et al.,* 2003, 2005a; Yi *et al.,* 2006). The jadeitite veins, e.g. the one at the Maw Sit mine near the north end of the Jade Tract, are almost vertical, strike N–S, are 1.5 to 5 m wide, and 5 to 100 m long. These veins are crosscut in some places by thin veins of late-stage albitite, which are commonly less than 5 mm wide. Adjacent to the peridotites, there are high-pressure rocks such as phengite-bearing glaucophane schists, stilpnomelane-bearing quartzites, and amphibolite facies rocks such as garnet-bearing amphibolites and diopside-bearing marbles (Shi *et al.,* 2001).

Primary and deformed textures

A few jadeitites retain an undeformed massive structure, with euhedral to subhedral jadeite prismatic crystals which can exceed 20 mm in length. Most jadeitites, however, have been deformed and are fine-grained. Accordingly, the jadeitite samples are described in two textural groups: 1) with primary texture and 2) with deformed, recrystallized texture.

The primary textures

Primary texture is defined as that of jadeitite which has formed through deposition from a jadeitic fluid within its host peridotite/serpentine and has undergone little or no ductile deformation. These jadeitites are coarse-grained and to variable degrees, porous; their quality is not considered as precious (see *Figure 3*) but they can be utilized as B-jade materials

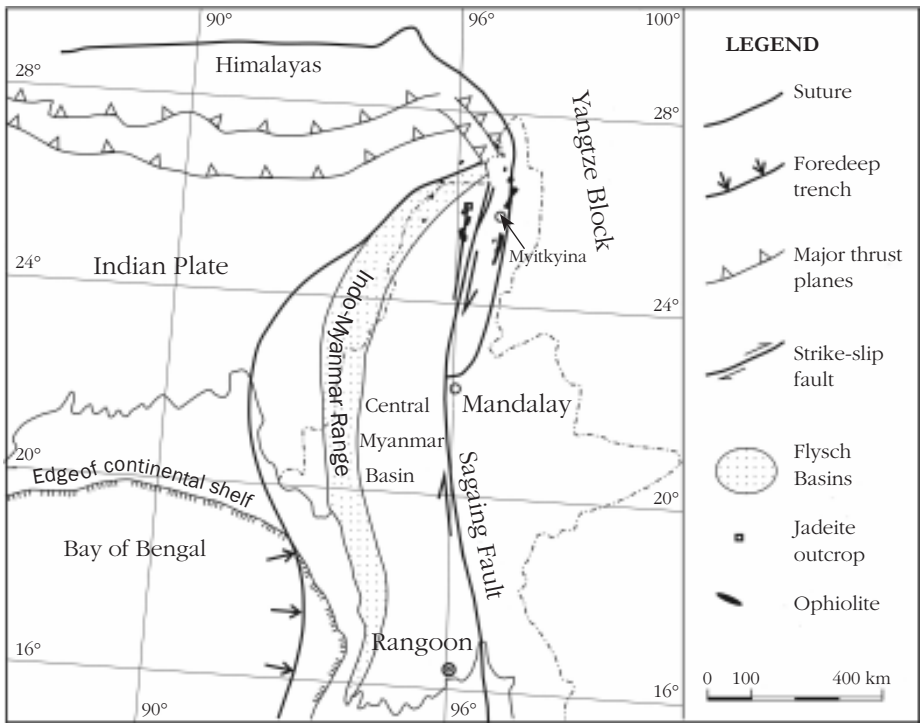

Figure 2: Simplified tectonic map of northern Myanmar. The jadeite deposits straddle a fault adjacent to the northern end of the Sagaing Fault and which is possibly a branch of it. The Fault is active and interpreted by some geologists as a plate boundary between India and Indochina accommodating nearly 60 % of the relative motion between the two plates (modified after Morley, 2004; Chhibber, 1934).

Materials and methods

From more than 150 samples collected in the Myanma jadeite area, we selected 20 white jadeitites of which four were coarse-grained with granite-like appearance, and 16 were fine-grained and chosen to represent a range of transparencies from translucent to icy and glassy semi-transparency. All samples were prepared as polished thin sections. Microscopes at the Institute of Geology and Geophysics, Chinese Academy of Sciences (IGGCAS) and at the Ruhr-University Bochum (RUB), Germany, were used for extensive textural and microstructural observations on each section and to obtain representative photomicrographs taken in polarized and cross-polarized light. Cathodoluminescene (CL) imaging was also performed on the thin sections and representative images of the undeformed and deformed jadeite materials were acquired.

The chemical compositions of the undeformed and deformed jadeites were obtained using electron probe microanalysis (EPMA) using a CAMECA-SX-51 at the IGGCAS with an operating voltage of 15 kV and a beam current of 12 nA. The microprobe standards comprise synthetic and natural jadeite, chromite, pyrope, amphiboles, feldspar and clinopyroxenes. Backscattered electron (BSE) images, which indicate the spatial distribution of the different elements, were also acquired. All samples were determined to consist of jadeite with more than 90 % of the jadeite molecule (Jd).

The orientations of the jadeite crystals were determined using electron backscatter diffraction (EBSD). The EBSD patterns and the orientation contrast images (OCI) were acquired using a scanning electron microscope (SEM) LEO 1530 at the RUB with field emission gun and forescatter detector, operated at an accelerating voltage of 25 kV, with the section tilted over 70º and a working distance of 25 mm. The EBSD patterns were indexed with the hkl software 'CHANNEL 4'.

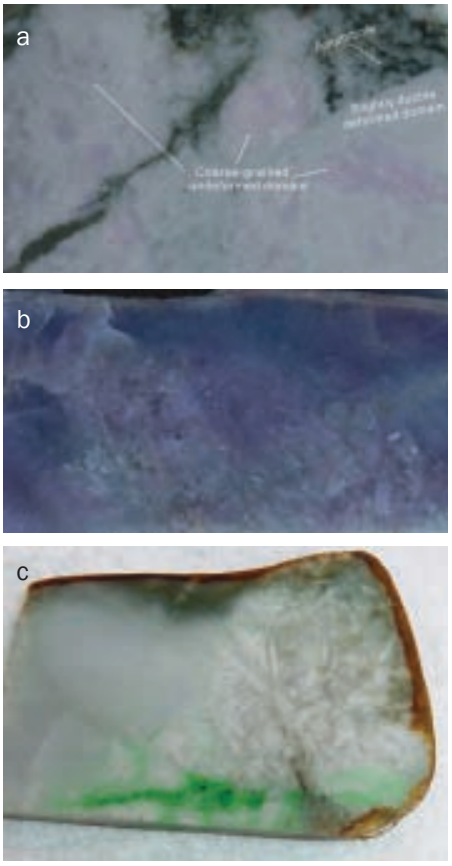

Figure 3: Cut jadeitite samples showing undeformed, coarse-grained jadeitite domains observed within and/or adjacent to slightly deformed jadeite aggregates. Sample widths (a) 30 cm, (b) 10 cm and (c) 12 cm.

and subject to acid-bleaching and resin-filling. The primary textures consist of zoned semihedral to euhedral jadeite crystals in mosaic and granitoid patterns.

Jadeite crystals in the mosaic and granitoid textures *(Figure 4a)* can be more than 3 cm long, and can be relatively even-grained (homogranular) or porphyritic. Most crystals are prism-shaped with flat contacts and random orientation. In some rocks, the crystals are in radial clusters. These jadeite crystals probably formed simultaneously with mosaic or granitoid textures. Mostly crystals have zones with slightly different extinction directions under cross-polarized light *(Figure 4b)* and this indicates some chemical variation. Cathodoluminescence imaging is even more effective in detecting such variation and can show distinct oscillatory zoning in crystals with no obvious optical variation: *Figure 4c* shows crystals with vivid blue, pink and yellow zones (see also Harlow, 1994; Sorensen et al., 2006). BSE images of the same area display almost the same oscillatory zoning patterns as the CL images, and are indicative of compositional zoning. With the aid of EPMA, we found that jadeites within the dark CL zones are very pure with more than 98 mol. % Jd, whereas 5-10 mol. % Di (diopside) is present in the bright CL zones (see details in Shi *et al.,* 2005b).

Due to these zonal differences in chemical composition, each jadeite crystal will have zones with variable refractive indices, thus producing optical interfaces or distortion between adjacent zones when light transmits. Therefore, the transparency of a zoned jadeite crystal will be less than that of an unzoned one. Crystals in primary textured jadeitites also have distinct cleavages and fluid inclusions (Shi *et al.,* 2000, 2005b) which will decrease their transparency further.

The deformed, recrystallized textures

These are the textures of jadeitites which have experienced shear stress, tectonic movement, apparent ductile deformation and recrystallization of their jadeite grains. The boundaries between the primary and recrystallized textures can be seen by careful examination of some hand specimens *(Figure 3)*, but they are better seen and more distinct under the microscope. As shown in *Figure 5*, primary jadeitite with one large crystal in excess of

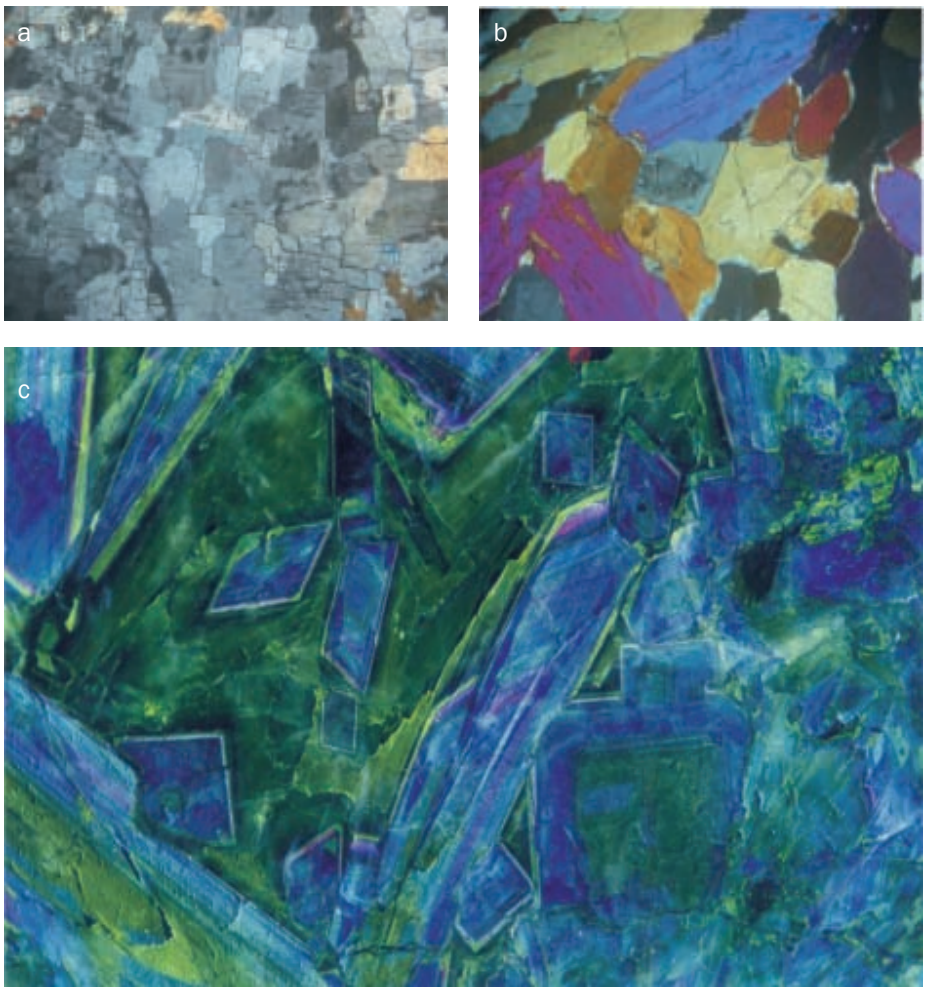

Figure 4: Representative primary textures of undeformed Myanma jadeitites: (a) Thin section photomicrograph of mosaic or granoblastic texture consisting of randomly orientated jadeite crystals with clearly visible cleavage planes (cross-polarized light, section width 2.5 mm); (b) Jadeite crystals intergrown in a hypidiomorphic texture. The pale yellow crystal near the centre has a patchy darker rim representing some compositional zoning (thin section cross-polarized light, section width 2.5 mm); (c) Complex rhythmical zoning patterns in jadeite crystals made apparent by cathodoluminescence imaging (section width 1.25 mm).

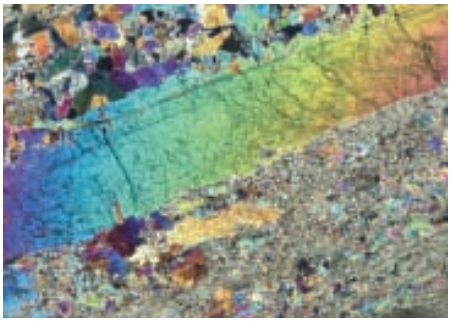

Figure 5: A 20 mm wide section showing the junction between coarse undeformed jadeitite (middle and upper left) and fine deformed jadeite domains (lower right). The original undeformed jadeitite evidently had a porphyritic texture.

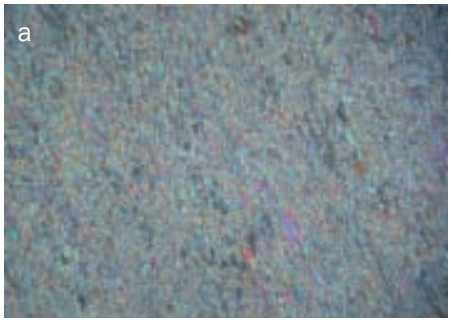

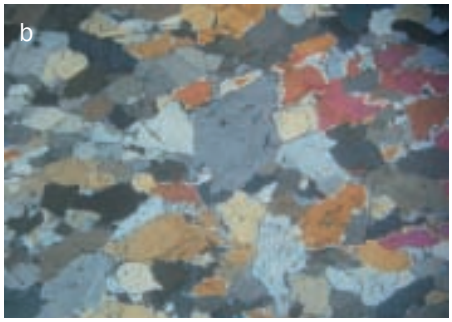

Figure 6: Thin sections showing semi-orientated to preferred orientated jadeite crystals in feitsui from Myanmar: (a) Fine-grained, orientated and compact texture of a near-glassy jade (section width 2.5 mm, cross-polarized light); (b) Semi-orientated grains of intermediate size form a translucent jade (section width 2.5 mm, cross-polarized light).

20 mm, is in contact with microcrystalline jadeite containing fragments of primary texture, suggesting that deformation and recrystallization occurred heterogeneously at the expense of the primary texture. With extensive deformation and recrystallization, the jadeites become nearly homogeneous in chemical composition, containing 95-98 mol. % Jd and display no compositional zoning (see detail in Shi *et al.,* 2005b). A number of sub-types of the deformed and recrystallized textures can be recognized, probably related to the deformation mechanism, and these are: textures with different degrees of preferred orientation of elongated crystals; sub-grain; micro-shear; sutured grain boundaries; mechanical twinning; and recovery texture. These are described below.

Textures with preferred orientation

Myanma jadeitites are composed dominantly of elongate jadeite crystals with length/width ratios (aspect ratios) ranging from 2.0 to 20; some are even fibrous. The grain sizes in this sub-group vary greatly, from thin fibres several micrometres wide to prisms more than 20 mm long and several mm wide. Microscope observations and EBSD results show that most of the jadeite aggregates have both shape-preferred orientations (SPO) and crystallographically preferred orientations (CPO). No obvious chemical zoning in jadeite crystals has been found in this texture. Sections of near-glassy jadeite jade *(Figure 6a)* reveal that their textures consist of very tiny jadeite grains with pronounced SPO and CPO, and indistinct grain boundaries; whereas translucent jadeitites with an exterior texture reminiscent of cooked sticky rice, have textures with larger grains of lower aspect ratio, more distinct grain boundaries and a lower degree of preferred orientation *(Figure 6b).* Taking into account previous work on this topic (Ouyang, 2003; Shi *et al.,* 2004), it is concluded that the sizes, shapes, crystallographic orientations and features of the grain boundaries of the jadeite crystals are closely correlated to a jade's transparency; the finer and more preferred the orientation (with a homogeneous extinction direction), and the more indistinct the grain boundaries are, the better the transparency.

Sub-grain

An example of Myanma jadeitite showing development of sub-grain texture is shown in *Figure 7.* Lines of tiny sub-grains are visible across some of the larger jadeite crystals and mark lines of shear stress and recrystallization. In *Figure 7* areas of similar interference colour but consisting of a number of grains represent the original larger jadeite crystals. Most of the boundaries among sub-grains are distinct, but a few are still indistinct. These sub-grains are almost homogranular and tightly interlocking. If there is continued or resumed stress, there can be further generation of sub-grains and reduction in grain size to less than 0.05 mm. When shearing and recrystallization has been prolonged and thorough, textures resembling that in *Figure 6a* are developed. Generation of sub-grains is the main way of reducing grain size in a rock. This takes place by means of dislocation of boundaries and change in the angular mismatch between the two sub-grains. Normally 10–15 degrees misorientation among the newly-generated grains is commonly quoted (e.g., Hirth and Tullis, 1992).

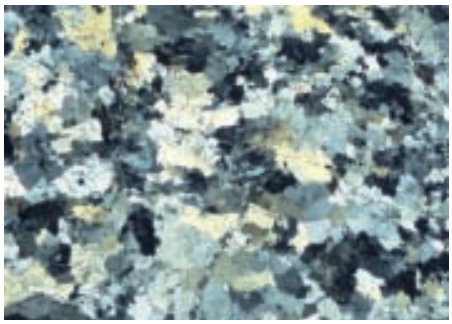

Figure 7: Photomicrograph in cross-polarized light of very compact sub-grain aggregate in Myanma jadeite (section width 10 mm), in which some precursor grains show sutured boundaries.

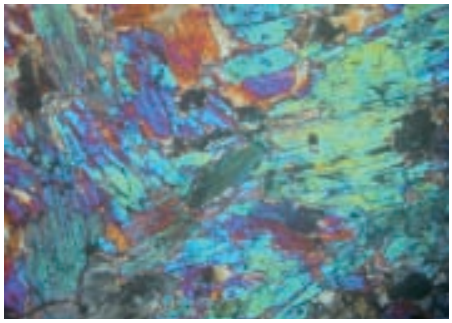

Figure 8: Photomicrograph showing medium to coarse jadeite crystals with cleavage and polysynthetic mechanical twinning in Myanma jadeitite. The presence of twinning is revealed by the parallel bands of alternating interference colours; some are slightly bent. (Section width 2.5 mm, cross-polarized light).

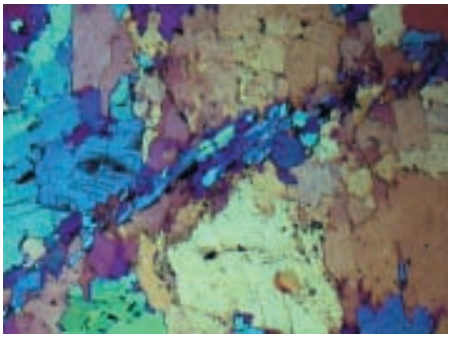

Figure 9: Section of medium to coarse-grained jadeite crossed by a zone of shearing which is marked by smaller more orientated crystals. Section 2 mm across, cross-polarized light with colours enhanced with inserted gypsum plate.

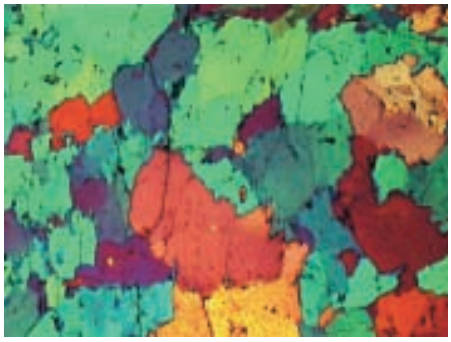

Figure 10: Thin section showing jadeite crystals with serrated high-angle sutured boundaries. Section 2 mm across, cross-polarized light with colours enhanced with inserted gypsum plate.

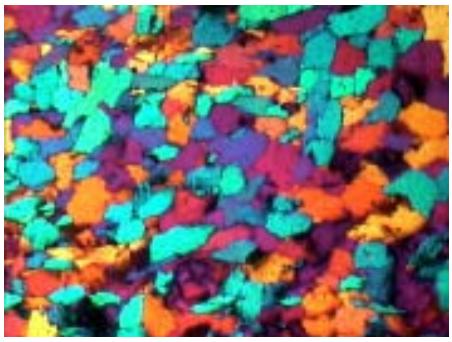

Figure 11: Thin section of jadeitite with a recovery texture resembling foam and showing a number of grains in the aggregate with triple junctions close to 120°. Section 2 mm across, cross-polarized light with colours enhanced by inserted gypsum plate.

Mechanical twinning

Generation of mechanical twinning is a stage in the process of grain size reduction; it commonly occurs in calcite, corundum, diamond and feldspar, but seldom in jadeite. So far, natural mechanical jadeite twinning has only been found in ultra-high pressure rocks and is regarded as the result of syn-seismic loading beneath the brittle-plastic transition conditions for such rocks (Treppman and Stöckhert, 2001; Orzol *et al.,* 2003). In Myanmar, mechanical twinning has occurred in both pure jadeitite and in surrounding amphibolite, and some twinned crystals have also been bent *(Figure 8).* These occurrences are useful for understanding how jadeite jade may form from the coarse-grained jadeitite.

Figure 12: Myanma jadeite jade showing abrupt changes in appearance. This is usually accompanied by changes in texture which are as important in understanding jades as inclusions are in other gemstones. Note that the appearance of jade in the centre resembles 'cooked sticky rice', but in the left of the picture looks like 'porcelain'. Length of carving 10 cm.

Micro-shear zones

In some jadeite jades, veinlets or lines, 10–100 mm long and about 1.0 mm wide, can be distinguished by their different colour and better transparency. They are a kind of deformed and recrystallized texture or microstructure described as micro-shear zones, which have not been distinguished before. They are not cracks, but do resemble 'healing fractures' and were formed by means of ductile deformation (e.g. Tullis and Yund, 1985). They are not real repairs, because they are part of an ongoing process of transformation of the rock, and are thus different from a simple healing texture. Micro-shear zones are characterized by tiny elongate jadeite crystals (like stacked tiles) with pronounced orientation (both SPO and CPO) at low angles to the shear zone walls *(Figure 9).* Some jadeite crystals crossed by a fracture or shear zone have conjugate profiles and crystallographic orientations suggesting that they are from one intact precursor crystal; the newly generated jadeite crystals in the shear zone have formed at the expense of this intact crystal. This is another cause of grain size reduction, of CPO, and ultimately of a tougher more transparent jadeitite.

Sutured grain boundaries

Some translucent to transparent jadeitites consist of crystals with sutured edges at high angles to adjacent grains and without interstitial spaces *(Figure 10).* They are the result of an integrated deformation process including dislocation,

Figure 13: A 'gamble stone' from Myanmar; the small polished window at one end is not sufficient to show the quality of the other part of the stone, but the patchy presence of some orientated crystals in the skin indicate good potential for a valuable piece. Stone length 13 cm.

granular flow and mass transfer (e.g. Tullis and Yund, 1985). The different boundary shapes are the result of different aspects of this process and could influence jade quality. The jades with such intergrown crystal boundaries have excellent toughness, even with grain-sizes up to 1–2 mm.

Recovery textures

The term 'recovery' in this context refers to textures formed through mutual annihilation and/or polygonization during or after the peak deformation, resulting from reduction in the strain produced by the deformation; such textures can show grain dislocation, development of sub-grains, polygonal patterns and recrystallization. Although some of these textures may be confused with the primary fine mosaic texture, they differ by the presence of the following features: the grains are crystallographically orientated, confirmed by EBSD results, they are nearly equal in size, mostly less than 0.08 mm, and have no obvious prismatic habit. The grain boundaries are straight or gently curved (resembling foam), a texture also similar to the quartz grains in mylonitized quartzite (e.g. Tullis and Yund, 1985), but not so far reported in jadeitite. In Myanma jadeitites with 'foam' texture, a few grains meet at perfect triple junctions with some boundary angles near 120° *(Figure 11)*. The jade with 'foam' texture usually has a high transparency, described as icy or glassy.

Discussion

Gemmological application

The importance of textures to the jadeite jades is comparable with that of inclusions to their host gemstones. Feitsui in Myanmar consists of jadeite aggregates of many different textures. In general, most carvings that appear similar probably have the same texture, whereas the parts and domains of different appearance reflect changes in texture (see *Figures 3, 5* and *12*). It is clear that the appearance and the transparency of jadeite jade are closely related to texture and if such correlations can be established, we could then predict the texture of a jade based on its appearance. The nature of the aggregate and its relative toughness could then be estimated quickly and non-destructively. Furthermore, if comparable data were collected from jadeite jades around the world, it may be possible to determine unique features for each locality. By studying textures of rough feitsui it is possible to identify, grade and evaluate them quickly. For instance, although bleached jadeite (B-jadeite) can be identified accurately using ultraviolet luminescence and the infrared spectrometer (see Fritsch *et al.,* 1992), a quick identification can be made using only the naked eye or a 10x lens. In this situation one should look for any damage to texture caused by bleaching (see Tay *et al.,* 1993, 1996). As for grading jadeite jade, toughness is an important factor, and the tougher a jade is, the better its quality. In this respect jadeitites with serrated high-angle sutured and interlocking grain boundaries are probably tougher than other jadeitites of similar grain size.

Figure 15: Another example of correlation between the texture and design in jadeite art; the coarsest part was designed as a rounded base and the 28th Olympics logo was carved in an area of relatively fine quality. Height 15 cm.

Figure 14: Dragon's head carved in the finest pure white jadeite jade but left unpolished to enhance the atmosphere of the piece: an example of the use of texture and colour in design of the jadeite carving. Height 6.5 cm.

Figure 16: The green parts in two Myanma jadeitite carvings are finer and more transparent than their neighbouring white regions, indicating differences in deformation textures. Lengths of carvings 6 cm.

Figure 17: The green parts in this Myanma jadeite bangle are finer and more transparent than their adjacent white regions; another example of differences in deformation textures between green and white regions, probably formed under the same P-T and stress conditions. Bangle diameter 5.8 cm.

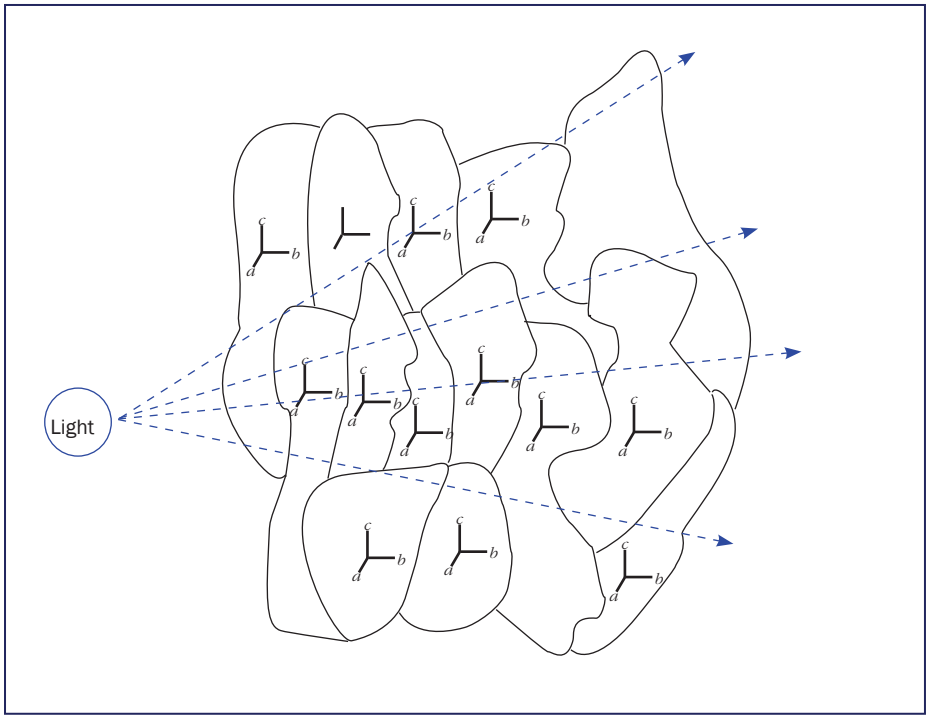

Figure 18: A model of the ideal texture for the best glassy jadeite aggregate. The jadeite crystals are fine-grained, with pronounced crystallographical orientation; they are compactly intergrown with minimal optical interfaces, and there is an absence of any obvious cleavage and chemical zoning; the net optical effect is of one jadeite crystal, allowing transmitted light to pass through without apparent internal reflection or refraction.

Rough jadeite jade normally has an opaque weathered crust (also known as the skin) with a thickness between 1 and 50 mm, thus it is difficult to evaluate without cutting into fresh rock. For the rough stone market, traders sometimes cut and polish a small 'window' through the weathered surface of a stone for a better sale; this is called a 'gamble stone' by the Chinese. In *Figure 13* is a good example of such a stone with a 'window' revealing an interior of glassy transparency when illuminated by a torch. A potential buyer would have to evaluate the overall quality of the stone, including the part still covered by the weathered skin, on the basis of this small illuminated area. The indistinct preferred orientation shown by the surface crystals (SPO texture) is a positive indication that the whole stone is of good quality; it turned out to be glassy after the skin was removed, so the initial indications proved positive.

Studies of the textures of feitsui also help a jade manufacturer in deciding on the best way to design and carve a particular piece of jadeite jade. Because of its textural heterogeneity, jadeite jade enables designers to use their imagination to the best effect, and the best designers know how to make full use of this variability. Two artworks shown in *Figures 14* and *15* are good examples; in *Figure 14,* the dragon's head was carved in the finest pure white area and its unpolished surface gives the art a sense of mystery, whereas in *Figure 15*, the coarsest part was designed as the base, supporting the 28th Olympics logo which was carved in a relatively fine area of jadeite.

Preliminary investigations indicate that green jadeite jades have slight differences in texture and microstructure from white jadeites under the same pressure and temperature *(P-T)* and stress conditions. One can even distinguish some textural differences at the colour boundaries: the green areas tend to consist of smaller grains with more pronounced orientation, thus appearing more transparent than neighbouring white areas (*Figures 16* and *17*). Our studies to date of homogeneous green jadeite jades indicate that they have similar deformation textures to

those described in the white jades. So, if textural studies of white feitsui can help understand green feitsui, the conclusions could provisionally be extended to the precious imperial green jadeite jade, which currently is too expensive to section for gemmological research!

Textural model of the glassy jadeite jades and how they formed

Its rarity indicates that jadeite cannot easily grow as large transparent crystals in Nature (see Zhang *et al.,* 2002). So far there have been no reports of a single jadeite crystal being cut or otherwise used as a gemstone. But some jadeite aggregates can come surprisingly close to appearing like a single crystal with an icy or glassy transparency nearly as clear as rock crystal. Our observations on the textures and microstructures of Myanma jadeitites suggest a theoretical textural model for such aggregates. In this model, the individual jadeite crystals are small equant grains or fine fibres too small to develop significant cleavage, which is therefore one factor that will not interfere with transparency. All the grains have preferred orientation, with their crystal and optic axes consistently aligned; therefore they show little, if any, differential refraction between neighbouring grains. This texture is also so compact that there are no spaces at any grain boundaries, so there are no obstructions to the transmitted light; this eliminates any significant internal reflection and refraction *(Figure 18).*

Transformation of coarse jadeitite into the transparent gem-quality jade, i.e. icy to glassy feitsui, should have undergone at least two coupled processes of grain size reduction and crystallographic orientation under conditions of jadeite stability.

The main process causing grain-size reduction is rotation recrystallization, also known as the progressive misorientation of sub-grains. This refers to the formation of sub-grains by the relative rotation of different parts of a crystal and was first identified in such minerals as quartz, feldspar and olivine under conditions of low pressure and high temperature. In jadeites, this phenomenon takes place at high pressure and low temperature in the jadeitites from Myanmar. Other processes causing grain-size reduction include mechanical twinning and shearing along micro-shear zones. In one crystal, such shearing can cause sub-grains that do mismatch but retain overall orientation within 15 degree limits of CPO. CPOs can also be generated from processes including grain-boundary migration (GBM) and diffusion processes (Tullis and Yund, 1985).

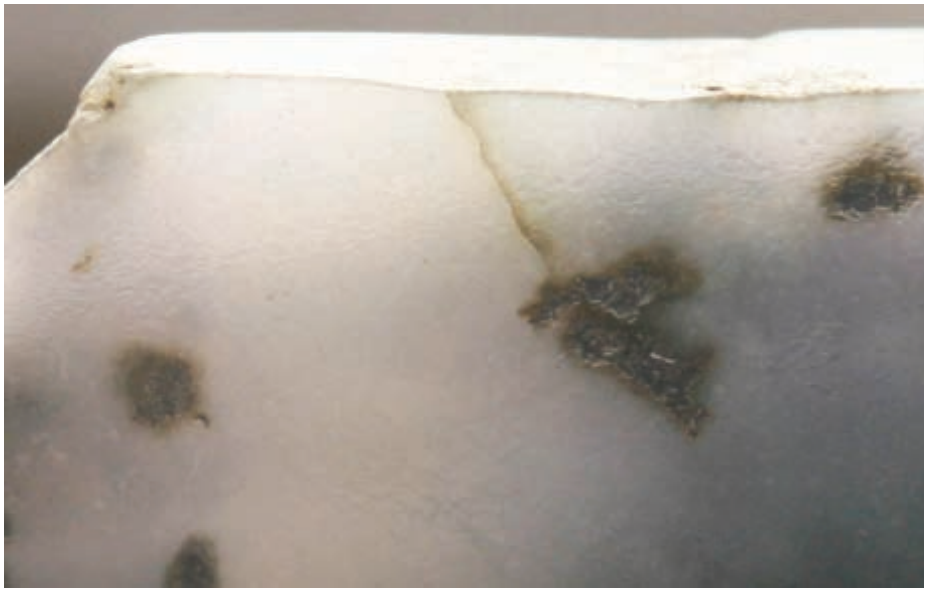

Figure 19: Jadeite from Myanmar described as water-like; the jadeite grains cannot be distinguished with the naked eye. Specimen 5cm across.

From the presence of some elongate jadeite crystals in the Myanma icy to glassy jadeitites, it is suggested that GBM had occurred during the transformation from coarse-grained jadeitite to fine jadeite jade. Since GBM tends to increase the size of the sub-grains, it is reasonable to include this process as part of the ideal or theoretical texture model. The linked processes of rotation recrystallization and GBM are the main causes of formation of the icy to glassy jades, and since both should have taken place under high pressure low temperature conditions, the conditions of formation for aggregates of jadeite with an icy to glassy appearance are thus very exacting. They are extraordinarily rare, only found so far in Myanmar, and the results are therefore precious.

The undeformed coarse jadeitite and the icy to glassy feitsui are the two end members of the transparency range of jadeite materials. Most jadeite jades from Myanmar are intermediate, being of moderate grain size, with partially orientated grains, and a translucent appearance.

Jadeite materials representing nearly all degrees of transparency are available on the market, and are sold under the varietal descriptions: 'glassy', 'icy', 'water', 'cooked sticky-rice', 'porcelain' and others *(Figure 19).* These varieties do not take into account colour or impurities – these are other variables that can lead to more commercial varieties.

Formation of the most transparent feitsui has required long-lasting and intensive, localized geological forces, and it is very likely that the source of these was movement along the Sagaing strike-slip faults which have a displacement 150–300 km. Displacement along the faults over a long period of time led to local developments of intense metamorphism inducing ductile deformation and recrystallization, and where coarse-grained jadeitites were caught up in these movements, they were variably recrystallized and transformed.

Gemmological applications will benefit from further related investigations into jadeitite textures and make it possible perhaps to establish an ideal model of how the textures of the glassy jades were formed.

Conclusions

Jadeitites from Myanmar can be considered in terms of two groups of textures: primary, and deformed and recrystallized. Those with primary textures are coarse-grained, and have mosaic, granitoid or radial textures consisting of chemically zoned jadeite crystals; they are porous to some degree, are not transparent, and are not therefore considered as being of gem quality. The jadeitites which are deformed and recrystallized developed at the expense of primary textures, and are intermediate to fine-grained, with semi-orientated to preferred orientated crystals, some mechanically twinned. They may also contain micro-shear zones, sub-grains, serrated high-angle sutured grain boundaries, and 'foam' textures. These rocks are compact, tough and translucent to transparent, and have the most potential as gems.

One model for the icy and glassy jadeite jades might include the following parameters: the crystals are very small and compact with preferred orientation, they lack obvious chemical zones and cleavages, and the whole rock resembles a single crystal optically. Most jade in the gem market is classed as glassy or coarse. These categories are further subdivided on the basis of three variables: compactness, orientation and grain size, so producing a large number of jadeite varieties.

Studies of the textures have gemmological applications not only in identifying and grading the rough and fashioned jadeite jades, but also in their design and manufacture. Moreover, such studies help understanding of the textural model of the icy and glassy jadeite jades, the textures and microstructures of green and other coloured materials, and how they are formed.

The movements of the Sagaing strike-slip faults, which the Myanma jadeite deposits straddle, are inferred as the main cause of the formation of the feitsui.

Acknowledgements

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A description and history of one of the largest nacreous pearls in the world

J.C. (Hanco) Zwaan and Herman A. Dommisse

Abstract: A large pearl, weighing approximately 2385 grains, is described. This pearl is one of the largest nacreous pearls ever found. Although the first known owner, Sir H.C. Sander, left this pearl to be auctioned in Amsterdam in 1778, and the pearl has been part of a Dutch private collection, at least from the nineteenth century onwards, it has never been described before. Its properties indicate a freshwater origin. Supported by an eighteenth century print and historical references, its properties point to the Far East as its most likely provenance. The weight of the pearl is slightly less than the recorded weight of the Pearl of Asia, as described in the literature.
Based on its shape, it had been suggested previously by the present owner that this pearl could actually be the disappeared Arco Valley Pearl, which until recently had been owned by one Italian family since 1700. After the sudden announcement that the Arco Valley Pearl had been put up for auction in Abu Dhabi in 2007, and the recent discovery that the pearl described herein had been sold in Amsterdam in 1778, the suggested Italian link could be refuted and a strong Dutch link confirmed.

Introduction

In 1979, a large baroque pearl was brought to the Netherlands Gemmological Laboratory for identification, by L.W. van Kooten, the Dutch owner at the time. Professor Dr P.C. Zwaan, the director of the Laboratory at the time, confirmed its natural identity in a letter written on 7 June 1979 and immediately recognized its uniqueness. For that reason, he stated that the pearl deserved to be shown to the public. However, no publicity was generated around the discovery, and the pearl stayed locked away after a change of ownership in the same year. However, in 1998 it was shown to the public for the first time during the Christmas period, right after the opening of the new exhibition halls and depot of the National Museum of Natural History, 'Naturalis', in Leiden. Now, after more than ten years out of the public eye, the pearl is described in detail for the first time and compared with other large pearls that have been reported in the literature.

History and lore

Only very recently, a print of an 'Oosterse Paarel' (oriental pearl) dated 1778, was found in the city archive of Amsterdam (Lakmaker, 2009). It was accompanied by a note stating: "A large pearl, of 578 carats, visualizing a sleeping lion, left by H.C. Sander, has been sold in 'the Munt' on 26th August 1778," A separate note stated that the pearl was sold for 2100 Dutch guilders (Muller, 1876–77). Comparing this drawing with the described pearl *(Figure 1),* we can confirm that it is the same pearl. It means that this illustration is the first account of this pearl that has been found so far.

Another note mentioned that the pearl was actually a 'well known Royal Cabinet piece' and gave more information on the first known owner. Sir Hendrik Coenraad Sander was an agent of the 'Duke of Tweebrugge'. He not only left the pearl, but also an "extremely beautiful brilliant, weighing *c.* 58 grains". Accordingly, the stone was sold at the same time for 17500 Dutch guilders.

The second known owner of the pearl was a Polish ship-owner named Plonsky, from Danzig (now known as Gdansk). Around 1865 Plonsky sent one of his daughters to Paris and to Rome, to sell the

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Figure 1: The first record of the described pearl is a print dated 1778. The marginal note, written in Dutch, translates as: "An Oriental pearl, weighing 578 carats." A photo of the described pearl in the same orientation shows that it is identical to the pearl on the drawing.

pearl (L.W. (Louk) Van Kooten, 1994, pers. comm.). At the time Gdansk was besieged by Russian troops trying to seize this German harbour on Polish territory. This might have been the reason that Plonsky urgently needed money.

At the same time in Rome, the jewellers Castellani were working on the crown jewels of Victor Emmanuel II (1820-1878, the first king of united Italy). The old royal regalia had been stolen by the French troops and had to be replaced. On behalf of the monarch they were looking for special pearls and gemstones for the crown, sceptre, orb and sword. The crown was finished first; it contained a pearl of around 500 grains. It is possible that Castellani advised the King to buy the pearl from Plonsky, to be used for the sceptre. At the time the young goldsmith Lodewijk Willem van Kooten from Amsterdam worked at Castellani. Van Kooten helped to manufacture the crown and was involved in preparations to make the other jewels. But these other jewels were not finished because the King needed money to fight Garibaldi and his troops. To prevent the King from losing face, Pope Pius IX advised him to present the crown as a gift to the Church of the Holy Sepulchre in Jerusalem (Kunz and Stevenson, 1908, p.468) but with no prospect of completing the other regalia, the unused pearl was sold privately to Lodewijk van Kooten *(Figure 2),* who returned to Amsterdam around 1868.

Tradition has it that the pearl made a single journey to Fabergé, the royal jeweller of Tsar Nicolas II, in St. Petersburg (L.W. (Louk) Van Kooten, pers. comm.). Louis Van Kooten, Lodewijk's son, and Fabergé knew each other from the 1910 World Exhibition in Brussels. At this event, the firm Van Kooten won a prize for manufacturing gold and enamel jewellery, after designs of Lambert Nienhuis (Van Diedenhoven, 1911), which is still present at the Rijksmuseum in Amsterdam (Anonymous, 1980).

Thereafter Van Kooten represented Fabergé in The Netherlands and its colonies. Van Kooten sent the pearl to St. Petersburg to be mounted in one of the spectacular and famous 'eggs' for the Russian monarch, but the pearl had to be brought back unsold from Russia because revolutionaries and a shaky throne had prevented a sale.

In 1914, Fabergé closed its doors. Between 1914 and 1979, the pearl stayed in a safe of the Van Kooten family, unseen and unnoticed. The Van Kooten jewellery firm ceased to exist in 1951, exactly 90 years after its foundation. In 1979 the pearl was sold, and from that time it has been in the hands of a well-known art collector from Amsterdam.

In 1992, the pearl was set in a mount designed by Jean Lemmens, a goldsmith based in Antwerp. He chose to design a

Figure 2: The young Amsterdam jeweller Lodewijk Willem van Kooten (1842-1900), pictured in Paris, August 1865, just after the purchase of the giant pearl in Rome.

Figure 3 (left): The described baroque pearl with an estimated weight of around 2385 grains, was set in this mount in 1992. The design is a stylized Lotus bud with the pearl in the centre, surrounded by golden 'stamens' which are decorated with ruby, sapphire and emerald beads at the upper ends, and mounted on a pedestal of lapis lazuli. Photo © Amsterdam Pearl Society
Figure 4 (above): Surface growth lines on the reverse side of the pearl indicate that parts were attached to the shell.

stylized Lotus bud with the pearl in the centre, protected by 'stamens' *(Figure 3)*. The 'stamens' consist of gold, with ruby, sapphire and emerald beads at the upper ends, and are mounted with a gold rod on a pedestal of lapis lazuli, which contains a gold frame set with various small coloured gemstones.

Properties

The pearl, measuring approximately 70 x 43 x 39 mm, has an irregular pear shape described as baroque, and is creamy white with a slightly brownish tint in some areas at the back *(Figures 3* and *4)*. The weight of the pearl is estimated to be approximately 2385 grains (119.25 g, see under 'weight estimation').

The pearl shows a good lustre and a subtle play-of-colour or 'orient' over much of its surface. Under magnification, the surface of the pearl shows characteristic irregular relief lines, which correspond to the borderlines of aragonite platelets, marking extremely thin layers of mother-of-pearl, stacked on each other. A part of the reverse side of the pearl reveals surface growth lines, indicating an area of the pearl originally attached to the shell *(Figure 4)*.

X-radiographs and computer tomography (CT) scans taken perpendicular to the direction of the X-radiographs, revealed a layered growth structure, which confirms that the pearl was naturally formed *(Figures 5* and *6)* and that it is solid; it does not contain any substantial cavities.

Under long wave UV radiation, the pearl showed a strong bluish to slightly greenish-white fluorescence. Under X-rays, the pearl distinctly fluoresced a slightly creamy white. Micro-EDXRF analyses on five selected spots (each of 300 µm diameter) on the pearl surface, revealed Ca as the main element and traces of Mn and Sr *(Table I)*. The fluorescence under X-ray combined with the relatively high concentrations of

Table I: Trace element contents in the described pearl.

Oxide	Spot analyses (wt.%)				
	1	2	3	4	5
MnO	0.21	0.22	0.26	0.26	0.30
SrO	0.03	0.03	0.03	0.07	0.06

NB: Measurements were done with micro-EDXRF. MnO and SrO values were corrected for the presence of CO_2 (carbon cannot be measured by this analytical technique).

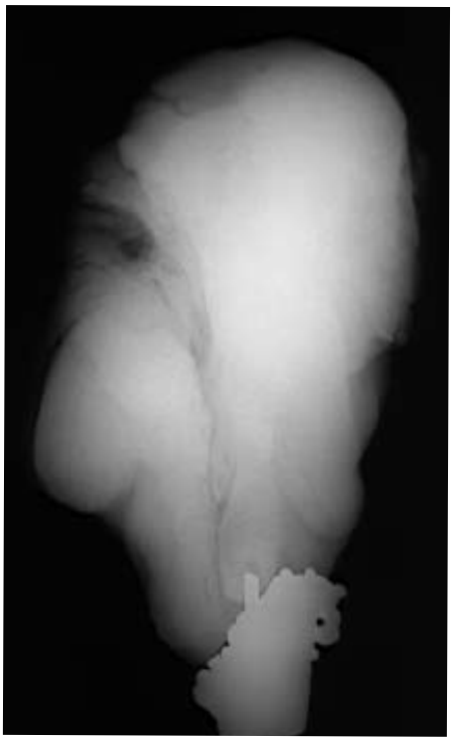

Figure 5: X-radiograph of the pearl, showing a layered growth structure, which confirms its natural identity.

manganese and low concentrations of strontium, point to a freshwater origin for this pearl (compare, e.g., Farn, 1986; Wada and Fujinuki, 1988; Gutmannsbauer and Hänni, 1994; Kennedy *et al.*, 1994).

Weight estimation

Ideally, a loose pearl should be weighed on an accurate balance to establish its exact weight. However, the pearl was tightly mounted on a gold rod, which would have to be drilled out to obtain an accurate weight, a procedure likely to cause damage and loss of weight. But by comparing the gross weight of the pearl with the sizes and weights of different gold rods, an approximate weight of the loose pearl could be calculated.

Based on X-radiographs, CT-scans and the length of the rod sticking out, the total length of the gold rod was estimated to be 22 mm. The designer of the mount, J. Lemmens, kindly provided a gold rod of identical thickness and a length of 11 mm, which weighed 0.2782 g. This means that the identical rod of 22 mm attached to the pearl should weigh 0.5564 g.

The pearl, including the gold rod, weighed 119.87 g. Based on the weight of the 22 mm gold rod, the weight of the loose pearl would be 119.87 – 0.5564 = 119.3136 g, that is rounded to 2386 grains. The uncertainty in this calculation mainly lies in the estimation of the length of the golden rod inside the pearl, which is partly hidden by a gold frame that covers the back of the pearl (unfortunately there was no opportunity to make radiographs of the pearl without the frame). Therefore it is possible that the rod could be up to 2 mm longer than estimated. In that case, the calculation would give 2385 grains and we have used this most conservative calculation as the approximate weight of the pearl.

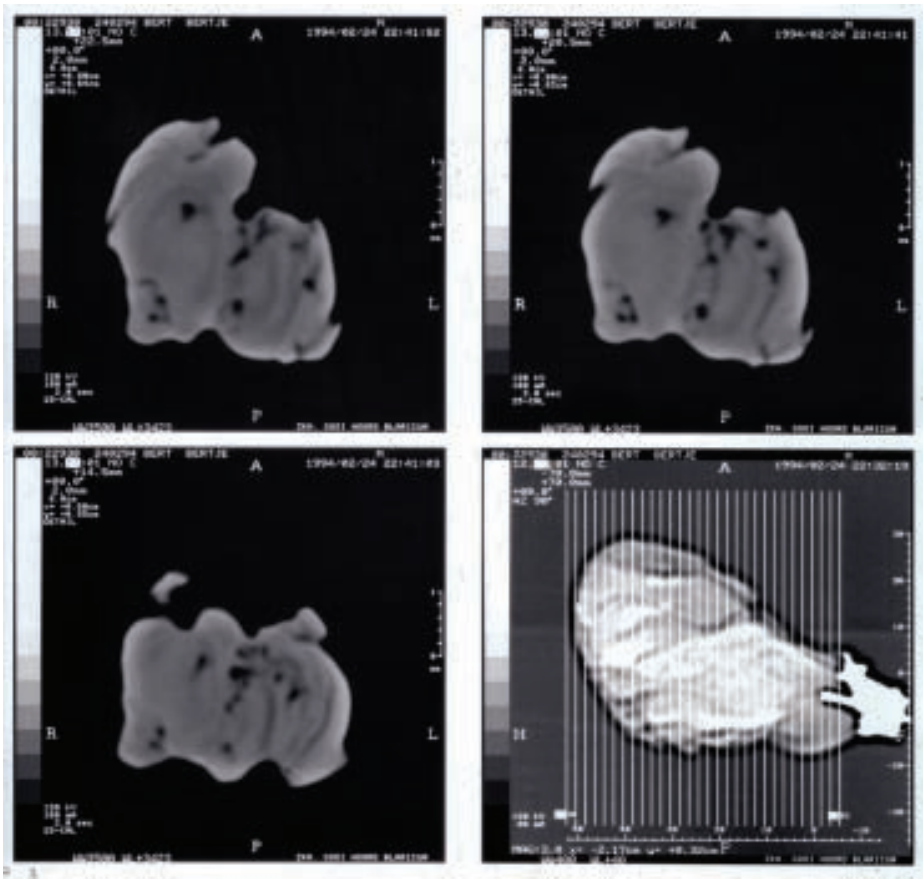

Figure 6: CT-scans also confirm the natural identity of the pearl, showing concentric layered growth structure in parallel sections, taken perpendicular to the direction of the X-radiograph. In total, 19 sections were scanned, three examples of which are shown here.

Figure 7: A box made specifically to hold the pearl is made of gilded copper. The box appears to be of Asian origin.

Metal box

A metal box that came with the pearl *(Figure 7)* was originally made for it, as it fits around the pearl perfectly. It has been made of gilded copper, and measures approximately 74 x 54 x 47 mm. The construction of the box is unusual. The lid is larger than the base which only has low rims no more than 5 mm in height. Thus by removing the lid, the pearl could be displayed on its base. The box contained a piece of paper with hand-written notes (in Dutch and French), "Concrétion perlière de Maleagrina margaritifera" on one side and the address of Madame Plonsky in Rome and the weight of the pearl in grams on the other.

The box is probably made in east Asia, possibly in China. This view is independently confirmed by specialists in antique metal objects. It is uncertain when it was made, but it may be significantly earlier than the nineteenth century.

Discussion

The first account of the pearl

The detailed print of the pearl made in 1778 clearly represents the same pearl as described. However, the mentioned weight, 578 ct (i.e. 2312 grains) deviates considerably from the approximate weight of 2385 grains as stated above. This difference can be understood, when realizing that the metric carat weight of 200 mg (0.2 g) was only standardized in the early twentieth century. Until that time the carat weight varied considerably in different parts of the world; with a range between 0.1885 and 0.2160 g (Lenzen, 1970, p.100). The value of 0.204304 grams was that defined for the old English carat, but never a legal weight, and only mentioned for the first time in 1878 (O'Donoghue, 2006). When comparing the 578 ct mentioned on the drawing with our approximate weight of 2385 grains (119.25 g), the carat weight used at the time must have been around 0.206 g. This is consistent with the value of the Amsterdam carat of 0.2057 g at the end of the nineteenth century, as given by Lenzen (op. cit.). After the pearl was sold in Amsterdam in 1778, the pearl's history is not known until 1865, when the second known owner from Poland appeared. The return of the pearl to Amsterdam around 1868 only appears to confirm strong ties between the pearl, Amsterdam and The Netherlands.

Origin

Which pearl-producing mollusc would have been capable of producing a pearl this size? Previous owners thought that the pearl was produced by a marine bivalve mollusc of the genus *Pinctada,* this being the main producer of natural pearls in the Persian Gulf/Red Sea region. There is a hand-written note with the pearl (see above) that states "concrétion perlière de *Maleagrina margaritifera*". The Pinctada genus was often referred to as *Maleagrina* from 1819 until the middle of the nineteenth century (Strack, 2006). Thus *Maleagrina margaritifera* can be read as a synonym of *Pinctada margaritifera.* This attribution was most probably based on the colour and iridescence ('orient') of this pearl, which closely resembles the appearance of natural pearls formed in salt water.

However, there is general consensus that marine pearls do not fluoresce under x-rays, although marine pearls coming from river deltas may show a weak fluorescence. The mother-of-pearl of especially American, Chinese and Japanese freshwater shells normally has a distinct fluorescence (see Strack, 2006). As concluded above, the distinct fluorescence and high manganese content of the described pearl indicate strongly a freshwater origin. However, most of the pearl-producing freshwater molluscs appear simply too small to produce such a huge pearl. The largest freshwater molluscs are part of the extensive family of Unionidae; purely based on size, species that could have produced a pearl this large may be pond 'mussels' like *Anodonta cygnea* and *Anodonta anatina,* which can reach lengths up to 22 cm and are widely distributed from Europe to Eastern Siberia. *Anodonta woodiana* can grow up to 19 cm in length, and occurs in China and Japan. Other possible sources are *Hyriopsis cumingii* or, less likely because of the size, *Hyriopsis schlegelii*. *Hyriopsis cumingii* can grow up to 25 cm in length and 20 cm in width, and occurs in rivers and lakes of China; *Hyriopsis schlegelii* may reach a size of 20 x10 cm and is found in Japan. *Cristaria plicata* can reach a length of 30 cm and is found in East and Southeast Asia. Finally, *Megalonaias gigantea*, the 'washboard' (up to 30 cm or more in length), and *Lasmigona (P.) complanata* (up to 20 cm) occur in North America (data from Strack, 2006; Sweaney and Latendresse, 1984, Williams *et al.,* 2008).

From descriptions in Williams *et al.* (2008), it appears that *Lasmigona (P.) complanata* has really white nacre, either going in the bluish or pinkish direction, and bears no resemblance to the nacre of the described pearl. Also *Megalonaias gigantea* usually produces white nacre, and rarely pale pink. In fact, most North American species produce white nacre, although many other colours also occur, including pink, orange, lavender and purple. White is the most prevalent body colour of freshwater pearls in America. Cream colours are commonly seen in freshwater pearls of Japan and China (Sweaney and Latendresse, 1984).

Although *Anodonta* has produced pearls in China and Japan for centuries, their sizes have not been exceptional (Strack, 2006). Kunz and Stevenson (1908) mentioned earlier that Anodonta produced pearly concretions that are less lustrous and not brilliant in colour.

Based on the size, colour and properties of the pearl, it seems to be most probable that this pearl grew in either *Hyriopsis cumingii, Cristaria plicata* or *Hyriopsis schlegelii,* with China or Japan as most likely sources. Statements in the (historical) literature do not appear to contradict this view, and also mention large pearls that came from these areas. Farn (1986) and Landman *et al.* (2001) confirmed that even in remote antiquity China had access to significant quantities of freshwater pearls from pearl mussels *(Cristaria and Hyriopsis)* native to the Yangtse delta and nearby rivers in central eastern China. Strack (2006) stated that the majority of Chinese natural freshwater pearls which are known since the third millennium BC have probably originated from *Hyriopsis cumingii.*

Marco Polo reported on the trade in pearls in China and mentioned a lake near 'Kain-du' (the north western part of Yunnan), where many pearls were found "of a white colour, but not round" (Polo, 1298, in Penzer, 1929). Kunz and Stevenson (1908) wrote that it appeared from ancient Chinese literature that pearl fisheries of considerable extent and importance have existed in the rivers and lakes of China for several thousand years. They reported that in about 200 BC a pearl dealer at Shao-hing, an ancient city (now Shao-xing, NE Zhejiang province, East

Table II: Comparison of the described pearl with the largest reported nacreous pearls.

Largest pearls	Approximate size (mm)	Weight	
		grains	grams
Pearl described in this article	**70 x 43 x 39**	**2385**	**119.25**
Historic pearls			
Pearl of Asia	76 x 50 x 28	2420	121
Arco Valley Pearl	Length 75, width 52.5	2300	115
Hope Pearl	Length 90, width 30-40	1800	90
Recent discoveries			
Centaur Pearl	69 x 49 x 35	3426	171.30
Myanmar Pearl	62 x 53 x 30	3380	169

Pearl of Asia data: Boutan (1925); Hope pearl data: Kunz and Stevenson (1908), Kennedy (1994); Arco Valley Pearl data: Taburiaux (1985); Centaur Pearl data: Scarratt (2001); Myanmar Pearl: Hlaing (2001).

China), furnished to the Empress a pearl of one inch in diameter, and to an envious princess the same dealer sold a "four-inch pearl". Kunz and Stevenson (1908) also indicated that numerous pearls were found in Manchuria, where they have long been exploited for the account of the Emperor of China. They further stated that many superb pearls were among the precious objects in the Yuen-Min-Yuen or Summer Palace in Beijing at the time of its capture by the European forces in 1860. Some of these pearls found their way to Europe, and were of "good size and lustre and were mostly yellowish in colour". Earlier on, Tavernier (1676) had seen some of the pearls the Dutch brought from Japan: "They were of very beautiful water, and some of them of large size, but all baroques." It is unclear though whether these pearls originated from coastal areas or lakes. Summarizing, historical sources indicate that since antiquity, large pearls, including freshwater pearls, were known to come from the Far East, in particular China and Japan, and were finding their way to Europe.

Comparison with other large pearls

The size and weight of the described pearl is compared with the largest pearls known so far *(Table II)*. Compared with the historic pearls, the pearl appears to weigh slightly less than the Pearl of Asia, which according to Boutan (1925) weighs 605 ct (2420 grains). However, Boutan did not report on weighing it himself and showed a drawing of a mounted pearl. The Pearl of Asia is still mounted in the same setting as became apparent when temporarily exhibited by the Smithsonian Institution in 2005. Consequently, as the Pearl of Asia has been known for around 300 years (Strack, 2006) and taking into account the variation in carat weight used at the time, as discussed above, the exact weight of this pearl could lie somewhere between 2280 and 2580 grains.

It was previously suggested by the present owner that the pearl described here could be the similarly-shaped Arco Valley Pearl which was in the possession of the Italian d'Arco family for a long time, at least since 1700 (Taburiaux, 1985). This family originally came from Arco village; the Count Carlo d'Arco (1799–1872), painter and art-historian, lived in Mantova, northern Italy. Until recently, the whereabouts of the Arco Valley Pearl were unclear. However, on 8 May 2007 it was announced that the Arco Valley Pearl would be put up for auction in Abu Dhabi. A picture of the pearl was shown, which closely resembled a drawing of the Arco Valley Pearl published by Taburiaux (1985). A death in the Emirates royal family postponed the auction (2007, http://abcnews.go.com/International). Since then, it is unclear whether this pearl has been offered at auction again, or perhaps secretly sold. Nevertheless, from the released information and photographs it appears that there is no link between the pearl described in this article and the Arco Valley Pearl. Additionally, the discovery that the described pearl was sold in Amsterdam in 1778 is not consistent with one family having owned the pearl since 1700.

Comparing origins for the Pearl of Asia, the Hope Pearl, the Myanmar Pearl and the Centaur Pearl, a marine origin is indicated or implied. For the Hope Pearl, the *Pinctada margaritifera* is the most likely source (Kennedy *et al.*, 1994). The Myanmar Pearl was found in a *Pinctada maxima* (gold-lipped pearl oyster; Hlaing, 2001). The Pearl of Asia is supposed to have come from *Pinctada maxima* as well (Strack, 2006). So far, the origin of the Arco Valley pearl remains unknown. Consequently, the described pearl could have the status of being the largest freshwater pearl found to date.

Conclusion

The pearl described, measuring 70 x 43 x 39 mm and weighing 2385 grains, is one of the largest nacreous pearls that have been documented. In contrast to the other few very large baroque pearls, the properties of this pearl suggest a freshwater origin. Taking into account its size and colour, it appears to be likely that the pearl was formed in a large freshwater mussel of the family Unionidae, somewhere in East Asia (China or Japan). The eighteenth-century print with the subscript 'Oosterse parel' appears to support a Far East origin. Historical references also confirm that from early times, large pearls were known to come from China and Japan.

Acknowledgements

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Geographic typing of gem corundum: a test case from Australia

F. Lin Sutherland and Ahmadjan Abduriyim

Abstract: A group of analysed sapphires attributed to the rather broad source region of New South Wales was investigated by comparison of their trace element contents with those of sapphires from known Australian fields. Both groups of sapphires were analysed using laser ablation inductively coupled plasma mass spectrometry (LA-ICP-MS) at the same Japanese laboratory. Blue sapphires from Anakie, Queensland, were included for comparison as these are also sold in New South Wales. Comparisons of Fe, Ti, Mg, Cr, Ga and other trace element contents suggest that the vaguely located group of sapphires came from the Inverell gem field in New England. The results give encouragement for more studies on geographic typing of gem corundum.

Keywords: Australia, gem sourcing, LA-ICP-MS analysis, sapphire, trace elements

Faceted blue sapphire, typical of Inverell area, New England, New South Wales, 3.56 ct, Australian Museum Collection (D48268). Photo Stuart Humphreys.

Dedication

This paper is dedicated to the memory of the late Professor Akira Chikayama, who donated a collection of New South Wales sapphires to the GAAJ-Zenhokyo Laboratory in Tokyo and provided many valuable services to gemmological studies during his career.

Introduction

Laser ablation inductively coupled plasma mass spectrometry (LA-ICP-MS) analysis is a useful geochemical technique for 'fingerprinting' an array of trace elements in gemstones (Günther and Kane, 1999; Shigley, 2008). Gem corundum, with colours related to trace element substitutions in the Al_2O_3 structure makes a particularly suitable target for LA-ICP-MS characterization (Gulliong and Günther, 2001; Rankin *et al.*, 2003; Abduriyim and Kitawaki, 2006; Khin Zaw *et al.*, 2006; Peucat *et al.*, 2007; Graham *et al.*, 2008; Sutherland *et al.*, 2008a,b). The Abduriyim and Kitawaki (2006) study on blue sapphires included a group of faceted stones with a reported source only as New South Wales, Australia. In New South Wales, however, several basaltic sapphire fields have supplied rough and faceted sapphire to the gem market from the late 1800s to present times (Coldham, 1992; Hughes, 1997). The main Inverell-Glen Innes-Tenterfield fields, in the New England area are 300–400 km north of Sydney, but faceted sapphires also come from intermittent small-scale mining elsewhere at Barrington Tops, near Gloucester, 150–200 km north of Sydney and Vulcan State Forest, near Oberon, 130 km west of Sydney (Sutherland and Graham, 2003; Sutherland and Webb, 2007). The New South Wales stones analysed by Abduriyim and Kitawaki (2006) came to the GAAJ-Zenhokyo Laboratory in Tokyo in the early 1990s from the late Professor A. Chikayama, so unfortunately the means of tracking the exact source of these stones through their trading history is denied us. That they may not even be New South Wales stones is possible because sapphires from the Anakie-Rubyvale gem fields in central Queensland are sold there also. These latter stones are supplied to New South Wales gem merchants, particularly by companies that operate sapphire fields in both states.

This paper aims to identify the source of the 'unsourced' New South

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Figure 1: Sapphire-ruby fields, East Australia, including localities discussed in this study. The dash-dot line represents the western exposure of the New England Fold Belt.

Wales sapphires (termed here the Unsourced NSW Group) by comparing their previously published trace element contents with similar LA-ICP-MS analyses on sapphires of documented origin from specific gemfields (made using the same instruments in the same laboratory and with the same operator). Recent LA-ICP-MS analyses of gem corundum from several New South Wales localities were reported at a recent Applied Mineralogy Congress (Sutherland *et al.*, 2008b) and these are incorporated with new LA-ICP-MS analyses in this paper.

Few LA-ICP-MS analyses of sapphires of known geographical origin from the main commercial New South Wales and Queensland fields have been available prior to this study. Sapphires from magmatic or metamorphic sources are now readily distinguishable in most cases using detailed trace element plots (Abduriyim and Kitawaki, 2006; Peucat *et al.*, 2007; Sutherland *et al.*, 2008b). The distribution of the main gem corundum fields in Australia including those used in this study are shown in *Figure 1* and examples of faceted sapphires from the main Australian gem fields are shown in *Figure 2*. Geological settings and locations for the analysed sapphire localities, summarized from referenced descriptions in Sutherland *et al.* (2009), are given in Appendix I.

Materials and analytical methods

The same methodology described by and instrumentation illustrated by Abduriyim and Kitawaki (2006) were used again in this study. The documented sapphires for this test case included faceted stones, polished wafers and grains held in the Australian Museum collection, viz:

- Two cut blue stones, and one blue and yellow, Inverell, NSW (0.984–1.022 ct, D.A. Porter collection)
- Two cut green stones, Inverell, NSW (1.890–2.229 ct, T. Coldham collection)
- Two cut purple stones, New England, NSW (0.154–0.340 ct, D. Cupit collection)
- One cut green-blue stone, Vulcan State Forest, NSW (1.514 ct, I. Hall collection)
- Three cut blue stones, two purple and one green, Barrington, NSW (0.10–0.16 ct, A. Chubb collection)
- Three cut blue stones, Anakie, Qld (1.538–2.163 ct, A. Wirth collection)

Analyses were made using an Agilent model ICP-MS 7500a with New Wave UP-213 laser ablation sampling system (Abduriyim and Kitawaki, 2006, pp 28–30). Two random sites on the table facet of each stone were analysed using a laser ablation spot 80 µm in diameter and the data were processed using Al_2O_3

98 wt% (Al 51.8 wt %) as an internal standard. The chemical concentration was calibrated using NIST glass 612 and 610. The detected trace elements in the samples include Mg, Sc, Ti, Cr, Mn, Fe, Ni, Ga, Sn and Ta and values are reported in *Table I*, apart from Sc and Mn, which were below detection limit or had negligible value for most analyses. The advantage in using this analytical technique for cut gem stones is its almost non-destructive nature (Rankin *et al.,* 2003).

Results

Main elements

The elemental ranges are grouped by colour of the sapphire from each locality along with an average for each colour group *(Table I)*. The blue Inverell and green Inverell groups both show relatively high Ga (> 120 ppm), low Mg (< 18 ppm) and low Cr (< 10 ppm), features that typify magmatic sapphires (Khin Zaw *et al.,* 2006; Peucat *et al.,* 2007). The blue Inverell group, however, shows lower Fe, V and Mg and higher Ti than does the green group. The purple sapphires from this general New England region differ from the Inverell stones in having higher Cr (>290 ppm), but still retain magmatic-like features such as high Ga (>170 ppm) and moderate Mg (< 43 ppm) contents.

The Vulcan State Forest blue sapphire, like the Inverell blue and green stones has high Ga (> 113 ppm) and low Mg (< 14 ppm), but has much more Fe (> 9600 cf < 8300 ppm). The Barrington Tops blue group in contrast mostly shows metamorphic signatures, with relatively low Ga (< 45ppm) and high Mg (> 262 ppm), with a pale blue zoned stone (Ga 101–102; Mg 45–50 ppm) having intermediate values and distinctly lower Fe (< 2750 cf > 3745 ppm). The yellow green Barrington Tops sapphire shows both low Ga (< 26 ppm) and Mg (<35 ppm) and is unrelated to the other groups.

The Queensland Anakie blue group differs marginally from the Inverell blue group, with higher Fe (av. 5300 cf 4000 ppm) and lower Ti (av. 67 cf 116 ppm) and noticeably lower Mg (av. < 1 cf 7 ppm).

Other elements

Some stones show noticeable V, Ni and Sn. The highest V values appear in the New England purple and Barrington Tops blue, purple and green sapphires (4–187 ppm), with lesser amounts in Inverell blue (1–7 ppm) and green (9–13 ppm), Vulcan State Forest blue (9–10 ppm) and Anakie blue (1–8 ppm) groups. The highest Ni is found in the Barrington Tops blue and purple sapphires (0–10 ppm) and is < 2 ppm in other sapphires. The Sn values have sporadic higher levels in a few Barrington Tops blue and purple sapphires (226–330 ppm) and are < 2 ppm or below detection in the other sapphires. Minor Ta values in the stones are mostly < 3ppm.

Discussion

The results from the sapphire groups are plotted in three trace element variation diagrams for comparison with the Unsourced NSW Group analyses. A Cr/Ga-Fe/Ti diagram *(Figure 3)* shows only partial separation of the analysed groups. The Inverell, Vulcan State Forest and Anakie blue and Inverell green groups all fall decisively into the magmatic field. The analysed Barrington blue and purple groups in contrast mostly show metamorphic affinities, even though magmatic Barrington blue sapphires are known (Sutherland *et al.,* 2008b). To overcome this sampling problem, a Barrington magmatic field from that work is depicted on the diagram (BAR). Overall, this discrimination diagram shows overlaps between the Inverell, Vulcan State Forest, Barrington and Anakie magmatic fields, so does not provide good discrimination. Consequently, the Unsourced NSW Group is not clearly linked to a specific field, although it lies near the Inverell and Barrington magmatic blue groups.

The Fe (ppm) – Ga/Mg diagram *(Figure 4)* shows better separation of the analysed groups, with the Barrington blue, purple and green groups all lying in the metamorphic screen (Ga/Mg < 3) suggested by Peucat *et al.* (2007). That screen was based on blue sapphires only, but further data for other coloured corundum show this screen to be generally applicable (Sutherland *et al.,* 2008a,b).

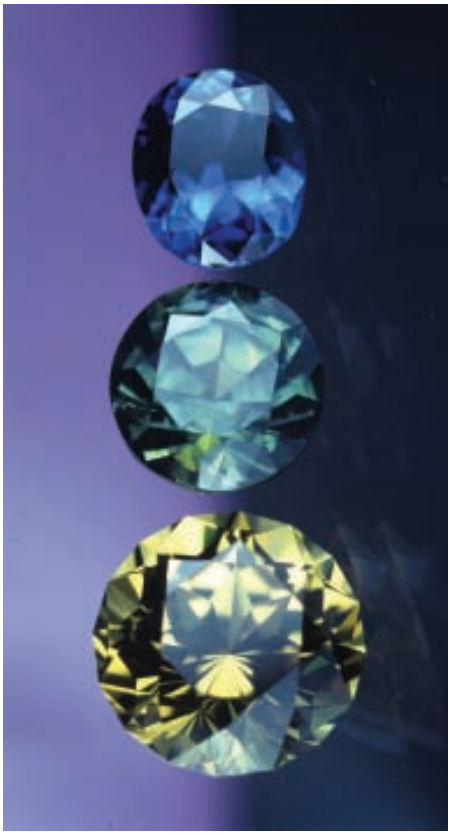

Figure 2: Faceted sapphires, from the main Australian gem fields. The golden yellow stone (12.2 ct) is from Tommahawk Creek, central Queensland, while the green (7.2 ct) and blue (3.5 ct) stones are from the Inverell area, New South Wales. Photo Australian Museum.

In this diagram, the average plot for the Unsourced NSW Group lies within the Inverell blue group and well apart from the other magmatic groups, which have higher Fe contents.

The triangular Fe–Ti (x10) – Mg (x100) diagram *(Figure 5)* is scaled after factors used by Peucat *et al.* (2007). They used this relationship to separate magmatic and metamorphic blue sapphires (Fe–Mg x 100 ratio = 0.64). This diagram largely separates the Inverell, Vulcan State Forest and Anakie blue and Inverell green groups, apart from some overlap with the Barrington magmatic blue group at the Fe-rich end (Fe/Mg x 100 > 0.70). The Inverell blue and New England purple groups overlap the magmatic–metamorphic boundary, suggesting some transitional features. The average for the Unsourced NSW Group plots near the Fe-poor end of the Inverell blue group and well apart from the other magmatic groups.

Table I: Trace element contents in ppm of East Australian sapphires determined using LA-ICP-MS.

Location	Sample	Colour (ct wt)	Number of spot analyses	ppm range								
				Fe	Ti	Cr	V	Ga	Mg	Ni	Sn	Ta
Inverell, NSW	D15778a	blue (1.022)	2	2927–3054	55.5–119.2	3.1–9.1	3.6–6.5	127.2–135.9	17.5–30.0	bdl–1.3	bdl	0.9
	D15778b	blue (1.940)	2	3391–3541	196.9–227.2	bdl	6.6	117.1–120.5	0.5–1.3	0.2–0.4	0.9–1.2	bdl
	D15778c	yellow blue (0.984)	2	5223–5729	26.3–69.4	0.1–0.3	1.5	137.3–149.2	9.9–13.1	bdl–0.2	bdl	0.1–0.7
	Average	blue	6	3978	115.8	<2.1	4.4	131.2	7.1	<0.4	<0.4	<0.4
	D46824	green (1.890)	3	6787–6898	24.0–30.4	0.7–4.3	12.4–12.9	137.0–139.8	10.3–12.1	bdl	0.3–0.9	bdl
	D46825	green (2.229)	2	6898–8260	32.8–35.4	1.7–4.9	9.3–9.6	132.4–134.7	10.2–12.1	bdl	0.1–0.2	bdl
	Average	green	5	7321	30.5	2.5	11.4	136.6	11.4	bdl	0.4	bdl
New England, NSW	D53903	purple (0.340)	2	4642–4966	42.4–62.7	290.2–291.2	37.3–37.6	169.8–173.1	20.0–24.1	bdl–1.4	bdl	bdl
	D53902	purple (0.154)	2	7841–8260	69.7–73.4	723.2–694.7	4.7–4.8	207.6–209.6	39.9–42.6	bdl–0.2	bdl	0.4–0.9
	Average	purple	4	6427	62.1	499.8	21.1	190.0	31.6	<0.4	bdl	<0.3
Vulcan State Forest, NSW	D53007	green–blue (1.514)	2	9626–9982	150.3–157.1	2.8–3.2	9.0–9.6	113.8–115.3	9.7–13.8	bdl	bdl	0.5–1.6
	Average	green–blue	2	9804	153.7	3.0	9.3	114.6	11.8	bdl	bdl	1.1
Barrington Tops, NSW	D54487a	blue (zoned) (0.160)	2	2390–2747	27.2–203.2	3.0–3.3	4.1–4.2	101.4–101.8	45.3–49.9	0.6–2.6	bdl–329.6	bdl
	Average	blue (zoned)	2	2569	115.2	3.2	4.2	101.6	47.6	1.6	164.8	bdl
	D54487b	blue (0.104)	2	4379–4721	436.4–467.4	12.4–13.7	182.6–186.6	42.1–44.4	265.7–293.3	3.7–4.6	bdl–324.6	bdl
	D54487c	blue (0.099)	2	3747–4265	408.7–426.4	187.9–203.0	80.0–86.2	29.7–33.3	262.5–271.8	0.6–2.6	bdl	bdl
	Average	blue	6	4278	434.7	104.3	133.9	37.4	273.3	2.9	<81.2	bdl
	D54487d	purple (0.105)	2	2852–2953	339.3–344.5	491.4–495.2	39.2–39.9	26.1–28.1	236.0–262.6	4.4–5.9	bdl–266.3	bdl
	D54487e	purple (0.241)	2	2450–2466	303.5–324.6	1626–1700	33.4–33.6	31.5–32.5	104.9–212.8	9.4–9.6	bdl	bdl
	Average	purple	4	2680	328.0	1078	36.5	29.6	204.1	7.3	<66.6	bdl
	EA BAR	green (0.211)	1	6811	61.1	2.8	10.6	25.6	34.8	bdl	bdl	bdl
Anakie, Queensland	D42708a	blue (1.899)	2	5128–5396	29.6–38.8	6.1–6.6	6.2	120.8–122.1	bdl–3.3	bdl–0.2	0.3–0.5	bdl
	D42708b	blue (1.852)	2	4518–4625	41.1–119.3	1.7–2.7	5.8–7.3	114.7–115.5	bdl	bdl	bdl	bdl
	D42708c	blue (1.538)	2	5723–6426	41.3–131.8	0.8–1.1	7.6–9.2	160.5–176.3	bdl–1.5	bdl	bdl–1.0	bdl–0.5
	Average	blue	6	5303	67.0	3.2	7.1	135.0	<0.8	<0.0	<0.3	<0.1

NB: bdl means below detection limit

Assessment of chemical comparisons

The results from the sourced sapphires and Unsourced NSW Group are plotted on three trace element variation diagrams *(Figures 3, 4 and 5)* that are commonly used to characterize gem sapphires. The Unsourced NSW Group field touches the edges of the Inverell and Barrington magmatic blue fields in *Figure 3,* falls in the Inverell blue group field in *Figure 4* and overlaps the Inverell blue group more closely than the other magmatic groups in *Figure 5*. Although in general this would suggest an up to 83% probability that the Unsourced NSW Group came from the Inverell sapphire field, the results in the three variation diagrams are subject to differences in errors related to the different plotting processes, which need assessment. The plus or minus errors for the chemical fields can either reinforce each other and favour closer overlaps or negate each other and favour greater separations. This will affect the extent of any overlaps in the plotted fields and needs consideration in assigning potential correlations.

The element ratios and values are plotted on a log–log scale in *Figure 3*, a linear–log scale in *Figure 4* and linear scales in *Figure 5*. The log–log plot errors will be relatively constant at about 10% for element abundances above 50 ppm, although analytical uncertainties will increase for element abundances below 50 ppm. Thus, the analytical uncertainty for a single element axis on a log scale would be about 0.1 of a log cycle and for element ratios would be about 0.2 of a log cycle. So over a whole ratio–ratio diagram *(Figure 3)*, the uncertainty in a ratio is 0.2 of a log cycle, perhaps increasing to 0.5 of a log cycle where element abundances under one ppm are involved. The uncertainties become harder to assess where a linear axis is used with a logarithmic axis *(Figure 4)* and even more so in triangular plots where axes are variously scaled *(Figure 5)*, so that potential correlations may be reduced to probabilities as little as 17%.

For further assessment of probable correlations between the sourced and unsourced sapphires, an additional ratio–

KEY

Inverell blue (IB)	New England purple (NEP)	Barrington green (BG)
Inverell green (IG)	Barrington blue (BB)	Anakie blue (AB)
Vulcan Forest blue (VB)	Barrington purple (BP)	Unsourced blue (NSW)

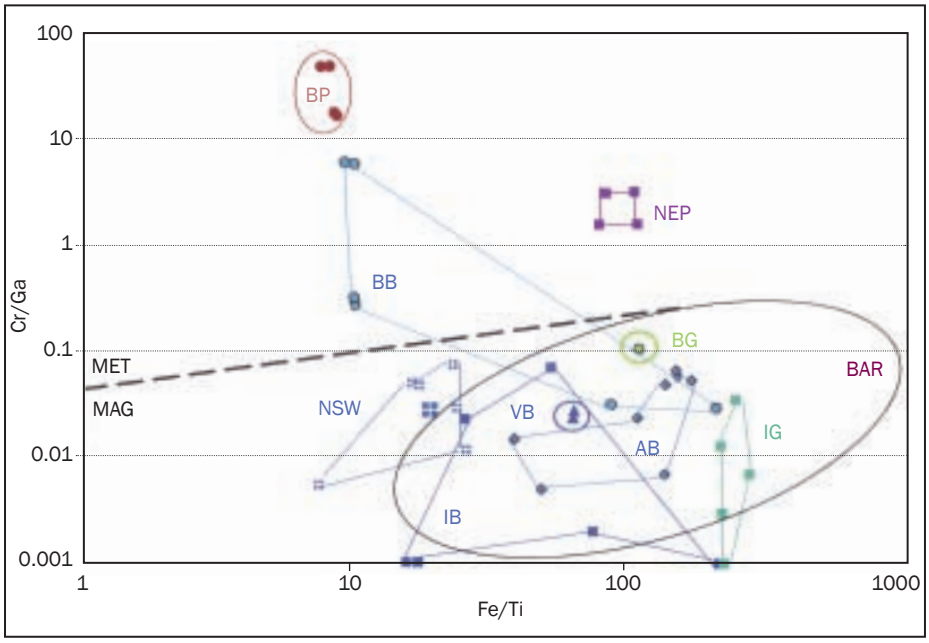

Figure 3: Cr/Ga and Fe/Ti log-log plots of sapphires analysed in this study and an average plot from data in Abduriyim and Kitawaki (2006). BAR is the oval area marking the Barrington magmatic sapphire field using data from Sutherland et al. *(2008b, 2009).*

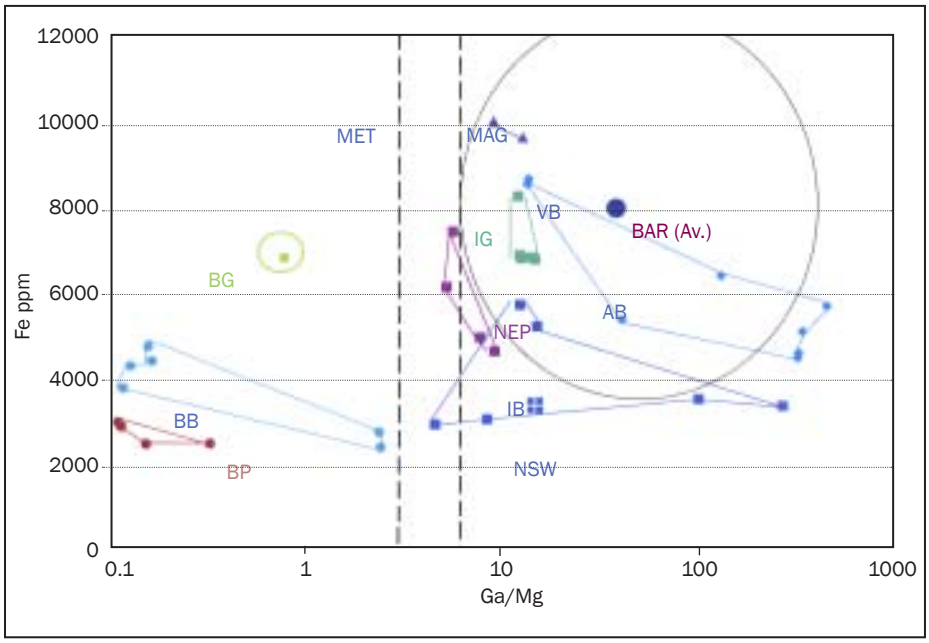

Figure 4: Fe (ppm) contents (linear scale) and Ga/Mg ratios (log scale) of sapphires analysed in this study and averaged from data in Abduriyim and Kitawaki (2006). BAR (av.) is the position of the average Barrington magmatic sapphire data in the near-circular field.

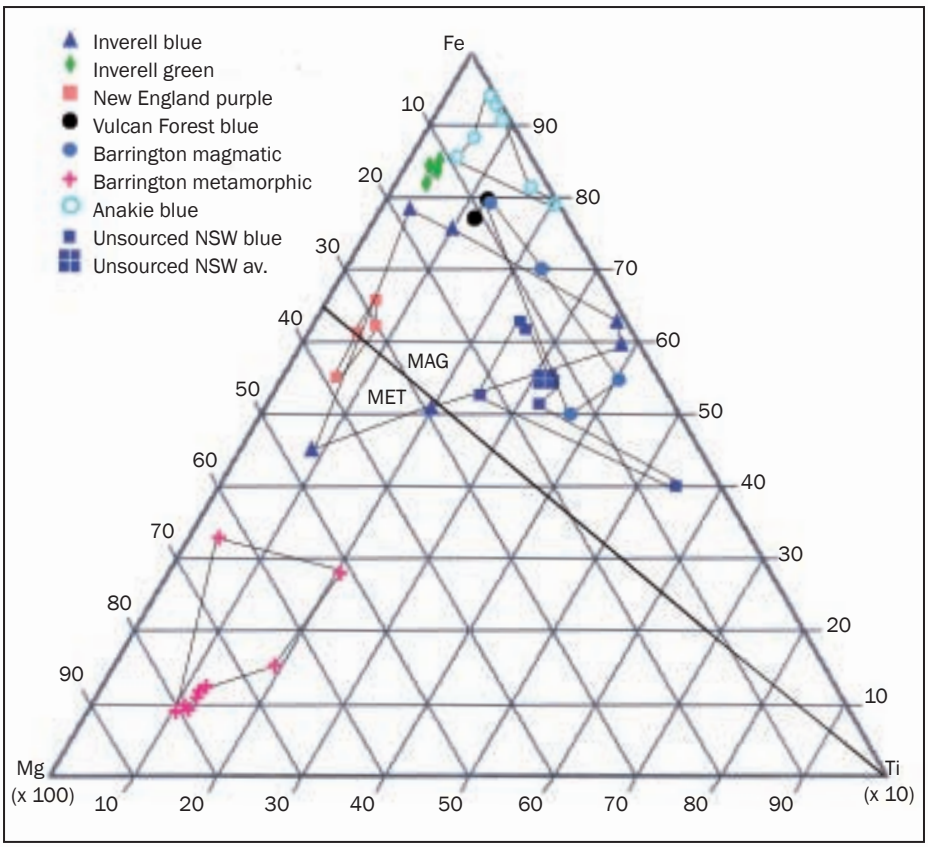

Figure 5: Trace element Fe– Ti × 10 – Mg × 100 diagram, with plots of analyses from this study; Barrington Tops magmatic blue sapphire plots are from Sutherland et al. *(2009) and NSW data are from Abduriyim and Kitawaki (2006).*

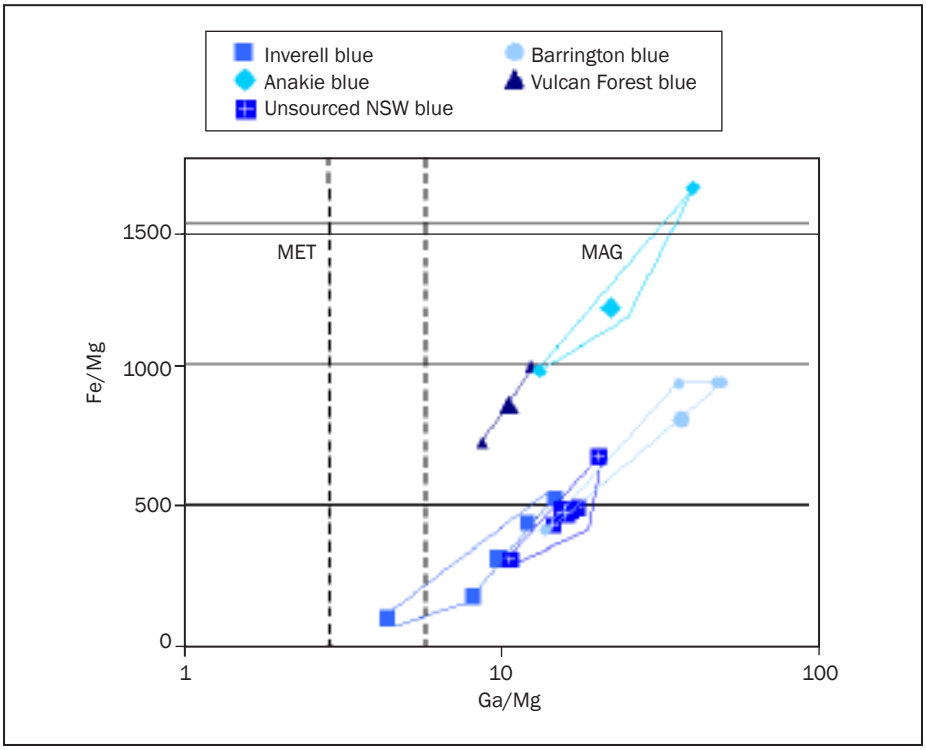

Figure 6: Trace element ratios Fe/Mg–Ga/Mg plotted for magmatic blue sapphires from this study, from Abduriyim and Kitawaki (2006) and from Sutherland et al. *(2009).*

ratio plot could provide tighter control on relative uncertainties. The results from the sourced sapphires in this study show that Ga and Mg are the two best indicators of origin (magmatic/metamorphic) and that Fe and Mg form another discriminating pair. So, a Fe/Mg–Ga/Mg diagram showing the different magmatic group plots is presented in *Figure 6,* for comparison with the other diagrams. An average (LA-ICP-MS) plot of magmatic blue Barrington Tops stones (4 analyses) is included from Sutherland *et al.* (2009) in this comparison. The results from the Unsourced NSW Group marginally overlap the Inverell blue field and the Barrington Tops magmatic blue average is farther away. The Vulcan State Forest and the Anakie blue results lie significantly apart from these localities. The average Fe/Mg and Ga/Mg ratios for the groups (excluding the extreme outlying Inverell plots) are respectively Unsourced NSW Group (477±201; 14.9±4.8), Inverell blue group (309±212; 9.35±5.1), Barrington Tops magmatic blue group (802±395; 34.0±11.3), Vulcan State Forest blue group (858±134; 9.7±1.7) and Anakie blue group (1197±437; 49.4±30.0). The two excluded Inverell blue plots show quite different ratios (off-scale) to the other Inverell blue and unsourced NSW blue plots and are regarded as representing a separate subsidiary magmatic source. Thus, the probabilities favour a likely correlation of the Unsourced NSW with the Inverell blue stones, rather than with any of the other groups. This assessment is consistent with a good match for the Inverell green group and analyses of green sapphires in the unsourced New South Wales donation (A. Abduriyim, unpublished analyses).

Other aspects

This study also highlights the unusual geochemistry of the New England purple group, which come from a zoned sapphire–ruby association (Webb, 2007; Sutherland and Webb, 2008). Unlike most known ruby, which has metamorphic associations, the New England ruby shows high Ga levels more typical of magmatic sources. In this, they resemble zoned

sapphire-ruby from Rio Mayo alluvial deposits, Colombia, South America, attributed to a transitional magmatic–metamorphic origin (Sutherland *et al.,* 2008a).

The sporadic high Sn values in some Barrington metamorphic/metasomatic sapphires is another curious feature. Elevated Sn is known in sapphires elsewhere, including Australian sapphires (Khin Zaw *et al.,* 2006). Introduction during polishing using Sn paste is a possibility for faceted stones from collections, although rough, unpolished sapphires from some localities contain significant Sn (I.T. Graham and F.L. Sutherland, unpublished data). Having taken extreme care to avoid any Sn contamination during polishing, high Sn values have still been found by Sutherland *et al.* (2008b) using LA-ICP-MS. In magmatic sapphires, this Sn accompanies elevated Be, Ta and Nb contents and cloudy fluid inclusions are present, so the sapphires may incorporate a mobile volatile component.

Debate exists whether locality of origin for gemstones is important for the gem trade and whether modern gem laboratories can distinguish gems from different localities (Abduriyim *et al.,* 2006). For gem corundum, the geological source can now be specified with some certainty (McClure, 2006 and this paper) and identifying the source can affect the values of stones (Rossman, 2009). The next step of exactly pin pointing precise gem localities or regional deposits is more problematic. The results from this study, however, provide a guide and encouragement towards this future feasibility.

Conclusions

Comparative trace element studies on gem corundum of unknown and known sources, as in this Australian case study, may guide geographical sourcing of unlocalized gemstones. Trace elements in the studied Australian sapphires, including Fe, Cr, Ga and Mg and their ratios, have proved useful in characterizing sapphire localities. In particular, Fe/Mg and Ga/Mg ratios plotted on a mutual diagram have provided good separations. Faceted sapphires labelled broadly from New South Wales in a previous LA-ICP-MS study are now related to an Inverell, New England gem field source.

Acknowledgements

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Appendix I: Geological settings of analysed sapphire localities

Inverell field, New South Wales

This long established mining field includes some of the highest grade sapphire placer deposits known. It is particularly renowned for its dark blue sapphire, while ruby and fancy-coloured sapphire are recovered as a minor component. The sapphires are recovered from basaltic volcaniclastic, sub-basaltic palaeo-alluvial and recent alluvial deposits associated with extensive alkali basaltic eruptive rocks most of which are between 85 and 30 Ma old (from K-Ar whole-rock basalt and reset zircon fission track ages). The rocks overlie Devonian to Carboniferous folded sequences and Late Carboniferous to Early Permian granites and volcanics that make up the New England Orogen and are unconformably overlain by less folded Permian to Triassic beds of the Sydney Basin sequence. Dating of syngenetic zircon included in the sapphires suggest there were several ages of gem-formation, particularly between 36 and 33 Ma.

Vulcan State Forest, New South Wales

An intermittently mined sapphire placer field in the Oberon area lies within folded Silurian to Devonian sedimentary and volcanic beds and Carboniferous granites of the Lachlan Orogen, which are overlain by Late Cenozoic alkali basalt remnants. Associated zircon megacrysts in the placers give fission track ages of 157 to 154, 24 to 20, 16 to 15 and 9 Ma and U-Pb dating of these zircons indicates several episodes of Late Cenozoic gem formation, but no zircon included in sapphire is as yet dated.

Barrington Tops, New South Wales

This field is noted for near-equal amounts of ruby, fancy coloured and blue metamorphic sapphire and blue magmatic sapphire. Recent mining, now ceased, was in placers shed from the adjacent basalt plateau, dominated by alkali basalts. Dating of basalts, a rare gem-bearing diatreme and associated zircon megacrysts suggest multiple eruptive discharges of gem materials between 61 and 4 Ma ago. The underlying rocks consist of folded Late Palaeozoic sequences, a Late Permian granodiorite pluton and minor Early Mesozoic dykes and tuffs within the New England Orogen. At least two ages of magmatic gem-formation are suggested by U-Pb dating of separate zircon megacryst types at 60 and 45 Ma, while the metamorphic sapphire and ruby was probably formed prior to initial basaltic eruption.

Anakie field, Queensland

This major sapphire mining field is made up of several alluvial fields lying within an eroded alkali basaltic province now largely represented by numerous plugs and rare lavas (dated from 58 to 14 Ma). The sapphires are recovered from multi-recycled alluvial deposits and rare volcaniclastic remnants, while rare sapphire xenocrysts and sapphire-bearing syenite xenoliths are found in a few plugs. The field is noted for its large yellow, orange and black star sapphires among the prevailing blue and green sapphires. The basalts intruded the Anakie Inlier, a basement feature that incorporates Neoproterozoic to Early Palaeozoic metamorphic rocks , a Middle Devonian granite pluton and overlying Late Devonian to Carboniferous sedimentary and volcanic beds. Sapphire formation extends to ages at least greater than 58 Ma.

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Dickite: a gem material for carving from Thailand

Seriwat Saminpanya, Chaichart Dharmgrongartama and Namrawee Susawee

Abstract: Dickite ($Al_2Si_2O_5(OH)_4$) from Saraburi, Thailand, is a raw material for the ceramics industries. It is also an ornamental gem material and its physical and gemmological properties are reported. In the gem trade, three grades are distinguished: grade A (cream and red with Al_2O_3 ~41 wt% and SiO_2 ~43 wt%), %); grade B (grey); and grade C (dull red) (Al_2O_3 ~15-16 wt% and SiO_2 ~79 wt%). The XRD results indicate that the samples of grades B and C contain quartz. The dickite occurs as cryptocrystalline aggregates and SEM images indicate that these are pseudo-hexagonal plates stacked like books. Even though dickite has a hardness of only 1½–2 on Mohs' scale, it is quite coherent and easily carved. A survey indicates that carvers prefer the unique colours and textures of grade A samples to produce animal figurines. The rough stones should be chosen with care in order to match the appearance and size of the expected product.

Keywords: carving, dickite, ornamental gem material, properties, spectroscopy, Thailand

Introduction

The demand for ornamental gem materials in the form of carvings is increasing in various markets. Some raw materials other than expensive mainstream and traditional materials such as jadeite and nephrite, have become a choice for some carvers and consumers. Indeed, several soft materials such as steatite, gypsum, marble, calcite and fluorite can be carved and sold in the market. These materials can be more easily carved and entail lower costs and less time than harder and tougher ones. The quality and the fascinating appearance of the products are dependent on factors such as the unique properties of the material itself, the design, and the skill and experience of the carver. Although less durable than tougher materials, their beauty and rarity make them interesting for consumers. Carvings are generally used for decoration or showcase display, therefore the hardness and toughness of the items are less important than their beauty.

Dickite, described here, is one of the soft materials in the mineral kingdom which can make fascinating products. A highly pure variety (red breccia-like appearance) has been used as a raw material for a long time. However, the products are still locally marketed as, for example, the decorations on some temples *(Figure 1)*. Carved dickite items can take various forms, for example Buddha statuettes, tables, jars and animal figurines. For industry, dickites can be used as a raw material for refractory products, tiles and white cement. Dickite ($Al_2Si_2O_5(OH_4)$) is a clay mineral with a low hardness on Mohs' scale of 1½–2 and occurs in fine-grained masses in a range of colours: generally cream, greyish green, pale greyish blue, white, pale green, yellow or dark blue (Khuentak, 1988b: 28-9). However, the owner of a mine in Thailand revealed that there are also red, pink and yellowish cream varieties with a waxy lustre. Khuentak (1988b: 29) classified dickites in the Thai deposits into three broad grades: i.e. grade A (high purity) grade B (less pure and contaminated by other minerals) and grade C (low quality and similar to rhyolite in appearance).

Originally, dickite in Thailand was thought to be pyrophyllite and this name appeared in the concessions for mining from the government (Yaemniyom, 1988: 27), so this is how it was sold. The two minerals are similar in appearance

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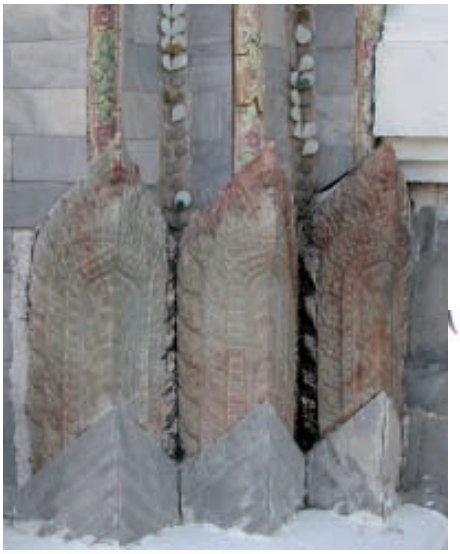

Figure 1: (Left) Three pieces of carved dickite (cream+red) are used to renovate parts of the throne-hall in the Phra Maha Monthien, a group of buildings in the Grand Palace, Bangkok. (Below) Phra Mondob (pavilion) of the footprint of Lord Buddha at Wat (temple) Phra Buddhabat in Saraburi Province, decorated with the carved dickite pieces (marked with arrows).

and some of their physical properties are very close to each other. However, misidentification of dickite may cause trading at unrealistic prices. Some mine operators sell their crushed dickite for 300–1000 Thai Baht (~ US$9–$30) per ton to the ceramics industry, while some Taiwanese customers may buy grade-A blocks of dickite for 10,000 Baht (~US$300) per ton specifically for carving (based on information from a mine operator). In this way dickite from Thailand may appear in Taiwanese markets as carved gem products.

The Department of Mineral Resources of Thailand (Yaemniyom, 1988: 27, Khuentak, 1988a: 67, 69; and Khuentak, 1988b: 28-9) reported that the reserves of dickite in Thailand total approximately 20,000 tons. Moreover, grade-A dickite is rare, so the reserves of this variety may be the largest in the world.

Dickite has been studied in many aspects by several authors. Spectroscopy and structure were investigated by e.g. Brindley *et al.* (1986), Johnston *et al.* (1998), Beaufort *et al.* (1998), Zamama and Knidiri (2000), Balan *et al.* (2002) and Johnston *et al.* (2002). Works on heat treatment of dickite include Kerr and Kulp (1948), Frost and Vassallo (1996) and Shoval *et al.* (2001). Marumo (1989) studied the origins of dickite, and isotope geochemistry has been reported by Girard and Savin (1996). However, dickite has not yet been reported in any gemmological literature.

Although carved dickite cannot be used to substitute for the much harder carving materials such as jadeite or nephrite, it has the advantages of low price, a unique beauty and ease in carving due to its low hardness and low brittleness. This paper will present a brief geology of the dickite deposits in the study area and the subjective points of view obtained from carvers will be compared. Finally, the physical, chemical, gemmological and spectroscopic properties of dickite will be discussed and compared with other carvable stones.

Location and brief geology of deposits

There are two known dickite deposits in Thailand. The larger is located near the border of Nakhon Nayok and Saraburi provinces and the other is in the Muang district of Nakhon Nayok province. Dickite occurs in Permo-Triassic volcanic rocks (Salayaphong, 1996) *(Figure 2)*. Khuentak (1998b) reported that at these localities mineral solutions and volatiles seeped into fractures and cavities in the host rocks, rhyolites and tuffs, and transformed them hydrothermally to dickite. This is consistent with its paragenesis in other world localities where the dickite is formed by replacement of volcanic rocks and fracture-filling (Choo and Kim, 2004; Viorica *et al.,* 2004; Deyell *et al.,* 2005). Alumina and H_2O are added by means of the hydrothermal process while CaO, Na_2O and K_2O are reduced. In the Khoa Cha-Om mine, Saraburi, this process resulted in

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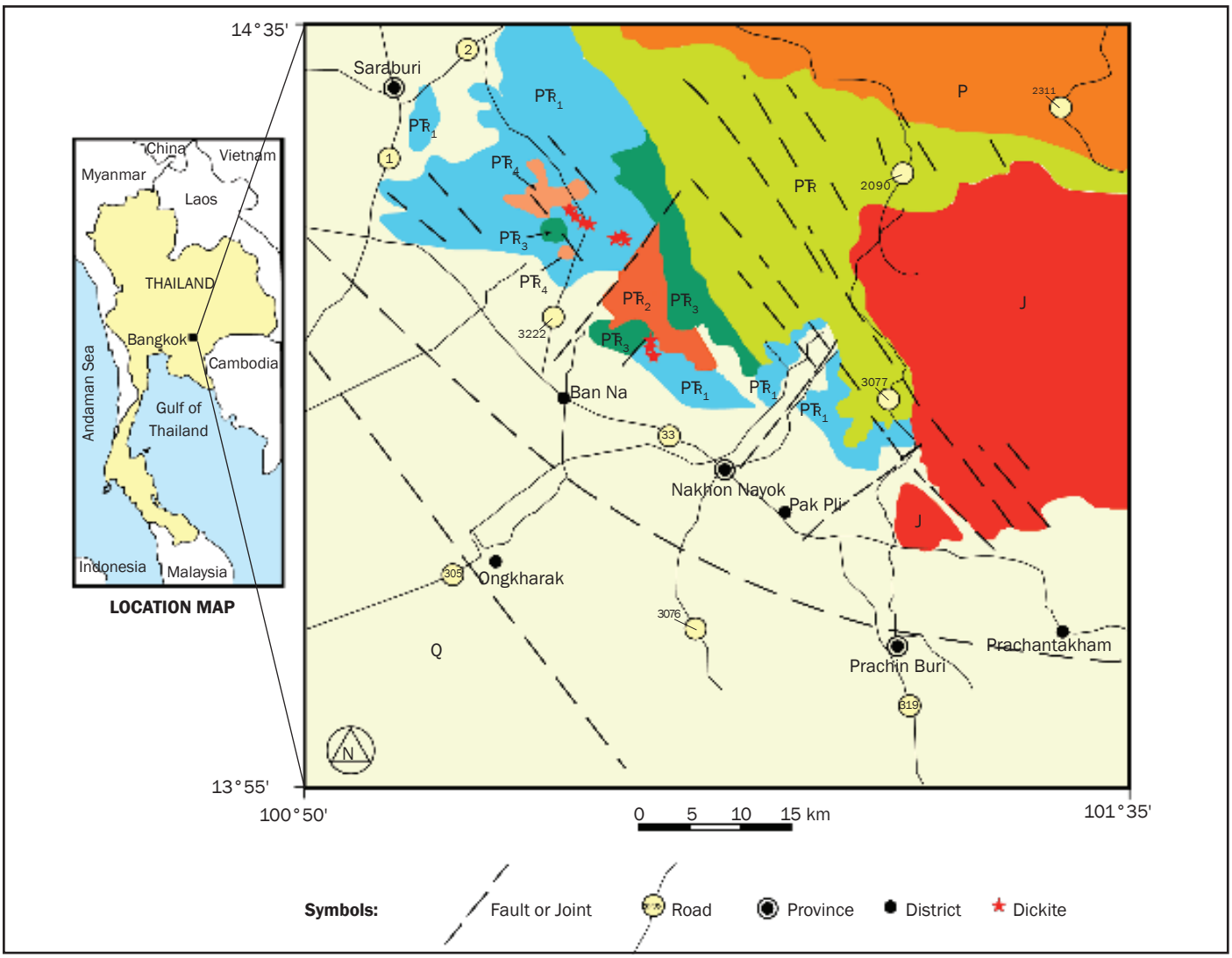

Explanation of Geological Map

	Q	Clastics	Clay, silt, sand and gravel	Quaternary
			Unconformity	
	J	Clastic rocks	White to brown quartzitic sandstone underlain by maroon micaceous and calcareous siltstone and sandstone with basal conglomerite.	Jurassic
			Unconformity	
Unclassified quartz-feldspar flow tuff overlain by lapilli flow tuff and volcanic breccia.	PŦ Volcanic rocks	PŦ$_4$ Lava flow and shallow intrusive	Deep green, medium- to fine-grained, locally vesicular, porphyritic andesites and equigranular basaltic andesites.	Permo-Triassic
		PŦ$_3$ Pyroclastic rocks and dyke rocks	Pink and greyish green, massive, medium- to course-grained quartz-feldspar flow tuff with flow orientation of rock fragments and local dykes of porphritic andesites and basaltic andesites.	
		PŦ$_2$ Pyroclastic rocks	Maroon, pink and green, massive, fine- to medium-grained plagioclase flow tuff with some oriented rock fragments.	
		PŦ$_1$ Pyroclastic rocks, dyke rock and volcanic plug	Maroon, bluish green, brown and pale brown to white plagioclase flow tuff, pumice flow tuff, dust flow tuff, shard flow tuff and quartz and/or plagiolcase flow tuff commonl;y massive or showing flow lamination including minor pumice fall tuff and dust fall tuff with prominent bedding and graded bedding, occasional dyke and plug (?) of rhyodacite.	
			Unconformity	
	P	Chemical and clastic rocks	Limestone, chert, shale, siltstone, sandstone and shale.	Permian

Figure 2: Geological map of Saraburi and Nakhon Nayok provinces showing locations of dickite deposits (modified from Salayaphong, 1996: 18).

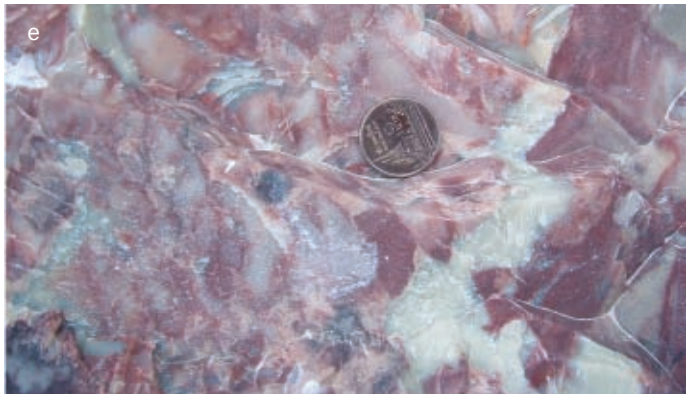

Figure 3: (a) The mine at Khoa Cha-Om, Tambon Cha-Om, Amphoe Kaeng Khoi, Saraburi province, picture taken from 21 km post on route No. 3222.
(b) The quarry at the mine.
(c) Cream and red grade A dickite occurs in the dark red vein near the centre of the picture.
(d) Block of cream and red dickite from the vein visible in (c).
(e) The detailed texture of cream and red dickite.
(f) The high quality, cream variety of dickite exists as veinlets in grey dickite of lower grade, but this cream grade is not abundant.

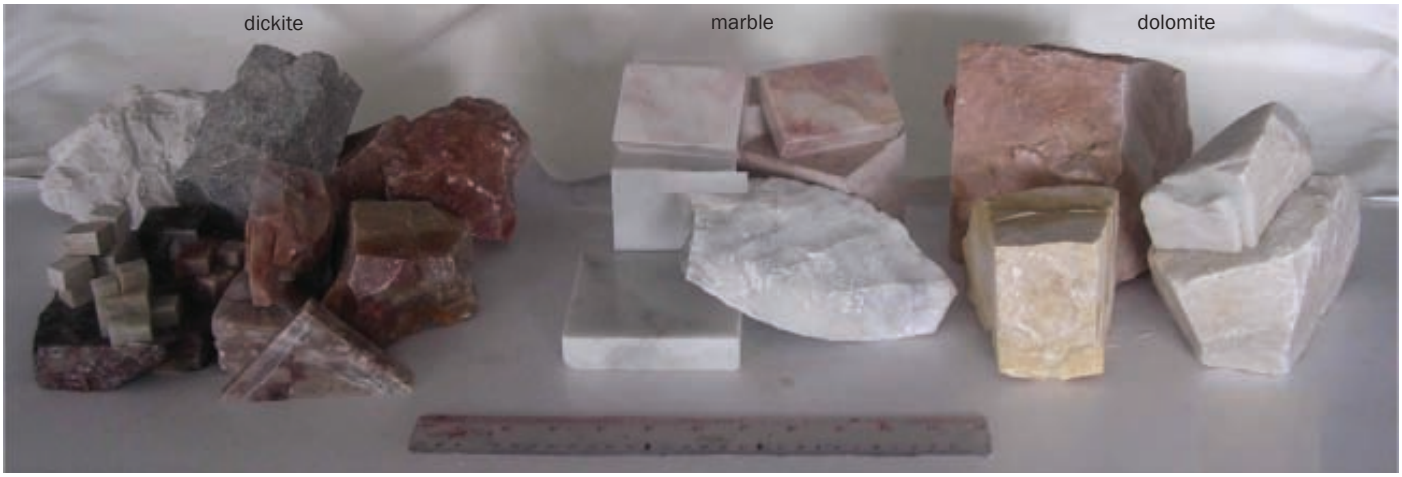

Figure 4: The rough materials used in this study showing the range of their colours.

small scale or vein-like ore bodies *(Figure 3)*. The distribution of the ore bodies is dependent on the structure (cavities or fractures) of the host rocks and may appear random. Some domains in the host rocks are completely converted to dickite while others have only been partially replaced. Small crystals of pyrite can be found disseminated in some zones.

Materials and methods

The dickite samples for the present study were collected from Suthakit Mining Co. Ltd, located in the area of Khao Cha-Om, Cha-Om subdistrict, Kaeng Khoi district, Saraburi province. Two low-durability materials which are actively mined and available in Thailand were also collected for comparison: first, marble from Na Phra Laan, Saraburi province (the quarries are located to the northwest and approximately 50 km away from the dickite deposit) and second, dolomite from P&S Pand's Group Co. Ltd., Kanchanaburi province (located to the west and about 300 km away from the dickite deposit) *(Figure 4)*. The marble and dolomite are commonly used for carving decorative items in Thailand. Dickite samples were sorted on the basis of different colours and textures *(Figure 5)*.

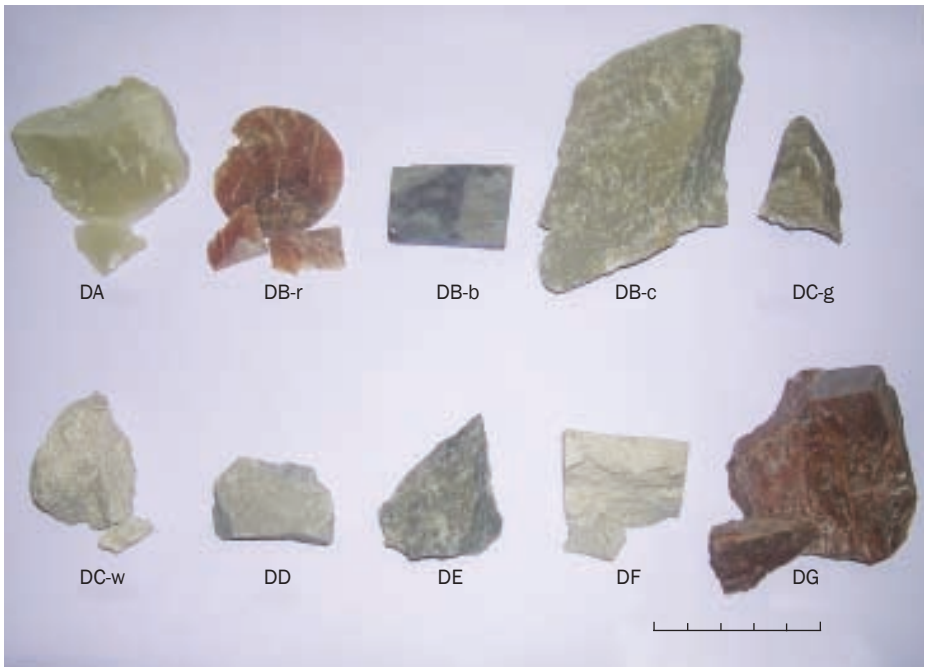

Figure 5: The varieties of dickite studied: samples DA, DB-r and DB-b were treated as the top-quality group (Grade A) for gem ornamental material due to their translucency, waxy appearance and beautiful colour and texture. The rest are dull, subtranslucent to opaque and more brittle. Sample DF is dull white and brittle with high porosity while DG is dark red, fine-grained and massive, harder and more brittle; these two samples are probably only partly converted to dickite from tuff and rhyolite respectively.

Carving dickite

According to chemical compositions presented later *(Table IV)*, dickite samples DA (cream) and DB (cream+red) are both of high purity. Therefore they are grouped in this study as grade A. Samples DC (grey-yellow), DD (grey), DE (dark grey) and DF (dull white) are grouped as grade B because of similarity in composition and significant impurity. The samples of DB (cream+red) with breccia-like appearance were selected to be carved in this study as they are available in relatively large amounts in the mine and the colours of the samples are more beautiful than the rest. Moreover, this variety is popular for carving in Thailand. The DA variety is too rare to be used in this carving survey and the DC and grade C varieties are either too dull or brittle — making them unsuitable as carving material.

The equipment used for carving includes rock saw, table, hose, foredom (flexible shaft) and mounted abrasive point, sanding paper, goggles, mask, etc. The DB samples with the fewest and least fractures were selected and sawn or trimmed to the required size. Then they were carved according to the following procedures (Wertz and Wertz, 1994: 12–42):

Figure 6: A selection of carvings made from dickite DB (cream and red). (a) Image of Buddha. (b) Chinese Buddha ('laughing Buddha'). (c) Cameo portrait of a lady. (d) Horse.

1. drawing an outline on the rough (designing);
2. pre-forming with a saw;
3. grinding the outline;
4. grinding the features;
5. sanding; and
6. polishing.

This job was done by nine carvers who have been working on carving rocks and minerals for more than five years, and the questions in this survey sought their opinions on carving dickite compared to marble and dolomite.

Physical gemmological and spectroscopic studies of samples

Grade A (DA and DB) and grade B (DC) dickites were investigated. Samples DD, DE and DF were also studied but not chemically analysed. The specific gravity (SG) was measured by the hydrostatic method using an electrical balance. The refractive index (RI) of dickite samples could not be obtained accurately using a standard refractometer with a glass table and attempts to measure RI by the use of a reflectance meter only gave unreliable results. However, the Becke Line method can give a single RI value regardless of birefringence. Hardness pencils were used to obtain Mohs' hardness values. Polarizing microscopy and scanning electron microscopy (SEM) were employed to study the habits of dickite crystals. Infrared and Raman spectra were obtained, and the mineral species present in the samples were identified using X-ray diffractometry (XRD). Chemical compositions of dickite

Table I: Summary of opinions of nine carvers on the rough samples of dickite, marble and dolomite prepared for carving.

Property	Dickite (cream+red)	Marbles (white-grey; pink; black)	Dolomite (yellow)
Colour and texture	Uneven colour and texture: can be used for carvings but the rough samples should be chosen carefully; not suitable for portrait but good for animal figurines.	Even colour: suitable for carving portraits, spiritual images and animal figures.	Even colour: suitable for carving as portraits and animal figurines.
Hardness	Lowest	Low	Low but harder than dickite and marble.
Toughness	Higher than marble and dolomite, less risky for breakage than marble and dolomite, suitable for both cameos and round work (three-dimensional items).	Less tough and more brittle than dickite: more suitable for cameos than round work.	The brittleness is intermediate between dickite and marble but it contains abundant fractures: more suitable for cameos than for round work.

Dickite: a gem material for carving from Thailand

Table II: Dickite, marble and dolomite carvings used in the survey of the nine carvers, and the summarized opinions of the carvers.

Carving form	Dickite (cream+red)	Marbles (white-grey; pink; black)	Dolomite (yellow)
Horse	Easier than marble due to higher toughness but care is needed, then the trunk may be carved to support horse's body.	The trunk must be carved to support the horse as the legs of the horse would not be tough or strong enough.	The trunk must be carved to support the horse as the legs have too many fractures and are too brittle.
Deer	Easier than marble and dolomite as dickite is tougher.	The product has some cracks due to brittleness.	The rock can be carved as a cameo. It is brittle probably because explosives were used to extract the ore.
Bear	The carving was easier than those of marble and dolomite because dickite is tougher and the object has fewer sharp edges.	Though the sample is brittle, no cracks have developed.	The product is good because the rock is hard and beautiful colour.
Boxers	The sample can be carved in round work but special care must be taken because the object has some thin and long components.	The rock sample is not suitable for this form of carving.	The sample is not suitable for this form of carving.

Table II (continued)

Carving form	Dickite (cream+red)	Marbles (white-grey; pink; black)	Dolomite (yellow)
Lady with a bowl	Can be carved as round work but uneven colour in the sample is not suitable for the this form of carving.	Can be carved in this form but the colour is too pale; the pink marble would be more suitable.	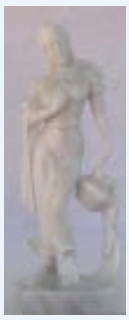 Can be carved but the raw material should be free of fractures.
Lady portrait cameo	Higher toughness but unevenness of cream and red colours in the sample can make the product less beautiful.	Suitable for this form of carving as cameos are less fragile than the round work and the even colour is not a drawback to the beauty of product.	Suitable for this carving form because the cameo is less fragile than round work and its even colour does not affect its beauty. Heavy fractures in the sample are difficult to avoid.

were analysed by wavelength dispersive-X-ray fluorescence (WD-XRF) for the major elements with the use of the standards SY-2 and SY-3 from CCRMP (Canadian Certified Reference Materials Project). The traces were analysed with an atomic absorption spectrophotometer (AAS) using the standard solutions with calibration curves. The H_2O^- data were obtained by heating the samples at the temperatures of 105–110°C and at 900–1050°C the values of loss on ignition (LOI) were collected. Details of these techniques can be found in, for example, Potts (1987), Skoog and Leary (1992), Reed (1996, 1997), Hibbard (2002) and http://www.crpg.cnrs-nancy.fr/Geostandards/GGR_ms.v03/ms072.html.

Results and discussion

It should be noted that in some parts of this paper the authors report or focus mainly on the properties of dickite samples DA, DB and DC since the rest are not important in terms of unsuitable conditions for carving and their properties are more likely to be the same as DC. The results for an experiment on carvings, physical and gemmological properties and XRD, FTIR and Raman microprobe, will be discussed as follows.

The results of a study on carving different subjects in different materials

Some examples of the dickite carvings studied are shown in *Figure 6*. Samples of dickite, marble and dolomite have their own unique blend of colour and texture as well as different hardnesses and strengths. For example, marble and dolomite are harder, but are more brittle than dickite and have a higher tendency to break if the carved object has a sharp corner or a long thin component. The evaluation information on the rough materials used in this work supplied by the carvers is summarized in *Table I*.

This study has concerned the carving of such subjects as a horse, a deer, a bear, boxers, a lady with bowl and a cameo of a lady. The images of the carved items and the opinions of nine carvers while they were carving them are summarized in *Table II*.

Physical and gemmological properties

The appearance and characteristics of dickite compared to marble and dolomite samples are shown in *Figure 4* and *Table III*. The crystal habit of dickite in polished section viewed under the polarizing microscope is not decipherable because of its intergranular texture; red inclusions can be clearly seen in sample DB *(Figure 7)*. Under the SEM, there are good images of polycrystalline habit in which the crystals show granular texture

Dickite: a gem material for carving from Thailand

Table III: Some physical and gemmological properties of dickite, marble and dolomite used for carving.

Property\Material	Dickite	Marble	Dolomite
Chemical formula	$Al_2Si_2O_5(OH)_4$	$CaCO_3$	$CaMg(CO_3)_2$
Crystal system	Monoclinic	Trigonal	Trigonal
Locality in Thailand	Cha-Om subdistrict, Kaengkhoi district, Saraburi province	Khao Ngob (for white-grey and pink varieties) and Khao Khaow (for black variety), Na Phra Laan subdistrict, Chalermphrakiat district, Saraburi province	Wang Dong subdistrict, Muang district, Kanchanaburi province
Crystal habit	Polycrystalline-massive	Polycrystalline-massive	Polycrystalline-massive
Colour	Cream, red, grey, white	White-grey, pink, black	Grey, light yellow, pink
Hardness (Mohs) scale*	1½–2	3	3½–4
Lustre of polished surface	Waxy	Subvitreous	Waxy to subvitreous
Transparency	Translucent to opaque	Translucent to opaque	Translucent to opaque
SG	DA = 2.58–2.66 (av. = 2.61, n=33)	2.58–2.75[a]	2.84–2.86[a]
	DB = 2.56–2.62 (av. = 2.61, n=33)		
	DC = 2.58–2.64 (av. = 2.61, n=33)		
RI	1.560[b]; 1.561–1.570[a]	1.486–1.660[a]	1.500–1.681[a]

a. Data from http://www.mindat.org/min-1287.html (the RI of marble is from calcite).
b. Tested by the Becke Line method under the transmitted light microscope.
Note: Other tests for gemmological properties, e.g. ultraviolet, Chelsea colour filter and spectroscope, do not give any useful result.

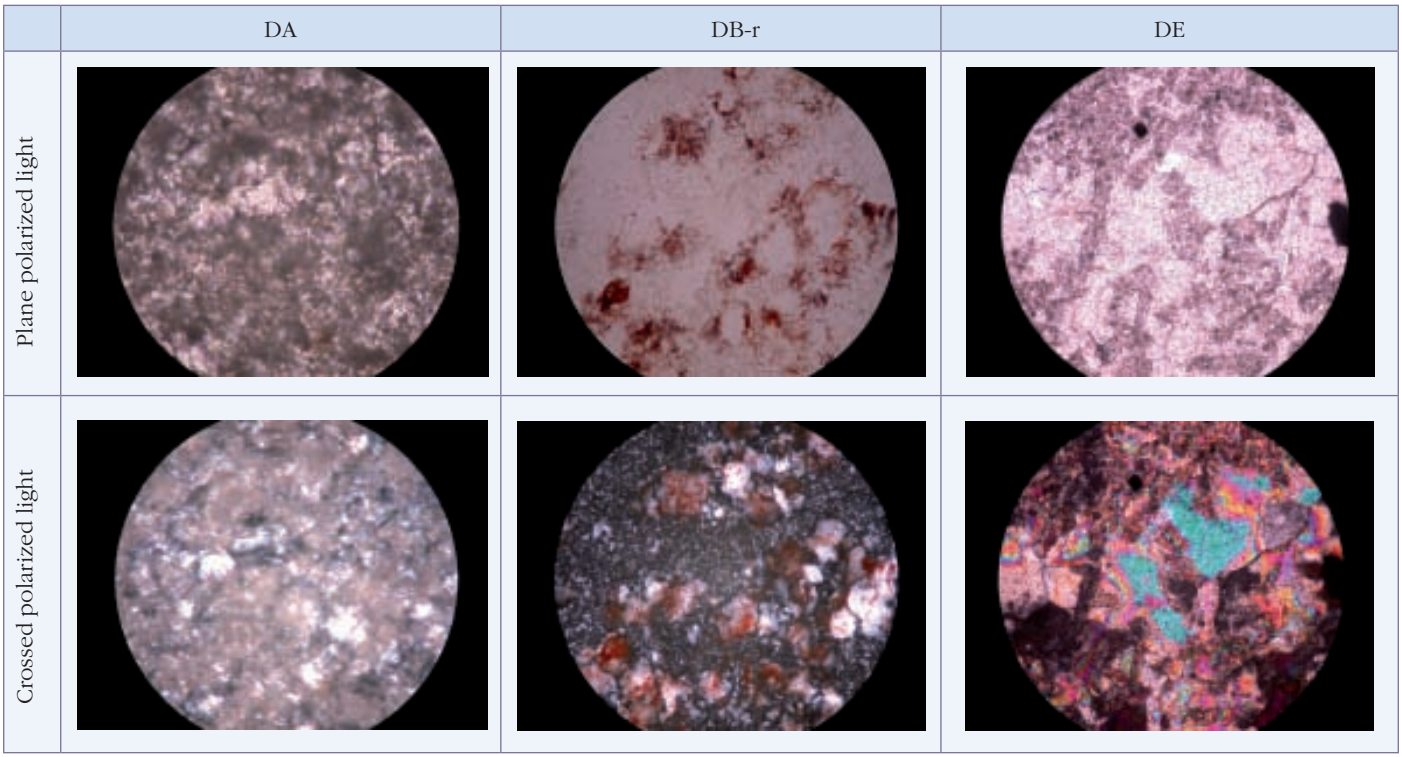

Figure 7: Photomicrographs of dickite thin sections from samples DA, DB-r and DE under a polarizing microscope. At these magnifications, all samples exhibit granular textures. Compositional and spectral information for DA are given in Tables IV, V and VI. The red area of the cream and red variety sample DB-r shows red platelet inclusions which are probably hematite. The DE sample contains some larger grains which show the uniaxial interference figure typical of quartz. The high birefringent colours on this slide are due to it being thicker than the normal 0.03 mm. Magnification 400x.

(a) Scale bars 100 μm

(b) Scale bars 10 μm

(c) Scale bars 1 μm

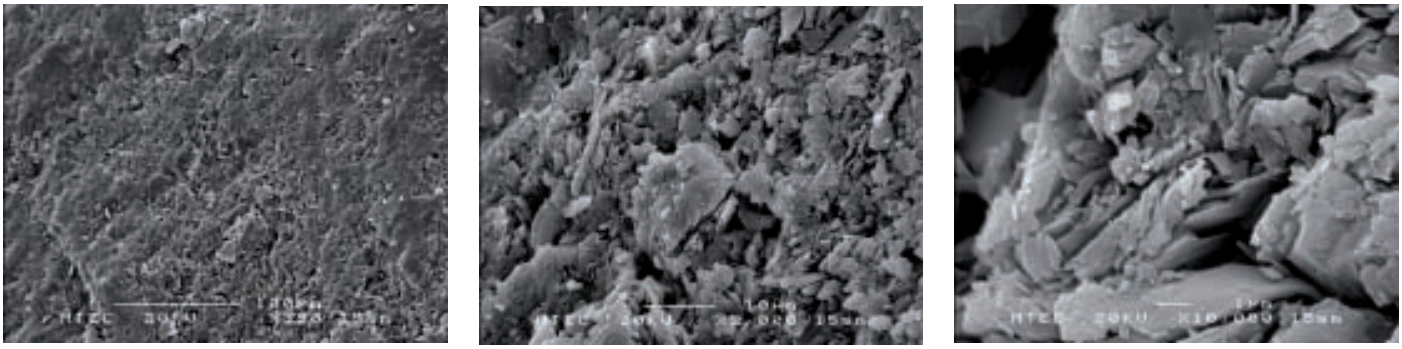

Figure 8: SEM images of cream dickite (DA). The plate-like crystals are tightly intergrown and very narrow spaces between crystals mean that porosity is low.

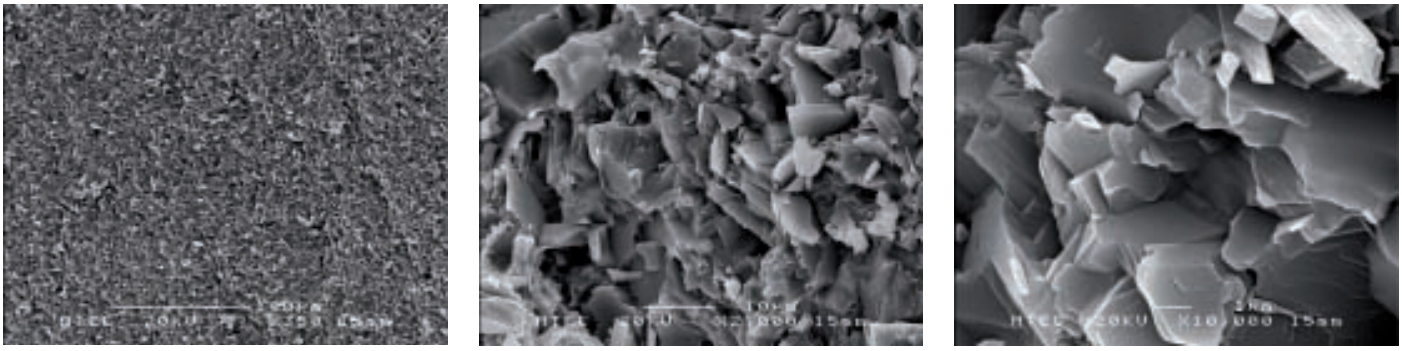

Figure 9: SEM images of dickite sample DB-r (cream and red). In c), the bright crystals at the top-right corner are probably hematite. The crystals are tightly packed, massive and porosity is low.

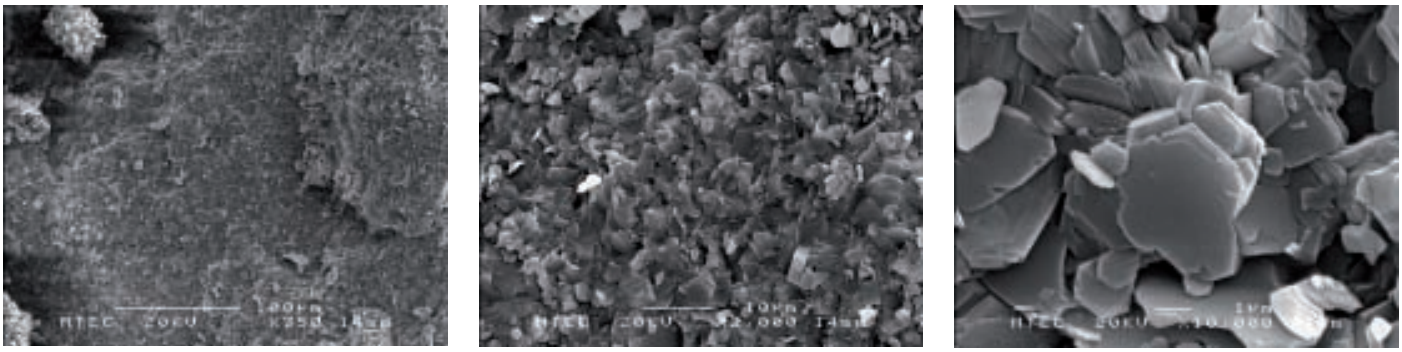

Figure 10: SEM images of white-grey dickite (DC-w). There are more spaces between grain boundaries in this sample and it has higher porosity than DA and DB. The image (c) clearly shows stacks of pseudo-hexagonal platy crystals. Note that the crystal habit of samples DD, DE and DF are similar to that of DC.

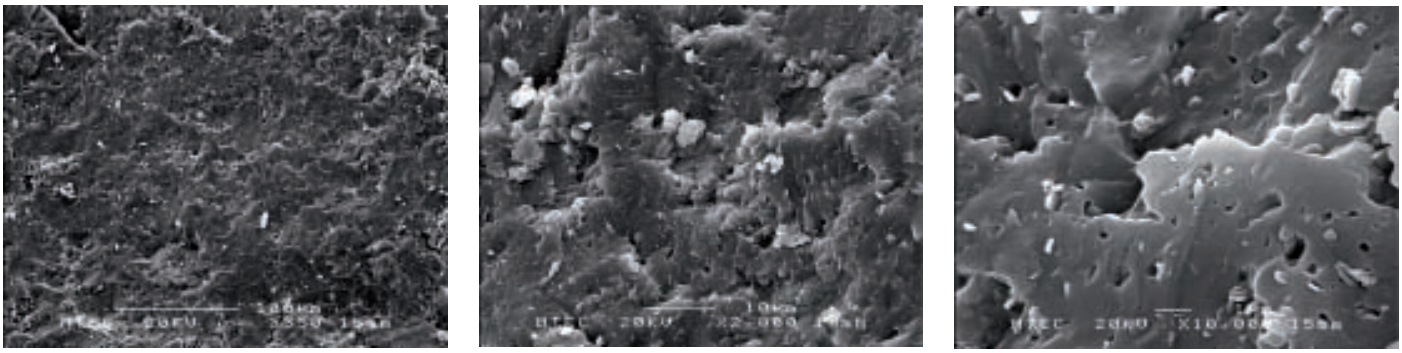

Figure 11: SEM images of dull-red sample DG (rhyolite?). Even at high magnification, the sample is very fine-grained (glass?) although it contains some pits which give it some degree of porosity. Some of the individual pits contain a platy or tabular crystal.

Table IV: The chemical compositions of dickite, marble and dolomite from Thailand.

Sample	Dickite						Marble[a]	Dolomite[b]	
	DA 1-3 (cream)	DB 1-3 (cream+red)	DC 1-3 (white grey)	DD 1-3 (dark grey)	DE 1-3 (dark grey)	DF 1-3 (dull white)	White-grey	White	Pink-yellow
Major element (wt%):									
SiO_2	43.39	42.85	76.12	79.37	75.52	78.18	0.65	0.15	0.32
TiO_2	<0.05	<0.05	0.12	0.11	0.16	0.13	n/a	n/a	n/a
Al_2O_3	41.39	41.73	16.89	14.60	17.21	15.41	0.03	n/a	n/a
Fe_2O_3	<0.10	0.10	0.43	0.34	0.45	0.22	0.10	0.20	0.24
MnO	<0.05	<0.05	0.06	0.05	0.05	<0.05	n/a	n/a	n/a
CaO	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	54.93	31.23	31.31
MgO	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	0.43	21.41	21.14
Na_2O	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	n/a	n/a	n/a
K_2O	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	n/a	n/a	n/a
P_2O_5	<0.05	0.16	<0.05	<0.05	<0.05	<0.05	n/a	0.01	0.01
LOI	14.15	14.20	5.63	4.83	5.90	5.32	43.55	n/a	n/a
H_2O^-	0.50	0.46	0.27	0.21	0.22	0.22	0.28	n/a	n/a
Trace element (ppm):									
Co	<3	<3	<3	<3	<3	<3	n/a	n/a	n/a
Cr	5	5	13	9	12	6	n/a	n/a	n/a
Cu	6	3	6	4	13	15	n/a	n/a	n/a
Ni	<2	<2	2	<2	3	<2	n/a	n/a	n/a
Sr	93	920	61	25	18	30	n/a	n/a	n/a
Zn	3	8	2	2	2	2	n/a	n/a	n/a

a. An analysis of marble from Khao Ngob, Na Phra Laan, Saraburi province, provided by Thai Marble Corp (TMC).
b. Analyses of dolomite from Wang Dong subdistrict, Muang district, Kanchanaburi province, provided by P&S Pand's Group Co. Ltd.
n/a = data are not available.

Table V: Absorption peaks, bands and shoulders in the infrared spectra of dickite samples, DA, DB and DC (in cm^{-1}).

Sample	Position																	
	1	2	3	4	5	6(B)	7	8(Sh)	9(Sh)	10	11	12	13(B)	14(B)	15	16	17	18
DA (Cream)	2140	2216	2678	2686	2706	3400-3900	4196	4353	4435	4529	4587	4732	5230	5553	7072	–	7231	7354
DB (Cream+Red)	2138	2216	2673	2686	2706	3000-4000	4194	4353	4435	4530	4585	4731	5222	5557	7070	7194	7246	7356
DC (Grey)	2135	2234	2672	2686	2705	3300-3800	4194	4353	4435	4528	4590	4732	5239	5564	7069	–	–	–
Average	2138	2222	2674	2686	2706	–	4194.7	4353	4435	4529	4587	4731.7	5230.3	5558	7070	7194	7239	7355

B=Band; Sh=Shoulder

Table VI: Raman peak positions in wave numbers (cm^{-1}) of three dickite samples (DA, DB and DC).

Sample	Position																
	1	2	3	4	5	6	7	8	9	10	11	12	13	14*	15	16	17
DA (cream)	133	–	–	242	269	334	434	–	460	748	793	914	1123	–	3624	3645	3687
DB (cream)	131	197	–	244	269	335	434	451	460	747	792	919	1123	2840–2940	3622	3646	3686
DB (red)	131	196	–	247	270	336	434	450	460	749	793	915	–	2840–2940	3622	3654	3690
DC (grey)	–	–	204	–	266	–	–	–	465	–	–	–	–	–	–	–	–
Average	132	197	204	244	269	335	434	450	461	748	793	916	1123	2840–2940	3623	3648	3687

* Plateau

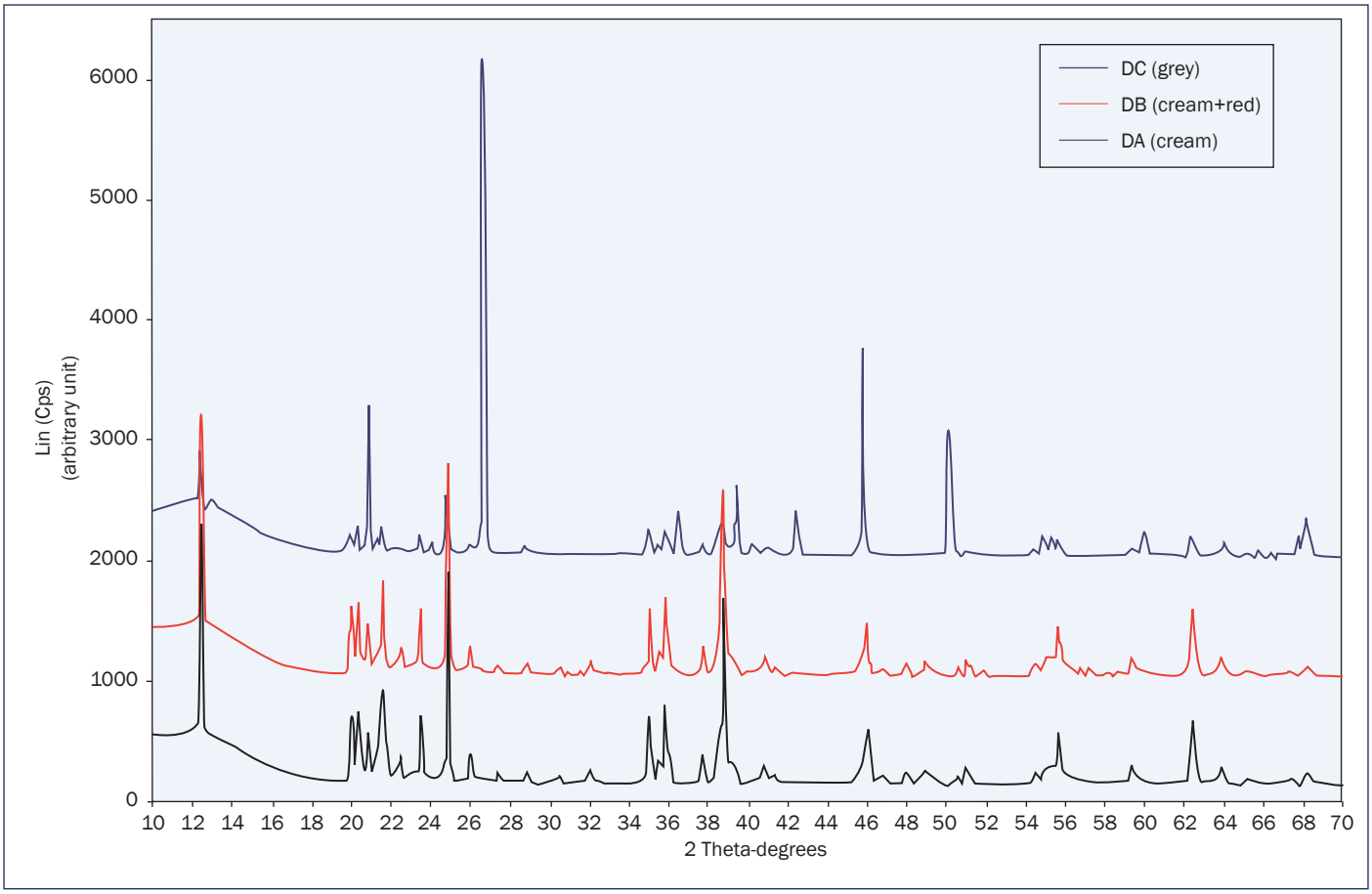

Figure 12: Diffractograms of samples DA, DB and DC. Sample DC contains both dickite and quartz. The major peaks of dickite are at 2 theta angles of 12.40, 21.56, 23.48, 24.88, 35.06, 35.86, 38.72, 45.96, 55.66 and 62.42, while those of quartz are at 20.86, 26.64, 39.46, 42.44 and 50.14.

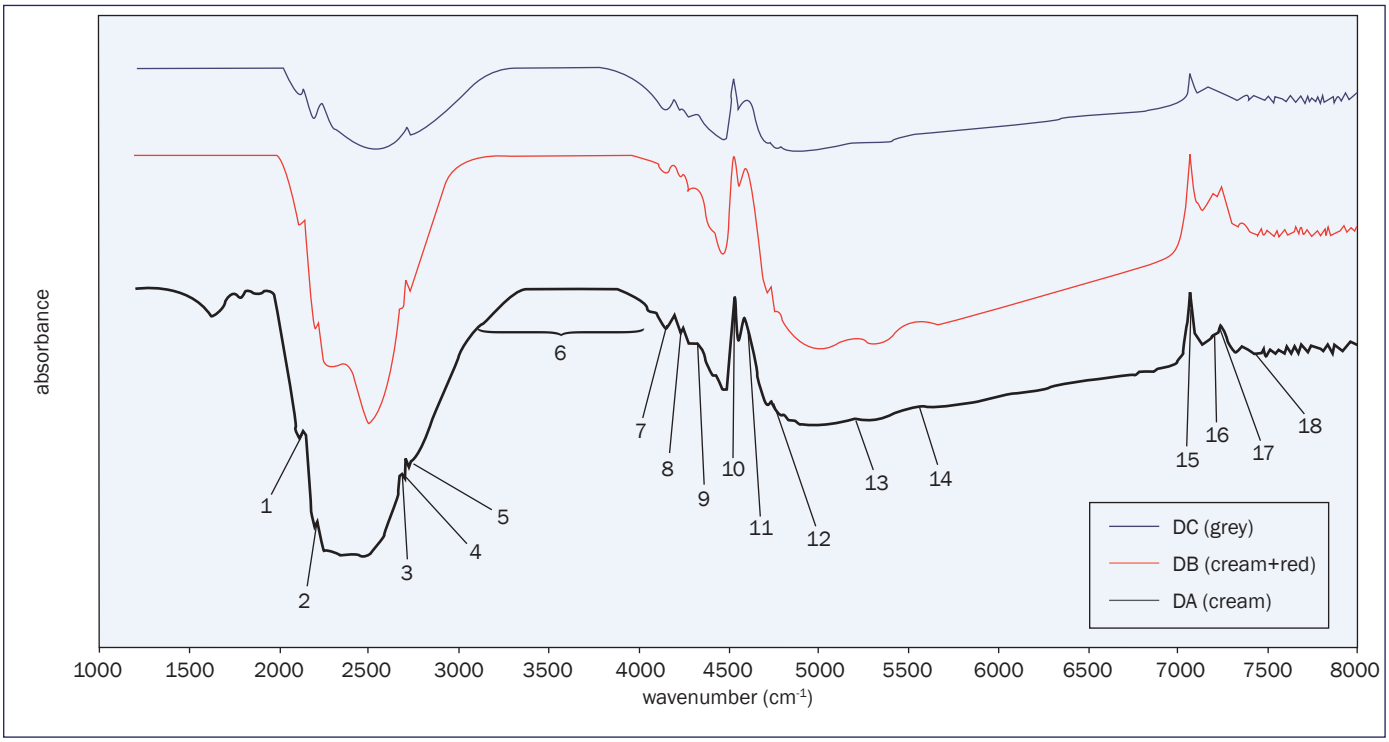

Figure 13: Infrared spectra of dickites DA, DB and DC. The peaks of sample DC are not as strong as those of DA and DB, probably because it is more opaque. The absorption wave numbers of the 18 indicator lines in spectrum DA are in Table V.

at low magnification but these are better resolved at high magnification where pseudo-hexagonal plates 1–10 µm across are stacked together like books *(Figures 8, 9* and *10)*. In contrast, sample DG (grade C dickite) is a dull red, resembling rhyolitic rock, and under the SEM it shows a different, very fine grained texture with tiny holes, some of which contain tabular crystals *(Figure 11)*.

Images frSEM illustrate the crystal habits of dickite samples under low and high magnifications (a and c images respectively in *Figures 8, 9 and 10*). Under low magnification (see 100 µm scale bars), samples DA and DB and DC look massive and granular. Under high magnification (see 1 µm scale bars), tabular or plate-like crystals approximately 3–5 microns across are apparent *(Figures 8c, 9c* and *10c)*.

The compositions of dickite obtained using wavelength dispersive XRF are given in *Table IV*. The higher quality (grade A) cream and red samples have

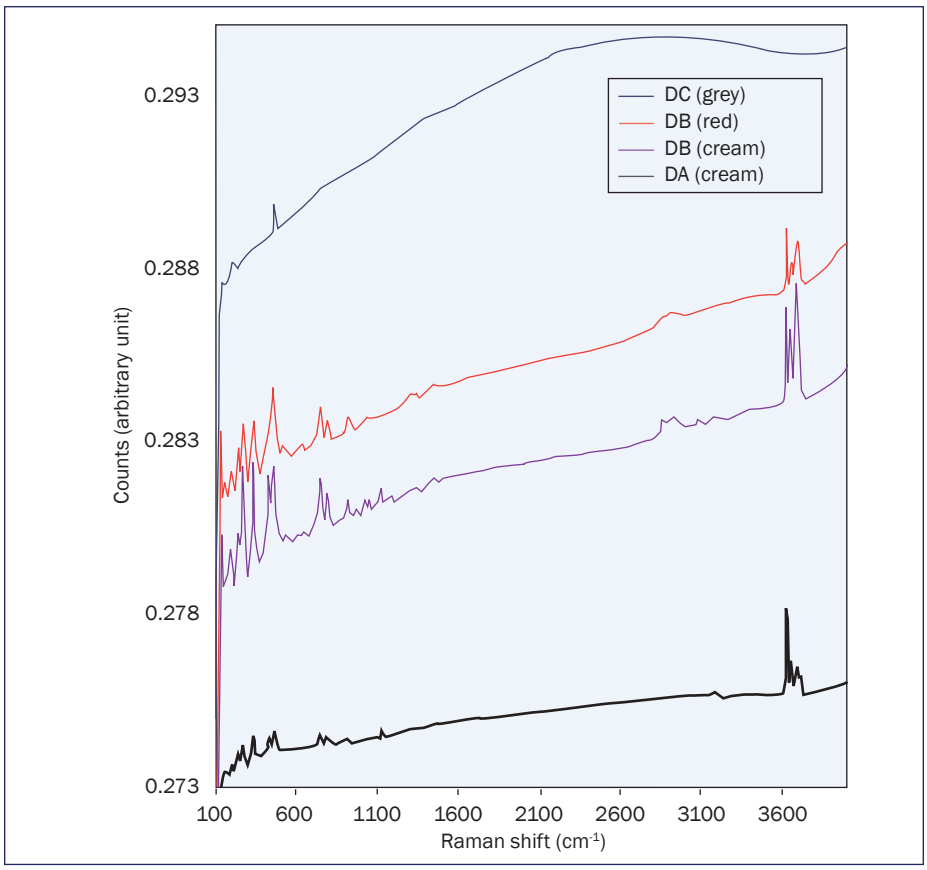

Figure 14: Raman spectra of dickites DA, DB and DC. Two spectra from DB represent the two different colours (cream and red) in the dickite. The significant Raman wave numbers are listed in Table VI).

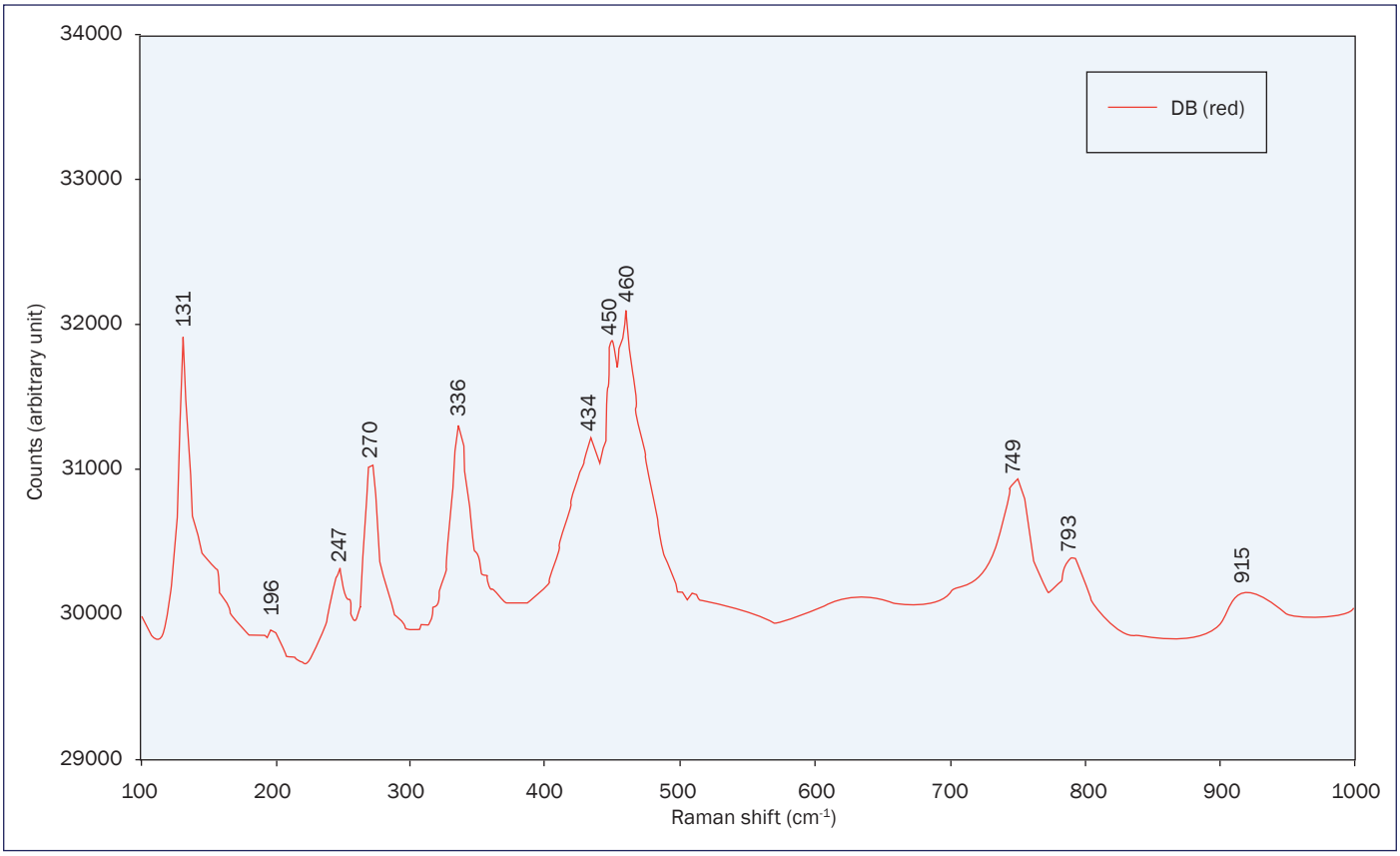

Figure 15: Raman peaks of dickite sample DB (red) in the region of 100–1000 cm^{-1} showing the detail of most typical peaks.

higher Al_2O_3 contents (41.39–41.73 wt%) and lower SiO_2 contents (42.85–43.39 wt%) than the grade B samples (DC–DF). Sample DB contains relatively high Sr (up to 920 ppm) and P, but not Ca, so it may contain unusual impurities.

The XRD results indicate that the DA (cream) and DB (cream+red) samples match the reference 72–1163 (Newnham and Brindley, 1965) for dickite and the major peak positions in terms of 2 theta are shown in *Figure 12*. The strong peak positions of DA and DB are at 2 theta angles of 12.40, 21.56, 23.48, 24.88, 35.06, 35.86, 38.72, 45.96, 55.66 and 62.42. In the DC (grey) sample, the presence of quartz peaks particularly at 26.64 and 50.14 2 theta (reference 79–1906, Dubrovinskii and Nozik, 1989) agrees well with the results from chemical analysis which indicate that this sample has nearly twice as much SiO_2 as DA or DB. The peak patterns of DE, DF, and DG, not shown here, are similar to that of DC.

Infrared absorption spectra of DA, DB and DC are presented in *Figure 13* and the positions of their most prominent wave numbers listed in *Table V*. The purest and most transparent dickite, DA, gives the clearest and most pronounced spectrum.

Raman spectra were collected from the surface of each sample and the cream and the red areas were measured separately on the DB sample *(Figure 14)*. The range of 100–1000 cm^{-1} is enlarged to clarify the peak positions in this region *(Figure 15)*.

Brindley *et al.* (1986) and Balan *et al.* (2002) studied phyllosilicate minerals and found that the OH stretching vibrations in dickite produced absorption bands at 3710, 3655 and 3620 cm^{-1}. Unfortunately our samples show only a single high and broad absorption band from 3000–4000 cm^{-1} but in the Raman spectra, there are three major peaks at 3623, 3648 and 3687 cm^{-1} (positions 15, 16 and 17 in *Table VI*).

Conclusions

Dickite, marble and dolomite each have their own unique colour, texture hardness and toughness. Marble and dolomite are harder but less tough than dickite. In terms of brittleness, they have a higher tendency to break if the carved object has a sharp corner or thin or long components. In comparison with marble and dolomite, carvers believe that dickite can be carved more easily and it can also have a distinctive range of colours and textures. For example, dickite with an uneven red colour should be used to carve animal figurines in the form of round work. Such carvings should ideally be from 75 mm to 150 mm across for reasons of packaging and transport but of course this depends on the original size of the rough.

The dickite deposits in Thailand are classed in three quality grades, A, B and C. To maximize the potential of the deposit, grade A dickite should be extracted from the mine by sawing without use of explosives, which can cause severe strain and fractures in the mineral. Dickite grades B and C, however, can be removed from the mine using explosives and then sold to the ceramics industries.

Dickite samples in the present study have a polycrystalline texture. Their crystal form cannot be seen by the naked eye and an optical microscope can help resolve some textures. SEM images of dickite show that it consists of pseudo-hexagonal plates stacked together like books.

However, standard gemmological instruments may not be sufficient to identify dickite. Advanced techniques may be needed: especially WD-XRF, XRD, FTIR and Raman spectroscopy. In particular, the Raman microprobe can give useful results, especially for grade A dickite.

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http://www.mindat.org/min-1287.html (accessed on 11 May 2008)

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Application of mineralogical methods to the investigation of some gem-quality corals

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Abstract: Infrared spectroscopy, microscopy, cathodoluminescence and X-ray analysis have been used to investigate corals from various sources. The red, pink and white corals are composed mainly of magnesian calcite with a poorly ordered structure; a lack of cathodoluminescence indicates that they are rather young. The organic corals consist mainly of biopolymers of collagen type with subordinate magnesian calcite. Their FTIR spectra contain bands attributed to vibrations of OH, H_2O, C-H and N-H in molecules occurring in the protein structures of collagen. Infrared spectra were also used to detect wax or resin treatment of red coral.

Keywords: coral, calcite, collagen, protein, FTIR, gem treatment

Introduction

Corals are marine Coelenterates most often found in warm, tropical or subtropical waters where they form colourful ecosystems which are especially appreciated by scuba divers. Today, global warming and environmental pollution are responsible for the extinction of many coral species, so in recent years the different corals have been the subject of various scientific investigations. Under pressure from biologists and ecologists all over the world, action to preserve corals was taken some years ago through the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES), agreed in Washington in 1973, and EU Wildlife Trade Regulation (Council Regulation (EC) no 338/97) of 9 December 1996. These were designed to regulate and supervise the international trade in corals and products derived from them.

Currently about 6500 coral species are known; some of them exist in waters down to 7000 m. The groups of contemporary living corals can be subdivided into two subclasses: i.e. *Octocorallia* and *Hexacorallia* (Cairns, 2007). Each coral is a tiny polyp with a stomach and a mouth surrounded by retractable, stinging tentacles. Corallum is a characteristic hard calcium carbonate shell that protects the polyp and has been used for adornment since prehistoric times. The oldest coral ornaments have been dated to the Upper Palaeolithic (Sobczak and Sobczak, 1995). Nowadays, in spite of very limited supply, the interest in coral products is still intense. Black coral *(Antipatharia)*, blue coral *(Heliopora coerulea)* and yellow-brown coral *(Melithaea ochracea)* have appeared on the jewellery market (Henn, 2006). However, coral imitations are commonly offered to customers as natural gems these days and distinguishing them from natural and treated coral can be a significant problem. For this purpose spectroscopic investigations seem to be the most effective way to solve such problems.

The bibliography on corals, especially concerning mineral corals, is very rich, since scientists active in biology, ecology and mineralogy as well as gemmology have been interested in these beautiful objects for many years. Special attention has been paid to horny corals by Brown (1977; 1988), Kim *et al.* (1992) and Hänni (2004). All results obtained with modern analytical techniques are aimed at better recognition of these organic gems.

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The natural corals and their classification in the gem trade

In gemmology and the jewellery trade, colour and shape are the criteria used to classify and name the corals. Henn (2006) distinguished red coral (noble coral), white, black, blue, golden, sponge, yellow (bamboo coral), yellow-brown (tiger coral), yellow-red (apple coral), organ-pipe and stony coral. In southern Europe, especially in Mediterranean countries, the classification used in Italy is more popular. There, the colour of coral is also the main criterion for its description. In the Italian classification, white coral *(bianco)*, pale pink *(pelle d'angelo)*, pink *(rosa palido)*, vivid pink *(rosa vivo)*, pink-red *(secondo coloro)*, red *(rosso)*, dark red *(rosso scurro)* and vivid red *(arciscuro lub carbonetto)* are distinguished. The extent of coral's development in terms of the thickness of its branches is another variable parameter. Here four subgroups are used: *Capo testa,* noble coral; *Barbaresco*, coral with twig fragments; *Terragila*, thin coral with twigs; and *Raspatelli*, coral shred.

In addition to colour, it is important in the jewellery trade that coral is as durable as possible and on this basis three subgroups are used:

a. Corals with a homogeneous and massive structure. These include red, pink and white corals *(Corallium rubrum, Corallium japonicum, Corallium elatius, Corallium konojoi, Corallium secundum)*, golden *(Gerardia sp., Narella sp., Callogoria gilberti and Calyptrophora sp.)* and black corals *(Antipathes grandis, Antipathes dichotoma and Cirrhipathes sp.)*.
b. Corals with a heterogeneous or porous structure. These include bamboo coral *(Lepidis sp., Keratosis sp., Isidella sp., Acanella sp.)*, blue coral *(Heliopora coerulea)* and yellow-brown corals (e.g. *Millepora alcicornis)*. These corals are less popular than those in (a) above.
c. Fossil corals

In recent years, corals have also been considered as mineral or organic. Here the main constituent (mineral phase or organic substance) determines how the coral is named. White, red, pink and blue corals belong to the mineral group, while, black and golden corals are organic.

Somewhat apart from the general ideas expressed above, there are also a few corals that have a distinctive colour and come from a particular locality, and these features determine their value on the gem market (Henn, 2006).

Samples and methods

Samples of white, red, pink, black and golden coral were obtained from gem trade sources and subjected to gemmological examination. Investigations were carried out at the laboratories of the Department of Mineralogy, Petrography and Geochemistry, Faculty of Geology, Geophysics and Environmental Protection, AGH-UST in Krakow, Poland. They included hand specimen and optical observations with the use of a 10x triplet lens, a binocular microscope and a standard polarizing microscope Olympus BX 51 with camera DP12. The bulk density of all corals was determined applying the hydrostatic method.

Scanning electron microscope (SEM) observations were performed on polished sections and natural surfaces of the corals with a FEI Quanta 200 FEG scanning electron microscope equipped with an Energy Dispersive Spectroscopy (EDS) detector. The system was operated at 15 kV accelerating voltage, high-vacuum mode.

The X-ray diffraction (XRD) analyses were done with a Philips APD PW 3020 X'Pert diffractometer in the angular range 5–75° 2Θ applying CuKα radiation, a graphite monochromator, voltage 35 kV, lamp current 30 mA.

Absorption infrared spectra were recorded with a BIO-RAD model FTS 165 spectrometer in the range 400–4000 cm^{-1}. The specimens were powdered, mixed with KBr, and pressed as pellets.

Contents of collagen in coral were estimated from residues after dissolution of carbonate minerals in 1M HCl solution.

Cathodoluminescence (CL) studies were carried out at the Polish Geological Institute in Warsaw. A Cambridge Image Technology 8200 mk3 device (cold cathode) linked to a Nikon Optiphot 2 polarizing microscope was used.

Results

Mineral corals

White coral

The sample of white coral *Corallium konojoi* comes from the South China sea (either from the Japanese coast or from Hainan Island, China). The coral's bulk density is *ca*. 2.66 g/cm^3.

The surface of the coral is smooth apart from tiny pinholes or pits which occur only locally and its whiteness may be interrupted by numerous pink spots *(Figure 1)*. The lustre of the polished coral is strong pearly. Under UV radiation the white coral fluoresces purple-red under short-wave and blue under long-wave.

Under the polarizing microscope, a section of coral shows complex structure. The growth zones are arranged concentrically around the core, but the main components of these corals (carbonates) have different optical orientations within the individual growth zones – indicated by their different interference colours *(Figure 2)*. The sizes of crystallites are bigger near the core than in the outer parts of the coral. In some places, deformation of the concentric-sector structure (so called 'nodes') can be observed.

XRD investigations revealed that calcite is the only mineral phase present in the coral. The location (i.e. the movement of the main calcite peaks to lower 2 theta values) and intensity of the recorded diffraction peaks, indicate that the calcium carbonate is characterized by low crystallinity index, and this is consistent

Figure 1: White coral typical of that tested.

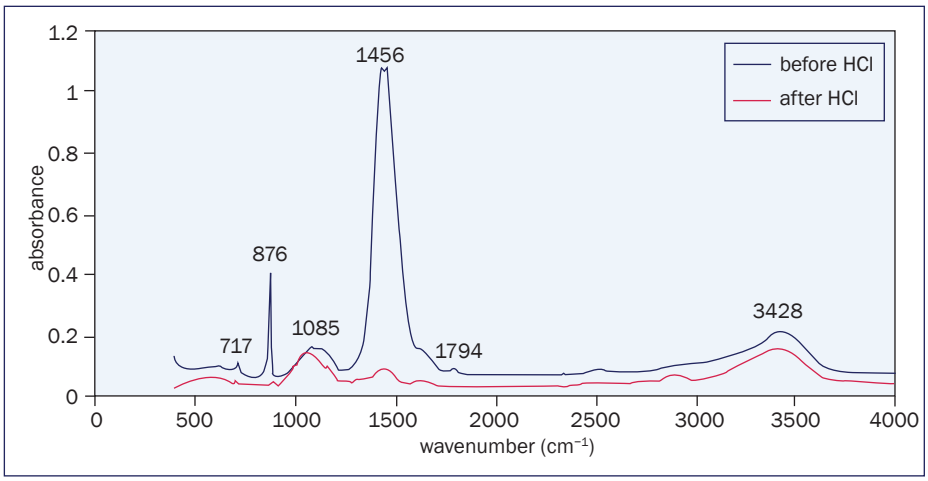

Figure 3a: Comparison of infrared absorption band intensities recorded for white coral before and after its treatment with HCl.

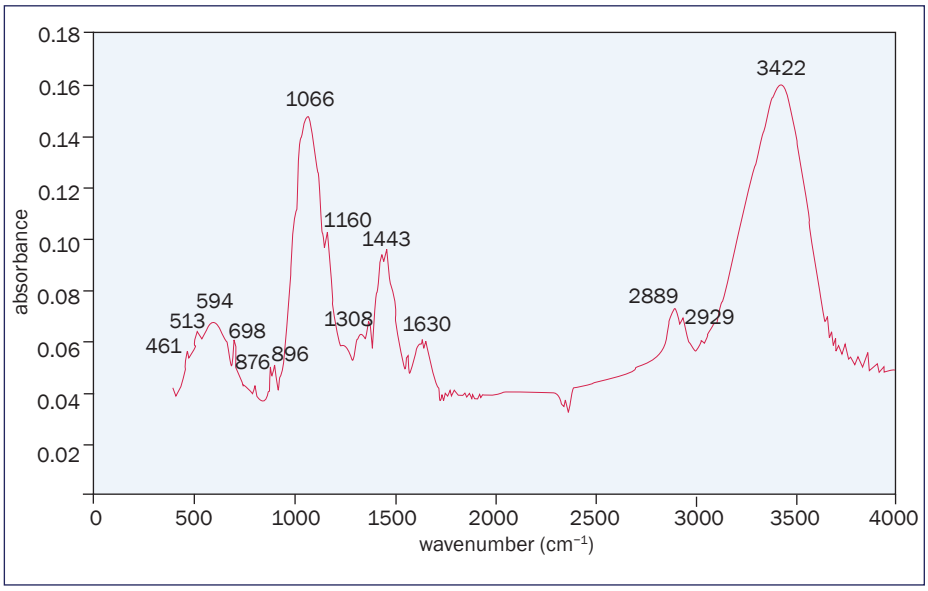

3b. Detail of infrared spectrum of white coral residue obtained after HCl treatment .

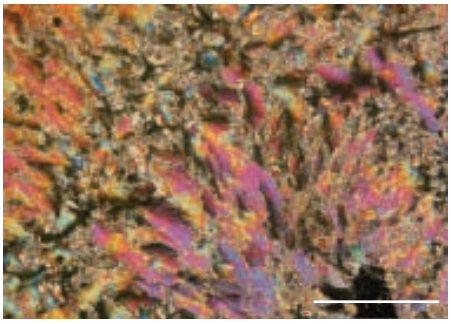

Figure 2: Magnesian calcite showing high birefringence in zones in the internal part of the white coral. Thin section, crossed polars. Bar 0.2 mm.

with the lack of cathodoluminscence. No cathodoluminescence indicates that the coral studied is rather young and has a poorly ordered structure.

In the SEM the white coral appears relatively homogeneous, with some porous structure. SEM-EDS analyses indicate that some Mg is present with the Ca and that there is also some sulphate.

Fourier transform infrared spectroscopy (FTIR) investigations of natural and HCl-treated samples of coral give detailed information on the character and composition of the coral skeleton. After treatment of white coral with 1M HCl solution, the proportion of residue remaining is 0.03 wt.%. Mineral coral consists of carbonates with traces of silicates. The bands at 1456, 876 and 717 cm^{-1} can be attributed to calcite which contains some magnesium *(Figure 3A)*. The substitution of Mg^{2+} for Ca^{2+} is responsible for the movement of the $\nu_4(CO_3^{2-})$ band in the IR spectrum from 712 cm^{-1} to 717 cm^{-1}. In the FTIR spectrum of an unprocessed white coral there is also a band at 900–1150 cm^{-1} which is attributed to a silicate admixture. After treating the coral with HCl, the carbonates were almost completely removed; in the FTIR spectrum the intensities of bands at 1450 and 876 cm^{-1} are visibly reduced. The bands at 950–1200 cm^{-1} and 400–800 cm^{-1} may be connected with quartz and poorly ordered silicate phases. Traces of organic substance in the white coral are indicated by the presence of bands at 2889 and 2929 cm^{-1} attributed to the CH_3 and CH_2 vibrations *(Figure 3B)*. These absorption

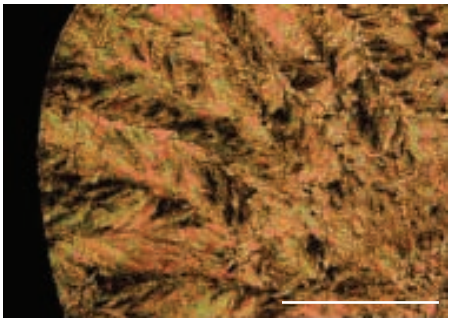

Figure 5: Radial and segment structure in red coral. Thin section, crossed polarized light. Bar 0.5 mm.

maxima, as well as the bands assigned to amide group vibrations may confirm the presence of collagen group substances.

Red coral

The fragments of red coral *(Corallium rubrum)* that were tested come from waters near the Sardinian coast in the Mediterranean Sea. The dark red colour of the coral skeletons is quite homogeneous *(Figure 4)*, but their surface is rather rough and lustre is dull; numerous pits are filled with secondary calcite. Its bulk density is *ca.* 2.43 g/cm^3.

In cross section, the red coral exhibits a structure of concentric growth rings. Under UV radiation it fluoresces dark red. Microscopic observations revealed three zones in the structure: an outer zone of several mm thickness, a thick internal zone and an elliptical core. In thin section, the interference colours and polysynthetic twinning both indicate that calcite is the main constituent of this mineral matrix. The calcite crystals vary in size and locally overlap to form characteristic cone-shaped patterns *(Figure 5)*. The deformation of the red coral's concentric-sector structure ('nodes') can be observed in each zone.

The XRD patterns indicate that calcite in the red coral has a poorly ordered structure, and the lack of any cathodoluminescence colours is consistent with recent formation.

The red coral appears to be completely homogeneous in the SEM. The analyses indicate that the coral consists of calcium carbonate with some magnesium, and traces of S, Si and P were also detected.

After treatment of the red coral with HCl, the residue makes up only 0.3 wt.%

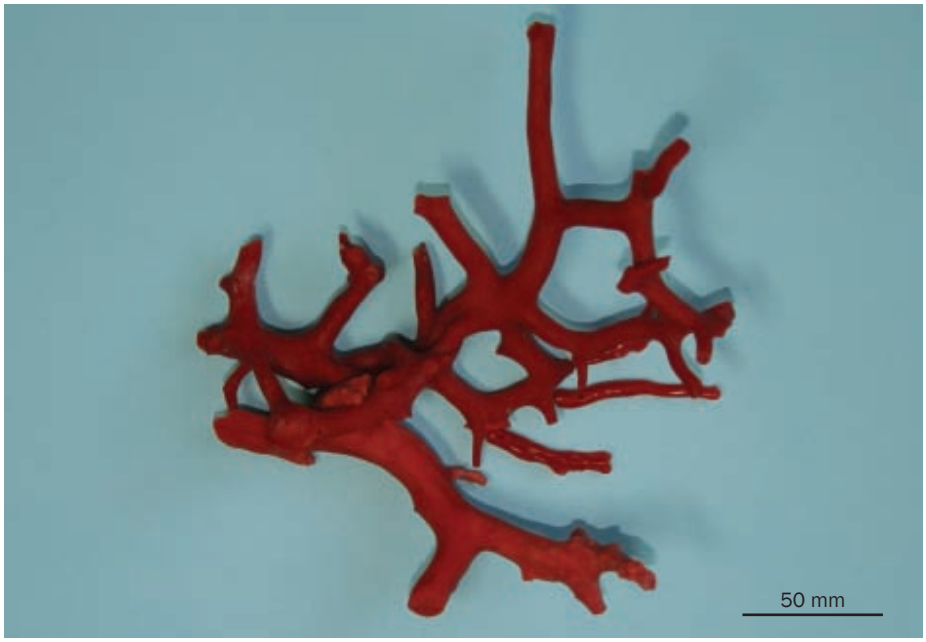

Figure 4: Red coral.

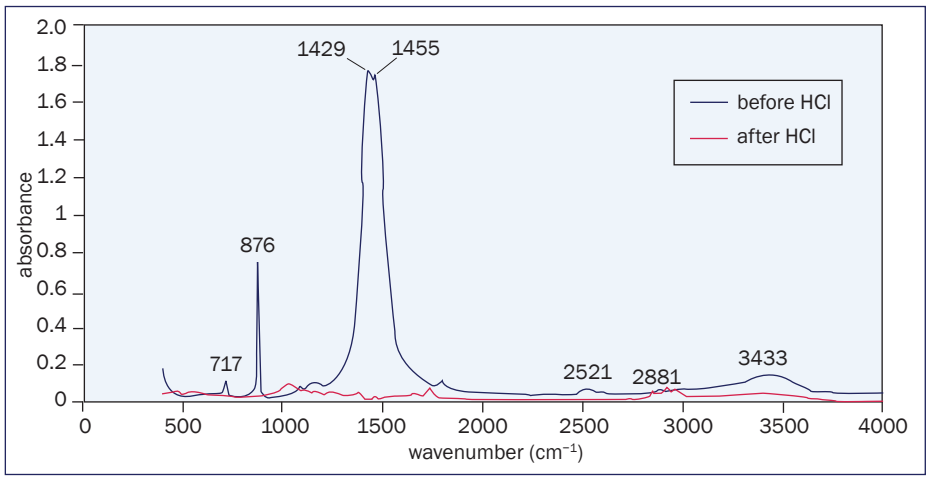

Figure 6a: Comparison of infrared absorption band intensities recorded for red coral before and after its treatment with HCl.

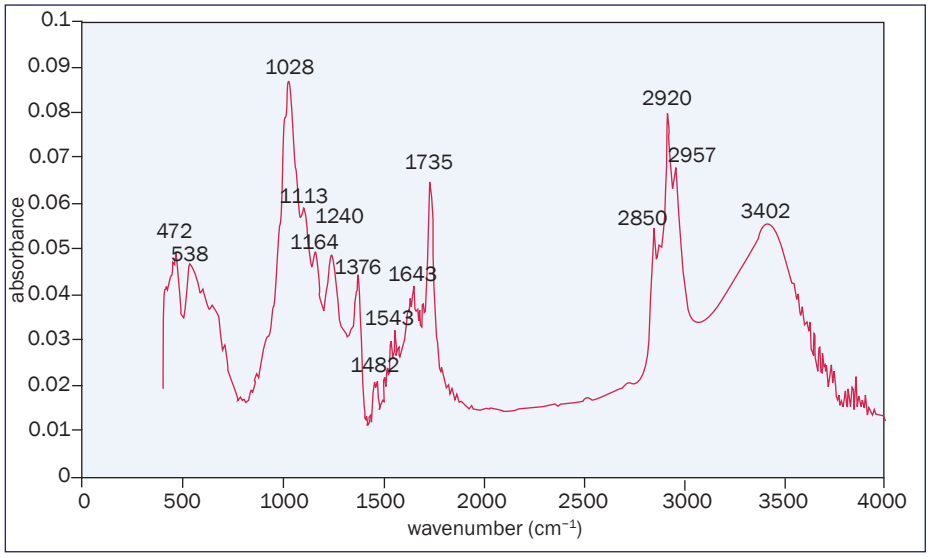

Figure 6b: Detail of infrared spectrum of red coral residue obtained after HCl treatment.

Figure 7: Pink coral.

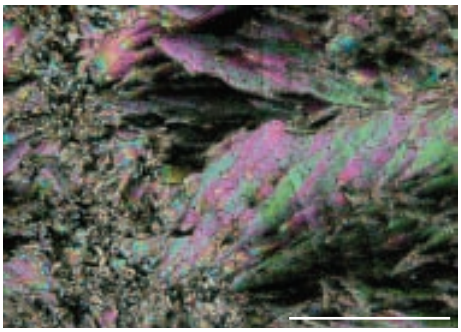

Figure 8: Segment structure in the centre of the pink coral showing calcite grain-size variation and characteristic 'nodes'. Thin section, crossed polarized light. Bar 0.5 mm.

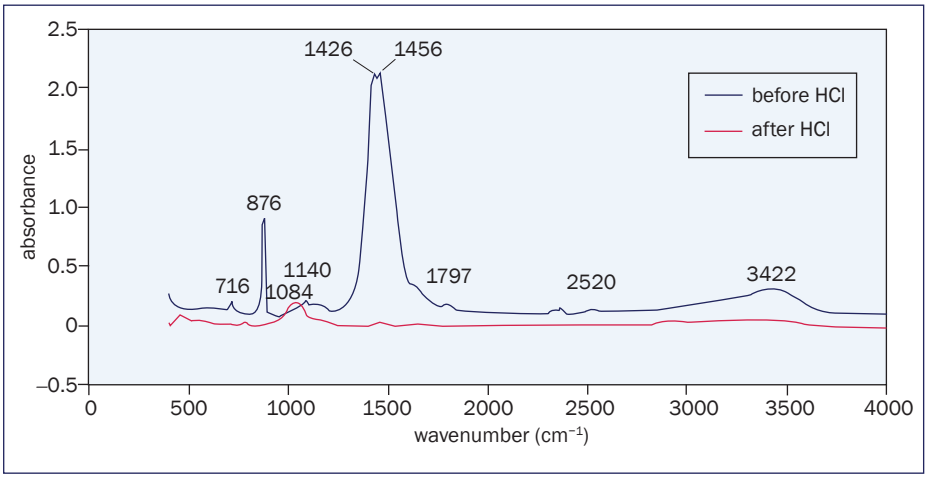

Figure 9a: Comparison of infrared absorption band intensities recorded for pink coral before and after its treatment with HCl.

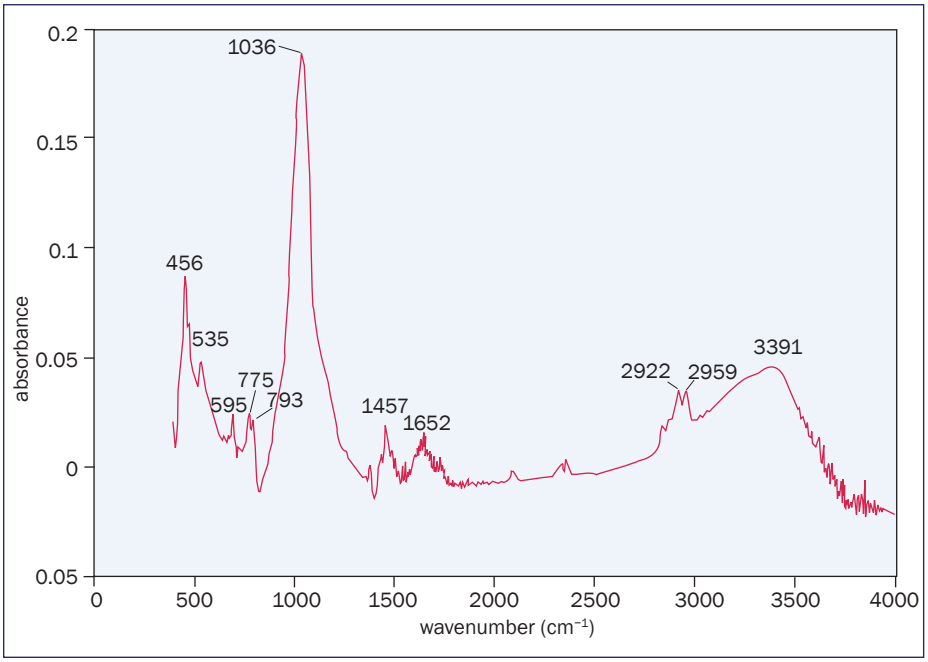

Figure 9b: Detail of infrared spectrum of pink coral residue obtained after HCl treatment.

of the original. The FTIR studies of natural and HCl-treated red corals confirmed that calcite is the main component; silicate minerals and organic substances are subordinate *(Figure 6a)*. Maxima in the range 2800–3000 cm^{-1} indicate the presence of organic material containing CH_3, CH_2 and COOH groups *(Figure 6b)*. In the spectrum of the HCl-treated sample the organic components predominate. The appearance of group frequencies coming from the strong $–CH_2$ and $–CH_3$ stretchings (2800-3000 cm^{-1}) and carboxyl –COOH groups (with strong C=O stretching vibrations at 1735 cm^{-1} and νC-O vibrations at 1240 cm^{-1}) may indicate that some foreign substances, such as resin and/or wax were used to impregnate a porous gem material to improve its colour and coherence. The natural collagen group substances are subordinate components of the HCl-treated sample and a weak absorption peak at 1543 cm^{-1} could be the Amide II band of collagen.

Pink coral

The sample of pink coral examined comes from the South China Sea, near the coast of Vietnam. In the trade it is known as *pelle d'angelo* (angel's skin). Its colour is heterogeneous with numerous red spots in a pink background and its surface is relatively smooth with pearly lustre *(Figure 7)*. Its bulk density is *ca.* 2.79 g/cm^3. The coral is pale purple-red under short and long wave ultraviolet light but CL is absent — indicating its recent origin.

Under the polarizing microscope, a thin section of the coral shows that three zones of calcite can be distinguished: an

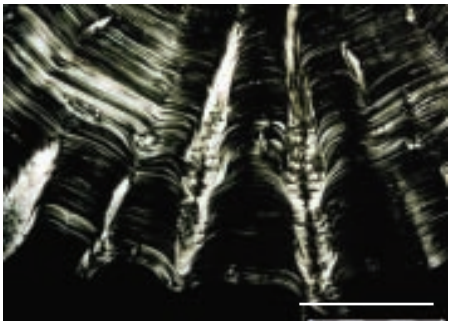

Figure 11: The segment structure of black coral. Bar 1 mm.

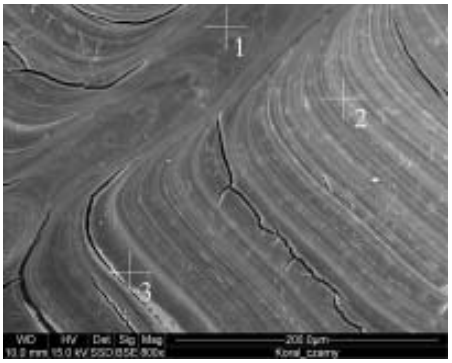

Figure 12: Back-scattered electron image of black coral showing its structure and three analysis points.

Figure 10: Two specimens of black coral.

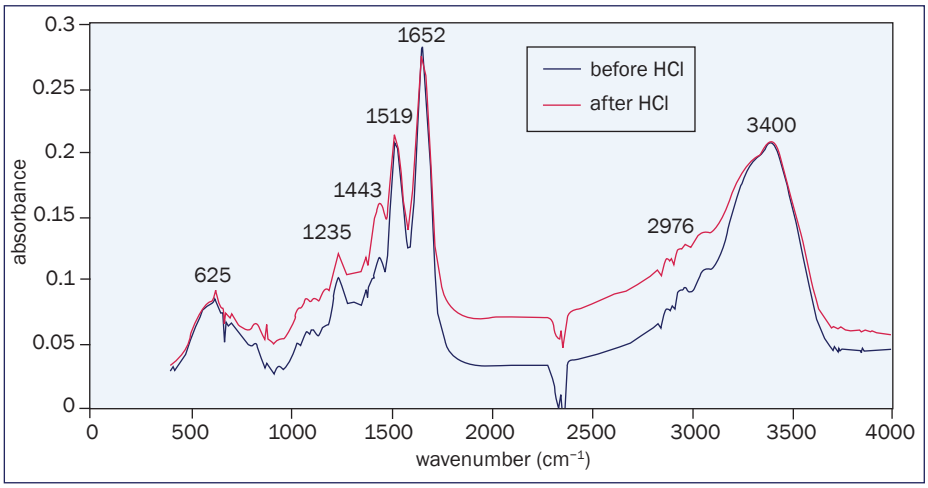

Figure 13a: Comparison of infrared absorption band intensities recorded for black coral before and after its treatment with HCl.

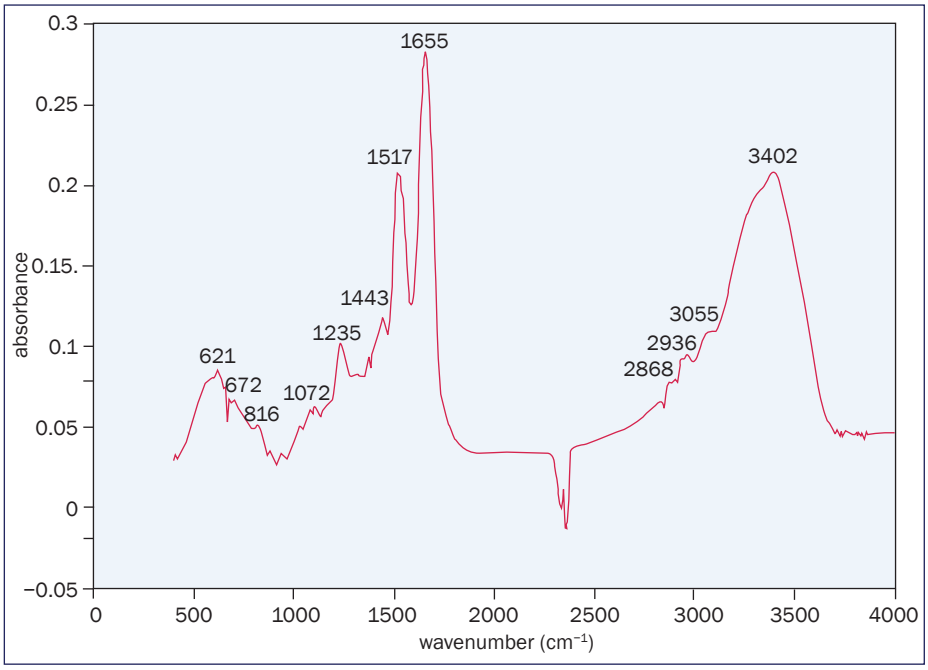

Figure 13b: Detail of infrared spectrum of the black coral residue obtained after HCl treatment.

outer, an intermediate zone and a core. All the zones differ in their crystal size and structure. The outer layer mainly consists of small crystals about 0.02 mm long which form a massive and chaotic matrix. In the intermediate layer the calcite crystals range from 0.1 to 0.5 mm long and two autonomous segments can be observed within this zone. One is coarsely-crystalline with elongated crystals, often overlapping, while the other has a much smaller grain size. The elliptically shaped core is composed of the largest calcite crystals which radiate from its centre. In this zone the deformation of the pink coral's concentric-sector structure ('nodes') is most apparent *(Figure 8)*.

The pink coral appears quite homogeneous in the SEM, although crystal nuclei (CN) can be observed within the calcite matrix and they are associated with numerous pores of 1–5 µm across. SEM-EDS analyses revealed the presence of calcium carbonate with magnesium and the admixture of S- and Si-bearing phases.

The infrared spectrum recorded for the pink coral is very similar to those of

Figure 14: Golden coral.

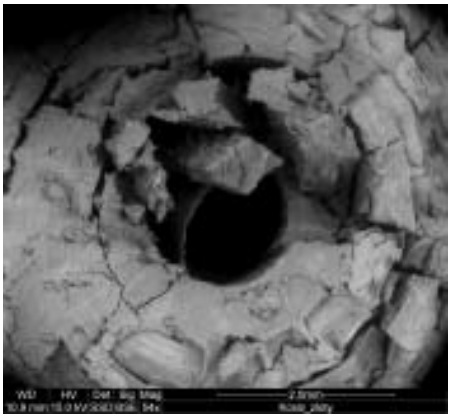

Figure 15: The concentric and segment structure of golden coral, back-scattered electron (BSE) image.

Figure 16: The wavy-shaped zone within an individual segment of the golden coral. Thin section, crossed polarized light. Bar 0.2 mm.

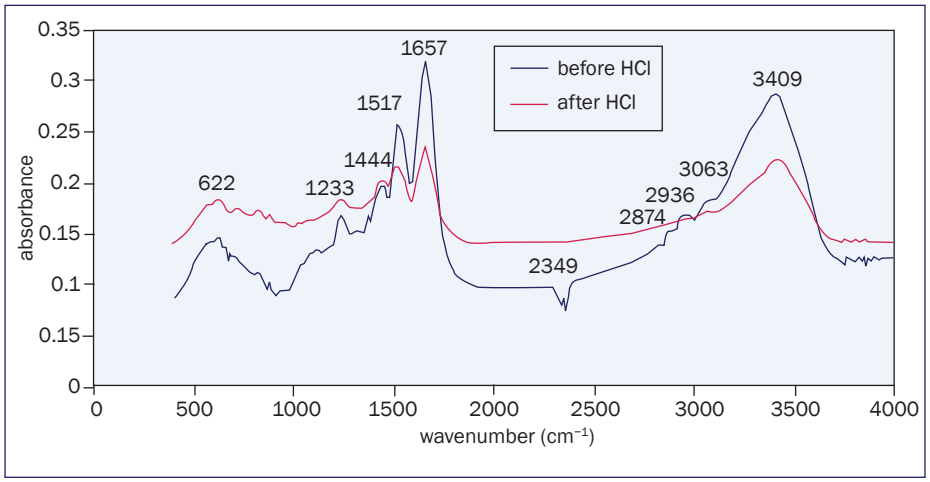

Figure 17a: Comparison of infrared absorption band intensities recorded of golden coral before and after its treatment with HCl.

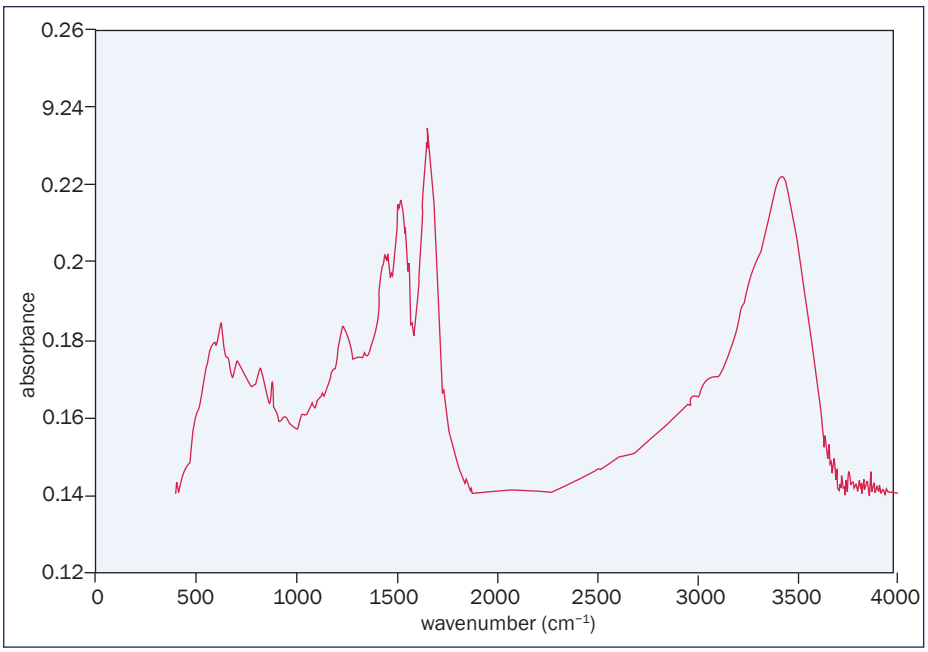

Figure 17b: Detail of infrared spectrum of golden coral residue obtained after HCl treatment.

the white and red corals described above. It indicates that calcite is a dominant component, while silicates appear as traces *(Figure 9a)*. After treatment of the pink coral sample with 1 M HCl solution, the residue makes up 0.017 wt.%. In the spectrum of the HCl-treated skeleton, the doublet at 775 and 793 cm^{-1} indicates the presence of quartz, while bands occurring in the range 2800–3000 cm^{-1} indicate the presence of an organic component *(Figure 9b)*.

Organic corals

Black coral

The specimens of black coral *(Antipathes)* come from tropical and subtropical reefs at depths of 30–40 m, in the waters of the Malay Peninsula. This coral is also found around Indonesia, the Philippines, Hawaii, Australia, and in the Caribbean and the Red Seas (Henn, 2006).

The smaller sample of black coral *(Figure 10)* has a rough and pitted

surface, dull lustre and a homogeneous colour, and in cross section its concentric-sector structure can be observed *(Figure 11)*. The larger fragment has a rougher surface with numerous spines. Its bulk density is *ca.* 1.40 g/cm^3. It shows pale blue fluorescence under long wave ultraviolet light, but under short wave UV it is inert. The CL colour of the black coral is dark brown. In cross section typical growth ring structure is visible, the borders between the growth zones being emphasized by thin layers composed of carbonates. The core is filled with secondary carbonates.

Thin section observations revealed that the main component of the coral is anisotropic with first order interference colours *(Figure 11)* and XRD investigations confirmed that the black skeleton is largely amorphous or a substance which is poorly crystalline.

The ring-sector structure of the black coral is well shown in SEM photos *(Figure 12)*. The elongated structural elements, like furrows, are often disrupted and dislocated, and some of them appear on the surface of the coral skeleton as spines. The wavy-shaped zones occur between these 'furrows' (Dumanska-Słowik *et al.,* 2008). Black coral is more porous than the mineral corals described above. Some pores are empty while others are filled with calcium carbonates.

SEM-EDS analyses were done in three characteristic areas, marked 1, 2 and 3 in *Figure 12*. The 'furrows' (1) are built mainly of organic molecules enriched in Cl, I and S, and subordinate magnesian $CaCO_3$. Wavy-shaped zones occurring among the elongated structural elements exhibit a similar composition (3). Preliminary work indicates that the light grey laminae (2) contain more iodine than the dark grey laminae (3).

It took longer to etch a powdered sample of black coral with 1 M HCl than it did for the mineral corals and organic residue weighs about 80 % of the original. FTIR investigations indicate that the black skeleton of this coral is built mainly of biopolymers of collagen type mixed with some magnesian calcite *(Figure 13a)*. The wide band at 2800–3700 cm^{-1} is attributed to O-H vibrations in the proteins in collagen. Weak maxima at 2868 and 2936 cm^{-1} are probably caused by C-H vibrations in CH3 and CH2 groups *(Figure 13b)*. The bands associated with N-H stretching vibrations in amino and amido (NH_2) groups in the collagen structures (Doyle Brodsky *et al.*, 1975; Twardowski and Anzenbacher, 1988; Kamińska and Sionkowska, 1998) overlap peaks caused by O-H stretching in water molecules. The band at 1655 cm^{-1} probably results from the coincidence of absorption caused by H_2O bending vibrations and C=O stretching vibrations in amido groups in the collagen ('the Amide I band'), and the weaker band at 1517 cm^{-1} is associated with N-H bending vibrations ('the Amide II band'). C-N stretching vibrations in amido groups probably cause the band at 1443 cm^{-1}, while the coupling of N-H bending vibrations and C-N stretching vibrations probably cause the band at 1235 cm^{-1}. Absorption in the region 550–850 cm^{-1} with a maximum at 621 cm^{-1} is probably due to N-H out-of-plane oscillation.

Golden coral

The origin of this golden coral is unknown. Its colour is homogeneous with dull lustre. The presence of characteristic nodules (the remains of spikes) indicates that it is black coral, probably treated by oxidation with hydrogen peroxide (Figure 14). Its bulk density is ca. 1.26 g/cm^3. Under UV the coral is strong blue in long wave; its CL colour is brown.

In cross section, the golden coral is similar in structure to black coral *(Figure 15)* and the borders between the growth rings are emphasized by thin laminae of carbonates *(Figure 16)*. SEM-EDS analyses indicate that secondary magnesian calcites are also present in numerous fissures is this coral. Even so, their total volume is low because after treatment with 1M HCl solution, the collagen content of the original coral was estimated at about 99 wt.%.

FTIR spectra of both raw and HCl-treated samples of golden coral are shown in *Figure17a–b*. These spectra are comparable to those recorded for black coral in *Figure 13a–b*.

Conclusions

In all the corals studied, growth zones round the core are clearly visible with the unaided eye or under the microscope. The mineral corals (white, pink and red) consist mainly of calcite which has a poorly ordered structure. The concentric structure of these corals is emphasized by size variation of the calcite crystals — the nearer the centre of the coral, the larger the calcite. The SEM-EDS analyses revealed that the carbonate is a magnesian calcite, and FTIR spectra indicate that silicate minerals and organic matter are present only in traces. The black and golden organic corals are composed mainly of biopolymers of collagen type with subordinate carbonate and also show a concentric-radial structure despite being composed of a different building material.

In this study spectroscopic analyses have proved to be most effective in distinguishing natural from treated corals: i.e. red coral containing wax or resin and 'golden coral' with the same structure and composition as black coral.

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Colour-change garnets from Madagascar: variation of chemical, spectroscopic and colorimetric properties

K. Schmetzer, H.-J. Bernhardt, G. Bosshart and T. Hainschwang

Abstract: A detailed account is given of the chemical composition and chromatic characteristics of a suite of 52 faceted colour-change garnets from Bekily, Madagascar. Microprobe results show them to be pyrope-spessartines with minor amounts of uvarovite (Cr) and goldmanite (V). All samples reveal absorption spectra with a dominant maximum in the visible range between 569 and 584 nm, which correlates with the chromium and vanadium contents of the garnets. From these considerations, it is concluded that the ratio spessartine : (goldmanite + uvarovite) is the key feature to understand the colour and colour changes of these samples.

Colorimetric parameters for all garnet samples were calculated for daylight and incandescent light for the CIE 1931 chromaticity diagram and for the CIELAB 1976 uniform colour space, which are described in detail and illustrated.

The three effects discussed are colour difference, hue angle difference, and chroma difference. The extent of colour change is described as a function of two fundamental parameters, colour difference and hue angle difference, and correlated with simple categories such as faint, moderate, strong and very strong.

Keywords: CIE, CIELAB, colorimetry, Cr-V-Mn content, garnet, Madagascar, UV-Vis spectra

Above: Colour-change garnet from Bekily, Madagascar, in daylight (top) and incandescent light; size of sample 4.7 x 6.8 mm, weight 0.74 ct.

Introduction

Gemstones revealing special light effects such as chatoyancy, asterism or colour change are much appreciated. The latter quality is the subject of this paper, and was first described for alexandrite, the chromium-bearing variety of chrysoberyl originating from the Tokovaya river area in the Urals, Russia (von Pott, 1842). Its property of appearing green in daylight and red in incandescent light was subsequently named the 'alexandrite effect' in gemmological literature. Other minerals showing an 'alexandrite effect', i.e. a colour change ranging from blue green in daylight to violet or purplish red in incandescent light, were only rarely described in the nineteenth and the first part of the twentieth century, but more species have been discovered in the second half of the twentieth century. As a first example, a chromium-rich colour-change tourmaline variety was mentioned by Cossa and Arzruni (1883), also originating from the Ural mountains. A century later in the 1980s, several alexandrite-like gem materials such as sapphire, spinel, garnet, fluorite, monazite,

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Figure 1: A striking example of colour-change in a garnet from Bekily, Madagascar; in daylight it is blue green and in incandescent light purple; diameter of sample 7.4 mm, weight 1.78 ct.

kyanite, and diaspore became known and their compositions and spectra reported (Schmetzer *et al.,* 1980; Schmetzer and Gübelin, 1980; Gübelin and Schmetzer, 1982; Bosshart *et al.,* 1982; Hänni, 1983).

Gem-quality garnets with an alexandrite-like colour change have been known for about three decades from Umba, Tanzania, and Sri Lanka. Chemical, spectroscopic and colorimetric data were published by Schmetzer and Ottemann (1979) and Schmetzer *et al.* (1980). The garnets were members of the pyrope-spessartine solid solution series with minor iron (almandine), vanadium (goldmanite) and chromium (uvarovite) contents. Additional chemical and spectroscopic data of colour-change pyrope-spessartine garnets were published in the 1980s by Stockton (1982), Manson and Stockton (1984) and Stockton and Manson (1985). In the subsequent decades, new occurrences of colour-change garnets have been reported in Sri Lanka (Johnson and Koivula, 1996; Zoysa 1999/2000), the Tunduru-Songea area in Tanzania (Henn and Milisenda, 1997) and from a Nigerian source (Milisenda, 2003).

Different types of colour-change in garnets from Madagascar including samples which are blue green in daylight and purple in incandescent light, or yellowish green or greenish yellow in daylight changing to an intense pink in incandescent light, have been reported by Johnson and Koivula (1998) and Schmetzer and Bernhardt (1999). Also, and in contrast, samples with high chromium contents showing a colour change from brownish purple red in daylight to purplish red in incandescent light were reported by Schmetzer *et al.* (2002).

The first colorimetric data of alexandrite-like gemstones were evaluated for chrysoberyl, corundum, garnet and fluorite. Chromaticity coordinates were calculated for daylight and incandescent light and presented graphically in the CIE 1931 chromaticity diagram which was traditionally used at that time (Schmetzer *et al.,* 1980). In the CIE 1931 colour space, the so-called dominant wavelength, which can be determined by graphical or by mathematical methods, was used to represent the observed colour in each of the four colour-change mineral species mentioned above (see also Boguth, 1990).

The more recent CIELAB 1976 colour space has been used to graphically demonstrate the colorimetric properties of colour-change gem materials by Liu *et al.* (1994, 1999 a,b). In these papers the term 'alexandrite effect' was no longer limited to the traditional alexandrite-like colour change but expanded and applied to all types of colour change between different pairs of illuminants, and even a 'reverse alexandrite effect' has been described in tourmaline by Liu and Fry (2006) and in zircon by Bosshart and Balmer (2006).

This expansion, however, did not include the pyrope-spessartine garnets (designated as malaya garnets in the gem trade), which can also show a colour variation from daylight to incandescent light; for them, the general term 'colour shift' has been and is used (Schmetzer *et al.,* 2001). There has been a tendency to use the term colour-change for gemstones with different colour behaviour under various illuminations when this behaviour is not typical for this gem variety as a whole, and to describe the behaviour as a colour shift when all samples of a certain gem variety show varying colours under different light sources (Liu *et al.,* 1999a). More confusingly still, the term 'colour shift' has been applied to garnets showing different colours in transmitted and reflected light (Manson and Stockton, 1984).

A detailed correlation of colorimetric with chemical data of 24 colour-change garnets from Madagascar by Krzemnicki *et al.* (2001) used the CIELAB 1976 colour space to demonstrate also that the extent of colour change was correlated with the hue angle difference for specific pairs of illuminants in the colour circle. The influence of the thickness of a sample on the saturation of colour was discussed by Liu *et al.* (1999b), and Krzemnicki *et al.* (2001) emphasized the influence of different saturation on the visually observed colour changes in a gemstone between different pairs of illuminants.

The vanadium and chromium contents of the garnets, which were correlated with the extent of colour change by Krzemnicki *et al.* (2001), are certainly two relevant properties in explaining colour-change behaviour, but they do not explain all the colorimetric data, and especially not the various types of colour change observed. Thus, the present authors decided to collect additional chemical, spectroscopic and colorimetric data from colour-change garnets of Madagascar, to compare with and augment the work of Krzemnicki *et al.* (2001).

The present study is based on 52 garnet samples (see example in *Figure 1*) from Madagascar which were chemically analysed by electron microprobe and spectroscopically measured with two different spectrophotometers. The samples have been collected within the last decade by two of the present authors (KS and TH). At first sight, some of our specimens obviously did not fit into any of the five groups described by Krzemnicki *et al.* (2001) indicating that there could be more groups or that we should subdivide some groups into specific subgroups in order

to investigate and explain their observed colour changes.

For clarity of terminology, the expression 'colour change' is used for minerals and gemstones which reveal a different coloration to the human observer under different pairs of illuminants (traditionally daylight and incandescent light, today also artificial daylight and other light sources). The expression 'colour change', however, is not to be used for samples with colours altered by various types of treatment, such as heat treatment or irradiation. These are best termed colour alterations. In other words, colour change is not a description of different states of coloration before and after the gemstone has undergone a specific treatment. Colour change should also not be used to describe a variation of colour due to bleaching, fading or other types of alteration involving colour centres (e.g. by heat treatment, irradiation, exposure to sunlight or even in darkness). Furthermore, colour change should neither be confused with pleochroism which describes different colours in different orientations of a stone (caused by optical anisotropy) nor with variation of colour caused by variation in thickness (caused by different path lengths of light, the Usambara effect, see Liu *et al.*, 1999b, Halvorsen, 2006).

As the number and variety of different light sources available on the market increase, it is becoming more important to be able to describe the colours in gems and how they may change precisely. Consequently, it is important to outline the background to and the basis for the authors' choice of colorimetric systems in this research. The two systems selected, i.e. the CIE 1931 and the CIELAB 1976 system, are the most commonly used colour spaces applied in the twentieth century, and a few gemmological texts have already applied one or both systems. Since, however, there is no readily available gemmological text which explains the background of both systems, an outline is given below, and those readers already well-versed in the CIE and CIELAB colour concepts may like to skip the 'Colorimetric systems' and move to 'Materials and Methods'.

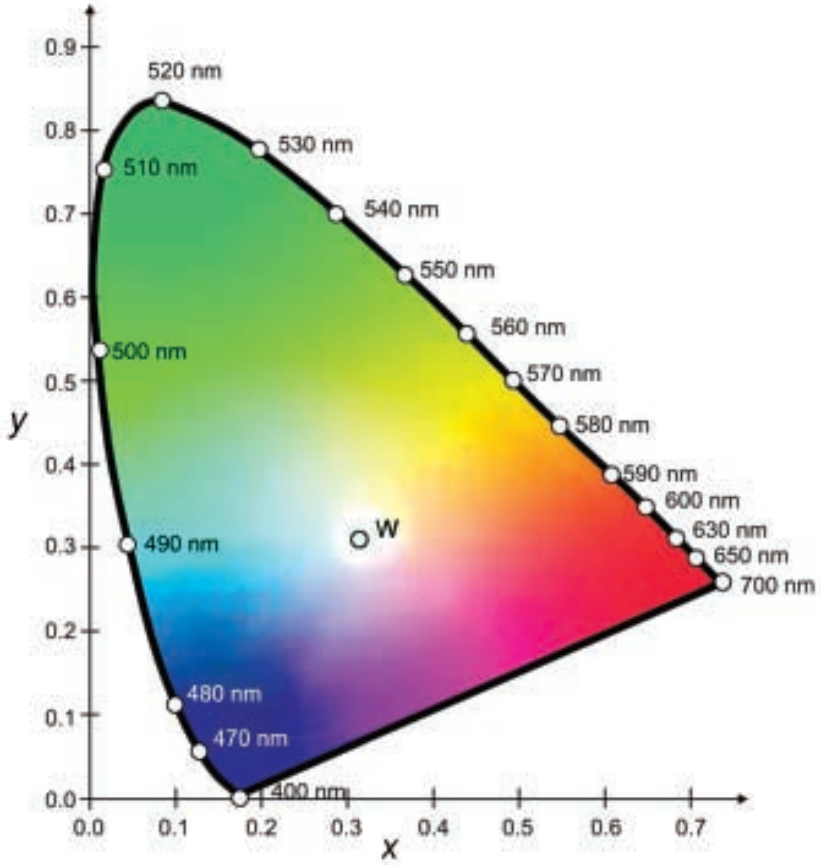

Figure 2: Colour distribution in the CIE 1931 chromaticity diagram. Copyright GretagMacbeth, Regensdorf, Switzerland (reproduced by permission).

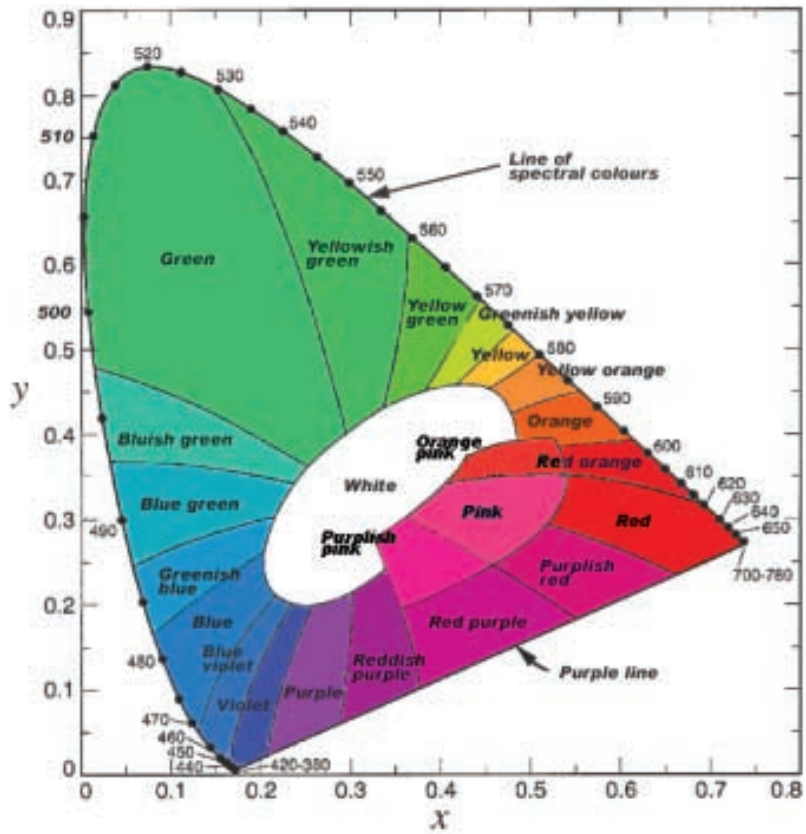

Figure 3: Colour regions in the CIE 1931 chromaticity diagram, prepared according to the black-and-white line drawing of Kelly (1943).

Table I: Spectral hue names, wavelength in the CIE 1931 chromaticity diagram and hue angle in the CIELAB 1976 colour circle.

Hue name	CIE 1931 chromaticity diagram, centre (nm)[a]	CIE 1931 chromaticity diagram, range (nm)[b]	Hue angle in the CIELAB 1976 colour circle[c]
Red	c493	620 – c495	25° (u c494 nm)
Red orange	606	595 – 620	42°
Orange	592	585 – 595	59°
Yellow orange	583	580 – 585	76°
Yellow	578	575 – 580	92° (u 574 nm)
Greenish yellow	573	570 – 575	110°
Yellow green	565	560 – 570	127°
Yellowish green	545	530 – 560	145°
Green	508	498 – 530	162° (u 503 nm)
Bluish green	495	492 – 498	190°
Blue green	490	486 – 492	217°
Greenish blue	485	482 – 486	244°
Blue	476	465 – 482	272° (u 475 nm)
Blue violet	454	420 – 465	286° (*)
Violet	c566	c565 – 420	300°
Violet purple			315° (*)
Purple	c560	c550 – c565	329°
Reddish purple	c545	c530 – c550	345° (*)
Red purple	c506	c500 – c530	357°
Purplish red	c496	c495 – c500	11° (*)

[a] Kelly (1943) for daylight C
[b] MacEvoy (2008) derived after Hunt (2004), based on Kelly (1943)
[c] hue angles based on the 16 hue colour circle of Richter (2008), intermediate hue angles (*) were calculated for this paper, hue names were adapted from Kelly (1943)
c before a wavelength indicates 'complement of' and is used in the line of purples (between red and violet)
u indicates the four unique hues, characteristic wavelength after Richter (1996)

Colorimetric systems

Colorimetric systems are used for the quantitative description and prediction of colour phenomena. For the description of colour, special colour coordinate systems (colour spaces) were developed, and two of the most practically used systems shall be described in this section. These colour systems were developed and published by the Commission Internationale de l'Éclairage (CIE, International Commission on Illumination, Internationale Beleuchtungskommission) in 1931 and 1976. Using special tristimulus functions, which were empirically determined to define the sensitivity of the red, green and blue colour receptors of the human eye, a given colour is represented by a vector in the XYZ colour space. Colour coordinates (chromaticity values, e.g., x,y or u',v' or a*,b*) of a sample, e.g. a faceted gemstone, within one of these different colour spaces can be calculated from the visible absorption spectrum of the sample which leads to the X, Y and Z values (tristimulus parameters) of the gemstone. These parameters are transformed into the relevant coordinates in different colour spaces. For further details, especially for the detailed mathematical algorithms needed for the calculation of coordinates in various colour spaces from spectroscopic data, the reader is referred to standard textbooks or treatises on colour and colorimetry, e.g. Wyszecki and Stiles (1982), CIE (1986, 2004), Richter (1996), Kuehni (1997), Nassau (1998), Hunt (2004), Ohta and Robertson (2005) and MacEvoy (2005), and to the recent article by Liu and Hurwit (2008).

The CIE 1931 system

A specific colour locus in the three-dimensional CIE 1931 colour space, which was developed in 1931 by the Commission Internationale de l'Éclairage (CIE), is conventionally represented by its projection onto a two dimensional x,y plane. The x and y coordinates are designated as chromaticity components or chromaticity coordinates. The x,y plane of the CIE 1931 colour space is represented by the CIE standard chromaticity diagram *(Figure 2)*. In this diagram, the spectral colours of maximum purity within the visible range (from red to violet) are located on a horseshoe-shaped curve which is also called the line of spectral colours. The non-spectral colours between red and violet are located on a straight line, the so-called purple line. *Figure 3* shows the chromaticity diagram subdivided into regions of various colours after Kelly (1943). The spectral hue names and the corresponding wavelengths for the pure spectral colours located on this line are listed in *Table I*. Colours located on the purple line between red and violet are conventionally represented by their complementary wavelengths which are located on the opposite side of the purple line within the chromaticity diagram. A complementary wavelength is found at the intersection point of the line of spectral colours with a straight line starting at a point on the purple line and running through the neutral point representing the light source towards the horseshoe-shaped line.

The colour of a sample located in the chromaticity diagram with specific chromaticity coordinates x,y is represented by its dominant wavelength λ_d. This characteristic parameter is obtained by drawing a line from the x,y coordinates of the light source through the sample point (see *Figures 4* and *5*). The dominant wavelength is found at the intersection

of this line with the horseshoe-shaped line of spectral colours. Again, non-spectral colours on the purple line are represented by their complementary wavelengths. Consequently the position of a complementary wavelength on the purple line varies according to the point of the illuminant used in the chromaticity diagram. The line between the coordinates of the light source and the point representing the dominant wavelength is subdivided into two fractions by the sample point *(Figures 4* and *5)*. The purity of a sample colour is the fraction of this line between the sample point and the locus of the illuminant and, consequently, a purity of 100% represents the pure spectral colour.

The CIE 1931 chromaticity diagram is a good representation for the colours of samples, but it is difficult to obtain a colour difference value in this colour space. Therefore the development of uniform colour spaces with improved representation of colour and colour differences was desirable.

Different solutions for colour spaces with uniform chromaticity spacing were obtained directly from tristimulus functions and XYZ values. They were designed by the CIE and designated as CIE L u v colour space (1960) or as CIE L* u* v* colour space (1976). The CIE L* u* v* colour space incorporates the u'v' chromaticity diagram, which is a projective transformation of the CIE (1931) x,y chromaticity diagram (*Figure 6;* Wyszecki and Stiles, 1982).

The CIELAB 1976 system

Many colour systems used today correlate with the uniform CIE L* a* b* colour space (CIELAB colour space), published first by the Commission Internationale de l'Éclairage (CIE) in 1976. The CIELAB colour space is the most complete colour model used conventionally to describe colours and colour differences visible to the human eye *(Figure 7 a,b)*. The term 'uniform' indicates that equally measured distances in the colour space ideally equate to equally perceived colour differences as seen by the standard observer. The three-

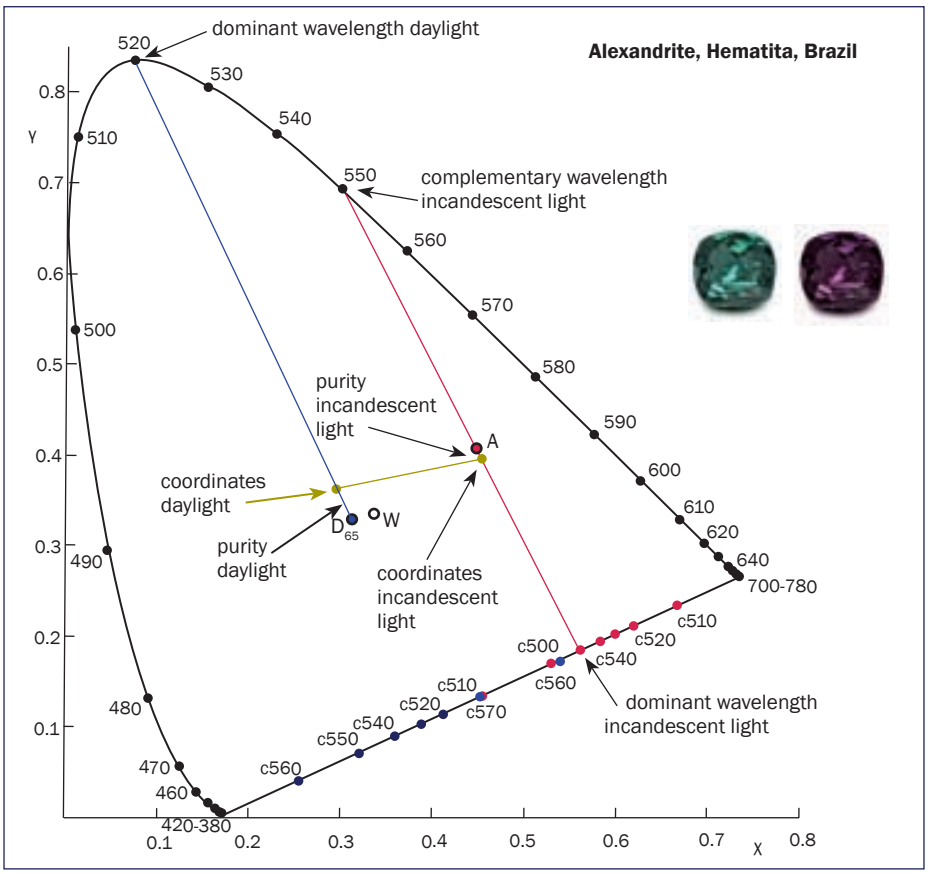

Figure 4: Colorimetric parameters of an alexandrite from Hematita, Brazil, in the CIE 1931 chromaticity diagram.

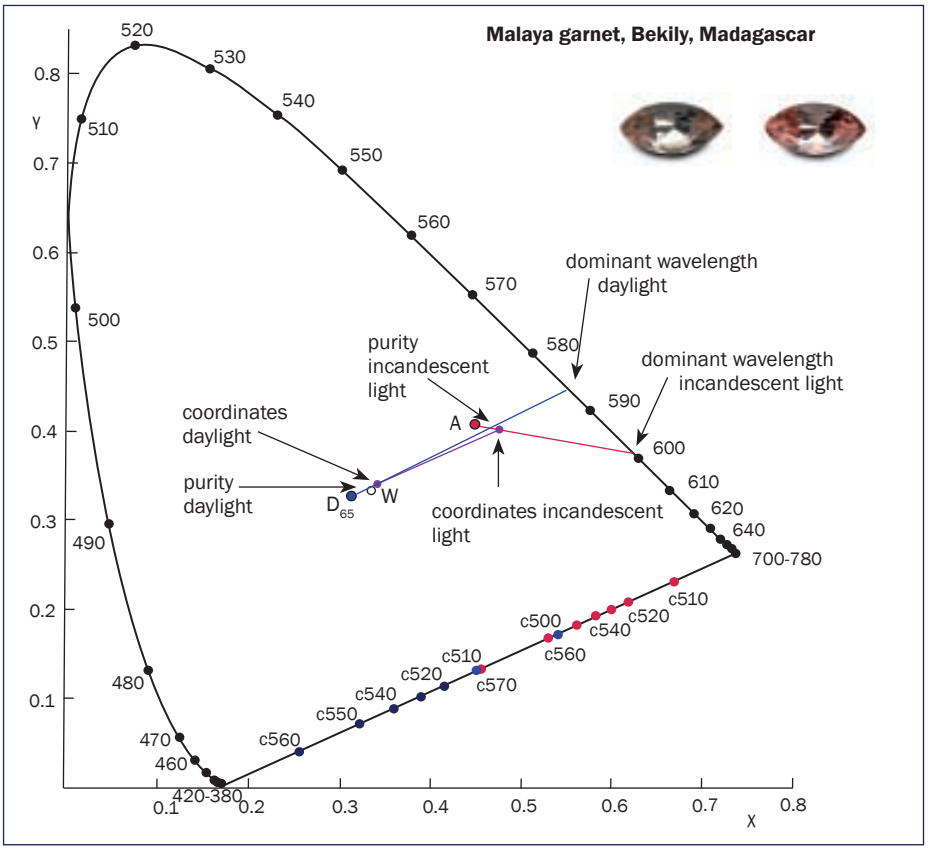

Figure 5: Colorimetric parameters of a malaya garnet from Bekily, Madagascar, in the CIE 1931 chromaticity diagram.

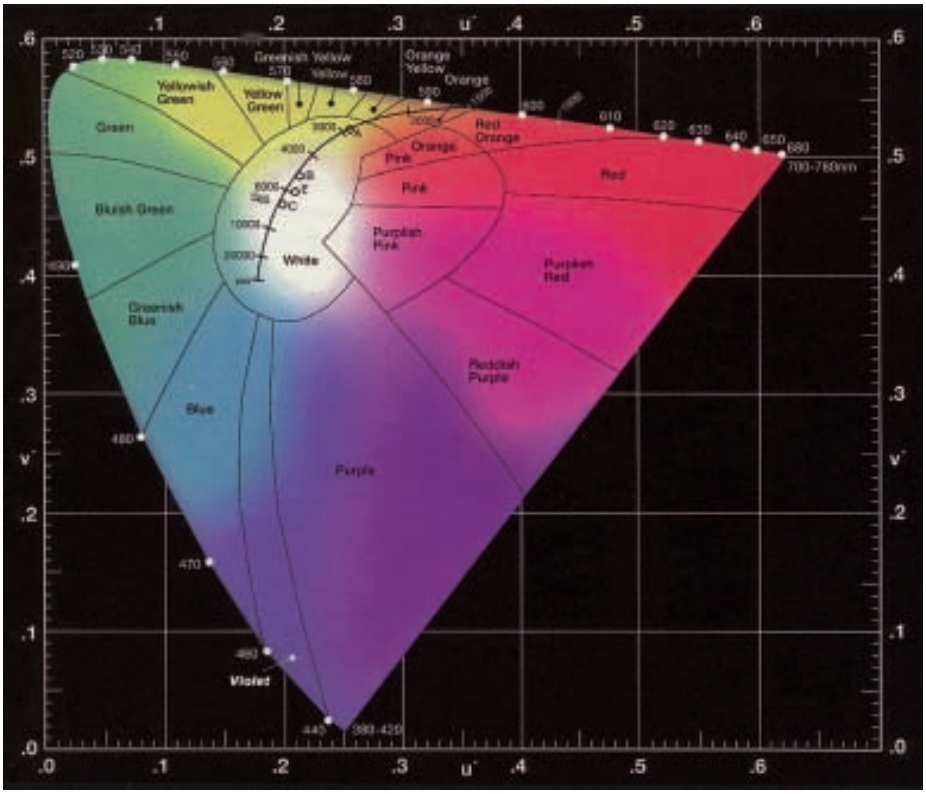

*Figure 6: Colour distribution in the u'v' 1976 chromaticity diagram; this diagram is based on a transformation from the CIE 1931 chromaticity diagram. The CIEL*u*v* colour space (which incorporates the u'v' chromaticity diagram) is one of the commonly used uniform colour spaces; the distance between two points on the diagram is approximately proportional to the perceived colour difference. Copyright HyperPhysics by Rod Nave, Georgia State University, USA (reproduced by permission).*

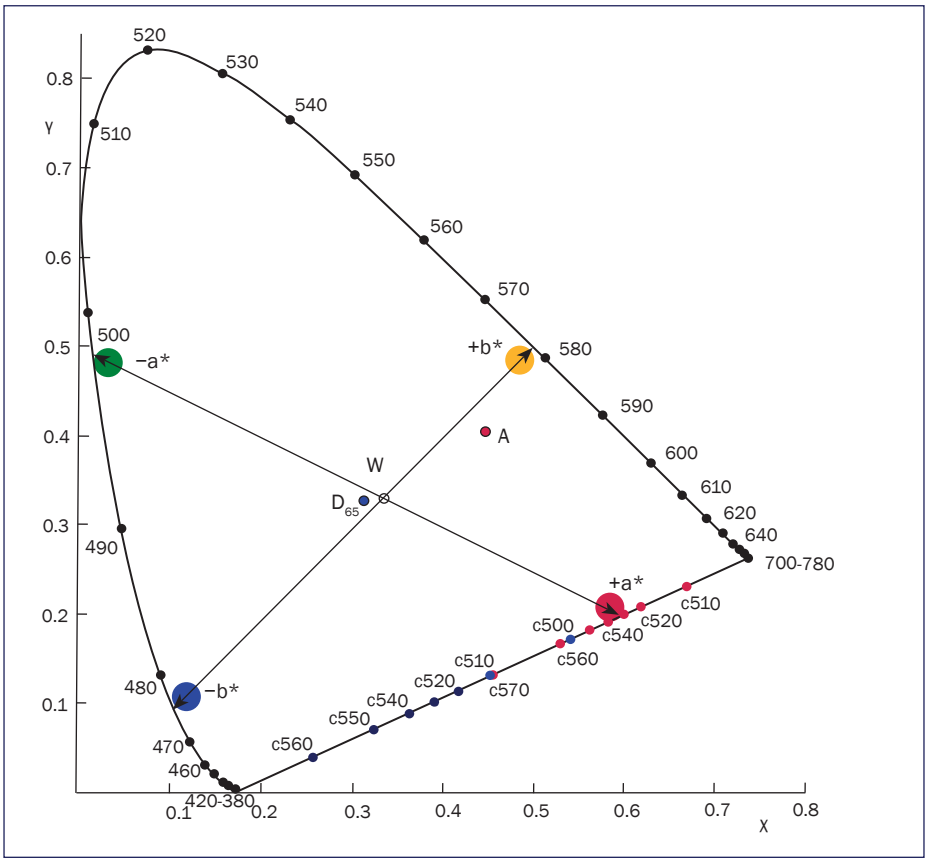

*Figure 8: Orientation of the CIELAB a*b* plane relative to the CIE 1931 chromaticity diagram; the a* and b* axes intersect the line of spectral colours and the line of purples of the CIE chromaticity diagram at red purple (+ a*), bluish green (− a*), yellow (+ b*) and blue (− b*).*

dimensional colour space shows lightness/darkness along the vertical axis (L*) and colours in a two-dimensional plane with redness/greenness along a first horizontal axis (a*) and blueness/yellowness along a second horizontal axis (b*). The colours related to this rectangular coordinate system are:

+ a* axis: red purple + b* axis: yellow
− a* axis: bluish green − b* axis: blue

The orientation of the CIELAB a*b* coordinate system in relation to the CIE 1931 chromaticity diagram is given in *Figure 8*.

Changing the first parameter L (lightness) in this colour space is like changing the brightness setting in a TV. Therefore only a few representations with various slices or projections (i.e. different cross sections) perpendicular to the lightness axis are used to visualize the CIELAB colour space (see again *Figure 7 a,b*).

The parameters a* and b* are also expressed as hue angle h_{ab} and chroma C^*_{ab}, which sometimes is also designated as saturation *(Figure 9)*. The hue angle h_{ab} is measured in degrees and ranges from 0° to 360° starting with h_{ab} = 0° at the +a* axis and increasing counterclockwise. Chroma C^*_{ab} represents the distance of a sample locus from the origin of the a*b* plane. Hue angle h_{ab} and chroma C^*_{ab} are calculated from a* and b* values as follows: $h_{ab} = \arctan(b^*/a^*)$ and $C^*_{ab} = (a^{*2} + b^{*2})^{1/2}$.

Two examples are given in *Figures 10* and *11*.

Quantitative data for colour difference, hue angle difference and chroma difference between two sample loci P_1, P_2 in the CIELAB colour space are easily obtainable as follows:

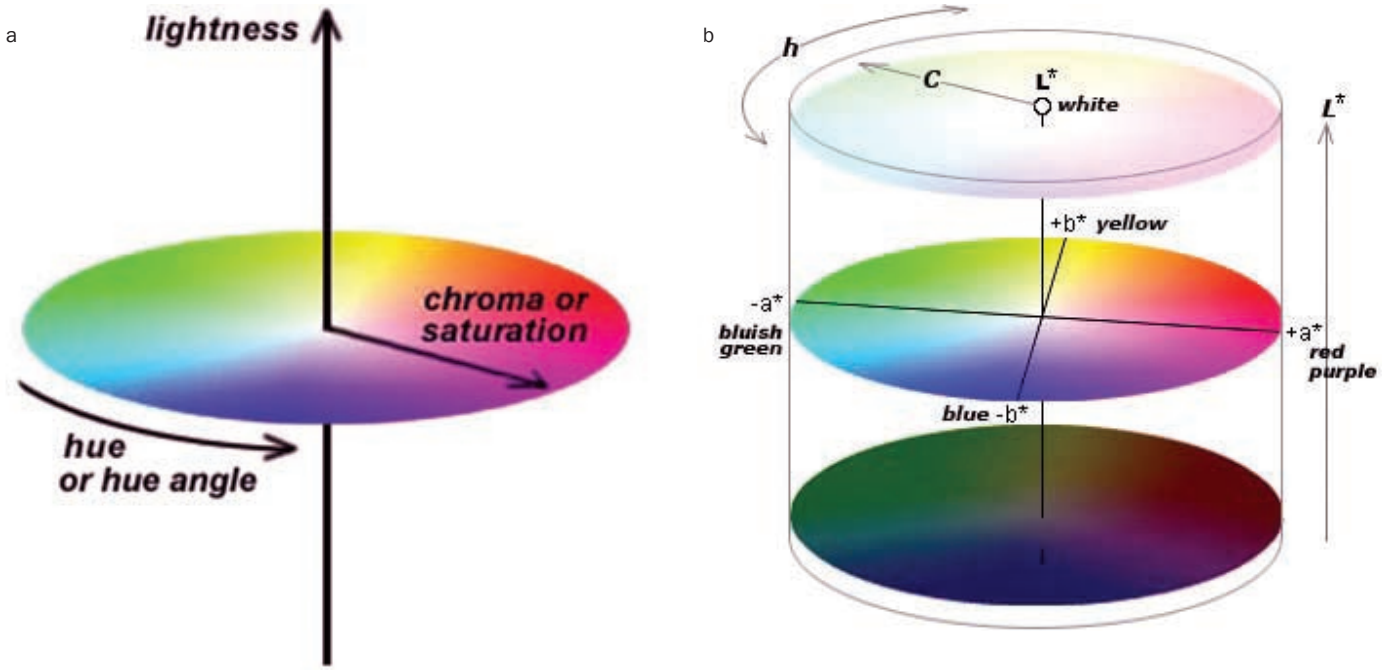

Figure 7a,b: Schematic outline of the three-dimensional CIELAB 1976 colour space; the principal parameters representing a specific colour are hue or hue angle (h_{ab}), chroma or saturation (C^*_{ab}) and lightness (L^*). Copyright handprint media by Bruce MacEvoy (reproduced by permission).

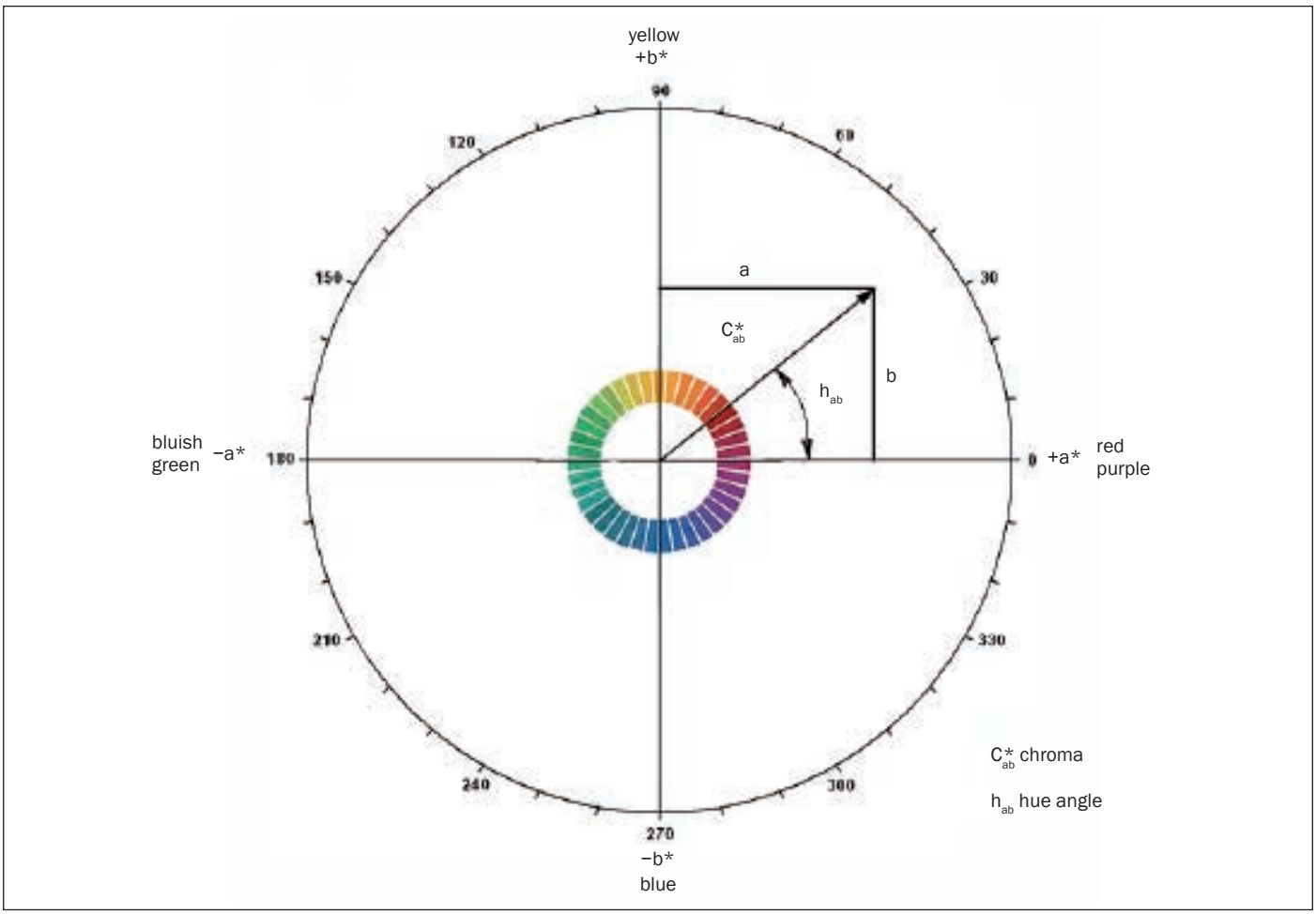

*Figure 9: Geometric representation of hue angle and chroma relative to the a*b* plane (the rectangular a*b* coordinate system) of the three-dimensional CIELAB colour space; the third parameter lightness L* is perpendicular to the a*b* plane; a and b are the coordinates of the sample locus.*

Colour-change garnets from Madagascar: variation of chemical, spectroscopic and colorimetric properties

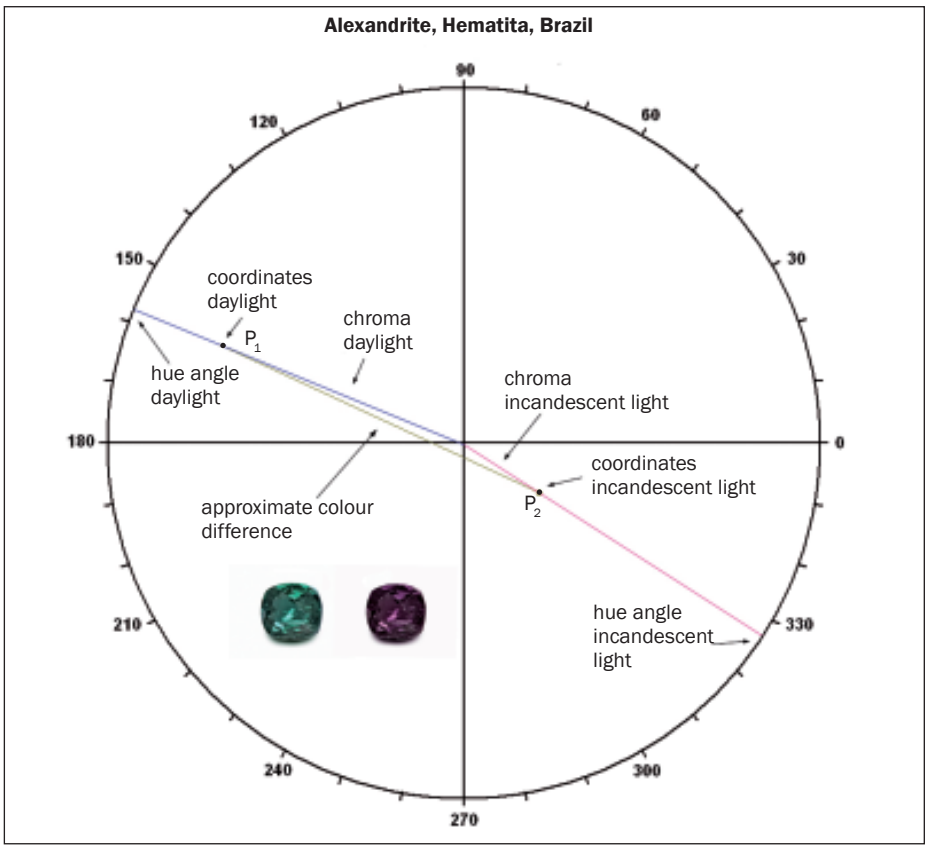

Figure 10: Colorimetric parameters of an alexandrite from Hematita, Brazil, in the CIELAB 1976 colour space.

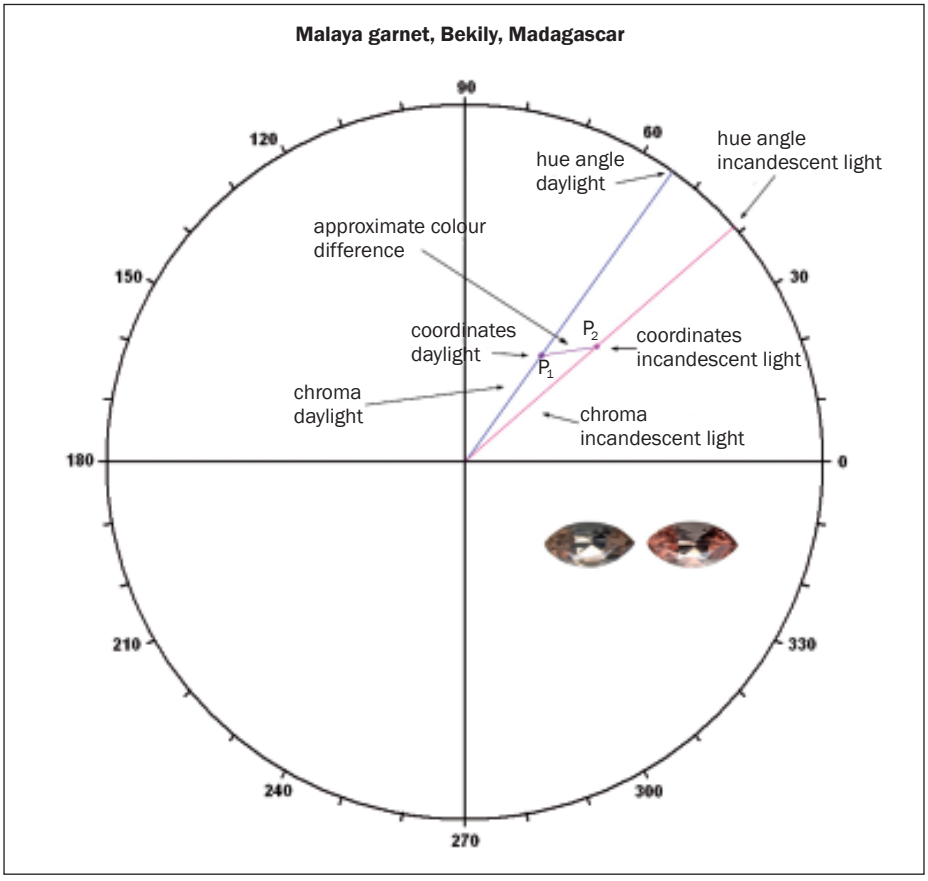

Figure 11: Colorimetric parameters of a malaya garnet from Bekily, Madagascar, in the CIELAB 1976 colour space.

a) The colour difference ΔE^*_{ab} is calculated as $\Delta E^*_{ab} = [(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2]^{1/2}$ where ΔL^*, Δa^* and Δb^* represent the difference between the L*, a* and b* values of the two points P_1 and P_2. This indicates, that colour difference is represented by the distance of two sample loci in the three dimensional colour space from each other.

b) The hue angle difference Δh_{ab} is calculated as $\Delta h_{ab} = h_{ab}(\text{point } P_1) - h_{ab}(\text{point } P_2)$.

c) Chroma difference differs from the parameter ΔE^*_{ab} (colour difference) and is calculated as $\Delta C^*_{ab} = C^*_{ab}$ (point P_1) $- C^*_{ab}$ (point P_2). Chroma difference is represented by the different distances of two sample loci from the origin of the a*b* coordinate system of the CIELAB colour space.

Colour differences ΔE^*_{ab} of less than 1 CIELAB unit are practically invisible, differences more than 3 CIELAB units are clearly visible.

The German RAL DESIGN system was specially developed for the visualization of the CIELAB 1976 colour space and can help to further illuminate details of this colour space. The individual colours were arranged according to hue, chroma and lightness *(Figure 12)*. The central non-chromatic axis of the colour space starts at black (minimum lightness) and runs through lighter shades of grey to white (maximum lightness, *Figure 13*). A specially developed colour wheel can illustrate the interdependency of hue angles and colours *(Figure 14)*. For this illustrative colour wheel, colours with high chroma were arranged at hue angle distances of 10° each (for practical use it was desirable to have intermediate colours at hue angle differences of 5° available for the yellow to orange range).

A good impression of the variability of colour for a given hue angle, with different chroma and lightness is illustrated in *Figure 15*. A very useful continuous colour wheel showing also the colours with different hue angle and chroma in the CIELAB colour space was developed by GretagMacbeth and is illustrated in *Figure 16*.

Colour-change garnets from Madagascar: variation of chemical, spectroscopic and colorimetric properties

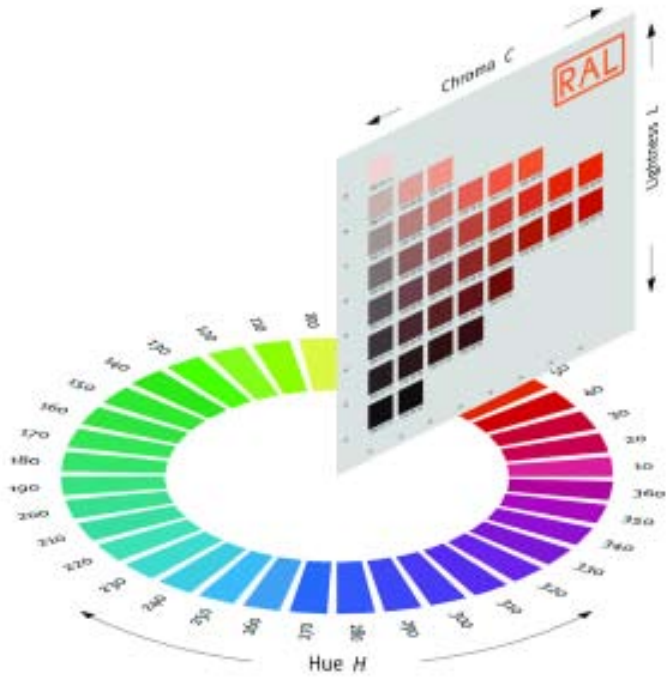

Figure 12: Outline of the RAL colour design system within the three-dimensional CIELAB colour space; the colour charts are systematically organized according to different hue angles, chroma and lightness; the printed colour chart represents an example of red orange at a hue angle of 50°. Copyright dtp studio Oldenburg and RAL gGmbH, Sankt Augustin, Germany (reproduced by permission).

Figure 13: Model of the three-dimensional CIELAB colour space, model of the colour solid, section parallel to the non-chromatic (black to white) lightness axis. Copyright dtp studio Oldenburg and RAL gGmbH, Sankt Augustin, Germany (reproduced by permission).

Figure 14: Hue circle (colour wheel) of CIELAB colour space representing examples of colours at different hue angles of the three-dimensional colour solid at high chroma and lightness 50. Copyright dtp studio Oldenburg and RAL gGmbH, Sankt Augustin, Germany (reproduced by permission).

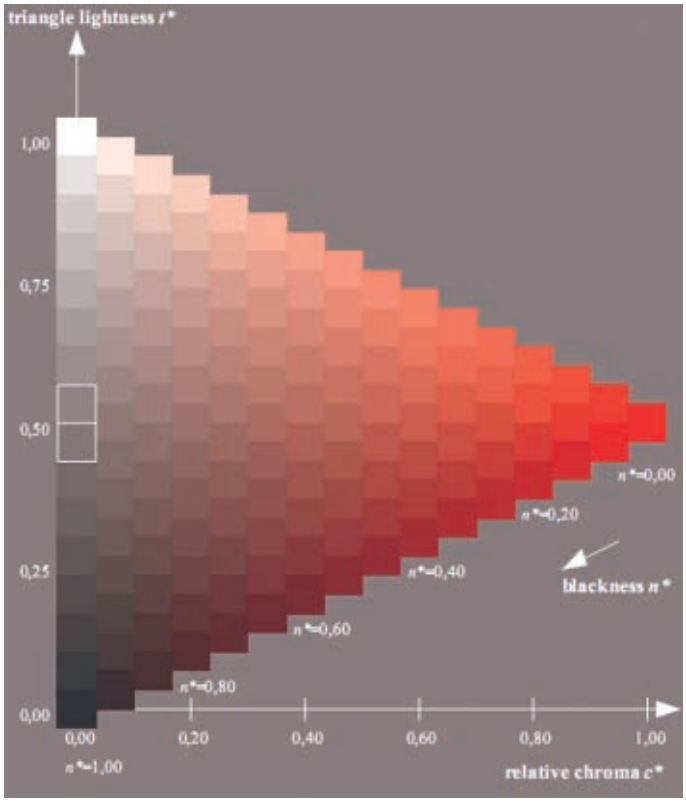

Fig. 15: Colour variation of red orange in the three dimensional CIELAB colour space at hue angle of 42° with varying lightness and chroma; at left the L axis of the CIELAB colour space from black to white is shown; with increasing chroma, more saturated, 'bright' colours are obtained. Copyright Relative Elementary Colour System (RECS) by K. Richter (reproduced by permission).*

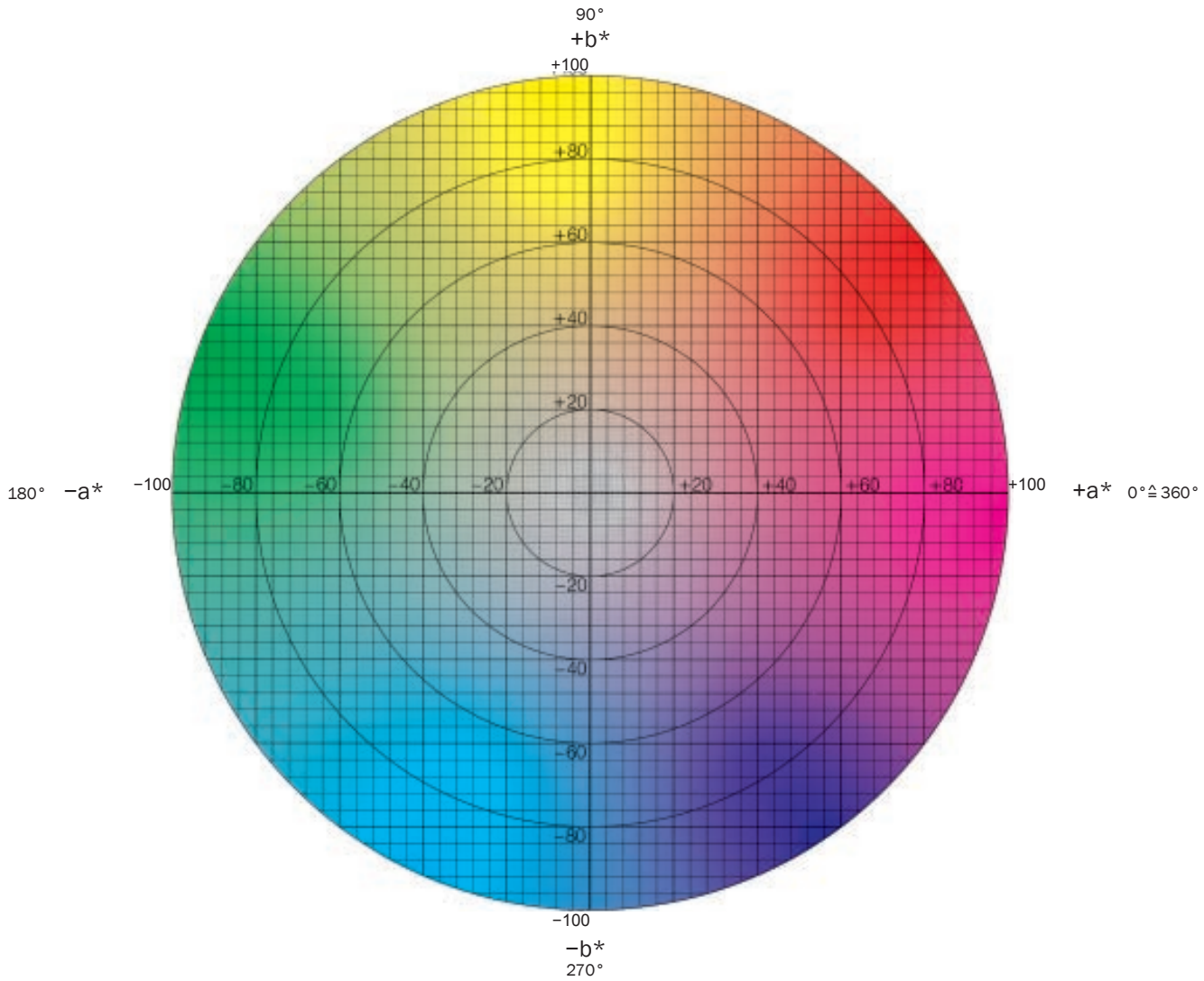

Fig. 16: Colour distribution in the CIELAB 1976 colour circle at various hue angles and chroma. Copyright GretagMacbeth, Regensdorf, Switzerland (reproduced by permission).

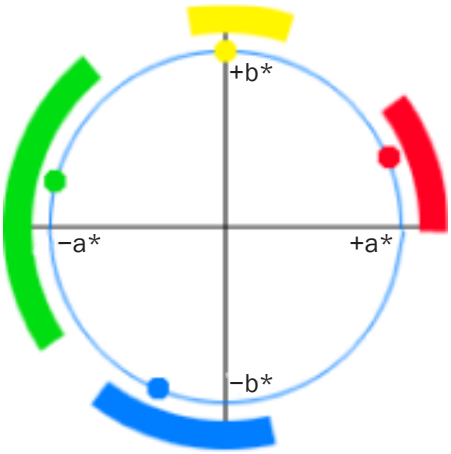

Figure 17: Variable location of the four 'unique' hues red, yellow, green and blue in the CIELAB colour circle; these are the hue angle ranges of 'unique' hues chosen by individuals in different colour studies. Copyright handprint media by Bruce MacEvoy (reproduced by permission).

There is, however, no 'correct' standardization and correlation of hue names related to hue angles in the CIELAB colour circle (see, e.g., Robertson, 1994; Liu, 2007; Liu and Hurwit, 2008). In particular the designation and selection of the four 'unique' colours red, yellow, green and blue is problematic as discussed in detail by Kuehni (2004) and MacEvoy (2005). The variability of the location of red, yellow, green and blue relative to the CIELAB colour circle is given in *Figure 17.*

For the present paper the authors decided to use the following scheme:

The hue angles for red, yellow, green, and blue were taken from Richter (1996, 2008b). These were calculated from the spectral data for the four test-colour samples red, yellow, blue and green as published by the CIE (1995) (K. Richter, pers. comm. 2008; for further information see Richter, 2007, 2008a; DIN 33872, 2007). The hue angles for the three equidistant colours between each of the four colours red, yellow, green, and blue were also taken from Richter (2008b). For illustration, this colour wheel is shown in *Figure 18,* with the names of colours assigned by the present authors, e.g. bluish green, blue green, greenish blue for the three colours between green and blue. Finally, the loci of intermediate colours, e.g. blue violet or reddish purple, were calculated by the present authors as desirable for the designation of colours in the present paper. The location of all these colours relative to the CIELAB colour circle and their designation in the present paper is given in *Table I* and *Figure 19.*

Examples: Natural alexandrite from Hematita, Brazil, and malaya garnet from Bekily, Madagascar

To demonstrate application of the above principles, the authors also examined two natural and two synthetic alexandrites and four malaya garnets from Bekily, Madagascar. The parameters calculated from the absorption spectrum of one example from each group are listed below and plotted in *Figures 4, 5, 10* and *11*.

Alexandrite, Hematita, Brazil

CIE 1931 system *(Figure 4)*:

Chromaticity coordinates for daylight D_{65}: x = 0.2974; y = 0.3622;
Dominant wavelength λ_d = 520 nm; purity p = 6.6 %; colour: green;
Chromaticity coordinates for incandescent light A: x = 0.4536; y = 0.3951;
Dominant wavelength λ_d = c551 nm; purity p = 5.5 %; colour: purple.

CIELAB 1976 colour space *(Figure 10)*:

Coordinates for daylight D_{65}: L* = 56.82; a* = −14.95; b* = 6.01;
Further parameters for daylight D_{65}: chroma C^*_{ab} =16.11; hue angle h_{ab} = 158°; colour: green;
Coordinates for incandescent light A: L* = 55.54; a* = 4.58; b* = −3.07;
Further parameters for incandescent light A: chroma C_{ab} = 5.51; hue angle h_{ab} = 326°; colour: purple;
Colour difference ΔE^*_{ab} = 21.56; hue angle difference Δh_{ab} = 168°.

Malaya garnet, Bekily, Madagascar

CIE 1931 system *(Figure 5)*:

Chromaticity coordinates for daylight D_{65}: x = 0.3379; y = 0.3412;
Dominant wavelength λ_d = 586 nm; purity p = 10.4 %; colour: orange;
Chromaticity coordinates for incandescent light A: x = 0.4744; y = 0.4031;
Dominant wavelength λ_d = 598 nm; purity p = 15.3 %; colour: red orange.

CIELAB 1976 colour space *(Figure 11)*:

Coordinates for daylight D_{65}: L* = 63.62; a* = 4.72; b* = 6.56;
Further parameters for daylight D_{65}: chroma C^*_{ab} = 8.08; hue angle h_{ab} = 54°; colour: orange;
Coordinates for incandescent light A: L* = 64.49; a* = 8.07; b* = 7.09;
Further parameters for incandescent light A: chroma C^*_{ab} = 10.74; hue angle h_{ab} =41°; colour: red orange;
Colour difference ΔE^*_{ab} = 3.51; hue angle difference Δh_{ab} = 13°.

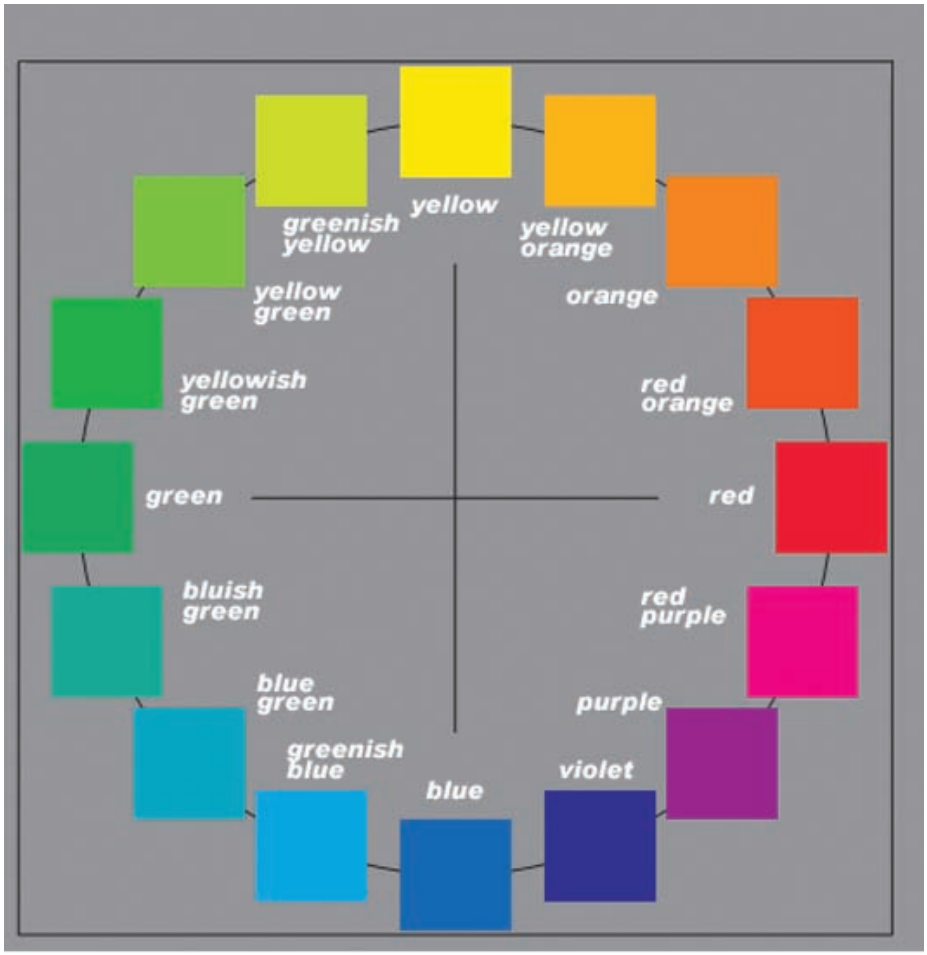

Figure 18: Colour circle in the CIELAB colour space with four unique colours and twelve (4 x 3) intermediate, equidistant colours; the verbal designation of colours was chosen by the present authors. Copyright Relative Elementary Colour System (RECS) by K. Richter (reproduced by permission).

Materials and methods

Two authors (KS and TH) collected 52 garnet samples showing clear colour changes, i.e. visually discernible colour changes upon changes of illuminant. Subsequent to earlier work on colour-change garnets from Bekily, Madagascar (Schmetzer and Bernhardt, 1999), which described mainly bluish green garnets with one yellow sample, the first author (KS) obtained garnets from Madagascar with a wider range of coloration from a German dealer who had purchased the garnets on local gem markets in Madagascar between 2000 and 2007. Most garnets were stated to come from Bekily, the classic locality mentioned in our previous paper, but it is possible that a few originate from other localities in Madagascar, e.g. from Ilakaka (where there are also many different gem varieties of garnets). However, we are confident that our samples have not originated from other countries. Most of the remaining samples studied come from the private collection of one author (TH), with specific colours that were rare or absent from the range in the first lot collected. For this second group, the history of the samples also points to Bekily as the source. Most samples are faceted, but a few rough garnets available to the authors were cut in Germany in order to study all samples under similar conditions.

Figure 19: Examples of the verbal designation of colours in the present paper are shown in the RAL colour wheel, which is based on the three-dimensional CIELAB colour space (see also Table I and Figure 14, copyright dtp studio Oldenburg and RAL gGmbH, Sankt Augustin, Germany (reproduced by permission).

For comparison, the authors also examined four vanadium- and chromium-free pyrope-spessartine garnets (malaya garnets) from Bekily (see Schmetzer *et al.*, 2001), two natural alexandrites from Hematita, Brazil, and two synthetic flux-grown alexandrites produced in Novosibirsk, Russia.

The chemical compositions of all 52 garnets were obtained using a Cameca Camebax SX 50 electron microprobe, and at least 10 point analyses from traverses across the table facet of each sample were recorded.

Colorimetric and spectroscopic data were obtained in transmission mode with a Zeiss multi-channel colour spectrometer, version MCS 311, and a Gemprobe GP 311 integration sphere. The MCS 311 is a double-beam colorimeter equipped with a pulsed Xenon lamp housed in a $BaSO_4$-lined integration sphere of 60 mm internal diameter providing diffuse, indirect illumination, Schott quartz-type fibre-light guides, two identical dispersive modules, each with a concave holographic grating and a 512-channel photodiode array, and a $BaSO_4$-lined sample platform with a central 3 mm mask hole for light transmission through the sample.

The instrument is designed for (nearly) simultaneous light intensity measurement of the sample beam and the reference beam and for colorimetric data processing.

The UV-Vis-NIR spectra of the garnets were also recorded on a second type of spectrophotometer, especially for the evaluation of absorption maxima of the main vanadium-chromium absorption band between 569 and 584 nm. This spectrometer system was designed and assembled by one of the authors (TH) using a $BaSO_4$-covered integration sphere, a 100 Watt Xenon light source and a high resolution spectrometer with a 2048 pixel CCD detector; the system had a resolution of 0.5 nm and covered the range of 245 to 1050 nm. Spectra were recorded with 200 to 500 sample scans to obtain a good signal to noise (S/N) ratio.

The spectra recorded using both spectrometer systems are closely comparable. The differences obtained for the vanadium-chromium maxima were mostly in the range of ±1 nm, with a few extending up to ±2 nm between both spectrophotometers. The differences in band positions of manganese and iron absorption maxima are also in the range of ±1 nm.

Colorimetric data processing was performed using the Zeiss MCS 311 system including the Zeiss DIAMOCR software which instantly provides the CIE 1931 chromaticity values x, y, Y and the CIELAB parameters L*, a*,b*, hue angle h_{ab}, and chroma C^*_{ab} for the two illuminants D_{65} and A in the present study. These values are based on the absorbance spectrum recorded from 375 to 774 nm at 10 ms integration time, 0.8 nm spectral pixel spacing, 2.4 nm spectral resolution, and ≦ 0.1 nm wavelength accuracy and reproducibility. Characteristic parameters such as dominant wavelengths for different light sources which were not available automatically from the Zeiss system, were calculated by a computer program written by one author (HJB).

The distance between the two loci of one sample with different illumination in the three-dimensional CIELAB colour space is represented by the parameter ΔE^*_{ab}, which represents the exact colour difference for the specific pair of illuminants used.

Visual determination of body and reflection colours of gemstones

It was desirable to compare the colorimetric results with visual determinations. The observed colours of these colour-change garnets are dependent not only on a major change of illuminants (from daylight to incandescent light), but also on more subtly different types of natural light such as direct sunlight, diffuse light from cloudy skies, or morning, noon or evening light. The colour temperature of daylight is mostly in the range 5500 to 6500 K but depends in detail on geographical location, time, date and atmospheric conditions.

The colours of many of the garnets in the suite changed in different types of daylight. Therefore, the visual estimation of colour was performed in a dark room using a daylight-equivalent fluorescent light source (Eickhorst, Hamburg, Germany) with 6400 K colour temperature (close to CIE standard illuminant D_{65}). For incandescent light, a tungsten bulb was used. D_{65} is an artificial daylight with an ultraviolet component which is also designated 'standard noon daylight'. Its colour temperature is approximately 6500 K. Illuminant A is tungsten light with a colour temperature of 2856 K. According to their spectral power distribution, both illuminants are the best suited, standardized substitutes of the traditional, natural light sources, diffuse daylight (not direct sunlight) and candle light. D_{65} is produced by xenon lamps (sometimes with UV filters) and is widely used in simultaneously recording spectrometric systems. Illuminant A is generated by tungsten-halogen lamps and is used in sequentially recording spectrometers. Illuminants D_{65} and A are widespread in the industry, e.g. in GretagMacbeth colour viewing booths.

The garnets were placed face-up on a white (neutral) background under 0° illumination and 0° observation (0°/0° geometry) as well as under 0° illumination and 45° observation (0°/45° geometry). The illuminated samples were visually compared in reflection with a printed

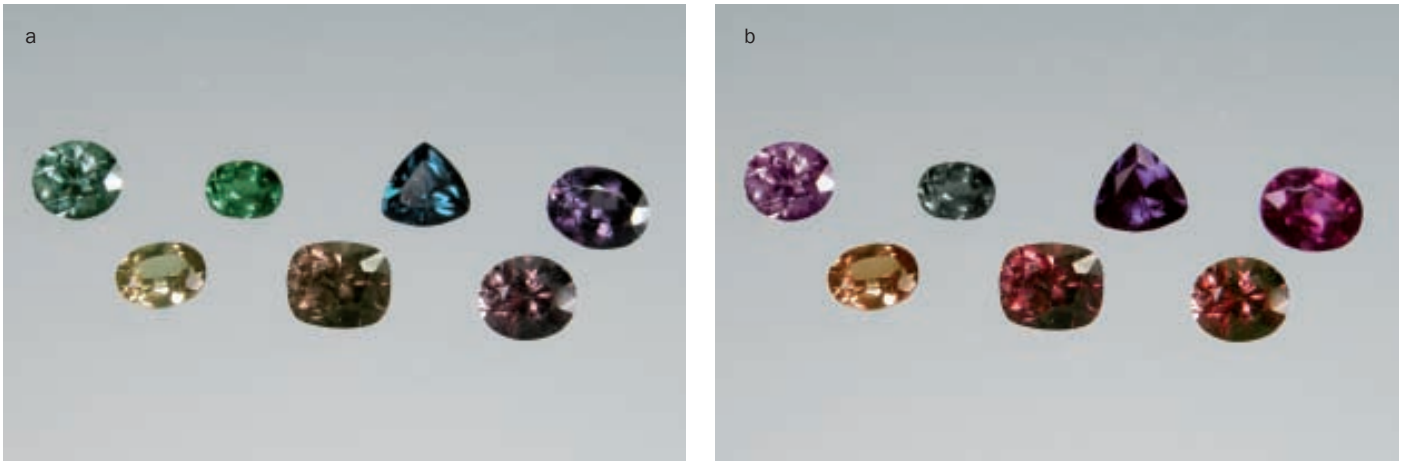

Figure 20 a,b: Colour-change garnets from Madagascar representing the seven groups of samples described in this paper in daylight (left) and incandescent light, upper row from left to right: Groups 1 to 4, lower row from left to right: Groups 5 to 7. Size of the garnet at the upper right 5.2 x 6.8 mm, weight 0.89 ct.

Colour-change garnets from Madagascar: variation of chemical, spectroscopic and colorimetric properties

Table II: Physical properties, chemical compositions and colorimetric data of seven groups of colour-change garnets from Madagascar.

Group	1	2	3	4	5	6	7
Sample numbers	1/1–1/10	2/1–2/9	3/1–3/7	4/1–4/3	5/1–5/14	6/1–6/7	7/1–7/2
Colour in daylight	green to slightly yellowish green or greenish yellowish grey	green to slightly yellowish green	bluish green or greenish blue	purple or violet or purplish red	yellow green to yellow or yellowish grey to greenish yellowish grey	orange to yellow orange	red
Colour in incandescent light	red purple to reddish purple or purple	red purple or yellowish grey to greenish yellowish grey or greyish bluish green	violet purple to purple or blue violet or blue green	reddish purple to red purple	orange to red purple	red	red or purplish red
Mol.% end members[a]							
Goldmanite	1.10–3.41	3.63–4.92	2.29–5.13	1.63–2.70	0.92–2.18	0.64–1.50	0.37–0.55
Uvarovite	0.34–0.73	0.19–2.02	0.44–1.86	1.03–1.61	0.15–0.74	0.61–1.06	0.34
Almandine[b]	2.87–7.24	6.09–10.57	3.21–9.29	7.45–14.95	3.18–5.15	5.61–7.85	10.02–16.35
Spessartine	24.95–45.73	54.69–62.03	33.41–41.29	29.24–36.62	27.09–73.83	48.75–61.87	22.96–26.24
Pyrope	42.42–62.42	22.41–31.20	38.29–55.04	44.06–58.08	14.49–59.57	28.99–39.54	55.43–59.27
Grossular	2.18–11.88	0.24–6.09	1.11–13.30	2.07–3.47	3.02–10.45	1.44–2.43	3.75–3.76
Goldmanite + Uvarovite	1.50–4.14	4.23–6.94	2.78–6.75	3.16–4.31	1.17–2.92	1.66–2.26	0.71–0.89
Spessartine : (Goldmanite + Uvarovite)	9.7–16.9	8.6–12.9	6.1–12.2	8.5–9.9	17.2–33.1	23.1–30.2	25.8–37.0
Absorption maximum (nm)	572–576	578–583	574–584	571–573	570–573	569–571	570–571
Colorimetric data CIE 1931[c]							
λ_D (nm) for daylight D_{65}	513–552	517–548	484–501	635–c563	567–577	581–587	598–608
Purity p for daylight D_{65}	1.0–5.0	7.6–11.4	1.1–17.1	4.5–7.1	2.1–34.2	9.0–15.6	9.9–12.5
λ_D (nm) for incandescent light A	c509 –c550	c507 or 504–576	c540–495	c510–c531	586–c511	609–633	619–c504
Purity p for incandescent light A	3.8–7.1	1.6–6.1	5.2–21.3	20.0–27.9	4.8–38.0	11.4–20.7	17.1–19.9
Colorimetric data CIELAB 1976[d]							
C^*_{ab} for daylight D_{65}	1.52–8.24	10.92–17.90	1.92–21.57	3.41–6.83	1.16–17.88	5.70–8.60	9.37–9.91
h_{ab} (°) for daylight D_{65}	141.5–161.8	144.4–159.4	173.4–238.5	307.9–14.2	79.4–119.1	51.6–69.4	22.2–30.7
C^*_{ab} for incandescent light A	3.07–6.37	1.21–4.13	5.41–14.30	15.27–17.98	4.54–18.16	10.42–15.11	13.59–15.66
h_{ab} (°) for incandescent light A	326.6 –357.3	4.3 or 105.9–193.9	223.3–332.5	336.5–355.8	353.8–65.4	19.2–28.7	14.6–23.2
Δh_{ab} (°)	144.3–176.2	147.8 or 0.6–34.5	48.9–159.1	13.0–29.4	30.7–119.7	28.8–48.9	7.5–7.6
ΔE^*_{ab}	6.8–12.4	8.9–16.1	7.3–17.1	11.4–12.4	5.1–11.2	7.8–9.8	4.6–6.1

[a] Formulae of garnet end members:
goldmanite $Ca_3V_2Si_3O_{12}$; uvarovite $Ca_3Cr_2Si_3O_{12}$; grossular $Ca_3Al_2Si_3O_{12}$
almandine $Fe_3Al_2Si_3O_{12}$; spessartine $Mn_3Al_2Si_3O_{12}$; pyrope $Mg_3Al_2Si_3O_{12}$

[b] Total iron calculated as FeO in almandine

[c] λ_D = dominant wavelength, c indicates 'complement of'

[d] C^*_{ab} = chroma; h_{ab} = hue angle

Δh_{ab} = hue angle difference between daylight and incandescent light

ΔE^*_{ab} = colour difference between daylight and incandescent light in the three dimensional CIELAB colour space

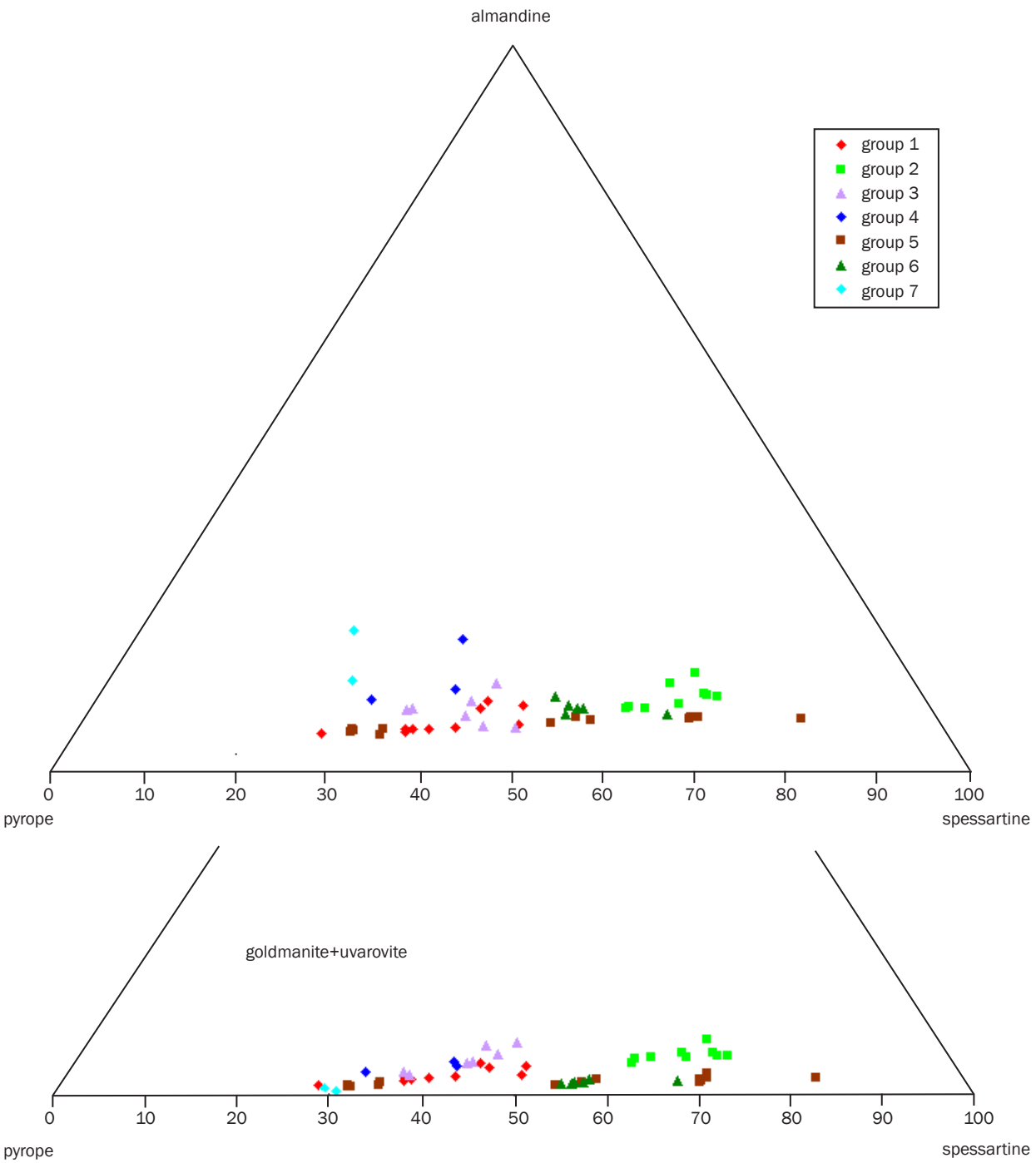

Figure 21: Compositions of colour-change garnets normalized to end-members (pyrope + spessartine + goldmanite + uvarovite) = 100 (below) and to (pyrope + spessartine + almandine) = 100 (above) and shown on triangular diagrams.

version of the CIE 1931 chromaticity diagram (the 'horseshoe') and a printed version of the CIELAB 1976 colour circle as well as with the diagrams published by Richter (2008b). Alternatively one could use *Figures 2, 16* and *19*. Using this procedure, it was confirmed that the visually estimated colour was identical or nearly identical with the colour coordinates of the sample calculated from spectroscopic data for the different colour spaces (see above).

For the designation of colours we use the hue names for highly saturated colours as summarized in *Table I*. In order to avoid numerous fantasy names which could lead to a great deal of confusion, we do not add special modifiers to these names and comment only if there is a relatively low or high chroma (saturation) measured for the colour of a specific garnet. Each garnet colour observed under standard illumination was compared with its computer screen colour of the

digitally photographed samples and, if necessary, the latter was adjusted to the closest match using Photoshop Elements 6.0 software. However, we are aware that these colours could look slightly different on other screens or in print.

Results

Presentation of data

The 52 garnets were divided into seven main groups based on their colour in daylight as determined (measured and calculated) in the CIE 1931 and the CIELAB 1976 colour spaces and confirmed by visual impression *(Figure 20 a,b)*. In the three-dimensional CIELAB colour space, the hue, represented by hue angle, was considered as the most important factor in grouping the garnets. This brings together those garnets with similar colour in daylight and with similar chemical and spectroscopic properties as well as a similar colour change, but such a group may also include samples with different spectra, composition and colour change.

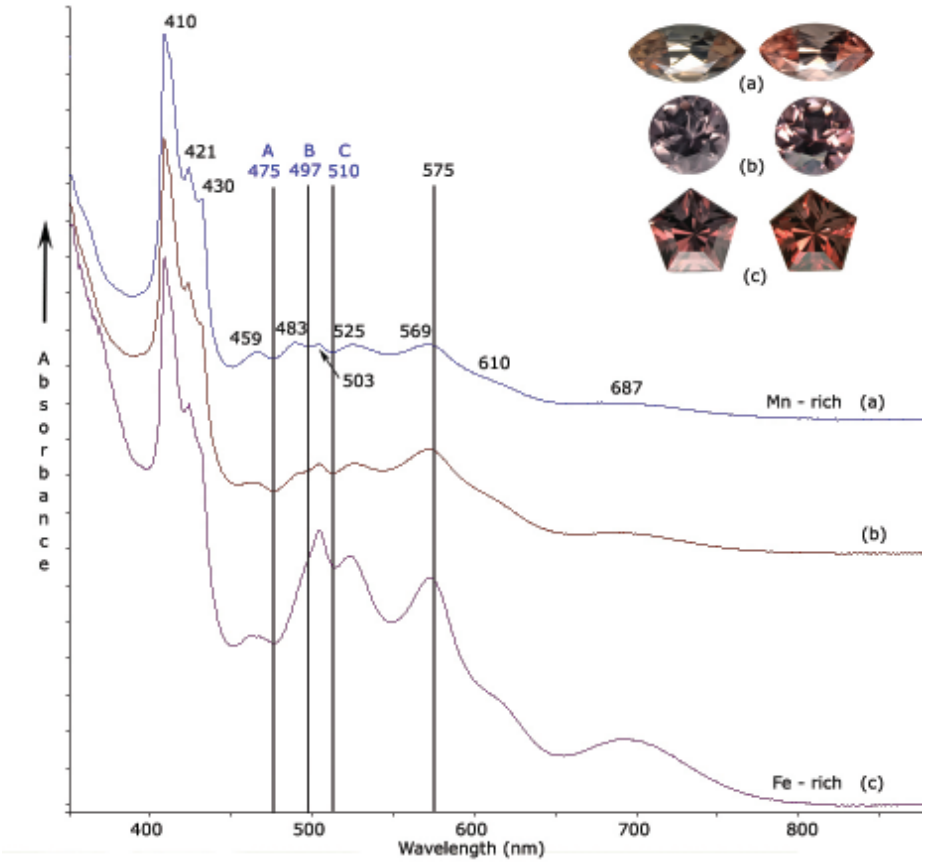

Figure 22: Absorption spectra of three vanadium- and chromium-free malaya garnets from Bekily, Madagascar, with different manganese and iron contents; the samples are shown in daylight (left) and incandescent light (right).

Chemical properties

The composition of each garnet is more or less homogeneous without any significant chemical zoning; this is consistent with the absence of any significant colour zoning. All samples are members of the pyrope-spessartine solid solution series with minor to major contents of iron (almandine) and minor contents of vanadium and chromium. Formally, the vanadium and chromium contents are calculated as minor percentages of the goldmanite and uvarovite molecules. In addition, a range of percentages of grossular is present. The compositional range of all 52 analysed samples is as follows:

pyrope $Mg_3Al_2Si_3O_{12}$ 14.49–62.42 mol.%
spessartine $Mn_3Al_2Si_3O_{12}$ 22.96–73.83 mol.%
almandine $Fe_3Al_2Si_3O_{12}$ 2.87–16.35 mol.%
grossular $Ca_3Al_2Si_3O_{12}$ 0.24–13.30 mol.%
goldmanite $Ca_3V_2Si_3O_{12}$ 0.37–4.92 mol.%
uvarovite $Ca_3Cr_2Si_3O_{12}$ 0.19–2.02 mol.%

The compositions of the differently coloured seven basic groups are given in *Table II* and shown graphically in *Figure 21*. It is evident that there is no clear correlation between the different colours of the groups and their compositions, nor with low, medium or high spessartine (manganese) contents. However, comparison of the composition of samples with a daylight colour from green, bluish green or greenish blue (Groups 1 to 3) indicates that they tend to have higher goldmanite (vanadium) and uvarovite (chromium) contents than garnets with a daylight colour from yellow to reddish orange (Groups 5 and 6). The few samples with violet, purple and purplish red coloration in daylight (Group 4) have relatively high goldmanite and uvarovite contents, but also contain high amounts of the almandine (iron) molecule. The two samples with red coloration in daylight (Group 7) are the garnets with the smallest vanadium and chromium contents, but have high or extremely high iron (almandine) values.

Table III: Assignment of iron- and manganese-absorption bands in pyrope-spessartine garnets from Madagascar[a].

Absorption maximum (nm)	Fe^{2+}	Mn^{2+}	Fe^{3+}
410		✓	
421		✓	
430		✓	✓
459	✓	✓	
483		✓	
503	✓		
525	✓	✓	
569	✓		
610	✓		
687	✓		

[a] after Schmetzer *et al.* (2001)

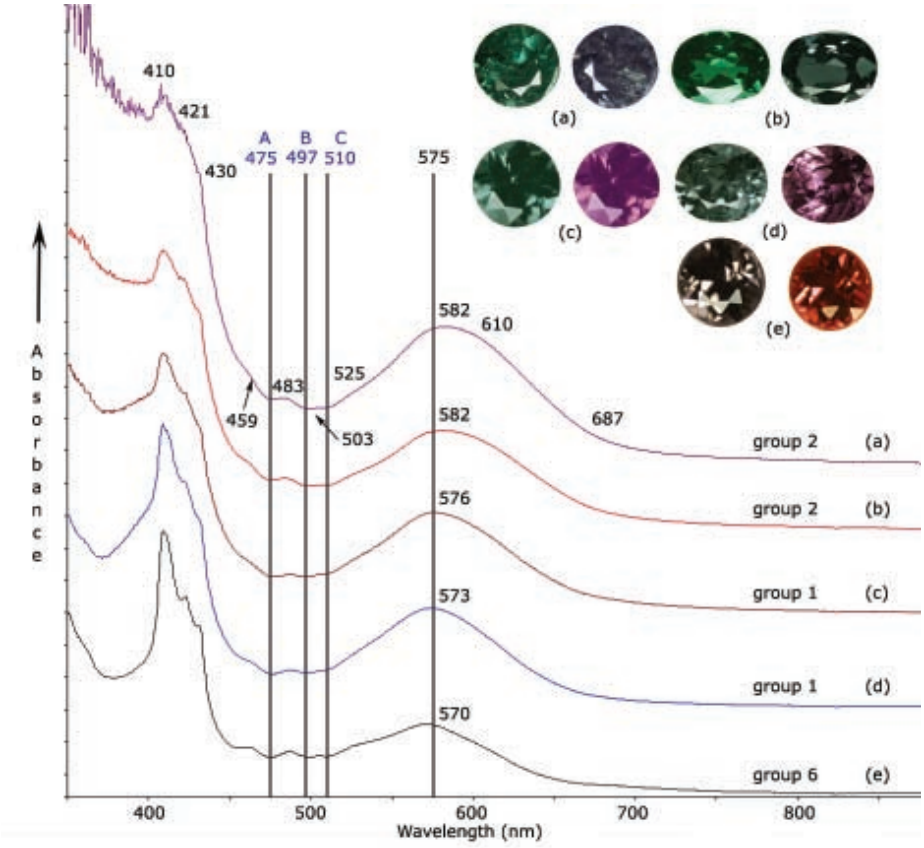

Figure 23: Absorption spectra of vanadium- and chromium-bearing colour-change garnets from Madagascar showing the variation of the position of the dominant vanadium-chromium absorption band in the yellow range of the visible; the daylight colour is shown on the left and incandescent light colour on the right in each pair of images of samples a–e.

Spectroscopic properties

Assignment and positions of absorption maxima

The chemical compositions of the colour-change garnets indicate that we should consider mainly the transition elements vanadium, chromium, iron and manganese for the assignment of peaks in the absorption spectra and in finding the causes of their colour. A general problem with the assignment of absorption bands in garnet spectra is the overlap of several bands with identical or almost identical absorption maxima which have different causes. In previous work by Schmetzer *et al.* (2001) some absorption bands in the spectra of iron-bearing pyrope-spessartine garnets (malaya garnets from Bekily, Madagascar) were assigned to manganese and iron *(Table III)*. Three spectra of this type with varying iron : manganese ratios are shown in *Figure 22*. For a more detailed discussion and additional spectra with varying iron : manganese ratios the reader is referred to the paper of Schmetzer *et al.* (2001) and the references cited therein.

The spectra of all the colour-change garnets in this study show the typical iron and manganese bands of malaya garnets with an additional dominant absorption band in the greenish yellow, yellow or yellow orange area of the visible range. In detail, the position of this absorption maximum shifts between 569 and 584 nm *(Figure 23)*.

The positions of iron and manganese absorption bands in pyrope-almandine-spessartine garnets are constant or almost constant, while the vanadium and chromium peak positions in these garnets do vary to a certain degree (Amthauer, 1976; Schmetzer and Ottemann, 1979). In general, both vanadium and chromium show two strong absorption bands in the yellow and in the blue to near ultraviolet range which are designated $\nu 1$ and $\nu 2$, respectively; their wavelength positions in garnets of various compositions are given in *Table IV*.

In garnets with strong manganese absorption bands, the position of $\nu 2$ of vanadium and/or chromium cannot be accurately determined because of overlap. However, from the spectra of manganese-free samples, especially synthetic garnets, the positions of both absorption maxima can be estimated. But even then, since the positions of $\nu 1$ and $\nu 2$ of chromium and vanadium lie in the same spectral range, when both elements are present in a garnet, their absorption maxima overlap and cannot be separated satisfactorily.

All the colour-change garnets in this study contain a distinct amount of the almandine end member. Iron has a strong absorption band at about 569 nm which cannot be distinguished from the vanadium and chromium absorption band in this area *(Figures 22* and *23)*. Therefore, the exact peak position and width of this absorption band may be influenced by the iron content of the samples, especially in samples with relatively low vanadium and chromium and high iron contents.

The variation of the absorption maxima of chromium and vanadium in natural garnets with the general composition $X_3Y_2(SiO_4)_3$ is caused by structural expansion (in literature also designated as lattice expansion) due to isomorphic replacement on the X- and Y-sites in the garnet structure. The three main replacements are:

- Starting with pure pyrope in pyrope-almandine-spessartine garnets, structural expansion is caused by replacement of aluminium on Y-sites by various amounts of vanadium and chromium or, to a smaller extent, by replacement of magnesium by various amounts of manganese and iron (as Fe^{2+}) on X-sites.
- In calcium-bearing garnets (grossular, goldmanite, uvarovite, andradite), expansion is caused by an isomorphic replacement of aluminium on Y-sites by vanadium, chromium or iron (as Fe^{3+}).

Table IV: Wavelengths in nm of vanadium and chromium absorption bands in natural and synthetic garnets.

Vanadium–bearing garnets	ν1 (V^{3+})	ν2 (V^{3+})	Ref.	Chromium–bearing garnets	ν1 (Cr^{3+})	ν2 (Cr^{3+})	Ref.
				synthetic pyrope	560	408	4
				pyrope	556–574	410–416	3
				Cr–rich pyrope (colour–change)	576	416	3
pyrope–spessartine (colour–change)	568–576		1	pyrope–spessartine (colour–change)	570–575		1
				synthetic knorringite (colour–change)	579	411	4
synthetic pyrope[a]	581	407	2				
Ca–Mg–spessartine	588		1				
grossular	606–610	425–427	1	grossular	606	435	3
Mn–goldmanite	621	446	1				
				uvarovite	615	440	3
goldmanite	625	444	1				
				andradite	621		3

References: 1. Schmetzer and Ottemann (1979); 2. Taran *et al.* (2002); 3. Amthauer (1976); 4. Taran *et al.* (2004).

[a] Containing V^{3+} and V^{4+}

- There is also a difference of absorption maxima between vanadium- and/or chromium-bearing pyrope and/or vanadium- or chromium-bearing grossular, which is caused by structural expansion following replacement of magnesium by calcium on X-sites.

As a result of one or more of these replacements, the absorption maxima of vanadium and/or chromium are shifted to higher wavelengths, and the effects may overlap.

Using this generally accepted background for interpreting measurements from our samples, we have to examine the effect of replacement of aluminium by vanadium and chromium and the effect of replacement of magnesium and/or manganese and/or iron by calcium. Any expansion in the structure due to the replacement of magnesium by manganese and/or iron has such a small influence on the position of the absorption maximum that it can be neglected in this discussion.

A graph of the absorption maxima in all the colour-change garnets versus the sum of their goldmanite and uvarovite contents is shown in *Figure 24* and indicates a positive correlation. The main shift of the absorption maximum from 569–584 nm is correlated with increasing isomorphic replacement of aluminium on Y-sites by vanadium and chromium, but we have to consider also the influence of other chemical components of the garnets, e.g. iron and calcium.

Considering the expansion of the structure caused by replacement of magnesium by calcium, the influence of the calcium content of our samples on the position of the dominant vanadium and chromium absorption maximum cannot be neglected. If the samples are now considered in terms of their calcium contents (represented by the sum of goldmanite + uvarovite + grossular), the line of correlation in *Figure 25* (representing samples with intermediate calcium contents) separates most of the low calcium-bearing samples below from most of the high calcium-bearing samples above. This means that the contents of magnesium and calcium are influencing the position of the vanadium-chromium maximum. With increasing calcium contents, there is a shift of the vanadium-chromium maximum to higher wavelengths. This is consistent with the peak positions of vanadium- and chromium-bearing garnets as summarized in *Table IV*. Consequently, the replacement of magnesium by calcium is also influencing the colour of the garnets, although magnesium and calcium themselves are not colour-causing elements.

In summary, the absorption maxima in colour-change garnets from Madagascar are assigned to vanadium and chromium on Y-sites and to manganese and iron on X-sites of the garnet structure. A general outline in *Figure 26* shows the wavelengths of maxima (peaks) and minima with the elements that caused them. The exact position of this maximum, however, is also slightly influenced by substitution of magnesium by calcium and by the overlap with an iron absorption band at 569 nm. The second strong absorption band of chromium and vanadium occurs in the range of the strong manganese triplet in the violet and cannot be separated from the three strong manganese bands in this range. Any possible shift of this second vanadium-chromium maximum is masked by the Mn peaks, so it is labelled 'shift?' in the figure.

Position of absorption minima

To discuss the causes of colour and colour change in garnets in this study, the areas of the spectra with high transparency in the visible range must be examined. In the spectra of all samples (see *Figure 23*) there are two areas of high transparency, one in the red to orange and the other in the yellowish green to blue violet. It is clear that transparency in the red to orange range is mainly dependent on the position and intensity of the vanadium-chromium band with a maximum measured between 569 and 584 nm (see above).

In the yellowish green to blue violet

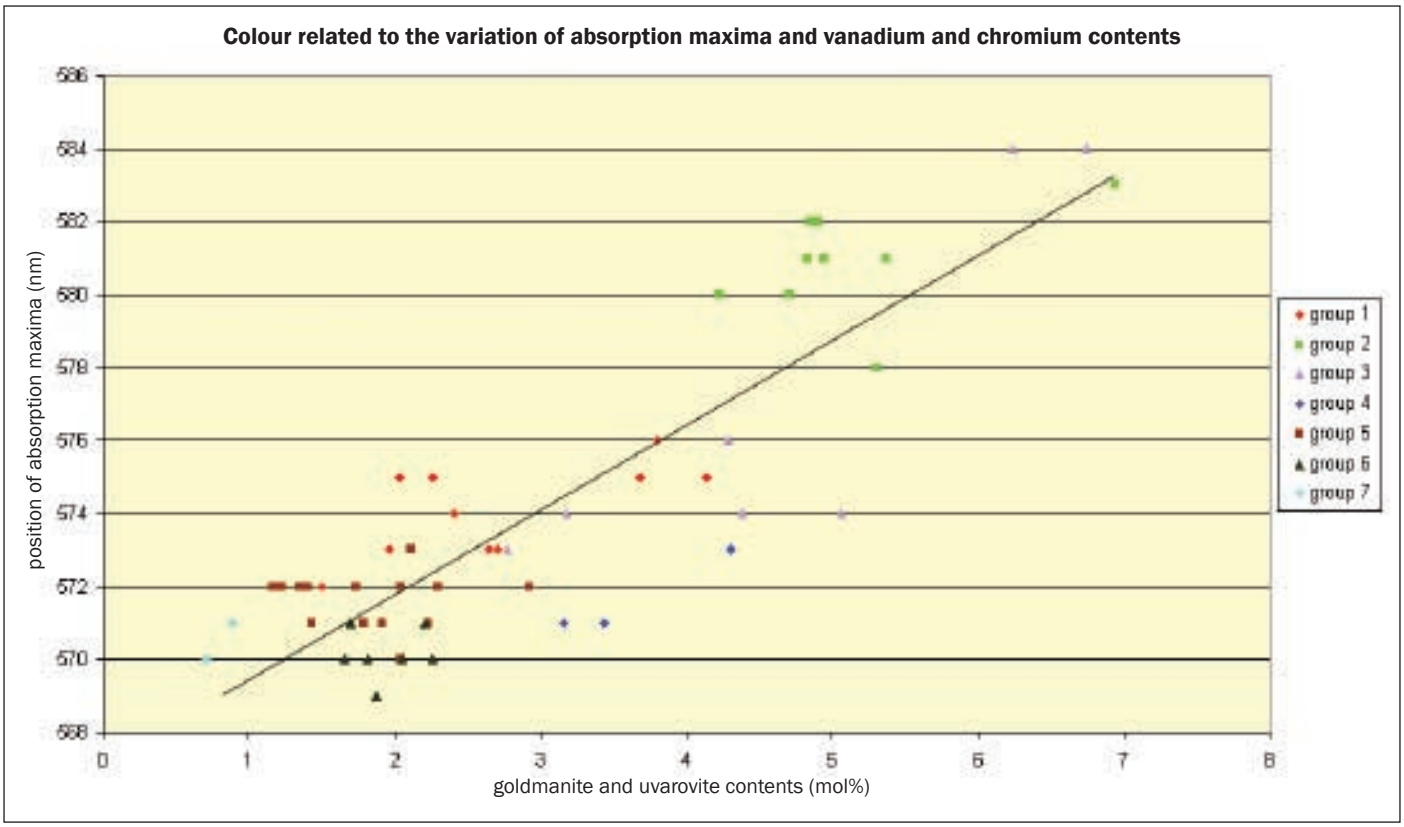

Figure 24: Correlation of the position of the absorption maximum of the vanadium-chromium absorption band in the yellow range of the visible and the vanadium+chromium contents within the seven groups of colour-change garnets.

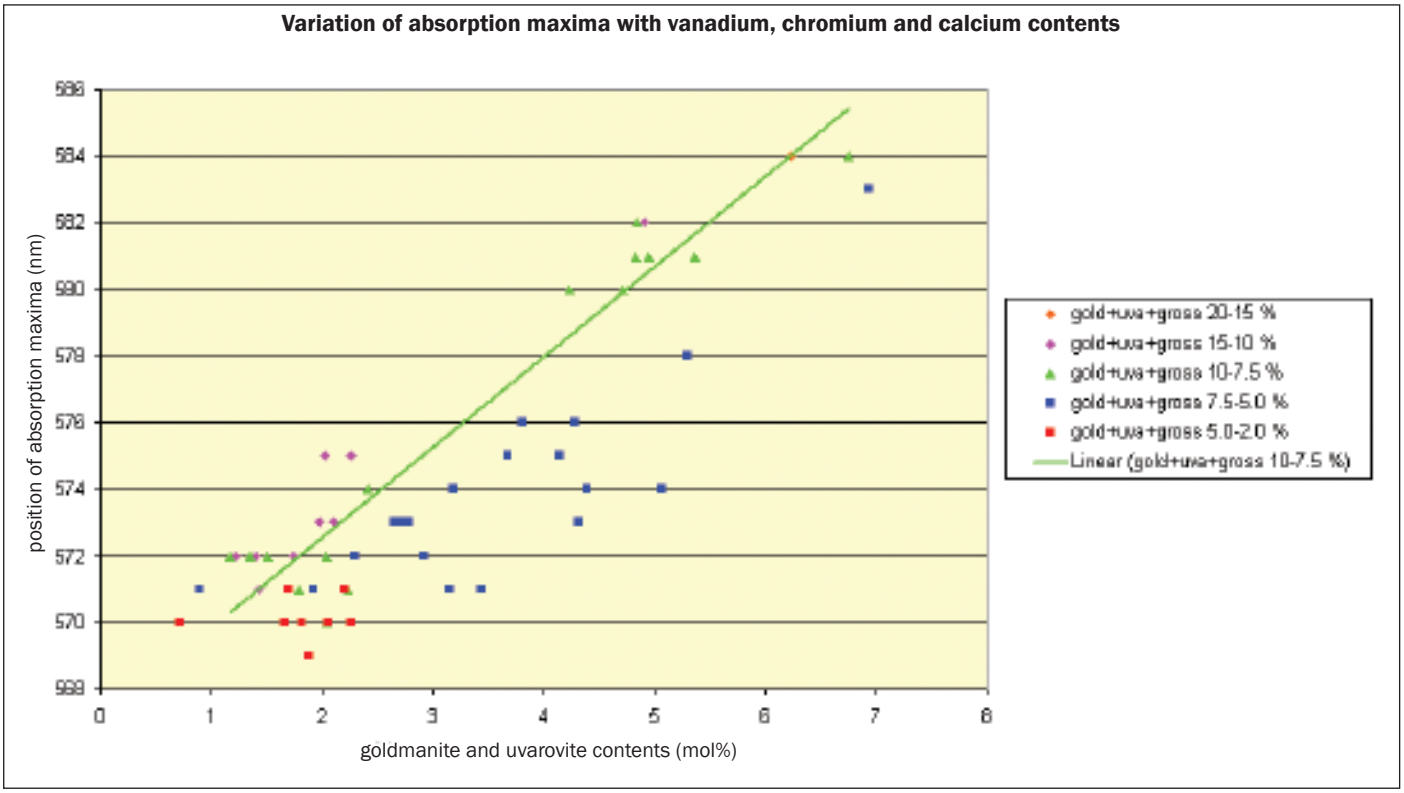

Figure 25: Correlation of the position of the absorption maximum of the vanadium-chromium absorption band in the yellow range of the visible and the vanadium+chromium contents of the garnets, with symbol identification of the different calcium contents (represented by goldmanite+uvarovite+grossular molecular percentages) of the samples.

Colour-change garnets from Madagascar: variation of chemical, spectroscopic and colorimetric properties

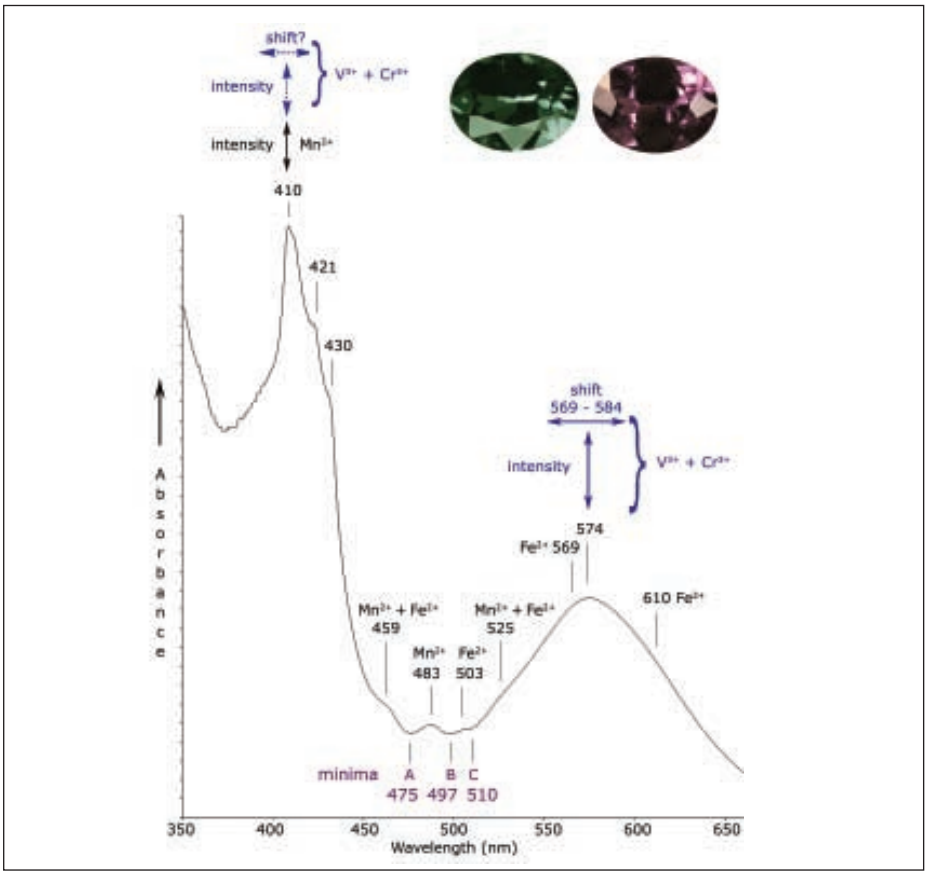

Figure 26: Schematic outline of the different parameters influencing the absorption spectra of vanadium- and chromium-bearing garnets within the pyrope-spessartine-almandine-grossular solid solution series; one such typical garnet is shown in daylight (left) and incandescent light (right), the spectrum of the same sample is also drawn.

range there are four manganese and/or iron absorption bands of low intensity at 525, 503, 483 and 459 nm (see *Table III*). Between these four absorption bands, three individual minima are located, which are designated as A = 475 nm (blue), B = 497 nm (bluish green), and C = 510 nm (green). The balance between these three minima can be used to estimate the area with highest transmission, i.e. the position of the centre of the absorption minimum. Together, the absorption minimum in the orange to red region, and that in the blue-green determines the colour and colour change of the garnet.

Table V: V, Cr and Mn contents and associated absorption maxima and minima in spectra of colour-change garnets from Madagascar.

Group	Sample	Goldmanite + uvarovite (mol.%)	Almandine (mol.%)	Spessartine (mol.%)	Ratio spessartine : (goldmanite + uvarovite)	Maxima (nm)	Minima*	
Groups with differently coloured garnets							*Figure 23*	
2	2/7	4.85	6.09	56.39	11.6	582	B>C>>A	(a)
2	2/3	4.23	6.21	54.69	12.9	580	B>C>>A	(b)
1	1/4	3.80	6.64	44.96	11.8	576	A≈B>C	(c)
1	1/6	2.65	3.74	38.82	14.6	573	A≈B>C	(d)
6	6/1	2.26	6.34	52.16	23.1	570	A≈B≈C	(e)
Green to greenish blue groups (1–3) and violet to purplish red group (4)							*Figure 27*	
3	3/5	6.24	3.21	38.96	6.2	584	B	(a)
2	2/4	5.37	7.90	61.68	11.5	581	B>C>>A	(b)
1	1/8	1.97	3.29	31.77	16.1	573	A≈B>C	(c)
3	3/1	2.78	6.34	33.86	12.2	573	A>B>C	(d)
4	4/1	3.16	7.45	29.24	9.2	571	A>B>C	(e)
Yellow green to orange groups (5–6) and red group (7)							*Figure 28*	
7	7/2	0.71	10.02	26.24	36.9	570	A>>C	(a)
6	6/7	1.66	7.85	48.75	30.4	570	A≈B≈C	(b)
5	5/4	2.04	4.81	60.78	29.8	570	B≈C>A	(c)
5	5/9	1.35	2.76	30.86	22.9	572	A≈B≈C	(d)
5	5/10	1.74	3.29	30.00	17.2	572	A≈B>C	(e)

* Minima: A = 475 nm blue, B = 497 nm bluish green, C = 510 nm green; A>C means that transmission is higher at the A wavelength, B>C higher at the B wavelength, etc..

Colour-change garnets from Madagascar: variation of chemical, spectroscopic and colorimetric properties

Since the region in the blue-green with the highest transparency is mainly dependent on the position and intensity of the vanadium-chromium absorption and on the intensity of the manganese triplet in the violet at 430, 421 and 410 nm, the ratio spessartine : (goldmanite + uvarovite), calculated from analytical data, could provide a parameter of help in understanding the colour behaviour of these garnets. This parameter is abbreviated s:(g+u) in the following text.

Chemical and spectroscopic parameters of selected samples with characteristic spectra *(Figures 23, 27* and *28)* are summarized in *Table V*. The first samples to be considered are those with s:(g+u) ratios smaller than 17 and a colour in daylight varying from green to greenish blue (Groups 1, 2 and 3) or from violet to purplish red (Group 4). If we start with a sample of Group 1 (a group which shows the strongest change in hue angle between daylight and incandescent light and a colour change from green to purple, reddish purple or red purple), in *Figure 27c* it is apparent that there is almost equal transparency at minimum A (blue) and B (bluish green) and a somewhat weaker transparency at minimum C (green). The parameter s:(g+u) of this garnet is 16.1. For samples with smaller s:(g+u) parameters, there are two situations:

- The absorption maximum lies at wavelengths above 576 nm and although the relative intensity of the vanadium-chromium absorption band is high, the highest transparency occurs at minimum B (bluish green) with high transparency also at minimum C (green) *(Figure 27 a,b)*.
- The absorption maximum is at 576 nm or lower wavelengths, and the highest transparency is at minimum A (blue) *(Figure 27 d,e)*.

The second collection of samples (Groups 5, 6 and 7) to be considered consists of those with s:(g+u) ratios larger than 17 and a colour in daylight between yellow and red. All these garnets have absorption maxima at 572 nm or below. A garnet sample with a s:(g+u) ratio slightly above 17 has a spectrum with almost

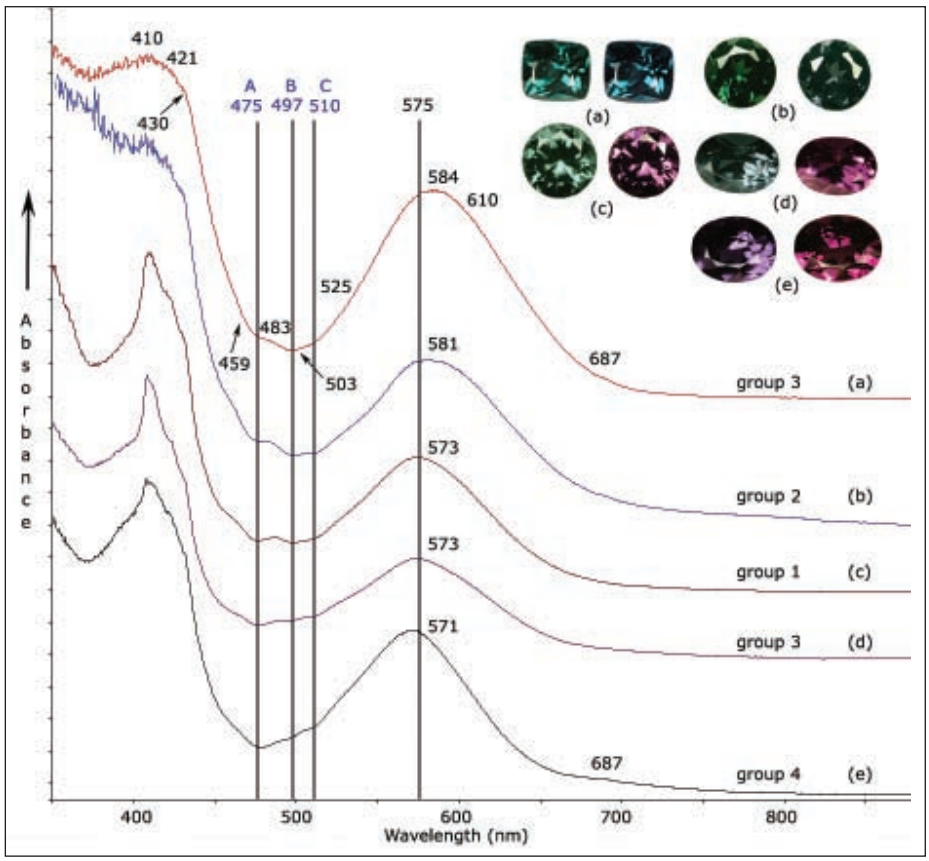

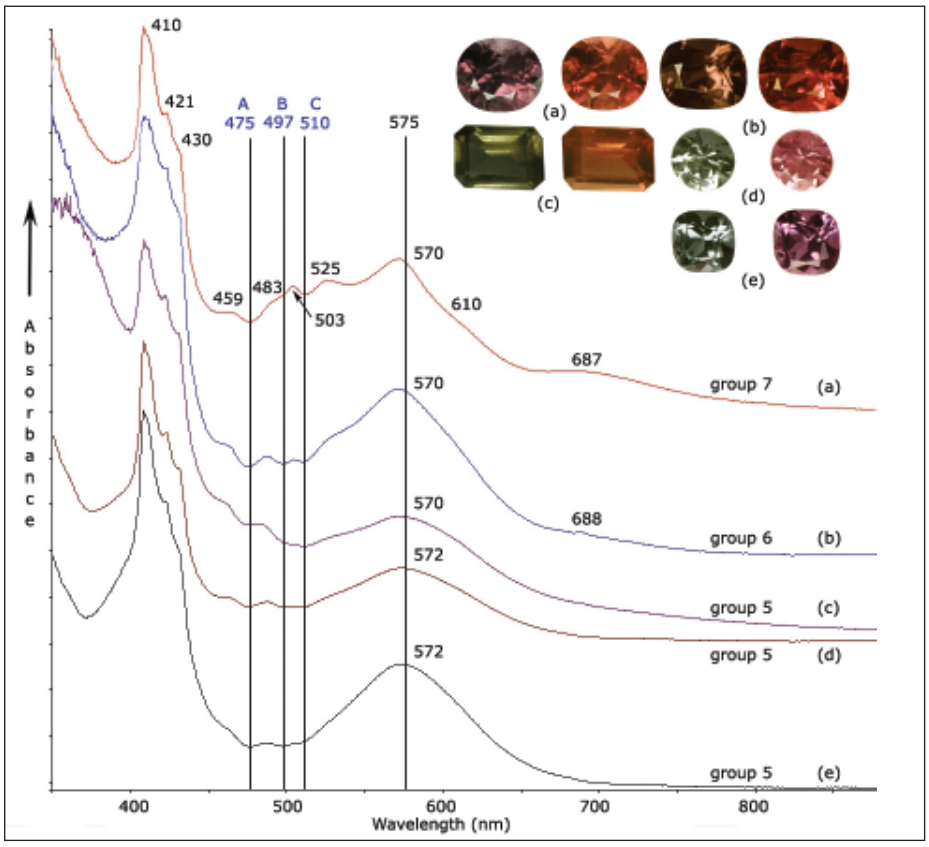

Figure 27 (top) and 28: Absorption spectra of vanadium- and chromium-bearing colour-change garnets from Madagascar showing the variation of the position of absorption maxima of the dominant vanadium-chromium absorption band in the yellow region and the variation of the position of absorption minima in the blue to green region; each sample pair is shown in daylight (left) and incandescent light (right).

Table VIa. Physical, chemical and colorimetric data of individual colour-change garnets from Madagascar

Group	1			2			3				
Sample	1/2	1/8	1/10	2/1	2/6	2/9	3/3	3/4	3/5	3/6	3/7
Colour in daylight	green	slightly yellowish green	greenish yellowish grey	green	green	green	bluish green	bluish green	bluish green	bluish green	greenish blue
Colour in incandescent light	red purple	red purple	reddish purple	red purple	greenish yellowish grey	greyish bluish green	violet purple	blue violet	blue green	blue violet	violet purple
Microprobe analyses (wt.%)[a]											
SiO_2	39.46	40.61	41.32	37.28	37.90	37.45	39.97	37.87	39.08	39.51	38.87
TiO_2	0.06	0.07	0.03	0.14	0.08	0.10	0.03	0.05	0.07	0.05	0.05
Al_2O_3	27.07	22.47	23.06	20.20	21.08	20.69	22.71	21.83	20.57	21.05	21.16
V_2O_3	1.08	0.47	0.39	1.57	1.42	1.46	0.94	1.24	1.65	1.61	1.12
Cr_2O_3	0.16	0.19	0.15	0.65	0.11	0.12	0.15	0.19	0.36	0.62	0.52
FeO[b]	3.45	1.62	1.44	4.79	2.89	3.48	2.98	2.56	1.49	1.84	4.45
MnO	19.22	15.39	12.31	26.74	24.98	27.58	16.06	18.60	17.85	19.41	19.04
MgO	12.17	14.31	17.49	5.69	8.06	5.70	15.04	13.05	9.98	12.55	11.63
CaO	2.34	4.94	3.81	2.54	2.72	2.70	2.06	2.61	7.08	2.92	2.68
Total	100.02	100.06	99.99	99.60	99.23	99.28	99.95	100.01	98.12	99.58	99.52
Cations[c]											
Si	2.972	2.992	2.990	2.963	2.963	2.973	2.958	2.985	3.008	2.985	2.966
Ti	0.004	0.004	0.002	0.008	0.005	0.006	0.002	0.003	0.004	0.003	0.003
Al	1.960	1.951	1.966	1.892	1.942	1.936	1.981	1.926	1.866	1.875	1.903
V	0.065	0.028	0.022	0.100	0.089	0.093	0.056	0.075	0.102	0.098	0.069
Cr	0.010	0.011	0.008	0.041	0.007	0.008	0.009	0.011	0.022	0.037	0.031
Fe	0.217	0.100	0.087	0.318	0.189	0.231	0.185	0.160	0.096	0.117	0.284
Mn	1.226	0.960	0.754	1.800	1.654	1.854	1.007	1.180	1.164	1.243	1.231
Mg	1.366	1.573	1.886	0.674	0.939	0.675	1.659	1.457	1.144	1.414	1.324
Ca	0.189	0.390	0.295	0.216	0.228	0.229	0.163	0.209	0.584	0.237	0.219
Mol.% end members											
Goldmanite	3.19	1.41	1.10	4.92	4.37	4.56	2.74	3.73	5.13	4.89	3.48
Uvarovite	0.49	0.56	0.40	2.02	0.34	0.39	0.44	0.56	1.11	1.86	1.59
Almandine	7.24	3.29	2.87	10.57	6.28	7.73	6.14	5.32	3.21	3.87	9.29
Spessartine	40.89	31.77	24.95	59.84	54.95	62.03	33.41	39.25	38.96	41.29	40.26
Pyrope	45.56	52.03	62.42	22.41	31.20	22.58	55.04	48.47	38.29	46.98	43.29

Grossular	2.63	10.94	8.21	0.24	2.86	2.71	2.23	2.67	13.30	1.11	2.09
Spessartine : (goldmanite + uvarovite)	11.1	16.1	16.6	8.6	11.7	12.5	10.5	9.1	6.2	6.1	7.9
Absorption maximum (nm)	575	573	572	583	581	581	574	576	584	584	574
Colorimetric data CIE 1931[d]											
λ_D (nm) for daylight D_{65}	541	552	550	538	538	517	494	493	500	491	484
Purity p for daylight D_{65}	3.0	5.0	1.0	9.4	7.7	11.4	2.1	11.1	16.8	17.1	10.3
λ_D (nm) for incandescent light A	c514	c509	c520	c507	567	504	c557	c575	495	437	c558
Purity p for incandescent light A	3.8	6.5	5.0	6.1	2.5	2.2	5.2	6.8	8.8	7.1	21.3
Colorimetric data CIELAB 1976[e]											
C^*_{ab} for daylight D_{65}	4.99	6.62	1.52	11.60	12.61	17.9	2.50	10.44	21.57	13.59	4.57
h_{ab} (°) for daylight D_{65}	149.0	141.5	143.9	150.0	150.3	159.4	189.0	190.9	174.4	199.0	238.5
C^*_{ab} for incandescent light A	3.39	6.14	5.32	4.13	1.59	2.31	5.41	9.10	9.38	12.34	14.30
h_{ab} (°) for incandescent light A	349.6	357.3	342.4	4.3	128.5	193.9	321.4	291.6	223..3	279.7	322.1
Δh_{ab} (°)	159.4	144.3	161.6	145.7	21.8	34.5	132.4	100.7	48.9	80.8	83.6
ΔE^*_{ab}	8.3	12.1	6.8	15.2	11.2	16.1	7.3	15.1	17.1	16.9	14.5

[a] Average composition of 10 analyses each

[b] Total iron as FeO

[c] Calculated on the basis of 12 oxygens

[d] λ_D = dominant wavelength, c indicates 'complement of'

[e] C^*_{ab} = chroma; h_{ab} = hue angle

Δh_{ab} = hue angle difference between daylight and incandescent light

ΔE^*_{ab} = colour difference between daylight and incandescent light in the three dimensional CIELAB colour space

Table VIb: Physical, chemical and colorimetric data of individual colour-change garnets from Madagascar

Group	4			5					6		7
Sample	4/1	4/2	4/3	5/6	5/9	5/10	5/11	5/13	6/1	6/7	7/2
Colour in daylight	purple	violet	purplish red	yellow	greenish yellow	yellow green	yellow	yellowish grey	yellow orange	orange	red
Colour in incandescent light	reddish purple	reddish purple	red purple	red orange	red	red purple	red	red purple	red	red	red
Microprobe analyses (wt.%)[a]											
SiO_2	40.83	39.67	39.06	37.58	40.81	40.70	38.00	40.89	38.32	39.55	40.50
TiO_2	0.07	0.08	0.06	0.16	0.06	0.05	0.05	0.01	0.03	0.03	0.05
Al_2O_3	22.91	21.73	21.94	21.03	22.99	22.89	21.62	22.79	21.86	22.51	23.19
V_2O_3	0.56	0.89	0.80	0.69	0.35	0.40	0.40	0.35	0.33	0.35	0.13
Cr_2O_3	0.53	0.54	0.30	0.24	0.11	0.20	0.22	0.13	0.22	0.21	0.12
FeO[b]	3.69	4.14	7.11	2.35	1.36	1.62	2.88	1.69	2.95	3.71	4.90
MnO	14.27	17.36	15.99	28.65	14.98	14.51	23.69	13.22	24.37	22.77	12.66
MgO	16.10	12.97	11.74	6.46	15.61	15.06	9.93	16.04	9.79	10.50	16.25
CaO	2.02	2.48	2.55	2.11	3.75	4.57	1.56	4.49	1.59	1.42	1.70
Total	100.98	99.86	99.60	99.27	100.02	100.01	98.36	99.61	99.46	101.05	99.50
Cations[c]											
Si	2.972	2.980	2.966	2.971	2.986	2.985	2.961	2.992	2.956	2.982	2.977
Ti	0.004	0.005	0.004	0.009	0.003	0.003	0.003	0.001	0.005	0.002	0.003
Al	1.965	1.924	1.963	1.959	1.982	1.979	1.985	1.966	1.976	2.000	2.016
V	0.033	0.054	0.049	0.044	0.021	0.023	0.025	0.020	0.030	0.021	0.008
Cr	0.031	0.032	0.021	0.015	0.006	0.012	0.014	0.008	0.015	0.012	0.007
Fe	0.224	0.260	0.451	0.155	0.083	0.099	0.188	0.103	0.190	0.234	0.301
Mn	0.879	1.105	1.028	1.918	0.928	0.902	1.564	0.819	1.590	1.454	0.788
Mg	1.746	1.452	1.329	0.761	1.702	1.647	1.154	1.750	1.129	1.180	1.781
Ca	0.157	0.199	0.208	0.179	0.294	0.359	0.130	0.352	0.139	0.115	0.134

Mol.% end members											
Goldmanite	1.63	2.70	2.41	2.18	1.05	1.14	1.24	1.02	1.50	1.05	0.37
Uvarovite	1.53	1.61	1.03	0.74	0.30	0.60	0.68	0.38	0.76	0.61	0.34
Almandine	7.45	8.63	14.95	5.14	2.76	3.29	5.15	3.42	6.24	7.85	10.02
Spessartine	29.24	36.62	34.08	63.66	30.86	30.00	51.51	27.09	52.16	48.75	26.24
Pyrope	58.08	48.15	44.06	25.26	56.60	54.77	38.02	57.86	37.04	39.54	59.27
Grossular	2.06	2.29	3.47	3.02	8.43	10.20	3.40	10.23	2.30	2.20	3.76
Spessartine : (goldmanite + uvarovite)	9.2	8.5	9.9	21.8	22.9	17.2	26.8	19.3	23.1	30.4	36.9
Absorption maximum (nm)	571	573	571	572	572	572	571	572	570	570	570
Colorimetric data CIE 1931[d]											
λ_D (nm) for daylight D_{65}	c550	c563	635	576	568	567	576	572	581	587	598
Purity p for daylight D_{65}	7.1	5.8	4.5	30.0	6.0	5.0	9.0	2.2	9.0	14.4	12.5
λ_D (nm) for incandescent light A	c531	c530	c510	595	608	c506	616	c509	625	621	619
Purity p for incandescent light A	20.0	27.9	22.1	34.9	5.8	6.4	11.4	4.8	11.4	19.7	19.3
Colorimetric data CIELAB 1976e											
C^*_{ab} for daylight D_{65}	6.83	3.41	5.01	13.80	5.00	3.96	6.21	1.49	5.70	7.99	9.37
h_{ab} (°) for daylight D_{65}	323.5	307.9	14.2	90.5	115.3	119.1	88.6	102.4	69.4	51.6	30.7
C^*_{ab} for incandescent light A	17.98	15.27	16.07	15.34	4.83	6.16	9.76	4.54	10.42	13.95	13.59
h_{ab} (°) for incandescent light A	336.5	337.3	355.8	49.9	27.9	5.9	23.6	358.7	20.5	22.8	23.2
Δh_{ab} (°)	13.0	29.4	18.4	40.5	87.5	113.3	65.1	103.8	48.9	28.8	7.6
ΔE^*_{ab}	11.4	12.4	11.4	10.2	6.8	8.5	9.1	5.1	7.9	8.0	4.6

[a] Average composition of 10 analyses each

[b] Total iron as FeO

[c] Calculated on the basis of 12 oxygens

[d] λ_D = dominant wavelength, c indicates 'complement of'

[e] C^*_{ab} = chroma; h_{ab} = hue angle

Δh_{ab} = hue angle difference between daylight and incandescent light

ΔE^*_{ab} = colour difference between daylight and incandescent light in the three dimensional CIELAB colour space

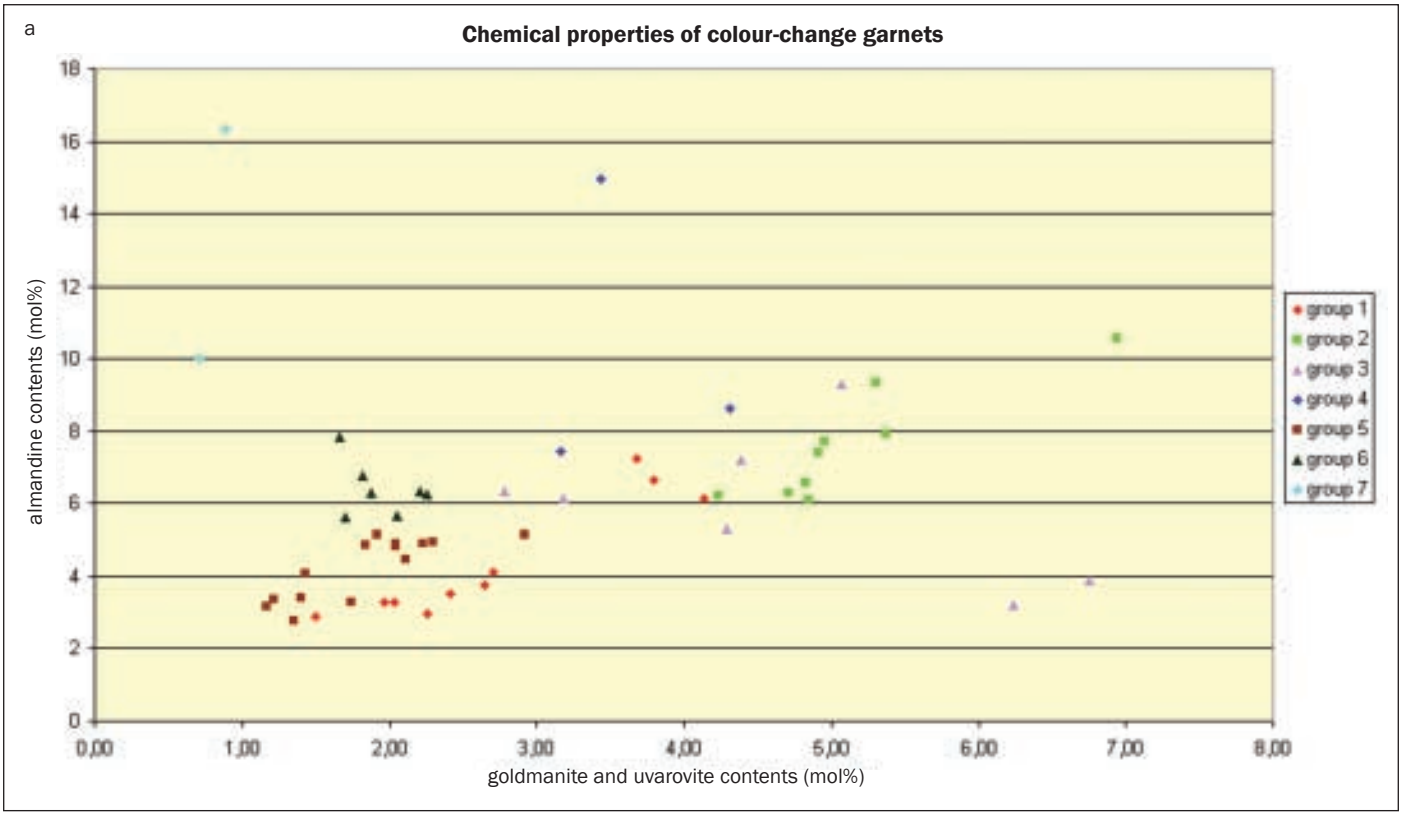

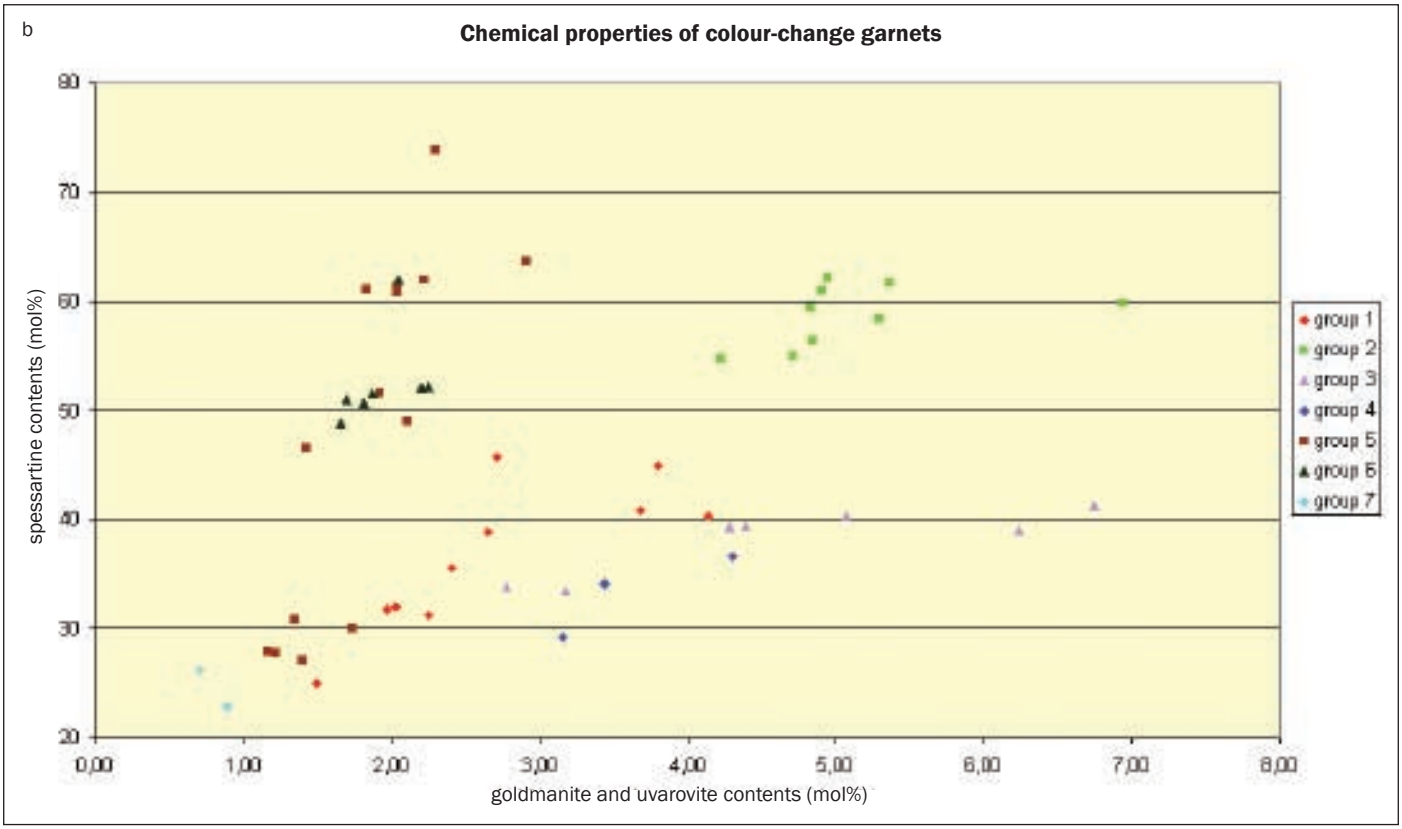

Figure 29: Compositional range of garnet; (a) range of goldmanite (vanadium) and uvarovite (chromium) contents versus almandine (iron) contents; (b) range of goldmanite (vanadium) and uvarovite (chromium) contents versus spessartine (manganese) contents in colour-change garnets from Madagascar.

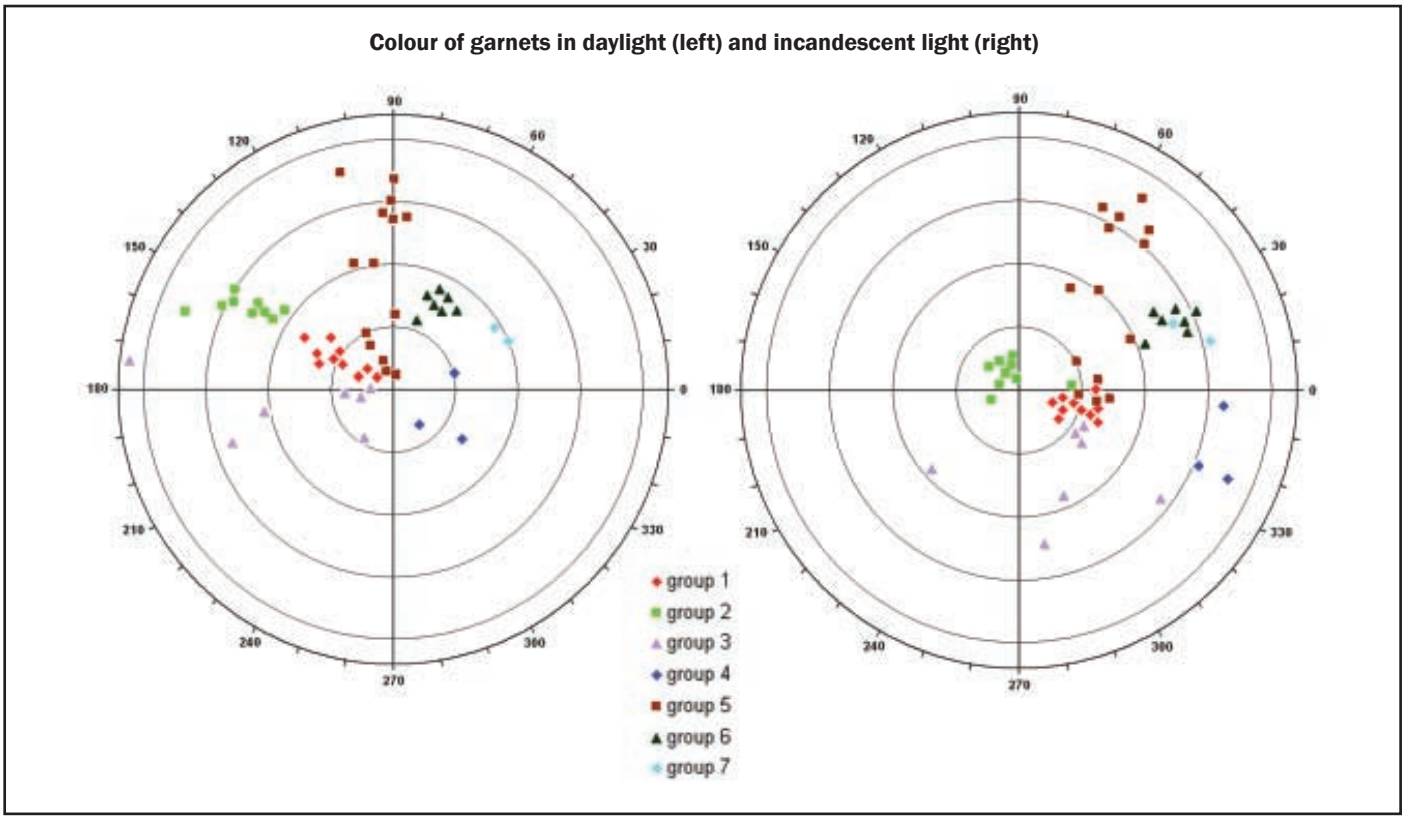

Figure 30: Colorimetric parameters of seven groups of colour-change garnets in the CIELAB colour circle showing the ranges of hue angle h_{ab} and chroma C^*_{ab} in daylight (left) and incandescent light. The hue angles can be read around the outer circles; chroma is represented by the radial distance of a colour locus from the centre of the coordinate system, the circles represent chroma differences of 5, with the outer circle at chroma 22.

equal transparency at minimum A and minimum B and a weaker transparency at minimum C (a 'balanced' spectrum; *Figure 28e*). With decreasing vanadium and chromium contents, i.e. with increasing s:(g+u) ratios, spectra with almost equal transparencies at minima A (blue), B (bluish green) and C (green) are present *(Figure 28d)*. For garnets with even higher s:(g+u) ratios, there are three situations:

- For samples with relatively low iron contents, the transparency at minima B (bluish green) and C (green) is almost equal, and higher than at A (blue) *(Figure 28c)*.
- For samples with moderate iron contents, the transparencies at A, B and C are comparable *(Figure 28b)*.
- For samples with high iron contents, the influence of the vanadium-chromium band on the transparencies at minima A, B and C is negligible and the spectrum is dominated by the known iron and manganese bands *(Figure 28a)*.

Description of garnet groups and individual samples

Chemical, spectroscopic and colorimetric data of all seven groups are summarized in *Table II*, the properties of individual samples are given in *Tables VIa* and *VIb*. The goldmanite, uvarovite, spessartine and almandine contents are plotted in *Figure 29,* and colorimetric data for the CIELAB 1976 colour space (hue angle h_{ab} and chroma C^*_{ab}) are pictured in *Figure 30*. In the following text the term 'daylight' refers to standard illumination D_{65}, and the term 'incandescent light' refers to standard illumination A. The main colour-causing components will be abbreviated as follows:

- gold = goldmanite (indicating the vanadium contents)
- uva = uvarovite (indicating the chromium contents)
- spess = spessartine (indicating the manganese contents)
- alm = almandine (indicating the iron contents)

Group 1

- These ten garnets form the most homogeneous group *(Figure 31 a–d)*. Nine are green to slightly yellowish green in daylight and purple, reddish purple or red purple in incandescent light. One sample (1/10) is greenish yellowish grey in daylight with a colour change to reddish purple in incandescent light. Their chemical properties show a wide variation for (gold + uva) from 1.50 to 4.41 %, for spess from 24.95 to 45.73 % and for alm from 2.87 to 7.24 %. Sample 1/10 had the lowest (gold + uva) content of 1.50 %.

Group 2

- Within this group are samples with higher vanadium and chromium (gold + uva from 4.23 to 6.09 %) and higher manganese contents (spess from 54.69 to 62.03 %). The iron contents vary between alm 6.09 and alm 10.57 %. All nine samples are green to slightly

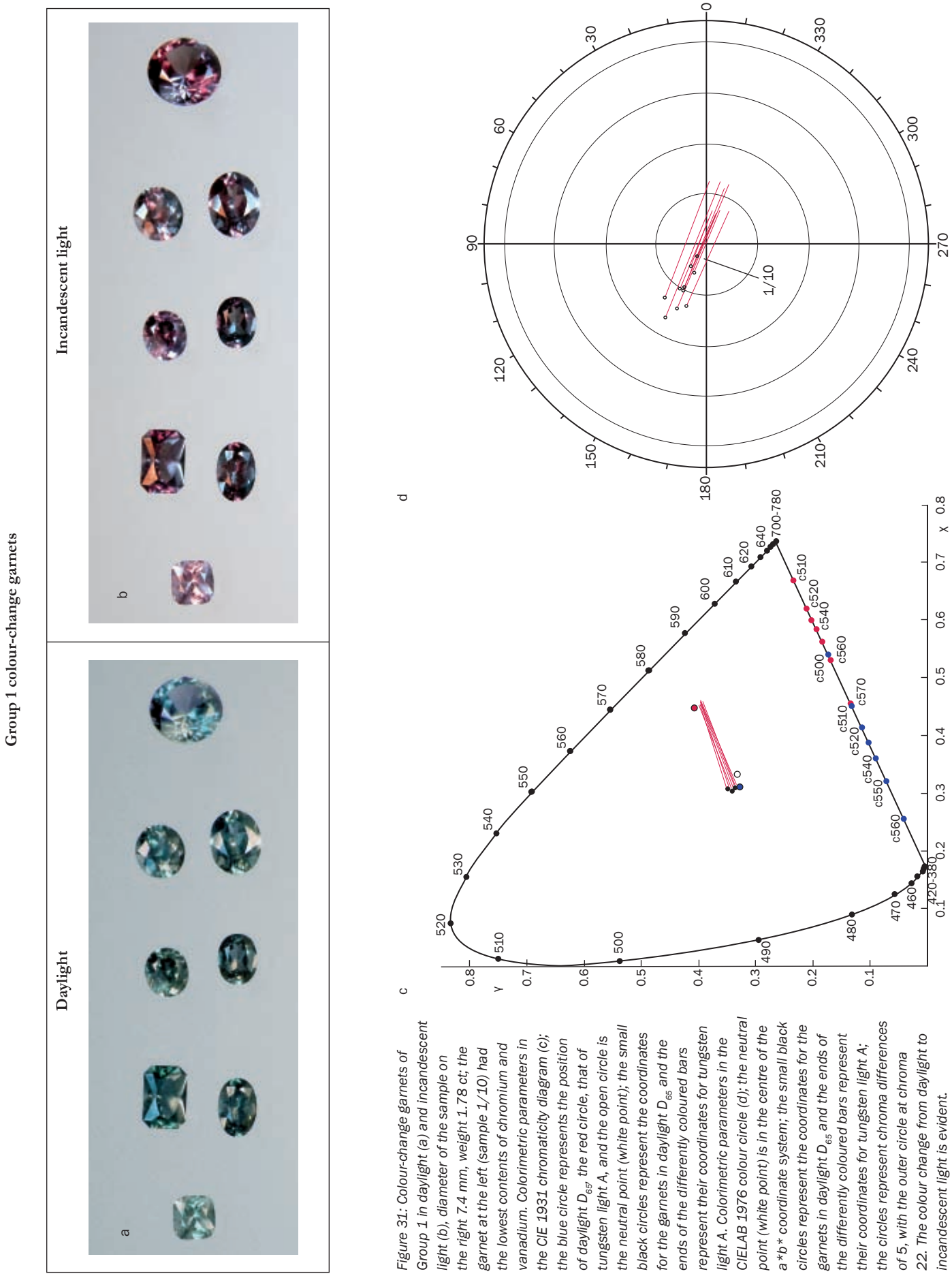

*Figure 31: Colour-change garnets of Group 1 in daylight (a) and incandescent light (b), diameter of the sample on the right 7.4 mm, weight 1.78 ct; the garnet at the left (sample 1/10) had the lowest contents of chromium and vanadium. Colorimetric parameters in the CIE 1931 chromaticity diagram (c); the blue circle represents the position of daylight D_{65}; the red circle, that of tungsten light A, and the open circle is the neutral point (white point); the small black circles represent the coordinates for the garnets in daylight D_{65} and the ends of the differently coloured bars represent their coordinates for tungsten light A. Colorimetric parameters in the CIELAB 1976 colour circle (d); the neutral point (white point) is in the centre of the a*b* coordinate system; the small black circles represent the coordinates for the garnets in daylight D_{65} and the ends of the differently coloured bars represent their coordinates for tungsten light A; the circles represent chroma differences of 5, with the outer circle at chroma 22. The colour change from daylight to incandescent light is evident.*

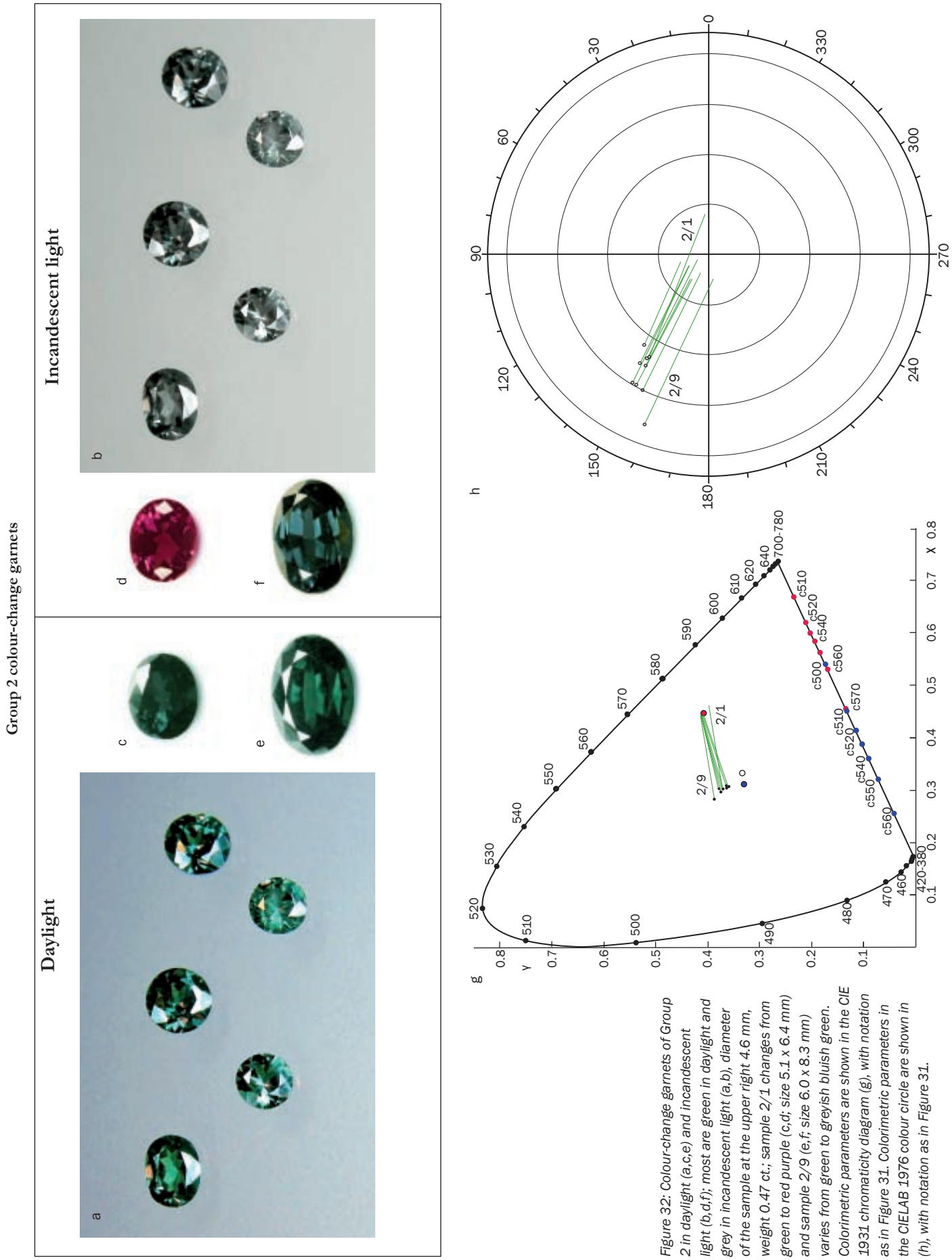

Figure 32: Colour-change garnets of Group 2 in daylight (a,c,e) and incandescent light (b,d,f); most are green in daylight and grey in incandescent light (a,b), diameter of the sample at the upper right 4.6 mm, weight 0.47 ct.; sample 2/1 changes from green to red purple (c,d; size 5.1 x 6.4 mm) and sample 2/9 (e,f; size 6.0 x 8.3 mm) varies from green to greyish bluish green. Colorimetric parameters are shown in the CIE 1931 chromaticity diagram (g), with notation as in Figure 31. Colorimetric parameters in the CIELAB 1976 colour circle are shown in (h), with notation as in Figure 31.

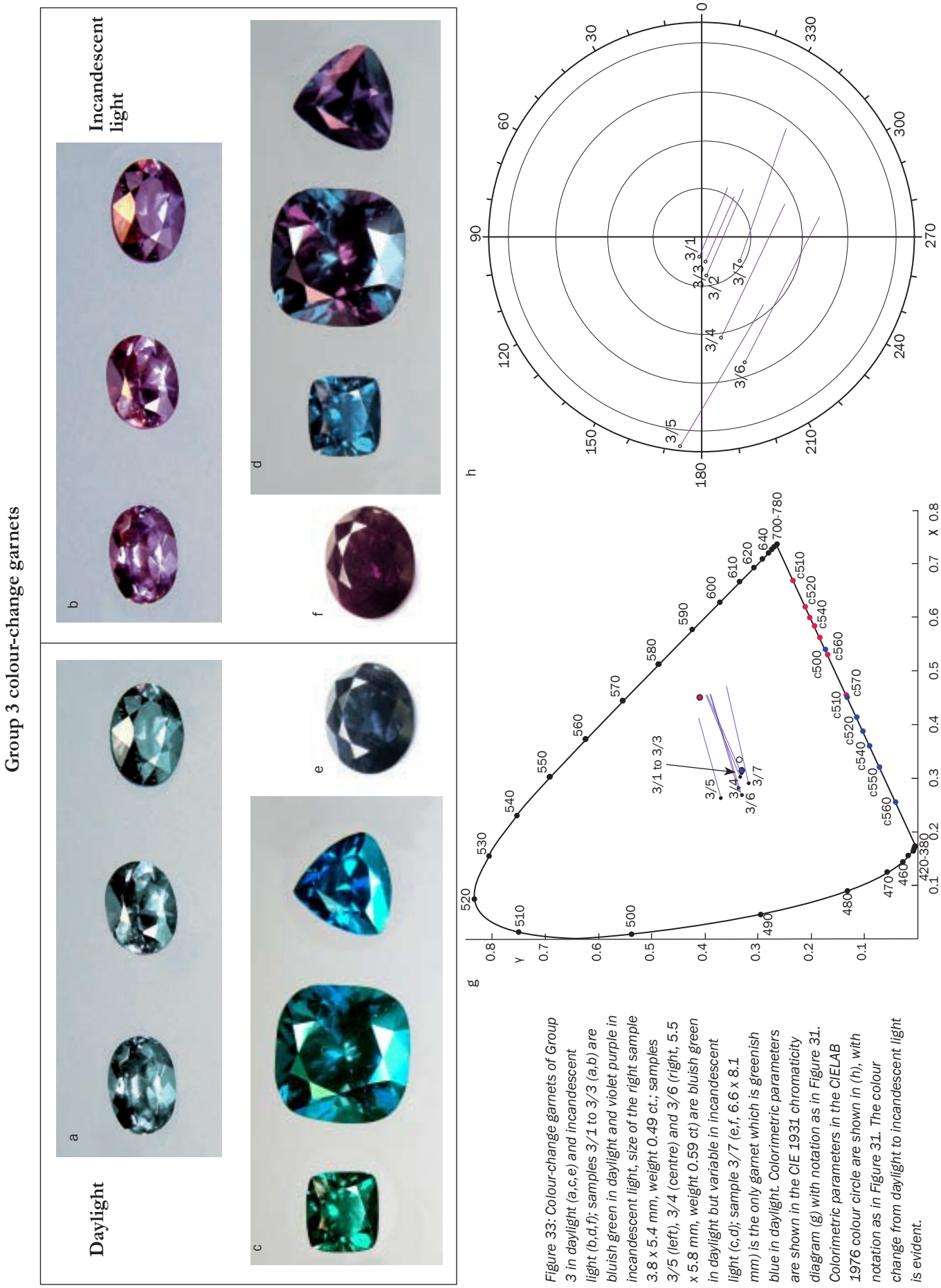

Figure 33: Colour-change garnets of Group 3 in daylight (a,c,e) and incandescent light (b,d,f); samples 3/1 to 3/3 (a,b) are bluish green in daylight and violet purple in incandescent light, size of the right sample 3.8 x 5.4 mm, weight 0.49 ct.; samples 3/5 (left), 3/4 (centre) and 3/6 (right, 5.5 x 5.8 mm, weight 0.59 ct) are bluish green in daylight but variable in incandescent light (c,d); sample 3/7 (e,f, 6.6 x 8.1 mm) is the only garnet which is greenish blue in daylight. Colorimetric parameters are shown in the CIE 1931 chromaticity diagram (g) with notation as in Figure 31. Colorimetric parameters in the CIELAB 1976 colour circle are shown in (h), with notation as in Figure 31. The colour change from daylight to incandescent light is evident.

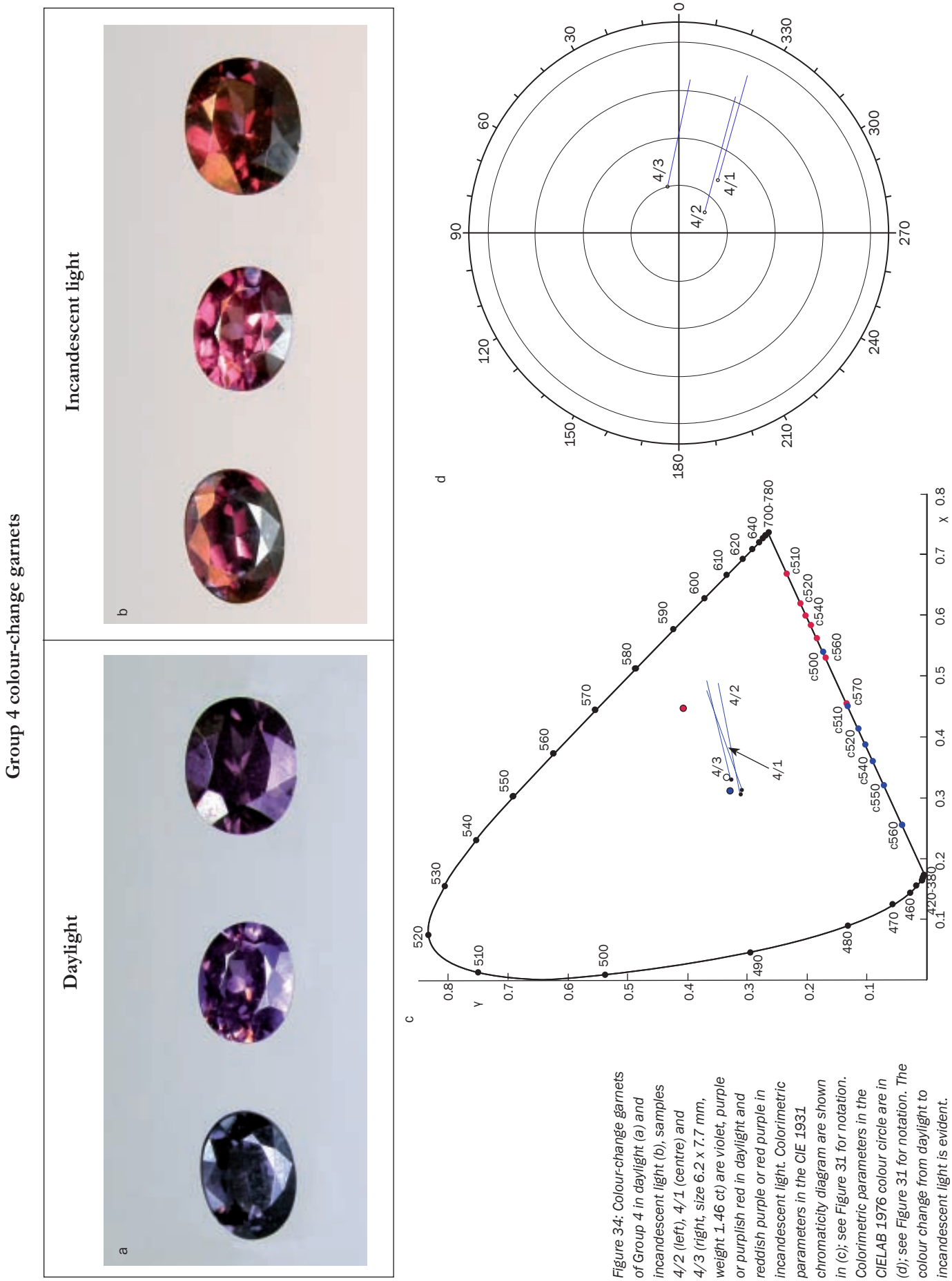

Figure 34: Colour-change garnets of Group 4 in daylight (a) and incandescent light (b), samples 4/2 (left), 4/1 (centre) and 4/3 (right, size 6.2 x 7.7 mm, weight 1.46 ct) are violet, purple or purplish red in daylight and reddish purple or red purple in incandescent light. Colorimetric parameters in the CIE 1931 chromaticity diagram are shown in (c); see Figure 31 for notation. Colorimetric parameters in the CIELAB 1976 colour circle are in (d); see Figure 31 for notation. The colour change from daylight to incandescent light is evident.

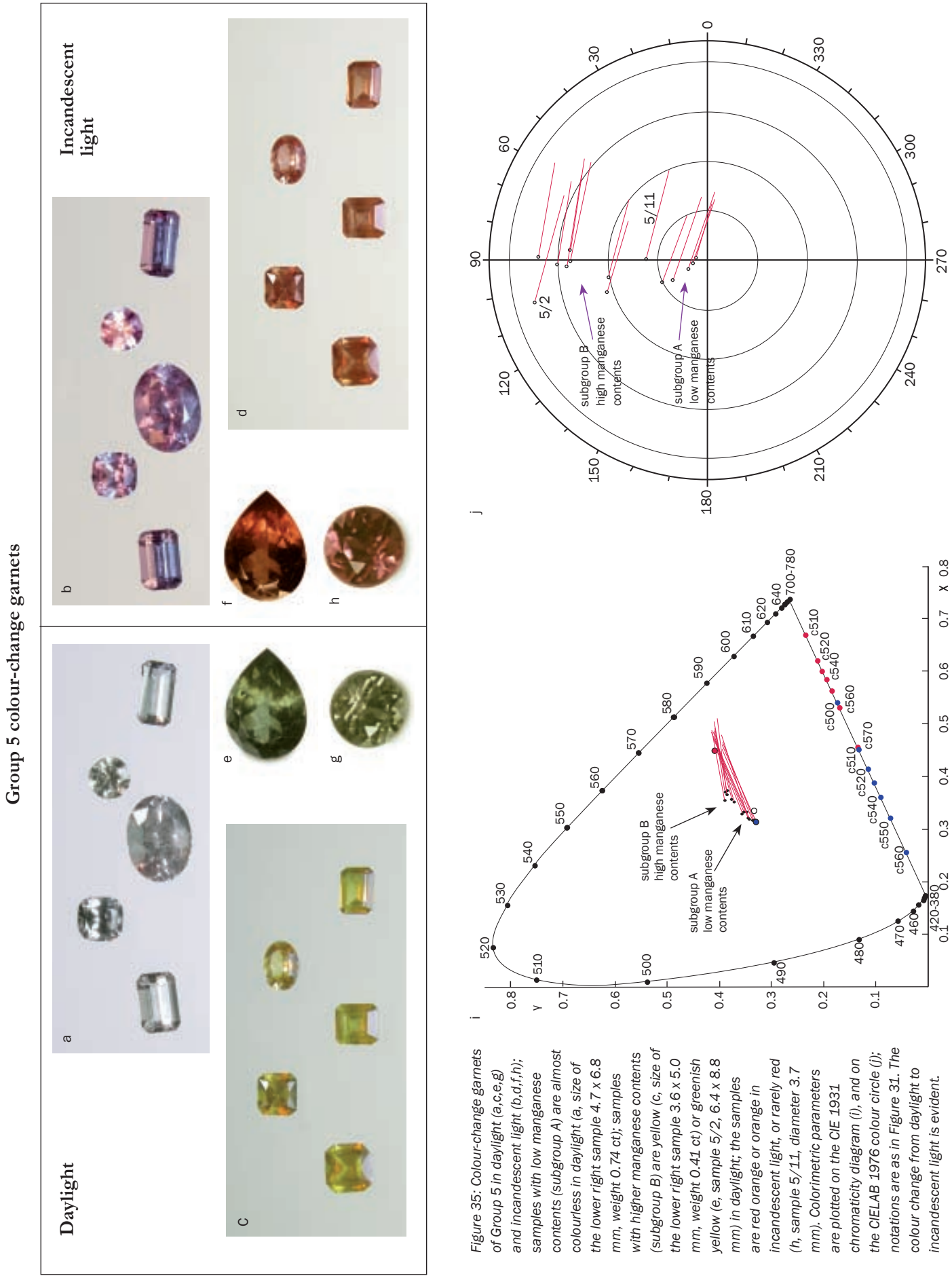

Figure 35: Colour-change garnets of Group 5 in daylight (a,c,e,g) and incandescent light (b,d,f,h); samples with low manganese contents (subgroup A) are almost colourless in daylight (a, size of the lower right sample 4.7 x 6.8 mm, weight 0.74 ct); samples with higher manganese contents (subgroup B) are yellow (c, size of the lower right sample 3.6 x 5.0 mm, weight 0.41 ct) or greenish yellow (e, sample 5/2, 6.4 x 8.8 mm) in daylight; the samples are red orange or orange in incandescent light, or rarely red (h, sample 5/11, diameter 3.7 mm). Colorimetric parameters are plotted on the CIE 1931 chromaticity diagram (i), and on the CIELAB 1976 colour circle (j); notations are as in Figure 31. The colour change from daylight to incandescent light is evident.

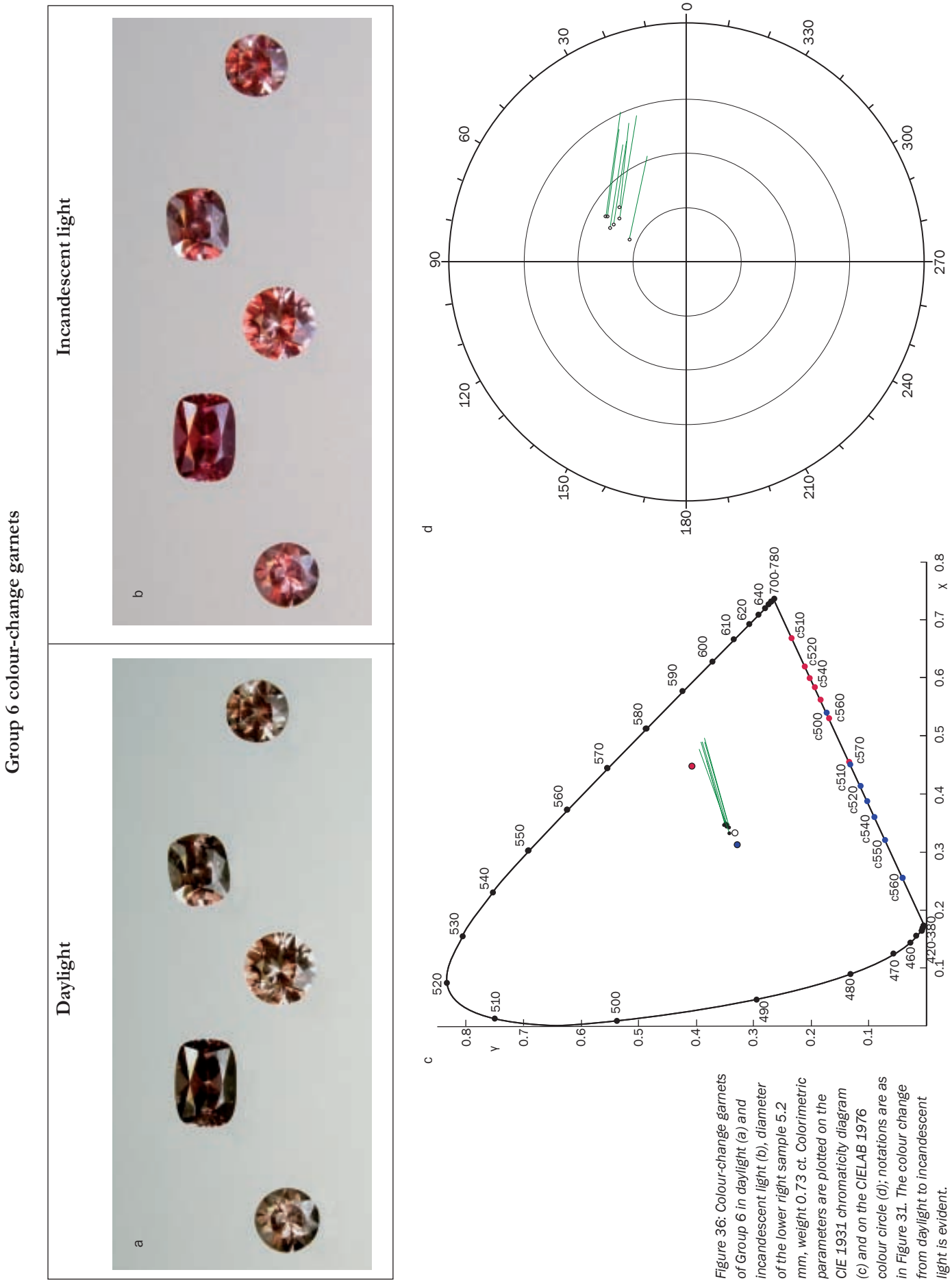

Figure 36: Colour-change garnets of Group 6 in daylight (a) and incandescent light (b), diameter of the lower right sample 5.2 mm, weight 0.73 ct. Colorimetric parameters are plotted on the CIE 1931 chromaticity diagram (c) and on the CIELAB 1976 colour circle (d); notations are as in Figure 31. The colour change from daylight to incandescent light is evident.

Colour-change garnets from Madagascar: variation of chemical, spectroscopic and colorimetric properties

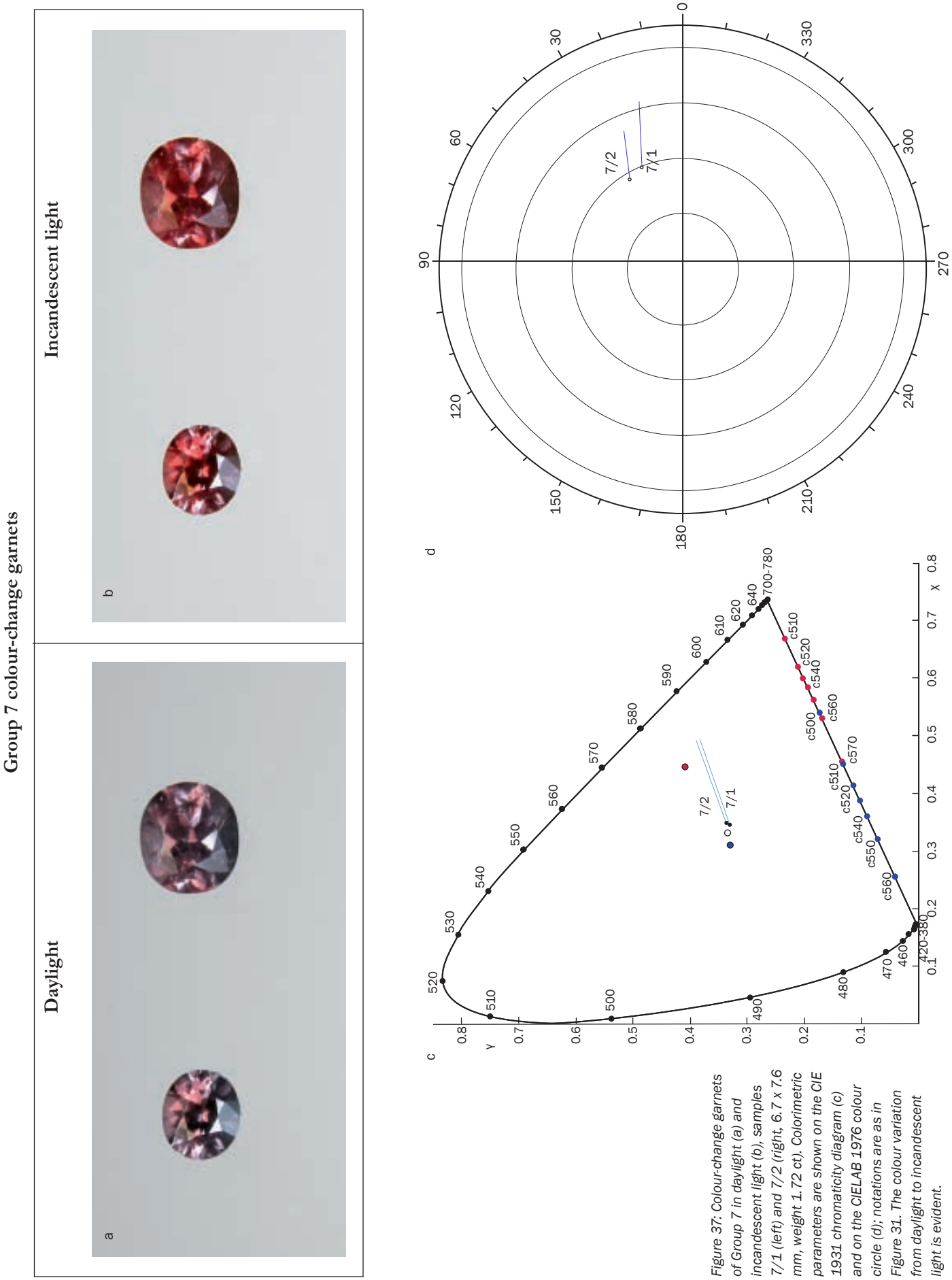

Figure 37: Colour-change garnets of Group 7 in daylight (a) and incandescent light (b), samples 7/1 (left) and 7/2 (right, 6.7 x 7.6 mm, weight 1.72 ct). Colorimetric parameters are shown on the CIE 1931 chromaticity diagram (c) and on the CIELAB 1976 colour circle (d); notations are as in Figure 31. The colour variation from daylight to incandescent light is evident.

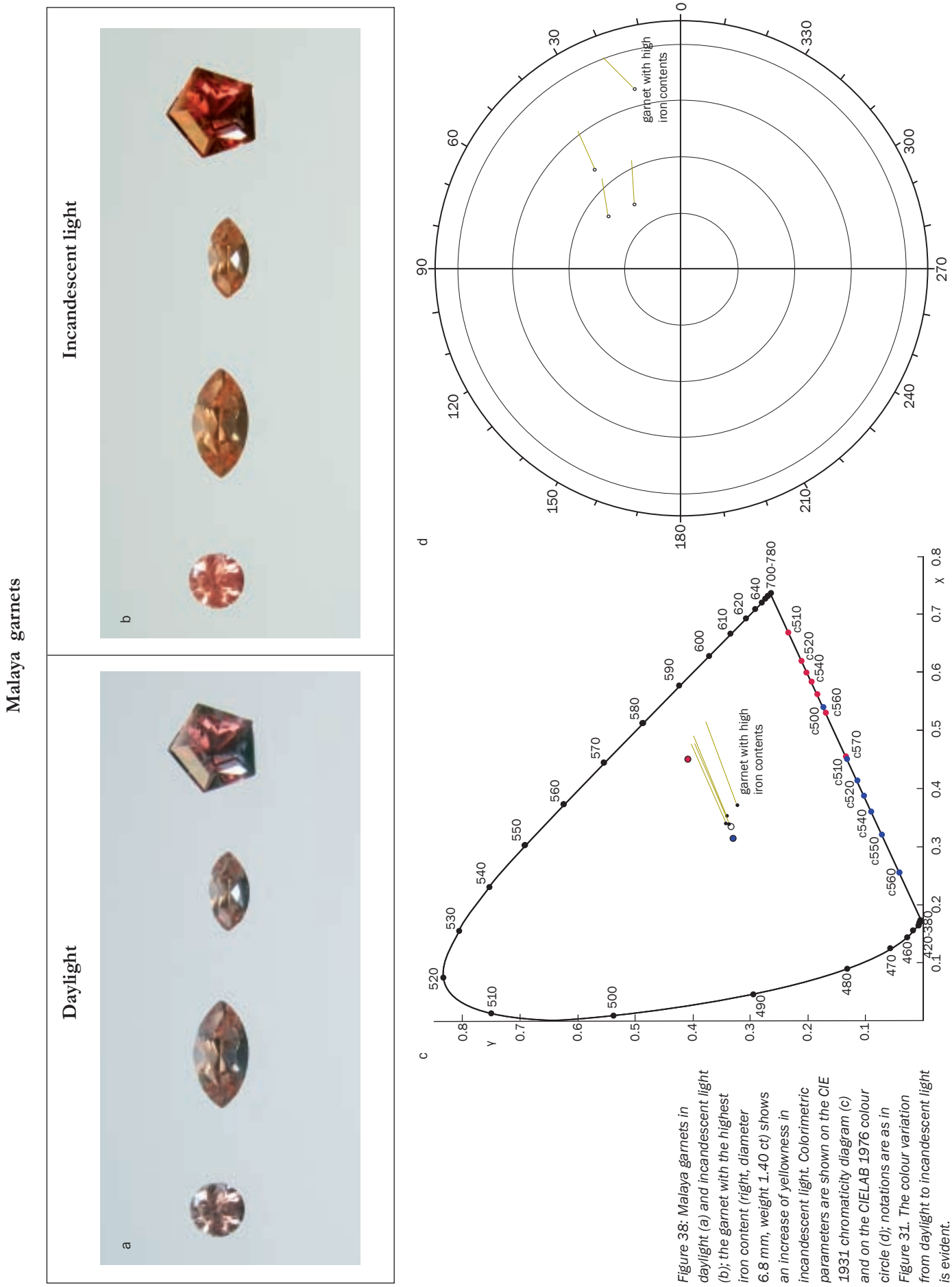

Figure 38: Malaya garnets in daylight (a) and incandescent light (b); the garnet with the highest iron content (right, diameter 6.8 mm, weight 1.40 ct) shows an increase of yellowness in incandescent light. Colorimetric parameters are shown on the CIE 1931 chromaticity diagram (c) and on the CIELAB 1976 colour circle (d); notations are as in Figure 31. The colour variation from daylight to incandescent light is evident.

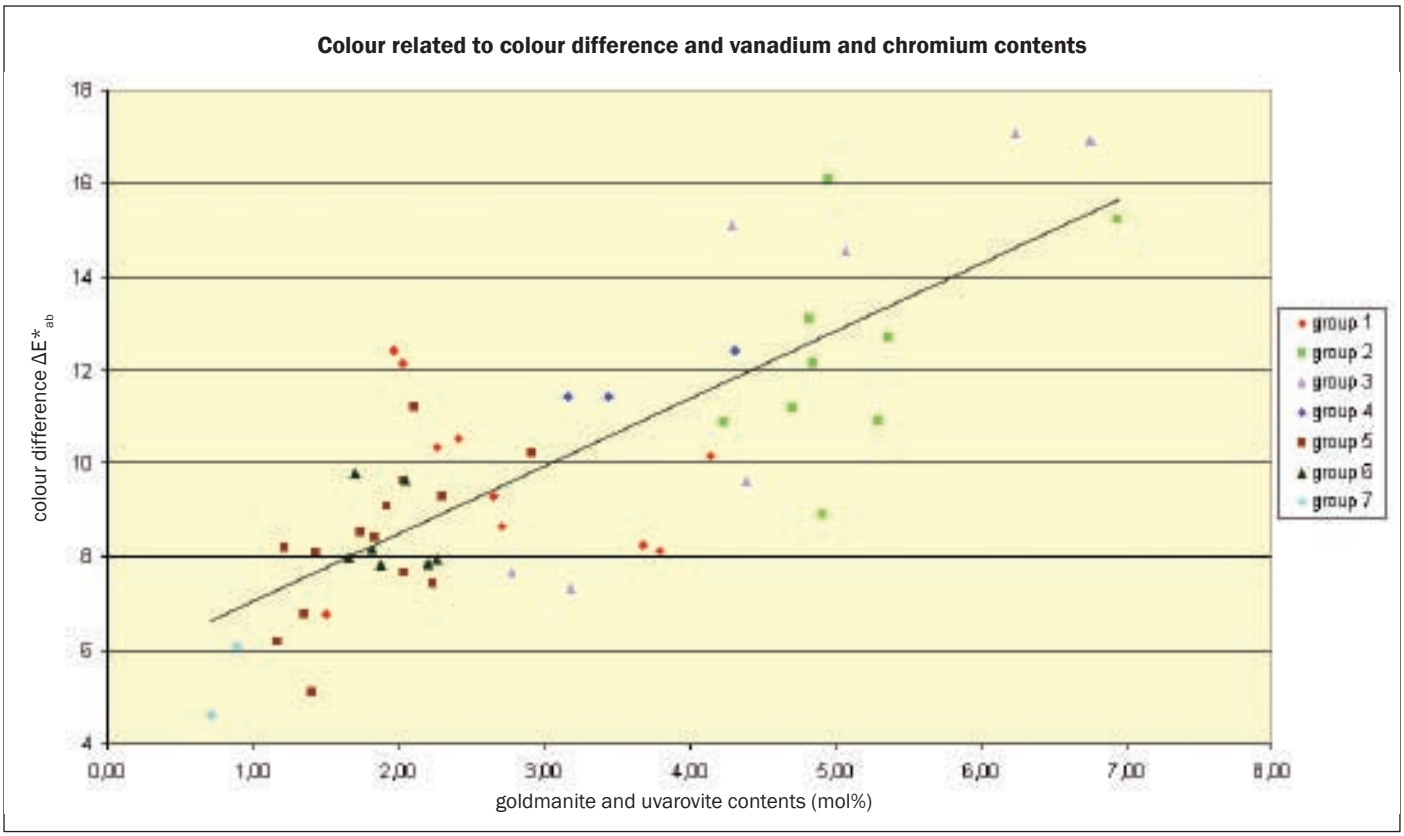

Figure 39: Correlation of vanadium and chromium contents within the seven groups of colour-change garnets with their colour differences ΔE^*_{ab} in the three-dimensional CIELAB colour space.

yellowish green in daylight *(Figure 32 a–h)*. Seven garnets are very slightly yellowish grey or greenish yellowish grey, and almost colourless in incandescent light. Sample 2/1 with the highest vanadium and chromium contents within this group (gold + uva 6.94 %) is green in daylight and red purple in incandescent light, and sample 2/9 with the highest manganese content (spess 62.03 %) is greyish bluish green in incandescent light.

Group 3

- This group contains seven samples which are bluish green or greenish blue in daylight *(Figure 33 a–h)*, but with otherwise varying chemical, spectroscopic and colorimetric properties. Vanadium and chromium contents vary widely (between gold + uva 2.78 and 6.75 %), and the spessartine and almandine ranges are 33.41 to 41.29 % and 3.21 to 9.29 % respectively. Three garnets *(Figure 33 a,b)* are slightly bluish green in daylight and somewhat more intense violet purple in incandescent light. Sample 3/4 (*Figure 33 c,d,* centre stone, gold + uva 4.29 %) is bluish green in daylight and blue violet in incandescent light. The remaining three garnets in this group have very high vanadium and chromium contents (*Figure 33 c* to *f;* gold + uva above 5 %), they range from bluish green in daylight and blue green in incandescent light (sample 3/5) to greenish blue in daylight and violet purple in incandescent light (sample 3/7).

Group 4

- This group consists of three garnets which are violet, purple or purplish red in daylight and reddish purple or red purple in incandescent light *(Figure 34 a–d)*. Vanadium and chromium contents vary between 3.61 and 4.31 % gold + uva. Spessartine contents lie between 29.24 and 36.62 %, and almandine contents are relatively high (7.45 or 8.63 %) or extremely high in garnet 4/3 (14.95 % alm).

Group 5

- The 14 garnets in this group *(Figure 35 a–j)* show relatively low vanadium and chromium contents (gold + uva from 1.17 to 2.92 %) and low iron percentages (alm 3.18 to 5. 15 %). The manganese contents, on the other hand, vary within a wide range (spess 27.09 – 73.83 %). Five samples with the lower manganese contents (*Figure 35 a,b;* subgroup A, spess 27.09 to 30.86 %) are yellowish grey or greenish yellowish grey, almost colourless or greenish yellow to yellow green in daylight and red purple to red in incandescent light. The nine samples with higher spessartine percentages (*Figure 35 c–h*, subgroup B, between 46.55 and 73.83 %) are yellow or greenish yellow in daylight and red orange or orange in incandescent light *(Figure 35 c–f)* and rarely red *(Figure 35 g,h)*.

Group 6

- The seven garnets in this group *(Figure 36 a–d)* have manganese, vanadium and chromium contents which are comparable to those of subgroup B of Group 5, i.e. goldmanite plus uvarovite percentages of 1.66 to 2.26 % and spessartine contents of 48.75 to 61.87. Iron contents, on the other hand are somewhat higher (alm 5.61 – 7.85 %). Their colours are orange or yellow orange in daylight to red in incandescent light.

Group 7

- The two garnets *(Figure 37 a–d)* in this group have the lowest vanadium and chromium contents of all the samples (gold + uva 0.71 and 0.89 %) and also have very low spessartine contents (22.96 and 26.24 %). Iron contents, on the other hand, are high or extremely high (10.02 and 16.35 % alm). They are red in daylight and red or purplish red in incandescent light.

Malaya garnets

- The four vanadium- and chromium-free malaya garnets examined for comparison are orange, red orange or red in daylight and red orange to red in incandescent light *(Figure 38 a–d)*. The garnet with the highest iron content showed a remarkable increase of yellowness in incandescent light, i.e. a reaction different from the vanadium-bearing garnets examined in this study. Colour difference and hue angle change in the CIELAB system for these four garnets are respectively ΔE^*_{ab} 3.51–4.43, and Δh_{ab} 4–13°, and these parameters will be referred to later when colour change is discussed.

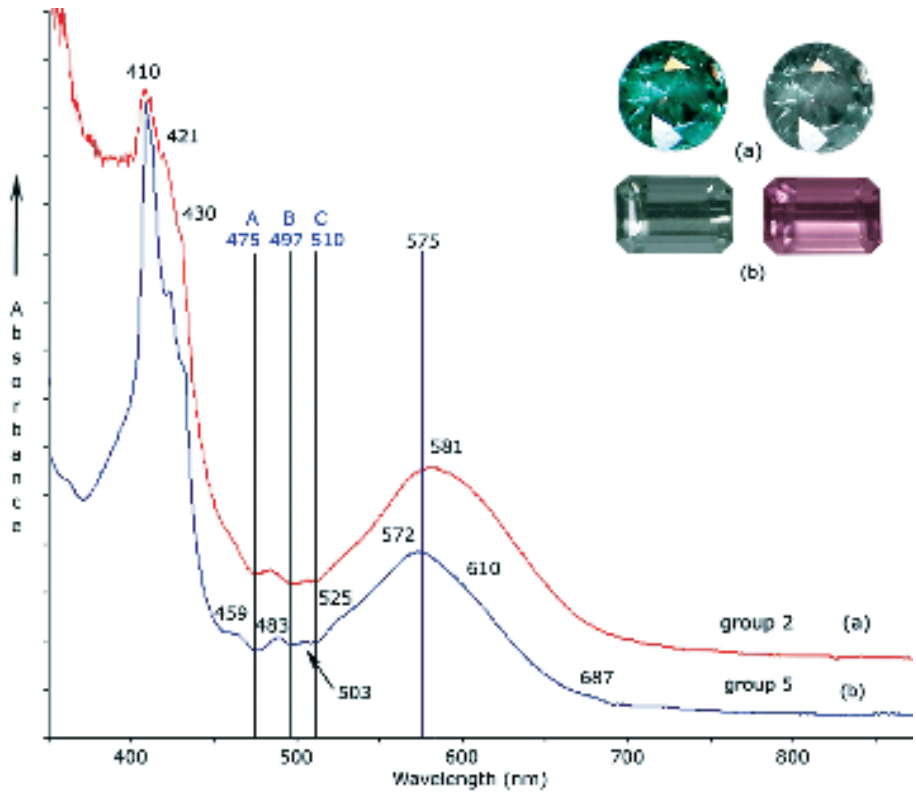

Figure 40: Absorption spectra of colour-change garnets from Madagascar which are light grey, almost colourless in incandescent light (a) or in daylight (b). Both garnets have the same type of absorption spectrum with only slight differences in the position of the vanadium-chromium absorption maximum; each sample pair is shown in daylight (left) and incandescent light (right).

Colorimetry

An evaluation of different chemical properties of the garnets and a possible relationship between chemical and colorimetric properties indicates that there is a clear correlation of the colour difference ΔE^*_{ab} with the contents of vanadium and chromium *(Figure 39)*.

This is consistent with conclusions from the garnet spectra because the contents of vanadium and chromium are directly responsible for the intensity of the dominant absorption maximum between 569 and 584 nm.

Furthermore, since the colorimetric parameters calculated for all 52 garnets in this study show only a minimal change of lightness for different illuminations, the graphical representations in the a*b* plane of the CIELAB colour circle in *Figures 30* to *37* are close approximations to the characteristic changes in three-dimensional CIELAB colour space. In other words: the length and direction of the line connecting the two loci of one sample in the a*b* plane give a good graphic representation of the colour difference.

As described above, the 52 garnets have absorption spectra with a dominant vanadium-chromium absorption maximum in the greenish yellow, yellow or yellow orange region of the visible range and two regions with high transparency — the red to orange and the yellowish green to blue violet. With a change of illuminants from daylight D_{65} to incandescent light A, all garnets in Groups 1 to 6 with this type of absorption spectrum show an increase of redness and blueness. The two garnets in Group 7 with the smallest vanadium and chromium contents show only an increase in redness, with minimal increase in blueness.

In most of the garnets studied, spectral purity p (in the CIE 1931 colour space) or chroma C^*_{ab} (in the CIELAB colour space) is relatively low. This indicates that even samples with distinct absorption maxima and minima in the visible range, may appear grey or almost colourless in daylight or in incandescent light (see *Figure 40*). The spectra in *Figure 40* do not provide a clear reason for such distinct colour changes so these are related to the complexities of colour perception by the human eye.

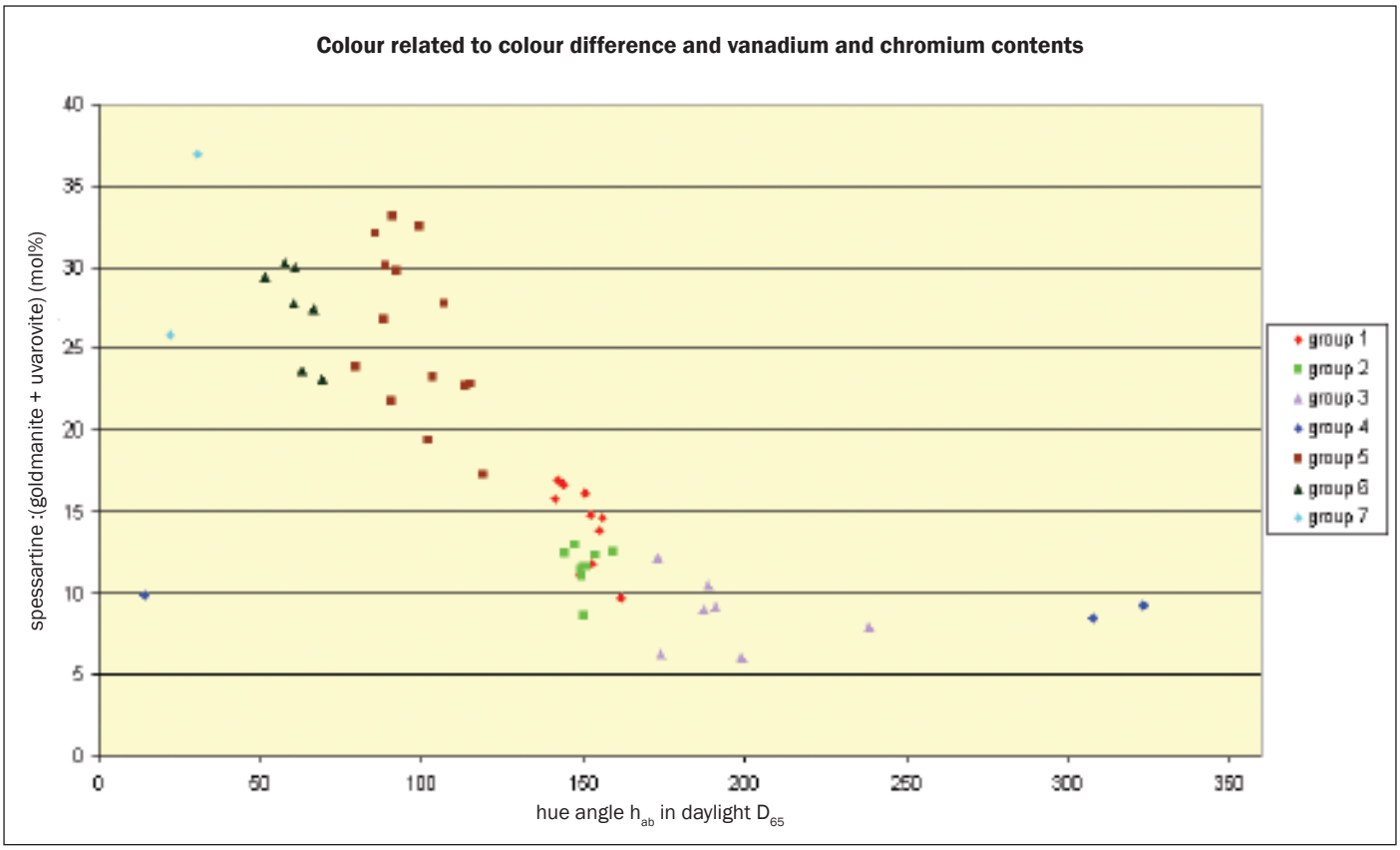

Figure 41: Variation of colour in daylight, represented by the hue angle h_{ab}, with the ratio spessartine : (goldmanite + uvarovite) in the colour-change garnets; the differently coloured groups are clearly separated.

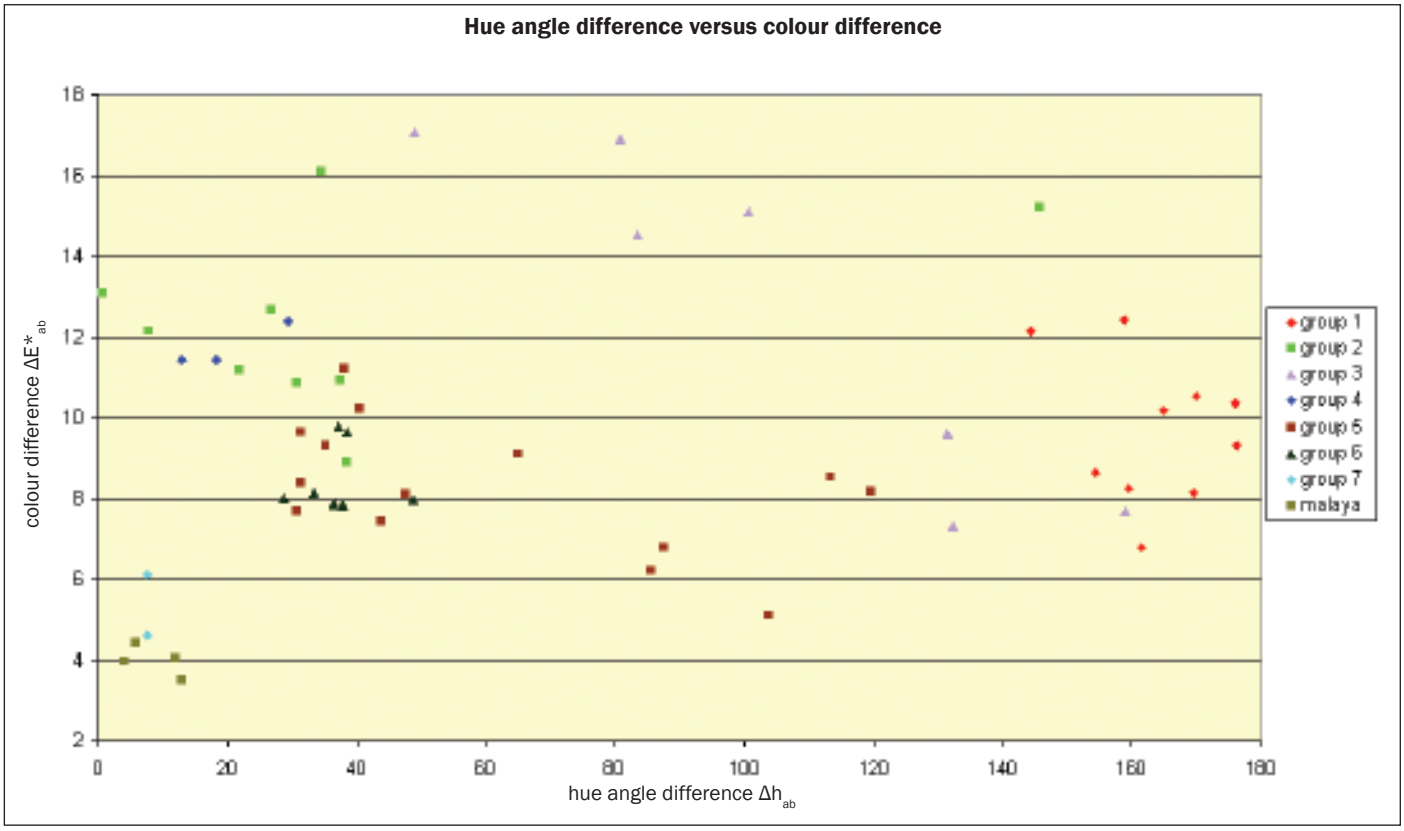

Figure 42: Variation of the main colorimetric parameters hue angle difference and colour difference of colour-change garnets from Madagascar.

Causes of colour: correlation of chemical, spectroscopic and colorimetric data

Important features of the chemistry of our garnets are plotted on *Figure 29* and their colours in daylight and incandescent light are plotted on *Figure 30*. In the section on spectra the various intensities of the (vanadium + chromium), manganese and iron absorption bands and the shift of the position of the dominant vanadium-chromium absorption maximum from 569 to 584 nm were discussed. The two regions in the spectra of low absorption (the red to orange and yellowish green to blue-violet ranges) and their ratios should play a major role in determining the colour of the garnets. The balance between these two regions of high transparency depends on the intensity of the first vanadium-chromium absorption maximum in the greenish yellow, yellow or yellow orange compared with that of the manganese triplet in the violet, on which is superimposed the second vanadium-chromium absorption band (see *Figure 26*).

On the basis of daylight colour, represented by hue angle h_{ab}, the seven groups of colour-change garnets can be plotted against the spessartine : (goldmanite + uvarovite) ratio *(Figure 41)*, and they can be subdivided further into

- garnets with a daylight colour of green to greenish blue and lower spessartine : (goldmanite + uvarovite) ratios (Groups 1, 2 and 3);
- garnets with a daylight colour of yellow green to orange and higher spessartine : (goldmanite + uvarovite) ratios (Groups 5 and 6);
- garnets of Group 4 with daylight colour violet, purple or purplish red with low spessartine : (goldmanite + uvarovite) ratios and very high iron contents; and
- garnets of Group 7, red in daylight with high spessartine : (goldmanite + uvarovite) ratios and very high iron contents.

In addition to these compositional factors, to understand the colour variations in the garnets, the intensity and position of the absorption maximum of the dominant vanadium-chromium band *(Figure 26)* and the intensity of the manganese triplet in the violet must be considered. As general background we know that standard daylight D_{65} has high percentages of blue and green compared with incandescent light A, which has higher amounts of red and orange. So, typical vanadium- and chromium-bearing pyrope-spessartine garnets show an increase of redness and blueness under light source A. The colour difference as measured by ΔE^*_{ab} in three-dimensional colour space is, in general, correlated with the vanadium and chromium contents *(Figure 39)*. The relationship between colour difference ΔE^*_{ab} and hue angle difference Δh_{ab} is shown in *Figure 42*.

Group 1 (see *Figure 31*):

- Garnets in this group are colorimetrically homogeneous with a colour change from green to slightly yellowish green in daylight to red purple, reddish purple or purple in incandescent light. They have an absorption maximum in the range 572 to 576 nm, and the absorption minima in the blue to green range are A (blue) ≈ B (bluish green) > C (green) (see *Table V* and *Figures 23* and *27*). The spessartine : (goldmanite + uvarovite) ratios vary between 9.7 and 16.9. These garnets have almost identical chroma in daylight and incandescent light lying equidistant from the centre of the CIELAB colour space. The hue angle differences vary between 144.3 and 176.2°. In order to better understand how these colours and colour changes vary from those of other groups, we may designate a typical spectrum of a Group 1 garnet as a 'balanced spectrum'.

The differences shown by other groups of garnets may then be summarized as follows:

Group 2 (see *Figure 32*):

- Garnets in this group have higher goldmanite, uvarovite and spessartine contents than Group 1 garnets, but the spessartine : (goldmanite + uvarovite) ratios are within the same range *(Figure 41)*.
- The absorption maxima of eight samples lie between 578 and 582 nm *(Figure 27, 40a)*. Thus the absorption minima in the blue to green become broader with B (bluish green) > C (green) >>A (blue) and the absorption in the red to orange is somewhat stronger. Consequently the chroma in daylight and the intensity of the green coloration in daylight is strong. However, the stronger absorption in the red to orange range means that under incandescent light most samples are still yellowish grey, greenish yellowish grey or greyish bluish green (almost colourless) and not red or purple (see *Figure 32b*).
- The absorption maximum of sample 2/1, which is green in daylight and red purple in incandescent light, lies at 583 nm. The percentage of goldmanite + uvarovite is 6.94 and the spessartine : (goldmanite + uvarovite) ratio is 8.6. Thus, the effect of the shift of the absorption maximum to higher wavelength is compensated by a somewhat higher vanadium and chromium content and the structure of the absorption minimum is similar to that of samples in Group 1. This higher transmission at A is the cause of the red purple coloration in incandescent light.

Group 3 (see *Figure 33*):

- Four garnets in this group have absorption maxima between 573 and 576 nm, i.e. in the range of the maxima measured for samples of Group 1 *(Figure 27)*. However, these garnets have somewhat smaller spessartine : (goldmanite + uvarovite) ratios. Thus the minimum in the blue to green is shifted to lower wavelength with A (blue) >B (bluish green) >C (green). Their colour in daylight is bluish green (samples 3/3 and 3/4),

and under incandescent light this changes to violet purple (sample 3/3) or blue violet (sample 3/4).

- The same type of spectrum with a maximum at 574 nm and minima according to the scheme A (blue) >B (bluish green) >C (green) is shown by sample 3/7. However, due to the higher contents of vanadium and chromium (gold + uva 5.07 %) the intensity of the absorption maximum is higher and the resulting colour in daylight is greenish blue. This is the bluest of the 52 studied garnets, and in incandescent light it is violet purple.
- Garnets 3/5 and 3/6 have extremely high vanadium and chromium contents, and their absorption maxima were measured at 584 nm *(Figure 27)*. This shift of absorption to a higher wavelength and the resulting structure of the minimum where B (bluish green) > C (bluish green) > A (blue), results in a daylight colour of bluish green. With the increase of blueness and redness in incandescent light, the blueness remains strong and 3/5 is blue green in this light and 3/6 is blue violet.

Group 4 (see *Figure 34*):

- The garnets in this group have somewhat lower spessartine : (goldmanite + uvarovite) ratios than comparable samples of Group 3 *(Figure 41)*. The vanadium-chromium maximum lies at 571–573 nm *(Figure 27)* and the transmission pattern in the blue is A (blue) >B (bluish green) >C (green). The intensity of the vanadium-chromium absorption band is probably enhanced by the high to extremely high iron contents of the garnets, and due to the position of this band at 571 nm, the red in daylight has more influence resulting in violet, purple or purplish red. The garnet with the highest almandine content (sample 4/3) is purplish red in daylight.
- Upon change of illuminant to incandescent light, the increase of blueness and redness result in a reddish purple or red purple coloration of the three garnets.

Group 5 (see *Figure 35*):

- Within this group, the three garnets with the lowest manganese contents (spess 27.09 – 27.90 %) and a vanadium-chromium absorption maximum at 572 nm (see *Figure 40b*) are slightly yellowish grey, almost colourless. The structure in the blue transmission region is A > B ≈ C. Although these samples reveal pronounced absorption spectra in the visible range, their chromas are extremely low (1.2 to 2.1). The resulting colour is only understandable in terms of the mechanism of human colour perception, but it proves the results of chromaticity calculation in the CIELAB colour space to be correct. In incandescent light, these stones are red purple.
- Two samples have somewhat higher spessartine contents and similar vanadium and chromium contents. The structure of the absorption minimum (see *Figure 28*) is A ≈ B > C (sample 5/10) or A ≈ B ≈ C (sample 5/9) and in daylight they are greenish yellow or yellow green; consequently, these two samples are closest to those of Group 1. In incandescent light redness and blueness are increased and the colour shifts to red or red purple.
- The remaining nine samples have distinctly higher manganese contents between 46.44 and 73.83 % spess. The ratio spess : (gold + uva) varies accordingly from 21.8 to 33.1 *(Figure 41)*. The structure of the absorption minimum (see again *Figure 28*) is B ≈ C > A or C > B > A and the daylight colour is greenish yellow or yellow. In incandescent light they are orange to red.

Group 6 (see *Figure 36*):

- The seven garnets in this group have similar manganese, vanadium and chromium but higher iron contents than the first three garnets mentioned in Group 5. The absorption maximum, which is influenced by the high iron contents, lies between 569 and 571 nm *(Figure 28)* and the structure at the absorption minimum is A ≈ B ≈ C. The resulting colour in daylight is orange or yellow orange. In incandescent light, the increase of blueness is weak or extremely weak, and the stones are red.

Group 7 (see *Figure 37*):

- The two garnets in this group show the smallest vanadium and chromium contents of the whole garnet series, and they also have high iron contents (alm 10.02 or 16.35 %). The spectra *(Figure 28)* are comparable with the spectra of iron-rich malaya garnets *(Figure 22)* which show a somewhat increased intensity of the absorption band at 569 nm. The structure at the absorption minimum is A >> B ≈ C and is not influenced by the vanadium-chromium band. The stones are red in daylight, and a somewhat more intense red or purplish red in incandescent light.

In comparing our groups with those of Krzemnicki *et al.* (2001) we can note the following similarities:

This paper:	Krzemnicki *et al.*:
Two samples of Group 3	Compare with Group 1
Groups 1, 3, 4	Compare with Group 2
Group 5, low manganese contents	Compare with Group 3
Group 5, high manganese contents	Compare with Group 4

Krzemnicki and his co-workers did not examine samples comparable with our Groups 2, 6 and 7, and the single garnet in their Group 5 has a particular combination of properties not represented among our 52 samples.

Most probably, according to the spectrum, this garnet specimen reveals — in addition to the 'normal' absorption bands of manganese, iron, vanadium and chromium discussed in detail in this paper — a continuously increasing absorption from red to violet. A similar spectroscopic feature was observed in samples from

Tranaroa, Madagascar (Schmetzer *et al.*, 2002), but such garnets are not included in the present study.

Evaluation of the extent of colour change

According to the colorimetric data obtained from our samples it is evident that the wide variety of colours in daylight and incandescent light relates to different spectroscopic properties. The data are presented in *Tables II, VIa* and *VIb*, and shown in *Figures 31* to *38*.

The colorimetric parameters of colour-change garnets in the CIE 1931 chromaticity diagram are useful to characterize stone colours in daylight and incandescent light. But if we want to characterize colour differences and especially to quantify the extent of any colour change, we have to refer to a uniform colour space such as CIELAB.

Upon measurement of 18 colour-change gem materials, Liu *et al.* (1994, 1999a) suggested a criterion for recognition and description of colour change, which is based on a hue angle difference Δh_{ab} of 20° or above (for gemstones with relatively saturated colour, i.e. with chroma higher than 5 CIELAB units). In these papers, they used a general, non-restricted definition of colour such as "colour in gemstones is the colour appearance that a person sees" (Liu *et al.*, 1999a, p.372) and "colour is described in words by means of three attributes – hue, … saturation, … and lightness" (op.cit. p.373).

While investigating the 52 colour-change garnets and four malaya garnets, the proposed 20° hue angle difference was assessed. Among these samples, there are six vanadium- and chromium-bearing garnets *(Figure 43 a,b; Table VII)* from Groups 2, 4 and 7, and four vanadium- and chromium-free malaya garnets *(Figure 38 a,b)* which, although having hue angle differences below 20°, show a clearly visible colour variation between daylight and incandescent light. This is understandable because the human eye is unable to distinguish clearly between various colorimetric parameters such as

Figure 43 a,b: Colour-change garnets from Madagascar with hue angle differences between daylight (a) and incandescent light of below 20°; two samples of Group 4 (left), two of Group 7 (centre) and two of Group 2 (right) are pictured; diameter of the garnet in the lower right 3.9 mm, weight 0.28 ct.

Table VII: Colorimetric data of six samples with hue angle differences < 20°.

Group	2	2	4	4	7	7
Sample	2/7	2/8	4/1	4/3	7/2	7/1
Colorimetric data CIE 1931[a]						
λ_D (nm) for daylight D_{65}	537	530	c550	635	598	608
Purity p for daylight D_{65}	9.2	9.4	7.1	4.5	12.5	9.9
λ_D (nm) for incandescent light A	555	538	c531	c510	619	c504
Purity p for incandescent light A	3.0	1.6	20.0	22.1	19.3	17.1
Colorimetric data CIELAB 1976[b]						
C^*_{ab} for daylight D_{65}	14.90	14.98	6.83	5.01	9.37	9.91
h_{ab} (°) for daylight D_{65}	151.0	153.8	323.5	14.2	30.7	22.16
C^*_{ab} for incandescent light A	2.83	1.93	17.98	16.07	13.59	15.66
h_{ab} (°) for incandescent light A	143.3	153.2	336.5	355.8	23.2	14.62
Δh_{ab} (°)	7.7	0.6	13.0	18.4	7.6	7.5
ΔE^*_{ab}	12.1	13.1	11.4	11.4	4.6	6.1

[a] λ_D = dominant wavelength, c indicates 'complement of'

[b] C^*_{ab} = chroma; h_{ab} = hue angle

Δh_{ab} = hue angle difference between daylight and incandescent light

ΔE^*_{ab} = colour difference between daylight and incandescent light in the three dimensional CIELAB colour space

Colour-change garnets from Madagascar: variation of chemical, spectroscopic and colorimetric properties

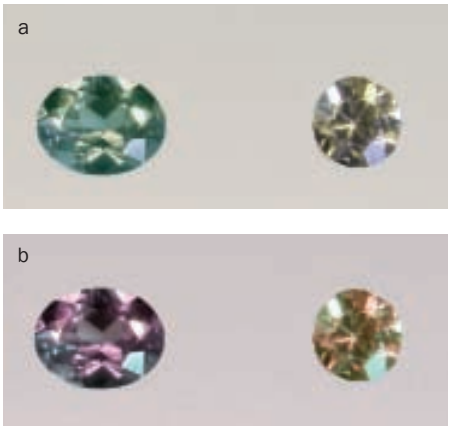

Figure 44 a,b: Two colour-change garnets from Madagascar with chroma below 5 CIELAB units for daylight (a) and incandescent light; samples from Group 1 (left) and Group 5 (right); diameter of the right garnet 4.7 mm, weight 0.47 ct.

hue and chroma (saturation) and only an overall colour impression is observed. Therefore, the hue angle change Δh_{ab} cannot be the only parameter important in understanding colour change.

In addition to a hue colour change above 20°, Liu *et al.* (1994, 1999a), also mentioned that the method seemed best suited to gems whose chroma C^*_{ab} is above 5 CIELAB units (i.e. for clearly observable colour change). This suggestion was tested with the 10 samples mentioned above and only two garnets from Group 2 have chroma below 5 in incandescent light (see again *Table VII*). However, these garnets still showed a clear colour change, and within the range of our 52 garnets there are numerous stones with low chroma C^*_{ab} for both daylight D_{65} and incandescent light A *(Tables II, VIa, VIb)*. Of these, there are two samples with both chroma values below 5 or close to 5 *(Figure 44 a,b)*. Since all our studied garnets show clearly observable colour changes, this indicates that the value of chroma has to be considered in the context of other criteria.

In the uniform CIELAB colour space, three parameters should be considered:

- The colour difference ΔE^*_{ab} which represents the distance between two sample loci in the three-dimensional colour space. Because the differences of lightness L* are so small in the range of samples under different illuminants, the lengths of the bars in the CIELAB graphics of F*igures 31* to *38* are graphical representations of this parameter projected into the a*b* plane.
- The hue angle difference Δh_{ab}, i.e. the hue angle h_{ab} representing the spectral point in daylight minus the hue angle h_{ab} representing the spectral point in incandescent light, is also shown in these graphics and summarized in *Figure 42*.
- The chroma C^*_{ab} under different illumination. Graphically C^*_{ab} is represented by the radial distance of the spectral point from the origin of the CIELAB a*b* plane (see *Figures 31* to *38* and especially *Figure 30*). So chroma difference in a stone under two light sources can be represented by the difference between two radial distances.

Because there is a large variation of hue angle differences Δh_{ab} from almost 0° to almost 180°, the hue difference

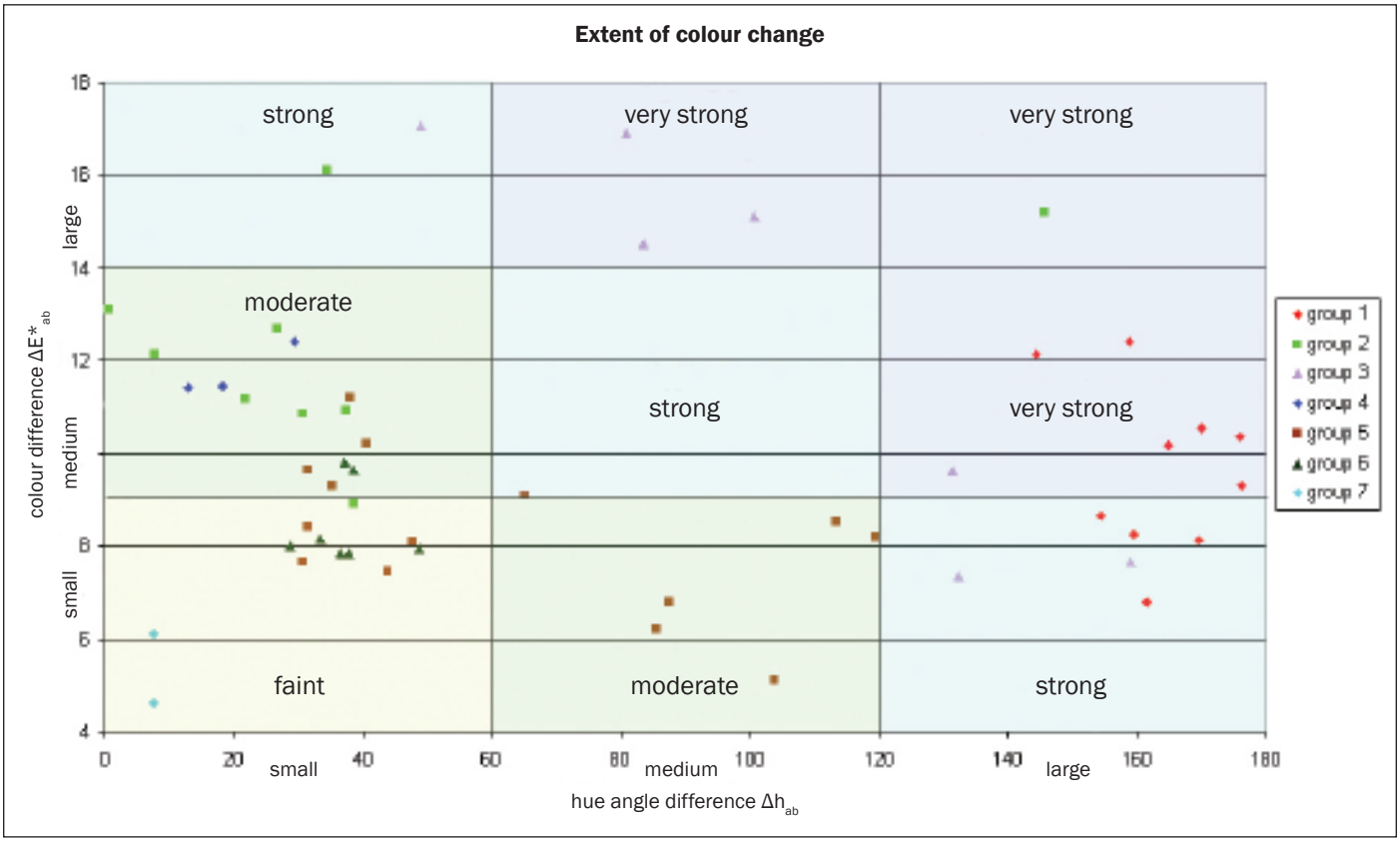

Figure 45: Correlation of the main colorimetric parameters hue angle difference and colour difference of colour-change garnets from Madagascar with the extent of colour change which is represented by broad categories such as faint, moderate, strong and very strong.

(which can be calculated from lightness difference ΔL^*, colour difference ΔE^*_{ab} and chroma difference ΔC^*_{ab}) is not used in our discussion. In general, hue difference is only used for investigating samples with smaller hue angle differences (see colorimetric textbooks).

The colour differences ΔE^*_{ab} and the hue angle differences Δh_{ab} of the garnets are plotted in *Figure 42*.

On the basis of hue angle difference Δh_{ab} we can separate the garnet points into three groups with small (0°–60°), medium (60°–120°) and large (120°–180°) hue angle differences *(Figure 45)*. Only some of the garnets (all of Group 1, one of Group 2 and three of Group 3) show a colour change from green or bluish green in daylight to violet purple, purple, reddish purple or red purple in incandescent light and can be designated as garnets with an alexandrite-like colour change; this category has large hue angle differences above 120°. The second category with hue angle differences between 60° and 120° consists of six samples of Group 5 and three of Group 3. The remainder with hue angle differences below 60° consists of numerous garnets from different groups.

For garnets with both small and large hue angle differences there is an almost continuous range of colour difference ΔE^*_{ab} values. Thus it is difficult to categorize the samples on this basis. Furthermore, there is a clear gap in the centre of *Figure 45* for garnets with medium hue angle differences, i.e. we measured no garnets with these colorimetric parameters. The effect of various colour differences on samples with similar hue angle differences, i.e. on samples with small, medium or large hue angle differences, is demonstrated in *Figure 46 a–h*. From the samples selected it is evident that there is stronger colour change with increasing colour differences. Therefore the extent of colour change, especially for faceted gemstones, is not only dependent on Δh_{ab} variation but also on ΔE^*_{ab}.

For practical communication in the gem trade and use in gemmological laboratories it is highly desirable to translate the numerical values of colour change, as measured by Δh_{ab} and ΔE^*_{ab}, into easily understandable terminology. One way of doing this is to subdivide the range of each parameter into three categories, called respectively small, medium and large *(Figure 45)*. This produces nine areas containing four strengths of colour change, i.e. faint, moderate, strong and very strong. A second way is to subdivide the hue angle difference Δh_{ab} versus colour difference ΔE^*_{ab} diagram by diagonal northwest-southeast lines into four diagonal zones depicting faint, moderate, strong and very strong colour changes. This scheme would change the categories of a few borderline samples, but would not change the general scope and usefulness of the diagram; two options for different boundary positions are shown in *Figure 47 a,b*.

The parameters of the four vanadium- and chromium-free malaya garnets measured for comparison are located close to the values of low vanadium- and chromium-bearing garnets and lie in the 'faint' zone of colour change. Consequently, there is no physical basis for distinguishing samples with faint colour change from those with 'colour shift'.

For the four alexandrites with 'good' colour change examined for comparison, we obtained colour differences ΔE^*_{ab} from 15.2 to 21.6 and hue angle differences Δh_{ab} between 97 and 168°. Consequently, these four samples would be classified according to the scheme described above as alexandrites with very strong extent of colour change. Although the system needs testing further for alexandrites and other pleochroic gemstones to establish a standard procedure, provisionally it seems to be an adequate solution for describing the extent of colour change and for the clear separation and designation of these samples in laboratory practice.

Although many may not have thought of, let alone expressed, the concept, it is very desirable that gemstones have good colour or colours in both daylight and incandescent light. This depends on the respective chroma of the samples under different illuminants *(Figure 30)*. The greater the chroma, the purer is the colour observed. Good examples are garnets of Groups 1 and 2, with similar ranges of hue angles but different chroma, i.e. lower chromas in Group 1 and higher in Group 2 *(Figures 20a, 30, 31a* and *32a)*.

Most Group 1 garnets have equal or almost equal chroma in daylight and incandescent light as do some garnets in Groups 3 and 5. Garnets with high chroma in daylight and low chroma in incandescent light are represented by most of the samples in Group 2, while those with smaller chroma in daylight and higher chroma in incandescent light are in Groups 4, 6 and 7.

Samples with a significant colour change and high chromas for both daylight and incandescent light are considered as most attractive gems in the trade and by the consumer.

Our data focus on quantifying colour change behaviour in garnets and the colour parameters discussed are not yet adequate to predict colour behaviour in other gem species. In order to predict behaviour, the colour-change data will have to be augmented by data from a wide range of other gems in order to precisely locate the important factors in colour change.

In the gem trade, the designation 'colour-change' is frequently used as an attribute of quality. Another widely-accepted attribute of gemstones is rarity, and to maintain this concept we suggest the use of the attribute 'colour-change' only for gemstones with moderate, strong or very strong colour-change according to *Figures 45* and *47*. Furthermore, we suggest that stones falling in the faint category of colour change, which is common in some gem materials, should be described as having colour variation, and not to be labelled 'colour-change' stones. This would, for example, lead to a clear separation between alexandrites and those pale green or yellowish green chrysoberyls which show only a slight variation of colour upon change of illuminants. However, we must emphasize that — especially for the garnets examined in this paper — there is an almost continuous variability of both hue angle difference and colour difference.

Daylight

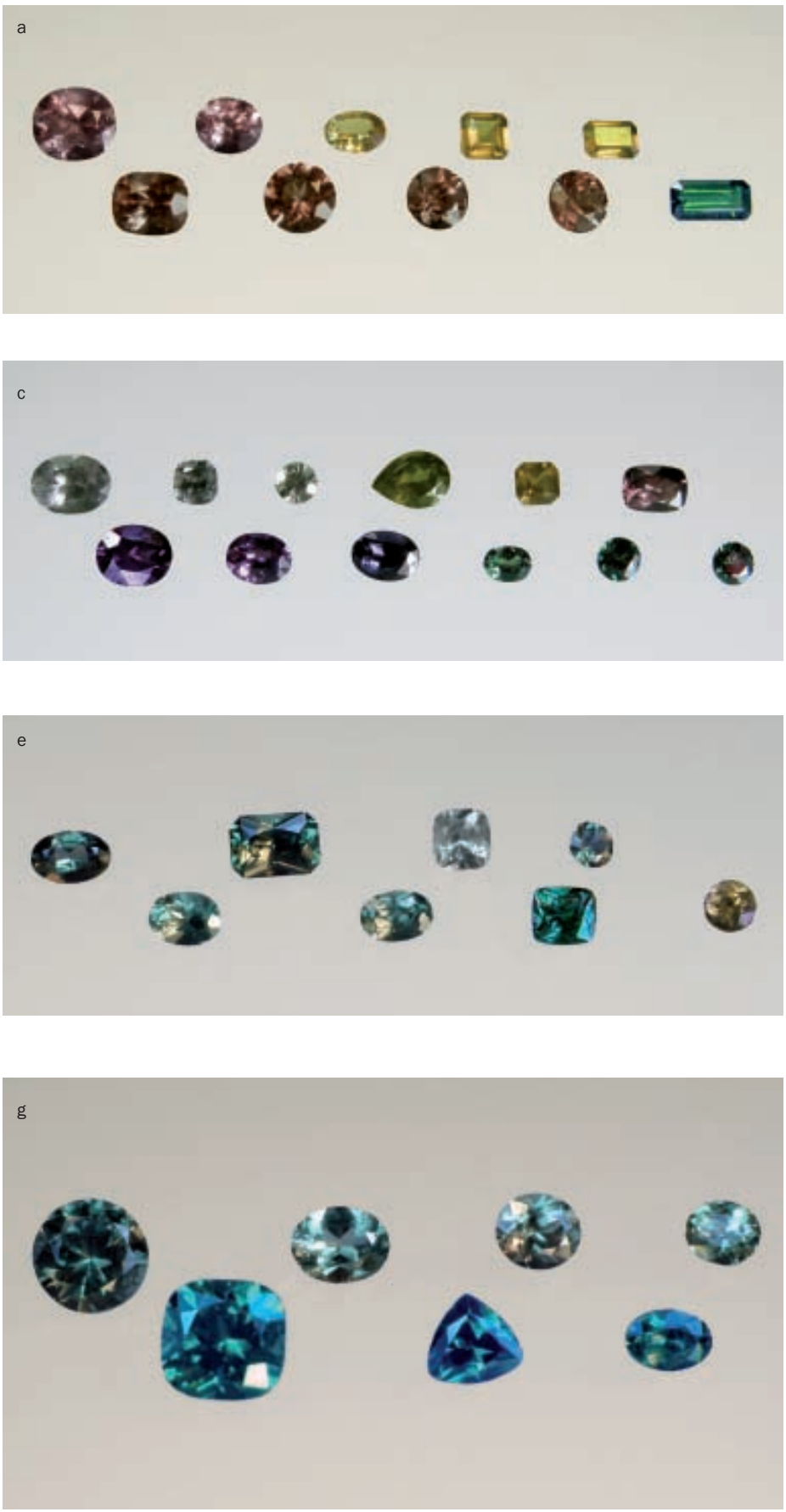

Figure 46: Colour change garnets assembled to demonstrate the faint, moderate, strong and very strong categories shown in Figure 45. Daylight colours are in a, c, e and g, and colours in incandescent light are in b, d, f and h. Garnets with faint colour change (a) and (b), upper row from left, two samples of Group 7, three of Group 5, lower row from left, four of Group 6, one of Group 2; size of the lower right sample 3.5 x 7.0 mm, weight 0.69 ct.
Samples with moderate colour change (c) and (d), upper row from left, five samples of Group 5, one of Group 6, lower row from left, three of Group 4, three of Group 2; diameter of the lower right sample 4.5 mm, weight 0.44 ct.
Garnets with strong colour change (e) and (f), upper row four samples of Group 1, lower row from left, four of Group 3, one of Group 5; diameter of the lower right sample 3.7 mm, weight 0.27 ct.
Samples with very strong colour change (g) and (h), upper row four samples of Group 1, lower row three of Group 3; size of the upper right sample 4.4 x 5.0 mm, weight 0.48 ct.

We are also unable to predict for which general type of absorption spectrum in gem materials colour change is observable. Furthermore, it is outside the scope of this article to discuss the mechanism of colour change under illuminants other than D_{65} and A and in all these materials in general.

In the absence of analytical equipment such as a colour spectrometers or spectrophotometers, values like colour difference or hue angle difference are not directly obtainable. Nevertheless, colorimetric parameters in daylight and incandescent light as well as the type and extent of colour change of gemstones can be determined by visual comparison with colorimetric standards. Some commercially available colorimetric standard sets (compare *Figures 12* to *19*) are based on the uniform CIELAB colour space. So, by visual estimation, the CIELAB coordinates a*, b* and L* are directly obtainable, and the chroma, hue angle, hue angle difference and colour difference may be calculated by simple mathematical equations. Only simple facilities are necessary:

- Colour viewing box with light to medium grey walls.
- Bright but diffuse daylight-equivalent

Incandescent light

and incandescent light sources, mounted in the top of the viewing box, alternately switched on and off or alternately shielded, best used in a darkened room.

- Complete and uniform set of spectral reference colours for comparison with the gemstone being tested.
- If possible colour-change reference stones with known colorimetric parameters would be helpful.

A computer-based system for the determination of CIELAB parameters of gemstones has recently been described by Liu (2007) and Liu and Hurwit (2008).

Conclusions

The results presented lead to a more detailed understanding of the complex relationship of chemical composition and spectra with parameters describing colour and colour change for 52 colour-change garnets. However, no simple parameters were found that could enable one to predict colour and colour change over the whole group of samples.

The ratio spessartine : (goldmanite + uvarovite), which can be calculated easily from analytical data, provides a parameter which can be helpful in understanding the causes of colour and colour change and was useful to subdivide the garnets into two larger groups: the green to greenish blue, and the yellow green to orange in daylight. The colour differences for the garnets between daylight and incandescent light are generally correlated with their vanadium and chromium contents. However, a wide range of minor elements in the garnets can cause very subtle differences in the absorption spectra of visually similar samples, and must be taken into account.

If the results of this study are applied in the gem trade and for practical work in the laboratory it is clear that colour change in gemstones should not be described without further specification. Although, in practice, a combination of effects is observed, an effort should be made to distinguish between

- a hue difference represented by the difference of the hue angle Δh_{ab} or

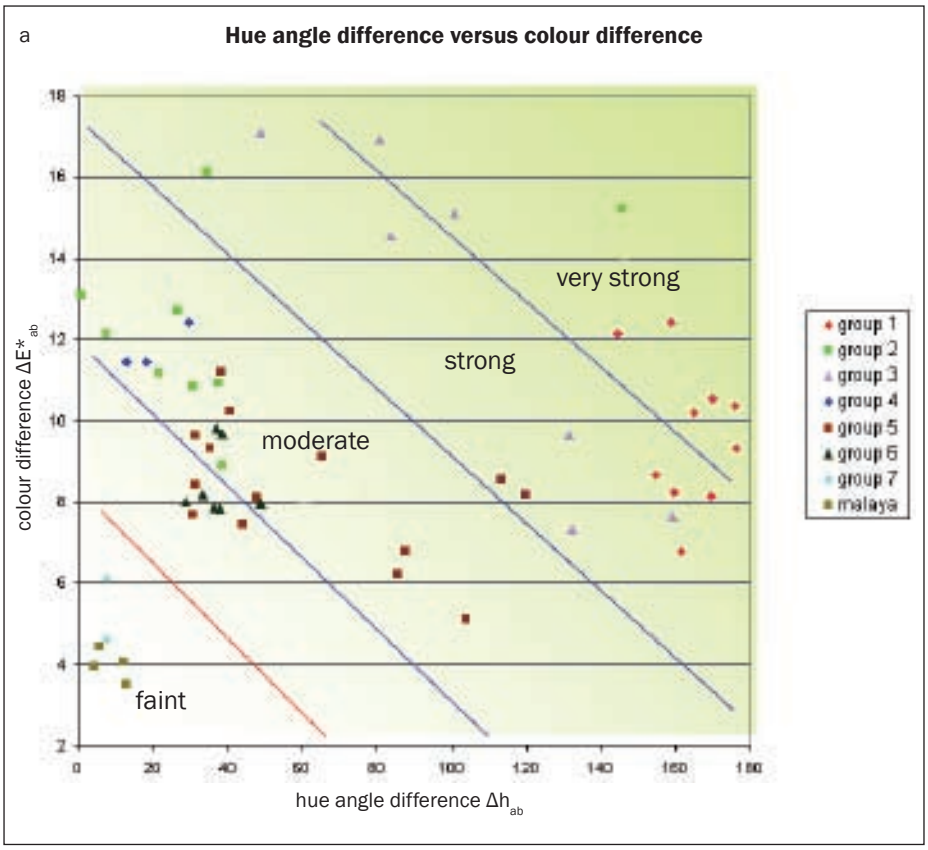

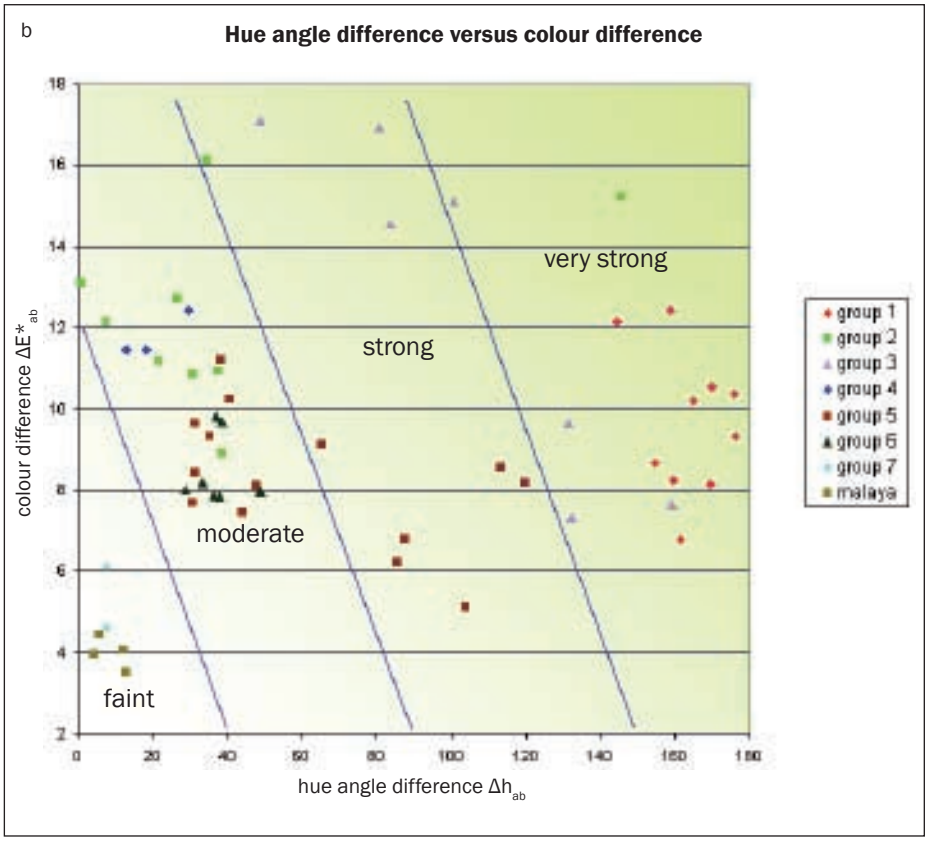

Figure 47 a,b: Graphs showing the correlation of the hue angle difference and colour difference of colour-change garnets from Madagascar with other possible groupings of the colour change behaviour into faint, moderate, strong and very strong. (a) This graph is almost consistent with Figure 45, i.e. only a few garnets grouped according to Figures 45 and 46 lie in neighbouring categories; according to the red line in this plot, the 'faint–moderate' boundary is shifted to include only garnets of Group 7 and malaya garnets (see Figures 37 and 38) in the 'faint' category, and most garnets of Groups 2, 4, 5 and 6 are 'moderate'. (b) Here, again, only samples of Group 7 and malaya garnets are 'faint', most samples of Groups 2, 4 and 6 and half of Group 5 are 'moderate', and all samples of Groups 1 and 3 and half the samples of Group 5 are 'strong' or 'very strong'

- a colour change represented by the colour difference ΔE^*_{ab} or
- a chroma difference represented by different chroma C^*_{ab} under different illuminants.

Without this type of specification, the description of a gemstone as having a 'good' colour change is almost meaningless. Furthermore, the recent introduction of many more kinds of lights under which gems may be seen, only strengthens the case for a more precise description of colour behaviour using colorimetric parameters.

The terms 'alexandrite-effect' and 'alexandrite-like colour change' should only be used for stones with a hue change in the range of natural alexandrite (as historically described), i.e. from green, bluish green or blue green in daylight to violet purple, purple, reddish purple, red purple, purplish red or red in incandescent light. For other colours the approximate hues and chromas under both illuminants should be given. This information (hue and chroma under both illuminants, see *Figure 30*) contains the necessary information about hue angle difference Δh_{ab} and colour difference ΔE^*_{ab} (see also *Figures 42, 45* and *47*).

Semi-quantitative measures of colour change can be specified as faint, moderate, strong or very strong according

to a combination of two fundamental parameters, i.e. hue angle difference and colour difference. But in the gem trade we suggest that the faint category stones are referred to as showing 'colour variation' not 'colour change' and that the term 'colour shift' be abandoned.

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Illustrations

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The characteristics of red andesine from the Himalaya Highland, Tibet

Ahmadjan Abduriyim

Abstract: Natural-coloured Tibetan andesine has been mined using simple hand tools from an alluvial deposit at Bainang County in the Xigazê area of Tibet. The gem-quality andesine is derived from Tertiary–Quaternary volcanogenic sediments related to Jurassic-Cretaceous volcanic rocks. Weathering and alluvial transport have resulted in round detrital crystals, most of which have an orangy-red body colour; a few stones have bicoloured zones of red and green. Top-quality stones in deep red are characterized by fine granular inclusions and some twin lamellae. Poorer qualities of andesine in orange-red and reddish-orange generally contain abundant turbid irregular colour patches, irregular dislocations, tubes and parallel lath-like hollow channels and a few tiny platelets of native copper. EPMA chemical analyses indicate a composition range of $(K_{0.03}Na_{0.46\text{-}0.49})_2Ca_{0.46\text{–}0.49}Al_{1.43\text{–}1.48}Si_{2.51\text{–}2.53}O_8$, the equivalent ratios of albite:anorthite:orthoclase being $Ab_{46.96\text{-}49.79}$:$An_{46.72\text{–}49.94}$:$Or_{3.03\text{–}3.50}$, which indicates andesine near the andesine-labradorite border. The lattice parameters are a_0=8.161–8.193 Å, b_0=12.849–12.919 Å, c_0=7.105–7.126 Å, α=93.26°–93.74°, β=116.27°–116.38°, γ=89.93°–90.16°, and the RIs are α=1.550–1.551, β=1.555–1.556, γ=1.560–1.561. LA-ICP-MS analysis indicates the presence of the trace elements; Li, Mg, K, Sc, Ti, Mn, Fe, Cu, Ga, Sr and Ba. An estimate of the degree of structural ordering of Al in tetrahedral sites in Tibetan andesine was made by measuring the parameters $\Delta=2\theta(1\bar{3}1) - 2\theta(131)$ and γ, from the X-ray powder diffraction pattern. Both Δ and γ values are plotted as a function of mole percent anorthite (An), and indicate that Tibetan andesine has a low degree of Al/Si ordering with only 22–29 percent of Al lying in the tetrahedral T1(o) site; this indicates that it formed at about 800°C in a volcanic environment. By plotting Ba/Sr versus Ba/Li ratios Tibetan red andesine can be differentiated from andesines of Inner Mongolia.

Keywords: andesine, EPMA, Inner Mongolia, labradorite, LA-ICP-MS, Tertiary–Quaternary, volcanogenic sediment

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Figure 1: Since 2007, natural-coloured orange-red and red-green pleochroic andesines have been recovered from a deposit in the Xigazê area. The faceted stones are up to 5 ct; rough samples (not shown) are up to 30 ct. Courtesy of King Star Jewellery Co. and M. P. Gem Corp. Photo by M. Kobayashi.

Introduction

A natural gem-quality plagioclase feldspar (andesine) has become available recently from Tibet. Orange-red or intense red andesine straight from the ground is a brilliant and treasured gemstone due to its rarity and colour, and the green variety is even rarer. In late 2005, a red andesine called 'Tibetan sunstone' was supplied by Do Win Development Co. Ltd of Tianjin, China, which reported its origin as Nyima in central Tibet (Laurs, 2005). Later, at the February 2007 Tucson gem shows, King Star Jewellery Co. (Hong Kong) and M.P. Gem Corp. (Kofu, Japan) introduced a similar red andesine from Tibet called 'Lazasine' and raised again the gem value of plagioclase sunstone *(Figure 1)*. However, a large supply of red andesine allegedly from China, was offered for sale as the official gemstone of the 2008 Summer Olympic Games in Beijing. Despite claims to the contrary, there has been widespread suspicion that the red Chinese andesines are diffusion-treated. In the light of this, the author investigated the mine in Tibet and also localities in the Inner Mongolian Autonomous Region in October–November 2008, to confirm the authenticity of the sources stated for the andesine (Abduriyim, 2008). The visit to Tibet was made possible with the cooperation of the mine owner Li Tong in Tibet, of the mine investors of Wong Ming (King Star Jewellery Co.) and of Christina Iu (M.P. Gem Corp.). Also participating in the expedition were Masaki Furuya of the Japan Germany Gemmological Laboratory, Kofu, Japan, David Chiang of BBJ Bangkok Ltd, Bangkok, and Marco Cheung of Litto Gems Co. Ltd, Hong Kong. This paper focuses on describing the geographical location of the andesine in Tibet, its recovery and its properties which are of interest to the gem industry.

Location and access

The Tibetan andesine mine is located at Bainang County (29.03984°N, 89.38791°E), 70 km south-east of the region's second largest city, Xigazê (or Shigatse), in southern Tibet (Qin Zang Gao Yuan) *(Figure 2)*. From the capital city of Lhasa, a well-paved road leads 280 km to Xigazê city, five hours drive in a van, and the road lies at an elevation between 4000 and 5000 m. During the winter season, the road is frozen and it is difficult to reach this city. It is another one to two hours from Xigazê on a mixture of paved and dirt roads to the mining area. The mine is located at an elevation of more than 4000 m, in freezing temperatures with thin oxygen.

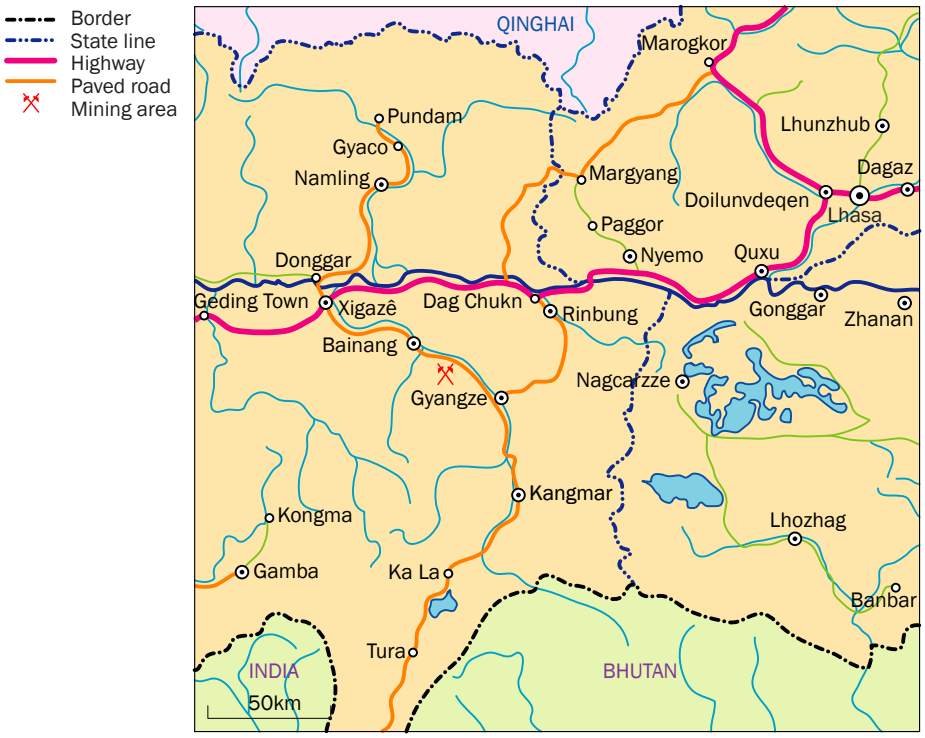

Figure 2: The andesine mine, marked with crossed hammers, is in the south of Bainang County, southern Tibet, close to the border with Bhutan, and at around 4000 m elevation.

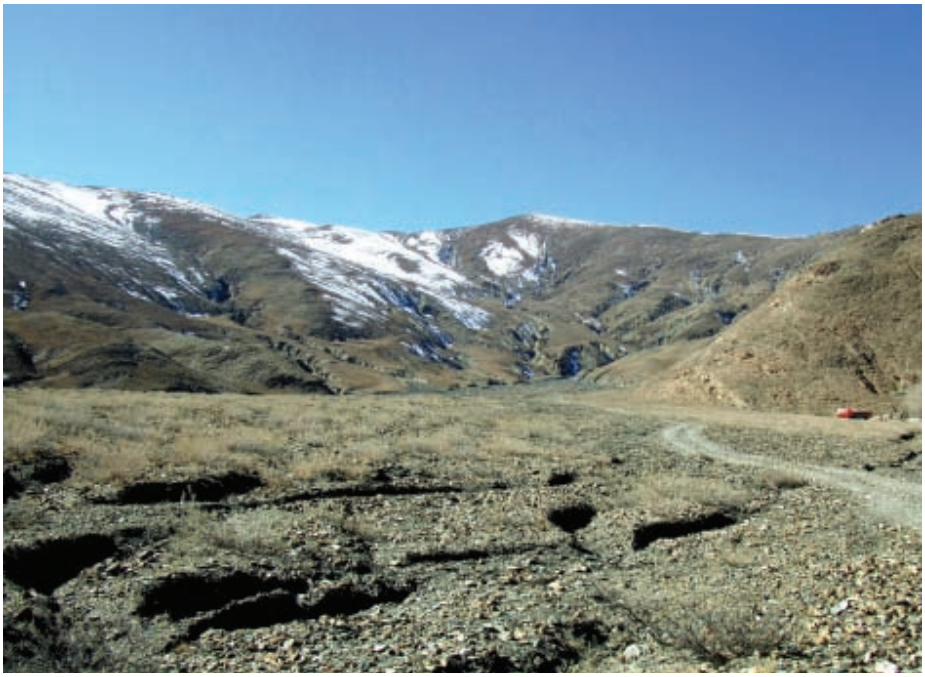

Figure 3: Red andesine is recovered from secondary deposits located at the base of the mountain on the far right and left (here, looking west). The mine site is divided into north and south areas. Photo by A. Abduriyim.

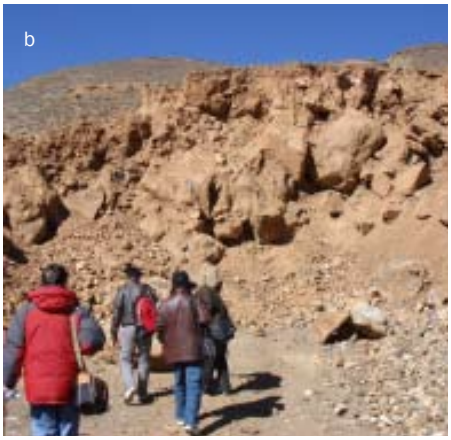

Figure 4: (a) Tibetan andesines are found in dark grey sand and gravel or soil in the southern mine area. (b) Andesine-bearing yellowish-red or greenish-grey soil in the northern area of the mine. A shaft was sunk several metres deep but mining there was discontinued after the devastating Chengdu earthquake. Photos by A. Abduriyim and M. Furuya.

Twenty to thirty local Tibetan families live there, and fewer than ten miners were digging pits near a riverbed when we visited. Without authorization from the Chinese government and without local permission, foreigners are not permitted to visit this area. According to the miners, red andesine was originally found in this area in the 1970s, and beads of this material appeared in Lhasa's largest bazaar — Bakuo Street — in 2003. However, andesine was not mined officially until 2006 when commercial mining began in January under the supervision of Li Tong. The work is not mechanized and is done by hand from April to November.

Geological setting and mining

The andesine mine is located in the alluvium of a riverbed at the foot of a mountain. This terrain may derive from an ice sheet. The site is divided into north and south areas with a total coverage spanning 3–4 km east west and 5–7 km north south *(Figure 3)*. The surface layer is weathered and consists of humic soil 0.5–3 m thick. Beneath this is greenish grey or dark grey sand/gravel in the southern area, and yellowish-red or greenish-grey soil in the northern area which contain the andesine *(Figure 4a* and *b)*. The andesine-bearing layers are apparently derived from Quaternary and Tertiary volcano-sedimentary deposits. The Chengdu Institute of Multipurpose Utilization of Mineral Resources, China Geological Survey, has recently carried out regional geological mapping in the Qin Zang Gao Yuan (Tibet highland) area *(Figure 5)*, but unfortunately the scale was not appropriate for any detail to be recorded for the mine area of Bainang County. A visit to the summit in the mining area revealed large quantities of late Jurassic to early Cretaceous detrital (clastic) and mixed with volcanic rocks *(Figure 6)*, and observations on these indicated that andesine crystals may grow to some size underground and then be carried to the surface with magma during eruption of the volcano. However, the author did not find any such crystals in the volcanic rock at the time of visiting. Weathering and ice transport of the primary deposits has resulted in secondary alluvial deposits on the lower parts of the mountain. These accumulations appear to have been concentrated across a wide area by water from seasonal snowmelt. In the southern area, mining activities are limited to a few small tunnels penetrating

Figure 6: Near the summit above the southern area of the mine area there is a contact (on the extreme left of the photo) between the main weathered sediment and massive clastic rock mixed with volcanic rock. Photo by M.Furuya.

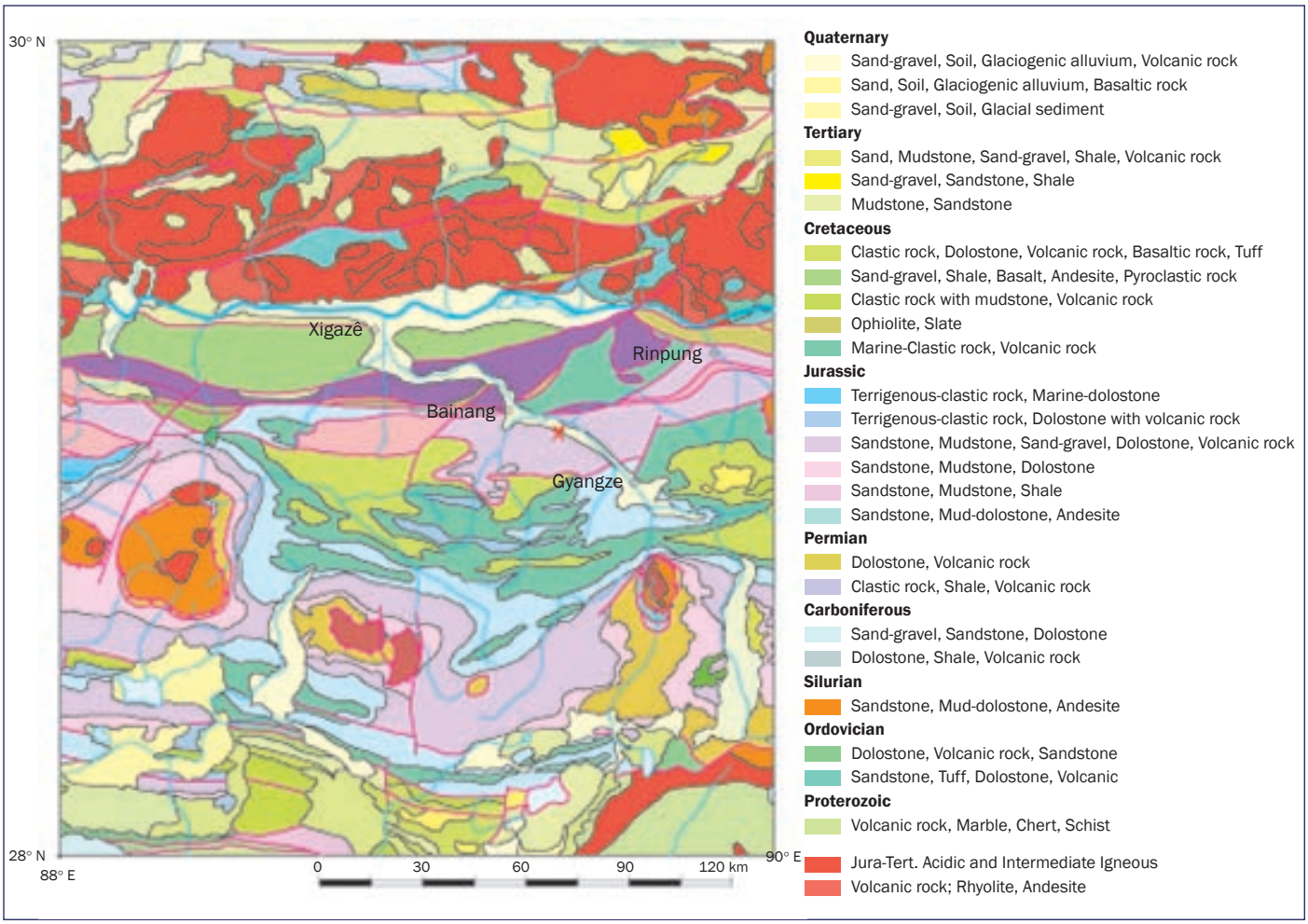

Figure 5: Geological sketch map of Bainang County (modified after 'Qin Zang Gau Yuan and Adjacent land Geological Map' made by the Chengdu Institute of Multipurpose Utilization of Mineral Resources, China Geological Survey, 2004). The Bainang deposit lies in alluvial rocks derived from various volcanic and clastic rocks.

several metres horizontally into the andesine-bearing horizons. These tunnels do not exceed 2–2.5 m^2 and 1–4 m depth. Local miners working in family groups use picks and shovels for extracting the gravel and searching for gems *(Figure 7a, b* and *c)*. The andesine crystals are concentrated in clusters of up to 20 (100–200 g total) in a matrix of sand, gravel or soil *(Figure 8a* and *b)*. The excavated material is placed on a hand-operated shaker screen to remove the soil and small pebbles and then the rough andesine is picked out by hand. In the northern mining area, a shaft was sunk several metres deep but mining there was discontinued after the devastating Chengdu earthquake in May 2008.

Alluvial transport has rounded the crystals, and although most were found as translucent to transparent stones that are <1 cm in diameter *(Figure 9)*, the largest pieces reached 4 cm. Approximately 80 percent of crystals are orangy red and the remainder are mostly deep red, but in the southern mining area there are a few red and green pleochroic crystals and bicoloured crystals; we did not see any andesines that were completely brown, yellow or colourless. The annual production from the region is estimated to be 700–800 kg, of which 4–6 percent crystals are top gem quality (T. Li and M. Wong, pers. comm., 2008). The cleaned rough crystals are pre-sorted into four grades; the finest rough will be faceted and the lower-grade stones will be fashioned as cabochons and beads in Guang Zhou, China (*Figure 10)*.

Materials and methods

For the investigation, 210 pieces of reddish-orange and orange-red rough crystals of Tibetan natural andesine were collected by the author from the alluvial sediments in Bainang County. All samples (up to 34 ct; see e.g. *Figure 11*) from this region were polished with two parallel windows, and were cleaned with acetone and aqua regia in an ultrasonic bath to remove surface contamination. All were characterized using traditional gemmological methods, to determine their optical and physical properties, and the following instruments were used for spectra collection and other measurements:

1. SHIMATSU-2450 polarized UV-Vis-NIR spectrometer to record the 220–860 nm range, operating in absorption-mode, equipped with intergrating-sphere and tungsten lamp; all samples were measured.

The characteristics of red andesine from the Himalaya Highland, Tibet

Figure 7 (a,b,c): The andesine is recovered from a series of tunnels, with the local Tibetan miners using simple hand tools and hand picking.
Photos by A. Abduriyim.

Figure 8 (a,b):Rounded crystals of red Tibetan andesine in a matrix of sand and gravel at the entrance to the pit and inside the pit.
Photos by A. Abduriyim.

Figure 9: Most of the orangy red andesine crystals are generally <1 cm in diameter, but some of the largest pieces reach 4 cm.
Photo by A. Abduriyim.

The characteristics of red andesine from the Himalaya Highland,Tibet

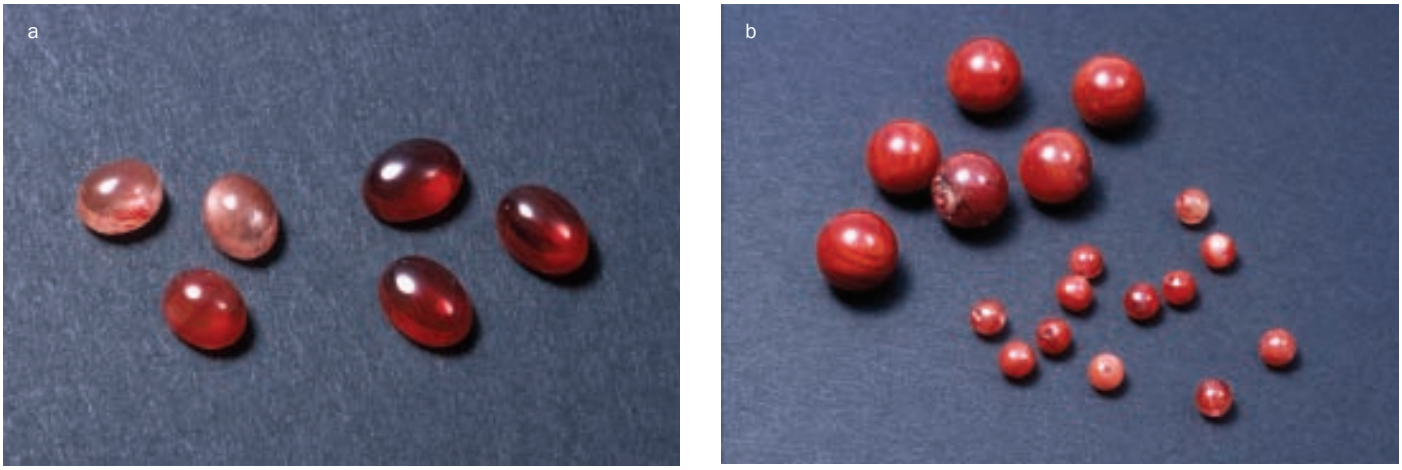

Figure 10: The Tibetan rough andesine is fashioned as cabochons (a) and beads (b) in China depending on its colour and transparency. Photo by M. Kobayashi. Courtesy of M.P. Gem Corp.

2. SHIMATSU Prestige-2000 spectrometer to record the 5000–400 cm^{-1} infrared range with a resolution of 4 cm^{-1}, operating in reflectance mode by a diffuse reflectance accessory, all samples were measured.
3. X-ray powder diffraction measurements were then carried out on ten samples from the Bainang region (TB-XRD-001-010), to calculate the lattice parameters of the andesine. Data collection was made using a Shimatsu LabX XRD-6000 X-ray powder diffractometer, using CuKα radiation (λ=1.5406Å) and a beam of 40 kV, 30 mA. Diffraction data were collected over 3–70°2θ, with steps of 0.02°2θ, and a counting time of 1 sec/step. This has enabled the lattice (unit cell) parameters to be calculated by the least-squares method using the CELLCalc software.
4. Chemical compositions of ten samples (TB-CH-R001-002 in deep red, TB-CH-OR001-004 in orange-red, TB-CH-RO001-003 reddish orange and TB-CH-RG001 bicoloured red-green) were obtained by electron probe microanalysis (EPMA) using a JEOL-8500 fitted with wavelength dispersive spectrometers (WDS), and using an accelerating voltage of 15 kV, a current of 7 nA, and counting times of 20 sec on peaks and 5 sec on backgrounds. Natural albite ($NaAlSi_3O_8$) for Na and Si, orthoclase ($KAlSi_3O_8$) for Al and K, wollastonite ($CaSiO_3$) for Ca, hematite (Fe_2O_3) for Fe, synthetic tenorite (CuO) for Cu and synthetic ($SrTiO_3$) for Sr were used as standards.
5. LA-ICP-MS trace element analyses of 56 samples (6 red TB-CH-R001-006, 30 orange-red TB-CH-OR001-030, 15 reddish-orange TB-CH-RO001-015, and 5 bicolour red-green TB-CH-RG001-005) were obtained using the laser ablation system NEWWAVE research UP-213 attached to an Inductively Coupled Plasma Mass Spectrometer (ICP-MS) Agilent 7500a series. Operating conditions were set as; 10 Hz repetition rate, 80 µm spot diameter, 25 second laser dwell time. Three spots were ablated on each sample. Calibration was done using NIST SRM 610, 612 multi-element glass as external element standard, with Al as the internal

Table I: Properties of gem–quality Tibetan andesine.

Colour	brownish-red, reddish-orange, orange-red and deep red bicoloured; red-green, red-colourless
Appearance	elongate habit with rounded faces, some cleavage surfaces, surface etching, melted glassy surface, transparent and translucent
RI	α=1.550–1.551, β=1.555–1.556, γ=1.560–1.561
Birefringence	0.009–0.010
Optic sign	biaxial positive
SG	2.67–2.72
Pleochroism	weak
UV fluorescence	
long-wave	weak chalky orange
short-wave	dark red or inert
Chelsea Colour Filter	red
Spectroscope	broad absorption at 560 , very weak band at 630 nm
Internal characters	twin lamellae, lath-like hollow channels, pipe-like growth tubes, irregular dislocations, irregular colour patches, turbid milky granular clouds, fissures, discoid fractures, cleavage cracks, gas bubbles, negative crystals, tiny native-copper colloidal grains or platelets
Lattice parameters	a_0=8.161-8.193(26) Å, b_0=12.849-12.919(16) Å, c_0=7.105-7.126(14) Å, α=93.26˚-93.74˚, β=116.27˚-116.38˚, γ=89.93˚-90.16˚.

Figure 11: A pile of andesine rough (behind) collected from the Bainang mine in Tibet. These untreated rough materials of various colours (2.4–34.42 ct), are rounded and have a water-worn appearance. Parallel 'windows' were polished on two sides of each crystal to enable thorough examination. Cut samples (3.52–4.95 ct) in the foreground were supplied by M. P. Gem Corp., Japan. Photo by M. Kobayashi.

standard element based on an average Al_2O_3 concentration of 27.7 % (Al, 14.7 wt.%) which was determined by EPMA.

6. The nanostructure analysis of one sample (TB-TEM-001) was carried out using a high-voltage and high resolution transmission electron microscope (TEM), JEM-3200FSK, operated at 300 kV.

Characteristics of the Tibetan andesine

After cleaning with acetone and aqua regia in an ultrasonic bath, most rough andesine crystals exhibit a highly saturated body colour, ranging from brownish-red, through reddish-orange, orange-red to deep red. Bicoloured stones, green in the centre surrounded by a red rim, are very rare; the sharp boundary of green and red can be seen in *Figure 12a–d*. Most stones also have colourless zones that reach the crystal surface. The transparency of a crystal depends on the content and concentration of inclusions. None of the samples exhibit a good pinacoidal crystal form but have a water-worn appearance, generally elongated with rounded faces, a few with broken cleavage surfaces, some andesines also have embayed areas that appear to have been created by chemical etching and some areas show a melted glassy surface *(Figure 12e)*.

Refractive indices and specific gravities of all Tibetan samples fall in the range for plagioclase feldspar; α=1.550–1.551, β=1.555–1.556, γ=1.560–1.561, and are consistent with the variety andesine ($An_{30–50}$); their birefringence is 0.009–0.010 and optic sign is biaxial positive. The SG was determined with a hydrostatic balance and ranges from 2.67–2.72. Pleochroism is weak. The andesines are weak chalky orange under long-wave UV, and dark red or inert under short-wave UV radiation. Under a Chelsea Colour Filter the andesine remains red. The gemmological properties of the Tibetan samples are summarized in *Table I*. Some red stones have a green hue on a white board in diffused light, and a red-green pleochroic stone appears red in white incident light.

Examination with a gemmological microscope revealed that most of the Tibetan samples contain prominent twin lamellae, parallel lath-like hollow channels and pipe-like tubes which are arranged

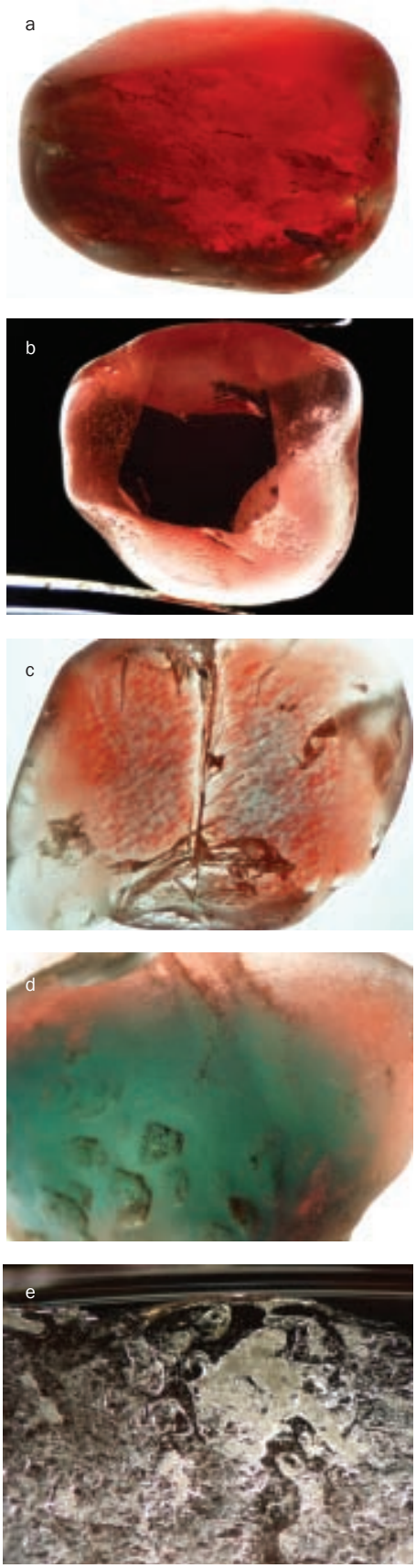

Figure 12: (a-d) Colours typical of Tibetan andesine water-worn crystals. (e) Surface etching and melted glassy surface of a Tibetan andesine crystal. Photos by A. Abduriyim; magnified 20×.

The characteristics of red andesine from the Himalaya Highland, Tibet

Figure 13: Characteristic inclusions in Tibetan andesine are (a) twin lamellae, (b) parallel lath-like hollow channels filled with a white solid substance, (c) dense concentrations of pipe-like growth tubes which are parallel to [010], (d) distinctive irregular dislocations, (e) concentrated turbid or milky uneven orange-red clouds composed of tiny granules, (f) leaf-like discoid fractures, cleavage cracks, gas bubbles and negative crystals, and (g) highly reflective small native-copper grains or platelets. Photomicrographs by A. Abduriyim; magnified 20–25×.

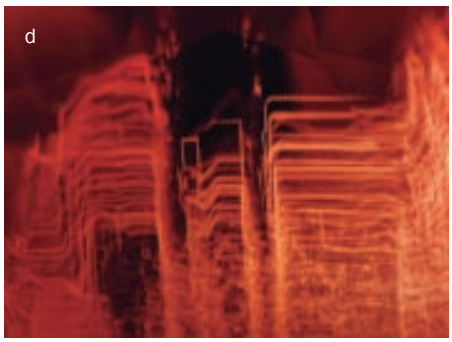

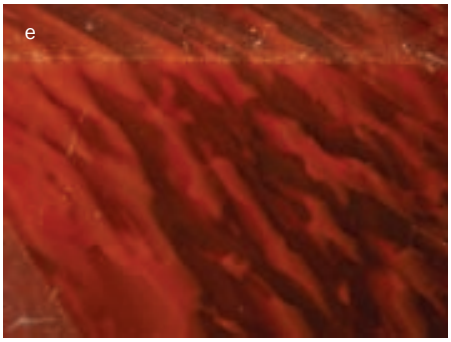

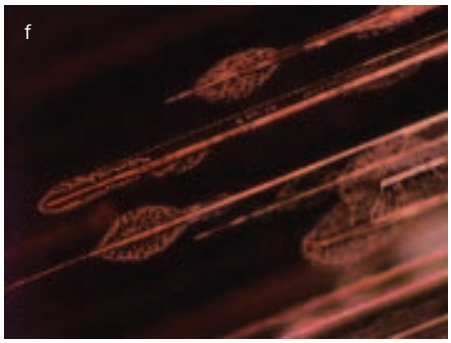

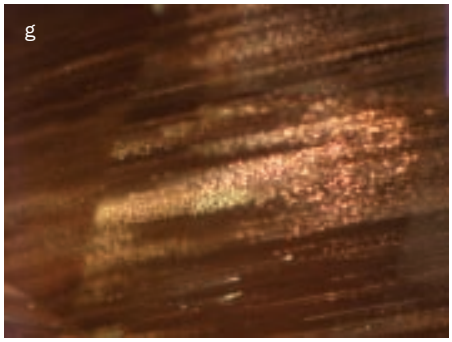

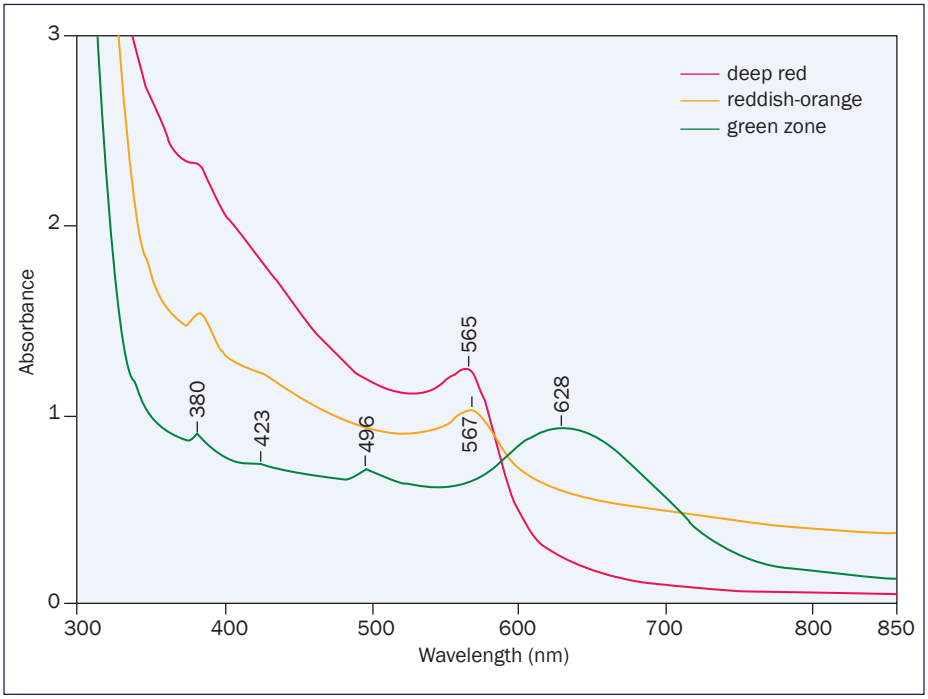

Figure 14: Polarized UV-Vis-NIR absorption spectra measured in the [010] direction (parallel to b axis) of representative reddish-orange, deep-red and bicoloured red-green Tibetan andesine. Reddish-orange and deep-red crystals show absorption bands at 565–567 nm attributed to colloidal copper (Cu^0), as well as weak absorptions near 423 and 380 nm due to Fe^{3+}. The absorption spectrum of a green zone in a bicoloured red-green crystal shows combination absorptions of 628, 496, 423 and 380 nm; strong absorption at 628 nm is attributed to Cu^0-Cu^+ and/or the size and shape of native copper particles.

parallel to the [010] direction *(Figure 13a, b* and *c)*, irregular dislocations *(Figure 13d)*, and irregular colour patches caused by milky turbidity from fine granular inclusions *(Figure 13e)*, fissures, discoid fractures, cleavage cracks, gas bubbles and negative crystals *(Figure 13f)*. One sample displayed reddish aventurescence caused by colloidal native-copper grains or platelets *(Figure 13g)*.

Absorption spectra of three typical colours of Tibetan andesine are shown in *Figure 14*. The deep-red andesine exhibits increasing absorption from 320 nm toward shorter wavelengths and a prominent broad band near 565 nm. In the reddish-orange sample, the absorption is shifted to 567 nm. A weak peak near 380 nm and a very weak peak 423 nm were detected in all samples, but some samples also showed a very weak peak at 450 nm. Spectra obtained in the near-infrared region (800–2500 nm) show a strong broad absorption peak centred near 1260 nm (not shown). Green andesine shows weak absorptions at 380, 423, 450 and 496, and a very strong broad absorption centred at 628 nm (see again, *Figure 14*). Like the red andesine, a strong and broad absorption is also present near 1260 nm.

No OH- or H_2O-related absorptions in the range of 2800–3700 cm^{-1} in the infrared spectra were detected in most of the samples, but some samples showed a small broad absorption band in the range 3000–3500 cm^{-1} in some crystal orientations *(Figure 15)*.

X-ray powder diffractograms of Tibetan andesine indicate a high-temperature disordered structure (see *Figure 16* and discussion below). Lattice parameters were calculated in ten samples as; a_0=8.161–8.193(26) Å, b_0=12.849—12.919(16) Å, c_0=7.105–7.126(14) Å, α=93.26°–93.74°, β=116.27°–116.38°, γ=89.93°–90.16°.

Electron probe microanalysis (EPMA) of ten samples, TB-CH-R001-002 (deep red), TB-CH-OR001-004 (orange-red), TB-CH-RO001-003 (reddish orange) and TB-CH-RG001 (bicoloured red-green) indicated compositions listed in *Table II*. Major amounts of Si, Al, Ca and Na were measured and there are minor contents of K, Fe, Cu and Sr. No significant difference in copper content was detected between red and green zones in the andesines. From the atomic proportions the ratio of albite:anorthite:orthoclase is calculated as $Ab_{46.96–49.79}$:$An_{46.72–49.94}$:$Or_{3.03–3.50}$, and the chemical formula as $(K_{0.03}Na_{0.46–0.49})_2Ca_{0.46–0.49}Al_{1.43–1.48}Si_{2.51–2.53}O_8$ *(Figure 17)*.

The major, minor and trace elements of 56 samples analyzed by LA-ICP-MS are summarized in *Table III*. The major elements Al, Si and Ca and minor element Na were converted to oxide weight percent values for comparison with EPMA

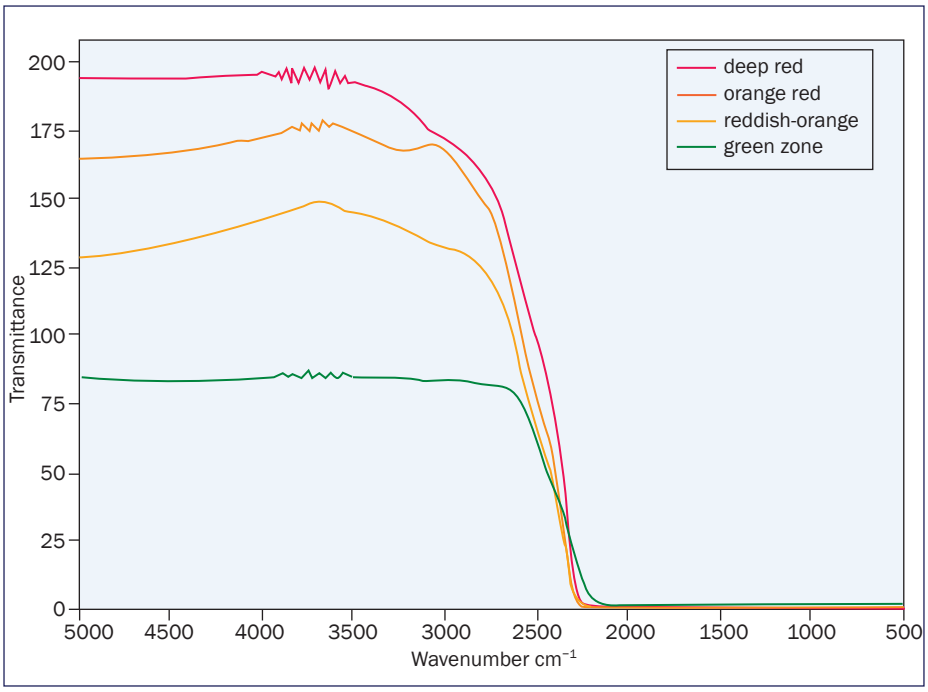

Figure 15: Representative infrared spectra of natural orange-red, reddish-orange, deep-red and bicoloured red-green Tibetan andesine from Baining.

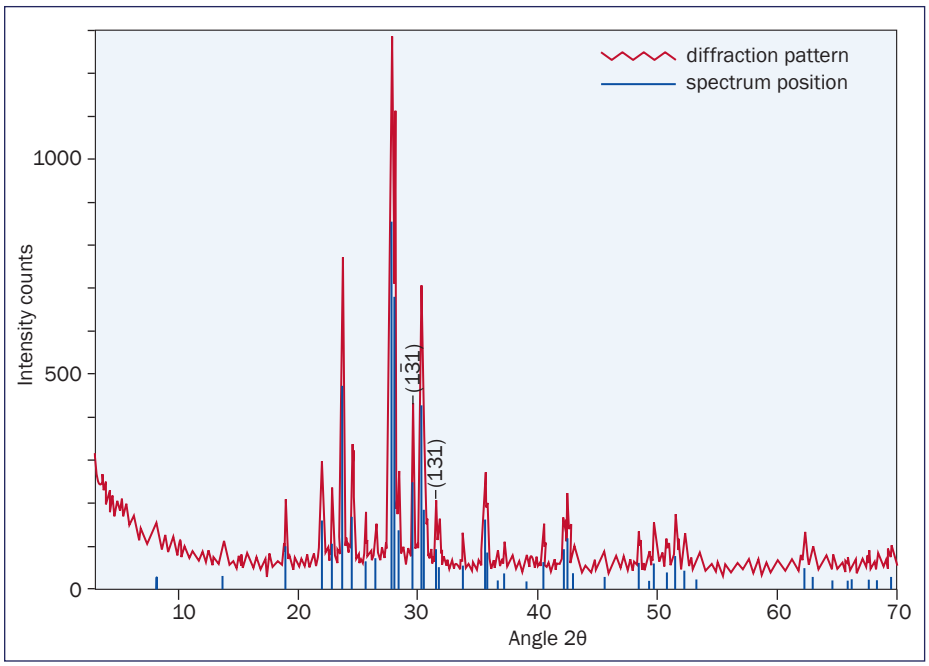

Figure 16: The X-ray powder diffraction pattern (3–70°) of Tibetan andesine from Bainang mine taken with CuKα radiation. (1$\bar{3}$1) and (131) face indices in degrees 2θ are indicated.

The characteristics of red andesine from the Himalaya Highland, Tibet

Table II: Compositions of ten andesines from Bainang, Tibet.

Weight %	Deep-red TB-CH-R001–002	Orange red TB-CH-OR001–004	Reddish-orange TB-CH-RO001–003	Bicoloured TB-CH-RG001	
				red zone	green zone
Na_2O	5.49–5.56	5.29–5.52	5.50–5.61	5.54	5.53
Al_2O_3	27.49–27.51	27.55–27.75	26.97–27.19	27.86	27.75
SiO_2	55.90–55.92	55.80–55.99	56.54–56.72	55.5	55.65
K_2O	0.52–0.56	0.53–0.56	0.59–0.6	0.54	0.56
CaO	9.85–9.87	9.84–10.18	9.53–9.64	10	9.99
FeO	0.39–0.40	0.29–0.34	0.36–0.41	0.3	0.31
CuO	0.08–0.14	0.05–0.11	0.04–0.1	0.11	0.1
SrO	0.15–0.17	0.10–0.13	0.09–0.11	0.15	0.12
Atom					
Na	0.48	0.46–0.48	0.48–0.49	0.48	0.48
Al	1.48	1.46–1.47	1.43–1.44	1.48	1.48
Si	2.52	2.52–2.53	2.54–2.55	2.51	2.51
K	0.03	0.03	0.03	0.03	0.03
Ca	0.48	0.48–0.49	0.46	0.48	0.48
Fe	0.01	0.01	0.01	0.01	0.01
Cu	0	0	0	0	0
Sr	0	0	0	0	0
Total	5	4.99–5	4.98–4.99	5	5
Ab-An-Or composition					
Ab	48.59–48.96	46.96–48.73	49.05–49.79	48.5	48.43
An	48.00–48.17	48.01–49.94	46.72–47.47	48.42	48.36
Or	3.03–3.23	3.09–3.26	3.48–3.50	3.09	3.2

NB: EPMA chemical compositional data represent an average of 3–5 analyses per sample, and data show a range of values for a number of samples from each colour variety.

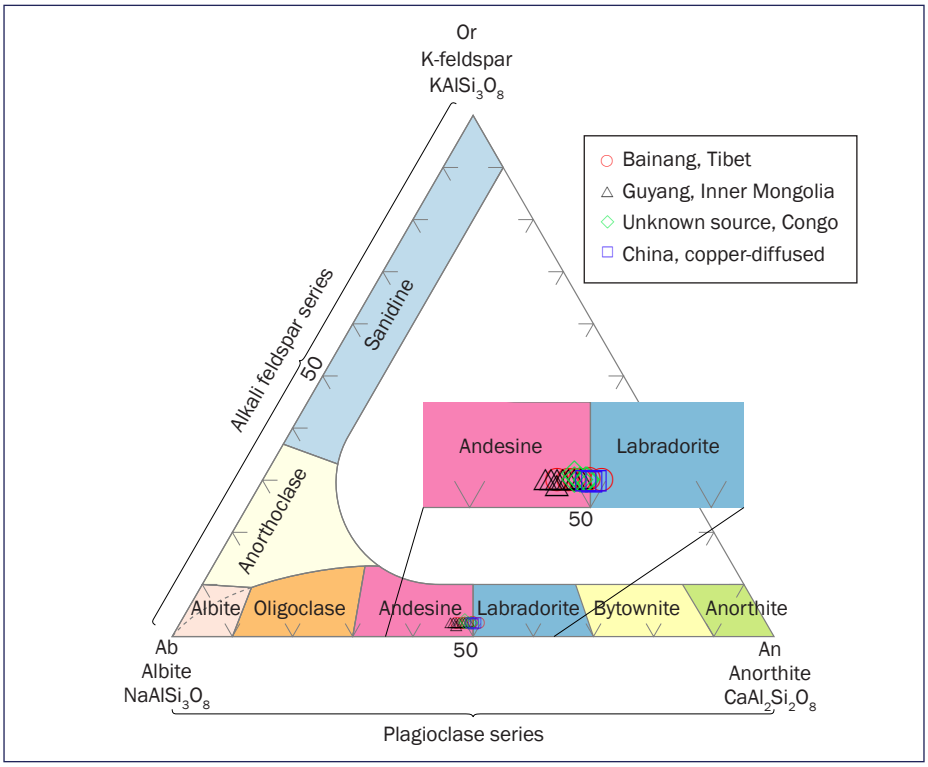

Figure 17: Compositions of Tibetan andesine from Bainang plotted in a ternary diagram of three end members orthoclase (Or), albite (Ab) and anorthite (An). EPMA data of ten samples from samples TB-CH-001 to 010 are indicated by circles. Feldspars from Inner Mongolia (10 samples, pale yellow), Democratic Republic of Congo (five samples, red) and copper-diffused stones from China (seven samples, red) are also plotted for comparison.

Table III: LA-ICP-MS analyses of 56 andesines from Bainang, Tibet.

Colour Sample nos.	Deep-red TB-CH-R001–006	Orange-red TB-CH-OR001–030	Reddish-orange TB-CH-RO001–015	Bicoloured crystals TB-CH-RG001–005	
				red zone	green zone
Major elements (ppm by weight)					
Na	38175–38341	37072–38222	38104–39650	36882–38320	36551–38780
Al	147000	147000	147000	147000	147000
Si	269637–271204	272301–280167	287513–291800	264540–280167	260740–283510
Ca	64900-69807	64756–70451	63174–68045	64956–71934	64900–71425
Trace elements					
Li	40–68	27–60	30–50	9–60	9–58
Mg	450–580	440–550	410–560	440–560	455–550
K	2230–4220	2340–3160	2280–3330	2320–3570	2390–3430
Sc	0.5–12	4–15	4–10	0.8–10	1–8
Ti	440–520	382–508	379–508	440–485	430–495
Mn	30–35	28–38	29–36	27–35	28–34
Fe	1000–3310	1969–2350	1891–2680	2010–4140	2030–4230
Cu	380–630	382–490	313–410	271–445	256–430
Ga	20–28	15–30	18–27	21–27	23–29
Sr	820–1000	756–960	761–950	807–970	792–960
Ba	100–150	99–140	104–143	117–143	116–147

NB: For LA-ICP-MS, external standard was NIST SRM 610, 612, internal standard was 27.7 wt.% Al_2O_3 (14.7 wt.% Al).
The values for each trace element are averages of three spots per sample, but not from the same position as the EPMA analysis. S, F, Cl were not measured in this study.
Operating conditions: Radio frequency power 1500w, Ablated particles and gas were carried to ICP by He gas at a rate of 1.0L/min, Nebulizer Ar gas flow 1.20L/min, Pulse frequency 10Hz, Laser spot 80 µm diameter, laser power 80%, Ablation time 25 sec.

data. The trace elements present are K (2230–4220 ppm), Fe (1000–4230 ppm), Sr (756–1000 ppm), Mg (410–580 ppm), Ti (379–520 ppm), Cu (270–630 ppm), Ba (99–150 ppm), Mn (27–38 ppm), Ga (15–30 ppm), Li (9–68 ppm) and Sc (0.5–15 ppm); B, V, Cr, Zn and Ce are <5.5 ppm each, and Be, Co, Ni, Ge, Rb, La, Pr, Nd, Eu, Gd and Pb occur in amounts less than 1.5 ppm or below the detection limits. The Cu contents tend to be higher in the redder colour zones.

Identification and discussion

The andesines from Bainang mine in Tibet show a RI range of 1.550–1.561 with birefringence 0.009, consistent with published values. These RI values overlap those of Inner Mongolian andesines from the Shuiquan and Haibozi mines in Guyang prefecture, China (Abduriyim, 2008), but are significantly lower than those of labradorite from Oregon, USA, and Chihuahua, Mexico. In addition the inclusions in the Tibetan material such as the parallel lath-like hollow channels, pipe-like tubes, irregular dislocations and milky clouds, are also features enabling distinction from Oregon red labradorite. The native-copper grains in Tibetan material which cause some aventurescence are less extensive and smaller than those in the Oregon feldspars. However, similar inclusions have been reported in red and green labradorite from the Democratic Republic of Congo (Krzemnicki, 2004) but the source is unspecified. In our recent studies of copper-diffused red andesine, material from Inner Mongolia that featured a pipe and tube-like structure, discoid fractures, recrystallized white residue filling the lath-like hollow channels and cloud inclusions, had been used for treatment in China. These inclusions resemble those in the Tibetan andesines *(Figure 18)* and may indicate that they were subject to a thermal event before eruption.

Recently, an experimental study has proved the viability of copper diffusion-treating such material (Roskin, 2008; Emmett and Douthit, 2009).

The depth of colour in Tibetan red andesine correlates with the concentration of copper. The highest content reaches 630 ppm Cu in deep-red andesine, whereas the reddish-orange variety only contains about 300 ppm. The absorption peak near 565 nm is caused by small particles of metallic copper (Cu^0) which are colloidal and less than 200 nm across according to data from a TEM *(Figure 19)*. In the spectra, there are also several weak bands at 380 nm, 423 nm and 450 nm, due to Fe^{3+} and a broad absorption band centred at 1260 nm due to Fe^{2+}. This suggests that both Fe^{3+} and Fe^{2+} should be assigned to tetrahedral sites in the plagioclase structure.

Figure 18: (a) Copper-diffused rough andesine crystals from China. (b–g) Sections of a copper-diffused andesine: an induced orange-red colour layer penetrates from the rim towards the core (b), but a colourless zone remains at the surface of the stone; red pipe-tubes, discontinuous lath-like hollow channels, a pipe and tube-like structure, irregular dislocations, milky turbid cloud, discoid fractures, and a recrystallized white residue can be seen in one treated stone. These features resemble Tibetan untreated andesine. Photos by A. Abduriyim; magnified 20–25x.

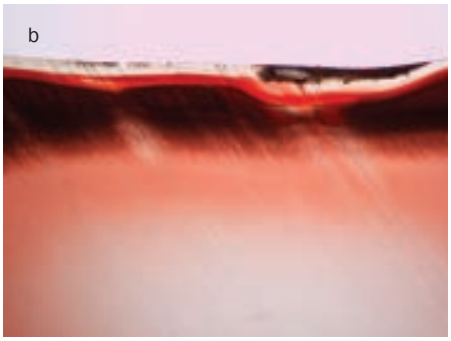

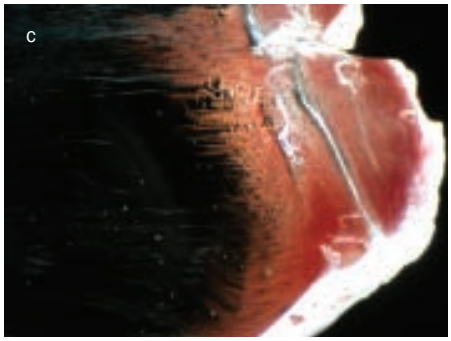

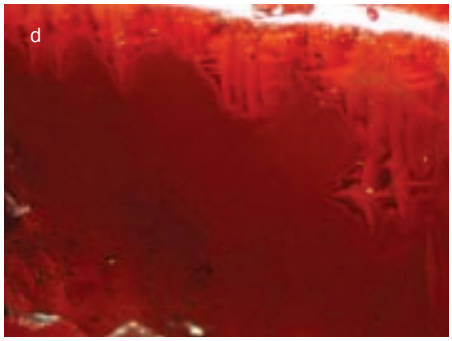

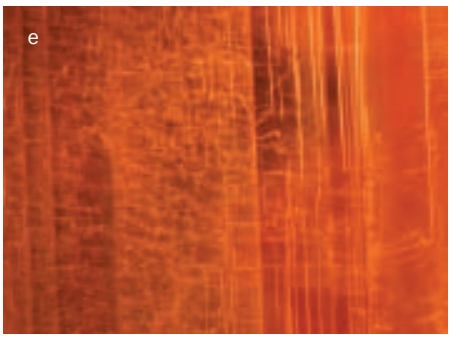

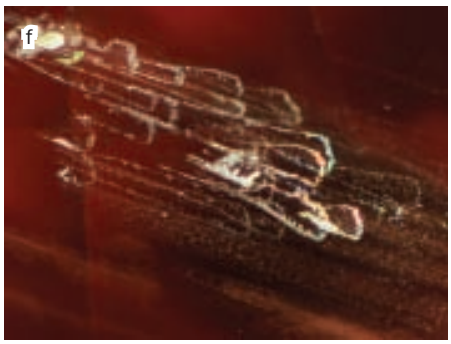

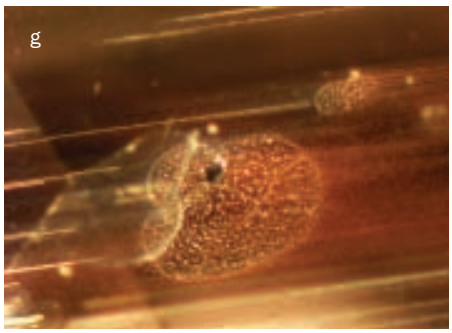

On the other hand, the green zones in bicoloured stones show a broad absorption near 628 nm, produced by Cu^0–Cu^+ intervalence charge transfer. This model also explains the green colour of labradorite from Oregon and Congo (Hofmeister and Rossman, 1985; Krzemnicki, 2004). However, Nishida and Kimata (2002) have attributed the red and green coloration to the shape and size of the copper particles. When a dominant green has an added red component, the peak at 628 nm decreases. A weak absorption band at 496 nm has so far only been found in Tibetan green andesine; this may be related to iron, as there is a slightly higher content of iron in the green zone compared to that in the red zone (2510 vs. 2420 ppm).

The detailed chemical study by EPMA showed that the feldspars from Tibet are poor in potassium and belong to the plagioclase series. The calculations of An and Ab proportions indicate a small range either side of the 50:50 Ab:An ratio, i.e. the stones fall into the high-Ca part of the andesine field in the ternary diagram and the low-Ca part of the labradorite field *(Figure 17)*. Tibetan material can therefore be said to be largely calcic-andesine but with a small amount of sodic-labradorite. Similar analyses of our mine collection of ten pieces of pale yellow andesine from Inner Mongolia, seven copper-diffused stones from China and five red stones from the Democratic Republic of Congo indicate a complete overlap with the Tibetan materials, very close to the boundary of andesine and labradorite, but not actually falling into the labradorite field. Stones from these three localities cannot be separated on the basis of chemical mapping.

Trace elements in the Tibetan andesines were discussed above, and one

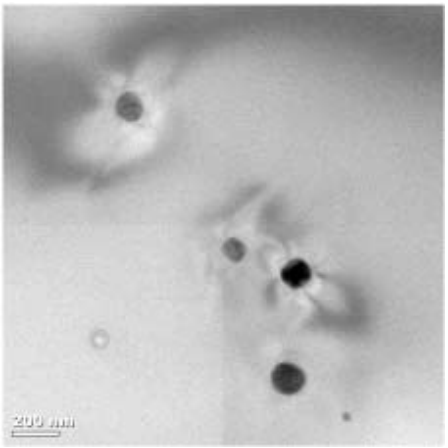

Figure 19: TEM image of round native copper grains in Tibetan red andesine. Photo by S.Toh, Kyushu University, Japan.

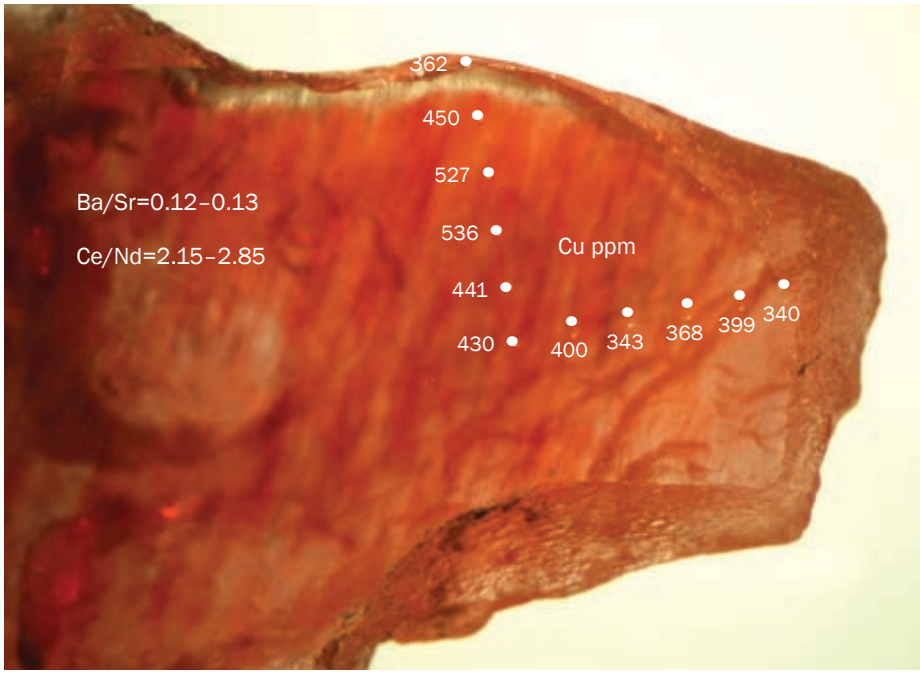

Figure 20: Two compositional traverses showing copper contents from rim to interior of an andesine crystal (TB-CH-001). The ranges of ratios Ba/Sr and Ce/Nd are also provided.

may add that the ratio of Ba/Sr and Ce/Nd in all the samples was rather constant, 0.12–0.13 and 2.15–2.85, respectively *(Figure 20)*. This chemical homogeneity is consistent with the possibility that these plagioclases were formed from a single parent magma.

Recent analyses of 40 andesines from Inner Mongolia, 5 andesines reportedly from the Democratic Republic of Congo and 13 of Cu-diffused andesines from China have shown trace element contents similar to those in Tibetan stones, but the Li content of Inner Mongolian pale yellow stones and of the Chinese Cu-diffused red stones was lower and Ba was higher. To evaluate the usefulness of chemical data for separating the andesine from these localities, the ratios Ba/Sr and Ba/Li were plotted and are shown in *Figure 21*. Tibetan red andesines have ratios of Ba/Li<9 and Ba/Sr ratios of 0.11–0.18, but bicoloured crystals tend to have lower Li contents and two samples showed a relatively high ratio of Ba/Li up to 12. The Inner Mongolian pale yellow andesines are characterized by Ba/Li ratios of >11 and a more limited range of Ba/Sr of 0.14–0.18. Most of these andesines can be clearly differentiated from Tibetan stones on this basis. The Congo andesines show a distinct variation in their Ba/Li ratio. Three have ratios similar to those of Inner Mongolian stones, but two are similar to Tibetan stones. However, these ratios in the 13 copper-diffused samples do not lead to clear conclusions about provenance and further work is needed.

In 1979, Trevena and Nash presented the compositions of hundreds of detrital plagioclases from various arkosic sandstones plotted on an An-Ab-Or ternary diagram and they defined seven provenance groups; volcanic, plutonic, metamorphic, volcanic and plutonic, volcanic and granophyric, plutonic and metamorphic, and plutonic, metamorphic and authigenic *(Figure 22)*. According to this diagram, the K_2O in plagioclase generally decreases from volcanic through plutonic to metamorphic

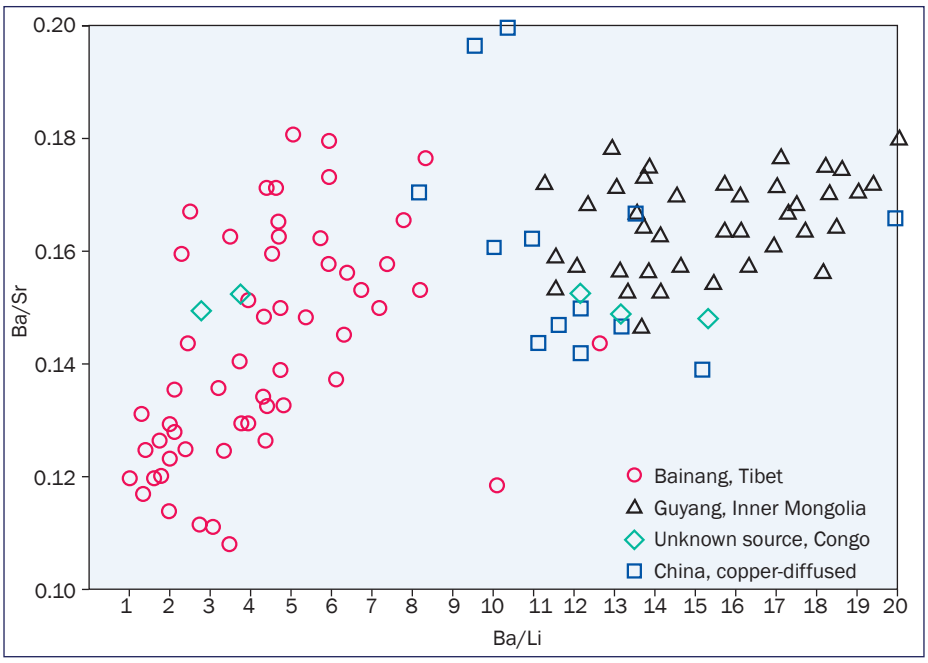

Figure 21: In this diagram, Ba/Sr and Ba/Li ratios obtained from LA-ICP-MS analyses of 56 samples from Tibet, 40 samples from Inner Mongolia, 13 copper-diffused samples from China and five samples from Democratic republic of Congo are shown. Most Tibetan andesine has low Ba/Li values and has a wide range of Ba/Sr. The Inner Mongolian andesine shows relatively high Ba/Li that enables distinction from Tibetan andesines.

The characteristics of red andesine from the Himalaya Highland,Tibet

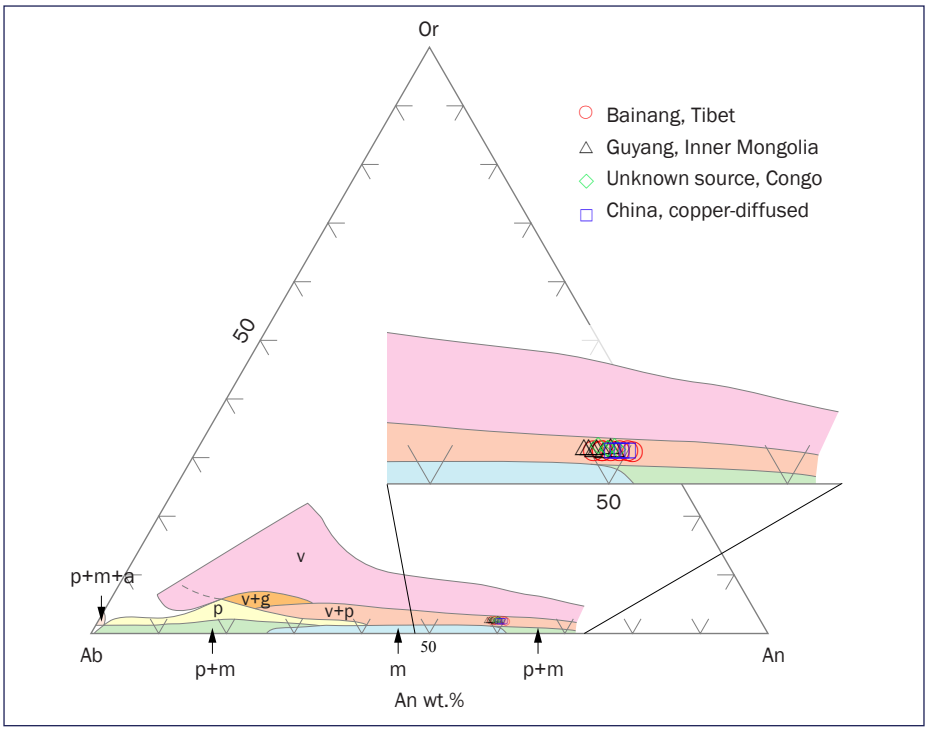

Figure 22: Plagioclase ternary diagram showing compositions of seven provenance groups: v=volcanic, p=plutonic, m=metamorphic, v+g=volcanic+granophyre, v+p=volcanic+plutonic, p+m=plutonic+metamorphic, p+m+a=plutonic+metamorphic+authigenic. Compositions of ten samples of Tibetan and Inner Mongolian andesine, seven copper-diffused samples from China and five samples of Congo andesine (wt.%) analysed by EPMA lie in the v+p field.

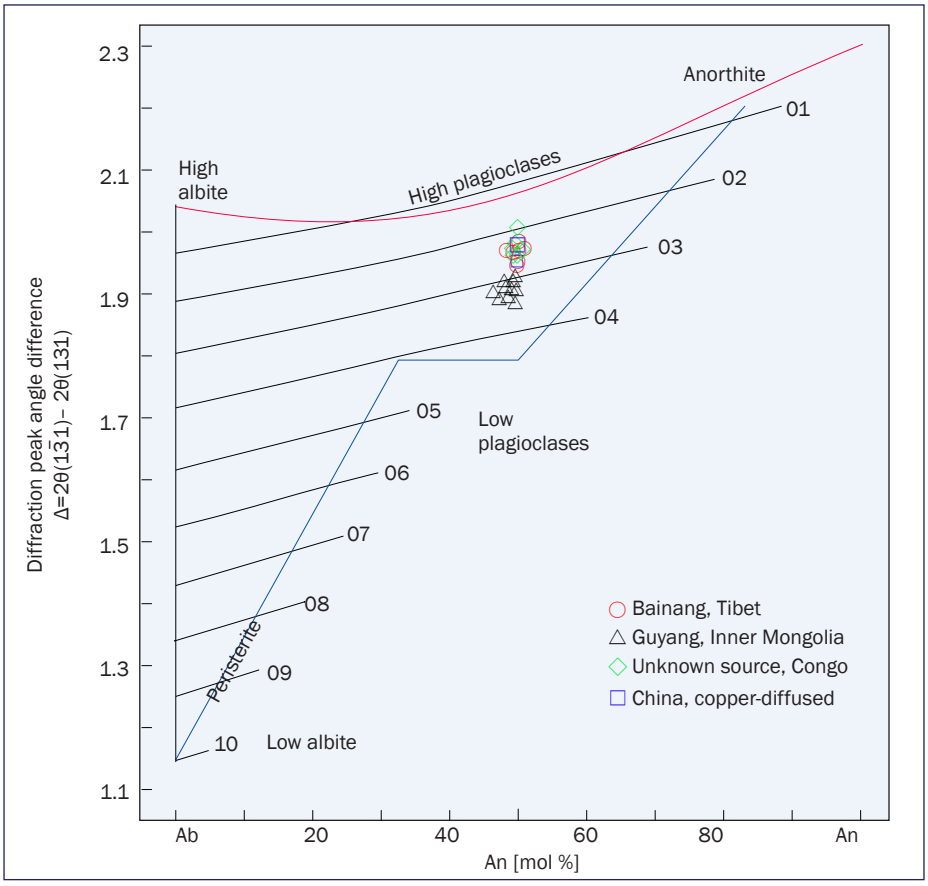

Figure 23: Diagram showing degree of ordering of Al in the plagioclase structure by means of contours 10 to 01 from low to high albite and anorthite. Andesines from Tibet, Mongolia and Congo are plotted. See text for discussion.

parageneses. Compositions of detrital plagioclase feldspar samples from Tertiary sedimentary deposits in Tibet are shown in part of the volcanic or plutonic field. The Tibetan material appears to consist almost entirely of plagioclase that is volcanic in origin.

Temperature is the most important factor that influences the degree of ordering of Al/Si in feldspar. Smith and Yoder (1956) introduced a simple method, based on measurement of the spacing between the (1$\bar{3}$1) and (131) peaks of the X-ray power diffraction pattern, to estimate the differences of Al content in four non-equivalent tetrahedral sites: $T_1(o)$ and $\{T_1(m), T_2(o), T_2(m)\}$. In 1980, Kroll and Ribbe used the parameter of $\Delta=2\theta(1\bar{3}1) - 2\theta(131)$ and the lattice angle parameter γ, combined with the anorthite (An) content of plagioclase to determine the Al/Si distribution among the four tetrahedral sites in the plagioclase structure. This study mentioned that the γ plot gives more precise results for plagioclase. On the other hand, the well-known method of $\Delta=2\theta(1\bar{3}1) - 2\theta(131)$ can be used somewhat less precisely to determine structural states, but the value of Δ is comparable from one sample to the next.

In studies of synthetic plagioclase, Eberhard (1967) and Smith (1972) examined the relationship between formation temperature and the parameter $\Delta=2\theta(1\bar{3}1) - 2\theta(131)$. They presented a model in which Δ was plotted against An content and contours were drawn of the different degrees of Al/Si ordering in the tetrahedral sites of the feldspar structure (01–10 in *Figure 23*). Our TEM observations of the microstructure of Tibetan and Inner Mongolian andesines confirmed that they do not include any complex exsolution lamellae, which means that accurate measurement of 2θ{131} can be obtained from a homogeneous matrix of feldspar by X-ray powder diffraction. The X-ray power diffraction data for ten Tibetan andesines gave values of Δ=1.9539–1.9668, and of γ, values of 89.93°–90.16°. The range of values measured for Δ indicate the degree of Al/Si ordering of 0.24–0.29 in *Figure 23*, and for γ the Al/Si degree of ordering

indicated is 0.22–0.28 *(Figure 24),* which indicates that 22–29% of aluminium moves into the tetrahedral site T_1 (o) from T_1 (m), T_2 (o), and T_2 (m). From a plot of the Δ data for Tibetan andesines, we estimate that the temperature at which this degree of Al/Si ordering is stable is about 800°C, consistent with temperatures in a volcanic environment at high crustal level *(Figure 25).* The ten samples of pale yellow andesine from Inner Mongolia have values of Δ=1.9161–1.9487, and γ= 89.69°– 89.83°, an Al/Si degree of ordering range of 0.32–0.36, and lattice angle γ values of 0.30–0.38, which indicates that the Inner Mongolian feldspar is more structurally ordered on the tetrahedral site and that it probably formed close to 700°C (see again, *Figures 23, 24* and *25*). Our data are closely comparable with those from a recent study of andesine from Inner Mongolia by Dong *et al.,* 2009. Our more recent work on seven samples of copper-diffused red andesine gave values of Δ=1.9595–2.0095 and γ= 89.83°–90.22°, and two Congolese samples gave Δ=1.9574–1.9729 and γ= 89.99°– 90.16°. These points lie in fields that almost completely overlap those of the Tibetan red andesines, so these parameters are not discriminatory.

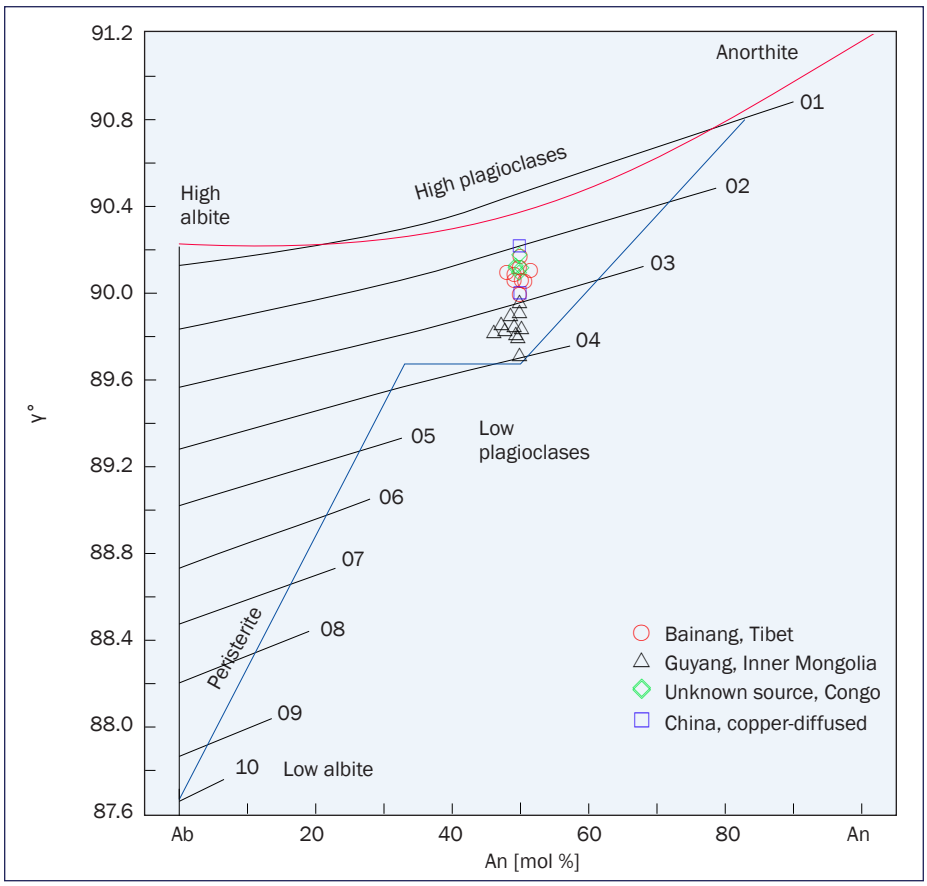

Figure 24: A diagram of lattice angle parameter γ (in degrees) as a function of anorthite in mole percent for low, high and intermediate structural states. Contours indicate the degree of ordering of Al in tetrahedral sites T_1(o)-T_1(m). These γ values of andesines from Tibet, Inner Mongolia and Congo, and of the copper-diffused China samples indicate similar degrees of order as does the parameter Δ=2θ(1$\bar{3}$1) – 2θ(131) (Figure 22).

Conclusions

The Bainang mine south-east of Xigazê in Tibet, is located in a volcanic-sedimentary deposit and produces gem-quality orange-red andesine feldspar. Simple hand-tool mining by local people currently yields several hundred kilograms of rough per year. Mining using heavy machinery could increase the productivity. Several new deposits have been discovered recently in Tibet in areas other than Bainang that produce andesine with such saturated colours (T. Li, pers. comm., 2009).

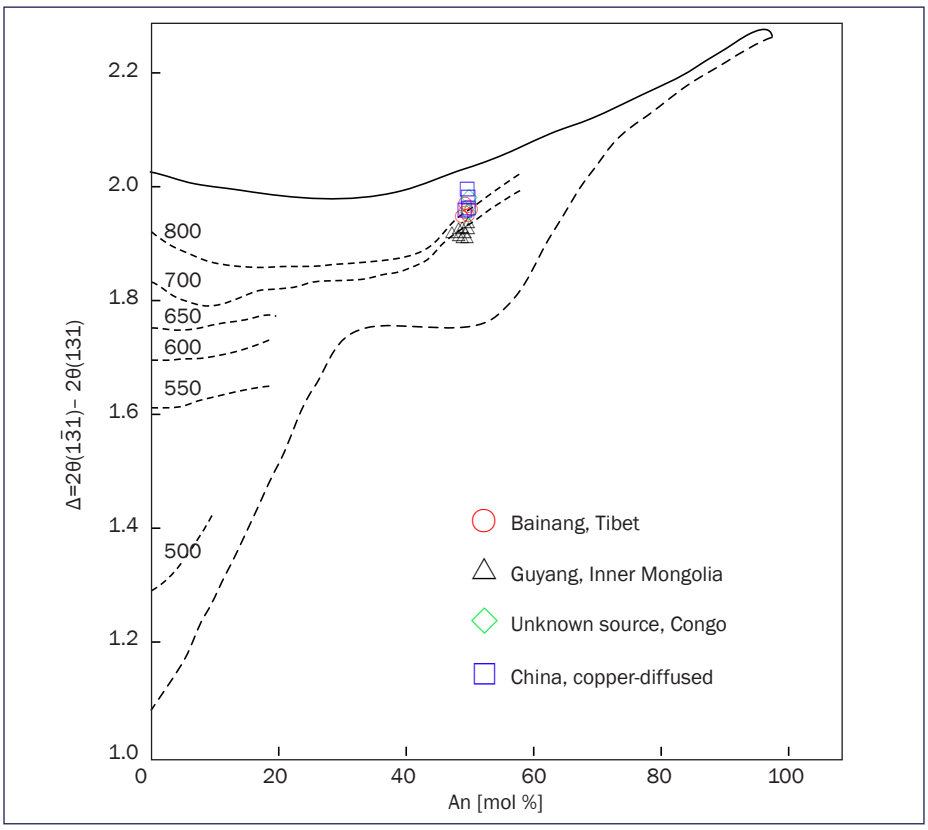

Figure 25: Shown is a plot of the parameter Δ=2θ(1$\bar{3}$1) – 2θ(131) versus An composition for various formation temperature isotherms for plagioclase. This provides information about the structural ordering of Al and Si that is produced when different compositions crystallize at various temperatures. The data from Tibetan, Congolese and copper-diffused Chinese andesines indicate that they had a higher formation temperature than Inner Mongolian material.

Gemmological and chemical investigations indicate that the red colour results from clusters of tiny copper particles (Cu^0) and the green colour may result from Cu^0-Cu^+ intervalence charge transfer or from differences in shape and size of the copper particles. RI and SG values and chemical data indicate an andesine composition of $Ab_{46.96–49.79}$:$An_{46.72–49.94}$:$Or_{3.03–3.50}$, i.e. an andesine near the andesine-labradorite border; its chemical formula is $(K_{0.03}Na_{0.46–0.49})_2Ca_{0.46–0.49}Al_{1.43–1.48}Si_{2.51–2.53}O_8$. The lattice parameters are (a_0=8.161–8.193 Å, b_0=12.849–12.919 Å, c_0=7.105–7.126 Å, α=93.26°–93.74°, β=116.27°-116.38°, γ=89.93°–90.16°). The parameter $\Delta=2\theta(1\bar{3}1) – 2\theta(131)$=1.9539–1.9668, calculated from XRD measurements indicates that Tibetan andesine is in a low state of structural order with a value of 0.22–0.29, and that it formed at a minimum of 800°C in a volcanic environment.

Chemical analysis of Cu-bearing Tibetan and non-Cu-bearing Inner Mongolian andesines by EPMA has shown comparable contents of major and minor elements. But trace element analysis using LA-ICP-MS and the plot of Ba/Sr versus Ba/Li has been found useful for distinguishing Cu-bearing andesine from Tibet.

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Abstracts

Diamonds

The SEM and CCL-SEM study of graphitic inclusions in natural brown diamonds.
A.S. Bidny, O.V. Kononov, A.G. Veresov and P.V. Ivannikov. *The Australian Gemmologist,* **23**(3), 2007, 126–30.

Plastic deformation, the supposed cause of colour in brown diamonds, closely parallels the high density of dislocations found in brown type I and type IIa diamonds. Using high-resolution Scanning Electron Microscopy (SEM) and Colour Cathodoluminescence Scanning Electron Microscopy (CCL-SEM) the characteristics of graphite inclusions in natural brown diamonds was researched. Graphite inclusions were found to lie along the {111} plane and of approximately 0.7 µm. Besides graphite, recrystallized micro-figures were visible with trigons on the octahedral surfaces. J.S.

Color variation and properties of johachidolite from Myanmar.
K.M. Chadwick and C.M. Breeding. *Gems & Gemology,* **44**(3), 2009, 246–51.

Various analytical techniques were used to study 15 faceted examples of the rare gem material johachidolite from Myanmar showing a range of colours: saturated orange, orange, yellow, desaturated yellow and desaturated green. Both orange-yellow-hued and green samples showed various trends for Be, U, Th and Pb. Orange/yellow samples also showed relatively constant amounts of REE, though the green samples had higher REE values, particularly for the lighter REE. R.A.H.

'Fluorescence cage': visual identification of HPHT-treated type I diamonds.
I.A. Dobrinets and A.M. Zaitsev. *Gems & Gemology,* **45**(3), 2009, 186–90.

High-pressure/high-temperature diamonds of various colours may exhibit unusually intense fluorescence at the facet edges and junctions. This effect (here named the 'fluorescence cage') is observed with a fluorescence microscope as a luminous network on the surface of the diamond; it is not seen in untreated diamonds or colourless type IIa HPHT-treated diamonds. This fluorescence pattern is considered to result from a high concentration of HPHT-induced optical centres which remain on facet edges after repolishing. R.A.H.

The Wittelsbach Blue.
R. Dröschel, J. Evers and H. Ottomeyere. *Gems & Gemology,* **44**(4), 2008, 348–63.

The 55.56 ct Wittelsbach Blue is one of the largest historic, blue diamonds ever fashioned. Its chequered history is reviewed; it was most recently sold at Christie's in December 2008 to the London jeweller Laurence Graff for £16,393,250 (or just over $683,000 per carat). R.A.H.

The French Blue and the Hope: new data from the discovery of a historical lead cast.
F. Farges, S. Sucher, H. Horovitz and J.-M. Fourcault. *Gems & Gemology,* **45**(1), 2009, 4–19.

Models of a recently discovered lead cast of the French Blue diamond and of the Hope diamond confirm that the latter could have been recut from the French Blue. R.A.H.

Color grading 'C to Z' diamonds at the GIA Laboratory.
J.M. King, R.H. Geurts, A.M. Gilbertson and J.E. Shigley. *Gems & Gemology,* **44**(4), 2008, 296–321.

The use of letter designations for diamond colour grades is virtually universal in the gem and jewellery industry but the use of GIA colour grading standards and procedures is not. The history and ongoing development and application of this grading system is described. Important aspects of this system include a specific colour grading methodology for judging the absence of colour in diamonds, a standard illumination and viewing environment, and the use of colour reference diamonds ('masterstones') for the visual comparison of colour. R.A.H.

Gem News International.
B.M. Laurs (Ed.). *Gems & Gemology,* **45**(3), 2009, 214–32.

A brief description is given of a 1.02 ct greenish-yellow diamond which has had a glass filling and HPHT treatment. R.A.H.

Lab notes.
T.M. Moses and S.F. McClure (Eds). *Gems & Gemology,* **44**(3), 2009, 252–60.

Notes are given on black diamonds coloured by hydrogen clouds and other diamond oddities. R.A.H.

Lab Notes.
T.M. Moses and S.F. McClure (Eds). *Gems & Gemology,* **44**(4), 2008, 364–8.

Notes are given on a 3 ct fancy dark brown-yellow zoned type IIa/IIb diamond and a 0.21 ct CVD synthetic diamond which was found to have been HPHT treated. R.A.H.

Lab notes.
T.M. Moses and S.F. McClure (Eds). *Gems & Gemology,* **45**(1), 2009, 53–8.

Notes include mention of a cut cubic zirconia coated with nanocrystalline synthetic diamond, and of a rare mixed type (Ia/IIb) diamond with nitrogen and boron centres. R.A.H.

Lab Notes.
T.M. Moses and S.F. McClure (Eds). *Gems &*

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Gemology, **45**(2), 2009, 134–40.

Items noted include a 1.79 ct cut bicoloured diamond (near colourless to orangy brown) and a 0.4 ct cut diamond graded as Fancy Black but which showed a deep violet colour when viewed through the pavilion. R.A.H.

Lab Notes.
T.M. Moses and S.F. McClure (Eds). *Gems & Gemology,* **45**(3), 2009, 208–13.

Items noted include a treated 0.28 ct diamond graded as Fancy Red (a very rare colour grade) and a 12.01 ct Fancy Vivid Yellow diamond (type Ib) coloured by isolated nitrogen. R.A.H.

A crystallographic analysis of the Tavernier blue diamond.
S.D. Sucher. *Gems & Gemology,* **45**(3), 2009, 178–85.

By correlating the facets on the Tavernier Blue (the 'grandparent' of the Hope diamond) with the facets of a diamond crystal, information has been obtained on the crystallography of the original rough. By using these data, the original drawings and a computer model of the French Blue diamond generated from a laser scan of a recently discovered lead cast, a computer model of the Tavernier Blue was obtained. This new model completely encloses the computer model of the French Blue, conforms to Tavernier's physical description and establishes the orientation of the finished diamond within the original diamond crystal. R.A.H.

Spectroscopic methods for the identification of natural yellow gem-quality diamonds.
L. Tretriakova. *European Journal of Mineralogy,* **21**(1), 2009, 43–50.

The characteristic spectroscopic features and identification criteria for different types of yellow diamonds are presented, including varieties of naturally occurring yellow diamonds and varieties of artificially produced yellow diamonds. The spectroscopic techniques discussed include infrared spectroscopy, optical absorption spectroscopy and laser-induced photoluminescence spectroscopy. The latter technique is much more sensitive than optical absorption spectroscopy and can excite defects which have very low concentrations in diamonds: examples are given of diamonds with high hydrogen contents or with high nitrogen and low hydrogen. R.A.H.

Gray-to-blue-to-violet hydrogen-rich diamonds from the Argyle mine, Australia.
C.H. van der Bogert, C.P. Smith, T. Hainschwang and S.F. McClure. *Gems & Gemology,* **45**(1), 2009, 20–37.

A study of 20 type IaB hydrogen- and nitrogen-rich grey to blue to violet diamonds from the Argyle mine showed that their unusual colour is the result of broad absorption bands centred at ~ 520–565 and 720–730 nm with a pronounced 551 nm band superimposed on the 520–565 nm feature. The photoluminescence spectra exhibit peaks associated with Ni-related defects which may be important in the more violet diamonds. R.A.H.

Gems and Minerals

Characterization of 'green amber' with infrared and nuclear magnetic resonance spectroscopy.
A. Abduriyim, H. Kimura, Y. Yokoyama, H. Nakazono, M. Wakasuki, T. Shimizu, M. Tansho and S. Ohki. *Gems & Gemology,* **45**(3), 2009, 158–77.

A peridot-like bright greenish yellow to green gem material is produced by treating natural resin (amber or copal) with heat and pressure in two stages in an autoclave. Differences in the molecular structure between the untreated materials and treated 'green amber' were studied by FTIR and ^{13}C NMR, using powdered samples. Regardless of the starting material, the FTIR spectrum of 'green amber' showed an amber pattern but with a characteristic small absorption feature at 820 cm^{-1}. Solid-state ^{13}C NMR of the treated material indicated a significantly lower volatile content than the untreated natural resin. A new absorption feature near 179 ppm in the NMR spectrum of all treated samples distinguished them from their natural-colour counterparts. R.A.H.

Characterization of peridot from Sardinia, Italy.
I. Adamo, R. Bocchio, A. Pavese and L. Prosperi. *Gems & Gemology,* **45**(2), 2009, 130–33.

Olivine-rich nodules in basalts near Pozzomaggiore, NW Sardinia, yield yellowish-green peridot crystals with gem quality potential and have α 1.650–1.652, β 1.669–1.670, γ 1.688–1.690, SG 3.32–3.36. Microprobe results give a composition of $Fo_{91}Fa_{9}$. R.A.H.

Aquamarine, maxixe-type beryl and hydrothermal synthetic blue beryl: analysis and identification.
I. Adamo, A. Pavese, L. Prosperi, V. Diella, D. Ajò, C.D. Gatta and C.P. Smith. *Gems & Gemology,* **44**(3), 2009, 252–60.

An investigation is reported of aquamarine, maxixe-type (irradiated) beryl and two types of hydrothermally grown synthetic beryl, using standard gemmological methods, chemical analysis (microprobe results are reported), UV-Vis-NIR and mid-IR spectroscopy to identify these materials conclusively. The maxixe-type beryl (as for natural colour maxixe beryls) is distinguished by its unusual pleochroism, green UV fluorescence (if present), iron-free chemical composition and distinctive UV-Vis-NIR spectrum. The blue hydrothermal synthetic beryls can be discriminated from their natural equivalents by their microscopic features, chemical composition, and their visible and infrared spectroscopic features. R.A.H.

The Lac d'Amiante mine.
M. Amabili, F. Spertini, M. Auguste and G. Bonin. *Mineralogical Record,* **40**(4), 2009, 297–304.

Fine ornamental green fluorite is described from the Lac d'Amiante mine, in the town of Thetford, Quebec, Canada. M.O'D.

Crystallization of biogenic Ca-carbonate within organo-mineral micro-domains. Structure of the calcite prisms of the Pelecypod *Pinctada margaritifera* (Mollusca) at the submicron to nanometre ranges.
A. Baronnet, J.P. Cuif, Y. Dauphin, B. Farre and J. Nouet. *Mineralogical Magazine,* **72**(2), 2008, 617–26.

Atomic force microscopy (AFM) and TEM were used to investigate the fine structure of calcite prisms from the pearl-oyster shell *Pinctada margaritifera.* The AFM analysis showed that the prisms are made of densely packed circular micro-

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domains (in the 0.1 μm range) surrounded by a dense cortex. The TEM images and diffraction patterns allow the internal structure of the micro-domains to be described: each of them is enriched in Ca-carbonate. Hosted in distinct regions of each prism, some are fully amorphous, and others are fully crystallized as sub-units of a large calcite single crystal. At the border separating the two regions, micro-domains display a crystallized core and an amorphous rim, probably marking out an arrested crystallization front having propagated through a previously bio-controlled architecture of the piling of amorphous micro-domains. Compared to recent data concerning the stepping mode of growth of the calcite prisms and the resulting layered organization at the μm-scale, these results give unexpected views regarding the modalities of biocrystallization. R.A.H.

Aquamarine from the Masino-Bregaglia Massif, Central Alps, Italy.
R. Bocchio, I. Adamo and F. Caucia. *Gems & Gemology,* **45**(3), 2009, 204–7.

Pale, blue-green aquamarine crystals occur in granitic pegmatites of the Masino-Bregaglia massif in the Central Alps of northern Italy. They have yielded three cut and faceted stones, the largest being a 2.33 ct pale greenish-blue aquamarine. An 8.5 ct cabochon is also illustrated. The UV-Vis-NIR and mid-IR absorption spectra are shown, and trace elements determined by LA-ICP-MS are reported for six crystals. R.A.H.

Topaz from near El Chalten, Santa Cruz Province, Agentina.
R. Brandstetter. *Mineralogical Record,* **40**(1), 2009, 1–15.

Topaz of ornamental or even gem quality is described from pegmatite pockets in a remote area of Patagonia, Argentina. Large white crystals of feldspar and milky quartz crystals accompany the topaz. M.O'D.

Edle Topase und Zepterquarze aus Patagonien.
R. Brandstetter. *Lapis,* **34**(5), 2009, 13–24.

Transparent yellow topaz of apparent ornamental quality is described from Patagonia, Argentina, from where sceptre quartz is also reported. M.O'D.

Die Rogerley Mine.
R. Brandstetter. *Lapis,* **35**(1), 2010, 13–26.

Fine, probably transparent, green fluorite crystals are described from the Rogerley mine in the northern Pennine orefield, England. M.O'D.

Fluorite from Riemvasmaak.
B. Cairncross. *Mineralogical Record,* **40**(4), 2009, 307–24.

Fine green ornamental to gem-quality fluorite is described from the Riemvasmaak area of Northern Cape Province, South Africa. M.O'D.

A study on the characteristics of some C- and CT-opals from Brazil.
F. Caucia, C. Ghisoli and I. Adamo. *Neues Jahrbuch für Mineralogie, Abhandlungen,* **185**(3), 2009, 289–96.

The physical properties of blue and fire opals from Piaui State, Brazil, have been determined by optical analyses, specific gravity, X-ray diffraction and IR spectroscopy, with chemical compositions via LA-ICP-MS and SEM-EDS. The values obtained for specific gravity and refractive index are 1.98-2.28 and 1.420-1.461, respectively. The presence of cristobalite is confirmed. Trace amounts of chromophore elements are correlated with variation in colour. The particular 'coral islands' structure, built of micro-spherules of amorphous silica, is observed by SEM analyses, and could explain the particular effects of iridescence shown by some blue specimens. The LA-ICP-MS analyses confirm the presence of Fe as the principal cause of colour in the fire opals (perhaps present as an Fe-oxyhydroxide); only in the darkest specimens is Mn significant. R.A.H.

About mineral collecting. Part 5 of 5.
R. Currier. *Mineralogical Record,* **40**(3), 2009, 193–202.

The author describes the Tucson Gem and Mineral Show and gives advice to prospective exhibitors and visitors. Examples of some classic items are illustrated in colour. M.O'D.

The color durability of 'Chocolate pearls' by Ballerina Pearl Co.
G. Du Toit, A.H. Shen and C.M. Breeding. *Gems & Gemology,* **44**(3), 2009, 234–41.

Seven colour-treated brown Tahitian cultured pearls supplied by the Ballerina Pearl Co. and 12 untreated Tahitian cultured pearls were exposed to typical conditions of customer use (heat, household chemicals, daylight and some typical cosmetics) to determine their effects on the colour. Both groups gave similar largely negative results, but subtle changes were noticed after exposure to heat, with more significant changes observed when the samples were exposed to chemically reactive household cleaning solutions (bleaches). R.A.H.

Zur Flammenstruktur bei einigen porzellanartigen Perlen.
H.A. Hänni, 2009. *Gemmologie. Z. Dt. Gemmol. Ges.,* **58**(1/2), 47–52. 2 photographs, 5 photomicrographs, bibl.

The sheen displayed on nacreous pearls is due to the structure of stacked aragonite tablets in parallel superimposition. Non-nacreous pearls often show a flame structure that is due to a crosswise array of bundles of aragonite laths or fibres. Small bundles alternate in their orientation, so that some light is reflected and some absorbed, producing brighter and darker patches as in a flame structure. This is typical for the porcellaneous lining of marine gastropod shells and some bivalves, and their pearls produced by the same mantle tissue. Some of these bundles can also occasionally produce interference colours. E.S.

Beschädigungen an geschliffenen Edelsteinen.
H.A. Hänni. *Gemmologie. Z. Dt. Gemmol. Ges.,* **58**(3/4), 2009, 91–104. 22 photographs, bibl.

The article deals with the various factors that can influence a gem's durability. These can be caused during mining, manufacture and setting, cleaning or wearing. Damage to diamonds includes damage caused during cutting and setting or use, such as chipped girdle, worn facet edges, or abrasion by rubbing against other diamonds. More marked is damage to other gemstones, especially if in contact with diamonds. Naturally caused damage with time is the expansion of uranium-containing zircon inclusions and uraninite inclusions in sapphires, which can lead to chipping or fractures, especially during

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repairs. During torch repairs diamonds are protected by coating with a borax compound; however, the same compound attacks rubies, sapphire and other gems during soldering. When borax is not used, diamond surfaces can be burned. Soldering can also cause heat stress and fracture in some set stones. An example shows a crater-shaped chip in a diamond caused by a soldering laser shot to a prong. Other examples show damage by removal of the polymer-filler in jade by ultrasonic cleaning and serious etching to peridot from acid cleaning after soldering. E.S.

Das neue Rubinvorkommen von Montepuez, Mosambik.
H.A. Hänni and M.S. Krzemnicki. *Gemmologie. Z. Dt. Gemmol. Ges.,* **58**(3/4), 2009, 127–30. 6 photographs, bibl.

The new deposit is in the north-east of Mozambique and the first faceted stones from there were shown at the Hong Kong autumn Fair 2008. The rubies are found in an amphibolite, a metamorphic rock that also hosts the Winza deposit in Tanzania. Crystal habit is tabular to prismatic. The iron-containing rubies often show twin lamellae, contain minor rutile silk, corroded amphibolite grains, some zircons, fluids and secondary minerals in fissures. E.S.

Mit Kunstharz stabilisierter Seraphinit (Klinochlor).
U. Henn. *Gemmologie. Z. Dt. Gemmol. Ges.,* **57**(3/4), 2008, 143–5. 2 photographs, 1 graph, bibl.

Radial to fibrous aggregates of clinochlore are known in the trade as seraphinite. Material from Korshunovskoye in Siberia has been found to be polymer impregnated. Infrared spectra and density proved the material to have been treated. E.S.

Zirkone von Tansania: 'Malaya-Zirkon'.
U. Henn. *Gemmologie. Z. Dt. Gemmol. Ges.,* **58**(1/2), 2009, 67–72. 4 photographs, 2 graphs, 2 tables, bibl.

The zircons are found in the Tanga province in northern Tanzania. They are transparent and brown, yellow or red, known in the trade as Malaya zircons. They are 'high crystalline', with high density and RI values, and with typical absorption spectra with narrow bands and fine lines of tetravalent uranium. All Malaya zircons fluoresce in brown or yellow-brown colours. E.S.

Sultanit — farbwechselnder diaspor aus der Türkei.
U. Henn. *Gemmologie. Z. Dt. Gemmol. Ges.,* **58**(1/2), 2009, 73. 1 photograph.

Diaspore from Mugla in Turkey shows an interesting colour change from greenish-brown in daylight to pink-brown in incandescent light. Material is called sultanate/zultanite. E.S.

Tiefgrüne Sphene aus Tansania.
J. Hintze. *Lapis,* **34**(10), 2009, 29-30.

Specimens of green sphene, some translucent, are reported from Tanzania. M.O'D.

Vorkommen von Achaten in rhyolitischen bis dacitischen Vulkaniten Deutschlands und deren historische Gewinnung sowie Nutzung — Teil I.
G. Holzhey. *Gemmologie. Z. Dt. Gemmol. Ges.,* **57**(3/4), 2008, 77–102. 27 photographs, 1 map. Bibl.

The article deals with agates from rhyolitic to dacitic volcanic rocks with relatively little free silica, which are generally less known. In Freiburg these types of agates were already worked in the fifteenth to sixteenth centuries, while other agates from the Black Forest came into favour in the eighteenth to nineteenth centuries. In Thuringia rhyolite balls were well known in the seventeenth and eighteenth centuries, while about the same time Saxony produced many agate articles. E.S.

Vorkommen von Achaten in rhyolitischen bis dacitischen Vulkaniten Deutschlands und deren historische Gewinnung sowie Nutzung — Teil II (Sachsen).
G. Holzhey. *Gemmologie. Z. Dt. Gemmol. Ges.,* **58**(1/2), 2008, 3–46. 44 Photographs, 1 table.

The author deals in some detail with the locations and occurrences in Saxony. Mining first became important under the reign of August I of Saxony in 1694 and gained popularity during the first half of the eighteenth century. Lapidary and goldsmiths' skills were developed in Dresden and master goldsmiths such as Taddel, Stiehl and Nueber produced beautiful pieces of hardstone mounted in gold, such as snuff boxes, table tops, fireplaces and cabochons for personal jewellery, mostly from banded jasper. E.S.

Fact or fiction: lessons from the history of gems.
D. Hoover. *The Australian Gemmologist,* **23**(3), 2007, 117–25.

A transcribed lecture stating how erroneous, fabricated and misinterpreted information passed down through history has skewed information we perceive to be true today. As the lecturer quotes from Thomas Katz: "Frequent repetition can turn fictional breakthroughs into common lore." Without proper correction the future will continue to believe these stories as true. Several interesting examples are given to illustrate how false information has been handed down and what the correct information really is. (NB: A 'must read', if not for the information the author provides, then for the strength of character to believe not what others deem to be true, but what you do). J.S.

Magnetic susceptibility for gemstone discrimination.
D.B. Hoover and B. Williams. The Australian Gemmologist, **23**(4), 2007, 146–59.

Delving into the past history, beginning with Pliny's writings of 2000 years ago, the author presents how magnets were used to aid in medicine, science and gemmology. Once calibrated, the presence and amount of a magnetic pull is an important indicator of the nature of growth and in differentiating between gem materials. For example, based on the amount of iron content in corundums, magnetic pull can differentiate between magmatic or metamorphic growth. In this example, the first of four magnetic principles is explored; the elemental make-up is magnetic (iron and magnesium). The other three are: diamagnetic (diamond and quartz),

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paramagnetic (peridot and garnet) and ferromagnetic (inclusions in a diamond). J.S.

Lune River petrified ferns: an overview.
R.E. Jones. *The Australian Gemmologist,* **23**(3), 2007, 131–5.

Tectonic movement led to volcanic activity creating the Lune River flora, an area of petrified plants in Tasmania. Dating zircon in the ash and sandstone in the area using Pb-U indicates that the specimens are from the Toarcian stage of the early mid-Jurassic period. Six genera are represented: *Cibotium tasmanense, Oguracaulis banksii, Osmundacaulis sp., Lunea jonesii, Ashicaulis wrightii* and *Tasmanopteris richmondii*. J.S.

Role of polyenes in the coloration of cultured freshwater pearls.
S. Karampelas, E. Fritsch, J.-Y. Mevellec, S. Sklavounos and T. Soldatos. *European Journal of Mineralogy*, **21**(1), 2009, 85–7.

The examination of 21 untreated cultured freshwater pearls from *Hyriopsis* by diffuse reflectance UV-Vis-NIR and Raman scattering measurements at high resolution is reported. All natural colour samples show the two major Raman resonance features of unmethylated (unsubstituted) polyenes, not carotenoids. Their general formulae are R-(-CH=CH)$_N$-R' with N = 6 to 14, and they give absorptions from violet to yellow-green. R.A.H.

Aquamarine, quartz and topaz in kimberlites: case studies from Minas Gerais State, Brazil.
J. Karfunkel, G.N.C. Sgarbi, P.B. de A. Sgarbi, P.A.F. de Brot, O.S. Franca, D.B. Hoover and R. Wegner. *Gemmologie. Z. Dt. Gemmol. Ges.,* **58**(3/4), 2009, 105–14. 10 photographs, 2 maps, bibl.

Most gems form in magmatic rock, with many coloured stones coming from pegmatites. Diamonds originate mainly from kimberlites. Recent finds of aquamarine, quartz and topaz in kimberlites from central-west Minas Gerais State apparently contradict accepted genetic aspects. The study from this region explains their occurrence in weathered pipes as 'hitchhikers'. Pegmatite fragments detached probably many hundreds of metres below surface from their original rock were plucked and incorporated into the ascending magma and transported to the surface. The gems were released near the surface and tropical weathering processes did not affect them as much as some kimberlite minerals. These finds might be important for coloured gem prospectors in avoiding wrong interpretations. E.S.

Identification of the endangered pink-to-red Stylaster corals by Raman spectroscopy.
S. Katampelas, E. Fritsch, B. Rondeau, A. Andouche and B. Métivier. *Gems & Gemology,* **45**(1), 2009, 48–52.

Raman scattering revealed that corals of the *Stylaster* genus (as opposed to those of the *Corallium* genus which include most pink-to-red corals used in jewellery) are made of aragonite and contain carotenoid pigments (polyenic pigments substituted with methyl groups), whereas those of the *Corallium* genus are coloured by unmethylated polyenic pigments and consist of calcite. R.A.H

Solution-generated pink color surrounding growth tubes and cracks in blue to blue-green copper-bearing tourmalines from Mozambique.
J.I. Koivula, K. Nagle, A. H-T. Shen and P. Owens. *Gems & Gemology,* **45**(1), 2009, 44–7.

From the examination of several transparent, faceted, blue to blue-green copper-bearing tourmalines containing growth tubes and cracks surrounded by sleeves of pink colour, it is suggested that the probable cause of the pink colour is treatment with a radioactive solution. There was no visual evidence of heat treatment. R.A.H.

Hackmanite/sodalite from Myanmar and Afghanistan.
D. Kondo and D. Beaton. *Gems & Gemology,* **45**(1), 2009, 38–43.

Many samples of sodalite from Myanmar and about half of those studied from Afghanistan showed the distinct tenebrescence characteristic of hackmanite, but a few saturated blue-to-purple Myanmar specimens and some very desaturated Afghan specimens showed little or no colour change on exposure to UV radiation or bright white light. Such stones with no or only very weak tenebrescence may best be referred to as sodalite (despite containing sulphur). It is suggested that only sodalite with notable tenebrescence be called hackmanite. R.A.H.

Gem news international.
B. Laurs (Ed.). *Gems & Gemology,* **44**(3), 2009, 262–82.

Items mentioned include fluorite impersonating colour-change garnet, colourless cut forsterite from the Mogok area and from Tadjikistan, a tourmaline crystal within a crystal, a cluster of aquamarine crystals from Namibia showing trapiche structure and long crystals of spodumene extending from a matrix of K-feldspar reportedly from Afghanistan. R.A.H.

Gem News International.
B.M. Laurs (Ed.). *Gems & Gemology,* **44**(4), 2008, 369–79.

Items mentioned include a visit to andesine mines in Tibet and Inner Mongolia, a particularly vivid gem-quality kunzite from Pala, California, synthetic citrine with abundant nail-head spicules and a cobalt-blue synthetic quartz. R.A.H.

Gem news international.
B. Laurs (Ed.). *Gems & Gemology,* **45**(1), 2009, 59–75.

Items noted include opals from Ethiopia, gem-quality rhodochrosite from China, colour-zoned Moroccan amethyst, cabochons of intergrown malachite and azurite, kornerupine from Tanzania, crystals of pink zoisite from Afghanistan, gem-quality blue kyanite from Myanmar, Australian chrysoprase with dendritic inclusions and inclusions of ankangite and celsian in quartz from Brazil (for which analyses are given). R.A.H.

Gem News International.
B.M. Laurs (Ed.). *Gems & Gemology,* **45**(2), 2009, 142–55.

Items mentioned include the first occurrence of a star apatite, translucent bluish-green crystals from Bahia State, Brazil, of 'sugarcane emerald' with white mottled veins (some set as jewellery), distinctly orange kyanite crystals from Tanzania, and unusual colourless cut stones of petalite (14.98 ct) and pollucite (11.30

Abstracts (continued)

and 12.10 ct) reportedly from Laghman province, Afghanistan. A description is also given of mining in Cambodia for brownish zircons which yield blue crystals after heat treatment. R.A.H.

Gem News International.
B.M. Laurs (Ed.). *Gems & Gemology,* **45**(3), 2009, 214–32.

Brief descriptions are given of an 8 cm long aquamarine crystals with inclusions resembling seaweed, a phenakite from Madagascar exhibiting chatoyancy, garnets from Kenya showing a colour change from greenish in daylight to bluish violet in incandescent light, lilac-coloured Cu-bearing tourmaline from Nigeria, sapphires from the Vortex mine in Montana showing a uniform cornflower-blue colour and mabe pearls from Vietnam with seashell nuclei. R.A.H.

Polymer-filled aquamarine.
Li Jianjun, S. Yuan, H. Wangjiao, L. Han, C. Youfa, L. Huafeng, L. Ying, Y. Hong and F. Chengxing. *Gems & Gemology,* **45**(3), 2009, 197–9.

Polymer-filled aquamarines which have been appearing on the Chinese jewellery market can be identified readily using a standard gemmological microscope as this material shows a flash effect and relief lines. Some of the filled fractures fluoresce chalky white in long-wave UV radiation. FTIR spectroscopy reveals diagnostic features at ~ 3100–2850 cm^{-1}. R.A.H.

LED lightsources and gemmological instruments that analyse colour.
T. Linton. *The Australian Gemmologist,* **23**(4), 2007, 177–9.

As the colour temperature of LEDs (light emitting diodes) can vary dramatically (from 5000 to 8000K). so does their effect on gemstones. The pleochroic and dichroic colours seen through a dichroscope have traditionally been obtained using tungsten lamps (2800K). Using the 'whiter' light of LEDs will alter these colours from what has hitherto been considered the standard. Three images show the different spectral absorptions of over 6000K LED, 6000K LED and 5000K daylight equivalent light, further showing how spectra can vary even within the close proximity of similar temperature colour. The author suggests LEDs are very good for microscopic evaluations while a Solux 50W halogen lamp will better serve the purpose for a dichroscope and Chelsea colour filter. J.S.

Sanidin aus der Eifel-als wasserklarer Edelstein.
H. Locker. *Lapis,* **34**(6), 2009, 13–18.

Notably inclusion-free sanidine feldspar is described from the Eifel region of Germany. M.O'D.

Echte Edelsteine?
H. Locker. *Lapis,* **34**(9), 2009, 13–19.

It is suggested that a translucent to transparent blue volcanic glass from the Eifel region of Germany may have ornamental potential. M.O'D.

Mushroom elbaite from the Kat Chay mine, Momeik, near Mogok, Myanmar: II. Zoning and crystal growth.
A. J. Lussier, F. C. Hawthorne, S. Herwig, Y. Abdu, P. M. Aguiar, V. K. Michaelis and S. Kroeker. *Mineralogical Magazine,* **72**(5), 2008, 999–1010.

A variety of mushroom tourmaline from the Kat Chay mine, Myanmar, has a black-to-grey single-crystal core, the remaining 50% consists of extremely acicular, sub-parallel crystals that diverge towards the edge of the mushroom. These acicular crystals are dominantly colourless to white, and pale pink outside the black zone. Microprobe results confirm that both the crystal core at the base of the mushroom and the material near the top are elbaite, the principal substitutions being Li + Al = 2 Fe and B + Al = Si + Fe. It is suggested that the changes in habit are driven in part by changes in external variables such as *T* and *P*. R.A.H.

Der Opal Jaspis von Tautenhain, Sachsen.
J. Lütich. *Lapis,* **34**(1), 2009, 40-4.

Jasper with an opal-like play-of-colour against a predominantly orange-brown background is described from Tautenhain, Saxony, Germany. M.O'D.

Famous mineral localities: Volodarsk-Volynski, Zhitomir Oblast, Ukraine.
P. Lyckberg, V. Chornousenko and W.E. Wilson. *Mineralogical Record,* **40**(6), 2009, 473–506.

Green beryl and blue topaz, some with apparent gem potential, are described from a major pegmatite in north-central Ukraine. M.O'D.

The Sapo mine.
L. Menzes. *Mineralogical Record,* **40**(4), 2009, 273–96.

Attractive and ornamental-quality crystals of apatite and tourmaline are described from the Sapo mine, located in a pegmatite about 40 km NW of Conselheiro Pena, Minas Gerais, Brazil. M.O'D.

Gemmologie Aktuell.
C.C. Milisenda and K. Wehr. *Gemmologie. Z. Dt. Gemmol. Ges.,* **58**(3/4), 2009, 77–89. 16 photographs.

Transparent to translucent orange-brown kyanite crystals were examined; these were found in the new spessartine garnet occurrence near Loliondo in north Tanzania. Two rectangular faceted stones of 0.30 ct and 0.80 ct were also received. Also from Tanzania (Longido) came some green oligoclase with an unusual mint-green colour; the transparent faceted stone weighed 8.64 ct. Also from Tanzania came two faceted green kornerupines and some faceted light yellowish-green diopside.

Other stones described included a demantoid garnet from Madagascar, a sillimanite cat's-eye from Guinea in West Africa, a trapiche tourmaline from Zambia, and pink fire quartz from Brazil. The latter are rock crystals with aventurescent inclusions. Also mentioned were euclase from Colombia and colourless pollucite from Pakistan; also from Pakistan some green pargasite crystals and a brown-yellow sphene twin with a greenish tinge weighing 92.79 ct.

Also described are some scapolite cat's-eyes from Afghanistan; these are violet transparent cabochons weighing between 1.40 and 8.63 ct. Some greenish-brown rough and faceted stones were offered in the trade as dunilite. These were identified as olivines, originally described by Dunil P. Gunasekera, hence the name dunilite.

Opaque white stones were recently offered in the trade as howlites, but were

Abstracts (continued)

identified as a barium-sulphate ceramic. A transparent cushion-cut sapphire of unusual neon-blue colour weighing 0.89 ct was shown to be cobalt treated. E.S.

Edle Zirkone aus dem Sächsischen Vogtland.
W. Modaleck, G. Seifert and S. Weiss. *Lapis,* **34**(2), 2009, 13–27.

Zircon of gem quality is described from the Vogtland area, Saxony, Germany. Specimens of various colour are illustrated: yellow to reddish-brown colours appear to dominate and phantom specimens (zircon in zircon) are also illustrated. M.O'D.

Collector profile: John S. White, Jr., and his single crystal collection.
T.P. Moore. *Mineralogical Record,* **40**(3), 2009, 215–23.

A biography of the former Curator-in-Chief of the mineralogical collection at the Smithsonian and founder of the *Mineralogical Record*. Some examples from his collection of single crystals and twins are illustrated in colour. M.O'D.

What's new in Minerals.
T.P. Moore. *Mineralogical Record,* **40**(3), 2009, 239–58.

Vayrynenite of gem quality was exhibited at the 2009 Tucson show. The orange crystal came from Shengus, Shigar Valley, Skardu District, Northern Areas, Pakistan. The crystal was displayed alongside a faceted stone of 1.89 ct. In the same show was a green twinned crystal of titanite from Mpwapwa, Dodoma Province, Tanzania. M.O'D.

Mexico V.
T.P. Moore, M. Origlieri, T.C. Wallace and B.L. Cross. *Mineralogical Record,* **39**(6), 2008, 13–26.

Beautifully illustrated survey of spectacular minerals found in Mexico. The text is well written. M.O'D.

Lab Notes.
T.M. Moses and S.F. McClure (Eds). *Gems & Gemology,* **44**(3), 2009, 252–60.

Notes are given on a citrine with Brazil law twinning visible to the naked eye, a 74 mm long inclusion of emerald in quartz, a calcite 'melt' in a Tanzanian grossular and a rare yellow trapiche sapphire. R.A.H.

Lab Notes.
T.M. Moses and S.F. McClure (Eds). *Gems & Gemology,* **44**(4), 2008, 364–8.

A note is given of induced copper contamination of two cut 'water-melon' tourmalines. R.A.H.

Lab Notes.
T.M. Moses and S.F. McClure (Eds). *Gems & Gemology,* **45**(2), 2009, 134–40.

Items noted include a 22.21 ct peridot with a distinct four-rayed star and a 5.44 ct tourmaline double cabochon showing silver chatoyancy on one side and a golden eye on the other. R.A.H.

Lab Notes.
T.M. Moses and S.F. McClure (Eds). *Gems & Gemology,* **45**(3), 2009, 208–13.

Items noted include a striking 6.64 ct polished quartz crystal coloured green by inclusions of pumpellyite and a 2.62 mm long, doubly terminated columbite crystal inclusion in colourless topaz from Pakistan. R.A.H.

Update on ammolite production from southern Alberta, Canada.
K.A. Mychaluk. *Gems & Gemology,* **45**(3), 2009, 192–6.

Since 2001, the dominant supplier of ammolite (a gem material composed of aragonite in the shells of ammonites) from the area southwest of Lethbridge, Alberta, reports a 40% increase in finished stone production. 'Dinolite', in which ammolite is combined with siliceous dinosaur bone, is being produced as yet another use of ammolite. R.A.H.

Lapis lazuli and phlogopite paragenesis from Sar-e-Sang deposit (Badakhshan, Afghanistan).
L. Natkaniec-Nowak, W. Heflik and M. Dumańska-Słowik. *Gemmologie. Z. Dt. Gemmol. Ges.,* **57**(3/4), 2008, 103–12. 9 photographs, 1 table, bibl.

From the investigations of the overgrowths of lapis lazuli on phlogopite flakes from the Sar-e-Sang deposit in Afghanistan, it can be concluded that the paragenesis is a product of postmagmatic and metasomatic activities. E.S.

'Cristalli' — Sonderschau die Sammlung Adalberto Giazotto in Florenz.
F. Pezzotta and G. Pratesi. *Lapis,* **34**(10), 2009, 61–4.

Gem quality minerals are a feature of the Florentian Adalberto Giazotto. M.O'D.

Gota de Aceite: nomenclature for the finest Colombian emeralds.
R. Ringsrud. *Gems & Gemology,* **44**(3), 2009, 242–5.

The finest and rarest emeralds have been said to have an optical effect termed *gota de aceite*, used to describe a particular aspect of emerald clarity associated with Colombian emeralds. This phenomenon and the gemmological causes of it are described and illustrated. The term should be used only after a careful examination and an understanding of the growth structures that cause the effect. R.A.H.

Winza, ein neues Rubinvorkommen in Tansania.
K. Schmetzer, W. Radl and D. Schwarz. *Lapis,* **34**(5), 2009, 41–6.

Ruby of gem quality is described from Winza in central Tanzania where it occurs in amphibolite. Some well-formed crystals are described and illustrated. M.O'D.

Rubine und Saphir aus Winza-eine Ergänzung.
K. Schmetzer, W. Radl and D. Schwarz. *Lapis,* **34**(6), 2009, 48.

Additional notes on ruby found at Winza, Tanzania. A table summarizing the morphologies of this material is given. M.O'D.

'Deutscher Lapis': Der Nunkircher Jaspis und seine Verwendung.
H. Schmitt. *Lapis,* **34**(9), 2009, 20–4.

A bluish jasper thought to resemble lapis lazuli is reported from the Nunkircher area, Germany. M.O'D.

Rubies and sapphires from Winza, central Tanzania.
D. Schwarz, V. Pardieu, J.M. Saul, K. Schmetzer, B.M. Laurs, G. Giuliani, L. Klemm, A.-K. Malsy, E. Erel, C. Hauzenberger, G. Du Toit, A.E. Fallick and D. Ohnenstetter. *Gems & Gemology,* **44**(4), 2008, 322–47.

Rubies and sapphires are being mined from both eluvial and primary deposits at Winza. The gem corundum is related to 'dykes' of Proterozoic amphibolitic rocks. Prismatic-tabular-rhombohedral and dipyramidal types occur. In general, medium and dark red rubies are rhombohedral, whereas pink, purple

Abstracts (continued)

and blue sapphires are, for the most part, dipyramidal. The top-quality rubies are characterized by long tube-, fibre-, needle- or hair-like inclusions containing limonitic material. The lower-quality material generally contains a larger amount of solid inclusions (mostly amphibole crystals), fissures and growth features. The corundum from this area has bluish violet colour zones parallel to the prism and basal pinacoid. A relatively high Fe content (>2370 ppm) of Winza rubies distinguishes them from most other natural and almost all synthetic counterparts. R.A.H.

Natural gamma radioactivity and exploration for precious opal in Australia.
B.R. Senior and L.T. Chadderton. *The Australian Gemmologist,* **23**(4), 2007, 160–76.

Through both spontaneous fissions, indicated by the high barium content, and radioactive decay of the trace elements uranium and thorium found in opals, there is a quantifiable amount of gamma ray emission. Utilizing the radioactive properties associated with opals and their surrounding environment it is possible using gamma ray logging to assess their location. Calibrated gamma ray logging can locate the host rock of opals, its quality and the relative depth. J.S.

Structural characterization and chemical composition of aragonite and vaterite in freshwater cultured pearls.
A.L. Soldati, D.E. Jacob, U. Wehrmeister and W. Hofmeister. *Mineralogical Magazine,* **72**(2), 2008, 579–92.

Vaterite and aragonite in freshwater cultured pearls from mussels of the genus Hyriopsis *(Unionidae)* were structurally and compositionally characterized by Raman spectroscopy, micro computer tomography, high resolution field emission SEM and LA-ICP-MS. The appearance of vaterite in pearls is related to the initial stages of biomineralization, but vaterite cannot be a precursor to aragonite. Vaterite is not related to a particular crystal habit and therefore does not have a structural function in the pearls. Larger contents of such elements as P and S in vaterite, as well as larger total organic contents in vaterite as opposed to aragonite, in conjunction with larger amounts of Mn^{2+} and Mg^{2+}, imply a stabilizing role for organic molecules and X^{2+} ions for biological vaterite. Distribution coefficients between aragonite and vaterite for provenance-independent elements, such as Mn and Mg (0.27 and 0.04, respectively) agree very well with those observed in fish otoliths. R.A.H.

The Miguel Romero collection of Mexican minerals.
T.C. Wallace and others. Supplement to *Mineralogical Record,* **39**(6), 2008.

Overview in colour of the Romero collection of Mexican minerals formed by the late Miguero Sanchez. Many specimens are ornamental or gem quality; none of the items illustrated have been fashioned. M.O'D.

Ruby suites from New South Wales.
G. Webb. *The Australian Gemmologist,* **23**(3), 2007, 99–116.

Corundum samples were analyzed for their gemmological features, absorption spectra, fluorescence, inclusions and chemical composition from seven New South Wales localities. Some trace elements seem to be diagnostic for the determination of geographic and geologic origin in some of the localities. Rubies from Swan Brook, Bingara, and Macquarie and Cudgegong rivers contain Sn, an element common in tin-bearing granite locations. Rubies from Swan Brook showed higher amounts of Ga compared to the surrounding localities, indicating magmatic inception. Other areas studied are Barrington Tops, Tumbarumba and Yarrowitch Valley. J.S.

Sammlersteine.
K. Wehr, C.C. Milisenda and M. Wild. *Gemmologie. Z. Dt. Gemmol. Ges.,* **57**(3/4), 2008, 113–32. 20 photographs, 2 graphs, 1 table, bibl.

Collector stones are not commercially viable due to their low hardness, perfect cleavage, low resistance to heat, brittleness or solubility in water, which makes cutting and faceting difficult. Some of these rare gemstones have recently been examined by the DSEF German Gem Lab and are presented in this article together with photographs and physical and optical properties. They are anatase from Pakistan, parisite from Colombia, anglesite from Morocco, charlesite from South Africa, rhodizite-londonite from Madagascar, powellite from India, montebrasite from Brazil, xenotime from Afghanistan, monazite from Brazil, lazulite from Brazil, triphylite-lithiophilite mixed crystal from Brazil, triplite from Afghanistan, kovdorskite from Russia, legrandite from Mexico, katapleite from Canada, hackmanite from Afghanistan and Canada, staurolite from Brazil, chromepidote (tawmawite) from Pakistan, vlasovite from Canada, leucite from Italy, enstatite from Tanzania, poldervaartite-olmiite mixed crystal from South Africa and whewellite from Saxony (Germany). Many reflection spectra are given. There is also an extensive table showing the chemical composition, colour, RI, DR, density, hardness and literary references for these stones. E.S.

Photochromismus in Hackmaniten aus Afghanistan und Myanmar.
K. Wehr, C.C. Milisenda and M. Wild. *Gemmologie. Z. Dt. Gemmol. Ges.,* **58**(3/4), 2009, 115–26. 10 photographs, 5 graphs, bibl.

Some gem-quality sodalites and hackmanites have recently appeared in the trade; they have been mined in the Badakhshan Province in Afghanistan and in the Mogok area in Myanmar. The term hackmanite has been used either for the sulphur-bearing and/or pink variety that shows tenebrescence (photochromism), i.e. they changed their colour commonly to an intense violet in response to either sunlight or UV exposure and faded when kept in the dark or by exposure to white light. E.S.

Röntgen-Mikro-Computertomographie: Zerstörungsfreier Einblick in das Innere von Zuchtperlen.
U. Wehrmeister, A. Soldati, H. Goetz, D.E. Jacob, W. Xu, H. Duschner and W. Hofmeister. *Gemmologie. Z. Dt. Gemmol. Ges.,* **58**(1/2), 2009, 53–66. 7 X-rays and tomographs, 1 table, bibl.

Computerized three-dimensional X-ray micro tomography is capable of revealing the internal structure and some of the material properties of pearls at high resolution, and is thus a more useful tool

Abstracts (continued)

in pearl testing than conventional X-ray radiography. Differences in transparency to X-rays (radiodensities) can be detected and speed up the process locating different $CaCO_3$ polymorphs. When combined with Raman spectroscopy, vaterite-containing areas can be identified. E.S.

Hyazinthe und 'Malakone' im Ofen: Zur Farbursache und Fluoreszenz sächsisch/bayerischer Zirkone.
S. Weiss and S. Meier. *Lapis,* **34**(2), 2009, 37–40.

The colour of zircon from different localities is described with notes on chemical composition and its possible influence on colour. M.O'D.

Neufund: Kupferhaltiger Aquamarin aus dem Binntal.
S. Weiss and A. Gorsatt. *Lapis,* **34**(10), 2009, 54–60.

Aquamarine is reported from the Binntal area of Switzerland which may owe its colour to copper. M.O'D.

Wilensky fine materials.
W.E. Wilson. Supplement to *Mineralogical Record*, **40**(3), 2009.

Several mineral examples with possible ornamental quality are featured in this survey of some of the collection of Wilensky Fine Minerals. The survey includes very high-quality colour photographs. M.O'D.

Famous mineral localities: the Merelani tanzanite mines, Lelatema Mountains, Arusha Region, Tanzania.
W.E. Wilson, J.M. Saul, V. Pardieu and R.W. Hughes. *The Mineralogical Record,* **40**(5), 2009, 346–408.

History of the discovery and development of the tanzanite mines at Merelani, Tanzania, with illustrations of major specimens retrieved and brief biographies of some of those engaged in the prospecting and marketing. M.O'D.

Pressures beyond rubies.
A. Wright. *Geoscientist,* **19**(11), 2009, 16–17.

An exceptionally large specimen of ruby in zoisite is described from the Merkerstein area of northern Tanzania. M.O'D.

Gem-quality yellow-green haüyne from Oldoinyo Lengai volcano, northern Tanzania.
A.N. Zaitsev, O.A. Zaitseva, A.K. Buyko, J. Keller, J. Klaudius and A.A. Zolotarev. (Ed.). *Gems & Gemology,* **45**(3), 2009, 200–3.

Yellow-green to green-yellow gem-quality haüyne is reported for the first time from an alkaline plutonic rock from the active Oldoinyo Lengai volcano. The haüyne has the typical optical and physical properties for sodalite-group minerals. Infrared and Raman spectroscopy showed that in addition to the $(SO_4)^{2-}$ group, this mineral also contains $(NO_3)^-$, $(CO_3)^{2-}$, and water in the structure. The presence of Ca, Al, and Si as major cations, with minor K, was confirmed. A 1.53 ct brilliant cut yellow-green faceted stone is illustrated. R.A.H.

Instruments and Techniques

Application of the Vis-NIR Avaspec-2048 portable automatic spectrometer to distinguish gem-quality materials.
D. Bernini, F. Caucia and M. Boiocchi. S. *Neues Jahrbuch für Mineralogie, Abhandlungen,* **185**(3), 2009, 281–8.

The use of the Avaspec-2048 fibre optic spectrometer to analyse the Vis-NIR spectra of cut gemstones is described. For each sample, however, the spectrum is influenced by such factors as the shape of the stone, the number of carats, the size of the exposed surface, and the intensity and tonality of the colour. An efficient use of this instrument to discriminate gemstones is only possible after a large and comprehensive database has been developed. R.A.H.

A new type of synthetic fire opal: Mexifire.
G. Choudhary and R. Bhandari. *Gems & Gemology,* **44**(3), 2009, 228–33.

A description is given of a new type of fire opal marketed as 'Mexifire'. Some of its gemmological properties are similar to those of natural fire opal, though the low specific gravity of <1.77 offers strong evidence for a synthetic origin. Further indications of this include the relatively low refractive index of <1.40 and the presence of scattered pinpoint inclusions when examined at high magnification. R.A.H.

Identification of melee-size synthetic yellow diamonds in jewelry.
H. Kitawaki, A. Abduriyim and M. Okano. *Gems & Gemology,* **44**(3), 2009, 202–13.

Melee-sized (0.05–0.30 ct) yellow synthetic diamonds have been examined using infrared microspectroscopy in combination with cathodoluminescence imaging for rapid and accurate distinction between these sizes of natural and synthetic diamonds, based on their characteristic mid-IR absorption spectra and growth structures. It has been established that approximately 10% of loose and dozens of mounted yellow melee diamonds submitted recently were synthetic. R.A.H.

The TrueGemColor system: a new computer color imaging system based on a uniform CIELAB color space for color grading of gemstones.
Y. Liu and K.N. Hurwitt. *Gemmologie. Z. Dt. Gemmol. Ges.,* **57**(3/4), 2008, 133–42. 6 charts, 3 graphs, bibl.

A computer colour imaging system has been developed that incorporates a Universal Colour Grading system based on a uniform CIELAB colour space with 22 hues, 7 lightness levels and 4 saturation intensities. This system gives a reference colour grade which matches the average colour of the gemstone to be graded under standard light conditions (CIE D65 light source and neutral surrounding background) and also provides a corresponding CIELAB colour coordinate. For coloured diamonds, it gives the colour grade using fancy colour diamond terminology. The colour is precisely profiled and can be calibrated by the user. E.S.

Abstractors

R.A. Howie – R.A.H. M. O'Donoghue – M.O'D. J. Sheby – J.S. E. Stern – E.S.

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Book reviews

Laboratory-grown Diamonds. Information Guide to HPHT and CVD-grown Diamonds. Second edition.
Branko Deljanin and Dusan Simic, 2009. Gemology Headquarters International, Mumbai, India. pp 86. £15.00.

Attractively produced, well referenced and with many small but sharp colour photographs, this is a useful guide to the fast-changing diamond synthesis scene. HPHT and CVD-grown diamonds are highlighted. M.O'D.

Eifel. Die Mineralien der Vulkaneifel. extraLapis No. 34.
2008. Weise, Munich, Germany. pp 98, illus. in colour. . €17.80.

Minerals, some of near-gem or ornamental quality, are described from the Eifel region of Germany. The area is noted for hauyne, a species of the forsterite-fayalite series, and for fine examples of bright orange hematite of micromount size. Details of the volcanic geology are described. M.O'D.

Freiberg. Mineralien, Bergbau und Museen. extraLapis No. 36.
2009. Weise, Munich, Germany. pp 100, illus. in colour. €17.80.

Survey, of the major mineral deposits, species and mineralogical museum collections of the Freiberg area of Germany. M.O'D.

The Immortal Stone: Chinese Jades from the Neolithic Period to the Twentieth Century.
James C.S. Lin, 2009. Scala, London. pp 160. Illus. in colour. Hardcover, ISBN 978 1 85759 581 9 £29.95; paperback ISBN 9781857595949 £14.95.

This attractive and welcome survey is the first catalogue of the important collection of jades in the Fitzwilliam Museum, Cambridge. The collection consists largely of specimens bequested by Oscar Raphael in 1946 and contains many items of high quality which are illustrated in colour in the book with a high standard of reproduction.

The book also includes an essay on the nature of the two jade minerals and on the use and significance of jade in different dynasties: there is a comprehensive bibliography and a table of Chinese characters to be found on the jade artefacts in the collection. Notes are given on the marketing of jade in and from the Song Dynasty of 960–1279, and from earlier dynasties. I have rarely seen a study in any field to equal this. M.O'D.

China: Mineralien, Fundstellen, Lagerstätten.
Berthold Ottens, 2008. Weise, Munich, Germany. pp 552, illus. in colour. Hardcover, €9.00. (In German.)

An English language version of this exhaustive survey of minerals of China would be most welcome. Many items depicted appear to be of ornamental quality. M.O'D.

Quartz. extraLapis No. 37.
2009. Weise, Munich, Germany. pp 100, illus. in colour. €17.80.

Well illustrated but lacking a bibliography, this survey of the quartz varieties is well up to the standard of this long-running series. M.O'D.

Emeralds: A Passionate Guide.
Ronald Ringsrud, 2009. Green View press, Oxnard, California. pp 382. £75.00.

Most attractively illustrated overview of the nature of emerald, printed on heavy art paper which allows excellent reproduction of the colour photographs. As well as being a guide to the history, appreciation and grading of emeralds, it is a good read and invaluable to the gem dealer and appraiser. M.O'D.

American Mineral Treasures.
G. Staebler and W.E. Wilson, 2008. Lithographie LLC, East Hampton, Connecticut. pp 368. Hardcover, ISBN 9780979099823. Price US$85.00.

This is a magnificent book, unequalled and a most welcome survey, beautifully illustrated with photographs of the highest quality. The page size is 33 x 24 cm and there are 368 of them. Every opening shows some colour. Due to the excellent paper and the solid binding, the book needs to be supported when consulted.

The arrangement of the text appears to be random but a clear index precedes the major descriptive section. A comprehensive bibliography and literature for further reading completes the book.

The aim of the book is to introduce and describe some of the major mineral deposits of the United States and to illustrate the finest specimens obtained from them. Very many of the sites described produce gem material and so the book is of especial value for the gemmologist. Naturally most of the alluvial deposits are not covered as site and product might be less visually arresting.

Historical notes are plentiful and their profusion shows the depth of the source material consulted for the book.

I cannot sufficiently praise the enterprise of the authors and their assistants. The book may perhaps provide a 'Tucson at home'. M.O.D.

Gems and Mines of Mogok.
T. Themelis, 2008. A & T Publishers, Bangkok. 352 pp. Over 800 colour figures, most of which are made up of several items. Hard cover. ISBN 0940-965-30-5. US$ 129 plus postage and packing.

There is far more in this book than the title would suggest and it is a photographic feast. It covers the history of the area, its geological evolution, mineralogy and crystallography; it

Book reviews (continued)

provides a cornucopia of fine photographs of mines, minerals and gems, and local life, almost all taken by the author. He describes himself as a 'non-trained geologist', but he has enjoyed the co-operation of Burmese university geologists and several eminent geologist/gemmologists in the field during his nine visits between 1996 and 2004. He is an internationally recognized expert on the heat treatment of gemstones.

The book is divided into five wide-ranging chapters with six appendices and a bibliography of over 400 references. In Chapter I – Geology of Mogôk – he describes (with the aid of diagrams) the geological evolution of the area from the break-up of Gondwanaland to the collision of the Indian and Asian plates, and the major regional structural features. He provides a new geological map of the Mogôk area (a collaborative work with Burmese geologists). The local rocks are described under the following broad types: Igneous, Mantle and Metamorphic, with excellent photos of hand specimens, field outcrops, mines and photomicrographs (PPL and crossed polars) of thin sections.

In Chapter 2 – Genesis of Ruby, Spinel, Sapphire and Peridot – he discusses the classification of Mogôk gems and divides them, according to their mode of formation, into conveniently tabulated Metamorphic, Igneous and Skarn or Contact origins. There is a useful map showing mining areas where ruby, sapphire, spinel, peridot, pegmatite gems, mixed gems and alluvial gems respectively are dominant. The main part of the chapter deals in detail with the crystal form and habit, chemistry and inclusions of the above gems, with an excellent series of photos of gem minerals in matrices.

Chapter 3 – Gem Mining in Mogôk – starts with a short history outlining mining developments from pre-history to 1886, under the British from 1886 to 1947 and then under various Burmese administrations after independence. He divides mining into primary workings (largely in syenites and marbles) and secondary (mainly alluvial workings). Mining methods include sinking shafts, sluicing, open-pit operations and recovery from twisted holes, cavity fillings and tunnelling. Sorting methods include washing by hand and in pulsating jigs, and recovery from discarded material – the 'kanase' tradition (largely carried out by women). There are maps of smuggling routes out of Burma and annual production tables. There is a detailed photographic coverage of these operations.

Chapter 4 – The Gem Mines of Mogôk – starts with a very useful map of the Mogôk area divided into ten sub-areas (running from East to West) showing the locations of the mines. Detailed maps of each area are accompanied by photos of mines showing working methods along with lists of the gem minerals recovered from them. There are excellent photos of crystals in matrix and cut stones from the mines.

Chapter 5 – Profiles of Mogôk Gems – is arranged alphabetically and gives details of some sixty gem species with their gemmological properties and lists the mines and rock assemblages in which the gems are found. Each species' description is accompanied by very good photos of cut stones showing colour varieties.

There are six appendices: (A) List of the Pain Collection of Mogôk gemstones in the Natural History Museum, London; (B) A short account of gem enhancement methods; (C) A brief description of gemstone identification techniques; (D) Tabulated properties of Mogôk gem minerals including colour; (E) List of Burmese gemmological jargon; and (F) Detailed list of Mogôk gem mines.

This book is probably the most comprehensive account of the Mogôk Stone Tract so far produced and is claimed to be correct to 2007. This is a volume for gemmologists, geologists, lapidaries, jewellers and many others with an interest in the Burmese scene. The book is expensive, but worth the money for the photographic pleasure and detailed accounts of the mines.

E.A.J.

Minerals of Britain and Ireland.
A.G. Tindle, 2008. Terra Publishing, Harpenden. pp viii, 616. ISBN 13–978–1–903544–22–8. £94.00.

Mineral species, many illustrated in colour, are described in alphabetical order in a larger book which effectively replaces Greg and Letsom's work of 1858. Particularly useful are the historical data provided as well as the expected notes on modes of occurrence which are supported by references to reliable sources. Both papers and monographs are included in a comprehensive bibliography and details of the mineral collections are noted.

This is a major work, long overdue to say the least, and reflects great credit on all who contributed to and worked on it.

M.O'D.

Private Mineral Collections in Texas.
Wendell Wilson, Wally Man and Gary White, 2009. Mineralogical Record, Tucson, USA. pp 180, illus. in colour. Hardcover, US$ 60.00.

Drawing upon the resources of dedicated collectors, this survey includes examples of gem-quality crystals with at least one synthetic product. Specimens are arranged in alphabetical order of the collector's surname. M.O'D.

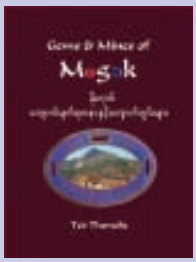

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Gem-A Events

Gem-A Conference: Showing Colour

The 2009 annual Conference, held on Sunday 18 October at the Hilton London Kensington Hotel, celebrated the 75th anniversary of the introduction of the Chelsea Colour Filter with the theme 'showing Colour'.

Speakers included Brian Dunn, Thomas Hainschwang, John Harris, Alan Hodgkinson, Harry Levy, Antoinette Matlins, Dr Karl Schmetzer and Dr Menahem Sevdermish.

The conference was followed by a candlelit dinner at the hotel.

A programme of events and workshops arranged to coincide with the Conference was held on Monday 19 and Tuesday 20 October. These included the Graduation Ceremony at Goldsmiths' Hall (see below), and a guided tour of the Crown Jewels at the Tower of London with David Thomas. Following the theme 'Showing Colour', a half-day workshop on the practical use of the spectroscope with John Harris as guest tutor was held on the morning of Monday 19 October and the final event was Gem Discovery Club with guest speaker Beatrice Gimpel who demonstrated how gems and pearls can complement a person's colouring and also how to mix stones for best effect.

A report of the Conference was published in the October 2009 issue of *Gems & Jewellery*.

Graduation Ceremony

On Monday 19 October the Graduation Ceremony and Presentation of Awards was held at Goldsmiths' Hall in the City of London. Professor Andy Rankin, President of the Gemmological Association, presided and Alan Hodgkinson, President of the Scottish Gemmological Association presented the awards and gave the address.

Following the presentations to the graduates, it was announced that John Harris of Dudar, Cumbria, had been awarded the R. Keith Mitchell Award for Excellence in the Field of Gemmological Spectroscopy, an award introduced in 2006 in honour of the late R. Keith Mitchell. A Gem-A gemmology tutor since 1986, John Harris is renowned for his work with the spectroscope and his outstanding photography of spectra.

During the ceremony it was also announced that E. Alan Jobbins and Michael J. O'Donoghue had been appointed Vice Presidents of the Association in appreciation of their commitment to gemmological education for many years.

In his address, Alan Hodgkinson stressed to the graduates the importance of taking every opportunity to improve and increase their gemmological knowledge and to 'go that extra mile'. He concluded: "Of all the careers that are on offer, I cannot imagine one which is so full

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Above: The Graduation Ceremony in the magnificent Livery Hall at Goldsmiths' Hall, London. Below: Guest speaker Alan Hodgkinson (right) speaking with Dominic Mok of Hong Kong who sponsored the new Dominic Mok Diamond Practical Prize. Photos © Photoshot.

of fascination and opportunity. So head back home full of gemmological commitment. Work as hard at building your career as you do at building friendships. Both need a good foundation and you now have that foundation by your award tonight. And finally realize this simple fact; if you enjoy your work, you will never have to work another day in your life. I wish you well." (Alan Hodgkinson's full address may be downloaded at www.gem-a.com/education/gem-a-graduation-and-awards.aspx)

The ceremony was followed by a reception for graduates and guests.

A report of the Graduation Ceremony was published in the October issue of *Gems & Jewellery*.

Nature's Treasures II: Minerals and Gems

A seminar organized jointly by Gem-A, the Mineralogical Society and the Russell Society, was held on Sunday 13 December 2009 at the Flett Theatre, Natural History Museum, London SW7.

Talks on a variety of subjects from mining the oceans to minerals in paints, were presented by Chris Carlon, Guy Clutterbuck, Alan Collins, John Faithfull, Martin Feely,

Norman Moles, Jolyon Ralph and Ruth Siddall.

During the lunch break, delegates had the opportunity to view displays by Gem-A, The Mineralogical Society, The Russell Society, Richard Tayler and the Mike Rumsey (Natural History Museum).

Gem-A Awards

Gem-A Examinations were held worldwide in January and June 2009. In the Examinations in Gemmology 376 candidates sat for the Diploma Examination of whom 205 qualified, including two with Distinction and 31 with Merit. In the Foundation in Gemmology Examination, 434 candidates sat of whom 335 qualified. In the Gem Diamond Examination 178 candidates sat of whom 108 qualified, including eight with Distinction and 14 with Merit.

The **Christie's Prize for Gemmology** for the best candidate of the year in the Diploma Examination was awarded to **Noémie Georgy** of St Remy Les Chevreuse, France.

The **Anderson Bank Prize** for the best set of theory papers in the Diploma in Gemmology examination was awarded to **Yang Shuo** of Hubei, China.

In 2008 we awarded for the first time a Diploma Practical Prize for excellence in the Diploma Practical Examination. This has has been named the **Read Practical Prize** in memory of Peter Read who sadly died earlier in the year. The prize was sponsored for 2009 by DeeDee Cunningham of Toronto, Canada, who also kindly donated a copy of her book *The Diamond Compendium*. The Read Practical Prize was awarded to **Amy Campbell-Jones** of Sheffield, Yorkshire.

In the Foundation Certificate in Gemmology examination, the **Anderson Medal** for the candidate who submitted the best set of answers which, in the opinion of the Examiners, were of sufficiently high standard, and the **Hirsh Foundation Award** for the best candidate of the year, were awarded to **Louise Dennis** of Halesowen, West Midlands.

In the Gem Diamond Diploma examination, the **Bruton Medal**, awarded for the best set of theory answer papers of the year, and the **Deeks Diamond Prize** for the best candidate of the year, were awarded to **Antonia Ross** of Fleet, Hampshire.

A new prize, the **Dominic Mok Diamond Practical Prize** for excellence in the Diamond Practical Examination, was awarded for the first time, sponsored by Dominic Mok from AGIL, Hong Kong. The Dominic Mok Diamond Practical Prize was awarded to **May Wai Ho** of Hong Kong

The Tully Medal was not awarded.

The names of the successful candidates are listed below.

Examinations in Gemmology

Gemmology Diploma

Qualified with Distinction

Georgy, Noémie, St Remy Les Chevreuse, France
Zhong Feng, Beijing, P.R. China

Qualified with Merit

Campbell-Jones, Amy V., Sheffield, Yorkshire
Cathelineau, Thierry, Les Breviaires, France
Chan Wai Sze, New Territories, Hong Kong
Chen Xi, Beijing, P.R. China
Cong Li, Wuhan, Hubei, P.R. China
Eastwood, Layla, Bellaire, Texas, U.S.A.
Gan, Cuiling, Guilin, Guangxi, P.R. China
Harris, Kay, Allendale, Northumberland
He Fei, Wuhan, Hubei, P.R. China
Hovi, Maria, Hyvinkää, Finland
Huby, Melanie, Liège, Belgium
Kong Jin, Wuhan, Hubei, P.R. China
Leavey, Harriet, Worcester
Li Yi, Guilin, Guanxi, P.R. China
Li Yujiao, Guilin, Guangxi, P.R. China
Li Xiao, Da Zu County, Ching Qing City, P.R. China
Liang Huan, Guilin, Guanxi, P.R. China
Liu Mei, Beijing, P.R. China
Ming Yan, Guilin, Guanxi, P.R. China
Ngan Yin Ying, Kowloon, Hong Kong
Pareek, Subhash, Gujarat, India
Parvela-Säde, Anu Liisa Johanna, Espoo, Finland
Qi Ming, Guilin, Guanxi, P.R. China
Rakotoharinavalona, Tahiana Lalaina, Antananarivo, Madagascar
Sugihara, Toshiyuki, Osaka, Japan
Versini, Valerie, Marseille, France
Wang Xia, Beijing, P.R. China
Xu Jiahui, Guilin, Guangxi, P.R. China
Yan Yaying, Guilin, Guanxi, P.R. China
Yang Shuo, Jingzhou City, Hubei, P.R. China
Zhan Zhanwen, Wuhan, Hubei, P.R. China

Proceedings of the Gemmological Association of Great Britain and Notices

Qualified
Abey, Sara, London
Aboosalih, Najeema Shahin, Colombo, Sri Lanka
Amrit, Paveet, Northolt, Middlesex
Au, Anita Suet Ki, Kowloon, Hong Kong
Bahri, Sebastien, Feucherolles, France
Baptiste, Karen Anne, Panadura, Sri Lanka
Becquaert, Gregory Julien Pascal, Saint-Jans-Cappel, France
Blagg, Natalie, London
Burton, Estelle, Surbiton, Surrey
Cai Min, Guilin, Guangxi, P.R. China
Cao Juan, Shanghai, P.R. China
Cao Weifeng, Guilin, Guanxi, P.R. China
Cartier, Laurent E., Ribeauvillé, France
Chan Kin Chung, Kowloon, Hong Kong
Chatellain, Yannick, Bonneville, France
Chen Anny Shin-Mien, Taipei, Taiwan R.O.C.
Chen Ge, Guilin, Guangxi, P.R. China
Chen Hsiang Ling, Taipei, Taiwan R.O.C.
Chen Tianran, Guilin, Guangxi, P.R. China
Chen Wenlong, Beijing, P.R. China
Chen Ying, Guilin, Guangxi, P.R. China
Chen Yuemei, Guilin, Guangxi, P.R. China
Cheng Qi, Guilin, Guangxi, P.R. China
Cheng Yu-Lin, Taipei, Taiwan R.O.C.
Cheung Suk Wan, New Territories, Hong Kong
Chien Hung-Dau, Wuhan, Hubei, P.R. China
Chit Su Su Lin, Mogok, Myanmar
Chou Mei-Lien, Taipei, Taiwan R.O.C.
Chrismas, Jacqueline, Godalming, Surrey,
Chu Chanyuan, Beijing, P.R. China
Chu Kong Ting, New Territories, Hong Kong
Chung Tsz Bun, Kowloon, Hong Kong
Coquel, Isabelle, Saint Germain Laprade, France
de Josselin de Jong, J.P., Amsterdam, The Netherlands
Donsin, Julie, Verviers, Belgium
Evans, Natalie, London
Feng Heng YI, Beijing, P.R. China
Fu Kangyu, Guilin, Guanxi, P.R. China
Gabay, Nicole, Montrouge, France
Gonzalez, Olga, New York, U.S.A.
Grounds, Camilla Sara, London
Guo Haifeng, Shanghai, P.R. China
Guo Hao, Guilin, Guanxi, P.R. China
Guo Yingli, Guilin, Guanxi, P.R. China
Guo Yunrong, Shanghai, Changning District, P.R. China
Hara, Shintarou, Sasebo City, Nagasaki Pref., Japan
Hartono, Djayani, Mount Tamborine, Queensland, Australia
Häyry, Tiia, Hinthaara, Porroo, Finland
Hirisy, Elisabeth, Ramboahangy Ranse, Madagascar
Hollaar, Alexa, Bias, France
Hong, Nabin, Shanghai, P.R. China
Honour, Kevin J., Yeading, Middlesex
Hu Jie, Guilin, Guangxi, P.R. China
Huang Shanshan, Beijing, P.R. China
Hughes, Kym Renaye, Nerang, Queensland, Australia
Jain, Devesh, Delhi, India
Jansch, Peter Alexander, Luxembourg
Jeong, Eun Ah, Kofu City, Yamanashi Pref., Japan
Johnston, Nanette LeTendre, Granite Bay, California, U.S.A.
Johnstone, Isobel Phebe, Brisbane, Queensland, Australia
Kagia, Georgia, Nikea, Greece
Kambale, Sonia, Maharashtra, India
Kettle, Georgina Elizabeth, Birmingham, West Midlands,
Keung Wing Fun, Hong Kong
Kovanovic, Milena, London
Krska, Gemma, Durban, South Africa
Kuchard, Monika, London
Lepage, Anick, Mont Saint Hilaire, Quebec, Canada
Leung Rakotovao, Anna, Antananarivo, Madagascar
Li Chunlin, Wuhan, Hubei, P.R. China
Li Geng, Beijing, P.R. China
Li Jiaxuan, Guilin, Guanxi, P.R. China
Li Lin, Guilin, Guanxi, P.R. China
Li Qian, Wuhan, Hubei, P.R. China
Li Qianhui, Wuhan, Hubei, P.R. China
Li Ruimin, Xi An City, Shanxi Province, P.R. China
Li Zhuonan, Shanghai, P.R. China
Lilley, Heather Jane, Newcastle-under-Lyme, Staffordshire,
Liu Hailan, Shanghai, P.R. China
Liu Jingna, Guilin, Guangxi, P.R. China
Liu Liping, Guilin, Guangxi, P.R. China
Liu Xianfeng, Shanghai, P.R. China
Loke Hui Ying, Singapore
Lu Yisha, Wuhan, Hubei, P.R. China
Ma Hoi Shan, Kowloon, Hong Kong
Ma Tsz Kwan, New Territories, Hong Kong
Ma Xu, Guilin, Guanxi, P.R. China
Maccaferri, Arianna, London
Mclachlan, David, Woking, Surrey
Man Sai Wing, Yuen Long, Hong Kong
Matsukawa, Kent, Yokohama, Japan
Mergalet, Caroline, Villefranche-sur-Mer, France
Mithaiwala, Priyanka M., Surat, India
Mizukami, Yusuke, Saitama City, Saitama Pref., Japan
Mooney, Robert John, Cooroy, Queensland, Australia
Muhhamedjanova, Jelena, Tallinn, Estonia
Muller, Paul, Antananarivo, Madagascar
Murakami, Akiko, Tokyo, Japan

Murray, Patricia A, Ottawa, Ontario, Canada
Nay Lin Aung, Mogok Township, Myanmar
Naylor, Peter D., Birmingham, West Midlands
Ng Fei Yeung, Kowloon, Hong Kong
O'Hagan, David Michael, Sutton Coldfield, West Midlands
Oncina, Christelle, St Raphael, France
Otterstrom, Camilla Anna, Bålsta, Sweden
Ouchene, Linda, Paris, France
Oxberry, Hannah Clare, Norwich, Norfolk
Partner, Robert, Cropston, Leicestershire
Patel, Maulika, London
Petropoulou, Eleni, Athens, Greece
Poore, Sarah, Worthing, West Sussex
Possen, Armand, Soumagne, Belgium
Preston, Paula, London
Prince, Ronald Fisher, Richmond, Surrey
Qin Qing, Guilin, Guanxi, P.R. China
Quiros, Marylene, Bordeaux, France
Qureshi, Erum Ali, Thane, India
Ramampy, Pierrot, Antananarivo, Madagascar
Raneke, Annamaria, Stockholm, Sweden
Ribarevic, Ivanka, Montreal, Quebec, Canada
Rousseville, Prisca, Nantes, France
Santer, Kurt, Jersey, Channel Islands
Share, Rebecca Louise, Birmingham, West Midlands
Shen, Huanqun, Shanghai, P.R. China
Shi, Hua Yan, Shanghai, P.R. China
Siegan-Smith, Breige, London
Soe Pa Pa, Yangon, Myanmar
Song Lanlan, Guilin, Guangxi, P.R. China
Song Liping, Beijing, P.R. China
Su Chenmin, Wuhan, Hubei, P.R. China
Sun, Norton, Central, Hong Kong
Sung, Sophia, Tapei, Taiwan R.O.C.
Szvath, Gabriella, Laukaa, Finland
Tang Kit Yee, New Territories, Hong Kong
Tian Mi, Guilin, Guanxi, P.R. China
Tidd, Lauren Elizabeth, Churchdown, Gloucester
Tissa, V.G. Samith Madhawa, Colombo, Sri Lanka
Tran Vinh-Logez, Caroline, Paris, France
Verma, Pragati, Delhi, India
Vlemmix, Joost M.A, Ravenstein, The Netherlands
Wan Qijuan, Wuhan City, Hubei Province, P.R. China
Wang Mengqing, Guilin, Guangxi, P.R. China
Wang Junyi, Guilin, Guanxi, P.R. China
Wang Zongyu, Guilin, Guangxi, P.R. China
Ward, Simon Francis, Leigh-on-Sea, Essex
Wei, Qiaokun, Guangzhou, P.R. China
Weng Chuxin, Guilin, Guangxi, P.R. China
Wickramarathne, Hettiarachchi Keerthi, Thalawatugoda, Sri Lanka
Wiguna, Aland, Surabaya, Indonesia
Wright, Lee Peter, Chaddesley Corbett, Worcestershire
Wu Na, Guilin, Guanxi, P.R. China
Xiang Tingyi, Wuhan, Hubei, P.R. China
Xu Gengbo, Wuhan, Hubei, P.R. China
Xu Zhao, Shanghai, P.R. China
Yang Pei-Chi, Taipei, Taiwan R.O.C.
Yang Yiwei, London
Yang Zhuo, Guangzhou, P.R. China
Yip Long Ching, Hong Kong
Young, Stephanie Lynne, Chalfont St. Peter, Buckinghamshire
Yu, Byron Kwai Sang, New Territories, Hong Kong
Yu Zhiwei, Shanghai, P.R. China
Yuan Yi, Guilin, Guangxi, P.R. China
Zhang Fan, Wuhan, Hubei, P.R. China
Zhang Li, Wuhan, Hubei, P.R. China
Zhang Xiao Wen, Wuhan, Hubei, P.R. China
Zhang Xiaohu, Guilin, Guanxi, P.R. China
Zhao Chunji, Shanghai, P.R. China
Zheng Wenting, Shanghai, P.R. China
Zhou Die, Wuhan City, Hubei Province, P.R. China
Zhou Jing, Wuhan, Hubei, P.R. China
Zhou Mengji, Shanghai, P.R. China
Zhou Xia, Shanghai, P.R. China

Foundation in Gemmology

Qualified

Aarsaether, Anita Ronning, Sandvika, Norway
Aderhold, Bryan Christopher, Ridgewood, New Jersey, U.S.A.
Agrawal, Shriraj, Nagpur, India
Åkerlund, Sophia, Lidingo, Sweden
Akintayo, Olusegun James, London
Allen, Amanda, Northampton
Alokhin, Andriy, London
An, Ran, London
Andren Georgsen, Cecilia, Lund, Sweden
Andriamanohisoa Axhel, Robert, Antananarivo, Madagascar
Aung Ko Ko, Yangon, Myanmar
Azema, Valerian, Le Val, France
Bagriacik, Didem, London
Bailey, Sarah, London
Balakchiev, Ruslan, Marseille, France
Beale, Sioned, Lapworth, Warwickshire
Becquaert, Gregory Julien Pascal, Saint-Jans-Cappel, France
Belanger, Jeannine, Quebec, Canada
Bergeron, Marie Josee, Quebec, Canada
Borenstein, Guy, Pardes-hana Karkur, Israel

Brenan, Amy, Dorchester, Dorset
Brown, Sandra Jane, Birmingham, West Midlands
Bryan, Daniel, London
Burgoni, Eva Maria, Carnoux-en-Provence, France
Butini, Enrico, Rome, Italy
Butini, Flavio, Rome, Italy
Byrne, Ruth, London
Cai Jia, Beijing, P.R. China
Caldwell, Neil Charles, Morningside, South Africa
Cambray, Elinor, Salisbury, Wiltshire
Cathelineau, Thierry, Les Breviaires, France
Cederferm, Magdalena, Rosersberg, Sweden
Cederqvist, Zarah, Lannavaara, Sweden
Cerutti, Gabriella, Valenza, Italy
Chan Kam Kong, Tseung Kwan O, Hong Kong
Chan Pei Pei, Betty, Quarry Bay, Hong Kong
Chan Pui Shan, Shatin, New Territories, Hong Kong
Chan Sau Kwan, Hong Kong
Chatagnier, Pierre Yves, Saint-Albin, Vareilles, France
Chatellain, Yannick, Bonneville, France
Chau Lai La, New Territories, Hong Kong
Chen Ge, Guilin, Guangxi, P.R. China
Chen Shan-Yi, Roquebrune Cap Martin, France
Chen Shifeng, Guang Dong, P.R. China
Chen Suoyi, Beijing, P.R. China
Chen Tianran, Guilin, Guangxi, P.R. China
Chen Ying, Guilin, Guangxi, P.R. China
Chen Yuemei, Guilin, Guangxi, P.R. China
Cheng Qi, Guilin, Guangxi, P.R. China
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Cheung Yuk King, New Territories, Hong Kong
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Cooper, Amy, Las Vegas, Nevada, U.S.A.
Coquel, Isabelle, Saint Germain Laprade, France
Darli Sein Win, Yangon, Myanmar
De Mey, Inge, Shanghai, P.R. China
de Nevi, Danilo, Genoa, Italy
De Witt Sandstrom, Ida, Lunde, Sweden
Delerholm, Peter, Enskede, Sweden
Deng Xiansong, Guilin, Guangxi, P.R. China
Dennis, Louise, Halesowen, West Midlands
Donsin, Julie, Verviers, Belgium
Du Liuyin, Beijing, P.R. China
Dumas, Anne Catherine, London,
Elliott, Marc, Birmingham, West Midlands
Elmetto, Pamela, London
Esteves, Catarina, Meudon, France
Evans, Rachel, London
Featherstone, Hazel, London,
Feng Yan, Guangzhou, P.R. China
Filipe, Muenga Ana Paula, Birmingham, West Midlands
Fontaine, Marie, London
Fung Sin Ting, Central, Hong Kong
Gabay, Nicole, Montrouge, France
Gamley, Alistair, Harare, Zimbabwe
Gan Cuiling, Guilin, Guangxi, China
Georgy, Noémie, St Remy Les Chevreuse, France
Gilson, Karen Margaret, Wanstead, London
Glendening, Sarah Louise, Eastbourne, East Sussex
Gomez, Amanda, London
Gorris, Tanja, Amsterdam, The Netherlands
Graham, Lisa J., Tunbridge Wells, Kent
Gram-Jensen, Margrethe, Vejle, Denmark
Grocholska, Katherine, London
Gu Ying, Shanghai, P.R. China
Guez, Arielle, Aix-en-Provence, France
Guo Fang Yu, Beijing, P.R. China
Hall, Josephus, Birmingham, West Midlands
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Han Yi, Beijing, P.R. China
Harnois, Dominique, Paris, France
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Hui Marilyn Hang-Chung, Hong Kong
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Meninno, Marco, London. 2008/2009
O'Hagan, David, Sutton Coldfield, West Midlands. 2009/2009
Taylor, Roger, Walsall, West Midlands. 1986/1994

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Cyrille Djankoff, London, for three pieces of morganite (one natural colourless, one greyish after irradiation and one pinkish after irradiation and heating) from the Marropino Mine, Zambezi province Mozambique; also for a piece of lapis from Tadjikistan, Pamir Region.

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Lisa Graham, Tunbridge Wells, Kent, for a carved ivory puzzle ball.

Marcia Lanyon, London, a selection of small faceted emeralds and sapphires, and some cut natural and synthetic gemstones.

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Emma Mouawad, West Hampstead, London, for a nephrite jade cylinder with fern leaf design finials.

So Pa Pa, Yangon, Myanmar, for a quartz crystal with rutile inclusions and mica crystals in matrix.

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Associate Membership to Fellowship (FGA)

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Chen, Anny Shin-Mien, Taipei, Taiwan R.O.C. 2009
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Subscriptions 2010

The membership subscriptions for 2010 are £85.00 for UK members and £90 for those in Europe and overseas.

Annual General Meeting

The Annual General Meeting was held at the National Liberal Club, Whitehall Place, London SW1, on Monday 22 June. The meeting was chaired by James Riley the newly appointed Chairman of the Council. The Annual Report and Accounts were approved. Professor Alan Collins was re-elected and Steven Collins, Brian Jackson, and Cally Oldershaw elected to serve on the Council. Dr Tony Allnutt was re-elected and Janice Kalischer elected to serve on the Membership Liaison Committee. David Lancaster retired in rotation from the Membership Liaison Committee and did not seek re-election. Hazlems Fenton were re-appointed as auditors for the year.

A presentation by Rui Galopim de Carvalho of the Gemological Laboratory in Portugal (LABGEM), entitled 'Lalique's gems: as seen in the collections of the Calouste Gulbenkian Foundation' followed the AGM.

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Obituary

Peter George Read
1927-2009

Born in London in 1927, Peter passed away quietly on 15 January 2009 after a brave fight with cancer: he will be sadly missed by his family and all his friends and colleagues who knew him as a most congenial, friendly and talented person.

Peter's education led him to become a Chartered Engineer with a strong background knowledge of electronics. He qualified as a Fellow of the Gemmological Association and also held the Diamond Certificate of the Association.

Peter held a number of professional positions during his working life in a diverse range of companies including GEC, Iliffe the publishers and Johnson Matthey & Co. Ltd, the bullion refiners, where he was the senior Development Engineer. Later he became Technical Manager of the Diamond Trading Company (Pty) Ltd. (part of the De Beers organization).

During his time with De Beers Peter spent some time in Namibia, where he was involved in the development of a diamond-sorting machine. Whilst in South Africa, he was able to visit many of the major diamond producing areas including the famous Premier mine near Pretoria, the Dutoitspan and Bultfontein at Kimberley and the Consolidated Diamond Mines coastal operation at Oranjemund in South West Africa.

As a technical author, Peter excelled and he produced a number of books, which included *Gemmology, Gemmological Instruments* and *Dictionary of Gemmology*. He also edited the 5th edition of Webster's *Gems*. Peter was also known to some of us as an author of several novels, including *The Phantom Diamond, Diamond Mine* and *The Peking Diamonds*; these were based on his experiences in the gemmological world.

Peter gave many talks on gemmological matters both in the UK and abroad. For many years he was a tutor for the Gem-A courses. Since 1994 he was an Assistant Editor of The Journal, and wrote many book reviews. For a number of years he was a Member of the Council of the Association and latterly a he sat on the Members' Council.

All the foregoing was still not enough for Peter. He became very involved in designing gemmological instruments, one of which was Gem Data, a computer-aided programme for gem identification. The most recent instrument that he designed was the Brewster Angle Meter for Gem-A, which is now in use worldwide.

Although retired, Peter kept in close touch with his gem friends and colleagues in both the UK and abroad. He was a gentleman in every respect, quiet, helpful, modest and with a great sense of humour. He will be greatly missed by all.

Noel W. Deeks

* * *

Alain A.M. van Acker FGA (D.1990), Tilburg, The Netherlands, died on 30 March 2009.

Bruno Bolli FGA (D.1976), St Gallen, Switzerland, died on 16 December 2008.

Leslie Punchihewa FGA (D.1983), Colombo, Sri Lanka, died on 26 April 2009.

Leonard Sanitt FGA (D.1949), London, died in 2009.

Richard A.F. Will FGA (D.1974), Peterborough, Cambridgeshire, died on 21 May 2009.

Wilhelm J.E. Van Deijl, FGA (D.1969), Bellville, South Africa, died on 23 July 2009.

Patricia J. Walker FGA DGA (D.1969 and 1970), London, died in 2009.

Daniel Taylor FGA DGA (D.2005 and 2004), Leeds, Yorkshire, died on 29 October 2009.

Gem-A Events 2010

Friday 26 February	**MIDLANDS BRANCH** **Emeralds: formation, treatment, manufacturing and identification by DOUG GARROD** *Venue:* The Earth Science Building, University of Birmingham, Edgbaston
Tuesday 2 March	**GEM DISCOVERY CLUB** **Gemmology on the Job - identifying set gemstones with KERRY GREGORY** Venue: Gem-A, 27 Greville Street (Saffron Hill entrance), London EC1N 8TN
Tuesday 2 March	**SCOTTISH GEMMOLOGICAL ASSOCIATION** **Members' Night: Tales from Tucson** *Venue:* British Geological Survey, West Mains Road, Edinburgh
Friday 26 March	**MIDLANDS BRANCH** **A practical and hands-on look at some rare stones and inclusions in quartz with MARCUS McCALLUM** *Venue:* The Earth Science Building, University of Birmingham, Edgbaston
Tuesday 30 March	**SCOTTISH GEMMOLOGICAL ASSOCIATION** **Wine and cheese reception and SGA AGM followed by Piteiras emeralds with PADRAIC LAVIN** Venue: British Geological Survey, W Mains Road, Edinburgh
Friday 30 April	**MIDLANDS BRANCH** **Jewellery of the Great Exhibition of 1851 by DAVID LANCASTER** *Venue:* The Earth Science Building, University of Birmingham, Edgbaston
Friday 30 April to Monday 3 May	**SCOTTISH GEMMOLOGICAL CONFERENCE** *Venue:* The Queens Hotel, Perth For further information see page 180
Sunday 7 November	**GEM-A CONFERENCE** *Venue:* The Hilton London Kensington Hotel
Monday 8 November	**GRADUATION CEREMONY AND PRESENTATION OF AWARDS** *Venue:* Goldsmiths' Hall, London
Sunday 12 December	**NATURE'S TREASURES III: MINERALS AND GEMS** A seminar organized jointly by Gem-A, The Mineralogical Society, The Russell Society and Rockwatch *Venue:* Flett Theatre, Natural History Museum, London

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Cover Picture: A large nacreous pearl (estimated weight 2385 grains) surrounded by golden 'stamens' decorated with ruby, sapphire and emerald beads, and mounted on a pedestal of lapis lazuli. Photo © Amsterdam Pearl Society. (See A description and history of one of the largest nacreous pearls in the world, page 196.)

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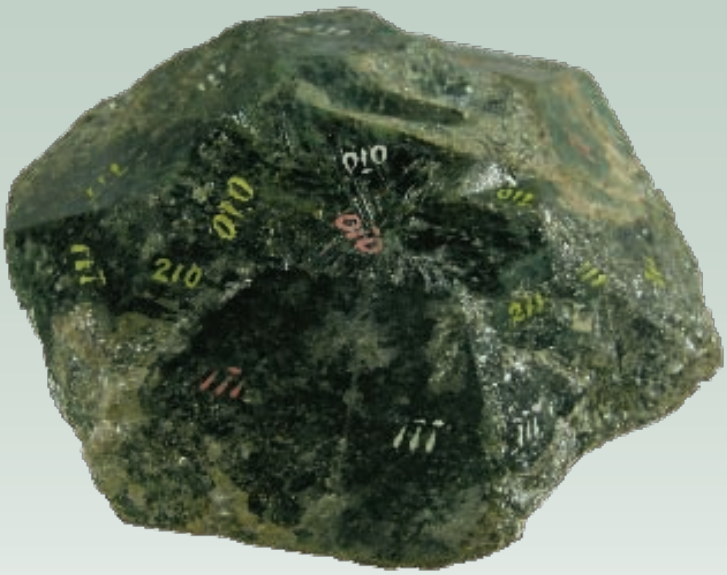

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Mexican jadeite-bearing rock: a first mineralogical and gemmological approach

Mikhail Ostrooumov and Alfredo Victoria Morales

Abstract: Jadeite-bearing pebbles have been found in secondary deposits overlying Cretaceous sediments in the Vizcaino Peninsula, Sierra San Andres, Baja California Sur, Mexico, the first in the country. These pebbles are probably derived from a blueschist assemblage associated with a serpentinite-matrix mélange complex about 2 km north of Puerto Nuevo. Jadeite is accompanied by omphacite and aegirine, and different associated minerals enable distinction from Californian and Guatemalan jadeites.

Keywords: EPMA, infrared spectra, jadeite, Mexico, Raman spectra, SEM, XRD

Introduction

Jadeite is a well-known but uncommon mineral that is found in rocks associated with fragmental serpentinites. Described occurrences are limited to about a dozen worldwide (Harlow and Sorensen, 2005). Among the few occurrences of jadeite, only two are described from the Americas. The major deposits in serpentinite bodies along the central Motagua Valley in Guatemala served as the source of carved jade for Middle America (Bishop *et al.,* 1993; Breuckner *et al.,* 2005). The minor but well-described occurrence along Clear Creek, New Idria serpentinite, in San Benito County, California (Coleman, 1961) does not appear to have been used as a cultural source of jadeite.

Jadeite rocks from other parts of California have been reported in lapidary literature (Foshag and Leslie, 1955; Foshag, 1957; Castro and Castro, 1979; Pashin, 1995) but observations by Harlow *et al.* (2006) find them to be selvages of jadeite-aegirine combined with a variety of other minerals and generally dissimilar to jadeite-rich rocks used for carving.

Figure 1: Jadeite-bearing pebble from Baja California Sur State, Mexico.

Panczner (1989) reported the presence of jadeite from Mexico in the state of Guerrero, municipalities of Arcelia and Texco, and in the state of Mexico, municipality of Tejupilco, without any mineralogical analysis, but more recent fieldwork has not confirmed the presence of jadeite in these geological settings (Keeman, 1999). The present authors have not found a description of any confirmed Mexican jadeite in geological, mineralogical and gemmological literature.

In 2007, Eng. Jorge Diaz de Leon (Mineral Technology Company) presented to the Mexican Mineralogical Society some green rocks which had been found in the Vizcaino peninsula, Baja California Sur, Mexico. Using non-destructive infrared reflection spectrometry we established that these samples (see *Figure 1*) contain jadeite (Ostrooumov, 2007), so this is the first confirmed occurrence of jadeite in Mexico. The purpose of the present work is to characterize the mineralogical and chemical composition, spectroscopic parameters and gemmological characteristics of these jadeite-bearing rocks.

Location

The Vizcaino peninsula is a mountainous region located on the western side of Baja California. The peninsula is underlain by Triassic ophiolite, Jurassic island-arc rocks,

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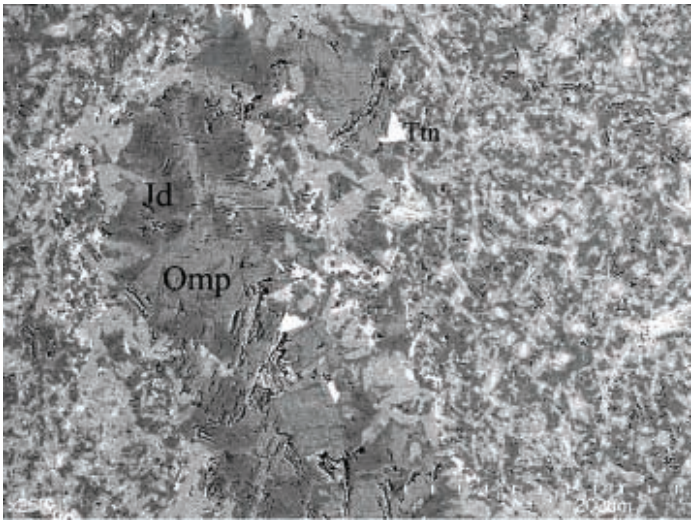

Figure 2: Back scattered electron (BSE) image of jadeite-bearing rock showing larger crystals of jadeite (Jd) and omphacite (Omp) in a finer-grained matrix which contains the same pyroxenes and some titanite (Ttn).

Mesozoic blueschist and Cretaceous submarine-fan deposits (Barnes and Mattison, 1981), overlain by a secondary deposit in which jadeite-bearing pebbles were discovered near 27°31' 40" N, 114°43' 39" W. The jadeite-bearing fragments range from a few cm to as large as 30 cm across. In our opinion, these pebbles were formed by abrasion and transportation of primary metamorphic rocks from their source in the blueschist-bearing serpentinite mélange at Puerto Nuevo. This mélange complex has been described in detail by Moore (1986).

Experimental and technical background

From a range of the green jadeite-bearing rocks three were collected for analysis. They were ground to produce flat surfaces and polished with diamond and alumina abrasives. The polished samples were microscopically imaged using a Hitachi S-4700 Field Emission-Scanning Electron Microscope (SEM) with a back-scattered electron (BSE) detector and PGT-Imix energy-dispersive X-ray spectrometric (EDS) analyser. Electron-microprobe analysis of these samples to determine concentrations of the major constituent elements in the minerals (except O) was carried out using a Cameca SX100 instrument operating at 15 kV and 10 nA sample current, employing a point beam. X-ray diffraction (XRD) analyses were obtained using a Brüker AXS-D8 Advanced diffractometer and a Brüker D8 Discover diffractometer with General Area Detector Diffraction System V4.1.27 (GADDS), both instruments with Cu-Kα monochromatic radiation.

In this study, three polished sections were examined with Raman microprobe (RMP). Their Raman spectra were recorded using the λL=514.5 nm line of an Ar+ laser with a Jobin-Yvon T64000 spectrometer equipped with a multichannel charge-coupled device (CCD) detector cooled at 77K. The samples were analyzed under an Olympus microscope with 50× and 100× objectives giving 2 µm spatial resolution. Infrared spectra were collected using a Tensor 27 FTIR spectrometer (Brüker) with a Hyperion microscope and Variable Angle Specular Reflectance Accesory (VeeMaxII, PIKE Technologies), accumulating 100 scans at a resolution of 4 cm^{-1}. The UV-Visible-NIR absorption spectra were recorded from 200 to 2500 nm using a Perkin-Elmer LAMBDA 900 microspectrometer operating at 1 nm resolution. Regions of 100 µm in diameter with homogeneous colour and nearly free of inclusions were chosen for spectroscopic measurements.

Results and discussion

Mineralogical and chemical composition

The main mineral phases in the Mexican jadeite assemblages are jadeite (pale green), omphacite (dark green), aegirine (green to black) and albite *(Figure 2)*. Also visible under the microscope is a network of very small prisms overgrown by a matrix of impure jadeite. There are sporadic grains of colourless titanite and analcime which are surrounded by overgrowths on omphacite prisms. Some less common minerals present are zoisite, allanite and celsian *(Table I)*.

This mineralogical assemblage differs from that of jadeite rock from Guatemala which commonly contains quartz, white-brown mica (phengitic muscovite, paragonite, phologopite and preiswerkite), amphibole (actinolite, taramite) and some typical accessory minerals (titanite, rutile, zircon, apatite and chlorite), and also from the jadeitites of the New Idria serpentinite (San Benito County, California) which contain quartz, lawsonite and zircon.

Fifty-five pyroxene analyses were obtained and typical compositions are shown in *Table II*; the molecular percentages of end-members jadeite (Jd), diopside (Di, $CaMgSi_2O_6$), hedenbergite (Hd, $CaFe^{2+}Si_2O_6$), aegirine (Ac, $NaFe^{3+}Si_2O_6$), enstatite (En, $Mg_2Si_2O_6$) and ferrosilite (Fs, $Fe_2Si_2O_6$) were then calculated from them. The compositions range from Jd100 to omphacite, nominally Jd50[Di+Hd]50 but could reach as low as Jd40[Di+Hd]60. The aegirine component typically increases with omphacite content. When plotted on the ternary diagram Jadeite–(Diopside + Hedenbergite)–Aegirine *(Figure 3)*, the 55 analyses show extensive isomorphic substitution. All analysed grains of the jadeites contain iron in ferric and ferrous states. At the same time, only five analyses showed traces of Cr. Thus, the Mexican jadeites typically contain little or no chromium.

Although the rocks resemble jadeitites, the order of crystallization of pyroxene shows a trend in composition from jadeite to omphacite to aegirine. There appeared

Mexican jadeite-bearing rock: a first mineralogical and gemmological approach

Table I: Minerals accompanying jadeite in jadeitites from Mexico, California, U.S.A., and Guatemala.

Location	Mexico	California	Guatemala
Mineral			
Omphacite	•	•	•
aegirine	•		
albite	•	•	•
white mica			•
quartz		•	•
analcime	•		•
amphibole		•	•
zoisite			•
lawsonite		•	•
rutile			•
titanite	•	•	•
zircon		•	•
other	allanite celsian	diopside pectolite pumpellyite vermiculite	diopside augite chlorite banalsite nepheline apatite chlorite cymrite hyalophane graphite glaucophane

Table II: Representative compositions of pyroxenes in Baja California Sur jadeite-bearing rocks.

Oxides (wt. %)	Jadeite OM117	Omphacite OM104	Aegirine OM143
SiO_2	54.77	58.85	54.52
TiO_2	0.20	0.11	0.90
Al_2O_3	21.63	6.22	4.78
Cr_2O_3	0.00	0.00	0.06
Fe_2O_3	2.53	5.66	24.72
FeO	0.00	5.43	0.62
MgO	0.87	6.87	1.33
CaO	1.29	13.82	2.85
MnO	0.03	0.81	0.12
BaO	0.03	0.00	0.01
Na_2O	14.83	6.27	12.44
K_2O	0.01	0.01	0.00
Total	99.64	99.71	101.05
Cation numbers based on 6 O			
Si	1.997	2.008	1.972
Al^{iv}	0.003	0.000	0.027
Sum	2.000	2.008	2.000
Ti	0.005	0.003	0.025
Al	0.871	0.270	0.180
Cr	0.000	0.000	0.002
Fe^{3+}	0.065	0.157	0.689
Fe^{2+}	0.000	0.167	0.019
Mg	0.044	0.377	0.074
Ca	0.047	0.545	0.113
Mn	0.001	0.025	0.004
Na	0.986	0.448	0.894
K	0.000	0.000	0.000
Ba	0.000	0.000	0.000
Sum	4.021	4.000	4.000

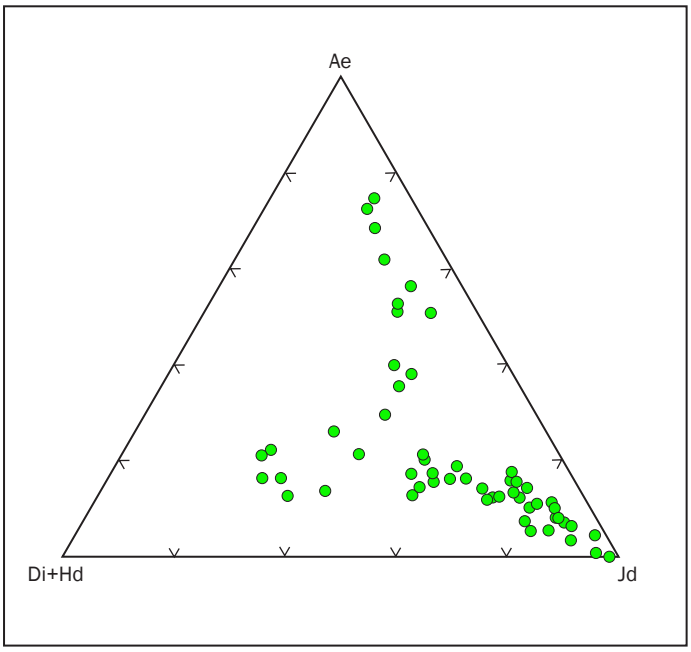

Figure 3: Individual microprobe analyses of pyroxene from jadeite-bearing rocks from Baja California Sur, Mexico, plotted as molecular proportions of diopside + hedenbergite (Di+Hd), aegirine (Ae) and jadeite (Jd) on a ternary diagram. The omphacite analyses lie in the region between jadeite and diopside + hedenbergite, and there appears to be continuous variation between these end-members.

Table III: Raman spectra (wavenumbers, cm^{-1}) of jadeite, omphacite and aegirine from Mexico compared with jadeite from the Urals.

Jadeite from Ural deposit (Ostrooumov, 1986)	Jadeite $Jd_{96}[Di+Hd]_4$	Omphacite $Jd_{50}[Di+Hd]_{40}Ae_{10}$	Aegirine $Ae_{75}Jd_{19}[Di+Hd]_6$	Assignments (Lazarev, 1995)
1038 m	1041 s	1035 s	1041 m	Si-O str (bridged)
987 m	994 m	979 m	969 s	Si-O str (non-bridged)
699 vs	701 vs	692 vs	678 vs	sym Si-O-Si str
575 m	578 w	558 w	546 m	O-Si-O def
525 m	525 w	518 w	498 w	O-Si-O def
432 m	435 w	435 w	433 vw	O-Si-O def
374 s	376 vs	368 vs	344 s	Al-O str/O-Si-O def
327 m	329 w	322 w	328 w	Al-O str/O-Si-O def
309 m	311 m	307 w	300 w	Al-O str/O-Si-O def
292 w	294 w	282 vw	280 vw	external mode
255 m	257 w	252 vw	250 vw	external mode
223 w	224 w	218 vw	208 w	external mode
204 s	205 w	201 m	183 w	external mode

N.B.: Relative intensities are denoted by: s=strong, m=medium, w=weak, v=very, sh = shoulder; assignments: str =stretch, def=deformation, sym = symmetric.

to be no compositional gaps in this trend, but unfortunately the grain size was generally too small to test whether this continuity was real *(Figure 3)*. This zoning trend, exclusive of inclusions in jadeite, has not been recorded from any other jadeite worldwide (Harlow *et al.,* 2006).

In the Mexican jadeite rock X-ray diffraction provides the possibility of precisely determining which pyroxenes are present by means of their d-spacing and intensities of some diffraction peaks. Some early X-ray investigations (Ostrooumov, 1986) have shown that omphacite and aegirine differ from jadeite in having larger d_{221} and d_{331} values and higher ratios of the intensities of these peaks. In this study X-ray diffraction investigations showed that the pale green crystals are pure jadeite with d_{221}=2.921–2.95 Å and d_{331}=2.817–2.831 Å. The d_{221}/d_{331} intensity ratio is 0.81. The diffractogram of dark green pyroxene (omphacite) was distinguished by increases in d values: d_{221}=2.931–2.982 Å and d_{331}=2.843–2.899 Å; and the ratio of intensities of these peaks increased to 0.96–1.80. The jadeite also has d_{110}=6.22–6.23 Å whereas in omphacite, d_{110} is higher at 6.344 Å. The black green pyroxene is characterized by a series of reflections at 3.162, 2.462 and 2.102 Å which confirmed that it is aegirine and thus three different pyroxene species (jadeite, omphacite and aegirine) are present in this rock.

Table IV: Infrared reflection spectra (wavenumbers, cm^{-1}) of jadeite, omphacite and aegirine from Mexico.

Jadeite $Jd_{96}[Di+Hd]_4$	Omphacite $Jd_{50}[Di+Hd]_{40}Ae_{10}$	Aegirine $Ae_{75}Jd_{19}[Di+Hd]_6$	Assignments (Ostrooumov, 2007)
1165 sh	1156 sh	1134 sh	Si-O str (bridged)
1083 vvs	1068 vvs	1062 vvs	Si-O str (bridged)
954 vs	940 vs	955 s	Si-O str (non-bridged)
926 w	912 w	905 s	Si-O str (non-bridged)
852 w	847 w	774 vw	Si-O str (non-bridged)
742 vw	741 vw	660 vw	asym Si-O-Si str
585 s	574 m	522 s	O-Al str
530 s	514 s	480 sh	O-Si-O def
468 s	460 s	454 s	O-Si-O def
433 m	420 vw	415 sh	-

N.B.: Relative intensities are denoted by: s = strong, m = medium, w = weak, v = very, sh = shoulder; assignments: str = stretch, def = deformation, sym = symmetric.

Spectroscopy and gemmological characteristics

The Raman spectrum of a jadeite jade sample from Mexico has been recorded in the wavenumber range 100–1500 cm^{-1}, and shows a very strong band at 700 cm^{-1}, two strong bands of high frequencies near 1000 cm^{-1} (990 and 1040 cm^{-1}), and two bands of low frequencies (376 and 205 cm^{-1}) which are characteristic of jadeite *(Figure 4a)*. Omphacite and aegirine show different Raman spectra (see *Table III* for comparisons).

In recent years, Infrared Reflection Spectrometry (IRS) has been widely used (Ostrooumov, 2007) to identify the different monoclinic pyroxenes. The spectra obtained by this technique can be measured from any surface with an area of 0.01–1 mm^2 and the Mexican jadeites did not require special preparation or removal from their matrix. The infrared reflection spectra of jadeite are characterized by typical bands at 1165, 1083 and 954 cm^{-1} *(Figure 4b)* and these are listed with the corresponding bands of omphacite and aegirine in *Table IV*.

Mexican jadeite-bearing rock: a first mineralogical and gemmological approach

In and near the visible range, the spectrum of green jadeite consists of absorption bands at 370, 382, 430, 437, 540, 575, 600, 830, 880 and 1170 nm. According to Langer *et al.* (1995), UV-visible-near infrared spectroscopy showed some absorption features that are related to Fe^{3+} or Fe^{2+} or to both valencies. The correlated set of bands consisting of those at 370, 382, 430, 437, 540, 600 and 830 nm show a pattern close to that characteristic of a d^5 trivalent ion in octahedral oxygen coordination. Our EPMA analyses of jadeite generally indicate the presence of some divalent iron. Spectra of ortho- and clinopyroxenes have absorption bands in the 900–1000 nm and 1150–1250 nm ranges which are assigned to Fe^{2+}, and corresponding absorption features are observed in the jadeite spectra at about 880 and 1170 nm. The simultaneous presence of both Fe^{3+} and Fe^{2+} means that intervalence charge transfer is possible and in accordance with Burns (1970), the 575 nm band is assigned to an $Fe^{2+} \rightarrow Fe^{3+}$ intervalence charge-transfer band. The typical absorption bands of Cr^{3+} in the visible region between 630 and 690 nm are absent, which is consistent with the EPMA results.

Some idea of the colour range of the Mexican jadeite rock can be obtained using the International Commission of Illumination (ICI) colour measuring system, which is based on the physiological perception of colour. This system has been found useful for describing the colour characteristics of minerals and gems (Ostrooumov, 1987 a,b; Langer *et al.,* 1995) where the colour is specified by three characteristics: (a) hue (nuance) or dominant wavelength - λ, (b) chroma, or saturation - P%, and (c) lightness - Y%.

Preliminary colorimetric calculations show that the colours of Mexican jadeite have very low saturation (P=7%) and lightness (Y=15%). Therefore they are characterized by darker colours in comparison with pure green jadeite from other deposits. The dominant wavelength of Mexican jadeite (λ=543) is a slightly yellowish green. However, this combination of colorimetric parameters defines a colour which differs from that of chromium-bearing jadeites. To take one example, measurements on the jadeites from the Polyarniy Ural (Russia) deposits yielded colorimetric parameters showing higher values of saturation (P=18-20) and lightness (Y=20-34%) and a purer green hue with λ=518-528 nm (Ostrooumov, 1986). These jadeites consequently have more attraction for the gem trade.

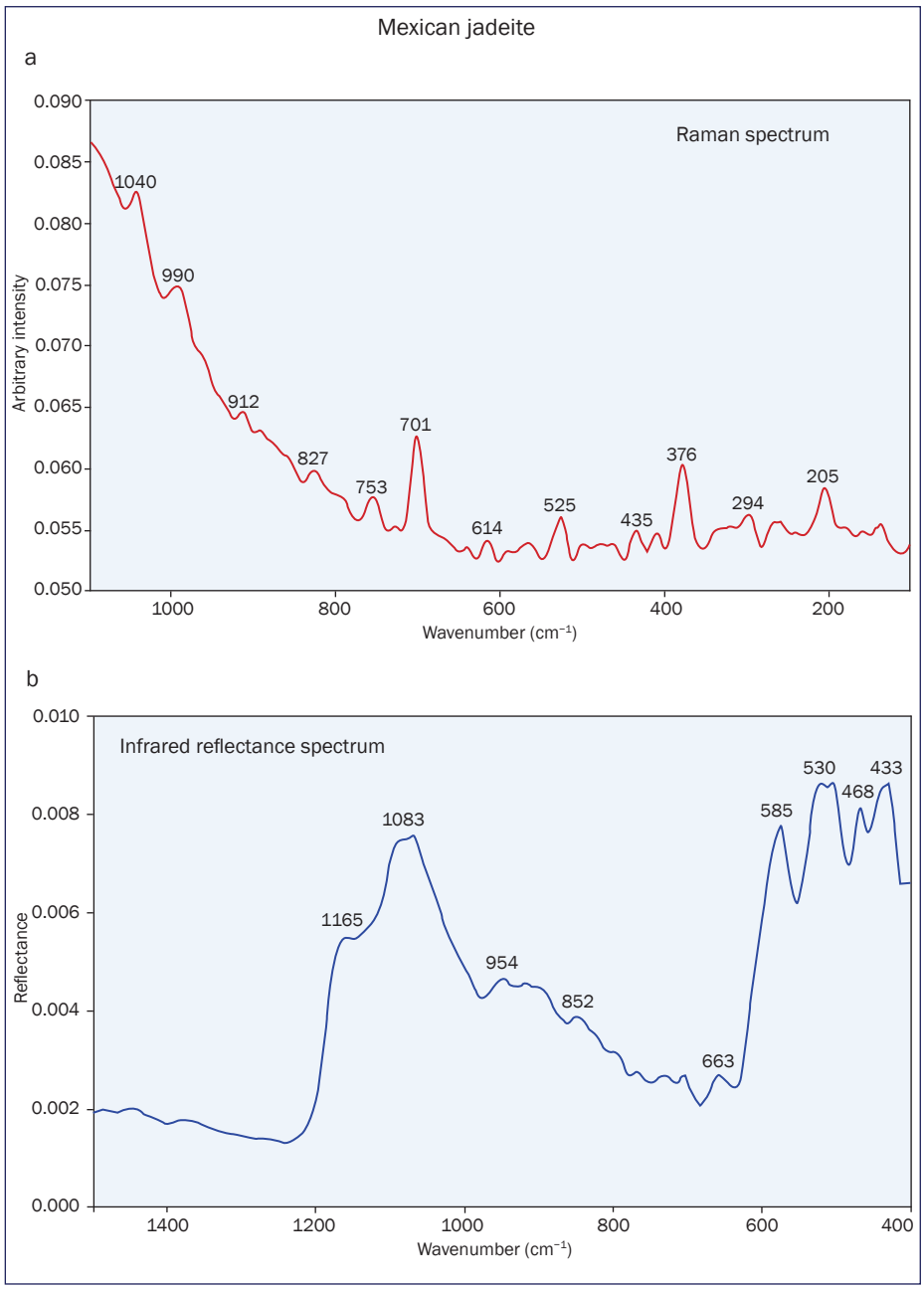

Figure 4: Raman (a) and infrared reflection (b) spectra of jadeite sample from Mexico.

The following properties were determined from three samples of rough jadeite-bearing rocks in the 1–2 cm size range:

colour	green
pleochroism	weak to moderate
RI	α = 1.654–1.668 β =1.643–1.645 γ =1.640–1.652
birefringence	0.012–0.020
hydrostatic SG	3.23–3.52
fluorescence	pale-green under long-wave and white or inert under short-wave UV radiation

Conclusion

X-ray diffraction, and chemical, spectrometric and scanning electron microscopy examinations confirmed the discovery of jadeite in the Sierra de San Andres, Baja California Sur, in northwestern Mexico. The material contains a possible blue schist assemblage and may be worthy of further study as a jadeite variant. The Sierra de San Andres jadeite rocks differ from those in California and from the Guatemalan jadeites in their associated minerals and can be distinguished on this basis. The jadeite discovery could represent an interesting mineralogical and gemmological opportunity and although the full range and economic potential of this jadeite has not been determined, it may well have features that distinguish it from other important jadeite deposits in the world.

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New data for distinguishing between hydrothermal synthetic, flux synthetic and natural corundum

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Abstract: Although the synthesis of coloured corundum became widespread long ago, it may still be difficult to distinguish some natural and synthetic specimens especially if no inclusions are visible. The analysis of oxygen isotopic composition in combination with standard gemmological measurements (especially UV spectroscopy) can prove very useful in the identification of hydrothermal synthetic and flux synthetic corundums and in distinguishing them from natural stones. The indicator of flux synthesis is the presence of a 290 nm line in the photoluminescence spectrum and hydrothermal synthetic corundums contain negative $\delta^{18}O$ values.

Keywords: corundum, EDXRF, isotope analysis, spectroscopy, synthetic corundum

Introduction

Along with diamond and emerald, gem-quality corundum (particularly ruby) commands the highest prices in the world market. Therefore finding criteria to distinguish gem-quality natural stones from synthetics is important. On the other hand, the market price of natural stones can be influenced by their geographical source and genetic type of deposit. For instance, in the early years of the last century, the best quality sapphires from lamprophyre of the Yogo Dike, Montana, U.S.A., were compared with 'Kashmir blue' sapphires, because the price of the latter was much higher (Allen, 1991). The same is true for vivid blue Sri Lankan sapphires, called 'Kashmir blue', although their prices are generally lower than Burmese 'Kashmir blue' sapphires.

The synthesis of coloured corundum became widespread on commercial production of Verneuil boules in the early twentieth century. The most common growth techniques today are Verneuil flame fusion, Czochralski pulling, flux and hydrothermal growth. Each of these methods may be used to grow large crystals of synthetic corundum in various colours, making them readily available and relatively inexpensive for the jewellery industry.

The key diagnostic feature of Verneuil synthetic corundum is the curved growth lines, best seen in dark-field illumination in pale to colourless stones or in bright-field illumination in strongly coloured stones. These lines reflect changes in growth rate, and result from minute differences in distribution of colouring agents and strain between adjacent layers. Locating curved growth lines in cut stones may present difficulties, especially with pale-coloured specimens, or with the yellow, orange and pale red (pink) varieties unless shadowing and polarization techniques are applied.

Czochralski-grown synthetic stones appear similar to Verneuil products. Careful examination reveals features allowing positive distinction from both natural corundum and Verneuil synthetics: gas bubbles, faint curved growth lines and roughly parallel rows of minute particles of unknown identity which resemble the rain-like flux inclusions found in Kashan flux rubies (Hughes, 1997). Overall, however, they are more difficult to recognize than flame fusion stones due to a generally more continuous (i.e. better controlled) growth process.

Flux and hydrothermal synthetics are relatively expensive compared to the products described above. This explains why they are not so widespread in the

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Table I: Characteristics and oxygen isotope compositions of studied samples.

Origin	Sample No.	Colour	Shape	Weight (ct)	$\delta^{18}O$‰ (SMOW)
syenitic pegmatite, Umba Valley, Tanzania	1	red	round brilliant	0.43	n/a*
	2	bluish-green	round brilliant	0.58	+9.1
syenitic pegmatite, Madagascar	3	red	rough	0.84	n/a
	4	red	rough	0.48	n/a
	5	red	rough	0.26	n/a
	6	blue	rough	2.45	+6.3
syenitic pegmatite, Potanin Mts, South Urals	7	bluish-grey	rough	1.68	n/a
syenitic pegmatite, Ilmen Mts, South Urals	8	greyish-blue	rough	1.20	+8.8
contact-metamorphic, Koltashi, Middle Urals	9	grey	rough	2.02	n/a
skarn, Pamir	10	pinkish-red	rough	8.36	+8.4
metasomatized gneiss, Khitostrovskoye, Karelia	11	purplish-red	rough	19.28	−14.7
	12	purplish-red	rough	15.34	−11.3
metasomatic margarite veinlets, Emerald mines, Middle Urals	13	blue	rough	4.31	+2.0
metasomatized gabbro, Rai-Iz, Polar Urals	14	red	rough	0.64	+3.1
metamorphic, West Keivs, Kol'skii peninsula	15	bluish-grey	rough	3.39	n/a
metamorphic, Svintsoviy stream, Khybini	16	blue	rough	0.98	n/a
'hydrothermal' breccia, Alabashka, Middle Urals	17	red	rough	1.20	+9.1
hydrothermal, Semizbugu, Kazakhstan	18	light blue	rough	0.86	n/a
skarn, Luc Yen, North Vietnam	19	red	rough	10.34	n/a
flux synthesis, CGL**	20	red	rough	0.43	+7.9
	21	pink	rough	0.35	n/a
flux synthesis, Kashan	22	red	rough	13.38	+4.8
flux synthesis, Ramaura	23	red	rough	14.66	+14.8
flux synthesis, Balitsky	24	dark red	rough	8.15	n/a
	25	dark red	rough	1.40	n/a
hydrothermal synthesis, Balitsky	26	light blue	rough	23.94	n/a
	27	black	rough	18.06	n/a
	28	brown	rough	10.71	n/a
	29	zonal: green on the edge, blue in the centre	rough	9.19	−5.0
	30	greenish-grey	rough	18.98	−0.7
	31	greyish-blue	rough	19.26	n/a
	32	grey	rough	26.06	−3.6
	33	red	rough	7.50	−1.3
	34	blue	rough	3.15	−5.8
	35	red	rough	6.32	−2.1
Summary of results from Giuliani *et al.* (2005)					
flux					+7.5 ... +18.5
Verneuil					+24.4
natural					+4.2 ... +22.7

* Not available

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jewellery market and their distinctive features have not been completely described.

The problem of separating synthetic and natural corundum is not really very challenging for a laboratory with modern testing methods such as microscopy, FTIR, UV-Vis and EDXRF spectrometry. However, experience in the identification of natural and synthetic corundum indicates that standard gemmological techniques occasionally may not be sufficient to distinguish for certain between natural, flux-grown and hydrothermally grown stones.

Here we consider two additional techniques, excitation spectroscopy and oxygen isotope analysis, to see whether these could contribute to the reliability of the testing procedure. In addition, isotopic study can help in the recognition of the genetic type of the source deposit of a corundum and occasionally in its geographical location.

Oxygen isotope contents in rubies and sapphires from 106 deposits worldwide were published by Giuliani *et al.* (2005), but the study contained no data on corundum from Russian deposits. Isotope data on some flux synthetic corundums were published by Polyakov and Ustinov (1997), but data for hydrothermal synthetic corundum have not been found.

Materials and methods

In this study we have used hydrothermal and flux synthetics and natural corundum from Russian deposits *(Figure 1)* in addition to natural corundums from Madagascar, Tanzania and Vietnam.

Thirty-five rough and cut samples of natural corundum from the deposits mentioned above, synthetic corundum grown by the flux method in the laboratories of Ramaura, Kashan, Balitsky and Lomonosov Moscow University (Moscow, Russia), and synthetics grown by the hydrothermal method in the laboratory of Balitsky (IEM, RAS, Chernogolovka, Russia), were studied using optical microscopy, spectroscopic techniques (IR, UV-absorption and photoluminescence analysis) and oxygen isotope analysis. Every specimen was prepared as a transparent slice with two parallel faces parallel to the *c*-axis.

The studied stones are red, blue, grey, green, pink, black and brown, and range in weight from 0.26 to 26.06 ct *(Table I)*. As natural red corundum is the most expensive variety, UV-absorption and photoluminescence data were obtained especially for them, as well as for some sapphires of other colours.

EDXRF analysis was carried out with a Camebax SX50 microanalyser using an accelerating voltage of 15 kV and current of 40 nA.

IR and UV spectra were recorded with a Fourier transform infrared spectrometer FSM 1201 and a UV spectrophotometer Lomo SFL-1 with xenon emission lamp respectively (both at room temperature), in the Gem Research Laboratory of Lomonosov Moscow State University. The wavenumber range of FTIR spectra was 400–4000 cm^{-1} with a resolution of 1 cm^{-1}; for UV spectra the wavelength range was 200–400 nm with a resolution of 0.1 nm.

Oxygen isotope compositions were measured on a mass-spectrometer MAT-250 in GEOCHI RAS, Moscow, Russia. The measuring procedure is standard and described by Faure (1986). Small samples are ground into powder to prepare solutions; to avoid contamination of oxygen values by included phases, microsamples were taken locally from pure corundum areas. After measuring the oxygen isotopes, δ values were calculated as described by Hoefs (1997).

Figure 1: Russian localities of corundum. The numbers correspond to those listed in Table I.

Results and discussion

Microscopic observation of corundum is especially useful when a stone contains foreign inclusions, inhomogeneous coloration or visible growth and strain features. Inclusions in corundums of different genesis are shown in *Figure 2*. While inclusions of minerals are indicators of natural genesis *(Figure 2a)*, flux and platinum or iridium particles indicate flux-grown stones *(Figure 2b)*. The distinctive feature of hydrothermal synthetic corundum is the presence of parallel undulating growth structures within the stone *(Figure 2c)*.

EDXRF data were obtained for 14 natural corundums from different deposits (*Figure 3a*), five flux synthetic samples and five hydrothermal synthetic samples (*Figure 3b*). The results show that

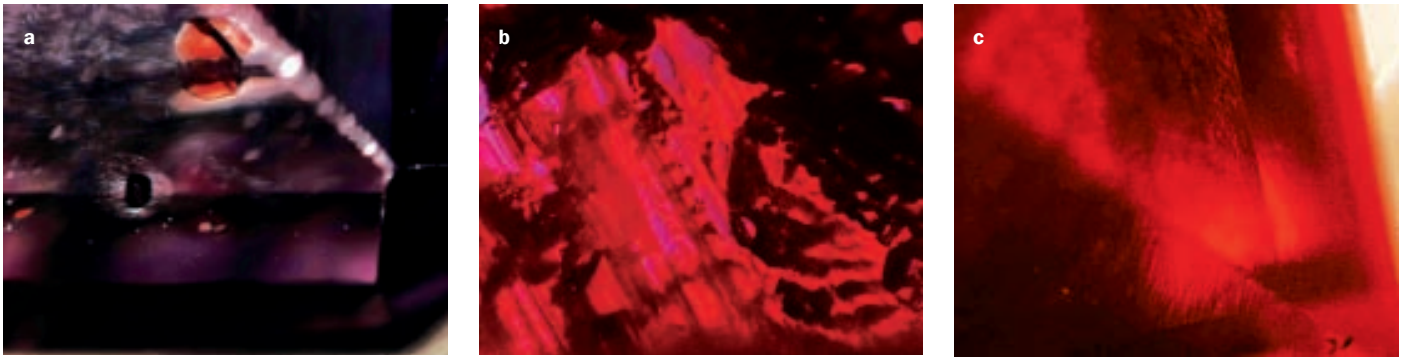

Figure 2: Inclusions in corundums of different genesis: (a) mineral inclusion (possibly rutile) in natural sample No. 1; (b) flux inclusions in flux-grown corundum sample No. 20; and (c) parallel undulating growth features in hydrothermal synthetic-grown corundum (sample 32, partially faceted).

there are three main impurity elements in corundums: chromium, iron and gallium. Their proportions are different in samples from different deposits due to various fluid and host rock compositions. So these proportions can be used to indicate a locality or growth laboratory. The diagrams in *Figure 3* show two genetic groups of natural sapphires: from deposits with syenitic pegmatite (Ilmen and Potanin Mountains, South Urals; Madagascar; Umba Valley, Tanzania) and desilicated and hydrothermal rocks (West Keivs, Kol'skii peninsula; Svintsoviy stream, Khybini; Koltashi, Middle Urals; Emerald mines, Middle Urals). The former appear to have high proportions of iron and low proportions of gallium, while the latter contain less iron and more gallium. The diagram of synthetic specimens shows no distinctive features for hydrothermal synthetics, but low proportions of iron in flux specimens is notable.

The FTIR spectra of the hydrothermal synthetic samples showed relatively strong absorption bands related to OH-complexes in the 3600–3100 cm^{-1} region:

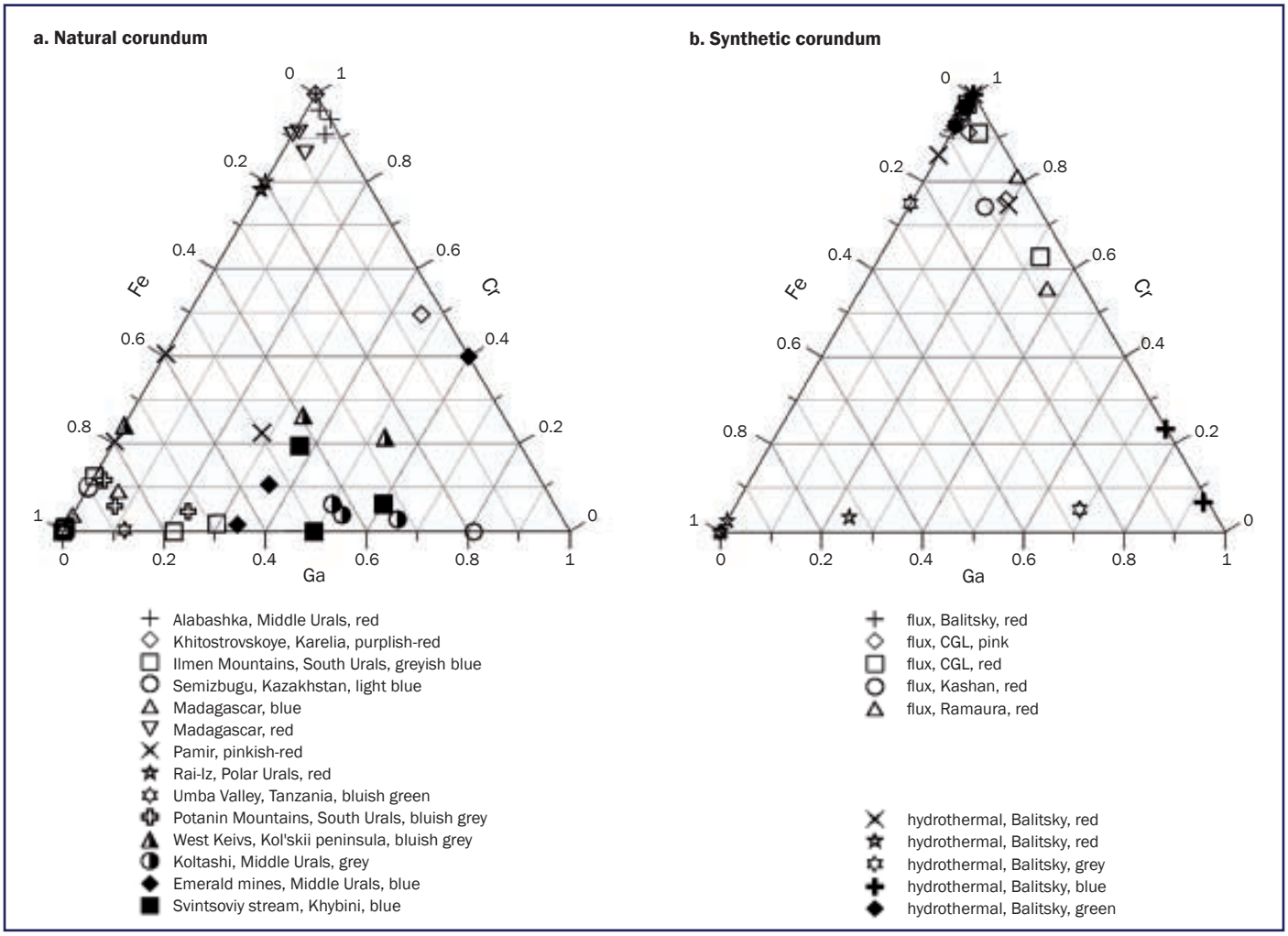

Figure 3: Cr, Ga and Fe proportions in weight percent in (a) natural corundum and (b) synthetic corundum, analysed in this study. See Table I *for descriptions of the samples.*

3193, 3209, 3233, 3262, 3289, 3304, 3384, 3484, 3564 and 3586 cm^{-1} *(Figure 4)*. The 'water' bands were much less evident in the spectra of the natural stones. In spite of the fact that hydrous components and water in infrared spectra of natural corundum vary greatly from sample to sample and depend on OH incorporated in the corundum structure, hydrous natural inclusions and healed fissures, they are distinctly different in pattern from the spectra of hydrothermal synthetics. The flux synthesis uses pure Al_2O_3 with minor added metals but not water and so 'water' bands are absent from FTIR spectra of flux synthetic corundum.

To distinguish between natural and flux rubies their photoluminescence and UV absorption spectra were studied. The excitation spectra of red chromium photoluminescence (which generates an emission line at 693 nm) showed a series of broad bands with maxima at 380, 390, 450 and 500 nm in all samples. Also there was an excitation band centred at 290 nm that was seen in spectra of synthetic rubies only, with both high and low contents of iron (*Figure 5,* left). The band at 290 nm is caused by an electron transition due to F^+ complexes (anion vacancies with one electron) found in pure single crystals of synthetic corundum (α-Al_2O_3) grown by the Verneuil method and by the method of directed crystallization (Syurdo *et al.,* 1998). The emission region for the 290 nm excitation in our case lies between 490 and 380 nm, and so may excite red chromium fluorescence.

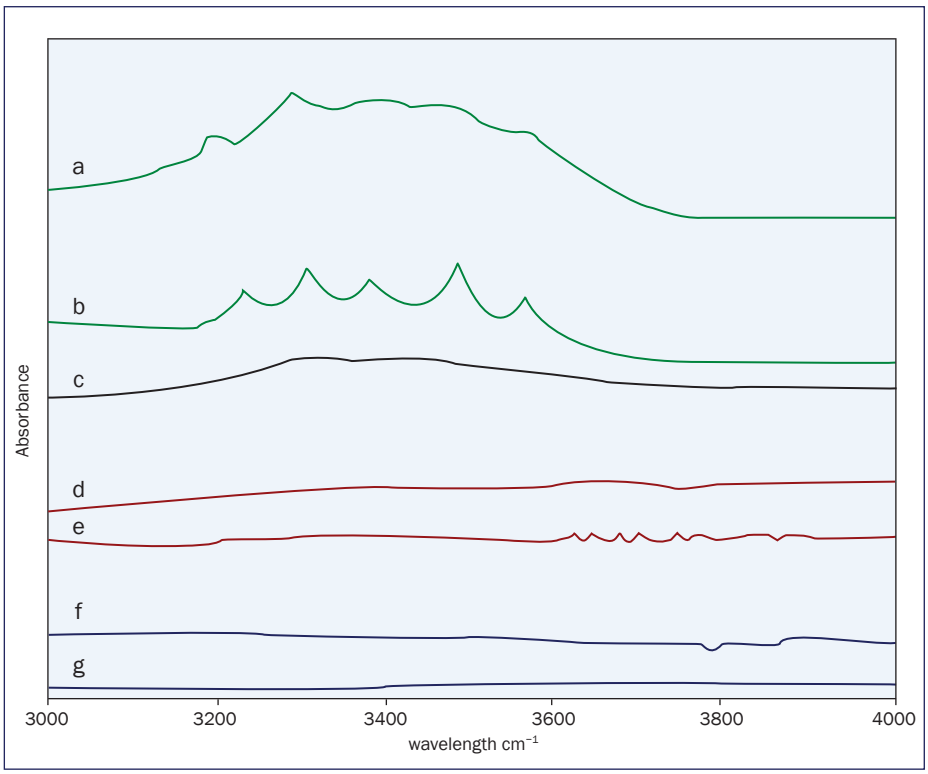

Figure 4: The 'water' bands in the IR spectra of synthetic and natural corundum. Hydrothermal synthetic: (a) sample No. 30, (b) sample No. 33, (c) sample No. 29. Natural: (d) sample No. 5, (e) sample No. 10. Flux synthetic: (f) sample No. 20, (g) sample No. 25.

Distinctive features were revealed in the UV absorption spectra of the investigated stones. In addition to common chromium and iron absorptions, there is a band at 342 nm in the spectra of the flux rubies (*Figure 5,* right). The

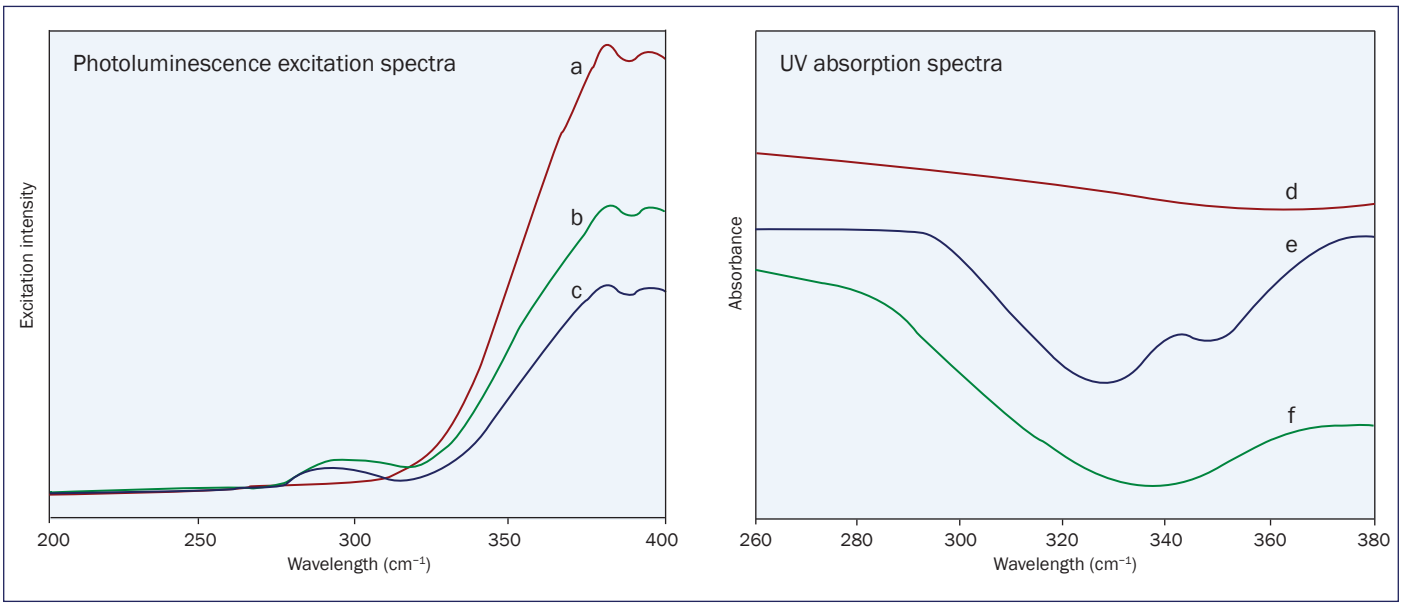

Figure 5: Details of the photoluminescence excitation spectra of Cr in Al_2O_3 (left) and UV absorption spectra (right) of natural and synthetic corundum. (a) Natural, sample No. 4; (b) hydrothermal synthetic, sample No. 35; (c) flux synthetic, sample No. 23; (d) natural, sample No. 14; (e) flux synthetic, sample No. 24; (f) hydrothermal synthetic, sample No. 35.

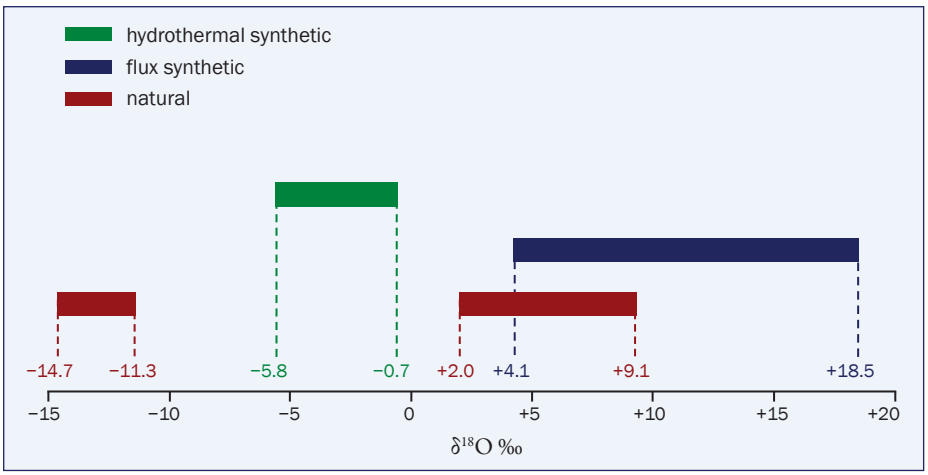

Figure 6: The oxygen isotopic composition ranges of corundums from different sources. The chart includes data for flux-grown corundum from Giuliani et al. *(2005).*

reason for this line is not known and further studies using a large collection of different flux corundums should be undertaken. Quantitative and non-destructive UV absorption spectrometry has also been described by Bosshart (1982).

The oxygen isotope compositions of corundum from igneous, skarn, hydrothermal and metamorphic deposits in Russia, and of some flux and hydrothermal synthetic corundums, are listed in *Table I*, see also *Figure 6*.

The $\delta^{18}O$ values for most natural samples lie in the range from +2.0 to +9.1‰, and taking into account published data (Giuliani *et al.,* 2005) this range increases up to +23.0‰; the one exception concerns corundums from the Khitostrovskoye deposit, Karelia, Russia, where this value lies in the range −14.7 and −11.3‰. Oxygen isotopic composition of flux corundum (+4.1 – +14.8‰) is similar to that for natural corundum.

The literature information about oxygen isotopic composition of hydrothermal synthetic corundum is limited. The work of Pomian-Srzednicki, 1997, for example, contains only one specimen of such material: hydrothermal synthetic corundum from Novosibirsk, Russia, with a $\delta^{18}O$ value of −11.5‰. Oxygen isotope compositions of six hydrothermal synthetic corundums of different colours in the present study indicate that their $\delta^{18}O$ values are distinctly different from natural and flux corundum, ranging from −5.8 to −0.7‰.

The oxygen isotope compositions of these studied corundums reflect the source compositions of water involved in their crystallization. The unusual $\delta^{18}O$ value for natural corundum from Khitostrovskoye is negative, and we postulate that fluids involved in its generation could well have involved predominantly meteoric water, while for other natural corundums, meteoric water was negligible.

Conclusions

Spectroscopic and isotopic studies of natural corundum from different deposits, as well as synthetic corundum grown by flux and hydrothermal methods have revealed some distinctive features:

1. PL excitation spectroscopy may allow one to determine whether the studied stone is natural or synthetic. The 290 nm excitation band due to F^+ complexes was found only in synthetic corundum (both flux and hydrothermal).
2. For identifying flux-grown corundum, UV-absorption spectroscopy can be useful, as a narrow band with a maximum at 342 nm occurs only in their spectra.
3. New oxygen isotope compositions of hydrothermal synthetic corundums and of natural corundums from different deposits allows one to distinguish between them very clearly. The differently coloured hydrothermal synthetic corundums have $\delta^{18}O$ values ranging from −5.8 to −0.7‰, which are distinct from those of nearly all natural and flux specimens which are more than +2.0‰. The corundums of the Khitostrovskoye deposit, Karelia, Russia, are unusual in having very low $\delta^{18}O$ values from −14.7 to −11.3‰; this allows us to distinguish the stones from this deposit. The main disadvantage of isotope analysis for gem testing is that it is a destructive technique, so studies are best carried out on rough corundum.

Acknowledgements

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A cautionary tale about a little-known type of non-nacreous calcareous concretion produced by the *Magilus antiquus* marine snail

Thomas Hainschwang, Thomas Hochstrasser, Irka Hajdas and Wolfgang Keutschegger

Abstract: Four most unusual objects represented as gastropod-shaped non-nacreous pearls (calcareous concretions) were analysed at the GEMLAB laboratory by standard gemmological and laboratory techniques. They were consistent with natural non-nacreous pearls, but these methods did not provide unambiguous proof that the samples are or are not unusual fossilized gastropods or something else. Therefore the objects were subjected to scanning electron microscopy and finally to a method only rarely used in the gemmological field — ^{14}C age determination. Results were still inconclusive until consultation with malacologists and conchologists led to the conclusion that the specimens are natural and belong to the species *Magilus antiquus*. Their terminology is discussed

Keywords: aragonite, calcareous concretion, calcite, flame pattern, non-nacreous pearl

1. Introduction

Challenges are a daily routine in a gemmological laboratory, but there are times when you are confronted with something that neither you nor your colleagues have ever seen; this paper describes such an event and how it was finally resolved.

Although natural nacreous and non-nacreous pearls are found in a wide variety of different molluscs around the globe, in fresh- and salt-water, due to environmental circumstances natural pearls are becoming increasingly difficult to find from many sources (Strack, 2001). The Philippines is one of the few countries where natural nacreous and non-nacreous pearls are still being found in appreciable but still very limited quantities. In past years the authors have examined many different and exotic natural pearls from this and other locations, but the four gastropod-shaped objects described as pearls and submitted to the GEMLAB for identification were by far the most unusual to date.

It is known that objects or animals trapped within a mollusc may end up as blisters or even as blister pearls, since the mollusc reacts to the intrusion of an object/animal with the formation of nacre (Strack, 2001). Therefore worms, small bivalves and even fishes can be found within blister pearls. Such intruder-formed blisters are often at least partially hollow and the object/animal can always be found in the interior (Hainschwang *et al.,* 2009).

If the gastropod-shaped objects described in this paper are pearls that would indicate that the captured gastropods had not been covered by $CaCO_3$, but that the hollow shells of the animals had been completely filled by the pearl substance. The difficulty of explaining the formation of such pearls and their unusual shapes raised doubts about their identity and the final task was to investigate whether they were counterfeits, fossilized gastropods or some other type of material.

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2. Materials and Methods

Figure 1: The largest gastropod-shaped sample of 84.77 ct, represented as a natural non-nacreous white pearl. Photo by T. Hainschwang.

Four non-nacreous white gastropod-shaped specimens weighing 7.06, 14.99, 19.74 and 84.77 ct *(Figure 1)* were studied.

They were examined using light microscopy, fluorescence microscopy, scanning electron microscopy, ultraviolet visible near infrared (UV-Vis-NIR) spectroscopy, Fourier transform infrared (FTIR) spectroscopy, photoluminescence spectroscopy, energy dispersive X-ray fluorescence (EDXRF) and scanning electron microscope/energy dispersive X-ray (SEM-EDX), chemical analysis, radiography and finally ^{14}C age determination.

Microscope observations were made in reflected light and darkfield illumination using a Leica M165C binocular microscope equipped with a Schott LED light source and a Leica DFC420 CCD microscope camera with a resolution of 5 megapixels. Luminescence of the samples was observed using a standard long wave and shortwave ultraviolet radiation lamp (365 and 254 nm respectively) and by the prototype of the GEMLAB fluorescence microscope using a selectively filtered 200 W xenon light source adjustable to a tuneable monochromatic excitation light source whenever necessary.

SEM imaging and semi-quantitative chemical analysis were carried out using a Zeiss Supra 40VP scanning electron microscope equipped with an EDAX Genesis 2000 EDX spectrometer at the research facilities of Ivoclar in Schaan/Liechtenstein.

Specular reflectance infrared spectra of all specimens were recorded in the range of 4000–400 cm^{-1} at 4 cm^{-1} resolution with a Perkin Elmer Spectrum BXII FTIR spectrometer. The instrument was equipped with a DTGS detector and a KBr beam splitter. A Perkin Elmer fixed angle specular reflectance accessory was used for experiments.

Reflectance UV-visible-near infrared absorption spectra in the 240–1050 nm range were recorded for two samples with the prototype of the GEMLAB Xenon UV-Vis-NIR spectrometer system with a resolution of 0.6 nm; the samples were examined in a reflectance setup within a custom made integration sphere.

Photoluminescence (PL) spectra of two specimens were recorded using a custom-built system using 532 nm and 473 nm diode-pumped solid state lasers coupled to an Ocean Optics Maya spectrometer with a resolution of 0.9 nm.

Quantitative EDXRF chemical analysis of all samples was carried out with a custom-built system equipped with a 40 kV X-ray tube and a thermoelectrically cooled Si detector; the analyses were done in air and for one sample under a helium atmosphere. Quantitative chemical analysis of one sample was carried out using the EDX system of the scanning electron microscope described above.

A ^{14}C isotope analysis of one specimen was carried out at the accelerator mass spectrometry (AMS) facilities of the Ion Beam Physics Department, ETH Zurich, for age determination. For this destructive method a small piece weighing 0.015 g was carefully removed from one of the objects and dissolved in concentrated phosphoric acid. The released CO_2 was then graphitized (Hajdas *et al.,* 2004) and pressed into cathodes for AMS measurements using a mini radiocarbon dating system (MICADAS) (Synal, 2007). In this method ions obtained from the graphite are accelerated to high kinetic energies to enable separation of the ^{14}C and ^{12}C isotopes.

For comparison, samples of aragonite (crystals, stalactitic aggregates ['eisenbluete']), calcite crystals and natural nacreous and non-nacreous pearls were analysed by FTIR, UV-Vis-NIR and photoluminescence spectroscopy as well as EDXRF chemical analysis.

3. Results and discussion

3.1. Visual observation, microscopy and luminescence

The four objects in this study apparently belong to the same species of gastropod; their form and shape are similar and there is variation in only minor details *(Figure 2)*. The samples were all non-nacreous white, semi-translucent, and their surfaces show great details of the original shell without any indications whatsoever of polishing or any other form of working, except that the original aperture of the gastropods showed indications that they were polished/worked.

All four specimens contain small holes such as that in the 7.06 ct specimen (*Figure 3a*); such holes are present in most sea shells and can be caused by drill molluscs or parasitic worms. Microscopic observation showed a distinct concentric structure in the zone of the original aperture of the shell, and in the 7.06 ct specimen there is a central grain surrounded by darker matter (*Figure 3b*).

A faint flame pattern is present in all samples but only clearly visible when the surface of the pearls was viewed carefully under the microscope *(Figure 4)*. Such a flame pattern is characteristic for certain non-nacreous pearls, of which the pink to orange pearls from *Strombus gigas* and *Melo melo* gastropods are the best known (Hänni, 2009; Strack, 2001). Besides

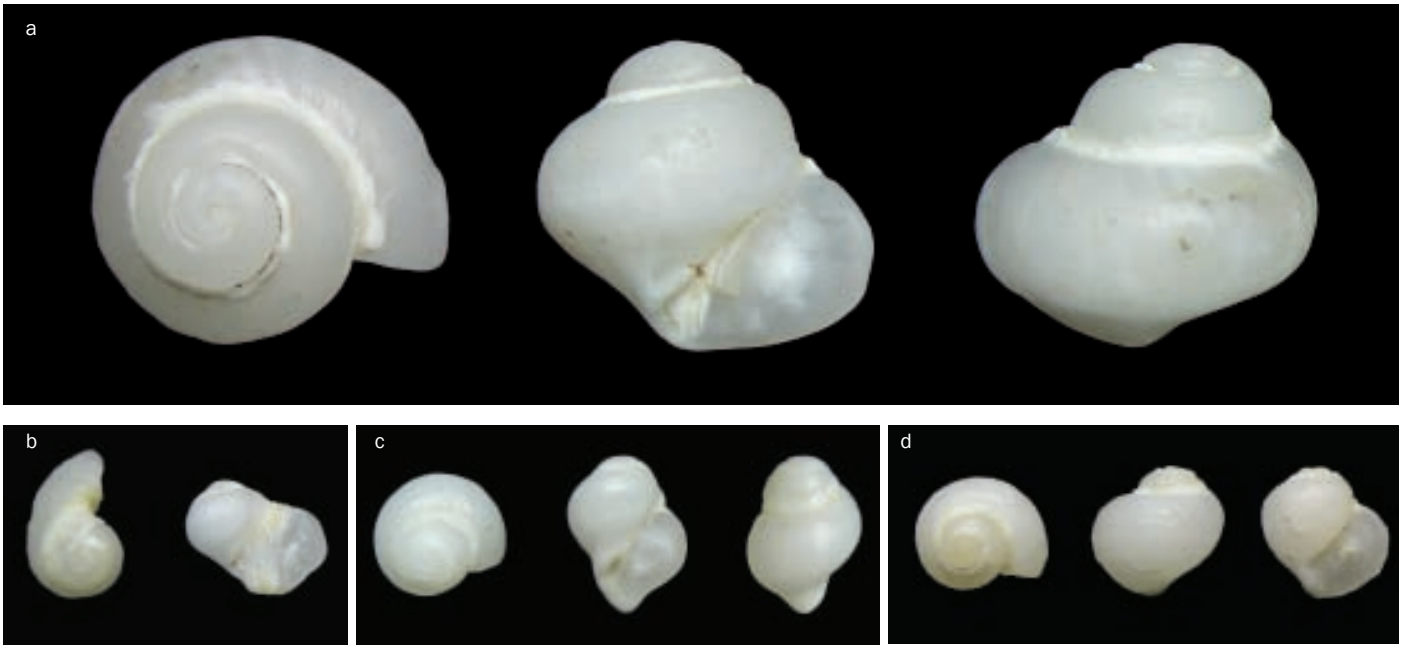

Figure 2: Different views of the four specimens examined in this study: (a) 84.77 ct, (b) 19.74 ct, (c) 14.99 ct and (d) 7.06 ct. The general shape of the specimens indicates that they belong to the same or a very similar species of gastropod. Photos by T. Hainschwang.

these pearls, this kind of flame pattern is also known from other non-nacreous gastropods and certain bivalve molluscs.

Under intense UV illumination, as used in the GEMLAB fluorescence microscope, all specimens exhibited a distinct blue fluorescence, reminiscent of the emission known for many pearls. In three specimens a lighter and yellower fluorescence was visible in the central portion of the gastropods' original aperture *(Figure 5)*. This emission followed the most evident concentric structures visible.

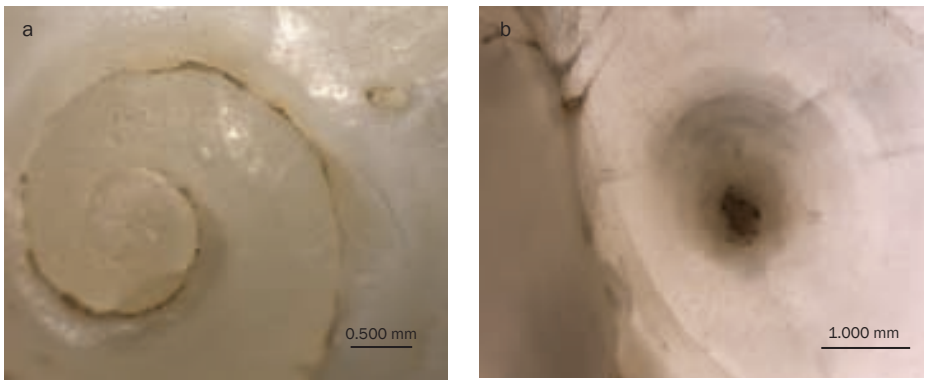

Figure 3: Close-up views of the 7.06 ct specimen: (a) view of the spiral and of a parasite-caused drill hole; (b) the concentric structure and central grain at the original aperture of the gastropod. Photos by T. Hainschwang.

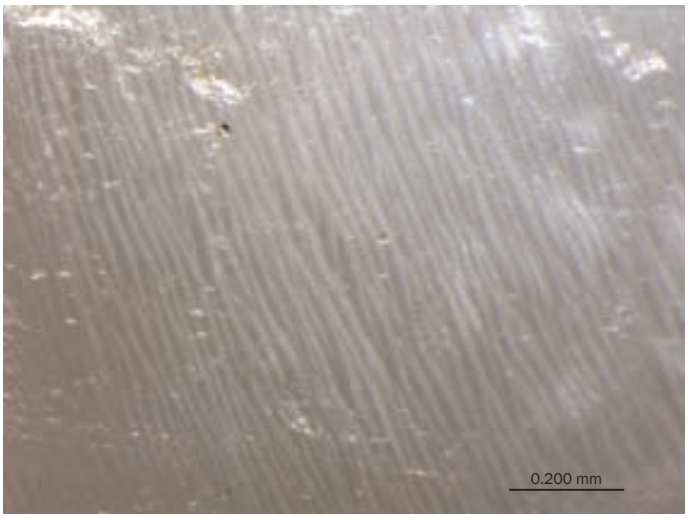

Figure 4: The fine flame pattern seen in the largest specimens, as seen in reflected light. Photo by T. Hainschwang.

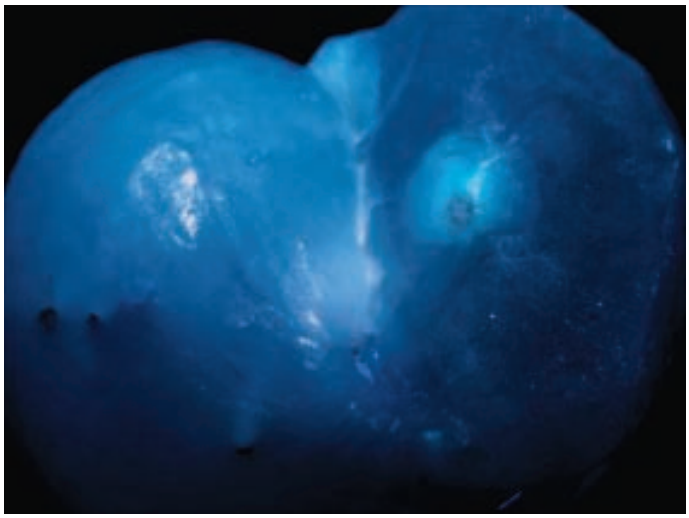

Figure 5: The 7.06 ct gastropod-shaped specimen under strong UV excitation shows distinct zoning at the gastropod's original aperture. Photo by T. Hainschwang.

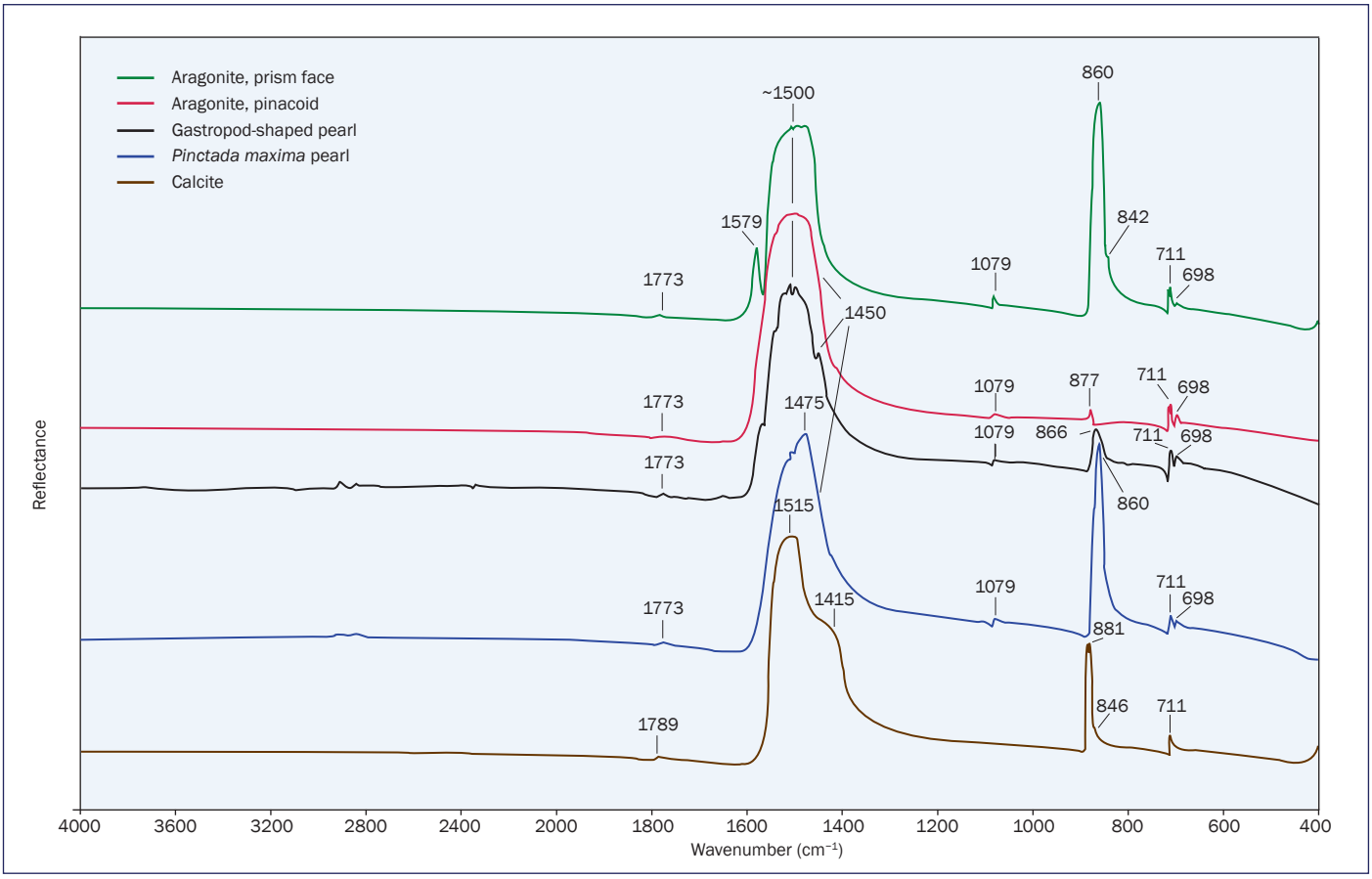

Figure 6: Specular reflectance infrared spectra of aragonite, calcite, a non-nacreous white pearl and a gastropod-shaped sample.

The initial results from these classical gemmological approaches seemed to indicate that the gastropod-shaped specimens were neither forgeries nor fossils; at the time of analysis in the laboratory it was believed that non-nacreous pearls and certain sea shells were the only materials exhibiting the characteristic flame structure visible in *Figure 4*. The lack of banded layers in strong transmitted light indicated that the objects could not be polished from shell, which is a common type of forgery to imitate non—nacreous natural pearls. The specimens appeared to be most unusual pearls, but the fact of the existence of such gastropod-shaped pearls would contradict all classical explanations of pearl formation and so further examination to try and clarify how they were formed was desirable.

3.2. EDXRF chemical analysis

Using EDXRF analyses major calcium and minor but distinct strontium were detected, a perfect match with what would be expected when testing saltwater aragonitic materials. The near-absence of manganese is consistent with a saltwater origin (Hänni *et al.,* 2005). One sample (7.06 ct) was additionally analysed by SEM-EDX, with identical results. For comparison, EDXRF data were collected for aragonite (crystals, stalactitic aggregates ['eisenbluete']), calcite crystals and natural nacreous and non-nacreous pearls. The chemical compositions of the nacreous and non-nacreous pearls were practically identical, while the aragonite and calcite mineral samples all contained significantly lower strontium.

3.3. Specular reflectance FTIR spectroscopy

Specular reflectance FTIR spectra recorded from all specimens confirmed that their main constituent is aragonite. The commonest polymorphs of $CaCO_3$ — calcite and aragonite — can be easily distinguished using this method since their band positions vary slightly and aragonite also exhibits weak features around 1085 cm^{-1} and 697 cm^{-1} which are absent in the calcite spectra *(Figure 6)* (Hainschwang and Notari, 2008). Certain non-nacreous pearls are calcitic (e.g. Pinna pearls), but we have not yet had a white non-nacreous pearl that was dominantly calcitic in the GEMLAB laboratory; so far all have been dominantly of aragonitic composition.

3.4. Reflectance UV-Vis-NIR spectroscopy

The spectra of all four specimens are identical to the spectra of white nacreous and non-nacreous pearls, with a strong absorption band at 285 nm; this band is characteristic for all aragonitic materials, including aragonite itself and is thus of no diagnostic value to distinguish a white non-nacreous pearl from other aragonitic materials.

3.5. PL and Raman spectroscopy

The PL spectra recorded with 473 nm

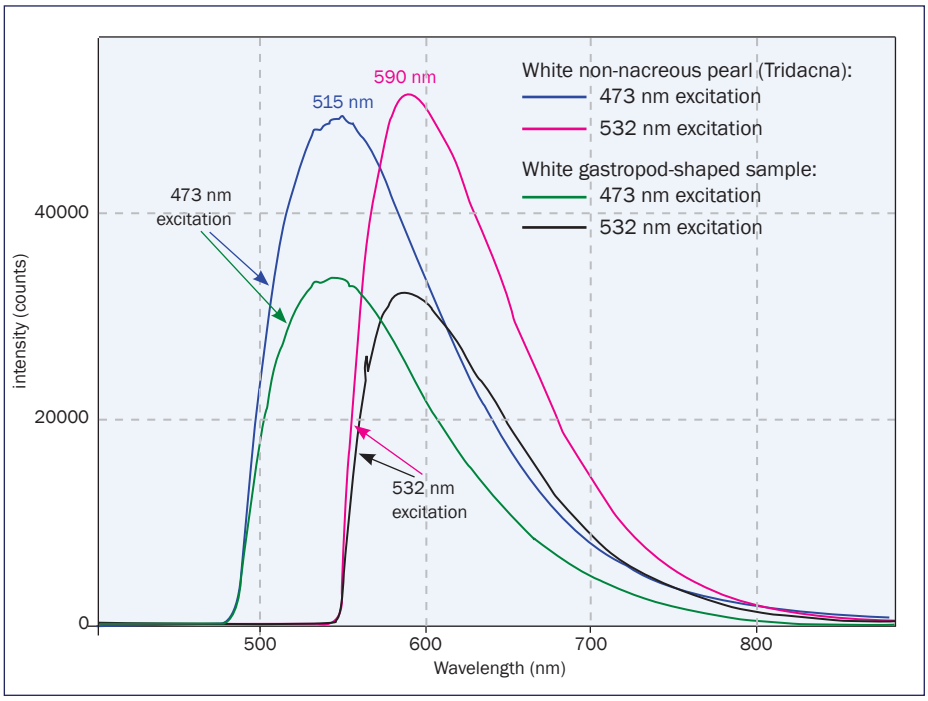

Figure 7: The PL spectra excited with 532 and 473 nm lasers of a non-nacreous white pearl and a gastropod-shaped sample (left), compared to aragonite ('eisenbluete') and calcite (right). The sharp features present and indexed in the graphs are Raman scattering peaks.

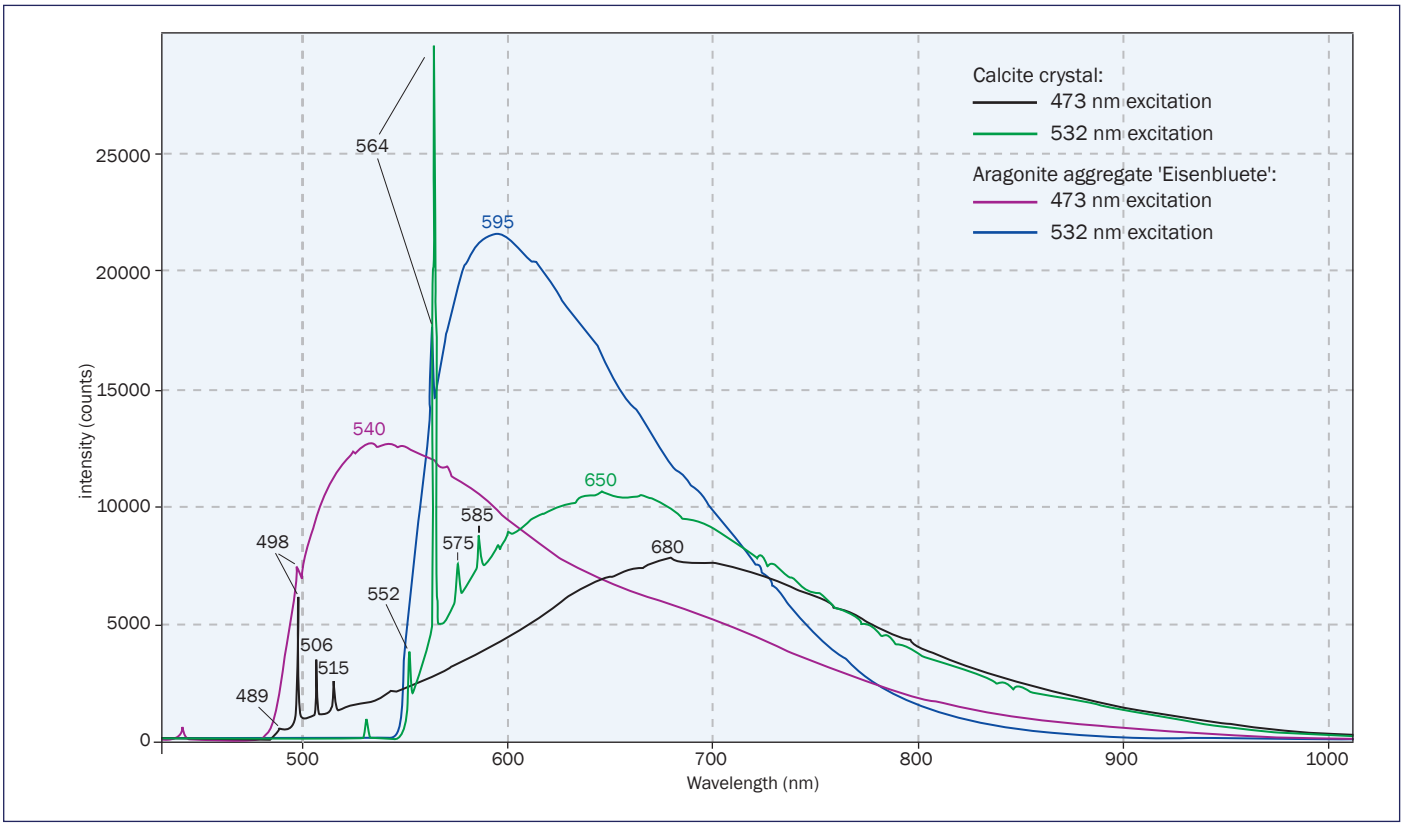

and 532 nm laser excitation are identical to the spectra obtained from non-nacreous white pearls. The spectra consist of a simple broad band emission centred at about 545 and 590 nm respectively with sharp peaks corresponding to the Raman lines of aragonite. The fibrous aragonite 'eisenbluete' samples that were used for comparison exhibit a very similar broad band PL while calcite shows a different broad band emission centred at 680 nm (473 nm excitation) and 650 nm (532 nm excitation) respectively *(Figure 7)*.

3.6. Radiography

Radiography of the samples revealed that the objects are all solid. Little structure is visible and no remnants of, for example, the original shell that could be trapped within the objects were found. The only significant features are the drill holes that can also be seen under the microscope *(Figure 8)*, and some of these holes cross the whole specimen. The

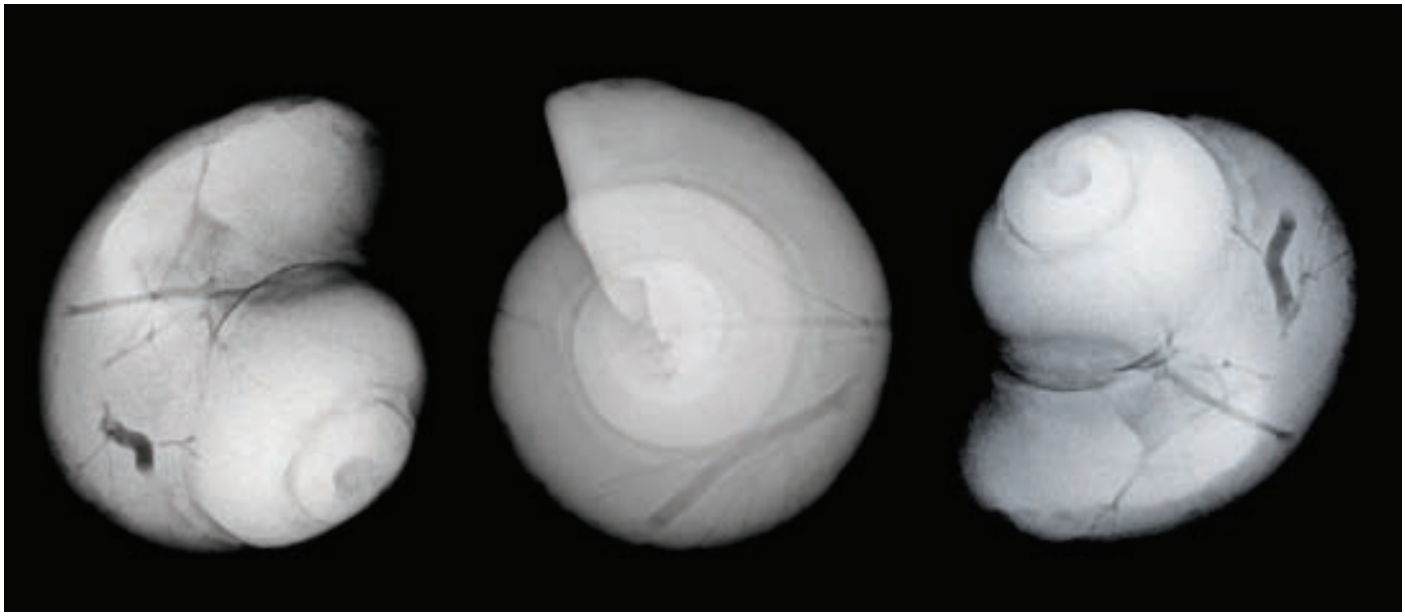

Figure 8: Radiographs in three different orientations of the largest gastropod-shaped sample. The grey linear features of variable width represent the hollow drill channels present in all the specimens.

extremely subtle structure of natural non-nacreous white pearls is — in the authors' experience — generally not visible in conventional radiography. When white non-nacreous pearls are sawn in half, there is normally no evidence of circular growth structure and only diffuse bands of slightly variable coloration can be seen.

The radiographs clearly pointed towards naturally grown solid pearl-like objects.

3.7. SEM

The 7.06 ct specimen was examined using the SEM in order to get a better picture of the structure of the material *(Figure 9)*.

The SEM images revealed platy and fibrous crystals of aragonite, which were in part arranged in a concentric structure. The fibres are not all near-parallel but are distributed in the form of 'bundles', some of which have a V-like appearance. The presence and distribution of these fibres is the reason for the flame pattern that is visible on the surfaces of the specimens (Hänni, 2009). These results are consistent with what would be expected from a natural non-nacreous pearl.

Although the presence of the concentric structure at the original aperture indicated that some of the original piece may be missing, there was no evidence of polishing; a possibility would be that part of the sample was broken off the original piece.

3.8. ^{14}C age determination

Radiocarbon dating was carried out to determine whether or not the specimens could be an uncommon type of fossilized sea mollusc.

The analysis of a small piece removed from one specimen indicates that the material was no more than 400 to 500 years old. That is, its age is well within the historical period and therefore it is not a fossil. Also, this is consistent with the fact that most aragonite transforms to calcite when aragonitic shells are fossilized. Aragonite in fossils is only known in the iridescent surface layers of so-called 'ammolite'.

4. Discussion

The data obtained using the above methods prove that the samples are not man-made forgeries, that they have not been polished from shell material and that they are not fossils. The composition of the specimens was identified as principally aragonite with distinct traces of strontium, radiography proved their solid nature and the presence of concentric growth structure combined with a very fine flame pattern due to fibrous aragonite growth in all samples, clearly points to the specimens being natural non-nacreous pearls.

Because we had no plausible explanation for the formation of solid non-nacreous gastropod-shaped pearls, we sought an expert in molluscs and shells (a malacologist and conchologist) who could identify the species that was represented by these specimens. The information obtained from two conchologists was a revelation: the specimens were confirmed to be of natural origin, but they were not formed inside another marine mollusc, but by the gastropod itself (Massin, 1982). There are some most unusual gastropods that live on and in, and feed from corals ('coral dwellers') and that grow together with the coral. Our four specimens were identified as *Magilus antiquus* (Montfort, 1810), belonging to the family Muricidae (subfamily Coralliophilinae, a name meaning 'liking coral'). When the coral grows, the *Magilus* fills up its shell with aragonite and lives on some sort of pedestal close to the surface of the coral (Oliverio, 2009, Figures 11F, G). Complete specimens usually have a rather long tube-like uncoiled shell; this solid tube-like 'prolongation' of the juvenile coiled shell is used as a 'house' by the animal, which can live close to the surface of the

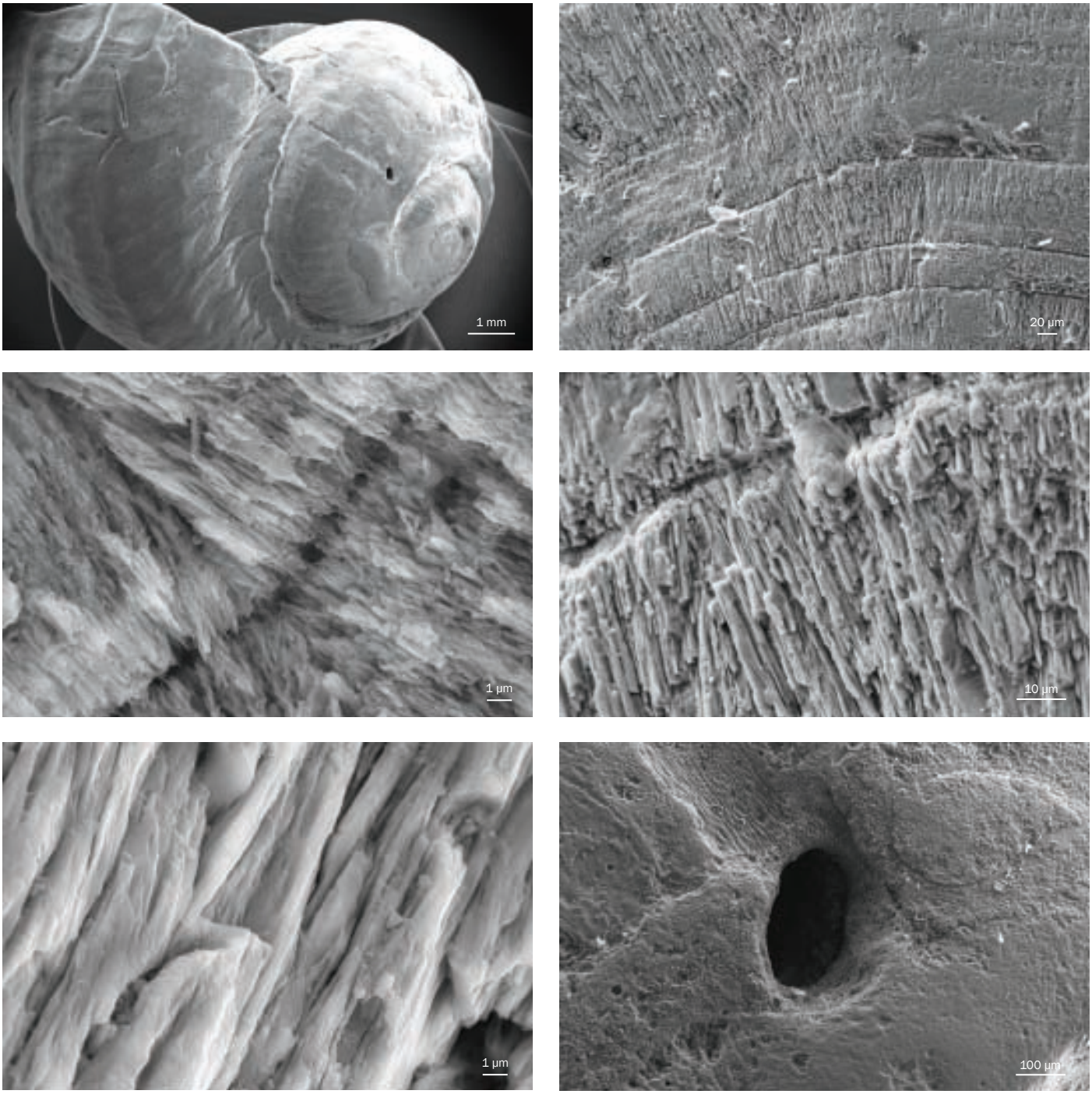

Figure 9: SEM images showing details of the gastropod-shaped specimen of 7.06 ct.

coral thanks to the pedestal. As the coral grows, the animal produces more and more aragonite to keep the pedestal at about the same distance from the coral surface. The shell of this gastropod is as white as the 'filled' pieces described in this study, but with time it becomes absorbed in the juvenile part. In the parts of the gastropod buried deeply in the coral, there is rarely any trace of the original shell remaining.

5. Conclusions

The four specimens described above constitute a clear demonstration that the utmost care must be taken before drawing conclusions about uncommon or new materials. The specimens of *Magilus antiquus* were sold as natural non-nacreous pearls and this is the basis on which they were examined. In this outstanding case the material showed exactly the same properties as the material that it was meant to imitate (a natural non-nacreous pearl); only the fact that there was no explanation for the formation of these objects finally led to the discovery of the real nature of these 'pearls'.

Concerning the nomenclature of such calcareous concretions formed by coral-dwelling gastropods, it is unclear whether they should be declared as 'non-nacreous pearls' or simply as 'calcareous concretions'; probably the

material, which demonstrably represents the filled shell of a mollusc, should be called a calcareous concretion. Although it is formed by marine gastropods, the process and motivation of the formation is quite different from that of 'regular' non-nacreous pearls and the fact that the animal lives on this formed material makes the decision on what to call these 'magilus pearls' an ambiguous one.

Despite the doubts over their name, these unusual objects could make attractive and very individual pieces when mounted in jewellery.

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Identification of CVD-grown synthetic melee pink diamond

Hiroshi Kitawaki, Ahmadjan Abduriyim, Jun Kawano and Makoto Okano

Abstract: Forty-eight faceted intense orangey-pink CVD-grown synthetic diamonds, most of which weighed less than 0.2 ct, have been examined in the GAAJ-ZENHOKYO laboratory. All proved to be coloured by the N-V centre that was formed by irradiation and annealing at low temperature after CVD synthesis and succeeding HPHT treatment. Using a combination of pinpoint inclusions and birefringence strain patterns, infrared absorption peaks in the range of 3150-2700 cm^{-1}, significant photoluminescence absorption lines at 575, 637 and 737 nm, and DiamondView™ and cathodo-luminescence images of layer growth patterns, CVD synthetic diamond can be distinguished from natural diamond. Annealing could change the colour of CVD diamond significantly from pink to purple but its colour was not stable and returned to its initial pink colour by UV radiation exposure in a short period. Features in the UV-Visible absorption spectra will be affected by annealing and UV radiation reaction.

Keywords: annealing, colour variation, crystal growth pattern, CVD-grown synthetic diamond, diamond treatment, melee

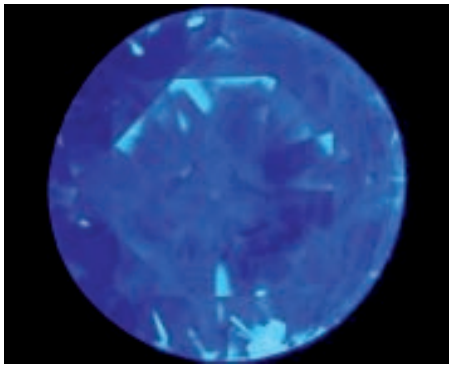

Introduction

Synthetic diamonds started to circulate in the gem market in the 1990s and became known to the gem industry. Most of such synthetics were grown by the high-pressure high-temperature (HPHT) method and the identification techniques revealed to date are all reliant on a knowledge of the growth environment or crystal forms essentially typical of HPHT synthesis. After Apollo Diamond Inc. announced their plan to sell them for jewellery use in August 2003 (Priddy, 2003), CVD-grown synthetic diamonds attracted attention first in the gem industry and then in the gemmological literature (Wang *et al.*, 2003, 2007; Deljanin *et al.*, 2003; Martineau *et al.*, 2004). Recently, fancy intense pink CVD type IIa diamonds in a size range of 0.28 to 0.67 ct and supplied by Apollo Diamond Inc. have been reported by Wang (2009).

The majority of natural pink diamonds are type I from the Argyle mine in Australia, and it is a concern for the gem trade that their price may increase due to the higher costs of moving from open-pit to underground mining. However, pink colours can also be produced in diamond containing isolated substitutional nitrogen atoms associated with vacancies (N-V centres: nitrogen vacancy pairs) by irradiation and annealing processes, and either natural or HPHT-grown synthetic diamonds with this property are used as raw material for such treatment.

Materials and methods

The samples used in this study consist of 48 loose pink diamonds, allegedly natural diamonds treated by a HPHT process, brought in to the GAAJ-ZENHOKYO Laboratory by a client for colour origin determination *(Figure 1)*. All stones are round brilliant-cut, six lie in the range 0.20–0.27 ct, and 42 in the melee size range of which seven are 0.10–0.19 ct, and 35 are under 0.10 ct.

An Olympus gemmological microscope was used to examine external features and inclusions. UV fluorescence was observed in a perfectly dark room using long- (365 nm) and short-wave (253.6 nm) UV lamps manufactured by the Manaslu Co. A Shimadzu recording

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Figure 1: Forty-eight CVD-grown synthetic pink diamonds (0.01 ct – 0.27 ct). Photo by H. Kitawaki.

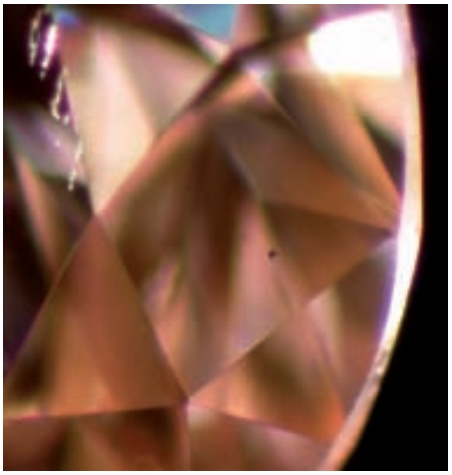

Figure 2: Black pinpoints seen in almost all samples appear dark and are irregular in shape (field of view 1 mm); they are probably non-diamond structure carbon. Photo by A. Abduriyim.

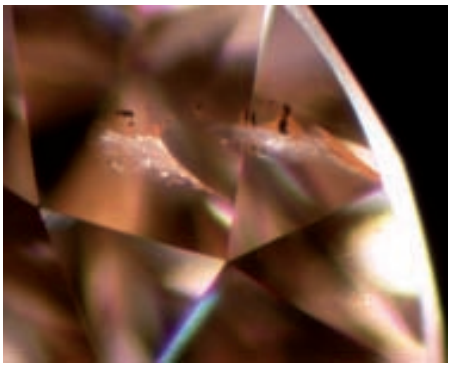

Figure 3: Traces of dark graphitization in a cleavage of CVD-grown synthetic pink diamond (right, cleavage width 300 μm). It is probably evidence of HPHT treatment. Photo by A. Abduriyim.

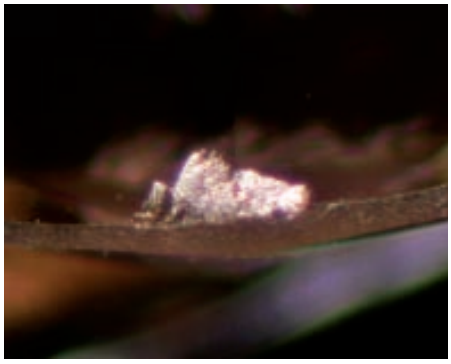

Figure 4: Etched surface resembling frosted glass in a CVD-grown synthetic pink diamond (frosted surface width 200 μm). It is probably evidence of HPHT treatment. Photo by A. Abduriyim.

spectrophotometer UV 2400 was used at room temperature for UV-Visible spectral analysis within the range 220 to 860 nm in reflection mode. Infrared spectral analysis was carried out using a Shimadzu IR Prestige-21 instrument equipped with a KBr beam splitter and DLATGS detector. The analytical range was 4000–400 cm^{-1} with resolution of 1.0 cm^{-1} and 50 scans per spectrum were collected. Photoluminescence (PL) analysis was performed with all samples being immersed in liquid nitrogen using a Renishaw inVia Raman Microscope using two lasers: He-Ne 633 nm and He-Cd 325 nm, recording ranges of 650–850 and 330–800 nm respectively. A Renishaw Raman system-model 1000 with an Argon-ion laser excitation at 514.5 nm was used to record the range 520–800 nm. UV luminescence images were observed using a DTC DiamondView™. A Premier American Technologies Corp. ELM-3R Cathodo-luminoscope was used for CL imaging. The colours and clarities of the diamonds were assessed by diamond graders using the JJA/AGL grading system, but one should note that in this system, regulations stipulate that synthetic diamonds are not graded.

Results and discussion

Gemmological observations

Among the 48 samples, colour grades ranged from fancy intense orange pink to fancy pinkish orange to light pinkish orange. The 13 stones over 0.1 ct were graded for clarity: three are VVS2, four are VS1, three are VS2, two are SI1 and one is SI2.

Most of the stones contain a few tiny pinpoints *(Figure 2)*; at high magnification they are dark with irregular shapes and are presumably non-diamond structure carbon. The pink colour is even in each stone and no patchiness in colour distribution was found. Several samples contain black graphite in their cleavages *(Figure 3)* and etched surface features resembling frosted glass *(Figure 4)*. These features are similar to those seen in HPHT-treated diamonds, so their presence strongly indicates that the samples have been HPHT treated after CVD synthesis. Many type Ia natural pink diamonds show traces of etching and almost all such stones display characteristic colour zoning described as 'pink graining'; this feature makes them clearly distinguishable from CVD-grown synthetic diamond. HPHT-grown synthetic pink diamonds which have been irradiated and annealed may be recognized by the presence of metal inclusions.

Most of the CVD-grown synthetic diamonds show double refraction in low-order interference colours in a characteristic streak pattern. The streaks run parallel with the growth direction of the crystal (when viewed through the pavilion side), parallel to {100} and were

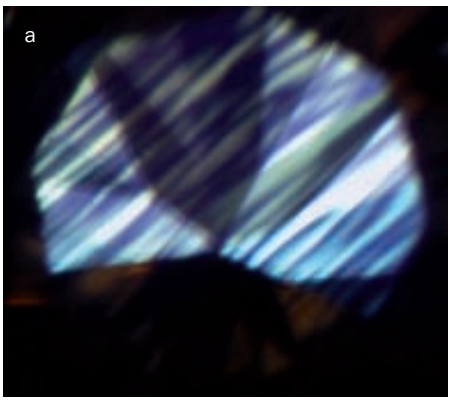

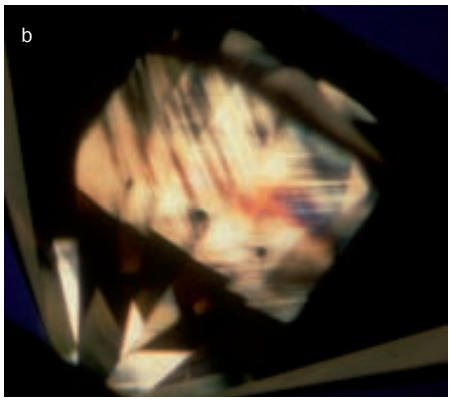

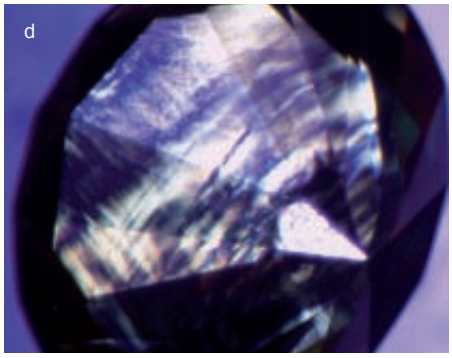

Figure 5: Four patterns of double refraction in diamond.
(a) Characteristic streak-pattern of double refraction due to strain present in CVD-grown synthetic diamond and visible under crossed polarizing filters (field of view 2.2 mm). The streaks are elongate in the direction parallel to the growth direction of the crystal, and are probably caused by linear defects (dislocations) during crystal growth. Photo by A. Abduriyim.
(b) Double refraction due to strain in natural pink diamond showing high order interference colours (field of view 4 mm). Photo by H. Kitawaki.
(c) Characteristic 'Tatami mat' structure in type II natural pink diamond under crossed polarizing filters (field of view 7 mm). Photo by H. Kitawaki.
(d) Double refraction in a CVD-grown synthetic pink diamond under crossed polarizing filters (field of view 1.4 mm). The pattern is similar to a 'Tatami mat' pattern in natural diamonds but rotation of the stone should reveal the streak pattern as in (a). Photo by A. Abduriyim.

supposedly produced by linear defects (dislocations) during crystal growth, causing internal strain *(Figure 5a)*. The kind of birefringence seen in natural pink diamond originates from plastic deformation and in most stones, strain accompanied by high order interference colours is associated with 'pink graining' *(Figure 5b)*. Rare type II natural diamonds also display strain but it appears under crossed polars as a pattern resembling a 'Tatami mat' *(Figure 5c)*. CVD-grown synthetic diamond is type IIa but some stones can show a 'Tatami mat'-like appearance if observed in directions other than the growth direction and care should be taken *(Figure 5d)*.

All the CVD-grown synthetic diamonds examined showed very strong orange fluorescence under UV, but no phosphorescence *(Figure 6)*. The fluorescence, generally stronger under LWUV than SWUV, originates from the N-V centre (associated with absorption at 575 nm), which was presumably formed as a result of the introduction of nitrogen gas to accelerate growth rate, and then by irradiation and annealing after the growth. Although some natural pink type IIa diamonds show orange fluorescence the great majority fluoresce bluish white. Irradiated and annealed natural or HPHT-grown synthetic diamonds also show orange fluorescence that originates from N-V centres.

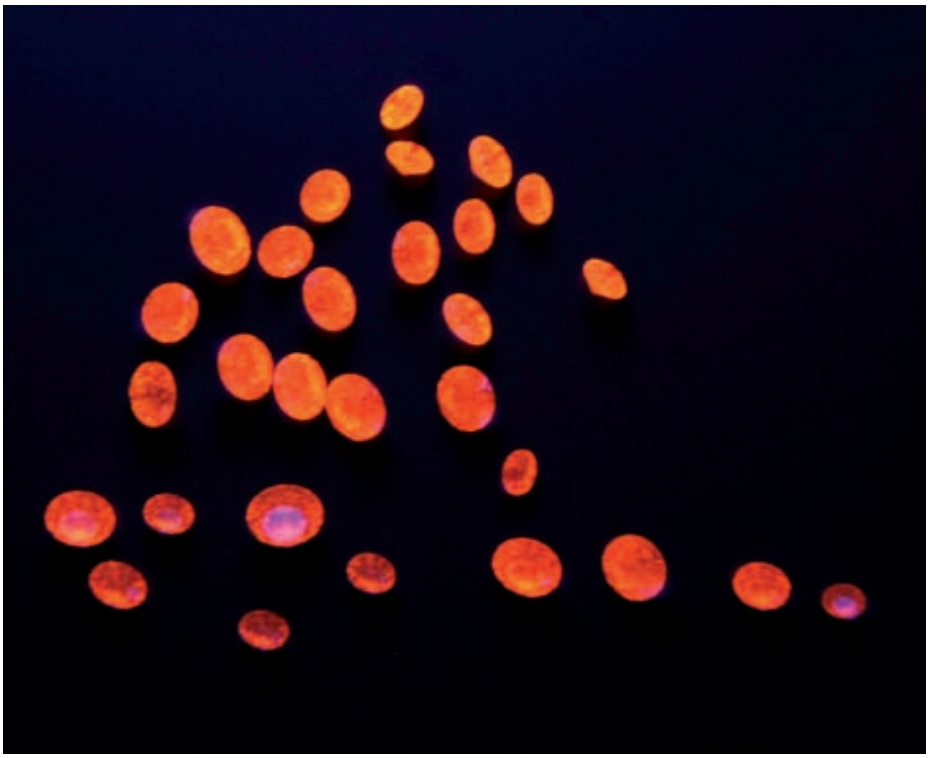

Figure 6: When exposed to long- and short-wave UV radiation, the CVD-grown synthetic diamonds display strong reddish orange fluorescence. Photo by A. Abduriyim.

Spectral analysis

UV-Vis-NIR

The UV-Visible absorption spectrum measured at room temperature and shown in *Figure 7* is representative of 13 CVD

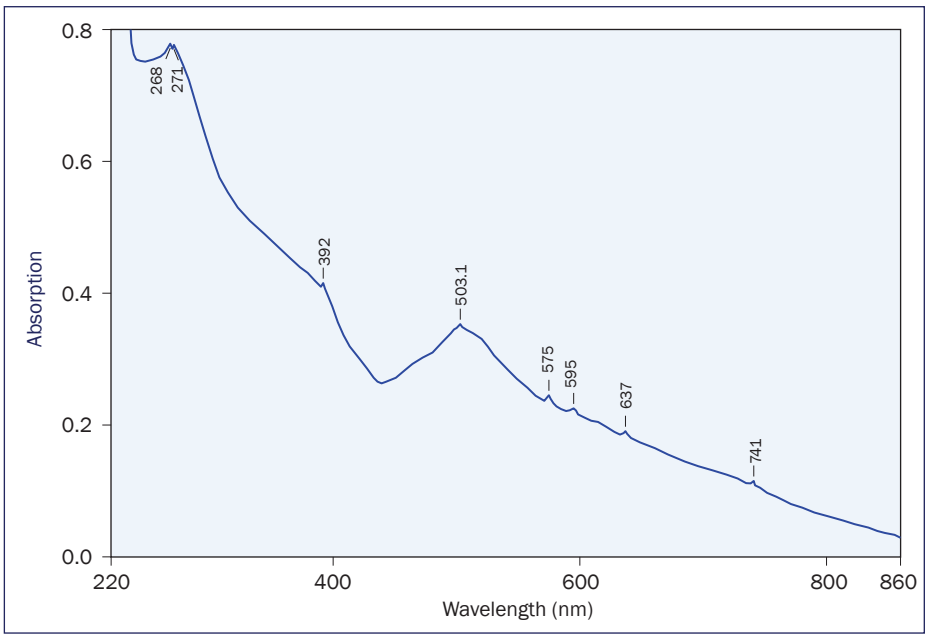

Figure 7: UV-Vis-NIR absorption spectrum of a representative CVD-grown synthetic diamond (from the stone weighing 0.19 ct) analysed at room temperature. Weak but sharp peaks at 637, 595, 575 and 503 nm were detected in 13 samples, but some samples showed very weak peaks at 741, 271 and 268 nm. There was no evidence of an absorption band at 737 nm, which is related to a silicon vacancy, in any of the samples.

synthetic diamonds weighing more than 0.1 ct. All displayed absorption at 637 nm due to the N-V$^-$ centre and at 595 and 575 nm due to the N-V^0 centre, but these samples exhibited much stronger absorption at 575 nm than at 637 nm. In addition, some of the stones showed very weak peaks at 741 (GR1), 503 nm (H3), 392 (ND1), and at 271 and 268 nm from isolated nitrogen centres. Among those, the GR1 and 595 nm peaks are related to irradiation and they indicate that these CVD-grown synthetic diamonds have been irradiated. Broad absorption centred at about 500–510 nm associated with the N-V^0 centre is the cause of the pink colour, a result consistent with current work elsewhere (P.M. Martineau, pers. comm., 2010). Wang (2009) showed that a broad band which has a maximum intensity near 550 nm in a CVD-grown pink diamond is the vibronic band associated with the 637 nm line related to the N-V$^-$ centre. In the present study, all the melee CVD synthetic diamond has a strong pink hue and their spectra have a broad band centred at 500–510 nm; the spectra were recorded before ultraviolet exposure to the UV-radiation lamp used in routine gem testing and the DiamondView™. To explore this difference between the broad band position in the spectra and determine whether this spectrum represented that from the as-produced material, we re-measured the absorption spectrum after an annealing experiment on two CVD synthetic diamonds weighing 0.25 and 0.08 ct using a Linkham LK-600 microscope hotstage to around 800 K in air in the dark. After annealing, a significant change was recorded from their original colour of Fancy Intense orangey-pink to Fancy Intense purple (*Figure 8a* and *b*). A strong broad band centred near 555 nm was recorded, and the relative intensities of absorption bands at 637 and 575 nm reversed after annealing *(Figure 9)*. This broad band may be the vibronic band associated with the 637 nm line. The purple hue changed slightly with time when the samples were kept in the dark, but returned to the initial pink colour when the stones were placed under the diamond grading lamp or in daylight for less than half hour. Also the purple colour returned to pink immediately after exposure to strong UV radiation when examined in the DiamondView™ instrument.

Heating to 800 K could increase the 637 nm absorption (related to the N-V$^-$ centre) intensity considerably, depending on the electron concentration in the vacancy defect, and result in an intense pinkish purple body colour. However, although the UV radiation exposure from daylight, a diamond grading lamp, gem testing UV lamp or a DiamondView™ instrument may produce a colour change in CVD-grown synthetic diamond from purple to orangey pink after the annealing process, this significant colour reaction may not be seen in natural pink diamond. Natural pink diamonds show a broad absorption band centred at 550 nm that is derived from plastic deformation and most of the stones show the N3 absorption at 415 nm. Natural or HPHT-grown synthetic pink diamonds which have been coloured

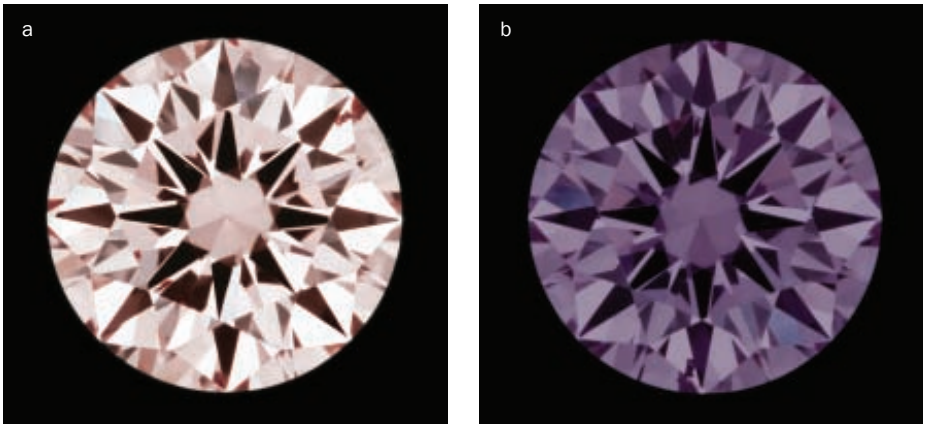

Figure 8: (a) The 0.08 ct CVD-grown synthetic diamond was graded as Fancy Intense orangey pink before the annealing experiment. (b) A significant colour change to Fancy Intense purple resulted when the samples were heated up to 800 K and then cooled over a period of one hour. Photo by K.Hirama.

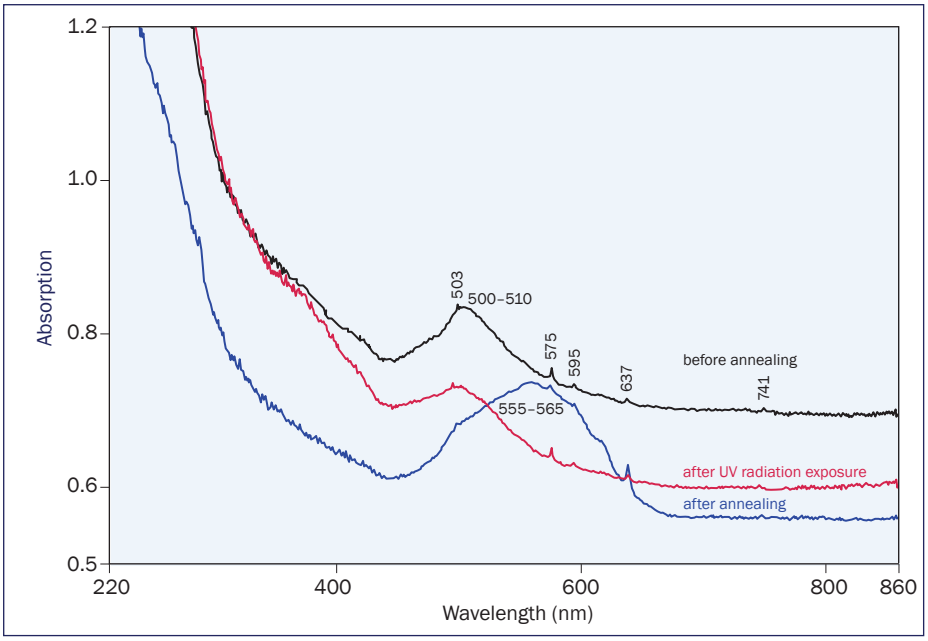

Figure 9: The UV-Vis-NIR spectra of this orangey-pink 0.08 ct CVD-grown synthetic diamond shows absorption characteristics before and after the stone was annealed at 800 K and after UV exposure under the standard daylight diamond grading lamp, respectively. The spectra show a decrease of absorption at 575 nm, an increase at about 637 nm, and a shift of broad band centre near 500 nm to near 555 nm after annealing at 800 K.

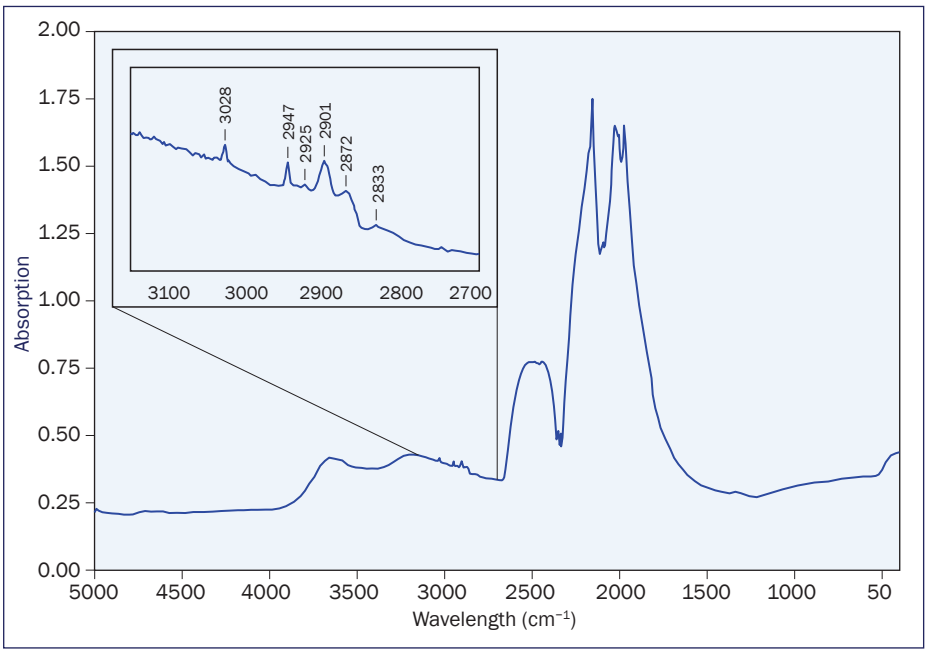

Figure 10: Infrared spectrum typical of our 48 CVD-grown synthetic diamonds which are all type IIa. The small absorption bands shown at 3028, 2947, 2925, 2901, 2872 and 2833 cm^{-1} were detected in only some of the samples. Isolated nitrogen-related peaks were not detected in any of our CVD diamonds.

pink by irradiation and annealing also show 637 and 575 nm absorptions similar to those in CVD-grown synthetic pink diamonds and the former also show absorption at 415 nm due to the N3 centre.

In addition, any absorption at 737 nm related to the silicon vacancy was not detected in these room temperature spectra (Zaitsev, 2001; Wang, 2009).

FTIR

Infrared spectra were obtained from all 48 stones. As they were apparently free of nitrogen, they were classified as type IIa. Absorption at 1344 cm^{-1} that originates from isolated single nitrogen atoms was not detected in any sample. However, it is well known that diamonds classified as type IIa using infrared spectroscopy can, nevertheless, contain small concentrations of nitrogen. Fisher and Spits (2000) for example, were also able to detect absorption in the 270 nm band (produced by isolated nitrogen centres) in some diamonds that showed no absorption at 1344 cm^{-1}. A hydrogen-related lattice defect absorption at 3123 cm^{-1}, which has been reported by Fuchs *et al.* (1995a, b) and also reported for stones produced by Element Six and Apollo Diamond Inc. as characteristic of CVD-grown synthetic diamond (Martineau *et al.*, 2004; Wang, 2009), was not detected in our samples. Wang *et al.* (2007) noted that this 3123 cm^{-1} line and other absorption lines in the near infrared range 5500–8900 cm^{-1} can be removed by HPHT treatment. In the range 3150–2700 cm^{-1}, we have found one or more weak absorptions of unknown origin at 3136, 3118, 3107, 3028, 2947, 2925, 2901, 2885, 2855, 2846, 2837, 2788, 2773, 2747 and 2724 cm^{-1} in 29 samples (see *Figure 10* for an example showing some of these peaks). These absorptions presumably originated from stretching vibrations due to hydrogen impurities in CVD-grown synthetic diamond. A C-H absorption at 3107 cm^{-1} which is common in natural diamond was not recognized as a distinct peak in some samples and was only vague in others.

Photoluminescence (PL)

PL spectra were obtained from all 48 stones stimulated by lasers of wavelengths 633 nm (red), 514.5 nm (green) and 325 nm (ultraviolet) as excitation sources. PL spectra stimulated by the He-Ne 633 nm laser in all 48 CVD diamonds contain a 737 nm peak, due to the presence of the silicon-vacancy defect, and the GR1 zero phonon line at 741 nm (which resolves to a doublet of 740.9 and 744.4 nm) *(Figure 11a)*. In one stone weighing 0.25 ct the

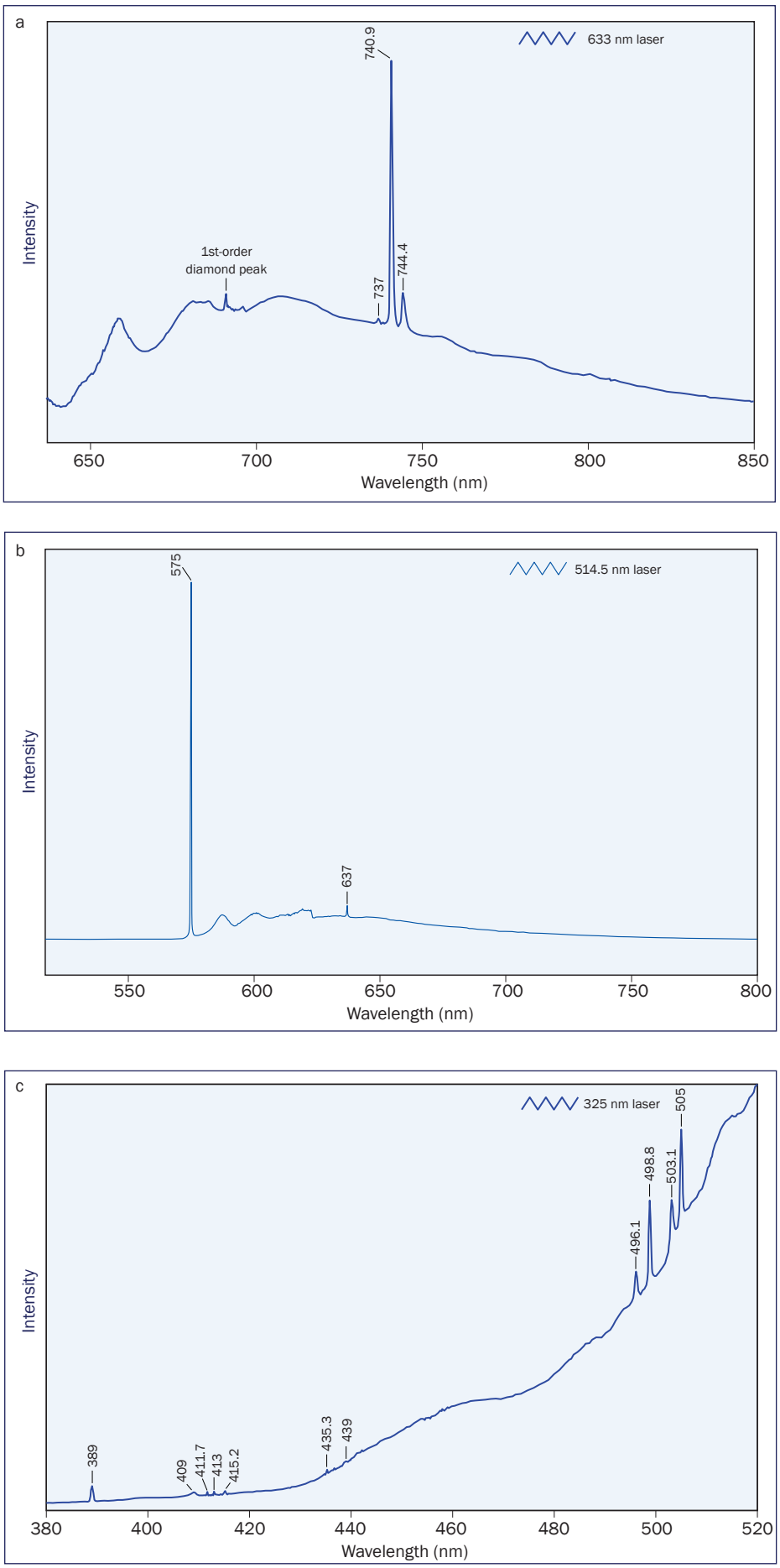

Figure 11: Representative photoluminescence spectra stimulated by three lasers of wavelengths 633, 514.5 and 325 nm.
(a) A 737 nm emission line is present in all spectra obtained using the 633 nm red laser, but was not displayed by most of the samples when stimulated by the other two lasers.
(b) Strong emissions at 575 and 637 nm, due to the N-V centre, are common in all stones.
(c) N3-centre-related luminescence at 415 nm was observed in six of the 48 stones.

737 nm emission was detected in only one of five spots analysed on the table facet. *Figure 11b* shows a representative spectrum stimulated by the 514 nm laser with the typical presence of 575 and 637 nm peaks. A weak peak at 737 nm was found in only four stones and the peak at 741 nm in only one stone.

PL spectra from the 325 nm laser in all samples show a 503.1 nm (H3) peak along with peaks at 498.8 and 505 nm *(Figure 11c)*. In 31 stones, a 496.1 nm (H4) peak is also present.

In six samples, a very weak peak at 415.2 was detected; this emission line is produced by the N3 centre that is commonly observed in natural diamond (Collins *et al.*, 1990; Martineau *et al.*, 2004), but the spectrum of one stone also contained a weak peak at 435.3 nm which may be unique to CVD diamond (see, e.g., Zaitsev, 2001). In all 48 stones, peaks at 389, 409, 411.7, 413 and 439 nm were detected, and these are probably related to irradiation and annealing.

Luminescence imaging

UV luminescence images of all 48 samples were observed using DTC DiamondView™ equipment. This instrument employs short wavelength UV light (<230 nm) instead of an electron beam that is used in the cathodoluminescence (CL) method and it proves very flexible and effective for preliminary observation before CL analysis.

Of our 48 CVD diamonds, seven show parallel laminated growth structure when examined in the DiamondView™, which may indicate an even rate of deposition of diamond from vapour *(Figure 12a)*. CL images of 13 stones weighing more than

0.1 ct and 13 weighing less than 0.1 ct were then obtained and a similar growth structure was observed in 15 of the 26 stones *(Figure 12b)*. In our experience, CL imaging has a lower penetration depth than UV but provides a highly sensitive image. All the samples showed vivid orange fluorescence due mainly to the N-V centre (in both UV and CL images).

Most natural pink diamonds show blue fluorescence and many display patterns indicating growth parallel to octahedral faces or growth of mixed-habit, in which domains of cubic and octahedral faces co-exist *(Figure 13a)*. Very rarely some natural diamonds may show orange luminescence (due to the N-V centre), but they also show a mosaic pattern that has not been seen in CVD-grown synthetic diamond *(Figure 13b)*. Irradiated pink diamonds similarly show orange fluorescence due to the N-V centre, but when the diamonds irradiated are natural, they show an intersecting linear pattern *(Figure 13c)*, and when they are HPHT-grown synthetic, they show characteristic sector zoning *(Figure 13d)*.

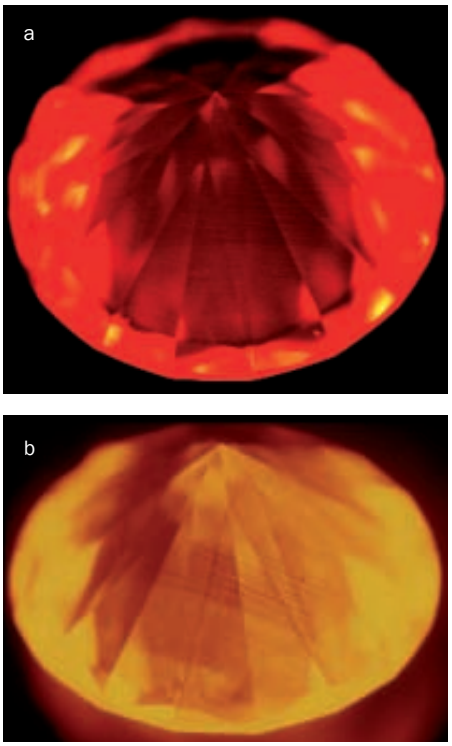

Figure 12: (a) All CVD-grown synthetic diamonds in this study display a strong orange fluorescence under UV radiation in the DiamondViewTM instrument. Parallel laminated growth layers were observed in seven samples, but no structural features were evident in the other 41 stones. Photo by J. Kawano.
(b) CL images of CVD-grown synthetic pink diamond showing a unique laminated growth structure. Photo by A. Abduriyim.

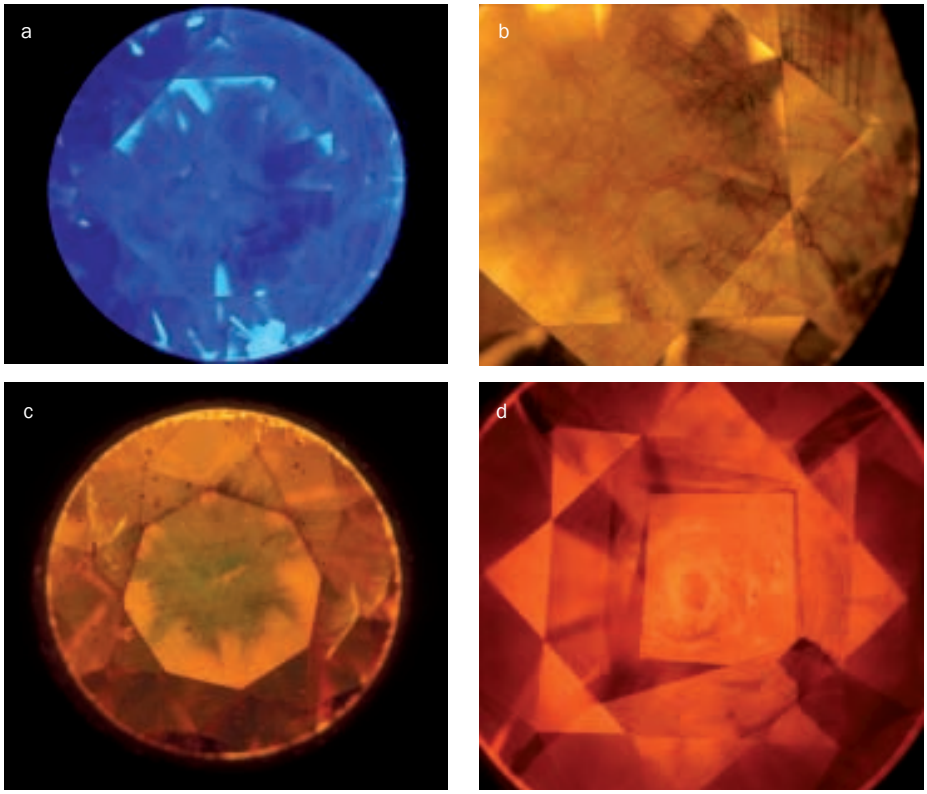

Figure 13: Four CL images of natural and synthetic diamond.
(a) CL image of natural pink diamond showing mixed-habit growth, in which growth domains of cubic and octahedral faces co-exist (field of view 8 mm). Photo by H. Kitawaki.
(b) Orange luminescence in a CL image of type IIa natural diamond with a rarely seen mosaic pattern (field of view 4.2 mm). Photo by H. Kitawaki.
(c) Irradiated pink natural diamonds show orange fluorescence (due to the N-V centre) with an intersecting linear pattern (field of view 6 mm). Photo by H. Kitawaki.
(d) HPHT-grown synthetic diamond showing characteristic sector zoning which indicates a combination of {100} and {111} faces (field of view 3.5 mm). Photo by H. Kitawaki.

Conclusion

CVD-grown synthetic pink diamonds in melee size can be easily distinguished from most natural pink diamonds (such as those from the Argyle mine) by means of their vivid orange UV fluorescence derived from the 575 nm centre. Diamonds (either natural or HPHT-grown synthetic) coloured pink by irradiation and annealing processes similarly show orange UV fluorescence but they may be distinguished on the basis of their different CL images. In the diamonds studied in the present investigation, the 737 nm peak related to Si was detected in the PL spectra excited by a 633 nm laser; this can be an important indication of CVD-grown synthetic diamond.

Use of CVD-grown synthetic diamonds in jewellery has just begun and production is limited so far, but the potential of the CVD-grown synthetic diamond for expanded technological application brings a sense of expectation for further technical development. The characteristic features described for the diamonds in this report are in stones being produced at the present time and gemmological laboratories should continue to make every effort to develop identification techniques for such new materials.

Acknowledgements

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Appearance of new bead material in cultured pearls

Prof. Dr H.A. Hänni FGA, Dr M.S. Krzemnicki FGA and Laurent Cartier MSc FGA

Abstract: A range of different materials has already been used as cores in beaded cultured pearls, and now two new alternative options, baroque shaped shell beads and Chinese freshwater cultured pearls, are being used. Experiments with beads of the latter, approximately 6.5 mm across, have been carried out with marine *Pinctada maxima* and *Pinctada margaritifera* oysters. After 13 months, nearly 200 pearls of each kind were harvested. Cross sections and further observations of resulting pearls are described. X-radiographs and X-ray microtomography are found to generally deliver clear evidence for identification. These pearls have been found to be very suitable for subsequent drilling. Natural pearls also have been used as nuclei for producing cultured pearls. The material used is either non-nacreous, brown or of an unattractive appearance. This new kind of cultured pearl is difficult to identify, because the radiographic structures of the natural cores are masking these cultured pearls.

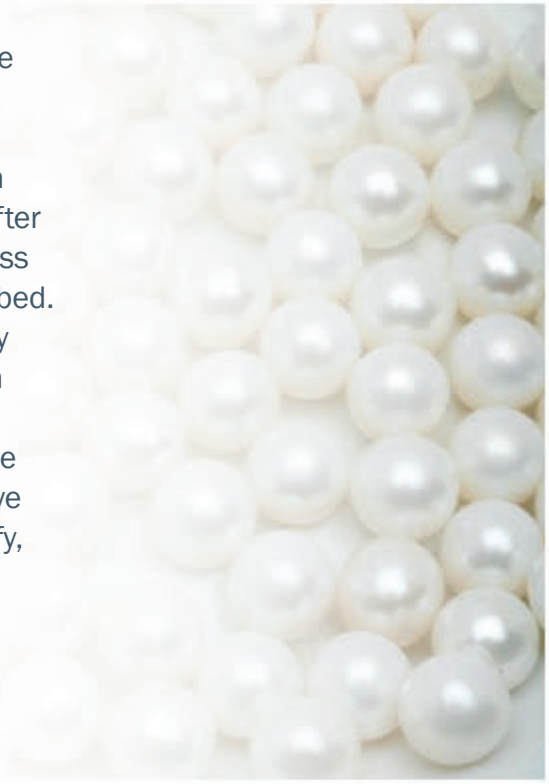

Keywords: baroque-shaped beads, bead nucleus, Chinese freshwater cultured pearls, cultured pearls, South Sea cultured pearls, Tahiti cultured pearls, X-ray microtomography

Introduction

Techniques concerning production of cultured pearls have been described in a number of recent books and papers (Müller, 1997; Hänni, 2002; Strack, 2006; Southgate and Lucas, 2009). A number of options for pearling can be selected and combined to produce cultured pearls successfully, and these are summarized in *Table I*.

Traditionally, most beads for cultured pearls have been manufactured from shell material from the Mississippi area, USA (pigtoe, washboard, butterfly, three ridge, dove shell) but since production is in decline and prices are rising, alternative materials are being tested. Recently, an excellent paper comparing different bead materials used in cultured pearls was published by Superchi *et al.* (2008) in which the following materials are mentioned: banded freshwater mother-of-pearl, banded saltwater mother-of-pearl, Tridacna shell and Bironite. The use of lauegrams to detect the structures of beads has been practised for more than

Table I: Possible combinations of parameters to produce cultured pearls — the two major ways are given in blue.

Host and medium	Pearl location in the body	Presence of bead	Examples and comments
Oyster saltwater	gonad-grown	**yes**	**Akoya, Japan; Tahiti; South Sea**
		no	'keshi', bead rejected
	mantle-grown	no	new type, baroque shape
		yes	not yet encountered
Mussel freshwater	mantle-grown	**no**	**Biwa, Japan; China; USA**
		yes	Chinese, 'coin bead', round
	gonad-grown	no	not yet encountered
		yes	not yet encountered

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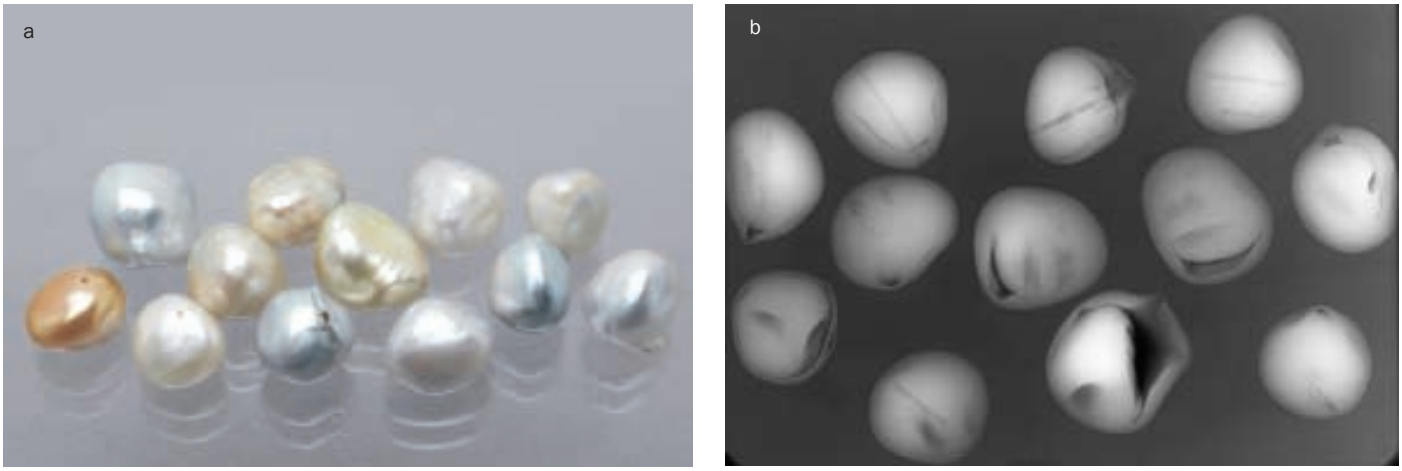

Figure 1: (a) Baroque-shaped South Sea cultured pearls containing irregularly-shaped shell beads. A number of such cultured pearls (largest dimension 17 mm) are seen in the left image. (b) A radiograph showing the irregular outlines of the bead material and some structures typical of growth near the hinge of the shell. Photo © H.A.Hänni and SSEF.

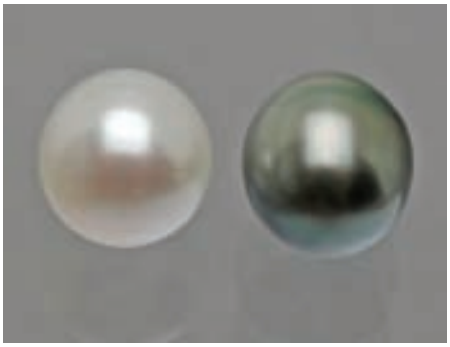

Figure 2: Gonad-grown cultured pearls of P. maxima *(left) and* P. margaritifera *(right) containing a CFCP as a nucleus bead. Diameter of the final product is approx. 9 mm. Photo © H.A.Hänni and SSEF.*

50 years, and in this context the structure of Tridacna shell and other non-nacreous shell has been discussed recently by Hanni (2004, 2009a). Besides Bironite, which consists of altered dolomitic marble, pressed barium sulphate beads in different colours have also been reported as cores in engraved dark *P. margaritifera* pearls (Hänni, 2009b). The latest substance used for producing baroque-shaped cultured pearls is irregularly-shaped shell material, used in *P. maxima (Figure 1).*

Another new material, thus far unreported, is probably still being used on an experimental scale. This material is a freshwater cultured pearl and the aim of this article is to shed light on this alternative, as it is likely to be increasingly applied and encountered in future *(Figure 2).*

From a consumer point of view, the composition of the core in the bead-cultured pearl may not seem to be important as this material is not visible. However, to give the feeling of a pearl, it should have the heft of a pearl (this means that light materials such as plastic are not appropriate). From a production point of view, a suitable material should be accepted by the oyster or mussel and possess properties suitable for drilling. For about 100 years shell beads have satisfied these requirements (Muller, 1997). Nacre has the perfect heft as it is of the same material as natural pearls. But its layered structure sometimes can be a source of difficulties: when the drilling hole is at a low angle to the layers, a tendency to split along the layers can divert the drill off course. When the drill is parallel to the layers, the bead often breaks along the layers. The use of bead material made from the Tridacna shell is now defunct mainly because this bivalve is a protected species, but also because it has a fibrous structure that is difficult to drill due to the criss-cross array of fibres (Hanni, 2009b).

Such constraints are not encountered when concentrically structured nacre, such as that in a beadless cultured pearl, is used as bead material. Considering that Chinese freshwater cultured pearls

Figure 3: A sample of Chinese cultured pearls (mantle-grown, beadless CFCPs) as used for beading of South Sea oysters P. maxima *and* P. margaritifera*. For a first beading of the oyster a diameter of approx. 6.5 mm is required. Photo © H.A. Hänni and SSEF.*

(CFCPs) of this kind are available in large quantities, close to round in shape, of white colour and at low prices, such material seems a perfect alternative to beads fashioned from shell. The only apparent disadvantage seems to be the lesser degree of roundness compared to the traditional manufactured beads. However, beadless CFCPs can easily be polished to spheres of standard sizes.

Figure 4: Cultured pearls containing the new CFCP beads from P. maxima *oysters (white) and* P. margaritifera *oysters (black) harvested after 13 months. The pearls are between 7.5 and 9 mm across. Photo © H.A.Hänni and SSEF.*

The experiment

Mantle-grown beadless CFCPs *(Figure 3)* were used to study the usability of the new bead material. A second objective was to examine the possibilities of identifying these alternatively beaded pearls in a gemmological laboratory. Because beadless CFCPs may exhibit concentric growth structures similar to those in natural pearls, it is important to find distinguishing features that one can use to differentiate these from natural pearls. Two hundred near-round to round and white to pale cream beadless CFCPs, unprocessed and with a diameter of approx. 6.5 mm, were delivered to each farm, one working with *P. maxima* and one with *P. margaritifera*. They went through the same preparatory steps in the pearl farms as conventional nacre beads. For comparison, a significant group of oysters was grafted and beaded with standard beads. After 13 months the pearls were harvested and the yield of CFCP beaded pearls was compared with the average of the normal production. The rejection rate was slightly lower for the CFCPs than for the traditional beads. This was the case for both *P. maxima* and *P. margaritifera*. The final cultured pearls from both farms had diameters between 7.5 and 9 mm. *Figure 4* shows a representative selection of the two lots produced from *P. maxima* and *P. margaritifera* oysters.

Twenty pearls from each production were randomly selected for tests. Some pearls were cut in half and polished so that the equatorial plane could be inspected under magnification *(Figure 5)*. Other samples were analysed non-destructively by X-ray techniques.

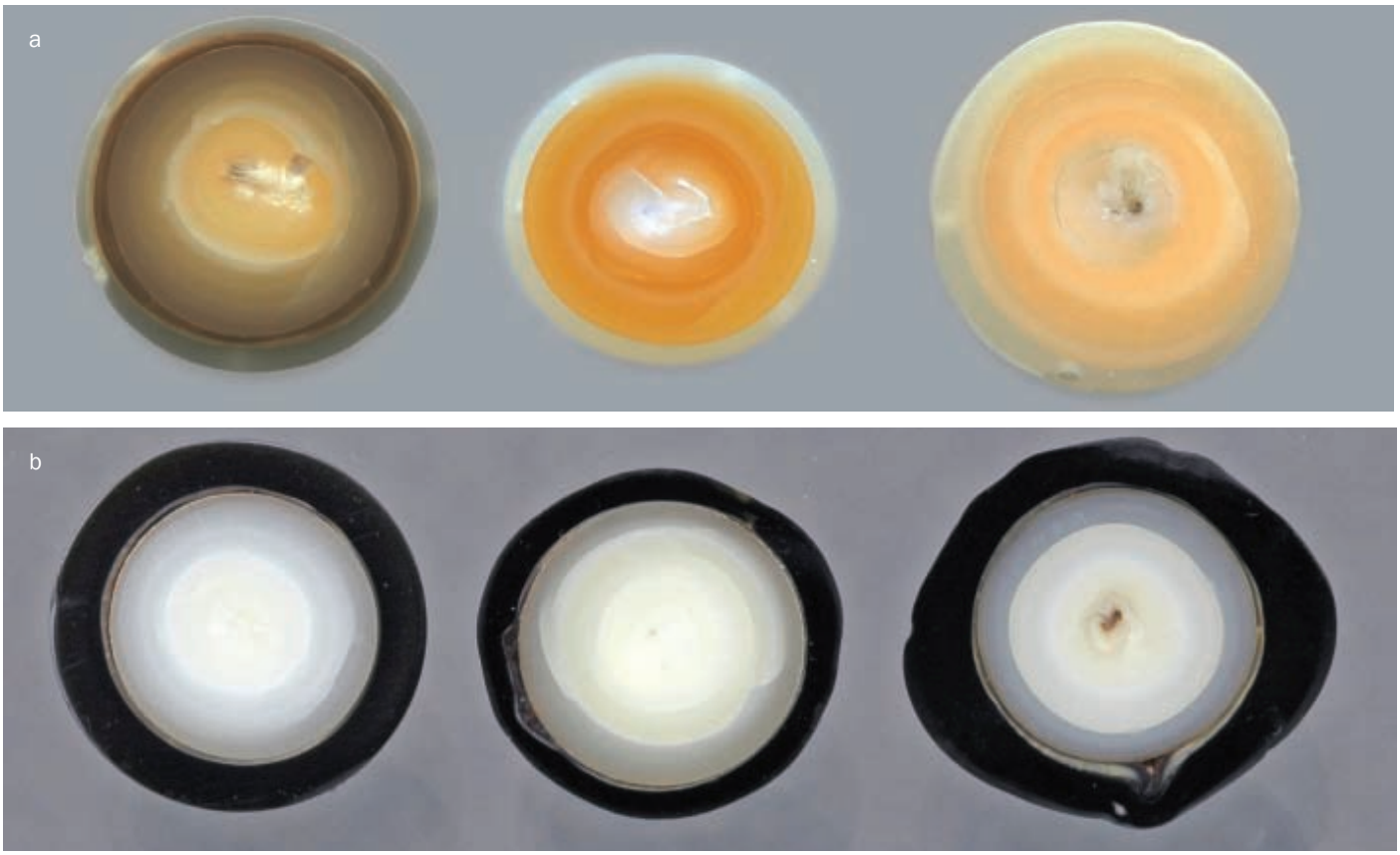

Figure 5: Cross sections through marine cultured pearls, containing a CFCP as a core. (a) Samples from the P. maxima *oyster, and (b) those from the* P. margaritifera *oyster. Photo © H.A.Hänni and SSEF.*

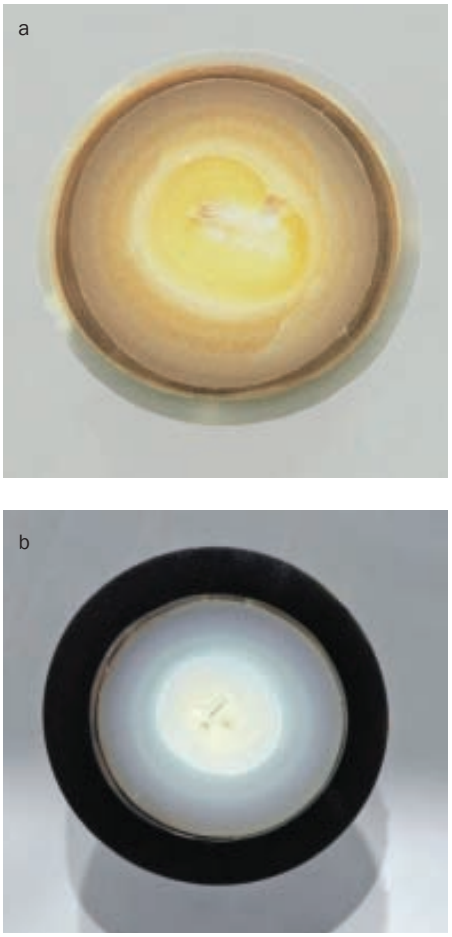

Figure 6: Cross-sections through P. maxima *and* P. margaritifera *cultured pearls, each containing a CFCP as a bead. The cavity, typically of complex shape, is visible in the centre and surrounded by a chalky area overgrown by nacre of the freshwater cultured pearl. These beads are coated by (a) white nacre in* P. maxima *and by (b) dark brown nacre in* P. margaritifera *oysters. Photo © H.A.Hänni and SSEF.*

Identification

The core

The most significant structure visible in the centre of the freshwater pearls used as beads is the central cavity. This complex cavity is bordered by the first precipitation in the young nascent pearl sac, and may be further surrounded by undulating hairlines and fine fissures between subsequent growth layers. In natural pearls, such fissures are concentric and bow-shaped. Drying fissures in natural pearls are usually across the pearl and cut through the concentric growth structure. The area immediately around the central cavity commonly consists of non-nacreous, pale yellow material that may include vaterite (Soldati *et al.*, 2008). This set of observations is typical for the CFCP bead material shown in *Figures 5* and *6*.

In comparison, natural pearls show an off-round central area consisting of a radiating array of pale brown columns, many of which have been identified as calcite (Lowenstam and Weiner, 1989; Baronnet *et al.*, 2008) (see *Figure 7*). This inner region contains more organic material and thus absorbs less X-ray energy, consequently appearing darker on the radiograph. It corresponds to the first formation of $CaCO_3$ deposited by the juvenile cells of the pearl sac. With increasing age, the cells change to producers of aragonite tablets and form a coat of nacre on the primary body. More on the formation of natural pearls is described by Hänni (2002) and Bari and Lam (2009).

The overgrowth

An average nacre thickness of 0.5 – 1.8 mm was measured on the beads. This overgrowth is less than usual because the growth time was only 13 months. Usually the overgrowth on the experimental beads sits very tightly on the CFCP. In some the innermost deposition on the bead is of columnar $CaCO_3$; this forms before the pearl sac begins to precipitate $CaCO_3$ as aragonite tablets, i.e. nacre; in others, aragonite is deposited directly on the bead. Most white South Sea pearls are close to round, but it is not uncommon for the black Tahiti pearls to have circle and drop shapes; this shape variation is not related to the material of the beads.

Identification by X-ray shadow pictures on film or digital image is usually a straightforward procedure for beaded pearls. The presence of a central cavity in the shape of a so-called 'moustache' structure, which is typical of beadless cultured pearls including CFCPs, would be a clear indicator of a bead's character (see ***Figure 8***). In situations where such structures are not clearly shown at the first attempt, a rotation of the pearl can result in better exposure of the cavity. Any flat

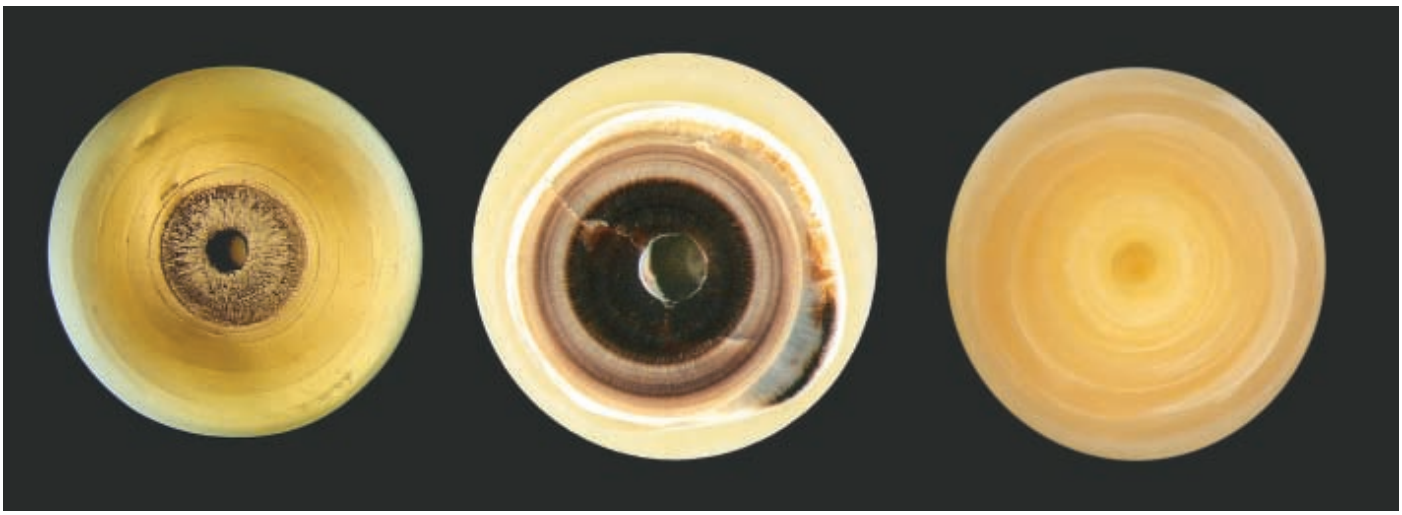

Figure 7: Sections through three natural pearls. The centres show radiating prismatic $CaCO_3$, containing brown organic material. This core is overgrown with nacre. Some natural pearls, such as the sample on the right, may lack the columnar brown part. Photo © H.A.Hänni and SSEF.

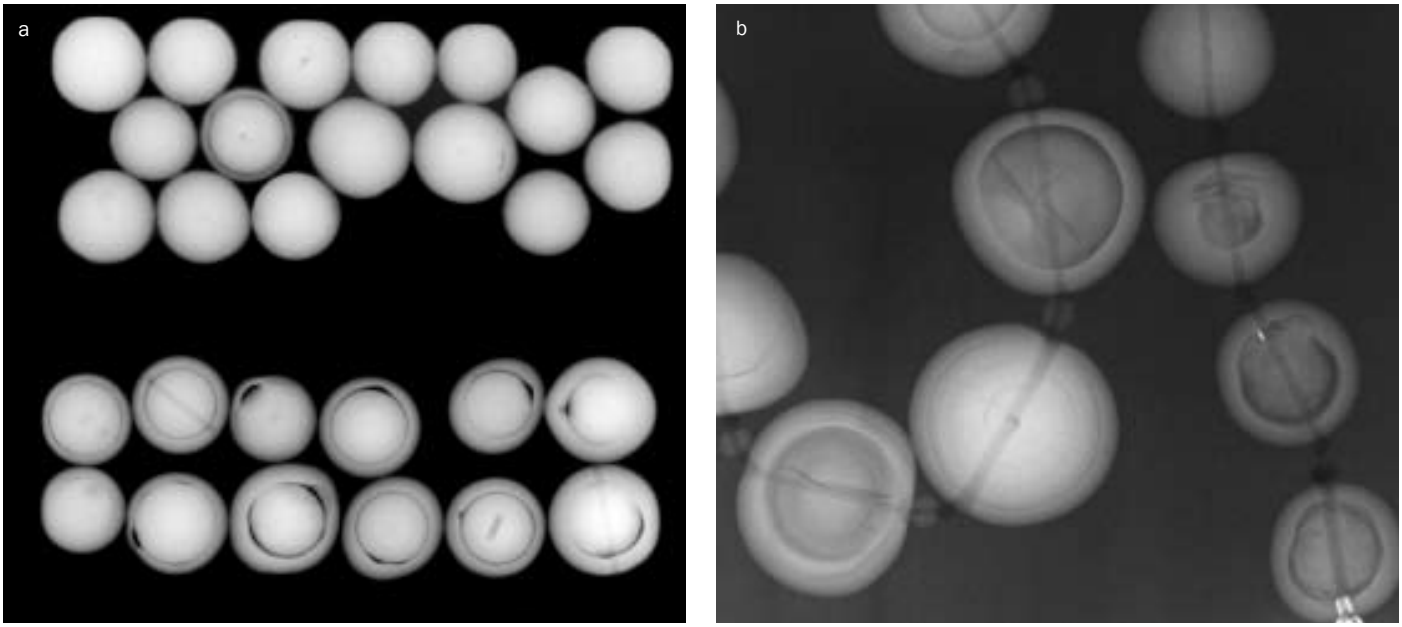

Figure 8: (a) Traditional X-radiographs, the central parts of which are examined under magnification, to look for the 'moustache' structure. The upper group are white South Sea beaded cultured pearls and the lower group consist of black South Sea cultured pearls. The straight line shadows indicate drill holes in three pearls of the lower group, and most pearls in this group show a clear gap between bead and nacre overgrowth.
(b) Radiographs of natural pearls with off-round outlines, most showing a conchiolin-rich central area and irregular wavy lines indicating fissures caused by drying. Only one pearl lacks a conchiolin-rich centre and that is the white one in the lower centre of the picture. Photo © H.A.Hänni and SSEF.

structure appears much more clearly when it is parallel to the incoming rays, thereby producing a sharp line. When the cavity is rather thin and flat and perpendicular to the incoming rays, it may be difficult to detect. It thus becomes clear that dynamic investigation such as real time radiography (Sturman, 2009) with the opportunity to rotate specimens is preferable for obtaining reliable results more quickly. In addition to the comments made above, it is worth noting that since freshwater pearls contain manganese, they are more absorbent of X-rays and thus appear brighter on the radiograph.

The latest development in pearl investigation by X-ray technology is X-ray microtomography (Strack, 2006, 2007; Wehrmeister *et al.*; 2008, Anon, 2009; Krzemnicki *et al.*, 2009). By three dimensionally recording the radio density of a pearl in very small increments, a complete representation of the interior of a pearl is obtained. Sections in all directions can be looked at and ultra-fine structures in pearls can be visualized. With a set of mapped tomography data it is possible to view a scan through a pearl, and find the features necessary for identification. As this instrument remains

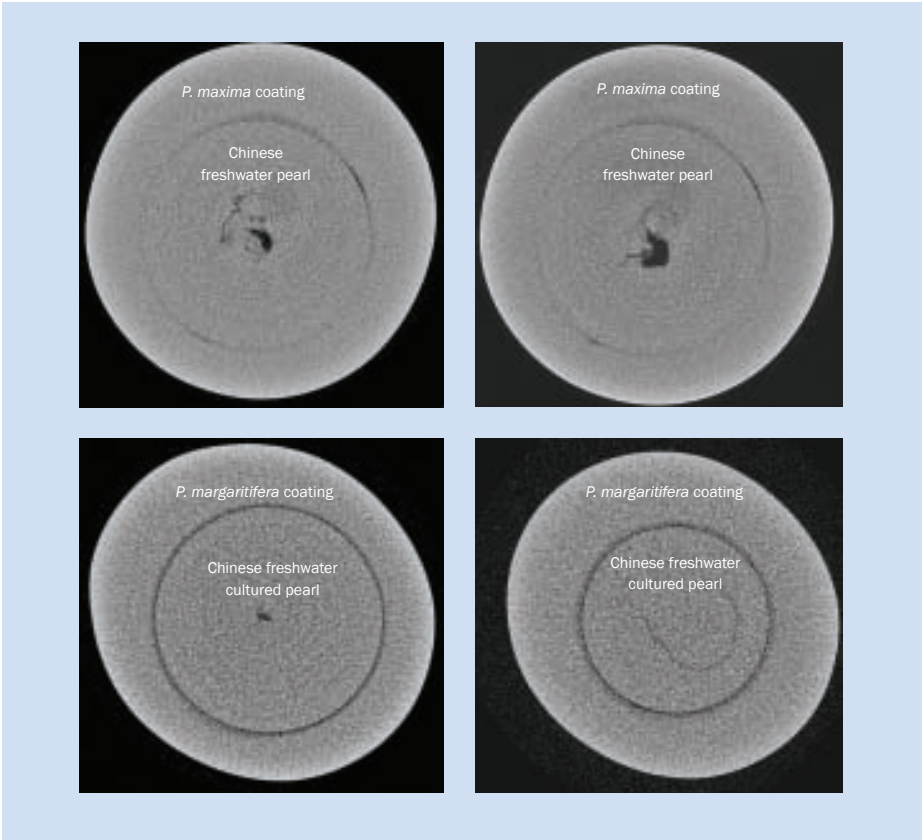

Figure 9: X-ray microtomographic sections of beaded cultured pearls. The beads consist of beadless CFCPs, showing central cavities and some irregular hairline fissures. The upper images are virtual cross-sections of a pearl from a white South Sea oyster P. maxima *taken at different levels and showing close contact of the bead and the nacre overgrowth. The lower images are virtual cross-sections of a pearl from a dark South Sea oyster* P. margaritifera. *This one has a prominent gap between core and overgrowth. Image © S. Friess, Gloor Instruments.*

expensive, it is currently used in rather exceptional situations where conventional radiography is not conclusive. To obtain tomographic data for the new type of beaded cultured pearls, two samples were recorded at Gloor Instruments (Uster) using a SkyScan microtomograph. Two cultured pearls with CFCP beads are shown in *Figure 9*. The CFCPs show central cavities and some irregular hairline fissures and again the boundary between the bead and the nacre coating is much more pronounced in the *P. margaritifera* oyster (lower) than in the *P. maxima* oyster. However, these are preliminary results and subject to change when more examples are available.

Larger CFCPs (from 9 mm upwards) can serve as second beads, after the first cultured pearl has been harvested, when the pearl sac is recharged.

Discussion

The purpose of creating a beaded cultured pearl is to produce an object of given shape and size coated with nacre to appear like a natural pearl. In the classical Japanese akoya cultured pearls the excellent nacre of the *Pinctada maxima* oyster can cover the nucleus with less than a millimetre of deposition, but this is only a thin paintwork to hide the nature of the core. Cultured pearls of better qualities usually display more than a millimetre of overgrowth. With this the body grows in size and optical attractiveness.

Seeing that the use of beadless freshwater cultured pearls in saltwater oysters causes no apparent problems, the next step seems logical. Unattractive natural pearls could be provided with a more beautiful surface if they stayed for a while in a farm-oyster. In order to recognize and understand the features of possible future varieties of cultured pearls, one author (HAH) has been experimenting with natural pearls as bead material. This turns out to be very relevant as recently cultured pearls with natural pearls as beads have reached the pearl trade, see reports on the internet (Gemlab, 2010; SSEF, 2010). This situation has similarities with that of blue sapphire in the 1980s. At that time, greyish unattractive rough corundum (geuda) could be transformed into a transparent blue gemstone rivalling natural sapphire. Although the pearl and sapphire technologies are different, the general aim is the same — that of transforming unattractive natural objects into good-looking and desirable jewels.

Conclusions

Market pressure for large, fancy-shaped cultured pearls has stimulated the use of baroque shaped pieces of shell to use as nuclei for South Sea cultured pearls. Using radiographs, these pearls are easily identified as cultured. Now a new bead material, which can be used for the first beading where a pearl sac has to be formed from a tissue graft around a spherical hard nucleus, has been found for cultured pearls: CFCPs are a viable replacement for beads cut from shell material. Experiments have shown that the new bead material gives good results in white South Sea oysters *P. maxima*, and dark South Sea oysters *P. margaritifera*. In a gemmological laboratory the CFCP beads can be identified using conventional radiography or X-ray microtomography. In each method the typical characteristics, a central complex cavity 'moustache' and undulating dark lines, can be detected. The comparative costs of these CFCP beads and conventional shell beads will probably determine whether this new bead material will be preferred in the trade. Since the structure of a CFCP bead is concentric, it is suitable for most drilling purposes as any variation in hardness due to growth factors will tend to be perpendicular to the drill direction.

Use of natural pearls of low quality (nacreous or non-nacreous) as beads is pushing the gemmological laboratories to develop new testing methods, and adapt terminology. Indeed, in some instances the authenticity of a pearl cannot conclusively be decided; structures such as those shown in *Figure 6* are no longer proof of authenticity. Some non-nacreous pebbles of columnar calcite have been called 'unripe pearls' by one author (HAH). Such 'pearls' have been harvested before deposition of a nacreous layer by the pearl sac, the latter still being at a juvenile stage before developing the capacity to form aragonite (Hänni, 2002). It seems that the lack of a nacreous layer on a pearl can now be remedied by a visit to a domestic oyster, but then of course, the status of the pearl changes from natural to cultured.

Acknowledgements

Much gratitude goes to the unnamed pearl farmers for their readiness to perform the experiment with CFCP. Support of Dr S.D. Friess from Gloor Instruments (Uster, Switzerland) is gratefully acknowledged. Andy Müller of Hinata Trading (Kobe) has supported us for many years with cultured pearls for SSEF pearl research and is sincerely thanked.

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The over-grading of blue-fluorescent diamonds: the problem, the proof and the solutions

Michael D. Cowing

Abstract: Decades after the establishment in the mid-twentieth-century of ultraviolet-free illumination for colour grading a diamond, an examination of diamond trade and laboratory grading practices finds nearly everyone employing some type of fluorescent tube lighting containing significant ultraviolet. This paper demonstrates and quantifies the over-grading of blue-fluorescent diamonds that often can result. Simple methods are proposed that, by themselves or in combination, provide inexpensive and workable solutions to resolve this problem.

Keywords: colour grading, diamond, fluorescence

Introduction

For over a hundred years, it has been recognized that the light yellowish tints in a type 1a diamond combine with the various amounts of blue fluorescence, stimulated by daylight and other illumination containing ultraviolet (UV) energy, to give blue-fluorescent diamonds a whiter perceived colour than the colour seen in lighting where fluorescence is not stimulated to a noticeable degree.

The problem is how to colour grade blue-fluorescing diamonds, which can appear a whiter colour grade in daylight than their colour as seen indoors under typical artificial lighting.

Not long after Robert Shipley founded the Gemological Institute of America (GIA) in 1931, he recruited academic members to a GIA advisory board to help advance the gemmology movement in America. An important contributor among these members, especially in the field of diamond science, evaluation and valuation, was Frank Wade. Wade was a pioneer in America of "the first series of scientific articles (from 1915 to 1948) on diamonds and gems written especially for the jeweler" (Gilbertson, 2007). Given his own studies and input from diamond experts and educators like Wade, it is no surprise to find Shipley concerned about fluorescence in the colour grading of diamonds. He addressed this fluorescent diamond grading problem in *Gems & Gemology,* 1941. There he says: "One of the most important causes of the anomalies that so often trouble a diamond grader is the change of colour shown by many fluorescent stones when viewed under different light conditions. Often a fluorescent diamond which appears slightly yellowish under artificial light, appears distinctly bluish in daylight" (Shipley and Liddicoat, 1941).

This simple term 'daylight' disguises the large variation in UV content depending on time of day, geographic location, and whether or not the day was sunny or cloudy. With the perceived colour of fluorescent diamonds varying with the illumination, what lighting should be used in laboratory colour grading? Historically, the standard lighting for colour grading was 'northern daylight', such as that through north-facing windows, for example in the Israel Diamond Exchange *(Figure 1)*.

In 1941, the GIA produced their first diamond colour grading instrument called the Diamolite (later renamed the DiamondLite), using an incandescent filament type of light source and a 'daylight filter' which produced "the equivalent of north light without the UV radiation" (GIA, 1969). At the same time the GIA stated that "a reasonably good substitute for the DiamondLite can be made by adapting a simple desk lamp fixture containing cool white fluorescent tubes". However, they caution: "The disadvantage of this kind of illumination is that fluorescent tubes emit a significant percentage of UV radiation. Although this does not affect the grading of non-

Figure 1: Trading floor of the Israel Diamond Exchange. (Inset) A closer look at the lights in use.
Courtesy of the Israel Diamond Exchange.

fluorescent stones, it causes fluorescent diamonds to be graded higher than is actually warranted due to the neutralizing, or masking effect, of the fluorescent colour on the true body colour" (GIA, 1969). Yet, by the 1970s we find that gemmologists and the diamond trade worldwide are universally using some form of UV-emitting fluorescent light to colour grade diamonds. An important example is the later version of the GIA DiamondLite that substituted unfiltered fluorescent tubes for the daylight-corrected incandescent light source in the early model.

In 1997, Moses *et al.* indicated that digital radiometer readings of UV content revealed similar intensities of long-wave UV content in four sources of fluorescent lighting including the Verilux tubes in the DiamondLite. They also found "indirect daylight through our windows has about as much UV radiation as the fluorescent light sources". With the GIA's finding that "fluorescent lighting" and "daylight through a window" have a similar amount of UV radiation, it would be expected that blue-fluorescing diamonds would be perceived to be whiter in daylight through a window and in the DiamondLite than they would when viewed on social occasions in indoor artificial lighting.

In 2008, King *et al.* described the evolution of colour grading lights and how the original UV-free source had changed to one with characteristics of daylight including its fluorescence-stimulating UV component. They concluded: "We believe that a standard light source for diamond colour grading should have key characteristics of daylight, including a UV component." (King *et al.*, 2008, p.320.)

GIA's study findings and conclusions are best summed up in the words of Moses (2001) who stated the GIA belief "that the best man-made light sources reproduce all the characteristics of traditional north daylight, including the 'good deal' of UV ... Not only do members of the trade typically buy and sell diamonds under lighting conditions that have a UV component, but they also colour grade them with a lamp that has

Figure 2: Six diamonds graded I colour in a DiamondLite showing a range of fluorescence. Picture reproduced courtesy of GIA; these three photographs were used in the assembly of Figure 3, I colour set pictured in the paper by Moses et al., 1997, p. 249

some UV content. Grading in a UV-free environment is contrary to this accepted practice and will cause confusion." (Moses, 2001).

However, not addressed in the 1997 and 2008 articles was consideration of the intensity of the UV and visible-violet (VV) energy present at typical light-to-diamond distances in normal viewing circumstances compared to the energy intensity present at the much closer distances to the lighting in grading instruments.

The key point is that most diamonds are seen in most forms of artificial illumination at night or indoors out of daylight, and in these viewing environments the UV and visible violet are too weak to stimulate grade-whitening fluorescence. In contrast, the relatively strong UV and visible violet at typical distances of 1 to 7 in. from the fluorescent tubes of grading instruments can stimulate a good deal of fluorescence which whitens the appearance of a diamond. The use of such unfiltered fluorescent lighting has today become almost universal and is an abandonment of the diamond grading standards originally established by GIA in accordance with diamond-trade practice at that time.

A closer look at the Israel Diamond Exchange in *Figure 1 (inset)* reveals the kind of fluorescent desk lamps being used in diamond grading. There is nearly universal use of fluorescent lighting in spite of it being the very same source of grading illumination that was originally considered by many to result in the over-grading of fluorescent diamonds. Corrective solutions are needed to this almost universal use of some form of fluorescent light to colour-grade diamonds at major grading laboratories and within the trade.

Where is the proof of the over-grading of many blue-fluorescing diamonds? To quote Tashey (2009): "I was shocked when I made the initial discovery, by placing a clear, UV filter, plastic film between the Verilux lamps in the GIA DiamondLite and the diamonds to be graded, that stones with very strong blue fluorescence could change to a lower colour by three or four letter grades." He spoke of a 0.89 ct marquise brilliant with 'Very Strong Blue' fluorescence: "In the DiamondLite [Verilux lamps, without UV filter] this stone was graded table down as a high 'D'. ... When viewed table down, with the UV filter between the lamps and the diamond, the colour grade of the diamond shifted to that of a low 'H'." Tashey (2000) had earlier found that diamonds with 'medium' to 'strong' blue fluorescence generally shifted one to two colour grades when the filter was used.

This example in a 'Very-Strong-Blue' fluorescing marquise diamond of close to a five grade colour improvement to high D in the DiamondLite from the UV-free colour grade of low H may be met with disbelief by professionals in the trade, all of whom grade in some form of UV-containing fluorescent illumination, and so have not witnessed this large a shift in colour. However, the data base in the current investigation contains a 0.63 ct marquise diamond with a similar close to five grade improvement in the DiamondLite over its unimproved colour as determined in UV-free artificial lighting.

Evidence of the over grading of blue-fluorescent diamonds was also contained in a photograph in the paper by Moses *et al.* (1997). Their *Figure 2* includes a set of six diamonds graded I colour in the DiamondLite and these show clear colour differences. The photograph was taken in incandescent illumination (Erica Van Pelt, pers. comm.,) which (by its nature and distance from the subject) was UV-free compared to the DiamondLite. This picture is reproduced here courtesy of GIA *(Figure 2)* and affords an opportunity to relate the colour differences, particularly in the face-up images, to the strengths of fluorescence. The fluorescent strengths, from left to right, are: 1 Medium, 2 Very Strong, 3 Faint, 4 Strong, 5 None and 6 Strong

Stones 2, 4 and 6 appear to have substantially more colour than the other three in spite of having been graded as I colour. It is no coincidence that these are the three with the strongest blue fluorescence. Revealed in this relatively UV-free lighting of the photographer is the darker colour unenhanced by blue fluorescence of the strongly fluorescing members of this I colour set.

While the difference is apparent, the magnitude of over-grading relative to the colour unenhanced by fluorescence cannot be quantified from this photograph. That quantification was accomplished by analysis of grading of the 25 diamond data base central to this study.

Figure 3: The 25-diamond data base in lighting showing diamond brilliance and fire.

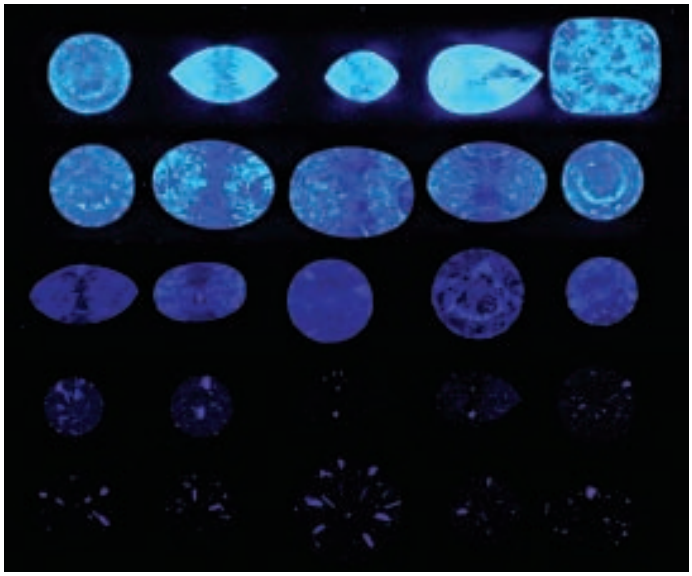

Figure 4: The 25-diamond data base in long wave UV 'black lighting'. Not to be mistaken for fluorescence are the flashes of visible violet reflected from the diamonds with negligible fluorescence in rows four and five.

Investigation

To explore and quantify the extent of the over-grading of blue fluorescent diamonds, and find possible solutions to this problem, a set of 25 diamonds with fluorescent strengths from 'none' to 'very strong' was assembled . The analysis contains not only the author's grading of the diamonds in several lighting environments, including the DiamondLite and the DiamondDock, but also the grading of GIA's Gem Testing Laboratory (GIA GTL) and the American Gem Society's Laboratory (AGSL). GIA's current grading environment and light grading standard consists of grading at a 7 in. distance from the twin 17 in. Verilux fluorescent tubes in their DiamondDock. It is the standard in use at GTL since 2000 (R. Geurtz, pers. comm.). The GIA grading reports on the diamonds in this study are all dated post-millennium. AGSL's grading of these diamonds was likewise accomplished in a DiamondDock.

One goal was to determine the range of perceived colour improvement or change in each fluorescent strength category caused by grading in these various lighting circumstances. A second goal was to investigate techniques to create illumination in which fluorescence is not noticeably stimulated. This was pursued both by using new, UV-free LED lighting and by modifications to currently used fluorescent tube lighting.

Observations on the five fluorescence strengths in the 25-diamond data base.

Investigation and photography of the fluorescence properties of the data base's 25 diamonds utilized a Raytech UV Lamp (black light), Model LS-88, with an LW-8, 8 in., 6W, mercury vapour, LWUV tube. This delivers an intensity of UV radiation centred near 360 nm of 180 μW/cm^2 at a distance of six inches.

The 25 diamonds are set out in *Figure 3* in five rows of five diamonds of each fluorescent strength. They are numbered from 1 to 25 from left to right and top to bottom. Strengths of blue fluorescence are indicated in grading reports by the major laboratories with the descriptions of Very Strong Blue, Strong Blue, Medium Blue, Faint or None. These five groups of fluorescent strength are visually apparent in *Figure 4*.

There can be variation in these descriptions from lab to lab especially for borderline stones. Nevertheless, for the purposes of this study it is desirable to assess fluorescence as accurately as possible.

Observations of blue fluorescence in particular data-base diamonds

Looking at *Figure 4*, the 'Very Strong Blue' fluorescing diamonds, 2, 3 and 4 appear the strongest fluorescing in this category. Diamond 5 is borderline with GIA calling it 'Strong Blue' and AGS 'Very Strong Blue'. Diamonds 1 and 6 appear identical in strength with both called 'Very Strong Blue' by AGS and a third lab, International Gemological Institute (IGI) calling 6 only 'Strong Blue'. The laboratories' descriptions were in agreement in the rest of the row of 'Strong Blue' diamonds: 7, 8, 9 and 10. The 'Medium Blue' row of diamonds 11–15 were so graded by everyone with the exception of 15 which only GIA called 'Strong Blue'.

So, this analysis and the photograph in *Figure 4* show reasonable consistency in describing fluorescent strength with an occasional miscategorization or equivocal borderline case.

Note the wide range of intensity in the 'Very Strong Blue' category. The ten diamonds in the 'Faint' and 'None' categories (which AGSL calls Negligible) are important to this investigation as a control group to provide data concerning variation in colour grading when there is no variability due to fluorescence.

Measurements of UV content in natural and artificial lighting

The degree of any perceived colour improvement due to fluorescence is proportional to both the diamond's

Box A: Analysis of fluorescence of diamond No. 5 in this investigation

Thomas Hainschwang has kindly provided the following details: fluorescence measurements of the 3.02 ct diamond 5 were obtained by exciting the diamond with near-monochromatic light in steps of 5 nm from 340 to 415 nm, produced from a Xenon light source via a monochromator; by this technique it is possible to excite fluorescence with any desired wavelength of the lightsource. The fluorescence was recorded for each excitation wavelength with a high sensitivity CCD spectrometer and the results normalized. Each recorded curve (in black) in *Figure A* represents fluorescence spectrum excited by the the near-monochromatic light tuned to distinct wavelengths. To give an example, the first emission curve in *Figure A* represents the intensity of the fluorescence of the diamond when excited by near-monochromatic light with a central wavelength of 340 nm. The 3D graph in *Figure A* thus shows the fluorescence intensity profile when the diamond is excited with such near-monochromatic light of various wavelengths.

These curves show what early diamond industry experts did not know, not just UV light, but also visible light up to 415 nm excites the blue fluorescence caused by the N3 centre (three nitrogen atoms surrounding a vacancy) in any diamond containing appreciable concentrations of A and B aggregates, and consequently N3 centres. Consequently wavelengths up to 415 nm can be important contributors to blue fluorescence in Cape Series diamonds. At normal viewing distances from artificial illumination the violet light intensity, just like the UV, is too weak to excite noticeable fluorescence. But observation too close to either fluorescent or incandescent lighting, where the intensity exceeds about 400 fc or 4000 lux, was found to excite blue fluorescence (fc and lux are the units used in photometry as measures of visible light intensity, as perceived by the human eye. They are analogous to the radiometric unit μW/cm², but with the intensity at each wavelength weighted according to the luminosity function, a standardized model of human visual brightness perception.)

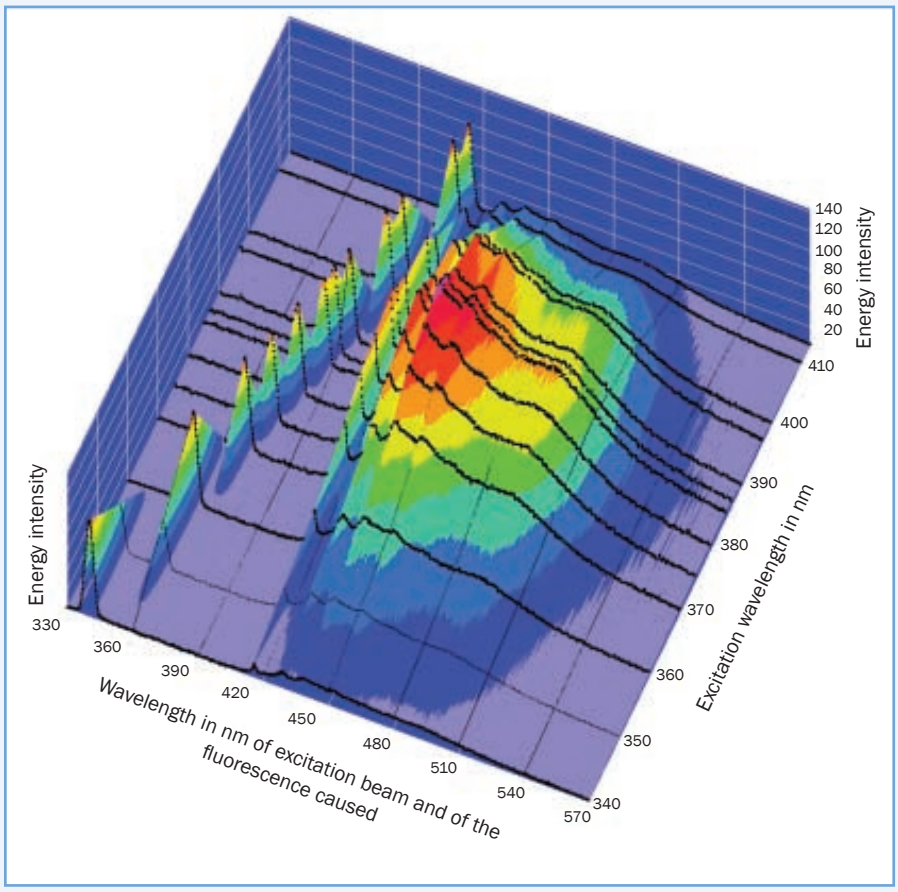

Figure A. Blue fluorescence intensity stimulated by UV and visible-violet radiation in diamond no. 5. The peaks of the near-monochromatic exciters are shown in the line of peaks on the left, and the fluorescence generated in the diamond is the colour-contoured profile centre-right. Energy intensity is shown in arbitrary units and colour-coded with red being the most intense. Courtesy of Thomas Hainschwang, Gemlab.

fluorescent strength and the strength of the UV energy from the light source used in grading. A Dazor Model 5.7 (UVA + B) total UV instrument was employed to measure the amount of UV present in each lighting environment. This meter was calibrated to NIST standards, and measures the UV band from 280–400 nm over a range of 0 to 1999 μW/cm².

Typical measurements of UV in blue sky, northern daylight in Maryland, at 11:00 a.m. 7 December 2008, were 500–600 μW/cm². The UV rapidly increased as the detector was rotated south and the vicinity of the sun was approached. Near but not including direct sun, the reading quickly exceeded the meter range of 1999 μW/cm². Hazy overcast and cloudy skies absorb UV and were observed to reduce these figures by more than a factor of two. On 8 March 2009 at noon on an overcast day readings in north light of 800–1100 μW/cm² were obtained. This large and highly variable amount of UV in natural daylight makes it clear why this illumination is unsuitable for consistent grading of fluorescent diamonds.

The over-grading of blue-fluorescent diamonds: the problem, the proof and the solutions

Discussions of lighting standards for colour grading are often concerned with the variability of daylight's colour temperature, which ranges from the reddish light of early morning and evening to the bluish mid-day light from a cloudless north sky. The historical north-daylight standard for colour grading was derived from the traditional lighting from large north-facing window areas in diamond bourses in the Northern Hemisphere *(Figure 1)*, and the restriction of grading times to between late morning and early afternoon. A colour temperature of 6500K is widely accepted. The more problematic, often unknown and neglected consideration for accurate and consistent colour grading is the variable stimulation of blue fluorescence by the highly variable amounts of UV and visible violet present in daylight from open sky, or from north-facing windows, and the fluorescent lighting used in diamond colour grading.

Away from open daylight and indoors, the UV intensities dropped by factors of 100 to 1000, and in typical artificial light to less than 1μW/cm². The greatest indoor sources of UV at noon were large glass windows and doors which faced daylight. These large glass areas filter out short wave UV, but pass a proportion of long wave UV. At the window surface the reading at the December 2008 date and time was 150 μW/cm² dropping to 65 μW/cm² at 3 ft and 35 μW/cm² at 6 ft.

In all other areas illuminated by artificial fluorescent and incandescent ceiling illumination the readings at typical 3–4 ft viewing distances from ceiling lights were an essentially UV-free, 0–1 μW/cm². These readings are consistent with results from extensive surveys conducted by the author and others and provide support for the observation that at distances of more than 3 ft from artificial illumination, including ceiling mounted fluorescent lighting, indoor light is essentially UV free. In addition, because the light intensity is below 400 fc, usually under 100 fc and often less than 50 fc, there is no noticeable stimulation of fluorescence from the visible violet.

The light sources used in this investigation were measured for UV energy intensity, which was plotted as a function of distance from the source. The graph in *Figure 5* shows those curves of UV fall off with distance from Source 1 and 1F (UV filtered), the DiamondLite; Source 3, a two tube desk lamp with the post 2000 GIA Lighting Standard of the twin Verilux tubes used in the DiamondDock; Source 4, AGSL's DiamondDock and Source 5 and 5D (diffused), the GIA Microscope Light. These plots document the high amount of UV present at close grading distances from all of the unfiltered fluorescent light tubes, and also show the rapid fall off with distance from them. Sources 3 and 4 (the cyan and green curves), both employing the post 2000 GIA standard grading illumination of twin 17" Verilux tubes are important examples showing the variability of this standard's UV component.

Lexan and Makrolon polycarbonate filters were used when experimenting with the removal of UV from the various lights used in grading. Polycarbonate plastic is particularly suited to removing UV without significant or noticeable effect on the visible light spectrum. Note that the dashed Source 1F red curve in *Figure 5* shows that the UV has been reduced to less than 1 μW/cm² within 3 in. of the DiamondLite filtered with Lexan polycarbonate plastic. It is opaque to UV below 385 nm and is transparent

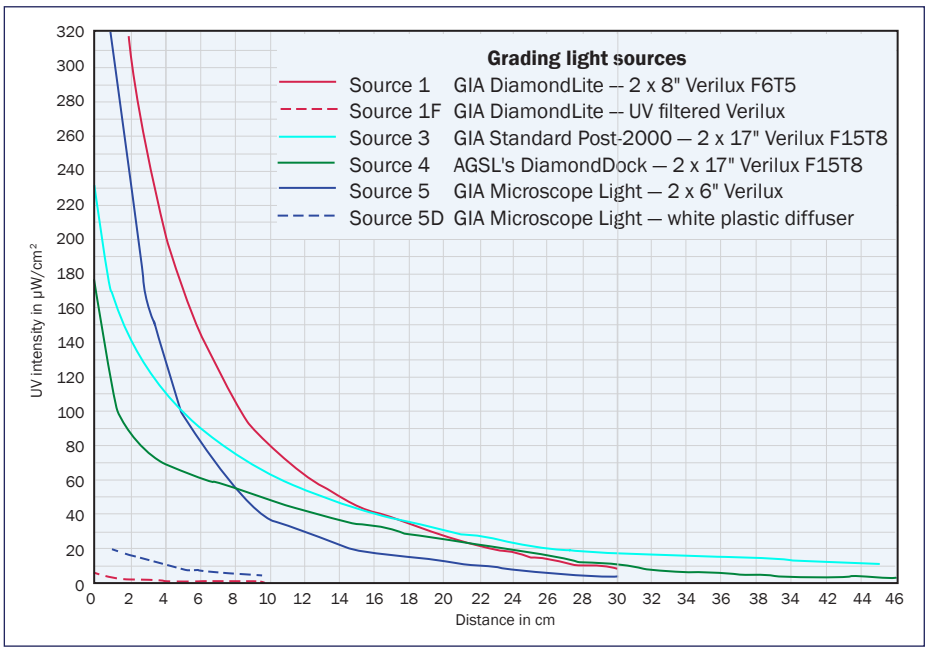

Figure 5: Reduction in intensity of UV with distance from study light sources.

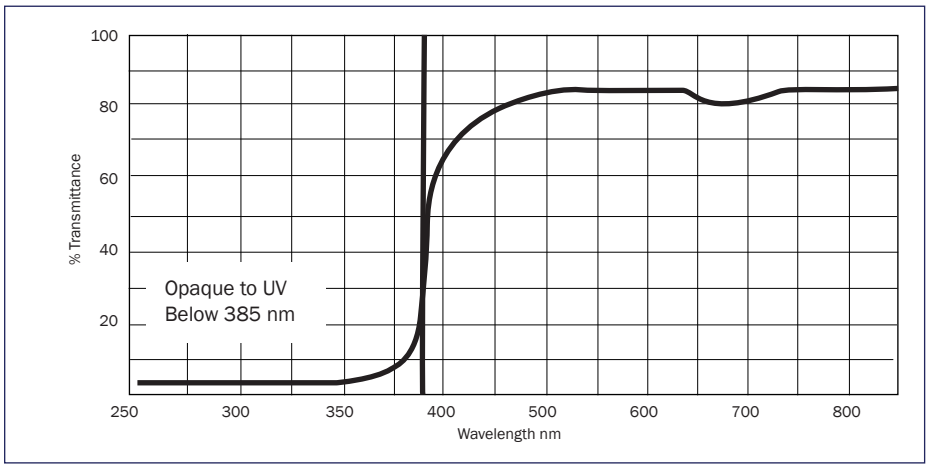

Figure 6: Graph of transmittance of polycarbonate UV filter. Courtesy of Dazor Lighting Manufacturing.

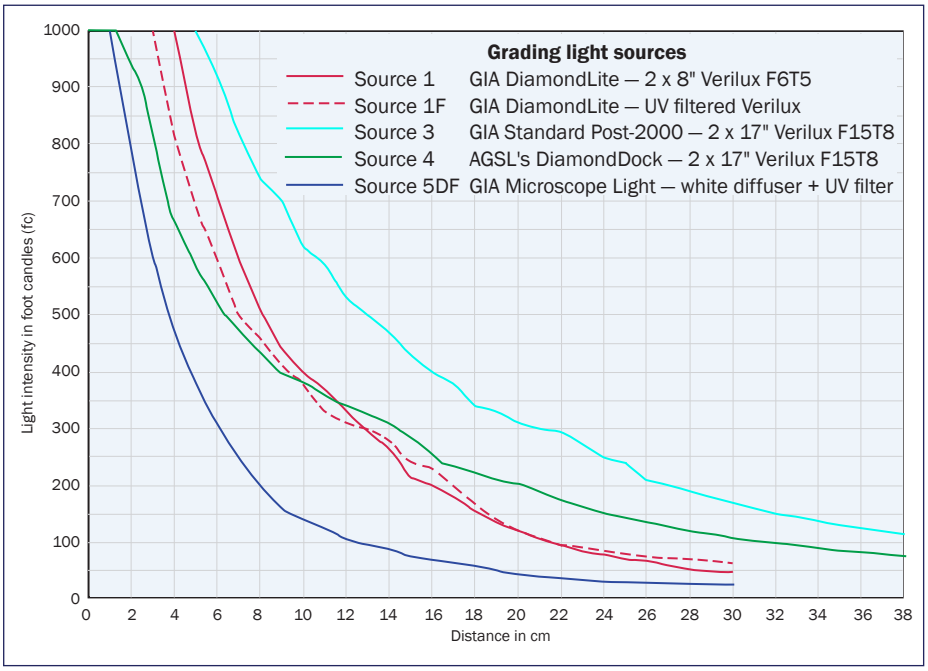

Figure 7: Reduction of light intensity with distance from study light sources.

to the visible spectrum. The range of wavelengths visible to the human eye is often listed as 400 to 700 nm, but "for the human eye, the visible radiations range from violet light, in which the shortest rays are about 380 nm, to red light, in which the longest rays are about 750 nm." (Curtis and Barnes, 1994). It should be stressed however that the eyes of any one individual may not possess this wide range. So for some fortunate individuals there could be 20 nm overlap between UV and visible violet from 380 to 400 nm. This region is at the transmission edge of the polycarbonate filter (see *Figure 6*).

Because the visible wavelengths at and below the 415.2 nm, N3-centre in diamond also excite blue fluorescence (see Box A), it was additionally important to measure the light intensity as a function of the distance from each of the grading lights to explore the visible light component's influence on grading of fluorescent diamonds. Measurements in foot candles of visible light intensity at different grading distances were obtained using a GE Light meter, Type 217. The curves in *Figure 7* show light intensity reduction with distance from four of the grading light sources. The shapes of these curves are broadly similar to the unfiltered UV curves, because the rate of reduction with distance is a function of the lighting geometry and essentially the same for visible and UV wavelengths.

Colour grading instruments and their light-source properties

Seven sources of light were investigated to study their influence on the colour grading of each of the five levels of diamond fluorescent strength present in the 25 diamonds. Each light source was used unfiltered or with the UV component filtered out.

1. The DiamondLite

The DiamondLite, shown in *Figure 8*, contains two Verilux F6T5 fluorescent tubes. In the 1960s it replaced the original Diamolite, renamed DiamondLite, which Shipley had designed to be largely UV free. It incorporated Verilux fluorescent tubes also believed to have a "minimum of UV." In the 1990s it came to be realized that their output contained a significant component of UV.

Because of the rapid increase in both UV and visible light intensity on coming close to the Diamondlite's fluorescent tubes, a colour grade given to a blue-fluorescent diamond could be significantly influenced by how close to these tubes it was graded. Conversations with former and current GIA GTL diamond graders indicate that grading was done between 1 and 4 in. from the fluorescent tubes to the diamonds in the DiamondLight tray or on a white plastic sheet on the instrument base. Grading practice varied somewhat at different times and with different graders. K. Hurwit (pers. comm., 2009), grader of diamond masters, relates that she adhered to Liddicoat's instruction to grade in the tray on the base, but would sometimes elevate the tray for a better view. Senior diamond grader, P. Yantzer, related a standard lab practice used by him and other lab graders since 1972; they placed the diamond table-down, with master stones, toward the rear on a flat sheet of plastic on the base and tilted or elevated this sheet towards the light when comparing to the masters (Yantzer, pers. comm., 2009).

In the 1 to 4 in. range available for grading in the DiamondLite, there are significant amounts and large ranges of UV and visible-violet energy. This variation makes for inconsistent colour grading of blue-fluorescent diamonds. The grading of the data-base diamonds was done between 2 and 3 in. beneath the tubes. At this typical grading distance a spot reading found the UV energy to be about 150 μW/cm², and the light intensity about 600 fc. As the radial distance from the diamonds to the nearest of the twin Verilux tubes increases from 1 to 4 in. the UV decreases from the vicinity of 300 μW/cm² to 80 μW/cm², as shown in *Figure 5*. These are the greatest amounts of UV found among the seven lighting environments investigated, and provide the reason that the unfiltered DiamondLite was found to cause the greatest whitening and, consequently, the greatest over-grading of blue-fluorescent diamonds.

2. GIA DiamondDock

At the turn of the twenty-first century the GIA discontinued the manufacture and use of the DiamondLite and replaced it with the DiamondDock, which employs two 17 in. F15T8VLX Verilux full spectrum fluorescent tubes. Diamonds

Figure 8: GIA DiamondLite containing two Verilux F6T5 fluorescent tubes.

Figure 9: Grading in the DiamondDock at the AGS Laboratory with (inset) a 10-diamond master set. Courtesy of AGSL.

are graded on a white tray placed on the DiamondDock shelf, which means that there is a 7 in. grading distance from the light tubes (see discussion below). The basic technical specifications of the DiamondDock lighting were given by King *et al.* (2008), and include:

- Stable, fluorescent lamps 17 in. (43 cm) or longer
- An intensity of light in the range of 2000–4500 lux at the surface of the grading tray
- An 8–10 in. distance between the lamps and the grading tray
- A colour spectrum close to CIE D55-D65
- A colour temperature between 5500 K and 6500 K
- A colour rendering index of 90 or above
- No noticeable output in the short- or medium-wave UV range (or a filter available to eliminate UV in this range)
- An emission for long-wave UV (between 315 and 400 nm, close to the reference spectrum of D55-D65)

It should be stated that although a grading distance of 8 to10 in. is specified, the maximum distance in the box that the diamonds can be positioned from the lamps is 7 in. Looking in *Figure 5* at the green graph of reduction in intensity of UV with distance in the AGSL's DiamondDock, the UV intensity at 7 in, is 28 μW/cm² falling to 17 μW/cm² at 10 in. The UV intensity is 65% higher at 7 in. compared to that at 10 in. The exact distance is important to establish what is, in essence, the chosen standard amount of UV and visible violet. GIA researcher R. Geurtz (pers. comm.) confirmed that the distance between the light source and the diamond will be close to 7 in.. He explains: "With the distance between shelf and the centre of the bulb at 8 to 10 in., the distance between the diamond and the surface of the bulb is around 7 in." But he notes another important point: the allowed range of light intensity of 2000–4500 lux at the surface of the grading tray means that the amount of UV and visible violet also can vary over the same 2.25 times range. Such an allowed range of UV and visible violet could lead, in different instruments, to different colour grades for a blue fluorescent diamond.

3. Floating arm desk lamp

For the multitude of owners of a standard floating-arm desk lamp, throughout the global diamond trade, this may be the most economical solution for those desiring compatibility with the GIA's DiamondDock. Two 17 in. F15T8VLX Verilux 'full spectrum' fluorescent tubes (the GIA standard lighting used in the DiamondDock) provide the light. Grading was done, without UV filtering at the 7 in. distance, as in the DiamondDock.

Figure 10: Microscope light fitted with white diffuser and Lexan UV filter.

4. AGSL DiamondDock

The DiamondDock in use at the AGS Laboratory is shown in *Figure 9;* the inset shows their ten-diamond E–N master set.

5. GIA microscope fluorescent light

GIA microscopes have provided a less expensive alternative to grading in a standard lightbox. These are fitted with a swing arm light attached to the front of the microscope stage, containing twin Verilux, 6 in. fluorescent tubes, whose light is filtered and diffused with a white plastic cover. This was a daylight-balanced grading light recommended to GIA students and is used to this day by many gemmologists and appraisers (the author included) as lighting for both diamond colour grading and final judgements of clarity grade. The author's

Table I: Colour grades of 25 diamonds with a range of fluorescence strengths.

				Grading of data base in lighting sources with different amounts of UV and VV energy									
				Source 1		Source 2	Source 3	Source 4	Source 5		Source 6		Source 7
				GIA DiamondLite		GIA DiamondDock	Two Verilux	AGSL's DiamondDock	GIA Microscope Lamp		Dazor – Lumileds		Philips 4 × 32 W
Grading distance				2–3 in.		7 in.	7 in.	7 in.	1 in.		3–5 in.		36 in.
				No filter	UV filter	No filter	No filter	No filter	Diffuser (D)	D+UV filter	Diffuser	Diffuser	Diffuser
Intensity (fc) at grading distance				600 fc	600 fc		350 fc	230 fc	600 fc	600 fc	600 fc	200 fc	200 fc
Ultraviolet (UV-A) at grading distance				150 μW/cm²	1 μW/cm²		33 μW/cm²	31 μW/cm²	9 μW/cm²	1 μW/cm²	0 μW/cm²	0 μW/cm²	0 μW/cm²
Grader[1]				MDC		GIA GTL	MDC	AGSL	MDC		MDC		MDC
No.	Cut	Weight (ct)	Fluorescence										
Diamonds with GIA report													
1	R	0.92	VST Blue	E	G	E	G	F		G		H	H
2	M	0.63	VST Blue	E	H	F	G	G	G	H	I		J
4	P	1.13	VST Blue	F	H	H	H	H		H		J	J
5	C	3.02	ST Blue (VST)[2]	D	D	D	D	D		D	E		E
7	O	2.01	ST Blue	E	E	E	E	F		E	F		G
8	O	2.02	ST Blue	E	E	E	E	F		E	F		G
9	O	1.56	ST Blue	E	F	F	E	F		F	G		G
10	R	1.00	ST Blue	E	E	E	E	G		F		G	G
12	O	0.68	MED Blue	F	F	F	F	G		F	F		G
13	R	1.09	MED Blue	G	G	G	G	G		G	G		G
15	R	0.59	ST Blue (MED)	E	E	E	E	F		E		E	E
20	R	1.01	None	J	J	J	J	J		J	J		J
21	R	0.77	None	G	G	G	G	H		G	G		G
22	R	0.73	None	G	G	G	G	G		G	G		G
23	R	2.28	None	H	H	I	H	H	H	H	H		H
Diamonds without GIA report						Non-GIA grading							
3	M	0.50	VST Blue	E	G		G	G		H	H		I
6	R	1.05	ST Blue	I	J	I(IGI)	I	I	I	J	J		K
11	M	0.84	MED Blue	G	G		G	H		G	H		H
14	R	1.50	MED Blue	G	H		G	H		G	H		H
16	R	0.50	Faint	D	D	D(EGL)	D	D		D	D		D
17	R	0.42	Faint	D	D		D	E		D	D		D
18	P	0.70	Faint	G	G		G	G		G	G		G
19	P	0.62	Faint	D	D		D	D		D	D		D
24	R	0.71	None	H	H		H	H		H	H		H
25	M	0.71	None	D	D		D	D		D	D		D

NB 1. Grader abbreviations: MDC = M.D. Cowing; GIA GTL = Gemological Institute of America Gem Testing Laboratory; AGSL = American Gem Society Laboratory; IGI = International Gemological Institute; EGL = European Gemmological Laboratories.

2. Brackets in this column indicate an AGSL opinion where it differs from that of GIA.

microscope light with the addition of a Lexan polycarbonate UV filter is shown in *Figure 10*. Unfiltered, at a distance of about an inch, this light has a strong UV component of 200 μW/cm² and a strong visible light intensity of 1000 fc. The standard white plastic diffuser reduces the UV to 10 μW/cm² and the light intensity to 800 fc. With the addition of a Lexan filter, the UV drops to a small 1 μW/cm² and the light intensity to 740 fc.

In the Verilux tubes in the DiamondLite and all commercial mercury vapour fluorescent lighting, at typical close grading distances the visible-violet wavelengths add to the stimulation of blue fluorescence formerly attributed only to UV. Even after filtering out UV, the visible violet present in light intensities at or above about 600 fc was found to whiten some 'Strong' and 'Very Strong Blue' fluorescent diamonds. To prevent the energy in the visible violet from noticeably affecting fluorescent diamond colour, provisional tests indicate that the maximum fluorescent-tube light intensity should not exceed 400 fc. This compares with the lighting intensity range of 2000–4500 lux listed by King *et al.* (2008), this being the equivalent of 186–418 fc.

6. LED desk lamp

In order to investigate the potential of LED technology for use in diamond colour grading, especially as a solution to the over-grading of blue-fluorescing diamonds, a white LED light, which emits no UV, was tested. It contains six high-power 'lumiled' LEDs with a high quality, thermally-managed, consistent 6000 K colour. An additional feature of this lamp, of interest because of visible-violet stimulation of blue fluorescence, is the ability to dim the light while maintaining its colour temperature. Initial grading of the 25 diamonds in the data base indicated that at a brightness of 600 fc the grades recorded were slightly whiter than those recorded in light of 200 fc (i.e. within the range recommended above); in the absence of UV this was attributed to fluorescence stimulation by the visible violet.

Figure 11: Overhead north-daylight balanced, (D65) fluorescent lighting.

7. Northern daylight balanced ceiling-mounted fluorescent light

The colour of a diamond can be seen and graded against master diamonds at distances from daylight fluorescent overhead illumination of 3 to 4 ft. Such distances are typical of those at which diamonds are viewed in a variety of social occasions. At this distance there is negligible UV and the amount of visible violet is not strong enough to whiten the colour grade. The example of this lighting chosen was the overhead daylight fluorescent light *(Figure 11)* containing four, 32 W Philips F32T8/DX tubes behind a clear plastic diffuser. Almost any artificial ceiling lighting could have been used, since at normal diamond viewing distances such illumination is essentially UV-free and has a visible light intensity which does not stimulate noticeable fluorescence. This lighting has a colour temperature of 6500 K, and at a distance of 3 ft, an intensity of 200 fc with no measureable UV.

Evaluation of the grading of the 25 diamonds

In *Table I* are the colour grades of the 25 diamonds in the data base obtained in each of the light environments.

To get a better visual understanding of the changes in grading which relate to different fluorescent strengths and light sources, the letter grades were changed to integers, 0 for D, 1 for E and so on. The integer number of grades improvement over the colour determined in the absence of fluorescence stimulation was then recorded in the 3-D scatter plot in *Figure 12* for each light source arranged in UV-strength order from the back: Row 1, Source 1, the unfiltered DiamondLite having the most UV to Row 6, Source 6, LED lighting front-left having no UV. In order of decreasing UV, Row 2, Source 2 is GIA's grading in the DD, Row 3, Source 3 is the author's grading in GIA standard DD type lighting, Row 4, Source 4 is AGSL grading in their DD, and Row 5, Source 5 is the author's grading in the UV-filtered and white-plastic-diffused microscope lighting.

Examination of the chart and scatter plot supports the observations of whitening from blue fluorescence made by Tashey (2009). The improvement due to blue fluorescence from both the UV and visible violet in 'Very Strong' blue-fluorescing diamonds was found to be up to four and one-half grades. By filtering out the UV it was calculated that between one and two grades of this four and a half was due to stimulation by the remaining energy post filtering, chiefly the visible-violet. In 'Strong Blue' fluorescent diamonds, the colour-change due to fluorescence was typically two grades. In 'Medium Blue' fluorescent diamonds the change was generally between zero and one grade. As expected, no differences in grade from UV stimulation were found in the 'Faint' and 'None' categories of diamond.

An issue arising in the course of this investigation was the observation by the author and many other gemmologists

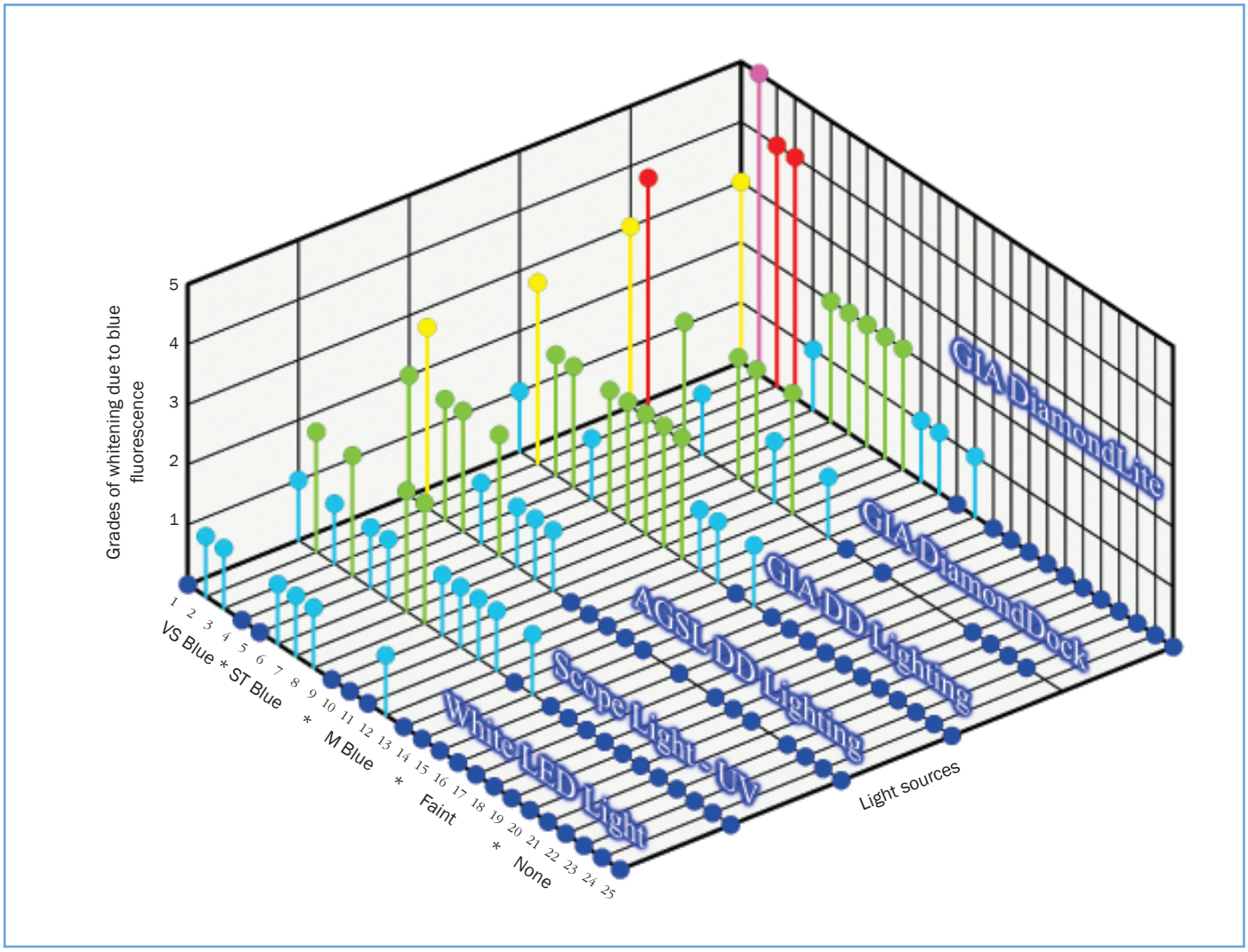

Figure 12: Scatter plot of grade changes of 25 diamonds under different light sources. The diamond numbers and their fluorescence characteristics are on the lower left; the light source numbers from the right are in sequence 1 (DiamondLite) to 6 (white LED light) — see text and Table I.

of a whitish, foggy fluorescence in 'Strong Blue' fluorescent diamonds seen in the high intensity incandescent light of the dark field illumination in gemmological microscopes. This study found that fluorescence stimulation from the relatively intense incandescent illumination that exists at short distances in gemmological microscopes and in other high intensity incandescent lighting was capable of causing colour improvement in some 'Strong' and 'Very Strong' blue-fluorescent diamonds. Even after filtering out UV from the high intensity incandescent microscope lighting, the excitation from the remaining narrow band of visible violet up to 415.2 nm was observed to stimulate this fluorescence. These observations of fluorescence stimulation from the UV and visible violet at short distances in high intensity incandescent lighting point to why not only fluorescent grading light but also incandescent light must be UV filtered and of intensity below 400 fc to grade fluorescent diamond colour consistently and unenhanced by blue fluorescence.

What was learned from the grading of 25 diamonds in different light environments

Degree of over-grading of 'Very Strong Blue' fluorescent diamonds

First and foremost is the documentation in 'Very Strong Blue' diamonds 2, 3 and 4 of a four grade improvement in the unfiltered DiamondLite (DL) compared with the colour grade in UV-free light. Diamond 2 changed from J to F in DiamondDock (DD) (GIA) to borderline E in the DiamondLite (DL), and to G in AGSL's DD. Diamond 3 with a grade of I was a low E in the DL; and diamond 4 with a grade of J changed to F in the unfiltered DL.

Stone 4 is particularly important to note, because its grading in the DL compared to its grading in the current DD standard illustrates the consequences of the change in GIA lighting standards brought about by the switch from grading at a distance of 2 to 4 in. in the DL, to 7 in. in the DD. Contrast the grade of F obtained in the unfiltered DL with the H

obtained by GIA, AGS and the author in the DD lighting. H is two grades lower and closer to the grade of J obtained in UV-free light. This is due to the much lower UV content and light intensity at the working distance of 7 in. in the DD. In changing from grading in the DL to the DD, the UV content in the lighting decreases from the vicinity of 150 µW/cm² to around 31 µW/cm², and the light intensity from 820 fc to 225 fc. The colour grade of J is obtained in both the Source 6, LED lighting with zero UV and the ceiling-mounted Source 7, fluorescent lighting.

So the changes from DiamondLite to DiamondDock and in procedure from grading at 2 to 4 in. to grading at 7 in. result in a lowering of both the UV and visible violet, and a consequent change in this instance of two letter grades closer to the unimproved colour for a 'Very Strong Blue' fluorescent diamond.

Degree of over grading of strong and medium blue fluorescent diamonds

Looking at the scatter plot of the 'Strong Blue' diamonds 6 to 10 a quite consistent two grade whitening is evident in the unfiltered DiamondLite as well as in the DiamondDock standard Verilux lighting used in the GIA and the author's grading, compared with the grades obtained in UV-free light. AGSL's grading of these 'Strong Blue' diamonds differed, obtaining on average only one grade of whitening in their DiamondDock lighting. Judging from this limited sample size, the change in lighting from the DiamondLite to the DiamondDock, while clearly reducing the likely amount of over-grading in 'Very Strong Blue' diamonds, appears to result in a less consistent reduction in the 'Strong Blue' fluorescent diamonds. The same can be said for the less consistent reduction seen in the half to one grade whitening typically seen in the 'Medium Blue' diamonds in the unfiltered DiamondLite. This lack of consistency is related to the stated range in strength of UV and visible light in the unfiltered Diamond Dock lighting.

Overall though, the scatter plot of this limited number of the five strengths of fluorescence shows a direct correlation between UV content in the grading light and diamond fluorescent strength, and the likely number of grades of whitening compared with their colour in UV-free light. Counting from the back in *Figure 11,* GIA's Source 2, DD grading, the author's grading in Source 3, DiamondDock fluorescent light, and AGSL's grading in their Source 4 DiamondDock, all use the new Verilux lighting in the DiamondDock. Although well within the allowed variation in strength in the current DiamondDock standard lighting, the grading of the data base diamonds by GTL and AGSL in this lighting varied by as much as two grades and was as much as four grades whiter than grades obtained in UV-free light.

Box B: Effect of fluorescence on diamond values in the gem trade

Example of inadequate discounting of fluorescent diamonds

Stone 4 is a textbook example of a 'false colour' diamond warned about by Wade in 1916. Based upon the possible over-grading of this type of fluorescent diamond, it would be reasonable to conclude that typical trade discounting of substantially sized 'Very Strong Blues' like 4 may be insufficient. For example, a 3 ct pear-shaped F VS2 'Very Strong Blue', might be discounted between 10 and 20% from its asking price of $54,000 to around $45,900. At its grade of J in UV-free light its corresponding price would be $33,600, well below the trade's typical discounted price of $45,900. (Note: the significance of these high wholesale asking prices from Rapaport (2009) lies more in their comparative values than in the absolute amounts.)

Example of over discounting of the rarer diamonds historically described as 'blue white'

Consider how unreasonable the current practice is of applying similar discounts to all 'Very Strong Blue' fluorescent diamonds in a particular colour and clarity range without knowledge of their colour in UV-free light. Where diamond 4 is likely not to be discounted enough, it appears unfair to similarly discount diamond 5, a 3.02 ct cushion shaped D VS1 'Very Strong Blue' that holds its colour within a grade in UV-free light. Diamond 5 is one of the rarer fluorescent diamonds whose price today would be discounted the same percentage from $73,000 to $62,000. Its price at its grade of E in UV-free light would be $69,000, $7000 above its discounted price. This rare D with its blue-white appearance in daylight, should command the premium it once did over the more common diamonds that are graded D because of their fluorescence.

This data base clearly indicates that these rare diamonds in the blue fluorescence strengths of 'Very Strong', 'Strong' and 'Medium' that hold their colour in the absence of UV can be unfairly discounted.

Solutions to the over-grading of blue-fluorescent diamonds

The curves in *Figure 5* illustrate that the UV energy in fluorescent and other indoor artificial illumination falls off rapidly with distance from the source. The reduction in UV with distance could provide a partial solution to the over-grading of blue-fluorescent diamonds: this is to grade the diamond at a sufficient distance from UV-containing grading lights that any fluorescence in the diamond being graded is not stimulated beyond faint. This study found no colour difference due to fluorescence in the strengths of 'Faint' and 'None'. However, because lab grading is done from about

2 to 10 in. from fluorescent tubes with significant fluorescence-stimulating UV and visible violet, increases in grading distance within that range can help, but do not solve the problem of over-grading diamonds with fluorescent strengths of 'Medium Blue', 'Strong Blue' and 'Very Strong Blue'.

The change in the lighting characteristics from the DL lighting environment containing upwards of 150 μW/cm² to DD lighting having in the vicinity of 30 μW/cm² was seen to reduce the typical amount of overgrading in Very Strong Blues from as much as four grades to two grades. With this change in the standard grading light the potential for over grading has been reduced but not eliminated.

A more practical way to eliminate UV in grading illumination, and at the same time not noticeably affect the visible spectrum is filtration by polycarbonate plastic, such as Lexan or Makrolon. As shown in *Figure 6,* polycarbonate is an effective and inexpensive filter to remove UV below 385 nm. At the same time there is negligible change to the visible spectrum that could affect grading the D-Z tints of yellow in diamond.

To reduce fluorescence stimulated by visible violet, an equally practical and inexpensive solution is the use of flat-white plastic diffusers which attenuate violet and all visible wavelengths equally. Below 400 fc or about 4000 lux, the reduced amount of visible violet does not excite noticeable fluorescence, and the diamond's colour is unaffected. Such white diffusers have the additional feature of reducing spectral reflections and glare. They were employed on GIA microscope lights *(Figure 10)* for this purpose and to filter UV.

Another solution with potential is the use of white LED technology. In this investigation, a Dazor LED desk lamp not only provided inherently UV-free grading light, but was dimmable without change in colour temperature down to 2000–4000 lux, so as not to stimulate fluorescence from the visible violet. Possible concerns about differences between LEDs and fluorescent lights in their colour rendering indexes (CRIs) should be resolved with further comparative studies in both diamond grading environments.

Conclusions

The term 'blue-white' had been synonymous with top diamond colour for centuries. But after the explosion in supply of Cape-series diamonds from South Africa in the late nineteenth century, the term was so misused that it became as synonymous with deception as with fine quality. In the early twentieth century, Wade (1916) warned diamond dealers to be "on their guard" against blue-fluorescent, 'false colour' diamonds that failed to hold their colour (colourlessness) in all lighting conditions. Those that didn't were penalized in value to the extent to which their body colour was revealed to be yellowish (Cape) when seen in artificial lighting. The more yellow the unimproved colour, the less the stone's value.

In social situations, diamonds are most commonly seen at viewing distances of a few feet in many kinds of artificial illumination at night or indoors away from daylight. In these viewing environments the UV and visible violet are too weak to stimulate grade-whitening fluorescence. This is in contrast to most colour grading environments where the diamond is typically 2 to 7 in. from fluorescent lighting with significant UV and visible-violet components.

Only by grading in lighting that does not stimulate grade whitening fluorescence can grading consistency be achieved. Yet, today gemmologists are advised to use unfiltered UV-containing fluorescent lighting that approximates northern daylight as the standard for colour grading. This requirement for UV in the lighting is an abandonment of Shipley's colour grading philosophy. In addition, the variability in UV in fluorescent lighting is a cause of inconsistent grading of fluorescent diamonds.

It is time to solve the problem of over-grading blue-fluorescent diamonds. The desired grade for a blue-fluorescent diamond should be re-established as that colour seen in typical artificial lighting where fluorescence is not noticeably stimulated.

Since lab grading is done close to fluorescent tubes, the use is recommended of a polycarbonate plastic (Lexan or Makrolon are examples) as an effective and inexpensive filter to remove UV below 385 nm. This polycarbonate filter is designed to screen out UV only, avoiding noticeable alteration of the visible spectrum.

Wavelengths in the visible-violet must also be reduced so they too do not stimulate noticeable fluorescence. This can be accomplished without altering the diamond's colour by keeping the visible light intensity below 400 fc by means of a white plastic diffuser. In addition to lowering the light intensity, such white diffusers were recommended to reduce UV and also reduce spectral reflections and glare from the diamonds being graded.

A different but equally effective solution is to use white LEDs such as this investigation's Dazor LED desk lamp. It not only provides inherently UV-free grading light, but is dimmable without change in colour temperature down to 200–400 fc (about 2000–4000 lux).

Either solution would be consistent with the aim that diamonds should be examined for their unenhanced body colour in lighting free of UV which is diffused to the extent that neither UV nor visible-violet excite any significant fluorescence.

A return to this procedure would benefit the diamond industry in a variety of ways. First it would remove the distrust and stigma attached to fluorescent diamonds. Second, the rarer blue-fluorescent diamonds that hold their high-white colour in the absence of fluorescence would be recognized for their superior beauty and rarity. Thirdly, blue-fluorescent diamonds could be shown to whiten, and sometimes appear blue-white in natural daylight. Promoting this advantage in comparison with non-fluorescent diamonds of similar grade would be of substantial benefit in the marketing of blue fluorescent diamonds.

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High pressure high temperature treatment of diamonds — a review of the patent literature from five decades (1960–2009)

Dr Karl Schmetzer

Abstract: The relevant patent literature describing high pressure high temperature treatment processes of natural and synthetic diamonds is reviewed. A general overview about high pressure high temperature treatment for various technical applications is presented and colour changes for jewellery-quality diamonds are described in detail. Three major groups of patent documents exist that deal with the treatment of intense yellow type Ib synthetic diamonds, the colour alteration of brown natural diamonds and colour improvement of chemical vapour deposition grown synthetic diamonds, respectively. The reaction mechanisms involved in various processes of colour alteration are briefly discussed. In an extended version on the worldwide web, the different types of patent documents are explained, and the most relevant technical descriptions of a range of equipment used to perform HPHT treatment of diamonds are summarized in appendices.

Keywords: cause of colour, CVD, colour alteration, colour centres, defects, HPHT, natural diamond, synthetic diamond, treated diamond

Introduction

Within the last two decades, the major challenge for gemmological laboratories has moved from problems of distinguishing natural gemstones from their synthetic counterparts more towards the recognition and proper disclosure of various treatment processes. Detailed knowledge of possible treatment processes is essential for the recognition of treated gemstones in the laboratory. Since the late 1990s, in addition to the diffusion treatment of rubies and sapphires, a 'new' treatment process for diamonds, mainly a decoloration of natural brown stones, caused major irritation in the trade when the first faceted stones that had undergone this enhancement for colour alteration in the laboratories or production plants of General Electric were brought to the market in 1999 (Moses *et al.,* 1999).

According to a comparison with patents issued by General Electric and De Beers in the late 1970s to early 1980s, which dealt with colour alteration of type Ib natural and synthetic intense yellow diamonds, first speculations pointed towards a possible application of a high pressure high temperature (HPHT) treatment for the 'new' process (Schmetzer, 1999a), which was later confirmed by General Electric (Anthony and Casey, 1999). Patent documents by General Electric, which had been filed and issued in the 1990s, were discussed

Above: This type Ia diamond of 0.07 ct was originally brown and treated in a three-step process by a) HPHT, b) electron irradiation and c) annealing. Photograph by courtesy of T. Hainschwang, Gemlab, Gemological Laboratory, Balzers, Liechtenstein.

Figure 1: This type IIa diamond of 1.20 ct was originally brown and treated in a HPHT process. Figures 2 and 3: These type Ia diamonds of 1.00 ct and 1.60 ct respectively, were originally brown and treated in a HPHT process.
Photographs courtesy of E. Erel, Carat Gem Lab, Gemological Laboratory, Montigny-les-Metz, France.

by Schmetzer (1999b, 2000). These documents are considered to describe a precursor of the new treatment, mainly the enhancement of synthetic diamonds grown by chemical vapour deposition (CVD). The reduction of defects and strain and the improvement of optical properties are caused in CVD-grown synthetic diamonds by the HPHT treatment process. The application of HPHT treatment to natural type IIa brown diamonds also causes the reduction of defects and strain and results, at least partly, in a decoloration (Smith *et al.,* 2000) or in a transformation into light yellow, pink *(Figure 1)* or blue diamonds. In contrast, the application of HPHT treatment to type Ia brown diamonds causes a colour alteration to yellowish green, greenish yellow or yellow (*Figures 2* and *3;* Reinitz *et al.,* 2000; Hainschwang *et al.,* 2005).

Although the patent documents from the late 1970s to the mid 1990s mentioned in the papers by Schmetzer (1999 a,b, 2000) were briefly reviewed recently by Overton and Shigley (2008), only some of the documents (which describe treatments of mostly brown or brownish natural stones), published mainly within the last decade, were mentioned in this article. Other, older, processes dating back to the 1960s as well as some additional technical developments and applications of HPHT treatment processes described since then for natural and synthetic diamonds are largely unknown to gemmologists. Thus, the author presents an overview of five decades of HPHT treatment of diamonds as disclosed in issued patent documents and patent application publications.

More details about patent documents can be found in an expanded version of this paper on the worldwide web where a short summary about patents and types of patent documents is given in Appendix A. Because technical details of the processes applied are largely unknown to gemmologists and only briefly discussed in gemmological papers, Appendix B is dedicated to the technical aspects of HPHT treatment processes.

General overview and chronology of HPHT treatment processes

The patent documents dealing with HPHT treatment of diamonds are listed in *Table I*; numbers in the right-hand column relate to superscript numbers in this text, and n, s and c relate to natural, synthetic (HPHT) and CVD-grown diamonds. The oldest documents known to the author date to the 1960s and describe diffusion treatment with aluminium and boron and the formation of diamond with semiconductor properties for electrical devices. In these two patents by General Electric[1] first hints towards a possible colour change are also given.

In later decades, numerous patents were filed by the two global players in diamond crystal growth on the world market, General Electric and De Beers (including their subsidiaries), by other companies involved in diamond synthesis (Sumitomo in Japan and Iljin in Korea), by research institutes (e.g. Carnegie Institution of Washington) and by companies involved in the application of diamond for electronic devices (e.g. Nippon Telegraph and Telephone Corporation or Akhan Technologies).

A group of patent documents from the late 1970s/early 1980s[2,3] described the treatment of natural and synthetic diamonds to alter and improve colour. In 1975, a first patent was filed by General Electric which described the improvement of mechanical properties of diamonds by annealing the samples in the field of plastic deformation.[4] A similar process was described by The Australian National University in 1990.[5] From 1988 to 1990, patent applications by Sumitomo again described the formation and alteration of specific defects (colour centres) and the improvement of colour in synthetic diamonds.[6,7,8,9] Since 1995, patent applications have been filed by General Electric which described the improvement of toughness and strength in diamonds. Parts of these applications dealt with synthetic diamonds grown by the HPHT techique,[10,11] but other documents described the treatment of synthetic diamonds grown by the CVD method.[12,13] In general, how defects in the diamond lattice are relieved and voids and stresses are removed by HPHT treatment were described. As mentioned above, the documents of this series are considered as precursors of the processes developed for decoloration and colour change of natural brown diamonds, the results of which were released to the market in Spring 1999.

A first document by Umeda[14] described the improvement of brightness and colour tone of jewellery-quality diamond. Shortly thereafter, the treatment of brown natural diamonds was described in a series of worldwide applications by General Electric[15,16,17,18] and De Beers.[19,20,21] The treatment of different types of diamond was described for decoloration of brown diamonds, and for changing this colour into yellow, orange, greenish yellow and yellowish green *(Figure 4)* and into pink and blue in such stones. All

Figure 4: These type Ia diamonds of 1.20 ct (left) and 1.10 ct were originally brown and treated in a HPHT process. Photograph courtesy of E. Erel, Carat Gem Lab, Gemological Laboratory, Montigny-les-Metz, France.

Table I: Chronology of HPHT patent applications and granted patents for the HPHT treatment of diamonds.

Author(s), applicant priority publication/date and/or WO publication/date	Related patents (patent family)/date	Temperature (°C)	Pressure (kilobars)	Time	Results	No. *
Cannon, General Electric US 3,134,739 (1964) Wentorf , General Electric US 3,141,855 (1964)	DE 1168396B (1964) FR 1341561A1 (1963) GB 1014226A (1965)	700–1500 1300–2000	10–60 8.5 or 63	20 min 12 or 15 min	Diffusion of aluminium to modify electrical characteristics and colour Diffusion of boron to modify electrical characteristics and colour	1 n,s n,s
Strong *et al.*, General Electric US 4,124,690 (1978) Strong *et al.*, General Electric US 4,174,380 (1979)	DE 2732793A1 (1978) GB 1578987A (1980) FR 2359071A1 (1978)	1500–2200 1500–2200	48–80 48–80	1 min–50 hr 1 min–50 hr	Partial or total conversion of Ib to Ia nitrogen, lighter yellow colour Partial or total conversion of Ib to Ia nitrogen, lighter yellow colour	2 n s
Evans and Allen, De Beers EP 0014528A1 (1980)	EP 0014528B1 (1983) US 4,399,364 (1983)	1600–2200	80	20 min–6 hr	Reduction of yellow colour in irradiated type Ib synthetic diamond	3 s, (n)
De Vries *et al.*, General Electric US 4,181,505 (1980)	DE 2519116A1 (1975) GB 1500817A (1978) FR 2275405A1 (1976)	Below 1500	Below 55	1–30 min	Improving mechanical properties of crystals by annealing in the field of plastic deformation	4 n,s
Ringwood, The Australian National University WO 86/01433A1 (1986)	US 4,874,398 (1989) US 4,948,388 (1990) US 4,985,051 (1991) EP 0191067B1 (1992)	1100–1600	10–40	3–60 min	Improving mechanical properties (hardness, strength) by annealing in the field of plastic deformation	5
Tsuji and Sato, Sumitomo Electric JP 63–291896A (vvvvv JP 01–183409A JP 63–291896 (1988)		1500–2200	10–30		Conversion of Ib to Ia nitrogen in irradiated type Ib synthetic diamond	6 s
Tsuji and Sato, Sumitomo Electric JP 01–020689A (1989) JP 02–000385A (1989)	EP 0275063A2 (1988) US 4,880,613 (1989)	1700–2500	> 30	> 20 hr	Conversion of Ib nitrogen in irradiated type Ib diamond, irradiation and heat treatment after HPHT treatment	7 s
Satoh and Tsuji, Sumitomo Electric JP 01–183409A (1989)	EP 0324179A1 (1989) EP 0324179B1 (1992) US 4,959,201 (1990)	> 1600	> 30	5–30 hr	Treatment of an irradiated Ib diamond to produce a green colour	8 s
Nakajima *et al.*, Sumitomo Electric JP 02–018980A (1990)		> 2000	> 30	> 5 hr	Formation of N3 centres in a type Ib synthetic diamond for use as diamond laser element	9 s
Jackson and Park, General Electric US 5,523,071 (1996)	JP 07–165494A (1995) EP0638670A1 (1995) EP 0638670B1 (2001)	800–1600	Up to 45	5 min–10 hr	Annealing in reducing atmosphere to improve the toughness and strength of diamond grains	10 s
Banholzer *et al.*, General Electric	EP 0668377A1 (1995) JP 08–002997A (1996)	900–2000	10–70	5 min–10 hr	Annealing in non-oxidizing atmosphere to improve the toughness and strength of diamond grains	11 s

Anthony *et al.*, General Electric	EP 0671482A1 (1995) JP 07–331441A (1995)	1000–2000	10–200	minutes–several days	Remove voids and stress to improve toughness in colourless CVD synthetic diamond	12 c, (n,s)
Anthony *et al.*, General Electric US 5,672,395 (1997)		1100–2300	above 3	2–60 min	Annealing in a non-oxidizing medium to improve the toughness of CVD synthetic diamond thin films by removing stress and voids	13 c, (n,s)
Umeda & Miyamoto, Umeda JP 09–164329A (1997)					Improve the quality and colour tone of jewellery-quality diamond	14
Anthony & Vagarali, General Electric WO 01/14050A1 (2001)	EP1210171B1 (2006) EP 1645328A1 (2006) CA 2382785A1 (2001) DE 60027441T2 (2006)	1500–3500	10–100	30 sec–96 hr	Production of yellowish-green, greenish–yellow and neon greenish-yellow stones from discoloured natural diamonds	15 n
Vagarali *et al.*, General Electric US 2001/0031237A1 (2001)	US 2002/0081260A1 (2002) US 2003/0143150A1 (2003) US 2004/0146451A1 (2004) US 2005/0249655A1(2005) US 6,692,714B2 (2004) US 7,323,156B2 (2008)	1500–3500	10–100	30 sec– 96 hr	Production of colourless stones from discoloured natural diamonds	16 n
Vagarali *et al.*, General Electric, US 2002/0172638A1 (2002)		1500–2700	50–200	30 sec–500 hr	Production of colourless, yellow, greenish yellow, pink, red, and blue stones from discoloured (mostly brown) natural diamonds	17 n
Anthony *et al.*, General Electric WO 02/13958A2 (2002)	EP 1315558B1 (2006) EP 1637218A2 (2006) US 2005/0260935A1 (2005) US 7,241,434B2 (2007)	1500–3500	10–100	30sec–96 hr	Production of colourless and fancy coloured stones from discoloured natural diamonds	18 n
Burns and Fisher, De Beers WO 01/72404A1 (2001)	EP 1272264B1 (2006) CA 2405362 (2001) DE 60123591T2 (2007)	1900–2300	69–85	10 min–10 hr	Production of pink stones from discoloured natural brown diamonds	19 n
Burns *et al.*, De Beers WO 01/72405A1 (2001)	EP 1272266B1 (2006) CA 2405409A1 (2001) DE 60123593T2	1800–2600	67–90	10 min–20 hr	Production of blue stones from discoloured natural brownish grey or grey diamonds	20
Burns *et al.*, De Beers WO 01/72406A1 (2001)	EP 1272265B1 (2006) CA 2405420A1 (2001) DE 60123592T2 (2007)	2200–2600	76–90	90 min –5 hr	Production of colourless stones from brown diamonds	21 n
Frushour and Li, Diamond Innovations US 2003/0230232A1 (2003)	US 6811610B2 (2004)	1500–2900	at least 40	1–30 min	Improving optical, electrical, thermal and mechanical properties of synthetic CVD diamonds	22 c
Frushour and Li, Diamond Innovations WO 2005/031033A1 (2005)		1500–2900	at least 40	1–30 min	Improving optical, electrical, thermal and mechanical properties of synthetic CVD diamonds	23 c

Table I: Chronology of HPHT patent applications and granted patents for the HPHT treatment of diamonds (continued)

Author(s), applicant priority publication/date and/or WO publication/date	Related patents (patent family)/date	Temperature (°C)	Pressure (kilobars)	Time	Results	No. *
Vins, Vins RU 2237113C1 (2004) WO 2004/113597A1 (2004)	EP 1645664A1 (2006) US 2007/0053823A1 (2007)	> 2150	60–70	10 min	Production of fancy red diamonds, irradiation and heat treatment after HPHT treatment	24 n
Baek *et al.*, Iljin Diamond KR 20040042576 (2004)					Colour change of diamond from brown to yellow, greenish yellow, yellowish green or colourless	25 n
D'Evelyn *et al.*, General Electric US 2004/0000266A1 (2004)	US 2006/0096521A1 (2006) US 7,175,704B2 (2007) EP 1378591A1 (2004) EP1715086A1 (2006) JP 2004–161604A (2004) JP 2007–015918A (2007)	1000–2000	55	30 min	Reduction of defect concentrations and strain in various non-diamond crystals, e.g. SiC, GaN, GaAs	26
Gill *et al.*, Element Six WO 2004/074557A1	US 2007/0054124A1 (2007)				Annealing CVD synthetic diamonds to enhance the wear rate	27 c
Godfried *et al.*, Element Six WO 2004/046427A1 (2004)	US 2004/0229464A1 (2004) GB 2432592A (2007) GB 2433737A (2007) GB 2433738A (2007)				Annealing CVD synthetic diamonds to enhance optical properties and to reduce strain	28 c
Twitchen *et al.*, Element Six WO 2004/022821A1 (2004)	CA 2495840A1 (2004) US 2004/0175499A1 (2004) US 2007/0079752A1 (2007) US 2009/0291287A1 (2009) US 7,172,655B2 (2007) GB 2430194A (2007)	1200–2500	65–80	3 sec–835 hr	Production of a desired colour in CVD– grown synthetic diamond, e.g. colourless or pink or green	29 c
Hemley *et al.*, Carnegie Institution of Washington US 2005/0025886A1 (2005) US 2006/0144322A9 (2006)	WO 2005/007936A2 (2005) WO 2005/007937A2 (2005) US 2006/0185583A1 (2006) US 2007/0290408A1 (2007) US 2008/0241049A1 (2008) US 7115241B2 (2006) US 7309477B2 (2007)	1800–2900	50–70	1–60 min	Enhancement of diamonds grown by microwave plasma chemical vapour deposition, lightening brown or yellow coloration, improvement of mechanical properties, e.g. hardness	30 c
Hemley *et al.*, Carnegie Institution of Washington US 2006/0065187A1 (2006)	WO 2007/018555A2 (2007) US 7594968B2 (2009)	2000–2700	50–70	10 min	Enhancement of diamonds grown by microwave plasma chemical vapour deposition, removal of brown coloration, increase of hardness	31 c

Namba *et al.*, Sumitomo Electric Industries WO 2005/041279A1 (2005)	EP 1713116A1 (2006) US 2006/0177962A1 (2006)	800–1800	30–80	10 hr	Producing n-type semiconductor diamond by annealing Li- and N-bearing ion-implanted crystals	32 s
Tkachenko and Timofeev RU 2281350 C2 (2006)		1700–2300	60–90	8–30 min per step, 1–3 hr in total	Decoloration of diamond in several annealing steps at different temperatures	33 n
Summerton *et al.*, Element Six WO 2006/061707A2 (2006)	US 2009/0258229A1 (2009)	2100–2500	60–80	0.1–48 hr	Improving the quality of type IIa HPHT- grown synthetic diamond	34 s
Williams *et al.*, Element Six WO 2006/136929A2 (2006)	GB 2428690A (2007) US 2010/0015438A1 (2010)	1200–3000			Improvement of CVD-grown synthetic diamond	35 c
Kasu *et al.*, Nippon Telegraph and Telephone Corporation WO 2006/137401A1 (2006)	EP 1895579A1 (2008) US 2008/0134959A1 (2008) US 2008/0134960A1 (2008) US2008/0217626A1 (2008) US 2009/0261347A1 (2009)	1200	60		Improving the properties of ion-implanted diamond semiconductor elements	36 c
Twitchen *et al.*, Element Six WO 2007/066215A2 (2007)	US 2009/0127506A1 (2009)	1600–2500	60–80	0.1–48 hr	Improving the quality of HPHT-grown synthetic diamond which is used as seed for CVD growth	37 s
Khan, Akhan Technologies WO 2008/019404A2 (2008)	US 2008/0073646A1 (2008) DE 112007001892T5 (2009)	1200	60	1 hr	Improvement of properties of boron–doped diamond field effect transistor	38 c

* n: natural diamonds;
s: synthetic HPHT-grown diamonds;
c: synthetic diamonds grown by chemical vapor deposition (CVD)

HPHT treatment predominantly for colour improvement

HPHT treatment in combination with diffusion of aluminium or boron into the diamond

HPHT treatment in combination with irradiation

HPHT treatment predominantly for the improvement of mechanical properties

HPHT treatment predominantly for the improvement of parts for electrical devices

Notes:

1. Patents related to the design of the equipment to create the temperature and pressure conditions for diamond synthesis are not included in this table.
2. Related patents (patent family members) are patents with the same title and/or by the same inventors and/or by the same applicant; only a selection of patent family members are given, others in different languages, e.g. Japanese, Chinese, Russian, may also have been published.
3. The patent country codes are as follows: CA – Canada, DE – Germany, EP – Europe, FR – France, GB – Great Britain, JP – Japan, KR – Korea, RU – Russia, US – United States, WO –World Intellectual Property Organization.

Table II: Colour change of diamonds by HPHT treatment

Starting material*	Original colour	Treatment	Colour after treatment	Mechanism	No.
n,s		HPHT + diffusion of boron	Patches of dark blue colour or dark blue surface regions	Diffusion of boron into the diamond structure	1
n,s		HPHT + diffusion of aluminium	Clearer and more colourless	Diffusion of aluminium along fractures	1
s Ib n Ib or Ib–Ia	Greenish yellow or intense golden yellow or yellow	HPHT HPHT	Towards yellow, paler yellow or almost colourless	Aggregation of single nitrogen atoms	1,2,30 2
s Ib		1) Irradiation 2) HPHT	Reduction of colour	1) Displacement of atoms 2) aggregation of single nitrogen atoms	3,6
s Ib	Bright yellow	1) Irradiation + 2) HPHT	Green	Formation of N-V-N centres	7
n Ia, IIa n IIa n IIb	Brown Brown Brown, brownish grey or grey	HPHT HPHT HPHT	Colourless or almost colourless Pink Blue	Removal of brown colour centres	16,17,18,21,25 16,17,18,19 16,17,18,20
n IaB and Ia A/B	Brown	HPHT	Yellowish green to greenish yellow or intense to light yellow	Removal of brown colour centres combined with the mobilization of vacancies, dissociation and association of A and/or B nitrogen defects, formation of N-V-N and other nitrogen-vacancy defects (colour centres)	15,16,17,18,25
n Ia	Near colourless to brown	1) HPHT + 2) irradiation + 3) annealing	Intense pink to red	1) Dissociation of A centres, 2) formation of vacancies 3) mobilization of vacancies and formation of N-V colour centres	24 (compare Ref. 7 for similar treatment of type Ib synthetic diamonds)
n	Brown, yellow and yellowish green	HPHT with annealing in different subsequent steps at various temperatures	Decoloration		33
c with variable nitrogen contents	Brown or orange brown or pinkish brown	HPHT	Near-colourless, pale brown or green or pink brown	Removal of an absorption band at 350 nm, at higher temperatures additional removal of a 510 nm band and a NIR absorption	29
c	Brown or yellow	HPHT	Colourless or near-colourless, reduces or eliminates yellow or brown colours	Removal of defects	30,31

* n: natural diamonds;. s: synthetic HPHT–grown diamonds. c: synthetic diamonds grown by CVD.

HPHT treatment predominantly for colour improvement

HPHT treatment in combination with diffusion of Al or B into the diamond

HPHT treatment in combination with irradiation

Figure 5: This type Ia diamond of 1.51 ct was originally brown and treated in a three-step process by a) HPHT, b) electron irradiation and c) annealing. Photograph by courtesy of V. Vins, Institute of Single Crystals, Novosibirsk, Russia.

these documents contain the most detailed descriptions of colour alteration in natural brown diamonds. A similar application was also filed by Iljin in Korea.[25] A special process for the production of red and pink diamonds was described by Vins using a combination of HPHT treatment, with subsequent electron irradiation and annealing *(Figure 5)*.[24] An application by Tkachenka and Timofeev also described the decoloration of natural diamond.[33] With the exception of the Umeda[14] and the first General Electric[17] patents, the various applications mentioned in this paragraph for colour improvement of natural, mostly brown or pale brown diamonds, have been published within the last decade.

After the year 2000, although there were some applications dealing with the improvement of mechanical properties of synthetic diamonds grown by the HPHT technique,[34] most were for diamonds grown by CVD [22,23,27,28,35] and for related superhard materials.[26] One document contains a description of how to improve the properties of HPHT-grown synthetic diamond crystals which are used as seeds for the growth of larger CVD synthetic diamonds.[37] The interest for possible improvement of CVD-grown synthetic diamonds is based on technical progress in CVD-related processes resulting in the growth of synthetic diamond layers or crystals with larger thickness; such products could be cut as faceted stones for jewellery purposes. Consequently, HPHT treatment is also applied to change or improve the colour of CVD-grown synthetic diamonds,[29,30,31] mainly to alter yellow and pale brown tones. The improvement of properties of specifically doped CVD synthetic diamonds for semiconductor application has also been described recently.[32,36,38]

Colour alteration of diamonds by HPHT treatment

In natural or synthetic diamonds destined for jewellery, the alteration and improvement of colour is the main purpose for application of HPHT treatment processes, although colourless type IIa synthetic diamonds have also been processed to improve quality and optical features.[34] The patents dealing with colour alteration clearly reflect the natural and synthetic material available and the desired colour changes to attain marketable material.

Diffusion treatment with boron and aluminium

Diffusion treatment with boron or aluminium is the oldest patent[1] dealing with the HPHT process applied for colour alteration of natural or synthetic diamonds which is known to the author. This described HPHT annealing in the presence of boron-bearing compounds which resulted in a blue coloration, at least of parts of the surfaces of the samples. Diffusion treatment with aluminium, on the other hand, was described to whiten the treated diamonds. It is not known to the author whether either process has been carried out commercially and samples released to the market, or whether any practical tests are available to detect this type of diffusion treatment and distinguish them from natural pale-blue to fancy-blue diamonds.

On request, the author received the following information from Victor Vins, Novosibirsk, Russia, which is helpful in assessing the potential of these two processes:

"In the mid 1980s we conducted experiments of thermal diffusion of boron and aluminium from the surface of natural diamonds. The experiments were carried out at high P and T conditions, boron and aluminium were in the graphite mixture. We did observe the colour change and we at first thought that we had managed to introduce these elements into the diamond lattice. Then we examined these samples more closely and found out that the colour change was due to thin layers on the surface of natural diamonds. We gradually etched the diamond surface and soon the conductivity decreased from metallic to zero conductivity."

Boron diffusion into type I and type II natural diamond up to a depth of about 2 µm at low pressure and high temperature has been described by Popovici *et al.* (1995 a,b), Sung *et al.* (1996) and Krutko *et al.* (2000).

Thus, two explanations are possible to explain the results mentioned above:

(a) Thin layers of synthetic HPHT-grown boron-containing diamond were formed on the surface of the natural diamond crystals. These layers were removed by subsequent etching.

(b) Boron was diffused into an extremely thin surface layer of the diamond, a layer that could be removed by subsequent etching.

In summary, a possible diffusion treatment of boron would produce a blue coloration only in thin surface layers, but would definitely influence the colour of faceted diamond. However, it is questionable if the thin blue layer produced by this technique would survive any re-cutting and re-polishing.

Transformation of colour centres

The patent applications available as public documents which are relevant to colour alteration of diamond are numbered in *Table II* and can be considered in three groups dealing with

- Colour improvement and alteration of intense yellow type Ib natural and synthetic diamond;
- Colour improvement and alteration of brown type I and natural brown type II diamond;
- Colour improvement and alteration of yellow to brown synthetic diamond grown by CVD.

Some applications also mention the lightening or decoloration of type Ia natural pale yellow diamonds.

In some patent documents, the 'prior art' (patent documents or scientific papers known to the applicant at the time of writing the text of the application or documents identified as relevant by an officer researching a patent application), including the mechanism of colour change and colour improvement is discussed, but in other documents only the desired process of colour alteration is stated, with no mention of the exact mechanism of colour change. From scientific research and review papers published within the last decade (e.g. Collins *et al.,* 2000; De Weerdt and Van Royen, 2000; Vins, 2001; Collins, 2001 a,b; De Weerdt and Collins, 2003; Avalos and Dannefaer, 2003; Katrusha *et al.,* 2003; Vins and Yelisseyev, 2008; Erel, 2009; Fisher, 2009; Fisher *et al.,* 2009) and patent documents the following general reaction mechanisms can be summarized as follows.

According to the type of nitrogen defects present in the diamond crystal and as a function of the annealing temperature(s) and the stabilizing pressure(s), nitrogen-related centres may associate and dissociate. In synthetic and natural type Ib diamonds containing isolated nitrogen atoms on carbon lattice sites (C centres), for example, nitrogen can migrate within the diamond structure and can form A centres (consisting of adjacent substitutional pairs of nitrogen). In natural type Ia diamond, A centres can transform into B centres (consisting of a vacancy trapped by four surrounding nitrogen atoms). A centres, on the other hand, can dissociate into isolated nitrogen atoms.

If vacancies (V) are produced, e.g. by electron or neutron irradiation, these vacancies can combine with existing nitrogen defects to form the following centres:

- C centre + V → N-V centre (a substitutional nitrogen atom adjacent to a vacancy);
- A centre + V → H3 centre (N-V-N centre, a vacancy trapped by a pair of substitutional nitrogen atoms); if an electron is trapped at the H3 centre (with C centres as electron donors), the H2 centre is formed;
- B centre + V → H4 centre (4N-2V centre, consisting of two vacancies and four nitrogen atoms).

H4 centres, on the other hand can become unstable upon HPHT treatment and dissociate into two H3 centres.

Furthermore, in brown diamonds, brown colour centres can be removed by HPHT treatment. In this process, vacancies are also formed or released, which combine with existing nitrogen defects according to the possible reaction processes given above. Some of the new colour centres may become unstable and dissociate.

In the following paragraphs, only short explanations will be given about the various processes; it is beyond the scope of the present paper to discuss all possible processes at different temperatures and the interpretation of spectroscopic measurements in detail. For these discussions, the reader is referred to the numerous scientific papers available. Furthermore, the mechanisms described in various patent documents are not always consistent with each other, but it would be extremely confusing to discuss these differences and discrepancies. Consequently, for these details the interested reader should refer to the original documents (*Table I* and Appendix C).

Colour improvement and alteration of intense yellow type Ib natural and synthetic diamond

Several patents deal with colour improvement and colour alteration of type Ib diamonds containing predominantly isolated nitrogen atoms (C centres). Most synthetic diamonds grown by the HPHT process are of this type and reveal a greenish yellow or intense golden yellow to yellow or even orange coloration. This coloration, which is sometimes too brown or dark for jewellery purposes, can be changed to a brighter yellow *(Figure 6)* or towards a somewhat paler yellow or even approaching colourless, if desired.[1,2,30] The A centres formed by this treatment do not absorb light in the visible range and this explains the lightening of the yellow coloration. Although the same process is also described for natural diamonds,[2] type Ib natural 'fancy yellow' diamonds are very rare and sought after, and therefore the practical application of this treatment to such stones is assumed to be limited.

Figure 6: This type Ib synthetic diamond of 0.33ct was originally intense yellow and treated in a HPHT process. Photograph by courtesy of T. Hainschwang, Gemlab, Gemological Laboratory, Balzers, Liechtenstein.

The same process can be carried out in a shorter overall time by first irradiating the diamond in a separate step before the HPHT treatment is performed.[3,6] Another patent application by Sumitomo Electric described electron irradiation to type Ib synthetic diamonds before HPHT treatment.[8] In this process, vacancies are formed which associate with two nitrogen atoms and form N-V-N centres (H3 and H2 centres). The colour of the processed diamond is green. This type of treatment was performed by Sumitomo for samples marketed by Chatham (for a gemmological description see Shigley *et al.,* 2004).

Colour improvement and alteration of type I and type II natural brown diamond

Details of the causes of colour in natural brown diamonds are still in debate (Hainschwang, 2003; Hainschwang *et al.,* 2005). Until recently, it was generally assumed that the coloration of most natural brown diamonds was associated with plastic deformation, which the diamonds had undergone between their formation and subsequent transport to the Earth's surface. Now, however, results of experimental research and theoretical considerations point towards a model in

Table III: Colour alteration in diamond by HPHT treatment*

Diamond type	Colour before annealing	Medium	Pressure (in kbar)	Temperature (in °C)	Time (in min)	Colour after annealing
IIa	Steely grey brown	Graphite	80	2300	18	Colourless
Ia	Light brown	Graphite	80	2300	20	Pale green
Ia	Light brown	Graphite	80	2300	18	Yellow
Ia	Light brown	Graphite	77	1900	18	Light brown
Ia	Light brown	NaCl	80	2400	12	Yellow
Ia	Medium brown	NaCl	77	1900	18	Medium brown
Ia	Medium brown	NaCl	79	2050	18	Light yellow
Ia	Light yellow	NaCl + KNO_3	79	2200	18	Greenish golden yellow
Ia	Dark brown	Graphite	80	2300	17	Yellow
Ia	Light brown	NaCl	80	2200	18	Light greenish yellow
Ia	Dark brown	NaCl + KNO_3	80	2200	18	Greenish golden yellow
Ia	Light brown	NaCl	80	2300	18	Light yellow
Ia	Light brown	NaCl	80	2300	18	Light yellow
Ia	Light yellow	NaCl	80	2400	18	Brownish yellow
Ia	Very light brown	NaCl	80	2200	18	Light yellow
Ia	Light yellow	NaCl	80	2400	18	Orange
Ia	Light brown	NaCl	80	2400	18	Orange
IIa	Light brown	NaCl	80	2300	18	Colourless
IaA/B	Light brown	Graphite	79	2300	18	Deep yellow
IaA/B	Dark brown	Graphite	79	2300	18	Very light yellow
IaA/B	Dark brown	Graphite	79	2300	18	Colourless
IaA/B	Light brown	Graphite	79	2000	18	Colourless
IaB	Brown	Graphite	79	2000	18	Brown
IaB	Brown	Graphite	79	2000	18	Brown
IIb	Light steely brown	Graphite	79	2300	18	Light blue
IIa	Medium brown	Graphite	80	2300	18	Light pink

* From US 2002/0172638 A1,[17]
Inventors: S.S. Vagarali, S.W. Webb, W.E. Jackson, W.F. Banholzer, T.R. Anthony; applicant: General Electric Company, Schenectady, NY, USA

which vacancy clusters are assumed to be responsible for the brown coloration of natural diamonds. A recent review by Fisher (2009) summarizes these aspects. Because these vacancy clusters are altered and become partly unstable by HPHT treatment, this process is applied to large quantities of natural brown diamonds to transform their colour into one that is more desirable for jewellery purposes.

This more recent interpretation that the brown is due to vacancy clusters, however, is not referred to in the various patent documents which are reviewed and summarized in the present paper. If the cause of colour change is discussed in a patent, the older interpretation based on the removal of colour centres associated with plastic deformation is normally quoted.

Table III shows examples of HPHT treatment of pale to dark brown diamonds, based on a patent application by General Electric which had been filed in October 1997 but only published in 2002.[17] It shows how different the colours can be after treatment and the major types of change are shown in a diagrammatic overview in *Figure 7*.

In nitrogen-free type II and almost nitrogen-free type I natural diamonds, the removal of brown colour centres results in colourless *(Figure 8)* or almost

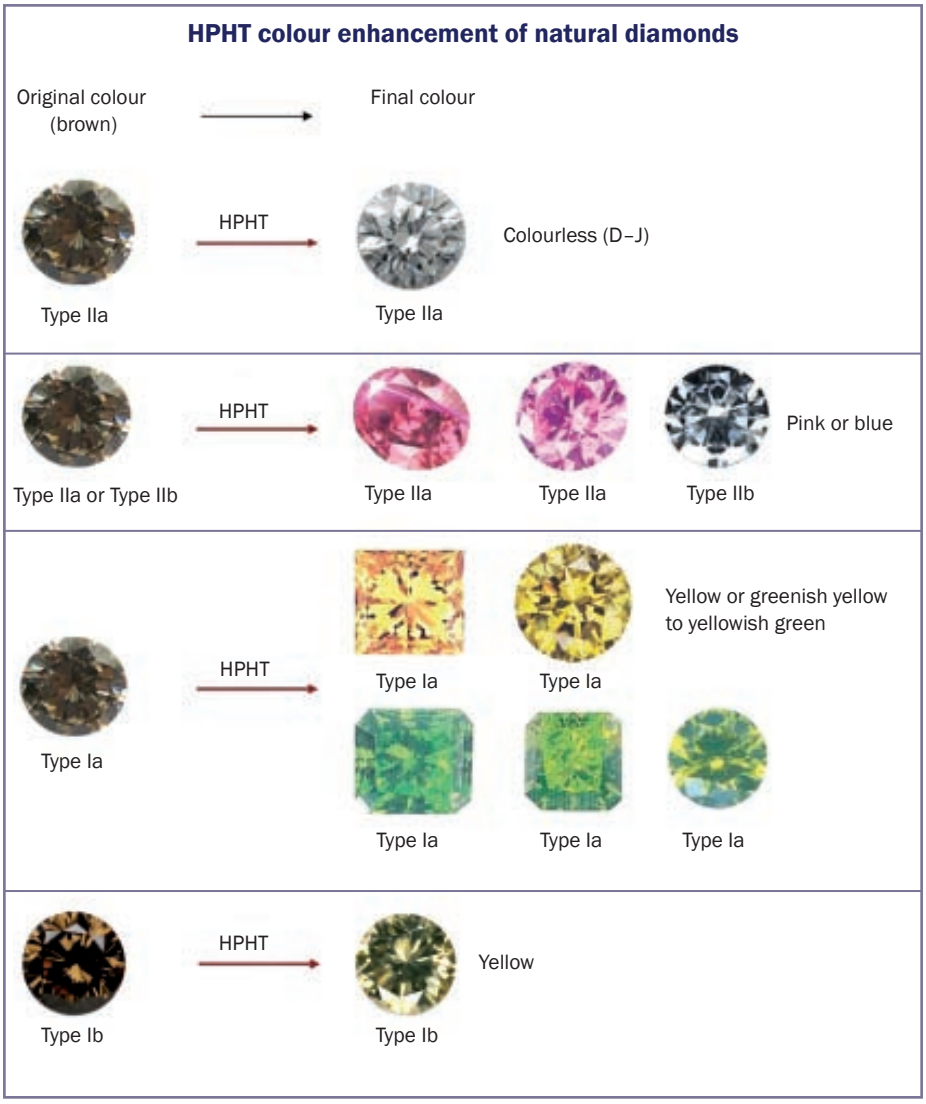

Figure 7: Systematic overview of possible colour alteration by HPHT treatment of natural brown type I and II diamonds. This diagram is based on a somewhat smaller schema by V. Vins, Institute of Single Crystals, Novosibirsk, Russia, which has been extended by the present author.

Figure 8: This type IIa diamond of 0.70 ct was originally brown and treated in a HPHT process. Photograph by courtesy of J.-P. Chalain, SSEF Swiss Gemmological Institute, Basel, Switzerland.

Figure 9: This type IIa diamond of 0.50 ct was originally brown and treated in a HPHT process. Photograph by courtesy of E. Erel, Carat Gem Lab, Gemological Laboratory, Montigny-les-Metz, France.

colourless diamonds.[16,17,18,21,25] If pink colour centres or their precursors, whose exact nature is still in debate, are present in the untreated material but hidden by the brown coloration, after HPHT treatment and removal of the brown colour centres and possible alteration of precursor centres, the diamonds become pink *(Figure 9)*, a colour which is highly sought after.[16,17,18,19] A similar mechanism applies to brown, brownish grey, grey or olive green samples with boron contents (type IIb diamonds, *Figure 10*). The HPHT treatment causes removal of brown colour centres and a possible change of blue precursor centres and can result in stones with the highly appreciated and extremely rare blue to pale blue coloration of natural diamonds.[16,17,18,20] Details of the reaction mechanism involved in the formation and/or alteration of the blue and pink coloration of natural diamonds by HPHT treatment were recently summarized by Fisher *et al.* (2009).

Brown nitrogen-bearing natural diamonds can contain a range of brown colour centres, nitrogen related A and B centres and, rarely, C centres (type Ib natural brown diamond); they may also contain nitrogen trapped as N3 centres (3N-V centre, consisting of one vacancy and three nitrogen atoms) as well as N2 centres (another nitrogen-related defect). If only N3 and N2 colour centres were present, a more or less pale to intense yellow coloration would result from treatment *(Figure 11)*. The colours of these types of natural brown diamonds resulting from treatment *(Figure 11)* show some variability between yellowish green, greenish yellow, a more or less intense yellow, orange and greenish orange.[15,16,17,18,25] The different colours *(Figures 12, 13* and *14)* are a function of the different ratios of N3 and N2 centres versus H4, H3 and H2 centres present in the treated samples. The intensity of the yellow component is related to the relative concentration of N3, N2, H3 and H4 centres and the intensity of the greenish yellow to green component is related to the concentration of H2 centres. Many HPHT-treated brown nitrogen-bearing natural diamonds also exhibit green H3 luminescence which increases the amount of green perceived.

The complex reaction mechanism is summarized as follows: brown colour centres are removed or modified, a process which is associated with the mobilization of vacancies. The vacancies are trapped at various nitrogen defects

present, e.g. at A and B centres forming N-V-N (H3) and other colour centres. The H4 centres formed in this process may become partly unstable and dissociate into H3 centres. The concentration of N3 centres may also be changed within these complex processes, especially when the samples are treated in a sequence of several steps at various temperatures.

Formation of intense pink to red diamonds by a three-step treatment process

The process discussed in this section is applied to natural type Ia colourless to brown diamonds.[24] HPHT treatment is performed for dissociation of A centres into N atoms that are isolated in the diamond structure (C centres). Subsequent electron irradiation forms a high concentration of vacancies, which combine with the isolated nitrogen atoms in a subsequent annealing step and form the desired N-V colour centres, which are responsible for the intense pink to red coloration of the diamonds *(Figure 15)*. Due to the formation of other nitrogen-vacancy defects, the colour of a diamond after this three-step treatment process can vary between violet, purple red, red, orange red and orange (for a gemmological description and spectroscopic characterization of such kinds of stones see Wang *et al.*, 2005). A similar process but in four steps is applied to synthetic type Ib diamonds:[7]

1. irradiation,
2. HPHT treatment,
3. second irradiation, and
4. annealing.

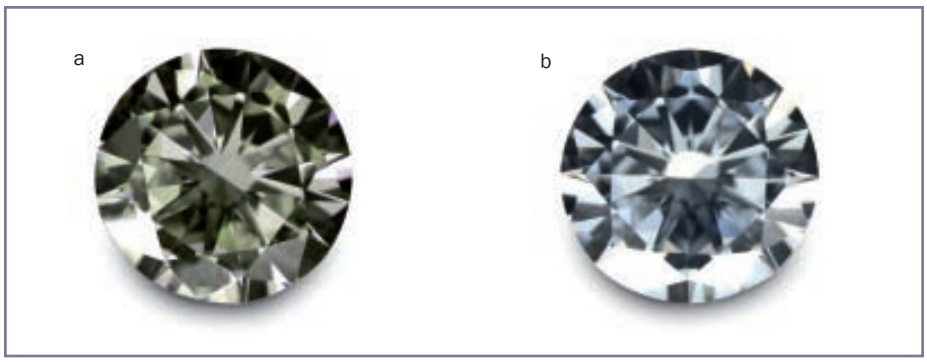

Figure 10 a,b: This type IIa diamond of 0.50ct (a) was originally olive green and treated in a HPHT process and became pale blue (b). Photograph by courtesy of T. Hainschwang, Gemlab, Gemological Laboratory, Balzers, Liechtenstein.

Figure 11: Suite of originally brown to yellowish brown diamonds before (above) and after HPHT treatment; weights range from 0.75 to 0.95 ct. Photograph by courtesy of J.-P. Chalain, SSEF Swiss Gemmological Institute, Basel, Switzerland.

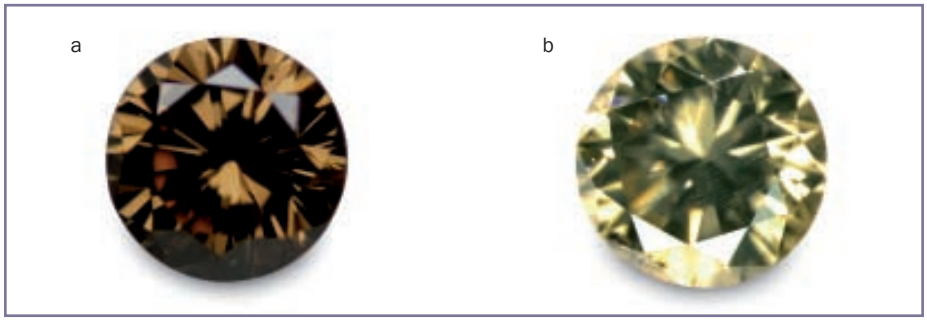

Figure 12 a,b: This originally brown type Ib diamond of 0.13 ct (a) was treated in a HPHT process and became pale yellow (b). Photograph by courtesy of T. Hainschwang, Gemlab, Gemological Laboratory, Balzers, Liechtenstein.

Figure 13: This type Ia diamond of 1.30 ct was originally brown and treated in a HPHT process. Photograph by courtesy of E. Erel, Carat Gem Lab, Gemological Laboratory, Montigny-les-Metz, France.

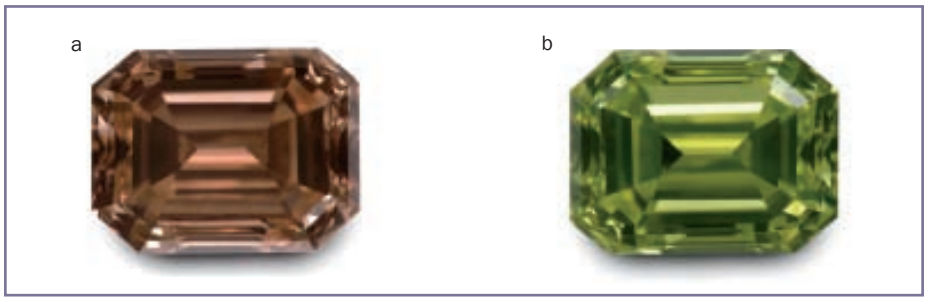

Figure 14 a,b: This type Ia diamond of 2.10 ct (a) was originally brown and treated in a HPHT process and became yellowish green (b). Photograph by courtesy of T. Hainschwang, Gemlab, Gemological Laboratory, Balzers, Liechtenstein.

Figure 15: This type Ia diamond of 1.25 ct was originally brown and treated in a three-step process by a) HPHT, b) electron irradiation and c) annealing. Photograph by courtesy of V. Vins, Institute of Single Crystals, Novosibirsk, Russia.

In steps 1 and 2, some of the isolated nitrogen atoms (C centres) are transformed into aggregated nitrogen (A centres). In step 3, vacancies are formed which combine with C and A centres in step 4 to form N-V and H3 centres. Although the patent application primarily describes the production of synthetic diamond for laser applications, it is obvious that with the actual parameters within this four-step process, e.g. nitrogen contents of the sample and variable treatment conditions (irradiation doses, annealing temperatures) a great variety of colours may be produced.

Colour improvement and alteration of yellow to brown synthetic diamond grown by CVD

The progress in crystal growth within the last decade in application of the CVD technique leads to synthetic diamonds grown on diamond seeds or other diamond layers with sufficient thickness and quality to be cut as gems. The as-grown material may be brown, orange brown, pinkish brown or yellow. HPHT treatment is applied to remove defects in CVD-grown synthetic diamonds, which — at least partly — are different from the major defects found in natural and synthetic HPHT-grown diamonds. The resulting colour of the samples is closely related to the treatment temperature and the concentration of different defects in the as-grown diamond crystals or diamond layers.[29,30,31] It is reported that the resulting coloration after HPHT treatment is colourless or near colourless *(Figure 16)*, but pale brown, green or pinkish brown colours may also result.

Conclusion

HPHT treatment of natural brown diamonds has become an important technical process of colour alteration in order to transform such diamonds into marketable qualities. With the progress of diamond synthesis by CVD, the importance of treatment of yellow to brown jewellery-quality CVD-grown synthetic diamonds is also increasing. The application of HPHT treatment in combination with electron irradiation is performed to acquire some specific rare colours, e.g. to transform the colour of natural diamonds into red or pink or to alter the colour of yellow synthetic diamonds to green or other colours.

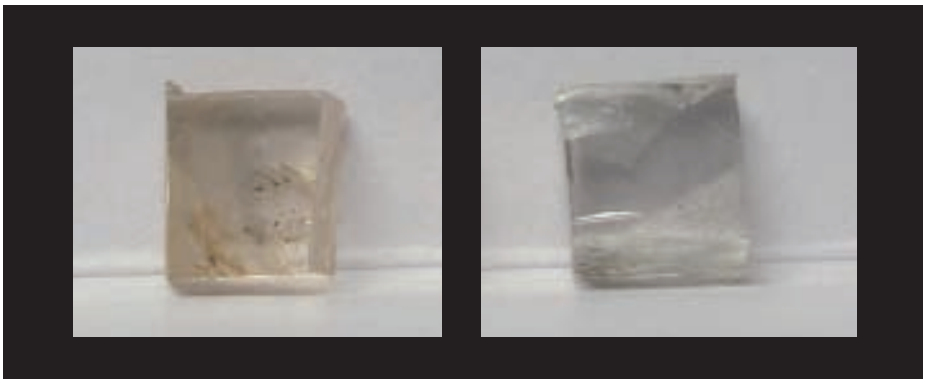

Figure 16: This pale brown CVD-grown synthetic diamond of about 0.25 ct (left) was treated in a HPHT process and became almost colourless (right). Photograph by courtesy of J.-P. Chalain, SSEF Swiss Gemmological Institute, Basel, Switzerland.

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THE GEMMOLOGICAL ASSOCIATION OF GREAT BRITAIN

The gemmological properties and infrared spectra of brucite, an imitation of nephrite and Shoushan stone

Li Jianjun, Yu Xiaoyan, Cai Jia, Liu Xiaowei, Fan Chengxing and Cheng Youfa

Abstract: Nephrite and Shoushan stones have a long history of use as ornamental gem material for jewellery and carving in China. However, the reserves of the stones have dramatically decreased recently and a growing number of their imitations, such as brucite, have entered the Chinese market. Microscope examination, testing with dilute hydrochloric acid, Fourier Transform Infrared (FTIR) spectra and energy-dispersive X-ray fluorescence (EDXRF) spectra have proved to be useful techniques to distinguish nephrite or Shoushan stones from brucite.

Keywords: brucite, gemmological properties, infrared spectra, nephrite, Shoushan stone,

Introduction

In China over the past 5000 years, high quality nephrite has been carved as royal seals, the emblem of power of emperors (Yang *et al.*, 1986; Chen et al., 2004; Tang *et al.*, 2002). Shoushan stone has also been carved as seals, and is named from its source in Shoushan in the northern suburbs of Fuzhou, Fujian province, P.R. China (Wu and Cui, 1999). Shoushan stone comprises around one hundred varieties, among which 'Tianhuang stone' is the most precious and enjoys a reputation as 'the emperor of stones'. Ever since Tianhuang stone became the favourite of Qianlong, an emperor of the Qing Dynasty, its price has been high. It is said that one Liang (a unit of mass equivalent to 50 g used in ancient China) of Tianhuang stone is worth ten Liang of gold.

However, because of scarce reserves, the trade price of Tianhuang stone has been up to a hundred times that of gold. In turn, this helps raise the price of other varieties of Shoushan stone.

In recent years the most sought-after gem materials mentioned above have become more available and have sold for very high prices. This in turn has led to a wider range of material being considered as gemstones. Hitherto, most Shoushan stone has consisted of the kaolin group minerals dickite and nacrite, or of pyrophyllite, rarely of illite (see Box A). This paper aims to characterize a recent imitation of nephrite and Shoushan stone which consists of brucite.

Materials and methods

The Laboratory of the National Gold and Diamond Testing Center (NGDTC) of P.R. China recently received a sample (numbered B1) that was described as Shoushan stone from the Shanbowei deposit by the retailer. Its diaphaneity, lustre and colour (greyish green and reddish brown) *(Figure 1)* are indeed similar to some varieties of Shoushan stone. In addition, two strands of beads (B2 and B3) *(Figure 2)* were submitted by a client who stated that they were sold to him as nephrite. However, both strands showed an unusually dim lustre compared to nephrite. B1, B2 and B3 are actually all the same material, brucite, although they show considerable differences in appearance. For the purposes of this investigation, a glass imitation of nephrite (B4) and a strand of nephrite beads with relatively strong lustre numbered B5, are characterized for comparison.

The samples were tested by routine gemmological methods. Mohs'

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Table I: Gemmological properties of samples B1 to B5, and Shoushan stone of the dickite and/or nacrite type and Shoushan stone of the pyrophyllite type.

Property	Carving	Strands of beads				Shoushan stone of the dickite and/or nacrite type†	Shoushan stone of the pyrophyllite type†
	B1	B2	B3	B4	B5		
Size (mm)	130×100×85	8	12	8	8		
Colour	greyish-green and reddish brown	white	white	white	white	greyish white, greyish yellow, brownish red	white, yellowish green, dark purple, yellow, brownish red, grey
diaphaneity	translucent to semitranslucent	translucent	translucent	translucent	semitransparent to translucent	semitranslucent to opaque	semitranslucent to opaque
Lustre	greasy	waxy	waxy	vitreous	vitreous	subvitreous to waxy	waxy
SG	2.39	*	*	*	*	2.57~2.68‡	2.65~2.90‡
Mohs' hardness	2.5	2.5~3	2.5~3	6	3~6.5	2.5~3	2~3
RI distant vision	1.55	1.56	1.56	1.52	1.57~1.62	1.56~1.57	1.56~1.57
UV fluorescence							
short-wave	inert	inert	very weak	weak to faint white	very weak	inert-strong white	inert-strong white
long-wave	inert	inert	parts faint white	strong bluish white	parts faint white	inert-strong white	inert-strong white
Internal features	resemble veins in radishes	wispy inclusions resembling cotton	fine-grained wispy inclusions	radial microcracks	fine-grained texture resembling 'glutinous rice'	fine pyrite inclusions, red spots, resemble veins in radishes	most common were red or yellow spots, red healed fractures
Reaction to hydrochloric acid (HCl)	no gas bubbles, but etch pits were observed	none to few gas bubbles with etch pits	none to few gas bubbles with etch pits	inert	abundant gas bubbles to no gas bubbles	inert	inert

* SGs of beads not measured

† Data from Sun *et al.* (2003) and Feng *et al.* (2008)

‡ SG data is a very important feature in distinguishing the two types of Shoushan stone, while advanced instruments should be applied to identify them with accuracy

hardnesses were obtained using standard minerals and the 2.5 values in *Table I* refer to comparisons with fingernails. Refractive indices (RIs) using the distant vision method were measured with a gemmological refractometer; specific gravity (SG) values were obtained using an electronic balance with deionized water as a measuring medium. Fluorescence was tested using standard long-wave (365 nm) and short-wave (254 nm) UV lamps. Internal features were examined with a binocular gemmological microscope using darkfield and brightfield illumination at 10× to 70× magnification.

In addition, dilute hydrochloric acid was used to test inconspicuous areas on the five samples to see if there was any effervescence.

A Thermo Nicolet NexusTM 470 Fourier Transform Infrared (FTIR) spectrometer equipped with a specular reflection accessory and a CentaurμsTM Infrared (IR) Microscope was used to obtain IR spectra. The range between 6000–400 cm^{-1} at a standard resolution of 4 cm^{-1} with 16 scans (per spectrum), was recorded for each sample using two methods. Powdered samples were compressed into KBr pellets for measurement in transmission mode; and the specular reflection method was used on the solid sample. The IR spectra of five samples were obtained before the backgrounds were scanned at room temperature. The IR spectra of B1 were recorded using the specular reflection accessory because its size exceeds the sample stage of the IR microscope. Other samples were examined by using the IR microscope.

Figure 1: Carving of a Chinese traditional pattern in brucite (sample B1); it is 130 mm tall and 100 mm wide. This imitates high quality Shoushan stone. Photo by Li Jianjun.

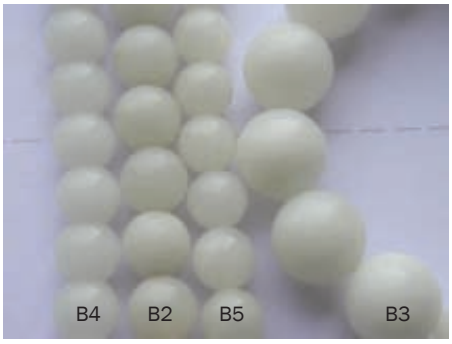

Figure 2: Sections of four strands of beads (of diameters between 8 and 12 mm) sample numbers B2, B3, B4 and B5. They are all pale grey and have a vitreous to waxy lustre that could easily be confused with white nephrite or some varieties of Shoushan stone. These strands of beads are identified as brucite (B2 and B3), glass (B4) and nephrite (B5). Photo by Li Jianjun.

X-ray fluorescence spectra of B2 and B3 were recorded using a Thermo Noran QuanX EC EDXRF spectrometer at 20 kV with a Rh target and no filter. The data acquisition time was 100 seconds for each sample spectrum at vacuum.

Results and discussion

Gemmological properties

Samples B1–B5 were subject to routine gemmological examination and the results are presented in *Table I*; the properties of Shoushan stone of the dickite and/or nacrite type as well as Shoushan stone of the pyrophyllite type are also given for comparative purposes.

No obvious absorption spectra were observed in samples B1–B5 when viewed with a hand-held spectroscope examined at NGDTC. The gemmological properties of B4 *(Table I)* indicate that the beads are glass and those of B5 suggest that the beads are nephrite, but the SG, hardness and RIs of B1, B2 and B3 are not diagnostic for identification.

FTIR spectroscopy

Two beads from B2 and three beads from B3 were selected at random and IR spectra obtained using the FTIR microscope. Also, spectra from B1 were obtained using the specular reflection accessory. Infrared spectra typical of the different kinds of Shoushan stone are given in *Box A*

In the range 1200–400 cm^{-1}, the IR reflectance spectra of B1, B2 and B3 showed strong and broad reflection bands below 800 cm^{-1} *(Figure 3)* indicating the presence of a metal oxide or hydroxide; this is consistent with the results of the IR transmission spectra of B3 (see *Figure 5*).

In the range 2000–800 cm^{-1}, B1, two beads from B2 (see *Figure 4,* B2a and B2b) and one bead from B3 (see *Figure 4,* B3a) exhibited broad reflection bands positioned at ~1550–1400 cm^{-1}. These are due to the stretching vibrations of the CO_3^{2-} group. Bands centred at 890 cm^{-1} detected in B1 (see *Figure 4,* B1) and B2 (B2a and B2b) can be assigned to the bending vibrations caused by the CO_3^{2-} group which are consistent with magnesite ($MgCO_3$) (Santillan *et al.*, 2005). Therefore both B1 and B2 contain a metal oxide or hydroxide as the main component and a small amount of magnesite.

Transmission IR spectra from a mineral mixed with KBr commonly give results

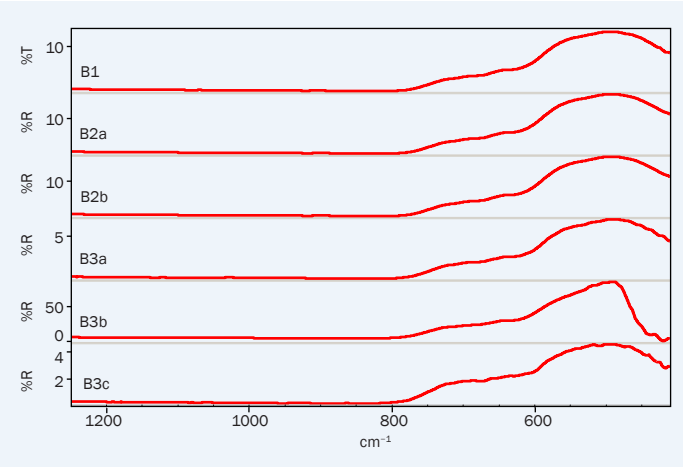

Figure 3: Reflectance IR spectra of sample B1 and five beads randomly selected from samples B2 and B3 show similar broad reflection peaks, centred below 800 cm^{-1}, indicating that all three materials are the same.

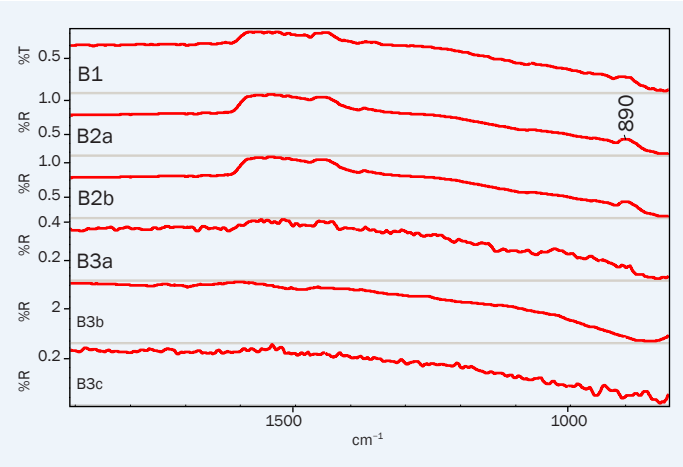

Figure 4: Reflectance spectra of the samples in Figure 3 in a different IR range, showing similar reflection bands between ~1550 and 1400 cm^{-1} due to the stretching vibration of the CO_3^{2-} group. B1, B2a and B2b show reflection bands centred at 890 cm^{-1} caused by bending vibrations of the CO_3^{2-} group, indicating that magnesite ($MgCO_3$) is present.

which are more accurate than spectra from the reflection mode. Therefore one bead of B3 was selected and powder scraped from an inconspicuous area. *Figure 5* shows the transmission spectrum of B3. In the 4000–3000 cm^{-1} region, a sharp band centred at 3698 cm^{-1} along with a broad band at 3420 cm^{-1} correspond to vibrations and stretching of OH bonds (Braterman and Cygan, 2006). Comparing the IR spectra of B1, B2 and B3 with those published by Peng and Liu (1982), the carving and beads can be identified as brucite ($Mg(OH)_2$).

The reflection IR spectra recorded from each bead of B4 were almost the same; the broad peak between 1200 and 800 cm^{-1} is assigned to Si-O vibrations in the [SiO_4] group. No split peaks caused by silicate minerals were observed, indicating that the beads are amorphous (see *Figure 6*).

However, the reflection IR spectra of beads of B5 showed obvious variation *(Figure 6)*. The main mineral component of B5 is tremolite and in some beads there are small amounts of ferroan dolomite (ankerite) which is indicated by reflection peaks in the 1600–1400 cm^{-1} region; these are due to stretching vibrations of the CO_3^{2-} group; also a peak at 877 cm^{-1} is assigned to a CO_3^{2-} group bending vibration. The presence of ferroan dolomite in B5 (nephrite) is in agreement with the fact that the nephrites occur in dolomitic marbles associated with metasomatic alteration (Wang *et al.*, 1990; Yui and Kwon, 2002).

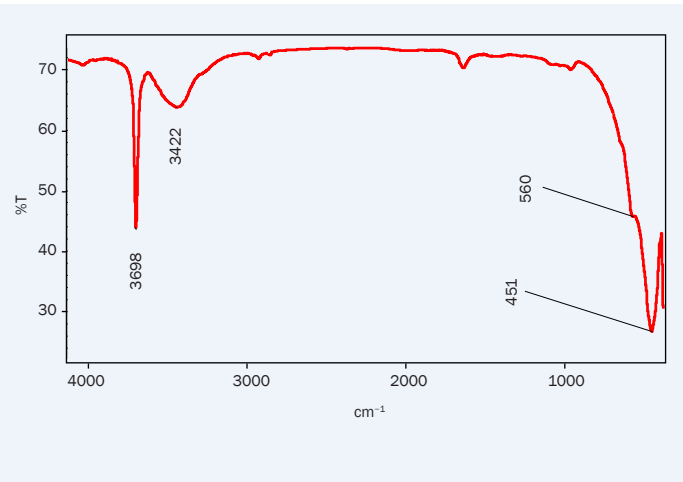

Figure 5: Transmittance IR spectrum obtained from powder from the drill hole of a B3 bead mixed with KBr and pelletized. The bands positioned at 3698 and 3422 cm^{-1} can be assigned to OH stretching vibrations (Braterman and Cygan, 2006). The bands at 451 and 560 cm^{-1} are consistent with brucite ($Mg(OH)_2$) (Peng and Liu, 1982).

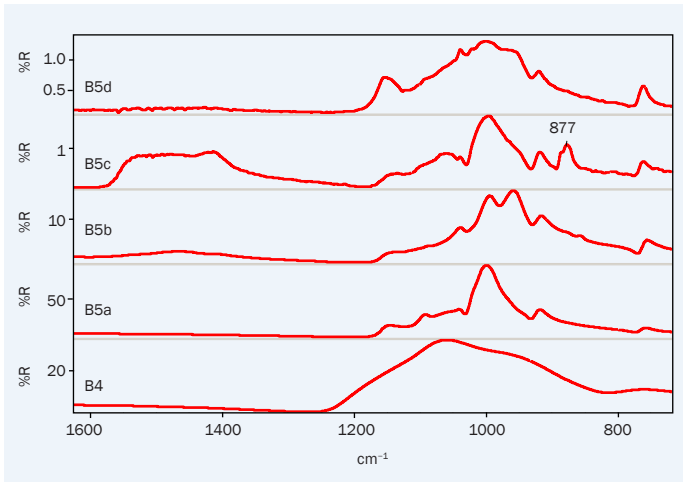

Figure 6: The reflectance IR spectrum of B4 shows only one broad band positioned at 1100–800 cm^{-1} due to Si-O vibrations, suggesting that it is amorphous. The reflectance spectra of the nephrite beads B5 show obvious variation. Note particularly that in the 1600–1400 cm^{-1} range, there are peaks in B5c which can be assigned to stretching vibrations of the CO_3^{2-} group, and a peak at 877 cm^{-1} due to bending vibrations in the CO_3^{2-} group, both indicating the presence in the nephrite of a carbonate mineral.

Box A

Almost all Shoushan stone is composed either of dickite and/or nacrite, or of pyrophyllite; rare specimens consist of illite and sericite. Typical IR spectra of the main Shoushan stone constituents are given below with comments.

Figure A1

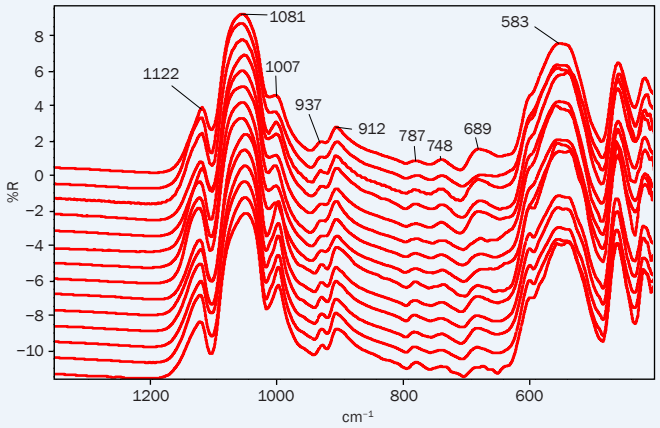

Figure A2

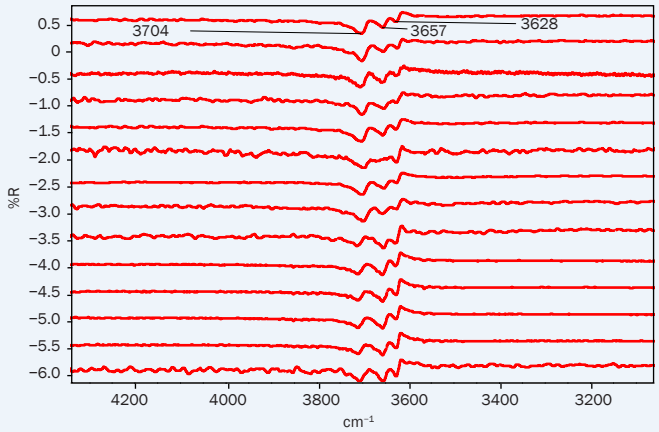

Figure A3

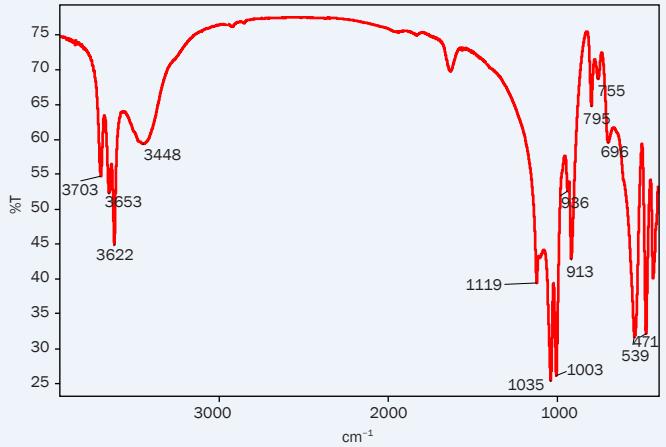

Figure A4

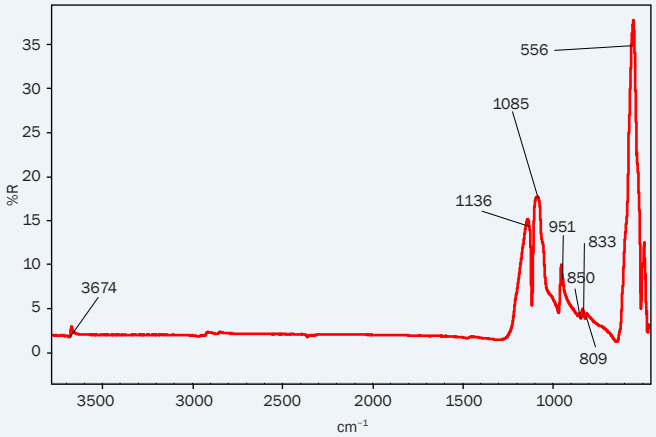

Figure A5

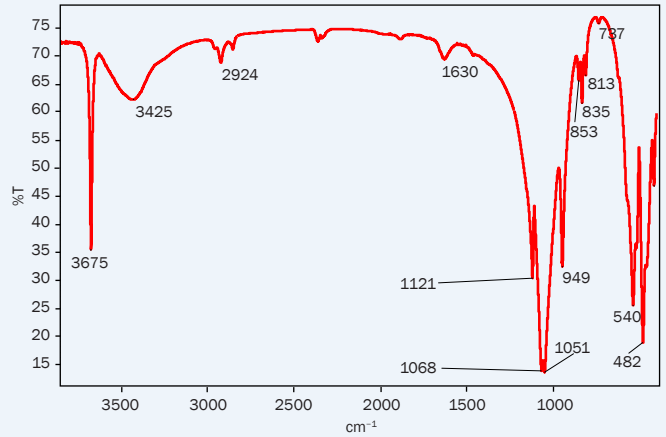

Figure A1: Reflectance spectra of Shoushan stone of the dickite and/or nacrite type showing peaks in the 1200–1000 cm^{-1} range arising from stretching vibrations of Si-O bonds (Shoval et al.*, 2002), 912 and 1007 cm^{-1} caused by bending vibrations of OH bonds (Fang* et al.*, 2005).*

Figure A2: Reflectance spectra of Shoushan stone of the dickite and/or nacrite type showing bands centred at 3704, 3657 and 3628 cm^{-1}, which are assigned to O-H stretching bonds (Franco et al.*, 2006).*

Figure A3: Transmission IR spectrum of dickite showing peaks at 3703, 3653 and 3622 cm^{-1} corresponding to OH stretching bonds (Balan et al.*, 2002).*

Figure A4: The IR reflection spectrum of Shoushan stone of the pyrophyllite type showing a weak band at 3674 cm^{-1} which arises from the u(OH) vibration (Wang et al.*, 2002); the peaks at 850 and 809 cm^{-1} show the presence of quartz and kaolinite (Amritphale* et al.*, 1992).*

Figure A5: Transmission spectrum of Shoushan stone of the pyrophyllite type showing a sharp band at 3675 cm^{-1} due to the u(OH) vibration (Ignacio Sainz-Diaz et al.*, 2004).*

EDXRF

Samples B2 and B3 were quantitatively analysed using an EDXRF spectrometer and the results indicate major Mg along with Si, Ca and Fe as trace elements in both samples (Li *et al.*, 2008).

Conclusions

Brucite, a layered magnesium hydroxide, is extracted on an industrial scale along with dolomite, dolomite marble and serpentinite and refined to produce magnesium. Most is white but some is multicoloured when traces of iron or manganese are present. Some of the more attractive material is now being used as an imitation of nephrite jade and Shoushan stone, both of which are highly valued by the Chinese people.

As the price of high-quality nephrite increased by virtue of its rarity, lower quality nephrite came onto the market to meet the demand for 'jade'. This lower quality nephrite can contain impurities of calcite and dolomite — which lower the RI, SG and hardness of the stone and, at the same time, provide the opportunity for materials of similar properties to come onto the market. Brucite is a good example.

It is not easy to identify brucite by using standard gemmological techniques although its unusually dim lustre would suggest that the material being examined is an imitation. EDXRF may provide clues to determine the material by analysing the major and minor elements it contains, but further work is necessary to confirm the applicability of this testing procedure. When examining samples like brucite which have gemmological properties such as a Mohs' hardness of 2–4 and are translucent to opaque, routine gemmological examinations are not sufficient to determine their identity. However, FTIR spectroscopy using both KBr pellets in transmission mode and the solid sample in reflection mode can provide conclusive evidence that the imitation is actually brucite.

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A new approach to the teaching and use of the refractometer

Darko B. Sturman

Abstract: Sets of simple and reliable procedures for determining gemstone RIs on the refractometer have been assembled. They have been tested with 70 calculated patterns of movements of shadow edges during the rotation of a gemstone on the refractometer. Some procedures described in literature are shown to have been based on limited understanding of observations; this may lead to incorrect identifications which can cause confusion, loss of confidence, and ultimately may lead to a waste of teaching time. All observations on isotropic, anisotropic uniaxial and biaxial gemstones in every possible orientation of the optical elements and facets can be represented by seven patterns described in graphical form in *Chart 1.* The chart shows how to identify a pattern and what can be determined from each one. Interpretation of observed data and identification of a gemstone is made on a birefringence/RI_{max} chart *(Chart 2)*. Most known faceted gemstones with RIs < 1.8 are shown on a single two-page chart.

Keywords: gem identification, optical properties, refractive index, refractometer

Introduction

Modern testing of gemstones relies more and more on the use of complex and expensive instruments. The role of the refractometer is diminished but it is still an instrument which is easily available to many gemmologists and gives very reliable and accurate data. Its proper use and proper interpretation of data may increase the confidence of observers and may give a feeling of great satisfaction to gemmologists.

Modern refractometers have better optics and larger scales than earlier models and monochromatic light is available in very small, inexpensive, easily portable and battery-operated units. Unfortunately, present practice and interpretation of data have not kept pace with improvements to the instruments; if anything, today's instructions are worse than they were a hundred years ago. Identifications of gemstones on the refractometer are still an important part of many gemmology courses but the better instruments and the greatly improved presentation possibilities have not resulted in the reduction of time needed to learn its proper use.

The reason for this is the existence of many confusing, incomplete and, even, incorrect procedures that can be found in many important textbooks or in the teaching manuals prepared by diploma-granting institutions. For a hundred years any statement or a procedure on the use of the refractometer could not be tested and, even if they were suspect, they were repeated from one edition of a textbook or a teaching manual to another.

Today, however, we have two methods available to calculate and predict the observations on any gemstone regardless of the orientation of its optical elements (optic axes or principal vibration directions X, Y and Z) and a facet. Xinhua Song *et al.* (2005) used the computer-assisted algebraic calculations to predict RI readings and the movement of the shadow edges during the rotation of a gemstone on the refractometer. Two years later in the same journal, Sturman (2007a, p.442) described a method based on the use of the stereographic projection to predict refractive index (RI) readings, movements of the shadow edges and, in addition, to determine the orientation of

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the vibration directions of the shadow edges at any point during the rotation of a gemstone.

Therefore, it is now possible to test any procedure or any statement on this topic in the published literature. In preparing this paper about 70 calculated patterns were studied, changing the orientation in small or large steps and comparing patterns observed in special orientations and in 'not so perfect' special orientations. As a result, some procedures and statements in the literature were found to be incomplete, confusing or incorrect — with the potential to lead to incorrect identifications.

Two solutions to the problem offered themselves immediately: examine and test every procedure published anywhere in the literature and prepare and keep an up-to-date a list of incorrect procedures, or prepare a set of simple but accurate and safe procedures to use in teaching and, later, in practice.

I believe that the second solution is simpler and easier. For this reason, and to provide an opportunity for instructors to change their teaching approach, Part I of this article contains simple procedures that are reliable in all circumstances and Part II shows how to use observed data in identification in an equally simple and reliable way. In Appendix 3 several suggestions for faster and easier instructions are listed.

Examples of incorrect procedures can be found in many important textbooks and teaching manuals. In this introduction a brief review of some examples is presented with explanations and references offered in Appendix 1.

Description of procedures in the selected examples can range from the very simple to very complex. One simple but incorrect statement has been repeated from one edition to the next in the *Handbook of Gem Identification* by R.T. Liddicoat. Where β cannot be determined directly, it is suggested that β is calculated as the average of the two possible readings of β on biaxial gemstones. We know that one of these possible β readings is true but the other is false. Using the average between these two numbers ensures that the result is always wrong. In some cases, the resulting error may be large enough to cause an incorrect identification. *Figures 1* and *2* in Appendix 1 show how a sinhalite may be identified as peridot if this procedure is followed.

Some textbooks and teaching manuals present incomplete and, therefore, potentially misleading information on observations on biaxial gemstones. For example, in *Gemmology* by P.G. Read referring to determination of the optic sign in biaxial gemstones, the statement that both variable shadow edges move to the same β reading is confusing for both student and graduate gemmologist because there is no indication in the text or drawings that this is observed on only a small number of gemstones — it can be seen only on facets where both optic axes are parallel, or almost parallel, to the facet (see *Pattern Va* and *b* in *Chart 1*). A gemmologist would very seldom, if ever, observe this on a gemstone. The unfortunate effects of a statement like this are that gemmologists will question their abilities as observers and, when they learn that the statement is incomplete, they may lose confidence in other statements in the book.

Similarly, a simple but incorrect statement can be found in *Gems* by R. Webster in editions up to 1994. It is stated that a gemstone with a small optic axial angle rotated on a refractometer shows one shadow edge that 'moves very little'. Studies by the author have shown that all biaxial gemstones with small, medium or large optic axial angles can have one shadow edge that 'moves very little'. Therefore, observing that one of the shadow edges of a biaxial gemstone has very little movement does not prove that it is a gemstone with a small optic axial angle. *Figure 3* in Appendix 1 shows that peridot, a gemstone with a large optic axial angle, in some orientations of the facet and the optical elements can have one shadow edge that 'moves very little'.

Another more complex procedure is found in Anderson's book (1990). Again, a diagram is used to show how, in some cases, a peridot gemstone can be incorrectly identified as sinhalite if this procedure is followed and only "the amount of movement" on the gamma shadow edge is observed (see *Figure 3* in Appendix 1).

Teaching manuals prepared by institutions granting diplomas in gemmology (for example GIA and Gem-A) are not discussed here. They are rewritten and improved every few years but may still have incomplete or confusing statements about the use of the refractometer.

The damage caused by the presence of confusing and incorrect information in the literature is twofold: it greatly increases the time needed for teaching the use of the refractometer, which is a subject of many gemmology courses, and it negatively affects a student's confidence.

However, the examples described here from textbooks should not detract from their overall value and important role in the education of many gemmologists; my comments should be seen in the context of improving the teaching of use of the refractometer.

The key aspect of the new approach described in this article in Part I is a set of simple but safe rules to recognize a favourably oriented gemstone where several optical properties can be easily recorded (optic character, optic sign and principal RIs). Equally important is the ability to recognize the unfavourably oriented gemstones where it is possible to determine only the maximum and minimum RI values, and where determination of other optical properties requires use of the polarizing filter or more complex procedures.

The straightforward interpretation of observed data described in this article in Part II is based on a graphical presentation of the range of refractive indices and birefringence that can be observed in some gemstones. This, in turn, allows easy and fast identification of overlaps in RIs between two or more gemstones.

It is hoped that description of the procedures and identification process presented in this article will provoke discussion, bring suggestions and

Seven Possible Patterns

Chart 1

Patterns I to *VII* represent all possible observations on isotropic or anisotropic gemstones regardless of the orientation of the optical elements and the gem table.

Identification of a pattern is based on observations during the rotation of a gemstone on the refractometer and include:

- The number of shadow edges observed (one or two).
- If a shadow edge is variable (shows various RIs during the rotation) or constant (shows a constant RI).
- If shadow edges remain apart during the rotation or join (where a single shadow edge is observed in certain rotation positions).

In order to make identification of a pattern easier, rotations should start in the positions outlined below:

- *Patterns I and II:* start rotation from any position — the shadow edges stay the same during rotation.
- *Patterns III and IV:* start rotation where the shadow edges are at maximum separation.
- *Patterns V, VI and VII:* start rotation where the maximum RI is observed.

	● Green dots show rotation positions at which principal RIs are determined.	
PATTERN I A single shadow edge	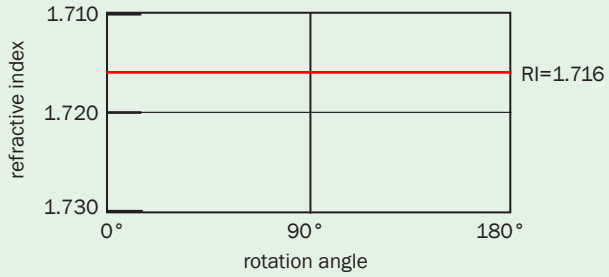	**MUST BE ISOTROPIC** Make sure that the RI reading stays constant during the rotation of a gemstone on the refractometer and that the shadow edge is not polarized (see Appendix 2).
PATTERN II Two constant and parallel shadow edges	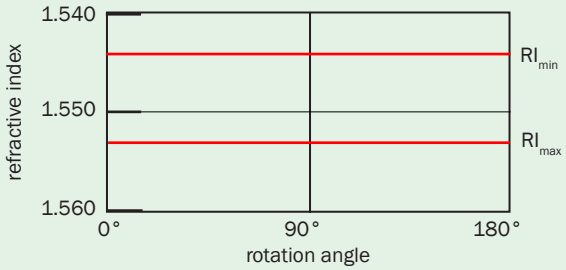	**MUST BE UNIAXIAL** Only RI_{min} and RI_{max} can be determined. Use a polarizing filter to determine the OPTIC SIGN.
PATTERN III One constant and one variable shadow edge touching	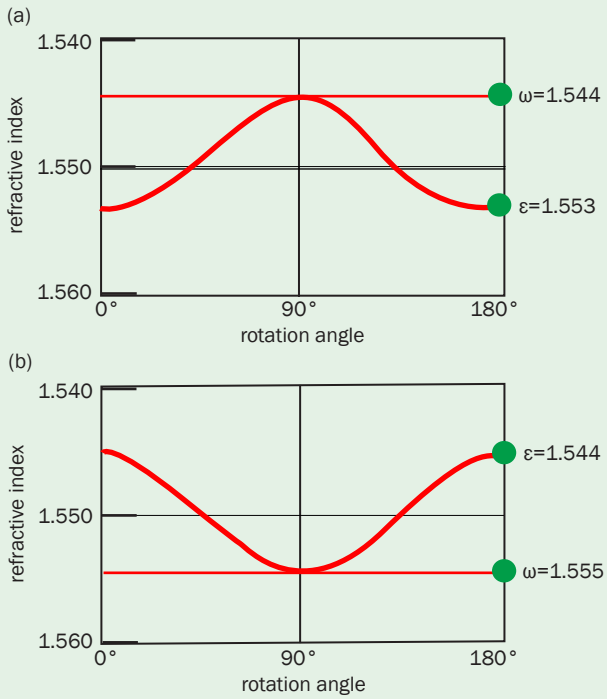	**MUST BE UNIAXIAL** Use the red box at the end of the Chart to determine the OPTIC SIGN from ω and ε. Make sure that shadow edges join at one point where only a single shadow edge is seen.

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● Green dots show rotation positions at which principal RIs are determined.

PATTERN IV

One constant and one variable shadow edge not touching

CAN BE UNIAXIAL OR BIAXIAL — each possibility should be tested. The polarizing filter must be used in interpretation.

(a) Uniaxial, positive (ω < ε)

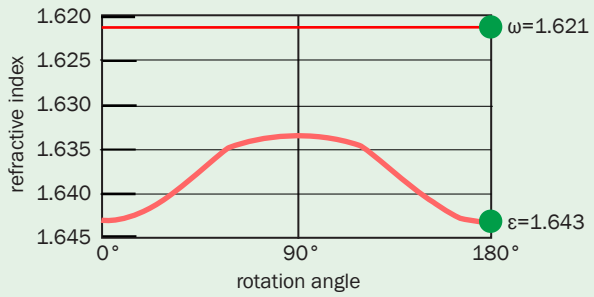

(b) Biaxial, negative (β closer to γ)

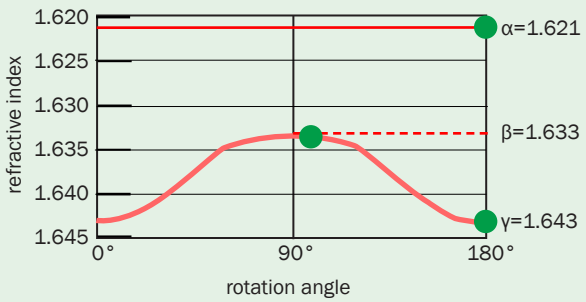

(a) If the example is considered as uniaxial, it means that the gemstone would be positive, so it cannot be tourmaline, which is uniaxial negative.
(b) If the example is considered as biaxial, it could be actinolite, which is biaxial negative.

PATTERN V

One constant and one variable shadow edge intersecting

MUST BE BIAXIAL — record α, β and γ. Use the box below to determine the OPTIC SIGN.

(a)

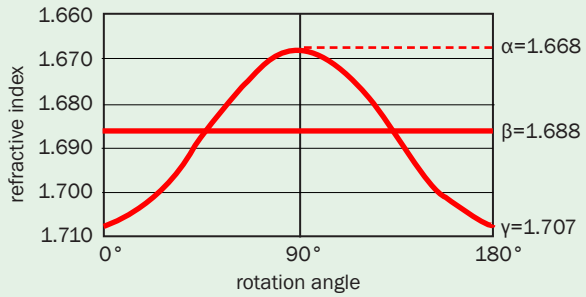

(b)

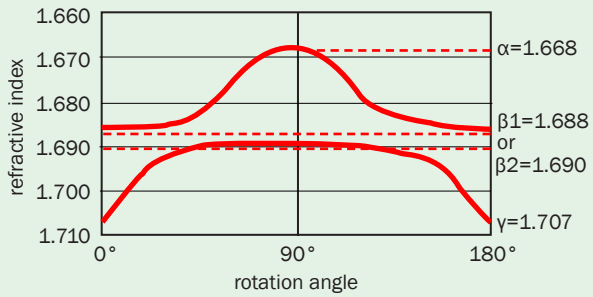

The more commonly seen pattern is shown in (b) where shadow edges do not intersect but both move to similar readings of β. Test both possible β readings during interpretation.

PATTERN VI

Two variable shadow edges not touching

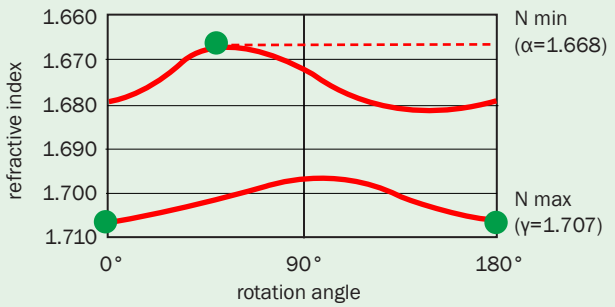

MUST BE BIAXIAL — only RI_{min} (α) and RI_{max} (γ) can be determined. Use a polarizing filter to determine the OPTIC SIGN.

PATTERN VII

Two variable shadow edges touching

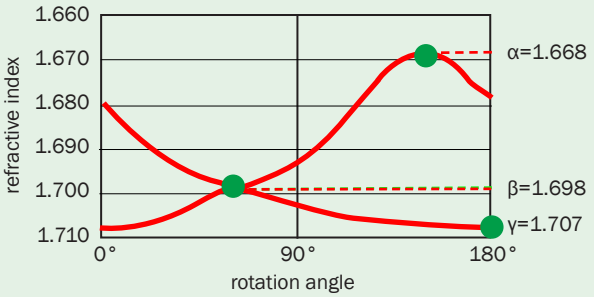

MUST BE BIAXIAL — β is determined in the rotation position where a single shadow edge is seen. Use the red box below to determine the OPTIC SIGN from α, β and γ.

OPTIC SIGN	
Uniaxial: ω > ε – negative ω < ε – positive	**Biaxial:** β closer to γ – negative β closer to α – positive

improvements or completely new ideas that will lead to the development of the new approach to teaching and, in this way, greatly shorten the learning process.

Part I: Observations on the refractometer

A. General statements

Rotation of a gemstone through at least 180° is an essential part of every determination on the refractometer. The observation repeats itself on further rotation.

Monochromatic light (sodium light or a source near 589 nm) should always be used.

Use of the polarizing filter may increase the accuracy of determinations. The first observations should be made without the polarizing filter. It is then inserted and rotated until one shadow edge disappears — then the other may be seen with more contrast. Any further rotation of a gemstone must be followed by an adjustment (rotation) of a polarizing filter.

Maximum and minimum RIs (RI_{max} and RI_{min}) of any anisotropic gemstone can be determined on any facet, regardless of the orientation of the optical elements (principal vibration directions X, Y and Z or the optic axis) in it.

Some anisotropic gemstones have constant RIs and determination of the RI_{max} and RI_{min} is all that is required for reliable identification. However, other gemstones may belong to groups with variable chemical composition, which is reflected in variation of their RIs. This may lead to an overlap of RIs of two or more gemstones, with the result that exactly the same RI_{max} and RI_{min} and, of course, the same birefringence, can be observed on several different gemstones. In such cases, identification is based on determination of other optical properties such as the optic sign and optic character.

In observations on favourably oriented gemstones, it is possible to determine the optic sign and optic character at the same time as RI_{max} and RI_{min}. Observations on other gemstones require additional tests, for example, the use of the polarizing filter for determination of the optic character or the optic sign.

A method is now available to predict observations on any gemstone (isotropic, uniaxial or biaxial) in any orientation of the optical elements and the facet (see Sturman, 2007a, p.442). All of these possible observations can be described in seven simple patterns *(Chart 1)* of the movement of shadow edges during the rotation of a gemstone on the refractometer.

B. Use of Chart 1

- *Patterns I* to *VII* are described in diagrams on *Chart 1*. The angle of rotation of the stone on the refractometer is plotted on the horizontal axis of the diagrams and the corresponding RI on the vertical axis.
- There is no need to keep a record of the rotation angles and the corresponding RIs or to construct a diagram for every observation. Identification of a pattern is based on facts 1 to 3 described below and also shown in the top panel of *Chart 1*.
  1. Determination of the number of shadow edges seen during the rotation of a gemstone on the refractometer.
  2. Determination of the shadow edges as
     - Constant (always giving the same RI reading during the rotation of a gemstone on the refractometer) or as
     - Variable (giving different RI readings — it seems that a shadow edge moves up and down during the rotation of a gemstone on the refractometer).
  3. Determine whether the shadow edges remain apart or join during rotation — a single shadow edge is seen at some rotation point.
- Identification of a pattern is further simplified by starting the rotation in preselected positions based on observation on the refractometer and not on the shape or marks on a gemstone.
  1. For *Patterns I* and *II,* one can start from any position – the shadow edges stay the same during the rotation.
  2. For *Patterns III* and *IV* rotation is started where the shadow edges are at the maximum separation.
  3. For *Patterns V, VI* and *VII* rotation is started where the largest RI is observed.
- Once the pattern has been identified, diagrams on *Chart 1* show rotation positions where the RI_{max} and RI_{min} are determined and or — if possible — where the principal RIs are determined (γ, β and α, or ω and ε). *Chart 1* also shows what other optical properties (optic sign and optic character) can be determined from a particular pattern and how to do it.
- In many textbooks, observations on the refractometer are described in the same order as optical properties of gemstones — from isotropic to uniaxial and biaxial. This requires that all of these observations are perfectly memorized for the proper interpretation of data. All this information is available on *Chart 1*. Nothing has to be memorized.
- Additional comments on patterns in *Chart 1* are shown in Appendix 2. They do not have to be memorized but should be easily available when a particular pattern is identified.
- The report of the study on a gemstone must first describe the observed facts and then the interpretation on which the identification is based. Some examples which could be useful for students are shown in Appendix 3. Included are, also, several suggested simple examples to start the teaching, which should progress to the unknown or more complex examples when the students are familiar with the use of *Chart 1*.

Part II: Interpretation of data

A. General comments

Lists and tables of gemstone data are often large in size and are sometimes

difficult to use. In order to simplify interpretation of the data obtained from the refractometer (i.e. between the RI limits of 1.43 and 1.80), some changes to the traditional identification table are proposed.

1. There is no need to use all three constants (RI_{max}, RI_{min} and birefringence) in identification. They are related and exactly the same results can be obtained from the use of only two constants. The list *(Table I)* and *Charts* (*2A* and *2B*) are based on only two constants: RI_{max} and birefringence.
2. The use of only two constants allows easy graphical presentations. *Charts 2A* and *2B* clearly show the variations and possible overlaps in the RIs of several gemstone species.
3. In order to simplify use of the charts, gemstones are divided into two groups; common gemstones are shown on *Chart 2A* and both common and rare are shown on *Chart 2B*. This grouping should enable easier and faster identification.
4. *Table I* and *Chart 2* include only gemstones that are generally faceted from single crystals; for example, opal, amber and similar gems are not shown. Well-researched data have been used and the list includes all gemstones described in O'Donoghue (2006) which have RIs between 1.43 and 1.80.
5. Mineral names have been used for the groups in *Chart 2*. The chart and accompanying table are intended as a help in identification of an unknown gemstone from data observed on the refractometer. Each of the groups such as corundum, beryl and garnet are represented by a single shape; it is left to the observer to use other properties to identify a gemstone as ruby, sapphire, emerald, almandine, etc.
6. We hope to receive comments on how to improve *Chart 2* (enlarge or modify shapes, include additional gemstones, improve the use of colours or fonts etc.). These comments will be considered for the next edition of the chart.

B. The use of Chart 2A — common gemstones

To commence identification of a gemstone, its RI_{max} and RI_{min} are determined first and recorded. Birefringence is calculated as $RI_{max} - RI_{min}$. Only the RI_{max} and birefringence are used in the further search.

RI_{max} is plotted first on the horizontal axis of the chart and birefringence on the vertical axis. The point obtained in this way may be within a single shape or in an area where several shapes overlap. In the latter case, several gemstones must be considered in the identification process. Eventually, determination may be based on additional optical properties, such as optic character or optic sign. For this reason the information is shown on the chart as different colours or different fonts as described in the Legend.

(In the teaching process, it is suggested that one should introduce the use of the chart as a black-and-white copy of *Chart 2A* so that students can concentrate only on finding the shape, the names of the gemstones and possible overlaps. The coloured copy is used later when students are familiar with the concept.)

- Names of uniaxial gemstones are written in capital letters (for example TOURMALINE)
- Names of biaxial gemstones are written in lower case letters (for example, actinolite).
- Names of isotropic gemstones are written in grey italics and are plotted on the horizontal axis of the chart where birefringence is zero (for example, fluorite, garnet, spinel).
- The gemstones with a positive optic sign are indicated by red area boundaries and text (for example, QUARTZ).
- Blue is used in a similar way to indicate a negative optic sign (for example, SCAPOLITE).
- Grey is used for gemstones that have a variable optic sign usually accompanied by variation in their RIs (for example, feldspars).

Data for *Table I* and *Chart 2* are drawn from gem and mineral textbooks. Shapes representing variations in RI_{max} and birefringence are interpretations of data in the literature. They indicate approximate limits for a particular gemstone. In some gemstones where only two elements are variable (for example, iron and magnesium in peridot) the shape is very simple. Ideally, it should be a line but narrow ovals were used to indicate that data in different publications are not always in perfect agreement.

Many gemstone species show a correlation between RI and birefringence. A quick look at *Chart 2A* shows that the great majority of the elongated shapes are inclined. In some gemstones a small increase in RI_{max} is accompanied by a large change (usually increase) in birefringence (for example, scapolite, epidote, iolite). In others the variation in RI_{max} is accompanied by only a small change in birefringence (for example, peridot).

Gemstones that have more than two variable elements may have more complex relations between RI_{max} and birefringence. Wide ovals or squares are used to represent these gemstones (for example tourmaline and feldspars). Where there is variation in properties, the shapes on the chart are drawn to include the maximum range known from measured gemstones.

This means that, for example, although peridot is part of the olivine group, the composition range in this group that provides the gemstones is relatively small and this is what is represented on the chart. Similar considerations apply to tourmaline.

The gemstones that do not show any variation in RIs, for example quartz, should ideally be represented by a small dot. However, in order to make them more visible on the chart, they are shown as small circles.

C. The use of Chart 2B (common and rare gemstones)

Chart 2B contains all the gemstones shown in *Chart 2A* and 80 rarer gemstones which, for reasons of clarity, are represented by numbers in circles and elongate ovals. The names of these rare

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Table I: The maximum RIs up to 1.8 and birefringences of faceted gemstones cut from single crystals.

Common faceted gemstones – shown by name on the charts.
Rare faceted gemstones shown by number on the charts.
Isotropic gemstones *(I)* names and numbers in italics on charts and the table.
Uniaxial (U) and biaxial (B) gemstones and the optic sign (+ or -) in normal text in the table.

No. (see Chart 2B)	Name	RI_{max}	Optic character and sign	Birefringence
	Fluorite	*1.432-1.434*	*I*	
1	Kogarkoite	1.442	B+	0.003
	Sodalite	*1.483-1.487*	*I*	
	Natrolite	1.485-1.496	B+	0.012
2	Creedite	1.485	B-	0.024
	Analcime	*1.487*	*I*	
3	Ettringite	1.491	U-	0.021
4	Thaumasite	1.498-1.507	U-	0.036
5	Tugtupite	1.499-1.502	U+	0.006-0.008
6	*Hauyne*	*1.502*	*I*	
7	Yugawaralite	1.502-1.504	B+/-	0.009
8	Mesolite	1.505	B+	0.001
9	Leucite	1.509	U+	0.001
10	Cancrinite	1.515-1.524	U-	0.022
11	Kurnakovite	1.515-1.525	B-	0.030
	Petalite	1.516-1.523	B+	0.013
12	Scolecite	1.517-1.521	B-	0.007
	Pollucite	*1.518-1.525*	*I*	
13	Thomsonite	1.518-1.544	B+	0.021
14	Leifite	1.519	U+	0.004
15	Carletonite	1.521	U-	0.004
	Feldspars	1.522	B+/-	0.006
		-1.588		0.010
		-1.599		0.011
16	Nepheline	1.526-1.542	U-	0.004
17	Shomiokite	1.531	B+	0.009
18	Poudrettite	1.532	U+	0.021
19	*Langbeinite*	*1.532*	*I*	
	Apophyllite	1.532-1.538	U/B+	0.000-0.002
20	Milarite	1.532-1.551	U/B-	0.003
	Cordierite (Iolite)	1.537	B+/-	0.005
		-1.578		0.018
21	Canasite	1.543	B-	0.009
22	Ussingite	1.543-1.545	B+	0.039
	Quartz	1.553	U+	0.009
	Scapolite	1.546	U-	0.005
		-1.600		0.035
	Beryllonite	1.561	B-	0.009
	Beryl	1.564	U-	0.006
		-1.600		0.009
23	Shortite	1.570	B-	0.039
24	Kammererite	1.576-1.597	B+/-	0.003
25	Brucite	1.580	U+	0.020
		-1.600		0.010
26	Zektzerite	1.584	B-	0.002
	Augelite	1.588	B+	0.014
27	Eudialyte	1.588-1.638	U+/-	0.004
	Herderite	1.589-1.620	B-	0.029-0.030
28	*Zunyite*	*1.592-1.600*	*I*	
29	Leucophanite	1.593-1.598	B-	0.028
30	Wardite	1.595-1.604	U+	0.009
	Amblygonite	1.598	B+/-	0.018
	(incl. Montebrasite)	-1.633		0.027
31	Hurlbutite	1.604	B-	0.009
32	Howlite	1.605	B-	0.022
33	Sogdianite	1.608	U-	0.002
34	Pezzottaite	1.612-1.620	U-	0.009-0.011
35	Meliphanite	1.613	U+	0.019
	Colemanite	1.614	B+	0.028
36	Sarcolite	1.615	U+	0.011
37	Phosphophyllite	1.616-1.620	B-	0.021-0.033
	Topaz	1.618	B+	0.010
		-1.638		0.008
38	Friedelite	1.620-1.625	U-	0.030
	Brazilianite	1.621-1.623	B+	0.019-0.021
39	Chondrodite	1.621	B+	0.028
		-1.636		0.034
	Grandidierite	1.623-1.639	B-	0.039
40	Vlasovite	1.625	B-	0.019
	Apatite	1.625-1.645	U-	0.002-0.004
41	Richterite	1.627-1.641	B-	0.017
	Hambergite	1.628-1.631	B+	0.072
42	Catapleiite	1.629	B+	0.039
	Actinolite	1.630	B-	0.026
	(incl. Tremolite)	-1.644		0.023
	Tourmaline	1.630-1.650	U-	0.018
		1.640-1.660		0.024
43	Celestine	1.631	B+	0.012
44	Wollastonite	1.631-1.653	B-	0.015
45	Burbankite	1.632	U-	0.012

A new approach to the teaching and use of the refractometer

No. (see Chart 2B)	Name	RI_{max}	Optic character and sign	Birefringence
46	Prehnite	1.632 -1.665	B+	0.021 0.033
47	Pectolite (incl. Serandite)	1.632 -1.703	B+	0.036 0.028
	Danburite	1.633-1.639	B+/-	0.006-0.008
48	Hemimorphite	1.636	B+	0.021
	Lazulite	1.637	B-	0.031
	(incl. Scorzalite)	-1.680		0.040
49	Narsarsukite	1.644-1.647	U+	0.033
	Andalusite	1.644 -1.648	B-	0.007 0.011
50	Jeremejevite	1.644 -1.652	U-	0.007 0.013
51	Durangite	1.647-1.685	B-	0.050
	Barite	1.648	B+	0.012
52	Weloganite	1.648	B-	0.090
53	Whewellite	1.649-1.650	B+	0.159-1.163
54	Rinkite	1.651-1.681	B+	0.009
55	Clinohumite	1.651 -1.728	B+	0.024 0.036
	Enstatite (incl. Bronzite)	1.657 -1.693	B+/-	0.010 0.014
	Calcite	1.658	U-	0.172
56	Hureaulite	1.660-1.667	B-	0.012
57	Eosphorite	1.660-1.680	B-	0.035
58	Dickinsonite	1.662-1.671	B+	0.013
	Spodumene	1.662 -1.679	B+	0.014 0.027
59	Vayrynenite	1.664-1.667	B-	0.026
60	Strontianite	1.666	B-	0.150
	Datolite	1.666-1.670	B-	0.044-0.047
	Phenakite	1.667-1.670	U+	0.016
	Axinite	1.668-1.701	B-	0.010-0.012
	Boracite	1.668-1.673	B+	0.011
	Euclase	1.669-1.675	B+	0.020
	Peridot	1.670 -1.705	B+/-	0.035 0.038
61	Sillimanite	1.672 -1.683	B+	0.020 0.022
	Kornerupine	1.674 -1.684	B-	0.013 0.017
62	Lithiophilite incl. Triphylite	1.674 -1.702	B+/-	0.008 0.005
	Aragonite	1.676-1.679	B-	0.150
63	Dolomite	1.681	U-	0.179
64	Lawsonite	1.682-1.686	B+	0.019

No. (see Chart 2B)	Name	RI_{max}	Optic character and sign	Birefringence
65	Ludlamite	1.688-1.697	B+	0.038-0.044
	Rhodizite	*1.694*	*I*	
	Diopside	1.694 -1.710	B+	0.026 0.030
	Dioptase	1.697-1.709	U+	0.053
	Tanzanite	1.700	B+	0.009
	Zoisite	1.695 -1.710	B+	0.005 0.015
66	Bustamite	1.701	B-	0.018
	Vesuvianite (Idocrase)	1.703-1.752	U+	0.001-0.004
	Sinhalite	1.705-1.712	B-	0.035-0.037
67	Sapphirine	1.705-1.734	B+/-	0.006
68	Serendibite	1.706-1.743	B-	0.005
	Clinozoisite	1.709 -1.734	B+	0.005 0.015
	Magnesite	1.710	U-	0.202
	Garnet	*1.714-1.8*	*I*	
	Taaffeite	1.717-1.727	U-	0.004-0.009
	Spinel	*1.718-1.794*	*I*	
	Willemite	1.719-1.725	U+	0.028
69	Dumortierite	1.723	B-	0.037
70	Johachidolite	1.724	B+	0.007
	Rhodonite	1.724-1.748	B+	0.013
	Kyanite	1.724-1.734	B-	0.017
71	Nambulite	1.730	B+	0.023
72	Holtite	1.730-1.761	B-	0.015
	Diaspore	1.732-1.750	B+	0.048
73	Neptunite	1.734	B+	0.029-0.045
	Epidote	1.734 -1.797	B-	0.015 0.049
	Periclase	*1.735-1.745*	*I*	
	Legrandite	1.740	B+	0.060
74	Chambersite	1.744	B+	0.012
75	Hodgkinsonite	1.746	B-	0.026
76	Staurolite	1.746 -1.761	B+	0.011 0.015
77	Pyroxmangite	1.746-1.758	B+	0.016-0.020
	Chrysoberyl	1.750-1.760	B+	0.008-0.010
78	Parisite	1.757-1.771	U+	0.081
79	Adamite	1.758-1.773	B+/-	0.041-0.050
	Corundum	1.767-1.772	U-	0.007-0.009
80	Scorodite	1.768-1.8	B+	0.027-0.030
	Zircon	1.780 -1.8	U+	0.001 0.007

Chart 2A: Common faceted gemstones

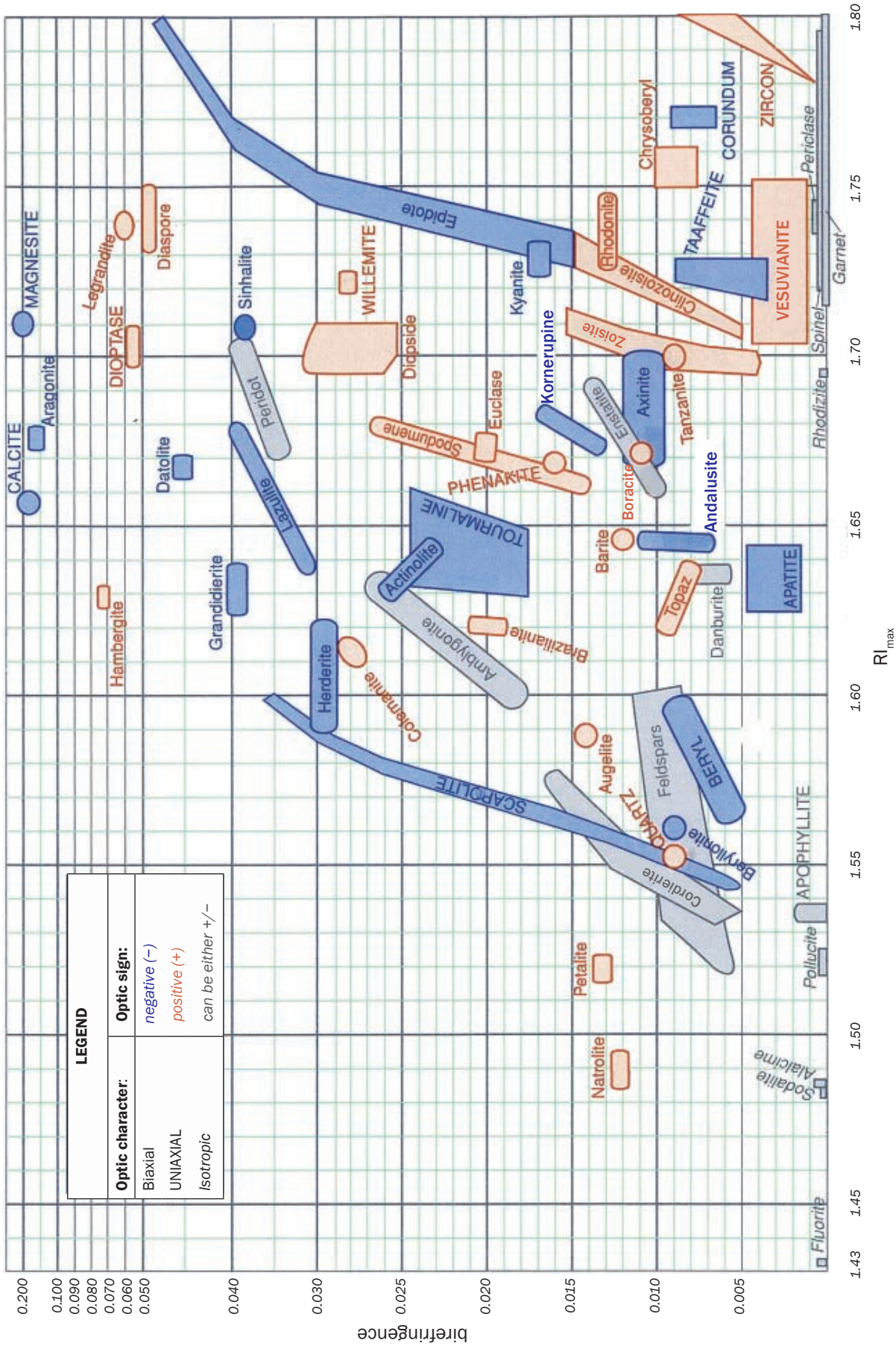

Chart 2B: Common and rare faceted gemstones

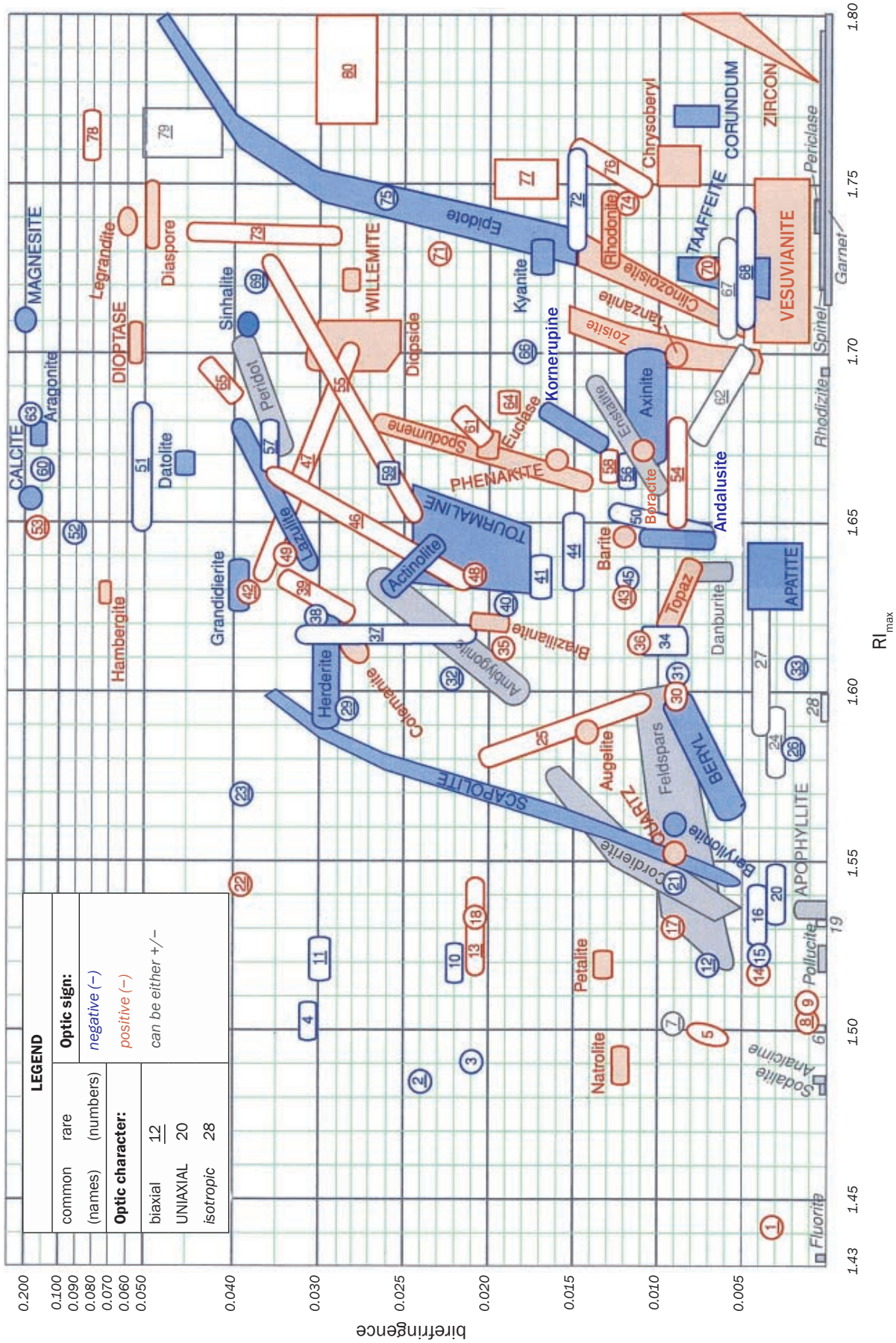

gemstones are in the list in *Table I*.

As in *Chart 2A*, the colours of numbers and outlines are used to identify the optic sign:

- red for positive
- blue for negative and
- grey for gemstones that may have positive or negative optic sign.

Some numbers are underlined or are written in italics to show the optic character of the gemstone:

- italics for isotropic (shapes and numbers are black),
- normal numbers for uniaxial gemstones
- underlined numbers for biaxial gemstones

The decision on whether to use *Chart 2A* or *Chart 2B* for identification depends on other observed data. *Chart 2A* can be used if a gemstone is already identified as one of the common gemstones by other tests and determination on the refractometer is used just for confirmation. *Chart 2B* should be used when an unknown gemstone is studied and all possibilities should be kept in mind.

Conclusions

This new approach introduces several new aspects in interpretation and procedures for identifying gemstones using the refractometer.

1. Nothing has to be memorized. *Chart 1* contains information on
   - how to identify a pattern,
   - what can be observed about a particular pattern and
   - further procedures and limitations.

   Many textbooks and teaching manuals describe observations on the refractometer in the same order as that in which the optical properties of gemstones are described — from isotropic to uniaxial and, finally, to biaxial gemstones. The gemmologist is expected to commit this information to memory and to accurately remember the range of possible observations on uniaxial and biaxial gemstones and their proper interpretation. Use of *Chart 1* simplifies this process and makes it more efficient in obtaining reliable results.
2. Many textbooks rely on three parameters RI_{max}, RI_{min} and birefringence in identifications. This practice makes tables or lists larger and, especially, increases the difficulty in identification of overlaps of RIs of gemstones. The range in RIs of many gemstones is best defined using only the two parameters RI_{max} and birefringence, which makes graphical presentations very simple. RI_{min} is used to calculate the birefringence but is not shown in the chart.

   Use of RI_{max} and birefringence in *Charts 2A* and *2B* allows presentation of information for a large number of gemstones on a single graph. This information includes variation in RIs, variation in birefringence, in addition to optic sign and optic character.
3. RI_{max} and birefringence should be shown to three decimal places. The figures for quartz for example are RI_{max} 1.553 and birefringence 0.009.

   In many textbooks and teaching manuals RIs are given only to two decimal places, and for quartz RI_{max} is given as 1.55 and RI_{min} as 1.54 or even as 1.56 to 1.54. However, birefringence may also be given as 0.009 (three decimal places). This means that quartz must be considered as a possible solution in any interpretation of data where there is a birefringence of 0.009 and RI_{max} and RI_{min} are between 1.535 and 1.565. This extended range includes many feldspars and scapolite.

Acknowledgements

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Appendix 1: Examples from the literature of confusing or incorrect procedures for use of the refractometer

Several examples from the literature are presented here in order to justify the need for a new approach to the teaching and use of the refractometer. The procedures described in these examples may work in many situations but they are not 100% reliable. They may lead to incorrect identifications of a gem when it is cut with the optical elements in some orientations with respect to the facet and these situations are presented with drawings in *Figures 1* to *4*. The descriptions of procedures are taken from excellent textbooks that have played a very important role in the training of many gemmologists and are still often used in practice. The authors were excellent gemmologists who successfully transferred their great experience to the books. However, in the attempts to simplify refractometer procedures, some descriptions have been made too brief and, for some gemstones, have become unreliable.

Calculated patterns of peridot and sinhalite gemstones in *Figures 1* to *4* and diagrams of *Pattern V* in *Chart 1* are used to show how procedures described by Liddicoat, Read, Webster and Anderson can be confusing and may lead to incorrect identifications. Instead of saving time, they may greatly increase the learning time needed to master the use of the refractometer.

Handbook of Gem Identification

Liddicoat (1981, p.61) describes in detail the interpretation of a relatively seldom observed situation when the optic axis is exactly parallel to a facet. In other orientations, the two shadow edges do not join at a point and Liddicoat suggests the following procedure:

> "In this event approximate the position of the intermediate index by taking a figure midway between … the minimum position of the high reading and the maximum of the low."

In biaxial gemstones one shadow edge gives true β and the other gives a false β (see *Figure 1*). Taking the average between the incorrect (false) value of β and the true one will always give an incorrect result. It is another question whether the error introduced by this procedure is large enough to lead to an incorrect identification but there is no doubt that this procedure is not reliable.

Figure 1 shows a pattern of movement of shadow edges when a sinhalite gemstone is rotated on the refractometer. The diagram shows the readings of principal refractive indices α and γ as well as of true β and false β.

Peridot and sinhalite may have very similar α and γ but the value of β is very different and can be used to differentiate between the two:

- in peridot β is close to the halfway point between α and γ, whereas
- in sinhalite β is close to γ.

Figure 2 shows the calculation of

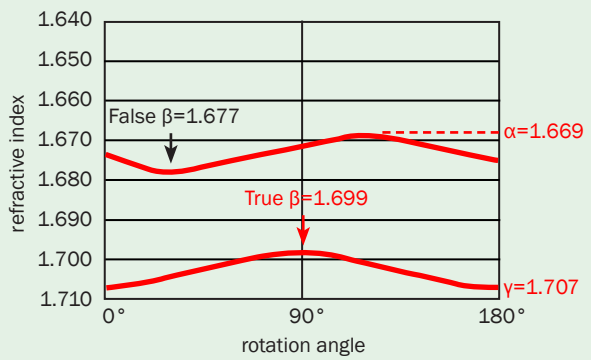

Figure 1: A pattern of movement of shadow edges observed on a sinhalite during rotation on the refractometer. Principal RIs, α, β and γ, are shown on the diagram.

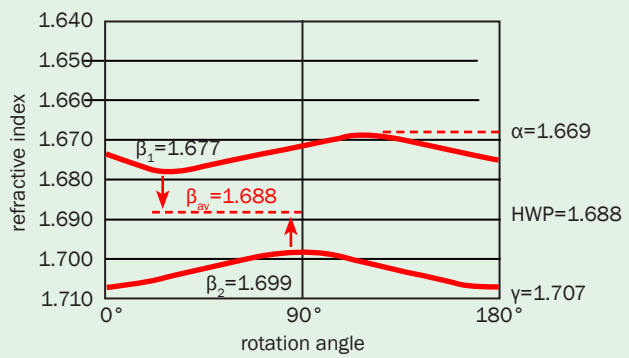

Figure 2: A pattern observed on a sinhalite. Two possible β readings (β_1 and β_2) were measured but a polarizing filter was not used to determine which was true. Instead the procedure described by Liddicoat was followed and average β (β_{av}) was calculated. β_{av} is in excellent agreement with β expected in peridot; the calculated β (1.688) is the same as the halfway point (HWP) between γ and α (1.688). Thus, an incorrectly determined β leads to an incorrect identification of a sinhalite as a peridot.

Liddicoat's average β which is identical to a half-way point (HWP) between α and γ. This procedure leads to the incorrect identification of this sinhalite gemstone as peridot.

Gemmology

An example of incomplete instruction occurs in Read (1999, p.91) who suggests that two variable shadow edges observed on biaxial gemstones move to the same reading.

> "This minimum RI reading of the γ ray is designated β. Note: On further rotation of the biaxial stone, the α ray shadow edge also moves from its lowest RI reading to a higher RI one, which is the same value as β for the γ ray."

There is no indication in the further text or in figures that this pattern is observed only from facets with special orientation — as shown in *Pattern V* in *Chart 1*. It is very seldom seen in practice; the great majority of observations on biaxial gemstones concern two variable shadow edges that do not move to the same value.

This observation of the movement of shadow edges is simplified even more in *Figure 9.13* (op. cit. p.92). In the caption of the Figure:

> "If the higher RI γ′ shadow edge moves more than halfway toward the lowest RI position of the α′ shadow edge, the optic sign is positive (left). If the γ′ shadow edge moves less than halfway, the 20 optic sign is negative (right)."

These statements and procedures are misleading for two reasons:

1. It is implied or suggested that whenever two variable shadow edges are observed during a 180° rotation, they will reach the same RI reading at some positions. However, a student would see this happen on only very few gemstones — the great majority of biaxial gemstones tested will have two variable shadow edges that do not reach the same value.
2. It is also suggested in Figure 9.13 that one should observe only the γ′ shadow edge to determine the optic sign. This works only if the principal refractive β is in the γ′ shadow edge. If β is in the α′ shadow edge, this procedure cannot be used. For biaxial gemstones with large to medium optic axial angles, it is estimated that β is found in the α′ shadow edge in about half of the observations and in the other half β is found in the γ′ shadow edge. Using this procedure therefore could lead to incorrect identifications in about half of all observations.

Gems

This very important textbook initially by Webster has had several editions and, latterly, several editors. The latest edition (O'Donoghue, 2006) has left out the section on identification of gemstones, but previous editions kept an unchanged description of a procedure for use of the refractometer that may lead to incorrect identifications:

> "When the angle between the optic axes is small, either the shadow edge with the higher index or that with the lower index will move very little; then

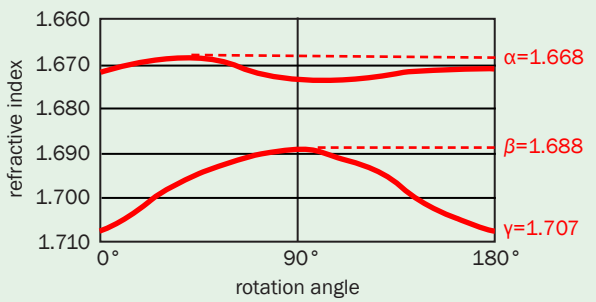

Figure 3: This pattern was observed on a peridot — a gemstone with a large angle between the optic axes (2V is about 90°). Note that there is only small variation in the α value; according to Webster (see text), this could indicate a stone with a small optic axial angle, which here is not the case.

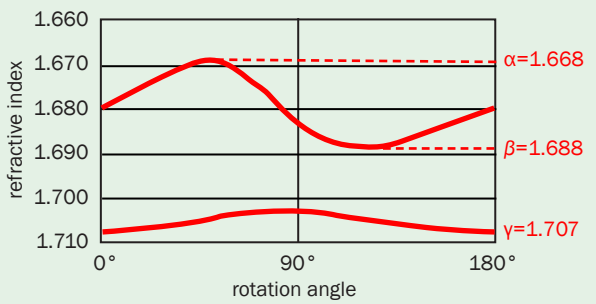

Figure 4: A pattern of movement of shadow edges observed on peridot. Note that the small movement on the γ shadow edge does not indicate that the stone could be sinhalite (see text concerning Anderson's comments).

it will be easy to see whether the sign is positive (β nearer to α) or negative." (Webster, 1994, p.713.)

This is misleading because any biaxial gemstone may be cut to produce a pattern with one of the shadow edges that moves a little. A pattern that may be observed on peridot — a gemstone with a large optic axial angle (about 90°) shown in *Figure 3* — has one shadow edge that moves a little and on the basis of the above quotation could indicate incorrectly a gemstone with a small optic axial angle. So it is important to establish that a pattern with one shadow edge that moves a little does not prove that a gemstone has a small optic axial angle or that its optic sign can be determined in this way.

Gem Testing

Anderson (1990, p.276) describes the following procedure to distinguish between sinhalite and peridot:

"In such a case, separation by means of refractive index readings depends upon the amount of movement seen in the shadow-edge representing the higher refractive index: in sinhalite the value for the intermediate 'beta' index is much nearer the maximum or 'gamma' edge than the lowest or alpha edge, whereas in peridot the value for the 'beta' index is nearly half-way between the greatest and the least index."

Therefore, Anderson correctly concludes that in all sinhalite gemstones a small movement on the γ' shadow edge is observed – from γ to β (if β is in the γ' shadow edge) or even less (if β is in the α' shadow edge).

This example best shows the problem that gemmologists faced before calculated patterns were available. Today on calculated patterns, it can be easily seen that peridot gemstones may also show small amount of movement of the γ' shadow edge in certain orientations — as in *Figures 3* and *4*. In fact, peridot and sinhalite may show identical movement on the γ' shadow edge and this test alone should not be used in identifications.

Descriptions not included in some textbooks and teaching manuals

Equally damaging to the learning process are descriptions of observations on the refractometer that are left out. An interested student looking through the literature may learn about the possibility of seeing a pattern where one optic axis is parallel to a facet (*Pattern VII* in *Chart 1*). They can then learn about a pattern where both optic axes are parallel to a facet (*Pattern V* in *Chart 1*), but I am not aware of both patterns described in the same textbook or teaching manual. It is left to the student to conclude that both patterns are possible.

Furthermore, making it even more difficult for a student is the fact that little or nothing is said about the most common patterns shown by biaxial gemstones where none of the optic axes are parallel to a facet *(Pattern VI* in *Chart 1).*

Some textbooks and teaching manuals describe in detail the determination of the optic sign of uniaxial gemstones from a constant and variable shadow edges but some do not even mention the fact that exactly the same pattern can be observed on biaxial gemstones (see *Pattern IV* in *Chart 1*), and neither do they mention that in this situation all three principal refractive indices (α, β and γ) can be easily determined.

Appendix 2: Additional comments on the patterns in *Chart 1*

Pattern I

A single shadow edge is shown by isotropic gemstones (cubic and amorphous, for example garnets and glass). This has a constant RI value during the rotation of a gemstone on the refractometer and is produced by light rays that are not polarized. A polarizing filter may be used to confirm this — the intensity of the shadow edge does not essentially change as the polarizing filter is rotated.

A single shadow edge can also be shown by anisotropic gemstones because:

- the other shadow edge is so far away that it may be overlooked, or
- the RI of the other shadow edge is higher than 1.8 and is outside the range of the refractometer, for example in gems such as benitoite and rhodochrosite.

Such a shadow edge can be easily recognized because it is polarized and its intensity will change from strong to zero when a polarizing filter is rotated on the eyepiece. The shadow edge is seen with maximum intensity when its vibration direction is parallel with the vibration direction of the polarizing filter and is invisible when its vibration direction is perpendicular to the polarizing filter.

Pattern II

This pattern is observed only on uniaxial gemstones. Light rays that produce two parallel and constant shadow edges are polarized and the polarizing filter must be used to identify which shadow edge is the ordinary ray and which the extraordinary ray (see Sturman, 2005). When ω and ε are determined then identification of the optic sign is shown in the red box at the end of *Chart 1*.

Pattern III

This pattern is observed only in uniaxial gemstones. If there is any doubt that the shadow edges come together, then the interpretation should follow the procedure discussed in *Pattern IV.* Identification of the optic sign is shown in the red box at the end of *Chart 1*.

Pattern IV

This is the only pattern that may be shown by uniaxial and biaxial gemstones. The polarizing filter must be used to identify the optic character (uniaxial or biaxial) and principal RIs ω and ε or α, β and γ. This in turn allows determination of the optic sign.

Sometimes, simply interpreting the observed data as uniaxial and then

as biaxial, may lead to elimination of a particular gemstone from further consideration. This process may take an additional 30 seconds but can lead to reliable identification as is shown by an example on the chart.

In the example on *Chart 1*, a constant shadow edge was observed at RI_{min} = 1.621 and the variable shadow edge gave RI_{max} = 1.643, a birefringence of 0.022. When these figures are plotted on *Chart 2A* the point falls in the middle of the tourmaline field. The point is also very close to the edge of the actinolite field and both of these gemstones must be considered in the identification process. Tourmaline is uniaxial and actinolite is biaxial, and the polarizing filter may be used to identify the optic character (uniaxial or biaxial). However, in this case, consideration of the optic sign can be used to eliminate one of the two possible gemstones.

First, the observed data are used to

- determine ω and ε — as if the gemstone is uniaxial and then
- determine α, β and γ — as if the gemstone is biaxial.

Interpretation of the observed data as uniaxial is shown on *diagram IVa;* ω = 1.621 and ε = 1.643. This gemstone — if it is uniaxial — must have a positive optic sign ($\omega < \varepsilon$), so it cannot be tourmaline, which has a negative optic sign ($\omega > \varepsilon$).

The pattern is then interpreted as biaxial *(diagram IVb).* The constant shadow edge gives α = 1.621 and the variable shadow edge gives β = 1.633 and γ = 1.643. This gemstone — if it is biaxial — must have a negative optic sign (β closer to γ) which is in good agreement with actinolite, which is biaxial, negative.

Therefore, the gemstone in the example in *Pattern IV* on *Chart 1* is identified as actinolite.

This is a good place to make a general comment on identifications based on observation on the refractometer or some other instrument. The identification is based on comparison of the observed data with the expected observation on all of the known gemstones. At present, we do not know of any uniaxial positive gemstone with RI_{max}=1.643 and birefringence of 0.022 and, in this case, a gemstone in the example in *Pattern IV* in *Chart 1*, can be safely identified as actinolite. Our identifications are only as good as our knowledge of properties of gemstones.

Pattern V

This pattern is easy to recognize because first the one and then the other shadow edge come to similar readings and stay stationary during much of the rotation; one of these readings will be β. However, the other shadow edge then can change rapidly on rotation and care should be taken to record the proper values of α and γ.

The pattern on the left is very seldom observed. It is seen only where both optic axes are exactly parallel to the facet. Much more common is the pattern on the right where one or even both optic axes are not perfectly parallel with the facet.

Determination of α and γ is the same in both patterns. The RI value at the intersection indicates β in *diagram Va*, but in *diagram Vb* each shadow edge may give slightly different values of β (the highest reading on α' shadow edge and the lowest reading on γ' shadow edge). In this case, both values of β must be used in interpretation (see Sturman, 2007). For example, both values of β may give the same optic sign — this is then reliable information that may be used in identification. However, if each β value leads to different optic signs, the polarizing filter must be used to identify true β and calculate the optic sign.

Pattern VI

This is the most common pattern observed in biaxial gemstones. Only α and γ can be determined without use of the polarizing filter. It is important to remember that α and γ are usually determined at different rotation positions and that each shadow edge must be observed separately.

Pattern VII

This is another pattern seen on biaxial gemstones that is the result of a particular orientation of the optical elements and a facet. It is observed when one of the optic axes is exactly parallel with the facet. Determination of all three principal RIs (α, β and γ) and, from them, determination of the optic sign is straightforward.

Appendix 3: Selection of examples for students and keeping a record

Examples and tests

Teaching should start with good examples of seven possible patterns *(Chart 1)*. Then low birefringence examples or more complex examples can be introduced when students become familiar with the chart. Monochromatic light must be used.

1. Students should first learn to recognize patterns with a single shadow edge *(Pattern I)*, and then move on to two shadow edges *(Patterns II* to *VII).* Good examples can be garnet, peridot and tourmaline.
2. Students should next learn to identify the shadow edges as constant or variable. Good examples can be tourmalines *(Patterns II* and *IV)* and peridots *(Pattern VI).*
3. Finally, students should learn to identify patterns where shadow edges touch at one or two positions during rotation for 180° of the gemstone. Good examples are tourmalines *(Pattern III)* and peridots *(Patterns V* and *VII).*

Note: *Patterns III, V* and *VII* do not have to be perfectly oriented. It is important that students can see what is expected in perfectly oriented patterns — how two shadow edges come closer and closer and may eventually touch (a single shadow edge is seen).

4. Finding the starting point and identification of a pattern is based on instructions in *Chart 1*. There is no need to construct diagrams for each observation. Good examples of each of the seven patterns are necessary.
5. Observe and record data for each pattern following the instructions on *Chart 1*.

Keeping a record

The observations on the seven examples in *Chart 1* should be recorded as:

Pattern I: isotropic, RI = 1.716

Pattern II: anisotropic, uniaxial, RI_{max} = 1.553, B = 0.009, optic sign ?

Pattern III: (a) anisotropic, uniaxial, ω = 1.544, ε = 1.553, optic sign positive ($\omega < \varepsilon$): search on *Chart 2* for uniaxial (+), RI_{max} = 1.553, B = 0.009 or on the lower diagram

(b) *Pattern III,* anisotropic, uniaxial, ω = 1.555, ε = 1.544, optic sign negative ($\omega > \varepsilon$): search on *Chart 2* for uniaxial (-), RI_{max} = 1.555, B = 0.011

Pattern IV:

(a) anisotropic, uniaxial or biaxial, RI_{max} = 1.643, B 0.022

Interpretation:

If uniaxial, then ω = 1.621, ε = 1.643, optic sign (+) , ($\omega < \varepsilon$)

(b) If biaxial, then α = 1.621, β = 1.633, γ = 1.643, optic sign (-), (β closer to γ) search on *Chart 2* for uniaxial (+), RI_{max} = 1.643, B = 0.022 or search on *Chart 2* for biaxial (-), RI_{max} = 1.643, B = 0.022

Pattern V:

(a): anisotropic, biaxial, α = 1.668, β = 1.688, γ = 1.707, optic sign (-), (β closer to γ)

(b): anisotropic, biaxial, α = 1.668, β = 1.690, γ = 1.707, optic sign (-), (β closer to γ) or anisotropic, biaxial, α=1.668, β=1.688, γ=1.707, optic sign (-), (β closer to γ).

Pattern VI: anisotropic, biaxial, α = 1.668, γ = 1.707, optic sign ?

Pattern VII: anisotropic, biaxial, α = 1.668, β = 1.698, γ = 1.707, optic sign (-), (β closer to γ).

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Use of the polarizing filter on the refractometer in determinations of the optic sign or optic character of a gemstone

Darko B. Sturman and Duncan Parker FGA FCGmA

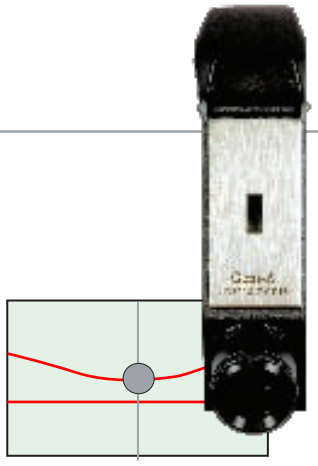

Abstract: Calculated patterns of movement of shadow edges during observations on the refractometer were used to modify procedures for the use of the polarizing filter in determination of the optic sign and the optic character. New procedures are presented in graphic form in three charts. Eight calculated patterns to suggest these procedures are presented in the Appendix.

Keywords: gem testing, optic character, optic sign, refractometer, RI

Introduction

The great majority of identifications of gemstones on the refractometer are based on determination of the maximum and the minimum refractive index (RI). The measurements can be made on any gemstone regardless of the orientation of the gem table and optical elements (optic axes or the principal vibration directions X, Y and Z).

In our descriptions we often refer to measurements taken from the gem table when set on the refractometer prism but any plane facet can be suitable.

The use of sodium or monochromatic light near 589 nm greatly increases the potential accuracy of determination. Easily portable monochromatic sources powered by batteries are now available.

Some gemstones have constant RIs and determination of the RI_{max} and RI_{min} is all that is required for reliable identification. Other gemstones have variable chemical compositions and this may be reflected in variation of their RIs. Where there is overlap of RIs of two or more gemstones, identification is based on determination of other optical properties such as the optic character or the optic sign. In some cases, determination of these optical properties is easy if the optical elements are favourably oriented with respect to the gem table. On other gemstones determination of the optic sign or the optic character r equires the use of a polarizing filter.

The movement of shadow edges on all gemstones during rotation on the refractometer and consequent variation in the RI readings can be summarized in seven patterns. Sturman (2010a) presented all patterns on a chart with information on how to identify them, described what can be observed on each pattern and gave instructions on how to do it. On four of these seven patterns the optic sign and the optic character can be easily identified without use of the polarizing filter. On the remaining three patterns determination of the optic sign or the optic character requires use of the polarizing filter with known vibration direction.

Hurlbut (1984) published the first article in the modern literature that described the use of the polarizing filter for determination on the refractometer of the optic character or the optic sign of gemstones. Since then several other descriptions have been published but they all followed his general concept and reasoning. This article does not compare or evaluate these subsequent methods or procedures but is intended to discuss a new aspect discovered during a study of calculated patterns.

Below, we describe first the problem, then the method used in this study and, finally, present the solution. At the end, we present modified procedures based on this new understanding summarized in three charts.

- *Chart A* refers to determination of the optic sign on uniaxial gemstones (Pattern II, Sturman, 2010a) where the optic axis is perpendicular, or near perpendicular, to the gem table. This pattern is easily recognized and is characterized by two constant shadow edges which stay at the same RI readings during the rotation of a gemstone on the refractometer.
- *Chart B* refers to determination of the optic sign on biaxial gemstones in their most commonly encountered

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orientation (Pattern VI, Sturman, 2010a) where none of the principal vibration directions is perpendicular to the gem table. This pattern is characterized by two variable shadow edges that stay separated during rotation of a gemstone on the refractometer.

- *Chart C* refers to determination of the optic character (uniaxial or biaxial) on patterns, which consist of one constant and one variable shadow edge (Pattern IV, Sturman, 2010a); during rotation of a gemstone these shadow edges stay separated — two shadow edges are seen at all times. This pattern may be observed on uniaxial or on biaxial gemstones and the polarizing filter is used to differentiate between the two.

The problem

The use of the polarizing filter in all previously published methods is described using examples of gemstones where the optical elements — principal vibration directions (X, Y, Z) or the optic axis — are exactly perpendicular or parallel to a facet or the gem table.

In these procedures, based on what may be called perfectly oriented examples:

1. a gemstone is identified as the one that requires the use of the polarizing filter for determination of the optic sign or the optic character;
2. (if needed) a gemstone is rotated to a particular position;
3. the polarizing filter is inserted with its vibration direction set in a certain position — usually in the E–W or N–S direction on the eye-piece;
4. the insertion of the polarizing filter leads to a disappearance of one of the two shadow edges and this allows identification of the optic sign or of the optic character of a gemstone.

Extending these procedures, we examined patterns from gemstones where the optical elements were not in such perfect orientations with the gem table. The study showed that, during rotation on the refractometer, many gemstones with not-so-perfect orientation produce very similar patterns to those with the exact orientation. In fact, the observations are not identical but the differences are too small to be seen on the refractometer scale. There was, however, one very important visible difference: when a not-so-perfectly oriented gemstone is observed and previously described points 1 to 3 exactly followed (including the placing of the polarizing filter on the eyepiece), then one shadow edge may not disappear as is described in the instructions (see point 4).

The study

The first assumption was that variation of about 0.001 in the RI readings during rotation of a gemstone was not detectable on a standard refractometer. Then patterns were produced where variation in RI readings on one shadow edge was 0.001 or less during extended rotation; this led to the discovery that orientations of vibration directions of shadow edges may substantially change during rotation while RI readings stay nearly the same. In consequence, at some rotation positions, the vibration direction of the shadow edge may be exactly perpendicular to the polarizing filter but at other positions the vibration direction of the shadow edge and the polarizing filter are *not* perpendicular to each other and some light may get through the filter – resulting in the shadow edge staying visible.

It is important to remember that the polarizing filter does not work as some kind of venetian blind letting through only the polarized rays that vibrate exactly parallel to the mobile strips see Sturman (2010b). In most cases, some light will be transmitted — the amount (intensity) depending on the angle between the vibration directions of the incoming ray and the polarizing filter (see *Figure 1* of the Appendix). Only if the vibration direction of the incoming ray is exactly perpendicular to the vibration direction of the polarizing filter will no light be transmitted.

Predicting orientations of vibration directions of the shadow edges for any gemstone during rotation on the refractometer is easy and very accurate (see Sturman, 2007). For example, in this study, calculated patterns for uniaxial gemstones were prepared using apatite and tourmaline showing variation of 0.001 in the extraordinary shadow edge. It was, then, easy to compare changes in the vibration directions of shadow edges of the two patterns (see *Figures 3* and *4* of the Appendix).

However, predicting the effect of the change in vibration direction of the shadow edge on its visibility through the polarizing filter is a much more complex problem. Whether a shadow edge is visible when its vibration direction is 10° or 20° or 30° away from perpendicular to the polarizing filter, depends on many factors such as the quality of polish of gemstone, and the construction and quality of the refractometer. However, the crucial point for a gemmologist to keep in mind is the possibility that a shadow edge may not disappear as expected.

The solution

Several examples in the Appendix describe various reasons why a shadow edge does not disappear as might be expected when a polarizing filter is inserted. However, in routine work a gemmologist does not have to remember or to refer to these examples or reasons. All that is required is to accept the fact that in some gemstones both shadow edges may stay visible when the polarizing filter is inserted and then to follow procedures presented in *Charts A, B* and *C*.

The new procedures are slightly modified from Hurlbut (1984) and other authors. In some cases the procedures described in our charts may require more time but gemmologists may be assured that these procedures are reliable in all gemstones whatever their orientation. When the time needed to prepare a gemstone for determination and the time needed for the cleaning afterwards is taken into account, then any added time needed for additional rotation of a gemstone is very small in comparison.

All our examples show that the simple gradual rotation of a gemstone on the

Use of the polarizing filter on the refractometer in determinations of the optic sign or optic character of a gemstone

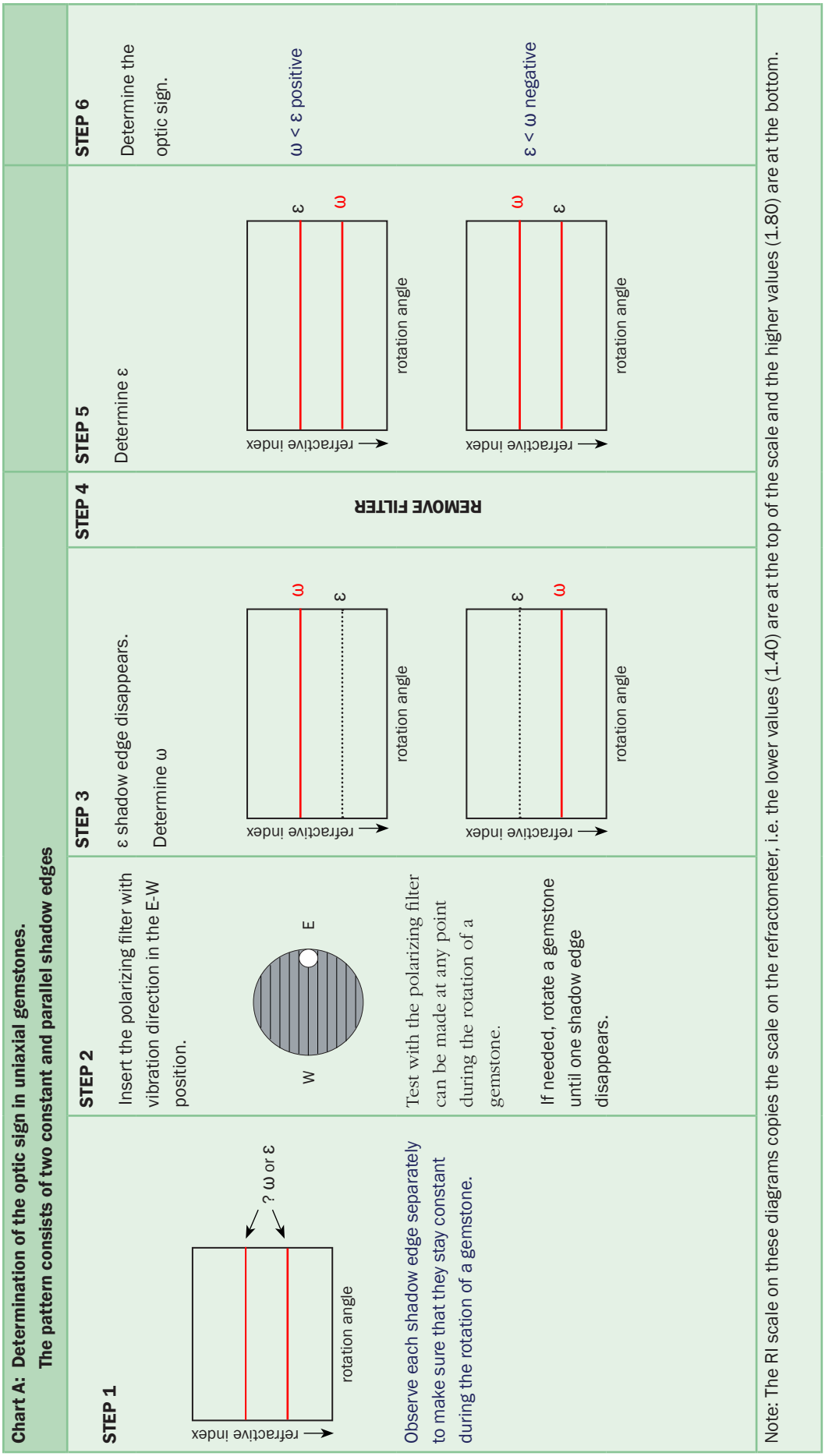

Use of the polarizing filter on the refractometer in determinations of the optic sign or optic character of a gemstone

Chart B: Determination of true β in biaxial gemstones.
The pattern consists of two variable shadow edges not touching.

STEP 1

Determine α (the smallest RI observed) and γ (the largest RI observed).

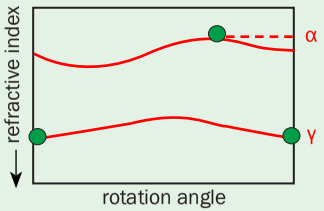

Each pattern has two positions where β can be determined — true β and 'false' β. They are marked A on the α′ shadow edge and G on the γ′ shadow edge.

Each shadow edge must be observed separately.

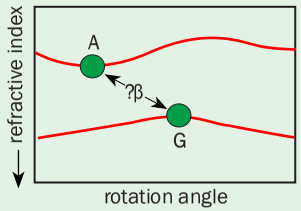

STEP 2 (A)
Rotate a gemstone to the position marked A — the highest reading on the α′ shadow edge.

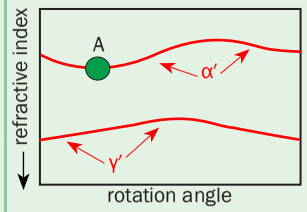

STEP 3 (A)
Insert the polarizing filter in the E–W position.
If needed, gradually rotate a gemstone left or right to make the α′ shadow edge disappear.

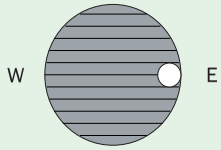

STEP 4 (A)
If the α′ shadow edge disappears in this rotation position or close to it, this is 'false' β.

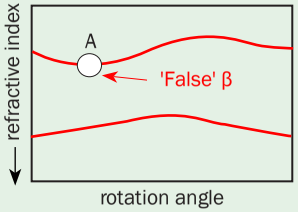

STEP 5 (A)
Remove filter.
Determine true β on the other shadow edge — the lowest reading on the γ′ shadow edge.

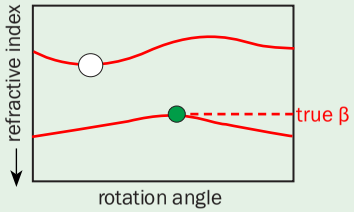

If the α′ shadow edge does not disappear in the rotation position 'A' (or close to it), try γ′ shadow edge in the position 'G' (or close to it).

STEP 2 (G)
Rotate a gemstone to the position marked G — the highest reading on the γ′ shadow edge.

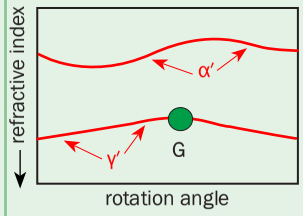

STEP 3 (G)
Insert the polarizing filter in the E–W position.
If needed, gradually rotate a gemstone left or right to make the γ′ shadow edge disappear

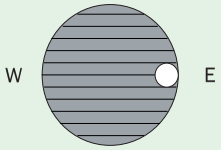

STEP 4 (G)
If the γ′ shadow edge disappears in this rotation position or close to it, this is 'false' β.

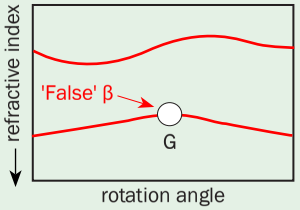

STEP 5 (G)
Remove filter.
Determine true β on the other shadow edge — the highest reading on the α′ shadow edge.

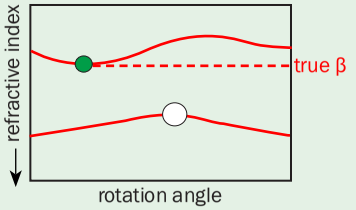

STEP 6

Determine the optic sign.

β closer to α
Positive

β closer to γ
Negative

Note: In some orientations (Y almost perpendicular to the gem table) both shadow edges disappear in the rotation positions A and G, when the polarizing filter is inserted with the vibration direction set in the E–W position. It is impossible to distinguish between 'false' and 'true' β.

In this event:

- both shadow edges give the same, or *almost* the same, readings for possible β
- both shadow edges are relatively constant for much of the rotation.

These rotation positions are shown by the heavy red lines on the example to the right.

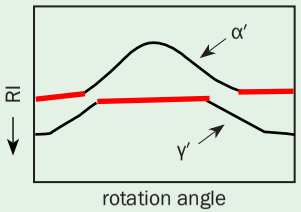

Use of the polarizing filter on the refractometer in determinations of the optic sign or optic character of a gemstone

Chart C: Determination of the optic character in uniaxial or biaxial gemstones.
The pattern consists of one variable and one constant shadow edge, not touching.

STEP 1

Rotate the gemstone to the position where the shadow edges are closest (shown by a green dot).

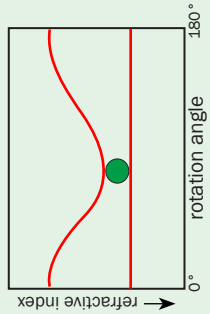

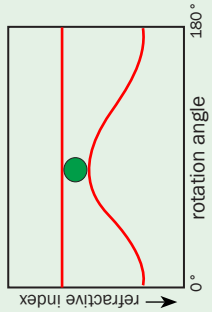

STEP 2

Insert the polarizing filter with vibration direction in the E-W position.

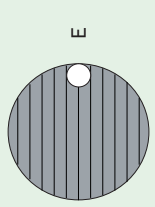

Observe which shadow edge disappears.

If needed, rotate a gemstone left or right in small movements until one shadow edge disappears.

STEP 3

Determine the optic character.

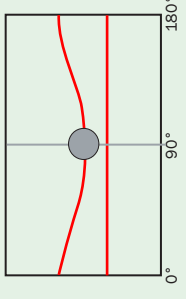

If the variable shadow edge disappears the stone is uniaxial.

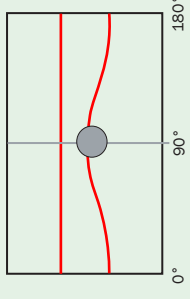

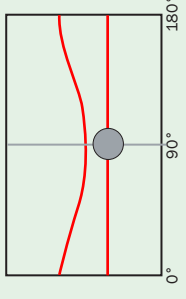

If the constant shadow edge disappears this stone is biaxial.

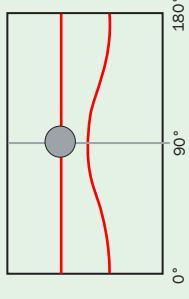

STEP 4

REMOVE FILTER

STEP 5

Determine principal RIs (ω/ε or α/β/γ)

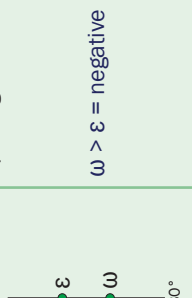

In uniaxial gemstones read

- ω on the constant shadow edge
- ε on the variable shadow edge where they are separated the most

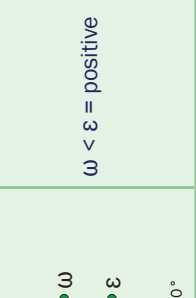

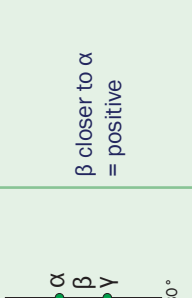

In biaxial gemstones read

- α as the smallest RI
- γ as the largest RI
- β on the variable shadow edge closest to the constant shadow edge

STEP 6

Determine the optic sign.

ω > ε = negative

In uniaxial gemstones

ω < ε = positive

β closer to α = positive

In biaxial gemstones

β closer to γ = negative

refractometer from the originally required rotation position would bring about the desired effect — a disappearance of one shadow edge.

Use of charts

Diagrams on the charts are calculated patterns of movements of the shadow edges during the rotation of a gemstone on the refractometer. Rotation angles are plotted on the horizontal axis of diagrams and RI readings of the shadow edges are plotted on the vertical axis. Six steps are used in all charts to describe the required procedures. The reasoning and the examples used in preparation of the charts are described in the Appendix.

Chart A describes procedure for determination of the optic sign on patterns composed of two shadow edges that stay parallel to each other and give the same RI readings during the rotation of a gemstone on the refractometer. This pattern can be observed only on uniaxial gemstones where the optic axis is perpendicular, or near perpendicular, to the gem table or facet being measured. The vibration direction of the extraordinary ray (see detailed explanation in the Appendix) is then perpendicular, or near perpendicular, to the vibration direction of the polarizing filter, which is set in the E–W orientation.

In perfectly oriented gemstones, the extraordinary ray shadow edge disappears when the polarizing filter is inserted during the rotation of a gemstone.

In not-so-perfectly oriented gemstones, the extraordinary shadow edge disappears in some rotation position but may be visible in other rotation positions.

If both shadow edge are still visible, when the polarizing filter is inserted, then the gemstone is rotated gradually left or right until one shadow edge disappears; this is always the extraordinary ray. Then the reading is made of ω on the shadow edge, which stays visible. Then the polarizing filter is removed (Step 4) and the reading of ε is made on the now visible shadow edge of the extraordinary ray (Step 5). Finally, ω and ε are compared and the optic sign is determined as shown in Step 6.

Chart B describes the procedure for determination of the intermediate RI β in biaxial gemstones; the position of β and whether it is closer to α or γ is then used to determine the optic sign. The pattern composed of two variable shadow edges can be observed only on biaxial gemstones; principal RIs α (RI_{min}) and γ (RI_{max}) are determined as the smallest and the largest RI observed during rotation of a gemstone on the refractometer. Determination of the principal RI β requires the use of the polarizing filter. Each shadow edge must be observed separately and must be rotated to different positions marked A and G on the chart. One of them is true β and the other is 'false' β. When the polarizing filter is inserted in an E–W orientation one shadow edge disappears and the true β is then determined on the other (visible) shadow edge.

Two problems may be encountered when this procedure is followed:

1. It may be difficult to locate the rotation positions A or G precisely if a shadow edge moves only slightly up or down when the gemstone is rotated near these positions.
2. Tests with the polarizing filter at positions A and G may give similar results; namely, the α' shadow edge disappears in rotation position A and the γ' shadow edge disappears in the rotation position G, i.e. both shadow edges behave as having a 'false' β.

To deal with the first problem, a gemstone is set in the approximate position A, then the polarizing filter is inserted and the α' shadow edge is observed as shown in Step 3(A). If it disappears right away, or if it disappears after further gradual rotation of a gemstone to the left or right, then it is the 'false' β. The same procedure is repeated on the other shadow edge (γ') when the gemstone is rotated to the position G as shown in Step 3(G).

It is important to observe each shadow edge separately — one shadow edge always disappears during gradual rotation left or right (either from position A or from position G) - as its vibration direction becomes perpendicular to the polarizing filter. This is the 'false' β. The true β is determined on the other shadow edge. Then follow instructions on the chart to determine α and γ, and calculate the optic sign.

The second problem arises in some biaxial gemstones where the principal vibration direction Y is perpendicular, or nearly perpendicular, to the gem table. In this situation the true β shadow edge may also disappear when the polarizing filter is inserted. Fortunately the pattern caused by this orientation can be easily recognized as is described in the note on *Chart B*. The readings of 'false' β and true β should be very close and, in most cases, may lead to the same optic sign.

It is important to keep in mind in any further interpretation that only one of these readings is true β — but that it is impossible to identify it.

On *Chart C,* when a gemstone is rotated to a position where the shadow edges are the closest, there are two possible reasons why neither of the shadow edges disappears when the polarizing filter is inserted.

1. Because the variable shadow edge moves very little up and down during rotation, it is difficult to locate the precise position where the shadow edges are at their closest.
2. The constant shadow edge may only appear to be constant, because the variation in readings may be 0.001 and not detectable for certain. However, the vibration direction of this shadow edge is not perpendicular to the gem table in every rotation position and in some positions it can be as far as 45° away from perpendicular. In this case, this shadow edge may not disappear as expected when the polarizing filter is inserted.

The solution to both problems is the same: a gemstone is rotated to the position where the two shadow edges appear to be at their closest. There is no need to waste time trying to make it perfect. Then the polarizing filter is inserted and the gemstone is gradually rotated left or right until one shadow

edge disappears (Step 2). Then follow the procedure in *Chart C.*

Conclusions

The gemmological refractometer was one of the first instruments designed for the study of gemstones. It is still a very important tool for many gemmologists and a large part of any gemmological training includes practical use of the instrument. Modern refractometers have better optics, a larger scale for better readings of the RIs, and monochromatic light is available in small battery-operated and easily transported units.

It is unfortunate that these technical improvements to the instrument have not resulted in improved and more confident use. One reason for this is the limited time allocated to the teaching of the refractometer because of the ever increasing number of other subjects that most be covered in gemmology courses. Several attempts have been made to simplify concepts and procedures but they have resulted in many incomplete, confusing, or, even, incorrect descriptions and statements. The fact that there was no way to properly test these new proposed procedures made the situation even worse.

Today we finally have a method for predicting the observations on the refractometer that includes the changes in vibration directions of the shadow edges during rotation of a gemstone on the refractometer (Sturman, 2007). The great advantage of this method is the possibility to gradually change the orientation of the optical elements in a gemstone and observe the corresponding changes in the vibration directions of shadow edges and, eventually, to predict observations with the polarizing filter.

The new procedures, based on better understanding of observations on the refractometer are presented in *Charts A, B* and *C.* There is no need for gemmologists to memorize these procedures; all that is required is to follow the instructions on the charts presented in six simple steps.

Figures 2 to *9* in the Appendix present some of the examples used in preparation of the charts.

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Appendix

Observations on the refractometer during rotation of a gemstone *(Figures 2* to *9)* are presented on diagrams in which the horizontal axis of a diagram shows the rotation angle and the vertical axis shows the observed RI. The scale on the vertical axis of the diagrams reflects the scale on the refractometer, with the lower RIs at the top and the higher RIs at the bottom. In some figures the vibration directions of the shadow edges at some rotation positions are shown by two-way arrows. The numbers next to the arrows indicate their directions, for example, 0° is vertical, 10° is 10° away from vertical, 30° is 30° away from vertical and 90° is horizontal.

In the procedures shown in *Charts A, B* and *C,* the polarizing filter is inserted in an E–W orientation. The shadow edge with a vertical vibration direction disappears when the polarizing filter is inserted because vibration direction of a shadow edge (vertical) is exactly perpendicular to the vibration direction of the polarizing filter (horizontal). However, as was mentioned before, the orientation of vibration direction of a shadow edge may vary during rotation of a gemstone on the refractometer. In this case, a shadow edge with vibration direction which is 20° or 30° away from vertical may still be visible.

Figure 1: The amount of transmitted light depends on the angle between the vibration direction of the incoming ray (shadow edge) and the polarizing filter. In this drawing the arrows (red for the transmitted light and black for the incoming light) are proportional to the intensity of light. The amount of the transmitted light increases proportionally with the increase in the angle between the vibration directions of the incoming light and perpendicular to the polarizing filter.

Figures 2, 3 and *4* were used to prepare *Chart A*. The shadow edge of the extraordinary ray in the apatite gemstone, which has an optic axis exactly perpendicular to the gem table, gives a constant reading during rotation on the refractometer — $\varepsilon = 1.640$ (see *Figure 2*) and its vibration direction remains perpendicular to the gem table. This shadow edge disappears when the polarizing filter is inserted in an E–W orientation.

A not-so-perfectly oriented gemstone (apatite) is shown in *Figure 3*. In apatite the birefringence is only 0.004 and in order to produce small variation of 0.001 in readings on the extraordinary shadow edge the optic axis must be inclined for 30° away from vertical. This in turn makes orientation of the vibration direction of the extraordinary ray as far away as 30° from vertical. In some rotation positions the extraordinary shadow edge may be visible when the polarizing filter is inserted in the E–W (horizontal) orientation.

Another not-so-perfectly oriented gemstone (tourmaline) is shown in *Figure 4*. In tourmaline the birefringence is five times stronger than in apatite and in order to produce a variation of 0.001 in

Use of the polarizing filter on the refractometer in determinations of the optic sign or optic character of a gemstone

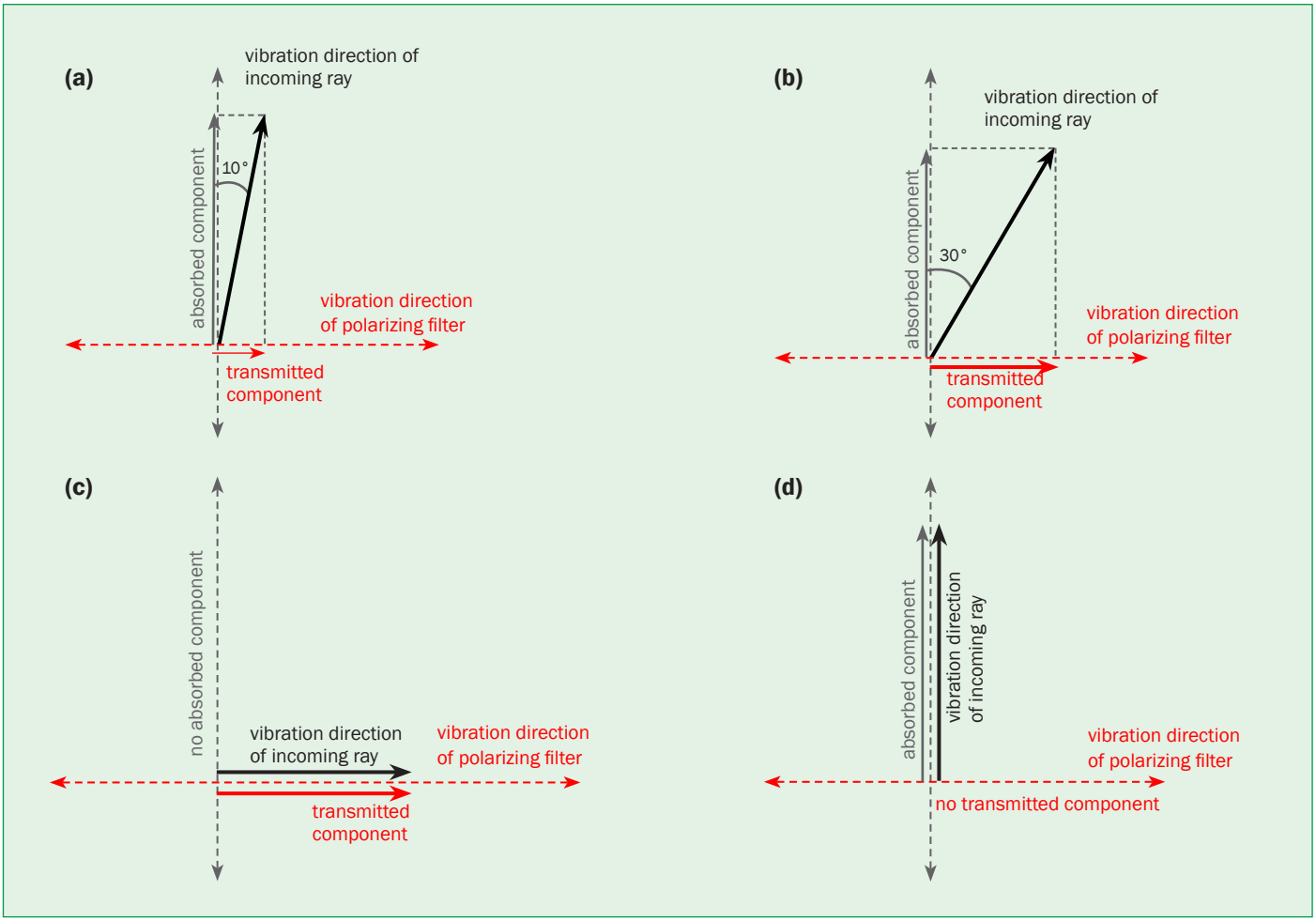

Figure 1: The amount of light transmitted through the polarizing filter depends on the angle between the vibration directions of the incoming ray (solid black arrows) and the polarizing filter (dashed red line).
(a) and (b): The amount of transmitted light (proportional to the red arrows) increases as the angle between the vibration direction of the incoming ray changes from perpendicular to 10° or 30° away from perpendicular.
(c): The maximum amount of light is transmitted when these vibration directions are parallel.
(d): No light is transmitted when these vibration directions are perpendicular to each other.

readings on the extraordinary ray shadow edge the optic axis must be inclined at only 13° away from vertical. This in turn makes orientation of the vibration direction of the extraordinary ray only 13° away from vertical. When the polarizing filter is inserted in the E–W (horizontal) orientation, the vibration direction of the extraordinary shadow edge is vertical, or near-vertical, during rotation of the gemstone. The extraordinary ray shadow edge totally disappears in some rotation positions and is very close to disappearance in others. The overall effect is that the extraordinary ray shadow edge is faint or invisible in every rotation position.

In this particular procedure *(Chart A)* not-so-perfectly oriented gemstones and perfectly oriented gemstones may produce identical patterns. However, on gemstones with a birefringence or 0.010 or less the extraordinary ray shadow edge may still be visible in some rotation positions.

Figures 5 and *6* were used to prepare *Chart B*. A biaxial gemstone (peridot) in general orientation is shown in *Figure 5*. None of the principal vibration directions X, Y and Z are perpendicular to the gem table. Sometimes it may be difficult to find the exact position of A or G if the shadow edges move only slightly on rotation. However, simple gradual rotation left or right from the estimated position A or G should result in one shadow edge ('false' β) disappearing

Figure 6 shows a pattern which can be observed on a biaxial gemstone (sinhalite) where the principal vibration direction Y is nearly vertical (perpendicular to the gem table). In this example it is 20° away from vertical but the shadow edge may disappear when the polarizing filter is inserted in the E–W (horizontal) orientation. It may be difficult to distinguish between true and 'false' β (see comments in the section on use of the charts).

Figures 7, 8 and *9* were used to prepare *Chart C*. *Figure 7* shows the importance of rotating a uniaxial gemstone to the required position B — the rotation position where the constant and the variable shadow edge are at their closest. In this rotation position the vibration direction of the variable shadow edge in uniaxial gemstones is exactly

Use of the polarizing filter on the refractometer in determinations of the optic sign or optic character of a gemstone

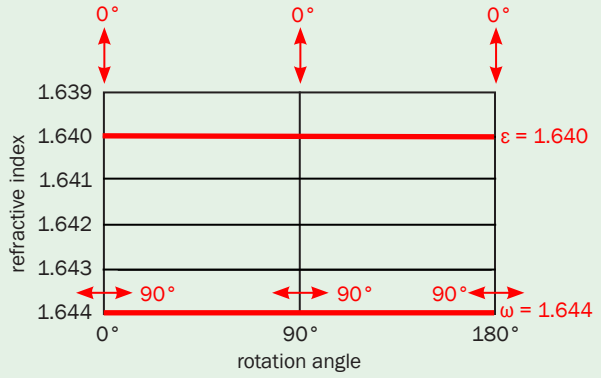

Figure 2: In this uniaxial gemstone (apatite) where the optic axis is exactly perpendicular to the gem table, the RI readings observed on each of the two shadow edges stay constant during the rotation of a gemstone on the refractometer. The vibration direction of the shadow edge produced by the extraordinary ray stays exactly vertical (perpendicular to the gem table) during rotation of a gemstone. This shadow edge disappears in any rotation position when the polarizing filter with a horizontal vibration direction (E–W direction of the eyepiece) is inserted

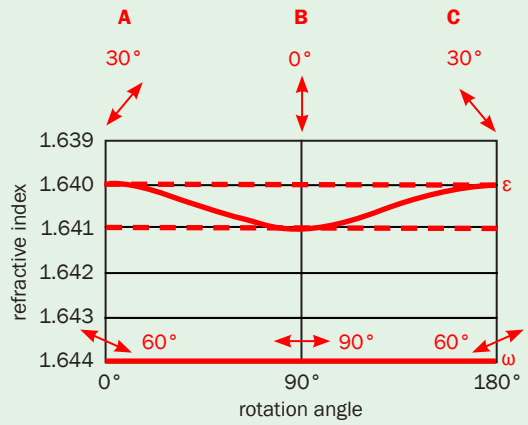

Figure 3: This orientation of the uniaxial gemstone apatite shows the extraordinary ray RIs which vary between 1.640 and 1.641. The shadow edge may apear constant but its vibration directions change from exactly vertical to 30° away from vertical during rotation. When the polarizing filter is inserted in the E – W (horizontal) orientation, the shadow edge of the extraordinary ray disappears in some rotation positions (B) but may be visible in other rotation positions (A and C)
Maximum birefringence is small — 0.004. Deviation in RI readings of 0.001 is reflected in deviation of up to 30° away from vertical for the vibration direction of the extraordinary ray.

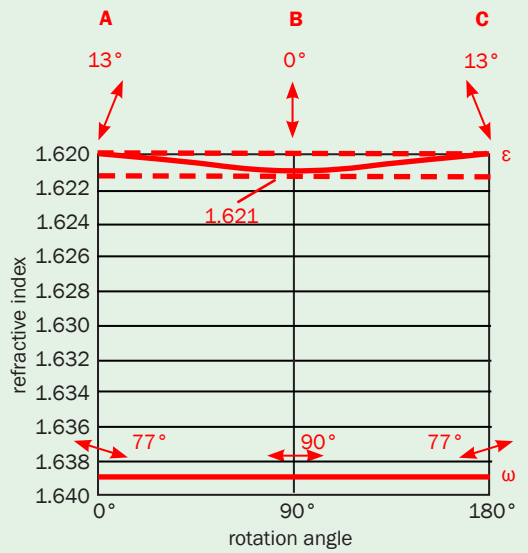

Figure 4: The uniaxial gemstone tourmaline showing a shadow edge produced by the extraordinary ray varying between 1.620 and 1.621. It may appear relatively constant but the vibration direction changes from exactly vertical to 13° away from the vertical during rotation on the refractometer.
A deviation of 13° from vertical is too small to make the extraordinary ray shadow edge visible at rotation points A or C. The extraordinary shadow edge disappears in every rotation position when the polarizing filter is inserted in the E–W orientation.
Maximum birefringence is 0.019. Deviation in RI readings of 0.001 is reflected in deviation of only 13° from vertical for the vibration direction of the extraordinary ray.

vertical and this shadow edge disappears when the polarizing filter is inserted in the E–W (horizontal) orientation. This position may be difficult to find precisely in gemstones with small birefringence because the variable shadow edge may move little up or down during rotation between A and C. However, gradual and small rotation of a gemstone left or right from the initially estimated position B, should result in the disappearance of the variable shadow edge.

Figure 8 shows a biaxial gemstone (topaz) with the principal vibration direction X exactly perpendicular to the gem table. The vibration direction of the constant shadow edge is also exactly perpendicular to the vibration direction of the polarizing filter set in the E–W orientation. The constant shadow edge disappears in every rotation position of the gemstone when the polarizing filter is inserted.

Figure 9 shows the same biaxial gemstone (topaz) as in *Figure 8* but the principal vibration direction X now makes an angle of 45° with the gem table.

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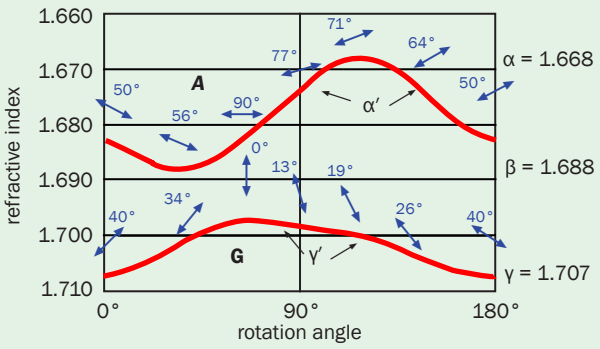

Figure 5: A biaxial gemstone (peridot) with two variable shadow edges α′ and γ′. Each shadow edge must be examined separately. First, the α′ shadow edge is rotated to position A and the polarizing filter inserted with E–W orientation. If the α′ shadow edge does not disappear — as is the case in this example — then this is true β.
In order to confirm this, the γ′ shadow edge is rotated to position G and the polarizing filter is inserted with E–W orientation. In the example shown in this diagram, the γ′ shadow edge disappears proving that it is a 'false' β.
Note: A is the highest reading on the α′ shadow edge and G is the lowest reading on the γ′ shadow edge. Sometimes it is difficult to find the exact positions of A or G if the shadow edge moves very little up and down during the rotation. In this case, rotation of a gemstone left or right from the estimated positions A or G should result in the disappearance of one shadow edge.

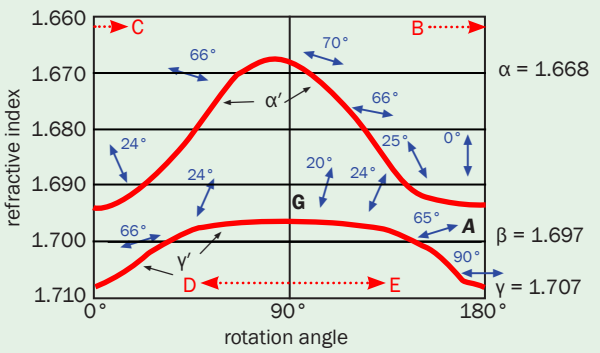

Figure 6: In this biaxial gemstone (sinhalite) both shadow edges have vertical, or near-vertical, vibration directions at rotation positions A and G and both my disappear when the polarizing filter is inserted in the E–W (horizontal) orientation. It may be very difficult, or even impossible, to distinguish 'false' β from true β. Fortunately, these patterns can be easily recognized because both shadow edges give almost the same readings for possible β and stay at these readings for much of the rotation (α′ shadow edge from B to C and γ′ shadow edge from D to E). However, since both shadow edges give similar readings for β, this is often sufficient for reliable identification.

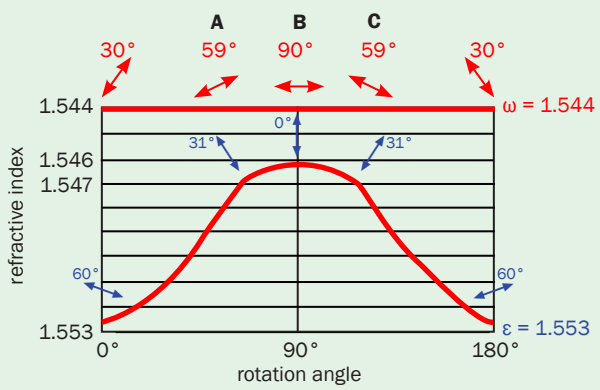

Figure 7: A pattern composed of one variable and one constant shadow edge can be observed on uniaxial and on biaxial gemstones. The pattern in this figure is of a uniaxial gemstone (quartz) – compare it to the pattern of a biaxial gemstone (topaz) in Figure 8. A gemstone must be rotated to the position B (where shadow edges are the closest); in uniaxial gemstones the variable shadow edge disappears when the polarizing filter is inserted in the E–W (horizontal) orientation. It may be difficult to find the exact position B if the readings on the variable shadow edge stay nearly the same (between 1.546 and 1.547) during the rotation of about 50° from A to C.
Both shadow edges may stay visible in positions A or C when the polarizing filter is inserted in the E–W orientation, but further rotation of the gemstone left or right will make the variable shadow edge disappear — proving that this is a uniaxial gemstone.

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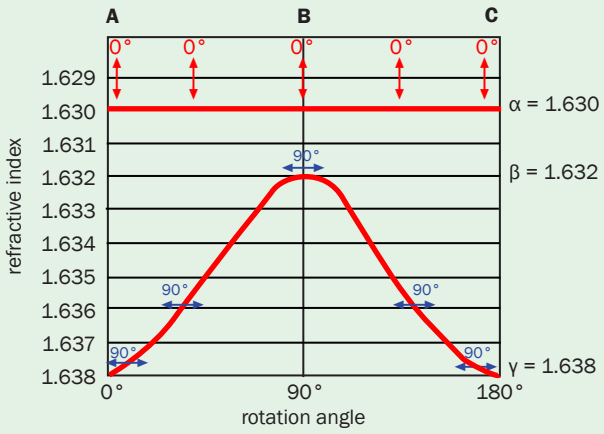

Figure 8: This is a pattern from a biaxial gemstone (topaz) where the principal vibration direction X is exactly perpendicular to the gem table. The vibration direction of the constant shadow edge remains vertical during 180° rotation of the gemstone. In biaxial gemstones, the constant shadow edge disappears when the polarizing filter is inserted in the E–W (horizontal) orientation.

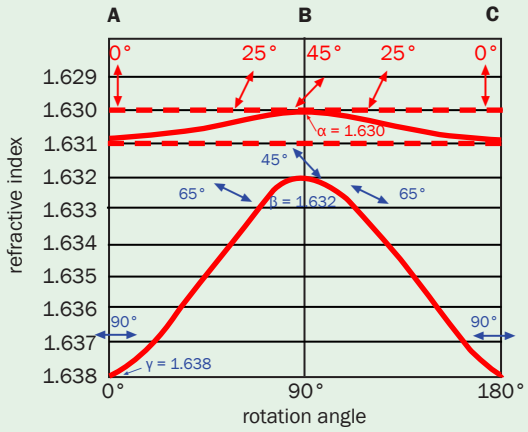

Figure 9: A biaxial gemstone where the principal vibration direction X is not vertical (perpendicular to the gem table) but makes an angle of 45° to the gem table. The variation in the RI readings of the near-constant shadow edge is very small — from 1.630 to 1.631. Both shadow edges are visible (with the polarizing filter inserted in the E-W orientation) when a gemstone is in position B — the rotation position where the shadow edges are the closest — but further rotation to positions A or C will result in the disappearance of this shadow edge.

Although the variation of the constant shadow edge from 1.630 to 1.631 may not be noticed, this small variation in the RI is accompanied by a very large variation in the orientation of the vibration directions. *Figure 9* shows that both shadow edges are visible when a gemstone is rotated to the B position and the polarizing filter inserted, but on further rotation the near-constant shadow edge will disappear at positions A or C, proving that this is a biaxial gemstone.

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Use of the polarizing filter to improve observations of the shadow edges on the refractometer

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Abstract: Proper use of the polarizing filter may greatly improve observation on the refractometer. Transmission of polarized light through a polarizing filter is described in detail and a simple construction is used to show how the strength of an image (for example, a shadow edge) depends on an angle between the vibration directions of the polarizing filter and the incoming polarized rays. Two examples are used to describe the incorrect use of the polarizing filter that may lead to wrong identifications.

Keywords: polarizing filter, proper measurement procedure, refractive index

Introduction

The polarizing filter is a very useful and a simple accessory of modern refractometers. It is easy to use and gives reliable results if proper procedures are followed.

In order to better follow instructions for the safe and reliable use of the polarizing filter, gemmologists should first have a full understanding of the way the polarizing filter works. This is described in the first section of this article. The correct procedure to increase the sensitivity of observation (to better see the shadow edges) is discussed in the second section. In the third section, two examples are used to show how incorrect use of the polarizing filter may lead to incorrect conclusions and, eventually, to incorrect identifications.

A. How does the polarizing filter work?

The polarizing filter does *not* work as some kind of vertical blind, for example, transmitting only rays with the vertical vibration direction when the vibration direction of the filter is set vertically.

The polarizing filter *transforms* the energy of an incoming polarized ray into two rays as the light moves through the filter; one ray is absorbed and the other is transmitted. The vibration direction of the transmitted ray is often marked on the filter and is referred to as the vibration direction of the polarizing filter. The intensity of an image, for example, the strength of the image of a shadow edge, depends on the angle between vibration direction of the polarizing filter and the vibration direction of light rays forming the shadow edge.

In *Figures 1, 2* and *3* a construction is used to indicate how the intensity of the transmitted ray, the strength of an image of a shadow edge, depends on the angle between the vibration directions of the incoming ray and the polarizing filter. In order to simplify this concept, we relate the word 'intensity' in these drawings to the lengths of the arrows. In fact, the lengths of the arrows represent the amplitudes of light waves, which are proportional to their intensities. The intensity of a light wave is the square of its amplitude. Therefore, if absolute values of intensities are calculated from these constructions, then the relation between the amplitudes and intensities must be taken into account.

Figures 1 and *2* show how a polarized ray is divided into two components by the polarizing filter. The intensity of a transmitted component — the strength of the image of a shadow edge — increases as the vibration directions of the polarizing filter and the incoming ray get closer.

In general, a part of the incoming ray is always transmitted through the polarizing filter but its vibration direction and the intensity are changed; however, there are exceptions to this general rule:

1. When vibration directions of the polarizing filter and the incoming ray are exactly parallel to each other then the intensity of the transmitted ray is identical with the incoming ray, and
2. When vibration directions of the polarizing filter and the incoming

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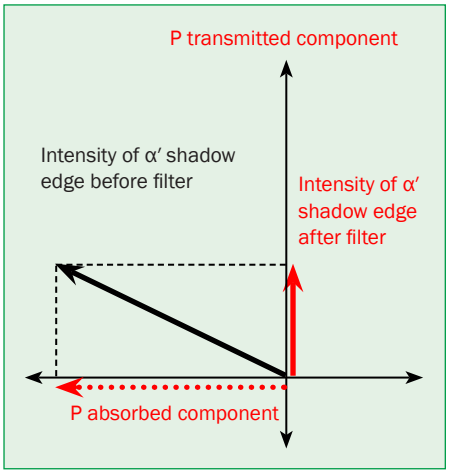

Figure 1: Polarized light producing a shadow edge α′ is transformed into two components on entering the polarizing filter. Vibration directions of the incoming ray and the two components (transmitted and absorbed) in the polarizing filter are shown by arrows and their intensities are related to the lengths of the arrows.
Note: The lengths of the arrows show the amplitudes of the light rays, which are proportional to their intensities — the intensity is the square of the amplitude.

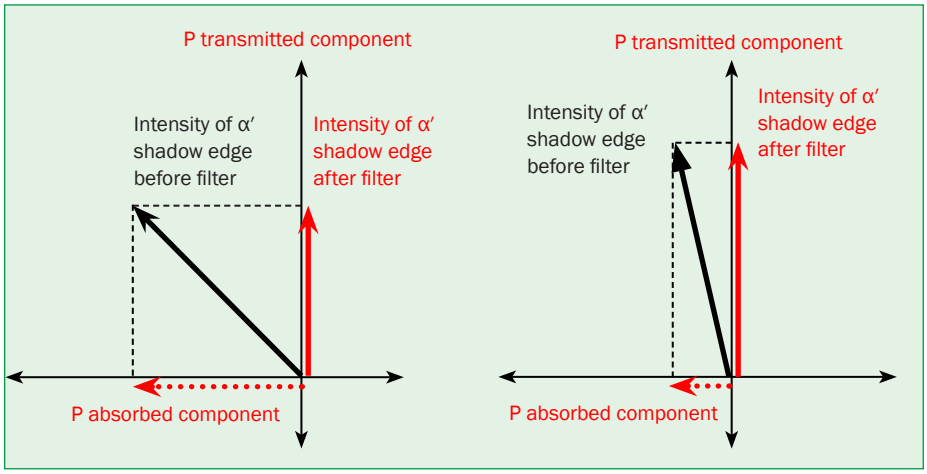

Figure 2: The intensity of the transmitted ray depends on the angle between vibration directions of the polarizing filter and the incoming ray. The decrease in this angle is reflected in the increased intensity of the transmitted ray.

ray are exactly perpendicular to each other, then the incoming ray is totally absorbed.

> When a polarizing filter is rotated on the refractometer's eyepiece, the strength of the image of a shadow edge of an anisotropic gemstone changes from zero to the maximum for every 90° rotation.

In the field of view of a refractometer, two shadow edges are usually observed during the rotation of anisotropic gemstones. In *Figure 3* they are marked γ′ and α′; their vibration directions change during the rotation of a gemstone on the refractometer.

Without the polarizing filter, the shadow edges are visible in different

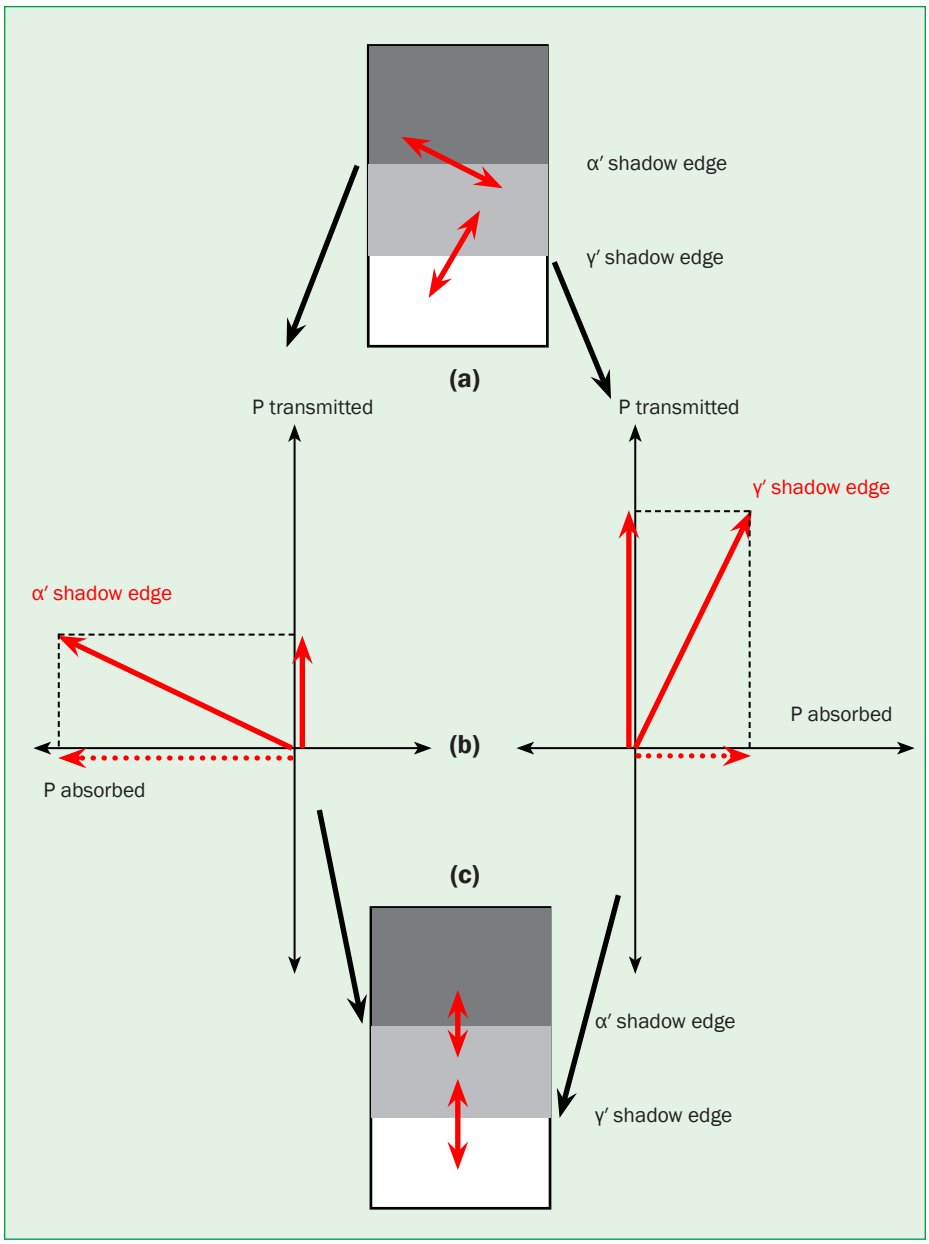

Figure 3: (a) Observation without the polarizing filter. Both shadow edges have similar intensities.
(b) Light rays of shadow edges are divided into two components in the polarizing filter. One is absorbed, the other is transmitted.
(c) Two shadow edges coming to the eye now have different intensities and are polarized parallel to the axis of the refractometer.

Use of the polarizing filter to improve observations of the shadow edges on the refractometer

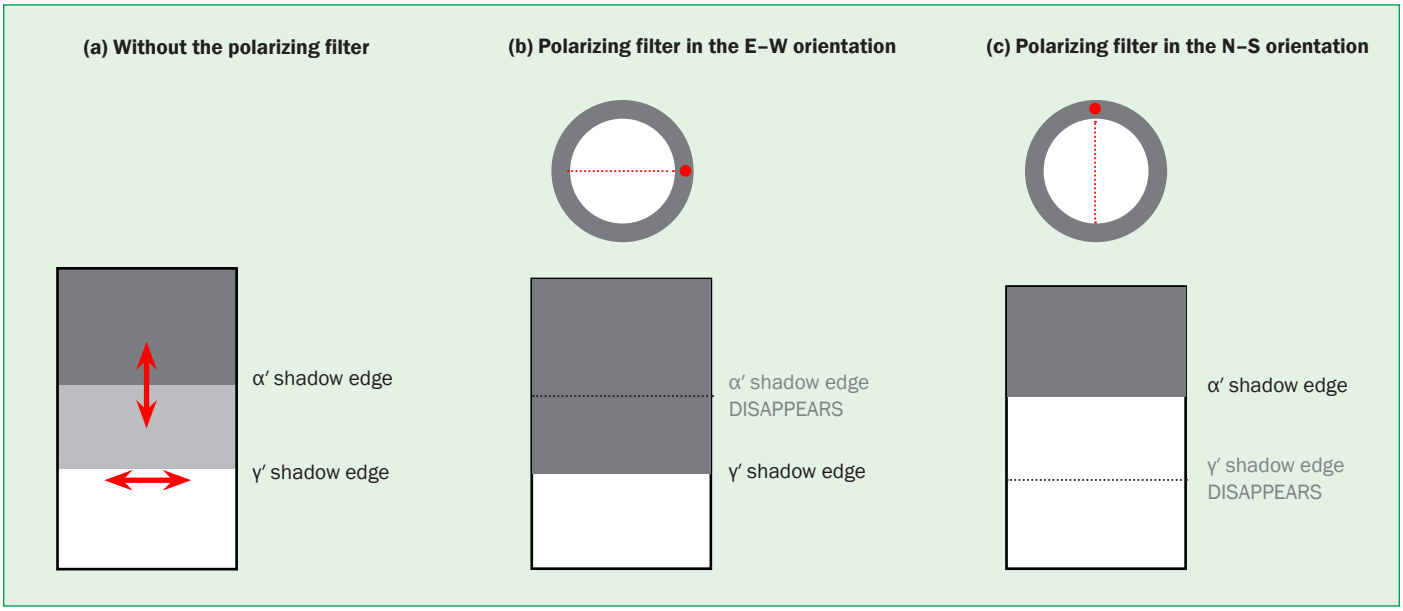

Figure 4: The use of the polarizing filter to bring one shadow edge to the extinction position. The other shadow edge may appear sharper and enable more accurate readings. (a) Observation without the polarizing filter. Both shadow edges are seen with similar intensity. Red arrows indicate the vibration directions of the shadow edges. (b) Po larizing filter is inserted and rotated until α′ shadow edge disappears. (c) Polarizing filter is inserted and rotated until γ′ shadow edge disappears.

positions in the field of view of the refractometer during the rotation of the gemstone. They indicate different refractive indices but, generally, they are seen as two lines with similar intensities. What the human eye does not see is that they are polarized and that their vibration directions are perpendicular to each other *(Figure 3a)*.

When the polarizing filter is inserted, then the shadow edges are seen in exactly the same positions on the scale but their intensities change because their vibration directions are at different angles to the polarizing filter (see *Figure 3b*). The human eye may notice the change in intensities of the shadow edges but cannot see that their vibration directions are now parallel to each other *(Figure 3c)* as they travel through the air to the eye.

When the polarizing filter is rotated and the vibration direction of one shadow edge becomes exactly parallel to the polarizing filter, it is seen at maximum intensity. The other shadow edge is then not seen at all.

The use of the polarizing filter produces better contrast because it eliminates one shadow edge and a grey zone between the shadow edges (see *Figure 4*).

- Without the filter we see two shadow edges: dark area/α′ shadow edge/grey area/γ′ shadow edge/ light grey area *(Figure 4a)*.
- When the filter is inserted and rotated so that one shadow edge becomes invisible, we see a single shadow edge: dark area/shadow edge/light grey area (*Figures 4b and c*).

B. The correct use of the polarizing filter to increase sensitivity of observations on the refractometer

When two shadow edges are very close or if we wish to increase the sensitivity with which they are seen, the polarizing filter can be used to bring one shadow edge to extinction. The other shadow edge may then be seen with better contrast and enable a more accurate reading.

The best practice is first to rotate a gemstone on the refractometer and observe any changes without the filter. If needed, the polarizing filter is then inserted and rotated to bring one, and then the other, shadow edge to extinction.

The procedure is straightforward:

1. Two shadow edges are observed first without the polarizing filter.
2. The filter is then set on the eyepiece and rotated until one shadow edge is invisible. Reading on the scale of the position of the other shadow edge may become easier.
3. After this, the filter is rotated 90° until the other shadow edge is invisible and the refractive indexof the now visible shadow edge can be read.

C. Incorrect procedures can lead to serious error in determination of the optic character and the optic sign of biaxial gemstones.

In some literature or equipment instructions, the measuring procedure is presented in a very simple and attractive form, for example: "Turn the gemstone gradually without readjusting the polarizing filter." It seems impossible that such a simple procedure may lead to a serious error in identification, but in some circumstances it can.

As mentioned above, rotation of a gemstone is accompanied by rotation of the vibration directions of the shadow

Use of the polarizing filter to improve observations of the shadow edges on the refractometer

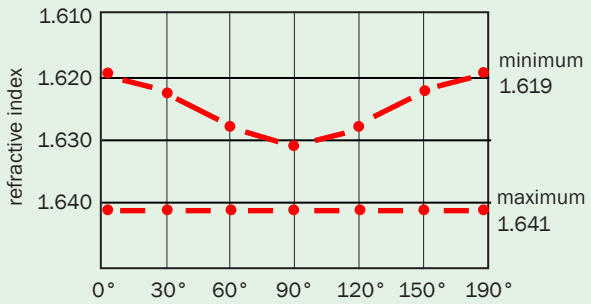

Figure 5a: Observation without the polarizing filter.

This gemstone could be tourmaline (uniaxial) or actinolite (biaxial).

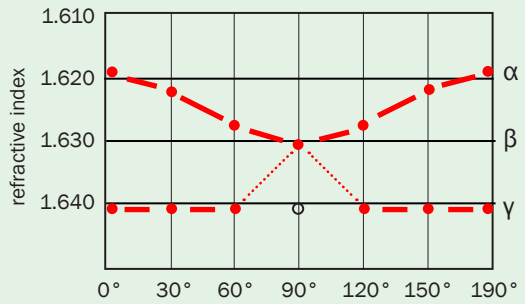

Figure 5b: If the polarizing filter was set as in Figure 4b and remains on the refractometer, the constant shadow edge would disappear at 90° rotation position. At this position, a single shadow edge would be observed and interpreted as two variable shadow edges joining together, a pattern possible only in biaxial gemstones

It would thus possibly be wrongly identified as actinolite. In fact, it may also be a uniaxial gemstone — tourmaline.

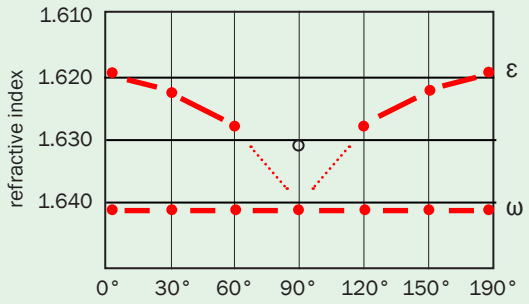

Figure 5c: If the polarizing filter was set as in Figure 4c, and remains on the refractometer, the variable shadow edge would disappear at 90° rotation position. At this position, a single shadow edge would be observed and interpreted as a common point of the constant and the variable shadow edge.

This pattern is only possible in uniaxial gemstones This interpretation leading to the identification of the gemstone as tourmaline (uniaxial) may not be correct, and the gem may be actinolite.

edges. If the polarizing filter stays in one orientation during rotation of a gemstone, sooner or later the vibration direction of one shadow edge will become perpendicular to the polarizing filter. This shadow edge will disappear and a single shadow edge will be observed. This may lead to an incorrect determination of the optic character *(Figure 5)* or to an incorrect determination of β *(Figure 6)* and, consequently, to incorrect determination of the optic sign in biaxial gemstones.

Wrong determination of optic character

A very common pattern of the movement of the shadow edges during the rotation of an anisotropic gemstone on the refractometer consists of one variable and one constant shadow edge that do not meet (see *Figure 5a*). This pattern can be observed in uniaxial gemstones and in biaxial gemstones if the facet being measured has a particular orientation of the optical elements and the facet.

Keeping the polarizing filter in the same orientation during the rotation of a gemstone on the refractometer, may result in the extinction of one of the two shadow edges just at the critical rotation position (90° in *Figure 5*). *Figures 5b* and *5c* show situations which would lead gemmologists to think that they had observations which are only possible in uniaxial gemstones or which are only possible in biaxial gemstones. In fact, such an error can be caused by wrong use of the polarizing filter bringing one of the shadow edges to extinction.

Wrong determination of the principal refractive index β

The most common pattern of the movement of the shadow edges during the rotation of biaxial gemstones on the refractometer consists of two variable shadow edges that do not join. Only the maximum principal refractive index γ and the minimum principal refractive index α can be determined *(Figure 6a)*.

Where the facet of a biaxial gemstones has a particular orientation of the optical elements (the optic axis is parallel to the facet) a different pattern can be observed: two variable shadow edges which join during the rotation. At this

Use of the polarizing filter to improve observations of the shadow edges on the refractometer

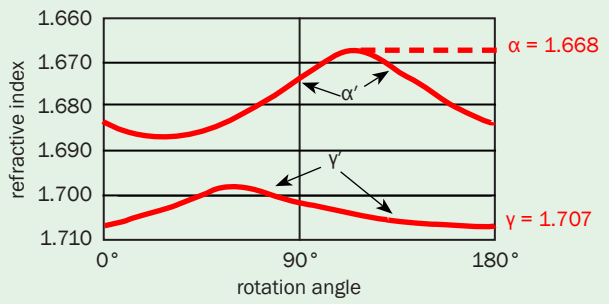

Figure 6a: Biaxial gemstone. Two variable shadow edges that do not join together. A special test must be used to determine the principal refractive index β.

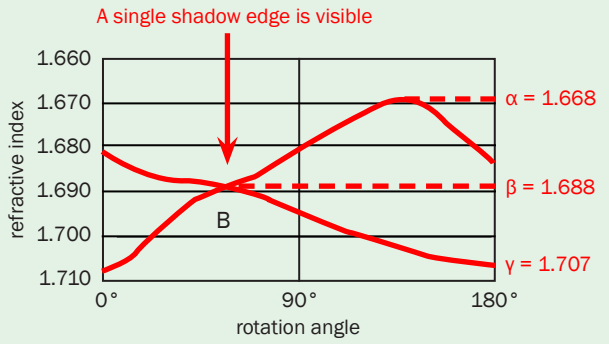

Figure 6b: A biaxial gemstone with the optic axis parallel to the gem table. At one rotation position (marked B), the two shadow edges join to form a single shadow edge. This single shadow edge allows a reliable determination of the principal refractive index β.

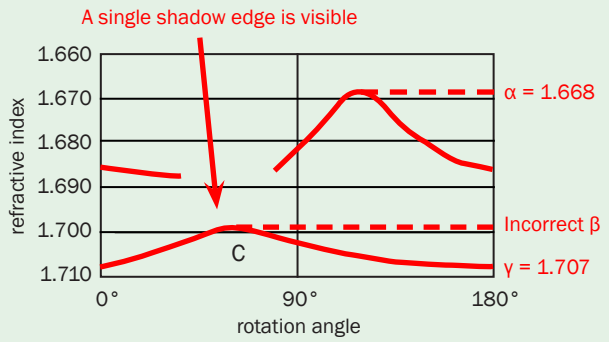

Figure 6c: A biaxial gemstone in a similar orientation to that in Figure 6a. A polarizing filter remains on the eyepiece of the refractometer in an orientation that makes the α′ shadow edge disappear in the rotation position marked C. A single shadow edge is visible and may be misinterpreted as the position where β can be determined (see Figure 6b). The incorrect β may lead to incorrect identification — in this example, a peridot could be misidentified as sinhalite..

rotation position, a single shadow edge is observed and allows reliable and accurate determination of the principal refractive index β *(Figure 6b)*.

However the same observation – a single shadow edge – can be observed at some stage in rotation of a gem with the common biaxial pattern *(Figure 6a)* if the polarizing filter is left on the eyepiece and the vibration direction of one, or the other, shadow edge becomes perpendicular to the polarizing filter. This shadow edge will disappear and a single shadow edge is seen and may lead to the wrong determination of the principal refractive index β.

This wrong determination of β can lead to incorrect determination of the optic sign and, eventually, to wrong identification of a gemstone (see *Figure 6c*).

These two examples show the importance of always following the correct procedure for the use of the polarizing filter. The polarizing filter must be adjusted every time a gemstone is rotated on the refractometer. However, the best practice is to use the polarizing filter when needed to increase the sensitivity of observation and to remove it immediately after.

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Abstracts

Diamonds

Diamond formation from $CaCO_3$ at high pressure and temperature.

L. Bayarjargal (bayarjargal@kristall.uni-frankfurt.de), T.G. Shumilova, A. Friedrich and B. Winkler. *European Journal of Mineralogy,* **22**(1), 2010, 29–34.

From a study by micro-Raman spectroscopy of the decomposition of $CaCO_3$ by laser-heated diamond-anvil cell experiments at 9–21 GPa up to 4000 K, it is indicated that calcite decomposes into $CaO+O_2+C$ across the whole pressure range at temperatures around 3500 K, initially forming graphite nanoparticles of ~3–11 nm. These graphite particles may aggregate and transform into ~20 nm diamonds if the sample is annealed in the diamond stability field. It is concluded that diamond can be crystallized directly from carbonatitic melts by the decomposition of $CaCO_3$ at high pressures and temperatures, and that phase diagrams showing a decomposition to $CaO+CO_2$ in the *P–T* range need to be re-evaluated. R.A.H.

The Wittelsbach-Graph and Hope diamonds: not cut from the same rough.

E. Gaillou (asteriee@yahoo.fr) W. Wang, J.E. Post, J.M. King, J.E. Butler, A.T. Collins and T.M. Moses. *Gems & Gemology,* **46**(2), 2010, 80–88.

The Wittelsbach-Graff and the Hope, two of the world's most famous blue diamonds, share similarities in history, colour and phosphorescence, but distinct differences in their luminescence emission and internal strain patterns demonstate that these two type IIb diamonds did not originate from the same crystal. Their overall resemblance and Indian origin, however, suggest that they formed in similar geological settings. R.A.H.

Gemmologie Aktuell (Gemmological news).

C.C. Milisenda. *Gemmologie. Z. Dt. Gemmol. Ges.,* **59**(3/4), 2010, 65–70.

A cross section of a diamond was submitted because it had been thought to be synthetic. The diamond showed grey-brown star- and cross-like growth structures representing undulating, non-planar cuboid growth features which only occur in natural diamonds. E.S.

Lab notes.

T.M. Moses and S.F. McClure (Eds). *Gems & Gemology,* **45**(4), 2009, 288–95.

Items include a 1.49 ct Fancy deep brown-orange diamond that owes its colour to laboratory radiation. R.A.H.

Lab notes.

T.M. Moses and S.F. McClure (Eds). *Gems & Gemology,* **46**(1), 2010, 48–57.

Notes are given on a cut diamond with rare green fluorescence and a 6.46 ct Fancy intense blue HPHT-treated type IIb diamond. R.A.H.

Morphology and defects of diamond grains in carbonado: clues to carbonado genesis.

V.A. Petrovsky, A.A. Shiryaev, V.P. Lyutoev, A.L. Sukharev and M. Martins. *European Journal of Mineralogy,* **22**(1), 2010, 35–47.

Paramagnetic and non-paramagnetic defects in grains of diamond from Brazilian carbonado indicate that many of the specimens of carbonado studied were annealed under mantle conditions, although for a relatively short time. Diamond grains show various morphological forms with low degrees of dissolution; these include re-entrant apices and incomplete growth layers on faces. It is suggested that micron-sized single crystals of diamond of predominantly octahedral and cubo-octahedral shape grew under conditions of decreasing carbon supersaturation. The temperature decrease is a plausible driving force for crystallization. During the second stage of carbonado formation, mass crystallization of diamond occurred; the necessary C supersaturation was probably caused by crystallization of other minerals, leading to a decrease in the volume and/or constitution of the parent solution. R.A.H.

Possible "sister" stones of the Hope diamond.

S.D. Sucher (scott@museumdiamonds.com), S.W. Attaway, N.L. Attaway and J.E. Post. *Gems & Gemology,* **46**(1), 2010, 28–35.

The recent discovery of a lead cast of the French Blue, the precursor of the Hope, has provided a more accurate model of the Hope diamond, which disappeared in 1792. Computer models of the French Blue and its parent stone, the Tavernier Blue, were used to determine whether other diamonds might have been created when the Tavernier was cut into the French Blue, or when the latter was cut to produce the Hope. It is demonstrated that it was not feasible for other significant diamonds to have been created during any recutting. R.A.H.

Gems and Minerals

Demantoid from Val Malenco, Italy: review and update.

I. Adamo, R. Bocchio, V. Diella, A. Pavese, P. Vignola, L. Prosperi and V. Palanza. *Gems & Gemology,* **45**(4), 2009, 280–7.

New data are presented for demantoid from Val Malenco in northern Italy, including results from electron microprobe, LA-ICP-MS and UV-Vis-NIR and mid-IR

Abstracts (continued)

spectroscopy. These garnets are shown to be almost pure andradite (> 98 mol %, RI > 1.81, SG 3.81–3.88) All 18 samples studied contained 'horsetail' inclusions characteristic of their geological origin in serpentinite. The coloration of this demantoid is controlled by the contents of Fe and Cr, the latter being the major influence. R.A.H.

Sächsischer Amethyst.
W. Beck. *Lapis.,* **35**(2), 2010, 23–8.

Amethyst of near ornamental quality is described from sites in Saxony, Germany. M.O'D.

The Kagem emerald mine, Kafubu area, Zambia.
S.C. Behling and W.E. Wilson. *The Mineralogical Record,* **41**(1), 2010, 59–67.

Emeralds from the Kagem mine are found in a pegmatite field and may occur with interpenetrant twins of quartz. M.O.D.

Röntgenamorph und lichtkristallin — Optische Eigenschaften opaliner Materialien.
R. Goldberg and H.J. Schöpe. *Gemmologie. Z. Dt. Gemmol. Ges.,* **59**(1/2), 2010, 19–34. 4 photographs, 7 diagrams, bibl

Opaline materials like natural precious opals are made up of spherical colloidal particles in a three-dimensional structure with lattice constants in the wave-length range of visible light. But unlike precious opals, close packing of the silica particles is not obligatory; this group includes structures made of chemically different particles with variable packing density as well as bidisperse arrays. A diffraction theory is presented to explain the observations, taking into account the scattering behaviour of the spherical particles. E.S.

Bastnäsite-(Ce) and parisite-(Ce) from Mt. Malosa, Malawi.
A. Guastoni (alessandro.guastoni@unipd.it), D. Kondo and F. Nestola. *Gems & Gemology,* **46**(1), 2010, 42–7.

Large (up to 20 cm) brownish orange crystals of bastnäsite-(Ce) interlayered with opaque yellow-brown parisite-(Ce) occur associated with aegirine and microcline in alkaline pegmatites on Mt Malosa, southern Malawi. Small parts of some of the crystals are suitable for cutting as gems. The gemmological and chemical properties of these rare-earth carbonates are presented. R.A.H.

Hibonite: a new gem mineral.
T. Hainschwang (thomas.hainschwang@gemlab.net), F. Notari, L. Massi, T. Armbruster, B. Rondeau, E. Fritsch and M. Nagashima. *Gems & Gemology,* **46**(2), 2010, 135–8.

A 0.23 g orangy-brown crystal yielding a 0.39 ct step-cut stone and a 0.71 g crystal were characterized by IR spectroscopy, XRD and SEM/XRF as hibonite. This material had RI 1.79–1.81, SG 3.84, H 7½–8 and was reputed to be from Myanmar. R.A.H.

Gemmologische Kurzinformationen. Zuchtperlen mit zerbrochenem Überzug.
H.A. Hänni. *Gemmologie. Z. Dt. Gemmol. Ges.,* **59**(3/4), 2010, 106–8. 3 photographs, bibl.

Drilling of South Sea cultured pearls sometimes gives rise to fissures on the surface. The pearls mostly contain classical beads from freshwater shells which have a layered structure. If the direction of the drilling coincides with the layering, the core may split. Cultured pearls with a thin coat are particularly vulnerable. E.S.

Zuchtperlen mit neuem Kernmaterial.
H.A. Hänni, M.S. Krzemnicki and L.E. Cartier. *Gemmologie. Z. Dt. Gemmol. Ges.,* **59**(1/2), 2010, 35–46. 15 photographs, 1 table, bibl.

Different materials have been used as cores for cultured pearls, mainly shell from Mississippi bivalves. As a new option for beads in cultured pearls, baroque-shape shell beads as well as Chinese freshwater cultured pearls have been found to serve this purpose. Experiments with freshwater cultured pearls of 6.5 mm have been carried out with marine *Pinctada maxima* and with *Pinctada margaritifera* oysters. After 13 months 200 pearls were harvested. Natural pearls have also been used as nuclei, the material being either non-nacreous, brown or of an unpleasant appearance; these are difficult to identify as the radiographic structure of the natural cores are masking these cultured pearls. E.S.

Gemmologische Kurzinformationen. Hypersthen aus Sri Lanka.
U. Henn. *Gemmologie. Z. Dt. Gemmol. Ges.,* **59**(1/2), 2010, 51–2. 3 photographs, bibl.

Gem-quality hypersthene shows remarkable golden-brown wavy zones due to lamellar twinning. Physical properties and chemical composition are given. E.S.

Gemmologische Kurzinformationen. Aventurisierender Feldspat (Sonnenstein) aus Tansania.
U. Henn. *Gemmologie. Z. Dt. Gemmol. Ges.,* **59**(1/2), 2010, 52–4. 2 photographs, 1 table, bibl

Gem feldspars occur in the Meto hills, northwest of Arusha, near the Kenyan border. They show typical physical and chemical characteristics of oligoclase feldspar. The aventurescent effect is caused by tabular hematite inclusions. E.S.

Gemmologische Kurzinformationen. Tourmaline aus dem Kongo.
U. Henn. *Gemmologie. Z. Dt. Gemmol. Ges.,* **59**(3/4), 2010, 111–13. 5 photographs, 1 graph, bibl.

Tourmalines from the Democratic Republic of Congo show green to blue-green to greenish-blue colours caused by divalent iron. Some crystals have distinct colour zoning showing green and greenish-blue segments. Typical capillary fluid inclusions can be observed. E.S.

Ein Beitrag zum Thema Onyx.
U. Henn, T. Häger and C.C. Milisenda. *Gemmologie. Z. Dt. Gemmol. Ges.,* **59**(3/4), 2010, 83–94. 17 photographs, 1 graph, bibl.

In contrast to earlier regulations, recent CIBJO nomenclature requires specific disclosure on the dyeing of chalcedonies and agates. In the trade most onyx is dyed. In addition to the traditional sugar treatment, black in chalcedonies can be induced by the use of cobalt-bearing substances such as cobalt nitrate or cobalt chlorite, which can be detected by XRF analysis. Natural coloured quartz aggregates or onyx can be obtained from India, Brazil and South Africa. The Brazilian specimens are fibrous aggregates coloured by natural organic carbon. Samples from India and South Africa are grained polycrystalline aggregates and take a weaker polish. Their dark colour is due to iron, manganese and titanium oxides. E.S.

Abstracts (continued)

Short gemmological notes. Emerald green muscovite as a gemstone.
J. Hyršl. *Gemmologie. Z. Dt. Gemmol. Ges.,* **59**(3/4), 2010, 109–11. 4 photographs, bibl.

Muscovite belongs to the mica group and is generally thought too soft (hardness 2.5–3) to be suitable for jewellery. It also has perfect cleavage. In 2009 a new emerald-green rough appeared from Tanzania, first offered as emerald, then zoisite, but proved to be muscovite. About 10 rough pieces and 15 cut stones were examined; the faceted pieces weighed between 0.25 and 1.25 ct. Under the Chelsea Colour Filter the stones showed red; Cr lines were seen with a spectroscope. Two other examples of muscovite are mentioned; one is a carving of a green monkey from Peru examined in 2009, which proved to be muscovite; the other are some cabochons on the base of a rock crystal vessel in St. Vitus cathedral in Prague which were previously thought to be emeralds. E.S.

Short gemmological notes. Barite from Alenquer, Brazil.
J. Hyršl, R. Scholz and K. Krambrock. *Gemmologie. Z. Dt. Gemmol. Ges.,* **59**(3/4), 2010, 103–5. 3 photographs, 1 graph, bibl.

A new source of rough baryte in Alenquer in the state of Para, Brazil, started to produce in 2009. It occurs there in loose crystals always free of matrix rock. Nothing is known of its geological context. The crystals are usually 2–5 cm across, rarely over 10 cm long, weighing a few hundred grams. They are very transparent which is rare in baryte from other parts of the world. Most crystals are colourless, very light yellow or smoky, often with thin parallel blue zones near the rim of some crystal faces. A few cut stones, the largest weighing 375 ct, were examined in more detail. E.S.

Gem News International.
B.M. Laurs (Ed.) (blaurs@gia.edu). *Gems & Gemology,* **45**(4), 2009, 296–311.

Items mentioned include cut stones of yellow grossular whose only inclusions are colourless crystals of apatite, an 83.45 ct transparent phenakite from Nigeria, transparent and bright blue sodalite reportedly from a locality near the Badakhshan lapis lazuli mines in Afghanistan and pink-to-red Cu-bearing tourmaline from Nigeria. R.A.H.

Gem News International.
B.M. Laurs (Ed.) (blaurs@gia.edu). *Gems & Gemology,* **46**(1), 2010, 58–72.

Items noted include brownish-yellow cut andradites (0.30-1.58 ct) from western China, strings of beads of coarse-grained lepidolite from Mozambique, a cat's-eye rhodonite (6.93 ct) from Brazil showing good chatoyancy, cut green diopsides (5.93 and 6.50 ct) from Ihosy, Madagascar, a 2.16 ct brownish-orange sapphire coloured due to Be-diffusion, and an amazing decorative prayer rug (106 x 60 cm) with 27,104 gemstones (including 1242 diamonds, 4580 emeralds, 1888 rubies and 9668 yellow sapphires) with all the gems in perfect alignment and arranged in attractive patterns (reportedly it took five years to gather and cut all the gemstones and another five years to assemble them in the final tapestry). R.A.H.

Gem News International.
B.M. Laurs (Ed.) (blaurs@gia.edu). *Gems & Gemology,* **46**(2), 2010, 147–62.

Descriptions are given of large (up to 11.2 cm) crystals of kunzite from the Pala district of California, scallop pearls containing calcite prisms, fine sapphire and ruby from eluvial deposits at Montepuez in northern Vietnam, green gemmy titanite from the Shigar valley area of northern Pakistan, tsavorite and other green garnets from Afghanistan, a 5.43 ct synthetic Ca-Nb-Ga garnet, serpentine doublets sold as pietersite, and an antique pendant with a 7.50 ct lead-glass-filled ruby. R.A.H.

Gemstone enhancement and its detection in the 2000s.
S.F. McClure, R.E. Kane and N. Sturman. *Gems & Gemology,* **46**(3), 2010, 218–40.

Advances in technology during the first decade of this century and the increasing demand for lower-priced gem materials both contributed to the proliferation of such developments as the diffusion treatment of corundum and beryllium, the diffusion of copper into feldspar, and the heat treatment of diamond, ruby and sapphire. The gemmological research laboratories have done their best to keep up with these treatments and the jewellery trade has struggled to cope with their disclosure. These developments are summarized, as are the methods used to identify the various enhancements. R.A.H.

Gemmologie Aktuell (Gemmological news).
C.C. Milisenda. *Gemmologie. Z. Dt. Gemmol. Ges.,* **59**(3/4), 2010, 65–70.

Some precious opals weighing between 1 and 13 ct from the Wollo province in Ethiopia were investigated. Due to high porosity the samples increased in weight significantly when immersed in water.

An interesting colourless scapolite was submitted for identification. When exposed to UV for five minutes, the colourless stone turned blue, but faded within a few seconds after removal from UV.

A faceted, translucent to opaque brown stone weighing 1.06 ct said to be from Myanmar was submitted and was found to be baddeleyite, zirconium oxide, used in the production of CZ.

Other specimens described include a faceted yellow milarite from Namibia, faceted bright yellowish-green titanite (sphene) from Madagascar, colourless faceted kurnakovite from California and a colourless transparent strontianite from California. E.S.

Spessartin: Vom Sammlerstein zum Topseller.
C.C. Milisenda, Th. Lind and U. Henn. *Gemmologie. Z. Dt. Gemmol. Ges.,* **59**(1/2), 2010, 3–18. 18 photographs, 2 tables, 7 diagrams, bibl.

Spessartine garnets, first found in the Spessart mountains in Bavaria, Germany, in 1832, followed by other locations, were comparatively rare until a new source was found in Namibia in 1992. These stones were tangerine-orange and became known as mandarin garnets. This article compares the physical and optical properties of spessartines from Ramona in California, Namibia, Pakistan, Nigeria, Tanzania and other occurrences. E.S.

Alpine pink fluorite.
T.P. Moore. *The Mineralogical Record,* **41**(1), 2010, 9–52.

A thorough survey of ornamental pink fluorite from Alpine sites. Includes a comprehensive bibliography. M.O'D.

Lab notes.
T.M. Moses and S.F. McClure (Eds). *Gems & Gemology,* **45**(4), 2009, 288–95.

Items include a colourless cat's-eye phenakite and a 9.28 ct blue sapphire

Abstracts (continued)

which had been diffusion treated with both Ti and Be. R.A.H.

Lab notes.
T.M. Moses and S.F. McClure (Eds). *Gems & Gemology,* **46**(1), 2010, 48–57.

Notes are given on a jadeite bangle with remarkable transparency due to having been impregnated with a polymer with an RI very close to that of the host, and a watermelon tourmaline in which a feldspar crystal had interrupted crystal growth, creating growth tubes which have a dramatic effect on the pleochroic colours. R.A.H.

Lab notes.
T.M. Moses and S.F. McClure (Eds). *Gems & Gemology,* **46**(2), 2010, 140–6.

Items noted include a 14.20 ct green sapphire treated by beryllium diffusion and a 17.02 ct red oval modified brilliant which was identified as a heated natural spinel. R.A.H.

Andradite from Antetezambato, North Madagascar.
F. Pezzotta [fpezzotta@yahoo.com], *Mineralogical Record*, **41**(3), 2010, 209-29

Near the village of Antetezambato situated in Antsiranana Province in North Madagascar a relatively new deposit of andradite garnet has been yielding not only gem quality varieties of demantoid and topazolite, but also some of the world's finest andradite mineral specimens. Mining activity is challenged by the fact that the productive area is located in a mangrove swamp, which at high tide is flooded by 50–80 cm of sea water every day. Prior to initial reports of andradite in 2006 (erroneously called green tourmaline, green zircon and green sapphire), the only other confirmed occurrence of green andradite was at Mount Bezavona in 1922. In 2008, the identity of the material was confirmed by a gemmological laboratory and by April of 2009 rumours of the find brought thousands of miners, buyers, and brokers to the previously sparsely inhabited area.

The author describes the extreme mining conditions, unstable political situation and ongoing problems with corruption which make the mining of andradite in the region very difficult and dangerous, if not at times impossible. He details the geology of the area and the genesis of the andradite, stating that it "is the first important mineral and gemstone deposit formed by contact metamorphism of the Permian-Mesozoic sediments to be discovered in Madagascar". The absence of titanium in the sedimentary rocks accounts for the demantoid and andradite varieties, rather than the more common titanium-rich melanite variety. Fossil shells and corals have been found replaced by garnet and quartz and forming the matrix for demantoid crystals. An overview of the history, nomenclature, properties and chromophores of andradite varieties is followed by a description the wide range of crystal specimen types seen at this locality. Note is made of a colour-change variety found at Antetezambato which shows greenish yellow in daylight and reddish yellow in incandescent light, as well as an unusual bluish hue observed in some green crystals visible only under daylight conditions. Other significant mineral specimens found at the site include quartz, calcite, stilbite-Ca, pyrite and probable wollastonite (as inclusions). E.A.S.

Play-of-color opal from Wegel Tena, Woolo province, Ethiopia.
B. Rondeau (benjamin.rondeau@univ-nantes.fr), E. Fritsch, F. Mazzero, J.-P. Gauthier, B. Cenki-Tok, E. Bekele and E. Gaillou. *Gems & Gemology,* **46**(2), 2010, 90–105.

A newly discovered opal deposit is reported from the village of Wegel Tena in northern Ethiopia. The material is mostly white, but with some brown opal, fire opal and white opal with high quality play-of-colour opal. The opals are found in a specific Oligocene volcanic sequence of alternating basalt and ignimbrite. Their properties are consistent with those of opal-CT. They become transparent when soaked in water, showing a remarkable hydrophane character. The white opals from this deposit contain an elevated content of Ba of 82–226 ppm. A Raman spectrum is shown; TEM reveals a microstructure of nanospheres ~ 170 nm in diameter. R.A.H.

Montebrasit in Edelsteinqualität: ein seltener Fund aus Brasilien.
J. Schnellrath, R. Scholz, K. Krambrock, C.C. Milisenda and A.M. de Figueiredo Epaminondas. *Gemmologie. Z. Dt. Gemmol. Ges.,* **59**(3/4), 2010, 95–102. 2 photographs, 1 map, 5 graph, bibl.

Amblygonite and montebrasite are rarely found in the trade. Most gem-quality specimens are often collectively known as amblygonite. The samples examined come from a mine 16 km north of Galileia in Minas Gerais, Brazil, amongst them an exceptionally large, faceted, light greenish specimen weighing 185.65 ct. Physical and chemical analysis showed that these samples were hydroxyl-rich montebrasite. E.S.

Alexandrite von Minaçu, Goias, Brasilien: ein primäres Vorkommen.
R. Schultz-Güttler, K.-J. Petersen Jr and U. Henn. *Gemmologie. Z. Dt. Gemmol. Ges.,* **59**(3/4), 2010, 71–82. 16 photographs, 2 maps, 1 table, 1 graph, bibl.

The alexandrites found in Minaçu, Brazil, are mostly small stones, yielding cut specimens of between 0.05–0.15 ct. They have many inclusions and the colour change ranges from weak to definite, mainly from blue-green in daylight to violet to orange-yellow in artificial light. It is a primary occurrence which is rare in Brazil. The mother rock is a mica schist mainly composed of biotite, muscovite and quartz. E.S.

Gem localities of the 2000s.
J.E. Shigley, B.M. Laurs, A.J.A. Janse, S. Elen and D.M. Dirlam. *Gems & Gemology,* **46**(3), 2010, 188–216.

During the past decade there were impressive discoveries of diamonds and coloured gemstones, but a decline in sales due to high development costs, environmental considerations, and a downturn in the global economy. The 'locality of origin' took on increasing importance for some coloured stones such as ruby, sapphire, emerald and copper-bearing tourmaline. The geographic sources of diamonds and coloured stones are reviewed and the production areas that were commerically important during the years 2001–2010 are each discussed. Maps of most of the important gem-producing areas in the world are included in an accompanying (folded) wall chart. R.A.H.

Chrysoprase and prase opal from Haneti, central Tanzania.
J.E. Shigley, B.M. Laurs and N.D. Renfro.

Abstracts (continued)

Gems & Gemology, **45**(4), 2009, 271–9.

Commercial quantities of gem-quality chrysoprase and green prase opal (Ni-bearing chalcedony and common opal, respectively) have been recovered from altered serpentinite deposits near Haneti, Tanzania. The largest mine, on top of Iyobo Mountain, has been actively exploited for two decades. Chrysoprase can be distinguished from prase opal by its higher RI (~ 1.55 vs ~ 1.45) and SG (~ 2.60 vs ~ 2.11). Chrysoprase is the main product of the mine, which shows a good potential for continued production. R.A.H.

Ruby and sapphire production and distribution: a quarter century of change.

R. Shor and R. Weldon. *Gems & Gemology,* **45**(4), 2009, 236–59.

During the past 25 years, the market for corundum gems has been transformed from one of medium to high prices to one encompassing nearly all price ranges. This transformation was brought about by the discovery of several large deposits and the development of treatment processes that enhanced the colour and clarity of very large amounts of previously non-commercial ruby and sapphire. More recently, however, controversial treatments have undermined confidence and prices in some material, while political events and press scrutiny have affected the supply chain for rubies and sapphires from such localities as Myanmar and Madagascar. R.A.H.

An era of sweeping change in diamond and colored stone production and marketing.

R. Shor and R. Weldon. *Gems & Gemology,* **46**(3), 2010, 166–87.

Since the start of the twenty-first century new markets for gems and distribution have emerged around the world as a result of economic forces and political pressures. De Beers abandoned its role as a single-channel seller, creating a competitive diamond market. Political pressures in Madagascar and a ban on gem exports from Myanmar disrupted supply channels for ruby and sapphire. A new class of well-informed customers who value ethically-, socially- and environmentally-friendly products are making their demands known in the gemstone business. R.A.H.

New occurrence of fire opal from Bemia, Madagascar.

M. Simoni (rsimoni@tin.it), F. Caucia, I. Adamo and P. Galinetto. *Gems & Gemology,* **46**(2), 2010, 114–21.

The investigation of 22 gem opals from a new volcanic deposit near Bemia, south eastern Madagascar, by classical gemmological, SEM-EDS, powder XRD, LA-ICP-MS and by both Raman and IR spectroscopy techniques is reported. None showed any play-of-colour, but exhibited a wide variety of hues, including those typical of fire opal, due to Fe-rich inclusions. These microcrystalline samples consist of opal-CT or opal-C. Their RIs and SGs are higher than those of typical fire opals from elsewhere, allowing their ready distinction. R.A.H.

The Clay Canyon variscite mine, Fairfield, Utah.

W.E. Wilson. *The Mineralogical Record,* **41**(4), 2010, 321–49.

A classic site for ornamental and even gem quality variscite is described. M.O'D.

Instruments and Techniques

Developments in gemstone analysis techniques and instrumentation during the 2000s.

C.M. Breeding, A.H. Shen, S. Eaton-Magaña, G.R. Rossman, J.E. Shigley and A. Gilbertson. *Gems & Gemology,* **46**(3), 2010, 241–257.

Advances in gem treatment and synthesis technology, together with the discovery of new gemstone deposits, led to the need for improved techniques in gem identification, and to the development and widespread use of chemical microanalysis techniques such as LA-ICP-MS, luminscence spectroscopy and X-ray imaging, together with the development of nanoscale analysis. Innovations in laser mapping and computer modelling of the appearance of diamond rough and faceted stones changed the way gemstones are cut and the manner in which they are graded by gem laboratories. R.A.H.

Cutting diffraction gratings to improve dispersion ("fire") in diamonds.

A. Gilbertson, B. Gudlewski, M. Johnson, G. Maltezos, A. Scherer and J. Shigley. *Gems & Gemology,* **45**(4), 2009, 260–70.

A new microlithography process developed to create high-resolution diffraction grating patterns on portions of certain facets can improve the dispersion of light and hence the amount of 'fire' in a diamond. These nanocut plasma-etched diamonds are identifiable under magnification by the presence of small, unpolished-looking areas on the facets where the grating pattern has been created. Round brilliant-cut diamonds showing such patterns will be classified by the GIA Laboratory as modified round brilliants: as such, they will be given colour and clarity grades, but not a cut grade. R.A.H.

Confocal micro-Raman spectroscopy: a powerful tool to identify natural and synthetic emeralds.

Le T.-T. Huong (letth@vnu.edu.vn), T. Häger and W. Hofmeister. *Gems & Gemology,* **46**(1), 2010, 36–41.

The examination of more than 300 natural and synthetic emeralds from various sources by confocal spectroscopy demonstrated that this technique can identify the different types of water in the beryl channel sites, making it possible to determine whether an emerald is natural or synthetic. This approach may also be able to provide information about the geographic origin or synthesis of the stone. R.A.H.

X-ray computed microtomography applied to pearls: methodology, advantages and limitations.

S. Karampelas, J. Michel, M. Zheng-Cui, J.-O. Schwarz, F. Enzmann, E. Fritsch, L. Leu and M.S. Krzemnicki. *Gems & Gemology,* **46**(2), 2010, 122–7.

X-ray computed tomography reveals the internal features of pearls in great detail, and can distinguish between some of the natural and cultured pearls that are difficult to separate using X-radiography. The disadvantages include a long measurement time, high cost of instrumentation and only being able to image one pearl at a time. R.A.H.

X-ray computed microtomography: distinguishing natural pearls from beaded and non-beaded cultured pearls.

M.S. Krzemnicki (gemlab@ssef.ch), S.D.

Abstracts (continued)

Friess, P. Chalus, H.A. Hänni and S. Karampelas. *Gems & Gemology,* **46**(2), 2010, 128–34.

The distinction of natural from cultured pearls using X-ray computed microtomography [preceding abstract] has shown this technique to be a powerful tool for pearl identification, including its ability to distinguish between natural pearls, beaded and non-beaded cultured pearls. R.A.H.

Synthetics and Simulants

A new type of composite turquoise.
G. Choudhary (gtl@giepcindia.com). *Gems & Gemology,* **46**(2), 2010, 106–13.

The examination of pink, purple-pink, yellow-green and blue specimens of dyed and/or stabilized turquoise revealed that all these specimens were composites of pieces of turquoise bonded together. The purple-pink and yellow-green samples were bonded with a coloured polymer, and the blue ones had a colourless polymer. The gemmological properties are listed, together with EDXRF and FTIR analyses; the reactions of these materials with the solvents acetone and methylene chloride are also discussed. R.A.H.

Synthetischer Feueropal — "MexiFire®".
U. Henn, K. Wehr and C.C. Milisenda. *Gemmologie. Z. Dt. Gemmol. Ges.,* **59**(1/2), 2010, 47–5. 2 photographs, 1 table 1 graph, bibl.

The synthetic fire opals are produced in India and marketed under the name 'MexiFire®'-.They have a lower RI and density than natural fire opals and can also be identified by chemical analyses and infrared spectroscopy. E.S.

Color alteration in CVD synthetic diamond with heat and UV exposure: implications for color grading and identification.
R.U.A. Khan (riz.khan@DTC.com), P.M. Martineau, B.L. Cann, M.E. Newton, H.K. Dhillon and D.J. Twitchen. *Gems & Gemology,* **46**(1), 2010, 18–26.

In response to heat (>450°C) and UV exposure, some cut and faceted synthetic pale-coloured diamonds grown by chemical vapour deposition exhibit large, reversible changes in colour. Conversely, a darker colour is shown by samples following exposure to UV radiation. Both types of change returned to their initial (stable) colour when they were illuminated for >30 minutes with a standard daylight lamp, but did not do so when kept in the dark. These non-permanent changes might affect the apparent colour grade of a CVD synthetic diamond. R.A.H.

Lab notes.
T.M. Moses and S.F. McClure (Eds). *Gems & Gemology,* **46**(2), 2010, 140–6.

Items noted include a 1.05 ct CVD synthetic diamond graded as G which developed strong pink fluorescence when exposed to strong UV radiation. R.A.H.

Strongly colored pink CVD lab-grown diamonds.
W. Wang (wwang@gia.edu), P. Doering, J. Tower, R. Lu, S. Eaton-Magana, P. Johnson, E. Emerson and T.M. Moses. *Gems & Gemology,* **46**(1), 2010, 4–17.

Samples of 19 faceted pink diamonds (0.3–0.7 ct) grown in the laboratory by Apollo Diamond Inc. using CVD methods were examined and their colour and clarity grades were found to be comparable with those of top-quality natural pink diamonds. A combination of optical centres similar to those seen in previously studied in pink-to-red diamonds that had been exposed to HPHT annealing, irradiation and further annealing at relatively low temperatures, were found. These pink CVD products can be distinguished from natural and treated-colour natural diamonds by a combination of fluorescence colour, growth zoning and absorption featres in the IR and UV-Vis regions. R.A.H.

Abstractors

R.A. Howie – R.A.H. M. O'Donoghue – M.O'D. E.A. Skalwold – E.A.S. E. Stern – E.S.

Book reviews

Studies on Agate. Microscopy, spectroscopy, growth, high temperature and possible origin.
Terry Moxon, 2009. Terra Publications, Doncaster, S. Yorks. pp 102. Paperback. ISBN 978-0-9528512-1-9. £20.00

This is Terry Moxon's second book on agates and is more wide ranging than his first which dealt with agate microstructures and possible origins. This one is intended for lapidary workers and mineral collectors who are keen to learn more about agate occurrence and genesis and at the scientifically-orientated general public. The prime aim is to introduce the reader to some of the scientific techniques that have been used to examine agate over the last twenty years. Has he been successful? To a degree — yes. Without doubt this is the best book covering the major problems associated with agate genesis. Other recent books on agates focus on agate beauty and worldwide occurrences whilst largely avoiding the thorny questions.

However, the content is incongruously couched in language on a variety of levels. Initially it gives the impression of "I'm not quite sure what kind of book I am" but it quite quickly moves into the research scientist mode with a basic science preamble. This may be a little daunting for some readers but their persistence will be rewarding.

This 96 page book is divided into nine chapters:

Chapter 1 Agates: occurrence, regions and hosts. Deals briefly with the varieties of microcrystalline quartz and types of agate. The majority of the chapter comprises brief descriptions of around 30 regions worldwide including the age of the deposits. It is rather superficial and does not compare well with recent 'Coffee Table' books that depict beautiful agate from all over the world.

Chapter 2 Optical microscopes and photomicroscopy: This chapter covers sample preparation and equipment and describes the simple techniques used to create many of the images in the book. Rather surprisingly about half of this chapter is devoted to superficial coverage of dyeing, structural features, pigmentation and interpretation that bear little relationship to the theme of the chapter.

Chapter 3 Electron microscopy. Chapter 3 begins with an historical review of the electron microscope imaging techniques. Twenty images using electron microscopy techniques are presented and their features described. There is sometimes poor correlation between the images and their descriptive text such that the reader may find it difficult to relate the description to the illustrated feature. More use of arrows pointing to the features would have helped overcome this as would have better captions. To aid clarity and ease of understanding the whole aspect of linking text, captions and images could have been better. Nevertheless the features are fascinating albeit that the interpretation is limited.

Chapter 4 X-ray diffraction. Basic descriptions of powder X-ray diffraction are given and the application of the technique to crystallite size, phase identification and their relationship to age is discussed.

Chapter 5 Visible, infrared and Raman spectroscopy. The basic principles of each spectroscopy method are described. Usefully the various forms of silica described in the book are defined in this chapter but there are omissions. However as one reads through the book some of these omitted terms are defined. It would have been helpful to have all the described terms together and to have extended this to cover all the silica phases mentioned including their relationships (for example the relationship between colloidal silica and sol). To have had this at the outset would have been beneficial. Spectroscopy investigations cover: identifying the effect of metal ions on silicic acid and colloidal silica; identifying water and hydroxyl groups in agate; and identifying moganite in agate.

Chapter 6 High temperature and pressure studies. This chapter begins with a brief simple introduction to reaction kinetics and then concentrates on experimental work on water loss at elevated temperature, the relationship between age and water content, the type of water (both free water and as silanol) and the implication for crystallite coarsening and linked moganite reduction. The diagrams complement the text discussion.

Chapter 7 Cathodoluminescence (CL). A short basic overview of cathodoluminescence and its methodology when applied to agate begins the chapter. The nature of chemical bonding is also discussed as a precursor to understanding defects, largely water-related Si-O-'X' bonds, in the crystal structure in agate. Figures associated with this are adequate without reaching high levels of clarity. Age-related changes in type and number of defects using CL are discussed.

Chapter 8 Agate from Cumbria, England, and the Pilbara Craton, Australia. Discussion in this chapter centres on the thermal history of these deposits employing the techniques of X-ray diffraction, infrared spectroscopy, Raman spectroscopy, cathodoluminescence and specific gravity determination. This case study takes the findings in the other chapters and applies them to these deposits to explain anomalies.

Chapter 9 Agate genesis. Explaining agate genesis is the Holy Grail of agate research. The author states that the origin of agate still remains an enigma and poses the five fundamental questions that need yet to be answered in order to solve the problem of agate genesis. He reviews

Book reviews (continued)

current research and thinking on these and presents the pros and cons of several possible explanations.

The analytical equipment generated images are useful and instructive whilst the colour images of agates are at best adequate with poor focus. Fortunately this latter aspect is not a crucial aspect of the book. The overall impression is that of an unsophisticated approach to imaging and the book would benefit from better images and annotations.

Readers will find the bibliography rewarding. The index however is rather sparse.

For anyone who has pondered over the paradoxical situation presented by the apparent simplicity of agate chemistry, the complexity of agate structures, agate abundance worldwide and agate occurrence in a variety of different rocks, this book offers, if not an answer, both a satisfying and at the same time tantalising journey into the science of agate genesis. For agate enthusiasts, *Studies on Agate* is a must-have item. For others this could be the beginning of a lasting quest for knowledge about this fascinating material, or dismissed (even though the science is often at a basic level), as a 'boffins book'.

Brian Jackson

Russian Alexandrites.

Karl Schmetzer, 2010. Schweizerbart Science Publishers, Stuttgart. pp 141, over 200 colour illustrations. Hard Cover. ISBN 978-3-510-65262-4. €34.80 (USA $49.90).

Having been able to facilitate the study of alexandrite specimens in the Natural History Museum collections with renowned gemmologist and author Dr Karl Schmetzer, it was with eager anticipation that I received his new book *Russian Alexandrites*. With contributions from George Bosshart, Marina Epelboym, Dr Lore Kiefert and Anna-Kathrin Malsy, the book seeks to be an all encompassing work on this valuable variety of chrysoberyl; the authors' intentions being made clear in the short introduction whereby they state that although much has been written on alexandrite, there is a paucity of data concerning inclusions, microscopic features and indicators of provenance.

My first impression of the book is one of quality, with a simple but elegant frontispiece of an alexandrite crystal group in both daylight and incandescent light. The book is slightly larger format at 275x215 mm, is superbly produced, and beautifully illustrated with over 200 coloured figures, photographs, maps and diagrams.

The introduction gives a summary of the geological setting of the Uralian deposits and recent mining activity including photographs of Schmetzer and Kiefert's visit to the Malysheva mine in 2007. Chapter 2 follows with a historical overview of the Tokovaya area, and whilst the author notes that this has been the subject matter of numerous publications beforehand, this is an excellent summary. Chapter 3 describes in great detail the discovery, naming and historical use of Russian alexandrite. This chapter can be regarded as the definitive chronology of Russian alexandrite, the author having excelled in bringing together a wealth of information that includes historical literature, family archives, published reports, illustrated portraits and discussions of the more famous specimens which includes emerald as these two gem varieties are so closely associated in the deposits in the Urals. Chapter 4 gives a brief overview of Russian alexandrites in mineralogical Museums and in the trade, the author having comprehensively studied over 400 alexandrite crystals, crystal groups and gemstones from major European and Russian museums and private collections. This leads us into chapters 5 and 6 which are closely linked. Chapter 5 on morphology and twinning is extensively illustrated with photographs of alexandrite crystals. The chapter is so 'photo rich' that it gives the impression of being able to personally browse the holdings of those great collections. I particularly liked how these images are compared to equivalent crystal drawings by the author who has colour-coded the faces to make it easy to distinguish the different forms and development of complex twinning. Chapter 6 looks at mineralogical and gemmological properties with beautifully illustrated sections on typical microscopic features such as twinning and inclusions. Chapter 7 discusses the chatoyant effects of alexandrite and chrysoberyl, and although Russian cat's-eyes are discussed, the chapter also includes sections on Sri Lankan material. Chapter 8 is very short at only three pages, but discusses the comparison of growth patterns of Russian, other natural and synthetic alexandrites. Chapter 9 discusses the colorimetric data of Russian alexandrite and yellowish green to green chrysoberyl using the CIELAB colour space model, with interesting discussion as to the practical application of colorimetry in provenance and nomenclature studies. Chapter 10 looks at trace element and locality determination of Russian alexandrites using LA-ICP-MS. As a relatively recent and increasingly important technique used in gemmology, I was pleased to see a short but concise summary of the principles of the application itself.

Aside from the appendix of seven tables of data, transcription of names, historical timetable, and index, the exhaustive research that the author has undertaken is reflected in an extremely useful and comprehensive reference list.

Overall, *Russian Alexandrites* is an excellent scholarly work and is the choice for anyone looking for a wealth of information on this most enigmatic of gem varieties. Indeed, it is one of the best 'single species' volumes ever published. There is more to this book than the title suggests, especially in the later chapters where comparisons and references to chrysoberyl and alexandrites from other localities including synthetics are made. The book is well laid out and is notable for its beautiful and relevant illustrations. This is a book for historians, enthusiasts, mineralogists, gemmologists and researchers and with its low price is an essential buy for any reference collection.

Alan Hart

Proceedings of the Gemmological Association of Great Britain and Notices

Gem-A Events

Gem-A Conference: Gemmology and the Gem Market: Micro and Macro

Gem-A Conference speakers and presenters: (left to right) Andrew Cody, Richard Drucker, Michael Krzemnicki, James Riley, Maggie Campbell Pedersen, Rui Galopim de Carvalho, Michael Hügi, Crhistopher P. Smith and Professor Andy Rankin.

The 2010 annual Conference, held on Sunday 7 November at the Hilton London Kensington Hotel, looked at gems from both gemmological and marketing perspectives, and in detail as well as giving the wider picture. Speakers included Andrew Cody, Rui Galopim de Carvalho, Christopher P. Smith, Michael Hügi, Michael Krzemnicki, Maggie Campbell Pedersen and Richard Drucker.

During the breaks delegates had the opportunity to browse through the latest books and instruments from Gem-A Instruments and to view displays including those by Maggie Campbell Pedersen on organics, the Institute of Registered Valuers, the Scottish Gemmological Association, Richard Drucker with *The GemGuide* and the GemGuide Appraisal Software, and Gem-A Education with samples of glass-filled rubies.

The day concluded with a dinner held at the Hilton followed by a disco.

A programme of events and workshops was arranged to coincide with the Conference. These started on Saturday 6 November with a one-day seminar held at the Gem-A headquarters by Ted Themelis entitled 'An update on the heat treatment of ruby and sapphire'. On Monday 8 November at Goldsmiths' Hall in the City of London, John Benjamin gave a one-day seminar entitled From Medieval to Modernism: a thousand-year tour of international jewellery design'. This was followed in the evening by the Graduation Ceremony at Goldsmiths' Hall (see below). On Tuesday 9 November Michael Hügi presented a half-day workshop on photomicrography. This was followed in the afternoon by a guided tour of the Crown Jewels at the Tower of London with David Thomas. The final event was Gem Discovery Club with guest speaker Marijan Dundek entitled 'The magic world of diamonds'.

A full report of the Conference and events was published in the Winter 2010 issue of *Gems & Jewellery*.

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We would also like to thank **dg3 Diversified Global Graphics Group** for sponsoring the leaflets and delegate badges for the conference. Visit their website at www.dg3.com

Nature's Treasures 3

A seminar organized jointly by Gem-A, the Mineralogical Society, the Russell Society and Rockwatch, was held on Sunday 12 December 2010 at the Flett Theatre, Natural History Museum, London SW7.

Short talks on a variety of subjects from mining the oceans to meteorites, were presented by William Burgess, Ron Callender, Maggie Campbell Pedersen, Doug Garrod, Fred Mosselmans, Caroline Smith and Peter Treloar.

During the lunch break, delegates had the opportunity to view displays by Gem-A, Leica, Marcus McCallum, The Mineralogical Society, RockWatch, The Russell Society, Richard Tayler and Andy Tindle. Harold Killingback displayed the 'White Flag' agate featured in the Autumn issue of *Gems & Jewellery* and Ron Callender gave a demonstration of gold panning.

Graduation Ceremony

On Monday 8 November the Graduation Ceremony and Presentation of Awards was held at Goldsmiths' Hall in the City of London. Professor Andy Rankin, President of the Gemmological Association, presided and Rui Galopim de Carvalho, founder of LABGEM in Lisbon, Portugal, presented the awards and gave the address.

Following the presentations to the graduates, the first members to be awarded Fellowship status in recognition of their high level of expertise and who had made a significant contribution to the field of gemmology for no less than ten years were presented with their Fellowship dilpomas. They were Dr Douglas Nichol of Wrexham, North Wales, Christopher P. Smith of New York and Mary Burland of Gem-A, London.

A certificate was awarded to Evelyne Stern, who retired from the Gem-A Council in 2010, recognizing her contribution to diamond education in the Association.

In his address, Rui Galopim de Carvalho stressed the importance of the Gem-A graduates to continue their education by learning as much as possible about gemmology. Addressing the graduates, he said: "Yours is an exciting and rapidly developing field which provides the background for a fascinating career and participation in a worldwide community of like-minded people."

The ceremony was followed by a reception for graduates and guests.

A report of the Graduation Ceremony was published in the October issue of *Gems & Jewellery*.

Photo courtesy of Photoshot

Gem-A Awards

Gem-A Examinations were held worldwide in January and June 2010. In the Examinations in Gemmology 209 students qualified in the Diploma Examination, including seven with Distinction and 18 with Merit. In the Foundation in Gemmology Examination 349 qualified. In the Gem Diamond Examination 98 qualified, including 21 with Distinction and 20 with Merit.

The **Christie's Prize for Gemmology** for the best candidate of the year in the Diploma Examination was awarded to **Louise Dennis** of Halesowen, West Midlands.

The **Anderson Bank Prize** for the best set of theory papers in the Diploma in Gemmology examination was awarded to **Chen Suoyi** of Beijing, P.R. China.

The **Read Practical Prize** for excellence in the Diploma Practical Examination, named in memory of Peter Read, was sponsored for 2010 by DeeDee Cunningham of Toronto, Canada. The Read Practical Prize was awarded to **Leung Ka Yee Ainsley** of Hong Kong.

In the **Foundation Certificate in Gemmology** examination, the **Anderson Medal** for the candidate who submitted the best set of answers which, in the opinion of the Examiners, were of sufficiently high standard, and the **Hirsh Foundation Award** for the best candidate of the year, were awarded to **Robin Hansen** of Warminster, Wiltshire.

In the **Gem Diamond Diploma** examination, the **Bruton Medal**, awarded for the best set of theory answer papers of the year, and the **Deeks Diamond Prize** for the best candidate of the year, were awarded to **Ben Wen** of Wuhan, P.R. China.

The **Dominic Mok Diamond Practical Prize** for excellence in the Diamond Practical Examination, is sponsored by Dominic Mok from AGIL, Hong Kong. The Dominic Mok Diamond Practical Prize was awarded to **Sheung Mei Tang** of Hong Kong

The Tully Medal was not awarded.

The names of the successful candidates are listed below.

Examinations in Gemmology

Gemmology Diploma

Qualified with Distinction

Chen Suoyi, Beijing, P.R. China
Dennis, Louise, Hasbury, Halesowen, West Midlands
Orsini, Paolo, Alessandria, Italy
Perosino, Lorenzo, Novi Ligure, Italy
Wang Shang Bai, Beijing, P.R. China
Yan Xiao-Xuan, Beijing, P.R. China
Zhang Rui, Beijing, P.R. China

Qualified with Merit

Benard, Guillaume, Montreal, Quebec, Canada
Cai Jia, Beijing, P.R. China
Cheng Lian, Wuhan, Hubei, P.R. China
Chunxia Shen, Chengdu, Sichuan, P.R. China
Fox, Karen Elizabeth, Toronto, Ontario, Canada
Grocholska, Katherine Rose, Highbury, London
Han Yi, Baotou, Inner Mongolia, P.R. China
Hart, Alan D., Beckenham, Kent
Jia Xiaodan, Beijing, P.R. China
Lau King Suen, Shau Kei Wan, Hong Kong
Lemaire, Alisson, Drummondville, Quebec, Canada
Li Yan, Beijing, P.R. China
Lian Guo, Shanghai, P.R. China
Liu Na, Beijing, P.R. China
Masselot, Joelle, Geneva, Switzerland
Nicolai, Namaste, Cardiff, Glamorgan
Tsai Min-Chieh, Taipei, Taiwan, R.O. China
Zhu Jiachen, Beijing, P.R. China

Qualified

Aderhold, Bryan C., Ridgewood, New Jersey, U.S.A.
Andersson, Lina, Sundbyberg, Sweden
Arpino, Delphine, Viroflay, France
Aung Ko Ko, Yangon, Myanmar
Austin, Megan, Rocklea, Queensland, Australia
Bailey, Sarah, London
Beale, Sioned Ann, Lapworth, Solihull, Warwickshire
Berezovsky, Florence Paulette Marie, Zurich, Switzerland
Bonnin, Romain Claude Michel, Montreal, Quebec, Canada
Borenstein, Guy, Pardes-hana Karkur, Israel

Bright, David, Riverside, Missouri, U.S.A.
Brown, Sandra Jane, Birmingham, West Midlands
Byrne, Ruth, South Woodford, Essex
Cederferm, Magdalena, Märsta, Sigtuna, Sweden
Cederholm, Jenny, Farsta, Sweden
Chatagnier, Pierre Yves, Saint Albin, Vareilles, France
Chatzipanagiotou, Ioannis Tzannis, Athens, Greece
Chen Shifeng, Beijing, P.R. China
Cheung Yuk King, New Territories, Hong Kong
Choi Chi Ho Jim, Tuen Mun, Hong Kong
Chun Lv, Xiamen, Fujian, P.R. China
Chunnong Du, Nanning, Guangxi, P.R. China
Cooper, Amy S., Las Vegas, Nevada, U.S.A.
Cox, Rebecca Jane, York
Dan, Wang, Beijing, P.R. China
Davis, Natasha, Northwood, Middlesex
De Gaetano, Antonella, Genoa, Italy
Delerholm, Peter, Enskede, Sweden
Deng Lei, Guangzhou, Guangdong, P.R. China
Deng Xiansong, Guilin, Guangxi, P.R. China
Dimitrakopoulos, Charalabos, Athens, Greece
Du Liuyin, Beijing, P.R. China
Duraffourg, Valerie, Belle Fontaine, France
Evans, Charles I., Camden, London
Evans, Daniel Raymond, Brisbane, Queensland, Australia
Evans, Rachel, London
Falah, Jamal, Concord West, New South Wales, Australia
Fang Yixiang, Yichang, Hubei, P.R. China
Gerez, Ingrid Kintgen, Wasquehal, France
Gokani, Anooj, Leicester
Goubert, David, Villeneuve Les Avignon, France
Gowans-Poli, Julie, London
Graham, Lisa J., Tunbridge Wells, Kent
Guenin, Nathalie, Sainte Foy, Quebec, Canada
Haifei Chen, Qixing District, Guilin, P.R. China
Hammond, Ross, Hackney, London
Harnois, Dominique Marie, Paris, France
Hell, Martine Svitlana, Hedalen, Norway
Ho Yue Yau, Tsuen Wan, Hong Kong
Huang Binli, Wuhan, Hubei, P.R. China
Huang Ting, Tianyang, Guangxi, P.R. China
Huang Yisheng, Shanghai, P.R. China
Hui Hang Chung, Marilyn, Hong Kong
Huijbrechts, Thomas N., Schoorl, The Netherlands
Iozzino, Vittorio, Genoa, Italy
Jia Liu, Beijing, P.R. China
Jia Lu, Wuhan, Hubei, P.R. China
Joannou, Christina Maria, Ilford, Essex
Kang Yanan, Wuhan, Hubei, P.R. China
Kapoor, Kushagra, New Delhi, India
Krontira, Sofia, Athens, Greece
Kuklinski, Frank, Niebull, Germany
Lai Yuen Wan, Eva, Hong Kong
Lai Siu Kwong, New Territories, Hong Kong
Lai Xiaojing, Guilin, Guangxi, P.R. China
Lawson, Charles Peter Grahame, Indooroopill, Brisbane, Australia
Lee Ka Chun, New Territories, Hong Kong
Lee Wai Yin, Kitty, New Territories, Hong Kong
Leon, Virginie, Marseille, France
Leung Ka Yee Ainsley, New Territories, Hong Kong
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Li Lingyun, Yining, Xinjiang, P.R. China
Li Pufu, Nanning, Guangxi, P.R. China
Liao Chengwen, Luoding, Guangdong. P.R. China
Lili Wan, Wuhan, Hubei, P.R. China
Liu Hongjie, Beijing, P.R. China
Liu Sui Chung, New Territories, Hong Kong
Liyan He, Nanxiong, Guangdong, P.R. China
Lo Wai Yee Bibian, New Territories, Hong Kong
Loeb, Nicolas, Paris, France
Logan, Peter M., Coventry, West Midlands
Lung Mei Ting, May, Shatin, Hong Kong
Luo, Helen Rong, North York, Ontario, Canada
Lust, Nathalie, Les Pennes Mirabeau, France
Lynch, Anne Lynette, Nundah, Queensland, Australia
Ma Hui, Beijing, P.R. China
Ma Yan Ting, Tsim Sha Tsui, Hong Kong
Maclean, Victoria E.F., London
McKeown, Julia, Oldbury, West Midlands
McNiven, Adrian, London
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Midwinter-Porter, Holly, London
Mo Qian, Guilin, Guangxi, P. R. China
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Ngao Mei Wan, New Territories, Hong Kong
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Palo, Markus Karl, Malmberget, Sweden
Petit, Gregory, Le Plessis-Robinson, France

Petropoulou, Alexia, Athens, Greece
Picard, Chloe, Vessy, Switzerland
Po Pui Chun, Tuen Mun, Hong Kong
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Pradat, Thierry, Francheville, France
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Ting Zhang, Fuan, Fujian, P.R. China
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Tsai, Emma, Barcelona, Spain
Tsai Su-Fen, Shanghai, P.R. China
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Vodyanova Hitzi, Elena, Athens, Greece
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Wang Jingyuan, Shenzhen, Guandong, P.R.China
Wang Lei, Shanghai, P.R. China
Wang Ping, Qiangjiang, Hubei, P.R. China
Wang Ting, Beijing, P.R. China
Wang Xiawen, Guilin, Guangxi, P.R. China
Wang Xu, Shanghai, P.R. China
Wangwei He, Guilin, Guangxi, P.R. China
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Westley, Penny, Hagley, Worcestershire
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Wong Yee Man, Quarry Bay, Hong Kong
Wu Yu, Urumqi, Xinjiang, P.R. China
Xi Zhang, Guilin, Guangxi, P.R. China
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Ye Hui, Ningbo, Zhejiang, P.R. China
Yi Yang, Guilin, Guangxi, P.R. China
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Yue Xuan, Jia, Beijing, P.R. China
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Zhang Yi, Beijing, P.R. China
Zhangrui Ouyang, Liuzhou, Guangxi, P.R. China
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Foundation Certificate in Gemmology

Qualified

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Arda, Basak, Geneva, Switzerland
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Tong Ching Man Yucca, Kowloon, Hong Kong
Tong Siu Han, New Territories, Hong Kong
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Tsoi Wai Yee, Joyce, Kowloon, Hong Kong
Tu Hui-Min, Taipei, Taiwan, R.O. China
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Valasmo, Hannu, Vantaa, Finland
Van Kolck, Nubar Francois William, Bray Park, Queensland, Australia
van Rossum, Wilhelmina F.J., The Hague, The Netherlands
Vazzana, Franck, Cosnes Et Romain, France
Verdoorn-De Vrede, Veronica Chantal, Dordrecht, The Netherlands
Vining, Robert Arthur Charles, London
Von Allmen, Andrea, Munsingen, Switzerland
Vorilhon, Alix, Antananarivo, Madagascar
Voulgaridis, Konstantinos, London
Walker, Katharine, London
Waltert Bigler, Rebecca, St Legier, Switzerland
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Wang Jinlan, Guilin, Guangxi, P.R. China
Wang Kun, Qi County, Shanxi, P.R. China
Wang Man, Taipei, Taiwan, R.O. China
Wang Ming Ying, Beijing, P.R. China
Wang Zi, Beijing, P.R. China
Wangwei He, Guilin, Guangxi, P.R. China
Watson, Abigail, Eynsham, Oxfordshire
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Weyers, Stefanus, Brandhof, Bloemfontein, South Africa
White, Lucy, Virginia Water, Surrey
Whiting, Marielle, Salisbury, Wiltshire
Wijesinghe, Jagath, Ipswich, Suffolk
Williams, Debbie Jane Louise, Quinton, West Midlands
Willmott, Karra Jane, Croydon, Surrey
Wilson, Claire E., Bristol
Win Htet Naung, Yangon, Myanmar
Win Yu Hlaing, Yangon, Myanmar
Windeyer, Patricia Annette, Brisbane, Queensland, Australia
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Wong Yick Chung, New Territories, Hong Kong
Woodcock, Olga Faye, Basingstoke, Hampshire
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Wu Yi-Hong, Taipei, Taiwan, R.O. China

Xu Yanran, Beijing, P.R. China
Xu Ying, Shanghai, P.R. China
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Yang Shuo, Auckland, New Zealand
Yang Xi, Beijing, P.R. China
Yat, Richard, New Territories, Hong Kong
Ye Hui, Ningbo, Zhejiang, P.R. China
Ye Xiaohan, Guangzhou, Guangdong, P.R. China
Ye Xiecai, Wenzhou, Zhejiang, P.R. China
Yeung, Kwok Li, Kowloon, Hong Kong
Yi Shuihan, Birmingham, West Midlands
Yi Yang, Guilin, Guangxi, P.R. China
You Shu-Lin, Taipei, Taiwan, R.O. China
Yu Jinping, Beijing, P.R. China
Zdeb, Robert, London
Zhang Di, Beijing, P.R. China
Zhang Hui, Beijing, P.R. China
Zhang Linlin, Qinyang, Henan, P.R. China
Zhang Ting, Fuan, Fujian, P.R. China
Zhang Xi, Guilin, Guangxi, P.R. China
Zhang Xiaochen, Shanghai, P.R. China
Zhang Xiaofan, Dalian, Liaoning Province, P.R. China
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Gem Diamond Diploma Examination

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Tyrrell, Siobhan Ann, Walthamstow, London
Watson, John Richard, Berkhamsted, Hertfordshire
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Qualified with Merit

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Qualified

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Asplund, Jan Olof, Kiruna, Norrbotten, Sweden
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Chan Ka Yee, Carrie, Stanley, Hong Kong
Chang Hsiao Huei, Westmount, Quebec, Canada
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Cote, Angela Marie, London
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Lam Pui Kwan, Kowloon, Hong Kong
Lam Ting Yan, New Territories, Hong Kong
Lau Wai Keung, Leslie, New Territories, Hong Kong
Leung Suet Kuen, Lam Tin, Hong Kong
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Li Yuen, Hong Kong
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Watson, James Alexander, Northwood, Middlesex
Wong Chiu Yung, Belinda, Kowloon, Hong Kong
Wong Chun, Jordan, Hong Kong
Xu Lingna, Zhujiang Newtown, Guangzhou, P.R. China
Yee Man Yuen, Ma On Shan, Hong Kong
Zaleszczyk, Alicja, London
Zeng Yuhua, Paty, Zhujiang Newtown, Guangzhou, P.R. China

Membership

During 2010, the Council approved the election to Membership of the following:

Fellowship and Diamond Membership (FGA DGA)

Ho Yue Yau, Tsuen Wan, Hong Kong. 2010/2007
Lee Wai Yin, Kitty, Hong Kong. 2010/2008
McNiven, Adrian, West Kensington, London. 2010/2010
Partridge, Jennifer Anne, Plymouth, Devon. 2008/2010
Tidd, Lauren Elizabeth, Birmingham, West Midlands. 2009/2008

Fellowship

Aboosalih, Najeema Shahin, Colombo, Sri Lanka. 2009,
Aderhold, Bryan C., Ridgewood, New Jersey, U.S.A. 2010
Andrianarimanana, Maminirina, Antananarivo, Madagascar. 2005
Arentsen, Ernst, Noordwolde, The Netherlands. 1999
Berezovsky, Florence Paulette Marie, Zurich, Switzerland. 2010
Blagg, Natalie, London. 2009
Brown, Sandra Jane, Birmingham, West Midlands. 2010
Cederholm, Jenny, Farsta, Sweden. 2010
Cederferm, Magdalena, Märsta, Sigtuna, Sweden. 2010
Chatagnier, Pierre Yves, Vareilles, France. 2010
Chatzipanagiotou, Ioannis Tzannis, Athens, Greece. 2010
Chen Shifeng, Beijing, P.R. China. 2010
Close, Helen Selby, North Yorkshire.1996
Davis, Natasha, Northwood, Middlesex. 2010
De Gaetano, Antonella, Genoa, Italy. 2010
Dimitrakopoulos, Charalabos, Athens, Greece. 2010
Duraffourg, Valerie, Belle Fontaine, France. 2010
Falah, Jamal, Concord West, New South Wales, Australia. 2010
Gokani, Anooj, Leicester. 2010
Gowans-Poli, Julie, London. 2010
Guenin, Nathalie, Sainte Foy, Quebec, Canada. 2010
Harnois, Dominique Marie, Paris, France. 2010
Hart, Alan D., Beckenham, Kent. 2010
Joannou, Christina Maria, Ilford, Essex. 2010
Lau King Suen, Shau Kei Wan, Hong Kong. 2010
Lee Ka Chun, New Territories, Hong Kong. 2010
Liu Sui Chung, New Territories, Hong Kong. 2010
Lo Wai Yee Bibian, New Territories, Hong Kong. 2010
Loke Hui Ying, Singapore. 2009
Lovering, Paula, Central Otago, New Zealand. 1985,
Luo, Helen Rong, North York, Ontario, Canada. 2010
Lynch, Anne Lynette, Nundah, Queensland, Australia. 2010

McKeown, Julia, Oldbury, West Midlands. 2010
Man, Camus, Sai Wing Yuen Long, Hong Kong. 2009
Manuelli, Piero Alberto, Genoa, Italy. 2010
Masselot, Joelle, Geneva, Switzerland. 2010
Matthews, Emma, Sunninghill, Berkshire. 2010
Mohammad, Aamir, Oldham, Lancashire. 2010
Mulrooney, Rosalyn, London. 2010
Ng Fei Yeung, Kowloon, Hong Kong. 2010
Ngao Mei Wan, New Territories, Hong Kong. 2010
Nicolai, Namaste, Cardiff, Glamorgan. 2010
O'Cock, Sabrina Alice Palmer, London. 2010
Palo, Markus Karl, Malmberget Sweden. 2010
Po Pui Chun, Tuen Mun, Hong Kong. 2010
Than Tin Kyaw, Yangon, Myanmar. 1997
Thomas, Ian William, Chermside West, Queensland, Australia. 1978
Tissa, V.G. Samith Madhawa, Colombo, Sri Lanka. 2009
Walters, George, London. 1964
Wang Jingyuan, Shenzhen, Guandong, P.R. China. 2010
Westley, Penny, Hagley, Worcestershire. 2010
Woolgar, Michael, Gillits, South Africa. 1971
Xu Zhao, Richmond, British Columbia, Canada. 2009
Zaleszczyk, Alicja, London. 2008

Diamond Membership (DGA)

Chan Ka Yee, Carrie, Stanley, Hong Kong. 2010
Haymes, Richard, Caterham, Surrey. 2009
Kwok Wing Hong, Kowloon, Hong Kong. 2010
Leung Suet Kuen, Lam Tin, Hong Kong. 2010
Poon Pak Kei, New Territories, Hong Kong. 2010
Tachiveyi, Brian, Birmingham, West Midlands. 2009
Wan Sai Man, New Territories, Hong Kong. 2010
Wong Chun, Jordan, Hong Kong. 2010

Associate Membership

Acharya, Rakesh, Bickley, Kent
Adcock, Kathryn, Wimborne, Dorset
Akester, Penelope, London
Algie, Joanne, Auckland, New Zealand
Alsvold-Torndahl, Rebecca, Skanor, Sweden
Antonucci, Andrea, Stockholm, Sweden
Arredondo, David, Geneva, Switzerland
Atkova, Atkova, London
Brianceau, Boris, Saint-Julien, France
Chambers, Ann, Cranbrook, Kent
Clutterbuck, Guy, London
Coldham, Terrence Stewart, Sydney, New South Wales, Australia
Conrey, Keith, Evergreen, Colorado, U.S.A.
Dudun, Svetlana, Dagenham, Essex
Duncan, Colleen, Aberdeen
Elliott, Paul, Woodville, South Australia, Australia
Elliott, Yvonne, London
Field, Stephen, Beckenham, Kent
Finn, Emma, Singapore
Gadsdon, Corin, Truro, Cornwall
Gibson, Antonia, Stockholm, Sweden
Godfroy, Ariane, London.
Goldhill, Richard, Bushey Heath, Hertfordshire
Hammerstein, Quirine, Geneva, Switzerland
Healy, Marilyn, Grange, Queensland, Australia
Hutchinson, Fiona, Albourne, West Sussex
Ikeuchi, Mototeru, Edogawa-ku, Tokyo, Japan
Jian-Zibaee, Shadi, London
Kalvig, Per, Copenhagen, Denmark
Keiko, Kamijima, Nishi-Tokyo City, Tokyo, Japan
Kendirci, Rebecca, Stone, Staffordshire
Kikkawa, Tomomi, Kofu City, Yamanashi Pref., Japan
Knutsen, Annmari Ellilia, Oslo, Norway
Kon, Keiko, Taito-ku, Tokyo, Japan
Konishi Mika, Kawasaki City, Kanagawa Pref., Japan
Kotsatos, Kristi, Houston, Texas, U.S.A.
Kruger, Louise, London
Lally, Joanne Claire, Southampton, Hampshire
Leblanc, Delphine, Hoboken New Jersey, U.S.A.
Lee, Jeffrey, Totnes, Devon
Lemeshkro, Natalie, London
Li, Richard, Taoyuan, Taiwan, R.O. China
McCallum, Neil Keith, Martinborough, New Zealand
McIntyre, Andrew, New South Wales, Australia
Maiko, Kawasaki, Yamanashi Pref., Japan
Mariko, Murakami, Osaka City, Osaka, Japan
Millen, Laura, North Chailey, East Sussex
Mousavi Pak, Niloofar, Tehran, Iran
Newlands, Sarajane, Bickley, Kent
O'Sullivan, Lauren, Glenside, Pennsylvania, U.S.A.
Palmieri, Donald A., New York, U.S.A.
Parkinson, Janine, Cambridge
Pimlott, Sandra, Adelaide, South Australia, Australia
Pradat, Thierry, Francheville, France
Quaintance, Katherine, Birmingham, West Midlands
Rambaran, David, Palm Springs, California, U.S.A.
Ratnayake, Dayanthi, Colombo, Sri Lanka
Roditi, David, London
Rust, Brigitte, Bonn, Germany
Seaman, Laura, Rugby, Warwickshire
Seto, Kuriko Setagaya-ku, Tokyo, Japan
Shavdia, Praful, Northwood, Middlesex,
Smith, Billy, Colchester Essex
Smith, Christopher P., New York, U.S.A.
Smith, Stephen Gibson, Newcastle upon Tyne, Tyne and Wear
Sørensen, René, Vibourg, Denmark
Staruch, Barbara, New Malden, Surrey
Sundheim, Jennifer, Southampton, Hampshire
Tew, Timothy David, Atlanta, Georgia, U.S.A.
Torretta, Janice, Glen Spey, New York, U.S.A.

Van Der Wolf, Nicole, Dublin, Republic of Ireland
Van Molendorff, Steffan, Woking, Surrey
Verwijk, Moira, Toronto, Ontario, Canada
Webb, Linda, Staines, Hertfordshire
White, Margot, Nailsworth, Gloucestershire
Winski, Jacqueline, Dunfermline, Fife
Woodrow, Gillian, Wokingham, Berkshire
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Yoshio, Kinoshita, Osaka City, Osaka, Japan
Yukiko, Horie, Chofu City, Tokyo, Japan

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L. & G. Webb Gemstones, Staines, Surrey

Transfers

Associate Membership to Fellowship (FGA)

Borenstein, Guy, Pardes-hana Karkur, Israel. 2010
Bright, David, Riverside, Missouri, U.S.A. 2010
Burland, Mary Ann, London
Evans, Charles I., London. 2010
Evans, Daniel Raymond, Brisbane, Queensland, Australia. 2010
Fox, Karen Elizabeth, Toronto, Ontario, Canada. 2010
Graham, Lisa J., Tunbridge Wells, Kent. 2010
Hell, Martine Svitlana, Hedalen, Norway. 2010
Kapoor, Kushagra, New Delhi, India. 2010
Michaelides, Emma, Enfield, Middlesex. 2010
Nichol, Douglas, Wrexham, North Wales
Paige Anderson, Denise, London. 2010
Pradat, Thierry, Francheville, France. 2010
Smith, Christopher P., New York
Trolle, Natascha, Copenhagen, Denmark. 2010
Wetherall, Alan, Hitchin, Hertfordshire. 2010
Wong, Phyllis, London. 2010

Associate Membership to Diamond Membership (DGA)

Delerholm, Peter, Enskede, Sweden. 2010
Huang Shih-Jung, Taipei, Taiwan. R.O. China. 2010
Mitchell, Shirley D., Windsor, Berkshire. 2010
Norris, Eddi, London. 2010
Segurado, Taynara Leao, Glasgow, Lanarkshire. 2010

Fellowship to Fellowship and Diamond Membership (FGA DGA)

Amrit, Paveet, Northolt, Middlesex. 2010
Blagg, Natalie, London. 2010
Chang Hsiao Huei, Westmount, Quebec, Canada. 2010
Chatzipanagiotou, Ioannis Tzannis, Athens, Greece. 2010
Chrismas, Jacqueline, Godalming, Surrey. 2010
Dimitrakopoulos, Charalabos, Athens, Greece. 2010
Evans, Charles I., London. 2010
Graham, Lisa J., Tunbridge Wells, Kent. 2010
Hell, Martine Svitlana, Hedalen, Norway. 2010
Horn, Chandra Leah, Montreal, Quebec, Canada. 2010
Li Dongsheng, David, Guilin, Guangxi, P.R. China. 2010
Lilley, Samantha, Hanwell, London. 2010
Mohammad, Aamir, Oldham, Lancashire. 2010
Naito, Ayako, Taito-ku, Tokyo, Japan. 2010
Partner, Robert Leslie, Cropston, Leicestershire. 2010
Poore, Sarah, Worthing, West Sussex. 2010
Preston, Paula, Blackheath, London. 2010
Sanders, Jacqueline, Towcester, Northamptonshire. 2010
Share, Rebecca Louise, Kingswinford, West Midlands. 2010
Tyrrell, Siobhan Ann, Walthamstow, London. 2010
Watson, John Richard, Berkhamsted, Hertfordshire. 2010
Woo Ka Yin, Agnes, Kowloon Bay, Hong Kong. 2010
Young, Stephanie Lynne, Chalfont St. Peter, Buckinghamshire. 2010
Zaleszczyk, Alicja, London. 2010

Diamond Membership to Fellowship and Diamond Membership (FGA DGA)

Huijbrechts, Thomas N., Schoorl, The Netherlands. 2010/2007
Lai Siu Kwong, New Territories, Hong Kong. 2010/2005

Gifts and Donations to the Association

The Association is most grateful to the following for their gifts and donations for research and teaching purposes:

Asia Gems, London, for a selection of cut gemstones.

Maggie Campbell Pedersen FGA, London, for *Amber views opinions*, a copy of the *Bilingual Newsletter of the International Amber Association* and pieces of natural and dyed bamboo coral.

Marijan Dundek, Noble Gems International, London, for his book *Diamonds*.

Gemmological Instruments Ltd, London, for copies of *Exotic Gems* by R. Newman, *Ruby, Sapphire and Emerald Buying Guide* by R. Newman, *Diamond Cuts in Historic Jewellery* by H. Tillander and *Photoatlas of Inclusions in Gemstones* Volume 3 by E. Gubelin and J.I. Koivula.

Steven L. Jordan FGA DGA, Biggleswade, Bedfordshire, for a selection of synthetic gemstones.

Cynthia Mendis FGA DGA, Ottawa, Canada for a selection of diamond simulants and a sample of synthetic diamond grit.

Damian J. Miles, Okehampton, Devon, for 20 sillimanite cat's-eyes.

Pravins, London, for a large selection of gem material.

Jean-Claude Rufli FGA and Lisbet Rufli FGA, Swedish Gemmological Association, Stockholm, Sweden, for cut samples of synthetic rutile and YAG.

Helen Serras-Herman MFA FGA, Rio Rico, Arizona, U.S.A., for sapphire crystals from Philipsburg, Montana, pieces of tumbled polished turquoise, a string of tumbled 'sugarcane' emerald from Brazil, two copies of *Cameos Old and New* and a signed copy of *Phenomenal Gems* by Fred and Charlotte Ward

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Thomson Gems, London, for selections of opals and cultured pearls.

Jason Williams, G.F. Williams, London, for a selection of cut stones including rubies and sapphires.

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Moe Moe Shwe FGA, Singapore
Paul Louis Siegel FGA, Rocky Point, New York, U.S.A.
Nancy Warshow FGA DGA, Nairobi, Kenya

Special thanks go to **Professor Johnny Lu,** Founder of the Jewelry institute of America, New York, U.S.A., for a substantial contribution towards the cost of Chinese translation of the Gem-A Gemmology course notes.

Annual General Meeting

The Annual General Meeting was held during International Jewellery London in The Whitehall Room, Earls Court 2, London W14 8UX, on Sunday 5 September 2010. The meeting was chaired by James Riley the Chairman of the Council. The Annual Report and Accounts were approved. James Riley was re-elected and Richard Slater and Landy Palmer elected to serve on the Council. Jason Williams retired from the Council in rotation and did not seek re-election; Evelyne Stern resigned. Peter Dwyer-Hickey was re-elected to serve on the Membership Liaison Committee. Hazlems Fenton were re-appointed as auditors for the year.

Subscriptions 2011

The membership subscriptions for 2011 are £90.00 for UK members and £95 for those in Europe and overseas. re-appointed as auditors for the year.

Obituary

Dr Kurt Nassau (1927–2010)

It is with deep sadness that we record the death of Dr Kurt Nassau who died on 18 December 2010. Born in Austria in 1927, Dr Nassau was educated in England gaining BSc Hons in Chemistry and Physics at the University of Bristol. He served in the US army as a medical researcher at Walter Reed hospital before earning a PhD in Physical Chemistry from the University of Pittsburgh.

In 1959 Dr Nassau joined AT&T Bell Laboratories at Murray Hill, New Jersey, where he earned a worldwide reputation for his research in crystal growth and structure. He retired as Distinguished Research Scientist in 1989.

Dr Nassau was awarded an Honorary Fellowship of the Gemmological Association of Great Britain in 1992 in recognition of his extensive contributions to understanding in the field of gemmology.

Dr Nassau was predeceased by his wife, Julia.

Remembrances

Many members posted tributes and shared their memories of Dr Nassau on Gem-A's MailTalk. Following is a selection of those received.

Dr Nassau was a good friend who always exhibited to a marked degree the true spirit of hospitality and generosity. I was fortunate enough to experience this first hand when I met him in 1976.

Kurt was my host for several days both at his home and in his workplace at the Bell Research Laboratories, Murray Hills, New Jersey. It was an unbelievable privilege to have him introduce me to the Bell research teams and show me through the extensive facilities. He explained and demonstrated many aspects of their ongoing solid state research. He also allowed me to examine numerous synthesized crystals, many of them unique at that time, together with an extensive collection of stones that had been faceted from these materials.

Farewell Kurt, you will be sadly missed.

Arthur Thomas FGA, Gauteng, South Africa

Kurt Nassau was such a knowledgeable man and so willing to share that knowledge. He was a good friend of my dad [Antonio Bonanno], and one of the few people with whom I could share stories — he shared some wonderful anecdotes with me after dad's death ... Kurt Nassau's death is another tragic loss.

With great sadness.

Antoinette Matlins, Woodstock, VT, USA

Though I didn't know Dr Nassau personally, I still feel a great loss. His work touched so many people I am sure; I for one appreciated his patient correspondence a few years ago with regard to the Usambara effect and colour-change — I wished I had kept up that correspondence, but got too busy and now that connection is lost. I am sitting here at work now, staring at his books on my desk and contemplating some of the dedications within — always to his wife Julia: "...Love is not love, which alters when it alteration finds" (William Shakespeare)and another: "For all knowledge and wonder (which is the seed of knowledge) is an impression of pleasure in itself" (Francis Bacon). In our own work, Dr Bassett and I very frequently refer to his text *The Physics and Chemistry of Color* and I often steer interested people to that wonderful book or the short version published in the *American Mineralogist,* 1978, **63**, 219-29 (www.minsocam.org/msa/collectors_corner/arc/color.htm). The answers to things we thought we might ask him sometime are probably somewhere in there or his many papers — what a great legacy.

Elise Skalwold FGA, Ithaca, New York, USA

George Harrison Jones (1924–2010)

George was born in Liverpool, educated at Liverpool Collegiate School and went on to Liverpool University to gain a first degree in chemistry. He then worked for a chemical company whilst studying as an external student for his doctorate in organic chemistry, which he was awarded in 1949. He then joined the staff of Mars Ltd, the confectioners, as a chemist. Early in his career at Mars, the then Government offered scholarships to promising young scientists/engineers to study in America (and encouraged by Mars to take up this offer) George spent nearly two years at Cornell University studying the 'technical aspects of manufacturing operations'. He returned to Mars and spent the rest of his career with the firm, retiring at managerial level in 1982.

George's interest in gemmology blossomed in the 1960s, and he gained his FGA (with distinction) in 1970. However he was a practical man and he became known to the British gemmological fraternity as a consummate lapidary. He excelled in cutting gemstones, usually finished with his distinctive faceted girdles. He also fashioned cabochons, including a magnificent suite of jade-like scapolites from remote localities in the Shetlands discovered by British Geological Survey geologists. His lapidary skills extended to the fashioning of table coasters from fossilized palm wood to producing spheres of rocks and minerals on a rig of his own design. He also produced optical components for a firm of gemmological instrument makers. These tasks were a labour of love – he never sought nor expected financial reward.

George gave yeoman service to the Gemmological Association. He was appointed as an examiner for the FGA diploma in 1975 and became Chief Examiner in 1993, retiring in 1999. He was a major player in the revision of the course notes for the FGA diploma in the 1980s. George supported the Association Education staff greatly with his painstaking attention to detail, great scientific integrity and wonderful dry sense of humour.

As a boy he always had a sense of community and he joined the Boy Scouts in his early teens. He was appointed a District Commissioner for the movement in the 1960s. He was a keen gardener, but ill health forced him to give up both gardening and his beloved lapidary hobby.

George is survived by his wife Anne whom he married in 1947. They had three children Nigel, Rosamund and Diana, but tragically Nigel died from pneumonia at the early age of sixteen. They have two grandchildren.

E. Alan Jobbins

Deidre Kay Alejo FGA (D.1990), Central, Hong Kong, died on 22 April 2010.

Norman H. Harding FGA (D.1934 with Distinction), Haywards Heath, West Sussex, died on 14 December 2009.

Sylvia Gwendoline Hyde FGA (D.1950), Tixover, Stamford, Lincolnshire, died in June 2010 aged 88. Mrs Hyde was the winner of the Rayner Prize in the Preliminary Gemmology Examinations in 1949.

Raymond George Lee FGA (D.1962), Torquay, Devon, died in 2010.

Thea McDonald FGA (D.1949 with Distinction), Edinburgh, Lothian, died in 2010.

Anthony William Round FGA (D.1975), Ewell, Surrey, died in 2010.

Carol Anne Lesley Saxton FGA DGA (D. 1993 with Distinction), Alton, Hampshire, died on 27 February 2010.

Daniel Taylor FGA DGA (D.2005), Leeds, Yorkshire, died in 2010.

Wilhelm Jacobus E. Van Deijl FGA (D.1969), Bellville, South Africa, died in 2010.

Patricia Joan Walker FGA DGA (D.1969), London, died in 2010.

Lizanne Welch FGA (D.1991), Taunton, Somerset, died in 2010.

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Full details at **www.gem-a.com/education.aspx** or call 020 7404 3334

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Cover Picture: Alexandrite trillings from the Ural mountains, which form part of the Koksharov collection at the Natural History Museum, London. The faces are labelled with Miller indices in different colours, allowing twinning and twin boundaries to be easily recognized. The samples measure approximately 3.5 x 4.5 cm (top) and 6.5 x 6.5 cm (the two photographs below, which give different views of the same stone). The photographs were taken by Karl Schmetzer during a visit to the Natural History Museum and are featured on page 60 of his book *Russian Alexandrites*. (See book review by Alan Hart of the Natural History Museum of *Russian Alexandrites* by Karl Schmetzer, page 113.)
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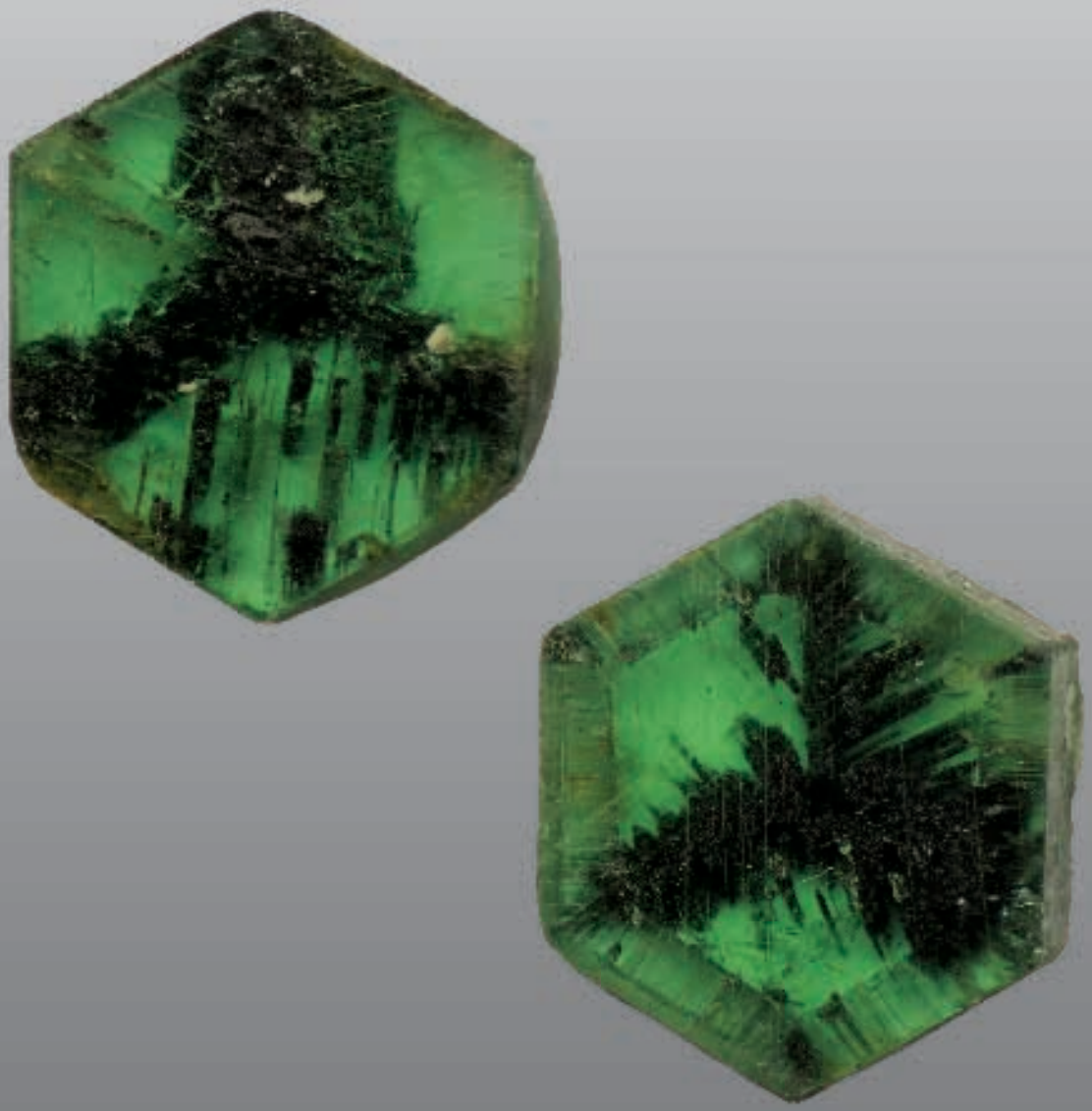

Trapiche tourmaline

The Gemmological Association of Great Britain

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Measurement and interpretation of growth patterns in chrysoberyl, including alexandrite

Dr Karl Schmetzer

Abstract: Procedures for identifying growth planes, growth zones and twin planes in optical biaxial gemstones are described and the most commonly observed interfacial angles are tabulated, using chrysoberyl as an example. The strong pleochroism of the chromium-bearing chrysoberyl variety alexandrite was found to be a useful indicator for locating the positions of the crystallographic axes, and the optic axes are determined using interference figures under crossed polarizers. Examples of the typical features of growth zoning in natural alexandrites from Russia, Sri Lanka and Brazil are shown. Twinned chrysoberyls from Madagascar are described in detail.

Keywords: alexandrite, Brazil, chrysoberyl, crystal habit, Madagascar, optic properties, pleochroism, Russia, Sri Lanka, twinning

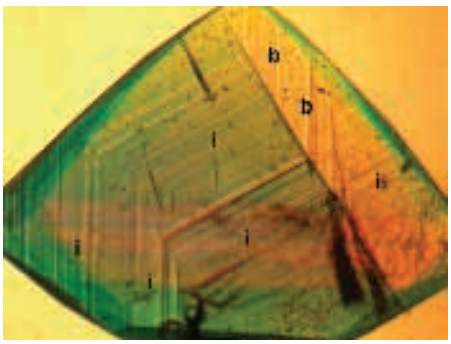

*Above: Growth structure and pleochroism in twinned alexandrite from Lake Manyara, Tanzania; the twin boundary separates a first individual with growth planes parallel to two **i** (011) faces and a second individual with growth faces parallel to **i** (011) and **b** (010). View parallel to the a-axis of both parts of the twin, immersion, 25 ×.*

Introduction

Origin determination has become an increasingly important requirement in the gem trade during the last decade, especially for larger rubies, sapphires and emeralds. In addition to the 'traditional' examination of inclusions, trace element chemistry, e.g. by X-ray fluorescence or laser ablation inductively coupled plasma mass spectrometry (LA-ICP-MS), can provide the necessary data to determine the provenance of a gemstone.

However, with the increasing number of new sources of gem-quality stones on the international market such as blue sapphires from Madagascar or Tanzania, inclusion and chemical information may be insufficient — especially due to overlapping trace element patterns — and the determination of the internal growth patterns of these uniaxial gemstones provides additional criteria to use for distinguishing between samples from different natural sources. With the exception of a few significant cases, growth patterns should be measured and assessed only in combination with a stone's other properties and not as a single technique.

The determination of the internal growth patterns of optically uniaxial gemstones, e.g. ruby, sapphire, emerald, amethyst and citrine, has been described in detail by Kiefert and Schmetzer (1991 a,b,c). The general technique was also comprehensibly described by Smith (1996) and applied to the distinction of natural and synthetic rubies. Further examples of characteristic growth patterns of optically uniaxial gemstones are also given in the literature, especially in connection with the description of new sources of ruby and sapphire and with the description of various synthetic quartz varieties.

In contrast, the description of characteristic growth patterns in optically

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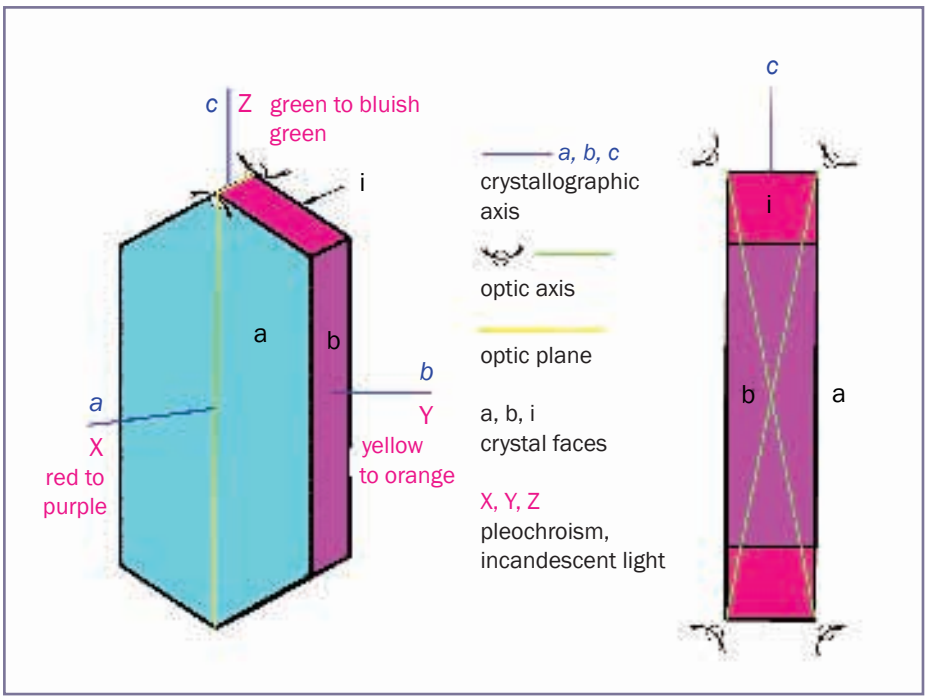

Figure 1: Orientation of the optic plane and the optic axes relative to the three crystallographic axes a, b *and* c *in optically biaxial chrysoberyl; the optic plane is represented by the* ac*-plane of the crystal. Left: clinographic projection, view almost parallel to the* a*-axis; right: parallel projection, view parallel to the* b*-axis.*

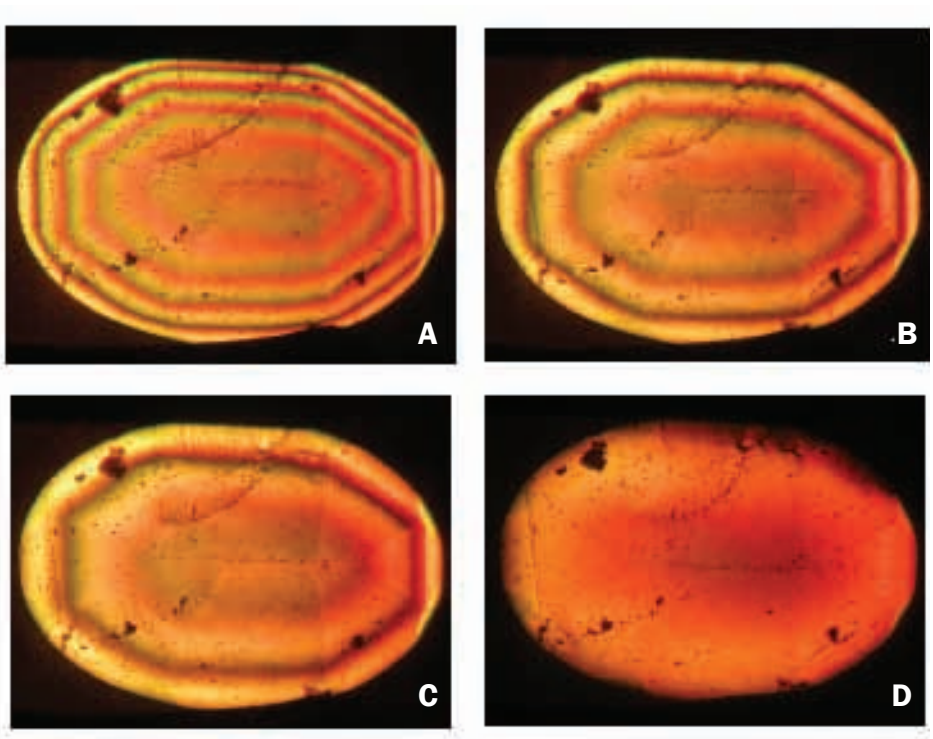

Figure 2: This series illustrates the variation of interference figures in alexandrite from Hematita, Brazil, during a slight rotation of the stone; tilting the alexandrite from a position, in which the optic axis is inclined to the direction of view (A) progressively towards positions in which the angle between the optic axis and the microscope axis is progressively diminished, moves the interference rings towards the centre (B and C); in (D) the optic axis is exactly parallel to the microscope axis. Consequently, this procedure is applied in a search for both optic axes and for the determination of crystal orientation in faceted samples by optical means. Immersion, crossed polarizers, 30×.

biaxial gemstones is limited. For flux-grown Russian synthetic alexandrites, the internal growth patterns were determined using immersion microscopy of rough and faceted samples (Schmetzer *et al.,* 1996). More recently, a detailed description of characteristic growth patterns in natural Russian alexandrites originating from the emerald mines in the Ural mountains has been published (Schmetzer, 2010) and includes practical guidance for the recognition of such characteristic patterns in Russian samples. However, a general overview of growth patterns in alexandrites from various natural sources and their determination is still missing.

General considerations

In optically uniaxial gemstones, the determination of the complete growth pattern is quite straightforward. Because the crystallographic *c*-axis is parallel to the optic axis, a growth plane can easily be determined by measurement of its inclination to the optic axis. The complete growth pattern can be seen by rotating the sample with the *c*-axis (coincident with the optic axis) as rotation axis of the sample holder.

In optically biaxial gemstones, on the other hand, neither optic axis can be expected to be parallel to any one of the three crystallographic axes (*a*-, *b*- and *c*-axes) and, therefore, the measurement of an angle of a growth plane relative to one of the optic axes or a rotation of the gemstone with one of the optic axes as rotation axis gives only limited information and doesn't show the complete growth pattern of a sample.

Consequently, the determination of growth patterns in optically biaxial gemstones can be considered as a trial and error process, which, depending upon the orientation of the table facet with respect to the crystallographic axes, may be very quick (comparable to the procedure for optically uniaxial gemstones) or somewhat more time consuming. For all biaxial gemstones it is necessary to rotate a faceted sample through an angle of 360° in a number of different orientations in the sample holder.

The observed structural properties and their orientation within the gemstone, e.g. relative to the table facet, can then be noted. In subsequent steps, an orientation of the alexandrite in selected settings and subsequent rotations will give the basic information to determine the most characteristic structural properties. In other words, each setting and rotation of the gemstone in the sample holder yields information to solve part of a three-dimensional puzzle, i.e. part of the complete growth information.

Technical equipment

The facilities used for the determination of growth patterns in optically biaxial gemstones are identical with the tools used for optically uniaxial gems. Detailed descriptions are given by Schmetzer (1986), Kiefert and Schmetzer (1991a) and Smith (1996).

For the measurement of angles between structural features in the immersion microscope, a special sample holder with two rotation axes and a 360° dial attached to the vertical rotation axis is applied to determine the angle of rotation, i.e. the angle between two structural features observed in two angular positions of the sample holder. The second horizontal rotation axis of the sample holder, in general, is not used for the measurement of angles between structural properties, but this axis is essential for an orientation of a rough or faceted sample in a direction of view exactly parallel to the observed growth planes. Furthermore, an eyepiece with crossed hairs and a 360° dial attached to the eyepiece tube are used for the measurement of angles between two different structural features, e.g. between two differently orientated series of parallel growth planes.

Determination of optic and crystallographic axes using interference figures and pleochroism

The optic axial plane in chrysoberyl, including its colour-change variety alexandrite, is always located in the plane formed by the crystallographic *a*- and *c*-axes *(Figure 1)*. The position of an optic axis in this plane is found by placing the stone in the sample holder in different initial orientations and rotating the stone 360° in each position under crossed polarizers. This uses the vertical axis of the sample holder as rotation axis. A position with a view somewhat inclined to the optic axis is indicated by a typical pattern of interference rings *(Figure 2A)*. Tilting the crystal continuously towards a position in which the optic axis is exactly parallel to the direction of view moves the interference rings continuously towards the centre of the sample *(Figure 2 B* to *D)*.

If the geometry of the stone is such that it is possible to find both optic axes, its orientation relative to the three crystallographic axes can be determined. With a starting position in which the crystallographic *b*-axis is parallel or almost parallel to the rotation axis of the sample holder, it is possible to observe both optic axes within one single rotation of the gemstone. In this case, the optic axial angle of the chrysoberyl can be measured. In most gem chrysoberyls the optic axial angle lies in the range 65 to 70°, and exactly half way between both optic axes, a view

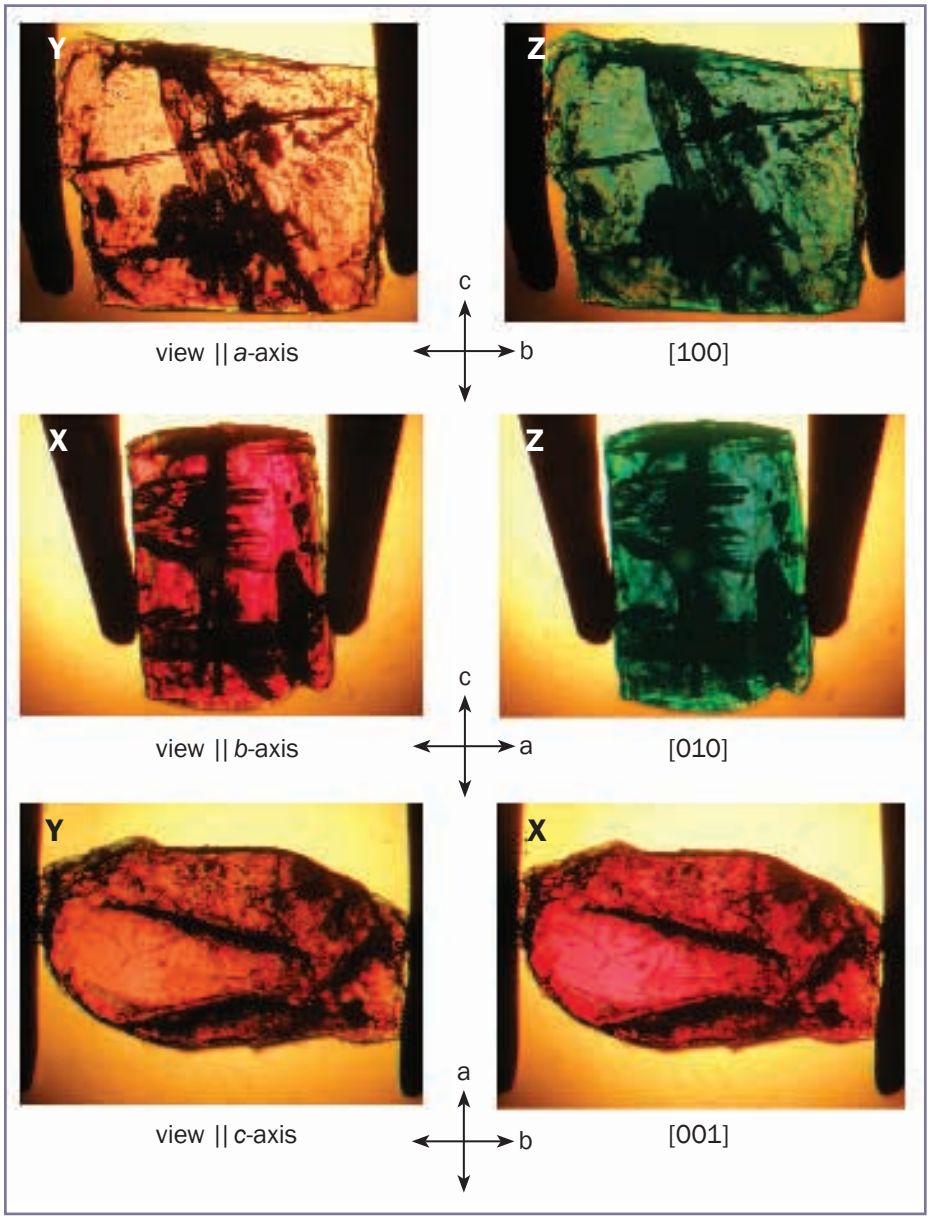

Figure 3: Pleochroism of an alexandrite crystal fragment from Hematita, Brazil, in immersion and incandescent light, view of the sample in directions parallel to the crystallographic a-, b- *and* c-*axis in a cell with transmitted polarized light, with an orientation of X*||a, *Y*||b *and Z*||c. *Size of the crystal fragment about 2.8 × 5.2 × 4.2 mm.*

parallel to the crystallographic *c*-axis can be obtained. After a rotation of 90° from this position with the *b*-axis chosen parallel to the rotation axis, the direction of view is exactly parallel to the *a*-axis.

This orientation in the sample holder, which enables determination of the position of both optic axes and — with that knowledge — the position of the three crystallographic axes, is ideal; to find it, the observation of pleochroism is helpful. For the chromium-bearing chrysoberyl variety alexandrite, the colours of X || *a*, Y || *b* and Z || *c* in incandescent light, as observed commonly in the immersion microscope, are always:

X red to purple, Y yellow to orange, and Z green to bluish green.

An example is given in *Figure 3*. Consequently, the observation of pleochroism is helpful to determine which crystallographic axis (in the setting of the crystal examined) is more or less parallel to the rotation axis of the sample holder.

Pleochroism can also be used to control the search for optic axes. If one optic axis is parallel to the direction of view, no pleochroism is observed when the polarizer is rotated. In views parallel to the three different crystallographic axes, the following colours are observed (see again Figure 3):

Direction of view	Pleochroism
View || to the *a*-axis [100]	Y yellow to orange Z green to bluish green
View || to the *b*-axis [010]	X red to purple Z green to bluish green
View || to the *c*-axis [001]	X red to purple Y yellow to orange

Table I: Morphological properties of chrysoberyls.
Crystal class 2/m 2/m 2/m = D_{2h}, single and repeated twinning on (031) and ($0\bar{3}1$).

Crystal form	Designation	Miller indices (hkl)*	Number of faces
Pinacoid	**a**	(100)	2
	b	(010)	
	c	(001)	
Prism	**i**	(011)	4
	k	(021)	
	m	(110)	
	s	(120)	
	r	(130)	
	x	(101)	
Dipyramid	**o**	(111)	8
	n	(121)	
	w	(122)	
	v	(211)	

Zone axis [uvw]	Direction of view	Crystal faces, designation and Miller indices (hkl)
[001]	parallel to the *c*-axis	**a** (100), **m** (110), **s** (120), **r** (130), **b** (010)
[100]	parallel to the *a*-axis	**b** (010), **k** (021), **i** (011), **c** (001)
[010]	parallel to the *b*-axis	**c** (001), **x** (101), **a** (100)
[011]	between *b*- and *c*-axis	**a** (100), **v** (211), **o** (111), **w** (122), **i** (011)
[012]	between *b*- and *c*-axis	**a** (100), **n** (121), **k** (021)
[101]	between *a*- and *c*-axis, almost parallel to the optic axis	**b** (010), **n** (121), **o** (111), **x** (101)
[110]	between *a*- and *b*-axis	**o** (111), **c** (001)
[111]	oblique to all three axes	**i** (011), **n** (121), **m** (110)

*Based on a morphological cell with a 4.42, b 9.39, c 5.47

Observation of characteristic faces and growth zones

The determination of the presence of a single *growth plane* or a series of parallel growth planes — in general — is neither helpful for the characterization of a faceted alexandrite regarding its original crystal morphology nor for origin determination. What is needed is the recognition of one or several characteristic *growth zones*, each growth zone consisting of a group of crystal faces.

In crystallography, a *zone* is defined as a set of faces which are parallel to a line (the *zone axis*) and intersect in parallel edges *(Figure 4)*. In general, two non-parallel crystal faces form a zone, but most characteristic zones in chrysoberyl consist of more than two crystal faces. A *crystal face* is indicated by Miller indices (hkl) in round brackets and a *zone axis* is indicated by the symbol [uvw] in square brackets.

To avoid confusion, the author will designate a part of a rough crystal or a faceted gemstone which shows parallel growth planes assigned to a single crystal face as a growth area. Consequently, several growth areas which are related to each other by a single zone axis form a growth zone.

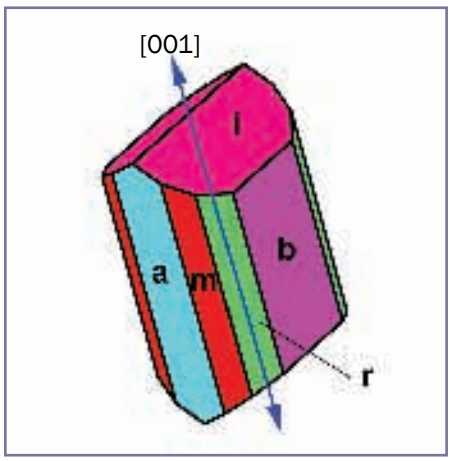

*Figure 4: Alexandrite crystal with simple morphology consisting of the faces **a** (100), **b** (010), **m** (110), **r** (130) and **i** (011); the intersection edges of the faces **a**, **b**, **m** and **r** are parallel to the zone axis [001]. In a view parallel to the zone axis, the growth planes equivalent to the faces **a**, **b**, **m** and **r** are visible in the immersion microscope as lines or bands.*

Measurement and interpretation of growth patterns in chrysoberyl, including alexandrite

In *Table I*, the major faces present in alexandrites from the most important sources are listed. The alexandrite crystals show the three pinacoids **a**, **b** and **c**, six prism faces **i**, **k**, **m**, **s**, **r** and **x**, and four dipyramids **o**, **n**, **w** and **v**. In *Figure 5*, a chrysoberyl crystal is drawn in different views, which show all 13 possible faces listed in *Table I*. In contrast to this theoretical crystal, natural alexandrite crystals from various sources reveal only a limited (smaller) number of crystal faces. In the simplest case, the alexandrite crystals are formed of three different faces only, e.g. the pinacoids **a** and **b** in combination with the prism **i** (see again *Figure 1*). Thus, the habit of alexandrite crystals from different sources is formed by a limited number of faces, in most crystals between three and ten. The morphological differences between alexandrites from different sources are due to a selection of faces present and the relative sizes of these faces.

In *Table I*, the most important zones and the faces forming these zones in natural alexandrites from different sources are also listed. In *Tables I* and *II*, the orientations of these zones, i.e. the directions of view in which the faces of these zones can be observed, are also given. These directions of view in the immersion microscope are identical with the zone axes. In *Table II*, the angles between different crystal faces of the most important zones are also listed.

In *Figure 6A*, the theoretical chrysoberyl crystal with all 13 crystal faces *(Figure 5)*, is shown in different

Table II: Characteristic interfacial angles common in chrysoberyls, including twins and trillings.

Direction of view	Faces/ Interfacial angles(°)					
View parallel to the *c*-axis, faces (hk0), zone axis [001]	**a b**	90				
	a m	25.21	**b r**	35.30	**m s**	18.06
	a s	43.27	**b s**	46.73	**s r**	11.42
	a r	54.70	**b m**	64.79		
View parallel to the *a*-axis, faces (0kl), zone axis [100]	**b c**	90				
	b i	59.78	**c i**	30.22	**i i′** (adjacent)	60.44
	i k	19.14	**k b**	40.64	**k k′** (adjacent)	98.72
View parallel to the *b*-axis, faces (h0l), zone axis [010]	**c a**	90				
	a x	38.94	**c x**	51.06		
View perpendicular to a twin plane, between *b*- and *c*-axis, rotation 30.22° versus a view parallel c (001), faces (hkl k=l), zone axis [011]	**a i**	90				
	a v	25.06	**v o**	18.02	**v v′** (opposite)	129.88
	a o	43.08	**i o**	46.92	**o o′** (opposite)	93.84
	o w	18.79	**i w**	28.13	**w w′** (opposite)	56.26
View oblique to the three crystallographic axes, zone axis [111]	**i n**	42.64	**n m**	34.97	**i m**	77.62
View between *b*- and *c*-axis, rotation 40.64° versus a view parallel b (010), faces (hkl k=2l), zone axis [012]	**a k**	90				
	k n	38.87	**n a**	51.13		
View almost parallel to one optic axis, between *a*- and *c*-axis, rotation 38.94° versus a view parallel a (100), faces (hkl h=l), zone axis [101]	**x b**	90				
	x o	20.11	**b o**	69.89	**o o′** (adjacent)	40.22
	o n	16.10	**b n**	53.79	**n n′** (adjacent)	72.43
View between *a*- and *b*-axis, rotation 25.11° versus a view parallel a (100), faces **o** and **c**, zone axis [110]	**o o′** (diagonal)	107.66	**o c**	53.83		
Further important angles between dipyramids, views between *a*- and *c*-axis					**w w′** (adjacent)	52.70
					v v′ (adjacent)	24.62

N.B.: The angles between growth planes visible in chrysoberyls in the immersion microscope can be obtained by subtracting the relevant interfacial angle from 180°.

Measurement and interpretation of growth patterns in chrysoberyl, including alexandrite

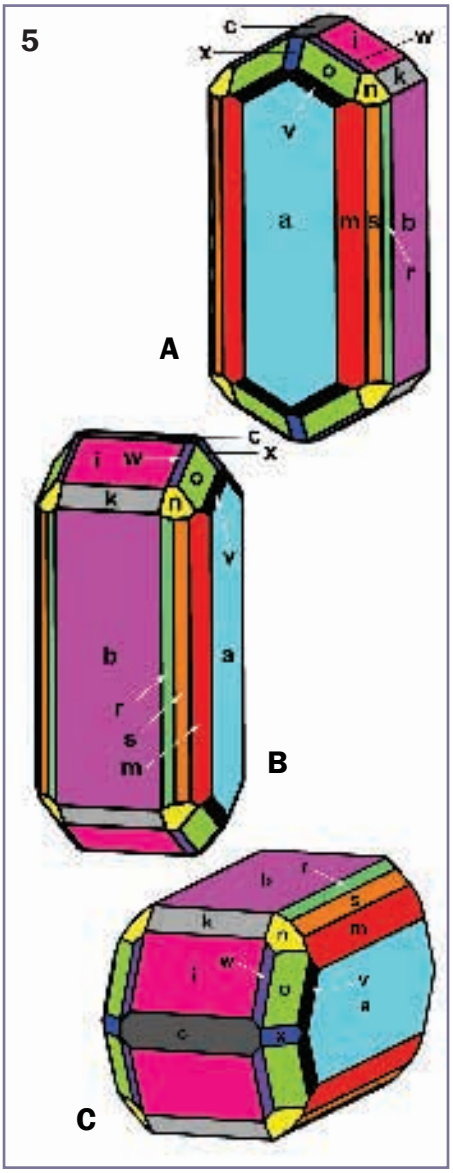

*Figure 5: Diagrams showing the positions and labels (**a**, **n**, **w**, etc) of the 13 important faces that were seen in natural alexandrites from all major sources worldwide; A, B and C are clinographic projections to illustrate clearly where each face lies.*

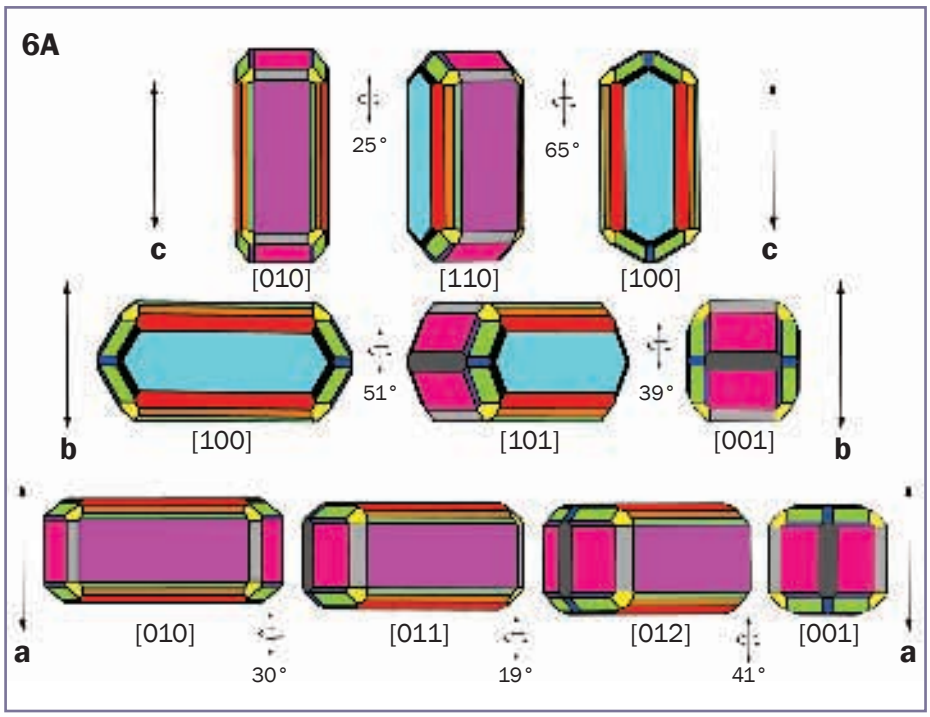

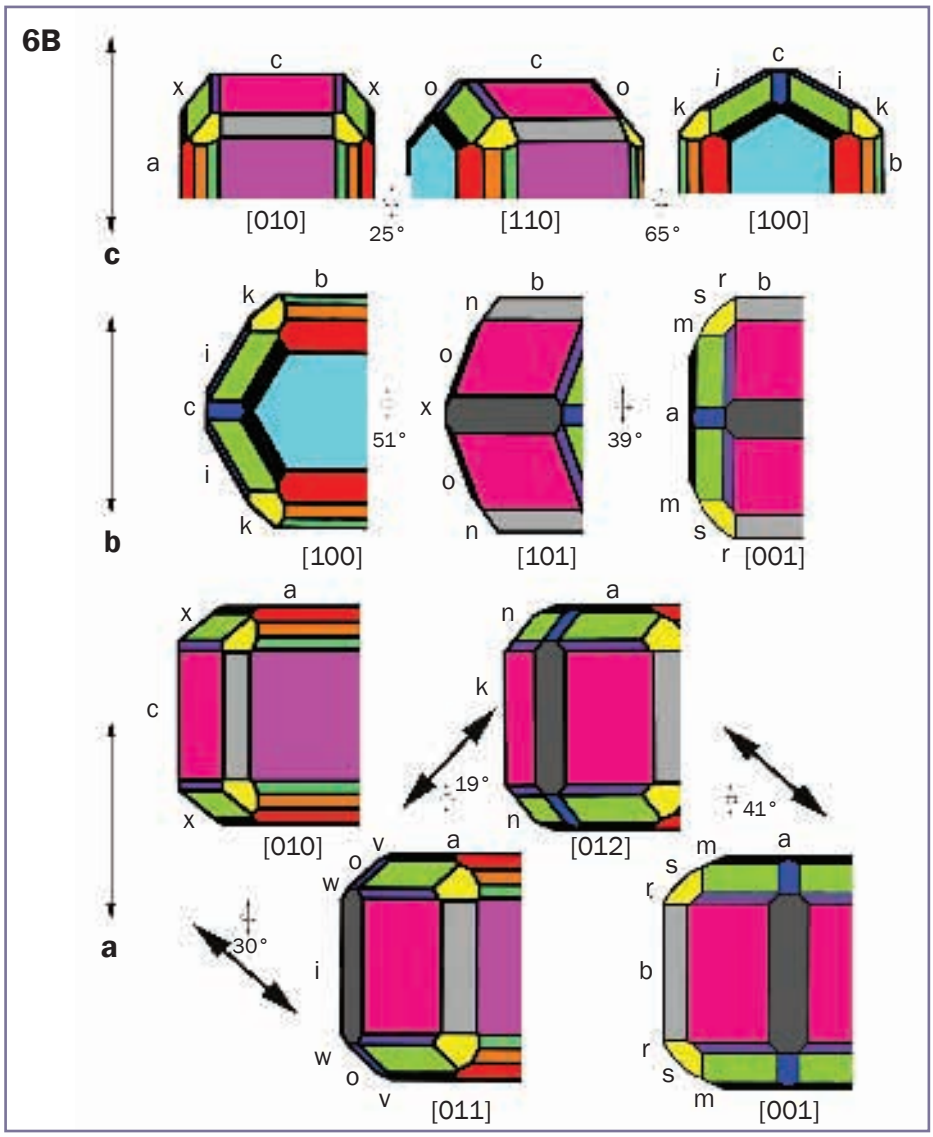

*Figure 6A: Diagrams of the dominant morphological zones of chrysoberyl. The crystallographic axes c, b and a are indicated, and the zone axis in square brackets indicates the direction of view, e.g. [100] is the direction perpendicular to the blue face **a**, and [110] is perpendicular to the deep orange face **m** (Figure 5). The rotation angles between the different views with the crystallographic axes a, b and c as rotation axes are given.*

Figure 6B: Enlarged parts of the crystal drawings of Figure 6A; the faces observable in the growth pattern of each view are indicated. Each crystal drawing represents a projection parallel to the respective zone axis (the number in square brackets); the rotation angles between the different viewings are also given.

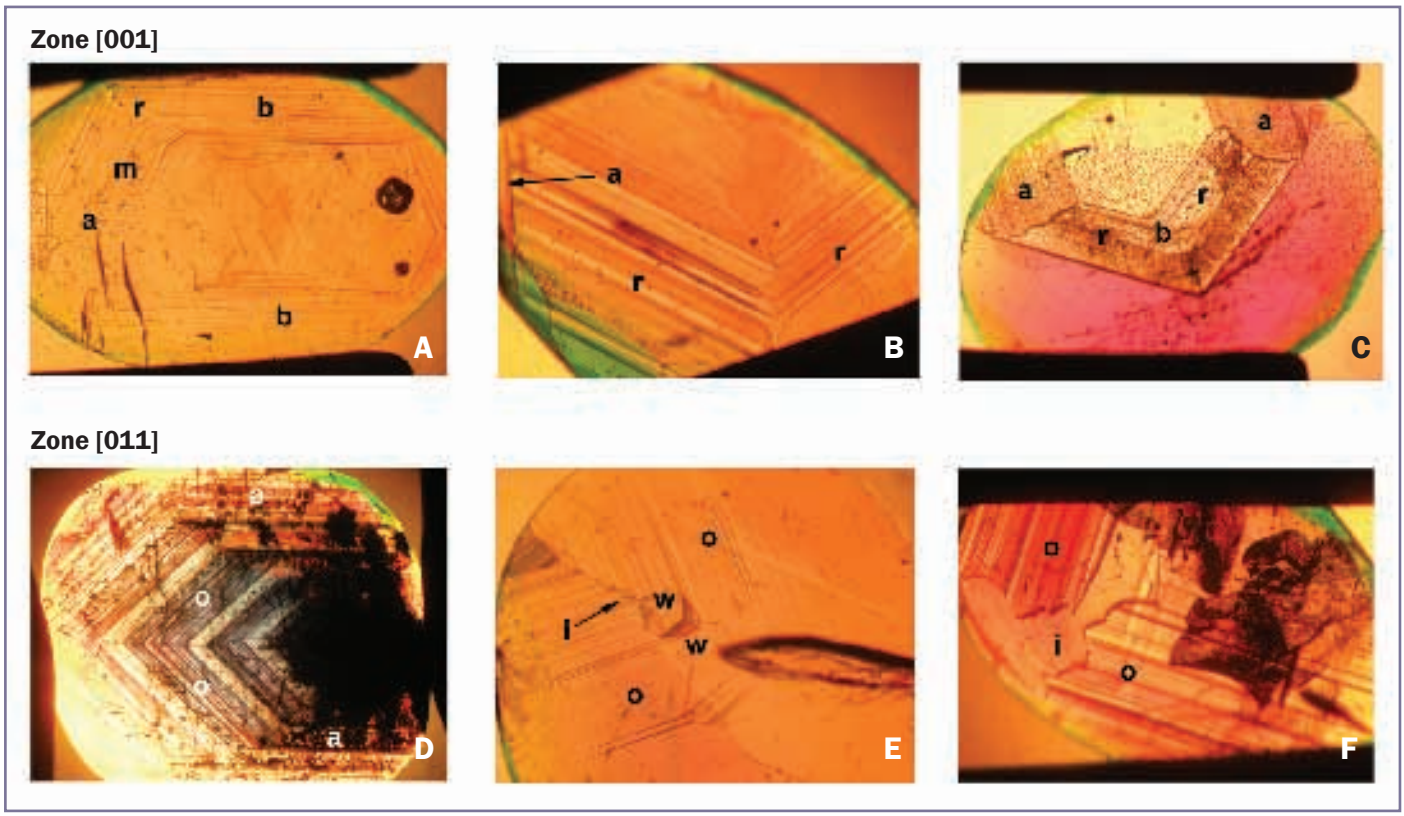

Figure 7: Examples of growth structures in alexandrites from three major natural sources (Urals, Russia; Hematita, Brazil; Sri Lanka). Top row, growth zone [001]: (A) Brazil, 50 ×; (B) Sri Lanka, 40 ×; (C) Sri Lanka, 30 ×; bottom row, growth zone [011]: (D) Russia, 30 ×; (E) Russia, 50 ×; (F) Sri Lanka, 35 ×. All photos in immersion.

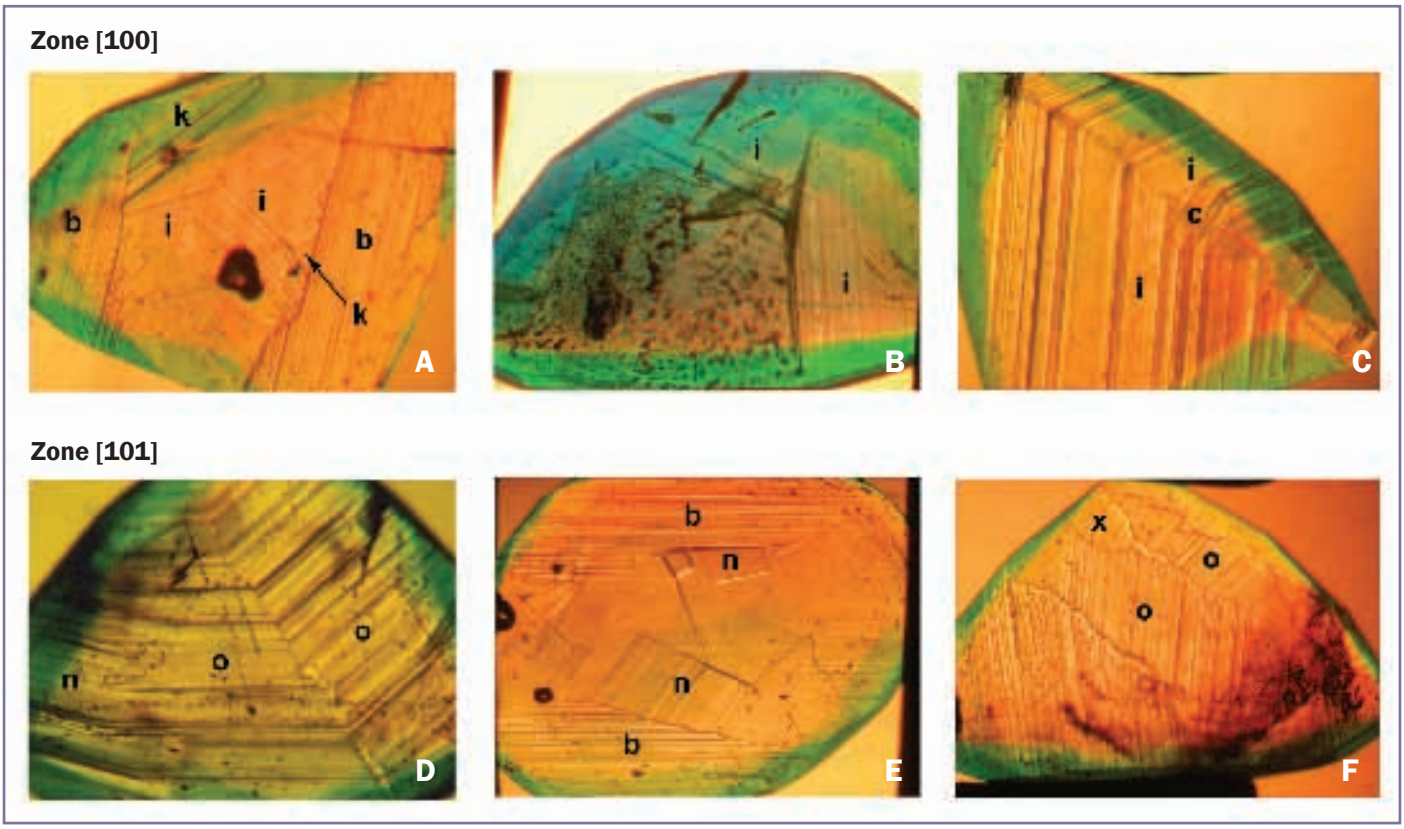

Figure 8: Examples of growth structures in alexandrites from three major natural sources (Urals, Russia; Hematita, Brazil; Sri Lanka). Top row, growth zone [100]: (A) Brazil, 50 ×; (B) Brazil, 40 ×; (C) Sri Lanka, 40 ×; bottom row, growth zone [101]: (D) Russia, 50 ×, (E) Brazil, 50 ×; (F) Sri Lanka, 35 ×. All photos in immersion.

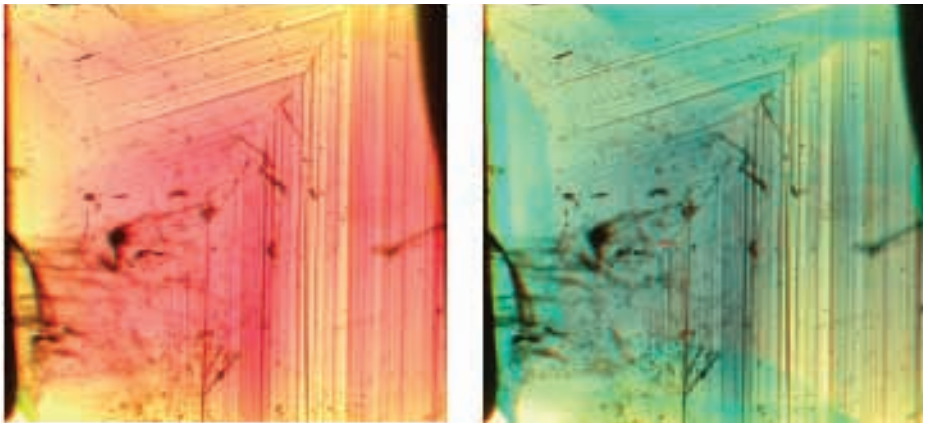

*Figure 9: Growth structure and pleochroism in alexandrite from the Urals, Russia; growth zone [110] (i.e. looking perpendicular to the deep orange face **m** (110) in Figure 5), two **o** dipyramids (again see Figure 5) form an interfacial angle of 108° (the angle formed by the two faces is 180° – 108° = 72°). Immersion, 50 ×.*

Table III: Structural pattern consisting of more than one growth plane.

Rotation axis of the sample holder parallel to one of the three crystallographic axes	Zone	Visible pattern of crystal growth planes (common examples)
c [001]	[010]	**a c a** *or* **a x c x′ a′**
	[110]	**o c o′** *or* **o o′**
	[100]	**b i i′ b′** *or* **b i c i′ b′** *or* **b k i c i′ k′ b′**
b [010]	[100]	**b i i′ b′** *or* **b i c i′ b′** *or* **b k i c i′ k′ b′**
	[101]*	**b o o′ b′** *or* **b o x o′ b′** *or* **b n o x o′ n′ b′**
	[001]	**b a b′** *or* **b m a m′ b′** *or* **b s a s′ b′** *or* **b r a r′ b′** *or* **b s m a m′ s′ b′** *or* **b r s a s′ r′ b′** *or* **b r m a m′ r′ b′** *or* **b r s m a m′ s′ r′ b′**
a [100]	[010]	**a c a** *or* **a x c x′ a′**
	[011]**	**a i a′** *or* **a o o′ a′** *or* **a o i o′ a′** *or* **a o w w′ o′ a′** *or* **a o w i w′ o′ a′** *or* **a v o o′ v′ a′** *or* **a v o i o′ v′ a′**
	[012]	**a n n′ a′** *or* **a n k n′ a′**
	[001]	**a b a′** *or* **a m b m′ a′** *or* **a s b s′ a′** *or* **a r b r′ a′** *or* **a m s b s′ m′ a′** *or* **a s r b r′ s′ a′** *or* **a m r b r′ m′ a′** *or* **a m s r b r′ s′ m′ a′**

Rotation axis of the sample holder perpendicular to a crystal face	Visible zones (examples)
Prism **i** (011)	[100], [111]***, [011]
Prism **x** (101)	[010], [101]
Dipyramid **o** (111)	[011], [101], [110]
Dipyramid **n** (121)	[101], [012], [111]***

* view almost parallel to one of the optic axes
** view perpendicular to a twin plane
*** faces **m, n, i**

projections. If one considers the three crystallographic axes *c*, *b* and *a*, each in turn parallel to the vertical rotation axis of the sample holder, it is apparent which zones can be visible in a single setting by rotation. In the upper part of *Figure 6A*, for example, the *c*-axis is selected as rotation axis. So, the different faces of each zone, [010], [110] and [100], can be seen after rotation of the crystal through angles of 25° and 65°, respectively.

In *Figure 6B*, only parts of the complete crystals shown in *Figure 6B* are drawn, and the crystal faces observable in different orientations are indicated. It needs to be mentioned that — in practice — only part of the crystal faces shown in *Figures 6a* and *6b* are generally observable. The zone [100], for example, may show all four different faces, **b**, **k**, **i** and **c**, but some crystals only display two or three of these four faces. Examples of characteristic zone patterns which are common in natural alexandrites from different sources are listed in *Table III*. Photomicrographs of cut immersed alexandrites from three of the major natural sources, namely the Urals, Russia, Hematita, Brazil, and Sri Lanka, are given in *Figures 7* and *8*. *Figure 9* shows an example of an additional growth pattern of zone [110] in a Russian alexandrite crystal and the pleochroism observed on rotation of the polarizer.

It should be emphasized that faceted gemstones normally represent only part of the original rough crystal, from which the gemstone was cut. This means that more or less included and impure parts of the original crystal might have been removed by the cutting process and, therefore, the pattern seen in the microscope might represent only part of a zone structure. It is the experience of the author that it is very helpful to have *Figures 6a* and *6b* or a similar general overview and *Tables I* to *III* available beside the microscope for practical work with samples of unknown origin or morphology.

It is possible that during the microscope examination, only one of the optic axes is found. It is also possible that none of the pinacoids **a**, **b** or **c** is present

or clearly recognizable, or that no growth zone with more than one face is visible. For such stones, it is recommended that a setting is selected with the most significant growth plane perpendicular to the rotation axis of the sample holder. In this setting, the strong growth plane is always visible and sharp in the microscope and any other faces forming a growth zone with this plane will appear during rotation. The measurement of angles in that particular zone together with a control by the observed pleochroism will determine this zone and the crystal planes present.

Examples of characteristic growth patterns which are common in alexandrites from Hematita, Brazil, are given. The first pattern consists of a distinct and jagged boundary between two growth areas (see, e.g., Bank *et al.,* 1987). In these areas the growth planes are rather weak (compared with the images in *Figures 7–9*) and are related by an interfacial angle of 43° *(Figure 10A)*. In this orientation, the two growth zones show distinct pleochroism. Thus, although two dipyramidal o growth areas in growth zone [101] would abut at a similar angle of 40°, such a view is almost parallel to one of the optic axes and would show no pleochroism, so the pattern in *Figure 10A* cannot be assigned to this zone. Neither is this characteristic pattern visible when one of the *a*-, *b*- or *c*-axes is parallel to the rotation axis of the sample holder. However, because the prism **i** is a common growth face in alexandrites from Hematita, samples were oriented with these growth planes perpendicular to the rotation axis of the sample holder. With that particular orientation, growth planes of the prism **i** are always sharp in the microscope. Starting with a view of zone [011], after rotation of 21° (measured), a characteristic pattern was observed *(Figure 10B)*, which consists of the prism **i** and the dipyramid **n** *(Figure 11)*. In the same orientation, the dipyramid **n** abuts the prism **m**, again with a jagged boundary, forming an interfacial angle of 35° *(Table II)*, and finally the growth zone is identified as [111]. The theoretical angle calculated for the rotation described is 22.13°.

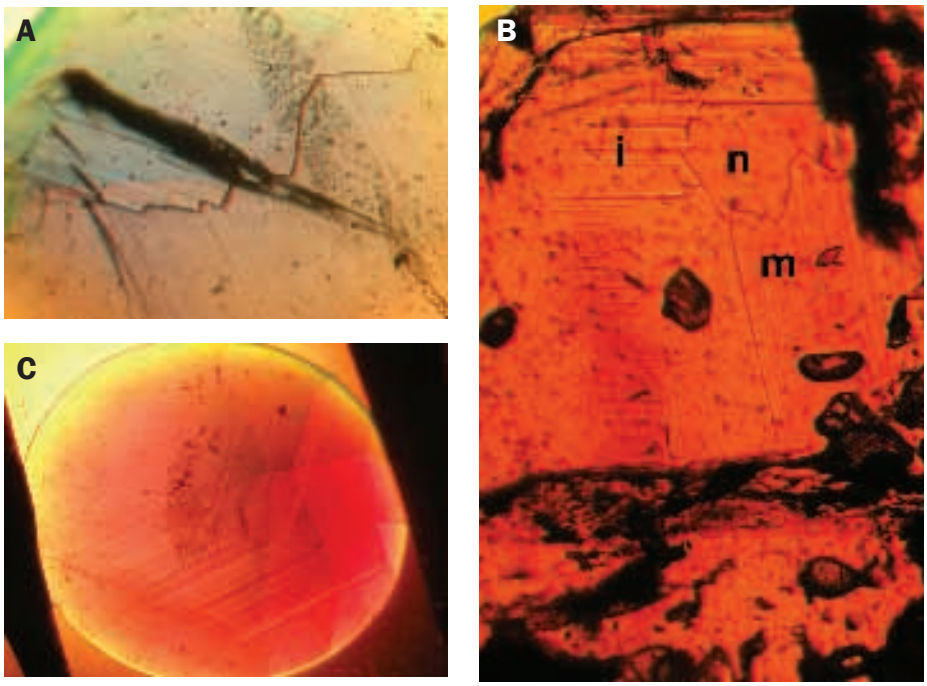

*Figure 10A: Growth structure in alexandrite from Hematita, Minas Gerais, Brazil; growth zone [111], the crystal faces **i** (011) and **n** (121) form an interfacial angle of 43° (the angle formed by the two faces is 180° – 43° = 137°). Immersion, 50 ×.*
*Figure 10B: Growth structure in alexandrite from Hematita, Minas Gerais, Brazil; growth zone [111], the crystal faces **i** (011), **n** (121) and **m** (110) form interfacial angles of 43° and 35°. Immersion, 60 ×.*
*Figure 10C: Growth structure in alexandrite from Hematita, Minas Gerais, Brazil; growth zone [011], the crystal faces **i** (011) and **o** (121) form an interfacial angle of 47° (the angle formed by the two faces is 180° – 47° = 133°). Immersion, 20 ×.*

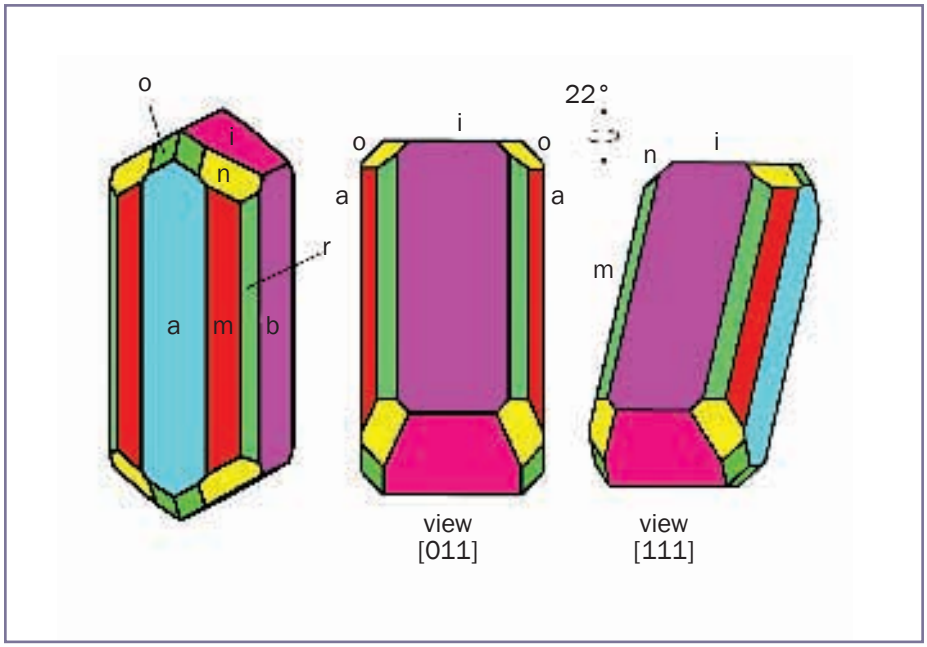

*Figure 11: Diagrams of an alexandrite crystal from Hematita, Brazil. Left: clinographic projection; centre: parallel projection with [011] as zone axis; right: parallel projection with [111] as zone axis. When looking parallel to [011], growth structures parallel to the faces **a**, **o** and **i** are visible; upon rotation about an axis perpendicular to the **i** face through 22°, the growth faces **i**, **n** and **m** related to the zone [111] are visible.*

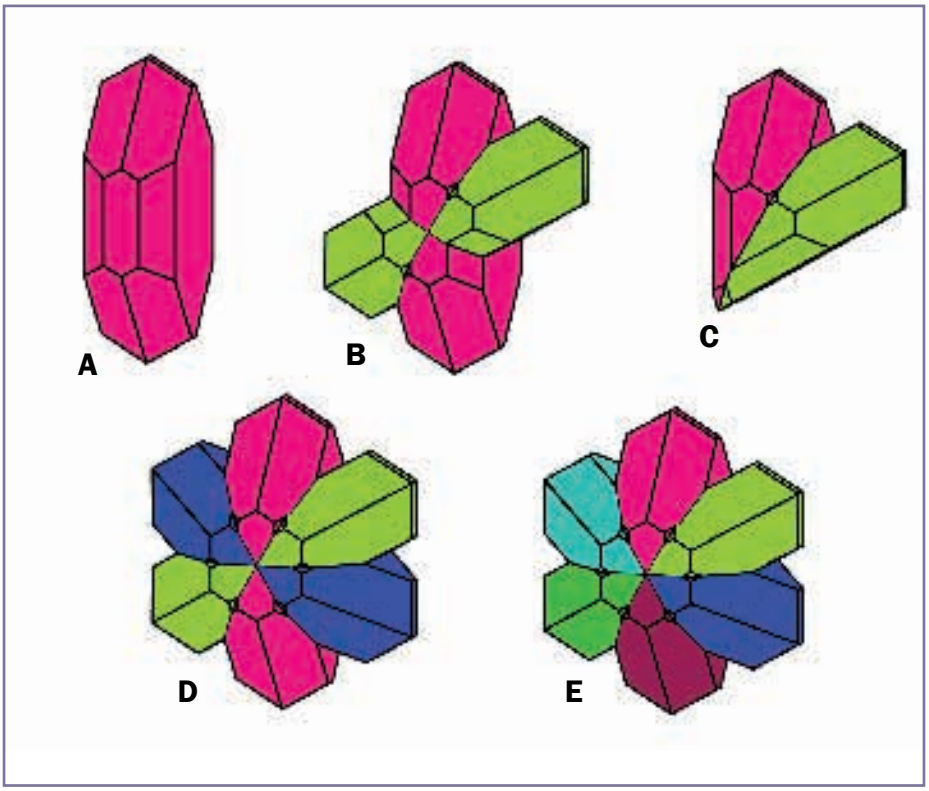

Figure 12: Diagrams of different types of twins in alexandrite: by reflection on the plane (031) a single crystal (A) forms penetration (B) or contact twins (C); a cyclic twin consists of three penetration twins (D) or six contact twins (E). According to the sizes of different faces of the single crystals, the twins may show distinct re-entrant angles (as shown here) or vanishingly small ones.

A second growth pattern commonly seen in alexandrites from Hematita which looks similar with planes forming an interfacial angle of 47° were identified as **i** and **o**, which are related to growth zone [011] *(Figure 10C)*.

Twinning in chrysoberyl and alexandrite

Twinning in alexandrite was described by Rose (1839) in one of the first scientific papers mentioning the new gem material. Of the crystal twins shown in *Figure 12*, those which are common among the alexandrites recovered from the Uralian emerald mines in Russia are described as cyclic twins or trillings, which consist of three interpenetrant individuals *(Figure 12D)*. However, such crystal twins may alternatively be interpreted as a contact twin of six independent individuals *(Figure 12E)*. The governing twin law is reflection on (031) or $(0\bar{3}1)$. Both twin planes are also composition planes of the crystals. In alexandrites from several other occurrences, however, trillings are

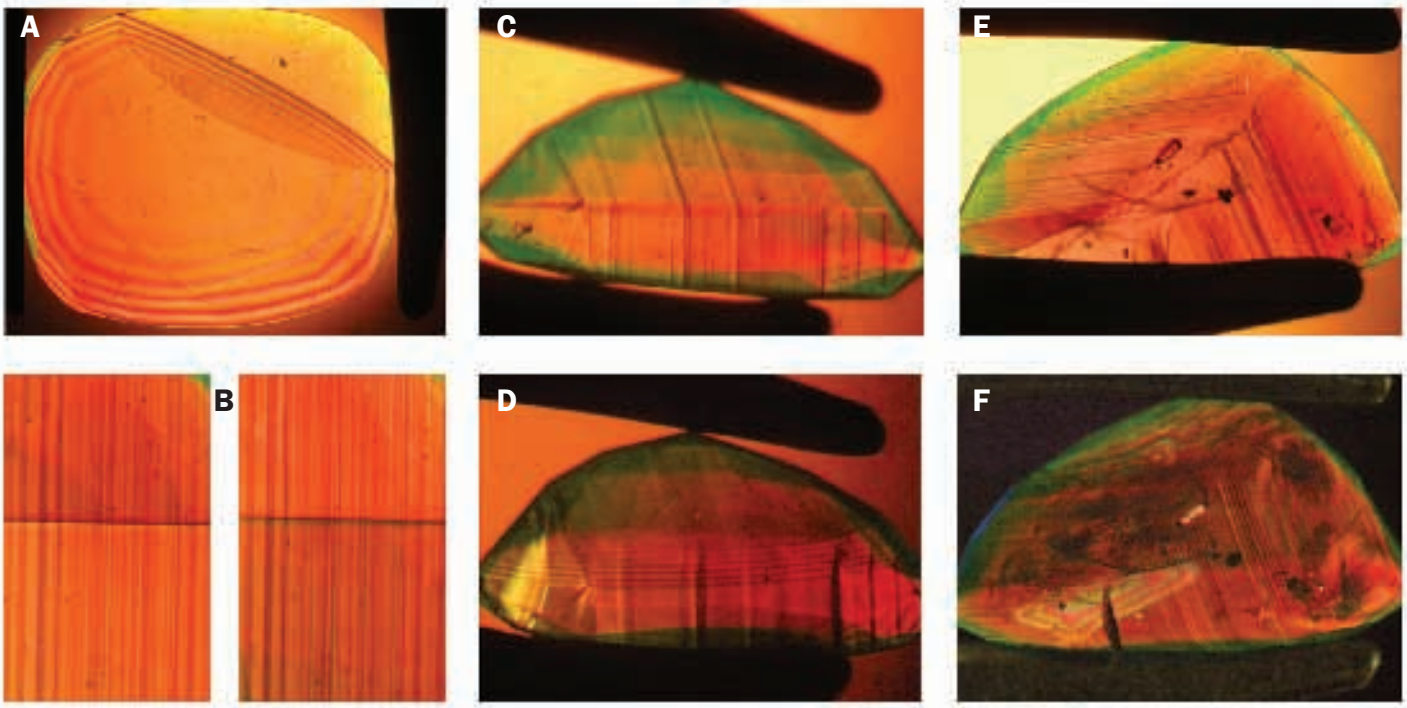

Figure 13: Interference patterns in twinned and untwinned alexandrites. (A) Alexandrite twin from Sri Lanka showing an interference pattern confined by the twin boundary; crossed polarizers; immersion, 25 ×. (B) View parallel to a twin plane of alexandrite from Sri Lanka. Growth planes run perpendicular to the twin plane; upon rotation of the polarizer, the different parts of the twin show distinct pleochroism in deeper and paler shades of orange; immersion, 50 ×. (C) Growth planes in alexandrite from Sri Lanka in plane polarized light, and showing interference patterns (D) under crossed polarizers; immersion, 30 ×. (E) Growth planes in alexandrite from Hematita, Brazil, showing interference patterns (F) under crossed polarizers; immersion, 30 ×.

either rare or absent, although other kinds of twins are quite common. Such twins follow the same twin law as trillings and are developed as contact or penetration twins *(Figure 12 B,C)*. In trillings and in contact twins or penetration twins on (031), the crystallographic *a*-axes of all parts of the twin are parallel to each other, and the *b*- and *c*-axes are inclined according to the twin law. For more details, the reader is referred to pp 62–67 in Schmetzer (2010).

In addition to reflection on (031), another twin law in chrysoberyl was described by Jeremejew in 1898 but this has not since been confirmed. Therefore, in this paper, studies are concentrated on twinning on (031).

Many faceted alexandrites show one simple twin boundary, but a few may show two or even three intersecting twin planes. The intersection line between different twin planes is always parallel to [100], i.e. parallel to the crystallographic *a*-axis. When rotating twinned crystals under crossed polarizers, the twin boundary shows a typical interference pattern *(Figure 13A)*. Similar interference colours confined to different growth planes may also be present in alexandrites from Sri Lanka, Hematita, Brazil, or elsewhere. In twinned crystals, however, distinct pleochroism can be observed between different parts of a twin or trilling *(Figure 13B)*, whereas such pleochroism is not present in crystals with interference colours related to simple growth planes *(Figure 13C to F)*.

Growth patterns in twinned chrysoberyls

The best orientation for the examination of growth patterns in twinned chrysoberyls is a setting with the crystallographic *a*-axis (which is parallel for all parts of the twin) as rotation axis, i.e. with the *a*-axis parallel to the rotation axis of the sample holder. With this setting, it is possible to view the twinned sample parallel and perpendicular to the twin plane. Measuring the rotation angle between the visible twin plane and *a* position, in which several growth planes

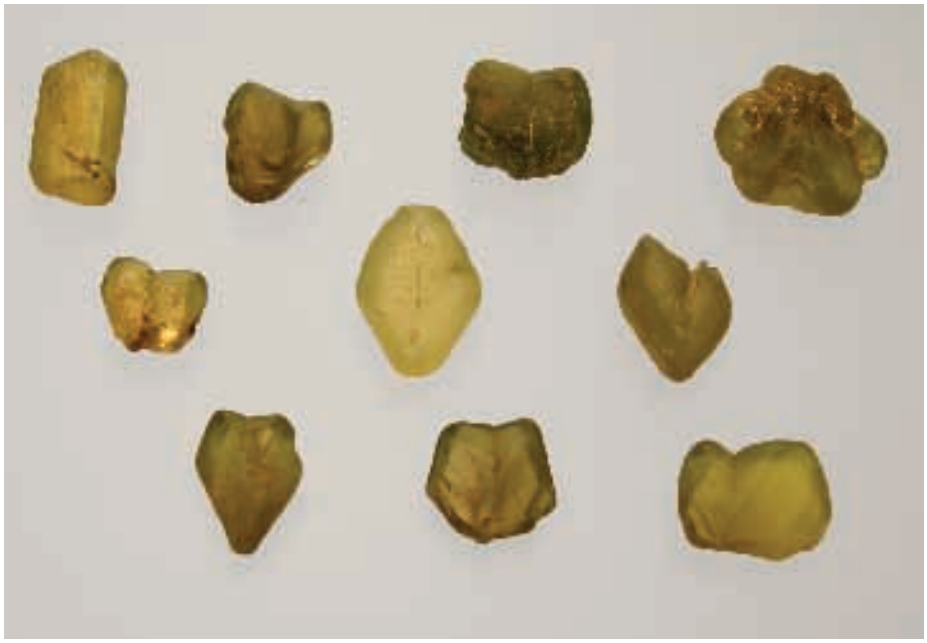

Figure 14: Slightly water-worn greenish yellow chrysoberyls from Ilakaka, Madagascar. The upper left sample is an untwinned single crystal, the crystal on the upper right is a trilling, all other samples are contact twins. The single crystal is about 8 × 15 mm.

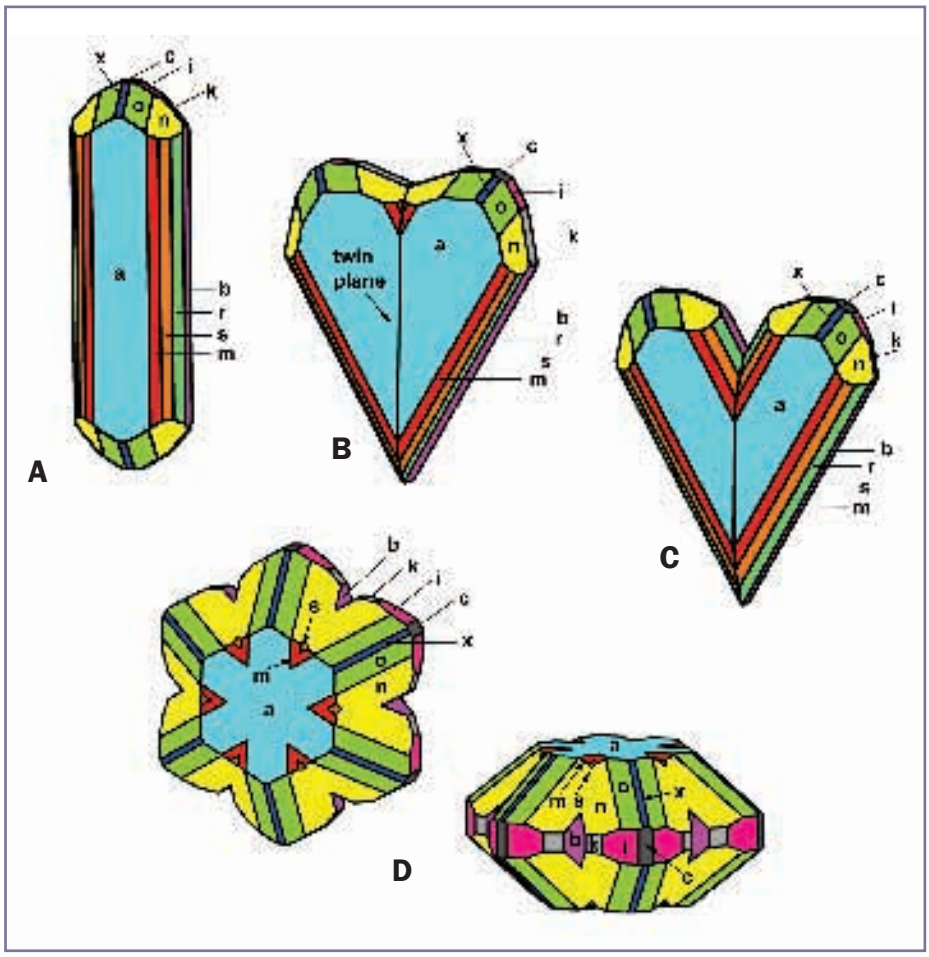

Figure 15: Diagrams of chrysoberyl crystals from Ilakaka, Madagascar. (A) Single crystal, (B) contact twin with small re-entrant angle, (C) contact twin with a more distinct re-entrant angle, and (D) cyclic twin (trilling), viewed from two directions close to parallel and perpendicular to the a-axis.

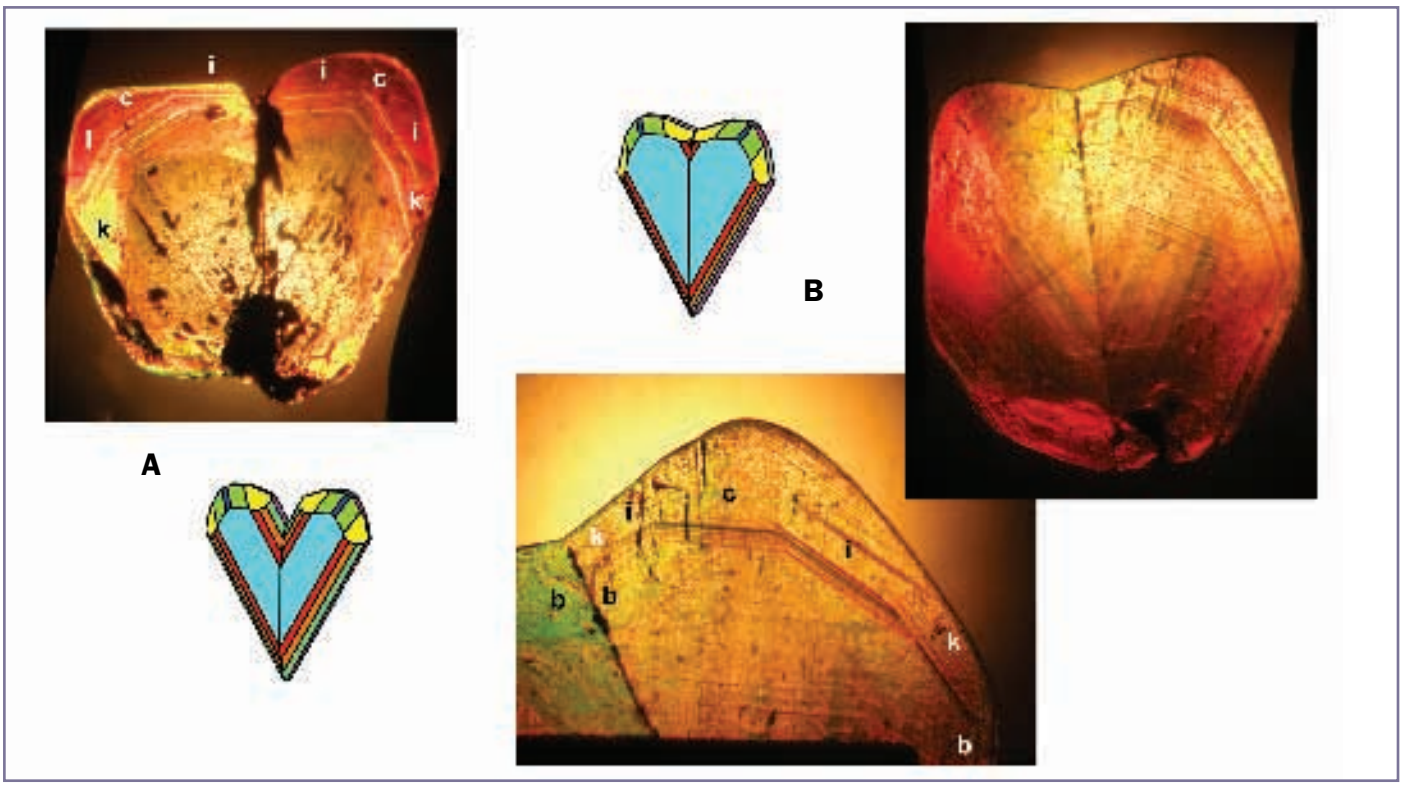

*Figure 16 (above): Chrysoberyl twins from Ilakaka, Madagascar with more (A) or less (B) separation of the twin components. Views in the direction of the a-axis showing the [100] growth zones; the pinacoids **b** and **c** and the prism faces **i** and **k** of the waterworn twinned crystals are visible in immersion. Sample (A) measures about 11 × 11 mm, sample (B) measures about 9 × 10 mm.*

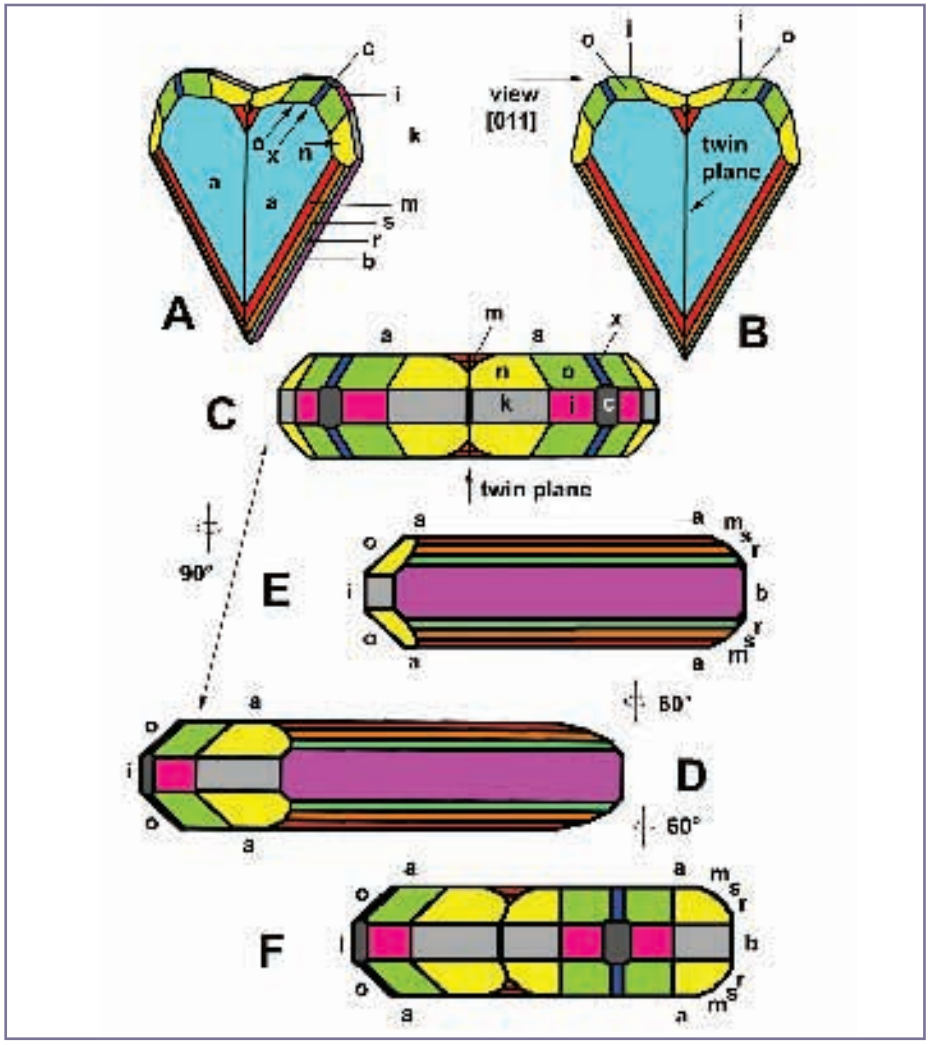

*Figure 17 (left): Diagrams of a chrysoberyl twin from Madagascar in different orientations. (A) Clinographic projection, and (B) parallel projection with [100] as zone axis. If one looks parallel to the zone [011] the two **i** prism faces are near-parallel as are the four **o** dipyramids of the two individuals of the twin (only two are shown); this direction of view is indicated in drawing (B) and a parallel projection of the sample in this orientation is shown in drawing (D). Drawing (D) is connected to drawing (C) showing a view parallel to the twin plane by a rotation of 90° with the a-axis as rotation axis; starting from an orientation as shown in drawing (D), a rotation in both directions through 60° leads to orientations as shown in drawings (E) and (F), in which one part of the twin shows a view parallel to the zone [011] with crystal faces **i**, **o** and **a**, and the other part of the twin shows a view parallel to the zone [001] with crystal faces **b**, **r**, **s**, **m** and **a**.*

of a growth zone are visible, identifies the growth zone. In addition, determination of the angles between different growth planes within such a growth zone enables identification of the different growth faces.

For a better understanding of these investigations, the author selected some greenish yellow to yellowish green chrysoberyls from Ilakaka, Madagascar. The stones examined consisted of one single crystal, several contact twins and one trilling *(Figure 14)*. Schematic crystal drawings are given in *Figure 15*. The crystal faces of 11 of the 13 crystal forms *(Table I)* are visible and, therefore, these Madagascan samples are useful to explain the sometimes really complex morphological properties and growth structures seen in twins. Due to the sizes of different crystal faces, twin crystals with deeper re-entrant angles are visible beside twins with vanishingly small re-entrant angles *(Figure 16)*.

For the recognition of typical growth zones in faceted chrysoberyls, it can be helpful to orientate a twinned sample with the rotation axis of the sample holder perpendicular to the twin plane. During rotation, one position may be found where the [100] growth zones are symmetrically developed for both individuals of the twin with regard to the twin boundary (view parallel to the *a*-axes of both individuals). In this direction, the different faces of the [100] zone of both individuals are visible *(Figure 16)*.

In simple contact twins, each part of the twin shows two [011] growth zones, i.e. for the complete twin four [011] growth zones are visible, each one with the faces **i**, **o** and **a** (*Figures 16* and *17*). Now, although the [011] axis is not exactly perpendicular to a twin plane on (031), it is sufficiently close (within 1°) so that in practice, the growth planes of the growth zone [011] are visible in a view perpendicular to a twin plane (see *Figure 20* for the relevant twin plane and view). So, in that particular view *(Figure 17 D)*, two of these four [011] zones with faces **i**, **o** and **a** (one of each of the two individuals) are virtually parallel and visible together in the microscope. This means that after a rotation through 180° (viewing the sample from the opposite direction), the same growth pattern can be observed (*Figure 17* and see *Table IV*). After a rotation of 60°, the remaining [011] growth zone of the first individual is parallel to the growth zone [001] of the second individual of the twin *(Figure 17 E)*. This indicates that at one side of the sample, the faces belonging to the [011] zone of the first individual are seen, and at the other side the faces of the growth zone [001] of the second individual are observed. This special feature is a geometric consequence of the twin law of chysoberyl, which is also responsible for the pseudohexagonal nature of the cyclic twins. After a rotation of -60°, the remaining [011] growth zone of the second individual is parallel to the growth zone [001] of the first individual of the twin *(Figure 17F)*.

In relatively small and clean chrysoberyls, growth zones of both individuals of such a twin are visible and careful measurements of the rotation

Table IV: Rotation of chrysoberyl and alexandrite twins and trillings with the *a*-axis [100] as rotation axis, view perpendicular to the rotation axis.

Chrysoberyl twin from Ilakaka, Madagascar; observed zones and faces

Rotation angle [°]	Zones and faces	
	Individual I	Individual II
-120	-[011] **a o i o′ a′**	-[001] **a m s r b r′ s′ m′ a′**
-101	-[012] **a n k n′ a′**	
- 90 view parallel to a twin plane		
-79		-[012] **a n k n′ a′**
-60	-[001] **a m s r b r′ s′ m′ a′**	-[011] **a o i o′ a′**
-30		[010] **a x c x′ a′**
0 view perpendicular to a twin plane	[011] **a o i o′ a′**	[011] **a o i o′ a′**
30	[010] **a x c x′ a′**	
60	[011] **a o i o′ a′**	[001] **a m s r b r′ s′ m′ a′**
79	[012] **a n k n′ a′**	
90 view parallel to a twin plane		
101		[012] **a n k n′ a′**
120	[001] **a m s r b r′ s′ m′ a′**	[011] **a o i o′ a′**

Alexandrite trilling from Tokovaya, Urals, Russia; observed zones and faces

Rotation angle [°]	Zones and faces		
	Individual I	Individual II	Individual III
-60 view perpendicular to a twin plane	[011] **a o i o′ a′**	[001] **a s b s′ a′**	[011] **a o i o′ a′**
-30 view parallel to a twin plane			
0 view perpendicular to a twin plane	[011] **a o i o′ a′**	[011] **a o i o′ a′**	[001] **a s b s′ a′**
30 view parallel to a twin plane			
60 view perpendicular to a twin plane	[001] **a s b s′ a′**	[011] **a o i o′ a′**	[011] **a o i o′ a′**
90 view parallel to a twin plane			
120 view perpendicular to a twin plane	[011] **a o i o′ a′**	[001] **a s b s′ a′**	[011] **a o i o′ a′**

After rotation through 180°, the same sequence of faces is observable; this is indicated by identical background colours of the respective rows within the table.

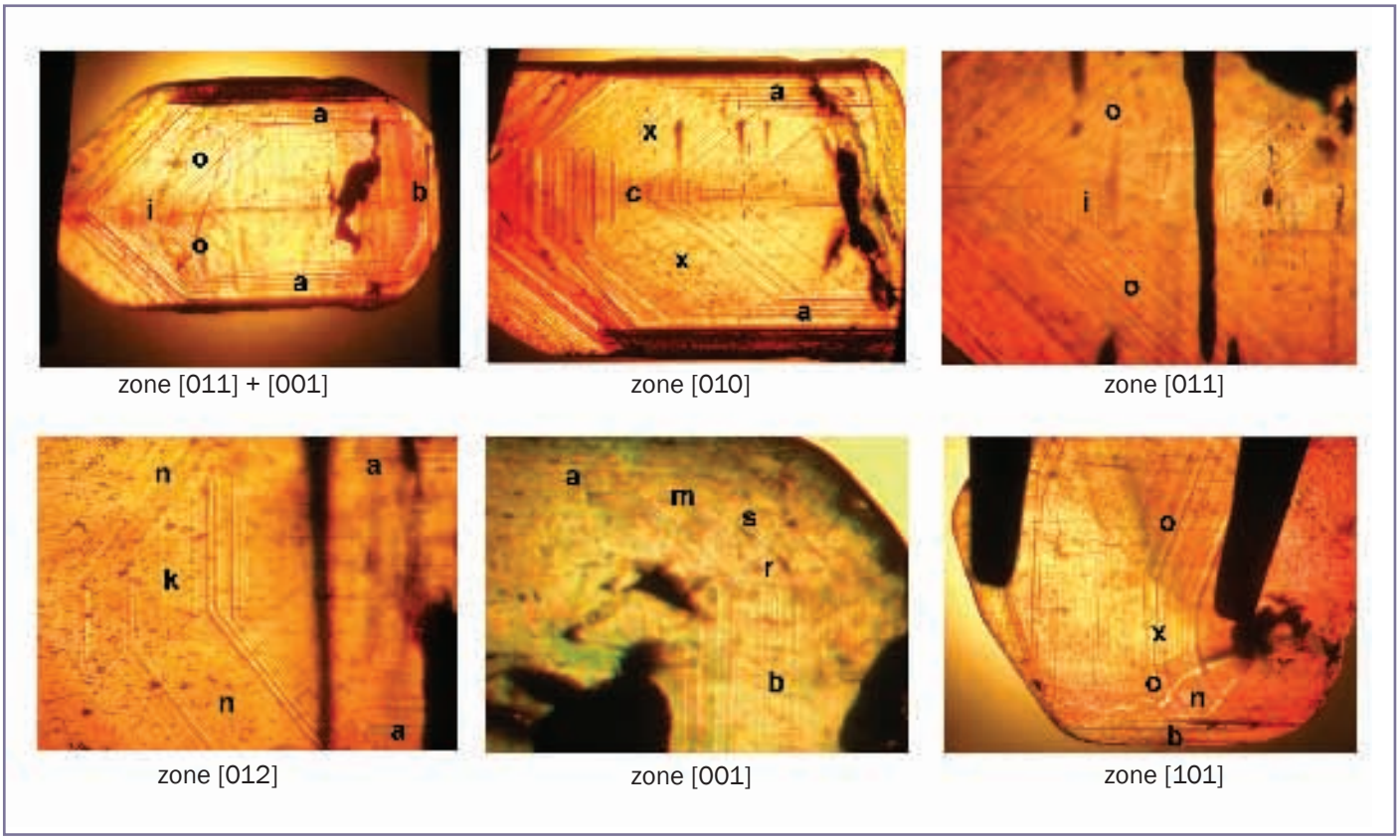

Figure 18: Different growth zones in chrysoberyl contact twins from Ilakaka, Madagascar. According to the orientation of the twin, the growth zones [011] and [001] of both parts of the crystal are shown together (upper left, see also Figure 17 E,F), in other parts of the twin, only one specific growth zone is visible. All photos in immersion, magnification from 15 to 40 ×.

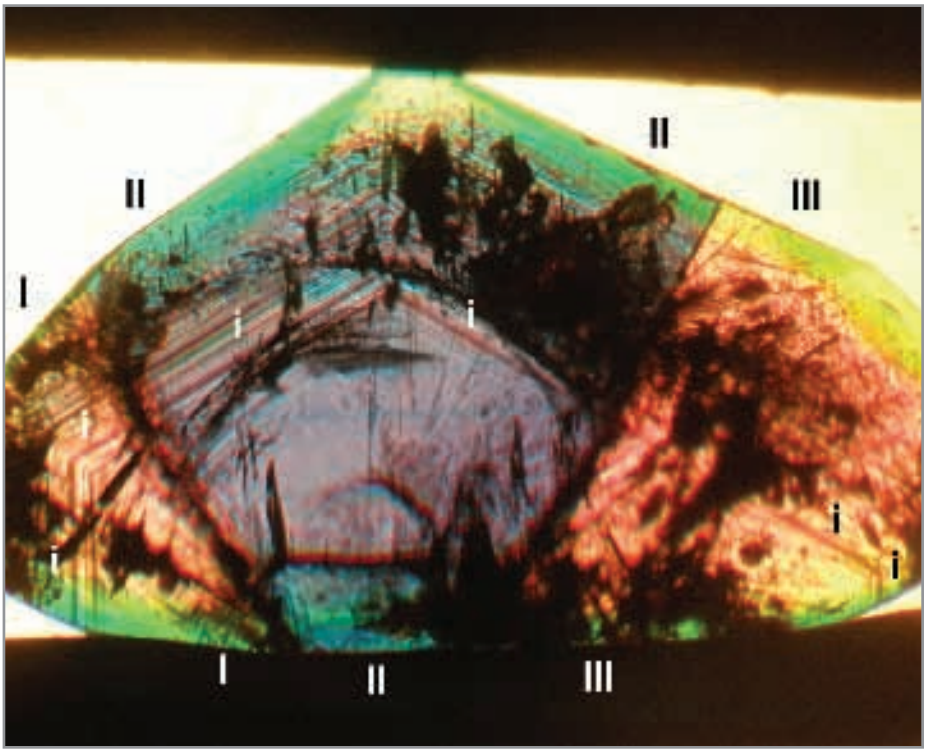

*Figure 19: Alexandrite trilling from the Urals, Russia, looking parallel to the a-axis. The a-axes of all three components of the twin, I, II and III, are parallel. In this orientation, in each part of the trilling two **i** prism faces are observed; this sample has no re-entrant angles. Immersion, 40 ×.*

angles versus the twin plane are necessary to assign the observed zones and faces to one of the two individuals (see *Table IV*). Using the *a*-axis of the twin as rotation axis of the sample holder, in addition to the various [011] and [001] growth zones mentioned above, the faces of the [010] and [012] growth zones can also be visible on rotation. An overview concerning rotation angles and growth zones is given in *Table IV* and examples are pictured in *Figure 18*. If a different setting is used with the *b*-axis of one individual of a twin as the rotation axis, the faces of the [101] growth zone can also be observed *(Figure 18)*.

In trillings, the *a*-axes of all three components of the twin are parallel to each other *(Figures 19* and *20)*. With the same orientation as mentioned above for twins, i.e. with the *a*-axes parallel to the rotation axis of the sample holder, similar observations are possible and can be interpreted with the help of the schematic drawing in *Figure 20*. In a view

perpendicular to one of the three twin planes, the [011] zones of two individuals of the trilling are virtually parallel *(Table IV)* and are visible right and left of the centre of the alexandrite. In the same view, the [001] zone of the third individual of the trilling may be seen in the centre. Consequently, these different patterns are not related to the same part of the rough or faceted trilling and would be seen on opposite parts or ends of a sample *(Figure 21)*. This pattern is repeated (for complete samples) after each rotation through an angle of 60°.

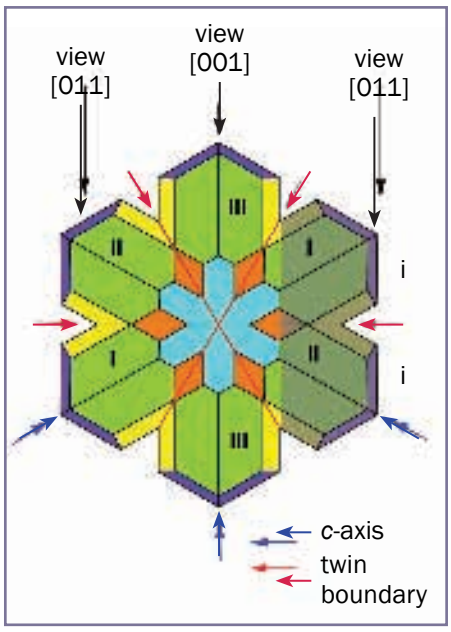

*Figure 20: Diagram of alexandrite trilling with deep re-entrant angles, projection parallel to the a-axis. In this orientation, all **i** prism faces of the different parts of the trilling are visible. In views perpendicular to this projection (indicated by → and view), which is consequently perpendicular to the a-axis, the [011] zones of two individuals (I and II) of the trilling are virtually parallel, and parallel to the [001] zone of the third individual (III); the grey part of the trilling is absent in the crystal pictured in Figure 21.*

Conclusions

With a detailed knowledge of what patterns of internal growth structure are possible, the measurement and interpretation of characteristic growth zones in faceted optically biaxial gemstones such as chrysoberyl is achievable using immersion microscopy. Although not as straightforward as in optically uniaxial gemstones, patterns perhaps consisting of up to several growth areas can be assigned to various growth zones. The orientation of growth planes relative to the twin boundary may also assist understanding of the observed structural pattern. The observation of pleochroism and search for the positions of optic axes can also provide useful complementary information. Currently growth patterns in alexandrites from all major commercial sources, e.g. Russia, Brazil, Sri Lanka, Madagascar, Zimbabwe, India and Tanzania, are being compiled and, in combination with trace element contents, they will be a useful factor in origin determination of these gems.

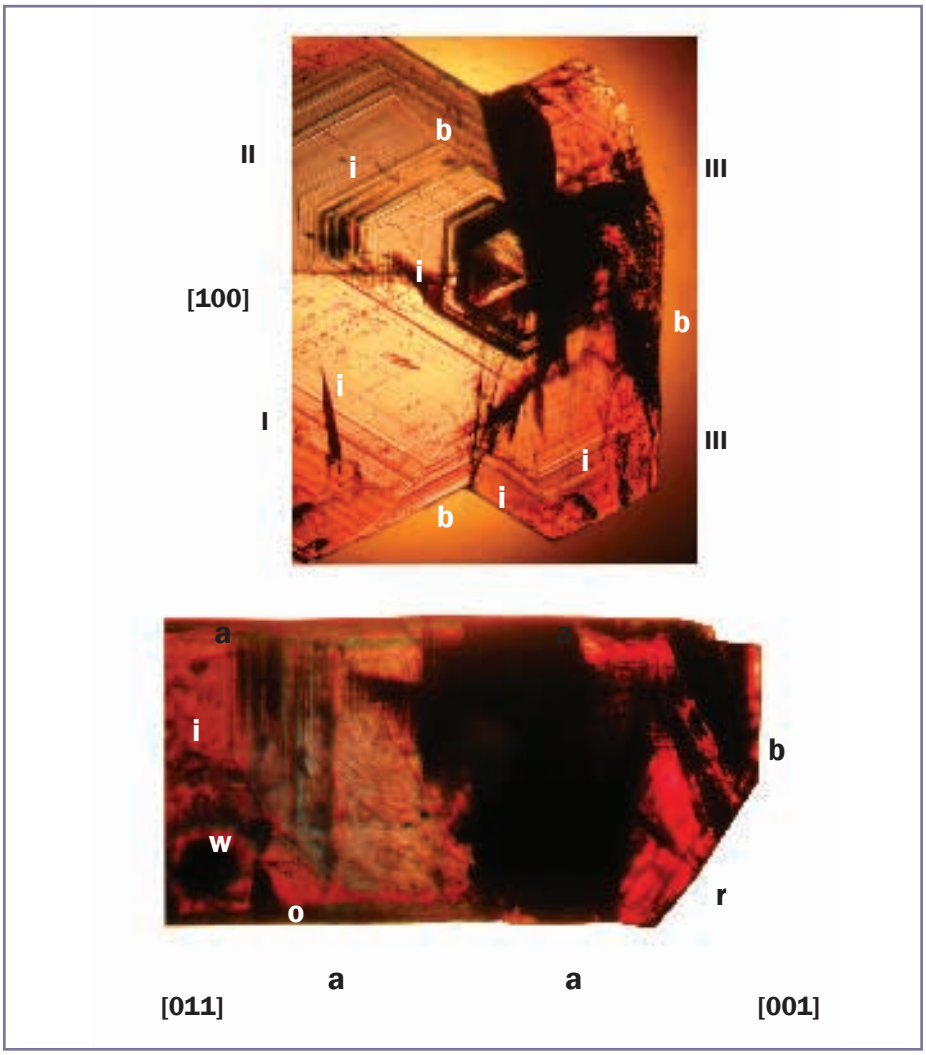

*Figure 21: Alexandrite trilling from Lake Manyara, Tanzania. Top: view parallel to the a-axis; the three individuals I, II and III show growth planes parallel to the faces **i** and **b**. Below: view perpendicular to the a-axis; for two parts I and II of the trilling (left), the zone [011] is visible in which the growth planes **a**, **o**, **w** and **i** of both parts of the trilling are near-parallel; for the third part of the trilling III (right) the growth zone [001] with faces **r** and **b** is visible. Immersion, 20 ×.*

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All photos and crystal drawings by the author.

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A Russian Maxixe beryl?

Lars Olov Andersson

Abstract: Maxixe beryl has a deep blue colour, which fades upon extended exposure of the crystal to daylight. In a 1976 publication a colourless Russian beryl was reported to contain a considerable amount of NO_2. The published EPR spectrum of this beryl is similar to that of a bleached Maxixe beryl. Analysis of the colour centres of Maxixe beryl and the artificially created Maxixe-type beryl indicate that samples of this Russian beryl could display the blue colour of Maxixe beryl after irradiation.

Keywords: EPR, Maxixe beryl, NO_2 in beryl

Introduction

The observation of NO_2 impurities in a colourless Russian beryl by Electron Paramagnetic Resonance (EPR) spectroscopy (Sukharzhevskii, 1976) suggests that this Russian beryl may have had (and can again obtain) the features of the rare Maxixe beryl found around 1917 in Brazil. This possibility is based on a study of the creation and decay of the colour centre in the Maxixe beryl. Comparison of these processes is also made with the behaviour of the colour centre in the Maxixe-type beryl which appeared on the gemstone market around 1973.

A crystal of beryl ($Be_3Al_2Si_6O_{18}$) consists of silicate rings stacked upon each other, like stacks of doughnuts. The holes in the middle form channels stretching throughout the crystal structure. These channels are parallel to the *c*-axis of the beryl crystal and have a diameter which varies between 2.8 Å in the rings and 5.1 Å between the rings. Neighbouring stacks are held together by Be and Al ions. Impurity ions like Fe, Mn and Cr can replace Al or Be ions in natural beryl crystals. Relatively large amounts (often more than one weight %) of other impurities, mainly alkali ions and water, but also CO_2 and CH_4 molecules, can be located in the channels.

Chemical bonds in molecules (such as CO_2), ions (such as CO_3^{2-}), and crystals usually contain paired electrons. NO_2 and NO_3 molecules are exceptions with unpaired electrons. Unpaired electrons are also a result from irradiation which can remove one electron (as in CO_3^-) or add one electron (as in CO_2^-). EPR spectrometers are used to detect such unpaired electrons and study their behaviour. They can also be used to study the unpaired electrons in paramagnetic ions (such as Fe^{3+} and Cr^{3+}). When a strong magnetic field is applied, the spin of the electrons will be oriented parallel or antiparallel to the magnetic field. These orientations have different energy levels and transitions between them occur in the microwave region. The EPR spectrometer registers the microwave absorption of the unpaired electrons. The spectrum is obtained by keeping the microwave frequency constant and changing the magnetic field.

Maxixe beryl and Maxixe-type beryl

Maxixe beryl was first described in the scientific literature by Wild (1933), who stated that the crystal had been found 15 years earlier in the Maxixe mine. This beryl had a deep blue colour, which faded when the crystal was kept for many days in daylight. It is strange that there are no earlier reports about this unusual beryl, after it had caused the gemstone dealers such disappointment. The samples investigated by Wild had been kept in the dark since about 1917 and had not lost their blue colour. More detailed investigations of this material were made by Schlossmacher and Klang (1935) and by Roebling and Tromnau (1935). Schlossmacher and Klang (1935) describe the location of the Maxixe mine in Minas Gerais, Brazil, and state that the mine was closed when the loss of colour caused a lot of trouble. One other of Wild's samples has been described in detail by Schiffman (1977). No other beryl with the same properties as Maxixe beryl has since been reported.

In 1972–1973 more beryl crystals of an intense blue colour appeared on

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the gemstone markets, but the initial enthusiasm for these beautiful stones changed to disappointment when it was found that their colour also faded upon extended exposure to daylight in shop window displays. Nassau *et al.* (1976) investigated these crystals and established that they have the opposite dichroism to that of aquamarine. The blue colour of the new beryl is carried by the ordinary ray, while that of aquamarine is carried by the extraordinary ray. Nassau *et al.* (1976) called these new beryls Maxixe-type beryls because their optical absorption spectra contained similar, but slightly different, absorption bands to those from the rare Maxixe beryl. They were also able to create similar blue crystals by irradiation of some other beryls. As will be seen below, this should be possible when the beryls contain enough carbonate ions.

Origin of the blue colour

The different colours of beryl are usually related to paramagnetic ions (iron, manganese, chromium, vanadium) substituting for aluminium in the octahedral sites between the stacks of silicate rings in the beryl crystal structure. However, Maxixe beryl has a very low content of such ions (Roebling and Tromnau, 1935) and the unusual blue colour centres of Maxixe and Maxixe-type beryl are instead located in the beryl channels.

Using EPR spectroscopy, Andersson (1979) determined that the colour centre in Maxixe beryl is the NO_3 molecule, while the colour centre in Maxixe-type beryl is CO_3^-. Since these centres have the same number of electrons in the same molecular orbitals (that is they are isoelectronic), their optical absorption spectra are very similar. However, their EPR spectra are different because the nuclei of the colour centres interact differently with the unpaired electron. The oxygen and carbon nuclei of CO_3^- have no influence on the EPR spectrum, but the nitrogen nucleus of NO_3 splits the EPR signal into three lines. It is therefore easy to separate Maxixe and Maxixe-type beryl by EPR spectroscopy.

Both the NO_3 and CO_3^- groups (radicals) are planar and fit in the widest part of the beryl channel where they are oriented with their trigonal symmetry axis parallel to the crystal *c*-axis. This well-defined orientation gives rise to the strong pleochroism of the blue colour.

Creation of NO_3 and CO_3^- colour centres in beryl

Nassau *et al.* (1976) concluded that the blue colour centre in Maxixe-type beryl is created by irradiation while the Maxixe colour centre is of natural origin. Different possibilities of how CO_3^- and NO_3 radicals could be created in beryl will now be considered.

One possibility is that CO_3^{2-} and NO_3^- ions existed in the original melt and were trapped in the channels of the beryl crystal during its formation. An electron can be removed from each of these ions by irradiation to create CO_3^- and NO_3. The released electron can be caught by an impurity proton to form a hydrogen atom. Such atoms have been detected in both Maxixe and Maxixe-type beryl by EPR. If this scheme is correct, it can be concluded that both colour centres have been created by irradiation.

A second possibility is that CO_2 and NO_2 molecules were trapped from the original melt during the beryl crystal formation. Wood and Nassau (1967) observed the optical absorption of CO_2 in many beryl crystals and Andersson (1979 and 2010) observed the EPR signal of NO_2 in Maxixe beryl. It has been shown that H_2O molecules can diffuse in the beryl channel (Fukuda, 2009). If a water molecule enters a wide portion of the channel containing a NO_2 molecule, it can combine with this molecule to form NO_3. The hydrogens are split off as single atoms, which have been detected in the EPR spectrum of Maxixe beryl. The probability that this combination of molecules will happen may be very small, so that it could have taken many thousands of years until a sufficient number of stable NO_3 molecules were created to give the Maxixe beryl its intense blue colour. This process was proposed by Andersson (2008) to explain the existence of NO_3 in natural beryl crystals. The corresponding process forms CO_3^{2-} in beryl containing CO_2 and in this case the hydrogen is split off as protons. Irradiation creates the Maxixe-type colour centre CO_3^- and the released electron is captured by a proton to form a hydrogen atom.

A third possibility is that OH^- ions diffuse in the structural channel and combine with CO_2 or NO_2 to form CO_3^{2-} or NO_3^-. This possibility has been discussed in detail by Andersson (2006). As in the first possibility, irradiation is needed to create the Maxixe beryl.

Decay of the NO_3 and CO_3^- colour centres

Nassau *et al.* (1976) found that the colour of both Maxixe beryl and Maxixe-type beryl disappeared when the crystals were exposed to daylight for one week or were heated to 200°C for one hour. They observed that while the colour of Maxixe-type beryl was created in one single process, its decay exhibited one fast and one slow component. Edgar and Vance (1977) found that the decay of the CO_3^- EPR signal upon heating of Maxixe-type beryl at 175°C correlated very well with the decay of the optical absorption, while the decay of the hydrogen atom signal was less pronounced in the initial stage.

Both Maxixe and Maxixe-type beryl contain hydrogen atoms which are stable at room temperature, which is rather unusual. The hydrogen atom easily dissociates into a proton and an electron. The released electron can combine with CO_3^- to form a CO_3^{2-} ion or with NO_3 to form a NO_3^- ion, and the colour centres will disappear. I therefore suggest that the dissociation of the hydrogen atom is the cause of bleaching in Maxixe and Maxixe-type beryl. The hydrogen atom loses its electron and the bleaching occurs when the crystals are heated above 100°C or are exposed to light.

Andersson (2008) found that some of the electrons which were released by the irradiation of Maxixe-type beryl were trapped by CO_2 molecules to form

CO_2^- radicals. (This explains why the CO_2 absorption in the infrared spectrum of Krambrock *et al.* (2002) disappeared upon irradiation.) These radicals lose their electrons at a lower temperature than the hydrogen atoms and cause the initial decay of the CO_3^- colour centres. That is why the decay curve has two components in Maxixe-type beryl, with the slow component corresponding to the decay of the hydrogen atoms. The decay of colour in Maxixe beryl will have only one component.

NO_2 in Maxixe beryl and in a Russian beryl

The EPR signal of NO_2 has been detected in a colourless Russian beryl by Sukharzhevskii (1976). It is split into three lines by the nitrogen nucleus. These lines are of equal width and intensity when the magnetic field is oriented parallel to the crystal *c*-axis and in the spectrum they are separated by 66 Gauss, which in modern units is 6.6 milliTesla (mT). This beryl was found on the Kola peninsula in northwestern Russia (Sukharzhevskii, pers. comm., 2011). The Kola beryl has a high content of Cs ions, like the other beryls in which NO_2 has been observed.

Dr Gübelin of Lucerne kindly donated a piece from the Maxixe crystal in his collection for the EPR measurements, which were performed in 1977. I was not able to orient this irregular mm-size piece parallel to the *c*-axis, but a later extrapolation of the NO_2 signal positions observed at other angles converges to three narrow lines for the orientation parallel to the *c*-axis. This extrapolation (Andersson, 2010) was made before I was aware of the 1976 publication by Sukharzhevskii, but fits very well with his spectrum.

EPR spectra obtained with different orientations of the magnetic field give information about the orientation of the NO_2 molecule. Sukharzhevskii (1976) found that the molecular plane is perpendicular to the crystal *c*-axis and suggested that the NO_2 molecules are located between the stacks of silicate rings. Solntsev (1981) interpreted the data differently and located the NO_2 molecules in the beryl channel, at the same position as the NO_3 molecules. He suggested that they are oriented in six equivalent positions in the hexagonal symmetry. Andersson (2010) found that the NO_2 molecules in Maxixe beryl are evenly distributed over all possible orientations in the plane perpendicular to the crystal *c*-axis.

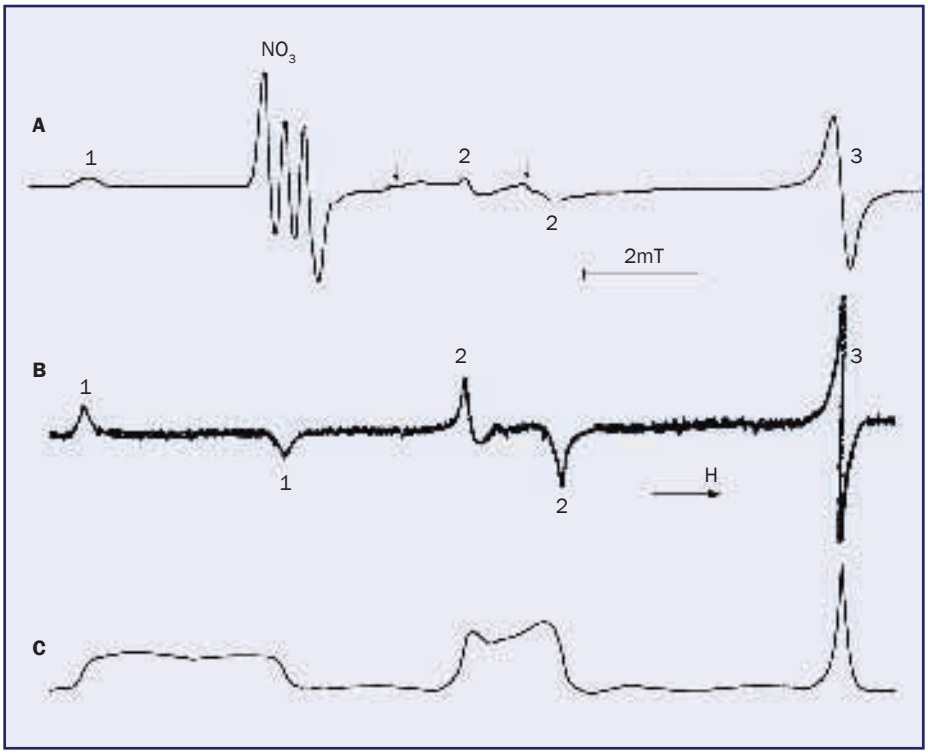

Figure 1: EPR spectra obtained at 9.2 GHz with the magnetic field H oriented perpendicular to the crystal c-axis. The strength of the field H is changed around the resonance field of the free electron near 330 mT. Trace A was obtained from Maxixe beryl at −180 °C and trace B from the Russian beryl at −196 °C. Trace C is the integral of the spectrum in trace B. Further explanations are given in the text.

The EPR spectra with the magnetic field oriented perpendicular to the crystal *c*-axis are shown for Maxixe beryl in trace A and for the Russian beryl in trace B of *Figure 1*. For technical reasons the EPR signal is recorded as the derivative of the absorption. An integration of trace B shows the three absorption lines in trace C of *Figure 1*. The two low field lines have been broadened. (Because of the background noise in trace B, the integral is not completely accurate: the areas beneath each of the three absorption lines should be equal.)

It can be seen that the intensity is evenly distributed over the range of the absorption for each of the two low field lines in trace C. If the NO_2 molecules had only six different orientations as suggested by Solntsev (1981), the low field lines should have consisted of a few separate absorptions. The absorption in trace C shows that there is an even distribution of NO_2 orientations over all angles in the Kola beryl, as there is in the Maxixe beryl.

The end points of the distributed absorptions appear clearly in the derivative spectrum in trace B and are marked with 1 and 2 for the two low field lines. These signals are also present in trace A from the Maxixe beryl. In this spectrum line 1 is partly overlapped by the signal from NO_3, which has a much smaller splitting of 0.5 mT. The EPR signal of the hydrogen atom is outside the range of *Figure 1* because the hydrogen nucleus splits the signal into two lines 50 mT apart. The EPR signal from NO_2 can

only be observed at temperatures below −140 °C and is still somewhat broadened at −180 °C. The derivative peaks are therefore not so sharp in trace A as in trace B which was obtained at −196 °C.

Andersson (2010) has shown that it is a coincidence that line 3 has the same narrow shape as in the spectrum with the magnetic field parallel to the *c*-axis and that the spread of line 1 is twice as large as that of line 2. In the spectrum from an EPR spectrometer operating at another microwave frequency line 3 would also be broadened.

Discussion

Reports about NO_2 and NO_3 impurities in other beryls are rare and their concentrations have been so small that no colour has been observed. The EPR spectrum from the 1973 Maxixe-type beryl contains very small signals from NO_2 (Andersson, 2010) and NO_3 (Andersson, 1979). Solntsev (1981) reported EPR parameters for NO_2 and NO_3 in natural beryl and in synthetic hydrothermal beryl, but does not mention a blue colour or the origin of his samples. Krambrock *et al.* (2002) detected EPR signals from CO_3^- and NO_3 in natural pink beryl from Minas Gerais in Brazil. It is strange that CO_3^- is present in the unirradiated crystal and that a signal identified as NO_2 was observed only after irradiation. In a later publication, Pinheiro *et al.* (2007) reported that only the NO_3 signal was present in the natural crystal while the CO_3^- signal appeared after irradiation. The intensity of the NO_3 signal remained about the same before and after the irradiation.

An interpretation of the observations by Pinheiro *et al.* (2007) is that the natural crystal contained CO_3^{2-} and an amount of NO_3 which was not enough to give the crystal a colour. The irradiation created enough CO_3^- to colour the crystal blue but no additional NO_3. If the natural crystal had contained NO_3^-, the irradiation should have created additional NO_3.

Two of the possible processes for creation of the colour centre in Maxixe beryl involve NO_3^- ions and irradiation. The irradiation need not have been artificial, but could have come from natural sources. Irradiation also creates CH_3 from CH_4 molecules in the beryl channel and the EPR signal from CH_3 can easily be detected in the spectrum from the artificially irradiated Maxixe-type beryl (Andersson, 2008). A much smaller CH_3 signal is detected in the Maxixe beryl and is indicated by arrows in trace A of *Figure 1*. Although natural radiation at the Maxixe locality may have created such a small signal, it was probably not sufficiently intense to have caused the much stronger NO_3 signal. (An alternative, but unlikely, interpretation is that the natural radiation was very strong and that the CH_4 content in Maxixe beryl was very small.) This supports the assumption that NO_3 was created by a different process and not by irradiation of NO_3^-.

The most likely process involves a combination of H_2O and NO_2 without the influence of radiation. The NO_2 molecules could have been trapped in the beryl crystals during their formation and some of these impurities have been transformed into NO_3 over geological time. This could have happened in both the Maxixe beryl and the Russian beryl. The NO_3 colour centres in the Kola beryl may then have been converted into NO_3^- by catching the electrons from the decay of the hydrogen atoms when the crystal was exposed to daylight or was heated above 100 °C in recent geological time. Sukharzhevskii (1976) mentions that a zone of the crystal is weakly blue, which may indicate that some NO_3 remains.

The rest of the original NO_2 molecules are not influenced by heat or light and their EPR signal remains the same in both Maxixe and Kola beryl. The signals from the hydrogen atoms and NO_3 molecules in Maxixe beryl disappear when the crystal is bleached. The colour centres are then not converted back to NO_2 but are transformed to NO_3^- ions.

Nassau *et al.* (1976) found that the colour of bleached Maxixe beryl could be restored by irradiation with neutrons or γ-rays. This would be the case if the irradiation removes the electron from NO_3^-, which recreates the NO_3 colour centre. Irradiation is therefore needed to restore the colour centre in Maxixe beryl, but not for its initial creation. Andersson (2008) showed that the colour of Maxixe-type beryl can be restored by UV irradiation. If this is the case also for Maxixe beryl, it may be possible that the Kola beryl could display the same deep blue colour as Maxixe beryl without the discolouring caused by more intense irradiation (Nassau *et al.,* 1976). This possibility should be borne in mind if such stones should appear in the gemstone market. Collectors and dealers should be aware that such a blue beryl would lose its colour upon extended exposure to daylight.

Conclusion

Considerable amounts of NO_2 impurities have been found in only two beryl crystals, the Kola beryl and the Maxixe beryl. The EPR spectrum of the colourless Kola beryl contains only the NO_2 signal, while that of the Maxixe beryl also contains NO_3 and hydrogen signals. The latter two signals disappear when the Maxixe beryl is bleached. The Kola beryl may therefore be a bleached Maxixe beryl and should turn blue when it is irradiated.

A definite classification of the Kola beryl as a Maxixe beryl could only be made if the NO_3 colour centre is detected after irradiation of a crystal from the same location as the beryl which was investigated in 1976.

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Chemical and growth zoning in trapiche tourmaline from Zambia — a re-evaluation

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Abstract: Trapiche tourmalines from Zambia show the hexagonal prism **a** $\{11\bar{2}0\}$, the positive pyramids **r** $\{10\bar{1}1\}$ and **o** $\{02\bar{2}1\}$ and the negative pyramid **–r** $\{01\bar{1}\bar{1}\}$ as dominant external crystal forms. The trapiche pattern is formed by the positioning of liquid and solid inclusions which are trapped at growth boundaries between pyramidal and prismatic growth sectors. Growth-induced elongate voids are also formed perpendicular to the dominant growth faces, which are inclined at 27°, at 46° or at 90° to the pedion {0001} of the tourmaline hosts.

All the trapiche tourmalines are chemically zoned with isomorphic substitutions of Ca by Na and Mg by Al, which is characteristic for tourmalines of the uvite-dravite solid solution series. Content of Na increases and of Ca decreases from core to rim of all tourmalines. However, at the boundaries between different growth sectors (forming the geometric trapiche pattern of the samples), tourmaline compositions with higher Na and lower Ca contents than measured in adjacent pyramidal and prismatic growth sectors were found.

The formation of this complex structural and chemical pattern is consistent with the formation of the tourmaline crystals in a two step process, with the skeletal growth of a sodium-rich dravite in a first step and the subsequent, layer-by-layer growth of a second tourmaline generation. The growth of the second generation started with calcium-rich fluor-uvite and was followed step-by-step by a more sodium-rich dravite. The green coloration of the samples is caused by minor contents of vanadium and chromium.

Above: Slices of trapiche tourmaline from Zambia cut perpendicular to the c-axis. In the centre of the slice, upper left, the dark arms of the fixed three-rayed star separate three pyramidal growth sectors. The slice, lower right, cut from the same tourmaline, has a rim with six prismatic growth sectors which are separated from each other and from the pyramidal growth sectors of the centre by less transparent boundaries. View parallel to the c-axis, size of the samples about 13 × 12 mm. Photos by T. Hainschwang.

1. Introduction

Gem materials designated as trapiche are rare in the gemstone and mineral trade, and this is because there is only a limited number of mineral species which show a clear trapiche pattern, i.e. a pattern with a clear separation into distinct growth sectors, best seen in cabochons or polished slices. The boundaries of these growth sectors are normally sharp and decorated with mineral or fluid inclusions, in this way separating a core from a rim or separating different parts within the rim. From these sector boundaries which are also described as arms of a fixed six-rayed or three-rayed star, growth tubes filled with mineral and/or fluid phases commonly run into the different

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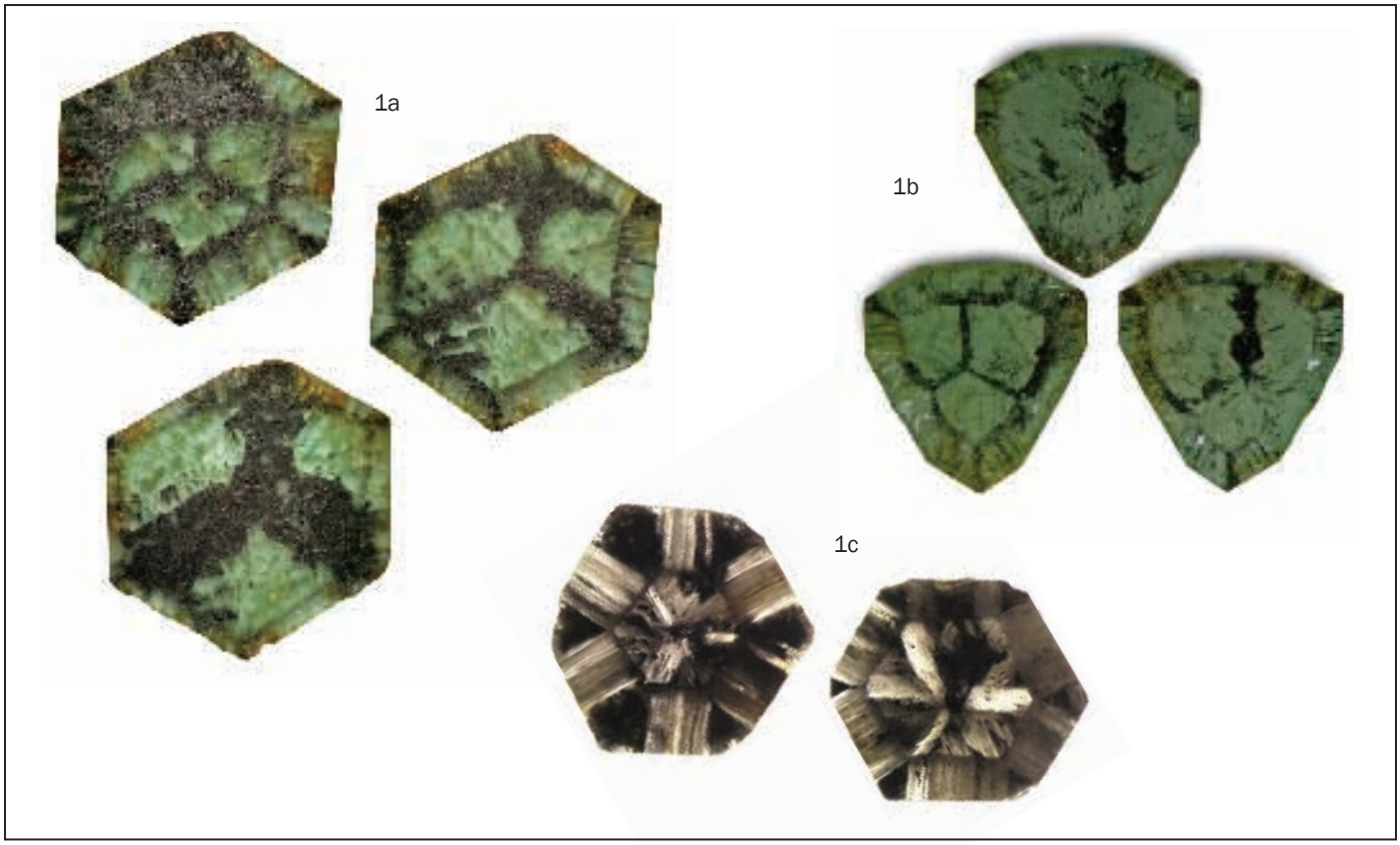

Figure 1a: Three slices of trapiche tourmaline from Zambia with hexagonal outline cut from the same crystal perpendicular to the c-axis; in the centre, the arms of a fixed three-rayed star separate three pyramidal growth sectors of the tourmaline crystal; the rim consists of six prismatic growth sectors which are separated from each other and from the pyramidal growth sectors of the centre by less transparent boundaries; the sizes of cores and rims vary according to the position of the slices along the c-axis of the tourmaline crystal. Views parallel to the c-axis, the samples measure about 32 mm in diameter.
Figure 1b: Three slices of trapiche tourmaline from Zambia with trigonal outline cut from the same crystal perpendicular to the c-axis; in the centre, the arms of a fixed three-rayed star separate three pyramidal growth sectors of the tourmaline crystal; the rim consists of nine (three plus six) prismatic growth sectors which are separated from each other and from the pyramidal growth sectors of the centre by less transparent boundaries; the sizes of cores and rims vary according to the position of the slices along the c-axis of the tourmaline crystal. Views parallel to the c-axis, size of the samples about 7 × 8 mm.
Figure 1c: Two slices of trapiche tourmaline from Zambia with hexagonal outline cut perpendicular to the c-axis; in the centre, the boundaries distinguish six (three plus three) different pyramidal growth sectors; at the rim there are six prismatic growth sectors which are distinguished from each other and from the pyramidal growth sectors of the centre by more included borders or boundaries. Views parallel to the c-axis, size of the samples about 9 × 10 mm.
All photos by T. Hainschwang: a and b in reflected light; c in transmitted light.

transparent growth sectors between these arms. The gem minerals showing a distinct trapiche pattern most commonly seen are emeralds from Colombia and rubies from Mong Hsu, Myanmar (Nassau and Jackson, 1970a,b; Schmetzer *et al.,* 1996). Different models have been described to explain the growth mechanism of the trapiche pattern (see, e.g., Nassau and Jackson, 1970 a,b; Sunagawa *et al.,* 1999). Recently, another trapiche mineral was added to this list, trapiche tourmaline from Zambia (Hainschwang *et al.,* 2007).

According to Hainschwang *et al.* (2007), the Zambian trapiche tourmalines originate from the Kavungu mine near the small village of Jivunda, southwest of Mwinilunga in the northwestern part of the country near the border with Angola. Tourmaline crystals show the hexagonal prism **a** $\{11\bar{2}0\}$ as well as the positive rhombohedron **r** $\{10\bar{1}1\}$ and the negative rhombohedron **−r** $\{10\bar{1}\bar{1}\}$ as external crystal forms.

Slices of trapiche tourmalines cut perpendicular to the *c*-axis can show two different patterns (see photograph on page 151):

(a) a three-rayed star with three transparent tourmaline sectors between the three arms of the fixed star and, in most crystals,
(b) the pattern described above in the centre of the slice, surrounded by six transparent sectors of tourmaline, with six boundaries between the centre and the rim and six boundaries between the six sectors of the rim.

The crystals may also contain two types of channels, running "nearly parallel to the *c*-axis" and "close to perpendicular" to the *c*-axis.

After the description of trapiche tourmaline from Zambia was published, one author (KS) examined some crystals reportedly from the same occurrence which showed additional crystal faces not mentioned in the Hainschwang *et*

al. (2007) paper and which indicated that additional or different patterns not yet described could also be present. Furthermore, one author (TH) obtained additional samples from his suppliers, mostly in the form of polished slices cut perpendicular to the *c*-axis, which also revealed a somewhat different trapiche pattern. These specimens warranted a more detailed description.

The first 15 tourmaline crystals available to the authors were mostly broken along the columnar outline formed by various prism faces and were not complete doubly terminated crystals. Most slices had been cut perpendicular to the *c*-axis, but a series of slices cut from one crystal along the *c*-axis was also available. To obtain additional information, the authors purchased seven unbroken tourmalines from the stock of a mineral and gemstone dealer who had also a large number of cut and polished slices of trapiche tourmaline from Zambia. These crystals were used for the determination of the polarity of the tourmalines. This is described in terms of the antilogous (+) and the analogous poles (-) of the crystals, and some were sliced parallel to the *c*-axis to relate polarity to internal structures. Finally, the authors received a large parcel of tourmaline crystals and fragments from the same supplier as a donation for research purposes.

2. Determination of the external morphology

The numerous tourmaline slices cut perpendicular to the *c*-axis were subdivided into three basic types, designated A, B and C in the following description *(Table I, Figure 1)*:

The main differences between the types are colour, outline, and number of growth sectors in core and rim. Also the numerous channel inclusions in the transparent tourmaline sectors show different orientations. In the rims of all samples, the channels run more or less perpendicular to the *c*-axis, but in all growth sectors of the core they are at various inclinations to it. Various slices parallel or perpendicular to the *c*-axis, which still show external prismatic or pyramidal crystal faces, indicate that all channels in the transparent growth sectors are perpendicular to these external prismatic or pyramidal crystal faces.

Table I: Main types of trapiche tourmalines from Zambia

	Type A (Figure 1a)	Type B (Figure 1b)	Type C (Figure 1c)
Colour	green, occasionally zoned	green	colourless
Outline of prism zone	hexagonal	trigonal	hexagonal
Clear transparent sectors in the core	3, with more or less broad, less transparent boundaries	3, with more or less broad, less transparent boundaries	6 (3 + 3), with more or less broad, less transparent boundaries
Clear transparent sectors in the rim	6, with more or less broad, less transparent boundaries	9 (3 + 6), with more or less broad, less transparent boundaries	6, with more or less broad, less transparent boundaries

Although no direct internal growth planes were visible in our samples, using this information in combination with goniometric measurements of external crystal faces of several rough tourmalines, we were able to determine the morphology and orientation of type A samples, which represented more than 90% of the tourmalines available. The tourmaline samples of types B and C contained no complete crystals with both poles; most pieces were broken or sliced perpendicular to the *c*-axis and showed only the external prism faces with no pyramids. In those samples containing at least one pole (end) of a rough crystal, the faces were not of suitable quality for goniometric measurement. Therefore, only an indirect reconstruction of crystal morphology on the basis of channel orientation was possible for types B and C.

2.1 External morphology of samples of type A

Most type A crystals show the hexagonal prism **a** as the dominant crystal form, sometimes in combination with a small trigonal prism **m** (see *Table II*). The few crystals which show trigonal prism faces **m** which are larger than the hexagonal prism faces **a** are classified as samples of type B. From goniometric measurements, the faces at the ends of the crystals were identified as the trigonal pyramids **r** or **o**, with some crystals having

Table II: Morphology and growth patterns of trapiche tourmalines from Zambia

	Crystal form	Designation (number of faces)	Miller indices	Inclination to the pedion c (°)
Antilogous pole (+)	trigonal pyramid	**r** (3)	$\{10\bar{1}1\}$	27.35
		y (3)	$\{40\bar{4}1\}$	64.21
		o (3)	$\{02\bar{2}1\}$	45.97
Prism zone	hexagonal prism	**a** (6)	$\{11\bar{2}0\}$	90
	trigonal prism	**m** (3)	$\{01\bar{1}0\}$	90
Analogous pole (-)	trigonal pyramid	**–r** (3)	$\{01\bar{1}\bar{1}\}$	27.35
	pedion	**–c** (1)	$\{000\bar{1}\}$	0
Both poles	edge between two trigonal pyramids **r** and **r′** or **–r** and **–r″**	-	-	14.50

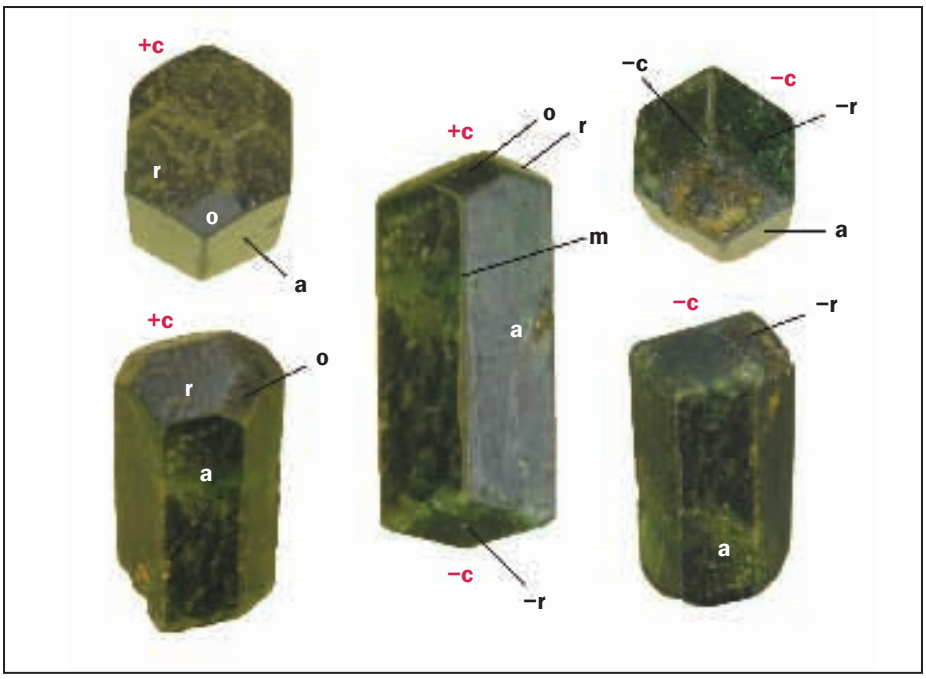

*Figure 2: Trapiche tourmaline from Zambia: one crystal in different orientations. Centre: view perpendicular to the c-axis; left: view of the antilogous pole (+); right: view of the analogous pole (-); the pedion sign in red **+c**, **-c** indicates the polarity of the crystal. The prism zone is formed by the dominant hexagonal prism **a** and by subordinate trigonal prisms **m**, the antilogous pole consists of the trigonal pyramids **r** and **o**, the analogous pole consists of the trigonal pyramid **–r** and the pedion **–c**. Size of the crystal approx. 7.5 × 15.5 mm. Photos by K. Schmetzer.*

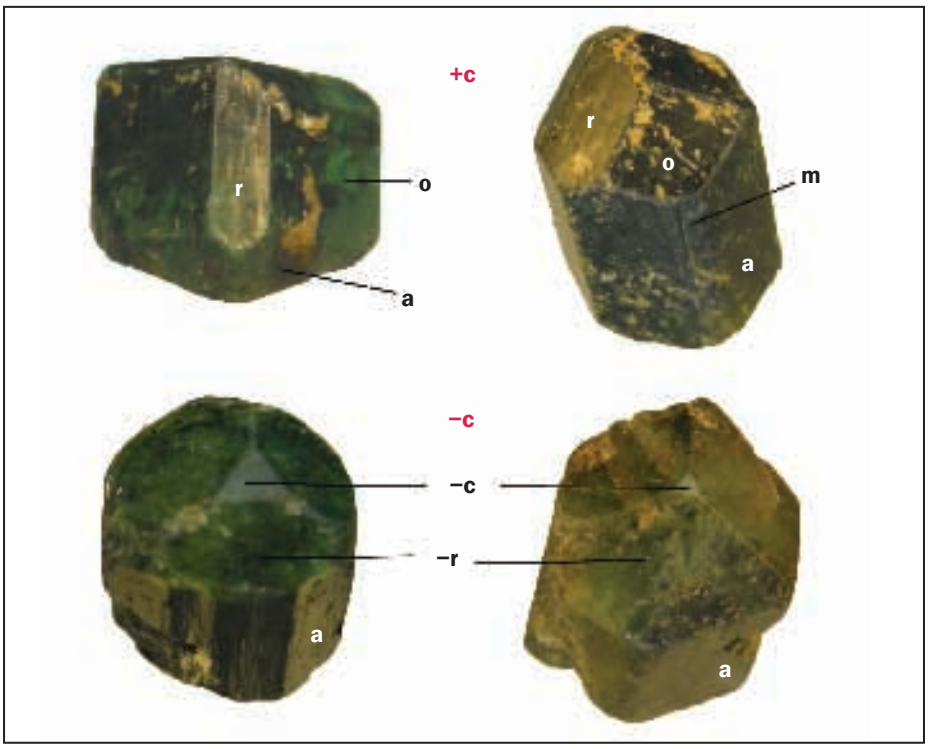

*Figure 3: Trapiche tourmalines from Zambia in different orientations; top line: view of the antilogous pole of two crystals; bottom line: view of the analogous pole of two crystals. The pedion sign in red **+c**, **-c** indicates the polarity of the crystal The prism zone is formed by the dominant hexagonal prism **a** and by subordinate trigonal prisms **m**, the antilogous pole consists of the trigonal pyramids **r** and **o**, the analogous pole consists of the trigonal pyramid **–r** and the pedion **–c**. Diameter of the crystals: top left 8 mm, top right 10.5 mm, bottom left 9.5 mm, bottom right 12 mm. Photos by K. Schmetzer.*

combinations of **r** and **o**, or combinations of the trigonal pyramid **r** and the pedion **c** (*Figures 2* and *3*).

For the experimental determination of the antilogous and the analogous poles (ends) of the polar tourmaline crystals, the method of Kundt (1883) which is based on pyroelectricity (see also Takahashi and Sunagawa, 1998) was applied. Upon heating the antilogous end (+c) of the tourmaline crystal is negatively charged and the analogous end (-c) is positively charged (Dietrich, 1985). Kundt describes that, when a mixture of fine powdered sulphur and red lead oxide (Pb_3O_4, minium) is blown through a fine sieve on a crystal charged at an elevated temperature, the lead oxide is attracted by the negatively charged end of a crystal and the sulphur is attracted by the positively charged end of a crystal.

When the Zambian tourmalines were heated at a temperature below 120° C, i.e. below the melting point of sulphur, the effect seen was very small. After heating the tourmalines above 300 or 400°C, a mixture of sulphur and lead oxide blown onto the heated crystals showed a clear attraction of the lead oxide by the antilogous end and a repulsion of red lead oxide particles by the analogous end of the tourmalines. Consequently, after determination of the polarity of the Zambian tourmaline crystals we can summarize the morphology of type A tourmalines as follows (*Figure 4* A,B,C):

In many tourmaline crystals, the antilogous end consists of three or six faces, i.e. of three **r** pyramids or of three **o** pyramids, but a combination of both faces, i.e. a combination of three **r** and three **o** pyramids, is also quite common. The analogous pole shows only three **–r** pyramids, often in combination with the pedion **–c**.

2.2 External morphology of tourmalines of types B and C

None of the tourmalines classified as B and C were complete crystals. Since only a clear outline of the external morphology of the prism zone can be obtained from slices perpendicular to the *c*-axis, this was combined with the

information available from the orientation of elongate voids in transparent internal growth sectors (see *Table II*).

Samples of type B (*Figure 4* D) show trigonal habits with larger trigonal prism faces m and smaller hexagonal prisms a. The orientation of growth tubes indicates that the trigonal pyramid **r** is the dominant crystal form.

Samples of type C (*Figure 4* E) show a hexagonal outline of the prism zone with larger hexagonal prism faces **a** and only subordinate trigonal prism faces **m**. Within the clear central growth sectors, two main orientations of needle-like growth tubes are visible and these indicate that two different trigonal pyramids, namely **o** and **y**, are present.

2.3 Single slices and series of slices of trapiche tourmalines from Zambia

For the European market, transparent tourmaline crystals or transparent parts within tourmaline crystals are normally sliced perpendicular to the *c*-axis and sold as individual slices or as complete series of tourmaline plates. Some crystals are cut as cabochons also in that particular orientation. Slices parallel to the *c*-axis were not available commercially.

Type A: In this study numerous single slices perpendicular to the *c*-axis and three complete series of slices consisting of seven, eight or nine individual tourmaline plates cut from almost completely transparent crystals or crystal fragments along the *c*-axis were examined. From another six crystals, purchased from the trade, with at least partly transparent or translucent areas, individual slices perpendicular to the *c*-axis were prepared. Some non-transparent parts of crystals were not sliced.

Types B and C: From these categories, only slices perpendicular to the *c*-axis or fragments of prismatic crystals were available. It was possible to study small series of two or three slices cut along c from a few single crystals, but no slice parallel to c with a complete internal morphology could be obtained.

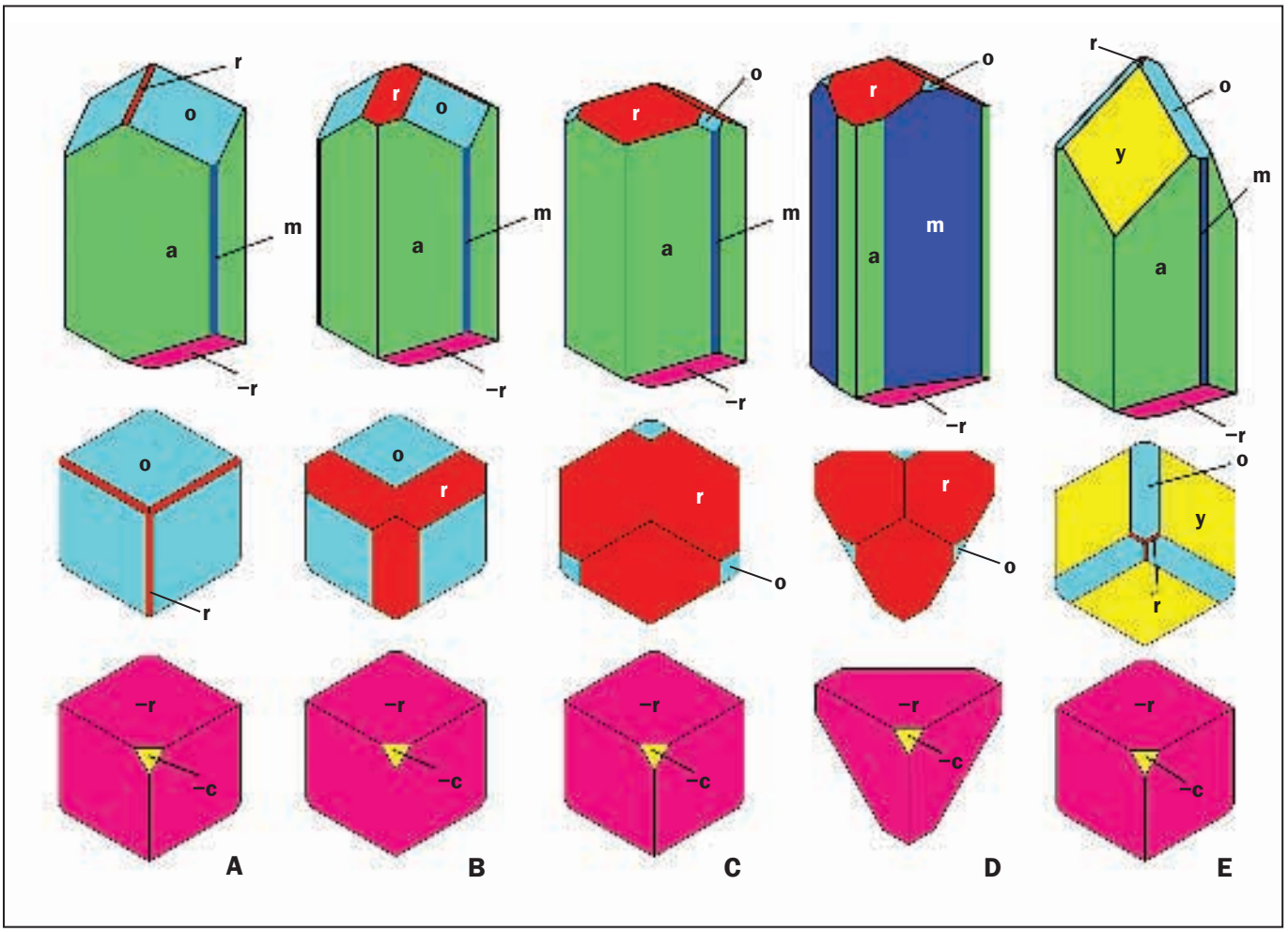

*Figure 4: Morphology of trapiche tourmalines from Zambia; the prism zone is formed by the dominant hexagonal prism **a** and by subordinate trigonal prisms **m** (examples A,B,C,E); in example D, the prism zone is formed by three dominant trigonal prism faces **m** and subordinate hexagonal prisms **a**; the antilogous pole consists of the trigonal pyramids **r**, **o** and **y**, the analogous pole consists of the trigonal pyramid **–r** and the pedion **–c**.*
Top line: view perpendicular to the c-axis (clinographic projections), middle line: view parallel to the +c axis (parallel projections), bottom line: view parallel to the -c axis (parallel projections). Crystal drawings and artwork by K. Schmetzer.

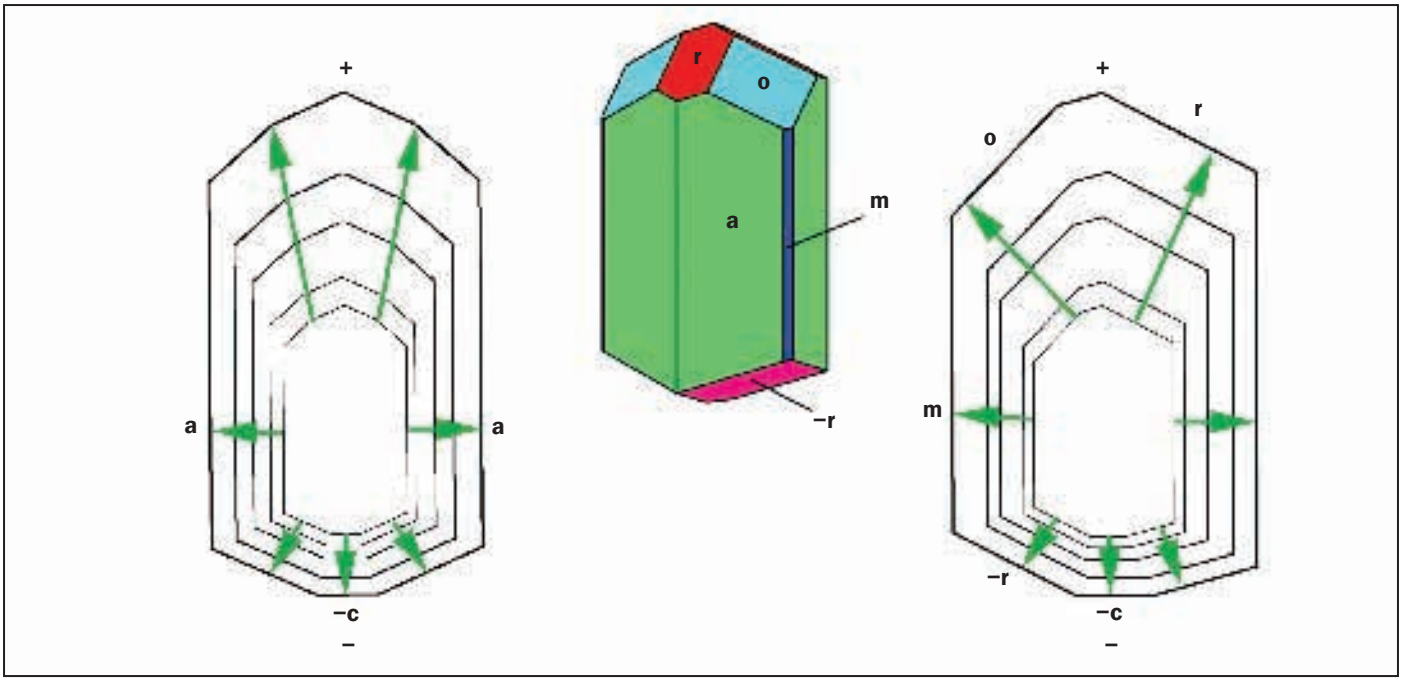

*Figure 5: Schematic sections through a tourmaline crystal (top middle, clinographic projection) with orientation of the sections perpendicular to the prism **a** (left) and perpendicular to the prism **m** (right), only crystal faces are labelled but not crystal edges; the directions of crystal growth are indicated by green arrows; a preferential crystal growth at the antilogous pole compared to the analogous pole is indicated. Crystal drawings and artwork by K. Schmetzer.*

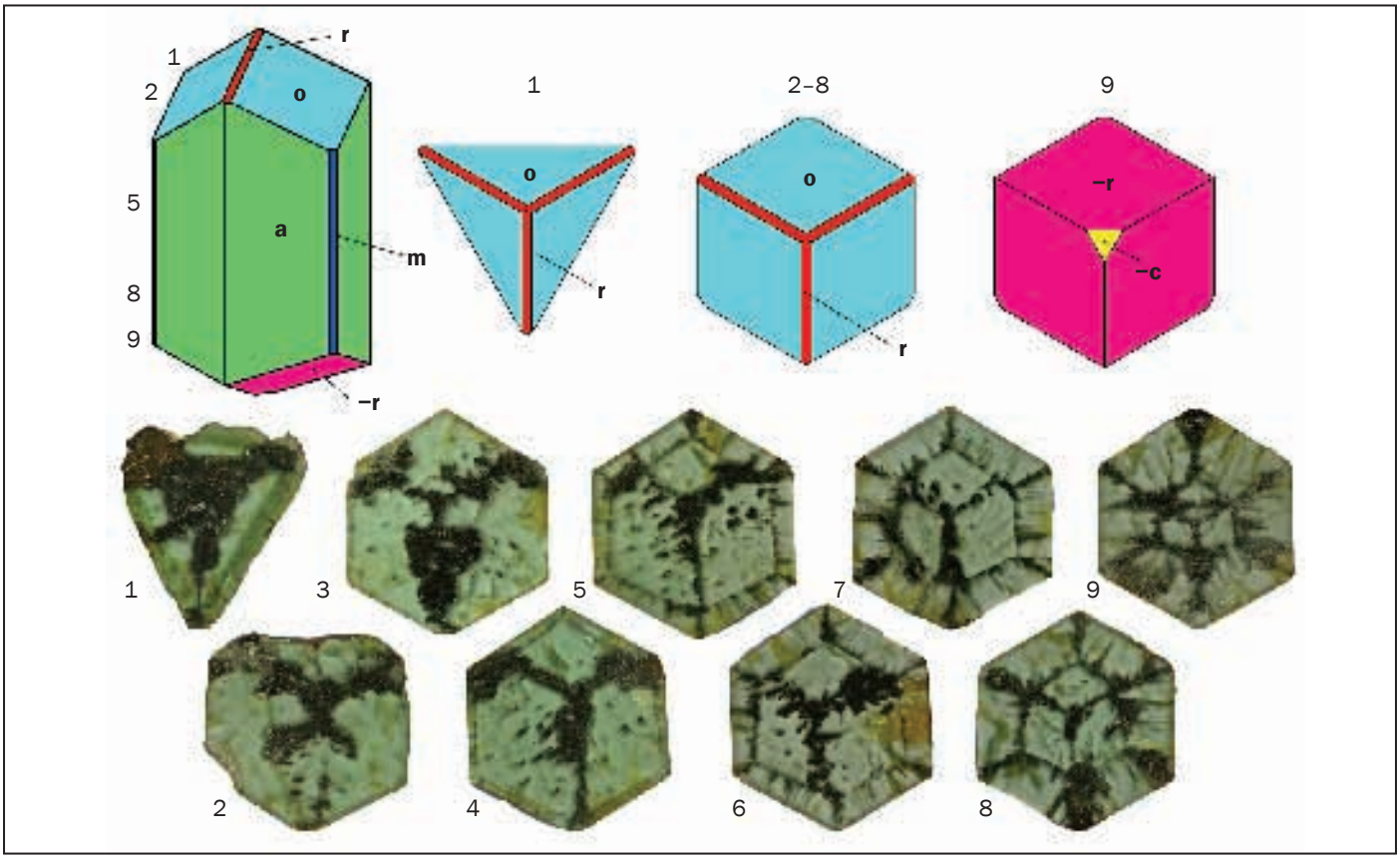

*Figure 6: Series of slices of a trapiche tourmaline crystal from Zambia cut perpendicular to the c-axis (middle and lower line); the sequence of slices (Nos. 1 to 9) runs from the antilogous pole towards the analogous pole. Slice 1 represents a section through three trigonal pyramids **o**, slices 2 to 8 represent sections through three trigonal pyramids **o** and six prism faces **a**; slice 9 represents a section through three pyramids **–r** and six prism faces **a**; the approximate position of the slices within the complete crystal is given in the upper left diagram; the trigonal and hexagonal outline of the sections is also given in the upper line (middle and right). Diameter of slices 2 to 9 approx. 8 mm. Photos by T. Hainschwang, crystal drawings and artwork by K. Schmetzer.*

3. The trapiche pattern: geometrical description

Tourmaline crystals from certain occurrences, especially samples from Madagascar, show a distinct growth and colour zoning with sharp boundaries (see, e.g., Benesch, 1990; Wöhrmann, 2002; Zang *et al.,* 2002; Rustemeyer, 2003; Lussier and Hawthorne, 2011). In cross sections parallel and perpendicular to the *c*-axis, growth and colour zoning parallel to the pedion as well as parallel to different prism and pyramidal faces is directly visible.

In contrast, the trapiche pattern in crystals from Zambia consists of different growth sectors, which are separated by more or less sharp boundaries. These boundaries, in general, are narrow areas within the tourmaline crystals with high concentrations of mineral and fluid inclusions, and where the elongated voids or channels were initiated to extend into the surrounding tourmaline sectors. These channels are always perpendicular to the growing crystal face of the relevant growth sector, i.e. perpendicular to the dominant hexagonal prism **a** or to one of the different trigonal pyramids **r**, **o**, **y** and **–r**.

Although individual growth layers with sharp boundaries are not visible, measurement of the inclination of the elongated voids allows the determination and identification of the growth plane and surrounding sector, i.e. the 'host' sector of the channel. The different positions of trapiche sector boundaries in successive slices of a crystal along the *c*-axis or the changes within trapiche sector boundaries allow an insight into the growth history of a crystal.

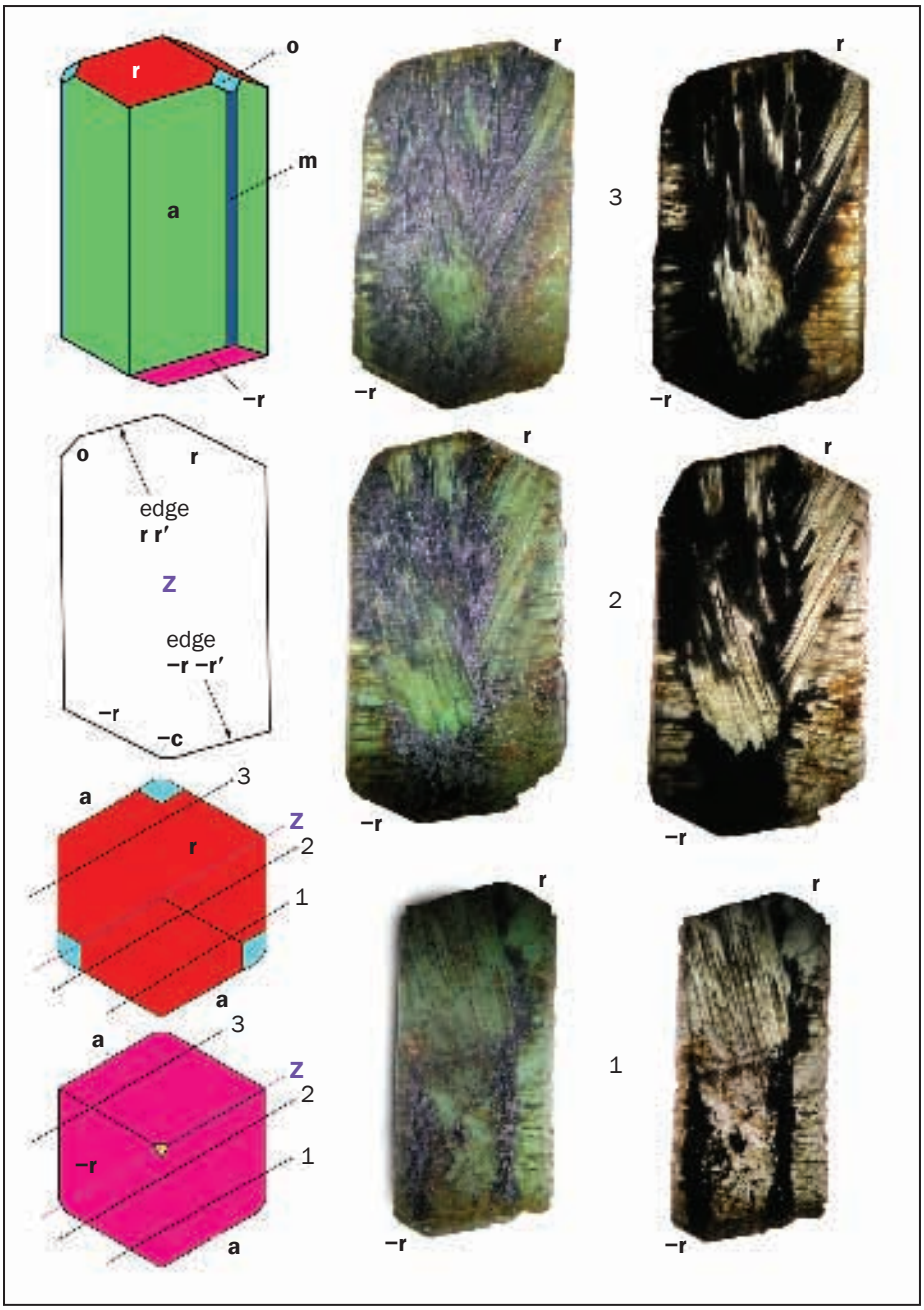

Figure 7: Series of slices of a trapiche tourmaline crystal from Zambia cut parallel to the c-axis (middle line in reflected light, right line in transmitted light); a schematic drawing of the original crystal (clinographic projection) is on the upper left; a schematic section through the centre (z) of the tourmaline crystal is on the centre left; in views parallel to the +c axis and the –c axis (lower left), the approximate positions of the three sections are indicated. Size of the tourmaline slices: top 14 × 25 mm, middle 14 × 25 mm, bottom 11 × 25 mm. Photos by T. Hainschwang and K. Schmetzer, crystal drawings and artwork by K. Schmetzer.

3.1 Samples of type A

From observations of slices parallel to the *c*-axis it is apparent that there was more crystal growth from the centre to the antilogous pole than from the centre to the analogous pole. In approximate terms, the length from the origin (centre) of crystal growth to the analogous end of the crystal is in the range of 5 to 15% of the total length of the crystal *(Figure 5)*. Furthermore, where the parts of the crystal between the centre and the analogous end are not transparent, those in the gem and mineral trade start a series of slices along the *c*-axis at or slightly above the crystal centre and run in a sequence towards its antilogous end. Several non-transparent ends of crystals, which were left over (i.e. which were not sliced) show the pedion **–c** and the trigonal pyramid **–r**.

One series of nine slices examined *(Figure 6)* consists of one slice with three central growth sectors with channels inclined at about 27° to the *c*-axis (slice 9, representing a core with the trigonal pyramid **–r**), and eight successive slices with three central growth sectors with elongated voids inclined at about 45° to the *c*-axis (slices 1 to 8, representing a

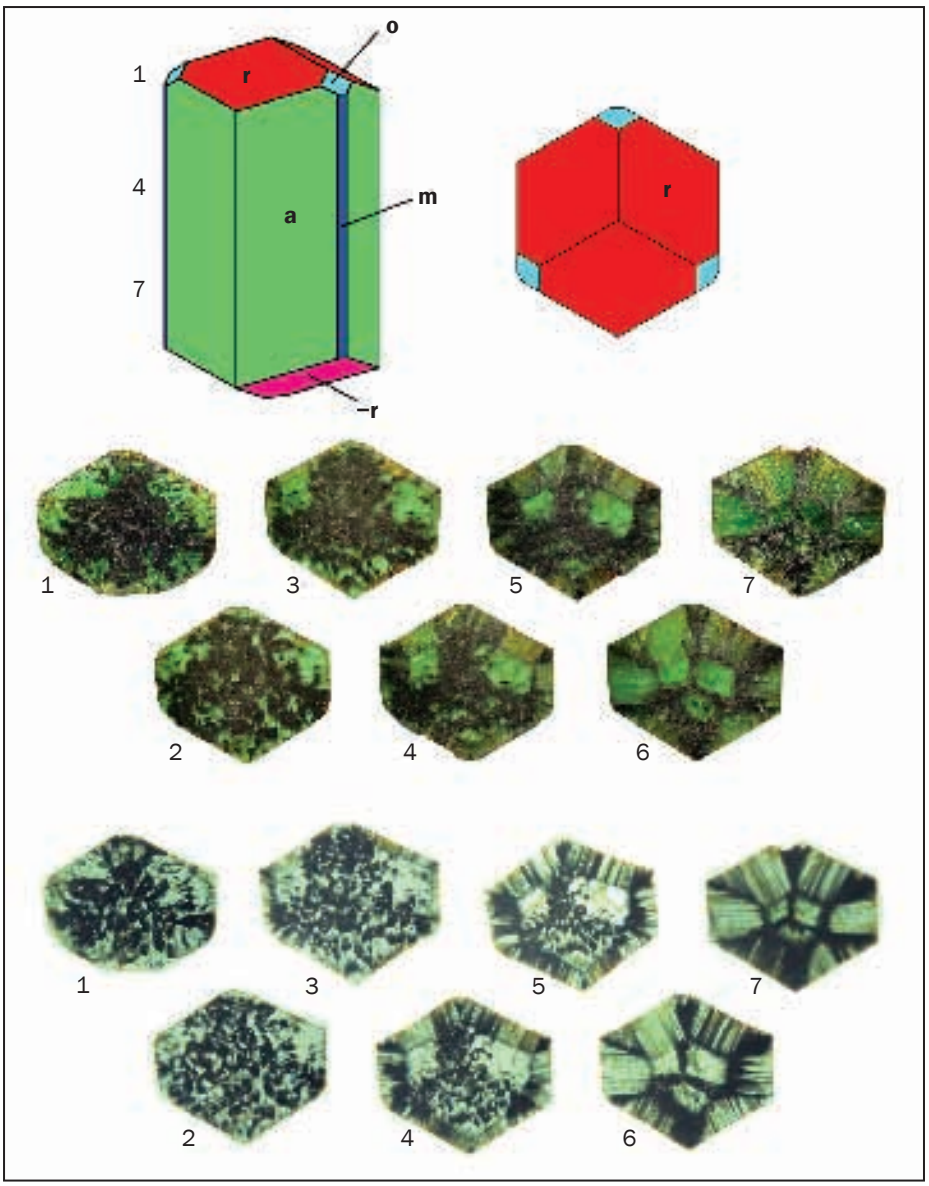

Figure 8: Series of slices of a trapiche tourmaline crystal from Zambia cut perpendicular to the c-axis (middle lines in reflected light, lower lines in transmitted light); as indicated in the diagram upper left, the sequence of slices (Nos 1 to 7) runs from the antilogous pole towards the analogous pole. Slices 1 to 7 represent sections through three trigonal pyramids ***r*** *and six prism faces* ***a****. Size of the slices 16 × 18 mm. Photos by T. Hainschwang and K. Schmetzer, crystal drawings and artwork by K. Schmetzer.*

core with the trigonal pyramid **o**). Slices 3 to 9, in addition, showed rims consisting of six growth sectors each, representing the hexagonal prism **a**. The two remaining slices in the series (slices 1 and 2) showed no rim related to prism zones.

Several slices of type A crystals parallel to the *c*-axis show external faces parallel to the prism **a** as well as parallel to the trigonal pyramids **r** (at the antilogous pole) and **–r** (at the analogous pole). From one larger crystal *(Figure 7)* three slices show the edges between adjacent **r** or between adjacent **–r** pyramids, with an inclination of about 14.5° to the pedion **c** *(Table II, Figure 7)*.

In *Figure 7*, it is apparent that these slices contain larger non-transparent areas of tourmaline with abundant trapped solid or liquid inclusions. Most of these channels are confined to margins between different growth sectors, and end irregularly within an adjacent transparent growth sector.

Two series of seven or eight tourmaline slices cut perpendicular to the *c*-axis are variably transparent *(Figure 8)*. Both series started on the antilogous side of the centre of crystal growth, so the analogous pole is not represented. In the slices closest to the crystal centres, the core of the crystals consists of three growth sectors with channels inclined at 27° to the *c*-axis, representing growth sectors related to the trigonal pyramid **r**. These are surrounded by six growth sectors with channels inclined at 90° to the *c*-axis, representing growth sectors related to the hexagonal prism a (slice 7 in *Figure 8*).

In both series of slices, the non-transparent margins between the three central **r** growth sectors become successively broader with distance from the centre of the crystal (slices 1 to 6 in *Figure 8*). Within these margins, numerous mineral and fluid inclusions were trapped, mostly in elongate voids. These channels are inclined at about 27° to the *c*-axis, which indicates that these areas represent growth sectors confined to the trigonal pyramid **r**. Within the two series of slices, the hexagonal prism growth zones gradually become smaller and are not present in the last tourmaline plates (slices 1 and 2) which show only larger, mostly non-transparent **r** growth sectors.

Slices 2 and 7 of the crystal depicted in *Figure 8* were used for microprobe analyses (see also *Figures 18* and *19*).

3.2 Samples of type B and C

Each individual part of a type B crystal or single slice shows three central growth sectors with channels inclined at about 27° to the *c*-axis (representing the trigonal pyramids **r** or **–r**), and three larger growth sectors at the rim (representing the trigonal prism **m**). In some samples, smaller growth sectors related to the prism **a** are also present in the rim. Slices cut from a single crystal are shown in *Figure 1b* (see also *Figure 4* D).

Type C tourmalines are mostly colourless and contain a core consisting of six transparent tourmaline growth sectors within a rim of six growth sectors related to the hexagonal prism **a**. The elongated voids within the six sectors of the central core show two different inclinations to *c*, which indicate that the faces within these zones are the trigonal pyramids

o and **y** (*Figure 1c* and see *Figure 4* E). These observations indicate crystals with hexagonal habit but with somewhat steeper pyramidal faces **y** *(Table II)*.

4. Thin sections of type A crystals parallel to the *c*-axis

In contrast to the slices parallel to c with thicknesses in the mm range several sections 60 µm thick were prepared and two examples are shown in *Figures 9* and *10*. Each section was cut parallel to one of the larger hexagonal prism faces **a**. One section shows a habit consisting predominantly of the hexagonal prism **a** in combination with **r** and **–r** pyramids *(Figure 9)* and the other shows additional **o** growth sectors increasing in size during crystal growth *(Figure 10)*. With crossed polarizers, the orientation of numerous elongate voids is clearly visible and most channels are orientated perpendicular to the external crystal faces. Some channels however are inclined or even perpendicular to the plane of the section.

The sections parallel to the *c*-axis show external faces parallel to the prism **a**, the trigonal pyramids **r** and **o** (at the antilogous pole) and **–r** (at the analogous pole). The outlines of idealized sections through the three crystals are also given in *Figures 9* and *10* and contain the edges between adjacent **r** or between adjacent **–r** pyramids, with an inclination of about 14.5° to the pedion **c** (see *Table II*). The individual growth zones within these sections were assigned to growth sectors related to the hexagonal prism **a** and

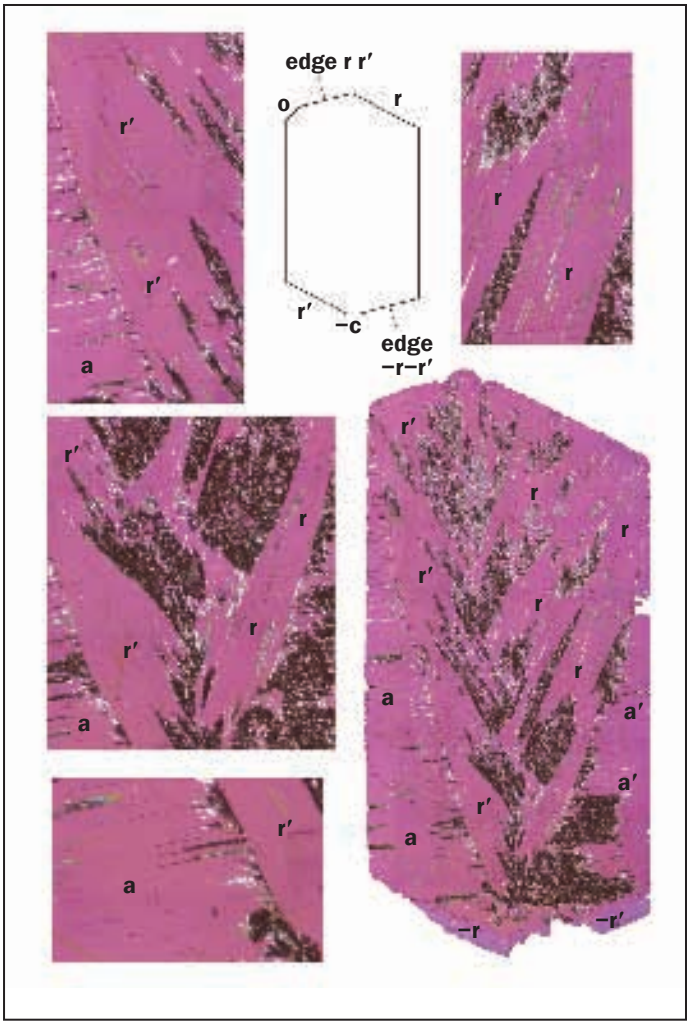

*Figure 9: Section through a trapiche tourmaline crystal cut parallel to the c-axis; the complete crystal is in the lower right, a schematic section is in the upper line (middle), and enlarged views of different parts of the crystal are given in other photographs. Growth sectors belonging to the trigonal pyramids **r** and **–r** and the hexagonal prism **a** are indicated; the growth sectors are distinguished by margins with abundant solid and liquid inclusions; and within the transparent areas of various growth sectors, channels filled with liquid or solid matter and irregularly shaped areas with a high concentration of inclusions are visible. The prime symbol denotes another face in the same zone, so that **r**, **r′** and **r″** are the three pyramid faces of the **r** zone. Size of the crystal approx. 10 × 20 mm; thickness of the section approx. 60 µm; crossed polarizers. Photos by H.-J. Bernhardt.*

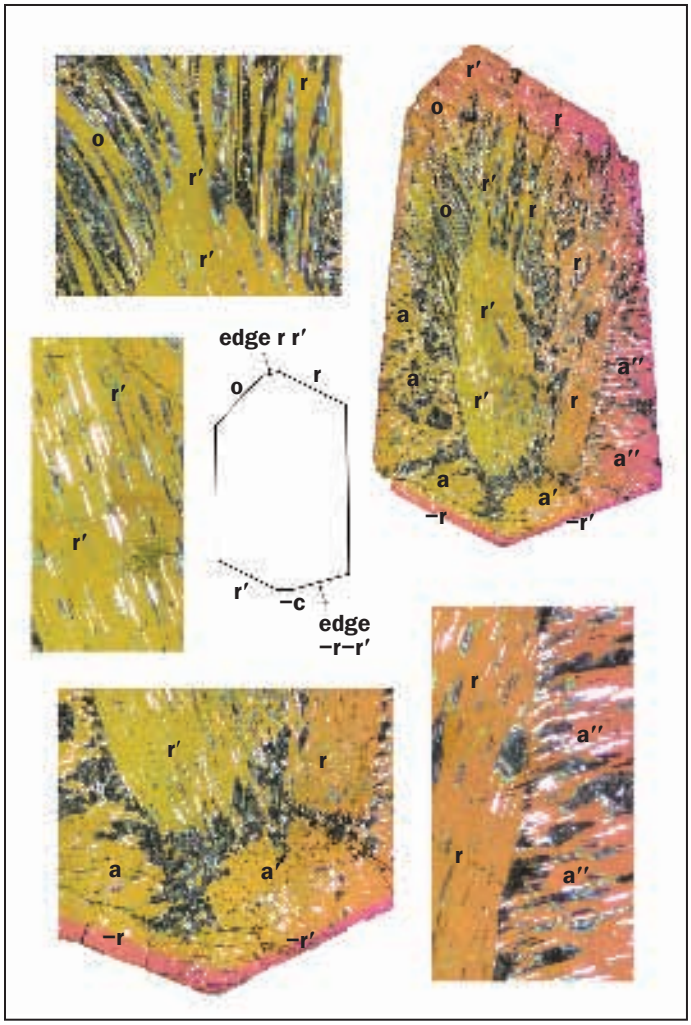

*Figure 10: Section through a trapiche tourmaline crystal cut parallel to the c-axis; the complete crystal is in the upper right, a schematic section is in the centre and enlarged views of different parts of the crystal are given in other photographs. Growth sectors belonging to the trigonal pyramids **r**, **o** and **–r** and the hexagonal prism **a** are indicated; the growth sectors are distinguished by margins with high concentrations of solid and liquid inclusions; within the transparent areas of various growth sectors, channels filled with liquid or solid matter, and irregularly shaped areas with a high concentration of inclusions are visible. Size of the crystal approx. 10 × 16 mm; thickness of the section approx. 60 µm; crossed polarizers. Photos by H.-J. Bernhardt.*

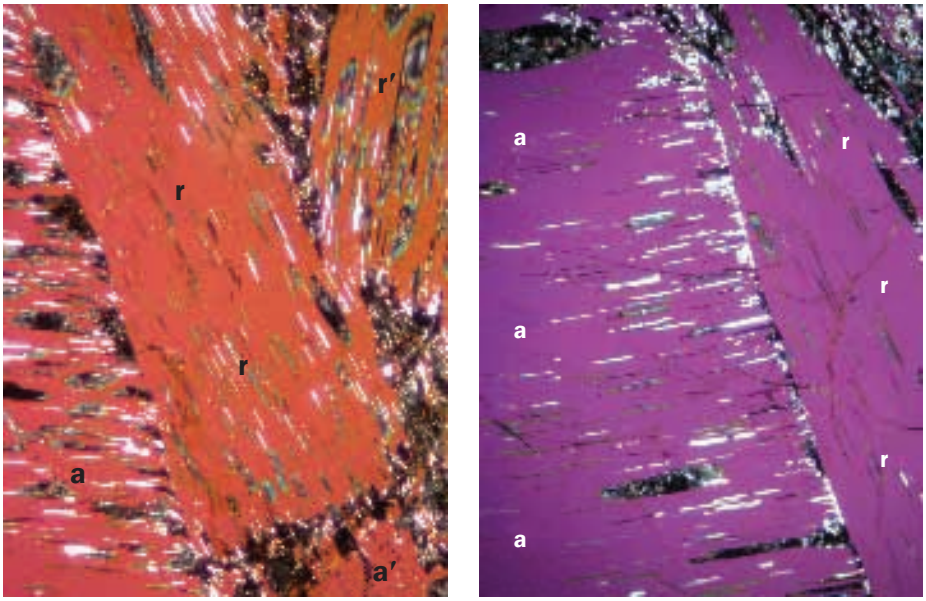

Figure 11: (a) In a section about 60 µm thick cut parallel to the c-axis, the pyramidal and prismatic growth sectors are separated by margins with abundant solid and liquid inclusions; (b) within the transparent areas of various growth sectors, channels filled with liquid or solid matter and irregularly shaped areas with a high concentration of inclusions are visible. Crossed polarizers, field of view (a) 2.04 × 2.72 mm and (b) 3.04 × 4.05 mm. Photos by H.-J. Bernhardt.

to different trigonal pyramids **r** and **–r**. Towards the antilogous end of the crystal pictured in *Figure 10*, there is also a small growth sector with an orientation of channels inclined at about 45° to the *c*-axis, corresponding with the trigonal pyramid **o**.

In detail, the thin section shown in *Figure 9* represents a cut more or less through the centre of the crystal and shows two growth sectors related to the hexagonal prism (**a** and **a′**) and two growth sectors related to the a trigonal pyramid (**r** and **r′**). The growth sectors of the trigonal pyramid (**–r** and **–r′**) at the analogous pole are distinctly smaller than those towards the antilogous pole. This may indicate more preferential growth towards the antilogous end of the crystal (see *Figure 5*).

The other example *(Figure 10)* shows three prismatic growth sectors (**a**, **a′** and **a″**) which indicates that the cut represents a section not exactly through the centre of the crystal. The cut is not exactly parallel to the *c*-axis but inclined to it at about 10°, so the two edges running north-south are not exactly parallel. The section shows larger trigonal **r** and smaller **–r** growth sectors. During growth of the crystal there was a change of habit with development of growth sectors related to the trigonal pyramid **o**.

5. Fine structure and determination of inclusions

The trapiche pattern is formed by inclusions which are concentrated at the margins of adjacent growth sectors related to different crystal faces. Irregularly shaped areas with inclusions and individual elongate voids commonly originate at these sector boundaries and extend into more transparent tourmaline areas *(Figure 11)*. The growth sectors of different crystal faces, such as **r** and **o** pyramids may contain different concentrations of inclusions, and there are also some bent channels *(Figure 12)* that follow closely the growth planes.

The inclusions were examined using optical microscopy and electron microprobe, and the main ones (i.e. non-tourmaline, see below) are graphite, calcite and dolomite, and irregularly shaped cavities or needle-like cavities filled with fluids of one or two phases *(Figure 12a,b)*. A coating on the surface of some channels *(Figure 12c)*, is most probably secondary iron oxide or iron hydroxide on the basis of electron microprobe analyses. In some irregular fractures there is also some secondary fracture filling and staining by iron oxides and hydroxides.

6. Chemical composition

To evaluate chemical composition, zoning and colour variation, 10 sections of Zambian tourmaline were analysed using the electron microprobe. Four type A sections were parallel to the *c*-axis, five type A sections and one type B section were cut perpendicular to the *c*-axis. Two of the five sections of type A cut perpendicular to *c* represented different parts of one tourmaline crystal (sections of slices 2 and 7 of *Figure 8*). Thus, the chemical analyses presented have been obtained from 10 sections of nine tourmaline crystals.

Since the pattern of chemical zoning was found to be quite fine, the number of analysis points in different automatic scans was set at a range of 50 – 150 per scan. In total, 2922 point analyses were obtained, of which 326 analyses were deleted, because the chemical composition obtained did not represent tourmaline analyses of acceptable quality, being affected by inclusions or cavities. Consequently, the discussion of chemical composition in this paper is based on 2596 point analyses.

6.1 Range of chemical composition

The traverses across all 10 sections show a distinct variation of chemical composition within the dravite-uvite solid solution series. In general, the sections prepared parallel to the *c*-axis show a somewhat larger compositional range than the sections cut perpendicular to c. This is because the latter represent only part of the growth history, while the sections parallel to *c* and along the cores of euhedral crystals represent much more complete growth histories.

Tourmalines are borosilicates with a complex chemical composition and general formula: $XY_3Z_6(T_6O_{18})(BO_3)_3V_3W$ (Schmetzer *et al.*, 2007; Novák *et al.*, 2009; Henry *et al.*, 2011)

For the two main magnesium-rich members of the tourmaline group, dravite and fluor-uvite, the following formulae are given:

Dravite: $NaMg_3Al_6(Si_6O_{18})(BO_3)_3(OH)_3OH$

Fluor-uvite:

$CaMg_3(Al_5Mg)(Si_6O_{18})(BO_3)_3(OH)_3F$

Coupled isomorphic substitutions between dravite and fluor-uvite are established according to the formulae

$Na + Al \leftrightarrow Ca + Mg$

and $OH \leftrightarrow F$

Average compositions of the tourmalines are given in *Table III*. In *Figure 13 a,b,* the atomic proportions of Na, Ca, Al and Mg obtained from the analyses of our four sections cut parallel to the *c*-axis and sample G (a total of 2101 analyses) are plotted. Isomorphic substitutions of Na and Ca, and of Al and Mg are evident. For calcium-rich (sodium-poor) tourmaline, the X sites are almost completely occupied by Ca and Na, with site vacancies mostly below 0.04 atoms per formula unit (apfu). For sodium-rich tourmalines, the number of vacancies in the X site increases to 0.15 apfu *(Figure 13c)* due to complex isomorphic substitution.

Sample A is the richest in fluorine *(Figure 13d)*, and the substitution of fluorine and OH on the W position in the tourmaline structure is shown in *Figure 13e*. In general, Na-poor (Ca-rich) areas of the tourmalines show higher fluorine contents than areas with higher sodium contents.

The following formulae were calculated representing the compositional range of the nine tourmalines analysed:

A. for eight tourmalines with lower fluorine contents

dravite-rich $(Na_{0.81}Ca_{0.08})(Mg_{2.79}Al_{0.21})Al_6(Si_6O_{18})(BO_3)_3(OH)_3(F_{0.2}OH_{0.62}O_{0.18})$

uvite-rich $(Na_{0.20}Ca_{0.80})Mg_3(Al_{5.40}Mg_{0.60})(Si_6O_{18})(BO_3)_3(OH_{2.95}O_{0.05})(F_{0.85}O_{0.15})$

B. for one tourmaline with higher fluorine content

dravite-rich $(Na_{0.80}Ca_{0.06})(Mg_{2.75}Al_{0.25})Al_6(Si_6O_{18})(BO_3)_3(OH)_3(F_{0.61}OH_{0.22}O_{0.17})$

uvite-rich $(Na_{0.14}Ca_{0.86})Mg_3(Al_{5.30}Mg_{0.70})(Si_6O_{18})(BO_3)_3(OH_{2.77}O_{0.16}F_{0.07})(F_{1.00})$

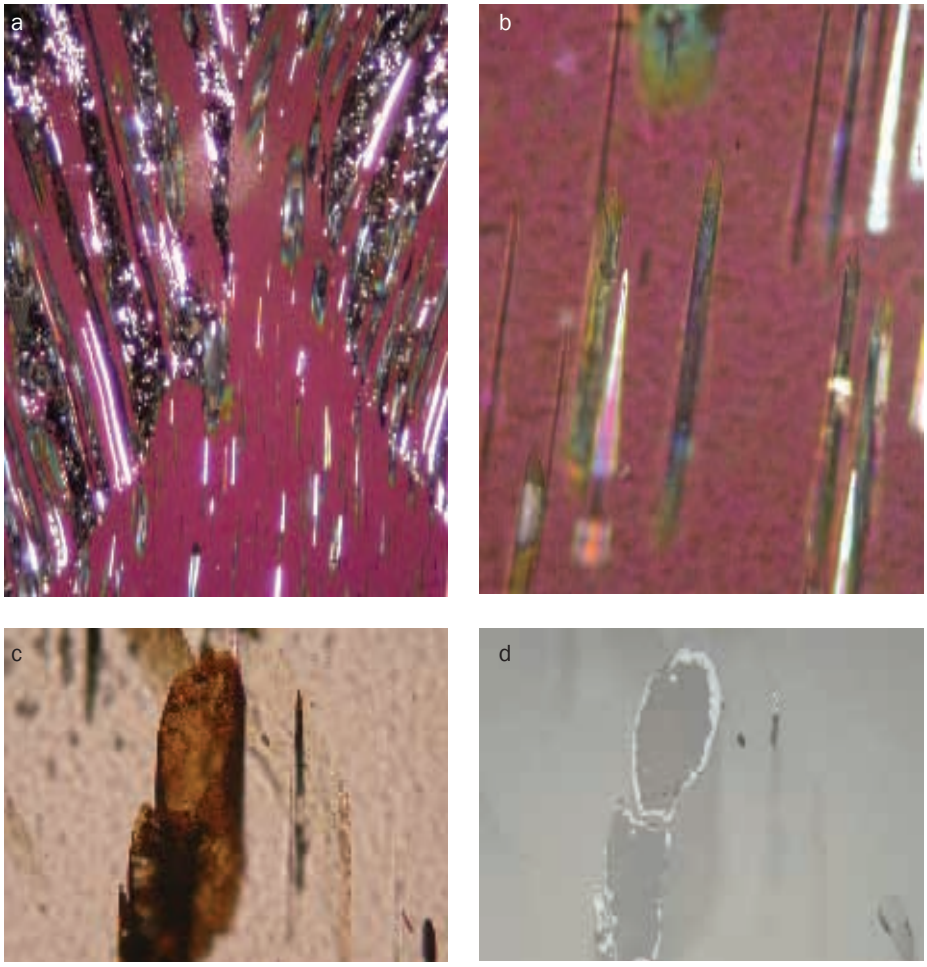

Figure 12 a,b: Different views of a section about 60 µm thick, cut parallel to the c-axis, showing channels filled with liquid or solid matter. Crossed polarizers, field of view (a) approx. 2.04 × 2.72 mm, and (b) approx. 0.51 × 0.68 mm; (c) and (d) view of an open channel which is stained with an iron-bearing mineral on its internal surface, in transmitted and reflected light respectively, field of view approx. 0.34 × 0.26 mm. Photos by H.-J. Bernhardt.

Compared to an ideal intermediate composition between dravite and uvite, these analyses show some excess calcium and some sodium deficiency. For example, analyses with an intermediate composition between the ideal end-members dravite and uvite, with a composition of 3.5 apfu Mg and 5.5 apfu Al, show approximately 0.3 Na and 0.7 Ca rather than 0.5 Na and 0.5 Ca which would have been expected if isomorphic substitution had been ideal. A 'dravite' with an ideal composition of 3.0 apfu Mg and 6.0 apfu Al (which should be free of Ca) shows approximately 0.22 apfu Ca, and approximately 0.72 apfu Na (instead of 1.0 apfu Na which may have been expected from the theoretical composition). Consequently, if these compositions are compared with many quoted in textbooks, the Zambian tourmalines would be considered as members of the dravite-uvite solid solution series but with excess calcium and deficient sodium.

6.2 Trace elements causing colour

Iron and manganese contents in all samples are each in the range of 0.01 to 0.02 wt.%, so neither trace element is likely to influence colour. The majority of the tourmalines (with smaller fluorine contents) contain vanadium in the range of 0.10 to 0.40 wt.% V_2O_3 and chromium between 0.0 and 0.27 wt.% Cr_2O_3 and the tourmalines with the higher contents of these elements are an attractive green *(Figure 13f)*. In contrast, tourmaline A with the higher fluorine content *(Table III)* shows colour zoning with a colourless or almost colourless core and an intense green rim. The core contains 0.0 to 0.1

Table III: Mean chemical compositions of nine trapiche tourmalines from Zambia

Specimen	A	B	C*	D	E	F	G**	H	I
Orientation of section	∥ c	⊥c	⊥c	∥ c	⊥c	∥c	⊥c	⊥c	∥ c
Number of analyses	346	148	59	516	166	409	545	122	285
Wt.%									
SiO_2	36.91	36.84	37.07	37.05	37.17	37.15	37.03	36.94	36.66
TiO_2	0.10	0.21	0.18	0.22	0.21	0.19	0.21	0.20	0.18
B_2O_3[1]	10.73	10.73	10.78	10.73	10.78	10.77	10.71	10.67	10.64
Al_2O_3	28.49	28.58	29.17	28.82	28.97	29.25	29.02	29.06	29.11
V_2O_3	0.09	0.25	0.12	0.16	0.29	0.26	0.23	0.22	0.31
Cr_2O_3	0.05	0.07	0.12	0.04	0.08	0.09	0.05	0.07	0.14
FeO[2]	0.02	0.01	0.01	0.01	0.02	0.01	0.01	0.01	0.01
MnO	0.01	0.01	0.01	0.02	0.01	0.01	0.02	0.02	0.01
MgO	14.70	14.51	14.27	14.27	14.26	14.03	13.97	13.76	13.65
CaO	4.08	4.04	3.74	3.78	3.68	3.45	3.41	3.22	3.13
K_2O	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.01
Na_2O	0.91	0.94	1.07	1.09	1.15	1.25	1.28	1.35	1.38
F	1.98	1.65	1.73	1.55	1.55	1.55	1.54	1.51	1.50
H_2O[3]	2.64	2.75	2.71	2.76	2.78	2.77	2.74	2.73	2.76
-O=F	0.83	0.70	0.73	0.65	0.65	0.65	0.65	0.64	0.63
Total	99.89	99.90	100.26	99.86	100.31	100.14	99.58	99.14	98.86

Number of ions based on 31 (O,OH,F)

Specimen	A	B	C	D	E	F	G	H	I
Si	5.978	5.969	5.979	5.999	5.993	5.994	6.007	6.017	5.997
Ti	0.012	0.025	0.022	0.026	0.026	0.023	0.026	0.024	0.022
B	3.000	3.000	3.000	3.000	3.000	3.000	3.000	3.000	3.000
Al	5.438	5.457	5.544	5.501	5.504	5.560	5.547	5.578	5.597
V	0.012	0.033	0.016	0.021	0.037	0.033	0.030	0.028	0.041
Cr	0.007	0.008	0.015	0.005	0.010	0.012	0.007	0.009	0.018
Fe	0.002	0.002	0.002	0.001	0.002	0.001	0.001	0.001	0.002
Mn	0.001	0.001	0.001	0.002	0.001	0.001	0.002	0.002	0.001
Mg	3.550	3.504	3.421	3.445	3.428	3.375	3.379	3.341	3.323
Ca	0.709	0.701	0.647	0.655	0.636	0.596	0.594	0.562	0.548
K	0.002	0.001	0.002	0.002	0.002	0.002	0.002	0.003	0.002
Na	0.285	0.294	0.335	0.341	0.360	0.392	0.402	0.427	0.436
F	1.012	0.848	0.881	0.793	0.791	0.793	0.788	0.780	0.775
OH	2.847	2.967	2.911	2.978	2.988	2.982	2.969	2.969	2.997

* Type B, all other samples type A

** two slices perpendicular to the c-axis

1 calculated as B = 3.00 atoms per formula unit (apfu)

2 total iron as FeO

3 calculated as OH + F + O = 31.00 apfu

wt.% V_2O_3 and between 0.0 and 0.06 wt.% Cr_2O_3, while the green rim has chromium up to 0.30 wt.% Cr_2O_3 and vanadium up to 0.8 wt.% V_2O_3. These elevated trace element contents are responsible for the intense green coloration of the rim of that particular sample.

6.3 Compositional zoning – scans across sections parallel and perpendicular to the c*-axis*

Chemical zoning in trapiche tourmalines from Zambia is extremely complex, especially because different patterns of zoning can be present in the same crystal. To demonstrate this, variation of sodium and calcium on the X positions in the tourmaline structure is shown, but the variation could be shown equally well by means of other element pairs such as magnesium and aluminium.

Numerous scans across the boundaries of prismatic/prismatic and pyramidal/pyramidal growth sectors in all analysed tourmalines show no changes in composition, but scans across adjacent prismatic and pyramidal growth sectors do show differences with higher sodium and lower calcium contents in the prismatic sectors *(Figure 14)*. These differences for Na and Ca are in the range of 0.1 atoms per formula unit (apfu).

In transparent prismatic growth sectors the values obtained indicate that as growth proceeds there is a continuous increase of sodium content combined with a decrease of calcium content in the direction of growth, i.e. with increasing distance from the centre of the tourmaline crystals. This chemical variation is present both in sections perpendicular to the *c*-axis *(Figure 15)* and in sections parallel to the *c*-axis *(Figure 16)*. In transparent pyramidal growth sectors of tourmalines cut parallel to the *c*-axis, a similar continuous increase of sodium contents coupled with a decrease of calcium contents also occurs in the direction of growth, i.e. in scans parallel to the *c*-axis (*Figures 16* and *17*). In scans of prismatic growth sectors with that particular direction however, the chemical composition is constant, because these analyses represent areas of the tourmaline

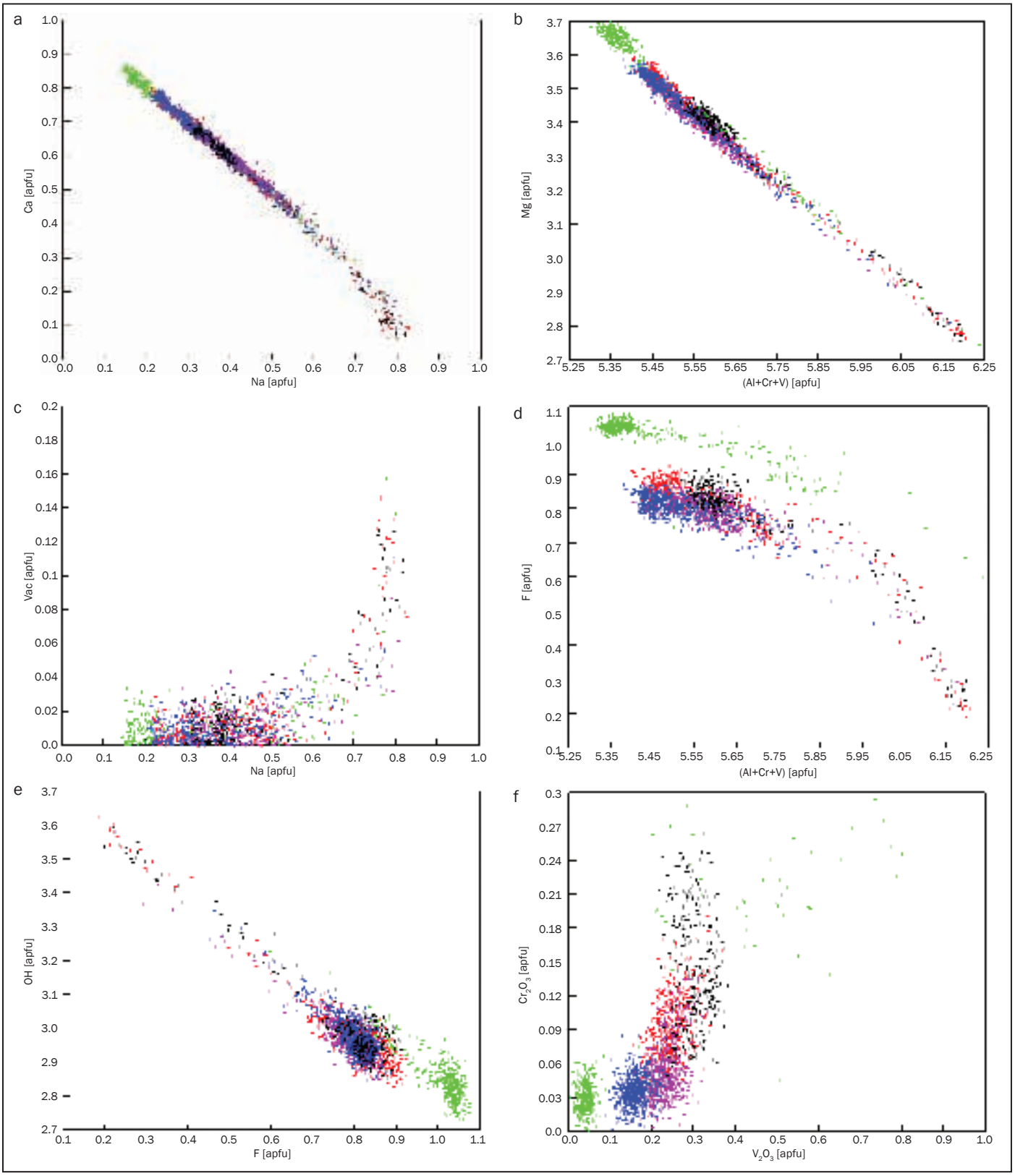

Figure 13: Variation of chemical composition in trapiche tourmalines from Zambia; five different colours indicate point analyses taken in various scans across the sections of five tourmalines, the diagrams represent a total of 2101 point analyses. (a) isomorphic substitution of calcium by sodium on X sites during tourmaline growth; (b) isomorphic substitution of magnesium on (Y+Z) sites by the sum of (aluminium plus chromium plus vanadium); (c) variation of vacancies with Na on X sites in the tourmaline; (d) variation of fluorine contents versus sum of (aluminium plus chromium plus vanadium); (e) variation of hydroxyl content versus fluorine content on W sites; (f) range of chromium and vanadium contents: A sample represented by green dots has a colourless core and an intensely green rim. All samples are members of the solid solution series between dravite and fluor-uvite and show a wide compositional range; one tourmaline (sample A in Table III represented by green dots) shows a higher fluorine content than the other four samples; apfu stands for 'atoms per formula unit'.

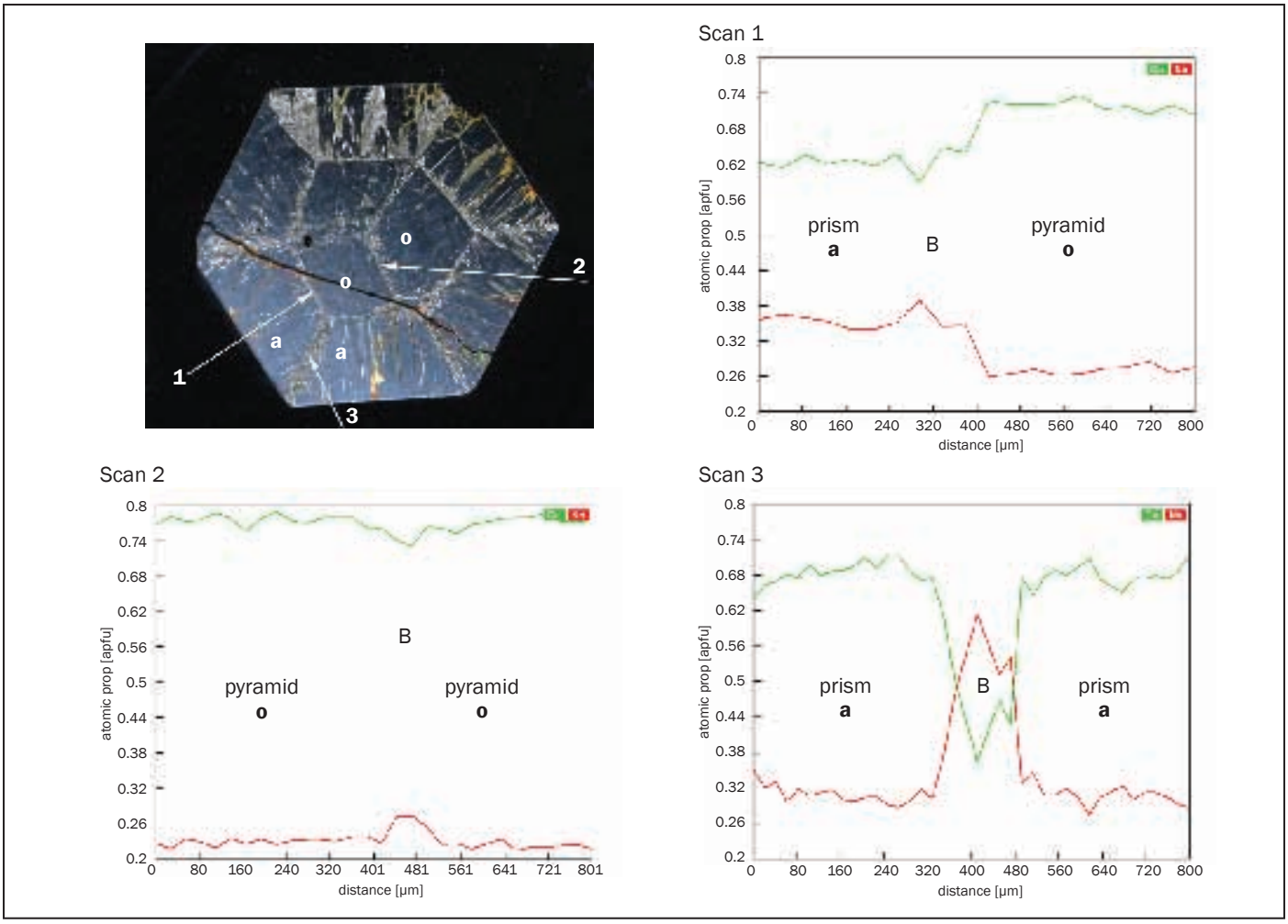

*Figure 14: Ca (green) and Na (red) variation across prismatic **a** and pyramidal **o** growth sectors in trapiche tourmaline from Zambia; section perpendicular to the c-axis. Scans 1, 2 and 3 were performed across the sector boundaries indicated by B. Pyramidal **o** growth sectors show higher calcium and lower sodium contents than adjacent prismatic **a** growth sectors (scan 1); no significant difference in composition is present between the two adjacent pyramidal **o** growth sectors measured in scan 2 or between the adjacent prismatic **a** growth sectors in scan 3, but in scan 3 in the marginal area between the two **a** growth sectors, the tourmaline has higher sodium and lower calcium contents than in either growth sector. Diameter of the sample approx. 13 mm. Photo by H.-J. Bernhardt.*

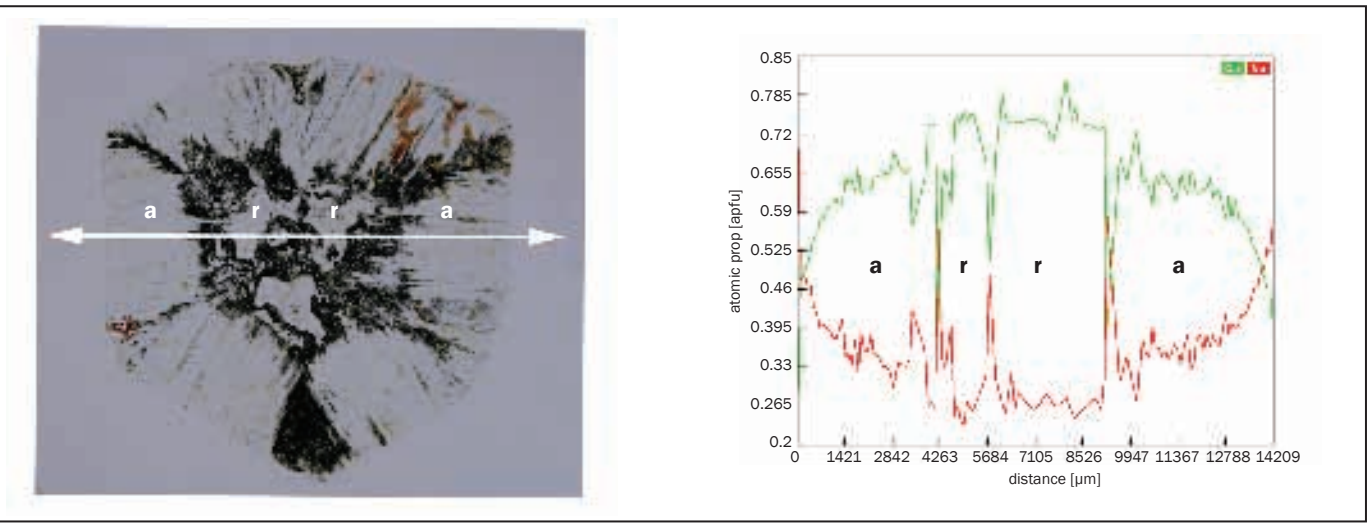

*Figure 15: Ca (green) and Na (red) contents in a scan across two prismatic **a** and two pyramidal **r** growth sectors in a trapiche tourmaline from Zambia; section perpendicular to the c-axis. Pyramidal **r** growth sectors have higher calcium and lower sodium contents than adjacent prismatic **a** growth sectors. Within the prismatic **a** growth sector, sodium increases and calcium decreases from centre to rim; in the margins of the various growth sectors and in irregularly shaped areas with abundant trapped inclusions, the tourmaline has higher sodium and lower calcium contents. Size of the sample approx. 15 × 16 mm. Photo by H.-J. Bernhardt.*

Chemical and growth zoning in trapiche tourmaline from Zambia — a re-evaluation

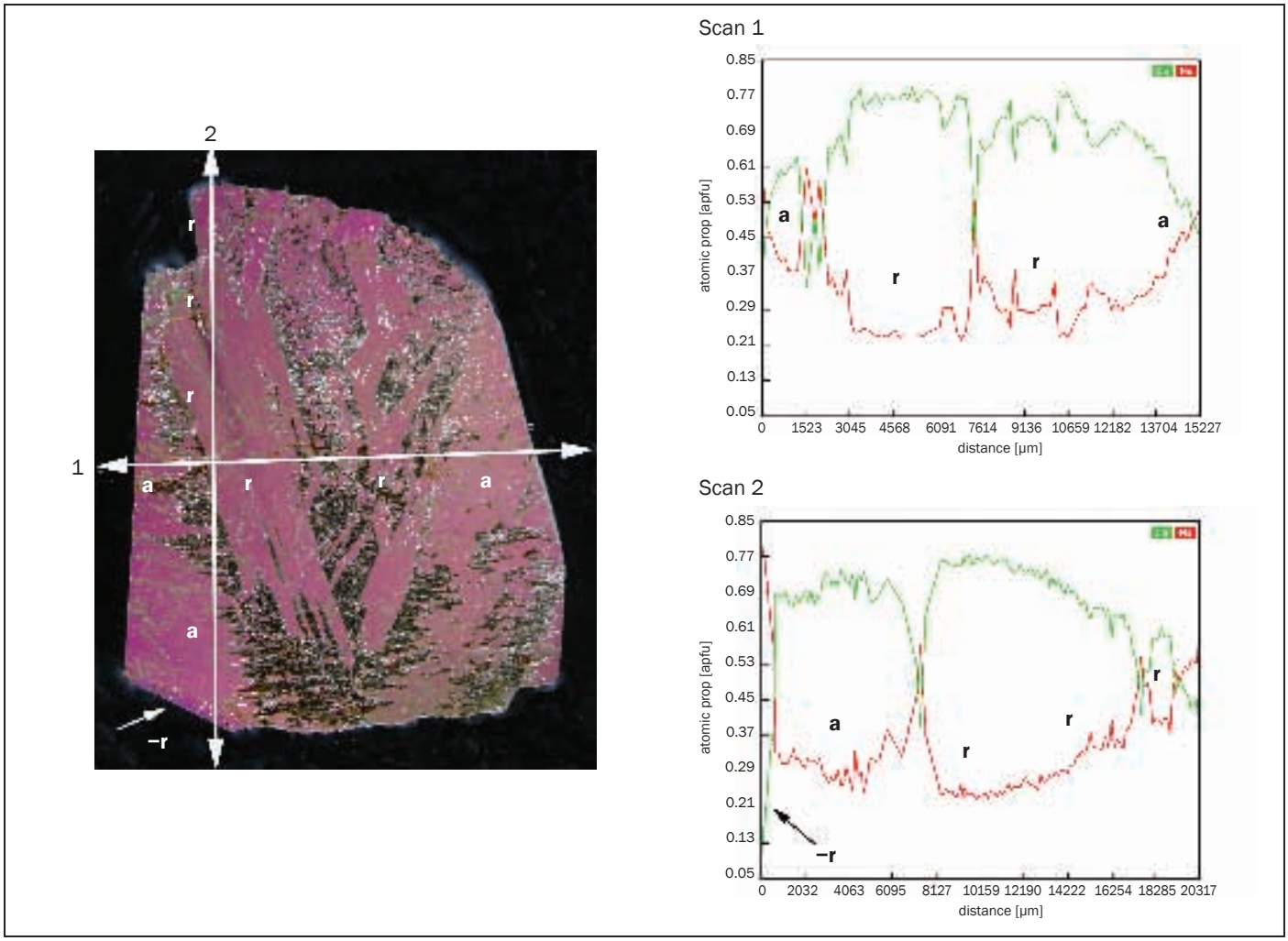

*Figure 16: Ca (green) and Na (red) contents in scans across prismatic **a** and pyramidal **r** and **-r** growth sectors in trapiche tourmaline from Zambia; section parallel to the c-axis. In the prismatic **a** growth sectors, sodium increases and calcium decreases from centre to rim (scan 1); within pyramidal **r** and **–r** growth sectors, sodium increases and calcium decreases along the c-axis from the centre to both analogous and antilogous ends of the crystal (scan 2); as above, where there are abundant inclusions the tourmaline has higher sodium and lower calcium contents than that in the various growth sectors (scans 1 and 2). Size of the sample approx. 15 × 21 mm; crossed polarizers. Photo by H.-J. Bernhardt.*

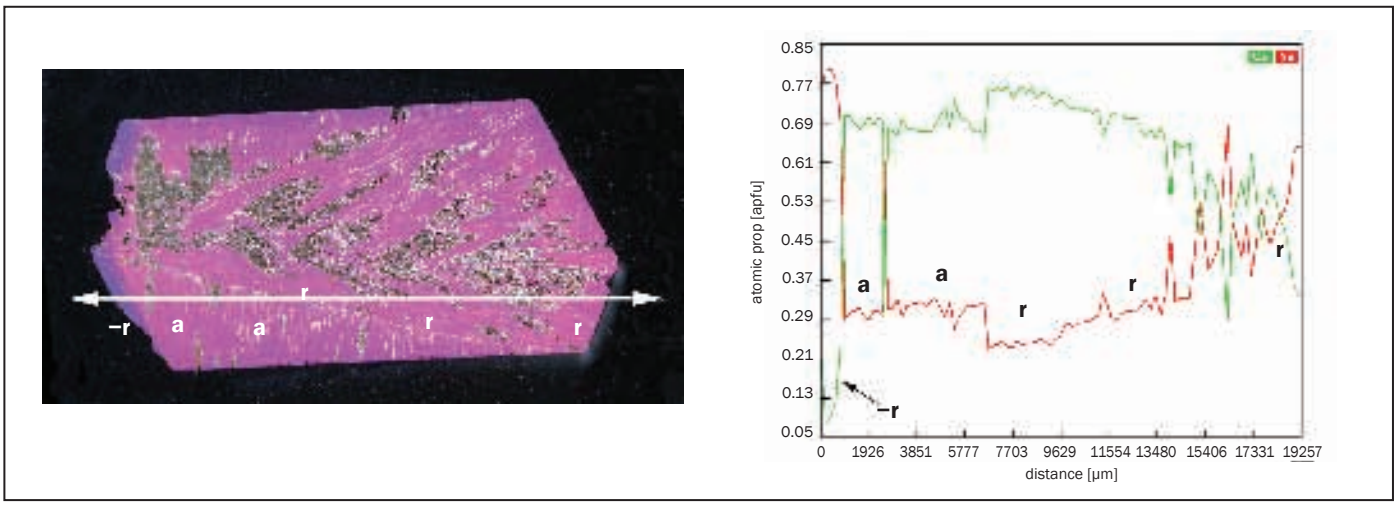

*Figure 17: Ca (green) and Na (red) contents across prismatic **a** and pyramidal **r** and **-r** growth sectors along the c-axis in trapiche tourmaline from Zambia. Pyramidal **r** growth sectors have higher calcium and lower sodium contents than adjacent prismatic **a** growth sectors; within pyramidal **r** and **–r** growth sectors, sodium increases and calcium decreases along the c-axis from the centre to both analogous and antilogous ends of the crystal. At the margin of various growth sectors and in irregularly shaped areas with abundant trapped inclusions, the tourmaline host has higher sodium and lower calcium contents compared to that in the surrounding growth sectors. Size of the sample approx. 10 × 20 mm; crossed polarizers. Photo by H.-J. Bernhardt.*

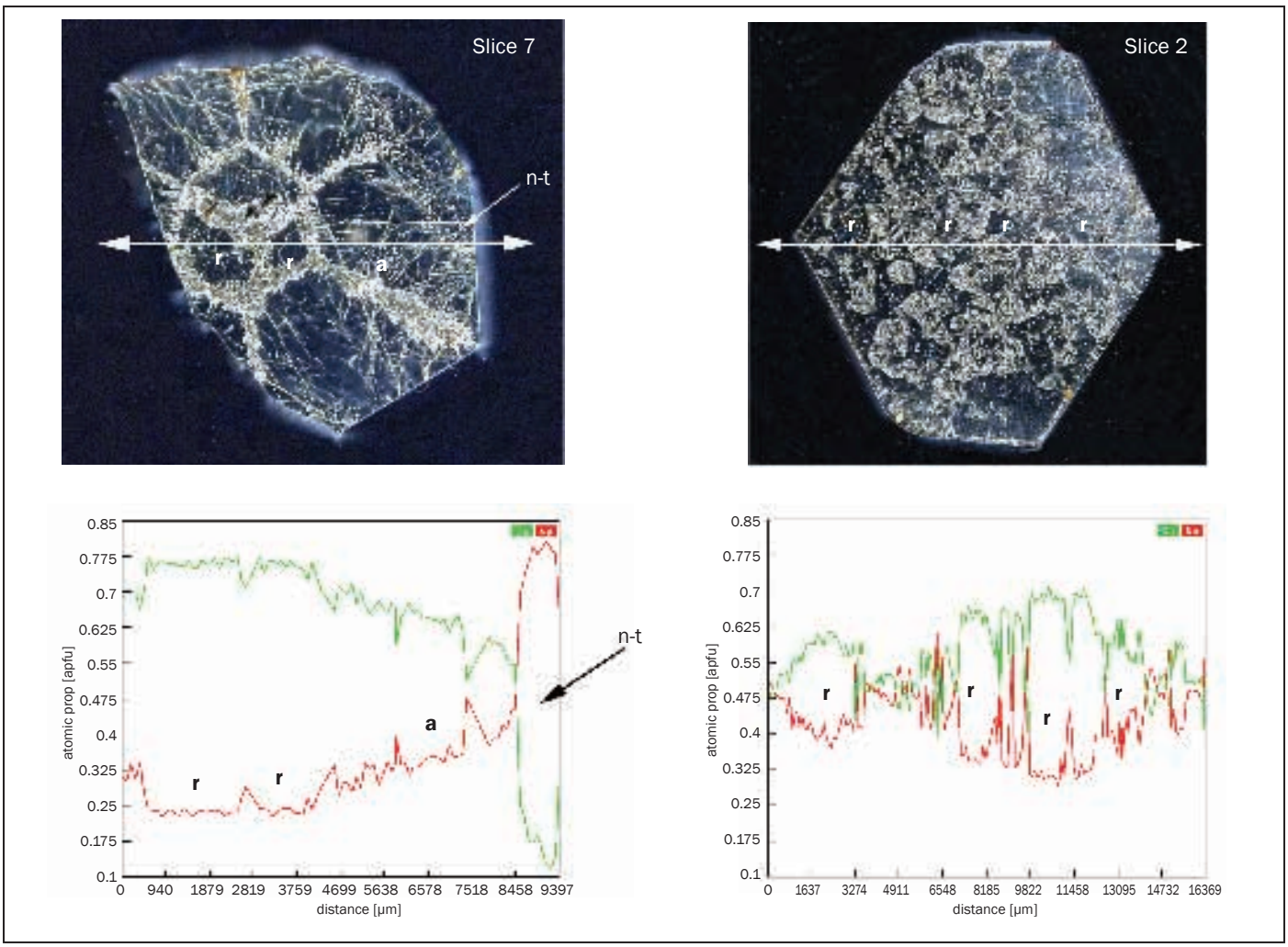

Figure 18: Ca (green) and Na (red) contents in trapiche tourmaline from Zambia. The slices are those shown in Figure 8 *and are perpendicular to the* c*-axis; slice 7 was broken when repolished.*
Thin section of slice 7: a scan across pyramidal ***r*** *growth sectors shows higher calcium and lower sodium contents than the adjacent prismatic* ***a*** *growth sector; no differences in composition were observed between two adjacent pyramidal* ***r*** *growth sectors. Within the prismatic* ***a*** *growth sector, sodium increases and calcium decreases from the centre to the rim; these trends become extreme at the outermost part of the rim, which shows no trapiche pattern (indicated with n-t).*
Thin section of slice 2: the scan across two ***r*** *growth sectors shows that sodium (red) increases and calcium (green) decreases from centre to rim. The common occurrence of irregularly shaped areas with abundant inclusions, is reflected in the fluctuating sodium and calcium contents in the scan.*
Size of slice 7 approx. 11 × 14 mm and of slice 2 16 × 18 mm. Photos by H.-J. Bernhardt.

crystal at the same stage of growth.

In the growth areas related to the negative pyramid **–r** (*Figures 16* and *17*), sodium contents are higher than in all other parts of the tourmaline crystals. Similar tourmaline compositions are present in the rim of a crystal with a normal trapiche pattern in the centre but which has an outer sector with no trapiche pattern (labelled n–t, *Figure 18*). Heavily included margins between adjacent growth sectors also have a more sodic tourmaline host than the non-transparent areas (*Figures 15* to*17*).

6.4 Compositional maps – the distribution of Na and Ca in tourmaline sections parallel and perpendicular to the c*-axis*

Na and Ca compositional maps were obtained on two sections of slices perpendicular to the *c*-axis, originating from the same rough crystal and for two sections of different crystals cut parallel to the *c*-axis. These show that in prismatic **a** growth sectors, the calcium contents are always somewhat lower than in adjacent pyramidal **r** growth sectors, while the sodium contents are higher (*Figures 19a* and *20*). In growth sectors confined to the negative pyramid **–r**, extreme chemical zoning is present on a small scale *(Figure 20)*, and this represents the complete range of chemical variation along the *c*-axis.

At the boundaries between different prismatic or pyramidal growth sectors with abundant inclusions two types of areas with a composition different from the surrounding transparent tourmaline may be present (*Figures 19* and *20*). One shows pixels representing material with high calcium or a high calcium and magnesium content and represents the

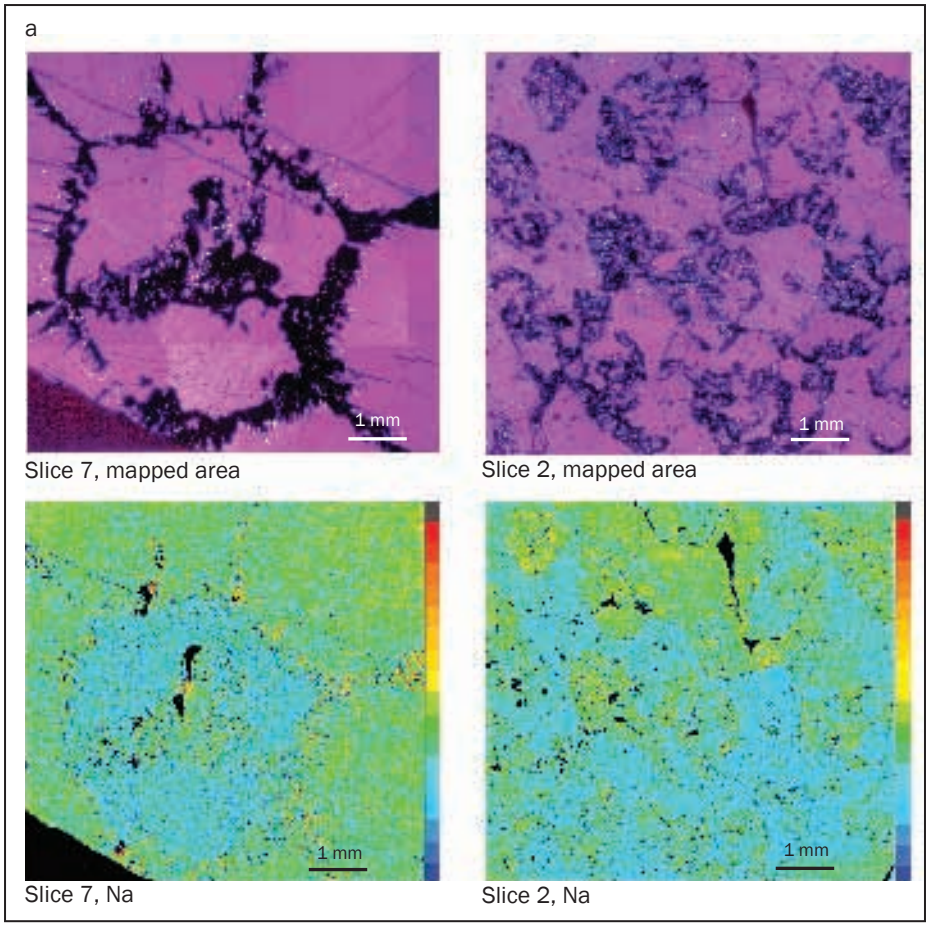

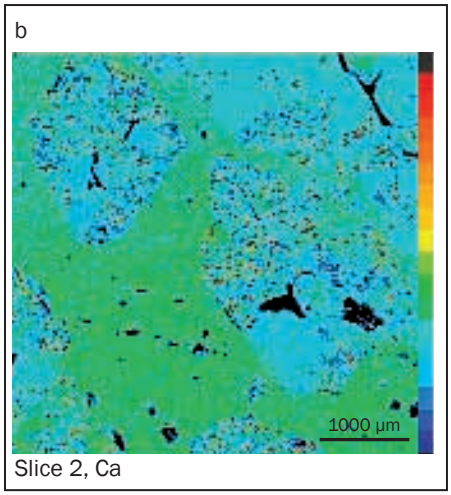

Figure 19a: Na content maps in parts of tourmaline slices 7 and 2 (see Figures 8 and 18). Low content is indicated by blue and higher contents in yellow and red. In slice 7, the increase in Na towards the rim is consistent with the profile in Figure 18. In slice 2, the irregularly shaped areas with abundant inclusions have higher Na contents.

*Figure 19b: Magnified view of part of slice 2 showing Ca in **r** growth sectors. Only the low-Ca areas (blue) contain abundant tiny high-Ca inclusions (yellow and red) of calcite and dolomite.*

many inclusions of magnesite or dolomite. The other type of pixel represents material with a somewhat higher sodium and lower calcium content than the surrounding tourmaline *(Figure 20b)*.

7. Discussion — chemical zoning and formation of structural patterns

7.1 Compositional zoning

The complexity of structural and chemical zoning in tourmaline crystals from different localities is due to one or a combination of several mechanisms (see Benesch, 1990; Henry and Dutrow, 1992, 1996, 2001; Kazachenko *et al.,* 1993; Sperlich *et al.,* 1996; Takahashi and Sunagawa, 1998; Vergilov and Kostova, 2000; Agrosi *et al.,* 2006; van Hinsberg *et al.,* 2006; Lussier *et al.,* 2008; Lussier and Hawthorne, 2011).

(a) Chemical growth zoning. This type of compositional variation from core to rim is common in tourmalines from different localities.

(b) Compositional polarity. Tourmalines from some localities have antilogous and analogous ends of different composition.

(c) Sector zoning. Adjacent growth sectors can have different compositions.

The chemical compositions of the transparent areas of all the trapiche tourmalines measured in this study varied from core to rim. At the beginning of crystal growth, a calcium-rich fluor-uvite crystallized. Subsequently there was a continuous decrease of calcium, magnesium and fluorine contents with corresponding isomorphic substitutions of Ca by Na, Mg by Al and F by OH. Consequently, by the end of crystal growth, sodium-rich dravite was forming. Sector zoning is present in all samples, and some compositional polarity is present; details are given above. At the end of growth, the sodium content of the crystal's analogous end is higher than at its antilogous end. The variation described for sodium and calcium applies also for magnesium and aluminium and for fluorine and hydroxyl groups.

The trapiche pattern is formed by numerous fluid and solid inclusions, mainly calcite and dolomite, at the margins of all combinations of pyramidal and prismatic growth sectors, i.e. at pyramidal/pyramidal, prismatic/prismatic and at pyramidal/prismatic growth sectors. Obviously, crystal growth was hindered by these inclusions for some period and then subsequent growth of tourmaline contained elongate voids. This mechanism of formation of the growth-induced elongate voids or channels has been described in detail by such authors as Slivko (1966) (see *Figure 21 a,b*), Liu and Lu (1986) and Rustemeyer (2003). The voids may form in two ways:

(a) Trapping of inclusions and formation of channels in the growth direction 'behind' these inclusions *(Figure 21a)*.

(b) Trapping of inclusions and formation of channels in the growth direction with the inclusion moving 'in front' of the growth channel *(Figure 21b)*.

The formation of an elongate void

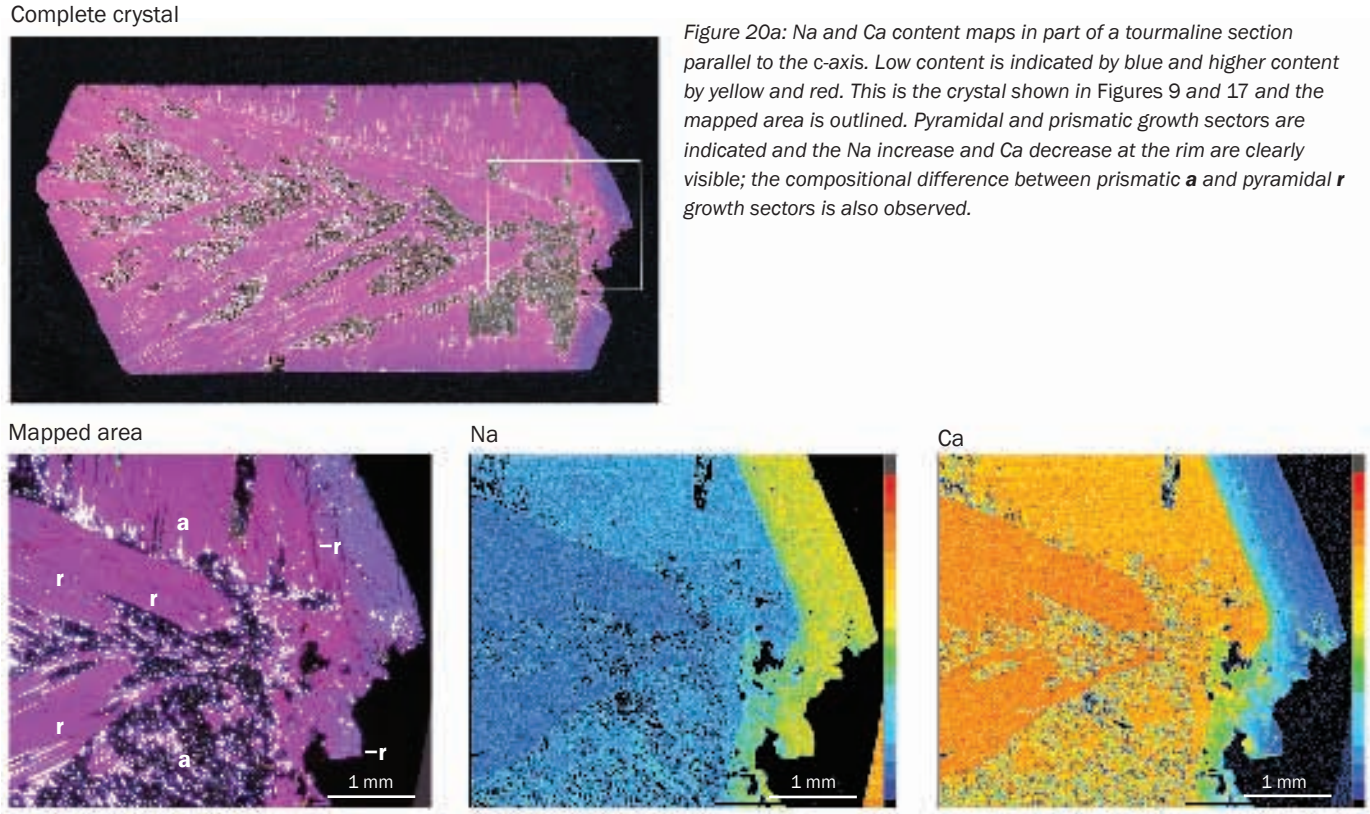

Figure 20a: Na and Ca content maps in part of a tourmaline section parallel to the c-axis. Low content is indicated by blue and higher content by yellow and red. This is the crystal shown in Figures 9 *and* 17 *and the mapped area is outlined. Pyramidal and prismatic growth sectors are indicated and the Na increase and Ca decrease at the rim are clearly visible; the compositional difference between prismatic* ***a*** *and pyramidal* ***r*** *growth sectors is also observed.*

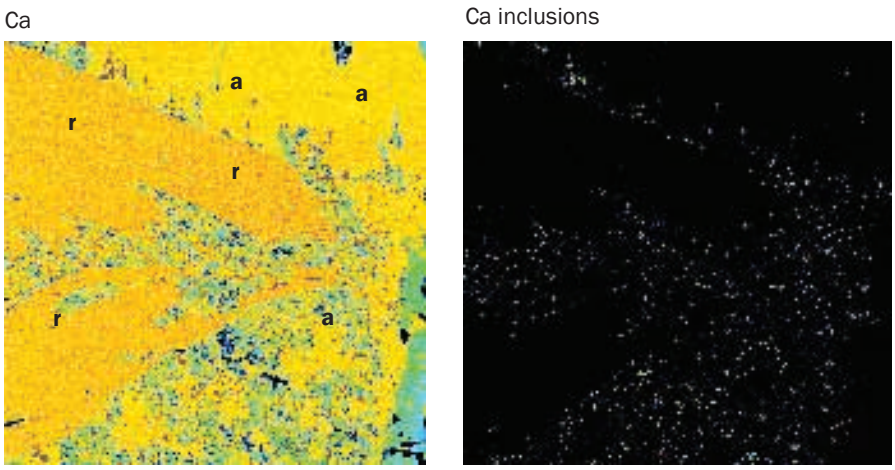

Figure 20b: Magnified view of part of the mapped area in Figure 20a showing Ca contents in tourmaline and calcium-bearing inclusions. The left part shows relatively 'clean' areas with light and dark amber colour representing transparent ***r*** *and* ***a*** *growth sectors of the tourmaline crystal. In the same figure, green and blue pixels indicate a second tourmaline composition with lower calcium contents. Only in these heavily included areas are tiny crystals of calcite and dolomite (right part) present.*

ends when the diameter of the channel diminishes and closes (case a, see *Figure 21a*) or when the inclusion at the forefront of the channel halts or is finally 'frozen' and normal tourmaline resumes growth (case b, see *Figure 21b*). One or both ways described could be responsible for the formation of channels in tourmaline cat's-eyes.

In some trapiche tourmalines, abundant channels of limited length are present only at the margins between different growth sectors. If growth-induced channels are not limited to an area close to the sector boundaries, they continuously extend into the growing tourmaline sectors. In such samples, the last slices along the *c*-axis of the tourmalines show only small 'clean' transparent areas with few growth tubes.

The various growth processes suggested so far do not explain the tourmaline analyses in the arms of the star with sodium contents that are higher than in the surrounding transparent tourmaline. Careful examination of thin sections showed that despite the difference, this tourmaline is not distinguishable from the main tourmaline on the basis of optical properties.

7.2 The trapiche pattern: nomenclature

Numerous gemstones have been designated as 'trapiche' in the trade and in various gemmological journals. In general

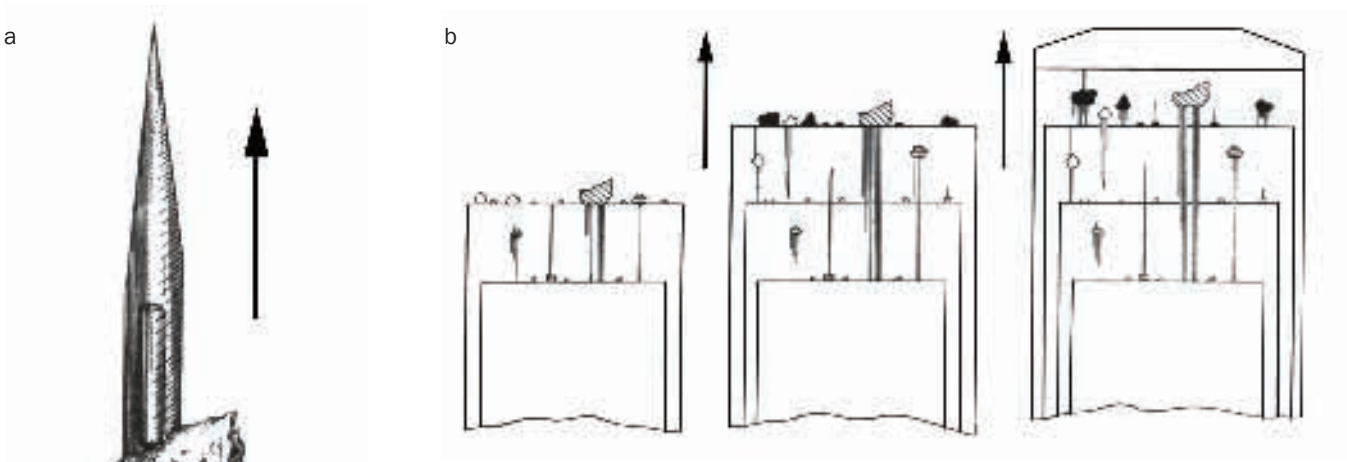

Figure 21: Two possible formation mechanisms of growth induced elongated voids in tourmaline (from Slivko, 1966):
(a) Trapping of a solid inclusion and subsequent blocking of crystal growth with the formation of a growth induced, elongated void in the direction of crystal growth (arrow) subsequent to trapping of the small mineral grain;
(b) Trapping of a solid inclusion, movement of the trapped small mineral grain in the direction of the arrow and of the growing crystal face and formation of a growth induced, elongated void in the wake of the moving mineral grain, a mechanism repeated in several steps.

the term is used to describe a pattern consisting of a fixed star in a transparent host matrix, with the arms of the star radiating from a central point or central core to the rim of the crystal, cabochon or slice. Several 'trapiche' materials with different visual appearance were recently described by Win (2005) and these can be considered in two groups.

The first group is characterized by more or less sharp boundaries, extending from a central intersection point or from the edges of a central core, which separate transparent to translucent growth sectors of the host (see ruby in *Figure 22*). The arms of the fixed star, which are formed by these boundaries, are mostly not transparent and run from the centre to the edges of the external crystal faces. They consist of the main mineral (e.g. beryl, corundum, tourmaline) and numerous tiny other mineral or fluid inclusions. Consequently, the areas separated by the arms of the star are crystallographically equivalent prismatic (beryl), dipyramidal (corundum) or pyramidal (tourmaline) growth sectors of the crystal. The most prominent gem materials of this group (see *Table IV*) are Colombian emerald, ruby from Mong Hsu, Myanmar and the uvite-dravite tourmaline from Zambia.

The second group is characterized by several alternating transparent and translucent areas which surround a central point or central core according to the symmetry of the host. The transparent and translucent areas are characterized by different concentrations of inclusions, which are trapped within specific central parts of symmetry-equivalent growth sectors of the host (see the sapphire in *Figure 22*). The sharp boundaries separating the different crystallographically equivalent growth sectors of the first group are not visible. The arms of the group 2 star are perpendicular to the external crystal faces, e.g. perpendicular to the hexagonal dipyramids of corundum or perpendicular to the prism faces of beryl. The most prominent gem examples of this second group are the blue basaltic sapphires described recently by Khotchanin *et al.* (2009). Slices of these sapphires perpendicular to the *c*-axis consist of milky white, translucent areas with a high concentration of inclusions.

The following examples highlight the differences in star pattern. The milky white translucent areas with abundant inclusions in the sapphires of Khotchanin *et al.*(2009) are equivalent

Figure 22: Trapiche ruby from Mong Hsu, Myanmar (top) and trapiche-type sapphire from Hunan province, China (bottom); slices perpendicular to the c-axis, the hexagonal outlines of the rough crystals are represented by dipyramidal faces. With identical crystallographic orientation of both corundum slices, the different orientation of the fixed star within these samples is observed. Diameter of the trapiche ruby 4.20 mm, size of the trapiche-type sapphire 10 × 12 mm. Photos by K. Schmetzer.

Table IV. Properties of gem materials with typical trapiche pattern

		Emerald, Colombia	Ruby, Myanmar	Tourmaline, Zambia[12]
Type of crystals		Hexagonal prisms, rarely with basal faces [1,2,4,5]	Fragments confined by hexagonal dipyramids ω [7]	Complete prismatic crystals
Sections or slices ⊥ to the *c*-axis	Geometrical pattern	Hexagonal core, rim formed by six trapezohedral sectors [1,2,3,4,5,6]	Hexagonal red, yellow or black core, rim formed by six red trapezohedral sectors [7,8,9,10,11] Growth zoning ∥ ω [10]	Hexgonal core consisting of several pyramidal growth sectors, rim formed by six trapezohedral sectors
	Chemical zoning	Zoning of trace elements [6]	Zoning of trace elements [8,9,11]	Uvite-dravite zoning
Fine structure in thin sections ⊥ to the *c*-axis, orientation of channels or needle-like inclusions		Fibrous texture ⊥ to the *c*-axis in the rim [1,5,6] growth planes parallel to the prism [1,5]	Channels ∥ to the *c*-axis and slightly inclined ⊥ to the *c*-axis [7]	Channels ⊥ to the pyramids in the core and ⊥ to the prism in the rim
Sections or slices ∥ to the *c*-axis	Geometrical pattern	Tapered core [1,2,4,5]	Tapered core, end of cores red, yellow or black channels ⊥ to the dipyramids ω [7]	Tapered core, sometimes skeleton growth
	Chemical zoning			Uvite-dravite zoning
Fine structure in thin sections ∥ to the *c*-axis, orientation of channels or needle-like inclusions		Fibrous texture ⊥ to the *c*-axis in the rim and ∥ to the *c*-axis in the core [1]		Channels ⊥ to the pyramids in the core and ⊥ to the prism in the rim
Main material trapped at the boundaries of growth sectors or in channels		Quartz, albite [3,5] or carbonaceous matter [5]	Fluid, calcite, dolomite, silicates [7,8,11]	Graphite, calcite, dolomite, fluid

Emerald: 1 Bernauer, 1926; 2 McKague, 1964; 3 Schiffmann 1968, 1969; 4 Tripp and Hernandez, 1970; 5 Nassau and Jackson, 1970 a,b; 6 Ohnenstetter *et al.,* 1998
Ruby: 7 Schmetzer *et al.,* 1996; 8 Schmetzer *et al.,* 1998; 9 Sunagawa *et al.,* 1999; 10 Schmetzer and Schwarz, 2000; 11 Garnier *et al.,* 2002 a,b
Tourmaline: 12 this paper

to the transparent growth sectors of trapiche rubies (*Figure 22*, see *Table IV*), and the blue transparent areas of basaltic sapphires are equivalent to the sharp non-transparent boundaries of trapiche rubies. If the pattern of Colombian emeralds *(Table IV)* is compared with that in aquamarine from Namibia (Koivula, 2008), the non-transparent arms of Colombian emeralds are equivalent to the transparent areas within the aquamarine material from Pakistan, and the transparent growth sectors of the emeralds are equivalent to the heavily included milky white areas of these aquamarines. Another example is given by DelRe (1994) in which he compares Colombian trapiche emerald with emeralds from Brazil which have a fixed six-rayed star with arms orientated perpendicular to the external prism faces of the beryl host. The author also mentioned that the two types of trapiche emeralds "almost seem to be a photographic negative" of each other.

These two star patterns indicate different mechanisms of formation. Consequently, to distinguish them, we suggest naming the first group (e.g. Colombian emeralds, ruby from Myanmar, tourmaline from Zambia) trapiche and the second group (e.g. basaltic sapphires from various origins) trapiche-type.

7.3 The trapiche pattern: formation

Several mechanisms of formation for the trapiche pattern have been suggested for the gemstones emerald and ruby, as well as for other non-gem materials such as cordierite or andalusite (chiastolite) (Petreus, 1974; Henderson, 1995).

A mineral which shows a clear trapiche pattern – cordierite from Japan – is not discussed in this paper because of the even more complex mechanism of formation, which includes a high temperature to low temperature transition between indialite and cordierite (see Rakovan *et al.,* 2006, and the papers cited therein). If we concentrate on the known

	emerald	ruby	tourmaline
core	basal pinacoid	basal pinacoid	different trigonal pyramids
rim	hexagonal prism	hexagonal dipyramid	hexagonal prism and/or trigonal prism

gem materials with trapiche patterns, i.e. emerald, ruby and tourmaline, we always have materials subdivided in growth zones related to a core and a rim. The equivalent faces of these growth zones are given above.

The most significant visual difference is the subdivision of the core of trapiche tourmalines into three different sectors, whereas the cores of emerald and rubies normally consist of a single hexagonally outlined area.

The formation of Colombian trapiche emeralds *(Table IV)* has been described as a process in which first the transparent core and then the rim (consisting of the six transparent sectors separated by non-transparent arms) were grown (McKague, 1964; Nassau and Jackson, 1970 a,b).

This mechanism does not explain the tapered form of the transparent core and the different orientations of the fibrous texture of the core and the rim (see *Figure 23* by Bernauer, 1926). In addition, it is not clear how a rare type of trapiche emerald with opaque tapered core (as proposed by Nassau and Jackson from their observation and literature data) was formed. If the tapered form of the core and the growth planes within the outer trapezohedral areas as well as the orientation of fibrous textures indicate basal and prismatic growth sectors, a growth in several growth steps with the subsequent formation of the core and the six sectors of the rim is rather unlikely.

Trapiche rubies from Myanmar were extensively studied in basal slices and thin sections (see *Table IV*), but only limited information is available from slices or sections parallel to the *c*-axis. Within the arms of the six-rayed star, ruby zones with distinctly lower chromium contents compared to the higher chromium contents of the trapezohedral ruby sectors were analysed. Thus, a dendritic (skeletal) growth of the arms and a subsequent growth of the transparent trapezohedral ruby sectors were suggested by Sunagawa *et al.* (1999).

However, the growth sectors representing the different red, black or yellow cores of trapiche rubies and the transitions between these parts within the same sample were not resolved clearly (see Schmetzer *et al.,* 1996, 1998; Sunagawa *et al.,* 1999). In particular, it is not understood if the complex formation of non-trapiche rubies from Mong Hsu with subsequent red and black cores parallel to the *c*-axis as described by Peretti *et al.* (1995) is part of the formation of the differently coloured cores of the trapiche rubies from this occurrence.

The compositional zoning of the uvite-dravite tourmalines described in this paper and the geometrical pattern of a core consisting of pyramidal and prismatic growth sectors both separated by trapiche boundaries makes the possibility that a partial core (consisting only of pyramidal growth sectors) grew first, followed by a rim consisting of prismatic growth sectors very unlikely. The complex chemical zoning within all growth sectors of these tourmalines shows a successive, layer-by-layer growth from a calcium- and magnesium-rich uvite towards a sodium- and aluminium-rich dravite.

The presence of mineral grains and fluid inclusions at the margins of different growth sectors and in the less transparent areas of the crystals is apparent. The formation of fluid filled channels originating from these inclusions with an orientation perpendicular to the growing crystal face is consistent with the description of a similar mechanism of channel formation in tourmaline as described by Slivko (1966).

A sodium- and aluminium-rich dravite with a composition different from the tourmaline forming the larger transparent growth sectors was found in all non-transparent boundaries between different growth sectors and in the less transparent irregular growth zones of the tourmalines. Using the model of Sunagawa *et al.*(1999) developed for trapiche rubies from Myanmar, this dravite is equivalent to the dendritic ruby forming the arms of trapiche rubies, and the transparent uvite-to-dravite growth sectors are equivalent to the trapezohedral growth sectors of these trapiche rubies. Consequently, the application of the model developed for trapiche rubies can explain the formation of the trapiche pattern in tourmaline from Zambia. First there was rapid skeletal growth of dravite with trapping of numerous inclusions followed by successive layer-by-layer growth of more transparent tourmaline. Starting this second generation of tourmaline growth with calcium-rich uvite, the composition slowly and continuously altered to a more sodium-rich dravite.

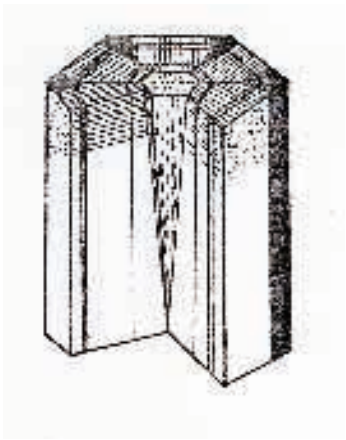

Figures 23: Schematic drawing of structural features in trapiche emerald from Colombia (from Bernauer, 1926). Fibrous textures within the tapered core are oriented parallel to the c-axis, and similar appearing fibrous textures within the rim are perpendicular to the external prism faces, layered growth zoning is observed within the prismatic growth sectors of the rim; the core and the six growth sectors of the rim are separated by dark non-transparent boundaries.

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Untreated yellowish orange sapphire exhibiting its natural colour

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Abstract: Orange sapphires of natural colour are rather rare. A 3.85 ct sapphire recently submitted for identification was confirmed as natural using conventional gemmological equipment and infrared spectrometry. Colour zoning, inclusions and twinning are described and compared with the features shown by synthetic sapphires.

Keywords: colour zoning, heat treatment, inclusions, infrared spectra, orange sapphire, synthetic

Introduction

Recently, the author received a 3.85 ct pear-shaped yellowish orange gemstone, measuring 11.38 × 9.55 × 4.88 mm, for identification *(Figure 1)*.

The refractive index (RI) determinations were carried out using a Rayner Dialdex critical angle refractometer with the use of a polarizing filter and monochromatic sodium light. Using the table facet, the stone was rotated every 45° and the indices recorded until a rotation of 180° was reached. The indices obtained showed two constant and parallel shadow edges, 1.762 and 1.770 (birefringence 0.008), proving the stone uniaxial, with its table facet cut perpendicular to the optic axis. A polarizing filter is needed to obtain the optic sign (Sturman and Parker, 2010), and this was checked by testing one of the pavilion facets, under the same working conditions, this gave ε = 1.762, ω = 1.770, optic sign U/-.

To confirm the uniaxial nature of the stone, it was examined table down in a Gem Illuminator Polariscope, set to its dark position (where the vibration directions of the polarizer and analyser are perpendicular to one another) and with a conoscope placed on the stone's pavilion; a uniaxial interference figure could be seen.

The specific gravity (SG) was obtained by hydrostatic weighing of the stone, employing a Mettler PL 300c electronic balance (accuracy ± 0.001 ct) with SG attachments. The SG is 3.99.

The pleochroism observed through the pavilion with a Rayner calcite dichroscope was very weak with a small range from yellow orange to slightly darker yellow orange.

The absorption spectrum seen through a Gem Beck Spectroscope Unit, showed no lines in the blue portion of the visible spectrum, but lines in the red at 660 and 680 nm.

A faint uneven dark apricot fluorescence could be seen with a Multispec combined LW/SW unit.

These physical properties correspond to those of corundum, yellowish orange sapphire, so to determine whether it was natural or synthetic, treated or untreated, further testing was necessary.

Distinguishing natural from synthetic corundum

Synthetic corundum was first obtained by M.A. Gaudin in 1837 by the Verneuil flame-fusion process (Bourgeois, 1884); this was followed by J. Czochralski in 1918 using the pulling method (Elwell, 1979), later by C.C. Chatham and F.T. Brown by flux fusion in the mid 1960s (Nassau, 1980) and more recently by Tairus using hydrothermal synthesis in the 1990s (Koivula *et al.,* 2000).

To test whether this orange yellow sapphire was synthetic, the stone was examined under a Bausch & Lomb Mark V Gemolite binocular microscope using dark field illumination or overhead lighting as appropriate. It revealed immediately under the table facet, broad parallel straight growth zonal striae lying in different planes, crossing each other at angles *(Figure 2)*. Numerous clouds of exsolved substances are aligned with these zonal striae and are responsible for

Figure 1 (above): Pear-shaped yellowish orange sapphire of 3.85 ct. Magnification 10×.

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Figure 2: Broad parallel straight growth zonal striae lying in different planes and crossing each other at angles. Dark field illumination, magnification 15×.

the 'sleepy' appearance of the stone. Lying in the bottom of the pavilion, parallel to a basal pinacoid is a tiny 'feather' consisting of very fine acicular droplets *(Figure 3)*. Polysynthetic twin lamellae *(Figure 4)* are visible with the stone immersed in ethyl alcohol between crossed polaroids.

These inclusions exclude Verneuil and Czochralski synthesis which display curved colour and growth banding (Gübelin and Koivula, 1986, 2008), often in the company of rounded gas bubbles with notably bold edges (although there is polysynthetic twinning in some Verneuil synthetics; Duroc-Danner, 1985).

In contrast, the most common inclusions in flux-grown sapphires are twisted veils of flux resembling net curtains or veils blowing in the wind (O'Donoghue, 2005; Gübelin and Koivula, 1986). While hexagonal, herring-bone or sets of straight growth bands forming an angle can occur in flux-grown synthetics, their synthetic origin can be ascertained by crystallographic investigation of structural features such as morphology and growth components. Straight parallel growth planes of the second-order hexagonal prism as well as growth planes parallel to different second-order hexagonal dipyramids (with the exception of **n** $\{22\bar{4}3\}$), do not appear in this type of synthesis (Schmetzer, 1986; Kiefert and Schmetzer, 1988, 1991). Occasionally one encounters inclusions of angular platelets of metallic appearance, often triangular or hexagonal in shape, but also in other forms such as needles. These originate from the platinum crucible in which the corundum is grown and have not been encountered in natural corundum (Gübelin and Koivula, 1986).

Hydrothermally grown synthetic corundums usually show fluid inclusions composed at room temperature of H_2O (liquid), H_2O (vapour) and carbonate solid daughter minerals (such as $CaCO_3$ and $KHCO_3$), while the fluid inclusions found in the natural counterparts (including the heat-treated ones) are composed of CO_2-rich compositions with completely different reactions to heating and freezing. By studying these reactions, it is therefore possible to identify this type of synthetic (Peretti *et al.,* 1997). Roiled-to-angular growth structures, sometimes described as chevron-spaced, and scattered flake-like 'breadcrumbs' can also occur (Renfro *et al.,* 2010). Solid inclusions are sometimes also observed, consisting of copper alloys, derived from the steel autoclave (copper inclusions have not yet been observed in natural corundum). Hydrothermally produced yellow, green, blue-green and blue synthetic sapphires owe their colour only to nickel, whereas blue-violet to violet orange and reddish-orange synthetic hydrothermal sapphires are coloured by traces of both chromium and nickel, while the three main causes of colour in natural corundum are due to colour centres or Fe^{3+} for yellow sapphires; Fe^{2+}/Ti^{4+} ion pairs with or without additional Fe^{2+}/Fe^{3+} pairs, for blue to violet sapphires; and Cr^{+} for rubies (Schmetzer and Peretti, 1999, 2000).

Magmatic or metamorphic corundum

Corundum can be of two different types:

- Magmatic yellowish orange sapphires owe their colour chiefly to Fe^{2+}/Fe^{3+}, Fe^{3+} and Fe^{3+}/Fe^{3+}, and to a lesser degree to IVCT $Fe^{2+} \rightarrow Ti^{4+}$, with high Ga^{3+} and minor Cr^{3+}.
- Metamorphic yellowish orange sapphires can owe their colour partially or wholly to trapped-hole centres, or mainly to Fe^{3+}, Fe^{3+}/Fe^{3+}, with sometimes minor IVCT $Fe^{2+} \rightarrow Ti^{4+}$, added to some Mg^{2+} and Cr^{3+} (F.L. Sutherland pers. comm., 2011; Schmetzer and Schwarz, 2005).

Some magmatic sapphires may be transported as xenocrystic passengers by basalt and brought to the surface from depths of up to 100 km (Keller, 1990, p.71) during volcanic eruptions. The infrared spectra of these magmatic sapphires show a peak at ± 3309 cm^{-1}, which is not present in natural metamorphic sapphires, nor in all (non-heat treated) synthetic sapphires except those issued from the Verneuil flame-fusion syntheses; this is due (as for peaks

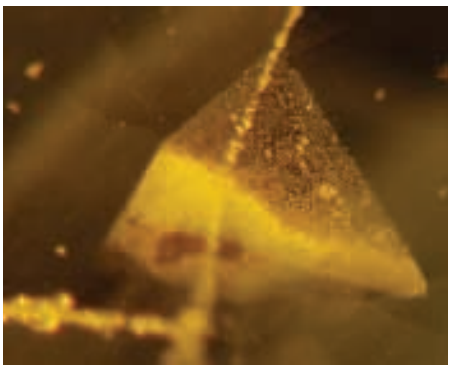

Figure 3: Tiny 'feather' consisting of very fine acicular droplets. Dark field illumination, magnification 30×.

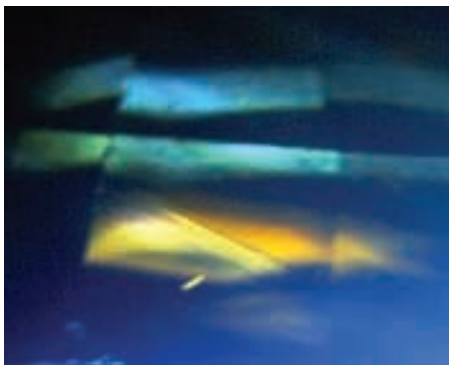

Figure 4: Polysynthetic twin lamellae, stone immersed in ethyl alcohol, between crossed polaroids, magnification 20×.

± 3295 cm^{-1}, ± 3232 cm^{-1}, and ± 3185 cm^{-1}) to a OH-dipole linked to atoms of iron and titanium in the corundum structure. The peak ± 3366 cm^{-1} is due to OH clusters linked to a titanium atom (Duroc-Danner, 2002).

The FTIR spectrum in the mid-infrared region between 4000 and 2100 cm^{-1} of the yellowish orange sapphire is shown in *Figure 5*. There is a strong absorption in the range 2300–1700 cm^{-1}, a 3161 cm^{-1} peak, accompanied by peaks at 3240 cm^{-1} and 3354 cm^{-1}.

The 3161-series occurs most commonly in natural-colour yellow-to-orange and padparadscha sapphires from low-iron metamorphic environments, which owe their colour partially or wholly to trapped-hole centres. LA-ICP-MS chemical data and heating experiments suggest that the 3161-series is actually due to structurally bonded OH associated with Mg^{2+} (Smith and Van der Bogert, 2006).

The absence of a 3309 cm^{-1} peak (location indicated on *Figure 5*), also confirms that this yellowish orange sapphire is of non-magmatic origin (probably metamorphic) and has not suffered heat-treatment.

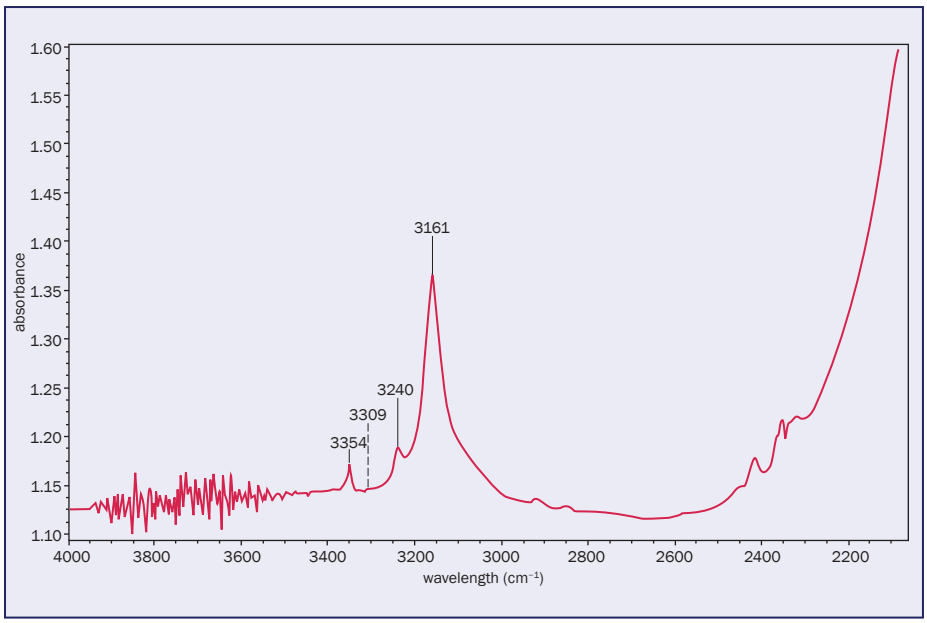

Figure 5: FTIR spectrum showing the 3161 cm^{-1} series of peaks due to structurally bonded OH associated with Mg^{2+}, and the absence of a 3309 cm^{-1} peak (indicated on the spectrum to show its location).

Natural colour versus beryllium treated corundum

Heat-treatment of corundum, with more or less colour improvement occurred in Sri Lanka around the second century AD, and is still performed today. Corundums were embedded in an open charcoal fire and air was blown through a bamboo pipe to raise the temperature up to 1000°C (Gunaratne, 1981; Hughes, 1988; Themelis, 1992, pp 113–14; Notari and Grobon, 2002).

More modern heat-treatment techniques were discovered apparently in the 1960s (translucent milky white Geuda sapphires from Sri Lanka transformed by atmosphere-controlled high temperatures around 1500°C into transparent richly coloured sapphires). Diffusion-treated corundum which first appeared on the world market in the late 1970s (heating in the range 1800°C with addition of colour-causing elements such as titanium results in a thin outer layer of saturated blue in otherwise colourless or pale coloured sapphire) produced dramatic results when compared with the subtle changes of the past (Kane *et al.,* 1990; Emmett *et al.*, 2003).

More recently, in late 2001, beryllium-diffused treated rubies and sapphires were produced (heating the corundum to around 1800°C with the beryllium obtained, for example, by crushed chrysoberyl, $BeAl_2O_4$). The reaction penetrates the entire sapphire to impart relatively homogeneous yellow-to-orange hues, although early examples of this treatment could be recognized when the stone was immersed in methylene iodide or ethyl alcohol by the presence of a colour zone that conforms to the external faceted shape of the stone (Emmett *et al.,* 2003). As can be seen in *Figure 6*, when immersed in ethyl alcohol the present yellowish orange sapphire has a colour distribution of angular yellow zoning alternating with colourless areas, which is characteristic of natural growth origin (Hurwit, 1987).

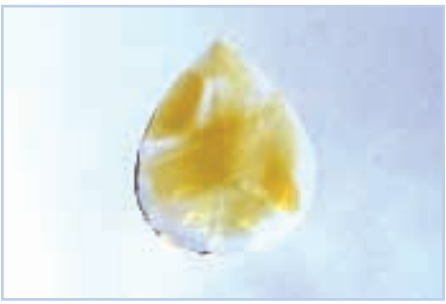

Figure 6: Straight angular yellow zoning alternating with colourless areas. Immersed in ethyl alcohol, magnification 10×.

Discussion

Standard gemmological properties, such as RI, optic character and sign, and SG, confirm that the stone is corundum, variety yellowish orange sapphire, but do not help in determining whether it is natural or synthetic.

Nowadays at least four kinds of process are used worldwide on a commercial basis to produce synthetic corundum, and the products are becoming more sophisticated, thus posing a real challenge to the unwary jeweller:

- Verneuil inverted blow-pipe process (Hrand Djévahirdjian S.A., Switzerland; Union Carbide, U.S.A.; Nakazumi Earth Crystals, Japan; Wiedes Carbidwerke Freyung, Germany; etc).
- Czochralski (pulling) growth technique (Union Carbide, U.S.A.; Deltronics, New Jersey, U.S.A.; Crystal

Optics Research, California, U.S.A.; Kyocera International Inc., Japan; etc).

- Flux fusion growth technique (C.C. Chatham, California; Douros, Greece; J. Osmer Crystals Co., California, U.S.A.; Kashan Inc., Texas, U.S.A.; P.O. Knischka, Austria; J. Lechleitner, Austria; etc).
- Hydrothermal growth process (Tairus Co., Thailand and Russia; etc).

Also most natural corundums in the gem market are heat-treated between 1000° and 1500°C. Additionally, some are diffusion-treated with colour-causing elements such as titanium (Ti) or more recently beryllium (Be), which can be detected using Secondary Ion Mass Spectrometry (SIMS) or Laser Ablation-Inductively Coupled Plasma-Mass Spectrometry (LA-ICP-MS).

The present yellowish orange sapphire was identified with conventional gemmological equipment and infrared spectroscopy, so recourse to the expensive SIMS or LA-ICP-MS facilities was not necessary.

The inclusions and internal characteristics point towards a natural stone devoid of heat-treatment (Panjikar and Panjikar, 2011).

The FTIR spectrum not only confirmed that the stone was not heat-treated, but also established its non-magmatic origin (probably metamorphic).

The faint uneven dark apricot luminescence to ultraviolet radiation provided helpful indications for non-Be-diffusion treatment since Be-diffused areas usually fluoresce a distinctive homogeneous orange (Notari *et al.,* 2003). This indication is also consistent with the angular yellow zoning alternating with colourless areas, which is characteristic of natural origin.

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Alexandrite and colour-change chrysoberyl from the Lake Manyara alexandrite-emerald deposit in northern Tanzania

Dr Karl Schmetzer and Anna-Kathrin Malsy

Abstract: Mineralogical and gemmological properties of alexandrite from the Mayoka deposit, Lake Manyara mining area, Tanzania, are described. The alexandrite crystals are located in a phlogopite-bearing schist which is part of a metamorphic-metasomatic association of mafic or ultramafic rocks in contact with pegmatitic intrusions. Emeralds are associated with the pegmatites. Single crystals, contact twins, penetration twins and cyclic twins (trillings) are all present in this area and are developed in two major habits, one tabular parallel to the **a** pinacoid and the other columnar along the *a*-axis. Microscopic features of faceted and rough alexandrites are characterized by internal growth structures reflecting the external morphology of the samples. Common mineral inclusions are phlogopite, apatite and zircon. Associated with series of channels parallel to the *a*-axis three groups of elongated or tabular negative crystals oriented in a plane parallel to the **a** pinacoid form milky white zones in some samples. The complexity of alexandrite colours is clarified to some extent by correlation of colorimetric parameters with trace element contents and with the orientation of the alexandrites. The designation of samples as alexandrites and a possible distinction from colour-change chrysoberyl is discussed. Alexandrite and green chrysoberyl from Lake Manyara is compared with samples from other occurrences in phlogopite-bearing schist such as the 'classical' alexandrite deposits in the Urals, Russia, and from Novello, Zimbabwe.

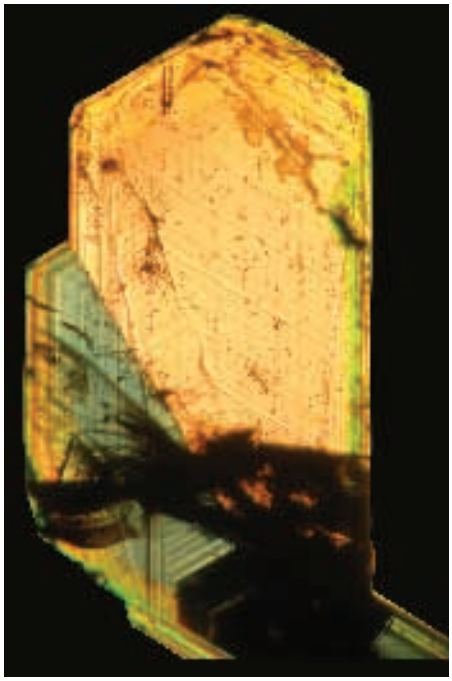

Irregular alexandrite twin from Lake Manyara, Tanzania; view parallel to the a*-axis, immersion, crossed polarizers, field of view 6.5 × 4.9 mm. Photo by K. Schmetzer.*

Historical background

The first emeralds originating from the Lake Manyara alexandrite-emerald deposit were discovered in 1968 or 1969 by local residents and after some time appeared in Arusha, in northeastern Tanzania, where they were seen by the prospector Hans Kristen. He and some of his group were able to trace the emeralds back to a place called Maji Moto (hot springs) in the Lake Manyara area. In February 1970, after months of prospecting activities, they finally discovered the primary deposit on the western bank of Lake Manyara. The mining rights were given to and the mine was exploited by Galai Mining Company Ltd., headed by George 'Papas' Papaeliopoulos (also spelled in the literature Papaleoupoulos, Papadopoulos) until 1973. Within this period, more than 100 workers were employed in the mine yielding more than 200 kilos of emerald (July 1970 to April 1972). In contrast, an official report by Mwakisunga (1972 a,b), a geologist who examined the mining area from July to September 1972 for Tanzania Gemstone Industries Ltd, a subsidiary of the State Mining Corporation, mentioned only the possible occurrence of gem materials in the mine and no commercial production.

In February 1973, the activities of Galai Mining Company were stopped by

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Figures 1a and 1b: Emerald crystals from the Lake Manyara deposit show a surface consisting of heavily etched crystal faces; such natural etching is common in beryls from pegmatitic deposits, but less so in emeralds (see, e.g., Honess, 1917). Collection of W. Radl, Niederwörresbach, Germany. Photos by K. Schmetzer.
Figure 1a: Samples from 33.2 to 3.7 ct in weight, the emerald in the centre measures 13 × 7 mm.
Figure 1b: Heavily etched emerald, 4.85 ct, 13 × 7 mm.

Figure 2: These two recently found alexandrite crystals were shown to the visitors at Mayoka mine in October 2009. Photo by Willow Wight.

the Tanzanian government and the mine was nationalized. The government had decided to take over the mine because no production figures had been reported for several months and no emeralds had ever been exported officially. G. Papas was arrested and imprisoned, being accused of smuggling emeralds out of the country. The mining activities continued under the guidance of Kristen for the state-owned Manyara Emerald Co. During their stay in Tanzania in November 1973 and July 1974, E. Gübelin from Lucerne and H. Bank from Idar-Oberstein were allowed to visit the mine. They reported on a mine in full production with several dozens of labourers. In 1976 the so-called Mayoka mine was taken over by the state-owned Stamico (State Mining Company). Activities declined and finally the mine was abandoned. Prospecting work was performed in the late 1970s and early 1980s by the companies Stamico and Gemco Ltd. (for the history from the discovery of the deposit to the 1980s see Mwakisunga, 1972 a,b; Thurm, 1972, a,b,c; Bank, 1974; Gübelin, 1974, 1976; Bank and Gübelin, 1976; Viswanatha and Shah, 1983).

For almost three decades, only limited mining activity in the area by local farmers or other residents has been reported; they sporadically worked, legally or illegally, the old veins in the Mayoka mine and other pits nearby (Simonet, 1997, 2010; Werner Radl and John Saul, pers. comm., 2010, 2011). Only small parcels of gem-quality emerald (*Figures 1a* and *1b*) or alexandrite *(Figure 2)* from this source reached the market.

In October 2009, participants of the International Gemmological Conference were able to visit the area and allowed to see a mine, which was operated by Charles Perfect (Coldham and Payette, 2010; Wight and Wight, 2010). The visitors were told that active mining had started only some months ago. They reported on an area with deeply weathered country rocks with darker bands, some metres wide *(Figure 3)*, which appeared to be deeply weathered amphibolite-, actinolite- and phlogopite-bearing schist, intruded by pegmatites. These darker

rocks were indicated by the miners as possibly alexandrite-bearing or as possibly emerald-bearing veins. To find emerald (*Figures 1a* and *1b*) or alexandrite *(Figure 2)*, the miners follow these dark, possibly emerald- or alexandrite-bearing amphibolite-actinolite-phlogopite bands in different parts of the mine (*Figures 4* and *5*) and remove these darker layers from the more or less weathered lighter country rock (Anne and George Bosshart, Terry Coldham, Francine Payette, Willow and Quintin Wight, Hanco Zwaan; pers. comm., 2010, 2011).

At present (2011) the mine visited by participants of the International Gemmological Conference in 2009 is still operated by Charles Perfect, and the gem material is marketed by Sailesh Pandit of Signature Gems, Arusha, Tanzania (Werner Radl, pers. comm., 2011). The claim adjacent to this location is exploited by Emanuel Pengo *(Figure 6)*. The term 'Mayoka' is used for both mining areas, but it is not clear to the present authors, which parts of these claims were originally covered by the claims of G. Papas in the early 1970s (see above).

The Mayoka mine was originally located close to the boundary of the Lake Manyara Game Reserve, but at least partly outside the park. Due to an expansion of the Reserve, the mining area is nowadays located completely within the park. This created a conflict (see Kondo, 2005; Nkwame, 2009) which was settled in December 2010 by a Tanzanian court allowing the continuation of mining activities in the main Lake Manyara

Figure 3 : Detailed view of the deeply weathered country rock traversed by darker bands of what appear to be actinolite-phlogopite-bearing zones or layers, mostly some metres wide. These bands were indicated by the miners at Mayoka mine as either alexandrite- or emerald-bearing veins. Photo by Quintin Wight.

Figure 4 : 'Emerald adit' at Mayoka mine with miner removing the rocks of the darker emerald-bearing vein from the surrounding country rock. Photo by Francine Payette.

Figure 5 : Miner digging for alexandrite in a weathered zone of the actinolite-phlogopite schist at Mayoka mine. Photo by Willow Wight.

Figure 6: Another area next to the Mayoka mine visited by participants of the International Gemmological Conference in 2009 is exploited by E. Pengo who is using also the term 'Mayoka' for his claim. Mayoka is also the name of a small village nearby. Photo (taken in 2011) courtesy of Werner Radl.

alexandrite-emerald deposit and also for some local miners working in the area.

Formation of emerald and alexandrite

The formation of emerald and alexandrite in phlogopite-bearing host rocks was recently summarized by Schmetzer *et al.* (2011). Alexandrite and emerald are the rare green varieties of chrysoberyl ($BeAl_2O_4$) and beryl ($Be_3Al_2Si_6O_{18}$), respectively. Trace amounts of chromium are the principal cause of the green colours of both gem minerals and are responsible for the colour-change of alexandrite. The development of both gemstones in a rock requires the simultaneous availability of beryllium and chromium and it is not uncommon to find both minerals near to each other but not in contact. Chromium is present to some extent in ultramafic rocks, such as dunite and peridotite and their metamorphic equivalents, serpentinite and talc schist. Although beryllium is usually associated with specific types of granitic pegmatites in which it commonly occurs as beryl, it can also be derived from feldspars and other minerals independent of a pegmatitic source.

It follows therefore that an interaction between a beryllium-rich pegmatite and an ultramafic or mafic host would provide a suitable environment for the formation of emerald and/or alexandrite, mostly in a complex metamorphic-metasomatic alteration process. The emerald occurs within and in close proximity to the pegmatite; the rarer alexandrite and chrysoberyl formed under silicon-poor conditions and occurs more distally. It need not be directly associated with the pegmatite. Deposits with a similar paragenesis, especially those containing alexandrite in phlogopite lenses or phlogopite bodies, include the Russian emerald-alexandrite-phenakite deposits in the Urals and the emerald-alexandrite occurrence from the Novello deposit, Masvingo District, Zimbabwe.

Geology of the Lake Manyara deposit, Tanzania

Several authors have mentioned that the Lake Manyara deposit belongs to the classical phlogopite-related metamorphic-metasomatic type described for the alexandrite occurrences in the Urals or in Novello (see Box 1). The most detailed description of the country rocks found in the area and the reaction zone between ultramafic or suitable mafic rocks and pegmatite veins at the Lake Manyara deposit is in an unpublished report by Viswanatha and Shah (1983):

> "The rock types within the area consist of permeated gabbroic amphibolite and meta-pyroxenite bordered on either side by banded granodioritic to granitic gneisses….The borders of the pyroxenite with the amphibolite are traversed by veins of pegmatite and quartzo-feldspathic permeations and are marked by the development of alteration zones rich in acicular bunches of actinolite and tremolite with interlocked flakes of vermiculite. Some of these pegmatites along this contact carry gem quality emerald, green aquamarine, chrysoberyl cat's-eye, alexandrite, alexandrite cat's-eye, ruby and garnet."

A more recent summary is in another unpublished report by Simonet (1997):

> "The Manyara deposit belongs to the

Box 1

In some older papers, the mica associated with emerald and alexandrite is described as biotite, but modern analyses show that most brownish micas in these alteration zones contain less iron than in biotite and, thus should be designated phlogopite. The actual analyses of some micas on rough alexandrite samples from Lake Manyara and from inclusions in faceted Lake Manyara alexandrites by the present authors gave between 7.86 and 8.57 wt% FeO. All micas analysed contained significant amounts of potassium and, thus, the samples were designated phlogopite and not vermiculite. This is consistent with the analysis of phlogopite inclusions in Lake Manyara emeralds reported by Moroz and Eliezri (1999).

category of emeralds in micaschists. Its main characteristics are the following: It is evidently associated with an alignment of altered ultrabasic bodies, which follows a big shear zone. Many pegmatite dikes have been observed and are thought to be the source of the beryllium. In one of the pits I visited, mineralizations are strikingly associated with black biotite veins, one to several meters thick, with strongly marked orientation, and surrounded by black amphibolites. Emerald is present as isolated crystals in biotitites, or in pockets associated with transparent quartz. Alexandrite appears in lumps of a whitish rock inside the emerald bearing biotitites, or associated with mica, in desilicified pegmatites."

Most other authors have described the emerald host rocks as massive biotite schists or biotite lenses and less commonly as pegmatites with emeralds occurring in these types of host rocks and especially at the contact between pegmatites and biotite schists (Thurm, 1972 a,b,c; Gübelin, 1974; Bank and Gübelin, 1976; Bridges, 1982). Mineral and fluid inclusions in Lake Manyara emeralds were examined with modern analytical methods by Moroz and Eliezri (1999) and Moroz *et al.* (2001). The P-T conditions of emerald growth are given as: T = 370-470 °C, P = 3.0-7.0 kbar.

Furthermore, alexandrite is mentioned to occur together with emerald in the biotite schist (Thurm, 1972 a,b,c), occasionally also together with emerald and ruby (Bank, 1974; Amstutz and Bank, 1977). However, the alexandrite has also been found in actinolite schist (Gübelin, 1976; Bank and Gübelin, 1976).

In summary, emeralds are found in the phlogopite and at the contact between phlogopite and pegmatite veins, while alexandrites are found in the phlogopite and within masses of deeply weathered white feldspar originating from desilicified pegmatite veins.

So far, the details described in the two unpublished reports by Viswanatha and Shah (1983) and Simonet (1997) and in various other papers are not completely consistent (see also the summary of Keller, 1992, 49–59) but fit within the general concept of formation of alexandrite and emerald in a complex metamorphic-metasomatic phlogopite-bearing alteration zone formed between an intruding pegmatite and mafic or ultramafic rocks. Consequently, the Mayoka mining area close to Lake Manyara is a deposit of the same kind as those metamorphic-metasomatic deposits in the alexandrite-emerald mining belt of the Urals, Russia, and the Novello deposit, Zimbabwe.

Figure 7: Alexandrite trilling in different orientations and mirrored to show habit, and faceted alexandrite from Lake Manyara, Tanzania, shown in both daylight and incandescent light; these extraordinary pieces are from the collection of W. Radl, Niederwörresbach, Germany. The trilling weighs 132 g, view almost parallel to the a-axis, size 62 × 43 mm, thickness along the a-axis 29 mm; the faceted alexandrite weighs 0.71 ct, size 4.8 × 4.7 mm. Photos and artwork by K. Schmetzer.

Scope of the present paper

Mineralogical and gemmological descriptions of alexandrite from Lake Manyara were made of a limited number of samples in the 1970s (Dunn, 1976; Gübelin, 1976; Liddicoat, 1976; Bank and Gübelin, 1976). Morphological properties of rough crystals are only briefly mentioned, and growth patterns in rough

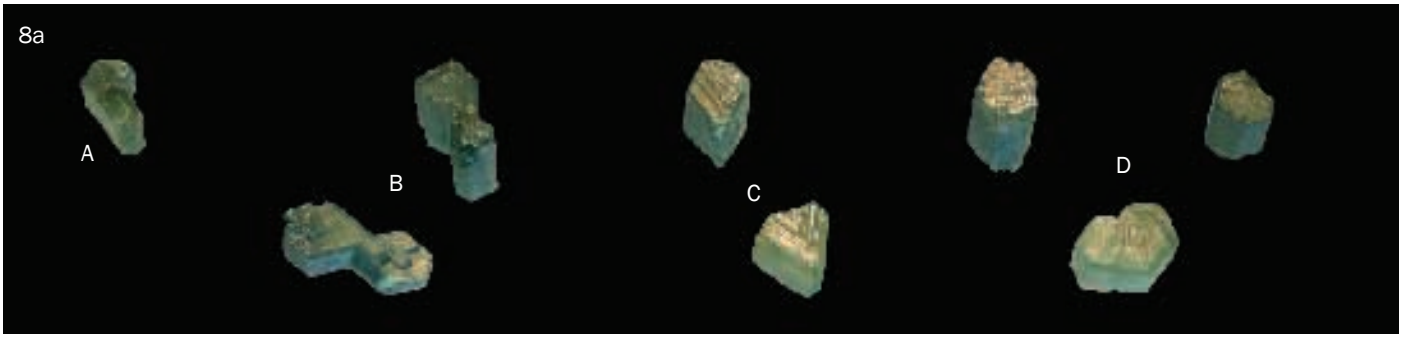

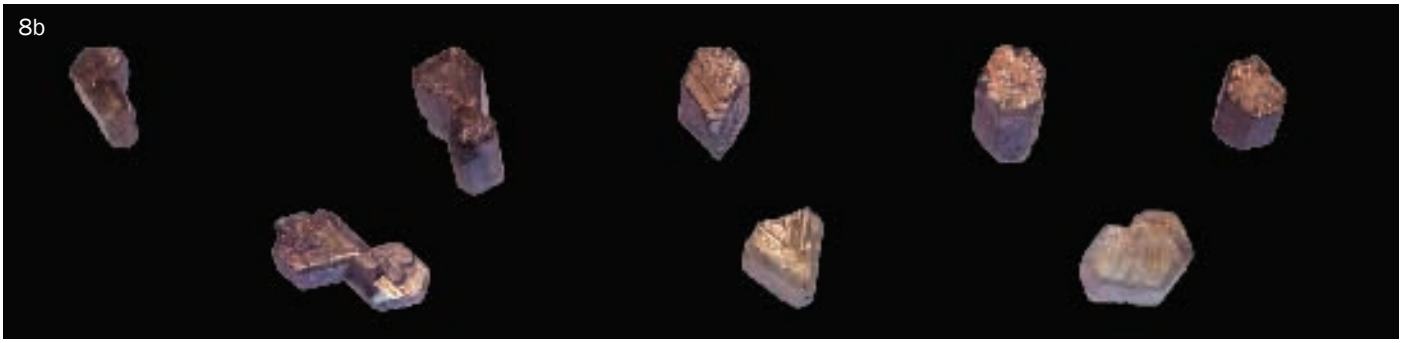

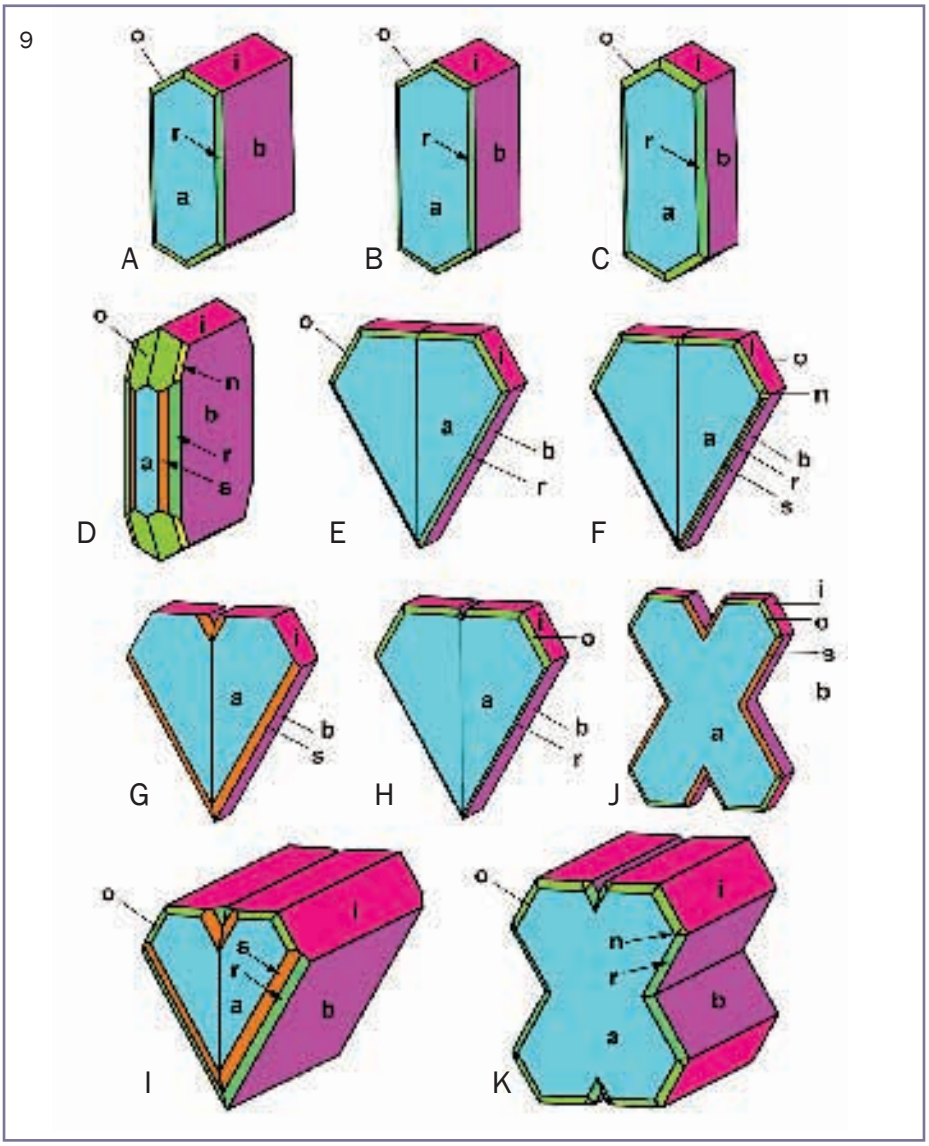

*Figure 8: Alexandrite crystals from Lake Manyara, Tanzania, shown in both daylight (a) and incandescent light (b); The alexandrites are found as single crystals (A), interpenetrant twins (B), contact twins (C) or cyclic twins (trillings, D); in the upper row, the crystals show columnar habit along the crystallographic a-axis, in the lower row, the crystals show tabular habit parallel to the **a** pinacoid. The two interpenetrant twins (B) measure 10.0 × 6.5 mm, length along the a-axis 10.0 mm (sample in the upper row) and 14.1 × 7.5 mm, thickness along the a-axis 3.8 mm (sample in the lower row). Collections of SSEF, Basel, Switzerland (H.A. Hänni collection), and W. Radl, Niederwörresbach, Germany. Photo by K. Schmetzer.*

*Figure 9: Schematic drawings of alexandrites from the Lake Manyara deposit, Tanzania. Single crystals (A to D), contact twins (E to I) and interpenetrant twins (J, K) are shown. The single crystals and twins are drawn in a view parallel to the a-axis, single crystals show tabular habit parallel **b** (A, D) or tabular habit parallel **a** (B, C), twins show tabular habit parallel **a** (E to H, J) or columnar habit along the a-axis (I, K). Crystal drawings and artwork by K. Schmetzer.*

Table I: Morphological properties of alexandrites from Lake Manyara, Tanzania.

Possible crystal forms and designation

Crystal form	Designation	Miller indices (hkl)*	Number of faces
Pinacoid	**a**	(100)	2
	b	(010)	2
Prism	**i**	(011)	4
	s	(120)	4
	r	(130)	4
Dipyramid	**o**	(111)	8
	n	(121)	8
	w	(122)	8

*Based on a morphological cell with a 4.42, b 9.39, c 5.47
Crystal class 2/m 2/m 2/m = D_{2h}, single and repeated twinning on (031) and $(0\bar{3}1)$

Habit of single crystals, twins and cyclic twins (trillings)

	Habit	Dominant forms	Subordinate forms	Accessory forms	Drawings in Figure
Single crystals	Tabular parallel **a**	**a**	**b**, **i**	**o**, **r**	9 C
	Tabular parallel **b** or columnar along *a*-axis	**a**, **b**, **i**		**s**, **r**, **o**, **n**	9 A, B, D
Contact twins	Tabular parallel **a**	**a**	**b**, **i**	**s**, **r**, **o**, **n**	9 E, F, G, H
	Columnar along *a*-axis	**a**, **b**, **i**		**s**, **r**, **o**, **n**	9 I
Penetration twins	Tabular parallel **a**	**a**	**b**, **i**	**s**, **r**, **o**, **n**	9 J
	Columnar along *a*-axis	**a**, **b**, **i**		**s**, **r**, **o**, **n**	9 K
Cyclic twins (trillings)	Tabular parallel **a**	**a**	**b**, **i**	**o**	14 A, B, C
	Columnar along *a*-axis	**a**, (**b**), **i**		**o**	14 D, E, F

or faceted samples were not reported. Analytical data for trace element contents or analytical determination of inclusions are limited. Thus, in the present account, the authors will try to fill this gap using numerous rough and faceted samples available from collectors closely associated with the Tanzanian gem trade for many years, from the reference collections of gemmological laboratories and from the gem trade.

Subsequent to the recent monograph containing detailed descriptions of the properties of alexandrite from the Uralian deposits (Schmetzer, 2010), and from the emerald-alexandrite occurrence at Novello, Zimbabwe (Schmetzer *et al.*, 2011), the current authors were also interested in comparing the mineralogical and gemmological characteristics of Lake Manyara alexandrite with stones from the other sources mentioned. Although the general occurrence of alexandrite from these deposits in a phlogopite matrix has been discussed in the literature, a detailed comparison of their characteristic features is not available.

Research materials

In the current investigation, the authors examined more than 200 complete crystals and crystal groups as well as crystal fragments, together with some alexandrite in matrix. Furthermore, 45 faceted stones in the range of 0.15 to 3 ct were available for examination *(Figure 7)*. The samples originated from private collections, from the reference collections of gemmological laboratories and from the stock of several companies. The samples are drawn from stones collected over the full time scale of four decades from the discovery of the mining area in the early 1970s to the most recent production (2009). No significant differences were found between samples unearthed in different decades within the Lake Manyara deposit.

Morphology, twinning and colour

Alexandrites from Lake Manyara show some variability in morphology, and especially in different forms of twinning. The crystals were determined as single crystals, contact twins, penetration twins or cyclic twins (trillings). Two major habits are found within each group (*Figures 8, 9* and *14*), which can be described as

I. tabular parallel to the **a** (100) pinacoid or
II. tabular parallel to the **b** (010) pinacoid or columnar along the *a* [100] axis.

From the crystal material available, the authors were able to determine seven external crystal forms for the orthorhombic chrysoberyls, namely the pinacoids **a** and **b**, the prisms **i**, **s**, and **r**, and the dipyramids **o** and **n** *(Table I)*. The habit of all crystals is determined by three crystal forms, the two pinacoids **a** and **b** and the prism **i**. The remaining prisms **s** and **r** and dipyramids **o** and **n**, are accessory forms only. The dipyramid **w** was only found as an internal growth feature.

All samples which are tabular parallel to the **a** pinacoid (group I), show dominant **a** pinacoids and somewhat smaller **b** and **i** faces. If the **b** pinacoids as well as the **i** prism faces are larger and dominant with **a** faces still being present (group II), the samples are mostly columnar along the *a*-axis or rarely tabular parallel **b** *(Table I)*.

Single crystals of both groups (*Figures 9* and *10*) are rare. The largest single crystal examined weighing 30 g is pictured in *Figure 11*. In contrast, contact twins with tabular habit are common, while columnar contact twins are rare *(Figure 12)*. Tabular penetration twins are rare,

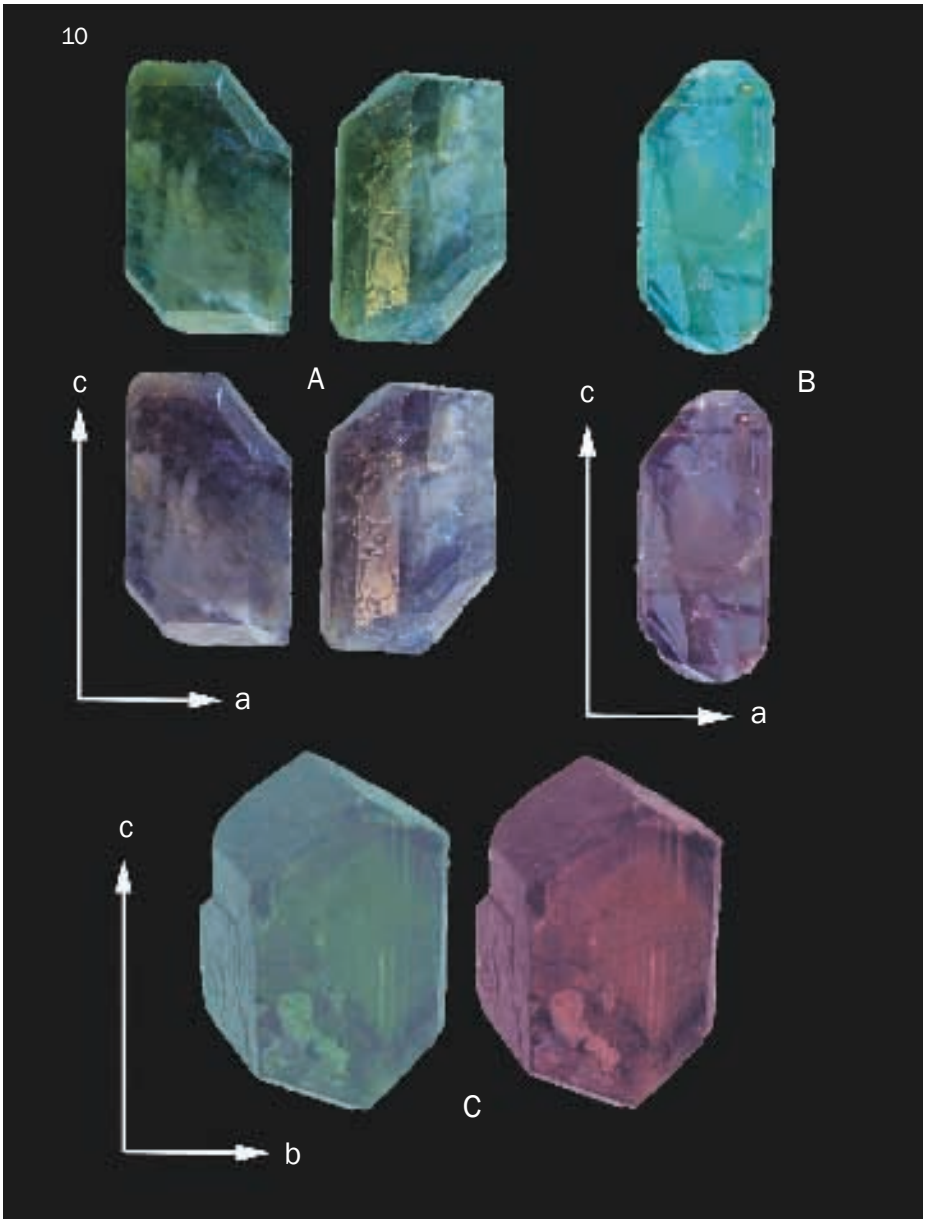

*Figure 10: Alexandrite single crystals from the Manyara area, Tanzania, shown in both daylight and incandescent light. Upper row: crystals A and B with tabular habit parallel **b**, lower row: crystal C with tabular habit parallel **a**; samples not to scale, sample A 15 × 9 mm, sample B 8.7 × 4.1 mm, sample C 16.5 × 10.5 mm. Collection of W. Radl, Niederwörresbach, Germany. Photos and artwork by K. Schmetzer.*

Figure 11: Alexandrite single crystal from Manyara, Tanzania; view almost parallel to the a-axis, weight 30 g, size 32 × 28 mm, thickness along the a-axis 15 mm. Collection of J.M. Saul, Paris, France. Photo by K. Schmetzer.

Figure 12: Contact twins of alexandrite from Lake Manyara, Tanzania; view almost parallel to the a-axis, the crystal on the upper left measures 10.2 × 9.1 mm, thickness along the a-axis 3.0 mm. Collection of W. Radl, Niederwörresbach, Germany. Photo by K. Schmetzer.

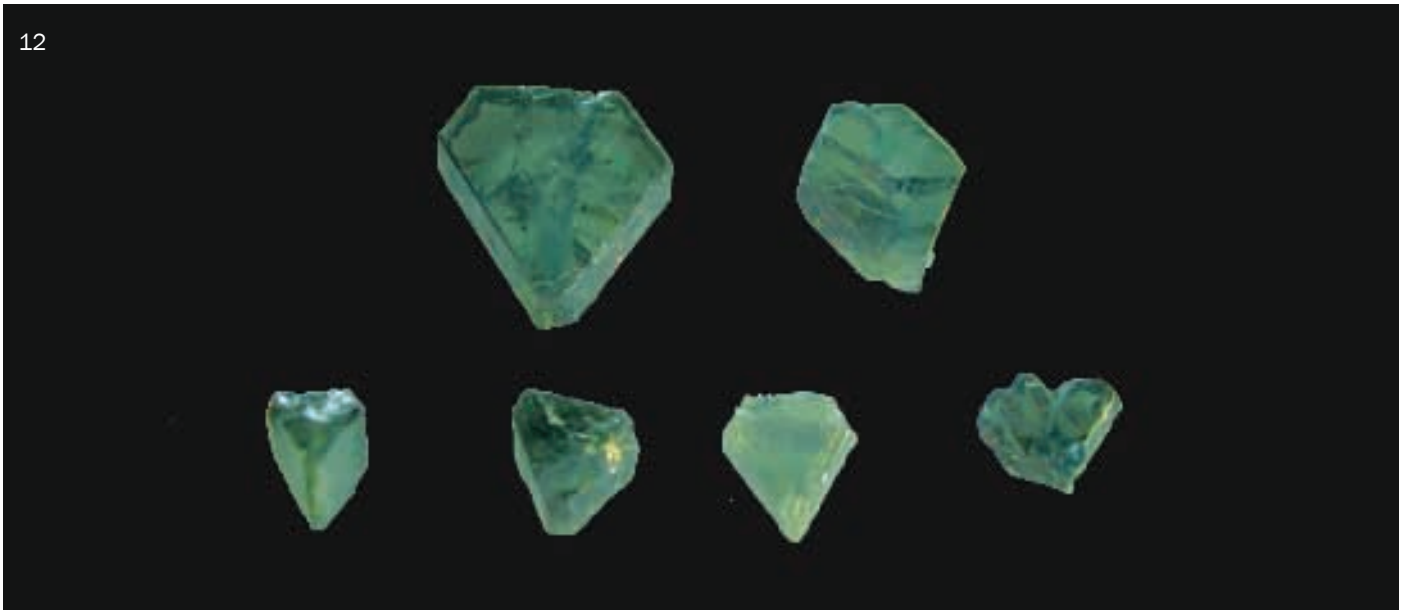

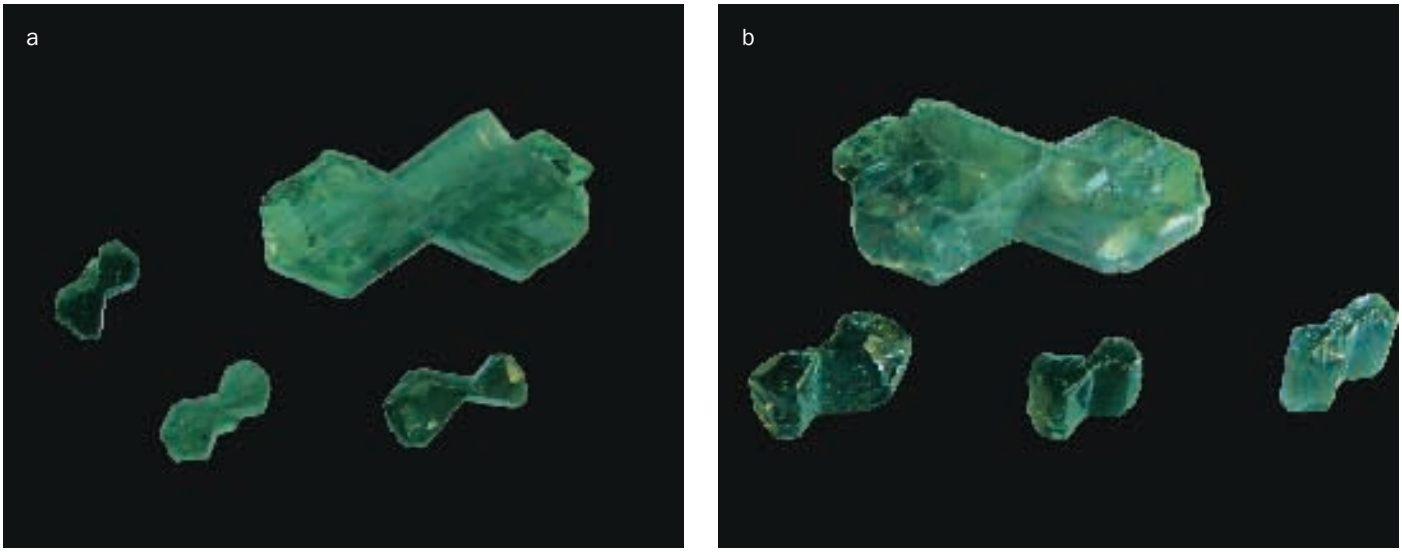

*Figure 13: Penetration twins of alexandrite from Lake Manyara, Tanzania; view almost parallel to the a-axis (a) and oblique to the a-axis (b), the largest sample shows tabular habit parallel **a**, the three smaller twins show columnar habit along the a-axis; size of the largest crystal 14.1 × 7.5 mm, thickness along the a-axis 3.8 mm. Collection of W. Radl, Niederwörresbach, Germany. Photos by K. Schmetzer.*

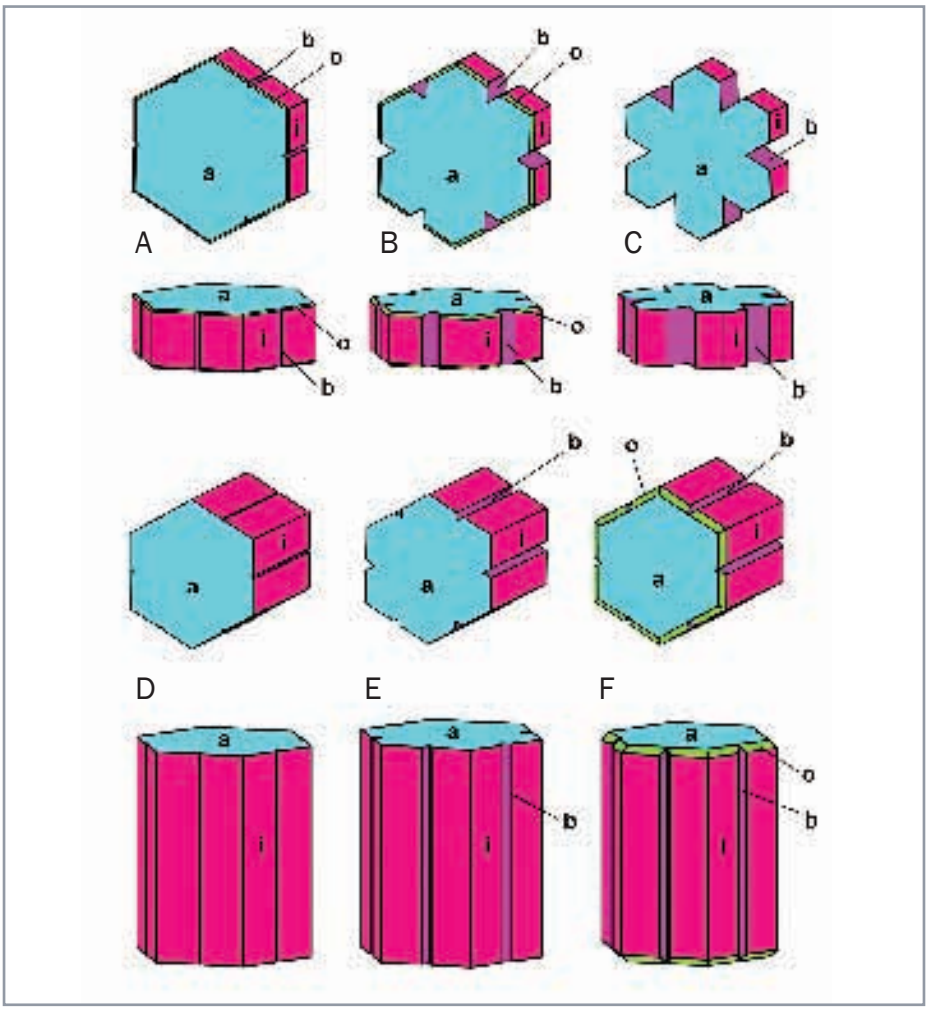

*Figure 14: Schematic drawings of alexandrite cyclic twins (trillings) from the Lake Manyara deposit, Tanzania. The cyclic twins are shown in views parallel to the a-axis (upper rows) and perpendicular to the a-axis (lower rows); the trillings show tabular habit parallel **a** (A to C) or columnar habit along the a-axis (D to F). Crystal drawings and artwork by K. Schmetzer.*

and columnar penetration twins were seen only occasionally *(Figure 13)*. On the other hand, tabular trillings (cyclic twins) are common (*Figures 14* and *15*), but only a few columnar trillings were seen *(Figure 16)*. Tabular trillings commonly show colour zoning with a transparent light green rim and an off-white, translucent core. In several samples, between rim and core, there are transparent green and translucent off-white layers. The two largest somewhat distorted trillings seen by the present authors weigh 132 and 16 g respectively (*Figures 7* and *17*).

Some more irregular twins can be described as contact twins with an additional crystal in twin position (*Figure 18* and *19*, sample A), as part of a penetration twin (*Figure 19,* sample B) or as part of a trilling *(Figure 20)*.

In summary, the variability of morphology, i.e. the presence of single crystals and a wide range of twins and trillings, is enormous. It is comparable with or even exceeds the wide variability of alexandrites from the large Uralian mining area in Russia. Two types of samples are commonest: tabular contact twins *(Figure 12)* and tabular trillings *(Figure 15),* both with dominant **a** pinacoids and subordinate **i** prism faces and **b** pinacoids. Tabular contact twins commonly show small **o** dipyramids and one or two

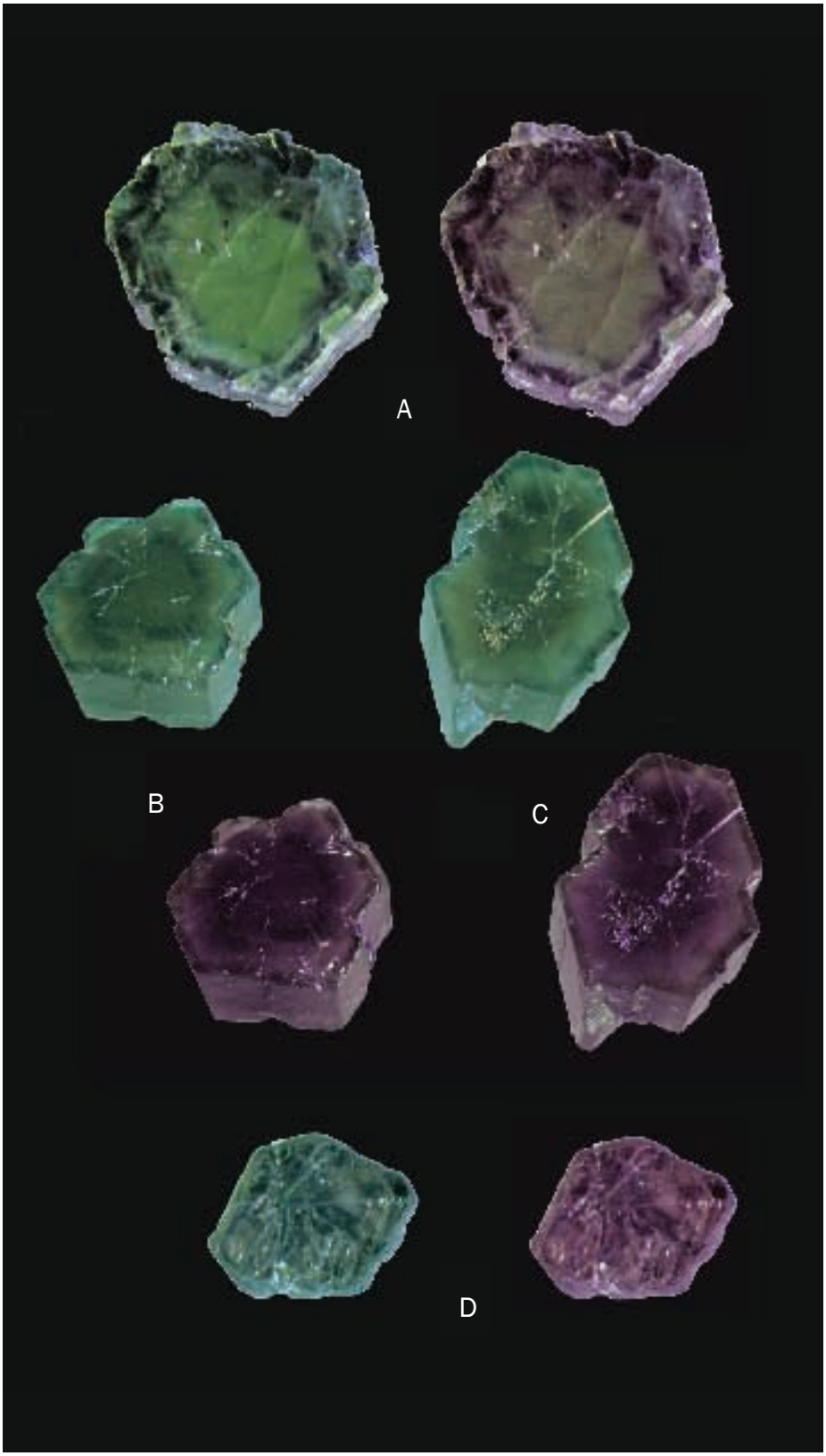

*Figure 15: Cyclic twins (trillings) of alexandrite from Lake Manyara, Tanzania, with tabular habit parallel **a** shown in both daylight and incandescent light, view almost parallel to the a-axis; samples A to C show distinct zoning with alternating green and milky white layers. Samples not to scale; sample A 21 × 17.5 mm, thickness along the a-axis 8.0 mm; sample B 8.8 × 8.2 mm, thickness along the a-axis 5.2 mm; sample C 12.5 × 8.5 mm, thickness along the a-axis 5.3 mm; sample D 11.0 × 9.0 mm, thickness along the a-axis 4.7 mm. Collection of W. Radl, Niederwörresbach, Germany. Photos and artwork by K. Schmetzer.*

Figure 16: Cyclic twin (trilling) of alexandrite from Lake Manyara, Tanzania, with columnar habit along the a-axis shown in both daylight and incandescent light; diameter of sample 9.5 × 9.0 mm, length along the a-axis 11.0 mm. Collection of F. Jurkutat, Einbeck, Germany. Photo by K. Schmetzer.

Figure 17: Alexandrite trilling from Lake Manyara, Tanzania. The trilling weighs 16 g, view almost parallel to the a-axis, size 27.5 × 14.5 mm, thickness along the a-axis 11.0 mm. Collection of Paul Wild Company, Kirschweiler, Germany. Photo by K. Schmetzer.

smaller prism faces (**s** or **r**). Tabular trillings, in general, show only small **o** dipyramids, but no **s** or **r** prism faces.

The colours of rough alexandrites and chrysoberyls from Lake Manyara range (in daylight) from various shades and intensities of green to yellowish green or bluish green. The pleochroism of Lake Manyara alexandrites in polarized light is distinct, and is as seen in most alexandrites from different sources (for the description of colour in different directions of view, i.e. pleochroism in non-polarized light, see below).

Pleochroism of alexandrite from Lake Manyara, Tanzania, in polarized light

	Daylight	Incandescent light
X ‖ *a*	yellow green	purple to purplish red
Y ‖ *b*	yellow	orange
Z ‖ *c*	blue green	blue green

Microscopic features of crystals

To understand the structural pattern, colour zoning and zoning of inclusions of faceted gemstones, it is helpful to examine the microscopic characteristics of transparent rough single and twinned crystals. The microscopic characteristics of contact twins and penetration twins are shown in *Figure 21*, and examples for cyclic twins are shown in *Figure 22*. In views parallel to the *a*-axis (in most cases perpendicular to the large **a** pinacoids of the crystals), a growth pattern with dominant **i** prism faces as growth structures is present. In some crystals, we noted also growth structures parallel to the **b** pinacoid. If a twin plane or several twin planes are present, the twin planes are perpendicular to **i** prism faces of the different parts of the twin.

In the centres of crystals, i.e. in the first stages of crystal growth, the faces **a**, **b**, **i**, **o** and **w** can be present (see *Table I*), but in later stages of growth, the

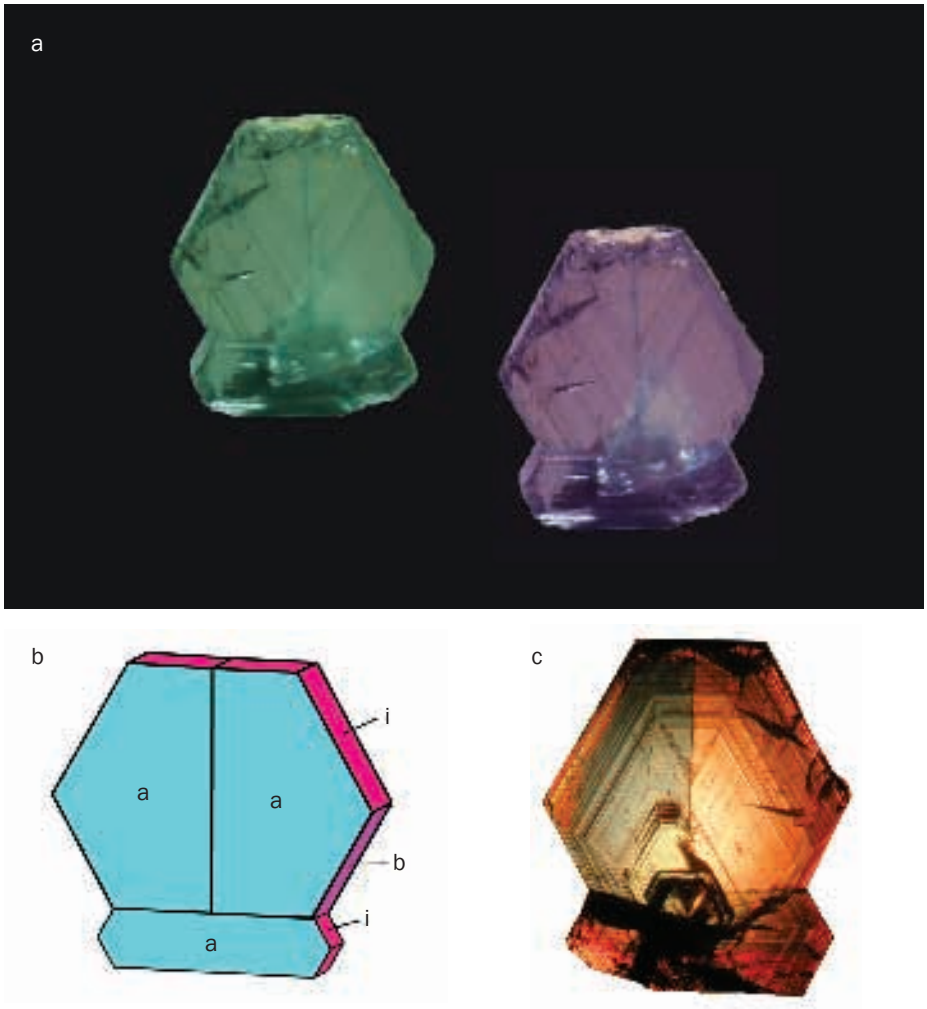

*Figure 18 a to c: Irregular alexandrite contact twin with tabular habit parallel **a** from Lake Manyara, Tanzania: (a) in both daylight and incandescent light; (b) in a schematic crystal drawing; and (c) in immersion showing growth planes and inclusion distribution. The crystal consists of three twinned individuals; view almost parallel to the a-axis, size 8.5 × 7.2 mm, thickness along the a-axis 2.7 mm. Collection of J.M. Saul, Paris, France. Photos and crystal drawing by K. Schmetzer.*

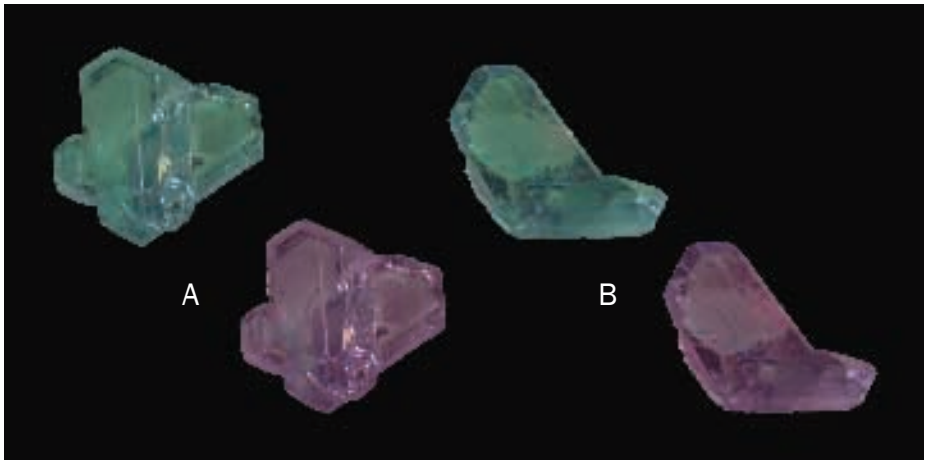

*Figure 19: Irregular alexandrite contact twins with tabular habit parallel **a** from Lake Manyara, Tanzania shown in both daylight and incandescent light; crystal A consists of three twinned individuals and crystal B consists of two twinned individuals; view almost parallel to the a-axis; sample A size 6.2 × 6.1 mm, thickness along the a-axis 3.2 and 1.8 mm (in different parts), sample B size 5.5 × 4.5 mm, thickness along the a-axis 2.7 mm. Collection of W. Radl, Niederwörresbach, Germany. Photos by K. Schmetzer.*

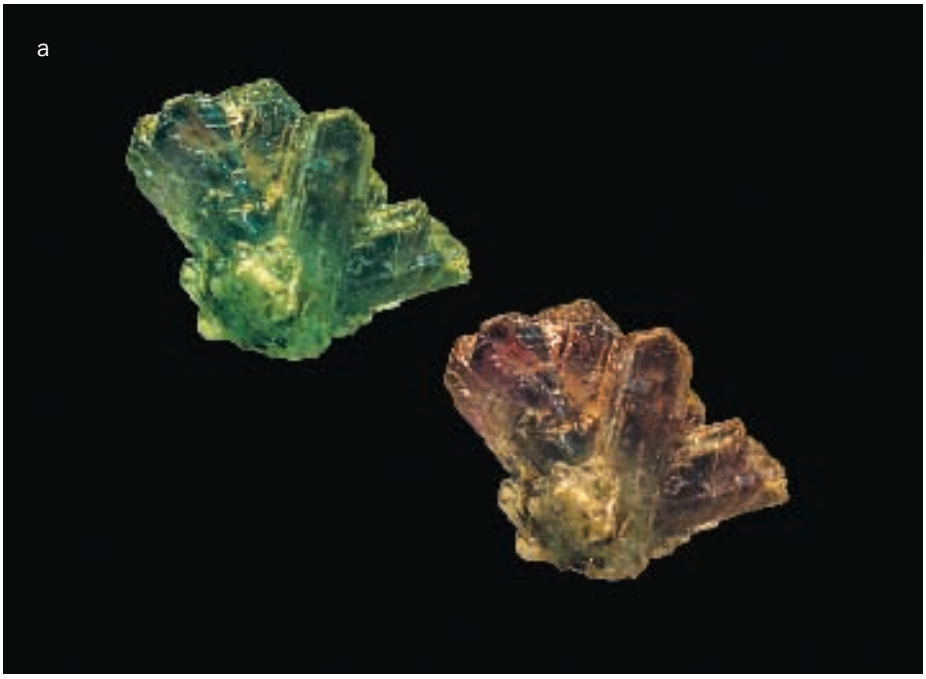

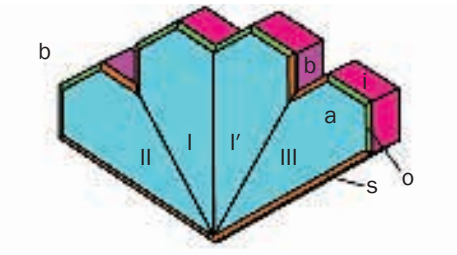

*Figure 20 a,b: Irregular alexandrite contact twin with tabular habit parallel to **a** from Lake Manyara, Tanzania, (a) in daylight and incandescent light; (b) schematic drawing; the crystal consists of four twinned individuals, two of the four crystals (in the middle, labelled I and I′) with parallel orientation are intergrown parallel to a virtual **b** plane, each of these two crystals is twinned with another crystal (labelled II and III); view almost parallel to the a-axis, size 23 × 17 mm, thickness along the a-axis 8.5 and 6.5 mm (in different parts). Collection of J.M. Saul, Paris, France. Photo and crystal drawing by K. Schmetzer.*

dipyramid **w** (122) is absent. An example of a single crystal showing this internal growth zoning reflecting the growth history of the alexandrites is given in *Figure 23*. This pattern is typical of rough single crystals and twins, which do not show the **w** dipyramid as an external crystal face.

Growth layers with milky white zones are common. They are separated from transparent zones by normal growth planes, mostly parallel to **i** prism faces *(Figure 24)*, and some parallel to **b** pinacoids. In views perpendicular to the *a*-axis, the milky zones can be seen to be formed by small needles, particles or channels with a dominant orientation parallel to the *a*-axis.

Microscopic features of faceted stones

Structural properties: growth structures and twinning

Faceted alexandrites from Lake Manyara commonly show growth structures and twinning. Under the microscope, twin boundaries can be separated from growth planes according to differences in the interference pattern visible under crossed polarizers *(Figure 25 a,b)*. Twinned individuals can also be distinguished by the different (pleochroic) colours of the parts of the twin using just plane polarized light. The growth patterns seen in faceted samples closely reflect the external morphologies of single crystals and twins. Dominant growth planes present are the pinacoids **a** and **b** and the prism **i**, in some stones in combination with smaller dipyramids (**o** and **n**) or smaller prism faces (**s** and **r**).

The most characteristic growth pattern in alexandrites from Lake Manyara is seen in a view parallel to the *a*-axis and consists of two **i** prism faces *(Figure 25c)*, occasionally in combination with **b** pinacoids. In twinned stones, a more complex pattern with a twin plane as well as **i** prism faces and **b** pinacoids from both parts of the twinned individual is present *(Figure 25d)*. In a direction of view perpendicular to a twin plane, i.e. in a direction inclined to the *b*- and *c*-axes, a pattern consisting of dominant **a** and **i** faces in combination with smaller **o** dipyramids is common *(Figure 25, e,f)*. In the same direction of view, this pattern can also be seen in untwinned stones.

Oriented particles and needles

In numerous alexandrites there are tiny, in most cases somewhat elongated particles or even needles or channels, which are orientated in one particular direction (*Figure 25 g* to *i*). This preferred direction was determined as the *a*-axis of the chrysoberyl crystals or twins *(Figure 25j)*. In a view parallel to the needle axis, i.e. parallel to the *a*-axis, these needle-like particles are frequently zoned parallel to **i** prism faces *(Figure 25k)*, occasionally also parallel to **b** pinacoids. In other samples, these 'needles' form special areas, zones or lines, which are inclined to the dominant **i** or **b** crystal faces *(Figure 25l)*. However, the 'needles' are all parallel to the *a*-axis of the alexandrite host (*Figure 26 a* to *c*).

In some stones, there is a second type of tiny inclusion, in most cases in addition to the needle-like particles described above *(Figure 26d)*. These tiny inclusions are concentrated on specific planes parallel to **a** pinacoids. Consequently, in a direction perpendicular to the *a*-axes, i.e. in a view perpendicular to the 'needle'-axes, a combination of both structural features is seen (*Figure 26 e* to g). In this direction of view, the 'needles' parallel to the *a*-axis and the areas on **a** pinacoids intersect at right angles. If both structural inclusion patterns are very dense, samples with complete off-white reflecting areas are present, consisting of numerous oriented reflecting particles (*Figure 26 h,i;* see also the section below 'Stones with larger milky white zones').

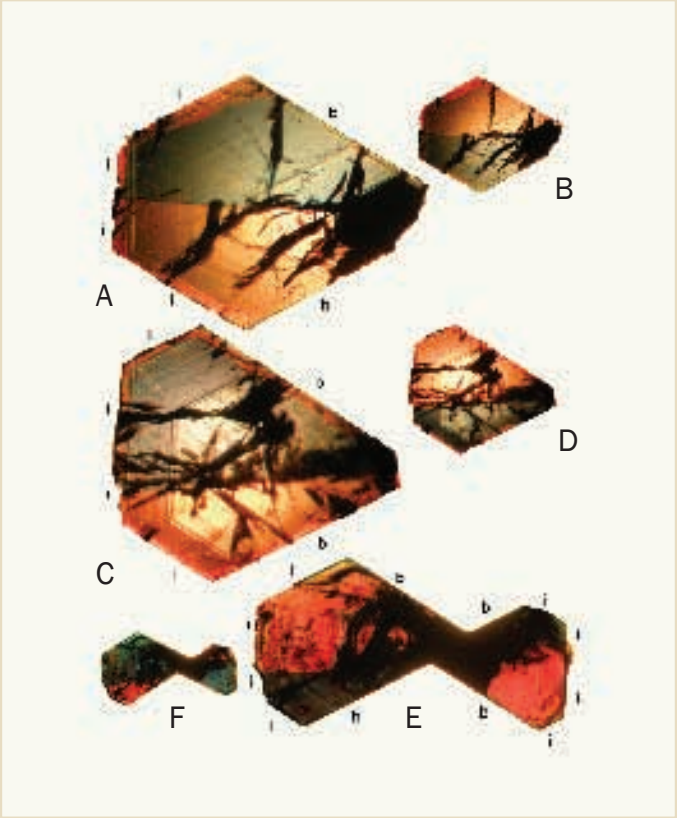

*Figure 21: Growth structures and twinning in two alexandrite contact twins (A,B and C,D) and one interpenetrant twin (E,F) with tabular habit; the samples are shown in a view parallel to the a-axis in polarized light with different orientations of the polarizer, which highlights the pleochroic colours. The dominant growth structures seen in this orientation are planes parallel to the prism **i**, subordinate growth structures are planes parallel to the **b** pinacoid. Immersion, samples not to scale, size of the twin A,B 8.2 × 6.8 mm; size of the twin C,D 10.2 × 9.1 mm, size of the twin E, F 6.2 × 3.2 mm. Photos and artwork by K. Schmetzer.*

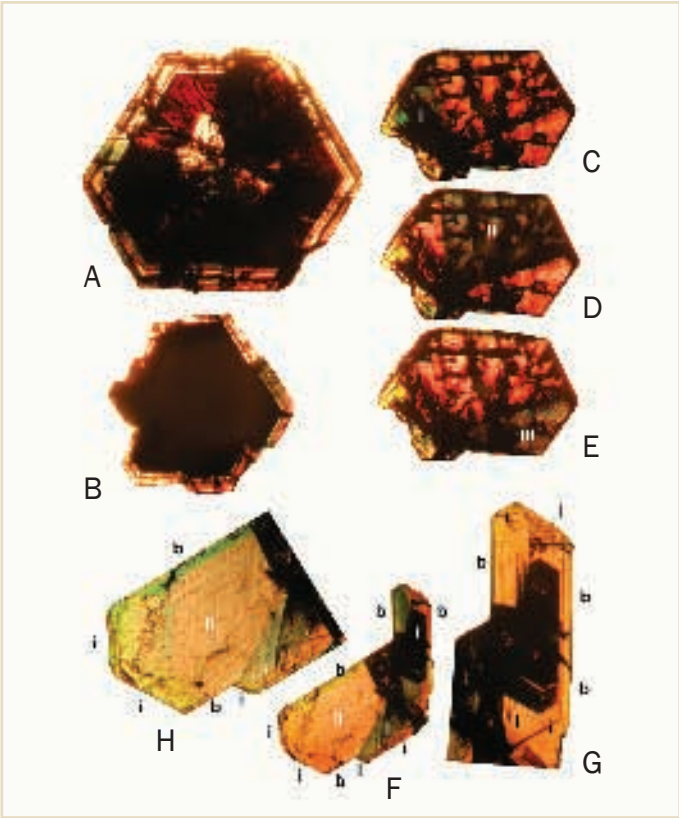

*Figure 22: Growth structures and twinning in three alexandrite trillings (A, B and C to E) and one irregular alexandrite contact twin (F to H) with tabular habit; the samples are shown in views parallel to the a-axis. The two trillings pictured in A and B show an intense growth zoning with alternating transparent and milky white layers; the trilling pictured in C to E is shown in polarized light with different orientations of the polarizer. The irregular contact twin shown in F (parts magnified in G and H) consists of two individuals, I and II, growth structures are seen parallel to the prism **i** and the pinacoid **b**. Immersion, samples not to scale, size of trilling A 5.5 × 5.2 mm; size of trilling B 8.8 × 8.2 mm, size of trilling C to E 3.8 × 2.6 mm, size of twin F to H 5.5 × 4.5 mm. Photos and artwork by K. Schmetzer.*

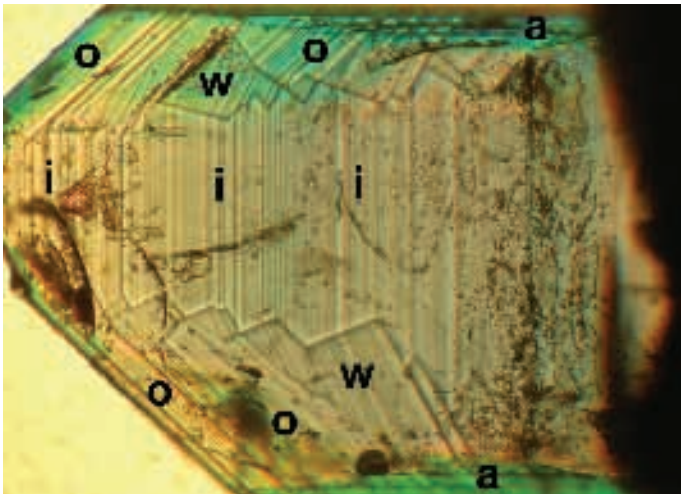

*Fig 23: Growth structures in an alexandrite single crystal (untwinned) from Lake Manyara, Tanzania. The internal growth pattern shows growth planes parallel to the pinacoid **a**, the prism **i** and the dipyramids **o** and **w**; in the final stages of crystal growth, the face **w** is not developed and is not seen as an external crystal face. Immersion, 40×. Photo by K. Schmetzer.*

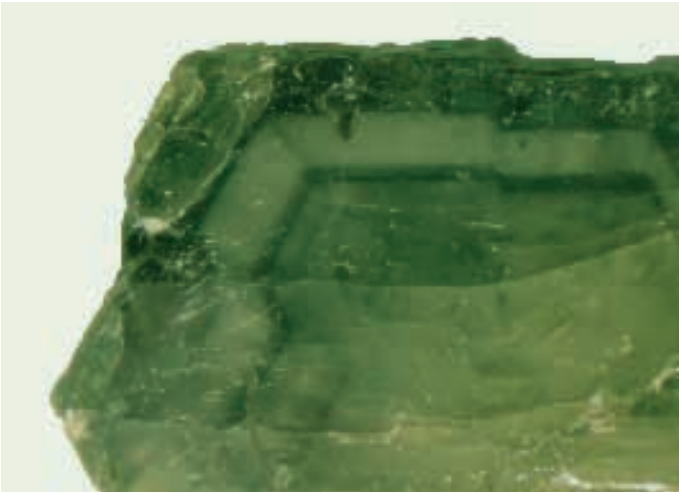

*Figure 24: Many alexandrite samples, especially trillings, from Lake Manyara show zoning which consists of alternating transparent zones of variable intensities of green and milky white layers; this milkiness is due to channels which are oriented parallel to the a-axis and small negative crystals in the **a** pinacoid. View parallel to the a-axis, field of view 11.5 × 8.6 mm. Photo by K. Schmetzer.*

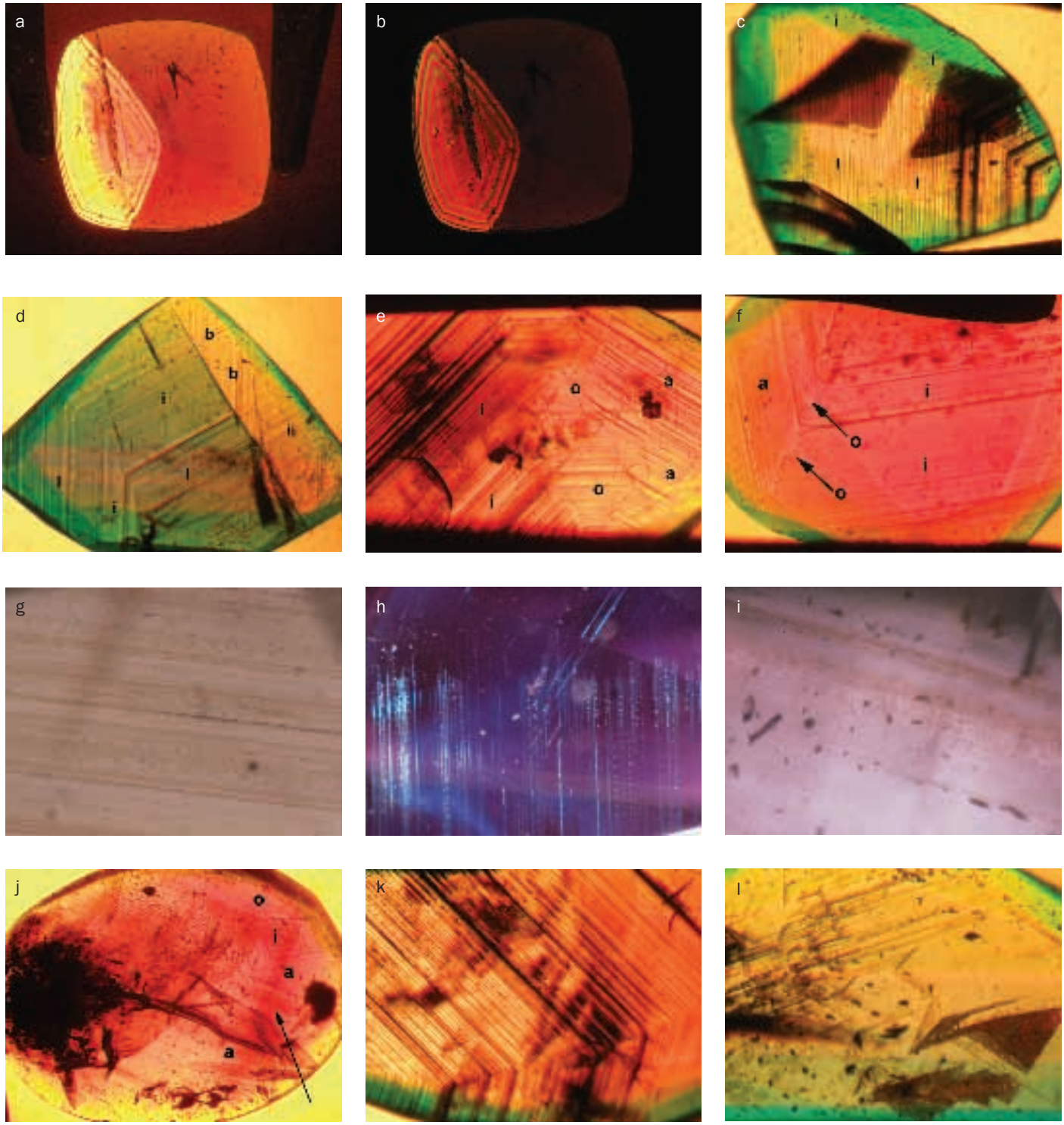

Figure 25 a to l: Microscopic properties of alexandrite and chrysoberyl from Lake Manyara, Tanzania.
(a and b) Twin boundary showing interference patterns: (a) immersion; (b) same sample with crossed polarizers, 25×.
*(c to f) Characteristic growth structures consisting of **a** and **b** pinacoids, **i** prism faces and **o** dipyramids; in (d) a twin boundary is also present; immersion (c,d) 25×; (e) 50×; (f) 60×.*
(g to i) Orientated needle-like particles or channels: (g) darkfield, 80×; (h,i) brightfield, 80×.
*(j) Growth structures parallel to the faces **a**, **i** and **o** with channels perpendicular to the **a** pinacoid (arrow), immersion, 35×.*
*(k) View parallel to the a-axis, showing a concentration of needles or channels or other inclusions on **i** prism planes, 50×.*
*(l) View parallel to the a-axis, showing a concentration of channels on **i** prism planes (upper part) or an irregular arrangement along specific planes or within specific zones (lower right), immersion, 60×.*
Photos a to f, j to l by K. Schmetzer, g to i by A.-K. Malsy.

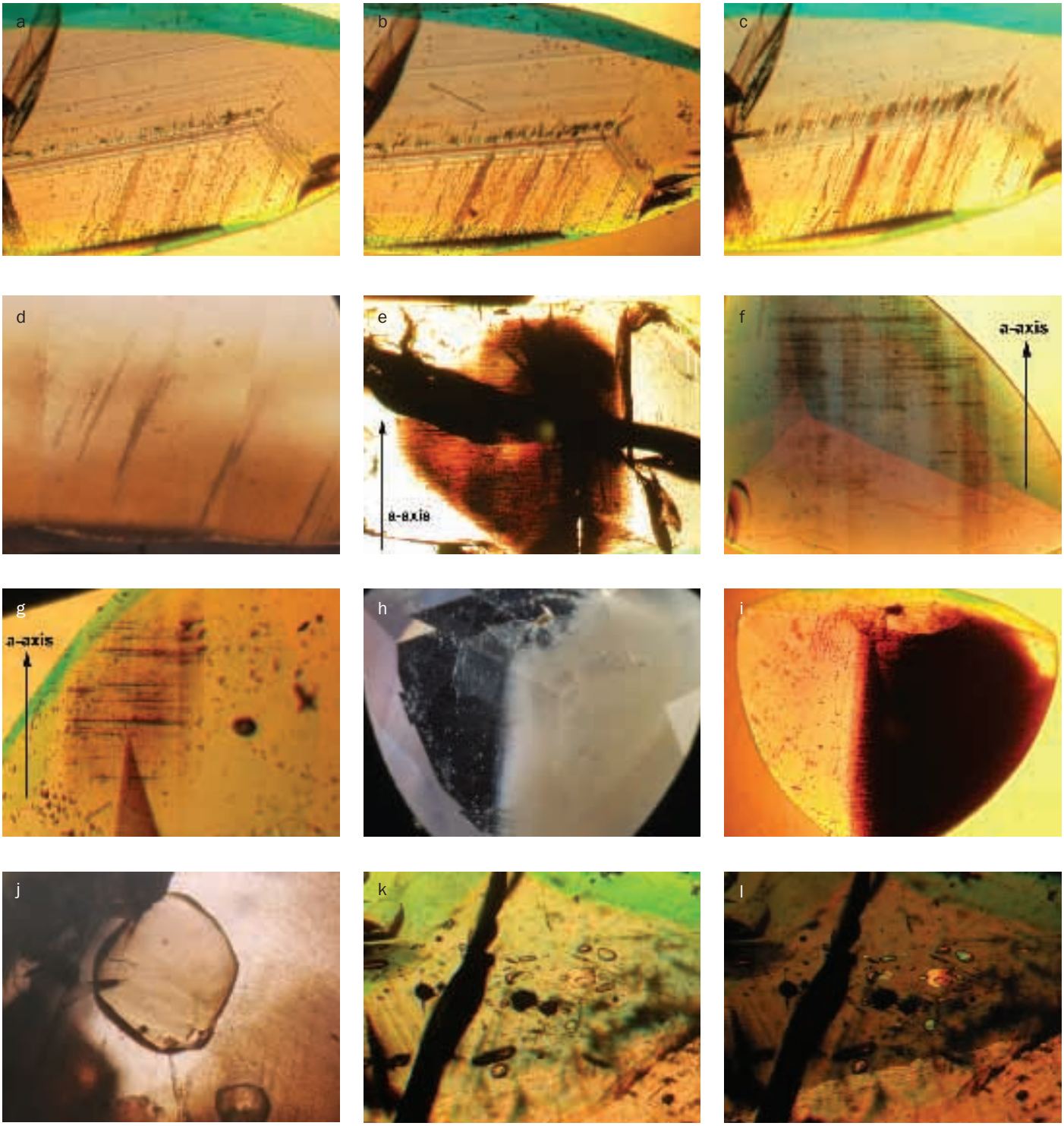

Figure 26 a to l: Microscopic properties of alexandrite and chrysoberyl from Lake Manyara, Tanzania:
*(a to c) Channels with an orientation along the a-axis in different views: (a) parallel to the a-axis; (b) slightly inclined to the a-axis; and (c) inclined to the a-axis; the channels are concentrated on **i** prism planes or show an irregular arrangement along specific other planes or within specific growth zones (lower part), immersion, 60×.*
(d to i) Two types of inclusions are developed as needles or channels parallel to the a-axis and as smaller particles concentrated on planes perpendicular to the a-axis; in high concentration, these inclusions cause a milky white appearance (h); (d) brightfield, 80×; (e) immersion, 40×; (f,g) immersion, 60×; (h) darkfield, 35×; (i) (same sample as h) immersion, 30×.
(j to l) Phlogopite inclusions: (j) brightfield, 80×; (k,l) immersion; (l) with crossed polarizers, 60×.
Photos a to c, e to g, i, k, l by K. Schmetzer, d, h, j by A.-K. Malsy.

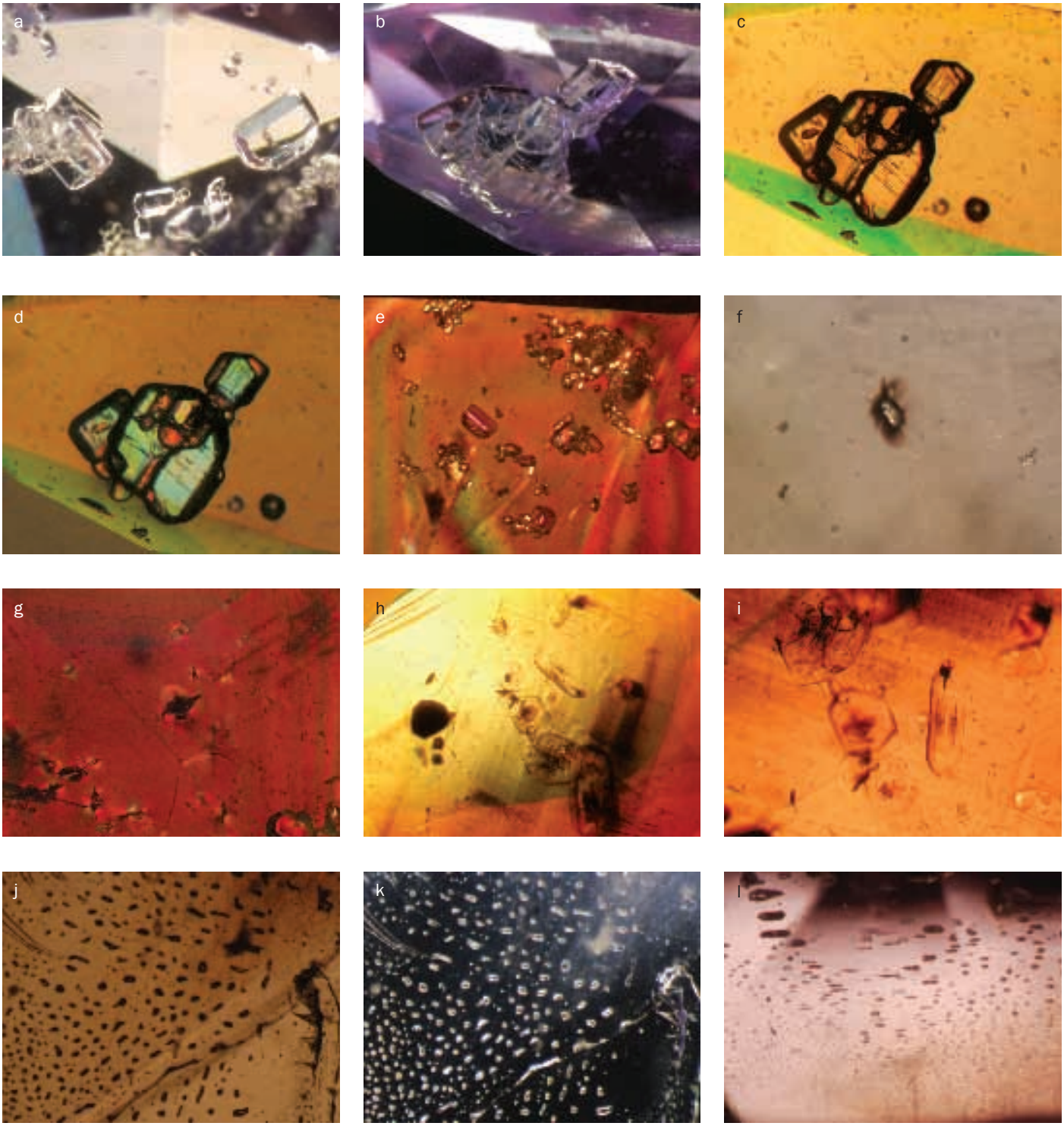

Figure 27 a to l: Microscopic properties of alexandrite and chrysoberyl from Lake Manyara, Tanzania.
(a to e) Inclusions of apatite crystals and apatite clusters (e): (a) brightfield, 50×; (b to d) same sample, (b) brightfield, (c) immersion, (d) immersion, crossed polarizers, all 60×; (e) immersion, crossed polarizers, 70×.
(f,g) Zircon crystals with tension cracks: (f) brightfield, 80×; (g) immersion, crossed polarizers, 60×.
(h,i) Chrysoberyl inclusions in alexandrite, immersion, crossed polarizers: (h) 40×; (i) 60×.
(j,k) Healing feathers consisting of small irregular liquid-filled cavities: (j) brightfield, 80×; (k) darkfield, 80×.
(l) Healing feather with two-phase inclusions in negative crystals, brightfield, 80×.
Photos c to e, g to i by K. Schmetzer, a, b, f, j to l by A.-K. Malsy.

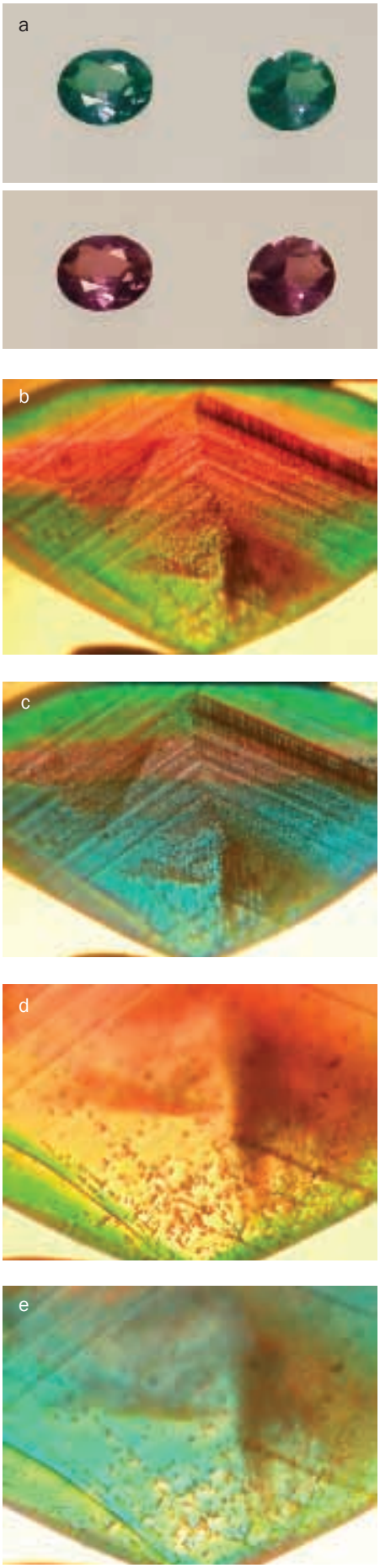

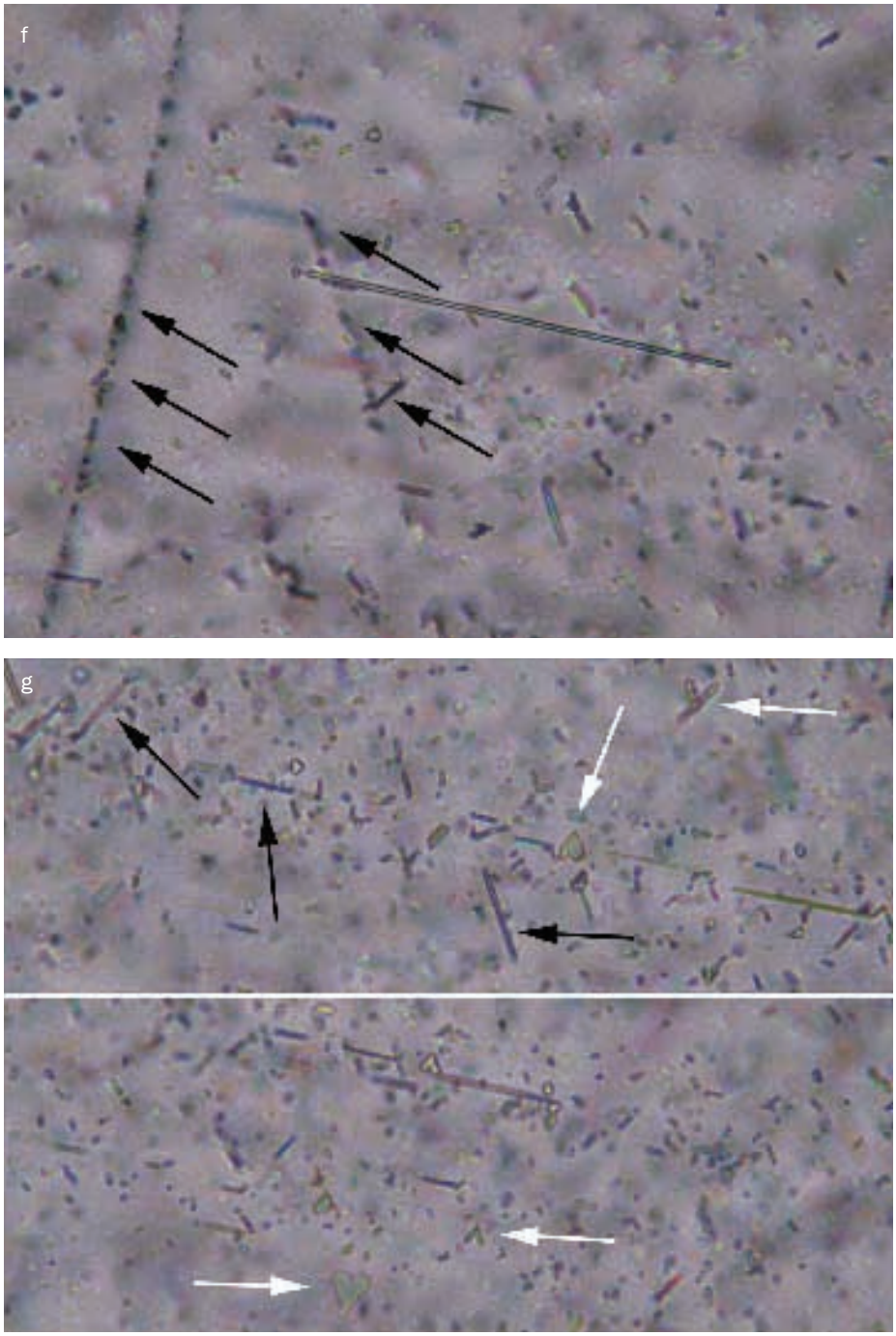

*Figure 28 (a to e): Alexandrites from Lake Manyara with growth layers parallel to the prism **i** showing a high concentration of channels forming milky white layers.*
(a) Faceted alexandrites in daylight and incandescent light, weights 0.41 and 0.35 ct, sizes 5.1 × 4.4 mm and 5.0 × 4.3 mm.
(b,c) and (d,e) Views of the two stones in (a) along the a-axis, i.e. parallel to the axes of the channels; with different orientation of the polarizer, the pleochroism (Y orange, Z bluish green) is clearly visible; immersion (b,c) 50× (d,e) 80×. Photos by K. Schmetzer.
*Figure 28 (f,g): Thin section of a milky white alexandrite with an orientation almost parallel to the **a** pinacoid:*
(f) two series of channels parallel to the a-axis, which are aligned along specific planes (indicated by arrows) of the host; field of view 110 × 82 µ.
*(g) Three orientations of groups of elongated cavities are present, which are aligned in the **a** plane at angles of about 60° to each other (indicated by black arrows); in places two of these negative crystals originate from a single point and/or form tabular negative crystals which closely resemble tabular alexandrite twins (indicated by white arrows); both fields of view 110 × 41 µ.*
Photos by H.-J. Bernhardt.

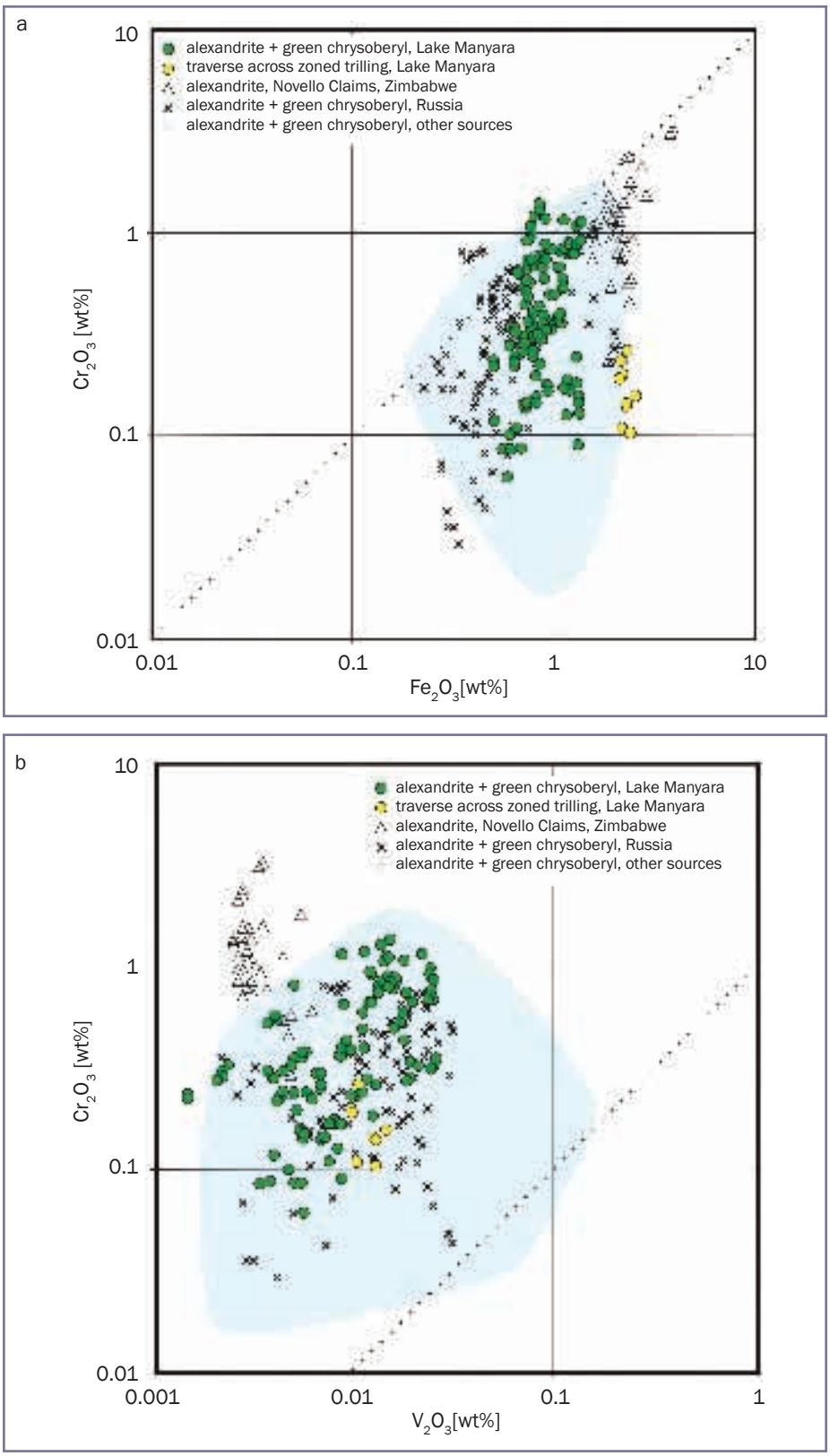

Figure 29 a,b: Iron/chromium and vanadium/chromium binary diagrams showing the variability of these trace element contents in alexandrites and green chysoberyls from Lake Manyara compared to alexandrites and green chrysoberyls from Russia, from Zimbabwe and other localities (pale blue area representing more than 220 samples including all market relevant sources). The individual points represent measurements on various alexandrites; multiple analyses of different spots on the same crystal are plotted separately. Iron contents in alexandrites from Lake Manyara are intermediate between those in samples from Russia and Zimbabwe, vanadium and chromium contents for all three sources overlap. Artwork by A.-K. Malsy.

Mineral and fluid inclusions

Numerous mineral inclusions were identified using Raman microspectroscopy and laser ablation inductively coupled plasma mass spectrometry (LA-ICP-MS) by one author (A.-K.M.). The results are given below.

Although alexandrites from Lake Manyara are found in phlogopite schist, mica (phlogopite) inclusions are not common in gem-quality samples *(Figure 26 j* to *l)*. The commonest inclusions were identified as prismatic apatite crystals or clusters of apatites (*Figure 27 a* to e). In several samples isolated zircons or groups of zircons, mostly surrounded by tension cracks *(Figure 27 f,g)* are also present. One alexandrite contains a group of well developed alexandrite crystals in no particular orientation *(Figure 27 h,i)*.

Some alexandrites also contain healed fractures with residual fluid inclusions *(Figure 27 j,k)*, and others may contain negative crystals filled with liquid or two-phase (liquid-gas) inclusions *(Figure 27l)*.

Stones with larger milky white zones

It should be mentioned that alexandrite crystals with larger milky white zones (see again *Figure 24*) can yield attractive gems if the direction of cut is carefully chosen. The two samples depicted in *Figure 28a* were cut with the table facet formed of a transparent zone which was free of any milky white reflecting particles as inclusions. The growth zones below the table facets consist of successive layers with different concentrations of milky white reflecting needles or channels *(Figure 28 b,c)*. The different growth layers are separated by two **i** (011) prism faces. This microscopic feature, however, does not disturb the overall appearance of the gems.

In a view perpendicular to the needle axis, the elongated particles within the milky white zones are clearly visible. In a view parallel to the crystallographic *a*-axis, i.e. parallel to the needle axis, the observer has the impression of looking into a fibre optic with light emanating from the needles. A view at somewhat higher magnification *(Figure 28 d,e)* indicates

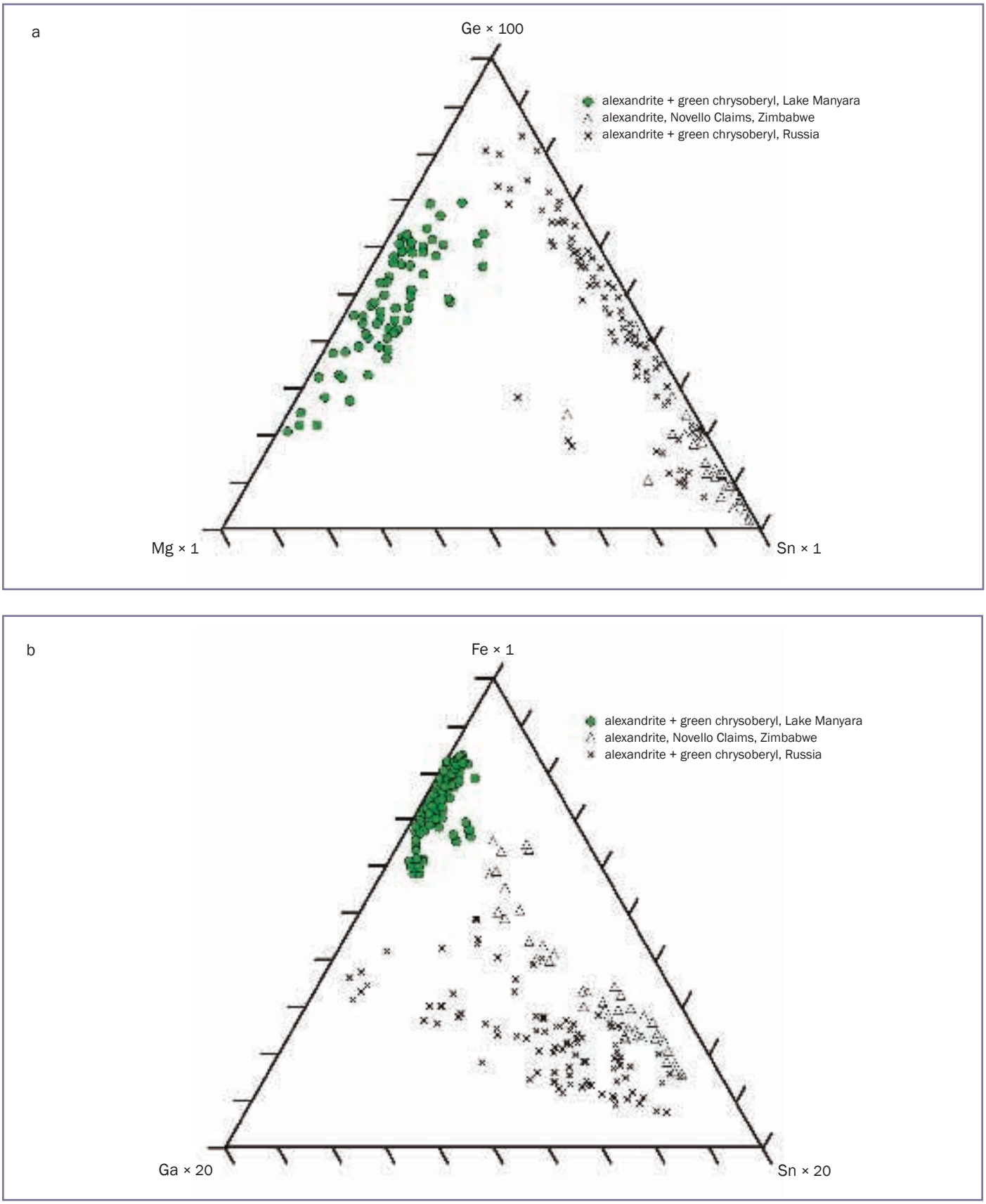

Figure 30 a,b: Ternary diagrams showing relative proportions of magnesium-germanium-tin and iron-gallium-tin in alexandrites and green chrysoberyls from Lake Manyara, Tanzania, Zimbabwe and Russia. The individual points represent measurements on various alexandrites; multiple analyses of different spots on the same crystal are plotted separately. The potential of trace element chemistry for distinguishing alexandrites from various localities is evident. Artwork by A.-K. Malsy.

Figure 31: Rough alexandrite crystals and fragments from Lake Manyara with colour change from green or bluish green in daylight (a) to purple or reddish purple in incandescent light (b). The largest crystal measures about 7 × 6 mm. Photo by K. Schmetzer.

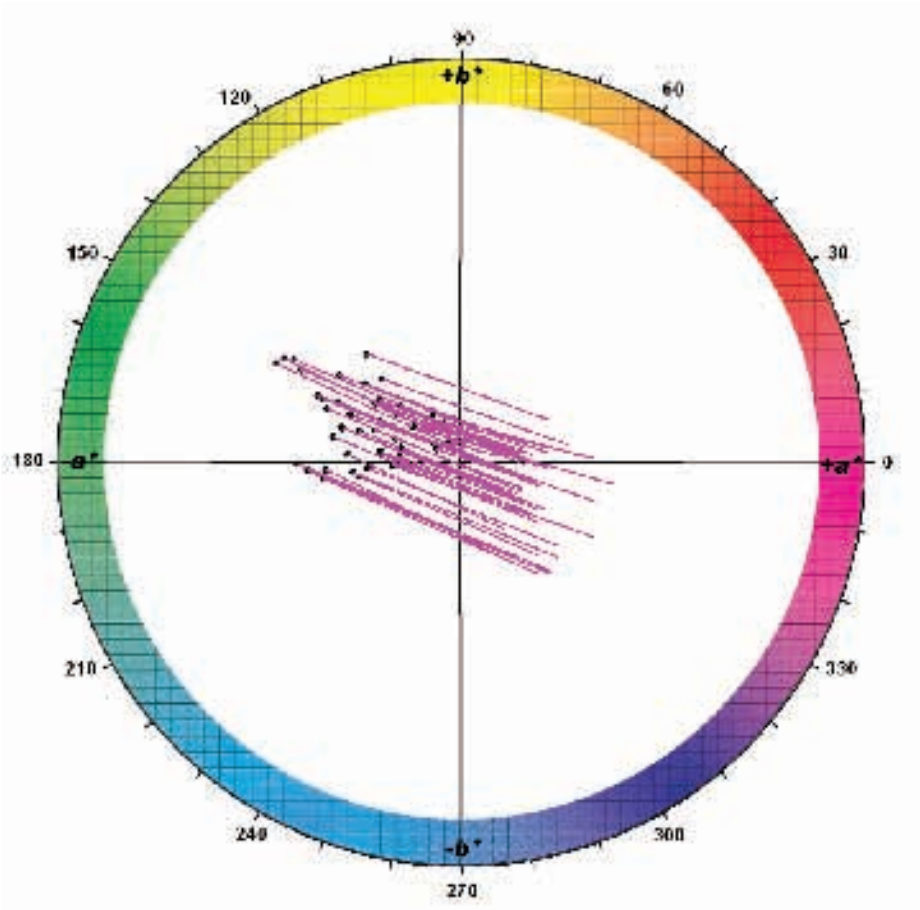

*Figure 32: Colorimetric parameters of rough alexandrites shown in Figure 31 in the CIELAB colour circle; the neutral point (white point) is in the centre of the a*b* coordinate system; the small black circles represent the coordinates in the daylight source D_{65} and the ends of the differently coloured bars represent the coordinates in tungsten light A, the outer circle represents a chroma of 18. These parameters show the typical alexandrite-like colour change from daylight to incandescent light. Colorimetric measurements of various samples by A.-K. Malsy and G. Bosshart.*

that at least part of these structures are hollow channels and not mineral inclusions such as rutile.

To identify all the needles and/or channels in Lake Manyara alexandrites and to further evaluate the inclusions causing the milky white appearance, a thin section almost parallel to the **a** pinacoid was prepared. The thin section showed several series of channels parallel to the *a*-axis, which were aligned along specific planes of the host *(Figure 28f)*. In addition, three groups of elongated cavities were present, which are aligned in the **a** plane at angles of about 60° to each other *(Figure 28g)*. Occasionally, two of these negative crystals originate from a single point and/or form tabular negative crystals which closely resemble tabular alexandrite twins in appearance (*Figure 28g*, compare *Figure 9*, especially crystal G). These results, indicating that the milky white zones are caused by channels parallel to the *a*-axis, occasionally in combination with negative crystals along the **a** plane, are confirmed by the chemical properties of a zoned green/milky white sample (see below).

We would like to mention that – although not found in our study - there might be also needle-like mineral inclusions in other samples of alexandrite from Lake Manyara and especially in chrysoberyl from other sources. It was found in numerous samples from different

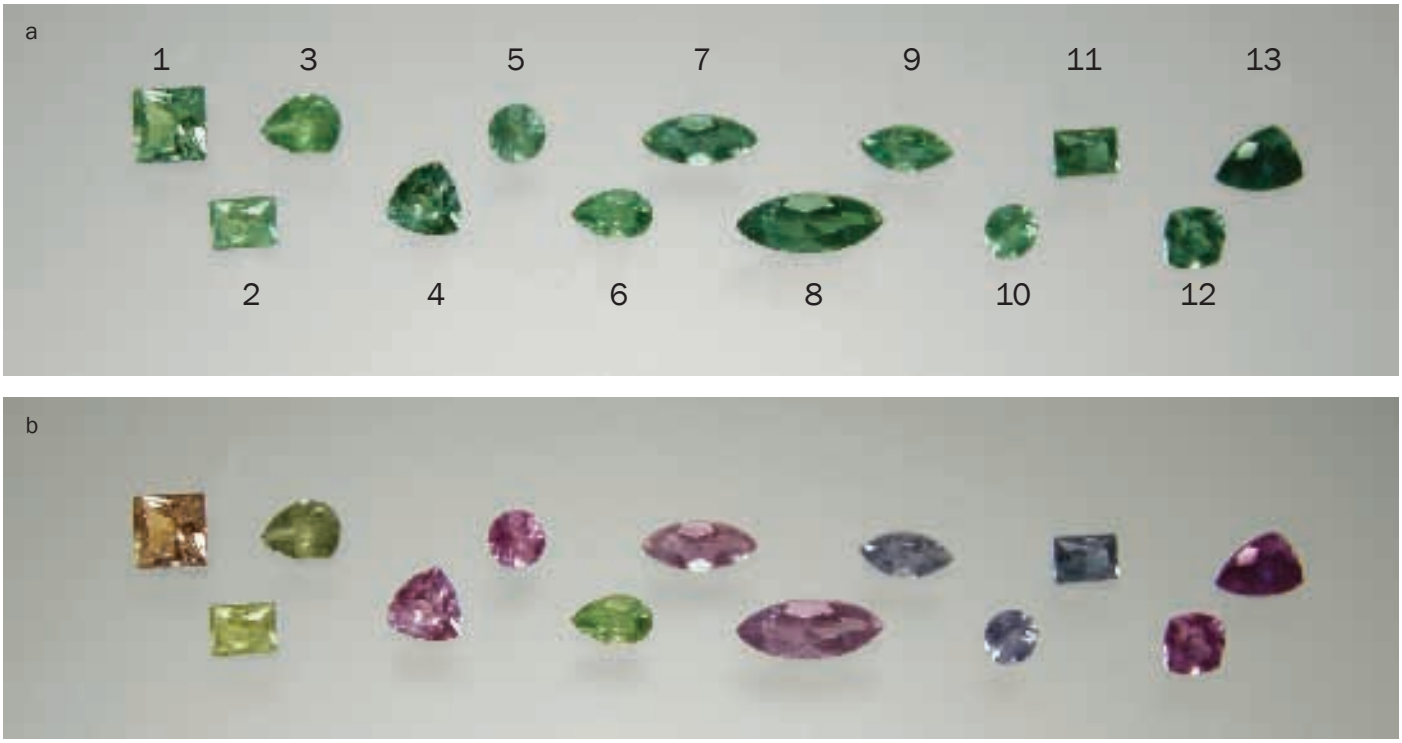

Figure 33: Faceted alexandrites and green chrysoberyls from Lake Manyara show a range of colours in daylight (a) and a much greater range in incandescent light (b); the numbers correspond to the numbers and their colorimetric parameters in the CIELAB diagram in Figure 34. Weights of samples from 0.16 to 0.68 ct, the square cut stone (1) weighs 0.56 ct, size 4.4 mm square. Photo by K. Schmetzer.

localities by microscopic examination by one of the present authors (K.S.) that chatoyancy in chrysoberyl or alexandrite is due to needle-like particles or channels with a preferred orientation parallel to the *a*-axis. However, to determine the exact nature of all different types of needles and/or channels in chrysoberyls and alexandrites from different sources, additional research is necessary, which is beyond the scope of the present paper.

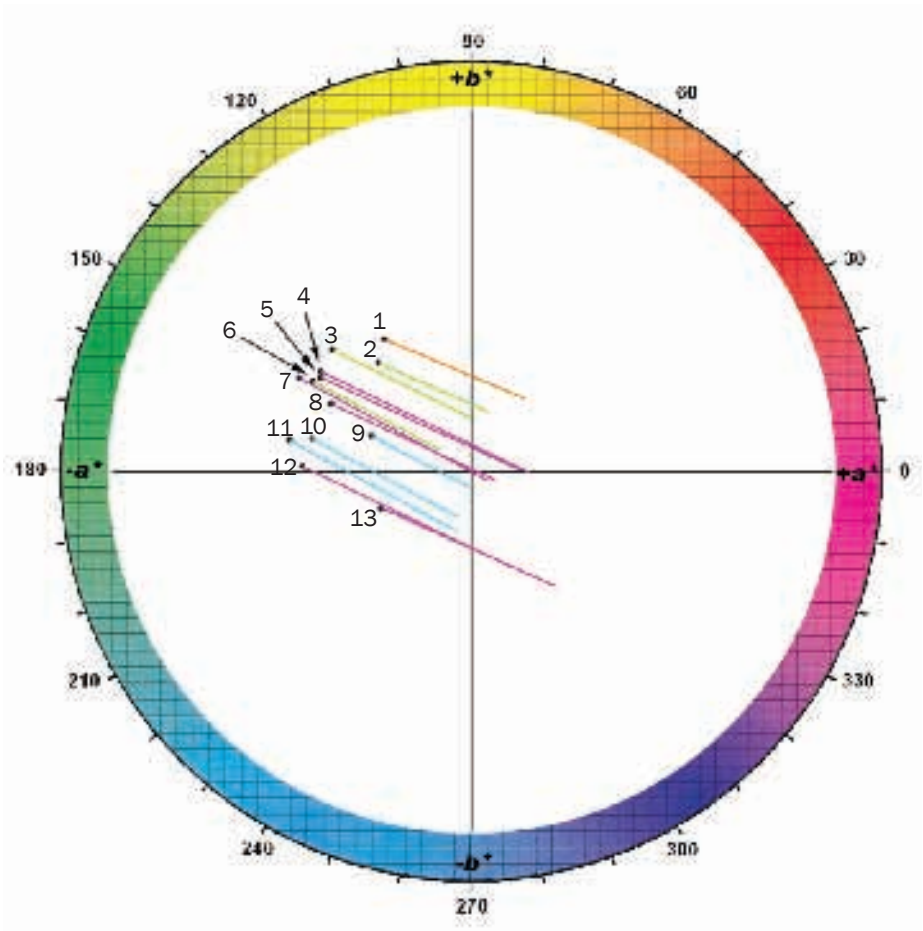

*Figure 34: Colorimetric parameters of faceted alexandrites and green chrysoberyls originating from the Lake Manyara deposit, Tanzania, in the CIELAB colour circle; the neutral point (white point) is in the centre of the a*b* coordinate system; the small black circles represent the coordinates in daylight D_{65} and the ends of the differently coloured bars represent the coordinates for tungsten light A, the outer circle represents a chroma of 18. Only a few stones show the typical alexandrite colour change of green to purplish red (e.g. 4, 5, 12, 13, represented by purple bars); other stones are green or yellow, orange or bluish grey in incandescent light. Colorimetric measurements of various samples by A.-K. Malsy. The numbers represent the stones in Figure 33 in daylight and incandescent light.*

Composition

The compositions of ten rough crystals (with colour change from an intense green or bluish green to purple or reddish purple, see *Figure 31*) and 28 faceted alexandrites and green to yellowish green chrysoberyl (with variable colour change, see *Figure 33*) using LA-ICP-MS were determined (for details of the technique, see Malsy, 2010). In addition, there was a traverse of nine analysis points across the **a** pinacoid of a rough alexandrite trilling with zoning consisting of alternating transparent and off-white layers from the centre to the rim (see *Figure 24*).

Table II. Ranges of trace element contents in differently coloured alexandrites and chrysoberyl from Lake Manyara, Tanzania (in wt%).

Samples	Colour in incandescent light	V_2O_3	Cr_2O_3	Fe_2O_3
Rough *(Figure 31)*	purple to reddish purple	0.002 – 0.016	0.28 – 1.38	0.70 – 1.35
Faceted *(Figure 33)*	purple to reddish purple	0.004 – 0.019	0.22 – 0.68	0.58 – 0.78
	bluish grey	0.007 – 0.012	0.14 – 0.25	0.70 – 1.29
	orange	0.004 – 0.005	0.10 – 0.12	0.51 – 0.60
	yellow to green	0.003 – 0.009	0.09 – 0.18	0.55 – 1.34
Traverse across zoned trilling *(Figure 24)*	purple, transparent	0.013 – 0.013	0.11 – 0.14	2.29 - 2.41
	milky white	0.009 – 0.014	0.15 – 1.27	2.13 – 2.55

Trace elements responsible for colour

The contents of trace elements that influence the colour of a stone are summarized in *Table II*. Vanadium, chromium and iron values for rough and faceted samples from the Lake Manyara deposit show a wide variability. The data, based on the analyses of 38 samples, are plotted in *Figure 29 a,b* and are compared with data from Russian samples (Malsy, 2010) and samples from the Novello mine in Zimbabwe (Schmetzer *et al.*, 2011). In all three localities, alexandrites or green chrysoberyls occur mainly in phlogopite schists and have a similar formation history.

In the Lake Manyara stones, chromium contents are always dominant over vanadium contents by a factor of at least 5. Chromium and iron values are found in comparable ranges. The iron contents of the zoned alexandrite trilling exceed the values found in other samples. This stone (see again *Figure 24*) also showed decreasing chromium values from the centre to the rim. Transparent areas showed titanium contents in the range of 278–317 ppm Ti, and in milky white areas titanium contents in the range of 298–362 ppm Ti were determined. Thus, the average titanium contents in milky white areas is only slightly higher than titanium contents of transparent green zones. This indicates that the particles responsible for the milky white appearance are not rutile needles, because — in that case — the difference in titanium contents of transparent to non-transparent zones should be distinctly higher.

The average iron content for all Lake Manyara chrysoberyls and alexandrites lies between the average iron content measured for Russian samples and alexandrites from Zimbabwe. Chromium and vanadium contents of Lake Manyara stones lie in the range of the Russian samples, and the average chromium content is somewhat smaller than that measured for alexandrites from Zimbabwe. In the light of these results, it is evident that these trace element values should not be considered as distinctive criteria for source determination.

Trace elements of potential use for origin determination

For origin determination, various ternary diagrams containing diagnostic trace element contents can be applied. Useful elements include boron, magnesium, gallium, tin and germanium, amongst others. Two examples *(Figure 30 a,b)* of ternary diagrams show a possible means of distinguishing Lake Manyara alexandrites from those of Zimbabwe and Russia. However, according to the particular nature of any stone, different combinations of elements may have to be plotted to establish its origin.

Colorimetric data and nomenclature

Colorimetric systems are used for the quantitative description and prediction of colour phenomena. For the description of colour, special coordinate systems, known as colour spaces, were developed. The CIELAB colour space is the most complete colour model conventionally used to describe colours and colour differences visible to the human eye. A detailed description of this uniform colour space, the application of this model to colour-change garnets as well as Russian alexandrites and experimental details of colour measurement are given by Schmetzer *et al.* (2009) and Schmetzer and Bosshart (2010). There is also an ongoing discussion in the gem trade and in gemmological laboratories about the border between colour-change chrysoberyl and alexandrite.

To describe colour for alexandrite and chrysoberyl from the Lake Manyara deposit in daylight and incandescent light and to evaluate the extent of colour change, the authors measured two groups of samples and calculated the CIELAB parameters for daylight (standard light source D_{65}) and incandescent light (standard light source A):

1. We visually selected 42 small crystals or crystal fragments with a distinct colour change from green or bluish green in daylight to violet purple, purple, reddish purple or purplish red in incandescent light *(Figure 31)* from several lots consisting of at least 300 rough samples. Absorption spectra were measured and colorimetric data were calculated for all 42 alexandrites.

For a group of 15 samples the spectra in different directions were also measured, if the morphology of the rough irregular fragments allowed this procedure. In summary, colorimetric data from 65 measured spectra were calculated and plotted in *Figure 32*. Ten of this group were also chemically analysed to determine the trace element contents (see above).

2. For the 28 faceted chrysoberyls and alexandrites, which were chemically analysed (see above), absorption spectra were measured and colorimetric data were calculated. These alexandrites and chrysoberyls show great variability of colour change between daylight and incandescent light and were selected to cover the full range of colour change present in Lake Manyara stones. The colour in daylight ranged from green either to bluish green or to yellowish green, with a large colour variability in incandescent light, which allowed subdivision of the samples into four subgroups according to their colour in incandescent light: (a) orange, (b) yellow to green, (c) grey to bluish grey, and (d) purple to purplish red. From these 28 spectroscopically examined samples 13 faceted stones were selected *(Figure 33)*, to represent the full range of colour and colour change in the population for the graphical presentation of colorimetric data *(Figure 34)*.

All colorimetric data closely reflect the visually observed colour (*Figures 31* to *34*). Colorimetric parameters of all rough alexandrites of the first group (*Figures 31* and *32*) reveal a large hue angle difference between daylight and incandescent light as well as a distinct colour difference between both light sources. These colorimetric parameters are typical for an alexandrite-like colour change from green or bluish green in daylight to a colour ranging from violet purple to purplish red in incandescent light.

All 13 faceted gemstones of the second group also reveal a distinct colour change between daylight and incandescent light, and a wide range of colours under the

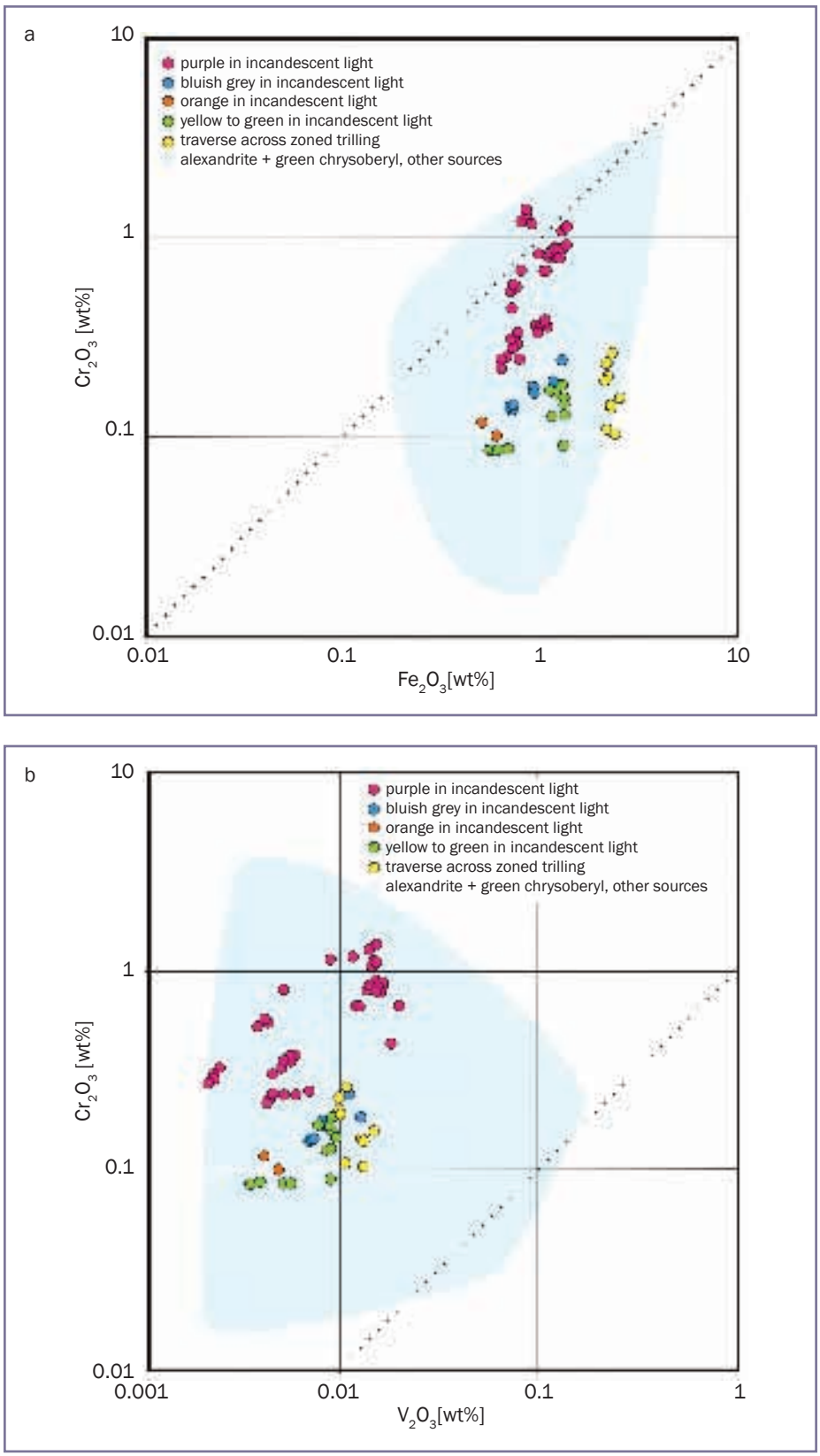

Figure 35 a,b: Iron, chromium and vanadium contents of alexandrites and green chrysoberyls from Lake Manyara and from other localities. The general light blue area represents more than 220 samples including all market relevant sources. The differently coloured symbols represent the approximate colours of the samples observed in incandescent light. Chromium contents in alexandrites from Lake Manyara with a colour change to purple or reddish purple are above the values measured in samples with other colours in incandescent light; the values for iron and vanadium, on the other hand, are comparable. Artwork by A.-K. Malsy.

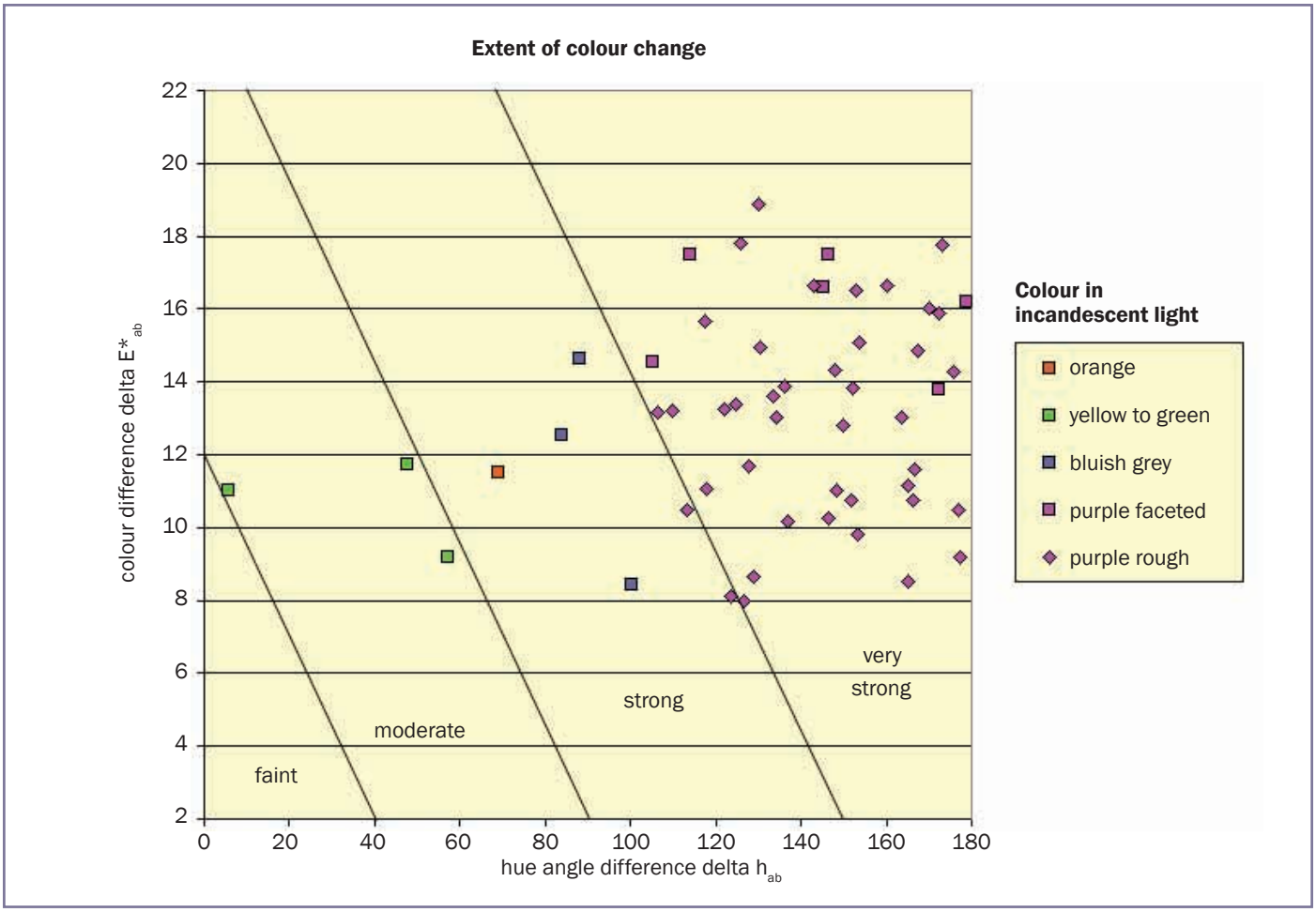

Figure 36: Graph showing the correlation of the main colorimetric parameters of hue angle difference and colour difference in alexandrites and colour-change chrysoberyls from Lake Manyara, with correlations representing the extent of colour change referred to as faint, moderate, strong and very strong. The extent of colour change for rough and faceted alexandrites with a purple or reddish purple coloration in incandescent light [samples of group I and of group II, subgroup (d)] is very strong, the extent of colour change for samples with different coloration in incandescent light [orange, yellow to green or bluish grey; samples of group II, subgroups (a), (b) and (c)] is moderate to strong. Artwork by K. Schmetzer.

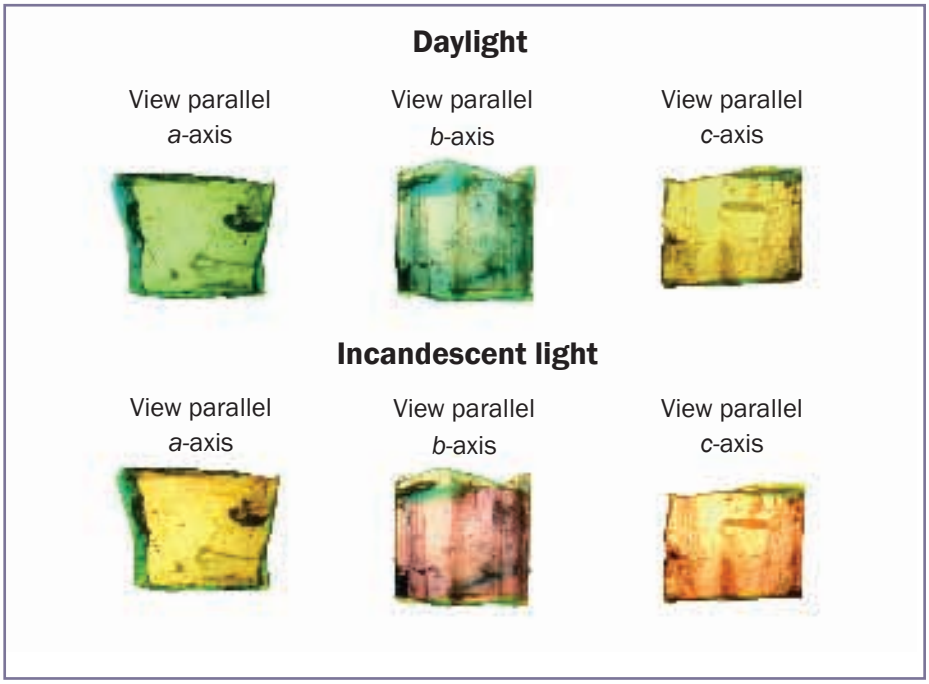

*Figure 37: Colour and pleochroism in a natural alexandrite single crystal from Lake Manyara, Tanzania, in daylight and incandescent light in views parallel to the a-, b- and c-axes. The crystal fragment shows **a** and **b** pinacoids and is broken at both terminations, size of the crystal 3.8 × 3.5 × 3.2 mm. With the unaided eye (non-polarized light), the observed coloration in all three directions varies distinctly, with the 'best' colour change in the view parallel to the b-axis. Parallel to the a-axis, the red colour component in incandescent light is very small. Photographs and artwork by K. Schmetzer.*

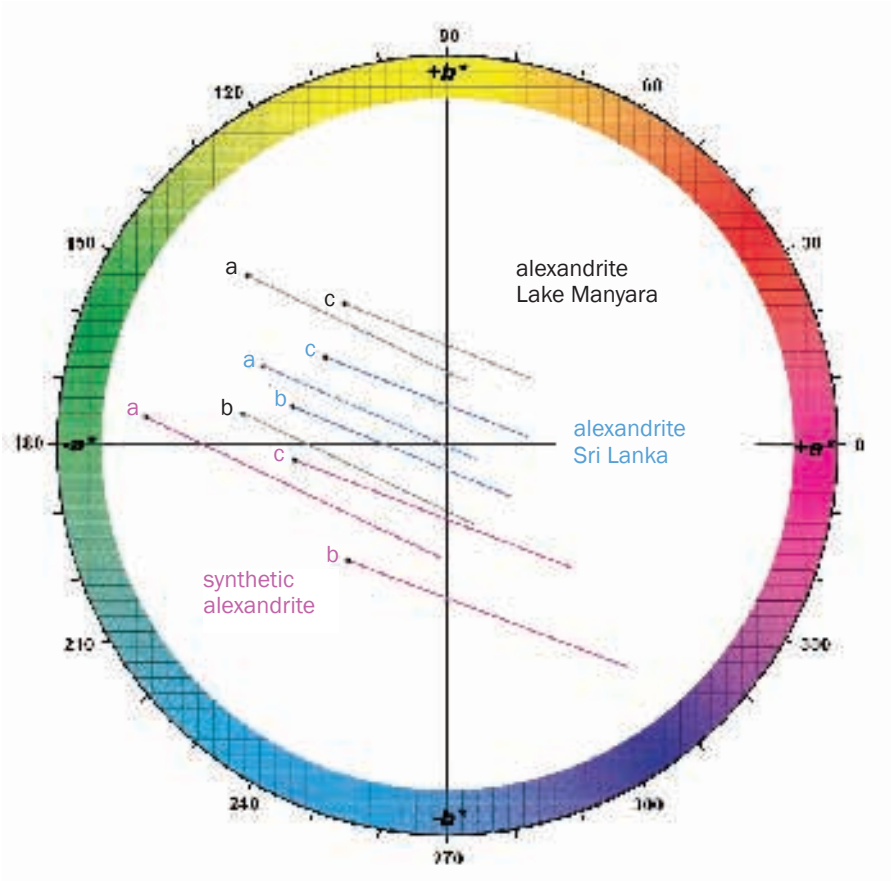

*Figure 38: Colorimetric parameters of three alexandrite cubes, i.e. of natural alexandrite from Lake Manyara, Tanzania (see Figure 37), and natural alexandrite from Sri Lanka as well as Czochralski-grown synthetic alexandrite from Russia plotted in the CIELAB colour circle. Each stone was measured parallel to the crystallographic a-, b- and c-axis) and the coordinates labelled accordingly; the neutral point (white point) is in the centre of the a*b* coordinate system; the small black circles represent the coordinates in daylight D_{65} and the ends of the differently coloured bars represent the coordinates in tungsten light A; the outer circle represents a chroma of 18. The typical alexandrite-like colour change from daylight to incandescent light is apparent in views parallel to the b-axis and partly also in views parallel to the c-axis. The red colour component in incandescent light is distinctly weaker in views parallel to the a-axis. Data for the synthetic Russian alexandrite from Schmetzer and Bosshart (2010), data for the natural samples from Tanzania and Sri Lanka measured by A.-K. Malsy.*

latter (*Figures 33* and *34*). Only six samples (subgroup d) show a colour change to purple or purplish red in incandescent light, which represents a typical alexandrite-like colour change between daylight and incandescent light. The other groups of samples [subgroups (b) and (c)] show a colour change to yellow or green or to greyish blue in incandescent light, and one stone [subgroup (a)] became brownish orange in incandescent light.

Chromium, vanadium and iron contents of rough alexandrite crystals and of the four different groups of faceted stones are plotted in *Figure 35 a,b*. It is evident that chromium contents of most samples with a typical alexandrite-like colour change of green to purplish red in daylight to incandescent light (rough samples of group I *[Figure 31]* and faceted samples of group II, subgroup (d) of *[Figure 33]*) exceed the chromium contents of samples with colour change to bluish grey, orange or yellowish green to yellow in incandescent light (faceted samples of group II, subgroups (a), (b), and (c) *[Figure 33]*). Vanadium and iron contents, on the other hand, are in similar ranges.

Table III. Trace element contents, colour and pleochroism in selected alexandrites.

Samples	Czochralski-grown synthetic alexandrite, Russia	Natural alexandrite, Lake Manyara, Tanzania	Natural alexandrite, Sri Lanka
Size (mm)	9.2 × 9.0 × 9.0	3.8 × 3.5 × 3.2	6.6 × 6.1 × 6.0
Trace element contents (wt%)			
V_2O_3	0.09	0.01	0.01
Cr_2O_3	0.21	0.60	0.15
Fe_2O_3	< 0.01	1.23	0.80
Colour to the unaided eye in daylight			
View ‖ *a*-axis	intense green	green	green
View ‖ *b*-axis	greenish blue	bluish green	bluish green
View ‖ *c*-axis	light green	yellowish green	yellowish green
Colour to the unaided eye in incandescent light			
View ‖ *a*-axis	bluish grey	yellow	purplish grey, almost colourless
View ‖ *b*-axis	intense purple	violet purple	intense purple
View ‖ *c*-axis	light greyish purple	orange	purplish red

To evaluate the extent of colour change, the two relevant colorimetric data, i.e. colour difference ΔE^*_{ab} versus hue angle difference Δh_{ab} were plotted in *Figure 36*. The rough and faceted samples with a typical alexandrite-like colour change [rough samples, group I, and faceted samples, group II, subgroup (d)] showed a wide variation of hue angle difference (from about 100° to 180°) and colour

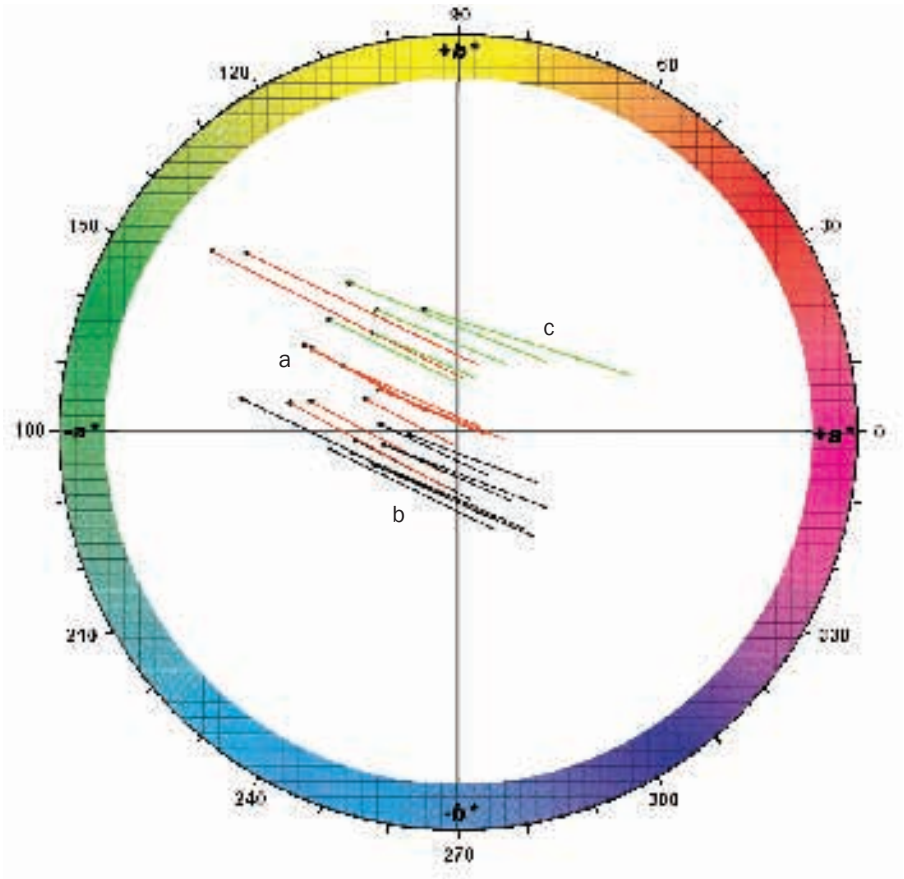

*Figure 39: Colorimetric parameters of rough and faceted alexandrites and chrysoberyls from Lake Manyara in the CIELAB colour circle; the neutral point (white point) is in the centre of the a*b* coordinate system; the small black circles represent the coordinates in daylight D_{65} and the ends of the differently coloured bars represent the coordinates for tungsten light A; the outer circle represents a chroma of 18. The coloured bars represent measurements of different samples with a predominant path of light parallel to the a-axis (red), parallel to the b-axis (black) and parallel to the c-axis (green) of each sample. The dependency of colour and colour change on stone orientation is evident. Colorimetric measurements of various samples by A.-K. Malsy and G. Bosshart.*

differences (between 8 and 19 CIELAB units). Using the definition for the extent of colour change given by Schmetzer *et al*. (2009) and Schmetzer and Bosshart (2010), the extent of colour change for all these alexandrites is very strong. The other samples show colour differences in the same range, but smaller hue angle differences. Although these samples show moderate [group II, subgroup (b), yellow to green,] or strong colour change [group II, subgroup (a), brownish orange sample, and subgroup (c), bluish grey samples], they do not show the traditional alexandrite colours in incandescent light.

The association or correlation of chemical properties, especially chromium contents, and colorimetric parameters, however, does not completely explain the pattern of colour change observed. It is generally known in the gem trade and especially by cutters of alexandrite rough, that the colours observable in incandescent light are strongly dependent on the orientation of the samples (Fischer, 1954, 94–6). This was demonstrated with colorimetric parameters measured for alexandrites in different orientations versus the non-polarized primary spectrometer beam (Schmetzer and Bosshart, 2010). In particular, colorimetric parameters were described for an exactly oriented, Czochralski-grown cube of synthetic alexandrite.

Similar orientation dependencies were observed and measured in two natural alexandrites. One fragment of an untwinned crystal from Lake Manyara is shown in *Figure 37* in different orientations in daylight and incandescent light. For comparison, an alexandrite cube from Sri Lanka was also measured. The size, chemical properties and colours to the unaided eye in daylight and incandescent light of the two samples are summarized in *Table III*, the colorimetric parameters are plotted in *Figure 38*. The parameters of the synthetic alexandrite cube mentioned above are also given.

The sample loci within the CIELAB colour circle *(Figure 38)* represent the colours for daylight and incandescent light. Although the connecting bars between the loci measured for a specific orientation of the three cubes are almost parallel to each other, the positions of the endpoints differ significantly and demonstrate the distinct pleochroism of alexandrite. The lengths of the bars are a graphical representation of colour difference in the a*b* plane of the CIELAB colour circle.

Although the three samples show large differences according to various trace element contents and variable paths of light (sample thickness), a general scheme is apparent for all three alexandrites. In daylight, in a view parallel to the *a*-axis, the most intense and pure green is visible. In a view parallel to the *b*-axis, the alexandrites are more bluish green and in a view parallel to the *c*-axis, the alexandrites are less intense green or more yellowish green. The most intense colour change is always parallel to the *b*-axis; the change is somewhat weaker parallel to the *c*-axis. In incandescent light, the colour parallel to the *a*-axis in these three samples changed only to yellow, bluish grey or purplish grey, in general without a distinct red colour component.

In the gem trade, only a small percentage of faceted alexandrites will be cut so that the table facets are exactly perpendicular to one of the three crystallographic axes *a*, *b* or *c*. To evaluate the orientation dependency of colour change in faceted alexandrites and green chrysoberyls from Lake Manyara, we determined the orientation of the table facets for colorimetrically measured and chemically analysed samples by optical

means (pleochroism, growth structures, twinning, observation of optical axes; see Schmetzer, 2011). We also selected the rough samples which had been colorimetrically measured through a natural crystal face (in this case, through an **a** or **b** pinacoid) and chemically analysed and examined all samples for the presence or absence of twinning, i.e. if the samples were single crystals or twins. According to the twin law of chrysoberyl, the *a*-axes of twinned individuals are parallel to each other, but the *b*- and *c*-axes are not. Thus, twinned samples can be measured through the **a** pinacoid to determine colorimetric parameters, but not through the **b** pinacoid (the **c** pinacoid is not present in Lake Manyara samples).

The above constraints meant that we could only use some of the faceted and rough samples for this research, simply because some stones were cut with a table facet oblique to the crystallographic axes or some broken crystals did not show an **a** or **b** pinacoid suitable for oriented spectroscopic measurement. Also, twinned stones were rejected. It should also be mentioned that the different cut and/or thickness of the faceted stone plays a certain role. Therefore we also tried to use samples of comparable thickness for this research. The results are plotted in *Figure 39*.

In general. the trend described above for the three cubes *(Figure 38)* was confirmed. Most stones with a table facet predominantly perpendicular to the crystallographic *a*-axis (i.e. in a view parallel to the *a*-axis) showed an intense green coloration in daylight. Samples examined parallel to the *b*-axis are less intense green or more bluish green. Samples viewed parallel to the *c*-axis are more yellowish green in daylight. For stones with a table facet predominantly perpendicular to the *b*-axis, various shades and intensities of purple to purplish red are shown in incandescent light. For samples with a table facet predominantly perpendicular to the *c*-axis, the colour in incandescent light varied between orange, yellow and green. Some samples viewed parallel to the *a*-axis did not show a distinct red colour component in incandescent light. In a view parallel to the *a*-axis, only stones with chromium contents in the range of 0.9 wt% Cr_2O_3 or above were red to purple in incandescent light.

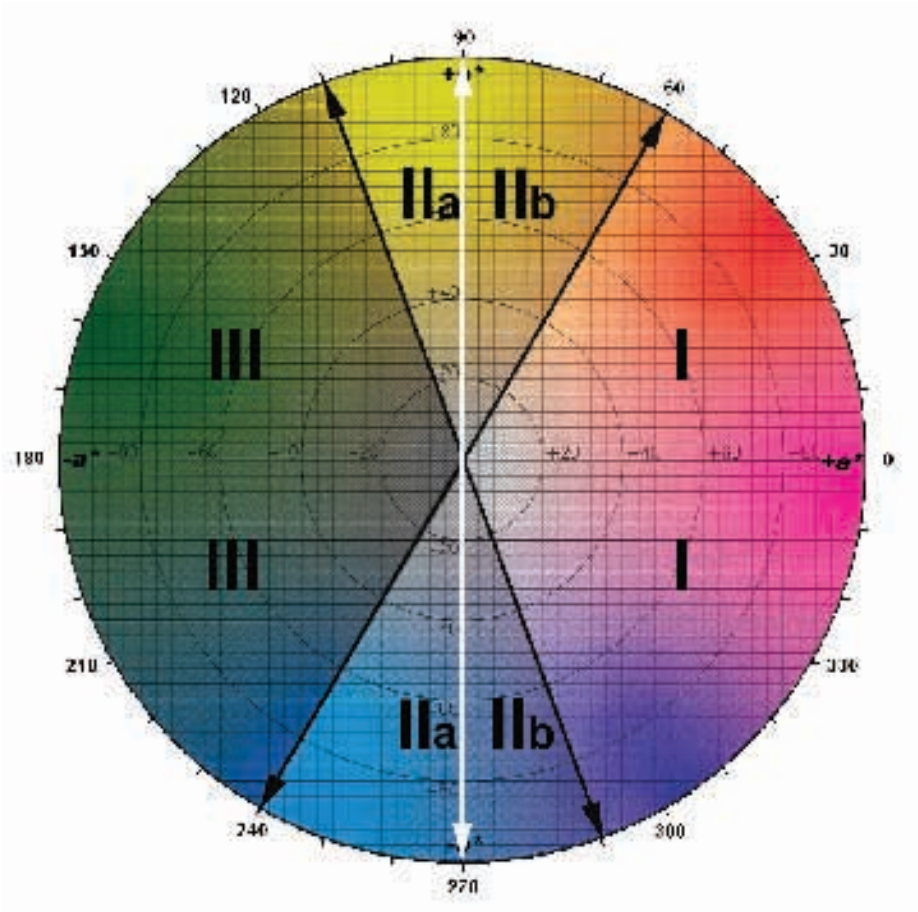

Figure 40: This schematic diagram is designed to aid thinking about the distinction and naming of alexandrite and green chrysoberyl in the gem trade. The colour wheel represents colours of these gems in incandescent light; the white line separates those with a red colour component (sectors I and IIb) from those without red (sectors III and IIa). Stones with colours in sector I are — in general — accepted as alexandrites in the trade, whereas those with colours in sector III are — in general — not designated as alexandrites. There are, however, some stones with colours in the yellow to orange or in the blue to blue violet ranges (sectors IIa and IIb), which are accepted by only some in the gem trade as alexandrites. The position of the boundaries between sectors I and IIb, representing possible boundaries between alexandrite and colour-change chrysoberyl, is also a matter of discussion. Artwork by K. Schmetzer.

These results enable one to explain the extreme variability of colour change of faceted and rough alexandrites. It is evident that the orientation of the table facet or the direction of view in rough samples plays a dominant role in establishing the extent and nature of the colour change and the classification of the faceted or rough stone as alexandrite or chrysoberyl. Therefore, the distinction of alexandrite from chrysoberyl based on the presence or absence of chromium and even the quantitative determination of chromium contents in specific samples is not sufficient to solve this nomenclature problem. The presence of a certain amount of chromium is necessary to produce a colour change in chrysoberyl, but in our opinion, there must be a distinct red colour component in incandescent light to call a stone alexandrite.

A chrysoberyl, rough or faceted, can show an alexandrite-like colour change in a specific direction of view, but not in others. Therefore, a faceted stone should only be assessed in a face-up orientation if the correct designation has to be given to a customer in the trade. However, it should be appreciated that in its current cut, a gemstone may not appear as an

alexandrite, but it might show a different colour change with different orientation of its table facet.

In the trade, there is a wide variation of opinion about the correct designation of alexandrites and chrysoberyls. If we apply our colorimetric measurements and place the sample loci for chrysoberyl and alexandrite samples in incandescent light into the colour wheel, we can subdivide the colour wheel into different areas *(Figure 40)*. In general, it is agreed that chrysoberyls with a coloration in the colour range designated as sector I should be called alexandrites, while those in a sector designated III should not be called alexandrites. In between, the areas IIa and IIb contain the colours of chrysoberyls subject to most variation in designation. These areas are centred in the blue and yellow. Although we do not want to formally define a boundary between alexandrite and chrysoberyl (boundaries between sectors labelled I and IIb in *Figure 40*), at present we would not designate samples with a colour in incandescent light represented by areas labelled IIa in *Figure 40* (e.g. yellow samples) as alexandrites, simply because they do not show any red colour component in incandescent light.

A system used by some in the gem trade which describes the colour change of alexandrites in terms of a certain percentage, e.g. 30 % colour change, 50 % colour change, is, in our view, not very helpful because neither the colour in daylight nor that in incandescent light is given or can be deduced from such a simple percentage figure.

Using the Lake Manyara stones pictured in *Figure 33* in daylight and incandescent light with sample loci plotted into the CIELAB colour circle in *Figure 34*, we contacted numerous people in the gem trade and found a wide range of opinions. The great majority told us that they would not designate our samples 1, 2, 3 and 6 as alexandrites, but a minority would do so for samples 1, 2 and 3, or only for sample 1. The opinions about samples 9, 10 and 11 with bluish grey colour in incandescent light were also different, with some dealers accepting these stones as alexandrites, and others not.

Discussion and comparison of the Lake Manyara material with alexandrites from other phlogopite-bearing schist-type deposits

Alexandrites from Lake Manyara, Tanzania, from various localities in the Urals, Russia, and from Novello, Zimbabwe, occur in a common type of emerald-alexandrite deposit comprising seams, layers or irregularly shaped ore bodies of phlogopite. This common lithological host had already been recognized in the 1960s, shortly after the discovery of the occurrence at Novello (Martin, 1962; Bank, 1964; Bank and Okrusch, 1967; Okrusch, 1971) and was again underlined in the 1970s after the discovery of the Lake Manyara deposit (Thurm, 1972 a,b,c; Bank, 1974; Gübelin, 1974, 1976).

Although emerald and alexandrite are occasionally found together in such deposits, they mostly form at some distance from each other. In the Novello area, the main emerald- and alexandrite-bearing bodies were found about 1 km apart (Taylor, 1976; Metson and Taylor, 1977). In Lake Manyara, the distance is very variable, between a few tens of centimetres to a few metres or tens of metres. Although details of the emerald-alexandrite formation within these schist-type deposits are still under discussion, a multistage metamorphic genesis in so-called 'blackwall' contact zones is generally accepted for this type of deposit (see detailed review by Franz and Morteani, 2002).

A comparison of alexandrites originating from massive phlogopite host rocks indicates that the samples from Novello are most similar to some of the Russian material and that an equivalent to the Lake Manyara material is also found in Russia. However, it must be emphasised that the Russian samples originate from numerous deposits exploited by surface and underground mining over a considerably larger area than the Lake Manyara and Novello sources. Consequently, the Russian samples show a larger variability of characteristic mineralogical and gemmological features.

The most impressive rough crystals from all three mining areas are cyclic twins (trillings), which show two main types of habit: dipyramidal-equidimensional-columnar or tabular. Below we compare samples with dipyramidal to columnar habit, but similar results would be obtained for trillings with tabular habit, twins or single crystals. The growth sequence of alexandrite trillings is given as a schematic overview in *Figure 41*. The first stage of crystal growth (A) is characterized by a simple dipyramidal habit with the dipyramid **o** and the pinacoid **a** as dominant crystal forms. In the last step of crystal growth (H), the columnar trillings are characterized by the prism **i** and the pinacoid **a**. Intermediate steps (B to G) are described as a step-by-step increase in size of **i** and a corresponding decrease in size of **o**. During this sequence, the dipyramid **w** also grows but only temporarily (E).

Specimens from Russia can show any or all the habits shown in *Figure 41*, but generally only two or three steps within this sequence are found within one alexandrite trilling. For example, a sample might show an external morphology as described in crystal (E), and with the microscope, a morphology varying from C (in the centre of the crystal) over D (in the middle) to E (at the outermost rim) might be seen. Another example with an external morphology of crystal G might show internal growth structures represented schematically by drawings E and F.

Specimens from Novello (Schmetzer *et al.*, 2011) show two types of trillings, both with **o**, **b**, **i** and occasionally with **w** faces (examples D and E). In the first type, these faces are combined with the **a** pinacoid, a feature also commonly observed in Russian samples from the Malysheva Mine (Schmetzer, 2010). On the

other hand, the second type from Novello with smaller or no **a** pinacoids and larger **m** prism faces, is extremely rare in Russian samples. Instead of the **m** prism, which is a larger face in Novello samples, alexandrite from the Urals commonly shows the **s** prism. Some of the Russian samples do not show the **i** prism and the **w** dipyramid, a common feature in crystals from Novello.

Trillings from Lake Manyara, on the other hand, show two dominant faces, the **a** pinacoid and the **i** prism, mostly in combination with small **o** dipyramids and **b** pinacoidal faces (see again *Figure 41*, examples F to H). Under the microscope growth patterns at the beginning of crystal growth showing the **w** dipyramid (E) are visible; this is not seen macroscopically on the mature crystals (see again *Figure 23*). This morphology has recently been found in Russian alexandrites which have been unearthed within the last two decades from the Malysheva Mine, but only in smaller crystals with columnar habit. In contrast to Russian samples and crystals from Novello, single crystals and twins from Lake Manyara commonly show the prism **r**.

The general crystal morphology of twinned and untwinned chrysoberyls from the Lake Manyara deposit is reflected in their growth patterns and consists of dominant **a** pinacoids and **i** prism faces with subordinate (smaller) **o** dipyramids. In contrast to some alexandrites from Russia and most from Zimbabwe, intense colour zoning is not present in the Tanzanian stones.

Inclusions or platelets of phlogopite mica are present in the chrysoberyls from all three areas. Other mineral inclusions which are common in material from Lake Manyara are apatite and zircon; channels parallel to the *a*-axis are also common.

Compositionally, Zimbabwean stones have higher chromium contents than most Russian alexandrites, while in samples from Lake Manyara, chromium contents are variable and overlap with those in Russian samples. It was also found that Lake Manyara alexandrites have iron contents intermediate between those in

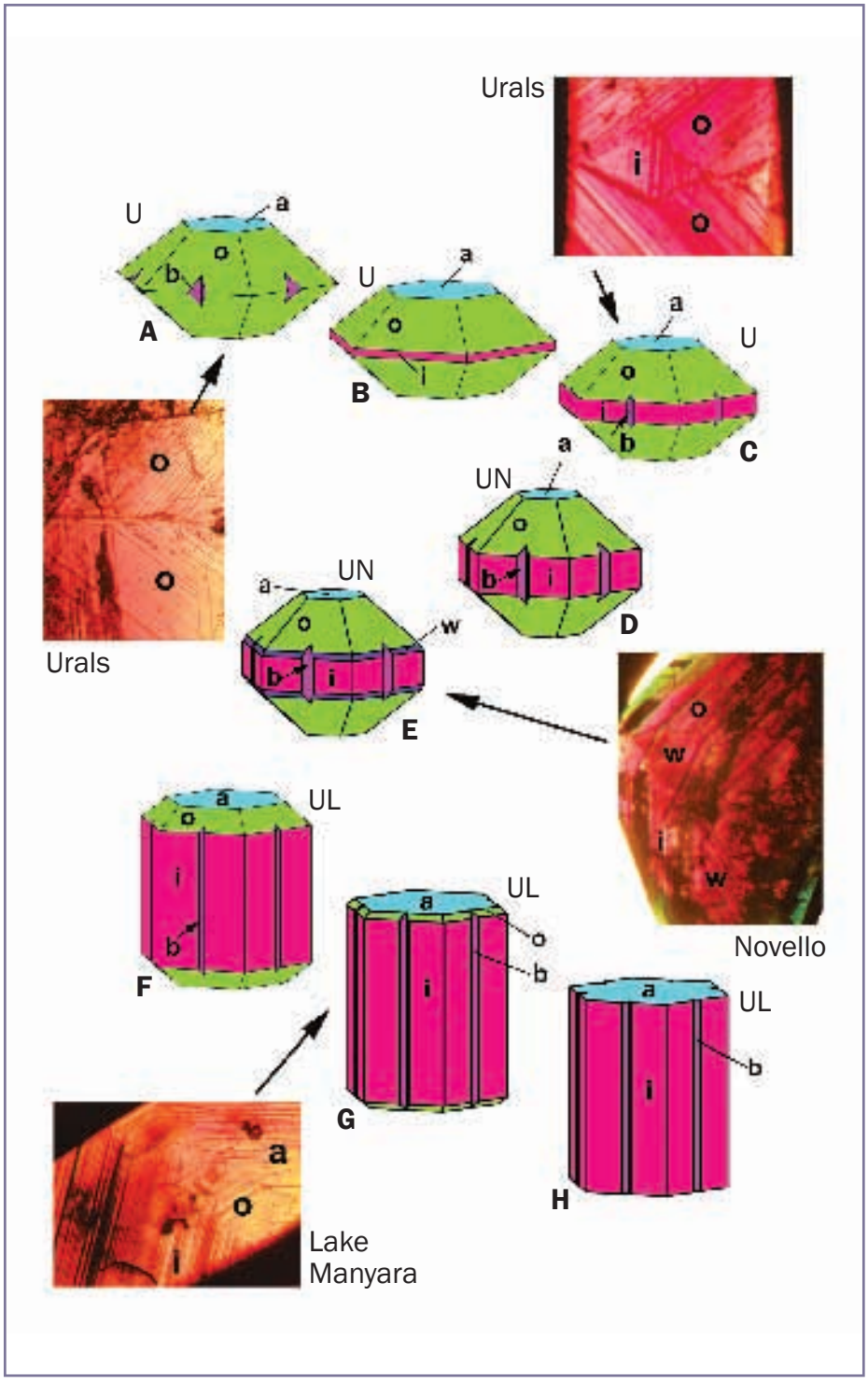

Figure 41: Growth sequence of alexandrite and chrysoberyl trillings with dipyramidal to columnar habit originating from phlogopite schist-related deposits. Examples of the complete growth sequence from A to H can be obtained from stones mined from the Uralian emerald-alexandrite belt (U), Russia, crystals A to C represent typical habits which were unearthed in the nineteenth century, samples D and E represent crystals mined in the twentieth century in the famous Malysheva Mine, and habits F to H represent mostly smaller crystals from the more recent production from Malysheva. Crystals D and E are typical examples of alexandrite trillings from the Novello deposit, Zimbabwe (N). Also E represents a morphology developed at the beginning of crystal growth in the Lake Manyara deposit, Tanzania, but not seen in well developed crystals from this deposit. F to H represent later stages of Lake Manyara (L) material and these habits are common in trillings from this locality. Examples of characteristic internal growth patterns corresponding to the external morphologies are also shown. Photos, crystal drawings and artwork by K. Schmetzer.

Russian and Zimbabwean alexandrites. A more fruitful distinction of stones from these three sources on the basis of composition can be made using various trace elements, such as boron, magnesium, gallium, germanium and tin.

The colour changes observed in alexandrites and chrysoberyls from Tanzania are extremely variable, and relate directly to their chromium contents and the orientation of the table facet with respect to the crystallographic axes.

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Review of ultraviolet sources for gem fluorescence and testing

Grant Pearson, FGAA

Abstract: The ultraviolet-visible spectra of emissions from mercury discharge lamps and light emitting diodes (LEDs) have been recorded. The emissions from five Hg discharge lamps nominally labelled to produce short wave ultraviolet (SWUV) radiation were found to also contain significant long wave (LWUV) components. The emissions of LWUV lamps also were found to contain wavelengths in addition to 365 nm LWUV mercury (Hg) line. This compromises the effectiveness of such lamps for diagnostic gem testing. The emission spectra of LWUV and violet LEDs were collected and found to show spreads of up to 20 nm either side of the nominal emission wavelength. Excitation-fluorescence diagrams obtained by Hoover[1] indicate that some gems such as ruby may not fluoresce when stimulated by SWUV at 254 nm, contrary to present gemmological belief. Experiments carried out with Wood's glass and with nickel sulphate and cobalt sulphate solutions indicate that they do not absorb all LWUV from nominal SWUV sources, so such filters for UV sources are not a reliable tool in gem testing.

Keywords: fluorescence, gem testing, Hg-discharge tubes, light-emitting diodes, ultraviolet, UV-visible emission spectra, Wood's glass filter

1. Introduction

Fluorescence responses evoked by ultraviolet light are frequently used as identity indicators for many gem species, particularly for those containing chromium. However, there has been little investigation and reporting of the consistency and purity of emission of ultraviolet radiation from the low-pressure mercury discharge tubes which have been generally assumed to emit just 365 nm (long wave ultraviolet, LWUV) and 254 nm (short wave ultraviolet, SWUV) radiation. These mercury discharge emissions are filtered by Wood's glass, a visibly opaque but UV-transparent glass with a high nickel content, or by other similar screening compositions to supposedly exclude all wavelengths other than the two mentioned above.

As a first step in establishing the nature of UV and visible emissions from UV sources used in gem testing, the writer's USB 'Ocean Optics' USB2000 CCD miniature spectrometer was used.

2. Equipment and procedures

The UV source equipment tested includes a dual handpiece instrument manufactured by the Gemmological Association of All Japan (GAAJ), a dual wavelength single handpiece instrument from UltraViolet Products (UVP), the UVSL-15 with selectable LW or SW outputs, and a smaller unbranded dual-band unit also with LW or SW outputs, all shown in *Figures 1, 2* and *3* respectively.

The USB2000 CCD spectrometer directly registers light emissions between 200 and 850 nm on 2048 discrete CCD channels. This contrasts with many analytical spectrophotometers which determine the relative transparency of a specimen to a monochromatic beam as its wavelength scans across the spectrum.

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Figure 1: Separate LWUV and SWUV lamps manufactured by the Gemmological Association of All Japan (GAAJ).

Figure 2: A combined LW and SWUV lamp UVSL-15 from UltraViolet Products (UVP).

Figure 3: A combined LW and SWUV lamp, unbranded.

Such instruments cannot register direct emissions from external radiant sources.

Emissions from the three UV sources mentioned above were scanned several times each at appropriate distances from the Ocean Optics USB2000 spectrometer's input optic fibre aperture to develop suitable spectra. This enabled the overall general shapes of their emission envelopes and the specific peak apex or peak centre locations to be recorded together with any wavelengths additional to the nominal ones. The scans are shown in *Figures 4, 5* and *6*, where the relative intensity of radiation is plotted against wavelength.

3. Results and discussion

The scan of the GAAJ shortwave source shown in *Figure 4* contains not just the emission at 254 nm but also SWUV emissions at 267 and 295 nm, LWUV emissions at 310, 334 and 365 nm, and visible emissions at 405 and 437 nm. The LWUV and visible emissions are of total energy exceeding that of the SWUV emissions, based on the relative areas beneath the curve representing the energy received.

Inspection of the GAAJ LWUV-output spectrum, *Figure 4,* shows that the 365 nm line which is supposed to be exclusively generated is actually accompanied by continuous and far more abundant LWUV emission ranging between about 320 and 390 nm. Any LWUV fluorescent reaction observed in a gem or mineral specimen examined with this illumination could then have been excited by any or all of the wavelengths represented in this emission. That is, a fluorescent reaction may not necessarily be specifically generated by only the 365 nm mercury line, but may be caused by any or all of the available LWUV wavelengths being emitted. Consequently, minerals or gems that may fluoresce to very specific and selective narrow LWUV excitations, not necessarily even the presumed 365 nm line, may give a positive but clearly erroneous reaction to this emission which is supposed to be exclusively the 365 nm line. A false-positive indication of identity could then result.

In addition, any gem that fluoresces to LWUV, especially at or near the 365 nm wavelength, will inevitably react positively to the source in *Figure 4* which is labelled short wave, because of its additional emissions. Despite the apparently visible SWUV fluorescence of a specimen, it could really be quite inert to any or all of the SWUV being generated, responding only to the accompanying LWUV. Any observed SWUV fluorescence that is visibly similar to its LWUV response should therefore be treated suspiciously until a genuine fluorescence excitation by

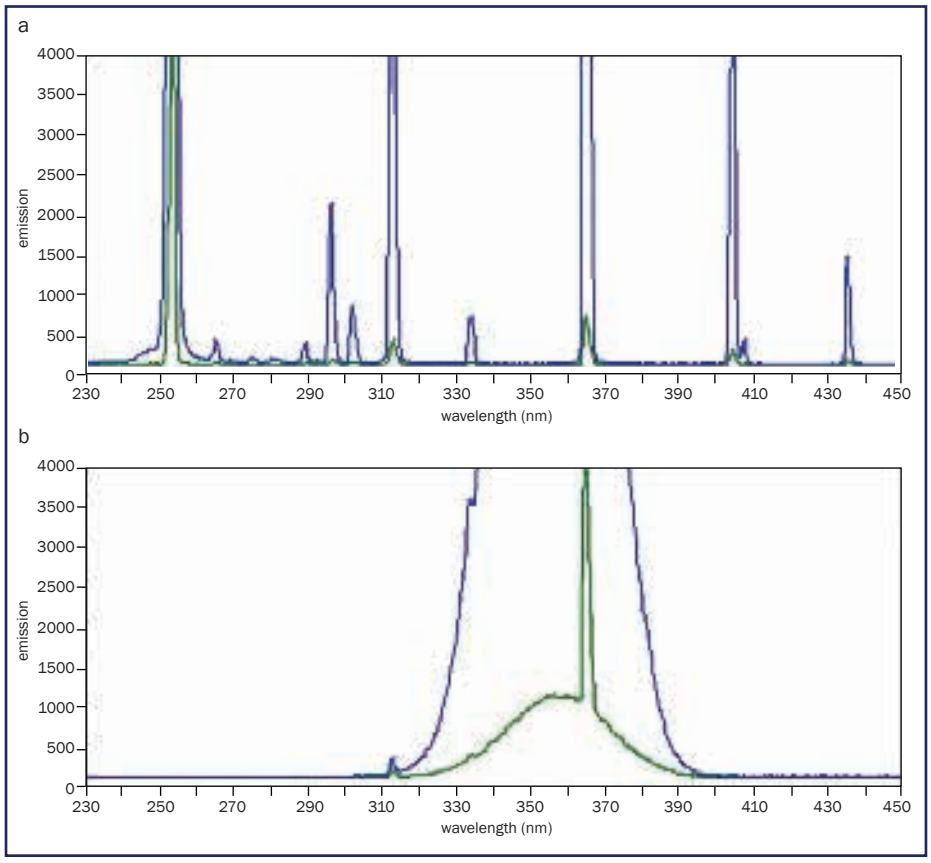

Figure 4: Emission spectra of GAAJ lamps: (a) SWUV range, (b) LWUV range.

exclusively SWUV can be demonstrated, rather than by any unsuspected accompanying LWUV.

The spectrum of the SWUV emission from the UVSL-15 lamps shown in *Figure 5* indicates a definite emission near 254 nm accompanied by a substantially larger output in the long wave region which is perhaps comparable with that from the nominal LWUV-only output (see lower graph). So, any visible fluorescence evoked in a gem by such LWUV will also appear when it is placed under the SWUV lamp. Any genuine fluorescence stimulated by the SWUV may not be perceptible since it could be overwhelmed by fluorescence excited by the more intense accompanying LW radiation, especially if the fluorescent emission wavelengths are visibly similar.

Examination of the SWUV emission spectrum of the unbranded dual-band UV unit shown in *Figure 6* also indicates the presence of substantial amounts of LWUV. This common feature of all three commercial lamps suggests that many if not most Hg-discharge UV lamps may suffer from this shortcoming. This implies that any fluorescence displayed by a gem under one of these lights may or may not be due to short-wave stimulation, which in turn casts doubt on attributions of cause and interpretations published in the past.

Just like the other two LWUV maps, the unbranded lamp emits light with a distinct peak near 405 nm. This is significant, since many chromiferous minerals and gems may strongly fluoresce red to the visible shorter wavelengths, often more intensely than to the shorter 365 nm LWUV band to which they may even be negligibly sensitive. This effect is at the core of the 'crossed filters technique' where fluorescence of a specimen is preferentially excited by visible blue light. Appropriate blue light can be screened from initially white continuous light by a solution of a blue copper salt such as the nitrate or sulphate to remove all wavelengths other than the blue to visible-violet (see the transmission spectrum of saturated copper nitrate solution produced by the writer on a

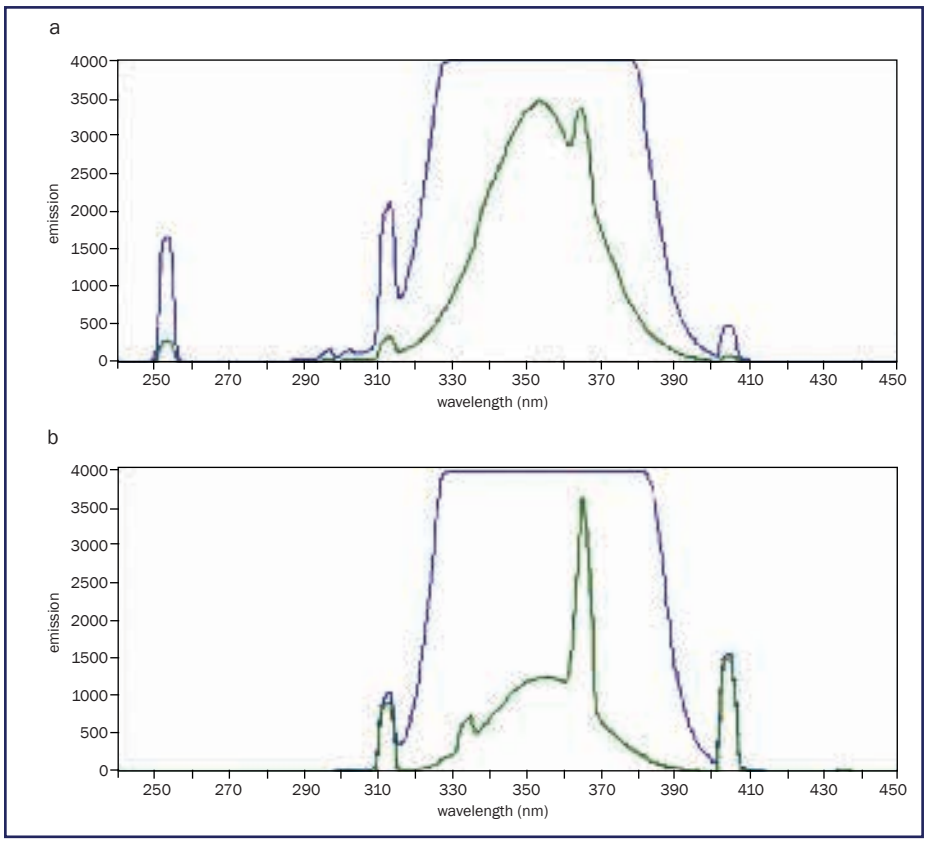

Figure 5: Emission spectra of UVSL-15 lamp: (a) in SWUV mode, (b) in LWUV mode.

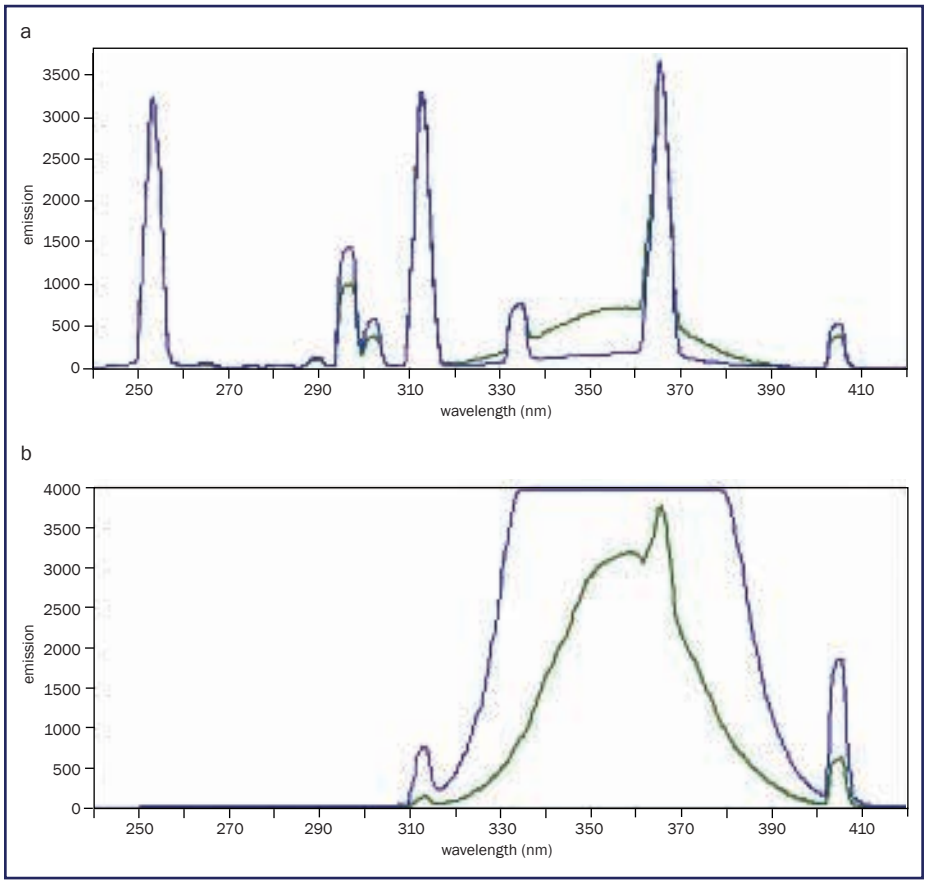

Figure 6: Emission spectra of unbranded lamp: (a) SWUV source, (b) LWUV source.

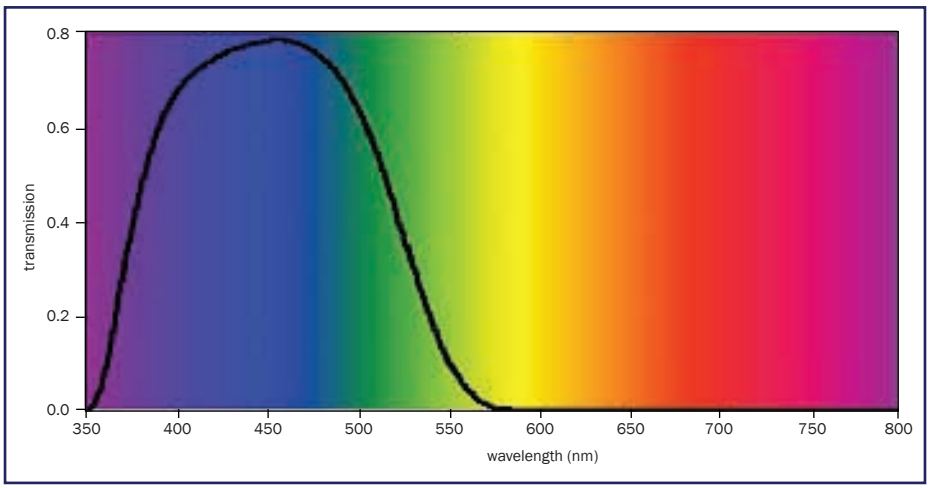

Figure 7: Spectrum showing transmission of visible light through a concentrated aqueous solution of $Cu(NO_3)_2$, used as the blue filter in the 'crossed filters' technique.

Varian Cary 3 spectrophotometer, *Figure 7*) and then viewing any red fluorescence of a specimen through an isolating red 'barrier' filter.[2] Consequently, any red fluorescence supposedly excited by the 365 nm LWUV could actually be due, partially or totally, to the accompanying blue-violet 405 nm Hg-emission band.

In order to decide how to clarify and improve the use of UV radiation in gem testing, a number of aspects need to be discussed in more detail. These include (a) materials which fluoresce under SWUV but not LWUV, (b) excitation-emission properties of minerals and (c) investigation of light emitting diodes (LEDs), filters and discharge tubes. The discussion is illustrated by the spectral excitation-emission spectra produced by Hoover and Theisen.[1]

(a) *Minerals which fluoresce under SWUV*

A few gem minerals fluoresce when stimulated by wavelengths in the 200 to 300 nm range. In *Figure 8* scheelite, benitoite, Verneuil synthetic spinel and hyalite are shown in ordinary light, then under the GAAJ lamp in SW mode. These substances yield genuine and unequivocal SWUV responses since they are inert to excitation by wavelengths in the LWUV 300 to 400 nm range.

(b) *Excitation-emission properties of minerals*

Using a unique, purpose-built fluorescence spectrophotometer, red fluorescence of various chromium-bearing minerals stimulated by UV and visible wavelengths was demonstrated by Hoover in a series of diagrams reproduced here in *Figure 9, a* to *n*. The application of fluorescence stimulated by visible wavelengths to gem testing was then expanded by Hoover and Williams[2] in their update of the 'crossed filters' technique. In this, they discussed the use of LEDs rather than an incandescent white light and filters of blue solutions of copper salts.

The graphs of excitation wavelength against the fluorescence wavelength stimulated in *Figure 9* reveal that significant fluorescence is not generated in many gem species by wavelengths in the SWUV. Unfortunately Hoover's experimental limit of 270 nm is not quite as low as the Hg discharge emission at 254 nm which has hitherto been considered the standard SWUV gem testing wavelength, so at present, the discussion is limited and based on the trends exhibited by the varying strengths of fluorescence to longer wavelengths.

For example, consideration of the three graphs for the different varieties of natural chromiferous corundum, i.e. purple sapphire, Burmese ruby and Thai ruby (see *Figure 9 j, k, l*) indicates that visible fluorescence, i.e. developed at

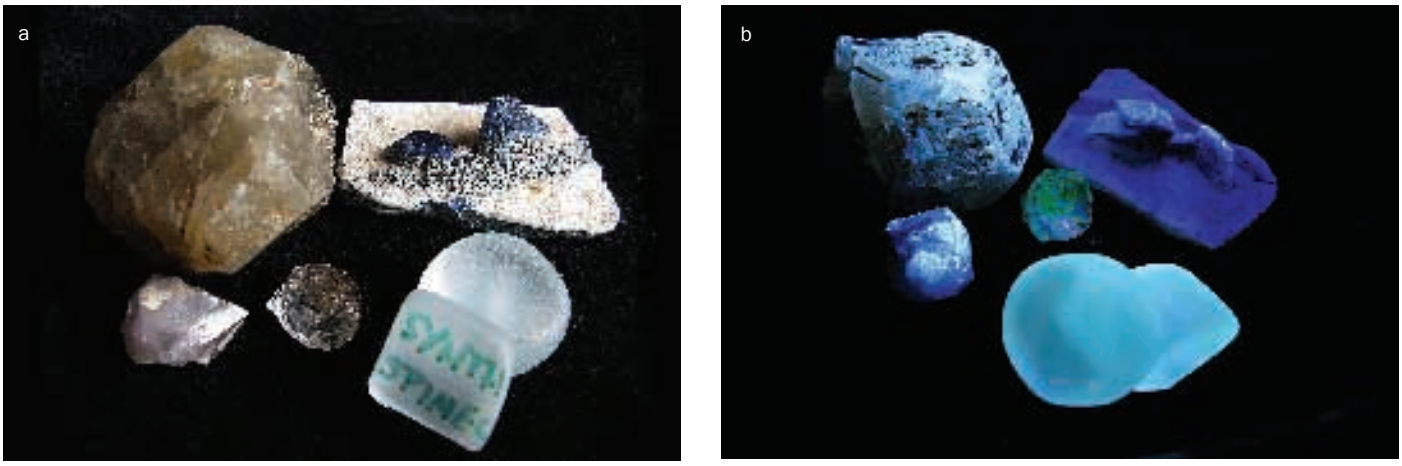

Figure 8: Minerals pictured in daylight and SWUV.
(a) (Clockwise from lower left) Daylight appearance of scheelite (Chinese, Australian crystals), benitoite crystals on natrolite matrix (California), synthetic Verneuil spinel and hyalite opal.
(b) SWUV (GAAJ lamp) fluorescent appearance of scheelite crystals (chalky bluish white to greenish white), benitoite crystals (chalky blue white) on natrolite matrix (also weakly fluorescing, probably due to the contaminating LWUV), synthetic Verneuil spinel (bright greenish white) and hyalite opal (vivid bright green).

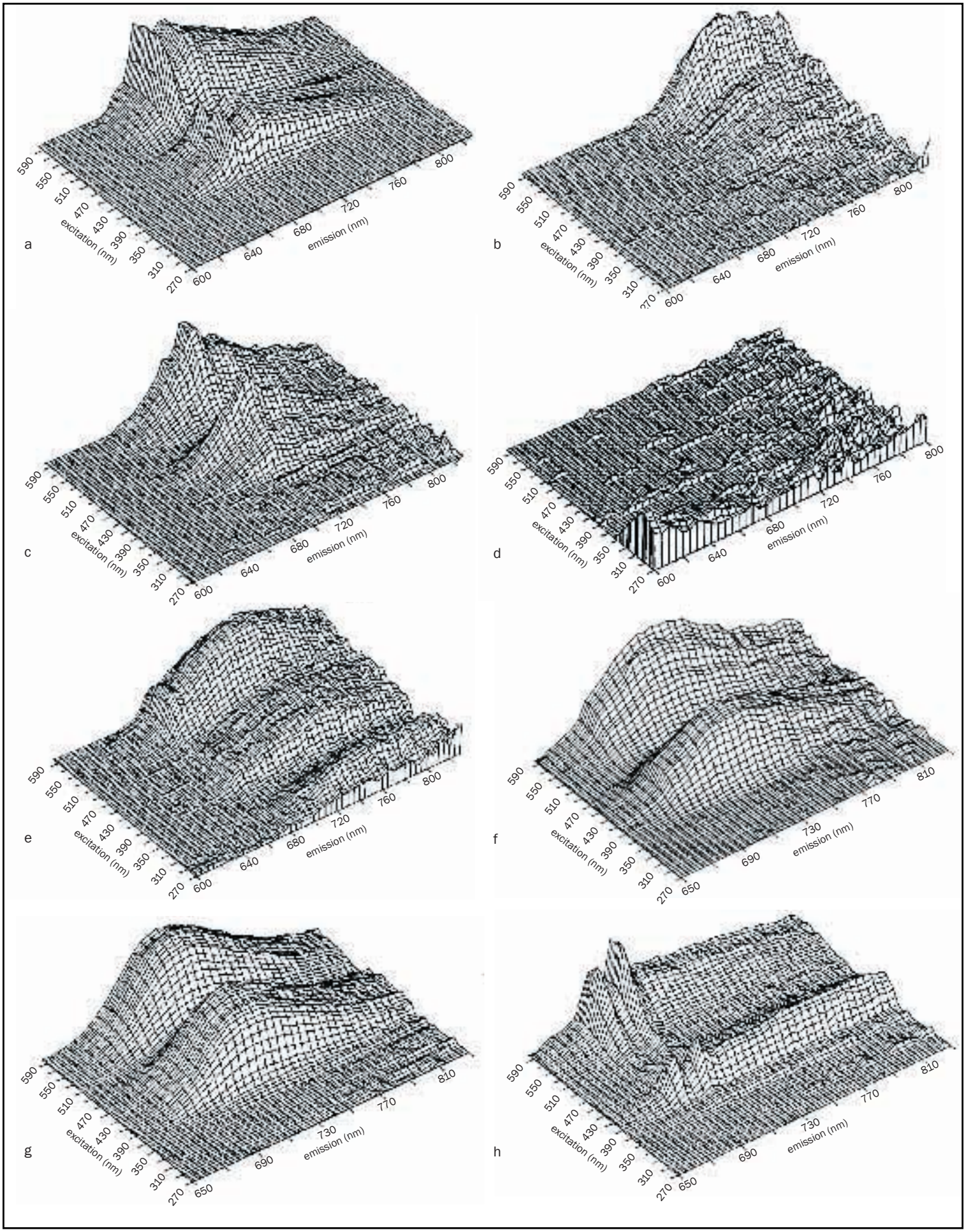

Figure 9 a–h: Fluorescence-excitation contour diagrams for (a) alexandrite, (b) chrome diopside, (c) chrome grossular, (d) chrome kornerupine, (e) chrome tourmaline, (f) Australian emerald, (g) Brazilian emerald, and (h) chrome kyanite.

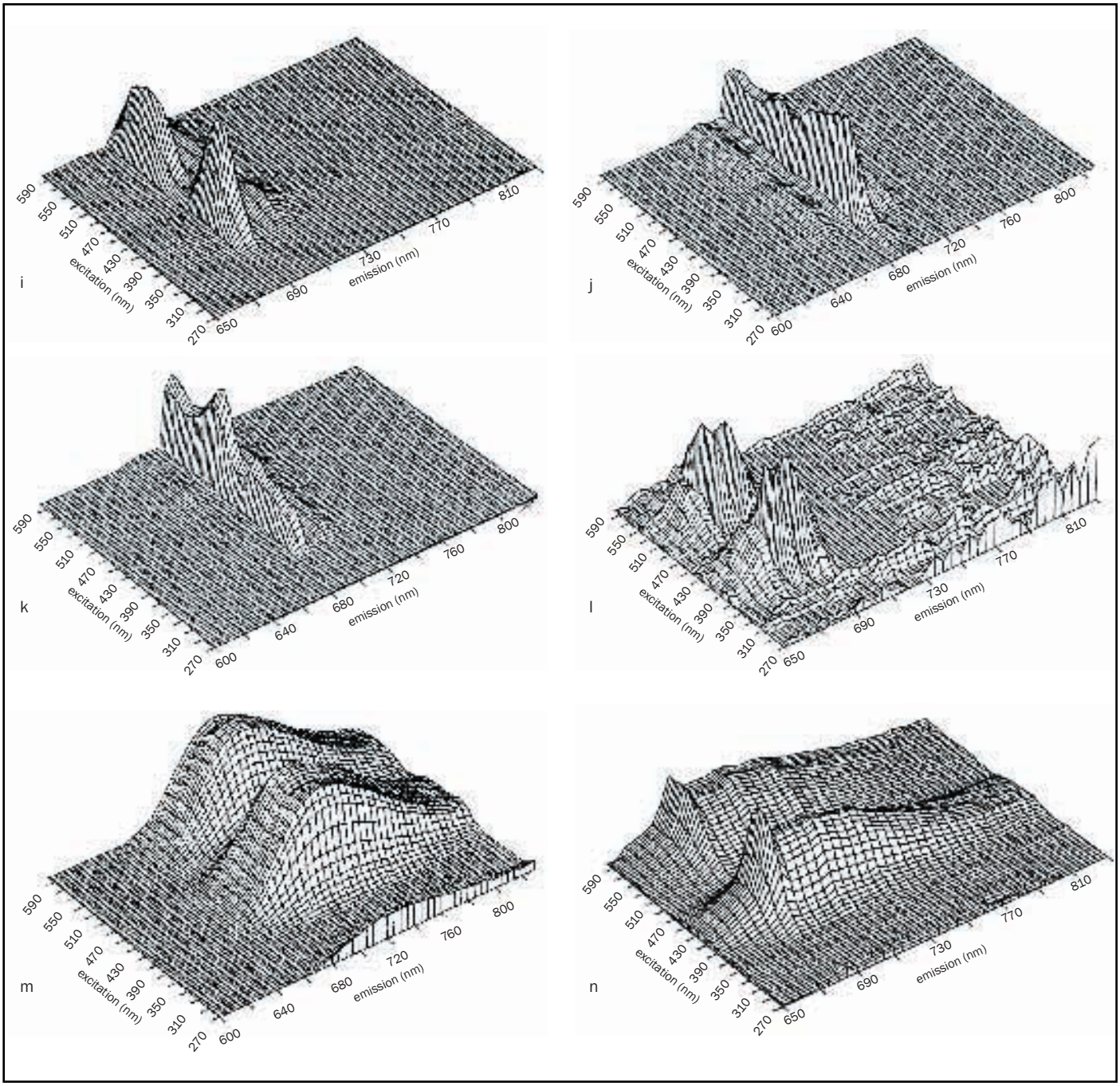

Figure 9 i–n: Fluorescence-excitation contour diagrams for (i) purple sapphire, (j) Burmese ruby, (k) Thai ruby, (l) purple spinel (Sri Lanka), (m) synthetic emerald, (n) pink topaz (Brazil).

wavelengths less than 700 nm, occurs only for excitation wavelengths in the LWUV, and even then only at values greater than about 350 nm for each of them, and with no indication of any fluorescence by excitation at any shorter wavelengths.

The onset of visible fluorescence of the natural Brazilian alexandrite *(Figure 9a)* only commences at excitation by wavelengths greater than 370 nm, again with no indication of any fluorescence from any shorter excitation wavelengths.

Exactly as for the alexandrite, the chrome grossular *(Figure 9c)* including green garnets such as Merelani 'mint' garnet or chrome-rich tsavorite), the Australian natural emerald *(Figure 9f)*, the Brazilian natural emerald *(Figure 9g)*, the Kenyan chrome tourmaline *(Figure 9e)* and the Brazilian pink topaz *(Figure 9n)*, also fluoresce but only to excitation wavelengths greater than 370 nm, suggesting that fluorescence to the usual 365 nm LWUV should not even be observed and that any detected fluorescence is due to the longer LWUV continuum up to about 390 nm. Some very minor longer wavelength fluorescence was noted for the chrome tourmaline at shorter excitations.

Chrome kyanite *(Figure 9h)* does not begin to significantly fluoresce until the excitation reaches as much as 390 nm and should be inert to 365 nm LWUV. Purple (chrome-rich) Sri Lankan spinel *(Figure 9l)*, did fluoresce red to 365 nm,

beginning at slightly shorter excitation wavelengths around 350 nm with some comparatively minor activity at even shorter excitation wavelengths.

The synthetic emerald *(Figure 9m)* shows the same fluorescence pattern as the two natural emeralds except that additional visible fluorescence does begin to develop as low as about 300 nm, and the fluorescence intensity is still increasing as the excitation wavelength falls to 270 nm. This suggests that this undisclosed variety of synthetic emerald may well fluoresce to some excitation band in the SWUV including 254 nm, in contrast to the natural emeralds.

African chrome kornerupine *(Figure 9d)* develops fluorescence to shorter excitation wavelengths from 350 nm down to at least 270 nm with trending indications that fluorescence may well also occur at the SWUV 254 nm and perhaps even at shorter wavelengths. Chrome diopside fluoresced strongly to excitation, but only emitted at greater than about 390 nm although its fluorescence was confined to the near-infrared with negligible visible fluorescence.

Of all of these instances discussed, only the synthetic emerald displayed significant fluorescence to wavelengths in the part of the SWUV band portrayed, i.e. 270 to 300 nm, and none except the chrome kornerupine showed any trends suggesting that fluorescence to 254 nm might be encountered. None of the various minerals, spinel, corundum, etc, usually considered to develop red diagnostic chrome fluorescence to SWUV, i.e. 254 nm, as well as to the usual LWUV band, actually displayed significant observable fluorescence to the available lower limit of 270 nm. This is consistent with the conclusion indicated above that previously noted fluorescence reactions to SWUV are false and really due to other wavelengths from the lamp emission that extend into the LWUV region.

(c) LEDs, discharge tubes and filters

LEDs have become useful illumination sources in gemmology, especially including some of the shorter-wavelength emitters which can stimulate possibly diagnostic fluorescence in various materials. LEDs producing visible deep blue from about 450 to 400 nm as well as some that generate LWUV at wavelengths near 395 and 385 nm have shown potential for gemmological identification, especially for stimulating fluorescence in susceptible diamonds and in chromiferous materials. The chromiferous gems particularly include ruby, red spinel, alexandrite and even some varieties of emerald. LEDs have significant advantages such as compactness, simplicity and portability, operating from low voltages while drawing only milliwatts of power and developing locally high light intensities appropriate for gemmology. One inexpensive recent development is the manufacture of a torch *(Figure 10)* containing several 385 nm LEDs with their output being filtered by a disc of Wood's glass *(Figure 11)* to remove most of the accompanying visible deep blue to violet emission. The deep blue to violet could mask visible fluorescence results (see the illustrations in *Figure 12* of visible emissions from a blue LED torch and the 385 nm filtered LED torch). Wood's glass is coloured with nickel, but unlike most bright-green nickel salts, Wood's glass is deep purple and essentially opaque to the visible spectrum although it is transparent to much of the LWUV range. The emissions from several different LED sources, including the 405 nm violet-LED torch (see *Figure 12* (left) and *Figure 13*), a single 405 nm violet LED 'key-ring' torch and a single isolated violet LED were scanned to determine the extents of their outputs (*Figures 14* and *15*).

Another source of LWUV is the fluorescent 'black light' which basically consists of an ordinary fluorescent tube with its glass tube consisting of Wood's glass filter to exclude the visible spectrum. The usual phosphors to convert the UV emissions of Hg into visible light have probably been replaced by ones which emit LWUV (see Gleason[4]). Also, information posted on the internet suggests that compositions such as

Figure 10: Multiple-LED battery-powered torch with a Wood's glass filter and nominal 385 nm emission.

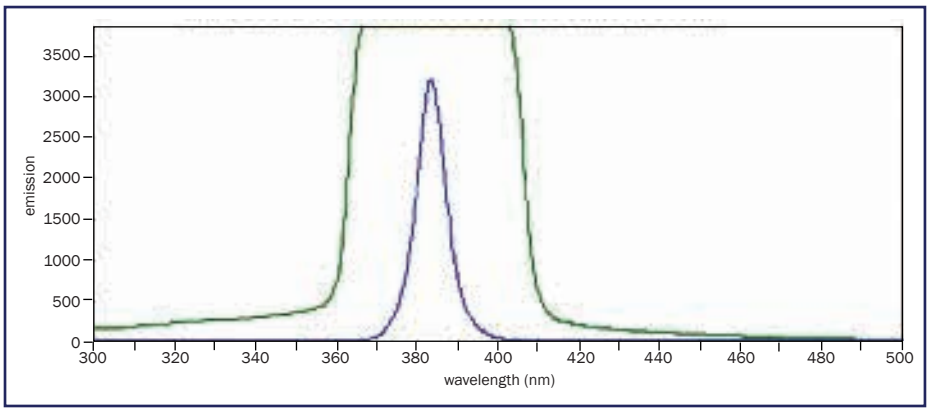

Figure 11: Emission spectrum from LED torch shown in Figure 10. At close range (green trace) the emission band is 50 nm wide but this surprisingly narrows with distance from the source (blue trace).

Figure 12: Multiple-LED torch of Figure 10 on the right next to a multiple-LED torch on the left which is unfiltered and emits light at and around 405 nm.

Figure 13: Another view of the torch on the left in Figure 12.

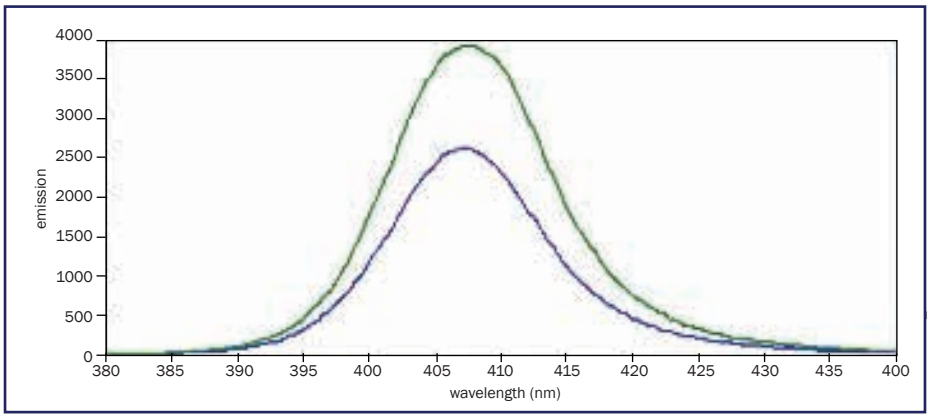

Figure 14: Emission spectrum of the multiple-LED torch of Figure 13, unfiltered and showing a spread from about 390 to 430 nm and centred about 407 nm. The green trace was measured closer to the source.

europium-doped strontium fluoroborate, europium-doped strontium borate or lead-doped barium silicate are often used as phosphors in these 'black-light-blue' or 'BLB' black-light tubes. This would explain the abundant wideband continuous emission accompanying the line spectra in the LWUV from Hg discharge tubes. Wide band emission is often a typical feature of some fluorescence. Black-lights have been used in various commercial applications such as advertising, counterfeit detection, skin-tanning and decoration, but their LWUV spectra and their applicability for gemmological purposes have not been widely discussed. The LWUV spectrum of the small (4 watt) BLB black-light fluorescent tube *(Figure 16)* was scanned *(Figure 18)* to compare it with those of the proprietary ultraviolet mercury-discharge lamps shown in *Figures 4* to *6* with which it is nearly identical.

Another lamp that has applications to gemmological testing is the 'germicidal' fluorescent tube with a SWUV-transparent envelope (*Figures 16* and *17*). The output is unfiltered and consists of mercury SWUV emission together with LWUV radiation and some visible emission. An earlier commercially unsuccessful attempt to employ this germicidal lamp for development of mineralogical and gemmological fluorescence employed a unique but rather fragile liquid filter. It consisted of a UV-transparent fused-silica ('vycor') tube filled with an iron-free and saturated aqueous solution of cobaltous sulphate. The spectrum of the LWUV BLB fluorescent tube is illustrated in *Figure 18* and the emission of the SWUV liquid-filtered prototype lamp is presented in *Figure 19*. The filtered germicidal tube develops a quite satisfactorily intense SWUV emission but is also accompanied by significant interfering LWUV and visible emissions.

To be an effective liquid filter for excluding visible light from ultraviolet

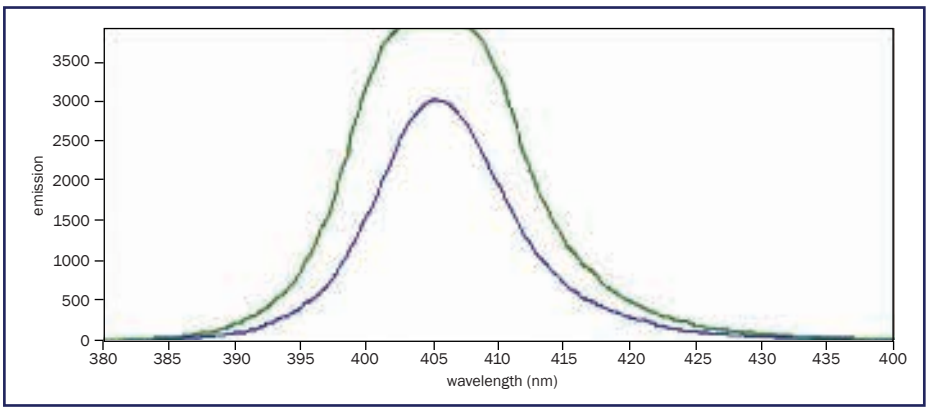

Figure 15: Emission spectrum of a single LED 'key ring' torch showing a range from 390 to 430 nm and centring about 405 nm. The green trace is closer to the source.

Figure 16: Small BLB 'black light' fluorescent LWUV tube (4 watt) above a 'germicidal' SWUV mercury based (4 watt) fluorescent tube fitted with a $CoSO_4$ solution filter and green sleeve.

Figure 17: Another view of the 'germicidal' SWUV tube shown in Figure 16.

emission, Strong (1938)[5] had suggested that the solution should be 3 cm thick and contain not only 100 grammes per litre (g/L) cobalt sulphate but also 140 g/L nickel sulphate which is then perhaps a composition perhaps rather analogous to Wood's glass. Backstrom (1933)[6] had also suggested that this solution transmits only 3.5% of the 334 nm Hg-emission, but 96% of the 313 emission, and that its transparency in the SWUV extends to 230 nm, thus apparently isolating SWUV from most UV of longer wavelengths, excepting 313 nm.

An experimental solution of this composition was prepared in distilled water using the usual commercial form of hydrated nickel sulphate, the hexahydrate, $NiSO_4.6H_2O$ of AR purity ('Analytical Reagent' grade) together with the usual commercial form of cobalt sulphate, the heptahydrate, $CoSO_4.7H_2O$, also of AR grade. A suitable source of full spectrum ultraviolet with a multiple line discharge spectrum (*Figure 20a*) was improvised using an unshielded high-pressure 100 watt mercury discharge tube *(Figure 21)*. It is notable that there was also an appreciable odour of ozone generation which usually occurs with emissions in the range of about 180 to 190 nm, very close to the transmission limit of silica.

In order to determine the UV transparency of each constituent in the experiment, the lamp emission itself was scanned in duplicate to ensure reproducibility, then the quartz cuvette filled only with water; and finally tthe $NiSO_4/CoSO_4$ solution in the quartz cuvette to record its UV filtering effect. (The first 'silica' cuvette used turned out to be glass which was opaque to UV below 300 nm!)

The spectra in *Figure 20* indicate that the solution removes much of the visible light between 440 and 550 nm from the emission but certainly does not remove any substantial proportion of the wavelengths between 300 and 370 nm.

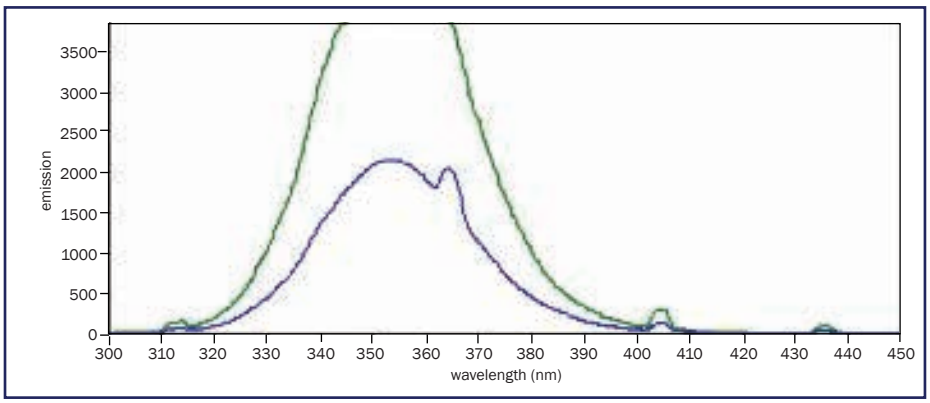

Figure 18: Emission spectrum of the BLB 'black light' fluorescent tube, showing a spread of emission wavelengths probably due to special phosphors.

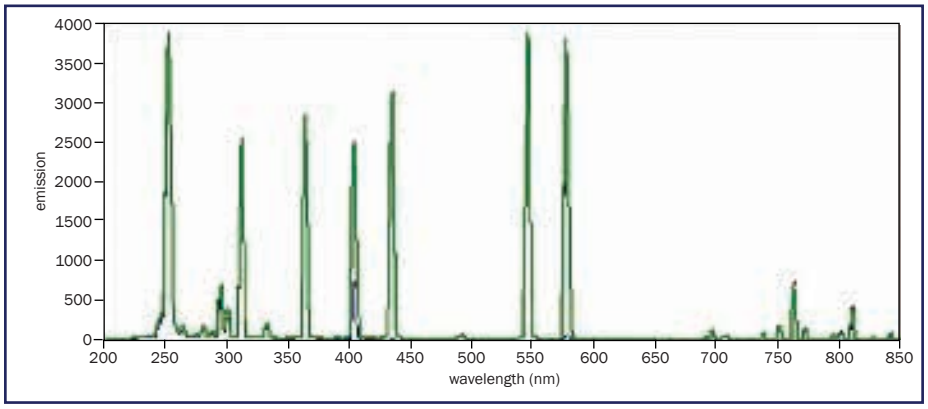

Figure 19: Emission spectrum of the 'germicidal' SWUV fluorescent tube showing multiple sharp Hg lines. The spectrum is very similar to that of the GAAJ SWUV tube shown in Figure 4.

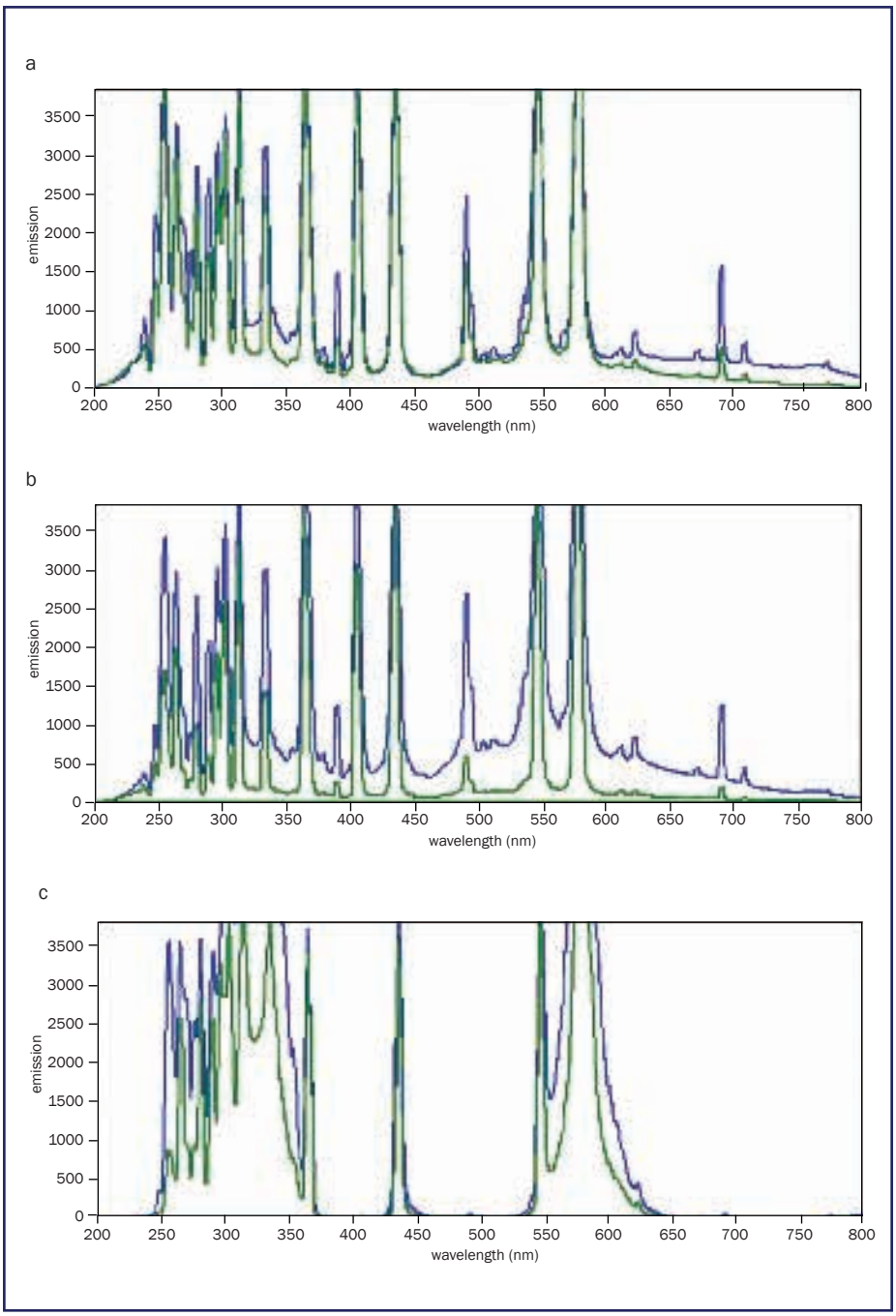

Figure 20: Emission spectra from the high-pressure mercury discharge lamp shown in Figure 21. (a) Unfiltered; (b) filtered by silica cuvette containing water; (c) filtered by silica cuvette containing $CoSO_4$ and $NiSO_4$ solution. Note that LWUV radiation between 300 and 370 nm is transmitted by this assembly.

The solution is not effective to isolate SWUV from unwanted LWUV.

It is also well known that filters of the Wood's glass type suffer from 'solarisation' which is a progressive loss of SWUV transparency and performance with continued exposure to SWUV which is chemically more active than longer wavelengths (see also Gleason[4]). Consequently, the SWUV performance of frequently used SWUV lamps may progressively deteriorate and any fluorescence effect from the accompanying LWUV can become even more accentuated. Gleason[4] (p.14) and Strong[5] (p.252) both suggest that solarisation is remediable by carefully heating the degraded glass filter in air just below 550°F (290°C) for several hours before slowly cooling to restore its original SWUV transparency.

A SWUV tube of Philips manufacture (TUV 4W 57416E/40) is shown in *Figure 22*. This is unshielded and unfiltered, and gives a bright blue central discharge and red glow around cold electrode terminals, emitting the spectra in *Figure 23(a)* and *(b)*. These reveal the usual Hg lines at 254 and 365 nm and various other Hg emission lines despite no liquid mercury droplets being visible before ignition.

The electrode red glow spectrum, shown in *Figure 23(b)*, suggests that the starter or carrier gas is probably neon with its characteristic red discharge consisting of numerous closely spaced sharp lines in the red. These emissions should clearly be excluded from any desired ultraviolet content to avoid confusion with any red fluorescence of the specimen. This SWUV source is obviously very similar to the filtered germicidal tube, and also

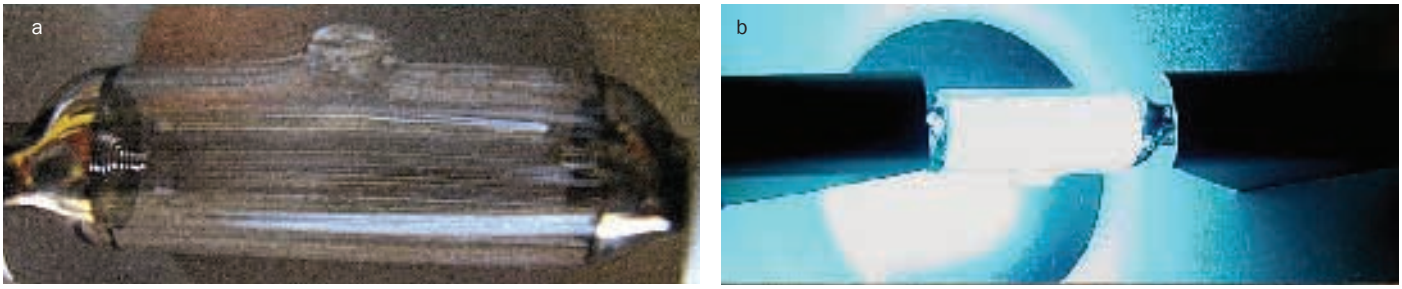

Figure 21: High pressure mercury-discharge unshielded bulb used as a broadband source of discontinuous line discharge of SWUV and LWUV (a) and the bulb upon ignition (b).

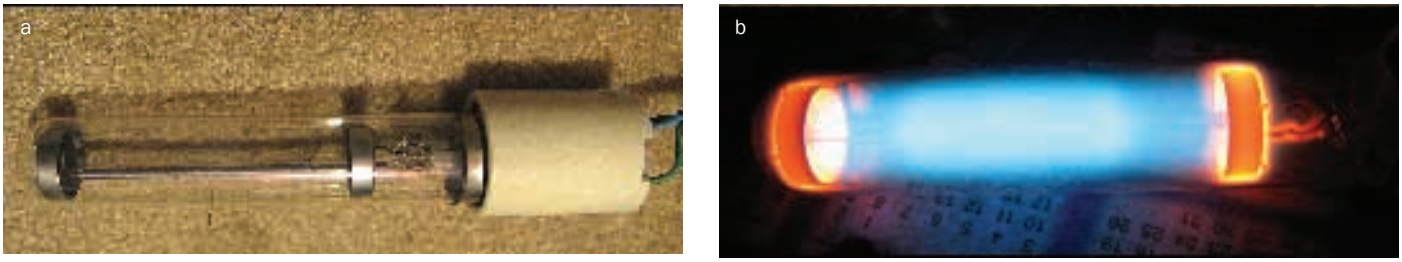

Figure 22: Unshielded SWUV discharge tube (a) and (b) in operation. The red glow at each end of the blue discharge indicates that the medium is a gas consisting of Ne and Hg.

to the GAAJ SWUV tube even with its Wood's glass filter. It appears to offer no advantage over the other proprietary SWUV sources regarding purity of any SWUV emission line(s).

Sunlight may contain variable amounts of UV depending upon latitude, atmospheric conditions, the season and even the time of day. Such UV, although not deliberately applicable to the induction of diagnostic fluorescence effects, can lead to uncontrolled fluorescence, such as bluish tints in some diamonds, red enhancement of some rubies or the well known green fluorescence in the bright yellow Verneuil synthetic spinel doped with manganese. An indication of the variability of the relative amount of UV that may occur in Melbourne early-afternoon summer daylight is illustrated in *Figure 24*. Solar spectra are recorded, from a clear blue sky a mildly overcast white sky, and through a glass window pane. Various Fraunhofer lines are visible, but the significant differences between the scans occur at wavelengths only below about 470 nm, and especially below 400 nm. Blue-sky LWUV was detected down to almost 300 nm although essentially all LWUV was removed by the glass window pane.

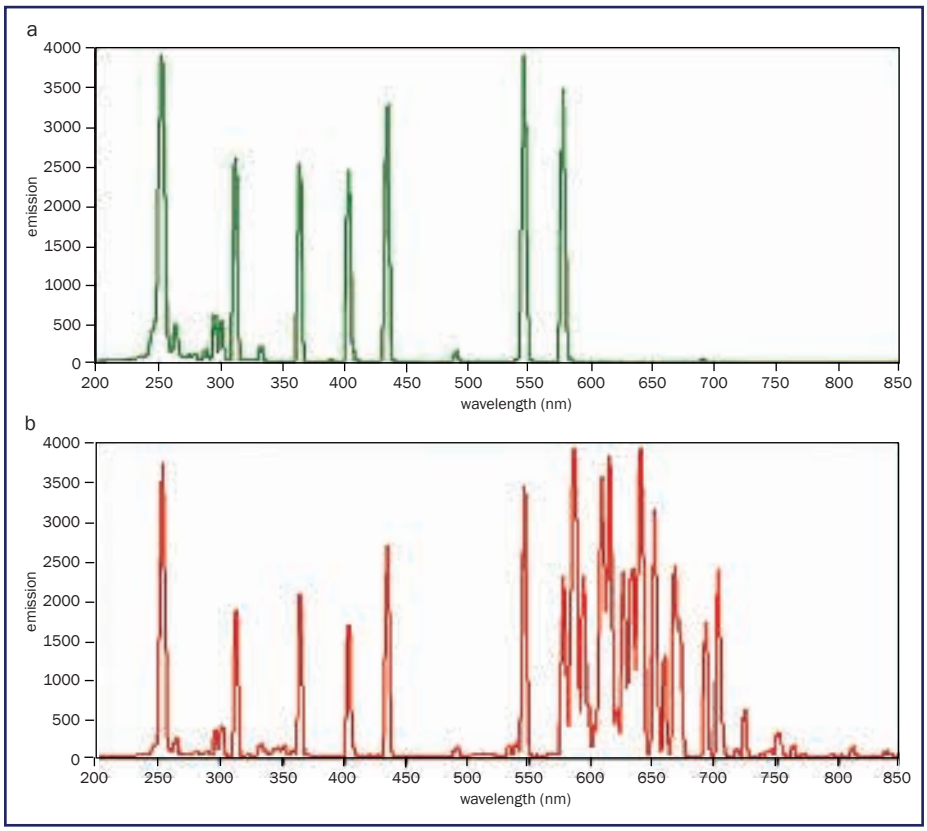

Figure 23: (a) Emission spectrum of discharge from the centre of the tube shown in Figure 22. (b) Emission spectrum of the blue and red components showing numerous neon lines.

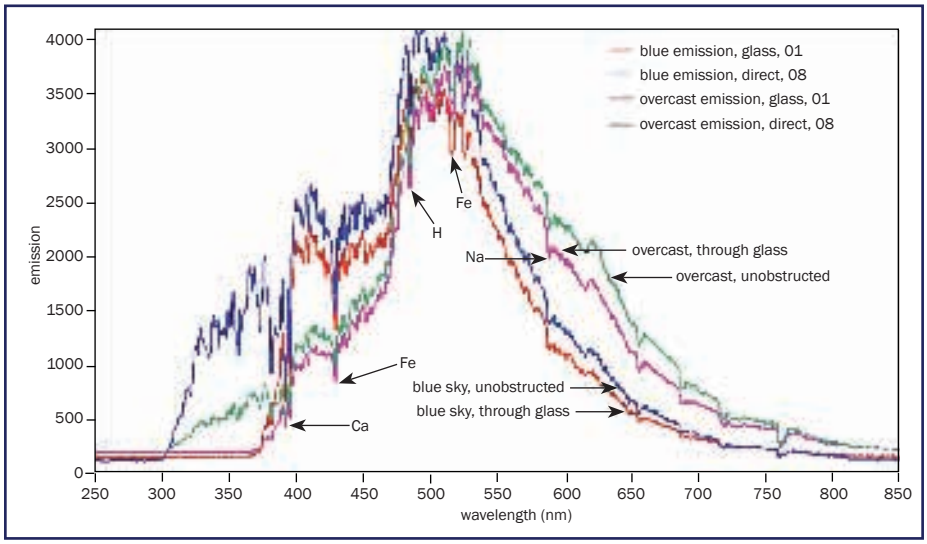

Figure 24: Spectral wavelength distribution of daylight showing differences due to cloud cover and filtering by window glass. Some Fraunhofer absorption lines are labelled.

4. Conclusions

Each of the three investigated proprietary UV lamps was based upon low pressure Hg-discharge and all showed appreciable contents of accompanying LWUV when operated in the SWUV mode. Any fluorescence stimulated in a gem in SWUV mode may thus be due to either SWUV or LWUV or both. This casts doubt on whether some fluorescence previously attributed to stimulation by

SWUV actually occurs, especially in many chromiferous gems. Unless the SWUV fluorescence response is observably different and distinguishable from any LWUV induced fluorescence generated by the accompanying contaminating LWUV emissions, fluorescence supposedly generated by 254 nm SWUV may actually be due to the LWUV contaminating 'bleed'. The contaminating LWUV 'bleed' in the SWUV mode may even be almost as intense as in the nominal LWUV-emission mode.

The excitation/fluorescence diagrams obtained by Hoover suggest that many LWUV-fluorescent gems, including ruby for instance, may show negligible fluorescence to shorter wavelengths — at least down to 270 nm which was the limit of that experiment. So, until exclusively monochromatic or specific narrow-band SWUV sources are available to the gemmological fraternity, it is suggested that any fluorescent responses in gems to discharge tubes in the SWUV mode and being used for identification purposes, are treated with suspicion.

In both LW and SW modes the emission spectra of the discharge tubes indicate the presence of many emissions at wavelengths in addition to those at 254 and 365 nm. In the SW region, these include emissions at 265, 288 and 296 nm, and in the (nominal) LW region, at 303 and 313 nm. All or any could evoke fluorescence that might otherwise be attributed to the 254 nm emission which in turn could result in an erroneous interpretation. Also in the LW mode, the nature of the '365 nm emission' is in reality broadband and only centred on 365 nm, and fluorescence could be stimulated by any or all wavelengths in this range. Again, erroneous interpretation could result if stimulation by exclusively 365 nm emission was assumed. The selective fluorescence response to particular LW emissions is indicated in Hoover and Theisen's diagrams.

It is suggested that the output from an ultraviolet lamp intended for gemmological identification purposes, both SWUV and LWUV ranges, should be scanned spectrometrically. Any fluorescence responses observed with its use can then be interpreted with the appreciation and knowledge of its actual radiation, rather than simply assuming that its emissions consist solely of the 254 nm SWUV Hg-line discharge and the 365 nm LWUV Hg-line discharges. Lamps apparently intended primarily to develop aesthetically attractive fluorescent-display responses from minerals may not be directly suitable for diagnosing fluorescence in gems unless their spectral emission content is known and the response is appropriately interpreted.

LEDs are currently providing single-band sources of LWUV but are not readily available yet with emissions in gemmologically useful SWUV ranges. However, the LWUV bands just below the visible range and down to the Hg-discharge line at 365 nm are eminently suited to develop fluorescence economically and conveniently for certain gemmological identifications. LEDs generally do not develop single, almost monochromatic emissions like low pressure gas discharges, but emit a single broadened band, typically spanning as much as about 10 to 40 nm. However, these compact and convenient radiation sources are still very useful to confirm LWUV fluorescence of commonly responsive gem materials.

The proposal by Strong[5] that a solution of cobalt and nickel sulphates would selectively filter out most of the interfering LWUV, especially the 365 nm emission, from the required SWUV emission, especially the 254 nm line, was not substantiated. The indicated concentrations of these salts removed some undesirable visible wavelengths, but unfortunately did little to diminish the level of the interfering LWUV emissions contaminating the SWUV range. There is apparently still no reliable absorption filter to be able to isolate the desired SWUV radiation from interfering LWUV.

Acknowledgements

The initial impetus for this investigation was generated by Bear Williams (Stonegroup Labs) and Dr Don Hoover (retired from USGS), of Missouri, USA. The subsequent assistance, discussions and criticisms from Dr Hoover and from Bear Williams and the permission from Dr Hoover to reproduce the excitation-fluorescence spectrophotometric diagrams of chromiferous materials compiled by Hoover and Theisen at the USGS, are very greatly appreciated.

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Gem-A Photographic Competition

The 2012 Competition is now open!

All Gem-A members are invited to participate. Once again there are four categories in which an image may be submitted:

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Digital photograph (including photomicrography) with minimal post-production work (may include basic cropping, contrast and minor hue/saturation adjustments).

2 **Treated**
Digital photograph (including photomicrography) with significant post-production work (such as background manipulation, HDR, and contrast masking).

3 **Synthetic**
Computer-rendered 3D models of gemstones, crystals, crystal structures, images from microtomography, etc.

4 **Melange**
This category includes any gem-related image that doesn't fit in the above and may include such things as photos of a spectrum, a scanning electron microscope image, mining, cutting, etc.

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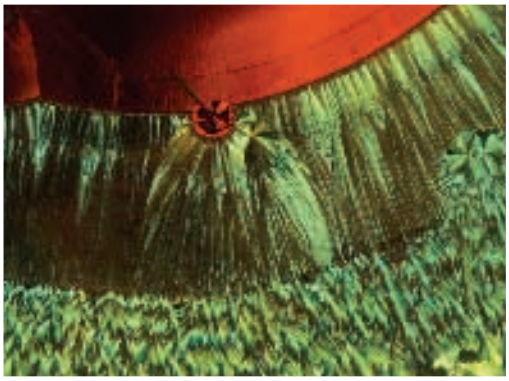

Overall winner and winner of Natural category:
Fibrous hematite and goethite aggregates in quartz from Minas Gerais. © Michael Hügi.

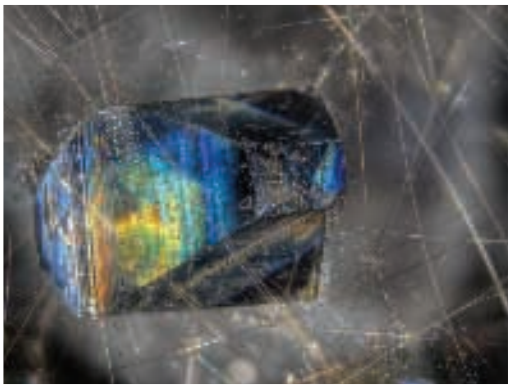

Winner of Treated category:
Blue anatase crystal and rutile fibres in quartz from Minas Gerais. © Michael Hügi.

Winner of Melange category:
Cut cultured pearls in round slices. © Keiko Kon and Gem Science Academy of Gemology, Tokyo.

Abstracts

Diamonds

G.I.A.'s symmetry grading boundaries for round brilliant cut diamonds.
R.H. Geurts, I.M. Reinitz, T. Blodgett and A.M. Gilbertson. *Gems & Gemology,* **47**(4), 2011, 286–95.

Basic measuring concepts are explained for symmetry parameters used in grading round brilliants. The ten symmetry parameters def ned are: out-of-round; table off-centre; culet off-centre; table/culet alignment; crown height variation; crown angle variation; pavilion depth variation; pavilion angle variation; girdle thickness variation; and table size variation. Several thousand diamonds assessed over ten years provided the basis for the recommended limits of the symmetry grades Excellent, Very Good and Good. Assessments of combinations of these parameters are discussed in the context of a constant need for visual monitoring. R.R.H.

GIA Symposium 2011.
Gems & Gemology, **47**(2), 2011, 105–36.

Topics covered in the presentations include: irradiated diamonds from Zimbabwe; radio-coloration of diamond; treated diamond identif cation; colour treatment of diamond; the unknown sources of some alluvial diamonds; and the relationship of diamond sources to cratons, particularly in Canada.

There were poster sessions concerning shapes of fancy-cut diamonds; hydrogen-rich diamonds from Zimbabwe; coloured diamonds from Argyle, W. Australia; optical properties, structural defects, spectra and photoluminescence studies of diamonds; colour zoning; colour origin determination; black diamonds from Brazil; Yakutian diamonds; rough diamond descriptions for use in exploration; and ultra-deep diamond cleaning technology. R.R.H.

Gem News International.
B.M. Laurs. *Gems & Gemology,* **47**(3), 2011, 234–53.

Two type Ib diamonds showing a colour change from greenish brown under a daylight equivalent light to orangy brown under incandescent light are described. Their grades include the effects of their fluorescence properties and there is some detailed discussion of the causes. R.R.H.

Lab notes.
T.M. Moses and S.F. McClure (Eds). *Gems & Gemology,* **46**(4), 2010, 298–307.

A type IIa HPHT-treated diamond with a hexagonal graphite inclusion typical of the treatment is illustrated. A 'tie' growth pattern in a coloured diamond revealed by examination in a DTC DiamondView indicates a natural stone and the similar but different pattern of a synthetic diamond is shown for comparison. Very thin coatings on fancy pink diamonds were detected from anomalous peaks in the visible spectrum near 505 and 540 nm. R.R.H.

Lab notes.
T.M. Moses and S.F. McClure (Eds). *Gems & Gemology,* **47**(1), 2011, 49–55.

Stones described include: a 28.65 ct orange diamond with IR and UV-Vis spectra which indicated treatment at HPHT; a 38.59 ct type IIa diamond graded F colour is the largest seen so far in the GIA laboratory that has been HPHT-treated; some pure type IaB diamonds display a blue thermoluminescence when they warm up after exposure to a laser at liquid nitrogen temperatures. R.R.H.

Lab notes.
T.M. Moses and S.F. McClure (Eds). *Gems & Gemology,* **47**(3), 2011, 222–32.

A 0.85 ct diamond was found to contain dark brown bands and strong plastic deformation, judged to be of natural colour and graded Fancy black. A 1.29 ct pear-shaped diamond was found to have had its blackness enhanced by coating. A 1.05 ct pink diamond had a coating that had not been detected from its visible-range absorption spectrum but which was apparent under the microscope. Two type IIa diamonds graded D and E colours had unusually pronounced 'tatami' strain patterns. Four diamonds in the J–M colour range had been subjected to HPHT treatment and their colour grades changed to E–F. HPHT treatment had also been used to remove a brown tint and improve the pink colour of a 21.73 ct marquise brilliant. A diamond with brown stains on a cleavage and associated green fluorescence indicated a complex history. R.R.H.

Lab notes.
T.M. Moses and S.F. McClure (Eds). *Gems & Gemology,* **47**(4), 2011, 308–15.

Unusual 0.81 ct diamond graded Fancy Vivid Purple, with green fluorescence. Grey-to-blue-to-violet 0.85 ct heart-shaped diamond with unusually dark tone, graded Fancy black, showed strong absorption features in mid IR (near 3107 cm^{-1}) attributed to H. HPHT treated diamond with fluorescence pattern of a HPHT-grown synthetic Type IIb diamond with D colour and IF clarity, greenish blue fluorescence to both long- and short-wave ultraviolet and then bright blue phosphorescence for several minutes. R.R.H.

Rio Tinto's Argyle Pink Diamonds Tender Update.
E. Sanders and C. Sanders. *Australian Gemmologist,* **24**(4), 2010, 80–4.

An update to the 1997 summary published in the *Australian Gemmologist* which chronicles the annual Argyle Pink Diamonds Tender since its inception

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in 1985. New information includes: an overview of the unique Argyle Pink Diamonds' colour grading system; the girdle laser inscription instituted in late 2004 for diamonds over 0.20 ct and later in 2009, stones over 0.15 ct; notable diamonds since 2000, as well as a chart showing each year's offerings since 1985. E.A.S.

Gems and Minerals

Research on gem feldspar from the Shigatse region of Tibet.
A. Abduriyim and 11 other authors. *Gems & Gemology,* **47**(2), 2011, 167–80.

Andesine was collected from Zha Lin and Yu Lin Gu about 55 km SE of Shigatse, Tibet. The samples are up to 2 cm across and most are red, some having blue-green or patchy red areas. They contain twin lamellae, turbid clouds, channels and some tiny copper grains or platelets. Glass residues are present on the surfaces and in cavities in some of the samples, but spectral and chemical analysis failed to establish the origin of the residue. Microprobe and LA-ICP-MS analyses were made of the samples and the latter indicated distinctly high amounts of silver in the rims of those from Yu Lin Gu. Powder X-ray diffraction results indicate that the andesines from Zha Lin and Yu Lin Gu had not been treated at high temperature; this conclusion is supported by argon isotope studies. It was noted that no andesines were collected that had adhering rock (volcanic) matrix, and in the Yu Lin Gu area, andesines were not found at depths of more than a few cm. R.R.H.

Ivory carving in Germany.
M. Campbell Pedersen. *Gems & Jewellery,* **19**(4), 2010, 20–2.

An outline of a unique German museum specializing in ivory and the history of carving. Based in Erbach, the museum's exhibits span over 300 years of historic ivory use, and the accompanying photographs within the article show some of these carved items (including the iconic Erbach Ivory Rose). The museum is a working example of the carving craft, in all its forms. A.S.F.

Brownish red zircon from Muling, China.
T. Chen, H. Ai, M. Yang, S. Zheng and Y. Liu. *Gems & Gemology,* **47**(1), 2011, 36–41.

Zircon occurs in alluvium derived from alkali basalt and is associated with other minerals of gem quality such as sapphire, spinel and garnet. RIs of >1.81 and SGs between 4.57–4.69 were determined, and apatite, metamict zircon, magnetite and dark ovoid glass inclusions were recorded. EPMA and LA-ICP-MS analyses indicate the presence of REE with up to 2440 ppm Th and 871 ppm U, which results are consistent with absorption peaks in the UV-Vis-NIR spectra. Raman spectra are recorded and samples subjected to heat treatment changed colours to lighter hues. R.R.H.

And now composite chalcedony.
G. Choudhary. *Gems & Jewellery,* **19**(4), 2010, 28–30.

As part of a series of articles published in various gemmological texts, Choudhary discusses a new composite stone consisting of chalcedony held in resins. A detailed table is provided with identifying features and results that cover observational and advanced laboratory techniques. Although readily identif ed as a composite, the analytical methods to identify the component parts give an insight into production techniques. A.S.F.

Greenish yellow zoisite.
G. Choudhary. *Australian Gemmologist,* **24**(4), 2010, 90–1.

An 8.33 ct faceted greenish yellow gemstone, at f rst glance resembling tourmaline, quickly reveals it is otherwise when striking strong trichroism is observed: yellow, blue and purplish pink. Standard gemmological testing indicates the specimen is zoisite; conf rmed by FTIR spectral patterns and qualitative EDXRF analysis (major elements: Al, Si, Ca and Sr, with traces of V and Fe). E.A.S.

Serpentine crystal with purple-red transmission.
G. Choudhary. *Australian Gemmologist,* **24**(7), 2011, 164–6.

Having been sold as alexandrite, a bluish-green crystal showing purplish-red coloration in transmitted light is found to be a member of the serpentine family. The tabular monoclinic crystal was revealed with EDXRF analysis to contain Mg, Si, Cr, Fe and Ni. These results and those of FTIR spectroscopy were both consistent with those of serpentine. The cause of the purplish red transmission remains unknown, but this and several other specimens mined in Andhra, Pradesh, Southern India, have recently been seen by the Gem Testing Laboratory of Jaipur — all represented as alexandrite in the marketplace. E.A.S.

A chatoyant malachite.
G. Choudhary. *Australian Gemmologist,* **24**(2), 2010, 44–5.

A 9.57 ct green cat's-eye cabochon was conf rmed to be malachite by standard gemmological testing along with FTIR spectroscopy and EDXRF. The eye was exhibited as a broad band, reminiscent of lower-grade cat's-eye quartz. This appears to be the f rst published report of chatoyant malachite, though an Internet search did turn up offerings of such material, predominantly as rough or tumbled specimens or as beads. E.A.S.

Mariupolite from the Oktyabrsky Massif (SE Ukraine) — a less well known rock in the gemstone trade.
M. Dumańska-Słowik, P. Baranov, W. Heflik, L. Natkaniec-Nowak, S. Shevchenko and L.I. Tsotsko. *Gemmologie. Z. Dt. Gemmol. Ges.,* **60**(1/2), 2011, 37–48. 16 photographs, 1 map, 1 geology map, bibl. [English with a German abstract.]

Mariupolite is a nepheline syenite rock from the south eastern Ukraine. A diversity of colours and texture is caused by variable mineral composition, the main constituents being albite, nepheline and aegirine. Those materials containing sodalite are suitable for jewellery components, clocks, vases, ashtrays and for the production of facing stones both for indoor and outdoor use. E.S.

Topaz crystals from various geological settings.
M. Dumańska-Słowik, J. Fijał and L. Natkaniec-Nowak. *Gemmologie. Z. Dt. Gemmol. Ges.,* **60**(3/4), 2011, 87–104. 16 photographs,7 graphs, 6 tables, bibl. [English with German abstract.]

This paper deals with topaz crystals

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from various geological settings, such as rhyolites, pegmatites, greisens and hydrothermal veins. Topaz crystals have various mineral and fluid inclusions, but have a fairly constant composition although they have different mineral associations. The major difference found in the samples is the F/OH ratio. Topaz from Ouro Preto, Brazil, has the highest content of the hydroxyl groups. The lowest amount of the hydroxyl groups and the highest fluorine content were found in topaz from the Thomas range in the U.S.A. Crystals from Volodarsk-Volynsky exhibit the most ordered lattice, while those from Ouro Preto have the most defects in their structure. E.S.

GIA Symposium 2011.
Gems & Gemology, **47**(2), 2011, 107–53.

Topics covered in the presentations include: the geological conditions for formation of ruby, emerald and alexandrite; pegmatites; opals from Ethiopia; origin determination; Australian opal nomenclature; lavender jadeite from Myanmar, Guatemala and Japan; natural colour tanzanite; durability of treated ruby and sapphire; archaeogemmology of peridot; natural and treated nephrite in China; the use of photoluminescence spectra in determining growth media and colour origins in cultured pearls; review of the range of testing methods used to distinguish natural and cultured pearls and their treatments.

There were poster sessions concerning blue and pink sapphires from Muling, N.E. China; a review of gems in southern Brazil; ruby from Liberia; petrogenesis of the Stewart pegmatite, Pala, CA; ruby overgrowths on painite from Mogok, Myanmar; gemstones from Mexico; tourmaline from the Pederneira pegmatite, Minas Gerais; blue cristobalite (described as opal) from Rio Grande do Sul; world production f gures for coloured gems compiled by the U.S. Geological Survey; tourmalines from Madagascar; use of discriminant analysis for identifying coloured stone sources and for distinguishing HPHT-treated from untreated diamonds; review of the range of quartz varieties and some notable gems tested in the Jaipur laboratory; exotically coloured Chinese freshwater cultured pearls; non-nacreous pearls from the giant clam; roundness and lustre variations in cultured pearls and their relations to grafting methods in *Pinctada margaritifera*; experiments to test ancient treatment techniques on gems; Oregon sunstones compared from two deposits; changes in colour of various sapphires by electron beam irradiation; experiments on the effects on sapphires of heating them with Be; the spectra of some gem tourmalines; and some new artif cially asteriated gemstones. R.R.H.

Black Beauty.
K. Gregory. *Gems & Jewellery,* **19**(4), 2010, 34–6.

Kerry Gregory's experiences of testing a faceted checkerboard style black opaque stone set into a pendant. Although not conclusively identif ed, the processes and reasoning involved show how cut and setting can affect and limit the choice of tests available. A full table of possible gem materials is provided, along with explanations of how certain materials were discounted. A.S.F.

Jaded.
K. Gregory, *Gems & Jewellery,* **20**(1), 2011, 15–17.

Reviewing a talk at the South-West Branch by Edward Johnson on Jadeite, this article looks at the possible alternatives to jadeite (tabulated), and highlights some precautionary tales. A.S.F.

Three-dimensional X-ray radiography.
T. Hainschwang. *Gems & Jewellery,* **20**(1), 2011, 11–14.

Micro X-ray tomography is a new technique that allows pearls and other gem materials to be represented in three dimensions in suff ciently high quality to allow detailed analysis. Whilst not suitable or cost effective for everyday use, a more viable alternative system has been designed that allows 3D f lms to be produced for analysis of inclusions/f llers, and in particular allow the nature of pearls to be determined. With the advent of cultured pearls using smaller pearls as bead nuclei, this technology will become more important, and is currently in use on all pearls sent to the GEMLAB (Liechtenstein) laboratory. A.S.F.

Explaining the flame structure of non-nacreous pearls.
H. Hänni. *Australian Gemmologist,* **24**(4), 2010, 85–8.

Through conventional microscopy and scanning electron microscopy (SEM), the flame structure of porcellaneous pearls is revealed and the appearance of the optical phenomenon is explained. Since the same structures are present in the shells of the molluscs from which the pearls originate (including *Melo, Tridacna, Strombus gigas*), such shells may be sacrif ced for analytical work. At magnif cation of 500x, *Tridacna* shell reveals a crisscross structure of f brous aragonite lamellae which alternately reflect and absorb light, producing spectral colours due to interference when found at a thickness of 500 nm. Other species exhibit different patterns of the same dull and bright effect, depending on how the f brous aragonite bundles of ultra-f ne f bres, laths or lamellae are arranged. E.A.S.

Neues aus China: Ming Perlen.
H. Hänni. *Gemmologie. Z. Dt. Gemmol. Ges.,* **60**(3/4), 2011, 105–10. 7 photographs, bibl. [German with English abstract.]

These cultured pearls are similar to the Japanese cultured pearls 'Kasumiga-ura'. They are freshwater, beaded and gonad grown. These new Ming pearls are round, often larger than 15 mm, and are white or pastel-coloured due to their producing shell which is a hybrid of *Hyriopsis schlegeli* and *Hyriopsis cumingii*. E.S.

Das Farbenspektrum der Quarze.
U. Henn and R.Schultz-Güttler. *Gemmologie. Z. Dt. Gemmol. Ges.,* **60**(3/4), 2011, 63–86. 17 photographs, 1 table, 8 graphs, 2 flow-sheets, bibl. [German with English abstract.]

Macro-crystalline quartz can be classif ed into several groups. Iron-bearing quartz is represented by amethyst which can be thermally modif ed to yellow or green. Prasiolite changes from blue to violet by irradiation and thermal treatment. Light amethyst can be thermally improved to lilac.

Aluminium-bearing quartz appears yellow (citrine) or brown (smoky quartz) or black (morion) which can be changed into greenish-yellow lemon quartz by heat treatment. Water-containing quartz can be modif ed to green by irradiation. Rose quartz is formed by adding dumortierite

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or produced by substitution of silicon by phosphorus.

Both iron-bearing and aluminium-bearing quartz can appear as multi-coloured stones. This article shows colour and colour modification as well as the absorption spectra and other testing methods such as pleochroism, twinning and IR-spectra. E.S.

Spinels from Ywathit, Kayah State, Myanmar.

U.T. Hlaing, W. Atichat, and C. Sutthirat. *Australian Gemmologist,* **24**(3), 2010, 61–3.

A description of the spinels found in alluvial deposits in the area of Bawlake Township, southeast of Ywathit in the eastern part of Myanmar. These apparently originated from the Pawn Chaung Series mountain range, north of Ywathit between the Salween River and Pawn Chaung. These mountains consist of schist and a fine-grained sugary white-grey marble. Chemical analysis of the spinels was conducted using Electron Probe Micro-Analyser (EPMA) and results are presented in chart form. A photograph illustrates the gems alongside a red and black *Abrus precatorius* seed. Also known as wild liquorice (English) and Ywe gale or Ywe nge (Burmese), these seeds are of a uniform 0.5 cm size and 0.5 ct weight and have been used locally as a unit of measurement for precious stones and metals. E.A.S.

A microstructural study of pietersite from Namibia and China.

K. Hu and P.J. Heaney. *Gems & Gemology,* **47**(4), 2011, 280–6.

Pietersite specimens from the two main sources, Kuraman, Namibia, and Xichuan, Henan Province, China, are mixed rocks largely blue-grey, golden and white (Namibian) or red brown and white (Chinese). They consist of major quartz or chalcedony, less calcite, and fibrous crocidolite (magnesioriebeckite) or chlorite embedded in (but not replaced by) the quartz; the latter structure gives rise to the rather contorted chatoyancy of the specimens. Gemmological properties of stones from the two localities are similar although the Namibian pietersite tends to be more fluorescent and have a higher SG, and in thin section, crocidolite in the Chinese samples is seen to be intensely coated with hematite. R.R.H.

Aquamarine from the Thuong Xuan District, Thanh Hoa Province, Vietnam.

L.T-T. Huong, W. Hofmeister, T. Häger, N.N. Khoi, N.T. Nhung, W. Atichat and V. Pisutha-Arnond. *Gems & Gemology,* **47**(1), 2011, 42–8.

Aquamarines from eluvial deposits derived from pegmatites intruding granites of Paleogene age are light to medium blue, elongate crystals up to 4.5 cm long. They contain biotite and hematite crystal inclusions and ubiquitous two-phase inclusions in channels. Their Fe and Cs contents are high compared with other aquamarines, and Raman and IR spectra indicate the presence of type I H_2O and CO_2 in the channels. R.R.H.

Synthetischer Smaragd – Topas – Dublette.

J. Hyrsl and U. Henn.*Gemmologie. Z. Dt. Gemmol. Ges.,* **60**(3/4), 2011, 111–12. 3 photographs. [German with English abstract.]

This interesting doublet comes from India. The upper part is a synthetic emerald, the lower a colourless topaz. E.S.

Scottish agates.

B. Jackson. *Gems & Jewellery,* **20**(1), 2011, 3–9.

An in-depth look at agates, which have been used as artefacts for over 9000 years. Through the use of photographs showing different formations of banding and other structural features, the controversy over the genesis of agates and the difficulties in forming a single explanation as to the structural mechanisms is explored. A.S.F.

UV-Vis-NIR reflectance spectroscopy of natural-color saltwater cultured pearls from *Pinctada margaritifera*.

S. Karampelas, E. Fritsch, J.-P. Gauthier and T. Hainschwang. *Gems & Gemology,* **47**(1), 2011, 31–5.

UV-Vis-NIR spectra of a range of colours of these pearls from shells grown in the Pacific Ocean revealed nine visible-range absorption features. One of these at 405 nm is attributed to uroporphyrin, but the attributions of the remainder are the subject of further work. R.R.H.

Infrared spectroscopy of natural vs. synthetic amethyst: an update.

S. Karampelas, E. Fritsch, T. Zorba and K.M. Paraskevopoulos. *Gems & Gemology,* **47**(3), 2011, 196–201.

When traditional gemmological techniques are inadequate to enable distinction between natural and synthetic amethyst, detection and study of the 3595 cm^{-1} absorption band at high resolution in the IR spectrum could lead to a reliable decision. But this criterion should be used along with other properties discussed; it is not valid for amethysts with large near-colourless zones. R.R.H.

A study of the gems in a ciborium from Einsiedeln Abbey.

S. Karampelas, M. Wörle, K. Hunger, H. Lanz, .D. Bersani and S. Gübelin. *Gems & Gemology,* **46**(4), 2010, 292–6.

This late sixteenth century treasure from a Benedictine abbey contains ten pinkish red stones (almandine), four orange (grossular) and three pale blue (sapphire) stones, identified by means of microscopy, EDXRF and Raman spectroscopy. Respectively they had been labelled ruby, hyacinth and sapphire by Fr. Tonassini around 1798. Their features and styles of cut are consistent with an origin in Sri Lanka. R.R.H.

Ruby and sapphire from the Tan Huong – Truc Lau area, Yen Bai Province, northern Vietnam.

N.N. Khoi, C. Sutthirat, D.A. Tuan, N.V. Nam, N.T.M. Thuyet and N.T. Nhung. *Gems & Gemology,* **47**(3), 2011, 182–95.

Rubies and pink sapphires are recovered from gneisses, amphibolites and marbles in the Red River Shear Zone, NW of Hanoi, and from eluvial and alluvial deposits nearby. Associated gem minerals included spinel, garnet and trapiche-like sapphire. Most rubies are cabochon quality but there are many good quality stones and they tend to come from the secondary deposits. Stones from this area are compared with those from older mines about 15 km away in the Khoan Thong-An Phu area and their inclusions, identified using microprobe analyses and Raman spectra, are abundant, including

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rutile, ilmenite, zircon, apatite, spinel, diaspore and calcite. The deposits yield many star stones and corundum crystals with spinel overgrowths are not uncommon. R.R.H.

A historic turquoise jewelry set containing fossilized dentine (odontolite) and glass.

M.S. Krzemnicki, F. Herzog and W. Zhou. *Gems & Gemology,* **47**(4), 2011, 296–301.

Six mid-nineteenth century brooches set with diamonds and pale blue cabochons were examined using microscopy, and Raman and EDXRF spectroscopy. Most of the pale blue stones proved to be odontolite (fluorapatite), but some were turquoise and some artif cial glass. Features seen on some of the odontolite surfaces include micropores, weak banding and curved bands showing intersections (cf. elephant ivory). R.R.H.

Gem News International.

B.M. Laurs (ed.). *Gems & Gemology,* **46**(4), 2010, 309–31.

Stones described include: clear yellow amber with pyrite and other mineral inclusions; Tibetan andesine at its alleged source; aquamarine from Vietnam and Madagascar; heliodor probably from Cambodia; diopside from Pakistan; the 'Carolina Emperor', an emerald from Hiddenite, N. Carolina, and the largest cut emerald from N. America; emerald in matrix from Bahia, Brazil; f fth century AD jewellery containing red garnets from Romania; natural pearls in *Pinctada radiata* shells in the waters off Bahrain; updates on sapphire mining in Pakistan, Afghanistan and Madagascar, and the rediscovery of sapphires in the Auvergne, Massif Centrale, France; a 16.17 ct green stone was identif ed as spodumene and while being examined under a f bre optic light became bright orange, displaying thermoluminescence, returning to green on cooling; four faceted oval greenish blue stones resembled Paraíba tourmaline but their compositions fall in the liddicoatite f eld, not the elbaite f eld of Paraíba stones. R.R.H.

Gem News International.

B.M. Laurs (ed.). *Gems & Gemology,* **47**(1), 2011, 56–73.

Stones mentioned include Vietnamese spinels with a range of colours; a new f nd of green grossular in Tanzania; blue quartz cabochons coloured by trolleite and lazulite inclusions from Minas Gerais; quartz with spectral interference colours caused by twinning along internal minor rhombohedral directions; yellow scapolite from Tamil Nadu, India; scapolite also from Afghanistan, colourless and blue and fluorescing yellow; yellow-brown pargasite from Tanzania; spectacular blue and green tourmalines from Mt. Marie, Paris, Maine; and the rare gems cavansite and zektzerite. R.R.H.

Gem News International.

B.M. Laurs (ed.). *Gems & Gemology,* **47**(3), 2011, 234–53.

A recent import from Afghanistan, gem-quality afghanite (a member of the cancrinite group of feldspathoid minerals, its identity conf rmed by microprobe analysis) is pale to medium blue resembling aquamarine and is probably from the Sar-e-Sang region of Badakshan. The regional context of aquamarine deposits on the west side of Thanh Hoa Province in northern Vietnam is described. Iridescent ammonites from southern Madagascar have been known for more than ten years and are now being fashioned into cabochons and some are sold as 'Madammolite'. Fine blue chalcedony and an intense red-brown sard or carnelian are described from Peru, and there is an update on emerald mining in Afghanistan. A new deposit of colour-change garnets in southern Tanzania has been found; their compositions are comparable with those from Bekily, Madagascar. Iridescent amphibole from Mauritania closely resembles the variety 'Nuummite' from Greenland although the Mauritanian colours are blue- to yellow-green rather than golden. Other stones mentioned include blue opal from Sinaloa, Mexico (to be marketed as 'Lightning Blue Opal'); pallasite pendants fashioned from the Esquel meteorite, a rare type of stony iron meteorite; cat's-eye quartz in which the colour and chatoyant effect are provided by pink tourmaline needles; green cat's-eye spodumene from Araçuai, Minas Gerais; and variscite from Peru. Chinese freshwater cultured pearls are described with off-round (baroque) beads which were produced from an alleged hybrid of *Hyriopsis cumingii* and *Hyriopsis schlegelii* whose shell has an unusual shape and intense iridescence. An oval black cabochon sold as a star sapphire was eventually considered to be a corundum-glass-corundum triplet. R.R.H.

Gem News International.

B.M. Laurs (ed.). *Gems & Gemology,* **47**(4), 2011, 316–34.

Stones and topics covered include: small gem-quality golden yellow chondrodites from Tanzania; blue dolomite with three-phase inclusions from the Muzo emerald mine in Colombia; orange and purple zoned fluorite cut and polished as small slabs for silver pendants from Namibia; two sections on opal: common opal from Laverton, W. Australia — red (f re opal), yellow and pale blue, all near-transparent and faceted; a hydrophane opal cabochon, probably from Ethiopia, with one end a white body colour with predominant blue and green iridescent colours, and the other end a brown body colour with much redder iridescence; three sections on quartz: a red cat's-eye quartz cabochon whose minute slender inclusions were identif ed as cinnabar; a marquise-shaped cabochon of colourless quartz with included elongate prisms of emerald; a skull carved in quartz by Harold van Pelt which has a network of silver grey submetallic inclusions identif ed as izoklakeite, a lead-antimony sulphide with some copper; colour-change titanite (sphene) from the Pakistan-Afghanistan border area containing vanadium but no chromium; blue spinel from Vietnam; pinkish orange to red spinel from Mogok, Myanmar, which shows a trapiche structure, best viewed in transmitted light. Imitations described include: black 'pearls' sculpted from calcite and showing a cat's-eye effect; and four large synthetic quartzes variously described as amethyst, citrine and two aquamarines. Experimental sugar-acid treatment of Ethiopian opal is also described to make future possible detection easier. R.R.H.

Gemmological News.

C.C. Milisenda and K. Schollenbruch. *Gemmologie. Z. Dt. Gemmol. Ges.,* **60**(1/2), 2011, 3–8. 10 photographs.

The authors report on two intense dark blue sapphires (5.42 ct and 4.78 ct)

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from a new occurrence in Gabon, Western Central Africa. The stones show a distinct colour and growth zoning accompanied by rutile silk. Some pink-red to red rubies weighing between 1.79 and 3.58 ct from the Macenta region in southeast Guinea, West Africa, were examined. The stones showed lamellae, cracks, boehmite tubes and rutile silk similar to stones found in East Africa. Some grey-yellow to green-yellow star sapphires weighing 3.65, 4.39 and 7.98 ct were submitted as untreated stones from Burma, but showed numerous round and flat bubble inclusions caused by a f ller of glass which contained lead. Some faceted danburites from Tanzania revealed f brous mineral inclusions which would allow danburite cat's-eyes to be cut from the rough. Further details given concerned transparent mint-coloured cupro-adamite from Mexico, transparent faceted red roselite from the Bou Azzer mining complex in Morocco, a faceted translucent blue-green grandidierite from Madagascar, an epistilbite from the Nasik and Khandivali quarries in India, and a 0.27 ct creedite from Mexico (the name deriving from an occurrence near Creede in Colorado, U.S.A.). Also mentioned is a colourless, faceted pear-shaped chiolite weighing 0.70 ct from the cryolite deposit Ivigtut in Greenland (the name derives from the Greek meaning 'snowstone'). E.S.

Schleifwürdige Titanite und Apatite aus der Eifel.

C.C. Milisenda, M. Wild and H.-J. Kolzem. *Gemmologie. Z. Dt. Gemmol. Ges.,* **60**(1/2), 2011, 49–52. 7 photographs, 1 graph, bibl. [German with English abstract.]

The Eifel is a volcanic zone in western Germany producing many minerals. Those of gem quality include peridot, sanidine and hauyne. The article describes pink apatite and orange-brown to reddish-orange titanite (sphene) recovered from a pumice quarry near Laacher Lake. E.S.

Lab notes.

T.M. Moses and S.F. McClure. *Gems & Gemology,* **46**(4), 2010, 298–307.

A rare green pearl of 6.72 ct is natural, of saltwater origin and considered to have grown in the black-lipped oyster from Baja California *Pinctada mazatlantica*. An intense blue triangular step-cut stone was found to be a mixture of sugilite and the amphibole richterite. R.R.H.

Lab notes.

T.M. Moses and S.F. McClure (Eds). *Gems & Gemology,* **47**(1), 2011, 49–55.

Three cabochons of similar green were identif ed as jadeite, omphacite and hydrogrossular; sapphires from a new deposit near the lapis lazuli mines in Afghanistan contain unusually high amounts of beryllium and tungsten and some of the blue stones have yellow cores displaying a star structure in transmitted light. R.R.H.

Lab notes.

T.M. Moses and S.F. McClure (Eds). *Gems & Gemology,* **47**(3), 2011, 222–33.

An orange clinohumite weighing 84.23 ct and cut as a pear-shaped brilliant contains two-phase inclusions, colour banding and twin planes. A natural sapphire coloured by iron and a synthetic sapphire coloured by cobalt had remarkably similar colours of green. A beryllium-diffused pink sapphire was detected from analyses of orange colour bands in the absence of any Be near the girdle — which is the usual location for search for this treatment. In contrast high Be contents (up to 33 ppma) were found in natural blue sapphires (one of which was unheated) and it was noted that these positively correlated with transition metals and light rare-earth elements. Cultured pearls from *Pteria sterna* proved to have plastic beads. A large conch pearl of about 100 ct has a very f ne flame structure and is overall pink, of natural colour. R.R.H.

Lab notes.

T.M. Moses and S.F. McClure (Eds). *Gems & Gemology,* **47**(4), 2011, 308–15.

Clarity-enhanced opal on artif cial matrix. Ethiopian black opal with a dark body colour attributed to the natural presence of black manganese oxides. Coated bead-cultured freshwater pearls, unusually large white baroque, with thin nacre and pearlescent coating. Review of tenebrescent zircon, i.e. one that can change colour when exposed to sunlight and return to its original colour when left in the dark, and although rare, comments are made on lack of reporting in gemmological literature. R.R.H.

Microstructures observed in Andamooka matrix opal.

G. Pearson. *Australian Gemmologist,* **24**(2), 2010, 32–7.

Contrary to statements in literature which incorrectly indicate that much of Australian opal is porous, Andamooka matrix opal is the only signif cantly porous opal found in Australia. Microscopic evidence suggests that this porosity, which enables the opal to be stained black, may be due to residual interstices and voids between pseudomorphed microcrystals. The use of stained opal specimens in this study facilitated the observation of microstructures, including pseudomorphed euhedral crystals resembling calcite. This and other structures were consistent with opal having pseudomorphed pre-existing components such as massive polycrystalline limestone, possibly initially arising from biogenic calcareous marine debris such as accumulating beds of Cretaceous foraminifera shells. Oolitic structures from Andamooka were also examined and the observations suggested their fossiliferous origin rather than the alternative mechanical origin of oolitic sands. E.A.S.

Demantoid and topazolite from Antetezambato, northern Madagascar: review and new data.

F. Pezzotta, I. Adamo and V. Diella. *Gems & Gemology,* **47**(1), 2011, 2–14.

Microprobe and LA-ICP-MS analyses, UV-Vis-NIR and FTIR spectroscopy conf rm recently published data on the Antetezambato andradites. They are near end-member andradite in composition with low Cr and V, the colours presumably being caused by Fe, although f nding any link of the green or golden brown colours examined to chemistry proved elusive. Fractures with partially healed 'f ngerprint' inclusions are present along with wollastonite crystals and diopside clusters, identif ed using Raman spectra. The contents of light rare earth elements found using LA-ICP-MS are consistent with a skarn origin for the stones. R.R.H.

Dyed purple hydrophane opal.

N. Renfro and S.F. McClure. *Gems & Gemology,* **47**(4), 2011, 260–70.

Purple opal specimens with play of colour are shown to have been dyed by means of microscopic examination and spectral analyses of the acetone solution after the opal had been immersed. The

Abstracts (continued)

gemmological properties of the opal are consistent with an origin in Wollo, Ethiopia, although it was said by the merchant/donor to come from Mexico. Inclusions also consistent with an Ethiopian origin are quartz with even rhombohedral and short prism faces, and dark brown to black radial patches; also inclusions of a zeolite, possibly chabazite, were found. The authors' experiments on dyeing Ethiopian hydrophane opals are reported. R.R.H

The Chinese red feldspar controversy: chronology of research through July 2009.

G.R. Rossman. *Gems & Gemology,* **47**(1), 2011, 16–30.

Active research on red feldspar variously suggested as originating in Democratic Republic of Congo, 'China', Tibet, Inner Mongolia and Mexico is chronicled. Spectra in the UV-Vis-NIR range indicate similarities of this feldspar with Oregon sunstone but EPMA analyses indicate a clear distinction with both the sunstone and suggested Mexican feldspars being more calcic. Argon release experiments were conducted to test for heat treatment and argon isotopes along with Ca, Sr, Ba, Zn and Pb isotopes were measured to test source correlation. In 2008 experiments, Cu was found to diffuse easily into plagioclase above 1200°C, experiments prompted by the presence of high levels of Cu in glassy residues on the surfaces and in cracks in rough andesine specimens. The provisional conclusion was that there was a strong case for at least some of the stones to be copper-diffused andesine from Inner Mongolia; however further research is needed. R.R.H.

Triphylite from Brazil — a rare colour-change gemstone.

K. Schmetzer and E. Erel. *Australian Gemmologist,* **24**(5), 2011, 104–5.

Triphyllite is a collector's stone which is rarely described in gemmological literature. Three faceted Brazilian specimens display yellow green or greenish yellow in daylight changing to yellowish orange or brownish orange in incandescent light — both conditions varied depending on viewing angle due to distinct trichroism. Refractive indices of α 1.690, β 1.691, γ 1.696 and a Fe:Mn ratio of 2.08 were consistent with the tryphylite-lithiophilite series in which the refractive indices increase with increasing Fe and decreasing Mn contents. Numerous absorption bands were present in the non-polarized spectrum, with maxima assigned to either Mn^{2+} or Fe^{2+}. Colorimetric parameters were also recorded. E.A.S.

Alexandrites from the Novello alexandrite-emerald deposit, Masvingo District, Zimbabwe.

K. Schmetzer, S. Stöcklmayer, V. Stöcklmayer and A.K. Malsy. *Australian Gemmologist,* **24**(6), 2011, 133–47.

The Zimbabwean Novello locality, which is similar geologically to the famous Ural Mountain deposit in Russia, has produced mineral specimens and a limited amount of facet-quality rough. Comparisons to the Russian material are drawn via an in-depth discussion of the crystallographic and gemmological features of Novello alexandrites, as well as an overview of the geology of the deposit and gem genesis. Both deposits are dominated by cyclic twins (trillings), while single crystals and contact twins are rare. Unlike most Russian alexandrites, the Novello gems have a higher Cr and Fe content and show strong colour-zoning. Though they have comparable colour-change, the Zimbabwean material is highly fractured and included; rarely of faceting quality. E.A.S.

Identification of extraterrestrial peridot by trace elements.

A.H. Shen, J.I. Koivula and J.E. Shigley. *Gems & Gemology,* **47**(3), 2011, 208–13.

Since their RI and SG properties overlapped, 26 peridot samples from the Esquel meteorite, a stony-iron (pallasite) meteorite, were analysed using LA-ICP-MS and compared with analyses of peridots selected from major terrestrial sources. The elements found to be useful in identifying a peridot as terrestrial or extra-terrestrial are Li, V, Mn, Co, Ni and Zn, and two-element plots such as V vs. Li, Ni vs. Mn and Zn vs. Co show clearly separate f elds. R.R.H.

Neue künstlich geritzte Sternsteine und ihre natürlichen Gegenstücke.

M.P. Steinbach. *Gemmologie. Z. Dt. Gemmol. Ges.,* **60**(1/2), 2011, 25–36. 21 photographs, bibl. [German with English abstract.]

Asterism in stones is usually created by minute, orientated inclusions forming 4-, 6-, 8-, 12-, 18- and even 24-rayed stars. As well as the well-known stones with 4- and 6-rayed stars, the article mentions a few new and rare varieties. About ten years ago, gems with scratched stars appeared on the market. The scratches were made by 'artists' in Sri Lanka and included garnet, chrysoberyl, rutile, sinhalite, cassiterite, scheelite or samarskite, tourmaline (schorl) and sphalerite. Newly described are scratched stars on pyrite, iolite, green garnet, chromian diopside, green tourmaline and sapphire, as well as twin stars and doublets imitating iolite and tourmaline. There are about 40 different star stones known plus the diverse trapiche varieties. E.S.

Mookaite — a Western Australian ornamental rock.

S. Stöcklmayer and V. Stöcklmayer. *Australian Gemmologist,* **24**(3), 2010, 56–60.

A description of the geological setting, mining practices, mineralogical properties and causation of colour is presented and is accompanied by photographs of petrographic thin sections and of mookaite's unique appearance following fashioning. Mookaite is a trade name for a porcellanite composed predominantly of massive ultraf ne silica and coloured by iron oxide granules. This ornamental material is popular because it takes a high polish, is f ne grained, is hard with no directional weakness and has an attractive mottled coloration. Due to the rock's variable mineralogy and composition, its gemmological properties also vary. Deposits are found in the former Mooka Pastoral Station located approximately 170 km east of Carnarvon and have been worked since the 1960s. E.A.S.

Yellow scapolite from Ihosy, Madagascar.

M. Superchi, F. Pezzotta, E. Gambini and E. Castaman. *Gems & Gemology,* **46**(4), 2010, 274–9.

Yellow scapolite has been recovered from veins in skarn rocks about 35 km south of Ihosy in southern Madagascar since the late 1990s. Twenty one representative samples have been studied

Abstracts (continued)

yielding RIs of 1.552–1.581 and SGs of 2.68–2.72, both ranges consistent with compositions rich in meionite (the Ca member of the meionite-marialite series). EPMA analyses confirmed the Me content between 60 and 70%. The fluorescence behaviour of yellow under long wave and purplish red under short wave ultraviolet differs from that of most gem scapolites, being however similar to rare crystals from Switzerland. The influence of a small component of silvialite in the composition is discussed. There are some channel inclusions in the samples and rare crystals of garnet, mica and pyroxene, identified using Raman spectroscopy. R.R.H.

Instruments and Techniques

GIA Symposium 2011.
Gems & Gemology, **47**(2), 2011, 123–58.

Topics covered in the presentations include: the range of effects of different light sources on the buying, grading and selling of gemstones; understanding luminescence in gems; applications of fluorescence in gemmology; and a review of the application and limits of advanced techniques used to investigate gems.

There were poster sessions on using a concrete mixer to sort limited quantities of gem-bearing gravels; IR and UV-Vis spectroscopy of emeralds; extreme conoscopy; Raman spectroscopy of garnets; chemical analysis and photoluminescence techniques applied to pearls; 3D mapping of diamond surfaces and inclusions; symmetry assessment of cut diamonds; instrumental colour measurement and grading of faceted gemstones; automated real-time spectral analysis of gems; laser-induced breakdown spectroscopy (LIBS) linked to pattern-recognition software to determine provenance of gemstones; provenance of rubies and sapphires; and colour science and standards for the gem trade. R.R.H.

Determining garnet composition from magnetic susceptibility and other properties.
D.B. Hoover. *Gems & Gemology,* **47**(4), 2011, 272–85.

The apparatus to measure the magnetic susceptibility of a gem is briefly described, and its advantage as a non-destructive gem testing method additional to RI, SG and other methods is discussed. The method is applied to 28 well characterized garnets from the GIA collections selected to cover the full range of compositions and RI values. The aim was to provide reliable data to enable gemmologists to estimate the end-member proportions in gem garnets being tested, and this can be done on the basis of the magnetic susceptibility versus RI or versus SG diagrams which record the 28 analysed garnets. The problems associated with multiple end members in the garnet group are discussed, but the usefulness of this additional technique in arriving at a reliable test result is clear. R.R.H.

Identifizierungshilfe zur Unterscheidung zwischen natürlichen und synthetischen (HPHT) gelben, gelb-braunen und rötlich-braunen Diamanten.
M. Seubert. *Gemmologie. Z. Dt. Gemmol. Ges.,* **60**(1/2), 2011, 53–5. 4 photographs. [German with English abstract.]

A blue-violet laser pointer (wavelength 405) can be helpful in distinguishing between natural and synthetic yellow, yellow-brown and reddish-brown diamonds. The strong energy of the laser pointer causes luminescence patterns which make the growth structure of synthetic diamond visible. This method should not be used as a reliable identification feature, but may be useful as an easy, portable and economic first step in the identification process. E.S.

The radioactive decay pattern of blue topaz treated by neutron irradiation.
J. Zhang, T. Lu, M. Wang and H. Chen. *Gems & Gemology,* **47**(4), 2011, 302–7.

A study of 15 neutron-irradiated blue topaz samples was conducted using high-purity germanium digital gamma ray spectroscopy. The specific activities in Bq/g of ^{134}Cs, ^{182}Ta, ^{46}Sc and ^{160}Tb, which were the radionuclides detected in this set of samples, were measured, and the times they took to decay to the exemption level of 74 Bq/g were determined. Most of the samples were relatively safe at the time of the first measurement, 95 days after irradiation, but if a radionuclide such as ^{182}Ta is present in unusually high quantities, the stone may require to be quarantined for longer than the two or three years it normally takes to reach the exemption level. Measurements were on Chinese topaz and the results should not be assumed relevant to topaz from other localities without further checks. R.R.H.

Synthetics and Simulants

Update on Mexifire synthetic fire opal.
R. Bhandari and G. Choudhary. *Gems & Gemology,* **46**(4), 2010, 287–90.

Current production of synthetic fire opal marketed as 'Mexifire' has different properties from those reported in 2008. RI is 1.47 (c.f. 1.38–1.41), SG is 2.19 (c.f. 1.63–1.77) and the FTIR spectrum shows more transmittance at longer wavelengths. The RI and SG values now overlap those of natural fire opals but the presence of scattered fine pin-point inclusions is said to help in identifying the synthetics.R.R.H.

Gem News International.
B.M. Laurs. *Gems & Gemology,* **46**(4), 2010, 309–31.

Stones mentioned include: copal and plastic beads; green glass with crystal inclusions; a quartz-synthetic ruby composite sold as natural ruby; and cubic zirconias and glass replica stones assembled to imitate Louis XV's Golden Fleece jewel of 1749. R.R.H.

Gem News International.
B.M. Laurs. *Gems & Gemology,* **47**(1), 2011, 56–73.

Stones mentioned include: doublets of lace agate and reconstituted turquoise are being sold as 'Coral Sea agate'; dendritic agate doublets and inlays; a trapiche emerald imitation which had been assembled from cut crystal(s) and patchy black adhesive; imitation nephrite consisting of decorated probable polyester resin and containing steel discs only revealed when the 'boulder' was broken; a non-nacreous pearl imitation made of shell with a deliberately engraved pattern; and a lead-glass-filled trapiche ruby. R.R.H.

Lab notes.
T.M. Moses and S.F. McClure. *Gems & Gemology,* **46**(4), 2010, 298–307.

Abstracts (continued)

An intense purplish-pink round brilliant was identified as a treated HPHT-grown synthetic diamond rather than a treated natural stone. Among HPHT-grown synthetic diamonds tested were a 4.09 ct yellow-orange stone, a blue 0.30 ct stone with silicon vacancy defects and melee-size yellow brilliants. Purple and greenish blue cabochons manufactured from turquoise, metal flakes and plastic appeared to contain metal veining and resemble some natural materials. A doublet with both components synthetic, one ruby and the other spinel, was identified. R.R.H.

Lab notes.

T.M. Moses and S.F. McClure (Eds). *Gems & Gemology,* **47**(1), 2011, 49–55.

A black submetallic round brilliant was identified using Raman spectroscopy as an intergrowth of synthetic moissanite and crystalline silicon. A cabochon that initially looked like moonstone was identified as a synthetic star spinel with a blue metallic coating on the base. R.R.H.

Lab notes.

T.M. Moses and S.F. McClure (Eds). *Gems & Gemology,* **47**(3), 2011, 222–33.

The features of 16 faceted CVD synthetic diamonds are described; all are type IIa and have a weak to moderate green fluorescence under SWUV radiation. Two pink diamonds graded Fancy Vivid purplish pink and Fancy Deep purple-pink were found to have quite different structures when seen with DiamondView equipment — one grown in HPHT conditions and the other formed by CVD. The HPHT diamond showed much more uneven colour zoning than the CVD diamond. R.R.H.

Synthetic gem materials in the 2000s: a decade in review.

N. Renfro, J.I. Koivula, W. Wang and G. Roskin. *Gems & Gemology,* **46**(4), 2010, 260–73.

Synthetic versions of diamond (particularly gem-quality CVD diamond), ruby, sapphire, emerald, aquamarine, red beryl, alexandrite, jadeite, quartz, opal and the unexpected examples of synthetic apatite and topaz are reviewed. Comments are made of the current status of methods of identification of these synthetic stones and the ever-present possibility of confusing them with heat-treated natural stones. R.R.H.

Characterisation of a new synthetic fancy yellow diamond.

V. Rolandi, A. Brajkovic, A. Giorgioni, A. Malossi and R. Scotti. *Gemmologie. Z. Dt. Gemmol. Ges.,* **60**(1/2), 2011, 9–24. 14 photographs, 1 table, 8 graphs, bibl. [In German and English.]

The stones examined were HPHT grown with BARS equipment, modifying the geometry of the high-pressure growth cell and treated post growth by annealing and high temperatures. These new attractive synthetic intense bright yellow diamonds are being sold by the Italian firm Malossi Gemcreate (Milan) and marketed as 'Malossi synthetic fancy yellow diamonds'. They have a homogeneous colour distribution and very good clarity grades. They can be distinguished from natural diamonds by some distinctive gemmological and spectroscopic properties such as evenly distributed green fluorescence to both long and short wave ultraviolet radiation, infrared features typical of type 1aA diamonds, a general increasing absorption from the visible towards the ultraviolet, characteristic UV-Vis and PL spectroscopic features, green cathodoluminescence and paramagnetic properties. Nine faceted and one rough synthetic diamond were examined. E.S.

High quality synthetic yellow orange diamond emerges in China.

S. Shonghua, L. Taijin, S. Meidong, S. Jun and S. Jingjing. *Australian Gemmologist,* **24**(4), 2010, 168–70.

Several Chinese universities and companies now have the ability to produce large HPHT yellow diamonds, some of which are of high quality and high clarity. This report describes a faceted 1.57 ct orange yellow synthetic diamond of relatively good clarity whose internal scene was comprised of tiny pinpoint inclusions and a pattern of internal graining in the form of a rectangle; metallic inclusions were absent. FTIR, Raman, Vis-NIR and EDXRF analysis were performed, and along with a DiamondView luminescence image of a green cross-shaped fluorescence, the diamond was confirmed as a type Ib synthetic — the first such large, high quality gem that the NGTC lab had encountered in the Chinese gem market. E.A.S.

Exploring the origin and nature of luminescent regions in CVD synthetic diamond.

B. Willems, A. Tallaire and J. Barjon. *Gems & Gemology,* **47**(3), 2011, 202–7.

In the DiamondView instrument, blue to blue-green luminescent zones may be seen in CVD synthetic diamond when the growth run has been interrupted and resumed, a well-known practice in the production of gem-quality CVD synthetics. DiamondView, photoluminescence (PL) and cathodoluminescence (CL) imaging were applied to study the origin and nature of these luminscent regions in two samples of high-purity single-crystal CVD synthetic diamond. DiamondView and PL measurements showed a correlation with silicon-related centres. In addition, CL analysis confirmed the presence of boron. Both silicon and boron showed preferential incorporation at the interface between CVD layers, where a higher uptake of impurities lead to the observed luminescence. Although the growth interruptions cannot be detected with the naked eye, the growth history can be determined accurately using luminescence imaging and spectroscopy techniques. Authors' abstract

Abstractors

A.S. Fellows – A.S.F. R.R. Harding – R.R.H. E.A. Skalwold – E.A.S. E. Stern – E.S.

Book reviews

The Diamond Compendium

Dee Dee Cunningham, 2011. Robert Hale, London. pp 888. Over 200 colour photos plus 150 f gures and charts. Hardback, ISBN-13 9780719804113. £150.00.

The f rst thing I do when I look at a diamond textbook is to check the entry on the Grand Condé. This fancy pink pear-shape weighs 9.01 ct; one would think that this fact would be relatively easy to verify, given that the stone has been sitting on public display in the Museé de Condé in Chantilly for over a century. However, for some reason, many texts state that the diamond weighs 50ct! Perhaps the name 'Grand Condé' misleads authors into thinking that the stone must be bigger than it really is? If a book quotes the correct mass, I usually take it as an indication that the author has taken the trouble to do some proper research. I was therefore pleased to discover that the *Compendium* states the correct f gure in Chapter 16 and, suitably reassured, I settled down for some serious reading: at nearly nine hundred pages, the *Compendium* certainly packs a punch.

In hindsight, it is just as well that I started off by delving into the middle, as the opening pages in Chapter 1, 'Diamond origin and geological occurrence', are unfortunately amongst the least readable in the book. At this point, one of the *Compendium's* two major flaws becomes apparent: diamond is not only the cornerstone of a multi-billion-dollar jewellery industry, but also a supermaterial. The books and journals devoted to diamond could f ll a library – something which cannot be said of any other gemstone. Whereas monographs on other gems (such as Hoover's *Topaz*) can be quite satisfying and accessible, to attempt to write a compendium of knowledge on the topic of diamonds is a mammoth challenge, and it is never entirely clear what kind of audience the author is trying to reach. Retailers or consumers wishing to know more about diamonds will f nd some chapters impenetrable, whereas those with a more scientif c background will f nd the same chapters inadequate when compared to dedicated academic texts such as Wilks & Wilks' *Properties and Applications of Diamond*. The end result is a slightly awkward compromise of a book. Chapter 1 also showcases the *Compendium's* second major flaw: in the author's enthusiastic attempt to compile the authoritative source of diamond-related knowledge, contentious statements are often presented as if they were undisputed fact. Unlike many coloured stones, diamond does not crystallize in accessible locations, but formed deep within the Earth under conditions that are still imperfectly understood. However, this is not the impression one gets from reading the *Compendium*. One unfortunate example is when carbonado is described as originating from meteorite impacts. Firstly, published research papers appear to suggest that the origins of carbonado are still controversial. Secondly, the author muddies the waters further by apparently confusing impact synthesis (the process that is thought to transform terrestrial carbon into microcrystals of lonsdaleite thanks to the heat and pressure of impact) with true extraterrestrial origin (where the meteorite itself contains non-terrestrial polycrystalline diamond that existed prior to impact).

Chapter 2, 'Geographical occurrence of diamond and diamond-bearing rocks', provides prof les of the world's diamond-producing countries. The diamond world is fast-changing and the author wisely admits that the chapter should be seen only as a snapshot at the time of writing (the situation in Zimbabwe, for example, has already been overtaken by events).

Chapter 3, on crystallography, is adequate, though readers who have a qualif cation in gemmology from Gem-A will compare it unfavourably to Wood's excellent *Crystals and Light*.

Chapters 4, 5 and 6 are very good. They cover the exploitation of primary and secondary deposits and diamond processing and recovery. Interesting historical background on obsolete techniques is accompanied by useful information on modern technology that is seldom found outside specialist geology texts.

Chapter 7, 'Diamond Properties' is useful although once again the author takes selected academic research, in this case Sunagawa's work on the morphology of Type II diamonds, and uncritically presents it as gospel. Although Sunagawa may not have been challenged academically to date, the article itself seems rather speculative upon close examination. It is rejected by some diamantaires for the simple reason that flat octahedral faces are practically never seen on Type II stones — surely it is a stretch to assume that they have all been etched or broken off? After all, the *Compendium* itself acknowledges that manipulating growth conditions can lead to synthetics crystallizing as cubes rather than octahedra, so one might wonder why the author is reluctant to admit similar possibilities for natural stones.

The author is to be congratulated

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Book reviews (continued)

on Chapter 8, on colour. It is a solid introduction into a highly specialized and vitally important topic that is inadequately covered in most gemmology textbooks. There are occasional slip-ups, such as when the author claims that orange can be modified by green, which is not possible as 'warm' and 'cool' colours don't mix. Perhaps this is why the *Compendium* states that there are 270 colour possibilities, whereas I calculate that the GIA recognizes a total of 101 colour grading terms for fancy diamonds (including black, 'white' and grey). In addition, it is asserted that gamma irradiation makes diamonds radioactive, which is untrue for gamma rays with energies of less than several megaelectronvolts.

Chapter 9, 'Manufacturing' is probably the best summary available on the topic, although it is already slightly dated: diamond technology is currently developing at an incredible pace. For example, there is no mention of the use of diamond-impregnated grinding wheels for bruting (so-called 'Russian bruting machines'), which are currently making great inroads into the industry. The text also somewhat underplays the key roles of laser technology and computerized planning in modern manufacturing. The section describing international polishing centres could also use an update, with barely a mention of the effects of resource nationalism and the consequent establishment of polishing centres ('benefiaciation') in Southern Africa. The author's tendency to rely uncritically on previous texts rears its head again when the *Compendium* states that cutting thicker girdles and crowns is a good way of improving depth-of-colour in fancy-coloured stones. This is an oversimplification; modern computer technology is now being used to design faceting patterns and angles that increase path length through the use of total internal reflection. Counter-intuitively, this can sometimes provide ways of increasing a stone's saturation by re-cutting it to *shallower* proportions.

Chapter 10, on cutting styles, is a good summary but for the unaccountable omission of the Asscher-cut, which helped to revitalize the popularity of emerald-cuts in the twentieth century. Amusingly, the author speculates that the baguette-cut owes its name to the French word *'bague'*, meaning ring. Although it is true that baguette-cuts have no relationship to loaves of bread, the etymology of the term is almost certainly better-explained by the fact that *'baguette'* in French simply means 'rod/stick'! It is also unfortunate that the *Compendium's* preferred line-drawing for heart-shapes includes impossible facets that cannot exist in real life.

Chapters 11, 12, 13 and 14, on the 'four Cs', are the strongest in the book: in these sections, the author is solidly within her comfort zone, displaying clear evidence of GIA training. Modern techniques are outlined and there is genuine strength in the detail, such as an explanation of the technique of 'wet grading' which helps to showcase the fact that the *Compendium* has truly been carefully constructed from the ground up rather than cobbled together from existing books. The only unfortunate omission is that the comparative tables contrasting various rather similar grading schemes do not mention the Russian grading system — the only maverick among diamond laboratory standards.

Chapter 15, on the global diamond market, is unfortunately somewhat shaky. In addition to being very out-of-date (De Beers' former sorting house on 2 Charterhouse Street was vacated and demolished years ago, and the author's quoted figure of 400 diamond-sorters in London is a distant memory), there are also factual errors. For example, not all of the world's bourses are affiliated with WFDB, and the account of De Beers' sorting activities contains numerous mistakes (although the author could perhaps be forgiven for failing to unearth the finer details of this proprietary process, which will in any case be of little relevance to readers given that every diamond company has its own assortment, machinery and procedures). However, the most misleading error is the claim that Sightholders are faced with a coercive, "like it or lump it" dilemma at every Sight. In fact, Sightholders can reject a portion of their Box — so-called 'buy-backs' — or refuse the Box in its entirety. They can and do exercise these rights freely, notably during the economic crisis in late 2008 that nearly crippled the entire diamond-mining industry. The author would have gained a better understanding had she referred to the diamond trade journals, or if she had simply downloaded a copy of the current Sightholder Contract from the company's website.

Chapter 16, 'Famous diamonds', is excellent. The list of largest gem-quality uncut diamonds shows signs of careful archival research: it is obviously more comprehensive than most of the existing lists, and includes several stones from Jagersfontein which others appear to have missed. Previous authors such as Bruton and Balfour have mentioned some additional 500-plus-caraters in passing, and there are reports of a 602 ct rough discovered in 1993 in the Santo Antônio do Bonito river (Minas Gerais, Brazil) but this list restricts itself to 'gem-quality' items, which perhaps explains why such stones are not listed — although the author certainly appears to have given the rather murky-looking 620 ct Sefadu the benefit of the doubt! It is sheer bad luck that the 550 ct Letšeng Star was discovered on 19 August 2011, obviously too late for publication. In fact, the only other notable omissions from the list appear to be the Wynn and the Star of Stanley Ho, diamonds owned by competing casino moguls. The former is said to have weighed 581 ct when discovered in Brazil in 2002, and the latter is said to have weighed 570 ct when discovered in Angola around 2003 (it is now the world's largest D-flawless cushion-cut, on display in a casino in Macau).

The author has taken the Mouawad Collection's ownership at face value, although few people who work in 'haute joaillerie' seem to genuinely believe that Mr Mouawad has built up this fabulous private collection of famous diamonds on his own account: it is widely rumoured that they have long since been re-sold to private clients. With the exception of the Excelsior I, the gems are, in fact, conspicuous by their absence from the Robert Mouawad Private Museum in Beirut, and I have been unable to verify the author's report of the stones being exhibited in Mouawad boutiques in recent times.

Chapters 17, 18, 19 and 20 (diamond identification, simulants, treatments and synthetics respectively) are all excellent and very comprehensive, along the same lines as the 'Four Cs' chapters.

Conclusion

In spite of some of the above comments, the *Compendium* is a worthy piece of work. It supplants Bruton's *Diamonds* as today's leading general diamond textbook (although it is admittedly rather less enticing and readable) and it deserves to take its place on every gemmologist's bookshelf along with that other indispensable 900-page behemoth, O'Donoghue's *Gems: their sources, descriptions and Identification*. Like both of these tomes, the *Compendium* deserves to have a long shelf life and go through multiple editions. Its flaws are usually minor — the occasional slightly wonky diagram, a persistent habit of mis-spelling surnames, an inconsistent approach to the inclusion of 'inline' references in the text — but, at its best, the *Compendium* manages to not only present a reasonably up-to-date summary of existing knowledge that is unavailable elsewhere, but also to add fascinating insights and background colour.

Michael Hing

(Michael Hing is a Fellow of Gem-A, and works as a diamond valuer in London.)

Proceedings of the Gemmological Association of Great Britain and Notices

Gem-A Graduation Ceremony and Presentation of Awards

On Monday 7 November the Graduation Ceremony and Presentation of Awards was held at Goldsmiths' Hall in the City of London. Professor Andy Rankin, President of the Gemmological Association, presided. James Riley, Chairman of the Gem-A Board, welcomed those present and introduced Jeffrey Monnickendam of Monnickendam Diamonds, a past Gem-A Council member, who presented the awards and gave the address.

Following the presentations to the graduates, Alan Hodgkinson was presented with an Honorary Lifetime Membership in recognition of his tremendous contribution to gemmology over fifty years. Alan is internationally recognized for his gem identification techniques using traditional gem testing equipment and for his book *Visual Optics*. Having been President of the Scottish Branch of Gem-A for many years, Alan is now Honorary President of the Scottish Gemmological Association formed in 2008.

The ceremony was followed by a reception for graduates and guests.

Graduates gather on the magnificent staircase at Goldsmiths' Hall following the ceremony. Photo courtesy of Photoshot.

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Gem-A Conference 2011

Record numbers attended the 2011 Gem-A Conference, held on Sunday 6 November at the Hotel Russell, Bloomsbury. Speakers included Steve Bennett, Brian Cook, Branko Deljanin, Alan Hart, Brian Jackson and Gary Roskin. Adolf Peretti was unable to attend due to flooding in Bangkok, but Willy Bieri kindly stepped in at the last minute to present his lecture.

During the breaks delegates had the opportunity to browse through the latest books and instruments from Gem-A Instruments and to view displays and demonstrations.

The day concluded with a dinner held at The Russell followed by a disco.

Conference Events

A programme of events and workshops was arranged to coincide with the Conference. These started on Saturday 5 November with two half-day seminars held by Branko Deljanin entitled 'Basic gemmology and diamond identification'.

On Monday 7 November two half-day seminars were held — 'Optical phenomena' with Brian Jackson and 'Snap decisions: photographing gems under less than ideal conditions' with Gary Roskin. The Graduation Ceremony and Presentation of Awards was held in the evening at Goldsmiths' Hall (see report opposite).

On Tuesday 10 November Alan Hart led a tour of the Mineral Gallery at the Natural History Museum, South Kensington, including the opportunity to view the Museum's new acquisitions. This was followed in the afternoon by a guided tour of the Crown Jewels at the Tower of London with David Thomas. The final event was Gem Discovery Club with guest speaker Dominic Mok who gave a presentation entitled 'Fei Cui: jadeite jade identification, from eye to high-tech'.

A full report of the Conference and events is to be published in the Winter 2011/2012 issue of *Gems & Jewellery*.

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Gem-A Awards

Gem-A Examinations were held worldwide in January and June 2011. In the Examinations in Gemmology 293 students qualified in the Diploma Examination, including nine with Distinction and 44 with Merit. In the Foundation in Gemmology Examination 389 qualified. In the Gem Diamond Examination 81 qualified, including 11 with Distinction and seven with Merit.

The **Tully Medal** is awarded to the candidate who submits the best set of answers in the Gemmology Diploma examination which, in the opinion of the Examiners, are of sufficiently high standard. **Robin Hansen of** Warminster, Wiltshire, was awarded the **Tully Medal** as well as the **Christie's Prize for Gemmology** for the best candidate of the year in the Diploma Examination, and the **Anderson Bank Prize** for the best set of theory papers in the Diploma in Gemmology examination.

The **Read Practical Prize** for excellence in the Diploma Practical Examination was sponsored for 2011 by DeeDee Cunningham of Toronto, Canada. The Read Practical Prize was awarded to **Xianzhi Zhang** of Wuhan, China.

In the **Foundation Certificate in Gemmology** examination, the **Anderson Medal** for the candidate who submitted the best set of answers which, in the opinion of the Examiners, were of sufficiently high standard, and the **Hirsh Foundation Award** for the best candidate of the year, were awarded to **Dr Simon Gowry** of Wolverhampton.

In the **Gem Diamond Diploma** examination, the **Bruton Medal** for the best set of theory answer papers of the year was awarded to **Julia Anna Griffith** of Southampton

The **Deeks Diamond Prize** for the best candidate of the year, was awarded to **Julia Gowans-Poli** of London.

The **Dominic Mok Diamond Practical Prize** for excellence in the Diamond Practical Examination, is sponsored by Dominic Mok from AGIL, Hong Kong. The Dominic Mok Diamond Practical Prize was awarded to **David Lawrie** of Solihull.

The names of the successful candidates are listed below.

Examinations in Gemmology

Gemmology Diploma

Qualified with Distinction

Antonucci, Andrea, Stockholm, Sweden
Di Cui, Beijing, P.R. China
Diamond, Marcia Jane, London
Hansen, Robin, Mere, Warminster, Wiltshire
Huang Rong, Ling Shui County, Hainan, P.R. China
Lacosta, Patricia, London
Mogridge, Emma Denise, Totnes, Devon
Tingting Ma, Shanghai, P.R. China
Weng Xiao Fan, Fu Zhou City, Fujian, P.R. China

Qualified with Merit

Callandreau, Alexandra Bokobsa, Paris, France
Chao Liu, Beijing, P.R. China
Chayathorn, Chanruangvanich, Bangkok, Thailand
Gao, Yu Jie, Henan, P.R. China
Guo Huimin, Wuhan, P.R. China
He Yiting, Jiangsu, P.R. China
Hsu Shu-Lin, Taipei, Taiwan, R.O. China
Hu Zhengying, Shanghai, P.R. China
In-Nang Cheong, Taipei, Taiwan, R.O. China
Jain, Sanjay, Bangalore, Karnataka, India
Jamieson, Pauline, Edinburgh, Midlothian
Jiao Yongling, Beijing, P.R. China
Lei Yuanyuan, Changsha City, Hunan, P.R. China
Mailly, Caroline, Versailles, France
Min Zhou, Beijing, P.R. China
Möhler, Anja, London
Papaux, David J.H., Geneva, Switzerland
Pei Yu, Beijing, P.R. China
Qiao Xiong, Honghu, Hubei, P.R. China
Raj, Amrit, Jaipur, India
Reynaud, Lucy, Singapore
Reynolds, Eva, Cheltenham, Gloucestershire
Ruiwei Ma, Guilin, Guangxi, P.R. China
Shao Xinyuan, Wuhan, P.R. China
Sheridan, Meghan E., Upper Montclair, New Jersey, U.S.A.
Shevchenko, Olga, Montreal, Quebec, Canada
Siyuan Bi, Guilin, Guangxi, P.R. China

Su Shi Zhen, Shandong, P.R. China
Sujie Ai, Guilin, Guangxi, P.R. China
Tang Pik Yin, Kowloon, Hong Kong
Tianyin Xu, Beijing, P.R. China
Vazzana, Franck, Cosnes-et-Romain, France
Wang Jing, Shanghai, P.R. China
Xu Ying, Shanghai, P.R. China
Yan Shen, Guilin, Guangxi, P.R. China
Yifan Li, Beijing, P.R. China
Yiru Shi, Beijing, P.R. China
Yu-Han Chen, Taipei, Taiwan, R.O. China
Zdeb, Robert, Epping, Essex
Zhang Di, Beijing, P.R. China
Zhang Dongfang, Beijing, P.R. China
Zhang Shengnan, Beijing, P.R. China
Zhao Lu, Shanghai, P.R. China
Zheng Yan, Beijing, P.R. China

Qualified
Aiming Cao, Beijing, P.R. China
Akerlund, Sophia, Lidingö, Sweden
Akintayo, Olusegun James, London
Allen, Amanda, Northampton
Al-Saif, Manar, Stavanger, Norway
An Yue, Beijing, P.R. China
Andoniaina Harijaona, Rabetaliana, Antananarivo, Madagascar
Andriamanohisoa Axhel, Robert, Antananarivo, Madagascar
Andriamboavonjy, Rasamuel, Antananarivo, Madagascar
Athavale, Seema Ashish, Mumbai, India
Bane, Jonathan William, Sheffield, South Yorkshire
Barnett, Myles, Unley Park, South Australia, Australia
Beer, Jasmin, Birmingham, West Midlands
Bell, Nicola, Newton Abbott, Devon
Bernau, Eric, La Ciotat, France
Bing Sun, Wuhan, P.R. China
Burgoni, Eva Maria, Carnoux-en-Provence, France
Butini, Enrico, Rome, Italy
Butini, Flavio, Rome, Italy
Caihuan Liao, Guilin, Guangxi, P.R. China
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Chan Pei Pei, Betty, Quarry Bay, Hong Kong
Chan Yuen Ping, Aberdeen, Hong Kong
Chandrasiri, Hemali Iresha Kumari, Kegalle, Sri Lanka
Chang Jing, Zhangjiakou City, Hebei, P.R. China
Chaoguang He, Wuhan, P.R. China
Charpentier, Frédéric, Fresnes, France
Chen Jiankang, Guangzhou, Guangdong, P.R. China
Chen Qian-Zheng, Beijing, P.R. China
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Chengxuan Li, Beijing, P.R. China
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Andre, Sandrine, London
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Au Siu Tong, Kowloon, Hong Kong
Au Sui Keung, New Territories, Hong Kong
Au Tsz Wai, New Territories, Hong Kong
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Bai Dan, Guangzhou City, P.R. China
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Forsner, Christina, Sodra Sandby, Sweden
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Gan Qian, Nanning City, Guangxi, P.R. China
Gao Liyuan, Jingning County, Gansu, P.R. China
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Gericke, Chanel, Nottingham
Gervais, Veronique, Brossard, Quebec, Canada
Glover, Katie, London
Goshanth, Namasivayam,, Sabaragamuwa , Sri Lanka
Goustiakov, Elodie, Boulogne Billancourt, France
Gowry, Simon, Wolverhampton, Staffordshire
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Ma Tingting, Shanghai, P.R. China
Matsura, Miho, Yokohama, Japan
Ratnayake, Dayanthi, Colombo, Sri Lanka
Sakakibara, Kenichi, Oita, Japan
Tew, Timothy David, Atlanta, Georgia, U.S.A.
Verwijk, Moira, Toronto, Ontario, Canada
Yamaguchi, Nao, Osaka, Japan

Associate Membership to Diamond Membership (DGA)

Lemeshko, Nathalie, London
Manasse, Daniel, Rome, Italy
Roditi, David, London

Annual General Meeting

The Annual General Meeting was held on Thursday 7 July 2011 at the Imperial Hotel, London WC1. The meeting was chaired by James Riley the Chairman of the Council. The Annual Report and Accounts were approved. Brian Jackson, Cally Oldershaw and Steve Jordan (who had been appointed by the Council since the 2010 Annual General Meeting) were re-elected to serve on the Council. Alan Collins retired from the Council in rotation and did not seek re-election. Gwyn Green was re-elected and Kerry Gregory and Elizabeth Gleave elected to serve on the Membership Liaison Committee. Hazlems Fenton were re-appointed as auditors for the year.

Subscriptions 2012

The membership subscriptions for 2012 remain at £90 for UK members and £95 for those in Europe and overseas.

Obituary

Brian R. Dunn FGA (D.1978), Staplehurst, Kent, died suddenly in December 2011. Brian, a former chairman of the NAG Valuations Committee, ran a number of seminars for Gem-A members on the valuation of antique and modern jewellery.

James (Jim) Gemmell FGA (D.1992), Kelloe, Co. Durham, died on 10 April 2011 aged 86. A skilled faceter, Jim was instrumental in setting up the UK Facet Cutters Guild (UKFCG) in 1994 and served as chairman of the Guild for nine years.

Helen Muller FGA (Tully Medal 1974) died on 4 January 2012. Helen was an expert on jet and published three books on the subject.

Edward H. Wain FGA (D.1964), Kings Lynn, Norfolk, died in 2011.

George Bosshart, MSc, SFIT, GG, CSEJ
1943–2012

George Bosshart, who died on 14 January aged 68, was one of the most stimulating and internationally respected gemmologists of the last thirty years. His main interest was diamonds, especially green diamonds, but his talent for incisive and well-researched investigation was applied also to emeralds, rubies, sapphires and a range of other coloured gem species.

George was born on 8 May 1943 in Rüti, canton of Zürich, Switzerland, the son of Georg Albert and Martha Magdalena Bosshart; his younger brother Robert was born the following year. His early education was in Rüti and with Robert he had a very active and 'sporty' childhood. He graduated from the cantonal college in Wetzikon in 1963 with languages and natural sciences as main subjects and then attended an air defence training school, qualifying as a radar operator. This phase of his life may well have sown the seed of his ambition to become a Swissair pilot but such a career was not to be — ruled out by injuries sustained in a near-fatal automobile accident.

He recovered, and instead directed his energy into earth science studies at the Swiss Federal Institute of Technology (Eidgenössische-Technische Hochschule (ETH)) in Zürich with the aim, as he put it, of an "uncommon future occupation involving language skills and travelling". He graduated in 1969 with a Master's degree in earth sciences and was employed first in ore prospecting using geophysics in Canada. However, a position in mineralogical analysis at the aluminium producer ALCAN in Quebec soon proved more attractive and he spent three years in their R and D division. It was during this time that his interest in gems started to grow and he studied in Los Angeles at the GIA, qualifying as a GG. By 1974 he was looking at ways of furthering his career and a project of the Swiss Watch and Jewellery Associations tempted him most. This was to set up a gem testing laboratory for the Swiss Foundation for Research of Gemstones (SSEF) in Zürich. This he established with the motto 'Reliability, rigour, integrity', and during his sixteen years there, he pioneered analytical techniques for

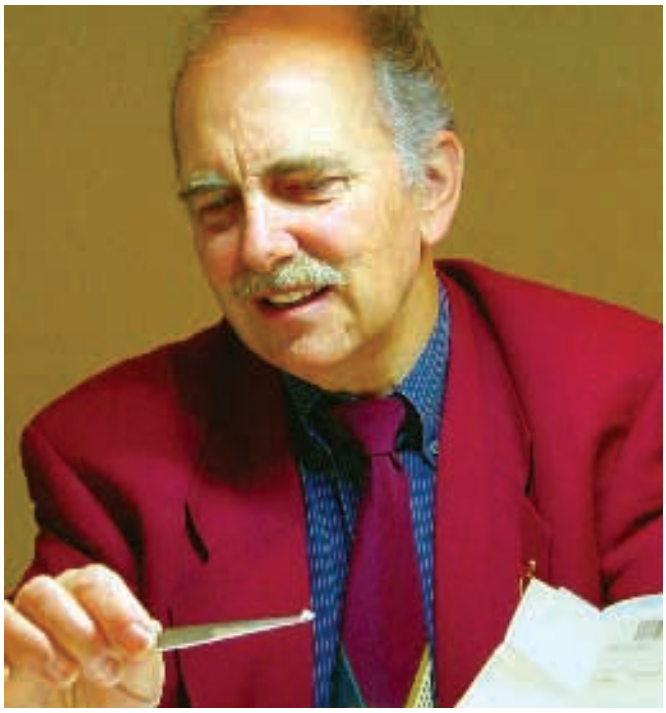

advanced gemstone testing, authored articles on gem identification in several languages, and, with his new colleague Dr Henry Hänni, introduced a service which offered opinions on the geographical origins of rubies, sapphires and emeralds on the basis of analyses of stones that they themselves had collected or sourced. After he left in 1990, it gave George much satisfaction to see the SSEF lab under its subsequent directors Drs Hänni and Krzemnicki grow and prosper. During his time at SSEF, he proposed and in 1988 was granted permission to record infrared and cryogenic, high-resolution ultraviolet to visible absorption spectra of the historic 'Dresden Green' diamond to establish its fundamental properties and also to improve the criteria for distinguishing natural green from artificially-induced green diamonds (i.e. artificially irradiated stones). The innocuous-looking words "... proposed ... granted ..." used above, gloss over a saga about which George could speak for a whole evening, one in which the Dresden authorities needed convincing about the security of the stone, introduction of analytical equipment to the Vaults, and reassurance about

measuring procedures not changing the diamond's colour. In addition, there was a dispute with GIA gemmologists which eventually led to each team's work being published separately. Indeed green diamonds continue to contain some mysteries and George's most recent publication on the topic was in 2008.

In 1990 George was appointed Chief Gemmologist of the Gübelin Gemmological Laboratory in Lucerne, a move prompted by the opportunity for more far-reaching visits to gem market centres and gem mining locations. First assignments took him to Kunming, Tokyo and Riyadh. Later he visited East African countries and many if not most of the countries in the Far East — of which treks in 1993 to Mogok and 1997 to the jadeite mines in upper Burma were the most challenging. Since 1995 the Gübelin Gem Lab has regularly offered external testing weeks to the gem trade and auction houses in Bangkok, Hong Kong and New York, services which helped their global recognition. George disliked the growing numbers of artificially treated and synthetic gems that came onto the market in the 80s and 90s but in 1999, with his typical realism, he became involved in researching detection of type IIa diamonds which had been decolourized by high pressure high temperature techniques in Russian and American laboratories.

In 2004 George took early retirement to concentrate on enlarging and improving the analytical database for blue-green to yellow-green diamonds, whether naturally or artificially irradiated. This 'Green Diamond Research Project' involved working with colleagues in the SSEF and Gübelin laboratories, with museums, and with colleagues in Paris, and highlights an important thread throughout his career that led to many publications and presentations at international meetings. In such research, he was a reliable co-worker, but the extent of his determination to complete everything he had committed himself to meant that meeting deadlines was at times quite tense.

The gem trade, gemmology and gem testing have, over the last forty years, seen a growing number of new stone localities, new synthetics and innovative treatments, and George has played a full part in their detection, description and disclosure. His first paper in *The Journal of Gemmology* in 1978 was a description of stabilized cubic zirconias, and this remains a first-class example to gemmology students of how to carry out and report on such an investigation. Since then he has graced the *Journal* pages with his work on the Dresden Green diamond, major papers on Colombian emeralds, freshwater pearl cultivation in Vietnam, and colour-change stones, to name but a few of the topics he addressed. In 1994 he accepted an invitation to join the *Journal's* board of Associate Editors and his critical, fair and balanced assessment of a submitted manuscript was always something to look forward to for the editor. He also served in the same way on the board of the *Australian Gemmologist*.

George was a Swiss delegate to the International Gemmological Conference and was on the organizing committee for their meeting in Interlaken in 2011. There he presented a paper on colour causes and stability in spodumene. His significant presence on the international stage did not mean that he neglected the national scene. George was strongly patriotic and was a member of the Swiss Mineralogical and Petrographic Society, the Geological Society of Zürich, and the Swiss Chamber of Technical and Scientific Forensic Experts.

In 1973 George met his future wife Anna Verena Geser in New York. They married on 22 April 1977, settled in Horgen, and in 1980 moved into their own home overlooking Lake Zürich and the Alps. George and Anne always enjoyed entertaining friends, and after George took early retirement they almost had an open house — some called it a gemmological hotel but with limited rooms! Anne worked at Gübelin in New York and Lucerne and became head of staff at Meister in Zürich, and shared a love of gems and jewels with George. This found expression in later years when she accompanied George on some of his more demanding treks in the Far East to see gems in their natural settings.

Despite suffering from cancer for many years, George was grateful he survived the accident when he was twenty and went on to experience a colourful world with many natural treasures, human and otherwise, and felt that he was particularly blessed with the companionship of a loving partner.

Roger Harding

This brief summary has drawn on notes provided by George himself, his wife Anne and his long-standing friend Karl Schmetzer.

A word of thanks . . .

Since the 1940s the status of the *Journal* has been built up by a succession of editors noted for their gemmological knowledge and integrity. By the 1970s the pace of scientific advancement in the discipline had started to accelerate, and by the time that Alan Jobbins relinquished the editorial chair in 1994 it made sense to formally seek some support for the editor from those in more specialist areas of expertise. Thus was established a band of Assistant and Associate Editors with a wide range of skills very relevant to today's gemmology. To them I owe a great deal, not only for their technical expertise in assessing manuscripts, but also for their constructive comments, common sense and wise counsel.

Some members of this band also contributed Abstracts — a technical and writing skill which I fear at the present moment is declining but which in the future I hope will revive as one antidote to the information deluge we have to contend with — and to them and the other abstractors who have so succinctly conveyed the essences of material published elsewhere, I offer my thanks.

Although gems have a very pervasive social impact, this cannot be said about the associated science, and to stimulate any appreciation about gemmology's practical, legal or intellectual benefits and values, it must be presented in an attractive way. The success of Mary Burland's efforts in this respect is brought home most vividly when Journal issues through the years are laid side by side, and the changes in size, style and impact are apparent. I thank her for her dedication to the task, for her ability to overcome the unforeseen and for her tolerance of my shortcomings.

In turn, both of us have relied upon staff at the Gem-A office, and I would like to thank them all for their consistent willingness over many years to help in matters concerning publications, an attitude which makes all the difference when outside the office and working from home.

. . . and a word of welcome!

Being out of the office does however have its disadvantages, and over time, the lack of close personal contact with many aspects which affect the gem trade in such places as Hatton Garden does affect how well one can assess material submitted for publication. I am very pleased that someone who is in the thick of gemmological activity and who has knowledge and access to many of the advanced techniques now being used to examine gems, has agreed to be the next editor. In this, the last issue of the Journal that I will be editing, my very best wishes go to Elise Skalwold and I wish her, the Journal and the Association a most successful future.

Roger Harding

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Cover Picture: Slices of trapiche tourmaline from Zambia cut perpendicular to the *c*-axis. In the centre of the slice, upper left, the dark arms of the fixed three-rayed star separate three pyramidal growth sectors. The slice, lower right, cut from the same tourmaline, has a rim with six prismatic growth sectors which are separated from each other and from the pyramidal growth sectors of the centre by less transparent boundaries. View parallel to the *c*-axis, size of the samples about 13 × 12 mm. Photos by T. Hainschwang. (See Chemical and growth zoning in trapiche tourmaline from Zambia — a re-evaluation by K. Schmetzer, H.-J. Bernhardt and T. Hainschwang, pages 151–173.)

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Determining the geographical origins of natural emeralds through nondestructive chemical fingerprinting

D.P. Cronin and A.M. Rendle

Abstract: Analytical methods capable of differentiating trace elements in natural emerald may enable their geographical point of origin (GPO) to be elucidated. Emeralds were sampled from six distinct GPOs and the elemental composition of each sample was obtained nondestructively using energy dispersive X-ray spectroscopy (EDX). EDX results were chemometrically assessed for compositional differences and the results reveal that emeralds from the six GPOs possess a chemical identity that is statistically heterogeneous between GPOs, with the chromophores V, Ni and Mg being the most important trace elements for elucidating GPOs.

Keywords: chemometrics, chromophore, emerald, energy dispersive X-ray spectroscopy, precipitation model

Introduction

Evidenced from the earliest remnants of human civilization, minerals have always been important natural resources intimately linked to distinct cultural attributes such as personal adornment, religious and secular customs, wealth and trade, and the arts. Determining the geographical point of origin of minerals and other gems from antiquity required little more than a qualitative understanding of cultural anthropology, geographically specific artisanship, traditional trade routes, and/or mining regions consistent with the age-specific attributes of the artefact. But with advances in geophysical surveying and increased global trade throughout the past century — coupled with a combination of corporatized, indigenous and illegal mining operations — elucidating the point of origin of any gem material from qualitative analyses alone would be irresponsible. The pursuit of scientific certainty relevant to mineral origin has greatly advanced in the past decade and continues to take monumental strides towards a unified body of science.

This research began towards identifying and relating trace elemental differences in emeralds from the Cordillera Oriental in Colombia, differences which had arisen as a result of interstitial fluid migration prior to precipitation. Although the more subtle processes that link geochemical interactions to the precise incorporation of trace elements remains poorly understood, this research revealed that the chemical composition of emeralds — particularly the chromophores — from mining locations separated by only a few kilometres (e.g. the Muzo and Cosquez mining localities of Colombia) are distinctively different. Hence, even within one basic precipitation model for fluid processes culminating within a single geological formation there exist a range of even more subtle precipitation mechanisms and fluid dynamics leading to chemical heterogeneity between emerald points of origin.

The initial data that emerged changed the course of the research when it was recognized that within-site chemical homogeneity and between-sites chemical heterogeneity was contingent on the chromophore concentrations in the crystal structure. This unanticipated result during the course of investigating the chemistry of interstitial fluids during

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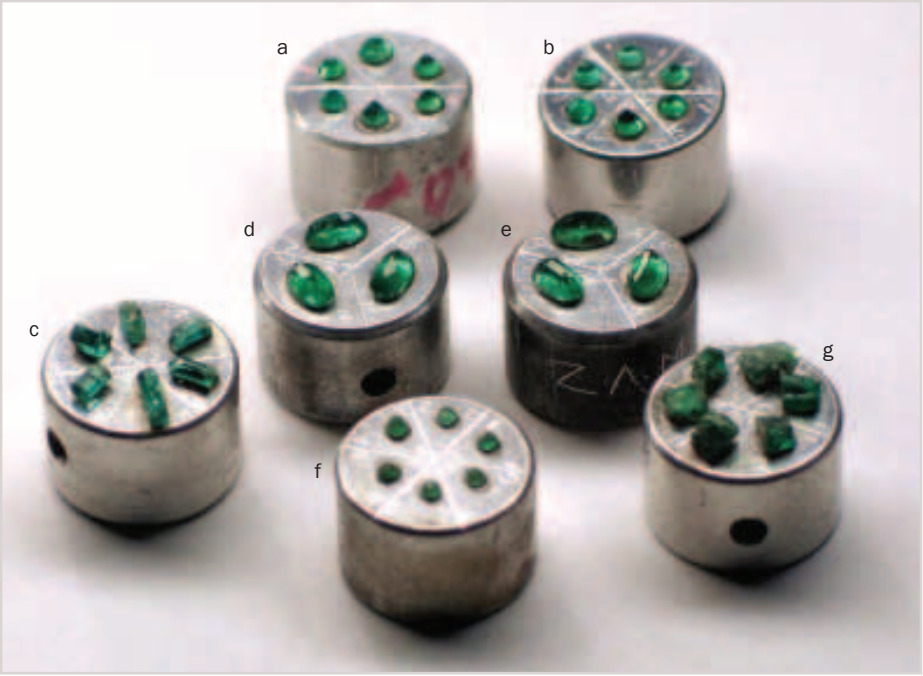

Figure 1: Each of the 36 emerald samples was mounted on an aluminium stud with silver conductive paint for SEM-EDX analysis. The studs were etched with numbered pie-shaped sectors for identification during SEM-EDX analysis and each stud was drilled for use with a positioning and removal tool to prevent contamination. (a) CZC, (b) MZC, (c) CVC, (d) ZAM, (e) ZAM, (f) GOB and (g) CFB. Photo by D. P. Cronin.

tectonic precipitation dynamics in the Cordillera Oriental quickly led to this research evolving to determine if chemical heterogeneity between emerald mining localities was chemometrically unique and statistically significant based on chromophore constituents alone. To test this assertion, three additional sites (two in Brazil and one in Zambia) were sampled and assessed for their architectural chemistries and chromophore constituents.

Natural emeralds

Emerald is the richly coloured green variety of the mineral species beryl. As an allochromatic mineral species that is colourless and transparent in its purest state (var. goshenite), beryl does not meet the defined characteristics of emerald unless the requisite chromophore elements are properly incorporated into the six-member cyclosilicate crystal structure. Furthermore, chromophore incorporation must occur in the proper quantity and configuration within the crystal structure to result in the characteristic visible absorption that transmits the distinctive green hue and treasured chroma that defines the emerald variety. Because beryllium and the primary chromophores necessary for emerald precipitation, chromium and vanadium, are not normally in close association in Nature, the rarity of this geochemical concurrence is the reason for the scarcity of emerald occurrences worldwide (Schwarz and Giuliani, 2001).

The selective substitution of metal cations in the beryl crystal structure, such as the incorporation of chromium ions (Cr^{3+}) in octahedral sites that would otherwise host the framework aluminium ion (Al^{3+}) (Hasan, Keany and Manson, 1986; Parikh *et al.,* 2003; Acharya *et al.,* 2000; Kim *et al.,* 2000; Nassau, 1978), produces the defining hue of emerald (Kleiðmantas and Skridlaitë, 2004). Emeralds with characteristically low chromium content often contain the trivalent primary chromophore vanadium (V^{3+}), approximately 0.3% by weight in the Al^{3+} sites (Moroz *et al.,* 2000). While it was once believed that the Al^{3+} site was the only location in which the primary chromophore Cr^{3+} could reside (Edgar and Hutton, 1978), it has since been suggested that Cr^{3+} in a coupled substitution with a monovalent cation may occupy tetravalent sites normally containing the framework silicon ion (Si^{4+}) (Parikh *et al.,* 2003).

Whereas the primary chromophore(s) in the chemical framework give emeralds their distinctive green colour, it is the incorporation of secondary chromophores (i.e. Fe^{2+}, Fe^{3+}, Ni^{2+}) that alter the chroma of emeralds and lead to their wide-range of visible chromaticity. Much of the chromaticity dynamics results from secondary chromophores competing for the Cr^{3+} and V^{3+} sites, thereby depleting concentrations of Cr^{3+} and V^{3+} (Platonov, Taran and Balitsky, 1984). More importantly, secondary chromophores are polyvalent ions that act as electron withdrawing groups. Their incorporation into the crystal structure imparts an effect on the visible spectrum that shifts the Cr^{3+} and V^{3+} absorption bands towards longer wavelengths. For example, Al^{3+} can be substituted with ferric iron (Fe^{3+}) or with magnesium (Mg^{2+}), the latter requiring a coupled substitution with a monovalent cation (Acharya *et al.,* 2000; Parikh *et al.,* 2003), leading to red-shifting in the absorption bands. With a lack of d-electrons and no electronic transitions in the visible region, Mg^{2+} would normally not be considered to be a secondary chromophore, but its presence can shift absorption bands and alter the colour of an emerald. In addition to Fe^{3+} and Mg^{2+} placement into Al^{3+} sites, Fe^{3+}, Mg^{2+} and divalent ferrous iron (Fe^{2+}) ions can each occupy the divalent beryllium (Be^{2+}) tetrahedral sites (Braga *et al.,* 2002); again, red-shifting the chromium and vanadium absorption bands and changing the hue and chroma of emerald.

In addition to the primary and secondary chromophore elements, emeralds also contain other trace elements that reflect the localized geology and fluid-rock interaction dynamics that exist during precipitation. For each of the six site-specific emerald occurrences the following aspects were considered in this study: the influence of the host rock chemistry on skeletal

crystal architecture, the occurrence of trace elements that link emeralds to their point of origin, the subsurface geology, fluid-rock interactions and the geochemical processes leading to emerald precipitation. By measuring the contents of framework elements, chromophore elements (both primary and secondary), and other trace chemical impurities in emeralds with EDX technologies and evaluating the results with a custom analysis of variance (ANOVA) program code for emerald chemical constituents both among and between known sample points of origin, we aimed to establish the chemical 'fingerprint' of emerald from six different geographical points of origin and test whether they can be chemically distinguishable from one another.

Materials and methods

For this work, 36 emeralds were randomly sampled (six individual samples from each of six commercial emerald-producing mines). Sampling procedure for both sites and specimens was executed in alignment with research sampling protocols set forth by ASTM International (formerly known as the American Society for Testing and Materials (ASTM)), and the mining localities were selectively chosen based on the merits of their geological and geographical similarities and differences, their importance in the international emerald market, and our ability to ensure that the collected samples originated from the mines in which sample acquisition was to occur. The 36 emerald samples acquired for this research originated from: (1) Guali, Colombia (CVC), (2) Cosquez, Colombia (CZC), (3) Muzo, Colombia (MZC), (4) Campo Verdes, Brazil (GOB), (5) Carnaíba, Brazil (CFB), and (6) Chantete, Zambia (ZAM). The gem quality emerald samples, as shown in *Figure 1*, include anhedral crystals (those from CFB), euhedral crystals (those from CVC), round brilliant cuts (those from CZC, MZC and GOB), and oval brilliant cuts (those from ZAM). Sample sizes were kept to a minimum (0.01 ct – 0.26 ct) to maximize the quantity of emeralds mounted on each stud for analysis in the scanning electron microscope (SEM). By maximizing the number of samples per stud, any contamination from successive openings of the chamber door of the SEM during data acquisition is minimized.

Sample preparation and analytical equipment

The emerald samples were mounted on cylindrical SEM studs custom crafted for this research from 6061-T6 aluminium to a diameter of 15 mm and a depth of 10 mm. The studs were soaked overnight in optical grade methanol and rinsed afterwards with fresh methanol to remove trace impurities on the stud surface. Emerald specimens were surface cleaned with a polishing cloth (3M High-Performance Polishing Cloth) and rinsed in methanol to remove epidermis oils, aerosols, residues of filling resins and any other extraneous particulates capable of altering the accuracy of chemical analysis. Following sample preparation, all emerald samples were immediately affixed to the aluminium studs using BUSCH Silber Leitlack silver conductive paint to ensure electrical contact with the SEM stage and to minimize sample charging. To optimize the validity of the elemental analysis results, sputter coating was not employed.

Elemental analysis was performed using an Amray (Bedford, Massachusetts) scanning electron microscope (SEM) coupled to an EDAX (Mahwah, New Jersey) CDU Leap Detector (model AMR-1200B) energy dispersive X-ray spectrometer (EDX). Initial calibration of the energy scale of the EDAX unit was performed using an uncoated piece of sheet copper over approximately one-half of the underlying aluminium stud (Cu-Al stud) and cross checked with a stud-mounted bead of casting alloy (Stuller, Inc.), also uncoated, composed of precise amounts of Ag, Cu, Zn, B and Si. Calibration was continuously performed throughout the research, using the standardized Cu-Al stud. For analysis using SEM-EDAX, the emerald sample studs were pressure mounted to the SEM stage with carbon adhesive tape (SPI Supplies, Inc.), tilted 30° with respect to the horizontal, and the sample stage was clamped to reduce vibration. The EDX detector was positioned at a working distance of 4.5 cm and the electron beam was rastered across the sample to average out any point-to-point chemical zoning or any variation resulting from inclusions, organic fracture filling, and/or surface contamination. The size of the raster field was adjusted to subtend a maximal surface area across only the emerald surface. The EDX was operated at an acceleration voltage of 30 kV, which produced an average of 2000 counts per second (cps) during a 200s acquisition interval; average dead time was between 10% and 15%. The electron beam spot size and acquisition times were periodically adjusted to maintain 2000 cps between samples in order to avoid morphology-induced intensity fluctuations that might alter the signal to noise ratio between experimental runs across the 36 emerald samples. To minimize drift, calibration was performed between all subsequent chamber evacuations using the standardized Cu-Al stud by adjusting the gain and zero offset controls to 8.038 keV for Cu and 1.485 keV for Al.

SEM-EDX, as is clearly relayed by Walzak, Davidson, and Biesinger (1998), "is the workhorse of many analyses because of the power inherent in being able to provide a pictorial representation combined with an elemental analysis" (p.

317). The pictorial representation of the sample through SEM methods allowed the emerald's morphology, surface matrix, and any inclusions to be chemically evaluated using point analysis prior to rastering the sample surface. In conjunction with SEM, EDX analysis provides a sensitive platform for reliable elemental analysis down to 0.01% by atomic weight (Chattopadhyay, Galeska, and Papadimitrakopoulos, 2002).

Quantification of X-ray data

Chemical interpretation of the EDX data was performed using the PC-based EDAX International DX-4:Edx-Zaf analysis software. The analytical software identifies peaks by evaluating spectral regions in comparison to the mean baseline. Energy emissions less than 0.266 keV are not detected due to the beryllium window in the EDAX, although beryllium windows provide more robust count rates by eliminating pile-up effects. Elemental abundances were normalized and reported by the software in both weight and atomic percentages (at.%) — the percentage of any one type of atom with respect to the total number of atoms that compose the mass. Preliminary analysis of the atomic percentages for all 36 emerald samples revealed that the composition of all emerald samples is fully described by 24 elements. Because some samples contained fewer elements, each of the 144 spectra were re-quantified and normalized to include all 24 elements; a group that ranged from carbon at 0.28 keV to mercury at 9.03 keV (see *Figure 2*).

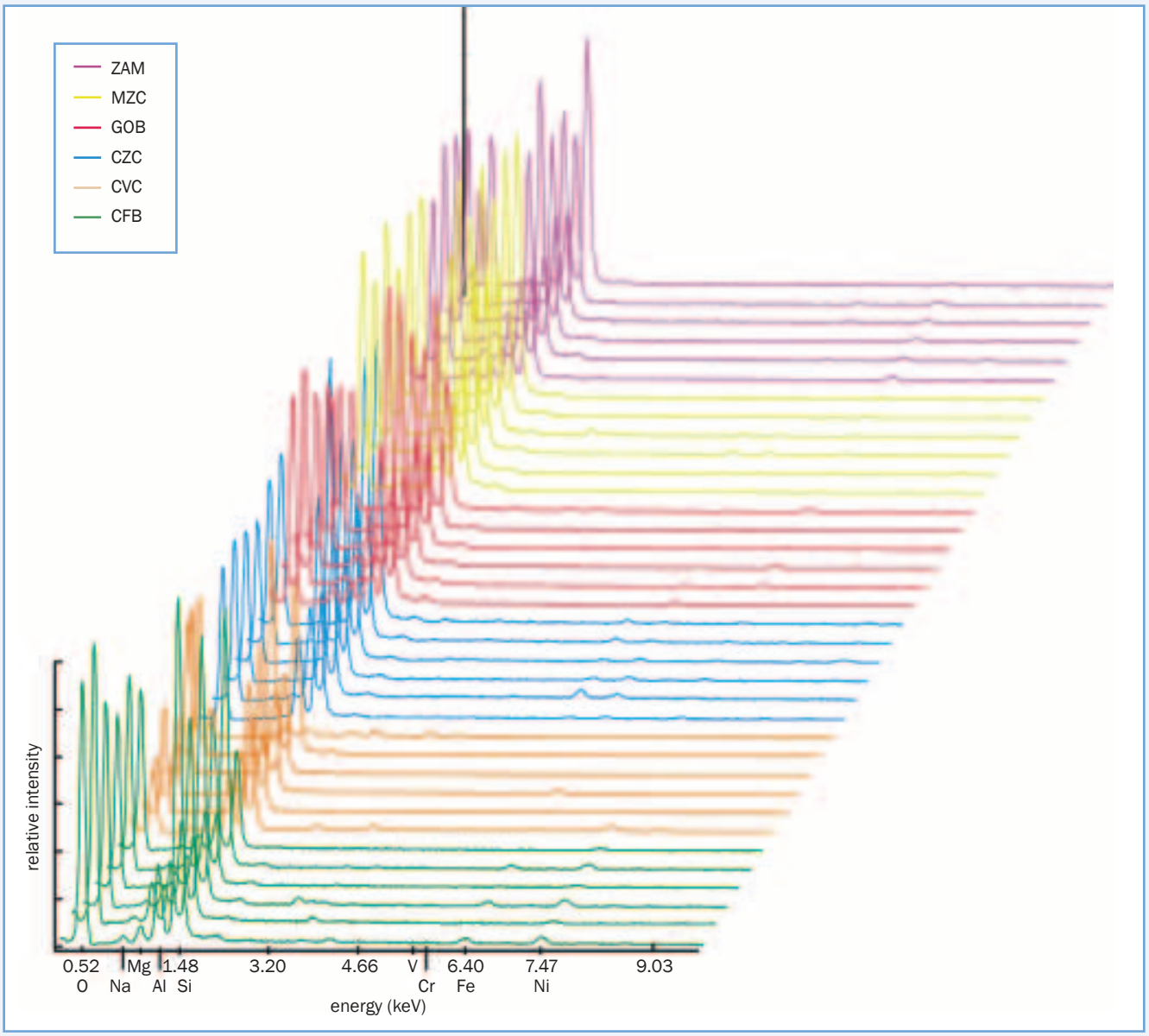

Figure 2: EDX spectra for all emerald samples showing the relative intensity of the individual elements by increasing energy level, from carbon to mercury, within each raster scan. The graphic is only intended to show minor changes in elemental trends for within sites and between sites.

Analysis of variance (ANOVA)

While many statistical procedures exist for scientific research, choosing the correct procedure is the most important component of any work and the correct choice lends validity and reliability to the results. Analysis of variance (ANOVA)* was employed to evaluate whether emeralds grouped according to geographical point of origin are statistically distinguishable based on their chemical signature. In setting out to show chemical homogeneity within sites and chemical heterogeneity between sites, the null hypothesis — that all emeralds have similar chemical compositions regardless of their geographical point of origin — was tested using original software written in MATLAB 5.3.0 (The MathWorks, Inc.). By demonstrating that the null hypothesis is not statistically supported, it can be concluded that the research hypothesis has merit (a high probability of being true). Applied to this work, this means that chemical heterogeneity exists between natural emerald points of origin which is sufficiently different to enable distinction of any of the six emerald mining localities from any of the remaining five. A null hypothesis is an opposing statement to the research hypothesis that can never be proven true but can be scientifically proven false. A null hypothesis is an important scientific component anytime the methods are designed to test the significance of differences between data sets. The MATLAB source code was written and employed to be an expeditious data analysis tool. The source code automatically imported the DX-4 eDX ZAF data acquired through EDX analysis, performed 1536 single factorial ANOVA tests and calculated the corresponding Fisher scores (F-scores)† for each ANOVA.

For the six emerald mining localities in this study, 64 site combinations (2^6) are possible, as can be viewed on the left graphic of *Figure 3*. However, seven site combinations have fewer than two sites represented and are empirically meaningless for this work. Consequently, the MATLAB source code performed 1368 meaningful ANOVA tests. Each of the 57 meaningful site combinations was evaluated 24 times, once each for the 24 elements quantified and normalized for each sample. The precision of the MATLAB source code algorithm was confirmed following the research and determined to be better than 10^{-5} and its accuracy was validated to the hundredths place by comparing a random subset of F-score results to those calculated using the SAS Institute, Inc. SAS 9.1.3 statistical analysis software.

Due to the site- and sample-specific variations in the number of sites during data analysis and the number of ANOVA tests performed, the degrees of freedom from test-to-test were in constant flux. Within the MATLAB source code the degrees of freedom for each ANOVA, which are used to determine the critical value and F-score, were calculated in accord with standard ANOVA execution as:

$$df_b = k-1 \quad (1)$$

and

$$df_w = k(n-1) \quad (2)$$

where df_b is the degrees of freedom between groups, df_w is the degrees of freedom within groups, k is the number of mining localities in each meaningful site combination (2 to 6) and n is the number of emeralds sampled from each mining locality (n=6). Hence, when evaluating the site combination that includes all six sites, the obtained F-score (F_{obt}) is compared against an F distribution based on 5 (df_b= 6-1) and 30 (df_w= 6(6-1)) degrees of freedom ($F_{5,30}$).

Critical values of the F distribution were obtained using the conventional significance value of 0.05 (α=0.05) (Howell, 2002; Kanji, 1993; Rohlf and Sokal, 1994), which corresponds to a probability (P) of less than or equal to 5% ($P \leq 0.05$) of making a Type I error. A Type I error is when the statistical results erroneously reject a null hypothesis that is actually true. To insure the ANOVA results are as robust as possible, the data were also evaluated at the scrutiny of α=0.025 ($P \leq 0.025$) and α=0.01 ($P \leq 0.01$) in order to identify the trace elements most responsible for distinguishing between emerald points of origin based on chemical signature. All ANOVA F-scores that exceed their corresponding critical value are considered statistically significant and their null hypothesis is rejected. Hence, F-scores larger than their corresponding critical values represent emerald mining sites that yield distinct emerald chemical signatures that exhibit a statistically significant difference in the atomic percentage of

* ANOVA is used to determine and evaluate how much of the variation in element-specific atomic percentages and element-combined atomic percentages can be attributed to variation between the mining sites sampled and how much can be attributed to factors other than those being explored. This within-site variation is considered in one category as error because the research makes no attempt to identify those factors responsible for the variation.

† The F-score is a point on a positively skewed F distribution matrix that enables the researchers to determine if a null hypothesis should be rejected based on a given statistical probability determined before research is performed. By selecting a statistical probability criterion for rejection prior to beginning the research, a critical value under the F distribution is assigned based on the degrees of freedom. If the F-score calculated by the ANOVA is greater than the critical value, the null hypothesis is rejected and the research hypothesis accepted. The greater the difference between the F-score and the critical value, the more reliable the statistical results are.

the element being evaluated compared to the remaining five emerald sampling sites included in this work. In total, 1425 meaningful null hypotheses are defined within the framework of this research. These null hypotheses correspond to 57 site combinations evaluated for 24 elements (1368 element-wise ANOVAs), and 57 summary comparisons that consider whether at least one element exerts a distinguishing effect for each site combination.

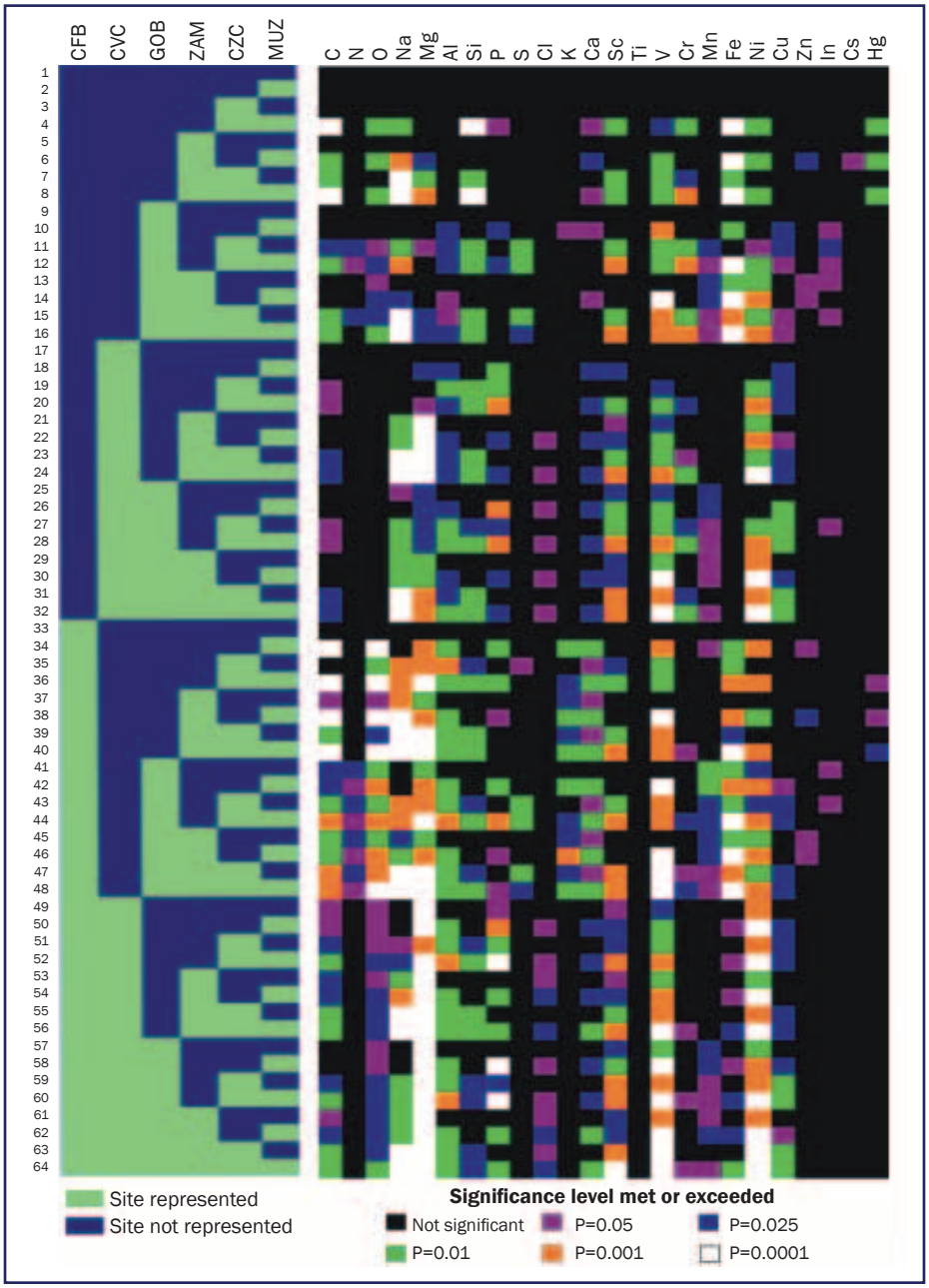

Figure 3: Graphical representation of both the site combination matrix used in each ANOVA analysis and the statistical results for each of the 24 elements included in the site combination ANOVA (site combinations and ANOVA results share the same row). Because the research only looked for statistically significant results, those elements that failed to have F-scores exceeding their critical value are blacked out. There are 64 rows (reading from the top) and those that are not meaningful have rows that are completely blacked out. The most important result for this work is the bottom row where all six sites included in this research are compared to each other for all 24 elements. In this row the most significant discriminatory elements (colourless) are Na, Mg, Sc, V and Ni.

Results and discussion

The hypothesis of primary importance for this work is that each of the six emerald mining sites produces emeralds having chemical signatures statistically distinguishable from all other research samples included in this work through EDX and chemometrics. In comparing the 24 elements for all six sites, 16 elements differed in their abundances at a traditional significance value of P≤=0.05 (see *Table I*). Since more than one element exhibited between site heterogeneity at the significance value of P≤=0.05, we employed successively

Table I: The 16 most important emerald constituents for revealing between site chemical heterogeneity (ANOVA critical value: $F_{0.05(5,30)}$=2.53).

Element	F score	P
Mg	16.0068	<0.0001
V	10.4929	<0.0001
Ni	10.1714	<0.0001
Na	9.6558	<0.0001
Sc	7.5607	0.0001
Al	5.5040	0.0010
C	4.3288	0.0044
Cu	4.2459	0.0049
P	3.9598	0.0071
Ca	3.9000	0.0077
Fe	3.8869	0.0078
O	3.8040	0.0087
Si	3.5507	0.0122
Cl	3.2157	0.0192
Cr	3.0286	0.0249
Mn	2.6262	0.0438

NB: While one or more of the elements may provide statistical distinction between all six points of origin, each element and combination of sites must be examined to determine if statistical significance continues to exist when the degrees of freedom are affected.

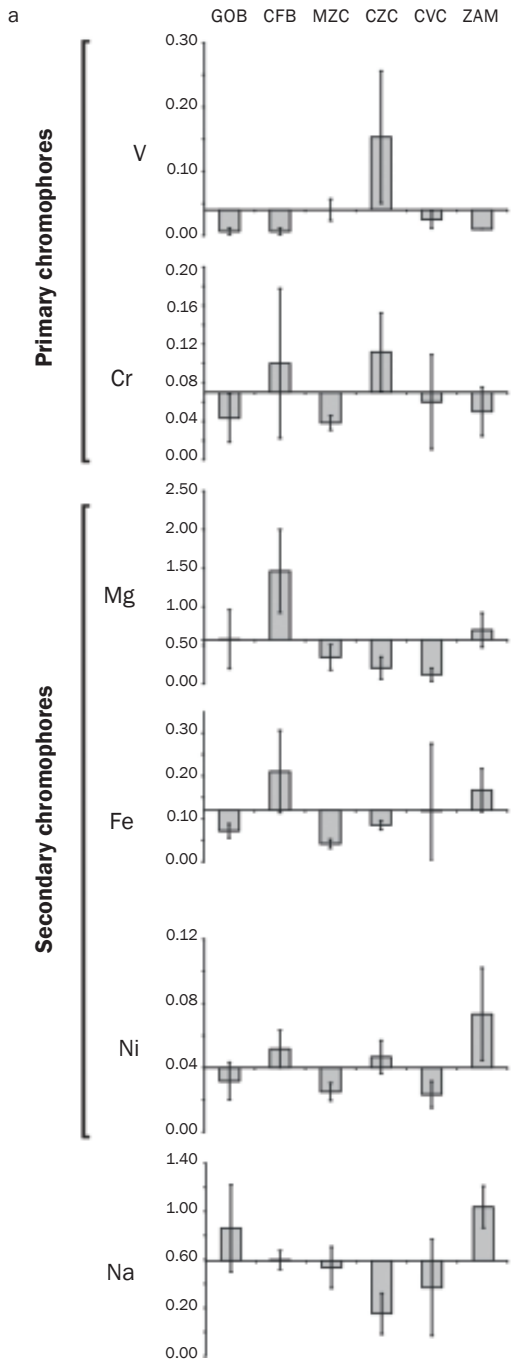

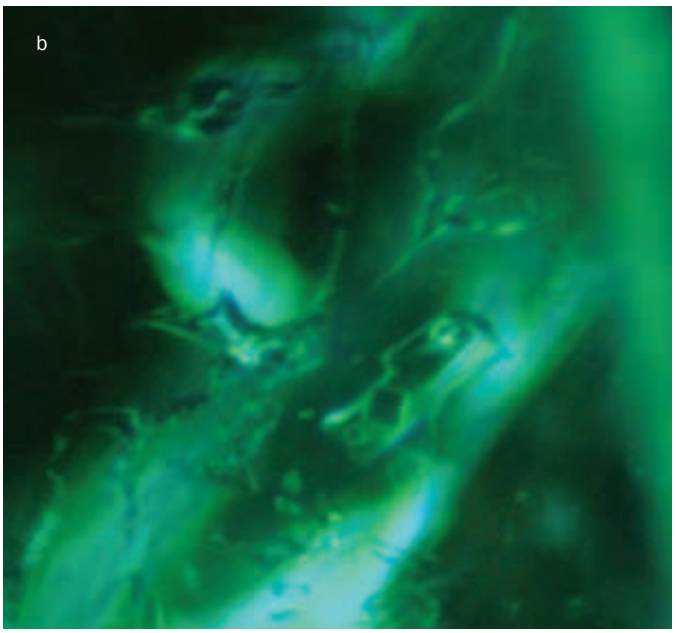

Figure 4: (a) The graphic shows site-specific trends in chromophore and sodium content among all the sampling sites. For each element, the horizontal line represents the mean atomic percentage for all sites while individual site means are represented by the parallel line capping each shaded box; coupled with vertical standard deviation whiskers. Sodium was an important aspect of a parallel piece of research given the brine solution that is the liquid component of both two- and three-phase inclusions and the sodium chloride crystals that are a common constituent in Colombian three-phase inclusions.
(b) Three-phase inclusion in a sample stone from Chivor. Photo D.P. Cronin.

smaller significance values in order to estimate which elements are the most statistically significant in indicating these differences. At the more conservative significance value of P≤=0.025, 15 elements exhibited chemical contents that are statistically distinguishable and at P≤=0.01, 12 elements continue to exhibit between site heterogeneity. As a result of these analyses, it is concluded that element-based heterogeneity does exist between the six emerald mining sites in this study. Consequently, natural emeralds originating from any one site are distinguishable from emeralds originating from any of the remaining five. Thus, through the employment of EDX in the acquisition of chemical data, statistically significant chemical heterogeneity between sites has been revealed by means of a technique that is non-destructive and preserves the integrity of the sample.

The ANOVA results provide a statistically robust estimate of whether or not differences exist among combinations of sites in a combinatorial matrix. *Figure 3* presents a graphical representation showing statistical trends by both element and site combination. As mining sites are added or removed from the matrix, consequent changes in the number of degrees of freedom result in variability among the F-scores and their corresponding significance levels for heterogeneity assessments. This variability makes pinpointing the

elements of greatest significance for additional site combinations much more complex than simply reviewing the ANOVA results for all sampling sites. In countering this tendency, *Figure 4* shows how site-specific trends in the elemental compositions are analyzed for use in conjunction with the statistical results.

As the calculated F-score (F_{obt}) for a given site combination increases, so does the probability (P) that the sampling sites differ. In other words, larger F-scores indicate a lower probability that a null hypothesis addressing a specific site sample's chemical signature was erroneously rejected. Towards ascertaining probability through as robust a modelling procedure as possible, subsequent analysis was performed for the four most important elements leading to the rejection of the combined-element null hypothesis for the summary comparison. All sites and samples remained represented and the four most important elements were identified as magnesium (F_{obt} = 16.0068; P<0.0001), vanadium (F_{obt} = 10.4929; P<0.0001), nickel (F_{obt} = 10.1714; P<0.0001) and sodium (F_{obt} = 9.6558; P<0.0001). Two other elements important to this research, the iron (F_{obt} = 3.8869; P=0.0078) and chromium (F_{obt} = 3.0286; P=0.0249) chromophores, both displayed statistically significant results as well. Furthermore, vanadium and magnesium, alone, are capable of differentiating the geographic point of origin of an emerald for 56 of the 57 relevant site combinations. By extending the analysis to include an additional secondary chromophore, nickel or iron, all 57 site combinations can in fact be distinguished. Because these chromophore elements are responsible for an emerald's visible colour — keeping in mind the role of Mg^{2+} that, as discussed, acts as a secondary chromophore through its ability to shift absorption spectra in emeralds — we believe that high-resolution visible absorption spectroscopy could be performed on natural emeralds in place of EDX in the future.

In addition to the primary goal of finding which elements in natural emeralds of known origins were useful in statistically establishing between-site chemical heterogeneity, the question of whether emeralds from mining locations in close proximity to one another exhibited geologically-based chemical heterogeneity was also addressed. By performing ANOVA on the chemical signatures of emeralds from the Brazilian sites, for example, we have discovered site-specific chemical differences that are consistent with the fluid-rock interactions that led to emerald precipitation. Within the context of discussing both geographically- and geologically-based chemical heterogeneity between mining locations, within-site chemical homogeneity of the six sampling sites and their chemometric results are presented according to geopolitical boundaries.

Colombia

Three of the emerald mining sites included in this research, Muzo, Guali and Cosquez, are located along the outer fringes of the traditional emerald zone of the Cordillera Oriental of Colombia. While the emerald zone of the Cordillera Oriental was once well-known for its emerald production, the zone currently has no emerald production and is better known today as the site of 'potatoes and coal'. Modern production actually occurs in two belts along the zone. Muzo and Cosquez lie in the Muzo Belt (the 1226 area) trending NNE along the western fringe of the emerald zone while Guali is a few kilometres east of Chivor in the Chivor Belt (the 1228 area) trending NE along the southeastern fringe. By performing ANOVA element-wise for each of the three Colombian sampling sites, 11 elements exhibited statistically significant differences in their elemental abundances (see *Table II*). The four most significant of the 11 elements are nickel (F_{obt} = 15.0000; P=0.0003), phosphorus (F_{obt} = 12.3774; P=0.0007), silicon (F_{obt} = 8.1434; P=0.004) and vanadium (F_{obt} = 8.0148; P=0.0043), each being well below the traditional significance level of α=0.05. Of primary interest were two of the most highly prized Colombian emerald mining localities, Muzo and Cosquez, located only 10.4 km apart. Chemical and chemometric analyses of the samples collected from the two locations unveiled statistically meaningful differences for 12 elements (see *Table III*). The four most significant of these are carbon (F_{obt} = 72.4751; P<0.0001), iron (F_{obt} = 54.5161; P<0.0001), silicon (F_{obt} = 37.2153; P=0.0001) and oxygen (F_{obt} = 20.9163; P=0.0001); with the latter two being basic framework constituents of the six-member cyclosilicate emerald crystal structure.

The results of chemometric analysis of Muzo and Cosquez samples raises

Table II: The 11 statistically significant elements revealing chemical heterogeneity between three Colombian emerald localities (ANOVA critical value: $F_{0.05(2,15)}$=3.68).

Element	F score	P
Ni	15.0000	0.0003
P	12.3774	0.0007
Si	8.1434	0.0040
V	8.0148	0.0043
Sc	7.4706	0.0056
Cr	6.2115	0.0108
Al	5.9548	0.0125
Ca	5.1033	0.0204
Cu	4.8995	0.0230
C	4.7375	0.0254
Mg	4.2431	0.0346

Table III. Twelve elements in Muzo and Cosquez emeralds showing statistically significant difference (ANOVA critical value: $F_{0.05(1,10)}$=4.97).

Element	F score	P
C	72.4751	<0.0001
Fe	54.5161	<0.0001
Si	37.2153	0.0001
O	20.9163	0.0001
Ni	20.6098	0.0011
Cr	18.8327	0.0015
Na	15.2731	0.0029
Sc	13.0000	0.0048
Hg	10.9459	0.0079
V	7.0920	0.0238
Ca	5.9756	0.0346
P	5.5479	0.0403

an important question addressing the cause of statistically significant chemical heterogeneity between emeralds drawn from localities in such close proximity to one another. Work published in references quoted above indicates that the emeralds of Colombia and the Cordillera Oriental region are the result of tectonic-hydrothermal precipitation in which emerald precipitation is generally linked to major faults or shear zones in basic and ultrabasic schistose rocks and crystal development is isolated to the fluid-rock interaction zone (see also the precipitation mechanics of emeralds in the southeast Yukon (Canada) described by Marshall *et al.,* 2003). The emeralds of the Cordillera are hosted within and around organic black shales in the western 1226 area (Guavio-Macanal) and carbonaceous black shales with intercalated dolomitic limestone in the eastern 1228 area (Rosablanca formation and Paja formation) (Cheilletz and Giuliani, 1996; Giuliani *et al.,* 1993; Banks *et al.,* 2000; Webster and Anderson, 1983). Due to the characteristically low chromium content of the organic sedimentary shale host rock of the Cordillera Oriental, the primary chromophore of the Colombian emeralds is not chromium but vanadium (Kleiðmantas and Skridlaitë, 2004).

Our results, reported in atomic percentage (at.%), reveal that the emeralds of Muzo have an average (μ) chromium content of 0.038 at.% (s.d.=0.007) that is only slightly less than their average vanadium content 0.040 at.% (s.d.=0.017), where s.d. is the standard deviation. While the vanadium content is consistent with the content average for all emerald samples included in this research (μ=0.040 at.%), the chromium content is just over one-half the content average of all samples (μ=0.067 at.%). Continued chemometric analysis of the secondary chromophore content averages revealed that magnesium (μ=0.343 at.%; s.d.=0.163) and iron (μ=0.041 at.%; s.d.=0.009) are significantly less than the magnesium (μ=0.567 at.%) and iron (μ=0.115 at.%) content averages for all other sites. Similar to the emeralds of Muzo, the Cosquez emerald samples have an average chromium content of 0.112 at.% (s.d.=0.041) that is lower in concentration than their average vanadium content of 0.150 at.% (s.d.=0.103). The secondary chromophores, again similar to the emeralds of Muzo, have magnesium contents (μ=0.205 at.%; s.d.=0.145) and iron contents (μ=0.085 at.%; s.d.=0.010) well below the content averages for all emerald samples in this research. However, unlike the Muzo emerald samples, the average vanadium content of the Cosquez emerald samples is nearly four times the average vanadium content of all samples (μ=0.040 at.%) and the chromium content is nearly twice that of all samples included in this work (μ=0.067 at.%).

While the contents of primary and secondary chromophores are invaluable in acquiring statistical knowledge that helps to separate the point of origin of emeralds, their position and concentration within the crystal structure help explain the prized colour of emeralds from in and around the Cordillera Oriental. The elevated concentration of vanadium in comparison to chromium, in comparison to chromium (11.6×10^{-24} cm^3), results in a stable spectral identity from the primary chromophores and a near absence of red-shifting due to the low concentration of secondary chromophores.

In stark contrast to the emeralds of Muzo and Cosquez, the average chromium content of Guali emeralds is 0.060 at.% (s.d.=0.049), 2.5× their vanadium content average of 0.025 at.% (s.d.=0.014) and 0.625× the average vanadium content of all samples included in this research (μ=0.040 at.%); having a chromium content similar to the average chromium content of all samples (μ=0.067 at.%). Analysis of the secondary chromophore content averages reveals that while magnesium's content average of 0.118 at.% (s.d.=0.083) is only one-fifth the magnesium content average of all samples (μ=0.567 at.%), iron (μ=0.118 at.%; s.d.=0.157) is nearly identical to the mean atomic percentage of iron (μ=0.115 at.%) for all samples included in this work. Although the Guali emerald samples, similar to Muzo emeralds, have a lower concentration of primary chromophores compared to the other mining localities, the relatively low concentration of secondary chromophores has resulted in absorption band stability and their richer hue and chroma.

Consistent with the research of Kleiðmantas and Skridlaië (2004), our results indicate a greater concentration of vanadium in the crystal structure of natural emeralds from the Cordillera Oriental. Their formation stems from the movement of Be-enriched hydrothermal fluids directed by tectonic events that concentrates fluid circulation along post-tectonic structures. Fluid inclusion research of minerals from rocks in the Cordillera has revealed that the mineral-forming hydrothermal fluids are of magmatic origins west of the Cordillera and of mixed magmatic/meteoric origins east of the Cordillera, with beryllium acquisition occurring during saline brine migration (Giuliani *et al.,* 2000; Schwarz and Giuliani, 2001). The consequential fluid-rock dynamics leading to metasomatic alteration of the sedimentary series incorporates the primary chromophore vanadium from the V-rich organic and carbonaceous shales of the Cordillera (Schwarz and Giuliani, 2001; Cheilletz and Giuliani, 1996; Giuliani *et al.,* 1993). The heightened concentration of vanadium in comparison to chromium primary chromophore leads to the characteristic green colour of the emeralds from Muzo and Cosquez. In contrast, the concentration ratio of chromium/vanadium (24:10) in the Guali emeralds indicates that chromium is the primary chromophore. Collectively, the emeralds of Colombia owe their colour not only to the contents of the primary chromophores, but also to the relatively depleted atomic percentage of secondary chromophores that would normally compete for similar positions in the crystal structure. The lack of secondary chromophore accumulation lends stability to the absorption bands created by the primary chromophores, thereby providing a rich chroma to an unaltered visible hue (Platonov, Taran and Balitsky, 1984; Braga *et al.,* 2002). As a consequence of

Table IV: Eight elements revealing chemical heterogeneity between the emeralds of Campos Verde and Carnaíba, Brazil at a critical value of 4.97 ($F_{0.05(1,10)}$=4.97).

Element	F score	P
O	15.8013	0.0026
Mn	14.4118	0.0035
Fe	12.1413	0.0059
Mg	10.7379	0.0083
N	9.2813	0.0123
Ni	8.7805	0.0142
C	7.9807	0.0180
In	5.2941	0.0442

the temperature and pressure reductions experienced by migrating hydrothermal fluids, emerald was co-precipitated with fluorite in pyritic, albitic and calcitic veins, fissures and vugs within brecciated black organic shales and sedimentary calcium-carbonate formations (Giuliani *et al.,* 2000; Banks *et al.,* 2000; Cheilletz *et al.,* 1994). The order of precipitation depleted secondary chromophores in solution prior to emerald precipitation; this is most apparent at Muzo where a distinct Fe depletion occurs due to pyritic precipitation prior to emerald formation.

Chemical heterogeneity between the organic sedimentary shales hosting emerald both west and east of the Cordillera Oriental, along with the widely proposed thermochemical reduction of evaporitic sulphate brines and the oxidation of organic matter originating in the black shale, account for the compositional differences of emeralds originating on opposing sides of the Cordillera (Giuliani *et al.,* 2000). What is not as clear is the cause of chemical heterogeneity between the two closely situated emerald occurrences west of the Cordillera in the Guavio-Macanal formation (Muzo mine and Cosquez mine). Banks *et al.* (2000) discovered that although Muzo and Cosquez are the result of the same subsurface fluid-host rock interaction, the intrinsic permeability, and consequently the hydraulic conductivity of the formations, was altered during a continuous stage of faulting and deformation during tectonic activity. As a result, migrating hydrothermal fluid dynamics were affected and multiple paths of fluid migration through the subsurface occurred in a way that allowed each path to acquire its own chemical identity. Thus, it is likely that the changing chemistry of the hydrothermal fluids during migration, along with the late stage precipitation of emerald crystals at Cosquez, are responsible for the compositional differences of emeralds originating at the neighbouring mines of Muzo and Cosquez in the 1226 area.

Brazil

Of the ANOVAs performed for the compositions of emeralds from the two Brazilian mines Campos Verdes and Carnaíba (line 41 of the combinatorial matrix in *Figure 3*), eight elements were found to be significant at P≤=0.05 (see *Table IV*). Of these, the four most significant elements are oxygen (F_{obt} = 15.8013; P=0.0026), manganese (F_{obt} = 14.4118; P=0.0035), iron (F_{obt} = 12.1413; P=0.0059) and magnesium (F_{obt} = 10.7379; P=0.0083), which are the only elements to remain significant at P=0.01. Although the secondary chromophores, iron and magnesium, are statistically important in differentiating the Brazilian mines at P=0.01, the concentrations of the primary chromophores (vanadium and chromium) are insignificant; a stark contrast to the chemical results for emeralds sampled from Colombia.

In comparing Campos Verdes and Carnaíba emeralds, vanadium yields an F-score of 0.00 (P=1.0) while chromium yields an F-score of 2.89 (P=0.12). Vanadium's probability of 1.0 (P=1.0) indicates a 100% chance of making a Type I error for the null hypothesis that the vanadium content of emeralds originating from Campos Verdes and Carnaíba are the same. This result reflects the near absence of vanadium in the Carnaíba and Campos Verdes samples. Our results, reported in atomic percentage, reveal that the emeralds of Campos Verdes have an average chromium content of 0.043 at.% (s.d.=0.025) six times greater than their average vanadium content of 0.007 at.% (s.d.=0.005) and the Carnaíba emeralds have an average chromium content of 0.100 at.% (s.d.=0.078) that is 15 times greater than their vanadium content of 0.007 at.% (s.d.=0.005). Overall, the Brazilian emeralds have a much higher chromium-vanadium content ratio than the Colombian emeralds, ranging from 64:10 for Campos Verdes to 151:10 for Carnaíba.

Analysis of the secondary chromophore content averages for Carnaíba reveals that the magnesium content average of 1.462 at.% (s.d.=0.538) and iron content average of 0.210 at.% (s.d.=0.096) are 2.57× and 1.90×, respectively, more than the content averages of magnesium (μ=0.567 at.%) and iron (μ=0.115 at.%) for all sites sampled for this work. In contrast, Campos Verdes emerald samples have a magnesium content average of 0.578 at.% (s.d.=0.382) and iron content average of 0.072 at.% (s.d.=0.016) that are 1.02× and 0.62× the content averages for all samples. While the primary chromophore concentration of the Brazilian sampling sites are elevated compared to the other sites sampled, the higher concentrations of secondary chromophores lead to increased red-shifting and a green hue that is not as saturated or distinct as that in their Colombian counterparts.

Examination of the emerald precipitation models for the Brazilian sites uncovers some of the causative differences between the chromophore concentrations in Colombian and Brazilian emeralds while lending insight into the unique chemical signatures of the samples from each of the Brazilian mining locations. The emeralds of Campos Verdes are best explained by the tectonic-hydrothermal precipitation model while the Carnaíba emeralds are more consistent with the magmatic associations model. The events leading to emerald precipitation at Carnaíba began with the intrusion of Be-rich granitic fluids through Archean rock (Campo Formosa ultramafic complex, Mundo Novo Greenstone belt and gneissic-migmatitic basement rock) and the Serra da Jacobina volcanic-sedimentary series (Cruz das

Almas, Rio do Ouro and Serra do Córrego formations) (Giuliani *et al.,* 1990; Webster and Anderson, 1983). Fluid migration was catalysed with the formation of fracture zones and faults resulting from tectonic deformation. Hydrothermal fluid ultimately migrated through the labyrinth of natural conduits created by the faults and fracture zones and metasomatically altered and broke down the mineral components of the schistose rock through deuteric reactions and other fluid-rock reactions. Fluid-rock interactions led to the progression of element enrichment of the hydrothermal solution preceding emerald precipitation in the peripheral veins of the pegmatite and metasomatically developed alteration haloes (Marshall *et al.,* 2003; Schwarz and Giuliani, 2001; Istituto di Geoscienze e Georisorse Sezione di Roma-Consiglio Nazionale delle Ricerche, 2005). As one might expect, the chemistry of the Carnaíba emeralds reflects the chemistry of the Serra da Jacobina rocks metasomatically altered to Mg-, C-, Ca- and Fe-rich biotite, carbonate-biotite and carbonate-biotite-talc schists (Giuliani *et al.,* 1990; Webster and Anderson, 1983). The lack of vanadium in the emeralds of Carnaíba is not completely understood but generally thought to be a consequence of the lack of organic complexes and the scarce association of vanadium-bearing mafic rocks with beryllium during metamorphic chemical exchange resulting from post-tectonic events.

Research of the sub-surface dynamics of the Campos Verdes region has shown distinct similarities to the emerald formation of the Colombian sample sites. Formation of the emeralds is consistent with the tectonic-hydrothermal precipitation model and results from tectonic fracture zones and faulting that catalysed Be-rich hydrothermal fluid migration through the host Santa Terezinha sequence. The metasedimentary formations of the Santa Terezinha sequence, greenstone schist and intercalated country rock (talc schist, carbonate-talc schist, chlorite-talc schist, biotite schist and dolomite schist) resulted from polyphase tectonic deformation (dip and rotation) and thrust faults (Kleiðmantas and Skridlaitë, 2004; Biondi, 1990; D'el-Rey Silva and de Souza Barros Neto, 2002). Hydrothermal fluid movement through the C-, K-, Cr- and Fe-rich metasedimentary formations led to metasomatism in which the fluid acquired chromophores and other trace elements prior to precipitating in alteration haloes and veins (D'el-Rey Silva and de Souza Barros Neto, 2002; Biondi, 1990).

Zambia

Although located more than 5000 miles across the Atlantic Ocean from Carnaíba, within Sub-Saharan Africa, the emeralds of the Chantete mine have also been shown to have resulted from the magmatic association precipitation model.

An examination of the atomic percentages for Chantete emeralds reveals that the content averages of magnesium (μ=0.697 at.%), nickel (μ=0.073 at.%), sodium (μ=1.036 at.%) and iron (μ=0.167 at.%) exceed the content averages of magnesium (μ=0.541 at.%), nickel (μ=0.073 at.%), sodium (μ=0.502 at.%), and iron (μ=0.105 at.%) for the samples from all remaining sites by 1.28× to 2.06×; in contrast, the vanadium content average of 0.01 at.% is extremely low and only approximately one-fifth the vanadium content average of 0.046 at.% for all remaining sites in this research. Chromium is the dominant primary chromophore, but in the emerald spectra, the Cr peaks show significant red shifts due to secondary chromophores.

The Chantete mine is located in the Ndola Rural Protected Area of the Lufwanyama district in the Copperbelt Province of Zambia. The Ndola region consists of a complex series of pegmatite dykes that penetrate thin zones of the meta-sedimentary Muva supergroup (biotite-phlogopite schist around talc-magnetite schist and tremolite-chlorite-magnetite schist) (Coakley, 2001). In the Chantete magmatic association precipitation model, metamorphism prior to emerald mineralization results from beryllium-laden granitic fluid intruding the chromium-vanadium rich basic-ultrabasic schistose host rock (Sinkankas and Read, 1986; Giuliani *et al.,* 1997; Coakley, 2001; Kleiðmantas and Skridlaitë, 2004; Zwaan *et al.,* 2005). Fluid migration occurs discordantly through the basement supergroup (granitic gneiss and migmatite) and Muva supergroup (Coakley, 2001; Zambian Ministry of Mines and Minerals Development, 2006) with quartz and tourmaline commonly precipitated first in the veins. Emerald precipitation occurs within the resultant alteration haloes and veins at the pegmatite-schist contact which cross-cuts the biotite-phlogopite schist that developed as a result of metasomatic alteration of the talc-magnetite schist formation (Coakley, 2001; Laurs, 2004; Zwaan *et al.,* 2005; Marshall *et al.,* 2003).

Conclusions

Initial investigations concerned interstitial fluid migration and tectonic precipitation dynamics of natural emeralds in and around the Cordillera Oriental, Colombia. Chemical and chemometric analyses of trace elements in the emeralds revealed that the chromophore constituents are the most statistically significant in evaluating chemical heterogeneity between the mining localities. In response to this unexpected twist, the research expanded to include three additional sites beyond the geopolitical boundary of Colombia — mining localities in Brazil and Zambia — towards determining whether chromophore constituents would remain statistically significant and useful in describing between site chemical heterogeneity. The results of this work reveal that chemical heterogeneity does statistically exist between natural emeralds and that vanadium, nickel and magnesium are site-specific elements capable of being used in a statistically significant way to distinguish the source locality of a natural emerald randomly chosen from any of the six emerald origins included in this work.

However, the results of this research are just a first step. Whereas this study has revealed the extent of chemical heterogeneity between six sites of gemmological importance, it has not assessed the compositions of all historical

and modern emeralds. But chemical links between emeralds, site heterogeneity and chromophores have been established, and this research opens up a whole new realm of possibility for determining the point of origin for natural emeralds, and perhaps other mineral species and varieties. Furthermore, because the three most important elements in site-specific chemical heterogeneity are vanadium and nickel, both chromophores and magnesium, which acts like a secondary chromophore by red-shifting the absorption bands, we believe that high-resolution visible absorption spectroscopy could be performed on natural emeralds in place of EDX. Visible absorption spectroscopy, similar to EDX, is a nondestructive analytical technique that can yield a quantitative assessment of an emerald's defined colour; an optical property measured subjectively within conventional emerald valuation processes. When this information is linked to the chemical signature of specific geographical points of origin, visible absorption spectroscopy could be used to discern the geographic origins of an emerald sample in a much more efficient and expeditious manner. We hope to both add to the growing foundation of emerald chemistries in the future through continued sampling and, in conjunction with our growing database, use chromophore data and high-resolution visible absorption spectroscopy to reveal how spectral analysis of natural emeralds may be used to determine the point of origin for samples with unknown provenance.

Acknowledgements

The authors are grateful to several individuals for lending their time and expertise to this work. We thank Jim Barker of the Cleveland State University Fenn College of Engineering for his assistance and guidance in procuring SEM-EDX data. We are indebted to Dr John F. Turner II for all his time, support, and guidance leading to this work. In addition, Dr Turner played an integral role in creating the source code enabling hundreds of analysis of variance to be performed in an expeditious manner; generating the hundreds of statistical results used in this work.

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Morphological and gemmological features of gem-quality spinel from the Goron deposit, southwestern Pamirs, Tajikistan

S.A. Ananyev and S.I. Konovalenko

Abstract: Spinel of gem quality from the Goron deposit, Shakhdarinsky Ridge, southwestern Pamirs, Tajikistan, is described. Its source is an essentially bimineralic spinel-chlorite rock with up to 54% by weight of spinel. Many euhedral crystals have stepped tabular growth surfaces and are up to 20 mm across. Colour is generally homogeneous and may be pink or violet. Ferrous iron is the dominant chromophore, and most crystals are distinctly more violet in daylight and pinker in incandescent light.

Keywords: colour change, gem-quality spinel, Goron, Pamir mountains, Tajikistan

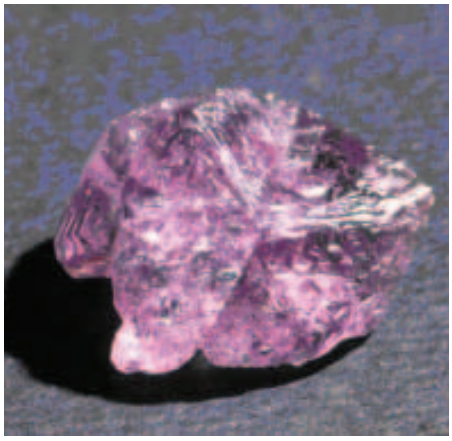

1. Introduction

In summer 1989 the authors discovered spinel of gem quality in the upper reaches of the Goron River, a left-hand tributary of the Badomdara River which is a left-hand tributary of the Shakhdara River in the Shakhdarinsky Ridge area of the southwestern Pamir Mountains *(Figure 1)*. The locality has the coordinates 37° 05' 22.4" N and 71° 44' 32.7" E at a height of about 5000 m. Exposure is sporadic and depends on snow/ice levels. The geology of this area was described by Konovalenko *et al.* (1991) but gemmological features of the spinels were not included and it is the purpose of this paper to fill this gap. Gem-quality spinel is also known in this general area from Kuh-i-lal which is approximately 30 km distant to the northwest.

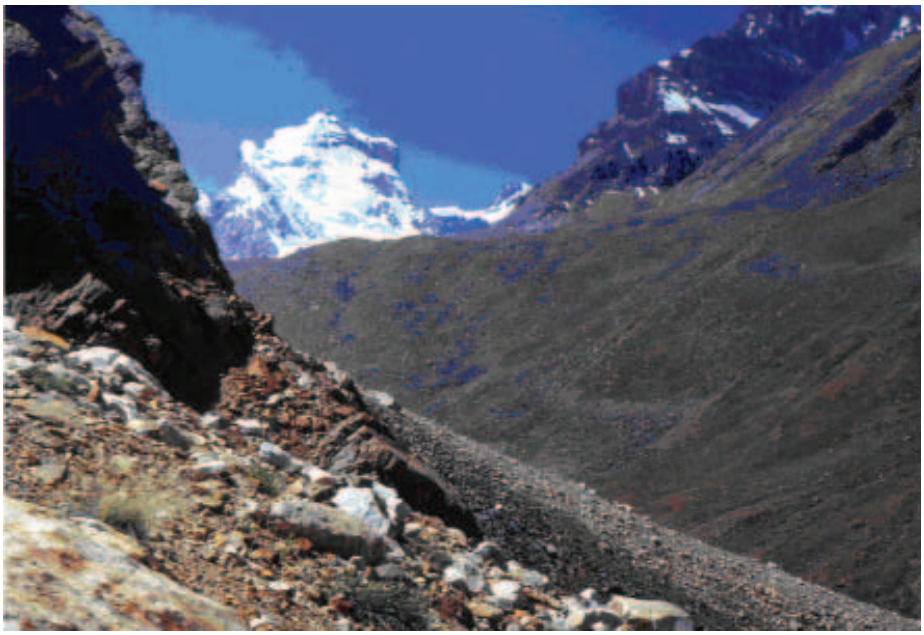

Figure 1: Screes containing rock fragments with gem-quality spinel in the Goron River Valley, southwestern Pamir mountains, Tajikistan. In the distance is the peak Shpil, SW of the spinel locality.

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2. Geological background

The Goron spinels occur at the base of the Vakhanskaya horizon in the upper part of the Archaean Goran Series (Konovalenko *et al*., 1991). This horizon consists of pale grey gneiss and migmatite with intercalated thick and extensive calcite-dolomite, dolomite, and dolomite-magnesite marbles, which themselves are the hosts to skarns. The alteration processes in these skarns have produced mineral assemblages consisting of spinel, forsterite, phlogopite and enstatite. In turn and in places, these have suffered further alteration to talc, serpentine and chlorite. The gem-quality spinel is associated with altered forsterite and almost all is now found in bi-mineralic chlorite-spinel pockets and filled cavities or in veins several metres long and up to 0.2 m thick *(Figure 2)*.

By volume the grey-green chlorite (clinochlore) marginally exceeds that of spinel, but by weight, spinel forms about 54% of the rock, with about 1% accessory minerals. Of the latter, the commonest is orange clinohumite which can be present as much-fractured concretions up to 5 cm across. Very much rarer are columnar crystals up to 1 mm across of black ilmenite and, in pockets, a range of low-temperature hydrothermal minerals including aragonite, hydrotalcite and manasseite. At their contacts, some spinel-chlorite clusters can merge into massive green to black-green serpentine rock.

3. Spinel

(a) Morphology

Spinel crystals are commonly octahedral or show twins on (111) planes and have stepped-tabular patterns or structures on their crystal faces; other crystals may be complex aggregates, and many may show traces of partial dissolution (see *Figures 3, 4*). All these habits are strongly idiomorphic to the co-existing chlorite in the rock, and the flakes of chlorite are adjusted to the adjacent spinel plane surfaces with their basal planes oriented along them. This makes the spinel-chlorite assemblage easily processable. Spinel crystals can be manually extracted from the softer chlorite host, leaving 'faceted nests' with complex patterns of imprinted octahedral planes on the walls. Some spinel crystals have narrow, crack-like dips on their surfaces which are filled with chlorite; these are the result of partial dissolution along composition planes or aggregate boundaries. But fractures are rare in the

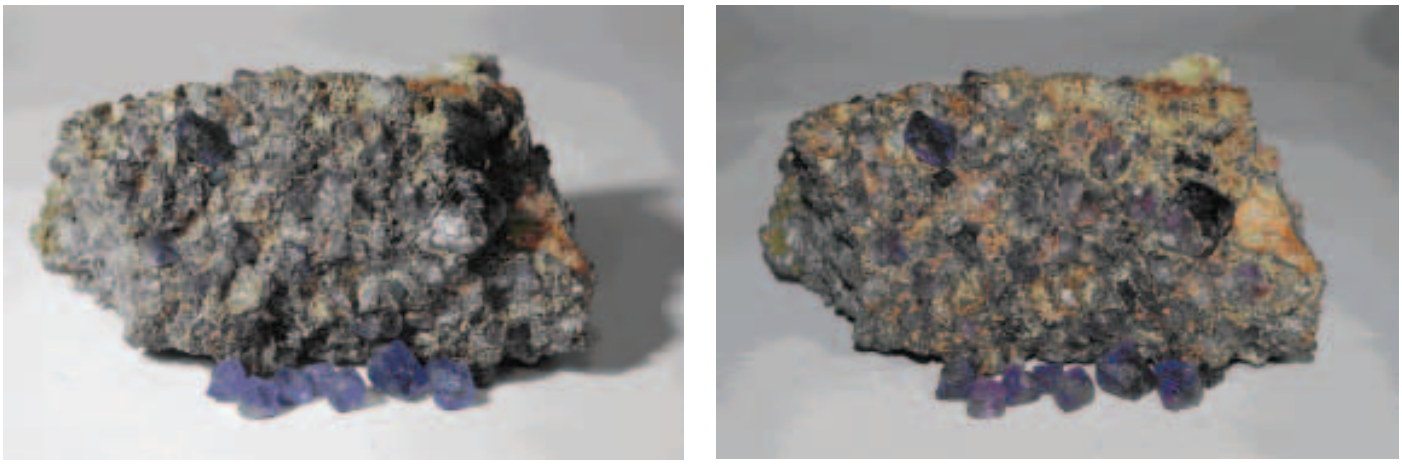

Figure 2: Spinel-chlorite aggregate with some minor clinohumite behind spinel crystals recovered from nearby rocks; the aggregate measures 14×8×7 cm. Photographed in daylight, left, and in incandescent light, right.

Figure 3: Spinels with stepped tabular crystal surfaces.

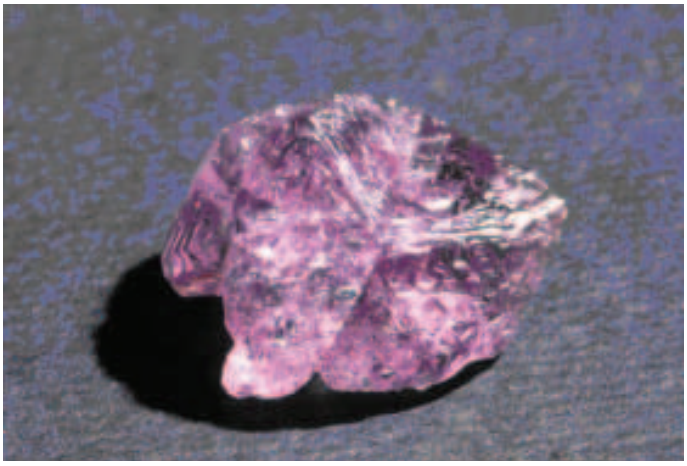

Figure 4: Spinel aggregate showing (111) twin plane and stepped octahedral faces.

Table I: Morphological and weight analysis of spinels from Goron deposit.

Type no.	Morphological types of crystals		Average size mm	Number of crystals	Content of crystals	Weight of crystals	Weight %
1	Octahedrons and octahedron fragments with at least four faces		7–12	11	1.37	16.60	7.89
			5–7	53	6.58	23.68	11.25
			3–5	120	14.91	22.86	10.86
Sub-total:				184	22.96	63.14	29.99
2	Crystal aggregates	Twins	7–15	26	3.23	28.11	13.35
			5–7	45	5.59	20.87	9.91
			3–5	201	24.97	41.74	19.83
		Three individuals	3–10	13	1.61	3.74	1.78
		Four individuals	3–7	2	0.25	0.81	0.38
Sub-total:				287	35.65	95.27	45.25
3	Shapeless crystals		5–10	96	11.93	29.63	14.07
			1.5–5	238	29.57	22.48	10.68
Sub-total:				334	41.49	52.11	24.76
Total:				**805**	**100.00**	**210.52**	**100.00**

spinel crystals and chlorite has not been found as an inclusion.

A sample of typical spinels weighing 210.52 g recovered from 389.85 g of rock from the Goron deposit in 1989 is categorized in *Table I*.

From *Table I* it is clear that in this sample, aggregates and shapeless crystals of spinel predominate. However, approximately a quarter are of gem quality, weighing between 1.5 and 11 ct. The average yield of cut stones from the gem-quality rough is about 20%, but recovery from some larger crystals can reach 40–50%.

(b) Gemmology

The size of the gem-quality spinel crystals ranges from 3 to 20 mm and they are consistently transparent. Their refractive index (RI) is 1.732 ± 0.002 and specific gravity (SG) 3.592. The average of three electron microprobe analyses is as follows:

	Wt.% oxide
TiO_2	0.10
Al_2O_3	71.26
Cr_2O_3	0.01
FeO	2.29
MgO	26.31
MnO_2	0.02
Total	99.99

This corresponds to the formula $(Mg_{.933}Fe_{.044})_{.977}(Al_{2.012}Ti_{.002})O_{3.997}$. The Mossbauer spectrum confirmed that the iron is present as ferrous iron.

The colours of the spinel crystals range from pink to violet and optical spectra obtained using the UMSP-50 spectrophotometer manufactured by Optan (Germany) indicate the presence of two main absorption bands: a narrow weak band at 459 nm and broader band centred at 560 nm. Any possible peaks attributable to Ti, Cr or Mn were not detected. However, a moderately intense emission band at 520–540 nm in the X-ray emission spectrum is attributed to Mn. This emission also occurs in the cathodoluminescence of spinel which glows green.

Many Goron spinels also show an alexandrite effect *(Figure 2)*. In daylight they are violet-blue but in incandescent light they show a distinct red component – making them violet-pink and more attractive as an 'evening stone'. Although rare, similar spinels are known from Tanzania, Sri Lanka and Madagascar (e.g. see *Modern Jeweler*).

The gem-quality spinels are generally free of inclusions but some contain tiny round grains which appear to be spinel rather than zircon or forsterite. Others can contain probable cavities that are at the centre of clusters of thin radial channels *(Figure 5)* which can reach the surfaces of some crystals and terminate in pyramidal-shaped depressions. The channels could have been formed by dissolution along dislocations in the crystal structure, and this kind of feature has been reported in diamond (Orlov, 1984).

4. Comparison with spinels from Kuh-i-lal

The host rocks of the spinels at both Goron and Kuh-i-lal are forsterite-bearing skarns but while the Goron rocks contain abundant chlorite and some clinohumite which is not of gem quality, any chlorite at Kuh-i-lal has been replaced by snow-white aggregates of lizardite serpentine,

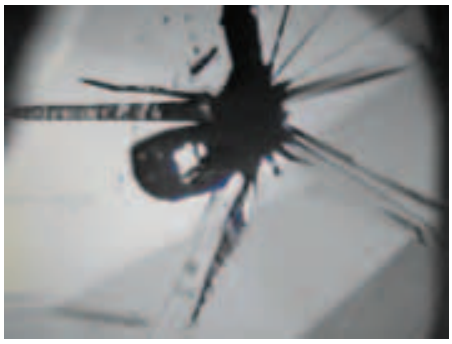

Figure 5: Inclusion typical of spinel from this locality in which a probable cavity is at the centre of a radial array of empty channels. The width of the field of view is 3 mm.

Figure 6: Spinel crystal flanked by a round-cut spinel of 4.61 ct with 73 facets (left) and a modified triangular-cut spinel of 3.12 ct (right).

Figure 7: Necklace pendant and earrings set with Volyn topaz from the Ukraine, spinel from Goron and brilliant-cut diamonds.

hydrotalcite and manasseite. Also at Kuh-i-lal, low temperature alteration processes seem to have involved intense dissolution of the surfaces of gem-quality varieties of spinel, forsterite and clinohumite .

5. Conclusion

Two cut spinels from Goron flanking a crystal from that deposit are shown in *Figure 6*, and similar stones set in jewellery are shown in *Figure 7*. The spinels are generally very homogeneous in colour and take a good polish. They also show good transparency and only rarely contain clusters of radial channels or barely-visible twin planes. The stones shown were cut from our collection and, so far as we know, inaccessibility of the site and lack of infrastructure in the area has precluded any commercial development.

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All photographs by S.A. Ananyev.

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Orangey-red to orangey-pink gem spinels from a new deposit at Lang Chap (Tan Huong-Truc Lau), Vietnam

A.-K. Malsy, S. Karampelas, D. Schwarz, L. Klemm, T. Armbruster and D.A. Tuan

Abstract: Gem spinels from a new source at Lang Chap, Vietnam, have been investigated for their gemmological, spectroscopic and chemical characteristics. The Lang Chap mining site produces spinels of orangey-red colour with inclusions and chemical composition which closely resemble similar coloured spinels from Myanmar. Experimental heat treatment at 850°C of one test sample resulted in reduction of the orange component of its colour. XRD, Raman and PL spectra indicate some disorder in the spinel structure after heating.

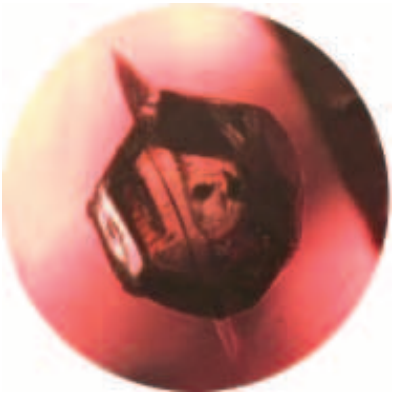

Keywords: colour, heat treatment, Lang Chap, photoluminescence, Raman, spinel, UV-Vis-NIR, Vietnam

Introduction

In the gem market, spinels have 'recovered' and become more popular during the last decade. The vast majority of gem-quality spinels have a composition of spinel *sensu stricto*, i.e. magnesium-aluminium spinel ($MgAl_2O_4$). Among the most popular are those in the red to pink range. In Nature, they are commonly associated with rubies and occur in metamorphic rocks such as gneisses, marbles or calc-silicates. Most gem spinels available on today's market have been mined from primary and secondary deposits in Sri Lanka, Myanmar (Mogok and Namya), Vietnam (Luc Yen area), Madagascar (Ilakaka region), Tajikistan (Pamir Mountains: Kuh-i-Lal) and Tanzania (Morogoro and Mahenge) as stated by Shigley *et al.*, 2010 (see also references therein).

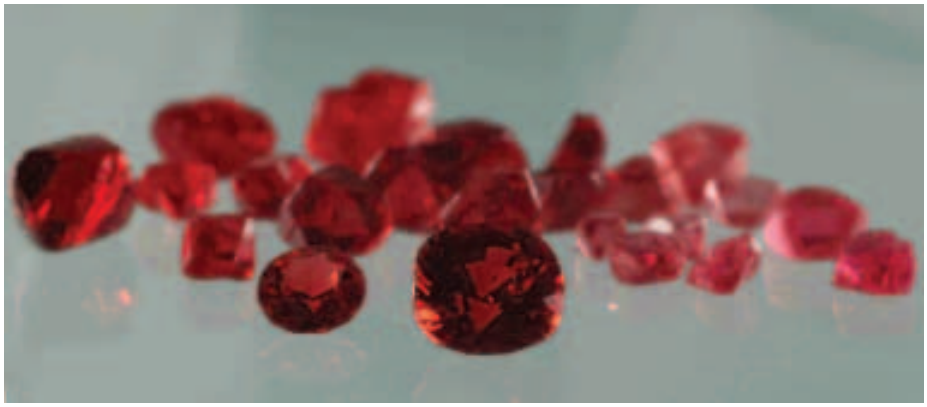

Figure 1: Spinels from the new Lang Chap mine in Vietnam, varying in colour from orangey-red to orangey-pink. The two faceted stones at the front weigh 0.4 and 1.3 ct and represent typical colours of spinels from this mine.

Some orangey-red to orangey-pink spinels *(Figure 1)* from a new alluvial deposit in Northern Vietnam have recently reached the market (Blauwet, 2010). The new deposit is situated at Lang Chap (22° 05' 86" N, 104° 34' 83" E), in the northern part of Yen Bai Province *(Figure 2)* and was discovered around April 2010 (Blauwet, 2011). The mining is on a small scale, operated by locals using primitive equipment, and a detailed description of the mining site is given by Blauwet

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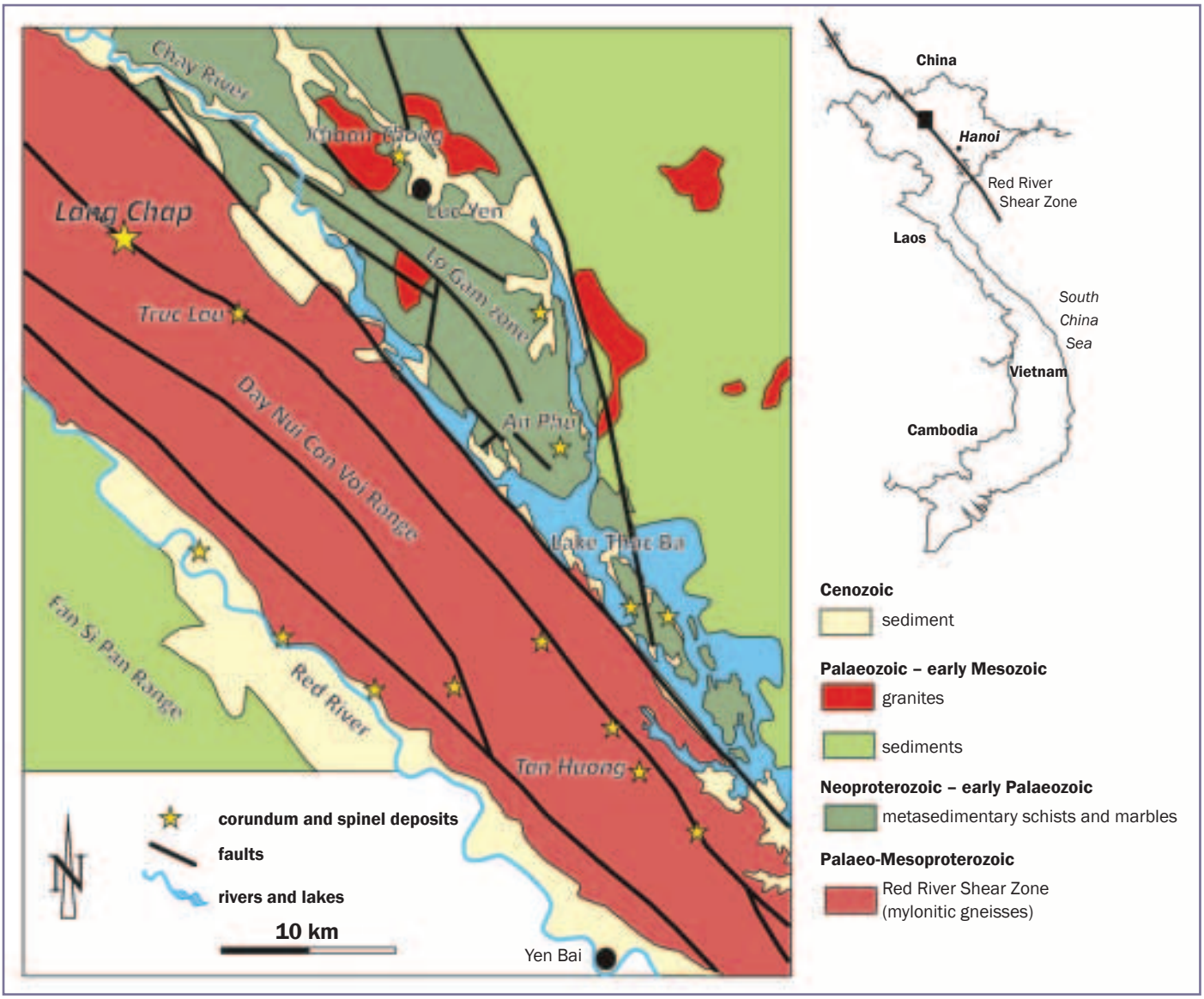

Figure 2: Geological sketch map showing the major tectonic units north of Yen Bai and location of corundum and/or spinel deposits (modified after Garnier et al.*, 2005, and Khoi* et al.*, 2011).*

(2010). In October 2010, when some areas around the mining region were visited by one of the authors (SK), less than 50 people were mining there. The mine sporadically produces spinels of excellent red colour.

In northern Yen Bai province *(Figure 2)*, the Chay River runs (NNW-SSE) through the Luc Yen district; primary and secondary deposits of gem quality corundum and spinel have been found on both sides of the river (Khoi *et al.*, 2011). The first deposits on the east side of the river were discovered in the eighties (Khoan Thong-An Phu mining regions); deposits on the west side (Tan Huong-Truc Lau mining regions) were discovered in the mid-nineties. The latest discovery of spinels described above is situated NW of Truc Lau, at Lang Chap.

The Khoan Thong-An Phu deposits are located on the eastern side of the Red River shear zone, within the Lo Gam tectonic zone (see again *Figure 2*) which consists of moderately to highly metamorphosed (amphibolite-facies) schists, gneisses and marbles (Phan Trong and Hoáng Quang, 1997). Primary spinel together with ruby occurs within marbles (Van Long *et al.*, 2004). The Tan Huong-Truc Lau mining region is situated within the Dai Nui Con Voi range consisting of high-grade (amphibolite-facies) metamorphic rocks with sillimanite-biotite-garnet gneisses and schists with local successions of marbles and amphibolites (Van Long *et al.*, 2004). The mountain range is bordered by large-scale lateral strike-slip faults forming the Red River shear zone.

Since their discovery there have been recurrent market rumours saying that Lang Chap spinels have been misleadingly identified as spinels from Myanmar. So, the present study was carried out to establish the chemical and spectroscopic characteristics of orangey-red to orangey-pink spinels from the new deposit at Lang Chap, and compare them with those previously reported by Malsy and Klemm (2010) on similarly coloured spinels

Table I: List of samples investigated.

Sample name		Colour	Weight [ct]	Condition
SPVNNM1		orangey-red	0.4	faceted
SPVNNM3		orangey-red	1.3	faceted
SPVNNM2/4		orangey-red	2.3/1.6	polished
SPVNL39–51		orangey-red	0.3–2.2	polished
SPVNL52–59		orangey-red	0.7–2.1	polished
SPVNL60		purple-red	4.6	polished
SPVNL61		purplish-red	3.5	polished
SPVNL62		pinkish-orangey-red	1.8	polished
SPVNL70	unheated	orangey-red	1.9	polished
	heated	red	1.8	
SPVNL66		orangey-pink	1.0	polished

from the Himalayan belt, i.e. Myanmar (Mogok), Vietnam (Luc Yen: Koan Thong-An Phu) and Tajikistan (Kuh-i-Lal). Some additional samples from Namya (Myanmar) have also been included in this study for comparison.

Moreover, heat treatment has been performed on one sample to examine its effect on the spinel's colour, transparency, spectral and structural features.

Materials and methods

For the present study, Dr Havy Le Thi-Thu Huong of the Vietnam National University, Hanoi, and Vietphuong/VPGemstones Co. Ltd. (Vietnamese mining company with retail shops in Hanoi and Bangkok) provided 30 spinels, which were stated to be from Lang Chap. Most samples are of gem quality, weighing from 0.3 to 22 ct in a wide range of colours from orangey-red to orangey-pink, although two have a purple component in their colour (see *Table I*). One homogeneously coloured orangey-red spinel (SPVNL 70) was cut in half: one part was heat treated, and the other was kept as the non-heated reference stone (see below for information on the heat treatment conditions).

Standard gemmological instruments were used to observe long- and short-wave UV fluorescence (365 and 254 nm wavelength, respectively), and to measure refractive indices (RIs) and birefringence. Specific gravity (SG) was determined using the hydrostatic method with an electronic balance. The internal structures and inclusions of the samples were studied with various gemmological microscopes. Inclusion microphotographs were taken with a Keyence VHX-500F digital microscope at the Institute of Geological Sciences of the University of Bern, Switzerland (IGSUB).

Absorption spectra in the 200–900 nm range were recorded at the Gübelin Gem Lab (GGL, Lucerne, Switzerland) on eight natural colour spinels and one heat-treated sample, with a Cary 5000 Ultra-Violet-Visible-Near Infrared (UV-Vis-NIR) spectrometer. The data sampling interval (DI) and spectral bandwidth (SBW) of each measurement were 0.7 nm; the scan rate was 60 nm/min.

Raman spectra were acquired on all spinels as well as on their inclusions, wherever accessible, using a Renishaw Raman 1000 spectrometer coupled with a Leica DMLM optical microscope at GGL. All spectra were recorded using an excitation wavelength of 514 nm emitted by an argon ion laser (Ar^+) and most were taken using standard mode (with ×50 magnification); however, confocal mode (with ×100 magnification) was used on some inclusions. Raman spectra were acquired from 200 to 2000 cm^{-1} using a power of 5 mW on the sample, with an acquisition time of 60 seconds (3 cycles) and about 1.5 cm^{-1} resolution. Rayleigh scattering was blocked by a holographic notch filter, the backscattered light was dispersed on an 1800 grooves/mm holographic grating and the slit was set at 50 µm. For the identification of mineral inclusions the spectra were compared with those from the GGL database as well as with spectra available from RRUFF (www.rruff.info). Photoluminescence (PL) spectra (laser induced) from 600 to 800 nm were acquired using the same instrument (×50 magnification) on all samples, most using a power of 1 mW and the remainder using 0.1 mW and 1 second acquisition time; spectral resolution is 0.1 nm.

Minor and trace elements of all the samples were measured by laser ablation inductively coupled plasma mass spectrometry (LA-ICP-MS). All analyses were performed at GGL on a Perkin Elmer ELAN DRC-e single collector quadrupole mass spectrometer combined with a 213 nm CETAC LSX-213 Nd:YAG laser ablation system. A set of four single-spot analyses (100 µm diameter) was collected on each sample with a laser frequency of 10 Hz. Multi-element glass standard reference material NIST610 was used for external standardization; internal standardization was done by normalizing to 100% cations of stoichiometric spinel. Detailed information on the instrument setting and data processing has been described by Malsy and Klemm, 2010. Mineral inclusions, which intersected the sample surface, were also identified using this method.

A chamber furnace (VMK 250 by Linn High Therm Gmbh) at IGSUB, Switzerland, was used for the heat treatment of one sample (SPVNL 70) in an oxidizing atmosphere. The sample was cut in two halves; one was kept as reference and the heat-treatment was applied to the other half. The oven temperature was raised (heating rate 3.5–4.2°C/min) to 850°C, kept at this temperature for 56 hours, and subsequently cooled to ambient temperature at a rate of 1.7°C/min. Unit cell dimensions and crystal structure parameters were determined on both heated and unheated halves of the sample with an Enraf-Nonius CAD4 single-crystal diffractometer using $MoK\alpha_1$ radiation (λ = 0.70930 Å) at IGSUB.

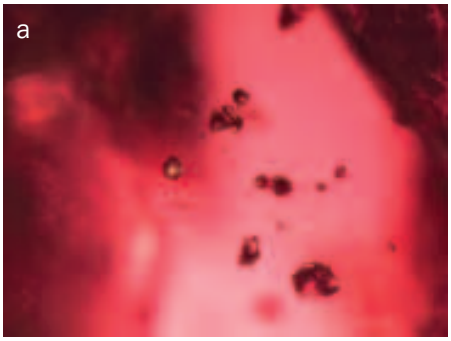

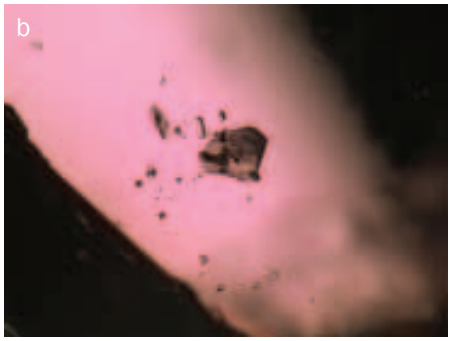

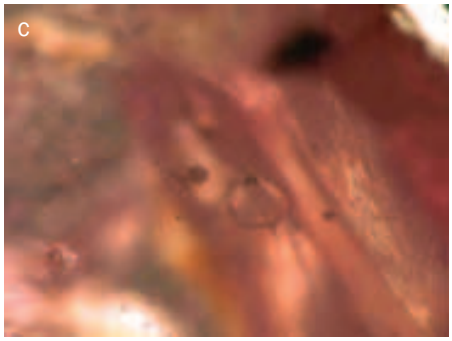

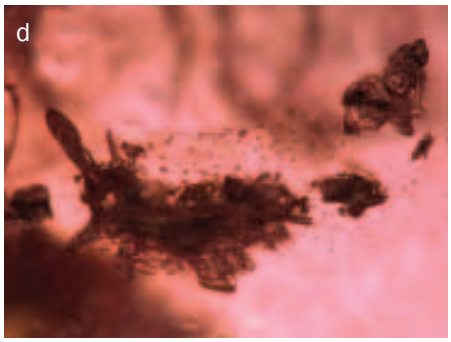

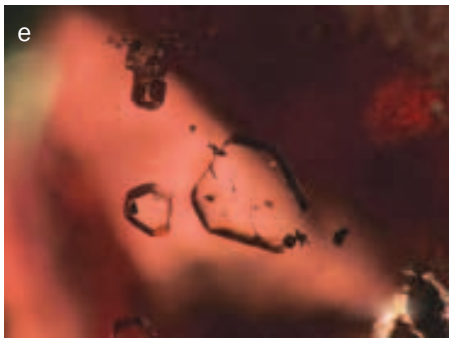

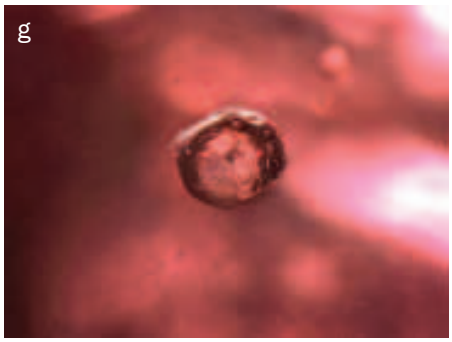

Figure 3: (a) Negative crystals of octahedral shape, which are partly filled with either dolomite or dolomite and calcite. Field of view width about 1.2 mm.
(b) Cluster of small rounded to prismatic transparent dolomite inclusions and a cavity which is filled with dolomite plus calcite. Field of view width about 1.3 mm.
(c) Rounded to nearly spherical calcite inclusion with an 'attached' black graphite platelet. Field of view width about 1.5 mm.
(d) Cavities associated with healed fissures with small fluid inclusions. Field of view width about 1.5 mm.
(e) Group of transparent tabular phlogopite inclusions. These are accompanied by 'attached' black hexagonal or irregularly shaped graphite platelets. Field of view width about 1 mm.
(f and g) Chondrodite inclusion with well-developed crystal faces and accompanied by a perfectly equatorial tension disc (f). The dark area in the central part of the crystal has been identified as mix of carbonate inclusions. Rounded chondrodite inclusion with a dark spot within the crystal (g). Field of view width about 1.3 mm (f) and 1.1 mm (g).

Results

Gemmological and internal features

Table II summarizes our recording of the gemmological and internal features of spinels from Lang Chap. The RI, SG and fluorescence reactions are consistent with those already reported for gem spinels (see, for example, Malsy and Klemm, 2010).

Internal features characteristic of Lang Chap spinels are shown in *Figure 3a–f*. Carbonate-filled negative crystals of octahedral or strongly distorted octahedral shapes of varying size are the most common inclusion feature (see *Figure 3a*). These were found to be filled with magnesite, dolomite or calcite (or a combination of these minerals), presenting a whitish, turbid or 'frosted' aspect. Rarely, dolomite occurs next to apatite. Negative crystals are commonly surrounded by tiny stress fissures giving them a 'frayed' aspect. Dolomite inclusions may also be present in a variety of other habits ranging from prismatic to substantially rounded *(Figure 3b)*. Calcite inclusions are common as transparent rounded grains *(Figure 3c)* and rare as euhedral crystals. Cavities and negative crystals are associated with healed fissures which contain isolated fluid inclusions *(Figure 3d)*. Healed fissures have poorly developed texture in the sense that network-like or fingerprint patterns are not developed. Few samples revealed healed fissures with fluid inclusions arranged on straight or curved lines. Phlogopite is typically present as colourless, pseudohexagonal platy to tabular crystals, with no preferential

Table II: Summary of gemmological properties of Lang Chap spinels.

Colour	orangey-red to orangey-pink
RI	1.718 ± 0.02
SG	3.58 ± 0.02
UV fluorescence	
long wave	weak to medium; red
short wave	inert to faint; red
Mineral inclusions[1]	dolomite
	calcite
	magnesite
	graphite
	phlogopite
	chondrodite
	apatite

[1.] Mineral inclusions identified by Raman spectroscopy and/or LA-ICP-MS.

Figure 4: (a) Group of negative crystals. (b) Reflective tension cracks have been induced by the heating process (similar position to 4a). (c) Graphite platelet surrounded by a discoidal tension crack indicating a thermal treatment. Field of view widths: (a) and (b) about 1.1 mm; (c) about 1.3 mm.

orientation relative to the host spinel structure *(Figure 3e)*. The phlogopite crystals show wide variation in size and are commonly accompanied by graphite platelets. Generally, irregularly shaped to well-developed hexagonal, black graphite platelets are present either isolated or in contact with other mineral inclusions *(Figures 3c* and *e)*. Inclusions of chondrodite (a member of the humite-group of minerals), with the general formula $(Mg,Fe^{2+})_5(SiO_4)_2(F,OH)_2$, are present in one third of the spinels studied; some are euhedral and others are rounded *(Figure 3f)*. Many have a dark spot near their centres, identified as carbonate in some, but as yet unidentified in others.

In the heat-treated spinel sample, microscopic observation of the same inclusion scene, before and after treatment *(Figure 4a–b)* clearly indicates alterations caused by the heating process: some mineral inclusions turned white and hazy, there are additional reflective tension fissures, and a graphite inclusion is surrounded by a discoidal tension crack *(Figure 4c)*.

UV-Vis-NIR, XRD, Raman and PL spectroscopy

Figure 5 shows the UV-Vis-NIR spectra of natural coloured orangey-red (SPVNL 43) and orangey-pink (SPVNL 66) spinels in the range from 250 to 900 nm. Absorption bands are present in the violet-blue and green regions of the electromagnetic spectrum, at about 400 nm and 550 nm, respectively. They are present in both samples, and are responsible for the colour. Both absorption bands are superimposed on a continuous absorption which increases from the near-infrared (NIR) region through the visible range to a complete cut-off below 300 nm (UV region). These characteristics are the same as in similar-coloured spinel from Myanmar *(Figure 5)*.

In *Figure 6*, the UV-Vis-NIR spectra of the one spinel that was subjected to heat treatment (SPVNL 70) are shown. After heating, a slight decrease and shift of the continuous absorption as well as a slight shift of the band from about 540 nm to 550 nm is visible in the red spectrum.

Raman spectra of the unheated and heated specimens are shown in *Figure 7*. The main band at about 405 cm^{-1} and the less intense bands at about 310, 665 and 765 cm^{-1} are present in both samples. All untreated spinels examined in this study presented similar spectra. In the

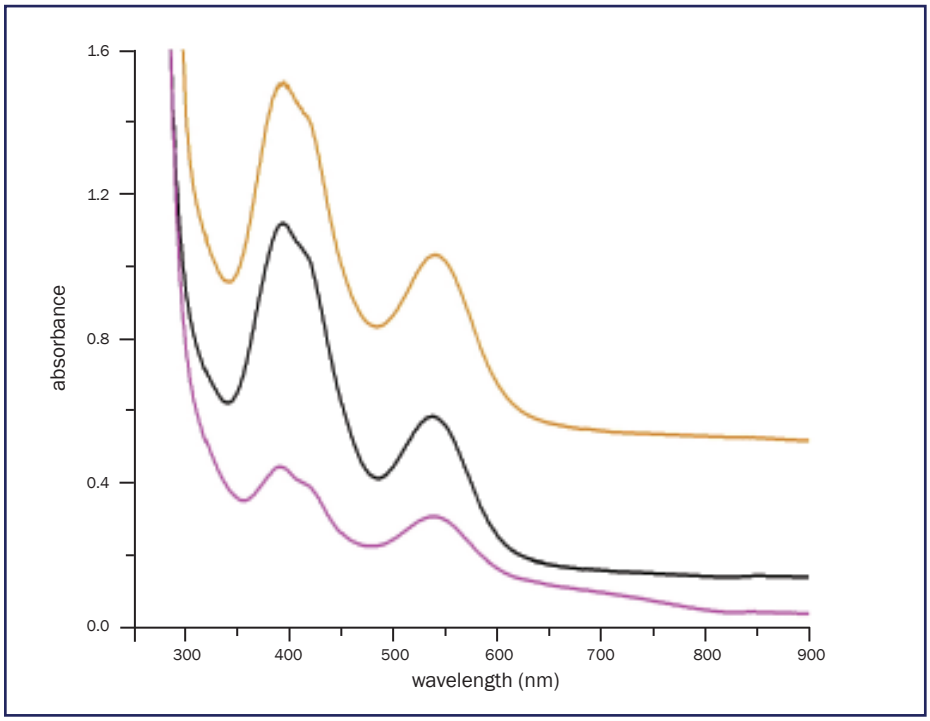

Figure 5: UV-Vis-NIR spectra from 250 to 900 nm of a natural-colour orangey-pink (SPVNL 66; purple line — V_2O_3: 0.23 wt%, Cr_2O_3: 0.20 wt%, Fe_2O_3: 0.38 wt%), an orangey-red spinel from Lang Chap (SPVNL 43; black line — V_2O_3: 0.61 wt%, Cr_2O_3: 0.47 wt%, Fe_2O_3: 0.37 wt%) and an orangey-red spinel from Mogok (orange line — V_2O_3: 0.60 wt%, Cr_2O_3: 0.46 wt%, Fe_2O_3: 0.35 wt%). An absorption band centred at about 400 nm (with two apparent maxima at about 390 and 410 nm) and one centred at about 550 nm are present in all three spectra. Continuous absorption increases steadily from 900 nm to a cut-off below 300 nm. All absorption features are less intense for the orangey-pink compared to the two orangey-red samples. The spectra have been corrected to compensate for differences in sample thickness. The top spectrum is shifted about 1 and the middle spectrum 0.2 absorbance units for convenience.

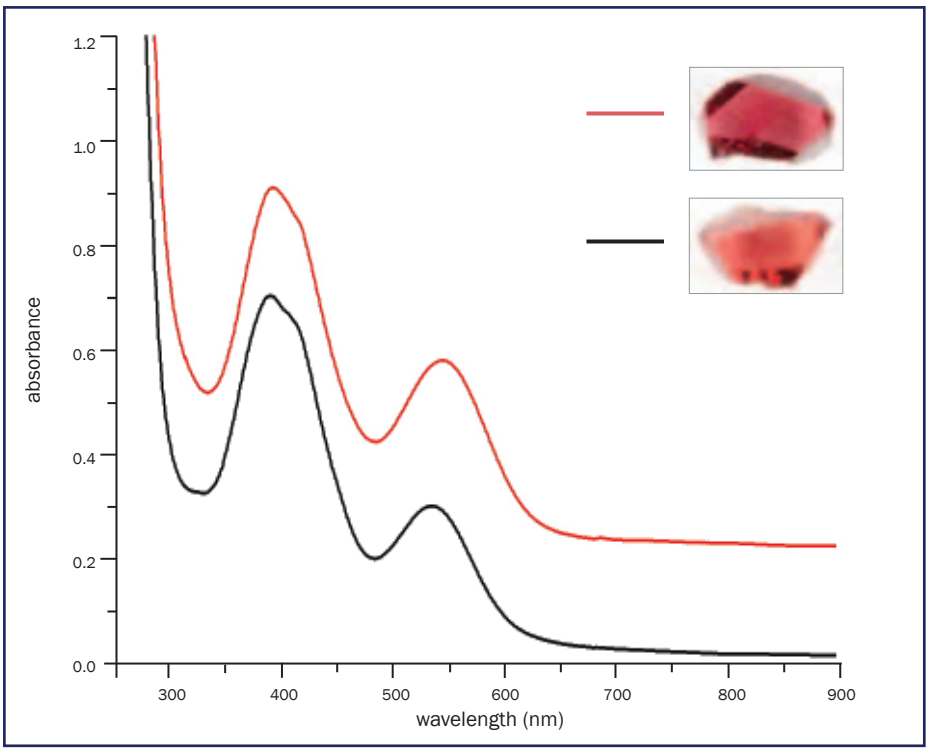

Figure 6: UV-Vis-NIR spectra from 250 to 900 nm of spinel SPVNL 70; unheated part (black line) and heated (red line). A slight decrease and shift of the continuous absorption and a slight shift of the band at about 540 nm to 550 nm after heating are visible. To validate comparison, the spectra are normalized to compensate for any difference in path length of light through the samples. The spectrum of the heated sample is shifted 0.2 absorbance units upwards to avoid overlap.

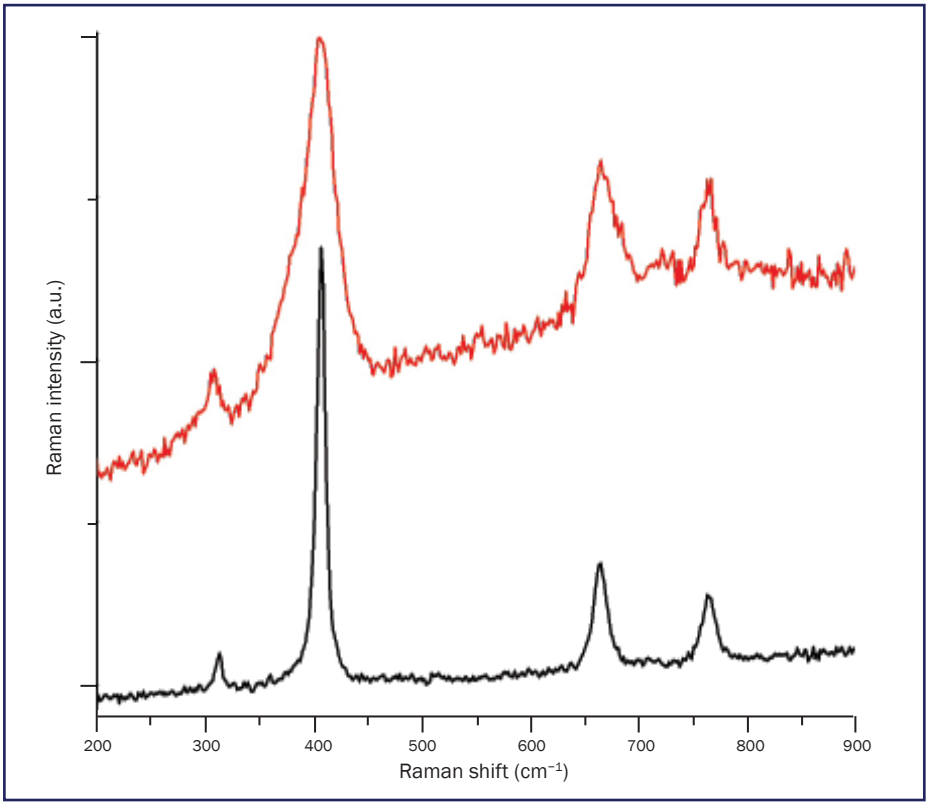

Figure 7: Raman spectra from 200 to 900 cm^{-1} of spinel SPVNL 70; unheated part (black line) and heated (red line). The Raman bands are wider after heating. Intensities of the spectra are normalized to the main band. The upper spectrum is shifted upwards for convenience.

heat-treated sample the Raman bands are slightly wider (i.e. larger full width at half maximum (FWHM)) and some bands (e.g. at 405 cm^{-1}) seem to consist of more than one component. Photoluminescence (PL) spectra of the stones *(Figure 8)* show a principal peak at about 685 nm and some less intense side bands. On heat treatment, the narrow bands in the black spectrum visibly broaden to those in the red spectrum and the largest peak shows a slight shift of centre to 688 nm.

An X-ray single crystal study of the unheated sample yielded a cell dimension a = 8.0902(2) Å, which, on heat treatment, decreased to a = 8.0891(2) Å. Also, more significantly the oxygen parameter u = 0.26342(6) changed to 0.26218(6).

Chemical composition

LA-ICP-MS data for selected elements, given as ranges, mean values and standard deviations are shown in *Table III*. The elements V, Cr, Fe and Zn are present in concentrations from 0.1 to a maximum of 0.7 wt% oxides, whereas Ga and Ti contents are significantly lower. With the exception of Ti, the homogeneity of these elements within all individual samples is quite high (variation <15%). Elements such as Li, Be, Mn, Co, Ni, Cu and Sn were detected as traces (<100 ppmw) only, but Ge, Zr, Sr, Nb, Mo and Pb were below the detection limit of the method.

Discussion

Characteristics of Lang Chap spinels

From our 30 samples and from other stones seen on the gem market in Luc Yen by one author (DS), it can be concluded that the Lang Chap mines principally produce strongly saturated 'blazing' orangey-red to orangey-pink spinels. Lang Chap spinels host a large variety of mineral inclusions and those identified in this study include phlogopite, graphite, dolomite, calcite, magnesite, apatite and chondrodite. These inclusions strongly indicate these spinels to originate from a marble host rock.

Observed absorption features in the UV-Vis-NIR range can be attributed to

V^{3+} (apparent maxima at about 390 and 560 nm) and to Cr^{3+} (apparent maxima at about 410 and 540 nm), both at octahedral sites (Schmetzer *et al.*, 1989). Orangey-red spinels from Lang Chap characteristically contain higher V_2O_3 than Cr_2O_3 (V_2O_3/Cr_2O_3 up to 3.5). Spinels of this colour type have been also described from Mogok (Schmetzer *et al.*, 1989) and Namya (Peretti and Günther, 2003), Myanmar.

Comparison with spinels from other deposits

Spinels from Lang Chap differ in many aspects from those described from mines around Luc Yen (Koan Thong-An Phu mining regions). Inclusion features typically observed in 'Luc Yen spinels', such as dislocation channels and 'blades' of högbomite (see Gübelin and Koivula, 2005, pp. 662–714), zircon and titanite (Malsy and Klemm, 2010), have not been found in our 30 samples. On the other hand, chondrodite and phlogopite inclusions have not been found as inclusions in 'Luc Yen spinels'. Spinels from Tajikistan (Kuh-i-Lal) are generally poorly included, but they do contain some cavities of octahedral shape which look different from Lang Chap inclusions, rarely zircon inclusions and tabular to prismatic colourless mineral inclusions, as yet unidentified (Malsy and Klemm, 2010). Internal features of spinels from Mogok may look very similar to those in Lang Chap spinels, and calcite, dolomite, magnesite, phlogopite and chondrodite may be present in samples originating from both sources. 'Belly button' inclusions, which describe the appearance of a rounded apatite 'decorated' with black graphite or ilmenite (Gübelin and Koivula, 2005), have hitherto been considered as diagnostic for spinel from Mogok *(Figure 9)*, but some inclusions (calcite but not apatite) with attached graphite contained in Lang Chap spinels (e.g. *Figure 3c*) look quite similar and can be confused with those observed in the Mogok spinels. For Namya spinels, octahedral negative crystals, transparent rounded mineral inclusions, and particles or needles have been described (Peretti and Günther, 2003).

Based on their minor element contents, Lang Chap spinels can be distinguished from Luc Yen spinels by their lower Fe contents *(Figure 10)* and lower Li, Be, Mn, ± Co, ± Ni. Spinels from Tajikistan characteristically have slightly higher Fe/Sn ratios and lower Ni contents compared to Lang Chap spinels. However, values of these elements in spinels from Myanmar (Mogok and Namya) widely overlap those of Lang Chap spinels (see again *Figure 10*). Moreover, an overlap is also observed for all other elements and their ratios.

Table III: Minor and trace element contents of Lang Chap spinels obtained using LA-ICP-MS and given as ranges, mean values (Mean) and standard deviations (Sdev).

wt.%	Range	Mean + Sdev
V_2O_3	0.213 – 0.700	0.505 ± 0.136
Cr_2O_3	0.142 – 0.688	0.362 ± 0.148
Fe_2O_3	0.103 – 0.410	0.237 ± 0.095
ZnO	0.103 – 0.522	0.268 ± 0.097
ppmw		
Li	0.50 – 17	4.2 ± 3.5
Be	1.34 – 12	3.7 ± 1.8
Ti	40 – 350	155 ± 57
Mn	4.0 – 14	5.8 ± 1.8
Co	0.23 – 2.7	1.2 ± 0.66
Ni	<0.49 – 64	5.3 ± 9.2
Cu	<0.16 – 2.3	0.46 ± 1.1
Ga	87 – 339	188 ± 46
Sn	0.21 – 1.8	0.77 ± 0.40

Notes: ppmw = parts per million by weight; < = value below the detection limit.

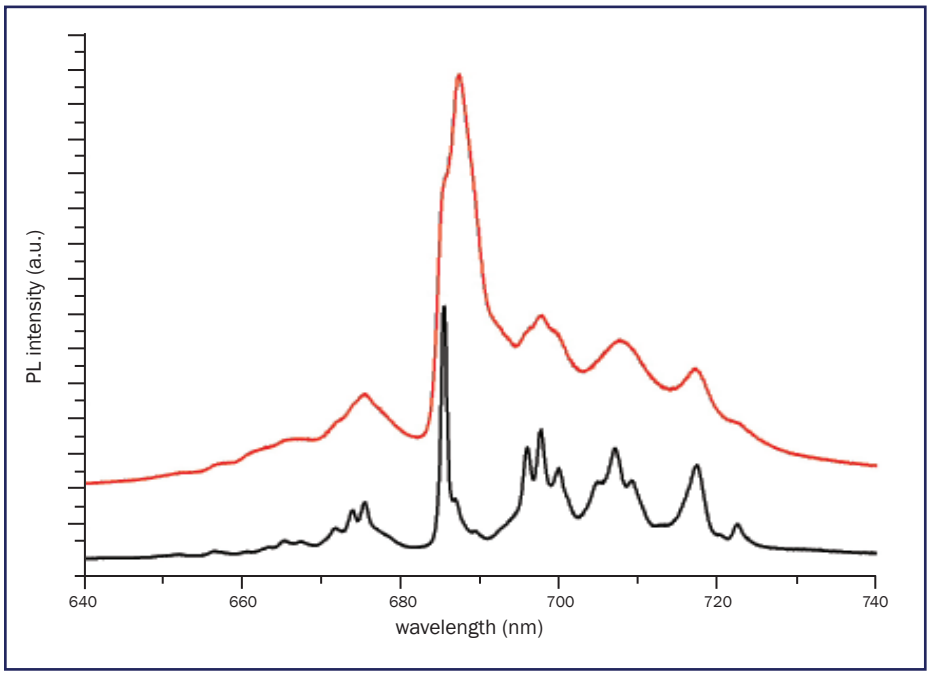

Figure 8: Photoluminescence (PL) spectra from 640 to 740 nm of Lang Chap spinel; unheated part (black line) and heated (red line). The PL pattern in the black spectrum with a main band at about 685 nm and numerous less intense side bands is characteristic for spinels which contain Cr^{3+}. On heating, all bands are broader and the main band shows a slight shift to about 688 nm. The upper spectrum is moved upwards for clarity.

Effects and detection of heat treatment

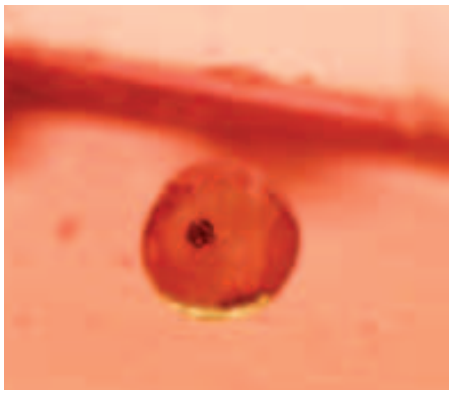

Figure 9: Typical 'belly button' inclusion in a spinel from Mogok, Myanmar. The central rounded crystal is apatite with small black graphite. See also Figure 3c for comparison. Field of view width about 0.3 mm.

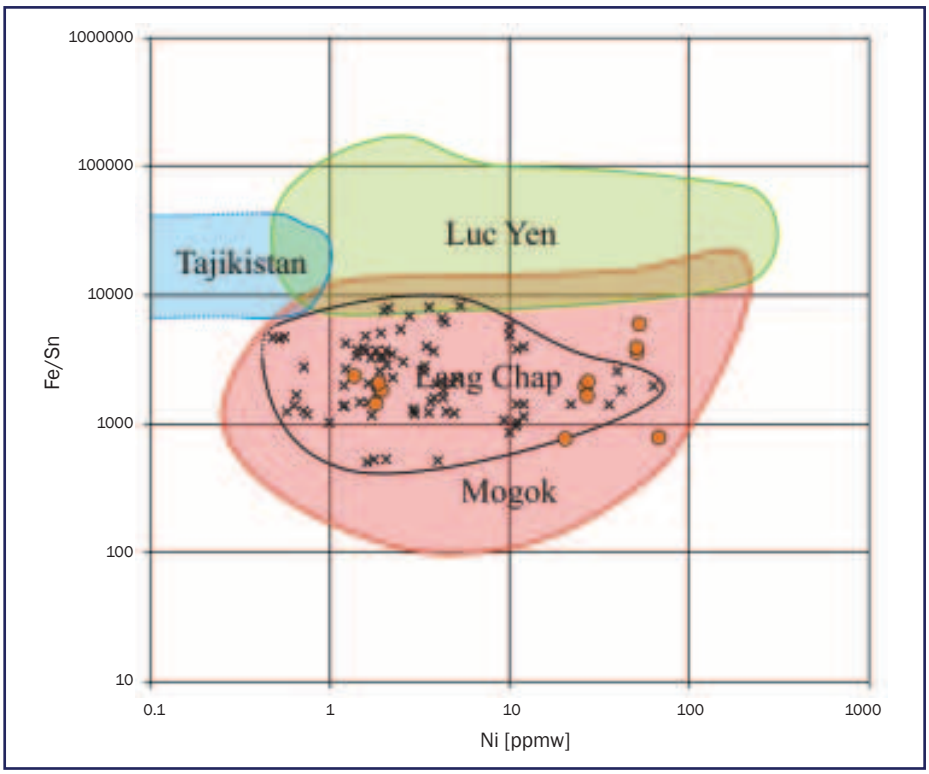

Figure 10: Plot of Ni [ppmw] versus the Fe/Sn ratio from LA-ICP-MS data, adapted from Malsy and Klemm (2010). Dotted lines represent values at the detection limit for the corresponding measurement. Lang Chap spinels differ from other Vietnamese spinels from Luc Yen in having lower Fe/Sn ratios; only a slight overlapping of the two clouds is visible. However, Lang Chap spinels have Ni contents and Fe/Sn ratios similar to those in Mogok and Namya (orange circles), Myanmar, stones.

The heat treatment of spinel from Lang Chap at 850°C in an oxidizing atmosphere caused colour alteration mainly observable as a decrease of orange hue. The observed differences in comparative UV-Vis-NIR spectra (see *Figure 5*) are in accordance with the macroscopic observations. The shift of the absorption band on heating from 540 nm to a longer wavelength and the unchanged position of the absorption at about 400 nm are in accordance with previous findings by Hoang *et al.* (2001). Microscopic examination of inclusions can yield conspicuous signs of heat treatment such as tension cracks often in a 'halo' formation surrounding an inclusion (see, for example, corundum described by Themelis (2003)). These features are generally accepted as strong indicators for heat treatment, but if a gem such as spinel contains very few inclusions, additional criteria for the detection of heat treatment are needed.

The relatively wide Raman bands in the heat-treated spinel spectrum in *Figure 7* are clearly visible. FWHM of the main band at 405 cm^{-1} broadened from about 10 to 30 cm^{-1} after the heating process. Similar observations in Raman spectra have been reported for heat-treated and synthetic high-temperature spinel by Cynn *et al.* (1992), Lazzeri and Thibaudeau (2006) and Saeseaw *et al.* (2009). The latter authors attributed these broadened bands to disorder in the spinel structure caused by the heating process or by high temperature synthesis.

All the PL bands are broader in the spectrum of the heated spinel in *Figure 8*. Moreover, the centre of the most intense band shifts from about 685 nm to about 688 nm and the side band becomes more intense compared with the main band. These changes suggest that the spinel has a more disordered structure after heating (Wood *et al.*, 1968; Tijero and Ibarra, 1993; Mohler and White, 1995). Similar PL observations have been reported for heat-treated and synthetic spinel (see some examples described by Notari and Grobon (2003) and by Saeseaw *et al.* (2009)). The exact position and shape of these Cr^{3+}-related PL bands change when measured at low temperature (Fritsch *et al.*, 2012). Additional confirmation for structural alteration of the spinel by a heating process was obtained from X-ray single-crystal structure analysis of the heated SPVNL 70 using the oxygen parameter u. It seems that during heat treatment the normal spinel structure where Mg has tetrahedral and Al has octahedral coordination ($Mg^{IV}Al^{VI}_2O_4$) transforms or readjusts towards an inverse spinel $Al^{IV}(MgAl)^{VI}O_4$. This is in accordance with previous work on the subject (see for example Preisinger, 1983; Lucchesi and Della Giusta, 1997; Andreozzi *et al.*, 2000).

Conclusions

Spinels from Lang Chap do differ microscopically and chemically from those found at other Vietnamese occurrences in the Koan Thong-An Phu mining regions. However, the Lang Chap samples examined for this study do microscopically and chemically resemble spinels from Myanmar (Mogok and Namya). It seems that the distinction of these spinels is only sometimes possible after careful examination of inclusion features and trace element chemistry.

The heat treatment experiment at 850°C of one Lang Chap sample showed that it is possible to reduce the orange colour component of these spinels. However, although the direct cause for this change is not yet completely understood, detection of any thermal treatment of such natural spinels can be done using Raman and photoluminescence spectroscopy: in both techniques, the spectral peaks of heated natural spinels are broader than their unheated equivalents. Our research team is currently working on the effect and detection of low temperature heat-treatment (i.e. below 850°C) on such coloured spinels.

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Review of some current coloured quartz varieties

Ulrich Henn and Rainer Schultz-Güttler

Abstract: Gemstones of the quartz group display a wide spectrum of colours, both natural and those colours produced by artificial enhancement. Colour modification methods such as heat-treatment and irradiation or a combination of these processes used on macro-crystalline quartz lead to an interesting colour palette for the jewellery trade. Characteristics of these materials are outlined and testing methods for gemmological distinction between naturally coloured and artificially enhanced quartz are described. In the context of the different types of colour centres, the quartz gems are considered in three groups: iron-bearing quartz, quartz containing mainly aluminium and quartz with high water content. In particular, optical absorption spectra are used in the characterization of different colour varieties of quartz. In addition FTIR-spectra in the near-infrared range as well as the observation of pleochroism, presence of Brazil-law twinning and reaction under the Chelsea Colour Filter may be helpful for the determination of particular quartz types.

Keywords: quartz, causes of colour, colour modifications, heat-treatment, irradiation, optical absorption spectra, amethyst, citrine, prasiolite, 'blueberry quartz', bleached quartz, bi-coloured quartz, smoky quartz, 'lemon quartz', green quartz, rose quartz

Introduction

Quartz perhaps shows a surprising variety among gemstones in terms of its macro-crystalline specimens, its micro- to crypto-crystalline structures, and particularly its wide range of colours.

General causes for the varieties of colour in quartz generally can be divided into three groups:

1. colour centres
2. optical effects
3. inclusions

In macro-crystalline quartz *(Figure 1)* colour is most commonly due to colour centres, which are associated with foreign ions in the structural framework of quartz. Of these, the commonest are iron and aluminium and for this reason the colour-centre mechanisms are discussed under the sub-headings iron-bearing and aluminium-bearing quartz. Comprehensive descriptions of the colours of quartz have been published by Lehmann and Bambauer (1973) and Rossman (1994).

This paper concentrates on colour centres rather than optical effects and inclusions and presents an outline of the commercially important colours and colour modifications of macro-crystalline quartz rather than the finer-grained varieties. The currently known mechanisms responsible for each colour variety are described in summary form, and further details may be found in the indicated references. Recent work (Henn and Schultz-Güttler) is augmented with

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Figure 1: Some colour varieties of quartz: from left to right — amethyst, prasiolite, citrine (yellow-brown) and smoky quartz. Photo by Rainer Schultz-Güttler.

more illustrations and outlines of possible defects and their interactions (see Box A).

Crystal structure and morphology

The structure of quartz (SiO_2) is represented by a trigonal trapezohedral lattice *(Figure 2)*. Each silicon atom is coordinated with four oxygen atoms and constitutes SiO_4-tetrahedra. These tetrahedra are helically arranged and form a three-dimensional network of helical chains which are aligned in the direction of the *c*-axis. They are linked in such a way that six-sided channels are formed, and within these channels there are vacant interstitial (I) sites which can offer both tetrahedral (I_4) and octahedral (I_6) coordination to possible foreign elements or ions.

Box A: Defects in quartz related to colour varieties

The illustration shows in a schematic way some possible defect centres in natural quartz.

Quartz has a very simple chemical formula SiO_2, and may be considered as a quite perfect substance. But as shown by innumerable investigations (Salh, 2011), quartz can contain large number of defects involving substitutional and interstitial ions, hydroxyl and molecular water, besides such growth defects as spiral growth, small angle boundaries and twinning. The basic structural unit is the AO_4-tetrahedron [AO_4], whereby A is mainly Si, but can be substituted by Al, Fe and (4 H). Where charges need to be balanced, the coupled ions, occupying interstitial positions, are shown nearby the tetrahedron as Li, Na, Fe^{2+} and OH. This scheme leads to the notation [AO_4/M] used in the text and illustrations to explain the modifications of colours by irradiation and heat treatment. Each [AO_4/M] unit may be neutral (º), positively (+) or negatively (-) charged, depending on the addition or removal of electrons. Shown also is molecular water (H_2O), which may interact with all defects shown; its location is not at structural sites but in the channels of the quartz structure or along grain boundaries, twin planes and micro-structural growth defects of the crystals. From these considerations it is clear that a multitude of combinations of defects in natural quartz can exist, any one combination being a reflection of its geological history.

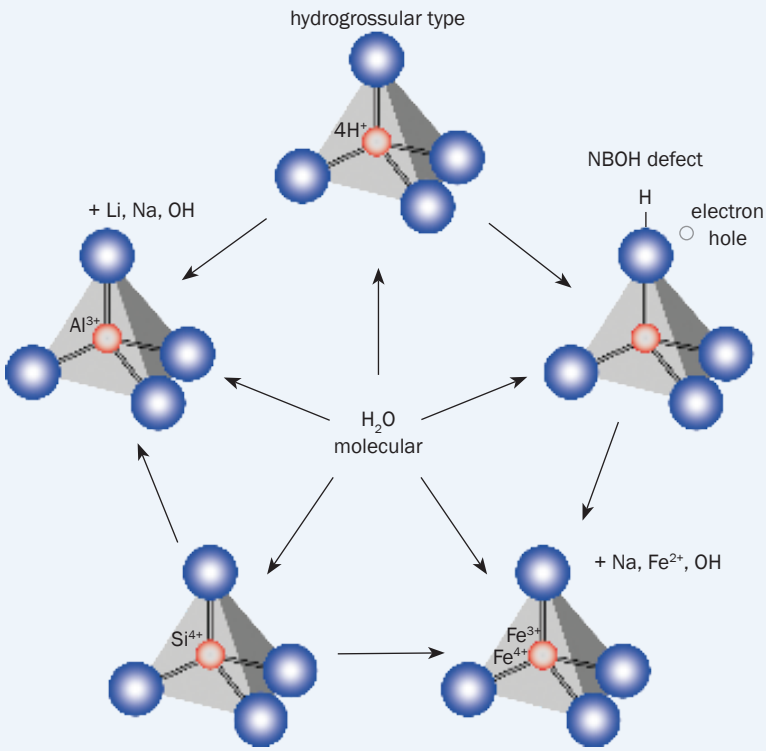

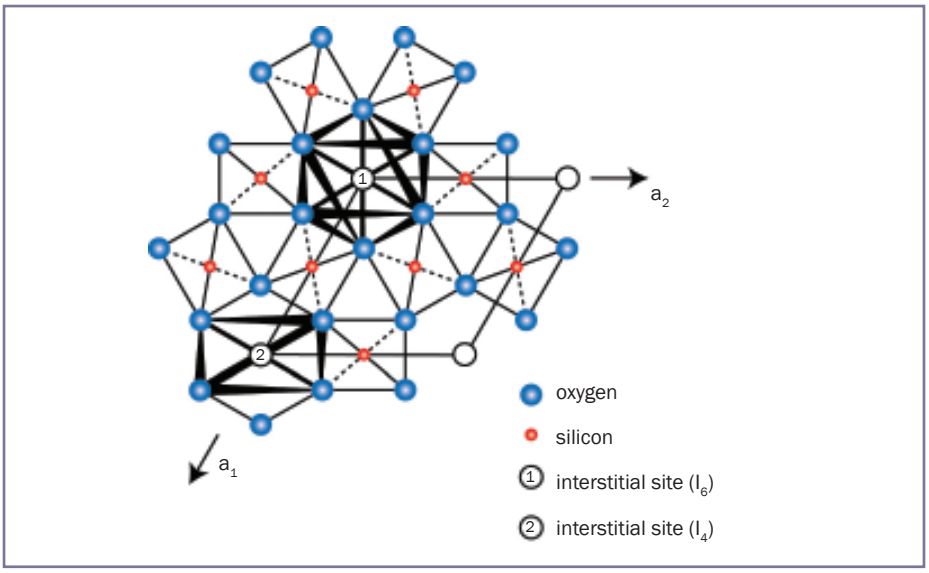

Figure 2: Crystal structure of quartz illustrating the Si sites and the interstitial sites of distorted octahedral (I_6) and tetrahedral (I_4) coordination (after Lehmann and Bambauer, 1973); a1 and a2 are unit cell parameters.

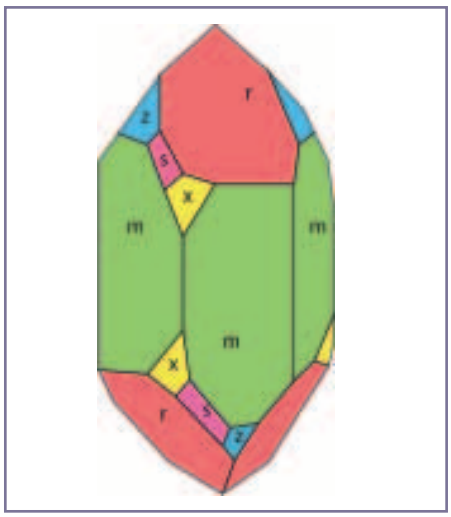

Figure 3: Morphology of a crystal with doubly terminated prismatic form. Perfect examples are rarely found in nature due to frequent twinning and growth defects. Diagram by German Gemmological Association.

Silicon atoms can be replaced by foreign ions. In the case of tetravalent ions such lattice sites are labelled S. If tetravalent Si is replaced by an ion of lower valency, this would lead to the need for charge balancing by alkali ions (e.g. lithium) or protons, and the lattice sites occupied in such a mechanism are labelled S_1 and S_2 respectively.

The helical arrangement of the SiO_4-tetrahedrons parallel to the *c*-axis is responsible for the development of right-handed and left-handed crystals with mirror-image symmetry. The crystal morphology of quartz *(Figure 3)* is dominated by rhombohedral and prismatic faces. The common crystal form is a prism with hexagonal-prismatic habit. The main crystal faces are the first order hexagonal prism **m** $(10\bar{1}0)$, positive and negative rhombohedron **r** $(10\bar{1}1)$ and **z** $(01\bar{1}1)$, second order dipyramid right-hand **s`** $(11\bar{2}1)$ and left-hand **`s** $(2\bar{1}\bar{1}1)$ and trapezohedra right-hand **x`** $(51\bar{6}1)$ and left-hand **`x** $(6\bar{1}\bar{5}1)$.

Iron-bearing quartz

In the crystal structure of quartz, iron can be present in both substitutional S sites and interstitial I sites. However, the replacement is limited because of differences in valency and ionic radii. Iron contents of 10 to 350 ppm were indicated for amethyst and citrine by Lehmann and Bambauer (1973). The first electron transition band of Fe^{3+} is located at about 210 nm in the UV, so does not absorb in the visible range and consequently no colour is produced. Those Fe^{3+} ions occupy both substitutional S_1 sites and interstitial I_4 sites and are considered as precursors of the colour centres in amethyst (Lehmann, 1967; Lehmann and Bambauer, 1973).

Colour causes and modifications of iron-bearing quartz are shown in *Figure 4*. Characteristics and distinguishing features are summarized in *Table I*.

Table I: Characteristics of iron-bearing quartz.

Type	UV/VIS/NIR absorption spectrum	Pleochroism	Brazil law twinning	Infrared spectrum	Upper temperature limit of colour stability; °C
Amethyst	bands at 545 and 357 nm as well as 950 nm	reddish-violet to bluish-violet	present	n.d.	350–450
Citrine: heated amethyst	continuous increase towards UV	none	present	n.d.	400–600
Prasiolite: heated amethyst	broad band maximum at 720 nm	weak in shades of pale green	present	weak H_2O and Si-OH bands	500–600
'Blueberry quartz': irradiated and heated prasiolite	band at 545 nm and shoulder at 720 nm	violetish-blue to reddish-orange	present	n.d.	350–400
'Neon quartz': heated amethyst	shoulders at 545 and 357 nm	-	present	n.d.	approx. 400

NB: n.d. = not diagnostic

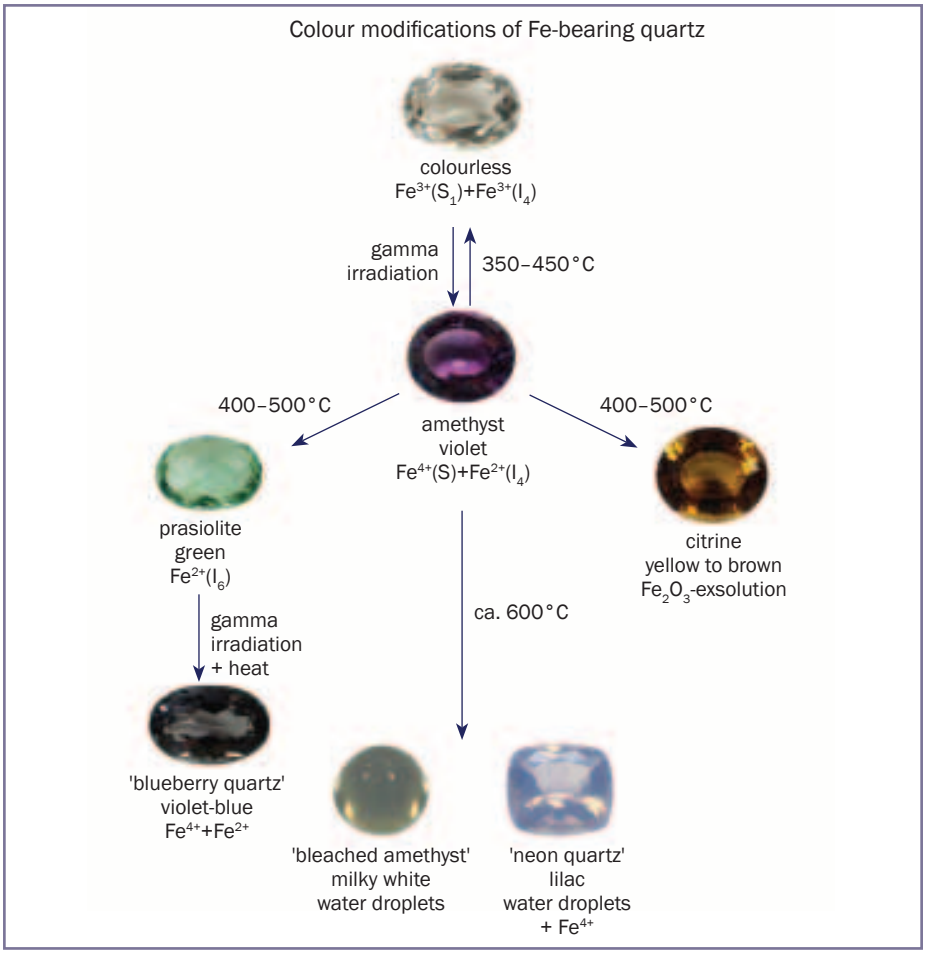

Figure 4: Colour causes and modifications of iron-bearing quartz. The possible ways of changing colours are indicated as are the causes. Photo by German Gemmological Association.

Figure 5: Rough amethyst crystals of different colour intensities; some show distinct colour zoning (for example, centre bottom) due to changing growth conditions. Size of specimens from 2 to 4 cm. Photo by Rainer-Schultz-Güttler.

Amethyst

The iron-related colour centres which are responsible for the violet colour of amethyst have been described by several authors (e.g. Lehmann, 1967; Lehmann and Bambauer, 1973; Cohen, 1985; Rossman, 1994). Following Lehmann and Bambauer (1973) the formation of the iron centres relevant to the violet colour of amethyst (*Figure 5*) can be characterized by the following formula:

$$Fe^{3+}(S_1) + Fe^{3+}(I_4) \leftrightarrow Fe^{4+}(S) + Fe^{2+}(I_4)$$

The mechanism is due to an electron transition caused by gamma irradiation: an electron is impelled or released from a substitutional Fe^{3+} and trapped by an interstitial Fe^{3+}. Consequently, by losing the negative electron, the substitutional Fe^{3+} is oxidized to an Fe^{4+} centre, while the interstitial Fe^{3+} is reduced to Fe^{2+}. This electron transition process is reversible by heat treatment. The stability limit of the amethyst centre is approximately 350-450°C. Exceeding that temperature the amethyst colour starts to bleach. The structural position of the Fe^{4+} centre and the exact mechanism of colour formation is still a matter for discussion. Cohen (1985) described irradiation-related Fe^{4+} centres, but located on interstitial rather than substitutional sites. Dedushenko *et al.* (2004) confirmed the model of Lehmann and Bambauer (1973) by Mössbauer spectroscopy, but Burkov *et al.* (2005) and SivaRamaiah *et al.* (2011) stress the influence of ferrous iron in amethyst.

In quartz generally, the concentration and distribution of trace elements is related to the growth sectors of the crystal. Generally, concentrations are highest at the positive rhombohedron and reduce at the negative rhombohedron and are lowest at the prism sectors. In amethyst, the violet colour is concentrated in the rhombohedral sectors, with the positive one possessing the deepest colour *(Figure 6)*, while the prismatic sectors are colourless or white *(Figure 7)*.

A diagnostic feature for natural (as opposed to synthetic) amethyst is the presence of Brazil-law twinning. This is due to polysynthetic twinning in the growth sectors of the positive rhombohedron **r** *(Figure 8)*. Twinning of

*Figure 6: Two amethyst cross sections indicating different colour intensity in different growth sectors. Sectors of the positive rhombohedron **r** possess more intense violet colours compared to sectors of the negative rhombohedron **z**. Size of specimens 2.5 and 2 cm. Photo by German Gemmological Association.*

Figure 7: Group of crystals extracted from an amethyst geode from Brazil. The rhombohedral growth sectors show amethyst colour, while the prism sectors are colourless to white. Size of specimen 6.5 cm. Photo by German Gemmological Association.

Figure 8: Unusually large macroscopic Brazil twin in an amethyst from Bahia, Brazil. Most examples of this type of twin are seen under the microscope. 4 cm length. Photo by Rainer Schultz-Güttler.

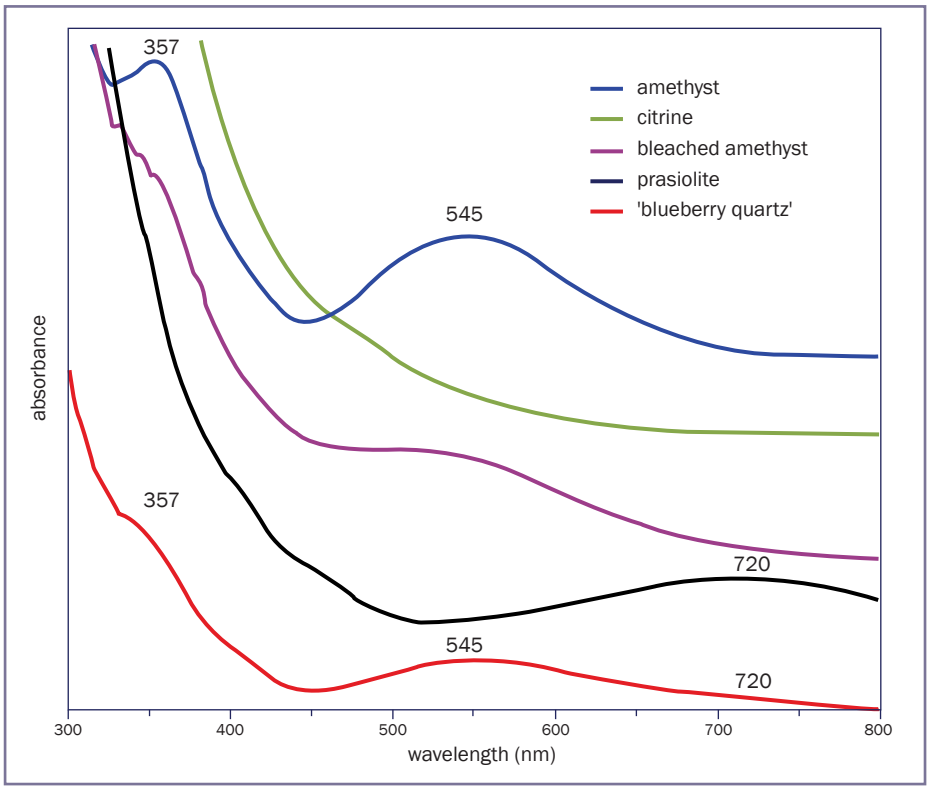

Figure 9: Unpolarized absorption spectra of different colour varieties of iron-bearing quartz. The spectra are displaced on the absorption scale for clarity.

this type also is visible in treated amethyst varieties, in particular in citrine, prasiolite, 'blueberry quartz' and bleached quartz.

The visible range absorption spectrum *(Figure 9)* of amethyst is characterized by a broad absorption band in the yellow-green, which is responsible for the violet colour (Neumann and Schmetzer, 1984). The maximum is located at 545 nm and is only weakly pleochroic (Rossman, 1994), the reddish-violet to bluish-violet change being caused by varying iron entrapment at crystallographically equivalent Si sites (Neumann and Schmetzer, 1984). Cox (1977) described this phenomenon as an anomalous trichroism. Outside the visible range, a second absorption band of Fe^{4+} is situated in the UV at 357 nm and is clearly pleochroic; a further band lies in the NIR with a maximum at 950 nm.

Citrine

Most citrines on the gemstone market are heat-treated amethysts. At temperatures of about 350 to 450°C amethyst bleaches to colourless or pale yellow and the concentration of the provisional iron centres $Fe^{3+}(S_1)$ and $Fe^{3+}(I_4)$ accumulates (Stock and Lehmann, 1977). Coincidently, the formation of iron particles derived from iron originating from these centres starts and the colour develops from yellow to brown. The particles consist of hematite (Fe_2O_3) with an approximate size of 100 nm. Because the distribution of the hematite particles is dispersed, random and relatively homogeneous, the coloration is isotropic and no pleochroism exists. The higher the temperatures are raised during the heat treatment the stronger becomes the brown

Figure 10: Citrine (heat-treated amethyst) of various yellow to brownish-orange colours: pale yellow, yellow, golden citrine, Palmeira citrine, Madeira citrine (from left to right). Weight of the specimens 7.43 to 10.85 ct. Photo by German Gemmological Association.

Figure 11: Amethyst (centre), heat-treated prasiolite (green) and irradiated and heat-treated 'blueberry quartz' from Montezuma, MG, Brazil. Size of amethyst 5 cm long, blueberry quartz 1.5 to 2.5 cm and prasiolite 0.8 to 1.5 cm. Photo by Rainer Schultz-Güttler.

Figure 12: Faceted prasiolite (heat-treated amethyst) from Montezuma, Brazil (6 ct). This colour is stable to light and heat up to 500–600 °C. Photo by Rainer Schultz-Güttler.

Figure 13: Faceted 'blueberry quartz', i.e. gamma-irradiated and heat-treated prasiolite (4 ct). This colour resembles that of much tanzanite. Photo by Rainer Schultz-Güttler.

to orange hue *(Figure 10)*. The optical spectrum *(Figure 9)* shows a continuous increase of absorption towards the UV (Neumann and Schmetzer, 1984).

In the gem trade, golden-yellow material is called golden citrine; more brownish-orange to orange stones are called Madeira citrine; the name Palmeira citrine describes stones from the Palmeira amethyst mine which provides amethyst suitable for heat treatment to citrine of fine quality, so these particular stones have a Brazilian origin.

Prasiolite

Certain amethysts can turn green on heat treatment (*Figures 11* and *12*). The so-called natural prasiolite is very rare and in Nature it has probably formed as a result of heating from nearby volcanic activities (Schultz-Güttler *et al.*, 2008).

The prasiolite offered on the gemstone market nowadays is heat-treated amethyst, much of it probably coming from the Montezuma mine in Minas Gerais, Brazil. The mechanism of the colour modification is a valency change of the amethyst iron centres. As in the heating process used to produce yellow citrine colours the iron centres $Fe^{4+}(S)$ and $Fe^{2+}(I_4)$ are transformed into the provisional centres $Fe^{3+}(S_1)$ and $Fe^{3+}(I_4)$ of the colourless state. Subsequently, a green colour is produced by heat treatment at 400–500°C when the interstitial $Fe^{3+}(I_4)$ changes to Fe^{2+} which is in octahedral coordination (I_6) (see again *Figure 4*). The colour is stable up to temperatures of 500 to 600°C.

Its visible range absorption spectrum *(Figure 9)* is characterized by a broad band with a maximum at 720 nm. Where there is a yellow component in the colour, as in yellow-green to champagne-coloured material, there is a distinct increase of absorption towards the UV (Schultz-Güttler *et al.*, 2008).

'Blueberry quartz'

Gamma irradiation and heat treatment of prasiolite produces violet, violet-blue to dark blue colours (Schultz-Güttler, 2006; Schultz-Güttler and Kohigashi, 2006). The violet-blue to blue material is called 'blueberry quartz' in the gem trade (*Figures 11* and *13*).

The absorption spectrum *(Figure 9)* is characterized by a broad band with a maximum at 545 nm which is caused by the amethyst iron centre Fe^{4+}. Contrary to amethyst, which shows large transmission between 600 and 800 nm, in blueberry quartz a further absorption continues with a shoulder at 720 nm and this is due to Fe^{2+} as in prasiolite. It is this feature which absorbs much of the red wavelength and produces the blue colour. It may be noted that the typical amethyst colour basically is a fine compromise of blue and red components producing lilac. Compared with amethyst the absorption minimum is located at a longer wavelength: at 465 nm rather than the 444 nm of amethyst. That phenomenon is caused by a prior increase of the absorption towards the shoulder in the UV at 357 nm.

Bleached quartz

Heat treatment of amethyst at temperatures above 500°C develops a slightly milky turbidity and bleaching of the violet colour, and some stones of this type have been called 'neon quartz' in the gem trade *(Figure 14)*. At higher temperatures of about 600°C the milky turbidity develops much more strongly and the violet to lilac colour completely disappears. What happens is that silanol (-Si-OH) groups bound in the quartz structure react to the heat by releasing the –OH as tiny water droplets which cause the light scattering and milky turbidity. The resulting appearance resembles adularescent gem materials and such stones are used as moonstone imitations.

The absorption spectrum *(Figure 9)* indicates the presence of amethyst iron centres, but in comparison with the amethyst spectrum, the Fe^{4+} absorption bands possess lower intensity and are less distinctly developed as shoulders.

Bi-coloured quartz

The best-known bi-coloured quartz is ametrine *(Figure 15)* and, as the name accurately implies, the stones consist of amethyst and citrine colour zones. The prime natural source of these stones is the Anahí mine, Bolivia (Vasconcelas *et al*., 1994). The violet amethyst colour is found in the sectors of the positive rhombohedron **r** and is caused by Fe^{4+} centres. The sectors of the negative rhombohedron **z** are yellow. Aines and Rossman (1986) described that phenomenon as follows: the rhombohedral **z** sectors contain higher water contents; natural ionizing radiation results in radiolysis, i.e. a breakdown of water into H_2 and O_2 (see also Hashimoto *et al.,* 2001); and the presence of hydrogen prevents the formation of Fe^{4+} amethyst centres, so there is no violet coloration.

Colour-zoned amethyst from both Bolivia and Brazil (Marabá/Pará or Brejinho das Ametistas/Bahia) can be heat treated to yellow/colourless stones *(Figure 16)* which are sometimes named 'Lunasol' in the trade. In heat treatment at about 475°C the sectors of the positive rhombohedron **r** can change to colourless ($Fe^{4+} \rightarrow Fe^{3+}$) while the sectors of the negative rhombohedron **z** turn yellow (due to precipitation of Fe_2O_3). The process is partially reversible by irradiation, i.e. the sectors of the positive rhombohedron **r** can be returned to violet (Nassau, 1981).

Quartz containing mainly aluminium

Independently or accompanying iron, aluminium is the other main trace element that can replace silicon in the crystal structure on tetrahedral lattice sites (substitution). The radii of aluminium ions are smaller than those of iron at equivalent sites, so substitution of larger quantities is easier and generally the concentration of aluminium is much higher than that of iron (hundreds to thousands of ppm). The difference in charge produced by the substitution of Si^{4+} with Al^{3+} in the structure is compensated for by the presence of alkali ions such as sodium, potassium, lithium, or the hydronium ion (H_3O^+) or a proton. These ions occupy interstitial sites or reside in the channels of the crystal structure. In quartz, as shown above, there are two types of channel parallel to the *c*-axis, one with a trigonal cross-section of smaller diameter and one with a distorted hexagonal cross section of larger diameter; in addition there are channels perpendicular to the rhombohedral faces and inclined to the *c*-axis whose influence on distributions of substitutional ions have not yet been clarified.

Therefore, there is a number of different sites for the compensating ions to occupy to achieve charge balance, with the result that a number of different configurations of colour centres may be present.

The causes of colour and processes of change of colour in aluminium-containing quartz are shown in *Figure 17*, and characteristics and distinguishing features are shown in *Table II*.

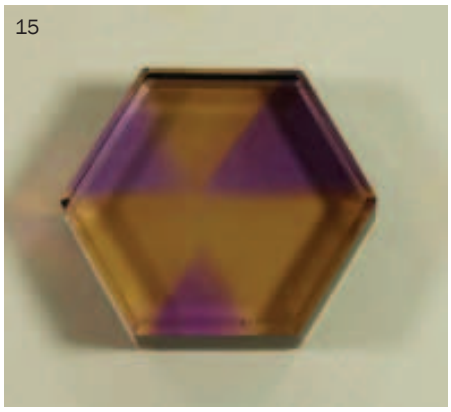

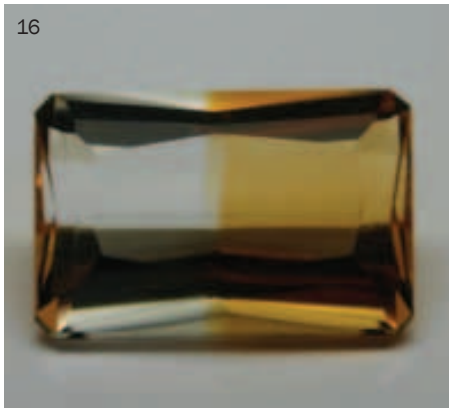

Figure 14: Faceted 'neon quartz', i.e. bleached amethyst. The milky appearance is produced by microscopic fluid inclusions, formed due to heat treatment. Weight of the specimen 4.84 ct. Photo by German Gemmological Association.

*Figure 15: Ametrine from Bolivia. The violet amethyst colour is concentrated at the growth sector of the positive rhombohedron **r**, while the yellow citrine colour is limited to the sectors of the negative rhombohedron **z**. Size of the specimen 4.6 cm. Photo by German Gemmological Association.*

Figure 16: Bi-coloured colourless/yellow quartz obtained by heat treatment of colour-zoned amethyst. Weight of the faceted stone 6.23 ct. Photo by German Gemmological Association.

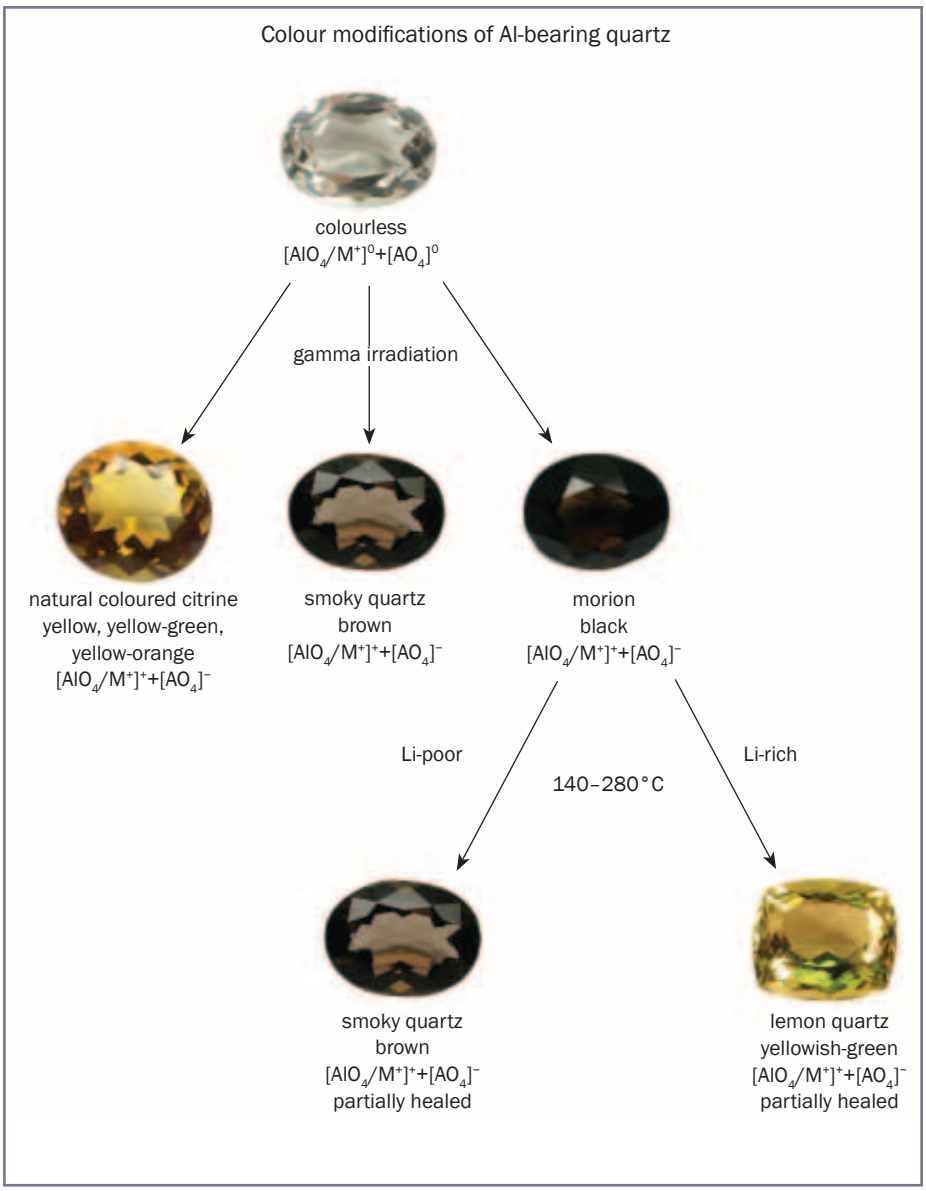

Figure 17: Colour causes and modifications of aluminium-bearing quartz. The colour-forming complexes are shown and the ways to change colour are indicated. Photos by German Gemmological Association.

Table II: Characteristics of aluminium-bearing quartz.

Type	UV/VIS/NIR absorption spectrum	Pleochroism	Brazil law twinning	Infrared spectrum	Upper temperature limit of colour stability, °C
Citrine	shoulder at 400 nm	light yellow to intense yellow	absent	n.d.	200–300
Smoky quartz	bands at 427, 486 and 670 nm	brown to reddish-brown	absent	weak Li-band	200–300
Lemon quartz	bands at 400 and 650 nm	yellow to yellow-green	absent	distinct Li-band (3483 cm^{-1})	200–300

NB: n.d. = not diagnostic

Citrine and smoky quartz

The main colours of this aluminium bearing quartz are all shades of lime green, yellow to yellow-orange (citrine in the real sense with natural colour, *Figures 18* and *19*) and all shades in brown to black, where the range grades into the greyer smoky quartz (*Figures 18* and *20*) and the opaque black variety called morion.

Some crystals contain a wide range of shades of yellow, indicating changing conditions of incorporation of trace elements with changing growth conditions and /or changes in the chemistry of mineral-forming fluids. As Rossman (1994) pointed out, the details of the natures of colour centres in this Al dominated quartz are not yet fully understood. Taking into account the above-mentioned variety of valence-balancing ions which can be incorporated in the quartz structure and more recent work — see for example Götze (2009) and Stevens-Kalceff (2009) — this statement is readily understandable.

The absorption spectra of Al-dominated colour varieties typically contain five bands (after Nassau and Prescott, 1975 and 1977) and the hue and colour depth are determined by their relative intensities. They have their maxima at 670 nm (A1), 486 nm (A2), 427 nm (A3), 314 nm (B) and 270 nm (C). The relative intensity of each absorption band in a spectrum determines the shade of yellow, orange, brown or almost black in that stone. It is outside the scope of this work to discuss further the possible allocation of individual bands to certain defects derived from the general case $[AlO_4/ M]$, whereby M represents a Na, K, Li, or hydronium ion or a missing electron in an orbital, i.e. a hole. However, it is worth stating that the presence of hydroxyl or hydronium ions will reduce the intensities of any yellow and brown colours (Guzzo *et al.*, 1997).

Thus, as was discussed above for iron, radiation is necessary for the creation of colour centres and therefore for colour in quartz with Al as the main impurity. Natural disintegration of radioactive elements in the quartz veins,

Review of some current coloured quartz varieties

Figure 18: An extensive range of natural-coloured citrine and smoky quartz from Santo Sé, Bahia, Brazil. This locality has recently furnished nearly all natural citrine-related quartz in Brazil. Size of specimens from 3 to 6.5 cm in diameter. Photo by Rainer Schultz-Güttler.

Figure 19a and b: Citrines of natural colour from Zambia. Weight of the faceted stones 7.21 and 8.93 ct. Photo by German Gemmological Association.

Fig ure 20: Smoky quartz from Brazil. Weight of the faceted stone 9.72 ct. Photo by German Gemmological Association.

for example, or in surrounding granites or pegmatites can irradiate quartz which, although maybe in small doses, over long geological time can accumulate and produce the colours found in natural material. In the laboratory, however, very high doses of irradiation, mostly gamma-rays, can produce in much shorter times the desired colour(s). It may be worthwhile to stress that irradiation be it natural or applied at the irradiation facility will turn all material nearly black and the described colours are the product of additional heating.

Heat, either through metasomatic or metamorphic processes in a geological setting or by heating under controlled conditions in the laboratory, increases the electron mobility in the quartz, thus counteracting the intensity of the formed colour centres. By careful observation

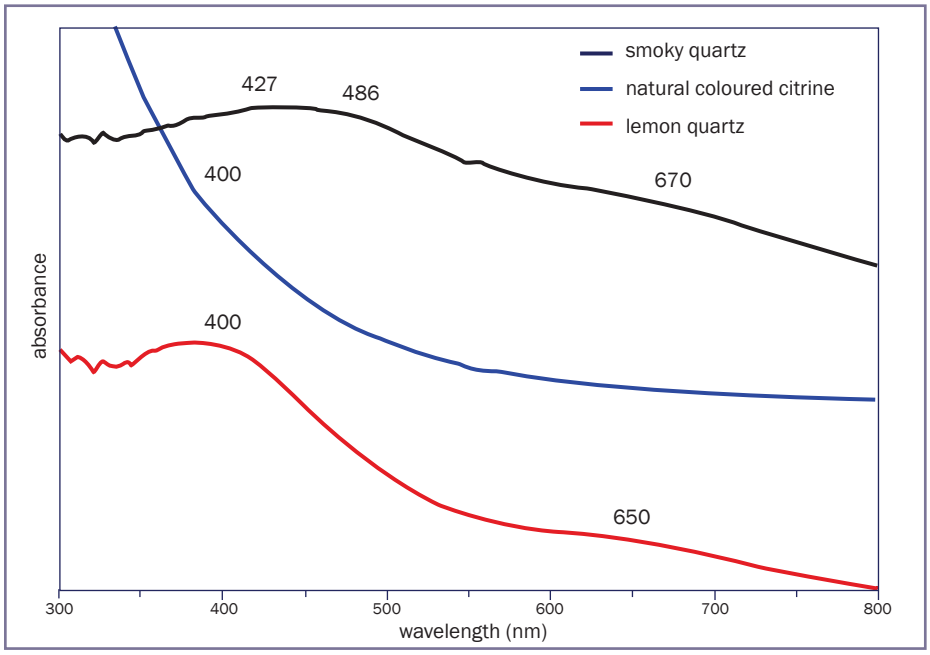

Figure 21: Absorption spectra of aluminium-bearing quartz. The typical absorption peaks for each variety are indicated.

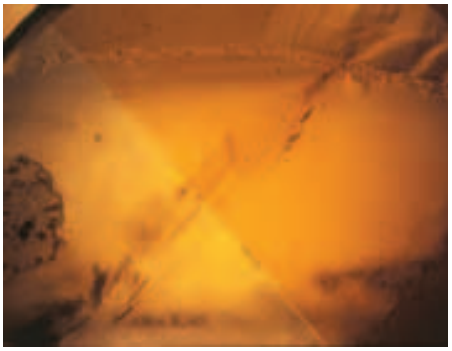

Figure 22: Pleochroism of natural-coloured citrine from Zambia. This is a strong colour difference seldom seen in citrine samples. Photo by German Gemmological Association.

Table III: Differentiation between natural-coloured citrine, citrine obtained by heat treatment of amethyst and lemon quartz.

	Citrine, natural colour	Citrine, heat treated amethyst	Lemon quartz, Heat-treated smoky quartz
Pleochroism	pale to intense yellow	none	yellow to yellow-green
Absorption spectrum	shoulder at 400 nm	continuous increase towards UV	peaks centred at 400 and 650 nm
FTIR spectrum	n.d.	n.d.	Li-band at 3483 cm^{-1}
Brazil law twinning	none	present	none

NB: n.d. = not diagnostic

under controlled heating any one of the commercial colours can be produced.

With appropriate heat treatment, all colours can be reduced and even completely bleached at temperatures of about 210 to 280°C and over periods of 60 to 360 minutes (Barbosa, 2009).

The absorption spectrum of smoky quartz *(Figure 21)* has a wide band with maximum centred about 427 nm and shoulders about 486 and 670 nm. Greenish-yellow, yellow and yellow-orange aluminium-containing crystals (citrine in the traditional sense or so-called 'citrine of natural colour') show a continuous increase in their absorption spectra from red to the ultraviolet with a more or less clearly defined shoulder or absorption band at 400 nm *(Figure 21)*. In contrast to the citrine created by heat treatment of amethyst, natural citrine possesses distinct pleochroism *(Figure 22)*, but no twin intergrowth according to the Brazil law.

Lemon quartz ('green gold')

Even though this variety is one of the above mentioned citrines, its economic importance justifies particular attention. In the gem trade, this quartz is known as 'lemon quartz' or 'green gold' *(Figure 23)*.

The colour is similar to the colour of the best chrysoberyls, a 'chartreuse', a yellow with a distinct touch of green. Only in a few quartz deposits in Brazil or the rest of the world can this attractive quartz be found. Previous studies (Nunes *et al.*, 2009; Trabulsi, 2010; Favacho Silva, 2000) indicate that this colour can only be found in quartz with a high lithium content. The absorption spectrum *(Figure 21)* of such quartz shows a well defined band centred at 400 nm, and one less pronounced at about 650 nm. The degree of intensity of the band at 650 nm relates to strength of the green component in the colour. The source of colour in this case is the molecule $[AlO_4/ Li, H]^0$, which releases an electron by irradiation and forms the colour centre. It should be mentioned that the intensity of the green component is reduced in the presence of a proton or of a hydronium ion.

The distinguishing features of 'lemon quartz', citrine of natural colour and citrine obtained by heat-treatment of amethyst are summarized in *Table III*.

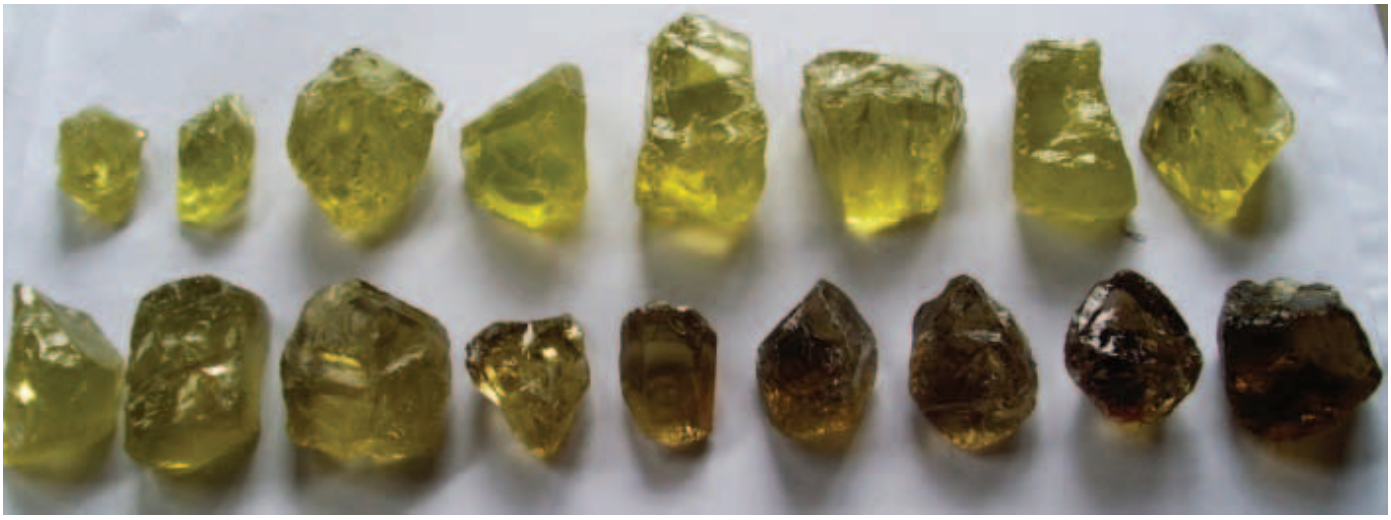

Figure 23: Range of colours of 'lemon quartz' and citrine from Pará, Brazil. They form a colour gradation from near-colourless to dark olive green brown. Sizes from 2 to 6 cm in diameter. Photo by Rainer Schultz-Güttler.

Quartz with high water content

In the last few years a new, green variety of quartz has appeared *(Figure 24)*. In the gem trade, it is sold under the pseudonym 'green amethyst' or 'greened amethyst' or it can be offered as prasiolite. Most of the raw material of this variety comes from the geode-bearing basalts in the south and southwest of Brazil, i.e. from the states of Rio Grande do Sul, Paraná and southwest Minas Gerais. It has been shown that this colour variety is different from the prasiolite obtained from amethyst (Schultz-Güttler *et al*., 2008), and each variety can be distinguished easily using a Chelsea Colour Filter: the prasiolite derived by heat treatment of amethyst from the Montezuma deposit, will show green and this new green variety will show red *(Table IV)*.

Optical spectroscopy and infrared studies have shown that this and similar quartz has a very high content (up to 5000 ppm, Iwasaki and Iwasaki, 1993; Hebert and Rossman, 2008) of molecular water and silanol, or Si-OH groups *(Figure 25)*. Other trace elements such as Fe, Al or Li are very low or are in the range of normal natural quartz as ongoing investigations showed (Guttler *et al*., 2009). So the trace elements in prasiolite and this new green quartz are quite different and the causes of their colours are based on completely different mechanisms.

Macroscopic examination of the original material shows a certain peculiar aspect of its appearance that can best be described as an 'greasy lustre'; this is certainly connected with the high water content of this type of quartz.

On heat treatment to temperatures higher than 500°C, the crystals show a milky, cloudy opalescence, due to water being exsolved as fine microscopic fluid inclusions, similar to the above-mentioned opalescent quartz (Iwasaki, 1980). Comparing the spectra of quartz of pegmatitic origin with those of quartz with the greasy lustre from geodes *(Figure*

Table IV: Distinguishing features of prasiolite and green quartz with high water content.

	Prasiolite	'Wet quartz' irradiated to result in green quartz
Main absorption peak in visible range spectrum	720 nm	610 nm
FTIR spectrum	weak H_2O and Si-OH bands	H_2O band at 1900 cm^{-1} Si-OH bands at 1400 and 2200–2400 cm^{-1}
Colour under Chelsea Colour Filter	green	red

Figure 24: Gamma-irradiated green quartz from Rio Grande do Sul, Brazil. Although the irradiation dose is the same, the difference in colour of the crystals from pale green in the lower left to dark green in the upper right is clearly visible. Size of specimens from 1.5 to 4.6 cm. Photo by Rainer Schultz-Güttler.

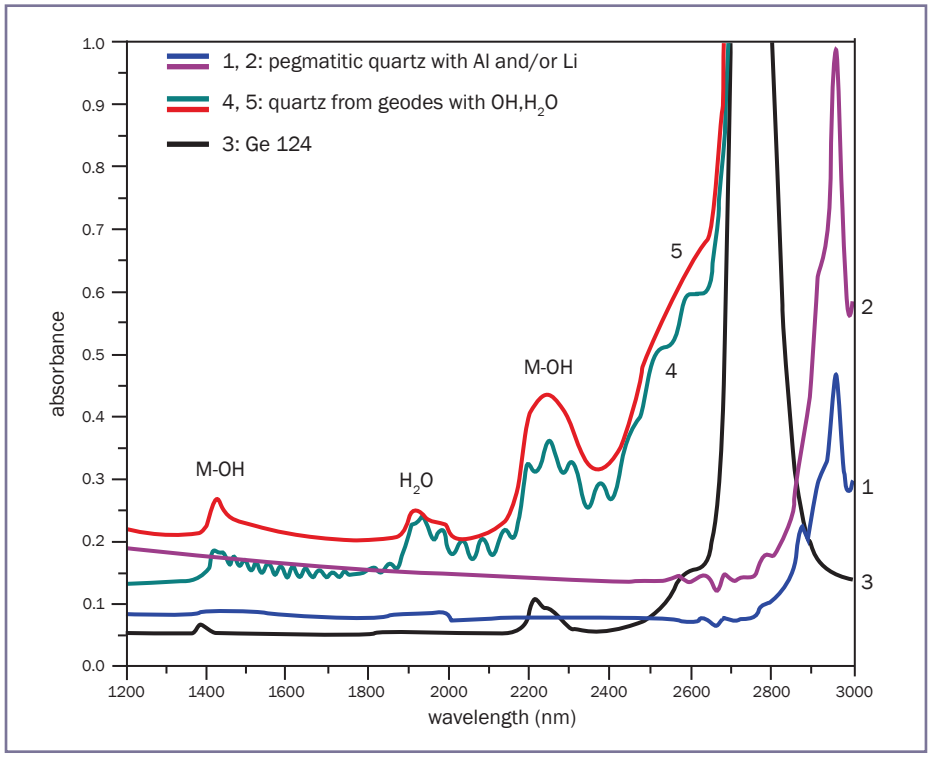

Figure 25: NIR-spectra of different types of quartz. Spectra 1 and 2 are from pegmatitic quartz with contents of Li and Al but no water or OH groups (labelled H_2O and M-OH respectively). Spectra 4 and 5 are from 'wet quartz' from geodes in Rio Grande do Sul, Brazil, and their H_2O and OH peaks are clearly visible. The wavy appearance of spectrum 4 is due to internal reflection of the light beam. The presence of silanol groups is made clear by comparison with spectrum 3, an ultrapure General Electric standard glass, GE 124 with < 5ppm OH.

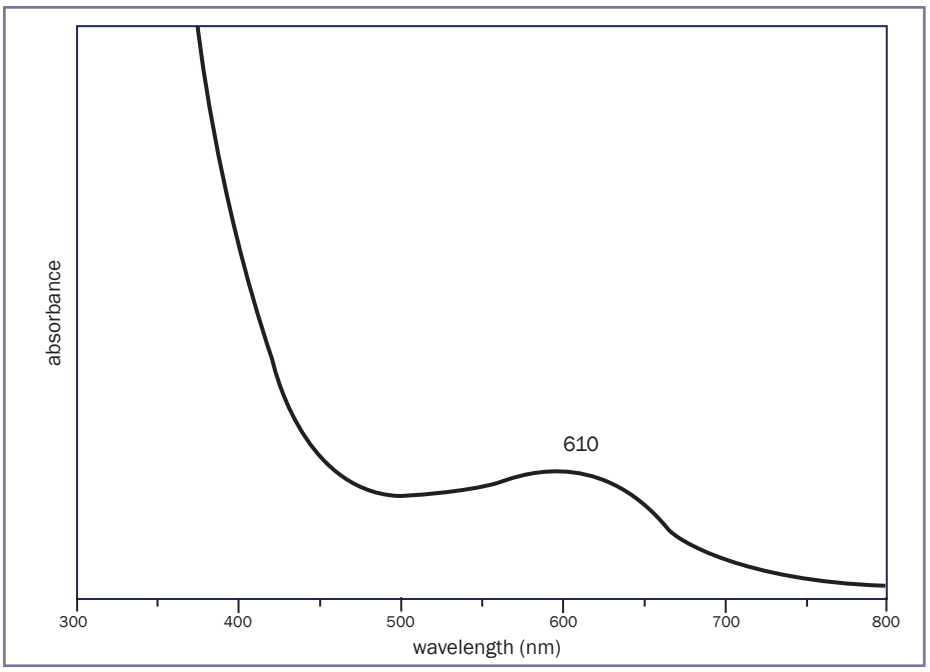

Figure 26: Absorption spectrum of gamma-irradiated green quartz from Rio Grande do Sul, Brazil. This absorption peak has long been specific for non-bonding oxygen hole (NBOH) defects in silica and glass, and more recently in quartz.

25), the intensities of the water and OH absorption bands are clearly higher in the latter. This type of quartz with high water content should therefore be called 'wet quartz' and its spectral characteristics resemble those of chalcedony as shown by Graetsch *et al.,* 1985.

The presence of molecular water and silanol quenches all tendency towards the formation of colour centres based on Al or Fe. Therefore, geodes commonly contain amethyst crystals of very pale colour even though their contents of Fe are comparable with those in quartz of intense amethyst colour which has come from other sources.

Since only irradiation produces this green colour one has to assume that gamma radiation interacts with water to form oxygen and hydrogen and that the groups Si-OH and Si-O already present as point or line defects along twin planes or growth defects will be split forming respectively hydrogen and oxygen (Hashimoto *et al.,* 2001). This Si-O group is now electronically active to form colour centres that produce a band at 590 to 620 nm in the visible absorption spectrum *(Figure 26)* and a strong absorption at 220–260 nm in the UV. This centre is called the 'non-bonding oxygen hole centre' (NBOHC) and occurs in various types of silica, both crystalline and amorphous. The two absorption bands effectively form a transmission window at about 490 to 540 nm which produces the green colour *(Figure 27)*.

These NBOHC defects are quite different from the Fe or Al substitutions described above. Rather, they find themselves on dislocations in the crystal structure with no direct bonding to neighbouring SiO_4 tetrahedra, or they exist in regions with highly strained bonds, such as twin lines, growth defects, spiral growth hillocks, step growth defects and so on. As such, they can be linked to a range of growth features in different crystals (Hosaka *et al.*, 1986; Stevens-Kalceff, 2009).

Perfection of growth in quartz depends strongly on growth velocity and suitability of solution chemistry. Quartz grown rapidly shows striations and the amount and thickness of these is a function of the growth rate. Higher growth rate will produce finer striations, whereas quartz grown slowly, fractions of mm a day, will show hardly any growth defects. In examining green quartzes, one can always find fine striations parallel to the rhombohedral faces —which may be produced by Brazil twins or growth defects.

It must then be concluded that this kind of 'wet quartz' grew rapidly. Since the growth of a crystal is a very local event, e.g. in geodes, it is understandable that there can be several generations of quartz in the same geode, each with certain specific growth features. Crystals which grew slowly can show intense

Figure 27: Untreated and gamma-irradiated wet quartz crystals. The same dose of irradiation produces different intensities of colour. Size of specimens between 2 and 4 cm. Photo by Rainer Schultz-Güttler.

Figure 28: Bi-coloured quartz with an amethystine core and a green outer layer from Rio Grande do Sul, Brazil, probably reflecting different growth rates in different growth solutions. Crystals with green cores and amethystine layers can also be found. Size 8.3 cm. Photo by Rainer Schultz-Güttler.

Figure 29: Massive rose quartz. The cloudy appearance is typical and is probably due to an intergrowth of quartz with dumortierite. Weight of the faceted stone 8.76 ct. Photo by German Gemmological Association.

amethyst colour and have a relatively low water content, while 'wet quartz' with its rapid growth will be colourless, even though it may have high amounts of iron and/or aluminium.

Sometimes the growth rate may vary and this can affect the number of defects in a single crystal. If initial growth is slow and later growth is fast, quartz can be produced which has a core with amethyst colour *(Figure 28)*, but which is green in the outer layers.

Studies of the colour stability of this green variety of quartz have shown that temperatures of 150°C are enough to bleach the quartz within one to two hours (Clerici, 2010), and its behaviour and stability under UV radiation and sunlight are currently being examined.

Rose quartz

Most pink quartz is found in massive compact form, only rarely as smaller euhedral crystals, and has a cloudy or translucent rather than transparent appearance *(Figure 29)*. A wide band with maximum at about 500 nm in the absorption spectrum *(Figure 30)* is characteristic. Lehmann and Bambauer (1973) ascribed this band to Ti^{3+} on substitutional sites of the crystal structure. The cause of the cloudy appearance is probably a light scattering process from tiny fibrous inclusions: Ignatov *et al.* (1990) and Goreva *et al.* (2001) found pink-coloured dumortierite in quartz and attributed the absorption band to Fe^{2+}-Ti^{4+}electron charge transfer. The pink single crystals are intrinsically different from massive rose quartz. In their absorption spectrum they have bands at 338 and 524 nm which have been attributed by Rossman (1994) to an Al O^{-}-P-associated complex forming a colour centre. The use of gamma irradiation intensifies the colour of these single-crystal rose quartzes *(Figure 31)*.

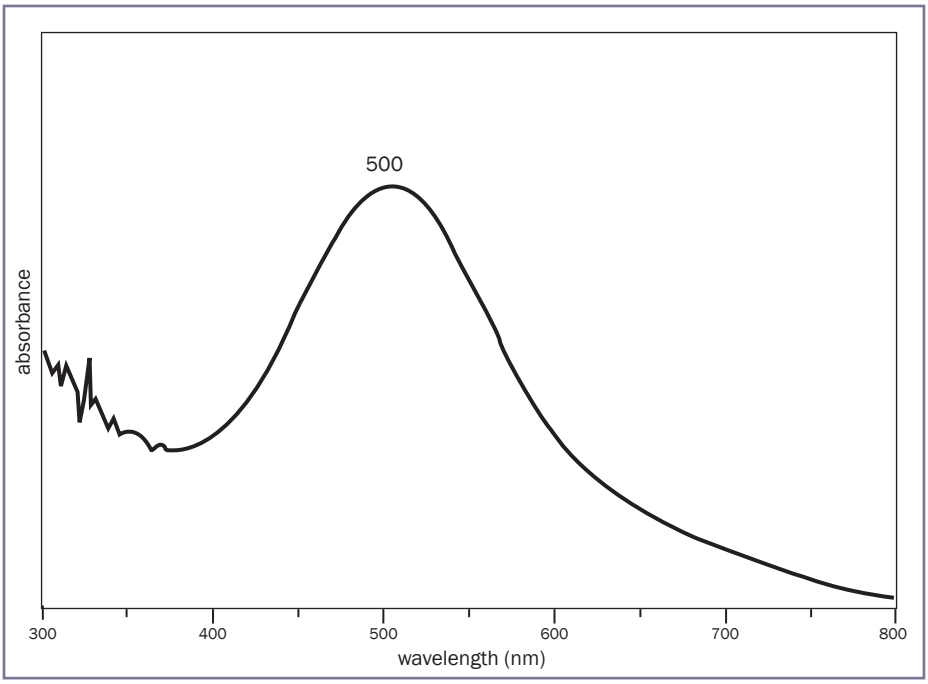

Figure 30: Visible range absorption spectrum of massive rose quartz, with a broad peak centred at about 500 nm.

Figure 31: Euhedral rose quartz crystal cluster: pale colour and irradiated sample with strong pink colour, which is quite stable to light. This sample is from Galileia, Minas Gerais; size 5 and 7 cm for each cluster. Photo by Rainer Schultz-Güttler.

Conclusions

Quartz, generally thought of as a gemstone with only a few colour varieties, such as amethyst, citrine and smoky quartz, has a more extensive range of colours, some of them induced by treatments. Heat and irradiation in particular have opened the way to increasing the range and availability of gem materials and to increasing their economic importance. So there is no need to search for deposits of these varieties, since so much colourless quartz with appropriate trace impurities can be found not only in Brazil but also in other parts of the world. The search for criteria to distinguish quartz susceptible to treatment is an ongoing task, since complex natural conditions of growth, as shown in this work, can influence and often determine the resulting colour of quartz.

However, the spectra and comparison tables presented here indicate some criteria that can already be used to identify the different kinds of quartz. Using spectroscopy, wet, hydrothermal quartz can be distinguished from quartz with very little water; using pleochroism and twinning, citrine and smoky quartz can be distinguished.

Besides this it is also important to know whether the colour of a gemstone is natural or induced by means of treatments. From the data discussed in this work it is clear that much has still to be done to decipher all the factors determining each type of colour. But what is now established is that it is easy to separate the two types of green quartz, prasiolite and green quartz by means of use of the Chelsea Colour Filter, and to recognize the colour of 'green gold' as a product of irradiation and heat treatment. The temperatures discussed in the text and on the charts also indicate that jewellers should take special care when using heat in repairing any jewellery that contains coloured varieties of quartz.

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The identification features of undisclosed loose and mounted CVD synthetic diamonds which have appeared recently in the NGTC laboratory

Zhonghua Song, Taijin Lu, Yan Lan, Meidong Shen, Jie Ke, Jianhui Liu and Yubing Zhang

Abstract: Since February 2012, undisclosed CVD synthetic diamonds, both loose and mounted, submitted to National Gemstone Testing Centre (NGTC), China, have been examined. It was found that these gem-quality CVD synthetic diamonds, particularly the mounted ones, are difficult to distinguish from natural diamonds using only routine identification techniques and procedure, but they were effectively identified using photoluminescence and DiamondView™ techniques. The 736 nm double lines in the photoluminescence spectra and the layered growth striations observed in DiamondView™ fluorescence images are the two most important characteristics for identification of the CVD synthetic diamonds. The gemmological and spectroscopic properties of the CVD synthetic diamonds identified are reported.

Keywords: CVD synthetic diamond, diamond testing, DiamondView™, fluorescence, internal features, phosphorescence, photoluminescence

Introduction

In recent years, a considerable number of gem-quality synthetic diamonds produced by chemical vapour deposition (CVD) have reached the market. Most of these have come from Apollo Diamond Inc. (Wang *et al.*, 2003). In November 2010, Gemesis Corporation announced plans to market CVD-grown synthetics. In autumn 2011, the GIA laboratory reported the identification characteristics of the CVD synthetic diamonds grown by Gemesis Corporation (Wang and Moses, 2011). Subsequently, this summer, Wang *et al.*, (2012) reported further gemmological and spectroscopic properties of CVD synthetic diamonds from Gemesis Corporation in detail.

In 2012, CVD synthetic diamond has been a subject of concern in the gem market, since the synthetic diamonds now being produced are very similar to natural diamond in visual appearance. It has been reported that undisclosed CVD synthetic diamonds were submitted to the International Gemological Institute (IGI), National Gemstone Testing Centre (NGTC)

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Figure 1: Undisclosed loose and mounted CVD synthetic diamonds submitted to NGTC lab. Photograph by Zhixin Wu and Fei Wang.

and Gemological Institute of America (GIA) laboratories as natural diamonds for standard grading reports (DTC, 2012; NGTC, 2012; Even-Zohar, 2012). From February to July 2012, a total of 49 loose and 14 mounted diamonds all undisclosed CVD synthetic diamonds, were submitted to the NGTC — in both the Shenzhen and Beijing laboratories — for identification and grading reports. Here, the gemmological properties, particularly the identification features for these undisclosed CVD synthetic diamonds, are reported and discussed.

Samples and identification techniques

The surfaces and internal features of all 63 stones were examined using a gemmological microscope. Luminescence to ultraviolet radiation and phosphorescence were observed using 254 nm (short-wave) and 365 nm (long-wave) excitation, and also with the DiamondView™ deep-ultraviolet (<230 nm) imaging system.

Infrared absorption spectra were recorded on all the samples covering the mid-infrared range (6000–400 cm^{-1}, 2 cm^{-1} resolution) and near infrared range (12000–4000 cm^{-1}) at room temperature with a Nicolet 6700 Fourier transform infrared (FTIR) spectrometer. A KBr beam splitter was used for the mid-infrared range, and a quartz beam splitter for the near-infrared range. Vis-NIR spectra in the range of 400–1000 nm were collected with the Avantes-2048 system. We recorded photoluminescence spectra with the diamond immersed in liquid nitrogen, using a Renishaw 2000 system with a 514.5 nm Ar ion laser as the light source. Qualitative chemical analyses were obtained using energy-dispersive X-ray fluorescence (EDXRF) with a Thermo Electron Quant'X spectrometer at a voltage of 18 kV and a beam current of 0.3 mA for metallic element detection.

Results

Visual appearance

All the stones are colourless or near-colourless (G–J colour grade) *(Figure 1)*, although some are pale grey; none shows any brown coloration. The loose stones weigh between 0.30 and 0.60 ct, and the size of the mounted stones ranged from an estimated 0.24 to 0.38 ct. All the diamonds are round brilliants and no laser inscriptions were found on the girdles.

Inclusions

A few dark irregular inclusions are visible under magnification *(Figure 2)*,

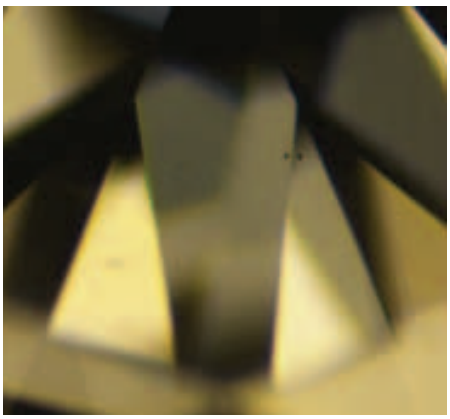

Figure 2: Dark inclusion in a 0.56 ct CVD synthetic diamond, Magnified 50 ×. Photomicrograph by Zhonghua Song and Licong Li.

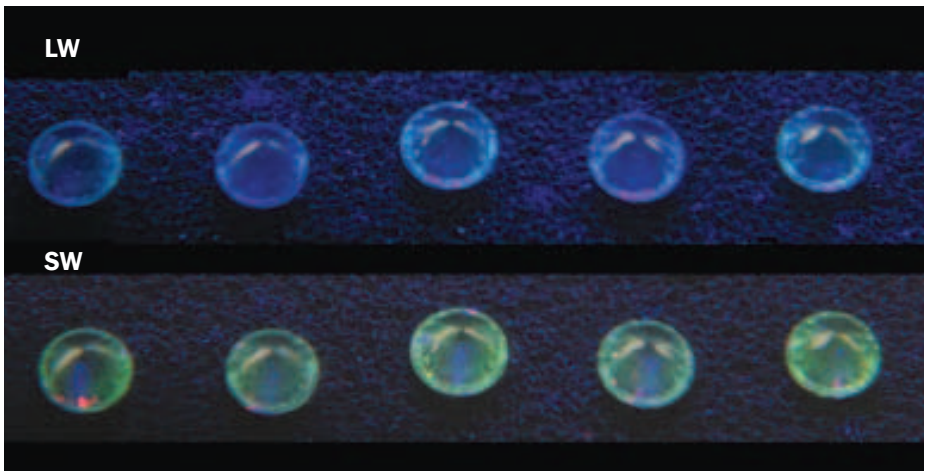

Figure 3: Fluorescence of some CVD synthetic diamonds under long-wave (top) and short-wave (bottom) UV light. Fluorescence under SWUV is stronger than that under LWUV.

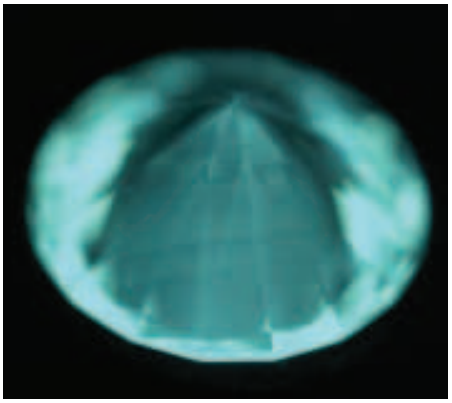

Figure 4: DiamondView™ fluorescence image of a CVD synthetic diamond showing layered growth striations and bluish-green fluorescence.

which are similar to the dark inclusions in natural diamonds. The dark inclusions were believed to be non-diamond carbon by Martineau *et al.* (2004). The clarity grades of these diamonds were equivalent to VS2 or better. When these diamonds are observed between crossed polarizers, they do not show the tatami structure typical of type IIa natural diamond.

Luminescence

When exposed to long-wave UV radiation, some of the stones were inert to UV, while others fluoresced very weak greenish blue. However, almost all showed weak to moderate greenish yellow fluorescence under short-wave UV radiation, and in any one stone, the fluorescence was stronger than under long-wave radiation *(Figure 3)*. No obvious phosphorescence was seen.

When viewed in DiamondView™, the diamonds displayed bluish-green fluorescence and noticeable blue phosphorescence, with characteristic layered growth striations *(Figure 4)*.

Spectra

The infrared absorption spectra in the mid-infrared region showed that these diamonds were all type IIa, with an absence of any absorption bands related to nitrogen and hydrogen. In the near-infrared region, there was no evidence of any H-related absorption.

The Vis-NIR spectrum revealed a smooth, gradual increase in absorption from long wave to short wave, but no distinct absorption lines such as 415 nm lines (found in many natural diamonds) were noted.

All of our CVD samples showed similar photoluminescence (PL) spectra *(Figure 5)*, including moderately strong photoluminescence N-V emission lines at 575 and 637 nm. The relative intensities of these two lines varied, but in general the 637 nm line was more intense. All samples tested had a weak to moderate to strong doublet peak at 736.3 nm and 736.0 nm that is attributed to silicon-vacancy centres (Clark *et al.*, 1995).

Composition

The EDXRF analysis of all the stones did not display any X-ray emission peaks associated with metal elements such as nickel, iron or cobalt, and the stones were not attracted to a magnet.

Discussion

Wang *et al.* (2011) reported on similar products introduced by Florida-based Gemesis Corporation and it was noted that although these CVD synthetic diamonds were more similar in appearance to natural diamonds, they did show differences in their spectra and fluorescence features under the DiamondView™ (Wang *et al.*, 2003; Martineau *et al.*, 2004).

In early 2012, the NGTC laboratory discovered undisclosed CVD synthetic diamonds during routine processing of submitted stones. The main features were found to be extremely similar to those that the GIA laboratory had reported in the autumn of 2011. What calls for special attention is that the undisclosed CVD synthetic diamonds were found mounted in diamond jewellery.

The colour grades of these synthetic diamonds lie in the range G–J. This differs from previously-grown CVD diamonds which generally had a brown tone. So the current CVD diamonds are closer to natural diamonds in visual appearance.

The clarity grades of these samples vary between VS2 and VVS2, and reflect the small quantities of black inclusions; these resemble those in natural diamonds *(Figure 2)*, so they are of no help in distinguishing the stones from natural diamonds.

The blue-green fluorescence and blue phosphorescence colours of the DiamondView™ images *(Figure 4)*

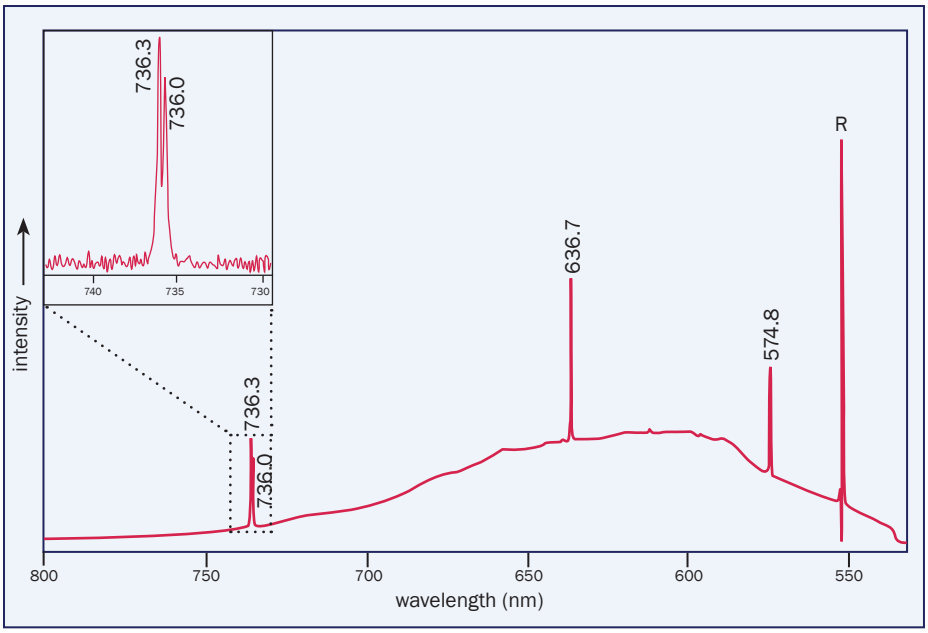

Figure 5: Photoluminescence spectrum of a CVD synthetic diamond, excited at 514.5 nm, recorded with the specimen at 77K. R is produced by first-order Raman scattering, the peaks at 574.8 and 636.7 nm are due to transitions at the neutral and negative N-V centres respectively, and the Si-related peaks at 736.0 nm and 736.3 nm are clearly visible.

described above are quite different from those of the traditional CVD products, which hitherto have been shades of orange. The blue phosphorescence is mainly caused by the boron added during the growth processes (Martineau *et al*., 2004). DiamondView™ images are best obtained from the pavilions of brilliants which reveal typical growth striations of CVD synthetics, but for mounted diamonds, obtaining a view of the pavilion is usually impossible. So the better method for these stones is to use the PL spectrum obtained at the liquid nitrogen temperature. Whether for mounted or loose stones, all display doublet lines at 736.3 and 736.0 nm caused by the Si-V defect lines in the PL spectrum *(Figure 5)*.

Wang *et al*. (2003) reported that Apollo CVD synthetic diamonds have the hydrogen-related absorption lines at 8753 cm^{-1}, 7354 cm^{-1}, 6856 cm^{-1}, 6425 cm^{-1}, 5563 cm^{-1} and 3123 cm^{-1} in the near- and mid-infrared areas, which were only found in CVD synthetic diamonds, not in natural diamonds. However, after high temperature and high pressure treatment, such absorption peaks disappeared and a new absorption peak at 3107 cm^{-1} appeared; unfortunately this peak also occurs in natural diamonds. Our CVD synthetic diamonds do not have any hydrogen-related characteristic absorption peaks in the near- and mid-infrared ranges.

Although these CVD synthetic diamonds were annealed after their growth to improve their colour and transparency (Wang and Moses, 2011; Wang *et al.,* 2012), the Si-V defect (736 nm line) is relatively very stable and is not likely to be destroyed by high temperature (Clark *et al*., 1995). Therefore, PL spectra and fluorescence properties are the key to identifying these recent CVD diamonds.

Summary

Gemmological and spectroscopic properties of loose and mounted diamonds submitted to NGTC laboratories have been identified as CVD synthetics. They are colourless or near-colourless, ranging from G to J, with clarity grades of VVS2 to VS2. Absorption spectra show all samples to be type IIa, and no other defect-related absorption features were detected in the mid- and near-infrared spectral ranges. Photoluminescence spectra were dominated by N-V and $[Si\text{-}V]^-$ centres. PL spectroscopy at low temperature and DiamondView™ fluorescence images are critical in separating these synthetic diamonds from their natural counterparts. For fast identification of mounted synthetic diamonds, PL spectra are more useful because the current DiamondView™ fluorescence imaging system is most effective if there is access to the pavilion of a stone.

Acknowledgements

The authors thank all the members of the NGTC for their great support and valuable comments; and Ning Hu for his skilled picture editing. Also grateful thanks are due to Dr David Fisher, Dr Philip M. Martineau of the DTC research centre and Yang Fan, Forevermark, China, who have all provided useful information about the CVD synthetic diamonds.

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Flux-grown synthetic alexandrites from Creative Crystals Inc.

Dr Karl Schmetzer, Dr Heinz-Jürgen Bernhardt and Thomas Hainschwang

Abstract: Mineralogical and gemmological properties of flux-grown synthetic alexandrites from Creative Crystals Inc. are described. The samples were grown with three different seed orientations parallel to the prism **r** (130), parallel to the pinacoid **b** (010) and parallel to the dipyramid **l** (133). Details of the growth process are indicated by the morphology of rough single crystals and by the internal growth patterns of the rough and faceted alexandrites. The samples were produced in numerous growth cycles in a slow cooling process, which is responsible for the growth of successive alexandrite layers and for distinct colour zoning within each layer. Detailed microprobe scans across several samples indicate that the colour zoning is due to variable chromium and iron contents. Absorption spectra in the visible and infrared ranges are presented. Absorption bands in the visible are assigned to chromium and iron as main colour-causing trace elements, and colour and pleochroism of samples in different orientations is evaluated using colorimetric data. The absorption bands in the infrared are polarized and assigned to structural OH-groups. The properties of the samples are compared with diagnostic features of Russian flux-grown alexandrites.

Keywords: alexandrite, chrysoberyl, chromium, colour zoning, comparison with Russian synthetic alexandrite, Creative Crystals Inc., crystal habit, inclusions, infrared spectra, iron, synthesis, visible spectra

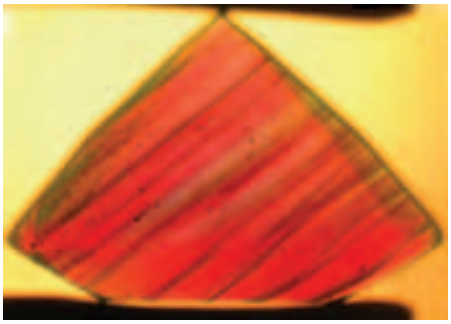

Layered growth zoning associated with an intense colour zoning in a faceted synthetic alexandrite grown by Creative Crystals Inc.; immersion, field of view 5.3 × 4.0 mm. Photo by K. Schmetzer.

Introduction

The first descriptions of flux growth of chrysoberyl date back to the mid-nineteenth century and an overview of this literature is given by Elwell and Scheel (1975). In the twentieth century, modern synthesis of chrysoberyl and chromium-bearing chrysoberyl (alexandrite) started in the 1960s. The first successful crystal growth experiments were conducted in fluxes of PbO, mixtures of PbO and PbF_2 or mixtures of Li_2MoO_4 and MoO_3. In general, the nutrient was added to the solvents (fluxes) and annealed in crucibles for some hours at temperatures between 1400 and 1350 °C. Reducing the temperature at a slow rate of about 12.5°C per hour initiated spontaneous nucleation and crystal growth to a maximum size of 5 mm, but mostly in the range of 1–2 mm in PbO or PbO/PbF_2 fluxes. From Li_2MoO_4/MoO_3 fluxes twinned platelets up to 3 mm were obtained. Seeded growth was also performed successfully (Farrell *et al.*, 1963; Farrell and Fang, 1964). However, using slower cooling rates of 0.5 °C per hour, much larger crystals up to 4.4 cm in diameter were obtained (Bonner and Van Uitert, 1968).

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Figure 1: One of the first synthetic alexandrites grown by Creative Crystals Inc. in the early 1970s in daylight (left) and incandescent light (right); diameter of the sample 5.5 mm. Photo by K. Schmetzer.

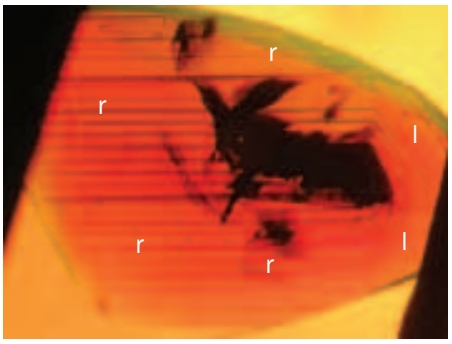

*Figure 2: Layered growth zoning associated with an intense colour zoning in a faceted synthetic alexandrite grown by Creative Crystals Inc.; the seed of the sample was oriented parallel to the **r** prism face, the internal growth pattern consists of layers parallel to the **r** prism and parallel to the **l** dipyramid; immersion, field of view 6.1 × 4.6 mm. Photo by K. Schmetzer.*

In the following decades, several papers about flux growth of synthetic chrysoberyl and alexandrite were published. Until the 1980s, growth was performed using the slow cooling method mentioned above, but experiments were done with different fluxes (see overview by Schmetzer *et al.*, 1996). Further progress in flux growth of chrysoberyl and alexandrite was made by the application of a temperature gradient to different parts of the crucible in specially constructed furnaces. This method, in which the nutrient is kept at a somewhat higher temperature than the growing crystals, was described by Russian and Japanese scientists (see again the summary in Schmetzer *et al.*, 1996). With this technique, crystal growth was performed both by spontaneous nucleation and by seeded growth (Bukin, 1993).

In 1972 the first commercially produced synthetic alexandrites were introduced to the US market by the company Creative Crystals Inc., residing at San Ramon, California *(Figure 1)*. The first descriptions by Liddicoat (1972) and Eppler (1974) indicated a flux growth technique and described various inclusion forms of residual flux as well as metallic particles, the latter most probably derived from the crucible walls. Both authors mentioned distinct growth zoning or growth banding in the faceted samples, a feature also indicated by cathodoluminescence images, and this indicates variable chemical composition within the crystals (Gaal, 1976).

The first faceted samples of Russian flux-grown alexandrite, which were produced from Bi_2O_3- and MoO_3-bearing fluxes at the Institute of Geology and Geophysics, Novosibirsk (Rodionov and Novgorodtseva, 1988; Bukin, 1993), appeared on the market in the mid 1980s and were described in detail in various papers correlating mineralogical and gemmological properties with the growth method used (Trossarelli, 1986; Henn *et al.*, 1988; Henn, 1992, 2000; Schmetzer *et al.*, 1996). In contrast, although a patent by Cline and Patterson assigned to Creative Crystals Inc. was published in 1975 and great quantities of synthetic alexandrites were produced and released to the market in the 1970s to 1980s (see, e.g. Elwell, 1979; Nassau, 1980 a,b), no further detailed studies of the material produced by Creative Crystals Inc., which correlates chemical, physical and microscopic properties with growth conditions were published. In addition, to the knowledge of the present authors, no gemmological data concerning any rough material is publicly available.

The most detailed examination of faceted alexandrites produced by Creative Crystals Inc. is found in an unpublished diploma thesis of Pohl (1989). In addition to the various forms of residual flux and platinum particles which had been mentioned by Liddicoat (1972) and Eppler (1974), she described a shell-like three-dimensional growth structure. Under crossed polarizers, the different growth planes of the successive growth layers show a distinct interference pattern. Furthermore, an angle of 54 ± 2° was found to be common between different dominant growth faces, but the individual faces were not identified.

Although it is generally understood that identification of the alexandrites grown by Creative Crystals Inc. and their distinction from natural alexandrites is straightforward because of the presence of various forms of residual flux and metallic platinum particles, this is not foolproof because faceted samples above 10 ct without any such diagnostic inclusions are available, and, in some slightly included samples, parts of the flux feathers can closely resemble healing feathers in natural alexandrites. So, for stones like these, the internal growth pattern might be the only microscopic feature of diagnostic value — if properly identified and understood.

History of research and challenges

In the process of Pohl's preparation of her diploma thesis in the late 1980s at Heidelberg University, Germany, one of the present authors (KS) had the chance to examine under the microscope her research material, which had been loaned from the collection of H. Bank, Idar-Oberstein. Several microscopic features were not understood in detail and could not be correlated with a specific growth process. In particular, all faceted samples showed a three-dimensional layered growth pattern *(Figure 2)*, occasionally

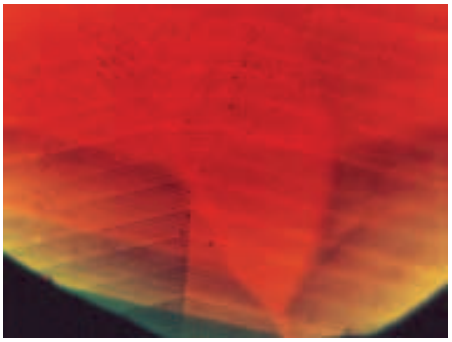

Figure 3: Characteristic interference pattern shown by the layered growth structure of a faceted synthetic alexandrite by Creative Crystals Inc.; immersion, crossed polarizers, field of view 4.1 × 3.1 mm. Photo by K. Schmetzer.

combined with an intense colour zoning. Under crossed polarizers, interference effects were visible at the boundaries of these layers *(Figure 3)*.

Because these interference effects closely resembled the optical impression which is commonly seen at the twin boundaries of alexandrite twins or trillings, the possibility that the different boundaries in the material from Creative Crystals Inc. represented twin boundaries of perhaps a sort of polysynthetic twinning was discussed. In contrast to the twinned components commonly seen in natural alexandrite however, the pleochroic colours of the area on each side of any boundary in a Creative Crystals Inc. alexandrite were always identical.

Having these unresolved problems in mind it was decided to dedicate some time to a new study of synthetic alexandrites grown by Creative Crystals Inc., mainly to understand the observed microscopic structures. With the experience gained from the study of natural alexandrites from different sources (Schmetzer, 2010, 2011), it was considered possible to interpret the internal growth patterns in more detail and to understand the basic growth technology of these samples. Because the faceted alexandrites studied in the late 1980s were no longer available, the authors started with five samples obtained from different collections and from gemmological colleagues.

In this period, with the help of A. Matlins, Woodstock, VT, U.S.A., we were able to contact David Patterson, one of the former owners of Creative Crystals Inc., residing now at San Ramon, CA, U.S.A. From the results obtained from the study of the first five faceted samples and some hints in the US patent by Cline and Patterson (1975), it was concluded that the alexandrites were grown using a process of several successive growth cycles (see below). Mr Patterson confirmed these first conclusions and agreed to help with further samples and information and especially to check if the interpretations obtained were consistent with his detailed knowledge about the general growth process and the variants applied. He also submitted a detailed history of alexandrite synthesis by Creative Crystals Inc., which was summarized for the present paper (see Box A).

Samples

The first faceted samples used for this study came from the personal collections of one author (KS) and gemmological friends and colleagues as well as from the reference and teaching collections of the German Gemmological Society, Idar-Oberstein, and the Swiss Gemmological Institute, Basel. Furthermore, David Patterson provided three rough crystals and five faceted alexandrites *(Figure 4)* from his personal collection, and a list of eight crystals which had been given to private museums and reference collections in the 1970s and 1980s. Finally, we were able to borrow four of these crystals and some additional faceted samples from the GIA collection, Carlsbad, and from the Smithsonian collection, Washington *(Figure 5)*. One additional crystal was submitted from the collection of Kevin Patterson.

D. Patterson (pers. comm., 2012) said that different orientations of the seed were used for crystal growth. After examination of the eight rough crystals available, it was concluded that each was grown on a seed with one of three different seed orientations, namely, parallel to the **r** (130), to the **b** (010) or to the **l** (133) faces of chrysoberyl. Most of the faceted samples in our study were found to belong to the type grown from seeds oriented parallel to the **r** prism. Therefore, in order to improve our representation of the Creative Crystals Inc. production, D. Patterson provided some faceted

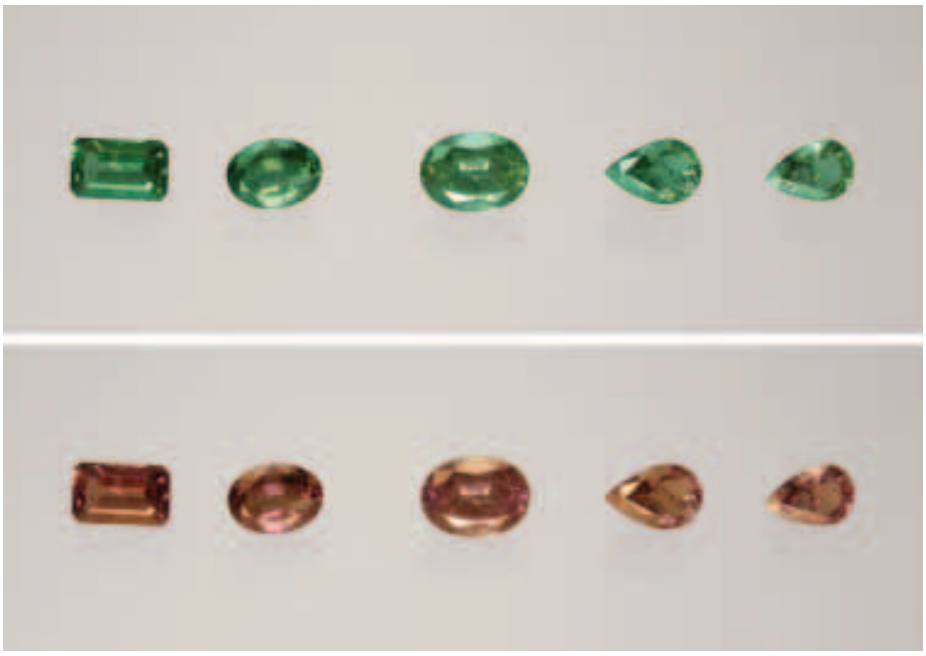

Figure 4: Faceted synthetic alexandrites grown by Creative Crystals Inc. in daylight (above) and incandescent light; weight of samples from 0.87 to 1.93 ct, the rectangular sample on the left (1.61 ct) measures 8.5 × 5.2 mm. Photo by K. Schmetzer.

Box A

Alexandrite synthesis by Creative Crystals Inc., a history[1]

By David Patterson

In 1970 I heard of a group, formerly from the Lawrence Radiation Laboratory (LRL), who had synthesized alexandrite and emerald. I contacted them and we started working together. They were then owned by Physics International, a manufacturer of electron accelerators. The group, at that time, consisted of Carl Cline and a very talented technician named Don Kingman. Carl was a theoretical metallurgist and Don was an expert at growing crystals. At that time, they were able to grow spontaneously-nucleated chromium-doped chrysoberyl and had just started looking at seeding. The solubility of the flux had been well established. Carl had accepted a job with Allied Chemical and was scheduled to move to New Jersey in a month.

Physics International approached me to see if I was interested in buying the operation. Creative Crystals Inc. was incorporated and I was made president. Neither Carl Cline nor Don Kingman had seen a fine alexandrite before. I had several of them and some Russian and Rhodesian rough. We ran a wet chemical analysis on rough of both origins and found chromium, iron, and vanadium as most likely involved in the colour change.

We concurrently started studying the chromium-iron relationship and seed orientation. The chromium additive level was about right. We added iron and ran several cycles until we could see what the green was going to be. In each series of cycles we doubled the iron from the previous series of cycles. It took about five of these series before the red started to fade. We then backed off the iron and tried one series with vanadium at about the same concentration as the chromium. That series produced a wonderful green and absolutely no red at all. Thus, we abandoned vanadium, because we had to get into production to bring some cash into the operation and couldn't experiment further. We ran tests on five possible growth planes and found the **r** (130) face to be the best to grow on. It was at the beginning of this process that Carl Cline moved to New Jersey, after which his role consisted of occasional consultations and interfacing with the patent attorney.

In late 1971, early 1972, we were in production. At the time we purchased the crystal growing operation there was one production furnace (12 inch muffle), and two small research furnaces (5 inch muffles). All of the composition and orientation studies were done using the two small research furnaces. We then built three production furnaces (8 inch muffles). Production continued with the large and three medium-sized furnaces until the operation was shut down.

For crystal growth, a seed frame was located in the middle of a platinum crucible. Most flux growing operations use ceramic crucibles with platinum liners at operating temperatures in the neighbourhood of 800°C. At the temperatures we used (1240°C), the platinum liner and the ceramic reacted. Therefore, we had to use freestanding platinum crucibles. A straight cylindrical crucible would sag toward the bottom of the cylindrical surface after some months of use. Accordingly, we had special crucibles manufactured for us with a significantly thicker wall toward the bottom of the cylindrical surface and the bottom itself. This controlled the distortion to an allowable extent.

Each seed was drilled by hand and a platinum wire was inserted through the drilled hole and twisted. Each seed was then individually hung from the seed frame. The crucible was charged with part of the eutectic lithium-molybdate/molybdenum oxide flux and the desired additives. The partly filled crucible was placed in the airlock of the glove box. A previously mixed and blended mixture of beryllium oxide and alumina was put into the crucible and covered with the remaining flux. This procedure avoided any chance of beryllium contamination outside the glove box.

The charged crucible was raised into the furnace, the temperature was brought up to the high of the cycle and the charge of flux was allowed to melt. When all temperatures had equalized at 1240°C, the seed frame was lowered into the crucible. After ageing for about an hour, the downward cycle was started. The cooling rate was 0.5°C per hour for about two hours, at which time it was increased to 1°C per hour. The finishing temperature was 1000°C. The typical cycle was approximately one week.

At the end of the cycle, the crucible, with spent flux, was removed from the furnace and the seed frame was removed. The seeds and seed frame were cleaned by boiling in water. This cleaning was followed by a second cleaning with distilled water and then followed by isopropyl alcohol. If the crystals were large enough, they were harvested. Those that needed more growth were re-hung on the seed frame along with new seeds and returned for the next cycle. This procedure was basically followed from the beginning of production until it was finally shut down.

The first seeds were oriented from diffraction patterns. Since the test was expensive, we based initial seed orientation on the crystal faces we could see in the natural chrysoberyl material. This severely limited the usefulness of the material

1. A more detailed text was originally written for another purpose and condensed by one of the authors (KS) for this paper.

at hand, as most of it was anhedral and had no visible faces. Then it dawned on us that we could put a quantity of natural seed material in a crucible and grow a couple of layers on it. It was then easy to determine the face orientation before we sliced the material into seeds. This was a real breakthrough and gave us the accuracy of orientation we needed without the expense of X-ray diffraction. It also allowed us to sort out the trillings, as they were useless for single crystal seeds. For much of the production, natural chrysoberyl was used as the original seed material. The rough was sawn into seeds about 1.5–2 mm thick, parallel to the desired plane and ground and polished. About five cycles were grown on the seeds. The resulting crystals were sawn into three layers, the middle one being the original seed. The two outside halves were then used as production seeds and the middle seed was used to grow more production seeds. Each seed was hand finished to maintain the desired orientation.

Five seed orientations were originally tried. We settled on the seed orientation parallel to **r** (130) because it seemed to be the best balance between growth-rate and the resulting colour change. It was also a preferred orientation for the table of cut stones. Since the resulting crystals were roughly the profile of a cut stone, cutting yields were excellent. A few crystals were grown with seeds sliced parallel to one of the faces of the synthetic alexandrites oblique to the crystallographic a-, b- and c-axes[2]. These produced a superior colour change but the growth rate was comparatively slow. The fastest growth rates were those grown on the **b** (010) face, but the resulting colour change was not as good. Production with **b** oriented seeds started in 1979 and after 1980, most of the production was grown on the **b** (010) face.

In about 1976 we found it difficult to obtain single-crystal chrysoberyl for seed material, as most of it was twinned. We bought a pulled boule of colourless chrysoberyl, put the boule in our large furnace and grew a couple layers on it, which allowed us to identify the various crystal faces. The boule was cut into about two inch sections and each section was sawn with a wire saw to slices parallel to **r** (130). The wire saw produced a smooth enough surface that we didn't have to finish them by hand. After several growth cycles, to produce additional production seeds, the flux grown synthetic portions of the crystal were separated from the colourless seeds. As a result, there were a few, very few, instances where a small amount of colourless material remained in a production seed and in rare instances in the final product.

David Patterson in his cutting shop in front of a furnace, taken in 2012.

The Creative Crystals Inc. synthetic alexandrite was introduced to the market at the 1972 AGS convention in New Orleans. It created a significant amount of interest. On the basis of that experience and the fact that my stone dealer friends were very enthusiastic about it, I thought we had an easy market. This was certainly not so. The members of the AGS were not the typical jeweller and made up a relatively small market. After a few years of selling synthetic alexandrite, we still found some resistance to the product by the retail jeweller. They wanted a reference stone, but didn't want to stock it. This was before Chatham and other products of flux-grown origin had developed the market. Therefore, we were unable to ride piggyback on what they had done. Emeralds and rubies were well known, but at that time alexandrites were rare and appealed to fewer people than the more well-known gems.

Cost of production was very high. Raising the prices was not an option because they were already higher than those of flux-grown emeralds and rubies. We came to believe the cost of marketing would exceed the size of the market. Therefore, we concluded it was a dead-end project for us. The operation was sold in 1979 to a limited partnership formed for that purpose. The operation and the equipment were moved to other quarters in 1980. By 1982 the furnaces were not properly monitored and the inside of the furnaces melted. The limited partnership continued selling the product in stock, primarily to jewellers.

2. It was established by the present study that these seeds were oriented parallel to the **l** (133) face.

Flux-grown synthetic alexandrites from Creative Crystals Inc.

*Figure 5: Different types of rough and faceted synthetic alexandrites grown by Creative Crystals Inc. in daylight (left) and incandescent light; the crystals were grown on seeds parallel to the **b** pinacoid (1,2), parallel to the **r** prism (3,6) or parallel to the **l** dipyramid (4); the faceted alexandrite of 13.49 ct measuring 16.6 × 11.8 mm (5) was grown on a seed parallel to the **r** prism. Photo by K. Schmetzer.*

Table I: Dimensions of eight synthetic alexandrite crystals grown by Creative Crystals Inc.

Sample	Seed orientation parallel r (130)			
	Crystal 1 GIA collection	Crystal 2a K. Patterson collection	Crystal 2 Smithsonian collection	Crystal 3 GIA collection
Weight (ct)	12.38	15.25	20.41	5.12
Habit	tabular parallel **r**	thick tabular parallel **r**	thick tabular parallel **r**	columnar along c-axis
Seed plate	chrysoberyl	alexandrite	alexandrite	alexandrite
Mean thickness perpendicular to the seed plate (mm)	3.7	6.0	7.2	4.4
Dimensions parallel to the seed plate (mm)	∥ c-axis 19.7 ⊥ c-axis 12.8	∥ c-axis 19.4 ⊥ c-axis 11.8	∥ c-axis 21.2 ⊥ c-axis 12.8	∥ c-axis 22.8 ⊥ c-axis 5.2

Sample	Seed orientation parallel b (010)		Seed orientation parallel l (133)	
	Crystal 4 D. Patterson collection	Crystal 5 S. Avery collection	Crystal 6 D. Patterson collection	Crystal 7 D. Patterson collection
Weight (ct)	54.90	78.22	5.15	3.08
Habit	tabular parallel **b**	tabular parallel **b**	tabular parallel **l**	tabular parallel **l**
Seed plate	alexandrite	alexandrite	chrysoberyl/ alexandrite	alexandrite
Mean thickness perpendicular to the seed plate (mm)	4.9	7.8	2.4	1.9
Dimensions parallel to the seed plate (mm)	∥ c-axis 29.8 ∥ a-axis 23.4	∥ c-axis 37.1 ∥ a-axis 17.9	∥ **r** (seed) 15.1 ⊥ **r** (seed) 11.8	∥ **r** (seed) 13.8 ⊥ **r** (seed) 8.6

alexandrites belonging to the two other types (**b**- and **l**-grown samples), which he had kept in his collection since the 1980s or which were faceted from some of his remaining rough for the present study.

In total, in addition to the eight complete rough crystals (from 3 to 78 ct in weight, see *Table I*), this study is based on 17 faceted samples (from 0.75 to 13.49 ct in weight), 11 of them with seeds oriented parallel to **r** (130), four cut from crystals grown with seeds parallel to **b** (010), and two cut from rough grown with seeds parallel to the **l** (133) face. For the study of colour change and pleochroism, a small alexandrite cube with faces exactly perpendicular the crystallographic a-, b- and c-axes of chrysoberyl was prepared. The dimensions of the cube (length of edges) weighing 3.32 ct were 5.9 × 5.8 × 5.8 mm.

Morphology of rough crystals

The dimensions and seed orientations of eight rough crystals are summarized in *Table I*. The faces found in these crystals were the pinacoids **a** and **b**, three prism faces **k**, **m** and **r** and two dipyramids **o** and **l** (*Table II, Figure 6*). Five of these seven forms, namely the pinacoids **a** and **b**, the prisms **m** and **r**, and the dipyramid **o** are forms which are common in natural alexandrites from different localities. The prism **k** is present in chrysoberyl and alexandrite from a limited number of localities, e.g. Sri Lanka, and is a dominant crystal form in Russian flux-grown alexandrites (Schmetzer *et al.*, 1996). The dipyramid **l** has been, to the knowledge of the present authors, only described as an accessory form in one twinned chrysoberyl from Sri Lanka (Goldschmidt and Preiswerk, 1900).

Figure 7 shows an idealized drawing of a crystal with all seven forms. To understand growth features in rough and faceted alexandrites, it is important to realize that the dipyramid **l** is a dominant form. In samples grown with **r** (130) and **b** (010) seeds, the formation of larger **l** faces is a function of all growth parameters and — most probably — strongly influenced by the molybdenum-bearing flux. In crystals grown on **l** (133) seeds, it is clear that the **l** face is dominant. Three different angles are visible between different **l** faces (see *Figure 7*), which are designated as adjacent (with an angle of 56.61°), opposite (with an angle of 39.24°) and diagonal (with an angle of 71.04°).

Although an idealized alexandrite crystal is drawn in *Figure 7*, the synthetic alexandrites grown on seeds with orientations parallel to the **r** and **l** faces form strongly distorted crystals, in contrast to those grown on seeds parallel to the **b** pinacoid (see again *Figure 6*). In **b**-oriented seeds, the seed is chosen parallel to the two existing **b** (010) faces, and no other **b** faces with different sizes can exist or grow according to the symmetry of chrysoberyl. Therefore near-

Table II: Morphological properties of synthetic alexandrites grown by Creative Crystals Inc. Observed crystal forms and designation.

Crystal form	Designation	Miller indices (hkl)*	Number of faces
Pinacoid	a	(100)	2
	b	(010)	2
Prism	k	(021)	4
	m	(110)	4
	r	(130)	4
Dipyramid	o	(111)	8
	l	(133)	8

*Based on a morphological cell with a 4.42, b 9.39, c 5.47
Crystal class 2/m 2/m 2/m = D2h, twinning on (031) and (0$\bar{3}$1) is not present in the samples examined

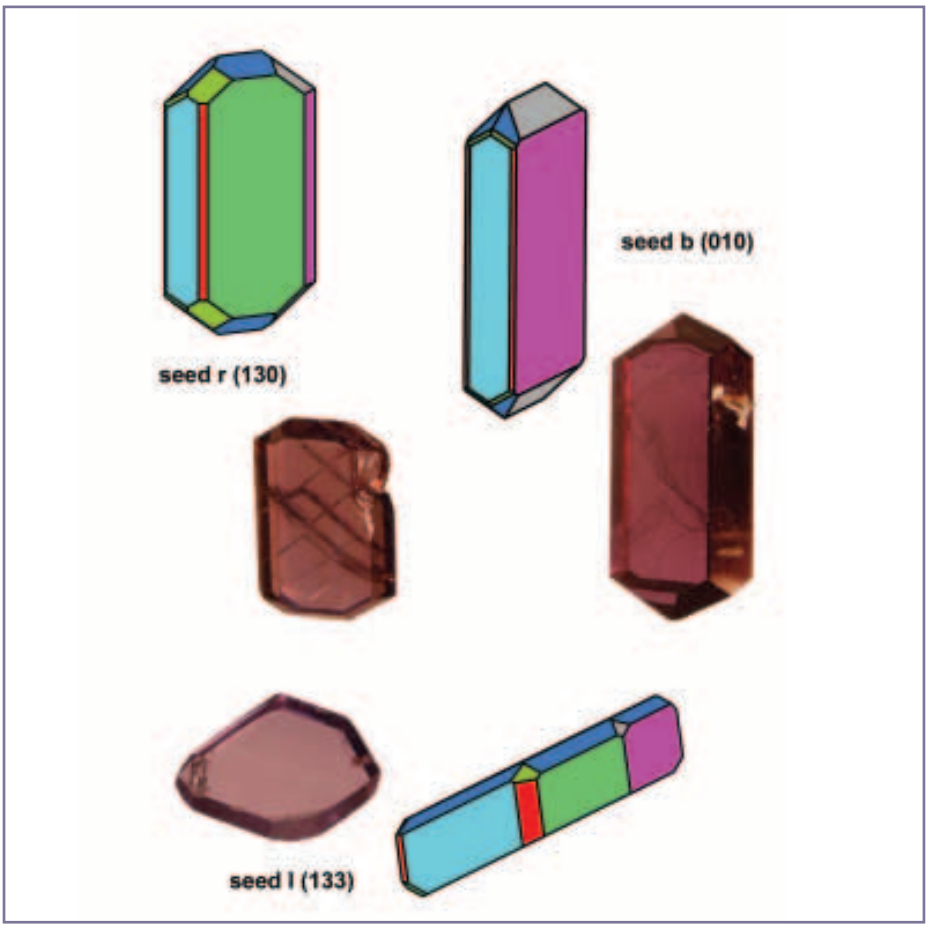

*Figure 6: Crystal drawings and samples of the three different types of synthetic alexandrite grown by Creative Crystals Inc., with seed orientations parallel to the **r**, **b** and **l** faces; crystals pictured in incandescent light, crystal with **r** seed 19.7 × 12.8 mm, crystal with **b** seed 37.1 × 17.9 mm, crystal with **l** seed 15.1 × 11.8 mm (samples not to scale). Photos and crystal drawings by K. Schmetzer.*

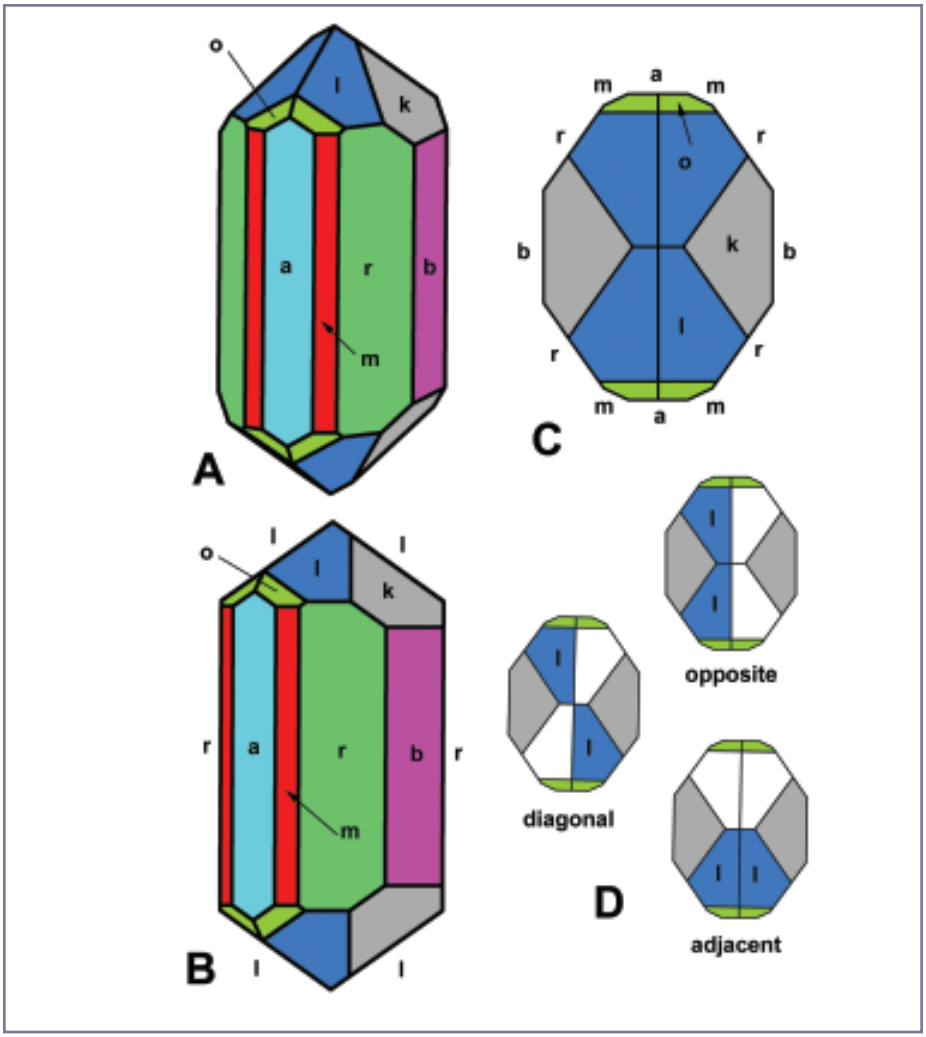

*Figure 7: Idealized drawing of a synthetic alexandrite crystal showing all faces observed in the different types of crystals grown by Creative Crystals Inc., namely the two pinacoids **a** and **b**, the three prisms **m**, **r**, and **k** and the two dipyramids **o** and **l**; (A) clinographic projection, (B) parallel projection of the zone [310] indicating a view perpendicular to the c-axis and parallel to two of the **r** faces, (C) parallel projection in a view parallel to the c-axis, (D) same view as in drawing (C) indicating the three different pairs of **l** dipyramids forming three different angles; in drawing (B) the pair of diagonal **l** faces is depicted forming an interfacial angle of 71°. Crystal drawings by K. Schmetzer.*

ideal undistorted crystals are grown with that seed orientation *(Figure 8)*.

In crystals grown on **r** seeds, in addition to the pair of crystal faces parallel to the seed, another pair of symmetry-equivalent **r** prism faces exists and grows. At the beginning of crystal growth, the two **r** faces parallel to the seed are large and dominant and the other **r** prisms are absent or distinctly smaller. This means that in various stages of crystal growth, the two different pairs of parallel **r** prism faces have different sizes, a feature which is also displayed by some of the other faces, namely the prism **m,** and the dipyramids **l** and **o** *(Figure 9)*. For alexandrites grown on seeds parallel to the **l** dipyramid, four pairs of symmetry equivalent **l** faces grow with different sizes. At the beginning of crystal growth, the two **l** dipyramids parallel to the seed are dominant, and the three other pairs are distinctly smaller. In the course of growth, these four different pairs of **l** faces (and other faces too) grow with different sizes and form strongly distorted crystals *(Figure 10)*.

The two crystals grown with seeds parallel to the **b** pinacoid are close to complete ideal crystals (*Figure 8*, see also *Figure 5*), showing no excessive development of one face over another. The two crystals with seeds parallel to the **l** dipyramid were flat tabular crystals, in which the pair of **l** faces parallel to the chosen seed was still dominant for the complete morphology of the samples

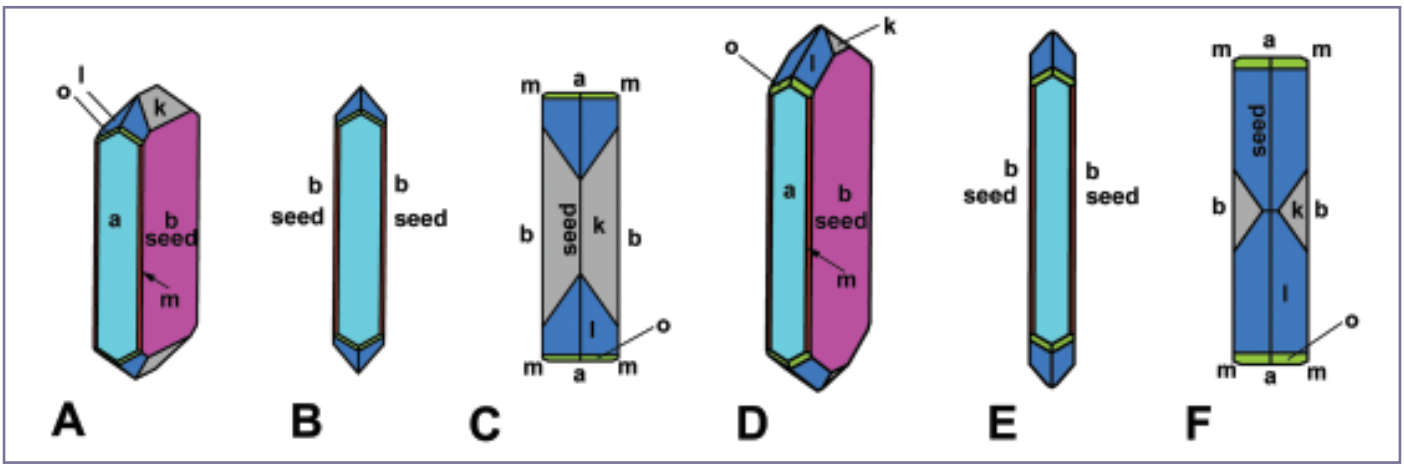

*Figure 8: Morphology of two crystals grown by Creative Crystals Inc. with **b** (010) seed orientation and tabular habit parallel to **b**, with drawings A to C representing crystal 4 and drawings D to F representing crystal 5, both in* Table I; *(A, D) clinographic projections, (B, E) parallel projections in a view along the a-axis, (C, F) parallel projections in a view along the c-axis. Crystal drawings by K. Schmetzer.*

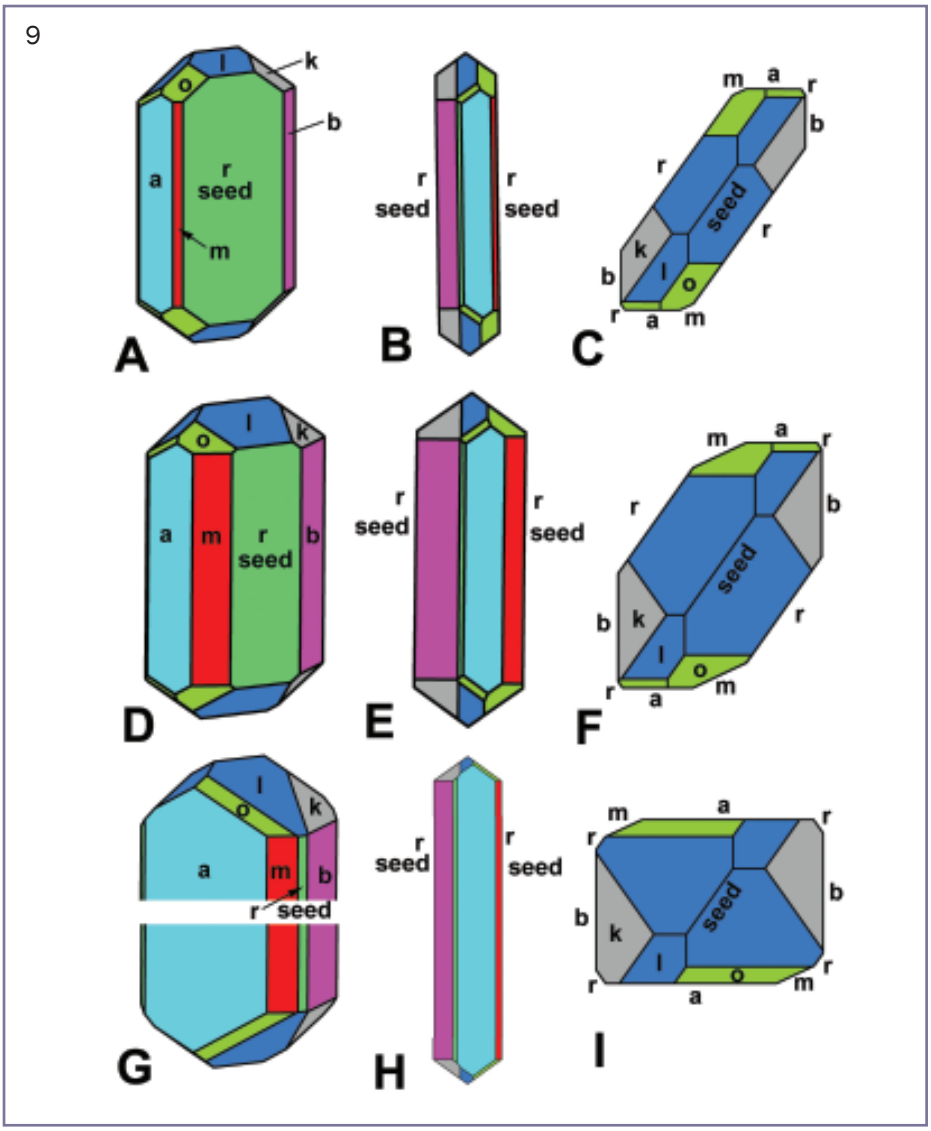

*Figure 9: Morphology of three crystals grown by Creative Crystals Inc. with **r** (130) seed orientation, with drawings A to C representing crystal 1, drawings D to F representing sample 2 and drawings D to F representing crystal 3, all in* Table I; *(A, D, G) clinographic projections, (B, E, H) parallel projections in a view parallel to the seed **r**, (C, F, I) parallel projections in a view along the c-axis. Crystal 1 shows tabular habit parallel to the seed **r**, crystal 2 shows thick tabular habit parallel to the seed, and sample 3 shows a columnar habit parallel to the c-axis. In drawing G the long columnar centre was omitted. Crystal drawings by K. Schmetzer.*

(*Figure 10*, see also *Figure 5*). In contrast, the four crystals grown from **r** seeds showed a wide variation in morphology (*Figures 9, 11 a,b*). In one, the two **r** faces parallel to the seed are much larger than the other **r** faces (*Figures 9 A–C, 11 a,b*). In the second, the crystal had been grown for a longer period resulting in a crystal with smaller **r** faces parallel to the seed (*Figures 9 D–F, 11 a,b*). In the third crystal, the **r** faces parallel to the seed are small and comparable in size with the other two symmetry-equivalent **r** faces present (*Figures 9 G–I, 11a,b*). The last sample, crystal 2a in *Table I*, shows features intermediate between crystals 1 and 2, but very close to sample 2.

Seeding technique

As we shall discuss later in greater detail, the substance between two plane growth boundaries represents one layer of synthetic alexandrite which was produced during a single growth cycle. Each run or growth cycle lasts from five to seven days during which the seed or crystal is immersed in and grows in the flux. After removal from the flux, the crystal is cleaned and placed again in the furnace for the next run.

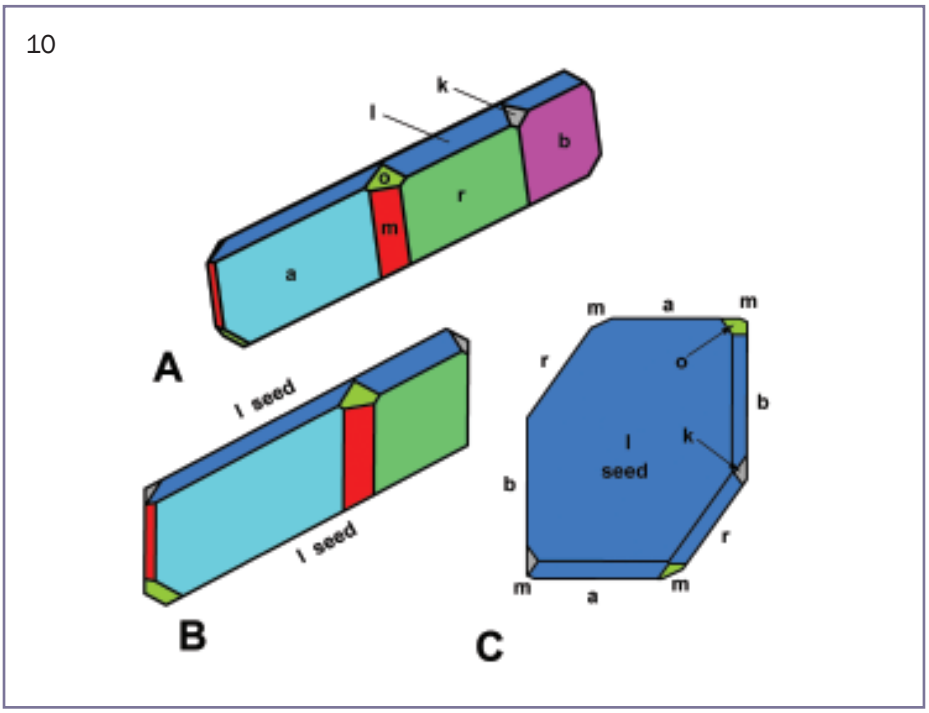

*Figure 10: Morphology of one crystal grown by Creative Crystals Inc. with **l** (133) seed orientation, with drawings A to C representing crystal 6 of Table I ; (A) clinographic projection, (B) parallel projection in a view parallel to the seed l, (C) parallel projection in a view along the c-axis. The crystal shows tabular habit parallel to the seed l, in drawing C the differences in size of the four **l** faces (blue violet) are clear. Crystal drawings by K. Schmetzer.*

Flux-grown synthetic alexandrites from Creative Crystals Inc.

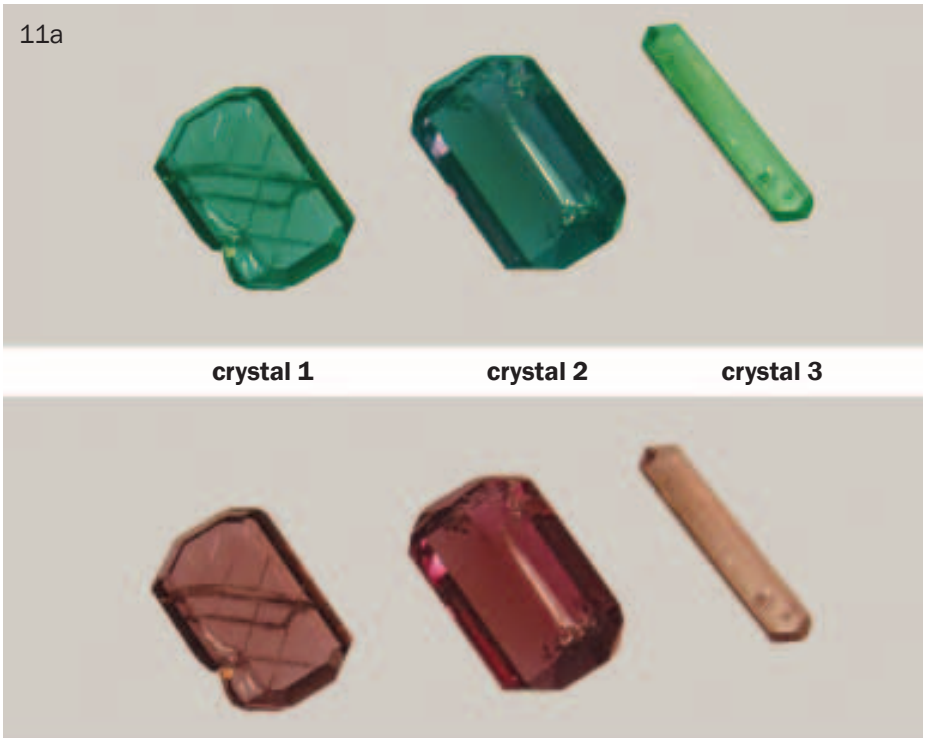

*Figure 11: Morphology of three crystals grown by Creative Crystals Inc. with **r** (130) seed orientation (crystals 1 to 3 of* Table I*). (a) samples in daylight (above) and incandescent light, size of the right columnar crystal 22.8 x 5.2 mm (samples to scale); (b) crystal drawings in parallel projections in views along the c-axis (left column) and photomicrographs of the samples in identical orientations in immersion (right column, samples not to scale). In the sequence of crystal 1 to crystal 3, the way in which the face parallel to the **r** seed grows and becomes gradually smaller with **a**, **b** and **m** faces becoming larger is visible. In crystal 3 the **r** faces parallel to the seed are comparable in size to the **r** faces which are not parallel to the seed. Photos and crystal drawings by K. Schmetzer.*

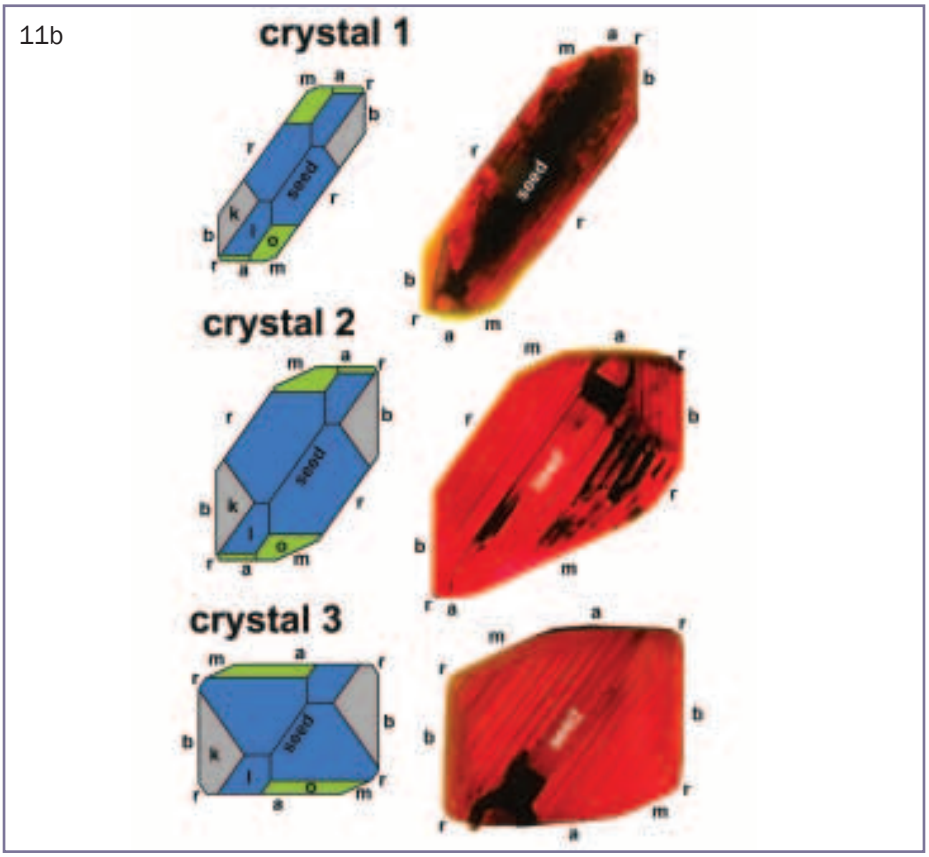

The simplest seeding technique is to cut a colourless or very pale yellow seed plate in the desired orientation from a Czochralski-grown synthetic or from a natural chrysoberyl crystal. Although these seeds have been completely avoided or removed in all the faceted alexandrites that we examined, they may be still present in some of the rough *(Figure 12)*. We shall call this type of rough 'first growth'.

In general, rough crystals which were grown in several growth cycles to a certain thickness, have been cut parallel to the seed orientation and then the resulting synthetic alexandrite plates used as new seeds for subsequent growth. If small and relative thin plates were used for the second growth, the resulting crystal is grown more or less symmetrically, layer by layer, parallel to the seed plate *(Figure 13)*. Depending on the position within the crystal from which the seed plate is sawn, it may consist of layers parallel to its surface *(Figure 13)* or of layers which differ in orientation from the faces of the seed *(Figure 14)*.

In some stones, it is very difficult to locate the boundary between the seed and

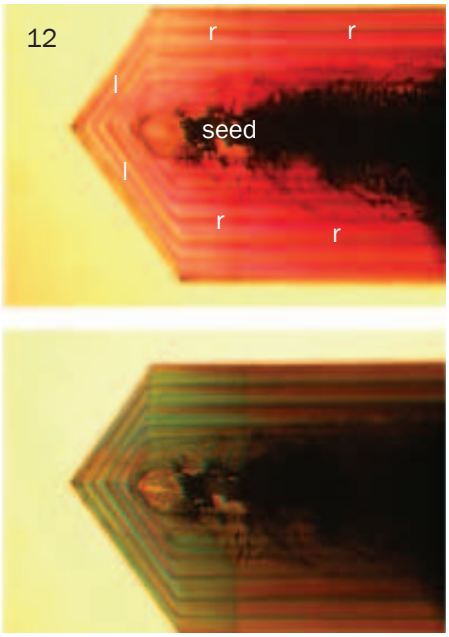

*Figure 12: Pleochroism and growth zoning, associated with colour zoning in r-grown synthetic alexandrite; the slightly yellowish seed is clearly visible in the centre; growth layers parallel to the faces **r** and **l** are indicated. Immersion, plane polarized light, field of view 6.0 x 4.5 mm. Photos by K. Schmetzer.*

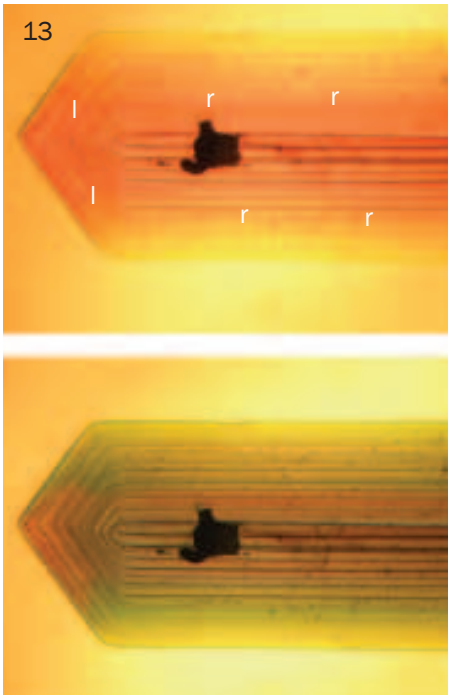

*Figure 13: Pleochroism and growth zoning, associated with colour zoning in r-grown synthetic alexandrite; the thin synthetic alexandrite seed in the centre shows the same coloration and pleochroism as the main crystal; growth layers parallel to the faces **r** and **l** are indicated. Immersion, plane polarized light, field of view 9.5 × 7.2 mm. Photos by K. Schmetzer.*

the layers related to the second growth. If the seed is relatively thick and consists of perhaps five to ten layers, subsequent synthetic alexandrite can grow in a non-uniform way around the seed. In such crystals, a real growth inconsistency may be visible in the immersion microscope *(Figure 15)* and the final crystal can show different thicknesses on each side of the seed. A general overview of these different seeding techniques is given for crystals with **r** and **b** seed orientations in *Figures 16* and *17*.

In synthetic alexandrites with seed orientation parallel to the **l** dipyramid, we found that these seeds had been cut from first or second growth crystals which had their seed orientation parallel to **r**. One sample showed a seed with a colourless central layer parallel to **r** and numerous alexandrite layers on both sides (*Figures 18, 19*). This indicates that the plate used for crystal growth had been cut from a complete r-grown crystal parallel to one of the larger **l** faces. In several growth cycles,

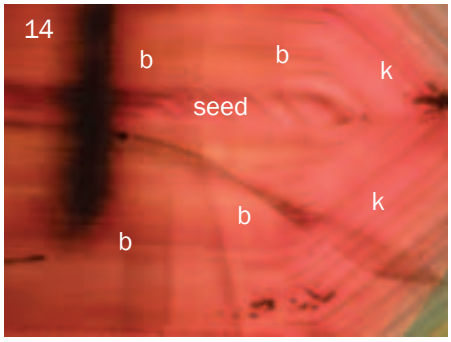

*Figure 14: Growth zoning associated with colour zoning in b-grown synthetic alexandrite; the thin synthetic alexandrite seed in the centre shows identical coloration but somewhat different growth zoning to that of the main crystal; growth layers parallel to the faces **b** and **k** are indicated. Immersion, plane polarized light, field of view 6.0 × 4.5 mm. Photo by K. Schmetzer.*

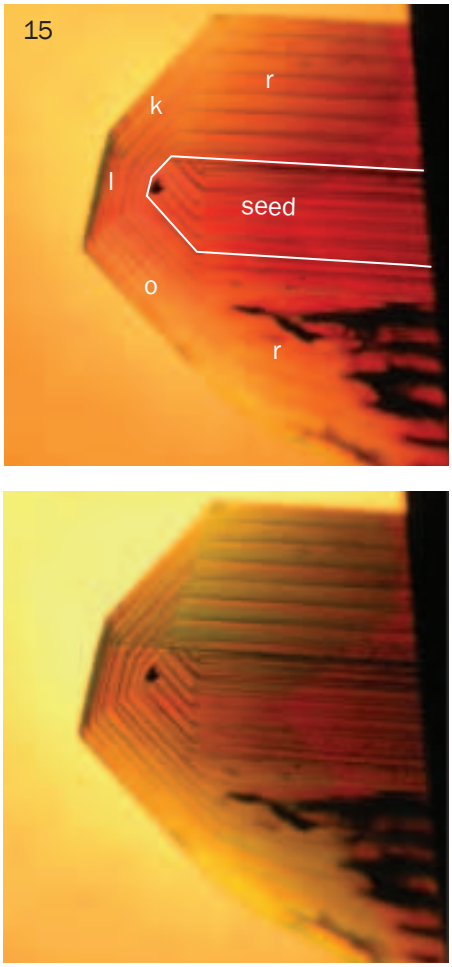

*Figure 15: Pleochroism and growth zoning, associated with colour zoning in r-grown synthetic alexandrite; the thick non-symmetrical synthetic alexandrite seed in the centre shows the same coloration and pleochroism as the main crystal; growth layers parallel to the faces **r**, **o**, **l** and **k** are indicated. Immersion, plane polarized light, field of view 9.5 × 7.2 mm. Photos by K. Schmetzer.*

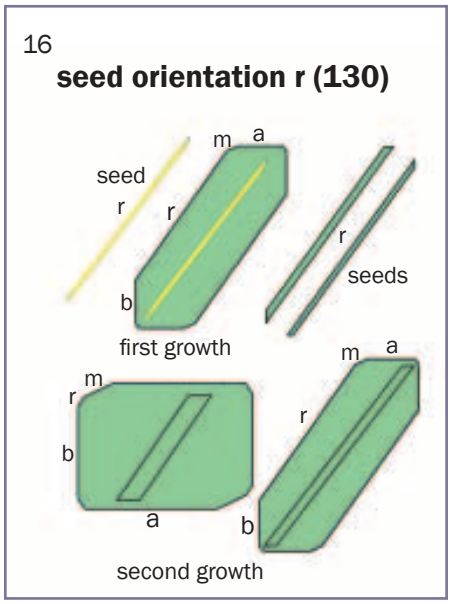

*Figure 16: Seeding technique in r-grown synthetic alexandrite; in the first growth cycle a synthetic colourless or pale yellow natural seed plate cut parallel to the **r** face is used; after this first growth period, synthetic alexandrite seeds were cut from the grown crystal and used as seeds for a second series of growth cycles; the final crystal consists of a synthetic alexandrite seed surrounded by numerous layers of synthetic alexandrite.*

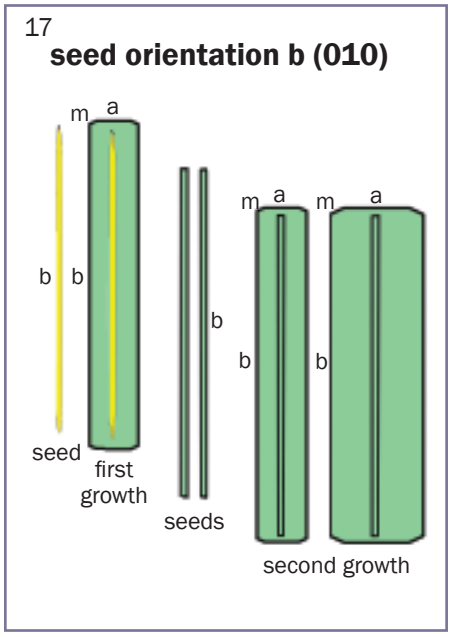

*Figure 17: Seeding technique in b-grown synthetic alexandrite; in the first growth cycle a synthetic colourless or pale yellow natural seed plate cut parallel to the **b** face is used; after this first growth period, synthetic alexandrite seeds were cut from the grown crystal and used as seeds for a second series of growth cycles; the final crystal consists of a synthetic alexandrite seed surrounded by numerous layers of synthetic alexandrite.*

Flux-grown synthetic alexandrites from Creative Crystals Inc.

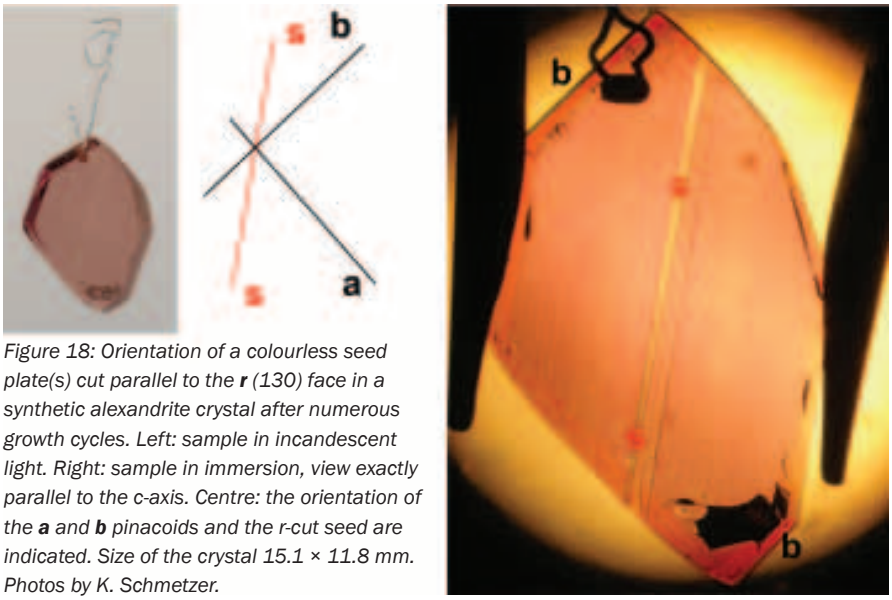

*Figure 18: Orientation of a colourless seed plate(s) cut parallel to the **r** (130) face in a synthetic alexandrite crystal after numerous growth cycles. Left: sample in incandescent light. Right: sample in immersion, view exactly parallel to the c-axis. Centre: the orientation of the **a** and **b** pinacoids and the r-cut seed are indicated. Size of the crystal 15.1 × 11.8 mm. Photos by K. Schmetzer.*

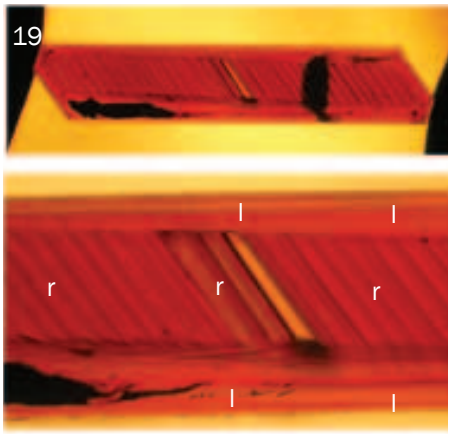

Figure 19: After the first growth cycle the crystal shown in Figure 18 *was sliced parallel to the **l** (133) face and overgrown in several growth cycles with layers of synthetic alexandrite. The seed for the second series of growth cycles consists of one colourless layer with r-cut and several layers of synthetic alexandrite grown with this seed orientation. The complete crystal measures 12.0 × 2.4 mm in this orientation (above); in the detailed picture (below) the **r** and **l** faces are indicated. Both photos by K. Schmetzer, immersion.*

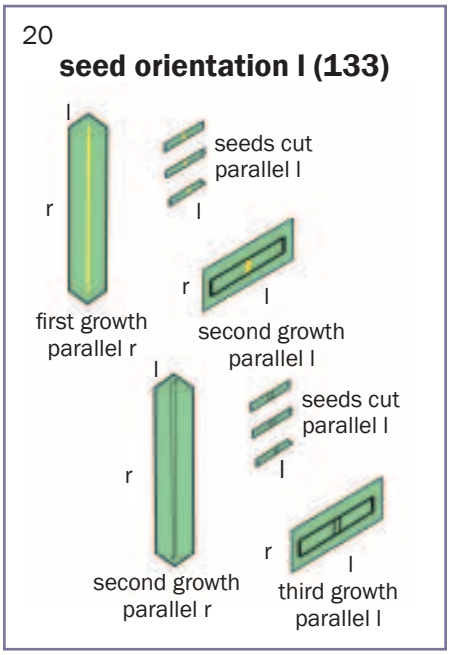

Figure 20: Seeding technique in l-grown synthetic alexandrite:
*Above: in the first growth cycle a synthetic colourless or pale yellow natural seed plate cut parallel to the **r** face is used; after this first growth period, synthetic alexandrite seeds were cut from the grown crystal parallel to an **l** face and used as seeds for a second series of growth cycles; this procedure represents a summary of the different growth steps performed with the crystal pictured in* Figures 18 *and* 19*;*
*Below: the seeds parallel to an **l** dipyramid are sliced from an r-grown synthetic alexandrite with synthetic r-grown seed (see* Figure 16*); these seeds were used for a third series of growth cycles. The final sample consists of a synthetic r-grown alexandrite seed surrounded by numerous l-grown layers.*

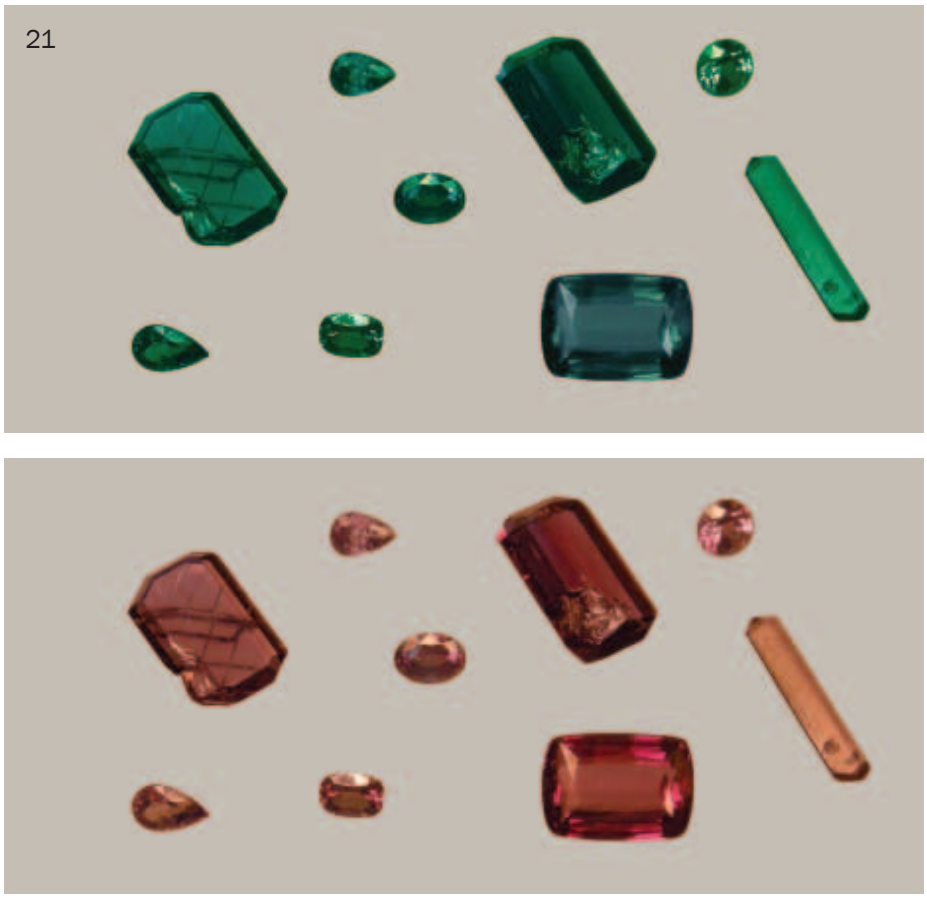

*Figure 21: Rough and faceted synthetic alexandrites grown with seeds which were cut parallel to the **r** (130) prism in daylight (above) and incandescent light (below); the crystals (see* Table I*) weigh 12.38 ct (left), 20.41 ct (centre) and 5.12 ct (right); the largest faceted alexandrite (lower right) of 13.49 ct measures 16.6 × 11.8 mm, the smaller faceted stones weigh from 0.86 to 1.91 ct. Photos by K. Schmetzer.*

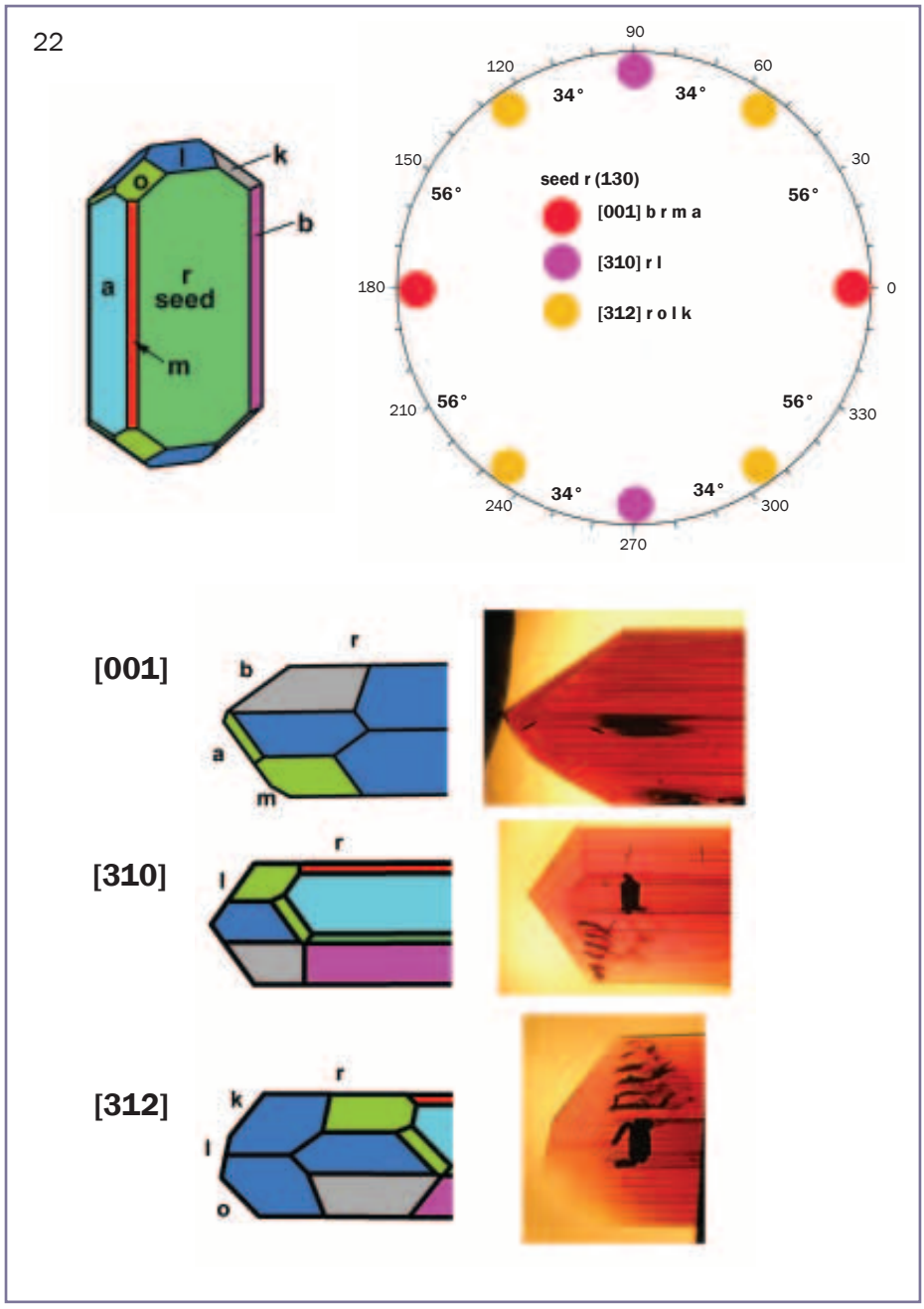

*Figure 22: Upon rotation of a rough alexandrite crystal (upper left) or a faceted alexandrite with seed orientation parallel to the **r** prism, with a rotation axis oriented perpendicular to the seed plate, three different growth zones [001], [310] and [312] are visible with each growth zone consisting of several growth faces. Schematic drawings of the three growth zones are given in the left column, examples are depicted in the right column (all photographed in immersion). The rotation angles which are needed to move from one of these views to the next are schematically plotted on the 360° diagram; according to the symmetry of chrysoberyl, during a full rotation of 360° several growth zones are repeated.*

this plate was 'overgrown' with several new layers of synthetic alexandrite. In another sample, the seed cut parallel to an **l** face consisted only of several **r**-grown layers of synthetic alexandrite. This indicates that this seed was cut from a second growth synthetic alexandrite which had been grown with a seed in **r** orientation. An overview of the seeding technique in **l** orientation is given in *Figure 20*.

Microscopic growth features

Crystals

The internal growth patterns of Creative Crystals Inc. rough and faceted alexandrites closely reflect the chosen seed orientations and their external morphologies. In all samples, a series of dominant internal growth planes runs

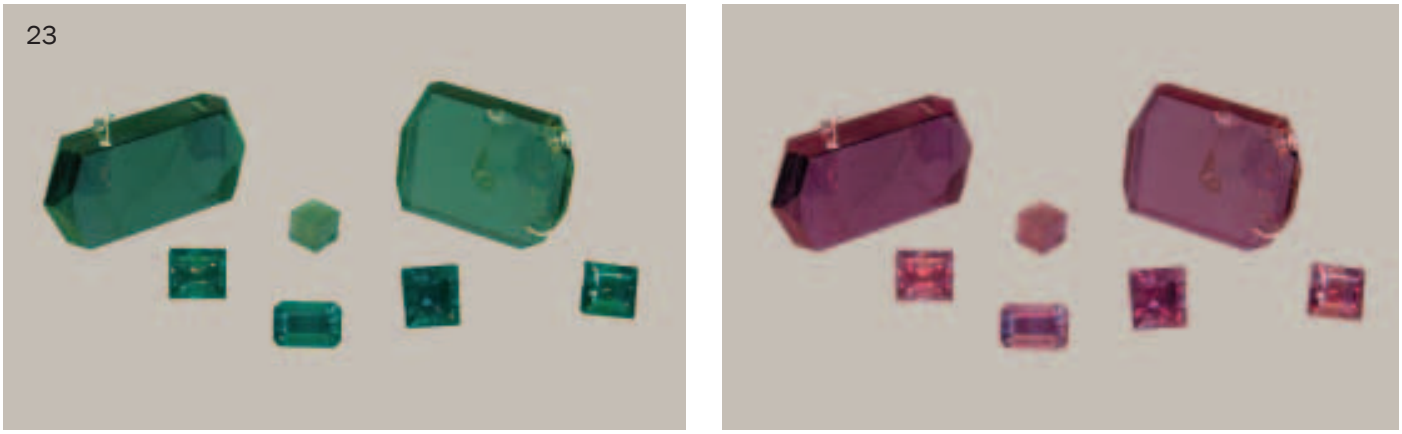

*Figure 23: Rough and faceted synthetic alexandrites grown with seeds which were cut parallel to the **b** (010) prism in daylight (left) and incandescent light; the crystals (see Table I) weigh 78.22 ct (left) and 54.90 ct (right); the cube in the centre weighs 3.22 ct and measures 5.8 × 5.8 mm; the faceted stones weigh from 3.22 to 5.84 ct. Photos by K. Schmetzer.*

Flux-grown synthetic alexandrites from Creative Crystals Inc.

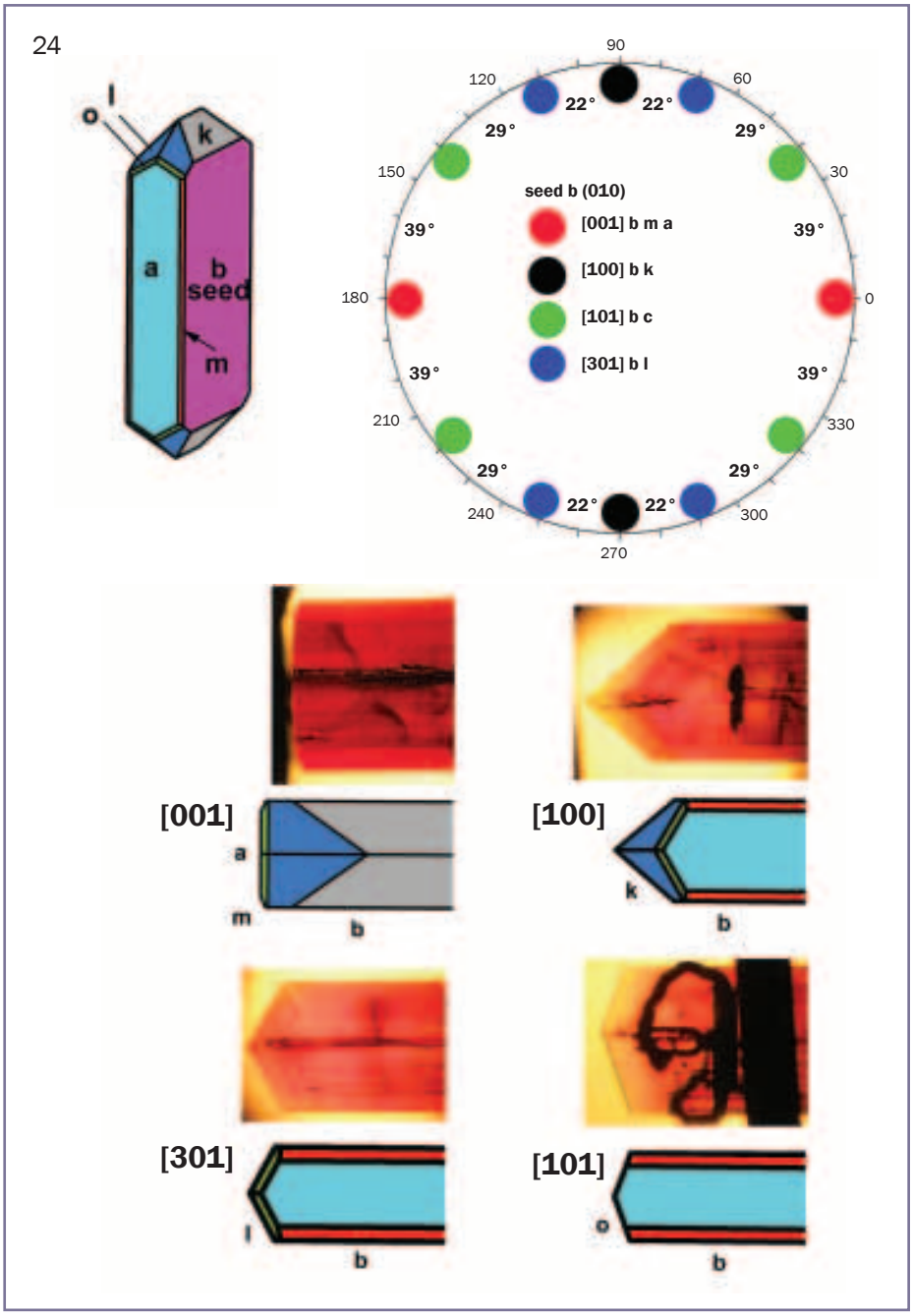

*Figure 24: Upon rotation of a rough alexandrite crystal (upper left) or a faceted alexandrite with seed orientation parallel to the **b** pinacoid, with a rotation axis oriented perpendicular to the seed plate, four different growth zones [001], [301], [100] and [101] are visible with each growth zone consisting of several growth faces. Schematic drawings of the four growth zones are shown, and examples are depicted above each line drawing (all photographed in immersion). The rotation angles which are needed to move from one of these views to the next are schematically plotted on the 360° diagram; according to the symmetry of chrysoberyl, during a full rotation of 360° several growth zones are repeated.*

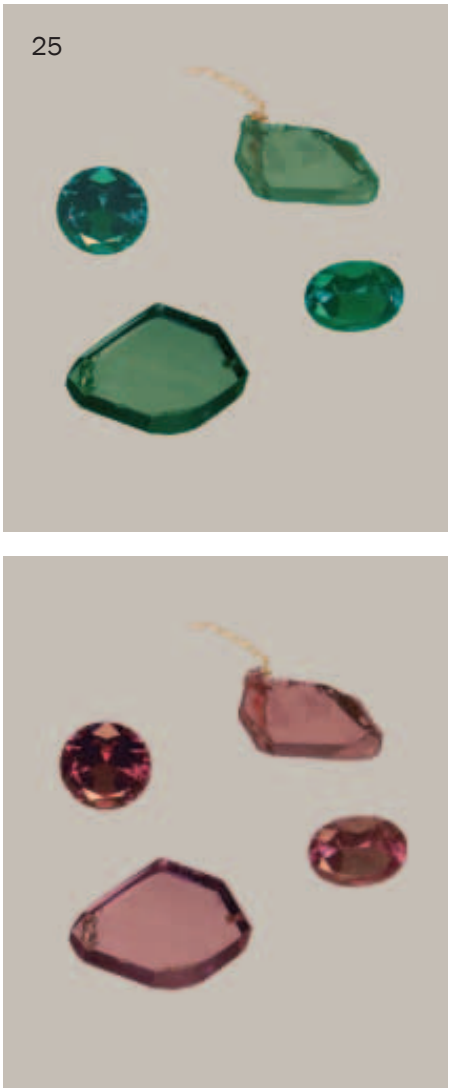

*Figure 25: Rough and faceted synthetic alexandrites grown with seeds which were cut parallel to the **l** (133) prism in daylight (above) and incandescent light (below); the crystals (see Table I) weigh 5.15 ct (lower left) and 3.08 ct (upper right); the faceted stones weigh 2.43 ct (upper left, diameter 8.4 mm) and 1.91 ct. Photos by K. Schmetzer.*

parallel to the seed plane, and in order to determine what other growth planes may be present, the samples were oriented in the sample holder with the dominant growth planes perpendicular to the rotation axes (see Schmetzer, 2011).

Upon rotation of the synthetic alexandrite crystals through 360°, several characteristic growth patterns may be obtained for each seed orientation. For **r**-grown alexandrites (*Figure 21 a,b*), three different zones with distinct growth patterns are visible *(Figure 22)*, and for b- and l-grown samples (*Figures 23 a,b; 25 a,b*), four different growth patterns are always present *(Figures 24, 26)*. The rotation angles between different zones and the angles between different crystal faces within these zones are given in *Table III*. The schematic overviews given in *Figures 22, 24* and *26* also show the rotation angles between different views of characteristic zones and the repetition of these positions according to the orthorhombic symmetry of chrysoberyl.

In **r**-grown crystals *(Figures 21 a,b; 22)*, for example, the three growth zones [001], [310] and [312] are present. The faces seen in these different orientations

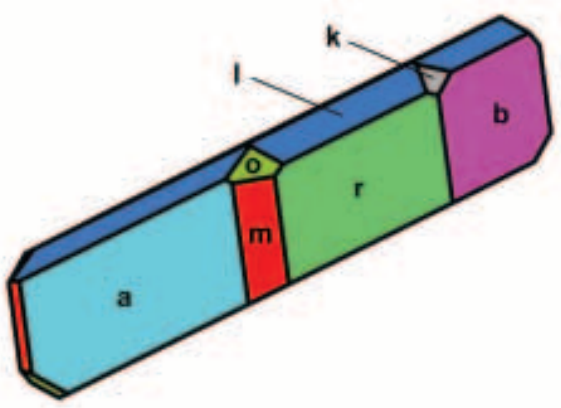

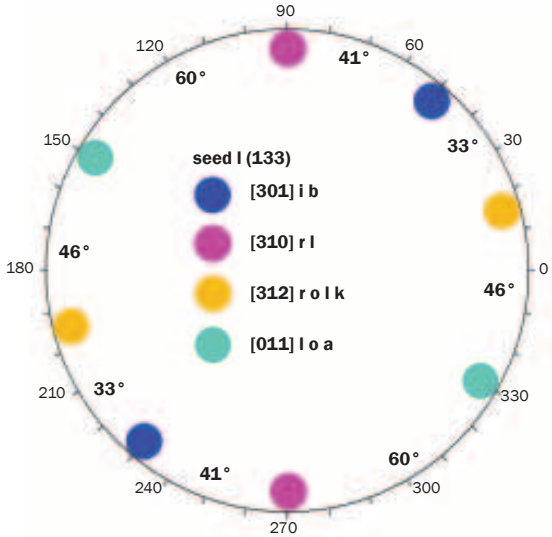

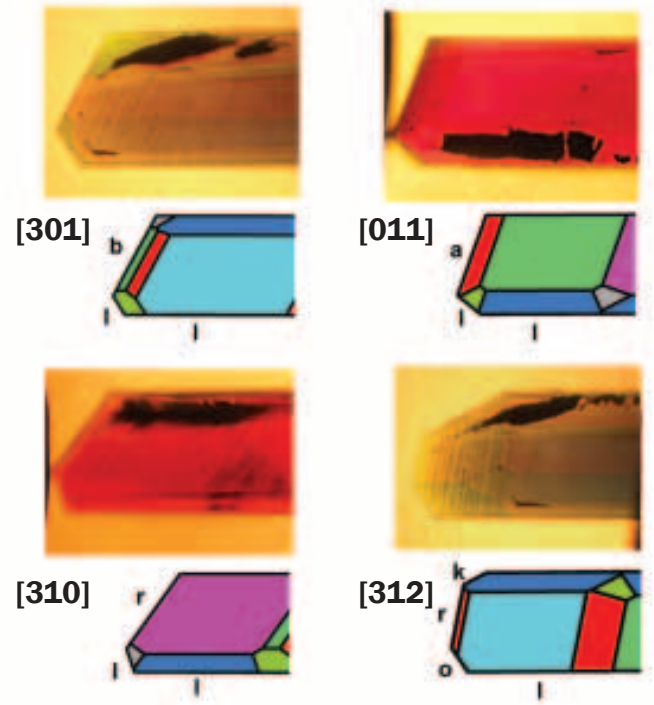

*Figure 26: Upon rotation of a rough alexandrite crystal (upper left) or a faceted alexandrite with seed orientation parallel to the **l** dipyramid, with a rotation axis oriented perpendicular to the seed plate, four different growth zones [301], [310], [011] and [312] are visible with each growth zone consisting of several growth faces. Schematic drawings of the four growth zones are given, and examples are depicted above each line drawing (all photographed in immersion). The rotation angles which are needed to move from one of these views to the next are schematically plotted on the 360° diagram; according to the symmetry of chrysoberyl, during a full rotation of 360° several growth zones are repeated.*

are **b**, **r**, **m** and **a** for zone [001], **r** and **l** for zone [310] and **r**, **o**, **l** and **k** for zone [312]. The rotation angles between the different zones are 34° for a rotation between zones [310] and [312] and 56° for a rotation between zones [001] and [312]. For symmetry reasons, several zones and rotation angles are repeated by full rotation through a circle of 360°. For **b**- and **l**-grown crystals, the schematic overviews in Figures 24 and 26 together with the angles in *Table III* are self explanatory.

In *Figure 27* the commonest growth patterns of rough and faceted alexandrites and the pleochroism in different orientations of the crystals are shown. In **r**-grown samples, growth and colour zoning is common in the three growth zones [001], [310] and [312] *(Figure 27 A–H)*, and for **b**-grown alexandrites growth zoning is visible in the zones [100] and [301] *(Figure 27 I–L)*.

Faceted alexandrites

In faceted samples, the same patterns are observed as have been described for rough crystals. In a few samples cut from the central parts of the rough crystals, only the dominant series of growth planes parallel to the seed was observed (see *Figure 28 A,H,K,* for **r**, ***b*** and **l** seed orientations), but in most samples a more complete picture was seen. Upon rotation of the faceted alexandrites around an axis perpendicular to the dominant **r**, **b** or **l** growth planes (which are parallel to the seed), this procedure generally revealed one or several growth zones with the complete number of faces as given in *Figures 22* to *27*. Some examples are pictured in *Figure 28 B–G* for alexandrites grown with **r** seed orientation, and in *Figure 28 I,J,L* for those with **b** or **l** seed orientation. With this overview it is now

possible to understand the patterns recorded by Pohl (1989). The samples examined at that time were **r**-grown synthetic alexandrites, and they contained patterns which can now be assigned to growth zone [310] with an angle of 55° between **l** and **r** faces and to growth zone [312] with an angle of 52° between **k** and **r** faces.

Colour zoning in crystals and faceted alexandrites and interference effects at growth boundaries

A common type of zoning with numerous lighter and darker layers is shown in *Figures 27* and *28*. A detailed examination showed that each successive growth layer from the centre outwards starts with strongly coloured alexandrite and grades to lighter or sometimes almost colourless material towards the subsequent growth boundary *(Figure 29)*.

Under crossed polarizers, an interference effect is visible at the boundaries between successive growth layers *(Figure 30)* and this pattern closely resembles that seen in many twinned rubies and sapphires. In corundum the cause is polysynthetic twinning, but in our synthetic alexandrites, this cause is most unlikely because the pleochroism in the successive growth layers is identical (in contrast to the varying pleochroic colours across the boundaries in natural alexandrite twins or trillings; see Schmetzer, 2010). This colour zoning and the cause of the interference effects is explained in detail in the chemistry section below.

Surfaces of growth layers

In numerous samples, the successive growth layers are either parallel to each other or are slightly inclined to the former boundary *(Figures 27, 28)*. This effect is due to growth inconsistencies. In some samples, the growth surfaces look like somewhat irregular cobbles *(Figure 31)*. This appearance is due to a dissolution process at the beginning of each growth cycle. The starting temperature for each run was slightly above the crystallization temperature (D. Patterson, pers. comm., 2012), which meant that dissolution occurred for a limited time before the slight cooling enabled new alexandrite material to commence crystallization on the etched surface. This dissolution at the beginning of each growth cycle explains the detailed structure of the growth boundaries. In some samples, numerous small particles of flux or crucible metal are visible close to parts of the growth boundaries *(Figure 31C)*, an indication of some disturbance and instability at the beginning of some growth cycles.

Table III: Characteristic angles of synthetic alexandrite crystals grown by Creative Crystals Inc.

Seed orientation parallel **r** (130)

Rotation through 180°, zone sequence and rotation angles*			↔ ↔ ↔ ↔ [001] 56° [312] 34° [310] 34° [312] 56° [001]	
Zone	[001]		[312]	[310]
View	∥ c-axis		intermediate	⊥ c-axis
Faces	**a b r m**		**r o l k**	**r l**
Interfacial angles (°)	**ab** 90 **am** 25.21 **ar** 54.70	**br** 35.30 **bm** 64.79 **rm** 29.49 **rr** 70.61 **rr** 109.39	**ro** 45.36 **rl** 101.12 **ol** 55.76 **lk** 27.14 **lr** 78.88 **kr** 51.74	**rl** 54.48 **ll** 71.04 (diagonal)

Seed orientation parallel **b** (010)

Rotation through 180°, zone sequence and rotation angles*			↔ ↔ ↔ ↔ ↔ ↔ [001] 39° [101] 29° [301] 22° [100] 22° [301] 29° [101] 39° [001]	
Zone	[001]	[101]	[301]	[100]
View	∥ c-axis	intermediate	intermediate	⊥ c-axis, ∥ a-axis
Faces	**b m a**	**b o**	**b l**	**b k**
Interfacial angles (°)	**ab** 90 **bm** 64.79 **am** 25.21	**bo** 69.89 **oo** 40.22 (adjacent)	**bl** 61.70 **ll** 56.61 (adjacent)	**bk** 40.64 **kk** 98.72

Seed orientation parallel **l** (133)

Rotation through 180°, zone sequence and rotation angles*		↔ ↔ ↔ ↔ [310] 60° [011] 46° [312] 33° [301] 41° [310]		
Zone	[310]	[011]	[312]	[301]
View	⊥ c-axis	intermediate	intermediate	intermediate
Faces	**l r**	**a o l**	**l o r k**	**l b**
Interfacial angles (°)	**rl** 54.48 **ll** 71.04 (diagonal)	**lo** 27.30 **la** 70.38 **ao** 43.08 **ll** 39.24 (opposite)	**lo** 55.76 **or** 45.36 **rk** 51.74 **kl** 27.14	**bl** 61.70 **ll** 56.61 (adjacent)

* rotation axis perpendicular to the seed plate

Flux-grown synthetic alexandrites from Creative Crystals Inc.

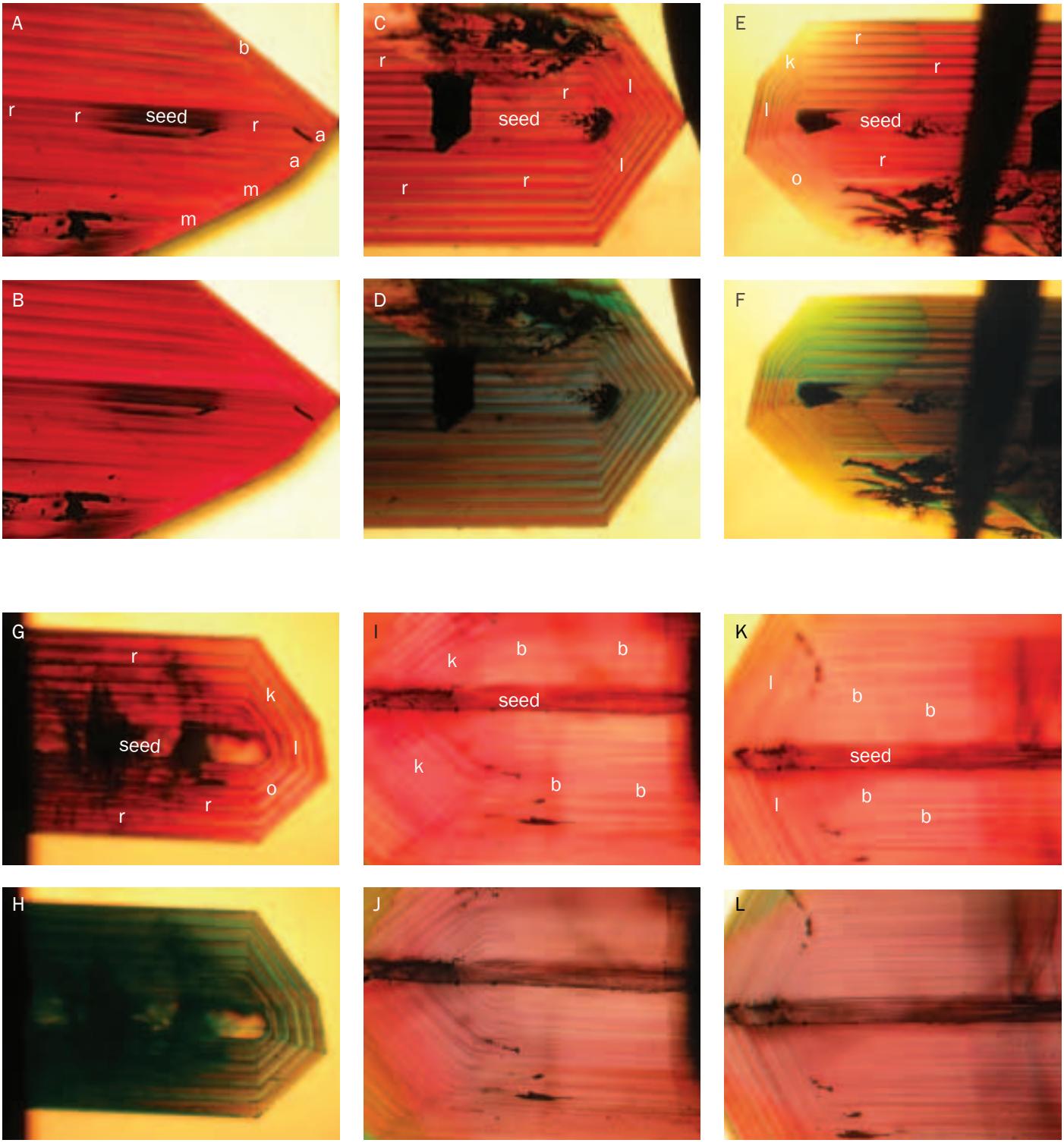

*Figure 27: Pleochroism and growth zoning, associated with colour zoning in synthetic alexandrite crystals grown with different seed orientation: (A–H) seeds parallel to the **r** prism, (A,B) growth zone [001], (C,D) growth zone [310], (E,F) growth zone [312], (G.H) growth zone [312]; (I–L) seeds parallel to the **b** pinacoid, (I,J) growth zone [100], (K,L) growth zone [301]; the position of the seed is indicated, the faces of the different growth zones are labelled.*

Immersion, plane polarized light, field of view (A,B) 6.7 × 5.0 mm, (C,D) 7.8 × 5.9 mm, (E,F) 9.1 × 6.9 mm, (G,H) 6.1 × 4.6 mm, (I,J) 7.6 × 5.7 mm, (K,L) 7.6 × 5.7 mm. Photos by K. Schmetzer.

Flux-grown synthetic alexandrites from Creative Crystals Inc.

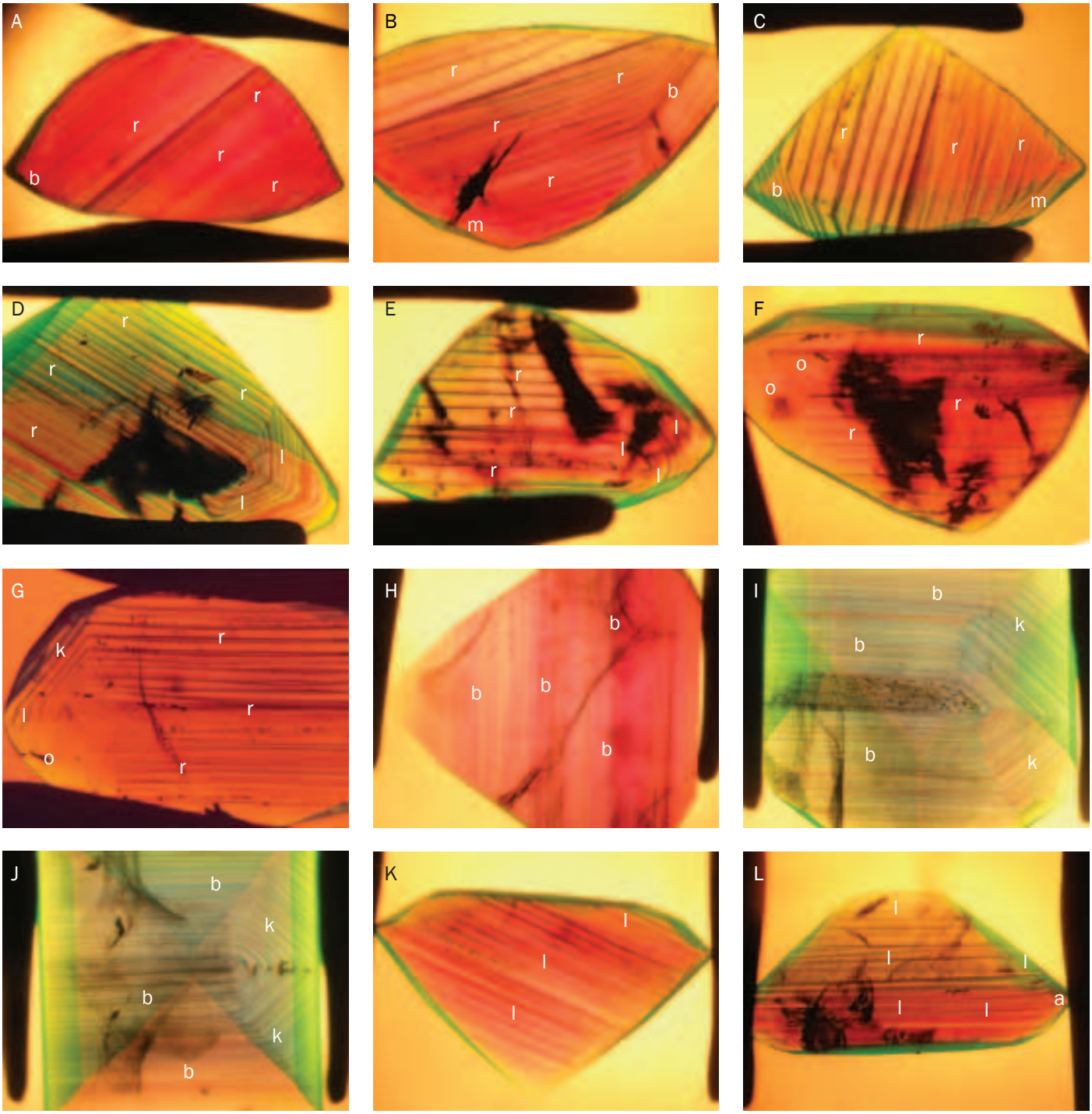

Figure 28: Growth zoning, associated with colour zoning in faceted synthetic alexandrite grown with different seed orientation:
*(A–G) seeds parallel to the **r** prism, (A,B,C) growth zone [001], (D,E) growth zone [310], (F,G) growth zone [312];*
*(H–J) seeds parallel to the **b** pinacoid, (H) growth zone [001], (I,J) growth zone [100];*
*(K,L) seeds parallel to the **l** dipyramid, (K,L) growth zone [011]; the faces of the different growth zones are labelled.*

Immersion, plane polarized light, field of view (A) 11.5 × 8.7 mm, (B) 6.3 × 4.7 mm, (C) 5.5 × 4.1 mm, (D) 6.5 × 4.9 mm, (E) 5.3 × 4.0 mm, (F) 4.9 × 3.7 mm, (G) 5.6 × 4.2 mm, (H) 8.5 × 6.4 mm, (I) 7.5 × 5.7 mm, (J) 8.8 × 6.6 mm, (K) 8.9 × 6.7 mm, (L) 9.5 × 7.2 mm. Photos by K. Schmetzer.

Flux-grown synthetic alexandrites from Creative Crystals Inc.

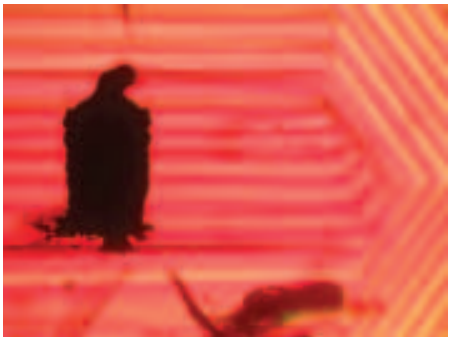

*Figure 29: Growth zoning, associated with colour zoning in a synthetic alexandrite crystal grown with **r** seed orientation, growth zone [310], faces **r** and **l**; from the centre to the rim, each growth layer starts with an intensely coloured area which gradually fades to a paler zone and then to a near-colourless part.*

Immersion, plane polarized light, field of view 4.6 × 3.5 mm. Photo by K. Schmetzer.

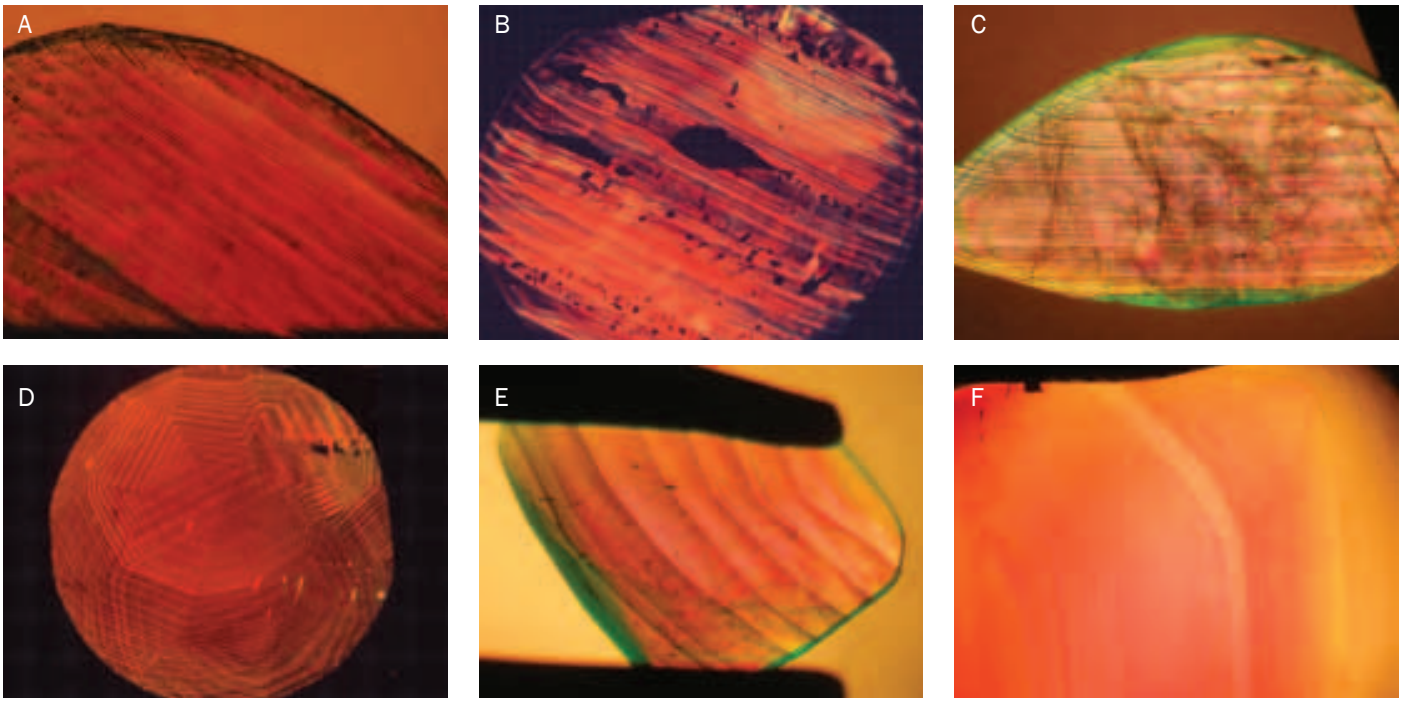

Figure 30: Characteristic interference patterns displayed by the layered growth structures of a faceted synthetic alexandrite.

Immersion, crossed polarizers or slightly uncrossed polarizers (for photography), field of view (A) 4.4 × 3.3 mm, (B) 5.6 × 4.2 mm, (C) 6.9 × 5.2 mm, (D) 10.1 × 7.6 mm, (E) 5.8 × 4.4 mm, (F) 11.9 × 9.0 mm. Photos by K. Schmetzer.

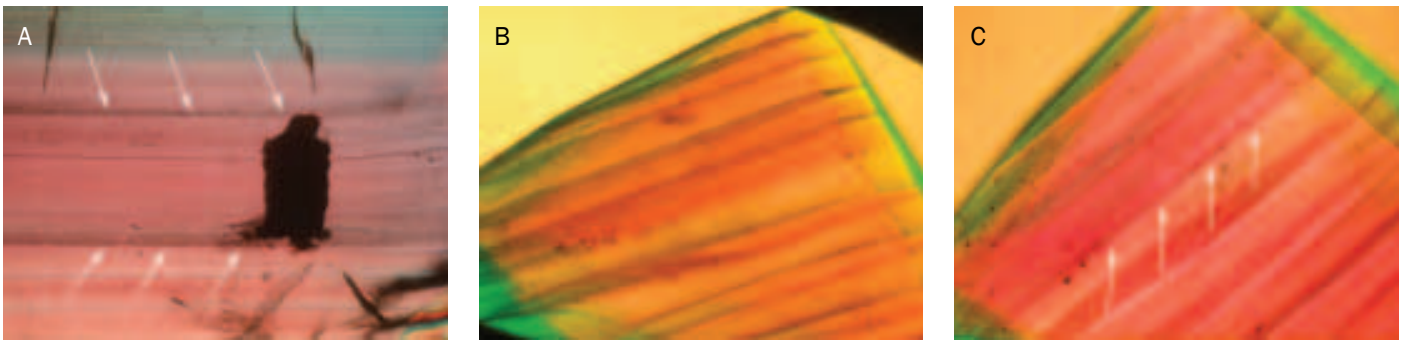

Figure 31: Growth boundaries showing somewhat irregular, 'cobbled' surfaces which are caused by some dissolution at the beginning of each growth cycle; occasionally, numerous small particles (indicated by arrows) are trapped close to some of these irregular surfaces. (A) seed confined to the outer layers by two irregular surfaces, (B) numerous irregular surfaces at successive growth boundaries, (C) numerous irregular surfaces at successive growth boundaries, one of them with a high concentration of trapped particles.

Immersion, plane polarized light, field of view (A) 6.0 × 4.5 mm, (B) 3.8 × 2.9 mm, (C) 3.6 × 2.7 mm. Photos by K. Schmetzer.

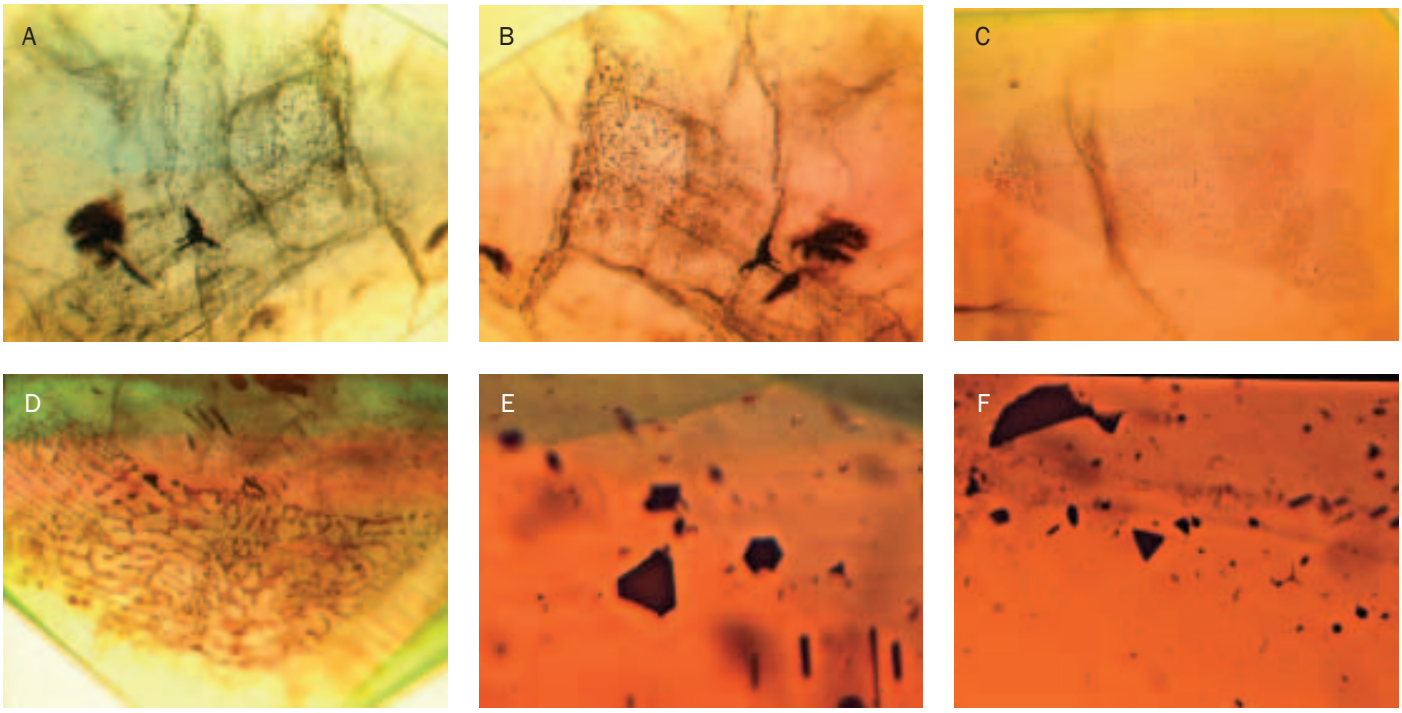

Figure 32: Various forms of residual flux are common (A–D); less common are platinum particles, needles or platelets (E,F). Immersion, plane polarized light, field of view (A,B) 6.0 × 4.5 mm, (C) 7.6 × 5.7 mm, (D) 3.6 × 2.7 mm, (E,F) 1.8 × 1.3 mm. Photos by K. Schmetzer

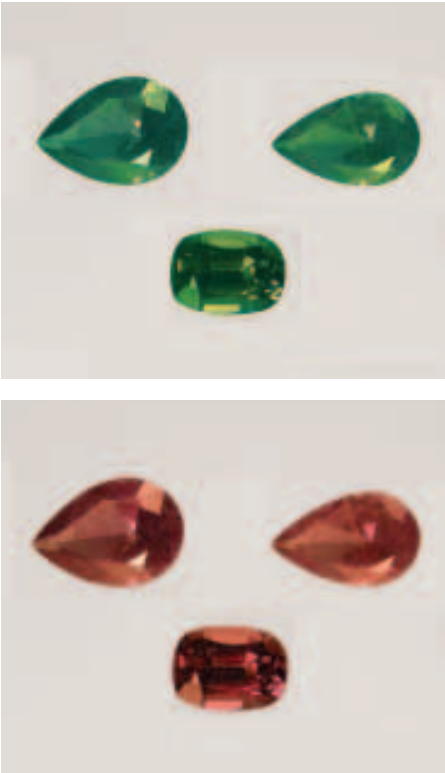

Figure 33: Electron microprobe scans of 9 or 10 analyses points were carried out across the table facets of these three synthetic alexandrites. The samples are shown in daylight (above) and incandescent light (below); their weights vary between 1.49 and 0.98 ct, the cushion-shaped stone measures 7.1 × 5.1 mm. Photo by K. Schmetzer.

Inclusions in rough and faceted alexandrites

Both the rough and faceted alexandrite samples show a range of clarities: some are heavily included, but others are very clean. The largest faceted sample of 13.49 ct, for example, contained neither platinum from the crucible nor any visible residual flux material. In most samples, however, there are variable quantities of residual flux in various forms, ranging from individual droplets to larger twisted veil-like feathers *(Figure 32 A–D)*. Only in a smaller percentage of the faceted samples are needles or triangular to hexagonal platinum platelets present *(Figure 32 E,F)*. In some samples, there are also small particles close to the growth boundaries *(Figure 31C)*.

X-ray fluorescence analysis

The compositions of seven rough crystals and 14 of the faceted samples were determined using X-ray fluorescence (XRF) analysis. Iron and chromium are the main colour-causing trace elements in all samples. In addition, in all heavily included faceted stones and in the more

Table IV: Ranges and average contents of colour-causing trace elements in alexandrites produced by Creative Crystals Inc. (in wt%).

Samples	A (Figure 34a)	B (Figure 34b)	C (Figure 34c)	D (Figure 35, 36)
No. of analyses	10	10	9	402
TiO_2 range	0.0 - 0.03	0.0 – 0.02	0.0– 0.03	0.0– 0.03
mean	0.01	0.01	0.01	0.0
V_2O_3 range	0.0 – 0.02	0.0 – 0.02	0.0 – 0.03	0.0 – 0.03
mean	0.01	0.01	0.01	0.01
Cr_2O_3 range	0.13 – 0.28	0.08 – 0.32	0.22 – 0.30	0.07 – 0.30
mean	0.20	0.20	0.26	0.18
Fe_2O_3 range	0.92 – 1.61	0.76 – 1.50	0.77 – 0.96	0.79 – 1.57
mean	1.14	1.0	0.86	1.05

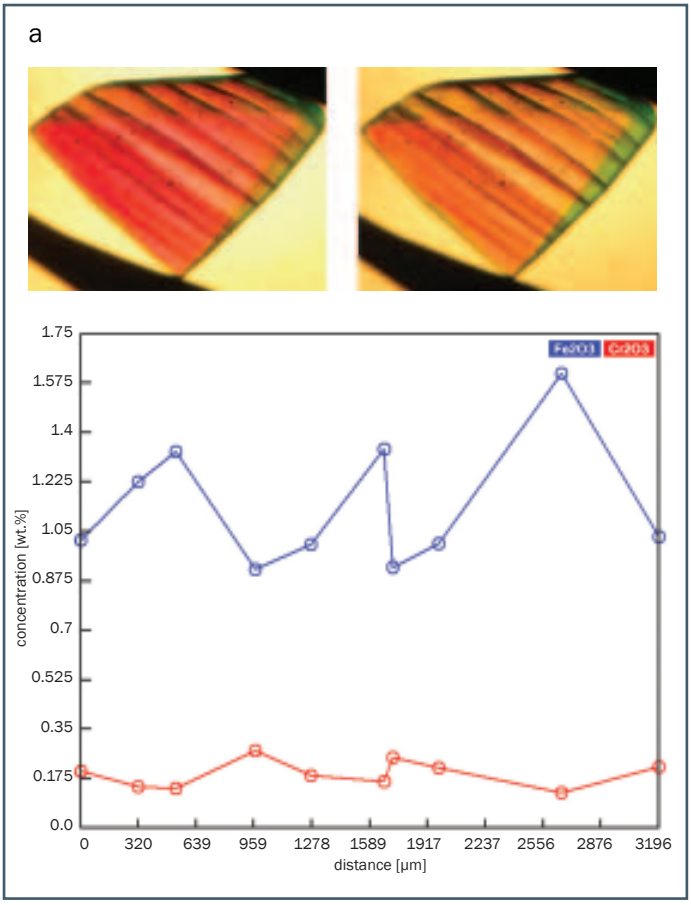

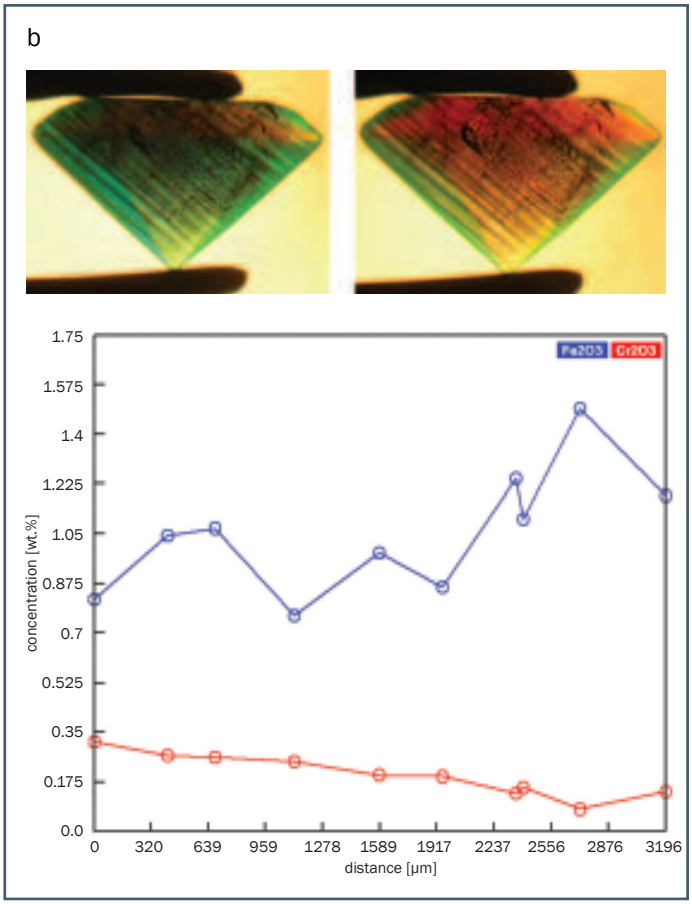

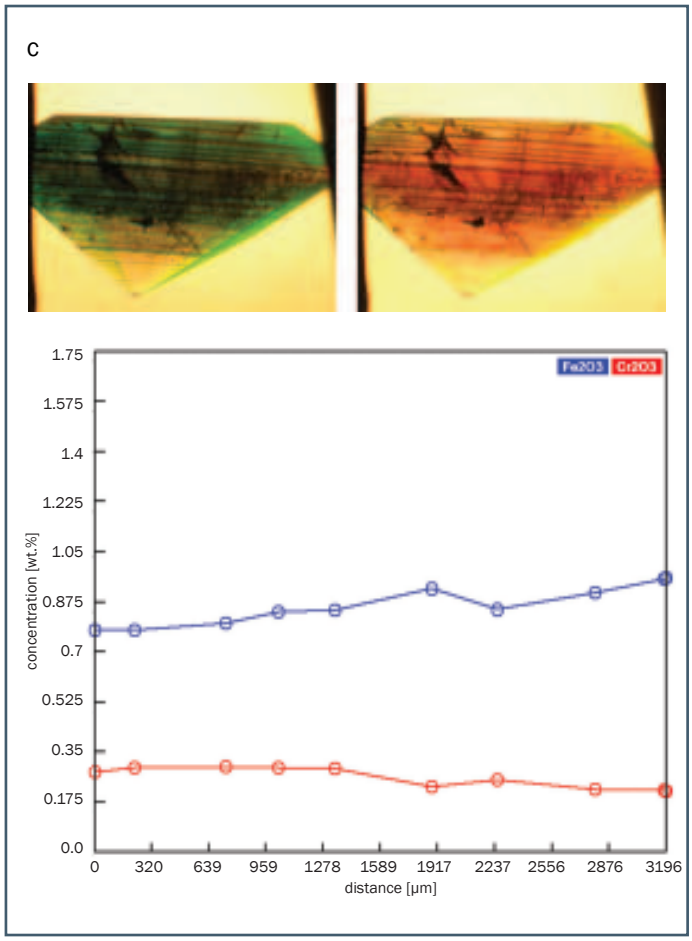

Figure 34 a,b,c: Pleochroism and growth zoning, associated with colour zoning in synthetic alexandrites (above, see also Figure 33*) and plots of chromium and iron concentrations measured by electron microprobe scans across the table facets; the trace element contents show clear variation in different growth layers.*

Sizes and weights of samples (a) 0.97 ct, 7.1 × 5.1 mm, (b) 1.02 ct, 9.1 × 5.6 mm, (c) 1.49 ct, 9.4 × 6.5 mm; all photos in immersion, plane polarized light. Photos by K. Schmetzer.

impure parts of the rough crystals molybdenum was detected and this has been derived from the flux. In some cleaner parts of the rough crystals and in clean or almost clean faceted samples molybdenum was not detected.

Surprisingly, traces of tin are present in all our samples. Upon request we were informed that no tin-bearing compounds were intentionally added to the flux or the nutrient; most probably these tin contents originate from the industrial grade lithium molybdate or the molybdic oxide used as the main components of the flux (D. Patterson, pers. comm., 2012).

Electron microprobe analysis

In most cut samples, the table facet is distinctly inclined to the dominant growth planes (which indicate the orientation of the seed), whereas in the remainder the table facet was almost parallel or only slightly inclined to the main growth layers. We obtained quantitative microprobe analyses for three samples *(Figure 33)*, specifically of two samples with distinct inclination of the main growth layers to the table facets *(Figure 34 a,b)*

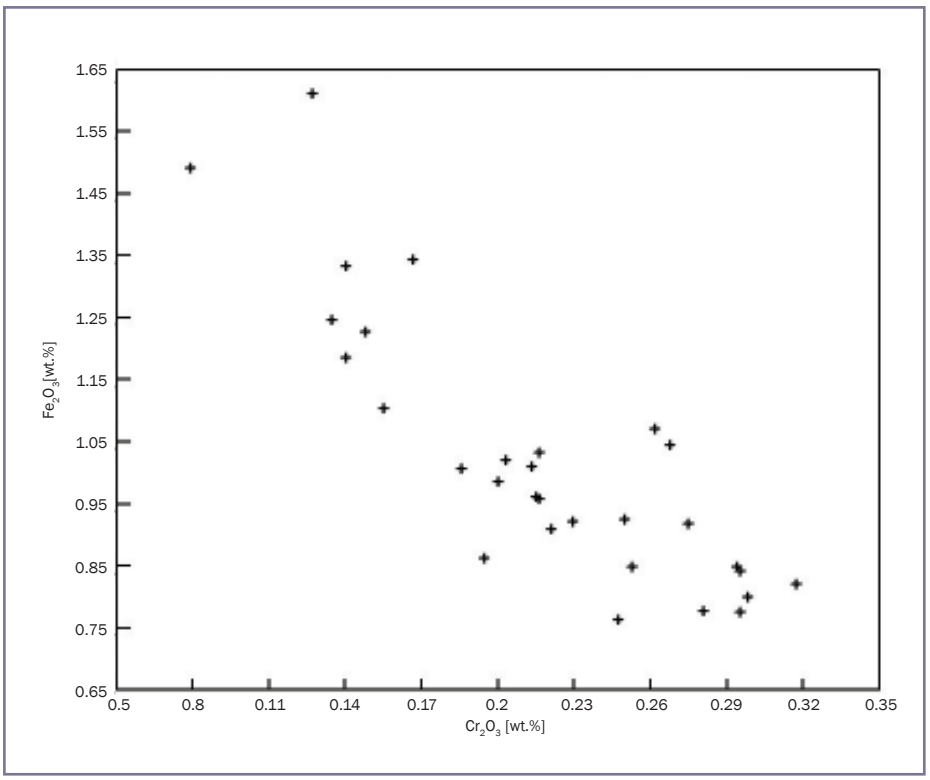

Figure 35: Chromium/iron binary diagram showing the ranges of these trace element contents in three synthetic alexandrites; the data are from microprobe scans (see Figures 33 *and* 34 a,b,c*) and show a negative correlation between the two trace elements, i.e. a decrease of iron with increasing chromium.*

and of one in which the table facet was slightly inclined *(Figure 34c)*. For all three of these **r**-grown samples, traverses with nine or ten point analyses each were measured across the table facets. The results are summarized in *Table IV*.

The main colour-causing trace elements, iron and chromium, show distinct zoning and extremely variable concentrations within the different growth layers. The iron contents ranged from 0.76 to 1.61 wt.% Fe_2O_3 and chromium contents ranged from 0.08 to 0.32 wt.% Cr_2O_3. In the first two samples (see *Figure 33 a,b*) it is clear that the ten analyses originate from eight to ten growth layers exposed at the table facets. In the third sample, only two growth layers are exposed at the table facet *(Figure 34c)*. The chemical data show a first zone with gradually increasing iron contents and gradually decreasing chromium contents (six analyses) and a second zone with similar iron and chromium variation (three analyses). An inconsistency between two analyses (Nos. 6 and 7) of this series indicates the transition between the two subsequent growth layers exposed at the table facet of this alexandrite. A plot of the analyses from these three samples (iron versus chromium contents) shows a clear negative correlation between both colour-causing trace elements, i.e. with increasing chromium content there is a decrease in iron *(Figure 35)*.

Detailed investigation of chemical zoning

For a more detailed examination of chemical zoning, one faceted sample was cut perpendicular to the table facet. The microscopic examination *(Figure 36A)* showed the sample to consist of seven somewhat broader central layers and one narrower layer on each side of this central area. Grown on each of these two small layers are two somewhat broader layers in the direction of the table facet and one broad layer in the direction of the culet. In a view perpendicular to this direction, an inconsistency in the internal growth pattern is present between the second broad layer (starting from the table facet) and the underlying narrower layer. The main growth boundary is oriented parallel to **r** indicating crystal growth with the most commonly observed **r** seed orientation.

A detailed microprobe scan was performed across the sample in a direction perpendicular to the table facet. This scan of about 2.3 mm in length crossed all the layers described above and consisted of 402 quantitative point analyses with point distances of about 6 µm each. Remarkable chemical zoning was recorded with iron contents between 0.79 and 1.57 wt.% Fe_2O_3 and chromium contents between 0.07 and 0.29 wt.% Cr_2O_3 *(Table IV, Figure 36A)*. These ranges are consistent with those measured for the other three alexandrites *(Figure 34 a,b,c)*.

A correlation of chemical data with the visually observed layer structure *(Figure 36B)* shows that the chromium content continuously decreases from the first to the second boundary of a specific layer, while the iron content continuously increases. This sequence is consistent in both the two smaller layers (marked 1 and 9 in *Figure 36B*) and the seven broader layers of the central area (marked 2 to 8). Subsequent to layers 1 and 9, a change of zoning of chromium and iron is present in the two layers towards the table (marked 10 and 11 in *Figure 36B*), but no change is apparent in the last broad layer towards the culet at the bottom (layer 10).

From these observations, the history of the sample is deduced as follows:

a) Synthetic alexandrite was grown in an unknown number of growth cycles on a seed cut parallel to the **r** prism of chrysoberyl.
b) From this crystal a section was cut which contained nine growth layers. After cutting and polishing this slab consisted of seven thicker layers in the centre and one thinner layer on each side of the central part.
c) This slab was used as seed for subsequent growth cycles. Towards the bottom, the growth direction was identical with the former growth direction of the central part, but towards the later table facet, growth was in the opposite direction (see the

Flux-grown synthetic alexandrites from Creative Crystals Inc.

A

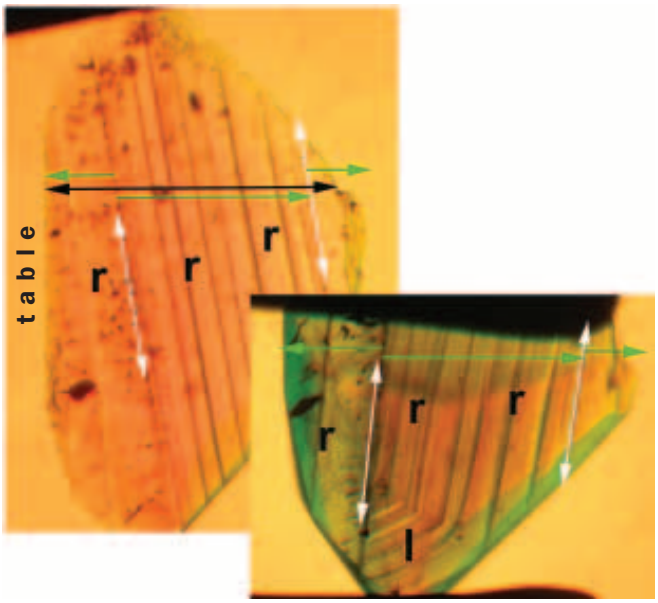

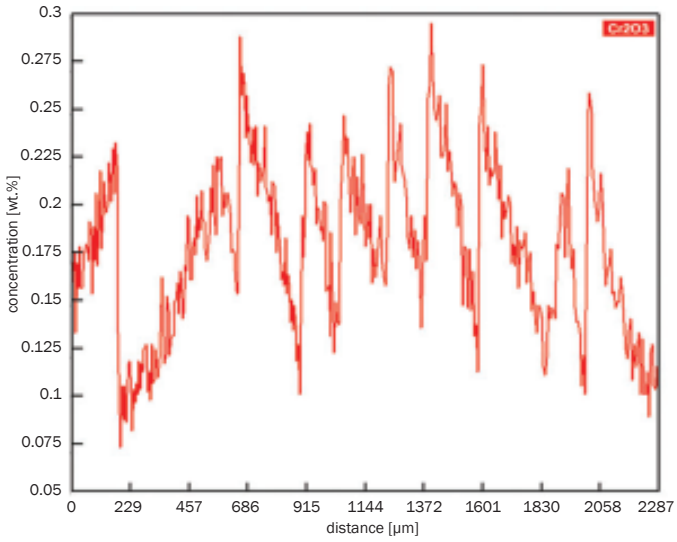

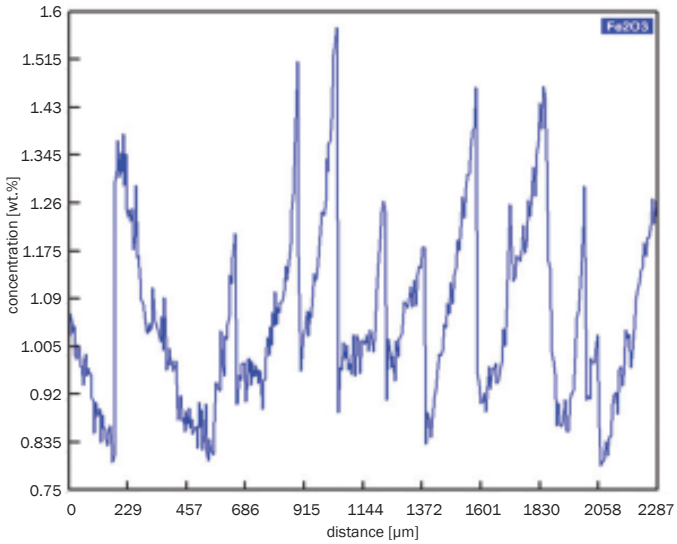

Figure 36A: Growth zoning, associated with colour zoning in synthetic alexandrite (above, photos of the same sample in two different orientations) and plots of chromium and iron concentration measured by an electron microprobe scan, about 2.3 mm long, consisting of 402 analysis points (black arrow). The alexandrite consists of a core which was overgrown after cutting and polishing; the boundaries between the core and the layers of the overgrowth are indicated by white arrows; the growth directions of the different layers of the core and the layers of the overgrowth are indicated by green arrows. The variation of trace element contents in each growth layer is clear; the plots of chromium (red) and iron contents (blue, below) and the patterns indicate a negative correlation.

Figure 36B: The Cr and Fe trace element contents are correlated with growth and colour zones in the alexandrite. This consists of a core with seven broader layers (labelled 2 to 8), two narrower layers (labelled 1 and 9) and an overgrowth of several layers on both sides of the core (labelled 10 and 11); the boundaries between the core and the layers of the overgrowth are indicated by white arrows; the growth directions of the different layers of the core and the layers of the overgrowth are indicated by green arrows.

At the beginning of each growth cycle, relatively high chromium contents and relatively low iron contents are incorporated into the growing alexandrite crystal; within each growth cycle, the chromium contents decrease and the iron contents increase. This variation in each growth cycle is the cause of the strong colour zoning (see Figures 27, 28 *and* 29*).*

B

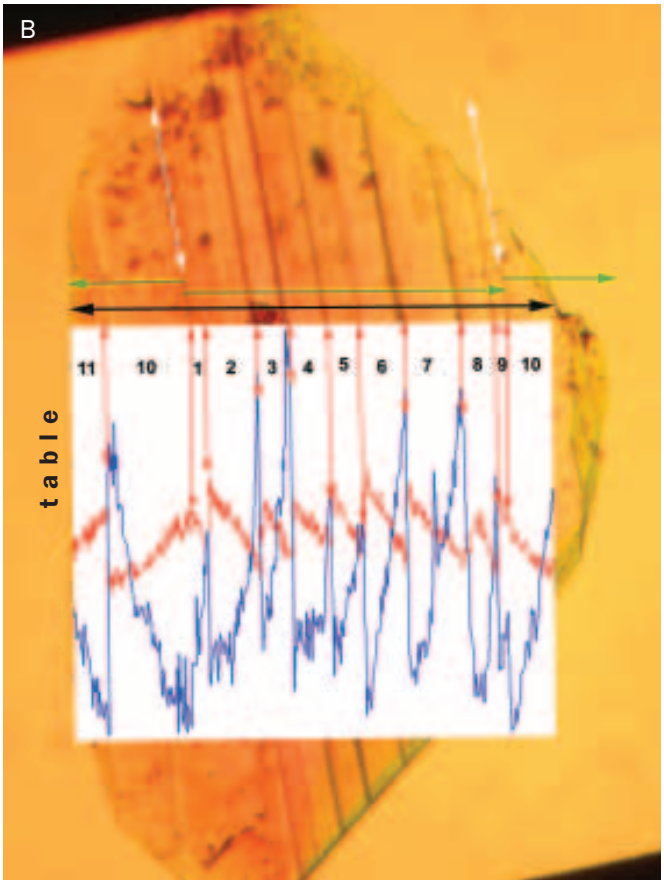

Table V: Colour and pleochroism in an oriented cube of synthetic alexandrite grown by Creative Crystals Inc.[1]

Direction of view	Light source	Colour to the unaided eye	Pleochroism		
			X	Y	Z
View ‖ a	daylight D_{65}	intense yellow green	–	yellow green	bluish green
	incandescent light A	greyish purplish red	–	orange	bluish green
View ‖ b	daylight D_{65}	blue green	blue violet	–	bluish green
	incandescent light A	violet purple	red purple	–	bluish green
View ‖ c	daylight D_{65}	light greenish yellow	blue violet	yellow green	–
	incandescent light A	red	red purple	orange	–

[1] Orientation: a 4.42, b 9.33, c 5.47; X ‖ a, Y ‖ b, Z ‖ c
lengths of the edges of the cube 5.9 × 5.8 × 5.8 mm

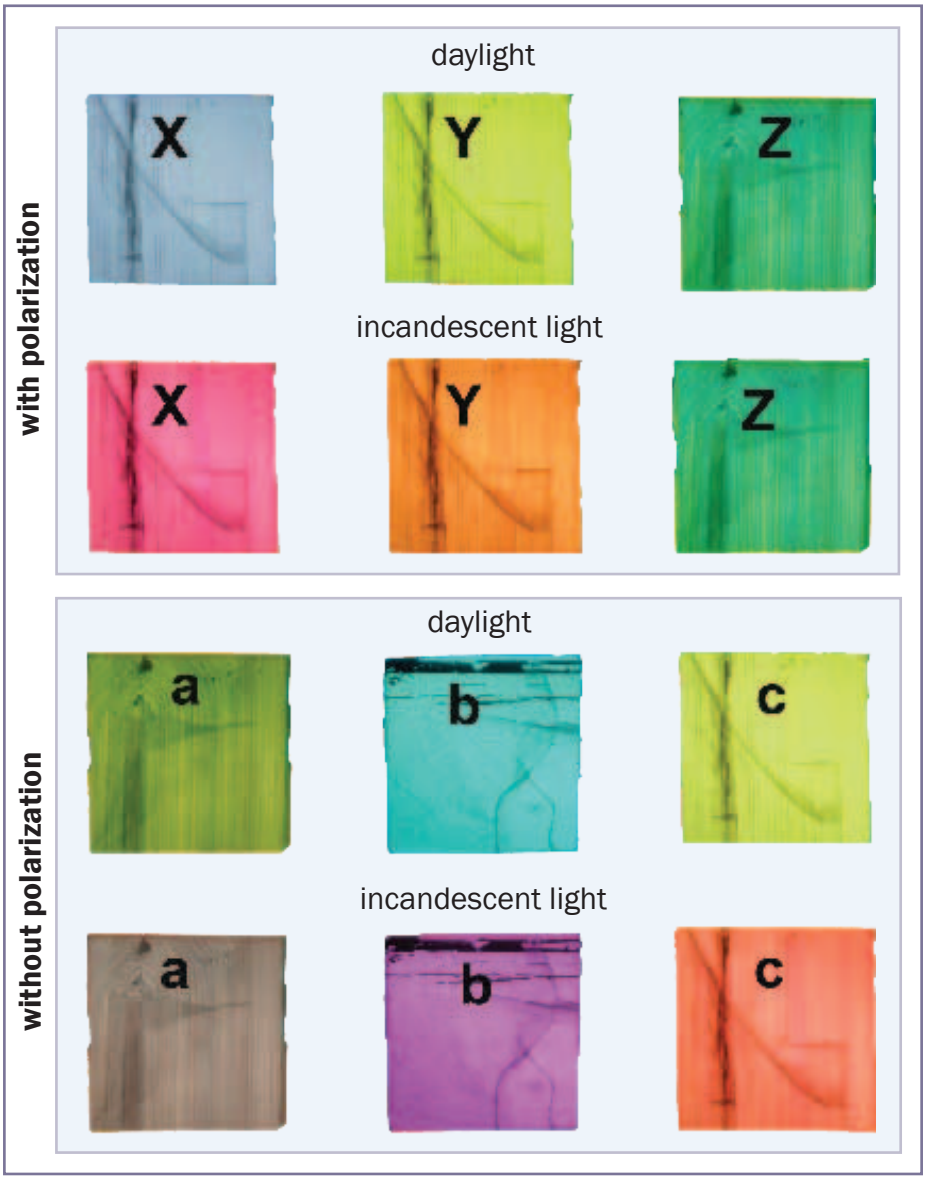

green lines in *Figure 36B*).

d) A stone was faceted from the final alexandrite crystal with a table cut somewhat oblique to the orientation of the seed.

Consequences of the applied growth technology

The synthetic alexandrites produced by Creative Crystals Inc. were grown in numerous successive growth cycles. In each growth period, the platinum crucible with solvent and seed crystals was continuously cooled within a period of about one week. This growth method is responsible for the three dimensional layered structure of the final product with each layer representing one individual growth cycle. Assuming a growth period of one week for one layer, the growth rate is about 0.03 – 0.04 mm per day.

The variation of growth conditions within each growth cycle caused distinct chemical zoning of chromium and iron within each growth layer, which is responsible for the observed colour zoning. At the beginning of each growth layer relatively chromium-rich alexandrite crystallized and towards the end of each growth layer, the chromium contents decreased and colour became less intense.

As each growth boundary is also a boundary between alexandrite layers of different chemical composition, the layers have slightly different optical properties, such as refractive indices. The interference pattern observed commonly at twin boundaries of natural or synthetic alexandrites is also based on the different optical properties displayed by adjacent parts of the twin which are in different

Figure 37: Schematic representation of colour and pleochroism in a cube of synthetic alexandrite in daylight and incandescent light; for polarized light (above) the three components X ‖ a, Y ‖ b and Z ‖ c are visible to the unaided eye; in non-polarized light different views parallel to the a-, b- and c-axes are depicted; growth zoning associated with colour zoning is also visible in some orientations of the sample.

Oriented cube of 3.22 ct, length of the edges 5.9 × 5.8 × 5.8 mm. Photos and artwork by K. Schmetzer.

orientations on each side of the twin plane. In natural alexandrites, series of parallel growth planes are common. In rare stones, the strongest or most visible boundaries between parallel growth planes can show distinct interference patterns under crossed polarizers (Schmetzer, 2011, 2012). This kind of pattern is comparable with that commonly present at each of the growth boundaries of the synthetic alexandrites from Creative Crystals Inc. But the interference pattern in the synthetic alexandrites is caused by the different optical properties arising from different trace element contents rather than by different structural orientations.

Absorption spectroscopy in the visible and ultraviolet range and colour of the samples

For the evaluation of colour and pleochroism, an alexandrite cube was prepared, with an exact orientation of the faces perpendicular to the three crystallographic axes of the crystal (a, b, c). The various colours of the sample in daylight and incandescent light and in polarized and non-polarized light, are summarized in *Table V* and depicted in *Figure 37*. Absorption spectra of X, Y and Z in polarized light are given in *Figure 38*, and spectra recorded in non-polarized light along the a-, b- and c-axes are depicted in *Figure 39a*. Colorimetric parameters in the CIELAB colorimetric system were calculated from the non-polarized spectra and are plotted in the CIELAB colour circle in *Figure 39b*.

The absorption maxima recorded *(Table VI)* were assigned to trivalent chromium and iron, and are consistent with literature data (see, e.g., Farrell and Newnham, 1965; Bukin *et al.*, 1980). In polarized light, there is a distinct change of colour from daylight to incandescent light for X and Y, but an almost identical bluish green is observed in the Z direction for daylight and incandescent light. Using this distinct pleochroism, it would be possible to determine the approximate orientation of a rough crystal or of a

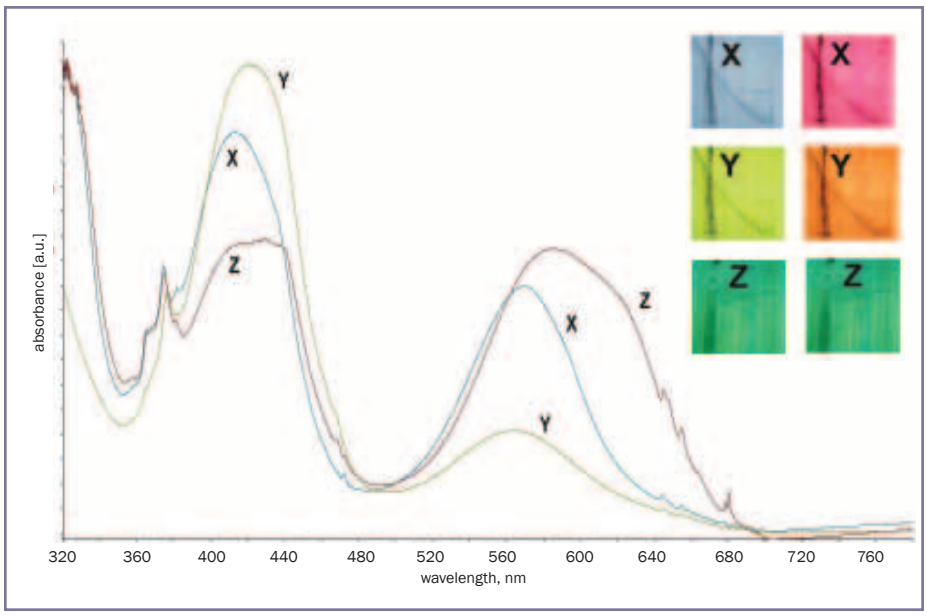

Figure 38: Absorption spectra of a synthetic alexandrite cube (see Figure 37) for polarized light (with X ∥ a, Y ∥ b and Z ∥ c); the colours in polarized light are also depicted for daylight (left column) and incandescent light (right column).

Table VI: Absorption peaks in the visible-range spectra of synthetic alexandrites grown by Creative Crystals Inc.

With polarization, absorption maxima and minima (in nm)

Polarization	X	Y	Z	Assignment
Maxima	570	564	586	Cr^{3+}
	–	–	440	Fe^{3+}
	–	–	430	Fe^{3+}
	414	421	420	Cr^{3+}
	381	381	381	Fe^{3+}
	375	377	375	Fe^{3+}
	365	364	365	Fe^{3+}
	–	–	356	Fe^{3+}
Minima	484	495	491	

Additional spin-forbidden chromium bands were observed at 680, 678, 655, 648, 645 and 472, 469, 467 nm.

Without polarization, absorption maxima and minima (in nm)

Orientation	a-axis	b-axis	c-axis	Assignment
Maxima	571	574	567	Cr^{3+}
	440	440 weak	–	Fe^{3+}
	430	430 weak	–	Fe^{3+}
	422	417	416	Cr^{3+}
	381	381	381	Fe^{3+}
	375	375	375	Fe^{3+}
	365	365	365	Fe^{3+}
	356	356	–	Fe^{3+}
Minima	494	488	490	

Additional spin-forbidden chromium bands were observed at 680, 678, 655, 648, 645 and 472, 469, 467 nm.

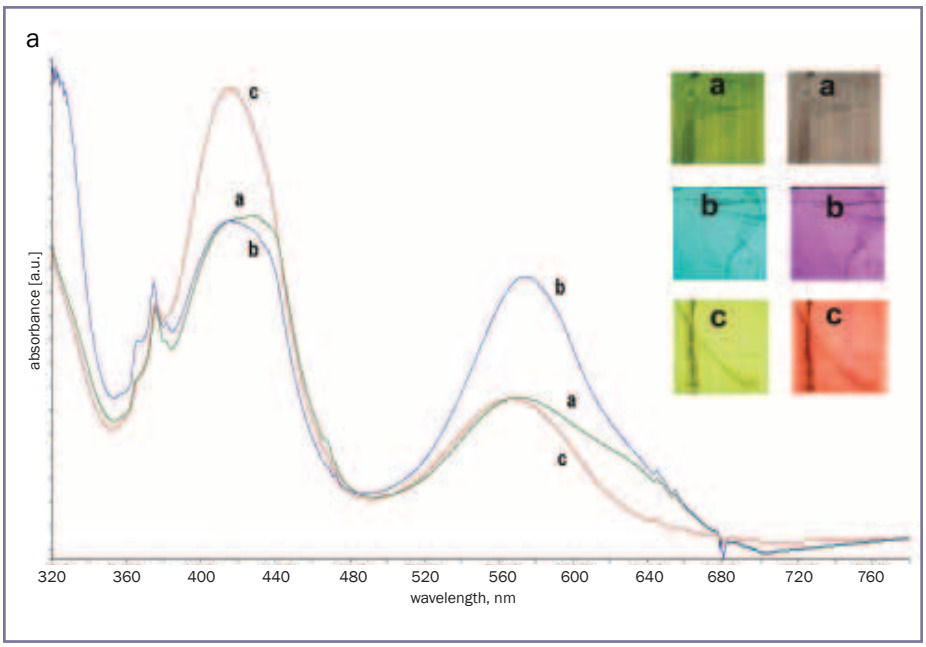

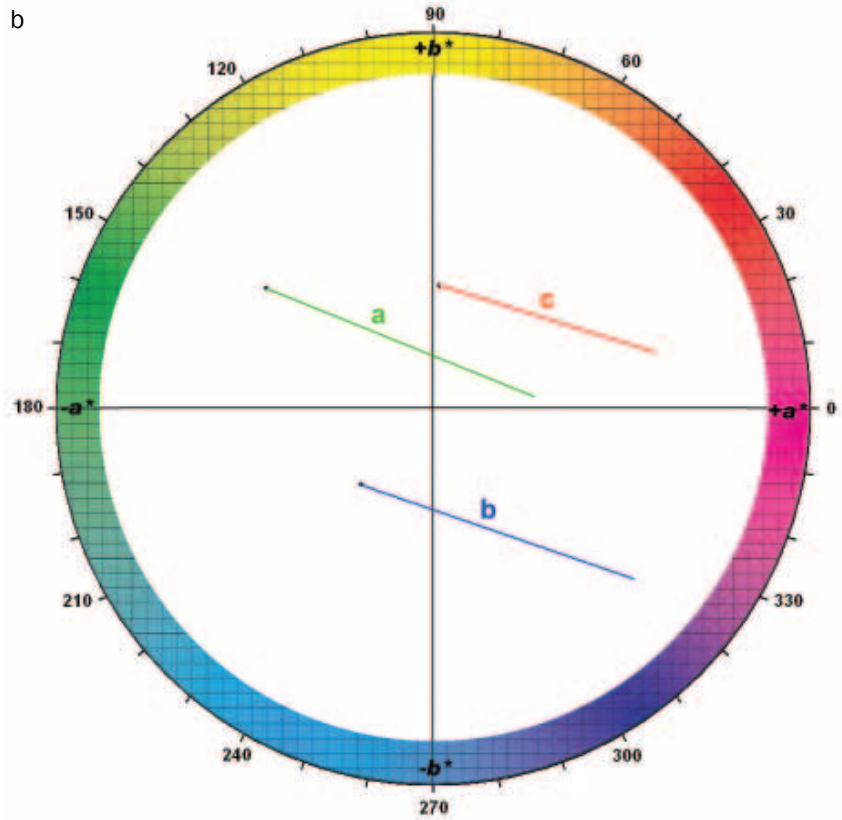

Figure 39: (a) Absorption spectra of a synthetic alexandrite cube (see Figure 37*) for non-polarized light in different views parallel to the a-, b- and c-axes, the colours in these directions are also depicted for daylight (left column) and incandescent light (right column); (b) colorimetric parameters are plotted for daylight and incandescent light in the CIELAB colour circle; they represent views parallel to the three crystallographic axes; the neutral point (white point) is in the centre of the a*b* coordinate system, the black circles represent the coordinates in daylight D_{65} and the ends of the differently coloured bars represent the coordinates in tungsten light A; the outer circle represents a chroma of 25. The pleochroism and typical colour change between daylight and incandescent light of the alexandrite for non-polarized light is consistent with the visual observation (see* Figure 37*). Colorimetric measurements by W. Balmer.*

faceted gemstone in the immersion microscope, especially by means of a commonly used tungsten bulb for incandescent illumination.

The two principal Cr^{3+} emissions of alexandrite are detected in some stones as 'negative' peaks in the absorption spectrum and, at the lower energy side (longer wavelength) of these peaks, additional luminescence bands may be present, also in the 'negative' direction; all other Cr^{3+} bands show a regular appearance *(Figures 38, 39a, 40a)*. This effect is caused by the use of a CCD-type Czerny-Turner spectrometer in combination with an integration sphere; such a setup permits the detection of all wavelengths at the same time in contrast to a traditional scanning spectrometer. In samples which can show strong luminescence, the light source used to record absorption spectra also excites fluorescence, which is detected at the same time. When the absorption dominates the emission, the peaks will point in the 'positive' direction while in the case of dominant emission, the peaks will point in the 'negative' direction.

As seen from *Figures 37* (lower half) and *39b* representing observations in non-polarized light, no 'ideal' orientation for the cutting of alexandrite exists. The most attractive intense green is seen in daylight in the direction along the a-axis, but the colour in incandescent light in this direction is not very attractive. In daylight, the colour along the b-axis seems to contain too much blue and the colour along the c-axis seems to contain too much yellow, although in incandescent light the colours along b or c are generally considered more 'attractive' than that seen along the a-axis. Therefore the search for the 'best' orientation of a rough sample for cutting to obtain the most attractive colours in both daylight and incandescent light is always a challenge.

Absorption spectra of different crystals recorded in directions perpendicular to the three seed orientations are presented in *Figure 40a*, and the colorimetric parameters calculated from absorption spectra for daylight and incandescent light are graphically represented in the

CIELAB colour circle in *Figure 40b*. The absorption minima in the visible range were determined at 487 nm for samples with **b** seed orientation, at 491 nm for samples with l seed orientation and at 495 for samples with **r** seed orientation. This indicates that the absorption minima show a clear shift for different seed orientations, which reflects the different colours of the samples.

The data obtained for crystals with seed orientation parallel to the **b** face (perpendicular to the b-axis) are comparable with the data obtained for the cube along the b-axis. In general trade opinion, the stones cut with this particular orientation of the table facet have 'too much blue' in daylight and 'too much violet' in incandescent light. Therefore, Creative Crystals Inc. stones for the trade were mostly cut with an orientation of the table facet inclined to the **b** (010) face.

For some of the samples with **r** seed orientation (see the upper example depicted in *Figure 40b*), the colours again may not be 'ideal', for in daylight there may be 'too much yellow' or in incandescent light, there may be 'too much red orange' and not enough blue. Therefore, most samples grown with r seed orientation have been cut with a table facet inclined to the **r** face (see, e.g. *Figure 34 a,b,c*). As seen for the samples with l seed orientation, their colours plotted in the CIELAB diagram represent, more or less, the most desired colours of alexandrite, green to bluish green in daylight and reddish purple to purple in incandescent light. This orientation is represented by a seed which is inclined to all three crystallographic axes. For practical application, this was also the best and most easily obtainable seed orientation for cutting purposes, i.e. for the best orientation of the table facet, which is inclined to all three crystal axes (D. Patterson, pers. comm., 2012).

However, we have to emphasize here that there are other factors which influence the colour of alexandrites in daylight and incandescent light. It has already been worked out, that — in addition to the orientation of the sample — the chemical composition, especially

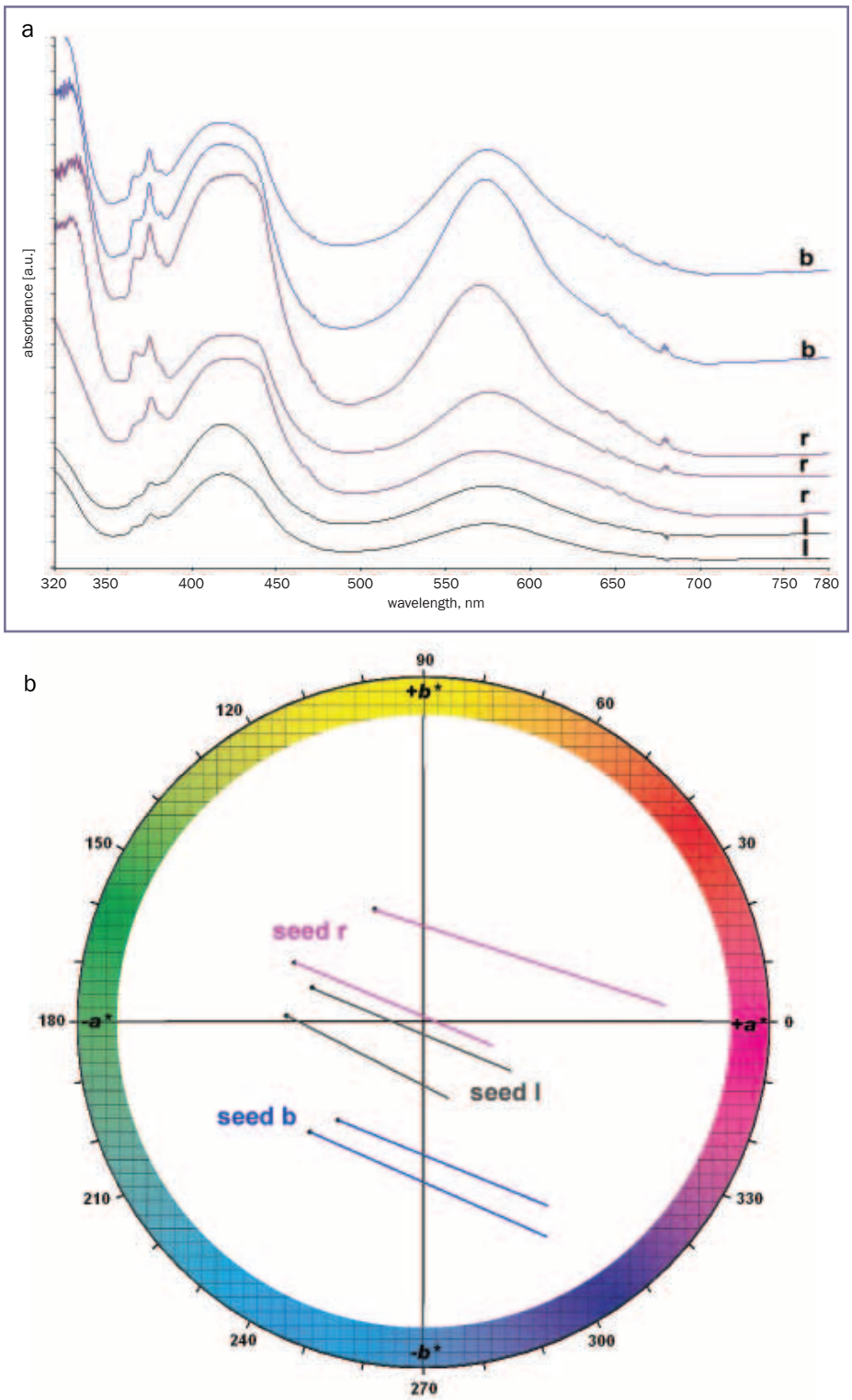

*Figure 40: (a) Absorption spectra of synthetic alexandrite crystals grown with different seed orientations for non-polarized light with the direction of the incident beam perpendicular to the seed plate; (b) colorimetric parameters are plotted for daylight and incandescent light in the CIELAB colour circle; they represent views perpendicular to the seed plate; the neutral point (white point) is in the centre of the a*b* coordinate system, the black circles represent the coordinates in daylight D_{65} and the ends of the differently coloured bars represent the coordinates in tungsten light A; the outer circle represents a chroma of 25. The dependency of colour and colour change on stone orientation is evident. The two samples with **l** seed orientation and one sample with **r** seed orientation show colours which are close to the desired 'ideal' coloration of alexandrite in daylight and incandescent light; the two samples with **b** seed orientation show 'too much blue', and the upper sample with **r** seed orientation shows 'too much yellow'. Colorimetric measurements by W. Balmer.*

the chromium content, plays an important role in determining the colour and colour change of a natural or synthetic alexandrite (Schmetzer and Bosshart, 2010; Schmetzer and Malsy, 2011). In addition, the length of the light path within a sample (influenced by cut and thickness) has also a strong influence on colour and colour change (Schmetzer *et al.*, 2012). Furthermore, in the cutting of alexandrite, the presence and/or variable concentration of inclusions, which causes variable transparency in different areas of the rough, must be taken into account to obtain the best stone.

Infrared spectroscopy

Infrared spectra were recorded for the oriented cube in the three directions parallel to the a-, b- and c-axes of the crystal. The spectra showed absorption bands with maxima at 3225, 2970 and 2655 cm^{-1} and shoulders at 2030 and 1995 cm^{-1} *(Figure 41)*. Although the spectra were recorded without polarization of the primary beam, the three bands at 3225, 2970 and 2655 cm^{-1} showed a clear polarization dependency. They were recorded in the spectra parallel to the b-axis (representing a combination of X and Z) and parallel to the c-axis (representing a combination of X and Y), but not in the spectrum parallel to the a-axis (representing a combination of Y and Z). This indicates a polarization of these lines parallel to X.

The data are consistent with infrared spectra published for Russian flux-grown chromium- and iron-bearing synthetic alexandrites, which showed small absorption bands in the same spectral range (Henn, 1992; Schmetzer *et al.*, 1996; Malsy and Armbruster, 2012). The different intensities of infrared absorption bands in natural and synthetic alexandrites measured in different orientations of the same gemstone were reported by Stockton and Kane (1988). The polarization dependency indicates structural OH-groups, as described in detail for polarized spectra of natural chrysoberyl (Bauerhansl and Beran, 1997). These OH-group absorption bands also showed a polarization in the X direction, but their absorption maxima were in somewhat different positions. For their stones, they proposed OH-dipoles parallel to the [100] direction, associated with Be vacancies, to account for the absorptions. This model might also apply for flux-grown synthetic alexandrite, but the shift of the band maxima is not yet understood in detail.

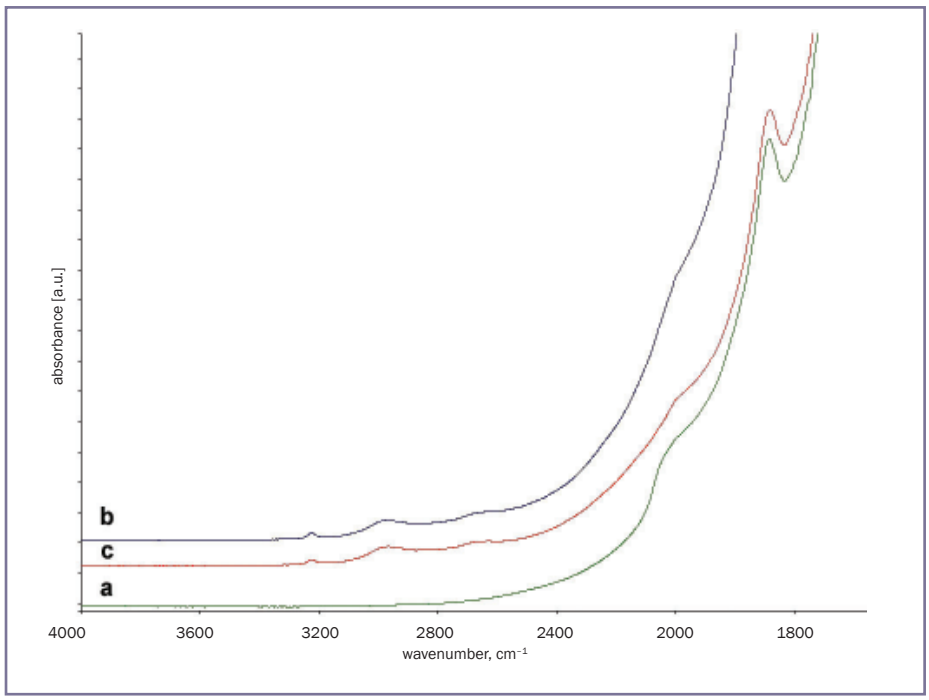

Figure 41: Infrared spectra of synthetic alexandrite cube in non-polarized light in views parallel to the a-, b- and c-axes of the crystal; the small absorption maxima near 3000 and 3200 cm^{-1} are present only in spectra representing views parallel to the b- and c-axes which indicates a polarization of these weak absorption bands parallel to X.

Comparison with Russian flux-grown alexandrites

Materials available on the market

Russian flux-grown alexandrite has been commercially available since the mid-1980s and has been described in detail in various mineralogical and gemmological papers (see, e.g., Trossarelli, 1986; Henn *et al.*, 1988; Henn, 1992, 2000; Schmetzer *et al.*, 1996). The samples were produced at the Institute of Geology and Geophysics, Novosibirsk, by a team around N.A. Novgorodtseva and G.V. Bukin from a bismuth- and molybdenum-bearing flux (Rodionov and Novgorodtseva, 1988; Bukin, 1993; Khranenko and Yurkin, 2000; A.Ya. Rodionov, pers. comm., 1988; G.V. Bukin, pers. comm., 1995; V.V. Gurov, pers. comm., 2011). In addition to the colour-causing trace elements, generally chromium and iron with some vanadium in some samples, these alexandrites are characterized by various contents of germanium (for details see Schmetzer *et al.*, 1996).

In a recent paper by Malsy and Armbruster (2012), three different types of Russian flux-grown alexandrite are mentioned. Two types labelled 'Tairus' and 'Bukin' (both types representing chromium- and iron-bearing alexandrites) show a similar chemical trace element pattern and relatively high concentrations of germanium. One might assume that the Tairus company, based in Novosibirsk, would have continued the production of the 'Bukin — Institute of Geology and Geophysics' type of synthetic alexandrite, but upon request, one author (KS) was informed that the Tairus company had never produced any iron- and chromium-bearing alexandrite by the flux method (V.V. Gurov, pers. comm., 2011, 2012). However, it was confirmed that Tairus is still selling stones produced at the Institute of Geology and Geophysics in Novosibirsk.

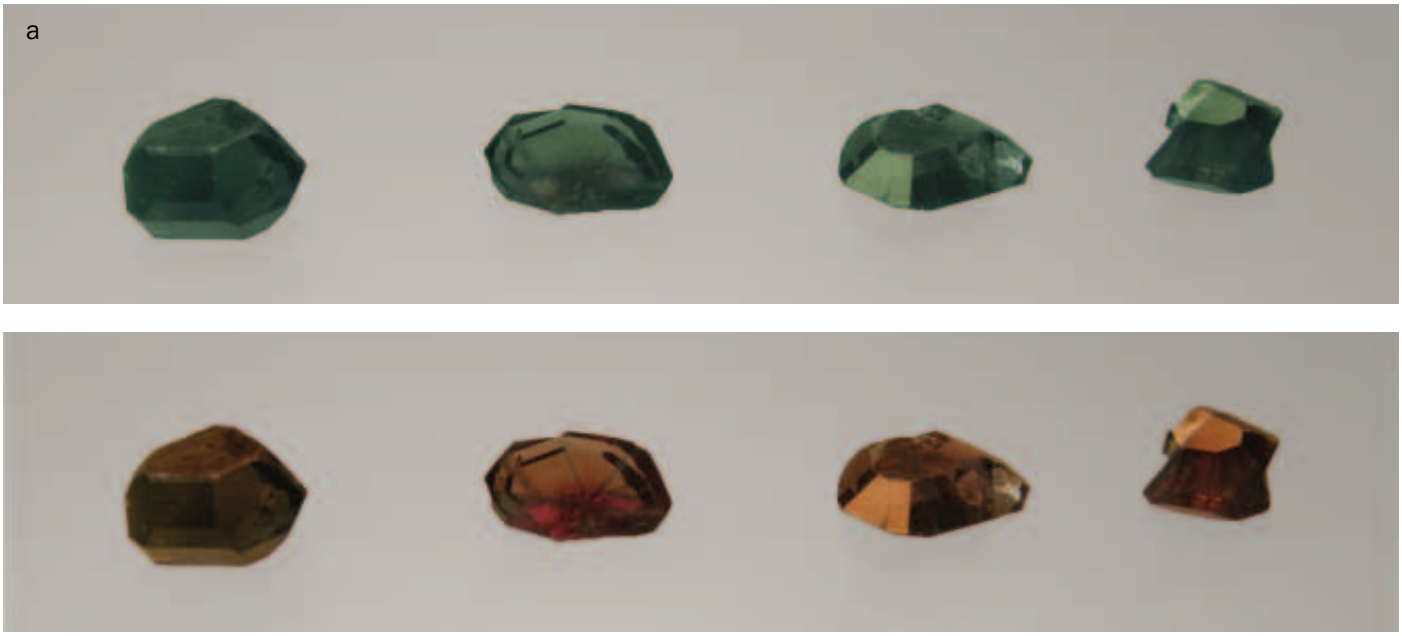

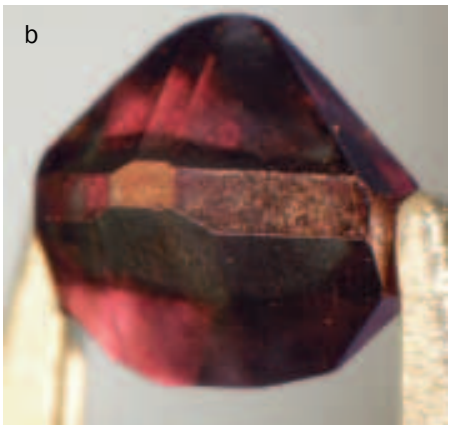

Figure 42: (a) Single crystal (left) and three cyclic twins (trillings) of flux-grown Russian synthetic alexandrites in daylight (above) and incandescent light (below); weight of samples from 5.47 to 2.45 ct; the single crystal on the left measures 11.5 × 7.5 mm.
(b) Single crystal flux-grown Russian synthetic alexandrite in incandescent light; weight of the sample 0.31 ct, size 3.9 × 3.7 mm; this sample is represented by Figure 43A. *Photos by K. Schmetzer.*

At present Tairus is producing and/or marketing synthetic alexandrites which are grown by the Czochralski technique and by a variant of the floating zone method described as "horizontally oriented crystallization (HOC)" (V.V. Gurov, pers. comm., 2011). Samples grown in Novosibirsk by the Czochralski technique were produced in iridium crucibles (see, e.g., Bukin *et al.*, 1981) which is consistent with the analytical data published by Malsy and Armbruster (2012) for the Czochralski-grown material assigned to Tairus. Alexandrites produced by the HOC method, on the other hand, are grown in boat-like containers of molybdenum (Gurov *et al.*, 2003; see also Schmetzer *et al.*, 2012).

A third type of 'flux-grown' Russian synthetic alexandrite, which did not contain significant amounts of germanium, was also attributed to Tairus by Malsy and Armbruster (2012). These chromium- and vanadium-bearing, iron-free samples contained traces of molybdenum. On enquiry by one author (KS) it was confirmed that the Tairus company had never produced any chromium- or chromium- and vanadium-bearing, iron-free alexandrites by the flux method and that the Tairus molybdenum-bearing stones are produced by the HOC technique (V.V. Gurov, pers. comm., 2012). Thus, it is likely that the chromium- and vanadium-bearing, iron- and germanium-free faceted Tairus material described by Malsy and Armbruster (2012) was produced by the HOC technique and is not flux-grown.

Growth technique and properties

The Russian alexandrite produced at the Institute of Geology and Geophysics, Novosibirsk, is grown in platinum crucibles in a reverse temperature gradient in which the nutrient is placed in the upper part of the crucible (dissolution zone) which is at a higher temperature than the base. The growth zone (crystallization zone) is in the lower part of the crucible. Small alexandrite crystals are formed by spontaneous nucleation at the bottom or close to the bottom of the crucible and grow continuously over several months. Most crystals grow in contact with the bottom of the crucible, and free-floating crystals are extremely rare (Rodionov and Novgorodtseva, 1988; Bukin, 1993; Schmetzer *et al.*, 1996; Khranenko and Yurkin, 2000). Although seeded growth is possible, with seeds placed at or attached to the bottom of the crucible (Bukin, 1993; Khranenko and Yurkin, 2000), no evidence of residual parts of seeds have been found so far in any sample examined by one author (KS).

Most crystals grown in contact with the bottom or with the wall of the crucible are twinned and have a somewhat dull and lustreless face, representing the contact plane of the crystal with the crucible. The highly reflecting crystal faces of the twins or trillings growing freely within the solvent show higher lustre *(Figure 42a)*. Only a few complete single crystals *(Figure 42b)* with no faces indicating contact with the crucible were found among 200 samples examined by one author in the study of 1995 and 1996 (Schmetzer *et al.*, 1996) and later. The morphologies of a single crystal and four

Flux-grown synthetic alexandrites from Creative Crystals Inc.

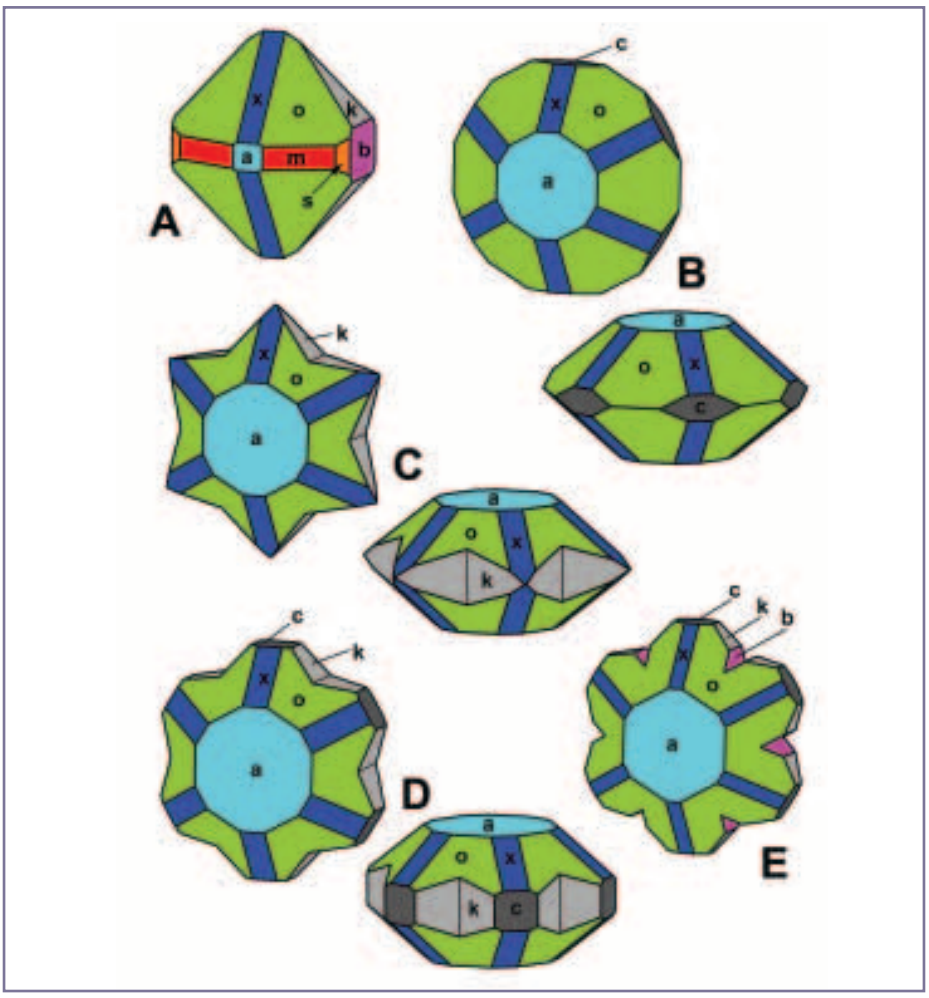

*Figure 43: Schematic drawings of a single crystal (A) and four cyclic twins (trillings, B to E) of flux-grown Russian synthetic alexandrites; three of the cyclic twins (B, C, D) are shown in views parallel to the a-axis (always upper left) and perpendicular to the c-axis, the other trilling (E) is shown parallel to the a-axis; single crystals (drawing A) and trillings with **b**-pinacoids (drawing E) are extremely rare. Crystal drawings and artwork by K. Schmetzer.*

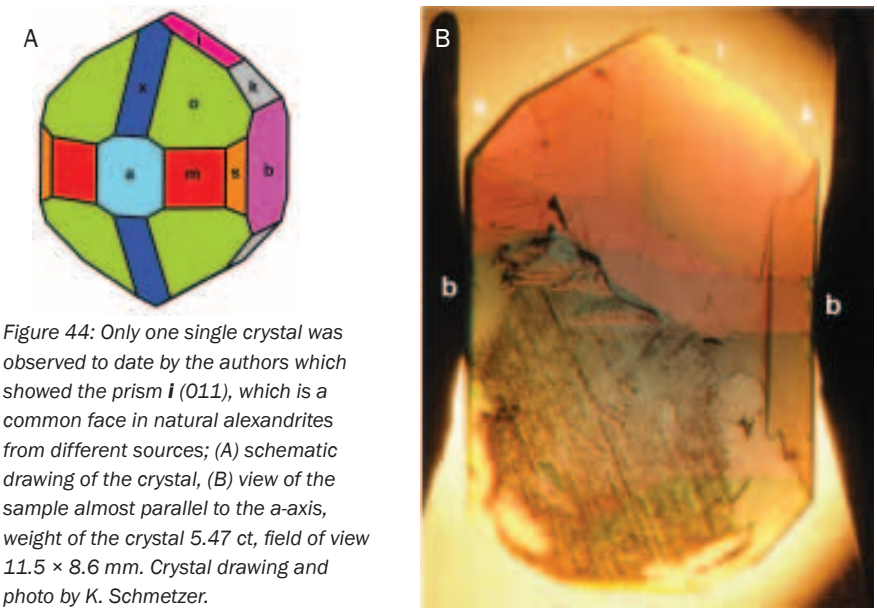

*Figure 44: Only one single crystal was observed to date by the authors which showed the prism **i** (011), which is a common face in natural alexandrites from different sources; (A) schematic drawing of the crystal, (B) view of the sample almost parallel to the a-axis, weight of the crystal 5.47 ct, field of view 11.5 × 8.6 mm. Crystal drawing and photo by K. Schmetzer.*

trillings are depicted in *Figure 43*. The various faces present in the single crystals and twins are the pinacoids **a** (100), **b** (010) and **c** (001), in combination with the five prism faces **m** (110), **s** (120), **x** (101), **i** (011) and **k** (021) and the dipyramid **o** (111). For all samples examined in the 1990s and for samples received from the trade in recent years, the two prism faces **s** and **i** were only observed in single crystals (*Figure 43*, sample A; Figure 44) and the pinacoid **b** is extremely rare in cyclic twins (see *Figure 43*, sample E).

The internal growth patterns of the samples closely reflect their external morphology *(Figures 42 a,b, 44A, 45)*. In the rough samples twins or trillings with re-entrant angles between different **k** prism faces are common *(Figure 46 A–C)*. This is the most characteristic pattern visible in a view parallel to the a-axis *(Figure 46 A,D)*. The most characteristic growth pattern in different views perpendicular to the a-axis are **a** pinacoids in combination with two **o** dipyramids *(Figure 46E)* or **a** pinacoids in combination with two **x** prism faces *(Figure 46F)*, occasionally also in combination with a **c** pinacoid.

As already mentioned, the Russian flux-grown material available in the trade contains significant amounts of germanium (up to 3.3 wt.% GeO_2) and traces of gallium and tin. Colour-causing transition metals are chromium (up to 4.6 wt.% Cr_2O_3) and iron (up to 1.6 wt.% Fe_2O_3), and some samples may contain up to 1.0 wt.% V_2O_3. Molybdenum- and bismuth-bearing compounds, from residual flux, have been detected, and a tungsten-bearing phase has also been found (Schmetzer *et al.*, 1996).

About 10 % of the samples examined in the 1990s (Schmetzer *et al.*, 1996), contained a pattern of colour zoning with an intensely dark core and a somewhat lighter rim. Between the core and rim, there was commonly a narrow zone with extremely high chromium content. These observations indicate, at least for these samples, crystal growth in several periods, with an addition of chromium to the nutrient between these periods.

Various forms of residual flux are present as inclusions in Russian flux-grown alexandrites. They range from isolated drops or dots to net-like patterns, 'feathers' or 'fingerprints'. Isolated particles of platinum originating from the surface of the crucible are present in some stones.

Discussion

To the best of our knowledge, this is the first detailed description of the synthetic alexandrites grown in the 1970s and early 1980s by Creative Crystals Inc. and correlates their properties with the applied growth technology. It is also the first account of flux-grown alexandrites (or other flux-grown gem materials), which were produced using a slow cooling technique in multiple successive growth cycles — in contrast to the Russian alexandrites which were grown in a furnace with a temperature gradient.

The main parameters influencing the final chemical and physical characteristics of the Creative Crystals Inc. gem material are:

a) orientation of the seed material
b) properties of the seed material (natural or synthetic, alexandrite or chrysoberyl)
c) concentration of colour-causing trace elements in the solvent at the beginning of each cooling phase and
d) varying concentrations of colour-causing trace elements during each cooling period of the solvent.

The orientation of the seed material and its properties (colourless or yellowish chrysoberyl or synthetic alexandrite) and the number of growth cycles performed to produce successive growth layers on both sides of the seed is responsible for the shape and habit of the final rough product. This indicates that strongly distorted crystals were grown from seeds with **r** and **l** orientation, but not from seeds cut parallel to the **b** pinacoid. The development of large **l** dipyramids — a face which is extremely rare in natural chrysoberyl and alexandrite — seems to be also a function of growth conditions, especially of the physical and chemical parameters of crystal growth (e.g. solvent composition, growth temperature). Colour and colour change of faceted stones are closely related to their trace element contents, to the thickness and cut of the stone, and especially to the orientation of the table facet to the crystal axes.

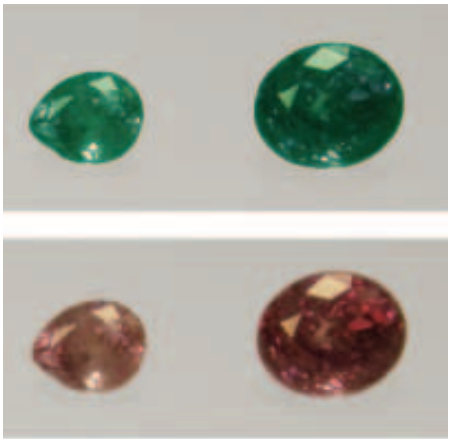

Figure 45: Faceted flux-grown Russian synthetic alexandrites in daylight (above) and incandescent light (below); weight of samples 0.43 and 1.08 ct; the oval sample on the right measures 6.3 × 5.3 mm. Photo by K. Schmetzer.

Chemical analyses (microprobe scans) clearly indicate strong variation of Cr and

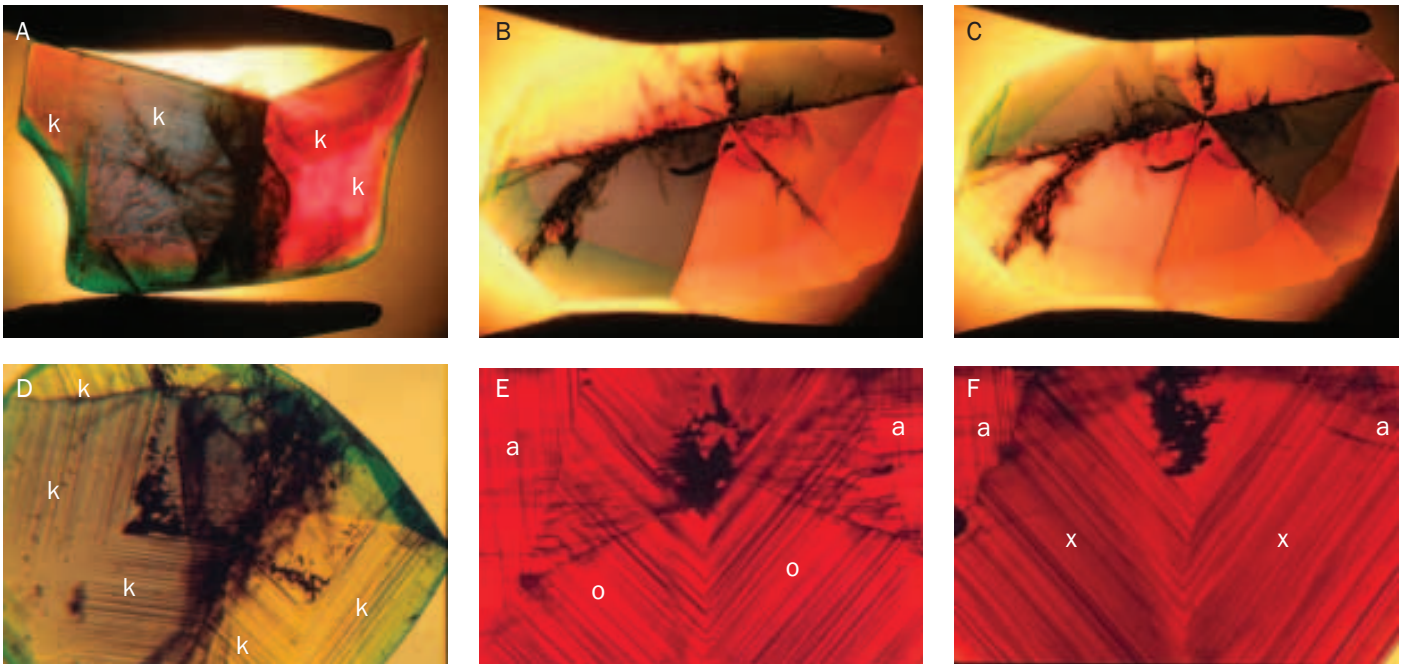

Figure 46: Microscopic features of Russian flux-grown synthetic alexandrites.
Twin (A) and trilling (B,C) in plane polarized light in views parallel to the a-axis; the pleochroism within the different parts of the samples is evident. The slightly curved lower surface of the twin (A) is the contact plane of the crystal with the crucible.

Immersion, field of view (A) 9.8 × 7.4 mm and (B,C) 10.5 × 7.9 mm.

Growth structures in faceted flux-grown Russian synthetic alexandrites (D,E,F) in different orientations; (D) growth zone [100], (E) growth zone [011], (F) growth zone [010], the faces of the different growth zones are labelled.

Immersion, field of view (D) 3.5 × 2.6 mm, (E,F) 4.5 × 3.4 mm. Photos by K. Schmetzer.

Fe contents within each growth layer. This variation is responsible for the colour zoning with an initial crystallization of intense colour followed continuously by less and less strongly-coloured alexandrite towards the outer margin of the growth layer. This production technology of multiple growth periods is also responsible for the abrupt changes of properties at the boundaries of the different growth layers, which explains both the layered growth zoning and the interference patterns visible at the growth boundaries.

In contrast, the Russian flux-grown material available on the market since the late 1980s was produced without seeds by spontaneous nucleation and crystal growth in a furnace in which the hotter nutrient at the top fed the growing crystals near the cooler base. Most crystals produced with this technique are twinned and show a slightly curved or almost plane face which is where there was contact with the bottom or wall of the crucible. Colour zoning is moderate and any layered or shell structure is absent.

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The authors are grateful to Antoinette Matlins, Woodstock, VT, U.S.A., for her assistance in contacting people and locating research material available for loan for our study.

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Further alexandrite crystals or faceted stones were kindly loaned by Stephen Avery, Lakewood, CO, U.S.A.; Cortney Balzan, Balzan Laboratories, San Francisco, CA, U.S.A.; Russell Feather, Smithsonian Institution, Washington DC, U.S.A.; Alan Hodgkinson, Portencross, Scotland, UK; Dr Michael Krzemnicki, SSEF, Swiss Gemmological Insitute, Basel, Switzerland; Dr Claudio Milisenda, Deutsche Gemmologische Gesellschaft, Idar-Oberstein, Germany; and Dr Terri Ottaway, Gemological Institue of America, Carlsbad, CA, U.S.A.

Thanks also go to Dr W. Balmer, Unterseen, Switzerland, who measured numerous rough and faceted alexandrites with his Zeiss MCS 311 colorimeter.

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Abstracts

Diamonds

The Vallerano diamond from ancient Rome: a scientific study.

A. Bedini, S. Ehrman, S. Nunziante, M. Pasini, I.A. Rapinesi and D. Sali. *Gems & Gemology,* **48**(1), 2012, 39–41.

Among the artefacts recovered from ancient Roman tombs at Vallerano during the 1990s was a gold ring set with an octahedral diamond crystal (approximately 0.15 ct). The ring can be linked to a young Syrian woman who died during the reign of Marcus Aurelius, making it the only Roman diamond jewel with a known background.

Examination of the mounted diamond's gemmological and spectroscopic properties was conducted at the National Roman Museum using portable instruments: a GIA Portalab equipped with a fibre optic light a binocular polarizing microscope; long- and shortwave UV lamps; and a Bruker Optics Alpha-R portable spectrometer. Infrared results point to a type Ia diamond with evidence of B aggregates and probable A aggregates. The diamond's internal features included a cluster of unidentified crystals. The diamond was inert to SW UV and fluoresced moderate blue to LW UV, exhibiting no phosphorescence to either.

Due to the fragile nature of the mounting, precautions were imposed for handling this historically valuable object. As a result, other observations are inconclusive and some questions remain unanswered. The ring's craftsmanship and simplicity of design, as well as the context in which it was found, provide insights into the burial practices and culture of the time period. E.A.S.

Diamonds can give moissanite results on testers.

A. Clark. *Gems & Jewellery,* **21**(1), 2012, 20.

A warning of the dangers of reliance on mechanical testing techniques by highlighting a case where a rare diamond type can fool even the most advanced combination tester. A.S.F.

Strain-induced birefringence in natural diamond: a review.

D. Howell. *Eur. J. Mineral.,* **24**, 2012, 575–85.

Birefringence in diamond is the result of strain modifying the isotropic properties of the ideal structure. The first to study this effect was Wertheim in the 1850s and between then and now there have been three major reviews of the topic by Lang (1967), Varshavsky (1968) and Orlov (1977). Howell considers five causes of strain-induced birefringence: Dislocations; Lattice parameter variations; Inclusions; Fractures; and Plastic deformation; and clearly describes the possible links between and combinations of these causes, at the same time putting them in the context of the three reviews mentioned above. Where Lang *(op. cit.)* categorized the different birefringent patterns in terms of their different causes, Orlov *(op. cit.)* differentiated the patterns themselves and Howell's study shows that Orlov's categories of 'stellate' and 'cruciform' patterns actually have the same cause. Birefringence patterns that are parallel to octahedral faces and relate to growth sequences are the result of variation in impurity contents across the layers. Birefringence in cross or star patterns is also due to impurity differences but between octahedral and cuboid sectors of mixed-habit diamonds. Laminations of birefringence that are parallel to octahedral planes but cut across growth layers are the result of slip on octahedral planes. A radial pattern of birefringence that is focused on a point indicates an inclusion. It is noted that the discussion of causes of birefringence will be applicable to synthetic diamonds grown at high pressures and temperatures but not necessarily to CVD diamonds which are grown in a different environment and can show very different birefringence patterns. The simplicity of imaging a diamond between crossed polarizers means that this technique can be a useful tool for learning about a diamond's history. R.R.H.

The magic circle.

A. Inns. *Gems & Jewellery,* **21**(1), 2012, 16–17.

A brief article attempting to explain a mysterious fluorescent circle seen in a diamond submitted to the American Gem Society (AGS) for testing. A.S.F.

Multiple core growth structure and nitrogen abundances of diamond crystals from Shandong and Liaoning kimberlite pipes, China.

T. Lu, H. Chen, Z. Qiu, J. Zhang, R. Wei, J. Ke, I. Sunagawa, R. Stern and T. Stachel. *Eur. J. Mineral.,* **24**, 2012, 651–6.

Diamond crystals from the Shandong and Liaoning kimberlites, China, display a distinct 'seed-like' multiple core growth structure with multi-stage growth history. Cathodoluminescence and DiamondView™ images revealed that the core portion of the diamonds is occupied by a 'seed-like' precipitated or smaller core which could be a resorbed early crystal formed by a cuboid growth mechanism. At the boundary between the core portion and the octahedral

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layers, the nitrogen concentration drops abruptly to ~1 ppm from a few hundreds of ppm in the core portion, suggesting a fundamental change in geochemical growth environments in the mantle. This is associated with a switch in zoning trends in $\delta^{13}C$ from outward increasing to outward decreasing values, confirming that a change in growth conditions occurred. Authors' abstract

Distribution of OK1, N3 and NU1 defects in diamond crystals of different habits.

V.A. Nadolinny, O.P. Yuryeva, M.I. Rakhmanova, V.S. Shatsky, Y.N. Palyanov, I.N. Kupriyanov, D.A. Zedgenizov and A.L. Ragozin. *Eur. J. Mineral.,* **24**, 2012, 645–50.

Diamond crystals with low nitrogen contents from placer deposits and kimberlite pipes of Yakutia have been investigated using cathodoluminescence, photoluminescence, Fourier Transform infrared, electron spin resonance and electron microprobe techniques. Mica inclusions with high silicon and titanium contents are reported and nitrogen-titanium defect centres in the diamond structure are described. N-Ti centres cause peaks at 440.3 and 485 nm in the PL spectrum. Such centres are preferably developed in octahedral rather than cuboid sectors during diamond growth. R.R.H.

Gem news from Gary Roskin.

G. Roskin. *Gems & Jewellery,* **21**(3), 2012, 5–7.

The discovery and subsequent journey of the Argyle Jubilee Pink, a rare and exciting pink diamond discovered at Australia's Argyle mine. Weighing 12.76 ct, this extraordinary diamond was destined to take ten days to facet, and to become one of the finest faceted pinks in the world, but as is reported, events, and nature, conspired against this. A.S.F.

Plastic deformation of natural diamonds by twinning: evidence from X-ray diffraction studies.

S. V. Titkov, S. V. Krivovichev and N. I. Organova. *Min. Mag.,* **76**(1), 2012, 143–9.

A fragment of a pink-purple diamond crystal from the Internatsional'naya kimberlite in the Mir field, Siberia, was studied using single-crystal X-ray diffraction techniques. Then the fragment was broken to assess any changes in results arising from smaller sample size. Initial direct indexing of the diffraction pattern suggested a primitive hexagonal unit cell but further results and theoretical considerations indicated the presence of two diffraction patterns with cubic symmetry that are superposed. This is consistent with spinel law twinning along (111). The predominance of plastic deformation by dislocation slipping over mechanical twins is discussed in the context of the pressures and temperatures at which they take place. R.R.H.

Records of mantle metasomatism in the morphology of diamonds from the Slave craton.

Z. Zhang and Y. Fedortchouk. *Eur. J. Mineral.,* **24**, 2012, 619–32.

Octahedral and tetrahedral diamonds with {111} faces representing unresorbed, kimberlite-induced and mantle-derived resorption morphologies from the Ekati mine, Northwest Territories, Canada, were examined using cathodoluminescence imaging and Fourier Transform infrared spectroscopy. CL zoning patterns helped distinguish growth and resorption patterns and a 'classification tree' for recognition of different resorption styles is described. The diamonds are type IaA and IaB with 0-98% nitrogen in B defects and total N contents between 20 and 1697 ppm. There is a distinct correlation between the characters of mantle-derived resorption and the internal properties of the diamond crystals related to their history in the mantle. R.R.H.

Gems and Minerals

Tsavorite and other grossulars from Itrafo, Madagascar.

I. Adamo, V. Diella and F. Pezzotta. *Gems & Gemology,* **48**(3), 2012, 178–87.

Itrafo, in central Madagascar, has been a source of tsavorite and other grossular varieties since 2002. Production has been limited by the mountainous, remote location combined with security concerns due to bandits in the area. The material ranges from greenish brown to brownish/yellowish green to pure green and rarely exceeds 2–3 g. Eye-clean faceted stones of green colour rarely exceed 5 ct and only a small percentage of these are saturated enough to be classified as tsavorite. These are coloured mainly by vanadium and contain more iron than tsavorite from other localities such as Tanzania, Kenya, Pakistan and Gogogogo, Madagascar.

Twenty-two grossular samples were examined, including thirteen faceted stones ranging from 0.34–3.16 ct and nine rough specimens ranging from 0.07–0.50 g. Their colours ranged from greenish brown to green, including two tsavorites. For comparison, three samples of tsavorite from Tanzania and three from Gogogogo were also examined. The typical gemmological properties of grossular garnet were seen in all samples. The outstanding feature of these garnets is their iron content, Fe_2O_3>1 wt% (other localities generally do not exceed 0.30 wt%) and a small but significant andradite component (>3 mol%). The Itrafo tsavorites also had lower vanadium content than from other localities; the Fe_2O_3:V_2O_3 ratio in the former was always greater than 1 while the ratio in the latter was less than 1. Additionally, the chromium content of the Itrafo tsavorites was lower than Tanzanian and Kenyan samples, but similar to some Pakistani specimens. E.A.S.

Rough grading system for Zambian emeralds.

A. Banks. *Gems & Jewellery,* **21**(1), 2012, 14–15.

A new emerald grading system is discussed, implemented to help buyers understand the differences between the various qualities. Cuttability, colour, size and clarity are the basic factors, but within each there are numerous subdivisions which are briefly explained in this article. A.S.F.

Never smile at a crocodile.

M. Campbell Pedersen. *Gems & Jewellery,* **21**(1), 2012, 26–7.

The use of crocodile teeth in jewellery from Australia is discussed. A.S.F.

Copal vs. amber.

M. Campbell Pedersen and B. Williams. *Gems & Jewellery,* **20**(2), 2011, 20–4.

In a two-part study, the increasing difficulty in differentiating between

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amber and copal is outlined, in light of the ever more complex treatments being undertaken. Tests range from simple observation and standard gemmological techniques, through to advanced lab testing by FTIR Raman, and crossed polarising filters. Of the treatments investigated, all can have the initial material (either amber or copal) determined by FTIR or Raman, through diagnostic peaks in the resultant spectra. A.S.F.

Cultured pearl farming and production in the Federated States of Micronesia.
L. E. Cartier, M.S. Krzemnicki and M. Ito. *Gems & Gemology,* **48**(2), 2012, 108–21.

A review is presented of the cultured pearl industry in the Federated States of Micronesia (FSM), including an evaluation of the viability of community-based farming projects and marketing opportunities for 'development pearls' and an examination of implications for FSM of recent developments in the global black cultured pearl industry. Oyster husbandry techniques and factors influencing pearl quality are discussed, along with the gemmological characteristics of the pearls.

Serious efforts to produce black cultured pearls in the FSM began about 25 years ago and utilize the *Pinctada margaritifera* oyster, cultivation of which was previously only practised in French Polynesia, the Cook Islands and Fiji. Farms on four islands in the state of Pohnpei (Pakin, Phonpei, Pingelap and Pweniou) are preparing for commercial pearl cultivation, with a total of 26,000 hatchery-reared oysters. These farms are projected to yield 6,500 cultured blister pearls and 2,000 loose bead-cultured pearls in 2012, with increasing production in the future. The cultured pearls show a range of colours; those with particularly distinct blue overtones are most prized and branded 'Micronesian Blue'. E.A.S.

Turquoise from Zhushan County, Hubei Province, China.
Q. Chen, Z. Yin, L. Qi and Y. Xiong. *Gems & Gemology,* **48**(3), 2012, 198–204.

Known since the late 1980s, turquoise deposits in Zhushan County in central China's Hubei Province are becoming a significant source of high quality material. These deposits form as lenses and fracture fillings within Cambrian-age slates and are projected to have significant potential for development. Eight rough and four polished untreated samples were studied, including their basic gemmological characteristics, as well as IR and UV-Vis-Nir spectral analysis. Most of these gemmological and spectral observations, including the presence of brownish-black veinlets/patches and irregular white blebs, were found to be similar to those noted in samples from elsewhere in Hubei Province. Chemical analysis revealed that the samples belong to the turquoise-chalcosiderite family. As it has a dense texture and uniform coloration (typically medium bluish green), the majority of Zhushan turquoise does not require treatment, though any lower-quality material usually undergoes polymer impregnation. E.A.S.

Composite malachite plates.
G. Choudhary. *Gems & Jewellery,* **20**(3), 2011, 3–5.

A report on a bonded malachite composite now being used to produce plates and decorative pieces. The composite can be detected using standard gemmological techniques, particularly the 10× lens. A.S.F.

Golden coral.
G. Choudhary. *Gems & Jewellery,* **21**(2), 2012, 12–13.

Details of a golden coral bead submitted for testing to the Gem Testing Laboratory of Jaipur, which showed evidence of both impregnation and surface polymer coating. A.S.F.

Inclusions in aquamarine from Ambatofotsikely, Madagascar.
F. Danet, M. Schoor, J.C. Boulliard, D. R. Neuville, O. Beyssac and V. Bourgoin. *Gems & Gemology,* **48**(3), 2012, 205–8.

Aquamarine with distinctive inclusions was found in the Ambatofotsikely area of central Madagascar in January 2012. Beryl from this deposit occurs as hexagonal prisms which are commonly highly fractured and of a moderate to strong greenish blue coloration. Only a very small amount of the aquamarine was suitable for faceting and several hundred stones weighing 1–35 ct have been cut. A gemmological examination was conducted of eight cut aquamarines (3047–13.59 ct) and nine rough samples (1.1–4.1 g) and Raman spectra of inclusions were collected. The inclusions consist of reddish-brown platelets of hematite along with black platelets, black needles and distinctive dark grey dendrites of ilmenite. Similar inclusions are known in beryl from Brazil, India, Mozambique and Sri Lanka, though this marks the first time dendritic ilmenite inclusions have been documented in aquamarine from Madagascar. E.A.S.

Surface features on gem crystal specimens.
A. de Goutière. *Gems & Jewellery,* **21**(1), 2012, 3–7.

Photomicrographs of various surface features on selected gem materials. highlighting the unique, and often overlooked, micro-world of rough crystals. A.S.F.

Sapphires from Thammannawa, Kataragama area, Sri Lanka.
P.G.R. Dharmaratne, H.M.R. Premasiri and D. Dillimuni. *Gems & Gemology,* **48**(2), 2012, 98–107.

The February 2012 discovery of commercial quantities of gem corundum near Kataragama in Southeastern Sri Lanka has revived gem mining activities in an area previously known only to contain hessonite garnet. The sapphires are hosted by weathered pegmatitic intrusions associated with mica layers which have yielded sharp-edged, well-formed crystals with a vitreous lustre that is unprecedented in Sri Lankan sapphires. These have transparent areas large enough to facet fine blue sapphires weighing more than 20 ct. The gemmological properties of 11 faceted sapphires and 22 crystals from the site are described. With the exception of two yellow crystals, all samples in the study were blue. Compared with other gem occurrences in Sri Lanka, this deposit seems to be unique in that only corundum has been found so far; other colours, star material and geuda sapphires have not been found. The blue crystals are a pure hue, unlike the violetish blue seen elsewhere in the country. A strong 450 nm absorption line was observed with both a prism and a diffraction spectroscope; this line is typically weak to moderate in other Sri Lankan blue sapphires. A weak red fluorescence was observed under longwave UV while they remained

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inert to shortwave UV. Characteristic internal features include short and fine rutile needles concentrated in parallel layers, liquid-filled feathers and parallel arrangements of tabular negative crystals. E.A.S.

The origin of black coloration in onyx agate from Mali.
J. Götze, L. Nasdala, U. Kempe, E. Libowitzky, A. Rericha and T. Vennemann. *Min. Mag.,* **76**(1), 2012, 115–27.

Natural sharply-banded black and white onyx agate from a location near the city of Gao, about 850 km NE of Bamaku in Mali, has been investigated using optical and electron microscopy, micro-Raman X-ray diffraction, isotope analysis and electron spin resonance techniques to determine the cause(s) of colour. The black coloration is produced by disseminated grains, a few nm across, of graphite which may show a degree of disorder. The carbon isotope value ($\delta^{13}C$) of −31.1 is consistent with formation of the graphite by heating of kerogen or hydrothermal methane. The dark bands can contain up to 1.88 wt.% C and they are closely related to primary structural banding. R.R.H.

Mythbusting mineral.
K. Gregory. *Gems & Jewellery,* **20**(2), 2011, 6–7.

The procedure on how to approach the testing of an unknown stone, without resorting to laboratory techniques is described. By standard gemmological tests, the identity of a faceted pollucite was confirmed. A.S.F.

Bonny Scotland.
K. Gregory. *Gems & Jewellery,* **21**(2), 2012, 30–9.

A report of the Annual Conference of the Scottish Gemmological Association (SGA) held at the Queen's Hotel, Perth, in May 2012. Keynote speaker Professor Henry Hänni gave two presentations, the first reviewing pearl formation and the second discussing GemExpert, a consultancy business offering advice to those wishing to invest in gemstones. Other speakers included Maggie Campbell Pedersen, Professor Godfrey Fitton, Dr Elizabeth Goring, Dr Ulrich Henn, Richard Slater and Darko Sturman. A.S.F.

Gemstones.
L. Groat. *American Scientist,* **199**(2), 2012, 128–37.

An overview of several economically important gems whose value is also measured by their importance to geologists studying conditions deep in the Earth. Genesis, gemmological and geophysical significance, new research areas, as well as outstanding questions are considered for diamond, corundum, beryl, chrysoberyl, tanzanite, tsavorite, topaz, jadeite and nephrite. High-tech gem hunting is now possible given advances in understanding geological processes, along with the advent of newer technologies and publicly accessible satellite imaging. With increased availability of gems, scientists can continue to use them in their efforts to explore such questions as the origin of diamond's carbon, the genesis of the finest ruby and sapphire found in marble deposits, the unique nature of some emerald occurrences and other mysteries associated with the inner workings of the Earth. E.A.S.

Natural pearls and cultured pearls: a basic concept and its variations.
H. Hänni. *Australian Gemmologist,* **24**(11), 2012, 258–66.

A brief overview of current thinking on pearl formation in natural occurrences, as well as in molluscs used in pearl-culturing operations (freshwater and saltwater), with an emphasis on proper terminology. Explanations are accompanied by schematic diagrams, photographs and radiographs. In an experiment to demonstrate how any suitably sized inert object can be coated by nacre, Cambrian-age trilobites were used as nucleating material in *Pinctada maxima* oysters. After nine months, several pearls were produced, all with the underlying fossil morphology present. E.A.S.

Rötlicher Grossular aus Mexiko und Hydrogrossular aus Südafrika.
U. Henn and Th. Lind. *Gemmologie. Z. Dt. Gemmol. Ges.,* **61**(1–2), 2012, 3–12. 9 photographs, 3 tables, 6 graphs, bibl. German with English abstract.

Reddish manganese-bearing grossular garnets are found in Mexico and South Africa. The Mexican material has its raspberry-red colour concentrated in an outer rim with a darker, more andradite-rich core. The cuttable zone is opaque to translucent, as is also the material from South Africa, which is hydro-grossular and has lower RI and density than pure grossular garnet. E.S.

Fossils in amber.
M. Hügi. *Gems & Jewellery,* **21**(2), 2012, 41–5.

Various insects trapped within the time capsule that is amber are illustrated and discussed. A.S.F.

Gemstones from Vietnam: an update.
L.T. Huong, T. Hager, W. Hofmeister, C. Hauzenberger, D. Schwartz, P.V. Long, U. Wehmeister, N.N. Khoi and N. T. Nhung. *Gems & Gemology,* **48**(3), 2012, 158–75.

Vietnam's geological position along the margins of two cratons gives rise to a great diversity of gem materials. The most important gem localities consist of the marble-hosted ruby, sapphire and spinel deposits in the Northern provinces of Yen Bai (Luc Yen and Yen Binh districts) and Nghe An (Quy Chau and Quy Hop Districts). Basaltic volcanism accounts for peridot, zircon and blue, green and yellow sapphires found in the Central Highlands. In addition to its relatively young gem industry (30 years), cultured saltwater and freshwater pearl farming is on the rise as small scale and privately owned operations. Vietnam is also the leading source of extremely rare and expensive natural melo pearls which are recovered by fishermen from its coastal areas.

Using samples collected at mines from 2009 to 2012, updated gemmological data is provided for ruby, sapphire, spinel, tourmaline, peridot and garnet, and new chemical information is presented for spinel, tourmaline, peridot and garnet. Comparative charts condense observations for these selected species and localities: old and new mine corundum at Luc Yen; gem corundum from other localities in Vietnam (Nghe An, Quang Nam, Central Highlands and southern provinces); spinel from Luc Yen; tourmaline from Luc Yen; peridot from the Central Highlands; garnet from Luc Yen and Kon Tum. Brief descriptions, mining histories and present production of these gems are included, as well as for other less economically

Abstracts (continued)

important varieties such as aquamarine, yellow beryl (irradiated), topaz, quartz, zircon and green orthoclase. E.A.S.

Die historische Verwendung von Olivin — die Herkunft des Peridots in Barockschmuck.

J. Hyrsl. *Gemmologie. Z. Dt. Gemmol. Ges.,* **61**(1–2), 2012, 35–42. 7 photographs, 1 table, bibl. German with English abstract.

Gem-quality peridot is formed either in secondary veins in peridotites or found in ultrabasic xenoliths in basalts. Peridots of the first type were found on Zabargad island in the Red Sea where mining was active for about 100 years between the seventeenth and eighteenth centuries. Historical pieces from Prague, Vienna and Limburg were examined. E.S.

Spectral characteristics of natural-color saltwater cultured pearls from Pinctada maxima.

S. Karampelas. *Gems & Gemology*, **48**(3), 2012, 193–7.

Twenty-one saltwater cultured pearls (SWCPs) from *Pinctada maxima* in a variety of natural colours and ranging in size from 9.1–16.8 mm were studied using UV-Vis-NIR and PL spectroscopy to better understand colour mechanisms and to separate from other SWCPs. These pearls are marketed as 'South Sea' pearls and their body colours depend on the relative intensity of up to six absorptions, which are probably determined by various combinations of several pigments. Natural-colour SWCPs from ***Pinctada margaritifera*** and *Pteria sterna* show similar absorption and PL bands, but their UV-Vis-Nir spectra also show a 405 nm band that is not seen in those from *P. maxima*. An additional band at about 700 nm is known only from *P. margaritifera* SWCPs, while *P. sterna* SWCPs display more-intense PL bands and characteristic red fluorescence to longwave UV radiation. Subtle differences help with the identification of host molluscs and to separate from artificially coloured counterparts. The exact nature of the pigments responsible for the colour of SWCPs from *P. maxima* requires further research using destructive means. E.A.S.

Radioactive morganite.

H. Kitawaki, Y. Horikawa, K. Shozugawa and N. Nogawa. *Gems & Gemology,* **48**(1), 2012, 42–4.

Since its appearance in the Japanese market in May 2010, the Central Gem Laboratory in Tokyo has identified at least 10 cases of radioactive morganite with measurable levels found to be above the recommended exposure limit set by the International Commission on Radiological Protection. These were confirmed to be the result of treatment, rather than a naturally occurring phenomenon. In the present study, the radionuclides of two radioactive faceted morganites are analyzed in order to determine whether they had been artificially irradiated by a neutron source. Both sample 1 (49.18 ct) and sample 2 (39.40 ct) were of a strongly orangey-pink colour which seems to be typical of this material. Their gemmological properties and EDXRF spectroscopy results were consistent with beryl. Gamma-ray spectroscopy detected ^{134}Cs, ^{54}Mn and ^{65}Zn in sample 1 and ^{134}Cs and ^{54}Mn in sample 2. These radionuclides are activation products, confirmation that these morganites had been neutron irradiated. ^{134}Cs has a half-life of about two years; the radioactivity of these morganites should decay to a safe level within a period of several years since being treated. While it is common to use gamma rays to deepen the hue of morganite, it is unknown why these samples were irradiated with neutrons. E.A.S.

A secondary ion mass spectrometry (SIMS) re-evaluation of B and Li isotopic compositions of Cu-bearing elbaite from three global localities.

T. Ludwig, H.R. Marschall, P.A.E. Pogge von Strandmann, B.M. Shabaga, M. Fayek and F.C. Hawthorne. *Min. Mag.,* **75**(4), 2011, 2485–94.

Elbaites containing copper from the Batalha mine, Paraíba, Brazil, the Mavuco mine, Alto Ligonha, Mozambique, and an unlocated pegmatite in Nigeria were analysed for their boron and lithium isotope contents. The results were validated using standard tourmalines and appropriate NIST reference materials, and replace erroneous ratios previously published. Plots of Li and B isotope ratios of tourmalines from the three sources are significantly different and indicate the suitability of using these isotopes in combination as a provenance tool for 'Paraíba type' tourmaline. R.R.H.

Conditions for emerald formation at Davdar, China: fluid inclusion, trace element and stable isotope studies

D. Marshall, V. Pardieu, L. Loughrey, P. Jones and G. Xue. *Min. Mag.,* **76**(1), 2012, 213–26.

Emeralds of gem quality occur in quartz veins at Davdar in China near the border with Pakistan, Afghanistan and Tajikistan. Cr, V, Fe, Mg and Na contents were determined on a typical sample, which is zoned, using electron probe microanalysis, and using ICPMS to determine Be, Li and Ce. The results overlap those from emeralds from worldwide localities but are most similar to those from Panjshir, Afghanistan. Three-phase inclusions are present in the emerald and accompanying quartz and microthermometry on them indicates that the emerald formed between 325 and 375°C at pressures up to 160 MPa (1600 bars). Oxygen isotope work supports these values and hydrogen-deuterium values combined with the oxygen isotopes are shown to be a possible means of distinguishing Davdar emerald. R.R.H.

Einige Besonderheiten der Opale aus Athiopien.

C.C. Milisenda and U. Henn. *Gemmologie. Z. Dt. Gemmol. Ges.,* **61**(1–2), 2012, 43–54. 26 photographs, 2 diagrams, bibl. German with English abstract.

The article deals with opals from the Wollo Province in Ethiopia which came on the market in 2008 and are more stable than those from the Shewa district discovered in 1993. They are mostly translucent, milky white with a vivid play-of-colour consisting of all spectral colours.

They are hydrophane, i.e. they can absorb water and become more transparent when the play-of-colour can disappear. However, this process is reversible. Because of their porosity, opals are often treated with artificial resin to stabilize them or with smoke or sugar-acid to darken their colour. Important for the understanding of the opal genesis are inclusions of well preserved plant fossils. E.S.

Abstracts (continued)

Tiger's-eye revisited.
D. Morgan. *Gems & Jewellery,* **21**(3), 2012, 8–12.

A new way of looking at tiger's-eye and the processes involved in its formation are discussed. Instead of the usually accepted ideology of it being formed by a quartz replacement process, with crocidolite being replaced with quartz and creating the chatoyant effect, a system that was first suggested by Heaney and Fisher a decade earlier is detailed, where the quartz occurrence is a result of a crack-seal vein-filling process. This article considers the cause and effect of this process, and provides supporting evidence for this alternative theory. A.S.F.

The sapphires of Australia.
J. Ogden. *Gems & Jewellery,* **21**(2), 2012, 14–18.

A report of the author's visit to the sapphire mines located in the New South Wales and Queensland areas of Australia. These deposits yield a wide range of colours and clarities of crystal, with each locality seeming to offer different combinations and proliferations. The various scales of production in Australia require different levels of mechanization in sapphire mining, which is still relatively low-tech by modern standards. The author reviews his visits to various areas and the stones that have been found, and relates tales told by the miners. A.S.F.

Bicoloured quartz with unusual colour combination.
F. Payette. *Australian Gemmologist*, **24**(11), 2012, 272.

A 28.83 ct faceted gem measuring 21.08 × 17.41 × 10.50 mm was submitted for gemmological examination in late 2011 and revealed to be synthetic quartz. The most significant visual observation under magnification was that of chevron growth similar to that seen in hydrothermally grown synthetic beryl and synthetic amethyst. This is believed to be the first documented example of bicoloured blue/green synthetic quartz. E.A.S.

Essential features of the polytypic charoite-96 structure compared to charoite-90.
I.V. Rozhdestvenskaya, E. Mugnaioli, M. Czank, W. Depmeier, U. Kolb and S. Merlino. *Min. Mag.,* **75**(6), 2011, 2833–46.

After more than 50 years of attempts to determine the structure of charoite from the Murun massif, Yakutia, Sakha Republic, Siberia, Russia, scanning-transmission electron microscopy and electron diffraction techniques have yielded data to conclude that charoite occurs as four different polytypes which are commonly intergrown in nanocrystalline fibres. Automated diffraction tomography is described in the investigation of the charoite order-disorder family. Charoite-90 and charoite-96 are the two maximum-degree-of-order polytypes. R.R.H.

Oriented inclusions in alexandrite from the Lake Manyara deposit, Tanzania.
K. Schmetzer and H.J. Bernhardt. *Australian Gemmologist*, **24**(11), 2012, 267–71.

Under reflected light, regions of milky white are often observed in alexandrites from the Lake Manyara deposit in northern Tanzania. These are caused by two different types of oriented inclusions which are too small to be resolved using a gemmological microscope: needles or hollow channels oriented parallel to the crystallographic a-axis and inclusions on planes perpendicular to the a-axis. Photomicrographs of thin sections reveal the inclusions and their orientations; these are further interpreted in accompanying crystal drawings. E.A.S.

Treated ruby.
K Schmetzer, M. Krzemnicki and A. Hodgkinson. *Gems & Jewellery,* **21**(3), 2012, 14–17.

A new treatment for gem-quality corundum is reported. By using a proprietary treatment involving the use of lithium-based fluxes and heat, Ted Themelis treats rubies to improve their colour. This article focuses on a purplish-red ruby that was purchased by Alan Hodgkinson and subsequently underwent treatment by this process, showing the different stages that the stone experienced during it's transformation. A.S.F.

Natural alexandrite with an irregular growth pattern: a case study.
K. Schmetzer and A.-K. Malsy. *Journ. Gemmol. Assoc. of Hong Kong,* **32**, 2011, 1–10.

A 1.10 ct alexandrite with an unusual growth pattern of plane parallel growth faces and curved grain boundaries is compared with growth features typical of synthetic alexandrites grown by Seiko in Japan. Although there are similarities, evidence of the presence of OH groups from the infrared spectrum and contents of iron and vanadium that are higher than in Seiko stones indicate the stone under test to be natural, and possibly comparable with Madagascan alexandrites. R.R.H.

Ein Beitrag zum Thema Bernstein – Unterscheidung von Bernstein und Kopal sowie Erkennung von behandeltem grünen Bernstein.
K.Schollenbruch. *Gemmologie. Z. Dt. Gemmol. Ges.,* **61**(1–2), 2012, 13-34. 20 photographs, 1 table, 5 diagrams, bibl. German with English abstract.

A contribution to the topic amber — differentiation between amber and copal as well as determination of treated green amber.

The author gives a short history of amber and a table summarizing the different classical techniques of distinguishing between amber and copal, most of which are not very reliable and some are destructive, such as scratching, burning and dissolving. The best test seems to be by Fourier Transform infrared spectroscopy (FTIR). Green amber was introduced to the market a few years ago and can be produced from amber as well as copal. The classical differentiation tests fail to reveal the source of any particular sample as green amber is an artificially matured resin. Only laboratory methods like the FTIR can help. E.S.

Granitic pegmatites as sources of colored gemstones.
W.B. Simmons, F. Pezzotta, J.E. Shigley and H. Berulen. *Elements,* **8**(4), 2012, 281–87.

Pegmatites are important sources of gemstones ranging from the rare and economically important species such as beryls and tourmaline to those which are abundant and less valuable such as quartz. Less-familiar 'collector' gems are produced as well, such as jeremejevite, brazilianite, danburite, petalite, euclase, pezzottaite and phenakite. Along with

Abstracts (continued)

the historic localities found in Brazil, Madagascar, Russia and the United States, important gem-bearing pegmatites have more recently been discovered in Congo, Mozambique, Namibia, Nigeria, Tanzania, Zambia, Afghanistan and Pakistan. These and other major gem-pegmatite localities are illustrated on a world geological map and summarized with their notable gem minerals in an accompanying table.

Gem-quality crystals are found in three settings: as crystals 'frozen' in massive quartz or feldspar in the core or core margin of a pegmatite (examples: beryl, variety aquamarine and tourmaline); as crystals in reaction zones surrounding pegmatites that intrude mafic rocks (examples: beryl, variety emerald, and chrysoberyl, variety alexandrite); as crystals in miarolitic cavities known as pockets (examples: beryl varieties aquamarine, heliodor and morganite; spessartine; spodumene, varieties kunzite and hiddenite; topaz; tourmaline, varieties indicolite, rubellite, verdelite, liddicoatite). Miarolitic cavities in some pegmatites have produced tons of gem crystals valued in excess of $50 million. Such spectacular occurrences are extremely rare and include: the Dunton pegmatite in Maine, USA; the Jonas pegmatite in Brazil; Antananarivo and Fianarantsoa regions in Madagascar; Volodark-Volynsky in the Ukraine; the Himalaya mine in California, USA; the Mount Mica pegmatite in Maine, USA.

An overview is given of the origin of gem-forming melts and subsequent formation of miarolitic cavities and gem-quality crystals. The three principal mechanisms discussed are (1) decompression in the ascending magma, or 'pressure quench', (2) fractional crystallization during isobaric solidification and (3) depletion of fluxing components by crystallization of minerals containing these elements, or 'chemical quench'. A model for pocket formation is described, concluding that while crystals growing from the margins of the pocket develop gemmy terminations, those growing entirely inside the pocket can be nearly flawless throughout. During final stages of pegmatite formation, damage to the crystals may result from pocket rupture, while changes in the growth environment may cause severe corrosion and alteration, making occurrences of gem-quality crystals extremely rare. E.A.S.

Emeralds from the Fazenda Bonfim region, Rio Grade do Norte, Brazil.

J.C. Zwaan, D.E. Jacob, T. Häger, M.T.O Cavalcanti and J. Kanis. *Gems & Gemology,* **48**(1), 2012, 2–17.

Since the 2006 discovery of the emerald deposit in the Fazenda Bonfim region of northeastern Brazil, exploration activities have produced a small amount of material from shallow pits and tunnels. These emeralds occur in association with small recrystallized pegmatite bodies and biotite schist. Though included crystals measuring several centimetres have been found, generally recovered transparent fragments and crystals average in size from 2–5 mm, yielding gems with a saturated bluish-green colour and a medium-light to medium tone.

Internal features consist of: partially-healed fissures with two-phase fluid inclusions (typically square, rectangular, or comma-like); hexagonally-shaped negative crystals forming CO_2-rich two-phase inclusions; partially decrepitated inclusions; parallel growth tubes; extremely fine unidentified fibre-like inclusions; homogeneous colour distribution and occasional moderate colour zoning parallel to the prism faces. Though uncommon, the following solid inclusions were observed: sodic plagioclase, platelets of phlogopite, thin flakes of hematite and clusters of minute grains of quartz. The emeralds' chemical composition is characterized by relatively high K; moderate Cr (the major chromophore), Fe and Mg; and low Na, V and Li. FTIR spectra show characteristics of alkalis, CO_2, and deuterated water.

The emeralds can be distinguished from those of other schist- and pegmatite-related commercial deposits based on these physical and chemical properties. Their higher Cs and lower Na contents separates them from the most closely matched emeralds of the Itabira District of Brazil. E.A.S.

Instruments and Techniques

Precision measurement of inter-facet angles on faceted gems using a goniometer.

A.H. Shen, W.A. Bassett, E.A. Skalwold, N.J. Fan and Y. Tao. *Gems & Gemology,* **48**(1), 2012, 32–8.

In this study, the authors examine the feasibility of using a well-established optical instrument to measure the angles of faceted diamonds to a very high precision, without relying on image analysis and computer algorithms. A Stoe & Rheinheimer two-circle reflecting goniometer (*circa* 1920) was used to measure inter-facet angles on five faceted diamonds that included round brilliants and fancy shapes. Historically, before the advent of X-ray diffraction techniques, this type of instrument was used by crystallographers to identify minerals by precision measurement of angles between crystal faces. This particular model was designed to handle large specimens; initially, to examine the newly discovered crystals of pink spodumene known as kunzite. Nearly 100 years later, this design innovation is what allowed the current investigators the space needed to accommodate their measurements of faceted gems.

Currently, non-contact optical scanners are important components for grading diamonds in gem laboratories. Such scanners are claimed to have a precision of ~0.1 degrees for facet angle measurements, compared to a precision of 0.034 degrees for the goniometer used in this study. Although time-consuming, goniometer measurements of facet angles are useful for highly precise applications such as producing reference stones, or 'master sets', or for independently calibrating optical scanners. Much like master sets used for colour-grading diamonds, these can be considered calibration standards for angle measurement. Another possible use of the goniometer is in the evaluation of facet quality, which was found to be evident during the measuring process. E.A.S.

Transmission X-ray diffraction as a new tool for diamond fluid inclusion studies.

E.M. Smith, M.G. Kopylova, L. Dubrovinsky, O. Navon, J. Ryder and E.L. Tomlinson. *Min. Mag.,* **75**(5), 2011, 2657–75.

Transmission X-ray diffraction using a high-brilliance diffractometer and a synchrotron were used to investigate fluid inclusions in fibrous diamonds from Mbuji-Mayi, Democratic Republic

Abstracts (continued)

of Congo; Wawa, Ontario, Canada; Panda kimberlite Ekati, NWT, Canada; and Jericho kimberlite, Nunavut, NWT, Canada. Daughter minerals identified include celadonite, dolomite and other carbonates, and sylvite and halite, the first positive identification of halite minerals in fibrous diamond. Further work is needed to understand detection limits of the method but it has potential as a useful complement to microprobe and infrared techniques. The authors comment that as fibrous diamond has a common nucleus and crystallographic orientation (i.e. it is not polycrystalline), the term 'monocrystalline diamond' should not be used to describe gem-quality diamond if one wishes to distinguish it from fibrous diamond. R.R.H.

Synthetics and Simulants

Recent advances in CVD synthetic diamond quality.
S. Eaton-Magaña and U.F.S. D'Haenens-Johansson. *Gems & Gemology,* **48**(2), 2012, 124–7.

The quality of synthetic diamonds produced by chemical vapour deposition (CVD) is currently very high due to improvements in gas-phase chemistry and growth parameters, the greater availability of high-purity HPHT synthetic diamond as a starting material, and the effective application of post-growth treatments. An overview of these developments is presented after a brief historical review of the CVD process. Spectroscopic measurements indicate that the purity of CVD synthetic diamonds is now comparable to or even higher than typical type IIa natural diamonds. It is predicted that CVD diamond sizes will continue to increase and the available colours will expand beyond colourless, pink and brown to include type IIb blue specimens doped with boron. E.A.S.

Aquamarine-coloured glass.
G. Millington. *Gems & Jewellery,* **21**(1), 2012, 32–4.

Details of a rough crystal submitted for testing as aquamarine which was identified as a form of devitrified glass. A.S.F.

Some days are stone.
G. Millington. *Gems & Jewellery,* **21**(3), 2012, 18–21.

A report on the necessity of microscopic examination of gemstones. Tell-tale inclusions in a selection of synthetic and imitation stones sent for testing were revealed under the microscope which had not been visible with 10x magnification. A.S.F.

Spherical cultured pearls: the early days.
J. Ogden. *Gems & Jewellery,* **21**(1), 2012, 28–30.

The author looks back at the history of cultured pearls, focusing on the spherical forms from their early development. through to 1921, highlighting the effect their introduction had on the market, and the early attempts to differentiate them. The different reactions of various markets are discussed and how pricing changed. . A.S.F.

Faith in opals.
J. Ogden. *Gems & Jewellery,* **21**(3), 2012, 41.

The author visits Len Cram who carries out opal research in a shed at Australia's Lightning Ridge. He has devised a process to produce opal which he claims proves that it can be former faster than originally thought. A.S.F.

Synthetic star alexandrite.
K Schmetzer and A. Hodgkinson. *Gems & Jewellery,* **20**(3), 2011, 9–11.

A review of two synthetic alexandrite cabochons, both of which show asterism to varying degrees. The history of the production of synthetic alexandrite (Kyocera and Sumitomi) is covered briefly, before the determination of the crystallographic orientation of the inclusions responsible for the asterism is explained in depth with the accompaniment of diagrams. Comparison of this orientation with that of natural star alexandrite reveals differences that may aid identification of the production origin of any stone. A.S.F.

Characterization of colorless coated cubic zirconia (Diamantine).
J.E. Shigley, A. Gilbertson and S. Eaton-Magaña. *Gems & Gemology,* **48**(1), 2012, 18–30.

One type of coated cubic zirconia (CZ) marketed as 'Diamantine' by California-based Serenity Technologies was analyzed to determine the nature of the coating, including its durability. No differences were found between the gemmological properties of Diamantine and those of uncoated CZ. Both are easily distinguished from diamond on the basis of thermal conductivity, weight-to-diameter ratio and specific gravity.

Reported to be composed of nanocrystalline diamond, the 30–50 nm coating cannot be detected with a standard gemmological microscope or seen in polarized transmitted light at 1000× magnification. The only standard gemmological laboratory technique that could establish the presence of a coating was EDXRF spectroscopy, which detected Ti from the adhesion layer deposited on the CZ during the initial part of the coating process. While SEM imaging detected a coating consisting of nanocrystalline particles that may be diamond, it is unlikely that standard analytical methods and instruments used in advanced gemmological laboratories would be able to confirm their actual identity (due to the thinness of the layer, Raman spectroscopy could not detect whether diamond was present as indicated by a peak at 1332 cm^{-1}).

The value of the coating was questioned when testing results concluded that the coating does not add to the long-time durability of the CZ and that it appears not to be stable to normal wear and simple cleaning (such as with a polishing cloth, with or without alcohol).

Serenity is reportedly planning to release a new version of Diamantine, along with a testing device that can detect the coating. Questions remain regarding the responsibility at various levels of the gem industry for disclosure of different types of coatings on gems. As increased numbers of gems are treated with sophisticated coatings, techniques used at gemmological laboratories may have to be refined in order to detect them. These include SEM imaging, Nomarski differential interference contrast microscopy and ellipsometry techniques. E.A.S.

Abstracts (continued)

Nano-polycrystalline diamond sphere: a gemologist's perspective.
E.A. Skalwold. *Gems & Gemology,* **48**(2), 2012, 128–31.

A completely transparent 5.09 mm sphere fashioned from a relatively new type of synthetic diamond is described in regards to its unique characteristics and the technological process which created it. Nano-polycrystalline diamond (NPD) is compared to single crystal and polycrystalline varieties of both natural and synthetic diamond. NPD is composed of a tightly bonded mixture of 10–20 nm equigranular crystallites and 30–100 nm lamellar crystalline structures formed during a sintering process which converts high-purity graphite directly into synthetic diamond. NPD is harder and tougher than either natural or synthetic diamond and as a result, requires lasers to fashion. It resists breakage and has no particular cleavage direction; this in addition to its high transparency makes it extremely valuable to industry and research applications, as well as making it an interesting potential new gem material.

Author's abstract

Characterization of a synthetic nano-polycrystalline diamond gemstone.
E.A. Skalwold, N. Renfro, J.E. Shigley and C.M. Breeding. *Gems & Gemology,* **48**(3), 2012, 188–92.

A potential new synthetic gem material in the form of a faceted 0.88 ct brownish-yellow nano-polycrystalline diamond (NPD) has undergone a full gemmological examination for the first time. In addition to a chart summarizing its basic gemmological properties, photomicrographs illustrate its internal scene and its tatami-like strain pattern. A Presidium diamond tester registered positive for diamond, while a DTC DiamondSure™ screening device referred the sample for further testing. Deep-ultraviolet (~230 nm excitation) fluorescence imaging using the DTC DiamondView™ revealed an unevenly distributed, web-like orangey-red luminescence. Detailed spectroscopic analysis showed absorption spectra which were distinct from those of natural diamond.

The key identifying features include a hazy, roiled appearance (similar to that seen in hessonite garnet) and distinctive mid-IR, visible-range, and photoluminescence spectra. The authors stress that this sample, which was fashioned from early production, is only one example from a rapidly improving technology. Visual observations do not necessarily apply to all NPD specimens, particularly newer production, and therefore the advanced instrumentation of a gemmological laboratory is needed to confirm its identity. While NPD has been developed primarily for high-tech applications that require superior hardness and toughness, this faceted NPD sample illustrates its potential as a gemstone.

E.A.S.

CVD synthetic diamonds from Gemesis Corp.
W. Wang, U.F.S. D'Haenens-Johansson, P. Johnson, K.S. Moe, E. Emerson, M.E. Newton and T.M. Moses. *Gems & Gemology,* **48**(2), 2012, 80–97.

The gemmological characteristics and spectroscopic features are examined in Gemesis Corp's latest generation of chemical vapour deposition (CVD) single crystal diamonds. The 16 specimens in this study ranged in size from 0.24–0.90 ct and all but the largest were cut as round brilliants. Three were graded as colourless (F colour) and 12 as near-colourless and one was faintly coloured (L colour). Four diamonds received VS clarity grades while 12 had clarity grades between IF and VVS, marking the first time GIA has given an IF grade to a CVD synthetic diamond. Unlike other CVD diamonds, no dislocation-related graining was observed in these samples. Irregular, linear or sometimes 'tatami' birefringence patterns were observed between crossed polarizers, but were relatively weak in comparison with those observed in previously studied CVD samples.

Unlike the orange-red fluorescence commonly associated with CVD diamonds, these samples displayed weak green fluorescence under shortwave UV and six samples had this same reaction to longwave UV (the remainder were inert). The high-intensity ultra-short UV wavelength of the DTC DiamondView™ (225 nm radiation) revealed green or blue fluorescence along with growth striations having a green fluorescence of varying intensities. Evenly distributed blue phosphorescence was also observed in the DiamondView™, stronger in the blue fluorescing samples than in those which had fluoresced green. The samples displayed relatively featureless absorption spectra in the infrared region, unlike those reported for CVD synthetics from other sources.

Separating these new CVD synthetic diamonds from natural diamonds is becoming increasingly difficult using conventional gemmological procedures, and may not be possible without advanced instrumentation. PL spectroscopy at low temperature and UV fluorescence imaging are critical in distinguishing these synthetics from type IIa counterparts, such as natural, natural but HPHT treated, and from HPHT-grown synthetics. While post-growth treatment improves colour and possibly clarity, it appears that the striated growth pattern observed in the DiamondView™ is not affected by it and so remains the most important, if not the only visual identification feature.

E.A.S.

Abstractors

A.S. Fellows – A.S.F. R.R. Harding – R.R.H. E.A. Skalwold – E.A.S. E. Stern – E.S.

Book reviews

Amethyst — Uncommon Vintage. H.A. Gilg, S. Liebetrau, G.A. Staebler and T. Wilson (Eds), 2012. Lithographie Ltd., Denver, 128 pages. ISBN 978-0-9836323-2-0. (US$40)

No. 16 in Lithographie's monograph series is so visually luscious one's mouth actually begins to water as page-after-page of exquisite purple-hued imagery greets the eye. This long anticipated volume brings together a diverse group of authors and photographers whose passion for this most highly-prized variety of quartz is self-evident in each of their contributions. Most appropriately, the volume opens and closes with the conjoined pens of the royal sovereigns of quartz, Si and Ann Frazier, as they offer first a historical overview and then a comprehensive glossary of terms related to amethyst. What comes in between leaves few mysteries untouched. Mineral collectors and gem enthusiasts of all levels will appreciate not only the aesthetic presentation, but also the level of detail contained in this volume, one which will surely become a standard reference on amethyst for years to come.

For our gemmological community, *Amethyst — Uncommon Vintage* offers an unparalleled resource for this classic gem. Jewellers, gemmologists, appraisers, coloured stone dealers, lapidaries, researchers and students will find that this volume provides a firm background for any pursuits related to amethyst and even quartz in general. While the overall visual presentation (dominated as it is by examples of amethyst in all its diverse natural forms) may seem to favour the collector of cabinet specimens rather than the lapidary arts, aficionados of the latter will not be disappointed. From Gerd Dreher's amethystine mouse — seemingly ready to bolt off the page with a swish of its golden tail — to a second-century intaglio featuring the binding of Herakles by Eros, the editors' carefully chosen photos of faceted stones, carvings and historic metal arts integrate with those of intact specimens, localities and other contextual scenes in an artful fashion that is both educational and compelling.

In addition to the Frazier's chapters, readers are treated to a concise lesson on the geological origins of amethyst by Dr H. Albert Gilg, followed by an overview by author Daniel Kile of its mineralogy, crystallography and optical properties, including that of ametrine. These two chapters very successfully convey relatively complex topics in a readable, easily understood, and most of all, enjoyable fashion — qualities which permeate the entire publication. They set the groundwork for the remaining chapters which focus on specific localities and types (see chapter listing below). Thereafter, the reader journeys around the world via authoritative text and visually stunning portraits as authors delve deeper into unique occurrences, morphologies, histories and personal stories surrounding amethyst. In closing, an extensive 'Literature and Cited Works' listing provides readers with added references to seek out on their own, while further validating its own place in one's gemmological library.

Arguably, the most valuable aspect of this tome for the gem community is the appreciation it brings for the natural crystal, perhaps for the first time. Comprehending amethyst's complexities broadens our understanding of it as a fashioned gem, a valuable asset whether faced with an unknown, educating a client or contemplating a bit of rough to buy or to facet. With its fine quality colour-rendition and printing, one would be hard-pressed to find any fault with this publication which packs so much information into just 128 pages.

Amethyst — Uncommon Vintage is destined to become a collector's item, just as have now hard-to-find previous titles such as *Tourmaline, Emerald, and Gold*. With that in mind and at its very reasonable price, one might even consider purchasing two copies, preserving one as pristine as the day it came off the press while the other not only provides personal enjoyment, but also may be shared with colleagues, clients and students.

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E.A.Skalwold

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Book reviews (continued)

Characterization of Diamonds Color-enhanced by Suncrest Diamonds USA. D. Simic and A. M. Zaitsev, 2012. Analytical Gemology and Jewelry Ltd, New York City, NY, U.S.A. 24 pp

In this booklet the authors describe studies they have carried out on 15 natural brown diamonds before and after they have been colour-enhanced by high-pressure, high-temperature (HPHT) treatment and, for diamonds with a final pink colour, subsequent irradiation and annealing. As a scientific investigation the work confirms results obtained by other researchers and adds some interesting new findings; however, for the purposes of differentiating naturally-coloured diamonds from diamonds with a treated colour the procedures described have some shortcomings, as described below.

The text is reasonably well written, and the authors have explained most of the technical terms in yellow-highlighted boxes. There are some typographical errors and the English is rather strange in places, although the meaning is usually clear. However, there are a couple of serious mistakes. On page 2, when discussing the 'Imperial Red' treated colour it is stated that "The NV^- and NV^0 colour centers strongly absorb light in the red spectral range and cause red coloration of diamond." It is because these centres do not absorb red light (wavelengths longer than 640 nm) that the diamonds appear red! In the box on page 6 the authors say that "Photoluminescence comprises light with wavelength shorter than that of the light used for illumination." In reality the photoluminescence occurs at longer wavelengths than the wavelength used for excitation (as is clear in the examples that the authors give).

Simic and Zaitsev point out that the HPHT treatment of diamonds is a fast growing business, and that there is a growing trade in undisclosed colour-enhanced diamonds. The company with whom they have collaborated (Suncrest Diamonds of Utah, U.S.A.) fully discloses the origin of colour of the processed diamonds, but the authors believe that the treated nature of these diamonds frequently remains undisclosed when they are being resold. The motivation for the present study was to develop new approaches for the identification of diamonds that have been colour-enhanced.

The study investigated 5 type IIa diamonds that became colourless after the HPHT treatment, 5 type IaA diamonds that became yellow and 5 type IaB diamonds that were processed at HPHT, then irradiated with high-energy electrons and annealed (probably at approximately 800°C) to produce pink diamonds. Fluorescence images of the 'yellow' and 'pink' diamonds were obtained before and after the treatments, using longwave ultraviolet excitation. The fluorescence intensities of the 'colourless' diamonds were very weak before and after treatment and images could not be obtained. The authors also used a homemade 'express spectrometer' which measures a low-resolution photoluminescence (PL) spectrum from a diamond at room temperature. They found that before treatment the maximum luminescence intensity was at approximately 510 to 520 nm, and that, after treatment the maximum moved to the range 440 to 490 nm.

The authors also used high-resolution photoluminescence studies with the diamonds cooled to liquid nitrogen temperature, with three different wavelengths for excitation (488, 514 and 532 nm). In addition they recorded some high resolution infrared spectra. For reasons that are not obvious they do not appear to have measured any absorption spectra in the ultraviolet, visible and near-infrared regions.

For diamonds that have experienced HPHT annealing only, the authors find that some infrared absorption features and some photoluminescence lines, that were present before the HPHT processing, were destroyed by that treatment. For the spectral features documented one can therefore conclude that if a diamond has any of these features then it has probably not been colour-enhanced. Similar conclusions have been reached in earlier studies.

The discussion about the presence of H4 photoluminescence in the treated pink diamonds is somewhat misleading. The authors report that "The H4 center is usually considered as an indication of untreated natural diamonds." However, this is not what is stated in the references they cite. That previous research showed that the H4 centre is destroyed by HPHT treatment, and so it is true that H4 centres will be absent in a diamond that has been subjected only to HPHT treatment. The converse is not true; it is well known that H4 absorption and luminescence can be produced by irradiation and annealing (at c. 800 °C) in a type IaB diamond. If that is the only treatment employed the end result can be a treated yellow diamond. If the diamond has first been subjected to HPHT treatment, as described by Simic and Zaitsev, the end result can be a treated pink diamond, but, of course, H4 centres will also be produced.

My major worry with this article arises from the claims that the authors make in the summary: "… fluorescence imaging may be useful as a quick and inexpensive test of pink and yellow diamonds. …we have demonstrated a photoluminescence 'express- spectrometer' which is capable of fast recording of PL spectra of any diamond including even nominally non-fluorescent type IIa diamonds. … Using this spectrometer we have confirmed that the position of PL maximum, under excitation in the near UV range, is a useful parameter for identification of HPHT treatment."

There are two problems in making far-ranging conclusions from this sort of investigation. The first is that — as with most 'before and after' studies — it is very time-consuming to make measurements on a large number of diamonds. Thus, while it is straightforward to see changes that have occurred for the few diamonds examined in detail, it is much more difficult deciding which diamond in a parcel of 1000 diamonds is the one that has been colour-enhanced. The second problem, which is certainly relevant in this study, is that the authors have not used any 'control samples'. They only examined brown diamonds that became colourless, yellow or pink after treatment; ideally they should have also examined colourless, yellow and pink diamonds that were known to have a natural colour. More than 30 years ago I was fortunate to have the opportunity to examine large batches of diamonds straight from the DTC sorting tables in London. Under a longwave ultraviolet lamp diamonds colour-graded as brown displayed a whole range of luminescence colours — blue, green, yellow, pink — whereas blue was the dominant luminescence colour for diamonds colour-graded as colourless. (For many diamonds from all batches the

Book reviews (continued)

luminescence was weak, or invisible by eye, for reasons that are well understood.) On the basis of those observations I believe it would be very risky to decide the colour origin of a diamond using only the 'express spectrometer' described in this article. The fluorescence imaging technique is also unhelpful when examining an unknown diamond because, if it had indeed been treated, there is no record of the luminescence image before the treatment was carried out.

Suncrest diamonds are producing a large number of pink diamonds using the three-stage process of HPHT treatment, irradiation with high-energy electrons and annealing at typically 800°C. This process produces nitrogen-vacancy centres which are responsible for the pink colour. An absorption spectrum in the UV, visible and near-infrared regions will clearly show the presence of the negative (NV^-) centre, together with many other absorption lines known to be produced by irradiation and annealing (see, for example, the article by W. Wang *et al.* (2005), *Gems & Gemology,* **41**(6–19). Simic and Zaitsev have not used absorption spectroscopy in this wavelength range, and their express spectrometer does not always yield unambiguous results for the pink specimens. As seen in their figure 10, for diamonds with a low nitrogen concentration, photoluminescence from the neutral NV^0 centre certainly provides clear evidence that the diamond is a treated pink, but for high-nitrogen diamonds it is difficult to see obvious PL from either the NV^- or NV^0 centres with their apparatus.

The major gem-testing laboratories believe that they can detect most colour-enhanced diamonds, but to do so (particularly with colourless and yellow diamonds) may require a whole gamut of spectroscopic measurements — absorption spectroscopy in the ultraviolet, visible and infrared spectral regions and high-resolution photoluminescence spectroscopy with the diamond cooled to liquid-nitrogen temperature, using a range of laser wavelengths for excitation. One can understand the authors' desire to develop quicker and cheaper methods for assessing coloured diamonds, but I am not confident that luminescence imaging and the express spectrometer will be sufficiently reliable on their own to determine whether an unknown diamond is naturally or artificially coloured. Nevertheless, anyone concerned with the detection of colour-enhanced diamonds will find this article an interesting read.

A.T. Collins

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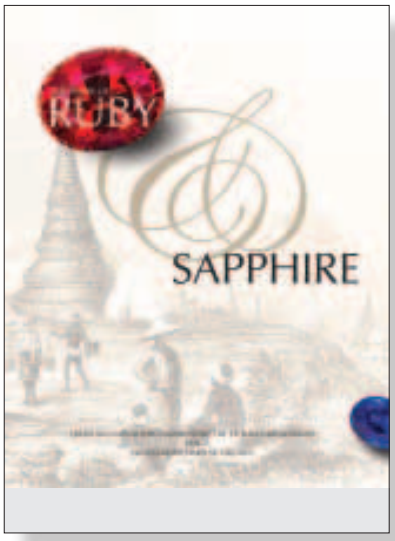

The Book of Ruby and Sapphire
by Col. J. Halford-Watkins (edited by Richard W. Hughes), copies signed by Richard W. Hughes.
Price £85.00

"... a marvellous record, providing information not available elsewhere."
Gems & Jewellery, Winter 2012, **21**(4)

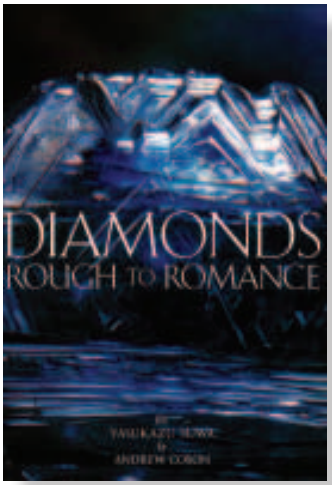

Diamonds: From Rough to Romance
by Yasukazu Suwa and Andrew Coxon.
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Gem-A
THE GEMMOLOGICAL ASSOCIATION OF GREAT BRITAIN

Proceedings of the Gemmological Association of Great Britain and Notices

Gem-A Conference 2012

The 2012 Gem-A Conference was held on Sunday 4 November at the Hotel Russell, Bloomsbury. Speakers included Dr Lore Kiefert, Thomas Hainschwang, Richard Hughes, Ron Ringsrud, Jerry Sisk, Joanna Whalley, Bear Williams and Dr Hanco Zwaan.

The day concluded with a dinner/dance held at The Russell.

Conference Events

A programme of events and workshops was arranged to coincide with the Conference. These started on Saturday 3 November with two half-day seminars held by Richard Drucker entitled 'Colour assessment of gemstones'.

On Monday 5 November two half-day seminars were held — 'Is it real? Identifying amber' with Maggie Campbell Pedersen and 'All things bright and beautiful: a history of gems and gem setting' with Dr Jack Ogden. The Graduation Ceremony and Presentation of Awards was held in the evening at Goldsmiths' Hall (see report opposite).

On Tuesday 6 November Alan Hart led a tour of the Mineral Gallery at the Natural History Museum, South Kensington, including the opportunity to view the Museum's new acquisitions. This was followed in the afternoon by a guided tour of the Crown Jewels at the Tower of London with David Thomas. The final event was Gem Central hosted by Amanda Good, at which attendees had the opportunity to test their gem dealing skills.

A full report of the Conference and events was published in the Winter 2012 issue of *Gems & Jewellery*.

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Gem-A Graduation Ceremony and Presentation of Awards

On Monday 5 November 2012 the Graduation Ceremony and Presentation of Awards was held at Goldsmiths' Hall in the City of London. James Riley, Gem-A CEO, welcomed those present which included graduates from Canada, China, France, The Netherlands, New Zealand, Sweden and the U.S.A., as well as those from the U.K.

Gem-A President Harry Levy then introduced the guest speaker, the President of CIBJO Dr Gaetano Cavalieri, who presented the awards and gave the address.

Following the presentations to the graduates, four members were awarded Fellowship status in recognition of their high level of expertise and who had made a significant contribution to the field of gemmology for no less than ten years were presented with their Fellowship diplomas by Cally Oldershaw, Chairman of the Gem-A Board. They were Richard Drucker of Glenview, Illinois, U.S.A., Antoinette Matlins of Woodstock, Vermont, U.S.A., James Riley of Knutsford, Cheshire, and Bear Williams of Jefferson City, Missouri, U.S.A.

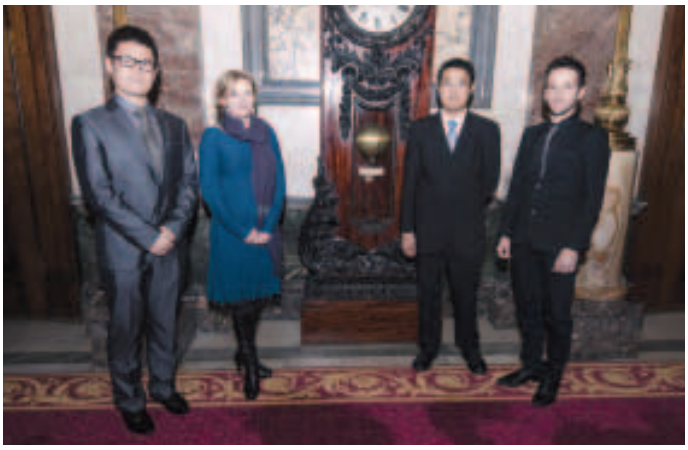

The prize winners (from left): Jiangli Tao, Beijing, China (Anderson-Bank Prize), Rona Bierrum, London (the Bruton Medal and the Deeks' Diamond Prize), Timothy Sheung Yin Li, Bradford, West Yorkshire (the Diamond Practical Prize) and Jonathan Tremblay, Bourth, France (the Christie's Prize for Gemmology).

Above: Dr Gaetano Cavalieri giving his address.
Below: Graduates gather on the magnificent staircase at Goldsmiths' Hall.

It had also been agreed to grant Honorary Life Membership to three individuals who had worked tirelessly for the Association for many years. These were presented to Dr Tony Allnutt of Chislehurst, Kent, Peter Dwyer-Hickey of South Croydon, Surrey, and Dr Roger Harding of Devizes, Wiltshire. A new Vice President elected at the AGM held in July 2012, Professor Alan Collins, was presented with a certificate.

Dr Gaetano Cavalieri gave the address, congratulating the graduates on their great achievement.

The ceremony was followed by a reception for graduates and guests.

A report of the event was published in *Gems & Jewellery,* Winter 2012, **21**(4).

All photos courtesy of Photoshot.

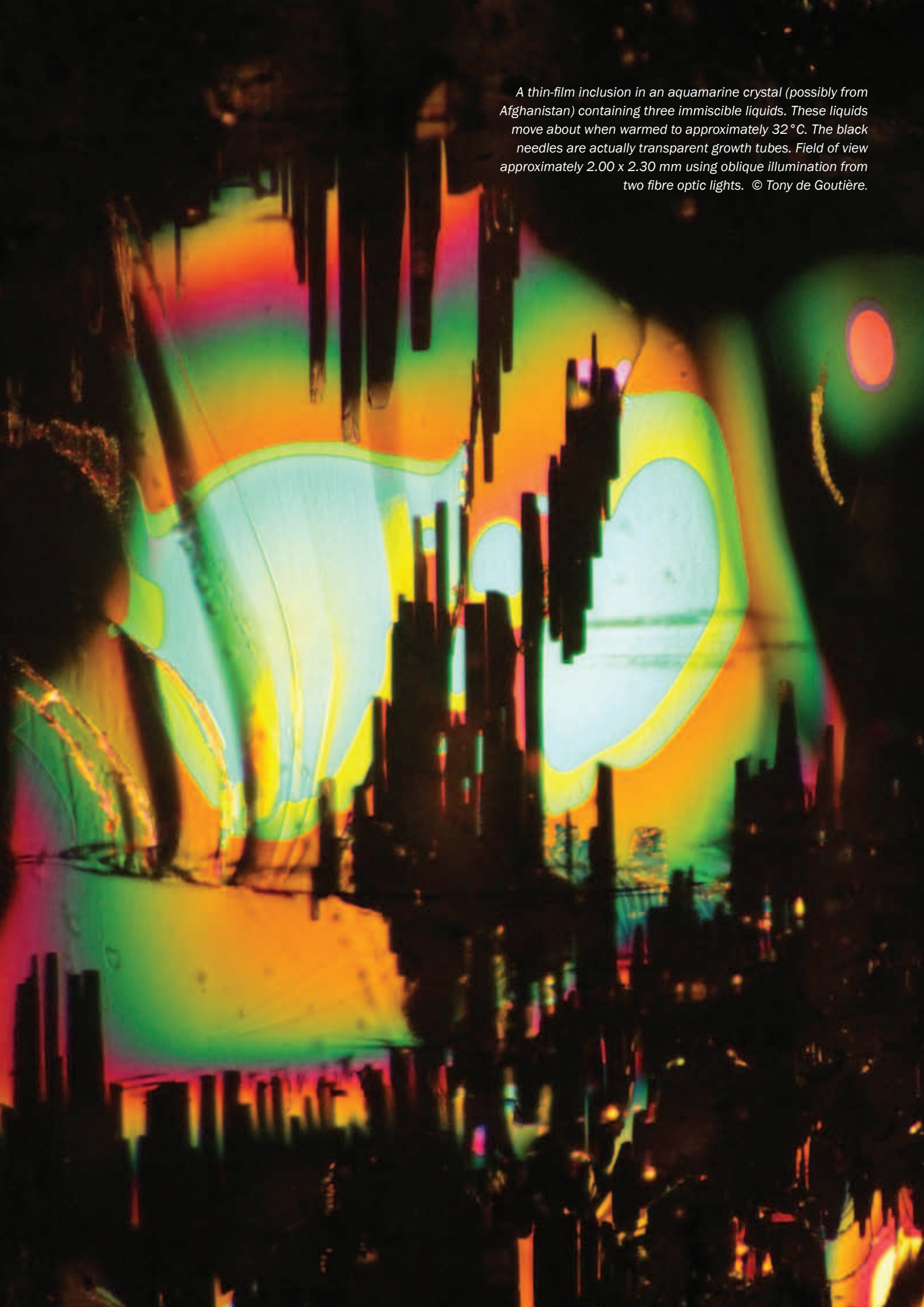

A thin-film inclusion in an aquamarine crystal (possibly from Afghanistan) containing three immiscible liquids. These liquids move about when warmed to approximately 32 °C. The black needles are actually transparent growth tubes. Field of view approximately 2.00 x 2.30 mm using oblique illumination from two fibre optic lights. © Tony de Goutière.

Gem-A Photographic Competition

2012 Competition winners

Overall winner and winner of Natural category
Tony de Goutière GG
Photomicrograph of a thin-film inclusion in an aquamarine crystal (see facing page)

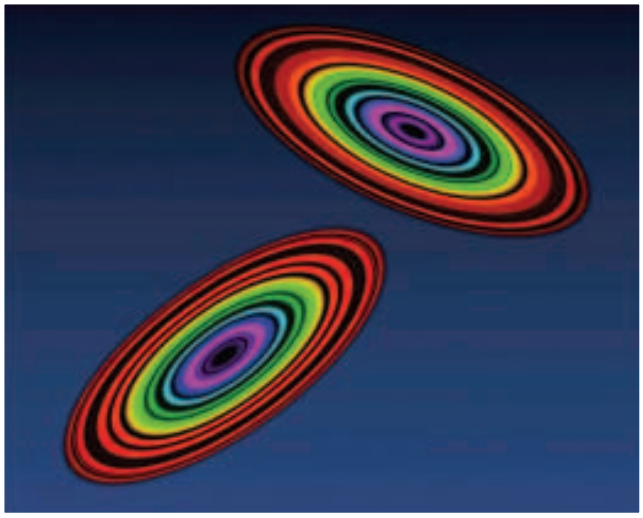

Winner of Treated category
John Harris FGA
'Close encounters.' Two spectra from the o-ray and e-ray of a Mogok zircon which have been altered to become an ellipse.

Winner of Melange category
Tay Thye Sun
The intense face of a miner making a last sales pitch, Tanzania.

The 2013 Competition is now open!

All Gem-A members are invited to participate. Once again there are four categories in which an image may be submitted:

1 **Natural**
Digital photograph (including photomicrography) with minimal post-production work (may include basic cropping, contrast and minor hue/saturation adjustments).

2 **Treated**
Digital photograph (including photomicrography) with significant post-production work (such as background manipulation, HDR, and contrast masking).

3 **Synthetic**
Computer-rendered 3D models of gemstones, crystals, crystal structures, images from microtomography, etc.

4 **Melange**
This category includes any gem-related image that doesn't fit in the above and may include such things as photos of a spectrum, a scanning electron microscope image, mining, cutting, etc.

The entries will be judged by an industry panel on the basis of gemmological interest, inspiration, artistic quality and, in the case of categories 2 and 3, computer skills and ingenuity. A prize will be awarded in each category and, depending on submissions and at the judges' discretion, an additional prize for the most humorous or unusual image might also be awarded. All prize winners will receive their image within a frameable mount. In addition there will be one overall winner who will receive a free Gem-A membership for the following year.

To enter
Please send a low resolution version of your photo to editor@gem-a.com. Entry forms and full details of the competition, including copyright information and Rules of Entry, can be accessed at www.gem-a.com/membership/photographic-competition.aspx or call Amandine on +44 (0)20 7404 3334.

Closing date: 28 June 2013

Winning entries will be announced at the Gem-A Conference 2013 and feature in *Gems & Jewellery*.

Gem-A Awards

Gem-A Examinations were held worldwide in January and June 2012. In the Examinations in Gemmology 311 students qualified in the Diploma Examination, including 16 with Distinction and 37 with Merit. In the Foundation in Gemmology Examination 381 qualified. In the Gem Diamond Examination 98 qualified, including 23 with Distinction and 15 with Merit.

Christie's Prize for Gemmology for the best candidate of the year in the Diploma Examination was awarded to **Jonathan Tremblay** of Bourth, France.

The **Anderson Bank Prize** for the best set of theory papers in the Diploma in Gemmology examination was awarded to **Jiangli Tao** of Beijing, P.R. China.

The **Read Practical Prize** for excellence in the Diploma Practical Examination was sponsored for 2012 by DeeDee Cunningham of Toronto, Canada. The Read Practical Prize was awarded to **Lauriane Forest** of Villeurbanne, France.

In the **Foundation Certificate in Gemmology** examination, the **Anderson Medal** for the candidate who submitted the best set of answers which, in the opinion of the Examiners, were of sufficiently high standard, and the **Hirsh Foundation Award** for the best candidate of the year, were awarded to **Andrea Blake** of Chevy Chase, Maryland, U.S.A..

In the **Gem Diamond Diploma** examination, the **Bruton Medal** for the best set of theory answer papers of the year and the **Deeks Diamond Prize** for the best candidate of the year, were awarded to **Rona Bierrum** of London.

The **Diamond Practical Prize** for excellence in the Diamond Practical Examination, is sponsored by Dominic Mok from AGIL, Hong Kong. The Diamond Practical Prize was awarded to **Timothy Sheung Yin Li** of Bradford, West Yorkshire.

The **Tully Medal** was not awarded.

The names of the successful candidates are listed below.

Examinations in Gemmology

Gemmology Diploma

Qualified with Distinction

Cheng Ping Shing, Kowloon, Hong Kong
Jin Bin, Zhuji, Zhejiang, P.R. China
Lally, Joanne Claire, Southampton, Hampshire
Li Dan, Beijing, P.R. China
Li Yuan, Beijing, P.R. China
Lin Ken, Wuhan, Hubei, P.R. China
Ma Autu, Xi'an, Shanxi, P.R. China
Ni Liang, Beijing, P.R. China
Nilsson, Paul G., Auckland, New Zealand
Porter, Rex, Hartley Whitney, Hampshire
Shi Miao, Beijing, P.R. China
Tereszczuk, Stasia, Berkhamsted, Hertfordshire
Tremblay, Jonathan, Bourth, France
Wu Xiaoting, Shandong, P.R. China
Zhou Haohao, Nantong, Jiangsu, P.R. China
Zhu Lin, Hebei, P.R. China

Qualified with Merit

Bai Xumeng, Beijing, P.R. China
Bierrum, Rona Ann Alison, London
Boisserand, Anne, Fréjus, France
Chen Xiao, Teda of Tianjin, P.R. China
Drouin, Claude, Loughborough, Leicestershire
Forest, Lauriane, Villeurbanne, France
Genet, Julie, Cagnes-sur-Mer, France
Huajie Jin, Hangzhou, P.R. China
Huang Xiaowan, Pan Yu District, P.R. China
Jiangli Tao, Glasgow,
Jie Liu, Guizhou, P.R. China
Lambert, Amelie Julia Sophie, London
Lei Ying, Beijing, P.R. China
Linlin Wang, London
Mack, Darling, Dollard-des-Ormeaux, Quebec, Canada
Mitchell, Shirley D., Windsor, Berkshire
Raoul, Julien, Élancourt, France
Rui Jia Zhang, Kunming, P.R. China

Sepper, Mariliis, Harjumaa, Estonia
Shuqiong Luo, Beijing, P.R. China
Si Tong Liu, Beijing, P.R. China
Sixun Yun, Ningxia, P.R. China
Van Colen, Louise, Tourgéville, France
Wang Jia, Jinzhou, P.R. China
Woodmansterne, Chloë Elinor, St. Albans, Hertfordshire
Wu Wenjun, Guangdong, P.R. China
Wyndham, Jessica, London
Xian Yu, Guangdong, P.R. China
Xiaona Zhang, Beijing, P.R. China
Xu Chun, Zhejiang, P.R. China
Young, Olivia, London
Yu Qingyuan, Guangzhou, P.R. China
Yuan Miao, Hangzhou, P.R. China
Yuan Ren, Beijing, P.R. China
Yumei Xia, Sichuan, P.R. China
Yutong Ma, Beijing, P.R. China
Zhang Jian, Beijing, P.R. China

Qualified
Ai Xia, Guilin, P.R. China
Andersson, Helene, Lannavaara, Sweden
Andre, Sandrine Marie, London
Armitage, Katherine Jane, Hove, East Sussex
Asplund, Jan Olof, Norrbotten, Sweden
Bai Meng, Xingan Meng, Inner Mongolia, P.R. China
Balasubramaniam, Subanthini, Birmingham, West Midlands
Bao Yi, Wuhan, Hubei, P.R. China
Bastidas, Emmanuel, Montmorency, France
Benistand, Angelique, La Chapelle-en-Vercors, France
Boele, Georgette, Almere, The Netherlands
Bombardier, Valerie, Candiac, Quebec, Canada
Branchard, Jean-Yves, Kamaryut Township, Yangon, Myanmar
Brianceau, Boris, Saint-Julien-des-Landes, France
Brom, Jean-Baptiste, London
Bruyère, Manon-Océane, L'Isle-sur-la-Sorgue, France
Buono, Pascal, Mont-Royal, Quebec, Canada
Burrows, Michael James, Kidderminster, Worcestershire
Cancé, Gregory, Montreal, Quebec, Canada
Cen Junxiao, Guangxi, P.R. China
Chan Shuk Lam, Kowloon, Hong Kong
Chan Chi Kin, Kowloon, Hong Kong
Chan Chui Wan, Annabel, Tsuen Wan, Hong Kong
Chan Miu Yee, New Territories, Hong Kong
Chan Wai Ling, New Territories, Hong Kong
Chandrasekera, Pali Kumari K., Nugegoda, Sri Lanka
Chang Cheng, New Taipei City, Taiwan, R.O. China
Chang Na, Qinghai, P.R. China
Chang YiMao, Shenzhen, Guangdong, P.R. China
Che Yandong, Hongshan, Chifeng, Inner Mongolia, P.R. China
Chen Hongyan, Hubei, P.R. China
Chen Kai, Guilin, P.R. China
Chen Tan, Guilin, P.R. China
Chen Ting, Jingzhou, Hubei, P.R. China
Chen Zejin, Beijing, P.R. China
Cheung Mei, Karen, New Territories, Hong Kong
Chiang Cheng-Hsien, New Taipei City, Taiwan, R.O. China
Chin Cheung, Beijing, P.R. China
Chow Po Ling, Sai Ying Pun, Hong Kong
Chu Yung-Huan, Taichung, Taiwan, R.O. China
Chu Zhongheng, Shangxi, P.R. China
Corton, Annabelle Rachael, Dubai, United Arab Emirates
David, Elysabeth, Bonn, Germany
Day, Kroy, Jimboomba, Queensland, Australia
De Vismes, Raphaele, Versailles, France
De Wit Sandstrom, Ida Marianne, Dalby, Sweden
Delor, Claude, Orléans, France
Di Geso, Alessandra Rosa, Kirkland, Quebec, Canada
Dingley, Stacey M., Dudley, West Midlands
Dong Yiting, Beijing, P.R. China
Duan Qi, Beijing, P.R. China
D'Ussel, Anne-Charlotte, Paris, France
Eastmond, Fiona M., Isleworth, Middlesex
Fayet, Timothée, Gland, Switzerland
Feng Liwei, Guilin, P.R. China
Forsner, Christina, Sodra Sandby, Sweden
Franchitti, Sarah Melle, Saint-Sébastien-de-Morsent, France
Fremy, Pierre, Bois-Colombes, France
Gao Minghao, Gan Su, P.R. China
Gao Rongxian, Guilin, P.R. China
Gautier, Isabelle Marie Nathalie Korenain, Bry-sur-Marne, France
Girard, Maxime, Agadir, Morocco
Goshanth, Namasivayam, Sabaragamuwa, Sri Lanka
Griffith, Julia Anna, Southampton, Hampshire
Gu Yian, Shanghai, P.R. China
Guo Jingqing, Fu Jian, P.R. China
Hameed, Aveen, Leicester
He Qing, Guilin, P.R. China
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Hsiao Yu-Hsin, Taichung, Taiwan, R.O. China
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Yue Wang, Shangxi, P.R. China
Yun-Fei Hsieh, New Taipei City, Taiwan, R.O. China
Yun-Wen Chou, Taipei City, Taiwan
Yu-Shin Peng, Taichung, Taiwan, R.O. China
Zeligman, Juriel, Laren, The Netherlands
Zhang Yi Chi, Beijing, P.R. China
Zhang Yiqi, Guilin, P.R. China
Zhang Yu Sheng, Beijing, P.R. China
Zhao Xiaohuan, Beijing, P.R. China
Zhao Yang, Shanghai, P.R. China
Zheng, Bowen, Beijing, P.R. China
Zhengqing Yan, Shanghai, P.R. China
Zhong Rui, Beijing, P.R. China
Zhu Lan Ling, Beijing, P.R. China
Zi-Ning Huang, Birmingham, West Midlands
Zins, Bertrand, Cadiere d'azur, France

Gem Diamond Diploma examination

Qualified with Distinction
Barbour, Alexandra Frances, Litton Cheney, Dorset
Bierrum, Rona Ann Alison, London
Birks, Cherie-Ann, London
Campbell-Jones, Amy V., Sheffield, South Yorkshire
Chan Mei Ying, New Territories, Hong Kong
Cheng Ka Yan, Kowloon, Hong Kong
Dickson, Julia Amy Victoria, London
du Plessis, Sarel P., Kingston-upon-Thames, Surrey
Fitzgerald, Alison, Sevenoaks, Kent
Hart, Alan, Beckenham, Kent
Hui Cheuk Fan, New Territories, Hong Kong
Kocak, Sim, London
Leung Ka Yee, Ainsley, New Territories, Hong Kong
Li Sheung Yin, Timothy, Bradford, West Yorkshire
Mogridge, Emma Denise, Birmingham, West Midlands
Ng Wing Ki, Joyce, Quarry Bay, Hong Kong
Peart, Jyoti, London
Peshall, Jessica Monica Eyre, West Kensington, London
Reading, Charlotte Marie, Nuneaton, Warwickshire
Voulgaridis, Konstantinos, London
Wang Linlin, London
Woodmansterne, Chloë Elinor, St Albans, Hertfordshire
Wu Ming Tak, Quarry Bay, Hong Kong

Qualified with Merit
Birch, Ritsuko, Shrewsbury, Shropshire
Chang Jing, Zhangjiakou, Hebei, P.R. China
Harb, Rawan Jalal, London
Holland, Kate Joy, Edinburgh,
Hou Hong Xi, Zhejiang, P.R. China
Matthews, Emma, Sunninghill, Berkshire
Ning Wentao, Beijing, P.R. China
Patel, Hiren, London
Piao Guicheng, Beijing, P.R. China
Platis, Alexandros, Nafpaktos, Greece
Santilal, Shahil, Gants Hill, Essex
Sawyer, Nicola Hester, Keynsham, Somerset
Sojka, Marta, London
Wong Yee Man, Quarry Bay, Hong Kong
Wong Yu Ting, Tai Po, Hong Kong

Qualified
Agnihotri, Riya, Twickenham, Middlesex
Avraam, Zoey Anastasia, Bush Hill Park, Middlesex
Bailey, Anneabell, Althorne, Essex
Balasubramaniam, Subanthini, Birmingham, West Midlands
Bane, Jonathan William, Sheffield, South Yorkshire
Beardmore, Lindsay Ann, Llandudno, Conwy
Belgrave, Liga, Richmond, Surrey
Chan Wing Shan, Kowloon, Hong Kong
Chen Meizhen, Central, Hong Kong
Cheung Hiu Yan, Brenda, Tsuen Wan, Hong Kong
Cheung Kui Wang, Shau Kei Wan, Hong Kong
Choi Yiu Hung, Kowloon, Hong Kong
Costanzo, Alessandra, Rahoon, County Galway, Republic of Ireland
Ding Jing, Akesu, Xinjiang, P.R. China
Dingley, Stacey Marie, Worcester, Worcestershire
Ellis, Jodie, Huddersfield, West Yorkshire
Gao Boqiu, Beijing, P.R. of China
Hu Jiesheng, Shanghai, P.R. China
Huang Fei, Beijing, P.R. of China
Hung Hoo, New Territories, Hong Kong
Imre, Alexandra, London
Jiang Wenhao, Beijing, P.R. China
Jiao Daohua, Hanzhong, Shanxi, P.R. China
Karimzadeh, Leyla, London
Kirkham, Sally Louise, Birmingham, West Midlands
Ko, Roxana, Tseung Kwan O, Hong Kong
Kuropatwa, Olivia Grace, Malmesbury, Wiltshire
Kwan Sin Yi, New Territories, Hong Kong
Lai Yih-Hwey, Taoyuan, Taiwan, R.O. China
Lam Shuk Yin, New Territories, Hong Kong
Lavy, Stephanie, London
Lawrie, David, Knowle, West Midlands
Leung Pui Sheung, Fennie, Welwyn Garden City, Hertfordshire
Leung Teng Chu, Quarry Bay, Hong Kong
Leung Wing Yee, East Finchley, London
Leung Yin Chun, Jeannie, Kowloon, Hong Kong
Li Tsui Ping, Kowloon, Hong Kong
Liu Yingchen, Beijing, P.R. China
Liu-Murphy, Vanessa Jing, Oldbury, West Midlands
Lu Fang, Wuhan, Hubei, P.R. China
Lu Yini, Beijing, P.R. of China
Mughal, Nazia, Hayes, Middlesex
Or Ting Ting, Tammy, Causeway Bay, Hong Kong
Pang, Virginia, New Territories, Hong Kong
Pang Lai Suen, Kowloon, Hong Kong
Parry, Tessa Pryce, Wantage, Oxfordshire
Sayers, Natalia, Pinner, Middlesex
Sheung Si Lai, Wan Chai, Hong Kong
Sun Miao, Beijing, P.R. China
Tsang Man, Judy, Siu Sai Wan, Hong Kong
von Schantz, Casimir, Helsinki, Finland
Wang Shanshan, Yujiashan, Hubei, P.R. China
Wilson, Maria Dorothea, Rugby, Warwickshire
Wong Lai Wah, Kowloon, Hong Kong
Wong Ling Sum, Olivia, New Territories, Hong Kong
Wu Jiayi, Beijing, P.R. China
Yung Hoi Yan, Central, Hong Kong
Zhang Danqiong, Taiyuan, P.R. China
Zhang Jinmengting, Shandong, P.R. China
Zhang Yuhong, Beijing, P.R. of China

Events

The Gem-A Midlands Branch celebrated its Diamond Anniversary during the weekend 1 and 2 December 2012, with a Celebration Dinner and a one-day conference held at the Menzies Strathallan Hotel, Birmingham. Speakers included David Callaghan, Professor Alan Collins, Davina Dryland, Alan Hodgkinson, Evelyne Stern and Stephen Whittaker.

During the dinner Gem-A CEO James Riley presented Gwyn Green with an Honorary Life Membership in recognition of her commitment to the branch and her tireless work to promote gemmological education. David Callaghan, who had been elected a Vice President at the 2012 AGM, was presented with a certificate.

The conference was preceded on 30 November by a lecture by John Benjamin held at Fellows & Sons Auctioneers, Birmingham.

Annual General Meeting

The Annual General Meeting was held on Wednesday 11 July 2012 at the Imperial Hotel, London WC1. The meeting was chaired by Cally Oldershaw, the Chairman of the Council. The Annual Report and Accounts were approved. Harry Levy was elected President for the period 2012–2014, and David Callaghan and Professor Alan Collins were elected as Vice Presidents. Steve Collins, Richard Slater and Jason Williams (who had been appointed by the Council since the 2011 Annual General Meeting) were re-elected, and Mary Burland, Professor Andy Rankin and Miranda Wells were elected to serve on the Council.

It was agreed that the Membership Liaison Committee be dissolved and that Articles 52 to 54 inclusive of the Memorandum and Articles of Association should be deleted.

Hazlems Fenton were re-appointed as auditors for the year.

The AGM was followed by a talk by Dr Emmanuel Fritsch entitled 'Ethiopian opals'.

Membership

During 2012, the Council approved the election to Membership of the following:

Fellowship and Diamond Membership (FGA DGA)

Asplund, Jan Olof, Stanmore, Middlesex
Balasubramaniam, Subanthini, Birmingham, West Midlands
Beale, Sioned, Lapworth, Warwickshire
Bierrum, Rona Ann Alison, London
Cheung Siu Lui, Sharon, New Territories, Hong Kong
Chung Tsz Bun, Kowloon, Hong Kong
Dingley, Stacey M., Dudley, West Midlands
Leung Pui Sheung, Fennie, Welwyn Garden City, Hertfordshire
Lo, Sunny, Kowloon, Hong Kong
Pietsch, Johanna, Stockholm, Sweden
Tao Jiangli, Glasgow

Fellowship (FGA)

Al-Saif, Manar, Stavanger, Norway
Andersson, Helene, Lannavaara, Sweden
Andre, Sandrine Marie, London
Astrom, Mikko, Vantaa, Finland
Barrows, Michael James, Kidderminster, Worcestershire
Chan Chui Wan, Annabel, Tsuen Wan, Hong Kong
Chan Chi Kin, Kowloon, Hong Kong
Corton, Annabelle Rachael, Dubai, United Arab Emirates
Daufresne, Marie, Antananarivo, Madagascar
Day, Kroy, Jimboomba, Queensland, Australia
Di Geso, Alessandra Rosa, Kirkland, Quebec, Canada
Gaonkar, Mahesh, Mumbai, India
Graff, Elliott, London
Grounds, Camilla Sara, London
Janse, Leo, Zutphen, The Netherlands
Jonsall, Lisa, Edsbyn, Sweden
Laszlo, Linda, Abu Dhabi, United Arab Emirates
Lee Lai Chun, Loletta, Hong Kong
Lu Jun, Yunnan, P.R. China
Marcus, Caroline R., Oxford
Marier, Valerie, Acton Vale, Quebec, Canada
Ngai Yip, Hong Kong
Orsini, Paolo, Alessandria, Italy
Osterlund, Anders, Lulea, Sweden
Phillips, Jane, Hendra, Queensland, Australia
Picard, Chloe, Vessy, Switzerland
Prickett, Sydney James, Huonville, Tasmania, Australia
Roberts, Deborah, London
Robinson, Laura Jane, Dudley, West Midlands
Russell, Lucy, Kidderminster, Worcestershire
Smither, Susi, London
Springe, Karl, Lannavaara, Sweden
Surensoy, Zubeyde, London
Thomas, Craig Arthur, Santon, Gauteng, South Africa
Timms, Ashley, Indooropily, Queensland, Australia
Ullmer, Jacquelyn, Dayton, Ohio, U.S.A.
Weir-De La Rochefoucauld, Juliet, Les Alluets-le-Roi, France
Weisenburn, Maria Johanna, Voorburg, The Netherlands
White, Lucy, Virginia Water, Surrey
Will, Diana Elizabeth, London
Willmott, Karra Jane, Croydon, Surrey
Wyndham, Jessica, London
Zhang Yu, Beijing, P.R. China

Diamond Membership (DGA)

Belgrave, Liga, Richmond, Surrey
Birch, Ritsuko, Shrewsbury, Shropshire
Dowding, Lucy Jane, St. Andrews, Fife
Holland, Katherine Joy, Edinburgh
Kocak, Sim, London
Lavy, Stephanie, London
Lawrie, David, Knowle, West Midlands
Li Sheung Yin, Timothy, Bradford, West Yorkshire
Liu-Murphy, Vanessa Jing, Oldbury, West Midlands
Patel, Hiren, London
Sawyer, Nicola, Keynsham, Somerset
Shi Su, Beijing, P.R. China

Associate Members

Barclay-Michaels, Allison, London
Chu, Dai, London
Clarkson, Deborah, Marlborough, Wiltshire
Collen, Mark, Tilford, Surrey

Gifts and Donations to the Association

The Association is most grateful to the following for their gifts and donations for research and teaching purposes:

Senarath B. Basnayake MSc FGA, Kandy, Sri Lanka, for a 3.46 ct parti-coloured yellow and blue faceted sapphire.

Patrick Coughlin, Yellow Emerald Mining Company LLC, St Clair, Missouri, U.S.A., for a selection of rough and cut 'yellow emeralds'.

Luc Genot FGA, Brussels, Belgium, for a can of jade lustre spray, a necklace of imitation chalcedony beads, and pieces of polished quartz with orpiment, dragon's blood jasper, azurite from China and jasper framed in marble.

Jie Han FGA, Beijing, P.R. China, for a copy of *The Golden Collections Jade Book*.

Emma Higgo, Hindhead, Surrey, for a copy of *The Diamond Compendium* by DeeDee Cunningham.

Richard W. Hughes FGA, Bangkok, Thailand, for a copy of *The Book of Ruby & Sapphire* from an unpublished manuscript by J.F. Halford-Watkins 1936, edited by Richard Hughes.

Akira Ito, Tokyo, Japan, for the books *Jewellery series 2: Design & Making* and a Japanese translation copy of *Gemstones of the World*.

Robert James FGA, San Antonio, Texas, U.S.A., for the World Gem Society book *2012 Guide to Tucson Treated & Created Gems*.

Kyalo Kiilu DGA, Coventry, West Midlands, for a selection of rough zoisite, iolite, apatite and ruby from East Africa.

Gary E. Megel, Fort Lauderdale, Florida, U.S.A., for a selection of faceted gemstones.

Damian Miles, Okehampton, Devon, for six faceted synthetic forsterites.

Elise A. Skalwold FGA, Ithaca, New York, U.S.A., for a copy of *The Edward Arthur Metzger Gem Collection* by W.A. Bassett and E.A. Skalwold.

David Weinberg, Bangkok, Thailand, for a selection of faceted gemstones including zircon, quartz and topaz.

Benjamin Zucker, New York, U.S.A., for a copy of *The Portrait Diamonds*.

Monetary donations were gratefully received from:

Petra C. Bardehle FGA, Holzhausen, Germany
Anthony de Goutiere GG, Victoria, British Columbia, Canada
Vincenzo De Michele, Milan, Italy
Ng Mei Hang DGA, Hong Kong
Raffi Katz, Watford, Hertfordshire
Kiyokatsu Koike FGA, Toride, Japan
Torbjorn Lindwall FGA DGA, Lannavaara, Sweden
Yuko Sekiguchi FGA, Saitama-Ken, Japan
Moe Moe Shwe FGA, Singapore
Paul L. Siegel FGA, Rocky Point, New York, U.S.A.
Susan M. Stocklmayer FGA, Perth, Western Australia
U Myint Tun FGA, Lulea, Sweden
Miranda Wells FGA DGA, Ironbridge, Shropshire

Bequest

The Association received a bequest from the estate of the late Professor Robert Howie for the sum of £3000. Professor Howie, who died on 10 March 2012, was a past President of the Association. An obituary is given on pages 110-111.

The Council of the Association is most grateful to Professor Howie for his bequest.

Davies, Anthony, Maidstone, Kent
De Marsac, Andre Emile, Beaconsfield, Buckinghamshire
Di Gregorio, Giuseppe, Spadafora, Messina, Italy
Drucker, Richard, Glenview, Illinois, U.S.A.
Elliott, Avril, Edinburgh
Farmer, Jane, London
Fitzner, Manuela, Malmö, Sweden
Friling, Beate, Berlin, Germany
Green, Beata, Radlett, Hertfordshire
Harris, Ruth, Borehamwood, Hertfordshire
Herold, Dorte, Zurich, Switzerland
Hersi, Ali Osman, Greenford, Middlesex
Hu, Ayahi Suda, London
Jung Che Kwan, Brenda, London

Karia, Raj, London
Lahner, Alen Mario, Vienna, Austria
Lawrence, Roger Vernon, Swythamley, Cheshire
Lecatsas, Maria, Hollywell, Queensland, Australia
Massingham, Olivia, Durley, Hampshire
McLauchlan, Kate, London
Ming Pik Sau, Caroline, Burnaby, British Columbia, Canada
Moore, Harriette, Newbury, Berkshire
Morton, Helen Skye Fugaccia, Aberdeen
Nichols, Caroline, Carmarthen
Noone, Mark, Cork City, Republic of Ireland
Perez, James, Enfield, Middlesex
Ryder, Adrian, Galway, Republic of Ireland
Saleem, Melanie, Manchester, Greater Manchester
Smith, Adam, Bleasby, Nottinghamshire
Springham, Melvin, Spandeau, Germany
Twist, Dewar, Saint-Congard, France
Vincent, Christopher, Bishops Stortford, Hertfordshire
Warren, Sharron, London
Wassell, Philip, Birmingham, West Midlands
Williams, Bear, Jefferson City, Missouri
Wright, Abby, New Plymouth, New Zealand
Yates, Elspeth, Aberdeen

Gold Corporate Membership

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Ian Quartermaine Ltd, Worcester
Rivoli Jewellers, St Helier, Jersey

Corporate Membership

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Nimmi Blu Designs Ltd, Wimbledon, London
Trent Diamonds Ltd, West Bridgford, Nottinghamshire
William & Son, London

Transfers

Fellowship to Fellowship and Diamond Membership (FGA DGA)

Bane, Jonathan, London
Campbell-Jones, Amy Victoria, Galway, Republic of Ireland
Costanzo, Alessandra, Rugby, Warwickshire
Hart, Alan, London
Karimzadeh, Leyla, Birmingham, West Midlands
Kirkham, Sally, Helsinki, Finland
Mogridge, Emma Denise, Birmingham, West Midlands
Von Schantz, Casimir, Sheffield, South Yorkshire
Voulgaridis, Konstantinos, Sheffield, South Yorkshire
Wilson, Maria Dorothea, London

Diamond Membership to Fellowship and Diamond Membership (FGA DGA)

Goshanth, Namasivayam, Sabaragamuwa, Sri Lanka
Griffith, Julia Anna, Southampton, Hampshire
Manasse, Daniele, Rome, Italy
Mitchell, Shirley D., Windsor, Berkshire
Visvanathan, Sokkalingam, Singapore

Associate Membership to Fellowship (FGA)

Armitage, Katherine Jane, Hove, East Sussex
Boele, Georgette, Almere, The Netherlands
Brianceau, Boris, Saint-Julien-des-Landes, France
Chang Cheng, New Taipei City, Taiwan, R.O. China
Knifeld, Stephanie Ann, Queens Park, Bournemouth, Dorset
Lally, Joanne Claire, Southampton, Hampshire
McCallum, Neil Keith, Martinborough, New Zealand
Molina-Talavera, Jose, Malaga, Spain
Nilsson, Paul Graham, Auckland, New Zealand
Shen Mei, Taipei, Taiwan, R.O. China
Sonoda, Yasuko, Shizuoka Pref., Japan
Tereszczuk, Stasia-Mae, Berkhamsted, Hertfordshire
Torndahl, Rebecca, Skanor, Sweden
Van Der Wolf, Nicole A., Dublin, Republic of Ireland
Wilkinson, June, Wellingborough, Northamptonshire
Woodrow, Gillian, Wokingham, Berkshire

Subscriptions 2013

The membership subscriptions for 2013 are £100, with a £10 discount for those paying by direct debit (UK bank accounts only) .

Obituary

Nancy J. Baker BHSc GG FGA (D.1972), Kingston, Ontario, Canada, died on 21 July 2012.

Thor A. Johne FGA (D.1962, with Distinction), Oslo, Norway, died in August 2012. Thor was a Gem-A examiner for many years, dealing specifically with Norwegian translations.

Gwilym M. Jones FGA DGA (D.1980 with Distinction), Gilwern, Abergavenny, died in 2012.

James A. Houseago FGA DGA (D.1981), Lowestoft, Suffolk, died in 2012.

Keith Wallis FGA (D.1977), Surbiton, Surrey, died on 19 September 2012. An obituary was published in *Gems & Jewellery*, Winter 2012.

Professor Robert Andrew Howie

4 June 1923 – 10 March 2012

Bob Howie was born on 4 June 1923 in Olney, north Buckinghamshire in England and grew up on a nearby farm. His parents were Scottish and his father had moved south from Ayrshire after the First World War. He was educated at Bedford School and in 1941, at the age of 18, Bob cycled over to the nearby Cardington air base to volunteer. He joined up and was sent to Edinburgh and specialized in meteorology. His years in the RAF were eventful, and dangerous; he sailed across the Atlantic with U-boats lurking, flew aerobatics in a Tiger Moth aircraft in Saskatchewan and narrowly escaped death when a Halifax bomber that was attempting to take off brushed the top of the hut he was in and crashed into the sea. He was posted to Gibraltar where he contracted polio. He was bed ridden for a year and was left permanently disabled.

Bob was invalided out of the air force and went to Trinity College, Cambridge, where he read Natural Sciences: Chemistry, Geology and Mineralogy. He graduated in 1950 and then completed his doctorate at Cambridge with S.R. Nockolds on Indian charnockites. Despite limited analytical facilities, Bob demonstrated remarkable tenacity and perseverance in his research, completing large numbers of rock and laboriously separated mineral analyses. The origin of charnockites was, at the time, a source of geological controversy (were they igneous or metamorphic?) and Bob was able to demonstrate their igneous origin.

In 1953 Bob was appointed to a lectureship in Manchester. It was here that he started his collaboration with W.A. Deer (then Head of Department in Manchester) and Jack Zussman. This collaboration (and friendship) lasted the remainder of his life and resulted in the publication of the five-volume *Rock-forming Minerals* series. This monumental work is the bedrock of modern mineralogy and established the national and international reputation and acclaim for the authors. DHZ is a work of outstanding scholarship and has remained the most widely used mineralogical reference book; it has sold more than 125,000 copies worldwide. Bob made a massive contribution to the work which is still being revised and updated, together with the student version which is about to enter its third edition.

In 1962 Bob was appointed Reader, and later Professor, at King's College, London, and he remained there until the merger of the King's, Bedford and Chelsea Departments into the Department at Royal Holloway in 1986. Bob was appointed Lyell Professor of Geology at King's College and he brought this post to Royal Holloway with the departmental merger.

When appointed to King's he had been warned by the then Head of Department (the distinguished sedimentologist J.H. Taylor) about the 'traditionalist' attitudes of the College hierarchy. On appointment he was asked if, in view of his disability, was there anything specific he needed. Bob asked only for permission to park his car in the very limited King's car park as commuting would be difficult. The College agreed but the College Secretary (who ran everything) asked him how many days a week did he need to park? Bob said "everyday" to which the College Secretary exclaimed in horror: "You cannot come in every day — why can't you work at home like everybody else." Bob told him he could not do chemical analysis at home — it ruined the dining room carpet.

At King's, the extent and scope of Bob's contribution was recognized. He continued to publish his research output on mineralogical assemblages and also revised the *Rock-forming Minerals* with his co-authors (it became an eleven

volume work). It was in 1963 that S.O. Agrell and colleagues found three new minerals in the metamorphic rocks of the Franciscan in California. Appropriately they were named deerite, howieite and zussmanite.

He was awarded a DSc by Cambridge University in 1974, the Murchison medal by the Geological Society in 1976, the Distinguished Public Service Award of the Mineralogical Society of America in 1999 and a DSc by the University of Derby in 2009. He was an Honorary Fellow and President (1996–2000) of the Gemmological Association of Great Britain, and Vice-President (1973–1975) and member of council of the Geological Society. In addition, he was very active in University of London politics from the 1970s until near his retirement, acting as Dean of Science from 1979 to 1983 and as chairman of Academic Council from 1983 to 1986. He was a member of the University of London Senate 1974–78 and 1980–90 and member of the University Court 1984–89. His contribution was much respected – his steadfast integrity and 'what you see and hear is what you get' approach in his dealings with academics was a welcome change in the murky waters of academic politics. Many senior academics (and others) will also have abiding memories of his offers of "a lift up to Senate House". A lift in Bob's car was a never-to-be- forgotten-'Alton Towers'-type experience; Bob had learned to fly before he drove a car, and it showed.

Bob also made a substantive contribution towards the establishment of the new department at Royal Holloway. The merger of the three small Geology Departments from King's, Bedford and Chelsea into the department at Royal Holloway was fraught with difficulty and faced considerable opposition. This was especially so at King's where the College was reluctant to give up anything but unwilling to provide real support to a new enlarged Geology Department. Although Bob had spent so much of his time at King's and was a loyal supporter of the College, he recognized that the merger was the best option. King's College had a great reputation but for Geology it was out of touch and out of money. At King's and within the University, Bob guided the merger through many difficult times and his contribution was appreciated. He also succeeded in maintaining great respect from the senior management at King's and was appointed a Fellow of King's College. To his colleagues, Bob was a loyal and much respected academic. He brought to the Royal Holloway Department a national and international reputation.

Despite his scientific eminence, Bob could also establish a great rapport with undergraduate and post-graduate students. His field trips to Skye were memorable experiences for generations of students. Not deterred by his disability, and complete with raincoat tied up with string, Bob would use his detailed knowledge of well chosen outcrops to generate real enthusiasm for mineralogy in the field. His lecture on gemstones was a firm favourite of student societies. This lecture traditionally ended with Bob asking the students if they had heard that evening's news — and then producing a very convincing gem-encrusted royal crown. More seriously, his awareness of the mineralogical foundation of gemmology and his nurturing of the understanding of this link underpinned his contributions as an Associate Editor of *The Journal of Gemmology* and in providing numerous highly readable abstracts both for this publication and for *Gems & Gemology*.

Bob was the most independent of men but benefitted greatly, especially in his later years, from the support of his sons Robin and Timothy and their families.

The contribution that Bob Howie made to the Mineralogical Society was immense and possibly the achievement of which he was most proud. He joined the Society in 1950, served on the Council from 1958–61 and 1963 onwards. He was General Secretary in 1965, was Vice President on three occasions and President in 1978–80. He served as Book Reviews editor for *Mineralogical Magazine* from 1980 and was a Managing Trustee from 1977 to 1987. At each meeting of Council, Bob 'stamped' the attendance sheet with the rubber support at the bottom of his walking stick. Even though in later years, he had a four-hour drive to get to London-based Council meetings, Bob was always first to arrive, complete with his plasticbag 'briefcase' containing a book or two in need of review (many fellow Council members were persuaded to swap one of his books for a review), the latest batch of *MinAbs* proofs to fill any spare time and a packed lunch. Bob edited *Mineralogical Abstracts* from 1966 onwards and continued to contribute some 1600 abstracts every year, a simply phenomenal volume of work. Although he officially retired aged 67, his contribution to *MinAbs* and the Society continued undiminished. Though he began in the time of paper and red ink, Bob embraced new technology, and oversaw the transition of his beloved *Mineralogical Abstracts* from paper, first to CD *(MinSource)* and later to an online version *(MinAbs Online)*. Throughout his academic life he remained a great servant of the Society and this was recognized in 1994 with the unique honour of his election as an Honorary Life Fellow of the Mineralogical Society.

Nick Walsh
Mineralogical Society
(Reproduced with permission)

Professor Dr Ichiro Sunagawa

27 August 1924 – 20 December 2012

It is with deep sadness that we record the death of Professor Ichiro Sunagawa, who died from pneumonia on 20 December 2012. He was born in Hamamatsu although his family 'clan' had long lived in the village which gave rise to the family name — Sunagawa-machi (now renamed Kashiwa-cho, situated in the city of Tachikawa, west of Tokyo). Professor Sunagawa was educated at Tohoku Imperial University, gaining a BSc in mineralogy and then joined the Japanese Geological Survey in 1948 as a researcher. In 1957 he was awarded a PhD by Hokkaido University for his thesis 'Morphological variations in pyrite'. Still working for the Geological Survey, he was granted time at Royal Holloway College, University of London, from 1957 to 1960 to conduct a study of the surface structures of hematite and silicon carbide. In 1963 he was awarded the Geological Society of Japan prize for 'Study on the surface structures of crystals' based on this work.

In August 1971 he was appointed Professor of Tohoku University in charge of the Department of Minerals and remained in post until March 1988 when he was awarded the title Professor Emeritus.

His research activities continued unabated, and in March 1991 he was head of the Organizing Committee of the 9th International Conference in Crystal Growth for its meeting in Japan. Also in 1991 he became Principal of the Yamanashi Institute of Gemmology and Jewellery Arts and served until his retirement in 2005.

In endeavouring to understand the kinetic processes taking place at atomic and molecular levels, he researched their effects on crystalline form, homogeneity, integrity and aggregation from simple systems to those as complex as those in the organic world. He then applied the basic theories and insights obtained to problems in gemmology and mineral exploration. As such, he played the role of a pioneer, developing the new discipline of crystal growth studies, and helping found the Japan Association for Crystal Growth.

Professor Sunagawa also founded the Gemmological Association of Japan and, from 1991 to the present, served as an Examiner for The Gemmological Association of Great Britain and was an Associate Editor of *The Journal of Gemmology* — he was a major influence in establishing the high standard of gemmology in Japan through support for education and the spread of local qualifications and the

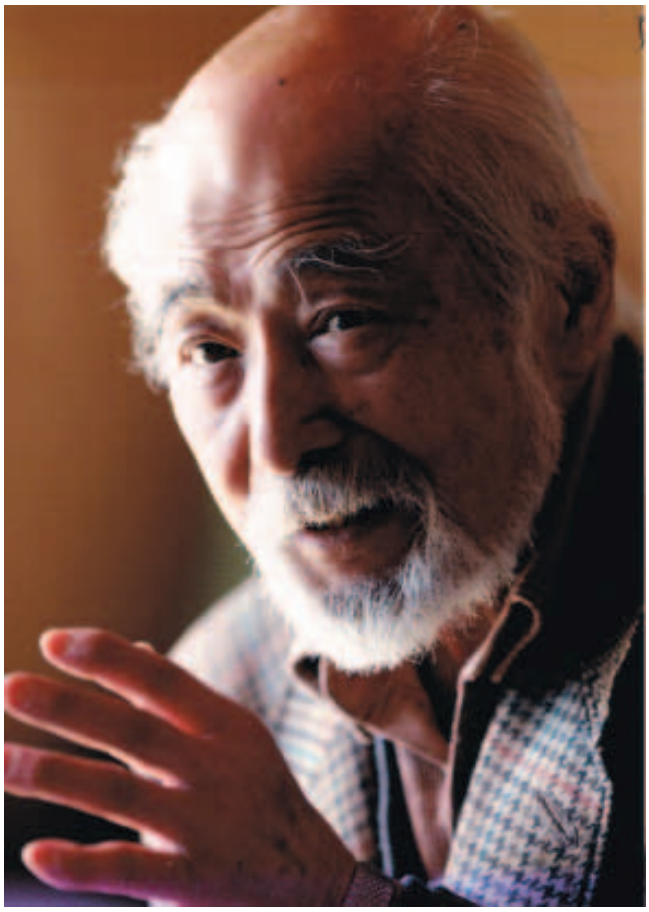

FGA. His international honorary awards include a doctorate from the University of Marseilles, France (for research on crystal growth mechanisms in minerals) in 1982, and Foreign Member of the Bulgarian Academy of Sciences in 1989, and he also held membership of the Russian Mineralogical Society, the Bulgarian Geological Society, the Mineralogical Society of Great Britain and Ireland, and the Korean Society of Crystal Growth; he was a member with honour of the Mineralogical Society of Japan.

He loved minerals from his schooldays until the end of his life and shared this love with his many international friends.

Farewell Professor Sunagawa, you will be sadly missed.

Takeshi Miyata
Tokyo, Japan

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Synthetic alexandrites grown by the HOC method in Russia: internal features related to the growth technique and colorimetric investigation

Dr Karl Schmetzer, Dr Heinz-Jürgen Bernhardt, Walter A. Balmer and Thomas Hainschwang

Abstract: Mineralogical and gemmological properties of synthetic alexandrites grown by the horizontally oriented crystallization (HOC) method are described. The method is used to grow crystal plates weighing up to 450 g. The morphology of the rough crystals is dependent on the form of the molybdenum boat used as a container for crystal growth. The most significant inclusions for gem identification are curved growth striations and flat, irregularly-shaped somewhat elongated cavities. Microprobe analyses revealed distinct amounts of chromium and vanadium but extremely low iron contents. Spectra in the UV-Vis range are consistent with published work. Six differently sized cubes were cut from an HOC alexandrite crystal and used to show pleochroism in combination with two optical phenomena: the alexandrite effect and the Usambara effect. Colorimetric parameters were calculated from the spectra of the cubes and plotted in the CIELAB colour space to demonstrate the alexandrite and Usambara effects graphically for different directions of view. The absorption bands in the infrared are polarized and assigned to structural OH-groups.

Keywords: alexandrite effect, colorimetry, inclusions, melt growth, microprobe analyses, pleochroism, synthetic alexandrite, Usambara effect, UV-Vis-IR spectra

Crystal of synthetic alexandrite produced by the HOC technique in Novosibirsk; the original crystal weighing 39.2 g and measuring about 38 × 23 × 14.5 mm, was cut into slices for further examination. Incandescent light. Photo by K. Schmetzer.

Introduction

Synthetic alexandrites which had been grown by a method designated as 'horizontally oriented crystallization' (HOC), have been available since the late 1980s (Gurov *et al.,* 1988; Gurov and Kirdyashkin, 2001; Gurov *et al.,* 2003). The method was recently mentioned by Malsy and Armbruster (2012) in a paper describing chemical properties of various types of synthetic alexandrites, but a complete gemmological description of the gem material grown using this technique is not yet available. The present paper tries to fill this gap.

In contrast to the 'vertical floating zone' method, which was applied by Seiko for the growth of synthetic alexandrites (see e.g. Schmetzer, 2012), we can describe the HOC method as the 'horizontal floating zone' technique. The synthetic alexandrites produced with this method in Novosibirsk typically show an intense bluish green to blue green coloration in daylight and a colour change to violet purple or purple in incandescent light *(Figure 1)*. Thus, the coloration of these alexandrites is

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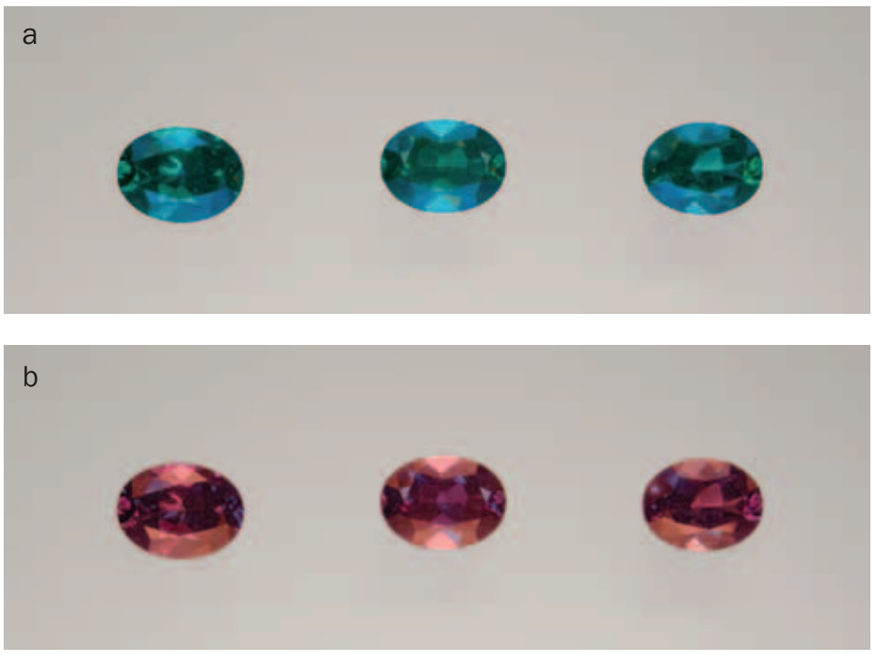

Figure 1 a,b: Faceted synthetic alexandrites grown by the HOC technique in Novosibirsk (a) in daylight and (b) in incandescent light; weight of samples from 1.63 to 1.75 ct, size 8.3 × 6.4 or 8.3 × 6.3 mm. Photo by K. Schmetzer.

Figure 2: Portrait of Vladimir V. Gurov (2011) who developed the technique for the growth of large alexandrite crystals by the HOC method at the Institute of Geology and Geophysics, Siberian Branch of the USSR Academy of Sciences in Novosibirsk; Dr Gurov is now growing synthetic alexandrites for jewellery purposes at the Institute of Geology and Mineralogy, Siberian Division, Russian Academy of Sciences, Novosibirsk, Russia, in cooperation with the Tairus company, Novosibirsk.

comparable to the natural alexandrites originating from Hematita, Minas Gerais, Brazil, which has been the most productive mine since the 1980s.

Growth of alexandrite by the HOC method

The apparatus used at the Institute of Geology and Mineralogy, Siberian Division, Russian Academy of Sciences, Novosibirsk, Russia, is described in detail by Gurov *et al.* (2003) *(Figure 2)*. The principal components of the crystallization apparatus are similar to those used in the facilities developed in the 1970s (see Box A). Because the crystallization of chrysoberyl progresses through a metastable phase, the known apparatus used mainly for growth of large sapphires needed some specific modification for the stable growth of large alexandrite crystals (V.V. Gurov, pers. comm., 2012).

In general $BeAl_2O_4$ crystallizes from a melt as the high temperature phase (β-$BeAl_2O_4$) and on cooling, undergoes a polymorphic transition to a low temperature phase (α-$BeAl_2O_4$, chrysoberyl) at 1826°C which is then stable down to and at room temperature. However, under special conditions, the α-phase (chrysoberyl) can be formed directly from the melt and chromium- and vanadium-bearing chrysoberyl crystals can be grown (Gurov *et al.,* 1986, 2003; Gurov and Tsvetkov, 1998, 2008; V.V. Gurov, pers. comm., 2012). Detailed knowledge of the role of dopants such as chromium and vanadium is essential for the growth of high quality crystals for optical applications, e.g. laser crystals, as well as of gem-quality alexandrite crystals.

Interest in the production of materials for jewellery purposes started in the late 1980s and samples have been grown since the mid-1990s at the Institute of Geology and Mineralogy (part of the former Institute of Geology and Geophysics) in a joint venture with the Tairus company, Novosibirsk. The first commercial samples were released to the market in mid-1994 (V.V. Gurov, pers. comm., 2011, 2012).

The practical growth of alexandrite single crystals is performed in boat-like molybdenum containers in an atmosphere of purified argon. Dimensions of the containers are at present 150–160 mm long and up to 70 mm wide *(Figure 3)*. The containers are filled with a mixture of

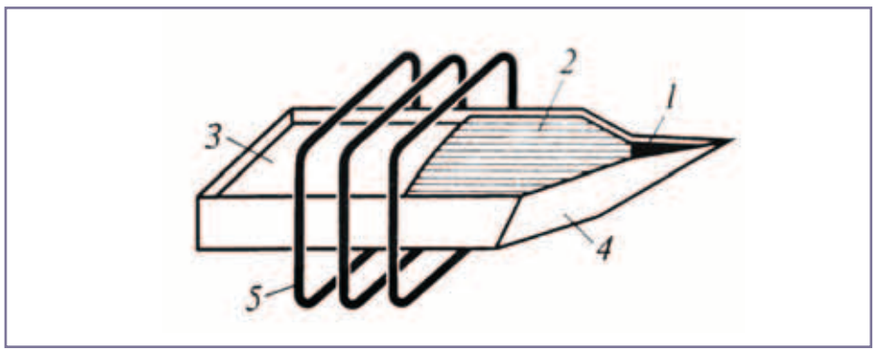

Figure 3: Crystallization container for the growth of alexandrite crystals by the HOC method; (1) seed crystal, (2) synthetic alexandrite, (3) melt, (4) molybdenum boat, (5) heater. Courtesy of V.V. Gurov.

Box A: The HOC growth technique

The horizontally oriented crystallization technique (HOC), also designated by some authors as 'horizontally directed crystallization' (HDC) or as 'horizontal directed solidification', is considered as a variant of the floating zone method and closely related to the technical development by Khachik Saakovich Bagdasarov and his research group (Bagdasarov *et al.,* 1975, 1977, 1978, 1981). The method is used for the growth of large crystal plates of compounds with high melting temperature such as corundum or rare-earth aluminium garnets, especially for laser or other optical applications. The crystals are grown in containers of molybdenum or tungsten, which avoids the use of expensive crucibles made of platinum or iridium. Some relevant extracts from Bagdasarov *et al.* (1975) are:

"The herein-proposed method of growing oriented monocrystals of corundum from a melt, say, in the shape of plates, is explained as follows [see *Figure A1*].

"A crystal seed 2 is placed into a container 1 having the required orientation. The container is then charged with a stock blend 3. The thus-charged container 1 is placed onto a pulling mechanism 4 of a crystallization chamber 5 and introduced into a heater 6 so that part of the crystal seed 2 goes into an expected temperature zone 7 of the melting of corundum.

Figure A2 : Production hall with numerous HOC facilities for the growth of large single crystals of compounds with high melting temperatures; Institute of Geology and Mineralogy, Siberian Division, Russian Academy of Sciences, Novosibirsk, Russia. Photo courtesy of V.V. Gurov.

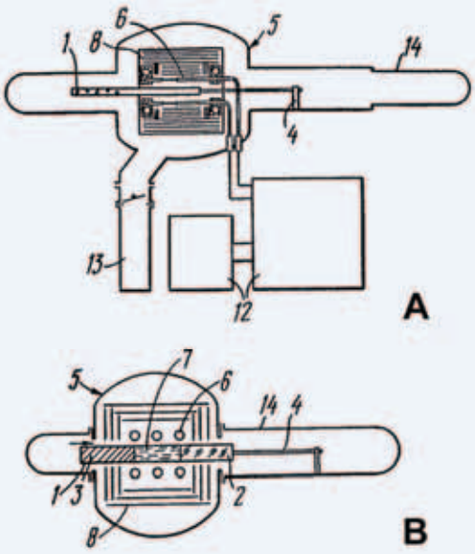

Figure A1: (A) Diagrammatic view of an apparatus for growth of large single crystals of materials with high melting temperatures; (B) a somewhat enlarged part of Figure A seen from above: (1) container, (2) seed crystal, (3) charge, (4) pulling mechanism, (5) crystallization chamber, (6) heater, (7) melt in high temperature zone, (8) heat screens, (12) electrical transformers, (13) vacuum pumps, (14) receptacle. From British patent GB 1 383 400, inventors: K.S. Bagdasarov et al.*, applicant: Institut Kristallografii Akademii Nauk SSSR, Moscow.*

"The heater 6 is fashioned as a bifilar rectangular coil whose ends are fixed to water-cooled current leads. In order to provide a more efficient operation for the heater and increase the consistency of the temperature field thereof, the heater is surrounded by a system of rectangular screens 8 arranged all around except for two opposite sides through which the container 1 is moved ... The electric power supply of the device is from transformers 12, while the required vacuum is established by corresponding vacuum pumps 13.

"Once a rarefaction of not higher than 5×10^{-5} Torr has been attained in the crystallization chamber 5, the blend 3 is subjected to melting. Due to the provision of the heater 6 using Joule heating and the system of the screens 8 a temperature gradient of from 5° to 40° per cm is attained across the crystallization zone. Further, the container 1 with the melt and a part of the crystal seed 2 is pulled into a receptacle 14 at a velocity of 4 to 10 mm/hr. When the growth process is completed, the resultant monocrystal is cooled and withdrawn from the receptacle 14."

A somewhat modified and improved apparatus is specified by Bagdasarov *et al.,* 1977, 1978, to which the reader is referred for further details. A photo of a production hall for HOC-grown synthetic single crystals is given in *Figure A2*, showing several growth facilities used for alexandrite synthesis.

Synthetic alexandrites grown by the HOC method in Russia

Figure 4: Complete alexandrite crystal grown by the HOC technique in a molybdenum container in Novosibirsk. Weight of the crystal approx. 420 g. Photo courtesy of V.V. Gurov.

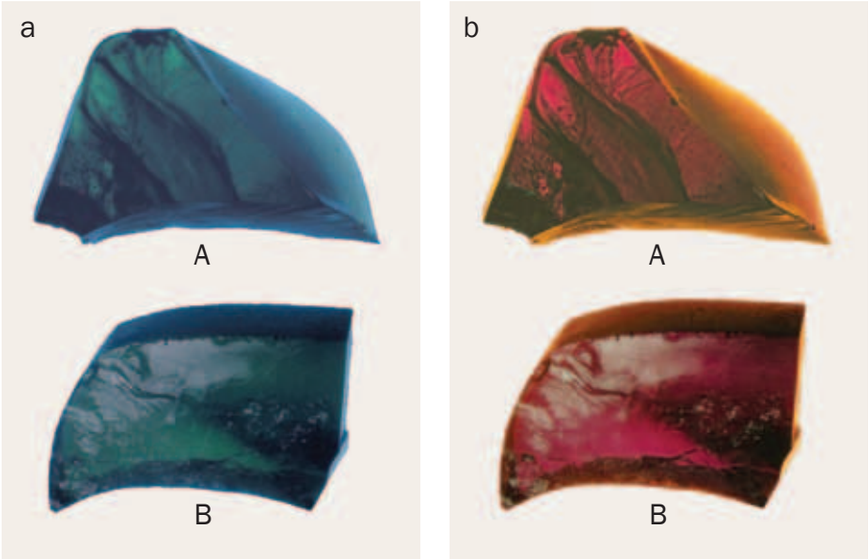

Figure 5 a,b: The two synthetic alexandrite crystals grown by the HOC technique in Novosibirsk investigated in this study; the samples are shown in daylight (a) and incandescent light (b); sample A measures approx. 48 × 24 mm, thickness variable up to 23 mm, weight 51.6 g; sample B measures about 38 × 23 mm, thickness 14.5 mm, weight 39.2 g. Photo by K. Schmetzer.

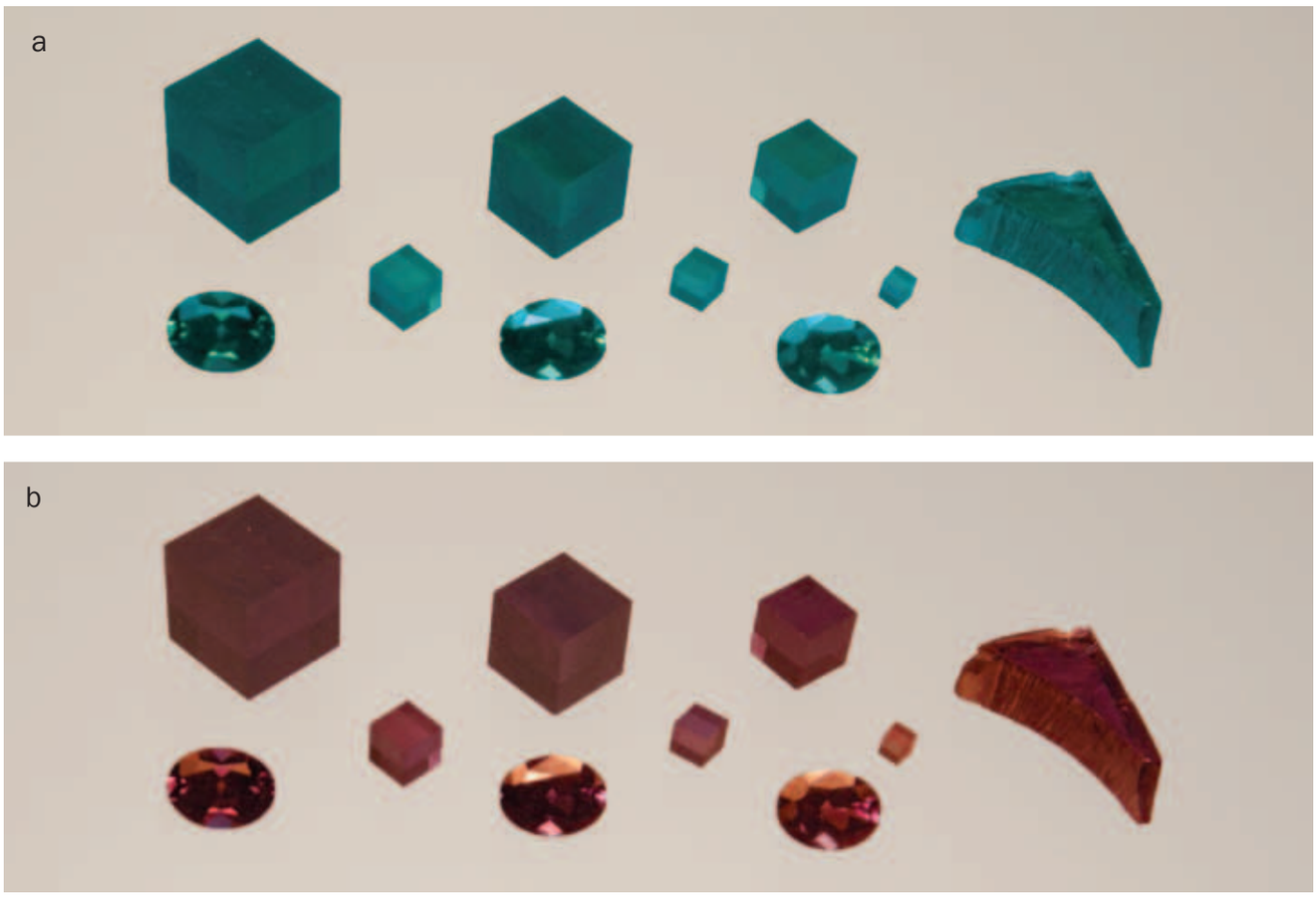

Figure 6 a,b: From sample B depicted in Figure 5 various research stones were prepared; the photos, (a) in daylight and (b) in incandescent light, show a slice from the crystal, three faceted alexandrites cut with the table facets exactly perpendicular to either the a-, b- or c-axis of the crystal (weighing 1.63 to 1.75 ct), and six cubes cut with their faces exactly perpendicular to the a-, b- and c-axes of the crystal (weighing 0.17 to 18.05 ct, edges of the cubes 2, 3, 4, 6, 8 and 10 mm). Photo by K. Schmetzer.

Figure 7 a,b: Faceted synthetic alexandrites purchased from the Tairus company, Bangkok, Thailand, (a) in daylight and (b) in incandescent light; the weights range from 1.38 to 1.74 ct; the rectangular sample at the right (1.74 ct) measures 8.7 × 5.1 mm. Photo by K. Schmetzer.

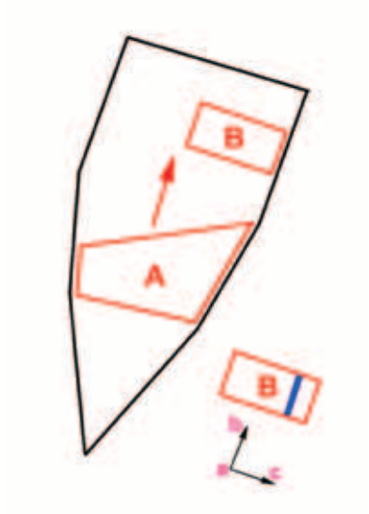

Figure 8: This schematic drawing shows the position of the two alexandrite crystals depicted in Figure 5 in the molybdenum container applied for crystal growth as indicated by the producer; the growth direction (red arrow) is almost parallel to the b-axis and perpendicular to the c-axis of the alexandrite crystal (indicated schematically below right with black arrows); the position and orientation of the slab cut parallel to the ab-plane and used for chemical analysis (five scans by electron microprobe) is indicated in blue.

beryllium and aluminium oxide and oxides of colour-causing trace elements, especially chromium. A special attachment allows the introduction of an oriented seed into the melt filling the nose of the container. The rates of moving the molybdenum boat through the heating zone are 1.5–3 mm per hour. Under these experimental conditions, single crystals are obtained which closely reflect the form of the boat-shape of the container *(Figure 4)*.

Various aspects of chrysoberyl and alexandrite synthesis have been discussed in the papers of V.V. Gurov and his co-authors, and the properties of alexandrites grown by the HOC method were compared to samples grown by the Czochralski technique (Gurov *et al.,* 1986, 1988, 2003, 2008; Gulev *et al.,* 1990; Gurov and Tsvetkov, 1998, 2008; Gurov and Kirdyashkin, 2001, 2012). The principal features of gemmological interest resulting from these discussions are:

- the orientation of seeds and the orientation of the free surface of the grown crystal;
- the nature and distribution of inclusions and the concentration and zoning of chromium and vanadium dopants;
- the sector zoning of the crystals.

Research materials

Two rough crystals of 51.6 g and 39.2 g were directly obtained from Dr Gurov in Novosibirsk via the Tairus company *(Figure 5 a,b)*. The smaller of these crystals was sliced and several faceted alexandrites and seven exactly oriented alexandrite cubes were prepared from these slices *(Figure 6 a,b)*. In addition, we studied seven faceted alexandrites which had been purchased from the Tairus company in Bangkok by Dr D. Schwarz of Lucerne, Switzerland *(Figure 7 a,b)*.

Observations on the crystals and the cut stones

a. Morphology

Both rough crystals *(Figure 5 a,b)* showed larger plane faces which are cleavage planes parallel to **b** (010). The positions of both crystals in the molybdenum container used for crystal growth were given schematically by the producer *(Figure 8)*. A photo of crystal A shows the contact faces with the bottom and the two sidewalls of the container *(Figure 9a)*. The growth direction of the crystal was slightly inclined to the b-axis (based on a morphological cell with a 4.42, b 9.39, c 5.47), and the free surface of the crystal (growing in contact with the argon atmosphere) and the face in contact with the bottom of the crucible were more or less parallel to the **a** (100) pinacoid *(Figure 9b)*.

This applies also to crystal B (Fig*ure 10)*. The two plane faces represent cleavage planes parallel to **b** (010), and the face in contact with the bottom of the container as well as the free surface of the crystal are almost parallel to the **a** (100) pinacoid. With this information, we were able to produce several alexandrite cubes with an exact orientation of the faces perpendicular to the a-, b- and c-axes of the crystal and a number of faceted alexandrites whose table facet was cut perpendicular to one of the three crystal axes *(Figure 6 a,b)*.

b. Microscopic features

Only limited information has hitherto been available about inclusion features of synthetic alexandrites grown in

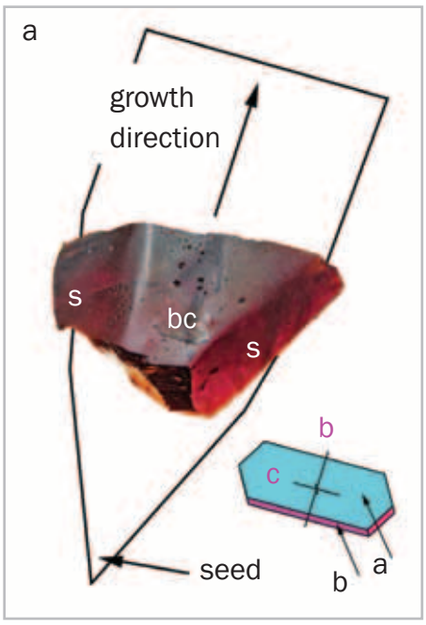

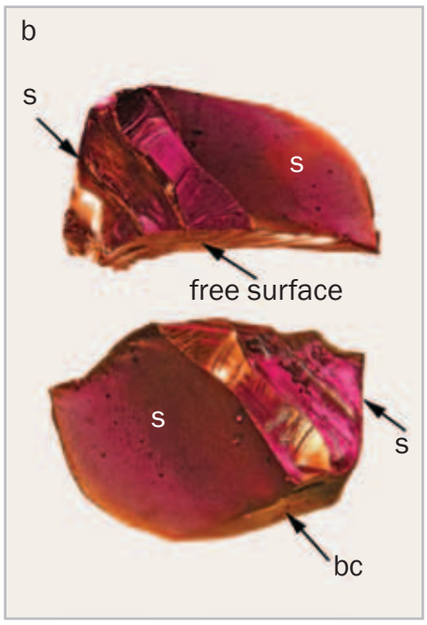

*Figure 9 a,b: View of sample A of Figure 8 parallel to the crystallographic a-axis (a) and parallel to the crystallographic b-axis (b). Photo (a) shows the sample from below and its approximate position in the molybdenum boat used for crystal growth; the position of the seed and the growth direction are also given. The sample shows two faces **s** which were in contact with the side walls of the container, and one face **bc** which was in contact with the bottom of the container; this latter face is parallel to the **a** pinacoid of an alexandrite crystal drawn schematically at the lower right, the growth direction is almost parallel to the b-axis, and perpendicular to the **b** pinacoid. Photo (b) shows the sample from the side, resting on a cleavage plane parallel to the **b** pinacoid, the two faces **s** in contact with the side walls of the container and the face **bc** in contact with the bottom of the container are indicated; the free surface of the crystal was grown in contact with the argon atmosphere within the crystallization chamber. Size of the crystal 48 × 23 × 24 mm, incandescent light. Photos by K. Schmetzer.*

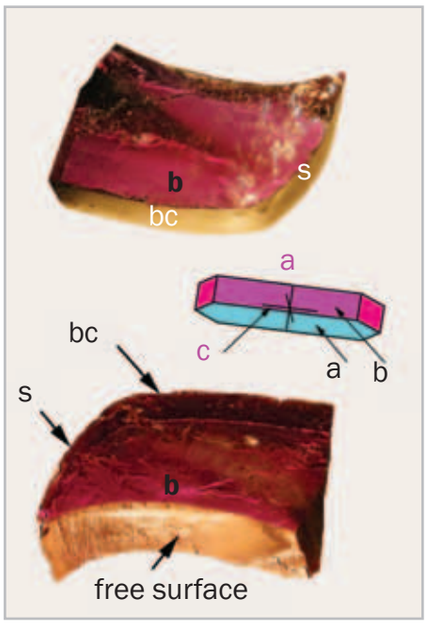

*Figure 10: Two different views of sample B of Figure 8 almost parallel to the crystallographic b-axis. The photos show the sample from each side, resting on a cleavage plane parallel to the **b** pinacoid (see schematic crystal drawing in the centre), the face **s** in contact with the side wall of the container and the face **bc** in contact with the bottom of the container are indicated. Size of the crystal about 38 × 23 mm, thickness 14.5 mm, incandescent light. Photos by K. Schmetzer.*

Novosibirsk by the HOC method. Gurov *et al.* (1988, 2003, 2008), Gulev *et al.* (1990) as well as Gurov and Tsvetkov (2008) mentioned the presence of growth striations and described small molybdenum platelets and molybdenum microparticles. Malsy and Armbruster (2012) pictured small cavities of unknown nature.

The microscopic features in both the samples obtained from V.V. Gurov and those found in the faceted samples purchased directly from Tairus, Bangkok, are identical, so they are now described together.

Structural features:

More or less curved growth striations, which represent the interface between the melt and the growing crystals *(Figure 11 a–d)*, are common. In some samples, numerous small bubbles or particles are related to the curved growth striations. In one part of the rough crystal an additional defect was present, which could be described as numerous irregularly oriented fissures and fibres *(Figure 12a)*. In areas with a lower concentration of these defects, the fibrous nature of the inclusions is clearly seen *(Figure 12b)*. Under crossed polarizers, no interference effects in adjacent parts of the alexandrite crystals were seen, so structural features such as twinning are ruled out as a cause *(Figure 12 c,d)*. At present, the formation mechanism of these inclusions, which could represent grain boundary defects within the alexandrite crystals, is not understood. These defects are only occasionally developed in the crystals (V. Gurov, pers. comm., 2012).

Irregularly shaped or elongated cavities:

In most slices of the rough crystals and in the faceted alexandrites, irregularly shaped, somewhat elongated cavities are present. In a view parallel to the b-axis, these cavities are normally transparent, but most appear opaque in a view parallel to the a-axis *(Figure 13)*. This morphology and especially the thickness in different directions indicates relatively flat and thin cavities, with their flat surface oriented perpendicular to the b-axis, i.e. perpendicular to the growth direction.

Under crossed polarizers, there was no microscopic evidence to suggest the presence of any solid phases, and only some reflections of the rims of these cavities were observed *(Figure 14 a,b,c)*. Upon rotation of the sample with that particular inclusion in the immersion microscope, total internal reflection for the complete surface of the flat cavities becomes visible *(Figure 14 d,e,f)*, which also indicates a homogeneous gaseous filling of the voids.

Very few birefringent small crystals were seen in the samples; some were

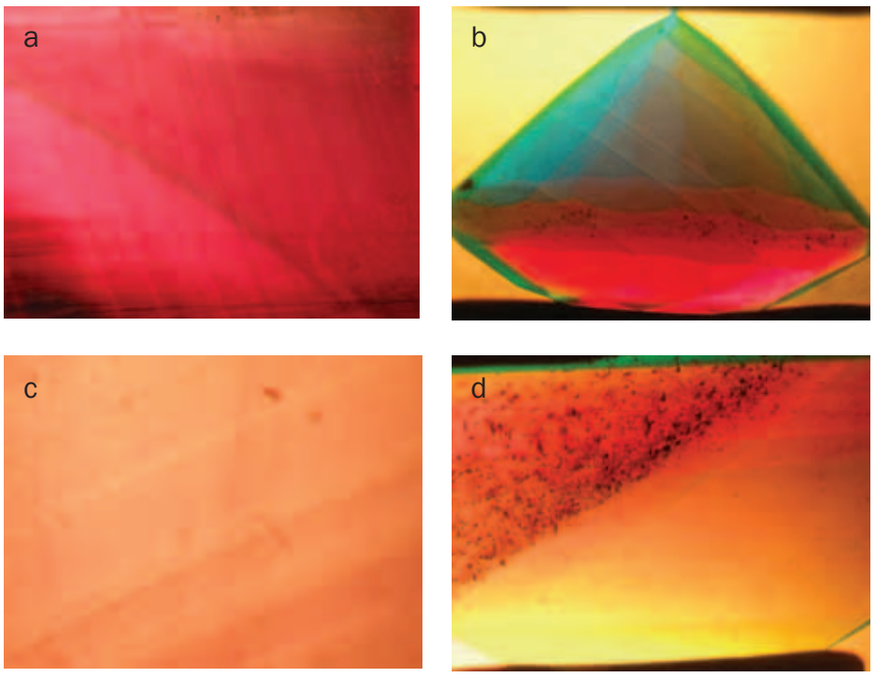

Figure 11: Various forms of growth striations in synthetic alexandrites produced by the HOC technique (a–d). Some samples contain numerous small particles concentrated along the growth striations (c); in others, the curved growth striations separate a part with extremely high concentrations of inclusions from more or less clean parts within the crystal (d). Immersion, field of view (a) 7.3 × 5.4 mm, (b) 6.3 × 4.7 mm, (c) 4.2 × 3.2 mm, (d) 6.7 × 5.0 mm. Photos by K. Schmetzer.

but others were not in contact with the flat voids described above (*Figure 15*). In plane polarized light, these birefringent tiny crystals are difficult to see, which indicates refractive indices close to the chrysoberyl host. Thus, these small crystals might be chrysoberyl or corundum.

In different samples, somewhat elongated voids or channels with partly transparent, partly opaque 'fillings' were seen *(Figure 16)*. After closer inspection of these inclusions in different orientations, the pattern can be attributed to flat cavities, which are transparent in a view parallel to the b-axis *(Figure 17B)*. In a view parallel to the a-axis, i.e. parallel to the thin rim of these cavities, and parallel to the flat side of the cavities, the formerly transparent parts become opaque, but additional transparent 'tails' or 'elongations' become visible at one or both ends of these elongated cavities *(Figure 17A)*. In a view along the c-axis *(Figure 17C)*, i.e. parallel

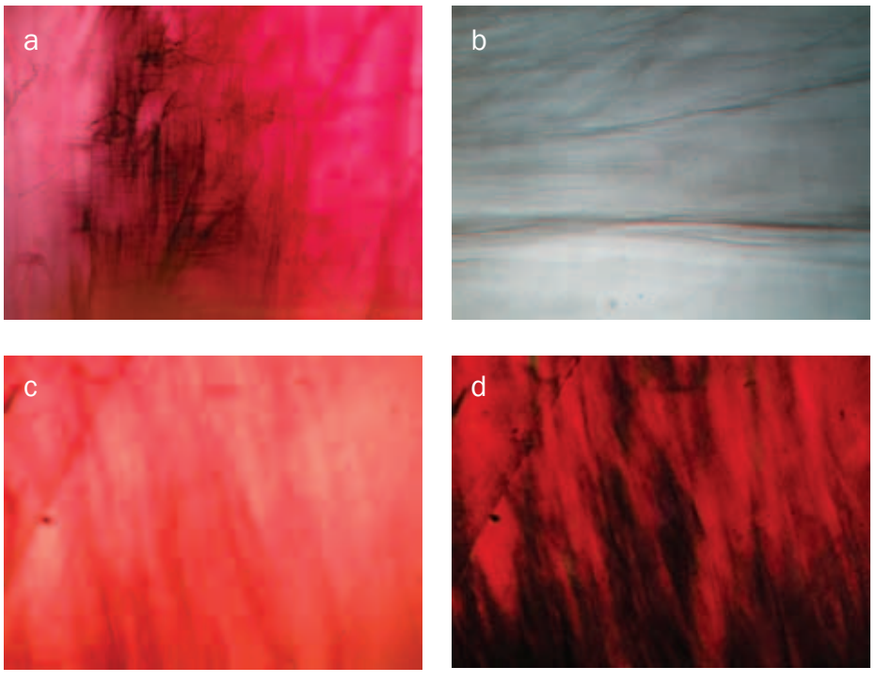

Figure 12: A few HOC alexandrites contain numerous irregularly oriented fissures and fibres (a–d); if a crystal with these features is viewed in plane polarized light (c) and then with crossed polarizers (d) it does not show any interference effects, which could indicate microtwinning if present. Immersion, field of view (a) 9.1 x 6.8 mm, (b) 7.6 x 5.7 mm, (c,d) 9.5 x 7.2 mm. Photos by K. Schmetzer.

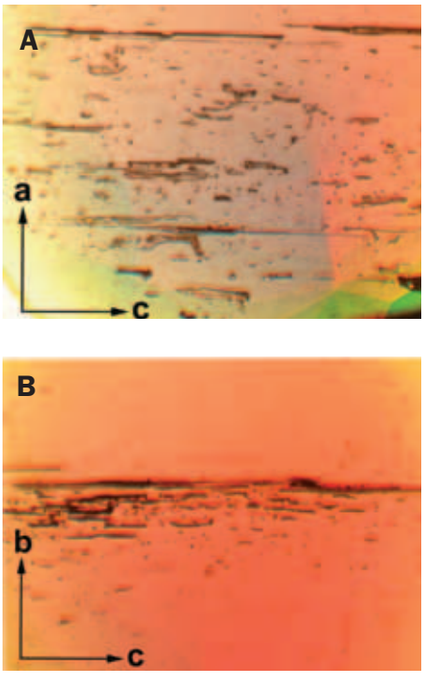

Figure 13: Elongated and occasionally somewhat irregularly-shaped flat cavities; viewed parallel to the crystallographic b-axis (A), the cavities appear transparent, whilst in a view parallel to the a-axis (B), they appear opaque. Immersion, field of view 4.2 × 3.1 mm. Photos by K. Schmetzer.

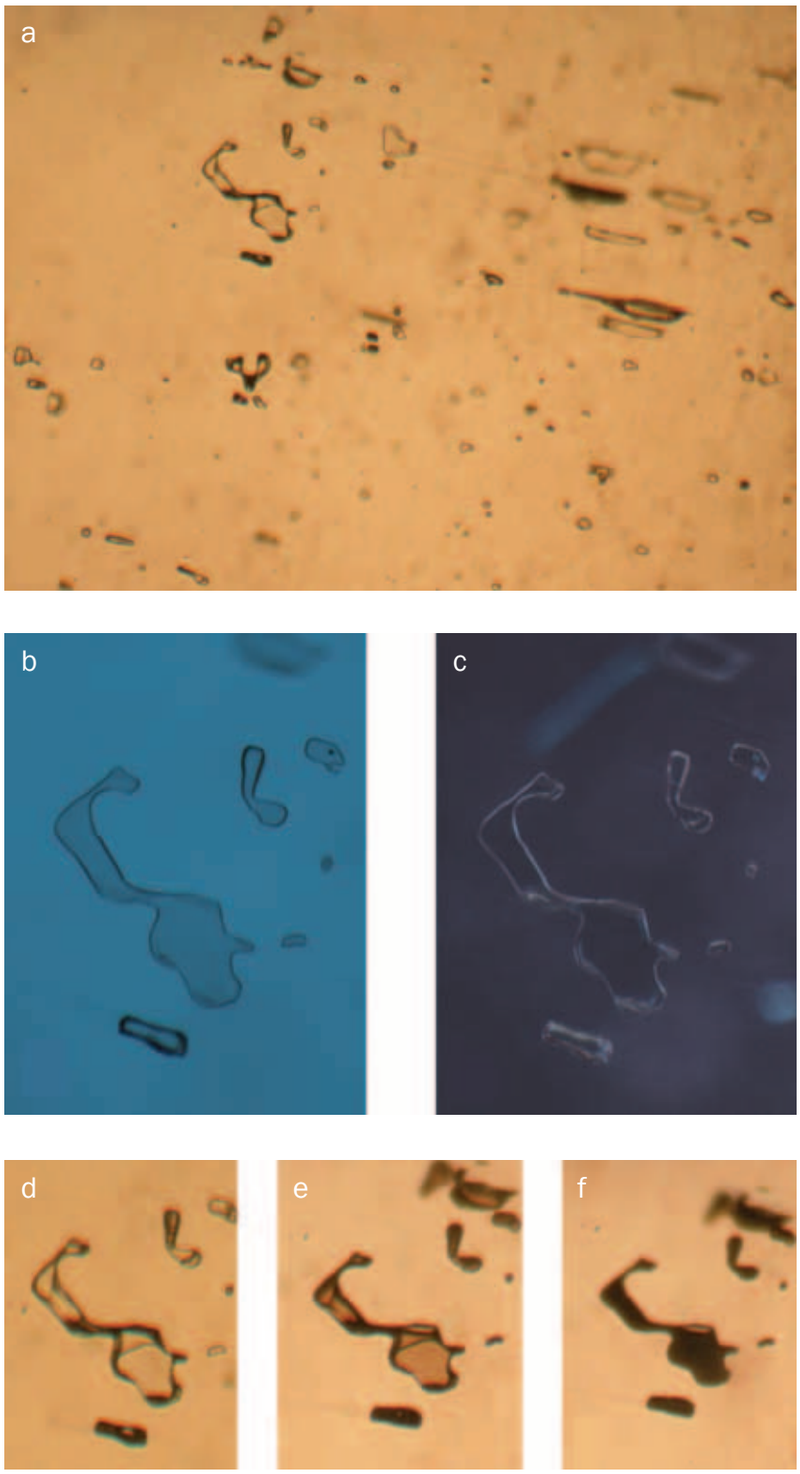

Figure 14: Irregularly-shaped flat cavities in an HOC alexandrite: (a) overview in the direction parallel to the b-axis; (b) in plane polarized light and (c) between crossed polarizers; in (c) only small reflections of the edges of the cavities are visible, but no birefringent solid phase is present; in immersion (d–f), under various angles to the illuminating light beam, the cavities appear transparent (d), semitransparent (e) or opaque (f). Field of view (a) 3.8 × 2.8 mm; (b–f) 1.05 × 0.8 mm. Photos a and d–f by K. Schmetzer; b and c by T. Hainschwang.

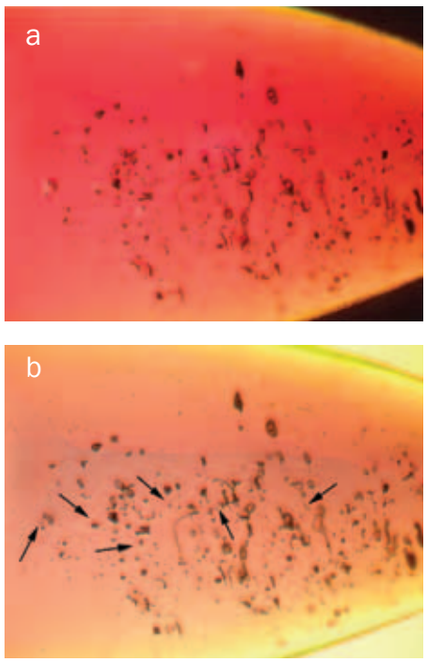

Figure 15: Rarely small birefringent inclusions are detectable under crossed polarizers (a), but these inclusions were extremely difficult to recognize in plane polarized light (b, see arrows); most of these birefringent crystalline inclusions were associated with flat cavities, but some were without contact with any internal cavity. Immersion, field of view 5.8 × 4.4 mm. Photos by K. Schmetzer.

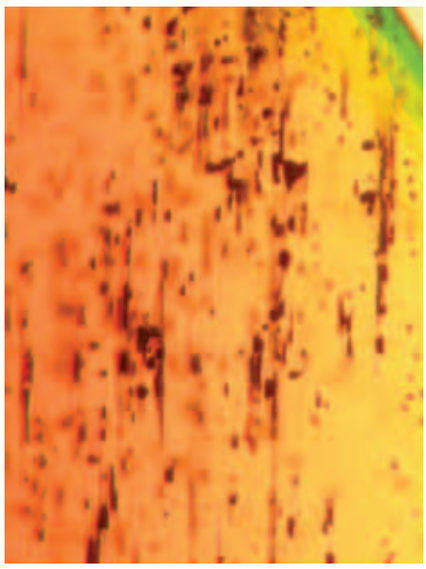

Figure 16: Some elongated voids or channels show partly transparent and partly opaque 'fillings'. Immersion, field of view 1.8 × 1.4 mm. Photo by K. Schmetzer.

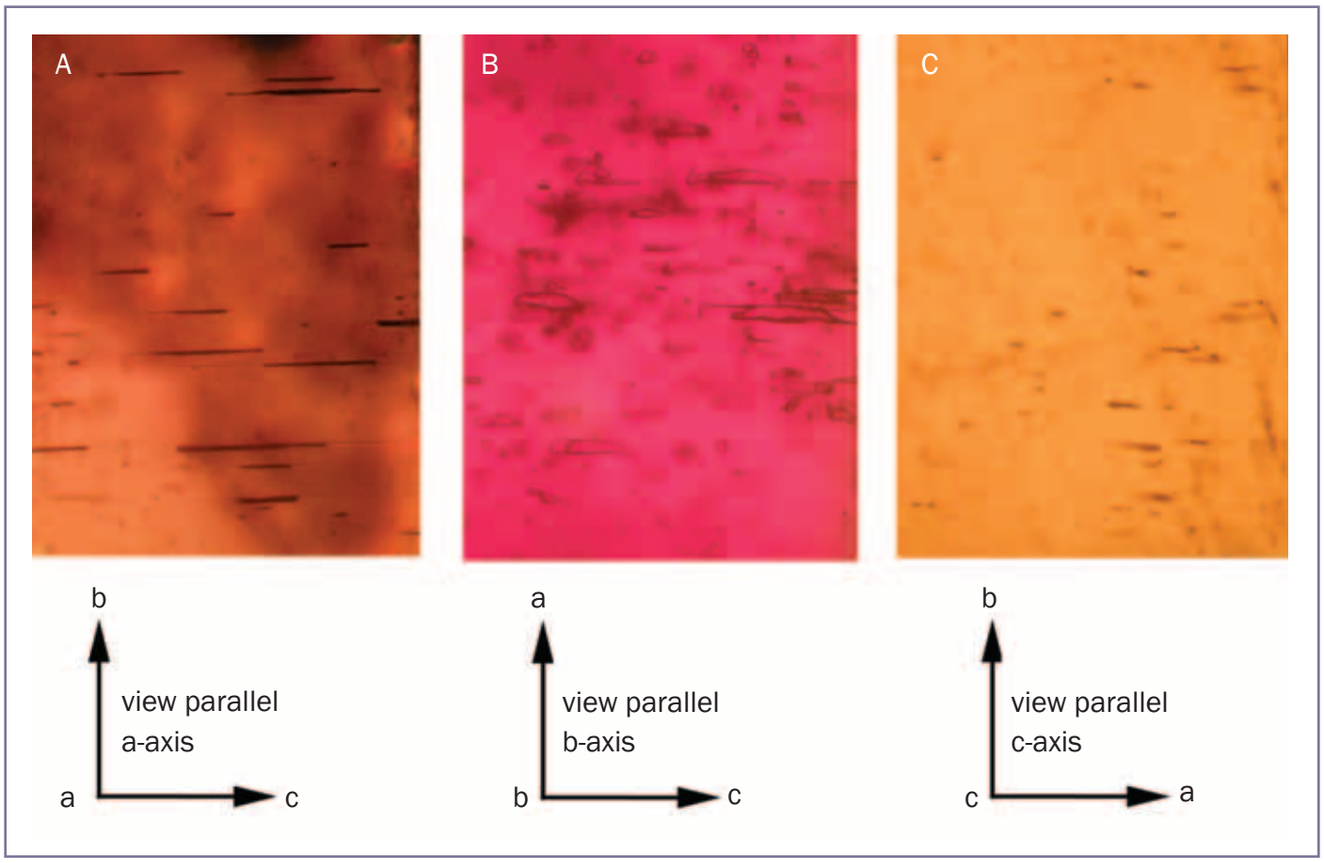

Figure 17: In different directions, the same flat cavities may appear transparent (B) or opaque with transparent 'tails' or 'elongations' (A), which are invisible in other directions; in a view parallel to the axes of these elongated cavities (C), only small flat inclusions are visible. Immersion, field of view (A–C) 2.3 × 1.7 mm. Photos by K. Schmetzer.

to the elongation of these flat cavities, only slightly elongated, flat channels or cavities are apparent. It seems that the 'tails' described above could represent the tracks of gases moving parallel to the c-axis to form the larger cavities and could be due to diffusion processes along the c-axis accompanying crystal growth from the melt.

Chemical properties

A slab of crystal B (see *Figures 5* and *8*) parallel to the **c** (001) face, i.e. parallel to the a- and b-axes of the crystal, was prepared. The dimensions were 18 mm from the free surface to the bottom of the container (parallel to the a-axis) and 14 mm in the growth direction (parallel to the b-axis; see also *Figure 10*). Five scans, each with 20 point analyses, were performed in the direction from the free surface to the bottom of the container along lengths from 12 to 16 mm, and at intervals between the different scans along the b-axis (parallel to the growth direction) of about 2 mm.

The results are presented in *Table I*. The dominant colour-causing element is chromium (0.30–0.43 wt% Cr_2O_3), with smaller amounts of vanadium also being present (0.07–0.14 wt% V_2O_3). The only other transition elements detected were Fe, Mn and Ti, near or at the limit of detection (0.01 wt% oxide) for the method. No systematic variation of these elements within the different scans nor between the five scans was observed *(Figure 18)*. These results show a relatively homogeneous distribution with no correlation between chromium and vanadium contents *(Figure 19)*. According

Table I: Trace element contents of synthetic alexandrites grown by the HOC technique (in wt%).

	This paper[1]		Malsy and Armbruster[2]	
	range	average	range	average
TiO_2	0.0–0.03	0.01	not detected	
V_2O_3	0.07–0.14	0.10	0.06–0.08	0.07
Cr_2O_3	0.30–0.43	0.38	0.25–0.46	0.38
MnO	0.0–0.03	0.01	below detection limit	
Fe_2O_3	0.0–0.03	0.01	below detection limit	

1. electron microprobe analyses, five scans each of 20 point analyses.
2. LA-ICP-MS analyses of five samples.

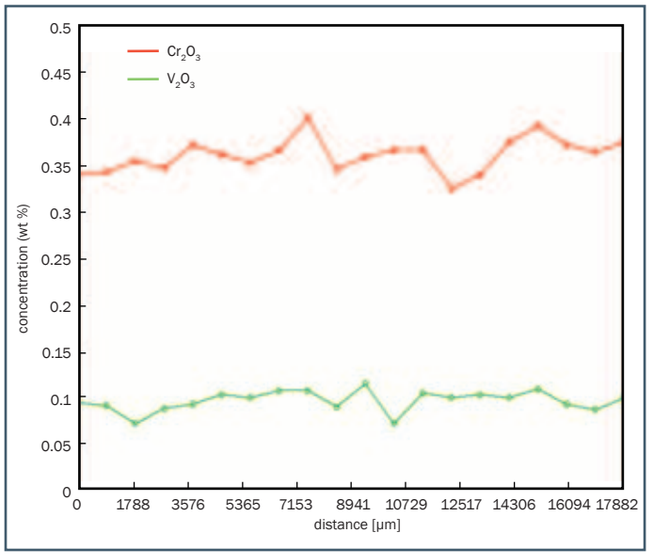

Figure 18: Plot of chromium (red) and vanadium (green) concentration measured by one electron microprobe scan across a polished slice of a synthetic alexandrite crystal which had been sawn parallel to the ab-plane (see Figures 5, sample B, and Figure 10); the chemical data reveal no specific pattern of chemical zoning in different parts of the crystal.

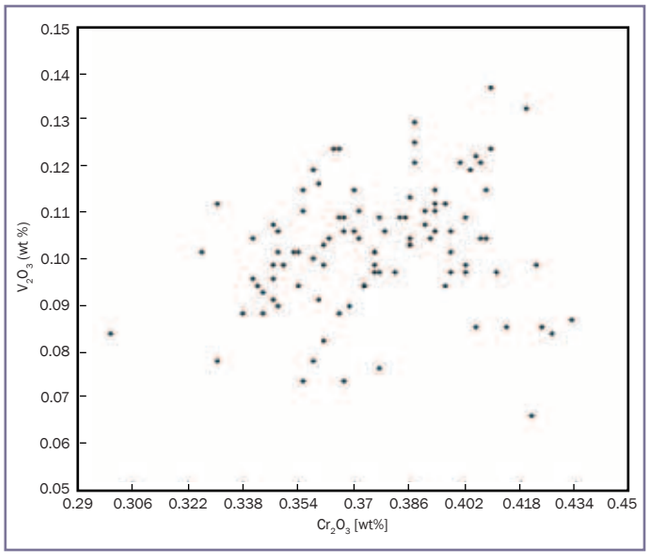

Figure 19: Chromium/vanadium binary diagram showing the variability of these trace elements in five scans of 20 analysis points each across a polished slice of synthetic alexandrite, sawn parallel to the ab-plane (see Figures 5 and 10); the scatter of points appears random, showing no correlation.

to information from the producer, any variation of trace element contents, especially of chromium, is found only at the beginning of crystal growth (close to the seed) and close to the end of growth next to the molybdenum container (V. Gurov, pers. comm., 2012). The contents of vanadium and chromium determined by Malsy and Armbruster (2012) for five samples grown by the same technique in Novosibirsk (material originating from Tairus, Bangkok) were in the same range (see *Table I*).

The colour of HOC alexandrites and their visible and ultraviolet range spectra

Colour and colour change in alexandrites are dependent on several factors, the three main ones being:

a. the direction of observation of a faceted gemstone or a rough alexandrite crystal relative to its orientation to the crystallographic axes, a, b and c;
b. the contents of colour-causing trace elements, especially chromium, vanadium and iron; and
c. the length of the path of light within a sample, which relates to its thickness.

Hitherto, to evaluate the dependency on orientation, faceted samples with different orientations of the table facet or crystals with known morphology have been measured spectroscopically and colorimetric parameters have been calculated. A correlation between colour and trace element contents has been established for alexandrites of known compositions. To examine orientation dependence within the same crystal, it has also been possible to examine three carefully oriented alexandrite cubes with faces parallel to the crystal axes (Schmetzer and Bosshart, 2010; Schmetzer and Malsy, 2011; Schmetzer *et al.,* 2012). However, it has not so far been possible to examine samples in different known orientations, which showed either an identical composition and different thickness, or samples with identical thickness and different composition. Therefore, because of the established small variation in chemical composition found in the HOC alexandrites, our samples seemed to be the ideal research material for the evaluation of colour and investigation of pleochroism for different orientations and thicknesses.

Chromium-bearing tourmalines, which have an absorption spectrum resembling that of alexandrite, show a colour variation with variable thickness, a phenomenon first described by Halvorsen and Jensen (1997) as the 'Usambara effect'. This causes these tourmalines to appear green when thin and red when thick. Colorimetric calculations in the CIELAB colour space assuming different sample thicknesses showed that samples showing the Usambara effect can also show an alexandrite effect, i.e. a colour variation between daylight and incandescent light (Liu *et al.,* 1999; Nassau, 2001). In addition, minerals showing these effects can also show pleochroism, and the relative influence of the different effects can be hard to separate (Halvorsen, 2006).

Thus, to evaluate and distinguish these various optical phenomena for alexandrite, several cubes were cut from the same optically homogeneous crystal (sample B) with their faces exactly orientated perpendicular to the three crystallographic axes of the chrysoberyl. Seven alexandrite cubes were prepared with edge lengths: 2 mm, 3 mm (two

Table II: Main features of the visible-range absorption spectra of HOC-grown synthetic alexandrites*

With polarization, absorption maxima and minima (in nm)

Polarization	X	Y	Z
Maxima	569	566	586
	414	420	422
Minima	483	494	489

Additional spin-forbidden chromium bands were observed at 680, 678, 655, 648, 645 and 472, 469, 467 nm.

Without polarization, absorption maxima and minima (in nm)

Orientation	a-axis	b-axis	c-axis
Maxima	570	572	569
	423	420	415
Minima	492	486	490

Additional spin-forbidden chromium bands were observed at 680, 678, 655, 648, 645 and 472, 469, 467 nm.

*Based on a morphological cell with a 4.42, b 9.39, c 5.47 and X || a, Y || b, Z || c.

cubes), 4 mm, 6 mm, 8 mm and 10 mm, all with polished faces. Their spectra were collected in the three directions parallel to the crystal axes, and colorimetric parameters were calculated for daylight and incandescent light in the CIELAB colour space. This information was plotted accordingly in the CIELAB hue circle (see Schmetzer *et al.,* 2009; Schmetzer and Bosshart, 2010).

Absorption spectra of X, Y and Z in polarized light for the cubes of 3 mm edge length are given in *Figure 20*, and spectra recorded in non-polarized light along the a-, b- and c-axis are depicted in *Figure 21*. The absorption maxima recorded *(Table II)* are consistent with literature data and assigned mainly to trivalent chromium with some influence of vanadium (see, e.g., Farrell and Newnham, 1965; Bukin *et al.,* 1980), because the absorption bands of vanadium and chromium cannot be distinguished in the spectra of vanadium- and chromium-bearing samples (Schmetzer and Bosshart, 2010); the influence of emission is commented on in Box B. No absorption bands of iron were detected, which is consistent with the

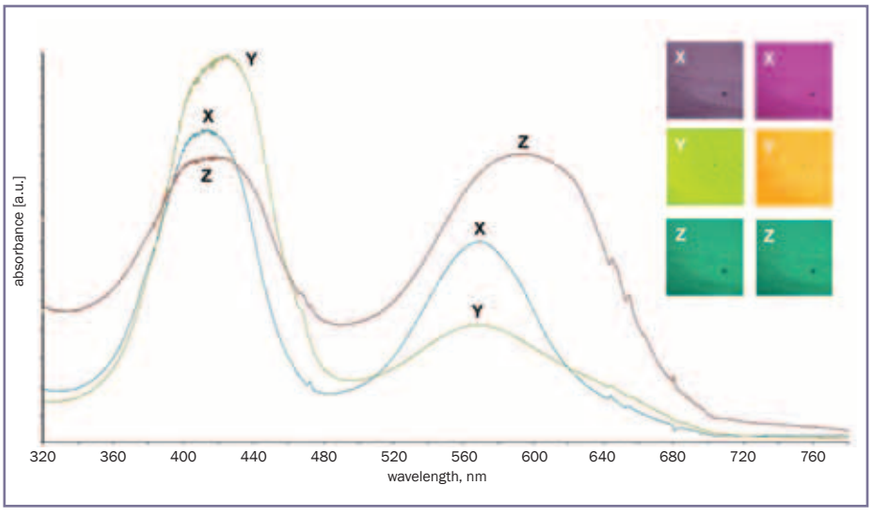

Figure 20: Absorption spectra of a synthetic alexandrite cube produced by the HOC technique (see Figure 6) for polarized light (with X || a, Y || b and Z || c); the colours of the cube in polarized light are depicted for daylight (left column) and incandescent light (right column).

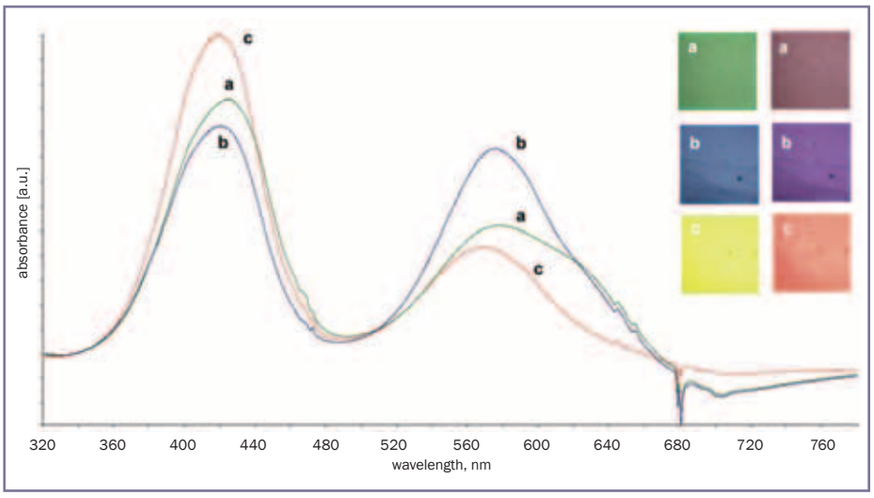

Figure 21: Absorption spectra of a synthetic alexandrite cube produced by the HOC technique (see Figure 6) for non-polarized light in different views parallel to the a-, b- and c-axes, the colours in these directions are depicted for daylight (left column) and incandescent light (right column).

Box B:

In addition to absorptions, there may be two principal Cr^{3+} emissions which are sometimes detected as 'negative' peaks in our spectra and, at the lower energy side (longer wavelength) of these peaks, additional luminescence bands may be present, also seen in the 'negative' direction. This effect is caused by the use of a CCD type Czerny-Turner spectrometer in combination with an integration sphere. Such a setup permits the detection of all wavelengths at the same time in contrast to a traditional scanning spectrometer. In samples with strong luminescence, the light source used to record spectra also excites fluorescence, which is detected at the same time. When the absorption dominates the emission, the peaks will point in the 'positive' direction while in the case of dominant emission, the absorption/luminescence peaks will point in the 'negative' direction.

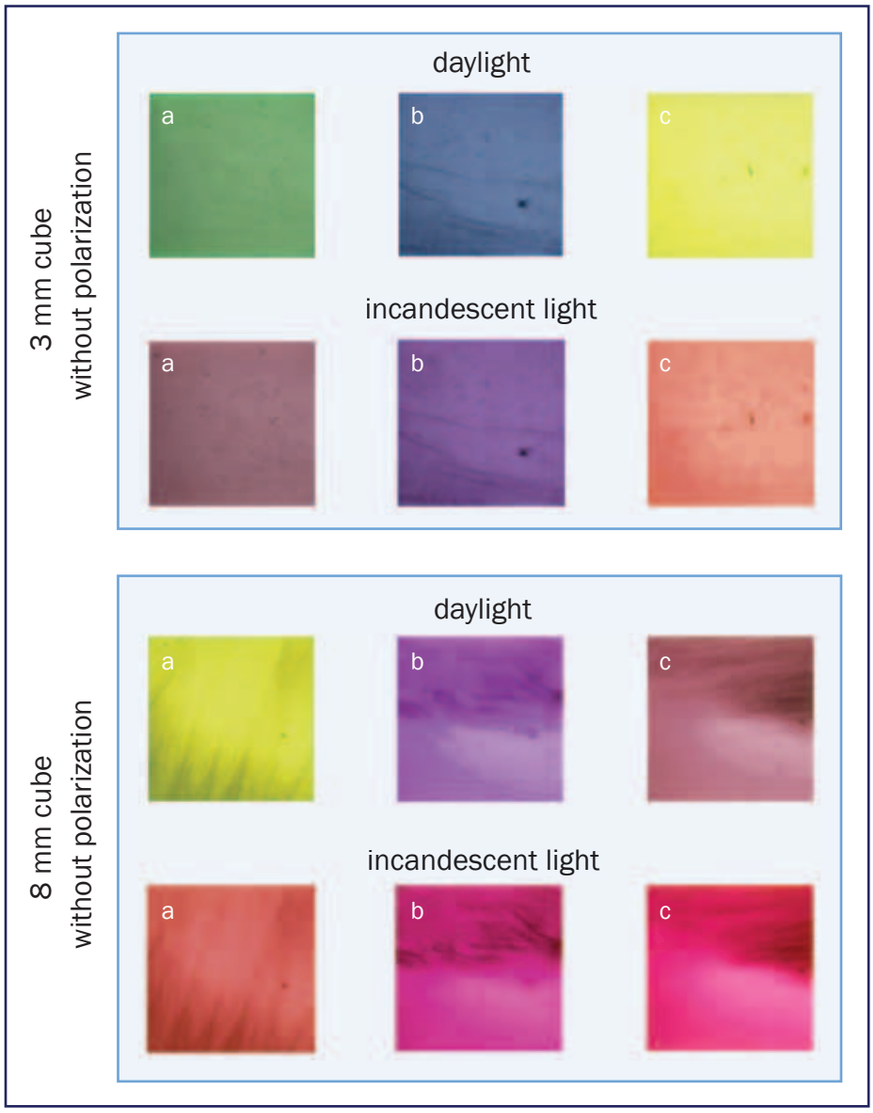

Figure 22: Schematic representation of colour and pleochroism in two cubes of HOC synthetic alexandrite with edges of 3mm and 8mm, in daylight and incandescent light; the cube faces are exactly perpendicular to the a-, b- and c-axes of the alexandrite crystal; with the unaided eye (in non-polarized light) different views parallel to the these three axes are depicted. The illustration demonstrates a combination of pleochroism, the alexandrite effect in daylight and incandescent light and the Usambara effect for different path lengths of light. Photos and artwork by K. Schmetzer.

low iron contents determined by electron microprobe.

In polarized light, there is a distinct change of colour from daylight to incandescent light for X and Y, but an almost identical bluish green is apparent in the Z direction for daylight and incandescent light *(Figure 20)*. This distinct pleochroism enables one to determine the approximate orientation of a rough crystal or a faceted gemstone in the immersion microscope, using a tungsten bulb or a light source with daylight-equivalent illumination.

In non-polarized light the colours and spectra along the three crystal axes a, b, and c are always dependent on two of the three vibration directions X, Y and Z *(Figure 21)*. The pleochroism indicates that the most brilliant green in daylight is visible parallel to a, but a more distinct colour change is seen in the direction parallel to c. Furthermore, in the direction parallel to b, the colour change is also distinct — from an intense greenish blue to violet purple. This indicates that there is no orientation of the alexandrite in which one can see both the most brilliant green and the most spectacular colour change from the same direction.

In *Figure 22* the colour and pleochroism of two alexandrite cubes (with edge lengths of 3 mm and 8 mm) are depicted for non-polarized daylight and incandescent light. The colours are summarized for non-polarized light in *Table III*. Also, the colorimetric parameters for the seven alexandrite cubes have been calculated from spectra for non-polarized light and are plotted in *Figure 23* to demonstrate the colorimetric parameters obtained graphically.

A strong dependence of colour and colour change on the length of the light path (Usambara effect) within the samples is evident. In particular, with increasing sizes of the alexandrite cubes, an increase of redness is observed for the colour in daylight and also for the colour in incandescent light. However, together with this increasing redness, there is a slight increase of blueness for the view parallel to the a-axis, a moderate increase of yellowness for the view parallel to the b-axis, and a distinct increase of blueness in the view parallel to the c-axis *(Figures 23, 24)*.

In chromium-bearing tourmaline showing the Usambara effect, absorption spectra reveal two areas with high transmission, namely in the red and in the yellowish green (around 540 nm). With increasing sample thickness, the transmittance in both areas is reduced, but the rate of decrease is greater in the green range compared to that in the red area. This effect is used to explain the increasing redness in tourmaline with increasing path length of light through the sample (Liu *et al.,* 1999; Nassau, 2001). In alexandrite spectra also there are two areas with high transmission (see *Figures 20, 21*), but in these stones the shorter wavelength transmission maximum is shifted to bluish green. In addition, the absorption maxima for alexandrite and tourmaline are different. Nevertheless, the

basic concept to explain the increase of redness with increasing sample thickness described for tourmaline might also apply to alexandrite.

Also, with increasing thickness, the lightness of the alexandrite cubes decreased in all three directions, e.g. from a range of L* 75–85 for the 2 mm cube to a range of L* 25–30 for the 10 mm cube. In other words, the larger samples were relatively dark. This effect explains why larger brilliant alexandrites with chromium contents in the region of 0.4 wt% Cr_2O_3 (as determined for our HOC-grown alexandrite) or above and that have good colour and colour change are extremely rare.

Although we could not measure exactly oriented cubes of the same size with different chromium contents, we would predict from basic spectroscopic and physical equations, that increasing chromium contents in samples with comparable light paths would cause a comparable alteration of colour as demonstrated in this paper for samples with identical chromium concentration and variable thickness (Usambara effect).

The samples examined for this paper are iron-free alexandrites. However, natural alexandrites from different sources as well as some flux-grown synthetic alexandrites contain various amounts of iron. Chromium- and vanadium-free, iron-bearing chrysoberyl is yellow and reveals only weak pleochroism. Thus, it is concluded that a distinct iron-content in an alexandrite increases its yellowness. Thus we selected samples with and without iron-contents but with other properties (thickness and trace element contents) which make them 'comparable'. If we plot the colorimetric parameters of the two 3 mm HOC cubes measured for this paper (average chromium contents 0.38 wt% Cr_2O_3) and the parameters of a flux-grown alexandrite cube produced by Creative Crystals with a 6 mm edge length (average chromium contents 0.20 wt% Cr_2O_3, average iron content 1.05 wt% Fe_2O_3, Schmetzer *et al.*, 2012) we observe an increase of yellowness for the iron-bearing sample for all three directions of view parallel to the crystal axes *(Figure 25)*. A similar effect, i.e. increase of yellowness, is predicted for natural iron-bearing samples.

The observed colour change shown in *Figure 22* and the schematic diagrams depicted in *Figures 23* and *24* illustrate the difficulty of finding the 'best' orientation for the table facet for alexandrites of different thickness or size as well as with different chromium contents. All three effects — pleochroism, alexandrite effect and Usambara effect — contribute to the colour of a faceted

Table III: Colours of two alexandrite cubes in daylight and incandescent light

Size (edge length)	Light source	Direction of view parallel to the		
		a-axis	b-axis	c-axis
3 mm	daylight D_{65}	green	greenish blue	greenish yellow
	incandescent light A	reddish grey	violet	slightly red orange
8 mm	daylight D_{65}	yellowish green	violet purple	reddish grey
	incandescent light A	red orange	red purple	purplish red

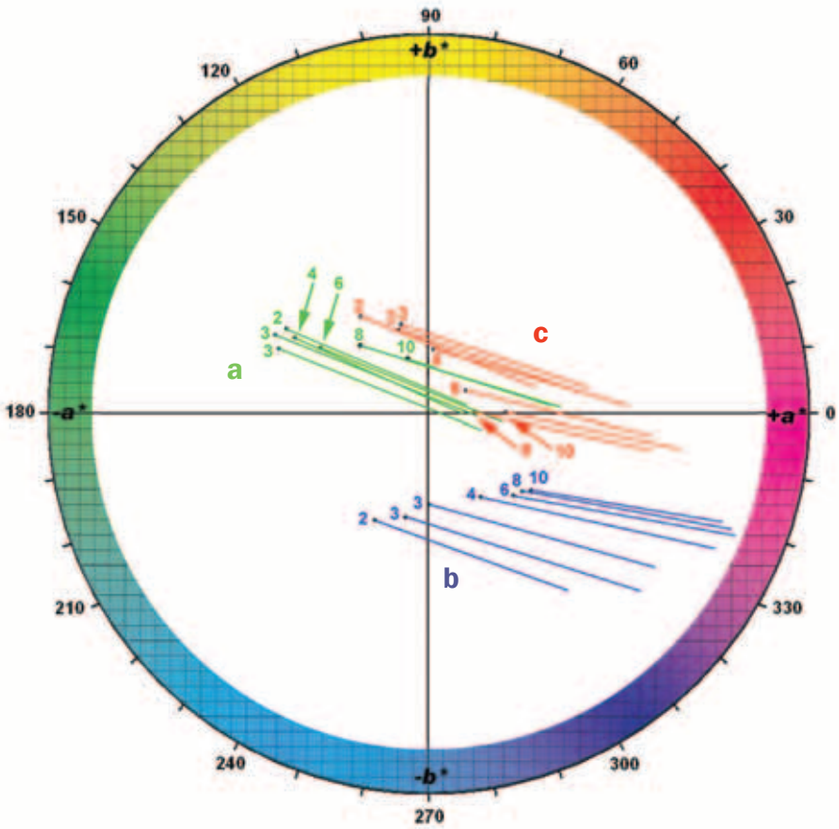

*Figure 23: Colorimetric parameters for seven exactly oriented alexandrite cubes with different sizes are plotted for daylight and incandescent light in the CIELAB colour circle; the neutral point (white point) is in the centre of the a*b* coordinate system, the black circles represent the coordinates in daylight D_{65} and the ends of the differently coloured bars represent the coordinates in tungsten light A; the outer circle represents a chroma of 40. The dependency of colour and colour change on stone orientation in views parallel to the a-axis (green bars), b-axis (violet bars) and c-axis (red bars) is evident. With increasing sizes of the cubes (edge lengths from 2 mm to 10 mm as indicated) a shift of colour is visible; for all three different orientations, the change from daylight to incandescent light is confined to an increase of redness and blueness (alexandrite effect); in addition, the larger the cube, the more red does the alexandrite appear in both daylight and incandescent light (Usambara effect).*

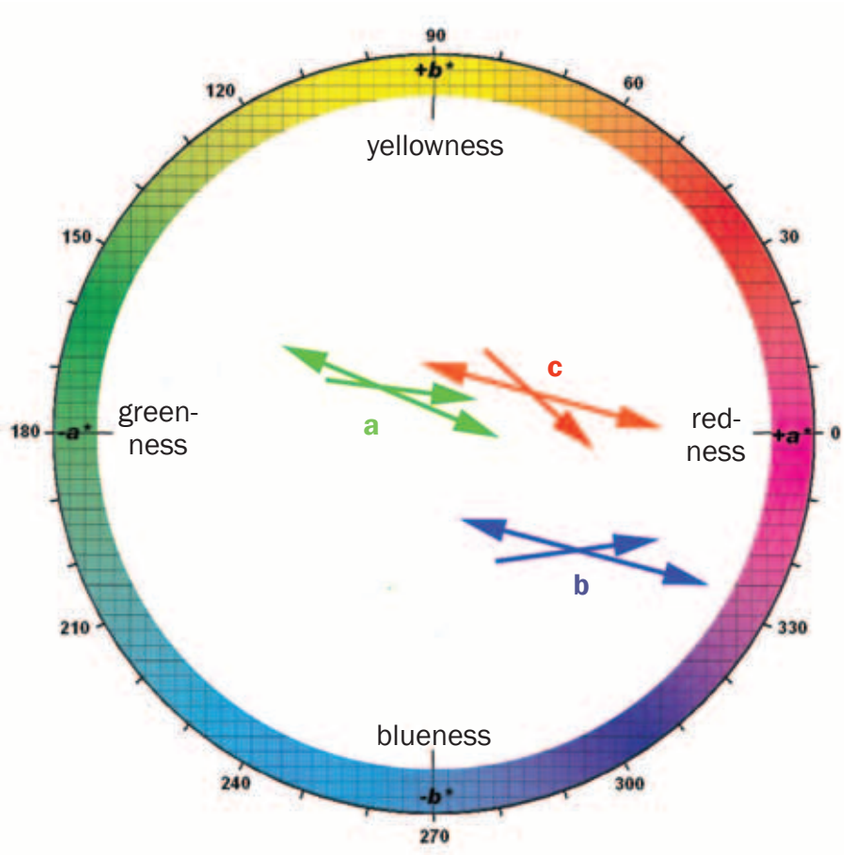

Figure 24: CIELAB colour circle with a schematic representation of the alexandrite effect (double-headed arrows) and Usambara effect (single-headed arrows) for the seven alexandrite cubes in directions of view parallel to the a-axis (green arrows), b-axis (violet arrows) and c-axis (red arrows). With a change of illumination between daylight and incandescent light, the alexandrite effect is based upon the increase of redness and blueness for all three directions of view. With a lengthening of the light paths within different cubes, the Usambara effect is caused by increasing redness of the samples, but with varying (increase or decrease) of blueness and yellowness for the three directions of view.

stone. This indicates why an orientation of the table facet that is appropriate for smaller samples or for samples with lower chromium contents can be inappropriate for larger samples or for samples with higher chromium contents for obtaining an alexandrite with the most desirable colours, green to bluish green in daylight and reddish purple to purple in incandescent light. It also clarifies why predicting the colour and colour change of a stone to be faceted from the rough is so difficult.

Infrared spectroscopy

Infrared spectra were recorded with beam directions parallel to the a-, b- and c-axes of the crystal, i.e. perpendicular to the faces of one oriented cube. The spectra showed absorption bands with maxima at 2970 and 2655 cm^{-1} and shoulders at 2030 and 1995 cm^{-1} *(Figure 26)*. Although the spectra were recorded without polarization of the primary beam, the two bands at 2970 and 2655 cm^{-1} showed a clear polarization dependency. They were recorded in the spectra parallel to the b-axis (representing a combination of X and Z) and parallel to the c-axis (representing a combination of X and Y), but not in the spectrum parallel to the a-axis (representing a combination of Y and Z). These results indicate a polarization of these absorptions parallel to X.

Spectra along the three crystal axes of a Czochralski-grown synthetic alexandrite were also recorded for comparison. The position and polarization of absorption bands found are identical with the spectra of the HOC crystal *(Figure 26)*. Similar spectra were recorded for a cube of flux-grown synthetic alexandrite produced by Creative Crystals. This sample, however, showed an additional band at 3225 cm^{-1} (Schmetzer *et al.,* 2012).

These results are consistent with infrared spectra published for different types of chromium-, vanadium- and iron-bearing synthetic alexandrites, which showed small absorption bands in the same spectral range (Henn, 1992; Schmetzer *et al.,* 1996; Malsy and Armbruster, 2012). The different intensities of infrared absorption bands in natural and synthetic alexandrites have already been mentioned by Stockton and Kane (1988). The polarization dependency indicates that absorptions are due to structural OH-groups, as described in detail for polarized spectra of natural chrysoberyl by Bauerhansl and Beran (1997) who also showed a polarization in the X direction, although the absorption maxima recorded in natural stones were in somewhat different positions compared to our synthetic samples.

Summary and Discussion

The HOC technique has been applied since the late 1980s in Novosibirsk for the growth of large alexandrite single crystals. The method allows the production of very homogeneous chromium- and vanadium-bearing crystals of 400 to 450 g in weight. There has been commercial production and release of rough and faceted material to the international market since 1994.

The examinations presented in our paper show that the internal properties of the gemstones closely reflect the growth conditions present during the HOC process. In most samples, with some searching, curved growth striations are visible, which represent the moving phase boundary between the melt and the growing alexandrite crystal. Flat elongated, sometimes irregularly shaped cavities are oriented parallel to the **b** (010) pinacoid, i.e. perpendicular to the main growth direction.

The large dimensions and homogeneity of the crystals have allowed

Synthetic alexandrites grown by the HOC method in Russia

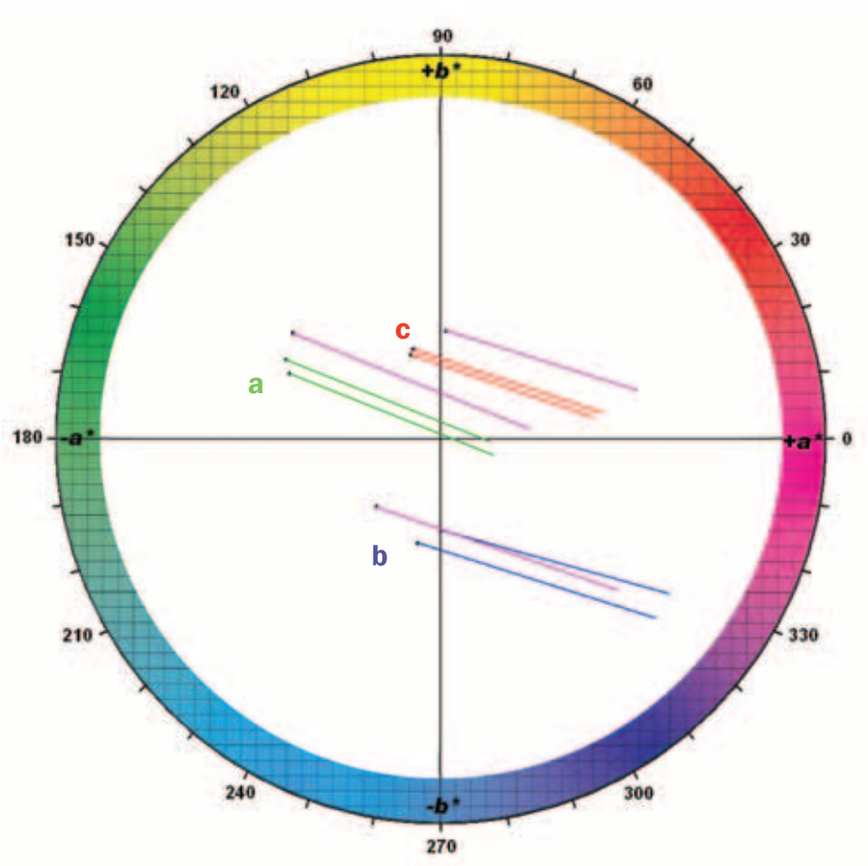

*Fig. 25: Colorimetric parameters for two exactly oriented iron-free alexandrite cubes grown by the HOC method with edge lengths of 3 mm are plotted for daylight and incandescent light in the CIELAB colour circle; the neutral point (white point) is in the centre of the a*b* coordinate system, the black circles represent the coordinates in daylight D_{65} and the ends of the differently coloured bars represent the coordinates in tungsten light A, the outer circle represents a chroma of 40. The dependency of colour and colour change on stone orientation in views parallel to the a-axis (green bars), b-axis (violet bars) and c-axis (red bars) is compared with colorimetric parameters of a flux-grown iron-bearing alexandrite cube (purple bars). This alexandrite crystal has edges of 6 mm, but its chromium content is about half that of the chromium contents measured in the two other alexandrite cubes. The influence of iron causes an increase of yellowness of the iron-bearing sample in all three directions of view.*

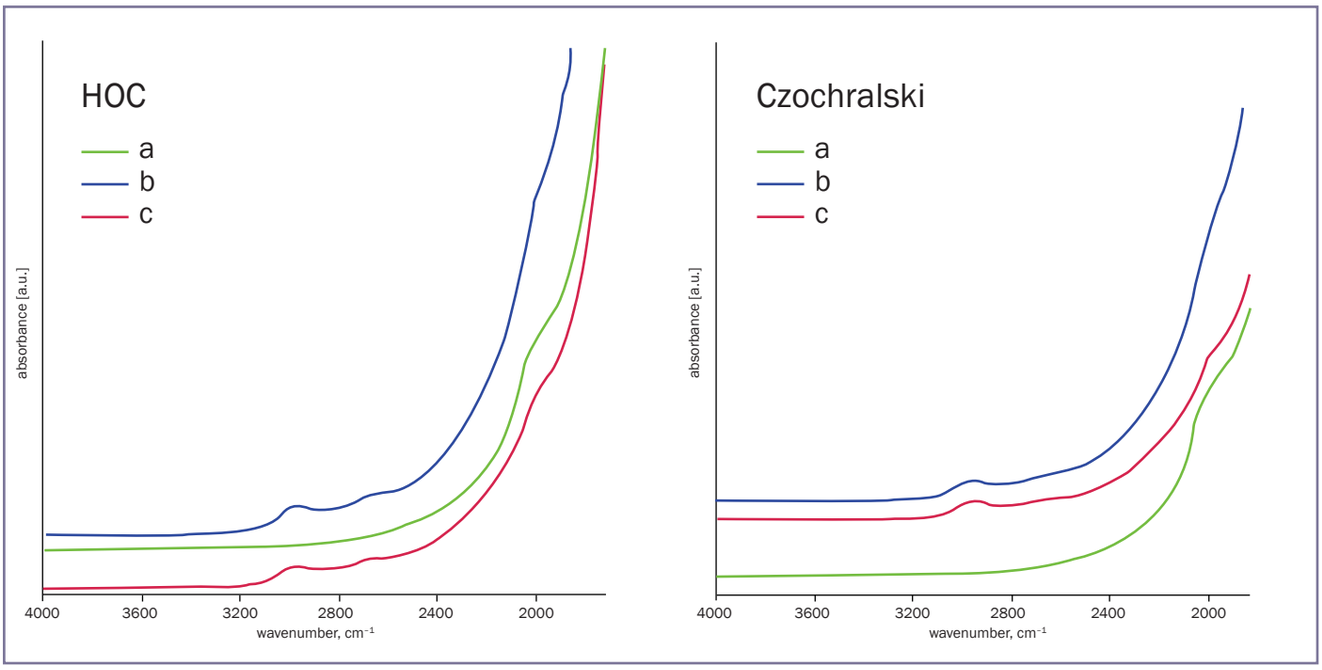

Figure 26: Infrared spectra of a HOC-grown synthetic alexandrite cube in non-polarized light in views parallel to the a-, b- and c-axes of the crystal (left): the small absorption maxima are observed only in spectra representing views parallel to the b- and c-axes which indicates a polarization of these weak absorption bands parallel to X. Spectra of a Czochralski-grown synthetic alexandrite, produced in Novosibirsk in the 1990s, are shown on the right for comparison and indicate no significant difference in this property from the HOC-grown stone.

the examination of several oriented cubes of different sizes. With this research material, the pleochroism, colour change (alexandrite effect) and colour variation with sample thickness (Usambara effect) in the crystals have been distinguished and clearly described.

In Czochralski-grown synthetic alexandrites, curved growth striations and gas bubbles are common and there can be a few somewhat elongated cavities. Thus, a clear separation of Czochralski- and HOC-grown alexandrites is not always possible using only the microscope, especially for the smaller faceted stones. However if a stone has cavities matching the description in this paper in detail, it is a good indicator that it is an HOC-grown stone.

In 1986, C. Trossarelli described three semi-rough (sawn) alexandrite crystals from a new production in the USSR. He mentioned curved striations associated with 'bubble streams', larger bubbles at or near the surface and various forms of flat irregularly-shaped and sometimes tailed cavities. He concluded in his paper that these samples were probably grown by the Czochralski method, but now he considers that they could have been actually produced using the HOC method (C. Trossarelli, pers. comm., 2012). Unfortunately, these were loan samples and are not available for re-examination but these three crystals could be samples of the first experimental state of crystal growth by the HOC method in Russia.

In the last two decades, at different times there have been rumours of the presence in the market of hydrothermally grown synthetic alexandrites. In 1992, U. Henn described several types of synthetic alexandrites which had been produced by different techniques (designated as flux-grown, hydrothermally-grown and Czochralski-grown samples) in various locations of the former USSR. The samples assigned to the hydrothermal production showed irregularly shaped, elongated flat cavities, which closely resemble the common inclusion type described in this paper for HOC-grown stones. The samples, which were loaned to Dr Henn with the designation 'hydrothermally-grown synthetic alexandrites' were only available for some days for examination and no similar material has since come to light (U. Henn, pers. comm., 2011, 2012). Another kind of synthetic alexandrite was briefly mentioned by Bank *et al.* (1997) and also designated as hydrothermally-grown, but this showed a quite different inclusion pattern.

Since then, the present authors have been informed that some limited research on hydrothermal synthesis of chrysoberyl and alexandrite was carried out at the Institute of Geology and Geophysics at the Siberian Branch of the USSR Academy of Sciences in Novosibirsk in the 1990s. Further research is now being performed at the Tairus company in Novosibirsk. However, according to the information available to the authors, no faceted or rough material of gem quality of hydrothermally-grown synthetic alexandrite has ever been released on to the market from Novosibirsk (V. Thomas, Tairus company, Novosibirsk, pers. comm., 2012). So the origin(s) of the samples described in 1992 and 1997 (see above), no longer being available for comparison, remain(s) in doubt.

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Structural features of new varieties of freshwater cultured pearls in China

Professor Li Liping and Wang Min

Abstract: Some new varieties of freshwater cultured pearls in different shapes have emerged onto the Chinese market, including both non-beaded and beaded special shape pearls, and second generation cultured pearls. The culturing process to produce the new-shaped pearls is investigated and many samples in pearl-culturing farms in the Shanxiahu area, Zhuji City, Zhejiang Province, China, were collected. The gemmological microscope, cathodoluminescence microscope and Raman spectroscope were used in detecting the structures of a comprehensive sample of the new varieties in special shapes, and X-ray diffraction was used to detect the composition of the central parts of the new varieties. The results reveal that the structures of the new varieties of freshwater cultured pearls compare closely with those of traditional varieties of freshwater cultured pearl: a series of concentric nacreous layers and, for beaded pearls, nacreous layers around the bead. The nacreous layers consist mainly of aragonite, a little vaterite and some organic substance, which is the same as that in traditional cultured freshwater pearls.

Keywords: composition, freshwater cultured pearls, new varieties, structure

Second generation pearls.

1. Introduction

The production of pearls in China has experienced rapid growth in the past five decades. Since 2005, the yield of freshwater cultured pearls in China has generally been more than 1200 tonnes, maintaining the highest national output in the world, and accounting for over 90% of the total annual yield (see *Table I*).

First and foremost, the achievement is attributed to optimization of the breeding of mussels, improvement of surgery techniques, and reinforcement of culturing management. By utilizing variety and quality appraisal, hybridization and other biological techniques, the Kang Le mussel, a new hybrid of *Hyriopsis schlegelii* and *Hyriopsis cumingii*, was successfully cultivated using a patented technique. Three years after the implant operation, compared with *Hyriopsis cumingii*, the average width and weight of Kang Le mussels increased by 25.66% and 46.98% respectively. Together with a 31.96% increase in yield, the average size of pearls produced increased 23.32% and the proportion of large and good quality pearls increased by a factor of 3.72[1].

Table I: The yield of Chinese freshwater cultured pearls in recent years.

Year	Yield (ton)	Percentage of the total yield worldwide
2005	1200	95%
2006	1550	96%
2007	1600	96%
2008	1400	94%
2009	1200	94%
2010	1000	93%

Traditional and simple ways of pearl processing – drilling and stringing – have evolved to include faceting, embedding and engraving[2]. Now, various kinds of beaded and non-beaded pearls can also be cultivated by changing the shape of the mantle implant and the position in which it is inserted.

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Figure 1: Long strip pearl.
Figure 2: Cross-shaped pearl.
Figure 3: Square flake beaded pearls.
Figure 4: Round disc-shape beaded pearls; the one indicated with the arrow is the round flake nucleus.
Figure 5: Rectangular flake beaded pearls.

Figure 6: Second generation flake or petal-shape pearls.

Figure 7: Soufflé pearls.

2. New varieties of freshwater pearl and their cultivation techniques

Roundness has traditionally played an important role in pearl quality appraisal — this also being an appreciation of the rarity of this shape in natural populations. Like the natural population, most non-beaded freshwater cultured pearls are off-round or elliptical, and their prices are rather low. The same is true for new varieties of baroque cultured freshwater pearls, which comprise:

a. Non-beaded cultured pearls of elongated bar shapes such as long strip pearl *(Figure 1)*, and cross-shaped pearls *(Figure 2)*.
b. Flat, beaded cultured pearls of rhombic shape *(Figure 3)*, circular or round (so-called coin pearls) *(Figure 4)*, and rectangular pearls *(Figure 5)*.
c. Second generation pearls of a thin flake or petal shape *(Figure 6)* and bubble-shaped so-called soufflé pearls *(Figure 7)*.

2.1 Appearance and culturing techniques of non-beaded cultured baroque-shaped pearls

Depending on the shape of the mantle tissue implant, non-beaded cultured pearls can accordingly take various shapes, such as elongated bars and crosses. Usually, additional characteristics will disturb the smoothness of the surface of the pearls and affect their appearance. Colours are typical for pearls of freshwater origin, mostly white, orange and purple. However, a colourful iridescence, leading to peacock, gold and purple hues, is quite common. Surfaces are usually wrinkled and folded to some degree and their lustre can vary over the surface of a single pearl; the larger non-beaded cultured pearls generally have a high lustre.

The culturing routine for non-beaded cultured pearls follows the established pattern of providing spat for the cultivation of parent mussels, followed by implantation and farming techniques prior to the pearl harvest. However, there are now stricter requirements in the selection and cultivation of parent mussels, and the method of implantation.

a. Donor mussels used for the grafting process should be high-quality *Hyriopsis cumingii* shells, one to two years old, with a length of over 10 cm, grown at the muddy bottom without fertilizers. They are moved into a pool and hung at a depth of 20–30 cm from the water surface for 10–15 days before they are operated on[3].
b. The mantle tissue (epidermal cells) of the donor mussel is cut into small pieces of different shapes. For instance, long-strip shapes are used if the desired pearl shape is an elongated bar.
c. For the grafting process, a shell opener and a cork are used to keep the shell open, and the inner soft body and the abdominal foot are pushed aside. Prepared tiny pieces of mantle tissue are now implanted into the mantle of the mussel. If the desired pearl is cross shaped, two strips of mantle tissue have to be implanted at a right angle to each other.
d. At the end, grafted mussels are put into the water to recover.

2.2 Appearance and culturing techniques of beaded cultured pearls displaying new shapes

The new shapes of beaded cultured pearls depend on the shapes of the beads. The surfaces of these new pearl varieties are usually not quite smooth, but the shapes are regular and their lustres are good.

Compared with the culturing routine for non-beaded pearls, there are differences in the implantation procedure. Beads are produced from freshwater shell. During the grafting process a round bead or a bead of another shape, such as a flat rhombus flake or a round disc, is implanted into the mantle, the visceral sac or the gonad of the recipient mussel, together with a prepared tiny piece of mantle tissue. The recipient mussel is then put back into the water for post-operative recovery.

Currently, most round beaded freshwater cultured pearls are gonad-grown as this technique produces a higher survival rate and higher yield.

2.3 Appearance and culturing techniques of second generation pearls

It is well-known that most freshwater cultured pearls have been obtained by killing the pearl mussel at the harvest, which means utilizing the mussel only

Figure 8: The cross section of a cross-shaped pearl.

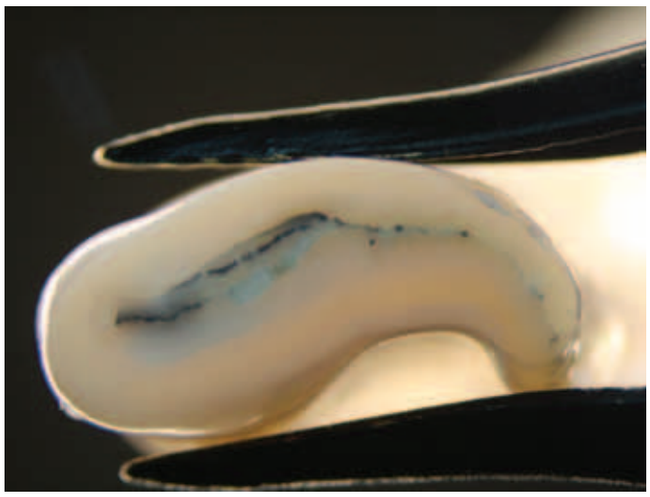

Figure 9: The cross section of an elongated bar-shaped pearl.

once. Second generation pearls are produced by operating on harvested mussels which have been kept alive. Immediately after the first harvest is finished, a bead or a piece of mantle tissue is implanted in the pearl sac from which a pearl has just been extracted, and then the mussel is put back in the water. After two or three years, a second generation pearl can be obtained. It may be beaded or non-beaded.

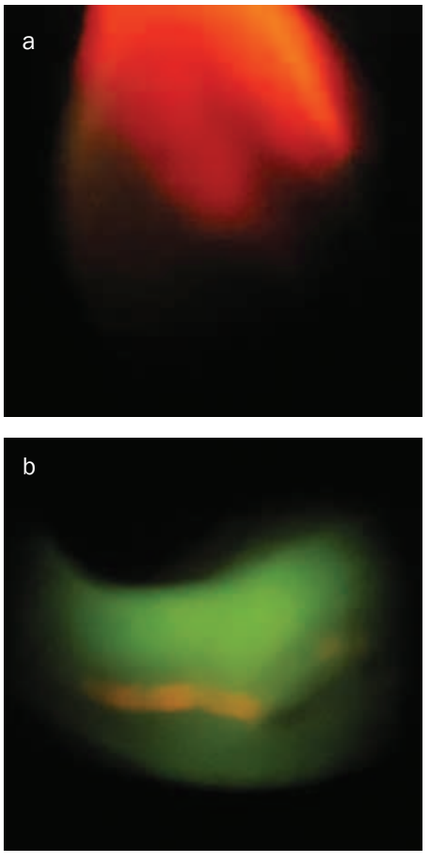

Figure 10: CL images of the cross sections of (a)cross-shaped pearls and (b) elongated bar-shaped pearls.

Depending on the shape of the pearl sac, non-beaded second generation pearls are usually thin and have the shapes of curved flakes or petals *(Figure 6)*. Mostly the surfaces of the pearls are not very smooth. Their colours are mostly white, orange or purple. However, the iridescence of the pearls varies on the surface, commonly being pink, peacock green, golden or purple. Another shape in this non-beaded category is the so-called soufflé pearl which is baroque shaped. Soufflé pearls are large in size but light in weight. They may also show a range of metallic pastel shades and mixed lustres *(Figure 7)*.

Before the grafting process, high-quality harvest mussels in good health and of large size are selected. After opening the shell, the viscera and the abdominal foot are pushed to one side, before cutting a suitable incision into the pearl sac to take out the first grown pearl. After carefully dressing the wound to prevent infection, tiny pieces of mantle or bead are implanted in the already existing pearl sac. If a soufflé pearl is desired, a muddy liquid is injected into the pearl sac using an injector. Finally the grafted mussel is put back into fresh water.

3. The structure of new varieties of freshwater pearls

The following samples were selected for our study: two non-beaded cultured shaped pearls, two new-shaped beaded cultured pearls and two freshwater cultured second generation pearls from a pearl-culturing farm in the Shanxiahu area, Zhuji City, Zhejiang Province, China. Their cross sections were polished and studied using the gemmological microscope, cathodoluminescence (CL) microscopy and Raman spectroscopy to record their structural features.

3.1 The structure of the non-beaded cultured new-shaped pearls

Under the gemmological microscope, the cross sections of non-beaded cultured new-shaped pearls show successive concentric lines parallel to the shape of the outline of the pearl, which is similar to that of already-known non-beaded freshwater pearls (*Figures 8* and *9*). In the centre of the pearl shown in *Figure 9* there is an irregular hole which contains some black organic substance.

Under the CL microscope, almost all samples show yellowish-green fluorescence, except in the centres of the cross-shaped and the elongated bar-shaped pearls where orange fluorescence is found *(Figure 10)*.

All the samples and the powders of the parts showing orange and

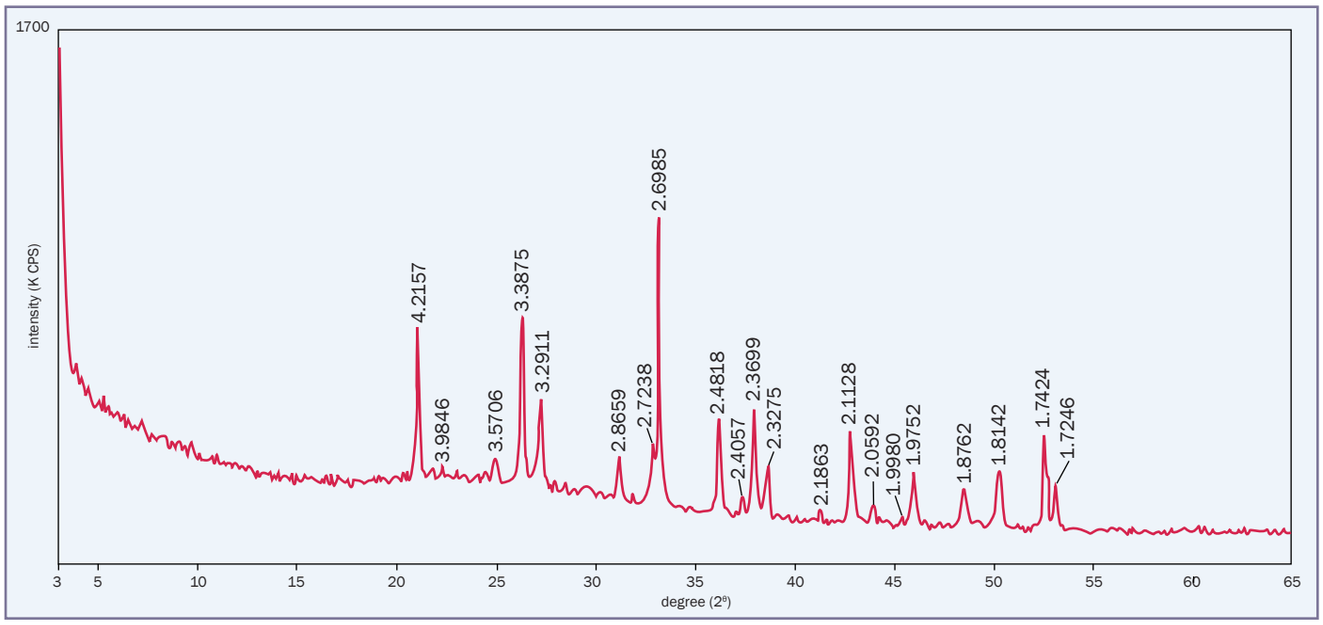

Figure 11: The XRD peaks of the powders of the central part of the cross-shaped pearl which shows orange CL, indicating the additional presence of vaterite.

yellowish-green CL were analyzed using X-ray powder diffraction (XRD) in order to investigate their mineralogical composition. Those samples showing yellowish-green CL contain only aragonite, as determined by comparing the peaks with the standard data of aragonite (diffraction peaks at 3.3875, 3.2911, 2.6985, 2.4818, 2.3699, 2.1863, 1.9752, 1.0876, 1.8142 and 1.7424). However, the powder sample collected from the central part of the cross-shaped pearl showing orange CL, shows peaks at 4.2157, 3.5706, 3.2911, 2.7238, 2.3275, 2.1128, 2.0592, 1.8142 and 1.7424 *(Figure 11)*, which indicates the additional presence of vaterite. Therefore, the freshwater pearls in the new shapes contain both aragonite with yellowish-green CL and vaterite showing orange CL. Such a composition is almost the same as that of freshwater pearls in traditional spherical shapes[4].

3.2 The structure of the new-shaped beaded cultured pearl

Observation of the cross sections of rhombic and coin-shaped beaded cultured pearls under the gemmological microscope shows a sharp boundary *(Figure 12)* and no prismatic layer or other dividing line between the pearl layer and the pearl bead — which features

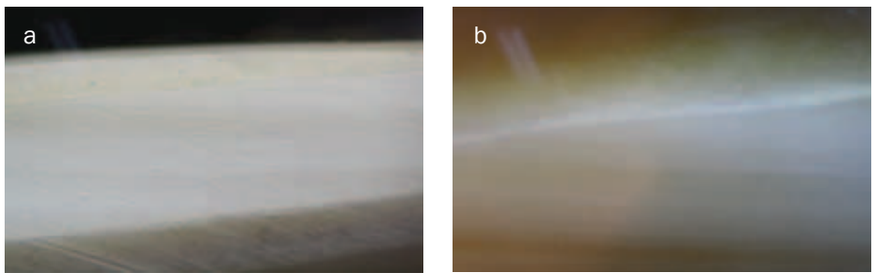

Figure 12: The microstructures of cross sections of (a) rhombic and (b) coin-shaped beaded pearls.

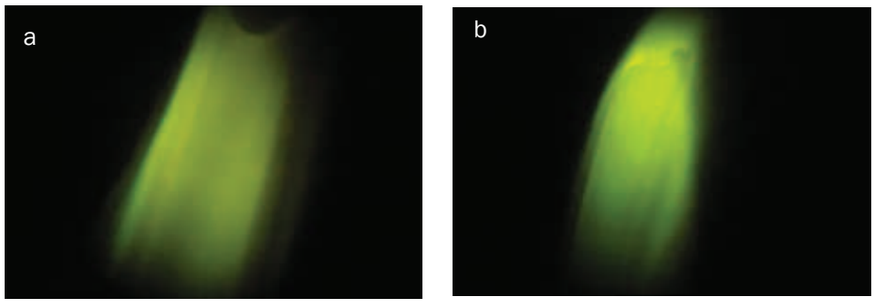

Figure 13: The CL images near the bead boundaries in (a) circular and (b) rectangular flat beaded pearls.

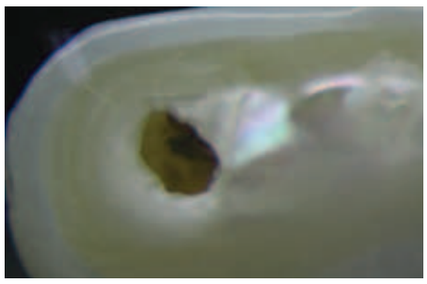

Figure 14: The concentric nacreous layers are visible in this cross-section of a flake-shaped second generation pearl.

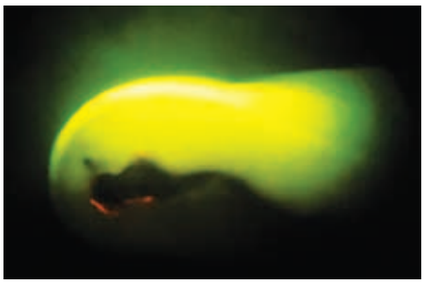

Figure 15: The CL image of a flake-shaped second generation pearl.

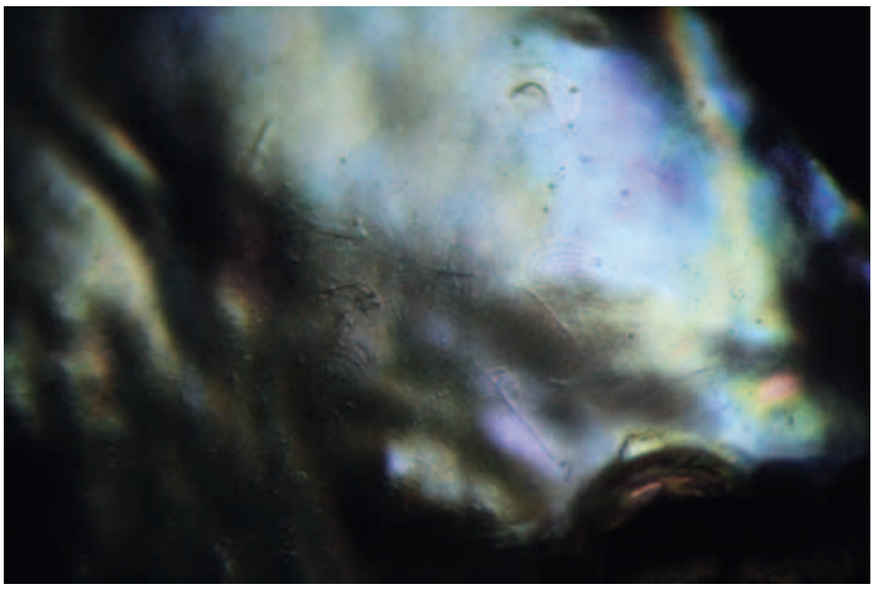

Figure 16: The surface of the soufflé pearl under the microscope.

are always present in beaded saltwater pearls[4].

Under the CL microscope, the bright yellowish-green CL and the clear laminar structure in the shell bead are distinctive, with a dark yellow-green CL at the boundary and in the surrounding pearly layers *(Figure 13)*.

3.3 The structure of second generation pearls

The cross section of a second generation non-beaded pearl *(Figure 14)* displays its concentric structure and a yellowish organic substance in an inner cavity. Overall yellowish-green CL with pinpoint orange CL in the cavity edge is visible under the CL microscope *(Figure 15)*.

The soufflé pearl is hollow and contains a large proportion of space, so it is very light. When it is cut in two, the nacreous layers are revealed to be very thin and there is a small amount of black mud powder in the central hole. However, its surface iridescence is very strong *(Figure 16)*. Under the gemmological microscope it shows thin nacreous layers and a visible laminar structure in the broken surface.

4. Conclusions

The implantation of different shapes of mantle tissue into the mantle of a mussel can produce new shapes of non-beaded cultured pearls. Also shell beads in different shapes can be implanted into the mantle or into the visceral sac or the gonad to produce beaded pearls in different shapes. By implanting a mantle tissue or injecting muddy liquid into the sac from which a pearl has just been harvested one can obtain second generation pearls. The basic structure of the new varieties of freshwater pearls is similar to that of traditional freshwater cultured pearls, which consists of concentric nacreous layers; these are mainly of aragonite with small quantities of vaterite, and some organic residue remaining in the central hole.

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Titanium-bearing synthetic alexandrite and chrysoberyl

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Abstract: The inclusions, compositions and spectra of synthetic reddish violet titanium-bearing chrysoberyl and synthetic alexandrites grown by the Czochralski method by Kyocera in Japan are described. These samples are compared with titanium-, chromium- and vanadium-bearing synthetic alexandrite cat's-eyes and six-rayed alexandrite stars. It is concluded that reddish violet chrysoberyl is coloured by trivalent titanium; the alexandrites are predominantly coloured by chromium with minor amounts of vanadium being also present. Both groups of samples contain inclusions typical of Czochralski-grown chrysoberyl. The colour and pleochroism of chatoyant and asteriated alexandrites is caused by a combination of some trivalent titanium and chromium with minor traces of vanadium. Three light bands are produced by three series of needle-like, titanium-bearing crystals, most probably rutile needles, which are orientated at about 60° to each other. The production technique of alexandrite cat's-eyes described in numerous patent documents is discussed.

Keywords: asterism, chatoyancy, Czochralski, electron microprobe analysis, rutile, synthetic chrysoberyl, titanium contents, visible range spectra

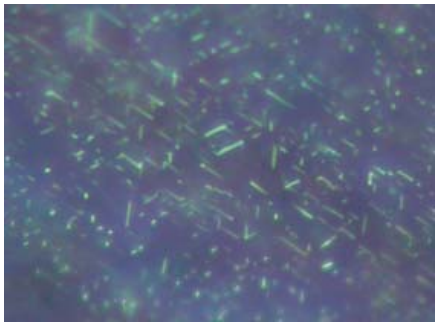

*A thin section of a star synthetic alexandrite from Kyocera oriented almost parallel to the **a** pinacoid shows three series of needles which form angles near 60° to each other. Reflected light, crossed polarizers, field of view 56 x 42 µm. Photo by H.-J. Bernhardt.*

Introduction

Synthetic alexandrite cat's-eyes produced by Kyocera in Japan appeared on the market in the late 1980s with the trade name 'Inamori synthetic alexandrite' or 'Inamori created alexandrite' (Kane, 1987; Scarratt, 1988; Koivula *et al.*, 1988). The material – when cut as cabochon in the proper direction – normally showed a well-centred light band *(Figure 1)*, but Kane (1987) mentioned that "when the cabochons were viewed under a strong, single incandescent light source down the long direction, asterism was observed".

When a cabochon is cut with its base perpendicular to that producing a good cat's-eye, a six-rayed asteriated alexandrite can be obtained (*Figure 1;* see also Schmetzer and Hodgkinson, 2011). During the microscopic examinations of the stones mentioned in that paper (*op. cit.*), in immersion it was observed

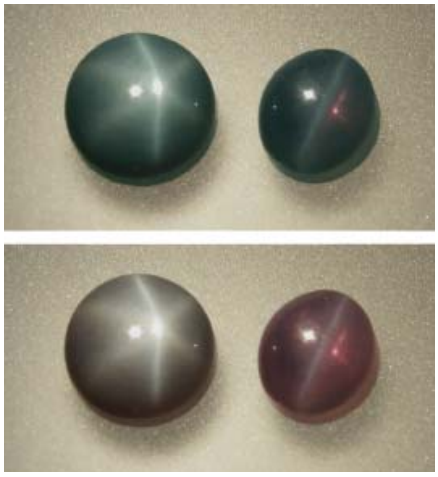

Figure 1: Synthetic asteriated alexandrite (left, 2.62 ct, diameter 8.0 mm) and synthetic alexandrite cat's-eye (1.55 ct, 7.0 x 6.0 mm) produced by Kyocera in Japan in daylight (above) and incandescent light. Photo by K. Schmetzer.

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*Table I: Trace element contents, colour and spectroscopic properties of titanium-bearing synthetic chrysoberyl and synthetic alexandrite.**

Reddish violet chrysoberyl

Colour and pleochroism

	X ‖ a	Y ‖ b	Z ‖ c
Daylight	light yellow orange	intense orange red	reddish violet
Incandescent light	light yellow orange	intense orange red	reddish purple

Spectroscopic properties, with polarization, absorption maxima (in nm)

Polarization	X ‖ a	Y ‖ b	Z ‖ c
Maxima	565 shoulder	565 shoulder	565
	490	498	495

Chemical properties (average, wt.%)

Sample	RV1 faceted	RV2 faceted	RV3 faceted	RV4 faceted
Technique	microprobe	microprobe	microprobe	microprobe
No. of analyses	10	10	10	10
TiO_2**	0.210	0.228	0.213	0.373
V_2O_3	0.008	0.006	0.019	0.005
Cr_2O_3	0.005	0.008	0.010	0.006
MnO	0.008	0.006	0.010	0.004
Fe_2O_3	0.009	0.006	0.009	0.014

Alexandrite

Colour and pleochroism

	X ‖ a	Y ‖ b	Z ‖ c
Daylight	blue violet	yellow green	blue green
Incandescent light	red purple	yellow orange	blue green

Chemical properties (average, wt.%)

Sample	A1 faceted	A2 faceted	A3 faceted	A4 faceted
Technique	microprobe	microprobe	microprobe	microprobe
No. of analyses	10	10	10	10
TiO_2**	0.014	0.008	0.007	0.007
V_2O_3	0.149	0.158	0.151	0.164
Cr_2O_3	0.393	0.291	0.254	0.308
MnO	0.007	0.009	0.009	0.009
Fe_2O_3	0.007	0.008	0.008	0.010

*Based on a morphological cell with a 4.42, b 9.39, c 5.47 ** total titanium as TiO_2

that the samples did not show the exact pleochroism which has hitherto been observed for synthetic vanadium- and chromium-bearing alexandrite (see, e.g., Schmetzer and Bosshart, 2010; Schmetzer and Malsy, 2011; Schmetzer *et al.*, 2013). In addition, a preliminary spectroscopic examination indicated some differences to the absorption spectra commonly observed for such chromium- and vanadium-bearing, iron-free synthetic samples (with distinctly higher chromium- than vanadium-contents). It was suspected that another colour-causing trace element might be present, but the analytical data had shown only traces of vanadium, chromium and titanium, with the titanium assumed to be present in the form of rutile precipitates, which in turn were responsible for asterism and/or chatoyancy.

Titanium-bearing chrysoberyl with pink coloration was briefly described by Krzemnicki and Kiefert (1999), but no data for pleochroism or spectroscopic properties were given. Titanium-bearing synthetic sapphires as well as titanium-doped synthetic chrysoberyls are grown for technical use as laser crystals. In some of these laser materials, the aim is to create and retain as much as possible of the titanium in its trivalent form. In gemmology, Ti^{3+} was reported as being responsible for the coloration of specifically doped synthetic corundum (Johnson *et al.,* 1995) and titanium-bearing Kashan synthetic ruby in which titanium is present in its trivalent state (Schmetzer and Schwarz, 2007). In the natural environment however, i.e. in most rocks and minerals, titanium is present as Ti^{4+} and trivalent titanium is unstable.

Thus, to explain the colours mentioned above in paragraph two for the phenomenal synthetic alexandrites grown by Kyocera, in this study we investigate the role of Ti in the Kyocera synthetic chrysoberyls and alexandrites, with or without stars or cat's-eyes.

Samples

Stones examined:

a) Reddish-violet chrysoberyl (see samples RV 1–4 in *Table I*): three rough crystals and nine faceted stones *(Figure 2)*. The rough crystals were of somewhat irregular hexagonal cylindrical shape with six side faces and upper and lower bases. Obviously, these cylinders had been sawn from rough Czochralski-grown crystals and the upper and lower bases as well as the side faces had been roughly polished to clean the crystals and give a better visual impression. The faceted gemstones had been cut without specific orientation. All samples had been donated by Kyocera Germany to the Bavarian State Collection for Mineralogy, Munich, Germany.

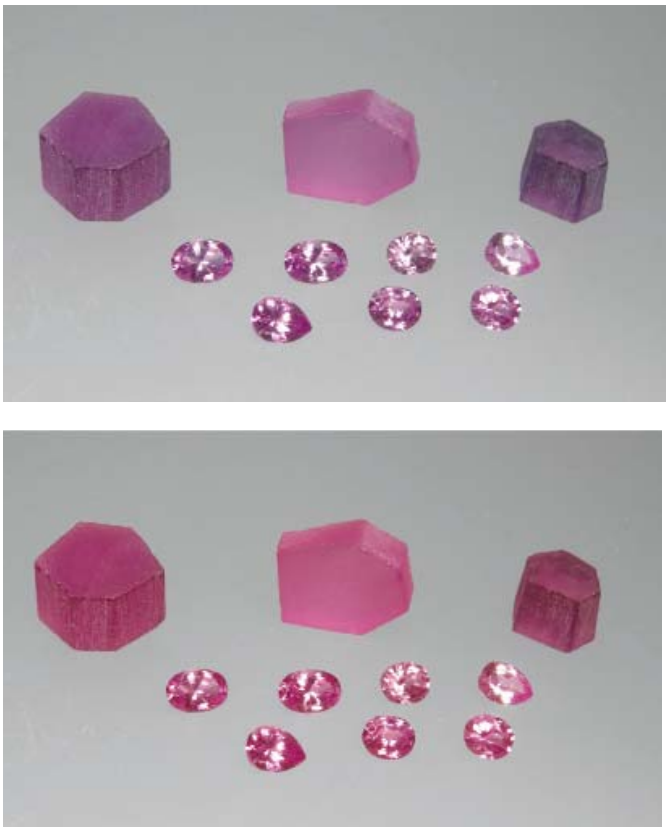

Figure 2: Rough and faceted titanium-bearing synthetic chrysoberyls produced by Kyocera in Japan in daylight (above) and incandescent light; size of the rough crystal above left 16.0 x 15.5 x 10.0 mm, weight 34.12 ct, the faceted sample below left weighs 1.08 ct and measures 7.8 x 5.7 mm. Photo by K. Schmetzer.

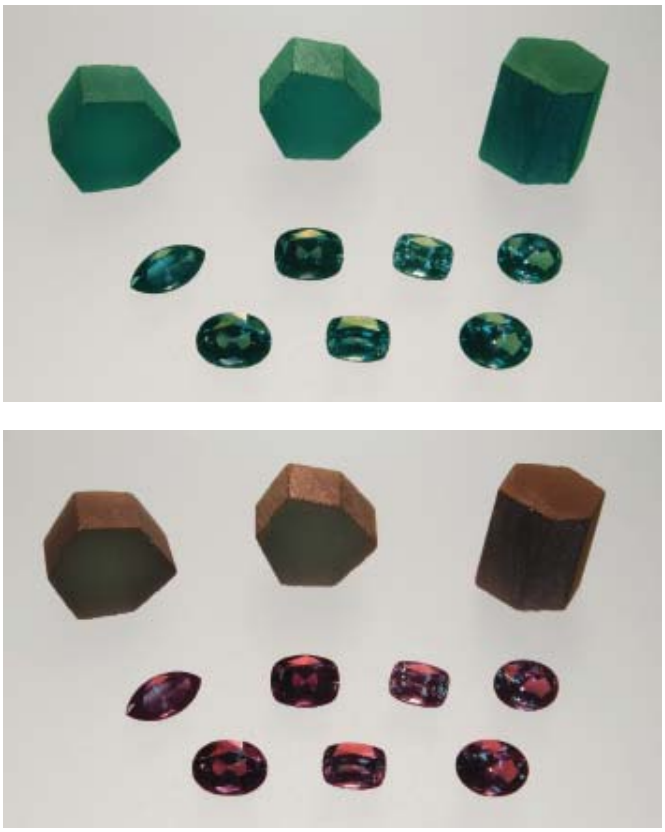

Figure 3: Rough and faceted synthetic alexandrites produced by Kyocera in Japan in daylight (above) and incandescent light; size of the rough crystal above right is 12.2 x 11.2 x 15.6 mm, weight 32.45 ct, the faceted sample below left weighs 1.71 ct and measures 8.0 x 6.0 mm. Photo by K. Schmetzer.

b) Alexandrites from Kyocera (see samples A 1–4 in *Table I*), three pseudohexagonal cylinders and nine faceted samples *(Figure 3)*. The features described in (a) for the rough cylinders of reddish violet chrysoberyl are similar to those shown by these alexandrites.
c) Alexandrite cat's-eyes and stars (*Table II*): three cabochon-cut samples had been prepared by A. Hodgkinson from a rod-shaped synthetic crystal of 18.84 ct that had been originally purchased in 1988. Two samples showed six-rayed asterism, and the other was a cat's-eye *(Figure 1)*. Two additional cat's-eyes (C2 and C3 in *Table II* and *Figure 4*) were available from the private collection of G. Bosshart.

Results

Titanium-bearing chrysoberyls

The orientation of the edges of the somewhat irregular hexagonal cylinders *(Figure 2)* was more or less parallel to the crystallographic a-axis, which indicates that this was the direction of pulling and growth in the Czochralski process. The overall colour of the samples was reddish violet in daylight with a colour variation to reddish purple in incandescent light.

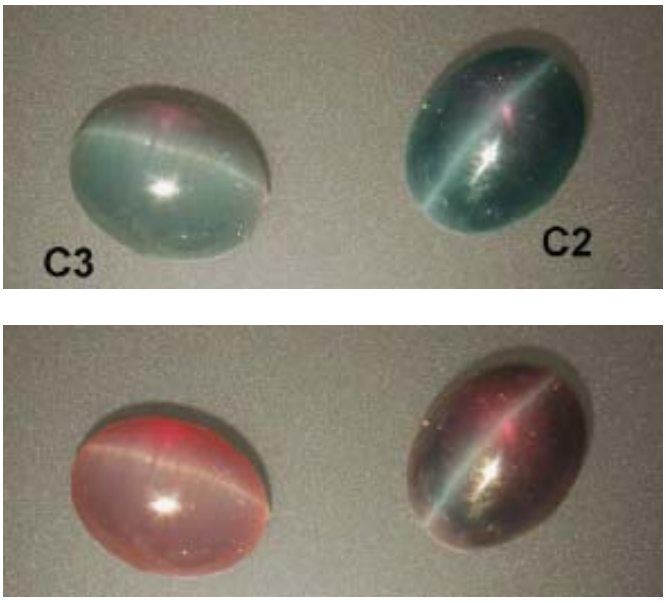

Figure 4: Synthetic alexandrite cat's-eyes produced by Kyocera in Japan in daylight (above) and incandescent light; sample C2 with lower Ti^{3+} contents weighs 3.29 ct and measures 9.2 x 7.2 mm, sample C3 with higher Ti^{3+} contents weighs 3.19 ct and measures 9.2 x 7.1 mm. Bosshart collection. Photo by K. Schmetzer.

*Table II: Trace element contents, colour and spectroscopic properties of synthetic alexandrite cat's-eyes and asteriated alexandrite.**

Colour, pleochroism and spectroscopic properties

Cabochon C1 base approx. || **a** (100) weak asterism		X || a	Y || b	Z || c
Incandescent light	view || a-axis, d = 2.5 mm		orange	orange
	view ⊥ a-axis, d = 8.0 mm	intense red orange	non-transparent	non-transparent
Spectroscopic properties, measurement || a-axis			Cr^{3+} spectrum, strong influence of Ti^{3+}	Cr^{3+} spectrum, strong influence of Ti^{3+}

Cabochon C2 base approx. || **b** (010) distinct cat's-eye		X || a	Y || b	Z || c
Incandescent light	view || b-axis, d = 2.8 mm	light purplish red		light green
	view ⊥ b-axis, d = 6.9 or 8.7 mm	intense purplish red	orange	intense green
Spectroscopic properties, measurement || b-axis		Cr^{3+} spectrum, moderate influence of Ti^{3+}		Cr^{3+} spectrum, moderate influence of Ti^{3+}

Cabochon C3 base approx. || **b** (010) weak cat's-eye		X || a	Y || b	Z || c
Incandescent light	view || b-axis, d = 2.6 mm	light yellowish orange		darker orange
	view ⊥ b-axis, d = 6.3 or 8.2 mm	intense red orange	non-transparent	non-transparent
Spectroscopic properties, measurement || b-axis		Cr^{3+} spectrum, strong influence of Ti^{3+}		Cr^{3+} spectrum, strong influence of Ti^{3+}

* based on a morphological cell with a 4.42, b 9.39, c 5.47 and X || a, Y || b, Z || c

d = diameter, representing the maximum path length of light in this orientation of the sample

Chemical properties (average, wt.%)

Sample	Cabochon C1 asteriated**	Cabochon C2 cat's-eye	Cabochon C3 cat's-eye
Technique	LA-ICP-MS	microprobe	microprobe
No. of analyses	2	10	10
TiO_2***	0.58	0.462	0.485
V_2O_3	0.11	0.123	0.119
Cr_2O_3	0.23	0.256	0.257
MnO	bdl	0.006	0.007
Fe_2O_3	bdl	0.007	0.005

** Schmetzer and Hodgkinson, 2011 *** total titanium as TiO_2

bdl = below detection limit

The pleochroism is variable, with similar colours observed for X and Y (yellow orange and orange red), and a more marked difference in the Z direction. The colour for both X and Y is almost identical in daylight and incandescent light, but in the Z direction a colour change from reddish violet in daylight to reddish purple in incandescent light is visible *(Figure 2)*.

The dominant colour-causing trace element of this group of samples is titanium *(Table I)*, the contents ranging from 0.21 to 0.23 wt.% TiO_2 in three samples, to 0.37 wt.% in a somewhat more intensely coloured stone (sample RV4). Other trace elements were only slightly above their respective detection limits in the electron microprobe.

The absorption spectra of the samples show a strong absorption band in the 495 nm range for X, Y and Z, and an additional band in the Z direction located at 565 nm *(Figure 5a, Table I)*. The absorption bands in the visible are assigned provisionally to Ti^{3+} which replaces Al^{3+} in the chrysoberyl structure, which is consistent with literature data (Segawa *et al.*, 1987; Anzai *et al.*, 1987, 1988; Sugimoto *et al.*, 1989). The spectra from the randomly orientated faceted stones *(Figure 5b)* are consistent with these data.

The microscopic examination showed almost plane, only slightly curved growth striations *(Figures 6, 7)* with a predominant orientation more or less parallel to the **a** (100) face, which represent the successive growth surfaces of the chysoberyl. As shown in *Figures 6* and *7*, the distances between these striations are variable. The centres of the rough crystals and the faceted samples were extremely clean with few, if any, inclusions. But in the outer areas of the rough samples, numerous gas bubbles and their migration traces within the growing crystal are present *(Figure 8)*.

Alexandrites

The synthetic alexandrites *(Figure 3)* contain two colour-causing trace elements, chromium and vanadium, with chromium contents always exceeding

those of vanadium. In detail, chromium ranges from 0.25 to 0.39 wt.% Cr_2O_3 and vanadium from 0.15 to 0.16 wt.% V_2O_3 *(Table I)*. Other trace elements were only slightly above their detection limits in the electron microprobe.

The orientation of the edges of the somewhat irregular hexagonal cylinders was more or less parallel to the crystallographic a-axis of chrysoberyl, which again indicates growth in this direction in the Czochralski process. Colour, colour change and absorption spectra (see *Table I*) are consistent with data from other iron-free, chromium- and vanadium-bearing synthetic alexandrites grown from the melt, e.g. Czochralski-grown or HOC-grown Russian alexandrites (for further details see Schmetzer and Bosshart, 2010; Schmetzer *et al.,* 2013).

The microscopic examination showed almost plane, only slightly curved growth striations *(Figure 9)* with an orientation parallel to the **a** (100) face, which again reflects the growth surfaces. Some samples showed extremely strong growth zoning which revealed a characteristic interference pattern under crossed polarizers *(Figure 10 a,b)*. Mostly rounded, occasionally also somewhat elongated gas bubbles were seen in some samples *(Figure 11),* and there are a few

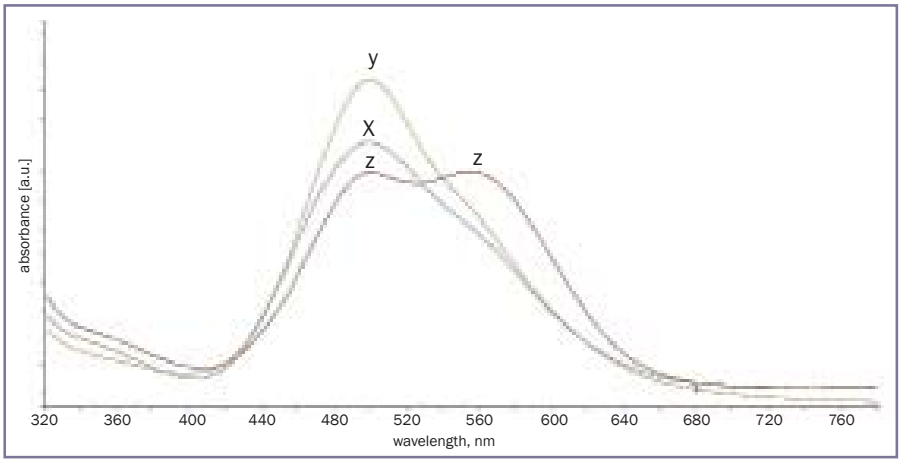

Figure 5a: Absorption spectra of a titanium-bearing synthetic chrysoberyl crystal in polarized light (with X || a, Y || b and Z || c).

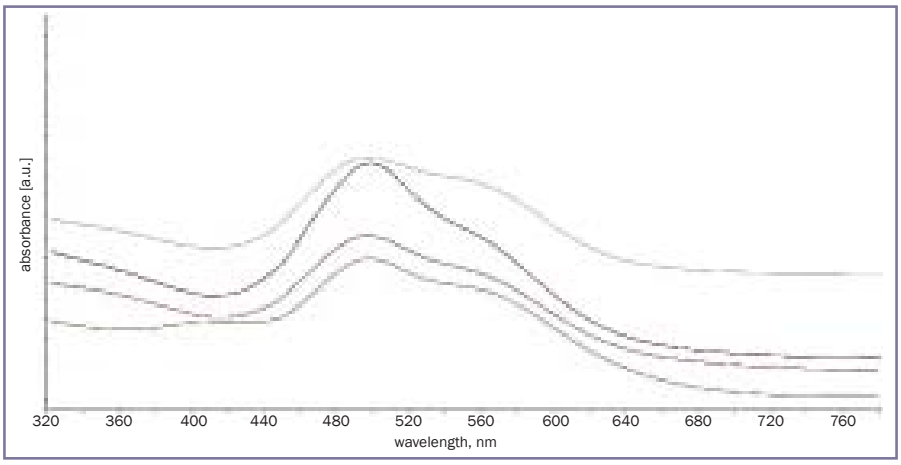

Figure 5b: Absorption spectra of four faceted titanium-bearing synthetic chrysoberyls in random orientation; the spectra of three chrysoberyls are vertically displaced for clarity.

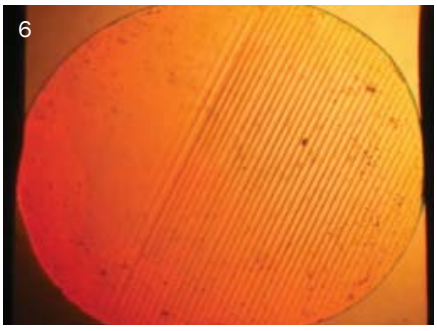

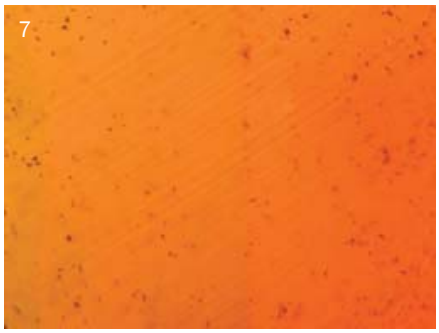

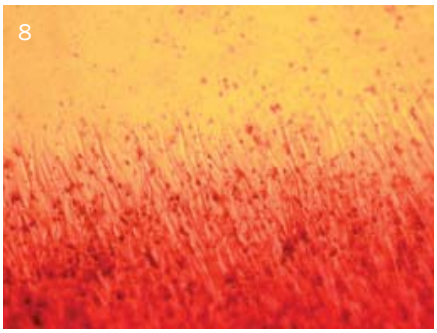

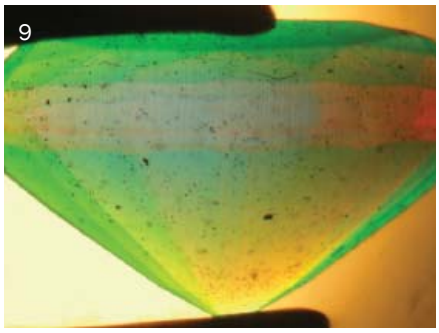

Figure 6: Slightly curved and quite coarse growth striations in reddish violet, titanium-bearing synthetic chrysoberyl produced by Kyocera in Japan. Immersion, field of view 6.9 x 5.2 mm. Photo by K. Schmetzer.

Figure 7: A sample of reddish violet, titanium-bearing synthetic chrysoberyl produced by Kyocera in Japan, is different from that in Figure 6, in which slightly curved growth striations show a much finer structure. Immersion, field of view 3.4 x 2.5 mm. Photo by K. Schmetzer.

Figure 8: Gas bubbles and the traces left as they migrated during growth of the crystal of reddish violet, titanium-bearing synthetic chrysoberyl. Immersion, field of view 2.4 x 1.8 mm. Photo by K. Schmetzer.

Figure 9: Slightly curved growth striations in synthetic alexandrite. Immersion, field of view 6.5 x 4.6 mm. Photo by K. Schmetzer.

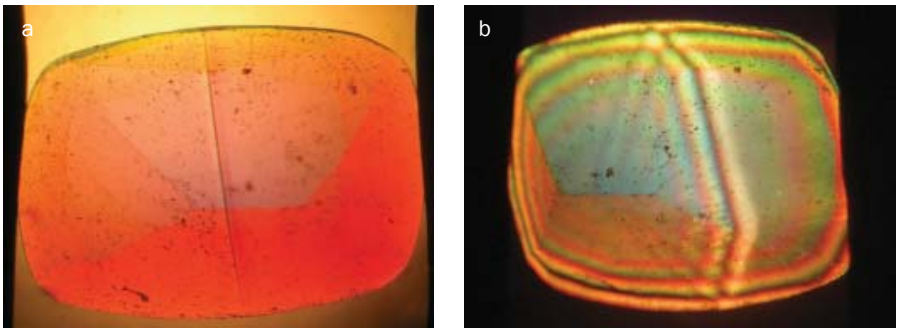

Figure 10: (a) Very distinct growth boundary in Kyocera synthetic alexandrite viewed in plane-polarized light. (b) Under crossed polarizers, a characteristic interference pattern is visible. Immersion, field of view 7.5 x 5.7 mm. Photos by K. Schmetzer.

Figure 11: Mostly rounded, occasionally also somewhat elongated gas bubbles in synthetic alexandrite. Immersion, field of view 3.7 x 2.7 mm. Photo by K. Schmetzer.

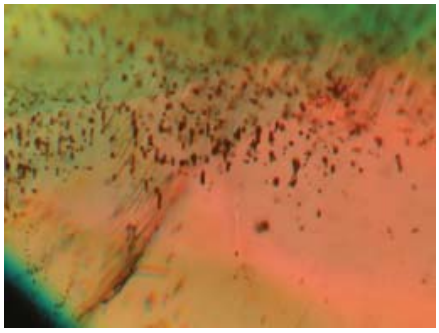

Figure 12: Gas bubbles and their migration traces within the growing crystal in Kyocera synthetic alexandrite. Immersion, field of view 2.1 x 1.6 mm. Photo by K. Schmetzer.

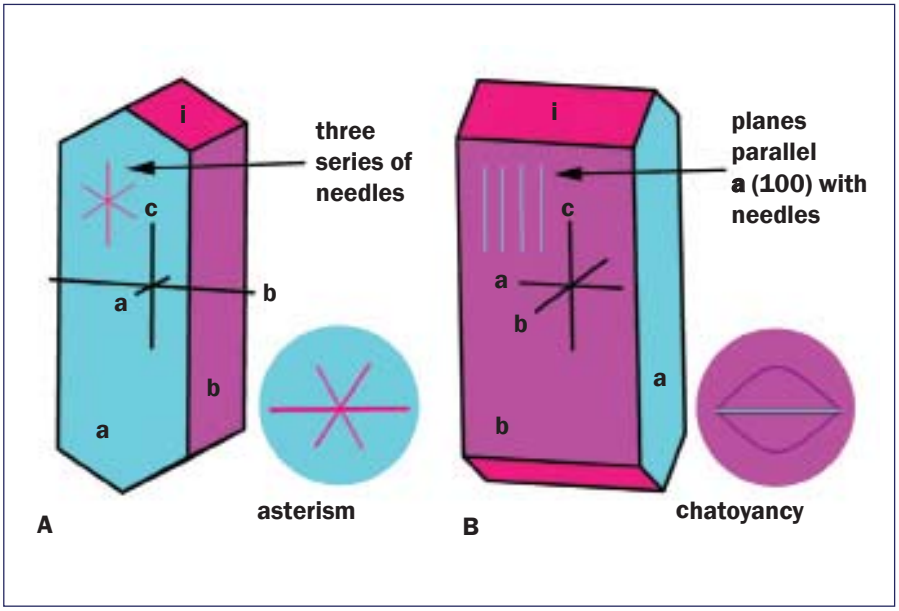

*Figure 13: Schematic drawings of asteriated or chatoyant synthetic alexandrite crystals in views parallel to the a-axis (A) and parallel to the b-axis (B). The light effect is due to three series of needles which are all located in planes parallel to the **a** (100) pinacoid; the orientations of the needles are parallel to the c-axis and the two **i** (011) faces. In a view parallel to the a-axis (A) the orientations of the needles reflect light to form a regular six-rayed star; in a view parallel to the b-axis (B), only one strong light band is seen in the centre of the chatoyant cabochon.*

gas bubbles with migration traces *(Figure 12*, see also *Figure 8)*.

In summary, both varieties — the titanium-bearing chrysoberyl and the chromium- and vanadium-bearing, iron-free alexandrite — showed the typical structural features and inclusions which are common in synthetic chrysoberyl grown by the Czochralski technique. Colour, colour change, pleochroism and absorption spectra of the alexandrites are comparable to other synthetic samples with similar trace element contents. The spectra of the pink titanium-bearing samples are consistent with literature data.

Alexandrites showing chatoyancy and/or asterism

All the Kyocera alexandrite cat's-eyes or star stones seen by the authors show three different light bands. With an orientation of the base of the cabochon parallel to the **a** (100) pinacoid, a star will be visible, but with the base of the cabochon parallel to the **b** (010) pinacoid, only one dominant light band will be seen through the centre of the cabochon's dome, and the other two light bands at the girdle are almost invisible *(Figure 13 A,B,* see also *Figures 1, 4)*.

From the orientation of these light bands it was concluded that three series of elongated particles are present which cause the reflections. These particles are located in layers parallel to the **a** (100) pinacoid, with one series of particles oriented parallel to the c-axis and the other two forming angles of 60° and -60° with the c-axis (i.e. particles elongated along the **i** and **–i** {011} prism faces of chrysoberyl). These minute particles, however, were too small to be identifiable with the gemmological microscope.

Chemical properties: The samples revealed distinct chromium and vanadium contents, with chromium contents always exceeding the amounts of vanadium measured. In detail, chromium contents were found between 0.23 and 0.26 wt.% Cr_2O_3 with vanadium contents ranging from 0.11 to 0.12 wt.% V_2O_3 *(Table II)*. The titanium contents range from 0.46 to 0.58 wt.% TiO_2, distinctly higher than the values found in the

reddish violet titanium-bearing samples (see *Table I*). Also, consistent with these small ranges, the microprobe scans across polished windows at the bases of the two cabochons indicate the absence of any distinct chemical zoning.

Examination of dark layers: The two asteriated alexandrite cabochons and the three cat's-eyes examined contain darker, non-transparent layers within a matrix of transparent alexandrite *(Figure 14)*. Careful optical orientation of the samples (for the method see Schmetzer 2010, 2011) indicate that these layers are oriented parallel to the **a** (100) pinacoid. To evaluate the nature of these dark layers, we cut thin slices parallel to the slightly curved base of two of the chatoyant cabochons and of one asteriated alexandrite and prepared petrographic thin sections approximately 60 µm thick. According to the orientation of these dark layers, the thin section cut from the asteriated alexandrite was parallel to, and the two thin sections prepared from the cat's-eyes were perpendicular to these layers.

The thin section of the asteriated alexandrite, i.e. the section parallel to the **a** (100) pinacoid, showed a dense pattern of small reflecting needles. These needles have three preferred orientations of their long axes and intersect with angles of approximately 60° (*Figure 15,* see also Figure with the Abstract). The other two sections perpendicular to the b-axis, i.e. perpendicular to the dark layers, showed a clear zoning consisting of layers with high concentrations of needles alternating with areas which are more or less free of any needles *(Figure 16 a,b)*. The needles are sometimes visible in the form of parallel strings *(Figure 16a),* but occasionally also thicker layers containing needles were seen *(Figure 16b)*.

The individual needles in the Kyocera samples were too small either for microprobe or for Raman analysis, but visually similar, somewhat larger needles with identical orientation in natural alexandrite crystals were proven by microprobe analysis to be rutile single crystals and twins (Schmetzer and Bernhardt, unpublished research). Thus,

*Figure 14: In a view perpendicular to the a-axis of a cat's-eye or star Kyocera alexandrite, numerous dark planes within a transparent matrix are visible using an immersion microscope; these layers parallel to the **a** (100) pinacoid contain numerous tiny titanium-bearing needles which are the cause of the three light bands observed. The a-axis runs vertically, field of view 3.6 x 2.7 mm. Photo by K. Schmetzer.*

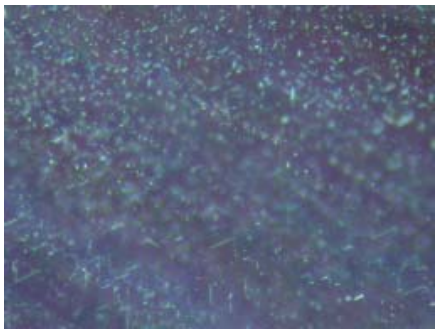

*Figure 15: A thin section of a star synthetic alexandrite from Kyocera oriented almost parallel to the **a** pinacoid shows three series of needles which form angles near 60° to each other. Reflected light, crossed polarizers, field of view 112 x 84 µm. Photo by H.-J. Bernhardt.*

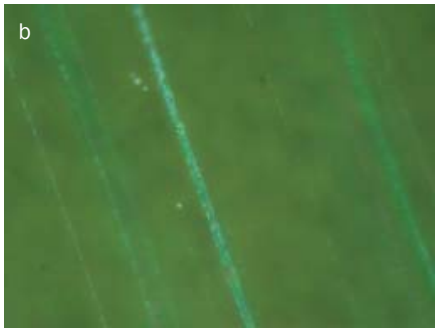

*Figure 16a,b: Thin sections of Kyocera chatoyant synthetic alexandrites oriented almost perpendicular to the **b** pinacoid show layers parallel to the **a** plane with numerous tiny needles alternating with layers of transparent alexandrite. The layers are thicker in b. Reflected light, crossed polarizers, field of view 112 x 84 µm. Photos by H.-J. Bernhardt.*

by analogy, these needles in the Kyocera titanium-doped synthetic alexandrites are most probably rutile. This probability is consistent with the information in various patent documents mentioned in Box A.

Colour and pleochroism: After careful orientation of the available cabochons using optical methods in the immersion microscope it was observed that the pleochroism of these samples was not always consistent with the pleochroism that had been and is commonly observed in natural and synthetic alexandrite. Although the slightly curved bases of the cabochons showed only minor deviations (< 15°) to the **a** (100) and **b** (010) pinacoids of the crystals, we found it difficult to obtain the exact position of all three crystallographic axes if not in immersion. This matters because we observed that only a slight deviation from a precise orientation (say, in a view exactly parallel to one of the three axes) causes quite large differences in the observed colours and pleochroism. We also noted that there are significant differences in colour, in different directions, which relate to the path lengths of the light through the stones.

Consequently, at this stage in the investigation, we confined our observations to the immersed stones in incandescent light. The presence of the dark layers in combination with the position of the optic axes obtained under crossed polarizers enabled an exact orientation of each cabochon in the immersion microscope. However, in assessing colour, one must keep in mind path length differences, and it is evident

Table A. Production of alexandrite cat's-eyes

Author(s)/applicant	Patent documents in Japanese/date*	Patent documents in English/date*	Method for crystal growth	Annealing step/ atmosphere	Dopant for cause of colour	Dopant/cause for asterism
Kawachi (Kochi) Suwa Seikosha KK (Seiko Epson Corporation), Tokyo	JP 54-006900 A (1979)	US 4,218,282 (1980)	Floating zone	Not mentioned	Chromium oxide	Titanium oxide
Kawachi and Kojima Miyasaka Kunugi Saito all assigned to Seiko Epson Corporation, Tokyo	JP 55-062884 A (1980) JP 58-130197 A (1983) JP 59-152291 A (1984) JP 59-152292 A (1984)		Floating zone	oxidising	Chromium oxide, iron oxide	Titanium oxide
Shindo *et al.*, National Institute for Research in Inorganic Materials, Tsukuba	JP 57-191297 A (1982) JP 57-191298 A (1982)		Floating zone	oxidising		Titanium oxide
Oguri and Hirota, Sumitomo Cement Co., Ltd., Tokyo	JP 58-120597 A (1983) WO 85/00392 A1 (1985)	EP 0148946 A1 (1985) US 4,634,492 (1987)	Floating zone	oxidising	Chromium oxide, vanadium oxide, iron oxide	Titanium oxide
Saito, Seiko Epson Corporation, Tokyo	JP 59-162196 (1984)		Floating zone, starting material is aluminium hydroxide	Not mentioned	Chromium oxide, iron oxide	Development of tubular fluid inclusions
Isokami and Nagata (Isogami and Nakata), Kyocera Corporation, Kyoto	JP 60-071598 A (1985)	US 4,621,065 (1986)	Czochralski, flux (lithium molybdate)	Not mentioned	Oxides of iron, cerium, vanadium, cobalt, tungsten, chromium, nickel, manganese	Oxides of titanium, tin, zirconium, germanium
Miyasaka, Seiko Epson Corporation, Tokyo	JP 61-256998 A (1986)			Diffusion treatment		Titanium oxide powder

* abbreviations: JP Japan; WO World Intellectual Property Organization; EP Europe; US United States of America
patent family members in other languages, e.g. German, were omitted

- annealing at high temperatures not mentioned
- growth from aluminium hydroxide, no annealing step
- annealing at high temperatures in oxidising atmospheres
- diffusion treatment

Box A

Production of synthetic alexandrite cat's-eyes in the patent literature

The production of synthetic chrysoberyl and alexandrite cat's-eyes is described in numerous Japanese and international patent applications, most of them published in the 1980s *(Table A)*. A first short note is found in two patent documents published in 1979 and 1980, assigned to Seiko Epson Corporation (Suwa Seikosha KK, see *Table A*). Later, two different processes were described in more detail, the first one published in various applications by Seiko Epson Corporation, by the National Institute for Research in Inorganic Materials and by Sumitomo Cement Co. The second process is assigned to Kyocera Corporation.

The first method for the production of alexandrite cat's-eyes involves a two-step growth and annealing process (see, e.g., the patent documents by Oguri and Hirota, 1983, 1985 a,b, 1987, assigned to Sumitomo Cement Co.). The first step includes the production of homogeneous single crystals containing titanium oxide as dopant. It is claimed that such specifically-doped crystals can be grown by any known technique suitable for the crystal growth of chrysoberyl, but the floating zone method is described in detail (the floating zone technique was described in a gemmological journal by Schmetzer, 2012). Crystal growth is performed under neutral (e.g. argon or nitrogen) or reducing atmospheres and most titanium is present in its trivalent state. In the second step, the crystal is annealed at elevated temperatures in an oxidizing atmosphere when the titanium is oxidized and elongated particles, most probably rutile needles, are precipitated. These exsolved particles are responsible for the chatoyant effect of the material when cut as a cabochon.

A process assigned to Kyocera Corporation describes the production of chrysoberyl cat's-eyes with a similar first step growth process using a specific dopant. But, there is no mention of a subsequent heat treatment step (Isogami and Nakata, 1985, 1986). Unfortunately, the authors were unable to obtain any conclusive information from the Kyocera Company to throw light on this omission. The following substances are listed by Kyocera as possible dopants: titanium oxide (TiO_2), germanium oxide (GeO_2), zirconium oxide (ZrO_2), and tin oxide (SnO_2). In addition to introducing a dopant to cause chatoyancy, the oxides of vanadium and/or chromium and/or nickel and/or cobalt and/or iron are added for colour. As examples, crystal growth by the Czochralski technique and the flux method are described, but there is no information about the orientation of the precipitates which are responsible for the cat's-eye.

Two further ways of producing cat's-eyes should be mentioned briefly. In a patent document assigned to Seiko Epson Corporation (Saito, 1984b), the production of alexandrite cat's-eyes by the floating zone technique is described. Due to the use of aluminium hydroxide as starting material and a special growth atmosphere, tubular fluid inclusions were developed, which are responsible for chatoyancy. Secondly, the production of alexandrite cat's-eyes by diffusion treatment of synthetic alexandrite crystals in titanium oxide powder was described by Miyasaka (1986).

that observations perpendicular to the bases of the cabochons (viewing only two of the three pleochroic colours X, Y or Z) are along much shorter path lengths than the two directions of view parallel to the bases of the cabochons. These latter paths of light range from 6.3 to 8.7 mm, while across the cabochons, the paths are 2.5 to 2.8 mm long. A summary of observations is given in *Table II*.

In detail, we observed that in one of the cabochons examined, the pleochroism shows only minor deviations from the pleochroism of chromium- and vanadium-bearing alexandrite (cabochon C2 in *Table II*). In contrast, the other cabochons (samples C1 and C3 in *Table II*) showed a yellowish orange or orange coloration for smaller paths of light. For observations in directions parallel to the bases of the cabochons (i.e. with longer paths of light) X was intense red orange, and Y and Z were dark (not transparent, see *Figure 17 A,B*).

Absorption spectra were recorded perpendicular to the bases of the cabochons. Cabochon C2 has a pleochroism almost identical to that of normal alexandrite but showed a chromium spectrum with somewhat less transparency around 500 nm, i.e. in the area between the two strong chromium absorption bands (*Figure 18,* sample C2). In contrast, the transparency in the same area was very much reduced within the spectra of cabochons C1 and C3 *(Figure 18)*. This means that, in addition to the chromium-vanadium absorption bands, there is also a stronger absorption in the 500 nm range.

From the pure spectra of chromium (Cr^{3+}) and titanium (Ti^{3+}) in chrysoberyl shown in *Figure 19,* it is evident that the maximum titanium absorption around 500 nm is more or less at the position of the absorption minimum between the two strong chromium bands. Consequently the absorption spectra of the asteriated and chatoyant Kyocera alexandrites can be understood if we postulate the presence of Ti^{3+} in the structure in addition to the Ti within the rutile needles. Sample C2 shows a smaller influence of Ti in the spectrum. This indicates that a higher percentage of the titanium is present in the form of rutile needles causing a stronger cat's-eye in this sample (see

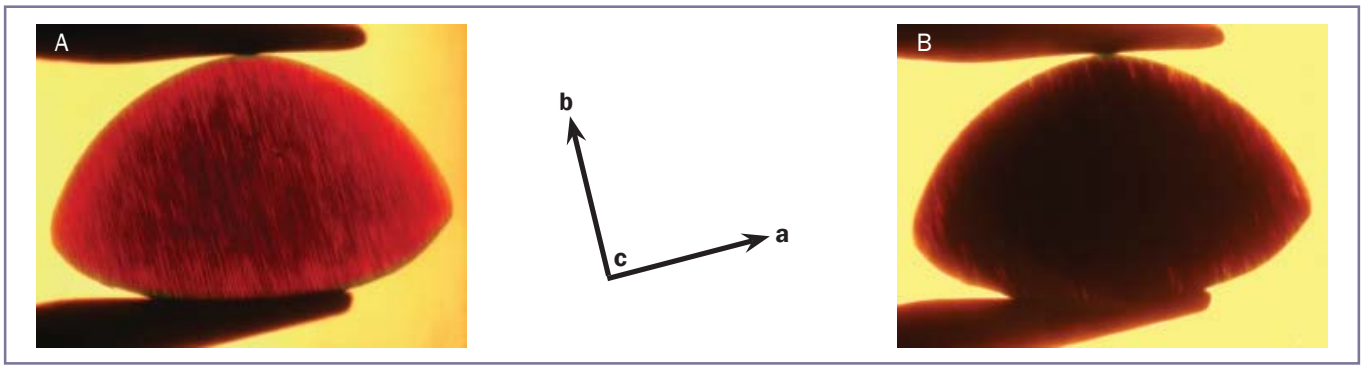

*Figure 17A,B: A view parallel to the c-axis of a Kyocera chatoyant synthetic alexandrite; the orientations of the three axes are indicated. The base of the cabochon is almost perpendicular to the b-axis (parallel to the **b** plane); dark layers with titanium-bearing needles are oriented perpendicular to the a-axis (parallel to the **a** plane). In this orientation in immersion and plane polarized light, with rotation of the polarizer (Figures A and B, respectively) the two pleochroic colours X and Y can be observed; X || a is intense red orange (A) and Y || b is non-transparent (B). Field of view 9.1 x 6.8 mm. Photos by K. Schmetzer.*

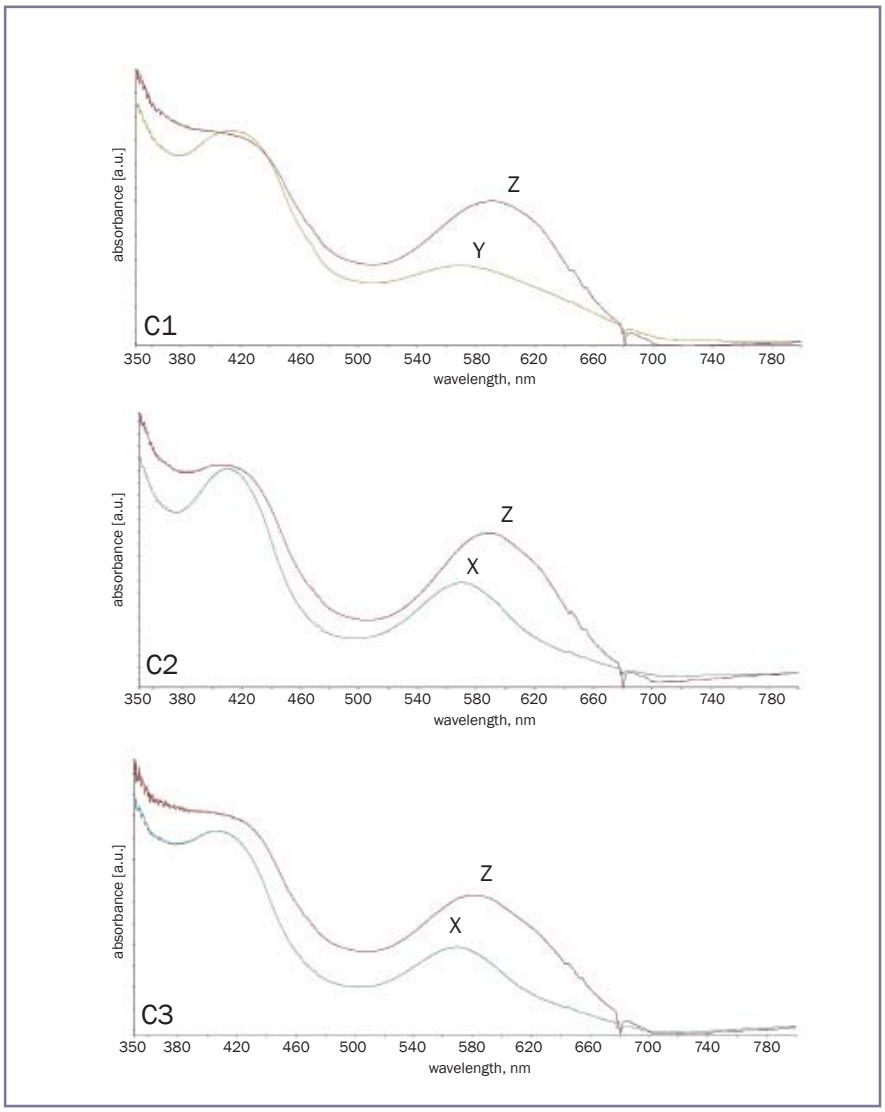

Figure 18: Absorption spectra for star synthetic alexandrite cabochon C1 (see Table II*) and cat's-eye cabochons C2 and C3 for polarized light with X || a, Y || b and Z || c; the spectra were recorded perpendicular to the bases of the cabochons with maximum sample thickness from 2.5 to 2.8 mm; for each sample, only two polarized spectra were taken, i.e. Y,Z for sample C1 (beam parallel to the a-axis) and X,Z for samples C2 and C3 (beam parallel to the b-axis).*

Figure 4). The two other cabochons C1 and C3 show a distinctly higher absorption in the 500 nm range probably caused by an elevated percentage of titanium in the trivalent state. Thus, the main light bands in these samples are somewhat weaker due to fewer rutile needles being present *(Figures 1,4)*.

Discussion

The average chromium and vanadium contents of Kyocera synthetic alexandrites showing asterism or chatoyancy are slightly lower than those measured in the 'normal' synthetic alexandrites from that producer. But their total titanium contents are higher and at least twice those of the reddish-violet chrysoberyls which are coloured by trivalent titanium.

The spectra indicate that titanium in asteriated or chatoyant alexandrites is present in the structure in its trivalent state on aluminium lattice sites (and so contributes to the colour). The titanium is present in its tetravalent state in the needle inclusions, probably as rutile, and is responsible for the light bands in the cabochons. Three series of needles are oriented parallel to the c-axis, to the **i** and to the **–i** {011} prism faces in layers parallel to the **a** (100) pinacoid. Although various amounts of titanium might also be present as Ti^{4+} within the chrysoberyl structure, Ti^{4+} does not cause absorption in the visible range. Therefore, most probably, the absorption spectra in our stones are due to a superimposition of the absorption bands of trivalent chromium,

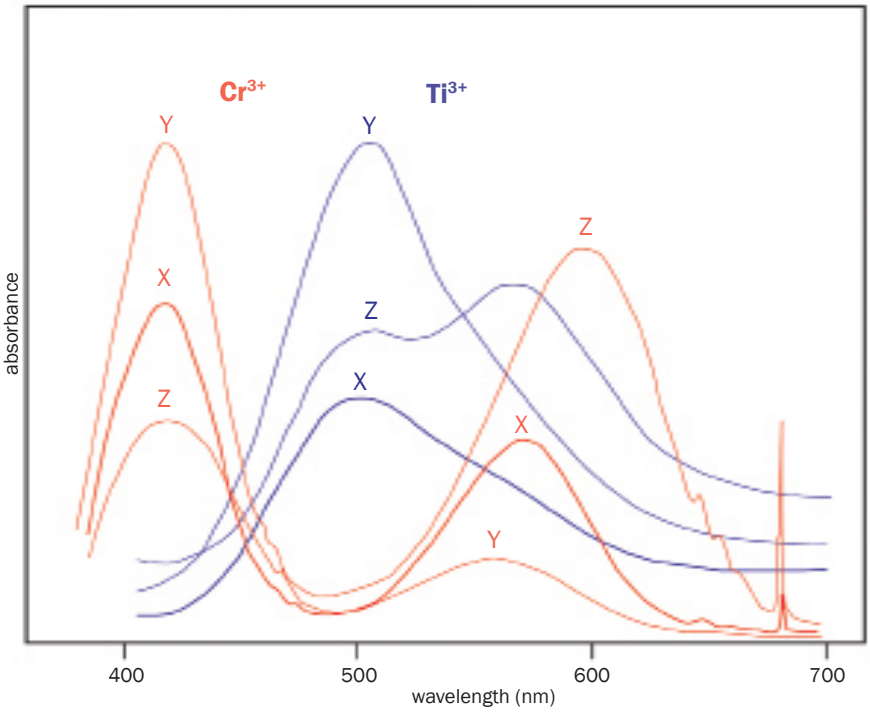

Figure 19: Plot of the polarized absorption spectra of chromium (Cr^{3+}, taken from Heller et al.*, 1999) and titanium (Ti^{3+}, taken from Anzai* et al.*, 1987) in chrysoberyl; for all three directions (X, Y and Z) the absorption maxima for titanium are located between the two strong chromium absorption bands; for samples which contain distinct amounts of chromium together with titanium in its trivalent state, only X is intense red orange, and Y and Z become very dark, almost non-transparent.*

vanadium and titanium — with variable intensity of the titanium absorption bands. This situation is similar to the presence of trivalent chromium and trivalent titanium in some Kashan synthetic rubies as described by Schmetzer and Schwarz (2007).

The formation of needle-like titanium-bearing precipitates in synthetic chrysoberyl by annealing the grown crystal is described in numerous patent documents (see Box A, *Table A*), but the mechanism of this process is not explained in them. It is not known whether titanium in its tetravalent state is first produced from Ti^{3+} before the exsolution of titanium oxide and formation of titanium-bearing precipitates. Neither do they contain the reason why there are bands or zones of needle-like inclusions in the stones. In synthetic titanium-bearing star corundum, a similar zoning of needle-like precipitates has been described. This zoning is present in crystals which were grown under fluctuating thermal conditions (Burdick and Jones, 1954) with zones with varying concentrations of needle-like precipitates only becoming visible after a subsequent annealing step. So it is possible that similar fluctuating temperatures during crystal growth might be responsible for the zoning of rutile precipitates in the Kyocera synthetic alexandrites, zones which are invisible until highlighted by the treatment.

Acknowledgements

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Liquid hydrogen sulphide (H_2S) fluid inclusions in unheated tanzanites (zoisite) from Merelani, Tanzania: Part 1. Recognition, characterization and gemmological importance

Dan Taylor*, Professor Andrew H. Rankin and Professor Peter J. Treloar

This is the first of two papers dedicated to the memory of Dan Taylor.

Abstract: Microscopic (*c.* 5 to 150 µm), multiphase liquid-filled inclusions have been identified in several samples of unheated blue-brown tanzanite (zoisite) rough stones from the D mine area, of Merelani, NE Tanzania. Raman and microthermometric analysis confirm that the liquid and vapour phase comprise 'pure' hydrogen sulphide (H_2S), with only very minor traces of methane and nitrogen in the vapour phase. Various solids are also present. The dominant phases, confirmed using Raman spectroscopy, are native sulphur (S_8), a disordered form of graphite (C) and a magnesium-rich calcite ($CaCO_3$ with *c.* 7% Mg). The inclusions typically occur in clusters and in planar to curvi-planar groupings, but larger, isolated inclusions can also occur. This shows that H_2S-dominant fluids were present during primary growth and subsequent fracture-healing of the zoisites during their natural cooling history. The highly unusual nature of this fluid, of presumed metamorphic origin, is hitherto unreported as a liquid phase in inclusions in the gemmological literature. The liquefied and compressed nature of this entrapped fluid means that it is very unlikely to withstand the high internal pressures generated on heating above 100 °C (the critical temperature of H_2S). Positive identification of liquid H_2S (strong Raman peak at 2583 cm^{-1}) in such inclusions therefore provides a valuable criterion for identifying natural, un-treated tanzanites and distinguishing them from any crystals that may be laboratory-grown. A simple laboratory scratch-chip test is outlined. This is based on the characteristic 'rotten egg' odour of H_2S when near-surface inclusions are opened, and the extreme sensitivity of the human nose to this gas (threshold value of *c.* 11 µg in 1 m^3 of air).

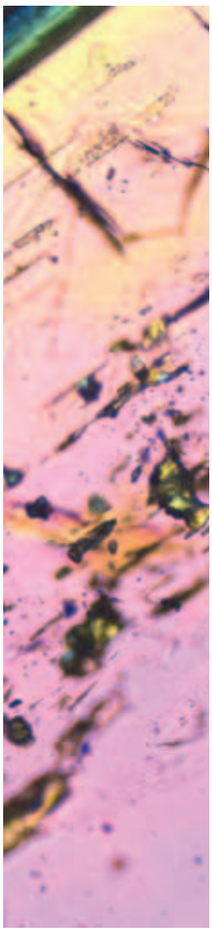

Keywords: fluid inclusions, gemmology, hydrogen sulphide liquid, metamorphic fluid, microthermometry, native sulphur, odour, Raman spectra, tanzanite, zoisite

* Sadly Dan Taylor died on 29 October 2009.

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Liquid hydrogen sulphide fluid inclusions in unheated tanzanites (zoisite): Part 1.

Introduction

Liquid inclusions containing varying proportions of liquid, vapour and solids are common microscopic features of many types of gemstones. Their importance in gemmology has long been recognized, and they often add interest and uniqueness to individual gems (Gübelin and Koivula, 2005; Roedder, 1982). Recognition of different types of inclusions in gemstones, and identification of phases present, even at low (×10) magnifications, is a particularly valuable guide to likely provenance. This is best illustrated by the characteristic three phase liquid (L) + vapour (V) + salt (halite) brine inclusions so typical of Colombian emeralds. Liquid inclusions also provide valuable insights into whether a gemstone has been subjected to heat treatment. For example, two-phase liquid plus vapour carbon dioxide inclusions, which become single phase on gentle warming up to 31°C, are a common feature in unheated sapphires and rubies but are usually destroyed during heating to much higher temperatures (Koivula, 1986; Hughes 1997; Rankin, 2002).

In view of the gemmological value of fluid inclusions, published reports of their nature and occurrence in tanzanite are notably lacking. Only very small (*c.* 5–10 µm (microns)) liquid-vapour inclusion trails have been reported in tanzanite (Malisa *et al.,* 1986) and associated quartz (Olivier, 2006), and their occurrence has only been briefly mentioned in a recent geological review of tsavorite occurrences in East Africa (Feneyrol *et al.,* 2013). Here we report on the common occurrence of well developed (up to *c.* 150 µm) multiphase (L+V+S) inclusions of exceptional distinctiveness and highly unusual compositions in unheated tanzanites (zoisites) from the Merelani mining area, Tanzania. Optical microscopy, laser-Raman microspectrometry and microscope cooling-heating studies have been used to identify the phases present. Most notable is the persistent and dominant presence of an extremely rare liquid phase in nature (Roedder, 1984) — liquid hydrogen sulphide (H_2S). The properties and origin of this unusual liquid, hitherto unreported in inclusions in the gemmological literature, are discussed. We also suggest a simple diagnostic 'chip and scratch' test, for gemmological purposes which is based on the distinctive 'rotten egg' odour of H_2S when inclusions are opened. We believe that recognition of inclusions containing liquid H_2S provides a characteristic feature of *unheated,* natural tanzanites (zoisites) compared to simulants or their manufactured counterparts.

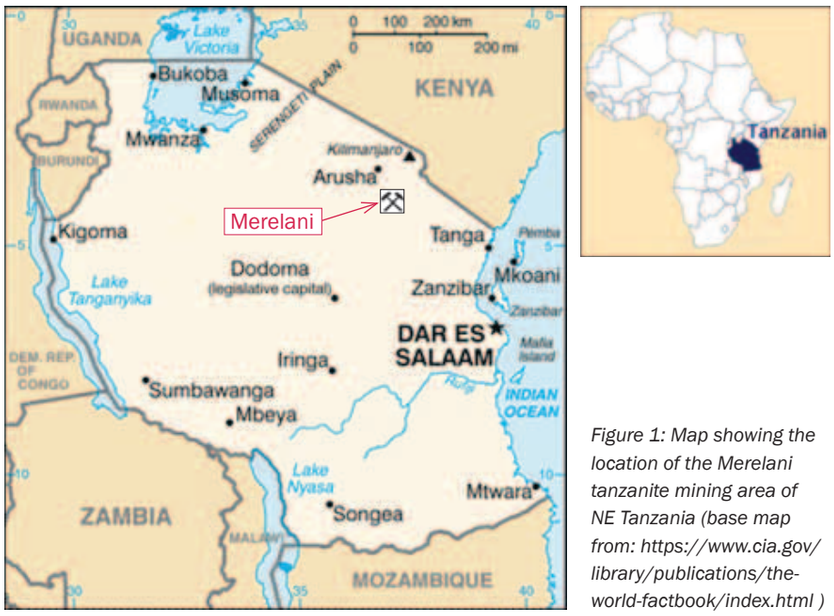

Figure 1: Map showing the location of the Merelani tanzanite mining area of NE Tanzania (base map from: https://www.cia.gov/library/publications/the-world-factbook/index.html)

In an accompanying paper (Rankin *et al.,* 2013, this volume) we discuss the likely effect of these inclusions on the thermal stability of natural and heat-treated tanzanites by modelling the internal pressures and stresses within the inclusions at different temperatures, to 800°C.

Samples description and preparation

The Merelani tanzanite mines are located in NE Tanzania due south of Mount Killimanjaro close to the town of Arusha *(Figure 1).* The deposits are centred on a latitude of 3° 33" and a longitude of 37° 01", occupying a zone some 7–8 km in length and 1 km wide. These are divided into separate mining blocks (A to D), with blocks C and D dedicated to artisanal mining operations. On a regional scale, the deposits form part of the important East African gem belt that continues through Mozambique, Kenya and Tanzania (Hughes, 1997). High-grade metamorphic rocks are a characteristic feature of this belt, but the geology of individual deposits is complex. Recent reviews of the geological setting, occurrence and mineral paragenesis of the Merelani tanzanite deposits are provided by Olivier (2006) and Walton and Marshall (2007).

For the purposes of the present study five samples of uncut, unheated blue-brown zoisite (tanzanite) were obtained by Dan Taylor from artisanal workings in the Block-D mine area of Merelani, during a visit to the Tanzanite mining district in 2008. The samples studied comprised stubby, single crystals ranging in size from about 1 × 1 × 0.5 cm to 0.2 × 0.2 × 0.4 cm, some with sharp terminations, showing colour variations from brown at the base to blue at the tip *(Figure 2).* For optical, microthermometric and Raman analysis of the fluid inclusion population, a series of optical quality polished wafers, *c.* 300 µm thick, were prepared. These

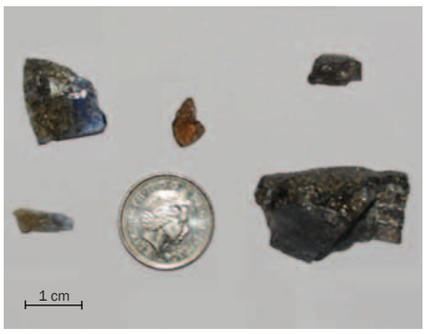

Figure 2: Uncut and unheated rough tanzanites (zoisites) from the D Block mine area used in the present study.

were obtained from slices cut parallel to the prism faces of the specimens where possible. To ensure the integrity of the inclusions care was taken to avoid heating the sample above 50°C during sample preparation by following established fluid inclusion wafer preparation techniques (Shepherd *et al.,* 1985).

Initial microscopic examination revealed a lack of suitable fluid inclusions in one sample (Tanz2), poorly developed inclusions in another (Tanz3) but abundant inclusions suitable for further study in the other three (Tanz1, Tanz6, Tanz8).

Analytical methods

The initial optical examination and characterization of inclusion populations was carried out on the polished wafers using a standard Olympus petrological microscope, in plane polarized light and under crossed polars, at magnifications up to ×1000.

Raman microanalysis was carried out on individual phases in selected inclusions, in confocal mode, using a Renishaw RM1000 Raman spectrometer attached to an Olympus BH-2 microscope. A neon ion laser (633 nm), with a source power of 500 mW and a focused spot size of ~2 µm, was used. The Raman equipment was calibrated regularly to check for instrument drift using a pure silicon standard at 520 cm^{-1} and the methane (CH_4) and carbon dioxide (CO_2) Raman peak positions at 2914, and at 1285 and 1387 cm^{-1}, respectively, in the KUFLINC fluid inclusion standard (Beeskow *et al.,* 2005). Peak positions above background were recorded and compared with published Raman data for phases likely to be present in fluid inclusions (Burke, 2001; Van der Kerkhof and Sousa, 2012: Frezzotti *et al.,* 2012).

Heating and cooling stage studies (microthermometry) provide information on fluid inclusion compositions based on diagnostic phase changes observed in inclusions during controlled heating and cooling runs (Shepherd *et al.,* 1985, Van der Kerkhof and Sousa, 2012). Studies were carried out over the temperature range -196°C and +80°C, on chips (a few mm^2) broken from selected wafers, using a Linkam THM600 heating-freezing stage with temperature controller, attached to a Nikon Optiphot microscope, with liquid nitrogen coolant. Details are shown in *Figure 3*. The microscope was equipped with long work distance (× 20 and × 40) objective lenses which allowed the various phase changes to be observed on heating and cooling the inclusions. The important changes reported here are the melting temperature of the frozen liquid phases on heating (Tm), and homogenization temperature of the liquid and vapour components into a single liquid phase (Th). These phase changes could be observed even in inclusions as small as 10 µm. The stage was regularly calibrated using synthetic fluid inclusion standards containing pure CO_2 (triple point at -56.6°C) and H_2O (critical temperature at 372.4°C; melting temperature at -0.2°C). Heating rates of 1–10°C/min were employed for measurements of phase changes after the inclusion contents had been frozen following rapid cooling down to *c.* -150°C. All microthermometric measurements reported here are believed to be accurate to within ± 0.2°C. Because of super-cooling effects the temperatures at which the contents of liquid inclusions freeze (Tf) is not a reliable indicator of the true freezing temperature. Under equilibrium conditions Tf is the same as Tm (the melting temperature). This is why Tm, rather than Tf, is used in conventional fluid inclusion studies (Shepherd *et al.,* 1985).

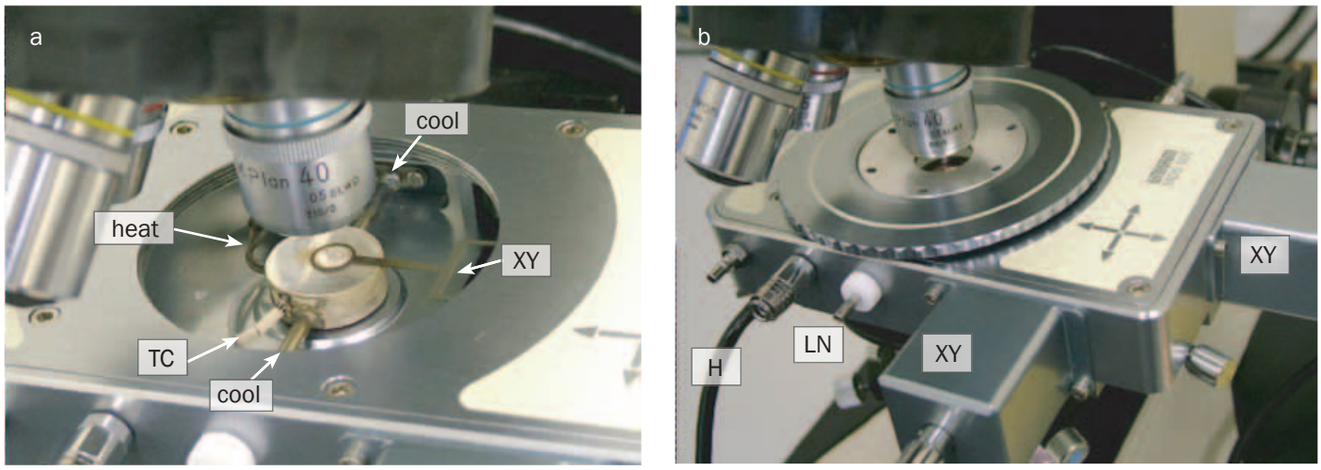

Figure 3: The Linkam THM600 combined microscope heating-cooling stage used in this study. (a) Close up of the inner heating-cooling block showing the inlet and outlet tubes for the liquid nitrogen coolant (cool), the platinum resistance heater (heat), thermocouple (TC) and sample carrier with X-Y movement controller (XY). (b) Outer stage with lid in place showing XY controls (XY), inlet valve for liquid nitrogen coolant (LN) and leads for the heat controller (H).

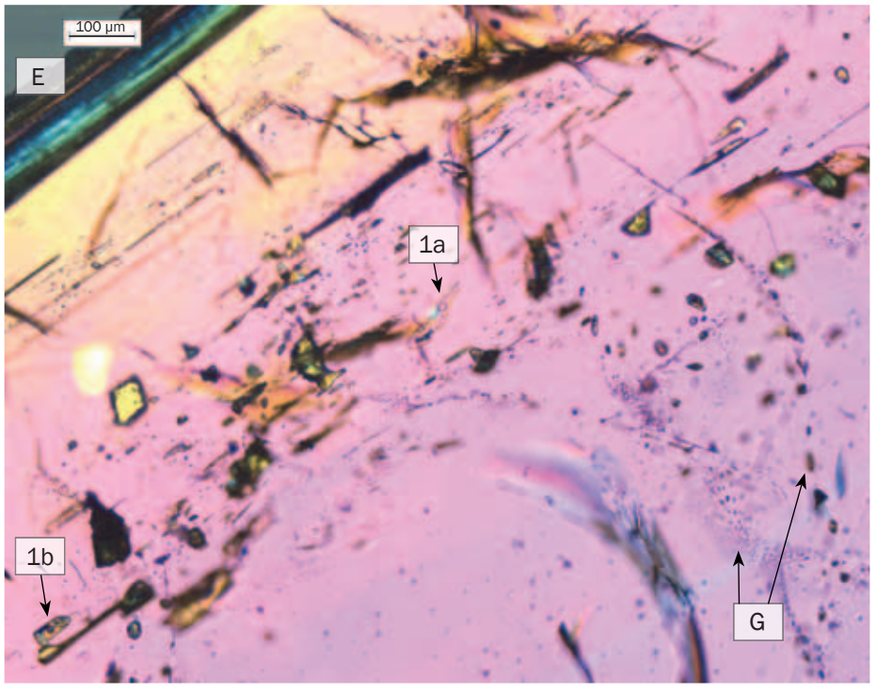

Figure 4: Photomicrograph of a thick polished section of unheated inclusion-rich tanzanite (zoisite) viewed under crossed polars. Note the variations in size and distribution of the fluid inclusions. Larger, elongate type I inclusions (e.g. 1a and 1b) tend to align parallel to crystal growth zones. These are picked out by variations in birefringence colour, parallel to the external crystal face (E). Smaller type II and III inclusions occur in curvi-planar groups and irregular clusters (G).

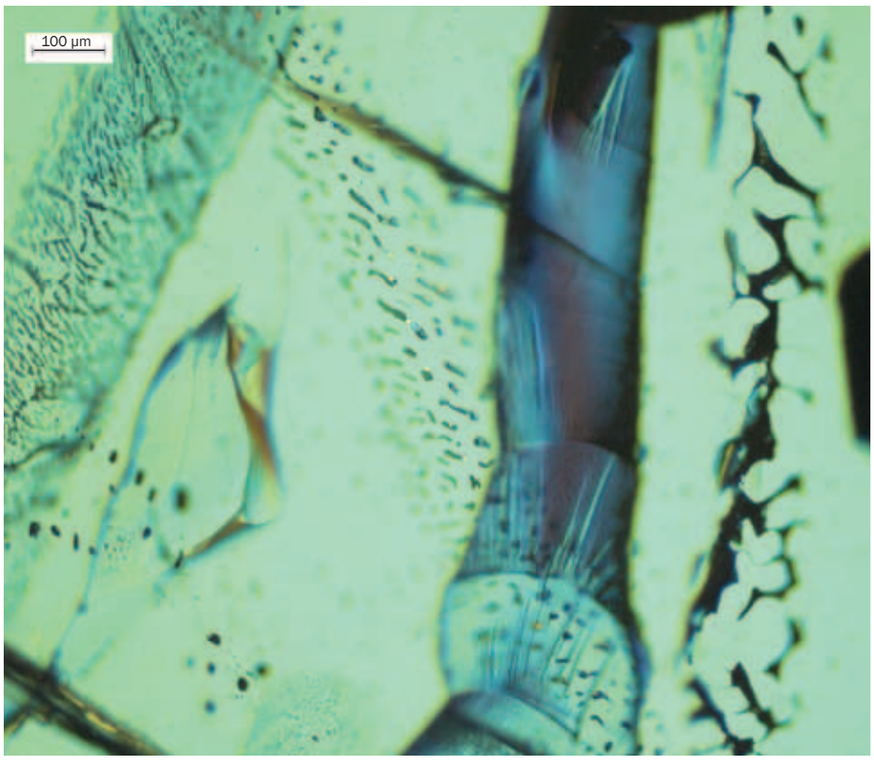

Figure 5: Planes of irregularly-shaped and branching (necked) type III inclusions decorating healed and partially healed fractures.

Fluid inclusion characteristics

Classification and distribution

Under the microscope the fluid inclusions are typically observed to be between 5 and 100 µm in size. However a few larger inclusions, reaching up to 150 µm in length are present. The inclusions occur in clusters and as isolated cavities (type I), as well as regularly-shaped inclusions in trails as linear and curvi-planar groupings (type II) as shown in *Figure 4*. Less commonly, they occur as indistinct and irregular-shaped planes that traverse the crystal (type III), as shown in *Figure 5*. Each type can be described as multiphase L+V+S inclusions at ambient temperatures (20–25°C) in which the liquid phase occupies *c*.75–45 volume percent of the inclusion. All type I, II and those III inclusions not showing any obvious signs of leakage, contain a small mobile vapour bubble within a colourless liquid. The bubble occupies *c*. 5 % of the inclusion volume, and several solid phases occupying up to 50% of the inclusion volume, are also present *(Figures 6, 7)*.

Fluid inclusions in minerals generally result either from entrapment of mineral-forming fluid during primary crystal growth as primary (P) inclusions, or during later recystallization or resealing of micro-fractures in the presence of a fluid phase to form secondary (S) inclusions, or pseudosecondary (PS) inclusions (Roedder, 1984). Primary inclusions tend to occur as isolated cavities or in clusters along growth zones. In contrast, S and PS inclusions typically occur in trails that traverse the crystals. In the case of PS inclusions, the fracturing and resealing took place during crystal growth, and the trails terminate inside the crystal. On this basis Type I correspond to P inclusions, Type II to PS and/or S inclusions and Type III to S inclusions.

Identification of phases present

The results of Laser Raman microanalysis of individual phases in the inclusions are illustrated in *Figure 8a,b* which shows typical Raman spectra for

the various phases present in inclusions. Identification of each phase was based on literature values for their characteristic major Raman peak positions (Burke, 2001; Van der Kerkhof and Sousa, 2012; Frezzotti *et al.,* 2012) and also their morphology and optical properties.

The Raman spectra of the liquid showed a strong diagnostic peak for liquid H_2S at ~2583 cm^{-1} in all inclusions analysed. Similarly, in every inclusion analysed the Raman spectra for the vapour phase showed a dominant peak at 2610 cm^{-1}, which is characteristic of H_2S vapour. Typical Raman bands and peaks for carbon dioxide and water (liquid or vapour) were not present, but traces of methane and nitrogen were detected in a few inclusions based on very small Raman peaks at the typical wave numbers of 2917 and 2331 cm^{-1} respectively. Native sulphur (S_8), characterized by its pale yellow colour and stubby crystal or globular habit, was also positively identified from its two strong diagnostic peaks at 473 and 218 cm^{-1}. Sometimes, this phase nucleated and reassembled as a globule inside the inclusion upon laser excitation during analysis. Similar behaviour has also been reported in S-rich fluid inclusions by Giuliani *et al.* (2003). A strong Raman peak at 1583 cm^{-1} and a lesser peak at 1625 cm^{-1} were recorded for a commonly observed opaque solid mass within the inclusion; these confirmed its identity as a disordered form of graphite. Well formed faceted colourless crystals which are commonly present inside the inclusion were identified as calcite based on Raman bands at ~1088 cm^{-1} and ~714 cm^{-1}; these Raman positions also suggest around 7% Mg in the calcium carbonate structure.

Gypsum was tentatively identified in some inclusions, but other solid phases could not be identified due to a lack of Raman signals. A summary of the phases identified in the inclusions based on their diagnostic Raman peaks and main optical/morphological characteristics is shown in *Table I.*

Microthermometric characteristics

Microthermometric data were obtained on type I and II inclusions

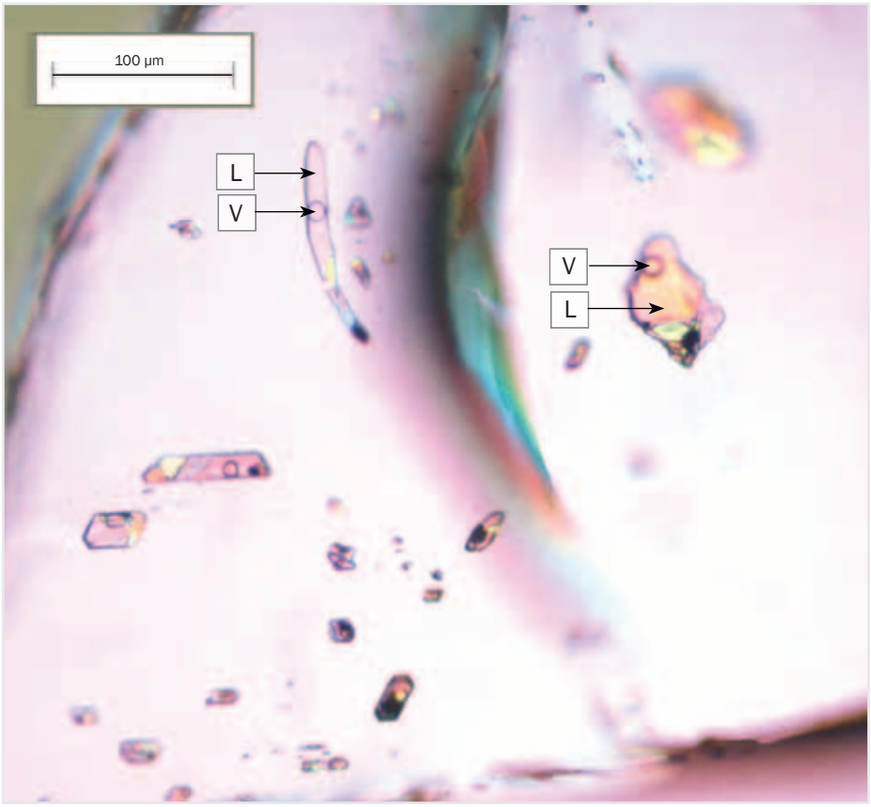

Figure 6: Clusters of multiphase (L+V+S) type I inclusions in an inclusion-rich area viewed under crossed polars. Note the rounded and oblate vapour bubbles (V) which can be made to move within the liquid (L) on gentle cooling and warming between 10 and 30°C, and various opaque, transparent and birefringent solid phases.

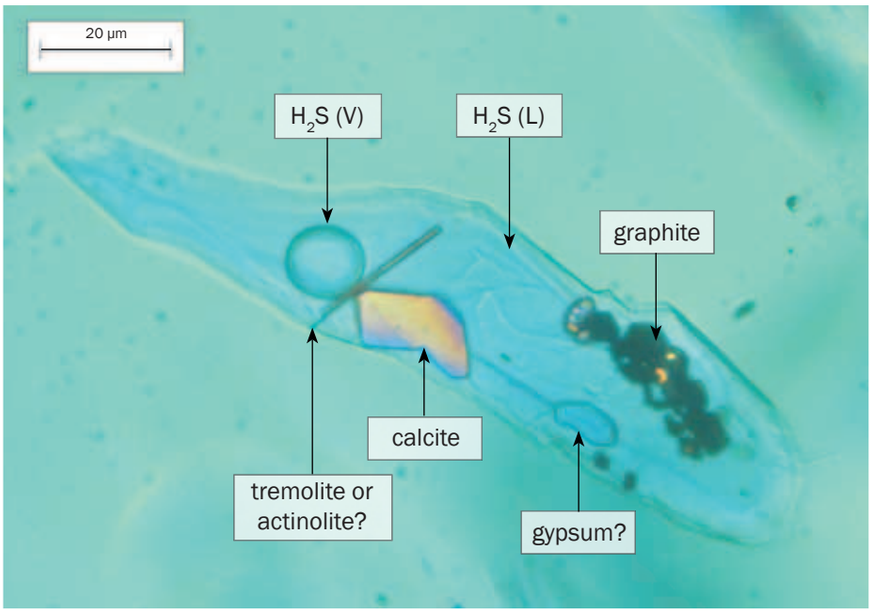

Figure 7: Close up of inclusion 1a shown in Figure 4 showing typical characteristics of phases identified in multiphase vapour-liquid-solid inclusions in unheated tanzanite observed under crossed polars. During Raman analysis a new mineral, sulphur, nucleated. This was pale yellow, of high relief and initially formed a perfect prismatic shape but later changed to a more amorphous blob. The high relief birefringent phases within the graphite cluster are tentatively identified as sphene, xenotime or rutile.

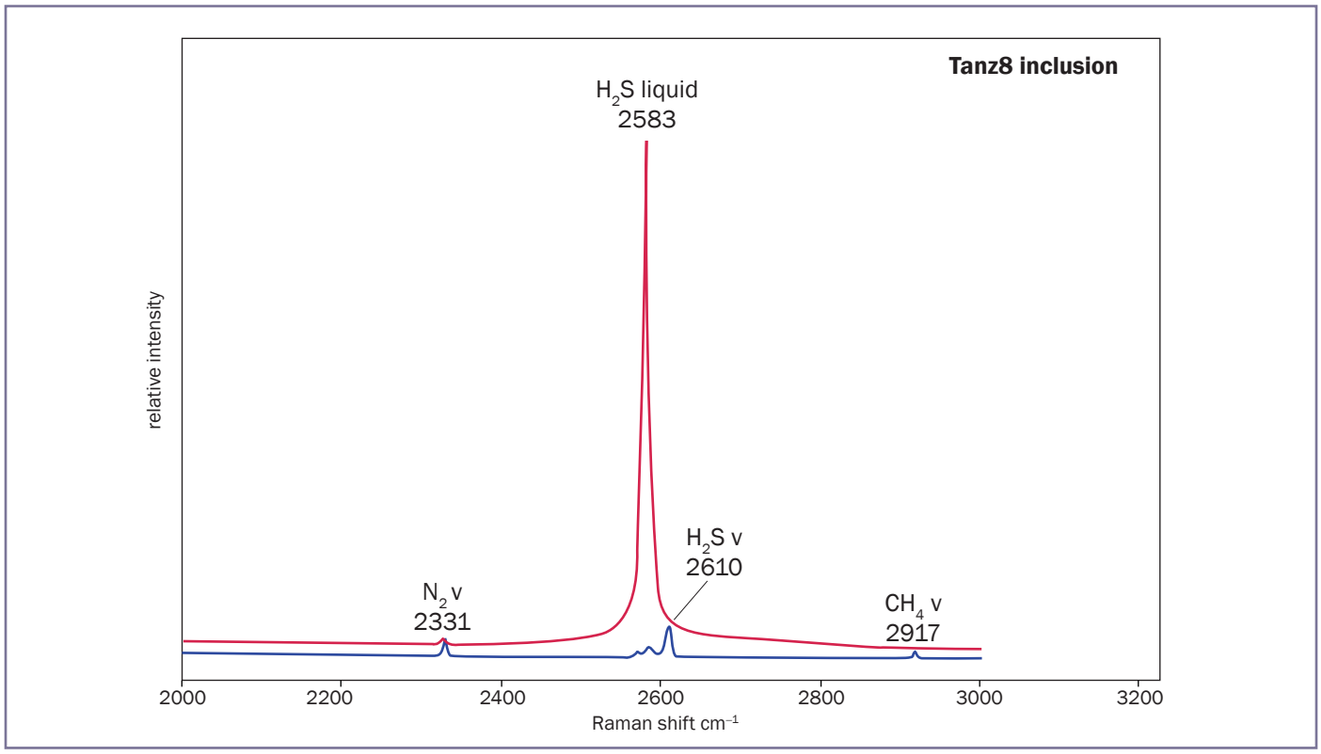

Figure 8a: Typical Raman spectra for fluid phases present in H_2S-bearing inclusions. Spectra vertically displaced for clarity.

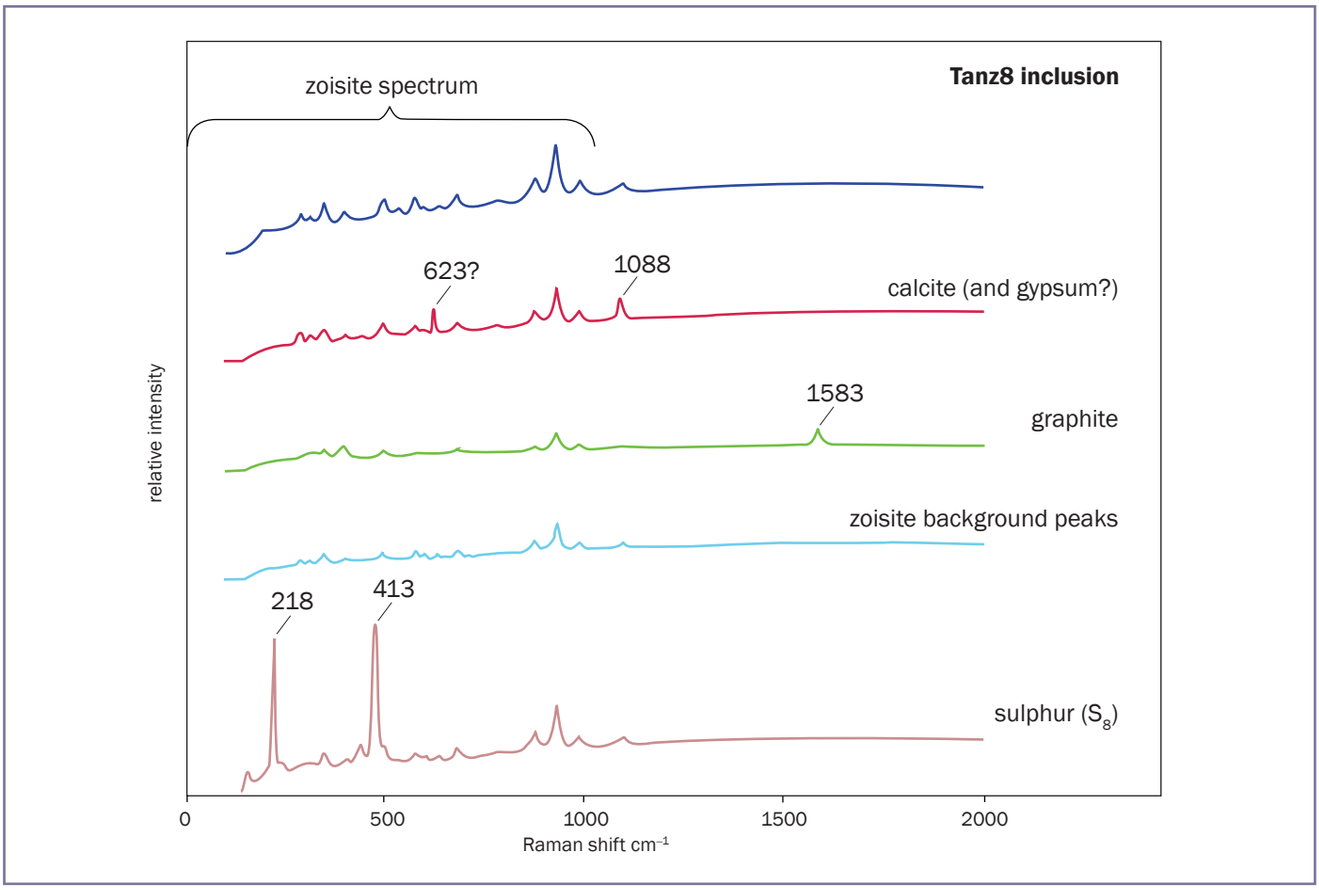

Figure 8b: Typical Raman spectra for solid phases present in H_2S - bearing inclusions. Spectra vertically displaced for clarity.

Table I: Summary of the major phases identified in the inclusions, their characteristic features and diagnostic Raman peaks.

Phase	Formula	Occurrence	Morphological and optical properties	Raman peaks cm^{-1}	Comment
Hydrogen sulphide (L)	H_2S	ubiquitous	colourless liquid	2583	
Hydrogen sulphide (V)	H_2S	ubiquitous	round or distorted bubble	2610	
Methane (V)	CH_4	traces	in bubble	2917	X <0.025
Nitrogen (V)	N_2	traces	in bubble	2330	X <0.025
Disordered graphite (S)	C	v. common	opaque, irregular mass	1583	
Sulphur (S)	S_8	common	transparent, high relief globules or stubby crystals	473 218	may nucleate under laser
Magnesian calcite (S)	$CaCO_3$	common	transparent, rhombic crystals high birefringence	1088 714	
Unidentified (S)		occasional	transparent, tabular crystals low birefringence	623?	gypsum?
			thin, acicular needles	n.d.	tremolite?
			yellow-brown transparent crystals in graphite clusters	n.d.	possibly sphene, xenotime or rutIle?

X means mole fraction in the inclusion

in three of the four samples. Sample Tanz6 was unsuitable because of the poor optical quality of the predominant type III inclusions present. The melting temperature of the liquid (Tm) was determined by rapidly cooling the inclusions until the liquid contents froze suddenly at between -90 and -120°C. The inclusions were then heated at a rate of 10°C/minute up to ~ -88°C, then at a rate of 1–2°C/minute until the onset of rapid melting of the frozen liquid occurred at the temperature of melting (Tm). The Tm values, based on measurements of some 47 inclusions, are shown in *Table II*. These ranged from -84.7 to -86.6°C, with the majority forming a very narrow range between -85 and -85.9°C. The freezing or melting point of pure liquid H_2S is at -85.5°C (NIST, 2011), which suggests that the main fluid present is H_2S of very high purity. This is in agreement with the Raman data on the main fluid and vapour phases, which only showed peaks for hydrogen-sulphide (H_2S). The occasional lower Tm values, at around -86 to -86.5°C can be ascribed to very minor amounts of methane and nitrogen (<0.025 of the total mole fraction) which are known to lower the melting temperature of pure H_2S (Van der Kerkhof and Sousa, 2012).

Table II: Summary of microthermometric data (T°C) for rough tanzanites (zoisites).

Sample no.	Inclusion type	Occurrence	Number	$T_{min.}$	$T_{max.}$	T_{mean}
a) Melting temperatures of frozen liquid (Tm) °C						
Tanz6	I and II	Cl	9	-86.3	-84.0	-84.7
Tanz1	I and II	Iso, Cl, Pl	24	-86.6	-84.7	-85.5
Tanz8	I and II	Iso, Cl, Pl	15	-86.0	-84.8	-85.5
b) Homogenization of liquid and vapour phases (Th) °C						
Tanz6	I and II	Cl	47	47.8	67.3	54.4
Tanz1	I	Iso	36	39.1	84.1	54.6
Tanz1	II	Iso, Cl, Pl	13	39.6	60.5	45.4
Tanz8 brown	I and II	Iso, Cl, Pl	15	28.1	73.9	43.0
Tanz8 blue	I and II	Iso, Cl, Pl	9	39.3	51.8	47.4

Iso = isolated, Cl = clusters, Pl = planes

This is confirmed by their detection in trace amounts by Raman analysis in a few inclusions.

The temperatures at which the liquid and vapour H_2S homogenized to a single liquid phase on heating (Th) were recorded for 120 inclusions. As shown in *Table II* these ranged from 28 to 84°C with mean values between 43 and 55°C for all samples. It is noteworthy that there is no significant variation in Th or Tm values between Type I and II inclusions, or between blue and brown colour zones in the samples.

The 'rotten egg' odour from opened inclusions

When small chips were broken off the polished wafers prior to microthermometric analysis a distinctive 'rotten egg' odour was commonly noted. This can now be attributed to the release and volatilization of liquid H_2S from opened inclusions, despite their very small size. The nose is extremely sensitive to H_2S. According to published data (Amoore *et al.,* 1983) the mean threshold for detecting this odour in air is around 8.1 parts per billion, although this varies

Table III: Estimates of the size and number of inclusions from which H_2S(V) needs to be released from inclusions into (10 cm)^3 and (20 cm)^3 of air in order to exceed the mean threshold value of 11µg/m^3 (indicated in red) to detect its odour.

Inclusion dimensions µm	H_2S (V) concentration (µg) in (10 cm)^3 of air	H_2S (V) concentration (µg) in (20 cm)^3 of air	No. of inclusions needed for (10 cm)^3 of air	No. of inclusions needed for (20 cm)^3 of air
10 × 10 × 10	0.6	0.08	200	>1000
10 × 10 × 20	1.2	0.15	10	80
20 × 20 × 20	4.8	0.6	3	24
30 × 30 × 30	16.2	2.25	1	5
50 × 50 × 50	125	15.4	1	2
100 × 100 × 100	600	75	1	1

somewhat depending on the health and age of individuals and other factors. This threshold corresponds to a detection limit of 11 µg in 1 m^3 of air. Estimates of the amount of gas released from inclusions of different sizes are shown in *Table III*. These are based on estimates of the mean density of the combined L+V H_2S components of the inclusions of between 0.5 and 0.7 g/cm^3 based on the Th values and published thermo-physical data as detailed in the accompanying paper (Rankin *et al.,* 2013). The estimates demonstrate that the fortuitous opening of just one large equidimensional inclusion, 50 µm across, is enough to release detectable levels of H_2S within 20 cm of the nose, or one equidimensional inclusion 30 µm across some 10 cm from the nose. Preferential breakage is more likely to occur along planes of weakness occupied by linear arrays of type II and III inclusions, in which case opening of just 24 smaller inclusions, 20 µm in size, is still detectable at a distance of just 10 cm.

Discussion

Occurrence and origin of H_2S in fluid inclusions

Hydrogen sulphide is a relatively common volatile in natural gas fields (usually referred to as 'sour gas' fields) in sedimentary basins. It can occur in inclusions in minerals from low temperature mineral deposits associated with these basins (e.g. Rankin and Shepherd, 1978; Beny *et al.,* 1982), in which the source of sulphur is generally believed to be from reduction of sulphate minerals (gypsum or anhydrite) from sedimentary evaporite sequences.

Gaseous H_2S often occurs in volcanic fumaroles and associated geothermal systems contributing to the distinctive sulphurous odour around these systems. Trace amounts have also been detected in fluid inclusions in associated epithermal (<300°C) minerals, and in both instances a magmatic source for H_2S-sulphur is generally accepted (Henley and Ellis, 1983).

A metamorphic source for H_2S may also be envisaged, resulting from the release of volatiles from de-sulphidation metamorphic reactions of rocks under moderate to high temperatures and pressures. For example, Giuliani *et al.* (2003) report a metamorphic origin for gaseous H_2S in well characterized inclusions in ruby from some gem-bearing high-temperature skarn deposits of Vietnam. Feneyrol *et al.* (2013) noted the occurrence of H_2S in inclusions in gem tsavorites (and tanzanite) from the Pan-African metamorphic belt of East Africa, and Olivier (2006) reported on H_2S-rich inclusions in quartz associated with the Merelani tanzanite mineralization within this belt. Both sets of authors suggest a metamorphic origin for the H_2S in the belt. Thus, a metamorphic origin is also envisaged for the high density H_2S fluids reported here.

Where might the sulphur come from?

Metamorphism is a process of devolatilization which essentially means that volatile species such as CO_2, H_2O, CH_4, SO_4 and H_2S will be released into the metamorphic fluids as a range of hydrous, carbonate sulphate and sulphide minerals break down during metamorphic reactions. Both Cr and V, normally insoluble and immobile, will go into solution under the right redox conditions. At low pH, as indicated by the presence of H_2S in the fluid phase, Cr^{3+} is soluble. The presence of tanzanite in quartz rich veins (Olivier, 2006) means that Cr and V must have been leached, likely from black shales, during metamorphism and then transported in solution to the site of crystal growth. Feyrerol *et al.* (2013) suggest on the basis of stable sulphur isotope data that the source of the S in the metamorphic fluids that are trapped in tsavorite crystals were a series of sedimentary sulphate phases (baryte and anhydrite) that formed during evaporation and were then later metamorphosed. A combination of reduced, organic rich black shales that fix Cr and V from sea water during sedimentation, and interbedded sulphate rich evaporate horizons will provide an appropriate chemical factory that will release reduced, H_2S rich fluids that will carry Cr and V to the site of growth of minerals such as tanzanite and tsavorite.

Optical, thermal and olfactory characteristics of liquid H_2S inclusions compared to other common liquid phases in gem minerals; gemmological implications

Liquid-filled cavities with vapour bubbles are a common feature of many minerals and gemstones at ambient temperatures. The most commonly reported liquids (Gübelin and Koivula, 2005; Roedder, 1982) in untreated gem

minerals in order of increasing rarity are water (aqueous brines), liquid carbon dioxide, silicate glass (supercooled silicate melts) and liquid petroleum (oil). Simple optical tests can be used to distinguish between them (Roedder, 1982). Liquid petroleum which is common in Herkimer 'diamonds' (quartz) is readily distinguished from other liquids because of its yellow to brown colour and UV fluorescence. The refractive indices of common inclusion liquids vary (Van der Kerkhof and Sousa, 2012) with typical values as follows: silicate glasses *c.* 1.50 to 1.65; water and brines *c.* 1.34; liquid CO_2 1.12. This can aid identification by means of the visible differences in relative relief between the host mineral and contained fluid. However, the refractive index of pure H_2S (1.374) is quite close to that for water and brines. So, both H_2S and aqueous liquids will show similar relative reliefs and would be difficult to distinguish optically.

An important property useful for recognizing CO_2 (V+L) inclusions is based upon gentle warming or cooling of the sample under the microscope. Liquid CO_2 cannot exist in the liquid state above its critical point temperature of 31.1°C. Thus, inclusions containing both CO_2 (V) and CO_2 (L) at room temperatures will show homogenization to a single phase on gentle warming up to this critical temperature. The test is so sensitive that even the heat from a microscope light source is sometimes sufficient to cause homogenization of liquid and vapour CO_2, unless infrared filters are used (Roedder, 1982). The critical point temperature for H_2S at 100.4°C is markedly higher. Therefore, liquid and vapour H_2S cannot co-exist above this temperature. This is reflected in the low homogenization temperature ranges for the inclusions reported here (28 to 84°C) compared to the Th ranges generally recorded in the literature for water and brine inclusions in minerals from a variety of geological environments from 70 to 550°C (Wilkinson, 2001). Thus, a simple heating test up to 100°C might seem appropriate for distinguishing between liquid H_2S, liquid CO_2 and liquid H_2O in L+V fluid inclusions. But this is inadvisable, due to potential irreversible damage to tanzanite even at these lower temperatures, as discussed in the accompanying paper (Rankin *et al.* 2013).

Diagnostic gemmological tests for liquid H_2S inclusions in tanzanites (zoisites)

We suggest that the H_2S inclusions reported here provide a valuable means of identifying natural, un-treated tanzanites (zoisites) and distinguishing them from any crystals that might be laboratory-grown. Identification of liquid H_2S is best achieved by Raman microanalysis based on its strong characteristic Raman peak at 2583 cm^{-1}. Positive results can be obtained on individual inclusions down to 10 µm in size in inclusion trails and clusters with signal count times of about 60 seconds.

A simple laboratory scratch-chip odour test is also suggested. This is based on the characteristic 'rotten egg' odour of H_2S when near-surface inclusions are opened by scratching or breaking off a very small chip from the underside of a rough stone (where inclusions are often most abundant). Zoisite (tanzanite) with a hardness of 6.5 on the Mohs scale is easily scratched. But care should be taken when taking a small chip because zoisite is easily cleaved and may break in an uncontrolled way if too much force is used. The human nose is extremely sensitive to this gas, provided the amount released exceeds the threshold value for H_2S at *c.*11 µg in 1 m^3 of air. Our current experience, and a previous study of inclusions in barytes (Rankin and Shepherd, 1978), has shown that it should be readily detected by immediately placing the nose close to (within 10 to 20 cm) the scratch or chipped area. *Table III* illustrates the sensitivity of the method by presenting the calculated amounts of H_2S released from inclusions of different size into different volumes of air. Even a single inclusion 30–50 µm in size, which is less than the width of a human hair *(Figure 9)* will release detectable amounts in volumes of air between (10 to 20 $cm)^3$.

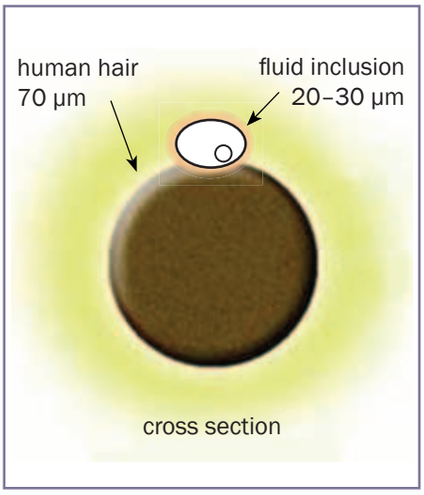

Figure 9: Typical size of type I and type II H_2S fluid inclusions in tanzanite in comparison to the width of a human hair.

Alternatively, detectable amounts can be released in similar volumes of air from a plane of some 20 inclusions averaging 20 µm in size.

One of the main limitations of the method is whether inclusions of relevant size and abundance are present. Most unheated gem-quality tanzanites are selected for their clarity and tend to be relatively inclusion-free. Therefore, a negative test would not rule out an unheated natural tanzanite from the Merelani district.

Summary of conclusions

Multiphase H_2S-bearing fluid inclusions, up to *c.* 150 µm in size, occur as both primary and secondary inclusions in some uncut, unheated blue-brown rough tanzanites from the Merelani deposits of Tanzania. All generations of inclusions are characterized by the presence of high density H_2S that represents trapped portions of metamorphic fluids present during primary growth and subsequent recrystallization of the host zoisite.

Inclusions containing liquid H_2S are rare in minerals and hitherto have barely been reported in the gemmological literature. Recognition of these unusual inclusions with such distinctive features provides a valuable criterion for identifying natural, un-treated rough

tanzanites from its type locality and for distinguishing them from laboratory-grown crystals or substitutes should these be produced in the future. Positive identification of cut stones, for which any fracturing is not an option, is based on the characteristic Raman peak for H_2S (liquid) at 2583 cm^{-1}.

A simple scratch-chip test on rough stones is proposed for gemmological purposes based on the distinctive 'rotten egg' odour of H_2S (gas), when the inclusion contents are released causing the liquid H_2S to spontaneously evaporate. The human nose is highly sensitive to this odour. Calculations show that it is possible to detect H_2S released from a single inclusion some 30–50 µm in size, or from an opened trail of some 20 inclusions, averaging 20–30 µm in size. Further studies are recommended on a wider range of material to more fully evaluate the potential of this olfactory test.

Acknowledgements

This paper is based on data collected by Dan Taylor as part of his Masters Research thesis on inclusions in tanzanites at Kingston University. Tragically, Dan died following a road traffic accident before he completed his research. The present paper is based primarily on the comprehensive optical, Raman and microthermetric data set and images that Dan methodically kept in his laboratory notebook and computer files. We gratefully acknowledge the kind permission from Dan's family to use these data to write up the present paper as a contribution to his beloved subject of gemmology, which we dedicate to his memory, Most of the data and ideas presented here have arisen out of numerous discussions with us (PJT and AHR) as his co-supervisors prior to his untimely death. We have meticulously checked their validity against his notebook entries and by re-plotting the data. As such, we take full responsibility for any errors, omissions, misrepresentation or misinterpretation of the scientific data.

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Liquid hydrogen sulphide (H_2S) fluid inclusions in unheated tanzanites (zoisite) from Merelani, Tanzania: Part 2. Influence on gem integrity during and after heat treatment

Professor Andrew H. Rankin, Dan Taylor* and Professor Peter J. Treloar

This is the second of two papers dedicated to the memory of Dan Taylor.

Abstract: The estimated densities of the H_2S phase (0.58 to 0.77g/cm^3) in isolated and fracture-bound multiphase inclusions in tanzanite have been used to model internal fluid pressures during progressive heat treatment to 600°C. When internal fluid pressures exceed the confining strength of the host, the inclusions will re-equilibrate and the contents will be lost through leakage and/or decrepitation. The internal pressures beyond which 'typical' microscopic inclusions in zoisite will leak (P_d) under an external atmospheric pressure of 1bar, is estimated at 90 MPa (901 bars), but for larger inclusions (>100 µm) this value will be much lower. Thermophysical modelling of internal fluid pressures shows that virtually all except the smallest (<2–10 µm) inclusions in zoisite would not survive the heating process to temperatures above 600°C. Some inclusions larger than 20 µm may survive heating to 450°C, but the largest (*c.* 100 µm) will decrepitate or leak at even lower temperatures. Alignment of planar groupings of re-equilibrated inclusions will produce zones of internal weakness or internal stress which may be exposed and could be 'unzipped' along these planes, after heat treatment, during cutting and polishing. This explains why tanzanites can be difficult to cut unless free of inclusions and may also explain, at least in part, why some cut tanzanites may be more susceptible to fracturing than others. The results, overall, support the view expressed in Part 1 of this preliminary investigation (Taylor *et al.,* 2013) that microscopic H_2S inclusions (*c.* 20 to 100 µm) are generally a distinguishing feature of tanzanite/zoisite from Merelani which has not been heat treated.

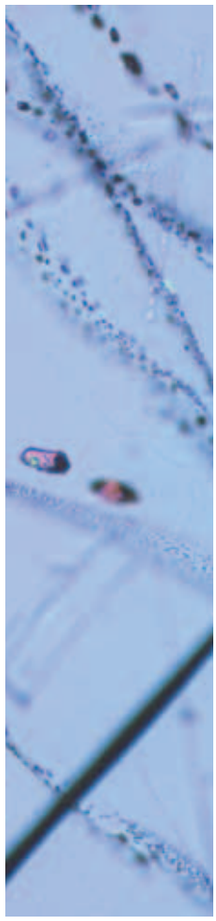

Keywords: decrepitation, fluid inclusions, gemmology, heat-treatment, hydrogen sulphide liquid, microthermometry, PVTX modelling, tanzanite, zoisite

* Sadly Dan Taylor died on 29 October 2009.

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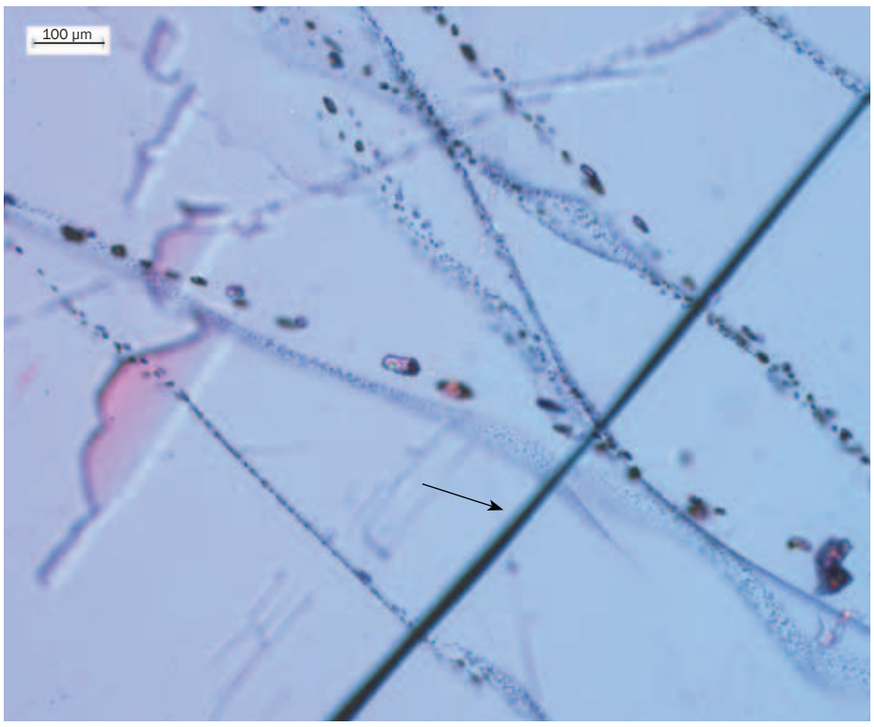

Figure 1: Planar and curviplanar criss-crossing trails of type II inclusions in unheated zoisite/tanzanite. Note relationship of inclusions to the linear cleavage direction (arrowed).

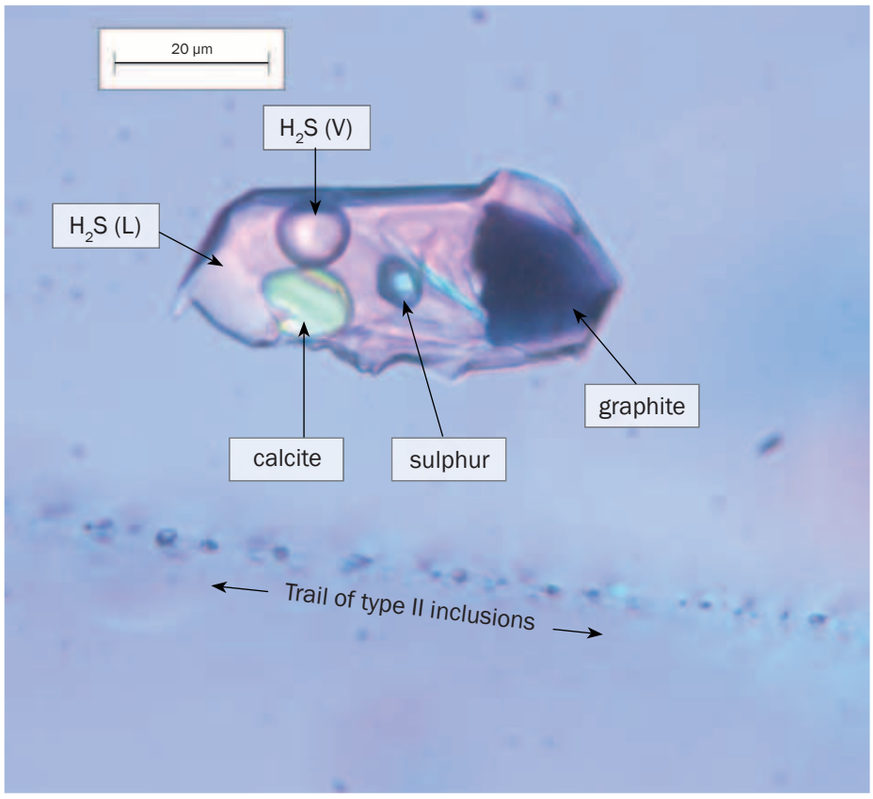

Figure 2: Typical phase proportions present in multiphase vapour-liquid-solid inclusions in unheated zoisite/tanzanite. Those illustrated in this isolated type I inclusion are similar to those present in very small type II inclusions in the trail below.

Introduction

In an accompanying paper (Taylor *et al.,* 2013) we reported on the occurrence and distribution of multiphase microscopic fluid inclusions of unusual and distinctive compositions characterized by the presence of unusually large amounts of liquid H_2S. We discussed their origin and highlighted their potential as gemmological indicators of provenance for unheated tanzanite (zoisite). Here we evaluate the likelihood of their survival after heat treatment; we also explore the effect that these inclusions will have on the integrity and mechanical stability of natural and heat treated tanzanites/zoisites i) during and after heat treatment, and ii) on cutting and polishing .

Nearly all trade tanzanites of gem quality are known to have been heat-treated to improve their colour (Bocchio *et al.,* 2012: GIA, 2013). Flawed rough stones, including those with inclusions visible with a 10× loupe, are avoided as far as possible because they are generally known not to survive the heating process up to 500–700°C causing the crystal to fracture and break apart (Roskin, 2005). Lower temperatures of 450°C are sometimes employed to minimize the risk of inclusion-induced fracturing, and it is conceivable that microscopic inclusions could survive the heating process to these lower temperatures as relict indicators of the original provenance of the stone. Where microscopic fluid inclusions have been destroyed, or partially opened, they could give rise to inherent weaknesses that may only be relieved or exposed during and after cutting. Tanzanite is known to be sensitive to thermal shock, which can increase its potential to fracture (GIA, 2013). Therefore, it is interesting to explore the likely influence that partly destroyed, or intact, inclusions might have on the thermal stability of cut tanzanites.

Approach and methodology

Information on the size and distribution of the H_2S inclusions in three rough zoisite/tanzanite crystals and their liquid-vapour homogenization temperatures (Th), have been previously

reported (Taylor *et al.,* 2013). These data form the basis of the present study. The homogenization temperatures of the liquid and vapour phases in fluid inclusions are widely used in mineralogical and petrological studies to determine the bulk density of the trapped inclusion fluid (Shepherd *et al.,* 1985). Here we use the Th data (28 to 84°C) for the three studied samples of rough tanzanite (zoisite) previously described (Taylor *et al.,* 2013) to estimate the bulk fluid densities of the homogeneous H_2S phase. The density estimates are then used to model internal pressures within these constant-density fluids, at different temperatures up to 800°C, using thermophysical data for pure H_2S. The temperatures at which the internal fluid pressures are likely to cause the inclusion in zoisite to leak or rupture are then estimated. The estimates are based on the established relationship between the Mohs hardness and the internal fluid pressures needed to initiate re-equilibration of fluid inclusions of varying size, in different minerals (Bodnar, 2003).

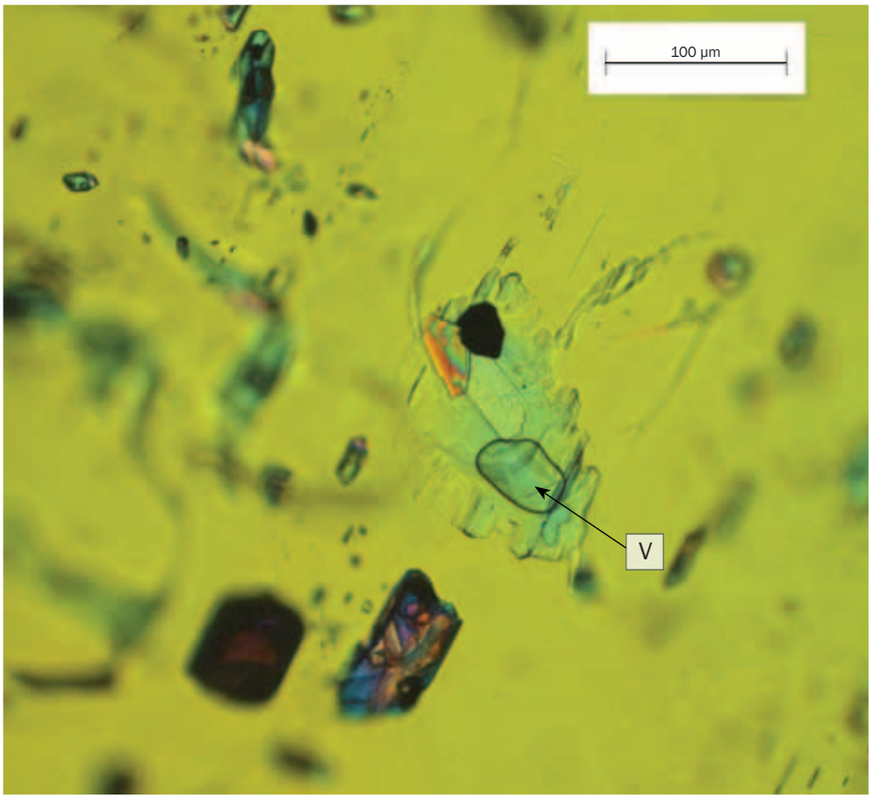

Figure 3: Large, highly irregular and flattened type I inclusions (c. 120 µm across) in a thick polished section of unheated zoisite/tanzanite viewed under crossed polars. Note the squashed and distorted vapour bubble (V) and elongated internal facets of the inclusion wall.

Fluid inclusion characteristics

As previously reported, three distinct groups of multiphase H_2S-dominant fluid inclusions, typically between 10 and 100 µm in size, are recognized (*Figures 1* to *4*). Type I inclusions are present in clusters and as larger isolated cavities which can be regular or highly irregular in shape (*Figures 2* and *3*). Type II inclusions occur as regularly-shaped inclusions in linear and curvi-planar groupings. Type III inclusions are less common and occur as indistinct and irregular-shaped planes that traverse the crystal *(Figure 4)*. In type I and II inclusions, at room temperature, the approximate volumetric proportions of the different phases identified are: liquid H_2S (75–45%), vapour H_2S (*c.* 5%) various solid phases (10–50%, see *Figures 2* and *3*). In type III inclusions H_2S liquid and vapour have been identified, but their small size and irregular shape precluded further identification of phases or

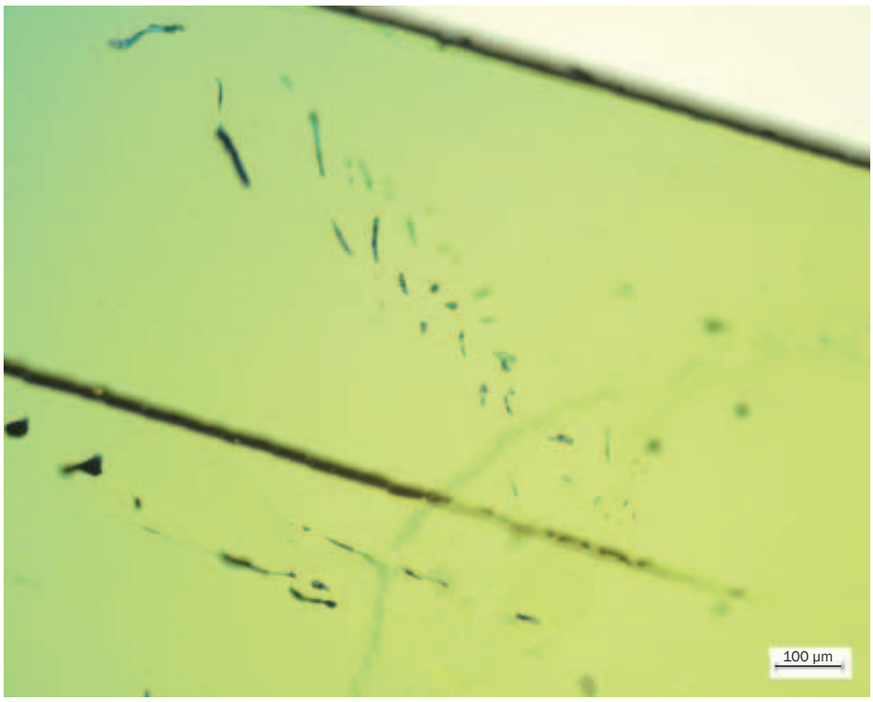

Figure 4: Elongate, irregular-shaped type II and III inclusions viewed under crossed polars. Note their small size and occurrence in trails in relation to the strong cleavage along the dark top of the section and the discontinuous straight line towards the centre of the image.

microthermometric measurements. The purity of the H_2S phase in all inclusions is greater than 95%.

Estimates of H_2S fluid densities from Th data

The distribution of homogenization temperatures for all 118 inclusions previously reported (Taylor *et al.,* 2013) together with separate data for isolated (type I) and fracture bound (type I and II) inclusions are presented in *Figure 5*. Some 95% of all inclusions homogenized over the temperature range from 45 to 75°C. The modal values for fracture bound inclusions (45°C) are slightly lower than for isolated inclusions (50°C) which also show a wider, skewed distribution of data up to 85°C.

The temperature at which the H_2S liquid (L) and vapour (V) phase in the inclusions homogenize to liquid will plot on the V+L ↔ L equilibrium curve as illustrated in *Figure 6*. Estimates of the densities based on this temperature-density diagram are also shown in *Figure 6*. These range from 0.58 to 0.77 g/cm^3 but most values are between 0.72 and 0.67 g/cm^3.

Internal fluid pressures within the inclusions

Estimates of changes in internal fluid pressure as a function of temperature are based on fundamental 'equations of state' that express the interdependence of pressure (P), temperature (T), and density (ρ) for fluids of fixed composition (see Bakker, 2009, for details). If two of these variables are known, or fixed, the other can be calculated, as evident from *Figure 6*. The use of bulk fluid density data to determine the internal P-T conditions, at any given temperature, is illustrated in *Figure 7* which shows the vapour-liquid equilibrium curve for H_2S based on available pressure-density-temperature (PρT) data (Lemmon *et al.,* 2011). On heating, an inclusion containing both liquid and vapour H_2S will follow the vapour-liquid equilibrium curve as the liquid expands and the vapour bubble shrinks. The point at which homogenization occurs (Th V+L → L) defines a unique position on this curve at which point all three variables (PρT) are fixed or can be calculated. Continued heating beyond Th will cause the inclusion to enter the single phase region. Provided the volume and mass, and therefore density, remain unchanged the inclusion will move along a PT path defined by a line of equal density (an isochore). It will continue to follow this isochoric path, maintaining its integrity, until the build up of internal fluid pressure exceeds the confining strength of the host mineral at atmospheric pressure (1 bar = 0.1 MPa). Beyond this point, relief of internal stresses will induce fractures or flexures in the host and the inclusions will either leak or decrepitate.

In the context of the previous paper (Taylor *et al.,* 2013) it will be apparent from *Figure 7* why a simple heat test for H_2S inclusions in natural tanzanites (zoisites) is inadvisable. For a typical inclusion homogenizing at 50°C

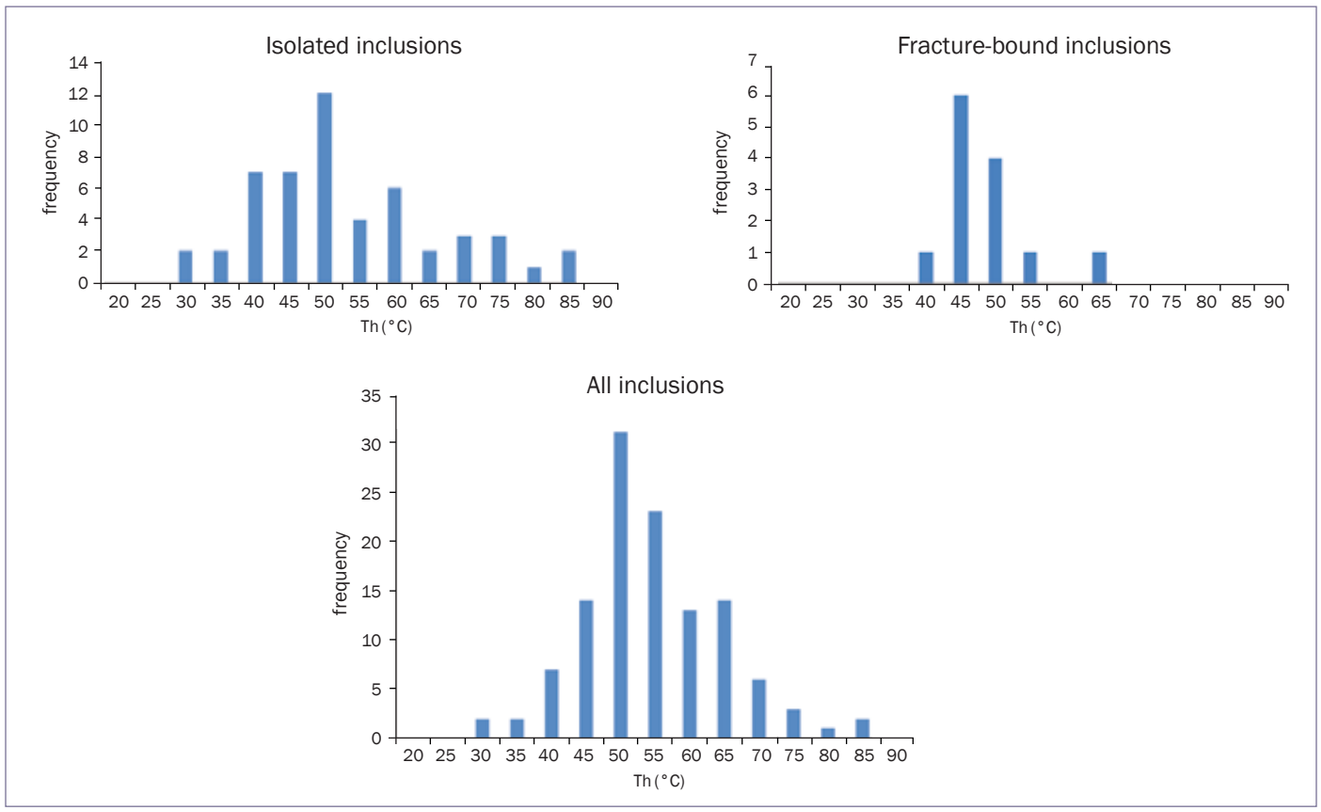

Figure 5: Histograms for vapour-liquid homogenization temperatures (Th) for isolated (type I) fracture-bound (type II) inclusions, and all inclusions in all three samples.

(ρ = 0.7) the pressure at the point of homogenization will be 35 bars (3.5 MPa), but if heated to just 75°C the internal fluid pressure would increase to 20 MPa which is 200 times greater than atmospheric pressure — significantly increasing the risk of fracture.

Experimental PρT data for pure H_2S is limited so for the present paper it is necessary to calculate the isochoric PT paths using 'equations of state'. Several are available but the Peng-Robinson equation (Peng and Robinson, 1976) is one of the most widely used, though uncertainties increase at temperatures > *c.* 500°C. However, the use is justified because ranges, rather than precise estimates of pressures, are adequate for evaluating the overall potential for leakage/decrepitation of inclusions on heating treatment to between 450 and 600°C. Calculations were carried out using the Loner PW computer programs developed by Bakker (2009). The results are shown in *Figure 8*. The minimum and maximum internal fluid pressures (P_i) for all inclusions, over the temperature range 450 to 600°C are 130 and 320 MPa respectively. For most inclusions (Th from 40 to 70°C) the P_i values are between 160 and 300 MPa.

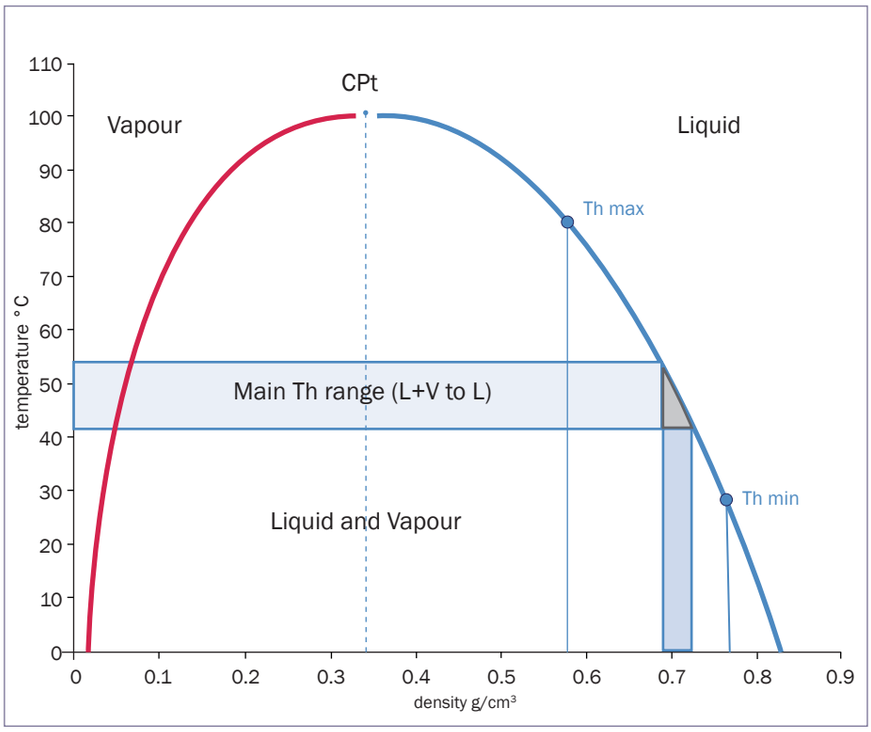

Figure 6: Temperature–density diagram for pure H_2S, constructed from NIST data (Lemmon et al.*, 2011) showing the equilibrium curve separating the two phase (liquid+vapour) and single phase (liquid or vapour) stability fields up to the critical point (CPt at 100°C). Homogenization temperatures (Th) for inclusions containing pure H_2S that homogenize to liquid (L+V → L) will plot on this right-hand side of the curve (in blue). The maximum, minimum and main Th ranges for inclusions in zoisites are shown in the shaded band together with their corresponding densities (g/cm³).*

Influence of internal fluid pressures on stress relief and inclusion integrity

Background

It has long been recognized that the build up of pressures in fluid inclusions during heating can cause the inclusion contents of minerals to leak. This is often accompanied by the sudden, and audible, explosive release of fluid and shattering of the crystal (decrepitation). Decrepitation may occur spontaneously in soft cleavable minerals such as baryte and halite containing compressed gas inclusions where heat from the hand may be sufficient to cause shattering, accompanied by audible 'pops' (popping salt) and 'jumping' of fragments out of the hand (Dons, 1956; Roedder, 1984). Even in more resistate minerals, such as quartz, spontaneous stress release

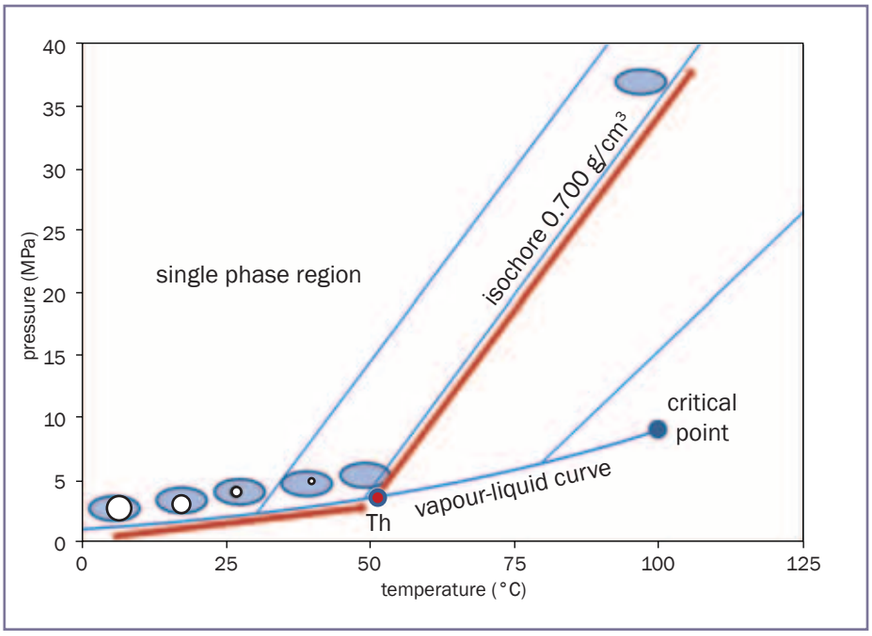

Figure 7: P-T plot for H_2S, constructed from NIST data (Lemmon et al.*, 2011) for pure H_2S illustrating the pathway (red) followed by an inclusion a) on heating along the vapour-liquid co-existence curve up to the point of homogenization (Th) which uniquely defines the bulk fluid density, then b) beyond along a PT isochoric path defined by this density. Note that the vapour bubble size in the inclusion schematically reduces on heating.*

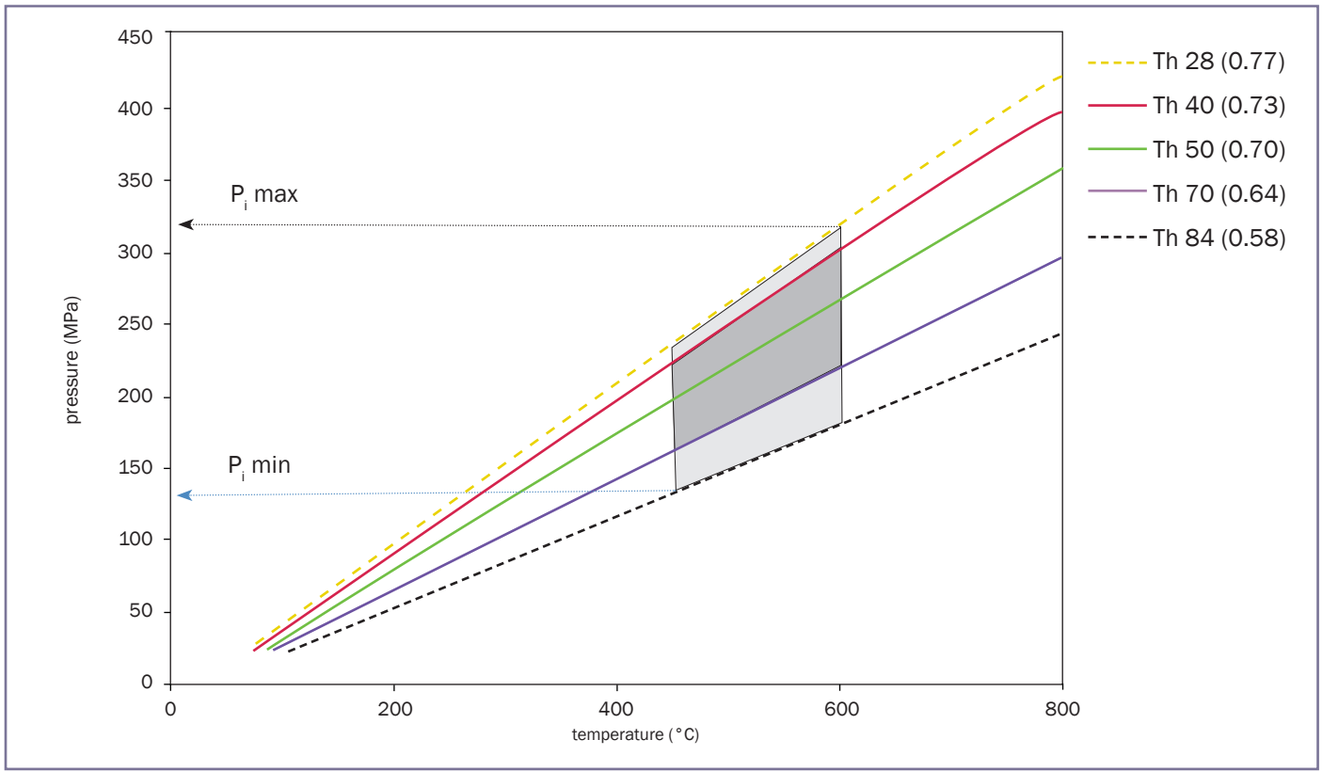

Figure 8: P-T plot for H_2S showing isochores for inclusions that homogenized over the determined temperature range of 28 to 84 °C. The light shaded area defines the internal pressures for all determined inclusion densities between 450 and 600 °C. The darker shaded area defines the PT region corresponding to the main range of fluid densities. The arrows define maximum and minimum P_i values.

may occur from compressed CO_2-gas inclusions, if they are sufficiently large (>*c.* 100 µm) and abundant. For example, Roedder (1982) records an instance where a museum specimen of Brazilian quartz containing planar groups of such inclusions spontaneously decrepitated breaking the glass display case.

Internal fluid pressure needed to initiate re-equilibration of fluid inclusions in zoisite

Published quantitative decrepitation data and estimated internal fluid pressures for individual inclusions in different minerals under a confining pressure of 1 atmosphere (0.1 MPa) have been compiled by Bodnar (2003). There is a linear relationship between internal fluid pressure needed to initiate re-equilibration (decrepitation) of fluid inclusions (P_d), and the Mohs hardness of the mineral host *(Figure 9)*. The relationship is expressed by the equation:

Pressure (bars) = 69 + (128 × Mohs hardness)

Based on this equation and Mohs hardness for zoisite between 6 and 7, the estimated mean internal pressure (P_d) is 901 bars (90.1 MPa). Fluid inclusion size is also an important factor. This is illustrated in *Figure 9* which shows the influence of both hardness and inclusion size on P_d values for several minerals. Quartz is only slightly harder than zoisite. It is therefore reasonable to suppose that the established P_d range for inclusions in quartz in the 1 to 100 µm size range also approximates to that for zoisite. *Figure 9* presents both the calculated and indicative P_d values for zoisite for inclusion sizes between 1 and 100 µm. Also shown are the internal fluid inclusion pressure estimates (P_i) for 95% of inclusions (160 to 300 MPa) from the present study based on isochore projections to between 450 and 600°C. These are significantly higher than the pressures at which all but the smallest inclusions would be expected to leak or decrepitate.

The influence of inclusion size on the P_d values for quartz, based on published experimental data, is shown in more detail in *Figure 10*. Superimposition of the P_i estimates for 95% of the inclusions from the present study are also shown. These are separated into P_i values at 450 and 600°C (160 to 230 MPa, and 220 to 300 MPa respectively). The lower and upper P_i values cross the 'best fit' P_d line at 7 and 2 µm respectively, further demonstrating the general inability of larger inclusions to maintain their integrity under these pressures.

Discussion

Validity of isochore projections

We have previously argued that extrapolating isochore projections above 500 °C is valid for the purpose of this paper. Another question to consider is the influence of variations in inclusion composition on the isochores. The determined isochores relate only to pure H_2S. They will differ if other components are present. The only other volatiles previously detected (Taylor *et al.* 2013) are very small amounts of methane

and nitrogen in a few vapour bubbles. Calculations based on PT estimates using the Loner PR computer program (Bakker, 2009) show that at such low levels (<0.025 mole fraction) there is little effect on the shape and position of the determined isochores. Water was not recognized optically or detected by Raman analysis as previously reported (Taylor *et al.,* 2013). This is somewhat unexpected in view of recent studies on mineralization at Merelani that suggest a significant hydrothermal component to the zoisite/tanzanite mineralization in the area (Olivier, 2006). However, this does not necessarily preclude its absence especially as liquid water has a similar refractive index to liquid H_2S and interfaces between these two, partially-miscible liquids will be indistinct. The hydrated mineral, gypsum, tentatively identified in some inclusions also suggests that the inclusion contents are not anhydrous. Further studies are needed to establish the extent to which water is present, but for reasons outlined in the Acknowledgements this has not been possible in the present study. However, the effect of water on pure H_2S isochores has also been modelled in data for the H_2S–H_2O system for fluids of similar or slightly higher densities (0.90 to 0.60 g/cm^3) using the Loner PR program of Bakker (2009). The results show that pure H_2S isochores steepen with increasing H_2O contents meaning that the inclusions will become more susceptible to decrepitation and leakage at even lower temperatures.

Major solid phases identified within the inclusions (graphite, calcite and native sulphur) may also have a significant effect on the isochore calculations. But this depends on whether or not they i) crystallized *in situ* within the inclusions after trapping (daughter minerals) or ii) were accidentally incorporated as captive daughter minerals, in which case they are unlikely to have a significant effect. Graphite and calcite are major components of the host rocks associated with the zoisite (Olivier, 2006) and are quite likely to be captive phases, whereas native sulphur is not. This is based on

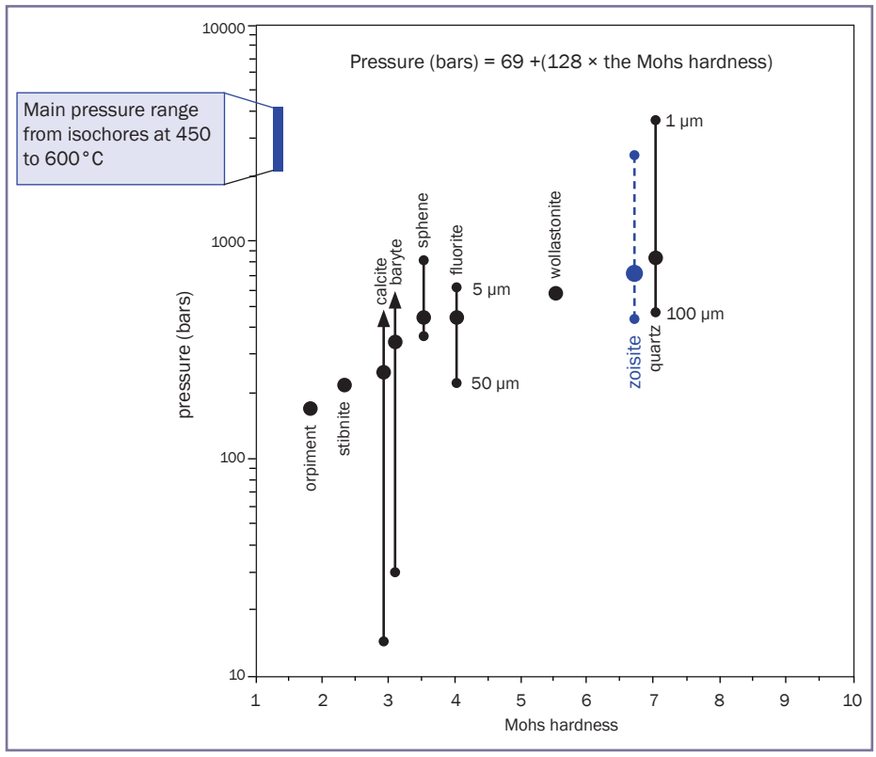

Figure 9: Relationship between internal pressure needed to initiate re-equilibration of fluid inclusions and the Mohs hardness, based on the compilation of Bodnar (2003). Note the effect of inclusion size in quartz and fluorite. The estimated range for zoisite (this work) and the internal fluid pressure estimates at 450 to 600°C are shown in blue.

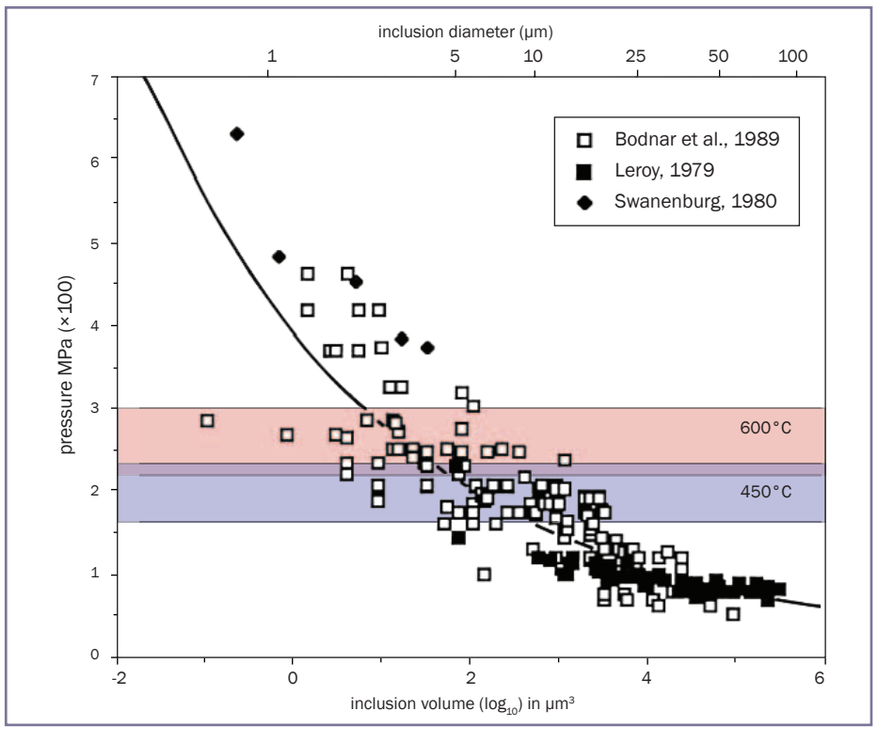

Figure 10: Relationship between inclusion size (and volume) and the pressure required to re-equilibrate fluid inclusions in quartz, based on three sources of published data, represented by different symbols (modified from Bodnar, 2003). The main internal pressure ranges determined for H_2S inclusions in the zoisite at 450 and 600°C are also shown.

the observed precipitation from the H_2S fluid under the laser beam (Taylor *et al.,* 2013) and also its known solubility in high density H_2S fluids at moderate temperatures and pressures (Migdisov *et al.,* 1998). However, as the volumetric proportion of native sulphur within the inclusions is less than about 5% (see *Figure 2*), the effects will be small.

Implications for the production, polishing and care of heat-treated tanzanites

Data on internal fluid pressures from calculated isochores *(Figure 8)*, combined with published P_i data for quartz (at 1 bar external pressure) are shown in *Figure 10*. The data demonstrate that all but the smallest (<2–10 µm), microscopic inclusions are unlikely to survive heat treatment to 600°C due to the high internal fluid pressures generated (to 300 MPa) and will leak or decrepitate above this temperature. On heating up to 450°C some larger inclusions (up 20 µm) may survive heating to this lower temperature, but the majority of inclusions in the size range 20 to 100 µm would not. This is apparent in *Figure 10* from the clustering of data points around the estimated P_d value for zoisite of 90 MPa. Larger inclusions (>100 µm) would be the first to leak or decrepitate at much lower internal pressures and are very unlikely to survive heating even to temperatures below 100°C. This is apparent from the steepness of the isochores for minimum and mean Th values shown *Figure 7*, and also direct observation of leakage from some large and irregularly shaped inclusions during microthermometric analysis to up 100°C (Taylor *et al.,* 2013).

Producers are acutely aware of the influence that 'flaws' or 'inclusions' have on the integrity of zoisites/tanzanites prior to, or during, heat treatment. Stones with inclusions visible with a 10× loupe can be avoided, but microscopic (*c.* 5–20 µm) inclusions can all too easily be overlooked. Leakage or decrepitation of H_2S inclusions may not necessarily lead to immediate fragmentation of the crystal. Instead, relief of internal fluid pressure may be accommodated by flexure of the crystal and creation of zones of stress or weakness in the vicinity of the ruptured inclusions which may be evident from microscopic 'veils' or wisps sometimes observed in heat treated tanzanites (Adamo *et al.,* 2010). Exposure of these internal microfractures or stress zones during cutting and polishing, especially if leaked inclusions occurred in discontinuous planar groupings (type II inclusions), means that stones may be 'unzipped' along planar or curvilinear fractures, not necessarily along cleavage directions as indicated in *Figures 1* and *4*. This suggestion also helps explain why heat-treated tanzanites may be susceptible to fracturing, not just because of good cleavage, when subjected to sudden changes from warm to cold ambient temperatures.

Implications for recognition of unheated, naturally-coloured tanzanites

In the accompanying paper (Taylor *et al.,* 2013) we suggested that the presence of an H_2S-liquid inclusion is a diagnostic feature of natural unheated tanzanites/zoisites. This is supported by the results of the present study which demonstrate that all but the smallest of the H_2S inclusions in heat treated tanzanites should not survive the heat treatment process to 600°C or more with their contents intact. Furthermore, any smaller inclusions that do survive would supply insufficient volumes of gaseous H_2S to the atmosphere to be detectable by the suggested scratch-chip odour test *(op.cit.)*. Some larger inclusions (*c.* 20 µm) could survive internal fluid pressures on heating up to 450°C, but the fortuitous opening of many such inclusions, unaffected by heat treatment, would be required to detect the odour of H_2S in $(20\ cm)^3$ of air (Taylor *et al.,* 2013). Therefore, the probability of this happening is considered to be very low.

Most tanzanites in the market are heat-treated, and currently there is little demand for unheated stones. For the specialist collector the simple scratch-chip odour test would be a useful criterion for helping to identify unheated crystals. However, the method is not entirely reliable as some small inclusions may survive less destructive heat treatment up to the lower temperature of 450°C sometimes employed in heat treatment. It is also suggested that a strong odour of this gas from rough or cut stones prior to heating might indicate those stones more likely to be susceptible to breakage during heat treatment, due to the presence of significant numbers of microscopic inclusions.

Summary of conclusions

The internal fluid pressures in H_2S fluid inclusions in natural zoisite (tanzanite) will increase systematically on heating, until a point where the pressure will exceed the confining strength of the zoisite host and the inclusions will leak or decrepitate. The mean pressure (P_d) at which this will occur is estimated at 901 bars (90.1 MPa), but will vary according to the size and shape of the inclusions.

The calculated densities (ρ) of the H_2S phase for both type I and II inclusions range from 0.77 to 0.58 g/cm³. On heating, inclusions in zoisite will follow linear pressure-temperature pathways above their determined vapour-liquid homogenization temperatures of between 28 and 84°C. These pathways are defined by the fluid densities (isochores), and are based on PρT modelling of pure H_2S. The determined isochores are useful for estimating internal fluid pressures (P_i) within inclusions at any point during the heat-treatment of zoisite (tanzanite). The effects of minor volatiles (methane and nitrogen) on the isochores are negligible, and water, if present, is shown to increase rather than decrease the internal fluid pressures on heating.

The internal fluid pressure estimates, based on data for three Merelani zoisites, show that only very small microscopic and submicroscopic inclusions (<2–10µm) are likely to survive temperatures to 600°C employed during heat treatment of probably most of the zoisite/tanzanite. The chances of survival of inclusions up to 20 µm in size would be greater if heat treatment were to be carried out to a lower temperature of 450°C. The

destruction or leakage of larger inclusions, especially in planes (type II inclusion), may leave linear zones of weakness or stresses in heat-treated tanzanites which can contribute to the fracture potential of the treated stone.

The resulting loss of H_2S from any sizeable inclusions in heat-treated tanzanite confirms that the scratch-chip odour test is an effective discriminator between natural (unheated) tanzanites and those heated to 600°C. For samples heat treated to lower temperatures (450°C) some larger inclusions (>20 µm) may survive but in most cases are unlikely to provide enough H_2S to be detected by odour alone.

This exploratory study is confined to just a few samples from the D block area of Merelani. Further studies are needed on a wider range of both heated and unheated samples to more generally assess the principles and ideas outlined in this paper.

Acknowledgements

This paper is based on the microthermometric data and microscopic observations collected by Dan Taylor as part of his Masters Research thesis on inclusions in tanzanites at Kingston University. Tragically, Dan died following a road traffic accident before he completed his research. We gratefully acknowledge the kind permission from Dan's family to use these data to write up the present paper as a contribution to his beloved subject of gemmology, which we dedicate to his memory. Many of the ideas presented here have arisen out of numerous discussions with us (AHR and PJT), his co-supervisors, prior to his untimely death. However, responsibility for any errors, omissions, misrepresentation or misinterpretation of the scientific data is ours alone.

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Abstracts

Diamonds

Gemmologie Aktuell. Notes from the DSEF German Gem Lab.
C.C. Milisenda and K. Schollenbruch. *Gemmologie. Z. Dt. Gemmol. Ges.,* **61**(3/4), 2012, 63–70. 12 photographs. German and English.

The lab received a faceted opaque black stone weighing more than 30 ct with an RI higher than the limits of the standard refractometer. It was said to be a diamond with a broken culet. Chemical analysis showed it to be an ilmenite. E.S.

Gems and Minerals

Bottled up.
G. Choudhary. *Gems&Jewellery,* **22**(2), 2013, 12–13.

An unusual report on the growth and identification of sulphur crystals within bottles of standard RI fluid. A.S.F.

John Kessler donation.
L. Gleave. *Gems&Jewellery,* **22**(4), 2013, 8

The importance of donations to the Gem-A gemstone collection and the significance of John Kessler's recently donated collection to the future of teaching and research. A.S.F.

Die Verwendung von Schmucksteinen aus der Gruppe mikro- bis krypto-kristalliner Quarze bei Tabatieren aus dem Nachlass des preußischen Königs Friedrich II(1712–1786).
G. Holzhey. *Gemmologie. Z. Dt. Gemmol. Ges.,* **61**(3/4), 2012, 71–90. 30 photographs, bibl. German with English abstract.

The author refers to the 300th anniversary in 2012 of the birth of Frederick II. An increase in prosperity during his reign resulted in an increase in the manufacture of gold and jewellery in Berlin. The king was a great collector of snuff boxes, often very ornate, carved and encrusted with diamonds. He was particularly fond of Silesian chrysoprase.

Nine chrysoprase snuff boxes are described, as well as some jasper/agate boxes. The agates might have come from Oberkirchen, south of Idar-Oberstein. E.S.

Saphirblauer Disthen (Kyanit) aus Nepal.
U. Henn and K. Schollenbruch. *Gemmologie. Z. Dt. Gemmol. Ges.,* **61**(3/4), 2012, 91–8. 8 photographs, 1 table, 1 diagram, bibl. German with English abstract.

Intense blue, relatively homogeneous, transparent kyanites have been found in Nepal since 1995. They can be faceted and resemble blue sapphires. Stones up to 10 ct have been on the market. The blue colour is due to iron and titanium. There are traces of chromium which might be the cause of a possible red fluorescence. The stones from Nepal are biaxial positive. There are some cleavage cracks and growth tubes which may cause iridescence. Colour zones, film-like fluid inclusions and a few dark mineral inclusions have been observed. E.S.

Gemmologie Aktuell. Notes from the DSEF German Gem Lab.
C.C. Milisenda and K. Schollenbruch. *Gemmologie. Z. Dt. Gemmol. Ges.,* **61**(3/4), 2012, 63–70. 12 photographs. German and English.

A translucent oval red cabochon weighing 40 ct was submitted to the lab as a ruby. However, the RI was 1.74 (a little low for a ruby) and it also had a slightly lower density; an infrared reflectance spectrum confirmed the stone to be a rhodonite; inclusions resembled those in Tanzanian rubies so reliance cannot be placed on this feature.

Other stones difficult to identify were some small transparent faceted yellow stones which the infrared spectrometer identified as sapphire; however under the microscope flux feathers and dark mineral grains with a blue halo were detected. The sapphires had been beryllium treated, but definite proof can only be obtained with mass spectrometric methods.

The lab received a cabochon-cut dark brown 12-rayed sapphire — a distinct six-rayed star with a weaker six-ray, with arms at nearly 30 degrees to the main star. The stone was double refractive, average RI 1.77. Further investigation showed the stone to be a composite of two pieces of star sapphire, the lower part being turned 30 degrees to produce a 12-rayed star. E.S.

The three feathers.
G. Millington. *Gems&Jewellery,* **22**(1), 2013, 8–11.

A report on three stones — a colour-change stone light yellowish-green in daylight changing to brownish-pink in incandescent light, and a yellow stone and purple stone — submitted for investigation. All displayed very similar feather-like inclusions. The stones were identified as a diaspore, a yellow sapphire and a purple synthetic corundum, respectively. The article concluded with a precautionary reminder for all gemmologists not to take things at face value. A.S.F.

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Abstracts (continued)

A tale of two rubies.
G. Millington. *Gems&Jewellery,* **22**(3), 2013, 14–16.

A description of the internal features and the testing process for two red stones. Both were found to be natural ruby, one glass filled. Some of the problems that gemmologists face when trying to identify natural from synthetic are discussed, and the various forms of treatments that abound for corundum. A.S.F.

Is it an emerald?
G. Millington. *Gems&Jewellery,* **22**(4), 2013, 8.

An interesting and precautionary report on the identification of a large green faceted stone, which at first appeared to be emerald but was identified as fluorite. A.S.F.

Red flag: are glass-filled rubies legal?
J. Ogden. *Gems&Jewellery,* **22**(1), 2013, 12–13.

An investigation into the implications of the EU's legislation on lead content in products and its possible impact on the jewellery sector; glass-filled rubies may no longer comply. A.S.F.

Holy chic: a very special man's ring.
J. Ogden. *Gems&Jewellery,* **22**(1), 2013, 14.

The research carried out by Joanna Angelett before designing a modern-day ecclesiastical ring. Named the Holy Kingdom Ring, the ring was set with an ametrine. A.S.F.

Exams.
J. Ogden. *Gems&Jewellery,* **22**(2), 2013, 18–19.

Jack Ogden looks back at the very first FGA examinations in 1913 and poses the question: "Can you answer the same questions successfully today?" A.S.F.

An old attraction: magnetic gems.
J. Ogden. *Gems&Jewellery,* **22**(3), 2013, 9.

The magnetic susceptibility of gemstones has been widely reported on in recent years in *The Journal of Gemmology* by various authors including Don Hoover, but in this article a history dating back as far as 1779 is revealed. A.S.F.

The Scottish Conference.
J. Ogden. *Gems&Jewellery,* **22**(4), 2013, 13–16.

An in-depth look at the annual Scottish conference, focusing on the range of presentations. Notable speakers included Clare Blatherwick (pearls of varying types), Ron Ringsrud (the emeralds of Colombia) and Dr Claudio Milisenda (Ethiopian opals). Humour and historical fact were provided by Jack Ogden, with his unusually titled 'Lap dancers and drill masters' which focused on the history of gem fashioning. A.S.F.

A new kyanite.
C. Williams. *Gems&Jewellery,* **22**(5), 2013, 13.

A look at the recent discoveries of kyanite in various colours (and chromophores), focusing mainly on the blue-green gem variety from Nepal. A.S.F.

Tucson Gem Shows 2013.
H. Seras-Herman. *The Jeweller,* Jan/Feb 2013, 44-7.

A guide for those planning a trip to the Tucson Gemshows. Whether they be seasoned veterans, or first-timers, 20 tips outline the best thoughts for buying strategies. A.S.F.

Instruments and Techniques

A point for pointers: lasers in gemmology.
J. Ogden. *Gems&Jewellery,* **22**(3), 2013, 20–1.

The use of laser pointers — red, green and blue — as a tool in gem identification. A.S.F.

Synthetics and Simulants

Beschichtete Steine und ihre Erkennung.
U. Henn and K. Schollenbruch. *Gemmologie. Z. Dt. Gemmol. Ges.,* **61**(3/4), 2012, 99–114. 15 photographs, 3 diagrams, 1 table, bibl. German with English abstract.

Surface-coated gems are mainly colourless, but there are also some coloured stones like quartz, topaz, glass or synthetic spinel which are colour- or lustre-improved by a thin coating of a metal or metal compound. The coating can be removed mechanically by grinding. Identification is partly possible using only the naked eye or by loupe and microscope. Coatings on synthetic diamond such as diamond-like carbon (DLC) are highly resistant and difficult to identify. CZs can be coated by a CVD process to make them more diamond-like, but can be distinguished from diamond by the different characteristics of the coated stone; however, coated diamonds can be difficult to determine. E.S.

Gemmologie Aktuell. Notes from the DSEF German Gem Lab.
C.C. Milisenda and K. Schollenbruch. *Gemmologie. Z. Dt. Gemmol. Ges.,* **61**(3/4), 2012, 63–70. 12 photographs. German and English.

The cat's-eye effect was imitated in stones in two rings, one green and the other pink. They were shown to be glass fibre imitations which can be identified by a 'window' when viewed parallel to the fibres; also the cat's-eye effect was too good to be expected in natural stones.

A rough green stone weighing approximately 100 g, RI 1.738, density 3.58, had perfect cleavage showing as rectangular cleavage planes visible to the naked eye. The stone was found to be a synthetic periclase which is produced in an electric arc furnace. E.S.

A rainbow... like unto an emerald.
G. Millington. *Gems&Jewellery,* **22**(5), 2013, 14–17.

A highly illustrated examination of a synthetic emerald that showed all the inclusions and features that any gemmologist should look for, as well as interesting interference colour patterns. A.S.F.

Abstractors

A.S. Fellows – A.S.F.
E. Stern – E.S.

Book reviews

Dictionary of Gemstones & Jewelry
1st English edition
A. Chikayama. Translated by S. H. Gill; E. A. Jobbins, editor, 2013. IMACBC Co. Ltd, Tokyo, Japan. 652 pp. ISBN 978-4-9906841-0-5. £85.00 ($100 US)

To some, 'Dictionary' might well portend a dry, utilitarian tome; this book is anything but that. A mirror of the author's own passion for the subject — or in his own words "my personal World Heritage" — it is a delightfully written, wholly interesting and valuable reference text for all those interested in or working within the world of gems and jewellery. As translator Stephen H. Gill writes in his foreword, "We feel that this book reflects something of his far-reaching curiosity and familiarity with so many aspects of this wonderful trade in natural beauty, a trade that has been with us since the Stone Age."

Akira Chikayama (1921-2007) first published his Japanese language dictionary *Hōseki Hōshoku Daijiten* in 1995. The present English version is based on his revised 2004 3rd edition. A monumental effort was put to bear on translating and editing its 900 pages in order to produce a volume whose scope would serve not just the Japanese gemmological community, but a world-wide audience. It accomplishes this while still retaining its cultural roots, thereby honouring its esteemed author, and in the process edifying the reader with a smattering of uniquely Japanese gem and jewellery terms. In his foreword, supervising editor Alan Jobbins writes of Chikayama's "whimsical sense of humour" and "wide scientific knowledge and experience". This is no less evident than when the reader seeks out a specific definition and, after finding it, is drawn by the diversity contained in surrounding pages, exploring hither and delighting in each interesting nugget of lore, scientific wisdom, gemmological concepts, historical trivia and more.

In order to get the most out of the Dictionary, the readers should be encouraged to read the forewords in order to understand the project's mission and also to familiarize themselves with the explanatory notes. The latter explain the organization and defines abbreviations used throughout, some of which might be unfamiliar. Appendices at the back of the book include some data which might diverge from what is expected, but thus is interesting and informative (e.g. Greek & Latin Prefixes Appearing in Mineralogical & Gemological Terminology). Noticeably absent, though not really missed, is a chart of gem properties; such data is instead included under individual entries in the body of text.

One might fault some entries, but certainly most quibbles have more to do with 'point of view' or the limitations imposed by brevity. For example, the definition for chameleon diamond indicates its 'base colour' is green. If one interprets 'base' to mean the diamond is at groundstate (which is in the dark), then the entry is misleading. If it is interpreted to mean the colour one observes in the light (the only time one can observe it), then it could be deemed perfectly correct. Similarly, when defining cerasite, it is given as a "mineralogical term for columnar trillings of cordierite (iolite)" when in fact these so-called cherry blossom stones (sakura ischi) are more properly described as mica pseudomorphs of complex cordierite-indialite intergrowths. Examples such as these are not in any way negatives unless the reader does not know to dig deeper (hardly the fault of the author); in fact they point to the diversity of the contents. Consider such entries as pikal, selenita, kandoro, kalanchu — just a very few of the terms which hale from gem localities around the world, but which might not be familiar to many readers.

Some minor typos aside, this reviewer would argue a few points, such as that early credit might better go to H.L. Chhibber (1934) rather than E. Gübelin (1965) as having described maw-sit-sit and that most references cited state hematite over lepidocrocite as the inclusion responsible for bloodshot iolite.

Another entry which gives pause due to its wording and punctuation, is that of 'FGA'. After correctly spelling out the abbreviation, it proceeds to identify this as a 'diploma' which is "generally regarded as the world's premium gemmological qualification". Punctuation and brevity of words ironically reflects a commonly held concept of the letters 'FGA' (no periods) as a kind of noun — that 'FGA' is synonymous with having successfully passed the coursework (itself often similarly referred to as 'The FGA'). A dozen more words would have made clear that course completion only makes one eligible for election to FGA status, along with yearly dues to retain the title.

The English translation of this Japanese modern classic is arguably the most important gemmology reference text to come off the press in recent years. It joins Robert Webster's *Gemmologist's Compendium* (revised by E.A. Jobbins) as one of the few gemmological dictionaries currently available in-print and competes neatly with the now out-of print GIA hardcover standards, *The Diamond Dictionary and Dictionary of Gems & Gemology*. While no such book can be considered a stand-alone and should rather be used as a companion to other sources, this exceptional and beautifully produced volume will certainly become a

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standard for gemmologists in a wide range of fields the world over. The completion of this project will forever remain a very fine tribute to the legacy of gemmologist Akira Chikayama FGA CG.

E.A. Skalwold

Ivory Identification, A Photographic Reference Guide

William R. (Bobby) Mann and Charles M. Marts, 2012. Published by Ivorymann Publishing. 20 pp, large format, approx. 200 photographs. Price $20 plus shipping from HP Mag Cloud Publications at http://magcloud.com/browse/issue/458047.

For many years we have relied on just one or two books for the identification of ivories, but now there is another book to aid us in this task. Its main author, Bobby Mann, is a Graduate Gemologist (Gemological Institute of America) and Professional Gemologist, Columbia School of Gemology, USA. He is also a co-founder of the International Ivory Society, and runs workshops on ivory identification in Washington DC.

The book is the first of three planned publications on ivory (books 2 and 3 will go into more detail on the subject of ivory identification); meanwhile this is an excellent reference to help with identifying a material that can be tricky.

Each page is devoted to a different ivory or ivory substitute, from elephant tusk to hornbill ivory, and each contains about 20 photographs – mostly in colour, but in black and white too where this better shows the structure, as is often the case with photographs of ivory. A brief description of each material accompanies the photographs, divided into clear sections: 'Natural Teeth', 'As seen in cross section' and 'LWUV'. Each section is again divided: 'Dentine layer', 'Grain pattern', and so forth.

The book is aimed at the gemmologists, collectors, hobbyists and students who have taken Bobby's ivory workshops. It is a very useful reference for anyone interested in the subject, or who comes into contact with ivory through their work. The facts are delivered by good quality photographs and there is no hunting for details – everything is clearly set out on each page. All in all it is an excellent little publication.

M. Campbell Pedersen

Amazing Amber

Andrew Ross and Alison Sheridan, 2013. 48pp, 150 colour photographs, paperback. £7.99. ISBN 978 1 905267 79 8.

The book *Amazing Amber* has been produced as a catalogue for the exhibition of the same name at the National Museum of Scotland in Edinburgh, which has run during the summer of 2013.

It is not aimed at gemmologists, but is an informative little publication in layman's language, and gives an overview of amber as a material, describing many of the most common types in chronological order. Following a Foreword and Introduction, there are eight chapters, starting with 'What is Amber?', 'Where is Amber from?' and continuing through its various uses, fakes, insect inclusions and ending with a brief mention of whether it is possible to obtain DNA from the insects embedded in the resin.

In spite of being an exhibition catalogue the publication is a good stand-alone book. It would make an ideal introduction to amber for someone who knows little about the material. The inclusion of a chapter entitled 'Amber in Scotland's Past' is the only indication that it was written specifically to accompany the Scottish exhibition. (Amber has been used there for over 5500 years.)

The authors, Drs Ross and Sheridan, are experts in their field, so the information given in the book is reliable. The publication is of a high quality, with plentiful, excellent photographs. A single, small criticism is that in some of the photos the resin looks green. As gemmologists know, this phenomenon often occurs when photographing golden amber, but unfortunately it can encourage the mistaken belief in those with less understanding of the subject that green amber occurs naturally. (It can be overcome by manipulating the photographs slightly to bring them back to the correct colour, but this practice is often frowned upon as 'altering' the pictures.)

This minor detail aside, it is a very pleasing book: a truly excellent 'starter' for anyone with less knowledge of amber, and an informative and pleasing addition to the bookshelf for those with more.

The book is available in bookshops, or from www.nms.ac.uk/books.

M. Campbell Pedersen

Gem-A

THE GEMMOLOGICAL ASSOCIATION
OF GREAT BRITAIN

Gem-A Conference 2013

Friday 1 November — Tuesday 5 November

Understanding Gems™

Visit www.gem-a.com

FRIDAY 1 NOVEMBER

Seminar day

A series of practical half-day workshops will be taking place at Gem-A headquarters.

Guest speakers:

- **Richard Drucker** FGA GG
  Coloured stone grading and pricing workshop II
  (Update on grading coloured gems with new grading methods and information)
- **Arthur Groom**
  Exploring emerald clarity enhancements
- **Craig A Lynch** GG, ACCREDITED SENIOR GEMOLOGIST, AGA
  Is the porridge too hot, too cool, or just right? That is the answer!
  (The Somewhere In The Rainbow™ collection of green grossularite garnet and zoisite from East Africa, with hands-on study)

SATURDAY 2 – SUNDAY 3 NOVEMBER

GOLDSMITHS' HALL, LONDON

Gem-A Conference

Guest speakers:

- **John Bradshaw** GG
  Non-traditional gemstones: The rare, medium-rare and well done
- **David Callaghan** FGA
  In the beginning...
  (The history of the London gem lab)
- **Dr John Emmett**
  The colours of corundum: A search for the soul of a padparadscha
- **Dr Emmanuel Fritsch** GG
  Luminescence — what's in a word?
  (Luminescence in gemmology from basic UV to photoluminescence in HPHT treated diamonds)
- **Arthur Groom**
  Emerald clarity enhancement
- **Brian Jackson** FGA DGA
  Scottish gemstones
- **Dr Jack Ogden** FGA
  Treasure, traders and trickery:
  The Cheapside gems in context
- **Sonny Pope**
  The future in coloured diamonds:
  An introduction to the HPHT multistep process
- **Martin Rapaport**
  The state of the diamond industry
- **Gary Roskin** FGA GG
  Mastering the challenges in diamond grading
- **Chris Sellors**
  English gemstones, Blue John and Whitby jet
- **Shelly Sergent**
  Somewhere In The Rainbow™ Toto, We're not in Kansas anymore!
  (A look at the celebrated The Somewhere In The Rainbow™ gem and jewellery collection)
- **Dr James Shigley**
  The evolving challenge of gem identification

EVENING SATURDAY 2 NOVEMBER

Anniversary Dinner

EVENING SUNDAY 3 NOVEMBER

Graduation Ceremony

- **Martin Rapaport** will present the Awards and give the address.

MONDAY 4 – TUESDAY 5 NOVEMBER

Exhibitions and Visits

Private viewings will be held at London museums, including the Cheapside Hoard at the Museum of London, the forthcoming Pearls exhibition at the V&A, and at the Natural History Museum. There will also be a private viewing of the Crown Jewels at the Tower of London.

To find out more about all of the above visit:
www.gem-a.com/news--events/gem-a-conference-2013.aspx

Proceedings of the Gemmological Association of Great Britain and Notices

New premises

Midsummer Day 2013 saw the departure of Gem-A from 27 Greville Street. The Gem Testing Laboratory first moved into part of no. 27 in 1982. They were joined by the Gemmological Association in 1990, with the second floor, fourth floor and basement being leased in subsequent years as they became available. Unfortunately recent negotiations to renew the lease broke down and the decision was taken to vacate the building, carrying out the necessary dilapidation work.

In April it was discovered that the freehold of 21 Ely Place was available and the Board of Trustees unanimously agreed to try to purchase this property. This was achieved at a price of £2.755 million plus VAT which was mitigated by the Association's charitable status and the use of much of the building for charitable purposes. By the same token Stamp Duty was also avoided due to the charitable status. The sale was completed on 11 June.

Built in 1775 on the site of the Bishop of Ely's London residence, no. 21 lies directly opposite a former home of the Association, Audrey House (named after St Audrey, the saint who founded the Abbey of Ely and after whom the thirteenth-century Chapel still standing in Ely Place is named; her Anglo-Saxon name St Etheldreda) which was bombed in 1941 causing our departure. Bomb damage repair can still be seen on no. 21.

The new building comprises 4250 sq ft over six floors including the basement. The top two floors will be used for administration while the remainder will be used for teaching and member services. The four classrooms on the lower floors have been named after prominent past members of the Association — Herbert Smith, Basil Anderson, Robert Webster and Eric Bruton.

For the first time in many years the Sir James Walton Memorial Library will be on display in its permanent new home on the first floor along with some of the Association's stone collection, and the book and stone collection of the South West Trust.

Editorship

This is the last issue of *The Journal of Gemmology* that will be presided over by Dr Roger Harding. He has been editor since 1994 and has done such an outstanding job that it has proved very hard to find a replacement. We thank Roger for his forbearance while we sought a suitable successor which has taken some time. Roger will remain on hand as advisory editor.

The new editor will be Brendan Laurs. Formerly editor of *Gems & Gemology* and having worked for GIA for almost 15 years, he is the ideal candidate to take on the role. He has many new ideas and would be very pleased to hear from anyone wishing to publish an article or with ideas about *The Journal*. He can be contacted at brendan@gem-a.com.

Brendan Laurs

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Gem-A Awards

In the Gem-A examinations held in January 2013, 131 students qualified in the Gemmology Diploma Examination, including six with Distinction and ten with Merit, and in the Foundation Certificate in Gemmology Examination 182 qualified. In the Gem Diamond Examination 42 qualified, including five with Distinction and ten with Merit.

The names of the successful candidates are listed below.

Examinations in Gemmology

Gemmology Diploma

Qualified with Distinction

Dai Huiru, Beijing, P.R. China
Fazlali-Zadeh, Sonia Ariana, Barnes, London
Lu Siyu, Lanzhou, Gansu, P.R. China
Wang Dongqiu, Baoshan, Yunnan, P.R. China
Wang Sijia, Mudanjiang, Heilongjiang, P.R. China
Yin Bei, Shanghai, P.R. China

Qualified with Merit

Ai Qing, Jingzhou, Hubei, P.R. China
Huang Xudong, Shanghai, P.R. China
Huo Kaijie, Beijing, P.R. China
Lin Chun-Yu, New Taipei, Taiwan, R.O. China
Qu Meng, Beijing, P.R. China
Thiebaud, Mandy, Paris, France
Tsai Ko-Wei, Tainan, Taiwan, R.O. China
Venturelli, Adelmo, Morges, Switzerland
Yang Xiaowen, Beijing, P.R. China
Zheng Chen, Anqing, Anhui, P.R. China

Qualified

Alessandri, Matthias, Central, Hong Kong
Altobelli, Martha Claire, Austin, Texas, U.S.A.
Alvernhe, Paul, Nancy, France
An Xueying, Baotou, Inner Mongolia
Au Sui Keung, Shatin, Hong Kong
Bailey, Kate, Aberdeen, Aberdeenshire
Bondar, Ilona, Tooting, London
Bouchard, Claudie, Terrebonne, Quebec, Canada
Buckley, Amanda, Takapuna, North Shore, New Zealand
Chan Chi-Keong, Gene, New Taipei, Taiwan, R.O. China
Chan Hei Yiu, Pok Fu Lam, Hong Kong
Chan Kuan-Lang, Roger Jan, New Taipei, Taiwan, R.O. China
Chau Wai Ying, Tsuen Wan, Hong Kong
Chen Danlu, Shanghai, P.R. China
Chen Gong, Wuhan, Hubei, P.R. China
Chen Jiyi, Huangshi, Hubei, P.R. China
Chen Jizhou, Beijing, P.R. China
Chen Wen-Chi, Taichung, Taiwan, R.O. China
Chen Yin-Chen, Taipei, Taiwan, R.O. China
Chen Ying, Nanning, Guangxi, P.R. China
Cheng Ke, Beijing, P.R. China
Cheng See Sze, Cissy, Sai Kung, Hong Kong
Dai Yu-Ying, Stephanie, Taipei, Taiwan, R.O. China
Dang Ming Li, Suzhou, Jiangsu, P.R. China
Dodero, Stephanie, Asnières-sur-Seine, France
Dong Hai-Chen, Taipei, Taiwan, R.O. China
Dong Yi Ao, Wuhan, Hubei, P.R. China
Doraliyagoda, Kankanamge Rusiru, Mount Lavinia, Sri Lanka
Dryland, Davina, Barton-under-Needwood, Staffordshire
Du Li, Zaoyang, Hubei, P.R. China
Elamri, Tarek, Montréal, Quebec, Canada
Elliott, Beth Ann, Ledgewood, New Jersey, U.S.A.
Fan Pik Shan, Maggie, Tsim Sha Tsui, Hong Kong
Fong Sum Wing, Serena, Tai Koo Shing, Hong Kong
Fritz, Eric William, Taylorsville, North Carolina, U.S.A.
Gan Riyao, Guangxi, P.R. China
Gao Yanzhen, Shihezi, Xinjiang, P.R. China
Glenn, Alison, Chertsey, Surrey
Guo Difei, Shanghai, P.R. China
Heilio, Saara, Bromley, Kent
Herold, Doerte, Zurich, Switzerland
Hu Yuting, Xinyu Jiangxi, P.R. China
Huang Chunxian, Shantou, Guangdong, P.R. China
Huang Yu Ming, Guangzhou, Guangdong, P.R. China
Jezova, Olesia, London
Jiang Wenchao, Laizhou, Shandong, P.R. China
Johansson, Sandra, Kungsbacka, Sweden
Kang Weirui, Shihezi, Xinjiang, P.R. China
Kronenberg, Hugh, Paddington, New South Wales, Australia
Kuo Wen-Yu, Taipei, Taiwan, R.O. China
Lejman, Travis, New York, U.S.A.
Lents, Joshua D., New York, U.S.A.

Leung Yin Chun, Jeannie, Kowloon, Hong Kong
Li Xin, Tianjin, P.R. China
Liang Genmeng, Guangxi, P.R. China
Lin Jin, Taizhou City, Zhejiang, P.R. China
Liu Gaoming, Beijing, P.R. China
Liu Ting Ying, Beijing, P.R. China
Liu Tingjun, Beijing, P.R. China
Liu Xu, Beijing, P.R. China
Loong Suk Min, Stanley, Hong Kong
Lu Baifei, Liuzhou, Guangxi, P.R. China
Lu Biyue, Beijing, P.R. China
Lu Min-Ju, Taipei, Taiwan, R.O. China
Lv Yandi, Beijing, P.R. China
Ma Yunlu, Linfen, Shanxi, P.R. China
Marshall, Angela, Cambridge
Martin-Gutierrez, Francesca Maria, Bounds Green, London
McArley, Lisa Maree, St Kilda, Victoria, Australia
Mei Lin, Nanning, Guangxi, P.R. China
Moussa, Farida, Yangon, Myanmar
Ng Siu Kwai, Kwai Tsing, Hong Kong
Ng So Ching, Tseung Kwan O, Hong Kong
Niu Xiaowei, Beijing, P.R. China
Peng Kuo, Beijing, P.R. China
Peng Mian Yu, Shanghai, P.R. China
Peng Yu-Shin, Taichung, Taiwan, R.O. China
Pino, Orazio, Chiavari, Genoa, Italy
Qian Xiang, Shaoxing, Zhejiang, P.R. China
Quinney, Holly F., Verdun, Quebec, Canada
Raoul, Ando, Aubervilliers, France
Rembeault, Benjamin, Montréal, Quebec, Canada
Roden, Rhiannon, Allestree, Derbyshire
Santarsiere, Miguel Angel, Folkestone, Kent
Shen Tengjie, Shaoxing, Zhejiang, P.R. China
Shi Xianglai, Beijing, P.R. China
Shu Yunsheng, Beijing, P.R. China
Sun Jingxuan, Tianjin, P.R. China
Tang Jiazhen, Wuhan, Hubei, P.R. China
Tang Yali, Beijing, P.R. China
Tian Jia Lu, Shanghai, P.R. China
To Siu Lun, Wong Tai Sin, Hong Kong
Tong Xiaofei, Shanghai, P.R. China
Tsang Yuk Lung, Billie, Shatin, Hong Kong
Tuovinen, Riikka, Vantaa, Finland
Vahman, Sarira, Florence, Italy
Van Lenten, Andrea, Lexington, Kentucky, USA
Wa Sze Man, Winnie, Tseung Kwan O, Hong Kong
Wang Cheng, Beijing, P.R. China
Wang Yang, Beijing, P.R. China
Wang Zi, Beijing, P.R. China
Warner, Simon, Tring, Hertfordshire
Wei Ting, Ledu, Qinghai, P.R. China
Win Htet Naung, Yangon, Myanmar
Wong, Vannessa, Lam Tin, Hong Kong
Wong Wing Nga, Quarry Bay, Hong Kong
Wong Yi Sai, Gloria, Tsim Sha Tsui, Hong Kong
Wu, Anna, Karamay, Xinjiang, P.R. China
Wu Zheng Yuan, Haimen, Jiangsu, P.R. China
Xin Tong, Xi'an, Shanxi, P.R. China
Xu Xiaoya, Ezhou, Hubei, P.R. China
Yang Dongxiu, Beijing, P.R. China
Yang Fei, Beijing, P.R. China
Yao Qiong, Shanghai, P.R. China
Yeung Sin Yee, Sindy, Tin Shui Wai, Hong Kong
Yin Lisha, Jingmen, Hubei, P.R. China
Yu Choi Lin, Tsuen Wan, Hong Kong
Yu Ho Fai, Miranda, Sai Kung, Hong Kong
Zeng Piao, Tianmen, Hubei, P.R. China
Zhang Dan Qiong, Taiyuan, Shanxi, P.R. China
Zhang Shiyin, Chang Tou, Neimenggu, P.R. China
Zhang Ya Peng, Wuhan, Hubei, P.R. China
Zhang Yi Xin, Wuhan, Hubei, P.R. China
Zhang Yichi, Beijing, P.R. China
Zhang Yusheng, Dalian, Liaoning, P.R. China
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Zhao Zhizhe, Chengdu, Sichuan, P.R. China
Zheng Fangyi, Shanghai, P.R. China
Zhong Rui, Beijing, P.R. China
Zhou Wei, Basel, Switzerland
Zong Xiang, Beijing, P.R. China

Foundation Certificate in Gemmology

Backes, Karina, London
Bai Fangfang, Heze, Shandong, P.R. China
Bailey, Anneabell, Plymouth, Devon
Ban Yuansheng, Nanning, Guangxi, P.R. China
Bhowmik, Abhishek, London
Brown, Victoria, Dunfermline, Fife
Cai Changhua, Ziyuan, Guilin, Guangxi, P.R. China
Cavalier, Sophie, Streatham, London
Chan Ka Lok, Choi Hung, Hong Kong
Chan Kai Hing, Tai Po, Hong Kong
Chan Wai Yu, Tseung Kwan O, Hong Kong
Chan Ya-Ting, Taipei, Taiwan, R.O. China
Chang Hsueh-Pin, Taipei, Taiwan, R.O. China
Chao Ting, Taipei, Taiwan, R.O. China
Cheer, Peter, Somerton, Somerset
Chen Chun-Wen, Taipei, Taiwan, R.O. China
Chen Jingli, Liuzhou, Guangxi, P.R. China
Chen Lingyu, Shanghai, P.R. China
Chen Man Lung, Lam Tin, Hong Kong
Chen Xiaobin, Beijing, P.R. China
Chen Yi, Shanghai, P.R. China

Chen Ying, Nanning, Guangxi, P.R. China
Cheng Cheuk Yu, Tuen Mun, Hong Kong
Cheng Cho Luen, Kowloon, Hong Kong
Cheng Kwok Hoo, Quarry Bay, Hong Kong
Chong, Tanya, Croydon, Surrey
Chong Mui, Yim, Tseung Kwan O, Hong Kong
Chong Ting-Fung, Lannavaara, Sweden
Chou Chia Chia, Taipei, Taiwan, R.O. China
Chung Ching Man, Sheung Wan, Hong Kong
Colloud Aballe, Lydie, La Chaux-de-Fonds, Switzerland
Cope, Emma, London
Corbin, Marie-Hélène, Montreal, Quebec, Canada
Crowther, Lucy, London
Crump, Emma, Reading, Berkshire
Dai Qin, Shanghai, P.R. China
Deng Heng, Guilin, Guangxi, P.R. China
Ding Hai Ju, Tseung Kwan O, Hong Kong
Dix, Eleanor Charlotte, Harrogate, North Yorkshire
Dong Hai-Chen, Taipei, Taiwan, R.O. China
Drake, Florence, London
Dulay, Sundeep, Leamington Spa, Warwickshire
Earl, Jeremy, Kettering, Northamptonshire
Edmundson, Laura, Anerley, London
Elamri, Tarek, Montreal, Quebec, Canada
Fang Qiaoling, Hangzhou, Zhejiang, P.R. China
Fang Xiang, Shanghai, P.R. China
Farr-Barron, Hannah, Newton Abbot, Devon
Féral, Catherine, Paris, France
Finn, Riona, Castleknock, Dublin, Ireland
Floch, Edouard, Paris, France
Ford, Nicola, Ryde, Isle of Wight
Fu Minli, Xiaogan, Hubei, P.R. China
Gong Xiaowen, Shanghai, P.R. China
Grant, Leigh, Gillingham, Kent
Gu Bin Quan, Shanghai, P.R. China
Guo Jing, Shanghai, P.R. China
Guy, Angharad, London
Harrison, Katharine, Worcester
Hasselrot, William Anders, Stockholm, Sweden
He Huishi, Zhuji, Zhejiang, P.R. China
Hector, Liv, Lannavaara, Sweden
Hedström, Emma, Hallstahammar, Sweden
Ho Chun Wai, Hung Hom, Hong Kong
Hong, Bindi, Shanghai, P.R. China
Hopkins, Prudence, Happisburgh, Norfolk
Hrustic, Ibrahim, Marieholm, Sweden
Hu Yue, Shenzhen, Guangdong, P.R. China
Huang Hui Meng, Kaohsiung City, Taiwan, R.O. China
Huang Lilin, Beihai, Guangxi, P.R. China
Huang Liuyun, Guilin, Guangxi, P.R. China
Huang Qicheng, Guangzhou, Guangdong, P.R. China
Huang Shengling, Hepu, Guangxi, P.R. China
Huang Yang Ting, Kaohsiung City, Taiwan, R.O. China
Hucker, Louise, Great Blakenham, Suffolk
Hui Cheuk Fan, Tuen Mun, Hong Kong
Hui Ka Ching, Sha Tin, Hong Kong
Jayarathne, Rasika Waruna, Moratuwa, Sri Lanka
Jayawardena, S.A. Dhaneshi Thamalika, Colombo, Sri Lanka
Jhu Syuan-Rou, Taichung City, Taiwan, R.O. China
Jiang Huiyue, Shandong, P.R. China
Kang Xiao Feng, Shanghai, P.R. China
Kenyon, Janelle, Auckland, New Zealand
Khabrieva, Dilyara, London
Khan, Amina, Kowloon Tong, Hong Kong
Kim Ri Na, Seoul, South Korea
Ko Chih-Li, Taichung, Taiwan, R.O. China
Kolator, Barbara, London
Ku Yun An, New Taipei City, Taiwan, R.O. China
Kuo Chun-Han, Taipei, Taiwan, R.O. China
Kwok Man Yee, Kwai Chung, Hong Kong
Kwok Siu Mi, Kwai Chung, Hong Kong
Lagerstedt, Cecilia, Lannavaara, Sweden
Lai Ruoyun, Lanxi, Zhejiang, P.R. China
Lam Chi Him, Siu Sai Wan, Hong Kong
Lam Wai Ting, Quarry Bay, Hong Kong
Lammertse, Max M. R., Amsterdam, The Netherlands
Lau Chui Ting, Tin Shui Wai, Hong Kong
Leclerc, Charlotte, Paris, France
Lee Yu Bin, Seoul, South Korea
Lei Yaxiu, Xi'an, Shaanxi, P.R. China
Levy, Elsa, Boulogne-Billancourt, France
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Li Pingting, Wuhan, Hubei, P.R. China
Li Sum In, Sally, Causeway Bay, Hong Kong
Li Wenfeng, Tai'an, Shandong, P.R. China
Li Xiaofeng, Lianjiang, Fujian, P.R. China
Li Yi-Chen, Taipei, Taiwan, R.O. China
Lin Kai Yuan, New Taipei City, Taiwan, R.O. China
Lin Kun-Yan, Taipei, Taiwan, R.O. China
Liu Nianchuan, Yangzhou, Jiangsu, P.R. China
Lo Kuo-Feng, Zhongli City, Taiwan, R.O. China
Lo Siu Kian, Sha Tin, Hong Kong
Lou Ying, London
Lueviboonrat, Gunyasiree, London
Lui, Jo Weng Allan, Chai Wan, Hong Kong
Luk Tong Teng, Yuen Long, Hong Kong
Mak Shuk Kwan, Kowloon, Hong Kong
Malarin, Christian, Paris, France
Mancioppi, Laura, Genoa, Italy
Meng Mingqi, Guilin, Guangxi, P.R. China
Minelli, Adriana, Toronto, Ontario, Canada

Moore, Harriette, Newbury, Berkshire
Moorhead, Anna, London
Nassi, David, Norwalk, Connecticut, U.S.A.
Nayak, Asha, Egham, Surrey
Nyein Aye Than, Khin, Yangon, Myanmar
Orlova, Elena, Genoa, Italy
Ovesen, Hasanthi, London
Pan Ai, Taipei, Taiwan, R.O. China
Parkin, Charlotte, Caterham, Surrey
Petropoulou, Eleni, Athens, Greece
Philippe, Sophie, Paris, France
Prochniak, Ada, Barnet, Greater London
Qin Yayun, Yulin, Guangxi, P.R. China
Quinlivan, Melissa, Christchurch, New Zealand
Ramlov, Hans, Copenhagen, Denmark
Reading, Charlotte, Nuneaton, Warwickshire
Regan, Lisa, Collaroy, New South Wales, Australia
Rodwell, Nathalie, Earlsfield, London
Rykova, Elena, Yangon, Myanmar
Saksirisamphan Rimml, Phornthip, Näfels, Switzerland
Saleem, Melanie, Manchester, Greater Manchester
Schuler-Immoos, Gertrud, Gants Hill, Essex
Shen Yi, Changzhou, Jiangsu, P.R. China
Shin Gi Eun, Kyunggi-Do, South Korea
Soe Ye Htet, Yangon, Myanmar
Su Yung Chu, Kaohsiung City, Taiwan, R.O. China
Syn Hla Maw, Phyu, Yangon, Myanmar
Tam Yin Hung, Tseung Kwan O, Hong Kong
Tang Tiankai, London
Tanswell, Thomas, Rochester, Kent
Than Oo, Bo Bo, Yangon, Myanmar
Thierrin, Laure-Anne, Porrentruy, Switzerland
Tiegler, Thomas, Sante Fe, New Mexico, U.S.A.
Tsang Lan, Kim, Tuen Mun, Hong Kong
Tung Jen-Hao, Taichung, Taiwan, R.O. China
Wang Lin, Xuzhou, Jiangsu, P.R. China
Weldon, Tamara, Whitefield, Greater Manchester
White, Holly, Shepton Mallet, Somerset
Wong Cheung, Kwai Chung, Hong Kong
Wong Fang, Singapore
Wong Fu Wing, Cheung Sha Wan, Hong Kong
Wong Mei Sze, Tseung Kwan O, Hong Kong
Wong Nga Ting, Tuen Mun, Hong Kong
Wong Yu Ting, Tai Po, Hong Kong
Woo Kyung Hee, Seoul, South Korea
Wright, Abby, New Plymouth, New Zealand
Xu Xinhang, Guilin, Guangxi, P.R. China
Yang Jiong, Tai'an, Shandong, P.R. China
Yang Qiujing, Singapore
Yeah Chia Kai, Singapore
Yeung Ming Wai, Percy, Kowloon, Hong Kong
Yung Hoi Yan, Central, Hong Kong
Zhang Mengyi, Shanghai, P.R. China
Zhang Ruxiang, Shanghai, P.R. China
Zhang Yun, Weihai, Shandong, P.R. China
Zhao Junlong, Wulumuqi, Xinjiang, P.R. China
Zhao Yijia, Shaoxing, Zhejiang, P.R. China
Zheng Juanjuan, Laibin, Guangxi, P.R. China
Zhou Qianmin, Jieshou Town, Guangxi, P.R. China
Zhou Yonghang, Jinhua, Zhejiang, P.R. China

Diamond Diploma examination

Qualified with Distinction

Higgo, Emma, Hindhead, Surrey
Li Wenli, Beijing, P.R. China
Li Ziyue, Zhuhai, Guangdong, P.R. China
Stevens, Sophie, Kingston-upon-Thames, Surrey
Tsang Yuet Ming, Tuen Mun, Hong Kong

Qualified with Merit

Bratek, Elizabeth Jane, Romford, Essex
Burden, Maxwell, Birmingham, West Midlands
Chiang Cheng-Hsien, New Taipei, Taiwan, R.O. China
Evans, Rachel Mary, Stebbing, Essex
Fung Hoi Ching, Yuen Long, Hong Kong
Leung Ho Chin, Taikoo Shing, Hong Kong
Lou Hongwei, Beijing, P.R. China
Mak Ka Wai, Kowloon, Hong Kong
Xie Chenyu, Beijing, P.R. China
Yates, Elspeth, Aberdeen, Aberdeenshire

Qualified

Anand, Shraddha, Uttaranchal, India
Armstrong, Larisa, London
Brar, Denesha, Hounslow, Middlesex
Chan Hoi Ping, Tsim Sha Tsui, Hong Kong
Chau Wai Yuk, Kowloon, Hong Kong
Chen Jing, Zhujiang New Town, Guangzhou, P.R. China
Chou Yun-Wen, Taipei, Taiwan, R.O. China
Chu Wai Hung, Kowloon, Hong Kong
Chui Kwan Fung, Kowloon, Hong Kong
Feng Wei, Guangzhou, Guangdong, R.O. China
Hui Sin Kam, Tseung Kwan O, Hong Kong
Kanda, Sonia, Farnham Royal, Buckinghamshire
King, Chantiel, London
Ku Yee Ling, Tsing Yi, Hong Kong
Kwok Hei Tung, Hung Shui Kiu, Hong Kong
Law Pui Lun, Sham Tseng, Hong Kong
Legros, Maria, London

Li Wenjie, Zhujiang New Town, Guangzhou, P.R. China
Lin Dongyu, Zhujiang New Town, Guangzhou, P.R. China
Lin Yi Ping, Taipei, Taiwan, R.O. China
Liu Jian Yi, Guangdong, Guangzhou, P.R. China
Lui Sin Ting, Fiona, Tsuen Wan, Hong Kong
Ma Yaqi, Beijing, P.R. China
McWhirter, Hannah Maeve, Bury St Edmunds, Suffolk
Mok Ka Yan, Kowloon, Hong Kong
Nadal, Cynthia, London
Ng Wai Fong, Kowloon, Hong Kong
Ng Yat Sen, Natalie, Hong Kong
Robinson, Kristin, Wanstead, London
Tang Ying, Xiangyang, Hubei, P.R. China
Tsai Ko-Wei, Tainan, Taiwan, R.O. China
Valle, David, Tunbridge Wells, Kent
Wang Jing, Beijing, P.R. China
Wang Shuishui, Beijing, R.O. China
Wang Xiaohan, Beijing, P.R. China
White, Lucy, Virginia Water, Surrey
Wilding, Mark, St Helens, Merseyside
Wong Hing Yee, Yuen Long, Hong Kong
Wu Shih-Yu, Taipei, Taiwan, R.O. China
Xu Min Min, Pok Fu Lam, Hong Kong
Yeung Woon Ying, Maggie, Kwai Chung, Hong Kong
Zhao Yichen, Beijing, P.R. China

Annual General Meeting

The Annual General Meeting was held on Wednesday 3 July 2013 at the Naval Club, London W1J 5NS. The meeting was chaired by Harry Levy, the President of the Association. The Annual Report and Accounts were approved. Brian Jackson and Cally Oldershaw who retired from the Council by rotation, and Paul Greer, Nigel Israel and Stephen Whittaker who had been appointed by the Council since the 2012 Annual General Meeting. were re-elected.

Hazlems Fenton were re-appointed as auditors for the year.

The AGM was followed by a talk by James Riley entitled 'One hundred not out', on the Gem-A Gemmology Diploma which celebrates its centenary this year.

Membership

During the period January to June 2013, the Council approved the election to Membership of the following:

Fellowship and Diamond Membership (FGA DGA)

Wong, Winnie, Tsimshatsui, Hong Kong

Fellowship (FGA)

Alessandri, Matthias, Central, Hong Kong
Boisserand, Anne, Fréjus, France
Bruyère, Manon-Océane, L'Isle-sur-la-Sorgue, France
De Wit Sandstrom, Ida Marianne, Dalby, Sweden
Dryland, Davina, Burton-upon-Trent, Staffordshire
Forsner, Christina, Södra Sandby , Sweden
Frederick, Helen, Wellington, New Zealand
Fremy, Pierre, Bois-Colombes, France
Glenn, Alison, Chertsey, Surrey
Huang Yuan, Birmingham, West Midlands
Jayawardene, D. M. Dulip, Peradeniya, Sri Lanka
Lavoie, Martine, Montreal, Quebec, Canada
Li Qi, Guilin, Guangxi, P.R. China
Marshall, Angela, Cambridge
Negus, Patricia, Ushaw Moor, County Durham
Perry, Charles, Ampthill, Bedfordshire
Porter, Rex, Hook, Hampshire
Roden, Rhiannon, Allestree, Derby
Sanders, Esmee, Amsterdam, The Netherlands
Venturelli, Adelmo, Morges , Switzerland
Verdoorn-De Vrede, Veronica, Dordrecht, The Netherlands
Yang Mingyu, Jinan, Shandong, P.R. China

Diamond Membership (DGA)

Burden, Maxwell, Birmingham, West Midlands
Thomas, Jade, London
Valle, David, Tunbridge Wells, Kent
Wilding, Mark, Ecclestone, Merseyside
Wong Yu Ting, Tai Po, Hong Kong

Associate Members

Bekker, Alina, Haywards Heath, West Sussex
Burley, Lorraine, Hythe, Cornwall
Hendry, David, Oakland, California, U.S.A.
McReynolds, Meghan, Evansville, Indiana, U.S.A.
Williamson, Eleanor, London

Gold Corporate Membership

Carl's Japan Inc., Takamatsu City, Kagawa, Japan
GemLab Jewellery Valuers, Auckland, New Zealand
Japan Germany Gemmological Laboratory, Kofu, Yamanashi, Japan

Gifts and Donations to the Association

The Association is most grateful to the following for their gifts and donations for research and teaching purposes:

Joanna Angelett, London, for a sample of rough rough stromatolite.

Jeffrey Lee Bergman, Las Vegas, Nevada, U.S.A., for a copy of *An Emerald Encryption – The Abhaya Emerald Buddha* by Cameron Cooper and Pascal Butel, and three cabochon-cut trapiche sapphires.

Bezalel Gems Ltd, London, for faceted diffusion-treated sapphires.

Chao-Ming Wu FGA DGA, Taipei, Tiawan, R.O. China, for a piece of nephrite from Hualian, Taiwan.

Dr Tanya Chong, Croydon, Surrey, for a twinned gypsum crystal.

Eiko Ito FGA DGA, Jewellery Craft School, Tokyo, Japan, for a copy of *Practical Wax Modeling : Advanced Techniques for Wax Modelers* by Hiroshi Tsuyuki and Yoko Ohba.

Charles M. Ellias GG, Palladot Inc., Clawson, Michigan, U.S.A., for an assorted collection of pallasite peridot crystals and cut stones.

John Greatwood FGA, Mitcham, Surrey, for a black synthetic moissanite simulating black diamond.

Bill Kasso, Eagle Creek Opals, Queensland, Australia, for samples of opal replacement of coral and wood in rock.

John Kessler, J.A. Kessler Ltd, London, for a large quantity of assorted stones (see *Gems&Jewellery,* **22**(4), June 2013, page 9).

Bart Krijger FGA, The Hague, The Netherlands, for a selection of artificial and synthetic gemstones, including glass, plastic, doublets, synthetic spinel and synthetic corundum. Mr Krijger donated the stones in celebration of 40 years as a Fellow of the Association; he was awarded his Gemmology Diploma with Distinction in 1973.

Shawn Maddox Gem Cutting, Austin, Texas, U.S.A., for a sphere of andradite displaying cat's-eye from Southern Diablo range, San Benito, California.

MRD Import-Export GmbH, Vienna, Austria, for rough and faceted demantoid garnet from Green Dragon mine, Erongo, Namibia.

Renee Newman GG, Los Angeles, California, U.S.A., for a copy of her book *Gold, Platinum, Palladium, Silver and Other Jewelry Metals.*

Helen Serras-Herman FGA, Rio Rico, Arizona, U.S.A., for a piece of galactic jade (black jadeite with pyrite) and a slab of pink angel skin chalcedony from Graham County, Arizona.

E.A. Thomson Gems Ltd., London, for a large number of faceted green soude stones.

Ray Zajicek, Equatorian Imports Inc., Dallas, Texas, U.S.A., for red beryls from the Wah Wah mountains, Utah, including crystals on the host rock and faceted stones.

Monetary donations were gratefully received from:

Vincenzo De Michele, Milan, Italy
James C. Finlayson FGA, Stoke-on-Trent, Staffordshire
Gwyn Green FGA DGA, Barnt Green, Birmingham, West Midlands
Barbara Kolator, London
Torbjorn Lindwall FGA DGA, Lannavaara, Sweden
Elaine Rowley FGA DGA, London
Moe Moe Shwe FGA, Singapore
Wanda Hoi Chi Wat FGA, Kowloon, Hong Kong
Jiewen Zhang DGA, Shanghai, P.R. China

Corporate Membership

M&J Gems Ltd , Birmingham, West Midlands

Transfers

Fellowship to Fellowship and Diamond Membership (FGA DGA)

Evans, Rachel, Stebbing, Essex
McWhirter, Hannah Maeve, Bury St Edmunds, Suffolk
Stevens, Sophie, Kingston-upon-Thames, Surrey
White, Lucy, Virginia Water, Surrey

Diamond Membership to Fellowship and Diamond Membership (FGA DGA)

Warner, Simon, Tring, Hertfordshire

Associate Membership to Fellowship (FGA)

Drucker, Richard, Glenview, Illinois, U.S.A.
Herold, Dorte, Zürich, Switzerland
Kronenberg, Hugh, Paddington, New South Wales, Australia
Matlins, Antoinette, Woodstock, Vermont, U.S.A.
Riley, James, Knutsford, Cheshire
Williams, Bear, Jefferson City, Missouri, U.S.A.

Obituary

Michael Ngan FGA DGA (D. 2004), Hong Kong, died recently.

Manuel Maria Ramos Pinto Rosas FGA (D. 1949 with Distinction), Porto, Portugal, died in December 2012. He was the first person in Portugal to qualify in the Gemmology Diploma examination, and was involved in the selection and setting of the gems in the Portuguese Crown Jewels.

Joseph W. Tenhagen FGA (D.1969), Miami, Florida, U.S.A., died 27 April 2013 at the age of 79.

Joseph (Joe) was involved in the gem and jewellery trade for over 40 years as an appraiser and consultant, and was actively involved in a number of trade organizations. He was a member of the Accredited Gemologists Association (AGA) and was appointed president from 1981 to 1984. Joseph joined the National Association of Jewelry Appraisers (NAJA) in 1992 and served as its associate director. He was also a charter member, past president and past secretary of the Diamond Dealers Club of Florida until 2005. Joe published the *Diamond Value Index* from 1995 to 1998, and many of his articles appeared in trade journals.

Joseph Tenhagen was a keen and much-valued supporter of Gem-A education. Over the years he donated large quantities of rough and cut gemstones for use in our courses and examinations. During a trip to the UK in 2002 he gave a presentation to Gem-A members entitled 'New aspects of cut in round brilliant-cut diamonds'.

Said Antoinette Matlins of AGA: "Joe was a close friend of AGA founder, Tony Bonanno, and the two made an awesome team! They were part of that special generation — that unique 'breed' of gemmologists — who helped determine the very course of gemmology in the USA, and the role that gemmologists would serve in raising the ethical and professional standards within the broader jewellery world."

Joe will be sadly missed by all who had the pleasure to know him. He leaves his wife Mary, a son and two grandchildren.

Lord Ian Balfour

21 December 1924 – 14 April 2013

The Hon. Ian Balfour, 2nd Baron of Inchrye — Ian to his friends and people he knew — died on 14 April 2013.

Balfour, diamond expert, author, composer, will be missed by many as a kind and loyal friend. Born on 21 December 1924, he succeeded his father in September 1988, entering the House of Lords as a Cross Bencher. Educated at Eton, he served in the Royal Navy during the Second World War and on his release went up to Magdalen College, Oxford, to read modern languages and music.

Coming down from university, he worked for a while at Anglo American. This did not tax him greatly and he went to work at the Diamond Trading Company (DTC), the selling arm of De Beers. There he sat at a bench like any other trainee and sorted diamonds. He was a burst of fresh air into the rather formal working conditions there. A great practical joker, he was not averse to bringing them into the office; a great peal of laughter would come from his bench as someone fell for one of his japes.

His sorting days came to an end when, as he once put it: "Catastrophe struck. All the trays were laid out for the right handed, but I am left handed. One day I caught my tweezers on something and all the contents went haywire."

This happened at a time when the press and the public were beginning to want to know more about diamonds. A knowledgeable person was required to do this and he was given the job. He settled into his new task producing a 'Glossary of Terms used in Sorting', a first of its kind. A copy is in the library of the Gemmological Association.

In collaboration with Norman Harper he wrote the first diamond courses for the Gemmological Association and, together with Professor Tolansky, Professor of Physics at London University, was an examiner.

It was around this time that his exhaustive research into famous diamonds bore fruit with a compilation in 1959 entitled *Notes on Famous Diamonds*. This was followed by two booklets on the subject. Further study was undertaken culminating in the production of the first edition of *Famous Diamonds* in 1987, which he dedicated to his wife Maria, whom he married in November 1953.

This was a labour of love and thought by some to come from his close association with Sir Ernest Oppenheimer, whose love of diamonds was well known.

Leaving the DTC, he joined Hennigs, the prestigious firm of diamond brokers. Established in 1890 it brokered the purchase of the Jonkers in 1935 and the Star of Sierra Leone in 1970, the third largest diamond found, weighing 968.9 ct (or nearly half a pound avoirdupois).

His easy manner and friendly attitude made him a great success with the clients, both when they came to London to the De Beers' Sights and when he visited them in their cutting centres.

In addition to his work in diamonds, researching new material for his next edition of *Famous Diamonds*, he also found time for his other love, music. He composed nine operas and a number of orchestral and vocal pieces, which were performed in a number of cities throughout the world. After thirty years in diamonds he retired and became a consultant. He was working on the sixth edition of his book when a car accident resulted in a broken collar bone. From then on his health deteriorated and he died on 14 April 2013. With his death the title became extinct. He is survived by his daughter Roxane, born in September 1955.

On page 48 of the first edition of *Famous Diamonds*, Ian had written: "All who write about the history of diamonds must forever remain grateful to Jean Baptiste Tavernier." A reviewer of the book at that time wrote: "Today, the same can be said about Ian Balfour." Never was a truer word written, for today he has left a monumental work which will be a boon for scholars for many years to come.

Johnny Roux

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Any opinions expressed in *The Journal of Gemmology* are understood to be the views of the contributors and not necessarily of the publishers.

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Editorial

A fond farewell to Dr Roger Harding

This issue marks a change in the editorship of *The Journal of Gemmology,* with Dr Roger Harding retiring and Brendan Laurs stepping in. Roger has been named Editor Emeritus in recognition of his nearly two decades of editing *The Journal*, and he remains active with proofreading the articles and giving sage advice borne of his long experience.

Roger began editing *The Journal* in 1994, when he succeeded Alan Jobbins, who came after John Chisholm and Gordon Andrews. Roger drew on his academic background in geology and mineralogy to raise the stature of *The Journal* in the scientific community. He recognized that gemmologists everywhere, and laboratory gemmologists in particular, face increasingly complex problems of identification that require more sophisticated solutions. Authors who have worked with Roger will remember his meticulous attention to detail and sympathetic rewriting if English was not the author's first language. This is an ethic which we will endeavour to continue.

On behalf of Gem-A, I would like to thank Roger for his many years of tireless service. Under his leadership *The Journal* became the most-circulated academic journal on gemmology, and with Brendan taking the helm, I'm sure it will continue to grow. A trained gemmologist, Brendan also has a master's degree in geology and 15 years of experience with *Gems & Gemology*, most recently as Editor and Technical Specialist. He has written extensively on the geology of gem deposits and is well known in the international gemmological research community.

James Riley
Gem-A Chief Executive
Executive Editor, *The Journal of Gemmology*

Exciting changes ahead for *The Journal*

I am very pleased to carry forward the legacy of Dr Roger Harding and those who came before him at the helm of *The Journal of Gemmology*. With the support of The Swiss Gemmological Institute SSEF and my colleagues at Gem-A, *The Journal* will evolve in exciting ways to meet the needs of today's gemmologists, researchers and enthusiasts. Starting in 2014, *The Journal* will be printed quarterly (rather than once per year), and digital versions of the articles in PDF format will be more easily accessible via Gem-A's updated website. In addition, readers will enjoy an updated design.

The Journal will continue to publish high-quality peer-reviewed feature articles describing cutting-edge laboratory studies and field research, whilst also introducing new sections that provide readers with announcements of new technological advancements, tips on practical gemmology, conference reports, learning opportunities and more. See *The Journal* on the Gem-A website for more information. A balance of regular columns, occasional sections and feature articles will deliver useful information that will increase readers' knowledge, enjoyment and effectiveness in their gemmological pursuits.

You will notice on the masthead of the present issue that we have expanded the team of Associate Editors. These experts are critical to the peer-review process that is the foundation of *The Journal,* as they ensure the technical accuracy and appropriateness of the feature articles. I feel very fortunate to have their support as we move toward making *The Journal* the preeminent publication of the international gemmological community.

Brendan Laurs
Editor-in-Chief, *The Journal of Gemmology*

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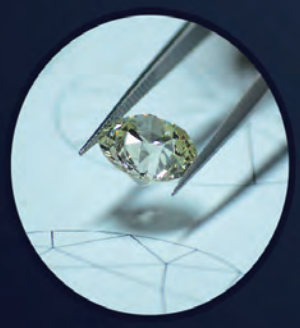

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Peñas Blancas: An historic Colombian emerald mine

Ron Ringsrud and Edward Boehm

Abstract: The Peñas Blancas emerald mine is part of Colombia's Muzo mining region, an 800 km^2 area that encompasses the famous Muzo, Coscuez and La Pita mines. This is the largest emerald district in Colombia, and it is the most productive and well-known emerald mining region in the world. Peñas Blancas has a fascinating and turbulent history, which sheds light on that of the entire Colombian emerald industry. Just as important, Peñas Blancas is finally accessible after more than 20 years of being closed to outsiders. This article describes the history, geology and gemmology of Peñas Blancas emeralds, and compares this historic mine to other famous producers in the region.

Keywords: Colombia, emerald, geology, inclusions, Peñas Blancas, RI, SG, trapiche

Introduction

From ancient artisanal beginnings with the Chibcha and Muzo Indians, the emerald mines of Colombia have supplied the world with fine material for hundreds of years. When the Spaniards, led by Hernán Cortés, conquered Mexico almost 500 years ago, legend has it that Aztec ruler Montezuma was adorned in gold and emeralds. The Spanish conquistador Francisco Pizarro also found emeralds, now known to be from Colombia, as far south as what are now Ecuador, Peru and Chile. After the conquered treasures made their way to Spain, the Spanish traded the emeralds with the Persians for gold. Thus, Colombian mines have been supplying the world with emeralds since the mid-1500s.

A relatively unknown Colombian emerald deposit is Peñas Blancas, located in the famous Muzo mining district. This mine has rarely been mentioned in gemmological literature except as an historical footnote. Long thought to be depleted, Peñas Blancas closed in the early 1980s because of a decades-long conflict between the two controlling families of the area. This conflict was finally resolved in late 2003, and by March 2004 the Peñas Blancas mine was producing high-quality rough. The authors are aware of one parcel yielding 270 carats of faceted emeralds that sold for US$810,000 ($3,000/ct). The authors first visited the mine in late 2004, and subsequent trips by one of us (RR) revealed good potential for future production, although mining continues slowly in the absence of investment and technology.

Peñas Blancas emeralds are known among local dealers for their exceptional colour and transparency. Although Peñas Blancas is hosted by a geological formation that is somewhat different from the three other Muzo-region mines, the fine quality of the emeralds (e.g., *Figure 1*) is similar to its more famous neighbours. The history of the mine has had a significant impact on the development of the entire Muzo district, and eventually Peñas Blancas may be partially responsible for the revival of this important mining region.

Figure 1: This superb mineral specimen taken from Peñas Blancas in February 2004 beautifully displays a cluster of emeralds that surround a quartz crystal. Quartz is more common in the emerald-mineralized zone at Peñas Blancas than at other Colombian localities. The specimen measures 55×65×90 mm and is courtesy of the Roz and Gene Meieran Collection; photo by Harold and Erica Van Pelt.

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Early history

According to general understanding in Bogotá's emerald trade, Peñas Blancas attained significance in 1959 when a large emerald pocket started a bonanza that revived a dormant national industry and launched the careers of many of its principal players. Formerly known as *Peña Blanca*, the mine first appeared on a sketch map published by J. Pogue (1916; see *Figure 2*). At the turn of the 20th century, Pogue along with Charles Olden and Robert Sheibe (Sinkankas, 1981), were among the few geologist-explorers who were adding to the published knowledge about gem occurrences in Colombia. After World War II, Victor Oppenheim was the first of many geologists assessing petroleum and coal deposits in South America, and he briefly mentioned the Peñas Blancas mine: "...Tambrias or Peña Blanca mine — This mine is located some 25 km northeast of Muzo but as is the case of the La Chapa mine, very little is now known of the emeralds there, as the mine has not been worked for a considerable time" (Oppenheim, 1948, p. 37). Apparently, after the passage of many decades and two World Wars, the Peñas Blancas prospect was nearly forgotten.

The rediscovery of Peñas Blancas as a source of fine emeralds is now legendary. Since 1955, San Pablo de Borbur has been the closest town to the Peñas Blancas mine. From Borbur, mules would take locals to the Peñas Blancas area once a week for agricultural work. Those *campesinos* would sometimes find emeralds on the ground and, not knowing what they were, simply give them away. According to a local legend, in 1958 a mule driver showed a Peñas Blancas emerald to one of his relatives in Muzo, and within a few months the rush began.

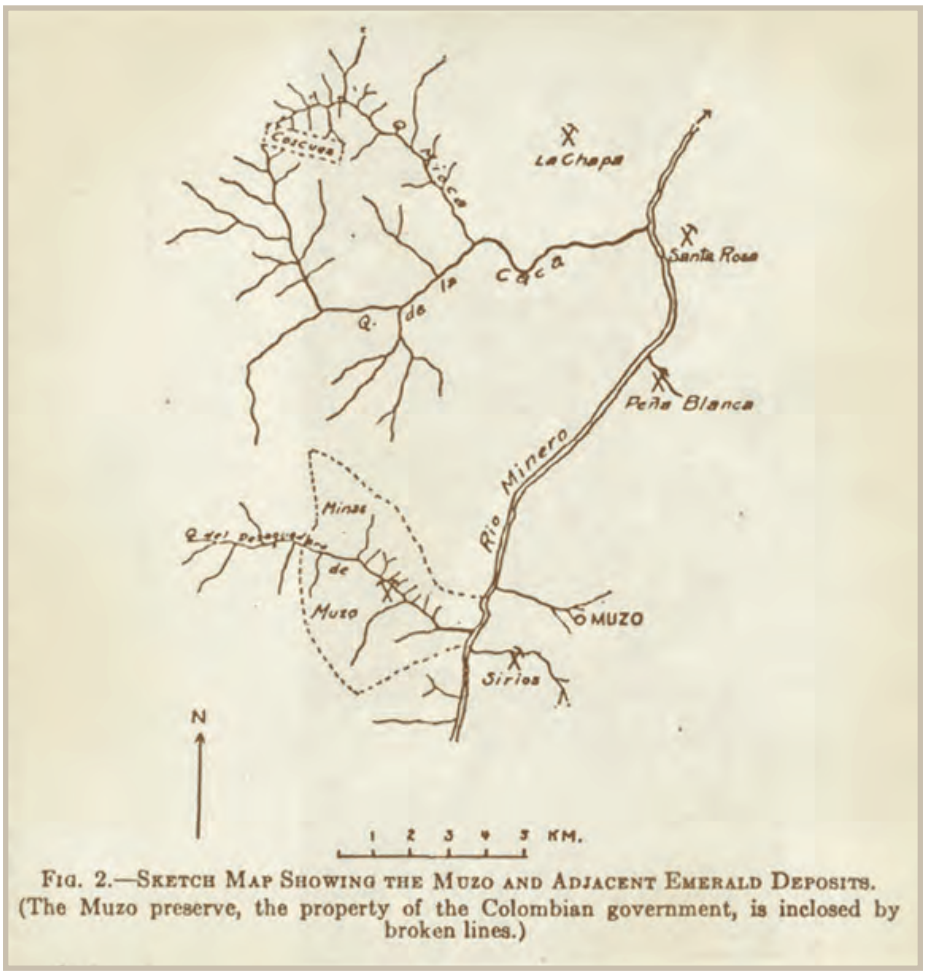

Fig. 2.—Sketch Map Showing the Muzo and Adjacent Emerald Deposits. (The Muzo preserve, the property of the Colombian government, is inclosed by broken lines.)

Figure 2: A sketch map of the Muzo mining region by J. Pogue (1916) depicting Peña Blanca (Peñas Blancas) a few kilometres north of the small town of Muzo.

Emeralds were initially found on the surface underneath an overgrowth of vegetation, in a rich vein more than 60 m long (Claver Téllez, 2011). During the initial years of the boom, shallow trenches provided miners with significant quantities of gem-quality rough.

Emeralds from this find eventually reached the Gemological Institute of America (GIA), then located in Los Angeles. An unattributed two-page article titled 'A new emerald find in Colombia' appeared in the Spring 1961 issue of *Gems & Gemology*. The article states (pp 142, 158):

> "Each of the clear, deep-green stones showed prism faces and the two or three with basal pinacoids also had very small bipyramid faces of the same order as the prisms. We understand that production has ranged in size from one carat to about thirty carats. The rich, velvety color of the few we saw was reminiscent of the Muzo product.
>
> "The new find … has been the scene of a wild rush of perhaps fifteen hundred miners. At this writing, the government has not yet determined who should be granted the right to work the property; the army, however, has surrounded the area, to keep order and prevent robbery."

It would be two decades until Peñas Blancas was cited again in the gemmological literature, when John Sinkankas included it in his 'Chronology of Colombian Emerald' section of *Emerald and other Beryls* (Sinkankas, 1981, p. 412). Sinkankas mentioned a new Colombian agency called *Empresa de Esmeraldas* (Emerald Company), formed by the Banco de la República to control the emerald region and to mine emeralds on behalf of the government, "including recently discovered deposits in Boyacá Province" (referring to Peñas Blancas). The government attempt to control the mining region was unsuccessful, and in 1968 the Colombian Ministry of Mines and Petroleum formed the *Empresa Colombiana de Minas* or ECOMINAS (Sinkankas, 1981). ECOMINAS ran the region more efficiently by granting mining

concessions to private companies (Keller, 1981).

Recent history

The vast wealth produced by Peñas Blancas during the 1960s and 1970s allowed aggressive and entrepreneurial leaders not only to launch themselves into the emerald business but also to gain influence in the entire region. In those years, Muzo and Coscuez were stagnating under government control while Peñas Blancas was a relatively new find, uncontrolled by the government, and yielding gems only 6 ft (1.8 m) below the surface. The 1960s were dominated by the irascible Isauro Murcia, whose son Jaime *El Pekinés* later assumed control at Coscuez during the infamous Emerald Wars of 1985–1990 (see below). A powerful syndicate composed of Palermo and Gilberto Molina, Victor Carranza and Juan Beetar consolidated their control of the Colombian emerald industry in the 1970s and 1980s, initially at Peñas Blancas and then at Muzo.

Gilberto Molina is credited with instigating the development in 1986 of a much-needed road from Muzo to Otanche (near the Coscuez mine) and an airstrip in Quípama (near Muzo). Molina was known on occasion to dump quantities of *moralla* (lower-quality emerald rough) into Muzo's Itoco River streambed just before religious holidays like Christmas and Easter. He wanted to assure that the thousands of *guaqueros* (independent diggers) had stones to trade and thereby enjoyed the holidays. In contrast, during the 1970s, the legendary *El Ganso* (The Goose) Humberto Ariza ruled his dominion from horseback, exercising his power daily with a small squadron of armed men based in Coscuez. In the 1980s, Ariza's enemies and rivals were so numerous that he would never stay more than 30 minutes in one location to avoid assassination attempts. Ariza ultimately died in a blaze of bullets. Later, the folklore and history of Peñas Blancas was further embellished by the menacing presence of scar-faced Pacho Vargas and the fearless Quintero brothers.

During the 1980s, the Muzo and Coscuez mines enjoyed strong production while Peñas Blancas was essentially closed and intermittently yielded only small amounts of rough. The Muzo region, while accessible, was strongly territorial with a violent rivalry between groups from Muzo and Coscuez (Angarita and Angarita, 2013). In 1985, the entry of the personal army of drug-lord José Gonzalo Rodríquez Gacha, a partner of Medellín Cartel leader Pablo Escobar, escalated this rivalry into what became known as the Emerald Wars.

This conflict lasted until 1990, with most of the violence localized in the Muzo mining region. Occasionally, shootings would occur in downtown Bogotá in the famous emerald district of Avenida Jiminez and 7th Avenue. Nevertheless, abundant emerald production from the region continued throughout those years, especially at Coscuez (Ringsrud, 1986). To avoid areas of fighting and danger, the routes taken by the gem couriers as they made their way to the cutting centres in Bogotá were extremely circuitous and laboured. Due to the violence, a road between the village of Santa Barbara and the Coscuez mine was closed for more than four years. It became known locally as *El Muro de Berlin* (The Berlin Wall) because no one could cross it and live to tell about it. Curiously, the actual Berlin Wall fell on 9 November 1989, the same week the road to the Coscuez mine was re-opened.

While federal forces of the Colombian government dealt with drug-lord Rodríquez, it was the emerald miners and guards associated with Carranza who finally secured the emerald region. The end of the Emerald Wars was so significant that on 7 November 1989 the Archbishop of Colombia presided over a peace accord that was signed in Chiquinquirá, a major city and religious centre in the province of Boyacá. With Gilberto Molina a casualty of the violence, Carranza and Beetar continued to consolidate their regional power in the 1990s, and controlled the region until Carranza's death in April 2013.

Although Colombia's emerald mines have been quite productive over the past 15 years, the region has remained uninviting to foreign buyers. However, as of this writing, the locals and many of the newer mine owners have expressed a strong desire to replace the violent past with forward-looking openness, productivity and planning. Many locals still remain armed, but there is improved accessibility to the region and a pride in talking about the relative safety of the roads and the lack of fighting during the past decade. There has been a major military presence since 2008, and strongly enforced gun laws. Government-mandated accountability and control at the mines has added to their accessibility. As a result, foreign-owned mining operations have entered the region; Muzo International (known in Colombia as Minería Texas Colombia) now controls the Muzo mine, while additional international companies are actively creating alliances in other districts.

Because the Emerald Wars were prolonged and escalated by groups involved in the drug trade, there remains an on-going regional enmity toward guerrilla- or drug-related groups who try to enter the mining areas. Not only the emerald miners and their families, but also the *campesinos* are vigilant in their efforts to keep out paramilitary groups and guerrillas. In 2004, fields of coca (used for making cocaine) were discovered just 15 km from the villages of Borbur and Otanche. They were uprooted with great fanfare through the cooperation of local emerald miners and the Colombian national police. The talk among farmers of the region is that lucrative crops like stevia (a sugar substitute) and cocoa (for chocolate) will eventually provide better and equally profitable alternatives for export. Fedesmeraldas, the umbrella organization that encompasses the organizations of emerald miners, dealers and exporters, as well as the Colombian Ministry of Mines and Energy, has completed several multi-year projects building clinics, schools and co-ops in the region (see, e.g., www.emeraldmine.com/2012Archive.htm).

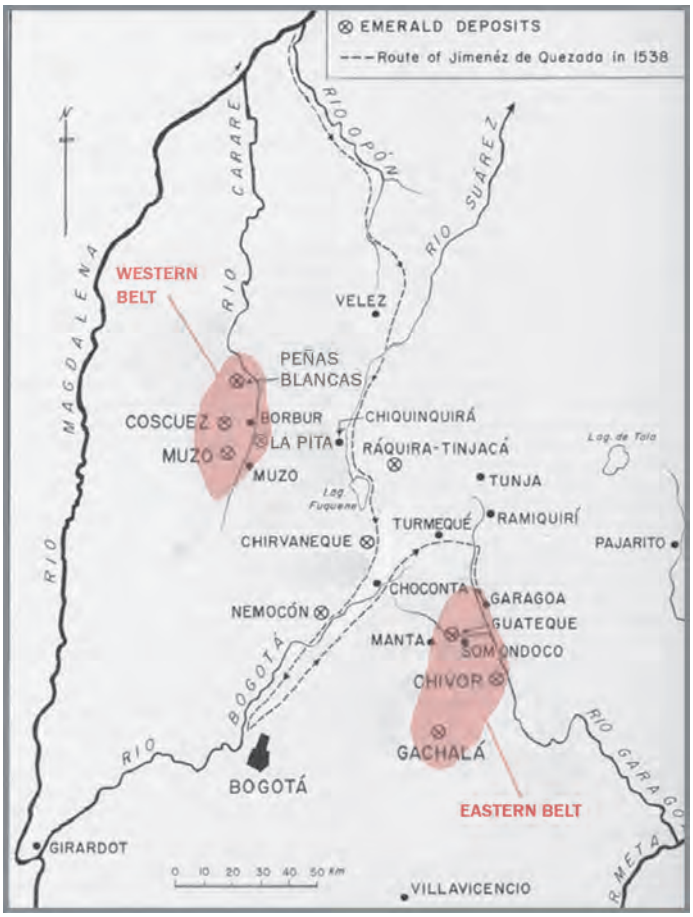

Figure 3: Emerald deposits in Colombia are situated in two belts within a mountain range known as the Eastern Cordillera. The western belt hosts the Peña Blancas, Muzo, Coscuez and La Pita mines, while the Chivor mine is located in the eastern belt. After Sinkankas (1981).

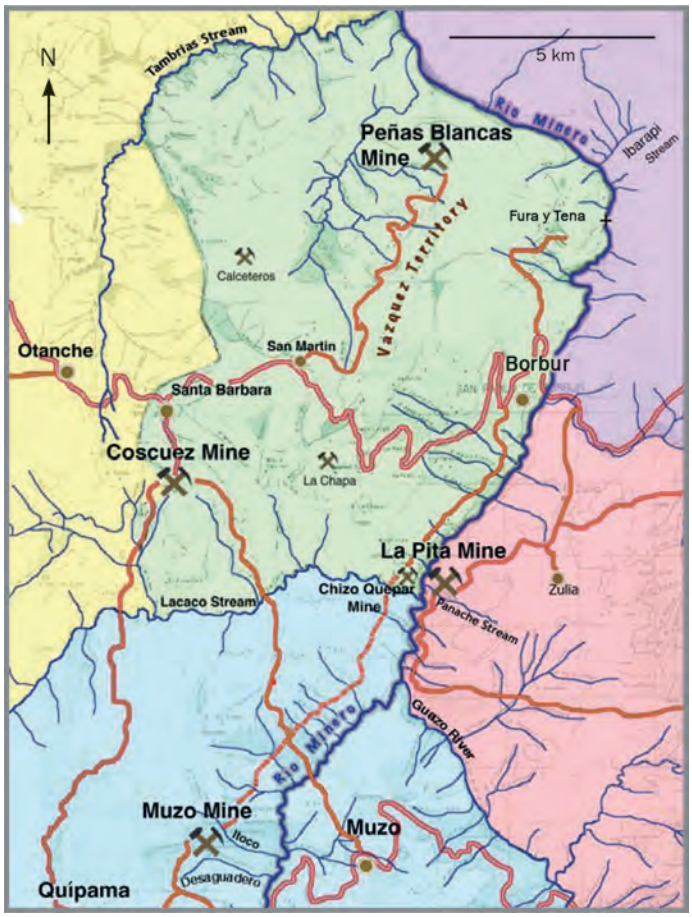

Figure 4: This map depicts the current active mines in the Muzo mining region. Peñas Blancas can be seen at the top, and the Muzo mine is at the bottom of the map. The town of Borbur is located just southeast of Peñas Blancas. Compiled by R. Ringsrud.

Location and access

Colombia's emerald deposits are situated in two belts that are hosted by a mountain range known as the Eastern Cordillera or Cordillera Oriental (e.g., Cheilletz *et al.,* 1994). Within this range, the Peñas Blancas, Muzo, Coscuez and La Pita mines are located in the western belt, while Chivor and others are situated in the eastern belt *(Figure 3)*. All of the mines are located within the state of Boyacá, about a day's drive from Bogotá. Peñas Blancas and the other western-zone mines can be reached by a challenging journey that descends from the capital city of Bogotá (2,600 m) in the central highlands through the lush, semitropical forest to the western flanks bordering the Andes Mountains. After five to six hours of driving on paved and unpaved roads, one reaches the mining region at an altitude of approximately 1,150 m. The area is marked by the twin peaks known as *Fura y Tena* (see Box A). The Peñas Blancas mine (5°43.0'N, 74°4.9'W) is located approximately 40 minutes by off-road vehicle from the town of Borbur (*Figures 4* and *5*). The name *Peña Blanca* that appears on older maps means 'white outcrop', in reference to the limestone layers where emeralds were first discovered. Today locals refer to the mine as *Peñas Blancas*, or simply as *La Peña*.

The village of Borbur lies at about 980 m above sea level, and is still principally a farming and mining town with a population of just over 1,000. The entire municipality surrounding Borbur has a population of almost 11,000. This area, bordered to the east by the Río Minero (Minero River), encompasses Peñas Blancas, Coscuez and part of the La Pita mine. A new road completed in 2011 along the western flank of the Río Minero valley extends from Borbur to the Muzo mine. This road provides direct access through Chizo Quepar to the Muzo mine rather than through the town of Muzo, which is on the other side of the river (see *Figure 4*). Another recent development in this formerly inhospitable region is the arrival of mobile phone coverage to many parts of the mining area. The rapid access to information about new finds enables buyers from Bogotá to respond quickly, making it more difficult and competitive to acquire top-quality gem rough at the mines.

Overall, the Muzo emerald region is rather small; the mines of Muzo, Coscuez, La Pita and Peñas Blancas could all theoretically be visited within a half-day's driving. However, access to any of the

emerald mines is impossible without also having an invitation from a manager, operator or owner of that mine, and visits must be made in the company of locals from each particular mine.

The major mines of Muzo and Coscuez are government-owned, and today access is provided to private companies in 10-year renewable leases from INGEOMINAS, an affiliate of the Colombian Ministry of Mines and Energy. Legal mining claims and filings must be accompanied by environmental permission from two agencies. Peñas Blancas is privately owned, and prospecting of its tunnels is negotiated individually with local strongmen and families from the region, as at other small mines such as Chivor and Gachalá.

Figure 5: The Borbur Cathedral tower is seen here, with the peaks of Fura y Tena in the distance. Photo © Robert Weldon.

Box A: Fura y Tena

Presiding over the lush valley of the Río Minero are the imposing monoliths known as *Fura y Tena (Figure A1)*. These twin peaks dominate the topography of the emerald region, and are visible from Borbur and Coscuez as well as locations close to Muzo and La Pita. The higher peak, Fura (850 m from base to peak), looks like an irregular pyramid topped by a pointed cone, while Tena is a shorter obelisk that reaches only to Fura's shoulder. Río Minero, another significant feature common to all the mines in the Muzo district, runs between the two peaks.

The Fura y Tena are subjects of an indigenous legend dating back to the time of the Muisca and Muzo Indians that dwelled in the area before the Spanish Conquest. The legend speaks of a creator named Ar-e who formed Tena, the first man, and Fura, the first woman, out of the earth. Their life in that land was paradise until Zarve, represented by the Río Minero, tempted and seduced Fura. The infidelity angered the creator, who condemned them to death. Tena, ordained to die first, was turned into stone. Three days later, Fura died at his feet and the god Ar-e sent the torrents of the Zarve River, now called the Minero, to separate them forever. After centuries, the waters purified them and the murmurs of Fura's sadness were converted into the millions of blue butterflies *(Morpho didius)* that populate the region, while her tears became the emeralds. Fura and Tena then became minor deities presiding over the sun's rays, the winds and the underworld.

Figure A1: The peaks of the Fura y Tena dominate the emerald mining region and are visible from the Coscuez mine, Borbur and the La Pita mine. Río Minero, another prominent feature in the mining region, flows between the two peaks. Photo by R. Ringsrud.

Box B: Formation of Colombian emerald deposits

By Terri Ottaway, Museum Curator, Gemological Institute of America, Carlsbad, California, U.S.A.

Colombia's emeralds, arguably the finest in the world, are geologically unique, occurring in organic-rich shales and limestones without the usual association of beryllium-bearing pegmatites. The absence of a well-defined source of Be, the key ingredient in emerald, has long been a perplexing problem for geologists.

In contrast, elsewhere in the world emeralds have formed in environments where pegmatites and related solutions have transected ultramafic country rocks such as serpentinites or amphibolites. Subjected to heat and fluids from the intruding pegmatite, the surrounding country rocks underwent metasomatism to form mica or amphibole schists. Within the schists a mixing zone of pegmatite solutions containing Be, Al and Si, and local solutions containing Cr, V and Fe, resulted in the crystallization of emeralds. For a thorough description of metamorphic emerald environments, see Kazmi and Snee (1989).

Emeralds formed in pegmatite-schist environments are frequently heavily included with mica or amphibole, which reduces the transparency of the crystals and lowers their value as gems. Additionally, Fe can substitute into the emerald structure and negatively affect the colour. Chromium and vanadium not only give the characteristic beautiful blue-green colour to emerald, but they also impart a strong red fluorescence (Nassau, 1983). Although not visible to the naked eye, it may act to enhance the perceived blue-green colour. The presence of Fe in the beryl structure quenches the fluorescence, causing the emerald's colour to appear less intense. Iron can also impart a yellow tinge, resulting in a more 'grass-green' colour. Colombian emeralds are renowned for their intense, velvety blue-green colour and are devoid of inclusions of mica and amphibole, which signifies that their environment of formation differed from the conventional schist-related model.

Despite the lack of evidence, early researchers attempting to explain the formation of emeralds in the black shales of Colombia proposed that emerald-bearing solutions were derived from some hidden igneous activity at depth (Pogue, 1916; Scheibe, 1933; Oppenheim, 1948; Campbell and Bürgl, 1965). Then an intriguing observation was noted that there was a strong spatial association between emerald deposits and evaporites (Oppenheim, 1948; Roedder, 1963; McLaughlin, 1972). Evaporites form through the evaporation of seawater to form large beds of gypsum (hydrous calcium sulphate) and halite (sodium chloride). Their relationship to emeralds becomes all the more evident when one examines the fluid inclusions inside emerald crystals. Fluid inclusions are tiny pockets of the actual solutions from which the emeralds formed that became trapped in tiny cavities during the crystallization process. Over time as the temperature and pressure surrounding the emerald decreased, gases and elements came out of solution to form three-phase (gas-liquid-solid) inclusions. Thus, fluid inclusions represent a geological 'fingerprint'. The presence of halite (salt) crystals within fluid inclusions in all Colombian emeralds indicates the extremely high salinity of the emerald-forming solutions. Perhaps brines from evaporites leached sufficient key elements from the shales and limestones and precipitated them as emeralds (Beus, 1979; Kozlowski *et al.,* 1988; Giuliani *et al.,* 1993).

A geochemical study of the fluid inclusions, isotopes and organic matter of the emeralds, veins and shales at Muzo points to emeralds having formed at approximately 330°C through the interaction of sulphate from incoming evaporitic solutions with the organic-rich shales and limestones (Ottaway, 1991; Ottaway *et al.,* 1994; Giuliani *et al.,* 1995). At certain locations, the sulphate was thermochemically reduced and the organic matter was oxidized to carbon dioxide, releasing organically bound Be, Cr and V. The resulting pressurized solutions were forced into the fractured shales and limestones where they precipitated pyrite, calcite, albite and emerald. The reaction sites where this occurred are distinctively bleached in contrast to the rest of the black shales due to the absence of organic matter. Miners refer to these areas as *cenicero* (ashtray). The abundance of native sulphur in the cenicero further enhances this descriptive term. The peculiar, hexagonally patterned trapiche emeralds are found in the shale surrounding the cenicero. The black shale adjacent to the cenicero also records exposure to a high-temperature event through the elevated reflectance levels as compared to the rest of the shales (Ottaway, 1991).

The removal of Fe from the system in the form of pyrite was critical to the colour of Colombian emeralds. With just Cr and V as chromophores, the emeralds show the renowned intense blue-green colour we value so much.

Emeralds from the Cosquez mine contain fluid inclusions almost identical to those studied at Muzo (Ottaway, 1991; Ottaway *et al.,* 1994). A site visit also confirmed that the greatest concentrations of emeralds were from zones close to bleached areas of shale rich in native sulphur. Indeed, evidence points to the same processes having occurred at the Chivor mine on the eastern flank of the Cordillera Oriental (Ottaway, 1991). Thus, given a favourable environment, the processes of emerald formation presumably occurred over and over, producing all of the known deposits in Colombia, including the emeralds at the Peñas Blancas mine. Although rocks matching the description of the cenicero have not been reported there, it may be that weathering, erosion or mining activity have removed all traces of their existence. Alternatively, it is likely that large emerald-producing areas indicated by reaction sites such as the cenicero are waiting to be discovered.

Geology

The diverse geology of Colombia gives rise to a wealth of varied mineral resources. Petroleum, coal, nickel and emerald are the most important minerals to the Colombian economy. In addition, the Western Cordillera and Central Cordillera are known for gold deposits in granitic rock. The Eastern Cordillera, where the emerald mines are located, consists mainly of sedimentary rock, principally limestones and shales with minor igneous and metamorphic rocks. The major emerald deposits, found as hydrothermal deposits in sedimentary rock, are limited to the western margin (Muzo region) and the eastern margin (Chivor region) of the Eastern Cordillera (again, see *Figure 3*).

Several authors have described the geology of the Muzo district, including Pogue (1916), Schiebe (1933) and Oppenheim (1948). This work is summarized in Keller (1981), Sinkankas (1981) and Ringsrud (1986). A thick layer of black carbonaceous shales and minor amounts of limestone underlies the emerald mining areas. Fossils in these rocks indicate that they are from the Cretaceous Period (approximately 120 million years old). The shales are intensely folded and transected by a number of north-northeast-trending faults that are accompanied by zones of brecciation (fracturing). Mining geologist Cesar Agusto Valencia, working at the Peñas Blancas and La Pita mines, found that fault zones are often rich in emerald, particularly where they intersect and are deformed (C.A. Valencia, pers. comm., 1998). The fault zones can sometimes be identified by changes in the colour or texture of the surrounding rock, or by water seepage. Ottaway *et al.* (1994) state that these fractures in the shales are weaknesses that allowed hydrothermal fluids to infiltrate and deposit calcite, dolomite, emerald, pyrite, quartz and other accompanying minerals such as albite, fluorite, parisite and baryte (for more details, see Box B). This deposition occurred in several episodes involving heat and sometimes violent pulses of pressure (Cheilletz *et al.,* 1994; Ottaway *et al.,* 1994; Giuliani *et al.,* 1995, 2000; Branquet *et al.,* 1999).

Figure 6: The Peñas Blancas mining area is visible in this photo. The green foliated area below and above the mining camp (centre-right) is where past mining yielded many fine-quality trapiche emeralds. At present this area is not being exploited. Photo by R. Ringsrud.

Two rock units are of significance to the emerald deposits: the Paja Formation, in which the mines of Muzo, Coscuez and La Pita are situated; and the Rosablanca Formation, which hosts Peñas Blancas (*Figure 6;* INGEOMINAS, 2005). (The Villeta Formation is also cited by some authors as the host of the emerald deposits.) In contrast to Colombia's other emerald mines, the prominent geological feature of the Rosablanca Formation at Peñas Blancas is its compact and blocky shale. This carbonaceous, fine-grained, argillite shale is penetrated by intersecting white calcite and quartz veins in which the emerald mineralization occurs *(Figure 7)*. By comparison, the Muzo, Coscuez and La Pita areas are characterized by softer, coarser grained, carbonaceous black shales that are highly fractured *(Figure 8)*. Peripheral to the Peñas Blancas exploitation zone, cavities and fissures in the shales give rise to many small, white stalactites of calcium carbonate, which are collected by the locals. Most shops in Borbur have at least one on display, which the locals call *gangas de agua* (water minerals).

Figure 7: The host rock at Peñas Blancas (Rosablanca Formation) is comprised of blocky fine-grained carbonaceous shale penetrated by intersecting white calcite and quartz veins that locally host emerald mineralization. Note the solid compactness of the rock. Photo by R. Ringsrud.

As with other areas in the Muzo mining region, pyrite formation preceded the crystallization of emerald and is one reason for the superior colour of Colombian emerald (see Box B). At Coscuez and Peñas Blancas, pyrite seems to form in thin veins and stock works running through the shales. The pyrite also weathers to form orangy brown iron

Figure 8: All other emerald mines in the Muzo region are located within the Paja Formation, which is characterized by more highly fractured and softer carbonaceous shales (here, being examined by Dr Peter Keller). Compare this with the blocky nature of the shale at Peñas Blancas in Figure 7. Photo by R. Ringsrud.

Figure 10: This large transparent quartz crystal (probably half of a Japan-law twin, 23 cm long) and accompanying emerald crystal were found at Peñas Blancas in 2004. Photo by E. Boehm.

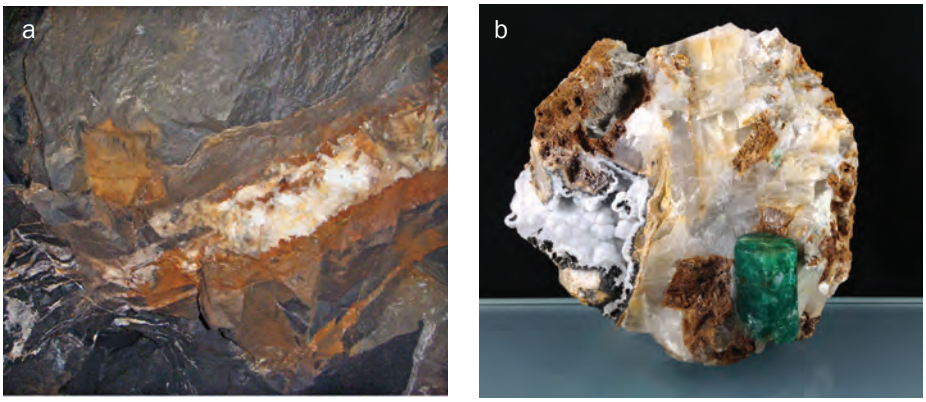

Figure 9: (a) Deep within the tunnels at Peñas Blancas, a white calcite vein (approximately 9 cm wide) shows typical orangy brown iron staining. (b) This mineral specimen from Peñas Blancas features a 2.5-cm-long emerald crystal embedded in the typical matrix of iron-stained calcite with a later secondary coating of botryoidal white calcite. Photos by E. Boehm.

stains along the veins, which are common at Peñas Blancas *(Figure 9)*. In Muzo and La Pita, the pyrite more often forms nodules in the veins or is found as crystals in the shales and veins.

At Peñas Blancas, the mineralized veins range in width from 1 to 30 cm and are usually filled with calcite, dolomite, pyrite and quartz. The emerald crystals occur most frequently attached to the walls of the vein, and are embedded in the vein material. Where the veins are wide enough to form cavities, the emeralds may be larger. Field observations indicate that the best emerald crystals usually occur in the narrower veins (~5 cm thick) and that quartz crystals increase in transparency toward emerald mineralization. Quartz crystals, some quite large and transparent *(Figure 10)*, are commonly found in association with the emeralds (see also *Figure 1*). Quartz found in or near emerald veins is referred to as *cuarzo de veta* (vein quartz), and is typically transparent and very clean, while the more common quartz found elsewhere is known as *cuarzo de tierra* and is not as transparent. The abundance of quartz as a vein mineral differentiates Peñas Blancas from other emerald mines in the area.

Mining

During the bonanza years of 1958–1965, emerald mining at Peñas Blancas consisted of uncovering the surface of *La Culata* (Spanish for gun breech [opening] or a mound, referring to landforms at the mining site) and following productive veins. Miners eventually dug down over 10 m, with intersecting trenches that were subsequently widened with a bulldozer into gullies. What remains of these workings today are four steep mounds separated by wide gullies. The mounds are perforated by prospecting holes and are overgrown with vegetation *(Figure 11)*. One tunnel, *El Tunel de los Dos,* was started in this time period above La Culata and was extremely productive for many years.

When the surface mining operations predominated, terms like *capas buenas* (emerald-bearing layers), *cambiado* (barren zones) and *cama* (breccia-like masses) were used to describe the rocks. These terms helped to orient the miners as they worked the faces of the slopes. Later, such terms fell out of use as mining moved underground, following productive veins with shafts and drifts. After the depletion of the surface-reaching deposits at Peñas Blancas in the early 1970s,

Figure 11: Mining at Peñas Blancas began 50 years ago at the top of these mounds, in an area known as La Culata. Emeralds found at the surface started a bonanza. The miners dug trenches that eventually reached a depth of over 10 m. Photo by E. Boehm.

Figure 12: The authors (RR on left and EB on right) and mine foreman Edilfo Ramírez inspect emerald crystals on matrix from Peñas Blancas. Photo by Willington López.

tunnelling became the only means of following the emerald-rich veins.

At the well-known mines of Muzo, Coscuez, La Pita and Chivor, the brecciated shale host rock provided little resistance to the use of dynamite, and sometimes the force of the explosions passed into the veins, thus damaging the emeralds. Rough stones from these localities sometimes show an indicative whitish percussion mark at the surface that may or may not have accompanying fissures emanating into the stone.

The harder, more blocky shale at Peñas Blancas requires the use of more dynamite than at the other emerald mines, but the uniform compactness of the shale helps insulate the veins from the force of the explosions. If well placed, the dynamite clears away the hard shale without damaging the actual veins, which are then worked manually. The emeralds mined by this process are generally free from percussion fractures caused by dynamite use. They are commonly recovered still embedded in the vein material *(Figure 12)*.

Because of the independent and artisanal nature of the mine workings at Peñas Blancas, there is little money to invest in infrastructure. Even the best-equipped tunnels have only one pump for ventilation and a generator for an electric hammer-drill.

Gemmology

In the authors' experience, Peñas Blancas emeralds are very slightly bluish green (e.g., *Figure 13*), like most Colombian emeralds, but they generally contain less colour zoning and possess a velvety appearance that is highly prized. Also like most Colombian emeralds, the crystals form first-order prisms with flat terminations. However, a unique characteristic of the Peñas Blancas rough material is called *cascocho* by some cutters and dealers. It refers to the tendency of the crystals to have numerous pits and cavities, which hinder the cutting of large stones. They are most likely due to secondary chemical etching after emerald formation.

While visiting Bogotá's downtown emerald market, the authors were fortunate to see two large pieces of rough from Peñas Blancas prior to cutting *(Figure 13)*. The larger crystal weighed 22 g and was faceted into nine stones weighing 32.90 ct (a 30% yield), with the largest being a ~9 ct heart shape *(Figure 14)*. Much sawing was required to remove the cavities from the rough. However, the attraction of Peñas Blancas emerald rough is that beneath the zone of cavities and pits there is sometimes fine material of exceptional purity. The hope of uncovering that fine material, which is not always evident when viewing the surface of the rough, is what often entices cutters and dealers to take risks on emerald

Figure 13: The colour and clarity of some Peñas Blancas emeralds make them highly prized. The 22 g crystal on the left yielded higher-quality material than the smaller crystal on the right. Photo by E. Boehm.

Figure 14: These nine emeralds, faceted from the larger Peñas Blancas crystal in Figure 13, *weigh 32.90 carats in total. The large heart shape weighs ~9 ct. Photo by E. Boehm.*

crystals from this mine. The cutters equate them to the seed of a peach, whose pitted and gnarly exterior *(cascocho)* covers an inner seed or nodule *(la almendra)* that is pure and fine.

The authors studied 10 rough or partially polished emerald samples that they purchased during their late-2004 trip to Peñas Blancas. The emeralds were obtained from an intermediary who bought them at the mine camp. Refractive indices (taken from at least one polished surface or crystal face) obtained with a GIA Duplex II refractometer were consistent with emeralds from the Muzo region (n_o=1.578–1.580, n_e=1.569–1.572; see *Table I*, cf., O'Donoghue, 2006). With the exception of sample 6 (SG=2.68), the hydrostatic specific gravity values were somewhat lower than reported for emeralds from this region (i.e., 2.63–2.67 vs. 2.70; O'Donoghue, 2006). These lower values may be due to the stones' higher 'porosity', resulting in trapped air bubbles, because of etch cavities present in the rough material. Faceted gems without cavities would likely yield higher SG values. Samples 7–10 contained significant fractures and surface cavities that were filled with oil and epoxy resin (e.g., *Figure 15*). These samples would have therefore rendered inaccurate specific gravity readings.

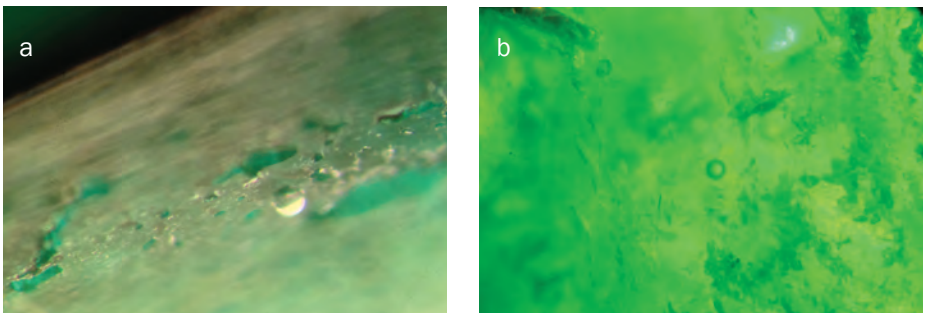

Figure 15: Rough emeralds from Peñas Blancas are sometimes fracture-filled with oil, resin or a combination of these. (a) The pitted surface etching typical of Peñas Blancas emeralds is shown, along with an air bubble that appeared on the surface as a result of the heat generated from the incandescent bulb of the microscope. The heat caused oil in the sample to expand, forcing a bubble and then some oil to the surface. (b) Air bubbles trapped in this emerald's filler could possibly be mistaken for two-phase inclusions. Photomicrographs by E. Boehm, magnified 66× (a) and 50× (b).

Table I: RI and SG values of 10 rough emerald samples from Peñas Blancas, Colombia.

Sample	Weight (ct)	n_o	n_e	SG
1	1.28	1.580	1.570	2.64
2	1.41	1.580	1.572	2.67
3	1.57	1.580	1.572	2.60
4	2.05	1.580	1.570	2.63
5	2.18	1.580	1.572	2.63
6	2.54	1.578	1.569	2.68
7	4.38	1.58	1.57	nd*
8	4.99	1.578	1.570	nd
9	6.88	1.580	1.570	nd
10	22.52	1.578	1.570	nd

* Abbreviation: nd = not determined.

Inclusions in emeralds from this mining area were first described by Dr E.J. Gübelin and J.I. Koivula (1986, p. 250) in samples coming from the 'Burbar' mine which we know today as Borbur, the closest village to Peñas Blancas. Those authors described the "greatly distorted and distended form of the secondary three-phase inclusions" as typical hallmarks of these emeralds *(Figure 16a)*. Similar secondary three-phase inclusions were also observed in the samples examined for this article *(Figure 16b,c)*. Primary or syngenetic three-phase inclusions are also seen in emeralds from Peñas Blancas. Some protogenetic inclusions of pyrite, calcite and quartz were noted, but such crystals are more commonly found as associated minerals within the gem-bearing veins or attached to the surface of the emerald crystals.

Trapiche emeralds

Most gemmologists are familiar with trapiche emeralds from Muzo, in which inclusions of carbonaceous matter form spokes radiating from a hexagonal centre, creating six black 'rays' in the emerald crystal (e.g., Ringsrud, 2009, pp 344–6).

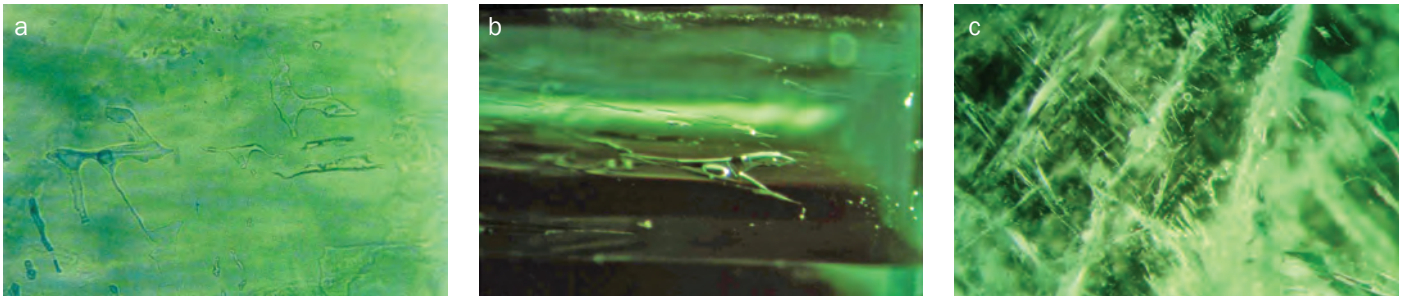

Figure 16: Secondary three-phase inclusions in Peñas Blancas emeralds. (a) Irregular shapes photographed by Dr E.J. Gübelin, magnified 50× (from Gübelin and Koivula, 1986, p. 250). (b) A classic inclusion scene containing a halite crystal, CO_2 gas, and liquid in a 1.41 ct emerald crystal from Peñas Blancas; photomicrograph taken by Dr E.J. Gübelin in 2004; magnified 66×. (c) View parallel to the basal plane of an emerald crystal with a small three-phase inclusion in the top-centre; photomicrograph by E. Boehm, magnified 50×.

The Spaniards called these peculiar emeralds *trapiche* because of their resemblance to the cogs and gears with which sugarcane was crushed. Trapiches are usually cut into cabochons to show off this cog-wheel pattern.

In the 1960s and 1970s, many well-formed large trapiches from Peñas Blancas with white (albite) or black (carbonaceous) interstitial material found their way into collections all over the world (e.g., *Figure 17*). Unfortunately, their size and abundance was also the cause of their destruction: the rays of the trapiche were often sawn through and the six transparent gem segments were then cut into calibrated stones. Rare chatoyant sections were polished into cabochons to form cat's-eyes. Trapiches are no longer being mined at Peñas Blancas. During our visit in 2004, the locals indicated the 'trapiche zone' was found in a steep area overgrown with vegetation (again, see *Figure 6*).

Conclusion and future potential

Since its rediscovery in 1958, the turbulent history of the Peñas Blancas mine demonstrates the necessity of not only solving the geological and engineering aspects of emerald extraction but also understanding the inherent social factors at play in the area. After the initial bonanza, the best emerald production at Peñas Blancas occurred during the presence of loyal, trained security forces headed by strong, undisputed leaders. The current trend of pacification, organization and investment in Boyaca's rich emerald region may allow Peñas Blancas to once again become a significant emerald producer.

Recent exploration at Peñas Blancas has consisted of little more than locals digging shallow test pits, of which only a few have shown potential. The lower trapiche zone could provide additional production, along with the upper area known as La Culata. However, as is the case elsewhere in the subtropical Boyacá mining region, heavy overgrowth has inhibited proper geologic exploration. Prospecting also has been hindered by the area's remoteness, steep topography and challenging social climate. However, it seems probable that more sources of fine Colombian emeralds will be found. One example is provided by the La Pita mine *(Figure 18)*. After two decades of dormancy, in 1998 the La Pita mine suddenly became a major producer in the region (Michelou, 2001). This gives an indication of the possible future of Peñas Blancas and the surrounding region.

However, for Peñas Blancas to realize its full potential, it must first become attractive to outside investment. A decade after the authors' initial visit, the road to Peñas Blancas is still barely passable. The original bonanza left behind a mining

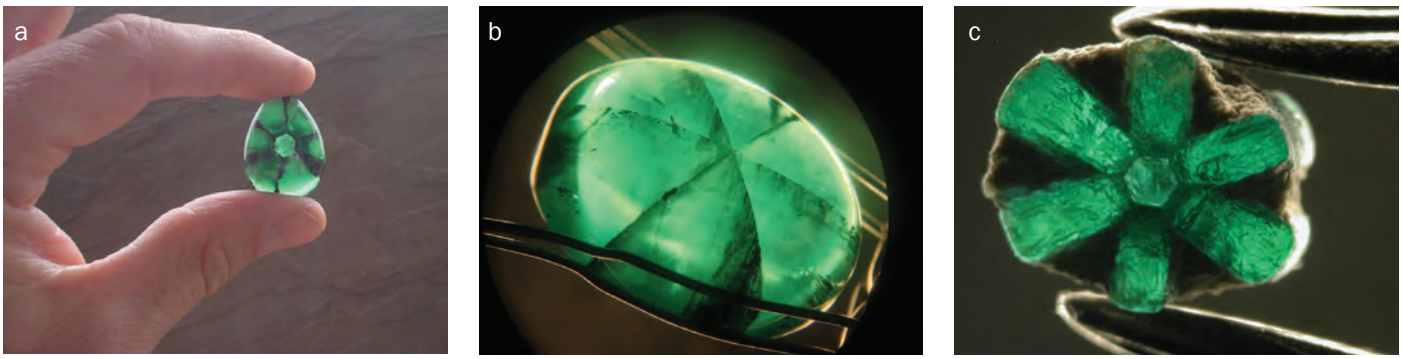

Figure 17: Trapiche emeralds from Peñas Blancas entered the market in the 1960s and 1970s. (a) The most common trapiche variety consists of emerald material intersected by spokes of dark carbonaceous inclusions (28 ct; courtesy of RareSource, photo by E. Boehm). (b) This 25 ct trapiche cabochon displays chatoyant segments, although any cat's-eye emeralds cut from them would be rather small; photomicrograph by E. Boehm, magnified 8×. (c) A 'reverse trapiche' example in which the spokes are formed by straight segments of emerald with albite or shale in between (here, 7 mm in diameter; photo by R. Ringsrud). This type of trapiche, now quite rare in the market, has been found in relatively large sizes (up to 20 ct).

Figure 18: The La Pita emerald mine (left-centre) had its own bonanza in the late 1990s. Continued steady production has elevated the La Pita to the legendary status of Muzo and Coscuez as one of the premier mines in the Muzo region. Photo by R. Ringsrud.

area full of potential but needing serious infrastructure improvements to make it worthy of exploitation.

Even after almost five centuries of supplying fine emeralds to the world, the Muzo region still shows no signs of exhaustion. World emerald demand will only increase, and it is expected that exploration and production in Colombia's premier mining region will grow to meet the demand. With the colour green in fashion and Hollywood actresses wearing more and more emeralds, the future importance of Peñas Blancas, and all emerald mines, will only grow.

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Greek, Etruscan and Roman garnets in the antiquities collection of the J. Paul Getty Museum

Lisbet Thoresen and Karl Schmetzer

Abstract: The results of quantitative electron microprobe analyses and observations of gemmological properties and microscopic features are presented for 11 garnets of ancient Greek, Etruscan and Roman manufacture. In addition to chemical data, the gemmological properties of the Getty Museum garnets are presented, including refractive index, density and inclusions. According to their chemical composition and gemmological properties, the 11 garnets were subdivided into four groups: Cr-poor pyrope, Mn-rich almandine, Ca-rich almandine and intermediate pyrope-almandine. Combining the data of the 11 Getty garnets with published analyses of 26 Greek and Roman garnets from ancient jewellery and glyptic, the chemical distribution pattern of all 37 garnets expanded the boundaries of the established four groups and added a fifth garnet group comprising Mn-poor almandine. The compositional fields for these five groups are compared with data reported for Early Medieval garnets, mostly from Merovingian cloisonné jewellery. The chemical composition and physical properties of the garnets yield insights into possible sources of rough gem material, networks of trade/transmission in the ancient world, and associations between finished objects now dispersed in different collections.

A late Hellenistic (323–30 BC) almandine carbuncle engraved with winged Eros carrying the attributes of Herakles, gem no. 5 of the present study (14.7×12.1 mm). The J. Paul Getty Museum, Villa Collection, Malibu, California. Photo by Harold and Erica Van Pelt.

Keywords: antiquities, carved gems, electron microprobe analysis, garnet, inclusions, optical spectra, pyrope-almandine

Introduction

The use of red garnets in ancient craft industries, primarily as beads, is attested in Egypt from the Predynastic period through the New Kingdom (i.e., 4th–2nd millennium BC; Aston *et al.,* 2000), and in some Western Asiatic and Near Eastern cultures of the 2nd–1st millennium BC (Moorey, 1994). Their early use was sporadic at best, but trade in gems from distant sources, including garnets, proliferated in the Hellenistic era (323–30 BC) under the successors of Alexander the Great, or *Diadochi*, who divided his empire. Among them, the Seleucids, who ruled Western Asia, and the Ptolemies, who ruled Egypt and territories in the Eastern Mediterranean, were able to control the overland and sea trade, respectively. The development of luxury arts, including glyptic (i.e., the art of gem carving), flourished under their patronage and garnets became the premier gem during the Hellenistic era. In workshops throughout the ancient world — from countries around the Mediterranean to the Black Sea region and Western and Central Asia — garnets were used to make intaglios, cameos, beads and jewellery inlays (e.g., *Figure 1*).

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Figure 1: A Hellenistic necklace from a jewellery hoard, dated 230–210 BC, found in ca. 1900 in a tomb in Taranto, southern Italy. The necklace consists of a chain of looped links of gold alternating with carved pyrope, and a Herakles knot clasp inlaid with pieces of pyrope (17 mm long). Orange cornelians with a tapered cone shape are set on either side of the Herakles knot centrepiece. © Antikensammlung, Staatliche Museen zu Berlin. Photo by Johannes Laurentius.

The popularity of garnets continued into the Roman Imperial era, but waned over time, and then enjoyed a resurgence in the Severan (AD 193–225) and Constantinian (AD 313–363) dynasties in the later Roman Empire. Polychromy and garnet inlays in cloisonné metalwork emerged as an altogether new expression in jewellery of the Byzantine East and persisted through the Medieval period. Originating with tribes of the Pontic-Caspian steppes and Central Asia, these distinctive artistic conceptions and objects spread across Western Europe and around the Mediterranean, as far as northwestern Africa. During this 'Garnet Millennium' (Adams, 2011) — from the Hellenistic era through the Early Medieval period (about AD 500–700) — ancient texts, gems and jewellery found in archaeological contexts, and also carved gems extant in modern collections, all attest to the availability of garnets from different sources occurring in a wide variety of colours, sizes and qualities.

Adams (2011) gave an excellent overview of the occurrence and distribution of garnets in disparate cultures throughout the ancient world from the late 4th century BC to the 7th century AD, including a discussion of nomenclature and garnet sources as described in ancient texts and in recent analytical provenance studies. Detailed discussions of Hellenistic engraved garnets were given by Spier (1989) and Plantzos (1999).

Traditionally, glyptic has been characterized, dated and attributed to a culture, workshop or individual artist based primarily on stylistic criteria such as subject/motif, shape of the fashioned gem, choice of gem materials and tool work. A strong reliance is placed on the jewellery setting to help narrow the date and sometimes likely place of manufacture. However, many ancient intaglios and cameos that survive to the present day lack their original mounting, and most such gems in modern collections — private or public — came from the art market, so their connection to a precise cultural horizon has been broken.

Complementing the tools at the disposal of scholars for attributing gems — comparanda (gems and settings that are stylistically or typologically similar), ancient texts and inscriptions, and archaeological context — the physical and chemical properties of the gems themselves provide additional criteria potentially useful to archaeologists for determining the period and place of production and tracing the materials to their original sources, which in turn may illuminate facts related to transmission and intercultural contacts in the ancient world.

Chemical composition and other properties such as inclusions may be helpful in identifying the geographic origin of gems. For example, using these criteria, some sapphires and rubies may be attributed to a gem-producing region or even a specific locality with a high degree of probability. However, localizing many otherwise distinctive gem materials to their sources can be difficult, because their geological environment often can be very similar in different regions. This is true of emeralds, for example, where they may occur in phlogopite or biotite schists in various countries; as such they are associated with similar minerals and may have similar inclusions and trace-element compositions, thus making difficult an unambiguous determination of origin.

Garnets are common gem materials, particularly metamorphic almandine and igneous/metamorphic pyrope. Fortunately, garnets have a chemical complexity that makes them at least partly distinctive, and it is sometimes possible to link specific garnets to a particular type of host rock and even to a specific source.

Historically, the identification of most garnets used in ancient glyptic (4th/3rd century BC to 5th century AD) has been based on visual observation of colour and seldom according to the stones' chemical composition as represented by garnet end-member percentages. Despite the numerous garnets extant in ancient Greek and Roman jewellery, only a few studies on a small number of stones have been published.

This article adds chemical data and gemmological properties of 11 ancient garnet intaglios and cameos from the J. Paul Getty Museum, Villa Collection, Malibu, California. Their chemical compositions are discussed in relation to the published analyses of a small number of other ancient Greek and Roman garnets, as well as additional data published on garnets belonging to the Early Medieval era. Although a

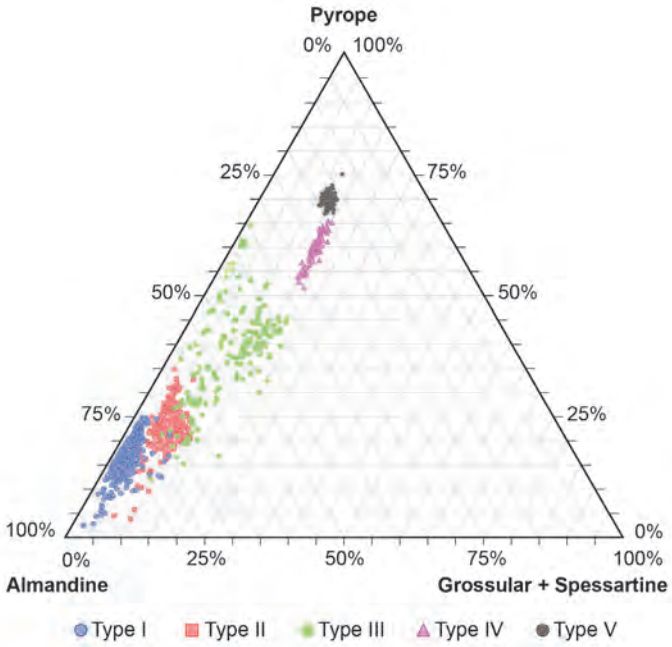

Figure 2: Ternary diagram of pyrope–almandine–(grossular+spessartine) end member compositions of garnet inlays in Early Medieval cloisonné metalwork, after Calligaro et al. *(2006–2007). The garnets were subdivided into five different types, some with partly overlapping compositional ranges.*

comparison with the later-dated garnets is not precisely parallel, they represent the nearest temporal association with Graeco-Roman garnets available currently.

Analytical provenance studies of Early Medieval garnets

Beginning about the 1970s, various analytical techniques were used to determine the geographical provenance of garnets mounted in objects produced during the Early Medieval period, including Anglo-Saxon, Frankish, Scandinavian and South Russian artefacts. Typically, the jewellery and other functional objects contained thinly sliced garnet inlays mounted in cells with metal bases and partitions or boundaries (i.e., cloisons).

Methods such as powder X-ray diffraction (Löfgren, 1973; Arrhenius, 1985) or Raman spectroscopy (Adams *et al.,* 2011), in general, may enable the subdividing of garnet samples of unknown origin and composition into pyrope-rich and almandine-rich groups. The application of X-ray fluorescence (XRF) analysis in air usually precludes quantitative determination of lighter elements such as Mg and Al (Bimson *et al.,* 1982; Greiff, 1998) and presents difficulties in comparing results of different researchers, because complete quantitative analyses (necessary to calculate the percentages of the garnet end members) are not available.

A recent study initiated at the British Museum included qualitative nondestructive analyses of 19 engraved garnets of Eastern manufacture (i.e., cultures of Central and South Asia) — Sasanian, Kushan and Hunnic (Adams *et al.,* 2011). Produced between the 1st and 6th century AD, these garnets were differentiated by colour and segregated into two groups by Raman spectroscopy: almandine with a low pyrope content and almandine with a somewhat greater pyrope content.

To obtain full quantitative analyses of ancient garnets, various nondestructive methods have been used, such as electron microprobe analysis (Löfgren, 1973; Rösch *et al.,* 1997; Quast and Schüssler, 2000), scanning electron microscopy–energy dispersive spectroscopy (SEM-EDS; Greiff, 1998; Mannerstrand and Lundqvist, 2003) or proton-induced X-ray emission (PIXE) analysis (Farges, 1998; Calligaro *et al.,* 2002). In addition, a combination of XRF and PIXE (Pappalardo *et al.,* 2005) or a combination of XRF and Raman spectroscopy (Gilg and Gast, 2012) have been used to obtain full quantitative data of garnets.

Additional analytical studies of Hellenistic and Roman garnets were published by Formigli and Heilmeyer (1990), Gartzke (2004) and Gliozzo *et al.* (2011), and data on Early Medieval garnets were published by Calligaro *et al.* (2006–2007; 2009), Pèrin and Calligaro (2007), Mathis *et al.* (2008), Gilg *et al.* (2010), and Horváth and Bendö (2011). To date, more than 2,000 full analyses have been published (or shown in comparative diagrams) on garnets of the Early Medieval period, and interpretation of these data has been discussed intensively. According to their chemical composition, these garnets (dating from the 5th to 7th century AD) reportedly originated mainly from areas known today as the Czech Republic, France, Germany, Belgium, Hungary, Italy and Spain. Most were identified as members of the pyrope-almandine solid-solution series, many also with spessartine and grossular components. Some contained up to several weight percent of Cr_2O_3, representing the uvarovite or knorringite end member of the garnet group.

The Medieval garnets in some of these studies were subdivided into five different types (*Figure 2;* see Calligaro *et al.,* 2006–2007). These subdivisions comprise two types of almandine, two varieties of pyrope with different Cr contents and one intermediate pyrope-almandine type. By contrast, in a later study by Gilg *et al.* (2010), garnets were divided into four clusters (representing four of Calligaro's types) plus one intermediate group X (nearly identical to Calligaro's intermediate pyrope-almandine type). Gilg *et al.'s* group X represents specimens with widely varying properties and compositions. Calcium-rich intermediate pyrope-almandine from Sweden and Denmark, mostly dating to the 8th century or later, forms another type (not shown in *Figure 2*) and is related mainly to Scandinavian deposits (Lundström, 1973; Mannerstrand and Lundqvist, 2003).

Table I: Description of 11 ancient garnets from the J. Paul Getty Museum, Villa Collection.

Gem no.	Identification	Description, inventory no., primary references and source	Culture/era (and location, if known)	Period
1	Cr-poor pyrope	Scarab, large corner winglets of diamond shape and ridge carination. On the flat side is engraved a helmeted head in profile. Inv. no. 81.AN.76.142 (13.3×9.4×8.1 mm). Boardman (1975), pp 34, 106, no. 142.	Etruscan	Late 4th–3rd century BC
2	Intermediate almandine-rich pyrope-almandine	Cameo portrait head of a woman in profile and wearing a veil. Inv. no. 81.AN.76.59 (19.1×12.9×6.2 mm). Boardman (1975), pp 92–93, no. 59. Possibly Berenike (d. *ca.* 222 BC); although Spier (1989) and Plantzos (1999) suggest that she is probably Arsinoë II (d. 270 BC), the sister-wife of Ptolemy II, and they concur on a probable date of manufacture in the second half of the 3rd century BC. Spier (1989), p. 30, no. 34, p. 35, fig. 36; Spier (1992), p. 157; and Plantzos (1999), p. 51, no. 87 and p. 64, pl. 90.9.	Hellenistic (Ptolemaic)	3rd century BC
3	Mn-rich almandine	Oval intaglio ring-stone, obverse highly convex, reverse flat. A woman wearing a himation swathed around her legs and over her arm; she rests her elbow on a column and holds a flower. Inv. no. 81.AN.76.56 (21.9×11.7×5.9 mm). Boardman (1975), pp 19, 92, no. 56.	Hellenistic	3rd century BC
4	Mn-rich almandine	Intaglio, obverse convex, reverse slightly concave, engraved with a man lifting a child onto his shoulder. Inv. no. 81.AN.76.54 (14.1×9.9×4.6 mm). Boardman (1975), p. 92, no. 54.	Hellenistic	2nd century BC
5	Mn-rich almandine	Intaglio, obverse highly convex, reverse concave, engraved with Eros with the attributes of Herakles; he carries a club, a lion skin, and a bow case. Inv. no. 85.AN.370.41 (14.7×12.1×6.6 mm). Spier (1992), p. 90, no. 213.	Hellenistic; Eastern, from Greece	2nd–1st century BC
6	Mn-rich almandine	Intaglio, obverse highly convex, reverse flat, engraved with Eros standing on and holding the reins of a flying butterfly. Inv. no. 83.AN.256.7 (11.4×7.7×4.9 mm). Spier (1992), p. 91, no. 214. Bequest of Eli Djeddah.	Hellenistic; Eastern	2nd–1st century BC
7	Mn-rich almandine	Intaglio, obverse highly convex, reverse flat, engraved female comic mask. Inv. no. 84.AN.1.53 (8.5×6.5×3.9 mm). Spier (1992), p. 92, no. 216.	Hellenistic; Eastern	2nd–1st century BC
8	Ca-rich almandine	Oval intaglio, obverse flat, reverse convex, engraved with head of Dionysos wearing an ivy wreath. Inv. no. 85.AN.444.22 (16.0×13.0×4.4 mm). Spier (1989), no. 48, 29, 33, fig. 31; Spier (1992), p. 21, no. 21; Plantzos (1999), pp 81, 125, no. 349, pl. 53. Gift of Jonathan H. Kagan.	Hellenistic (Ptolemaic); from Iran	Late 2nd–1st century BC
9	Ca-rich almandine	Oval intaglio ring-stone, obverse slightly convex, reverse slightly concave, mounted in a thin gold wire setting, possibly from a ring; engraved with bust of Hermes wearing a petasos. Inv. no. 83.AN.437.28 (8.1×6.8×2.7 mm). Spier (1992), p. 92, no. 217. Gift of Damon Mezzacappa and Jonathan H. Kagan.	Hellenistic; from Asia Minor	1st century BC
10	Intermediate almandine-rich pyrope-almandine	Intaglio, obverse flat, reverse convex, engraved with Minerva seated, holding a branch and sceptre; a shield is at her feet. Inv. no. 82.AN.162.90 (16.1×12.6×4.9 mm). Unpublished. Gift of Stanley Ungar.	Roman Imperial	1st century BC – 1st century AD
11	Cr-poor pyrope	Cameo carving of head of Eros, circled by a ridge or plaque. Inv. no. 83.AN.437.42 (11.7×9.5×5.5 mm). Spier (1992), p. 157, no. 434. Gift of Damon Mezzacappa and Jonathan H. Kagan.	Roman Imperial; from Asia Minor	1st century AD

Figure 3: Ten of the 11 garnet intaglios and cameos in the Getty Museum's Villa Collection are the products of Greek and Roman Imperial workshops. Top: a pyrope-almandine cameo (gem no. 2) and five almandine intaglios with high convex oval or 'carbuncle' shapes (nos. 6, 5, 4, 7 and 3). Bottom: a small round almandine intaglio encircled in a gold hoop (no. 9), an asteriated pyrope-almandine intaglio (no. 10), an almandine intaglio (no. 8) and a pyrope cameo (no. 11). The gems range in dimensions from 8.1×6.8 mm (no. 9) to 21.9×11.7 mm (no. 3). The J. Paul Getty Museum, Villa Collection, Malibu, California. Photo by Harold and Erica Van Pelt.

Gemmological and chemical study of ancient garnets from the J. Paul Getty Museum

Samples

Eleven garnet intaglios and cameos from the J. Paul Getty Museum, Villa Collection, were studied (*Figures 3* and *4*). The objects are catalogued in *Table I* and consist of one Etruscan scarab (late 4th–3rd century BC), a Hellenistic group of one cameo and seven intaglios (3rd–1st century BC), and a Roman group of one intaglio and one cameo (1st century BC – 1st century AD). Detailed descriptions of all these carved gems, except no. 10, were published by Boardman (1975), Spier (1989, 1992) and Plantzos (1999).

Methods

Electron microprobe analysis was performed on all 11 garnets at the Division of Geology and Planetary Sciences, California Institute of Technology, Pasadena, California. For this technique, a specimen must be stable in a 10^{-5} torr vacuum environment. Typically, garnets are durable and subjecting them to vacuum in a microprobe poses no special risk. Fractured stones, however, should not be subjected to vacuum.

The gems were mounted with Elmer's brand white glue in specially machined brass templates with die-cut bevelled apertures of various sizes. A reasonably flat, polished surface was located on each specimen and positioned on the masking plate over an aperture of appropriate size. Four intaglios could be mounted on a single template. A carbon coating with a thickness of about 225 Å was deposited over the exposed gem surfaces in a carbon evaporator. After analysis,

Figure 4: Gem no. 1, a pyrope (13.3×9.4 mm), is the earliest dated and only Etruscan gem in the present study. It is carved in the form of a scarab, with a flat side that contains an engraving of a helmeted head in profile. It appears opaque black in reflected light and red in strong transmitted light. While the scarab shape is characteristic of Etruscan glyptic, the use of garnet as a carving material is rare. The J. Paul Getty Museum, Villa Collection, Malibu. Composite photo by Ellen Rosenbery.

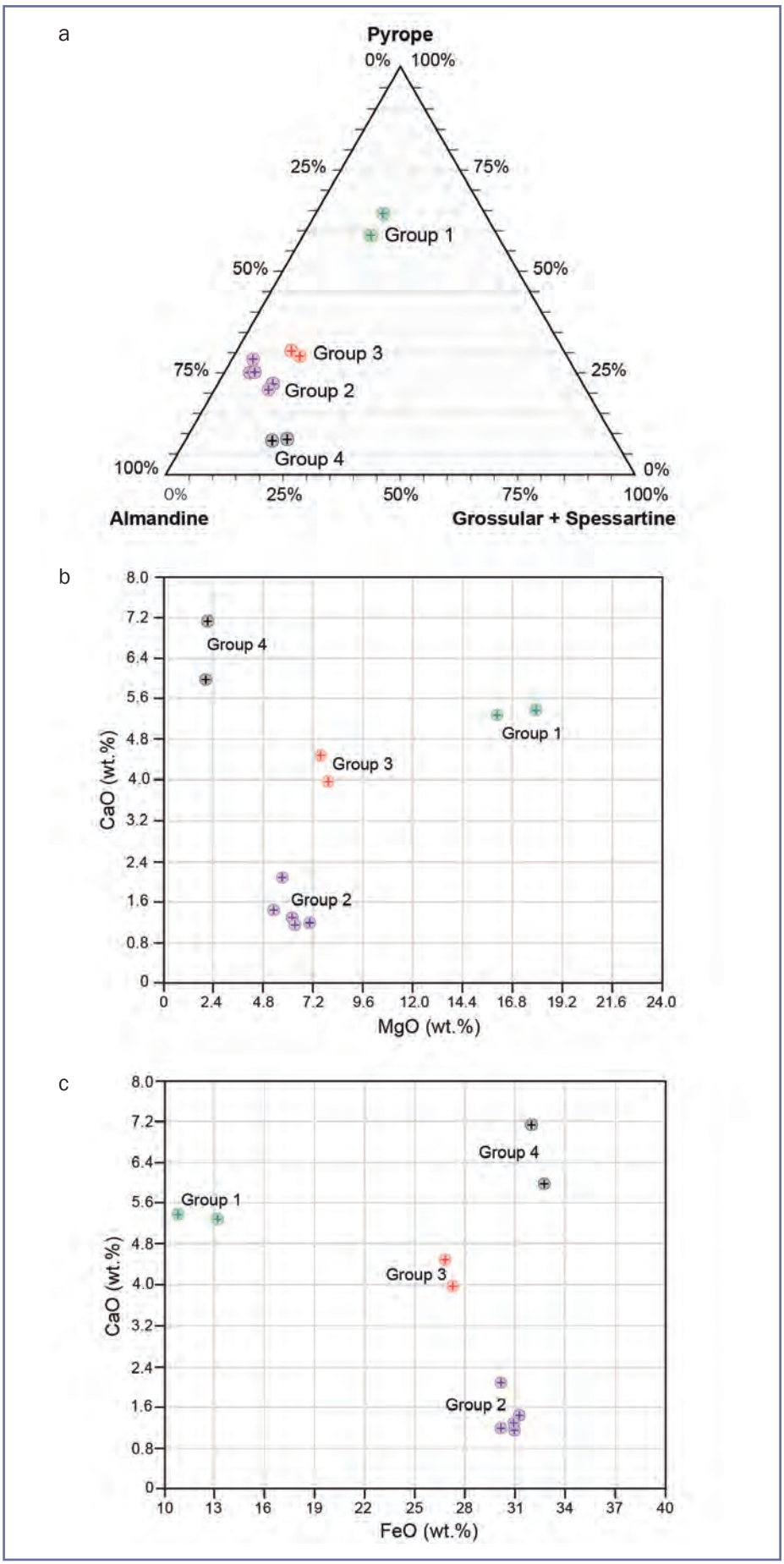

Figure 5: Compositional plots of 11 Etruscan, Greek and Roman garnets from the J. Paul Getty Museum, Villa Collection: (a) ternary diagram of end member compositions; (b) binary MgO–CaO diagram; (c) binary FeO–CaO diagram. The 11 garnets are subdivided into four groups according to their chemical composition: Cr-poor pyrope (Group 1), Mn-rich almandine (Group 2), intermediate pyrope-almandine (Group 3), and Ca-rich almandine (Group 4).

soaking the mounted garnets in warm water easily removed the white glue and the carbon coating was cleaned from the flat, polished surfaces by swabbing with ethanol. (Removal of the carbon from porous or engraved areas can be difficult, so coating of these areas was avoided.)

In successive runs, each template holding the mounted and coated garnets was placed in the chamber of a JEOL JXA-733 electron microprobe. This instrument was equipped with five wavelength-dispersive spectrometers, a Tracor Northern TN-5600 energy-dispersive spectrometer and a TN-5000 X-ray analyser. Surface-reaching inclusions in several of the garnets were identified using the energy-dispersive system of the microprobe.

The microprobe analyses were performed using well-characterized oxide and mineral standards, with a 15 keV accelerating voltage and 25 nA probe current. At least two sample sites on each gem were analysed and then averaged. Data correction was accomplished using CITZAF software. Total iron was taken as FeO, because the electron microprobe cannot discriminate the valence state of Fe^{2+} from Fe^{3+}. The detection limit of trace elements in the garnets was approximately 100 parts per million by weight. The proportion of end-member molecules was calculated from the chemical analyses using the methods of Rickwood (1968) and Locock (2008). However, because the calculated andradite components are very small and the measured Cr contents are low (if present at all), for the simplicity of the discussion we present the composition only as the four dominant end members pyrope, grossular, spessartine and almandine.

Physical and spectroscopic properties were determined using classical gemmological techniques or calculated from chemical composition. Densities for most samples were measured by hydrostatic weighing. However, the density for gem no. 1, the Etruscan scarab, was calculated because undercuts in the carving and the presence of a drill hole made the evacuation of air difficult. Density was also calculated for gem no. 9 because it was mounted in a gold hoop. Density calculations were performed after the method of Skinner (1956), using the percentages of the four end members shown in *Table II* and the physical constants of pure synthetic garnet end members. RI data were obtained using a refractometer and represent average values from measurements made independently by three gemmologists. Due to the poor polish and curved surfaces of some of the gems, RI values could only be measured to the hundredths. All stones were observed with a binocular gemmological microscope and a Beck prism spectroscope.

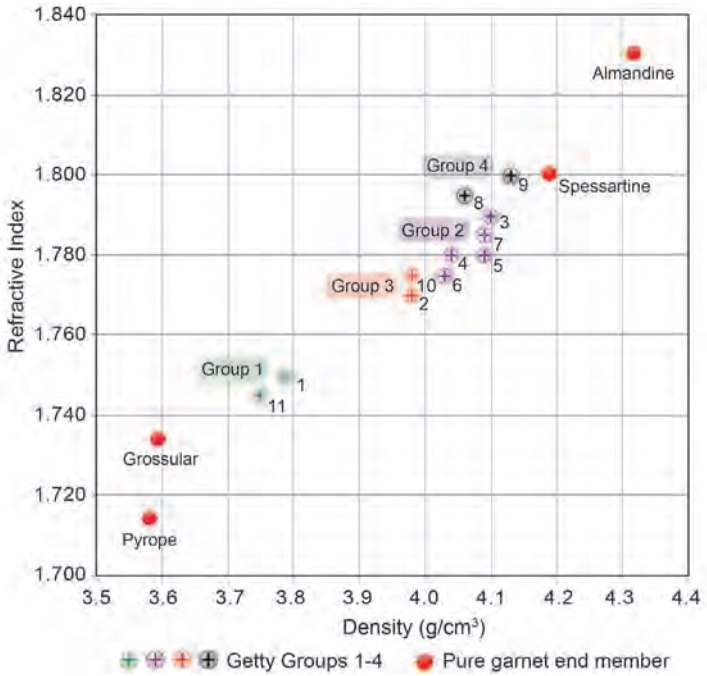

Figure 6: Refractive index versus density of the 11 Getty Museum garnets. The individual data are given in Table III*, and values for some pure end members of the garnet solid-solution series are also depicted. The values for both density and refractive index increase from Cr-poor pyrope (Group 1), to intermediate pyrope-almandine (Group 3) and Mn-rich almandine (Group 2), to Ca-rich almandine (Group 4).*

Chemical composition and molecular percentages of end members

The compositional range of the 11 Getty Museum garnets *(Table II)* shows they are members of the pyrope-almandine solid-solution series. Two of the garnets are pyrope, each containing 14% grossular and 1% spessartine. Nine garnets are almandine, containing 3–20% grossular and 1–7% spessartine. Compositional plots *(Figure 5)* show distinct separation between the pyrope (Group 1) and the various Fe-rich almandine samples, which can be subdivided into three groups described as Mn-rich almandine (Group 2), intermediate pyrope-almandine (Group 3) and Ca-rich almandine (Group 4).

Gemmological characteristics

The physical properties of the Getty Museum garnets, including RI, density, colour and internal features, are presented in *Table III*. A plot of density vs. RI *(Figure 6)* again shows the clear separation of pyrope (Group 1) from almandine (Groups 2 and 4) and the corresponding increase in both values with greater almandine content. The two intermediate pyrope-almandine samples (Group 3) have slightly lower RI and density values than the almandines of Groups 2 and 4.

The two Group 1 pyropes are dark coloured with internal features that are difficult to resolve, even with strong transmitted illumination. The Roman gem

Table II. Electron microprobe analysis and percentages of end members calculated for 11 ancient garnets in the J. Paul Getty Museum, Villa Collection.

Group	Group 1 Pyrope		Group 2 Mn-bearing almandine					Group 3 Intermediate pyrope-almandine		Group 4 Ca-rich almandine	
Oxide (wt.%) / Gem no.	1	11	3	4	5	6	7	2	10	8	9
P_2O_5	0.04	0.02	0.03	0.08	0.15	0.11	0.08	0.03	0.02	0.05	0.03
SiO_2	42.10	43.00	38.51	39.10	37.96	38.78	38.85	39.81	39.82	38.03	37.90
TiO_2	0.45	0.37	nd[a]	0.03	0.02	0.03	0.02	nd	0.02	0.04	0.05
Al_2O_3	23.51	24.06	22.00	22.29	21.53	21.96	22.19	22.57	22.63	21.53	21.40
V_2O_3	nd	0.02	nd	nd	nd	0.03	0.01	0.02	nd	0.03	0.01
Cr_2O_3	nd	0.03	nd	nd	nd	0.01	nd	nd	nd	nd	nd
FeO[b]	13.20	10.82	31.23	30.14	30.90	30.97	30.14	27.25	26.77	31.98	32.74
MnO	0.36	0.31	3.42	0.42	0.61	1.35	2.58	0.34	0.81	0.67	0.54
ZnO	nd	0.01	0.02	0.01	0.02	0.05	0.02	0.04	0.02	0.02	0.01
MgO	16.05	17.91	5.32	7.03	6.18	6.32	5.70	7.93	7.55	2.16	2.03
CaO	5.27	5.37	1.44	1.19	1.29	1.14	2.08	3.96	4.48	7.12	5.97
Na_2O	0.06	0.02	0.02	0.08	0.12	0.11	0.07	0.03	0.01	0.04	0.04
Total[c]	**101.06**	**101.94**	**102.03**	**100.37**	**98.80**	**100.85**	**101.72**	**101.98**	**102.13**	**101.68**	**100.73**
Cations per 12 oxygens											
P	0.002	0.001	0.002	0.005	0.010	0.007	0.005	0.002	0.001	0.003	0.002
Si	3.016	3.018	2.990	3.023	3.008	3.011	3.002	3.008	3.008	2.992	3.008
Sum Z	**3.018**	**3.019**	**2.992**	**3.028**	**3.018**	**3.018**	**3.007**	**3.010**	**3.009**	**2.995**	**3.010**
Ti	0.024	0.020	nd	0.001	0.001	0.001	0.001	nd	0.001	0.002	0.004
Al	1.985	1.990	2.013	2.031	2.011	2.010	2.020	2.010	2.014	1.996	1.998
V	nd	0.001	nd	nd	nd	0.002	0.001	0.001	nd	0.002	0.002
Cr	nd	0.002	nd	nd	nd	0.001	nd	nd	nd	nd	nd
Sum Y	**2.009**	**2.013**	**2.013**	**2.032**	**2.012**	**2.014**	**2.022**	**2.011**	**2.015**	**2.000**	**2.004**
Fe	0.791	0.635	2.028	1.949	2.048	2.011	1.947	1.722	1.691	2.104	2.173
Mn	0.022	0.019	0.225	0.027	0.041	0.089	0.169	0.022	0.052	0.045	0.034
Zn	nd	0.001	0.001	0.001	0.001	0.003	0.001	0.002	0.001	0.001	0.001
Mg	1.714	1.874	0.616	0.811	0.730	0.732	0.657	0.893	0.851	0.254	0.242
Ca	0.404	0.404	0.120	0.099	0.110	0.095	0.172	0.321	0.363	0.600	0.520
Na	0.009	0.003	0.003	0.012	0.019	0.017	0.010	0.004	0.001	0.006	0.007
Sum X	**2.940**	**2.936**	**2.993**	**2.899**	**2.949**	**2.947**	**2.956**	**2.964**	**2.959**	**3.010**	**2.977**
End member percentages[d]											
Pyrope	58.49	63.91	20.60	28.09	24.92	25.01	22.30	30.19	28.78	8.45	8.16
Grossular	13.79	13.79	4.02	3.42	3.74	3.24	5.84	10.84	12.28	19.98	17.51
Spessartine	0.75	0.63	7.52	0.95	1.41	3.03	5.73	0.75	1.74	1.50	1.14
Almandine	26.97	21.67	67.86	67.54	69.93	68.72	66.13	58.22	57.20	70.07	73.19

[a] Abbreviation: nd = not detected.

[b] Total iron as FeO.

[c] Slightly high totals for some analyses are due to the fact that the ancient garnets did not have perfectly flat polished surfaces that could be oriented exactly perpendicular to the electron beam. Nevertheless, the sum of cations at the X, Y and Z sites indicates that all of the analyses are of high quality.

[d] Percentages of end members were calculated as the four end-members pyrope ($Mg_3Al_2Si_3O_{12}$), grossular ($Ca_3Al_2Si_3O_{12}$), spessartine ($Mn_3Al_2Si_3O_{12}$) and almandine ($Fe^{2+}_3Al_2Si_3O_{12}$). The end members uvarovite ($Ca_3Cr_2Si_3O_{12}$), andradite ($Ca_3Fe^{3+}_2Si_3O_{12}$), and knorringite ($Mg_3Cr_2Si_3O_{12}$) were not included because the amounts were negligible.

Table III: Gemmological properties of 11 ancient garnets from the J. Paul Getty Museum, Villa Collection.

Gem no.	RI	D (g/cm^3)	Colour and diaphaneity	Internal features
Group 1: Cr-poor pyrope ($Py_{58-64}Gro_{14}Sp_1Alm_{22-27}$)				
1	1.75	3.79 (calc.)	Very dark red, nearly black in reflected light; semitransparent	Difficult to resolve, due to the stone's dark colour and roiled internal appearance
11	1.745	3.75	Dark orange-brown to reddish brown; thinner parts of carving around edges appear yellowish brown in transmitted light; semitransparent	Roiled appearance; fractures in front surface, in the right cheek, and across back of the plaque; and scattered, fine tubes (some curved or bent), tapering to a point into the body of the stone
Group 2: Mn-rich almandine ($Py_{21-28}Gro_{3-6}Sp_{1-8}Alm_{66-70}$)				
3	1.79	4.10	Vivid reddish purple; transparent	Numerous transparent crystals (zircon and/or monazite), some with colour zoning, some with brown strain halos; irregularly shaped transparent colourless crystals (probably quartz), which, in turn, contain opaque black inclusions; metamict zircon* crystals; angular transparent inclusions (possibly quartz); rutile needles oriented at 70° and 110°; small transparent rods with rounded ends (probably apatite); and long, curved transparent colourless crystals (probably sillimanite)
4	1.78	4.04	Medium to dark reddish purple; transparent	Strong ADR; transparent zircon(?) and monazite* crystals with strain halos; irregularly shaped two-phase inclusions arranged in a plane; angular transparent inclusions, probably quartz; rutile needles oriented at 70° and 110°; and small transparent rods with rounded ends, probably apatite
5	1.78	4.09	Medium to dark reddish purple; transparent	Strong ADR; numerous zircon* crystals with strain halos; transparent colourless crystals with strain halos, possibly monazite and/or zircon; rutile needles oriented at 70° and 110°; small transparent rods with rounded ends, probably apatite; long, curved transparent crystals, probably sillimanite; numerous large, irregularly shaped transparent crystals, probably quartz; large, irregularly shaped black inclusions of ilmenite, some flat; high-relief crystals (rutile?); opaque black crystals (rutile or ilmenite?); transparent colourless crystals containing unidentified inclusions, some agglomerated in masses of opaque black crystals of corroded ilmenite; and a stained fracture
6	1.775	4.03	Medium to dark reddish purple; transparent	Numerous stained fractures; zircon(?) and brownish stained, transparent monazite* crystals; and quartz*, including numerous aggregates of irregularly shaped transparent crystals
7	1.785	4.09	Vivid pinkish purple; transparent	Few inclusions overall; transparent crystals of zircon and monazite with strain halos; metamict zircons*; a fracture; and several transparent stubby, rod-shaped crystals with rounded ends, probably apatite
Group 3: Intermediate pyrope-almandine ($Py_{29-30}Gro_{11-12}Sp_{1-2}Alm_{57-58}$)				
2	1.77	3.98	Light red-purple, with very slight brownish/ greyish cast and flashes of orange when turned under a light; transparent	Stained micaceous flakes; irregularly shaped transparent colourless crystals, probably quartz, included with opaque black corroded crystals, probably ilmenite; rutile with a cottony/silky appearance; dashes and dots; small transparent rods with rounded ends, probably apatite; several transparent crystals of zircon and/or monazite, surrounded by strain halos; a fracture; and surface-reaching, blocky black inclusions, probably rutile or ilmenite
10	1.775	3.98	Reddish orange with brownish purple cast; semitransparent	Turbid, zoned, heavily fractured and asteriated; corroded, opaque black inclusions of various sizes; stained fractures; flat, irregularly shaped, transparent, colourless crystals, probably quartz, included with black corroded crystals, probably ilmenite; zircon*; transparent crystals intersecting irregularly shaped opaque black inclusions; a dense arrangement of short rutile needles with a silky appearance; dots and dashes; and numerous minute micaceous flakes scattered throughout
Group 4: Ca-rich almandine ($Py_8Gro_{17-20}Sp_1Alm_{70-73}$)				
8	1.795	4.06	Medium to dark brownish red; semitransparent	Numerous partially healed fractures and wispy, minute two-phase inclusions arranged in stained planes; and several zircon crystals surrounded by tension haloes
9	1.80	4.13 (calc.)	Medium orange-brown; transparent	Partially healed fractures, stained and showing high relief; tattered micaceous(?) flakes and blocky and irregularly shaped, opaque black inclusions, variable in size; and minute inclusions (some appear two-phase)

* This inclusion was identified by energy-dispersive spectroscopy; otherwise inclusions were identified visually and not confirmed by analytical instrumentation.

(no. 11) appears yellowish brown around the edges where it is thin — a feature sometimes observed in pyrope *(Figure 7)*. It contains fine tubes that terminate in tapered points *(Figure 8)*.

The five Hellenistic intaglios comprising Group 2 (Mn-rich almandine) all exhibit the vivid, saturated reddish purple to purple colour *(Figure 9)* that is typically associated with rhodolite or 'Grape garnet'. However, they show a compositional range and physical properties that are different from rhodolite (i.e., pyrope-almandine: Stockton and Manson, 1985; Webster, 1994; Lind *et al.*, 1998; Hanneman, 2000; Adamo *et al.*, 2007). All five of the ancient gems have relatively high RI and density values due to their large almandine component. Gem nos. 3 and 7 are the two brightest stones in Group 2. They also have the greatest spessartine content of all the garnets studied, at 7.5 and 5.7 mol%, respectively *(Table II)*. Gem nos. 4, 5, and 6 have a more turbid appearance and all show a darker, more purple hue. The inclusions exposed at the surface of the Group 2 garnets were identified using EDS as quartz, zircon, metamict zircon (in which radioactive elements were detected) and monazite (*Figures 10–12)*.

Tension halos surround both zircon and monazite crystallites *(Figures 10a–c)*. Some of these halos are stained brown, as expected for those surrounding monazite (J.I. Koivula, pers. comm., 2013). Other internal features include oriented rutile needles *(Figure 10d)* and irregularly shaped quartz *(Figures 11* and *12)*. Additional inclusions that were identified by their visual appearance include apatite rods *(Figure 12)*; long, slender sillimanite with a fibrous or tubular appearance *(Figure 13)*; transparent crystals (quartz and/or apatite) agglomerated with opaque black material, possibly decomposed ilmenite *(Figure 14)*; and ilmenite *(Figure 15)*.

The two intermediate pyrope-almandines of Group 3 (gem nos. 2 and 10; *Figures 16* and *17*) are very close in chemical composition, RI and density *(Tables II* and *III)*. However, they are quite different in appearance and belong to different periods of production. Gem

Figure 7: Gem no. 11 (11.7×9.5 mm) is a Roman pyrope cameo encircled by a flat plaque; it is semitransparent and dark orange-brown to reddish brown. The front-facing head of Eros was a popular motif carved in garnets and other gems during the Roman Imperial era. The J. Paul Getty Museum, Villa Collection, Malibu, California, gift of Damon Mezzacappa and Jonathan H. Kagan. Photo by Ellen Rosenbery.

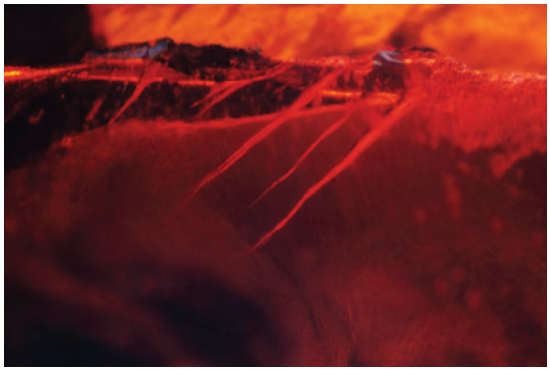

Figure 8: Fine tubes originating at a surface-reaching fracture taper into the body of gem no. 11, a Roman pyrope cameo carving. Photomicrograph by Lisbet Thoresen; magnified 50×.

Figure 9: These five almandine intaglios, representing the Getty Group 2 garnets, all share very similar optical properties, chemical composition and a saturated reddish purple to purple colour. They are cut en cabochon *with the engraved sides highly convex. The shapes of the stones and the subjects depicted are characteristic signatures of Hellenistic glyptic. Clockwise from left: gem nos. 3 (21.9×11.7 mm), 7, 4, 6 and 5. The J. Paul Getty Museum, Villa Collection. Photo by Ellen Rosenbery.*

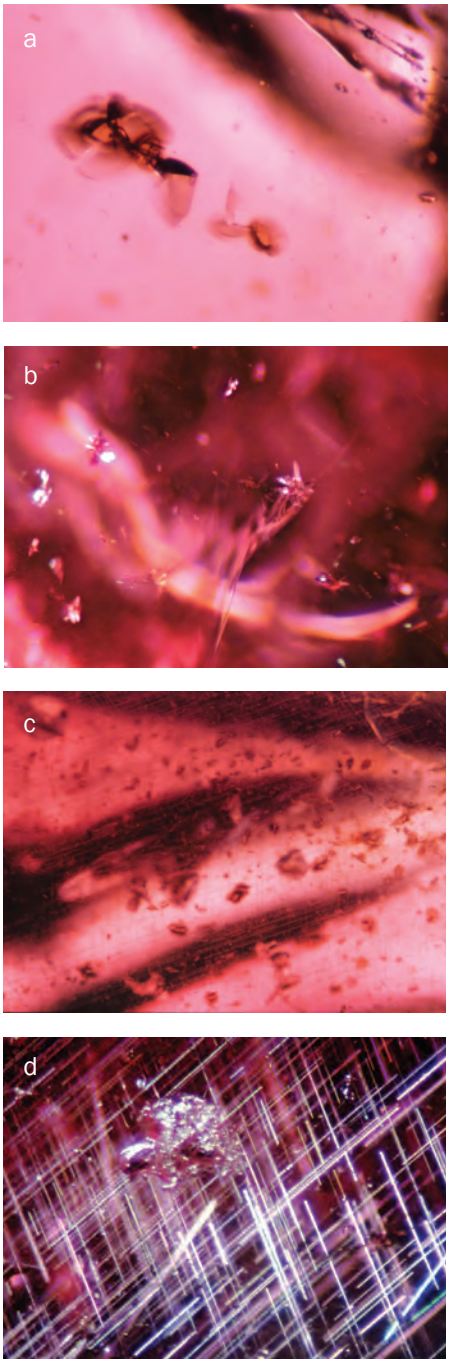

Figure 10: (a) Tension halos around zircon inclusions (here, in gem no. 4).
(b) Scattered zircon crystals surrounded by tension halos (here, gem no. 7).
(c) Monazite inclusions with brown-stained strain halos, visible against a background of oriented fine rutile needles in gem no. 4.
(d) Radioactive elements contained in its crystal lattice caused this metamict zircon crystal to rupture in its almandine host (gem no. 3). In the background, acicular crystals of rutile are oriented in two directions, forming angles of 70.5° and 109.5°.
Photomicrographs by John I. Koivula; magnified 85× (a), 52× (b), 63× (c) and 50× (d).

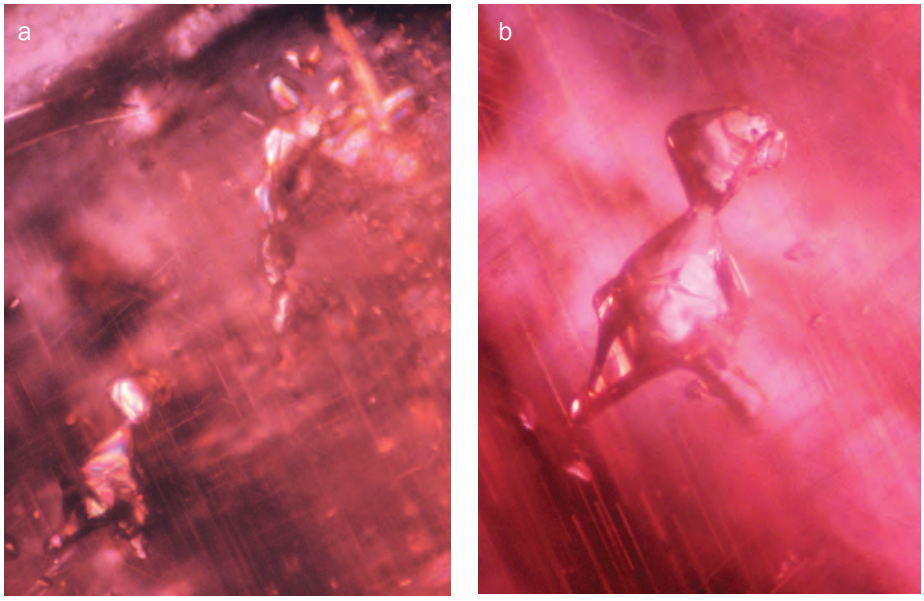

Figure 11: Relatively large, blocky crystal inclusions of irregular shape in the garnets are often quartz, as in these images of gem no. 5. Viewed with crossed polarizing filters (a), the inclusions exhibit spectral colours. Photomicrographs by Lisbet Thoresen (a, magnified 50×) and John I. Koivula (b, magnified 110×).

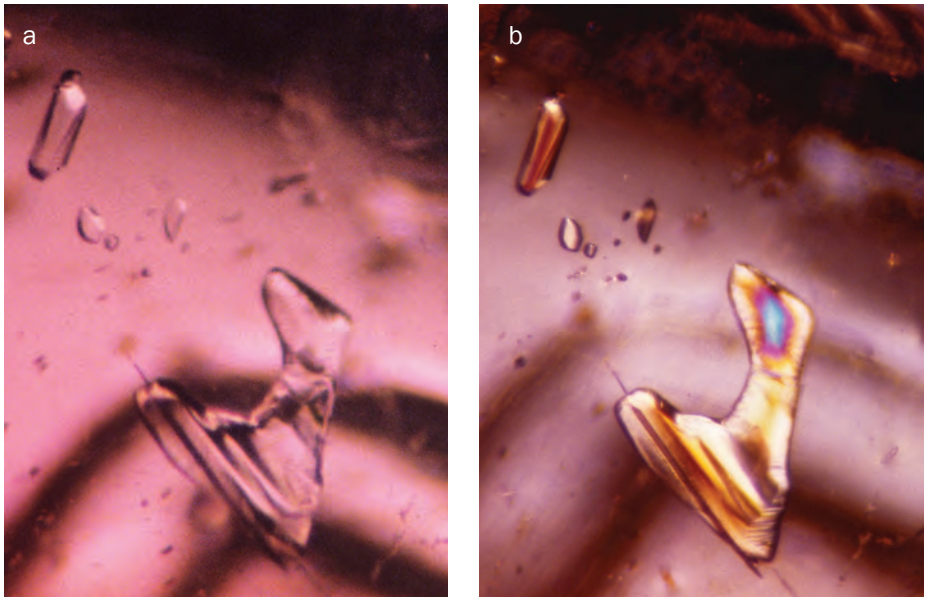

Figure 12: The transparent rod-shaped inclusion (at top left) observed in almandine gem no. 4 under plane polarized light (a) and crossed polarizers (b) appears to be apatite. Also seen is a large irregularly shaped crystal, probably quartz, with a rutile needle captured along its lower edge. Photomicrographs by John I. Koivula and Lisbet Thoresen; magnified 50×.

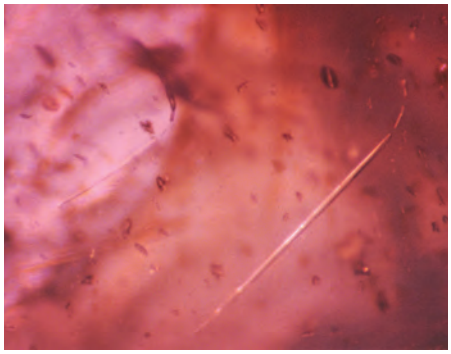

Figure 13: Slender tubular-shaped inclusions, both curved and straight, such as the one seen here in gem no. 5 (magnified 46×) were observed in several of the Group 2 almandines. They are probably sillimanite. Also present are monazite inclusions hovering in the background. Photomicrograph by Lisbet Thoresen.

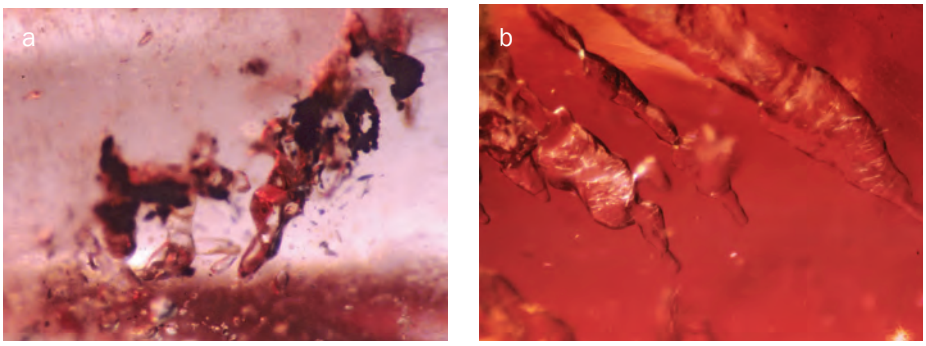

Figure 14: (a) Irregularly shaped, high-relief crystals, probably quartz with opaque black inclusions (ilmenite and/or rutile?), like the ones seen here in gem no. 10, are typical of several of the Groups 2 and 3 garnets. (b) Large irregularly shaped transparent crystals (probably quartz) contain randomly oriented inclusions having the appearance of small fibres or rods, seen here in gem no. 10. Photomicrographs by Lisbet Thoresen (a, magnified 30×) and John I. Koivula (b, magnified 65×).

Figure 15: Irregularly shaped opaque black inclusions (ilmenite?), such as the one seen here in gem no. 5, can be observed in several Group 2 and 3 garnets. Photomicrograph by John I. Koivula; magnified 40×.

no. 2 is a Hellenistic cameo portrait of a Ptolemaic queen that exhibits lower saturation and brightness than the Group 2 almandines, but its appearance is otherwise very similar to gem nos. 3 and 7. It is relatively clean internally and contains inclusions similar to those seen in the Group 2 garnets. Gem no. 10 is a Roman intaglio that appears turbid and is predominantly reddish orange with a brownish purple cast. It is unique among the Getty Museum garnets for its colour and moderate asterism caused by a dense arrangement of silky rutile. Other internal features include transparent blocky crystals with black material (possibly decomposed ilmenite, *Figure 14a*), and several large irregularly shaped crystals (probably quartz) that in turn contain inclusions resembling stubby rods or thick fibres *(Figure 14b)*.

Figure 16 (left): Portrait bust, probably Queen Arsinoë II (d. 270 BC), the deified sister-wife of Ptolemy II. This fine cameo (gem no. 2, 19.1×12.9 mm) was cut from a large piece of pyrope-almandine of exceptional clarity. It has a light red-purple colour that weakly flashes an orange hue when turned under a light. The J. Paul Getty Museum, Villa Collection. Photo by Ellen Rosenbery.

Figure 17: An early Roman Imperial intaglio (gem no. 10, 16.1×12.6 mm) depicting the goddess Minerva seated and facing front, engraved in the flat side of an asteriated pyrope-almandine cabochon. The J. Paul Getty Museum, Villa Collection, gift of Stanley Ungar. Photo by Ellen Rosenbery.

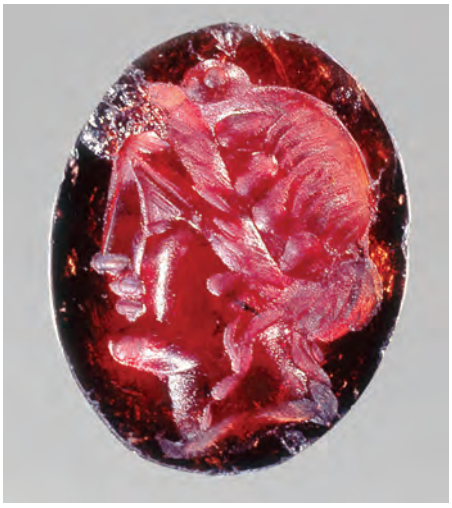

Figure 18 (left): The Hellenistic Group 4 almandines include a Ptolemaic (2nd–1st century BC) intaglio engraved with the profile head of Dionysos (gem no. 8, 16.0×13.0 mm) on the flat face, from Iran. The J. Paul Getty Museum, Villa Collection, gift of Jonathan H. Kagan. Photo by Ellen Rosenbery.

Figure 19: A late Hellenistic (1st century BC) ring-stone mounted in a gold hoop depicting a profile bust of Hermes (gem no. 9, 8.1×6.8 mm), from Asia Minor. The J. Paul Getty Museum, Villa Collection, gift of Damon Mezzacappa and Jonathan H. Kagan. Photo by Ellen Rosenbery.

The two Ca-rich almandines of Group 4, both Hellenistic intaglios (gem nos. 8 and 9; *Figures 18* and *19*), are characterized by significant grossular components of 20 and 17.5 mol%, respectively. They have the greatest almandine components of the Getty Museum garnets — above 70% — so their RI and density values are correspondingly high *(Table III)*. Gem no. 8 is semitransparent and medium to dark brownish red, while no. 9 is medium orange-brown and transparent. Both gems contain high-relief partially healed fractures, but the latter stone also contains blocky, irregularly shaped black inclusions, as well as micaceous(?) flakes. These intaglios belong to two different periods of manufacture and have no typological association, but they are both purported to be of eastern origin (i.e., Iran and Asia Minor).

Spectroscopic properties

Optical spectra of the Getty Museum garnets are illustrated in *Figure 20*. Both pyropes of Group 1 show strong absorption through most of the visible range in the spectroscope, and individual absorption bands are difficult to resolve. All garnets of Groups 2–4 show a clear line spectrum consisting of four absorption bands: A at 610 nm, B in the range between 570 and 590 nm, C

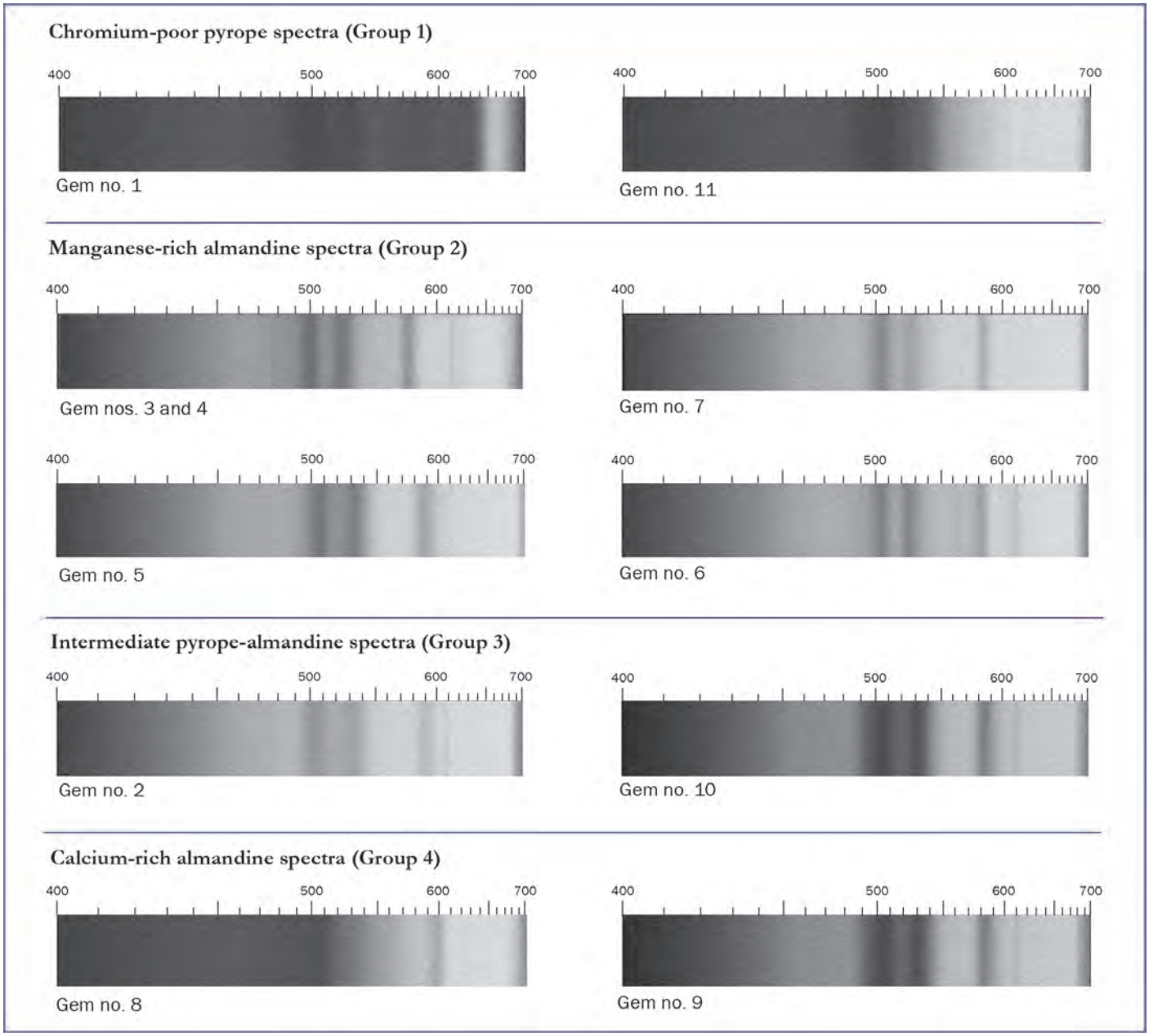

Figure 20: Optical spectra of the 11 garnets in the J. Paul Getty Museum, Villa Collection. The Group 1 pyropes show strong absorption through most of the visible range, while the Groups 2–4 garnets show a clear line spectrum consisting of four absorption bands assigned to bivalent iron (Fe^{2+}) in the garnet structure.

Table IV: Description of 26 Greek and Roman garnets analysed in five studies.

Gem no.	Identification	Description[a]	Culture / period
Antikensammlung, Staatliche Museen zu Berlin (Formigli and Heilmeyer, 1990), electron microprobe analysis			
12, 13	Cr-poor pyrope	Two inlays in a Herakles knot centrepiece belonging to a gold and garnet chain necklace *(Figure 1)*; no. 1980.17	Hellenistic, 230–210 BC; all belong to a jewellery hoard from a tomb in Taranto, southern Italy (excavated *ca.* 1900)
14	Cr-poor pyrope	One garnet carved in the form of a chain link in a gold and garnet chain necklace (with Herakles knot centrepiece; *Figure 1*); no. 1980.17	
15	Cr-poor pyrope	One small plain cabochon in a gold hairnet *(Figure 24)*; no. 1980.22	
Museum für Kunst und Gewerbe, Hamburg (Gartzke, 2004; Gartzke *et al.,* 2004), electron microprobe analysis			
16, 17 18, 19	Mn-rich almandine Mn-poor almandine	Two plain cabochons (7.0×6.0 and 9.5×8.0 mm) Two small beads (All set in a gold earring, no. 1918.58; *Figure 22a*)	Hellenistic, 3rd–1st century BC; although manufactured at different times, all belong to a jewellery hoard from a tomb at Palaiokastro in Thessaly, northern Greece (excavated 1909)
20, 21 22	Mn-rich almandine Mn-poor almandine	One plain cabochon and one small bead One small bead (All set in a gold earring, no. 1918.59; *Figure 22a*)	
23, 24, 25 26	Ca-rich almandine Cr-poor pyrope	Three small beads One small bead (All set in a gold earring, no. 1918.60; *Figure 22b*)	
27	Ca-rich almandine	One plain cabochon (9.8×7.7 mm) set in a gold mount; no. 1917.206	
28	Ca-rich almandine	One plain cabochon (14.4×11.6 mm) set in a gold mount; no. 1918.63	
29	Intermediate almandine-rich pyrope-almandine	One plain cabochon (11.0×8.5 mm) set in a gold mount; no. 1917.205	
Benaki Museum, Athens (Pappalardo *et al.,* 2005), PIXE combined with XRF analysis[b]			
30	Ca-rich almandine	One inlay in a gold diadem; no. 1548	Hellenistic, early 2nd century BC; from Thessaly, northern Greece
31	Cr-poor pyrope	One large oval cabochon engraved with Nike driving a biga, set in a gold finger ring; no. 1551	Hellenistic, *ca.* 200 BC; from Thessaly, northern Greece
Museo Palatino, Rome (Gliozzo *et al.,* 2011), PIXE analysis			
32	Ca-rich almandine	One oval garnet (20×16×5 mm) engraved with a male head in profile surrounded by a taenia; no. 473579	Flavian, AD 69–96; from the Vigna Barberini at Palatine Hill, Rome (excavated 1985–1998)
Staatliche Antikensammlungen und Glyptothek, James Loeb Collection, Munich (Gilg and Gast, 2012), Raman spectroscopy combined with XRF analysis			
33	Cr-poor pyrope	One high-domed oval cabochon (12.0×7.7 mm) engraved with Eros standing in a three-quarter frontal pose and holding a lyre to the side, set in a gold finger ring; no. 632	Hellenistic, end 2nd/1st half of 1st century BC
34	Ca-rich almandine	One high-domed oval cabochon (15.6×11.8 mm) engraved with Tyche/Fortuna wearing a diadem, perhaps in the guise of the Ptolemaic Queen Kleopatra VII. She holds a rudder in the lowered right hand and a double cornucopia raised in the left, set in a gold finger ring; no. 636	Early Roman Imperial, 2nd half of 1st century BC
35	Ca-rich almandine	One oval cabochon (21.4×15.2 mm) engraved with symbolic iconography related to Apollo connoting support of Cassius and Brutus in the aftermath of Julius Caesar's assassination, set in a gold finger ring; no. 637	Roman Republican, 42 BC
36	Ca-rich almandine	One flat oval garnet (20.6×12.8 mm) engraved on the flat front with a thyrsos with fillets, set in a gold finger ring; no. 638	Early Roman Imperial, 2nd half of 1st century BC
37	Intermediate pyrope-rich pyrope-almandine	One plain round (*ca.* 9.9 mm) cabochon set in a gold finger ring; no. 630	Late Roman Empire, 3rd/4th century AD

[a] Only approximate dimensions are given for mounted gems, and no dimensions were reported for gem nos 12–15, 18–26 and 30–31.
[b] Specimen no. 1562 with 4.7 wt.% Na_2O was omitted.

in the range of 523–533 nm and D at 503 nm. All four bands are assigned to bivalent iron (Fe^{2+}) in the garnet structure, and no additional bands of bivalent manganese (Mn^{2+}) or trivalent iron (Fe^{3+}) are detectable. (For the assignment of iron and manganese bands in garnets, refer to Lind *et al.,* 1998, Schmetzer *et al.,* 2009 and the references therein.) These spectral features are consistent with the chemical analyses. While a prism spectroscope is useful for identifying garnets in general (e.g., in a museum setting), it is inadequate for differentiating pyrope-almandine garnets according to different types.

Comparison of chemical composition of Graeco-Roman and Early Medieval garnets

Only limited chemical data for garnets used in ancient glyptic are available presently from a total of 26 stones: 16 beads, inlays and small cabochons set in jewellery, four unengraved cabochons set in a finger ring and other gold mounts, five intaglios set in finger rings and one loose intaglio (Formigli and Heilmeyer, 1990; Gartzke, 2004; Gartzke *et al.,* 2004; Pappalardo *et al.,* 2005; Gliozzo *et al.,* 2011; Gilg and Gast, 2012). A description of these objects and their cultural attributions is given in *Table IV*.

Plots of chemical composition *(Figure 21)* show that the 26 carved gems from the published literature lie within similar compositional ranges as given for the 11 Getty Museum stones. It is difficult to clearly delineate the boundaries of distribution fields for the different groups, especially given the limited number (37) of analysed stones with properties that are so variable; however, the plots show that the compositional ranges of most of the garnets segregate into four different clusters:

- Cr-poor pyrope
- Mn-rich almandine

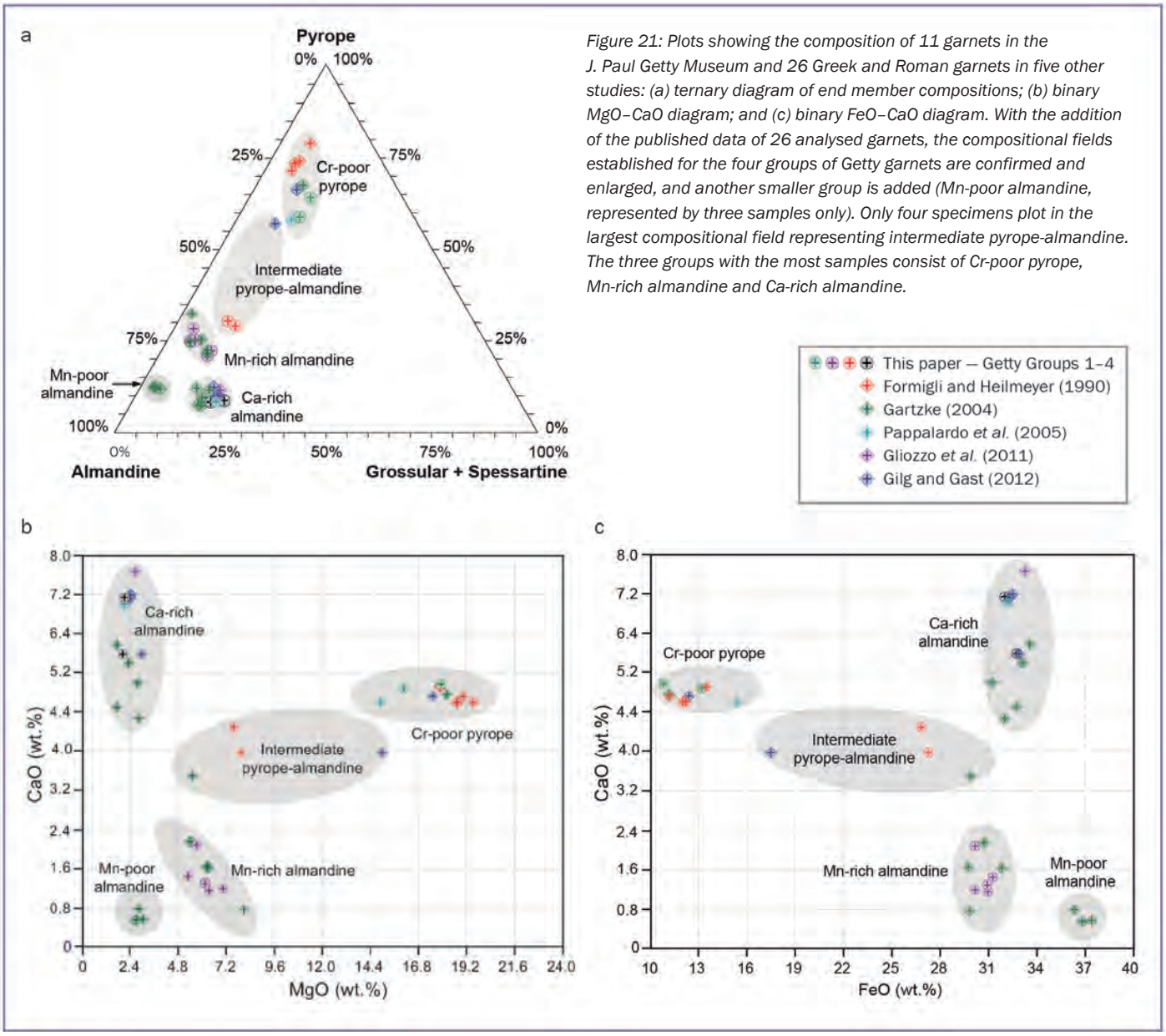

Figure 21: Plots showing the composition of 11 garnets in the J. Paul Getty Museum and 26 Greek and Roman garnets in five other studies: (a) ternary diagram of end member compositions; (b) binary MgO–CaO diagram; and (c) binary FeO–CaO diagram. With the addition of the published data of 26 analysed garnets, the compositional fields established for the four groups of Getty garnets are confirmed and enlarged, and another smaller group is added (Mn-poor almandine, represented by three samples only). Only four specimens plot in the largest compositional field representing intermediate pyrope-almandine. The three groups with the most samples consist of Cr-poor pyrope, Mn-rich almandine and Ca-rich almandine.

*Figure 22: Three earrings from a Hellenistic jewellery hoard found in a tomb at Palaiokastro in Thessaly, northern Greece. (a) Pair of gold earrings (approximately 8.1–8.2 cm long) adorned with two winged Erotes suspended between two chains, each terminating in a garnet bead and surmounted by bezel-set gems, including pearls and garnet cabochons (*Table IV*, nos. 16–22). The green stone was analysed by Gartzke (2004) and identified as Cr-bearing mica. (b) Single gold earring (10.2 cm long) adorned with garnets carved as small beads (*Table IV*, nos. 23–26) and suspended from chains, surmounted by a round plaque with a helmeted bust of Athena in gold repoussé. Courtesy of F. Hildebrandt, © Museum für Kunst und Gewerbe, Hamburg; photos by Maria Thrun.*

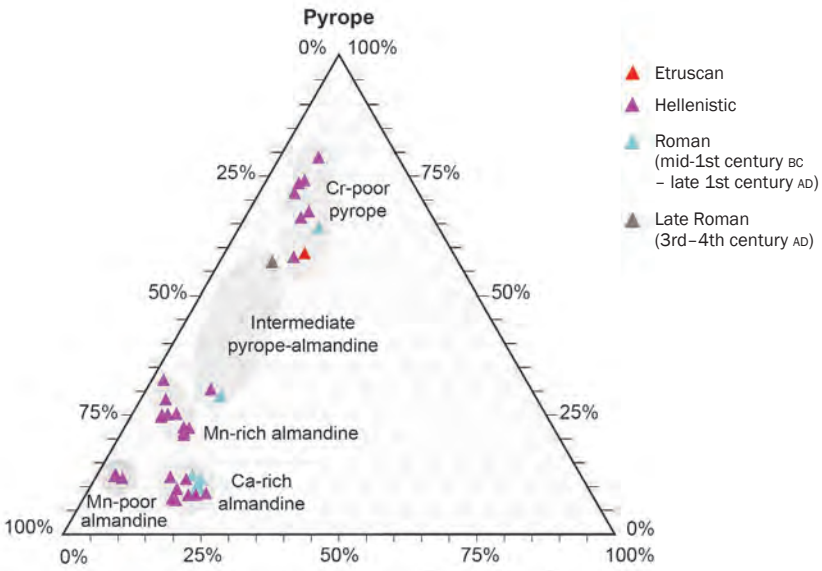

Figure 23: Ternary diagram of end-member compositions of 11 Greek, Etruscan and Roman garnets in the J. Paul Getty Museum and 26 ancient Greek and Roman garnets from the literature, relating compositions to different cultural attributions. The three largest-populated groups are represented by Cr-poor pyrope, Mn-rich almandine and Ca-rich almandine. Garnets of all different chemically separated groups were used in the Hellenistic era. Less heterogeneity of types is seen in the earlier-dated Roman garnets (late 1st century BC to late 1st century AD).

- Ca-rich almandine
- Intermediate pyrope-almandine

One additional field consists of Mn-poor almandine documented by Gartzke (2004), but such compositions were not found in the 11 Getty Museum stones. Stones in this field correspond to three small beads (nos. 18, 19 and 22 in *Table IV*) set in gold earrings from Palaiokastro, in Thessaly, northern Greece *(Figure 22)*. Most contain less Ca than the neighbouring group of Mn-rich almandine.

In the binary diagrams of *Figure 21*, the two Getty Group 3 intermediate pyrope-almandines plot near a mounted garnet cabochon (no. 29 in *Table IV*) analysed by Gartzke (2004). (Note that when plotting no. 29 in the ternary diagram, it overlaps the field of Mn-rich almandine as a result of calculating for [grossular+spessartine], while in the binary diagrams it clearly plots in the pyrope-almandine field. This underscores

the importance of gemmological properties and not only chemical composition for assigning the correct type/cluster/group.) A plain garnet cabochon set in a late Roman gold finger ring (no. 37 in *Table IV*; Gilg and Gast, 2012) also plots within the intermediate pyrope-almandine distribution field. These four garnet analyses are the only data of intermediate pyrope-almandine from the Greek and Roman era that have been published to date. However, in Merovingian cloisonné jewellery of the Early Medieval period, intermediate pyrope-almandine garnets with variable composition are common. In addition, several garnets dating to the Byzantine era (beginning in the 5th century AD) plot within this intermediate group (A. Gilg, pers. comm., 2013). Due to the variable composition of these garnets, it is evident that this heterogeneous group contains gems from different host rocks and/or origins.

The distribution of the ancient garnets having different cultural attributions *(Figure 23)* shows that garnets from all the groups were used in the Hellenistic era. Less heterogeneity of types is seen in the Roman garnets (mid-1st century BC to late 1st century AD). To date, the majority of garnets found within this era are Ca-rich almandine (represented by the two Getty Group 4 garnets and 12 others).

The data published by Gartzke (2004) and Gartzke *et al.* (2004) show that the Hellenistic garnets set in three earrings are different types of garnets and therefore did not originate from the same source. One pair of earrings *(Figure 22a)* contains several Mn-rich almandine cabochons and one small bead (nos. 16, 17, 20 and 21 in *Table IV*), in addition to three beads of Mn-poor almandine (nos. 18, 19 and 22 in *Table IV*). Suspended from gold tassels in a third earring *(Figure 22b)* are three small beads of Ca-rich almandine (nos. 23, 24 and 25 in *Table IV*) and one pyrope (no. 26 in *Table IV*). These observations of different types of garnets set within one item of jewellery are consistent with similar variability in numerous items of cloisonné metalwork containing garnet inlays produced in the Early Medieval period.

In contrast to the variable composition of the garnets in the Hellenistic gold jewellery belonging to the hoard from Palaiokastro in northern Greece, the garnets mounted in the gold necklace and hairnet belonging to the Hellenistic hoard from Taranto, Italy, appear to be homogeneous in composition (Formigli and Heilmeyer, 1990; *Figures 1* and *24*). Analyses performed on four stones characterized all of them as Cr-poor pyrope.

In *Figure 25*, the chemical compositions of earlier Greek and Roman garnets are compared against those of the Early Medieval garnets in the Calligaro *et al.* (2006–2007) study. The nomenclature of different 'types' or 'clusters' used by different researchers is shown in *Table V*. Two of the three main types of Greek and Roman garnets *(Figure 21)* plot within the distribution field of the garnets used in the Early Medieval period:

Figure 24: A Hellenistic gold hairnet with small pyrope cabochons (1.65–4.40 mm in diameter) from a jewellery hoard, dated 230–210 BC, found in ca. 1900 in a tomb in Taranto, southern Italy. The medallion in the centre is 4.1 cm in diameter. © Antikensammlung, Staatliche Museen zu Berlin; photo by Johannes Laurentius.

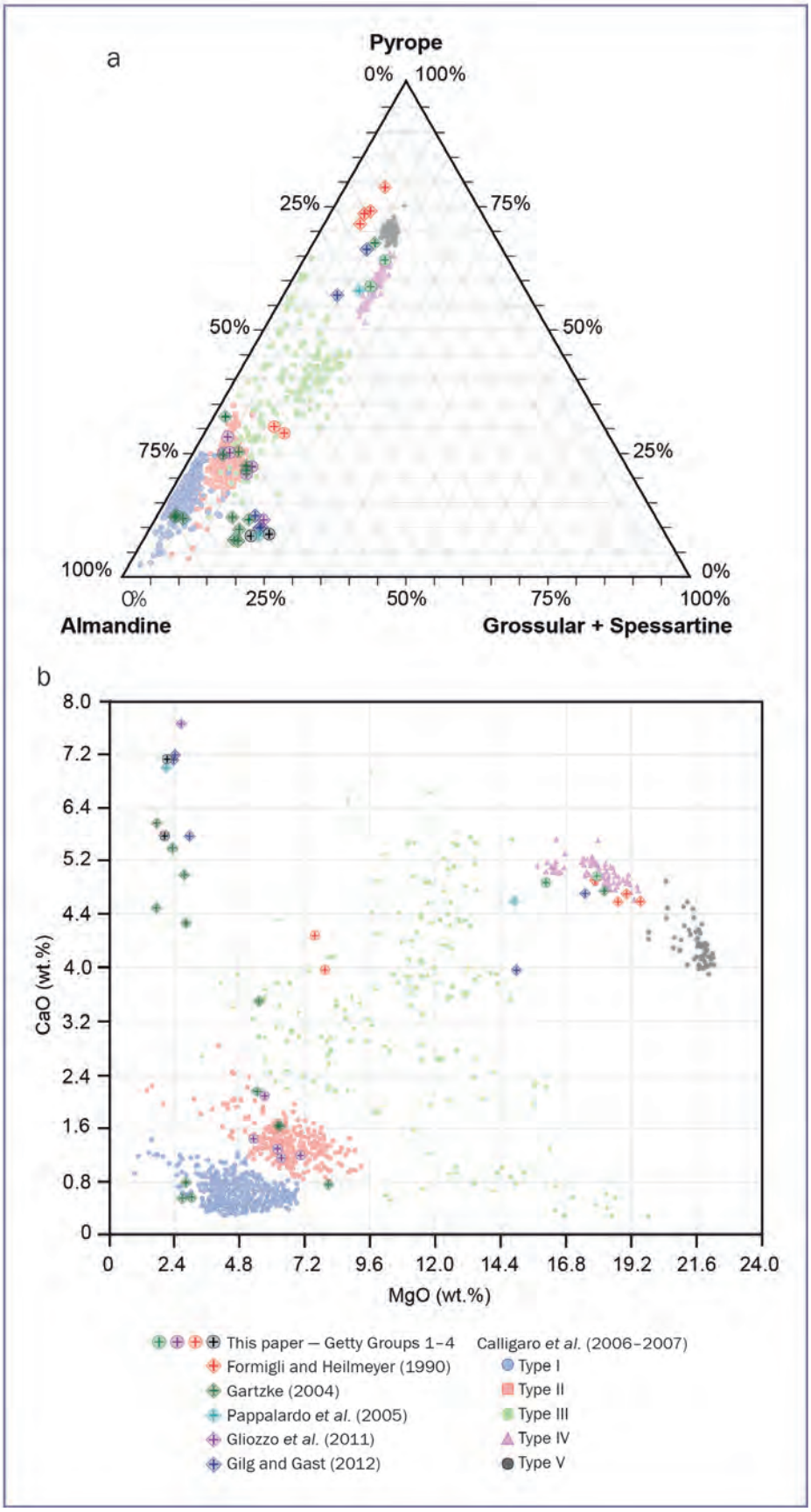

Figure 25: Data from 11 Graeco-Roman garnets in the current study and 26 garnets in five other studies overlaying the data of Early Medieval garnets from Calligaro et al. *(2006–2007). (a) Ternary diagram of end-member compositions, (b) binary MgO–CaO diagram.*

- Mn-rich almandine plots with almandine of Type II of Calligaro *et al.* (2006–2007), identical to Cluster A of Gilg *et al.* (2010).
- Cr-poor pyrope plots with pyrope of Type IV of Calligaro *et al.* (2006–2007), which is identical to Cluster D of Gilg *et al.* (2010) and Gilg and Gast (2012).

Cr-rich pyrope used in later-dated cloisonné metalwork was not represented among the Graeco-Roman garnets analysed. The third cluster of stones found among the Greek and Roman garnet groups, namely Ca-rich almandine, was not found among the garnets analysed in Early Medieval objects. The three almandines with low Ca and Mg contents analysed by Gartzke (2004) plot within the distribution field of Type I almandine of Calligaro *et al.* (2006–2007) or the Cluster B field of Gilg *et al.* (2010). The analyses of Gartzke's Hellenistic specimens, however, show somewhat higher Mn than the comparable group of Medieval garnets. Further work is needed to ascertain whether or not the earlier-dated garnets originated from the same locality represented in the Early Medieval jewellery.

Discussion and conclusions

Considerable analytical data are available on garnets used in the Early Medieval era (5th–7th century AD), primarily in cloisonné metalwork, and a limited number of specimens have been examined together with their gemmological properties (e.g., inclusions). For garnets used in Hellenistic and Roman jewellery, a comparatively small number of analyses were performed and published before 2010, and the inclusion features of most of these specimens were not reported. The first nearly complete data, including identification of inclusions, some confirmed by chemical analyses, were presented by Gilg and Gast (2012) on five ancient Greek and Roman garnets in the James Loeb Collection in the Staatliche Antikensammlungen und Glyptothek in Munich, Germany. The present article provides additional data for 11 Greek, Etruscan and Roman garnets in the J. Paul Getty Museum, Villa Collection.

Table V: Nomenclature and distribution of various garnet types in Merovingian, Hellenistic and Roman glyptic and jewellery.

Period / References	Chemical characteristics and designation of garnet species					
	Mn-poor, Cr-free almandine	Mn-rich, Cr-bearing almandine	Ca-rich almandine	Intermediate pyrope-almandine	Cr-poor pyrope	Cr-rich pyrope
Merovingian (5th to 7th century AD)[a]						
Calligaro *et al.* (2002; 2006–2007), Périn and Calligaro (2007)	Type I almandine	Type II almandine	–	Type III 'rhodolite'	Type IV pyrope	Type V pyrope
Gilg *et al.* (2010)[b]	Cluster B almandine	Cluster A almandine	–	Group X intermediate between pyrope and almandine	Cluster D pyrope	Cluster E pyrope
Hellenistic (3rd to 1st century BC) and Roman (1st century BC to 4th century AD)						
Gilg and Gast (2012)	–	–	Cluster Z	Group X	Cluster D	–
This paper, Getty Museum	–	Group 2	Group 4	Group 3	Group 1	–
Number of specimens (from 11 Getty Museum garnets and 26 garnets in other studies)	3	9	12	3 (almandine-rich) + 1 (pyrope-rich)	9	–

[a] See also Rösch *et al.* (1997), Farges (1998), Greiff (1998), Quast and Schüssler (2000), Mathis *et al.* (2008), and Horváth and Bendö (2011).

[b] Cluster C representing Ca- and Mg-rich almandine from Scandinavia is omitted.

The data from the five earlier studies and the results of the present study help to characterize garnets used in Classical antiquity and differentiate them from one another and also from later-dated stones, specifically Early Medieval garnets and material from the modern market. Unfortunately, because of the lack of quantitative chemical data, the stones examined by Adams *et al.* (2011) cannot be compared directly with our groups and plotted within our diagrams. It appears likely that additional groupings will emerge in future studies, particularly for garnets originating from Western and Central Asia; however, data are needed on reference samples from these regions. Comparison with chemical data available on garnets of the Early Medieval period may reveal distinctive patterns that illuminate details about sources of garnets in antiquity and the ancient gem trade, in general.

Some recent studies lack detailed descriptions of inclusions in the garnets. Inclusion studies may not have been performed, and some garnets such as pyrope frequently do not contain mineral inclusions observable with available magnification. Also, some of the garnets used in antiquity are only semitransparent and/or are mounted in closed-back jewellery settings, which can make observation of inclusions difficult.

According to chemical data from the Getty Museum specimens, four groups of garnets were identified. Comparing our data with published analyses for other Graeco-Roman garnets, these four groups were confirmed and their compositional ranges were enlarged. A fifth group of ancient garnets, also documented among Medieval garnets, is limited to three small beads set in earrings *(Figure 22a)* from Palaiokastro in northern Greece (Gartzke, 2004; Gartzke *et al.,* 2004). Cr-poor pyropes were identified in the Hellenistic necklace and hairnet (*Figures 1* and *24*) belonging to the Taranto Hoard (Formigli and Heilmeyer, 1990), and their uniformity contrasts against the heterogeneity of the Palaiokastro hoard, which suggests that a single source supplied sufficient quantities of raw material for construction of the jewellery found in the tomb at Taranto.

The compositional range of Graeco-Roman garnets in the studies published to date show some overlap of four of the five groups with the different fields of Early Medieval garnets *(Figure 25)*. Ca-rich almandine represented among the ancient Greek and Roman garnets was not found in cloisonné jewellery of the Merovingian period. Cr-rich pyrope, which is documented among Medieval garnets, was not identified among the Greek and Roman gems.

Previously, other researchers have classified Merovingian garnets according to different types *(Table V)*, and they have suggested several possible origins for the Medieval-era stones. The data for the Cr-rich pyrope fit well with the data for Bohemian garnets, which are still mined today in the Czech Republic. For the two types of almandine found frequently in cloisonné metalwork of the Early Medieval period, various localities in India (especially in Rajasthan) have been suggested as possible origins and Sri Lanka has been postulated as a source of intermediate pyrope-almandine (Calligaro *et al.,* 2002, 2006–2007; Gilg *et al.,* 2010; see also Quast and Schüssler, 2000). The data for some ancient pyropes fit with those from Nigeria and Portugal (Cachão *et al.,* 2010; Gilg and Gast, 2012). Some of the ancient garnets published to date,

including the Getty Museum garnets, fall into the distribution fields for some of these gem-producing regions.

A discussion of the sources of ancient garnets is outside the scope of this paper, as it requires a detailed examination in relation to archaeological evidence and ancient texts, as well as comparison of the compositional ranges of ancient garnets against analyses performed on material recently mined (e.g., since 1900), especially from the modern gem trade. Nevertheless, a preliminary comparison of such data suggests that some deposits used in antiquity were different from deposits used later. The distinctive compositions of some ancient Greek and Roman garnets indicate that some stones may have originated from the same source during the same periods of production, although the source may be unknown currently. Relating chemical compositions and gemmological properties, especially inclusions, to stylistic features may help to corroborate attributions to workshops or individual artists.

In workshops of any culture or period, lapidary artists will have had in their inventories of raw materials gems originating from disparate sources. Patrons commissioning custom-made jewellery might also supply their own stones. Blanks or pre-formed rough-outs were prepared in lapidary centres specifically for export and also for use in local workshops. Zwierlein-Diehl (2007) produced a comprehensive reference on glyptic production and workshops in Classical antiquity; for garnets, specifically, see also Spier (1989) and Plantzos (1999). A survey of bead-making industries and a discussion of lapidary centres in the Near East, South Asia (including Sri Lanka) and Southeast Asia (i.e., Oc Eo, Vietnam), from which raw materials and finished garnet beads were exported to Western markets, was given by Francis (2002), with a discussion of garnet beads (almandine and brown grossular) from the Roman colony at Arikamēdu on India's eastern seaboard.

The scope of this discussion precludes considering the myriad correlations between the compositional ranges of ancient Greek and Roman garnets and those of garnets from deposits mined during the past century. For some gems grouped according to composition, more than one locality fits as a prospective source in the ancient world, but the data are far from unequivocal, as noted previously. Also, they are an incomplete representation of the major regions where gems may have originated in antiquity. Specimens from localities in Anatolia, the Levantine littoral to the Iranian Plateau, and more localities in west-northwest Africa and also East Africa are of particular interest. It would not be surprising to see more overlapping of chemical composition, inclusions and other physical properties as additional data from more localities are published. To better differentiate the distribution fields, more detailed characterization — particularly the zonation within garnet specimens, which was not undertaken in this study — will be an important consideration.

This paper has focused on integrating the data for the Getty Museum garnets into a framework that relates isolated analytical studies. The efficacy of such studies lies in their application to a critical re-examination of gemstone origins, their transmission, and their uses or occurrence in the ancient world. Based on a growing body of data from analytical provenance studies published to date, it is clear that complete gemmological characterization and chemical composition provide useful criteria to complement the methods used traditionally in ancient gem studies by archaeologists, historians, connoisseurs, and philologists.

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Natural and synthetic vanadium-bearing chrysoberyl

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Abstract: Mineralogical and gemmological properties of natural and synthetic V-bearing chrysoberyls are described. The natural samples originate from four sources (Tunduru in Tanzania, Ilakaka in Madagascar, Sri Lanka and Mogok in Myanmar) and the synthetic material was produced by Kyocera Corporation in Japan. The natural crystals show tabular habit with one of the pinacoids **a** {100} or **b** {010} as dominant crystal forms. Their morphology is consistent with internal growth structures determined in the immersion microscope. A few samples contain mineral inclusions of apatite, feldspar, or calcite. Dominant colour-causing trace elements are either V (Tunduru and Ilakaka) or a combination of V and Cr (Sri Lanka and Myanmar). Iron is present in samples from Tunduru, Ilakaka and Sri Lanka, but not from Mogok. Other trace elements such as Ga and Sn were detected in most of the natural samples and were absent from the synthetics.

UV-Vis spectra show superimposed V^{3+} and Cr^{3+} absorptions, as well as minor Fe^{3+} bands. According to the specific V:Cr ratio of the samples, the major ν_1 absorption band in the visible range is shifted from the red-orange (~607 nm) for Cr-free or almost Cr-free non-phenomenal chrysoberyls to the orange range (~589 nm) for a sample with the greatest Cr contents (0.24 wt.% Cr_2O_3). In comparison, colour-change Cr-dominant alexandrites show this major absorption band in the greenish yellow range (about 576–573 nm).

Diagnostic features of V-bearing natural chrysoberyl are compared with their synthetic Kyoc--era counterparts and with samples produced in Russia by flux growth and the horizontally oriented crystallization (HOC) technique. A distinction of natural from synthetic samples is possible by evaluating a combination of chemical, spectroscopic and microscopic features.

Keywords: chromium, colorimetry, crystal habit, inclusions, Madagascar, microprobe analyses, Myanmar, pleochroism, Sri Lanka, Tanzania, UV-Vis spectra, vanadium, X-ray fluorescence analysis

In the mid-1990s, V-bearing synthetic chrysoberyl was grown by Kyocera Corporation as a synthetic counterpart to material discovered at Tunduru, Tanzania. Shown here are a 1.53 ct V-bearing chrysoberyl from Tunduru (top) and a 1.06 ct synthetic chrysoberyl grown by Kyocera (bottom, 7.0×5.0 mm). Photo by K. Schmetzer.

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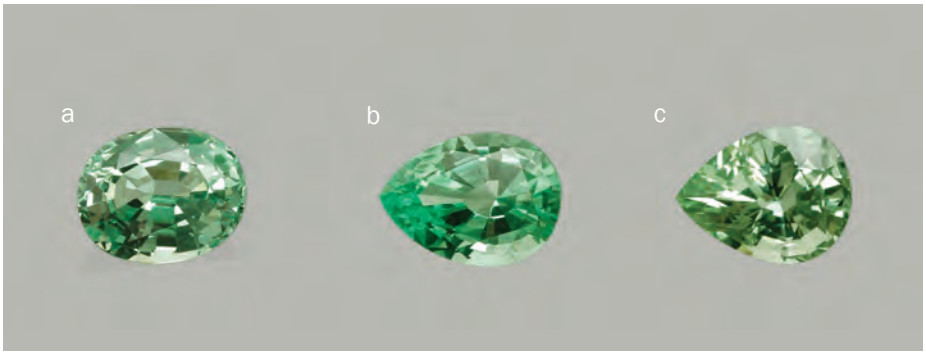

Figure 1: (a) Vanadium-bearing chrysoberyl was first discovered at Tunduru, Tanzania, which is the source of this 1.53 ct oval cut (7.8×6.2 mm). (b) Its synthetic counterpart was grown by Kyocera Corporation (here, 1.12 ct or 7.6×5.7 mm). (c) The Ilakaka area in Madagascar is also a source of V-bearing chrysoberyl; this sample weighs 2.09 ct and measures 9.1×7.2 mm. Composite photo by M. S. Krzemnicki (not to scale).

Introduction

In the mid-1990s, some new bright green chrysoberyls (e.g., *Figure 1a*) found their way to gemmological laboratories worldwide (Johnson and Koivula, 1996; Bank *et al.,* 1997; McClure, 1998; also see Hänni, 2010, who also gives a summary of the different varieties of chrysoberyl). The first faceted stones were extremely clean and thus a synthetic origin was considered possible. Mainly trace-element analysis was applied to establish criteria to distinguish these samples from synthetic counterparts known at that time. The natural samples reportedly originated from the large alluvial mining area of Tunduru in southern Tanzania. Faceted samples of this 'mint' green chrysoberyl variety are considered rare and valuable gems (Mayerson, 2003). Their coloration was found to be due to vanadium and they contained very little or no chromium. Furthermore, no distinct colour change was observed between daylight and incandescent light, as it is commonly seen for Cr-bearing chrysoberyl (alexandrite).

Most alexandrites from various natural sources with a clear colour change (i.e., from green or bluish green in daylight to a colour ranging from violet-purple and reddish purple to purplish red in incandescent light) show distinctly higher Cr than V contents (Schmetzer and Malsy, 2011). Chrysoberyl with almost equal amounts of V and Cr (e.g., from Orissa or Andhra Pradesh, India) also appears green in daylight, but changes in incandescent light only to a pale greyish green (Schmetzer and Bosshart, 2010).

The first synthetic alexandrite, grown by Creative Crystals and marketed since the early 1970s, contained Cr and Fe as the only significant colour-causing trace elements (Cline and Patterson, 1975; Schmetzer *et al.,* 2012). To improve the colour and grow samples that were "comparable to natural alexandrite from the Ural mountain region", distinct amounts of V were added, in addition to various quantities of Cr (Machida and Yoshibara, 1980, 1981). Distinct V contents were also found in some flux-grown synthetic alexandrite trillings produced in Novosibirsk, USSR, and some flux-grown single crystals with V>Cr also were reported (Schmetzer *et al.,* 1996). Furthermore, distinct amounts of V have been recorded in some samples of Russian synthetic alexandrite grown from the melt by the Czochralski technique, as well as by the HOC method (horizontally oriented crystallization, a horizontal floating zone technique; see Schmetzer and Bosshart, 2010; Malsy and Armbruster, 2012; Schmetzer *et al.,* 2013a).

In the patent documents by Machida and Yoshibara (1980, 1981) mentioned previously, which were assigned to Kyoto Ceramic Corporation (Kyocera) from Kyoto, Japan, the growth of almost Cr-free, V-bearing synthetic chrysoberyl was also reported. This material is comparable to the non-phenomenal V-bearing green synthetic chrysoberyl that was grown at the same time by the Czochralski method in Novosibirsk (Bukin *et al.,* 1980). Another type of non-phenomenal green synthetic chrysoberyl was grown some years later by Tairus in Novosibirsk using the HOC method (Koivula *et al.,* 1994).

Subsequent to the discovery of V-bearing gem chrysoberyl in Tunduru in the mid-1990s (see above), another

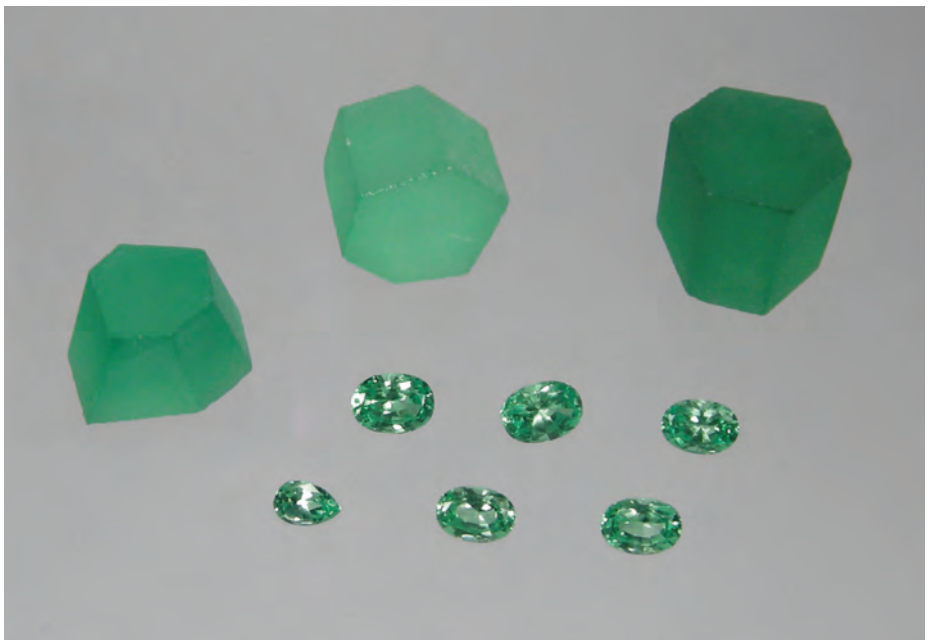

Figure 2: Rough and cut V-bearing synthetic chrysoberyl grown by Kyocera Corporation. The top-right piece weighs 10.5 g and measures 15.5×15.5×14.4 mm; the faceted samples weigh 0.49–1.33 ct. Photo by K. Schmetzer.

patent application was filed by Kyocera in Japan that described the production of the V-bearing counterpart of this gem material (Nishigaki and Mochizuki, 1998). This material was probably of the same type as the samples described briefly by Krzemnicki and Kiefert (1999; see also *Figure 1b*), and also those donated to the Bavarian State Collection for Mineralogy in Munich, Germany *(Figure 2)*.

To the knowledge of the present authors, only one polarized spectrum of a Czochralski-grown V-bearing chrysoberyl is published and it appears in an article that is difficult to access (Bukin *et al.,* 1980). Furthermore, pleochroism and colour were not mentioned in that paper, and descriptions of natural V-bearing chrysoberyl are often vague. This is due to the difficulty in orienting faceted chrysoberyl properly for spectroscopy in relation to the crystallographic axes. There is also a lack of published data on V-bearing non-phenomenal chrysoberyl from sources other than Tunduru, such as from Ilakaka, Madagascar *(Figure 1c)*. The present paper investigates the coloration and other gemmological and mineralogical properties of non-phenomenal natural and synthetic V-bearing chrysoberyl, and aims to fill some of the gaps mentioned above.

Samples

For the synthetics, we examined three pieces of rough and 12 faceted samples from Kyocera. All the rough and nine of the cut stones had been donated by Kyocera Germany to the Bavarian State Collection for Mineralogy in Munich. The other faceted samples were donated by Kyocera Corp. to the Swiss Gemmological Institute SSEF, Basel, Switzerland.

The natural samples consisted of 27 rough and faceted chrysoberyls with V>Cr. They originated from the large placers at Tunduru (14 samples) and Ilakaka (6), as well as from secondary deposits in Sri Lanka (5) and unspecified sources in Mogok (2). Many of the samples were obtained from the H.A. Hänni gemstone collection, which is housed as a reference collection at SSEF. Four rough pieces from Tunduru were obtained in Tanzania by S. Pfenninger for her diploma thesis (2000). Several samples were also obtained from museums or private collections and from the trade. The two chrysoberyls from Mogok were loaned from public or private collections in England where they had been housed since the 1970s (for further details, see Schmetzer *et al.,* 2013b).

In addition to these chrysoberyls from known sources, we also examined five faceted samples from private collections and from the trade with unspecified origins. The data from these samples, which revealed V>Cr by microprobe analysis, are not specifically included in the present study, but notably their chemical and spectroscopic properties all fell within the ranges determined for the larger group of 27 chrysoberyls from known localities. Furthermore, data from 12 light green samples that were found to contain Cr>V (e.g., from Ilakaka and Sri Lanka) are not presented in this study, since such material has already been described elsewhere (see, e.g., Schmetzer *et al.,* 2002).

Table I. Trace element contents, colour, pleochroism, and spectroscopic properties of V-bearing synthetic chrysoberyl grown by Kyocera Corp. in Japan.

Colour and pleochroism[a]

Orientation	X || a	Y || b	Z || c
Daylight	Yellowish green	Green	Bluish green
Incandescent	Yellowish green	Green	Bluish green

Spectroscopic properties

Property	Polarization, position (nm)			Assignment in all three directions of polarization
Orientation	X||a	Y||b	Z||c	
Maxima	607	618	608	V^{3+} first absorption band (ν_1)
	408	411	418	V^{3+} first absorption band (ν_2)
Minima	510	518	498	

Chemical properties (wt.%)

Sample	Ky1	Ky2	Ky3	Ky4	Ky5	Ky6	Ky7
No. analyses[b]	10	10	10	10	1	1	1
TiO_2	<0.01	<0.01	<0.01	<0.01	0.002	0.001	0.002
V_2O_3	0.11	0.12	0.13	0.12	0.115	0.119	0.081
Cr_2O_3	<0.01	<0.01	<0.01	<0.01	nd[c]	0.004	0.006
MnO	<0.01	<0.01	<0.01	<0.01	nd	nd	nd
Fe_2O_3	<0.01	<0.01	<0.01	<0.01	0.002	0.001	0.002

[a] Based on a morphological cell with a = 4.42, b = 9.39 and c = 5.47 Å.
[b] One analysis = EDXRF, 10 analyses (averaged) = electron microprobe.
[c] nd = not detected.

Instrumentation and methods

Gemmological and microscopic properties were determined for all the samples using standard instrumentation. The determination of growth structures and crystal morphology was detailed by Schmetzer (2011). Six samples that contained inclusions of measurable size were studied with a Renishaw InVia Raman microspectrometer, using an argon laser (514 nm) in confocal mode coupled with an Olympus microscope.

Quantitative chemical data for all samples were obtained by electron microprobe (JEOL JXA-8600 and Cameca Camebax SX 50 instruments) or energy-dispersive X-ray fluorescence (EDXRF) spectroscopy using Spectrace 5000 Tracor X-ray and ThermoScientific Quant'X instruments. In addition to the trace elements given in *Tables I* and *II*, aluminium contents were also measured as normal and used as a control value for

the quality of data (since BeO cannot be measured reliably by electron microprobe and EDXRF analyses). Furthermore for all samples semi-quantitative data for Ga and Sn were obtained by one of the analytical techniques mentioned above.

Absorption spectra were recorded with a CCD-type Czerny-Turner spectrometer in combination with an integrating sphere (for further details, see Schmetzer *et al.,* 2013a). Non-polarized spectra were obtained for 12 synthetic and 25 natural samples from known sources as well as for five chrysoberyls from unknown localities. In addition, polarized spectra were performed for about half of these samples. Colorimetric data were obtained in transmission mode for 15 samples with a Zeiss MCS 311 multichannel colour spectrometer (see Schmetzer *et al.,* 2009; Schmetzer and Bosshart, 2010).

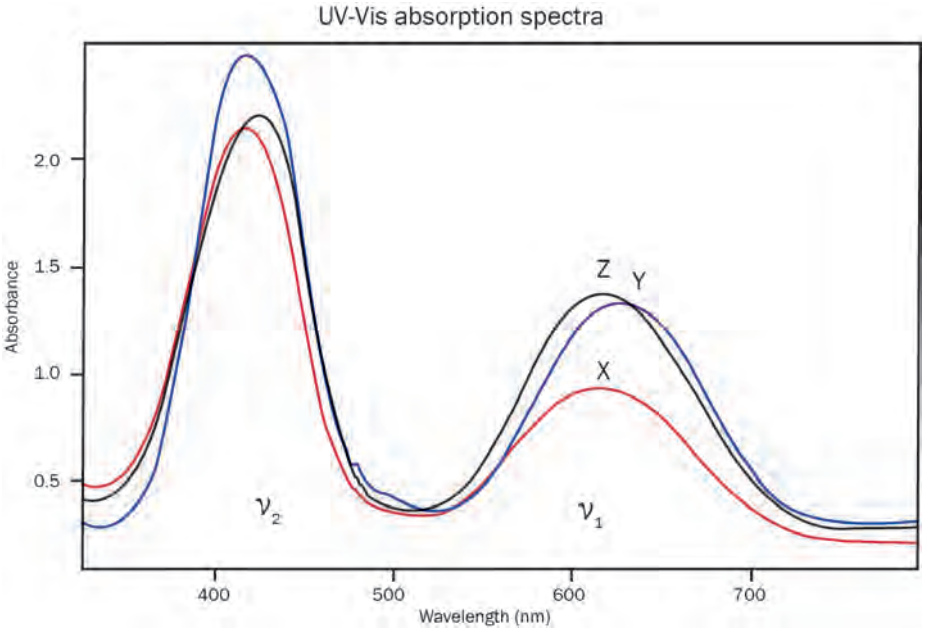

Figure 3: Polarized absorption spectrum of a V-bearing synthetic chrysoberyl grown by Kyocera Corp., with X || a, Y || b and Z || c. The dominant absorption bands are designated ν_1 and ν_2 (see Table I*).*

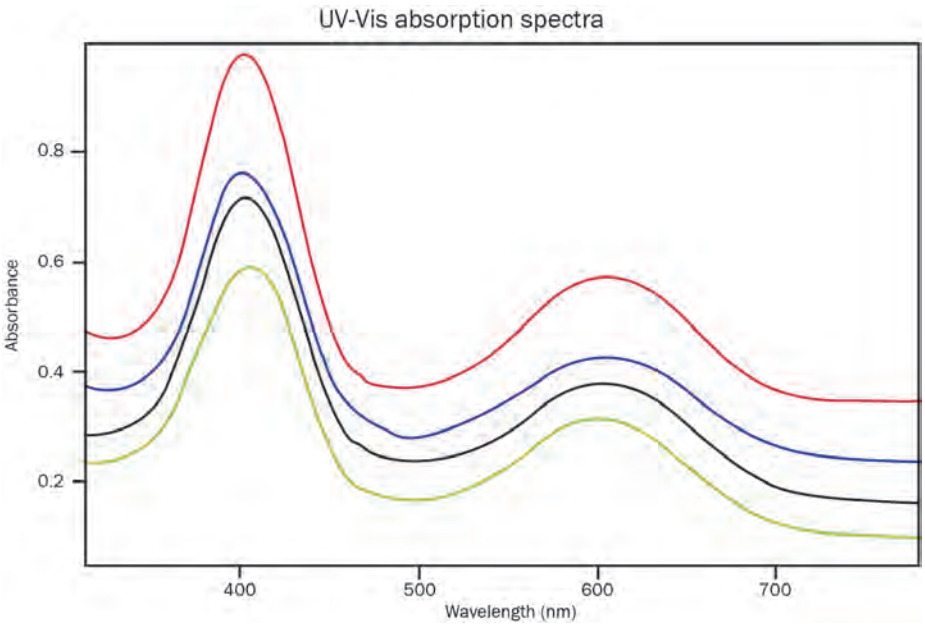

Figure 4: Absorption spectra of four faceted V-bearing synthetic chrysoberyls in random orientation. The top three spectra are displaced vertically for clarity.

Kyocera synthetic V-bearing chrysoberyl

The rough samples consisted of two somewhat irregular pseudo-hexagonal cylinders and one pseudo-hexagonal pyramid *(Figure 2)*. They had been sawn from Czochralski-grown crystals, and their upper and lower bases as well as the side faces were roughly polished to clean the surfaces and to give a better visual impression. The faceted gems were cut without specific orientation.

The overall colour of the samples was bright green in both daylight and incandescent light. Pleochroism was weak in the faceted samples but clearly observed in the rough pieces, with X = yellowish green, Y = green and Z = bluish green, independent of lighting.

The dominant colour-causing trace element in this group of samples is vanadium (0.08–0.13 wt.% V_2O_3; *Table I*). Other trace elements were, in general, below the detection limits of the electron microprobe, with small traces of Cr and Fe observed occasionally by EDXRF (see *Table I*).

Polarized absorption spectra of the rough samples showed two strong absorption bands in the red-orange range (~610 nm, designated as first strong absorption band ν_1) and in the violet area (~415 nm, designated as second strong absorption band ν_2) for X, Y and Z, with some variation in maxima positions and intensities *(Table I, Figure 3)*. These absorption bands in the visible range are assigned to V^{3+} which replaces Al^{3+} in the chrysoberyl structure. These absorption features are similar to those depicted by Bukin *et al.* (1980). Also, the non-polarized spectra from the faceted synthetics which are mostly randomly orientated *(Figure 4)* are consistent with these data.

The ν_1 absorption bands for Y and Z have approximately the same intensity, but due to the different position of their absorption maxima (618 and 608 nm, respectively), the minimum for Y at 518 nm is in the green range of the spectrum, while the minimum for Z at 498 nm is in the bluish green range. Thus, the different colours of Y and Z are understandable. The ν_1 absorption band in the X spectrum

Table II. Trace-element contents (wt.%), colour, and pleochroism of V-bearing chrysoberyl.

Source	Tunduru, Tanzania								
Colour	Pale to moderate intense green (Type 1)					Intense to very intense green (Type 2)			
Pleochroism[a] X Y Z	Not observed or very weak					Yellowish green Green Bluish green			
Sample	Tu1	Tu2	Tu3	Tu4	Tu5	Tu6	Tu7	Tu8	Tu9
No. of analyses[b]	10	16	8	10	1	1	7	20	15
TiO_2	0.01	0.08	0.01	0.01	0.001	0.007	0.15	0.11	0.01
V_2O_3	0.04	0.06	0.06	0.06	0.103	0.166	0.18	0.21	0.30
Cr_2O_3	0.01	0.01	0.01	0.01	0.004	0.038	0.03	0.03	0.04
MnO	nd[c]	nd	nd	0.01	nd	nd	nd	nd	nd
Fe_2O_3	0.17	0.13	0.10	0.24	0.317	0.227	0.08	0.09	0.20

Source	Ilakaka, Madagascar					Sri Lanka				Mogok, Myanmar
Colour	Pale to moderate intense green				Intense green	Moderate yellowish green				Intense bluish green
Pleochroism[a] X Y Z	Not observed or very weak				Yellowish green Green Bluish green	Not observed or very weak		Yellowish green Green Green		Greyish violet Yellowish green Intense blue-green
Sample	Il1	Il2	Il3	Il4	Il5	SL1	SL2	SL3	SL4	M1
No. of analyses[b]	8	10	10	9	10	10	10	10	10	12
TiO_2	0.01	0.05	0.02	0.01	0.01	0.05	0.01	0.11	0.10	0.08
V_2O_3	0.03	0.04	0.06	0.08	0.15	0.05	0.07	0.08	0.11	0.38
Cr_2O_3	<0.01	<0.01	<0.01	<0.01	<0.01	0.03	0.02	0.05	0.10	0.24
MnO	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	nd
Fe_2O_3	0.55	0.11	0.23	0.50	0.17	0.90	0.47	0.82	0.65	<0.01

[a] Daylight, based on a morphological cell with a = 4.42, b = 9.39, c = 5.47 Å, and X||a, Y||b, Z||c.
[b] One analysis = EDXRF, 7–20 analyses (averaged) = electron microprobe.
[c] nd = not detected.

is weaker than in Y and Z, which explains the somewhat more yellowish green colour of X.

Microscopic examination of faceted samples revealed no inclusions, growth striations, or clearly visible gas bubbles. Furthermore, gas bubbles were easily observed in only one of the rough pieces *(Figure 5)*.

Natural V-bearing chrysoberyl

Morphology of the rough and internal growth structures

Due to their origin from secondary deposits, most of the rough samples from Tunduru, Ilakaka and Sri Lanka were heavily waterworn and broken. Thus, we could determine the complete morphology only for a few samples *(Figure 6)* by goniometric measurements in combination with the examination of internal growth structures. *Figure 7* shows some examples of internal growth patterns seen in a crystal from Ilakaka, a faceted stone from Tunduru, a crystal from Mogok and a twinned crystal from Sri Lanka.

The crystal forms noted in our samples are well-known and seen frequently in natural chrysoberyl: the pinacoids **a** {100}, **b** {010} and **c** {001}; the prisms **i** {011}, **k** {021}, **m** {110}, **s** {120}, **r** {130} and **x** {101}; and the dipyramids **o** {111}, **n** {121} and **w** {122}. (For further details on chrysoberyl morphology and identification of crystal faces, see Schmetzer, 2011.) Idealized crystal drawings representing all four localities, for which a complete habit determination was possible, are presented

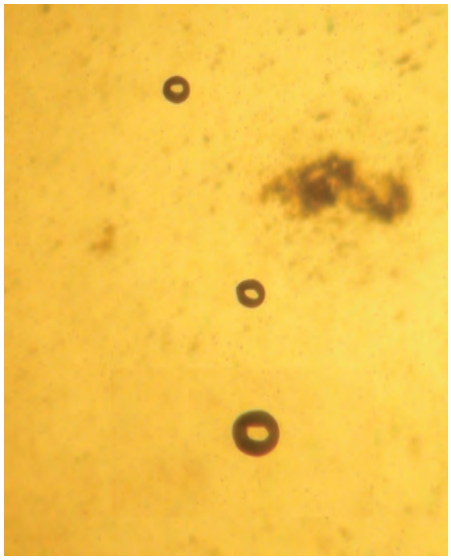

Figure 5: Gas bubbles are rarely seen in synthetic V-bearing chrysoberyl from Kyocera. Immersion, field of view 2.0×2.7 mm. Photo by K. Schmetzer.

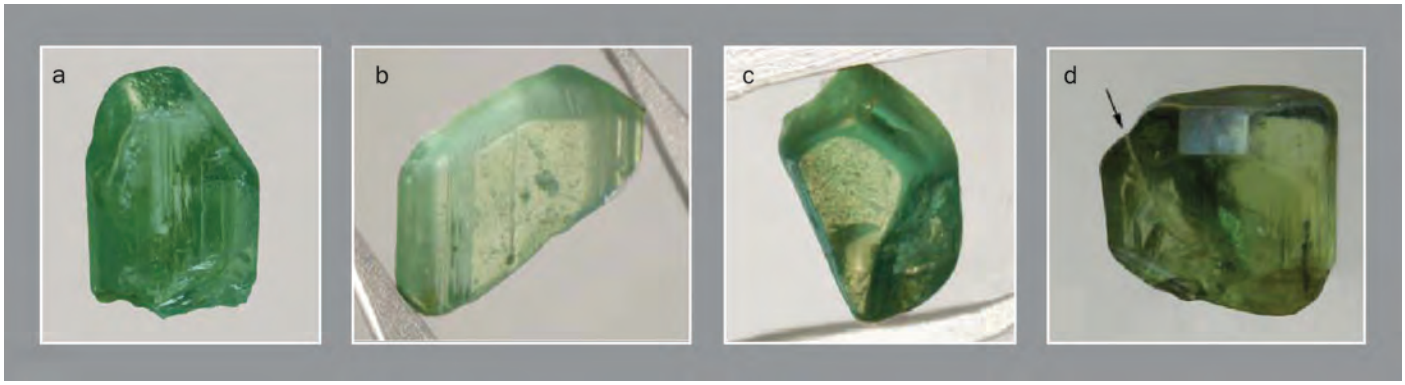

*Figure 6: Morphology of V-bearing chrysoberyl crystals. (a) Ilakaka, 12.7×8.4 mm, tabular parallel to **b** {010}; (b) Ilakaka, 7.4×6.5 mm, tabular parallel to **a** {100}; (c) Tunduru, 5.2×3.1 mm, tabular parallel to **a** {100}; (d) twinned crystal from Sri Lanka, 6.9×6.1 mm, the largest face is **a** (100), and the arrow indicates the twin boundary. Photos by K. Schmetzer.*

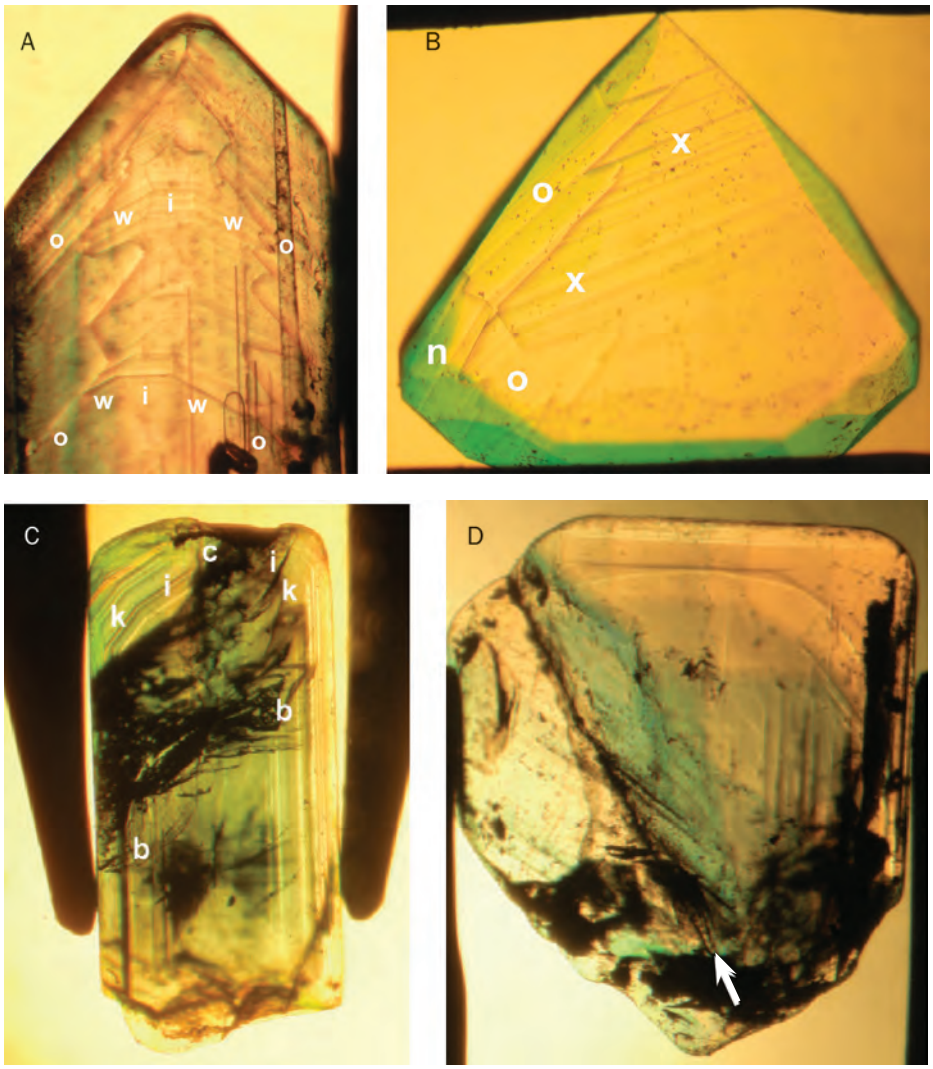

Figure 7: Growth structures in V-bearing chrysoberyl. (A) Crystal from Ilakaka (see Figure 6b*), tabular parallel to **a** {100}; view inclined to the c-axis, showing growth faces parallel to the prism **i** and to the dipyramids **w** and **o**; field of view 2.4×3.2 mm. (B) Cut stone from Tunduru, showing growth zoning parallel to the prism **x** and to the dipyramids **n** and **o**; field of view 5.1×4.7 mm. (C) Crystal from Mogok; view parallel to the a-axis, showing growth faces associated with colour zoning parallel to the pinacoids **b** and **c** and to the prism faces **i** and **k**; field of view 5.3×7.1 mm. (D) Crystal from Sri Lanka (see* Figure 6d*); the largest face is **a** (100) and the arrow points at the twin boundary; field of view 6.7×7.7 mm. Photos in immersion by K. Schmetzer.*

in *Figure 8*. Most samples consisted of untwinned single crystals with variable morphology, but two specific habits were frequently seen, both of which were elongated along the c-axis: tabular with a dominant **b** pinacoid (*Figures 6a* and *8A,D*), or tabular with a dominant **a** pinacoid (*Figures 6b,c* and *8B,C*).

Although twinning was rarely observed, *Figures 6d* and *7D* depict a sample from Sri Lanka that consists of a dominant crystal with a smaller second crystal in twin position. The morphology of the larger crystal is depicted in *Figure 8E*.

Colour, pleochroism and colour-causing trace elements

An overview of the chemical properties and coloration of selected samples from all four sources examined is given in *Table II*, and *Figure 9* provides a comparison of the coloration of the faceted natural and synthetic samples. Vanadium-bearing chrysoberyl from Ilakaka *(Figure 10a)* and Tunduru *(Figure 10b)* ranged from pale to very intense green, in very light to medium-light tones. In lighter green chrysoberyl from both sources, pleochroism was not observed or was very weak. All intense or very intense green stones showed identical pleochroic colours with X = yellowish green, Y = green and Z = bluish green, comparable to the pleochroism observed in the synthetic rough from Kyocera (*Tables I* and *II*). Colour intensity is dependent on and directly correlated with V concentration, which was found

to vary between 0.03 and 0.15 wt.% V_2O_3 in chrysoberyl from Ilakaka and between 0.04 and 0.30 wt.% V_2O_3 from Tunduru. Chromium contents in the Ilakaka samples were <0.01 wt.% Cr_2O_3. The pale to moderately intense green samples from Tunduru (designated Type 1 in this study) also showed very low Cr contents in the range of 0.01 wt.% Cr_2O_3, while the more intensely coloured samples with higher V contents (designated Type 2) had somewhat greater Cr contents in the range of 0.03–0.04 wt.% Cr_2O_3 *(Table II)*. Iron contents were between 0.08 and 0.32 wt.% Fe_2O_3 for samples from Tunduru, with somewhat higher amounts in chrysoberyls from Ilakaka (0.11–0.55 wt.% Fe_2O_3).

Vanadium-bearing chrysoberyls from Sri Lanka *(Figure 10c)* were yellowish green with moderate saturation. The more intensely coloured samples showed pleochroism with X = yellowish green, Y = green and Z = green. Vanadium contents ranged from 0.05 to 0.11 wt.% V_2O_3, and Cr varied between 0.02 and 0.10 wt.% Cr_2O_3 (i.e., somewhat higher Cr than samples from Ilakaka and Tunduru). Iron ranged from 0.47 to 0.90 wt.% Fe_2O_3.

The intense bluish green samples from Myanmar (e.g., *Figure 10d*) showed strong pleochroism with X = greyish violet, Y = yellowish green and Z = intense blue green. The sample analysed by microprobe had the highest V and Cr contents of our chrysoberyls (0.38 wt.% V_2O_3 and 0.24 wt.% Cr_2O_3), with Fe below the detection limit.

The chemical properties of V-bearing natural and synthetic chrysoberyls given in *Tables I* and *II* are plotted in *Figure*

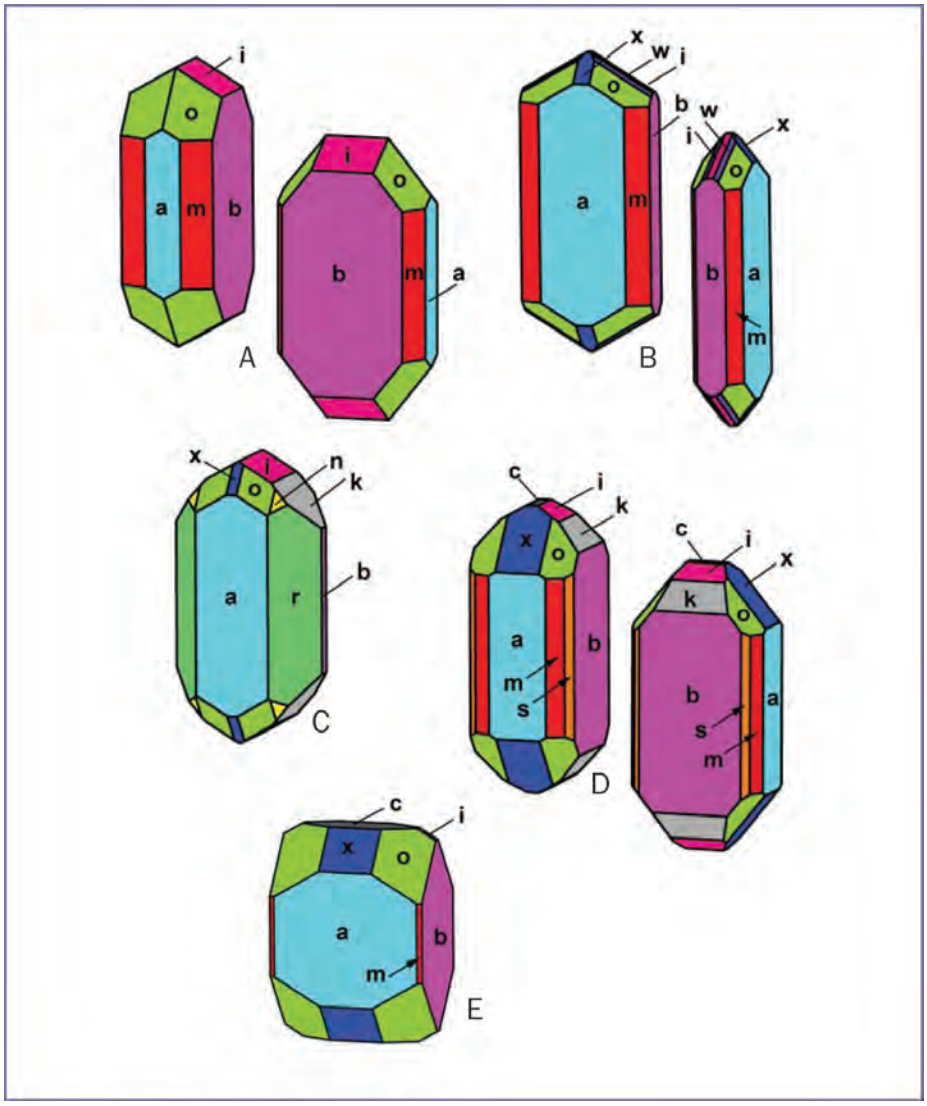

Figure 8: Idealized drawings (clinographic projections) showing the morphology of V-bearing chrysoberyl crystals from various localities; all equivalent crystal faces have the same colour. (A) Ilakaka, views parallel to the a-axis (left) and b-axis (right); the sample (see Figure 6a*) is tabular parallel to* ***b*** *{010}; (B) Ilakaka, views parallel to the a-axis (left) and b-axis (right); the sample (see* Figures 6b *and* 7A*) is tabular parallel to* ***a*** *{100}; (C) Tunduru, view parallel to the a-axis, the sample (see* Figure 6c*) is tabular parallel to* ***a*** *{100}; (D) Mogok, views parallel to the a-axis (left) and b-axis (right); the sample (see* Figure 7C*) is tabular parallel to* ***b*** *{010}; (E) Sri Lanka, view parallel to the a-axis; the drawing represents the larger part of the twin depicted in* Figures 6d *and* 7D*, and the largest face is* ***a*** *(100). Crystal drawings by K. Schmetzer.*

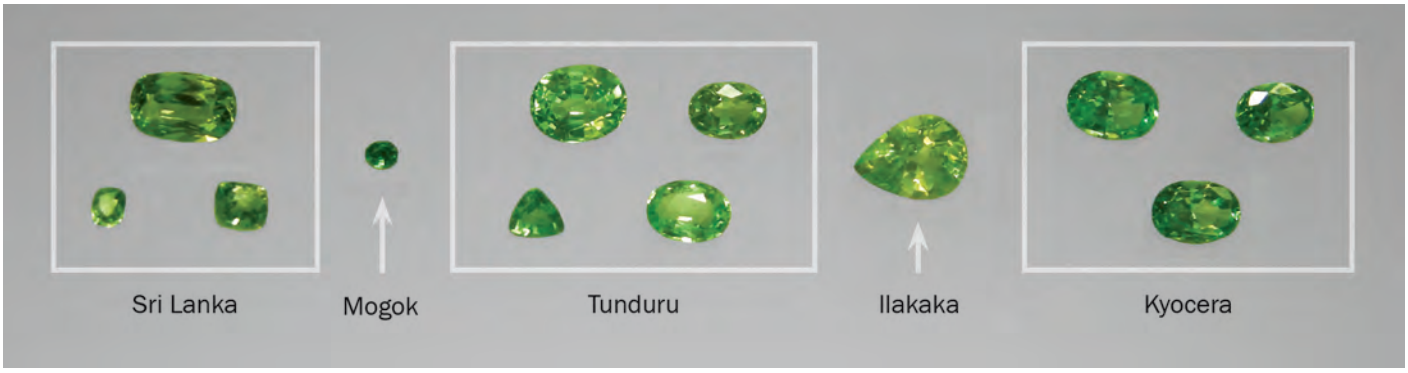

Figure 9: Colour comparison of faceted V-bearing chrysoberyl from various localities and synthetic chrysoberyl grown by Kyocera Corp. The chrysoberyl from Ilakaka weighs 2.09 ct and measures 9.1×7.2 mm. Photo by K. Schmetzer.

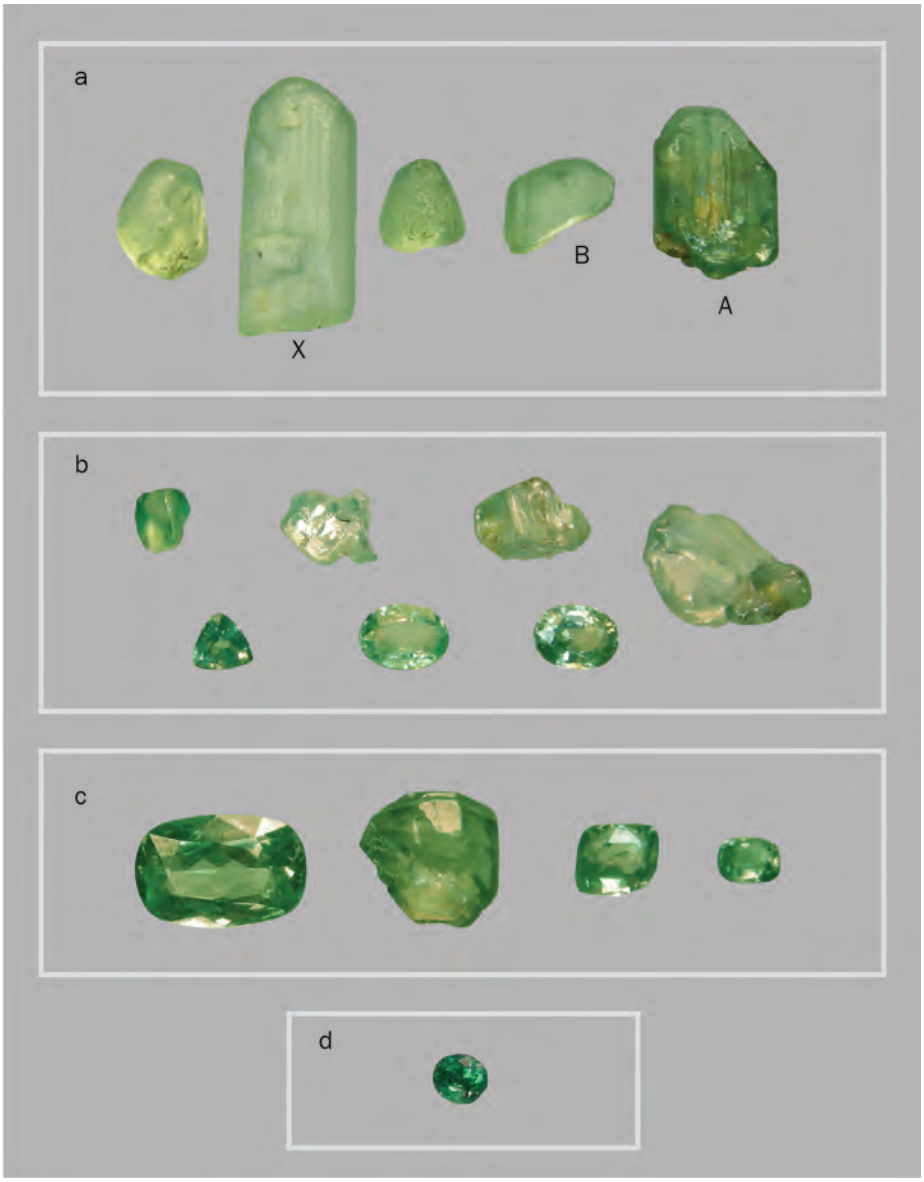

Figure 10: Vanadium-bearing chrysoberyl from various localities. (a) Ilakaka: for the three labelled single crystals, the external morphologies are: sample X (17.9×7.6 mm), tabular parallel to ***b*** *{010}; sample B (7.4×6.5 mm), tabular parallel to* ***a*** *{100}; and sample A (12.7×8.4 mm), tabular parallel to* ***b*** *{010}. (b) Tunduru: the faceted samples weigh 0.38 ct (4.3×4.2 mm) to 0.89 ct. (c) Sri Lanka: the cut stones weigh 1.44 ct (8.4×5.6 mm), 0.53 ct and 0.13 ct. (d) Mogok: the sample weighs 0.08 ct and measures 2.6×2.3 mm. Photos by K. Schmetzer (*Figures a–d *not to scale).*

11. The V and Cr contents are similar in the synthetic chrysoberyl from Kyocera and the natural samples from Ilakaka and Tunduru Type 1. In contrast, the more intense green Tunduru Type 2 samples revealed higher V and Cr contents, and the stones from Sri Lanka showed greater Cr and Fe. The bright bluish green stone from Mogok was unique according to its highly enriched amounts of both colour-causing trace elements, V and Cr *(Figure 11a)*. Iron contents were variable: the synthetic material from Kyocera and the Mogok sample were Fe-free, while moderate Fe contents (0.05–0.35 wt.% Fe_2O_3) were found in chrysoberyl from Tunduru and in some of the Ilakaka samples. Greater Fe values were found in the stones from Sri Lanka and in some of the Ilakaka material *(Figure 11b)*.

Gallium and tin as trace elements

Gallium and tin are common trace elements in natural alexandrite from various sources (Ottemann, 1965; Ottemann *et al.*, 1978). It was no surprise that quantitative or semi-quantitative chemical analyses showed significant amounts of Ga in all samples from the four sources examined in this study. The characteristic X-ray lines of Sn were seen in all of the chrysoberyls from Ilakaka and Sri Lanka, and in most samples from Tunduru. No Sn lines were observed in two of the Tunduru Type 2 gems or in the chrysoberyls from Mogok.

Spectroscopic properties and colour variation under different light sources

Polarized absorption spectra were recorded for rough crystals with tabular habit showing dominant **a** (100) or **b** (010) pinacoids (see *Figures 6, 8* and *10*) and for a few faceted samples that were cut with the tables more or less parallel to one of those pinacoids. None of the faceted stones had the table facet oriented parallel to **c** (001). Due to the morphology of the crystals and the table orientations of the faceted stones, we normally could measure only two of the three possible polarized spectra X, Y and Z for each sample. Therefore, we recorded polarized spectra for X and Z (beam parallel to the b-axis) or for Y and Z (beam parallel to the a-axis); example spectra are depicted in *Figure 12*.

Even with these restrictions, it was evident that the positions of absorption maxima and intensity ratios of absorption bands of V^{3+} (in Cr-free or almost Cr-free samples) are consistent with those observed in the Kyocera synthetics (see *Table I*). In most natural samples, the V^{3+}-related features are superimposed on the known Fe^{3+} spectrum of chrysoberyl. The main absorption maxima assigned to Fe^{3+} are located at 365, 375–376 and 439 nm, with somewhat weaker absorption bands or shoulders at 357, 381 and 430 nm. Only the main absorption band showed a slight polarization dependency, with the maximum at 375 nm for X and Z, and at 376 nm for Y. The Fe^{3+} absorption bands we recorded are consistent for chrysoberyl in the literature (Farrell and Newnham, 1965).

A comparison of non-polarized spectra from the four localities *(Figure 13)* shows

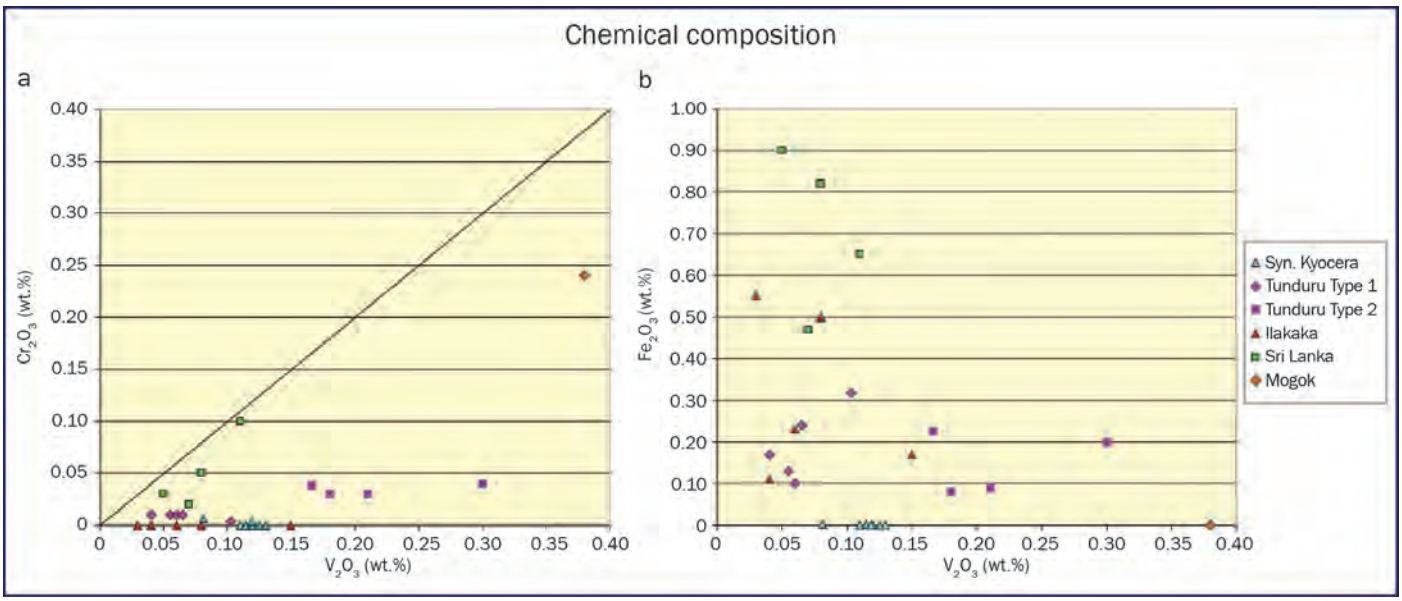

Figure 11: Chemical plots of synthetic chrysoberyl from Kyocera and natural samples from various sources. (a) V_2O_3 versus Cr_2O_3: All points are below the diagonal, as the gems contain more V than Cr. Trace-element contents in the Tunduru Type 1 and Ilakaka stones are similar to the Kyocera material. The Tunduru Type 2 samples reveal higher V and Cr contents, and the chrysoberyls from Sri Lanka also have greater Cr. The sample from Mogok shows highly enriched contents of both trace elements. (b) V_2O_3 versus Fe_2O_3: The Kyocera synthetics and the bright green stone from Mogok are Fe-free, while samples from Tunduru, Ilakaka and Sri Lanka show variable Fe.

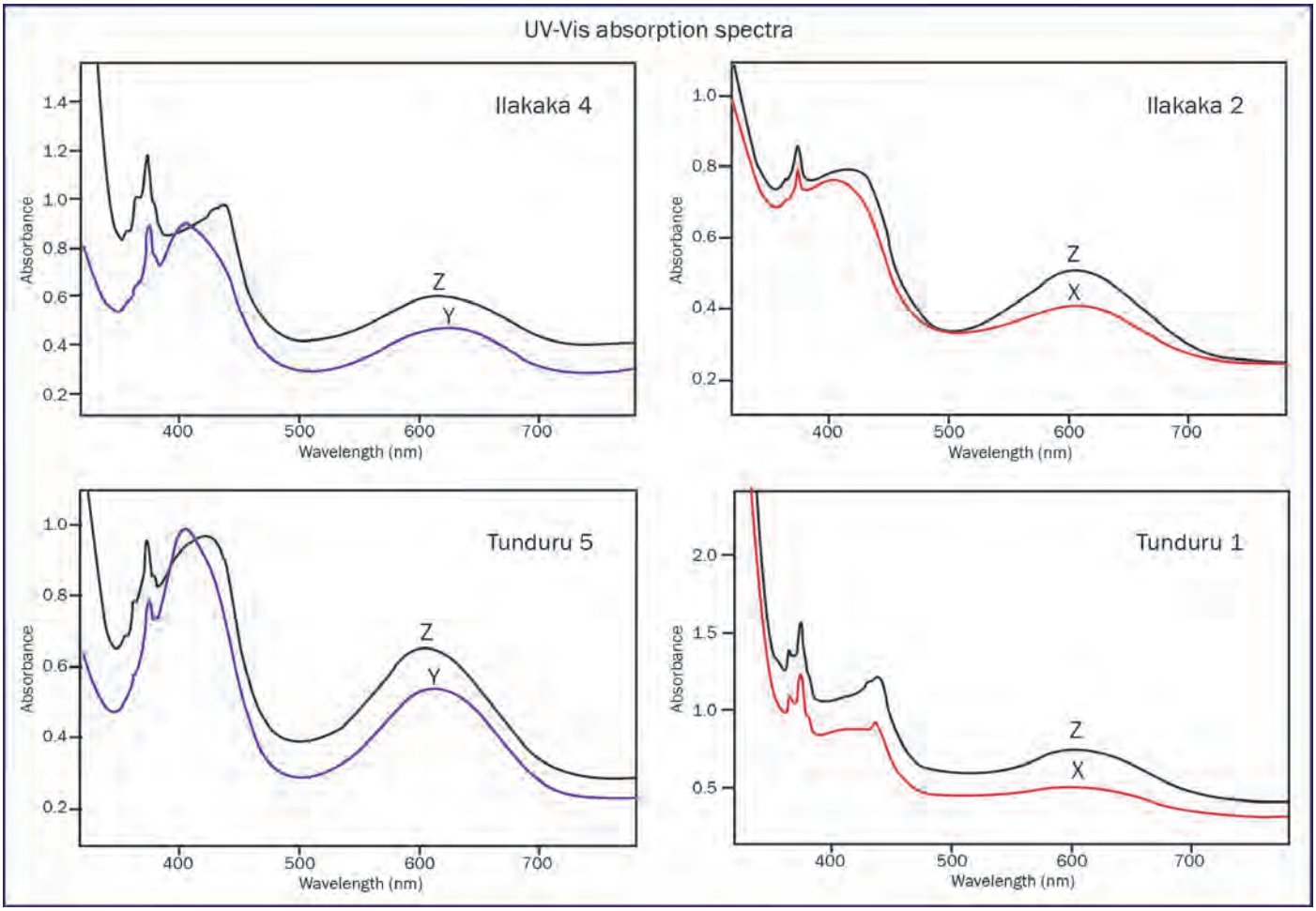

Figure 12: Polarized UV-Vis absorption spectra of one faceted sample and three V-bearing chrysoberyl crystals from Ilakaka and Tunduru, with X || a, Y || b and Z || c. According to the morphology of the samples, polarized spectra were recorded either with the beam parallel to the a-axis (Y and Z polarizations) or parallel to the b-axis (X and Z polarizations). Thickness of samples: Ilakaka 4 = 2.3 mm; Ilakaka 2 = 3.2 mm; Tunduru 5 (faceted) = 3.1 mm; Tunduru 1 = 3.8 mm.

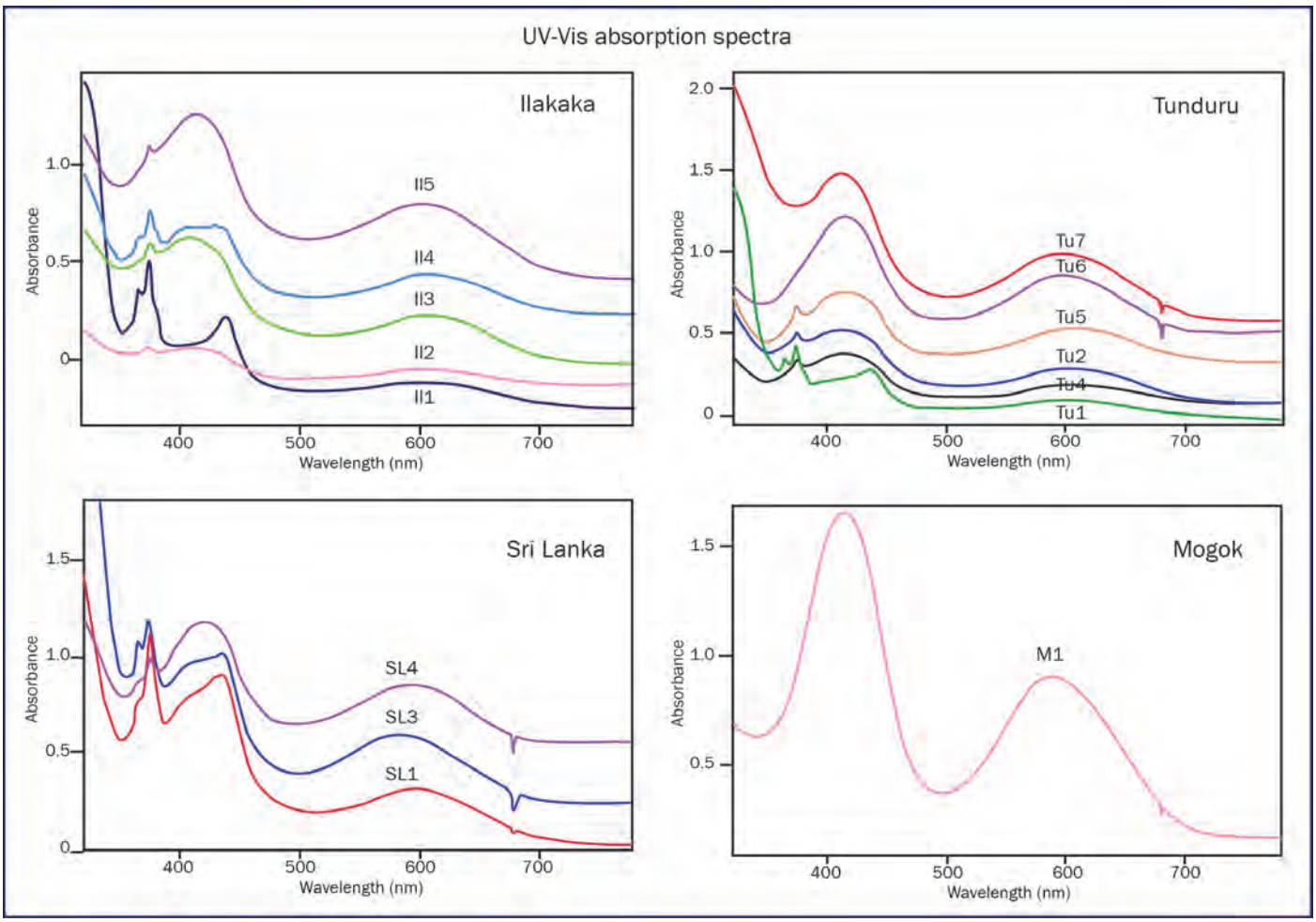

Figure 13: Non-polarized UV-Vis spectra of V-bearing chrysoberyl show absorption bands of V^{3+} and Fe^{3+} (Ilakaka and Tunduru), of V^{3+} and Cr^{3+} (Mogok), and of V^{3+}, Cr^{3+}, and Fe^{3+} (Sri Lanka). Sharp Cr^{3+} lines at ~ 680 nm are recorded for some of the samples only (Tunduru Type 2 [Tu6, Tu7], Sri Lanka and Mogok). The spectra of samples Il2–Il5, Tu2–Tu7, and SL3–SL4 are displaced vertically for clarity; the chemical properties of the samples are given in Table II.

that samples from Ilakaka and some of those from Tunduru do not show the two sharp Cr^{3+} lines at 680 and 678 nm. The Cr contents of these samples are low (<0.01 wt.% Cr_2O_3). In contrast, Cr^{3+} lines were observed in higher-Cr Tunduru samples and in those from Sri Lanka and Myanmar. Due to the experimental conditions, these Cr^{3+} lines are shown in the spectra as 'negative' luminescence peaks (see details in Schmetzer *et al.,* 2013a). Depending on the iron contents of the individual samples, the Fe^{3+} bands described above are also seen with variable intensity in the samples from Ilakaka, Tunduru and Sri Lanka.

In non-polarized spectra (see again *Figure 13*), the position of the first strong V^{3+} absorption band (ν_1) was recorded in the red-orange range at 608–606 nm for Cr-free or almost Cr-free chrysoberyls. Although there is some influence of sample orientation, it is clear that this strong absorption band shifts towards shorter wavelengths with greater Cr contents and with increasing Cr:V ratios *(Figure 14)*. For both samples from Myanmar (Cr:V ratio near 1:1.6), the position of this strong absorption band was recorded in the orange region at 589 nm. For Cr-dominant natural and synthetic alexandrites, this absorption band was shifted further to the greenish yellow range at about 576–573 nm *(Figure 14, Table III)*.

To compare polarized spectra of V-bearing, Cr-free synthetic chrysoberyl with V-free, Cr-bearing synthetic alexandrite, we selected samples grown by Kyocera Corp. (this study) and Creative Crystals (Schmetzer *et al.,* 2012), respectively. As already mentioned for V-bearing synthetic chrysoberyl, the polarized spectra for both trace elements, Cr and V, consist of two strong absorption maxima which are located in the greenish yellow to red-orange range (first maximum, ν_1) and in the blue-violet to violet range (second maximum, ν_2). In *Figure 15* these absorption maxima are shown in all three polarizations. For ν_1, in all three polarization directions the absorption bands for V^{3+} are located at higher wavelengths than for Cr^{3+} *(Table III)*. For this discussion, the Fe^{3+} bands of the synthetic alexandrite are neglected because they are all below 500 nm and therefore not within the range of the ν_1 band. In contrast, the ν_2 bands are much closer to one another in all three polarization directions for both V^{3+} and Cr^{3+}.

For all V- and Cr-bearing chrysoberyls, the V^{3+} and Cr^{3+} absorption bands are superimposed and, in general, no separation in absorption maxima are recorded for these two chromophores. Depending on the Cr:V ratio of an individual sample, the position of ν_1 is

shifted from the red-orange at about 608–606 nm (for Cr-free or almost Cr-free samples) towards lower wavelengths (for Cr-bearing samples, see *Table III*). For V-free or almost V-free natural alexandrite, the maximum of ν_1 is observed in the greenish yellow range at 576–573 nm *(Figure 14)*. This shift in the position of the ν_1 band is responsible for the variable coloration of V-dominant chrysoberyl from different sources. It is also responsible for the colour change seen in Cr-dominant alexandrite.

Colorimetric measurements confirm the visual impressions. For V-bearing samples without Cr (e.g., Kyocera synthetic chrysoberyl), a slight variation from green to bluish green is measured from daylight to incandescent light, and for V- and Cr-bearing chrysoberyls with distinct Fe contents (e.g., from Sri Lanka), a small variation from yellowish green to yellow-green is detected *(Figure 16)*. This different colour behaviour is due to the greater Cr as well as the somewhat higher Fe content (see again *Figure 11b*), which in general increases the yellowness of chrysoberyls. Samples with somewhat higher Cr than V (e.g., from Ilakaka) have been described as yellowish green or green (Schmetzer *et al.,* 2002).

These colour variations within V-bearing samples from various sources are quite different from the characteristically distinct colour change seen in Cr-bearing chrysoberyl (alexandrite) between daylight and incandescent light (see, e.g., Schmetzer *et al.,* 2012, 2013a). In alexandrite, the colour change is normally observed in two of the three polarization directions, X and Y. The third direction, Z, remains green or bluish green under both illumination sources. These observations can be explained by the different positions of the ν_1 absorption maxima (see again *Table III*), with X at 570 (greenish yellow) and Y at 564 nm (yellow-green), while Z is at somewhat higher wavelengths (~586 nm) in the orange range. For vanadium all three maxima are above 600 nm in the red-orange range and therefore none of the polarization directions shows a distinct colour change (rather, only a slight colour variation). Consequently, V-bearing chrysoberyl does not show distinct colour change behaviour (for further details on V- and Cr-bearing samples, especially from Myanmar, see Schmetzer *et al.,* 2013b).

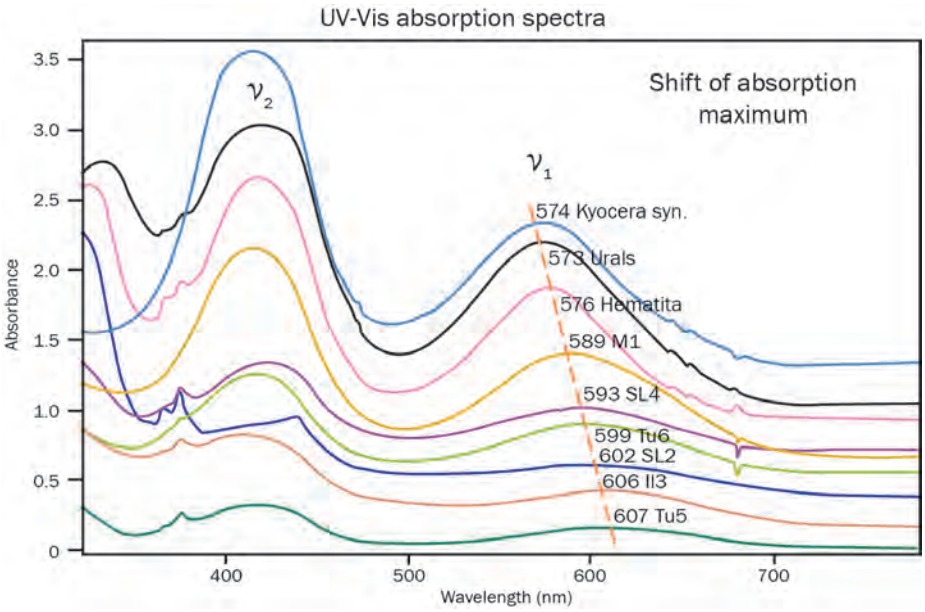

Figure 14: Non-polarized UV-Vis absorption spectra of V-bearing chrysoberyl from various sources (Il = Ilakaka; Tu = Tunduru; SL = Sri Lanka and M = Mogok), together with Cr-bearing alexandrite from Hematita (Brazil) and the Ural Mountains (Russia), as well as synthetic alexandrite grown by Kyocera. Increasing Cr contents cause a shift of the ν_1 absorption maxima towards lower wavelengths. With the exception of sample Tu5, the spectra are displaced vertically for clarity.

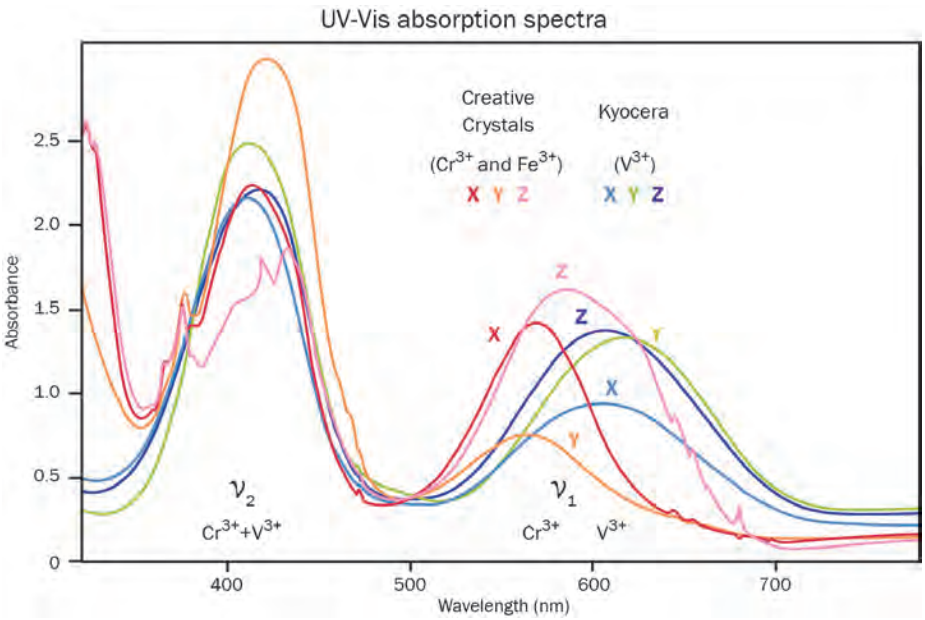

Figure 15: A plot of the polarized UV-Vis absorption spectra of V^{3+} in synthetic chrysoberyl from Kyocera (this paper) and Cr^{3+} in synthetic alexandrite from Creative Crystals (taken from Schmetzer et al., *2012) shows the position of absorption maxima for all three polarization directions (X, Y and Z). The positions of the absorption bands of Cr^{3+} and V^{3+} are close to one another, which explains why separate bands for these ions are not observed in visible-range spectra for samples containing both V and Cr.*

Inclusions

Consistent with previous descriptions of V-bearing natural chrysoberyl from Tunduru, most of our samples from this locality were clean and did not show any mineral inclusions. However, in two Type

1 chrysoberyls we identified numerous tiny apatite crystals *(Figure 17a)* that were partly associated with cavities or growth tubes oriented parallel to the c-axis *(Figure 17b,c)*. Raman analysis of the fluid phase within these elongated cavities showed characteristic peaks of CO_2. A third Type 1 chrysoberyl contained isolated tubes running parallel to the c-axis *(Figure 17d)* and a tiny negative crystal that also was found to contain liquid CO_2. In addition, small partially healed fractures were observed in some samples *(Figure 17e)*. In contrast to this inclusion pattern, one Tunduru Type 2 stone contained numerous minute inclusions identified as feldspar, with Raman spectra indicative of orthoclase (K-feldspar).

A light green chrysoberyl from Ilakaka showed an inclusion pattern consistent with that seen in the Tunduru Type 1 samples. It showed numerous tiny, birefringent, isolated crystals *(Figure 17f)* that were identified as apatite. Some of these apatite inclusions were connected to elongated tubes running parallel to the c-axis of the host. The other samples from Ilakaka did not contain any mineral inclusions.

Table III. Absorption maxima (nm) of the first absorption band (ν_1) in V- and Cr-bearing chrysoberyl and alexandrite.

Property	Polarization			Without polarization
	X || a	Y || b	Z || c	
V-bearing, Cr-free synthetic chrysoberyl from Kyocera	607	618	608	608–606
V- and Cr-bearing chrysoberyl, Mogok[a]	570[b]	599	593	589
Cr-bearing, V-free synthetic alexandrite from Creative Crystals[c]	570[b]	564[b]	586	576–573[b]

[a] Cr:V = 1:1.6.
[b] These directions show a colour change between daylight and incandescent light.
[c] From Schmetzer *et al.* (2012).

In the faceted chrysoberyl from Mogok we identified several small mineral inclusions as calcite. Some of these calcites were part of two- or multi-phase inclusions with a fluid component also showing the Raman lines of CO_2.

In the V-bearing chrysoberyl from Sri Lanka we were unable to identify any characteristic mineral inclusions by Raman spectroscopy.

Characteristic features and distinction of synthetic and natural V-bearing chrysoberyls

Two types of V-bearing synthetic chrysoberyl were produced in the 1990s, by Kyocera in Japan and at various institutes in Novosibirsk, USSR (Academy of Science and/or Tairus). The Kyocera material was characterized for this report and its properties are compared to natural V-bearing chrysoberyl in *Table IV*. The Russian synthetics were examined by H. A. Hänni and K. Schmetzer (Johnson and Koivula, 1996, 1997; see *Figure 18a*) and found to contain extremely high

Table IV. Diagnostic properties of some natural and synthetic V-bearing chrysoberyl[a].

Feature	Characteristic	Kyocera synthetic	Tunduru		Ilakaka	Sri Lanka	Mogok[b]
			Type 1	Type 2			
Chemical	Chromophores	V	V, Fe	V>>Cr, Fe	V, Fe	V>Cr, Fe	V>Cr
	Other trace elements	Not observed	Ga, Sn	Ga or Ga, Sn	Ga, Sn	Ga, Sn	Ga
Microscopic	Growth structures	Not observed	Growth patterns in various directions	Growth patterns in various directions	Growth patterns in various directions	Growth patterns in various directions	Growth patterns in various directions
	Mineral inclusions	Not observed	Apatite, occasionally associated with growth tubes	K-feldspar	Apatite, occasionally associated with growth tubes	Not observed	Calcite
	Other inclusions	Gas bubbles	Negative crystals with CO_2, isolated growth tubes		Isolated growth tubes		Fluid inclusions with CO_2
Spectroscopic	Absorption bands	V	V, Fe	V, Fe	V, Fe	V, Cr, Fe	V, Cr
	Sharp Cr lines	Not observed	Not observed	Present	Not observed	Present	Present

[a] For diagnostic properties of V- and Cr-bearing synthetic chrysoberyl and alexandrite grown by the floating zone method (HOC), see Johnson and Koivula (1996, 1997) and Schmetzer *et al.* (2013a); for diagnostic properties of V- and Cr-bearing synthetic chrysoberyl and alexandrite grown by the flux method, see Schmetzer *et al.* (1996, 2012).
[b] For further details, see Schmetzer *et al.* (2013b).

Natural and synthetic vanadium-bearing chrysoberyl

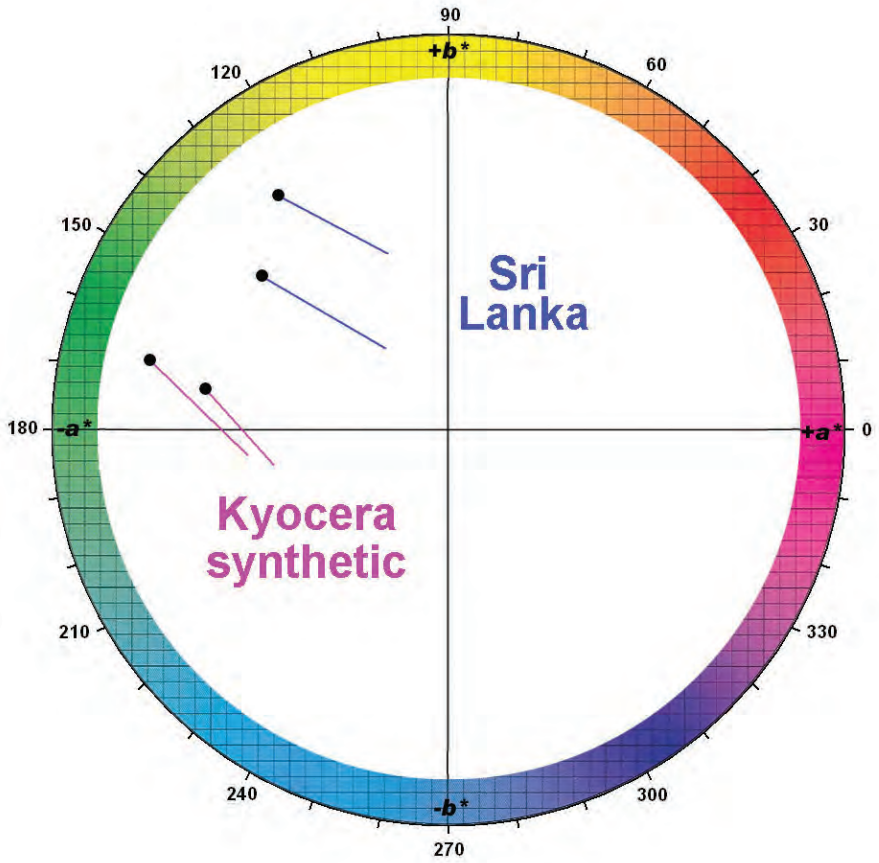

*Figure 16: Colorimetric parameters for two V- and Cr-bearing, Fe-rich chrysoberyls from Sri Lanka (with V>Cr), and V-bearing, Fe- and Cr-free synthetic chrysoberyl from Kyocera are plotted for daylight and incandescent light in the CIELAB colour circle. The neutral point (white point) is in the centre of the a*b* coordinate system and the outer circle represents a chroma of 40. The black circles plot the colour coordinates in daylight D_{65} and the other ends of the differently coloured bars represent the coordinates of the same samples in tungsten light A. The V-, Cr- and Fe-bearing chrysoberyls from Sri Lanka show a small colour variation from yellow green to greenish yellow, whilst the V-bearing, Fe- and Cr-free synthetic chrysoberyls from Kyocera shift slightly from green to bluish green.*

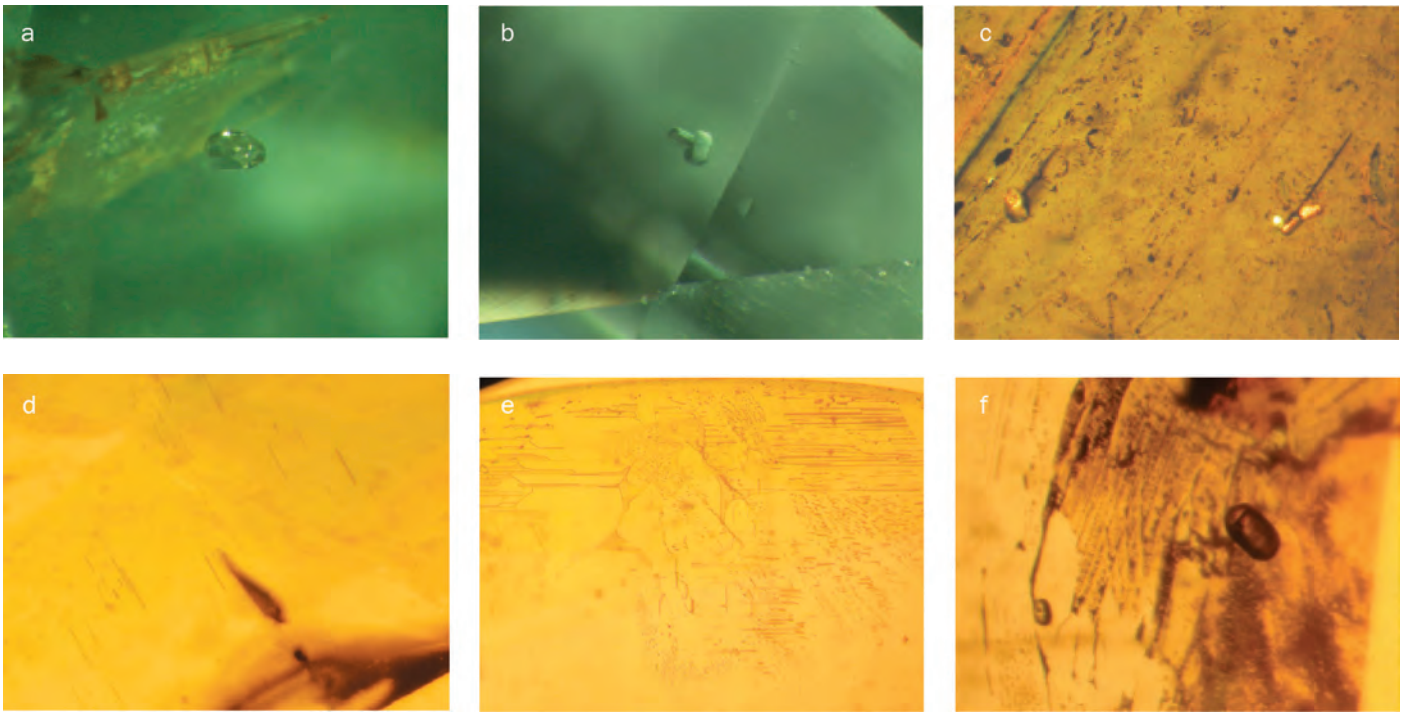

Figure 17: Inclusions seen in V-bearing chrysoberyl from Tunduru (a–e) and Ilakaka (f). Shown here are (a) apatite, (b) apatite next to a cavity, (c) apatite crystals associated with growth tubes oriented parallel to the c-axis, (d) growth tubes running parallel to the c-axis, (e) a partially healed fracture, and (f) apatite. (a,b) Fibre-optic illumination, field of view 1.6×1.2 mm; (c) immersion, crossed polarizers, 3.1×2.3 mm; (d,e,f) immersion, 2.3×1.8 mm, 2.8×2.1 mm, 2.0×1.5 mm, respectively. Photos by M.S. Krzemnicki (a,b) and K. Schmetzer (c–f).

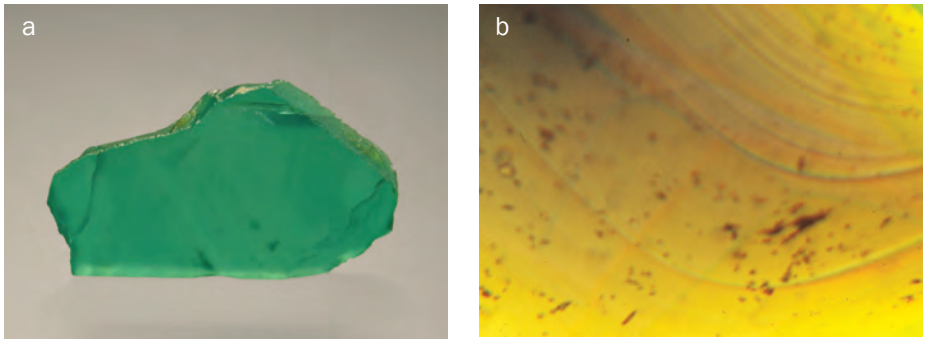

Figure 18: Vanadium-bearing synthetic chrysoberyl grown by the HOC technique in Novosibirsk, Russia. (a) Slice of 1.5 mm thickness, 19.3×10.8 mm; (b) irregularly curved growth striations; immersion, field of view 2.0×1.5 mm. Photos by K. Schmetzer

V contents (1.8 wt.% V_2O_3). Irregularly curved growth striations *(Figure 18b)* suggested this material was produced by the HOC technique. Recently, it was confirmed that a limited quantity of V-bearing synthetic chrysoberyl was grown by this method in Novosibirsk in the 1990s and released into the gem trade (V.V. Gurov, pers. comm., 2012).

Schmetzer *et al.* (1996) examined numerous flux-grown Russian synthetic alexandrites and a few samples were analysed that showed traces of V (up to 0.29 wt.% V_2O_3) in addition to Cr. One such sample even contained more V than Cr. All of the samples with relatively high V contents showed the same twinning, growth structures and inclusions (mostly various forms of residual flux) as observed in the Cr-dominant samples with lower V contents. Extremely high amounts of germanium (up to several wt.% GeO_2) are a characteristic chemical property that can be used to identify this type of synthetic alexandrite and V-bearing chrysoberyl.

Figure 19: Light yellowish green or greenish yellow chrysoberyls such as this 2.44 ct gem (9.7×5.3 mm) typically contain — in addition to some Fe — small amounts of V and/or Cr (in this instance, microprobe analyses showed 0.77 wt.% Fe_2O_3, 0.02 wt.% V_2O_3, and 0.01 wt.% Cr_2O_3). Photo by K. Schmetzer.

Chemical properties of samples from Tunduru reflect two different types: Type 1 is almost Cr-free and contains Sn, while Type 2 contains somewhat greater amounts of Cr (with V>>Cr) but no Sn was detected in some of those samples. These data are consistent with the literature (Johnson and Koivula, 1996; Mayerson, 2003). The trace-element pattern of V-bearing chrysoberyl from Ilakaka is similar to Type 1 Tunduru material. The few samples examined from Sri Lanka showed traces of both V and Cr, as well as unambiguous X-ray emissions of Sn. The samples from Mogok showed relatively high V and Cr contents, but no Sn. All natural samples with the exception of chrysoberyl from Mogok showed distinct Fe and characteristic X-ray lines of Ga were detected in stones from all localities. In contrast, the Kyocera synthetics contained little or no Cr and Fe, and neither Ga nor Sn was detected.

The majority of the natural V-bearing chrysoberyl displayed diagnostic growth patterns that were clearly observable in immersion. Some of the natural samples also contained characteristic inclusions such as apatite (occasionally associated with cavities or growth tubes), K-feldspar, calcite and negative crystals. The Kyocera synthetics showed no growth structures or mineral inclusions.

The absorption spectra of V-bearing chrysoberyl from three localities show dominant maxima due to V^{3+} (Tunduru and Ilakaka) or mixed V^{3+} and Cr^{3+} (Sri Lanka), as well as the characteristic absorption lines of Fe^{3+}, which were not present in the synthetic chrysoberyl grown by Kyocera.

Consequently, a combination of microscopic, spectroscopic and chemical features provide a clear distinction of natural V-bearing chrysoberyl from its known synthetic counterparts.

Conclusions

Since its discovery in Tunduru, Tanzania, in the mid-1990s, 'mint' green V-bearing chrysoberyl has remained a rare gem material. Despite the demand for this attractive gem, only small quantities have been produced from the known deposits at Tunduru, Ilakaka, Sri Lanka and Mogok.

Until now, the more yellowish green material from Sri Lanka containing relatively higher Fe contents and V>Cr have not been separated from green chrysoberyl from Sri Lanka with Cr>V. This also applies to chrysoberyl from other sources containing both V and Cr in variable but low amounts. Several chrysoberyls from various sources, typically with high Fe contents and low V and/or Cr (<0.04 wt.% oxide) have been analysed by the present authors. Such stones (see, e.g., *Figure 19*) are consistently light yellowish green or greenish yellow, and no separation of these gemstones according to colour or colour cause (i.e., V:Cr ratio) is presently done by the trade.

The two intense bluish green samples examined by the present authors came from Mogok to collections in the UK in the 1970s, and additional samples produced during this time may exist in other private or museum collections. The rediscovery of the original source in the Mogok area of these magnificent, bright gems would certainly cause excitement.

The separation of natural from synthetic V-bearing chrysoberyl can be successfully accomplished by a combination of microscopic, spectroscopic and chemical criteria, provided the gemmologist has an awareness of the different types of natural and synthetic materials produced in the past. Characteristic microscopic features that may help identify natural materials are inclusions and growth structures, while the synthetics contain no inclusions or

may reveal curved growth structures, gas bubbles or residual flux inclusions (depending on the growth technique used). Spectroscopic and chemical data are useful for indicating the presence and ratio of various colour-causing trace elements (V, Cr and Fe). Natural chrysoberyls contain traces of Ga and usually Sn, which are both absent from synthetic material.

Acknowledgements

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Tracing cultured pearls from farm to consumer: A review of potential methods and solutions

Henry A. Hänni and Laurent E. Cartier

Abstract: This article reviews various methods that could be used to determine the geographic origin of cultured pearls, potentially allowing a consumer to trace them back to the farm. Chemical marking using different substances is possible due to the porosity of the nucleus and nacre. It is also possible to affix a logo marker to the nucleus that can later be imaged using X-radiography. In addition, radio-frequency identification chips are today so small that they can be housed within the nucleus of a cultured pearl. Also discussed is the potential of using trace-element chemistry to differentiate mollusc species and pearling regions. Carbon and oxygen isotopes could also be useful given that they reflect the waters in which a cultured pearl grew, and DNA testing may offer options in the future.

Keywords: cultured pearl branding, cultured pearl traceability, LA-ICP-MS, RFID chips, shell and cultured pearl DNA

Introduction

Branded jewellery products are more successful than non-branded goods (Kapferer and Bastien, 2009). There is continued demand from jewellery consumers for branded goods and increasing desire for traceability of products (Conroy, 2007; Ganesan *et al.,* 2009). Cultured pearls are an interesting case study where some products are branded (e.g., *Figure 1*), but traceability to source is something that is difficult to verify independently at present. A cultured pearl strand with a branded tag does not provide a clear guarantee of origin for the end consumer, given that individual cultured pearls can easily be exchanged or strands re-strung. At the same time, there is a growing interest in tracing cultured pearls through the supply chain, so that an end consumer knows which farm their cultured pearls came from. Producers who operate responsibly are investigating ways of marking their cultured pearls so that provenance can be guaranteed to the end consumer.

Any method used to trace cultured pearls must largely be invisible so as to maintain the commercial value of the end products. Cultured pearls are produced both with a nucleus (e.g., Akoya, South Sea and Tahitian) and without a nucleus (e.g., Chinese freshwater beadless products); for general reviews, see for example Gervis and Sims (1992) and Southgate and Lucas (2008). Different labelling/traceability approaches may be required for these two types of cultured pearls, based on their internal structure. This article reviews a wide range of methods — chemical, physical and biological — that potentially could be used in tracing cultured pearls through the supply chain.

Chemical marking

Pearls consist of fine polycrystalline calcium carbonate ($CaCO_3$) crystals and traces of organic matter. The mother-of-

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Figure 1: A branded necklace of South Sea cultured pearls (12 mm in diameter) produced by Atlas Pearls in northern Bali and West Papua (Indonesia). Photo courtesy of Atlas Pearls, Claremont, Western Australia.

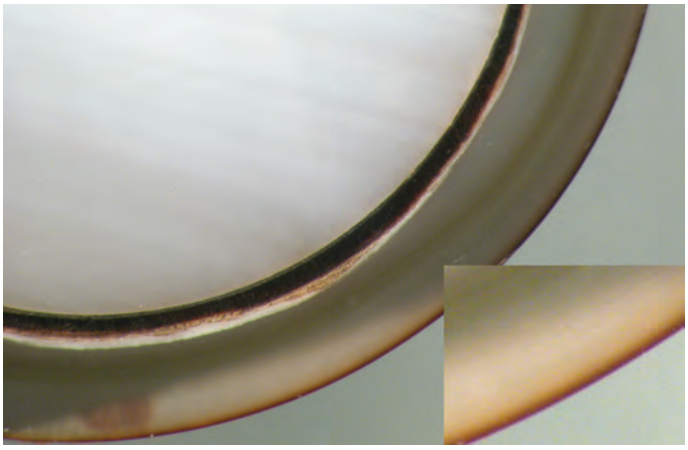

Figure 2: Cross-section of a 'chocolate' beaded cultured pearl. The light-coloured bead (i.e., nucleus) and the darker overgrowth are clearly visible. It is evident in the enlarged image at the bottom right that the brown colour has been artificially added. This demonstrates the porosity of a cultured pearl and its potential for absorbing chemically doped or colour-doped solutions. The colour has penetrated approximately 0.5 mm. Photo by H. A. Hänni.

pearl (also called nacre) surface of pearls is made up of aragonite tablets. A pearl's porous structure means that it has a good potential for absorbing chemically doped or colour-doped solutions. A good example of this are dyed cultured pearls (e.g., *Figure 2*), which can be found in many different colours (Hänni, 2006; Strack, 2006). In a similar way, cultured pearls from selected producers could be marked using a colourless doped solution — that is unique to a pearl producer — after harvest. If chemically doped, these pearls could later be identified in a gemmological laboratory using EDXRF spectroscopy (Hänni, 1981). However, the applicability of this approach is limited given that EDXRF spectroscopy is not in widespread use in the jewellery industry.

Alternatively, rather than marking the cultured pearl after harvest, one could mark the nucleus before insertion using a specific solution. However, if the nacreous overgrowth is too thick, it may not be possible to identify the chemical signal from the nucleus. Another approach would be to remove a tiny amount of nucleus material from a drilled cultured pearl for chemical analysis.

The authors have experimented with the diffusion of fluoroamine (NH_2F) into a cultured pearl, something a pearl farmer could easily do. The subsequent detection of fluorine could then be linked back to that farm. Fluorine is a relatively light element that is not detectable by EDXRF spectroscopy, but is best analysed by nuclear magnetic resonance (NMR). However, NMR is cost-intensive and the instrument's sample chamber is typically smaller than the diameter of a cultured pearl.

If only a limited number of pearl farms are involved in such chemical marking of their cultured pearls, it could be viable to supply each of them with different cost-effective and nontoxic chemicals that could be detected in a gemmological laboratory.

Labelling the nucleus or the surface of a cultured pearl

Initial experiments using physical labels affixed to a cultured pearl nucleus were carried out in 2010 by author HAH. Thin (0.05 mm) rings consisting of gold wire were affixed to several Mississippi shell nuclei (the nucleus material commonly used in the pearl industry) and used to produce cultured pearls. The aim was to investigate the possible rejection of labelled nuclei by the molluscs and to see whether this gold label (or the associated adhesive) would influence cultured pearl growth. Results after six months showed that the labelling materials (gold and glue) had no influence on cultured pearl production and this spurred further efforts to investigate the production of nucleus logos.

Any such logo marker must be extremely thin, be composed of noble metal (and therefore be resistant to corrosion) and have the same convex shape as the nucleus to ensure that the resulting cultured pearl is also round. However, the production of such round metal labels, generally 3–4 mm wide and 0.05 mm thick, is relatively expensive. Different label production techniques were tested, such as galvanic production, pressing, etching and cutting with a

Figure 3: Silver logo labels (3 mm in diameter) for a pearl farm. These can be affixed onto the bead prior to insertion and later be used to trace a beaded cultured pearl back to its farm. Photo by H. A. Hänni.

laser or water jets; these are widely used techniques in manufacturing (Schultze and Bressel, 2001). The water jet technique was most precise for cutting the contours of the logo, but still considered too expensive.

Several dozen logo tags (e.g., *Figure 3*) were affixed to shell nuclei and sent to different marine farms to be tested in cultured pearl production. After the usual 12–18 month growth period, these 'tagged' cultured pearls were harvested and successfully examined with X-radiography *(Figure 4)*. Due to the position of the logo in the peripheral part of a cultured pearl, there is only a statistically small chance of the logo being damaged during drilling.

The production of such logo markers is relatively expensive, even if produced in large quantities. In addition, these cultured pearls need to be tested using X-rays, which is relatively unfeasible for a jeweller. (X-rays used for medical purposes, such as in dentistry, are not strong enough to visualize all required details within a cultured pearl of, e.g., 10 mm.) Nevertheless, for beaded cultured pearls that use a nucleus (e.g., Akoya, South Sea and Tahitian), this method is an option. For beadless cultured pearls (e.g., Chinese freshwater cultured pearls), the introduction of a label together with the saibo (donor mantle tissue) would have the disadvantage of positioning the logo in the centre of the cultured pearl, resulting in a high likelihood of damage during the drilling process.

Another approach is to mark the surface of the cultured pearl rather than the nucleus. This could involve either laser engraving with a unique number (similar to laser inscriptions on diamonds) that can later be used to identify its source or embossing a hologram onto the surface of the cultured pearl that can be read with a suitable reader. Both of these methods are currently being investigated in French Polynesia ('Redonner ses Lettres…', 2013; 'Le Tahiti Pearl Consortium Disparaît', 2013). These methods are slightly destructive to a cultured pearl's surface and it remains to be seen if they are acceptable to the pearl trade.

Only the laser engraving method should have been described as slightly destructive.

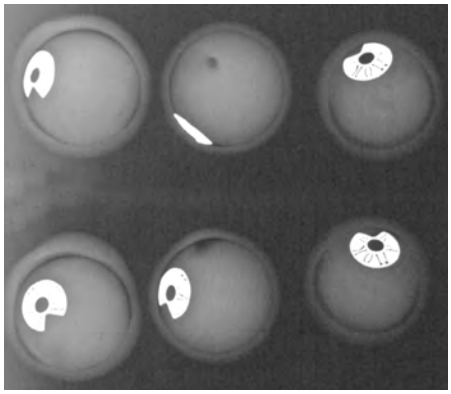

Figure 4: X-radiographs of three Tahitian cultured pearls with a branded nucleus. The farm-specific logos are in silver, which has a high density making it quite visible with X-rays. Three cultured pearls are shown in two slightly different orientations in this composite image. The diameter of the cultured pearls is approximately 8 mm and the width of the logos is 3 mm. Image by H. A. Hänni.

RFID – radio frequency identification

Radio frequency identification (RFID) technology has undergone rapid development in the past decade and is now a widely used method in many technology applications (Want, 2006). It is increasingly being employed in jewellery management solutions (Wyld, 2010). Through the miniaturization of RFID chips (transponders in millimetre sizes), the use of electromagnetic frequencies is a feasible option for the tagging/traceability of cultured pearls. Transponders are chips that contain relevant data which can be accessed with an RFID reader. These devices are inexpensive and they could be easily used in jewellery retail stores ('June HK Fair Special…', 2013). Information stored on the chips could include the production location, harvest date and details about the pearl farm. Additional information can be added to the RFID chip after a cultured pearl has been harvested, including its quality grade, inventory data and unique identification information that could be useful for theft recovery.

RFID chips have been introduced into commonly used Mississippi shell nuclei, which are currently being piloted by pearl farmers in the Pacific Ocean.

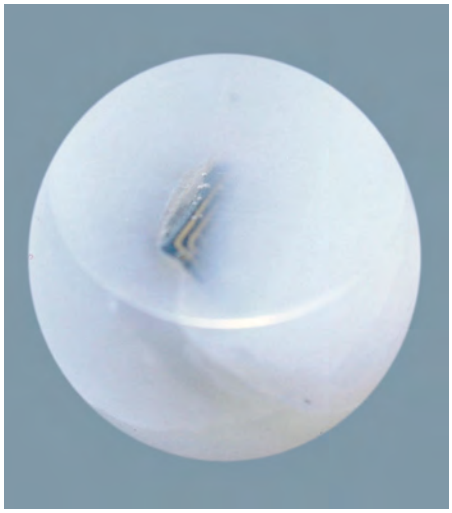

Figure 5: A composite shell bead that has been sliced and polished to show a small RFID chip (3 mm long) embedded within it. The information on such a chip can be accessed using an RFID reader. Photo by H. A. Hänni.

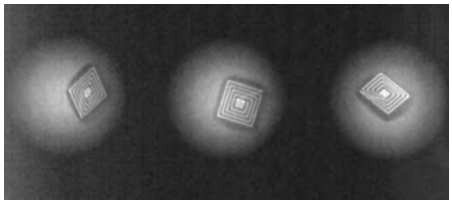

Figure 6: X-ray shadow images of bead nuclei (7.5 mm diameter) consisting of pieces of shell with embedded RFID chips. These are being marketed by Fukui Shell Nucleus Factory. Image by H. A. Hänni.

One nucleus manufacturer (Fukui Shell Nucleus Factory, Hong Kong) has already brought to market nuclei that contain RFID chips (see 'June HK Fair Special…', 2013). *Figure 5* shows such a 'micro-chip embedded nucleus' which, depending on its size, costs US$2–3 per piece. According to the manufacturer, these nuclei consist of two layers of shell material (i.e., laminated nuclei) and a 3 mm RFID chip that is located 1 mm below the surface of the nucleus *(Figure 5)*. *Figure 6* shows an X-ray shadow image of such chip-embedded nuclei.

One disadvantage of these nuclei is the relatively high cost of the chips, which would be wasted in cultured pearls of low quality. Also, the 3 mm size of the straight-edged chips is rather large when taking into account that the nucleus has a spherical shape. The size and position

*Table I: LA-ICP-MS analyses of cultured pearls and shells from various species and locations.**

Habitat		Saltwater														
Sample		*Pinctada maxima* (silver) shell			*Pinctada maxima* (gold) shell			*Pinctada radiata* shell			*Pinctada margaritifera* cultured pearl			*Pinctada margaritifera* cultured pearl		
Source		Indonesia			Philippines			United Arab Emirates (RAK)			Rangiroa, French Polynesia			Fiji		
CaO	wt.%	56.03	56.03	56.03	56.03	56.03	56.03	56.03	56.03	56.03	56.03	56.03	56.03	56.03	56.03	56.03
Na_2O	wt.%	0.91	0.91	0.88	0.84	0.84	0.86	0.97	0.92	0.95	0.75	0.75	0.74	0.90	0.86	0.93
Li	ppm	0.53	0.40	0.40	0.40	0.33	0.23	0.56	0.50	0.56	0.38	0.44	0.40	0.57	0.64	0.69
B	ppm	18.2	20.5	21.2	15.1	15.1	15.6	1.8	1.9	1.7	10.7	10.8	10.6	16.3	14.6	14.0
Mg	ppm	169	180	199	115	115	121	476	392	463	206	198	226	120	98	98
P	ppm	34.0	33.0	35.0	6.6	6.5	6.6	73.2	71.5	71.7	13.8	13.2	12.9	13.3	13.5	12.7
K	ppm	71.1	63.6	51.1	131	157	180	104	118	106	60.0	51.2	42.7	82.7	87.2	83.7
Cr	ppm	2.3	1.9	2.1	2.0	1.9	1.8	2.0	1.8	2.0	2.5	2.2	2.2	2.3	2.4	2.2
Mn	ppm	3.4	3.3	3.4	6.2	6.6	6.2	0.19	0.18	0.18	1.3	1.4	1.4	88.5	92.9	56.9
Fe	ppm	18.4	19.6	17.3	18.3	19.1	22.8	15.6	18.1	18.1	26.9	26.7	29.0	25.4	26.8	28.3
Cu	ppm	0.14	0.08	<0.06	0.09	0.11	0.10	0.26	0.35	0.29	0.11	0.10	0.06	0.04	0.08	0.07
Zn	ppm	<0.08	0.34	0.41	0.38	0.44	0.55	0.59	0.73	0.59	0.28	0.21	0.45	<0.05	0.31	0.12
Sr	ppm	1030	1070	1130	1040	1040	1080	802	775	795	166	169	163	964	138	113
Ba	ppm	0.35	0.49	0.43	0.28	0.26	0.30	0.17	0.15	0.23	0.28	0.37	0.30	0.19	0.39	0.23
Pb	ppm	0.12	0.10	0.10	3.0	3.6	14.9	0.13	0.13	0.12	0.06	0.05	0.05	0.05	0.05	0.04
Ag	ppm	<0.003	<0.004	<0.006	<0.005	0.01	0.01	<0.009	<0.009	<0.004	<0.004	<0.004	<0.004	<0.005	<0.005	<0.005

Habitat		Saltwater						Freshwater								
Sample		*Pteria sterna* shell			*Pteria penguin* shell			*Hyriopsis* shell			*Unio* shell			Ming cultured pearl		
Source		Mexico			Irian Jaya, Indonesia			China			Scotland			China		
CaO	wt.%	56.03	56.03	56.03	56.03	56.03	56.03	56.03	56.03	56.03	56.03	56.03	56.03	56.03	56.03	56.03
Na_2O	wt.%	0.97	0.95	0.88	0.67	0.66	0.70	0.28	0.28	0.28	0.25	0.25	0.25	0.34	0.34	0.35
Li	ppm	0.64	0.57	0.47	0.47	0.56	1.14	<0.07	0.12	0.09	<0.07	<0.09	<0.08	<0.03	0.07	<0.03
B	ppm	5.0	5.5	7.3	8.5	8.5	9.7	4.0	4.0	3.5	3.7	4.4	4.4	0.20	<0.13	<0.14
Mg	ppm	132	73	57	165	147	112	23.9	23.5	15.4	18.3	18.7	56.4	14.0	20.0	18.0
P	ppm	123	122	135	158	150	121	192	183	188	100	113	127	183	191	160
K	ppm	65.7	66.0	65.0	41.8	40.8	50.5	19.6	8.9	5.6	34.6	66.4	95.7	19.0	28.0	6.0
Cr	ppm	2.2	2.0	2.0	2.1	2.2	2.2	2.1	1.7	1.6	2.3	1.4	1.8	2.3	2.6	2.3
Mn	ppm	1.7	1.5	0.8	1.6	1.5	2.2	661	1580	861	519	501	477	133	268	137
Fe	ppm	11.6	13.4	12.8	12.4	12.4	13.7	13.3	12.3	15.1	14.9	16.3	16.3	28.0	29.8	32.4
Cu	ppm	0.10	0.10	0.07	0.06	0.05	0.05	0.17	0.20	0.22	0.33	0.25	0.38	0.25	0.41	0.38
Zn	ppm	0.41	0.40	0.56	0.43	0.33	0.30	0.29	<0.11	0.18	0.67	0.26	0.53	2.3	2.6	1.8
Sr	ppm	1000	908	923	1280	1320	1170	761	877	360	250	260	267	305	446	409
Ba	ppm	0.20	0.17	0.90	1.11	0.96	1.03	247	288	225	469	516	543	57.6	117.3	76.2
Pb	ppm	0.36	0.45	0.40	0.27	0.24	0.29	0.02	0.02	0.02	0.12	0.07	0.14	0.05	0.06	0.13
Ag	ppm	<0.003	0.005	<0.003	<0.002	<0.003	<0.003	<0.006	<0.003	<0.005	<0.004	<0.004	<0.005	<0.02	<0.02	<0.02

* CaO = 56.03 wt.% was used as an internal standard on the basis of the $CaCO_3$ formula for aragonite and calcite. Ag was measured to identify cultured pearls dyed black using silver nitrate. Iodine was analysed in all samples but could not be quantified for lack of an iodine standard. Be, Al, Sc, Ti, V, Co, Ni, As, Rb, Y, Cd, REEs (La, Ce, Nd, Tb, Yb and Lu), and Bi were measured at or just below the detection limit (sub-ppm). Each sample was analysed in three different spots, corresponding to the three columns for each sample.

of these chips within the nucleus means they may often be damaged during the cultured pearl drilling process. Rapid developments in RFID technology are promising, but we may need to await the further miniaturization of the chips before they become a feasible option for the cultured pearl industry.

Advanced fingerprinting of pearl and shell materials

Laser ablation–inductively coupled plasma–mass spectrometry (LA-ICP-MS) has become more widely used in the last few years in geosciences, even in gemmology (e.g., Saminpanya *et al.,* 2003; Abduriyim and Kitawaki, 2006). Many laboratories and researchers now employ it for the chemical characterization of gems because it has a low detection limit and can also detect light elements. With this method it is possible to carry out high-resolution spot analyses, which allows us to take into account possible chemical zoning in gem materials, including cultured pearls. The technique has been used for characterization of cultured freshwater pearls (Jacob *et al.,* 2006) and natural saltwater pearls from Australian *Pinctada maxima* molluscs (Scarratt *et al.,* 2012). To our knowledge, there are no published LA-ICP-MS data on a wider range of cultured pearls or shell samples from various mollusc species.

For this study, a preliminary LA-ICP-MS investigation of cultured pearls and shell material was undertaken at the University of Bern. The instrumentation used a 193 nm ArF laser, and synthetic glass (SRM612) was used as a standard for calibration before and after each round of measurements. This was also done to ensure the reproducibility of measurements and detect possible impurities in the chamber that might affect subsequent data. The pits produced on the surface of the samples during ablation had a diameter of 160 µm. As such, the technique is quasi-nondestructive.

Table I lists the results for the seven shell samples and three cultured pearls from different locations that were analysed. It is clear that further research is required to compile a useful LA-ICP-MS database that might permit origin determination of cultured pearls from different species.

Figure 7: The Atlas Pearl farms that produced the necklace shown in Figure 1 *are located in Bali (shown here) and West Papua, Indonesia. Giving consumers access to the origin of their cultured pearls may create additional value for pearl farmers. Photo by L. Cartier.*

Another possible (and nondestructive) method for chemically fingerprinting gem materials is particle-induced X-ray emission (PIXE), which has been applied to ruby and emerald (Calligaro *et al.,* 1999; Yu *et al.,* 2000). More recently, PIXE was used on cultured pearls (Murao *et al.,* 2013). Other studies have measured oxygen and carbon isotopic values of nacre and cultured pearls in an attempt to identify geographic origin (Yoshimura *et al.,* 2010). However, all these techniques remain academic and expensive, and they presently do not fulfil the requirements for a rapid and cost-effective tracing method for cultured pearls.

A final method that is very new but merits description is DNA fingerprinting of cultured pearls. Oyster shells and pearls have a biological origin and contain small amounts of organic matter between aragonite layers and in the form of organic pockets. A recently published study described how DNA can be extracted from this organic material in cultured pearls in a practically nondestructive manner (Meyer *et al.,* 2013). The DNA can be used to identify the oyster species of the cultured pearl and the authors also proposed that geographic origin determination might also be possible using next generation sequencing (NGS) techniques in the near future. A similar approach has been used for geographic origin and species determination of ivory (Wasser *et al.,* 2004).

Conclusion

The aim of this review is to show the range of currently available methods that potentially could be used to trace cultured pearls through the supply chain. Supply chain accountability and product traceability are becoming increasingly important issues in the jewellery industry. The branding strategies of various producers, wholesalers and jewellery companies would benefit from additional support through an efficient traceability method. Furthermore, there is a potential for responsible pearl farmers (e.g., *Figure 7*) to capture greater value for their products if they can be traced all

the way to the consumer, but the supply chain accountability and provenance need to be guaranteed (Conroy, 2005; Cartier 2012; Cartier and Ali, 2012). As technology continues to evolve, the search for methods to trace cultured pearls through the supply chain should be addressed in collaboration with the gemmological community and the focus should be on developing cost-effective solutions that are feasible for those at all levels of the supply chain (producer, wholesaler, retailer and consumer).

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Abstracts

Diamonds

The Ellendale diamond field: exploration history, discovery, geology and mining.
A.L. Ahmat. *Australian Gemmologist,* 24(12), 2012, 280–8.
This article concentrates on the history and geology of this significant hard-rock diamondiferous region. Regarded as a source of high-value fancy yellow diamonds, a summary of recent mining production is included along with an expected life span. L.G.

The Kimberley Diamond Company Ellendale diamond collection at the Western Australian Museum.
P.J. Downes, A.W.R. Bevan and G.L. Deacon. *Australian Gemmologist*, **24**(12), 2012, 289–93.

The authors describe a representative collection of yellow and colourless rough diamonds (38.06 carats total weight) in the Kimberley Diamond Company Ellendale diamond collection at the Western Australian Museum, from the operations at Ellendale in the West Kimberley region of Western Australia. History, geological setting and characteristics of diamonds from this region are outlined. L.G.

The Kimberley Process: it's a question of provenance, not origin.
H. Levy. *Gems&Jewellery,* **22**(7), 2013, 10–11.

The author outlines the beginnings of the Kimberley Process and its purpose, and questions whether in the future it can incorporate such issues as human rights. Perceptions of origin and provenance from inside and outside the gemmological community are compared and examples discussed. L.G.

Diamonds: not all is explained with clarity.
A. Matlins. *Gems&Jewellery,* **22**(7), 2013, 17.

The author and a reporter from ABC-TV follow up a previous investigation in New York regarding the disclosure of clarity-enhanced diamonds. Their experiences are documented and comparisons made to the industry eight years ago when the previous investigation on filled diamonds was carried out. L.G.

Lab Notes.
T.M. Moses and S.F. McClure (Eds). *Gems & Gemology,* **48**(4), 2012, 300–3.

A 1.04 ct round brilliant diamond was graded Fancy reddish brown. Whilst the colour appeared natural, it was obviously attributed to heavy irradiation and annealing. UV-Vis-NIR absorption spectroscopy yielded additional interesting features.

A 15.01 ct cushion-cut diamond was graded as Fancy Intense yellow. The stone had previously been submitted and had then been graded Fancy Light yellow. Additional strengthening of the H3 and H4 optical centres was detected by infrared absorption spectroscopy; previously only moderate concentrations were observed in spectra at liquid nitrogen temperatures. The results suggested that artificial treatment had been carried out to strengthen the colour.

Two crystal inclusions, a green diopside and a reddish pyrope, in contact with one another were seen in a 2.34 ct cape Fancy yellow diamond. DiamondView images suggested that the inclusions were formed during the diamond's growth. In a peridotite environment, singular and binary inclusions can be useful in calculating the equilibrium pressure and temperature of diamond formation, although post-growth events may alter the preservation of these conditions.

A 2.03 ct Fancy yellow-green diamond contained inclusions of greyish blue omphacite in contact with orange garnet. This was the first time this assemblage was seen in the Carlsbad laboratory. C.M.

Lab Notes.
T.M. Moses and S.F. McClure (Eds). *Gems & Gemology,* **49**(1), 2013, 44–7.

Thirty unusual 'buff-top' round-cut diamonds weighing 0.25–1.50 ct were graded. Their cut style made grading challenging. The cutting methods were considered.

An unusually large HPHT-treated Fancy pink diamond of 20.32 ct displayed no secondary colours that are common in HPHT-treated diamonds, making this a rare case. Interference colours observed with crossed polars were associated with HPHT treatment. The diamond demonstrates improvements in the HPHT technique.

A 1.53 ct heart-shaped Fancy Intense pinkish orange diamond showed an absorption band at 550 nm, which is usually associated with pink-to-red coloration. The reason for the unusual colour was not fully understood.

A near-colourless 0.70 ct round brilliant diamond displayed subtle cuboctahedral growth structure with the DiamondView, which usually indicates HPHT-grown synthetic diamond. Small cuboctahedral forms can be found in nature but are very rare. Microscopic observation confirmed the diamond to be natural.

A Fancy Deep green 3.17 ct round brilliant diamond was examined. Microscopic observation revealed it had been coloured by radioactive salts, rarely

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Abstracts (continued)

encountered today. Unusual surface coloration was seen in diffused light.

A 4.72 ct Light blue rectangular-cut diamond showed an extremely strong 579.9 nm emission centre and lattice dislocations that were the strongest yet observed in the laboratory. C.M.

Gems and Minerals

Experiences on the South Australian Mintabie opal fields – past and present.
P. Blythe, M. Novelli and T. Coldham. *Australian Gemmologist,* **25**(2), 2013, 46–54.

A brief history of the Mintabie opal field is outlined. The area was listed as a gem field in 1933 and substantial recovery began during the 1960s. The experiences and photographs of miners Peter Blythe and Max Novelli are documented through the rest of the paper as they lived and worked in the field spanning from the early 1980s until today. L.G.

New developments in cultured pearl production: use of organic and baroque shell nuclei.
L.E. Cartier and M.S. Krzemnicki. *Australian Gemmologist,* **25**(1), 2013, 6–13.

In this detailed paper the authors discuss the context, composition, process and application of organic nuclei for the production of baroque cultured pearls. Expansion of this organic material allows large cultured pearls to be produced. Varying generations of cultured pearls with different nuclei are examined and their appearance, identification features and properties compared using both standard and laboratory equipment. L.G.

Violet and pink coated opals.
G. Choudhary. *Australian Gemmologist,* **25**(2), 2013, 55–7.

Since the discovery of opal in the Wollo province of Ethiopia, a variety of colours of treated opal have appeared on the market. The author studies two beads of violet and pink coated opals, using both standard and laboratory equipment. As well as identifying the source of the coloration, the author makes the surprising discovery that the base material is different from that of the Wollo province. L.G.

Echte Perlen und Zuchtperlen: ein Grundkonzept und seine Variationen. (Natural and cultured pearls: a basic concept and its variation.)
H.A. Hänni. *Gemmologie. Z. Dt. Gemmol. Ges.,* **62**(1/2), 2013, 3–18.

Natural pearls are the results of an injury to the mollusc's mantle tissue in which some cells are displaced to form a cyst. Natural pearls are not formed by grains of sand, as these cannot drill themselves into the mantle. To produce cultured pearls there are a number of options: non-beaded cultured pearls are usually mantle-grown in freshwater mussels. Beaded cultured pearls are usually gonad-grown in saltwater oysters. There are minor variations which lead to the great number of different products available on the market today. The author describes in detail the operation performed on the oyster or mussel to produce a cultured pearl as well as the materials inserted, which can vary from mother-of-pearl beads to natural or cultured pearls of poor quality. E.S.

Highlights from the Giazotto mineral collection.
R. Hansen and L. Rennie. *Australian Gemmologist,* **24**(12), 2012, 302–3.

This article shows some spectacular well-formed 'museum sized' crystal specimens from the more than 500 minerals displayed at the Museo di Storia Naturale in Florence, Italy. Collected over some 50 years, they include 'The Emperor of India', a 9.8 kg prismatic aquamarine that is 32 cm high, and clusters of 'blue cap' tourmaline from Lavra da Sapo, Minas Gerais, Brazil. L.G.

Gemmologische Kurzinformationen. Gelber transparenter Opal aus Mali. (Yellow transparent opal from Mali.)
U. Henn. *Gemmologie. Z. Dt. Gemmol. Ges.,* **62**(1/2), 2013, 46–8.

A yellow transparent opal from a region near Kayes in western Mali was found to be similar to material found in Mexico and Brazil, with RIs = 1.446–1.453 and SG = 2.05. The yellow colour is due to inclusions of iron hydroxides. E.S.

Infrared spectroscopic study of filled moonstone.
Jianjun Li, Xiaofan Weng, Xiaoyan Yu, Xiaowei Liu, Zhenyu Chen and Guihua Li. *Gems & Gemology,* **49**(1), 2013, 28–34.

Twenty-two beads of plagioclase moonstone were studied. Infrared spectroscopy confirmed 15 of the 22 had been filled with material of a benzene structure, their composition having been identified as close to albite. Links are described between the strength and distribution of UV fluorescence with the filling. It is also noted how filler may be suspected using standard magnification and warns of this treatment now being found in gem materials other than the more well-known emerald. L.G.

Gemological characteristics of saltwater cultured pearls produced after xenotransplantation.
S. Karampelas and A. Lombard. *Gems & Gemology,* **49**(1), 2013, 36–41.

Cultured pearl samples grown by the xenotransplantation between bivalve species are considered. Spectroscopic techniques and X-radiography were used on 10 of these experimental cultured pearls of various colours and sizes, and the study allowed links between the host animal and the donor when creating cultured pearls to be further investigated. Interestingly, using spectroscopy the mantle donor species may be identified but not the host. The investigation further confirms previous research regarding whether the donor animal or the host will dictate coloration and nacre thickness of the resulting cultured pearl. L.G.

Cobalt-doped glass-filled sapphires: an update.
T. Leelawatanasuk, W. Atitchat, V. Pisutha-Arnond, P. Wattanakul, P. Ounorn, W. Manorotkul and R.W. Hughes. *Australian Gemmologist,* **25**(1), 2013, 14–20.

Updated information is provided regarding the latest generation of blue glass-filled sapphires. A short history

Abstracts (continued)

of the process is outlined along with properties of both earlier and newer material. It is concluded that standard gemmological equipment may be used to identify either material, with advanced tests able to provide more information. L.G.

Color origin of lavender jadeite: an alternative approach.
R. Lu. *Gems & Gemology,* **48**(4), 2012, 273–83.

The colour origin of lavender jadeite is examined using gemmological observation, UV-Vis spectroscopy and modern trace-element analytical techniques. Analysing high-quality single crystals of closely matched materials with laser ablation–inductively coupled plasma–mass spectrometry (LA-ICP-MS) provided detailed chemical compositions.

Nine natural jadeite slabs, 16 impregnated and/or colour-enhanced jadeites, plus three natural crystals of spodumene were tested. The spodumene was used since the properties of this pyroxene are similar to that of jadeite. Polycrystalline jadeite was found to be difficult to analyse.

Through analysis, confirmation was obtained that manganese and chromium are the causes of lavender and green coloration in jadeite, respectively. C.M.

Korunde mit blauem kobalthaltigem Bleiglas gefüllt. (Corundum with blue cobalt-bearing lead glass filling.)
C.C. Milisenda, K. Schollenbruch and S. Koch. *Gemmologie. Z. Dt. Gemmol. Ges.,* **62**(1/2), 2013, 19–24.

The article describes the gemmological properties of corundum which has been dyed blue and clarity enhanced with cobalt- and lead-bearing glass. There is concentration of blue colour in surface-reaching fissures and cavities, and bubble-like inclusions can also be seen. There is also the flash effect commonly seen in glass-filled rubies. Chemical analysis shows elevated lead and cobalt contents. The spectrum shows cobalt-related absorption lines at 530, 590 and 635 nm. This treatment can easily be identified with a 10× loupe. E.S.

Sammlersteine — Teil II. (Collectors' stones — part II.)
C.C. Milisenda, S. Koch and M. Wild. *Gemmologie. Z. Dt. Gemmol. Ges.,* **62**(1/2), 2013, 31–45.

This article describes gem specimens that were submitted to the German Gemmological Laboratory. Gemmological data is given for each specimen. Included are transparent, faceted brown axinites from Pakistan weighing 4.18 and 4.56 ct; a cut, blue opaque ceruleite from Chile; samples of iron-containing orthorhombic crystals of yellow-brown childrenite-eosphorite from Brazil and Pakistan; opaque, faceted davidite from Norway; a green, faceted, transparent actinolite and a transparent faceted yellow-green tremolite, both from Tanzania; a grey-blue 0.14 ct stone from the U.S.A. identified as lawsonite; a transparent faceted octagonal mellite from Hungary; a pale yellow octagon from Kazakhstan identified as preobrazhenskite; a transparent, yellow sellaite from Brazil; a transparent, orange-pink serandite from Canada; a round grey-blue faceted vesuvianite from Pakistan; an oval greyish white wardite from Austria as well as a pyrargyrite from Peru; an orange-pink bustamite from South Africa; and round faceted sphalerites from the Las Manforas mine in Cantabria, Spain, a well-known source of cuttable sphalerite. E.S.

Lab Notes.
T.M. Moses and S.F. McClure (Eds). *Gems & Gemology,* **48**(4), 2012, 303–4.

Two green stones were submitted for emerald origin reports. Unusually low SG readings of 2.43 and 2.37, a lack of chromium lines in the spectrum and strong fluorescence to long-wave UV radiation raised suspicions. Further tests including microscopic examination and Raman spectroscopy revealed a natural beryl top and core, with a polymer layer on the bottom.

The results are given of UV-Vis spectral readings on both the blue and red areas of a 14.60 ct bicoloured spinel with unusual colour zoning. This was the first bicoloured spinel seen by the Bangkok lab. C.M.

Pennies from heaven: a market for meteorites.
J. Ogden. *Gems&Jewellery,* **22**(6), 2013, 8.

The author discusses Steve Arnold's passion and profession as a meteorite hunter, and his travels worldwide to acquire specimens. A wide range of meteorites and associated minerals are listed from his inventory, and methods of tracking and recent imitations are given. L.G.

Spell bound.
J. Ogden. *Gems&Jewellery,* **22**(7), 2013, 20–1.

Nineteenth-century acrostic jewellery is discussed in which names and sentiments are conveyed through each gemstone's name. Early recorded French examples are examined through well-known pieces such as the 'regards ring' to more unusual political pieces of the 1920s. Complications involving alternative names are considered with the possibility that some secrets will never be revealed. L.G.

Dichromatism, the cause of the usambara and alexandrite colour change effect.
G.M. Pearson and D.B. Hoover. *Australian Gemmologist,* **25**(2), 2013, 62–70.

The authors first discuss and define the term dichromatism within minerals; adding a context of its different meanings within several branches of the sciences and a history documenting its discovery and research. The Beer-Lambert law is described in relation to dichromatism and hypothetical situations presented that would simulate the effect. Finally, a number of gemmological examples and their transmission spectra are examined, including Tanzanian chromium-vanadium dark green tourmaline, Brazilian rhodolite garnet and synthetic chrome spinel. L.G.

Big gem trend.
G. Roskin. *Gems&Jewellery,* **22**(6), 2013, 9–11.

The author considers the current trend for large and wearable gems, and discusses such stones seen at JCK Las Vegas Show in June. These pieces were more affordable and wearable than the described museum pieces, but they were still both rare and spectacular. L.G.

Abstracts (continued)

Natural pearls from Australian *Pinctada maxima.*

K. Scarratt, P. Bracher, M. Bracher, A. Attawi, A. Safar, S. Saesaw, A. Homkrajae and N. Sturman. *Gems & Gemology,* **48**(4), 2012, 236–61.

A history of natural pearling in Australia is given, comparing the properties of natural and cultured pearls from the area.

Early trading and diving methods for *Pinctada maxima,* values and expenditures are detailed, from the early writings of E.W. Streeter, Kornitzer and Gale through to modern-day literature. A table illustrates values of pearl shell recovered in 1889–1898 (from Gale, 1901).

Broome, Western Australia, has always played a large part in the industry and even today it continues as an important part of the cultured pearl market. In early times it was considered a 'wild west' town with high mortality due to sickness, natural disasters and the dangers of diving; attention is drawn to a cemetery with the graves of some 900 Japanese pearl divers.

The article considers the wane in popularity of the *Pinctada maxima* and its re-emergence, with major pearl finds, qualities and quantities from that area noted, including the 'Southern Cross' pearl which is mentioned in detail and was examined by one of the authors (KS).

Other products produced by *Pinctada maxima* are considered, i.e. utensils, inlays and edible meat.

Production regulations and harvesting methods are given briefly. Studies were done of wild unopened *Pinctada maxima* through microscopic observation, X-ray, LA-ICP-MS, UV-Vis-NIR, Raman and photoluminescence (PL) data at GIA's Bangkok laboratory. Results are provided through photos, graphs and tables.

In conclusion, "microradiographic structures previously used to distinguish between natural *Pinctada maxima* pearls and accidently cultured specimens are not conclusive" plus "the products of pearl sacs formed by nature within hatchery-reared shell are virtually indistinguishable from natural pearls and could not be identified as cultured". More samples are to be collected and examined and data provided in a future report. C.M.

Vanadium- and chromium-bearing chrysoberyl from Mogok, Myanmar.

K. Schmetzer, H.J. Bernhardt and C. Cavey. *Australian Gemmologist,* **25**(2), 2013, 41–5.

The two historic samples studied are examples of chrysoberyl of a bright bluish green colour rarely submitted to laboratories today for testing. Morphology, gemmological properties and microscopic features are described along with coloration, trace-element contents and spectroscopic properties. It is investigated why, despite their coloration and chromium content, these samples do not show a distinctive colour change between light sources. It is also speculated whether these may have come from the same Myanmar source as an intensely coloured crystal described by Payne in 1956 said to come from the collection of A.C.D. Pain. L.G.

Unusual organic gem materials — chitons.

S. Stocklmayer. *Australian Gemmologist,* **25**(2), 2013, 58–9.

The author discusses the use of an unusual type of decorative material. Chitons are marine creatures found worldwide in cold and tropical seas with an aragonite shell of eight articulated plates. Pendants containing these creatures' shells up to 50 mm in length were observed in Ushuaia, on the extreme south coast of Argentina. L.G.

Non-decorative jewels – with particular reference to watch jewel bearings and components.

J. Warner. *Australian Gemmologist,* **24**(12), 2012, 294–301.

Due to their hardness and inert properties, many gem materials have long been used in industrial applications as well as for decorative use. The author lists applications of these from the Stone Age to the present with emphasis upon development of their use within watches. L.G.

Hibonit aus Myanmar (Burma). (Hibonite from Myanmar [Burma].)

M. Wild and C.C. Milisenda. *Gemmologie. Z. Dt. Gemmol. Ges.,* **62**(1/2), 2013, 25–30.

The authors studied gem-quality hibonite from Myanmar consisting of a crystal weighing 0.10 g and two faceted yellowish brown and orangey brown specimens weighing 0.50 and 0.45 ct, respectively. Hibonite is a calcium-aluminium oxide, Mohs hardness = 7½–8, RI = 1.788–1.792, dichroic yellow-brown to orange-brown. Hibonite is fairly rare and seldom faceted above half a carat. It might be taken for phlogopite as the rough material looks very similar and is found in the same mine. E.S.

A comparison of modern and fossil ivories using multiple techniques.

Zuowei Yin, Pengfei Zhang, Quanli Chen, Chen Zheng and Yuling Li. *Gems & Gemology,* **49**(1), 2013, 16–27.

Samples of both fossil and modern ivory (mammoth and elephant) were examined using standard gemmological equipment, followed by laboratory equipment. These materials may look very similar, especially if the fossil ivory is only weakly weathered. Samples and their sources are described, with many being sliced for analysis and some ground to powder. Observation of 'Schreger lines' to distinguish them requires much caution as the angles can vary between layers as well as cutting direction and consequently overlap. High magnification proved useful, showing a differing structure between each material, and spectroscopy revealed distinct water and collagen contents. Trace elements may also indicate their differences. L.G.

Instruments and Techniques

Update on the identification of dye treatment in yellow or 'golden' cultured pearls.

Chunhui Zhou, Artitya Homkrajae, Joyce Wing Yan Ho, A. Hyatt and N. Sturman. *Gems & Gemology,* 48(4), 2012, 284–91.

Dye treatments in yellow or 'golden' cultured pearls have dramatically improved, leaving little surface evidence. The authors used routine observations, UV-Vis reflectance and Raman PL spectroscopy to analyse eight sample groups of the cultured pearls. The groups consisted of natural-coloured South Seas cultured pearls from the Philippines and

Abstracts (continued)

Myanmar, dyed South Sea and Akoya cultured pearls, dyed freshwater non-beaded cultured pearls and heat-treated yellow cultured pearls. Observational results are provided in a table and graphs illustrate the results of advanced testing.

Conclusions were drawn that many dyed yellow or 'golden' cultured pearls can still be easily detected using observational techniques. Those lacking any visible evidence of dye can be identified by nondestructive testing techniques. C.M.

Detecting HPHT synthetic diamond using a handheld magnet.
K. Feral. *Gems & Gemology,* **48**(4), 2012, 262–72.

The use of magnets is investigated for testing individual HPHT-grown synthetic diamonds, either loose or mounted in jewellery, down to melee-sized goods. The author tested five types of magnets, and a total of 85 HPHT synthetic diamonds of varying size and colour were studied. The direct method (dragged along a smooth dry surface), and flotation method (reducing friction therefore enhancing sensitivity) and pinpoint testing methods were applied. Results were classified according to weak, drag, pickup and strong diamagnetism (repelled). Magnet size and strength was considered and terminology of magnetism is provided for the reader.

As a control, 168 natural diamonds were also tested — with one containing inclusions large enough (over 0.5 mm and close to the surface) to be attracted to the magnet (using the flotation method). This is the first reported case of a facetable natural diamond attracted to a magnet due to minute inclusions. Also tested were 58 HPHT-treated natural diamonds, 48 natural diamonds in gold jewellery and 19 CVD-grown synthetic diamonds.

Although a significant percentage of HPHT-grown synthetic diamonds could be detected, CVD synthetics could not be separated using this method. Natural diamonds may contain ferromagnetic or paramagnetic inclusions either as inclusions or as contaminants from polishing and handling, but they are rarely detectable with a magnet.

The article concluded that N52-grade neodymium magnets achieved the highest rate of detection. C.M.

Miscellaneous

Auction houses, a powerful market influence on major diamonds and coloured gemstones.
R. Shor. *Gems & Gemology,* **49**(1), 2013, 2–15.

The article highlights the fact that today the highest-profile sellers of major diamonds are the world's two largest auction houses, Sotheby's and Christie's, being major competitors with traditional jewellery houses, influencing and increasing the prices and awareness of coloured diamonds. This trend commenced with the sale of the Wittelsbach Graff diamond in December 2008, with subsequent records being reached.

The histories of both auction houses are given, including observations of the market influence of 'celebrity' gem auctions commencing with what was to be the Taylor Burton. As a consequence, a new market channel known as the 'auction effect' on trade and retail markets stabilized in the early 1980s. The emergence of a strong relationship between luxury jewel houses, dealers and auction houses developed.

High-profile sales such as those of the Duchess of Windsor's jewels are considered as a 'watershed event', establishing auction houses as major players and strongly influencing prices and creating more consumers through media awareness. Cataloguing has become more detailed, including origin reports and treatment information.

Controversy over pricing and selling directly to clients and the legal consequences of such are reviewed.

In the early part of the 21st century, new ultra-wealthy markets were emerging in places such as Asia, creating a renewed demand. Important auctions are now being offered there and becoming market leaders, with fancy-colour diamonds playing an important role in the market over the past 15 years; price increases during this time are given and their reasons are discussed. C.M.

Synthetics and Simulants

Gemmologische Kurzinformationen. Synthetischer zweifarbiger Quarz. (Synthetic two-coloured quartz.)
U. Henn. *Gemmologie. Z. Dt. Gemmol. Ges.,* **62**(1/2), 2013, 49–51.

Bicoloured synthetic quartz is described that shows a blue and a green colour zone. The green is coloured by Fe with two absorption bands at 743 and 923 nm, while the blue is due to Co^{2+} with absorption bands at 547, 591 and 646 nm. E.S.

A mystery jewel.
J.G. Henry and T. Coldham. *Australian Gemmologist,* **25**(1), 2013, 21–5.

An unusual inclusion within a ring-mounted purple gem is examined. Under 40× magnification the inclusion transpires to be a microphotograph family portrait embedded in the 6.5×4.5 mm faceted sample. Methods of production and makers are speculated with a description of the inclusion and observations under magnification. L.G.

Follow up on the 'mystery jewel'.
J.G. Henry. *Australian Gemmologist,* **25**(2), 2013, 60–1.
This is a continuation from the article 'Mystery Jewel' that was published in the *Australian Gemmologist,* 25(1). Having received more information about the photograph, further thoughts are added regarding the caption upon the image and possible manufacturers. Upon a second viewing, the stone is identified as glass and, thanks to other specialists, the location, construction and date of the ring with its contents are revealed. L.G.

Gemmologische Kurzinformationen. Künstliches Glas als Diasporimitation. (Synthetic glass as diaspore imitation.)
C.C. Milisenda and S. Koch. *Gemmologie. Z. Dt. Gemmol. Ges.,* **62**(1/2), 2013, 52.

The authors studied loose and mounted stones that were sold in Turkey

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as 'Zultanite', which is a trade name for the mineral diaspore. They were identified as light-rare-earth–doped artificial glass. E.S.

Lab Notes.
T.M. Moses and S.F. McClure (Eds). *Gems & Gemology,* **48**(4), 2012, 304–5.

Two HPHT-grown synthetic diamonds were tested, a 0.51 ct round brilliant Fancy Light blue and a 0.79 ct round brilliant Fancy Deep blue. DiamondView fluorescence images showed octahedral and cubic growth patterns typical for HPHT synthetics. PL emissions at 736.6 and 736.9 nm were recorded and attributed to the $[Si\text{-}V]^-$ centre common in CVD synthetic diamonds but believed to be rare in HPHT-grown synthetics. C.M.

Lab Notes.
T.M. Moses and S.F. McClure (Eds). *Gems & Gemology,* **49**(1), 2013, 47–50.

A 0.94 ct Fancy yellow-brown emerald-cut CVD synthetic diamond was examined. This was the first to be observed at GIA with aggregated nitrogen impurities that had not undergone additional HPHT treatment.

Three CVD synthetic diamonds were tested, a rectangular step cut of 0.93 ct, and two round brilliants of 0.52 and 0.57 ct. Different growth and/or treatment histories were detected by a combination of laboratory techniques. With the DiamondView, the 0.57 ct sample displayed a fluorescent colour combination not seen before in a GIA lab.

A CVD synthetic diamond of 2.16 ct was the largest seen by GIA so far. The stone indicates the rapid improvement of CVD growth technology.

A 2.58 ct yellow synthetic sapphire was reported, coloured by a trapped–hole mechanism. C.M.

Abstractors

C. Mitchell — C.M. E. Stern — E.S. L. Gleave — L.G.

Book reviews

HPHT-Treated Diamonds
Inga A. Dobrinets, Victor G. Vins and Alexander M. Zaitsev, 2013. *Springer Series in Materials Science,* Volume 181. Springer-Verlag, Berlin and Heidelberg, Germany, 257 pages, http://link.springer.com/book/10.1007/978-3-642-37490-6. ISBN 978-3-642-37489-0 (print, US$139.00) and 978-3-642-37490-6 (online, US$179.00).

This is the first book that attempts to describe the process of high-pressure, high-temperature (HPHT) treatment of diamonds and the characteristics of diamonds so treated. The objective of HPHT treatment is the reduction or removal of the undesirable brown colour, frequently found in natural diamonds, to produce more valuable colourless, near-colourless or fancy-colour diamonds. Following the first announcement of this treatment, the then-president of GIA, Bill Boyajian, wrote in 2000 that HPHT treatment was "arguably one of the most serious challenges the diamond industry has ever faced". Even today, the identification of HPHT-treated diamonds remains a major and complex task for gemmological laboratories, and the authors make clear in the preface that the main aim of this book is to aid those dealing with potentially HPHT-treated diamonds in their identification.

All three authors began their scientific careers in Russia, and each has been engaged in diamond research for many years. Dr Inga Dobrinets is now at RUBION, an ion beam and radionuclide research facility at Ruhr-Universität Bochum, Germany, having previously been employed as a gemmologist at EGL New York. Prof. Alexander Zaitsev is now in the Engineering Science and Physics Department of the College of Staten Island, New York. Prof. Zaitsev is best known for his data handbook, *Optical Properties of Diamond* (2001), which attempts to provide a comprehensive list of all optical spectroscopic features found in diamond. Dr Victor Vins is the only one of the three still in Russia where, in Novosibirsk, he runs his own business, VinsDiam Ltd, a company that carries out irradiation and HPHT treatment of both natural and synthetic diamonds. He is therefore able to provide interesting insight into both the technological and commercial aspects of the HPHT treatment of diamonds.

Brown colour in natural diamonds is believed to be due to clusters of vacancies that form following the interaction of dislocations that were introduced by plastic deformation during their geological history. The very high temperatures used in HPHT treatment, typically 1900–2300°C, with the application of high pressure to avoid graphitization, lead to the breakup of the vacancy clusters with a loss of

Book reviews (continued)

brown colour, and the formation of various defects such as isolated nitrogen and nitrogen-vacancy defects if nitrogen is present in sufficient concentrations. As the authors point out, the precise details of the changes induced by HPHT treatment depend upon the defects that are present in the starting material and the temperature, pressure and duration of the treatment. Treatments are often carried out for only a few minutes and this can result in highly non-equilibrium concentrations of defects, which complicates understanding of what is going on during treatment. In some cases, HPHT-treated diamonds are subsequently irradiated and heated to somewhat lower temperatures than used in HPHT treatment to produce, for instance, high concentrations of nitrogen-vacancy defects that give rise to the so-called 'Imperial Red' colour. The nature of the features present or absent in HPHT-treated diamonds is extremely complex so identification can be challenging in some cases. This is especially the case when treaters deliberately reintroduce features destroyed during treatment with the sole intention of concealing the treatment.

The book describes the characteristics of the various kinds of diamonds that may be subjected to HPHT treatment and how these may change upon treatment. The main body of the book, some 100 pages, follows the format of Zaitsev's earlier handbook in listing the optical absorption and photoluminescence spectroscopic features that may be relevant to identification of HPHT-treated diamonds. Some of this data comes from the authors' own research but most has been carefully gleaned from the published literature. Some of the references that they have found are extremely obscure and it is very valuable that they have brought them to light. Several of the optical features listed are thought to be due to nickel-related defects found in HPHT synthetics and, occasionally, in some natural diamonds. Whilst it is okay that these defects are included for completeness, it is unlikely that many will be encountered in a gemmological laboratory in the context of HPHT treatment identification. The authors clearly expect the book to be used as a reference handbook rather than as a textbook, and have attempted to make each section stand on its own. The result is a great deal of repetition. It might have been better if specific points had been explained clearly and completely once rather than explained briefly several times. A reader who is unfamiliar with concepts such as radiation damage or nitrogen aggregation in diamond may find the explanations given in this book rather confusing.

The book, unfortunately, has not been well edited. Some references are missing or incomplete, and one or two figures are missing or referred by the wrong number in the text. Whilst one accepts that none of the authors is a native English speaker, it is a pity that several grammatical and spelling mistakes have not been corrected (e.g., the frequent absence of the definite article can be irritating, and the word 'peak' is written as 'pick' in several instances). However, this does not really detract from the comprehensibility of the text.

The list of optical features is very comprehensive but there are a few instances where the information given is not altogether accurate. One example is the discussion of the line-width of the zero-phonon line of the GR1 centre, where the authors say that this "cannot be practically used for recognition of HPHT treatment (Fisher et al 2006)." In fact, this reference does indicate how the line-width might be used for this purpose. In another case, the authors do not distinguish between a line seen in photoluminescence at 648 nm, found in untreated type IIb diamonds, and a line at 649 nm, which is found in some HPHT-treated diamonds as well as some untreated diamonds.

Those engaged in identifying HPHT-treated diamonds will find this book a useful reference but it will need to be used with caution. Leading gem testing laboratories have developed their identification criteria over many years by careful research and observation of many thousands of stones. Much of this data remains unpublished for the simple reason that gem laboratories want to avoid assisting those who might seek to undermine their identification criteria. Consequently, this kind of material has not been available to the authors for inclusion in their book.

Dr C.M. Welbourn

The Handbook of Gemmology

Geoffrey Dominy, 2013. Amazonas Gem Publications, Vancouver, British Columbia, Canada, 652 pp, http://handbookofgemmology.com, ISBN 978-0-9918882-0-7. US$39.95 per digital download or US$49.95 for a DVD containing all formats.

This book is the latest addition to the electronic arsenal of the gemmologist, picking up and covering areas previously neglected by other commercially available software. *The Handbook* offers all the information found in traditional reference books, but in a new and more versatile format. The 'deluxe' edition comes packaged in several formats, covering a wide range of devices and platforms (iPad, iPhone, Android, e-reader, Mac and Windows). For this review, *The Handbook* was tested using Windows 8, iPad, iPhone and Android devices.

The program itself is relatively intuitive and runs well, without problems or hitches, even while other programs are running in Windows 8. On iPad and iPhone, *The Handbook* runs equally well, with the functionality being maintained. Despite the smaller screen it works well on a smartphone, although only sections of each page can be viewed at a readable size at any time. The search function works effectively, displaying a list of results for the location of any word within the entire *Handbook*, and each links back to the relevant section, enabling cross reference of data. There is also a bookmark facility, enabling key sections to be marked for quick access, which can be combined with a note function, enabling the user to record their own findings or thoughts wherever desired. Highlighter and zoom functions complete the set of available tools, and these should keep even the most gadget-minded gemmologist happy. The zoom functionality is especially helpful for smartphone users, as it allows sections of a page to be enlarged whilst maintaining

Book reviews (continued)

the quality of the original. Once enlarged, the viewing area can be moved around the page fluidly.

Thumbing through *The Handbook* in any of its non-PDF formats is reminiscent of a true paper book, with a page turn setup that works responsively and provides a good user interface.

Split into the 30 sections listed below, covering 652 pages, *The Handbook* sets out to systematically cover the key areas that any gemmologist or student would need to know:

1. What is a gemstone?
2. The chemical nature of gemstones
3. Physical, chemical and optical properties
4. Basic crystallography
5. The absorption of light and the spectroscope
6. The 3 Rs — reflection, refraction and the refractometer
7. Polarized light and the polariscope
8. Pleochroism, the dichroscope and colour filters
9. Specific gravity
10. Luminescence
11. Magnification and thermal conductivity
12. Imitation and assembled stones
13. Synthetic gemstones
14. Gemstone enhancements
15. Gem mining
16. Gem cutting and grading
17. Gem identification
18–27. Identifying gems, based on their colour
28. Identifying phenomenal and unusual gemstones
29. Natural, cultured and imitation pearls
30. Advanced gem testing techniques

Appendices

Each of these sections outlines the necessary and relevant information in an easy-to-read and visual style, accompanied by numerous colour photographs and diagrams throughout. Students would find the section on the refractometer of particular use, as it sets out in simple terms how to use and interpret the results (which many find difficult when first studying gemmology).

The sections on enhancements, imitations and synthetics are extensive, and cover the vast range of these materials available. Synthesis covers all the current commercial and historic techniques, as well as lesser known methods (e.g., ultrasound cavitation), giving an overview of what is potentially in the market. The same applies to treatments, giving a good grounding for any gemmologist, and making the reader aware of the potential pitfalls that can arise from the misidentification of features.

Sections 18 to 27, which cover the identification of gem materials based on their colour, is probably of greatest benefit to students (as it offers a useful reference basis), but for the more advanced gemmologist, or those who realize that colour isn't always the key, a full listing of gem materials ordered by descending RI is included in the Appendices, as well as a full alphabetical listing, with all the usual values and constants at your fingertips.

Sections 11 and 30 give a basic overview of the more equipment-driven aspects of gemmology, covering thermal conductivity and advanced testing. For diamonds, only individual testers (thermal or electrical) are covered, although the majority of people nowadays use combination testers. Minor omissions such as this do not, however, detract from the overall appeal of the book. The description of such advanced techniques as Raman, LIPS (LIBS), EDXRF and LA-ICP-MS (although only briefly), makes this an all-round useful reference.

Overall, *The Handbook* is very well presented and thought-out, covering all necessary and relevant aspects of gemmology, and providing a reference work at your fingertips, no matter where you are. This is truly a gemmology text for the 21st century, and although the digital format is probably not to everyone's liking, it does fit in with the modern lifestyle of today's gemmologist and student, whether used on desktop computer, tablet or smartphone.

A.S. Fellows

Conference reports

Hong Kong Jewellery & Gem Fair

Held 11-17 September, this enormous show organized by UBM Asia featured more than 3,600 exhibitors from 48 countries and regions. There were numerous educational opportunities, and those attended by this author are reported here.

The Gemstone Industry and Laboratory Conference (GILC), organized by the International Colored Gemstone Association, took place on 12 September and featured four speakers. **Chris Smith** (American Gemological Laboratories Inc., New York) described the history, properties and nomenclature of cobalt-coloured lead-glass-filled blue sapphires. The treatment debuted in 2007, and in 2012 Mr Smith noted significant improvements in the appearance of this material due to more careful selection of rough by the treaters and refinements in the process. The main identification features are wispy colour concentrations following fractures, gas bubbles within larger volumes of glass, and surface inhomogeneities seen in reflected light; flash-effect colours are subtle, unlike those seen in lead-glass-filled rubies. The treatment can also be revealed by UV-Vis, IR or EDXRF spectroscopy. **Prof. Dr Henry Hänni** (GemExpert, Basel, Switzerland) reviewed potential methods for tracing cultured pearls from the farm to the consumer (see article on pp 239–45 of this issue). **Prof. Mimi C. M. Ou Yang** (Hong Kong Institute of Gemmology) surveyed the value factors, mineralogical composition and nomenclature of Burmese jade. She recommended calling such material by the trade name *Fei Cui* together with mineral modifiers (jadeite, omphacite or kosmochlor) to designate specific varieties according to the most abundant constituent. **Dr John Ho Chun-Wah** (Hong Kong Accreditation Service [HKAS]) explained the process and benefits of accreditation in support of the gem and jewellery industry. HKAS follows a three-part process for evaluating gem laboratories in Hong Kong: testing, inspection and certification. Accredited laboratories enjoy improved acceptance and consumer confidence. At the conclusion of the programme, **Richard Hughes** (Sino Resources Mining Corp. Ltd., Hong Kong) was invited to give an update on his recent visit to Mogok, Myanmar. He described efforts by local diggers to prevent large mechanized mining projects from rapidly exploiting the area's gem deposits and depriving them of their way of life.

On 14 September, **Robert Weldon** (Gemological Institute of America [GIA], Carlsbad, California) gave a GIA GemFest presentation on gem and jewellery photography. He suggested photographing light-coloured gems on a dark background and vice versa. In addition, he recommended using a light-coloured neutral background to best show a transparent gem's coloration. Lighting is of paramount importance, and techniques should be adjusted according to the requirements of the stones/metals being photographed (e.g., *Figure 1*).

Also taking place on 14 September, the International Gemological Conference organized by the Asian Gemmological Institute and Laboratory Ltd. (AGIL), Hong Kong, featured 11 speakers. **Prof. Dr Henry Hänni** discussed value factors, treatments and sources of ruby. He pointed out that 'silk' inclusions in ruby can remain unaffected by treatment involving glass filling since the process is done using glass that has a relatively low melting temperature. **Manfred Eickhorst** (Eickhorst & Co., Hamburg, Germany) explained the benefits of using LED lighting in gemmological instruments, including monochromatic illumination for refractometers and high-intensity darkfield lighting in microscopes. **Prof. Lijian Qi** (China University of Geosciences, Wuhan) described the detection of irradiated HPHT-treated diamonds, in colours ranging from yellow-to-green, blue and pink. **Dr Hyun-Min Choi** (Hanmi Gemological Institute, Seoul, Korea) reported using ESR spectroscopy to detect gamma irradiation of South Sea cultured pearls, by looking for enriched amounts of CO_2^- radicals in their nacre. In his experience, the dark colour of such cultured pearls faded after five months' exposure to light. **Alan Hodgkinson** (Ayrshire, Scotland) described the use of top-lighting with the refractometer to observe RI values slightly greater than 1.81 and for obtaining more accurate RI measurements of small gems. **Prof. Dr Zhili Qiu** (Sun Yat-Sen University, Guangzhou, China) explained how to differentiate jadeite from Myanmar, Guatemala, Russia and Kazakhstan. Compared to jadeite from the other localities, the material from Myanmar shows the largest colour variety, is available in the finest quality, and has the lowest rare-earth element content and highest amount of the jadeite molecule in its composition. **Lin Sung Shan** (World Gem Identification and Study Center, Taoyuan City, Taiwan) surveyed jewellery markets in Taiwan and mainland China. He said that compared to the 'mature' market in Taiwan, the emerging market in China

Figure 1: The challenge in photographing this tourmaline pendant from Frank Heiser was to illuminate the tourmaline crystals (55 and 71 mm long) while also inducing the cat's-eye effect in the cabochons. This required two types of lighting: fibre-optic for the cabochons and diffused illumination for the crystals; these lighting techniques also worked well for the melee diamonds in the piece. Photo © Robert Weldon.

holds unlimited opportunities for the jewellery industry. Diamond is the most popular gemstone in China, and although smaller sizes make up the majority of the market, in recent years he noted a 15% annual increase in the demand for stones weighing 1–3 ct. **Dominic Mok** (AGIL, Hong Kong) described the use of advanced gem testing equipment to tackle gemmological challenges in his laboratory. In one instance, he used portable Raman spectroscopy to identify a large (80 kg) black carving as jadeite. **Ted Themelis** (Gemlab Inc., Bangkok, Thailand) illustrated his experiments with the treatment of white opaque corundum from Madagascar using blue cobalt-coloured lead glass. The procedure involves opening voids and channelways in the material with hydrofluoric acid pre-treatment, and then glass filling at 1,200–1,300°C in oxidizing conditions (i.e., in air) for several hours. Approximately 25% of the material showed satisfactory results and the remainder was re-treated under different conditions. **Dr Taijin Lu** (National Gems & Jewelry Technology Administrative Center, Beijing, China) described Hetian jade (nephrite) pebbles from Xinjiang Province in China. He determined that microscopic pits on the surface of the pebbles are caused by the dissolution of carbonate by chemical etching during alluvial transport. The microscopic characteristics of these pits are helpful in separating natural nephrite pebbles from various imitations in the Chinese marketplace. **Branko Deljanin** (Canadian Gemological Laboratory, Vancouver) summarized the properties of natural and synthetic diamonds. He noted that most natural diamonds show stronger fluorescence to long-wave UV radiation than to short-wave UV, while the opposite is the case for synthetics (both HPHT- and CVD-grown). Also, natural diamonds are most commonly type Ia (with rare type Ib, IIa and IIb stones), whereas HPHT-grown synthetics are mostly type Ib (less commonly type IIb and rarely type IIa) and CVD synthetic diamonds are mostly type IIa or possibly type IIb.

A launch seminar for the Gübelin Academy took place on 16 September and featured two presentations. **Dr Lore Kiefert** (Gübelin Gem Lab, Lucerne, Switzerland) showed video footage from visits by Dr Edward Gübelin to the famous Mogok Valley in Myanmar. Simple mining methods depicted in a 1962 video were similar to those seen during a recent (July 2013) visit to Mogok by Dr Kiefert and colleagues. She also reported that ruby mining is currently taking place at several primary deposits, including Dattaw (reopened recently after being closed for eight years), Yadanar Shin and Baw Lone Gyi. Sapphires are being mined from both primary (e.g., Baw Mar) and secondary deposits (e.g., in the Pyaunggaung area). Then **Dr Daniel Nyfeler** (Gübelin Gem Lab, Lucerne, Switzerland) explained the importance of undertaking field research in support of geographic origin determinations by his laboratory. Currently his lab does origin reports for ruby, sapphire (blue and fancy coloured), emerald, spinel (red and pink), alexandrite and Cu-bearing tourmaline. As more deposits have been discovered, some yielding gems with overlapping properties, origin determination has become more challenging—particularly for blue sapphires, for which Dr Nyfeler estimated 20–30% of his lab's reports in the last two years have indicated unknown origin.

Brendan M. Laurs

33rd International Gemmological Conference (IGC)

This biennial conference was held 12–16 October 2013 in Hanoi, Vietnam, and was attended by invited delegates, observers and Vietnamese honorary attendees. It was organized by Vietnam National University and DOJI Gold & Gems Group (both located in Hanoi). There were 41 talks and 16 posters presented. The conference abstracts are published in a 182 pp proceedings volume that can be downloaded at www.igc-gemmology.org.

A pre-conference excursion took place on 10–12 October to Halong Bay. The group first visited the retail showroom of VietPearl, where they were given a brief presentation on pearl culturing in Halong Bay and then saw cultured pearls and jewellery from both saltwater *(Figure 2)* and freshwater farms in Vietnam. The following morning they boarded a ship for an overnight tour of the bay including visits to a pearl farm *(Figure 3)* and a large limestone cave. The farm reportedly produces 10 kg annually of akoya-type cultured pearls from *Pinctada martensii* molluscs (or a related hybrid). The shell bead nuclei *(Figure 4)* are typically 5–6 mm in diameter, and they are left in the molluscs for 18 months before harvesting the cultured pearls.

Conference reports

Figure 2: The akoya-type cultured pearls from Halong Bay in this necklace are 13 mm in diameter. Photo by B.M. Laurs, © Gem-A.

Figure 3: This pearl farm in Halong Bay was visited as part of the IGC pre-conference excursion. It is a popular stop for tourists, and houses an active pearl culturing area and a showroom. Photo by B.M. Laurs, © Gem-A.

The opening programme of the conference included an informative overview of Vietnam's gemstone industry by **Dr Do Minh Phu** (DOJI Gold & Gems Group). He indicated that although gems were only discovered two decades ago in Vietnam, the revenue from the jewellery industry totals more than US$3.5 billion/year. The most important gem material produced in Vietnam is heat-treated pink sapphire in 1–3 mm calibrated sizes.

In diamond presentations, **Dr Emmanuel Fritsch** (University of Nantes and Institut des Matériaux Jean Rouxel, France) reviewed the morphology of natural and synthetic diamonds. He noted some particular aspects of natural diamonds that he has yet to properly document: hopper growth, true cube faces and signs of dissolution that occurred during growth. **Thomas Hainschwang** (GGTL Gemlab–Gemtechlab Laboratory, Balzers, Liechtenstein) discussed the origin of colour and properties of natural type Ib diamonds (i.e., those containing isolated nitrogen, or C centres, detectable with infrared spectroscopy). Although the C centre is known to be a strong producer of yellow colour, the vast majority of natural type Ib diamonds show combinations of yellow, orange, brown, grey and 'olive' green that are caused by variable C centre contents together with related defects. **Dr Hiroshi Kitawaki** (Central Gem Laboratory, Tokyo, Japan) examined numerous natural and synthetic diamonds with the DiamondView and noted the following general trends: colourless natural type Ia diamonds have blue-white luminescence, commonly with octahedral growth sectors; yellow natural type Ib diamonds display greenish yellow luminescence and mosaic patterns; HPHT synthetics show yellow or blue luminescence with cross-shaped intersections of {111} and {100} growth sectors; and CVD synthetics display layered growth striations. **Dr James E. Shigley** (GIA, Carlsbad, California) summarized observations of CVD-grown synthetic diamonds seen in GIA's laboratory. Most of the colourless CVD synthetics were G–J colour, VVS clarity, and inert to long- and short-wave UV radiation. Of the fancy-coloured CVD synthetics, pink was the most common hue, with the majority having Fancy Vivid,

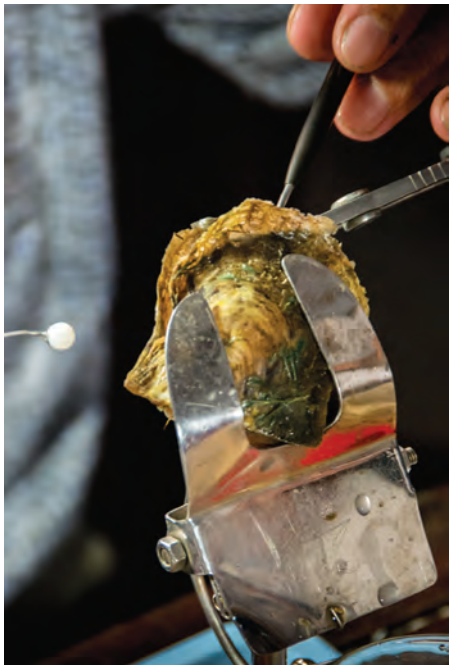

Figure 4: A shell bead (~6 mm in diameter) is inserted into a mollusc at the pearl farm in Halong Bay. Photo by B.M. Laurs, © Gem-A.

Conference reports

Fancy Intense and Fancy Deep colour grades, VS clarity, and orange fluorescence to long- and short-wave UV radiation.

There were several presentations on gem corundum. **Dr Dietmar Schwarz** (AIGS Lab, Bangkok, Thailand) reviewed the geology and gemmology of ruby and sapphire from Kenya and Tanzania. The main deposit areas are Lake Baringo (basalt-related) and Mangari (micaceous lenses and veins cutting serpentinite) in Kenya, and Longido (metamorphic 'anyolite'), Umba (desilicated pegmatitic veins in serpentinite), Winza (amphibolite dikes) and Tunduru-Songea (alluvial deposits) in Tanzania. **Hpone-Phyo Kan-Nyunt** (Gübelin Gem Lab, Hong Kong; delivered by co-author Dr Stefanos Karampelas) provided an update on the mining and characteristics of sapphires from the Baw Mar deposit near Mogok, Myanmar. The sapphires formed at the contact between syenite and gneiss, and the mine workings reach a depth of 40 m. About 300 people are mining and processing the material, which is faceted on site (typically in 0.5–4 ct sizes). They are relatively free of inclusions and have high iron contents, making them distinct from 'classic' Burmese sapphires. **Hai An Nguyen Bui** (University of Nantes, France) discussed the challenges and limitations of determining the geographic origin of Kashmir sapphires. Stones from Kashmir, Sri Lanka, Madagascar and Myanmar may show similar or overlapping characteristics, and in her opinion a Kashmir origin can be determined with satisfactory confidence in only 20% of cases. **Gamini Zoysa** (Mincraft Co., Mount Lavinia, Sri Lanka) reviewed some sapphire deposits of Sri Lanka. He focused on alluvial deposits in the Hasalaka area near the town of Mahiyangana in central Sri Lanka, as well as eluvial-primary deposits discovered in 2012 near Tammanawa village (Kataragama, southern Sri Lanka). **Dr Jayshree Panjikar** (Panjikar Gem Research & Tech Institute, Pune, India) characterized bicoloured yellow-blue sapphires from Chinnadharapuram, southern India. Their most common inclusions are apatite, mica, zircon, feldspar, ilmenite, 'silk', negative crystals and corundum crystals. These sapphires show similarities to those from Garba Tula, Kenya. **Dr Pornsawat Wathanakul** (Gem and Jewelry Institute of Thailand, and Kasetsart University, Bangkok) reported that sapphires associated with the Denchai basalt in Phrae Province, northern Thailand, are concentrated in both placer and residual deposits derived from at least two basaltic episodes. The alluvial deposits consist of both recent and older gravel beds related to point-bar and terrace deposits. **Dr Nguyen Ngoc Khoi** (DOJI Gold & Gems Group; delivered by co-author Dr Nguyen Thi Minh Thuyet) explained the geology of gneiss-hosted corundum deposits from the Tan Huong–Truc Lau area in northern Vietnam. Exploration guides include corundum and associated minerals (spinel, sillimanite, ± garnet) in heavy mineral concentrates in streams, lakes and soils; aluminous rocks within high-grade metasedimentary sequences; and the contacts of migmatized pegmatoid bodies with surrounding mafic and ultramafic rocks or marbles. **Maxim Viktorov** (Gemological Center, Lomonosov Moscow State University [MSU], Russia) described sapphires from the Koltashi deposit in the Ural Mountains, Russia. Discovered in deeply weathered soil in 1999, the sapphires are mostly colourless with blue zones and rarely pink. Although none are gem quality as found, they do respond to heat treatment (1600°C for two hours in a reducing atmosphere). **Dr Hanco Zwaan** (National Museum of Natural History [Naturalis], Leiden, The Netherlands) studied alluvial sapphires from Montana (mostly Rock Creek) and found a mineral inclusion assemblage indicative of a complex geological history involving incompatible elements (e.g., alkali magmas or carbonatites). **Kentaro Emori** (Central Gem Laboratory, Tokyo, Japan) used LA-ICP-MS to measure the concentration of beryllium in more than 1,000 samples of untreated and treated corundum. He found the highest amounts in Be-diffused yellow sapphires (9.2–11.4 ppmw). Traces of Be were also detected in untreated sapphires from Cambodia, Laos and Nigeria, together with various combinations of Nb, Ta, Zr, Hf, Th and other elements. **Shane McClure** (GIA, Carlsbad) documented Ti-diffused synthetic sapphires submitted for lab reports that were free of inclusions and therefore presented difficulties in determining natural or synthetic origin. Initial LA-ICP-MS analyses gave unexpected results, and further studies of a sliced sample showed that Ga and Mg (and, in places, Be) were associated with Fe, Ti and V in a diffused layer that was thicker than typically seen. This raises the question of whether treaters are using additional elements to help facilitate the diffusion into corundum of relatively immobile elements such as Ti.

There were three talks covering beryl. **Dr Jürgen Schnellrath** (Centro de Tecnologia Mineral, Rio de Janeiro, Brazil; delivered by co-author Stefanos Karampelas) described a new emerald occurrence from the Itatiaia mine near Conselheiro Pena, Minas Gerais, Brazil. The emeralds were discovered in 2010 in biotite-phlogopite schist near a gem-bearing pegmatite, and initial mining in 2012 produced a limited amount of gem-quality material that was cut into stones weighing up to ~2 ct. These emeralds typically show light green to slightly bluish green colour, and are notable for their enriched Cs content. **Prof. Dr Jean-Marie Dereppe** (University of Louvain, Belgium) used EPR spectroscopy to separate untreated Maxixe beryls from irradiated Maxixe-type beryl which has a more unstable colour. EPR was useful for differentiating the colour centres in each type of beryl (NO_3 groups in Maxixe and CO_3 groups in Maxixe-type beryl). **Dr Le Thi-Thu Huong** (Vietnam National University, Hanoi) presented preliminary data on previously unrecognized features recorded using Raman and infrared spectroscopy that may prove useful for separating natural from synthetic emerald. Specifically, natural emeralds have a Raman band at 1072–1068 cm^{-1}, while in synthetics this band is shifted slightly to 1068–1067 cm^{-1}. Infrared spectra recorded on K-Br pellets show a shoulder adjacent to a band at ~1200 cm^{-1} in natural emeralds, while no such shoulder is present for synthetic emeralds.

Conference reports

In presentations on other coloured stones, **Edward Boehm** (RareSource, Chattanooga, Tennessee, U.S.A.) reviewed the inclusions in spinel from various localities. He indicated that inclusions are of more use for simply identifying a stone as spinel, rather than indicating a spinel's geographic origin. **Dr Tobias Häger** (Johannes Gutenberg–Universität Mainz, Germany) examined the causes of colour in natural untreated spinels from Vietnam, and compared them to flame fusion– and flux-grown synthetics. Various combinations of the chromophores Fe^{2+}, Co^{2+}, Cr^{3+} and V^{3+} are responsible for the different colours. **Dr Karl Schmetzer** (Petershausen, Germany) studied the effect of vanadium and titanium on the coloration of natural and synthetic chrysoberyl and alexandrite. (For details of this research, see pp 223–8 of this issue, and pp 137–48 of *Journal of Gemmology,* **33**(5–6), 2013). **Prof. Dr Henry Hänni** (GemExpert, Basel, Switzerland) documented traces of rare-earth elements (REE) in 'mint' green grossular from Merelani, Tanzania. The element with the greatest abundance was dysprosium (up to ~20 ppm by LA-ICP-MS). Although not enough REE were present to produce absorptions visible with the spectroscope, Raman analysis showed a series of photoluminescence peaks that are not typically seen in grossular. **Dr Jaroslav Hyršl** (Prague, Czech Republic) used UV-Vis-NIR spectroscopy to separate chrome pyrope from various localities. In addition to a small Cr peak at 685 nm that is seen in chrome pyrope from all localities, samples from both of the important Czech sources (Podsedice and Vestřev) show just one absorption peak at 575 nm, while those from Arizona, Tanzania and Yakutia have two peaks at 445 and 575 nm. **Prof. Mimi C. M. Ou Yang** (Hong Kong Institute of Gemmology) used cathodoluminescence to examine the zonal texture of jadeite. Growth zoning was indicated by differences in luminescence intensity and/or colour within individual grains. The luminescence hue varied according to the colour of the jadeite analysed: blue with pink zones in white jadeite, pink with blue zones in lavender material, and green to yellow-green (and orange in some samples) in the Hte Long Sein variety of chromian jadeite. **Masaki Furuya** (Japan Germany Gemmological Laboratory, Kofu) performed electron-irradiation and annealing experiments on Imperial topaz from Ouro Preto, Brazil. Orange-red or violetish pink samples became more orange after electron irradiation and annealing to 350°C by increasing Cr^{4+} absorption. However, the colour of yellow-to-orange topaz (i.e., without a reddish component) was not enhanced by the treatment. **Dr Ulrich Henn** (DSEF German Gem Lab, Idar-Oberstein) surveyed the many colours seen in quartz and explained their causes (i.e., colour centres, inclusions and optical effects). He noted that some 'greened amethyst' is produced by the gamma irradiation of colourless quartz (not amethyst) from Brazil's Rio Grande do Sul State. It shows a 610 nm absorption feature and fades when heated to just 120–150°C (vs. natural prasiolite, which has a 720 nm absorption and is colour-stable to at least 600°C). **Dr Claudio C. Milisenda** (DSEF German Gem Lab, Idar-Oberstein) characterized pale greyish greenish brown zoisite from Pakistan. Internal features include hollow tubes, actinolite needles, growth zoning and healing planes. Absorption spectra are dominated by Fe^{3+}, and heating to 850°C had no effect on coloration. **Willow Wight** (Canadian Museum of Nature, Ottawa) examined the history and coloration of Canadian labradorite. The two main localities of labradorite in Canada are Newfoundland (Nain) and Labrador, and the most unusual colour in the material is purple. **Elisabeth Strack** (Gemmologisches Institut Hamburg, Germany) examined three jewels from the Veliki Preslav treasure in Bulgaria and suggested the emeralds in the pieces may have an Egyptian source. Also, purple stones that were thought to be amethyst turned out to be mostly garnets and one sapphire. **Anette Clausen** (Ministry of Industry and Mineral Resources, Nuuk, Greenland) reviewed gem materials from Greenland, including the unusual materials greenlandite, tugtupite and nuumite, as well as ruby and pink sapphire. The latter materials are being investigated by True North Gems and another venture called Moxie Pictures. True North has completed a pre-feasibility study and they plan to start infrastructure developments in 2014. **Michael Gray** (Coast-to-Coast Rare Stones, Fort Bragg, California, U.S.A.) surveyed gem mining in the United States during the past 10 years. While some mines closed or ceased operation (i.e., for red beryl and benitoite, as well as spessartine from the Little 3 mine in Ramona, California, and sapphire from Yogo Gulch in Montana), others saw renewed activity (Mt. Mica in Maine for tourmaline, Hiddenite in North Carolina for emerald and hiddenite, Jackson's Crossroads in Georgia for amethyst, and the Oceanview mine in Pala, California, for spodumene, tourmaline and beryl). Other gems were mined continuously during this period (sunstones in Oregon, aquamarine at Mt. Antero in Colorado, and diamonds in Arkansas). **Dr Karen E. Fox** (Waterloo, Canada) performed optical spectroscopy of iron in sodium silicate glasses, and indicated that natural high-silica glass (i.e., fulgurite) shows no evidence of non-bridging oxygens in the structure since any iron impurities take on the role of a network former.

In pearl presentations, **Shigeru Akamatsu** (Japan Pearl Promotion Society, Tokyo) described current efforts to produce high-quality akoya cultured pearls at two new farms near Aino-shima island in Japan. The farms use the latest technology to monitor ocean conditions and conduct genetic analyses, while also protecting the environment and conserving oyster resources in the area. **Terry Coldham** (Gemmological Association of Australia, Sydney) documented the harvesting (10 years ago) of natural 'pipi' pearls from *Pinctada maculata* molluscs in Tongavera Atoll, Cook Islands. Of the 600 shells collected from coral heads in the lagoon, only 17 contained pearls or blisters. **Laurent Cartier** (Swiss Gemmological Institute SSEF, Basel; delivered by Prof. Dr Henry Hänni) provided an update on Galatea cultured pearls from French Polynesia. This product line contains bead nuclei

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composed of coral, synthetic opal, amethyst and other gem materials, which are partially exposed by carving various patterns through the nacre. Some of the 'turquoise' beads used in these cultured pearls were later identified as barium sulphate that had been pressed and dyed; the company is actively disclosing this. **Dr Stefanos Karampelas** (Gübelin Gem Lab, Lucerne, Switzerland) reported the current status of pearl cultivation at Guaymas (Sonora) Mexico, using *Pteria sterna* molluscs. Over the past 10 years, both the success rate of the harvesting and the average size of the cultured pearls have increased. In 2012 approximately 4,000 gem-quality cultured pearls were produced, and the goal is to reach 10,000 per year. Pearls cultured from *Pteria sterna* are commercially produced only in Mexico, and they can be easily identified with diffuse reflectance spectroscopy by their lack of absorption at 700 nm. **Steve Kennedy** (The Gem & Pearl Laboratory, London) described the history and characteristics of The Pearl of Asia. The large blister pearl, estimated to weigh 155 g, is mounted together with pink tourmaline, jadeite, opal and synthetic ruby. X-radiography showed it to be a hollow blister pearl containing what appear to be pieces of shell and metal that were apparently added to give it the proper heft. **Sutas Singbamroong** (Dubai Gemstone Laboratory, United Arab Emirates) showed how to use a digital SLR camera to observe and record the X-ray luminescence of pearls. He placed the camera in a conventional Faxitron X-ray cabinet (with no viewing window) and used the timer to photograph the luminescence after the door was closed. A reference pearl was included in each photo to provide a consistent colour and strength of luminescence. The best camera settings were found to be a 30 second exposure with an aperture of *f*3.2 and a sensitivity of 6400 ISO. **Abeer Al-Alawi** (Ministry of Industry & Commerce, Manama, Bahrain; delivered by co-author Stefanos Karampelas) compared the characteristics of cavities in natural vs. beadless cultured saltwater pearls. Features seen in X-radiographs or micro-CT scans were compared to the appearance of the corresponding cavities after the samples were sliced in half.

Three talks addressed the application of new technology to gemmology. **Menahem Sevdermish** (Gemewizard Ltd., Ramat Gan, Israel) described further research into the digital analysis and communication of colour in gemmology using the Gemewizard software package. The newest developments include the GemePro for obtaining the 'colour DNA' from the photo of a gem, GemePrice for allocating wholesale prices to diamonds and coloured stones, GemeFancy for evaluating the colour of fancy diamonds, GemeEdu for establishing colour borders according to gem name (e.g., ruby vs. pink sapphire) and teaching colour grading, GemeMatch for finding gems of a desired colour, and GemeShare for locating suppliers for those stones. **S. Sivovolenko** (OctoNus Software, Tampere, Finland; delivered by co-author R. Serov) explored cut optimization technology for fancy-colour diamonds. A case study for a yellow piece of rough showed that the highest cutting yield did not correlate to the greatest stone value, due to differences in the depth of face-up colour showed by various stone shapes. **Dr Yuri Shelementiev** (MSU Gemological Center, Russia) demonstrated digital microscopy applications in gemmology. Advantages include three-dimensional viewing of gems and their inclusions (with suitable software and 3D glasses) and image enhancements (e.g., contrast and high dynamic range).

Poster presentations covered a wide range of subjects, particularly gem corundum. **Gagan Choudhary** (Gem Testing Laboratory, Jaipur, India) studied inclusions in rubies from various localities (covering five states) in India. Most of the inclusions were of similar type, pattern and appearance, and no definitive locality-specific features were noted. Some minerals were identified only in rubies from one locality, such as hematite (from Chhattisgarh), chromite and green mica (from Orissa), and apatite and yellow spinel (from Tamil Nadu). **Dr Christoph A. Hauzenberger** (Karl-Franzens-Universität Graz, Austria) investigated the genesis of corundum crystals with spinel coronas from Truc Lau and Kinh La in northern Vietnam. Colourless sapphire or ruby may be surrounded by brown Al-Mg spinel or dark hercynite ($FeAl_2O_4$) overgrowths, which formed in metacarbonate and Fe-rich gneiss, respectively. **Natthapong Monarumit** (Kasetsart University, Bangkok, Thailand) applied dielectric constant values to differentiating rubies from Mong Hsu, Myanmar, and Montepuez, Mozambique. The average dielectric K values measured for Mong Hsu and Montepuez rubies were greater 20 and less than 12, respectively. **Aumaparn Phlayrahan** (Kasetsart University, Bangkok, Thailand) documented changes in structural OH groups in the FTIR spectra of rubies from Mong Hsu and Montepuez, before and after heat treatment. The spectra revealed differences in the 3400–3100 cm^{-1} range that probably relate to the dehydration of hydrous aluminium-phase inclusions in the presence of certain trace elements. **Y. Shelementiev** (MSU Gemological Center, Russia) studied the alteration of zircon, boehmite and kaolinite inclusions in corundum during heat treatment. Systematic changes were noted in the visual appearance and Raman spectra of the zircon, and in the FTIR spectra of the boehmite and kaolinite due to dehydration of those phases.

Several poster presentations dealt with the treatment of gems other than corundum. **Chanikarn Sanguanphun** (Kasetsart University, Bangkok, Thailand) used atomic force microscopy to detect the electron irradiation of faceted diamonds. After treatment, the surfaces of the irradiated green and bluish green diamonds showed increases in the calculated values of step height and root mean square (RMS) roughness. **Prof. Dr Panjawan Thanasuthipitak** (Chiang Mai University, Thailand) performed heat treatment experiments on aquamarine and morganite from Madagascar. The experiments were done in a reducing atmosphere (using Ar gas), and the optimum temperature for intensifying the blue colour of aquamarine was 400°C, while 350°C was sufficient for

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Figure 5: Miners search for spinel after washing soil through a sieve at this small mine on the edge of a rice paddy near Luc Yen. Photo by B.M. Laurs, © Gem-A.

Figure 6: IGC participants search for spinel in tailings at the Cong Troi mine near Luc Yen. The active mining face is obscured by clouds. Photo by B.M. Laurs, © Gem-A.

enhancing the pink colour of morganite. **Dr Shang-i Liu** (Hong Kong Institute of Gemmology) used EPR spectroscopy in a preliminary study to investigate the causes of colour in untreated and irradiated green spodumene. EPR data showed that an untreated hiddenite from North Carolina contained Cr^{3+} in octahedral coordination (and no colour centres), whereas a laboratory-irradiated spodumene showed a Cr^{3+} signal overlapping with a related colour centre, and a naturally irradiated spodumene contained only colour centres. **Dr Somruedee Satitkune** (Kasetsart University, Bangkok, Thailand) compared the heat treatment of reddish brown zircon from Ratanakiri, Cambodia, and Kanchanaburi, Thailand. The Cambodian samples turned blue after heating to 1000°C for 1 hour in a reducing atmosphere, due to the absorption of U^{4+} at 653 nm. In contrast, the Thai samples became colourless after heating.

Other posters covered various issues related to coloured stones. **Dr Arūnas Kleišmantas** (Vilnius University, Lithuania) investigated 17th- and 18th-century garnet-garnet doublets imitating rubies in liturgical objects from Lithuania. These doublets are particularly convincing because they have an empty space at the glue-garnet interface that reflects light and gives them greater brilliance. **Elizabeth Su** (Gemsu Rona, Shanghai, China) examined the classification of jadeite by deposit type, colour, texture, transparency and composition. **John M. Saul** (ORYX, Paris, France) proposed three origins for foul odours emitted by gem-bearing host rocks from southeast Kenya and northeast Tanzania when they are struck or crushed. The gases may come from (1) materials of primordial origin, (2) mobilization of evaporites, and/or (3) serpentinization of ophiolites, producing hydrogen gas and hydrocarbons. **Dr Nguy Tuyet Nhung** (Vietnam Gemstone Association, Hanoi) surveyed gem materials from the Luc Yen pegmatite in Vietnam. Tourmaline is most important and a relatively small amount of green orthoclase feldspar also has been polished. Large blocks of purple lepidolite have been produced but not used for display purposes. **Dr Nguyen Thi Minh Thuyet** (Hanoi University of Science, Vietnam) reported the gemmological characteristics and chemical composition of peridot from southern Vietnam. No systematic differences were noted in their properties compared to peridot from other sources that are hosted by xenoliths within basalt flows. **Sora Shin** (Hanyang University, Seoul, Korea) compared the characteristics of the colourless gems phenakite, petalite, pollucite and goshenite. **Chakkrich Boonmee** (Kasetsart University, Bangkok, Thailand) characterized Thai ivory from Lampang Province using SEM-EDS and LA-ICP-MS.

A post-conference excursion on 17–19 October took participants to Luc Yen in the Yen Bai Province of northern Vietnam to visit the Cong Troi mine and the local gem market. Cong Troi is a primary deposit that is worked mainly for mineral specimens of pink-to-purple spinel crystals embedded in white marble. The mine was reached by walking for about two hours through rice paddies and jungle. Along the way participants passed a small secondary deposit *(Figure 5)*. The miners washed the soil in a sieve using water pumped from a nearby pond. The spinel they found that day consisted only of non-gem-quality material. At the Cong Troi mine no activity was taking place due to the rainy weather. The deposit is worked by blasting or sawing blocks of spinel-bearing marble from a large open-cut at the top of the mountain. In the extensive tailings pile *(Figure 6)*, some fieldtrip participants found samples of marble containing spinel associated with colourless forsterite, orange clinohumite and/or green pargasite. None was of gem quality, but they made attractive mineral specimens. Such pieces were offered for sale in the local gem market in Luc Yen *(Figure 7)* and also seen in numerous shops around town.

The next IGC conference will take place in Lithuania in 2015.

Brendan M. Laurs

Figure 7: At the gem market in Luc Yen, these local vendors offer ruby, sapphire, spinel, yellow tourmaline, green feldspar, citrine and tektite. Photo by B.M. Laurs, © Gem-A.

2013 GIC International Gems and Jewellery Conference

The annual Gemological Institute of China (GIC) conference was held on 13 October at the China University of Geosciences campus in Wuhan. A total of 102 delegates from the United Kingdom, Hong Kong, Taiwan and from 11 provinces in China participated in the conference. There were 17 oral presentations and a post-conference field trip. A proceedings volume is planned for publication in *The Journal of Gems and Gemmology* later this year.

Two of the talks addressed gemmological education in China, focused on a formal academic environment. Four presentations were on jewellery art and design. Five talks examined the gem and jewellery business and markets in mainland China and Hong Kong, covering the following topics: integrating ISO standards with jewellery branding; high-end jewellery market strategy; diamond investment in 2013–2014; the impact of the internet on traditional jewellery business; and research on consumer psychology. The other six talks covered new research in gemmology and precious metals, as described below.

Prof. Ren Lu (Institute of Gemology, China University of Geosciences) presented his recent study on the colour origin and identification of lavender jadeite using UV-Vis spectroscopy and LA-ICP-MS. Through an analogous study on another pyroxene mineral (kunzite), he firmly established Mn as the trace element that is responsible for the lavender colour in jadeite.

Baozheng Tian (Hunan Provincial Gem Testing Center, Changsha, China) described a new dark violet-blue jade called *zimo xiangyu* from the Liuyang area of Hunan Province that is composed of cryptocrystalline cordierite-biotite amphibolite.

Guolong Yao (Enyu Jewellery, Haikou, Hainan Province, China) surveyed various imitations of sea tortoise shell, in which he showed hundreds of slides comparing natural tortoise shell to different imitations (such as plastic) and assembled materials.

This author explored applications of LA-ICP-MS analysis to gemmology, including instrument development and techniques for evaluating Be-diffused sapphires, chrome chalcedony treatment and peridot country-of-origin determination.

The field trip took place on 14 October, when over 80 delegates visited a freshwater pearl farm near Ezhou in Hubei Province. The delegates were shown procedures for producing the cultured pearls *(Figure 8)* and they had a chance to purchase the local products.

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Figure 8: Technicians at a pearl farm in Hubei Province demonstrate the insertion of tissue nuclei into mussels used for producing freshwater cultured pearls. Photo by Xiong Ni.

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2013 China Gems & Jewelry Academic Conference

This annual conference took place on 30 October in Beijing *(Figure 9)*, organized by the National Gems & Jewelry Technology Administrative Center (NGTC, Beijing) and the Gems & Jewelry Trade Association of China. The attendees consisted of nearly 400 gemmologists, researchers, educators, leading industry representatives and students, as well as Chinese government officials. The programme encompassed 21 talks selected from 85 short research articles published in a special issue of *China Gems* (September–October 2013; mostly in Chinese with English abstracts). The topics included diamond, coloured stones, organic gems, nephrite and other jade varieties, precious metals and their testing techniques, and jewellery appraisal, marketing and design. Highlights of some of the research presented at the conference are given here.

Prof. Mark Newton (University of Warwick, Coventry) explained how electron paramagnetic resonance (EPR) can be applied to the study of treated and synthetic diamond. His talk concentrated on three aspects: (1) the importance of EPR spectroscopy for studying the electronic structure of crystal defects; (2) how to identify HPHT-treated type IIa and IaB brown diamond by analysing nitrogen aggregation with EPR; and (3) how to identify HPHT- and CVD-grown synthetic diamonds by detecting defects that are absent from natural diamonds.

Prof. Guanghai Shi (China University of Geosciences, Beijing) examined the mineral composition and structure of Myanmar jade and its nomenclature. He showed a variety of mineral compositions and textures, and demonstrated how the study of these characteristics are important not only for understanding the genesis of jadeite jade, but also for the proper naming and quality evaluation of this complex material.

Prof. Jongwan Park (Hanyang University, Seoul, Korea) described his study of 12 Madagascar tourmaline samples that were irradiated by an electron beam. The treatment modified their colours to various degrees, which he correlated to features recorded in their UV-Visible and IR spectra. The tourmalines' original colours were restored by heating to 550°C for three hours.

The afternoon talks expanded into two conference rooms. **Prof. Zuowei Yin** (China University of Geosciences, Wuhan) investigated fossil mammoth ivory. He discussed differences between mammoth and modern ivories using gemmological testing, IR spectroscopy (to analyse molecular water- and collagen-related absorptions) and X-ray diffraction (to study the crystallization of hydroxyapatite).

Prof. Zhili Qiu (Sun Yat-Sen University, Guangzhou, China) examined the development of modern Chinese jade carving arts, with an emphasis on the driving forces for the divergence and subsequent convergence of art styles. **Prof. Shiqi Wang** (Peking University, Beijing, China) discussed the visual characteristics of tremolite in nephrite jade from several localities: China (Xinjiang, Qinghai and Liaoning), Russia and Korea. He suggested that these jades can be distinguished by their colour, lustre, transparency, texture and structure.

Prof. V.K. Garanin (Moscow State University, Russia) compared kimberlitic diamonds from Russia's two major deposit areas: Yakutia and Arkhangelsk. Mineralogical and gemmological research were presented on diamonds from both localities.

Prof. Lijian Qi (Tongji University, Shanghai, China) reported that some 'insect amber' and 'dark amber' currently on the market are produced from copal resin using heat and pressure. In addition, imitation amber is made by treating copal powder. The identification of treated copal with gemmological testing and IR and EPR spectroscopy was described, and absorption characteristics of amber from various global deposits were presented.

Dr Taijin Lu (NGTC) examined tarnish spots on the surface of high-purity gold jewellery (99.9% Au). He correlated the spots with silver and sulphur impurities in the gold, and indicated that they might be prevented by using improved cleaning processes during gold manufacturing.

Figure 9: The 2013 China Gems & Jewelry Academic Conference was recently held in Beijing. Here, the audience listens to Prof. Mark Newton's presentation. Photo by R. Lu.

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Gemological Research in the 21st Century: Characterizing Diamonds and other Gem Minerals

The Geological Society of America (GSA) held its annual meeting on 27–30 October in Denver, Colorado. While this venerable organization celebrated its 125th Anniversary with a record number of submitted abstracts and a high attendance drawn from all segments of the geological sciences, gemmologists may also find reason for celebration in that their science was represented for the very first time in the history of GSA as a session all its own. Session conveners Dona Dirlam and Dr James E. Shigley of GIA (Carlsbad, California) organized and moderated the session's presentations, which were held over two days in both oral and poster formats. Both were well attended and received positive comments from the participants (for details see 'Gemology bears triumphant tidings', www.palagems.com/gem_news_docs/GSA_Gemology_Session.pdf). The abstracts of the presentations may be accessed at http://gsa.confex.com/gsa/2013AM/webprogram (in the Final Session Number box, type T216), and below is a listing of the titles.

- Geochemical methods to address the challenges facing modern gemological research (Prof. Georg e R. Rossman)
- Recent advances in the understanding of the distribution, origin, age and geological occurrences of diamonds (Prof. Steven B. Shirey)
- Comparison of luminescence lifetimes from natural and laboratory irradiated diamond (Dr Sally Magana)
- Identification of green colored gem diamonds: An on-going challenge (Dr Christopher M. Breeding)
- Chemical characterization of gem tourmaline (Prof. William B. Simmons)
- Crystal-filled cavities in granitic pegmatites: Bursting the bubble (Prof. David London)
- Trace element comparison of ancient Roman intaglios and modern samples of chromium chalcedony: An archaeogemological provenance study (Dr Cigdem Lule)
- Country-of-origin determination of modern gem peridots from LA-ICPMS trace-element chemistry and linear discriminant analysis (LDA) (Prof. Andy Shen, Dr Troy Blodgett, Dr James E. Shigley)
- Precisely identifying the mines from which gemstones were extracted: A case study of Columbian emeralds (Catherine E. McManus)
- Sapphire — a crystal with many facets (Dr Jennifer Stone-Sundberg)
- Gem pargasite from Myanmar: Crystal structure and infrared spectroscopy (David Heavysege, Dr Yassir A. Abdu and Prof. Frank C. Hawthorne)
- Comparison of surface morphology of Montana alluvial sapphires by SEM (Dr Richard B. Berg)
- Investigation of gem materials using 405 nm laser spectroscopy (Prof. Henry L. Barwood)
- Provenance determination of rubies and sapphires using laser-induced breakdown spectroscopy and multivariate analysis (Kristen Kochelek, Prof. N.J. McMillan, Catherine McManus, and Prof. David Daniel)
- Reversible color modification of blue zircon by long wave ultraviolet radiation (Nathan D. Renfro)
- Scholarly treasure: The role of gems in a university setting (Elise A. Skalwold and Prof. William A. Bassett)
- Spatial distribution of boron and PL optical centers in type IIb diamond (Troy Ardon)
- Trace element and chromophore study in corundum – application of LA-ICP-MS and UV-visible spectroscopy (Prof. Ren Lu).

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Gem-A Conference 2013

This annual conference took place 1–6 November in London and featured a diverse line-up of 13 speakers. A variety of seminars and museum visits were arranged to coincide with the conference (see page 265 of this issue).

David Callaghan (Harrow) recounted the history of the London Gem Lab, mostly using notes made by Basil Anderson. Of particular importance was the development of the endoscope in 1926–7, which was critical to addressing the trade's need to confidently identify natural vs. cultured pearls.

Dr Emmanuel Fritsch (University of Nantes and Institut des Matériaux Jean Rouxel, France) described luminescence in gemmology. Luminescence is the emission of visible light caused by some type of excitation, and it should be described according to its strength, turbidity and zonation. Two types of luminescence spectroscopy — excitation and time-resolved — are expected to have increasing applications to solving gemmological problems in the future.

Dr James Shigley (GIA, Carlsbad, California) chronicled the evolving challenges of gem identification, particularly those due to treatments. He predicted that future concerns will involve treated and synthetic melee diamonds, ceramic materials, and high-tech coatings.

Martin Rapaport (Rapaport Diamond Corp., New York, U.S.A.) discussed the overall state of the diamond industry, commenting that mining companies are responsible for driving up the price of rough to unsustainable levels, artisanal diamond miners (particularly in West Africa) are not benefitting from their work, and synthetic diamonds are not being disclosed properly in the trade (especially in melee sizes).

Gary Roskin (Roskin Gem News, Exton, Pennsylvania, U.S.A.) examined some challenges in diamond grading. For evaluating clarity, he stressed the need to consider the following aspects of diamond inclusions: colour and relief, location, nature, number, and size in relation to the stone. He also had suggestions for successfully grading colour in the D–Z range: have master stones re-graded in a lab, move the master stones further away from the light source and use magnification.

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Sonny Pope (Suncrest Diamonds, Orem, Utah, U.S.A.) discussed the multi-step treatment of diamonds using high-pressure, high-temperature (HPHT) processing and irradiation. Of the diamonds on the market, only some stones have the potential to be treated to various colours (approximately 30% yellow, 50% green, 20% orange and 2% colourless), so the starting material is carefully pre-screened using infrared spectroscopy. The treatment is done on faceted stones (therefore requiring some post-treatment repolishing), in weights ranging from 2 points to 60 ct.

Arthur Groom (Arthur Groom & Co., Ridgewood, New Jersey, U.S.A.) surveyed emerald clarity enhancements on the market today. He said that the main challenges are seen in emeralds from Brazil and Colombia, which are being enhanced as rough material with 'permanent' methods such as Gematrat resin (which expands as it hardens). Only about 5% of the emeralds he encounters are treated with cedarwood oil, and repeated treatment with this oil (involving heating without prior cleaning) can result in yellow staining within fractures.

Dr John Emmett (Crystal Chemistry, Brush Prairie, Washington, U.S.A.) explained how various chromophores (i.e., Fe^{3+}, V^{3+}, Cr^{3+}, Fe^{2+}-Ti^{4+} and trapped hole centres involving Fe, Cr and Mg) affect the colour of corundum. The coloration depends on their concentration and absorption cross section (or strength of imparting coloration), as well as the optical path length through a stone. He also showed how padparadscha colour is produced by a combination of Cr^{3+} and trapped hole centres involving Cr.

Dr Jack Ogden (Striptwist Ltd., London) described the Cheapside Hoard, which dates to the 1640s and was discovered in 1912 under the floor of a former goldsmith's shop in London. The jewellery in the Hoard contains a variety of coloured stones (but only one diamond), and several imitations have also been identified such as foil-backed glass to imitate emerald, ruby and sapphire, and quench-crackled quartz that was stained red (now faded to orange) to imitate spinel.

Chris Sellors (C W Sellors Fine Jewellery, Ashbourne, Derbyshire) focused on two English gemstones: Blue John and Whitby jet. Mined for centuries in Derbyshire, Blue John consists of banded purple and colourless fluorite that is locally iron-stained. The deposit is located within a national park, and only one-half ton of the material can be mined each year. Whitby jet is the fossilized wood of the monkey puzzle tree *(Araucaria araucana)*, and the material is gathered from beaches after it erodes from cliffs near the town of Whitby in Yorkshire. Cabochons of both Blue John and Whitby jet are now being manufactured into higher-end jewellery with gold and diamonds.

Brian Jackson (National Museums Scotland, Edinburgh) provided an overview of Scottish gem materials, which include jet, amber, freshwater pearls, smoky quartz, aquamarine, topaz, tourmaline, garnet, sapphire, agate, prehnite, ammolite, zircon and serpentinite. The diversity of these materials results from the variety of rock types that underlie Scotland. Overall there is not enough Scottish gem production to make a sustained commercial impact on the market.

Shelly Sergent (Somewhere In The Rainbow™, Scottsdale, Arizona, U.S.A.) described the Somewhere In The Rainbow™ gem and jewellery collection, which was founded in 2008 and became an educational resource in 2012. The collection, which is still growing, consists of high-quality examples of coloured stones and pearls that are loose or mounted in jewellery (e.g., *Figure 10*).

Figure 10: This pendent, which features a 13.57 ct tsavorite from the Komolo mine in Tanzania, is one of many jewellery pieces that was on display during the Gem-A conference. The stone was mined in 1979 by Campbell Bridges, and the pendent was designed in 2013 by Shelly Sergent and Harry Tutunjian of Goldbench Jewelers, Scottsdale, Arizona. Courtesy of Somewhere In The Rainbow™; photo by B.M. Laurs, © Gem-A.

John Bradshaw (Coast-to-Coast Rare Stones, Nashua, New Hampshire, U.S.A.) examined some rare and collector stones on the market. Of the approximately 200 mineral species (out of more than 4,000) that have been faceted, only about 20 are common in jewellery. The remainder are important for the collector market, particularly benitoite, sphene, rhodochrosite, apatite, fluorite and sphalerite.

Brendan M. Laurs

Proceedings of the Gemmological Association of Great Britain and Notices

Gem-A Conference 2013

The 2013 Gem-A Conference, in celebration of the centenary of the Gemmology Diploma and the 50th anniversary of the Diamond Diploma, was held on Saturday 2 and Sunday 3 November at Goldsmiths' Hall in the City of London. The weekend also included an Anniversary Dinner and Graduation Ceremony.

Speakers were John Bradshaw, David Callaghan, Dr John Emmett, Dr Emmanuel Fritsch, Arthur Groom, Brian Jackson, Dr Jack Ogden, Sonny Pope, Martin Rapaport, Gary Roskin, Chris Sellors, Shelly Sergent and Dr James Shigley. Highlights of the presentations are given in the Conference Reports, pages 263–264.

Delegates were able to view a number of exhibits and demonstrations during the breaks, including those by Somewhere In The Rainbow™, C.W. Sellors, the Institute of Registered Valuers, GemmoRaman and Alan Hodgkinson, President of the Scottish Gemmological Association.

Conference Events

A programme of seminars, workshops and visits over a period of six days was arranged to coincide with the Conference. These started on Friday 1 November with half-day seminars presented by Richard Drucker, Arthur Groom and Craig Lynch.

On Monday 4 November visits were arranged to the Pearls exhibition at the Victoria & Albert Museum and to view the Cheapside Hoard at the Museum of London. On Tuesday 5 November a guided tour of the Mineral Galley at the Natural History Museum was held and on Wednesday 6 November there was a private viewing of the Crown Jewels at the Tower of London with David Thomas.

A full report of the Conference and events was published in the November/December 2013 issue of *Gems&Jewellery*.

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Anniversary Dinner

An Anniversary Dinner was held at Goldsmiths' Hall on Saturday 2 November. The evening commenced with a drinks reception sponsored by Somewhere In The Rainbow™ held in the Drawing Room. Those who attended were welcomed to the event by the music of harpist Zuzanna Olbryś as they made their way up the magnificent staircase.

This was followed by dinner in the candlelit Livery Hall, attended by over 180 members and guests from around the world. Speeches were given by Gem-A CEO James Riley and President Harry Levy. Katrina Marchioni, President of Gemmological Association of Australia, also gave a speech and presented Gem-A with a ceremonial plaque of prasiolite mounted on Australian gumtree sap.

The evening finished with a raffle, and the Association is most grateful to those who generously donated the prizes.

Harpist Zuzanna Olbryś, a student at the Guildhall School of Music and Drama, playing at Goldsmiths' Hall. Photo by Miles Hoare. © Gem-A.

Graduation Ceremony

Martin Rapaport giving the address at the Graduation Ceremony at Goldsmiths' Hall. Photo courtesy of Photoshot.

The Graduation Ceremony and Presentation of Awards was held at Goldsmiths' Hall on Sunday 3 November. Cally Oldershaw, Chairman of the Gem-A Council, welcomed those present which included graduates from Australia, Canada, China, India, Japan, Madagascar, Sri Lanka, Taiwan, Thailand and the U.S.A., as well as well as those from Europe and the UK.

James Riley, Gem-A CEO, then introduced the guest speaker, Martin Rapaport, who presented the diplomas and awards. Special mention was made of Charlotte Leclerc of Paris, France, whose excellent answers in the examinations qualified her for all the Gemmology Diploma prizes — the Anderson-Bank Prize, the Read Practical Prize and the Christie's Prize for Gemmology, as well as the Tully Medal.

Following the presentations to the graduates, in recognition of their enormous contribution in their own fields of gemmology, Dr Emmanuel Fritsch of Nantes, France, and Martin Rapaport of New York, U.S.A., were awarded an Honorary Fellowship and Honorary Diamond Membership, respectively.

Three members were awarded Fellowship status in recognition of their high level of expertise and who had made a significant contribution to the field of gemmology for no less than 10 years were presented with Fellowship diplomas. They were Ronnie Bauer of Glen Iris, Victoria, Australia, Brendan Laurs of Encinitas, California, U.S.A., and Tay Thye Sun of Singapore.

Life membership was awarded to Leonard Baker of Ferndown, Dorset, the longest-standing Fellow of the Association, who had qualified for his Diploma in 1948. Life memberships were also awarded to David C.B. Jones of Adligenswil, Switzerland, Douglas M. Leake of Nuneaton, Warwickshire, John F. Marshall of Sutton Coldfield, West Midlands, William Richard H. Peplow of Worcester, Sarah A. Riley of Strensham, Worcestershire, and John M.S. Salloway of Lichfield, Staffordshire, all of whom qualified in the first Diamond Diploma examinations held in 1963. David Jones and Sarah Riley were present to receive their certificates of life membership.

Martin Rapaport gave an enthusiastic and stimulating address, congratulating the graduates on their great achievement and emphasizing that theirs was an industry with the highest moral and ethical codes. He encouraged them not to rest with the knowledge that they had qualified in their examinations but now to "strive to be excellent".

Charlotte Leclerc receiving the Tully Medal from Harry Levy, President of Gem-A. Photo courtesy of Photoshot.

The vote of thanks was given by Harry Levy, Gem-A President.

The ceremony was followed by a reception for graduates and guests in the Drawing Room.

Gifts and Donations to the Association

The Association is most grateful to the following for their gifts and donations for research and teaching purposes:

Leonard Baker FGA, Ferndown, Dorset, for a selection of crystal models, handheld gem equipment and a Moe gauge, and a large pearl oyster shell with pearl colour testing blotting paper.

John Bradshaw, Coast-to-Coast Rare Stones, for 32 rare and collectors' stones.

Elaine Branwell, Wellington, Somerset, for a selection of treated, imitation and synthetic stones.

Terry Coldham, Sydney, New South Wales, Australia, for a bag of small rough blue spinel from Vietnam.

Andrew Fellows FGA DGA, Gem-A, London, for four doubly terminated apatite crystals and one sharply terminated tourmaline crystal.

The Gemmological Association of Australia for a ceremonial plaque of prasiolite mounted on Australian gumtree sap.

Denis Ho, Myanmar, for a set of seven diamond simulants, a set of A, B, C and B+C jades, and three rough and three cut chrome tourmalines.

Brendan Laurs FGA, Gem-A, Encinitas, California, U.S.A., for a pearl oyster shell and cultured pearl from Halong Bay, Vietnam; a pearl oyster shell with a shell-shaped blister pearl from Halong Bay; also rough spinel-bearing marble and a bag of spinel-bearing gem gravel from the Cong Troi mine, Luc Yen, Vietnam.

Dominic Mok FGA DGA, AGIL, Hong Kong, for pre-treated and treated rough and faceted samples of corundum, showing the stages of cobalt-infused lead-glass-filled blue sapphire. A sample card displaying rough crystals of gemstones of Burma.

Tawee Khankaew, Bangkok, Thailand, for a small parcel of lead-glass-filled sapphires.

Ted Themelis, Bangkok, Thailand, for pre-treated and treated rough and faceted samples of corundum, showing the stages of cobalt-infused lead-glass-filled blue sapphire.

Gem-A Photographic Competition

2013 Competition winners

Overall winner and winner of Natural category

Michael Hügi FGA

Gilalite aggregates in rock crystal (Medusa quartz) from Brazil. Gilalite is a rare hydrous copper silicate. (Polarization filter used on the microscope objective to eliminate blurring of the image due to the double refraction of quartz. Magnified approximately 25×.)

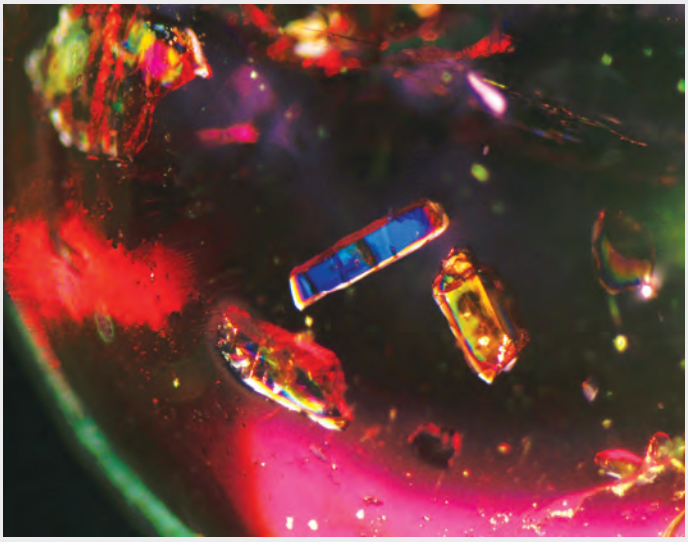

Winner of Treated category

Edward Ferder FGA DGA

Almandine seen with crossed polars. The photomicrograph shows vivid interference colours of doubly refractive crystal inclusions. (Magnified approximately 50×.)

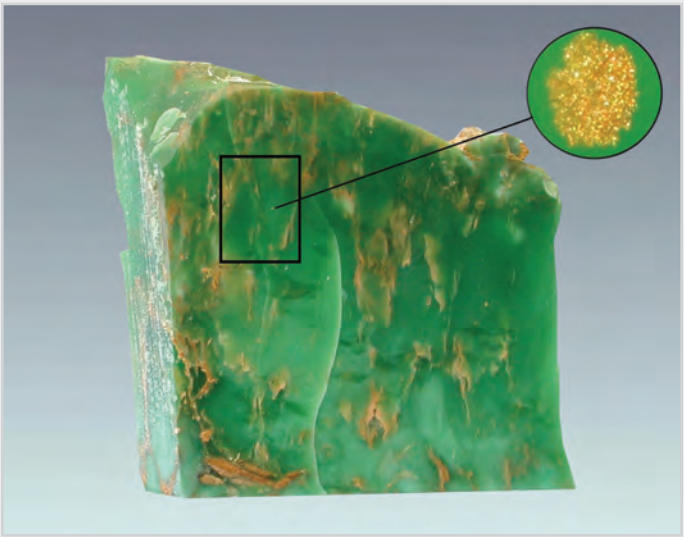

Winner of Synthetic category

John Harris FGA

A polished section of Australian variscite (2.6 cm across) with a microscopic surface-reaching inclusion of gold (inset, magnified approximately 200×).

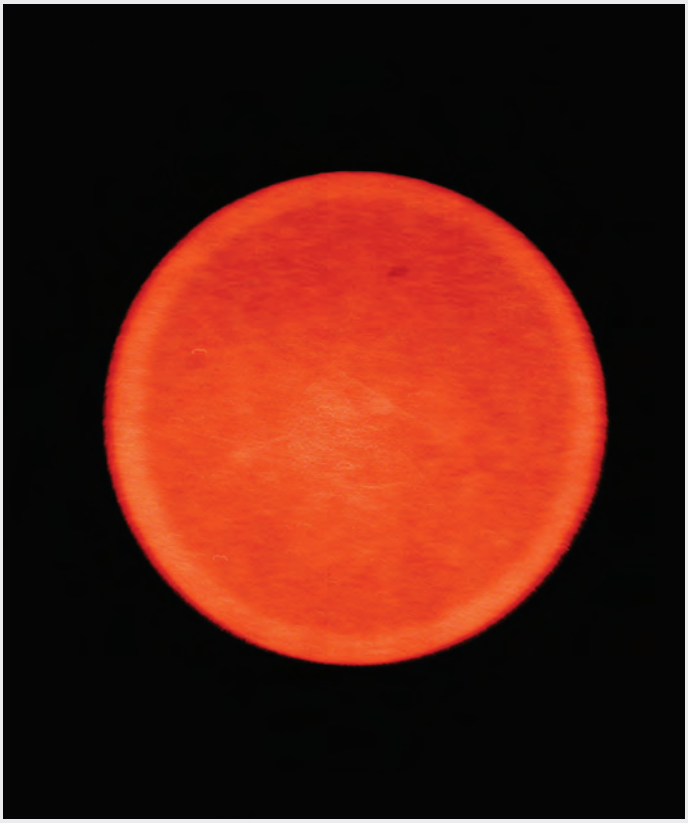

Winner of Melange category

John Harris FGA

A ground glass diffusion filter capturing the polarized extraordinary ray from an orangey pink sapphire giving an impression of solar energy.

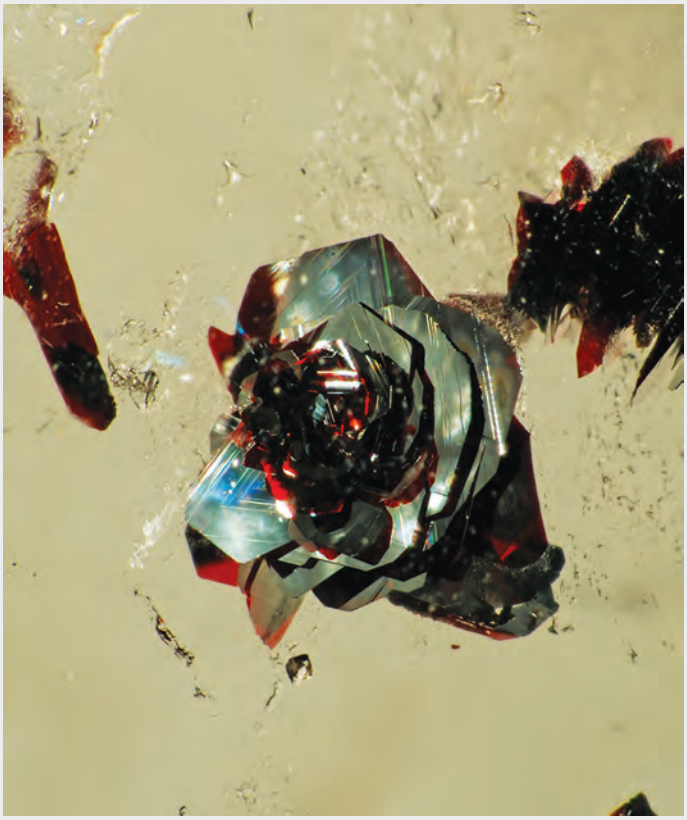

Honourable mention

Conny Forsberg FGA

Hematite rose in quartz from Brazil. (Magnified approximately 70×.)

The 2014 Competition is now open!

All Gem-A members are invited to participate. Once again there are four categories in which an image may be submitted:

1 **Natural**
Digital photograph (or photomicrograph) with minimal post-production work (may include basic cropping, contrast and minor hue/saturation adjustments).

2 **Treated**
Digital photograph (or photomicrograph) with significant post-production work (such as background manipulation, HDR and contrast masking).

3 **Synthetic**
Computer-rendered 3D models of gemstones, crystals, crystal structures, images from microtomography, etc.

4 **Melange**
This category includes any gem-related image that doesn't fit in the above and may include such things as photos of a spectrum, a scanning electron microscope image, mining, cutting, etc.

The entries will be judged by an industry panel on the basis of gemmological interest, inspiration, artistic quality and, in the case of categories 2 and 3, computer skills and ingenuity. A prize will be awarded in each category and, depending on submissions and at the judges' discretion, an additional prize for the most humorous or unusual image might also be awarded. All prize winners will receive their image within a frameable mount. In addition there will be one overall winner who will receive a free Gem-A membership for the following year.

To enter

Please send a low resolution version of your photo to editor@gem-a.com. Entry forms and full details of the competition, including copyright information and Rules of Entry, can be accessed at www.gem-a.com/membership/photographic-competition.aspx or call Amandine Rongy at +44 (0)20 7404 3334.

Closing date: 30 June 2014

Winning entries will be announced at the 2014 Gem-A Conference and be featured in *Gems&Jewellery*.

Gem-A Awards

In the Gem-A examinations held in June 2013, 177 students qualified in the Gemmology Diploma Examination, including nine with Distinction and 23 with Merit, and in the Foundation Certificate in Gemmology Examination 276 qualified. In the Gem Diamond Examination 78 qualified, including 11 with Distinction and 12 with Merit.

In the Gemmology Diploma examination, the Tully Medal is awarded to the candidate who submits the best set of answers which, in the opinion of the Examiners, are of sufficiently high standard. The Christie's Prize for Gemmology is awarded to the best candidate of the year, the Anderson Bank Prize for the best set of theory papers and the Read Practical Prize (sponsored for 2013 by DeeDee Cunningham of Toronto, Canada) for excellence in the practical examination. The **Tully Medal**, the **Christie's Prize for Gemmology**, the **Anderson Bank Prize** and the **Read Practical Prize** were awarded to **Charlotte Leclerc** of Paris, France.

In the Foundation Certificate in Gemmology examination, the **Anderson Medal** for the candidate who submitted the best set of answers which, in the opinion of the Examiners, were of sufficiently high standard, and the **Hirsh Foundation Award** for the best candidate of the year, were awarded to **Nicole Mouralian** of Montreal, Quebec, Canada.

In the Gem Diamond Diploma examination, the **Bruton Medal** for the best set of theory answer papers of the year was awarded to **Li Ziyue** of Zhuhai, Guangdong, P.R. China.

The **Deeks Diamond Prize** for the best candidate of the year was awarded to **Stefanus Salomon Weyers** of Brandhof, Bloemfontein, South Africa.

The **Diamond Practical Prize** for excellence in the Diamond Practical Examination, sponsored by Dominic Mok from AGIL, Hong Kong, was awarded to **Caroline R. Marcus** of Oxford.

The names of the successful candidates are listed below.

Examinations in Gemmology

Gemmology Diploma

Qualified with Distinction

Blake, Andrea Renae, Chevy Chase, Maryland, U.S.A.
Bosshard Schreckenberg, Astrid, Zurich, Switzerland
Caruel, Maxime, Antananarivo, Madagascar
Choquette, Carolyne, Laval, Quebec, Canada
Leclerc, Charlotte, Paris, France
Saeseaw, Sudarat, Bangrak, Bangkok, Thailand
Suthiyuth, Ratima, Bangrak, Bangkok, Thailand
Walker, Megan G., Edinburgh
Yao Shun, Beijing, P.R. China

Qualified with Merit

Chen Yang, Wuhan, Hubei, P.R. China
Corbin, Marie-Hélène, Montreal, Quebec, Canada
Floch, Edouard, Paris, France
Haeringer, Manuelle, Marseille, France
Howard, Naomi Victoria Georgina, Brussels, Belgium
Huang Lilin, Beihai, Guangxi, P.R. China
Jiang Huiyue, Punan, Shandong, P.R. China
Li, Timothy, Idle, Bradford, West Yorkshire
Li Pengfei, Kuytun, Xinjiang, P.R. China
Lindt, Yulia, Vaucluse, New South Wales, Australia
Massot, Marie-Caroline, Ambatobe, Antananarivo, Madagascar
Miao Ruiyuan, Liaocheng, Shandong, P.R. China
Rafalimanana, Laza Andriamizaka, Antsirabe, Antananarivo, Madagascar
Raynaud, Victoria, Grilly, France
Ren Qianqian, Nanyang, Henan, P.R. China
Rodrigues, Silvio, Geneva, Switzerland
Steele, Sarah Caldwell, Nether Poppleton, North Yorkshire
Wang Xiaodi, Beijing, P.R. China
Zhang Bailu, Beijing, P.R. China
Zhang Yingxin, Foshan, Guangdon, P.R. China
Zhao Qiannan, Beijing, P.R. China
Zhao Yijia, Shaoxing, Zhejiang, P.R. China
Zheng Yi, Wenzhou, Zhejiang, P.R. China

Qualified

Armin, Leonie, Edinburgh
Assemmar, Soundouss, Montreal, Quebec, Canada
Au Siu Tong, Kowloon, Hong Kong
Bai Fangfang, Heze, Shandong, P.R. China
Bai Yuxutao, Anda, Suihua, Heilongjiang, P.R. China
Baker, Jan L., Rockhampton, Queensland, Australia
Ban Yuansheng, Nanning, Guangxi, P.R. China
Berros, Laura, Montigny-lès-Cormeilles, France
Billot, Nathalie, Marseille, France

Boucher, Edouard, Isle, France
Bouts, Antonia, Amsterdam, The Netherlands
Cai Changhua, Ziyuan, Guangxi, P.R. China
Caussinus, Alice, Beausoleil, France
Cha Liwen, Funing, Jiangsu, P.R. China
Chan Ngai Man, Tsing Yi, Hong Kong
Chang Hsueh-Pin, Taipei, Taiwan, R.O. China
Chao Ting, Taipei, Taiwan, R.O. China
Chen Chun-Wen, Taipei, Taiwan, R.O. China
Chen Jingli, Liuzhou, Guangxi, P.R. China
Chen Lingyu, Shanghai, P.R. China
Cheng Pei-Ling, Taipei City, Taiwan, R.O. China
Chong, Ronald R.K.K., Amsterdam, The Netherlands
Chou Chia Chia, Taipei, Taiwan, R.O. China
Chow Man Man, Shatin, Hong Kong
Chui Chun Hin, Shatin, Hong Kong
Coert, Edward James, Amsterdam, The Netherlands
Dai Qin, Shanghai, P.R. China
Deng Heng, Guilin, Guangxi, P.R. China
Devlin, Janet, Belfast, Northern Ireland
Dishington, Megumi, Shizuoka, Shizuoka Pref., Japan
Elazzouzi Louraoui, Celine, Ile de la Reunion, France
Fan Yun, Beijing, P.R. China
Fang Qiaoling, Hangzhou, Zhejiang, P.R. China
Faure, Florian, Versailles, France
Feng Wei, Guangzhou, Guangdong, P.R. China
Ferder, Edward, Lyndhurst, Hampshire
Fredolin, Christophe, Jurançon, France
French, Lucy, London
Fu Siyi, Beijing, P.R. China
Gauthier, Danielle, Laval, Quebec, Canada
Gellini, Roberta, Nice, France
Geng Yuxin, Huangshi, Hubei, P.R. China
Guo Jing, Shanghai, P.R. China
Guo Mengyan, Hebi, Henan, P.R. China
Guo Yikai, Jieyang, Guangdong, P.R. China
Hammarqvist, Susanne E., Stockholm, Sweden
Harris, Natalie, Merstham, Surrey
Hasselrot, William Anders, Stockholm, Sweden
He Huishi, Zhuji, Zhejiang, P.R. China
Ho Wai Fun, Margaret, Tseung Kwan O, Hong Kong
Homkrajae, Artitaya, Bangrak, Bangkok, Thailand
Hou Hongxi, Hangzhou, Zhejiang, P.R. China
Hou Lu, Montreal, Quebec, Canada
Hu Yue, Shenzhen, Guangdong, P.R. China
Huang Hui Meng, Kaohsiung City, Taiwan, R.O. China
Huang Jen Yu, Taipei City, Taiwan, R.O. China
Huang Shengling, Hepu, Guangxi, P.R. China
Huang Zi-Ning, London
Hughes, Erin Billie, Bangrak, Bangkok, Thailand
Ibison, Hannah, Bowgreave, Lancashire
Jendoubi, Faouzi, Paris, France
Kennedy, Ramona, Brunswick, Victoria, Australia
Kikkawa, Tomomi, Kofu, Yamanashi Pref., Japan
Kitcharoen, Kunakorn, Taling Chan, Bangkok, Thailand
Kuroda, Makiko, Hirakata City, Osaka, Japan
Kwong San Fong, Cathy, To Kwa Wan, Hong Kong
Lai Ruoyun, Lanxi, Zhejiang, P.R. China
Lau Man Wa, Eukice, Mong Kok, Hong Kong
Levy, Elsa, Boulogne-Billancourt, France
Li Jia, Beijing, P.R. China
Li Man Kit, Shatin, Hong Kong
Li Pingting, Wuhan, Hubei, P.R. China
Li Xiaofeng, Lianjiang, Fujian, P.R. China
Li Xin, Kaifeng, Henan, P.R. China
Li Xuemeng, Zhengzhou, Henan, P.R. China
Li Zhidong, Haifeng, Guangdong, P.R. China
Liang Zixin, Dongwan, Guangdong, P.R. China
Lin Jih Hsiang, Taipei City, Taiwan, R.O. China
Ling Yu, Beijing, P.R. China
Liu Jiatong, Lianyungang, Jiangsu, P.R. China
Liu Nianchuan, Yangzhou, Jiangsu, P.R. China
Liu Xiaotong, Zhengzhou, Henan, P.R. China
Liu Yingjiao, Beijing, P.R. China
Lo Yi-Ting, Luzhu Township, Taiwan, R.O. China
Ludlam, Louise, Birmingham, West Midlands
McKenzie, Troy, Greenslopes, Queensland, Australia
Matetskaya, Samantha, Pokrov, Vladimir Oblast, Russia
Matur, Fabienne, Lambesc, France
Mendes, Isabella, Dagnall, Hertfordshire
Meridoux, Marion, Saint-Gervais-les-Bains, France
Ming Lu, Shenzhen, Guangdong, P.R. China
Moore Laja, Sarah Elizabeth, Austin, Texas, U.S.A.
Mukamucyo, Marie-Claire, Montreal, Quebec, Canada
Muyal, Jonathan Daniel, Bangrak, Bangkok, Thailand
Norris, Edward, London
Ouyang Huiping, Shenzhen, Guangdong, P.R. China
Peshall, Jessica Monica Eyre, Pimlico, London
Pino, Loredana, Sestri Levante, Genova, Italy
Qin Yayun, Yulin, Guangxi, P.R. China
Qiu Yun, Conan, Zetland, New South Wales, Australia
Ramanasse, Anthony Heritiana, Ampandrianomby, Antananarivo, Madagascar
Randrianarivony, Cedric Dimakias, Antananarivo, Madagascar
Robinson, Molly, Quenington, Gloucestershire
Rodriguez, Faritza, London
Rongy, Amandine, London
Ryalls, Lucy, Birmingham, West Midlands
Saengbuangamlam, Saengthip, Bang Khun Thian, Bangkok, Thailand
Sang Miao, Taiyuan, Shanxi, P.R. China

Shen Yi, Changzhou, Jiangsu, P.R. China
Sheung Si Lai, Tin Hau, Hong Kong
Siritheerakul, Piradee, Bangrak, Bangkok, Thailand
Skinner, Jasmine Georgina, Birmingham, West Midlands
So Sau Man, Bernadette, Tsing Yi, Hong Kong
Street, Neil, Wilton, Connecticut, U.S.A.
Sun Lin, Wuhan, Hubei, P.R. China
Sun Ruijie, Korla, Xinjiang, P.R. China
Tan Cuiying, Shenzhen, Guangdong, P.R. China
Teissier, Virginie, Marseille, France
Thierrin-Michael, Gisela, Porrentruy, Switzerland
Thompson, Noah, Chiddingfold, Surrey
Tin Zaw Win, May, Pabedan Township, Yangon, Myanmar
Tjioe, Ay Djoen, Montreal, Quebec, Canada
Tsalis, Nicholas Alexander, Wellington, New Zealand
Tseng De-Luen, Taipei, Taiwan, R.O. China
van Gulik, Barbara Sophie, Edam, The Netherlands
Wang Jing, Beijing, P.R. China
Wang Chenfei, Qingyang, Gansu, P.R. China
Wiriya, Songserm, Chiangmai, Thailand
Wong Ying Ha, Kwai Chung, Hong Kong
Wu Yuqi, Xining, Qinghai, P.R. China
Yan Chi Kit, Nicholas, Sai Kung, Hong Kong
Yang Jiong, Tai'an, Shandong, P.R. China
Yang Nan Nan, Beijing, P.R. China
Yang Yilun, Shenzhen, Guangdong, P.R. China
Yoda, Takahiro, Ota-ku, Tokyo, Japan
Yuan Yihao, Wuhan, Hubei, P.R. China
Zhang Ruxiang, Shanghai, P.R. China
Zhang Sisi, Nanyang, Henan, P.R. China
Zhang Yiling, Montreal, Quebec, Canada
Zhang Yingjian, Xiamen, Fujian, P.R. China
Zhao Junlong, Wulumuqi, Xinjiang, China
Zhao Junlong, Beijing, P.R. China
Zhao Yanglan, Beijing, P.R. China
Zheng Juanjuan, Laibin, Guangxi, P.R. China
Zheng Qiuting, Beijing, P.R. China
Zhou Yonghang, Jinhua, Zhejiang, P.R. China
Zhu Lanling, Beijing, P.R. China

Foundation Certificate in Gemmology

Qualified

Adenaike, Bosun, Stevenage, Hertfordshire
Ahlstrom, Shawn, Bordon, Hampshire
Amoaku, Emefa, Ruislip, Greater London
Angel, Natalie, Redditch, Worcestershire
Aubert, Lea, Ivry-sur-Seine, France
Baggott, Sophie, Plymouth, Devon
Bai Xiao, Beijing, P.R. China
Battocchi, Francesca, Nairobi, Kenya
Belahlou, Fatima, Castelnau-le-Lez, France
Berros, Laura, Montigny-lès-Cormeilles, France
Boucher, Edouard, Isle, France
Cao Ri, Bangbu, Anhui, P.R. China
Caplan, Candice, Geneva, Switzerland
Carter, Nicole, Leeds, West Yorkshire
Caruel, Maxime, Ambohidratrimo, Antananarivo, Madagascar
Cazanescu, Cristina, Genova, Italy
Chai Jing, Beijing, P.R. China
Chaisinthop, Yodying, Suan Luang, Bangkok, Thailand
Chan Hang Cheung, Central, Hong Kong
Chen Lei-An, Taichung, Taiwan, R.O. China
Chen Miaofen, Chenxi, Guangxi, P.R. China
Chen Ming-Hsueh, I-Ian Hsien, Taiwan, R.O. China
Chen Qian Ran, Beijing, P.R. China
Chen Qianyu, Guangzhou, Guangdong, P.R. China
Chen Silei, Shanghai, P.R. China
Chen Xiao Ai, Dalian, Liaoning, P.R. China
Cheng Pei Fen, Tai Kok Tsui, Hong Kong
Cheng Qian, Shanghai, P.R. China
Cheng Tsz Yan, Repulse Bay, Hong Kong
Cheng Tze Kin, David, Shatin, Hong Kong
Cherrak, Djamila, Paris, France
Cheung Hoi Fun, Ho Man Tin, Hong Kong
Cheung Lok Yu, Hung Hom, Hong Kong
Cheung Tak Yee, Tseung Kwan O, Hong Kong
Choi Lai Kiu, Kwun Tong, Hong Kong
Choquette, Carolyne, Laval, Quebec, Canada
Chung Yu-Chen, Taichung, Taiwan, R.O. China
Clark, Bryan, Old Saybrook, Connecticut, U.S.A.
Cole, Stephanie, Bournemouth, Dorset
Convert, Nicolas, Mantes-la-Jolie, France
Dai An, Beijing, P.R. China
Dai Li Li, Beijing, P.R. China
De Lamberterie, Isabelle, Ambohidratrimo, Antananarivo, Madagascar
Delaye, Aline, Singapore
Dias Da Rosa, Caroline, Dublin, R.O. Ireland
Disner, Emilie, Geneva, Switzerland
Dray, Marine, Allauch, France
Du Hua Ting, Beijing, P.R. China
Duffy, Alex, Sutton Coldfield, West Midlands
Dunn, Lauren, Trowbridge, Wiltshire
Elazzouzi, Celine, Ile de la Reunion, France
Ellis, Angela, Hamilton, New Zealand
Fan Jing, Beijing, P.R. China
Fang Tzu-Liang, Hualien City, Taiwan, R.O. China
Fang Yi Bin, Beijing, P.R. China
Farmer, Jane, Stratford-upon-Avon, Warwickshire
Fayyer, Irina, Jersey City, New Jersey, U.S.A.

Fiebig, Jim, West Des Moines, Iowa, U.S.A.
Föge, Kerstin, Dijon, France
Forster, Helen, Stanley, County Durham
Fuchs, Alice, Vaud, Switzerland
Fujiki, Otoe, Shibuya, Tokyo, Japan
Gao Manmengxi, Wuzhou, Guangxi, P.R. China
Gaudion, Tina, Gagny, France
Gibson, Jane, Durham, County Durham
Gichonge, Stephen, Kalimoni, Juja, Kenya
Gordon-Finlayson, Camilla Rose, Singapore
Griffon, Denise, Montreal, Quebec, Canada
Guo Bi Jun, Beijing, P.R. China
Gyde, John, Abingdon, Oxfordshire
Hagbjer, Sarah, Lannavaara, Sweden
Hall, Claire-Louise, Newcastle-upon-Tyne, Tyne and Wear
Han Jie, Beijing, P.R. China
Han Ying Hui, Beijing, P.R. China
Hancock, Nancy, London
Harper, Kate, Edgbaston, West Midlands
Hoi Mou Lin, Southern District, Hong Kong
Holland, Katherine, Liverpool, Merseyside
Hon Pui Yee, Kwai Chung, Hong Kong
Hopkins, Gary, East Grinstead, West Sussex
Hou Lu, Montreal, Quebec, Canada
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Hsu Yu Lan, Taipei City, Taiwan, R.O. China
Hu Yizhi, Shanghai, P.R. China
Huang Hui-Min, Taichung, Taiwan, R.O. China
Huang Jiajun, Guangzhou, Guangdong, P.R. China
Huang Qiong, Liuzhou, Guangxi, P.R. China
Huang Yong, Beijing, P.R. China
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The 2014 subscription for Fellow, Diamond and Associate members is £125 and that for Corporate and Gold Corporate members £275. Members paying by direct debit (UK bank accounts only) may take a £25 discount.

James Heatlie
1937–2013

It is with great sadness that I report the death of James (Mac) Heatlie FGA DGA BSc (Hons). He will be forever remembered as a stalwart of the Scottish Gemmological Association (SGA). Mac was a man of few words; he had little regard for 'blethering' and tended to summarize everything he said.

The study of science was his great passion and he took a Degree in Chemistry and Physics at St Andrews University. After university Mac was employed as a Research Scientist with Imperial Chemical Industries and later at Edinburgh Pharmaceuticals Ltd. Following a teacher training course at St Margaret's Training College, Mac taught his beloved sciences at Broughton School and after a few years settled into a role at Telford College, becoming a senior lecturer teaching physics, computing, photography and even hair science with the hairdressing students!

Mac enjoyed sharing his knowledge and interest for the sciences, but his real passion was for gemmology, particularly the study of diamonds. This held his interest for 25 years. Mac did manage to teach gemmology at Telford for a couple of years before he retired in 1994 through ill-health. Exposure to chemicals was one of the key causes of his unusual serious medical condition: doctors only expected him to live six months, a year at the most. Although surviving against the odds, Mac never returned to full health again.

Mac was one of the founding members of the SGA, attending monthly lectures, the annual conference and going on field trips to discover hidden gems. Mac loved the field trips and even when battling with ill-health, he still took to the hills. He was the first to sign up for the SGA field trip to Russia.

Mac spent many hours volunteering at the National Museums of Scotland, identifying minerals from around the world and providing information for the collection. He also tutored and lectured on gemmology — the Gemmology Diploma and the Diamond Diploma courses.

Mac set about making his own gemmological instruments, and those who participated in the gold panning field trip that was part of the 2013 SGA Conference will remember his 'sookers', an essential aid for sucking up gold-bearing gravel.

Shortly after the conference Mac became ill and suddenly but peacefully died at home on Sunday 23 June, aged 76 years.

Mac, you will be remembered for your vast knowledge on so many subjects and your many years of sharing your expertise with students, friends and colleagues. You never let your illness knock you down and showed your strength until the end.

I would like to share with you a line from the *Colour of Magic* by Terry Pratchett, from the Discworld series which Mac loved: "And there were all the stars, looking remarkably like powered diamonds spilled on black velvet, the stars that lured and ultimately called the boldest towards them..."

Our thoughts and sympathy go out to his widow Katalin and son Andrew.

Brian Jackson

Mac Heatlie at the Karkodino demantoid mine, Ural Mountains, Russia. Photo by Maria Alferova.

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Cover Picture: A pair of ancient cameo carvings in garnet. The Hellenistic pyrope-almandine carving on the left (19.1×12.9 mm), probably Queen Arsinoë II of Egypt, is one of most beautiful examples of glyptic art produced in the Classical world and is one of the earliest dated extant cameo carvings in gem garnet. On the right is a pyrope cameo of the head of Eros encircled by a plaque (11.7×9.5 mm). This motif was popular in Roman glyptic of the 1st century BC to 1st century AD. Inv. nos. 81.AN.76.59 (left) and 83.AN.437.42 (right, gift of Damon Mezzacappa and Jonathan H. Kagan). The J. Paul Getty Museum, Villa Collection, Malibu, California. Photo by Harold and Erica Van Pelt. (See 'Greek, Etruscan and Roman Garnets in the antiquities collection of the J. Paul Getty Museum', pages 201–22.)

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Cover Photo: Rough and cut gems (spinel, ruby and moonstone) photographed at the home of a mine owner in Mogok, Myanmar. Two field reports on Mogok appear in the Excursions section of this issue. Photo by Marco Lorenzoni.

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Exciting Changes for *The Journal*

The Journal of Gemmology is the largest-circulated scholarly journal in gemmology. When first published in 1947, *The Journal* was a black-and-white booklet measuring 8¼ × 5½ inches with a grey cover. Occasional colour pages were introduced in the 1970s. A full-colour cover was added and *The Journal's* size increased to 9½ × 6¾ inches in 1986; it subsequently was expanded to A4 format in 2004. *The Journal* was published quarterly (except in 1987, when there were only three issues) until 2005. From 2005 to 2008 *The Journal* was published biannually, and during 2009–2012 it appeared annually in hardcopy, with PDF files of articles posted online as they were finalized. In 2013 two issues were published…and starting with the current issue *The Journal* will return to a quarterly format.

In this issue, you will notice a fresh look and the addition of some new sections, including regular columns titled Learning Opportunities, What's New, Gem Notes and From the Archives, as well as occasional sections called Practical Gemmology, Excursions and Conferences (which debuted last issue). Additional sections are planned for selected future issues: Appraiser's Corner, Instrumentation and Making History. Descriptions of all of these sections, and information on how you can contribute to some of them, are available on *The Journal's* web page at www.gem-a.com/publications/journal-of-gemmology.aspx.

In other regular sections, Gem-A Notices will continue to bring you the information communicated in the previously titled 'Proceedings of The Gemmological Association of Great Britain and Notices'. Book Reviews has been renamed New Media in anticipation of including DVDs as well as books, and this section also includes a supplemental list of additional titles that are not actually reviewed. The Abstracts section has been restructured into Literature of Interest, which features an extensive listing of articles useful to gemmologists, with links to the abstracts of those articles that are available online.

The foundation of *The Journal* will continue to be feature articles that have undergone rigorous peer review to ensure they are of high quality, are understandable to a wide audience and have practical value to gemmologists. Peer review of each article is done by at least three experts in the field, mostly drawn from an expanded list of 38 Associate Editors (see the masthead for their names). Three formats are envisioned: Feature Articles, Review Articles and Gemmological Briefs.

I am also pleased to announce that volume indexes are being created for issues dating back to 2004, and a cumulative index from 1947 to 2013 is in preparation. In addition, we are in the process of scanning all back issues of *The Journal* into PDFs, and in the future they will be made freely available to Gem-A members (in addition to the 2008–2013 issues currently online). Non-members will eventually be able to instantly purchase individual articles online.

I am grateful to Gem-A and the Swiss Gemmological Institute SSEF for their support of *The Journal's* transformation. Partial funding is also being supplied by a limited amount of select advertising. The previous issue marks the first time that outside advertisements have been included since 2006.

I hope that you enjoy the expanded content and high-quality research offered by *The Journal*, as well as the resumption of the quarterly publication schedule. I welcome your suggestions on how we can make future issues even more useful and educational.

Brendan Laurs
Editor-in-Chief

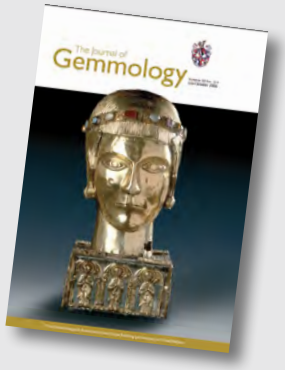

What's New

INSTRUMENTS AND TECHNIQUES

Identifying HPHT-treated Natural Type IIa Colourless Diamonds and CVD Synthetic Diamonds

Since November 2012, a series of Application Notes have been posted on the M&A Gemological Instruments website at www.gemmoraman.com/articles.aspx. These cover various topics, including the use of a Raman spectrometer for separating heated from unheated spinel, identifying the colour origin of cultured freshwater pearls, red coral and conch pearls, and detecting resin-impregnated jadeite. Most recently (in September 2013 and January 2014), Application Notes were posted on two important diamond topics.

Photo by Alberto Scarani

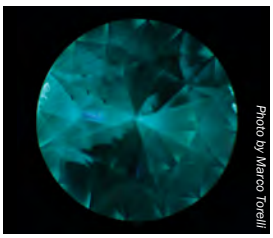
Photo by Marco Torelli

Detecting HPHT Treatment of Natural Type IIa Colorless Diamonds describes subtle differences in the gemmological properties and photoluminescence (PL) spectra between untreated natural type IIa diamonds and their HPHT-treated counterparts. The PL spectral acquisitions were carried out with a GemmoRaman spectrometer utilizing 532 nm laser excitation. Spectra were collected at both room temperature and with the samples cooled to liquid nitrogen temperature to obtain sharper PL peaks and reveal additional features not detectable at room temperature. Although the results obtained at room temperature were surprisingly good, cryogenic testing is recommended for confirmation of treatment detection in type IIa colourless diamonds.

Detecting Synthetic CVD-Diamond with Gemmo-Raman-532SG™ describes a testing procedure for identifying colourless to near-colourless CVD-grown synthetic diamonds. After initial screening for simulants and establishment of type II diamond type, a combination of UV fluorescence microscopy and PL spectroscopy is described for identifying CVD synthetics. The authors note that the SiV^- defect—which is typical of CVD origin—can often be detected at room temperature as a somewhat broadened PL peak at about 738 nm. However, careful interpretation of the spectrum is important, as many natural type IIa diamonds exhibit a weak-to-moderate GR1 peak located in close proximity, at 741 nm. Cryogenic cooling of the sample is recommended.

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M&A Gemological Instruments
Rome, Italy and Järvenpää, Finland

Tourmaline Magnetism

In December 2013, a study of the relationship between magnetic susceptibility and coloration of gem tourmaline was posted at www.gemstonemagnetism.com/how_to_page_7.html. Quantitative magnetic measurements were taken with a Hoover balance of more than 150 samples, including a number of Paraíba-type tourmalines. A specific range of magnetic susceptibility was associated with each colour variety.

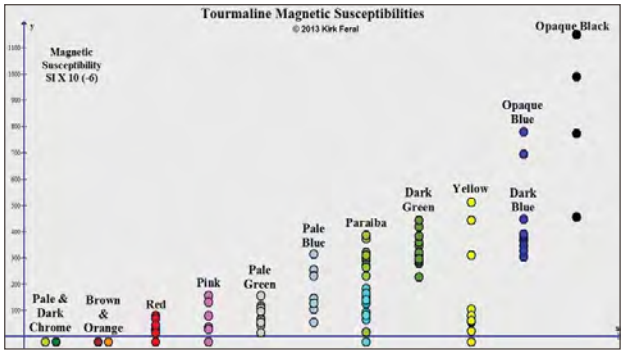

Of the transparent samples tested, red and pink gems had some of the lowest values, while dark green and blue gems had some of the highest; yellow samples showed the greatest variations in magnetic susceptibility. The study also showed that magnetic responses to a handheld neodymium magnet can be used to identify certain tourmaline varieties. For example, a drag response from any blue tourmaline was diagnostic of indicolite, while diamagnetic (repel) behaviour from any blue tourmaline was indicative of the Paraíba type. A diamagnetic response from any green tourmaline was consistent with 'chrome tourmaline' (coloured by chromium and/or vanadium).

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San Diego, California, USA

PUBLICATIONS

CIBJO Blue Books

Updated (2013) versions of *The Diamond Book, The Gemstone Book* and *The Pearl Book* are available for download at www.cibjo.org. These useful reference books cover terminology and classification as well as terms and definitions. In addition, comprehensive appendices supply the following information:

- *The Diamond Book*—contents of diamond grading reports, possible treatments, parts and facet arrangement of a round brilliant cut, and terms for colour and clarity grades.
- *The Gemstone Book*—a list of common and unusual coloured stones, their possible treatments (including stability and advice for their care) and whether they are available as synthetics.
- *The Pearl Book*—descriptions and definitions of pearl-producing molluscs, treatments (including advice for their care) and localities for natural and cultured pearls according to mollusc species.

Other CIBJO Blue Books available for download are 2012 editions of *The Precious Metals Book* and *The Gemmological Laboratory Book.*

GGTL Labs Newsletter

GGTL Laboratories has released its latest newsletter (No. 2, 2013), available at www.ggtl-lab.org/science/newsletter. It documents an F-colour natural type IaA diamond that had been misidentified by a laboratory as a synthetic diamond, the screening of melee-sized diamonds for CVD synthetics, properties of HPHT-grown synthetic diamonds that are irradiated and then annealed (or HPHT treated), a blue sapphire with subsurface synthetic corundum crystallites that formed due to treatment at very high temperatures, a bicoloured purple and blue 'Maxixe' beryl, an aquamarine that was fracture-filled with epoxy resin and an unpolished calcitic pearl with an 'olive' green overgrowth. Announced is the availability of GGTL photomicrographs for use in publications. Images can be freely downloaded from www.ggtl-lab.org/pictures, provided that the photos are credited to GGTL.

Gem Testing Laboratory (Jaipur, India) Newsletter

The latest Lab Information Circular (Vol. 68, November 2013), available at http://www.gtljaipur.info/Lab%20Information%20Circular.asp, describes sapphires enhanced with cobalt-coloured lead glass, CVD synthetic diamonds and rough diamond imitations (cubic zirconia and topaz).

GIT Lab Updates

Since July 2013, the Gem and Jewelry Institute of Thailand has posted four lab updates at www.git.or.th/2013/index_en.html.

1. *GIT Exploring Ruby and Sapphire Deposits of the Mogok Stone Tract, Myanmar,* describes a June 2013 expedition to visit ruby, sapphire, peridot and spinel mines in this important gem-producing area.
2. *An Unusual Pink Opal* focuses on a 0.27 ct faceted opal with an orangey pink body colour that was found to be due to dye treatment.
3. *Reconstructed Sapphire: A New Type of Manmade Gem Corundum* identified two faceted dark blue stones (5.13 and 6.53 ct) as granular aggregates of corundum that were artificially assembled together with a new type of process.
4. *A Treated Stone Sold as 'Black Sapphire'* documents two representative faceted stones (1.44 and 1.91 ct) that were taken from a parcel of gems sold as 'black sapphire'. The report suggests low-quality colourless to pale-coloured sapphires with abundant open fissures were treated by the typical Ti-diffusion

1 Photo by Boontawee Suptrasert

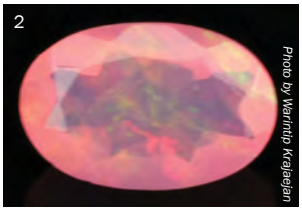
2 Photo by Wathnitip Krajaejan

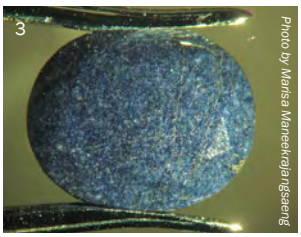
3 Photo by Marisa Maneekrajangsaeng

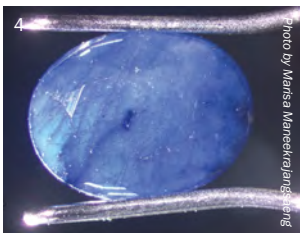
4 Photo by Marisa Maneekrajangsaeng

technique, and the exceptionally dark coloration resulted from Ti diffusion into fissures that were subsequently healed during high-temperature heat treatment.

ICGL Newsletter

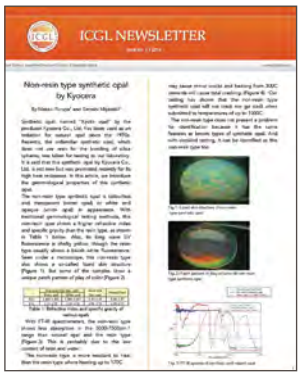

The International Consortium of Gem-Testing Laboratories has released its latest newsletter (No. 1, 2014), available at http://icglabs.org. It describes a non-resin type synthetic opal by Kyocera, profiles petalite as a collector's gem and contains a review of the exhibition titled *The Cheapside Hoard: London's Lost Jewels*, on display at the Museum of London until 27 April 2014.

JVC Releases Two Essential Guides

In 2013, the Jewelers Vigilance Committee published two additions to its Essential Guides series (see www.jvclegal.org/index.php?categoryid=601). *The Essential Guide to Conflict Minerals and the Dodd Frank Act* explains legislation passed in 2010 that addresses 'conflict minerals' (tin, tantalum, tungsten and gold). *The Essential Guide to the U.S. Trade in Materials from Plant and Wildlife Products* covers organic gem materials that have been classified as protected by international, federal, and/or state laws.

SSEF Facette and Lab Alert

The Swiss Gemmological Institute SSEF has released the latest Facette Magazine (No. 21, 2014), which is available at www.ssef.ch/research-publications/facette. It describes several exceptional items sold at auction by Christie's and Sotheby's in 2013, an expedition to Mogok (Myanmar), a technique called 'automated spectral diamond inspection' for authenticating melee size-diamonds, DNA fingerprinting of pearls, blue cobalt-bearing spinel from Vietnam, a stability experiment on Ethiopian opal, colour-change garnets from Tanzania showing the Usambara effect, jadeite from Kazakhstan, an imitation amber carving, a brooch featuring a 110 ct non-nacreous natural pearl, rubies from Didy (Madagascar), spessartine from Nigeria and Mogok, 'Pipi' pearls from the Pacific Ocean, vanadium-bearing chrysoberyl, a topaz pendant that was evidently damaged in a barbeque, cultured pearls from French Polynesia containing new bead materials (organic nuclei and freshwater shell pieces) and a report on the International Gemmological Conference in Vietnam.

In September 2013, SSEF issued a lab alert on a new, unstable treatment of conch pearls that results in surface damage (see www.ssef.ch/research-publications/press-releases).

MISCELLANEOUS

MIM Mineral Museum Opens in Beirut

In October 2013, the MIM Mineral Museum opened at the Campus of Innovation and Sport, Saint-Joseph University, Beirut, Lebanon (www.facebook.com/mim.museum). The collection includes more than 1,400 minerals, and of particular interest to gemmologists are world-class gem crystals selected for their transparency, colour and morphology. There is also a large display of multi-coloured liddicoatite slices.

Photo by Makhmout Doumani

What's New provides announcements of new instruments/technology, publications, online resources and more. Inclusion in What's New does not imply recommendation or endorsement by Gem-A. Entries are prepared by Brendan Laurs unless otherwise noted.

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Photomicrography Using a Smartphone Camera

Edward Boehm

While visiting mines, gem offices or trade shows, the travelling gemmologist is often challenged to come up with creative ways to identify gems and minerals using portable instruments. A few years ago, while in an office documenting some spinels that contained beautiful inclusions, I had access to a nice microscope but no SLR camera or attachment. So, I decided to try using the camera from my smartphone (iPhone) to see if I could capture the inclusions. It took a bit of practice and lots of patience, but I was able to make it work (Figure 1). Since then, I have improved the technique and also managed to take photomicrographs through a darkfield loupe (Figure 2).

When learning to take photomicrographs with a smartphone camera, it is best to start at a lower magnification and simply try to capture the entire gem in the field of view. The camera lens should be held approximately 1 cm away and directly over the centre of an ocular. Hold the camera phone as steady as possible using both hands, while using the other ocular for stability (Figure 3). If your microscope is equipped with eye shields, try resting the camera phone on a shield for stability. However, it may be easier to remove the shield if it is not positioned at the

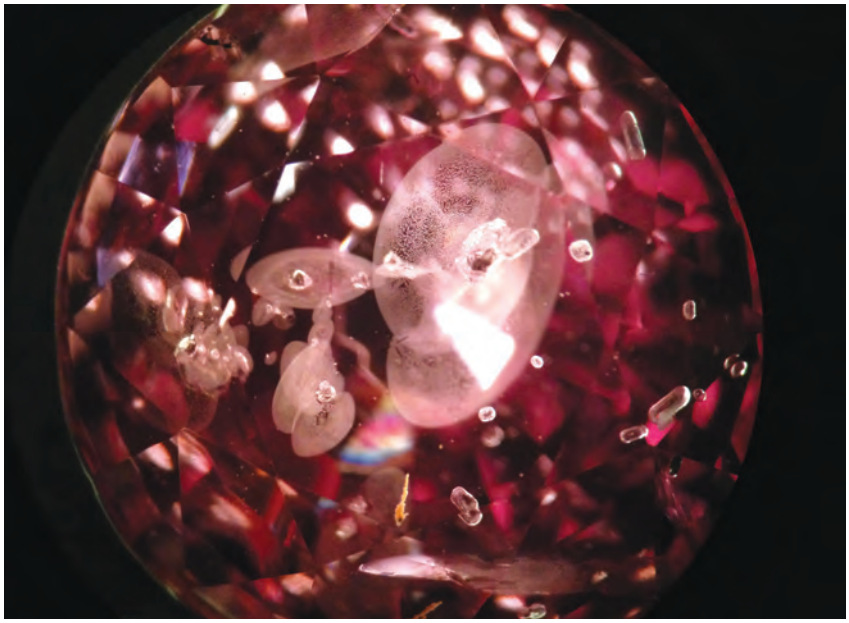

Figure 1: Viewed with a Zeiss microscope and photographed with an iPhone, these inclusions in a pink Burmese spinel consist of negative octahedral crystals with stellate clouds and rounded protogenetic apatites. A single black inclusion is also present (probably ilmenite or graphite). Photomicrograph by E. Boehm; magnified 20×.

Figure 2: These uraninite crystals with tension halos in a lavender Burmese spinel were captured with a 10× darkfield loupe and an iPhone camera. Photomicrograph by E. Boehm.

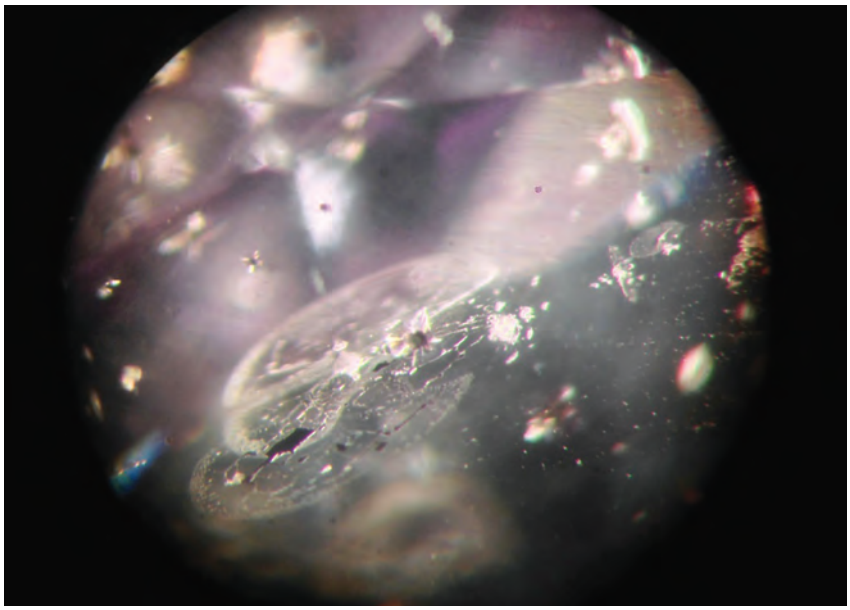

Figure 3: The author demonstrates the technique for taking photomicrographs using a smartphone camera. Here the lens of the camera is positioned over the right ocular, and the left hand is resting on the left ocular for stability. The camera lens is held approximately 1 cm above the ocular. Photo by Carley Boehm.

ideal distance from the ocular, or if it prevents the camera from being moved around until the correct image is displayed.

Tapping on the focus square and using the HDR mode should improve the picture quality. After a bit of practice, you will be able to zoom the microscope closer on the individual inclusions or surface characteristics that you wish to document. Although macro photography attachments are available for some camera phones, they should not be necessary for taking good photomicrographs using the technique described here.

While smartphone cameras cannot achieve the sharp focus or depth-of-field of digital SLR cameras, their ability to capture micro-features as well as the true colour of the host gem is exceptional. And, of course, their portability is superior. A smartphone camera should be considered one more indispensable tool in the travelling gemmologist's arsenal.

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Email: edward@raresource.com

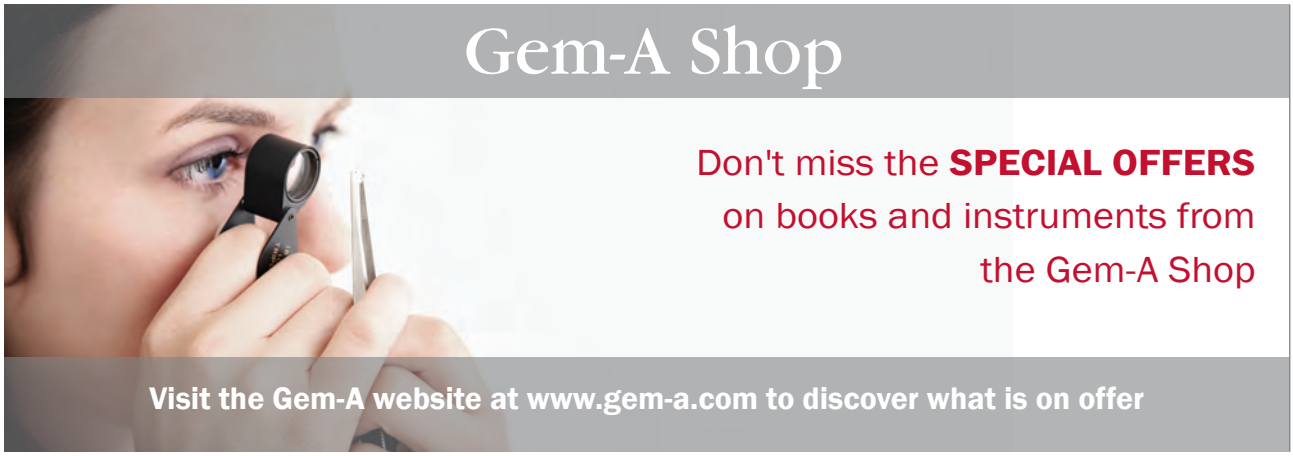

Gem Notes

COLOURED STONES

Colourless Cat's-eye Apatite from Brazil

Intense blue apatite is known from Minas Gerais, Brazil, and cat's-eye stones in yellow and green have also been documented from this gem-rich country (O'Donoghue, 2006). In addition, a small amount of colourless cat's-eye apatite was recently produced, and shown to this author at the recent Tucson gem shows by David Epstein (Precious Resources Ltda., Teófilo Otoni, Brazil). He reported that the material was found in January 2013, and came from a parcel consisting mainly of greenish blue cat's-eye apatite. Some of the rough was colour zoned, and the colourless portions were polished into 40–50 pieces ranging from 1 to 4 ct (e.g. Figure 1), for a total of approximately 100 carats. The material is known to have been cut in Teófilo Otoni, but the origin of the unusual rough material within Brazil is unknown.

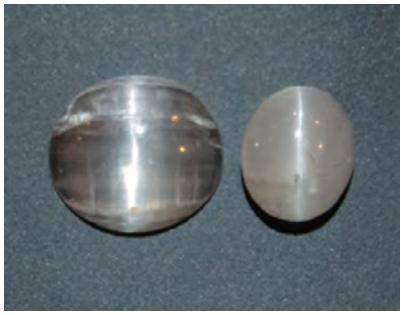

Figure 1: These cat's-eye apatites (2.45 and 3.80 ct) from Brazil are colourless, which is highly unusual for this material. Photo by B.M. Laurs.

Brendan M. Laurs

Reference

O'Donoghue M. (Ed.), 2006. *Gems,* 6th edn., Butterworth-Heinemann, Oxford, 382–384.

Prismatic Aquamarine Crystals from Ethiopia

Aquamarine has been mined from southern Ethiopia since at least 2010, but typically only a small proportion is of gem quality (Laurs et al., 2012). This is apparently because much of the production comes from crystals that were 'frozen' within pegmatite (rather than forming in open cavities) and therefore have low transparency. Most of the aquamarine has been recovered as broken pieces, some rather large.

Figure 2: These aquamarine crystals were reportedly produced in Ethiopia in mid-2012. They range from 3.5 to 7.5 cm long. Photo by B.M. Laurs.

During the September 2013 Hong Kong gem show, Farooq Hashmi showed this author some more recent production of Ethiopian aquamarine that was quite different from material seen in the past: the crystals were prismatic, well formed, and of fine gem quality (e.g. Figure 2). He first encountered this aquamarine during the September 2012 Hong Kong show, when he obtained approximately 2 kg of the better crystals from a parcel weighing 20–25 kg; about 30% of that parcel showed good transparency. He was told that the aquamarine was produced in mid-2012. Most of the crystals were partially covered with a hard coating that appeared to consist of iron-stained clay.

During a January 2013 buying trip to Ethiopia, Hashmi encountered more of these prismatic aquamarine crystals, with the same hard coating mentioned above. However, these were much smaller, ranging from 2 to 3 cm long and 2–4 mm in diameter. The parcel weighed a total of about 2/3

kg, and most of the crystals were <1 g. Although too small for cutting gemstones, they could make attractive pendants for jewellery.

Brendan M. Laurs

Reference

Laurs B.M., Simmons W.B. and Falster A.U., 2012. Gem News International: New gem discoveries in Ethiopia. *Gems & Gemology,* **48**(1), 66–67.

Blue Chrysocolla Chalcedony from Peru

In mid-2012, gem dealer Hussain Rezayee (Rare Gems & Minerals, Beverly Hills, California, USA) obtained some newly produced 'gem silica' from the Arequipa region of southern Peru. This area is known to produce fine-quality gem silica (chrysocolla chalcedony) that is typically greenish blue to blue-green (e.g. Hyrsl, 2001; Emerson and Darley, 2010). However, this newer material was bluer than previously reported. Rezayee obtained additional material on another trip to Peru in May 2013, bringing his total amount to 183 kg in various grades. He was told that the blue gem silica was found at the bottom of a mine shaft, and was completely worked out by the miners. Pieces weighing up to 58 kg were recovered, with gem-quality samples of 750+ g. None of the material is known to have undergone any treatment.

Rezayee initially cut 22 cabochons weighing 2.49–22.02 ct, and he loaned three samples for characterization (18.07–22.02 ct; Figure 3). Examination by one of us (BC) showed the following properties: colour—light greenish blue to blue; diaphaneity—opaque; lustre—waxy, dull; RI—1.55 (spot method); hydrostatic SG—2.58–2.61; Chelsea colour filter reaction—none; and fluorescence—inert to long-wave and zoned chalky bluish white to short-wave UV radiation. The zoned fluorescence was apparently due to the local presence of an unidentified impurity mixed with the silica. However, when the fluorescent areas were analysed with Raman spectroscopy, the signal was overwhelmed by the quartz matrix. Ultraviolet-visible–near infrared (UV-Vis-NIR) spectroscopy showed a broad absorption band from approximately 430 to 530 nm (Figure 4). Chemical analysis by energy-dispersive X-ray fluorescence (EDXRF) spectroscopy showed only Si and Cu as major elements. These properties (other than the short-wave UV fluorescence) are consistent with those reported for chrysocolla and quartz by O'Donoghue (2006).

Microscopic examination revealed a polycrystalline texture consisting of minute blue and white interlocking crystals. Magnification also showed faint colour banding of lighter and darker blue layers. Small yellow and dark-appearing discolorations were disseminated throughout the stones, and were probably due to epigenetic staining and inclusions.

Figure 3: These cabochons of blue chrysocolla chalcedony (18.07–22.02 ct) were cut from material recently produced in southern Peru. Photo by Bilal Mahmood.

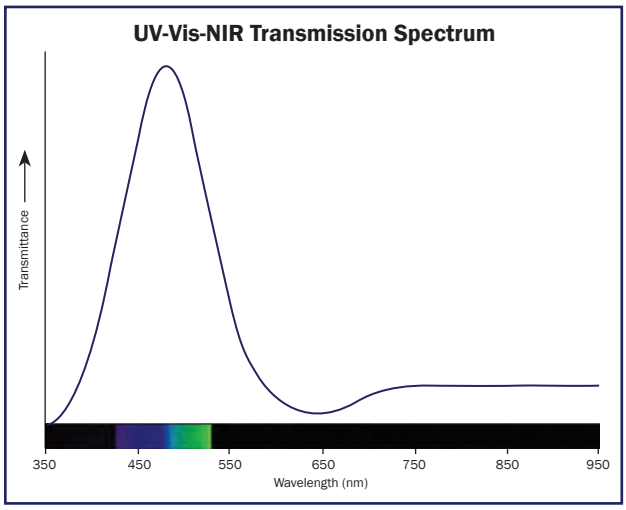

Figure 4: A broad transmission band extending mainly from approximately 430 to 530 nm was recorded in the UV-Vis-NIR spectrum of the chrysocolla chalcedony, which is consistent with copper as the chromophore for this material.

While calling this material *gem silica* is not technically incorrect, gemmologically it would be classified as chrysocolla within quartz, or simply chrysocolla chalcedony.

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Brendan M. Laurs

References

Emerson E. and Darley J., 2010. Chrysocolla chalcedony from Acari, Peru. *Gems & Gemology,* **46**(2), 148–149.

Hyršl J., 2001. Gemstones of Peru. *Journal of Gemmology,* **27**(6), 328–334.

O'Donoghue M. (Ed.), 2006. *Gems,* 6th edn. Butterworth-Heinemann, Oxford, 306 and 339.

A Wonderfully 'Painful' Discovery

The Natural History Museum in London has been at the centre of several mineralogical and gemmological discoveries over the past two centuries. Many of these have interesting stories behind them, such as the recognition of a hitherto unknown specimen of the rare mineral painite in the Museum's main systematic mineral collection.

In 1952 A.C.D. Pain sent to London a small 1.7 g unidentified crystal found in the gem gravels of Mogok, Burma. It was not until 1956 that this crystal was described as a new species, painite (Claringbull et al., 1957), after analytical tests were performed at what was then the British Museum (Natural History). In 1959 a second painite crystal weighing 2.12 g entered the Museum's collection, and for 20 years these two crystals remained the world's only known specimens of the species. As such, these two slightly waterworn crystals were given the distinction of being the world's rarest gem mineral by the *Guinness Book of World Records* (McWhirter, 1983). In 1979 a third specimen was found and donated to the Gemological Institute of America by Ed Swoboda (Shigley, 1986). The fourth painite was not discovered until 2001 (http://minerals.caltech.edu/FILES/Visible/painite/Index.html), by which time the mineral had obtained an almost legendary status, with many collectors looking for this elusive gem species.

William Larson of Pala International (Fallbrook, California) was inspired to trace this enigmatic mineral when visiting Peter Embrey in the 1970s, then Curator of Mineralogy at the British Museum (Natural History). Through Larson's endeavours during numerous trips to Myanmar, and the efforts of local miners and geologists, painite was rediscovered and new specimens started to appear in 2002 (see www.palagems.com/painite.htm). When painite was later discovered in-situ near Mogok in 2005, many thousands of crystals and fragments were recovered (Rossman, 2005). Larson brought some of this new material to the Tucson Gem and Mineral show, and the Museum obtained samples to complement its original type holdings.

Figure 5: Originally acquired by the British Museum (Natural History) as a specimen of ruby and brown tourmaline in 1914, the 'tourmaline' actually turned out to be the as-yet undescribed gem mineral painite (top, 47×32×26 mm, BM 1914,1118). Also shown are the original type specimens of painite from gem gravels near Ohngang village in the Mogok area (bottom, BM 1954,192 and BM 1961,144). Photo by Harry Taylor, The Natural History Museum Picture Library.

It was through looking at this new material and noting the distinct differences from the original type specimens that a surprising discovery was

made by one of the authors (AH) in the Museum's main systematic mineral collection. Within the corundum collection was a specimen from Mogok labelled 'Corundum (ruby) pitted crystals on crystals of brown tourmaline with limonite'. The 'brown tourmaline' was an immediate visual match with material from the new painite discovery, and in December 2007 an electron microprobe analysis confirmed it was indeed painite. It is a fine specimen in terms of its form, size and association with ruby crystals that are up to 8 mm across (Figure 5). Astonishingly, the specimen had been acquired in 1914, from Francis Powell & Co., London. It was registered into the collection (BM 1914,1118) and remained misidentified for 93 years—and it also was present for 38 years before painite was formally discovered using the crystal donated to the Museum by Pain. It is ironic that this far superior specimen was sitting within the collection just meters away from the 1952 specimen that was on display for so many years as the 'best of species'. It is also interesting to note that the mineral would not have been named *painite* if the 'tourmaline' on the specimen acquired in 1914 had been recognized as a new species at that time.

For us it raises some important points. Although large mineral collections are known to play a role as long-term accessible repositories of important specimens, there is always the potential for new discoveries to be made within them. The distinctive look of the new painite specimens and our usual procedure of continually appraising the collection—especially acquisitions of new pieces and associated species—led us to visually identify this rather ordinary 'brown tourmaline' as a painite. Also, this example underlies the importance for collections staff having the opportunity to be 'out there', knowing what is on the market and critically comparing new materials against existing collections. We have scoured the collection for similar material, but have yet to find any more painite surprises. We urge other collections' custodians to take another look at their tourmaline drawers, as you never know what you might find.

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Mercaptans in Tanzanite from Merelani, Tanzania—A New Type of Stinkstone?

Stinkstein, or *stinkstone,* is a term used to describe the foetid odours when certain rocks and minerals are scratched or broken. The foul odours are usually described as being sulphurous, anthracitic or ozone-like. One of the earliest reports was from Agricola (1546) who recorded the smell of 'burning horn' when the Hildesheim marble from Saxony was 'struck with an iron or stone'. More graphic, present-day descriptions include the smell of decayed animals, which can be so distinctive from some feldspars to warrant the use of the varietal term *necronite*.

A common cause of these smells is release of malodorous volatiles trapped inside fluid inclusions. Notable gemmological examples include: (1) the bituminous smell from petroleum-bearing inclusions in 'Herkimer diamonds' (quartz crystals) from New York, USA; (2) fluorine compounds which account for the characteristic odour of *stinkspar* or *antozonite*, a dark purple fluorite from Bavaria, Germany; and (3) the recently reported 'rotten egg' odour of hydrogen sulphide in unheated zoisite from Merelani (Saul, 2013; Taylor et al., 2013).

Fluid inclusions in Merelani zoisite (including tanzanite; Figure 6) have unusual and distinctive carbon-hydrogen-sulphur (C-H-S) compositions compared to those commonly encountered in other gem minerals. Hydrogen sulphide (H_2S) is predominant in both the liquid and vapour phase. Besides minor nitrogen and methane, no other volatiles were previously identified from the

Figure 6: This multiphase C-H-S fluid inclusion in an unheated Merelani tanzanite comprises H_2S-rich liquid and vapour (distorted bubble), as well as solid graphite (opaque mass). Photomicrograph by D. Taylor.

Raman spectra of the vapour bubble. However, higher-resolution spectra have now revealed two smaller, previously undescribed bands at 2572 and 2585 cm^{-1} (Figure 7). The 2585 cm^{-1} peak can be ascribed to interference from Raman scattering of liquid H_2S surrounding the bubble, but the peak at 2572 cm^{-1} cannot. A search of published Raman spectral data revealed that this feature is well within the range of the S-H stretching mode (2560–2590 cm^{-1}) of thiol C-H-S compounds (Dollish et al., 1974), most notably methanethiol and ethanethiol (peaks at 2575 and 2571 cm^{-1}, respectively). Low molecular weight thiols such as methanethiol (CH_3SH, boiling point 6°C), and ethanethiol (C_2H_5SH, boiling point 35°C), also known as mercaptans, are renowned for their unpleasant smell even at concentrations down to 1 ppb in air. The odours are variously described as being like 'decaying animals', 'rotten cabbage' or 'smelly socks'. Methanethiol, a minor waste product of normal metabolic processes in humans, is particularly noteworthy as one of the main compounds responsible for the foul smells from bad breath and flatulence. Low molecular weight mercaptans are known to occur together with H_2S in some natural gas fields, and in associated minerals, in sedimentary rocks. But their presence in minerals formed at much higher temperatures and pressures such as those envisaged for the Merelani deposit is exceptional.

The proposed occurrence of mercaptans in fluid inclusions in unheated Merelani zoisite suggests that a small portion of 'putrid cabbage' can be added to the major presence of 'rotten egg' to account for the distinctive the odour from the opened inclusions. The contrast between the beauty of some unheated tanzanites and the foul smelling H_2S and mercaptans inside them is so striking that it begs the question as to whether it is appropriate to refer to inclusion-rich unheated Merelani zoisites as *stinkstones*. Maybe so, but an added benefit of heat treatment is that it not only enhances colour, but it also destroys most of the foul-smelling inclusions inside thus transforming the *stinkstone* into a desirable gem.

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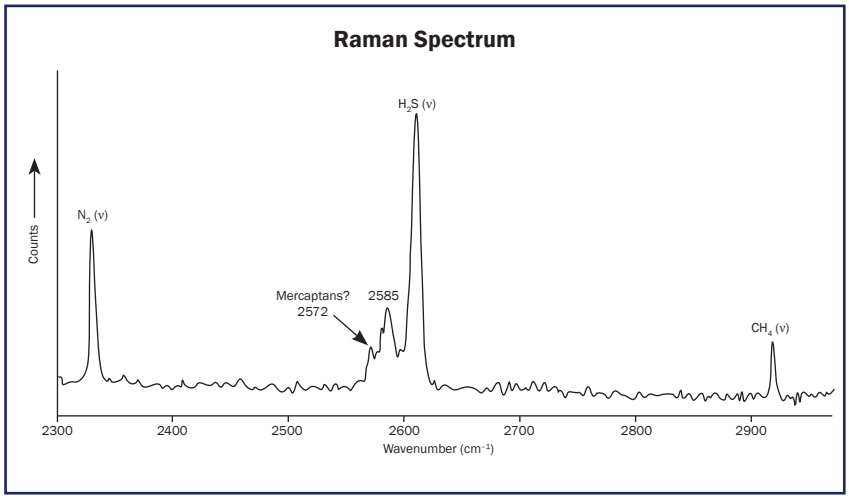

Figure 7: Raman spectroscopy of the H_2S-rich vapour phase in a C-H-S fluid inclusion in unheated Merelani tanzanite shows a suspected peak for mercaptans at 2572 cm^{-1}. Another peak at 2585 cm^{-1} may be ascribed to H_2S liquid and/or mercaptans.

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PEARLS

A Beaded Cultured Pearl Mistaken for a Natural Pearl

The Laboratoire Français de Gemmologie (LFG) received a 10.55 ct pearl for analysis that was accompanied by a recent laboratory report stating 'natural saltwater pearl'. Measuring 11.7 mm diameter, this round light grey pearl was undrilled and appeared to be from the *Pinctada maxima* species.

The saltwater origin was straightforward to confirm with EDXRF chemical analysis (there was more Sr than Mn), and as expected the pearl showed no visible X-ray luminescence.

Magnification revealed a few blemishes such as 'comet tails' and spots that are usually seen in cultured pearls. However, those characteristics also can be found occasionally in natural pearls, so they are not conclusive.

To further investigate the natural or cultured origin of the pearl, we analysed it with a Desktom X-ray microradiography-tomography instrument that was co-developed by LFG and RXSolutions (Chavanod, France). Our initial observation using a 'classical grey scale' (Figure 8) indicated a structure consistent with a natural pearl: a curved growth pattern a few millimetres below the surface, and a void or organic material located further down, in the shape of a shark's dorsal fin. There is no apparent nucleus or bead.

When observing radiographs at the LFG, the usual process is to vary the grey histogram in order to highlight different zones of a pearl, and thus to have a better perspective of the structures at different depths. As shown in Figure 9, this clearly revealed a round homogeneous structure as a central bead, on which the 'shark fin' structure seems to lie. The pearl is thus undeniably cultured. The diameter of the nucleus was measured at around 4.4 mm. This is a bit surprising, as one would not expect such a small bead in an 11.7 mm

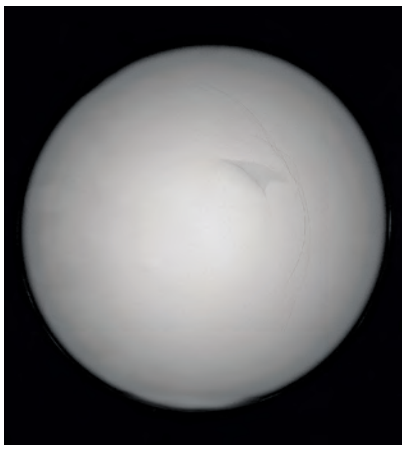

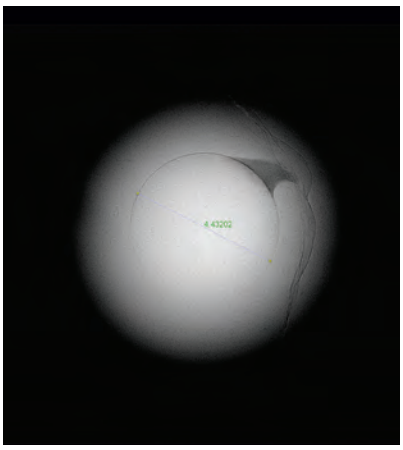

Figure 8 (left): Without the use of special techniques, micro-radiography of this 11.7 mm diameter 'natural saltwater pearl' showed only a curved growth pattern and a deeper feature interpreted as a void or organic material.

Figure 9 (right): With an appropriate selection of the grey value, micro-radiography revealed a 4.4 mm bead inside the 11.7 mm cultured pearl. (Note that the pearl outline is no longer visible in this view.) It is surprising to see a cultured pearl with more than 3.5 mm nacre thickness.

round cultured pearl. Usually the culturing process grows only a 1–2 mm thick layer of nacre around the nucleus.

In Figure 9 the void adjacent to the bead also became clearly perceptible. It corresponds with the location where the graft was inserted during the nucleation process. The line detected between the nucleus and the surface can be interpreted as a regrowth pattern, which is commonly seen in natural pearls or cultured pearls with a thick nacre layer.

This is a good example of the value of X-radiography technology designed specifically to work with pearls. Simpler instrumentation probably would not have detected this cultured pearl's unusual structure. Also, by highlighting different depths, the internal structures became obvious and further testing with X-ray computed tomography (very time consuming) was not necessary. This incident points out once again the difficulty in some cases of establishing whether a pearl is natural or cultured.

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Testing Natural Pearls with Micro-focus X-radiography—A Case Study

Pearls are routinely tested for natural or cultured origin using imaging techniques such as X-radiography (Schloßmacher, 1969; Strack, 2006). Such identifications require clear visualization of internal structures. This brief report explores how a recent advance in technology, the micro-focus technique, can enhance the capabilities of traditional X-radiography.

A pearl necklace was submitted to author ES for identification (Figure 10). Initial testing comprised taking a series of radiographs of various pearls in the necklace with a Kodak 2200 digital X-ray system (60–70 kV, 49 W). The radiographs showed various growth characteristics indicative of natural pearls, such as concentrically arranged lines, arcs and inner cores of organic substance. However, the centre pearl (7.8 mm diameter) revealed only a single irregular growth line that was suggestive of a natural pearl (Figure 11a) but not conclusive. Examination of the drill hole with a gemmological microscope revealed an inner core with a slightly more creamy colour than the pearl's body colour (Figure 12).

Consequently, the necklace was subjected to further testing with a Y.Cougar micro-focus X-ray system at YXLON company. The inspection was performed using 80–100 kV, depending on pearl size, and 3 W of power for the X-ray tube. A small focal spot of 1 μm, in conjunction with a digital flat-

Figure 10: This necklace contains 107 natural pearls of 3.2–7.8 mm in diameter, and has a total weight of 10.3 g. Courtesy of F. Hauser; photo by E. Strack.

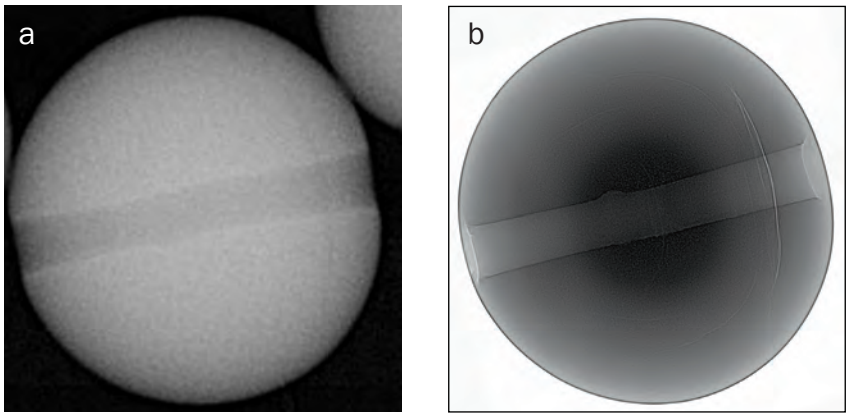

Figure 11: (a) This traditional X-radiograph of the centre pearl in the necklace (7.8 mm diameter) shows a single growth feature on the right side, which appears as a dark line in this 'positive' image. (b) The micro-focus radiograph of the same pearl shows several slightly curved growth lines, which appear as white lines in this 'negative' image.

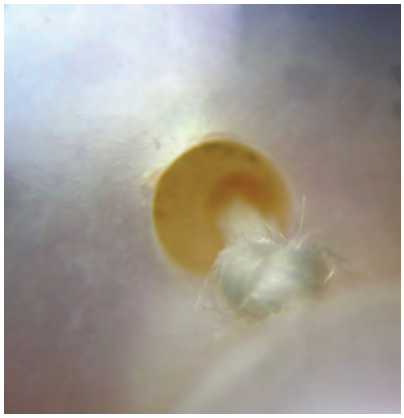

Figure 12: The drill hole of the centre pearl, when examined with a microscope, revealed an inner core with a more creamy colour. Photomicrograph by E. Strack; magnified 20×.

panel detector, allowed for high magnification with a resolution of ~1 μm. Radiographs were taken of several individual pearls (including the centre one), as well as the entire necklace. The radiograph of the centre pearl (Figure 11b) shows several growth lines in a generally circular arrangement. This pattern positively identifies the pearl as natural. The differently coloured inner core seen through the drill hole with the gemmological microscope is therefore interpreted as being an internal layer of the natural pearl.

The high-resolution capability of the Y.Cougar instrument further allowed us to visualize a record of the growth processes in some of these natural pearls. The radiograph of pearl no. 51 (Figure 13a) shows an inner core with a prismatic-concentric structure, surrounded by rings in a circular arrangement within the nacre layers. A much different pattern is shown by pearl no. 68 (Figure 13b), which has an inner core composed of less-dense material (probably an organic substance), accompanied by additional arcs and rings.

In cases where higher resolution is desired than can be achieved with traditional X-radiography, the Y.Cougar instrument provides a viable option, in addition to X-ray computed tomography (e.g. Krzemnicki et al., 2010, and references therein).

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Figure 13: Micro-focus X-radiography may record details of the growth history of pearls. (a) Pearl no. 51 shows an inner core with a prismatic-concentric structure, surrounded by rings in a circular arrangement. (b) Pearl no. 68 shows an inner organic-rich core with an irregular round shape, surrounded by arcs and rings in a circular arrangement.

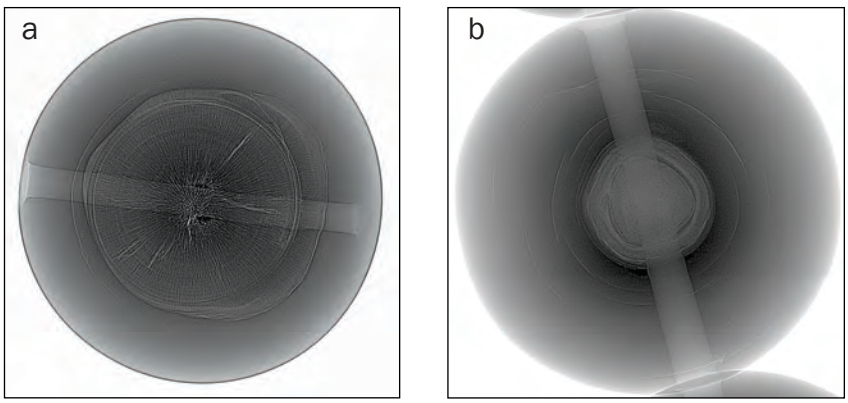

An Exceptional, Recently Discovered Quahog Pearl

Quahog pearls are produced by the clam *Mercenaria mercenaria* (or *Venus mercenaria*), which ranges along the Atlantic Coast of North America (Matlins, 2008). These pearls are so unusual that thousands of clams may be opened before one is found, and it is even rarer to find a quahog pearl that is round, of the desirable lilac-to-purple hue, and relatively large.

Figure 14: Seen at this year's Tucson gem shows, this 11.4 mm quahog pearl weighs 11.04 ct and was found in July 2012 in Rhode Island, USA. A depression near the edge of the shell on the right marks the place where the pearl formed in the host clam. Photo © Robert Weldon.

Therefore it was most interesting to see a recently discovered quahog pearl of exceptional quality, complete with its host shell (Figure 14), at this year's Tucson gem shows. The pearl was acquired by William Larson (Palagems.com, Fallbrook, California, USA), who reported that it was found in July 2012 at Misquamicut in Washington County, Rhode Island, USA. The location where the pearl formed in the clam was clearly evident by a depression near the edge of one of the shells. The 11.4 mm pearl was surprisingly large when compared to the size of the clam from which it came (57.5 mm long).

Brendan M. Laurs

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SYNTHETICS AND SIMULANTS

Two Synthetic Diamonds Identified in a Parcel of 7,000 Melee-size Yellow-Brown Diamonds

In late 2013, the Laboratoire Français de Gemmologie analysed a parcel of 7,000 melee-size (1 to 2.5 mm in diameter) yellow-brown diamonds. They were presented as natural 'cognac' diamonds, and reportedly had already been screened for synthetics.

The first step in our examination was to observe all the diamonds in long- and short-wave UV radiation (see Figure 15). Two of them emitted an intense green luminescence to short-wave UV, but remained inert to long-wave UV

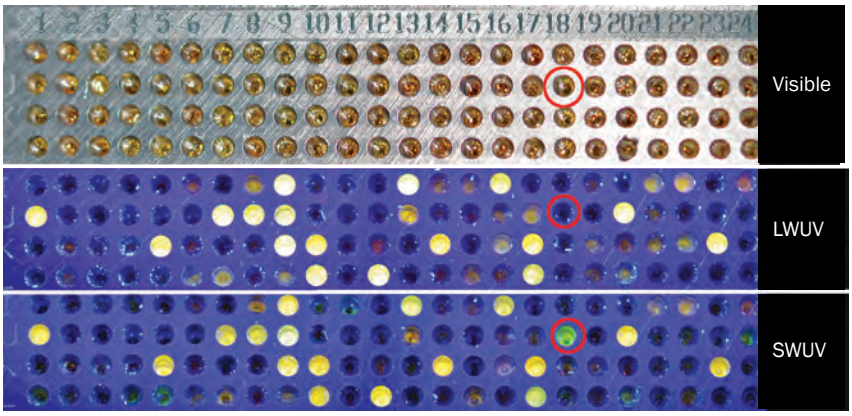

Figure 15: A portion of the melee-size diamond parcel is shown here in visible light (top) and while being exposed to long- and short-wave UV radiation (365 and 254 nm, respectively). The gem at position J18 has an intense green luminescence under short-wave UV and is inert to long-wave UV radiation. This observation raised suspicion that J18—as well as another gem in the parcel (not shown)—are synthetic diamonds. Photos by A. Delaunay.

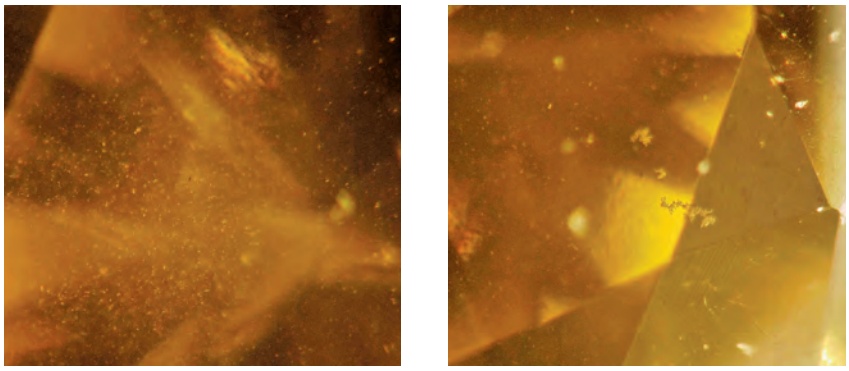

Figure 16: In the two suspect samples, clouds of pinpoints (left) or breadcrumb inclusions (right) provide further indication of synthetic origin. Photomicrographs by A. Delaunay; magnified 320×.

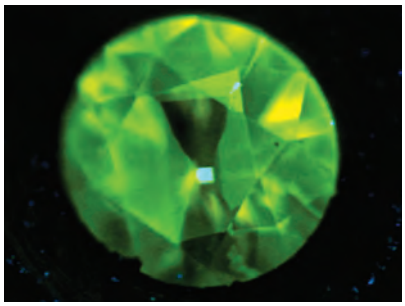

Figure 17: The DiamondView image of sample J18 (1.7 mm in diameter) is typical of synthetic diamond, with cubic and octahedral growth sectors. Photo by A. Delaunay.

radiation (e.g. the gem at J18 in Figure 15). Such behaviour may be indicative of high-pressure, high-temperature (HPHT)–grown synthetic diamond (see, e.g., Shigley et al., 1986).

The parcel was then subjected to infrared spectroscopy using a special automated batch analysis system (HTS-XT, meaning High Throughput Screening eXTension) developed in partnership with Bruker Optics (Marne-la-Vallée, France), and later patented. The spectra of the two gems tagged earlier as potentially synthetic showed them to be purely type Ib, with only isolated nitrogen impurities and no trace of hydrogen. This is typical of synthetic diamonds grown by the HPHT process, furthering our suspicions. The other stones in the parcel were all type Ia with aggregated nitrogen and often with hydrogen impurities.

Under magnification (Figure 16), one of the suspect gems revealed a cloud of pinpoints, the other breadcrumb-like inclusions. Such features, due to remnants of the metal solvent used in the growth process, are often observed in HPHT-grown yellow synthetic diamonds (see, e.g., Kitawaki et al., 2008).

To further study the two potentially synthetic diamonds, we examined their growth structures with the DiamondView, a high-energy ultra-short-wave (almost 220 nm) UV luminescence imaging device. It is well known that HPHT-grown synthetic diamonds display cubic growth sectors, in addition to the typical octahedral growth sectors seen in natural stones. Both of the gems clearly showed a central square pattern surrounded by the two types of growth sectors (Figure 17), identifying them without ambiguity as HPHT-grown synthetics.

Photoluminescence spectroscopy (e.g. Figure 18) of the two synthetic diamonds at liquid-nitrogen temperature with 514 nm laser excitation

Figure 18: Photoluminescence spectroscopy of the two synthetic diamonds (here, sample J18) showed an emission at 728 nm that is due to nickel impurities. Also present is a peak at 637 nm attributed to N-V⁻ centres.

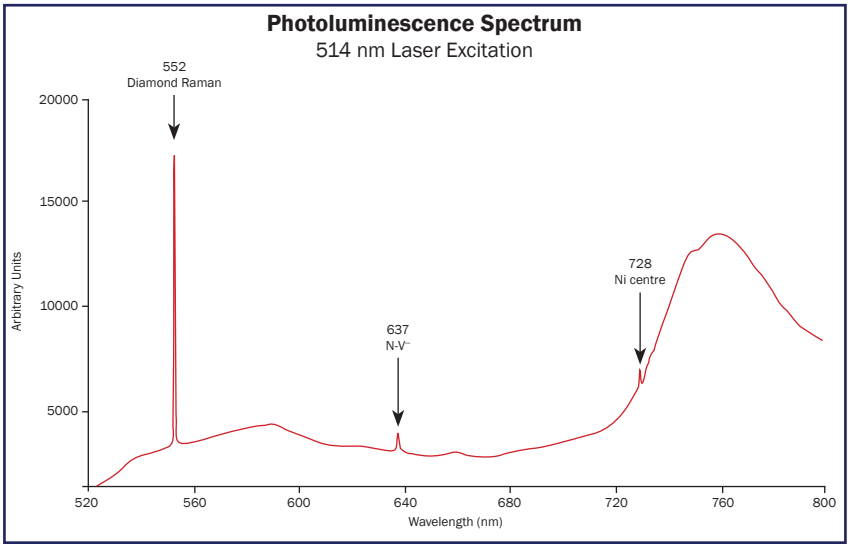

showed the 728 nm emission that is attributed to nickel impurities in diamond. Although Ni-related defects may be found in some unusual natural diamonds (see e.g. Hainschwang et al., 2013), nickel is also the most common solvent used in HPHT diamond growth. Its presence, in combination with the other characteristics described above, is proof positive that these diamonds are indeed synthetics.

These are the first synthetic diamonds ever identified in our laboratory, from more than 100,000 stones submitted. This discovery thus provides an initial indication that even with careful screening, yellow-brown synthetic diamonds are being mixed with natural diamonds on the French market.

Aurélien Delaunay and Emmanuel Fritsch

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MISCELLANEOUS

A Visit to Mogok, Myanmar

During the last week of January 2014, this author visited the Mogok area to obtain information on rare stones for a research project. The largest mine toured during this trip was operated by Lian Shan Co. and located at Ingaung village (near Kyatpyin, west of Mogok; Figures 19 and 20). Recent production has consisted of ruby, sapphire, spinel, quartz, zircon, apatite, tourmaline and topaz (e.g. Figure 21). During a visit to a small private mine east of Bamon village (located south of Mogok), the owner showed this author some nice samples of ruby in marble matrix, as well as a diverse collection of rare stones. Various mines in the area continue to occasionally produce good-quality rubies in marble (e.g. Figure 22).

A new road was taken for the trip home, which went from Mogok to Pyin Oo Lwin via Mong Long. Fine-quality orange spessartine has been produced from secondary deposits in the Mong

Figure 19: Residual deposits of gem-bearing gravels are mined from weathered karst at the Lian Shan mine near Ingaung. Photo by U Tin Hlaing.

Figure 20: The washing plant at the Lian Shan mine is fully mechanized. Photo by U Tin Hlaing.

Figure 21: Some of the recent production from the Lian Shan mine consists of spinel, quartz, blue apatite and green tourmaline. Photo by U Tin Hlaing.

Figure 22: This ruby specimen (~10 cm across) is from the Bawpadan area north of Mogok. Photo by U Tin Hlaing.

Long area (Nam Pai stream valley), along with rubellite, chrysoberyl, rose quartz, rock crystal, black tourmaline and gold. Spessartine is becoming popular in the Burmese gem market, even at half-carat sizes, and prices are increasing.

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Learning Opportunities

CONFERENCES

Annual Conference of the Scottish Gemmological Association
2–5 May 2014
Peebles, Scotland
www.scotgem.co.uk/SGAConference2014

Swiss Gemmological Society Conference
4–6 May 2014
Flüeli Ranft, Switzerland
www.gemmologie.ch/de/Aktuell.php

28th Santa Fe Symposium [of Jewellery Manufacturing Technology]
18–21 May 2014
Albuquerque, New Mexico
www.santafesymposium.org

2014 CIBJO Congress
19–21 May 2014
Moscow, Russia
http://congress2014.cibjo.org

New Diamond and Nano Carbons Conference
25–29 May 2014
Chicago, Illinois, USA
www.mrs.org/ndnc-2014

Mindat.org 2014 Conference and Field Trip: Madagascar
28 May–13 June 2014
Antananarivo, Madagascar
www.mindatconference.org

Accredited Gemologists Association Conference: Synthetic Diamonds—Prevalence, Pricing and an Inside Look at the Industry
29 May 2014
Las Vegas, Nevada, USA
http://accreditedgemologists.org

Historical Metallurgy Society Conference and Annual General Meeting 2014: Metals Used in Personal Adornment
31 May–1 June 2014
Birmingham Museum and Art Gallery, Birmingham, West Midlands
http://hist-met.org/meetings/personal-adornment.html

5th Italian Scientific Gemology Conference (CIGES 2014: V Convegno Italiano di Gemmologia Scientifica)
15–17 June 2014
Rome, Italy
http://musmin.geo.uniroma1.it/Ciges

11th International GeoRaman Conference
15–19 June 2014
St. Louis, Missouri, USA
http://georaman2014.wustl.edu

Machinery, Equipment, Technology & Supplies for Jewellery & Watch Industry (METS 2014)
25–28 June 2014
Hong Kong
www.mets.hk/en

Jewelry Television 'Gem Lovers' Conference
18–20 July 2014
Knoxville, Tennessee, USA
www.jtv.com

68th Gemmological Association of Australia Annual Federal Conference
Adelaide, Australia
26–29 July 2014
www.gem.org.au/68th_gaa_annual_federal_conference

Jewelry Camp
31 July–1 August 2014
New York, New York, USA
www.jewelrycamp.org

South American Symposium on Diamond Geology
3–7 August 2014
Patos de Minas, Minas Gerais, Brazil
www.simposiododiamante.com.br/apresentacao.htm

25th Colloquium of African Geology (CAG25)
11–14 August 2014
Dar es Salaam, Tanzania
www.cag25.or.tz
Note: Field trips will include visits to the Merelani tanzanite mines and the Williamson diamond mine.

Northwest Jewelry Conference 2014
15–17 August 2014
Bellevue, Washington, USA
www.northwestjewelryconference.com

Dallas Mineral Collecting Symposium
22–23 August 2014
Dallas, Texas, USA
www.dallassymposium.org/2014-symposium

21st General Meeting of the International Mineralogical Association (IMA2014)
1–5 September 2014
Johannesburg, South Africa
www.ima2014.co.za
Sessions:
- The Geology of Gems and their Geographic Origin
- Cratons and Diamonds
- Pegmatites and Pegmatite Mineralogy
- Africa: A Mecca of Kimberlite, Alkaline Rock and Carbonatite Geology
- Certification of Geological Materials / Analytical Fingerprint of Minerals
- Computed Tomography—Pushing Frontiers in Imaging of the Third and Fourth Dimensions
- Modern Luminescence Methods and their Application to Mineralogy
- Mineral Inclusions—Their Genesis and Fate

Field Trips:
- Cullinan Diamond Mine and Tswaing Tour
- Gem Potential Madagascar Pegmatites
- Rosh Pinah and Oranjemund Alluvial Diamonds
- Namibian Pegmatites and Industrial Minerals

International Conference on Diamond and Carbon Materials
7–11 September 2014
Madrid, Spain
www.diamond-conference.elsevier.com

Kimberley Diamond Symposium
11–13 September 2014
Kimberley, South Africa
http://ima2014.co.za/documents/kimberley-diamonds-first-announcement.pdf

Manufacturing Jewelers' and Silversmiths' Association Jeweler's Bench Conference & Trade Fair
13–14 September 2014
Warwick, Rhode Island, USA
www.mjsa.org/events_and_programs/jewelers_bench_conference_and_trade_fair

Institute of Registered Valuers Loughborough Conference
13–15 September 2014
Loughborough
www.jewelleryvaluers.org/Loughborough-Conference

77th Annual International Appraisers Conference
14–17 September 2014
Savannah, Georgia, USA
www.appraisers.org/Education/conferences/ASA-Conference

Association for the Study of Jewelry & Related Arts 9th Annual Conference and Study Day: Jewelry & Related Arts of Asia
20–21 September 2014
New York, New York, USA
www.jewelryconference.com

World of Gems IV
20–21 September 2014
Rosemont, Illinois, USA
http://gemguide.com/events/world-of-gems-conference

National Association of Jewelry Appraisers 42nd ACE-It Mid-Year Conference
22–23 September 2014
Rosemont, Illinois, USA
www.najaappraisers.com/html/conferences.html

30th International Conference on Ore Potential of Alkaline, Kimberlite and Carbonatite Magmatism
29 September–2 October 2014
Antalya, Turkey
http://alkaline2014.com

Portland Jewelry Symposium
6 October 2014
Portland, Oregon, USA
www.portlandjewelrysymposium.com

Geological Society of America Annual Meeting
19–22 October 2014
Vancouver, British Columbia, Canada
http://community.geosociety.org/gsa2014
Note: Topical Sessions titled 'Gemological Research in the 21st Century: Exploration, Geology, and Characterization of Diamonds and Other Gem Minerals' and 'Pegmatites I Have Known and Loved'

Gem-A Conference 2014
1–2 November 2014
London
www.gem-a.com/news--events/gem-a-conference-2014.aspx

GIT 2014: The 4th International Gem and Jewelry Conference
8–9 December 2014
Bangkok, Thailand
www.git.or.th/2013/index_en.html

EXHIBITS

Asia

India: Jewels that Enchanted the World
Until 27 July 2014
Moscow Kremlin Museums, Russia
www.kreml.ru/en

Urartian Jewellery Collection
Until 31 July 2015
Rezan Has Museum, Istanbul, Turkey
www.rhm.org.tr/en/events

Europe

Fabergé. The Tsar's Jeweller
Until 18 May 2014
Kunsthistorisches Museum, Vienna, Austria
www.khm.at/de/besuchen/ausstellungen/faberge

Chroma Jewellery Collective
Until 7 June 2014
Museum of the Jewellery Quarter, Birmingham, West Midlands
www.bmag.org.uk/events?id=3120

Hellhounds and Doves of Love—5,000 Years of Animal Myths in Jewellery
Until 22 June 2014
Schmuckmuseum, Pforzheim, Germany
www.schmuckmuseum.de

Silversmithing: A Celebration of Excellence
Until 30 June 2014
The Goldsmiths' Centre, London
www.goldsmiths-centre.org/whats-on/exhibitions/silversmithing-a-celebration-of-excellence

51st Sainte-Marie-aux-Mines Mineral and Gem Show
27–30 June 2014
Sainte-Marie-aux-Mines, France
www.sainte-marie-mineral.com/centre/an_centre_vis_min_exp.php
Note: Jewellery and gem exhibits will be on display during the show.

The Treasure of San Gennaro
Until 20 July 2014
Musée Maillol, Paris, France
www.museemaillol.com/expositions/tresor-de-naples/english-informations

From the Coolest Corner: Nordic Jewellery
Until 11 May 2015
The Estonian Museum of Applied Art and Design, Tallinn, Estonia
www.coolestcorner.no

North America

Turquoise, Water, Sky: The Stone and Its Meaning
Until 2 May 2014
The Museum of Indian Arts & Culture, Santa Fe, New Mexico, USA
www.indianartsandculture.org/upcoming-exhibitions&eventID=1989

From the Village to Vogue: The Modernist Jewelry of Art Smith
Until 18 May 2014
Cincinnati Art Museum, Ohio, USA
www.cincinnatiartmuseum.org/explore/exhibitions/current-exhibitions

Fabergé: A Brilliant Vision
Until 31 May 2014
Houston Museum of Natural Science, Houston, Texas, USA
www.hmns.org/faberge

Jewels, Gems, and Treasures: Ancient to Modern
Until 1 June 2014
Museum of Fine Arts, Boston, Massachusetts, USA
www.mfa.org/exhibitions/jewels-gems-and-treasures

Bangles to Benches: Contemporary Jewelry and Design
Until 8 June 2014
The High Museum of Art, Atlanta, Georgia, USA
www.high.org/Art/Exhibitions/Bangles-to-Benches.aspx

Colors of the Universe: Chinese Hardstone Carvings
Until 6 July 2014
The Metropolitan Museum of Art, New York, New York, USA
www.metmuseum.org/exhibitions/listings/2013/chinese-carving

Arts of Islamic Lands: Selections from The al-Sabah Collection, Kuwait
Until 31 August 2014
Museum of Fine Arts, Houston, Texas, USA
www.mfah.org/exhibitions/al-sabah-collection

Multiple Exposures: Jewelry and Photography
13 May–14 September 2014
Museum of Arts & Design, New York, New York, USA
http://madmuseum.org/exhibition/multiple-exposures

Arthur Koby Jewelry: The Creative Eye
Until 5 October 2015
Kent State University Museum, Kent, Ohio, USA
www.kent.edu/museum/exhibits/exhibitdetail.cfm?customel_datapageid_2203427=3506741

Bulgari: 130 Years of Masterpieces
2 May–5 October 2014
Houston Museum of Natural Science, Houston, Texas, USA
www.hmns.org/index.php?option=com_content&view=article&id=687&Itemid=722

Fabergé: Jeweller to the Tzars
14 June–5 October 2014
Montreal Museum of Fine Arts, Canada
www.mbam.qc.ca/en/expositions/a-venir/faberge

***Gems & Gemology*: 80 Years of Excellence, Featuring the Artistry of Harold & Erica Van Pelt**
19 May–December 2014
Carlsbad, California, USA
www.gia.edu/gia-museum-gems-gemology-anniversary

Cartier: Marjorie Merriweather Post's Dazzling Gems
7 June–31 December 2014
Hillwood Estate, Museum & Gardens, Washington DC, USA
www.hillwoodmuseum.org/whats/exhibitions/cartier-marjorie-merriweather-posts-dazzling-gems

Gemstone Carvings: Crystals Transformed Through Vision & Skill
On display (closing date to be determined)
Houston Museum of Natural Science, Houston, Texas, USA
www.hmns.org/index.php?option=com_content&view=article&id=481&Itemid=502

Australia

Afghanistan: Hidden Treasures from the National Museum, Kabul
26 July–16 November 2014
Western Australian Museum, Perth, Australia
http://museum.wa.gov.au/whats-on/afghanistan-hidden-treasures

OTHER EDUCATIONAL OPPORTUNITIES

American Society of Appraisers Introduction to Gems & Jewelry Appraising – Intended Use, Insurance Coverage
30 April–3 May 2014
Carlsbad, California, USA
www.appraisers.org/Education/View Course?CourseID=448

2nd China Mineral & Gem Show 2014
15–20 May 2014
Changsha, China
www.chinaexhibition.com/Official_Site/11-4519-CMGS_2014_-_The_2nd_China_(Changsha)_Mineral_and_Gem_Show_2014.html
Note: Forums and 'science learning experiences' will take place.

JCK Las Vegas
30 May–2 June 2014
Las Vegas, Nevada, USA
http://lasvegas.jckonline.com/Education--Events/Events-Schedule
Note: Educational events take place 29 May–1 June.

Hong Kong Jewellery & Gem Fair
19–22 June 2014
Hong Kong
http://exhibitions.jewellerynetasia.com/6jg/fairinfo/specialevents/tabid/5294/language/en-us/default.aspx
Note: Educational presentations take place 21–22 June.

Gem-A Field Trip to Idar-Oberstein, Germany
21–28 June 2014
www.gem-a.com/news--events/events/gem-a-field-trip-to-idar-oberstein.aspx

51st Sainte-Marie-aux-Mines Mineral and Gem Show
27–30 June 2014
Sainte-Marie-aux-Mines, France
www.sainte-marie-mineral.com/centre/an_centre_vis_min_con.php
Note: A variety of workshops, seminars, film screenings and a photo contest will take place.

Gem Stone Safari Tanzania
5-22 January 2015
www.free-form.ch/tanzania/gemstonesafari.html

Galileo as Gemmologist: The First Attempt in Europe at Scientifically Testing Gemstones

A. Mottana

Galileo Galilei is credited with being one of the greatest contributors to the 'scientific revolution', particularly because of his discoveries in astronomy. He also introduced into European gemmology his 'language of mathematics' (i.e. experimental science) with the invention of the *bilancetta* (little [hydrostatic] balance). He conceived it to recheck Archimedes' determination of the gold content of a royal crown, and also used this balance to measure the mass of 23 gem samples in air and in water. However, much of his data was inconsistent with the inferred identity of his samples, since many were simulants. The results of his investigations did not circulate, and only after three centuries was Galileo's handwritten *tavola* (table) of gem data discovered.

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Introduction

In 1586 Galileo Galilei (1564–1642; Figure 1), a 22-year-old drop-out from the University of Pisa, returned to Florence and wrote a short essay describing a hydrostatic method (Figure 2) for testing precious metal alloys. He developed the technique to improve upon the methodology articulated by Vitruvius (1567, IX.10–12), who described the ancient Greek scientist Archimedes' efforts to verify the composition of the gold in the crown of King Hiero (the Greek Sicilian king of Syracuse from 270 to 215 BC). Archimedes devised a method based on buoyancy, and determined that the crown was not pure gold but rather a silver-gold alloy. Galileo did not believe in the fairly simple solution reported by Vitruvius and looked for a more sophisticated one, also based on buoyancy, but with rigorous hydrostatic constraints. He wrote his essay in Italian, in a first attempt at breaking the use of Latin as the universal language of science and scholarly pursuits. Indeed, the name *bilancetta* (little [hydrostatic] balance) plays down, perhaps intentionally, the instrument he conceived and built; his balance was far from being little, with a yoke over 1 m long. Galileo tested his new instrument on three metals (gold, silver and copper) and, seeing that it worked well, pursued additional measurements on gem materials (see below).

Galileo's results exceeded his own expectations, going beyond Archimedes' ingenuity. Even so, he set aside his manuscript (and the balance) and forgot it. Only several years later, after he had attained wide notoriety in Europe because of his discoveries in astronomy, did he allow one of his pupils (Benedetto Castelli) to copy the essay. After

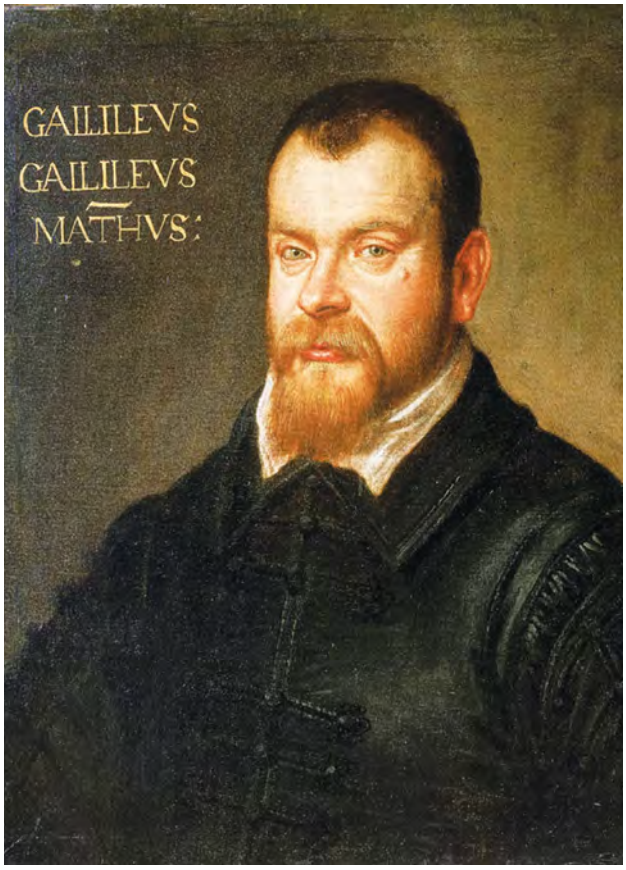

Figure 1: This portrait of Galileo as a professor of mathematics at Padua University was painted in 1605 by Domenico Tintoretto (Domenico Robusti; Venice, 1560–1635).

Galileo died, one of his followers from Palermo (Gian Battista Hodierna) dared to print it, being careful to forge a vague title to avoid stirring the suspicions of the Inquisition (Hodierna, 1644). *La Bilancetta* appeared under this title in all early editions of Galileo's *Opera* (Collected Works)—Bologna (1656), Florence (1717) and Padua (1744)—and in numerous others until the publication of the state-sponsored Edizione Nazionale (National Edition) compilation by Favaro (1890). It was not translated into a foreign language until Fermi and Bernardini (1961) published a selection of Galileo's works in English.

Archimedes' approach to verifying the composition of the gold in King Hiero's crown had stirred interest among many people, leaving them unsatisfied with the technique described by Vitruvius. The hydrostatic weighing solution suggested by Galileo generated a few imitations and improvements, as well as clever alternatives (e.g. the pycnometer made by Wilhelm Homberg in 1699 and the aerometer devised by William Nicholson in 1785). Nevertheless, that was all. Information from the Arab world—where effective instruments to hydrostatically measure gem materials had been used since the 10th century AD (e.g. by al-Rāzi, al-Bīrūnī and al-Khāzinī, just to mention a few)—had not arrived in Europe, or such knowledge was too vague to give rise to substantial practical results.

The reason for the scientific community's lack of consideration or recognition of *La Bilancetta* probably lies in an editorial blunder. When Castelli copied the essay, he omitted the three sheets containing the results originally described by his master: those that are now known as the *tavola* (table). So, when Hodierna asked Castelli for a copy of the essay, he received only the description of the instrument, but no examples of its application. The incomplete work was published by Hodierna, as well as by all subsequent compilers of Galileo's works, for almost three centuries. The *tavola* was finally discovered in 1879 by Antonio Favaro, a mathematician and science historian who was collecting everything written by Galileo and his pupils in an effort to compile an official complete edition of his work. Favaro found a few of Galileo's handwritten papers inserted in the surviving scripts preserved at the Florence National Library (Par. II. T. XVI. Car. 60–62), relating to *La Bilancetta* (Par. II. T. XVI. Car. 55). Favaro immediately published them under the title *Tavola delle proporzioni delle gravità in specie de' metalli e delle gioje pesate in aria ed in aqqua* (Table of the proportions of gravities

Figure 2: (Top) Galileo's original schematic diagram of his hydrostatic balance as it appears in his draft manuscript (Mss. Galil. Vol. 45, Car. 55v, Raccolta Palatina, Biblioteca Nazionale di Firenze) and (bottom) redrawn in the Edizione Nazionale of his collected works (Favaro, 1890, p. 217). Key: a–b = balance yoke; b = weight; c = suspension point; d = counterweight in air; e = counterpoise in water for pure gold; f = counterpoise in water for pure silver; g = counterpoise in water for a metal alloy or gem material.

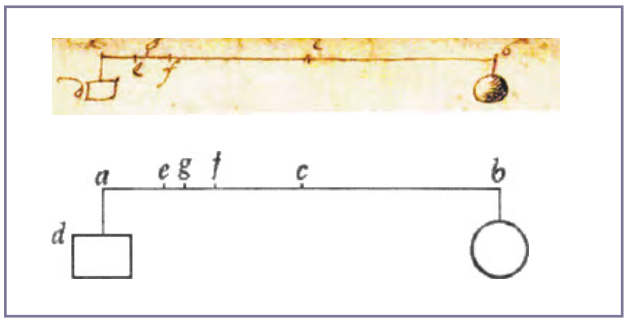

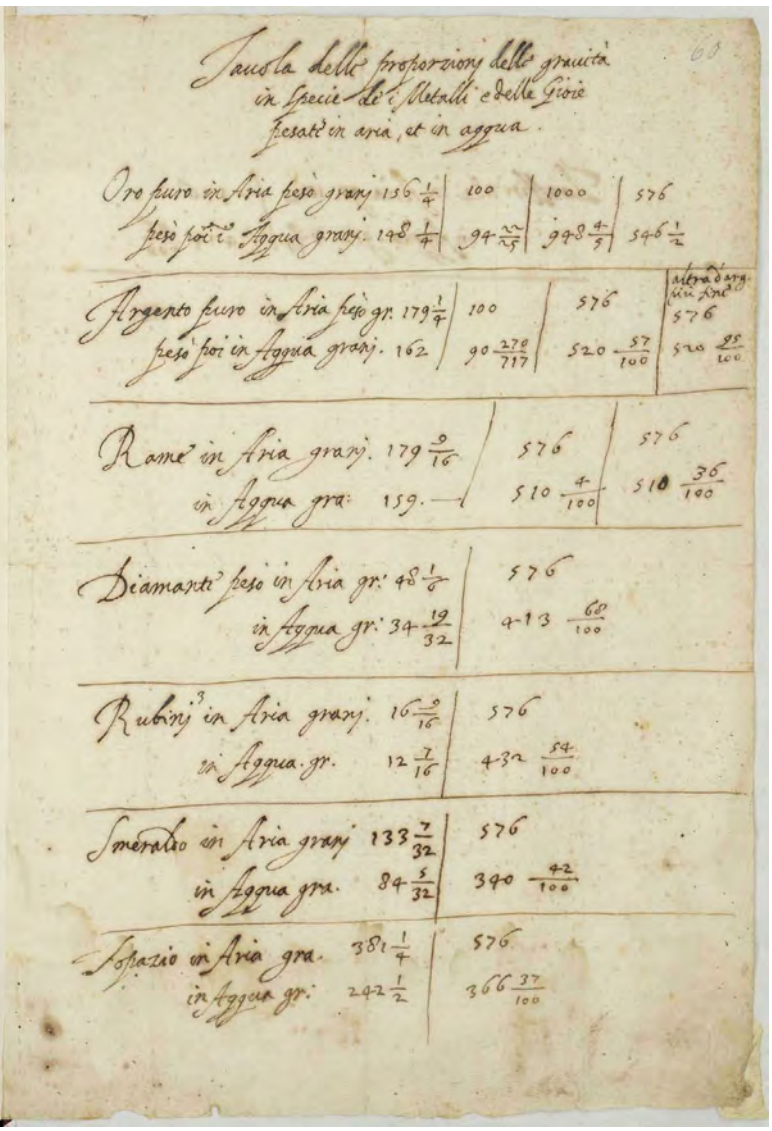

Figure 3: The first hand-written page of the 'Table of the proportions of gravities especially of metals and gems weighed in air and water' by Galileo (Mss. Galil. Vol. 45, Car.60r, Raccolta Palatina, Biblioteca Nazionale di Firenze). The weighing unit was the Florentine grain (1 grain = 0.5894 gram). It was followed by additional sheets containing the results obtained during two sessions of measurements.

especially of metals and gems weighed in air and water; Favaro, 1879). Indeed, this was a slightly modernized version of the title given by Galileo himself (Figure 3). Favaro later republished the table, with trifling modifications in the numbers, in Book 1 of Edizione Nazionale (Favaro, 1890, pp. 211–212) which contains all the works by the young Galileo: the *Juvenilia* (Youth Works; cf. Castagnetti and Camerota, 2001).

Surprisingly, the publication of Galileo's experimental data did not spur scientists to a thorough analysis of the results. The one exception was the German doctoral student Heinrich Bauerreiß: in his dissertation he calculated SG values from the experimental data recorded in the table, for metals and gem materials alike. He pointed out how good the data were for the metals, but did not comment on the gems (Bauerreiß, 1914, pp. 62–64).

The Materials Studied by Galileo

Why Galileo measured the buoyancy behaviour of metals is obvious: he wanted to find a better method than the one devised by Archimedes and described by Vitruvius. For pure metals, Galileo's measurements yield SGs of 19.53 for gold (versus a calculated ideal density value D = 19.302 g/cm^3), 10.46 for silver (D = 10.497 g/cm^3) and 8.83 for copper (D = 8.930 g/cm^3). His data were quite close to the ideal calculated values, although somewhat higher for the heaviest metal and lower for the lighter ones. Such results were obtained without many of the experimental constraints required by modern methods, thus showing that the young Galileo was possibly still rather crude as an experimental scientist, but his results were trustworthy. Indeed, the scatter is less than ~1%. In addition, Galileo tested metals used for minting coins: the gold-silver alloy of an *óngaro* (Hungarian ducat) and the silver-lead alloy of a *testone* (one fourth of a Florence gold ducat, locally called a *fiorino* or florin). His data showed that their SG values were lower than those of refined metals, but within the expectation of what was then considered an honest mintage composition (~2%): their calculated finenesses were 968‰ and 987‰, respectively.

Galileo tested an even greater number of gem materials (Table I). He apparently made the measurements in two sessions, as the table consists of two parts written on separate sheets. In the first session, the paper sheet (Par. II. T. XVI. Car. 60r–60v; e.g. Figure 3) lists: *diamante* (diamond), *rubini* (ruby), *smeraldo* (emerald), *topazio* (topaz) and *zaffiri* (sapphire). In the second one, the two paper sheets (Par. II. T. XVI. Car. 61r–62v) list again the data for the same gems and, in addition: *crisolito* (chrysolite, referring to peridot), *turchina* (turquoise), *perla* (pearl), *granata* (garnet), *calcidonio* (chalcedony), *amatista* (amethyst), *aqqua marina*

Table I: The gem materials studied by Galileo, with their inferred identification via calculated SG values.[a]

Name given by Galileo	Expected SG range[b]	Weight in air (grains)[c]	Weight in water (grains)[c]	Calculated SG[d]	Inferred identification	Range of known SGs[e]
Session 1						
Diamante	3.50–3.53	48.17	34.59	3.55	Colourless topaz	3.49–3.57
Rubini 3	4.00	16.56	12.44	4.02	Ruby	4.00
Smeraldo	2.67–2.78	133.22	84.16	2.72	Emerald	2.67–2.78
Topazio	3.49–3.57	381.25	242.50	2.75	Heliodor	2.68–2.74[f]
Zaffiri 2	4.00	10.50	7.56	3.57	Blue spinel	3.54–3.63
Session 2						
Diamante	3.50–3.53	48.17	34.59	3.55	Colourless topaz	3.49–3.57
Smeraldo	2.67–2.78	133.22	84.16	2.72	Emerald	2.67–2.78
Topazio	3.49–3.57	210.34	131.19	2.66	Citrine	2.65
Crisolito	3.28–3.38	310.19	217.88	3.36	Peridot	3.28–3.38
Crisolito	3.28–3.38	68.56	40.94	2.48	Green glass	Variable
Topazio	3.49–3.57	381.25	242.50	2.75	Heliodor	2.64
Zaffiro	4.00	5.75	4.25	3.83	Gahnospinel(?)	3.54–4.00
Rubini 3	4.00	16.56	12.44	4.02	Ruby	4.00
Rubino	4.00	49.10	35.31	3.56	Red spinel	3.54–3.63
Zaffiri 2	4.00	10.50	7.56	3.57	Blue spinel	3.54–3.63
Turchina	2.31–2.84	36.75	23.31	2.73	Turquoise	2.31–2.84
Turchina	2.31–2.84	22.81	14.56	2.77	Turquoise	2.31–2.84
Perla	2.60–2.85	91.88	56.38	2.59	Pinctada sp. pearl or nacre	2.60–2.85
Perla	2.60–2.85	29.13	19.00	2.88	Strombus sp. (conch) pearl	2.18–2.87
Granata	3.78–4.10	89.77	64.88	3.61	Grossular (hessonite)	3.57–3.65
Granata	3.78–4.10	224.50	168.13	3.98	Pyrope-almandine	3.80–3.95
Zaffiro	4.00	103.38	63.25	2.58	Blue glass (or iolite?)	Variable (or 2.58–2.66)
Calcidonio	2.58–2.64	61.56	37.94	2.61	Chalcedony	2.58–2.64
Smeraldo	2.67–2.78	192.25	129.63	3.07	Tourmaline (uvite)	2.82–3.32
Crisolito	3.28–3.38	102.63	72.19	3.37	Peridot	3.28–3.38
Amatista	2.65	102.81	56.81	2.24	Purple glass	Variable
Aqqua marina tenera	2.68–2.74	65.31	41.31	2.72	Aquamarine	2.68–2.74
Cristallo	2.65	229.75	143.25	2.66	Quartz (rock crystal)	2.65

[a] The screened rows refer to simulants.
[b] Expected values if the gem names given by Galileo were correct (Dominy, 2013).
[c] Fractions have been converted to decimals; in units of Florentine grains (1 grain = 0.5894 gram).
[d] Calculated here from the weights in air and water measured by Galileo.
[e] Empirical measurements on relevant gem-quality minerals (Dominy, 2013).
[f] Values reported are for aquamarine, as there are no typical SG values for heliodor given in the literature.

LIBRI TRE
DI M. LODOVICO
DOLCE;
NE I QVALI SI TRATTA
delle diuerse sorti delle Gemme,
che produce la Natura,
DELLA QVALITA',
grandezza, bellezza, & virtù loro.
CON PRIVILEGIO.
IN VENETIA APPRESSO
GIO. BATTISTA, MARCHIO
SESSA, ET FRATELLI.

BIBLIOTH
CORSINIA
VETVS
BIBLIOTHECA

Figure 4: The title page of Lodovico Dolce's 1565 translation of Camillo Leonardi's 1502 book, nowhere showing the name of the true author. This is a typical case of Renaissance-style plagiarism, yet with the very effective outcome of spreading knowledge on gem materials with their proper Italian names.

tenera ('soft' aquamarine) and *cristallo* (quartz). Unfortunately no description of the samples was provided, so their transparency and rough/cut state are unknown. Only indirectly can we infer that all samples were single gems except for *rubini 3* (three rubies measured as a single sample) and *zaffiri 2* (two 'sapphires', actually spinel, again measured together). All the names used by Galileo were the current Italian gem names, which were those given by Lodovico Dolce (1565; Figure 4) when translating Camillo Leonardi's (1502) *Speculum Lapidum* (Mirror of Stones). Dolce's definitions include a description of the colour for some gems (e.g. topazio is a yellow stone), but the colours of several of Galileo's samples cannot be inferred.

The *'diamante'* measured by Galileo was not a diamond at all. He should have guessed this from the start, as the gem weighed slightly more than 48 grains (i.e. 28.3 grams or 141.5 ct), and therefore would have been extremely costly. According to de Boot (1609, pp. 128–132), a *perpolitus, & absque omni vitio* (flawless diamond) of 12 ct—which was considered to be an enormous crystal for diamond at that time—would then sell for 11,600 florins, which was the price of a very large house. A stone like that certainly did not belong either to Galileo or his family. Galileo's own perspicacity should have advised him that the man (a friendly gem dealer, possibly) who had loaned the gem to him either wanted to test his instrument or make a fool of him, considering Galileo too young for such a business. In any case, Galileo measured the stone twice and his data yield a consistent SG of 3.55. This is very close to the SG of OH-free topaz (3.56), which can have a rather similar appearance to diamond. Simulants for diamond were common in Galileo's time, and were well known to gem merchants. The main ones cited at the time were very light coloured sapphire, amethyst, chrysolite and, indeed, topaz (de Boot, 1609, pp. 117–118). All these gems, except topaz, have SG values much different from Galileo's measurements.

The reliability of Galileo's balance is strongly supported by the SG value of the next gem he tested, ruby. His data for *rubini 3* yielded an SG of 4.02, against a theoretical D = 3.989 g/cm^3, which is within the 1% error of determination. A second round of measurements on *rubini 3* gave the same value. By contrast, Galileo's data for another sample called *rubino* gave an SG value of 3.56, which does not fit with corundum, but is consistent with spinel. Most likely, this gem was a *balascio* (balas) or red spinel. *Balas ruby*, as it was sometimes called, was a very popular stone. An additional sample measured by Galileo, consisting of two blue stones named *zaffiri 2* (sapphire), yielded an SG of 3.57, also likely spinel.

It is possible that all the gem samples mentioned so far were from Sri Lanka (then known as Ceylon) or Myanmar (then Pegu), where gem-quality spinel, topaz and, to a wider extent, corundum are well known. Sri Lanka and southern India were the major sources of gems arriving in Europe through the Portuguese maritime trade, which at Galileo's time had ousted the traditional long-distance caravan route through Asia (Vassallo e Silva, 1993). A Sri Lankan origin is also supported by the fact that one of the three 'emeralds' Galileo measured

had an SG of 3.07, corresponding to uvite, which is occasionally found together with spinel in the Uva Valley gravel beds (Dunn et al., 1977).

Galileo used the names *zaffiro* and *smeraldo* for blue and green stones, respectively, irrespective of their measured values. However, two green stones did yield measurements giving SG = 2.72, which is within the range of emerald (Dominy, 2013). Another sample with the SG of beryl was referred to as aquamarine, but its description as *'tenera'* (soft) is inexplicable. As for the three samples labelled sapphires, none of them was corundum: one was a blue spinel (SG = 3.57); another was possibly a gahnospinel (SG = 3.83), which is a gem that only recently was encountered in the European market; and the third one (SG = 2.58) may have been either cobalt-blue glass or cordierite (i.e. iolite). All these gem varieties are known from some Sri Lankan basement rocks and related gravel beds (Oltean et al., 2011; Gorghinian et al., 2013). They additionally support Sri Lanka as the possible origin of some gems available in Europe during the Renaissance, although we cannot rule out the possibility of their coming from elsewhere in southern Asia.

The case of Galileo's yellow *topazio* is rather peculiar. None of the three *topazio* stones weighed by Galileo met the SG requirements of topaz: two appear to have been beryl (SG = 2.75), in the yellow variety that came to be known as heliodor in the early 20th century, and the other one apparently was citrine, the yellow variety of quartz (SG = 2.66). At that time, citrine was the most widespread yellow gem available, as it was found sparsely in the Bohemia-Saxony silver-bearing ore district. Notably, true topaz was also well known there, and was commonly mistaken for citrine if yellow or for diamond if colourless (i.e. *Adamas Bohemicus:* Bohemian diamond; de Boot, 1609, p. 219).

Quartz (*cristallo,* i.e. the colourless variety known as rock crystal) was measured by Galileo with amazing precision (SG = 2.66 versus D = 2.655 g/cm^3). The *calcidonio*, with SG = 2.61, fits well into the highly variable properties of chalcedony, which is always less dense than macrocrystalline quartz because of its porous texture. By contrast, Galileo's *amatista* was by far too light (SG = 2.24) to be amethyst; it may have been purple glass. It appears that one of his *crisolito* (chrysolite) samples was also glass, with a relatively low SG of 2.48. Glass imitations are known from Roman times and were not uncommon during the late Middle Ages, where the production of glass of various colours and forms had advanced considerably although only by empirical methods (O'Donoghue, 1997). Notably, not all *crisolito* samples measured by Galileo were imitations. Indeed, two of them had SG = 3.37, which is consistent with olivine that is intermediate in the forsterite-fayalite series (i.e. peridot).

At the time of Galileo one would already easily distinguish between massive dark blue lapis lazuli and light blue *turchina* (turquoise), which displays variable specific gravity due to its porous texture (for Galileo's samples, SG = 2.73 and 2.77). One would also be able to distinguish garnets from other red stones (Gilg, 2008), although there was not yet knowledge that garnets constitute a large group. Indeed, Galileo used *granata* (garnet) to refer to a stone that, on the basis of its SG value (3.61) might have been the orange hessonite variety of grossular, and also to another sample that could have been pyrope-almandine (SG = 3.98). In the same way, he was unable to distinguish between pearls from what were later known to be from a *Pinctada sp.* mollusc (SG = 2.59) and a *Strombus sp.* gastropod (i.e. conch; SG = 2.88).

Conclusion

Within the framework of late Renaissance gemmology, Galileo was unique as a scientifically inclined researcher, which also made him a pioneer for all Western Europe. At his time, almost all treatises on minerals and gems consisted of the mere description of a number of stones from the viewpoint of a traditional set of external characteristics such as colour, shape, transparency and hardness. Most often, this objective information would be provided with remarks on their mysterious properties, mostly of a mystical nature, which had been passed down from the Middle Ages (Mottana, 2006). Galileo introduced a scientific measurement that, eventually, would prove to add significantly to the characterization of minerals and gems (e.g. Figure 5).

In actuality, the young Galileo had no idea about specific gravity as a property of materials, nor had he developed systematic thought about it: he only conceived an instrument appropriate

Figure 5: The Medici coat of arms, a Florentine artwork made in 1590–93 that originally decorated the front of the disassembled cabinet of grand duke Ferdinand I (1587–1609). It provides a good example of the need for scientific gemmology to be applied to historical jewels. The faceted 6 × 4 × 2 cm stone was originally believed to consist of a 'topaz of Spain' (citrine), and was set with six half-spheres of rock-crystal (four had backs painted in red, one in blue and one was left unpainted). The half-spheres simulate rubies, a sapphire and a diamond (Heikamp, 1963). The faceted stone was recently re-identified as a smoky quartz (Fantoni and Poggi, 2012, p. 54, Fig. 1). This artwork is preserved as Inv. 13201 in the historical collection of the Museo di Storia Naturale, Sezione di Mineralogia e Litologia, Università di Firenze. Photo by Saulo Bambi.

to determine if Archimedes could accurately test the composition of objects made by two alloyed precious metals, and extended its use to gem materials. He did not even describe the gem materials he measured, but apparently only took for granted the names provided by the merchant(s) who loaned or sold the samples to him, with only the precaution of checking their spelling against Dolce (1565), which was the gemmological reference book in Italian of his time (again, see Figure 4).

Galileo's hydrostatic balance was a valuable scientific innovation for Europe, where the Arabic studies on hydrostatics applied to gem materials had not filtered in yet. However, the new instrument did not continue to be used for testing gems, since neither Galileo himself nor any of his pupils and followers did so with a consistent methodology. There were indeed hydrostatic essays made and reported by innovative scientists such as Simon Stevin (1586) in The Netherlands, Gian Battista Della Porta (1589) and Marino Ghetaldi (1603) in Italy, and Francis Bacon (quoted in Davies, 1748, p. 421) in Britain in the early 17th century, but they mostly used metals for their experiments. Consequently, Robert Boyle is credited for the most significant 17th-century gemmological treatise, which includes considerations of specific gravity (Boyle, 1672).

One reason for the neglect of Galileo's attempt at testing gem materials by the hydrostatic method may be that the possible users (i.e. gem merchants) would have considered it slow and confusing. Indeed, gemmology continues to wrestle with this problem: being a branch of applied mineralogy, it must always balance the requirements of science with those of the business of gems.

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Purple to Reddish Purple Chrysoberyl from Brazil

Karl Schmetzer, Jaroslav Hyršl, Heinz-Jürgen Bernhardt and Thomas Hainschwang

Mineralogical and gemmological data of two intensely coloured chrysoberyls from Brazil are presented. Both samples are twinned, and they appear violet-purple or purple in daylight, and reddish purple or red-purple in incandescent light. They have good transparency, but appear very dark in reflected light due to their enriched chromium contents. In one sample, an average of 1.54 wt.% Cr_2O_3 was measured, together with 0.60 wt.% Fe_2O_3. The high Cr content is responsible for a reduced transmission in the blue-green range of the visible spectrum, which causes a shift in the daylight coloration from blue-green for typical Cr-bearing chrysoberyl (alexandrite) to violet-purple or purple for such samples with distinctly higher Cr values.

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Introduction

Alexandrite deposits were discovered near the town of Malacacheta in Minas Gerais, Brazil, in 1975. These secondary (alluvial) deposits are located about 20–30 km north of Malacacheta and west of Teófilo Otoni, along the Córrego do Fogo, Ribeiro Setubinha and Ribeiro Soturno rivers. Prior to the discovery of the Hematita deposit in 1987, Malacacheta was the major alexandrite-producing area in Brazil (Bank, 1986; Proctor, 1988; Cassedanne and Roditi, 1993; Basílio et al., 2000, 2001). It is situated within the so-called Eastern Brazilian pegmatite province in Minas Gerais State (Pedrosa-Soares et al., 2009).

Based on the mineral assemblages present in the secondary deposits and as inclusions in the alexandrites, a metasomatic-metamorphic formation is assumed, specifically an interaction of granite-related or pegmatitic Be-rich fluids with ultramafic rocks (Basílio et al., 2000, 2001; Pedrosa-Soares et al., 2009). This is the classic formation mechanism of alexandrite in various deposits worldwide, such as in the Ural Mountains of Russia, at Lake Manyara in Tanzania, and at the Novello Claims in Zimbabwe.

Purple to reddish purple chrysoberyl (also designated as 'red' chrysoberyl) from the Malacacheta area was briefly described by Proctor (1988) and has also been mentioned more recently as a rare gem mineral from that area (e.g. D. Schwarz, pers. comm., 2011, 2012). However, to the knowledge of the present authors, gemmological and mineralogical data for this type of reddish purple chrysoberyl are not available. Thus, the purpose of this article is to describe two chrysoberyl samples with this rare coloration (Figure 1) and to evaluate the cause of their colour.

Background

The pleochroism and colour-change behaviour of typical chromium-bearing chrysoberyl (alexandrite) recently have been studied in natural samples from various sources and in synthetic material produced by various techniques (e.g. Schmetzer and Bosshart, 2010; Schmetzer and Malsy, 2011; Schmetzer et al., 2012, 2013). The coloration and colour change of individual samples is a complex function of different parameters, mainly trace-element contents (especially Cr, but also Fe and V), crystallographic orientation and sample thickness. Different coloration is observable in polarized light (designated colours of X, Y and Z) and in non-polarized light (designated colours parallel to the a-, b- and c-axes).

Faceted alexandrites from various localities that weigh about 0.5 to 1.0 ct and are accepted in the gem trade as having a 'good' colour in daylight and incandescent light (i.e. samples that appear transparent and are not overly dark) generally contain 0.4–0.7 wt.% Cr_2O_3. Smaller faceted samples showing good colour may have up to 1.0 wt.% Cr_2O_3 (see, e.g., Bank et al., 1988; Malsy, 2010; Schmetzer and Malsy, 2011). Alexandrites with higher Cr are known, but are mostly valued as collectors' stones due to their interesting morphology and twinning, rather than for jewellery purposes. Samples from the Novello Claims in Zimbabwe, for example, reveal extremely high chromium values of up to 3.2 wt.% Cr_2O_3 (Bank et al., 1988; Okrusch et al., 2008; Schmetzer et al., 2011). In reflected daylight, this material, which in general is also heavily fractured, appears extremely dark green or nearly black. Relatively dark alexandrite is also known from the Carnaíba and Campo Formoso mining areas in Bahia State, Brazil (Couto, 2000). These crystals may contain 1–3 wt.% Cr_2O_3 (K. Schmetzer, unpublished research), but they are, in general, also heavily fractured and translucent at best.

Samples and Methods

Both of the samples described in this article (Figure 1) originated from Brazil. A twinned crystal weighing 1.91 ct that shows intense purple and colourless portions was purchased in 2006 from a local dealer in the Malacacheta area by one of the present authors (JH). The second sample, a faceted gemstone of 0.49 ct, is from a private collection and is known only as originating from 'Brazil'. According to this gem's properties, it might have also come from the Malacacheta area, but other contact metamorphic sources such as Carnaíba cannot be ruled out completely.

Figure 1: These two purple to reddish purple chrysoberyls were studied for this report, and are shown here in daylight (top) and incandescent light (bottom). The faceted stone weighs 0.49 ct and the crystal is 1.91 ct. Photos by K. Schmetzer.

The growth structures, inclusions, and coloration of both samples were studied in immersion with a horizontal gemmological microscope. Inclusions in the faceted stone were identified by micro-Raman spectroscopy. Energy-dispersive X-ray fluorescence (EDXRF) spectroscopy utilized a Spectrace 5000 Tracor X-ray spectrometer. Electron microprobe analyses were performed across the table of the faceted stone—and also on a faceted 0.11 ct alexandrite from Hematita, for comparison—with a Cameca Camebax SX 50 instrument. The Hematita sample (from the collection of author KS) appears intense blue-green in daylight and purple in incandescent light; it was selected for analysis because its thickness of 1.8 mm is somewhat comparable with that of the 0.49 ct faceted chrysoberyl of the present study (2.4 mm). Ultraviolet-visible (UV-Vis) spectra were recorded for both of the reddish purple Cr-rich samples, and for our faceted Hematita alexandrite, using a CCD-type Czerny-Turner spectrometer in combination with an integrating sphere.

Figure 2: Fibre-optic illumination of the chrysoberyl samples reveals the intense colour and transparency of both the faceted stone (0.49 ct) and the crystal (1.91 ct). Photos by K. Schmetzer.

Appearance, Mineralogical and Gemmological Properties

In reflected light, both the crystal and the cut stone appear very dark violet-purple or purple in daylight, and reddish purple or red-purple in incandescent light (Figure 1). Fibre-optic illumination shows them to be intensely coloured and transparent (Figure 2). The colour and colour variation between daylight and incandescent light resemble some dark purple or purplish red garnets of the pyrope-almandine series, or some purplish rubies.

The crystal specimen consists of a tabular contact twin with (031) or ($0\bar{3}1$) as the twin plane, as commonly observed in chrysoberyl and alexandrite. A dark, somewhat rounded core is partially surrounded by a colourless overgrowth (Figure 3). The rounding of the core indicates that a period of chemical resorption or transport and, most probably, a mechanical abrasion of the edges of the crystal took place between two different growth phases. The colourless part of this twinned crystal shows a dominant **a** pinacoid

Figure 3: The chrysoberyl crystal is colour zoned, with a dark reddish purple core and an almost colourless overgrowth; the edges of the core are somewhat rounded. Immersion, incandescent light, view parallel to the a-axis (top, crystal measures 8.8×7.7 mm) and perpendicular to the a-axis (bottom, crystal measures 8.8×3.3 mm). Photomicrographs by K. Schmetzer.

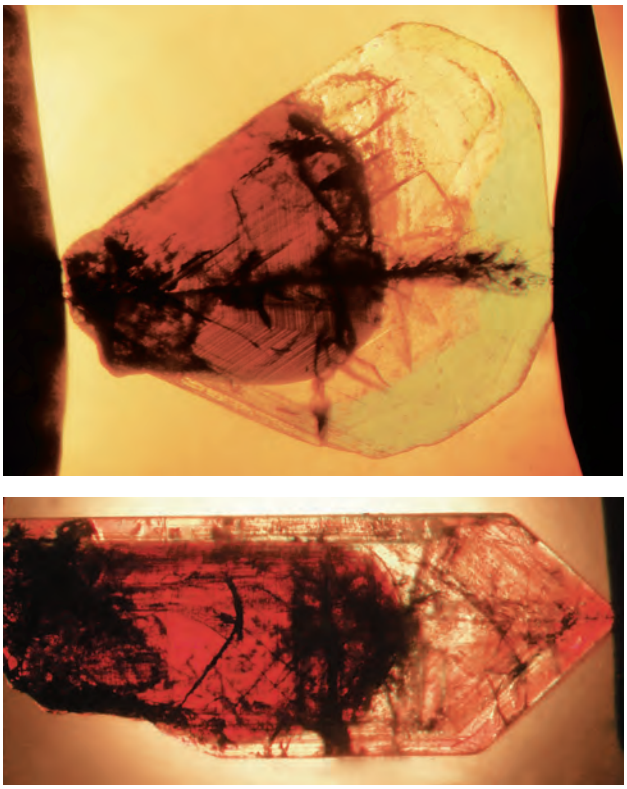

*Figure 4: This idealized crystal drawing (clinographic projection) of the twinned chrysoberyl crystal from Malaca-cheta shows a tabular habit with a dominant **a** {100} pinacoid (the other forms are listed in Table I). Drawing by K. Schmetzer.*

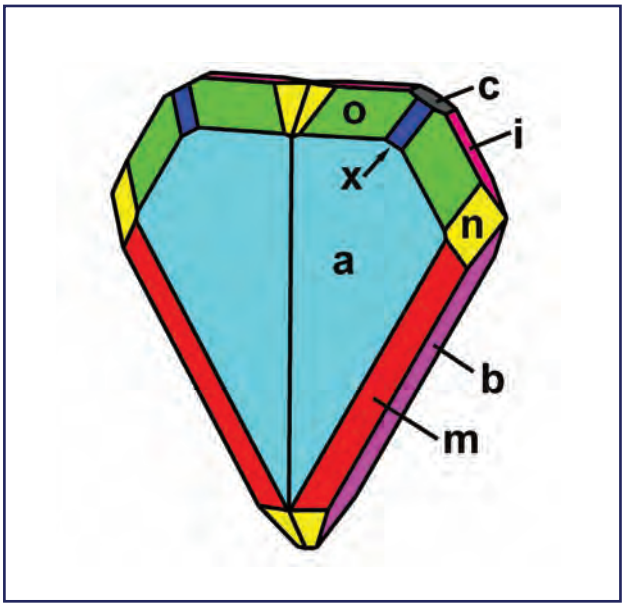

Table I: Mineralogical and gemmological properties of two Cr-rich chrysoberyls from Brazil.

Morphology*, microscopic, chemical and spectroscopic properties			
Sample	Crystal specimen, twinned 1.91 ct, 8.8×7.7×3.3 mm		Faceted gemstone, twinned 0.49 ct, 4.8×4.6×2.4 mm
	Overgrowth	Core	
Variety	Colourless chrysoberyl	Reddish purple chrysoberyl	Reddish purple chrysoberyl
Habit	Tabular after **a** {100}	Tabular after **a** {100}	Unknown
Forms	**a** {100}, **b** {010}, **c** {001} **x** {101}, **i** {011}, **m** {110} **o** {111}, **n** {121}	**a** {100} **i** {011} **o** {111}	**a** {100}, **b** {010} **i** {011}, **m** {110} **o** {111}
Mineral inclusions	None	None	Birefringent platelets (phlogopite)
UV-Vis spectrum	Fe	Cr	Cr
EDXRF spectrum	Fe	Cr, Fe	Cr, Fe
Colour and pleochroism to the unaided eye in different directions			
Daylight	Yellowish orange, blue-green, violet-purple		
Incandescent light	Purple, blue-violet, red-purple		
Colour and pleochroism for polarized light*			
	X ‖ a	Y ‖ b	Z ‖ c
Daylight	Violet-purple	Yellowish orange	Blue-green
Incandescent light	Red-purple	Reddish orange	Blue-green

** Based on a morphological cell with a = 4.42, b = 9.39 and c = 5.47 Å.*

with smaller **b** and **c** pinacoids; **x**, **i** and **m** prism faces; and **o** and **n** dipyramids (Figure 4, Table I). This morphology, especially with **c** pinacoids and **x** prism faces, represents a habit that is typical for pegmatitic chrysoberyl from many localities, such as Sri Lanka (see, e.g., Schmetzer, 2011). The internal growth pattern observed in the coloured portion consists of **i** prism faces in a direction of view parallel to the a-axis (Figure 5), and of growth faces parallel to the **a** pinacoid and parallel to the **o** dipyramid in other directions of view.

The faceted stone is also twinned, with an orientation of the twin boundary slightly oblique to the table facet, thus subdividing the table plane into two different parts (Figure 6). Growth planes showing distinct zoning associated with layers having a lighter and darker coloration (Figures 6 [left] and 7) are seen parallel to the pinacoids **a** and **b**, parallel to the prism faces **i** and **m**, and parallel to the dipyramid **o**. This chrysoberyl also contains birefringent platelets (Figure 8), identified as phlogopite by micro-Raman spectroscopy.

Similar platelets have been previously described as inclusions in Malacacheta alexandrite (Basílio et al., 2000, 2001), but they are not commonly seen in samples from Hematita (Bank et al., 1988; Pohl, 1989). The growth structures seen in Hematita alexandrite (Schmetzer, 2011; Schmetzer and Hainschwang, 2012) are also different from those described in the two reddish purple chrysoberyls. Specifically, stones from Hematita frequently show a distinct, jagged boundary between different growth zones, while growth planes within the individual zones are weak. Occasionally, this growth feature is combined with colour zoning consisting of an intensely coloured core and a lighter but not colourless rim (for further details, see the references cited above).

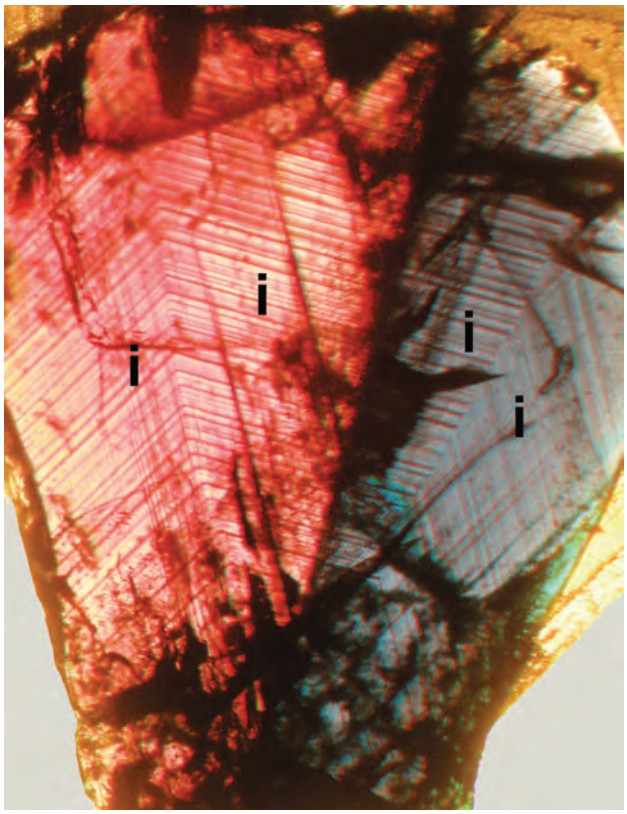

*Figure 5: This view parallel to the a-axis of the twinned chrysoberyl crystal shows growth planes parallel to different **i** (011) prism faces. Note also the pleochroism displayed by the two portions of the twin. Immersion, polarized light, field of view 5.3×4.0 mm. Photomicrograph by K. Schmetzer.*

Colour and Pleochroism

Due to the twinned nature of both samples, it is not possible without immersion microscopy to view them parallel to each of the three axes (a, b and c) in an orientation where light passes through only a single individual of the twin. In the crystal specimen in particular, it is only possible to look parallel to the a-axes of both individuals (which are parallel to each other). This view is perpendicular to the larger **a** (100) pinacoid (see again Figures 3 [top] and 4). In views perpendicular to this direction (Figure 3, bottom), the light path travels through both individuals.

In the faceted sample, the two parts of the twin show different coloration face-up in transmitted polarized light. The twin plane is slightly oblique to the table facet, and a view parallel to the a-axes of both individuals is nearly parallel to the girdle of the faceted stone (Figure 6, left). The table facet is subdivided by the twin plane into two different parts (Figure 6, right) and is oriented oblique to all three axes. For observations parallel to the b- and c-axes (i.e. oblique to the table facet), the light also travels through both individuals of the twin. In contrast, in the immersion microscope, and especially using polarized light, it is possible

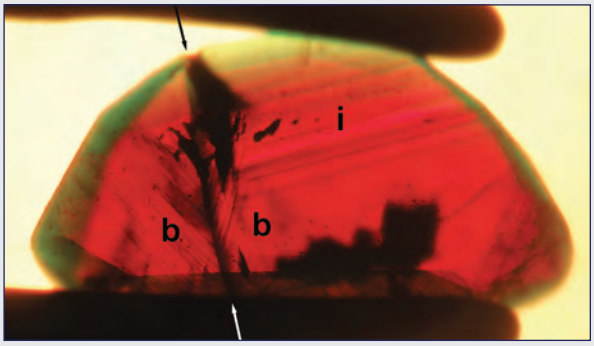

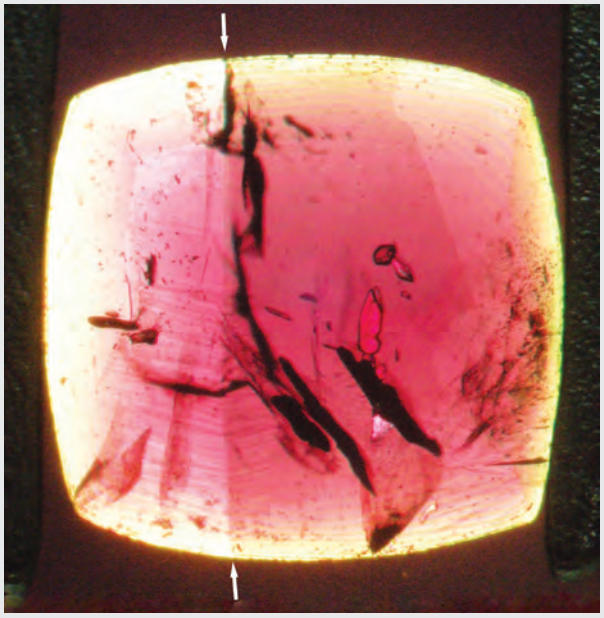

Figure 6: Twinning, growth patterns and inclusions are seen in these photos of the faceted chrysoberyl.
*Left: Viewed parallel to the a-axis, which is also parallel in both parts of the twin, growth planes parallel to two different **b** {010} pinacoids and parallel to one **i** (011) prism are observed (immersion, field of view 5.3×4.0 mm).*
Right: Viewed perpendicular to the table facet, the twin boundary subdivides the sample into two parts of different size; the birefringent platelets are phlogopite (immersion, crossed polarizers, field of view 5.6×5.6 mm). The twin plane in both photomicrographs is marked by arrows. Photomicrographs by K. Schmetzer.

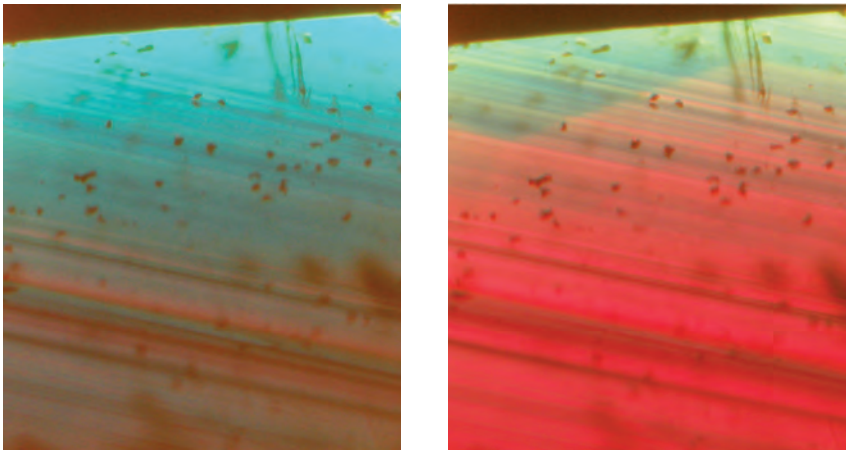

Figure 7: Growth zoning and pleochroism associated with colour zoning are seen in these images of the faceted chrysoberyl. Immersion, polarized light, field of view each 0.9×1.1 mm. Photomicrographs by K. Schmetzer.

to orient the different parts of the twin parallel to the light path in the microscope and to correctly observe the colours of X, Y and Z.

Consequently, for non-polarized light we can give just an approximate description of the pleochroism in daylight and incandescent light, since only a slight deviation from the ideal direction causes a large divergence in the colour that is visible to the observer. Observations with both polarized and non-polarized lighting are summarized in Table I.

Compared to the colour change seen in alexandrite, the most significant difference in the coloration of these Cr-rich samples is for Y in polarized light. Y is normally the lightest of the three colours, but shows the largest hue angle difference between daylight and incandescent light. For typical Cr-bearing chrysoberyl (alexandrite), Y is yellow-green or yellowish green in daylight and yellow-orange to orange in incandescent light. In contrast, for the two Cr-rich samples examined, Y is yellowish orange in daylight and reddish orange in incandescent light. The colour of X and Z, on the other hand, is less significantly changed: X is violet-purple to purple in daylight and reddish purple to purplish red in incandescent light for typical alexandrite. For our samples, the redness of X only slightly increased from daylight to incandescent light. The third colour, Z, of our samples is blue-green in both daylight and incandescent light.

Chemical and Spectroscopic Properties

Qualitative EDXRF spectroscopy of both samples generally showed strong Cr peaks and additional distinct Fe signals. The colourless part of the rough twin, however, revealed only weak Fe lines.

In Table II, quantitative electron microprobe analyses of the faceted stone are compared with data for alexandrite from the Malacacheta and Hematita areas. The analyses of the 0.49 ct faceted reddish purple chrysoberyl show a strong variation in Cr concentration across the table facet. This wide range (1.36–2.23 wt.% Cr_2O_3), which is consistent with the observed colour zoning (see again Figure 7), is quite unusual, and the average value (1.54 wt.% Cr_2O_3) is also much higher than the range of chromium contents reported in the literature for alexandrite from Malacacheta. The Fe content of this stone, on the other hand, is comparable to the values given in the literature for alexandrite from this deposit.

Figure 8: Birefringent platelets of phlogopite form inclusions in the faceted chrysoberyl from Brazil. Immersion, crossed polarizers, field of view 2.2×2.2 mm. Photomicrograph by K. Schmetzer.

*Table II: Chemical properties of a reddish purple chrysoberyl from Brazil and typical alexandrites from Malacacheta and Hematita, Minas Gerais, Brazil.**

Variety	Reddish purple chrysoberyl		Alexandrite	
Locality	Brazil		Malacacheta	
Reference	This paper		Bank et al. (1988)	Pinheiro et al. (2000); Basílio et al. (2001)
Oxide (wt.%)	Range (10 analyses)	Average	Range (7 samples)	Range (2 samples)
TiO_2	0.04–0.26	0.10	na	0.29–0.33
V_2O_3	nd–0.03	0.02	0.02–0.05	na
Cr_2O_3	1.36–2.23	1.54	0.26–0.74	0.59–0.65
MnO	nd–0.02	0.01	na	na
Fe_2O_3	0.50–0.78	0.60	0.40–0.60	0.57–0.59

Variety	Alexandrite				
Locality	Hematita				
Reference	This paper		Bank et al. (1988)	Pohl (1989)	Malsy (2010)
Oxide (wt.%)	Range (10 analyses)	Average	Range (12 samples)	Range (18 samples)	Range (46 analyses)
TiO_2	0.08–0.12	0.10	na	nd–0.34	na
V_2O_3	0.01–0.03	0.02	0.01–0.03	nd–0.11	0.01–0.02
Cr_2O_3	0.58–0.66	0.63	0.30–0.50	0.03–0.64	0.05–0.55
MnO	nd–0.01	0.01	na	na	na
Fe_2O_3	1.11–1.16	1.13	0.87–1.59	0.63–1.61	0.71–1.39

** Abbreviations: na = not analysed, nd = not detected. All analyses are by electron microprobe except for those of Malsy (2010), which are by laser ablation–inductively coupled plasma–mass spectrometry.*

The Cr content of our intense blue-green/purple alexandrite from Hematita is at the upper range measured for material from this important Brazilian deposit. This is understandable since the other studied samples were described as having varying colour intensities, some of which were substantially lighter than our stone. In addition, our stone was a relatively small sample of only 0.11 ct. In general, the Fe contents measured for the different samples from Hematita are higher than those observed for alexandrite from the Malacacheta area.

The absorption spectra of the faceted reddish purple chrysoberyl and the analysed alexandrite from Hematita (Figure 9) both show the known Cr^{3+} absorption bands of chrysoberyl, with some additional weak Fe^{3+} bands in the spectrum of the Hematita alexandrite. The spectrum of the dark part of the colour-zoned crystal specimen was similar to the spectrum of the faceted reddish purple chrysoberyl depicted in Figure 9, while the colourless portion showed only some weak Fe^{3+} absorption lines. This is consistent with the chemical data of both samples (Tables I and II).

The main difference in the spectra of the reddish purple chrysoberyl and the alexandrite from Hematita is an elevated intensity of the Cr^{3+} absorption. This difference is caused by the enriched Cr contents of the reddish purple material, which is more than twice the value measured for the Hematita alexandrite. The elevated intensity of the Cr^{3+} absorption bands results in a distinctly lower transmission for the absorption minimum at about 490 nm in the blue-green range.

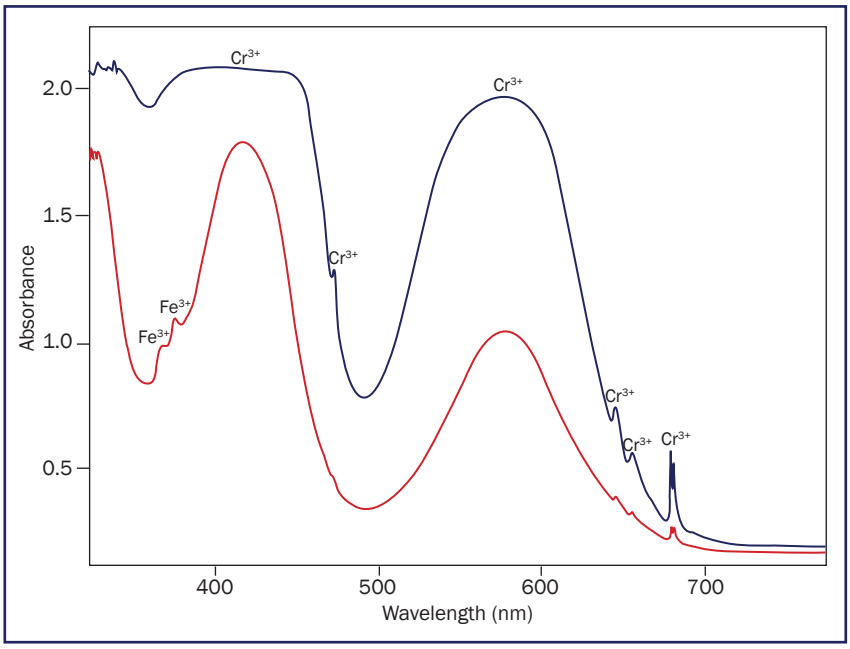

Figure 9: UV-Vis absorption spectra are shown for a faceted alexandrite from Hematita, Brazil, with an average of 0.63 wt.% Cr_2O_3 (red line, sample thickness 1.8 mm) and a faceted reddish purple chrysoberyl from Brazil with an average of 1.54 wt.% Cr_2O_3 (blue line, sample thickness 2.4 mm). In the sample with higher Cr, the transmission in the blue-green range at about 490 nm is distinctly reduced.

Discussion

The external morphology and internal growth patterns of the faceted gemstone and the dark reddish purple portion of the crystal specimen are consistent with the properties of alexandrites from Malacacheta (K. Schmetzer, unpublished research). The inclusions seen in the faceted stone are also similar to those documented in alexandrite from this locality, as are the Fe contents (Basílio et al., 2000, 2001). The famous Hematita deposit can most probably be excluded as a possible origin for both Cr-rich samples due to their inclusion pattern, growth structures and trace-element contents.

Colourless chrysoberyls are very rare; they are known mainly from Mogok, Myanmar, and from Sri Lanka. A colourless overgrowth on a dark, high-chromium core was not previously known to the present authors. The growth structure of the colourless portion is typical for chrysoberyl of pegmatitic origin.

The intense coloration of these chrysoberyls in daylight and incandescent light is a result of their enriched Cr contents. Even higher Cr contents are known for samples from the Novello Claims (Zimbabwe) and from Carnaíba and Campo Formoso (Brazil). Recently, the Cr analogue for chrysoberyl [$BeAl_2O_4$] was discovered in the famous Mariinsky mine (also called the Malysheva deposit) in the Ural Mountains, and named mariinskite [$Be(Cr,Al)_2O_4$]. With a chromium content of 58 wt.% Cr_2O_3 (Pautov et al., 2013), this material shows that replacement of even far greater percentages of Al by Cr is possible in the crystal structure of chrysoberyl.

For typical chrysoberyl, in both daylight and incandescent light it is known that with increasing thickness of a sample (which produces a correspondingly longer path of light travelling through the stone), the redness likewise increases in all three directions of view (i.e. parallel to the a-, b- and c-axes; Schmetzer et al., 2013). In the present samples, a similar effect is observed, which here is caused by enriched Cr. In the visible range, the transmission in the blue-green area of the spectrum is distinctly reduced, as compared to the absorption spectra of typical alexandrite that shows a good colour change.

Conclusion

The high Cr contents of the studied chrysoberyls cause a distinct change in transmission in the blue-green spectral range. In typical alexandrite showing a good colour change, the transmission in this area is balanced with the transmission in the red, causing the colour change between daylight and incandescent light. For reddish purple chrysoberyl with enriched Cr, this balance is not present, and the consequence is an increase in the redness of the colour in both daylight and incandescent light. In daylight, this increase in redness causes a dramatic change in the overall coloration of a sample, but in incandescent light this effect is less noticeable to the observer.

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The Fire Within

"For in them you shall see the living fire of the ruby, the glorious purple of the amethyst, the sea-green of the emerald, all glittering together in an incredible mixture of light."

– Roman Elder Pliny, 1st Century AD

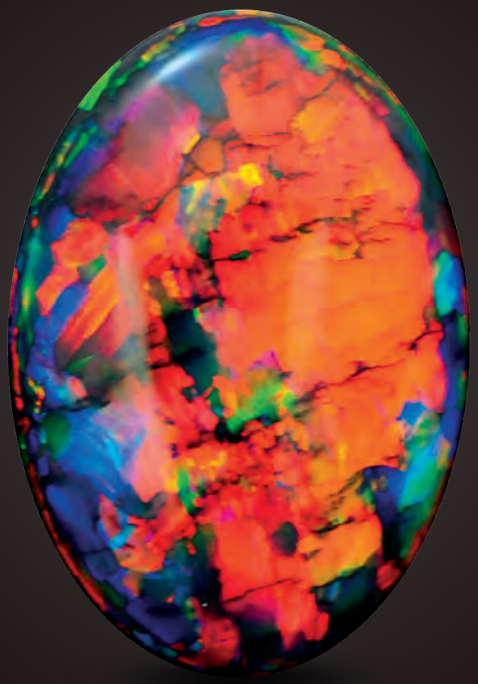

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Identification Characteristics of Natural and Imitation Hornbill Ivory

Jie Liang, Haibo Li, Taijin Lu, Jun Zhang, Meidong Shen and Jun Zhou

Natural hornbill ivory (from the bird *Rhinoplax vigil*) is a rare gem material, and in recent years imitations and composites have appeared on the Chinese gem market. In this study, the gemmological properties of these products were systematically investigated using microscopic observation, FTIR spectroscopy and UV fluorescence. The key identification features for natural hornbill ivory are a layered structure with minute pigmented dots, which were not present in polymer resin imitations. Air bubbles were detected in both the imitations and in composites made from hornbill ivory and resin. FTIR spectroscopy is useful for confirming the presence of resin.

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Introduction

Hornbill ivory is an attractive organic gem material derived from the colourful casque of the bird *Rhinoplax vigil*, also called the helmeted hornbill. The bird is native to Southeast Asia, particularly the Malay Peninsula, and also Sumatra and Borneo in Indonesia (Brown and Moule, 1982). The male hornbill grows a large beak and a solid casque that is composed of keratin, which is typically pale orangey yellow with a thin outer red layer. The casque, which is a large protuberance covering a portion of the head and bill (Kane, 1981), has been carved and polished into ornamental objects and jewellery pieces. Although referred to as hornbill 'ivory', the material has no relation to mammal tusks or teeth, and the name is only an expression of the material's resemblance to ivory (Espinoza and Mann, 1991).

Rhinoplax vigil is a near-threatened species (International Union for Conservation of Nature, 2012) that is listed in Appendix I of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES). It is illegal to trade in specimens of species listed in CITES Appendix I, except under exceptional circumstances (see www.cites.org/eng/app/index.php).

Hornbill ivory is named *Hedinghong* in Mandarin Chinese which means the red part of the red-crowned crane. This beautiful name refers to the bright red colour present on some samples (e.g. Figure 1). The earliest full description of the bird *Rhinoplax vigil* in ancient Chinese history dates back to the Ming Dynasty (1368–1644; Zheng, 1947). However, the use of hornbill ivory in decorative arts probably dates back much earlier than this record (Brown and Moule, 1982).

The material was carved into various art objects and incorporated into belts for men, personal seals and jewellery items (e.g. Hurwit, 1997). Its historic popularity in China was due to its rarity, beautiful colorations, and its ability to take a fine polish. The material shows a subdued waxy lustre, which is similar to elephant ivory (Zhang, 2006) and rhinoceros horn.

Today hornbill ivory is an unusual and precious organic gem material that is generally unknown in the modern gem industry. Nevertheless, with the growth of the jewellery market in China over the last few years, new gem materials continue to appear and some old-fashioned products such as hornbill ivory are being seen again.

Given the protected status of *Rhinoplax vigil*, the authors oppose any trade in contemporary hornbill ivory; the purpose of this article is to aid in the identification of hornbill ivory from a gemmological point of view. For this purpose, hornbill ivory is compared to its polymer resin imitations, and also to recently encountered composite specimens made with natural yellow hornbill ivory and red resin.

Figure 1: Hornbill ivory is a rare gem material that has been fashioned into a variety of decorative objects and jewellery, such as this beaded bracelet (average 17 mm in diameter; sample no. 8 in Table I). Three of the beads turned out to be composites made of genuine hornbill ivory and red resin. Photo by Jie Liang.

Samples and Methods

For this study, the authors obtained eight samples (some of which consisted of multiple pieces) from various Chinese collectors. These included hand-carved art pieces, beaded bracelets, loose beads, hornbill raw material and a sawn fragment (see Table I and Figure 2). The authors also visited international exhibitions and marketplaces to make visual observations of several samples that consisted mostly of beaded bracelets and carved pieces of varying weight and form.

Standard gemmological testing was carried out at the National Gemstone Testing Center Laboratory in Beijing. All samples (including each bead in samples 2, 7 and 8) were observed with microscopy and a long- and short-wave UV lamp. Microscopy employed various light sources, using a GIA tripartite microscope with an electronic camera, and a Keyence VHX-600 microscope equipped for three-dimensional observation. The Keyence microscope can be used to observe surface and internal features down to the micron scale, and can take photographs. All polished samples were tested with the refractometer using the distant vision technique. Mid-infrared spectral analysis was performed on all samples (including each bead of each bracelet) with a Nicolet 6700 FTIR spectrometer in the range of 4000–400 cm^{-1}, with a resolution of 4.0 cm^{-1} and 16–64 scans (with the minimum number of scans needed to get high-quality spectra). Several points on each sample were analysed, especially in different colour regions.

Results

During the course of our investigation, it became clear that while some samples were genuine hornbill ivory, others consisted of polymer resin imitations or composites of natural hornbill ivory with polymer resin (Table I). The resin identification was confirmed by IR spectroscopy.

Colour, Lustre and Structure

The genuine hornbill ivory varied from pale to bright yellow and orangey yellow with a red patch on one side of the carvings or beads. These

Table I: Gemmological characteristics of hornbill ivory, plastic imitations, and composites.[a]

Sample no.	Type	Size/weight	Colour	Lustre and transparency	RI[b]		UV fluorescence		Identification
					Y	R	Long-wave	Short-wave	
1	Carving	50×30×30 mm	Patchy yellow and vivid patchy red	Waxy Translucent to opaque	1.52	1.53	Y: moderate bluish white R: inert	Y&R: inert to very weak	Natural, except red dot on forehead was artificial
2	Bracelet (14 beads)	20 mm in diameter	Patchy yellow; each bead had a round red spot	Waxy Translucent to opaque	1.54	1.53/1.48	Y: inert to weak whitish blue R: weak–moderate bluish white	Y&R: inert to very weak	All yellow portions were natural; all red spots except one were composite
3	Bead	12 mm in diameter	Yellow with red spot, both patchy	Highly waxy Translucent	1.52	1.53	Y: inert R: weak–moderate bluish white	Y: inert R: inert to very weak	Natural
4	Carving	115×35×10 mm/ 23.53 g total	Orangey yellow and patchy red with some dark brown streaks	Waxy Translucent to opaque	-	1.54	Y: inert R: moderate bluish white	Y: inert R: weak	Natural
5	Sawn fragment	35×8 mm; 1.28 g	Orangey yellow, with vivid red ends	Dull waxy Translucent to opaque	-	-	Y: whitish R: moderate bluish white	Y: inert R: weak bluish white	Natural
6	Raw material	~200×125 mm; 190.47 g total	Yellow and patchy red	Waxy Opaque	-	-	Y: inert R: moderate bluish white	Y: inert R: weak	Natural
7	Bracelet (14 beads)	16 mm in diameter avg.	Orangey yellow (patchy) and vivid red (mostly even)	Waxy Translucent to opaque	1.54/1.49	1.52/1.48	Y: inert to very weak bluish R: inert to weak bluish white	Y: inert to very weak R: inert	Only one bead was natural; others were imitations
8	Bracelet (14 beads)	17 mm in diameter avg.	Patchy yellow and dark brownish red	Waxy Translucent to opaque	1.51-1.52	1.53/ 1.48-1.49	Y: inert to strong whitish R: inert to moderate bluish	Y: inert R: weak bluish	11 were natural and three were composites

[a] *Abbreviations: Y = yellow and R = red part of sample.*

[b] *Lower values (1.48–1.49) correspond to polymer resin imitations.*

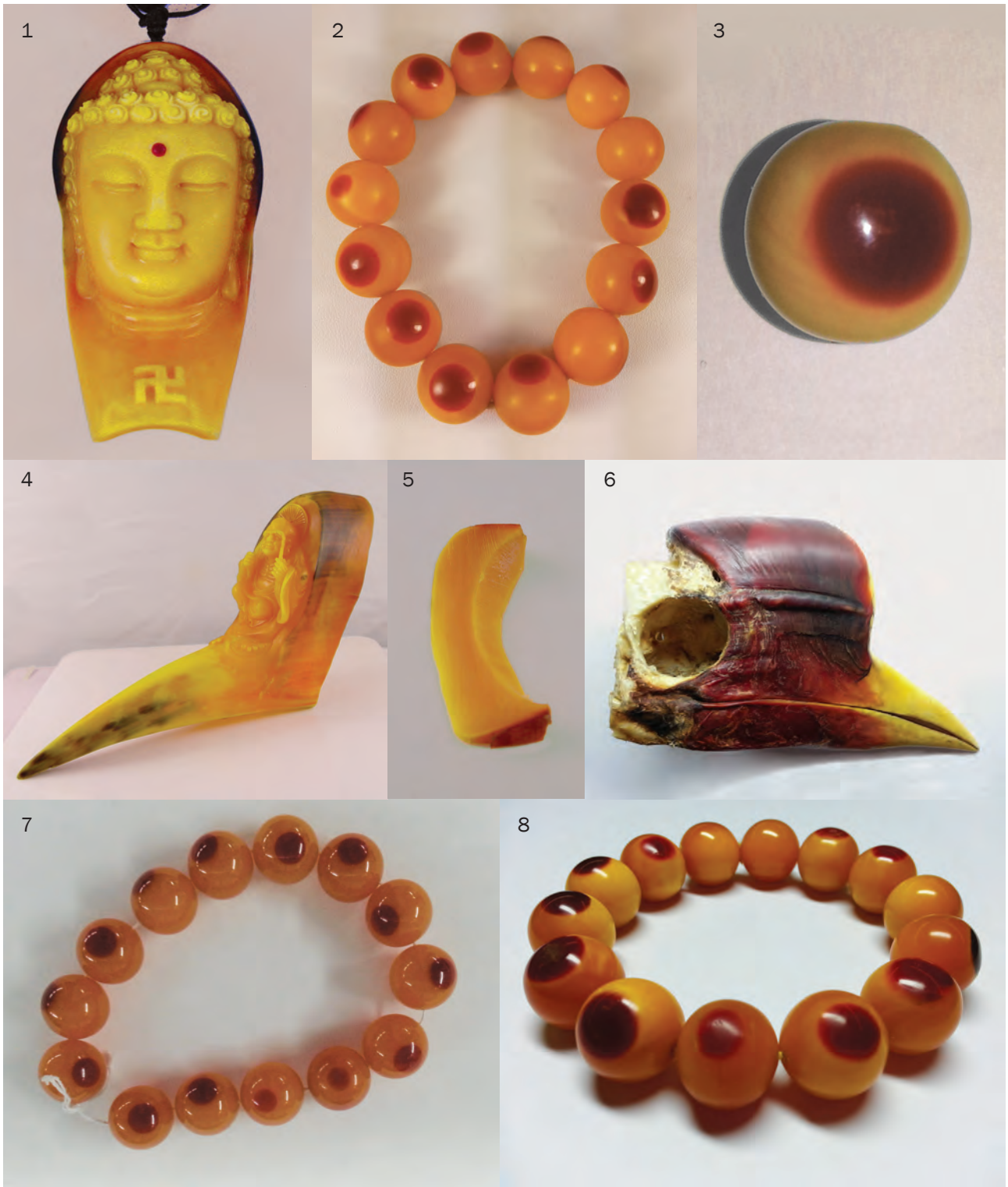

Figure 2: Eight samples were examined for this study: (1) a hand-carved pendant with a Buddha motif that is mostly orangey yellow with a red portion framing the upper part of the head, and a red dot added to the forehead (50×30 mm); (2) a beaded bracelet showing bright red patches (each bead is ~20 mm in diameter); (3) a single loose bead (12 mm in diameter); (4) a hand-carved art piece made from a beak and associated casque which has been polished so the red layer is very thin, producing a paler red colour (115×35 mm); (5) a sawn fragment with red patches at both ends (35×8 mm); (6) the beak, casque and part of the skull of a hornbill (~200×125 mm); (7) a beaded bracelet with most pieces showing even yellow and red coloration (average 16 mm in diameter); (8) a beaded bracelet displaying colour patches that are mostly brownish and dark red (average 17 mm in diameter). See Table 1 for the identification of each sample as natural, imitation or composite. Photos by Jie Liang.

patches commonly ranged from light pinkish red, dull red and brownish red to vivid red, and in some samples they were very dark brownish red (nearly brown-black). The best colours after polishing were bright orangey yellow with vivid red. The coloration of the resin imitations was quite similar (typically orangey yellow and vivid red), but more even.

The genuine hornbill ivory samples displayed a waxy lustre, and were translucent to nearly opaque. By comparison, most of the resin imitations had a highly waxy to vitreous lustre and were mostly translucent.

Important differences were seen in the structural features of the hornbill ivory and the resin imitations. The yellow portion of the hornbill ivory was layered (Figure 3), resembling the growth structure of shells. The layers were of variable thickness and were marked by differences in transparency and saturation of the yellow colour. The layers were not always perfectly parallel; some were wavy and others displayed intersections at various angles. The red portions of the hornbill ivory also displayed layered growth (e.g. Figure 4), which was more easily observed in the unpolished raw material and/or larger carved pieces with red areas preserved. In the beads, the layered structure was not always observed in the red portion. However, the boundary between the red and yellow areas may show dark brown striations (e.g. Figure 5, left). In addition, there were commonly small cracks oriented almost perpendicular to these dark brown striations. By contrast, the resin imitation did not show any layered structures, brown striations or small cracks.

Microscopic Characteristics

Observed with the microscope using low magnification, the colour boundary in the hornbill ivory appeared vague. At higher magnification, the more translucent samples showed pigmented spots along the boundary between the two colours (Figure 5). These tiny dots were yellow in the yellow region and red or brownish red in the red part (or dark brown in the brown coloured patches).

The imitation hornbill ivory showed a sharp colour boundary in the full-resin beads, and only a somewhat sharp boundary in the hornbill-resin

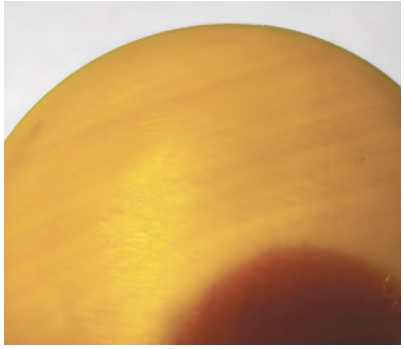

Figure 3 (top left): A layered structure is apparent in this bead of hornbill ivory (sample no. 3; 12 mm in diameter). Photomicrograph by Jie Liang; magnified 10×.

Figure 4 (bottom left): The layered structure of hornbill ivory is obvious in unpolished sample no. 6 (125 mm tall). The red colour forms a thin layer over the yellow core. Photo by Jie Liang.

Figure 5 (below): On the left, a hornbill ivory bead from sample no. 8 shows tiny yellow-pigmented dots, which are easiest to observe along the colour boundary; note also the underlying brown striations in this area. On the right is a composite bead from sample no. 2, which displays a sharp curved boundary between the hornbill ivory (top) and the resin (bottom). Air bubbles in the resin create a sponge-like structure, while tiny red- and yellow-pigmented dots are visible in the hornbill ivory. Photomicrographs by Jie Liang; magnified 12.5× (left) and 20× (right).

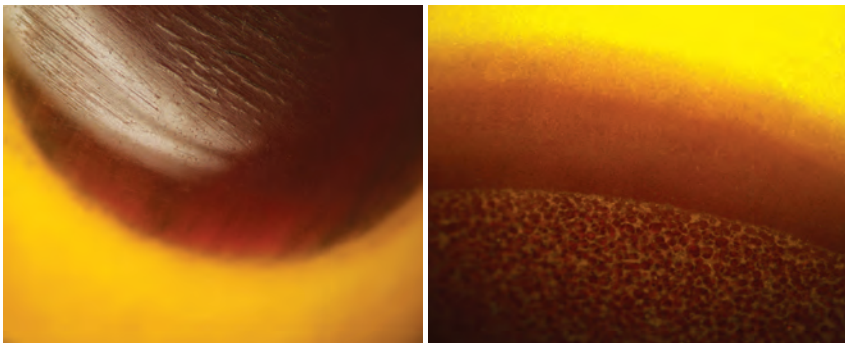

Figure 6: This imitation hornbill ivory bead from a bracelet (sample no. 7; 16 mm in diameter), shows a sharp and regular colour boundary. It appears that the red portion was set into the yellow area and then the sample was fashioned into a bead. Photo by Jie Liang.

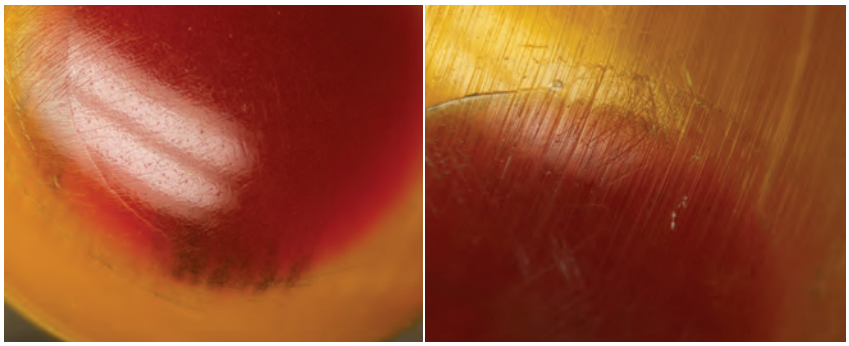

Figure 7: These beads from sample no. 8 (16 mm in diameter) proved to be composites of hornbill ivory (orangey yellow) and resin (red). Both show the boundary with the resin as a distinct line in reflected light. In the left photo, a small amount of red hornbill ivory was retained, with resin added on top of it; note the higher lustre in the resin. The sample on the right shows distinct polishing lines on both the hornbill and resin portions, and the boundary is clear. Photomicrographs by Jie Liang.

composites (Figures 6 and 7). In both of those products, a distinct line could be seen with reflected light on the beads' surface, which corresponded to the boundary between the two coloured areas. Careful observation of the resin with transmitted lighting showed a grainy sponge-like structure due to the presence of numerous minute air bubbles, as well as larger and more distinct bubbles (Figure 8). These features provide proof of artificial origin.

Other Gemmological Properties

RI readings taken from the hornbill ivory were significantly higher (1.51–1.54) than those measured from the resin (1.48–1.49; Table I). In addition, most hornbill ivory samples showed some areas of whitish blue to bluish white UV fluorescence (stronger to long-wave [Figure 9] than short-wave UV), while the resin was inert.

Infrared Spectroscopy

Both the yellow and red parts of the hornbill ivory samples showed the same absorption bands, at 3300–2860 cm^{-1} and 1750–1200 cm^{-1}, with the strongest absorption at ~1650 cm^{-1} (Figure 10, top). The imitations showed a series of absorption bands that were different from the natural material, with the strongest at 1730 cm^{-1} (Figure 10, bottom). Spectra from the imitations were consistent with polymer resin (Wang et al., 1990).

Identification Features

Identification criteria are summarized in Table II. All of the imitations examined in this study had a red colour patch. Material showing such coloration should be carefully screened. In natural hornbill ivory, the red area (if present) is restricted to a thin outer layer surrounding the orangey yellow core. The amount and distribution of any red patches in carved or otherwise polished samples should be consistent with this distribution in the raw material. In addition, red patches that are deeply coloured or show an even vivid red colour should arouse suspicion.

Figure 8: The red (resin) portion of these composite beads from bracelet sample no. 2 displays a grainy sponge-like structure due to the presence of numerous minute air bubbles. Larger bubbles are also visible in the image on the right. Photomicrographs by Taijin Lu (left, magnified 10×) and Jie Liang (right, magnified 12.5×).

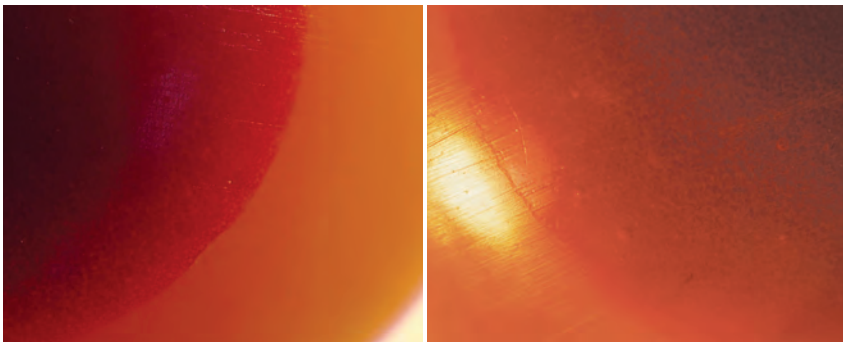

Figure 9: Sample no. 4 is shown here in incandescent light (left; photo by Jie Liang) and under long-wave UV radiation (right; photo by Haibo Li). The main orangey yellow portion is inert, while the thin red edge of the sample displays moderate bluish fluorescence.

A layered structure is a key diagnostic feature of hornbill ivory. Microscopic observation shows a diffuse boundary between the orangey yellow and red colours in hornbill ivory, whereas this boundary appears sharper in imitations and composites. The resin used for those materials also displays a grainy sponge-like appearance, as well as distinct air bubbles.

FTIR spectroscopy can be used to confirm the presence of resin, either forming entire samples or in composites together with genuine hornbill ivory.

Conclusions

Like elephant ivory and rhinoceros horn, trade in hornbill ivory is presently illegal due to the protected status of these species. In recent years resin imitations of hornbill ivory have entered the market, but they are straightforward to identify. All the imitations tested for this study consisted of polymer resin.

The most effective methods to identify hornbill ivory are microscopic observation and

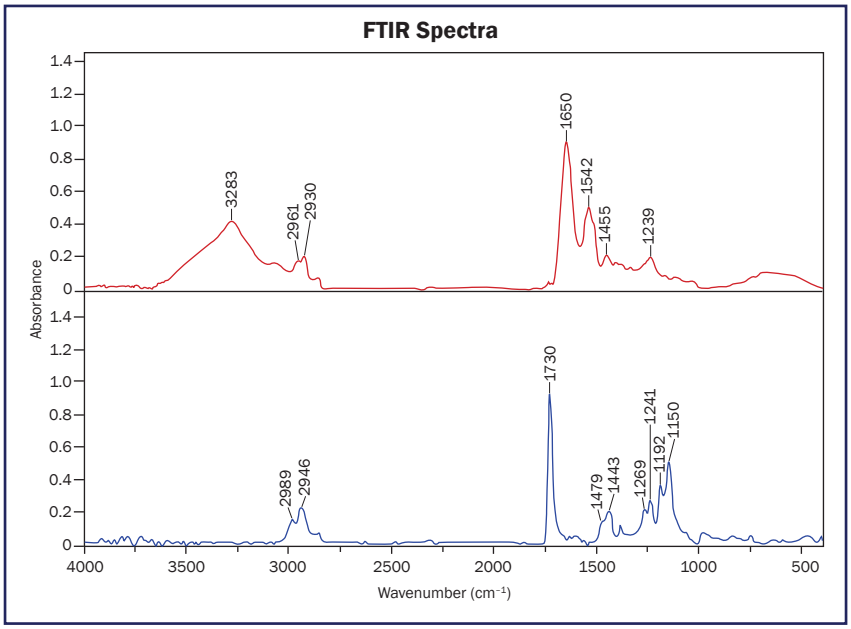

Figure 10: The FTIR spectrum of hornbill ivory (top, from sample no. 6) is distinctive from the spectrum of a resin imitation (bottom).

Table II: Gemmological properties of natural hornbill ivory, its resin imitation and composite material.

	Natural	Resin	Composite
Colour	Patchy, in orangey yellow and red	Even yellow and red colour	Yellow: often patchy Red: even
Diaphaneity	Translucent to opaque	Translucent	Translucent to opaque
Structure	Layered	Grainy, sponge-like	Yellow: layered Red: grainy, sponge-like
Microscopic features	Tiny pigmented dots that are more obvious at the colour boundary	Air bubbles	Yellow: tiny coloured dots Red: air bubbles
RI	1.51–1.54	1.48–1.49	Yellow: 1.51–1.54 Red: 1.48–1.49
UV fluorescence	Inert or weak-to-moderate, bluish white and whitish blue	Inert	Yellow: Inert or weak-to-moderate, bluish white and whitish blue Red: Inert
IR features	Main band at 1650 cm^{-1}; smaller bands at 3300–2860 cm^{-1} and 1750–1200 cm^{-1}	Main band at 1730 cm^{-1}	Combination of natural and resin features

FTIR spectroscopy. Other tests, such as RI and UV fluorescence observations, provide additional distinguishing criteria but not conclusive identification.

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Detection of Ruby Crystals in Marble Host Rock by X-ray Computed Tomography

Antonia Bouts

X-ray computed tomography (CT) is a technique that is most commonly used in the medical field to visualize the internal organs and structures of the human body. To investigate whether a medical CT instrument can be used to detect gems inside their host rock, a piece of ruby-bearing marble was imaged with CT. The scanning indicated the presence of a ruby inside the specimen, and this was confirmed by slicing the sample in half, which revealed a ruby crystal at the predicted location within the marble.

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Introduction

Most imaging techniques in gemmology have been developed to analyse the properties of a gemstone (or pearl) itself and to examine its inclusions. However, little research has been done on detecting the presence of gems inside their host rock. Some gems mined from primary deposits—such as marble-hosted ruby (e.g. Figure 1), schist-type emerald and others—may not be directly visible without crushing or sawing the rock in which they formed, which could lead to breakage or damage of valuable gem material.

This study investigates whether X-ray computed tomography (CT) can be used to reveal the presence of a gem within its host rock, using instrumentation developed for medical applications. CT is a non-destructive technique that visualizes the internal structure of objects, and is dependent on variations in the density and atomic composition of the material. Besides a wide range of applications in medical science, the use of CT has also been explored in geology, such as imaging the interior of fossils or meteorites, examining

Figure 1: Marble-hosted rubies, such as this fine crystal from Jegdalek, Afghanistan, need to be exposed from their host rock before they can be evaluated for gem rough or used as mineral specimens. The piece shown here measures 3 cm across and is courtesy of Jim and Gail Spann; photo by Thomas Spann.

the texture of igneous and metamorphic rocks, studying the porosity of rocks and soils, and analysing ore samples (e.g. Baruchel et al., 2000; Ketcham and Carlson, 2001; Cnudde et al., 2006; Cnudde and Boone, 2013; Mees et al., 2013). In gemmology, micro-CT has proved useful for discriminating between natural and cultured pearls when ordinary X-radiography proved insufficient (Wehrmeister et al., 2008; Karampelas et al., 2010; Krzemnicki et al., 2010).

The present author, who is a medical doctor, became interested in whether the CT instrumentation used in human clinical practice (e.g. Figure 2) could be applied to detecting rubies in marble host rock during the course of her gemmology diploma studies. The article reports on the process and results of imaging this sample.

Figure 2: The Philips Brilliance CT 64-slice scanner was used for this study. Courtesy of Philips.

Background

In human medicine the CT imaging technique is used to give detailed information on the internal organs and other structures of the body (e.g. Prokop et al., 2003; Bellin et al., 2004; Patel et al., 2009). The CT scanning method was developed by Godfrey Hounsfield, for which he received the Nobel Prize in Physiology and Medicine in 1979. The first clinical CT scans of human patients were performed in 1972. The instrumentation consists of an X-ray irradiation source (the X-ray tube) and a detection system that measures the attenuation of the X-ray beams that traverse an object from various angles. The attenuation values from all different angles are stored in a matrix, from which a computer reconstructs images of the interior of the object using the so-called filtered back projection algorithm (Prokop et al., 2003). The attenuation value for each point of the matrix is called the CT value or Hounsfield unit (HU), which indicates the attenuation of X-rays in the object with reference to water. The HU is calculated using the following formula: HU = $((\mu_{material} - \mu_{water})/\mu_{water}) \times 1000$ (Prokop et al., 2003). The μ value of various materials is defined as the attenuation coefficient at a certain kV (kilovolt, referring to voltage of the X-ray tube). Water has an HU = 0, air = –1000 and bone ≥ 1000. In a CT scan that is used for human medical applications, the HU may range from –1000 (least attenuating) to +3071 (most attenuating; Prokop et al., 2003).

CT scanners can be grouped into four categories, based on their spatial resolution and the size of the objects that are imaged: conventional, high-resolution, ultra-high-resolution and micro-tomography scanners (Ketcham and Carlson, 2001; Cnudde et al., 2006). Most medical systems fall into the category of conventional CT. The other types of scanners generate much more detailed images (Landis and Keane, 2010; Cnudde and Boone, 2013). A further important difference between a medical CT and micro-tomography is the rotational movement. In medical CT the patient remains stationary while the X-ray source and detector rotate (Figure 3). In most micro-tomography systems it is the object that rotates. The limitation of micro-tomography is the penetrating ability of the X-rays relative to the

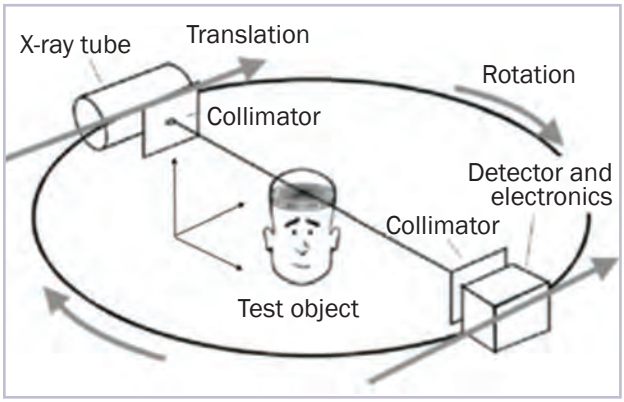

Figure 3: This schematic diagram shows the working principle of a medical CT scanner. Adapted from Kalender (2000).

Figure 4: The ruby-bearing marble specimen used in this study measured approximately 75×50×40 mm. Photo by A. Bouts.

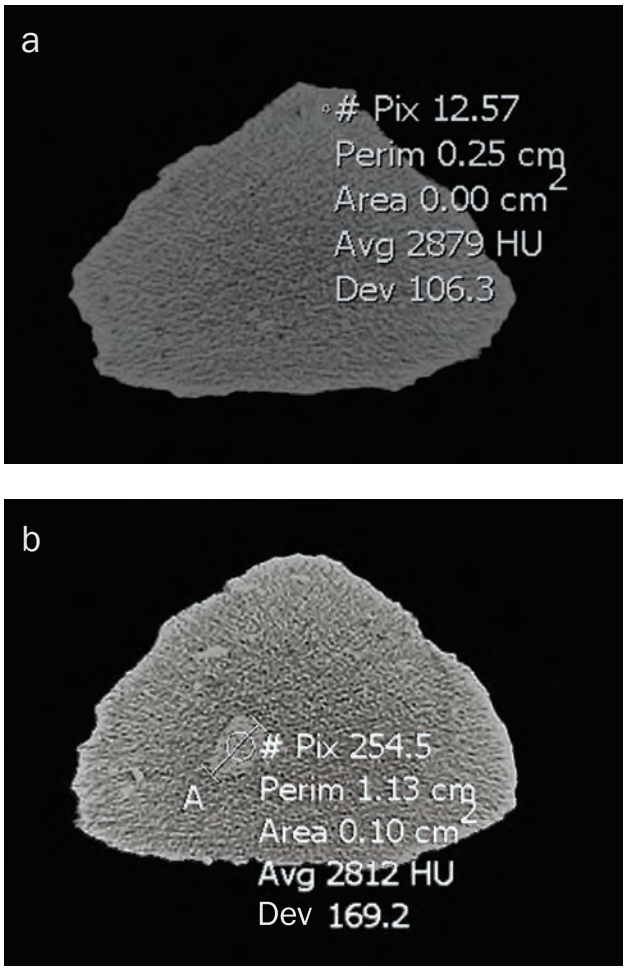

Figure 5: (a) This CT scan shows a slice through the marble specimen, underneath the exposed ruby crystal at the top of the piece showing a mean HU value of +2879. (b) A slice through the centre of the sample revealed a crystal with a mean HU value of +2812, which proved to be a ruby.

density of the sample. For example, dense metals require either very high-energy X-rays, or very small specimens.

Visualization of CT images can be generated by the computer in two- or three-dimensional views (Landis and Keane, 2010).

Methods

This study utilized a piece of white granular marble measuring approximately 75×50×40 mm that showed some small ruby fragments on the surface (Figure 4). We wondered if the marble contained more ruby crystals inside.

The sample was initially investigated with a 10× loupe, a microscope and a spectroscope. To get information about the internal structure, we then used a Philips Brilliance CT 64-slice scanner (typical for medical investigations). The marble fragment was placed in the CT scanner, together with a faceted synthetic ruby and a natural ruby crystal to compare and calibrate the imaging results. In addition, pieces of feldspar, quartz, fluorite, topaz, beryl and amber were tested with the CT scanner, to use as separation values for various other gem materials.

Three scan series were performed with different settings as follows: (1) 120 kV voltage and 199 mAs (milliampere seconds), (2) 80 kV and 400 mAs, (3) 140 kV and 197 mAs. The voltage determines the beam quality or the ability of the beam to penetrate the object. The mAs value controls the beam intensity or the number of X-ray photons in the beam. The thicker the object, the more absorption of X-rays occurs, requiring higher mAs values. CT slices of the sample were generated at 1 mm intervals.

Results

The surface of the specimen showed a pink-red opaque crystal of 7×3 mm with a dull vitreous lustre. In addition, three other pink-red crystals of smaller size and one brown-black crystal were present on the surface of the stone. The pink-red crystals were semi-translucent and had no discernible crystal habit. Parallel striations were present on the faces of the largest crystal, and the absorption spectrum in general was typical for ruby.

CT scanning showed that the mean HU of the loose faceted synthetic ruby was +2976, exactly the same as for the loose natural ruby crystal. The mean HU of the ruby crystal on the surface of the investigated marble was +2879 (Figure 5a), while the mean HU of the host rock was +2516. The scans revealed an object inside the marble with a similar HU (mean +2812) as the ruby crystal on the surface and the loose natural and synthetic ruby samples (Figure 5b). The dimensions of this object were 8.0×6.0×6.6 mm. These findings indicated the presence of a ruby crystal within the marble.

The results for the mean HU of feldspar, quartz, fluorite, topaz, beryl and amber are shown in Table I. All these samples have different HU values. However, the HU value of the fluorite is in the same range as the rubies tested. Since these measurements were made from only one specimen each, the results should be considered provisional, and it will be necessary to measure more samples to confirm these values.

Table I: Results of HU measurements of various minerals.

Mineral	Mean HU
Feldspar	+1880
Quartz	+1915
Fluorite	+2976
Topaz	+2640
Beryl	+2033
Amber	+22

To confirm the CT results, the marble specimen was then cut open, revealing a ruby crystal in the expected position inside the host rock (Figure 6). The ruby crystal was also the size predicted by the CT scanning.

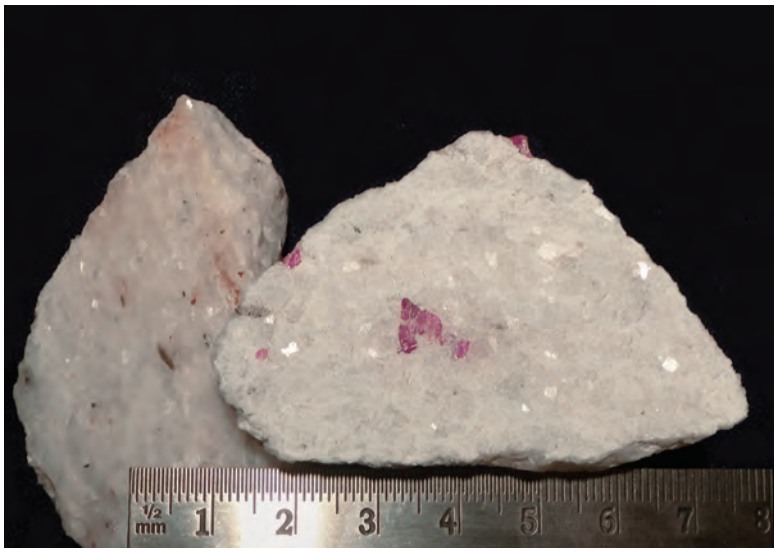

Figure 6: The presence of ruby in the marble sample was confirmed by cutting the stone into two pieces. Photo by A. Bouts.

Discussion and Conclusion

This study indicates that computed tomography can be used to identify the presence of a ruby within its marble host rock. Whether CT can be used to detect other gem materials inside their host rocks needs to be analysed: this depends on the difference in HU between the gem material and the surrounding material.

In this study the tested sample had a diameter of less than 80 mm. The upper size limit of rock material that can be accurately scanned by CT remains to be determined.

In practice, CT scanning may prove helpful in identifying the presence of gem minerals within high-value specimens being investigated for rough material or being prepared for museums or collectors. However, the technique does not give any information about the actual quality of the gems detected inside their host rock.

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A Journey to the Legendary Mogok Mines in Myanmar

December 2013

Federico Pezzotta

This author was invited by gem dealer Federico Barlocher (Lugano, Switzerland), who has over 30 years of gem-trading experience in East Asia, and especially in Myanmar, on a trip to Mogok. This area was re-opened to foreigners in July 2013 (after being closed for approximately 10 years), although access to Mogok still requires special visa permission from the Burmese government. Accompanying us were videographer Bryan Swoboda (BlueCap Productions, Honolulu, Hawaii, USA), former mineral collector and dealer Dave Wilber (Tucson, Arizona, USA), and mineral specimen miner and speleologist Marco Lorenzoni (Lucca, Italy). The trip took place from 28 November to 10 December, and Barlocher's goal was to produce a unique film documentary for television containing unseen footage of mining for rubies and other gems in Mogok.

For reference during the trip, the author brought the book *Gems and Mines of Mogok* (Themelis, 2008), which was of fundamental importance for understanding the relations between the local geomorphology and the geology and distribution of the gem mines. The book was also helpful for learning about the history of Mogok mining and the nature and quality of the gem material from each mine. Also, Atichat and Hughes (2013) provide a useful introduction to the geologic processes responsible for the exceptional mineralogical and gemmological variety of Mogok.

We travelled in a four-wheel-drive minibus from Mandalay, via the historic route through Thabeikkyin, and then to Mogok. The trip took about seven hours on a good paved road. On the way we passed through Latpanhla village, which is known for tourmaline-bearing pegmatites. However, mining activities were stopped at least three years ago by the government. Most of the tourmaline was recovered in 2006–2008. The area produced several tens of kilograms of vivid pink gem tourmaline of faceting and carving quality, and also crystals in pegmatite matrix, that were sold in markets in Mandalay and Yangon.

At sunrise, mist shrouds the Mogok valley. Photo by F. Pezzotta.

The author (centre) and Federico Barlocher (far right) discuss the geology of the Bawpadan mine. Photo by M. Lorenzoni.

The author enters the Sakangyi topaz mine, without shoes as requested by the Buddhists who operate some mines. Photo by M. Lorenzoni.

While exploring Mogok, we resided at the Golden Butterfly, a good hotel (considering the remote location) that is perched on a hillside several kilometres from the town and has a spectacular view of the valley. The most important localities visited by the group are described below.

Sakangyi: This area become famous for the late-2006 discovery of a spectacular giant pegmatite cavity lined with quartz, feldspar and mica crystals, with associated colourless to pale blue and pale yellow topaz (Praszkier and Sacchi, 2012). With permission obtained by Barlocher from the mine owner, we visited the short tunnel where the cavity had been found. During our visit, several small mines were actively exploring both primary and alluvial deposits in the area. They produce mostly topaz, but also some aquamarine and multi-coloured tourmaline. Minor amounts of ruby and sapphire were recently found in a narrow coarse-grained calcitic marble lens discovered at the bottom of a small valley.

The pegmatitic veins seen by our group were mostly steeply dipping, up to a few metres wide, and hosted by deeply weathered gneiss. They cut across the foliation and metamorphic structures in the gneiss, and were characterized by (1) a border zone composed of a fine-grained biotite-bearing aplite or medium-grained pegmatite; (2) an intermediate zone consisting of coarse-grained pegmatite composed of quartz, feldspars and biotite; and (3) a core zone containing coarse- to very coarse–grained miarolitic pegmatite with smoky quartz, graphic intergrowths of perthite and quartz, 'clevelandite' feldspar, and large muscovite blades, with accessory topaz and beryl. The large cavity mentioned above was associated with a coarsening of the vein minerals, and was located where the orientation of the pegmatite changed from a steep to gentle dip.

Bawpadan: This famous mining area follows a layer of ruby-bearing marble for more than 1 km. The ruby-mineralized unit, called the 'Marble Arc' by Themelis (2008), extends more than 15 km east of Mogok town. As for many ruby mines in Mogok, the surface is divided into mining claims measuring 200×200 ft (61×61 m). The claims are assigned at auction, and a single company can obtain multiple claims. The mine we visited had been greatly improved in the past few years, with tunnels providing access for large dump trucks. Here the ruby-bearing layer had a thickness of ~1–4 m, and it was still productive where it was currently being mined at a depth of more than 200 m below the surface.

Kodoke-tat: Located at the western termination of the Marble Arc, this mining area follows about 1.5 km of the

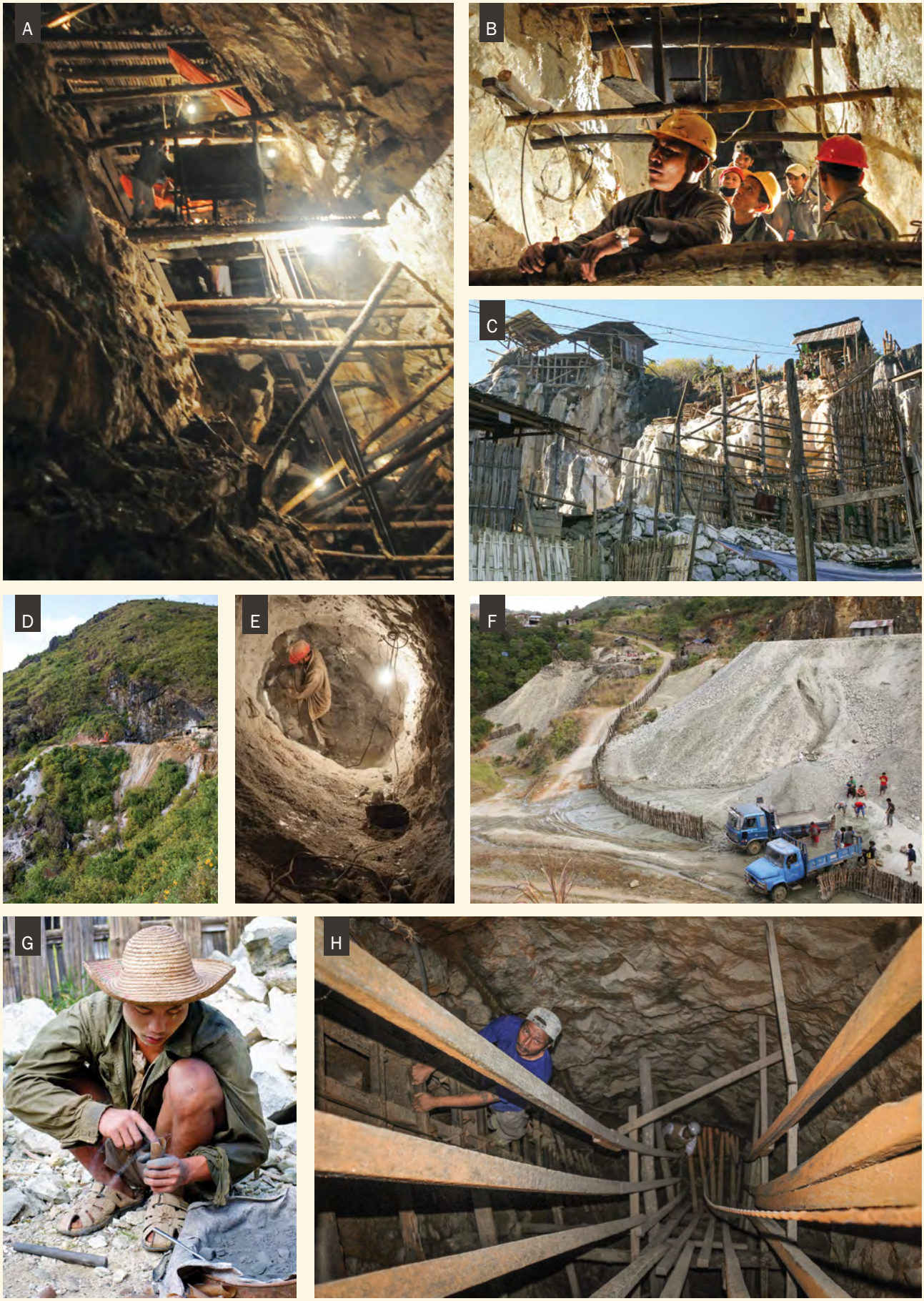

(A) A complex network of timbers, scaffolding and cables is seen here at Kodoke-tat, at about 200 m depth. (B) Local miners pause at the 380 m level of Kodoke-tat. (C) Winches are perched on top of marble outcrops at Kodoke-tat. (D) This old mining operation at Dattaw is being reopened. (E) A miner looks for rubies in a tunnel at Dattaw. (F) Large piles of tailings mark the location of peridot mines at Pyaunggaung. (G) A miner makes explosive charges at Pyaunggaung. (H) A wooden chute is used to remove mined material from the shaft at a peridot mine in Pyaunggaung. Photos by M. Lorenzoni (A, B, E, G and H) and F. Pezotta (C, D and F).

ruby-bearing layer. The deposit has been mined in an enormous trench excavated along the near-vertical ruby-mineralized band. The trench is interrupted by wooden barriers representing the limits of the mining claims assigned to different companies. Down-dip below the trench are subvertical interconnected galleries that have been excavated to a depth exceeding 400 m. The workings are supported by a few rock pillars and by thousands of timbers. Wooden ladders with small landings are attached to the marble walls to allow access to the bottom of the mine. We saw complex systems of ropes and winches that were used to bring the excavated marble to the surface, where it was routed to crushing and washing machines. The rubies were hand-picked from the washed and crushed marble. The marble tailings were then dumped into a publically accessible area where local people (mostly women and children) tried their luck in finding small fragments of ruby.

A single mine at Kodoke-tat can have around 200–300 miners, with two groups of workers allowing 24 hours of activity. The total number of miners at Kodoke-tat, in both the trench and underground workings, was around 6,000 at the time of our visit. At least as many people were working at the surface, making this one of the largest mining operations in the world for a primary coloured gemstone deposit.

Dattaw: This mining area is located north-west of Mogok. Dattaw hill is composed of exceptionally coarse-grained calcite marble that contains several ruby-bearing bands. Tunnels have been driven along these bands, and also follow residual

(A) A peridot miner rests next to buckets containing powdered rock and rolls of explosives. (B) This pendant containing a large faceted peridot gemstone was seen in Mogok. (C) Miners excavate gem-bearing soil at Pyant-Gyi, a source of high-quality red spinel. (D) Women search for gems at Pyant-Gyi. (E) Residual deposits are mined from weathered karst in this open pit at Htin-Shu-Myaing. Photos by M. Lorenzoni (A–D) and F. Pezzotta (E).

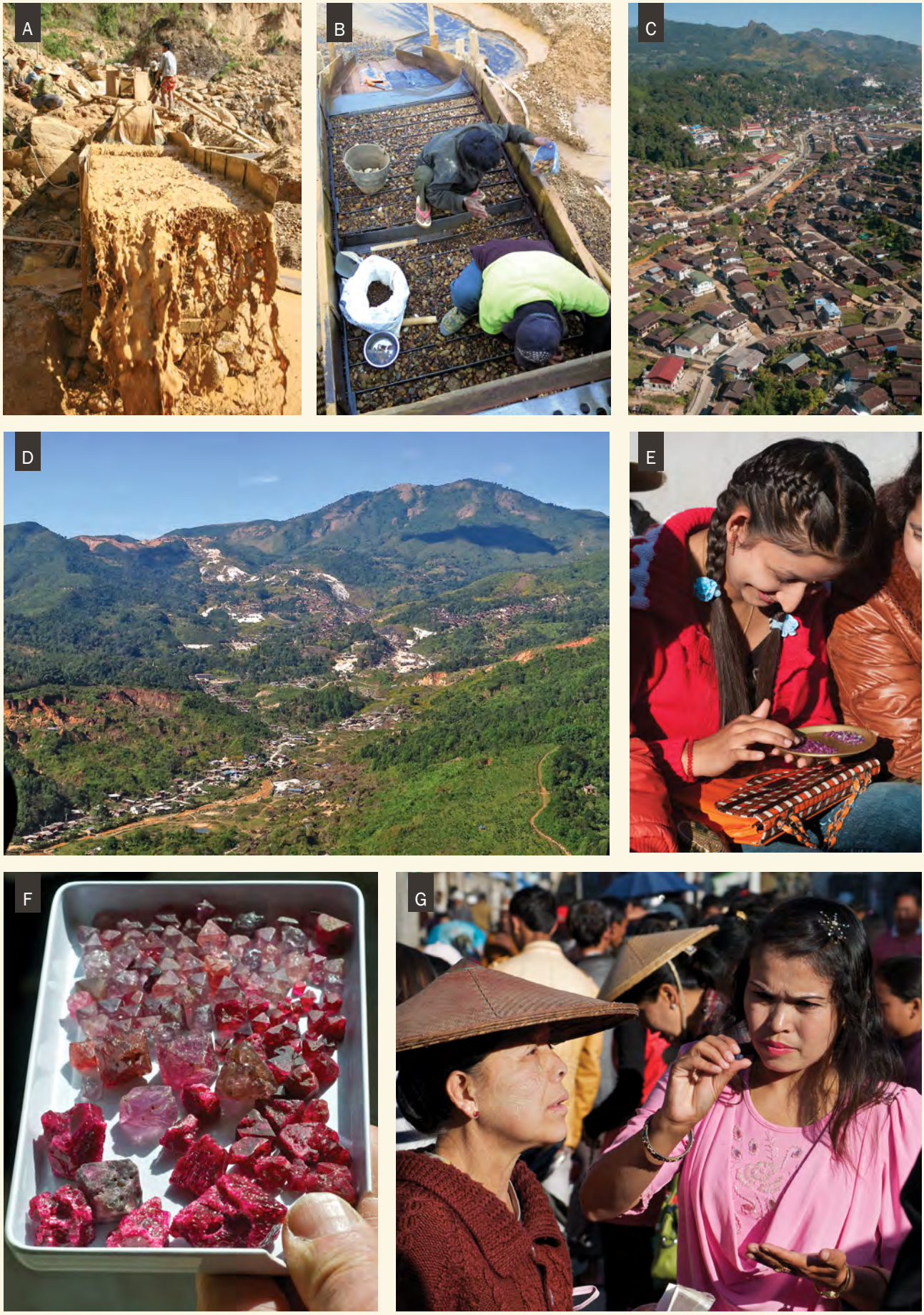

(A) Miners operate a small washing plant at Htin-Shu-Myaing. (B) At the end of the day, gems are hand-picked from the jig at Bernardmyo. (C) This view from a helicopter shows a portion of the Mogok valley. (D) The Kodoke-tat mine is visible on the left skyline in this aerial photo. (E) A merchant examines rough rubies in the Mogok market. (F) These spinel crystals were presented at the home of a local dealer. (G) A woman examines a rough blue gem in the busy Mogok gem market. Photos by F. Pezzotta (A), F. Barlocher (B and D) and M. Lorenzoni (C, E and F).

A Mogok dealer wearing a ring containing a locally mined sapphire and ruby presents a large ruby crystal. Photo by M. Lorenzoni.

deposits concentrated at the bottom of naturally occurring caves and karst formations. Most of the mines were recently assigned to new companies from Hpakan (the jadeite area located in northern Myanmar). During our visit, two major mining operations were under development. One was located halfway up the hill, with plans to restore and partially mechanize the old large underground workings. The other was situated at the bottom of the hill, where a vast area was apparently being prepared for open-pit mining by numerous dump trucks and excavators. In addition, small underground mines have begun in the last two years at various elevations on the hill.

Pyaunggaung: Deposits in this area are famous for producing magnificent peridot crystals from dunite host rock. We visited the Panlin-Pyaunggaung F7/8 mine, the largest in the area. The dunite was rather fine-grained and compact, but it locally contained coarse-grained pods and veinlets that sometimes host gem-quality peridot. We observed at least two such pods, with a diameter up to ~30 cm, that were filled with talc and what appeared to be enstatite, amphibole and phlogopite, together with rounded crystals of gem-quality peridot up to 2 cm in diameter. During the past year, this mine produced several kilograms of high-quality peridot gem rough, including some crystals approaching 100 g.

We also visited several alluvial mines and residual karst deposits in the Mogok area, such as Hta-Yan-Sho and Pyant-Gyi (located west of town), and Htin-Shu-Myaing, Bernardmyo and Panlin-Injauk (located north of Mogok). All these mines typically produce a variety of gems. Some rather large-scale mechanized operations have been developed in these areas.

While we were in Mogok, an eminent Burmese politician arrived by helicopter and Barlocher was able to arrange a flight for our group over the town and the nearby mines, allowing a spectacular panoramic view of the area.

Despite the huge amount of mining activity in the area, we were surprised to find that rough and cut stones offered in the local markets were rather scarce and of low quality (with the possible exception of peridot). Prices of the few good cut stones were typically high. One possible reason for the lack of gems being offered is that most of the mine owners are storing their production as an investment for the future.

We departed Mogok on a new paved road to Pyin Oo Lwin (formerly Maymyo) and then Mandalay; this route took nearly six hours. The road passed close to Mong Long, which is famous for producing coloured tourmaline from secondary deposits. Unfortunately, this area was inaccessible due to a resurgence in the activity of rebels belonging to the Shan ethnic group.

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Mines and Markets of Mogok, Myanmar

December 2013

*Emmanuel Fritsch**

This author visited the Mogok area with Henry Ho (Jewelry Trade Center and Asian Institute of Gemological Sciences, Bangkok, Thailand) and two of his associates, Ho Yu Low and Win Aung. We flew from Bangkok to Mandalay, where we met with 'Jordan' Aung Naing, a Mogok miner who was our guide. We then drove to the Mogok area, an approximately six-hour trip, with about four of those spent on very windy roads. From 10–15 December we visited mines and the two local markets: the morning 'crystal' market and the afternoon gem market.

We were told that about 100 'billionaires' live in the Mogok valley. This may explain why you can find excellent bottles of Bordeaux wine for sale (e.g. Pauillac vintage 2002 for about US$45), but there is no heating available in the hotel rooms! With an estimated 1,200–1,500 gem mines, and innumerable shrines, the Mogok area exhibits something seen nowhere else in the world: wherever you turn, you see either a mine or a stupa (Buddhist shrine).

Ball Lone Gyi: Located approximately 10 km west of Mogok, this ruby deposit is marked by a large white scar on a hillside above Ball Lone Gyi village. A portion of the village actually had to be moved so that mining could take place. Piles of crushed marble from the mine were evident throughout the village, where the material had been processed for gems. It was not difficult to find well-recrystallized greyish blue calcite specimens with a bright red ruby spot. The primary deposit was being worked by mechanized equipment, but the most visible activity was a crowd of locals looking through the crushed rock. They used metal blades (as seen almost everywhere in the Mogok area) to sort through the centimetre-size pieces of marble in search of ruby and other gems.

We purchased on-site a large number of small ruby crystals of excellent colour. The euhedral crystals were mostly bipyramids up to 1 cm in their longest dimension, with an almost prismatic appearance. A smaller number of blue sapphires were offered. Although they were larger sized (up to ~3 cm), they were generally translucent at best. Polished surfaces of these crystals showed typical pseudohexagonal growth patterns highlighted by whitish silk. Also available was zircon, although small and of greyish colour. Unidentified green and black crystals were shown to us as well.

Many karst outcrops in the Mogok area are topped with a golden stupa. This one (~1 m tall) is located near Pyaunggaung.

* All photos by the author.

BALL LONE GYI AREA

(A) Locals sort through bags of crushed and washed marble, looking for gems. (B) Women in traditional straw hats peddle rough gems. The white tailings pile in the background marks the location of the mine. (C) Ruby and sapphire are offered for sale on a traditional round brass tray.

Yadana Shin: Located on top of a hill, this highly mechanized operation was active both underground (in a small shaft) and on the surface (in an open pit). As we often saw in the Mogok region, the excavators were large, numerous, of top brand and appeared quite new. This gives an indication of the financial backing behind such ventures. The treatment plant was most impressive. The mined material was first routed through a large screen (mesh size ~10 cm) and then passed into a concrete holding area where four people used water jets to wash everything into a large triple jig. The concentrate was poured onto a conveyer belt and hand-picked for ruby, red spinel, moonstone and other gems. The oversize and rejected material was passed through a crusher, washed, and then delivered to four workers who sorted through it with metal blades. The tailings were then deposited down the hill in a spectacular stream of muddy debris, where they were processed further by small groups of local people.

Shunt Pann (Shon-Ban-Lay) Mine: At this large open-pit mine owned by 'James' Bhone Myint Aung, the miners extract gem gravel, or *byon*, from the bottom of ancient underground river and cave deposits in the weathered karst. The marble landscape exhibits typical karst relief, with subsurface depressions that have captured and accumulated accessory minerals—including gems—concentrated by erosion.

The byon was excavated, stockpiled and then processed with hydraulic washing. The resulting slurry was pumped into a large jig. The concentrate was then sorted further by hand. The mud leaving the jig was panned outside the limits of the mine by many locals, who commonly find small red spinel octahedra.

The mine mainly produces rubies ranging from light red to purple- red, some several centimetres in size. We also observed large non-gem spinel octahedra, tabular black tourmaline, brown zircon, light blue apatite, and quartz and feldspar. Some of the transparent quartz crystals had translucent central cores filled with tiny whitish fibres.

Dragon Ruby Mine: We were told that we were among the first foreigners to visit this famous mine, where a 128 ct piece of ruby was discovered in August 2013. The mine extends

YADANA SHIN MINE

(A) The mined material is washed in a large triple jig. (B) A relatively new excavator works a portion of the open pit. (C) Workers sort through material that has been recrushed and washed. (D) Material is hoisted from a small mine shaft. Explosive charges hang from the pole on the far left.

SHUNT PANN (SHON-BAN-LAY) MINE

(A) Stockpiled byon undergoes hydraulic washing. The inset shows Win Aung (left) and mine owner 'James' Bhone Myint Aung. (B) In this large open pit, gem gravels are mined from residual deposits within weathered karst. (C) These recently mined rubies measure up to ~3 cm in longest dimension. (D) The Shunt Pann mine forms the major brown scar at the centre of this view of Mogok. Compare this image to the lead photo of Federico Pezzotta's article on p. 55 of this issue.

(A) At the Dragon Ruby mine, buckets made from recycled tyres are stacked on boulders of marble awaiting processing. (B) After the mined material is crushed and washed at the Dragon Ruby mine, it is passed into these two sorting lines. Note the 'Safety First' sign, absent from most mines of the area. (C) Local people look for peridot and other gems in mine tailings near Pyaunggaung. (D) This man collected a handful of peridot crystals from the mine tailings.

over 100 m underground via three sequential vertical shafts. The ruby-bearing marble layer dips at about 45° and is up to 2 m thick. The marble is brought to the surface for crushing and hand sorting, and that morning we saw only half a dozen rubies, a few millimetres in size, come from the ore.

Compared to other mines we visited in the Mogok area, this one seemed to be operated with the most sophistication. They employ a mine geologist (U Tint Aung), and the mine's office contains a display of all the rocks found there, properly labelled. This display itself showed the diversity of Mogok's geology:

- a multiplicity of white marble varieties (not as coarsely recrystallized as the 'blue' marble that hosts the ruby mineralization) that locally contain spinel, graphite, phlogopite and sometimes dark brown titanite (up to 3 cm) or dark green diopside
- marble with lapis-lazuli, which deserves special mention, as magnificent pieces of lapis have been unearthed in this area (and are quite unexpected next to ruby)
- garnet-biotite gneiss
- skarn (i.e. formed by the reaction between granite and marble)
- black phlogopitite (more familiar at an emerald deposit than next to a ruby mine)

Also found in the mine area are huge colourless scapolite

crystals, with one over 10 cm across that was on display. Some broken scapolite pieces showed an attractive, fairly dark pink colour, but were not gemmy.

Peridot Deposits: In the Pyaunggaung area, next to the main peridot mine (Panlin-Pyaunggaung F7/8) are several small ones consisting of a single shaft or small incline. There was little activity at these small mines, with no significant finds in over a year. We visited locals working the tailings of the small mines, and they were finding well-formed crystals of peridot up to 1 cm in size within small talc-lined 'pockets'. We were also shown a large piece of brown transparent rough material, up to 20 cm long, that was probably an amphibole. In the tailings we observed pieces of what they called agate, but they were actually veins of common opal.

Local Markets: Almost every afternoon around 3:00, the Mogok gem market opens. Upon arriving, we were impressed by the perfect, almost crystalline organization of the numerous motorbikes. Inside, under large umbrellas, customers sit at tables and wait for dealers to offer gems. We were presented mostly ruby, sapphire and spinel, but also some peridot and zircon. We also saw a fine yellow star sapphire, which is not a common sight anywhere. Attractive large crystals, mostly corundum, were also offered for sale. However the prices seemed well above market value. Food was often offered on the various tables, a pleasant testimony to the Burmese hospitality toward foreigners and potential customers. This author's favourites were Mogok fried chicken, clementine oranges and papayas.

MOGOK GEM MARKETS

(A) At the afternoon gem market, trading occurs under umbrellas at tables where food such as clementine oranges are offered to potential buyers. (B) These large red spinels were available at the gem market. (C) Also seen was this unusual yellow star sapphire displaying sharp asterism. (D) A variety of rough material was offered at the Mogok morning crystal market, from river pebbles to lower-quality sapphire and ruby, feldspar, quartz and even black tektites.

Another attraction was the so-called 'crystal market', which takes place early in the morning. On both sides of the street, gem-selling women (recognizable by their straw hats or woolly bonnets) offered small treasures on brass plates or simply laid out on white bed sheets. They had everything from river pebbles to modest faceted gems. Ruby and sapphire of lower quality were quite common, as was red spinel. Some of the parcels looked like little more than gravel. Feldspar rough was cheap, as were local black tektites, some reaching well over 20 cm. Fine hackmanite and deep violetish blue lapis could be found as well. There was a variety of unusual rocks and ornamental stones (e.g. cabochons consisting of graphic intergrowths of feldspar and quartz mined from local pegmatite). For the more bizarre samples, the sellers were not always certain of their identity, leading to animated discussions (provided one speaks Burmese). We saw little evidence of any imitations or synthetics.

Other Attractions: Just above town, in a beautiful, luxuriant setting, is the former home of famed gemmologist A.C.D. Pain. This wooden structure has been abandoned for years but was in the process of being restored, with the goal of turning this historical building into a gem museum.

One of the most spectacular monuments in the Mogok area is the Kyauk Pyat That temple, perched on a weathered black karst outcrop. From the top of the temple (accessible only to men) there is a wonderful view above the village of two old mines in which painite was found. It is said that the sacred ground just around the temple hides some of the best blue sapphires of the Mogok gem tract. This explains why, despite the religious constraints on mining in this area, local people sometimes dig at night in search of treasure. A few hundred metres down the road, just outside the limit of the sacred ground, we saw three locals removing byon from the weathered karst and washing it with water.

Although the Mogok area has been mined for centuries, numerous holes are opened every week in search of rich gem gravel still hidden in the thousands of cubic kilometres of unexplored weathered karst.

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Crowning a karst outcrop, the Kyauk Pyat That temple offers a view of nearby painite occurrences, and reportedly hosts a blue sapphire deposit on its sacred ground.

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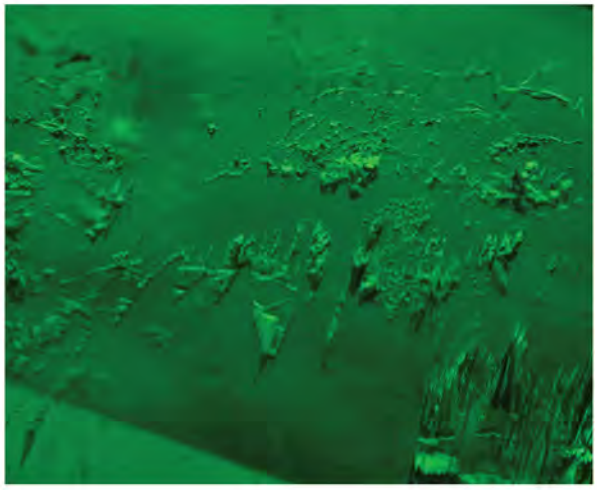

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The Journal of Gemmology has published many ground-breaking and thought-provoking articles over the years. We thought it would be interesting to reprint some of the best which show us what gemmology was like yesteryear and how in some cases it has barely changed. This article demonstrates the historical importance of visualizing pearl structures to help determine their natural vs. cultured origin. A comparison between the X-radiographs in this article and those shown, for example, in the Gem Notes section of this issue (pp. 13–15) clearly illustrates the advancements in technology for imaging pearls, and the need for a highly trained gemmologist to interpret such images.

SOME UNUSUAL STRUCTURES in PEARLS and CULTURED PEARLS*

By ROBERT WEBSTER FGA

MODERN techniques employing the revealing eye of the X-ray beam have opened up a new era in pearl testing, and during the past decade many peculiar structures in pearls have been observed by X-ray photography, some of which may well be of interest to readers of the *Journal of Gemmology*.

It may be an advantage to preface these notes with a short explanation of the principles of direct X-radiography. Quite soon after Röntgen made his classic discovery of X-rays it was observed that the degree of transparency of a substance to the rays was, broadly speaking, in inverse ratio to the atomic density of the substance. Therefore, a body having a structure made up of different substances may show different intensities of shadow to rays and thus so affects a photographic film, or a fluorescent screen, as to make the structures visible.

From the foregoing it will quite easily be understood that the structures of the animal frame will be readily revealed by the density of shadow given by the bones, containing the atoms of calcium (atomic weight 40) and phosphorus (atomic weight 30), as against that of the flesh which is made up of the light atoms, carbon, nitrogen, oxygen and hydrogen (with atomic weights of 12, 14, 16, and 1 respectively). This is illustrated by the radiograph of part of a human hand. Fig. 1.

Fig. 1. X-ray picture of a human hand showing the greater opacity of the bones to the rays than is the case with the flesh.

The radiography of pearls is based upon the same principle of differential X-ray transparency, but owing to the very fine structures usually involved, special techniques are necessary. Gemmologists know that a genuine pearl consists of a mineral part, calcium carbonate ($CaCO_3$), usually in the form of pseudo-hexagonal twinned crystallites of aragonite arranged in concentric layers with their vertical axes radial to the centre, cemented with an

* Reprinted from *The Journal of Gemmology, Vol. 4, No. 8, October 1954, 325–334.*

Fig. 2. Radiograph of a number of genuine pearls; some of which show the "tree ring" effect.

organic substance called conchiolin. Therefore the analogy of bone and flesh again becomes evident. The conchiolin, however, need not be sufficiently concentrated to show up boldly like the picture of flesh and bone. It is much more likely to show up as fine line structures where the organic matter has been relatively more thickly deposited between the layers of the crystallites. The X-ray picture may then show black lines as arcs or even complete circles, the latter producing a "tree ring" effect. Most oriental pearls will show very little or nothing at all, although a conchiolin-rich centre is sometimes seen and indicates a natural pearl. Some of the structures seen in natural pearl are illustrated in Figure 2, which is a radiograph of some pearls showing much structure, an effect which is not often seen.

Fig. 3. Radiograph of cultured pearls showing the bead nucleus outlined by the conchiolin layer (white in this positive print but would show dark in the negative). One pearl appears to have had a cultured pearl used as the nucleus.

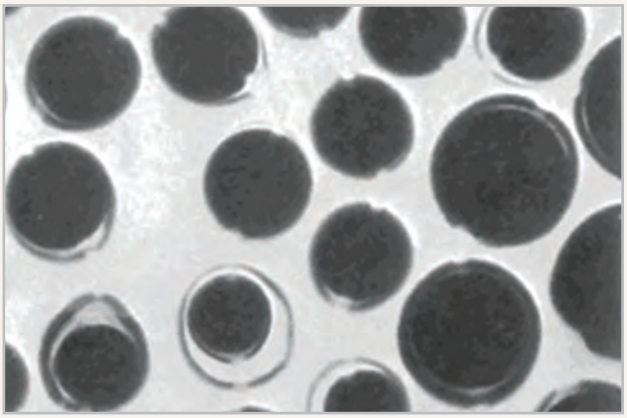

The finer structures seen in the X-ray photographs of genuine pearls rarely bear reproduction for illustrations. In every case of identification it is the film that is studied and even then must be examined closely in order to discern these fine structures which indicate the natural origin of the pearl. It must be mentioned at this stage that all the illustrations are positive prints, and are also (except Figure 1) enlargements of the original film. Thus the white parts in the illustration will be black in the original negative—the blackening showing where the beam has been more easily able to penetrate. That is where the conchiolin patches lie.

In the case of cultured pearls with their relatively large mother-of-pearl nucleus, the bead centre often shows a slightly greater opacity to X-rays than the outer nacreous layer, and, shows no structure, except, when the position of the straight layers is parallel to the X-ray beam, when some differential absorption of the beam produces a weak but distinct banded appearance to the opacity of the bead nucleus.

What is usual in cultured pearls is to find that the bead is surrounded by a relatively thick layer of conchiolin. It is as though the oyster objected to the job of coating a large insertion and secreted conchiolin first and then completed the surface with pearly nacre. Figure 3 shows this effect well, but many cultured pearls show only a fine line encircling the bead—or sometimes the nature of the pearl may be seen only by the slight difference in the transradiability of the nucleus and the outer nacre. Often, especially with baroque pearls, the conchiolin deposit is considerable and irregularly arranged, an effect seen in some of the pearls shown in Figure 10. This is true also in the case of cultured drop-shaped pearls, which usually owe their shape to a patch of conchiolin producing the "pip" at one end (Figure 4).

It is not, however, the intention here to discuss the techniques of pearl X-radiography, but merely to illustrate some of the more unusual structures met with in the course of routine testing.

In general the bead nucleus inserted into the Japanese pearl oyster *(Pinctada martensi)* is a spherical bead, but this need not be so, and some cultured pearls may show nuclei of different shapes. These

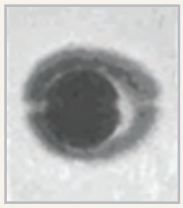

Fig. 4. Radiograph of a drop-shaped cultured pearl showing an excess of conchiolin at one end thus producing the pear shape, the bead nucleus being spherical.

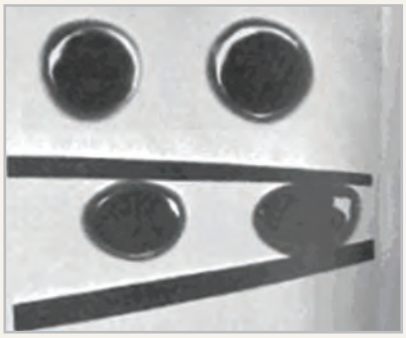

Fig. 5. Button-shaped cultured pearls with oval-shaped nuclei. Radiograph by Robert Crowningshield of New York.

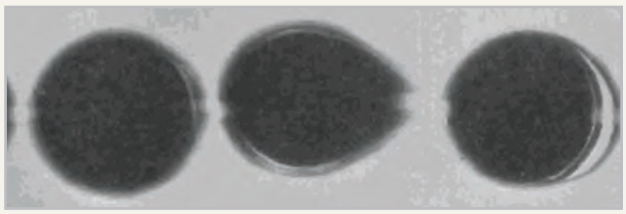

Fig. 6. A drop-shaped cultured pearl with a pear-shaped bead nucleus. The pearls on each side are normal cultured pearls with spherical beads.

are rare, for it is understood that the oyster does not take kindly to a nucleus of any shape other than spherical. It is said that nuclei of other shapes produce a greater mortality in the animals making the controlled production of pearls of other shapes than round to be less commercially practical, so that they are rarely used. That drop and button-shaped cultured pearls often occur adventitiously is well known, but these have round mother-of-pearl beads as cores and the resultant shape is due to vagaries of deposition of the conchiolin and nacre produced by the animal.

The writer has not happened upon an oval bead nucleus (used to produce button-shaped pearls) but is indebted to Mr Robert Crowningshield of the Gem Trade Laboratory at New York for the illustration of a pair of such pearls (Figure 5). Mr Crowningshield reports having met several pearls with such oval nuclei. Recently a case where the nucleus was pear-shaped was observed (Figure 6). Proof that this pearl was indeed a cultured pearl was made by the lauegram method. Laboratory records show that once before such a drop-shaped nucleus had been encountered, but in this case the direct picture did not show the outline at all well.

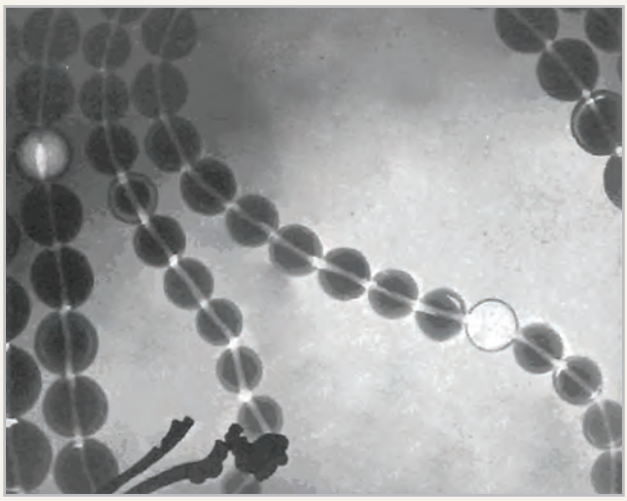

Fig. 7. The two cultured pearls with light coloured centres were found to have nuclei made of steatite (soapstone).

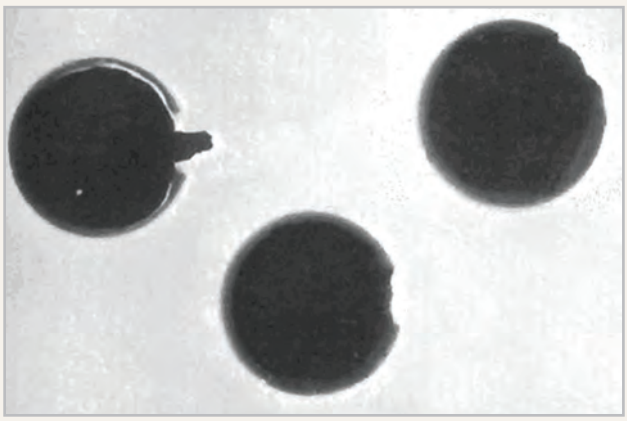

Fig. 8. Three cultured pearls which had their centres filled with cement.

Several other cases of unusual nuclei in cultured pearls have been shown by direct X-radiography. Particularly interesting are the two pearls shown with white centres (black on the film) in the illustration of part of a cultured pearl necklet in Figure 7. As permission was given for these pearls to be removed and examined the nature of the nucleus could be determined. They were found to be banded steatite (soapstone). This effect has been seen since, a necklet subsequently tested showing a similar transparent-centred lone pearl. No opportunity was given to test this bead, which may even be one with a plastic core, it not being unreasonable to suppose that such a type of core could have been tried out experimentally.

Figure 8 shows three cultured pearls—at least they had nacreous skins—in which the inside was filled with some form of cement. Figure 9 shows three different views of a cultured pearl with

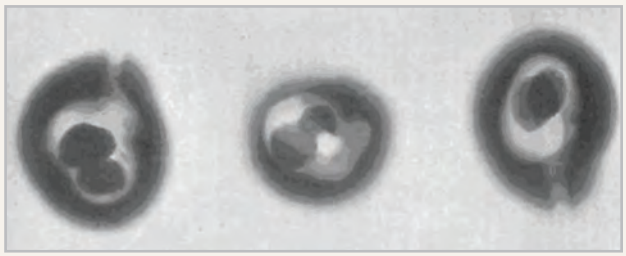

Fig. 9. A cultured pearl with "twin" nuclei. The pearl has been radiographed in three different directions.

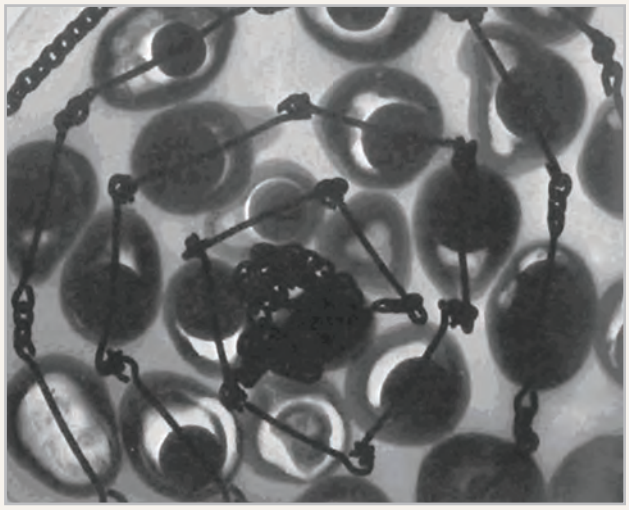

Fig. 10. Radiograph of a very baroque necklet showing some pearls without nuclei. These pearls are probably from the fresh water pearl clam (Hyriopsis schlegeli) *of Japan. The nucleated pearls may probably be also from the same animal.*

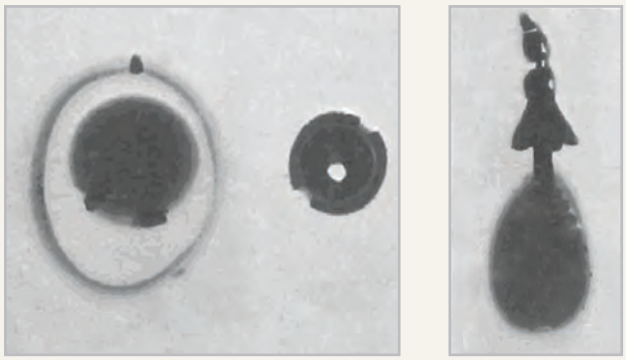

Fig. 11 [left]. Cultured pearls in which the bead nucleus had become loose and had rotated.
Fig. 12 [right]. A genuine drop pearl with secondary drilling filled up with several seed pearls.

Fig. 13. One of this pair of pearls was seen to be clearly genuine from the negative. The other seemed to be just as clearly cultured. Both pearls were found to be natural by the lauegram method.

irregular "twin" nuclei. The mate of this pearl was a perfectly good baroque cultured pearl with spherical nucleus.

The necklet illustrated in Figure 10 shows various types of baroque pearls including some without a nucleus. These latter are thought to be some experimental non-nucleated pearls cultured from the freshwater pearl clam *(Hyriopsis schlegeli)* which lives at the south-eastern edge of the Biwa-Ko in Shiga Prefecture, Japan. The other pearls showing bead nuclei may also be from the same animal, for it is known that experiments with nucleated pearls were also carried out using the *Hyriopsis schlegeli*.

It is often noticed that the bead nucleus of a cultured pearl becomes loose and is able to rotate within the nacreous shell. Figure 11 shows two examples of this effect, in one of which metal pins are evident.

Figure 12 shows a genuine drop-shaped pearl which has been "Chinese drilled", or drilled to relieve stress in a cracked pearl. In this case the secondary drilling has been filled up with four or five seed pearls.

Finally, reference must be made to the danger of direct X-radiography as a testing tool. The method requires experience in mastering the techniques necessary to produce a good negative but considerably more in the interpretation of the negative itself. Figure 13 illustrates this point well, for on inspection of the negative it seemed clear that one of the pearls was genuine but that the other was cultured. The arcs and rings in the one pearl (much more clearly seen in the negative than in the positive reproduction) left no doubt as to its genuineness. The other pearl, however, showed only the one ring and there seemed little doubt that it was cultured. Lauegrams of the pearls, however, showed *both* to be natural pearls.

Conferences

IGE 2014 International Gemmological Congress and 16th FEEG Symposium

On 17–19 January, in Madrid, Spain, the IGE 2014 Congress was organized by the Spanish Gemmological Institute (Instituto Gemológico Español or IGE), and held together with the annual Symposium and Diploma Ceremony of the Federation for European Education in Gemmology (FEEG). More than 200 attendees from 16 countries took part in the event. Sixteen oral and four poster presentations were given, and nine workshops and demonstrations were held, covering a wide range of topics related to modern gemmology. All materials from the event, including extended abstracts of the presentations, can be downloaded at www.ige.org/congress2014.

Diamonds were covered in various presentations. **Juan Cózar** (IGE Gem Testing Lab, Madrid) and co-authors explained the use of a combination of advanced techniques—Raman and photoluminescence (PL) spectroscopy and the DiamondView—for the detection of colourless HPHT- and CVD-grown synthetic diamonds and HPHT-treated colourless diamonds. A comparison of PL spectra recorded at room temperature and at −180ºC confirmed the necessity of cryogenic testing when performing PL spectroscopy. In another presentation, **Cózar** (with **Anthony Cáceres**) provided colour grading data for hundreds of diamonds examined in his lab using a Sarin Colibri colorimeter, and compared these results to traditional visual grading with diamond master stones. The Colibri instrument showed variations of up to four colour grades from visual grading, especially in diamonds with non-typical colours. **Geoffrey Dominy** (Gemmologist FGA with Distinction, Canada) focused on the importance of the cut grade in diamond valuation, including the role of the cutter, the importance of yield, and how shape, clarity, colour, cut, optical phenomena and market considerations affect the overall value of a faceted diamond. (In a separate presentation, he also presented his new book titled *The Handbook of Gemmology,* which was reviewed on pages 252–253 of *The Journal of Gemmology,* Vol. 33, No. 7–8, 2013). **Dr Pilar Diago Diago** (Zaragoza University, Spain) provided an overview of the problem of 'conflict diamonds' in international trade, with a general explanation of the Kimberley Process and related international and European laws. **Igor Klepikov** (St. Petersburg State University, Russia) and co-authors presented a detailed spectroscopic study of diamonds from alluvial deposits of the north-eastern Siberian platform. Optical absorption, infrared, PL and electronic paramagnetic resonance spectroscopy were used to characterize nitrogen aggregates and crystal structure defects in 120 diamonds. The micromorphology of diamond crystals from the north-eastern Siberian platform was reported by **Nadezhda Erysheva** (St. Petersburg State University, Russia), who found a direct relationship between microrelief features and crystal habit. **G.F. Anastasenko** (St. Petersburg State University, Russia) and co-authors studied the morphological characteristics of alluvial diamonds from the north-eastern Siberian Platform by scanning electron microscopy. The crystals were dominated by octahedral, dodecahedral and combined forms, with flat- and curve-sided shapes. **Anastasenko** and co-authors also described a diamond collection in the mineralogical museum of St. Petersburg State University consisting of more than 1,000 rough samples. The collection started in 1875 with the acquisition of diamonds first from Brazilian deposits and then from South Africa. After the discovery of diamonds in Yakutia (Siberia) in 1954, the museum obtained a large number from both primary and secondary deposits.

Among coloured stone presentations, **Miguel Ángel Pellicer García** and **Dr Cinta Osácar Soriano** (Zaragoza University, Spain) discussed the challenges of the geographic origin determination of coloured stones (Figure 1), with some examples from published studies on emerald, ruby, sapphire and garnet. The authors emphasized the importance of using comparison samples of known origin in such studies, and

Figure 1: The IGE 2014 Congress and 16th FEEG Symposium were held at the Spanish Gemmological Institute in Madrid. This photo was taken on the first day of the Congress during a presentation by Miguel Ángel Pellicer García and Dr Cinta Osácar Soriano. Courtesy of IGE.

also the necessity of establishing the range of property variations within each deposit. **Dr Klaus Schollenbruch** (DGemG, Idar Oberstein, Germany) summarized glass filling treatments for ruby and sapphire, including the processes used, diagnostic features and stability issues for the treated stones. **José Antonio Espí** (Madrid School of Mines, Spain) explained the geological setting, formation process and mining of larimar (blue pectolite) deposits in the Dominican Republic. He showed spectacular photos of larimar substituting for ancient fruit and tree trunks. He found greater amounts of vanadium and copper in larimar samples with a deeper blue coloration. **Espí** also described the origin and geology of amber deposits in the Dominican Republic. The amber is hosted by two major geographic domains: the Cordillera Septentrional (or Northern Range, where primary deposition sites occurred in clay-rich host rocks) and Cordillera Oriental (or Eastern Range, where remobilization and concentration of amber occurred in alluvial paleochannels with an abundance of organic material). Texture and sometimes colour are related to the specific conditions of amber formation. **Oscar R. Montoro** (Madrid Complutense University, Spain) and co-authors provided evidence of chemical processes that occurred during the formation of fossil resins, by examining the reactivity of pure communic acids and comparing their FTIR and Raman spectra to those of fossil resins. The results may help differentiate amber from other natural and synthetic resins.

Three presentations covered evolving technology. **Helena Calvo del Castillo** (University of Liège and Belgian Gemmological Association, Belgium) presented a review of a wide range of advanced spectroscopic techniques used in gemmology, their principles, advantages and limitations, as well as examples of their use to resolve contemporary problems. **Mikko Åström** and **Alberto Scarani** (M&A Gemological Instruments, Finland and Italy) described their GemmoRamanPL-532SG instrument, a scientific grade Raman-PL spectrometer for gemmological laboratories. They also explained some applications of this instrument beyond standard gem identification, such as identifying jade and spinel treatments, characterizing emerald, determining the colour origin of cultured freshwater pearls and coral, discriminating Imperial topaz according to chromium content and quickly separating type I from type II diamonds. **Menahem Sevdermish** and **Guy Borenstein** (GemeWizard, Ramat Gan, Israel) presented the latest developments of GemeWizard, a digital colour communication and analysis system for coloured gemstones and fancy-colour diamonds. The system allows users to describe, grade, price and communicate the colour of gems. A digital colour-based online gem marketplace, GemeShare, is used to perform colour analysis on a vast scale, and a search engine

enables the user to search for a stone of a specific colour.

In other presentations, **Gonzalo Moreno Díaz-Calderón** (IGE, Madrid) explained the Virtual Gemmological Laboratory, an online educational tool from IGE designed for distance learning of gemmology. Students are taught how to use basic gemmological equipment and even virtually analyse gems using a polariscope, refractometer, spectroscope, hydrostatic balance and microscope. **Dr Pilar Diago Diago** (Zaragoza University, Spain) and **Dr Cinta Osácar Soriano** provided an example of cooperative and interdisciplinary education through seminars on the legal aspects of gemmology that are attended by students of both gemmology and law, as well as professionals from the jewellery sector. **Viktor Tuzlukov** (College of Gem Cutting, Moscow, Russia) provided his vision of lapidary work as an artistic creation process. He showed how his designs can evoke symbols in the pattern of their facets.

The following **workshops and demonstrations** were held during the Congress:

- Raman and photoluminescence spectroscopy in the gemmological laboratory, by Mikko Angstrom and Alberto Scarani, M&A Gemological Instruments, GemmoRaman.com
- GemRam Raman gem identification system, by Ignacio Sánchez-Ferrer Robles, Microbeam S.A.
- Digital grading and pricing of coloured stones and fancy-colour diamonds with the GemeWizard system, by Menahem Sevdermish and Guy Borenstein, Gemewizard.com
- Detection of synthetic diamonds using the DiamondView, by Juan Cózar and Anthony Cáceres, IGE Gem Testing Laboratory
- OGI Scanox Planner HD, a device for the digital analysis of diamond cut quality, by Juan Cózar and Anthony Cáceres, IGE Gem Testing Laboratory
- Inclusion photomicrography using MacroRail products and software, by Óscar Fernández Arcís, MacroRail.com
- Automated 3D/360º photography applied to gems and jewellery, by Óscar Fernández Arcís, MacroRail.com
- Advanced methods for the design and manufacture of new gem cuts: GemCad, GemRay and DiamCalc, by Egor Gavrilenko, IGE
- Analysis of jewellery and precious metals with X-ray fluorescence, by Joan Pujol, Fischer Instruments S.A.

The FEEG Diploma Ceremony and the IV Antonio Negueruela Jewelry Design Awards Ceremony took place during the last evening of the Congress.

Egor Gavrilenko (info@ige.org)
Spanish Gemmological Institute
Madrid, Spain

AGA Tucson Conference

The 2014 Accredited Gemologists Association Conference in Tucson, Arizona, USA, took place 5 February, with the theme 'Gems: Fabulous, Fake, and Nefarious!' **Donna Hawrelko** chaired the conference and was also warmly recognized for her leadership of AGA at this conclusion of her term as president.

Olivier Segura (Laboratoire Français de Gemmologie, Paris, France) summarized the identification criteria for natural, treated and cultured pearls. Treatments may be revealed by observation of dye concentrations or by chemical analysis and Raman spectroscopy. General indications of a cultured origin may be provided by observations of the drill hole (if present) and surface characteristics. For confirmation of natural or cultured origin, it is necessary to view the internal structures with X-radiography or X-ray computed tomography, and some challenging case studies were described (for one example, see pages 14–15 of the Gem Notes section).

Thomas Hainschwang (GGTL Gemlab–Gemtechlab Laboratory, Principality of Liechtenstein) delivered a presentation for **Franck Notari** on the cause of colour and potential radiation hazards of green diamonds. He indicated that

the only samples that can be reliably ascertained as natural colour are those mined during the early part of the 20th century (mostly from Brazil) that have been kept in museums since that time. Extremely high residual radioactivity may be shown by diamonds irradiated by direct contact with radium salts, particularly those with residues that are trapped in open cracks and cavities. By contrast, diamonds that have been treated by modern irradiation methods (e.g. with electrons) pose no radiation risk to the end user.

Hainschwang then reviewed luminescence phenomena in diamond and their importance in gem testing. The colour and distribution of luminescence can be a useful indicator for the origin of a diamond's colour, but extensive experience is needed. Similar luminescence colours may be caused by a variety of defects, so photoluminescence spectra are needed to assess and measure defects at extremely low concentrations when determining the origin of colour or whether a diamond is natural or synthetic.

Manfred Eickhorst (Eickhorst & Co., Hamburg, Germany) explored applications of LED lighting in gemmology, including refractometer stands with built-in strong yellow LEDs, polariscopes with LEDs that provide diffuse lighting, and microscopes with intense illumination of a yellowish colour that mimics traditional incandescent lamps.

Craig Lynch (Somewhere In The Rainbow Collection) described the challenges of building a world-class gemstone and modern jewellery collection. In addition to the problem of finding available pieces due to their rarity, establishing a fair price for them can be difficult since there are so few top-end pieces for comparison.

Dr Lore Kiefert (Gübelin Gem Lab, Lucerne, Switzerland) documented the mining and gemmology of sapphires from Mogok, Myanmar. During a 2013 visit to the mines, she witnessed extensive sapphire mining activity, and she noted that some of the stones recently produced (which are of metamorphic origin) may be confused with sapphires of basaltic origin.

Shane McClure (Gemological Institute of America, Carlsbad, California, USA) examined the potential for the co-diffusion of multiple elements into sapphire. Relatively thick layers (up to 1 mm) of diffused blue colour due to Ti and Fe have been seen recently in both natural and synthetic sapphires, and the presence of surface-related concentrations of additional elements such as Mg, Ga, V and/or Be suggests that they may enhance the diffusion process.

Brendan M. Laurs

NAJA Conference in Tucson

The 41st Annual Winter ACE-It Education Conference organized by the National Association of Jewelry Appraisers took place in Tucson, Arizona, USA, on 2–3 February 2014. (Also, a preconference seminar on 1 February was given by **Dr Cigdem Lule**, titled 'Emerald Treatments and Pricing Workshop'.) NAJA executive director **Gail Brett Levine** introduced the conference and helped everything run smoothly. This author attended the talks described below, and additional presentations were also given by **Steve Begner** ('Southwestern Indian Silverwork and Jewelry—In The Eye of The Appraiser'), **Martin Fuller** ('The Many Faces of Value'), **Sindi Schloss** ('Exotic Organics in Jewelry'), **Patrick Coughlin** ('Discovering, Marketing and Branding a Gemstone') and **Arthur Skuratowicz** ('How Much is that Bauble in the Window?').

Edward Boehm (RareSource, Chattanooga, Tennessee, USA) presented useful techniques for assessing gem rough while on the go. He described using a loupe (and especially the darkfield loupe) to help identify rough material and determine its quality for cutting, and how a dichroscope is useful for separating spinel from sapphire and tourmaline from pezzottaite. To become proficient at using a loupe to observe inclusions, he suggested looking at several example stones with a microscope and then training your eye to see the same features with the loupe. He also emphasized the importance

Figure 2: This carved Mogul emerald is photographed to show its transparency, colour and the intricate carved patterns on its surface. Known as the Schettler Emerald, it weighs 87.64 ct and was probably used in the head ornament of a prince. Courtesy of the American Museum of Natural History, New York, USA; photo by Tino Hammid.

of learning the properties of gems, and how a collection of journals and the *Photoatlas* books are gemmological tools in themselves.

Tino Hammid (Tino Hammid Photography Inc., Los Angeles, California, USA) discussed gem photography while showing examples of spectacular images (e.g. Figure 2) to illustrate several points: (1) lighting defines an object, and the use of selective and subtle reflections helps to convey its shape; (2) shadows provide a sense of place, and reflections of the object below the stone add reality to the image; and (3) colour accuracy is critical, and using a ColorChecker card and a monitor calibrator are highly recommended.

Gary Bowersox (GeoVision Inc., Honolulu, Hawaii, USA) described his multiple trips over 42 years to Afghanistan for exploring mines, purchasing gem rough, and helping the local people through education and donations. He mentioned that access to the Panjshir Valley emerald deposits is much easier since a new road from Kabul to Khenj was constructed in 2013. However, reaching the original lapis lazuli mines at Sar-e-Sang in Badakhshan Province is much more difficult, as shown in a fascinating film clip that he screened for the audience.

Brendan M. Laurs

Gem-A Notices

GIFTS AND DONATIONS TO THE ASSOCIATION

The Association is most grateful to the following for their gifts and donations for research and teaching purposes:

Apache Gems, San Carlos, Arizona, USA (Warren Boyd and Charles Vargas), for two andradites and a chalcedony from San Carlos, Arizona.

Don H. Ariyaratna FGA DGA, London, for a copy of the 7th edition his book *Gems of Sri Lanka*.

Marcus McCallum FGA, London, for three rough Usambara-effect tourmalines.

William R. (Bobby) Mann GG, Temple Hills, Maryland, USA, for a copy of his book *Ivory Identification: A Photographic Companion*.

Guillermo Ortiz, Bogota, Colombia, for two 'trapiche' quartz tablets.

Mauro Pantò, The Beauty in the Rocks, Citta della Pieve, Italy, for an orange lizardite and a lizardite-included quartz.

Nalini Pattni, Anaheim, California, USA, for a rough garnet reportedly from Benin.

German Salazar, Bogota, Colombia, for a tablet of 'trapiche' quartz from Penas Blancas, Colombia.

Jason Williams FGA DGA, G.F. Williams & Co., London, for a large selection of coloured faceted cubic zirconias.

Monetary donations were gratefully received from:

Manon-Océane Bruyère FGA, Nouméa, New Caledonia

Caroline Maclachlan FGA DGA, Edinburgh

Maggie Yuk Ling Pun FGA, Richmond, British Columbia, Canada

Paul Siegel FGA, New York, USA

Tak Yi Yung FGA, Shau Kei Wan, Hong Kong

MEMBERSHIP

At a meeting of the Council of the Association held on 5 March 2014, the following were elected to membership:

Fellowship and Diamond Membership (FGA DGA)

Ferder, Edward, Lyndhurst, Hampshire
Leung, Jeannie, Kowloon, Hong Kong
Yu Ho Fai, Miranda, Sai Kung, Hong Kong

Fellowship (FGA)

Bailey, Kathryn, Aberdeen
Bosshard Schreckenberg, Astrid, Zurich, Switzerland
Bouts, Antonia, Amsterdam, The Netherlands
Buckley, Amanda, Auckland, New Zealand
Chandrasiri, Hemali, Colombo, Sri Lanka
Chong, Ronald R.K.K., Amsterdam, The Netherlands
Corbin, Marie-Hélène, Montreal, Quebec, Canada
Day, Helen, Walsall, West Midlands
Delor, Claude Pierre, Orléans, France
Fritsch, Emmanuel, Nantes, France
Fritz, Eric, Banner Elk, North Carolina, USA
Gautier, Isabelle, Bry-sur-Marne, France
Hammarqvist, Susanne E., Stockholm, Sweden
Homkrajae, Artitaya, Bangkok, Thailand
Howard, Naomi, Calgary, Alberta, Canada
Ijima, Kaori, Saitama-ken, Japan
Knochenhauer, Cecilia, Stockholm, Sweden
Lau Man Wa, Eukice, Mong Kok West, Hong Kong
McKenzie, Troy, Greenslopes, Queensland, Australia

Mendes, Isabella, Dagnall, Hertfordshire
Muyal, Jonathan Daniel, Bangkok, Thailand
Noble, Frances, Wendover, Buckinghamshire
Ostergaard, Marlon, Caloundra, Queensland, Australia
Qiu Yun, Conan, Zetland, New South Wales, Australia
Ranatunga, Gallage, Meetiyagoda, Sri Lanka
Saeseaw, Sudarat, Bangkok, Thailand
Siritheerakul, Piradee, Bangkok, Thailand
Steele, Sarah Caldwell, York, North Yorkshire
Suthiyuth, Ratima, Bangkok, Thailand
Walker, Megan G., Edinburgh
Watrelos, Céline, Joinville-e-Pont, France
Wijesekera, Maduni Champika, Kandy, Sri Lanka

Diamond Membership (DGA)

Brown, Debra, Great Sutton, Cheshire
Crowther, Lucy, London
Hancock, Elizabeth Ann, Leatherhead, Surrey
Horst, Kirsti, Trier, Germany
Ilich, Helen, Haymarket, New South Wales, Australia
Karlsson, Patrik, Lidingö, Sweden
Legros, Maria, London
Li Wenjie, Guangzhou, Guangdong, P.R. China
Rapaport, Martin, Las Vegas, Nevada, USA
Reimi, Olesja, Tallinn, Estonia
Tsang Wing Hang, Wong Tai Sin, Hong Kong

Associate Membership

Adejugbe, Murphy Opeyemi, Lagos, Nigeria
Berger, Claudia, Vienna, Austria
Brossmer, Teri, Glendora, California, USA
Dempsey, Michael, Golden, Colorado, USA
Groat, Lee A., Vancouver, British Columbia, Canada
Guanghai Shi, Beijing, P.R. China
Harlow, George, New York, USA
Hatzigeorgiou, Michael, Brighton-Le-Sands, New South Wales, Australia
Henn, Ulrich, Rheinland-Pfalz, Germany
Jain, Raj, London
Jones, Samuel, Newark, Nottinghamshire
Karampelas, Stefanos, Lucerne, Switzerland
Khanbhai, Saifudin, Arusha, Tanzania
Kimsey, Kristi, London
Larson, William, Fallbrook, California, USA
Laurs, Brendan, Encinitas, California, USA
McClure, Shane, Carlsbad, California, USA
Menon, Sreekumar, Cambridge
Middleton, Nick, Billingsley, Shropshire
Nielsen, Stig, Toftlund, Denmark
Oppenheim, Ruth, London
O'Sullivan, Shawn, New York, USA
O'Sullivan, Terry, Glenside, Pennsylvania, USA
Ozen, Fazil, Istanbul, Turkey
Pezzotta, Federico, Milan, Italy
Post, Jeffrey, Washington DC, USA
Revell, John, London
Rossman, George, Pasadena, California, USA
Roy, Ajit, North Little Rock, Arizona, USA
Saito, Mari, Tokyo, Japan
Santo, Valentina, London
Scherer, John, New York, USA
Spencer, Sally Jane, Didcot, Oxfordshire
Tay Thye Sun, Singapore
Turner, James, London
Turner, Stephen, Atlanta, Georgia, USA
Venturi, Anna, London
Welbourn, Chris, Waltham St Lawrence, Berkshire
Willems, Bert, Bayern, Germany

Transfers

Fellowship to Fellowship and Diamond Membership (FGA DGA)

Barrows, Michael James, Kidderminster, Worcestershire
Hardy, Sarah, Bryngwran, Isle of Anglesey
Hughes, Beata, Sutton Coldfield, West Midlands
Hunt, Glynis, Andover, Hampshire
Lally, Jo, Southampton, Hampshire
Riley, James H., Knutsford, Cheshire
Simon, Gowry Raji, Wolverhampton, West Midlands
Weyers, Stefanus, Bloemfontein, Free State, South Africa
Woodrow, Gillian, Wokingham, Berkshire

Diamond Membership to Fellowship and Diamond Membership (FGA DGA)

Ludlam, Louise, Birmingham, West Midlands

Associate Membership to Fellowship (FGA)

Bauer, Ronnie, Glen Iris, Victoria, Australia
Blake, Andrea Renae, Chevy Chase, Maryland, USA
Dishington, Megumi, Shizuoka-ken, Japan
Laurs, Brendan, Encinitas, California, USA
Rongy, Amandine, London
Street, Neil, Wilton, Connecticut, USA
Tay Thye Sun, Singapore

Associate Membership to Diamond Membership (DGA)

Bragg, Caitlin Louise, Bristol

New Media

The Fundamentals of Mining for Gemstones and Mineral Specimens

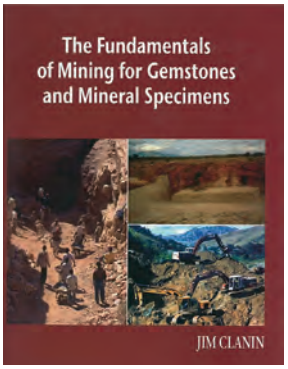

Jim Clanin, 2012. New England Historical Publications, Boston, Massachusetts, USA, 402 pages, illus., hardcover, www.jcmining.com, ISBN 978-0-615-50108-6. US$49.95.

This book covers fundamental knowledge for small-scale mining, covering aspects of geology, mineralogy, mining practices and marketing, as well as the all-important but readily forgotten aspects of local regulations, first aid and safety.

Following an introduction to gem mining, the author covers several topics from basic geology to how to map and understand the potential scope of a gem deposit. He describes the various types of mining tools available and the best way of investing in them, from hand tools to large equipment such as excavators. Also discussed is the proper way to use explosives so as not to damage and devalue gem material or specimens, as well as best practices for safely handling and storing explosives. Then the main types of mining are described, detailing the most cost-effective methods of extraction of gem material. The author proceeds to explain a number of different processes for cleaning and preparing mineral specimens for sale.

The next couple of chapters cover site management and logistics, and there is also a comprehensive first aid section detailing the potential injuries associated with mining and their appropriate treatment. This is followed by a section describing the author's experience with local customs and etiquette in the areas where he has worked. Such considerations are especially important when working in remote localities.

A very interesting part of the book is a section describing eight case studies showing how mining techniques are customized for different localities and mineral types. Some examples include open-pit mining for emeralds in Madagascar, alluvial deposits in Tanzania that produce a range of gems, ruby deposits in Kenya and underground mining for fluorite in northern England. Each case study reinforces the fundamentals discussed in the previous sections with real-life scenarios and whether the mining ventures were successful.

The book has colourful photography and several detailed annotated diagrams. Its only disappointments are the need for editing and the fragmented nature of the layout on some pages. Nevertheless, the author has managed to share his 35 years of hands-on mining experience in a clearly passionate way, and the book should therefore be inspiring and educational for any gem or mineral miner.

Davina Dryland BSc (Hons) FGA

A Geologist Speculates

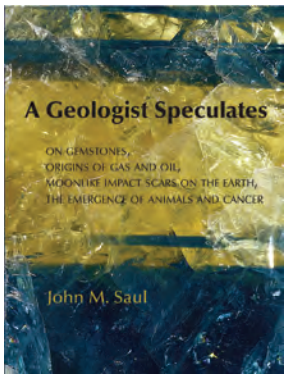

John M. Saul, 2014. Les 3 Colonnes, Paris, France, 149 pages, illus. in colour and black-and-white, paperback, ISBN 978-2-37081-004-5. €28.

This book's subtitle, 'On Gemstones, Origins of Gas and Oil, Moonlike Impact Scars on the Earth, the Emergence of Animals and Cancer' is, at first sight, a very disconnected series of topics. But a revealing comment on page 119 indicates the fundamental motivation of the author in light of a discussion with Professor Théodore Monod deep in Egypt's Western Desert. They explored the twin tasks of scientists in describing nature in all its

detail and of synthesizing these descriptions in the search for reasons and understanding. Monod was a prolific devotee of the former task while Saul made the case for periodic review and synthesis, and this book is the timely result of one such assessment.

Of immediate and absorbing interest for gemmologists is the first section in which the topics addressed include not only gem rarity but also other ways in which gems are peculiar and the important but infrequently tackled question of why they are so transparent. There is considerable analysis and discussion of metamorphism, pressure and temperature and the role of each in the genesis of gems, with copious notes, explanations and references augmenting the 30 pages of text and illustrations in this section. The marked concentration of beautiful gem minerals in only a few geographical locations is attributed to a pattern of continental drift and collision which brings into play much recent thinking on global tectonics and mineral age determination.

In my career as a geologist having mapped a number of new areas, I have often seen how easy it is to miss certain features of the rocks that one only appreciates with another look after seeing surrounding areas. I think Saul may be keenly aware of this aspect of scientific understanding as revealed in his comment (p. 94) '…once we had the idea in mind…'. The relative significance and connectedness of different features of gems is important to understand, and sections 2 and 3 of the book on deep carbon and impact scars go a long way to augment and clarify the ideas developed in the first gem section.

Section 2 summarizes evidence for the abiogenic origin of most deep carbon in the form of gas and oil; diamond is also briefly discussed in this context. Section 3 is the longest in the book. It deals in detail with ascribing to asteroid impacts a wide range of features on the earth's surface that are visible from space, and includes linking some of the plainly visible arcuate patterns with specific gem deposits in a most convincing way. Linkages are also made with hydrocarbons (Section 2) not only because they appear in these generally arcuate areas but also because they are sometimes found within inclusions in gems such as tanzanite.

While looking all the time for patterns, Saul repeatedly emphasizes the uniqueness of particular features of Earth history, which of course is very relevant to gem occurrences. On p. 87 he quotes Lyell's '…the present is key to the past…' (1833) and comments on the discussions this generated about uniformitarianism and catastrophism—with the ultimate general acceptance of the former. At first sight, Saul's emphasis on the uniqueness of features may not seem to fit comfortably within the uniformitarian framework, but Lyell's principle continues to have merit so long as 'key' is not misinterpreted to mean 'the same as'.

In Section 4 Saul first outlines six major gem deposits that lie along the circumference of a circular topographic feature about 300 km in diameter in Kenya/Tanzania, all within rocks that emit noticeable foul-smelling odours when cracked apart. The rest of the section then deals with the development of single- and multi-celled life, the ways they survive in dealing with oxygen and calcium toxicities, links with the Pan-African mountain-building events just before the explosion of life in Cambrian times, and the 'sudden' global availability of phosphorus. These developments and conditions enabled the first biominerals to form which in turn enabled shells (exoskeletons) and bones (endoskeletons) to form, with a few being preserved for posterity as fossils. This has particular relevance for gemmologists studying the origin of ivories and pearls. Regarding the latter, Saul also speculates about which factors might control secretion of calcite or aragonite.

The last section of the book is very short and highlights the relatively new situation where the principles and laws of physics, chemistry and biology, which controlled the development of Earth materials, have been joined by mental and historical parameters that have a great influence on human evolution. The elements of consciousness and desire are major factors in what we do and how we do it, and the discussion includes a number of pointers to a contemporaneous book by the author titled *The Tale Told in All Lands*. We are all, ultimately, stardust, and in that book astronomy is demonstrated to have had as great an influence on the mental activities of humans (from the earliest times) as it has in the formation and history of the earth.

A few minor aspects detract somewhat from the book: there is no index, and the black-and-white photographs are poorly reproduced (in contrast

to the beautifully clear black-and-white aerial photograph on the back cover). In terms of ideas, one also has to consider the limitations imposed by the relatively few gem species the author is considering. But the author quite clearly states in the title that the book is about speculations, and if one provisionally accepts this, the book goes on to assemble such a large, well-referenced collection of information that the ideas gain considerable credibility and provide a platform to stimulate the next wave of thinking about the origins of gems.

Roger Harding

OTHER BOOK TITLES

Coloured Stones

Emerald: Twenty-One Centuries of Jewelled Opulence and Power
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Erratum

Page 241 of the article by H.A. Hänni and L.E. Cartier titled 'Tracing cultured pearls from farm to consumer: A review of potential methods and solutions' (Vol. 33, No. 7–8, 2013) indicated that both laser engraving and embossing a hologram onto the surface of the cultured pearl are slightly destructive techniques. The article should have referred to only the laser inscription method as being destructive.

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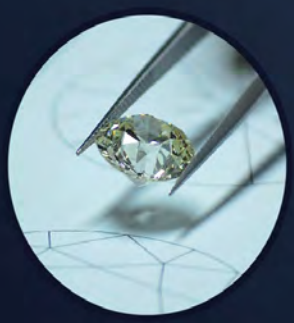

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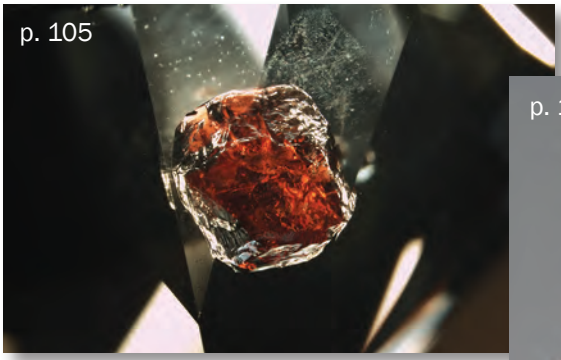

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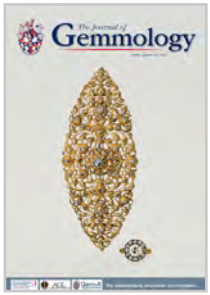

These two historic Portuguese jewels feature different diamond cutting styles: the gold stomacher (15.7 × 6.5 × 3.0 cm) from the late 17th to early 18th century is set with rose cuts, and the gold and silver ring (2.8 × 1.7 × 1.2 cm) from the late 18th century is set with brilliant-cut diamonds. For more on historic diamond cutting styles in Portugal, see the article by R. Galopim de Carvalho on pp. 114–128. Photos by Carlos Pombo Monteiro; © Fundação Eugénio de Almeida / Arquidiocese de Évora, Portugal; composite image by Orasa Weldon.

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What's New

INSTRUMENTS AND TECHNIQUES

GIA DiamondCheck

The Gemological Institute of America (GIA) recently unveiled the DiamondCheck device for screening unmounted faceted colourless to near-colourless stones (D-to-N range). The instrument is designed to accurately separate natural and untreated diamonds from non-diamond simulants (e.g. cubic zirconia) and from diamonds that need to be referred to a gemmological laboratory for further testing, as they are potentially treated natural or synthetic diamonds. The DiamondCheck consists of a commercially available infrared spectrometer coupled with GIA-developed software for automatic data interpretation. It does not require any technical training to operate. The system can rapidly analyse individual stones ranging from 0.01 to 10 ct, providing one of three results in a matter of seconds: *natural diamond; non-diamond;* or *diamond, refer for further testing*. When used as indicated, the DiamondCheck will correctly refer all colourless and near-colourless synthetic diamonds.

Photo © GIA

GIA is leasing these devices at no cost to major diamond bourses around the world. The DiamondCheck is available for purchase from GIA for US$23,900. For more information, visit www.gia.edu/instruments.

HRD Alpha Diamond Analyzer

In August 2012, HRD Antwerp released the Alpha Diamond Analyzer, which is a diamond detection and type screening instrument. Using the FTIR diffuse reflectance method, it distinguishes diamonds from imitations, and through its determination of diamond type, it allows the user to select potentially HPHT-treated or synthetic colourless diamonds for further testing in a gem laboratory. Also, by knowing the specific diamond type, the user can more effectively sort and value their diamonds. The software instructs the user how to bring the stone into position for analysis, and the measurement is performed within one minute. The gem's infrared spectrum is saved as a report file in PDF format. The minimum sample size that can be tested is 2–3 points (~0.03 ct) and the maximum size is approximately 70 ct. The current system can only accommodate unmounted diamonds, but in the future it will be possible to test gems mounted in jewellery using a separate module that will fit on the same instrument.

Photo © HRD Antwerp

The Alpha Diamond Analyzer weighs 7 kg and may be operated using a battery pack, making it quite portable. It costs €21,700, and further information can be found at www.hrdantwerp.be/equipment/ada.html.

Sarine Loupe

Launched in July 2014, the Sarine Loupe is a comprehensive imagery solution for viewing diamonds online. The system takes 360° scans of a diamond, and creates a shareable digital file that allows a user to see details of the stone as if holding it in their hand and viewing it through a loupe. The user may rotate the virtual diamond, both horizontally and vertically, and features such

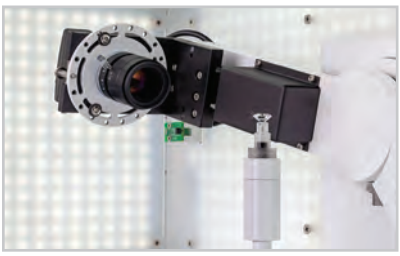

as inclusions, reflections, and workmanship are perceptible from any direction. A magnifier allows closer examination of minute details.

The Sarine Loupe device consists of advanced optics and mechanics with a controlled illumination environment, creating an accurate virtual representation without any image manipulation. The resulting images are digitally combined, allowing the creation of a fully 'floating' virtual diamond without any concealments. Images show high consistency and fidelity, and cutting-edge technology is used to handle the large video files online to provide a user interface with a rapid response time.

The imagery generated with the Sarine Loupe may be embedded into any online platform, attached to an email or examined through an intuitive viewer online. The system currently supports viewing of faceted round diamonds weighing 0.5 to 3 ct, but the capabilities will soon be expanded to other shapes and larger stones. A demonstration of the imaging capability of the Sarine Loupe is available at www.sarine.com/m2.php, for a 2.5 ct round brilliant diamond with H colour, VS_1 clarity and Excellent cut.

Tamar Brosh (tamar.brosh@sarine.com)
Sarine Technologies Ltd., Kfar Saba, Israel

NEWS AND PUBLICATIONS

2014 CIBJO Congress Reports

The 2014 CIBJO Congress took place on 19–21 May in Moscow, Russia. On the Congress website, http://congress2014.cibjo.org, a series of reports are available that were posted before the conference to review issues for discussion by the various commissions (click the Special Reports button). In addition, several news entries review the outcome of the conference sessions (click the News button).

Gem Testing Laboratory (Jaipur, India) Newsletter

The latest Lab Information Circular (Vol. 69, March 2014), available at www.gtljaipur.info/Lab%20Information%20Circular.asp, describes emeralds (and their simulants) from East Singhbhum District, southern Jharkhand State, India; composites consisting of pieces of multi-coloured tourmaline that are cemented together with a colourless polymer; and a report written in Hindi on a dyed bone imitation of coral.

The Handbook of Gemmology, 2nd Edition

The 2nd edition of *The Handbook of Gemmology* by Geoffrey M. Dominy (with photos by Tino Hammid) was released in June 2014 as individual digital downloads for US$39.95 each, via http://handbookofgemmology.com. The following formats are available: .exe for Windows, .app for Mac, ePUB/PDF for iPhones and iPads and a PDF format for androids and most e-readers. Users can also purchase all of these formats by downloading the 'deluxe' version for $49.95.

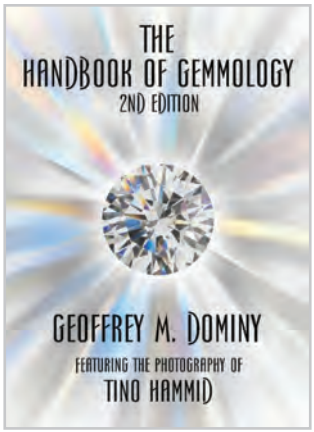

The 2nd edition contains 206 more pages and 200 additional photographs, for a total of 860 pages. Chapters on *Diamond Grading* and *Coloured Gemstone Grading* have been added, and updated information is provided on gem magnetism, electrical properties, synthetic gemstones, treatments and more.

A print version of *The Handbook of Gemmology* is planned for release in 2015.

International Consortium of Gem-Testing Laboratories Newsletter

The International Consortium of Gem-Testing Laboratories has released Newsletter No. 2, 2014, available at http://icglabs.org. It includes brief reports on the oiling of Burmese star rubies; ancient Roman bead-makers of Arikamedu, South India; black synthetic moissanite sold as black diamond; the use of QR (quick response) codes in gemmological coursework in Korea; and a book review of *Colour of Paradise—The Emerald in the Age of Gunpowder Empires* (by Kris Lane, 2010).

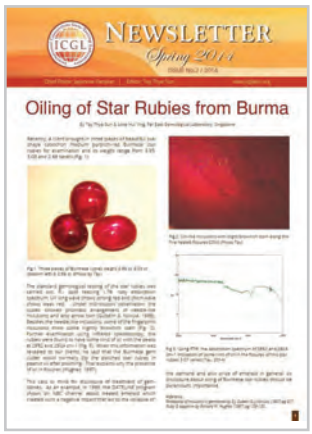

Responsible Jewellery Council Reports and Presentations

In May 2014, RJC released its Annual Progress Report (www.responsiblejewellery.com/annual-progress-report), in which they focus on conveying the benefits of RJC certification and supporting responsible business practices.

At www.responsiblejewellery.com/monitoring-and-evaluation, users can download two documents that were posted in June 2014: (1) RJC's first *Impacts Report*, which reviews the first four years of RJC's certification programs during 2010 to 2013 (including a focus on the diamond cutting sector in India), and (2) RJC's *Monitoring & Evaluation System Report*, which provides an overview of the design and operation of this program.

RJC's updated Code of Practices was launched in November 2013 and is being implemented in 2014. Several documents pertaining to this Code can be downloaded at www.responsiblejewellery.com/code-of-practices-2013-english.

Presentations from RJC sessions at several recent trade shows can be downloaded at www.responsiblejewellery.com/recent-events.

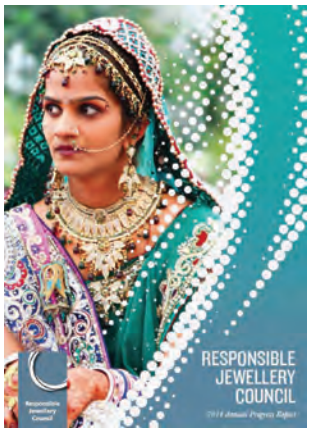

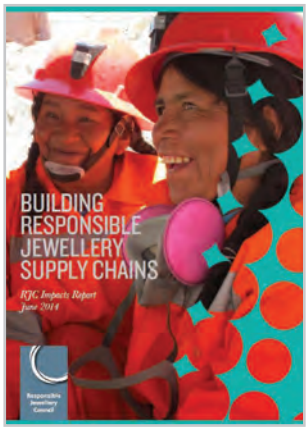

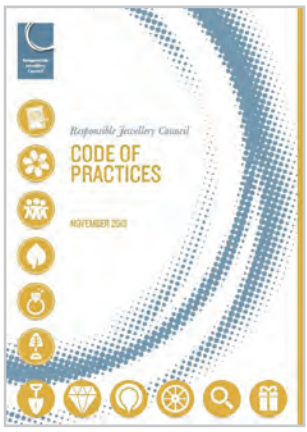

OTHER RESOURCES

Help With Hallmarks App

In October 2013, the Birmingham Assay Office released the *Help With Hallmarks* app for both iPhone and iPad as well as Android devices. The app enables users to quickly research and identify the date letter on precious metal jewellery and silverware, and includes date letters from the 11 key assay offices in the UK, going back to 1544. An updated version (1.3) of the app was released in January 2014, and it is available from iTunes or the Google Play store for £9.99 or US$13.99.

What's New provides announcements of new instruments/technology, publications, online resources and more. Inclusion in What's New does not imply recommendation or endorsement by Gem-A. Entries are prepared by Brendan Laurs unless otherwise noted.

Spinel Masquerading as Taaffeite or Sapphirine: A Clever Scam

Alan Hodgkinson

Several years ago, an 'enterprising' gem cutter in Sri Lanka capitalized on the similar appearance between spinel and two much rarer, more valuable gems: taaffeite (Figure 1) and sapphirine. The typical RI of violet spinel (1.72) is quite close to that of taaffeite of a similar colour (1.719–1.723), although taaffeite is doubly refractive with a birefringence of 0.004. In a similar fashion, the darker blue tones of spinel resemble those of sapphirine (1.706–1.712, birefringence = 0.006). The anisotropic RI readings of taaffeite or sapphirine do of course change as the stones are rotated on the refractometer, but their low biaxial birefringence is not easy to observe in full.

Figure 1: The 1.47 ct spinel on the left has a violet colour that strongly resembles the 1.49 ct taaffeite on the right. Photo by A. Hodgkinson.

Probably by accident originally, it was found that polishing a spinel with two slightly angled planes on the table (Figure 2a) results in two simultaneous shadows on the refractometer (Figure 2b). This deception enables such a spinel to be passed off as taaffeite or sapphirine.

How does this deception work? When the refractive indices of a gemstone are recorded on a refractometer, the table facet should lie flat on the hemicylinder, with a thin layer of contact liquid between the two surfaces. In these contrived table facets, the two facet planes are at an angle of only about 1–2° from one another. The contact liquid makes optical contact with both of the contrived planes, and each of the two table surfaces registers its own shadow edge simultaneously on the refractometer.

Just how much can a refractometer measurement be distorted by the hemicylinder/gemstone contact angle? As an experiment, a small piece of Blu-Tack was used to position a large 37.99 ct orange synthetic spinel (RI = 1.727) so that its table was tilted on the refractometer's

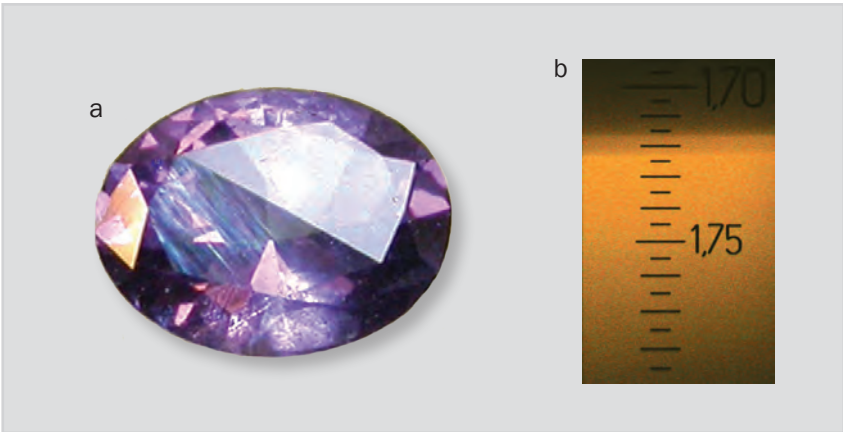

Figure 2: (a) This 1.89 ct spinel has two contrived table facets. (b) Two shadow edges are seen when this spinel is placed on the refractometer. Photos by A. Hodgkinson.

prism. When the far end of the stone was raised, the shadow edge lowered to 1.710. When the front end of the stone was raised in the same fashion, the shadow edge rose to 1.750. This created an error span of 0.040. This distortion is far more than that of the natural spinel described above, but this is due to the exaggerated angles that this large gem was tilted on the refractometer. Such false RI readings only occur when a stone is inadvertently tilted in the north-south direction (along the length of the hemicylinder); no errors are produced when it is tilted in the east-west direction (across the refractometer prism from left to right). A discussion of the erratic readings that can result from such tilting of a stone is provided by Koivula (1985).

The use of a large drop of contact liquid will show such rogue readings more readily than a small drop, since a greater volume of liquid is available to fill the two spaces between the stone and the refractometer. Therefore only the smallest amount of fluid necessary for a reading should be used, and it is essential that a facet makes flat optical contact with the prism. This may require the help of a fingertip or back end of a pencil.

To avoid being deceived by such scams, the gemmologist must be forever vigilant when examining gemstones. By first using a 10× loupe, the keen observer should see a discrepancy in the light reflected from contrived table facets, as shown in Figure 2a. Since light will not reflect simultaneously across the entire table facet, the two contrived table facets will be revealed.

Reference

Koivula J., 1985. Errors in refractive index. *Canadian Gemmologist,* **6**(3), 86–87.

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Acknowledgement: The author thanks the late H. Karunananayaka of Sri Lanka for custom cutting two spinels with 'contrived' tables.

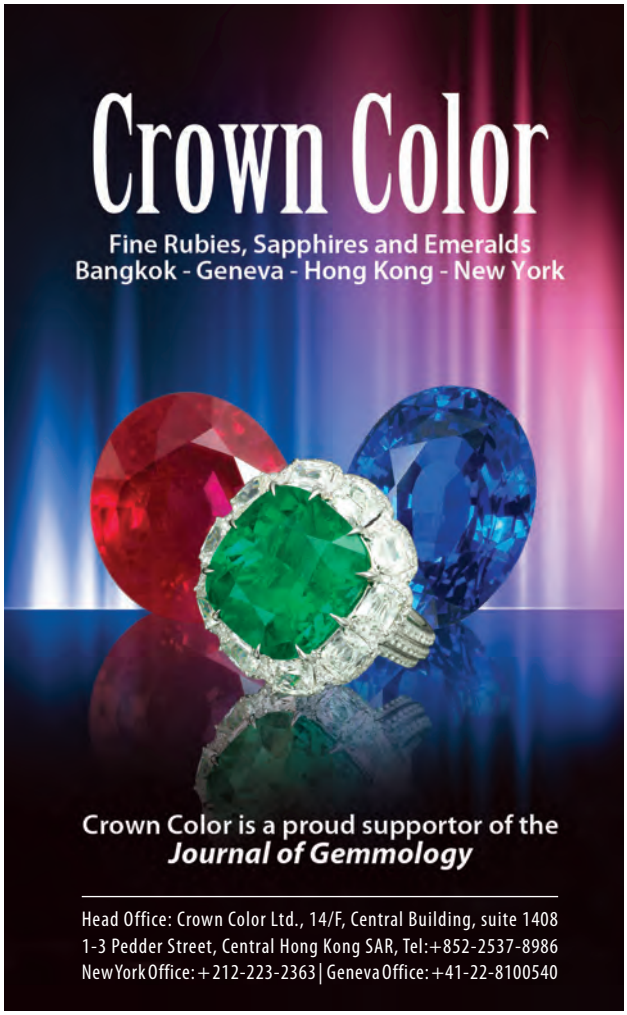

Gem Notes

COLOURED STONES

Andradite from San Carlos, Arizona

During the 2014 Tucson gem shows in Tucson, Arizona, USA, this author was shown some new production of faceted andradite from the San Carlos Reservation by Warren Boyd FGA (Apache Gems, San Carlos, Arizona, USA). Two andradites (0.87 ct total weight) were donated by Apache Gems to Gem-A's research and teaching collection. Although gem-quality andradite from San Carlos is not new (e.g. Johnson and Koivula, 1997), recent mining activities have resulted in the greater availability of this greenish to brownish yellow garnet (Figure 1). The andradite is being marketed by Apache Gems as *Apache demantoid,* along with other gem varieties from the reservation or nearby areas including *Diné chrome pyrope, San Carlos peridot* and *Slaughter Mountain fire agate.*

The main andradite deposits on the reservation were recognized nearly two decades ago, as a result of prospecting by Charles Vargas and his brother Michael Haney in a region where ranchers had been active for many years. Charles and Michael are descendants of the Chiricahau Apache Ndeh Nation, and they live and work on the San Carlos Reservation. The mining area is only accessible by all-terrain vehicle, and then on foot. The occurrences are worked with simple hand tools in shallow pits. The mining season is limited by the heat of the summer, and the multi-day mining excursions take place under challenging conditions in areas patrolled by mountain lions, bears and other predators. Although no formal geological mapping has been done to date, it is apparent that the garnet is associated with skarn zones that contain a variety of associated minerals.

Figure 1: These andradite gemstones were cut from material recently mined near San Carlos, Arizona. The gems weigh up to 1.2 ct. Photo by Jeff Scovil.

The mining and recovery of the gems is done with a spiritual reverence and respect for nature that is rarely seen in mining activities worldwide. Over the course of several seasons, the gem rough has been accumulated, sorted, classified and cobbed. Facet-quality material is rare, and most of the andradite is suitable only for use as mineral specimens, bead material or cabochons. Nevertheless, to date Apache Gems has cut over 20,000 stones, with most weighing less than 5 ct; the vast majority are under 2 ct. Many of the smaller gems were cut in Sri Lanka using precision cutting equipment, while some larger and finer stones were cut in the USA, including the San Carlos reservation.

Brendan M. Laurs

Reference

Johnson M.L. and Koivula J.I. (Eds.), 1997. Gem News: Andradite from Arizona. *Gems & Gemology,* **33**(1), 61.

Bobdownsite, a Relatively New Mineral from Canada, Faceted as a Gemstone

Bobdownsite, ideally $Ca_9Mg(PO_4)_6(PO_3F)$, was first discovered in 2001 on a ridge on the west side of Big Fish River (Figure 2), Yukon, Canada, at coordinates of approximately 68°28'N, 136°30'W, by Rod Tyson of Tysons' Fine Minerals (Parrsboro, Nova Scotia, Canada). It was initially misidentified as another phosphate, whitlockite, before being correctly described by Tait et al. (2011), who named it for Dr Robert Downs (University of Arizona, Tucson, USA). The mineral is hosted by narrow veins cutting bedded ironstones and shales, and is associated with siderite, quartz and various phosphates (lazulite, an arrojadite-group mineral, kulanite, gormanite and collinsite). It forms colourless tabular crystals up to 27 mm wide and 4 mm thick, and has a Mohs hardness of ~5 with no cleavage observed.

Three faceted bobdownsite samples from the collection of Brad Wilson (Alpine Gems, Kingston, Ontario, Canada) were loaned to the Royal Ontario Museum (ROM) for examination (Figure 3). The stones ranged from 0.05 to 0.23 ct, and the following properties were recorded: colour—colourless; lustre—vitreous; diaphaneity—transparent to semi-transparent; RI—n_o = 1.625 and n_e = 1.622; optic character—uniaxial negative; Chelsea colour filter reaction—none; fluorescence—weak red-purple to long-wave and inert to short-wave UV radiation. In addition, a weak orange phosphorescence was noted. A density value of 3.14 g/cm^3 was measured by Tait et al. (2011), and Raman and IR spectra for bobdownsite are available at http://rruff.info/bobdownsite/display=default/R050109, along with XRD data.

Figure 3: These bobdownsite gemstones were faceted by Brad Wilson and weigh 0.23 ct (left), 0.13 ct (centre) and 0.05 ct (right). Photo courtesy of the Royal Ontario Museum, © ROM; photo by Brian Boyle, MPA, FPPO.

ROM personnel visited the bobdownsite locality in the summer of 2012, but no more material was found in situ. However, several small pieces were recovered from the talus slope and reside in the ROM collection. To this author's knowledge, this is the first time that faceted bobdownsite has been characterized in the literature. With only a few such gems in existence, this is certainly a very rare collectors' gemstone.

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Reference

Tait K.T., Barkley M.C., Thompson R.M., Origlieri M.J., Evans S.H., Prewitt C.T. and Yang H., 2011. Bobdownsite, a new mineral species from Big Fish River, Yukon, Canada, and its structural relationship with whitlockite-type compounds. *Canadian Mineralogist,* **49**, 1065–1078, http://dx.doi.org/10.3749/canmin.49.4.1065.

Figure 2: Bobdownsite is known only from this steep terrain on the west side of the Big Fish River in Canada's Yukon territory. Photo by K. Tait.

Orange Lizardite from South Africa

Lizardite, $Mg_3(Si_2O_5)(OH)_4$, is a member of the kaolinite-serpentine group, and is probably the most common serpentine mineral. It has a Mohs hardness of 2–3, and is noticeably softer than antigorite and harder than chrysotile (Gaines et al., 1997). It is commonly green to yellow-green, bluish green, or nearly black, and rarely yellow or white. It was a surprise, therefore, to encounter faceted bright orange stones sold as 'lizardite' at the 2014 Tucson gem shows. The material was offered by Mauro Pantò (The Beauty in the Rocks, Laigueglia, Italy), who had two varieties: pure lizardite (Figure 4) and lizardite-included quartz (Figure 5). Pantò obtained the rough material at the February 2012 Tucson gem shows, in a parcel mixed with sugilite reportedly from the Wessels mine in South Africa. Although the orange stones in the parcel were sold to him as bustamite, an X-ray diffraction (XRD) analysis performed by John Attard (Attard's Minerals, San Diego, California, USA) showed that the material was actually lizardite.

Pantò reported that most of the rough lizardite was opaque with rare translucent areas. From the most saturated rough material, he had approximately 40 stones cut between 0.5 and 2 ct. In addition, from rough pieces of lizardite-included quartz he had around 20 stones cut, ranging from 0.80 to 1 ct. He donated to Gem-A one faceted lizardite (1.10 ct) and one faceted lizardite-included quartz (3.33 ct), and these were sent to one of the authors (GRR) to confirm the identity of the material and investigate the cause of its orange colour.

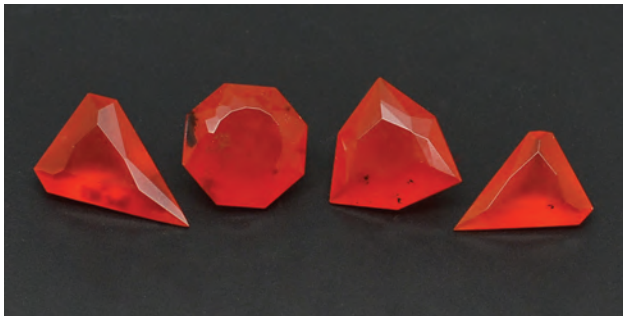

Figure 4: These translucent orange stones (0.80–1.88 ct) proved to be lizardite that is coloured by hematite micro-inclusions. Photo by Mauro Pantò.

Figure 5: These lizardite-included quartz specimens range from 1.87 to 3.33 ct. Photo by Mauro Pantò.

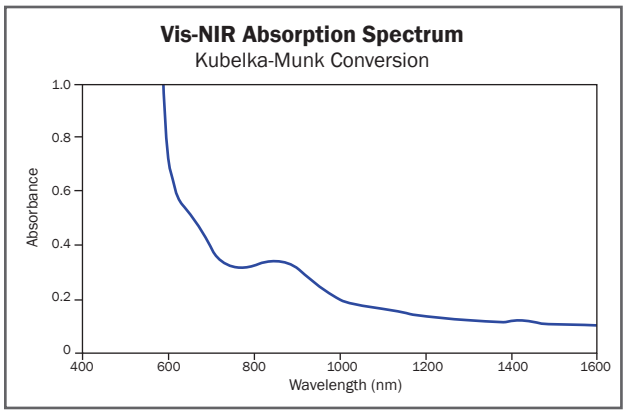

Figure 6: Vis-NIR spectroscopy of the orange lizardite gave a reflectance pattern typical of hematite. A Kubelka-Munk transformation of the reflectance pattern yields an absorption spectrum that is also characteristic of hematite.

Raman spectroscopy was performed on both samples, and the results were compared to data reported by Rinaudo et al. (2003). The spectrum of the 'lizardite' sample was a much closer match to lizardite than to antigorite, with the strongest peaks located at 688.7, 385.9 and 235.4 cm^{-1}. The 'lizardite-included quartz' sample was confirmed as quartz with weak, noisy features consistent with lizardite. Vis-NIR spectroscopy of this sample gave an excellent reflectance pattern for hematite (cf. Scheinost et al., 1998), with features at ~870 and ~680 nm (and saturation below 600 nm), as well as an OH band near 1400 nm that would be expected from lizardite. Following a Kubelka-Munk transformation, the data resemble an absorption spectrum that is typical of hematite (Figure 6). A similar spectrum was obtained from the 'lizardite' sample, although the transmission pattern was of lower quality, apparently due to the presence of black impurities in the stone. Still, the pattern indicated that hematite is the cause of colour. The hematite is apparently present as micro-inclusions within the lizardite.

To confirm the identity of the 'lizardite' sample that was used for the analyses described above, a small portion of it was sent to Attard for XRD analysis. The pattern matched lizardite, with a minor amount of garnet (probably andradite). Although hematite was not detected in the XRD pattern, this technique does not detect admixtures of minerals present at low concentrations, and only trace amounts of hematite would be needed to impart the orange coloration exhibited by this material.

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References

Gaines R.V., Skinner H.C.W., Foord E.E., Mason B. and Rosenzweig A., 1997. *Dana's New Mineralogy,* 8th edn. John Wiley & Sons Inc., New York, New York, USA, 1418–1420.

Rinaudo C., Gastaldi D. and Belluso E., 2003. Characterization of chrysotile, antigorite and lizardite by FT-Raman spectroscopy. *Canadian Mineralogist,* **41**, 883–890, http://dx.doi.org/10.2113/gscanmin.41.4.883.

Scheinost A.C., Chavernas A., Barron V. and Torrent J., 1998. Use and limitations of second-derivative diffuse reflectance spectroscopy in the visible to near-infrared range to identify and quantify Fe oxide minerals in soils. *Clays and Clay Minerals,* **46**, 528–536, http://dx.doi.org/10.1346/CCMN.1998.0460506.

Large Faceted Quartz from Arkansas, USA

The McEarl mine in Garland County, Arkansas, is located within the Blue Springs area, which is famous for producing some of the world's finest quartz crystals. The deposits are hosted by the Blakely sandstone (Engel, 1951), and there are 10 mines in the area, two of which are currently active. Avant Mining LLC is the largest landholder in the district, and owns five mines on approximately 150 acres. Avant acquired a 50 acre portion of the McEarl mine (Figure 7) from Weyerhaeuser Co. in 2010, and has been developing the property since 2011.

The McEarl mine was first opened in 1940 and operated until 1943 by the Diamond Drill Carbon Co. of New York City, to explore for optically clear quartz suitable for use as radio frequency oscillators. Mini McEarl then owned the property from 1943 until 1981, when she sold the mine to Jimmy Coleman. (The well-known Coleman mine is located only 1 km from the McEarl property.) The last major McEarl find occurred in 1986–1987, when Coleman encountered a large pocket at the property's boundary (marked by the line of trees on the right side of Figure 7).

Figure 7: The McEarl mine is currently worked as an open pit with a trackhoe and dump truck. Photo by J. Zigras.

Figure 8 (left): This exceptionally fine quartz specimen (23 cm long) from the McEarl mine was found in 1986–1987. Fine Minerals International specimen, now in the MIM Collection, #880; photo by Elliott/Fine Minerals International.

Figure 9 (below): The largest faceted quartz from the McEarl mine is this 804 ct stone cut by Joel Baskin. At 57 mm in diameter, the Portuguese cut is shown together with a typical apple to give an idea of its scale. Photo by Jason Baskin.

Figure 10: This 428 ct quartz from the McEarl mine appears eye-clean in normal lighting (above), but displays conspicuous 'blue needles' when illuminated in certain orientations by strong transmitted light (right). Photos by Tino Hammid.

This pocket produced some exceptionally fine quartz crystals (e.g. Figure 8), and their quality remains unmatched worldwide.

Avant's current operation has now merged with the historically mined portion of the deposit, in an open pit worked with a trackhoe and dump truck (again, see Figure 7). As Avant has mined down to the pocket zone, numerous broken crystals of clear quartz that are suitable for lapidary use have been found. So far, seven large stones have been cut, ranging from 150 to 804 ct (e.g. Figures 9 and 10). The quartz was faceted as Portuguese cuts by Joel Baskin of Baskin & Sons (Wolf Creek, Oregon, USA).

Interestingly, the optically clear quartz from the McEarl mine commonly contains localized clouds and needle-like inclusions that appear blue when they are illuminated with bright transmitted light in certain orientations (e.g. Figure 10). These inclusions are only seen when illuminated in this fashion, and similar features also were described in optical quartz from unspecified localities by Gordon (1945, p. 286) as follows:

> 'Blue needles' and 'blue feathers'…are inexplicable linear clouds which appear bluish because of selective absorption of rays of others colors. They occur as pairs of needles forming a V, with the apex of the V always towards the base of the crystal, and the two arms of the V have a preferred orientation parallel to *r*:*z* edges….'Blue needles' are not uncommon in quartz…. These structures are hard to resolve, even under a magnification of 150×, but they seem nothing more than systems of linear parting planes.

Gordon (1945) ascribed their blue appearance to the Tyndall effect (i.e. due to light scattering from the extremely small needles).

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References

Engel A.E.J., 1951. Quartz crystal deposits of western Arkansas. *United States Geological Survey Bulletin 973-E,* Washington D.C., USA, 260 pp., pubs.usgs.gov/bul/0973e/report.pdf.

Gordon S.G., 1945. The inspection and grading of quartz. *American Mineralogist,* **30**(5–6), 269–290, www.minsocam.org/ammin/AM30/AM30_269.pdf.

Gold Inclusions in a Large, Clear Quartz Crystal

Quartz is host to an amazing diversity of mineral inclusions. Quartz is also a common ore mineral in vein-hosted gold deposits, so it should be no surprise to find native gold as inclusions in quartz. However, such inclusions may be difficult to appreciate since the host quartz is almost always milky (e.g. Gübelin and Koivula, 2005, pp. 140, 604, 605).

Therefore, this author was most interested to encounter a large transparent crystal of quartz containing gold inclusions at the 2014 Tucson gem shows. The crystal was featured in a sculpture titled 'Gold Rush' (Figure 11) by Lawrence Stoller of CrystalWorks, Bend, Oregon, USA. The quartz originated from Brazil, and it was polished on all sides except the back, which had been naturally etched by hydrothermal fluids (Figure 12). The etched quartz hosted several inclusions of native gold measuring up to 4.4 mm long that were partially embedded in the underlying clear quartz (Figure 13). When the sculpture was viewed from the front, the inclusions reflected through the quartz crystal; their colour was mimicked by the metallic base that supported the specimen.

While it is quite rare for gold inclusions to be hosted by clear quartz (Gübelin and Koivula, 1986, p. 319), their presence in a large transparent quartz crystal is even more unusual.

Brendan M. Laurs

References

Gübelin E.J. and Koivula J.I., 1986. *Photoatlas of Inclusions in Gemstones.* ABC Edition, Zurich, Switzerland.

Gübelin E.J. and Koivula J.I., 2005. *Photoatlas of Inclusions in Gemstones,* Vol. 2. Opinio Publishers, Basel, Switzerland.

Figure 11 (left): The large polished quartz crystal (21.5 × 16.0 × 10.0 cm) in this sculpture titled 'Gold Rush' contains inclusions of native gold that are seen reflecting through the faces on the upper left. Photo by Gary Alvis and Lawrence Stoller.

Figure 12 (above): Viewed from the rear, the quartz crystal exhibits a flat partially iron-stained surface that has been naturally etched by hydrothermal fluids, and hosts inclusions of gold. Photo by Gary Alvis and Lawrence Stoller.

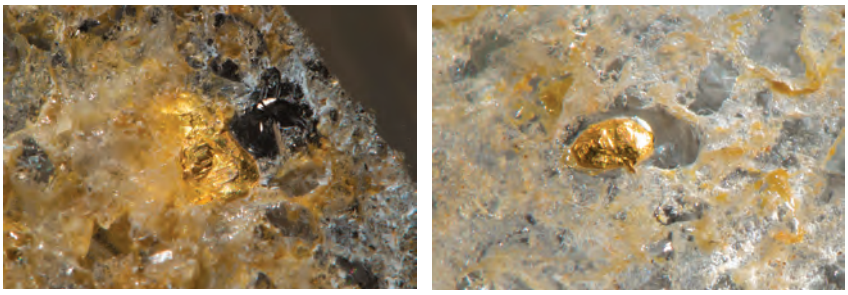

Figure 13: Bright yellow inclusions of gold are present within the etched iron-stained layer of quartz. The gold inclusions seen here measure 4.4 mm (left) and 4.0 mm (right). Photos by Gary Alvis and Lawrence Stoller.

Some Gemmological Rarities Seen in Tucson

The annual gem shows in Tucson, Arizona, USA, provide a wonderful opportunity to encounter many unusual gem materials. During the 2014 shows, rare-stone dealer Mauro Pantò (The Beauty in the Rocks, Laigueglia, Italy) had several such gemstones: yellowish green kyanite from Madagascar, blue halite from New Mexico, lepidolite from Brazil and tinzenite from Italy, as well as orange lizardite from South Africa (see Gem Note on pp. 100–101 of this issue).

Pantò initially obtained the yellowish green kyanite rough during the 2012 Tucson shows. The material reportedly came from an unspecified locality in Madagascar, and was easily identified by its visual appearance (confirmed by Thierry Cathelineau using IR reflectance spectroscopy). Most of the rough was heavy included, and Pantò selected the cleanest pieces to cut stones ranging from 0.40 to 3.00 ct (e.g. Figure 14). Green kyanite is also known from Brazil and Tanzania, and its coloration is due to Fe^{3+} (see Hyršl and Koivula, 2002; Renfro and Shen, 2013; http://minerals.caltech.edu/FILES/Visible/Kyanite/Index.html).

The blue halite came from the Intrepid Potash East mine, Eddy County, New Mexico. From two

pieces of rough that Pantò obtained in Tucson in 2011, eight gemstones were cut, ranging from 5 to 8 ct (e.g. Figure 15). The stones were faceted by Luigi Mariani (Milano, Italy), using a special cutting process that employs a mixture of alcohol and acetone on the cutting wheel. Blue colour in halite is caused by exposure to natural radiation, which results in the formation of colloidal-sized aggregates of sodium metal (documented in halite from Germany: http://minerals.caltech.edu/COLOR_Causes/Radiate/index.html). However, traces of colloidal gold also occur in the blue halite from New Mexico and may be the cause of its coloration (Bickham, 2012).

Very good–quality lepidolite has recently appeared on the market from Araçuaí, Minas Gerais, Brazil, and it is translucent and 'tough' enough to be faceted. Pantò had about 25 stones cut that ranged from 1 to 15 ct (e.g. Figure 16). Most were cut in China, except for the largest piece that was cut by Luigi Mariani.

Tinzenite is a reddish orange borosilicate with the formula $(CaMn^{2+})_2Mn^{2+}Al_2BSi_4O_{15}(OH)$ and a Mohs hardness of 6½–7. In 2013, Pantò obtained some rough material that had been gathered by local collectors from the famous manganese deposits near the Graveglia Valley, about 40 km east of Genova, Italy (Marchesini and Pagano, 2001). The tinzenite typically occurs in flat pieces and is commonly mixed with white quartz and black veins of braunite and manganese oxide, so it is difficult to obtain facetable material. Most of the ~50 faceted tinzenites offered by Pantò ranged from 1 to 3 ct, although a few pieces were larger (e.g. Figure 17).

Brendan M. Laurs

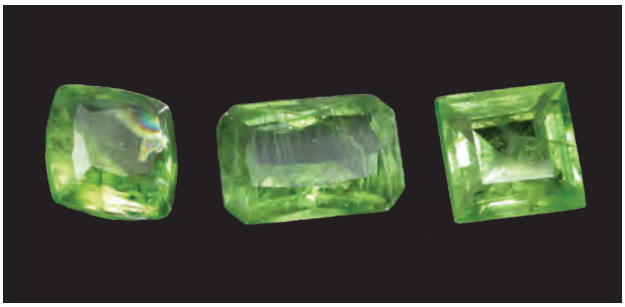

Figure 14: Madagascar is reportedly the source of these unusual yellowish green kyanites (1.40–1.70 ct). Photo by Mauro Pantò.

Figure 15: These halite gemstones (6.26–6.93 ct) from New Mexico, USA, display an attractive blue colour. Photo by Mauro Pantò.

Figure 16: These faceted Brazilian lepidolites (5.10–11.39 ct) are remarkable for their transparency and size. Photo by Mauro Pantò.

Figure 17: Tinzenite displays a bright reddish orange colour. The unusually large 7.02 ct stone on the left is pure tinzenite, while the 3.52 ct piece on the right displays the more typical appearance of tinzenite mixed with quartz. Photo by Mauro Pantò.

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Pastel Green Sapphire from Myanmar (Burma)

The pastel shades of Burmese corundum are not as well known as their more famous brethren, ruby and blue sapphire. However some of the mines in the Mogok area produce lovely pastel shades of yellow, pink, purple and blue-to-green sapphire (Figure 18). Within the blue-to-green range, the gems commonly share a blend of these two colours ranging from greenish blue to bluish green. However, it is much less common to encounter sapphires in pure green pastel shades. Recently American Gemological Laboratories had the opportunity to examine a relatively large, 26.12 ct, pure green Burmese sapphire (Figure 19), submitted by Hussain Rezayee of Rare Gems & Minerals, Beverly Hills, California, USA.

Microscopic examination revealed narrow bands of faint rutile needles and pinpoint particles, as well as pristine negative crystals and healed fissures. The stone also contained subtle planar growth features and colour zoning, and was inert to long- and short-wave UV radiation. Taken together, these characteristics confirmed the natural, unheated condition of the sapphire. The absorption spectrum in the ultraviolet-visible–near-infrared (UV-Vis-NIR) region revealed dominant features related to Fe^{3+}, as well as a weak broad absorption due to $Fe^{2+} \leftrightarrow Ti^{4+}$ intervalence charge transfer (Figure 20). Energy-dispersive X-ray fluorescence spectroscopy showed traces of Fe (0.35 wt.%), Ti (0.008 wt.%) and Ga (0.006 wt.%), with other elements such as V and Cr below the detection limit.

Figure 18: A variety of pastel shades are shown by these sapphires (0.75 to 1.20 ct), which were recently acquired by the AGL during a research expedition to the Mogok area of Myanmar. Photo by Kelly Kramer and Bilal Mahmood.

Figure 19: This 26.12 ct green sapphire from Myanmar is unusual for its size and clarity, as well as the lack of any bluish or yellowish undertones to the colour. Photo by Bilal Mahmood.

Large, gem-quality, pastel-coloured, pure green sapphires from Myanmar are not frequently encountered in the trade. However, the properties of this sapphire are consistent with those that have been examined previously by the author.

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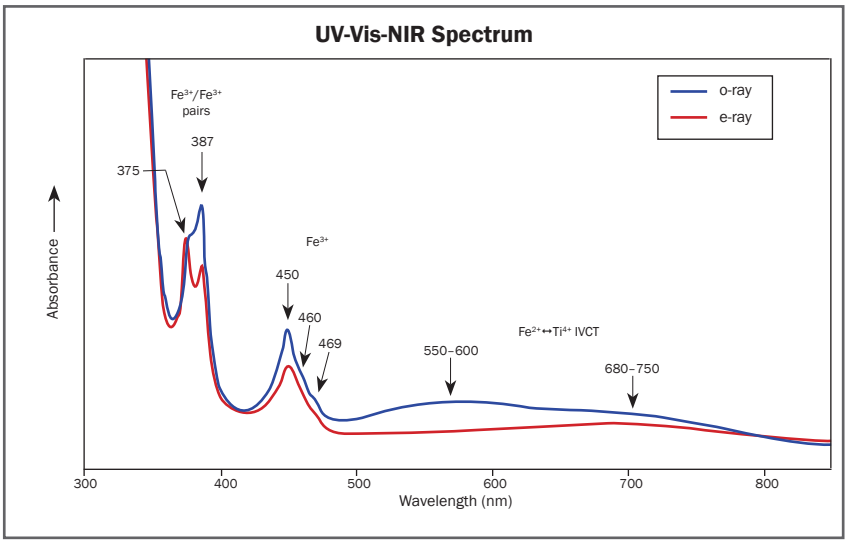

Figure 20: The UV-Vis-NIR spectrum of the pastel green Burmese sapphire revealed dominant absorption bands positioned at ~375 and 387 nm, as well as ~450, 460 and 469 nm, which are all related to trivalent iron (Fe^{3+}). Also present are weak broad absorptions between ~550 and 600 nm for the ordinary ray (vibrational direction perpendicular to the c-axis) and at ~680–750 nm for the extraordinary ray (vibrational direction parallel to the c-axis) related to Fe^{2+}↔Ti^{4+} intervalence charge transfer (IVCT).

Sapphire with a Large Spessartine Inclusion from Songea, Tanzania

The American Gemological Laboratories (AGL) recently examined an interesting 3.61 ct blue sapphire (Figure 21), reportedly from Songea, Tanzania, that was loaned by Don Thompson (Quest Minerals, Billings, Montana, USA). The stone contained a large, ~2.1 × 1.8 mm, surface-reaching crystal inclusion (Figure 22). It showed similarities to the cover photo of Gübelin and Koivula (2008), which depicts an inclusion identified as 'garnet' in a blue sapphire from Tunduru, Tanzania.

The inclusion in Thompson's sapphire was easily identified as spessartine using Raman spectroscopy, and this was consistent with the presence of Mn recorded by energy-dispersive X-ray fluorescence (EDXRF) spectroscopy.

Figure 21: This 3.61 ct sapphire contains a large reddish orange crystal inclusion that is obvious without magnification. Photo by Bilal Mahmood.

Figure 22: Using basic gemmological tools, the large, surface-reaching inclusion was identified as a pyralspite garnet. Further analytical testing using Raman and EDXRF spectroscopy refined the identification to spessartine. Photomicrograph by Christopher P. Smith; magnified 25×.

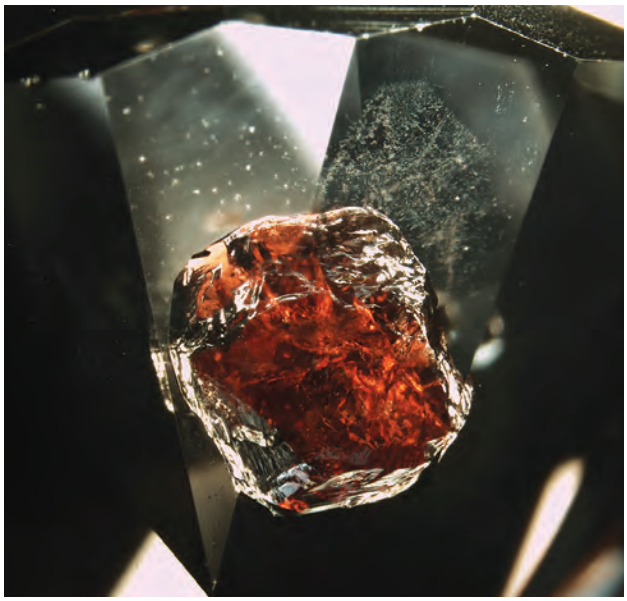

Considering the inclusion's large size and exposure on the surface, we thought it would be interesting to see if we could have identified the mineral species without the use of advanced instrumentation. Examination with a 10× loupe revealed the inclusion was reddish orange with an equant subhedral shape. It was inert to both long- and short-wave UV radiation. When the host sapphire was placed in a polariscope, it exhibited the expected 'blinking' effect intrinsic to optically anisotropic material. The inclusion, however, stayed dark during a full rotation in the polariscope, indicating that it was isotropic. We then attempted to take an RI reading of the inclusion where it was exposed on the surface of a pavilion facet, and obtained a measurement ~1.80 or OTL (depending on the upper limit of the RI fluid used). These features are sufficient to conclude that this inclusion is a pyralspite garnet (O'Donoghue, 2006).

While many of the stones encountered by gemmologists have inclusions that can be conclusively identified only with Raman micro-spectroscopy, this particularly rare sapphire contained an inclusion that could be identified—to the level of its mineral subgroup—by its standard gemmological properties alone.

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New Tourmaline Production from the Cruzeiro Mine, Brazil

At this year's Tucson gem shows, Paulo Vasconcelos (Vasconcelos Brazil, Governador Valadares, Brazil) displayed some tourmaline crystals that were obtained from a series of pockets found in September–October 2013 at the famous Cruzeiro mine in Minas Gerais. The Cruzeiro pegmatite is well known for producing pink and green tourmaline suitable for both mineral specimens and cut gemstones (e.g. Cassedanne et al., 1980), and is currently operated by Vasconcelos' company and partners.

According to Vasconcelos, when the miners initially broke into the main pocket, water drained from the drill hole for three days. This suggested the presence of a large cavity, and subsequent mining revealed a series of interconnected

Figure 23: Numerous well-formed pink-red tourmaline crystals such as this one (5.7×1.8 cm) were recently found at the Cruzeiro mine in Brazil. Photo by B. M. Laurs.

Figure 24: The recent Cruzeiro production included some large bicoloured pink and dark green tourmalines, such as this 70 kg crystal. Photo by B. M. Laurs.

pockets that in total measured 10–15 cubic feet (0.3–0.4 m^3). Approximately 300 kg of tourmaline were recovered, as well as a few quartz crystals. The tourmaline was pink-to-red (Figure 23) and bicoloured pink-green (Figure 24), and the largest crystals weighed 70 and 22 kg. Many of the pink-red crystals were of gem quality, but the company has focused on selling the tourmaline as mineral specimens, and no gems have been faceted yet from this material.

This find shows that the Cruzeiro mine still has good potential for producing gem tourmaline, and it comes at a time when relatively few other pegmatites in Brazil are being commercially mined.

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DIAMONDS

A Natural Diamond Showing a 'Synthetic' Pattern in the DiamondView

The Laboratoire Français de Gemmologie (LFG, French Gemmological Laboratory) in Paris recently had the opportunity to study a near-colourless, 1.01 ct, old-cut diamond (Figure 25) with a DiamondView pattern reminiscent of a high-pressure, high-temperature (HPHT)–grown synthetic diamond.

The G-colour SI_1-clarity stone was inert to long- and short-wave UV radiation, and no phosphorescence was observed. Between crossed polarizers it showed a banded strain pattern with low first-order interference colours (Figure 26). The infrared spectrum revealed the diamond was type IaB with low nitrogen; it also showed a small hydrogen-related peak. These characteristics are consistent with natural diamond, and they rule out the possibility of a synthetic.

Nevertheless, when the stone was placed in the DiamondView ultra-short-wave imagery system, to our surprise the blue emission formed a cross-shaped pattern of less-intense luminescence with a square-shaped central core (Figure 27), corresponding to the cubo-octahedral growth pattern generally observed in near-colourless HPHT-grown synthetic diamonds. The square core and the four branches of the cross corresponded to {100} or cube growth sectors (see e.g., Shigley et al., 1997).

Photoluminescence spectra collected at liquid-nitrogen temperature (Figure 28) showed the GR1 (741 nm), N-V (637 and 575 nm), H4 (496 nm) and N3 centres (415 nm). The presence of

Figure 25: This 1.01 ct old-cut diamond showed a very unusual growth pattern in the DiamondView instrument. Photo by A. Delaunay.

Figure 26: Banded graining is observed in the diamond between crossed polarizers. Photomicrograph by A. Delaunay; magnified 70×.

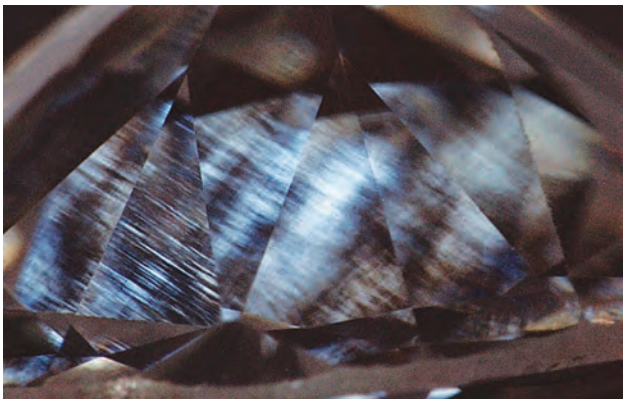

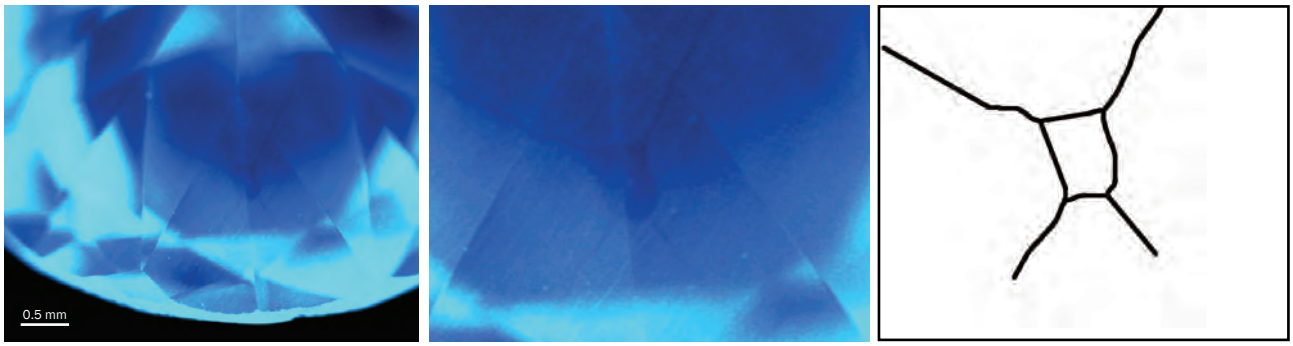

Figure 27: The DiamondView images of the 1.01 ct diamond show a luminescence pattern reminiscent of near-colourless HPHT synthetics, with a square core and four branches radiating from the corners. Photomicrographs and drawing by A. Delaunay.

all these features in the PL spectra further proves the natural origin of the stone. The ratio of the intensity of the N-V centres at 575 and 637 nm was 1.23, and the full width at half maximum (FWHM) of the N-V$^-$ centre peak was 11 cm^{-1}, which indicates that the diamond was not HPHT treated (see, e.g., Hänni et al., 2000).

To the authors' knowledge, this is the first time that a cubo-octahedral growth pattern has been reported in a natural faceted diamond. It probably corresponds to very small cubic growth sectors, which are known to occur in natural diamonds, but are always minute (typically much less than a millimetre; Moore, 1979). This demonstrates that on rare occasions, identifying natural vs. synthetic origin solely on the basis of DiamondView imaging could be misleading. Complementary tests are always needed to ensure that the DiamondView-based conclusion is consistent with all observable properties.

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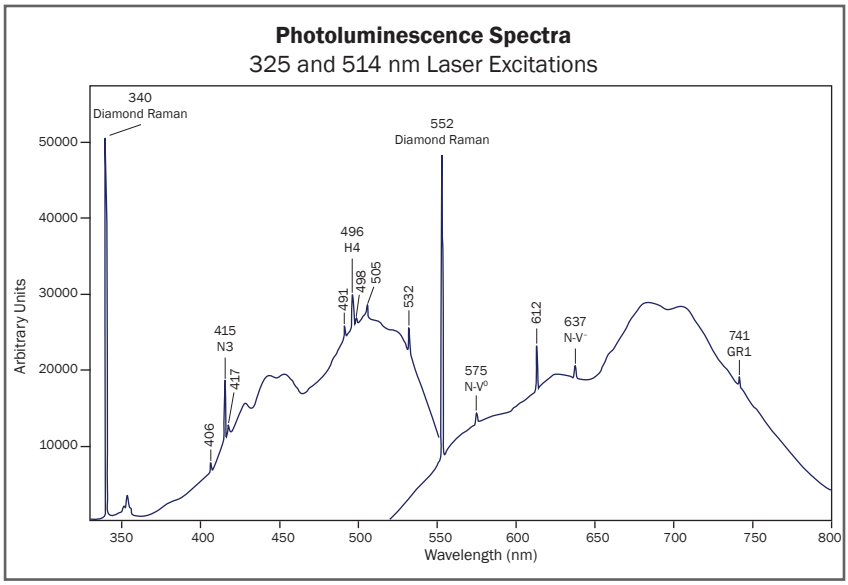

Figure 28: These photoluminescence spectra of the diamond were recorded at liquid-nitrogen temperature with 325 nm (left) and 514 nm (right) laser excitations. The presence of the GR1 (741 nm), H4 (496 nm), and N-V centres at 575 and 637 nm (both their ratio and the FWHM of N-V$^-$) confirm that the stone is natural and untreated.

SYNTHETICS AND SIMULANTS

Beryl Triplets Imitating Colombian Emerald, set in Jewellery

During the September 2013 Hong Kong gem show, this author was shown some new triplets that imitated emerald by Anil Dholakia (Anil B. Dholakia Inc., Franklin, North Carolina, USA). Marketed as Emerald Essence, the triplets were assembled using pieces of colourless beryl (and, less commonly, petalite) from Brazil, which are joined together with a proprietary coloured cement that is designed to imitate the appearance of fine Colombian emerald (Figure 29). The triplets are produced in sizes ranging from ~5 mm to 8 × 10 mm, and since January 2013 they have been mounted into a line of jewellery (e.g. Figure 30). The jewellery is hand-fabricated in China using silver with a platinum plating, and contains Emerald Essence accented by 1-mm-diameter topaz or cubic zirconia. So far, jewellery including pendants, rings and earrings has been manufactured (approximately 100 pieces of each).

Phenakite corrected to petalite (see note below).

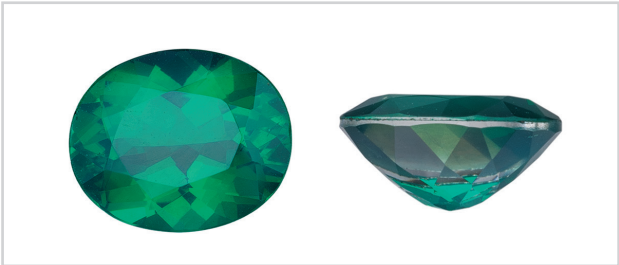

Figure 29: This 2.29 ct beryl-beryl triplet, marketed as Emerald Essence, is shown from the top and side. Gift to Gem-A from of Anil Dholakia; photo by Orasa Weldon.

Figure 30: These earrings contain 8-mm-diameter Emerald Essence beryl-beryl triplets that are mounted in platinum-plated silver with cubic zirconia. Photo by Orasa Weldon.

In addition, Dholakia has created six bracelets consisting of the Emerald Essence triplets set in 18 ct gold together with diamonds. The presence of triplets in fine jewellery is quite unusual.

Brendan M. Laurs

It should have been indicated that some of the gems were assembled using colourless beryl for the pavilion and petalite (not phenakite) for the crown. According to Anil Dholakia, petalite was used because of its brighter appearance than beryl.

Glass Imitation of Tanzanite

In June 2014, a jeweller submitted a group of three loose gems and a man's ring containing what looked like tanzanite (Figure 31). The ring consisted of 18 ct white gold, and the centre stone was surrounded by one-point diamonds.

Upon initial inspection, the purplish blue colour of the material showed a strong resemblance to tanzanite. However, testing of an 8.83 ct cushion cut showed it to be singly refractive, with an RI of 1.705 and an SG of 4.13. With magnification and transmitted light, the gem was clean except for swirl-like structures (Figure 32). The presence

Figure 31: These attractive purplish blue gems proved to be glass, rather than tanzanite. The cushion cut on the far right weighs 8.83 ct. Photo by Tay Thye Sun.

Figure 32: Swirl marks were evident in the glass (particularly on the left) when viewed with magnification and transmitted light. Polishing marks are also seen on some pavilion facets. Photomicrograph by Tay Thye Sun; magnified 15×.

of abundant polishing marks (again, see Figure 32) and some scratches suggested it was a relatively soft material. It was inert to long-wave UV radiation, and fluoresced a weak chalky white to short-wave UV. No absorption features were evident with a desk-model spectroscope. These features are similar—but not identical—to those documented for a high-RI glass imitation of tanzanite by Quinn (2003). Fourier-transform infrared spectroscopy confirmed the identification of this material as artificial glass.

Although this type of tanzanite imitation has been known for more than a decade, it continues to circulate on the market. It is also interesting to note that even fine jewellery may contain such glass imitations. Therefore, it is important to exercise vigilance and always be sure that a 'tanzanite' gemstone has the strong pleochroism (and other expected properties) characteristic of this gem material.

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Reference

Quinn E., 2003. Lab Notes: High-R.I. glass imitation of tanzanite. *Gems & Gemology,* **39**(4), 317–318.

Synthetic Ruby Doublet with a Natural-Appearing Sheen

Doublets and triplets are some of the oldest manufactured products to imitate the appearance as well as the optical effects of natural gems. Emeralds, rubies and sapphires are the most common materials imitated by such composites. In the case of rubies and sapphires, doublets or triplets are made using pieces of natural and/or synthetic corundum, and they may even imitate the asterism seen in natural gems (e.g. Kammerling, 1993; Yeung and Mayerson, 2004).

Recently, the Gem Testing Laboratory (Jaipur, India) received a purplish red, 4.78 ct, 10.04 × 8.50 × 6.21 mm, pear-shaped gem for identification (Figure 33). Upon initial observation with the unaided eye under normal room lighting, the specimen displayed sheen-like reflections when viewed face-up. This appearance is typically associated with dense 'silk' inclusions in rubies and sapphires. However, when the gem was observed with the microscope, no silk inclusions were present. Instead, a plane consisting of fine reflective dendritic inclusions was visible (Figure 34). This plane was positioned just below the girdle, and was easily visible in reflected light as a thin gap between the crown and pavilion (Figure

Figure 33: This 4.78 ct doublet, composed of synthetic ruby pieces, shows sheen-like reflections from within the gem that resemble the 'silk' in natural ruby. Photo by G. Choudhary.

Figure 34: Reflective dendritic features are visible within the cement used to assemble the doublet. These features are responsible for the sheen-like reflections shown by this synthetic ruby doublet. Photomicrograph by Sandeep Vijay; magnified 32×.

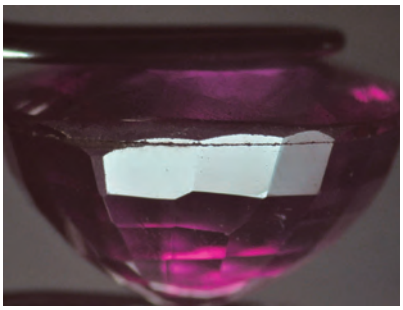

Figure 35: The junction plane of the synthetic ruby doublet is positioned just below the girdle. Photomicrograph by Sandeep Vijay; magnified 32×.

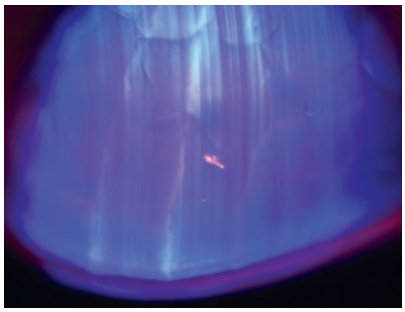

Figure 36: DiamondView imaging of the synthetic ruby doublet revealed distinct curved growth lines, proving its synthetic origin. Photo by Sandeep Vijay.

35). This confirmed the specimen was a doublet. The sheen-like reflections were produced by the reflective dendritic features that formed along the junction plane with the cementing material. Triplets displaying a pronounced sheen or adularescence to imitate moonstone have been known for years (e.g. McClure, 2006), and the cause of their sheen was shown to be a metallic foil placed along the cement layer—which is not the case here.

Gemmological testing gave RI values of 1.760–1.770 (for both the crown and pavilion) and a hydrostatic SG of 3.98, as expected for corundum. A typical ruby spectrum was observed with a desk-model spectroscope. The doublet fluoresced bright red with a chalky blue glue line when exposed to long-wave UV radiation, and the entire gem showed chalky blue luminescence when exposed to short-wave UV. No distinct inclusion features were visible in either the crown or pavilion portion of the doublet. Because of the composite nature of the specimen, we did not observe it using any type of immersion liquid. However, when examined with the DiamondView, prominent curved striae were evident in both the crown and pavilion portions (e.g. Figure 36), thereby proving the doublet was assembled from synthetic corundum.

The subtle sheen-like reflections visible in this doublet were quite convincing, and its identification could have been challenging, especially if bezel set in jewellery. In addition, such doublets can easily be passed as natural stones in ruby parcels.

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TREATMENTS

Corundum with Coloured Lead-Glass Fillings

Since 2004, large numbers of faceted, transparent-to-translucent rubies containing fracture fillings of lead glass have appeared on the gem market. The treatment technique and identification methods of this clarity enhancement process were published in this journal by Milisenda et al. (2006). In 2007, corundum treated with blue cobalt-bearing lead-glass fillings was observed for the first time (Abduriyim, 2007); a further description was given by Milisenda et al. (2013).

Figure 37: These faceted tablets of red and pale green corundum (6.03 and 10.41 ct, respectively) have been treated by coloured lead-glass fillings. Photo by S. Koch, DSEF.

Recently, red and pale green corundum have been found on the market with coloured fracture fillings of lead glass (e.g. Figure 37). According to information from the trade, the original material consists of pieces of brown to grey corundum that are cut into thin tablets so they show sufficient transparency after the treatment process.

The red sample in Figure 37 contained what appeared to be dark bubbles that were visible to the unaided eye. Microscopic observation confirmed the presence of these dark bubbles, and also revealed distinct red colour concentrations, as well as the typical flash effect seen in lead-glass-filled corundum (Figure 38). The high-RI glass causes blue-to-violet or purple colour flashes when viewed approximately parallel to the fissures. Unlike typical lead-glass-filled rubies, the filling in this material possesses a strong red colour that is responsible for the coloration of the host corundum. The green sample showed dull green residues in the surface-reaching fractures (Figure 39).

The identification of the coloured fillers as lead glass was confirmed by X-radiography (Figure 40) in combination with chemical analysis by EDXRF spectroscopy, which detected Pb in addition to Al. The coloration of the lead glass in the red corundum is assumed to be due to 'red lead' (Pb_3O_4). The colour of the green specimens might be due to Cr or Cu, which are both known colouring agents in glass. Traces of both these elements were detected by EDXRF, but more work is needed to determine whether they are constituents of the glass filling or residues of the cutting/polishing process.

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Figure 38: The treated red corundum contains dark bubbles of lead glass, and also shows distinct red colour concentrations (best seen on the left side) in addition to the typical flash effect resulting from lead-glass-filling. Photomicrograph by U. Henn; magnified 40×.

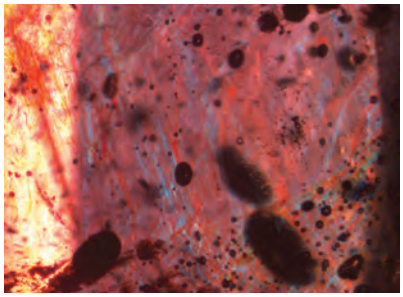

Figure 39: Flat lead-glass residues of dull green colour are observed in surface-reaching fractures of the green corundum sample. Photomicrograph by U. Henn; magnified 50×.

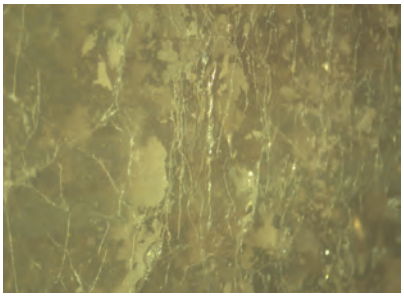

Figure 40: This X-radiograph of the pale green sample shows a distinct contrast between the host corundum (dark) and the lead-glass–filled fractures, which appear light due to the lower permeability of the lead-glass fillings to X-rays. The sample is 18.11 mm wide.

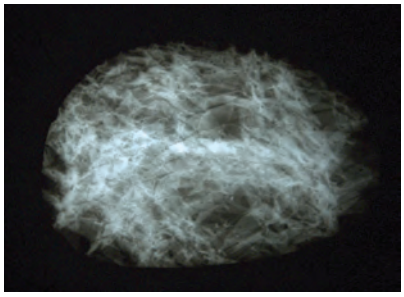

Dyed Labradorite

Recently, large amounts of colourful material sold as dyed rainbow moonstone were observed at the Europe Jewellery & Gem Fair in Freiburg, Germany. The most common colours were 'turquoise' blue, purple and pink (Figure 41). The coloration does not show an even distribution, due to its concentration in cracks that follow the two cleavage directions in feldspar.

Figure 41: Sold as dyed rainbow moonstone, these cabochons proved to be labradorite that has been treated with organic dyes. The diameter of the light blue cabochon is 16 mm. Photo by S. Koch, DSEF.

The term *rainbow moonstone* is used on the gem market for certain white feldspars (mostly from India) that show both labradorescence and adularescence (Henn, 2006). The adularescence is not always present or may only be visible to a limited extent, so Prof. Henry Hänni has suggested describing such material as white labradorite (Koivula, 1987).

An examination of the three samples in Figure 41 showed an approximate RI (spot reading) of 1.56 and a hydrostatic SG of 2.67–2.69. Both values characterize the material as labradorite. Electron microprobe analyses confirmed the material as plagioclase, with a Na/Ca ratio of labradorite, close to the border with andesine.

The dye is of an organic nature and can be removed easily by cleaning with a solvent.

Ulrich Henn (ulihenn@dgemg.com)
and Klaus Schollenbruch

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Evolution of Diamond Cuts in Portuguese Jewellery and Sacred Objects During the 16th–18th Centuries: A Brief Review

Rui Galopim de Carvalho

This review of the evolution of diamond cuts during the 16th to 18th centuries is illustrated with Portuguese jewellery and sacred objects from this period. We follow the evolution from point cuts already in existence prior to Portuguese navigational discoveries in the late 15th century, to *table* and *rose cuts* that co-existed for most of the 16th and 17th centuries, to the now-called *old brilliant* (or *old mine*) *cut*, which became popular a few decades after the discovery of the Brazilian diamond fields in the 1720s. The use of each cut and shifts in their popularity are discussed. These observations of diamond cuts in Portuguese jewellery and devotional objects may also be applicable to trends within wider European manufacture.

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Introduction

Diamond has been used as a gemstone for millennia, particularly in Asia where it was originally found (Bruton, 1978; Harlow, 1998; Bari and Sautter, 2001). Diamond's unique visual properties (brilliance, fire and scintillation) only began to be fully appreciated in Europe with advancements in cutting technology during the last quarter of the 14th century, in what is today Italy (Tillander, 1995). This evolution of cutting techniques, in addition to advancements in understanding of the optical properties of diamond as well as fashion trends, have all influenced the way that diamonds were cut and polished through the ages, and continue today (Bruton, 1978; Bari and Sautter, 2001; Klein, 2005; Ogden, 2006, 2012; Gilbertson, 2007).

The vicissitudes of jewellery use throughout history have resulted in the dismantling of many artefacts that fell out of fashion. In addition, the liquidation of old jewellery has served as an efficient way to realize financial gain. The diamonds in such pieces were frequently re-cut to meet the demand of the period in terms of cutting style, and then set into more fashionable pieces. As a result, the quantity of diamonds with ancestral cutting styles is inversely proportional to their antiquity. In fact, going back to the pre-17th-century era, there are only a few such artefacts that are still set with their original diamonds in period cuts. In addition to jewellery, sacred gem-encrusted objects, such as those kept in churches (e.g. Figure 1), provide a valuable record of the progression of early diamond cutting. Additional

Figure 1: The magnificent late-17th-century silver-gilt, gold and gem-set reliquary of the Holy Cross of Évora's cathedral (51 × 25 × 25 cm) contains 1,374 gemstones. The 845 diamonds are mostly rose cuts, with table cuts reserved for the smallest stones. The close-up photo shows some details of the reliquary, where rose-cut diamonds and four Colombian emeralds surround a carved hessonite (22.5 × 16.5 mm) depicting the Ecce Homo. *Photos by Carlos Pombo Monteiro; © Fundação Eugénio de Almeida—Arquidiocese de Évora, Portugal.*

insights may be gleaned indirectly through the interpretation of ancient documents and portraits.

This article reviews the evolution of diamond cuts in Portuguese jewellery and sacred objects from the late 15th to late 18th centuries. Since the progression of fashion and taste was somewhat consistent throughout Europe, the reader may extrapolate this review to the evolution of diamond cutting styles in jewellery throughout the Old Continent. Although some of the information in this article has been published previously in Portuguese (Galopim de Carvalho, 2000, 2006b; Galopim de Carvalho et al., 2011; Vasconcelos e Sousa, 2010), this is the first time it has been compiled together in English.

Background

The systematic gemmological study of historical Portuguese objects has taken place for nearly two decades in both national museums and, more importantly, in churches where a significant number of both devotional items and secular jewellery are still kept (e.g. Orey, 1995; Falcão, 2000, 2002; Goulart de Melo Borges, 2004; Galopim de Carvalho, 2009, 2010). Occasionally, private collectors and auction houses provide opportunities for jewellery historians and gemmologists to inspect their items, thus adding to the inventory of dated artefacts with accurate gemmological descriptions (Vassalo e Silva, 2005). Thousands of jewellery pieces have been studied in these contexts, with emphasis placed on identifying the gems and describing their cutting styles. This has resulted in the publication of various books and articles, mostly in Portuguese (e.g. Galopim de Carvalho, 2006b; Galopim de Carvalho et al., 2011) and less commonly in English (e.g. Galopim de Carvalho, 2010).

The most relevant historical period for Portugal's jewellery industry goes from the 16th century to the late-18th or early-19th centuries. For the purpose of this article, diamond-bearing artefacts from this period are described with a special focus on cutting style. Only the most important and significant cuts are taken into consideration, although several less-common styles of cutting have been identified. For example, smaller double cuts and even small-sized rough diamonds from this era have been reported in the literature, but they are not considered in this review. The focus of this interpretative article is the evolution of the mainstream cutting styles in Portuguese jewellery during the considered period.

The information gathered for this review is based on the author's own observations of hundreds of jewels, in conjunction with the limited published works on them by other researchers. The actual dating of historical jewellery is not the author's expertise, necessitating reliance on the work of local jewellery historians that has been published in the literature or recorded on the collections' information sheets.

Diamond Cuts

During the period considered for this review, four cutting styles stand out as the most popular in Portuguese jewellery: the *point cut* (from prior to the 16th century until the very end of the 1500s), the *table cut* (from the first half of the 16th century until the 18th century), the *rose cut* (developed in the 15th century with a long-lasting presence in jewellery, even rarely seen today), and the *old brilliant cut* (from the mid-18th century onward). Following are some considerations about these four cutting styles and their use in Portuguese jewellery.

Point Cut

Until the late 1300s, diamonds were set in jewellery in their rough state, often displaying a euhedral crystal form (most commonly the octahedron). There are examples of Roman jewellery dating back to the 2nd century AD that contain uncut diamond crystals as gems (Bedini et al., 2012). Octahedra set in jewellery resemble a pyramid, so the name *point* became common to describe them. In Portugal during the 16th century, such a diamond was also called a *naife* (Barbosa, 1519; Orta, 1563), a French term possibly dating back to the 12th century (Tillander, 1995).

During the 15th century, advances in technology and expertise permitted the cutting and polishing of diamond crystals. Since the square pyramidal shape described above was prized and popular all around Europe, it was natural for early diamond cutters to mimic this shape (Figure 2). In addition, by following the

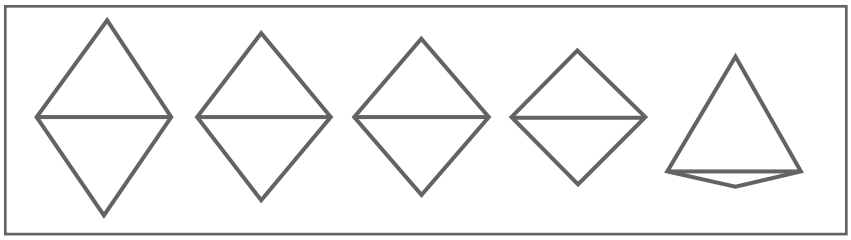

Figure 2: The point cut roughly follows the shape of an octahedral diamond crystal. These drawings show the appearance of different proportion variations. After Tillander (1995).

shape of the octahedral faces, the cutter could obtain the best weight retention (Bari and Sautter, 2001). Note that the designation of *point* can be misunderstood in the literature, since it has been used for uncut octahedra, and also for actual point cuts with proportions different from those of natural diamond crystals (as well as poorly or superficially cut octahedra; J. Ogden, pers. comm., 2014). The proper use of *point cut* should be restricted to fashioned diamonds (Tillander, 1995; Harlow, 1998), whereas the word *point* by itself may refer to the shape of either rough or cut diamonds.

In Portugal, and elsewhere in Europe, this shape had a significant impact beyond jewellery, in both architecture and decorative arts. The facade of the Casa dos Bicos in Lisbon (Figure 3; built in ca. 1523 by D. Braz de Albuquerque) provides a stunning example of the presence of diamonds in architecture. The point motif is also evident in the Palazzo dei Diamanti, in Ferrara and Bevilacqua (Bologna, Italy), which both predate the Lisbon building. In the decorative arts, clear allusions to point-cut diamonds are shown by small pyramid decorations, (1) on a late-1400s silver platter from the collection of the Fundação Ricardo Espírito Santo Silva, and (2) on a 1500s rock-crystal pectoral cross from the Museum Nacional de Machado de Castro, in Coimbra, Portugal. Probably the most famous examples are depicted by late-16th-century tiles manufactured in Seville, Spain, with motifs representing both point and table cuts (Figure 4). These tiles commonly decorate the interior of period churches and important homes. The richness of these references to point-shaped diamonds reveals the importance they had in European society at that time.

In central Europe, there are only a few examples of point-cut diamonds in jewellery, mainly from the 15th–16th centuries, but they are not from Portugal. In fact, among the numerous Portuguese artefacts currently referenced in both public and private collections, only one has a point-cut diamond: the reliquary of the Holy Thorn and Holy Cross (Figure 5), which was commissioned by Queen Leonor, widow of King John II of Portugal (1445–1495); this sacred object was made in 1510 by a foreign goldsmith known as 'Mestre João' (Vassalo e Silva, 1991; Galopim de Carvalho, 2010). The near-colourless point-cut diamond that it contains has an apparent black

Figure 3: Point-cut diamonds are clearly represented on the facade of Casa dos Bicos (House of Spikes; ca. 1523) in Lisbon, Portugal. Photo by Joaomartinho63, via Wikimedia Commons.

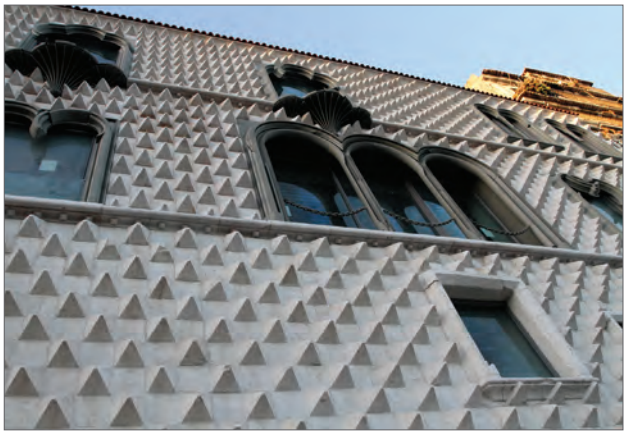

Figure 4: These late-16th-century Spanish tiles in the Church of São Roque, Lisbon, have motifs representative of point- and table-cut diamonds. Each tile measures approximately 14 cm across. Photo by R. Galopim de Carvalho.

Figure 5: The gold, enamel and gem-set reliquary of the Holy Thorn and Holy Cross (35.0 × 15.5 × 12.0 cm), commissioned by Queen Leonor of Portugal (ca. 1510), contains the only point-cut diamond known in a Portuguese artefact. The diamond is located under the cross in the upper-middle part of the relic (see arrow and the enlarged view in the inset). Note the apparent dark colour of the stone. Photo courtesy of Museu Nacional de Arte Antiga, Lisbon; © IMC-DDF.

colour that is due to the extinction of light within the gem, combined with the closed setting and dark backing (Tillander, 1995). This circumstance is also visible in the work of the period's painters, who would use a dark colour to represent point-cut diamonds in their portraits. For example, a portrait of Maria Maddalena Baroncelli by Hans Memling (ca. 1435–1494) clearly shows a necklace set with gems, in which a point-cut diamond is represented using dark paint (Figure 6).

Table Cut

The opening of the sea route to India by Portuguese navigators in the late 1500s contributed to the greater availability of diamonds (and other gemstones) in Europe (Vassalo e Silva, 1989). As more stones became available to the continent's diamond cutters, new cutting styles started to take off along with the established point cuts that remained in use throughout the 16th century. The *table cut* became popular during the first quarter

Figure 6: In this portrait of Maria Maddalena Baroncelli (ca. 1471) by Hans Memling, a point-cut diamond in the necklace (see arrow) is painted in a dark colour, thus representing its appearance. Oil on wood, 42.2 × 32.1 cm; photo courtesy of the Metropolitan Museum of Art, New York, USA.

of the 16th century, although small numbers of these diamonds may have been present in European inventories dating back to the 15th or even 14th centuries. Table-cut diamonds were cut in a quadrangular (usually square) shape with 10 facets (Figure 7). A large quadrangular top facet (or table) replaced the apex of a point-cut, and a smaller parallel facet was placed on the opposite point (the culet). This cutting style was conveniently used to repolish point-cut diamonds that were damaged in jewellery. It represents the first time a popular diamond cutting style embraced the concept of a crown and pavilion (although these words seem to have appeared much later, when describing brilliant cuts).

Figure 7: These drawings of a table-cut diamond show views from the top (left) and bottom (right).

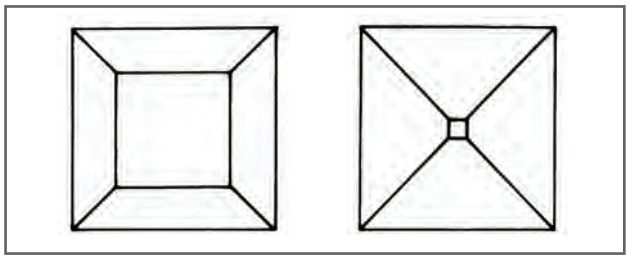

Figure 8: In this early-17th-century gold-and-enamel pendant (5.9 × 3.5 cm), six table-cut diamonds form the arms of the cross together with a rose-cut diamond at the base. Note the darker appearance of the table-cut diamonds. Photo courtesy of Museu Nacional de Arte Antiga, Lisbon; © IMC-DDF.

Table cuts were extensively used in the 16th century to the first half of the 17th century, and they still enjoyed occasional use in the 18th century, but mainly in smaller sizes. Two rings containing table-cut diamonds are present in the Museu Nacional de Arte Antiga, Lisbon; one is dated ca. 1550 and the other is from a later period in the same century (Orey, 1995). The museum also has a gold-and-enamel cross pendant dating from the beginning of the 1600s that is set mainly with rectangular table cuts (Figure 8). Additional examples are described in the literature (Orey, 1995).

As with point cuts, table-cut diamonds commonly have a dark appearance due to

Figure 9: In this Joos van Cleve portrait (ca. 1530) of Eleanor of Austria, all the diamonds in her jewellery are painted to look dark, as was consistent with the appearance of table-cut stones. The inset is an enlarged view to show the diamonds in more detail. Oil on panel, 35.5 × 29.5 cm; photo courtesy of Museu Nacional de Arte Antiga; © IMC-DDF.

Figure 10: This close-up of the reliquary of the Holy Cross of Évora's cathedral shows a line of small table-cut diamonds, each with an estimated weight of less than 0.05 ct. Photo by R. Galopim de Carvalho.

extinction, but not to the same extent. Again, paintings offer valuable information, as seen in a ca. 1530 Joos van Cleve portrait of Eleanor of Austria (third wife of King Manuel I of Portugal; Figure 9). The quadrangular gems and the triangular centre stone are depicted by the artist using dark paint.

The popularity of table-cut diamonds started to decline significantly in the 17th century, in favour of more fashionable rose cuts (see below). Table cuts were reserved almost exclusively for smaller stones. As an example, the reliquary of the Holy Cross of Évora's cathedral (Figures 1 and 10), from the late 1690s, is set with 845 diamonds—but only 46 are table cuts, and all of these are under 0.05 ct (Galopim de Carvalho et al., 2011).

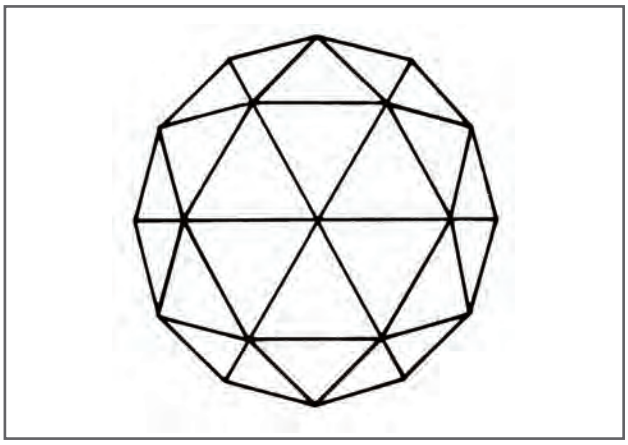

Figure 11: The top view of a rose cut (specifically, the Holland rose) is shown in this drawing. The bottom view is not shown since rose cuts have a flat base.

Diamond simulants were also cut according to fashion, and some curious examples have been identified with table cuts. For example, a 17th century devotional pendant in the collection of the Museu Nacional de Machado de Castro (Coimbra, Portugal) is set with table-cut rock-crystal (Luz Afonso, 1992, pp. 338–339).

Rose Cut

The *rose cut* began gaining popularity in the 1500s, although its presence in jewellery was more pronounced during the 1600s and in the first half of the subsequent century. This cut generally consists of a flat-based dome covered with triangular facets of diverse symmetry resembling a fully-blossomed rose (Figure 11). This cut may show several variations, depending on the number of facets and their disposition (Tillander, 1995). The most popular variation from Portugal has 24 facets arranged in two circular rows, with six-fold symmetry, in a pattern known as the *Holland rose cut*. Various stone shapes were used (e.g. round, oval, pear, etc.), with round being most common. However, the rounds almost always showed an irregular outline until technology improved during the second half of the 19th century. Rose cuts show greater light reflection from the surface of the faceted dome, creating a visual effect that is much brighter than shown by the previously mentioned cutting styles, especially when illuminated by candlelight.

Rose cuts coexisted with table cuts for many decades, but in the 17th century they became the cut of choice. This is exhibited by the late-17th-century reliquary of the Holy Cross of Évora's cathedral (Figure 1), in which the vast majority of diamonds, some with estimated weights of more than 2 ct, are rose cuts (Figure 12). Another example is provided by the Patriarchal Monstrance, a 17 kg solid gold gem-set implement ordered by King John V of Portugal (Lourenço, 1996; Galopim de Carvalho, 2010). The vast majority of diamonds except those set in the aura (of later manufacture) are rose cuts in various shapes, suggesting that this style of cut was the most appreciated, available and sought after at the time of King John's order in the second quarter of the 18th century. Likewise, diamond simulants were cut in this style, and an interesting example is provided by a pair of gold earrings

Figure 12: The top of the reliquary of the Holy Cross of Évora's cathedral contains a rose-cut diamond with an estimated weight of 2 ct. Photo by Carlos Pombo Monteiro; © Fundação Eugénio de Almeida—Arquidiocese de Évora, Portugal.

Figure 13: These 18th-century gold earrings (each 7.0 × 1.6 × 1.2 cm) are set with colourless pastes in rose cuts, simulating diamonds as they were supposed to look. The inset has been enlarged to show one of the pastes in more detail. Photo by Carlos Pombo Monteiro; © Fundação Eugénio de Almeida—Arquidiocese de Évora, Portugal.

from the 18th century set with small rose-cut paste (Figure 13).

Such appreciation for rose-cut diamonds is also seen in secular jewellery (both gold and silver) manufactured in the first half of the 1700s. Some important jewels from this period containing large rose-cut diamonds are housed in the Museu Nacional de Arte Antiga in Lisbon, which holds one of the most important collections of Portuguese historical jewellery in the country.

With the advent of the brilliant cut in the mid-18th century, the popularity of rose cuts declined in larger and in most smaller diamonds. Many of the larger diamonds were subsequently re-cut as brilliants (Jeffries, 1751).

Old Brilliant Cut

Massive quantities of diamonds started to arrive in Portugal and Europe after the discovery of Brazil's gem fields in the 1720s; the amounts far surpassed production from India and Borneo (Lenzen, 1970; Ogden, 2005; Drumond Braga, 2007). With the greater abundance and availability of diamonds, jewels progressively transformed into metal structures to hold as many stones as their face-up surface would allow (e.g. Figure 14), rather than the elaborate gold or silver artefacts in which diamonds served as isolated details throughout the design. As such, diamond jewellery became lavishly plentiful of diamonds, making the metal progressively more invisible as it merely was used to secure the stones. This trend was also seen in historical Portuguese coloured gemstone jewellery, known for its extensive use of Brazilian gems (Vasconcelos e Sousa, 1999, 2010; Galopim de Carvalho, 2006a, 2010).

The plentiful supply of diamonds during this period may also have been responsible for greater boldness and experimentation in cutting diamonds. Even prior to the discovery of the Brazilian deposits, a new cutting style was evolving, consisting of a distinct crown (with a table facet) and a pavilion (containing a culet). In the crown there were two sets of triangular facets, which is a possible reason why some authors have called this the *double cut* (Gaal, 1977). This cutting style has only been seen in rather small diamonds (less than a quarter carat) in 18th-century jewels observed by the author. However, during the late 17th century, a more complex development of this cut was made in Europe, comprising a greater number of facets on the crown (33) and pavilion (25), for a total of 58, with a squarish shape (Jeffries, 1751; see Figure 15). This style is called the *brilliant cut* due its much greater brilliance compared to the other cutting styles of that period. In the candlelight that illuminated the salons where social events took place, these brilliants reflected back much of the incident light, generating scintillation and fire. This visual effect

Figure 14: This mid-18th century demi-parure demonstrates the trend of using as many diamonds as possible in a jewellery piece, which occurred after the discovery of Brazil's diamond fields in the 1720s. Although this jewellery contains rose cuts, the preferred faceting style later shifted to brilliant cuts toward the end of the century. The pendant is 7.3 × 4.9 × 1.2 cm, and the earrings each measure 4.8 × 2.8 × 1.9 cm. Photo by Carlos Pombo Monteiro; © Fundação Eugénio de Almeida—Arquidiocese de Évora, Portugal.

played an important role in the way diamonds were perceived in fashion (Becker, 1987).

If we look at diamond-set jewellery of this period through the eyes of a painter, diamonds were no longer depicted with a dark grey or black colour, but rather with white, light grey or slightly tinted whites. This is consistent with a major evolution in the appearance of diamonds in jewellery that is still valued today: whiteness and brilliance. Even the name *brilliant* is still used today to describe the most popular modern proportioned cutting style. Curiously, the original style is now called *old brilliant* or *old mine* to distinguish it from the 20th century's modern brilliant which has different proportions.

Brilliant-cut diamonds rapidly surpassed rose cuts in popularity in the second half of the 18th century, in both gold and silver jewellery of devotional as well as secular use (Galopim de Carvalho, 2009). By this time, table cuts were almost non-existent and double cuts were seen only occasionally in small sizes. Rose cuts were still in use, but to a much lesser extent in progressively smaller sizes, and particularly in shallow stones where the brilliant proportions would result in excessively low yield from the rough. Brilliant cuts eventually were preferred even in smaller stones, as seen in many jewels of the period. An interesting variation of the brilliant cut is the little-known *Lisbon cut* (see Box A).

The Portuguese royal collections are useful repositories for illustrating the importance of the brilliant cut in regalia dating mostly from the last quarter of the 18th century. An abundance of large, good-quality brilliant-cut diamonds entirely covers the surface of some of the jewels (Silveira Godinho, 1991). Also, some important devotional implements are richly decorated with diamonds

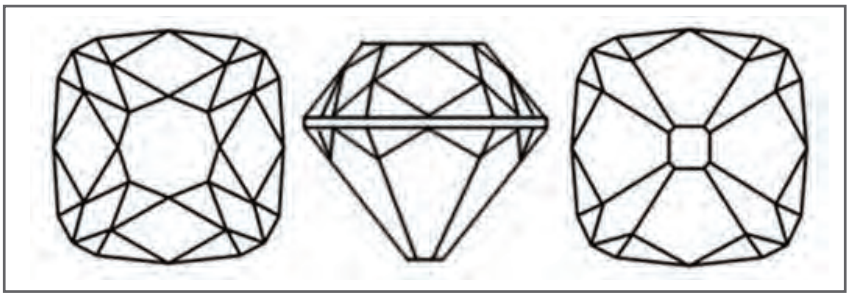

Figure 15: The facet pattern of the early brilliant cut is shown from the crown (left), side (centre) and pavilion (right) in these drawings.

BOX A: The Lisbon Cut

The Lisbon cut is usually defined as a modified old-mine cut with 16 extra facets (eight on the crown and eight on the pavilion), for a total of 74 facets (Figure A-1). Little is known about the development of this brilliant cut or the origin of its name. It seems to have appeared in the literature only around the 1850s (J. Ogden, pers. comm., 2014).

Of the many thousands of diamonds inspected in 18th-century Portuguese jewellery, only one diamond that provides evidence for the Lisbon cut has been identified by this author. This approximately 10 ct oval-shaped diamond (Figure A-2) is mounted in a gold snuff box that was made in ca. 1755–1756 by a French jeweller (Jacmin, who lived 1718–1770). However, the extra facets are present only on the crown and not the pavilion, so this stone has a total of 66 facets rather than the 74 that have been proposed in the literature for the Lisbon cut. Nevertheless, this diamond provides the only known physical evidence of the Lisbon cut in Portuguese jewellery and elsewhere.

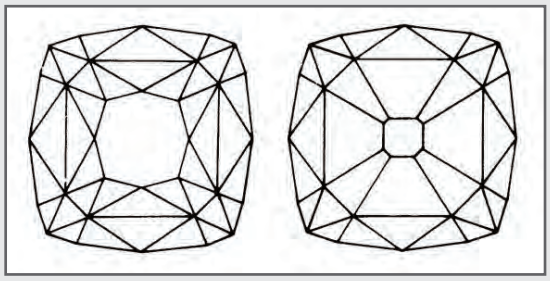

Figure A-1: These diagrams of the Lisbon cut show the facet arrangements on the crown (left) and pavilion (right).

Considering Portugal's connection with Brazil and its diamonds, one would assume that diamond manufacturing was important in Portugal during the 17th–18th centuries. Research is on-going into Portugal's diamond cutting industry at that time, and more information on the Lisbon cut should become available in the future.

Figure A-2: This approximately 10 ct oval diamond, set in a gold snuff box made in ca. 1755–1756 for King José I of Portugal, contains extra facets on the crown that are consistent with the design of the Lisbon cut. The bezel facets are each divided into two triangular facets. Photo by R. Galopim de Carvalho; courtesy of Palácio Nacional de Ajuda, Lisbon.

Figure 16: The aura of the Bemposta Monstrance (97 × 33 cm), a late-18th-century implement richly set with thousands of gems, is decorated with brilliant-cut diamonds. Photo courtesy of Museu Nacional de Arte Antiga, Lisbon; © IMC-DDF.

faceted in this style (Vassalo e Silva, 2000). Some artefacts stand out for their size and importance, such as the Bemposta Monstrance (Figure 16) and the Estrela Monstrance (Figure 17). In the latter piece, not all the colourless gems in the aura are diamonds. Some are substitutes, namely topaz and very slightly blue to colourless beryl (Galopim de Carvalho, 2008).

In pre-19th-century Portuguese jewellery, most diamonds were set in silver, whereas coloured gemstones (e.g. ruby and emerald) were typically set in gold. The settings commonly were close-backed, not *a jour* as open settings were called. This caused the apparent extinction of the brilliant's culet, making it appear as a dark point in the centre of the diamond (e.g. Figure 18). This visual characteristic was perceived as proper for diamonds in those days, and even diamond simulants were made to look as if the culet was dark. In Portugal, the most popular simulants were quartz, topaz and beryl, all colourless to near-colourless, and because they were set with a foil back, the culets were painted black to achieve the desired appearance face-up (Galopim de Carvalho, 2008). However, there is no significant record of the use of foils (either colourless or coloured) in diamond settings in Portuguese jewellery, as reported for European jewels of the same period in the late 18th century (Becker, 1987), since the foils were only used for coloured gemstones.

Conclusion

The jewellery industry in Portugal was vibrant from the late 15th century (when navigators opened the sea route to Asia) until the early 19th century, prior to Napoleonic invasions. The significant amount of dated diamond-set jewellery and sacred objects in Portuguese public and private collections tells the story of the evolution of diamond cuts during this period. The greater number of more recent

Figure 17: The colourless gems set in the aura of the Estrela Monstrance, commissioned in the last quarter of the 18th century, consist of brilliant-cut diamonds as well as topaz and beryl. The dimensions of the monstrance have not been published, but the entire piece is estimated to be 1 m tall. Photo © Patriarcado de Lisboa, Portugal.

jewellery pieces is interpreted as evidence that out-of-fashion jewels were dismantled, either motivated by fashion or as a consequence of the sale of those pieces for financial gain. In the same manner, recutting diamonds to meet fashion trends also explains the scarcity of older cuts.

Point-cut diamonds were in existence prior to the 16th century. They were eventually overtaken by the table cut, which remained popular during the first half of the 16th century before being progressively relegated to smaller-sized stones. The rose cut emerged in the 1500s and coexisted with small table cuts until newer cutting styles became more fashionable. The brilliant cut became prominent in the mid-1700s, coincident with the availability of large quantities of diamonds from Brazilian mines. The brilliant cut rapidly surpassed the rose cut as the style of choice.

A distinct change in the visual appearance of faceted diamonds occurred when brilliant cuts came into play, as they showed much better light return, sparkle and fire than the previous cuts, a circumstance that was well illustrated in portraits from the 18th and 19th centuries. Moreover, due to the fact that brilliant-cut diamonds were mostly set in closed-back settings, their culet looked like

Figure 18: This gold and silver breast pin (ca. 1758; 6.8 × 7.8 × 1.8 cm) is set with brilliant-cut diamonds, rubies, garnets and a foil-backed pink topaz for the centre stone. Note the diversity of the brilliant-cut shapes and the dark culets shown by the diamonds. The pin also demonstrates the use of different metals to set diamonds (silver) and coloured gemstones (gold). Photo by Carlos Pombo Monteiro; © Fundação Eugénio de Almeida—Arquidiocese de Évora, Portugal.

a black dot. This visual effect was replicated in diamond simulants, in which the culets were painted black.

The information provided in this brief review, based on the observation of Portuguese jewellery and devotional objects, may serve as an illustration of the trends in diamond cutting within wider European manufacture.

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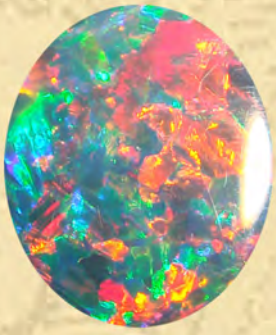

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Beryllium-Diffused Corundum in the Japanese Market, and Assessing the Natural vs. Diffused Origin of Beryllium in Sapphire

Kentaro Emori, Hiroshi Kitawaki and Makoto Okano

More than a decade has passed since Be-diffused corundum was first recognized by gemmologists, and such material is still present in the gem market. This study summarizes data from about 22,000 pieces of corundum submitted for identification to the Central Gem Laboratory in Japan in 2012. LA-ICP-MS analysis revealed an average of 10 ppm beryllium in Be-treated samples, regardless of corundum colour or the specific spot analysed on a stone. Traces of naturally occurring Be also were detected in corundum that was identified in the laboratory as being heat treated without Be-diffusion treatment. Such stones were identified by their colour distribution and by wide variations in Be measured in different spots, which was positively correlated with other trace elements (i.e. Nb and Ta in blue sapphires, and Zr and Hf in yellow to yellowish orange sapphires). These elements were typically associated with clouds of minute inclusions, but they also were present in the blue sapphires in areas where no inclusions were visible with the gemmological microscope. While the LA-ICP-MS technique is useful for identifying Be-diffused corundum, the simple presence of Be is not always proof of this treatment.

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Introduction

Since September 2001, vividly coloured sapphires including orangey red, orange, pink and yellow have been widely seen on the gem market (e.g. Figure 1). In particular, the sudden emergence of numerous orangey pink to pinkish orange (padparadscha-like) sapphires raised concern in the jewellery industry. These stones showed a surface-conformal layer (coloured rim) that was not due to conventional heat treatment. Research by international gem laboratories elucidated that these sapphires had been subjected to a new

Figure 1: Various colours of Be-diffused corundum in the marketplace are shown here. The rough pieces weigh 0.10–0.13 ct, and the faceted stones range from 0.42 to 1.53 ct. Photo by H. Kitawaki.

heating process called Be-diffusion treatment, in which the light element beryllium originated from pieces of chrysoberyl that were also present in the crucible (Emmett et al., 2003). Nowadays Be-diffusion treatment is also applied to some blue, violet and green sapphires, as well as to ruby.

The existence of a surface-conformal layer suggests the diffusion of elements of external origin. However, some Be-diffused corundum does not show such a colour layer, and therefore cannot be visually identified. Thus, direct chemical analysis of Be is needed to detect the treatment. Beryllium is a light element, so it cannot be detected by standard analytical techniques in gemmological laboratories such as X-ray fluorescence. More sophisticated analyses including laser ablation–inductively coupled plasma–mass spectrometry (LA-ICP-MS) or laser-induced breakdown spectroscopy (LIBS) are required to detect the trace levels of Be. Well-equipped laboratories now employ such instrumentation for the identification of Be-diffused corundum on a daily basis (e.g. Abduriyim and Kitawaki, 2006).

Initially, the detection of Be by LA-ICP-MS was regarded as evidence of Be-diffusion treatment because it was thought that this element did not exist within untreated corundum. However, traces of naturally occurring Be have subsequently been confirmed in untreated corundum (e.g. Shen et al., 2007), which has made the identification of Be-diffusion treatment more complicated.

In this study, we report on (1) statistical data regarding the presence of Be-diffused corundum in the Japanese gem market, and (2) a method for distinguishing between stones treated by Be diffusion and those containing Be of natural origin by measuring their trace-element signatures using LA-ICP-MS.

Materials and Methods

More than 22,000 samples of corundum that had been submitted to the Central Gem Laboratory (CGL) in 2012 were evaluated for this study. More than 1,000 of these were suspected to be Be-diffused after standard gem testing, due to their coloration, inclusions that showed evidence of high-temperature heating, and absence of hydrogen-related absorption features recorded by infrared spectroscopy (cf. Emmett et al., 2003). Those stones were therefore analysed by LA-ICP-MS when permitted by the client.

Since CGL's identification service is not based on a membership system and the laboratory accepts stones from any client, the samples of this study are considered representative of the sapphires and rubies in the Japanese market. In addition, to study the relationship between natural-origin Be and other trace elements, we obtained LA-ICP-MS analyses of 86 pieces of corundum that were collected for a geographical origin determination project. Although some of these samples had undergone conventional heat treatment, none were Be diffused.

A New Wave Research UP213 laser ablation unit and an Agilent 7500a ICP-MS system were used for trace-element analysis (see Table I for

Table I: Analytical parameters of LA-ICP-MS.

Laser Ablation	New Wave Research UP213
Wavelength	213 nm
Crater size	15 µm or 30 µm
Laser power	0.025 mJ
Pulse	10 MHz
Ablation time	25 sec
ICP-MS	**Agilent 7500a**
ICP	27.15 MHz
RF power	1200 W
Gas flow	Plasma gas: 14.93 l/min
	Auxiliary gas: 0.89 l/min
	Carrier gas: 1.44 l/min
Analysis mode	Al: analog mode
	Be, Zr, Nb, Hf, Ta, W, Th: pulse counting mode
Sample introduction	Torch: SiO_2
	Skimmer cone: Ni
	Sampling cone: Ni
Integration time	Al: 0.01 sec
	Be, Zr, Nb, Hf, Ta, W, Th: 0.1 sec

equipment parameters). The size of the analytical crater was 15 µm for the qualitative detection of Be and 30 µm for quantitative trace-element analysis. Two points were analysed on the girdle of each stone, and if Be was detected and suspected to be of natural origin, then up to eight points were analysed. The external standard used was NIST SRM 612 multi-element glass, and we set the internal standard to Al_2O_3 = 99.0%. The analyses are reported in units of parts per million by weight.

Results and Discussion

The Proportion of Be-Diffused Corundum and Its Be Content

Figure 2 shows the colour variations of all the corundum submitted to CGL in 2012 on the left, and the coloration of just the Be-diffused corundum from that year is shown on the right. Among the former, ruby and blue sapphire were dominant, while the latter mostly consisted of pink to orange (including padparadscha-like) and yellow to yellowish orange stones.

For each of the colour groups shown in Figure 2, the proportion of corundum samples was then calculated according to the following parameters:

- Beryllium diffused, as determined by LA-ICP-MS
- Beryllium diffused, as determined by standard identification methods
- Not analysed, due to client preference or jewellery mounting
- Not beryllium diffused

As depicted in Figure 3, the yellow to yellowish orange stones showed the maximum probability of being Be-treated, and a significant proportion of the pink to orange samples also were diffused with Be. Among those samples determined to be Be-diffused, some of the pink to orange sapphires had surface-conformal layers, but the yellow to yellowish orange and blue sapphires did not have such layers.

Figure 4 shows the range of beryllium concentration in Be-diffused corundum analysed by LA-ICP-MS in each colour group. The average concentration of Be in each colour variety was approximately 10 ppm, regardless of the stones'

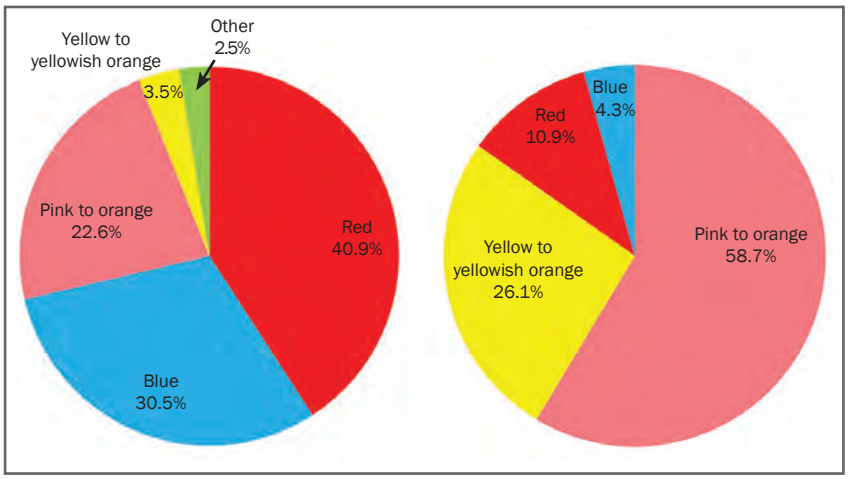

Figure 2: The colour variations of the corundum submitted to CGL in 2012 are plotted on the left, and the coloration of the Be-diffused samples is shown on the right.

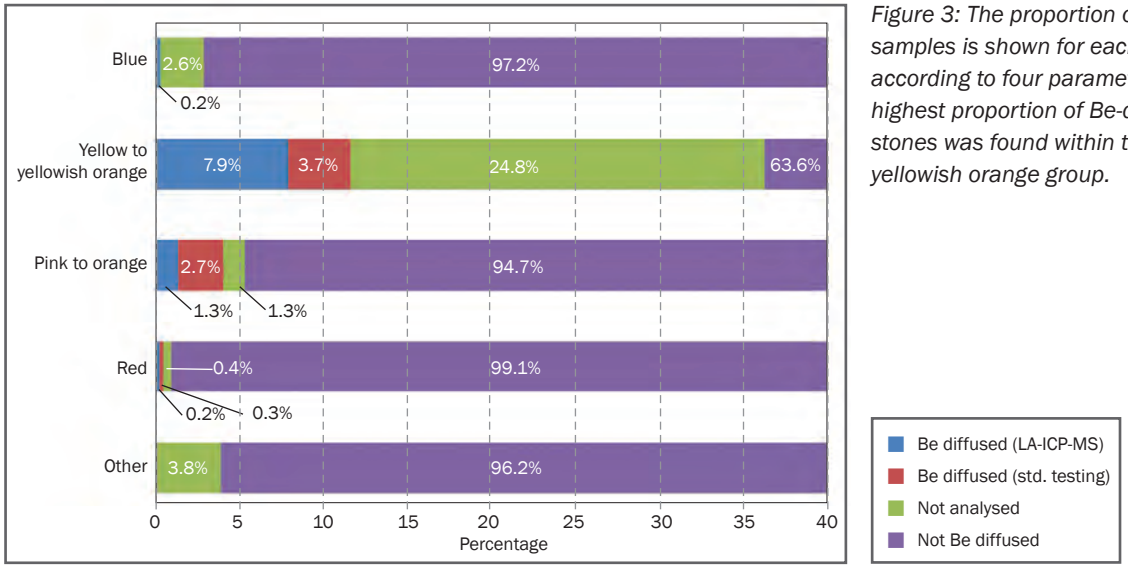

Figure 3: The proportion of corundum samples is shown for each colour group according to four parameters. The highest proportion of Be-diffused stones was found within the yellow to yellowish orange group.

coloration or the location of the analytical spots on the sample. This is quite close to the average value (9.74 ppm) obtained for 20 samples of Be-diffused corundum of various colours that were directly obtained from gem treaters in Bangkok, Thailand, by one of the authors (HK) in 2002 and 2007. The lowest beryllium concentration measured in the Be-diffused samples was 2 ppm. There was no correlation between Be and other trace elements in the corundum samples treated by Be diffusion.

Sapphires Containing Natural-Origin Beryllium

Yellow to Yellowish Orange Sapphires: A 16.95 ct yellowish orange sapphire (Figure 5) of unknown origin was identified in our laboratory as having undergone standard heat treatment, and it did not show features of Be-diffusion treatment such as a coloured rim. However, since the lack of a coloured rim does not preclude Be-diffusion treatment, we analysed it by LA-ICP-MS. Analyses of eight random points on the stone's girdle showed the following: 1.42–7.14 ppm Be, 0.65–11.11 ppm Zr and 0.09–2.24 ppm Hf; the elements Nb, Ta, W and Th were not detected. Shen et al. (2009) reported a similar correlation between Be, Zr and Hf, and concluded that these trace elements were of natural origin. Figure 6 shows a fairly well-defined positive correlation of Be with Zr and Hf.

Similar trace-element results were obtained for 34 pieces of yellow to yellowish orange sapphires identified as containing natural-origin Be that were analysed in routine daily work in

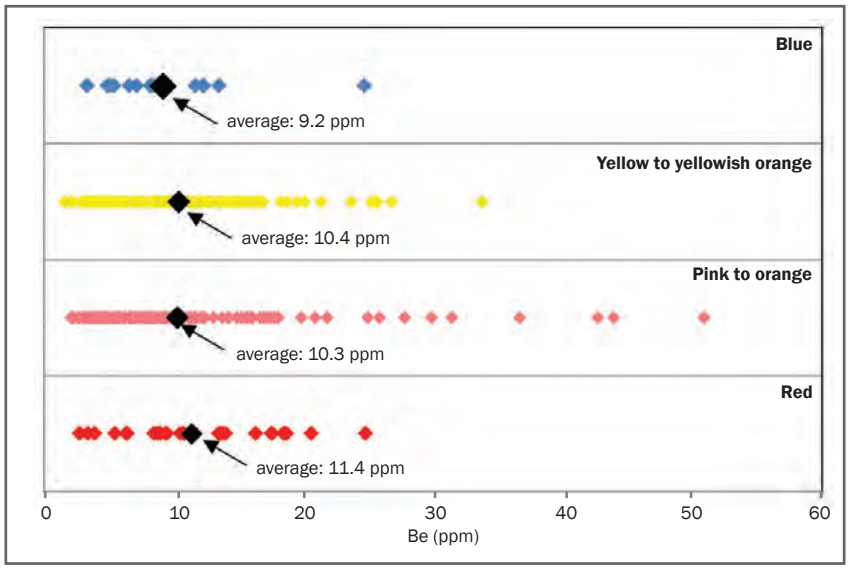

Figure 4: Beryllium concentration ranges are shown for the four colour groups of Be-diffused corundum analysed in this study. The average value for each colour group is approximately 10 ppm Be.

Figure 5: This 16.95 ct yellowish orange sapphire of unknown origin is inferred to have undergone standard heat treatment, but not Be-diffusion treatment. Nevertheless, the stone contains concentrations of 1.42–7.14 ppm Be, together with Zr and Hf. Photo by K. Emori.

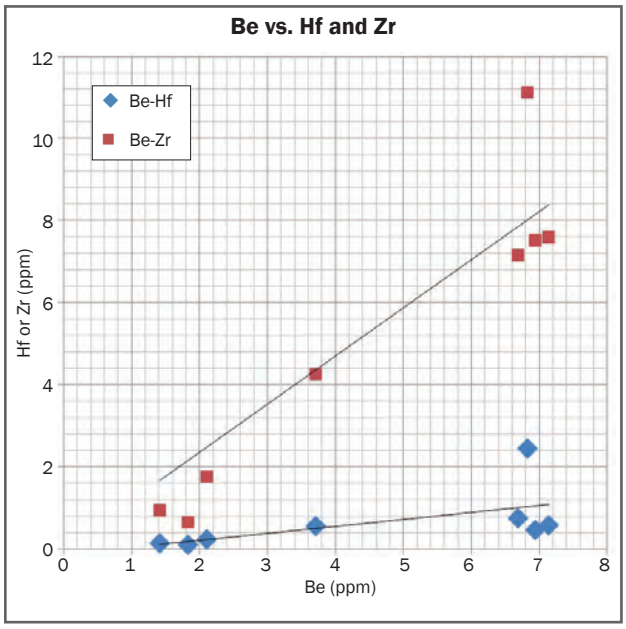

Figure 6: A fairly well-defined positive correlation of Be with Zr and Hf is shown by the 16.95 ct yellowish orange sapphire. This correlation is consistent with the presence of natural-origin Be.

2012. These sapphires constituted 4.4% of the overall number of yellow to yellowish orange sapphires that were examined in our laboratory during that time.

Blue Sapphires: We also found natural-origin Be in 14 blue sapphires from Cambodia, Nigeria and Laos (Figure 7), which are of magmatic origin (Hughes, 1997), that were obtained for our studies of geographical origin determination. These stones were provided by a dealer in Chanthaburi, Thailand, who owns mines all over the world. We were told that they had undergone standard heat treatment but were not Be-diffused. Our examination showed inclusion features that were consistent with this claim, and none of the stones had the coiled spring-like inclusions that are commonly seen in Be-diffused blue sapphires (DuToit et al., 2009). However, LA-ICP-MS analyses (five spots per sample) showed widely varying amounts of Be in all these samples, ranging from undetectable to nearly 10 ppm (Table II), typically in association with clouds of particles observed with the gemmological microscope. Nevertheless, Be was also detected from some areas in which no clouds or other inclusions were visible. The trace elements Nb and Ta were well correlated with Be, as plotted in Figure 8. The majority of the analysis showed <1 ppm Be.

Figure 7: These blue sapphires of magmatic origin were found to contain naturally occurring beryllium. Top row: Pailin, Cambodia (0.59–0.74 ct), middle row: Mabila, Nigeria (0.88–1.44 ct) and bottom row: Ban Huay Xai, Laos (0.92–1.11 ct). Photo by K. Emori.

Table II: Trace elements in blue sapphires from Cambodia, Nigeria and Laos containing natural-origin Be.[a]

Element	Cambodia	Nigeria	Laos
Be	nd–5.65	nd–9.69	nd–7.15
Nb	nd–191	nd–5.53	nd–25.1
Ta	0.32–140	nd–18.4	nd–175

[a] The elements Zr, Hf, W, and Th were sought but not detected.
Abbreviation: nd = not detected.

Among the client stones submitted to our laboratory in 2012, 14 of the blue sapphires (or 0.2%) proved to contain natural-origin Be, with the same trace-element associations described above. Some were of magmatic origin, but others were of metamorphic origin resembling sapphires from Madagascar or Sri Lanka.

Summary: The presence of natural-origin Be in sapphire is correlated with the following characteristics:

(1) The absence of the coloured rim that is shown by some pink to orange Be-diffused corundum
(2) Be concentrations that vary significantly from undetectable or very small amounts up to 10 ppm in different spots of a sample
(3) Most importantly, a well-defined positive correlation between Be and Zr and Hf in yellow sapphires, or Be and Nb and Ta in blue sapphires.

Figure 8: The blue sapphires with naturally occurring Be collected for our geographical origin studies showed a good correlation between the concentration of Be and that of Ta and Nb.

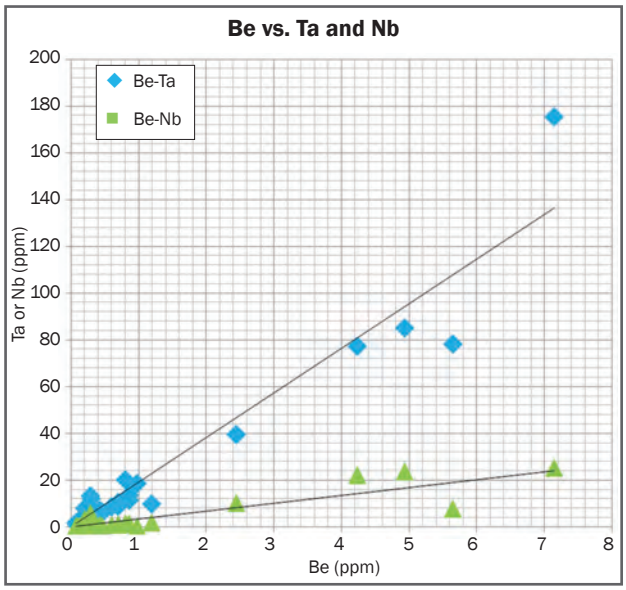

Natural Incorporation of Be and Associated Trace Elements into Corundum

Chemical elements are divided into four categories depending on their affinity: *atomophile* (gaseous elements), *lithophile* (elements concentrated in a silicate phase), *chalcophile* (elements concentrated in a sulphide phase, such as Cu) and *siderophile* (elements with an affinity for metallic Fe; see e.g., Gill, 1996). The elements Be, Zr, Hf, Nb, Ta, W and Th are lithophile (Figure 9), and they also are known as geochemically *incompatible* since they typically are omitted from the crystallization of rock-forming minerals and are therefore concentrated into the residual liquid phase during magmatic crystallization. They also may be the first elements to be released during the partial melting of the earth's crust (Gill, 1996).

Elements with an ionic potential (i.e. nominal cation charge divided by ionic radius) that fall in the range between 30 and 80 nm^{-1} are called *hydrolysates* (Figure 10), and these elements become insoluble precipitates when they undergo

Figure 9: The four affinity categories of chemical elements are shown in this diagram. Beryllium, Zr, Nb, Hf, Ta, W and Th are considered lithophile elements, meaning they are concentrated in a silicate phase. Adapted from Gill (1996, p. 247).

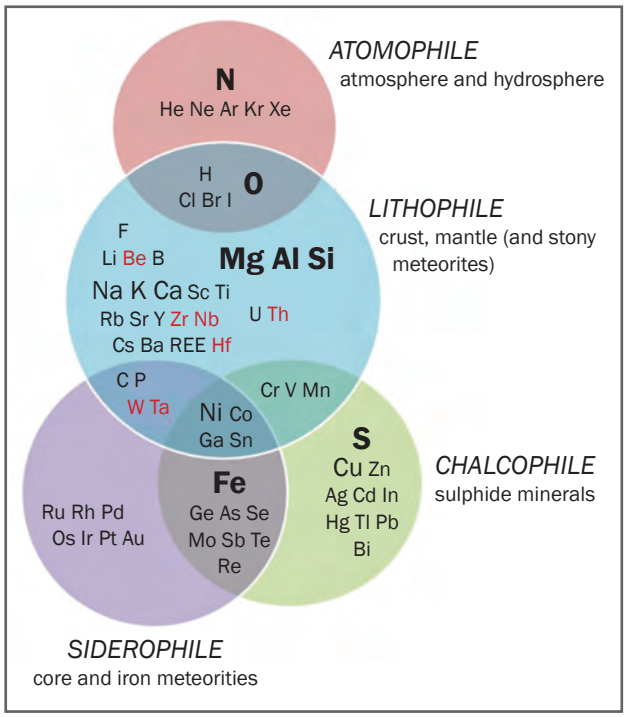

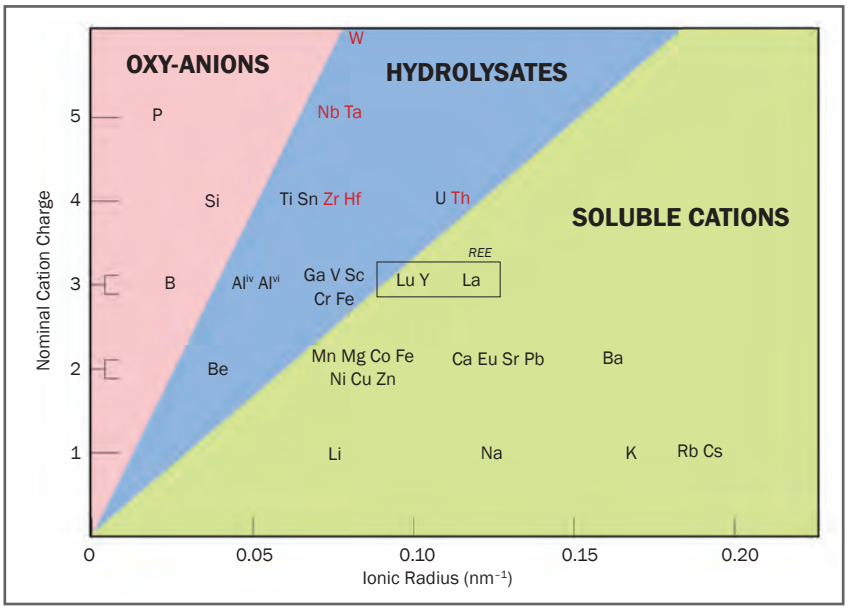

Figure 10: Based on their ionic potential, Be and the other elements shown in the blue area are categorized as hydrolysates. Adapted from Gill (1996, p. 207).

hydrolysis (Gill, 1996). For example, in the case of aluminium:

$$Al^{3+} + 3H_2O \Rightarrow Al(OH)_3 + 3H^+$$
(insoluble precipitate)

We propose that in corundum containing natural-origin beryllium, the incompatible lithophile elements Zr, Nb, Hf, Ta and potentially other elements were concentrated and underwent hydrolysis together with Be, and were then incorporated into corundum as minute inclusions.

A different type of minute inclusion was documented by Shen and Wirth (2012) in a blue sapphire from Ilakaka, Madagascar, that had cloudy inclusions associated with Be, Nb and Ta. High-resolution transmission electron microscopy showed that the clouds consisted of nano-inclusions of an unnamed Ti-rich phase that had the same crystal structure as scrutinyite (α-PbO_2). The Be, Nb and Ta are evidently incorporated together into this unnamed phase.

Figure 11: Viewed in immersion, this 5.55 ct yellow sapphire shows distinct colourless and yellow areas related to the corundum's crystal growth. Photomicrograph by H. Kitawaki.

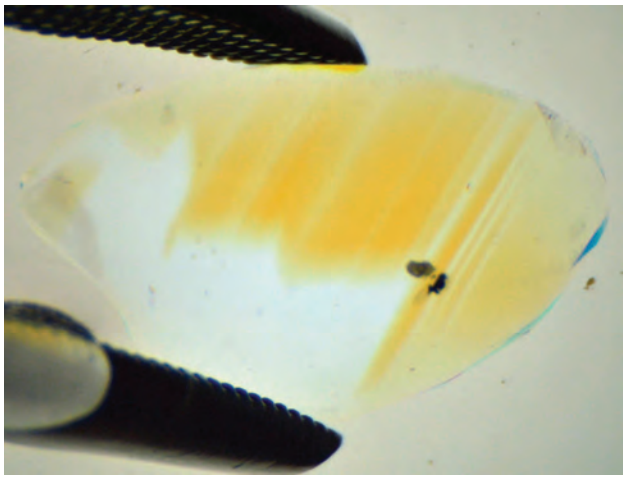

Sapphire Containing Be, Possibly from Secondary Contamination

We also studied a 5.55 ct yellow sapphire that contained tension haloes indicative of heat treatment when viewed with the microscope, but did not show the coloured rim associated with Be diffusion treatment. Immersion in diiodomethane revealed distinct colour zoning with sharply defined colourless and yellow areas related to the corundum's crystal growth (Figure 11). In contrast, most of the Be-diffused stones we examined showed uniformly distributed colour. In those samples that did show colour zoning related to their crystal growth, there were no colourless areas observed. Thus the type of zoning shown by the 5.55 ct sapphire is not characteristic of Be diffusion treatment (although it is not inconsistent with standard heat treatment).

Figure 12 shows the results of analysing six spots on the girdle of the 5.55 ct sapphire by LA-ICP-MS. Only very small amounts of Be were measured (0.47 to 1.29 ppm), and there was no correlation between Be concentration and colour zoning. Also, trace elements such as Zr, Nb, Hf, Ta, W and Th that have been found to accompany natural-origin Be were not detected in this stone.

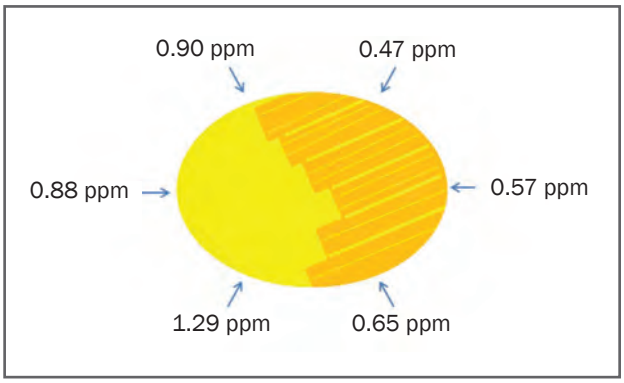

Figure 12: LA-ICP-MS analyses of six spots on the girdle of the 5.55 ct yellow sapphire show very low concentrations of Be (0.47–1.29 ppm). There is no correlation between Be concentration and coloration, and the lack of those trace elements associated with natural-origin Be suggest that the beryllium originated from secondary contamination.

The properties exhibited by this stone suggest that the beryllium originated from secondary contamination, perhaps due to reusing a crucible or furnace that was previously employed for Be-diffusion treatment.

Conclusion

More than a decade after its appearance on the gem market, Be-diffused corundum is still seen on a daily basis in gem laboratories. According to our statistical analysis of the corundum submitted to the CGL laboratory in 2012, yellow to yellowish orange sapphires form the maximum proportion (about 10%) of the stones identified as Be-diffused.

In gemmological laboratories, LA-ICP-MS analysis is generally used to analyse Be in corundum. Stones with no detectable Be are determined as not being treated by Be-diffusion. However, trace amounts of Be in some corundum may be of natural origin, or possibly due to secondary contamination by reusing a crucible or furnace that was previously employed for Be-diffusion treatment. Natural-origin Be is not distributed evenly in corundum, and it is found together with Nb and Ta in blue sapphires and with Zr and Hf in yellow to yellowish orange corundum. Detection of Be-diffused corundum should be done in a careful manner, by considering data of not only Be but also associated elements such as Zr, Nb, Hf, Ta, W and Th, as well as the concentration distribution of Be.

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A Rare 100+ ct Jeremejevite

Christopher P. Smith

Collectors' stones represent some of the most intriguing gems in our industry. Not often, however, do gemmologists get the opportunity to present a complete study on such unique items. American Gemological Laboratories (AGL) has documented a 106.50 ct jeremejevite, the largest faceted example of this mineral reported to date. The gemmological properties of this stone are consistent with those published previously for jeremejevite. The first published LA-ICP-MS analyses on jeremejevite, obtained from this stone, showed the presence of the following trace elements: Si, Ca, Ga, Fe, Zn, Ti, V and Mg.

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Introduction

Of the nearly 5,000 recognized mineral species and varieties, fewer than roughly 400 are known to occur in suitable transparency for faceting as a gemstone. The vast majority of these are considered collectors' stones, as they do not occur in sufficient quantities to establish a broader market, or their low hardness precludes jewellery use. Further still, such stones tend to be small after fashioning, most commonly less than 1 ct.

One example of such a collectors' stone is jeremejevite. Jeremejevite (pronounced 'year-ah-mee-yeah-vite') is a rare aluminium borate mineral with the formula $Al_6(BO_3)_5(F,OH)_3$. It was discovered in 1883 at Mt Soktui in the Adun-Chilon Mountains of Siberia (Arem, 1987), and was named after Russian mineralogist Pavel Vladimirovich Eremeev (from the German spelling, Jeremejev).

Jeremejevite typically forms during a late hydrothermal phase in granitic pegmatites, where it is associated with albite, tourmaline and quartz (O'Donoghue, 2006). As a result of this restricted formation, there are relatively few places where jeremejevite has been found,

Figure 1: The well-proportioned cutting and fine polishing of the 106.50 ct jeremejevite complement its high clarity. Photo by Bilal Mahmood.

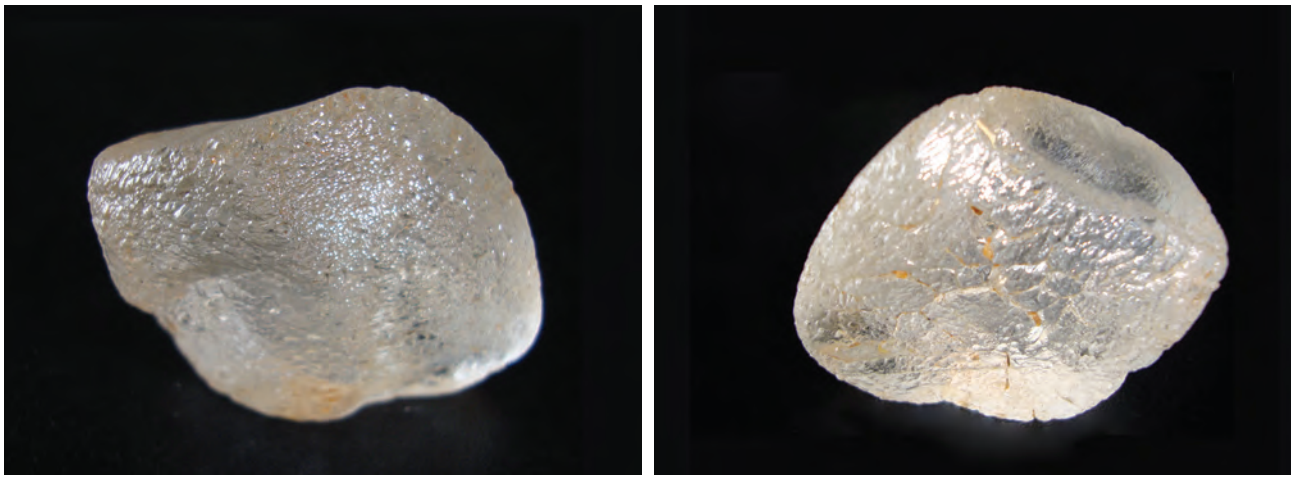

Figure 2: The 106.50 ct jeremejevite described in this article reportedly was cut from this 254 ct piece of rough. These two views show the overall shape and surface characteristics of the pebble. Photos courtesy of Visaka Gems.

including Russia, Tajikistan, Myanmar, Sri Lanka, Madagascar and Namibia. In addition, a seemingly unique occurrence is known in Germany, where jeremejevite formed in cavities within basalt (see, e.g., Stachowiak and Schreyer, 1998; Blass and Graf, 1999). Typically jeremejevite ranges from colourless to blue, as in material from Namibia, or colourless to yellow, as from Myanmar and elsewhere.

Jeremejevite has a Mohs hardness of 7, so it is appropriate for jewellery use. However, the majority is not of gem quality, although a number of faceted specimens have been produced over the years (see, e.g., Scarratt et al., 2001; Laurs and Fritz, 2006). The cut stones typically weigh less than 2–3 ct and possess obvious inclusions. In very rare instances, faceted jeremejevites approaching 60 ct have been seen (e.g. www.curiousnotions.com/gemstones).

Recently, however, the author was given the opportunity to examine a very large jeremejevite (Figure 1). At 106.50 ct, it is the largest faceted jeremejevite reported to date. This article describes the gemmological properties of this unique gemstone.

Background

The owner of the jeremejevite indicated that it came from a 254 ct piece of rough (Figure 2) that had been acquired by his father in the early 1990s. It reportedly was found in Sri Lanka. Although Sri Lanka is not an important source of jeremejevite, it is known to have produced a few examples of this gem (Laurs and Fritz, 2006). Considering the diversity of mineral wealth found on this island, we cannot eliminate the possibility that this large jeremejevite was found there.

In 2006, a Sri Lankan gem lab reportedly documented an even larger jeremejevite pebble weighing 374 ct (http://gemologyonline.com/Forum/phpBB2/viewtopic.php?t=1471), but its quality is unknown and its identity has not been confirmed by the author.

Materials and Methods

Gemmological properties were recorded on the 106.50 ct jeremejevite using standard instrumentation, including a binocular microscope, refractometer, hydrostatic balance, polariscope, desk-model spectroscope, and a long- and short-wave ultraviolet lamp. Spectroscopy in the ultraviolet-visible–near infrared (UV-Vis-NIR) region was performed with a Perkin-Elmer Lambda 950 spectrophotometer, and in the mid-IR region using a Thermo Nicolet 6700 spectrometer. Raman spectra were recorded using a Renishaw InVia micro-Raman spectrometer equipped with 514 nm argon-ion laser excitation. Chemical analyses were obtained using an EDAX energy-dispersive X-ray fluorescence (EDXRF) spectrometer. Laser ablation–inductively coupled plasma–mass spectrometry (LA-ICP-MS) was performed with a Thermo X-Series ICP-MS equipped with a New Wave 213 nm laser-ablation sample introduction system. Five spots were analysed on the girdle of the stone.

Table I: Gemmological properties of the 106.50 ct jeremejevite.

Shape and cutting style	Cushion mixed cut (brilliant/step cut)
Measurements	32.45 × 26.70 × 15.78 mm
Appearance	Colourless, transparent
Refractive index	n_o = 1.648, n_e = 1.638
Birefringence	0.010
Optic character	Uniaxial negative
Polariscope reaction	DR, uniaxial figure
Specific gravity	3.29
UV fluorescence	Inert
Visible-range spectrum	No distinct features

Results

Visual Appearance and Gemmological Properties

Viewed face-up, the 106.50 ct jeremejevite appeared colourless. However, careful inspection through the pavilion showed a very faint bluish tint. The stone possessed a high degree of transparency with few inclusions (see below).

It is rather common for collectors' stones to be cut poorly to retain as much weight as possible. Conversely, the cutting and polishing of this gemstone were very good, resulting in a well-proportioned cushion mixed cut that displayed brilliance all the way down to the keel, with no windowing when viewed face-up and perpendicular to the table facet.

All of the stone's standard gemmological properties were consistent with those previously reported for jeremejevite (Table I).

Microscopy

Considering its large size, this gemstone possessed few inclusion features. Most notably, these consisted of etch tubules or channels that ranged from straight and angular to quite erratic, some with squarish or geometric fringes (Figure 3). Very subtle internal growth structures were also noted.

UV-Vis-NIR and Mid-IR Spectroscopy

No distinct absorptions were recorded in the UV-Vis-NIR region of the spectrum. The large size of the gemstone prevented the collection of mid-IR spectra, since the long path length using the diffuse reflectance method resulted in the saturation of the detector. For spectral properties of jeremejevite, the reader is referred to Scarratt et al. (2001) and Thanachakaphad (2010), as well as Frost and Xi (2012).

Figure 3: The only inclusion features in the large jeremejevite consist of etch channels. The left photo shows straight etch channels, one of which is decorated with a fringe of angular geometric features. The image on the right depicts the erratic path of irregular etch channels through this remarkable gem. Photomicrographs by C. P. Smith; magnified 30× (left) and 20× (right).

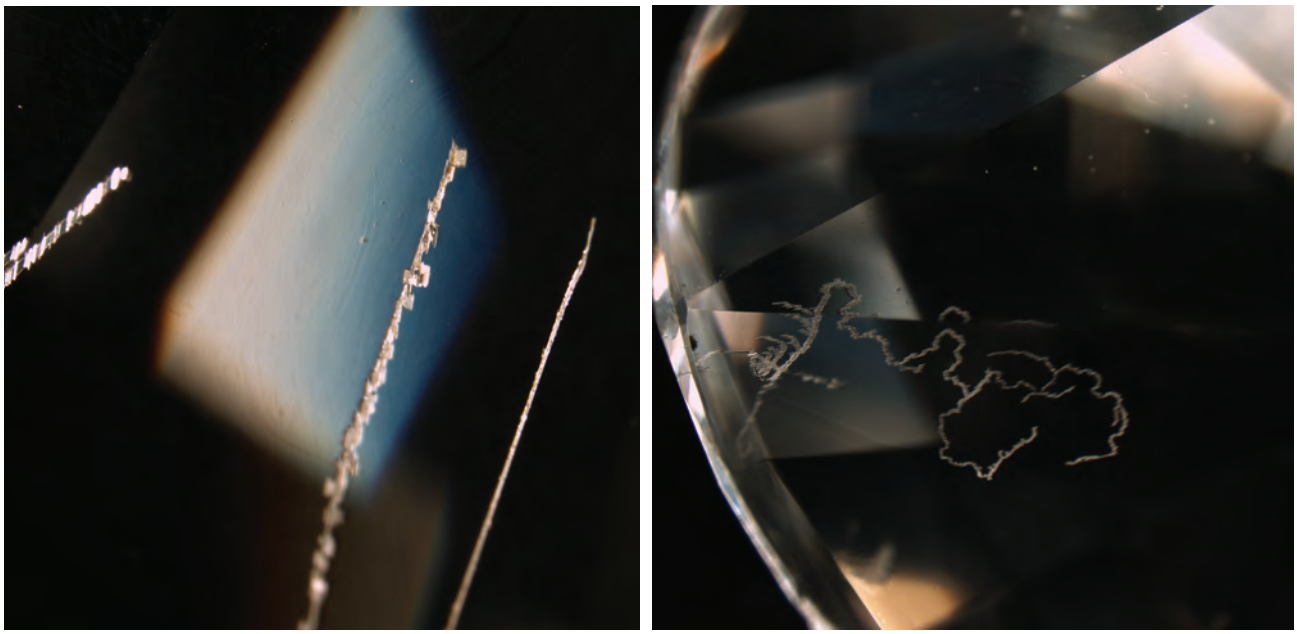

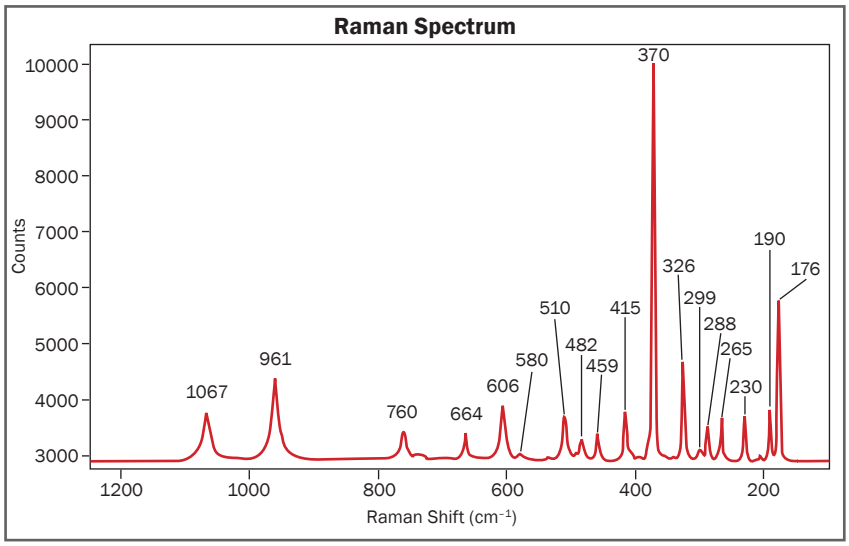

Figure 4: The Raman spectrum of the 106.50 ct gemstone conclusively identifies it as jeremejevite.

Raman Spectroscopy

Raman spectra taken in random orientations showed a number of distinct bands (Figure 4). The dominant Raman band was positioned at 370 cm^{-1} and three bands of secondary prominence were at 961, 326 and 176 cm^{-1} Raman shift. A series of subordinate bands were positioned at 1067, 760, 664, 606, 580, 510, 482, 459, 415, 299, 288, 265, 230 and 190 cm^{-1} Raman shift. These spectral features are consistent with those previously recorded for jeremejevite (see, e.g., Scarratt et al., 2001; Frost and Xi, 2012).

Chemical Composition

EDXRF spectroscopy revealed a large amount of Al, as expected; the other major components B and F were not recorded since these light elements are not detectable by this technique. In addition, traces of Ga and Fe were detected by EDXRF. LA-ICP-MS analyses showed the presence of several trace elements: Si, Ca, Ga, Fe, Zn, Ti, V and Mg (Table II).

Table II: LA-ICP-MS trace element composition (in ppmw) of the 106.50 ct jeremejevite.

Element	Spot 1	Spot 2	Spot 3	Spot 4	Spot 5	Average
Mg	1.04	0.58	0.56	1.72	0.57	0.89
Si	na*	509	1630	1130	1750	1250
Ca	1148	978	926	1240	1450	1150
Ti	15.4	17.6	3.01	4.07	3.63	8.73
V	0.96	0.94	0.92	1.32	1.25	1.08
Fe	100	109	166	203	132	142
Zn	9.35	15.6	12.6	14.2	16.4	13.6
Ga	139	147	146	154	162	150

* na = not analysed.

Discussion

The size and quality of this 106.50 ct gemstone set it apart from all other jeremejevites encountered by the author and described in the literature (e.g. Foord et al., 1981; Scarratt et al., 2001; Johnston, 2002). The natural origin of this stone is indicated by its inclusions and its large size; gem-quality synthetic jeremejevite is unknown in the market, and published experiments have succeeded in producing only micro-crystals of synthetic jeremejevite and a hydrated form of synthetic jeremejevite (OH fully replacing fluorine), using both high-pressure and hydrothermal growth methods (see, e.g., Sokolova et al., 1987; Stachowiak and Schreyer, 1998).

This is the first time that LA-ICP-MS data on jeremejevite have been published. A trace element assemblage consisting of Si, Ca, Ga, Fe, Zn, Ti, V and Mg further confirm the natural origin of this gemstone.

Conclusion

The diversity of collectors' gemstones reflects a variety of growth environments in the earth, but these conditions rarely produce minerals with suitable transparency to be faceted. Although the average consumer is not aware of these unusual

Figure 5: At 106.50 ct, this is the largest faceted jeremejevite reported to date. Here it is shown together with a 2.40 ct yellow Burmese jeremejevite for comparison. Photo by Jeremy Prowitz and Bilal Mahmood.

stones, gemmologists, enthusiasts and collectors find such gems fascinating and highly desirable.

It is a rare pleasure to have the opportunity to examine collectors' stones such as the present 106.50 ct jeremejevite (Figure 5). This unique and highly important gem is the largest known faceted jeremejevite to date. Its size and stature are likely to help elevate the awareness and appreciation of this little-known gem material.

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The Fire Within

"For in them you shall see the living fire of the ruby, the glorious purple of the amethyst, the sea-green of the emerald, all glittering together in an incredible mixture of light."

– Roman Elder Pliny, 1st Century AD

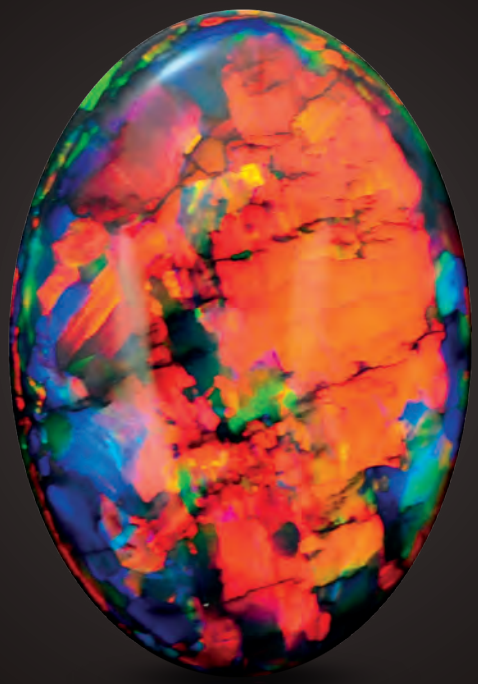

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Some Characteristics of Taaffeite from Myanmar

Thanong Leelawatanasuk, Wilawan Atichat, Tay Thye Sun, Boontawee Sriprasert and Jirapit Jakkawanvibul

Although taaffeite from Myanmar was reported over 30 years ago, few gemmological studies have been published on this material. Five specimens of very pale purplish pink and heavily included taaffeite from the Mogok area were characterized for this report. Chemical analysis revealed 75.2–76.4 wt.% Al_2O_3 and 18.2–19.1 wt.% MgO, with trace amounts of Fe, Zn, Ga, Mn and other elements. Compared to similarly coloured taaffeite from Sri Lanka and Africa, these Burmese samples showed no significant differences except for lower Fe content.

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Introduction

Among gem minerals, taaffeite is considered one of the rarest, with only a handful of deposits reported to date. The mineral was named in 1945 after its discoverer, Count Edward Charles Richard Taaffe, a Dublin gemmologist. He noticed a stone within a parcel of spinel from Sri Lanka that exhibited a slight birefringence. He sent the gem to London, where it was eventually confirmed as a new mineral species (Anderson et al., 1951). Its chemical formula is $BeMg_3Al_8O_{16}$ (Schmetzer 1983a,b), intermediate between chrysoberyl ($BeAl_2O_4$) and spinel ($MgAl_2O_4$). Since the nomenclature revisions by Armbruster (2002), *taaffeite* has been considered a group name, consisting of the members magnesiotaaffeite-6*N*'3*S* (which used to be called musgravite), magnesiotaaffeite-2*N*'2*S* (taaffeite) and ferrotaaffeite-6*N*'3*S* (pehrmanite). More recently, a new iron-rich end member of the taaffeite group was defined by Yang et al. (2012) as ferrotaaffeite-2*N*'2*S*. For simplicity, in this article magnesiotaaffeite-2*N*'2*S* will simply be referred to as *taaffeite*.

Due to its scarcity, taaffeite is considered a collectors' stone. The mineral is known to crystallize in metasomatized limestone or in high-grade amphibolite- or granulite-facies rocks (Kampf, 1991; Chadwick et al., 1993). Gem-quality material is mainly known from Sri Lanka (e.g. Schmetzer et al., 1999; Abduriyim et al., 2008), but also has been found in Tanzania (Schmetzer et al., 2007) and Myanmar (Kampf, 1991; Schmetzer et al., 2000). Madagascar was mentioned as a possible source of gem-quality taaffeite by Schmetzer et al. (2007), but this has not yet been confirmed.

Burmese taaffeite was first reported in 1983, when Bangkok-based gemmologist William Spengler found a near-colourless piece of rough in a parcel of spinel from the Mogok Stone Tract (Spengler, 1983). Later, additional Burmese specimens were found. In the Mogok area, taaffeite is associated with spinel in a marble belt that developed along the contact of dolomitic

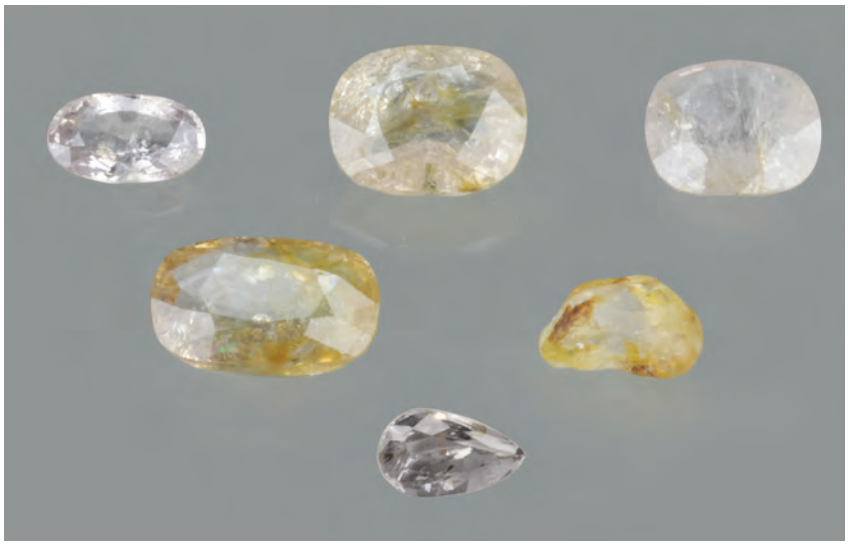

Figure 1: One rough (1.92 ct) and four faceted (1.33–5.16 ct) taaffeite samples were examined in this study. Also shown is a faceted taaffeite from Sri Lanka (bottom; 1.09 ct) that was analysed for comparison. The colour of some samples is obscured by iron staining in surface-reaching fissures. Photo by Jirapit Jakkawanvibul.

limestones with granitic intrusives; the granites provided a source of beryllium for the taaffeite (Drev et al., 2012). The Burmese taaffeite is reportedly found at Chaung Gyi, north of Mogok, in rocks of the Chaung Magyi Group. These rocks have undergone regional metamorphism, followed by contact metamorphism in the vicinity of granitic intrusions (Bender, 1983).

Materials and Methods

This study was performed on four very pale purplish pink faceted gems and a rough stone, all provided by co-author TTS from his reference collection (Figure 1; 1.33–5.16 ct). All of these samples were originally obtained from gem dealers in Yangon, who reported that they were mined from Chaung Gyi in the Mogok area of Myanmar. For comparison, we also analysed a 1.09 ct pale purple faceted taaffeite from Sri Lanka from the collection of co-author TTS (Figure 17).

Gemmological properties were determined at the Gem and Jewelry Institute of Thailand's Gem Testing Laboratory in Bangkok, using standard instruments such as a refractometer, hydrostatic balance, polariscope, long- and short-wave UV lamp, and binocular microscope. Further testing was carried out on all samples using a Renishaw inVia Raman spectrometer (2000–200 cm^{-1} range, using 785 nm laser excitation), a PerkinElmer Lambda 950 ultraviolet-visible–near-infrared (UV-Vis-NIR) spectrophotometer (250–800 nm range, with a data collection interval of 3 nm), a Thermo-Nicolet 6700 Fourier-transform infrared (FTIR) spectrometer (mid-IR range of 400-4000 cm^{-1}, 4 cm^{-1} resolution, 128 scans), an EDAX Eagle III energy-dispersive X-ray fluorescence (EDXRF) spectrometer (40 kV voltage, 250 µA beam current) and an Agilent 7500 laser ablation–inductively coupled plasma–mass spectrometer (LA-ICP-MS) with a 213 nm laser, laser output energy of 12–13 J/cm^2, carrier Ar gas flow rate of 0.8 L/min, and a 55 µm crater size.

Results

Gemmological Properties

The basic gemmological properties are summarized in Table I. The Burmese samples were very pale purplish pink (though some samples were iron-stained) and heavily included. The RIs of the faceted samples were n_o = 1.720–1.721 and n_e = 1.716–1.717, with a birefringence of 0.004. The SG values ranged from 3.60 to 3.61 for the cut stones, and the SG was 3.57 for the rough sample. All specimens showed a typical doubly refractive character in the polariscope. All were inert to short-wave UV radiation, and some showed weak chalky green or white fluorescence to long-wave UV.

Microscopic examination revealed prominent fingerprint-like fluid inclusions (Figure 2). In addition, several tiny colourless mineral inclusions were observed in the rough specimen. Unfortunately, those inclusions could not be identified by Raman spectroscopy due to their position below the surface.

Table I: Gemmological properties of the studied taaffeite samples from Myanmar and Sri Lanka.[a]

Sample no.	Weight (ct)	RI			SG	UV fluorescence (long-wave/short-wave)
		n_o	n_e	Birefringence		
TA01	1.33	1.720	1.716	0.004	3.61	Inert/inert
TA02	4.99	1.720	1.716	0.004	3.60	Inert/inert
TA03	2.86	1.721	1.717	0.004	3.60	Weak chalky white/inert
TA04	5.16	1.720	1.716	0.004	3.60	Weak chalky green/inert
TA05	1.92	1.72 (spot)			3.57	Weak chalky white/inert
TA-SRI	1.09	1.721	1.718	0.003	3.63	Inert/inert

[a] Samples TA01–TA05 are from Myanmar; all are faceted except TA05, which is a water-worn pebble. Sample TA-SRI is from Sri Lanka.

Spectroscopy

Raman spectroscopy confirmed that all five stones were taaffeite. The Raman spectra perfectly matched our reference spectrum for taaffeite and also were consistent with the representative taaffeite spectrum given by Kiefert and Schmetzer (1998).

The UV-Vis-NIR spectra displayed absorption peaks and bands at approximately 370, 385, 460 and 550 nm, with increasing overall absorption toward the UV region (Figure 3). The mid-IR spectrum showed broad transmission in the 3500–1500 cm^{-1} range with weak absorption bands at approximately 1937, 1795 and 1674 cm^{-1} (Figure 4). In addition, small peaks at approximately 2923 and 2856 cm^{-1} are due to C-H stretching vibrations, possibly from oil residue in fractures.

Chemical Composition

Semi-quantitative EDXRF chemical analyses revealed that the Burmese taaffeite samples contained 75.2–76.4 wt.% Al_2O_3 and 18.2–19.1 wt.% MgO; beryllium is assumed present at 4.5 wt.% BeO according to the theoretical formula (Schmetzer et al., 2007). In addition, EDXRF measured traces of Fe, Zn, Ga, Mn and Cr. LA-ICP-MS analyses of the Burmese samples showed the expected major elements (Al, Mg and Be), as well as several trace elements (Li, B, Ti, V, Cr, Mn, Fe, Zn, Ga and Sn; see Table II).

Comparison with Taaffeite from Sri Lanka

Our Burmese taaffeites—and those from the literature—showed no significant differences in RI, SG and UV fluorescence compared to similarly coloured taaffeite from Sri Lanka (i.e. data from the studied sample and from Schmetzer et al., 2006). In addition, the UV-Vis-NIR spectra (see Figure 3) and mid-IR spectra were also quite similar.

Discussion and Conclusions

Our study samples of taaffeite from Myanmar were pale purplish pink and highly included. The most prominent inclusion feature consisted of clusters of fingerprint-like fluid inclusions. Their properties are comparable to similarly coloured

Figure 2: Planes of reflective fluid inclusions hosted by partially healed fissures were prominent in the Burmese taaffeite samples examined in this study. Photomicrographs by Jirapit Jakkawanvibul; darkfield illumination, magnified 40×.

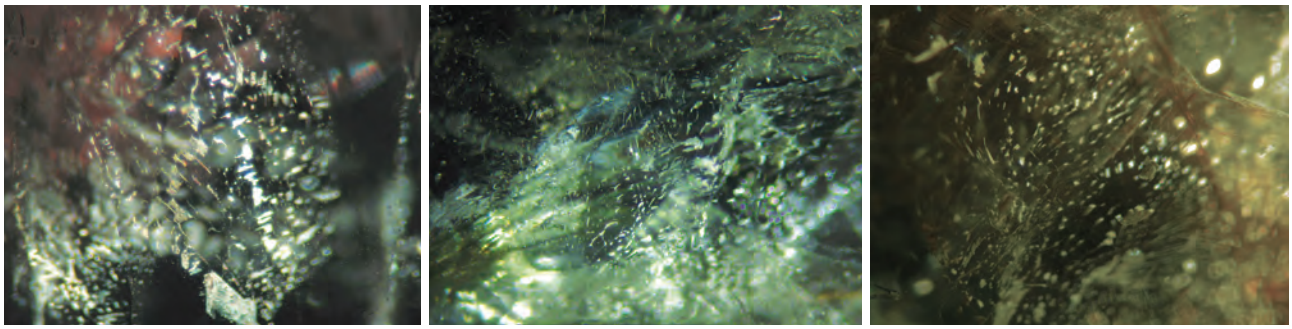

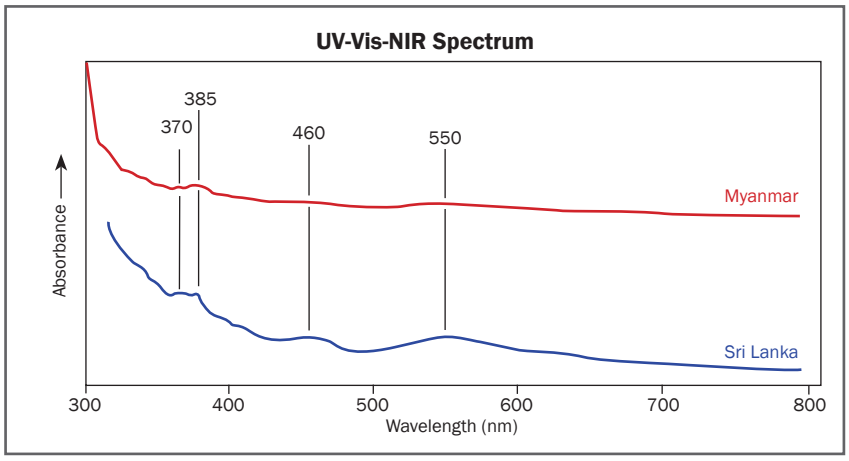

Figure 3: This representative non-polarized UV-Vis-NIR spectrum of sample TA03 shows absorption features due to iron. The same features (though somewhat stronger) are visible in the spectrum of a Sri Lankan taaffeite that was recorded for comparison.

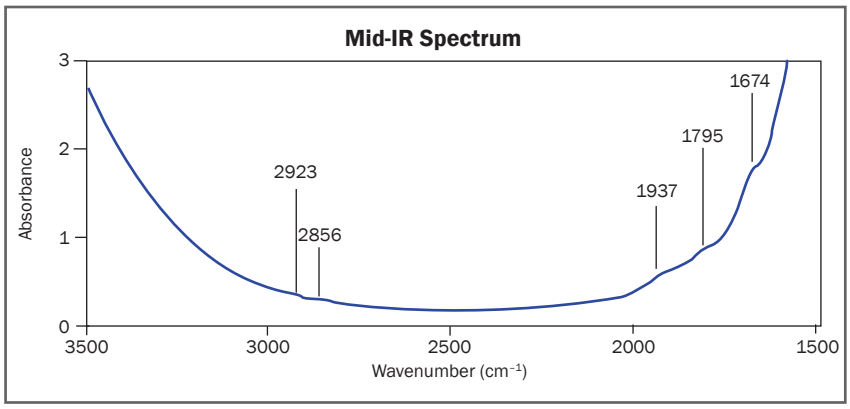

Figure 4: This representative mid-IR spectrum of sample TA03 shows broad transmission in the 3500–1500 cm^{-1} range.

Table II: LA-ICP-MS analyses (in ppmw) of selected taaffeite samples from Myanmar and Sri Lanka, compared to data for taaffeite from Africa.[a]

Element	TA01	TA02	TA05	TA-SRI	Samples from Schmetzer et al. (2007)
	Myanmar			Sri Lanka	Africa
Li	24.9	52.6	19.8	13.2	3–22
B	42.2	46.3	44.6	15.8	24–50
Ti	35.9	13.5	14.9	16.1	0.01 wt.% TiO_2[b]
V	16.4	13.1	17.5	13.3	nd–0.01 wt.% V_2O_3[b]
Cr	9.18	3.04	4.06	nd	nd–0.02 wt.% Cr_2O_3[b]
Mn	46.7	66.8	32.1	104	0.01–0.05 wt.% MnO[b]
Fe	1150	1190	558	1680	0.31–2.79 wt.% FeO[b]
Co	nd	nd	nd	2.58	nr
Zn	570	633	330	1930	nr
Ga	224	134	207	475	172–610
Sn	5.00	3.97	7.37	2.64	1–9

Abbreviations: nd = not detected, nr = not reported.

[a] For data obtained in this study, the values are averaged from two analysis spots per sample.

[b] Obtained by electron microprobe, and therefore not directly comparable to LA-ICP-MS data.

taaffeites from both Sri Lanka and Africa, although our Burmese samples had lower Fe contents. Research on a violet 4.02 ct taaffeite reportedly from Myanmar also showed it to contain low Fe contents compared to purple to purplish red samples from Sri Lanka (Schmetzer et al., 2000).

The UV-Vis-NIR spectra of the studied Burmese samples clearly show iron-related absorption

features at 370, 385, 460 and 550 nm, matching previous studies of taaffeite and musgravite from Sri Lanka and Africa (Schmetzer et al., 2007). The main absorption peak of chromium in the visible range is close to the maximum of an iron-related absorption band (Schmetzer et al., 2000), and thus cannot be separated in the spectra of Cr-bearing samples. However, the low Cr contents of our Burmese samples (Table II) probably have little if any influence on the coloration of these samples. The spectra show normal iron-related absorption features, and the very pale purplish pink coloration of the samples is due to their low Fe content (as compared to taaffeite from Sri Lanka or Africa). The low iron content of the Burmese material is the main difference from gem-quality taaffeite from other sources.

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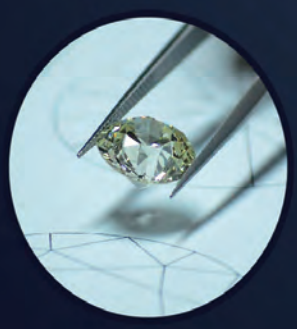

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Natural Pearls from Edible 'True Oysters' in Zeeland, The Netherlands

J. C. (Hanco) Zwaan and Peter Groenenboom

Recently, some natural pearls were found in Zeeland, The Netherlands, reportedly from the Grevelingenmeer and Westerschelde areas. Three whole pearls and one blister, still attached to its shell, were examined. These non-nacreous pearls were white, although the blister also had a light grey portion. They displayed a dull lustre and showed an uneven, bumpy surface in the microscope. X-radiography and micro-CT scanning of the whole pearls revealed concentric structures consistent with their natural origin; the blister pearl was partially hollow. Raman spectroscopy identified calcite as the sole component for three samples; one showed only features of aragonite. A relatively low Mn and high Sr content (with SrO/MnO>>12) confirmed their saltwater origin. The host oyster for these very rare pearls was identified as *Crassostrea gigas* (Thunberg, 1793), a common 'true oyster' species in Zeeland, which is harvested for its meat but not used for pearl cultivation. There is no human intervention in the growth of these oysters, which supports the conclusion that these pearls are truly natural.

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Introduction

From mid-2013 to March 2014, four pearls of very similar appearance were sent to the Netherlands Gemmological Laboratory for examination (Figures 1 and 2). They were submitted by different sources, but were all claimed to be from oysters originating from Zeeland Province in the south-western part of The Netherlands. Zeeland has a long history harvesting meat from native oyster banks, as well as gathering oysters that have been introduced for the seafood industry, especially in the Westerschelde, Oosterschelde and Grevelingen sea inlets that divide Zeeland into separate pieces of land (Figure 3). In the early 1970s, Grevelingen was cut off from the sea by two dams, creating the Grevelingenmeer, which is the largest saltwater lake in Western Europe (13,872 hectares; http://nl.wikipedia.org/wiki/Grevelingenmeer). The Westerschelde and Oosterschelde are still open to the sea, but the latter inlet can be closed during severe storms by a weir, called the *Oosterscheldekering*.

The origins of the submitted pearls were indicated as 'Zeeland', the 'Westerschelde' and 'Grevelingen'. The most precise locality was given by a nine-year old boy, Boris de Kort, who found an oyster containing a blister pearl 'at the bank of the Westerschelde, along the beach near

Figure 1: Pearl sample P5234 (~7.7 mm in diameter) was found in this oyster, reportedly from Grevelingen, Zeeland, The Netherlands. Photo by Dirk van der Marel.

Figure 2: Blister pearl sample P5235 is shown together with two whole pearls measuring ~5.8–8.2 mm and ~3.6 mm in diameter (samples P5229 and P5301, respectively), from Zeeland, The Netherlands. Photo by Dirk van der Marel.

De Griete or at Ossenisse/Zeedorp'. The pearl from 'Zeeland' was found in a 'Zeeuwse creuse', an oyster from Zeeland, that was purchased by the owner at a local food store called the Marqt. When asked about the source of their oysters, Marqt personnel stated that they came from Grevelingenmeer. The pearl mentioned above as coming from 'Grevelingen' was evidently also found in this area, reportedly in December 2012.

Materials and Methods

Three whole pearls and one blister, still attached to the shell, were studied for this article (Figures 1 and 2). The basic characteristics of each pearl are listed Table I. Also examined was the oyster shell in which the ~7.7-mm-diameter round pearl was found (Figure 1). The pearls were characterized using a standard gemmological microscope, X-radiography, X-ray computed

Figure 3: Zeeland, a south-western province of The Netherlands (below), is divided by sea inlets: the Westerschelde, Oosterschelde and Grevelingen. The last inlet has been converted to a saltwater lake called the Grevelingenmeer. All three areas are well-known for their oyster beds.

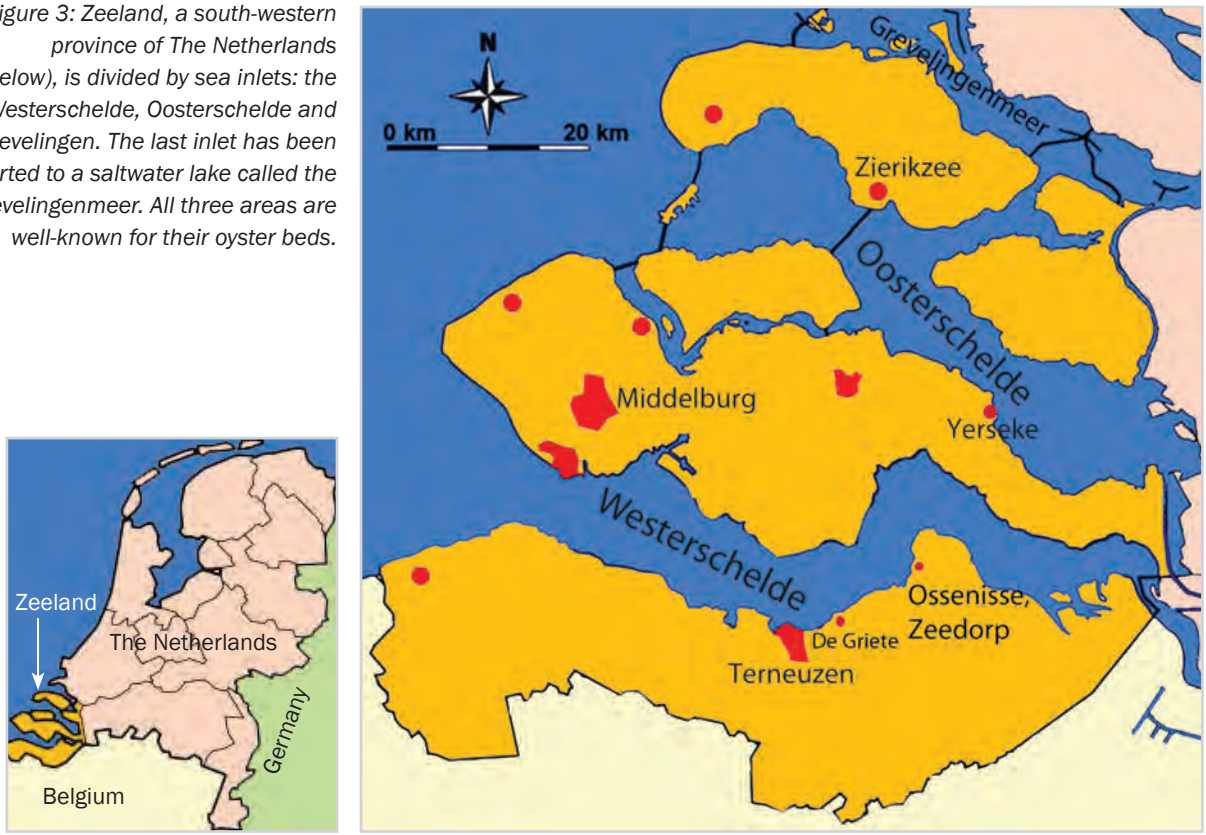

Table I: Examined pearls from Zeeland, The Netherlands.

Sample no.	Shape	Weight (ct)	Measurements	Reported origin
P5229	Drop	2.00	8.18 × 6.61 × 5.77 mm	Westerschelde
P5234	Round	3.01	7.69–7.72 × 7.67 mm	Grevelingen
P5301	Button	0.32	~3.6 mm in diameter	Zeeland
P5235	Blister	--	~13 mm in diameter	Westerschelde

microtomography (micro-CT), energy-dispersive X-ray fluorescence (EDXRF) spectroscopy and micro-Raman spectroscopy at Naturalis in Leiden. X-radiography was performed with a Faxitron 43855 Cabinet X-ray system operating at 100 kV and 3 mA, with 20–30 seconds of exposure time. High-resolution micro-CT scanning used a Skyscan 1172 instrument. For the two pearls that were scanned (P5229 and P5234), the operating conditions were very similar, at 65 kV and 153 µA, and 70 kV and 141 µA, respectively, using an Al-foil filter of 0.5 mm and an exposure time of 750 milliseconds for each image. The pearls were rotated 360°, in rotation steps of 0.35° and 0.30°, resulting in 1,028 and 1,200 images, respectively. For each position, respectively 5 and 4 frames were averaged. The camera pixel size was fixed at 8.70 µm. An Orbis µProbe EDXRF spectrometer was used to chemically characterize the pearls. This instrument has a focus spot of 200 × 200 µm and a beam diameter of 300 µm. A voltage of 20 kV and a count time of 100 seconds were used for each measurement. For Raman spectroscopy, a Thermo DXR Raman microscope with 532 nm laser excitation was used. Raman spectra were collected at room temperature in the confocal mode, which is necessary for analysis of individual layers of a sample on a micron scale (1–2 µm). In this study, random spots at and slightly underneath the surface were analysed. A grating of 1800 grooves/mm and a pinhole size of 25 µm were used, which combined with the optical path length yields a spectral resolution of ~1.0 cm^{-1}. Spectra were collected in the range of 1800–100 cm^{-1} to study the vibrations of the carbonate anion $(CO_3)^{2-}$.

Results

The pearls were all white in colour. In addition, a portion of the blister pearl was light grey, and the 3.01 ct sample also showed a very small greyish area. All had a dull lustre, and viewed with the microscope they showed an uneven, bumpy surface (Figure 4). X-radiographs of all the samples showed a concentric layered structure that is expected for natural pearls (c.f. Alexander, 1941; Farn, 1986; Sturman, 2009). The blister

Figure 4: The examined pearls are non-nacreous, and typically display a dull lustre and an uneven, bumpy surface when viewed with the microscope. The slightly darker spots on this pearl (P5234; ~7.7 mm in diameter) indicate areas of higher transparency. The inset shows the surface texture in more detail (image width: 4.5 mm). Photos by J. C. Zwaan.

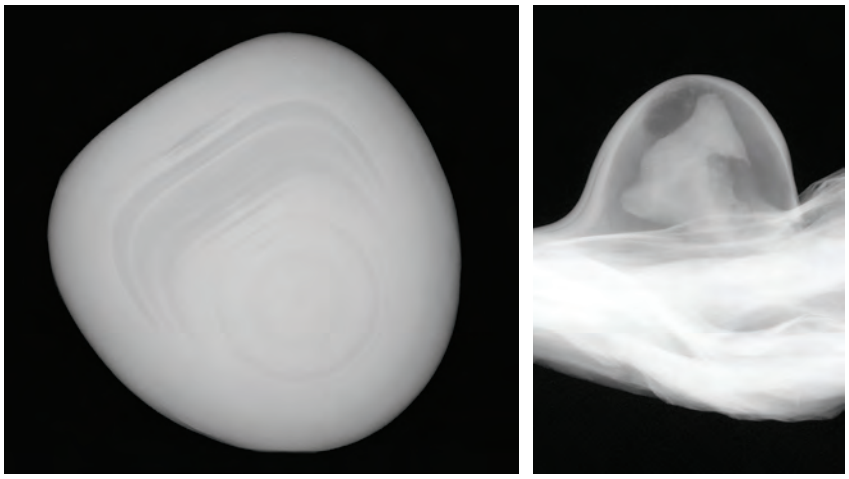

Figure 5: X-radiography of pearl P5301 (left, ~3.6 mm in diameter) reveals concentric layering that is typical of natural pearls. The X-radiograph of the blister pearl (right, 13 mm across) shows that it is partially hollow. The irregular structure underneath may have been caused by the drilling of an intruding worm (H. Hänni, pers. comm., 2014).

pearl turned out to be partially hollow, and its internal structure appeared to be a continuation of the highly irregular shell underneath it (Figure 5). Micro-CT scanning confirmed the concentric structure characteristic of natural pearls (Figure 6).

Raman analysis of various points on each sample revealed that all of the pearls except for the drop shape consisted of calcite, with two main peaks at 1086–1085 and 712–711 cm^{-1} (compare, e.g., Wehrmeister et al., 2010). The strongest band, at 1086 cm^{-1}, derives from the symmetric stretching mode (ν_1) of the carbonate ion; the peak at 711 cm^{-1} corresponds to in-plane bending (ν_4) of the carbonate ion (Urmos et al., 1991; Wehrmeister et al., 2010). Also, the surface of the inside of the associated shells consisted of calcite. However, the drop-shaped pearl only gave Raman spectra for aragonite, with a main peak at 1085 cm^{-1} and a doublet at 705 and 701 cm^{-1}.

EDXRF analysis showed a low manganese content (≤0.03 wt.% MnO) and varying strontium (0.28–0.46 wt.% SrO), consistent with the pearls' saltwater origin (compare, e.g., Gutmannsbauer and Hänni, 1994).

Frank Wesselingh, a malacologist at Naturalis, identified the shells associated with the round pearl (Figure 2) and the blister pearl (Figure 3) as belonging to *Crassostrea gigas* (Thunberg, 1793; also known as the 'Japanese oyster'), a member of the Ostreidae family.

Figure 6: Micro-CT images in the XYZ direction of pearls P5234 (left, ~7.7 mm in diameter) and P5229 (right, ~5.8–8.2 mm) show concentric structures that confirm their natural origin.

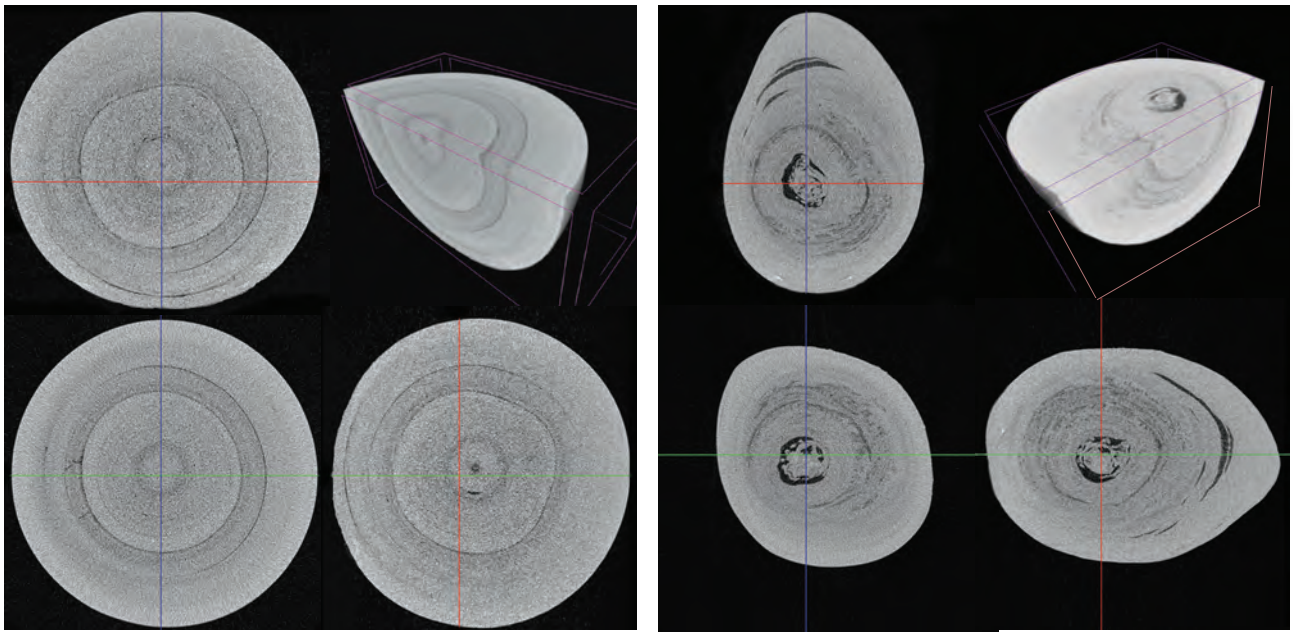

Box A: Cultivation of Edible Oysters in Zeeland, The Netherlands

In Zeeland, an oyster producer obtains a licence for gathering oysters in specific areas of the delta/sea inlets. The oyster beds are found in shallow waters (<3 m) close to shore, sometimes even falling dry at low tide. The oysters are gathered about once a year. The larger oysters are taken to holding tanks onshore (Figure A-1), where they stay from a few days to two weeks while awaiting transport to local and international markets. The smaller ones are returned to the oyster beds and given more time to grow. When the oysters spawn, most of the larvae will attach to a hard substrate, hopefully located close to the same area.

It takes about five years for an oyster to reach harvestable size. The oysters are distributed to clients in The Netherlands and in many other countries throughout Europe. The best ones are sold to France to grow further. After some years those oysters are harvested, and their meat is considered to be of the highest quality.

The method used for gathering the oysters means that there is no human intervention in terms of producing more or fewer oysters, or influencing their quality. It is nature that decides if, and how many, oyster larvae will grow in an area. That depends on the weather, temperature, currents and, most of all, the water quality.

The oyster shells are not cleaned (as is done on pearl farms), so when harvested they are encrusted with all kinds of seaweed and algae. Also, worms may infest the oysters, which may cause the growth of a pearl. However, the commercially important edible oysters (Ostreidae family) are not used for pearl cultivation since they do not yield nacreous pearls.

Figure A-1: These tanks hold oysters at Delta Ostrea, Yerseke, Oosterschelde, Zeeland. Photo by Franz Ulrich.

Discussion and Conclusion

The described pearls can be seen as curiosities from The Netherlands that are very rarely found. Although they have all the characteristics of natural pearls, due to their low lustre and imperfect surface, they are of limited commercial interest. However, larger pearls, such as the ~7.7 mm round sample with a precisely known origin, may have considerable value—especially in light of the recent popularity of natural pearls from all types of molluscs. Furthermore, calcitic pearls are very rare; only scallop and pen shell pearls have been described as mostly calcitic (Fritsch et al., 2012), although some low-quality pearls from *Pinctada radiata* may also be fully calcitic (S. Karampelas, pers. comm., 2014). Both calcite (as purplish spots) and aragonite have been documented as part of a pearl attached to the inner shell of *Crassostrea virginica* (American or Eastern oyster; Scarratt et al., 2006).

The calcitic nature of three of the examined pearls is consistent with the shell composition of edible oysters (e.g. Strack, 2006). While it was claimed that the drop-shaped pearl was found in an oyster from the Westerschelde, its aragonite composition is inconsistent with the composition of oysters present in Zeeland. It has a very similar surface and appearance, though, when compared to the other pearls, and aragonite can also be observed inside the shells of *Ostrea edulis* and other molluscs from the Ostreidae family (Checa et al., 2007). *Ostrea edulis,* the so-called 'flat oyster', is the autochthonous species that formed the wild oyster banks until the 1960s, when they suffered an illness and were then gradually overtaken by *Crassostrea gigas*, a species from the Pacific that was introduced in the 1960s (Wolf, 2005). The shells examined in this study are from this species, which continues to be gathered and harvested in Zeeland for its delicate meat (see Box A).

Although the *Crassostrea gigas* species was originally introduced to the Zeeland area by man, there is otherwise little to no human intervention in growing the oysters. This supports the conclusion that the described pearls are natural, without any reservation. Concerning the relatively large size of the round pearl (~7.7 mm in diameter), the growth must have started when the oyster was young and continued until the shell was of harvestable size (i.e. perhaps exceeding five years).

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Conferences

12th Annual Sinkankas Symposium: Peridot and Uncommon Green Gem Minerals

This annual symposium in honour of noted author John Sinkankas took place 5 April 2014 at the Gemological Institute of America (GIA) in Carlsbad, California, USA, with approximately 120 people in attendance. The conference theme was *Peridot and Uncommon Green Gem Minerals,* and a proceedings volume is available for US$45 (plus shipping and handling) at www.sinkankassymposium.net; it contains presentation summaries as well as outside contributions. As in prior years, the conference was expertly organized by **Roger Merk** (Merk's Jade, San Diego, California, USA).

The opening presentation was given by **Lisbet Thoresen** (Beverly Hills, California, USA) on the archaeogemmology of peridot. A collaborative study with Dr James A. Harrell (University of Toledo, Ohio, USA) showed that the earliest use of peridot as a gem material occurred during the Hellenistic era, dating back to perhaps the mid-2nd century BC. The peridot was obtained from Zabargad Island (Egypt) in the Red Sea until the 6th century AD, when the island was abandoned of human habitation. In a separate presentation, Thoresen examined another green gem, chrome chalcedony, in ancient cameos and intaglios. Most of them originated from the Roman Empire during the 1st century BC through the 1st century AD. They are commonly incorrectly identified in the literature as 'plasma', 'chrysoprase' or 'prase'.

Dr William 'Skip' Simmons (University of New Orleans, Louisiana, USA) reviewed the mineralogy and crystallography of olivine (peridot), which consists of a solid-solution series between forsterite (Mg_2SiO_4) and fayalite (Fe_2SiO_4). He said that the best colour of peridot is seen when it contains 12–15 wt.% FeO; higher Fe contents produce a brown tint.

Dr James E. Shigley (GIA, Carlsbad) surveyed the geology of peridot, which is a major constituent of the earth's mantle. It may be transported to the earth's surface within tectonically-emplaced assemblages (ophiolites) or as xenoliths in eruptions of alkali basalt or kimberlite. Forsterite is also found in metamorphosed carbonate rocks. In addition, peridot is the only gem with the distinction of also having an extraterrestrial origin, from pallasitic meteorites. In a separate presentation, Dr Shigley gave a brief review of 13 other green gem materials besides peridot.

Nathan Renfro (GIA, Carlsbad) covered the faceting of peridot and described its inclusions. He explained how he uses GemCad to perform computer modelling of a desired cut stone before working on a piece of rough, a process he called digital cutting. Renfro showed photomicrographs of an amazing variety of internal features in peridot, including mineral/fluid/melt inclusions, cleavage discs (e.g. Figure 1), growth zoning and dislocation channels.

Dr Raquel Alonso-Perez (Harvard University, Cambridge, Massachusetts, USA) examined the geological origin of peridot from Supat, Pakistan. The deposits are located at an elevation of approximately 16,000 ft. (4880 m), where the miners search for veins containing olivine, calcite and magnetite that cross-cut dunite host rock. **Dr George E. Harlow** (American Museum of Natural History, New York, New York, USA) studied the

Figure 1: This peridot from Arizona, USA, is host to a large 'lily pad' cleavage disc. The inclusion appears to record the 'double-burst' of a fluid-filled negative crystal during the host peridot's multi-stage ascension to the earth's surface. Photomicrograph by Nathan Renfro/GIA; field of view 8.68 mm.

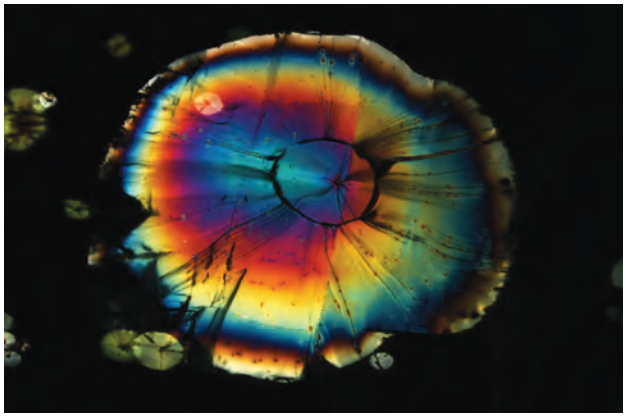

Myanmar, and noted similarities to the deposits in Pakistan and Egypt. He found abundant evidence for the involvement of hydrous fluids in the formation of Burmese peridot, and suggested that it crystallized during the exhumation of the host dunite.

In a well-illustrated presentation, **William Larson** (Palagems.com, Fallbrook, California, USA) reviewed important green gem materials in his collection. He indicated that jadeite is the most sought-after gem in the world after diamond, with approximately US$10 billion traded since 2006.

Corrected from 'annually' to 'since 2006'. For additional Burmese jadeite production data, see www.palagems.com/gem_news_burma_stats.php.

Robert Weldon (GIA, Carlsbad) provided photos and videos from his visit to the Cheapside Hoard at the Museum of London. The green gems in the Hoard consist of Colombian emerald and Egyptian peridot.

The causes of coloration in peridot and other green minerals were reviewed by **Dr George Rossman** (California Institute of Technology, Pasadena, California, USA). The colour of peridot depends on the overall amount of Fe present and its oxidation state, with Fe^{2+} producing green and Fe^{3+} giving brown-to-black.

Brendan M. Laurs

Scottish Gemmological Association Conference

The 2014 conference of the Scottish Gemmological Association took place on 2–5 May in Peebles, Scotland, with about 120 people in attendance. Presentations covered a diverse array of topics.

Dr Michael Krzemnicki (Swiss Gemmological Institute SSEF, Basel) delivered a presentation titled 'The Quest for "Kashmir" Sapphires and "Burma" Rubies—Origin Determination of Gemstones: Possibilities, Challenges and Limitations'. He stated that by analysis of colouring elements using UV-Vis spectroscopy, it is possible to determine the origin of similar-looking gem corundum from various sources, and even the origin of treated stones may be determined, provided that the inclusions remain intact. In a separate presentation, Dr Krzemnicki described interesting items that recently have been encountered in his laboratory. Examples include jadeite from Kazakhstan, which is identifiable by petrographic analysis, and a colour-change garnet that exhibited elements of the Usambara effect.

Antoinette Matlins (gem and jewellery author, South Woodstock, Vermont, USA) discussed lead-glass-filled corundum, and posed the question of whether selling this treated material without disclosure could cost jewellers and gemmologists their reputations. Some faceted pieces have been encountered that essentially consist of a sponge-like matrix of corundum that is held together with lead glass (potentially with colouring agents), raising the issue of the proper nomenclature for such material.

Figure 2: This early 18th century wooden quaich (shallow two-handled drinking cup from Scotland) is decorated with silver. It was made by Hugh Ross and Robert Anderson, and measures approximately 13 cm in diameter. Photo courtesy of Bonhams.

Gordon McFarlan (Bonhams, Edinburgh, Scotland) reviewed the history and value associated with Scottish provincial silver. Using examples of surviving silver spoons and cups (e.g. Figure 2), as well as auction results, he illustrated differences in the silverwork from various Scottish provinces.

Alan Hodgkinson (Scottish Gemmological Association, Ayrshire, Scotland) explored the characteristics of zircon, from its 'high' state through its metamict state, showing how the gemmological properties change as the crystal structure is modified by the radioactive decay of naturally occurring impurities in the gem.

Dr Cigdem Lule (Gemworld Inter-national Inc., Glenview, Illinois, USA) described the multidisciplinary approach of archaeogemmology. This science combines archaeological practices with gemmological identification to determine historic trade routes.

Robert Weldon (GIA, Carlsbad) provided an update on East Africa's gems, in which he surveyed the vast range of materials found in this region. From garnets to diamonds, the sources and colours of these gems were discussed, against a backdrop of gemmological and wildlife images, and interesting stories about the late Campbell Bridges.

Malcolm Appleby (Grandtully, Scotland) recounted his life and experiences as a silversmith and engraver, working first for gunsmiths, then as an independent artist. His commissions have included condiment sets for past prime ministers of the United Kingdom.

Andrew S. Fellows (andrew@gem-a.com)
Gem-A, London

Swiss Gemmological Society Conference 2014

On 4–6 May, the annual meeting and conference of the Swiss Gemmological Society (Schweizerische Gemmologische Gesellschaft, or SGG) took place at the Jugendstilhotel Hotel Paxmontana in Flüeli-Ranft, central Switzerland. The multi-lingual conference was attended by about 85 members and guests (Figure 3). The conference theme was tourmaline and its deposits, and there were also talks given on other topics. The conference was chaired by Michael Hügi, head of the Scientific Committee of the Society.

Prof. Henry Hänni (GemExpert GmbH, Basel, Switzerland) gave an overview of the mineralogical characteristics and classification of the tourmaline group, focusing on the tourmaline species important to the gem trade as well as on the most recently described tourmaline end-members. **Paul Rustemeyer** (Gundelfingen, Germany) gave a beautifully illustrated presentation on the growth characteristics and crystal forms of tourmaline, as seen in slices of numerous samples. He highlighted the relationship between crystal structure and macroscopic growth structures as well as the internal colour zonation. **Alexander Wild** (Wild & Petsch, Kirschweiler, Germany) gave an extensive market report on tourmaline. Mozambique has become the principal producer of Cu-bearing (Paraíba-type) tourmaline, providing some large stones that often show strong colour saturation. Tourmaline is in high demand, and the market is witnessing skyrocketing prices for top-quality stones, not only for 'Paraíba' colours, but also for indicolite, rubellite and 'mint'-green stones. The use of tourmaline in the work of famous jewellers was documented by **Catherine DeVincenti** (CdV Consulting, Lausanne, Switzerland). Her well-illustrated presentation explored the presence of tourmaline as central stones in masterwork jewellery.

Michael Hügi (Swiss Gemmological Society, Bern, Switzerland) discussed indicolite from the Neuschwaben mine in Namibia. A recent visit to

Figure 3: Some of the participants who attended the 2014 Swiss Gemmological Society Conference. Photo courtesy of M. Hügi.

this pegmatite showed that small-scale artisanal mining continues to yield small quantities of fine-quality indicolite and some green tourmaline. Spectrophotometry of the indicolite showed that the typical 'ink'-blue colour may be influenced by Mn^{3+}, in addition to the dominant absorption due to iron. **Dr Ulrich Henn** (German Gemmological Association, Idar-Oberstein) provided a detailed summary of the tourmaline deposits of Rwanda, Democratic Republic of Congo, Malawi and Mozambique. Except for Mozambique, these countries produce only small quantities of tourmaline. In Rwanda and Congo, tourmaline is recovered as a by-product of artisanal mining for other economically important minerals such as cassiterite or columbite-tantalite ('coltan').

Brian Cook (Nature's Geometry, Tucson, Arizona, USA) gave a beautifully illustrated description of the discovery and history of the original deposits of Paraíba tourmaline near São José da Batalha in Brazil. The gems were mined from very steeply dipping dykes of weathered pegmatite and associated alluvial deposits. Recent mining is focusing on a new section of the deposit, which hopefully will produce some additional material of high quality. The Paraíba tourmalines from the Batalha mine are widely regarded as showing superior colour saturation compared to any other source of Cu-bearing tourmaline. This explains why prices of more than US$100,000/carat have been paid for top-quality stones.

On the subject of gem corundum, **Dr Daniel Nyfeler** (Gübelin Gem Lab, Lucerne, Switzerland) provided characteristics of sapphires from the Baw Mar mine near Mogok, Myanmar. These sapphires are typically characterized by polysynthetic twinning with boehmite exsolutions along the twinning planes, and absorption spectra revealing distinct Fe^{3+}. Dr Nyfeler also announced the recently launched Dr Eduard Gübelin Research Scholarship (£20,000), directed at researchers in earth science and related fields who are pursuing innovative projects that contribute to the advancement of gemmological knowledge. **Dr Walter Balmer** (Chulalongkorn University, Bangkok, Thailand) described a recent journey to the ruby and sapphire mines of Mogok with gemmologists from the Swiss Gemmological Institute SSEF. His presentation gave an overview of the current mining activities—including those at the Baw Mar sapphire mine—and of the geological context of this famous gem mining region.

Dr Thomas Hainschwang (GGTL Gemlab–Gemtechlab Laboratory, Principality of Liechtenstein) summarized the criteria for identifying synthetic diamonds in melee parcels, mainly focusing on yellow diamonds. The use of short-wave UV transparency may be problematic with the presence in the market of colourless nitrogen-doped and heat-treated CVD synthetic diamonds. He described a sophisticated instrument used at his laboratory that is capable of testing large quantities of such melee diamonds using photoluminescence spectroscopy. On a similar subject, **Jean-Pierre Chalain** (Swiss Gemmological Institute SSEF) introduced the automated spectral diamond inspection (ASDI) machine, recently developed by SSEF to enable the automatic sorting of colourless natural diamonds from imitations and synthetics. **Walter Muff** (Muff Fine Diamonds, Muri, Switzerland) presented a diamond market report, including developments in diamond pricing in Switzerland, which in recent years were mostly driven by favourable currency exchange rates between the Swiss franc and US dollar.

René Lauper (Frieden AG, Thun, Switzerland) reviewed the cultured pearl market. The markets in Europe and USA are generally saturated with top-quality cultured pearls, but there is some growth potential for moderate-to-good quality saltwater cultured pearls (Akoya, Tahitian, etc.), especially in the emerging markets in Asia. A reduced demand for South Sea cultured pearls may generate serious problems for the Australian cultured pearl industry. **Prof. Henry Hänni** surveyed the most recent developments in pearl farming, especially regarding the traceability of the origin of cultured pearls (see full article in *The Journal of Gemmology,* Vol. 33, Nos. 7–8, 2013, pp. 239–245). **Dr Laurent Cartier** (Swiss Gemmological Institute SSEF) showed how it is possible to separate cultured pearls from *Pinctada radiata, P. maxima* and *P. margaritifera* molluscs using DNA fingerprinting.

Frederik Schwarz (Christie's, Berlin, Germany) recounted the history of the magnificent crown jewels of The Netherlands. Many pieces of the historical jewellery are still in use, although several have been modified from their original

settings and designs according to the demands of their owners.

Dr Michael Krzemnicki (Swiss Gemmological Institute SSEF) gave the closing lecture summarizing news from the SSEF laboratory. He included some highlights of items tested recently at SSEF such as the Hutton-Mdivani jadeite necklace, which recently sold at Sotheby's Hong Kong for more than US$27.4 million. He also described a faked 'historic' emerald necklace containing Zambian emeralds, a Melo pearl containing a cavity filled with artificial resin, and exceptional spessartines from Namibia, Nigeria and Mogok.

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Swiss Gemmological Society
Bern, Switzerland

Michael Krzemnicki
Swiss Gemmological Institute SSEF
Basel, Switzerland

Accredited Gemologists Association's 2014 Las Vegas Conference

This educational event took place on 29 May, one day before the start of the JCK Las Vegas Show in Nevada, USA. The conference theme was 'Lab Grown Diamonds: In the Labs…in the Trade…and in YOUR Future!' The event was attended by approximately 60 people, and chaired by **Stuart Robertson**, AGA president and vice president of GemWorld International Inc. (Glenview, Illinois, USA).

Dr James Shigley (GIA, Carlsbad) began the conference by noting that effective research and identification of synthetics can only be accomplished when laboratories have a large and trustworthy database of known natural and synthetic diamonds. Dr Shigley summarized optical defects useful for identification. He also noted that by determining a diamond's type, a gemmologist can get a sense of whether further testing is needed to assess natural or synthetic origin.

Dusan Simic (Analytical Gemology and Jewelry, New York, New York, USA) described the challenges of identifying loose as well as mounted synthetic diamonds. At his lab, he separates diamonds into several categories: (1) natural diamond/natural colour, (2) natural diamond/treated colour, (3) synthetic diamond/as-grown colour, (4) synthetic diamond/treated colour, and (5) diamond imitation. Simic also mentioned the industrial and scientific uses for gem-quality synthetic diamonds; the identification of these materials can be quite challenging. He pointed to De Beers' Element Six laboratory as just one source of 'electronic grade' CVD synthetic diamonds, which are more valuable in electronics applications than in the jewellery industry.

Tom Chatham (Chatham Created Gems, San Francisco, California, USA) gave a fascinating first-hand family history of producing synthetic gems and how the jewellery industry has been affected as each new product has entered the market. It was Chatham's father who created the first commercially available flux-grown synthetic emerald, and the company has also produced and/or marketed synthetic corundum, alexandrite, opal and, most recently, diamond. With synthetic gem-quality diamond now being so accessible, Chatham pointed to the inevitable availability of calibrated-cut synthetic diamonds. Natural diamonds are not necessarily cut to calibrated sizes, but this is where lab-grown products can compete extremely well. Chatham finished his talk by noting that "natural diamond prices staying high is critical for the synthetic growers' maintaining a profitable margin".

Ronnie VanderLinden (Russian Classics Inc., Diamex Inc., and Pintura Cultured Diamonds, New York, New York, USA) is in the unique position of being in both the natural and synthetic gem diamond businesses. With this perspective, he stated: "To produce lab-grown diamond in the factory is 1/10th the cost of the natural. We want that differentiation." Diamond is forever, but diamond mines are not. About synthetic diamonds he stated: "Don't be afraid of the product. It's 100% diamond.…Embrace it!"

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Gem-A Notices

GIFTS AND DONATIONS TO THE ASSOCIATION

The Association is most grateful to the following for their gifts and donations for research and teaching purposes:

Maggie Campbell Pedersen FGA, London, for specimens of burmite amber and wild boar tusk.

Christopher Cavey FGA, Amersham, Buckinghamshire, for a rhino horn and rhino skin specimen.

Steven Collins FGA DGA, Potton, Bedfordshire, for two Presidium gauges.

Anil Dholakia of Anil Dholakia Inc., Franklin, North Carolina, USA, for an 'Emerald Essence' beryl triplet.

Dennis Ho, Yangon, Myanmar, for a large selection of spinel crystals, a crystal-system stone set carved from hackmanite, and a 'Popular Gems' board displaying a selection of rough gems.

Marcus McCallum FGA, London, for ruby crystals and a large selection of garnets, each 'foil-backed' with a piece of metal.

Michael O'Donoghue FGA, Sevenoaks, Kent, for a selection of chrome, pink and green tourmalines.

Prof. Chiu Mei (Mimi) Ou Yang FGA, Hong Kong, for a 'bouquet' of carved orange jade flowers.

Rosemary Routledge, Bath, for a selection of opals and other cut stones.

John E. Roux, Horsham, Sussex, for a quantity of books for the Sir James Walton Library.

Dominic Seligman FGA DGA, London, for gemstones from his personal collection, including carved jadeite, a large red spinel crystal, a hackmanite cabochon and specimens of spinel, tourmaline, chrysoberyl, sapphire, garnet, topaz, ruby, apatite, blue moonstone and amethyst.

Alexandros Sergoulopoulos FGA DGA, Athens, Greece, for a dodecahedral diamond crystal and a bag of rough stones.

Paul Siegel FGA, Rocky Point, New York, USA, for a monetary donation.

Antonio Silva, London, for *Russian Gemstones Encyclopedia* by V. V. Bukanov.

Miranda Wells FGA DGA, Birmingham, West Midlands, for five older back issues of *The Journal of Gemmology*.

Jason Williams FGA DGA, G. F. Williams & Co., London, for a large selection of fashioned stones including quartz, onyx, topaz, turquoise and plastic imitations of amber.

ANNUAL GENERAL MEETING

The Gem-A Annual General Meeting (AGM) was held on Thursday 12 June 2014 in the Bruton Room at Gem-A, 21 Ely Place, London EC1N 6TD. The meeting was chaired by Jason Williams, the Chairman of the Board. The Annual Report and Accounts were approved.

Harry Levy was re-elected President for the term 2014–2016. Professor Andrew Rankin stepped down from the Board and was thanked for his time as trustee and president. Professor Rankin was then elected a Vice President. Mary Burland, Miranda Wells and Jason Williams, who retired from the Council by rotation, and Jonathan Lambert, who had been appointed by the Council since the 2013 AGM, were re-elected.

Hazlems Fenton were re-appointed as auditors for the year.

The AGM was followed by a presentation by Vivien Johnson entitled 'The evolution of ethical jewellery in the UK'.

GEM-A AWARDS

In the Gem-A examinations held in January 2014, 151 students qualified in the Gemmology Diploma Examination, including 13 with Distinction and 22 with Merit, and 201 students qualified in the Foundation Certificate in Gemmology Examination. In the Gem Diamond Examination 75 qualified, including 13 with Distinction and eight with Merit. The names of the successful candidates are listed alphabetically.

Examinations in Gemmology

Gemmology Diploma

Qualified with Distinction

Chen Miaofen, *Chenxi, Guangxi, P.R. China*
Fan Xingyu, *Xuancheng, Anhui, P.R. China*
Féral, Catherine, *Paris, France*
Guo Yaling, *Beijing, P.R. China*
Han Haoyu, *Beijing, P.R. China*
Ke Jiayu, *Beijing, P.R. China*
Khabrieva, Dilyara, *London*
Li Wenli, *Beijing, P.R. China*
Lu Gujun, *Beijing, P.R. China*
Qu Qi, *Paris, France*
Rigaud, Matthieu, *Bayonne, France*
Wu Jingyi, *Beijing, P.R. China*
Zhang Gaoyang, *Beijing, P.R. China*

Qualified with Merit

Bian Jinjin, *Beijing, P.R. China*
Chang Qian, *Shanghai, P.R. China*
Chen Qiang, *Beijing, P.R. China*
Dai An, *Beijing, P.R. China*
Dai Li Li, *Beijing, P.R. China*
Fan Jing, *Beijing, P.R. China*
Guo Bi Jun, *Beijing, P.R. China*
Han Ying Hui, *Beijing, P.R. China*
Lu Xiao, *Beijing, P.R. China*
Marleau, Diane, *Ville Mont-Royal, Quebec, Canada*
Mo Hongyan, *Nanning, Guangxi, P.R. China*
Shi Yang, *Guilin, Guangxi, P.R. China*
Si Yitong, *Pingdingshan, Henan, P.R. China*
Sun Xue Ying, *Anqing, Anhui, P.R. China*
Wang Feidi, *Wuhan, Hubei, P.R. China*
Wang Siyi, *Beijing, P.R. China*
Wang Yan, *Beijing, P.R. China*
Wang Yue, *Beijing, P.R. China*
Wenyan Luo, *Daqing, Heilongjiang, P.R. China*
Xie Meinan, *Beijing, P.R. China*
Yang Meng, *Beijing, P.R. China*
Yuan Yi Rong, *Beijing, P.R. China*

Qualified

Baduza-Sutton, Buyisa, *Birmingham, West Midlands*
Bai Xiao, *Beijing, P.R. China*
Cao Ri, *Bengbu, Anhui, P.R. China*
Chai Jing, *Beijing, P.R. China*
Chant, Francesca, *Chichester, West Sussex*
Cheer, Peter, *Somerton, Somerset*
Chen Qian Ran, *Beijing, P.R. China*
Chen Xiao Ai, *Dalian, Liaoning, P.R. China*
Chen Yaqing, *Hanzhong, Shanxi, P.R. China*
Chen Zhujun, *Wuhan, Hubei, P.R. China*
Cheng Xinyi, *Xi'an, Shanxi, P.R. China*
Colloud Aballe, Lydie, *La Chaux De Fonds, Switzerland*
Cong Xuesong, *Guangzhou, Guangdong, P.R. China*
Corona Blandin, Marie-Azilis, *Belz, France*
De Lamberterie, Isabelle, *Saint-Nom-la Bretèche, France*
Deng Yuli, *Meishan, Sichuan, P.R. China*
Deriaz, Julie Ann, *St John's, Newfoundland, Canada*
Donaldson Lie, Gillian, *Toronto, Ontario, Canada*
Dong Yidan, *Beijing, P.R. China*
Dong Yiping, *Guangxi, Guilin, P.R. China*
Du Hua Ting, *Beijing, P.R. China*
Dupuy, Harold, *Lafayette, Louisiana, USA*
Esterhuysen, Stephanus, *Viljoenskroon, South Africa*
Fang Ao, *Hedong, Tianjin, P.R. China*
Fang Yi Bin, *Beijing, P.R. China*
Feng Xiaoxi, *Xinjiang, P.R. China*
Fiebig, Jim, *West Des Moines, Iowa, USA*
Fu Minli, *Xiaogan, Hubei, P.R. China*
Fu Yu, *Beijing, P.R. China*
Gao Dan, *Wuhu, Anhui, P.R. China*
Gao Manmengxi, *Wuzhou, Guangxi, P.R. China*
Gao Wenting, *Shenzhen, Guangdong, P.R. China*
Gao Xue, *Nanyang, Henan, P.R. China*
Geo Chao, *Guangzhou, Guangdong, P.R. China*
Gericke, Chanel, *Nottingham*
Granic, Kata, *Auckland, New Zealand*
Griffon, Denise, *Montreal, Quebec, Canada*
Han Jie, *Beijing, P.R. China*
Han Yue, *Beijing, P.R. China*
Hu Haifeng, *Wuhan, Hubei, P.R. China*
Huang Liuyun, *Guilin, Guangxi, P.R. China*
Huangzheng Xiao, *Wuhan, Hubei, P.R. China*
Ji Xiaoliu, *Rugao, Jiangsu, P.R. China*
Jia Qiuying, *Beijing, P.R. China*
Katsof, Erika, *Lachine, Quebec, Canada*
Kenyon, Janelle, *Auckland, New Zealand*
Kolator, Barbara, *London*
Kuo Hsin, *Taipei, Taiwan, R.O. China*
Lammertse, Max, *Amsterdam, The Netherlands*
Lee Hsiu Fen, *Leeuwarden, The Netherlands*
Lee Tak Fai, Eric, *Kowloon, Hong Kong*
Leedham, Laura, *Oldbury, West Midlands*
Lei Yaxiu, *Xi'an, Shanxi, P.R. China*
Leung Ying, *Tsing Yi, Hong Kong*
Li Mei-Hui, *Taichung, Taiwan, R.O. China*
Li Wen Xin, *Beijing, P.R. China*
Li Wenqing, *Beijing, P.R. China*
Li Yi-Chen, *Taichung, Taiwan, R.O. China*
Liang Lu, *Taiyuan, Shanxi, P.R. China*
Lin Feiyu, *Beijing, P.R. China*
Liu Chen Pu, *Beijing, P.R. China*
Liu Hongwei, *Tianjin, P.R. China*

Liu Mengzhuo, *Beijing, P.R. China*
Liu Xiaoyu, *Shenzhen, Guangdong, P.R. China*
Liu Yinghui, *Beijing, P.R. China*
Liu Yuecong, *Beijing, P.R. China*
Mak Yee Ki, *Tuen Mun, Hong Kong*
Matthews, Timothy, *Knoxville, Tennessee, USA*
Meissirel, Mathilde, *Canterbury, Kent*
Men, Oxana, *Athens, Greece*
Millet, Angélique, *Ville d'Avray, France*
Nijzink-Brandt, Saskia, *Arnhem, The Netherlands*
O'Sullivan Walter, Lauren, *San Francisco, California, USA*
Ovesen, Hasanthi, *London*
Pan Shenchao, *Shanghai, P.R. China*
Pan Yongyi, *Shenyang, Liaoning, P.R. China*
Perkkio, Maria, *Helsinki, Finland*
Qin Wenjie, *Shanghai, P.R. China*
Routledge, Susannah, *Reading, Berkshire*
Rykova, Elena, *Paris, France*
Saleem, Melanie, *Manchester, Greater Manchester*
Sapault, Jordan, *Antony, France*
Schuler-Immoos, Gertrud, *Lucerne, Switzerland*
Shekarriz, Toktam, *Hampstead, Quebec, Canada*
Sun Chen, *Wuhan, Hubei, P.R. China*
Sun Yitian, *Beijing, P.R. China*
Swaving, Christine, *The Hague, The Netherlands*
Tang Boli, *Hanzhong, Shanxi, P.R. China*
Tsai Chi-Chieh, *Taichung, Taiwan, R.O. China*
Tseng Yen-Chun, *Changhua, Taiwan, R.O. China*
Wang Chengbo, *Taian, Shandong, P.R. China*
Wang Xinyi, *Danjiangkou, Hubei, P.R. China*
Wong Man Ho, *Kowloon, Hong Kong*
Wu Min, *Chongqing, P.R. China*
Wu Wei Ran, *Beijing, P.R. China*
Wu Zhe, *Beijing, P.R. China*
Xie Ena, *Beijing, P.R. China*
Xu Jing, *Hangzhou, Zhejiang, P.R. China*
Xu Ting, *Shaoxing, Zhejiang, P.R. China*
Xu Yan, *Beijing, P.R. China*
Xue Cen, *Shanghai, P.R. China*
Yang Qiujing, *Singapore*
Yang Xiao, *Zibo, Shandong, P.R. China*
Yang Yufan, *Guiyang, Guizhou, P.R. China*
Ye Fangqi, *Beijing, P.R. China*
Yiu King San, Sunny, *Tuen Mun, Hong Kong*
Zhang Cheng, *Beijing, P.R. China*
Zhang Di, *Baoding, Hebei, P.R. China*
Zhang Guoqing, *Nanning, Guangxi, P.R. China*
Zhang Hanyan, *Wuhan, Hubei, P.R. China*
Zhang Jie, *Jinan, Shandong, P.R. China*
Zhang Yun, *Weihai, Shandong, P.R. China*
Zhao Hong, *Beijing, P.R. China*
Zhao Jia Hui, *Beijing, P.R. China*
Zhou Si Si, *Beijing, P.R. China*
Zhu Younan, *Beijing, P.R. China*

Foundation Certificate in Gemmology

Qualified

Allen, Tara, *Carlsbad, California, USA*
Ardon, Troy, *Carlsbad, California, USA*
Arrive, Elodie, *Annecy, France*
Bassil, Sophie-Marie, *Malakoff, France*
Batisse, Sylvia, *Gallardon, France*
Bealey, Philip, *Ilfracombe, Devon*
Bernard, Amy, *South Darenth, Kent*
Blanchard, Alain, *Paris, France*
Boemo, Julien, *Lorraine, France*
Borreill, Daniel, *Serralongue, France*
Boubouillon, Yasmine, *Cretail, France*
Brown, Gareth, *Bristol*
Campbell, Rosanna, *London*
Cederlund, Johanna, *Lannavaara, Sweden*
Chan Meng-Hua, *New Taipei City, Taiwan, R.O. China*
Chan San San, *San Wan, Hong Kong*
Chan Shih, Sally, *Flushing, New York, USA*
Chan Tsz Ying, *Yuen Long, Hong Kong*
Chan Wing Chi, *Tsuen Wan, Hong Kong*
Chan Yee Ha, *Tsuen Wan, Hong Kong*
Chang Cheng-Yi, *Taichung, Taiwan, R.O. China*
Chau Hoi Yim, *Tsing Yi, Hong Kong*
Chen Chun-Yi, *New Taipei City, Taiwan, R.O. China*
Chen Mei Zhen, *Ngau Tau Kok, Hong Kong*
Chen Po Chuan, *Taipei, Taiwan, R.O. China*
Chen Xiao Mei, *Kowloon, Hong Kong*
Chen Yaqing, *Hanzhong, Shanxi, P.R. China*
Cheng Xiang, *Shanghai, P.R. China*
Chetwynd, Doreen, *Leicester*
Cho Shuk Ping, *Hunghom, Hong Kong*
Choi Hon Por, *North Point, Hong Kong*
Chong Oi Lin, *Sheung Shui, Hong Kong*
Chow Hiu Yan, *Central, Hong Kong*
Chui Kwan Fung, *Kowloon, Hong Kong*
Cisamolo, Marie-Cecile, *London*
Cohen, Jason, *East Barnet, Hertfordshire*
Craig, Deborah, *Sundbyberg, Sweden*
Crispino, Gary, *Albany, California, USA*
Desile-Dejean, Celine, *Yangon, Myanmar*
Desmortiers, Patricia, *Paris, France*
Ding Qian, *Guiyang, Guizhou, P.R. China*
Dong Yiping, *Guilin, Guangxi, P.R. China*
Dubinsky, Emily, *New York, New York, USA*
Egre, Virginie, *Paris, France*
Fong Yee Kan, *Kowloon, Hong Kong*
Fong Lap Kit, *Yuen Long, Hong Kong*
Foskett, Emily, *London*
Foxwell, Kim, *Twickenham, Middlesex*
Fung Hoi Ching, *Yuen Long, Hong Kong*
Gallegos, Jenefer, *London*
Gandhi, Hemang, *London*

Garnier, Georgina, *London*
Guicheney Mahler, Jean Philippe, *Garches, France*
Guo Xiaocheng, *Longyan, Fujian, P.R. China*
Hall, Lucy, *London*
Hou Fei-Feng, *Taipei, Taiwan, R.O. China*
Huang Kaixi, *London*
Huang Li-Lien, *Taichung, Taiwan, R.O. China*
Huang Lingxi, *Guilin, Guangxi, P.R. China*
Huang Tien Hua, *Taoyuan, Taiwan, R.O. China*
Huang Wenjie, *Guilin, Guangxi, P.R. China*
Hui Sin Kam, *Tseung Kwan O, Hong Kong*
Ito, Claire, *New York, New York, USA*
Jayawardhana, Jayamini, *Ratnapura, Sri Lanka*
Jiang Rongxian, *Guangzhou, Guangdong, P.R. China*
Jones, Oliver, *Bern, Switzerland*
Kadigamuwa, Nethmin, *Hounslow, Middlesex*
Kang Zhiyuan, *Shanghai, P.R. China*
Katsurada, Yusuke, *Tokyo, Japan*
Kwan Sin Yi, *Tseung Kwan O, Hong Kong*
Kyaw Zay Yar Naing, *Yangon, Myanmar*
Kyle, Jennifer, *Montreal, Quebec, Canada*
Lai Xiaolin, *Guangzhou, Guangdong, P.R. China*
Lai Cheng, *Guilin, Guangxi, P.R. China*
Lai Ka Man, *London*
Lam Lai Yuen, *Tseung Kwan O, Hong Kong*
Lawton, Lesley, *Nantwich, Cheshire*
Lee Yan Ho, *Taipo, Hong Kong*
Legros, Maria, *London*
Leleu, Cédric, *Levallois-Perret, France*
Li Hung Mui, *Mong Kok, Hong Kong*
Li Jing, *Surbiton, Surrey*
Li Mei-Hui, *Taichung, Taiwan, R.O. China*
Li Tsung Han, *Hsinchu, Taiwan, R.O. China*
Li Wenjie, *Guangzhou, Guangdong, P.R. China*
Li Xiaoyi, *Vancouver, British Columbia, Canada*
Li Yikun, *Guilin, Guangxi, P.R. China*
Li Zhen, *Guilin, Guangxi, P.R. China*
Li Zhixiang, *Guangzhou, Guangdong, P.R. China*
Liang, Shr-Hua, *Taichung, Taiwan, R.O. China*
Liao Yi Chen, *Taipei, Taiwan, R.O. China*
Lin Moqing, *Central, Hong Kong*
Lin Ta Wei, *Taichung, Taiwan, R.O. China*
Lin Wen Yu, *Taipei, Taiwan, R.O. China*
Lin Yu Ju, *Taipei, Taiwan, R.O. China*
Lin Yu Ping, *Pingzhen, Taoyuan, Taiwan, R.O. China*
Liscouet, Marie-Solène, *Saint Cloud, France*
Liu Bingjie, *Shanghai, P.R. China*
Liu Can, *Shanghai, P.R. China*
Liu Chien-Yu, *Hsinchu, Taiwan, R.O. China*
Liu Jiamin, *Guilin, Guangxi, P.R. China*
Liu Ying, *Shanghai, P.R. China*
Liu Yuli, *Shaoyang, Hunan, P.R. China*
Liu Zhiyu, *London*
Lo Ching-Hui, *Taipei, Taiwan, R.O. China*
Lodha, Rahul, *Kalwa, India*
Long Songyun, *Guilin, Guangxi, P.R. China*
Louie Rayki Man Yam, *San Po Kong, Hong Kong*
Lu Yi-Lun, *Taichung, Taiwan, R.O. China*
Lusher, Lila, *Whangarei, Northland, New Zealand*
Ma Sin Yue, *Kowloon, Hong Kong*
Machen, Andrea, *West Byfleet, Surrey*
Mak Ka Lun, *Mongkok, Hong Kong*
Mak Ka Wai, *Shatin, Hong Kong*
Man Sui Wan, Joy, *Shatin, Hong Kong*
May, Eric, *Verbier, Switzerland*
Moe Kyaw, *Fishkill, New York, USA*
Mok Ka Yan, Noelle, *Kowloon, Hong Kong*
Molon, Valentina, *London*
Monnin, Antony, *Morteau, France*
Moulton-Cox, Amy, *Whangaparaoa, New Zealand*
Mutsaers, Gerard, *Dieren, The Netherlands*
Naing Min Phone, *Yangon, Myanmar*
Nazz, Marzena, *Jersey City, New Jersey, USA*
Ng Wai Fong, *Kowloon, Hong Kong*
Ng Siu Lun, *Kwun Tong, Hong Kong*
Nicolson, Kirsty, *Portland, Dorset*
Nigam, Pooja, *London*
Odake, Shoko, *Tokyo, Japan*
Pageaut, Thierry, *Courbouzon, France*
Paing Kyaw Thet, *Yangon, Myanmar*
Pear, Bradley, *Bloomfield, Michigan, USA*
Peens, Ruley, *Johannesburg, Gauteng, South Africa*
Peng Mingqiang, *Guilin, Guangxi, P.R. China*
Praill, Gregory, *Hockley, Essex*
Qin Qiaohong, *Guilin, Guangxi, P.R. China*
Reeder, Nicola, *Royston, Hertfordshire*
Regan, Karen, *Dublin, R.O. Ireland*
Renfro, Nathan, *Carlsbad, California, USA*
Rocchi, Natalia, *London*
Rodrigues, Suelle, *Utrecht, The Netherlands*
Rong, Zhen, *Shanghai, P.R. China*
Ryan, Veronica, *London*
Sangsawong, Supharart, *Bangkok, Thailand*
Saruwatari, Kazuko, *Tokyo, Japan*
Sawyer, Nicola, *Bristol*
Schwartz, Virginia, *Carlsbad, California, USA*
Scott, Louisa, *London*
Shen Fangqing, *Shanghai, P.R. China*
Shen Qi, *Shanghai, P.R. China*
Shen Jiamin, *Guilin, Guangxi, P.R. China*
Shi Yan, *Guilin, Guangxi, P.R. China*
Sit Mei Mei, *Central, Hong Kong*
Soo See Sheng, *Singapore*
Soonthorntantikul, Wasura, *Bangkok, Thailand*
Stancliffe, Sarah, *London*
Stephan, Michaela, *McLean County, Illinois, USA*

Su Liping, *Guilin, Guangxi, P.R. China*
Sun I-Shan, *Taichung, Taiwan, R.O. China*
Sutton, Stephen, *Tonbridge, Kent*
Tam Hee Lan, *Tuen Mun, Hong Kong*
Tang Kwok Ying, *Tai Po, Hong Kong*
Tay Meng Leong, *Singapore*
Tsai Chi-Chieh, *Taichung, Taiwan, R.O. China*
Tsao Wen Ting, *Taipei, Taiwan, R.O. China*
Tse Siu Fung, *Kwun Tong, Hong Kong*
Tseng Yi Ming, *Taipei, Taiwan, R.O. China*
Van Hoecke, Audrey, *London*
Velickaite, Akvile, *London*
Venville, Sarah, *Auckland, New Zealand*
Wang Shuang, *Guilin, Guangxi, P.R. China*
Waters, Renee, *Market Harborough, Leicestershire*
Whittington, Flora, *St Helier, Jersey, Channel Islands*
Williams, Kathryn, *Dover, Kent*
Williamson, Anna, *Hamilton, New Zealand*
Wong Tsz Ting, *Tseung Kwan O, Hong Kong*
Wong Surjit, *Brooklyn, New York, USA*
Wright, William, *London*
Wu Bin, *Guilin, Guangxi, P.R. China*
Wu Kun Tse, *Taoyuan, Taiwan, R.O. China*
Xin Cuihong, *Shanghai, P.R. China*
Xu Yanfei, *Guilin, Guangxi, P.R. China*
Yang, Qiankun, *Shanghai, P.R. China*
Yang Jingwen, *Shanghai, P.R. China*
Yang Ya-Chu, *Taipei, Taiwan, R.O. China*
Yang Yi-En, *Taipei, Taiwan, R.O. China*
Yang Jia Sin, *Taipei, Taiwan, R.O. China*
Yano Yukari, *Singapore*
Yau Ka Ki, *North Point, Hong Kong*
Yazawa, Emiko, *Woodside, New York, USA*
Yin Yunan, *Shanghai, P.R. China*
Yu Ning, *Foshan City, Guangdong, P.R. China*
Yu Xinyuan, *Changsha, Hunan, P.R. China*
Yuan Wei, *Guilin, Guangxi, P.R. China*
Zhang Baijie, *Shanghai, P.R. China*
Zhang Meng, *Shanghai, P.R. China*
Zhang Shi, *Guilin, Guangxi, P.R. China*
Zheng Long, *Guangzhou, Guangdong, P.R. China*
Zhou Xinyi, *Guilin, Guangxi, P.R. China*
Zhu Ying, *Shanghai, P.R. China*
Zuo Tenglong, *Zhengzhou, Henan, P.R. China*

Diamond Diploma Examination

Qualified with Distinction

Barber, Simon, *London*
Chai Jing, *Guangzhou, Guangdong, P.R. China*
Glenn, Alison, *Chertsey, Surrey*
Hartstone, Bradley, *New Barnet, Hertfordshire*
Herold, Doerte, *Zurich, Switzerland*
Ji Ang, *Chatham, Kent*
Kanevskij, Aleksandr, *London*
Lowther, Joan, *Stockholm, Sweden*
Mendes, Isabella, *Berkhamstead, Hertfordshire*
Porter, Rex, *Hook, Hampshire*
Stancliffe, Sarah, *London*
Sternbeck, Julie Louise, *Wakefield, West Yorkshire*
Wong Ching Man, *Discovery Bay, Hong Kong*

Qualified with Merit

Chan Yin Tong, *Kwun Tong, Hong Kong*
Khoo Shoew Peng, Penny, *Yuen Long, Hong Kong*
Li Ying, *Guangzhou, Guangdong, P.R. China*
Meng Fang, *Beijing, P.R. China*
Van Eerde, Christa, *London*
Woodcock, Olga Faye, *Basingstoke, Hampshire*
Xue Ru, *Beijing, P.R. China*
Yu Chunchao, *Beijing, P.R. China*

Qualified

Aggarwal, Lisa, *Northolt, Middlesex*
Bai Xuemei, *Guangzhou, Guangdong, P.R. China*
Barnett, Faye, *Birmingham, West Midlands*
Byrne, Amie, *Solihull, West Midlands*
Chan Sum Yi, *Kowloon, Hong Kong*
Chan Yong Yong, Angela, *Hunghom, Hong Kong*
Chan Lai Yi, *Ho Man Tin, Hong Kong*
Cheng Hin Wah, *Aberdeen, Hong Kong*
Choi Wai Hung, *Sham Shui Po, Hong Kong*
Choi Lai Shan, *Kowloon, Hong Kong*
Chu Chi Ting, *Sheung Shui, Hong Kong*
Chung Kit Shuen, *Kwun Tong, Hong Kong*
Cousins, Julian, *Faversham, Kent*
Deng Yufei, *Shanghai, P.R. China*
Du Jialin, *Beijing, P.R. China*
Kong Fanbo, *Beijing, P.R. China*
Kwok Men Yee, *Kam Tin, Hong Kong*
Lai Shan Shan, *Kowloon, Hong Kong*
Lam Tik Nga, *Pok Fu Lam, Hong Kong*
Lam Ching Yee, *Fanling, Hong Kong*
Lam Man Yee, Maria, *Kowloon, Hong Kong*
Lau Fung Shan, *Tuen Mun, Hong Kong*
Lau Chui Ting, *Tin Shui Wai, Hong Kong*
Lee Hsiu Fen, *Leeuwarden, The Netherlands*
Lee Sze Hang, Florence, *Kwai Chung, Hong Kong*
Leung Wai Yee Jouie, *Tai Po, Hong Kong*
Li Wai Hon, *Shek Tong Tsui, Hong Kong*
Lo Man Sze, *Tai Po, Hong Kong*
Lui Kai Yin, *Kwai Chung, Hong Kong*
Lutumba, Salomon, *Coventry, West Midlands*
Men, Oxana, *Athens, Greece*
Ng Wan Yuen Eoroy, *Kowloon, Hong Kong*

Ng Koon Hei, *Lai Chi Kok, Hong Kong*
Ngo, Peter, *London*
Panfil, Alexandra, *London*
Santarsiere, Miguel Angel, *Folkestone, Kent*
Sharpley-Fanner, Harriet, *London*
Shaw, Rebecca, *Huddersfield, West Yorkshire*
Si Cong, *Beijing, P.R. China*
Skinner, Jasmine, *Birmingham, West Midlands*
So Shuk Man, *Shatin, Hong Kong*
Sze Hoi Lee, *Kowloon, Hong Kong*
Tong Hoi Yum, Louise, *Sham Shui Po, Hong Kong*
Tsai Sung Fung, *Sai Ying Pun, Hong Kong*
Tsang Pui Yee, *Tsuen Wan, Hong Kong*
Tsui Yuen Shan, *Ma On Shan, Hong Kong*
Wang Sida, *Beijing, P.R. China*
Wong Hoi Ting, *Tai Po, Hong Kong*
Wong Wai Yin, *Sheung Shui, Hong Kong*
Wu Muyun, *Beijing, P.R. China*
Wu Jiahui, *Beijing, P.R. China*
Yan Xiaolan, *Fuzhou, Fujian, P.R. China*
Zhao Wen Ting, *To Kwa Wan, Hong Kong*
Zhu Di, *Beijing, P.R. China*

MEMBERSHIP

At a meeting of the Council of the Association held on 12 June 2014, the following were elected to membership:

Fellowship and Diamond Membership (FGA DGA)

Craddock, Natalie, *Birmingham, West Midlands*
Green, Edward, *Edinburgh, Midlothian*
Matthews, Timothy, *Knoxville, Tennessee, USA*
Wang Linlin, *London*

Fellowship (FGA)

Choquette, Carolyne, *Laval, Quebec, Canada*
Haeringer, Manuelle, *Provence-Alpes-Côte d'Azur, France*
Harris, Natalie, *Merstham, Surrey*
Hayashi, Hidenori, *Tokyo, Japan*
Heilio, Saara, *Bromley, Kent*
Huang Mulin, *Beijing, P.R. China*
Hughes, E. Billie, *Bangkok, Thailand*
Kajita, Yukio, *Tokyo, Japan*
Kolator, Barbara, *London*
Mak Yee Ki, *Tuen Mun, Hong Kong*
Manorotkul, Wimon, *Bangkok, Thailand*
Peng Hsiang-Chieh, *New Taipei City, Taiwan, R.O. China*
Pino, Orazio, *Liguria, Italy*
Schuler-Immoos, Gertrud, *Lucerne, Switzerland*
Van Heesewijk, Jacqueline, *Ripley, Surrey*
Wang Kai, *Guangzhou, Guangdong, P.R. China*
Wang Minmin, *Guangzhou, Guangdong, P.R. China*
Wang Xiaojuan, *Beijing, P.R. China*
Yamagishi, Shoji, *Kanagawa, Japan*
Yang Jiong, *Taian, Shandong, P.R. China*
Yoda, Takahiro, *Tokyo, Japan*
Zhang Tianyang, *Guangzhou, Guangdong, P.R. China*
Zheng Fangyi, *Shanghai, P.R. China*

Diamond Membership (DGA)

Avraam, Zoey, *London*
Bratek, Elizabeth Jane, *Harold Hill, Essex*
Choi Wai Hung, *Kowloon, Hong Kong*
Cousins, Julian, *Faversham, Kent*
Fortunato, Claudio, *London*
Lin Huaxia, *Guangzhou, Guangdong, P.R. China*
Selant, Sabbir, *Preston, Lancashire*
Wilson, Naomi, *Selly Oak, West Midlands*
Yuan Chih-Chung, Joe, *Zhengzhou, Henan, P.R. China*

Associate Membership

Abramowitz, Lauren, *Glendale, Arizona, USA*
Atkins, Roy, *Newhaven, East Sussex*
Avallon, Elena, *Stockholm, Sweden*
Barker, Bill, *Scotsdale, Arizona, USA*
Brady, Aoife, *London*
Brakovic, Marin, *Koper, Slovenia*
Caplan, Evan, *Los Angeles, California, USA*
Chaput, Aurelie, *London*
Clarke, Barry, *London*
Delaye, Aline, *Singapore*
Dholakia, Anil B., *Franklin, North Carolina, USA*
Dieu de Bellefontaine, Mary, *Billericay, Essex*
Fitzgerald, Alison, *Sevenoaks, Kent*
Gargour, Karim, *Beirut, Lebanon*
Goldingay, Raymond, *St John, Jersey, Channel Islands*
Griffin, Patricia, *Yarra Glen, Victoria, Australia*
Gunn, Timothy, *London*
Hall, Samuel, *Heathfield, East Sussex*
Jebb, Loraine, *Hillsborough, Co. Down, Northern Ireland*
Kinoshita, Yoshio, *Montreal, Quebec, Canada*
Knuckey, Samantha, *Prestbury, Cheshire*
Komatsu, Hiroshi, *Tokyo, Japan*
Lazzarelli, Herve Nicolas, *Geneva, Switzerland*
Llopis Lopez, Manuel, *València, Spain*
Marsh, Clare, *Swadlingcote, Derbyshire*
Mastroianni, Carol, *West Melbourne, Victoria, Australia*
Mathieu, Eloise, *London*
Mehdi, Jonathan, *Bushey, Hertfordshire*

Merk, Roger, *San Diego, California, USA*
Olivares Salmon, Elka, *Gibraltar*
Poultney, Sue, *Ashford, Kent*
Pragnell, Charles, *Stratford-upon-Avon, Warwickshire*
Ralph, Jolyon, *Mitcham, Surrey*
Reedie, Kathryn, *London*
Remy-Clarke, Helene, *London*
Renshaw, Mark, *Wakefield, West Yorkshire*
Salem, James, *Kings Langley, Hertfordshire*
Shaikh, Nasiruddin, *London*
Sim Hwa San, *Singapore*
Stone-Sundberg, Jennifer, *Portland, Oregon, USA*
Thierrin-Michael, Gisela, *Jura, Switzerland*
Thompson, Don, *Billings, Montana, USA*
Tiamiyo, Soulikifouli, *Cotonou, Benin*
Traisirichok, Thunyathorn, *Chiang Mai, Thailand*
Watanabe, Koichiro, *Tokyo, Japan*
Yawata, Keiko, *Kanagawa, Japan*

Gold Corporate Membership

Berganza Ltd, *London*
IGR Reports, *London*
George Pragnell Ltd, *Stratford-upon-Avon, Warwickshire*

Corporate Membership

J Co Gems Ltd, *London*
Scarab Antiques, *Ashford, Kent*

Gem-A Photographic Competition 2014

Gilalite aggregates in rock crystal by Michael Hügi FGA. Winner of the 2013 competition.

Submit your photographs for the 2014 Photo Competition and you could win a year's FREE Gem-A Membership. Current Gem-A members may enter the contest under any of the following four categories:

1. **Natural:** Digital photograph or photomicrograph with minimal post-production work (may include basic cropping, contrast and minor hue and saturation adjustments).
2. **Treated:** Digital photograph or photomicrograph with significant post-production work (such as background manipulation, HDR and contrast masking).
3. **Synthetic:** Computer-rendered 3D models of gemstones, crystals, crystal structures, images from microtomography, etc.
4. **Melange:** This category covers any gem-related image that doesn't fit in the above, and may include such things as photos of a spectrum, a scanning electron microscope image, mining, cutting, etc.

The subjects may include any type of gem material (including organics, and synthetics and simulants), crystals or cut stones, and internal or other features of these. Jewellery settings may be included, even wearers, but the gem or gems must be the main subject. In the case of categories 1, 2 and 4, the original photo as taken, with no cropping or manipulation whatsoever, must also be submitted to us.

Please submit all entries to editor@gem-a.com by FRIDAY 19 SEPTEMBER 2014, taking care to read the Rules of Entry first. For more information and for Rules of Entry, please visit www.gem-a.com/membership/photographic-competition.aspx.

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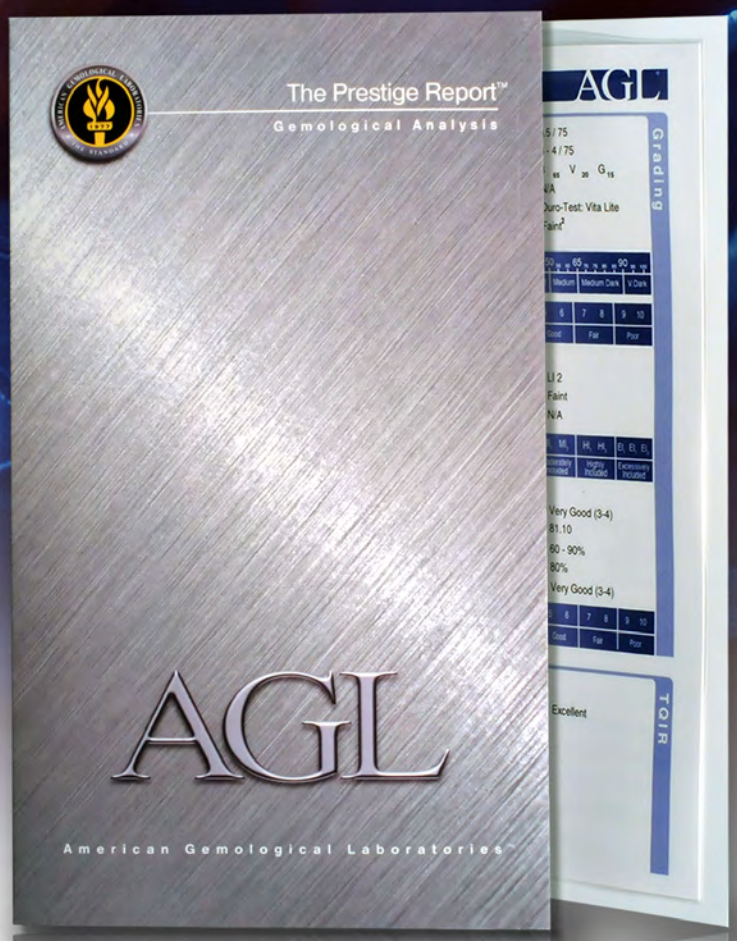

AMERICAN GEMOLOGICAL LABORATORIES AGL

580 5th Ave . Suite 706 . New York, NY 10036
www.aglgemlab.com 212.704.0727

Learning Opportunities

CONFERENCES AND SEMINARS

South American Symposium on Diamond Geology
3–7 August 2014
Patos de Minas, Minas Gerais, Brazil
www.simposiododiamante.com.br/apresentacao.htm

25th Colloquium of African Geology (CAG25)
11–16 August 2014
Dar es Salaam, Tanzania
www.cag25.or.tz
Note: Field trips will include visits to the Merelani tanzanite mines and the Williamson diamond mine.

Northwest Jewelry Conference 2014
15–17 August 2014
Bellevue, Washington, USA
www.northwestjewelryconference.com

Dallas Mineral Collecting Symposium
22–23 August 2014
Dallas, Texas, USA
www.dallassymposium.org

International Jewellery London
31 August–2 September 2014
London
www.jewellerylondon.com/show-highlights/seminars/#

21st General Meeting of the International Mineralogical Association (IMA2014)
1–5 September 2014
Johannesburg, South Africa
www.ima2014.co.za
Sessions of interest:
- The Geology of Gems and their Geographic Origin
- Cratons and Diamonds
- Pegmatites and Pegmatite Mineralogy
- Africa: A Mecca of Kimberlite, Alkaline Rock and Carbonatite Geology
- Certification of Geological Materials/Analytical Fingerprint of Minerals
- Computed Tomography—Pushing Frontiers in Imaging of the Third and Fourth Dimensions
- Modern Luminescence Methods and their Application to Mineralogy
- Mineral Inclusions—Their Genesis and Fate

Field trips of interest:
- Cullinan Diamond Mine and Tswaing Tour
- Namibian Pegmatites and Industrial Minerals

Compiled by Brendan Laurs and Diane Flora

International Conference on Diamond and Carbon Materials
7–11 September 2014
Madrid, Spain
www.diamond-conference.elsevier.com

Kimberley Diamond Symposium
11–13 September 2014
Kimberley, South Africa
http://rca.co.za/conferences/kimberley
Note: Field trips will be organized to kimberlite pipes and fissure mines, alluvial diamond deposits, old tailings dumps and historical places of interest in and around Kimberley.

11th India International Gold Convention 2014
12–14 September 2014
Pune, India
www.goldconvention.in/programmee.html

Manufacturing Jewelers' and Silversmiths' Association Jeweler's Bench Conference & Trade Fair
13–14 September 2014
Warwick, Rhode Island, USA
www.mjsa.org/events_and_programs/jewelers_bench_conference_and_trade_fair/2014_conference_sessions

Institute of Registered Valuers Loughborough Conference
13–15 September 2014
Loughborough
www.jewelleryvaluers.org/Loughborough-Conference

77th Annual International Appraisers Conference (IAC'14)
14–17 September 2014
Savannah, Georgia, USA
www.appraisers.org/Education/conferences/ASA-Conference

Asian Jewelry & Related Arts
20 September 2014
Rubin Museum of Art, New York, New York, USA
www.rubinmuseum.org/asianjewelry
www.jewelryconference.com

World of Gems IV
20–21 September 2014
Rosemont, Illinois, USA
http://gemguide.com/events/world-of-gems-conference

National Association of Jewelry Appraisers 42nd ACE-It Mid-Year Conference
22–23 September 2014
Rosemont, Illinois, USA
www.najaappraisers.com/html/conferences.html

Goldsmiths' Fair
22 September–5 October 2014
London
www.goldsmithsfair.co.uk/events

30th International Conference on Ore Potential of Alkaline, Kimberlite and Carbonatite Magmatism
29 September–2 October 2014
Antalya, Turkey
http://alkaline2014.com

Portland Jewelry Symposium
6 October 2014
Portland, Oregon, USA
www.portlandjewelrysymposium.com

Geological Society of America Annual Meeting
19–22 October 2014
Vancouver, British Columbia, Canada
http://community.geosociety.org/gsa2014
Sessions of interest:
- Gemological Research in the 21st Century
- Pegmatites I Have Known and Loved

Gem-A Conference 2014
1–2 November 2014
London
www.gem-a.com/news--events/gem-a-conference-2014.aspx

GIT 2014: The 4th International Gem and Jewelry Conference
8–9 December 2014
Bangkok, Thailand
www.git2014.com

Jaipur Jewellery Show
20–23 December 2014
Jaipur, India
www.jaipurjewelleryshow.org/Seminars.aspx

Antwerp Diamond Trade Fair
25–27 January 2015
Antwerp, Belgium
www.antwerpdiamondfair.com/EN/the-adtfnews.html

International Diamond School: The Nature of Diamonds and their Use in Earth's Study
27–31 January 2015
Bressanone-Brixen, Italy
www.indimedea.eu/diamond_school_2015.htm

The Original Miami Beach Antique Jewelry Series 2015
28–29 January 2015
Miami Beach, Florida, USA
www.originalmiamibeachantiqueshow.com/TheShow/JewelrySeries.aspx

Association for the Study of Jewelry and Related Arts 10th Annual Conference
2–3 May 2015
Chicago, Illinois, USA
www.asjra.net/event.html

Society of North American Goldsmiths' 44th Annual Conference
20–23 May 2015
Boston, Massachusetts, USA
www.snagmetalsmith.org/conferences/impact-looking-back-forging-forward

9th International Conference on New Diamond and Nano Carbons
24–28 May 2015
Shizuoka, Japan
www.ndnc2015.org

EXHIBITS

Asia

A Little Clay on the Skin: New Ceramic Jewellery
Until 9 November 2014
World Jewelry Museum, Seoul, South Korea
www.wjmuseum.com/eng/e_exhibition.html

Europe

All that Glisters: 18th Century Steel Jewellery
Until 10 August 2014
Bantock House Museum, Wolverhampton
www.wolverhamptonart.org.uk/events/all-that-glisters

Staffordshire Hoard
Until 24 August 2014
Birmingham Museum, Birmingham
www.bmag.org.uk/events?id=1997

Splendours of the East: Ancient Golden Jewellery from Goa
Until 7 September 2014
Museu Nacional de Arte Antiga, Lisbon, Portugal
www.museudearteantiga.pt/pt-PT/destaques/ContentDetail.aspx?id=662

From the Coolest Corner: Nordic Jewellery
Until 21 September 2014
Röhsska Museum, Gothenburg, Sweden
www.coolestcorner.no

Gemmes, une Brillante Histoire
Until 5 October 2014
Musée de Saint-Antoine-l'Abbaye, France
www.musee-saint-antoine.fr/825-expositions.htm

Jewellery by Winfried Kruger
Until 19 October 2014
Schmuckmuseum, Pforzheim, Germany
www.schmuckmuseum.de

Kevin Coates: A Bestiary of Jewels
20 August–19 October 2014
The Harley Gallery, Welbeck, Worksop, Nottinghamshire
www.harleygallery.co.uk/exhibition/bestiary-jewels

Shine 2014 – Young Emerging Design Talent
12 September–24 November 2014
The Goldsmiths' Centre, London
www.goldsmiths-centre.org/whats-on/exhibitions/shine-2014-young-emerging-design-talent

Treasures of the Middle Ages: Archaeological Finds from Poland
20 September 2014–15 March 2015
Museen Stade, Poland
www.museen-stade.de/schwedenspeicher/vorschau-ausstellungen

Splendor et Gloria. Cinco Joias Setecentistas de Exceção
24 September 2014–4 January 2015
Museu Nacional de Arte Antiga, Lisbon, Portugal
http://www.museudearteantiga.pt/Data/Documents/2014/Comunicado_SplendorGloria.pdf

L'Oro nei Secoli dalla Collezione Castellani
Until 2 November 2014
Basilica di San Francesco, Arezzo, Italy
www.museistataliarezzo.it/mostre-eventi

"Iron Urge". Jewellery and Objects Made Out of Iron
Until 11 May 2015
The Estonian Museum of Applied Art and Design, Tallinn, Estonia
www.etdm.ee/en/exhibitions

An Adaptable Trade: The Jewellery Quarter at War
Until 27 June 2015
Museum of the Jewellery Quarter, Birmingham
www.bmag.org.uk/events?id=3307

North America

100 Rings: Contemporary Studio Jewelry of Peter Schmid and Atelier Zobel
14–31 August 2014
Patina Gallery, Santa Fe, New Mexico, USA
www.patina-gallery.com/exhibits/exhibit_sched_14.php

Unique by Design: Contemporary Jewelry in the Donna Schneier Collection
Until 31 August 2014
The Metropolitan Museum of Art, New York, New York, USA
www.metmuseum.org/about-the-museum/press-room/exhibitions/2014/donna-schneier

Protective Ornament: Contemporary Armor to Amulets
Until 7 September 2014
National Ornamental Metal Museum, Memphis, Tennessee, USA
http://craftcouncil.org/event/protective-ornament-contemporary-armor-amulets

Multiple Exposures: Jewelry and Photography
Until 14 September 2014
Museum of Arts & Design, New York, New York, USA
http://madmuseum.org/exhibition/multiple-exposures

Bulgari: 130 Years of Masterpieces
Until 5 October 2014
Houston Museum of Natural Science, Houston, Texas, USA
www.hmns.org/index.php?option=com_content&view=article&id=687&Itemid=722

Fabergé: Jeweller to the Tzars
Until 5 October 2014
Montreal Museum of Fine Arts, Quebec, Canada
http://faberge.mbam.qc.ca

Remarkable Contemporary Jewellery
Until 30 November 2014
Montreal Museum of Fine Arts, Quebec, Canada
http://wsimag.com/fashion/9308-remarkable-contemporary-jewellery

***Gems & Gemology* celebrates 80 years, Featuring the Artistry of Harold and Erica Van Pelt**
Until December 2014
Gemological Institute of America, Carlsbad, California, USA
www.gia.edu/gia-museum-gems-gemology-anniversary

From the Village to Vogue: The Modernist Jewelry of Art Smith
Until 7 December 2014
Dallas Museum of Art, Texas, USA
www.dma.org/art/exhibitions/Art-Smith

Cartier: Marjorie Merriweather Post's Dazzling Gems
Until 31 December 2014
Hillwood Estate, Museum & Gardens, Washington DC, USA
www.hillwoodmuseum.org/whats/exhibitions/cartier-marjorie-merriweather-posts-dazzling-gems

Arts of Islamic Lands: Selections from the al-Sabah Collection, Kuwait
Until 4 January 2015
Museum of Fine Arts, Houston, Texas, USA
www.mfah.org/exhibitions/al-sabah-collection

René Lalique: Enchanted by Glass
Until 4 January 2015
The Corning Museum of Glass, Corning, New York, USA
www.cmog.org/collection/exhibitions/lalique

The Life and Times of Robert Ebendorf, Jeweler and Metalsmith
Until 18 January 2015
Racine Art Museum, Wisconsin, USA
www.ramart.org/content/life-and-times-robert-w-ebendorf-jeweler-and-metalsmith

Hollywood Glamour: Fashion and Jewelry from the Silver Screen
9 September 2014–8 March 2015
Museum of Fine Arts, Boston, Massachusetts, USA
www.mfa.org/exhibitions/hollywood-glamour

Arthur Koby Jewelry: The Creative Eye
Until 5 October 2015
Kent State University Museum, Kent, Ohio, USA
www.kent.edu/museum/exhibits/exhibitdetail.cfm?customel_datapageid_2203427=3506741

Gold and the Gods: Jewels of Ancient Nubia
Until 14 May 2017
Museum of Fine Arts, Boston, Massachusetts, USA
www.mfa.org/exhibitions/gold-and-gods

Gemstone Carvings: Crystals Transformed Through Vision & Skill
On display (closing date to be determined)
Houston Museum of Natural Science, Houston, Texas, USA
www.hmns.org/index.php?option=com_content&view=article&id=481&Itemid=502

Australia and New Zealand

Wunderrūma: New Zealand Jewellery
Until 28 September 2014
The Dowse Art Museum, Lower Hutt, New Zealand
http://dowse.org.nz/exhibitions/detail/wunderruma-schmuck-aus-neuseeland

Afghanistan: Hidden Treasures from the National Museum, Kabul
Until 16 November 2014
Western Australian Museum, Perth, Australia
http://museum.wa.gov.au/museums/perth/afghanistan-hidden-treasures

A Fine Possession: Jewellery and Identity
Opens 20 September 2014 (closing date to be determined)
Powerhouse Museum, Sydney, Australia
www.powerhousemuseum.com/exhibitions/coming.php

OTHER EDUCATIONAL OPPORTUNITIES

The Great Australian Opal Tour
24–30 September 2014
Australia
www.wj.com.au/artman5/publish/article_647.shtml

Montreal School of Gemmology Rough Diamond Grading Course
27 September–4 October 2014 (in French)
4–11 October 2014 (in English)
Montreal, Quebec, Canada
www.ecoledegemmologie.com/en/c/12

Gem-A Workshops
www.gem-a.com/education/workshops.aspx

Understanding Gemstones
28 August and 7 November 2014: London

Understanding Practical Gemmology
29 August 2014: London
14 November 2014: Birmingham

Understanding Diamond Grading
25 September 2014: London
26 November 2014: Birmingham

Understanding Diamond Simulants
26 September 2014: London

Investigating Gemstone Treatments
3 October 2014: London
17 October 2014: Birmingham

Investigating Ruby, Sapphire and Emerald
17 October 2014: London

Gem-A Diamond Grading and Identification Course
10–14 November 2014
London
www.gem-a.com/education/lab-classes-and-workshops/diamond-grading-and-identification.aspx

Gemstone Safari
5–22 January 2015
Tanzania
www.free-form.ch/tanzania/gemstonesafari.html

Montreal School of Gemmology Intensive 6-month FGA Preparatory Course
10 January–25 June 2015 (in French and English)
Montreal, Quebec, Canada
www.ecoledegemmologie.com/en/c/9

Montreal School of Gemmology Gem and Jewellery Appraisal Course
6–29 July 2015 (in English and French)
Montreal, Quebec, Canada
www.ecoledegemmologie.com/en/c/10

New Media

Gemstones of Western Australia

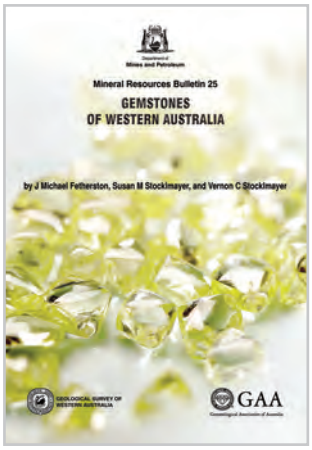

J. Michael Fetherston, Susan M. Stocklmayer and Vernon C. Stocklmayer, 2013. Geological Survey of Western Australia, Mineral Resources Bulletin 25, East Perth, Western Australia, 306 pages, illus., www.dmp.wa.gov.au/GSWApublications, ISBN 978-1741684490. AUS$50 or free PDF version.

Perhaps the best way to illustrate the comprehensive nature of *Gemstones of Western Australia* is to describe how it has been so thoroughly and masterfully compiled. When I interviewed first-author Mike Fetherston about this compilation of all currently known Western Australian gem occurrences, he revealed that, for him, the book was a labour of love. It was a work over two years in the making, with the onerous and time-consuming task of compiling and verifying the accuracy of historically reported gem and mineral localities. This was achieved through field visits, personal knowledge of the deposits or, in difficult cases, by using high-resolution geo-referenced Landsat image mosaics to locate evidence of past mining activity. For co-authors Susan Stocklmayer and her husband Vernon, the book represents the realization of a dream to bring together, for the first time under one cover, information about Western Australia State's better- and lesser-known gem wealth—to build a compendium of information that was previously scattered about as specialist articles throughout the geological and gemmological literature. Another significant task the team undertook as part of the project was visiting lapidary clubs and factories around the state to photograph examples of the state's gems and ornamental stones.

The following list of gem materials and precious metals that are covered (listed in order of appearance), each in its own chapter, includes many rare and unusual stones: diamond, beryl group, tourmaline group, tourmalite and warrierite, feldspar group, topaz, minor pegmatite gems (lepidolite, petalite, spodumene, phenakite), quartz group, opal, chalcedony group, fossil wood, pearls, gold and silver, andalusite and chiastolite, chrysoberyl and alexandrite, corundum, copper gemstones (turquoise, malachite, chrysocolla, azurite), diopside, fluorite, garnet group, gaspeite, iron-rich gemstones (hematite, specularite, turgite, pyrite, marcasite, tiger eye, tiger iron), prehnite, rhodonite, variscite, carbonate group, Chinese writing stone, epidote group (epidote, zoisite, clinozoisite, thulite, unakite), grunerite, jade, mookaite, orbicular granite, siliceous decorative stones (aventurine, fuchsite), serpentine and talc, tektites, and decorative stones from the Kununurra region (zebra stone, ribbon stone, okapi stone, primordial stone and astronomite).

Each of these materials is presented in a tried-and-true format, beginning with its physical properties, a description of the material and its workability, its geological setting, plus the location of occurrences, deposits or mines in Western Australia. Useful tables of physical and gemmological properties abound throughout as highlighted boxes, making this book a valuable reference, and all gem localities are shown on geological maps within their relevant chapters. Production data are also given where available. Information is as detailed as historical publications and other sources allow, and a comprehensive bibliography is provided at the end of each chapter. Mines and prospects are also listed in an appendix table together with their map coordinates, which means they can be loaded into a GPS, enabling an enthusiastic fossicker to head directly to the locality (with permission from the owner, as appropriate).

Naturally, diamond is 'first cab off the rank' with quite a high level of detail presented. Today, diamond is the focus of one of Western Australia's major industries, having grown from nothing in the last three decades. This chapter includes general diamond exploration techniques followed by those specifically relating to the discovery of the Western Australian deposits, commencing with the Argyle AK1 lamproite pipe in October 1979. Regional locality maps showing the North Kimberley and Central Western diamond regions, with detailed geological maps of the Argyle AK1, Aries and Ellendale 9 pipes, plus photographs of mine workings, crystals and cut stones, make for a most interesting read. The current status of each pipe is discussed, including its geological setting, exploration results and, where applicable, grade and production data, which also makes the chapter an

important compendium for the exploration geologist.

A chapter titled 'Prospecting for Gemstones' covers important matters such as safety and survival in the bush, outback travel, mining rights, and how to access useful state databases of geological maps, exploration reports, mineral deposits and exploration titles. Another chapter, titled 'Aspects of the Gemstone Industry', explains the lapidary and gemmological terminology used in the book.

As an avid gem fossicker, lapidarist, gemmologist and geologist, I find that this book covers all my spheres of interest and, as such, will likely be of interest to all, from amateur hobbyist to professional. Whenever the opportunity presents itself for travel into the Western Australian countryside, for either work or pleasure, this Bulletin will surely be my trusty companion along the way.

Dr Robert R. Coenraads

Imperial Jade of Burma and Mutton-Fat Jade of India

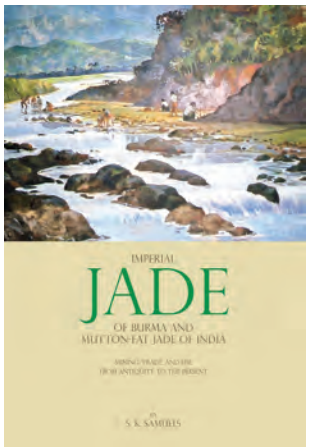

S. K. Samuels, 2014. SKS Enterprises Inc., Tucson, Arizona, USA, 262 pages, illus., hardcover, www.sksent.com/books.htm, ISBN 978-0972532341. US$65.

This book tells the story of Burmese jadeite, using fables and actual history, from ancient times to the present. It also covers the Chinese influence and fascination with jade. This is, of course, a monumental task. The history, mining, cutting and appreciation of jade are as complicated and complex as the histories—both ancient and modern—of Burma and China combined. Samuels also includes various influences from India and the West. Being Burmese himself, Samuels adds a unique local colloquial perspective on the jade trade.

The opening chapters provide an interesting discussion of historic events in both Burma (now Myanmar) and China, combined with various aspects of the Chinese passion for jade. In the context of this discussion, Samuels often jumps to modern information, including 2012 auction results, to emphasize his various points. In a concise and accurate narrative, the many centuries of Chinese and Burmese trade in jadeite are discussed up to the time of British influence (i.e., chapter 8, titled 'The British Arrive'). This is followed by 'The Jade Trade, British Times to Ne Win Era'. A multitude of historical anecdotes, regulations, maps and photographs are included.

The next chapter provides a well-illustrated look at the Ne Win era (1962–1988), when this Burmese politician and military commander broke off most relations with the West, effectively isolating the country. During this time, the Burmese jade and gem auctions came into being to raise foreign currency. The next chapters cover smuggling and dangers of the jade trade. This is followed by descriptions of the area in Kachin State where much of the jadeite is found; Samuels devotes a chapter to a personal trip he took to Myitkyina to visit the jade mines and includes over 20 of his own photos.

The following chapter discusses the difference between jadeite and nephrite. Their complex mineralogies are discussed, but not always well explained. Samuels seems to prefer using *jade* when he's actually referring to *jadeite*. This is likely out of local custom, as one does not often hear the word *jadeite* in Burmese markets.

The following chapters cover jade examination, especially the effect of treatments, followed by the history and techniques of cutting and carving. The last few chapters cover sanctions and the Burmese economy. Curiously, a chapter on maw-sit-sit and another on 'mutton-fat' jade of India are placed in between the above chapters.

Also included are an appendix on Myanmar gemstone laws and an errata sheet, as well as a folded map of the Lonkin/Hpakan jadeite mining district.

I agree with Samuels' statement that in "America most people cannot distinguish among the various types of Jade....but it is not true in the Orient". Most westerners are quite ignorant of the beauty and rarity of fine jadeite.

Samuels offers a credible, albeit a bit disjointed, examination of Burmese jadeite. With better editing, layout and photographic reproductions, a second edition could be much improved. However, I recommend purchase of this edition for anyone who is curious or serious about jade.

William Larson

Ruby & Sapphire—A Collector's Guide

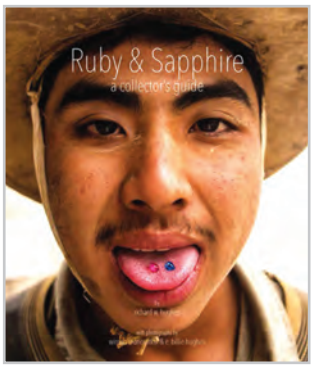

Richard W. Hughes, 2014. Gem and Jewelry Institute of Thailand, Bangkok, 384 pages, illus., hardcover, www.git.or.th/library_book/Default.aspx, ISBN 978-6169145035. US$99.

Richard Hughes has once again masterfully crafted a tome that will be the ruby and sapphire reference-of-choice for decades to come. Though it follows his original 1997 work titled *Ruby & Sapphire*, this new book is entirely different yet equally enthralling.

Hughes begins with an introduction to what he calls "humanistic gemology", focusing on "the relationship between gems and the people and places from which they come" rather than on just the science of gemmology. He supports this focus throughout the book with fascinating stories and beautiful photographs from his extensive travels to gem sources. In many cases he was accompanied by his wife and daughter who were not only his travel companions, but also contributors in content review and photography. He was also supported in concept, design, and funding by the Gem & Jewelry Institute of Thailand, a non-profit governmental organization with a mandate to serve society as a whole.

The reader is immediately immersed in the rich history of ruby and sapphire with a colourful fresco of a bejewelled maiden from 5th- and 6th-century wall paintings found along the steep mountain paths leading to the ancient Sri Lankan fortress of Sigiriya. Hughes states that it is likely that the first rubies and sapphires traded in early Greco-Roman times came from Sri Lanka. He elucidates that our instinctual and primal attraction to colourful rocks and minerals led to their use as objects of adornment and thus also as items of value. The size-to-value ratio of gems made them the perfect transportable currency for early commerce and trade that often required months or even years of travel. Gems and jewellery are still the most highly sought-after form of transportable wealth that exists today.

Hughes goes on to dissect the psyche of collecting into two primordial instincts. One is defined by a purely basic emotional connection, and the other supports our need to understand the rational, analytical and clinical attributes of what we are collecting. "At once, it is emotion and erudition. What could be better?" This is why people collect any object they ultimately deem to be worthy of their time and attention. When focusing on gems, it is helpful to have a better understanding of their geographical origin, so as to know the people and the cultures from which they emanate. He then balances that section with an easy-to-understand lesson on how the geological forces of plate tectonics and volcanism created the gems we find in some of the most remote places on the planet. Then he switches back again to an ancient folk tale about the 'Valley of the Serpents' where gems, in a remote mountainous area guarded by poisonous snakes, are picked up by birds. This legend can be heard, in various forms, at almost every major historical gem-mining locality around the globe and even appears in the tale of Sinbad the Sailor in *One Thousand and One Nights*. Hughes beautifully combines lore and emotion with fact and reality. He also explains how gems became associated with supernatural powers and how human fascination and appreciation for gems and jewellery has evolved over the centuries. Throughout the book, the reader is treated to inspiring and informative quotes from famous gem authors, miners, merchants and enthusiasts such as Albert Ramsay, Ambrose Bierce, Otto Ehlers, Sir Henry Yule, Annie Dillard and others. Hughes also delights the reader with his own poetic prose throughout: "In our world, so much that is beautiful is ephemeral. We grow old, our clothes wear out, styles come and go. Gems have both immediate magic and eternal beauty."

The largest portion of the book focuses on the many lands in which ruby and sapphire are found. The first stop on the tour of producing countries is Afghanistan, followed by others ranging from India to Madagascar, Myanmar to Sri Lanka, Laos to Tanzania and many more. Magnificent photos of the people, their homelands and the mining sites accompany each chapter. The featured photos are clearly focused on the people, pleasantly reminding us of their importance in bringing these gifts of nature from the earth for the world to enjoy. Many photos cover a full page and a few landscape shots are given well-deserved two-page spreads. Hughes also gives the geological and social history of each country. Along with their gemstone wealth, homage is duly paid to the ethnic and biological diversity found in each of these amazingly rich lands. Every known ruby and sapphire deposit is covered in exacting detail. In separate sidebars, Hughes shares his own thoughts and experiences at specific deposits

he has personally visited. In many of these excerpts he adds delightful stories. One of my favourites is his explanation of how Lake Nyasa in Malawi earned its name through a "glorious linguistic screw-up".

What sets this book apart even more are the two final chapters, which focus on the value of creating a collector's library and compiling a wonderful selection of photographs. The generous bibliography of books that Hughes recommends is an invaluable reference. Photos speak a thousand words, and the 'Portfolio' that follows collects together thumbnail images of many of the photos of gems and jewellery featured throughout the book, providing another valuable resource that is a wonderful parting gift, delighting the senses one last time.

Edward Boehm

Sea of Pearls: Seven Thousand Years of the Industry that Shaped the Gulf

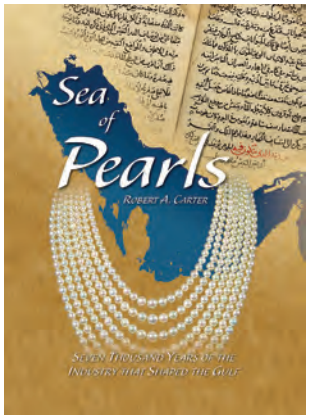

Robert A. Carter, 2012. Arabian Publishing Ltd., London, 364 pages, illus., hardcover, www.oxbowbooks.com/oxbow/sea-of-pearls.html, ISBN 978-0957106000. £95.00.

This beautifully and lavishly illustrated work fills a gap in the gemmological and jewellery literature by detailing the development over the past 7,000 years of one of the largest and most important pearl fishing areas in the world. Covering not only the pearl industry, the book details the development of the Gulf States, and the important role that pearls played in their economic, political and social development through the ages. These progressions are charted from both the Persian and Arabian sides of the Gulf.

Starting in the Neolithic period, Carter shows how pearls have a far longer history in the gem world than most people realize. For example, he describes the discovery of two drilled pearls in a burial cairn at As-Sabiyah, in modern-day Kuwait, a site that has been dated to between the 3rd and 4th millennium BC, potentially demonstrating that pearls are one of the earliest gem materials. From this ancient starting point, Carter takes the reader through to modern times using stories and factual documents to immerse the reader in a "sea of pearls".

Subsequent chapters work through the early times of Islamic development (up to 1330), then into the Portuguese influences that were felt up to around 1650. After that date, Carter charts the rise of the modern Arab powers, and how "pearls were part of a universal language of luxury and diplomacy", playing a significant role in the interactions between the various ruling powers, conquerors and other political entities. These chapters also cover some of the great pearls from history, including such examples as the Durr Yatimah, a 10th-century pearl reputed to weigh in excess of 12 g.

At its height, Carter reports that there were over 300 different pearl fisheries in the Gulf area, centred around the island of Bahrain, and that this area was more productive than all the seas of India and Yemen. As with all industries and markets, there are times of boom and recession, and the pearl trade in the Gulf was no exception. In the period leading up to 1912, the Gulf region supplied between 65% and 80% of the world's pearls and, in most cases, the surrounding economies were built entirely on pearl markets and trading. This continued until the start of World War I, when the market fell from a record high to an all-time low within 12 months, closely followed by a subsequent, but smaller crash in 1921. The end of Gulf control over the market came, as detailed by Carter, in 1924 with the introduction of cultured pearls. It is with this, and the subsequent recovery of Gulf pearls into a position of importance (albeit not at the previous level), that Carter ends the book.

Beyond the main body of the book, Carter also provides two interesting appendices. The first covers the technical side of the industry, defining over 50 terms relating to pearls and pearl production—and a further 80 different designations of pearl types—showing how widespread and influential the pearl trade has become over the centuries. The second appendix charts annual pearl production in the Gulf from 1602 to 1943, giving the valuation in rupees for the various areas, allowing the reader to build a picture of the development of the industry in the region.

In summary, this book provides a valuable reference to one of the most historically important and interesting areas of pearl fishing in the world.

Andrew S. Fellows

Terra Garnet

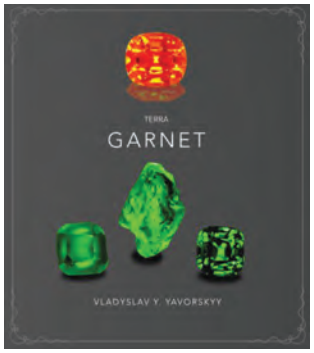

Vladyslav Yavorskyy, 2014. Self-published by Vladyslav Yavorskyy, 201 pages, illus., hardcover, www.garnetbook.com, ISBN 978-0615925332. US$100.

This is another great collaboration between Vladyslav Yavorskyy and Richard W. Hughes, and just like the book *Terra Spinel – Terra Firma*, it does not disappoint. It is written by Hughes and Jonas Hjornered in a captivating style.

The book is about Yavorskyy's enchanting pursuits of tsavorite, malaia, rhodolite, mandarin, demantoid and colour-change garnet, and is illustrated with wonderful photographs. Yavorskyy starts by telling the enticing story of how he fell in love with garnets on his first trip to Tanzania over 20 years ago. Tanzania is where he purchased his first vibrant malaia and tsavorite crystals, which left him and others spellbound. Malaia garnet comes from the Umba Valley, and was found by 'accident' in the mid-1960s when miners were looking for sapphires. When they discovered that these stones were not sapphire, they were cast out (malaia is the Swahili word for 'outcast'). Yavorskyy speaks enthusiastically of Tanzania's garnet wealth, as well as its wildlife and other gem deposits, allowing the reader to re-live his experiences as if accompanying him on his journeys.

There are also sections describing other countries, including Nigeria, Madagascar, Russia, Namibia, Myanmar and Sri Lanka. Yavorskyy illustrates the cultures and garnets from those countries with vibrant photographs. In many cases, the garnets are depicted in their rough, pre-formed and fully-faceted states.

This photographic odyssey is a book for anyone who is enthusiastic about gems and the countries where they are found.

Mia Dixon

Dallas Mineral Collecting Symposium 2013 DVD

BlueCap Productions, Honolulu, Hawaii, www.bluecapproductions.com, 3-DVD set, 307 minutes, NTSC format. US$19.99.

Rob Lavinsky of the mineral dealership The Arkenstone once again hosted the Dallas Mineral Collecting Symposium, held 23–24 August 2013, in Dallas, Texas, USA. An experienced line-up of eight speakers covered a wide range of topics, from mineral dealer Brice Gobin enthusiastically recounting a rather dangerous expedition to the Democratic Republic of Congo, to MinDat.org founder Jolyon Ralph discussing one the world's largest online mineral databases, to Dr Robert Downs of the University of Arizona describing geological analysis by the Mars rover *Curiosity*.

There were three presentations with a greater focus on gemmological topics. Daniel Trinchillo, principal of Fine Minerals International, Edison, New Jersey, USA, has been a co-owner of the Pederneira tourmaline mine in Minas Gerais, Brazil, for the past 14 years. Trinchillo's team has invested fresh capital and ideas into this mine, which has been worked since the 1940s, and was rewarded with a number of incredible tourmaline-bearing pockets. The mine is famous for its elongate, multi-coloured, pencil-like tourmalines, and the team took painstaking steps to reassemble many of the crystals that had been broken over geologic time or by mining processes. The resulting matrix specimens are stunning. Although discoveries have recently dwindled, Trinchillo is revaluating the mine's complicated pegmatite geology with the assistance of Dr Federico Pezzotta of the Natural History Museum of Milan, Italy, and is optimistic about its future.

The first trips by a 'westerner' to visit the former Soviet Union's vast gem wealth provided rewarding and frightening experiences, as recounted by Peter Lyckberg, Luxembourg. Much like Gobin's Congo talk, Lyckberg relates just how dangerous the gem and mineral business can be in the field. Excursions starting the mid-1980s took him to the beryl and topaz mines near Volodarsk, Ukraine, and the emerald and alexandrite mines in the Ural Mountains, among other localities. Lyckberg's slides and knowledge of these localities are unparalleled for this time period.

William Larson of Palagems.com, Fallbrook, California, USA, reminisced about his long association (including ownership) with the Himalaya tourmaline mine in San Diego County, California. Although much

less structured than the other talks at the Symposium, Larson's unequalled experience in the field combined with his clear passion for the topic made for a fun trip down memory lane.

All the speakers are well-known in the mineral collecting community, and many jokes and side-bar comments would be best appreciated by viewers who are also involved in this area. Examples include Larson's aforementioned talk, Dave Wilber's personal recount of his 60 years of mineral collecting and especially Gene Meieran's review of Wayne Thompson's *Ikons* book on exceptional contemporary mineral specimens.

Overall this DVD set includes an entertaining and informative international line-up of speakers from the mineral collecting business. The audio/video quality and editing are very good, and I recommend this DVD set to anyone with an interest in gem and mineral collecting.

Keith Mychaluk

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is mixed with the light of the sun and fire,

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The Journal of Gemmology
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Cover Photo:

Burmese jadeite is well known for its attractive coloration and transparency. Jadeite-bearing rocks may contain a wide variety of mineral assemblages in fine-grained aggregates that create challenges for the proper characterization and naming of these materials, as discussed in the article by L. Franz et al. on pp. 210–229. The brooch on the cover features a carved piece of Burmese jadeite (6.40 × 5.30 cm) that is set with amethyst and diamonds in platinum and silver. Courtesy of Carnet by Michelle Ong, Hong Kong; photo by Tino Hammid.

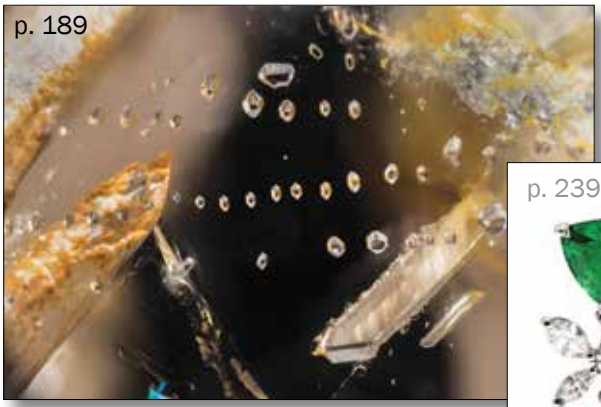

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The Editor-in-Chief is glad to consider original articles, news items, conference/excursion reports, announcements and calendar entries on subjects of gemmological interest for publication in *The Journal of Gemmology*. A guide to the preparation of manuscripts is given at www.gem-a.com/publications/journal-of-gemmology.aspx, or contact the Production Editor.

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Understanding Gems™

What's New

INSTRUMENTS AND TECHNIQUES

Gem Spectra Database

Images and descriptions of absorption and emission spectra (the type collected with a hand-held or desktop spectroscope) have been compiled into a useful database by John Harris FGA at www.gemlab.co.uk. According to notes on the website, "This database is mainly for use by students studying gemmology in the courses offered by the Gemmological Association of Great Britain and the National Association of Goldsmiths."

As of September 2014, the spectra database covers gem materials of the following colour groups: colourless, red, pink, orange, yellow, green, brown and blue. The spectra are available as downloadable Excel files for gems of specific colour ranges, such as the following for blue stones: BL1 Blue, BL2 Greenish Blue and BL3 Lavender and Indigo Blue. Work on the final gem colour group (violet and purple) is in progress, and should be completed within a few months.

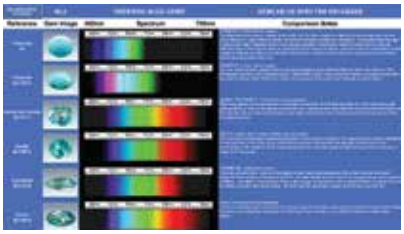

Users may also view spectra according to gem variety. As of September 2014, these include beryl (emerald), chrysoberyl (including alexandrite), corundum (ruby, blue sapphire and synthetic colour-change corundum), diamond, garnet (almandine), glass (cobalt blue), jadeite (green), peridot, spinel (red, green, blue and synthetic blue spinel) and zircon (high and low types).

Sarine DiaMension Axiom

In the 1990s Sarine (then Sarin) Technologies introduced the first system to measure the cut characteristics of polished diamonds based on shadow technology, becoming a standard in most well-equipped gemmological labs and cutting workshops. In August 2014, Sarine added a new breakthrough to the measuring technology using an automatic microscopic dimension. The result is the DiaMension Axiom, which includes a sophisticated new illumination technology combined with a highly accurate optical system and a state-of-the-art motion system, resulting in micron-scale accuracy. The instrument makes direct measurements of a faceted diamond's geometry, in addition to the traditional three-dimensional modelling of cut characteristics. This gives complementary symmetry measurements that are not obtained with shadow mapping, while enabling full automatic symmetry grading. In light of the instrument's accuracy, the measurement results are repeatable regardless of where or how many times a diamond is measured. The DiaMension Axiom also offers the user important visual microscopic information as required for evaluating the cut perfection of a diamond.

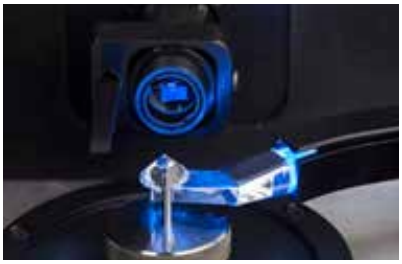

Tamar Brosh (tamar.brosh@sarine.com)
Sarine Technologies Ltd., Kfar Saba, Israel

NEWS AND PUBLICATIONS

Gem Testing Laboratory (Jaipur, India) Newsletter

The latest Lab Information Circular (Vol. 70, July 2014), available at www.gtljaipur.info/Lab%20Information%20Circular.asp, describes microscopic features in emeralds fracture-filled with resin and oil, quartz coated with diamond chips, 'Bumble-

bee' jasper, Raman spectroscopy with a 375 nm UV laser, Ti-diffused synthetic sapphires, beads and faceted stones composed of a ceramic material imitating hematite, and coated and/or dyed mollusc shell.

GSA Gem Session Abstracts

A session titled 'Gemological Research in the 21st Century: Exploration, Geology, and Characterization of Diamonds and Other Gem Minerals' will take place at the 2014 Geological Society of America Annual Meeting in Vancouver, British Columbia, Canada (19–22 October 2014), and abstracts for this session are available at https://gsa.confex.com/gsa/2014AM/webprogram/Session 35272.html and https://gsa.confex.com/gsa/ 2014AM/webprogram/Session36607.html.

GIA Reports on Mozambique Rubies and Nigerian Sapphires

The Gemological Institute of America posted reports describing the location, geology and gemmology of corundum from these two localities in October 2013 and August 2014, respectively. 'Rubies from the Montepuez Area (Mozambique)' can be accessed at www.gia.edu/gia-rubies-from-montepuez-area, and 'Blue sapphires from the Mambilla Plateau, Taraba State, Nigeria' at www.gia.edu/gia-news-research-nigerian-source-blue-sapphire.

Goldsmiths' Review 2013/2014

In July 2014, The Goldsmiths' Company released the 2013/2014 issue of the *Goldsmiths' Review*. The issue features articles on history, jewellery design, objets d'art and a new line of replica Cheapside Hoard jewellery, as well as an overview of the Company's activities. The issue costs £6 within the UK and £10 for locations elsewhere. Visit www.thegoldsmiths.co.uk/library/goldsmiths'-review.

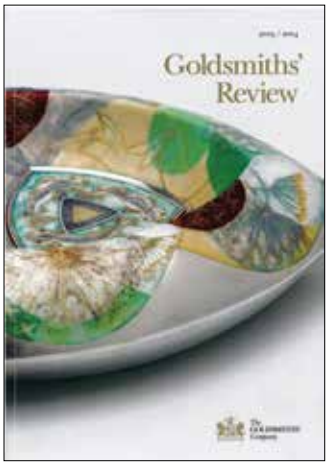

ICA Congress 2013 Speaker Presentations

The International Coloured Gemstone Association has posted PDF files of presentations from the 15th ICA Congress held in Changsha, China, on 12–16 May 2013. Some presentations are in Chinese and some are in English. Visit http://tinyurl.com/pg4x5zm.

ICGL Newsletter

The International Consortium of Gem-Testing Laboratories has released Newsletter No. 3, Summer

2014, available at http://icglabs.org. It includes two reports on CVD synthetic diamonds and descriptions of treated-colour black diamond earrings, a 10 ct asteriated diamond and pieces of topaz fashioned to look like diamond crystals.

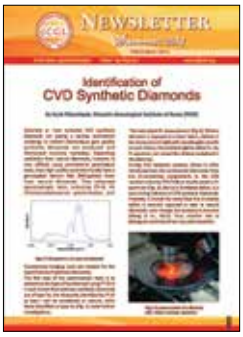

'World of Color' Communication System

In September 2014, GemWorld International Inc. released its new colour communication system, based on the Munsell system. It has more than 1,500 colours represented on 40 individual hue pages, accompanied by overlay charts showing universal scientific nomenclature for all the colour names. Also included is a proprietary simulated gemstone crown for use when comparing the colour of an actual gem, and a companion guide that includes an explanation of colour science, how to grade coloured stones, and grading charts for approximately 50 stones relating the colour system to GemGuide's 1–10 grading scale. The colour system is available for US$495; visit http://gemguide.com/products-page.

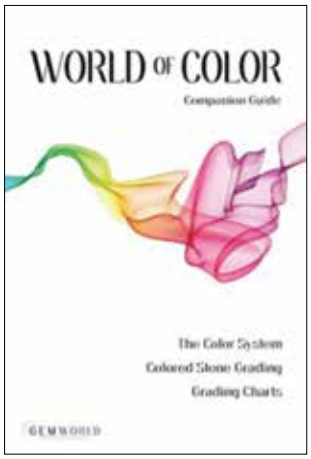

Updated *Fei Cui* Testing Standards in Hong Kong

In July 2014, The Gemmological Association of Hong Kong (GAHK) finalized updates to the document *Standard Methods for Testing Fei Cui for Hong Kong*, which is available for download at www.gahk.org/attachment/fcteststd2.pdf. The report defines the term *fei cui,* lists properties for jadeite jade, omphacite jade and kosmochlor jade, and briefly reviews the types of treatment used on this material. The main part of the document gives recommended methods for testing *fei cui* for gem laboratories. GAHK developed these updated standards in consultation with *fei cui* experts, gemmologists and academia in mainland China and overseas.

World Gold Council's Gold Demand Trends

Every quarter, the World Gold Council releases a report on gold demand trends, and each issue includes a section on jewellery. The Q2 report was released in August 2104. For free downloads, visit www.gold.org/supply-and-demand/gold-demand-trends.

The Journal of Gemmology Indexes: Vols. 29–33

In November 2014, Gem-A will release indexes for Vols. 29–33 (covering 2004–2013). As with previous volume indexes, each will contain a contents listing followed by a detailed subject index. Use these valuable tools to take full advantage of the large amount of information available within these back issues of *The Journal*. A limited number of hard copies will be available, and PDF files will be freely downloadable from *The Journal's* website at www.gem-a.com/publications/journal-of-gemmology.aspx.

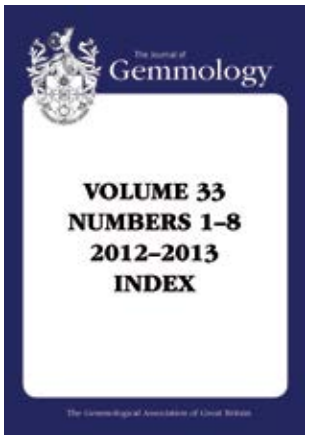

What's New provides announcements of new instruments/technology, publications, online resources and more. Inclusion in What's New does not imply recommendation or endorsement by Gem-A. Entries are prepared by Brendan Laurs unless otherwise noted.

Use of Stacking Software for Expanding Depth-of-Field in Inclusion Photomicrography

Nick Prince

Photomicrographers often desire the ability to capture full scenes (rather than just individual objects) that are completely in focus. This may be important for aesthetic reasons, and also for scientific purposes to give photographic subjects additional context and scale. This is difficult at best with single-shot photography due to depth-of-field limitations, particularly at higher magnifications. However, a photographic method called image stacking can virtually eliminate depth-of-field issues and therefore provide tremendous flexibility for photomicrographers. This process involves taking a series of images of the scene with slightly overlapping depths of field so that all desired elements are captured in focus in the complete photo series. These images are then processed with special 'stacking' software to produce a single photo that represents the entire scene in sharp detail.

For my inclusion photography I use a digital SLR camera, bellows, focusing rail, tripod and extension tubes as necessary. Although high-end equipment may make things easier and add flexibility, I believe that a photographer's technique is more important to the quality of the final image.

Figure 1: This polished crystal of quartz (reportedly from Brazil) contains a series of inclusions (outlined by the red box) that were photographed and processed using image-stacking software. The specimen is 5.6 cm tall and 5.0 cm wide at its base. Photo by N. Prince.

To illustrate my technique for photographing inclusions over a large depth of field, this article provides a case study of the quartz specimen in Figure 1. I obtained this polished quartz crystal many years ago and, although I did not realize it at the time, it contained a series of inclusions that proved wonderful for photography.

To search large specimens such as this quartz crystal for areas of photographic interest, I usually begin at the base and work my way up each face. Lighting is critical, and patience is key when discovering and capturing inclusion scenes that may span several millimetres in depth. Once a scene is identified, I begin the task of positioning the specimen and the lighting for best effect. Lighting does not have to be expensive; I often use Ikea Jansjö LED lamps that sell for about US$10. LEDs minimize heat issues, and the light heads are mounted on goosenecks so several can be easily positioned around a specimen. If the light is too bright or direct, it can be diffused with lens-cleaning sheets or facial tissues attached to the light heads with rubber bands. (However, care should be exercised using this method on hot light sources due to fire

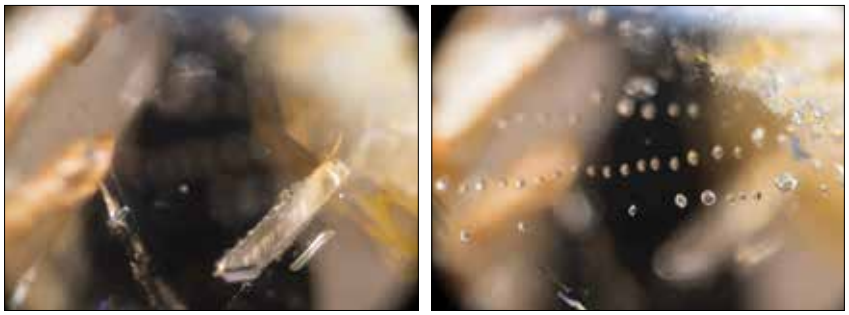

Figure 2: The left image is the first picture in a series of 84 images, showing a large negative crystal at the deepest point photographed in the inclusion scene. The haze across the dark area is created by the out-of-focus series of negative crystals that are shown in the image on the right, which represents the shallow end of the image stack. Photomicrographs by N. Prince; image width 12 mm.

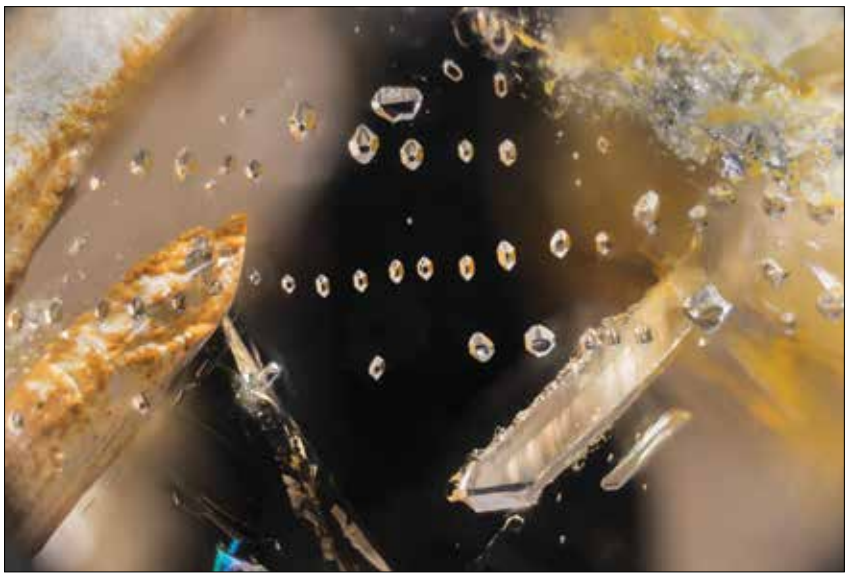

Figure 3: After processing the 84 photos with photo stacking software, the final image, called 'Stars in Alignment', shows the various inclusion features in sharp detail. Photomicrograph by N. Prince; image width 12 mm.

danger.) Although most LEDs produce 'cool' light, the white balance of your photos can be adjusted in-camera or when the image is processed.

When I am ready to 'frame up' the shot, I find the nearest and farthest points in the scene that I want to be in focus. In Figure 2, notice how little of the view is in focus in these photos taken at the 'top' and 'bottom' of the scene, covering a depth of ~10 mm. To capture the complete scene, I shot a series of 84 images, each one after moving the camera so that the focus was slightly shallower in the scene. I suggest 'over shooting' several shots at the beginning and end to compensate for mechanical tolerances in the camera rig. Out-of-focus frames are easily removed before the stacking process, and this is better than having to reshoot the scene for lack of a clean shot or two. Note that when photographing typical inclusion scenes in faceted gemstones, the total depth of field is substantially smaller than in this example, so fewer images will be required to capture a crisp photo. When using a gemmological microscope, the focus knob performs the same function as the focusing rail, and a bellows (or extension tube) is also not necessary.

After all of the photos have been taken, I transfer them to my computer for processing with the stacking software. (I use Zerene Stacker.) The result for this case study, which I call 'Stars in Alignment', is shown in Figure 3.

For readers who desire more information on photo stacking technology, there are a variety of useful articles and online resources (e.g., Piper, 2010; Thiérya and Green, 2012; and http://en.wikipedia.org/wiki/Focus_stacking).

References

Piper J., 2010. Software-based stacking techniques to enhance depth of field and dynamic range in digital photomicrography. In T.D. Hewitson and I.A. Darby (Eds.), *Histology Protocols, Methods in Molecular Biology,* Vol. 611, Humana Press, New York, New York, USA, 193–210, http://dx.doi.org/10.1007/978-1-60327-345-9_16.

Thiérya V. and Green D.I., 2012. The multifocus imaging technique in petrology. *Computers & Geosciences,* **45**, 131–138, http://dx.doi.org/10.1016/j.cageo.2011.10.027.

Nick Prince is a mineral collector and photomicrographer in Atlanta, Georgia, USA. Email: pndpapl@mindspring.com

Gem Notes

COLOURED STONES

Adularia (Including Moonstone) from Austria

For decades, gem and mineral collectors have appreciated gem-quality adularia (a hydrothermal low-temperature variety of orthoclase) from the Zillertal Alps, Tirol, Austria. However, presently it is rare to encounter faceted material from this historic deposit. In February 2012, gem dealer Dudley Blauwet (Dudley Blauwet Gems, Louisville, Colorado, USA) purchased a 947 g rough parcel of this adularia that was reportedly mined during or before the 1980s. Cutting of this material has so far produced numerous stones in the 2–5 ct range, and approximately 10 large gems weighing ~15–30 ct. When the cutting is complete, Blauwet anticipates obtaining more than 1,000 carats. A small proportion of this material shows adularescence, and would therefore be considered moonstone.

Blauwet loaned two of the larger oval-cut gems (18.69 and 27.56 ct; Figure 1) to the American Gemological Laboratories for examination. When viewed with strong transmitted light, both stones showed a distinctive white adularescence with a slight blue component that is typical of moonstone. The RIs of 1.520–1.530 (birefringence 0.008–0.010) and SG of 2.57 were consistent with orthoclase (O'Donoghue, 2006).

Figure 1: These oval-cut moonstones (27.56 and 18.69 ct) from Austria display noticeable adularescence. Photo by Bilal Mahmood and Alex Mercado.

Figure 2: Elongate, centipede-like inclusions are seen in one of the Austrian moonstones. Photomicrograph by M. Chaipaksa; magnified 70×.

The stones fluoresced weak blue to long-wave UV radiation and weak orange to short-wave UV. Both samples were highly transparent, and microscopic examination revealed only a few elongate, centipede-like inclusions in one of them (Figure 2); similar features are well known in moonstone (e.g. Gübelin and Koivula, 1986). Chemical analysis by energy-dispersive X-ray fluorescence (EDXRF) spectroscopy showed the expected major-to-minor amounts of K, Si, Al, Ba and Sr.

The majority of alkali feldspar possessing adularescence is semi-transparent and has a somewhat 'milky' appearance. It is uncommon to find samples that have both an attractive adularescence and a high degree of transparency.

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References

Gübelin E.J. and Koivula J.I., 1986. *Photoatlas of Inclusions in Gemstones.* ABC Edition, Zurich, Switzerland, 135.

O'Donoghue M. (Ed.), 2006. *Gems,* 6th edn. Butterworth-Heinemann, Oxford, 248–251.

Cat's-eye Apatite from Namibia

In March 2013, this author obtained a parcel of yellow gem rough from a small informal market on the road leading to the Spitzkoppe beryl and topaz area in west-central Namibia. At first glance the material appeared to be heliodor, which is well-known from Klein Spitzkoppe (e.g. Cairncross et al., 1998). The parcel consisted of ~500 g of mostly small fragments (<1 g each), as well as one larger piece that showed obvious chatoyancy.

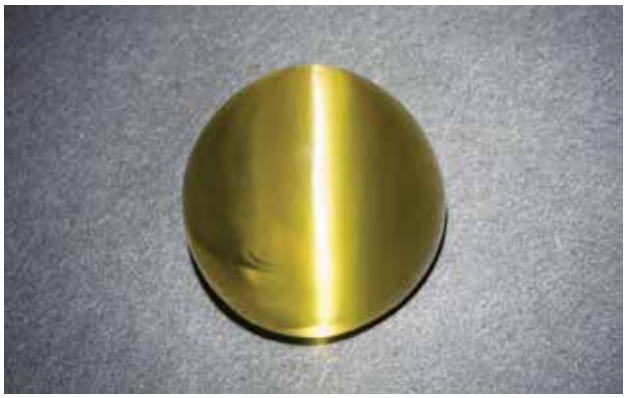

Figure 3: Namibia is the source of this 26.10 ct chatoyant apatite, which resembles fine cat's-eye chrysoberyl. Photo by C. L. Johnston.

To clean the parcel prior to a closer examination, the material was placed in a rock tumbler (together with some aquamarine obtained from the same dealer), and it soon became apparent that the 'heliodor' was actually yellow apatite. There are several apatite localities in Namibia, but the origin of this particular material is unknown. Cutting of the single chatoyant apatite yielded a 26.10 ct round cabochon measuring 15.8 mm in diameter (Figure 3). It is the best Namibian cat's-eye apatite known to this author, with both a sharp eye and an attractive 'golden' yellow colour that are strongly reminiscent of cat's-eye chrysoberyl.

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Reference

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Colour-change Axinite-(Mn) from Tanzania

During the June 2014 JCK show in Las Vegas, Nevada, USA, gem dealer Mark Kaufman (Kaufman Enterprises, San Diego, California, USA) informed one of us (BML) about an interesting colour-change stone from Tanzania that he had recently faceted. Kaufman obtained the rough material, represented as magnesioaxinite [renamed axinite-(Mg) after the scheme proposed by Burke (2008)], from a supplier who had purchased it in Tanzania in late April 2014. The rough consisted of a large crystal that was broken into several pieces, two of which were facetable. Kaufman cut a 4.48 ct oval stone that showed a distinct colour change, from greenish blue in daylight to lavender purple in incandescent light (Figure 4). He loaned the gem to authors CW and BW for examination and confirmation of its identity.

Figure 4: This 4.48 ct axinite-(Mn) appears greenish blue in daylight and lavender purple in incandescent light. Composite photo by B. Williams.

Members of the axinite group typically exhibit trichroism, and this sample showed pleochroic colours of violet-blue, pink and yellow (with some green appearing at certain angles, presumably due to the facet arrangement creating a blending of the yellow and blue directions

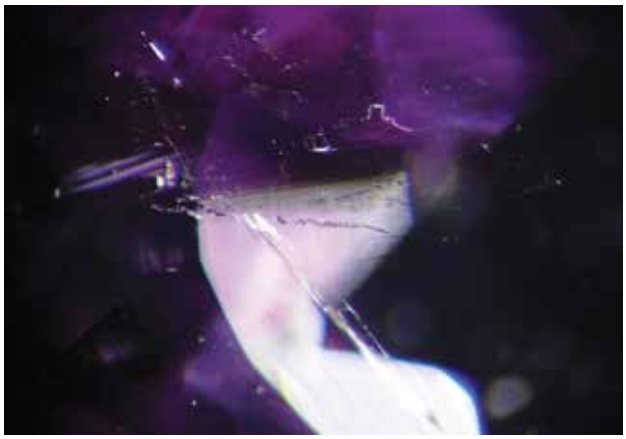

Figure 5: The only internal features seen in the axinite-(Mn) consisted of thin blade-like inclusions. One of them (top-centre) contains fluid and a vapour bubble. Photomicrograph by C. Williams; magnified 40×.

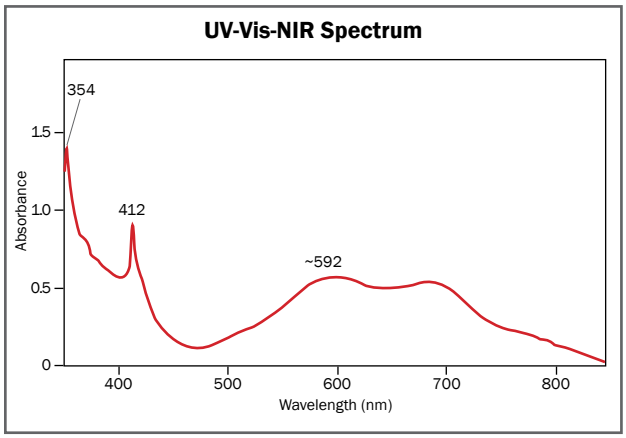

Figure 6: UV-Vis-NIR spectroscopy of the axinite-(Mn) shows features that may be ascribed to Mn^{2+} and V^{3+}.

when viewed from certain angles). The gem was eye-clean. Microscopic examination revealed a few thin colourless blade-like inclusions; one of them contained fluid and a vapour bubble (Figure 5). The RIs were 1.672–1.687, yielding a birefringence of 0.015. Hydrostatic SG was 3.27. When viewed with the Chelsea colour filter, the stone appeared distinctly purplish pink. It fluoresced moderately strong orangey red to long-wave UV radiation, and weak green to short-wave UV. EDXRF spectroscopy showed major amounts of Si and Ca, a significant Mn component, and only traces of Fe and V. (Although no Mg was recorded, this relatively light element is not easily detected by EDXRF.) Taken together, the physical and chemical properties identify the stone as axinite-(Mn) [or manganaxinite, $Ca_2MnAl_2BSi_4O_{15}(OH)$] rather than axinite-(Mg), and this was consistent with the Raman spectrum. The presence of significant Mn was also evident with simple magnetic testing, in which the stone was easily pulled across the desk by a rare-earth magnet.

An ultraviolet-visible–near infrared (UV-Vis-NIR) absorption spectrum of the axinite-(Mn) collected with an Ocean Optics USB4000 spectrometer showed sharp peaks at 354 and 412 nm, and a broad absorption centred at ~592 nm (Figure 6). Similar features were documented in a fragment of pale blue axinite-(Mn) by Arlabosse et al. (2008): a broad band centred at ~597 nm due to V^{3+} and several features that could be due to Mn^{2+}, including sharp peaks at 355, 368, 413 and 421 nm and two broad bands at 515 and 733 nm.

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Green Fluorite from Stak Nala, Pakistan

Pegmatites at Stak Nala in northern Pakistan are famous for producing exceptional specimens of tourmaline, as well as a variety of other minerals (e.g. Laurs et al., 1998). Particularly coveted by mineral collectors are matrix specimens consisting of tricolour tourmaline with white albite and green fluorite. According to gem dealer Dudley Blauwet, there has been sporadic production of small amounts of gem fluorite from Stak Nala since 1982. In June 2013, he obtained a parcel

Figure 7: These fluorites from Stak Nala, Pakistan, weigh 24.07, 28.68 and 17.98 ct, from left to right. Photo by Dirk van der Marel.

of broken fragments of Stak Nala fluorite while visiting Skardu, Pakistan. He sent the 12 cleanest pieces totalling 249.6 g to his cutting factory, and in January 2014 he received 44 stones weighing 226.70 carats that ranged from sub-carat sizes to nearly 30 ct. On a return trip to Skardu in November 2013, Blauwet purchased another similar parcel weighing 243 g from the same dealer, and those pieces will be faceted in the future.

Blauwet loaned three Stak Nala fluorites to this author for examination. The stones weighed 17.98–28.68 ct (Figure 7) and showed an attractive light, strong, bluish green colour. The gemmological properties were consistent with fluorite: RI of 1.434, singly refractive, and a hydrostatic SG of 3.18. The stones appeared green under the Chelsea filter, and showed weak, dark grey anomalous birefringence with the polariscope. They luminesced a weak yellowish 'mustard' green to long-wave UV radiation, and a strong greenish yellow to short-wave UV. After switching off the short-wave UV lamp, the stones showed weak green phosphorescence for a few seconds. All three gems were eye-clean, and microscopic examination of each stone revealed a few rounded to euhedral, transparent, colourless crystal inclusions (Figure 8) that were doubly

Figure 8: Euhedral mineral inclusions were seen in all three of the fluorites. Photomicrograph by J. C. Zwaan; image width 0.9 mm.

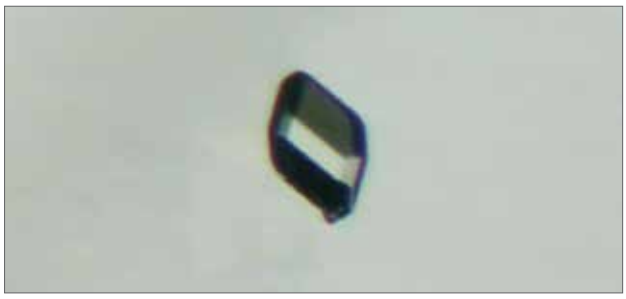

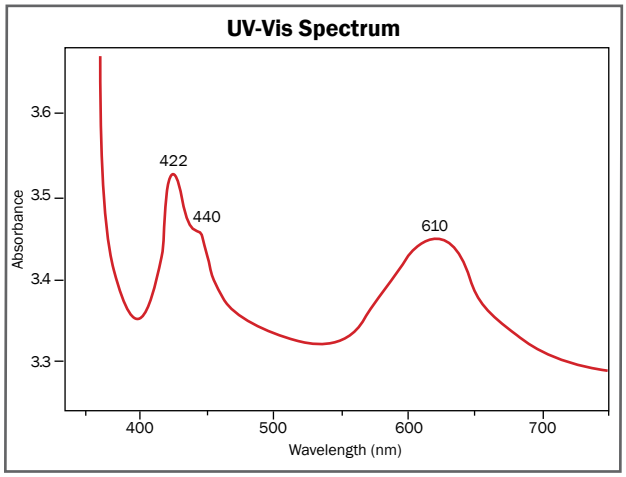

Figure 9: UV-Vis spectroscopy of the fluorite reveals bands at 422, 440 and 610 nm that are associated with Sm^{2+}, which is responsible for the green coloration.

refractive. The inclusions could not be identified with Raman analysis due to the strong fluorescence of the fluorite and their positions deep inside the stones.

In all three stones, EDXRF analyses revealed traces of Y (~0.7-0.9 wt.% Y_2O_3), Yb (~0.2 wt.% Yb_2O_3) and Mn (~0.04–0.05 wt.% MnO). UV-Vis spectra showed absorptions at 422 nm (with a shoulder at 440 nm) and at 610 nm (Figure 9). These features are reportedly associated with Sm^{2+} ions in light to 'emerald' or 'bright' green fluorite (e.g. from Brazil and from Weardale, England: Bill and Calas, 1978; http://minerals.gps.caltech.edu). Although Sm was not detected by EDXRF, only small concentrations (ppm level) of divalent rare-earth elements such as Sm^{2+} are needed to cause colour in fluorite (cf. Marchand et al., 1976). Yttrium is commonly known to associate with F-centres (produced when an electron is trapped in a vacancy that occupies the position of a fluorine ion) within fluorite to produce various colours. Y-associated F-centres are known to cause blue colour in fluorite, with absorptions at 400 and 590 nm, and may also produce a bluish green colour, with bands at 350, 400 and 600 nm (Kim et al., 2012). However, comparing the latter spectrum with the Sm^{2+}-related features in the Stak Nala fluorites, the position of the peaks is slightly shifted, the shoulder at 440 nm is absent, and the absorption at 400 nm is much stronger than at 600 nm.

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Kim M., Yoon Y., Kang M. and Shin D., 2012. Spectroscopic characteristics of natural fluorite induced by electron-beam irradiation. *Journal of Ceramic Processing Research,* **13**(5), 541–546.

Green Fluorite from Vietnam

On three separate trips to Luc Yen, Vietnam, in May 2008 and in May and November 2012, gem dealer Dudley Blauwet obtained some interesting dodecahedral crystals of green fluorite. According to his supplier, the fluorite was mined from Cao Bang Province, northeast of Yen Bai. The crystal surfaces were corroded with dendritic grooves and appeared blackish, much different than the 'emerald' green colour of their interior. Black string-like inclusions were visible in some of the material. From the crystal he purchased in 2008, Blauwet had a 55.24 ct stone cut that he donated in 2010 to the National Gem Collection at the Smithsonian National Museum of Natural History in Washington D.C., USA (http://geogallery.si.edu/index.php/en/10209869/fluorite). The rough material he obtained in 2012 consisted of 11 pieces weighing a total of ~430 g. After having them faceted at his cutting factory, in January 2013 he received 62 stones weighing ~480 ct, ranging from sub-carat pieces to nearly 30 ct.

Blauwet loaned a 29.05 ct cushion-cut fluorite (Figure 10) to American Gemological Laboratories for examination. The RI of 1.437 and hydrostatic SG of 3.18 were consistent with fluorite (O'Donoghue, 2006). The stone was inert to UV radiation (both long- and short-wave). EDXRF analysis showed only the presence of Ca, and Raman spectroscopy confirmed it was fluorite.

When observed with the unaided eye, the stone displayed an assortment of dark inclusions (Figure 10). Microscopic examination revealed that they actually consisted of angular patterns of dark purple colour concentrations (Figure 11). Other internal features in the fluorite were primary (Figure 12) and secondary two-phase (liquid-gas) inclusions and fluid 'fingerprints' along partially healed fractures (Figure 13). In addition, the stone displayed conspicuous colour banding (green to near-colourless) when viewed through the pavilion with diffused lighting.

Figure 10: This 29.05 ct fluorite is reportedly from Cao Bang Province in northern Vietnam. Photo by Bilal Mahmood.

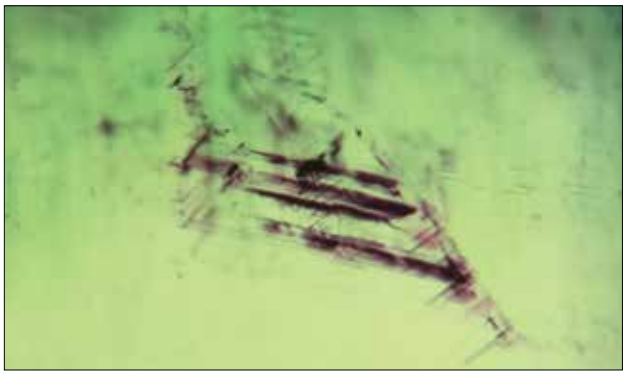

Figure 11: The dark 'inclusions' in the fluorite actually consist of purple colour concentrations. Photomicrograph by M. Chaipaksa; magnified 50×.

In three subsequent trips to Luc Yen, Blauwet has not encountered any more of this fluorite. The angular patterns of dark colour concentrations are quite distinctive, and may be unique to green fluorite from this locality.

Monruedee Chaipaksa

Reference

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Figure 12: Primary two-phase (liquid-gas) inclusions display various jagged forms in the Vietnamese fluorite. Photomicrographs by M. Chaipaksa; magnified 70×.

Figure 13: This partially healed fracture in the fluorite consists of a plane of fluid inclusions. Photomicrograph by M. Chaipaksa; magnified 50×.

Bicoloured Grossular from Kambanga, Kenya

Light yellow-green grossular from Kambanga, Taita-Taveta District, Voi, Kenya, is notable for having a significantly lighter colour than the tsavorite that is commonly known from this part of East Africa (Jang-Green and Beaton, 2009). Recently, some additional production of grossular from this area has included some interesting bicoloured stones. In September 2013, gem dealer Dudley Blauwet received a shipment of rough from his East African supplier that included a small parcel of grossular. Of the 67 small pieces it contained, about 26 of them weighing a total of 6.1 g were strongly colour zoned in green and near-colourless. Blauwet instructed his cutting factory to facet some of the stones as step-cuts to show their distinctive coloration. Of the 38 gems that were faceted from the parcel in January 2014, 10 were bicoloured; these had a total weight of 2.80 carats and the stones ranged from 0.04 to 0.61 ct.

Two bicoloured emerald-cut stones that weighed 0.42 and 0.61 ct (Figure 14) were examined by this author. The pronounced colour zoning exhibited by each stone consisted of two shades of a pure green: (1) a medium, strong green; and (2) a very light green. Face-up, the very light green portion appeared very slightly yellowish. The two stones showed RIs of 1.739 and 1.740, were singly refractive, and had a hydrostatic SG value of 3.64. These properties are consistent with grossular, and are comparable with those obtained by Jang-Green and Beaton (2009) except those authors reported somewhat lower SG values of 3.58–3.60.

Figure 14: These bicoloured grossulars (0.61 and 0.42 ct) are from Kambanga, Kenya. Photo by Dirk van der Marel.

The darker parts of the stones fluoresced very weak dark red to long-wave UV radiation and very weak dark orange to short-wave UV. The lighter parts luminesced weak red to long-wave and weak orange to short-wave UV. The stones were moderately to heavily included. Partially healed fissures were most prominent, consisting of randomly positioned voids (Figure 15, left) or of smaller voids arranged in linear arrays (Figure 15, centre); many of the voids contained transparent to whitish solid phases. Raman spectroscopy of these solids in about 10 voids identified calcite; a few voids also contained sulphur. An isolated inclusion of titanite (sphene) also was found in the 0.61 ct grossular (Figure 15, right).

Chemical analysis with EDXRF spectroscopy identified Ca, Al and Si as the main elements, indicating a pure grossular composition, with traces of Mn (~0.2–0.6 wt.% MnO), Fe (~0.1 wt.% FeO) and Ti (~0.3–0.4 wt.% TiO_2). Traces

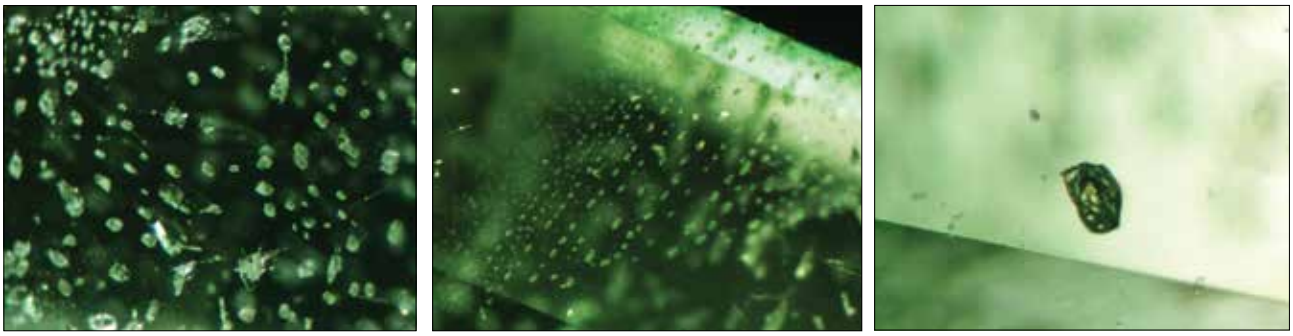

Figure 15: Partially healed fissures were prominent in the grossulars, consisting of randomly arranged voids (left) or smaller voids arranged in linear arrays (centre). Solid inclusions in some of the voids were identified as calcite, with sulphur in a few cases. Also present in one of the stones was an isolated titanite inclusion (right). Photomicrographs by J. C. Zwaan; image width 1.3 mm (left and centre) and 1.2 mm (right).

Table I: Range of trace elements in bicoloured grossular from Kenya, measured by EDXRF.[a]

Oxide (wt.%)	Medium green	Very light green
TiO_2	0.26–0.35	0.25–0.39
V_2O_3	0.32–0.38	0.04–0.08
Cr_2O_3	0.41–0.47	0.09–0.14
MnO	0.51–0.59	0.17–0.48
FeO	0.09–0.10	0.08–0.09

[a] Ranges are based on 20 spot analyses.

of V and Cr also were present, with greater concentrations in the darker green portions (Table I), indicating that both of these elements play a role in causing the green colour (cf. Muije et al., 1979).

UV-Vis-NIR spectra (Figure 16) showed large asymmetrical absorption bands at about 430 and 605 nm, with the most intense absorption at the blue end of the spectrum. The spectra of the darker green portions showed more intense absorption peaks than the lighter green parts, which created a more pronounced and narrower transmission window (centred at about 520 nm). Fourier-transform infrared (FTIR) spectra recorded bands at 3642, 3598, 3564 and 3544 cm^{-1} (Figure 17), which indicate the presence of hydroxyl groups in the garnet structure (Rossman and Aines, 1991).

The chemical composition and UV-Vis-NIR and FTIR spectroscopic features correspond to 'type 4' tsavorites (Mn-bearing chromian-vanadian grossular, with Mn>Cr>V), as

Figure 16: These UV-Vis-NIR spectra of the medium green and light green areas of a bicolour grossular show greater absorption for the darker area, with a more pronounced transmission window centred at about 520 nm, resulting in the darker green colour.

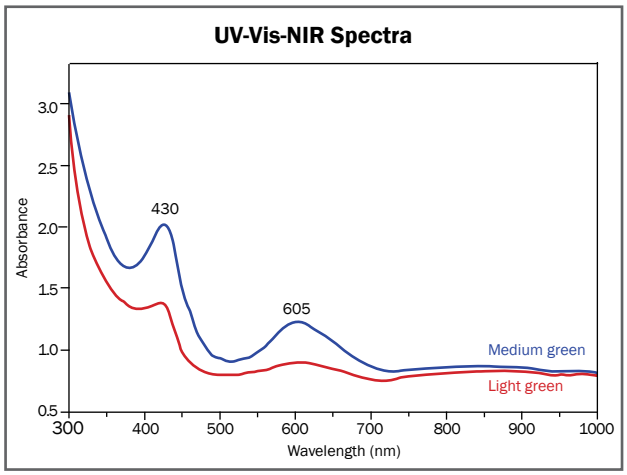

Figure 17: This FTIR spectrum shows the presence of structural OH^- in the grossular.

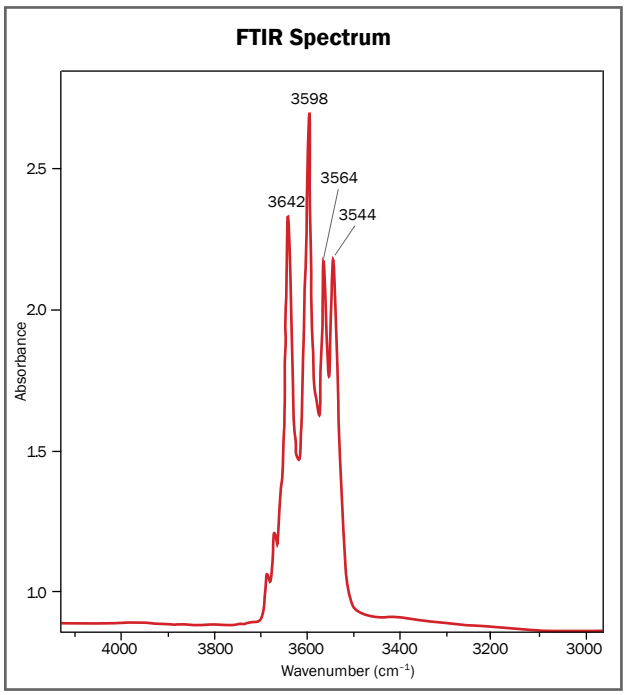

distinguished by Feneyrol et al. (2014). The V/Cr ratio of the samples ranged from 0.7 to 0.9, similar to the ratio in tsavorite from Baraka, Kenya. Also the FTIR spectra, with a main peak at 3598 cm^{-1}, are consistent with tsavorites from this area. In the UV-Vis-NIR region, the absorption bands at 430 and 605 nm are both produced by V^{3+} and Cr^{3+}, but their concentrations were too low to create noticeable features at 697 and 701 nm. In addition, small peaks related to Mn at about 408 and 418 nm were not visible, because they only show up at values greater than ~1.2 wt.% MnO (Feneyrol et al., 2014).

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Jade-like Jewellery Materials Sold in Myanmar

A portion of the Myanmar Gems Museum in Yangon consists of the Gems Mart, where numerous gem and jewellery stalls sell various items such as bracelets, bangles, necklaces, rings and decorative objects to tourists as souvenirs (e.g. Figure 18). These materials are also offered at the Myanmar Gems Emporium in Naypyidaw (as rough stones, partially cut pieces, cabochons and bangles), and at the Yangon airport. The jewellery is manufactured in Mandalay, Sagaing and Naypyidaw, using a variety of materials from both the jadeite mining area in north-central Myanmar and the Myitsone area near Myitkyina (located ~10 km east of the jadeite deposits). The colour of these items includes white, yellow, orange to brown, and green to blue (e.g. Figures 19 and 20).

The items sold at the Emporium are tested by gemmologists from the Myanmar Gems Enterprise, and according to a 2013 catalogue the non-jade materials consisted of quartzite, albite, amphibole, serpentine and petrified wood. Approximately 70% of the Emporium parcels consisted of quartzite, and they were bought by foreign merchants from China and Hong Kong. For the experienced gemmologist, it is not difficult to separate the various non-jade materials by their appearance (colour, lustre, and texture) and specific gravity (heft). There was

Figure 18: There are approximately 50 stalls like this one at the Gems Mart within the Myanmar Gems Museum in Yangon. Photo by U Tin Hlaing.

Figure 19: These bangles consist of jadeite (left, 5.5 cm in diameter) and quartzite (right, 6.5 cm). Photo by U Tin Hlaing.

Figure 20: All of the beads in these bracelets are quartzite. Each bracelet is ~6 cm in diameter. Photo by U Tin Hlaing.

no visual evidence of dyeing, waxing, or other treatments in the non-jade materials.

Since the items offered at the Gems Mart are for the tourist souvenir market, they are not labelled with their identities (jadeite or otherwise), but they are priced according to the type and quality of the material and its polish. For example, the asking price for quartzite cabochons was €0.5–1 and bangles ranged from €23 to €350. Bracelets made of round quartzite beads were €0.8–1.5. Petrified wood bangles were €2, and jadeite bangles were €230–765.

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Blue Kyanite from Tanzania

Tanzania has been known as a source of gem-quality kyanite for many years (e.g. Quinn and Laurs, 2004). While the material documented previously was light greenish blue or very dark blue, some additional kyanite was recently produced that shows a particularly attractive blue colour. Gem dealer Dudley Blauwet obtained two pieces of this material from his supplier in Kenya in September 2013. The combined weight of the pieces was 6.17 g, and they were reportedly mined from the Umba area in Tanzania. Blauwet stated that they were fairly well crystallized (for kyanite), and each had a deep blue stripe along its centre that extended the length of the crystal. After the material was cut in January 2014, he obtained nine stones weighing a total of 6.47 carats that ranged from 0.19 to 1.68 ct.

Two of the kyanites were examined by this author. They weighed 0.19 and 1.68 ct, and showed a medium light, moderately strong, slightly greenish blue coloration (Figure 21). RI readings were 1.716–1.730, yielding a birefringence of 0.014, and the hydrostatic SG was 3.67. These values are typical for kyanite.

Figure 21: These attractive blue kyanites from Tanzania weigh 1.68 and 0.19 ct. Photo by Dirk van der Marel.

Viewed with the dichroscope, both stones showed distinct trichroism in strong, slightly greenish blue, light violetish blue and colourless. They fluoresced weak red to long-wave UV radiation and chalky green-white to short-wave UV. The stones appeared bright red under the Chelsea filter. Using a prism spectroscope, two sharp dark lines were observed in the deep red region, with a red fluorescent line between them. A grey band partly absorbed the green region between about 550 and 610 nm, and the spectrum showed a cut-off in the blue at about 430 nm.

Microscopic examination revealed that the kyanites mainly contained cleavage planes (oriented in two directions) and needle-like tubes (in the larger stone, mainly along the longitudinal direction). Some were connected in such a way that they looked like icicles (e.g. Figure 22). The girdle of the round stone displayed small parallel-oriented incipient cleavage breaks that were reminiscent of the 'bearding' observed in bruted diamonds.

Raman spectra gave an excellent match with the kyanites in the RRUFF database (http://rruff.info/Kyanite). Besides the main elements Al and Si, EDXRF analyses indicated traces of Cr (0.14–0.16 wt.% Cr_2O_3), V (0.09–0.14 wt.% V_2O_3) and Ti (0.02–0.03 wt.% TiO_2). Remarkably, no Fe was detected. FTIR spectra showed features at 3437, 3409, 3386 and 3276 cm^{-1}, confirming the presence of OH^- in the crystal structure of these kyanites (cf. Bell et al., 2004).

The UV-Vis-NIR spectra showed two main absorptions, centred at 400 and 590 nm, with smaller sharp features at 371, 690 and 710 nm (Figure 23). A transmission window centred at 470 nm is responsible for the slightly greenish blue coloration. The feature at 371 nm is known to be associated with Fe^{3+} (Henn and Schollenbruch, 2012), although it must be present in very low concentrations since Fe could not be detected by EDXRF. The peaks at 690 and 710 nm are attributed to Cr^{3+} (Pradat and Choudhary, 2014). This spectrum differs from those reported for 'sapphire'-blue kyanite from Nepal (Henn and Schollenbruch, 2012) that show small peaks at 370, 380, 435 and 445 nm (related to Fe^{3+}), as well as a dominant band centred at 610 nm and a large shoulder at 800 nm, which are attributed to Fe^{2+}-Ti^{4+} and Fe^{2+}-Fe^{3+} intervalence charge transfer, respectively. It also differs from the spectra of blue kyanite from India (Pradat and Choudhary, 2014), which showed features at 690 and 710 nm due to Cr^{3+}, as well as a band centred at 590–610 nm, and smaller peaks at 370, 380, 417, 431 and 446 nm, attributed to Fe^{2+}-Ti^{4+} and Fe^{3+}, respectively. It is also unlike an East African kyanite with a colour change ('alexandrite') effect, probably caused by the presence of chromium and iron, or chromium alone (Bosshart, 1982). On the contrary, the spectrum of this kyanite from Tanzania looks very similar to that of the Cr,V-bearing grossular documented on pp. 195–197 of this issue, except

Figure 22: The intersection of these needle-like tubes with subtle cleavage planes (nearly horizontal in this view) resembles icicles hanging from a roof in this kyanite. Photomicrograph by J. C. Zwaan; image width 4.2 mm.

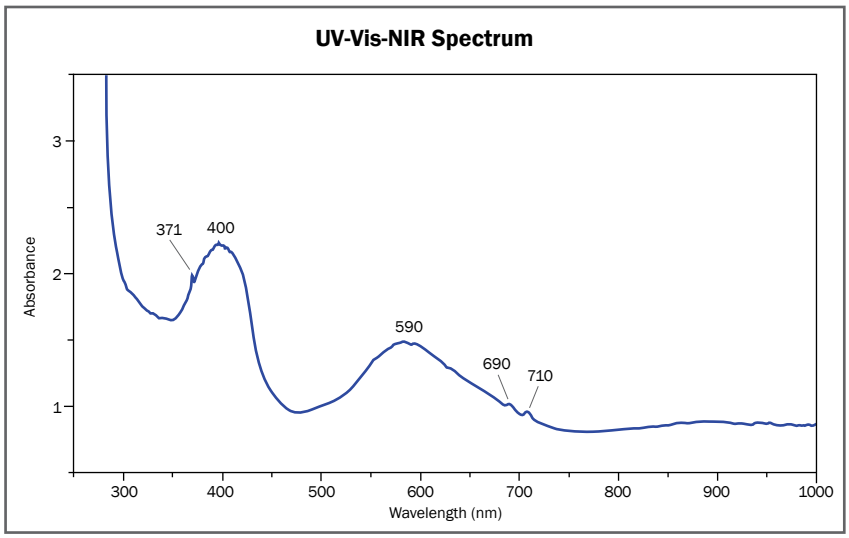

Figure 23: The UV-Vis-NIR spectrum of the kyanite suggests that Cr^{3+} and V^{3+} are the cause of the blue colour, and not Fe^{2+}-Ti^{4+} intervalence charge transfer as in blue kyanite from most other localities. The very small feature at 371 nm does indicate the presence of Fe^{3+}, although iron must be at low concentration since it was not detected by EDXRF.

that the major bands are shifted to 400 and 590 nm, resulting in a slightly greenish blue colour. Together with the fact that Cr and V were the only trace elements detected in these samples, this strongly suggests that both Cr^{3+} and V^{3+} are the colour-causing elements, rather than Fe^{2+}-Ti^{4+} charge transfer. However, more analytical work needs to be done to confirm this hypothesis for the blue kyanite from this locality.

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Rainbow Moonstone from Malawi

Rainbow moonstone is a trade name that has been used for colourless labradorite (a plagioclase feldspar) that displays iridescent colours in the form of labradorescence. This phenomenal behaviour appears quite different from the billowy blue or white glow (adularescence) that is displayed by typical *moonstone* (alkali feldspar). Gem dealer Mark Kaufman recently encountered an old parcel of rainbow moonstone from an unusual locality—Malawi. According to him, Malawi has occasionally produced this material for several years, but the deposit has not proved economically viable due to the small amount of cuttable rough. Nevertheless, some impressive stones have been cut, including a 28.8 ct gem (Figure 24). The parcel seen by Kaufman consisted of ~100 kg of rough, but only 2 kg were of facetable quality. The best stone that he has cut from this lot is a 12.22 ct cushion (Figure 25), which he loaned to Stone Group Labs for examination.

The gem showed pronounced spectral colours when viewed from all angles. The RIs of 1.553–1.566 (birefringence 0.013) were within the expected range for labradorite, and the hydrostatic SG was 2.69. A moderately strong chalky purplish pink fluorescence was observed

Figure 24: Malawi is reportedly the source of this exceptional 28.8 ct rainbow moonstone. Courtesy of James Zigras; photo by Jeff Scovil.

Figure 25: Bright iridescence is displayed by this 12.22 ct rainbow moonstone from Malawi, which was studied for this report. Photo by B. Williams.

under long-wave UV radiation and a weaker greenish yellow luminescence was seen under short-wave UV. This fluorescence behaviour is quite different from that reported for rainbow moonstone from other localities, including India (Johnson and Koivula, 1997), Madagascar (Ito, 2012) and Zambia (Win and Moe, 2012).

Inclusions are to be expected in this type of feldspar, with loupe-clean stones being rare. The only eye-visible inclusion in this stone appeared to consist of a small fracture oriented along a cleavage direction. Microscopic observation revealed lamellar twin planes with needle-like interfaces oriented parallel to the crystal axes. In addition, a tiny surface-reaching fissure appeared to be due to cleavage and contained minor polishing residues.

The distinctive UV fluorescence may help separate Malawi labradorite from other localities, although more samples will need to be examined to confirm this.

Cara and Bear Williams

Brendan M. Laurs

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Recent Smoky-Citrine Quartz and Tourmaline Discoveries at the Oceanview Mine, Pala, California, USA

During the past several years, a number of important gem-bearing pockets have been found at the Oceanview mine in Southern California, USA (e.g. Mauthner, 2011). These finds have yielded beryl (morganite and aquamarine), spodumene (kunzite and triphane), tourmaline and other minerals. Recently, mine owner Jeff Swanger and his crew have made some interesting discoveries of quartz and pink tourmaline. Since early 2013, a series of pockets have produced some large and clear quartz crystals with an attractive smoky-citrine colour. One of these crystals was polished by gem artist Lawrence Stoller to showcase its clarity and coloration (Figure 26). In addition, some large gemstones have been cut from this material, including a 1,030 ct Portuguese cut (Figure 27) and a 615 ct Mikan cut that was faceted by Philip Osborn, one of Oceanview's miners.

Most recently, in late July 2014, Swanger and his crew found a small pocket in a part of the mine known as Osborn Alley that contained pink tourmaline crystals with flat blue terminations (e.g. Figure 28). This find generated a lot of excitement since the crystals resembled the famous 'blue-cap' tourmalines found in 1972 at the Tourmaline Queen mine, also in the Pala District (e.g. Larson, 2012). So far, approximately three dozen of these tourmalines have been recovered—from both

Figure 26: This crystal of smoky citrine from the Oceanview mine was polished by Lawrence Stoller and measures 31 cm tall and 18 cm wide. Courtesy of James Zigras; photo by Gary Alvis and Lawrence Stoller.

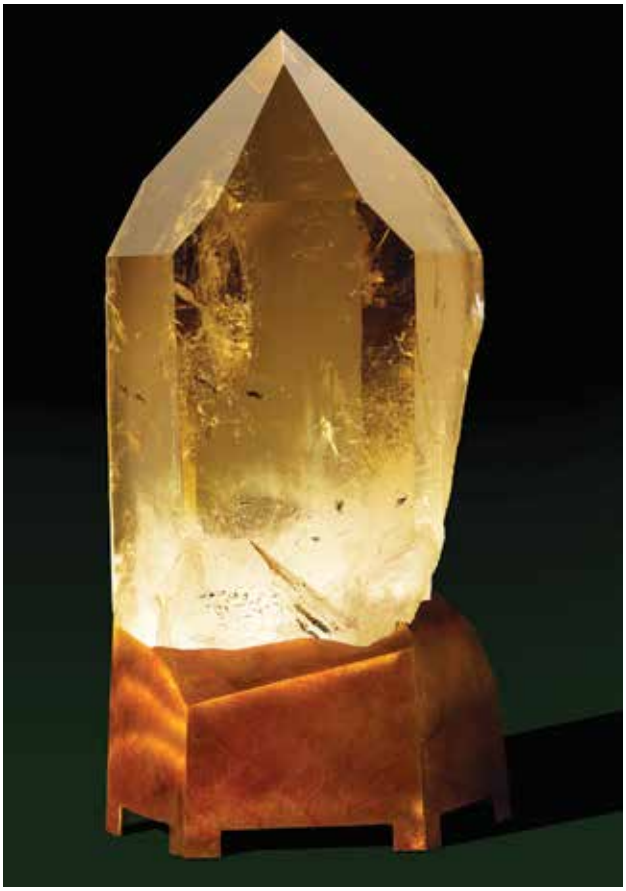

Figure 27: Some large gems have been faceted from smoky citrine produced at the Oceanview mine, such as this 1,030 ct Portuguese cut by Joel Baskin. Courtesy of James Zigras; photo by Jason Baskin.

the underground workings and from the mine tailings by fee diggers—and the largest crystal measured 4.2 × 3.3 cm. Additional small pockets in this area of the mine have produced a few crystals of morganite and kunzite.

Swanger recently completed a new haulage tunnel that will significantly decrease the distance for removing material from the mine. This will increase efficiency and hopefully bring the miners closer to more gem finds in the near future.

Brendan M. Laurs

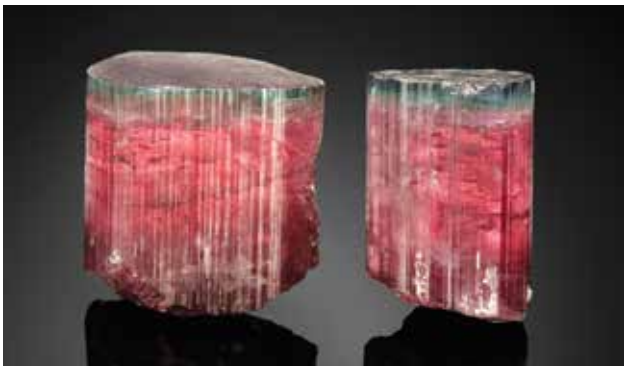

Figure 28: The Oceanview mine is also the source of these 'blue-cap' tourmalines (each 3.3 cm tall). Courtesy of Oceanview Mines LLC; photo by Mark Mauthner.

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Scheelite from Inner Mongolia

During the 2014 gem shows in Tucson, Arizona, USA, one of us (BML) was informed about an unusual gem originating from Inner Mongolia, China. Gem dealer Mark Kaufman reported that in 2012 some colourless crystals were found at the Huanggang mine that were represented by his Chinese supplier as powellite [$Ca(MoO_4)$]. Powellite forms the molybdenum-rich end member of an isomorphous series with scheelite [$Ca(WO_4)$], which is the tungsten-rich end member. Kaufman obtained one of the crystals in late 2013 that measured about 10 cm long and 3 cm wide, and was broken at its base. He used strong transmitted lighting to detect a facetable area through the naturally etched surface of the crystal, near its termination. He cut a 41.38 ct square cushion, measuring 17.4 × 17.2 mm (Figure 29), and the stone was loaned to authors CW and BW for examination and confirmation of its identity.

The colour of the gem was so white as to appear 'silvery' white, presumably due to the high lustre and refraction. The RI could not be measured since it was over the limit of the refractometer (>1.81). The stone's hydrostatic SG was 5.71. It fluoresced strong chalky yellow to

Figure 29: This scheelite weighs 41.38 ct and is reportedly from Inner Mongolia. Photo by B. Williams.

long-wave UV radiation and moderate chalky yellowish pink to short-wave UV. These properties are largely consistent with those reported for scheelite by O'Donoghue (2006), except that the SG values in that publication are slightly higher. However, this would be expected for scheelite that contains some Mo (i.e. some of the powellite end member). The stone was free of any eye-visible inclusions, and microscopic examination revealed only a few small 'fingerprint' inclusions. In addition, the use of darkfield lighting and higher magnification showed some mist-like diffuse lines of pinpoint dots.

UV-Vis spectroscopy revealed a narrow weak absorption at 378 nm and a broad weak absorption centred at 700 nm. EDXRF spectroscopy showed major amounts of Ca and W, as expected for scheelite, as well as moderate Mo and some Yb. Raman analysis confirmed the stone was scheelite.

Facetable scheelite is considered a collectors' stone due to its rarity and low hardness (4½–5 on the Mohs scale). This 41.38 ct stone is the first faceted scheelite from Inner Mongolia that is known to these authors, and its large size and eye-clean transparency are particularly notable for a gem from a new locality.

Cara and Bear Williams

Brendan M. Laurs

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PEARLS

Aging Silver-treated Cultured Pearl

The Laboratoire Français de Gemmologie (LFG) recently received a round dark brown pearl for analysis that was taken from a necklace composed entirely of pearls with the same appearance. The owner stated that the necklace was bought in the 1950s and was represented to consist of natural black pearls from the Red Sea region.

The pearl measured 6.8 mm in diameter and was very dark brown with no secondary colour. Magnification revealed an inhomogeneous coloration, as well as a darker area around the drill hole (Figure 30). These features strongly suggest colour treatment.

The pearl was then analysed with X-ray microradiography to observe its inner structures and determine its natural or cultured origin. A round bead was clearly seen inside (Figure 31), establishing that it is a beaded cultured pearl. However, the most interesting aspect of the X-radiograph was a bright-appearing layer surrounding the nucleus. This feature is typically seen within pearls treated with silver nitrate (Webster, 1949; Crowningshield, 1950). In this treatment, pearls are immersed in a silver nitrate solution in the dark. Then the pearls are exposed to light or treated with hydrogen sulphide to precipitate dark-coloured colloidal silver. It is well known that this treatment is used to blacken Akoya cultured pearls. Because the silver nitrate reacts more intensely with organic material, a greater concentration of silver precipitates in the tiny space surrounding the nucleus. Since silver has a much higher opacity to X-rays than the $CaCO_3$ composing the pearl, the X-rays are blocked, producing the bright layer around the nucleus.

Figure 30: The inhomogeneous colour and darker area concentrated around the drill hole of this 6.8 mm cultured pearl are indications of colour treatment. Photo by O. Segura.

Figure 31: With microradiography, a round bead is clearly visible, identifying the sample as a beaded cultured pearl.

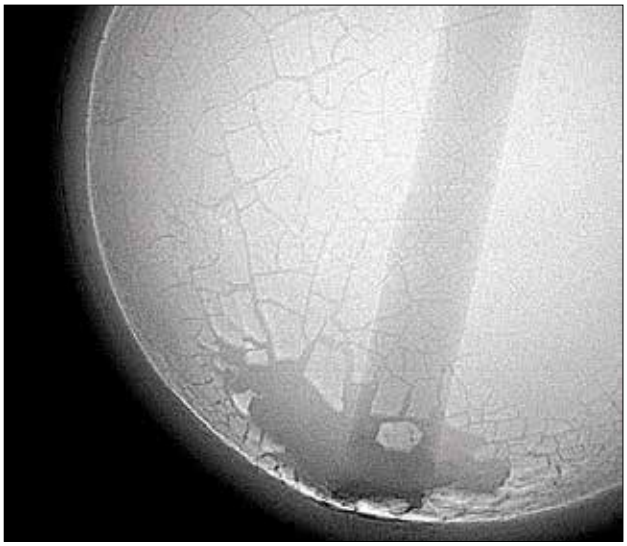

Figure 32: At higher magnification, desiccation cracks are easily seen with microradiography in the aged silver-treated cultured pearl.

As the pearl was rotated and the area near the drill hole inspected and magnified, an unusual fracture pattern was observed in the radiographs. The cultured pearl exhibited a network of desiccation cracks (Figure 32), as commonly seen in mud when it dries and contracts. Near the drill hole, some of the cracked material appeared to be missing, possibly ejected by the movements of the cultured pearl in the necklace. To the authors' knowledge, this has not been previously reported in old untreated cultured pearls of similar nature. Hence, we suggest that the silver nitrate provoked or accelerated the drying of the layer of organic matter present around the nucleus. This eventually resulted in cracking, then flaking. It is likely that similar patterns might be observed if more old treated cultured pearls of a similar nature are observed with high-resolution X-ray microradiography. However, the relatively unattractive nature of such aged, treated cultured pearls makes it unlikely that they would be submitted for detailed inspection by a well-equipped gemmological laboratory.

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TREATMENTS

Dyed Hessonite as a Ruby Imitation

Ruby imitations consisting of dyed-red quartz, sillimanite and corundum are known in the gem trade (e.g. Schmetzer et al., 1992; Singbamroong, 2005). Recently we encountered a different imitation in a parcel of rubies submitted for testing at our laboratory. According to the client, the stones (both faceted and cabochons) had been removed from an old piece of jewellery.

At first glance, the cabochons in the parcel appeared typical of ruby (e.g. Figure 33). Most of the stones had inclusions consisting of short rutile needles and negative crystals, as are commonly

Figure 33: The largest cabochon (2.68 ct) shown here proved to be dyed hessonite. Its appearance closely resembles the accompanying ruby cabochons (0.56, 0.69 and 1.10 ct). Photo by J. Panjikar.

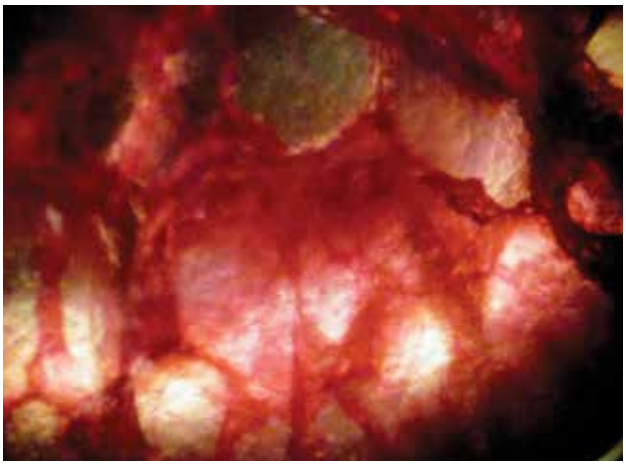

Figure 34: The hessonite showed a typical roiled appearance, as well as red dye concentrations along fractures. Photomicrograph by J. Panjikar; magnified 60×.

seen in rubies from Mogok, Myanmar. However, one of the cabochons proved much different, with the following gemmological properties: isotropic optic character, spot RI of 1.74 and hydrostatic SG of 3.68. Microscopy revealed a roiled appearance with red dye concentrations along fractures (Figure 34), as well as small transparent crystals. These properties identified the stone as dyed hessonite. UV-Vis spectroscopy confirmed that there was no chromium present, and the material was indeed hessonite.

This example serves as a reminder for gemmologists to remain vigilant about detecting imitations in gem parcels, even in those represented as 'old' stones.

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MISCELLANEOUS

The Mirasety Ring: An Ethiopian 'Rainbow' Opal Set with a Hologram

During the 2014 Tucson gem shows, these authors briefly exhibited a unique jewel for the first time: the Mirasety ring, named *FS01*. The ring is shaped like a flying saucer and features an opal bead from Wollo, Ethiopia, that is set over a hologram embedded within a glass disc (Figure 35). This ring is the first embodiment of a new concept by a group of designers, jewellery

Figure 35: Mirasety ring FS01 (42×42 mm) is shown here resting on a dichromate gelatine hologram created by Michael E. Crawford. Photo by F. Mazzero.

Figure 36: A 26.60 ct 'rainbow' opal bead from Wollo, Ethiopia, is set with gold and diamonds for the Mirasety ring. Although not visible in the photo, when this opal is viewed in person the rainbows appear to extend well outside of the stone. The diameter of the bead is 19 mm. Photo by F. Mazzero.

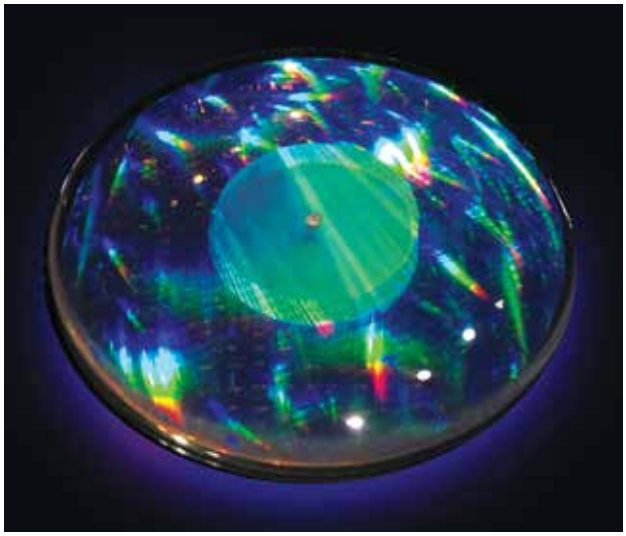

Figure 37: A hologram is embedded in a 38×8 mm round glass disc that in profile forms an ellipse. The upper surface has been drilled and flattened to accommodate the mounted opal in Figure 36. The hologram is registered in a dichromate gelatine emulsion, and was created by one of the authors (AM). Photo by F. Mazzero.

manufacturers, holographers and opal experts, in which jewels associate opals with holographic optical elements. The origin of the concept comes from the unique optical properties displayed by some Ethiopian opals (Gauthier et al., 2004; Fritsch and Rondeau, 2009), as described below.

Play-of-colour opal is composed of a regular three-dimensional grid of isodiametric spheres or lepispheres of hydrated silica ranging from about 150 to 250 nm in diameter; this grid diffracts white light into single spectral colours, producing play-of-colour (Sanders 1964, 1968). The hydrated silica composing the spheres is not crystalline, so therefore opal is not crystalline either. However, their regular and uniform stacking resembles the arrangement of atoms in a crystal. Therefore, play-of-colour opal can be considered a pseudo-crystal, and since it diffracts light in a visible fashion it can also be thought of as an 'optical crystal'.

Sometimes Ethiopian opals show beautiful full rainbows generated by diffraction, as seen in the bead used in the Mirasety ring (Figure 36). The phenomenon is still not well understood, as it contradicts the model of diffraction into single spectral colours (Rondeau et al., 2010; Gauthier et al., 2013). These gems are quite rare, constituting less than 1% of Wollo opals, and this phenomenon has not been observed in opal from any other deposit. The rainbows actually appear to float in space as they project above the surface of the stone. Although this effect is impossible to capture in photos or videos without three-dimensional viewing capability, readers wishing to learn more can access a video that has been placed in the online data depository on *The Journal*'s website.

For this line of jewellery, the holograms are created using an argon laser (488 nm wavelength) in a dichromate-sensitized emulsion with a thickness of only 10 µm that is coated on glass. The emulsion is protected with another glass plate on top. Then this assemblage is cut with high precision to a shape matching the requirements of the designer (e.g. Figure 37). In the Mirasety ring, the hologram generates rainbows that add to those produced by the opal (Figure 38).

Some Ethiopian opals display remarkable optical effects. By combining these 'optical' opals with holograms in jewellery, designers exploring this new field can create unusual pieces that act to sculpt colour and unveil dancing lights which appeal to our emotions.

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Figure 38: The completed Mirasety ring FS01 consists of 54.68 g of 18 carat gold, a 26.60 ct Ethiopian 'rainbow' opal, a 16.3 g hologram set in glass, and four diamonds that have a total weight of 0.61 ct. Photo by F. Mazzero.

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Errata

1. The Gem Note on Emerald Essence triplets (Vol. 34, No. 2, 2014, p. 109) should have indicated that some of the gems were assembled using colourless beryl for the pavilion and petalite (not phenakite) for the crown. According to Anil Dholakia, petalite was used because of its brighter appearance than beryl.
2. The conference report on the 12th Annual Sinkankas Symposium (Vol. 34, No. 2, 2014, pp. 156–157) should have reported that US$10 billion in Burmese jadeite has been traded since 2006 (not annually). For additional Burmese jadeite production data, see www.palagems.com/gem_news_burma_stats.php.

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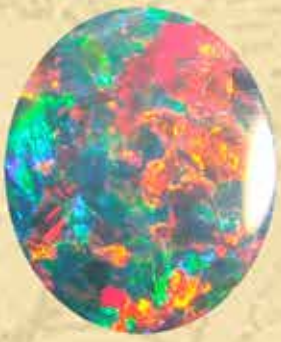

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A Comparative Study of Jadeite, Omphacite and Kosmochlor Jades from Myanmar, and Suggestions for a Practical Nomenclature

Leander Franz, Tay Thye Sun, Henry A. Hänni, Christian de Capitani, Theerapongs Thanasuthipitak and Wilawan Atichat

Jadeitite boulders from north-central Myanmar show a wide variability in texture and mineral content. This study gives an overview of the petrography of these rocks, and classifies them into five different types: (1) jadeitites with kosmochlor and clinoamphibole, (2) jadeitites with clinoamphibole, (3) albite-bearing jadeitites, (4) almost pure jadeitites and (5) omphacitites. Their textures indicate that some of the assemblages formed syn-tectonically while those samples with decussate textures show no indication of a tectonic overprint. Backscattered electron images and electron microprobe analyses highlight the variable mineral chemistry of the samples. Their extensive chemical and textural inhomogeneity renders a classification by common gemmological methods rather difficult. Although a definitive classification of such rocks is only possible using thin-section analysis, we demonstrate that a fast and non-destructive identification as *jadeite jade, kosmochlor jade* or *omphacite jade* is possible using Raman and infrared spectroscopy, which gave results that were in accord with the microprobe analyses. Furthermore, current classification schemes for jadeitites are reviewed.

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Introduction

The word *jade* is derived from the Spanish phrase for *piedra de ijada* (Foshag, 1957) or 'loin stone' from its reputed use in curing ailments of the loins and kidneys. In former times, jade simply included nephrite (Werner, 1774) and jadeite (Damour, 1863); therefore, its nomenclature was rather simple. Jadeite jade is usually a green massive rock consisting of jadeite ($NaAlSi_2O_6$; see Ou Yang, 1999; Ou Yang and Li, 1999; Ou Yang and Qi, 2001). Nephrite jade, a rock mainly composed of the amphibole tremolite [$Ca_2(Mg,Fe)_5Si_8O_{22}(OH)_2$], shows a similar colour and massive structure, and can be difficult to visually separate from jadeite

Figure 1: The Hutton-Mdivani necklace sold for US$27.44 million at Sotheby's Hong Kong auction in April 2014—a world-record price for a piece of jadeite jade jewellery. It features 27 colour-matched beads (15.4–19.2 mm in diameter) that consist of translucent bright green Imperial jadeite. Photo by Luc Phan, © Swiss Gemmological Institute SSEF.

jade. Microscopically, jadeite jade shows a mixed texture of granular and fibrous polycrystalline aggregates, while nephrite mainly shows a fibrous structure. International bodies such as CIBJO have agreed to use the terms *jadeite jade* or *nephrite jade* for the two materials (CIBJO, 2013). Serpentine and other green rocks are not accepted under the jade umbrella. The most valuable jade variety is so-called *Imperial jadeite,* consisting of pure intense green translucent material from Myanmar (e.g. Figure 1).

In the 1960s, Dr Eduard Gübelin described an interesting new gem material also originating from the Burmese jadeitite area: Maw-sit-sit (Figure 2). It is a rock composed of many minerals, and ranges from white to green and black (Gübelin, 1964–1965, 1965). It was later found that maw-sit-sit contained the first terrestrial occurrence of ureyite ($NaCrSi_2O_6$; cf. Harlow and Olds, 1983), later renamed kosmochlor (Ou Yang, 1984; Harlow and Olds, 1987; Hänni and Meyer, 1997). It became evident that jadeite-related rocks are often composed principally of both pyroxenes and amphiboles, and frequently represent members of solid-solution series. Isovalent ionic substitution such as $Al^{3+} \leftrightarrow Cr^{3+}$ and coupled substitution such as $Na^{+} + Al^{3+} \leftrightarrow Ca^{2+} + (Mg^{2+} + Fe^{2+})$ are both common. In addition, samples may contain a variety of non-pyroxene minerals, such as clinoamphibole (mainly sodic and sodic-calcic amphiboles), albite, chromite and others (cf. Harlow and Olds, 1987; Htein and Naing, 1994; Shi et al., 2005a, 2012). Furthermore, individual mineral grains may show pronounced chemical zoning (e.g. Harlow and Olds, 1987; Shi et al., 2005a, 2009, 2012). These factors pose a major problem to gem testing laboratories, firstly for the identification of the mineral constituents and their amounts by straightforward non-destructive procedures, and secondly due to the absence of

Figure 2: Kosmochlor is one of the many constituents of maw-sit-sit, a rock that also commonly contains chromian jadeite, albite, clinochlore, amphibole and chromite. The cabochon shown here weighs 12.09 ct and the polished cobble is 128.02 g (65.7 × 45.3 mm). Photo by Tay Thye Sun.

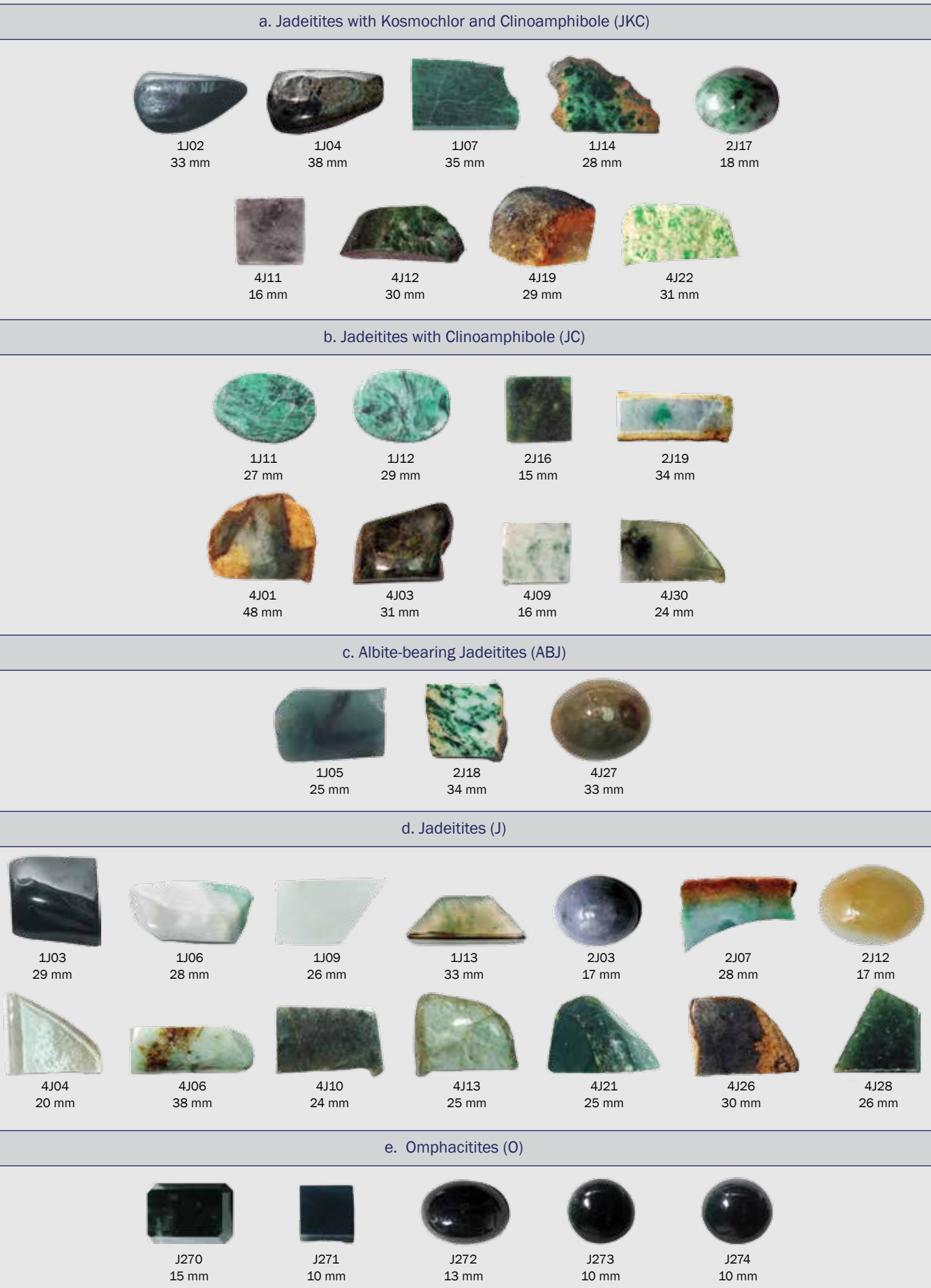

Figure 3: The samples studied for this report are grouped here according to their classification into five groups based on thin-section investigations. The longest dimension of each piece is shown under the sample number. Photos by Tay Thye Sun.

a simple terminology that can be applied to such a complex gem material.

In 2006, the term *fei cui* was officially implemented by the Hong Kong government to cover jadeitite* gemstones. This umbrella term is used for jadeite, omphacite and kosmochlor jades (Ou Yang et al., 2003; Prosperi et al., 2011). The expression *fei cui* or 翡翠, when used in the course of any trade or business to describe an object, means it is a granular to fibrous polycrystalline aggregate that is composed solely or principally of jadeite, omphacite and/or kosmochlor, or any combination of these minerals (cf. www.gahk.org/attachment/fcteststd2.pdf). However, under this regulation, any rock containing one or more of these three minerals can now be sold in the same category as jadeite jade.

Most jadeite jade in the market comes from the classic Uru River area (Kyaukseinmyo) in northern Myanmar (Chhibber, 1934; Bender, 1983; Hughes et al., 2000; Harlow et al., 2014). For the trade it should not be a problem to communicate to consumers that such material may fall into a number of categories, including some that are more rare and others that are more common. However, for the gemmologist and research scientist, the questions arise: What do these Burmese jades consist of, and how common are omphacite, kosmochlor and mixed members of these pyroxenes? These questions have become even more pertinent with the recognition that there is material circulating in the trade with the appearance, colour and gemmological properties of fine-quality jadeite jade, but it is actually omphacite jade (e.g. McClure, 2012).

Materials and Methods

Eighty-eight samples of rough and cut (slabs and cabochons) 'Burmese jade' were collected in jade markets in Myanmar, Singapore and Hong Kong. From these, petrographic thin sections were cut and polished for 39 of the samples that we considered representative of what one would expect to encounter as cut jades in the marketplace (Figure 3).

Mineral abbreviations used in this article are after Whitney and Evans (2010), except for the following: Q = quadrilateral pyroxenes (diopside-hedenbergite-enstatite-ferrosilite), Cr-Jd = chromian jadeite and Cr-Omp = chromian omphacite. *Chromian* is used to refer to material with <0.01 Cr^{3+} per formula unit (cf. Morimoto et al., 1988).

Gemmological and Petrographic Methods

All 88 samples were visually examined, and their refractive indices were determined by either the spot method or by normal readings from flat-polished surfaces. Specific gravity was determined hydrostatically for all of these samples, and they also were examined with a desk-model prism spectroscope.

The mineralogy and micro-textures of the 39 petrographic thin sections were studied using a Leica DMRX polarized light microscope.

Chemical Analysis

The compositions of rock-forming minerals in the 39 thin sections were quantitatively measured by electron microprobe. The main focus of this investigation was the various types of clinopyroxene. Chemical analyses were performed with a JEOL JXA-8600 electron microprobe at the University of Basel, Switzerland. The instrument was equipped with an ultra-dry silicon energy-dispersive X-ray detector (Noran System 7 spectral imaging system by Thermo Scientific). The accelerating voltage was 15 kV and beam current was 20 nA, and we used a peak counting time of 30 seconds for all elements. Data correction was performed using the Proza (φρZ) method. To avoid volatilization of Na we chose a beam size of 10 µm. As the analyses were performed without the use of standards, an overall error of 2% is assumed. Ferric iron in the clinopyroxenes was estimated according to stoichiometry, following the method of Droop (1987). Ferric iron in amphibole was calculated using the min-max method (see Appendix 2 of Leake et al., 1997) using the intermediate value of Fe^{3+}. The quantitative results obtained with the microprobe permit calculation of the end-member percentages in solid solutions (e.g. from the jadeite-kosmochlor series).

* *Jadeite* is the name of a mineral, while *jadeitite* is the petrographic name for a rock composed predominantly or entirely of jadeite (synonymous with *jadeite jade*). Likewise, *omphacite* is a mineral name and *omphacitite* is a rock composed primarily of that mineral.

Following the recommendation of S. I. Liu (pers. comm., 2013), backscattered electron (BSE) imaging was done at low magnification in a scanning electron microscope at the University of Basel to investigate the mineralogical composition of the samples. With this technique, the amount of non-jadeite constituents in a polymineralic rock can be quickly estimated, since a relatively higher mean atomic weight (e.g. due to Ca, Fe or Cr) shows up as a brighter image. For example, in the BSE image of sample 4J12, which consists of jadeitite with kosmochlor and clinoamphibole, pure jadeite appears dark grey and omphacite as well as chromian jadeite appear distinctly brighter (Figure 4).

Chemical data obtained by the electron microprobe are very precise and quantitative, but the instrument is expensive and needs a professional technician to operate it, making it impractical for gem labs. Energy-dispersive X-ray fluorescence (EDXRF) spectroscopy used in gem labs has an excitation spot that is too large to resolve individual components of Burmese jade, and also it is only a qualitative technique (without a careful and painstaking standardization procedure). Furthermore, Na is too light an element for measuring with this technique. However, EDXRF is suitable to check for the presence of Ca, to give an indication of the presence of omphacite or sodic-calcic amphibole.

Raman Spectroscopy

Confocal Raman micro-spectroscopy was used to non-destructively characterize individual mineral grains in all 39 of the polished thin sections. We used a Bruker Senterra Raman dispersive microscope spectrometer equipped with a green laser (532 nm). The high resolution of this method (measurement of spots with diameters of 1–3 µm is possible) even allows the identification of complex mineral intergrowths and mineral zoning. For clinopyroxenes, we only measured spots that had been previously analysed by the electron microprobe, to have an absolutely certain identification of the mineral and to avoid sub-microscopic intergrowths or exsolution lamellae. Measurements were performed at 20 mW with a 100 second counting time; we used objective lenses with 50× and 100× magnification, and an aperture of 25 µm.

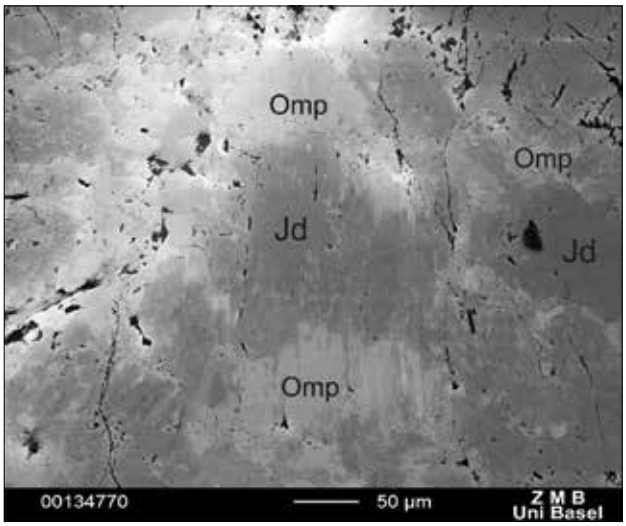

Figure 4: Backscattered-electron imagery of sample 4J12 (jadeitite with kosmochlor and clinoamphibole) shows a jadeite grain (Jd; appears dark) mantled by omphacite (Omp; appears bright). Note also the presence of omphacite along jadeite grain boundaries and fractures. Image by Marcel Düggelin.

Mineral identification was performed using the RRUFF database (Downs, 2006) and our own Raman database at the mineralogical institute in Basel.

Infrared Spectroscopy

Mineral identification also was accomplished using Fourier-transform infrared (FTIR) spectroscopy, performed with a Bruker Lumos FTIR microscope at Bruker's laboratories in Fällanden, Switzerland. Two samples (2J17 and 4J22) were analysed, as well as four additional cabochons from author HAH's collection. Data were collected in the range of 7000–650 cm^{-1} with a resolution of 4 cm^{-1}. The accuracy was ≤0.05 cm^{-1} at 1576 cm^{-1}, and the spectral resolution was <2 cm^{-1}. A mercury-cadmium-telluride (MCT) detector cooled with liquid nitrogen was used. Time-resolved measurements were performed by averaging eight interferograms per spectrum, for a total acquisition time of 8 seconds. Reflection IR measurements of two polished thin sections containing jadeite + omphacite (section 4J12) and chromian jadeite + kosmochlor (2J17) also were undertaken. The size of the measured spots ranged from 15 × 40 µm to 60 × 100 µm. We measured several spots with minerals showing different crystallographic orientations, which had little effect on the main IR bands.

Results

Gemmological Data

The gemmological and petrographic data for each of the 39 samples that were also cut into thin sections are reported in an online data depository on *The Journal*'s website. The colour of the samples ranged from light to dark green (coloured by Cr), lavender (coloured by Mn and/or Fe; see Harlow and Shi, 2011), yellow to brown (coloured by Fe) and black. Kosmochlor-bearing samples were spotted dark green within a lighter green and white matrix. Our samples of omphacitite appeared black, and only the use of transmitted light revealed a dark to very dark green colour.

For our jadeitite samples, spot RI values mostly ranged from 1.65 to 1.66, whereas the omphacitites had a slightly higher RI (1.67–1.68). The SG of our jadeitites was variable but most values fell in the range 3.27–3.35, while the omphacitites varied from 3.26 to 3.36. The large variations in SG can be explained by mineral compositional zoning and the presence of impurities such as clinoamphibole and kosmochlor.

The absorption spectra of the jadeitites revealed a typical sharp line at 437 nm, which was sometimes masked in green chromian jadeite jade, the latter showing absorption lines at 630, 655, and 690 nm (as documented by Liddicoat, 1981). The omphacitites showed no distinctive absorption line (as mentioned by Okano et al., 2009).

Petrographic Examination

Microscopic examination allowed us to visually identify the mineral content and study the micro-textures in the samples. The following groups of jadeite-bearing rocks could be distinguished.

Jadeitites with Kosmochlor and Clinoamphibole (JKC): Samples belonging to this category are 1J02, 1J04, 1J07, 1J14, 2J17, 4J11, 4J12, 4J19 and 4J22 (Figure 3a). These rocks consist mainly of jadeite (modal vol.% estimated at 60–75%; some with additional chromian jadeite) and variable amounts of kosmochlor (1–25%), omphacite (0–10%), clinoamphibole (10–39%), phlogopite (up to 3%), and chromite, as well as other rare accessories like titanite (<1%). In hand specimen, they ranged from green to dark green with nearly opaque spots (2J17). Some samples were entirely dark green (1J07), while others showed dark green veins. A wide variety of different micro-textures were observed. Sample 2J17, for example, contained aggregates of radiating kosmochlor formed around chromite grains, which were embedded in a matrix of randomly oriented short-prismatic jadeite crystals (Figure 5a), similarly described by Shi et al. (2005a, 2009). Long-prismatic, faintly yellow (in thin section) clinoamphibole prisms formed isolated crystals and some sheaf-like clusters. Other samples like jadeitite schist 1J02 showed compositional banding with jadeite-rich, clinoamphibole-rich and kosmochlor-bearing layers. The minerals were aligned parallel to the compositional banding, with fractures oriented oblique to the layering. Secondary limonite and zeolite were found in some specimens, and biotite (appearing 'olive' green in thin section) rimmed and filled fractures in larger jadeite crystals.

Jadeitites with Clinoamphibole (often with Chromian Jadeite; JC): Samples in this category are 1J11, 1J12, 2J16, 2J19, 4J01, 4J03, 4J09 and 4J30 (Figure 3b). These rocks consist of jadeite and chromian jadeite (60–99%), omphacite (0–10%), clinoamphibole (10–40%), and accessory opaques and titanite (<1%). They looked quite variable in hand specimen, such as white with small green spots (4J09), dark green (2J16), and striped green and dark grey (1J11 and 1J12), which was due to the presence of chromian jadeite (bright green in 1J11), omphacite (4J30) or dark amphibole (4J03). In thin section, a distinct compositional banding of jadeite- and clinoamphibole-rich layers and lenses was visible. The main foliation, which was oriented parallel to this banding, experienced an intense micro-folding with partially isoclinal fold structures (Figure 5b). Polygonal arc structures of minerals in fold hinges point to pre-crystallization folding and mimetic crystallization (i.e. recrystallization that reproduces pre-existent textures; Spry, 1969; see also Hibbard, 1995, p. 297). There were a number of jadeitites that lacked chromian jadeite (e.g. 2J19, 4J01, 4J03, 4J09 and 4J30). According to our Raman investigation, the clinoamphiboles in these rocks consisted of sodic-calcic (richterite) and sodic (arfvedsonite) varieties.

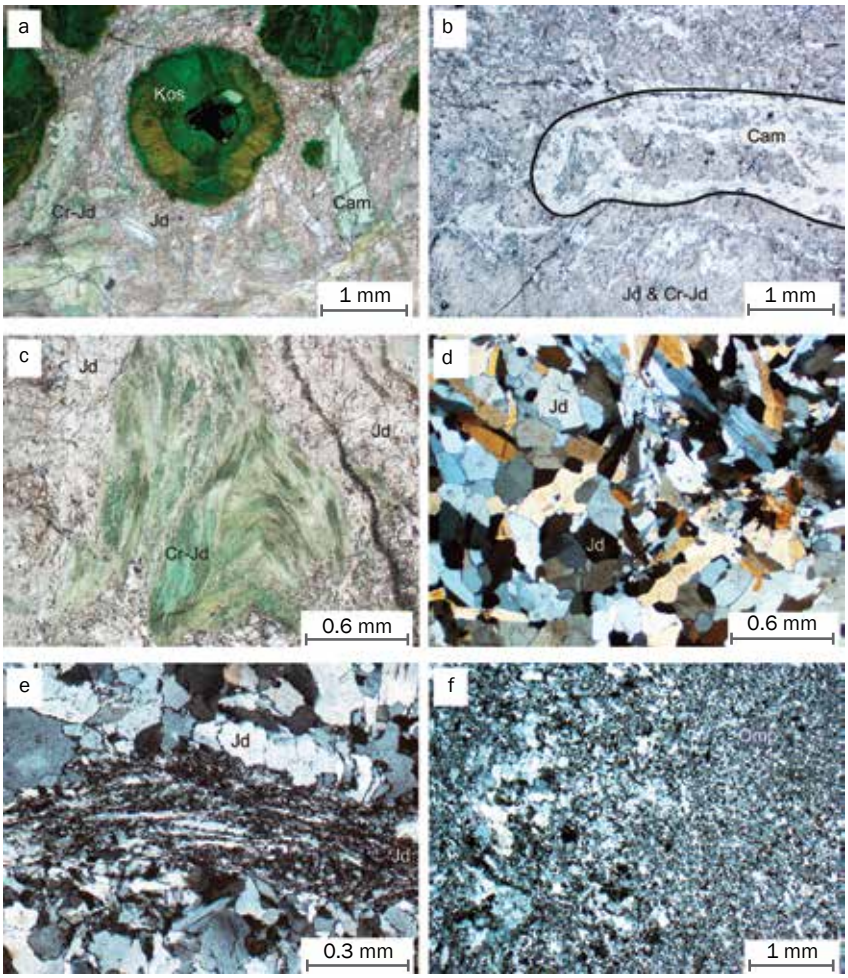

Figure 5: These photomicrographs show the texture and mineralogy of selected samples. (a) Dark green radiating aggregates of kosmochlor with chromite cores are surrounded by a matrix of jadeite, chromian jadeite and clinoamphibole in JKC-type sample 2J17. (b) An isoclinally folded layer of clinoamphibole (low-relief mineral Cam; folding is shown by the black line) is surrounded by jadeite and chromian jadeite in JC sample 1J12. (c) Green chromian jadeite prisms show intense micro-folding and are bordered by colourless jadeite in ABJ sample 2J18. (d) Jadeite prisms show a decussate texture in J sample 2J03. (e) An ultramylonitic shear zone with dynamically recrystallized jadeite grains (centre) cuts through randomly oriented, larger jadeite grains in J sample 4J13. (f) Patchy sections of larger omphacite grains are present in a fine-grained matrix of omphacite crystals in O sample J274. Photos a–c are in plane-polarized light, and d–f are in cross-polarized light. Photos by L. Franz.

Albite-bearing Jadeitites (with Chromian Jadeite or Omphacite; ABJ): Samples of this category (1J05, 2J18 and 4J27; Figure 3c) show wide petrographic variability. Sample 1J05, for example, consisted of almost pure jadeite (99%) with <1% albite and omphacite. Other samples showed darker green veins and irregular spots due to the presence of chromian jadeite (e.g. 2J18). Macroscopically, the albite-bearing jadeitites often resembled the darker samples from the second group, however they contain no amphibole. Thin-section examination showed a distinct compositional banding of medium-grained jadeite-rich layers alternating with fine-grained layers rich in chromian jadeite, with the latter displaying a distinct mineral alignment and local micro-folding (Figure 5c). The semi-polygonal arc structures in the fold hinges point to syn-crystallization folding according to Misch (1969). Accessory minerals were albite (forming angular inclusions in jadeite) and rare titanite. Secondary limonite was found as brownish staining at the rim and along fractures in the samples.

Jadeitites (without Chromian Jadeite; J): Fourteen samples (1J03, 1J06, 1J09, 1J13, 2J03, 2J07, 2J12, 4J04, 4J06, 4J10, 4J13, 4J21, 4J26 and 4J28; Figure 3d) consisting of pure and almost pure jadeitites (92–100%) are grouped into this category. Macroscopically, these rocks often appeared homogeneous with a broad range of colour, from yellowish white to distinctly green or brown. Besides jadeite, the samples contained minor amounts of omphacite (2J07 and 4J06), vesuvianite (4J04), amphibole (4J04; grunerite/cummingtonite according to Raman spectroscopy), analcime (4J06 and 4J13) and phlogopite (4J13). Accessory minerals were disordered graphite (identified by Raman spectroscopy in 4J10 and 4J13) occurring as tiny inclusions in jadeite and also rare titanite. Secondary minerals consisted of biotite and limonite present along the rim and in fractures of jadeite (1J03). Furthermore, tiny fibres with a low RI were zeolite (probably natrolite) that formed at the expense of analcime (4J06). Viewed with the microscope (e.g. Figure 5d), the jadeitite fabrics were rather variable, with most of them showing

a medium-grained decussate texture (i.e. the axes of contiguous jadeite crystals lie in diverse, crisscross directions without any alignment; Spry, 1969; see also Yardley et al., 1990, p. 89). Some of the rocks showed a fine-grained foliated texture with aligned jadeite prisms and micro-folds, while others contained shear bands made up of dynamically recrystallized jadeite neoblasts surrounding coarser-grained porphyroclastic rock fragments (Figure 5e).

Omphacitites (O): The omphacitites (J270–J274) in this study were easily distinguished from the jadeitites by their very dark green colour and almost opaque appearance (Figure 3e). Thin sections of two samples (J271 and J274) proved to be monomineralic omphacitite without any accessory minerals or secondary alteration. While sample J271 displayed a homogeneously fine-grained texture, sample J274 showed an inhomogeneous size distribution with patchy sections yielding larger, irregular omphacite crystals in a matrix of tiny omphacite prisms (Figure 5f).

Electron Microprobe Analysis

Chemical data for eight representative samples are plotted in jadeite-aegirine–quadrilateral pyroxene (Jd-Ae-Q) diagrams following Morimoto et al. (1988) and in a kosmochlor–(jadeite+aegirine)–quadrilateral pyroxene diagram to highlight the wide variability of the mineral composition within the rocks (Figure 6).

In all the investigated samples, jadeite and omphacite crystals revealed distinct chemical inhomogeneities due to zoning or variations from crystal to crystal, which are described in detail below. Selected microprobe analyses of clinopyroxenes are listed in Table I. The entire dataset is available via *The Journal*'s online data depository.

Jadeitites with Kosmochlor and Clinoamphibole: Clinopyroxenes from these rocks show obvious chemical variations, which is particularly evident for jadeite from sample 2J17. The BSE image (Figure 6a) shows distinct zoning with dark, Na-rich sections (cf. spot 3; $Jd_{90.6}Ae_{4.3}Q_{5.2}$), bright, Na-poor sections (cf. spot 2; $Jd_{74.3}Ae_{15.2}Q_{10.4}$) and intermediate sections (cf. spot 1; $Jd_{85.6}Ae_{8.9}Q_{5.4}$; see Table I). Such a pronounced mineral zoning in jadeitites from Myanmar was already described by Harlow and Olds (1987). Jadeite from sample 4J12 showed a compositional range of $Jd_{71.6–96.8}Ae_{8.6–0.1}Q_{19.8–3.1}$ while omphacite yielded a composition of $Jd_{34.9–50.8}Ae_{8.8–6.8}Q_{56.3–42.4}$ (plotted in Figure 6a).

When data for these two samples are plotted in Figure 6b, it becomes evident that Cr-bearing pyroxene in sample 4J12 is mainly chromian omphacite (represented in the diagram by the Jd+Ae apex), whereas sample 2J17 contains major amounts of both chromian jadeite and kosmochlor. The data reveal a distinct compositional gap between kosmochlor and chromian jadeite as well as between chromian jadeite and jadeite, which suggests a solvus between these phases similar to the jadeite-omphacite–Ca-Mg-Fe-pyroxene solvi (Davidson and Burton, 1987; Green et al., 2007). (A *solvus* separates a homogeneous solid solution from a field of several phases that may form by exsolution.) Electron microprobe analyses furthermore showed that the clinoamphibole in sample 2J17 is mainly katophorite and subordinately winchite according to the classification of Hawthorne et al. (2012).

Jadeitite with Clinoamphibole: Sample 4J30 contained jadeite with a compositional range of $Jd_{83.5–97.5}Ae_{2.3–0.2}Q_{14.2–2.3}$, including some crystals revealing a distinct decrease in Na from core to rim. Omphacite in this sample formed solitary grains in contact with clinoamphibole (katophorite and richterite) and showed an intense irregular zoning pattern. Its composition ranged from $Jd_{41.8–62.8}Ae_{8.4–4.2}Q_{49.8–33.0}$ (plotted in Figure 6c).

Albite-bearing Jadeitites: Sample 1J05 contained jadeite with patchy Na-rich and Na-poor sections showing a compositional variation of $Jd_{82.6–96.5}Ae_{4.4–0.2}Q_{13.0–3.3}$. Omphacite formed inhomogeneous rims on jadeite and showed a compositional range of $Jd_{40.3–55.8}Ae_{1.1–5.1}Q_{58.7–39.1}$ (plotted in Figure 6d). The albite in sample 1J05 was close to the end member ($Ab_{97.9-99.9}An_{0-2}Or_{0-0.1}$).

Jadeitites: Samples 4J06 and 4J26 contain clinopyroxenes that have a very similar composition to the foregoing samples, with jadeite ranging from $Jd_{83.0–98.0}Ae_{1.6–0}Q_{15.5–2.0}$ and omphacite varying from $Jd_{36.8–55.5}Ae_{6.5–1.7}Q_{56.7–42.7}$ (plotted in Figure 6e). Similar to the albite-bearing jadeitites,

a. Jadeitites with Kosmochlor and Clinoamphibole

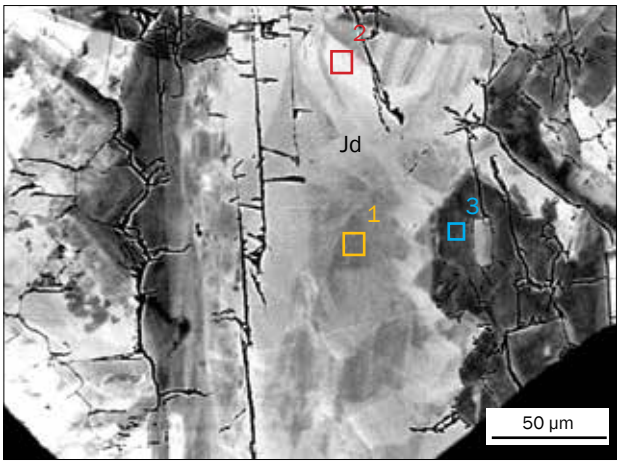

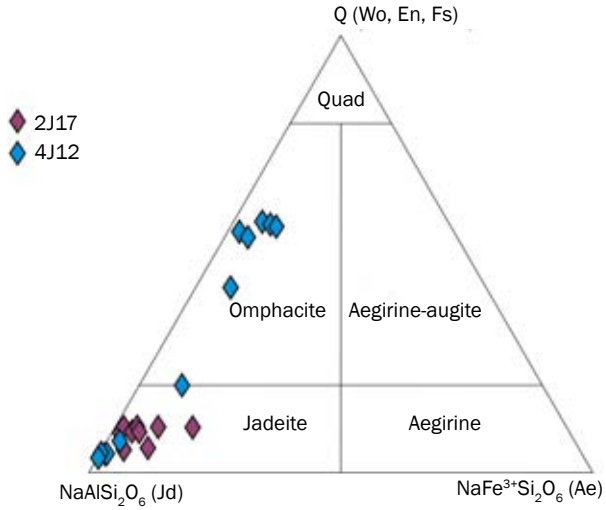

b. Jadeitites with Kosmochlor and Clinoamphibole

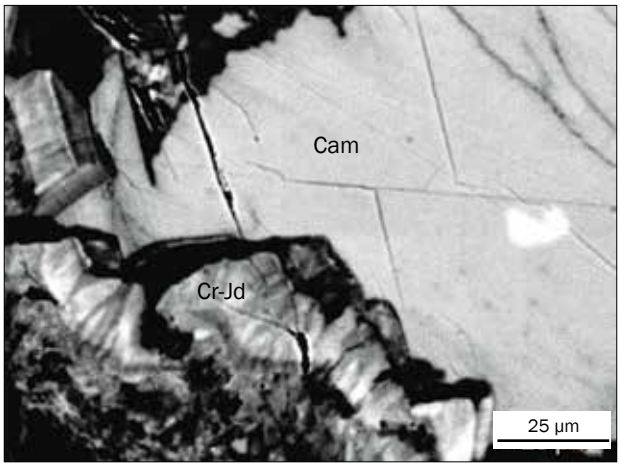

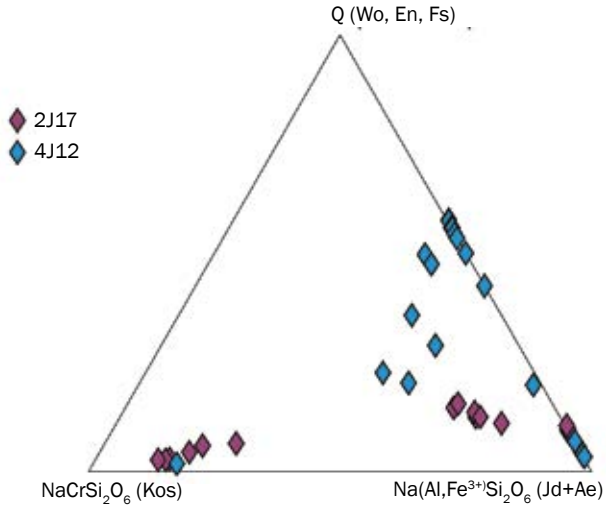

c. Jadeitites with Clinoamphibole

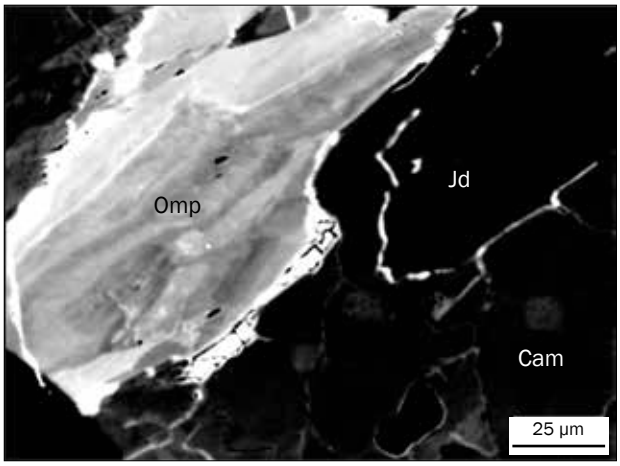

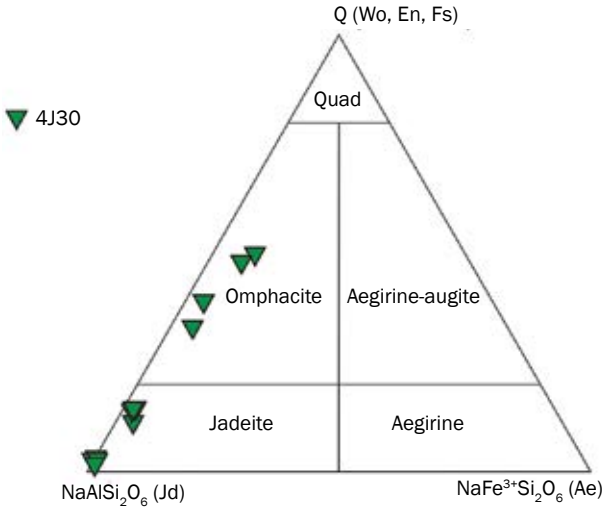

Figure 6: Electron microprobe data of pyroxenes are shown with BSE images of some of the corresponding areas that were analysed. The microprobe data are plotted in the Jd-Ae-Q diagram of Morimoto et al. (1988), except for Figure 6b which shows a Kos-(Jd+Ae)-Q diagram. The data for all samples demonstrate distinct compositional gaps between jadeite and omphacite, except for omphacitite sample (f) which does not contain any jadeite. BSE images: (a) JKC-type sample 2J17 shows distinct

d. Albite-bearing Jadeitites

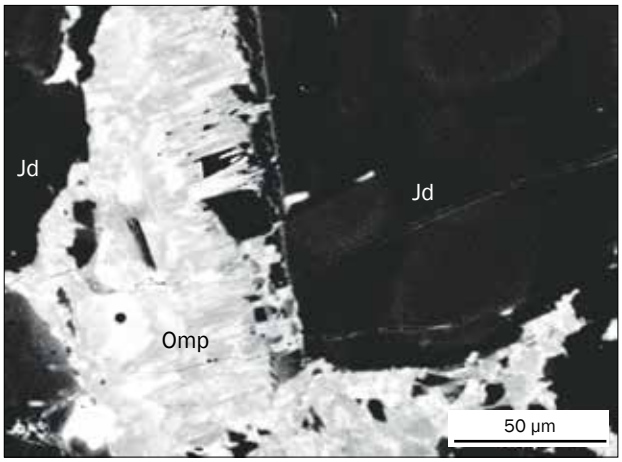

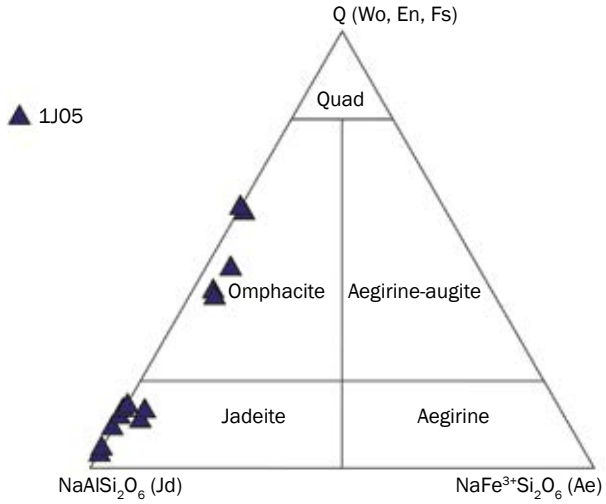

e. Jadeitites

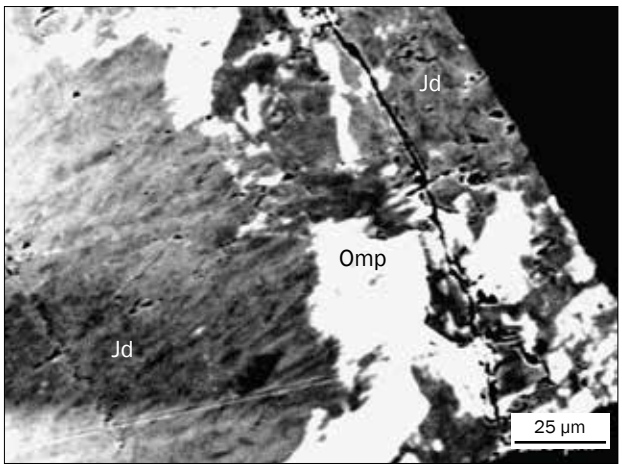

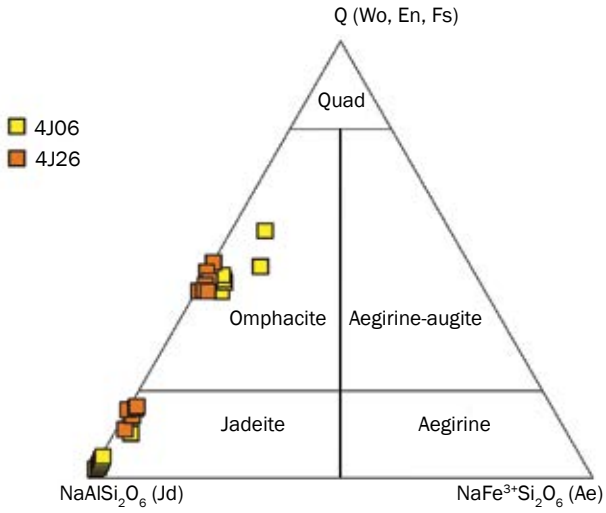

f. Omphacitites

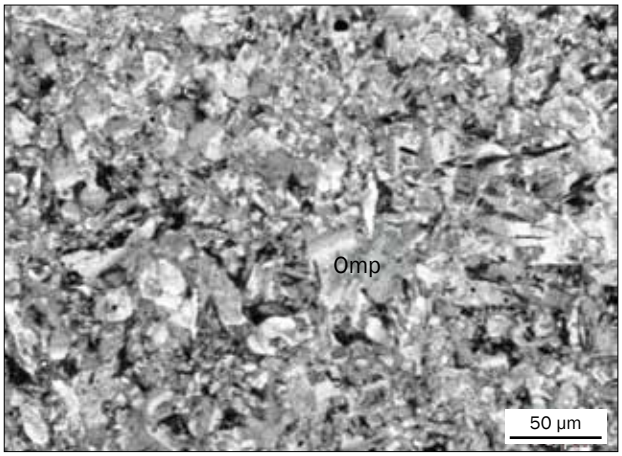

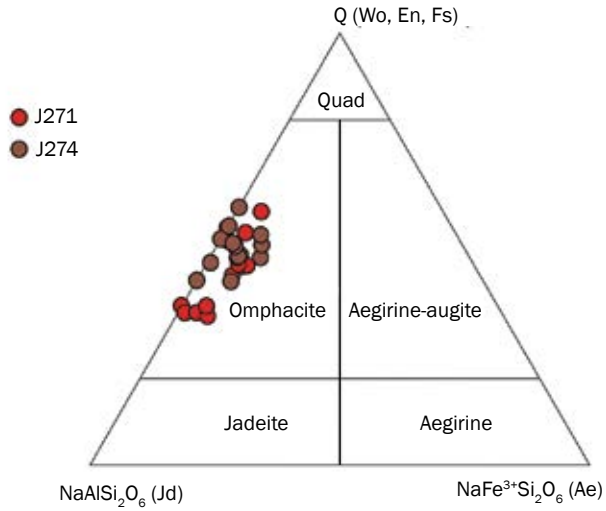

chemical zoning within a jadeite crystal. (b) This portion of sample 2J17 consists of a clinoamphibole crystal that is rimmed by chromian jadeite. (c) JC sample 4J30 shows an inhomogeneous omphacite next to jadeite and clinoamphibole crystals. (d) In ABJ sample 1J05, a jadeite crystal is rimmed by irregularly zoned omphacite. (e) J sample 4J26 displays a patchy replacement of jadeite by omphacite. (f) O sample J271 consists of an intergrowth of small omphacite crystals. Images by C. de Capitani.

*Table I: Selected microprobe analyses of clinopyroxenes from jadeitites with kosmochlor and clinoamphibole (JKC), jadeitites with clinoamphibole (JC), albite-bearing jadeitites (ABJ), jadeitites (J) and omphacitites (O).**

Sample No.	**2J17**						**4J12**		
Rock type	JKC						JKC		
Spot	F2 1	F2 2	F2 3	F2 K 1	F2 K 6	F2 K2 2	F3 1	F3 3	F1 1
Mineral	Jd			Kos		Cr-Jd	Cr-Omp	Omp	Jd
SiO_2	57.59	57.12	58.42	53.35	53.79	56.22	54.66	55.57	58.55
TiO_2	nd	0.07	nd	0.03	0.02	0.01	3.24	0.07	0.03
Al_2O_3	22.78	19.43	23.59	2.90	5.24	12.93	3.54	9.78	25.13
Cr_2O_3	0.02	nd	0.02	29.55	23.86	6.26	5.10	0.03	0.01
Fe_2O_3	3.56	5.96	1.70	nd	1.54	7.08	8.39	2.95	0.06
MgO	1.91	2.76	1.81	0.71	1.45	2.80	7.44	10.50	1.23
CaO	0.29	1.79	0.30	0.05	0.68	2.33	7.40	13.54	nd
MnO	nd	0.12	nd	0.03	nd	0.10	nd	0.23	0.01
FeO	nd	nd	nd	0.16	0.57	0.29	1.59	1.43	nd
Na_2O	14.20	13.35	14.33	13.21	13.01	12.70	9.48	6.21	14.99
Total	**100.35**	**100.60**	**100.17**	**99.99**	**100.15**	**100.72**	**100.84**	**100.31**	**100.01**
Cations (O=6)									
Si	1.959	1.964	1.976	1.988	1.981	1.984	1.981	1.967	1.973
Ti	nd	0.002	nd	0.001	0.001	nd	0.088	0.002	0.001
Al	0.913	0.787	0.940	0.127	0.227	0.538	0.151	0.408	0.998
Cr	0.001	nd	0.001	0.871	0.695	0.175	0.146	0.001	nd
Fe^{3+}	0.091	0.154	0.043	nd	0.043	0.188	0.229	0.079	0.001
Mg	0.097	0.141	0.091	0.039	0.080	0.147	0.402	0.554	0.062
Ca	0.011	0.066	0.011	0.002	0.027	0.088	0.287	0.514	nd
Mn	nd	0.003	nd	0.001	nd	0.003	nd	0.007	0.000
Fe^{2+}	nd	nd	nd	0.005	0.017	0.008	0.048	0.042	nd
Na	0.936	0.890	0.940	0.955	0.929	0.869	0.666	0.426	0.980
Total	**4.007**	**4.008**	**4.002**	**3.989**	**4.000**	**4.000**	**4.000**	**4.000**	**4.016**
End-members (mol%) after Morimoto et al. (1988)									
Jd	85.6	74.3	90.6	97.6	77.9	64.5	23.6	35.9	96.8
Ae	8.9	15.2	4.3	0	15.9	23.2	40.8	7.5	0.1
Q	5.4	10.4	5.2	2.4	6.2	12.3	35.6	56.6	3.1

* Ferric iron is calculated according to Droop (1987). Potassium was analysed for, but not detected in any of these samples.
Abbreviation: nd = not detected.

omphacite formed rims around jadeite but also appeared as relatively homogeneous crystals in sheared zones. A distinct compositional gap exists between jadeite and omphacite (e.g. Figure 6e; see also Green et al., 2007), which has been observed in other jadeitites but curiously not mentioned in the literature for those from Myanmar.

Omphacitites: The fine-grained omphacitites show a decussate intergrowth of omphacite crystals with distinctly variable composition. The BSE image of sample J271 (Figure 6f) shows an aggregate of bright, Na-poor and darker, Na-rich omphacite crystals. Similar mineral intergrowth phenomena were observed in sample J274. The composition of omphacite in these rocks ranged from $Jd_{36.4–63.6}Ae_{4.9–0}Q_{58.7–36.4}$ (plotted in Figure 6f).

Raman Spectroscopy

With this method a reasonably good identification of the different pyroxenes was possible. Jadeite shows a prominent band at 700 cm^{-1}, with weaker bands at 1039, 991, 575, 524, 374 and 203 cm^{-1} (Figure 7a). In contrast, omphacite shows a main band at 684 cm^{-1}, and weaker

4J30		1J05		4J06		4J26		J271		J274	
JC		ABJ		J		J		O		O	
F1 1	F3 3	F2 7	F1 9	F2 7	F2 1	F1 4	F1 8	F3 xt 4	F1 4	F2 4	F3 1
Jd	Omp	Jd	Omp	Jd	Omp	Jd	Omp	Omp		Omp	
59.05	57.30	58.65	56.57	58.70	56.82	57.87	57.27	56.35	55.44	56.16	56.98
0.02	0.05	nd	0.05	0.01	0.29	0.09	0.13	0.16	0.05	0.15	0.15
25.03	16.24	25.24	15.19	24.77	13.04	21.94	14.16	15.71	10.27	10.21	14.77
nd	0.03	nd	0.02	0.01	0.01	nd	0.01	nd	0.01	0.02	nd
0.07	1.67	0.09	2.03	0.24	1.15	0.62	0.67	1.94	1.89	2.91	nd
0.91	7.20	1.29	8.27	1.58	9.35	3.89	9.22	7.81	12.41	10.47	8.54
nd	7.69	nd	9.16	0.20	10.94	2.96	9.88	8.61	13.93	12.43	9.52
nd	0.04	nd	0.01	0.02	0.01	0.05	nd	0.14	0.13	nd	nd
nd	nd	nd	nd	nd	0.56	nd	0.25	nd	nd	1.13	1.58
14.92	9.95	14.74	8.89	14.49	7.97	12.64	8.48	9.45	6.06	6.81	8.45
100.00	**100.17**	**100.01**	**100.19**	**100.02**	**100.14**	**100.06**	**100.07**	**100.17**	**100.19**	**100.29**	**99.99**
1.987	1.976	1.974	1.960	1.977	1.979	1.966	1.983	1.954	1.949	1.978	1.979
0.001	0.001	nd	0.001	0.000	0.008	0.002	0.003	0.004	0.001	0.004	0.004
0.993	0.660	1.001	0.620	0.983	0.535	0.878	0.578	0.642	0.426	0.424	0.605
nd	0.001	nd	0.001	0.000	0.000	nd	0.000	nd	0.000	0.001	nd
0.002	0.043	0.002	0.053	0.006	0.030	0.016	0.017	0.051	0.050	0.077	nd
0.046	0.370	0.065	0.427	0.079	0.485	0.197	0.476	0.404	0.650	0.550	0.442
nd	0.284	nd	0.340	0.007	0.408	0.108	0.367	0.320	0.525	0.469	0.354
nd	0.001	nd	0.000	0.001	0.000	0.001	nd	0.004	0.004	nd	nd
nd	0.000	nd	nd	nd	0.016	nd	0.007	nd	nd	0.033	0.046
0.974	0.665	0.962	0.597	0.946	0.538	0.832	0.569	0.635	0.413	0.465	0.569
4.002	**4.003**	**4.005**	**4.000**	**4.001**	**4.000**	**4.001**	**4.001**	**4.013**	**4.018**	**4.000**	**3.999**
97.5	62.8	96.5	55.8	95.0	51.2	83.0	55.5	58.7	36.4	39.4	57.5
0.2	4.3	0.2	5.1	0.6	3.0	1.6	1.7	5.0	4.9	7.6	0
2.3	33.0	3.3	39.1	4.4	45.8	15.5	42.7	36.3	58.7	53.1	42.5

bands at 1016, 567, 382, 144 and 76 cm^{-1} (Figure 7b). Chromian jadeite has its maximum band at 364 cm^{-1} and two prominent bands at 1025 and 685 cm^{-1} (Figure 7c). Kosmochlor shows a main band at 418 cm^{-1} and four characteristic bands between 1058 and 951 cm^{-1} (Figure 7d). Although the Senterra Raman spectrometer was not equipped with a depolarizer, crystal orientation had only a small effect on the intensity of these bands and almost no effect on their position, according to our measurements taken with the beam parallel to the a-, b- and c-axes of the crystals.

Many of the jadeite crystals in the investigated samples had dark, elongate inclusions in their core that were identified as graphite by Raman spectroscopy.

Infrared Spectroscopy

Figure 8 shows the FTIR spectra of jadeite, omphacite, chromian jadeite and kosmochlor, which can be distinguished easily by the relative height of their prominent absorption bands at 689–665 cm^{-1} and 643–623 cm^{-1}. The jadeite spectrum (Figure 8a) shows a distinctly greater absorbance at 643 cm^{-1} than at 689 cm^{-1}, which is the opposite for

omphacite (Figure 8b). Here, the band at 629 cm^{-1} shows a weaker absorbance than the one at 665 cm^{-1}. For chromian jadeite (Figure 8c) the bands at 671 and 631 cm^{-1} show almost identical absorption, while kosmochlor (Figure 8d) reveals a pronounced absorption at 671 cm^{-1} and a distinctly smaller absorption at 623 cm^{-1}. These results could also be reproduced for the four additional cabochons from author HAH's collection.

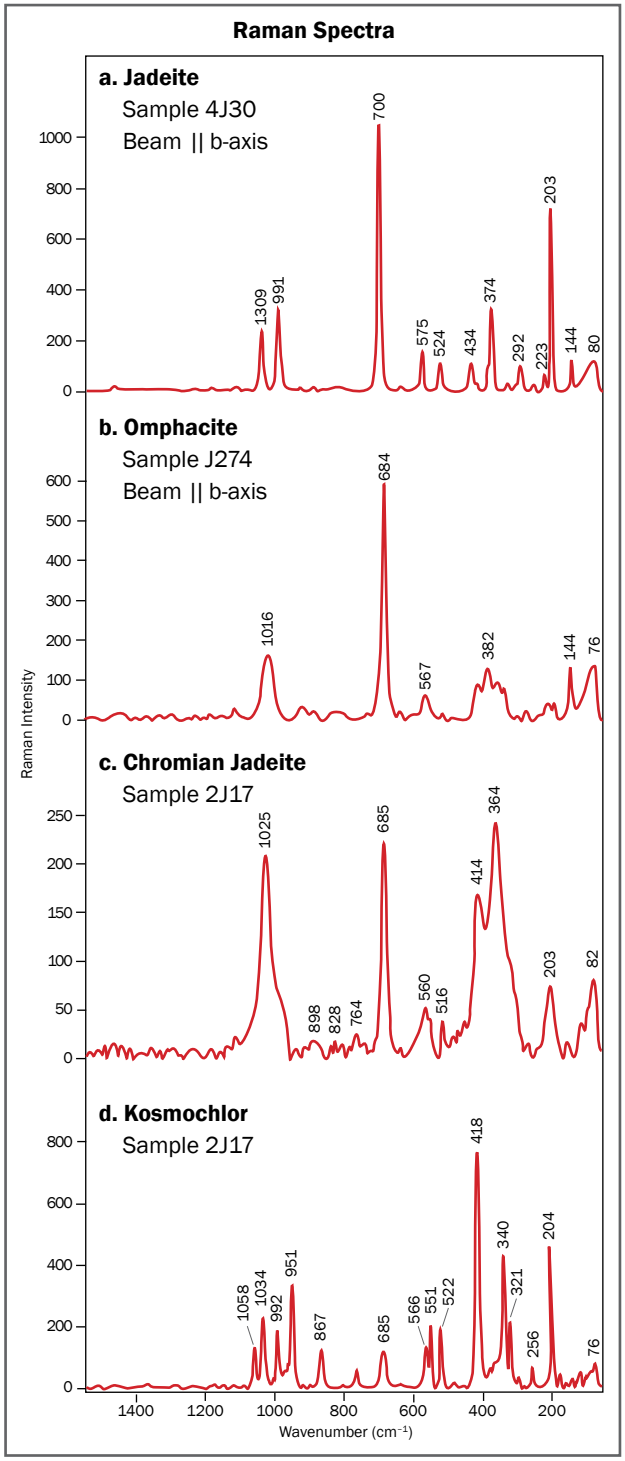

Figure 7: Raman spectra of selected minerals are shown for: (a) jadeite, (b) omphacite, (c) chromian jadeite and (d) kosmochlor.

Discussion

Pyroxene Mineralogy and the Genesis of Burmese Jadeite-bearing Rocks

Ideally, the composition of jadeite should not depart greatly from $NaAlSi_2O_6$. In most natural jadeite, at least 80% of the pyroxene's M1 site is occupied by Al, and at least 80% of the M2 site is taken by Na (Deer et al., 1997). Omphacite, on the other hand, is chemically much more complex. It is essentially a solid solution of jadeite and diopside with some aegirine. Omphacite is simplistically defined as $Jd_{50}(Di+Hd)_{50}$, but may show a considerable range of jadeite, diopside and hedenbergite, and may also contain aegerine and kosmochlor components (see Morimoto et al., 1988; García-Casco et al., 2009). Following the classification of Morimoto et al. (1988; see Figure 6), the compositional ranges

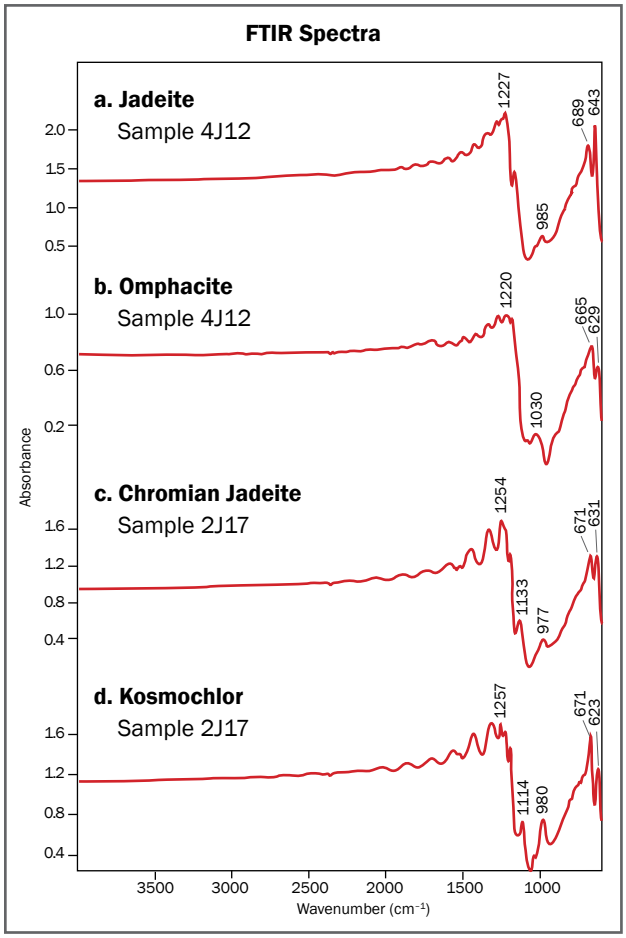

Figure 8: Representative FTIR spectra are shown for: (a) jadeite, (b) omphacite, (c) chromian jadeite and (d) kosmochlor.

of the quadrilateral (Ca-Mg-Fe) pyroxene, the Na-Al pyroxene (jadeite), and the Na-Fe^{3+} pyroxene (aegirine) are as follows: Omphacite lies within the area defined by $0.2 \leq Na/(Na+Ca) \leq 0.8$, and $Al/(Al+Fe^{3+}) \geq 0.5$, while jadeite lies in the field defined by $Na/(Na+Ca) \geq 0.8$ and $Al/(Al+Fe^{3+}) \geq 0.5$. If we follow this mineralogical classification strictly, a sample should not be called *jadeite* if it contains less than 80% Al as compared to $Mg+Fe^{2+}$, less than 50% Al as compared to Fe^{3+}, and less than 80% Na as compared to Ca. Furthermore, two temperature-dependent miscibility gaps between jadeite and Ca-Mg-Fe pyroxene have been described by several investigators (Davidson and Burton, 1987; Green et al., 2007; García-Casco et al., 2009; Harlow et al., 2011). At temperatures of 400°C, for example, they lie roughly between Na/(Na+Ca) ratios of 0.5–0.95 and between 0.2 and 0.4. This is also clearly visible in the ternary plots of Figure 6.

Apart from the chemical, and hence mineralogical, differences between omphacite and jadeite, there are also differences in the crystal structures of the two minerals, due to the differences in pressure and temperature of their formation. Although both minerals are clinopyroxenes crystallized in the monoclinic system, jadeite belongs only to one space group (C2/c), while omphacite has three polymorphs with symmetry C2/c, P2/n and P2 (Gaines et al., 1997). The crystallographic differences between jadeite and omphacite justify using separate terms (*jadeite jade* and *omphacite jade*) for referring to rocks composed predominantly of each mineral (see also Ou Yang et al., 2011).

The investigation of thin sections for this study has revealed the following facts: Several samples showed indications of pre- and syn-crystallization folding (i.e. polygonal arc textures, mineral alignment and micro-folds). Other samples had randomly oriented, decussate textures and lacked any tectonic overprint. Coarse-grained jadeitites with recrystallized textures (as described by Shi et al., 2009) were not observed in this study, which may be due to our randomly acquired samples. While the omphacitites often showed a monomineralic composition, the jadeitites mostly displayed complex mineral associations that usually included sodic and sodic-calcic amphiboles (e.g. arfvedsonite, richterite and katophorite). In some samples, both jadeite and omphacite were present; in many cases (e.g. samples 4J12 and 1J05), the jadeite appears to be the older phase, because it was rimmed by omphacite. In some samples (e.g. 4J39), the presence of omphacite next to clinoamphibole (richterite) created macroscopically clearly visible, millimetre-sized green spots in a white matrix consisting of jadeite. Omphacite also occurred as prismatic crystals in foliated layers, in shear bands and in fractures, which points to late metasomatic processes (addition of Ca) along the foliation and shear zones. A compelling feature of most of the investigated rocks was the marked chemical zonation of jadeite and omphacite, indicating rapid growth of these minerals at relatively low temperatures (cf. Shi et al., 2003; 2005b; 2012; Oberhänsli et al., 2007). According to Harlow et al. (2014), jadeitite in Myanmar occurs along the intersection of the Burmese Western and Eastern provinces along an offset of the Sagaing Fault. The primary occurrences of jadeitite consist of dykes or veins within serpentinites, which formed by crystallization from fluids during high-pressure metamorphism (Harlow and Sorensen, 2005; Shi et al., 2005b; Yi et al., 2006; Nyunt, 2009). Investigations of Goffé et al. (2000) on jadeitites from northern Myanmar point to subduction-related metamorphic conditions of approximately 400°C at 1.5 GPa. Due to these relatively low temperatures and the short time of the metamorphic overprint during the subduction process, mineral homogenization by diffusion was not possible.

Gemmological Identification of Burmese Jadeite-bearing Rocks

The identification of these Burmese rocks simply by their appearance is problematic. Omphacitite tends to be darker in appearance than jadeitite, although some jadeitite can be dark (as seen in Figure 9 and noted in Harlow et al., 2014) and omphacite jade also may have a lighter tone resembling jadeite jade (McClure, 2012). However, compared to jadeitite, omphacitite typically appears less transparent when viewed with transmitted light and tends to be greyish green.

A short summary of the gemmological properties of jadeite, omphacite and kosmochlor jades is given in Table II. Our findings confirm that it is sometimes possible to separate jadeite-from omphacite-dominant rocks using basic

Figure 9: The translucent medium-dark green carvings in this diamond necklace are jadeite jade (spot RI readings of 1.65–1.66), while those in the earrings had a higher RI of 1.67. This, combined with their slightly darker appearance, suggests the presence of an omphacite component. All of the carvings are 2–3 mm thick, and the largest ones measure 2.7 cm long. Photo by Tay Thye Sun.

gemmological properties such as RI, SG and the 437 nm absorption line. However, the samples analysed in this study reveal that Burmese jadeitites are not so pure after all, as they contain various modal proportions of clinoamphibole, kosmochlor, omphacite and other minerals. Our investigations show some similarities to the grouping by Htein and Naing (1994), who describe monomineralic (pure) and polymineralic (impure) jade, although some additional accessory minerals such as rutile and ilmenorutile were found by those authors (see also Htein and Naing, 1995). Predominantly monomineralic samples can be inhomogeneous due to solid solution and solvi, as well as chemical zoning. While some high-quality jadeitites are homogeneous and monomineralic, a large number of greyish, greenish and dark stones sold as jadeite jade have a complex polymineralic composition. Our studies reveal that in other than pure jadeitite, clinoamphibole or omphacite also contribute to variable RI and SG. Therefore, the use of RI spot readings and SG values does not lead to a rigorous identification. This is particularly true for the SG of jadeitite samples containing abundant clinoamphibole (e.g. 1J02 and 1J04), which had much lower values of 3.16 and 3.25, respectively. However, the RI values of both these samples were still within the typical jadeite jade range of 1.65–1.66. Nevertheless, the 437 nm absorption line was not detected, in contrast to pure jadeitite.

Among the more advanced methods available in a well-equipped gemmological laboratory, Raman micro-spectroscopy is the best technique for jade identification. With an appropriate database it is possible to non-destructively analyse spot-by-spot the composition of a rock being tested. In addition, micro-FTIR spectroscopy can provide a good distinction between jadeite, chromian jadeite, omphacite and kosmochlor. A high-resolution analytical apparatus like the Bruker Lumos micro-FTIR spectrometer should be used. Our FTIR

*Table II: Gemmological properties of jadeite, omphacite and kosmochlor jades from Myanmar.**

	Jadeite jade	Omphacite jade	Kosmochlor jade
Colour	Colourless, white, lavender, brown, yellow, green and dark green	Dark green to black	Green to black; uneven
Transparency	Transparent to opaque	Translucent to opaque	Opaque
RI	1.65–1.67	1.66–1.68	1.68–1.75
SG	3.25–3.40	3.30–3.45	3.35–3.50
Magnification	Fine-to-coarse grained, granular to fibrous texture	Fine grained, fibrous texture	Fibrous and radiating aggregates
Absorption spectrum	437 nm line; chromian jadeite shows lines at 630, 655 and 690 nm	No 437 nm line or Cr^{3+} absorption	None observed

* Data from this study, Webster (1995), and www.gahk.org/attachment/fcteststd2.pdf.

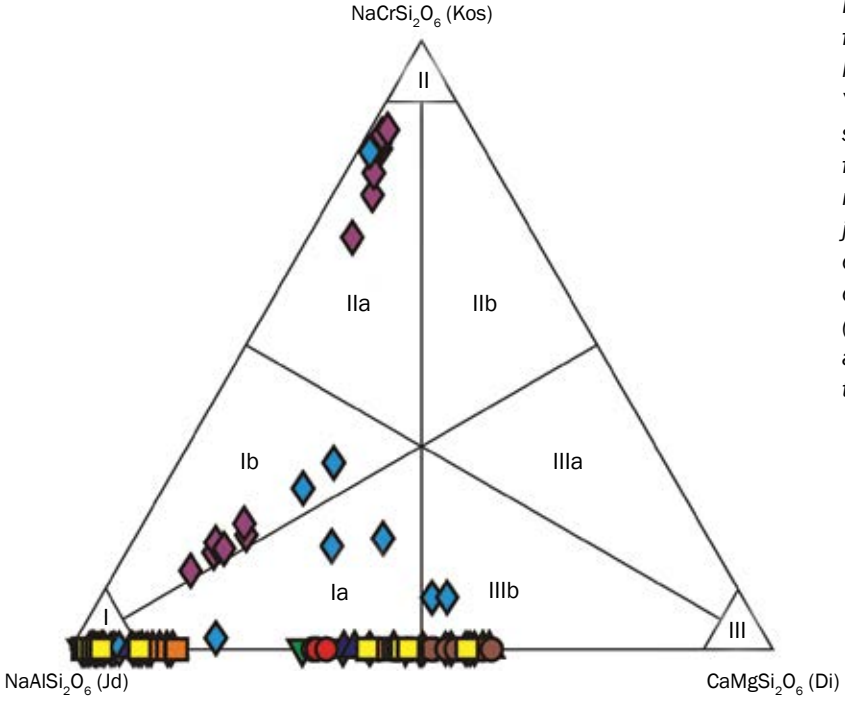

Figure 10: Electron microprobe analyses from this study are plotted in the kosmochlor-jadeite-diopside diagram of Ou Yang and Ng (2012). In the classification scheme proposed by those authors, the fields define pure jadeite (I), jadeite with minor omphacite (Ia), chromium-containing jadeite (Ib), pure kosmochlor (II), jadeite-containing kosmochlor (IIa), diopside-containing kosmochlor (IIb), pure diopside (III), kosmochlor-containing diopside (IIIa) and jadeite-containing diopside (IIIb). For the key to symbols, see Figure 6.

spectra gave equally satisfactory identifications as Raman spectroscopy and the electron microprobe. With these micro-analytical methods, tiny grains down to 1 µm (Raman) or 5 µm (FTIR) can be investigated. Raman or FTIR spectroscopy of larger analytical areas may yield mixed spectra that are not useful for identification, especially for samples that were not previously investigated microscopically and with microprobe analysis.

Current Classification/Nomenclature and Proposal for a New System

As a consequence of the results of this study, the present terminology of jadeitic gem materials should be seriously reconsidered. Such rigid schemes as the ternary jadeite–diopside–kosmochlor diagram of Ou Yang and Ng (2012) may be applied to monomineralic samples with a homogeneous mineral composition, but they are not appropriate for polymineralic samples. This becomes evident from Figure 10, in which we have plotted our microprobe analyses using the classification diagram of Ou Yang and Ng (2012). Jadeitites with kosmochlor fall into a large area ranging from the jadeite field (I) to the jadeite-containing kosmochlor field (IIa), while jadeitites, albite-bearing jadeitites and jadeitites with clinoamphibole plot in the fields for pure jadeite (I), jadeite with minor omphacite (Ia) and jadeite-containing diopside (IIIb). Due to their mineral chemical variability, even the monomineralic omphacitites cover a broad field from jadeite-containing diopside (IIIb) to jadeite with minor omphacite (Ia). Furthermore, the scheme does not consider minerals like clinoamphibole, albite or phlogopite, which are common constituents of the jade rocks.

Similarly, Hänni (2007) started from the assumption of a monomineralic composition, which may be true for some pure-appearing green jadeitites (e.g. Figure 11). However, as demonstrated in this investigation, many jadeitites and kosmochlor-bearing jadeitites from Myanmar are polymineralic and extremely inhomogeneous due to their textures and complex mineral zonation patterns. Furthermore, such observations have also been made for jadeitites from Kenterlau-Itmurundy (Lake Balkhash, Kazakhstan; Ernst et al., 2013) and a number of other locations (for an overview, see Harlow et al., 2014). In many cases, the rocks display strong compositional variability with complex mineral intergrowths of micrometre size. Common gemmological methods of investigation like RI, SG and energy-dispersive X-ray fluorescence spectroscopy (EDXRF) are not applicable to such small-scale structures. The rigorous identification of all the phases present is only possible using polarization microscopy of

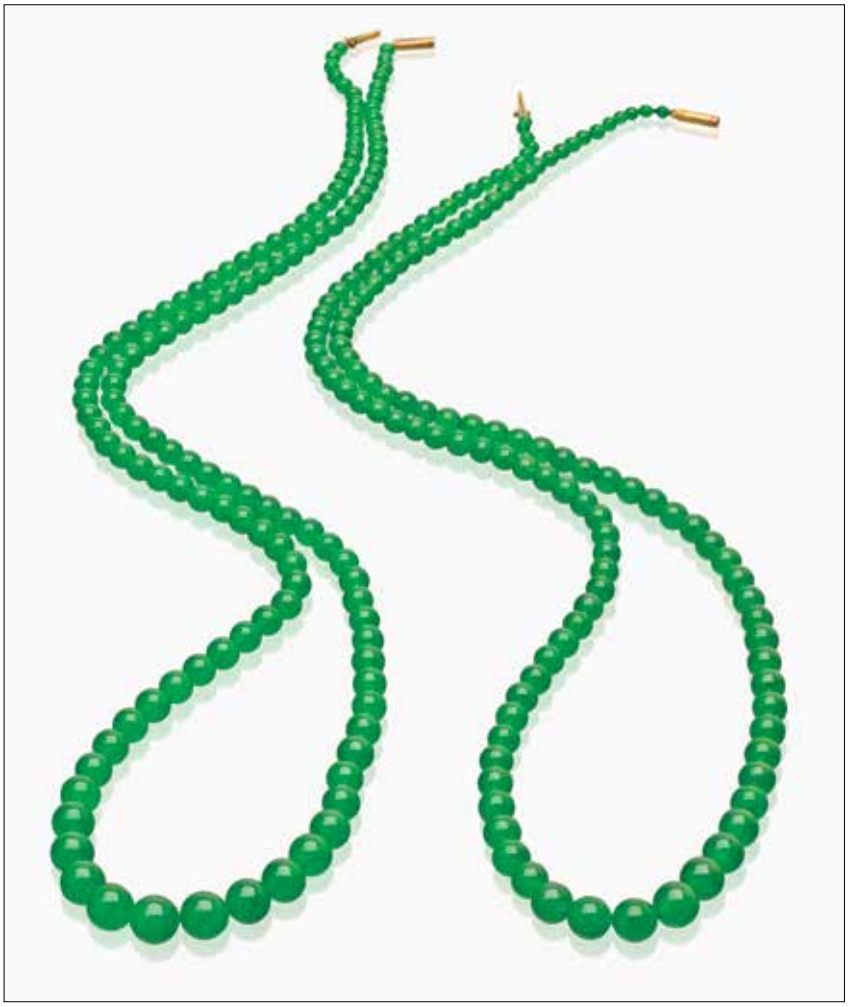

Figure 11: The pure, translucent appearance and high quality of the beads in these necklaces suggests that they consist only of jadeite with little or no impurities. Each of the necklaces is composed of 127 Imperial jadeite beads in graduated sizes ranging from 3.45 to 10.15 mm in diameter. They are approximately 75.5 and 79.5 cm long, and sold for HK$42,680,000 at the Sotheby's Hong Kong auction in October 2013. Photo by Luc Phan, © Swiss Gemmological Institute SSEF.

thin sections and electron microprobe analysis, which is unfeasible for gem samples.

An appropriate non-destructive approach used by gemmological laboratories should employ Raman or FTIR analysis to assess the composition of jadeite-bearing rocks and identify them correctly. As an example, we suggest that 20 spots on the surface of a medium-grained sample should be analysed. (The total number of analysed points should, of course, depend on the texture and grain size of the sample, with more points necessary for heterogeneous and finer-grained samples and fewer points needed for coarse-grained specimens.) When the same result is obtained for 15 of these spots (75%), this should be used to name the sample. Therefore, if 15 out of 20 analysed points were jadeite and the remaining spots were kosmochlor or omphacite, the rock should be called kosmochlor-jadeite jade or omphacite-jadeite jade, respectively. We propose that *jade* should be used as part of the name, as this word has traditionally been used for the classification of such polymineralic rocks.

The International Mineralogical Association (IMA) has already established a nomenclature framework that has been useful for mineralogists worldwide since 1988, and jadeite, kosmochlor and omphacite are all mineral names that are accepted by the IMA. According to the nomenclature given by CIBJO, we suggest using the terms *jadeite jade, kosmochlor jade* and *omphacite jade* to describe gems that consist predominantly of these constituents. As described above, we propose analysing a grid on a sample, with the most abundant mineral used to determine the name. This method would provide a simple and helpful tool for jade dealers and gemmologists who have some basic training to understand the complexity of jade classification. It is hoped that such a practical classification will be widely accepted, thus making the trading of jade easier.

Fei Cui *and Jade Terminology*

The use of the term *fei cui* by the Hong Kong government to refer to a granular to fibrous polycrystalline aggregate composed of jadeite, omphacite and/or kosmochlor is in accordance with Chinese tradition. However, we feel that the terms *jadeite jade, kosmochlor jade* and *omphacite jade* are more in-line with the mineralogical and scientific nomenclature of jade identification. Nevertheless, the term *fei cui* can be added as an optional modifier. In such a case, an example of this terminology would be 'jadeite jade *(fei cui)*'—rather than the wording '*fei cui* (jadeite jade)' that is currently used in Hong Kong. In English, the latter format could imply that all *fei cui* is jadeite jade, which would be misleading.

Conclusion

This study shows a wide diversity in the jadeite-bearing rocks from Myanmar that are used for decorative and jewellery purposes. Petrographic and micro-chemical studies reveal that these rocks exhibit extensive chemical and textural inhomogeneities, which render a classification by common gemmological methods rather difficult. With the help of thin-section investigations in combination with electron microprobe analysis, five different groups of jadeitite and omphacitite rocks were recognized. These rocks display a wide range of mineral content and rock fabric, resulting in quite a variable macroscopic and microscopic appearance.

With the recognition of this diversity, and with more advanced instrumentation available in gemmological laboratories, there is a call for revising the former jade nomenclature. We propose analysing a sample using Raman or FTIR spectroscopy on a point grid, with the most abundant mineral giving the name (i.e. *jadeite jade, omphacite jade* or *kosmochlor jade*).

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The Discoverer of Tsavorite—Campbell Bridges—and His Scorpion Mine

Bruce Bridges and Jim Walker

Geologist Campbell Bridges was the first to discover gem-quality green grossular in Tanzania in 1967 and in Kenya in 1970. In 1973, Campbell collaborated with Tiffany & Co. in New York, USA, to develop a trade name for this garnet, which they called *tsavorite*—in reference to the nearby Tsavo National Park in Kenya. In 1980, the Scorpion mine, located in the Taita-Taveta District of south-east Kenya, was developed by Campbell and his team into the world's most important consistent and long-term producer of tsavorite. Operations at this mine continued until the tragic murder of Campbell in 2009. His death has had a profound effect on tsavorite production in the region, and activities at all of the Bridges' mining operations have been suspended until a protracted court case is resolved for prosecuting the accused murderers. This article describes the history of the Scorpion mine and the unique geology of the deposit that makes it so productive. Also discussed is the planned reopening of the mine in the near future.

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Introduction

Campbell Bridges (1937–2009; Figure 1) was a visionary geologist, miner, and entrepreneur, who lived and worked in Tanzania and Kenya for over 40 years. His mother was of Scottish descent and his English father was a geologist who lived and worked in Africa since before Campbell's birth. Campbell grew up in southern Africa and moved to East Africa in the mid-1960s, shortly before discovering important deposits of the green grossular (coloured by V ± Cr) that became known as *tsavorite* (e.g., Figures 2 and 3). Many in the gem and jewellery industry consider tsavorite to be the finest green gemstone that is commercially available in the marketplace.

Campbell and his team consistently produced commercial quantities of tsavorite from his Scorpion mine for nearly 30 years. Then, on 11 August 2009, Campbell, his son Bruce (author BB) and four of Bridges' employees were ambushed on their own mining concession by a group of 35 assailants. Tragically, Campbell was murdered in the premeditated attack. Bruce and his employees fought back with such force and determination that they drove off the attackers—despite sustaining severe injuries—and due to their resolve they prevented the attackers from desecrating Campbell where he had fallen. International media coverage was extensive, and news of the murder spread rapidly throughout the

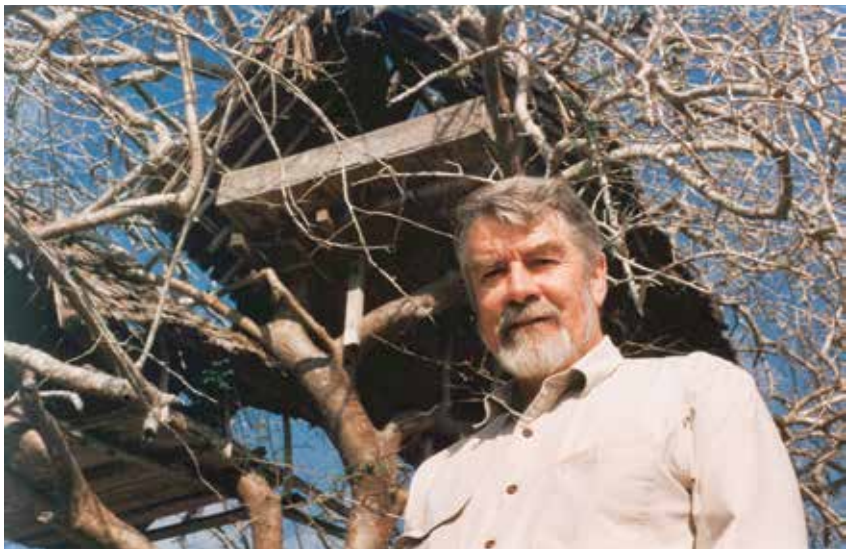

Figure 1: Campbell Bridges stands in front of his first tree house, where he and his wife Judith lived for several years during the period when he discovered and initially mined tsavorite in Kenya. Photo by Judith Bridges, 1993.

gem industry. The Bridges have been inundated with emails of condolence and outrage from over 40 different countries. The international gem community continues to show solidarity and support (e.g. www.thepetitionsite.com/130/justice-for-campbell-bridges), which has been most comforting and humbling to Campbell's family.

In this article, we examine the importance of the Scorpion mine as an historical source of tsavorite. We also look at the impact of Campbell's death on overall tsavorite production from Kenya, and discuss plans for the re-opening of the Scorpion mine, which has the potential to once again become the world's leading source of tsavorite.

Brief History of the Discovery and Naming of Tsavorite

The story of tsavorite's discovery and naming is best described in Campbell's own words, in the following excerpt from an interview with author BB:

> I initially discovered tsavorite in 1961 in Zimbabwe (then Rhodesia) while working for the United Kingdom Atomic Energy Authority. We were locating and assessing beryl deposits, as beryllium was thought at the time to be the best metal for lining atomic reactors. A geological map showed that a range of hills near my camp contained an interesting combination of different rock types

Figure 2: This platinum ring contains a 3.28 ct antique cushion tsavorite from the Scorpion mine surrounded by 0.52 carats of diamonds. The band is set with 1.16 carats of tsavorite. Named 'Eternity', the ring is part of the Bridges Collection jewellery line. Photo by B. Bridges.

Figure 3: These fine-quality tsavorites from the Komolo and Scorpion mines weigh 5.22–12.46 ct. Photo by B. Bridges.

that could well have resulted in the formation of gemstone or other mineral deposits. So one Sunday, when I was off duty, I set out to explore an area near the top of these hills. As I was making my way up the edge of a steep gully, an old rogue buffalo charged out of the bush at me. I jumped down into the gully. The buffalo followed me in a menacing manner along the edge of the ravine for a while, then gave up and went off into the bush. I continued upward, inspecting the rock exposures in the bottom and sides of the gully. Where it neared the top of the hill, I found an outcrop that contained small bright green crystals. This was my first encounter with green garnet.

My second discovery of green grossularite garnet occurred in northern Tanzania in 1967. It occurred in a small hidden valley in a low range of hills just over 100 km south-west of Mt. Kilimanjaro, about 13 km south-east of the village of Komolo. Between Komolo and these hills lies a belt infested with tsetse fly. Sansivera (wild elephant sisal) was abundant in this valley, and because of this ready food supply, a large rhinoceros had made this area his home. The following morning after we had dug a new pit in our search for the green gem, we would find the rhino's tracks firmly implanted in the soil on the edge of the pit. For this reason he came to be known as 'The Mining Inspector' and a sharp eye was always kept out for him as we walked along the narrow trails through the sword-tipped elephant sisal.

A characteristic inclusion of the green garnet from this area was open capillary tubes (sometimes containing gypsum) and when abundant, they resembled a bank of reeds within the body of the stone.

Subsequently, this deposit yielded for a short time some of the largest tsavorites ever found, including one beauty weighing just under 35 ct. But that was long after I had lost the mine due to nationalization by the Tanzanian government and moved to Kenya. The colour of the grossular at this location ranged from pale to a fine rich 'grass'-green.

Toward the end of 1970, I had located a small range of grey, humpbacked hills in southeast Kenya, 135 km south-east of Mt. Kilimanjaro, not unlike the hills of Komolo in appearance. More important, these hills formed part of a belt of similar rock types to those in which the green garnet of Tanzania occurred. Before the end of 1970 I had found my first Kenyan green garnet in these hills, and in 1971 I pegged the first blocks of mineral claims. The area was uninhabited and comprised Hunting Block No. 64. Lying close to the border with Tsavo National Park, elephant, lion and other wild game were abundant. To keep cool during the scorching days of the hot summer months, we constructed a sturdy tree-house in a large gamble flam tree on the side of a hill with a magnificent panoramic view out over the plains to the east. At various times, the flam tree would blossom and surround the tree-house with beautiful orchid-like flowers.

Between the tree-house and the coast, the skyline is broken by the great mountain of Kasigau, rising sheer out of the plain for more than 1,000 m. Each morning the sun rises in a blaze of glory behind this mountain, and as the shimmering air cools towards evening a little cloud appears and lands like a flying saucer on top of Kasigau.

When we were away from the tree-house for any length of time, one of the two leopards that inhabited the range would drag its kill (usually a lesser kudu) up the tree and eat it on my bed. For a short while after our return he would express his displeasure by walking around the tree at night, growling and clawing at the bark, though he still had the benefit of drinking water from the tsavorite-studded bird bath at the bottom of the tree.

In late 1973, Henry B. Platt [then president of Tiffany & Co.; Figure 4], who had taken a keen interest in my discoveries right from the start, decided that it was time to give this gem a trade name. Modern mineralogical convention suggests that the naming of a mineral should end with *-ite*. As Tsavo was the obvious locality choice, Mr Platt and I named the magnificent fiery green gemstone *tsavorite*, while the Germans proposed the name *tsavolite*. My wife had been pushing for *campbellite*—but I had staunchly refused to consider it—I felt very strongly the gem needed to be named for Tsavo.

Figure 4: In 1973, green grossular was given the trade name tsavorite *by Campbell Bridges and Harry Platt, president of Tiffany & Co. Photo by Judith Bridges.*

CIBJO, a European confederation originally founded in 1926 as 'BIBOA', was expanded in 1961 and renamed CIBJO (Confederation Internationale de la Bijouterie, Joaillerie, et Orfevrerie). Among other purposes, it cements nomenclature and sets 'best practice' guidelines to better engender consumer confidence. CIBJO made a ruling to accept the name 'tsavorite'. The rest is history.

General Geology

The geology of the Scorpion mine area is well understood as a result of observations by Campbell (e.g. Bridges, 1974, 1982) and the present authors, and has been corroborated in several reports by other researchers (Gübelin and Weibel, 1975; Pohl and Niedermayr, 1978; Key and Hill, 1989; Suwa et al., 1996; Keller, 1992; Hauzenberger et al., 2007; Feneyrol et al., 2013). Tsavorite deposits in East Africa are hosted by metamorphic rocks of the Mozambique Belt. The protoliths of these rocks were deposited in a shallow marine environment and subsequently metamorphosed during the East African Orogeny between 650 and 550 million years ago (Feneyrol et al., 2013). Bituminous black shales that were deposited in the marine basins were metamorphosed to form graphite gneiss. Black shales are typically enriched in V, the colouring agent (sometimes with Cr) in tsavorite. The basement rocks in the Scorpion mine area consist primarily of gneisses that are interbedded with mica, kyanite and graphite schists, as well as lesser amounts of quartzites, calc-silicate rocks and marbles. Tsavorite mineralization is hosted by graphite gneisses, which are typically interlayered with schists and bands of marble ranging from 10 cm to 2 m thick. The graphitic gneisses consist of quartz, alkali feldspar, biotite and graphite. Sillimanite, epidote, allanite, titanite, zircon, apatite, hematite and magnetite are also common accessory minerals.

Location and Access

The Scorpion mine and other nearby tsavorite deposits (Figure 5) are located in the Taita/Taveta District of south-eastern Kenya, approximately

Figure 5: The map shows the Bridges' tsavorite mines, which are located near Mindi Hill and the Mgama Ridge in the Mwatate area of south-eastern Kenya.

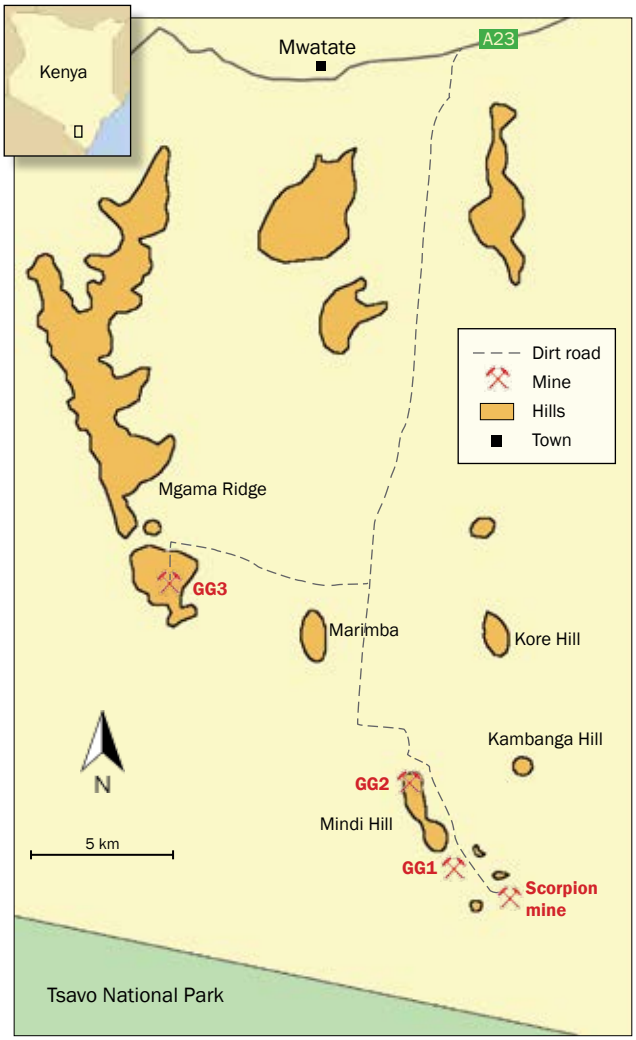

Figure 6: This 1998 photo of the Scorpion mine shows the team opening up a side cut along the No. 4 decline. Photo courtesy of J. Walker.

30 km south of the town of Mwatate, and 5 km outside Tsavo National Park. From Nairobi, this area is accessed by driving south on highway A109 for 329 km to the town of Voi. Then, the route turns west on highway A23, continuing approximately 20 km to Mwatate. This was originally a small bush town inhabited by sisal workers, shopkeepers, small-time mechanics, bar owners, prostitutes, *zurura* (wanderers), gem dealers and *waganga* (medicine men or witch doctors). From Mwatate, the mines are accessed via dirt tracks that lead roughly 30 km south, through rocky outcrops and African savannah that hosts umbrella acacias and *ngoja kidogo* (wait-a-bit) bushes. The tracks are well maintained by the Bridges, but during the rainy season they can become extremely difficult to traverse and in some places impassable.

Early Tsavorite Mining in Kenya

From 1970 to 1979, Campbell worked on what was then called Exclusive Prospecting License No. 164 and surrounding claims. His main operations were called GG1, GG2 and GG3 (GG = green garnet). GG1 is located at the southern end of Mindi Hill, just south of his original tree-house. GG2 is situated on top of the northern-most section of Mindi Hill. GG3 is positioned at the southern end of Mgama Ridge, approximately 7 km north-north-west of Mindi Hill. Both GG1 and GG3 produced tsavorite in a variety of green shades, but most of the material was of a lighter tone, and the cut gems very rarely exceeded 3 ct. Material from GG2 exhibited a variety of tones, and this deposit eventually produced large stones in lighter shades. However, during the 1970s these latter gems were not well accepted in the market. This, of course, has changed today.

When Campbell started working in this area, it was still uninhabited. As news of his discoveries spread, and he gained recognition for his geological knowledge and ability to find gem material, he started seeing more and more people prospecting and staking surrounding claims. As tsavorite continued to gain acceptance in the gem industry, primarily as a result of Campbell's tireless efforts of education and promotion, he realized that he needed to find a deposit that would consistently produce material with a richer colour and in larger sizes. In 1980, approximately 1.5 km to the south-east of GG1, he found exactly what he was looking for. This deposit came to be known as the Scorpion mine, due to the numerous and large scorpions found at the site.

The Scorpion Mine

The Scorpion mine (e.g., Figure 6) is located a few kilometers south-east of Mindi Hill, at a position where the general trend of the rocks turns northward. This general bending of the rocks created a series of tight recumbent folds. This fold structure created an environment in which the hydrothermal solutions needed to form tsavorite collected in channels along the crests and troughs of the folds (Figures 7 and 8a). These 'saddle reefs' at Scorpion were easier to follow than the planar reef structures of

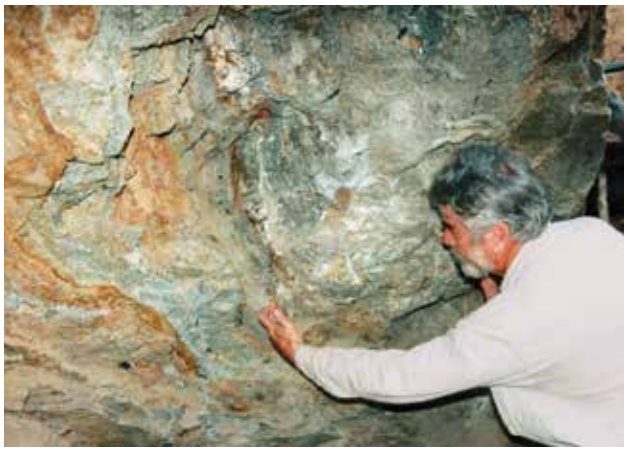

Figure 7: Campbell Bridges indicates the gem-bearing reef in the hinge of a syncline in the No. 2 tunnel of the Scorpion mine. Photo by J. Walker, 1997.

GG1 and GG3, resulting in a larger, more consistent gem production. Campbell strategically engineered his mining tunnels to follow these folds so that the tsavorite mineralization along the crests and troughs could be easily extracted from the ceiling, floor or sidewalls. The folds are tight enough that there commonly are two or more ore shoots containing tsavorite nodules within a single tunnel. The nodules are situated between boudins (i.e., sausage- or barrel-shaped structures formed when a rigid body is stretched and deformed amidst less competent rocks; Figure 8b). The boudins acted as catalysts for tsavorite formation by promoting the formation of conduits for the hydrothermal solutions moving along the fold hinges (Figure 8c). During the mining process, the boudins help mark the locations of the fold hinges, making the ore zones easier to follow than the 'warp zones' in a planar reef. The structure of mineralization in a planar reef is analogous to a plastic pool cover, with air pockets forming in areas where the plastic is warped. The hydrothermal solutions collected in the warp zones between layers of graphite gneiss and marble. Tsavorite mineralization in such zones is inconsistent in frequency—in sharp contrast to saddle reefs. While a saddle reef structure does not assure production at every metre, it does make following the mineralization easier and allows for a more regular formation of tsavorite nodules. Scorpion's reef structure thus combines conditions ideal for both the consistent production of tsavorite and cost-effective mining: by following the hinge of a fold, a relatively steady production of tsavorite is likely.

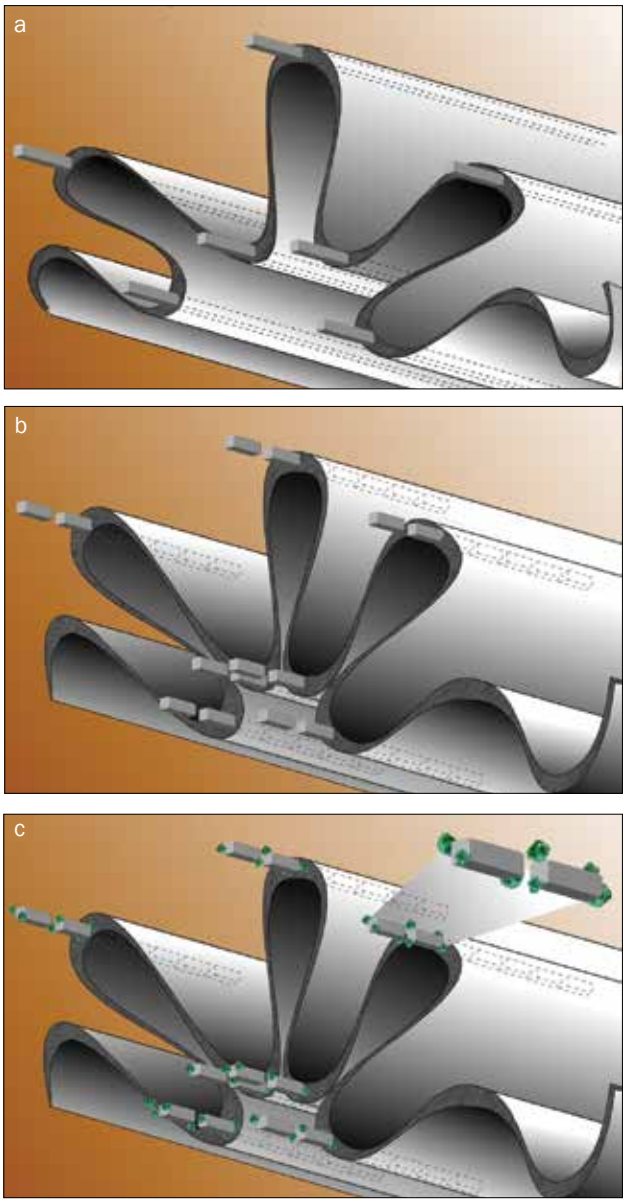

Figure 8: The host rocks at the Scorpion mine were initially deformed into a series of tight recumbent folds (a). With further compression, competent rock units along the hinges of the folds were stretched apart to form boudins (b). Hydrothermal solutions were channelled along the fold axes and boudins, leading to the formation of tsavorite nodules between the boudins (c). Drawings by J. Walker, 2009, not to scale.

In one part of the Scorpion mine (No. 4 tunnel), the nodules were rimmed by blue zoisite (fractured tanzanite). Tsavorite and tanzanite have similar chemical compositions, and Campbell believed the zoisite shell was due to a secondary influx of hydrothermal solutions that reacted with the tsavorite nodule, but at lower temperature and pressure. This was confirmed by Feneyrol et al. (2013), who indicated that zoisite formed

during retrograde metamorphism at ~500°C and ~2 kilobars. In another part of the mine (No. 2 tunnel), the rims surrounding the tsavorite nodules consist of kaolinite, epidote and scapolite.

Mining and Production

From the earliest beginnings of the Scorpion mine, Campbell knew he had found a deposit with tremendous potential. He established four declines (tunnels), and kept track of each one's productivity. Ultimately, the No. 2 and No. 4 tunnels proved most productive, and each is now more than 150 m long. The tunnels have proper supports, ventilation, electrical power, and plumbing for water and/or compressed air (e.g., Figure 9).

The No. 2 and No. 4 declines were worked in rotation by three specialized teams (i.e. blasting, jackhammering and pocketing). Since the tunnels penetrate well below the weathered horizon (Figure 10), the rock is extremely hard and therefore requires drilling and blasting. The blasting team marks the face for drilling so that the gem-bearing reef will be undercut by the explosive charge. Depending on the rock conditions, holes are drilled to a depth of 0.5–1.5 m with a burden of 10–15 inches (25–38 cm; the burden is the distance between rows of holes). The holes are charged with gelignite and ammonium nitrate, and the explosives are set off with detonating cord. After the tunnel is cleared of the blasted waste rock, the jackhammer team moves in to 'square up' the face and remove any remaining country rock, while being careful not to disturb the gem-bearing reef. Again the waste rock is removed, in preparation for the pocketing team. This team utilizes hand tools to minimize damaging the gem rough in any unexposed

Figure 9: The tunnels at the Scorpion mine have been properly outfitted for a safe and efficient mining operation, with timbering, ventilation, electricity, a concrete floor and a water line, as shown here in the No. 2 decline. Photo by B. Bridges, 2008.

Figure 10: Here the team uses an 80 lb (36 kg) jackhammer to break up the country rock in the weathered horizon, at a depth of ~30 feet (9.1 m) from the surface. At greater depths, the unweathered rock is extremely hard and requires blasting with explosives. Photo by J. Walker, 1997.

Figure 11: A portion of a tsavorite nodule is shown right after it was extracted from the working face of the No. 2 tunnel of the Scorpion mine. Photo by J. Walker, 1997.

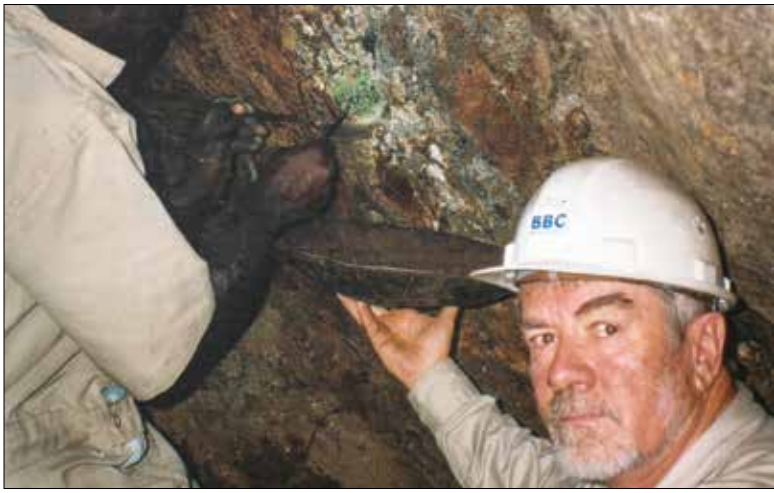

Figure 12: Campbell Bridges supervises the extraction of a tsavorite nodule from the No. 2 tunnel of the Scorpion mine. Lightweight hand tools are utilized to minimize damage to the gem material. Photo by J. Walker, 2003.

nodules. Hammers and chisels are employed for the majority of the work until a nodule is located. Then smaller hammers, fine chisels and even nails are used to carefully extract the gem material. The nodules initially appear intact, but they are quite fractured (Figure 11). By first removing the surrounding host rock, the gem material can be extracted without damage (Figure 12).

The No. 4 tunnel follows a curved lenticular-shaped saddle reef positioned at the nose of a recumbent fold. In its early days, tunnel No. 4 proved so rich that it became known as the Bonanza Reef, since the quality and quantity of the tsavorite it produced was unlike anything Campbell had ever seen before. The colour was consistently medium-to-deep 'grass' green, sometimes with a slight blue secondary modifying hue (Figure 13).

Figure 13: This tsavorite gem rough from the Scorpion mine ranges from pure green to slightly bluish green. From left to right, the pieces weigh 26 g, 15 g and 9 g. Photo by B. Bridges.

The No. 2 decline follows the hinge of a syncline. Its production increased gradually until reaching a maximum in the 1990s. Tsavorite from this tunnel showed a wide colour range, from a vivid medium-light 'spring' green to a vibrant medium-dark 'forest' green. It has also produced some of the largest concentrations of fine tsavorite ever recovered, including one nodule in 2005 that contained over 5 kg of top gem-grade rough. The most impressive stone cut from this production was the Scorpion King, a beautiful medium-dark cushion-shaped gem weighing 20.20 ct (Figure 14).

The most recent production from the Scorpion mine occurred in the No. 2 tunnel in April 2010, when author JW supervised the removal of a section of reef that Campbell and Bruce had prepared for extraction just one day before the attack. The team mined two nodules of tsavorite that yielded beautiful medium to medium-dark material, and cutting of this rough produced a few stones between 2 and 6 ct.

For nearly 30 years, from the time the Scorpion mine was opened until the day Campbell was murdered, the deposit yielded a consistent supply of tsavorite in terms of both quality and quantity.

Figure 14: The Scorpion King is an exceptional 20.20 ct cushion-shaped tsavorite. It was cut from rough material that was recovered in 2005 from a large nodule in the No. 2 tunnel at an approximate depth of 155 m. It is laser inscribed on the girdle with serial number 001 of the Campbell Bridges Signature Collection (see inset, photo by Martin Fuller). Photo by B. Bridges.

This long-term production makes the Scorpion mine the most prolific tsavorite deposit known. While other mines in both Kenya and Tanzania have had productive periods, the planar structure of those deposits has resulted in more sporadic yields of tsavorite.

Marketing and Pricing

During the early years following Campbell's discovery, it was hard to convince anyone to buy tsavorite due to a general lack of awareness. Campbell received comments such as "What is it?", "It's just a garnet" and "The only precious green gemstone is emerald". In response to these and numerous other such remarks, Campbell would cheerfully reply, "Tsavorite is the king of green gemstones, and one day people will be clamouring for it. It will be so popular that there won't be enough supply to meet the demand." Though he is not here to witness it, the present-day tsavorite market is the fulfilment of this prophecy, and supply is indeed struggling to meet demand. In fact, since Campbell's death, tsavorite production has fallen dramatically while the demand for tsavorite has skyrocketed, and prices have leapt to keep pace.

There are a number of reasons for these developments. The Bridges have closed all of their tsavorite mining operations pending the resolution of the trial of Campbell's accused murderers, and this has led to a marked decrease in tsavorite inventory. Production from surrounding tsavorite miners also plummeted after Campbell's passing, since he regularly provided them with guidance in mining techniques and in finding their ore shoots after they pinched or shifted. In addition, many of the miners have redirected their efforts to the low-cost recovery of chrome tourmaline from alluvial deposits that are found in abundance in the 'tsavorite belt' of Kenya and Tanzania; such tourmaline is in strong demand in China. Lastly, continued security problems in the tsavorite-mining area of Kenya have caused many of the legitimate miners to cease operations.

In 1974, when Tiffany & Co. debuted tsavorite to the world, a fine-quality 1 ct stone wholesaled for approximately US$150/ct. Such a gem now sells for between $750/ct and $1,250/ct wholesale. It is important for the gem trade to make the distinction between tsavorite and lighter green grossular (marketed under such names as *mint garnet, mint green grossular, Merelani mint,* etc.). This distinction is akin to the difference between emerald and green beryl. Tsavorite exhibits a richer and deeper colour, whereas green grossular is lighter in tone. The deeper green coloration is produced by higher V and/or Cr (Switzer, 1974), and the availability of green grossular in large sizes appears to correlate with lower concentrations of these chromophoric elements.

In the opinion of the present authors, green grossular should be priced at approximately 20–25% of tsavorite of similar size, shape and clarity. Throughout its short history, tsavorite has witnessed a steady increase in value, even during the U.S. stock market crash in the late 1980s when the prices of the majority of other gemstones fell.

Tsavorite's Unique Properties

The properties of tsavorite were studied by Campbell (e.g. Bridges, 1974) and added to by others (Switzer, 1974; Gübelin and Weibel, 1975; Pardieu and Hughes, 2008–2009). Tsavorite typically is not treated in any way to enhance its colour or clarity.

A well-cut tsavorite is remarkably brilliant. Its bright appearance is due to its relatively high RI of 1.74 and its considerable dispersion of 0.028. Its hardness is substantial, at 7¼–7½ on the Mohs scale, and tsavorite is a tough and durable gemstone with no cleavage. Tsavorite is considerably rarer than emerald, especially in larger sizes (i.e. 3+ ct), and is unique to East Africa in terms of commercial production of gem-quality material.

Being an isotropic gem, the purity of tsavorite's green colour is a defining characteristic. Yet, tsavorite can exhibit a wide range of green hues and tones, from a medium-light yellowish green, to a vibrant bluish green, to a deep 'forest' green (again, see Figure 14). The middle tones (i.e. medium to medium dark) are most sought after, while over-light or over-dark stones are of less value. The most valuable hue is a pure green (Figure 15), or green with a bluish secondary hue. Stones showing the latter coloration are typically more included than those without the bluish hue, which is believed by the authors to be due to a higher Cr content. Indeed, a clean, bright, pure green to bluish green tsavorite weighing more than 2 ct is extremely rare and a gemstone to be prized.

Figure 15: The tsavorites in these platinum earrings show a vibrant pure green colour. Named 'Papillon' in the Bridges Collection jewellery line, the earrings contain 8.34 carats of tsavorite from the Scorpion mine and 0.67 carats of diamonds. Photo by B. Bridges.

Present and Future of the Scorpion Mine

Since Campbell's murder in 2009, the Scorpion mine and the Bridges' surrounding tsavorite claims have been placed on 'care-and-maintenance' status while the family endures a protracted court process (Pike, 2012). The court case does not have any bearing on the ownership of the mine, but is focused on prosecuting the accused murderers. The Bridges family and their employees continue to receive death threats, so they have decided to minimize any further incidents by keeping a low profile and a smaller work force. The Bridges currently employ 20–30 local people, while in the past they had more than 50 employees. Some of these workers have been with the Bridges' company for 20+ years, and the family feels an acute sense of responsibility towards them and their dependents—all of whom would suffer extreme hardship if the Bridges were to permanently cease operations in Kenya. In addition, by eventually reopening the mine, the Bridges family will continue Campbell's legacy as the founding father of tsavorite and life-long promoter of East African gemstones.

To keep their concessions and employees secure, a private security team funded by the Bridges has been placed at the Scorpion mine and elsewhere on their claims until the court case is resolved. The Bridges family and their security staff (assisted by high-level Kenyan government authorities) have been able to identify the majority of the conspirators involved in planning and perpetrating Campbell's murder (Mwaura, 2013). The witnesses have all given testimony in the court case, and the judge should give a final ruling in the near future. In anticipation of this, preparations are currently being made to reopen the Bridges' mining claims.

The present authors strongly believe there is excellent potential for further sustained commercial production of tsavorite from the Scorpion mine. As the tunnels have been mined at depth, multiple additional ore shoots have

Figure 16: Campbell Bridges enjoys the view from his 'luxury edition' tree-house at the Scorpion mine. His legacy of bringing the beautiful green gemstone tsavorite to the gem trade lives on. Photo by B. Bridges, 2008.

been encountered, and these should continue to considerable depth unless they are truncated by faulting or other structural features in the area, which have not been observed. Also, in late 2010, a geophysical survey was conducted to help identify new tsavorite targets in the area formerly known as Exclusive Prospecting License No. 164. The results of this study were favourable, with the survey verifying what Campbell had intuitively already known to be true. As such, this survey will help guide mining efforts in the future.

Conclusion

Pioneers, adventurers and discoverers throughout history have often received their greatest accolades after they have passed from this Earth. This also can be said for Campbell Bridges (Figure 16). Since his tragic murder, tsavorite has seen a dramatic increase in public awareness and appreciation. This, combined with limited additional production, has helped push the price of tsavorite to levels never seen in its approximately four decades on the market. It is most regrettable that the man who moved people with his love of Africa and its gems is not here to see his dream come true. His vision is now inherited by those he loved and inspired.

On her desk, Judith Bridges has a bronze cast from a scorpion that her husband found in the red-gold earth of Tsavo. Campbell encountered the scorpion when they were young and the mining camp was just starting. Their children were young, too, and Tsavo was still very wild. Judith remembers the stories her husband would tell their children at bedtime in the tent by the light of the hurricane lantern—stories of mighty scorpions named 'Crusher' and 'Smasher', 'Steel Claw' and 'Fire Sting'. It was in honour of these warriors that Campbell

gave the Scorpion mine its name. When Judith is asked why she fights on to retain control of the mine, although she is so much the underdog, the words of the scorpion in the fable 'The Scorpion and the Frog' come to her…"it is my nature".

The Scorpion mine was instrumental to the emergence and promotion of tsavorite in the global gem industry. It was the first mine to produce tsavorite in consistent quantity and quality due to the structure of its gem-bearing reef. The importance of this mine—and of Campbell's activities in the area—is poignantly demonstrated by the abrupt decrease in tsavorite production since his death. It is the hope of the Bridges family, the friends and colleagues of Campbell and the international gem community, that justice will be served and that security will be restored to the area so that legitimate tsavorite mining can resume. With the court case coming to completion in the near future and the planned reopening of the Bridges' mines, tsavorite production is projected to increase and the Scorpion is set to reassert itself as Africa's premier tsavorite mine once again.

Dedication

This article is dedicated to Campbell Bridges, who shall live forever through his discovery of tsavorite and the love he shared with family and friends. The Bridges family expresses a heartfelt thanks to all those who have supported us in our most trying times and enabled Campbell's legacy and dream for tsavorite to live on.

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Emeralds Partially Coated with Amorphous Carbon

Gagan Choudhary

Recently, nine faceted emeralds submitted to the Gem Testing Laboratory, Jaipur, India, were identified as coated owing to the metallic to sub-metallic reflections on their pavilion facets. The coated surfaces did not show any diagnostic features with routine EDXRF and Raman spectroscopy. However, some samples had concentrations of the coating substance in surface cavities, and Raman analysis of those areas revealed the presence of amorphous carbon. Specifically, a broad feature at ~1550 cm^{-1} with a shoulder at ~1360 cm^{-1} identified the coating substance as an 'a-C' type film. Microscopic observation showed that the coating was damaged and removed from several areas, suggesting its instability to normal wear and tear.

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Introduction

The coating of gems is one of the oldest forms of enhancement, and is done to improve the appearance and/or durability of the stone, and thereby its value. The use of traditional coating materials such as paint, ink, plastic or coloured polymers still continues today (e.g. Choudhary, 2011, 2013), but they have been largely replaced by more sophisticated coatings. With advances in technology, improved coating methods have been developed to provide a wider range of colours and optical effects with better durability. During the past several years, a variety of gem materials such as diamond, topaz, quartz, beryl and cubic zirconia have been coated with metals (gold, silver, etc.), oxides (of aluminium, silicon, zirconium, etc.), or fluorides (of calcium, magnesium, etc.), and many of these have been described in the literature (e.g. McClure and Smith, 2000; Evans et al., 2005; Shen et al., 2007; Schmetzer, 2008). In addition, treaters have claimed using other types of films—such as diamond-like carbon (DLC) and nanocrystalline synthetic diamond—to reportedly modify the colour, appearance and/or durability of diamonds and coloured gemstones (e.g. McClure el al., 2010; Shigley et al., 2012). Serenity Technologies (www.serenitytechnology.com), one of the companies that performs such treatments, claims to use a nanocrystalline diamond coating process to improve surface wear resistance of various 'soft' gem materials, including emerald, apatite, tanzanite and others. A Japanese company, Apple Green Diamond Inc., is marketing various synthetic coloured gemstones

Figure 1: These nine faceted emerald samples (3.54–33.64 ct) proved to be coated with an ultrathin carbon-based film on their pavilion facets. Composite photo by G. Choudhary.

(as well as cubic zirconia) that also reportedly have nanocrystalline diamond coatings (http://diamondlite.co.jp).

Although coloured gemstones supposedly coated with DLC have been available in the trade for years (Koivula and Kammerling, 1991), no detailed documentation of these materials is available to the author's knowledge. Recently, the author examined nine faceted emeralds (Figure 1) at the Gem Testing Laboratory, Jaipur, that were identified as coated with an amorphous carbon film. According to the client, these stones made their way to Jaipur from Hong Kong. This article provides a brief characterization of these coated emeralds.

Background on Carbon Film Coatings

Broadly, carbon films have been divided into three types: amorphous carbon (a-C), nanocrystalline and microcrystalline. In materials science, *diamond-like carbon* is defined as amorphous carbon containing an unstructured mixture of sp^2 (as in graphite) and sp^3 (as in diamond) bonds, resulting in variable hardness, chemical inertness, transparency, colour, etc. (e.g. Robertson, 2002; Filik, 2005). The higher the sp^3 content, the greater the hardness and durability of the material. DLC films exist in various sub-forms, depending on their structure and method of production; a few examples are 'a-C:H', 'ta-C', 'ta-C:H' and 'polymeric a-C:H' (e.g. Chu and Li, 2006). However, in the gem industry, treaters frequently claim they use a 'diamond-like-coating' rather than amorphous carbon. Members of the gem trade commonly associate such coatings with diamond and simply call the gems 'diamond coated', but these amorphous carbon or diamond-like carbon films do not have the hardness or durability associated with diamond. Nano-crystalline and micro-crystalline carbon films have quite different structures and properties than amorphous carbon films, and are more closely related to diamond (e.g. Chu and Li, 2006).

Samples and Methods

Nine emeralds, weighing 3.54–33.64 ct (Figure 1), were submitted to the Gem Testing Laboratory, Jaipur, for routine identification without any prior information. Standard gemmological testing was performed to establish their identity. Qualitative energy-dispersive X-ray fluorescence (EDXRF) chemical analyses of all samples were conducted using a PANalytical MiniPal 2 instrument under two different conditions: elements with a low atomic number (e.g. Si) were measured with a tube voltage of 4 kV and current of 0.850 mA, while transition and heavier elements were measured at 15 kV and 0.016 mA. Raman spectra in the region 2000–200 cm^{-1} were collected from all samples using an Airix Corporation – TechnoS Instruments STR 300 confocal microspectrometer with 532 nm laser excitation, an exposure time of 10 seconds per scan, and 10 scans per spot.

Figure 2: The pavilion facets of this 13.45 ct emerald show a golden metallic to sub-metallic lustre that indicates the presence of a coating. Also note the chip in the coating near the keel of the pavilion toward the upper left. Photo by G. Choudhary.

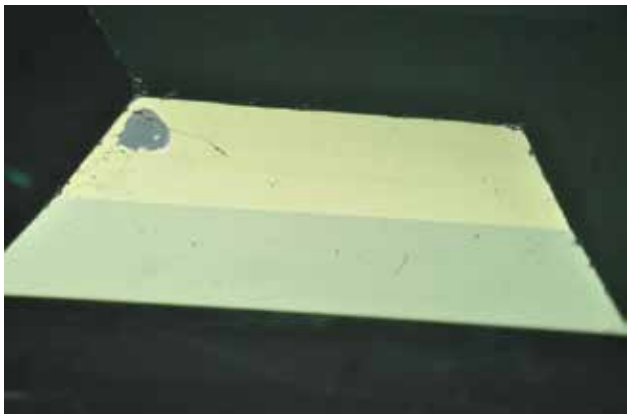

Figure 3: The chipped areas on the pavilion of the 13.45 ct emerald show the duller lustre of the underlying emerald against the bright metallic lustre of the coated facets. Also note the dark line corresponding to a surface-reaching fracture that cross-cuts the large chip. Photomicrograph by G. Choudhary; reflected light, magnified 24×.

Results and Discussion

Visual Observations

When viewed face up, all samples displayed a similar green colour with a slight yellowish tint and moderate saturation (again, see Figure 1) that is typically associated with emeralds. The samples appeared transparent with minor to significant inclusions visible to the unaided eye, and had a vitreous lustre. These initial observations suggested the samples were natural emeralds. However, when their pavilion side was viewed, a golden metallic to sub-metallic lustre was apparent (Figure 2), which raised the suspicion that a surface-related treatment, such as coating, was present on those facets.

Gemmological Properties

All the measured gemmological properties were consistent with emerald. Although it would not have been surprising to find some difference in refractive indices between the crown and pavilion surfaces due to the coating on the pavilion, identical RI values were obtained with similar sharpness of the shadow edges on the refractometer scale.

Microscopic Features

Viewed with the gemmological microscope, all the emeralds displayed typical liquid films, 'fingerprints' and prominent jagged three-phase inclusions along with growth and colour zoning, confirming them as natural and of probable Colombian origin (see e.g. Gübelin and Koivula, 1997). In addition, all the emeralds had been clarity enhanced using a colourless resin, in amounts ranging from minor to significant. The presence of resin was suggested by golden/blue colour flashes along the fractures, and this was later confirmed by infrared spectroscopy (cf. Kiefert et al., 1999).

Viewed with reflected light, even at higher magnification, the crown sides of the emeralds did not display any features related to surface coating, while all the pavilions showed the golden metallic to sub-metallic lustre that was visible with the unaided eye; some chipped areas displayed the vitreous lustre of the underlying emerald (Figures 2 and 3). In addition, some surface-reaching fractures stood out as highly contrasting dark lines against the bright surrounding facet. When the samples were observed in diffused transmitted light, the coating substance appeared brown (Figure 4), particularly where it was more visible around the chipped areas, enabling a comparison between the coated surface and the underlying emerald. Some of the cavities and/or surface-reaching tubules appeared darker than the rest of the coated surfaces, suggesting a thicker concentration of the coating substance in those areas (Figure 5). Under oblique fibre-optic lighting, some of the facets also displayed a strong blue iridescence along with fine lines that appeared to be polishing marks (again, see Figure 5). The coating substance apparently scattered the white light from the polishing lines/grooves, resulting in the blue iridescence.

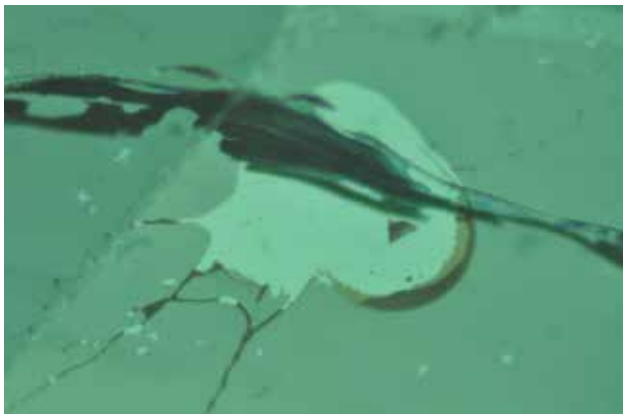

Figure 4: Under diffused transmitted light, the coating layer appears brown, particularly around the chipped areas. Note the difference in colour between the underlying emerald and the surrounding coated surface. Also, the underlying fracture contains some subtle bluish flashes suggesting the presence of resin filler. Photomicrograph by G. Choudhary; magnified 64×.

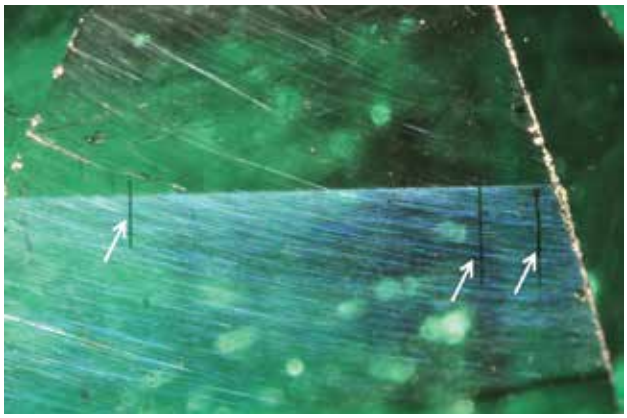

Figure 5: Surface-reaching tubules (see arrows) appear darker than the rest of the coated surface of this emerald, suggesting a thicker concentration of the coating substance within these cavities. In addition, oblique fibre-optic lighting shows an area of blue iridescence that apparently corresponds to light scattering from coated polish marks. Photomicrograph by G. Choudhary; magnified 32×.

EDXRF Analysis

Although the metallic to sub-metallic lustre of the coating suggested the presence of some metallic oxide, EDXRF spectroscopy revealed only those elements associated with emerald: impurities of Ca, V, Cr and Fe were present along with Al and Si. Traces of Ti, which provide one of the key identifying features of the coating process associated with Diamantine (Shigley et al., 2012), were not detected in these samples.

Raman Analysis

Raman spectroscopy of a typical coated surface did not produce any features besides those associated with the underlying emerald, but this was not surprising considering the extremely thin nature of some coating materials. However, Raman analysis of surface-breaking cavities and growth tubes that displayed concentrations of the coating substance showed a broad feature at ~1550 ± 5 cm^{-1} with a shoulder at ~1360 ± 5 cm^{-1} (Figure 6). The band at ~1550 cm^{-1} is designated as the 'G' peak for graphite, while that at ~1360 cm^{-1} is a 'D' (disorder) peak (e.g. Mednikarov et al., 2005; Chu and Li, 2006); both of these features are due to sp^2 bonding of carbon atoms. Further, the Raman spectral pattern observed for this coating substance was consistent with that reported for a-C films (i.e. softer carbon films formed without hydrogen, usually at low energy or higher temperature; Chu and Li, 2006). The characteristic strong peak of diamond at 1332 cm^{-1} was completely missing from the coating substance.

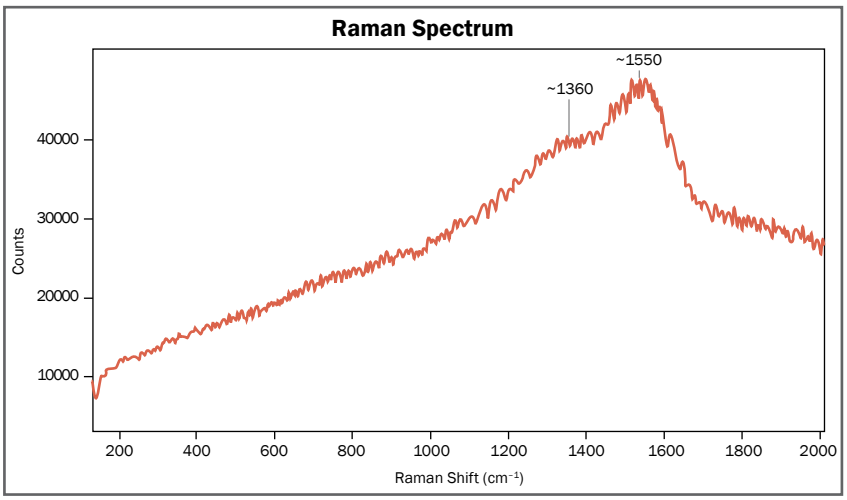

Figure 6: Raman analysis of surface-breaking growth tubes (see Figure 5) containing thicker concentrations of the coating substance produced a broad feature at ~1550 cm^{-1} with a shoulder at ~1360 cm^{-1}. This spectral pattern is consistent with amorphous carbon films and is due to sp^2 bonding of the carbon atoms.

Conclusions

The identification of these emeralds as coated was quite straightforward because of the presence of metallic to sub-metallic surface reflections on the pavilion facets. However, determining the nature of the coating substance was more challenging, as reported previously for ultrathin carbon-based coatings (e.g. McClure et al., 2010; Shigley et al., 2012). Fortunately, four samples had concentrations of the coating substance in surface features, and Raman spectroscopy of these areas identified the coating as amorphous carbon. Although technically such coatings may be referred to as 'diamond-like carbon', in the gem trade this terminology is often falsely equated to diamond (i.e. 'diamond coated'). However, these coatings do not possess the hardness and durability associated with diamond, and therefore must not be called 'diamond coated'.

Gemstones are typically coated to improve their appearance and/or durability, but in this case a lot has been left for assumption regarding the improvement of either of these factors. These emeralds were coated only on their pavilion facets, which implies that the treatment was intended to improve their brilliance. In a stone like emerald, which is rarely inclusion-free, such a coating will hardly make an impact. Further, the coating on these emeralds had been chipped from several areas, suggesting its instability to normal wear and tear.

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The 'Sleeping Lion' Baroque Pearl: An Update

J. C. (Hanco) Zwaan, Dirk M. van der Marel and Herman A. Dommisse

The Sleeping Lion is one of the largest-known nacreous pearls and has an interesting history. Newly discovered early references indicate that soon after the pearl was sold in Amsterdam in 1778, it was offered for sale in St. Petersburg in 1779. The pearl was recently removed from its setting, allowing its weight to finally be determined at 2,373 grains (593 ct or 118.65 grams). High-resolution X-ray micro-CT scanning revealed the inner structure of the pearl in much greater detail than could be seen during a previous study, and together with Raman spectroscopy, confirmed that the Sleeping Lion is a natural blister pearl. As properties presented in a previous study indicate that this pearl has a freshwater origin, it can be reaffirmed that this is the largest natural freshwater blister pearl documented to date.

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Introduction

Five years ago, two of the present authors described the properties and history of one of the largest-known nacreous pearls (Zwaan and Dommisse, 2009; Figure 1). At the time we had to estimate the weight of the pearl because it was tightly mounted on a gold rod that was used to set the pearl in the centre of a stylized Lotus bud (Figure 1, inset). However, this rod was removed after the owner decided to show the pearl loose, in order to showcase its 'sleeping lion' appearance when presented on its original display box (described in Zwaan and Dommisse, 2009; see Figure 2). This gave us the opportunity to weigh the loose pearl, and also to examine it with high-resolution X-ray computed microtomography (micro-CT). This short note gives additional historical information and also updates the properties of this remarkable pearl.

History

From historical accounts, Zwaan and Dommisse (2009) reported that the pearl was sold in Amsterdam in 1778, as "a large pearl, of 578 carats, visualizing a sleeping lion…". After it was sold, the pearl's history was unknown until 1865, when the second-known owner from Poland appeared, shortly before the return of the pearl to Amsterdam around 1868.

New information on the history of the pearl was found in an old recipe book for edible molluscs (Lovell, 1867), and kindly brought to our attention by Dr Jack Ogden. It reveals that the pearl probably left Amsterdam shortly after it was

Figure 1: The Sleeping Lion Pearl, which measures approximately 70 × 43 × 39 mm, has been removed from its former setting in the centre of a stylized lotus bud (lower right, photo © Amsterdam Pearl Society). It is now displayed as a loose pearl, as drawn in 1778 (upper right); photo by J. C. Zwaan.

auctioned in 1778, to be sold in St. Petersburg, Russia, the following year: "In 1779 a pearl, which from its shape was called the Sleeping Lion, was offered for sale at St. Petersburg by a Dutchman; it weighed 578 carats, and was bought in India for £4500" (Lovell, 1867, p. 60). Further, Dr Ogden indicated that this information was evidently taken from Nicholson (1808, unpaginated, from the section 'Pearls'): "A pearl, called from its figure the sleeping lion, that weighed 578 carats, was offered for sale at Petersburg in 1779 by a Dutchman. On one side, which was flattish, it was beautifully striped. It was bought in India for 4500*l*." The young Nicholson (1753–1815), a scientist and inventor, arrived in Amsterdam in the summer of 1777 as a sales representative for the English pottery firm of Wedgwood & Bentley (Lamp, 2004). For three years he worked in the old town centre, a few steps away from the Munt tower where the Sleeping Lion Pearl would be auctioned on 26 August 1778. His quote strongly suggests that he had seen the pearl and had

Figure 2: The Sleeping Lion Pearl is displayed on the gilded copper box (approximately 74 × 54 × 47 mm) that was originally manufactured for it. Photo by Tom Haartsen, © Amsterdam Pearl Society.

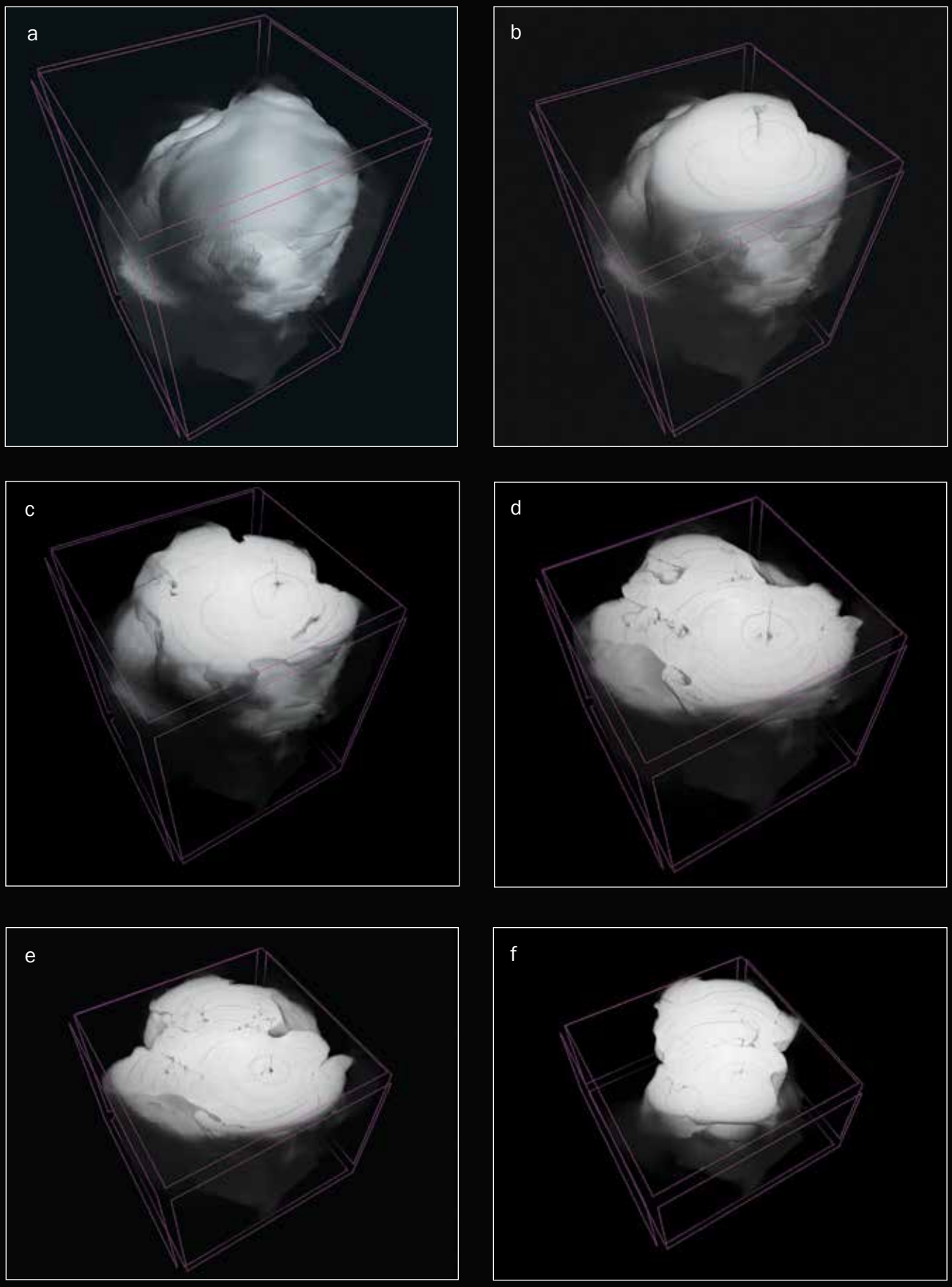

Figure 3: A 3D model of the Sleeping Lion Pearl (a) was reconstructed from X-ray micro-CT scans. Concentric layering is seen in the five scans shown here that were taken along the length of the pearl, from top to bottom (b–f).

carefully observed it himself (the pearl indeed has a rather flat 'striped' reverse side; compare with Figure 4 in Zwaan and Dommisse, 2009). Otherwise he must have taken these observations from somewhere else, but then there would have to be another (slightly older, Dutch?) reference which, to date, has not been found.

This new piece of information, stating that the pearl was bought in India, does not contradict a Far East (or Chinese) origin, as postulated earlier; it also indicates that the pearl probably went to Russia twice, as the previous Dutch owner Louk van Kooten stated that his grandfather Louis van Kooten took the pearl to Fabergé in St. Petersburg, sometime between 1910 and 1914 (Zwaan and Dommisse, 2009).

Weight

The weight of the pearl immediately after the removal of the mounting rod was 593.29 ct (2373.16 grains). Subsequently, the small and narrow drill hole was filled with a mixture of mother-of-pearl grit and glue. The weight of the pearl including this filling is 593.43 ct (2373.72 grains). Thus we have confirmed that the actual weight of the pearl is 2373 grains (118.65 grams), which is 0.6 grams lower than the weight estimated by Zwaan and Dommisse (2009).

Comparing this weight with the 578 ct mentioned by Nicholson (1808) and Lovell (1867), the carat weight used at the time (before the standardization of the metric carat in the early 20th century) must have been around 0.2053 grams, which is exactly the value of the London carat and close to the value of the Amsterdam carat of 0.2057 grams at the end of the 19th century, according to the values given by Lenzen (1970).

Inner Structure and Composition

With the pearl unmounted, we also had the opportunity to study its internal structure with high-resolution X-ray micro-CT scanning, without having to deal with interference problems due to the presence of a metal rod. A Skyscan 1172 micro-CT scanner was used for this purpose. The operating conditions were set at 100 kV and 100 µA, using both Al- and Cu-foil filters and an exposure time of 5,500 milliseconds for each image. Due to its large size, the pearl was divided into five parts that were separately scanned, with the camera offset turned on. For each scan, the pearl was rotated 180° in steps of 0.30°. For each position, three frames were averaged. The five separate scans were stitched together, and after reconstruction a total of 5,325 images were processed. The camera pixel size was fixed at 8.70 µm; after reconstruction, the image pixel size was 13.17 µm. From the reconstructed three-dimensional (3D) model of the pearl, a video was made to show the internal structures along almost the entire length of the pearl, and then going into the pearl from its reverse side (available in an online data depository on *The Journal*'s website).

The high-resolution X-ray micro-CT scans (Figure 3) provide much more detail than the original CT scans (compare with Figure 6 of Zwaan and Dommisse, 2009). Although the shape of the pearl is highly irregular, it shows remarkably consistent concentric layering—typical of natural pearls—that is oriented perpendicular to the long axis of the pearl. The scans also confirm that the pearl is solid throughout, without any substantial hollow cavities. Where cavities are present, they are small and very shallow or thin. When the pearl was viewed from its reverse side (Figure 4; compare with Figure 4 of Zwaan and Dommisse, 2009), parallel growth lines were observed on and near the surface, indicating that this side of the pearl was attached to the shell of the host mollusc. These properties indeed confirm that this is a natural blister pearl.

Raman spectroscopy, using a Thermo DXR Raman microscope with 532 nm laser excitation, was employed to analyse five randomly chosen spots at and slightly underneath the surface of the pearl. The Raman spectra revealed that the white surface consisted of aragonite, with main bands at 1085, 706 and 701 cm^{-1}. The strongest band, at 1085 cm^{-1}, derives from the symmetric stretching mode (ν_1) of the carbonate ion; the doublet at 706 and 701 cm^{-1} corresponds to in-plane bending (ν_4) of the carbonate ion, which is in contrast to the single band at ~711 cm^{-1} found in Raman spectra of calcite (compare, e.g., Urmos et al., 1991; Wehrmeister et al., 2010). Therefore, Raman analysis confirms the nacreous nature of this pearl, as already concluded by Zwaan and Dommisse (2009) on the basis of its

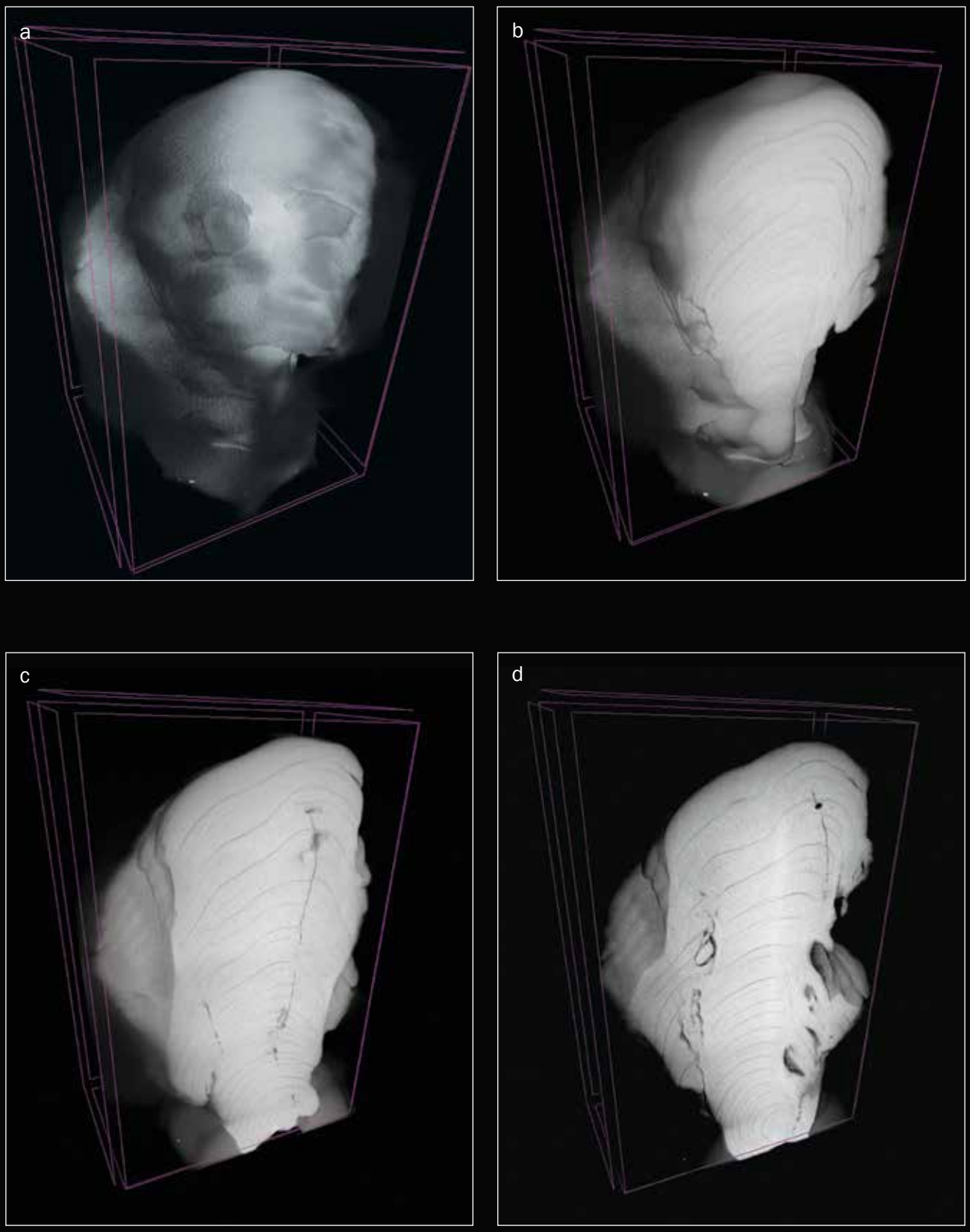

Figure 4: Viewed from its reverse side, the Sleeping Lion Pearl is shown as a 3D model (a) and also in slices (b–d) that reveal parallel growth lines which are oriented roughly parallel to the orientation of the pearl's attachment with the shell of its host mollusc.

optical features. A small, slightly brownish area near the borehole did not reveal bands related to a particular pigment; the Raman spectrum was influenced by relatively strong fluorescence instead. It is possible that this slight coloration formed during the drilling of the borehole.

Conclusion

New evidence shows that soon after the Sleeping Lion Pearl was auctioned in Amsterdam in 1778, it was then offered for sale in St. Petersburg in 1779.

The measured weight of the pearl is 2,373 grains; it is therefore confirmed to be one of the largest-known nacreous pearls, slightly less in weight than the Pearl of Asia (2,420 grains) and slightly greater than the Arco Valley Pearl (2,300 grains; cf. Table II of Zwaan and Dommisse, 2009).

High-resolution X-ray micro-CT scanning and Raman analysis confirmed that this is a naturally formed nacreous blister pearl without any substantial hollow cavities.

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Field Studies in Sri Lanka by GIT

April 2014

Pornsawat Wathanakul

The Gem and Jewelry Institute of Thailand (GIT) recently visited Sri Lanka with the aim of educating five young Thai academic staff from three universities in Thailand about the geology of gem deposits in that country. The trip was accomplished with the technical cooperation of Sabaragamuwa University in Balangoda, Sri Lanka. GIT provided academic support with the participation of associate professor Dr Visut Pisutha-Arnond and this author. The young Thai researchers are all PhD university lecturers in geology, earth sciences and gemmology, namely Drs Krit Won-In, Bhuwadol Wanthanachaisaeng, Somruedee Satitkune, Prayath Nantasin and Pitsanupong Kanjanapayont. Also in attendance was GIT research staff member Ms Nadya Nilhad. The group was led by Gamini Zoysa, a renowned authority on Sri Lankan gems and good friend of GIT.

From Colombo, our route followed highway A26 northeast to the Elahera gem area in Central Province. From Elahera we visited gem deposits in the Kaluganga and Hassalaka areas. We then proceeded southwest through the core terrane of the Sri Lankan highland, and overnighted in the holy city of Kandy before proceeding to the Avissawella gem area in Western Province. Then, on the way to the great gem town of Ratnapura, we visited

The team poses with local Sri Lankan leaders at Mahiyangana quarry in north-western Uva Province, which provides a good exposure of hornblende-biotite-garnet gneiss of the Highland Complex. Photo by C. Wathanakul.

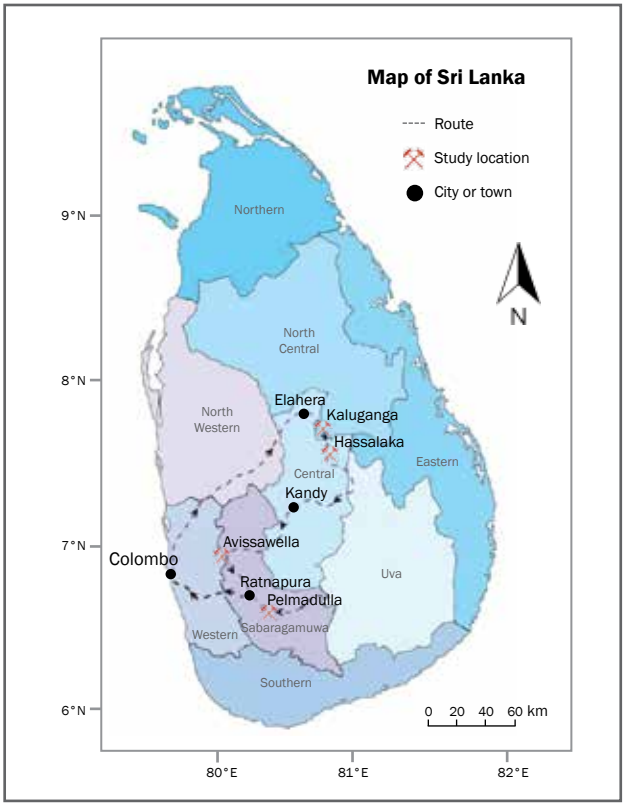

Our route followed a clockwise loop from Colombo, proceeding to Elahera and gem deposits in the Kaluganga and Hassalaka areas, then to the holy city of Kandy, and onward to mines near Avissawella, Ratnapura and Pelmadulla.

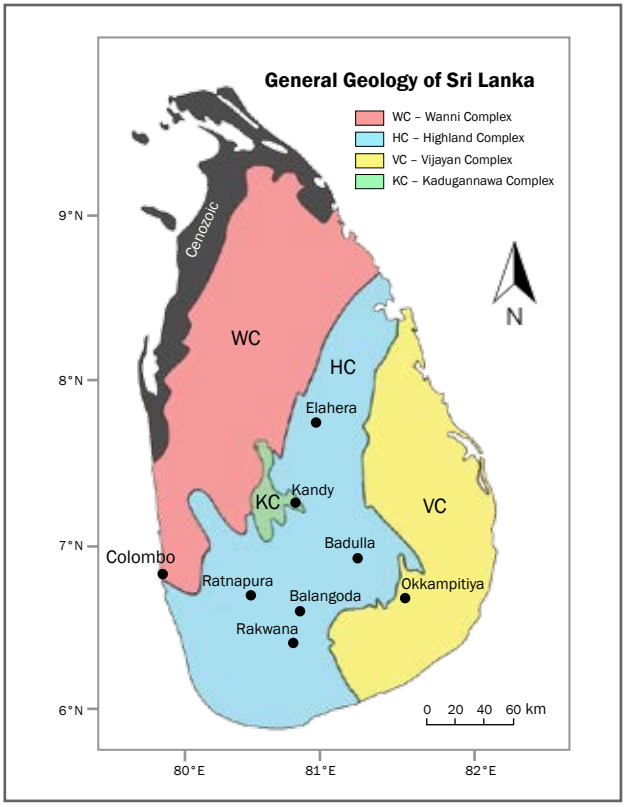

The rocks of Sri Lanka are composed of various Precambrian metamorphic complexes, as well as Cenozoic limestones. Redrawn after Chandrajith et al. (2001) and Zoysa (2013).

Sabaragamuwa University. We studied many gem mines in the Ratnapura area and also near Pelmadulla. We then returned to Colombo, having covered nearly 800 km.

Geology: Sri Lanka consists mainly of three metamorphic rock units called the Wanni, Highland and Vijayan Complexes; there is also a small unit named the Kadugannawa Complex in the Kandy area. The island is composed mostly of metamorphic and sedimentary rocks, as well as igneous rocks including pegmatites of granitic or syenitic derivatives. The metamorphic rocks are mainly made up of charnockite, charnockitic gneisses, quartzo-feldspathic gneiss, calc-gneiss and granulite (Zoysa, 2013). Sri Lanka produces various gems, notably blue sapphire, 'geuda' corundum, chrysoberyl (including cat's eye), kornerupine, several varieties of garnet, topaz, tourmaline, aquamarine and more. Although some primary gem deposits are known on the island, most of the mining exploits gravels, which reflect the original rock types and various gem origins that existed prior to their erosion.

Central and North Central Provinces: The Elahera gem mining area is known for producing good-quality sapphires. Here square-pit mining is done with simple hand tools to access the gem-bearing gravels at depths of about 5–20 m depending on the topography. (Sri Lankan mining law allows the use of mechanised equipment only by special permission.) Gem panning is done directly in the pits, using water pumped from a nearby stream. Fortunately, during our visit a few sapphires were collected together with other gems (garnet, chrysoberyl and tourmaline).

Mining with hand tools is also done around the village of Kaluganga. Here, the eluvial and residual deposits are explored using shovels and iron bars. The miners find residual rock fragments by feeling and listening as they drive the bars into the ground. These rocks and soils are carried to a nearby stream for panning. Our

(A) Miners pan gems within a pit at Dasgiriya, south of Elahera (7°38'13.49" N, 80°49'20.58" E). (B) This sapphire was recovered from the Dasgiriya pit during our visit. (C) Also produced from the Dasgiriya pit was this assortment of gem rough. (D) Dr Krit Won-In gets a lesson on gem panning from an experienced miner. (E) In Thorapitiya village near Hassalaka, this pit is being dug in a rice field (7°22'10.24" N, 80°56'36.81" E). (F) A fruit plantation hosts this gem mining pit in Thorapitiya village (7°22'07.25" N, 80°56'48.45" E). Photos by S. Satitkune (A, B and C), P. Wathanakul (D) and N. Nilhad (E and F).

(A) Gems have been concentrated in this bend of the Seethawaka River near Avissawella (6°57'11.93" N, 80°13'12.32" E). (B) Material from the Seethawaka River is washed and sorted using simple equipment. Photos by P. Wathanakul (A) and K. Won-In (B).

staff was trained in local panning techniques, but we usually kept the sand and threw the concentrates away! Correct panning involves knowing how to move both the pan and your body.

In the Hassalaka area, gems are also mined from compact soil, particularly near Thorapitiya village. The gem pits are dug in all possible areas such as in rice fields and fruit plantations.

Almost at the apex of the highland core is situated the famous holy city of Kandy, where there is a temple that houses Sri Lanka's most important Buddhist relic—a tooth of the Buddha. We witnessed a ceremony with people lined up to pray at the relic, carrying beautiful flowers such as lotus and wild jasmine.

Western Province: In the Avissawella area, we saw gem mining along the Seethawaka River. According to the National Gem & Jewellery Authority of Sri Lanka, this deposit reportedly earned around US$8 million (River bank gem mining projects…, 2014) and produced over 5,000 g of sapphire rough (G. Zoysa, pers. comm., 2014). Mining takes place where the river makes a 90° turn, resulting in the concentration of heavy minerals (including gems) in the river bed.

Sabaragamuwa Province: The Sabaragamuwa region is situated in an intermontane basin within the highland mountains of Sri Lanka. Here lie the great placer deposits of the Ratnapura area, where gems have been derived from rocks of the Highland Complex.

At Sabaragamuwa University, the Sri Lankan government recently established programmes covering the management of gem mining and the gem industry. GIT has been invited to engage in academic cooperation with the university.

On the way to our next destination, we detoured from our route to take a closer look at some outcrops near Pelmadulla. We then noticed a mining pit in a nearby paddy field. While the square pits in Sri Lanka are normally 3×3 m, this one was twice as large (3×6 m). The miners were competing against the seeping groundwater, and they had to work quickly to reach the gem-bearing gravels without the need for a pump to remove water from the pit.

To mine gems in areas of soft wet soil such as paddy fields, the miners have developed a clever method to keep the pits from collapsing. They support the pit walls with wooden timbers together with local plants (such as ferns) to retain the soil between the timbers. This allows only water to seep into the pit.

We obtained a variety of sapphire samples from the Ratnapura area.

Gem Deposit Types: In summary, most of the gem deposits we visited were associated with gravel beds, in which mineral density controls the assemblages that are deposited. A good

(A) Miners search for gems in a paddy field at Migahagoda near Pelmadulla (6°37'00.30" N, 80°33'30.80" E). (B) This square pit at Migahagoda employs timbers and local fern vegetation to support the pit walls. (C) Another pit at Migahagoda uses a water pump in addition to structural support of the pit walls. (D) Well-formed, slightly rounded sapphire crystals (here, up to 13.5 mm long) are mined from the Ratnapura area. (E) A variety of colours is seen in these sapphires (up to 12.0 mm) from the Ratnapura area. Photos by P. Wathanakul (A), P. Nantasin (B), V. Pisutha-Arnond (C), P. Kanjanapayont (D) and G. Zoysa (E).

example of this is provided by deposits along the Seethawaka River. Other geological types noted from previous visits to Sri Lanka include the primary deposit of pink sapphires hosted by metamorphic rocks at Wellawaya, as well as gems hosted by pegmatites and skarns.

A wide diversity of rocks of the Highland Complex provided the sources of gems in the gravels. Contact metasomatism is an important mechanism for producing good-quality gem corundum. In addition, various gem minerals can originate from shear zones in the metamorphic host rocks.

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Acknowledgements

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The Association is most grateful to the following for their gifts and donations for research and teaching purposes:

Maggie Campbell Pedersen FGA, London, for back issues of *Gems & Gemology,* the *Goldsmiths' Review* and *Jewellery Studies*.

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MEMBERSHIP

At a meeting of the Council of the Association held on 3 September 2014, Jessica Cadzow FGA was appointed to serve on the Council. The following were elected to membership:

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1–2 November 2014
London
www.gem-a.com/news--events/gem-a-conference-2014.aspx

Geology and Medicine: Exploring the Historical Links and the Development of Public Health and Forensic Medicine
Geological Society, Burlington House, London
2–4 November 2014
http://tinyurl.com/mgr6cfo

GIT 2014: The 4th International Gem and Jewelry Conference
8–9 December 2014
Bangkok, Thailand
www.git2014.com

Jaipur Jewellery Show (JJS) Seminars
20–23 December 2014
Jaipur, India
www.jaipurjewelleryshow.org

ICDCMT 2015: XIII International Conference on Diamond, Carbon Materials and Technology
13–14 January 2015
Zurich, Switzerland
www.waset.org/conference/2015/01/zurich/ICDCMT

Antwerp Diamond Trade Fair
25–27 January 2015
Antwerp, Belgium
www.antwerpdiamondfair.com/EN/the-adtfnews.html

International Diamond School: The Nature of Diamonds and their Use in Earth's Study
27–31 January 2015
Bressanone-Brixen, Italy
www.indimedea.eu/diamond_school_2015.htm

The Original Miami Beach Antique Jewelry Series 2015
28–29 January 2015
Miami Beach, Florida, USA
www.originalmiamibeachantiqueshow.com/TheShow/JewelrySeries.aspx

Compiled by Georgina Brown and Brendan Laurs

AGA Tucson Conference
4 February 2015
Tucson, Arizona
http://accreditedgemologists.org/currevent.php

Hasselt Diamond Workshop 2015, SBDD XX
25–27 February 2015
Hasselt, Belgium
www.uhasselt.be/UH/SBDD-overview/SBDD-overview-SBDD-XX.html

AGS International Conclave
22–25 April 2015
New Orleans, Louisiana, USA
www.americangemsociety.org

Association for the Study of Jewelry and Related Arts 10th Annual Conference
2–3 May 2015
Chicago, Illinois, USA
www.asjra.net/event.html

2015 CIBJO Congress
4–6 May 2015
Salvador, Brazil
http://tinyurl.com/myp9fjv

ICA Congress
16–19 May 2015
Colombo, Sri Lanka
www.gemstone.org/index.php?option=com_content&view=category&layout=blog&id=53&Itemid=38

Society of North American Goldsmiths' 44th Annual Conference
20–23 May 2015
Boston, Massachusetts, USA
www.snagmetalsmith.org/conferences/impact-looking-back-forging-forward

9th International Conference on New Diamond and Nano Carbons
24–28 May 2015
Shizuoka, Japan
www.ndnc2015.org

Jewelry Camp: 2015 Antique Jewelry & Art Conference
30–31 July 2015
West Harrison, New York, USA
www.jewelrycamp.org

EXHIBITS

Asia

A Little Clay on the Skin: New Ceramic Jewellery
Until 9 November 2014
World Jewelry Museum, Seoul, South Korea
www.wjmuseum.com/eng/e_exhibition.html

Europe

L'Oro nei Secoli dalla Collezione Castellani
Until 2 November 2014
Basilica di San Francesco, Arezzo, Italy
www.museistataliarezzo.it/mostre-eventi

Shine 2014—Young Emerging Design Talent
Until 24 November 2014
The Goldsmiths' Centre, London
www.goldsmiths-centre.org/whats-on/exhibitions/shine-2014-young-emerging-design-talent

With their Heads Held High—Headgear from all over the World
30 November 2014–22 February 2015
Schmuckmuseum, Pforzheim, Germany
www.schmuckmuseum.de

Jewelry. Revisited
Until 31 December 2014
Pinakothek der Moderne, Munich, Germany
www.pinakothek.de/en/kalender/2014-03-15/42328/danner-rotunda-jewelry-revisited

Divine Jewellery: The Art of Joseph Chaumet (1852–1928)
Until 4 January 2015
Musée du Hiéron, Saône-et-Loire, France
www.musee-hieron.fr/expositions/exposition-2014

Splendor et Gloria: Five Exceptional 18th-century Jewels
Until 4 January 2015
Museu Nacional de Arte Antiga, Lisbon, Portugal
www.museudearteantiga.pt/exhibitions/splendor-et-gloria

Treasures of the Middle Ages: Archaeological Finds from Poland
Until 15 March 2015
Museen Stade, Germany
www.museen-stade.de/schwedenspeicher/vorschau-ausstellungen

Gold of the Gods from Java
Until 6 April 2015
Wereldmuseum, Rotterdam, The Netherlands
www.wereldmuseum.nl/en/tentoonstellingen/goud-der-goden.html

Iron Urge: Jewellery and Objects Made Out of Iron
Until 11 May 2015
The Estonian Museum of Applied Art and Design, Tallinn, Estonia
www.etdm.ee/en/exhibitions

An Adaptable Trade: The Jewellery Quarter at War
Until 27 June 2015
Museum of the Jewellery Quarter, Birmingham
www.bmag.org.uk/events?id=3307

North America

Treasures from India: Jewels from the Al-Thani Collection
28 October 2014–25 January 2015
Metropolitan Museum of Art, New York, New York, USA
www.metmuseum.org/about-the-museum/press-room/exhibitions/2014/treasures-from-india

Cycles of Life: Rings from the Benjamin Zucker Family Collection
31 October–6 December 2014
Les Enluminures, New York, New York, USA
http://tinyurl.com/k6lhw2o

Glittering World: Navajo Jewelry of the Yazzie Family
13 November 2014–11 January 2016
The National Museum of the American Indian New York, New York, USA
http://nmai.si.edu/explore/exhibitions/item/?id=890

Brilliant: Cartier in the 20th Century
16 November 2014–15 March 2015
Denver Art Museum, Colorado, USA
www.denverartmuseum.org/exhibitions/brilliant-cartier-20th-century

Ancient Luxury and the Roman Silver Treasure from Berthouville
19 November 2014–17 August 2015
The Getty Villa, Pacific Palisades, California, USA
www.getty.edu/visit/exhibitions/future.html

Kiff Slemmons
20–23 November 2014
Gallery Loupe for Contemporary Art Jewellery, Montclair, New Jersey, USA
www.galleryloupe.com/exhibitions.php?sn=0&exhibit=57

Remarkable Contemporary Jewellery
Until 30 November 2014
Montreal Museum of Fine Arts, Quebec, Canada
http://wsimag.com/fashion/9308-remarkable-contemporary-jewellery

***Gems & Gemology* celebrates 80 years, Featuring the Artistry of Harold and Erica Van Pelt**
Until December 2014
Gemological Institute of America, Carlsbad, California, USA
www.gia.edu/gia-museum-gems-gemology-anniversary

From the Village to Vogue: The Modernist Jewelry of Art Smith
Until 7 December 2014
Dallas Museum of Art, Texas, USA
www.dma.org/art/exhibitions/Art-Smith

The Greeks—Agamemnon to Alexander the Great
12 December 2014–26 April 2015
Montréal Museum of Archaeology and History, Old Montréal, Québec, Canada
www.pacmusee.qc.ca

Cartier: Marjorie Merriweather Post's Dazzling Gems
Until 31 December 2014
Hillwood Estate, Museum & Gardens, Washington DC, USA
www.hillwoodmuseum.org/whats/exhibitions/cartier-marjorie-merriweather-posts-dazzling-gems

Blue Moon Diamond [12 ct blue diamond]
Until January 6, 2015
Natural History Museum of Los Angeles County, California, USA
www.nhm.org/site/research-collections/mineral-sciences/temporary-displays/blue-moon-diamond

Arts of Islamic Lands: Selections from the al-Sabah Collection, Kuwait
Until 4 January 2015
Museum of Fine Arts, Houston, Texas, USA
www.mfah.org/exhibitions/al-sabah-collection

René Lalique: Enchanted by Glass
Until 4 January 2015
The Corning Museum of Glass, Corning, New York, USA
www.cmog.org/collection/exhibitions/lalique

Hollywood Glamour: Fashion and Jewelry from the Silver Screen
Until 8 March 2015
Museum of Fine Arts, Boston, Massachusetts, USA
www.mfa.org/exhibitions/hollywood-glamour

Arthur Koby Jewelry: The Creative Eye
Until 5 October 2015
Kent State University Museum, Kent, Ohio, USA
www.kent.edu/museum/exhibits/exhibitdetail.cfm?customel_datapageid_2203427=3506741

Gold and the Gods: Jewels of Ancient Nubia
Until 14 May 2017
Museum of Fine Arts, Boston, Massachusetts, USA
www.mfa.org/exhibitions/gold-and-gods

Middle East

Urartian Jewellery Collection
Until 31 July 2015
Rezan Has Museum, Istanbul, Turkey
www.rhm.org.tr/en/event/rezan-has-museum-urartian-jewellery-collection

Australia and New Zealand

Afghanistan: Hidden Treasures from the National Museum, Kabul
Until 16 November 2014
Western Australian Museum, Perth, Australia
http://museum.wa.gov.au/museums/perth/afghanistan-hidden-treasures

A Fine Possession: Jewellery and Identity
Until 20 September 2015
Powerhouse Museum, Sydney, Australia
www.powerhousemuseum.com/exhibitions/jewellery

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Gem-A, London
www.gem-a.com/education/course-prices-and-dates.aspx

Special Topics in 20th Century Jewelry
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Christie's, New York, New York, USA
www.christies.edu/new-york/courses/short-course-jewelry.aspx

Gemstone Safari
5–22 January and 13–30 July 2015
Tanzania
www.free-form.ch/tanzania/gemstonesafari.html

Montreal School of Gemmology Gem and Jewellery Appraisal Course
6–29 July 2015 (in English and French)
Montreal, Quebec, Canada
www.ecoledegemmologie.com/en/c/10

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New Media

The Antoinette Matlins 'Right Way' Series on Using Gem Identification Tools

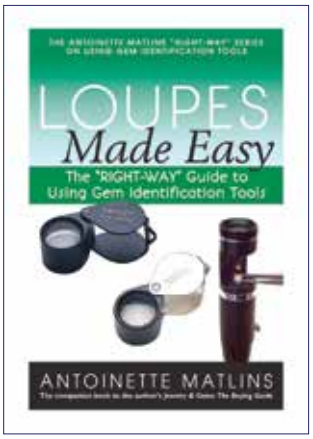

By Antoinette Matlins, 2013. GemStone Press, Woodstock, Vermont, USA, www.gemstonepress.com.

- *Loupes Made Easy,* 57 pages, ISBN 978-0943763941. US$9.99 eBook.
- *Dichroscopes Made Easy,* 52 pages, ISBN 978-0943763965. US$9.99 eBook.
- *Chelsea and Synthetic Emerald Filters Made Easy,* 45 pages, ISBN 978-0943763958. US$9.99 eBook.
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- *Ultraviolet Lamps Made Easy,* 57 pages, ISBN 978-0943763972. US$9.99 eBook.
- *SSEF Diamond-Type Spotter and Blue Diamond Tester Made Easy,* 47 pages, ISBN 978-0943763996. US$9.99 eBook.

The six publications in Antoinette Matlins' 'right way' series are available as e-books. The aim of these guides is to introduce the layperson or novice gemmologist to the correct use of various gemmological tools, giving basic (and some more advanced) techniques, and also providing a reference for the results expected for various stones when tested with each tool.

In the loupe book, Matlins covers the key features to look for when purchasing this basic and essential instrument, including the style of casing, which can affect the colour of the stone under examination. Then basic techniques for good observation are provided, as well as examples of how inclusions can be indicative of certain gems.

From the loupe the series moves on to the dichroscope, and here again Matlins demonstrates, without resorting to scientific detail, how it is possible to obtain usable results. Although a dichroscope is seldom diagnostic on its own, the reader is shown how (in conjunction with other tools) it can help identify a gem.

Next to be considered is the Chelsea Colour Filter (developed by Gem-A), and it is covered in significant detail. After initially describing its correct use (and pitfalls), Matlins provides a comprehensive list of results for stones that the reader might encounter in the market. She also covers the 'synthetic emerald support filter', which provides additional information when evaluating whether an emerald is natural or synthetic.

The refractometer is next under the spotlight and, although this is an instrument that many students struggle with initially, the book provides clear instructions on how to obtain good data and interpret the results. The use of both white and monochromatic yellow light is covered, and the process of reading the measurement is clearly and concisely detailed. A comprehensive list of the RIs of the most common gems is provided in the latter section of the book, but this would benefit from a more tabular layout, with headings on each page. This is a minor point on what is otherwise a useful guide.

The gemmological uses of UV lamps are also given due consideration, and here Matlins is careful to emphasize the dangers associated with short-wave UV radiation, whilst still maintaining the enjoyment of seeing different reactions and colours produced by various gems. Some of the details provided on synthetic diamonds (both here and in the final book of the series on the SSEF Diamond Spotter) have been superseded by changes in technology and production methods, but generally the book provides a good reference to a wide range of fluorescent and phosphorescent effects that should satisfy any gemmologist.

The final book in this series deviates slightly from covering the more standard gemmological tools, insofar as it describes the Swiss Gemmological Institute SSEF's Diamond Spotter. This instrument relies on the use of short-wave UV radiation to separate colourless diamonds into two categories: types IaA, IaAB and Ib (i.e. those not decolorized by HPHT treatment) and types IIa, IIb and rare IaB (i.e. those that may have undergone HPHT treatment). Again, Matlins is careful to remind the user of the dangers of short-wave UV radiation. Although not an everyday tool for most gemmologists, this, along with the Blue Diamond Tester (also from SSEF), is given the same

level of detail as the other tools previously covered. Again, recent changes in technology and production techniques have affected some of the areas covered, but as a guide to get started using these instruments, this is a very good reference.

Although probably not a replacement for classroom training, these 'right way' guides provide a very good and understandable introduction to gem testing, and can, if used correctly, prevent costly gem identification mistakes.

Andrew S. Fellows

London's Lost Jewels: The Cheapside Hoard

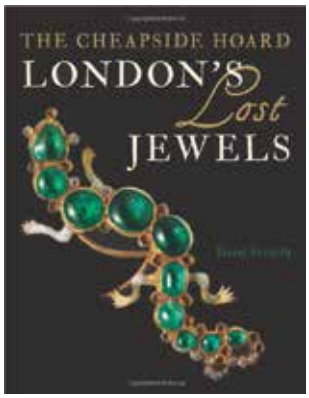

Hazel Forsyth, 2013. Philip Wilson Publishers, London, 248 pages, illus., softcover, www.museumoflondonshop.co.uk/store, ISBN 978-1781300206. £19.95.

Within its 248 pages, Hazel Forsyth has compiled more than one book. It is both history and mystery combined. The history covers the period up to the mid-17th century, a time that saw the plague, the overthrow of the British monarchy and the Great Fire of London. The mystery came to light in 1912 when buildings on the corner of Cheapside and Friday Street were to be demolished due to their subsidence and dangerous condition. They had stood there since 1667, the year after the Great Fire had razed much of the city. Although the name *Cheapside* seems far removed from the realm of precious jewels, in fact the whole area was a hive of industry—particularly for jewellery manufacturing.

With the prospect of redevelopment after the Great Fire, an unusual clause was inserted into the contract between the owners of the property (the Worshipful Company of Goldsmiths) and the building contractors and developers. It stated that any antiquities and articles or objects of interest or value should be preserved by the lessees and handed over to the lessors—the Worshipful Company. As the workmen began to break open the cellar floors, their picks uncovered the stock in trade of a 17th-century jeweller and the biggest cache of its kind in the world.

From the moment of discovery, there was a problem. The workmen did not hand over the jewels to the authorities, but took them to George Fabian Lawrence, better known as 'Stony Jack' (1862–1939): a pawnbroker, dealer, collector of antiquities and sometime employee of the Guildhall and London Museum. He cultivated the navvies of London and by gaining their confidence, was able to acquire 15,000 items in 15 years for what is now known as the Museum of London, which is located in the Barbican, close to Goldsmiths' Hall and the Cheapside Hoard site.

The workmen from the Cheapside site turned up at Stony Jack's office with 'many great lumps of caked earth which revealed intriguing gleams at various points'. The men thought they had unearthed a toyshop. Lawrence set about cleaning off the earth to reveal a treasure of tangled enamelled gold chains, cameos, intaglios, carbuncles, assorted gems and hard stones, rings, pendants and watches—a veritable fortune. Unique to the collection is a watch movement of the period which uses for its casing a Colombian emerald crystal!

The treasure was assembled in the Viscount Harcourt's house, where King George V and Queen Mary had a private viewing, and then was examined by the treasury solicitors on behalf of the crown. Surprisingly there was no treasure trove enquiry, and title to the entire collection of almost 500 pieces was granted to the London Museum.

This book was published on the occasion of an exhibition of the Cheapside Hoard that took place at the Museum of London from 11 October 2013 to 27 April 2014. It is filled with photos that explore and reveal the range of items in the Hoard. Regarding the date when the jewels were hidden, two pieces provide clues. One relic (a complicated timepiece with alarm and calendar) bears the name of the Swiss maker Gaultier Ferlite, which dates the watch to between 1610 and 1620. The other is a cornelian seal with the heraldic engraved swan of the Viscount Stafford. The intervention of King Charles I on his behalf points to a date close to 1640.

Hazel Forsyth has researched the Hoard and its history with extraordinary zeal and scholarship, and the reader is entertained with a wealth of fascinating information. The book is a must for anyone interested in gemstones, jewellery or history.

Alan Hodgkinson

Splendour and Science of Pearls

Dona Mary Dirlam and Robert Weldon (Eds.), 2013. Gemological Institute of America, Carlsbad, California, USA, 139 pages, illus., hardcover, http://store.gia.edu/product_p/0201055.htm, ISBN 978-0873110600. US$89.00.

My first impression of this attractive book was that it resembles an exhibition catalogue. After studying it in more detail, I became convinced that it would serve as a very good reference for anyone wanting to stage a comprehensive exhibition about pearls.

The book is divided into 11 chapters that cover a variety of topics, including the formation of pearls, their localities, pearl culturing, grading systems, treatments, identification procedures and fashion. The book excels in its superb photography that makes it pleasing to look at and renders it a *Bildband* (picture book in German), in the true sense of the word. There are 153 photos that show both rare old pearl jewels and creations by modern designers. Many types of pearls are documented, including traditional types of both saltwater and freshwater origin and exotic ones such as abalone, conch and Melo pearls.

Chapter 1, titled 'What is a Pearl?', deals with the formation and structure of pearls (what the authors call the 'nature of pearls'). Explanations are short and precise, and transmit rather complicated facts in a way that is easy to understand for the beginner, even sometimes putting too much emphasis on simplicity. In this context, I was grateful to see the authors speaking of 'molluscs' and not of 'oysters' (with a few exceptions), thus applying correct terminology. However, I would have liked to see pearls from bivalve molluscs other than *Pinctada* included in the chapter (e.g. Quahog or *Tridacna* pearls), as well as those from other gastropods like *Turbo* or *Cassis*.

Chapter 2, on 'Pearl History', consists of neatly arranged passages that explain the appreciation and evaluation of pearls in human history. An entire chapter (Chapter 3) is dedicated to the history of pearls in India, going from antiquity to the present day; pearls still play an important role in Indian culture. The chapter emphasizes the Mughal period, which has witnessed perhaps the most sumptuous use of pearls in history, and it is illustrated by equally sumptuous, beautiful photographs. Chapter 4, 'Natural Pearl Localities', lists the main pearling areas in order of their importance in history, starting with the Gulf (in the text, the authors speak of the Arabian Gulf while geographically speaking it is still the Persian Gulf), the Red Sea and the Strait of Manaar, and ending with river pearls from China, Europe and the United States. The paragraph on Europe seems rather short, as for example pearls from Bavaria or Saxony are not mentioned. I found it interesting that this chapter explains the ancient bow drill method, a topic that is often neglected in other books.

Chapter 5, 'Cultured Pearl Markets', covers the entire history from the beginnings in Japan to the modern markets for South Sea and Tahitian cultured pearls, as well as China with its varieties of cultured pearl shapes and colours, again illustrated by beautiful photographs (e.g. 'soufflé pearls' and 'fireballs'). Chapter 6, 'Pearl Farming', describes each individual step from collecting or growing the host molluscs to the first harvest. Chapter 7 provides a fine description of the advanced analytical methods that are available for pearl identification, like microradiography, X-ray computed microtomography, infrared spectroscopy, EDXRF and LA-ICP-MS. The chapter is based on a comparison study of Gulf saltwater pearls and Tennessee freshwater pearls, and is exemplary for the methods in pearl testing today that allow for the exact distinction of both natural vs. cultured and saltwater vs. freshwater pearls. The reader learns valuable information and inevitably wants to know more.

Chapter 8, 'How GIA Classifies Pearls', is valuable indeed as GIA was the first institution worldwide to introduce a pearl grading system (which still sets the standard today). The chapter nicely illustrates how size, shape, colour (including overtone and orient), lustre, surface characteristics and matching are determined. Chapter 9, 'Treatments and Identification', reviews dyeing, bleaching, heating, irradiation, coating, polishing and filling. Methods of detection are explained, and in addition to the advanced techniques described in Chapter 7, simple methods are also referred to. Chapters 10 and 11 focus on different types of pearl jewellery and on the influence of fashion and design. Again, the many photographs provide a delight for the reader's eyes.

Every chapter is preceded by a poem that the authors have carefully selected from the literature, going back as far as the Persian poet Saadi, which adds another sophisticated aspect to the significance of pearls as an object of culture.

I found *Splendour and Science of Pearls* to be a very pleasant book to read and look at. It is logically structured and conveys all the necessary basic information in a clearly arranged way.

Elisabeth Strack

Wonders within Gemstones II

Anthony de Goutière, 2014. FriesenPress, Victoria, British Columbia, Canada, 72 pages, illus., softcover, http://anthonydegoutiere.com/the-book, ISBN 978-1460232774. US$23.99.

The new book by Anthony de Goutière is the most recent addition to many publications about the microscopic features of gem materials—in particular, inclusions and surfaces or fractures in gem crystals. This one is mainly artistic, and most of the photomicrographs can easily be viewed as abstract art. There are 60 pages of photos, containing 72 images of various sizes. The book is printed on matt rather than glossy paper, but the quality of the printing is very good. The most abundant gem materials featured in the book are topaz (24 pictures), beryl (17) and quartz (8).

I found a few errors in the descriptions of the photos. The origin of the moldavite on page 10 should be the Czech Republic, as Czechoslovakia has not existed since 1993, and moldavite comes from Bohemia, not Moravia. The 'silica outcrop' in moldavite on page 11 is formed by lechatelierite, which is the most diagnostic feature of genuine moldavite. The needles in a blue sapphire on page 16 are boehmite, not bhoemite. The inclusions in a topaz on page 38 are two-phase, not multi-phase. The red 'beetle-legs' on page 45 are described as lepidocrocite, but they are actually very thin hematite; true lepidocrocite has not been confirmed in quartz. The 'rutile' needles in quartz on page 54 are more probably tourmaline, as they are too white to be rutile. The hematite platelets on page 57 are most probably not in spectrolite (an almost opaque variety of labradorite), but rather are hosted by sunstone (a transparent variety of plagioclase).

However, none of the labelling errors diminish the overall quality of the photomicrography. Indeed, with this book, anybody—not only a gemmologist—can enjoy the beauty found in gems. The images are superb, and personally I would like to have some of them enlarged as posters to hang in my laboratory.

Jaroslav Hyršl

OTHER BOOK TITLES*

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A Beautiful Hobby: Selecting, Salvaging, and Caring for Welo Ethiopian Opal
By Robert L. Nolan, 2014. Self-published, 160 pages, ISBN 978-0692234976. £14.63 softcover or £13.90 Kindle edition.

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* Compiled by Georgina Brown and Brendan Laurs

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* Article freely available for download, as of press time.

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The Fire Within

"For in them you shall see the living fire of the ruby, the glorious purple of the amethyst, the sea-green of the emerald, all glittering together in an incredible mixture of light."

– Roman Elder Pliny, 1st Century AD

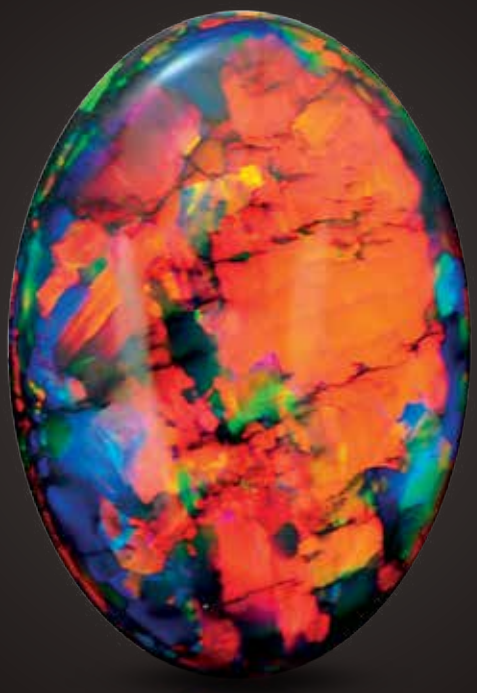

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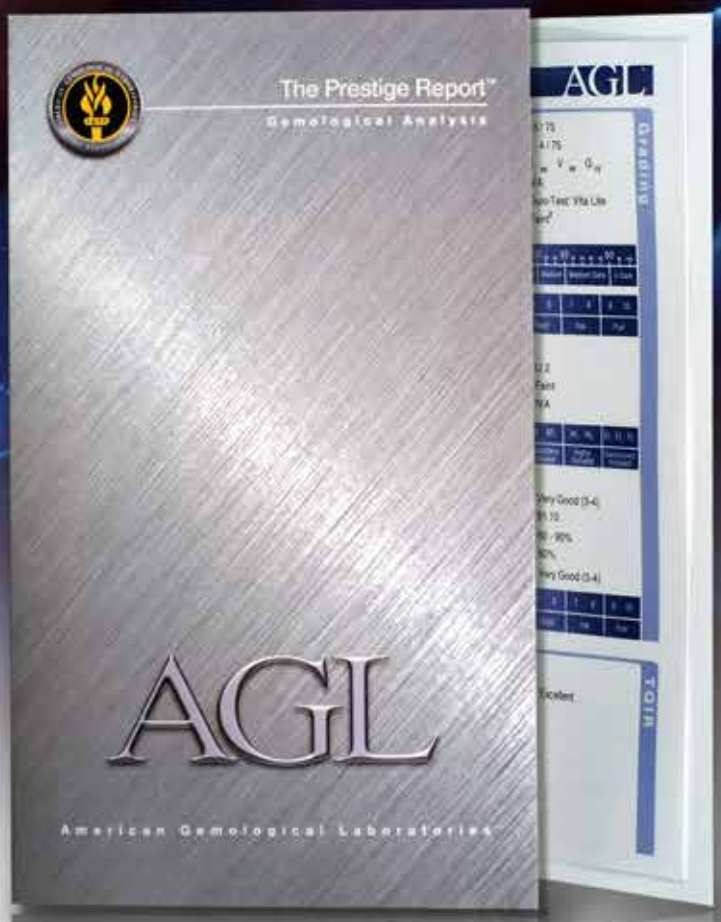

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- **Dr Ulrich Henn**
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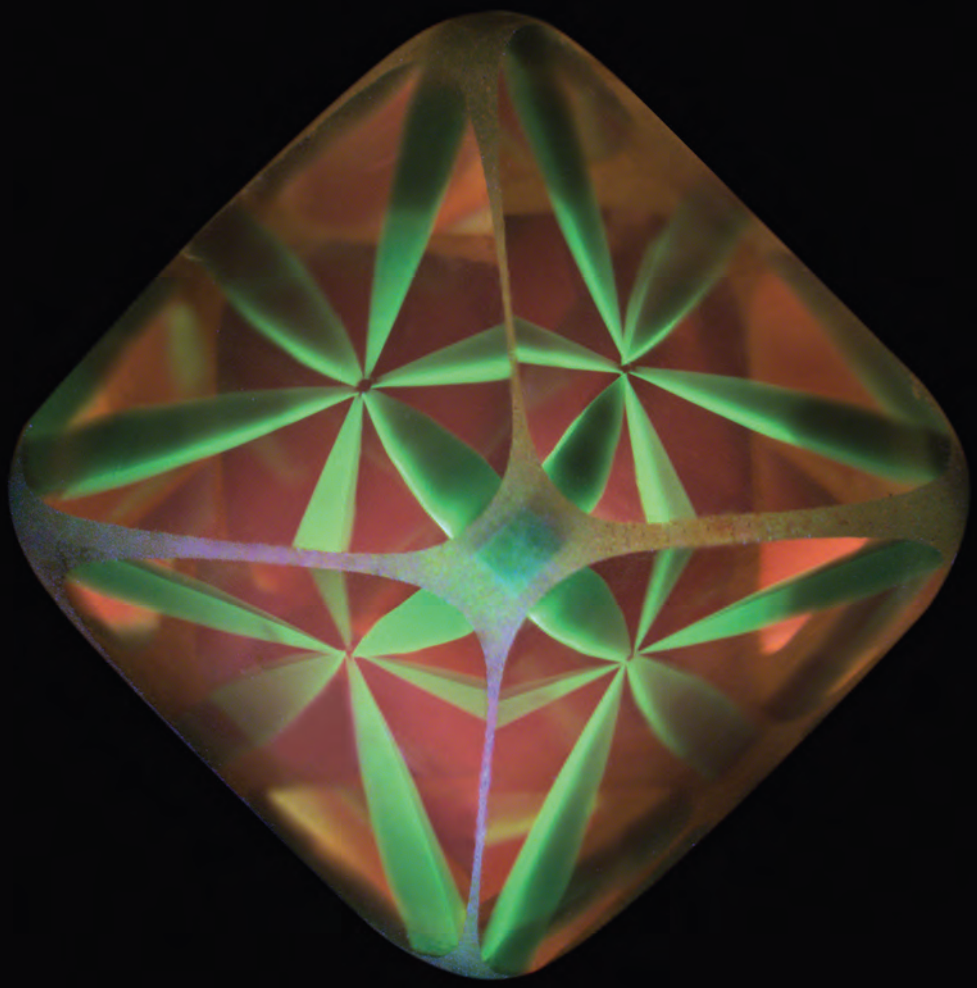

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An 11.38 ct diamond with an asteriated hydrogen cloud is photographed under 250–350 nm broadband UV excitation. See article by Thomas Hainschwang, Franck Notari and Erik Vadaszi on pages 306–315. Photo by T. Hainschwang.

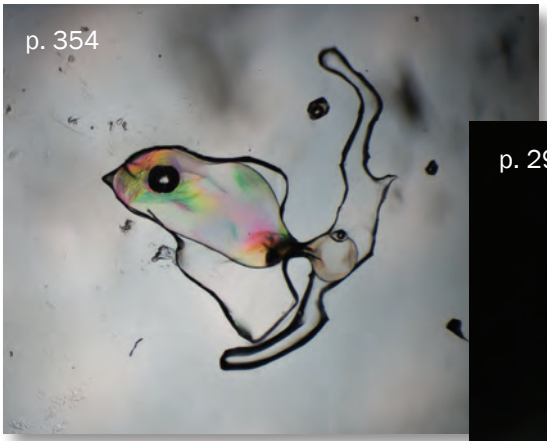

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The Editor-in-Chief is glad to consider original articles, news items, conference/excursion reports, announcements and calendar entries on subjects of gemmological interest for publication in *The Journal of Gemmology*. A guide to the preparation of manuscripts is given at www.gem-a.com/publications/journal-of-gemmology.aspx, or contact the Production Editor.

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What's New

INSTRUMENTS AND TECHNIQUES

GemmoFtir

The GemmoFtir, a new Fourier-transform infrared spectrometer developed specifically for gemmological analysis, was unveiled on 1 November 2014 at the Gem-A Conference in London. The instrument uses a gold-coated DRIFT sampling module and employs user-friendly software that follows the manufacturer's philosophy of providing a consistent platform for all of its spectrometer products. The user interface contains easy-to-follow acquisition wizards and includes searchable spectral libraries for important gem species and their color variations. The software also enables interactive peak labelling and features applications for facilitating spectral interpretation. The GemmoFtir was designed and

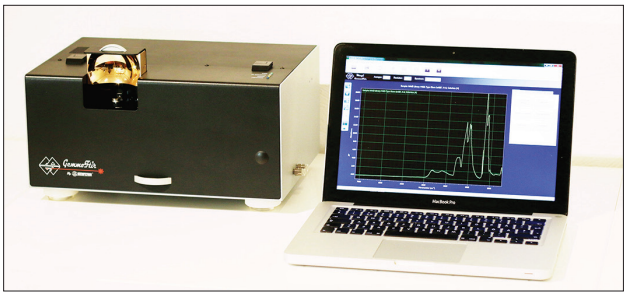

manufactured together with Interspectrum, an Estonian company that has supplied spectrometers for space stations. For more information, visit www.gemmoraman.com/GemmoFtir.aspx.

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NEWS AND PUBLICATIONS

GSJ Abstracts

Abstract of papers presented at the 2014 Annual Meeting of the Gemmological Society of Japan are available for free download at www.jstage.jst.go.jp/browse/gsj. The website also hosts papers from previous GSJ conferences dating back to 2001.

Making polycrystalline diamond under very high pressure: Synthesis and application of ultrahard nano-polycrystalline diamond (Hime-diamond).

Tetsuo Irifune

Geodynamics Research Center, Ehime University; Earth-Life Science Institute, Tokyo Institute of Technology

We succeeded to synthesize pure polycrystalline diamond by direct conversion from graphite at very high pressure and high temperature using Kawai-type multianvil apparatus (KMA), which was found to be made of nano-sized crystals with peculiar fine textures and have extraordinary high hardness. Thus synthesized nano-polycrystalline diamond (NPD or " Hime-diamond ") has following features in addition to its outstanding hardness: higher fracture toughness, higher thermal resistance, and relatively low thermal conductivity, etc., relative to single crystal diamond. NPD is highly transparent, but exhibits rather yellowish in color due to absorption of optical lights in shorter wave lengths, probably because of grain boundary scattering/absorption of sintered diamond crystals. Application of NPD to various high-pressure apparatus has been attempted. In addition to its industrial applications, yielding some promising results particularly in higher pressure generation using diamond anvil cell with relatively large culet size. X-ray absorption studies at high pressure combined with synchrotron radiation, and high pressure generation in multianvil apparatus. The techniques to synthesize NPD are also applied to synthesize high-pressure phases, yielding some novel polycrystalline materials, such as nano-polycrystalline stishovite, nano-polycrystalline cubic BN, and nano- to micro-polycrystalline garnets, some of which are highly transparent and named as "poly-crystalline gems (poly gems). Thus, the KMA has opened a new field of making novel functional

Historical Facet Designs

Year corrected from 2014 to 2013.

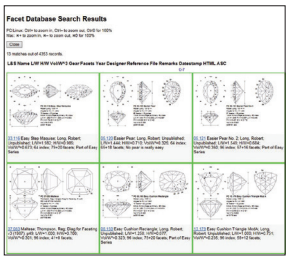

Facet Database Search Results

In June 2013, www.facetdiagrams.org was launched to make a comprehensive collection of faceting diagrams freely available to the hobbyist or professional gem cutter. Users can view nearly 3,900 historical designs that date back to 1902.

ICGL Newsletter

The International Consortium of Gem-Testing Laboratories has released Newsletter No. 4, Fall 2014, available at http://icglabs.org. The theme of the newsletter is sapphire, and it includes reports on HPHT-treated blue sapphires; pink sapphires from Batakundi, Pakistan, showing blue adularescence; cobalt-doped glass-filled blue sapphires; Punsiri-type heat treatment of blue sapphires done in Khambat, India; and heat-treated sapphires from the Nigeria-Cameroon area.

NEWSLETTER Fall 2014

Appearance of new treatment method on sapphire using HPHT apparatus

By Hyun-min Choi, Sun-ki Kim and Young-chool Kim
Hanmi Gemological Institute & Laboratory (GIGL), Seoul, Korea

Margaritologia Pearl Newsletter

A new pearl newsletter prepared by Elisabeth Strack debuted in October 2014, titled *Margaritologia*. It is intended to cover all aspects of natural and cultured pearls, from their history to new developments, including farming, grading, testing procedures, pricing and market trends. The inaugural issue (No. 1, 2014) focuses on cultured pearls from Vietnam; pearl presentations at the International Gemmological Conference in Hanoi, Vietnam; DNA fingerprinting of pearls; *Spondylus* pearls; cultured pearl necklaces produced by Mikimoto in the 1950s; and a report on an exhibition at the Schwerin Museum in Mecklenburg, Germany. The newsletter is published quarterly, in both English and German, and an annual subscription costs €70. To sign up, visit www.strack-gih.de.

Pearl Presentations

Videos of presentations from pearl forums that took place at the Inhorgenta Munich jewellery show (14–17 February 2014) and the Hong Kong Jewelry & Gem Fair (21 June 2014) are freely downloadable at www.sustainablepearls.org/about-contact/events. In addition, a pearl presentation from an earlier Hong Kong Jewellery & Gem Fair (12 September 2013) is available at www.hinatatrading.com/hongkong.pdf.

Proceedings of the Santa Fe Symposium

Papers from this important conference on jewellery manufacturing technology are available for free download at www.santafesymposium.org/papers/year.html. The most recent Symposium proceedings are from 2013, with earlier papers dating back to 1999.

Silver Jewellery Buying Trends

A survey conducted by National Jeweler on behalf of the Silver Institute's Silver Promotion Service showed very strong sales of silver jewellery in the USA in 2013. The report, released in March 2014, is available at www.silverinstitute.org/site/2014/03/18.

OTHER RESOURCES

Pueblo Gem & Mineral Show Lectures

BlueCap Productions has released audio recordings of presentations given at the 2014 Pueblo Gem & Mineral Show in Tucson, Arizona, USA. The podcasts can be heard directly from the website (www.buzzsprout.com/35310) or downloaded as MP3 files.

What's New provides announcements of new instruments/technology, publications, online resources and more. Inclusion in What's New does not imply recommendation or endorsement by Gem-A. Entries are prepared by Brendan Laurs unless otherwise noted.

Visual Optics and the Birefringence/ Dispersion Ratio of Gemstones

Alan Hodgkinson

Gemmologists are familiar with the concepts of birefringence (the maximum double refraction of a gem material) and dispersion (the difference in the refractive index for red and violet light). The latter optical phenomenon is generally beyond the measuring capability of gemmologists, and yet both of these factors are easily accessible to the unaided eye.

In most anisotropic gems, double refraction is easily seen with a 10× loupe. However, to see its effect at maximum will involve some manoeuvring of the stone, and this can be even more difficult with biaxial gems, where the maximum doubling may not be fully visible depending on the orientation of the optic axes in the faceted gem.

Dispersion (fire) catches the eye unsolicited when we are in the proximity of lead-crystal domestic ware, or light crossing the threshold of a glass panel with a bevelled edge. In a faceted gemstone, dispersion typically is seen as flashes of colour that come from various crown facets. These flashes are seen when the gem, or the light source, is moved. While some gem species have more dispersion than others, there are also situations when two gems of the same identity appear to show contrasting fire—a result of differences in their crown and pavilion facet angles. The size of the facets also has a bearing on the apparent fire of a gemstone, but this is purely subjective: the larger the facet, the greater the width of the spectrum seen. However, the constant measure of dispersion is the length of the spectrum from the red to violet extremities of white light.

There is a simple procedure to evaluate the birefringence and dispersion of a gem without any instrumentation. If a faceted gemstone (loose or mounted) is held with the table facet close to the eye and the culet pointed toward a distinct light source (e.g. a fibre-optic light, penlight, candle or even the moon), the light passes through the stone and enters the eye to register on the retina as an array of spectral images, each one corresponding to a pavilion facet, as for the zircon shown in Figure 1. This procedure I christened 'Visual Optics' (Hodgkinson, 1978). The concept appealed to Dr William Hanneman, and in 1980 he authored an article that explored the method further and introduced the concept of the birefringence/dispersion (B/D) ratio—which is obtained simply by dividing the birefringence by the dispersion. A later article explored the Visual Optics principle in more detail (Hanneman, 1982). The method was later taken up and pursued by Dr Don Hoover (1998), who subsequently collaborated with Trevor Linton to provide an extensive list of dispersion measurements and B/D ratios (Hoover and Linton, 2000; Linton, 2005).

Figure 1: The Visual Optics method was used to produce this trio of doubled primaries from a faceted high-type round-cut zircon, which has a B/D ratio of 1.5. Photo by A. Hodgkinson.

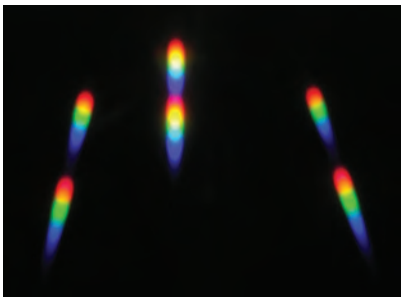

For doubly refractive gemstones, each of the multitude of spectral images seen with Visual Optics will consist of two spectra (corresponding to the birefringent rays) that show various amounts of separation or more commonly superimposition. Double refraction will be evident in some of the images more than in others—seen as a linear separation of the two spectra—dependent on the facet angle to the optic axis. Some will of course be single images, where the direction follows the optic axis.

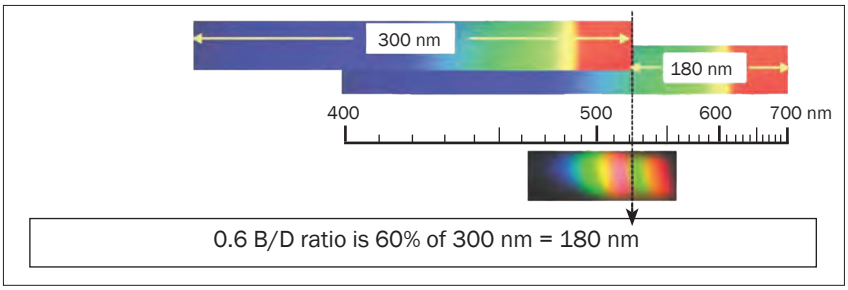

Figure 2: The B/D ratio of quartz is 0.6, which corresponds to the 60% overlap in the doubled primaries seen with Visual Optics. Photo by A. Hodgkinson.

When observing the kaleidoscopic pattern seen with Visual Optics, the B/D ratio is manifested in the widest spacing between the doubled spectral images. For practical purposes, the beginner looks at the gap between the red components of the two images. To see the doubled spectral primary images ('primaries') at their maximum separation, the observer should first locate an image which is obviously doubled, even if the spectral images are partially superimposed. Concentrate on this doubled primary, and then tilt the gem in various directions to coax the doubled primaries to their widest separation. With this spacing, and thus an idea of the B/D ratio, much can be learned instantly in terms of a gemstone's identity, or more commonly, the elimination of possible identities. As this observation can be performed on the spot, wherever the user happens to be (indoors or outdoors), this method provides the gemmologist with useful information—even before reaching for a loupe, which is not always instantly available.

The transparent quartz varieties of amethyst, citrine, smoky quartz and rock crystal are easily accessible to the gemmologist and provide good examples for observing and practising Visual Optics. Figure 2 displays the B/D ratio of quartz (0.6), but what exactly does this number convey? When a faceted quartz is observed with the Visual Optics technique, in no case will the doubled images separate completely. Where doubled, they will always be partially superimposed. By studying one such doubled image and tilting the stone, the partial superimposition will close or open until the B/D ratio 0.6 is seen. This is demonstrated in Figure 2, which shows a photo of a doubled spectral image and the corresponding positions of the superimposed spectra. Bear in mind that the spectral images observed are of a prism format (not a linear diffraction format), as the light has to pass through a faceted gemstone which is an assemblage of prisms. With a B/D ratio of 0.6 (60%), the outer primary spectrum commences at 180 nm (60% of the 300 nm–wide visible spectrum) from the 700 nm red end of the inner spectrum—that is, near the blue-green boundary at 520 nm (700 nm minus 180 nm).

Tourmaline also provides a useful Visual Optic example. With the price escalation of the 'electric' blue and 'neon' green Paraíba-type tourmalines, it is surely useful to have an instant method to check the claimed identity of such a gem—even if it seems an innocent gesture of eyeballing the stone to further enjoy its colour. Dividing the typical tourmaline birefringence (0.02) by its dispersion (0.02), the resultant B/D ratio is 1.0. The significance of this is that when the eye's retina perceives the doubled spectral primary images of a tourmaline at their widest separation, the violet of the inner spectrum of the pair is followed immediately by the red of the outer primary to form a continuous linear repeated spectrum (Figure 3).

Gem dealers initially greeted the amazing Paraíba tourma-

Figure 3: The Visual Optics view of tourmaline shows an outer primary image immediately following the inner primary with no separation or superimposition, corresponding to the B/D ratio of 1.0. The image on the left is from a brightly coloured Paraiba-type gem, while the one on the right is derived from a darker colour-saturated tourmaline (and therefore shows a dimmer outer spectrum that corresponds to the ordinary ray). Photos by A. Hodgkinson.

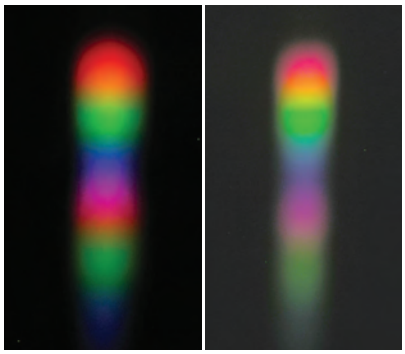

lines with nothing short of incredulity. By an extraordinary quirk of nature, the trade was simultaneously confronted by finds of apatite that showed very similar bright colours (after heat treatment). However the B/D ratio of apatite is very small—with a typical birefringence of 0.003 and dispersion of 0.013, the B/D ratio is only 0.23. This produces a Visual Optic image which is so superimposed that it is quite difficult to see its doubled nature—a problem familiar to the user of a 10× loupe when searching for doubling of the back facets of an apatite.

In all of the darker colour-saturated tourmalines, a further corroboration of the mineral's identity is revealed by the comparative absorption factor of the ordinary and extraordinary rays. The outer image of the spectral pair is the ordinary ray, and it is more heavily absorbed and therefore appears dimmer (Figure 3, right).

The challenge of measuring dispersion explains the rather limited listing of this property in gem reference books. Nevertheless, this 'no-go area' has been vigorously pursued by Hoover and Linton (2000). The measurement of dispersion using a Hanneman/Hodgkinson air refractometer is also described in a forthcoming book by the author titled *Gem Testing Techniques*, due for release mid-2015.

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The following individuals served as guest reviewers during the past publication year. The editors extend their special thanks to all of them for lending their expertise to reviewing manuscripts submitted to *The Journal*. Together with the Associate Editors, these individuals have enhanced the quality of *The Journal* through their knowledge and professionalism.

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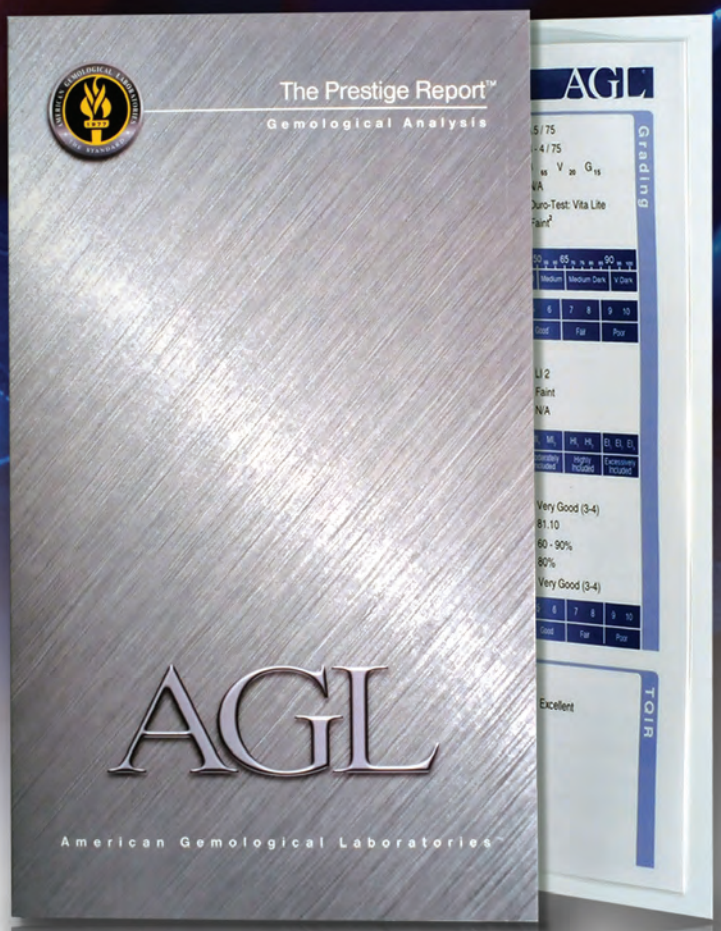

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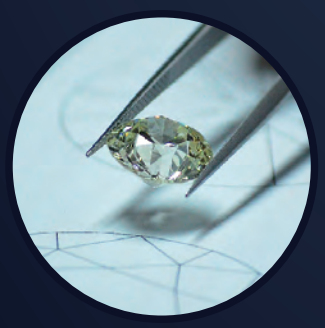

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Gem Notes

COLOURED STONES

Almandine from Erving, Massachusetts

At the Springfield Gem and Mineral Show (Massachusetts, USA) in August 2014, a new production of almandine debuted (see, e.g., www.minerals.net/news/post/2014/09/11/Garnet-from-Red-Embers-Mine-Erving-MA.aspx). The garnets were mined from an area near Erving, Massachusetts, by Jason Baskin of Jay's Minerals (Flemington, New Jersey). Currently named the Red Embers mine, Baskin has been secretly working the deposit with hand tools since 2008. Baskin has heard that a major retailer of fine coloured stone jewellery once sourced garnets from this deposit around the turn of the 20th century, but this has yet to be confirmed. The authors first viewed these garnets in 2009, but due to confidentiality agreements with the owner of the property, no announcements could be made at that time.

According to Baskin, mining these garnets will 'leave their mark' on you. The almandine is hosted by a layer of biotite-graphite schist, and Baskin wears a protective suit (Tyvek; see Figure 1) during the digging process since everything gets coated with a dark, slick layer of graphite. This tough and dirty work would thwart most hobbyist prospectors.

Figure 1: At the Red Embers mine, Jason Baskin wears a Tyvek suit while digging for garnets within graphite-rich schist. Courtesy of Red Embers Mining.

Much of the garnet production consists of attractive mineral specimens (e.g. Figures 2 and 3). Baskin prepares the specimens by carefully removing the matrix from both sides of garnet-bearing schist slabs using an air abrasion tool equipped with plastic media. Light can then be transmitted through the garnets to show their deep red colour (Figure 3). Indeed, with proper lighting one can see how appropriate the 'Red Embers' name is. Most of the specimens contain multiple garnets, while some feature only a single crystal; the largest garnet found to date measures 21.36 mm in diameter. Embedded along the foliation within the graphite of some of the specimens (e.g. Figure 2) are dark needles that have been identified as dravite. Gems up to 4.74 ct (Figure 4) have been faceted from the garnets, although most are less than 0.80 ct (5.5 mm in diameter). Numerous stones have been cut into calibrated sizes.

Eight mineral specimens and 28 cut samples (0.20–4.74 ct) were examined for this report. The faceted material showed a saturated red colour, with faint brown tones seen in some of the gems; none exhibited bluish tones. RI was over the limit of the refractometer, but based on other measured properties, it is estimated at just over 1.81 (cf. Hoover et al., 2008). SG was measured hydrostatically as 4.24, and the magnetic susceptibility of these garnets was determined by D. Hoover as 32.8 SI (see Hoover et al., 2008, for an explanation of magnetic data). Raman spectroscopy indicated the garnet to be predominantly almandine with some spessartine and minor pyrope components. Chemical analysis by energy-dispersive X-ray fluorescence (EDXRF) spectroscopy showed a

Figure 2: This slab of graphite schist (10 × 8 cm) from the Red Embers mine contains several almandine crystals and dravite needles. Photo by B. Williams.

Figure 3: Transmitted lighting shows the ember-like appearance of the garnets in this multi-crystal specimen (16 × 11 cm). Photo by B. Williams.

Figure 4: The largest almandine cut to date from the Red Embers mine is this 4.74 ct round brilliant. The other cut stone (5 mm in diameter) displays the red colour typical of most of the smaller faceted stones. Photo by B. Williams.

high Fe content, consistent with almandine. There was also significant Mn and a minor amount of Ca. However, Mg (being a relatively light element) was below the detection limit of the instrument. Crystal inclusions were plentiful in many of the stones, and although they were not positioned where they could be identified by Raman analysis, most appeared to be apatite, with dark mica (probably biotite) also present. The results obtained from the current samples matched those of the specimens we first examined five years ago.

While the cut stones provided good material for gem testing and inclusion observations, it was the matrix specimens that were our favourite. The red glow of the garnets against the matte silver of the biotite-graphite schist makes for very attractive display pieces, especially when multiple crystals are present.

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Reference

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Observations of Pegmatitic Amethyst from São Paulo State, Brazil

In many parts of the world, construction can be halted by the discovery of ancient ruins or burial sites. In July 2006, during road construction in a rural area of southern São Paulo State in Brazil, an interruption occurred for a different reason—the discovery of a rich deposit of amethyst hosted by granitic pegmatites (see www.cprm.gov.br/publique/media/evento_1776.pdf). The site was rapidly overtaken by *garimpeiros* (Brazilian artisanal miners), causing the government to close the area, which lies approximately 90 km from the city of São Paulo. Due to the local poor economic conditions, the deposit may be reopened to the miners in the future as a potential source of income. However, environmental legislation would require that any future digging be done in a responsible manner.

Recently submitted for analysis by George Williams, a senior buyer for Jewelry Television (Knoxville, Tennessee, USA), was a selection of 39 amethyst gemstones reportedly obtained from this locale. Several of them were quite large, weighing more than 100 ct (e.g. Figures 5 and 6). Standard gemmological testing yielded results that were expected for single-crystal quartz (RI of 1.543–1.552 and hydrostatic SG of 2.65). The samples were a medium strong purple, and straight and angular colour zoning was prominent when they were viewed in certain orientations (Figure 6), which is not unusual for amethyst. No twinning was seen in the samples, which is consistent with the reported pegmatitic origin (Guzzo, 1992). Viewed with darkfield illumination, some of the stones contained numerous, evenly spaced, undulating dotted lines of fluid droplets that were oriented in various directions (Figure 7). Of the 39 stones examined, all but seven contained these inclusions. While fluid inclusions are common in all varieties of quartz, this type and arrangement has not been previously observed by the authors, and a literature search did not reveal any such inclusions in amethyst.

The presence of abundant molecular H_2O was detected with Fourier-transform infrared

Figure 6: Straight and angular colour zoning is evident in this 113.79 ct São Paulo amethyst. Photo by B. Williams.

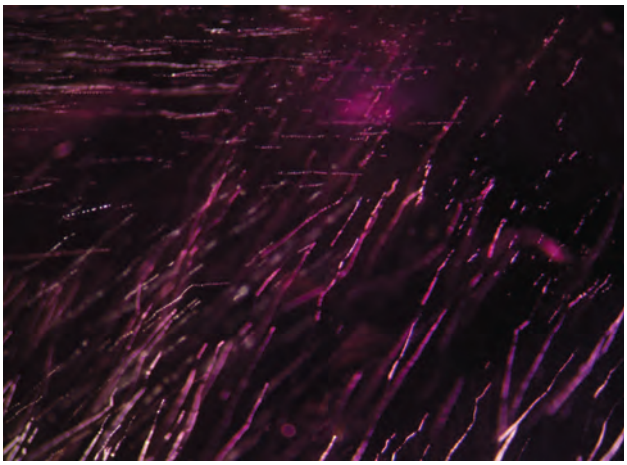

Figure 7: Undulating dotted lines of fluid inclusions such as these were present in most of the São Paulo amethysts examined. Photomicrograph by B. Williams; magnified 35×.

Figure 5: These large amethysts (113.79 and 114.15 ct) are from southern São Paulo State in Brazil. Photo by B. Williams.

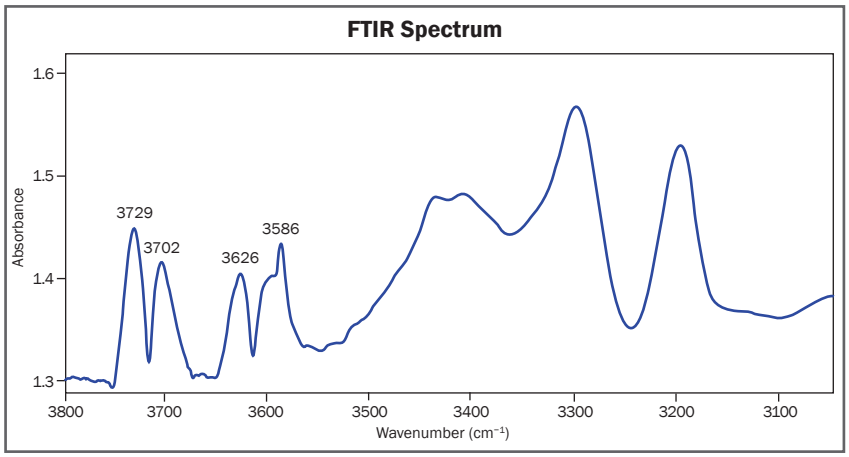

Figure 8: FTIR spectroscopy showed an unusually high water content in the amethyst. The four bands in the 3750–3550 cm^{-1} region correspond to molecular H_2O within the fluid inclusions of this pegmatitic amethyst.

spectroscopy (FTIR; see Figure 8, cf. Fukuda, 2012). This water was trapped in the fluid inclusions described above.

Determining provenance for any material as plentiful and diverse as amethyst is problematic at best, but the unusual fluid inclusions could help differentiate material from this São Paulo locality. In addition to these inclusions, the pegmatitic origin of this amethyst makes it an interesting gem for collectors.

Cara and Bear Williams

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Apatite from Kenya

In September 2013, gem dealer Dudley Blauwet (Dudley Blauwet Gems, Louisville, Colorado, USA) received a 35.1 g parcel of rough green apatite from his supplier in Nairobi. The material was obtained from local dealers who confirmed that it came from the Machakos area in south-central Kenya, but did not want to give more specific location information to protect their source. The parcel consisted of 39 pieces, and after cutting Blauwet obtained 54 stones totalling 30.93 carats that ranged from 0.10 to 3.78 ct each.

Blauwet loaned two of the apatites (1.28 and 3.78 ct; Figure 9) to this author for examination. Their colours were a medium-dark to dark, moderately strong, slightly yellowish green. Refractive indices varied between 1.638 and 1.644, with a birefringence of 0.003–0.005, and the hydrostatic SG of both stones was 3.17. These values are consistent with apatite. Both stones showed remarkably strong dichroism, in bluish green and greenish yellow. No fluorescence was observed under UV radiation, and neither stone showed any well-defined features when viewed with a prism spectroscope. They were moderately included, with growth tube–like inclusions oriented parallel to the c-axis that looked

Figure 9: These apatites (3.78 and 1.28 ct) are reportedly from Kenya. Photomicrograph by Dirk van der Marel.

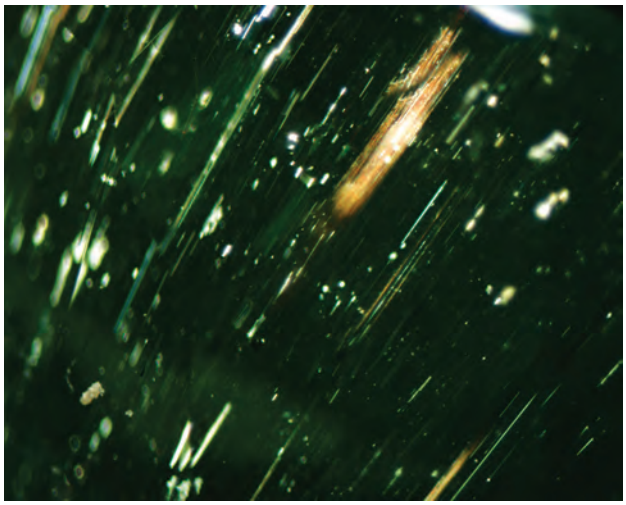

Figure 10: The Kenyan apatites contain long tube-like inclusions that show red-brown reflections in certain orientations. Photomicrograph by J. C. Zwaan; image width 3.5 mm.

transparent or brownish in transmitted light, and in certain directions produced bright red-brown reflections (Figure 10). Oriented at 120° to these features were shorter tubes and long prismatic mineral inclusions. None of the inclusions could be identified by Raman spectroscopy due to the strong fluorescence generated by the apatite when excited by the laser. However, Raman spectra of the host gemstone did give close matches with reference spectra for fluorapatite, $Ca_5(PO_4)_3F$.

EDXRF spectroscopy showed Ca and P as the main elements, and also revealed traces of Mn (~0.1 wt.% MnO) and Fe (~0.05 wt.% FeO). FTIR spectroscopy recorded a relatively weak but significant band at about 3550 cm^{-1} (Figure 11), which indicated the presence of some hydroxyl groups (OH). It is known that varying percentages of F can be replaced by OH in fluorapatite (Shi et al., 2003; Rodrigo, 2005). The presence of a band at 3540 cm^{-1} confirms that the main crystal structure corresponds to fluorapatite with trace substitutions of hydroxyl groups (OH-F pairs), while a small but clear band at 3494 cm^{-1} indicates minor replacement of Cl by OH (Tacker, 2004). Hydroxyl groups of pure hydroxyapatite (OH-OH pairs) show a peak at 3573 cm^{-1} (e.g. Rodrigo, 2005). In the present apatites, the position of the main peak at 3550 cm^{-1}—which is also seen in fluorapatite from other localities (e.g. Durango, Mexico, and Tamil Nadu, India)—could be due to a combination of OH-F with the edges of the OH-OH peak, which shifts the apparent maximum from 3540 cm^{-1} to higher wavenumbers (cf. Tacker, 2004).

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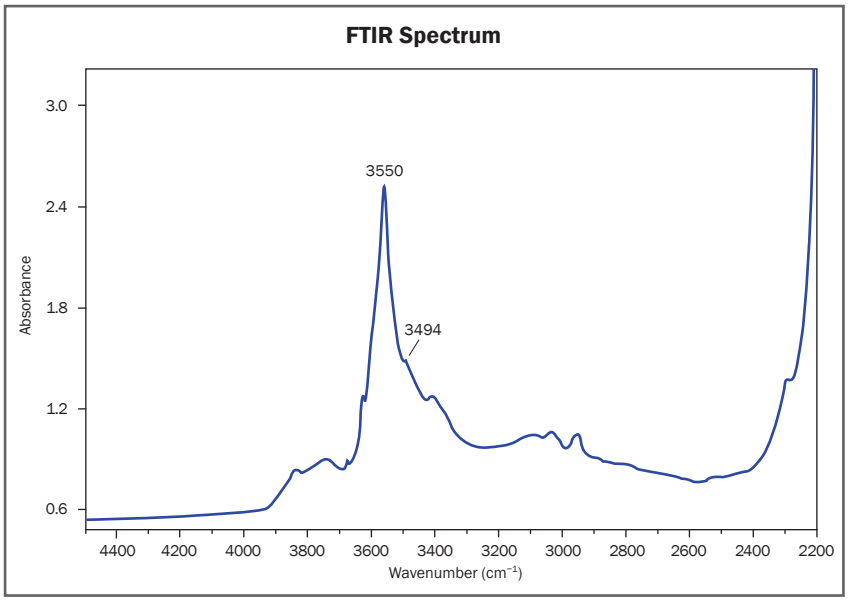

Figure 11: FTIR spectroscopy of both stones indicated that they are fluorapatite, with a diagnostic peak at 3550 cm^{-1}, mainly indicating replacement of F by OH, and a minor peak at 3494 cm^{-1}, showing that some Cl has been replaced by OH.

Colourless to Near-colourless Diopside from Canada and Kenya

Diopside, a calcium-magnesium clinopyroxene ($CaMgSi_2O_6$) and Mg-rich end-member of the diopside-hedenbergite series (Deer et al., 2013), is rather unusual as a gem material. It is commonly greenish brown (mostly due to iron impurities) to dark brown (typically as cabochons displaying asterism), but its most attractive gem variety is emerald-green Cr-diopside from Russia.

Gem-quality colourless to near-colourless (thus chemically rather pure) diopside has been described from the Mogok Stone Tract in Myanmar (Themelis, 2008), Tanzania (Milisenda and Wehr, 2009) and Kenya (Renfro and Shen, 2012), in rather small sizes (generally <2 ct). These gems reportedly formed in contact-metamorphosed Ca-rich sediments (e.g. skarns) and silica-enriched marbles (Themelis, 2008; Deer et al., 2013).

Recently the author had the opportunity to examine five samples of colourless diopside from an additional locality—Canada—and compare them to some from Kenya (e.g. Figure 12). The samples were supplied by gem dealer Brad Payne (The Gem Trader, Cave Creek, Arizona, USA). He obtained the Canadian samples at the 2014 Tucson gem shows in Arizona, USA, from Brad Wilson (Coast-to-Coast Rare Stones International, Kingston, Ontario, Canada). Wilson stated that the gems were cut from old rough material that was mined more than 20 years ago in Cawood, Quebec. He had around 20–30 carats of cut stones in the 0.25–1.5 ct range. The Kenyan samples were selected by Payne at the 2010 Tucson gem shows from approximately 100–200 faceted pieces that mostly weighed less than 0.50 ct (larger stones were rather included).

Analysed for this report were two stones from Canada (0.64–0.91 ct) that were absolutely colourless, and three samples from Kenya (0.13–0.25 ct) that were very pale yellow. Raman analyses of all five samples revealed spectra that perfectly matched our diopside references. The properties measured for one sample each from Canada (0.91 ct) and Kenya (0.25 ct) fit well with reported values in the literature (Deer et al., 2013): RIs of 1.667–1.695 and 1.670–1.695, birefringence of 0.028 and 0.025, and hydrostatic SG of 3.28 and 3.30, respectively. The properties obtained for the Kenyan sample were consistent with those reported by Renfro and Shen (2012). The EDXRF chemical compositions of the two samples showed slight differences in Fe content (0.24 wt.% FeO in the colourless Canadian diopside and 0.40 wt.% FeO in the very pale yellow Kenyan sample; Table I). The Canadian diopside contained a marked concentration of Na (2.23 wt.% Na_2O), but this element was below the detection limit in the Kenyan sample.

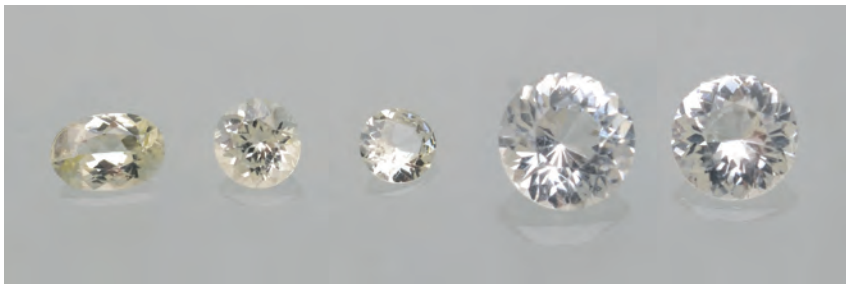

Figure 12: Studied for this report were these three near-colourless diopsides from Kenya (0.25, 0.24 and 0.13 ct from left to right) and two colourless diopsides from Canada (0.91 and 0.64 ct). The slightly higher Fe concentration in the samples from Kenya is responsible for their very pale yellow colour. Photo © M. S. Krzemnicki, SSEF.

*Table I: Chemical composition of the analysed diopside samples.**

Location	Kenya	Canada
Weight (ct)	0.25	0.91
Colour	Very pale yellow	Colourless
Long-wave UV	Inert	Orange
Oxide (wt.%)		
SiO_2	47.4	47.0
TiO_2	0.11	0.08
MgO	22.9	23.3
MnO	0.01	0.05
FeO	0.40	0.24
CaO	28.7	26.7
Na_2O	nd	2.23
K_2O	0.08	0.07
Total	**99.6**	**99.7**

* V and Cr were analyzed for, but not detected. Abbreviation: nd = not detected.

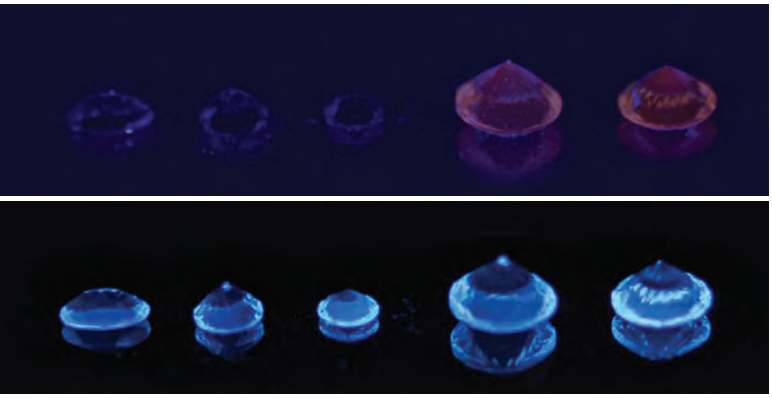

Figure 13: The three samples from Kenya (left side) and the two larger diopsides from Canada (right side) are shown under long-wave (top image) and short-wave (bottom image) UV radiation. The orange reaction of the Canadian diopsides under long-wave UV is quite marked. Photos © M. S. Krzemnicki, SSEF.

Microscopically, all five investigated samples contained a few tiny fluid inclusions and partially healed fissures ('fingerprints'). One of the Canadian specimens additionally had some slightly curved hollow tubes. All samples showed a characteristic strong doubling effect under the microscope due to their high birefringence.

Interestingly, the studied diopsides from these two different localities showed distinctly different reactions to long-wave UV radiation (Figure 13). The samples from Canada exhibited a distinct orange reaction, whereas those from Kenya were inert. This difference in fluorescence was also noted in their PL spectra (taken with 514 nm laser excitation); the sample from Canada had a distinct and broad PL band centred at about 580 nm (Figure 14). When exposed to short-wave UV radiation, all of the samples showed an equally bluish white reaction. This observation of varying UV reactions for diopside has been previously reported in the literature (Henkel, 1988–1989). In this case, however, this property allows a quick separation of these diopsides from Kenya and Canada. Nevertheless, not all Kenyan diopside shows the same fluorescence: the colourless samples studied by Renfro and Shen (2012) fluoresced a strong chalky greenish yellow to short-wave UV radiation and were inert to long-wave UV.

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Figure 14: PL spectra (using 514 nm laser excitation) of two selected diopsides from Kenya and Canada show distinct differences. The Canadian diopside has a strong PL band (at about 580 nm), whereas the sample from Kenya exhibits only very weak PL emission.

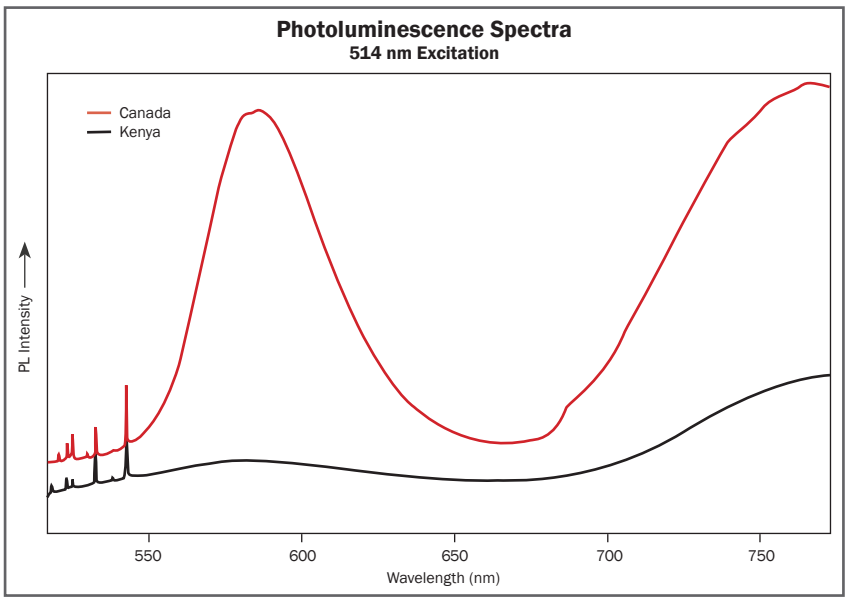

Hessonite from Somalia

Somalia is not often reported as a source of gem materials, although small amounts of beryl (emerald and aquamarine), quartz and pyrope are known from there (Eliezri and Kremkow, 1994). Recently, another gem was found there—hessonite. According to gem dealer Dudley Blauwet, his supplier encountered the rough garnet in July or August 2011 in Nairobi, Kenya, where there is a large population of Somalis. He obtained about 10 pieces of rough ranging from orange to 'honey'-tan to red-brown, and Blauwet had them faceted into stones weighing 0.18–1.05 ct. His supplier is not aware of any additional production of this garnet.

Figure 15: This 1.05 ct hessonite, reportedly from Somalia, shows an attractive orange colour and good transparency. Photo by Bilal Mahmood.

Blauwet loaned a 1.05 ct orange faceted hessonite (Figure 15) to the American Gemological Laboratories for examination. The RI of 1.741 and faint band at 430 nm in the absorption spectrum were consistent with grossular (Stockton and Manson, 1985). This identification was confirmed by FTIR and EDXRF spectroscopy. Microscopic examination showed small flake-like inclusions as well as transparent needle-like and tabular crystals. The roiled appearance that is typical of some hessonite was not obvious in this sample.

It is always interesting to see gem varieties that reportedly come from new sources, and this hessonite from Somalia is no exception.

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Polycrystalline Kyanite from Tanzania

Recently the Swiss Gemmological Institute SSEF received two samples of a blue translucent material from Tanzania for examination (Figure 16). They consisted of a sawn waterworn pebble and a 1.72 ct faceted stone that was cut from the same piece. The pebble was obtained by gem dealer Farooq Hashmi in December 2013 while on a buying trip in Arusha. The person who sold him the stone was unaware of its identity, but noted that it was very hard.

Testing of both samples revealed an anisotropic polycrystalline optic character (i.e. always bright in the polariscope). As a consequence of this, it was difficult to obtain a precise RI value on the refractometer; the faceted sample showed an indistinct reading of approximately 1.72. SG was

Figure 16: These translucent blue samples proved to be polycrystalline kyanite. The sawn pebble (7.48 ct) is what remains after cutting of the pear-shape gem (1.72 ct). Photo © M. S. Krzemnicki, SSEF.

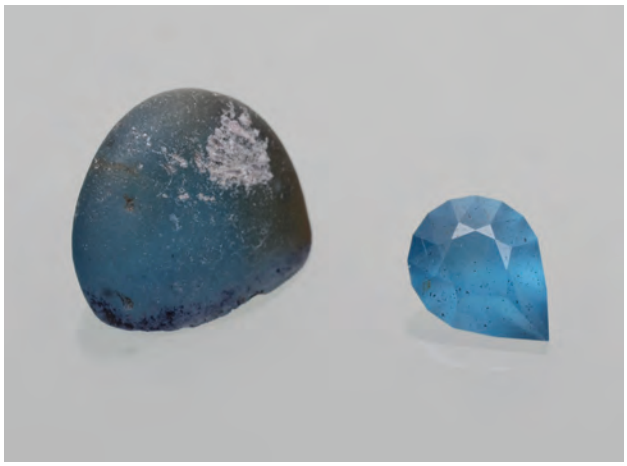

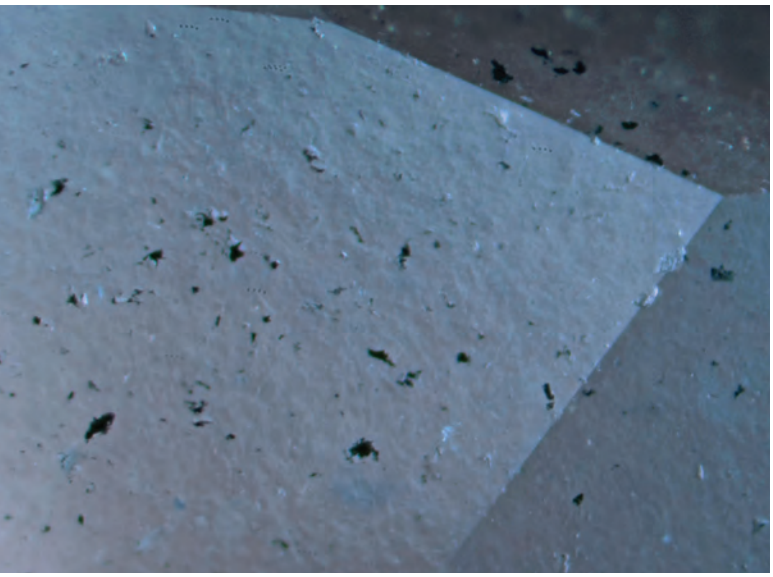

Figure 17: Viewed with the microscope, the faceted polycrystalline kyanite showed a treacle-like appearance and numerous black residues of polishing powder in small cavities on the polished surface. Photomicrograph © M. S. Krzemnicki, SSEF; magnified 60×.

determined to be 3.67 for both samples using a hydrostatic balance. They were inert to long- and short-wave UV radiation. Since the identity of the material was still not evident after this initial testing, it was analysed by Raman spectroscopy, which revealed a distinct kyanite spectrum. This identification was also in agreement with the RI and SG values. Chemical analysis confirmed that it was kyanite, showing Al and Si as main constituents, with small amounts of Fe and Ti, as well as traces of Cr, V, and a few alkaline earths. The blue colour of kyanite is most commonly linked to intervalence charge transfer of Ti^{4+}-Fe^{2+} (elements present in this sample) through the replacement of two Al^{3+} ions on adjacent crystal sites (Platonov et al., 1998; Henn and Schollenbruch, 2012; Krzemnicki, 2013); this mechanism is also well known in blue sapphire.

Microscopic observation revealed an interesting treacle-like appearance (Figure 17), similar to polycrystalline hessonite, created by an abundance of tiny fluid inclusions along kyanite grain boundaries. As a consequence of its microgranular nature and the directional hardness of kyanite, polishing of this material obviously was quite difficult, resulting in numerous black accumulations of polishing powder in small cavities on the surface of the faceted stone (again, see Figure 17).

To the author's knowledge, this is the first time that polycrystalline kyanite of gem quality has been reported. Hashmi has not encountered any other examples of this material on previous or subsequent buying trips.

Michael S. Krzemnicki

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Green Daylight-Fluorescent Hyalite Opal from Mexico

At the 2014 Tucson gems shows, some interesting rough specimens of transparent hyalite opal from Mexico entered the market (Moore, 2014). The material shows noticeable green fluorescence in daylight (e.g. Figures 18 and 19-left), but when viewed in incandescent light there is almost no body colour (Figure 19-right). Although production of this opal is quite limited, one of the authors (PM) obtained several pieces of rough material, and five faceted stones ranging from 0.83 to 3.84 ct were cut by Michael Gray of Coast-to-Coast Rare Stones, Fort Bragg, California. In October 2014, author PM visited the opal deposit in the mountains of western Zacatecas State (Figure 20) and obtained more material from the miners. The opal occurs as botryoidal coatings or crusts within iron oxide-filled fractures cutting a quartz-rich devitrified rhyolite welded tuff.

Twelve rough specimens and three faceted stones (0.83–1.81 ct) were examined by one of us (EF). RI was approximately 1.45 (measured with white light), and hydrostatic SG ranged from 2.12 to 2.16; these values are typical for opal. The absorption-related body colour was light to very light yellow (near-colourless). When properly faceted, the gem may concentrate the daylight fluorescence to display a brilliant green appearance. The green emission is much less noticeable in weak lighting and in incandescent light. A UV lamp causes intense green luminescence, generally slightly brighter in short-wave than long-wave, which is also classic behaviour for opal.

Raman spectra of 10 samples were collected using a Bruker RFS100 Fourier-transform Raman spectrometer equipped with a 1064 nm near-infrared Nd:YAG laser (400 mW power), at a resolution of 4 cm^{-1}. The main feature was a broad band with an apparent maximum at about 450 cm^{-1}, indicating that the material is opal-A (*A* for amorphous). Narrower bands were present at approximately 1550, 1075, 975 and 790 cm^{-1}, all characteristic of opal (Ostrooumov et al., 1999). However, this material has a very different appearance from typical opal-A from Australia. The transparency and botryoidal morphology indicate that it is most likely opal-AN (i.e. amorphous with a network- or glass-like structure). Often called hyalite in gemmology, this is probably the rarest gem opal variety.

A Horiba Jobin-Yvon FluoroLog-3 spectrofluorimeter was used to gather both emission and excitation spectra of three opal samples. The green luminescence is a typical uranyl emission, with a wide band that extends from about 400 nm (end of the blue range) to slightly past 600 nm (red region). There were four maxima, with the strongest at about 524 nm (in the green region, as expected).

Figure 18: This specimen (4 cm tall) of daylight-fluorescent opal from Mexico shows the typical botryoidal appearance of this material. P. Megaw specimen; photo by Jeff Scovil.

The excitation spectrum (which measures the wavelengths that excite a given luminescence) showed a broad band from about 400 to 440 nm, with an apparent maximum at about 420 nm, all in the violet region. This maximum explains why daylight, which contains violet wavelengths, so effectively excites the luminescence.

The presence of uranium was confirmed by EDXRF analysis on three samples using a Rigaku NEX CG spectrometer, which showed approximately 2,000–4,000 ppmw UO_2 (an estimated range since the water content of the

Figure 19: The green appearance of the 3.44 ct opal trilliant (left, photo by Tino Hammid) is due to its daylight fluorescence. The 2.81 ct oval (right, photo by Michael Gray) shows the near-colourless body colour of the opal when viewed in incandescent light. Both gems were cut by Michael Gray and are courtesy of P. Megaw.

Figure 20: In western Zacatecas State, miners dig shallow trenches (indicated by the arrow) along the base of a hill in search of opal. They follow iron-oxide-filled fractures cutting a rhyolite welded tuff. Photo by P. Megaw.

opal is unknown). Nevertheless, a study of these three faceted samples at the School of Mines in Nantes showed that their radioactivity was not dangerous. Their dose rate was measured with a Canberra Inspector 1000 instrument (NaI detector) for approximately one-half hour. The samples were measured together (total weight ~4 ct), yielding a dose rate that fell within background levels of 0.052–0.065 µSv/h.

This new Mexican gem, currently marketed as 'Electric Opal', is a rare example of opal-AN that is thick and transparent enough to be faceted. Usually such material is cut into flat cabochons, such as 'Satin Flash Opal' from Utah. It is also one of the rare gems that is almost exclusively coloured by luminescence.

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Quartz with Radiating Fibres, Sold as 'Trapiche' Quartz

Rock crystal is well known for containing a wide variety of inclusions. However, it is rare for these inclusions to create interesting optical effects.

During the 2014 Tucson gem shows, dealer German Salazar (Bogotá, Colombia) had some interesting tablets of colourless 'trapiche quartz' from Colombia. He stated that the quartz was found in 2011 in the Boyacá and southern Santander Departments, about 300 km (190 miles) north of Bogotá by road. Artisanal miners produced ~300 kg of quartz crystal clusters, but only 6 kg showed the optical phenomenon,

which is restricted to areas near the base of the specimens. The optically interesting areas were not visible from the outside of the specimens, but only after they were sawn in a direction perpendicular to the c-axis of the quartz crystals. The tablets were cut from phenomenal portions measuring 10–45 mm in diameter and up to 40 mm thick, so large amounts of quartz had to be processed to find the areas of interest.

Salazar kindly donated a 25.18 ct tablet to Gem-A, and it was examined by one of the authors (MSK) for this report. The hexagonal cross-section was cut perpendicular to the main c-axis of a quartz crystal, and was polished as a slightly domed cabochon (Figure 21, top). It exhibited very fine and slightly curved fibres (presumably hollow) that extended radially from a nearly inclusion-free central part of the quartz crystal (Figure 22). A closer look with the microscope revealed that these fibres were not continuous, but rather 'dotted'. They emerged in bundles from a slightly milky zone (presumably due to sub-microscopic hollow fibres) at the spiky interface with the relatively clean core.

The fibres appear to represent growth channels that formed perpendicular to the growing prism faces (parallel to the growth direction), similar to the so-called comet structures seen, for example, in corundum (Gübelin and Koivula, 2008). Much less probable is that these features are hollow remnants of dissolved fibrous minerals that originally grew syngenetically with the prism faces of the quartz crystal. It was not possible to identify any mineral phase within these fibrous structures by Raman microspectroscopy. The irregular and spiky interface between the fibrous quartz and the nearly inclusion-free core may be due to an initial episode of deep natural etching by a corrosive fluid. This would have then been followed by a second stage of quartz growth that was intensely disturbed by growth perturbances, resulting in the fibrous channels.

The radiating structure of this quartz is particularly noticeable when viewed in cross-polarized light (Figure 21, bottom). Although this pattern is reminiscent of the trapiche growth phenomenon shown by some minerals (e.g.

Figure 21: This 25.18 ct tablet of quartz shows a fine radiating fibrous structure (top), which is particularly noticeable when viewed between crossed polarizers (bottom). Gift of German Salazar; photos © L. Phan, SSEF (top) and by B. M. Laurs (bottom).

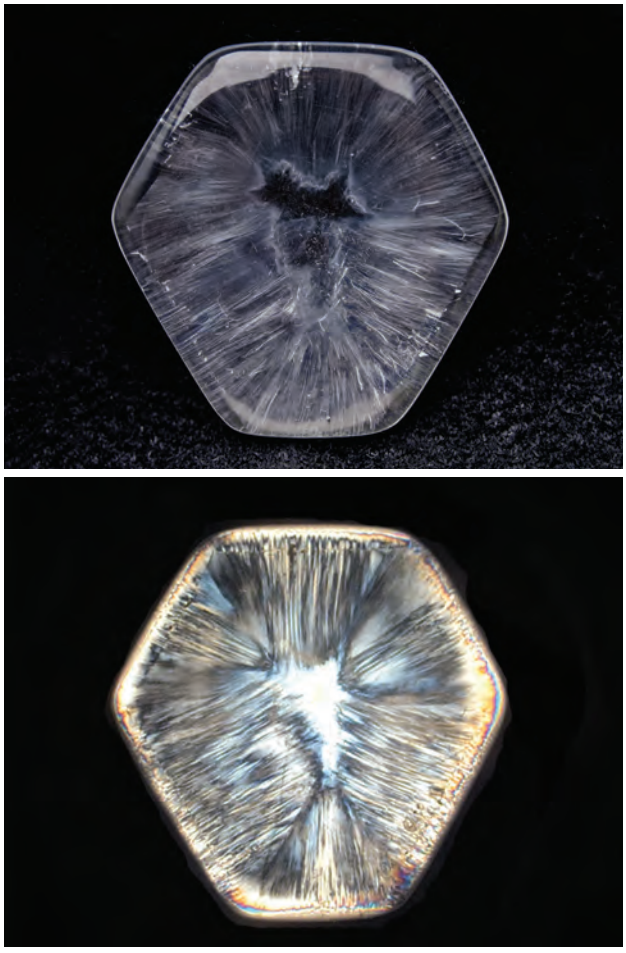

Figure 22: This closer view of the studied quartz shows the nearly inclusion-free core with an irregular spiky outline that is overgrown by a second quartz generation containing a fine fibrous pattern. The fibres are presumably hollow, and they are interpreted as growth channels due to perturbances at the growing prism faces. Photo © M. S. Krzemnicki, SSEF; image width 13 mm.

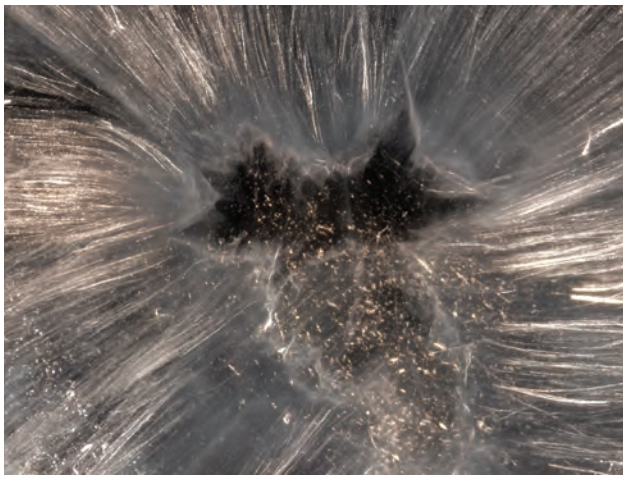

Figure 23: The skeletal crystal growth pattern in the two trapiche rubies at the bottom right shows distinct differences from the quartz studied for this report. Photo © L. Phan, SSEF.

ruby), the observed phenomenon is not the result of growth dynamics responsible for the trapiche pattern, and is also quite different in appearance (e.g. Figure 23). Previous studies have attributed the trapiche structure to skeletal crystal growth during which the edges of certain crystal planes grew much faster than the faces themselves (e.g. Schmetzer et al., 1996; Sunagawa, 2005).

Nowadays, the term *trapiche* is widely used in the gem trade for any material showing a fixed star-like pattern. Based on the fact that *trapiche* should be used only to describe material showing a skeletal growth pattern, one of the authors (MSK) suggests using another name for fixed star-like patterns of other origins. One possibility is the term *Polaris* (also known as the North Star, which is a fixed star in the northern hemisphere). Therefore 'Polaris Quartz' could be a poetic option for this interesting material that shows a fixed-star pattern.

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Brendan M. Laurs

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Yellow Scheelite from Khaplu, Pakistan

In early 2012, gem dealer Dudley Blauwet obtained a large piece of rough 'golden' yellow scheelite that reportedly came from the Khaplu area, Ghanche District, Gilgit-Baltistan (formerly Northern Areas), Pakistan. He first encountered scheelite from this locality in the 1990s, and most of it was orange-brown although rare pieces were red and weighed 7+ ct after faceting. The sample he obtained in 2012 weighed 102 g, but only a small part of it was cuttable. In January 2014 his cutting factory returned 34 stones weighing a total of 19.56 carats, which ranged up to 4.28 ct.

Blauwet loaned the 4.28 ct oval brilliant cut to this author for examination. It showed a light, slightly brownish, yellow colour with a high lustre and strong dispersion, somewhat similar to diamond (Figure 24). Doubling of the pavilion facets was readily seen when looking through the table with low magnification, which indicated a rather strong birefringence (the RI values were above the limit of a standard refractometer). The stone was virtually clean, with only one small cleavage fracture near the culet. Viewed with a prism-type spectroscope, the sample showed faint but sharp lines at about 560 and 570 nm, and a narrow grey band at ~580–590 nm. It fluoresced strong whitish blue to short-wave UV radiation, and very weak orange to long-wave UV. These properties, and its hydrostatic SG of 5.94, are consistent with those expected for scheelite. The absorption spectrum is attributed to the presence of 'didymium', a mixture of the rare-earth elements praseodymium and neodymium, and similar spectra are known in scheelite from other occurrences (e.g. Gunawardene, 1986; Dedeyne and Quintens, 2007). EDXRF chemical analysis

Figure 24: This 4.28 ct scheelite from Khaplu, northern Pakistan, exhibits an unusually light colour for material from this locality. Photo by Dirk van der Marel.

confirmed the presence of Ca and W as major elements; no minor elements were detected.

The FTIR spectrum exactly matched the spectra of brownish yellow scheelite from Sri Lanka (Godakawela, Sabaragamuwa Province) and colourless scheelite from Mexico (Santa Cruz, Sonora State), both present in the Dr Edward J. Gübelin Gem Collection and documented in the GIA Gem Project (i.e. https://s3.amazonaws.com/gubelin/scheelite-34884.pdf and https://s3.amazonaws.com/gubelin/scheelite-34472.pdf). The Raman spectrum matched very well with the spectra of both yellow and colourless scheelite from Sonora, Mexico, that are present in the RRUFF database (http://rruff.info/scheelite), with well-defined peaks at approximately 911, 837, 796, 399, 332, 210, 114 and 82 cm^{-1}. The peaks at 911 and 796 cm^{-1} are due to the stretching of the WO_4^{2-} anion in the structure of scheelite, whereas those at 399 and 332 cm^{-1} are caused by the bending of this anion (Frost et al., 2004).

J. C. (Hanco) Zwaan

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Spessartine from the Democratic Republic of Congo

In approximately 2009, some unusual yellow-brown crystals were purchased by gem dealer Dudley Blauwet from his East African supplier. His supplier obtained them in Kenya from someone who had reportedly brought them from the Democratic Republic of Congo (DRC). Because of their elongate habit, his supplier thought they were zircon. However, subsequent testing at the Gemological Institute of America laboratory in Carlsbad showed they were actually spessartine (D. Blauwet, pers. comm., 2014). Blauwet planned to sell the crystals to mineral collectors, but due to their small size he eventually decided to have them faceted. He had ~40 stones cut that ranged from 0.20 to 0.84 ct, and loaned four of the faceted samples (0.62–0.84 ct; Figure 25) to the American Gemological Laboratories for examination.

The most interesting characteristic of these spessartines is their unusual yellow-brown colour, quite different from the typical orangy yellow to yellow-orange that is shown by this garnet species. As expected for spessartine, the RI of all samples was over-the-limit of a standard refractometer. Their SG values ranged from 4.19 to 4.21, consistent with spessartine. Inclusions in all the stones consisted of small flake-like particles, partially healed fissures and goethite

Figure 25: These near–end-member spessartines (0.62–0.84 ct), reportedly from the Democratic Republic of Congo, display an unusual yellow-brown colour. Photo by Bilal Mahmood.

(identified by Raman spectroscopy). EDXRF analysis showed major amounts of Si, Al and Mn, and traces of Fe and Mg; this is consistent with nearly pure spessartine. Visible-range spectroscopy showed strong absorptions at 409, 430, 461 and 485 nm, all of which are due to Mn^{2+} (Manning, 1967). A broad absorption at 527 nm was also present, and is due to Fe^{2+} (Manning, 1967). These absorption features are all typical of spessartine, despite the unusual yellow-brown colour of these samples.

Spessartine is known from several African countries (i.e. Nigeria, Namibia, Madagascar, Tanzania and Kenya; Shigley et al., 2010), but this is the first time that this author is aware of it being reported from the DRC. According to Blauwet, his supplier has not encountered any additional production of this material.

Bryan Clark

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SYNTHETICS AND SIMULANTS

First CVD Synthetic Diamond Discovered in a Parcel of Natural Melee-sized Diamonds

The GGTL Laboratories specialize in testing melee-sized diamonds, and virtually all parcels of yellow diamonds analysed in recent years have contained at least some HPHT-grown synthetics. Parcels of colourless diamonds tested in our laboratories have—thus far—been spared from such 'pollution' by synthetics. With the increasing availability of gem-quality CVD-grown synthetic diamonds in the past few years, the market has become concerned about finding them mixed into melee-sized parcels of colourless natural diamonds. Thus far, not a single melee-sized CVD synthetic diamond has been found at the GGTL Laboratories, even though we test large quantities of colourless melee diamonds.

Recently, however, our Liechtenstein laboratory received some parcels of colored diamond melee for testing. The stones, which had been sold through Hong Kong, included yellow, orange and pink diamonds, and as usual we found some HPHT-grown synthetics (5–10%) in the yellow parcels. Using the DFI fluorescence imaging system developed in our laboratories, we noticed one gem in a parcel of vivid yellow 1.4–1.7 mm melee that displayed unusual luminescence (Figure 26). When excited by the strong broadband long-wave UV source, it luminesced a relatively weak orange. Orange luminescence in diamonds showing a saturated yellow body colour is very rare. Through the luminescence spectrometer in use with the DFI system, the fluorescence of this

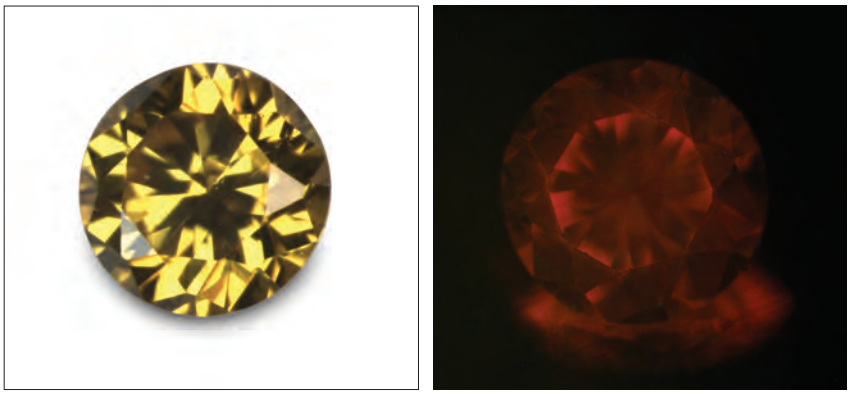

Figure 26: This 1.4-mm-diameter vivid yellow round brilliant (left) shows weak orange luminescence under strong broadband long-wave UV excitation (right). The gem proved to be a CVD-grown synthetic diamond. Photos by T. Hainschwang.

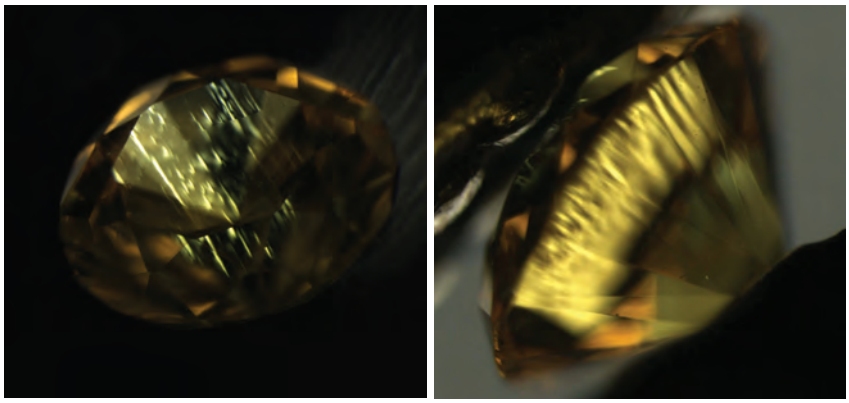

Figure 27: Viewed between crossed polarizers, in immersion, the 1.4-mm-diameter CVD synthetic diamond shows lamellar strain patterns associated with its planar growth structure. Photomicrographs by T. Hainschwang.

gem was immediately revealed to be related to NV centres, and the obvious presence of a silicon centre also was detected. Hence we strongly suspected it to be a CVD-grown synthetic.

Yellow CVD synthetic diamond is very uncommon, and has not been previously described as commercially available in the gem trade, with the exception of one 0.40 ct sample containing 4.5 ppm of C centres (Moe et al., 2014). HPHT-grown synthetic diamonds do not normally contain Si-centres, but the author has analysed one such sample that was produced in the Ukraine (unpublished data); in order to exclude the possibility that the present diamond was an HPHT-grown synthetic, all testing procedures were used to characterize it.

Viewed with crossed polarizing filters, the suspect stone clearly showed grey extinction along its lamellar growth structure (Figure 27). This type of growth pattern is characteristic of CVD-grown synthetic diamonds (e.g. Deljanin et al., 2003).

The infrared spectrum showed that the tiny gem was almost pure type Ib with a very low content of A aggregates (Figure 28). The C-centre content was determined to be approximately 175 ppm. The spectrum also showed several very

Figure 28: The infrared spectrum of the sample defines it as nearly pure type Ib, with tiny absorptions characteristic of CVD synthetic diamond.

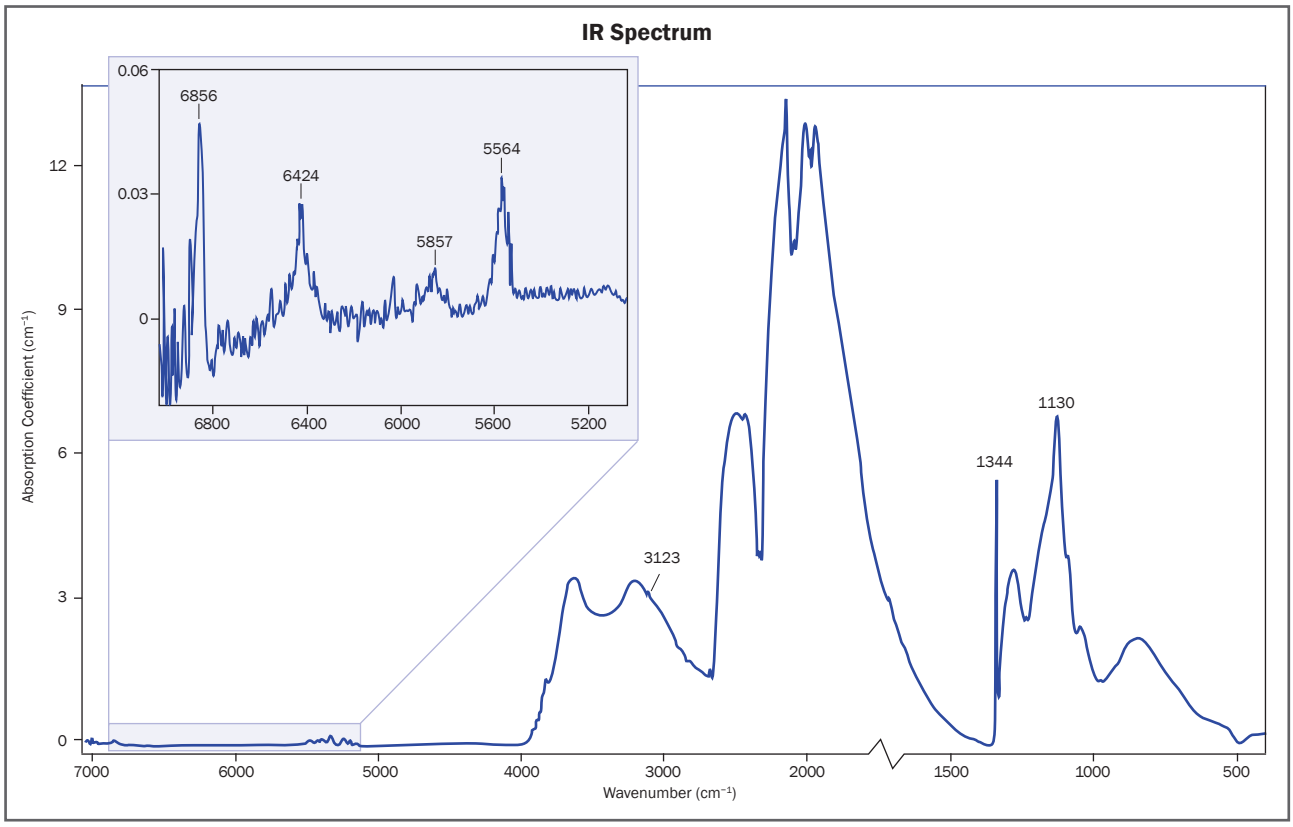

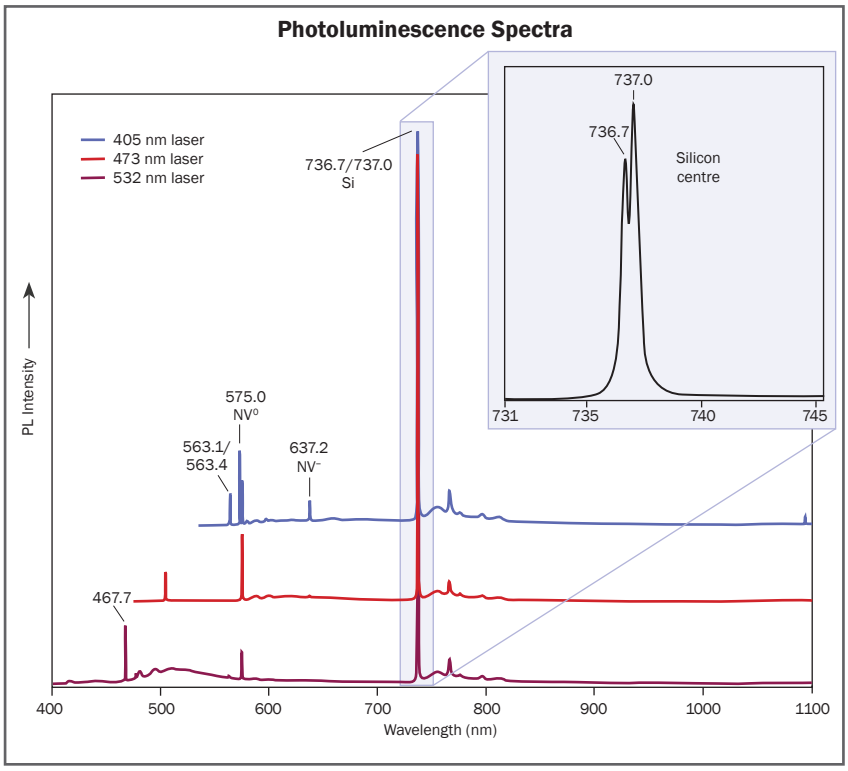

Figure 29: PL spectroscopy recorded using 405, 473 and 532 nm excitation shows dominant Si centre PL and several peaks that are unique to CVD synthetic diamond.

small absorption features that are characteristic of CVD synthetic diamond, such as a hydrogen-related peak at 3123 cm^{-1} and absorptions at 6856, 6424, 5857 and 5564 cm^{-1}.

Photoluminescence (PL) spectra were recorded with three different lasers (Figure 29) while the gem was immersed in liquid nitrogen. These spectra confirmed what the rest of the data had pointed toward: the vivid yellow gem was indeed a CVD synthetic diamond. The spectra were dominated by very strong Si-centre PL with its split zero-phonon lines at 736.7 and 737.0 nm and its vibronic structure extending to 820 nm. All other sharp PL features—with the exception of the NV^0 and NV^- centre emissions—are unique to CVD synthetic diamond: the sharp peak at 467.7 nm (Field, 1992) and the doublet at 563.1/563.4 nm (amongst many very weak sharp peaks) are additional emissions that prove the CVD synthetic origin of this gem.

This sample is the first CVD synthetic diamond known to this author that has been found in a parcel of melee-sized natural diamonds. Although the present case involves yellow melee, it will not be surprising to also find CVD synthetics in (near)-colourless diamond parcels in the future.

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Glass Imitation of Malachite

Malachite is a very common and popular ornamental material, with commercial amounts formerly mined especially from the Katanga Province of the Democratic Republic of Congo (DRC). Malachite from the Ural Mountains in Russia has been widely used in that country for

Figure 30: These silver earrings contain a glass imitation of malachite (9.5 mm in diameter). Photo by J. Hyršl.

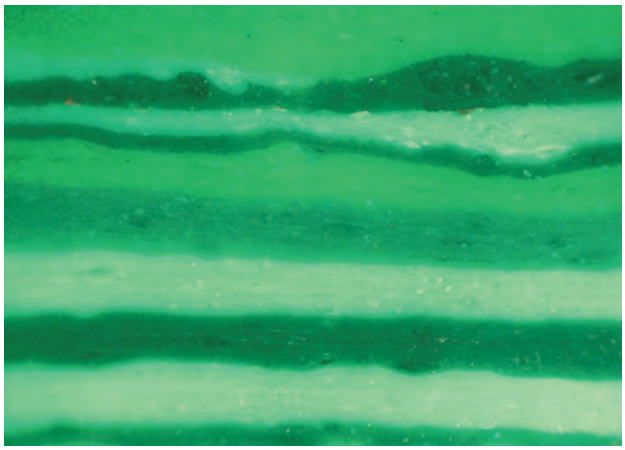

Figure 31: Viewed with the microscope, the glass imitation of malachite consists of irregular layers showing various amounts of green coloration. Photomicrograph by J. Hyršl; image width 4.0 mm.

decorative objects since the 19th century and is still popular there. After some of the historical sources of malachite were exhausted, synthetic malachite entered the market in the 1990s. This material was prepared in Moscow, but it proved too expensive in comparison with the natural stone.

This author recently examined some sterling silver earrings (probably manufactured in China) that appeared to be set with malachite (Figure 30). The gems showed typical parallel banding with light green, green and green-black bands that varied in width from 0.3 to 1.0 mm. The spot RI was 1.57 and the typical birefringence 'blink' exhibited by carbonates such as malachite was not seen. The cabochons were inert to short-wave UV radiation, but the light green bands fluoresced white to long-wave UV. These properties identify the material as a glass imitation. Microscopic observation showed an irregular thickness and inhomogeneous structure of the bands (Figure 31) that were probably caused by successive solidification of different-coloured layers of glass.

Natural malachite from the DRC is still quite cheap and abundant in the market, and it is surprising that such a time-consuming process was used to imitate such material.

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Dyed Quartzite and Chalcedony Beads Imitating Amazonite

Amazonite, the green-to-blue variety of microcline K-feldspar, is an attractive ornamental material that is commonly impregnated with various materials due to its platy structure and its susceptibility to damage along cleavage planes. Recently submitted to Stone Group Laboratories for identification was a suite of bead jewellery (earrings and a necklace) that reportedly featured amazonite. We presumed that the atypical appearance of this 'amazonite' (Figures 32 and 33) was the reason for its submission.

The beads in the earrings were a muted, uniformly coloured pastel greenish blue (e.g. Figure 32), and showed faint mottling and subtle banding with a granular texture. Their colour was too pale for typical amazonite, and they did not exhibit the iridescent platy structure commonly associated with this mineral. Raman analysis with a GemmoRaman-532 instrument readily identified them as quartz, and their granular texture indicated that the beads in the earrings were quartzite.

The beads in the necklace (Figure 33) varied broadly in both colour and pattern, but all of them tested as quartz with Raman spectroscopy. Most of the beads were of the chalcedony variety, although four of them had the granular texture of quartzite. Microscopic observation of the chalcedony beads revealed typical agate structures and banding, and a few would be best described as carnelian due to their reddish brown colour.

Figure 32: This 'amazonite' earring (16 mm in diameter) was found to consist of dyed quartzite. Photo by B. Williams.

Figure 33: The wide variation in colour and pattern seen in these 12 mm beads provided a strong indication that they were not amazonite. The beads proved to consist of chalcedony and quartzite, most of which had been dyed. Photo by B. Williams.

In some beads, faint dye concentrations could be seen along fissures and areas of greater porosity, but many of them showed no evidence of dyeing other than an unnatural colour for quartz. While it was not possible to confirm the type of dye used, traces of Cu were detected in the greenish blue beads by EDXRF spectroscopy; copper salts are commonly used as a blue dye.

Amazonite is readily available and affordable, so there is little reason for such imitations. These days it seems that anything can be imitated, even less expensive, plentiful materials.

Cara and Bear Williams

MISCELLANEOUS

Gem Notes from Myanmar

The jadeite mining area near Hpakan was closed to mining for nearly two years due to armed fighting between government forces and the Kachin Independent Army. Mining was allowed to resume at the end of September 2014 under a peace agreement. At present in the Hpakan region there are 808 private mining companies registered, with a total of 15,638 claims. Twenty-two percent of the companies are in partnership with the Myanmar government. These larger companies control 302 mining plots. Now 36 companies are preparing to start mining jadeite.

A jade and gems emporium was held 15 October 2014 in Naypyidaw for domestic gem merchants paying in local currency (kyats). There were nearly 7,000 rough jadeite lots shown, all classified as 'utility jade' (low-quality material), and some sold for higher prices than expected. In the gemstone section, 160 lots were displayed (51% ruby, 17% sapphire, 14% peridot and 12% other gems). The outcome of this sale has not yet been announced.

The information for this report was obtained from the *Weekly Eleven* newspaper (20 October and 3 November 2014).

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The Fire Within

"For in them you shall see the living fire of the ruby, the glorious purple of the amethyst, the sea-green of the emerald, all glittering together in an incredible mixture of light."

– Roman Elder Pliny, 1st Century AD

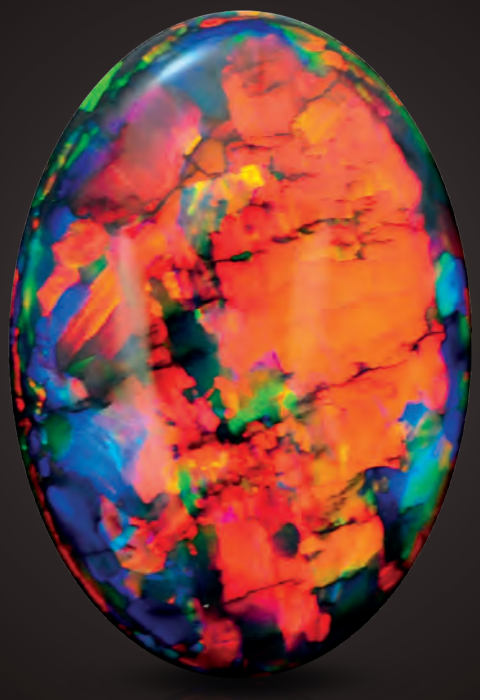

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The Rhodesian Star: An Exceptional Asteriated Diamond

Thomas Hainschwang, Franck Notari and Erik Vadaszi

The physical and optical properties of an exceptional asteriated diamond called *The Rhodesian Star* are described in detail. The stone shows a dramatic six-lobed star pattern formed by a dark grey cloud that strongly contrasts with the diamond's light greenish grey-yellow body colour. Analysis by various optical and spectroscopic methods identified the growth of the diamond as mixed-habit cuboid-octahedral, with the lobes forming the star pattern corresponding to cuboid growth sectors. These sectors are rich in hydrogen and nickel and are full of microscopic inclusions, possibly consisting of voids that are partially filled with graphite.

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Introduction

'Asteriated' diamonds contain a star-shaped cloud of light-scattering inclusions, and they used to be quite rare (Wang and Mayerson, 2002; Darley et al., 2009). With the discovery of enormous diamond deposits in Zimbabwe in 2006 and the appearance of such stones in the international markets around 2011, these diamonds have become more common. In very rare cases, attractive, well-defined star-shaped patterns are seen in complete diamond octahedra without the need to cut them into slices to make the star pattern more visible. Such is the case for the diamond studied for this report (Figure 1), named *The Rhodesian Star* after the old nomenclature of Zimbabwe. It is extremely likely that the diamond was mined in that country, since rough diamonds of similar appearance and properties are virtually unknown from other localities.

Asteriated diamonds from historical sources (Brazil and India) were described by Rondeau et al. (2004) using samples dating from 1802 to 1844. They characterized such diamonds as nitrogen-rich, with mixed-habit cuboid-octahedral growth and enrichment of hydrogen and nickel in the cuboid sectors. The correlation between symmetrical clouds and high hydrogen content was also pointed out by Wang and Mayerson (2002). Virtually all asteriated diamonds have a near-colourless to light brown or brown-yellow body colour with a somewhat darker brown-to-grey star pattern. The pattern always consists of two stars with three-fold symmetry, hence a six-fold star can be seen in complete octahedra. When such diamonds are sliced to enhance the contrast between the cloud and the surrounding diamond, patterns with two, three, four or six lobes can be seen (e.g., Figure 2).

Until now only a very few attractive complete octahedra of asteriated diamonds have appeared in the market and been analysed by a laboratory. This study reports the physical and optical properties of an exceptional 11.38 ct asteriated diamond: The Rhodesian Star.

Figure 1: The Rhodesian Star, a spectacular 11.38 ct asteriated diamond, is positioned here to show the star pattern reflected through four of the polished octahedral faces. Photo by E. Vadaszi.

Background

When the diamond was purchased by one of the authors (EV) in early 2014, it had windows polished on the octahedral faces in order to make the star pattern more visible, since its surface had an otherwise sandblasted look. Such matte-surfaced diamonds are common from Zimbabwe, and they typically also have a thick translucent-to-opaque green to nearly black crust. The original weight of the diamond was indicated to be close to 14 ct, and the polishing of the windows reduced it to a little over 13 ct.

After purchase, the stone's eight octahedral faces were repolished to display the star pattern to the best extent possible. Since polishing precisely parallel to the octahedron is virtually impossible due to diamond's greatest hardness along this plane (Kraus and Slawson, 1939), the faces were polished slightly oblique to the original octahedral surfaces. The polishing process was a very noisy and rather long process that took five full days. The boundaries between the octahedral faces were left with their original sandblasted appearance, hence resembling the surface of a nicely bruted girdle.

The result of this work is a unique and spectacular asteriated diamond weighing 11.38 ct and measuring 13.57 × 13.52 × 13.51 mm, of light greenish grey-yellow colour. The dark grey star-shaped cloud is much sharper and shows a far higher contrast than any other asteriated diamond that these authors are aware of.

Materials and Methods

The diamond was analysed at the Liechtenstein branch of GGTL Laboratories. The inclusions and strain pattern were visualized using a Leica M165C trinocular microscope, equipped with a Leica DFC420 CCD camera with a resolution of 5 megapixels. The strain pattern was analysed with the stone immersed in alcohol between crossed polarizing filters.

The luminescence of the diamond was observed in 254 nm short-wave (SW) and 365 nm long-wave (LW) radiation from a 6 W UV

Figure 2: Asteriated diamonds are commonly sliced to best display their star patterns. These two diamond slices in the collection of the French National Museum of Natural History date from 1844 and originate from India. Reprinted with permission from Rondeau et al. (2004).

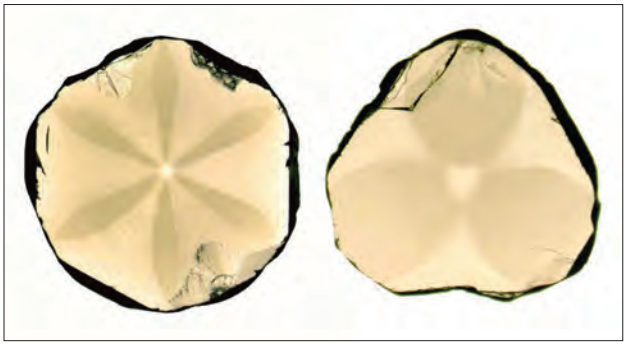

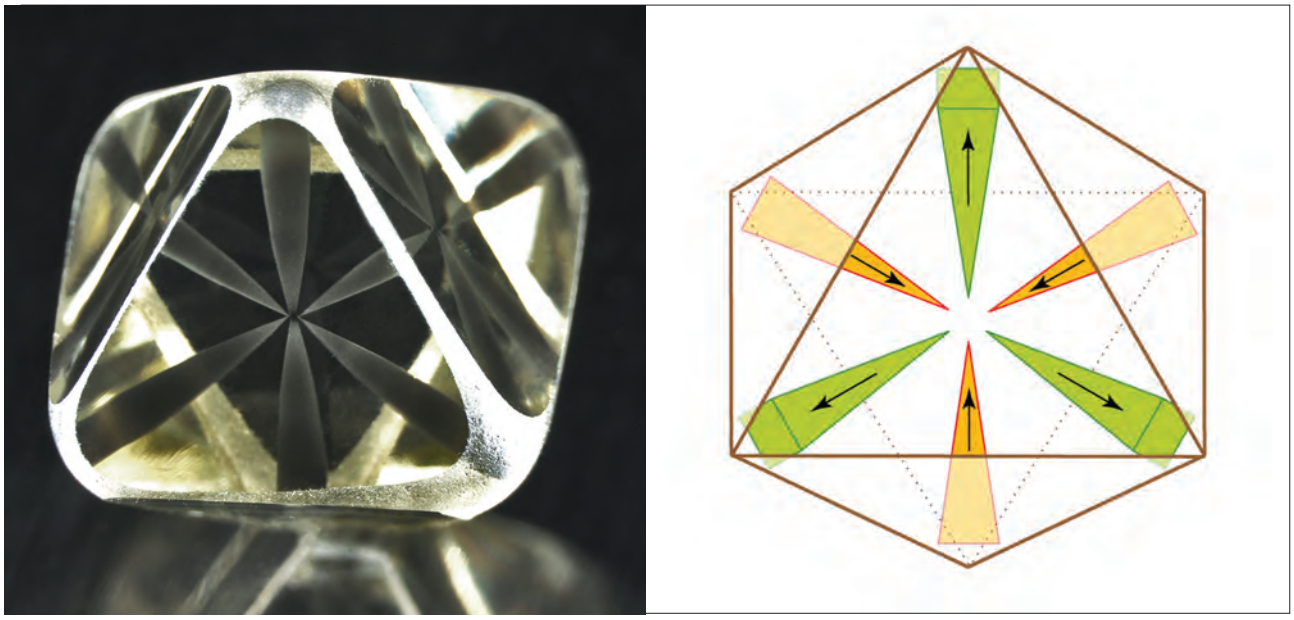

Figure 3: The star pattern shows exceptionally high contrast to the rest of the diamond (left, photo by T. Hainschwang). On the right is a graphical representation of the two sets of three-fold stars, which shows the pattern seen in The Rhodesian Star.

lamp (model UVP UVSL-26P). The luminescence was also observed in broadband UV using three different excitation bands (LW band 1: 300–410 nm; LW band 2: 355–375 nm; SW/LW band: 250–350 nm) from a GGTL DFI luminescence microscope using a suitably filtered 300 W full-spectrum xenon lamp. The luminescence images recorded with the GGTL DFI system were acquired with a Leica DFC450 C CCD camera with a resolution of 5 megapixels and the CCD sensor thermoelectrically cooled with a delta of −20°C compared to the surrounding temperature. Infrared spectra were recorded in transmission mode with a resolution of 4 cm^{-1} on a PerkinElmer Spectrum 100S Fourier-transform infrared spectrometer equipped with a thermoelectrically cooled DTGS detector, using a 5× beam condenser, over a range of 8500–400 cm^{-1}, with 100–500 scans.

Photoluminescence spectra were recorded on a GGTL system using 405, 473, 532 and 635 nm laser excitations, and a high-resolution echelle-type spectrograph by Catalina Scientific equipped with an Andor Neo sCMOS camera with a resolution of 5 megapixels, thermoelectrically cooled to −40°C. The system was set up to record spectra in the range of 350–1150 nm with an average resolution of 0.04 nm. All photoluminescence spectra were recorded with the diamond cooled to 77 K by direct immersion in liquid nitrogen.

Ultraviolet-visible–near infrared (UV-Vis-NIR) spectra were recorded on a GGTL D-C 3 spectrometer system using a combined xenon, tungsten-halogen and LED light source. A quadruple-channel spectrometer with a Czerny-Turner monochromator and a thermoelectrically cooled CCD detector was employed, with an average resolution of 0.3 nm. The spectrum was measured with the diamond placed in an integrating sphere of 15 cm diameter and cooled to about 77 K (−196°C).

Results and Discussion

Visual Observation and Microscopy

The asteriated pattern is caused by the combination of two stars, each showing the typical three-fold symmetry of diamond (Figure 3). The stars are oriented in different planes, so when they are viewed with magnification only one star is in focus at a time (Figure 4).

The tiny black inclusions forming the star patterns in some asteriated diamonds have been identified with Raman spectroscopy as highly crystalline graphite (Rondeau et al., 2004). The dark appearance and strong contrast of the lobes in The Rhodesian Star are due to a high density of such grey-to-black microscopic inclusions (Figure 5). The exact nature of these inclusions

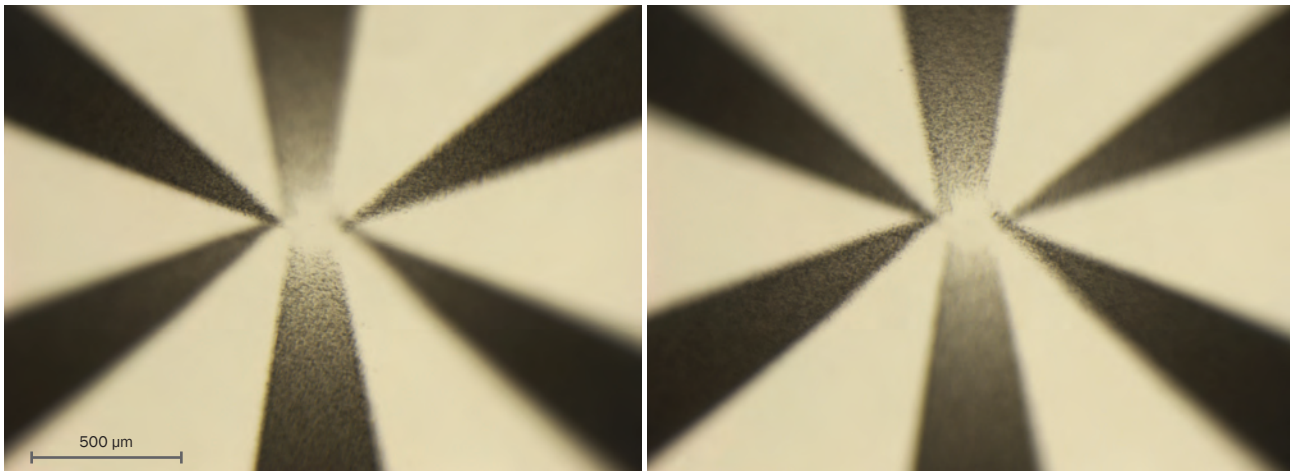

Figure 4: Each three-lobed star in the diamond originates from a separate plane, so only one star is in focus at a time when viewed with magnification. Photomicrographs by T. Hainschwang.

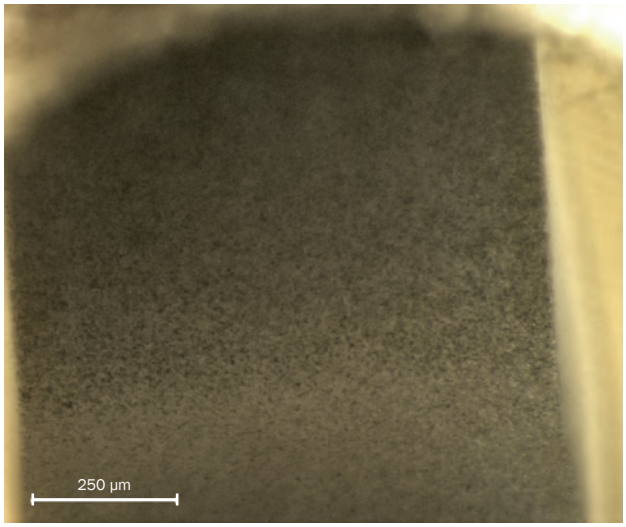

Figure 5: The dark appearance of the star pattern in the diamond is caused by microscopic particles that probably consist of voids that are partially or completely filled by graphite. Photomicrograph by T. Hainschwang.

was not determined due to time restraints when testing the diamond, but it is likely that they consist of voids that are partially or completely filled by graphite (cf. Klein-BenDavid et al., 2007).

Also observed in The Rhodesian Star were dark green radiation stains (Figure 6). Such stains are—as the name indicates—related to radiation and are characteristic for many natural rough diamonds (Nasdala et al., 2013). The stains on The Rhodesian Star are of natural origin. Similar stains may be observed in laboratory-irradiated diamonds treated by direct contact with radium salts, but such stains typically have a perfectly round shape, in contrast to the irregular shape of the stains in naturally irradiated diamonds (Hainschwang and Notari, 2014). The latter stains are caused by natural alpha radiation, and because of the low penetration depth of alpha particles, they are always limited to an area very near the surface. As determined by optical microscopy combined with the measurement capability of the Leica DFC450 C CCD camera, the depth of the stains in this diamond was found to be 5–10 µm. The presence of the pristine green radiation stains shows that the diamond has not been exposed to heat above 400–500°C, since such stains turn brown upon annealing (Nasdala et al., 2013).

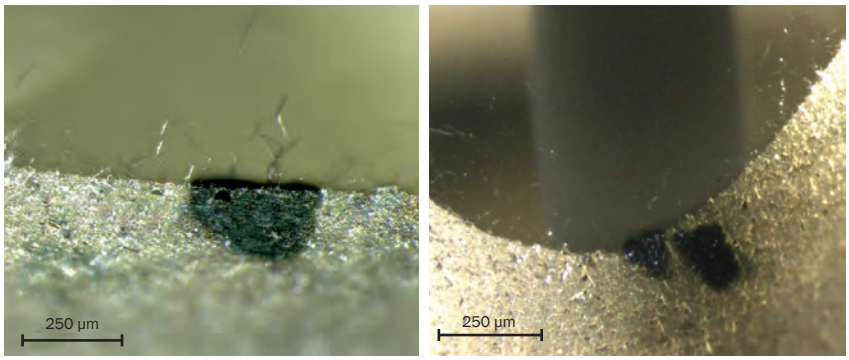

Figure 6: Several irregularly shaped dark green radiation stains on the surface of the diamond clearly show that it was exposed to natural alpha radiation and that it has not been heated to more than 400–500°C during the polishing process. Photomicrographs by T. Hainschwang.

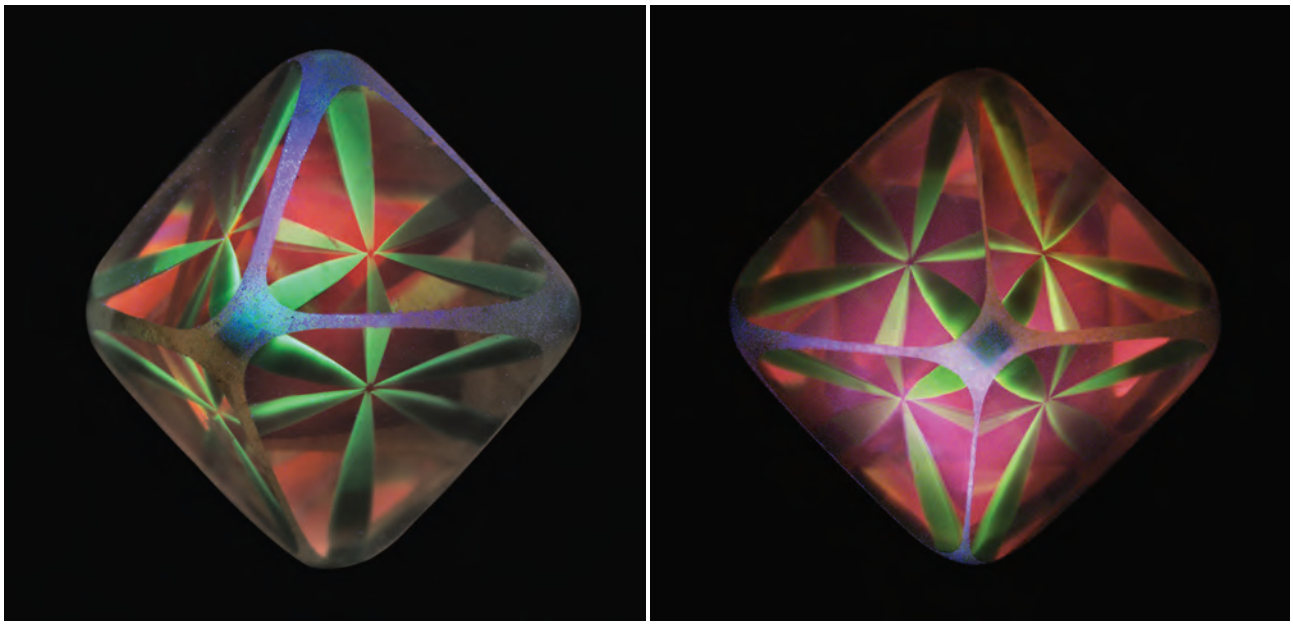

Figure 7: The Rhodesian Star displays beautiful luminescence patterns when exposed to the strong broadband UV excitation of the GGTL DFI fluorescence microscopy system (left = 300–410 nm and right = 355–375 nm excitation). Photos by T. Hainschwang.

While radiation stains are known in diamonds from many deposits, they are especially prominent in diamonds from Zimbabwe, which is the likely origin of this diamond.

Luminescence

Luminescence imaging is a technique where a material is typically excited by a UV source and its emission colours are observed.

The Rhodesian Star shows no apparent fluorescence under standard long- and short-wave UV lamps. However, when exposed to a high-power UV source such as the GGTL DFI fluorescence microscope, the stone exhibits a spectacular fluorescence pattern (see Figures 7– 9 and the cover of this issue). The star pattern glows green while the rest of the diamond luminesces pink-orange to purple-pink, depending on the specific UV excitation band used: 250–350 nm excitation causes pink-orange PL, 300–410 nm produces orangy pink PL, and 355–375 nm excites purple-pink PL.

UV excitation reveals that the lobes forming the star pattern have a square cross-section, which is particularly apparent at the corners of the octahedron (Figure 8). The square shape could lead to the conclusion that the lobes correspond to cube sectors such as those present in synthetic diamond. However the sectors almost certainly are of cuboid growth, a rather common form that exists

Figure 8: In this luminescence image (250–350 nm excitation), the square cross-section (and hence the cuboid nature) of a lobe of The Rhodesian Star is evident at the corner of the diamond octahedron. Photomicrograph by T. Hainschwang.

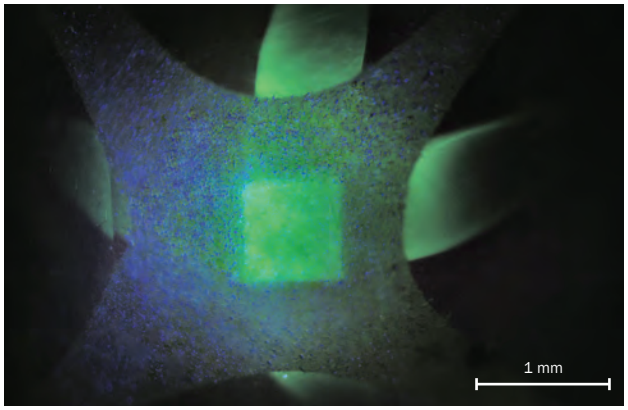

Figure 9: This close-up view of the luminescence of The Rhodesian Star under 250–350 nm excitation displays the green-luminescing lobes, which follow the cuboid directions of the diamond. Photomicrograph by T. Hainschwang.

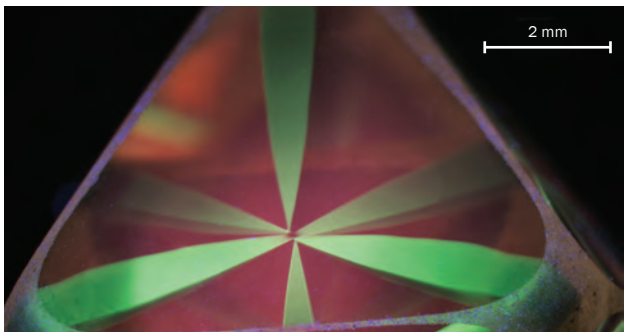

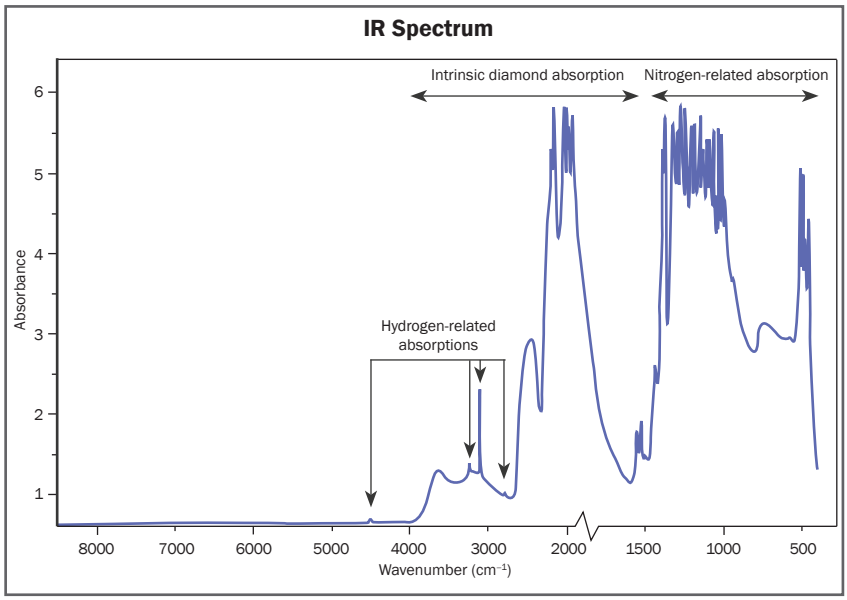

Figure 10: The infrared spectrum of The Rhodesian Star shows it is a type IaA>B diamond with very high nitrogen and moderate hydrogen content.

only in natural diamond. Cuboid sectors are known to be typically rich in hydrogen and nickel-related defects (Lang et al., 2004). These nickel-related defects are responsible for the green luminescence in these sectors (see PL Spectroscopy section for more details). A sketch of the two three-fold stars observed in this diamond, and the square cross-section of the lobes, is shown in Figure 3.

Infrared Spectroscopy

Infrared spectroscopy is a well-known method used to distinguish different diamond types based on the presence or absence of substitutional nitrogen and/or boron impurities and the aggregation state of the nitrogen. The presence of hydrogen also can be confirmed by this technique, and certain radiation-related defects can be detected.

The infrared spectrum of The Rhodesian Star characterizes the stone as a type IaA>B diamond (Figure 10); hence the A-aggregate form of nitrogen dominates the B-aggregate form of nitrogen. The stone contains very high concentrations of nitrogen and moderate amounts of hydrogen. The nitrogen content could not be properly determined; due to the thickness of the diamond and its enriched nitrogen content, the necessary nitrogen absorptions (482 cm^{-1} for A aggregates and 1010 cm^{-1} for B aggregates) could not be properly resolved. Infrared spectra recorded from the individual sectors show that by far most of the hydrogen is located within the 'star' cuboid sectors.

UV-Vis-NIR Spectroscopy

Performed at low temperature (−196°C, with the sample immersed in liquid nitrogen), UV-Vis-NIR spectroscopy is useful for detecting many important defect centres in diamond. Among these are the N3/N2 centres, which are responsible for the yellow coloration of many diamonds, and several radiation-related defects such as GR1, the 594 nm centre, etc.

The Rhodesian Star shows a standard cape spectrum, with distinct N3 and N2 absorptions at 415.2 and 478 nm, respectively. Several radiation-related features also can be seen, such as GR1 at 741.2 nm (caused by the neutral carbon vacancy), 3H at 503.5 nm and the 594 nm centre (Figure 11). These absorptions are rare in untreated natural diamond—with the exception of naturally irradiated green to greenish blue stones—although they have been found to be rather common in untreated diamonds from Zimbabwe (Breeding, 2011; Crepin et al., 2011). These rough stones often have a thick very dark green 'skin' from natural irradiation, and although the vast majority of the diamonds have a mixed brown/yellow body colour in their transparent core, they show minor traces of natural radiation damage in their spectra.

PL Spectroscopy

Laser-excited PL spectroscopy is a very sensitive method for detecting the defects responsible for the observed luminescence. The diamond sample is immersed in liquid nitrogen, and the

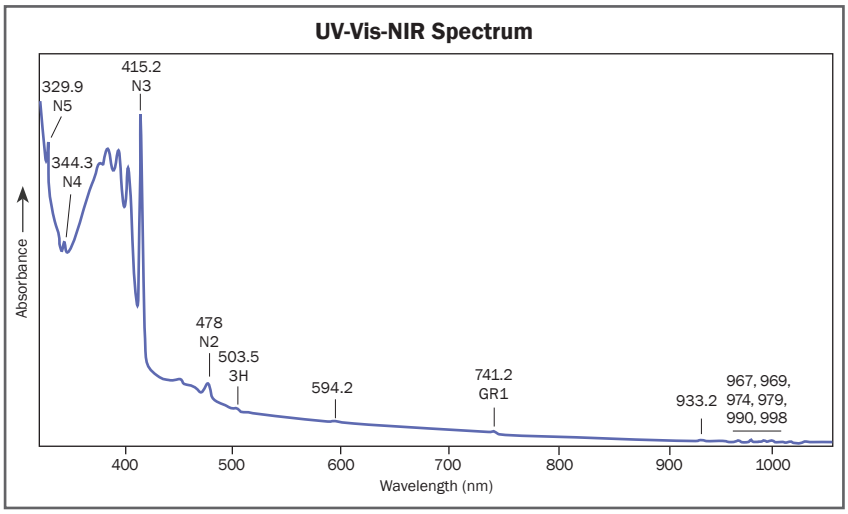

Figure 11: The UV-Vis-NIR spectrum of The Rhodesian Star indicates that its light greenish grey-yellow body colour originates from strong N3/N2 absorption combined with GR1 absorption. The overall slight green hue originates from surface-related green coloration caused by natural radiation exposure. The path length of the beam through the GR1-damaged surface is very short, so absorbance of the GR1 band is very low. Several other absorptions, such as the 594.2 nm peak, also indicate that the stone experienced exposure to radiation.

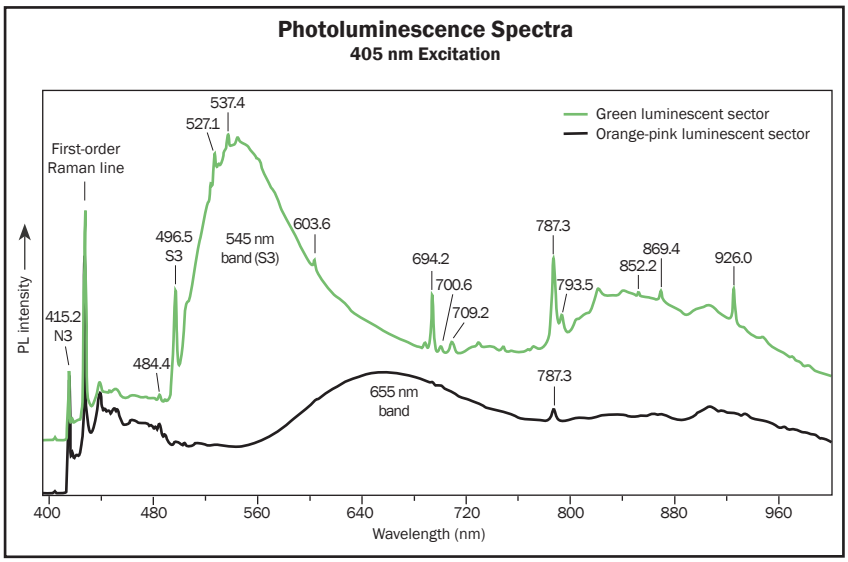

Figure 12: The PL spectra of the differently luminescing sectors of The Rhodesian Star obtained with 405 nm excitation show that the green PL of the lobes is due to strong nickel-related (S3) defect luminescence, while the orange-pink PL from the octahedral sectors originates from a broad emission band of unknown origin centred at 655 nm. The spectra clearly show that the cuboid sectors are rich in nickel while the octahedral sectors are not.

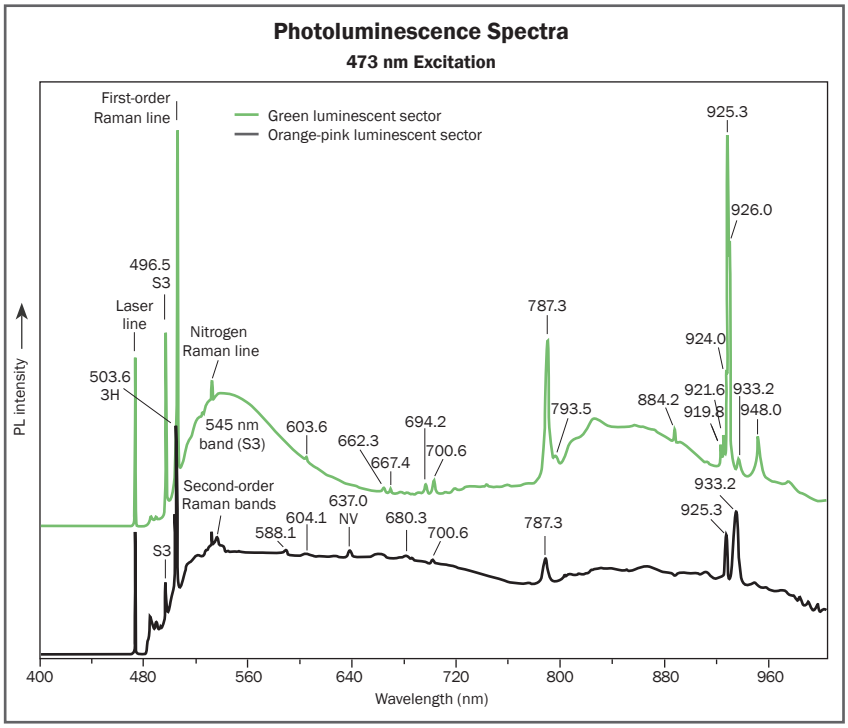

Figure 13: As with the 405 nm laser, PL spectroscopy of The Rhodesian Star obtained with 473 nm excitation shows that the green PL of the lobes originates from strong S3 defect luminescence. The extremely broadband emission seen in the octahedral sectors indicates a much different PL colour than was seen with 405 nm and strong UV excitation; the colour most closely resembles 'beige' or some sort of brown hue. The cuboid sectors are richer in nickel defects than the octahedral sectors. (The nitrogen line is produced by Raman scattering from the liquid nitrogen surrounding the specimen.)

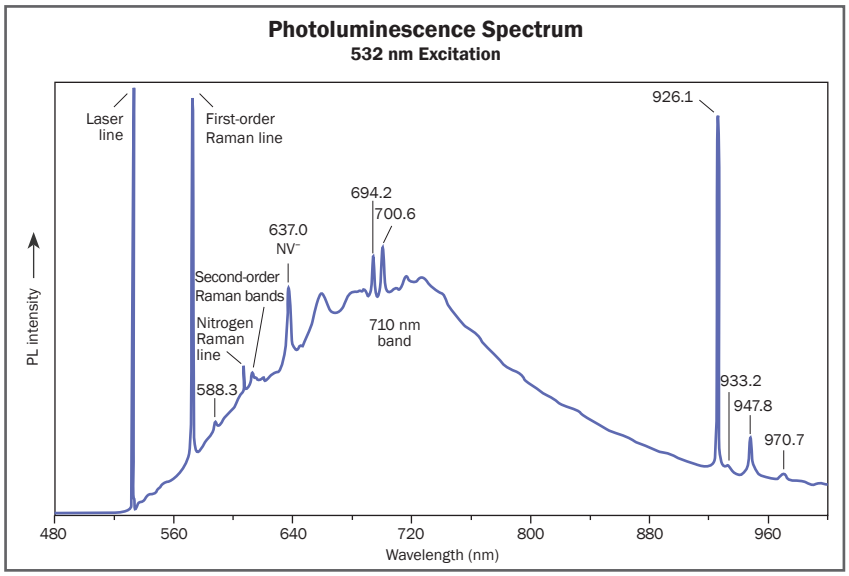

Figure 14: The PL spectrum of The Rhodesian Star obtained with 532 nm excitation is characterized by a broad band centred at 710 nm, along with distinct NV^- centre PL and several nickel-related emissions (possibly including those in the 900–950 nm range). Both growth sectors in the diamond were simultaneously excited by the laser when recording this spectrum. (The nitrogen line is produced by Raman scattering from the liquid nitrogen surrounding the specimen.)

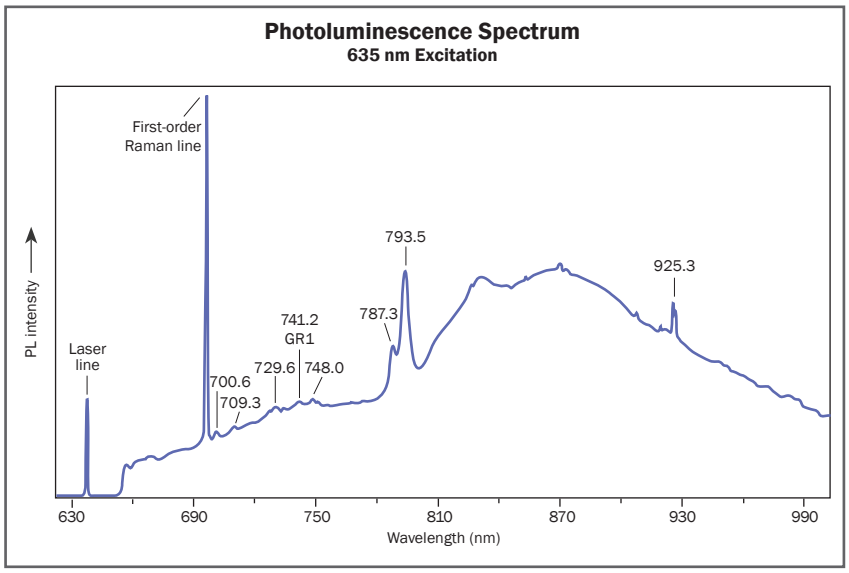

Figure 15: The PL spectrum of The Rhodesian Star obtained with 635 nm excitation is characterized by several nickel-related defects, with those at 787.3 and 793.5 nm being particularly intense. Both growth sectors in the diamond were simultaneously excited by the laser when recording this spectrum.

luminescence is produced using laser excitation of various wavelengths. The resulting luminescence is measured by a high-resolution spectrometer and plotted as a spectral curve.

The Rhodesian Star was tested with four different lasers (405, 473, 532 and 635 nm; Figures 12–15). Using 405 and 473 nm excitations, differences in PL luminescence between the octahedral and cuboid growth sectors could be depicted in the corresponding spectra. However, it was not possible to measure the green luminescence in the 'star sector' using the 532 or 635 nm excitations, because these wavelengths are longer than 500 nm and therefore do not excite the centre responsible for the green PL.

The green luminescence of the star-shaped cloud is caused by the S3 centre, which is a nickel-related defect that can be seen as a sharp line at 496.5 nm and a broad band centred at 545 nm (Kanda and Watanabe, 1999; Figure 12). This defect is characteristic of diamonds of mixed cuboid-octahedral growth, and is mainly present in the cuboid sectors of natural diamonds (Welbourn et al., 1989; Lang et al., 2004; Hainschwang, 2014). It is the predominant defect in so-called re-entrant cube mixed-habit cuboid-octahedral natural diamonds (Hainschwang et al., 2013). It is also characteristic of HPHT synthetic diamonds grown using a nickel-iron solvent, particularly after annealing, but may be found in as-grown synthetic diamonds produced using relatively high temperatures. However, in synthetic diamonds the defect is predominant in octahedral growth sectors (Kupriyanov et al., 1999).

The orange-red to orange-pink luminescence of the rest of the diamond is caused by an

unknown defect that is seen as a broad emission band centred at 655 nm (using 405 nm laser excitation; Figure 12).

Many of the other emission bands and lines detected with the four lasers can also be assigned to nickel-related defects (Zaitsev, 2001), such as those at 694.2, 700.6, 787.3 and 793.5 nm (again, see Figures 12–15). The causes of the PL features above 900 nm are unknown, although the 926.1 nm emission has been tentatively assigned to a nickel-related defect (Hainschwang et al., 2005). It is possible that the other lines from around 900 to 950 nm are nickel-related as well, with the exception of the 933.2 nm feature which is very probably nitrogen related. This line shows up in absorption and also in luminescence when the N3 and N2 absorptions are intense.

With the exception of a very weak GR1 feature at 741.2 nm (Figure 15) and an NV^- centre emission at 637.0 nm (Figure 14), no radiation-related features were detected by PL spectroscopy. The straightforward detection of many radiation-related features with absorption spectroscopy and the quasi-non-detectability of these defect centres by PL spectroscopy can be explained by the fact that they are present only in the upper few microns of the stone. Since the PL spectra were taken from either the lobes or from the bulk of the diamond—without the use of a microscope—the radiation-related PL from the surface was not well excited and thus not detected.

The very sensitive method of photoluminescence spectroscopy clearly shows that the sectors containing the star pattern originate from nickel-rich cuboid growth, while the rest of the diamond consists of normal octahedral growth that is poor in defects other than nitrogen.

Conclusions

The Rhodesian Star is a superb example of an asteriated diamond. Gemmological testing has demonstrated that the star pattern is the result of cuboid-octahedral growth and that the grey-to-black particles are restricted to the cuboid sectors only. Spectroscopy confirmed that hydrogen and nickel defects are confined to the cuboid sectors, as previously documented in such diamonds. The spectacular luminescence patterns seen when the diamond is exposed to a high-power UV source are the result of nickel-related defects (S3) in the cuboid sectors, which are responsible for the bright green PL. The orange-red to purple-pink luminescence of the octahedral portions of the crystal originate from a broadband emission from unknown defect(s). Although it is extremely rare to see such luminescence with the use of standard UV lamps, the purple to nearly red luminescence is actually quite common in natural diamonds when they are exposed to intense UV excitation from our GGTL DFI fluorescence microscope. While orange-to-red PL (excited by UV to violet light) is known from various types of emission centres, the only well-characterized defects known to produce this luminescence are the NV^- and NV^0 centres, although it is very rare for them to emit strong PL in untreated diamonds.

The properties of The Rhodesian Star—particularly its surface texture and appearance, and the spectral data such as the radiation-related defects—indicate that its origin is Zimbabwe, which is one of the best-known sources for asteriated diamonds.

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Objective Diamond Clarity Grading

Michael D. Cowing

The diamond clarity grading scale used worldwide today was introduced by the Gemological Institute of America (GIA) in 1953. To help address varying interpretations and inconsistencies in clarity grading between laboratories (and even within some labs), this article introduces an objective system for diamond clarity grading. The determination of the clarity grade is influenced by up to five factors: size, number, contrast (colour and relief), position and nature of the inclusions. The proposed system assesses these factors (with emphasis on the first four) by using an objective metric that emulates the intuitive analysis done by experienced diamond graders. Using high-quality photographs of more than 100 randomly selected diamond examples, this article demonstrates a high degree of agreement between clarity grades obtained using this system and those determined by GIA and the American Gem Society Laboratories (AGSL). The system's objective methodology may offer a means for improving inter- and intra-laboratory grading consistency.

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Introduction

Diamond grading by gem laboratories, gemmologists, and valuers/appraisers consists of an evaluation of the four diamond characteristics of cut, colour, clarity and carat weight. These '4 Cs' are the criteria upon which cut and polished diamonds (e.g. Figure 1) are valued and marketed.

Clarity grading is a judgement of the degree to which a diamond is free of inclusions and imperfections when viewed with the 10× magnification of a jeweller's loupe or gemmological microscope. In April 1953, GIA under then-president Richard T. Liddicoat introduced systems for both the colour and clarity grading of diamonds (Shuster, 2003). GIA's clarity grading scale expanded upon terms and definitions that had evolved through trade usage over more than a century. For example, Wade (1916) described diamond imperfection with terms such as 'v. v. s., or very very slight', 'slightly imperfect' and 'imperfect'. GIA's expansion of clarity grading terminology was necessary, as Liddicoat noted, because "There weren't a large enough number of grades to fit the market….We had to have more" (Shuster, 2003).

GIA's clarity grading scale, like its diamond grading system, has become the model for laboratories throughout the world. The terminology and definitions of this scale are universally used to communicate to the gem trade and consumers the purity aspect of diamond quality.

Today, non-GIA laboratories commonly employ clarity scales and terminology that largely retain the nomenclature and definitions of the original GIA system, although these systems have evolved and their implementations vary to

Figure 1: Faceted diamonds such as these are graded according to the '4 Cs' of cut, colour, clarity and carat weight. The round brilliants shown here have clarity grades ranging from VS_1 to SI_1 and weigh 1.12–1.83 ct. Photo by M. Cowing.

differing extents from GIA and from one another. This evolution has resulted in inconsistent grading from lab to lab and even within labs. Standardized clarity grading remains an elusive goal that, due to its subjective nature, many believe is unattainable.

This article introduces a new method of clarity grading that challenges this belief. It is comprised of objective metrics that are used to model the techniques of expert graders whose proficiency results from extensive experience and practice. Photographic examples that use GIA-graded diamonds demonstrate the accuracy and consistency of this system. First, a review of the GIA definitions of each clarity grade will show the subjective nature of existing methodology. Then the new objective system will be introduced and illustrated by various examples from several clarity categories.

The Diamond Clarity Grading Scale

GIA's clarity grading scale consists of 11 grades (Figure 2a): Flawless (Fl), Internally Flawless (IF), two grades of Very Very Slightly Included (VVS_1, VVS_2), two grades of Very Slightly Included (VS_1, VS_2), two grades of Slightly Included (SI_1, SI_2), and three grades of Included (formerly Imperfect; I_1, I_2, I_3).

Diamond imperfections are classified as either external surface features called blemishes or internal features called inclusions (which may also extend to the surface). Blemishes include features such as small extra crown facets, surface graining and certain naturals. They affect determinations between the top two clarity grades of Fl and IF. Below IF, inclusions are the principal determiners of a diamond's clarity grade. Surface scratches, which have depth, are graded as inclusions. In practice, no distinction is made between a shallow feather and a deep scratch. What counts most is inclusion noticeability, which is strongly weighted toward the face-up view (P. Yantzer, pers. comm., 2014). Although inclusions are three-dimensional in nature, it is their two-dimensional appearance mainly observed face-up that is assessed for noticeability.

A diamond's clarity characteristics are plotted using darkfield illumination (side lighting against a dark background), but the final judgement of clarity is made with the diamond held face-up using overhead (above-diamond) lighting. The latter arrangement reveals the noticeability of inclusions as seen under typical viewing circumstances.

The following clarity grade definitions (GIA, 1994; GIA, 2004, 2006) assume a skilled grader working with 10× fully corrected magnification (loupe or microscope) and effective illumination (diffused horizontal lighting with a loupe or darkfield illumination with a microscope):

- Flawless (Fl): No inclusions or blemishes of any kind.
- Internally Flawless (IF): No inclusions and only insignificant blemishes.

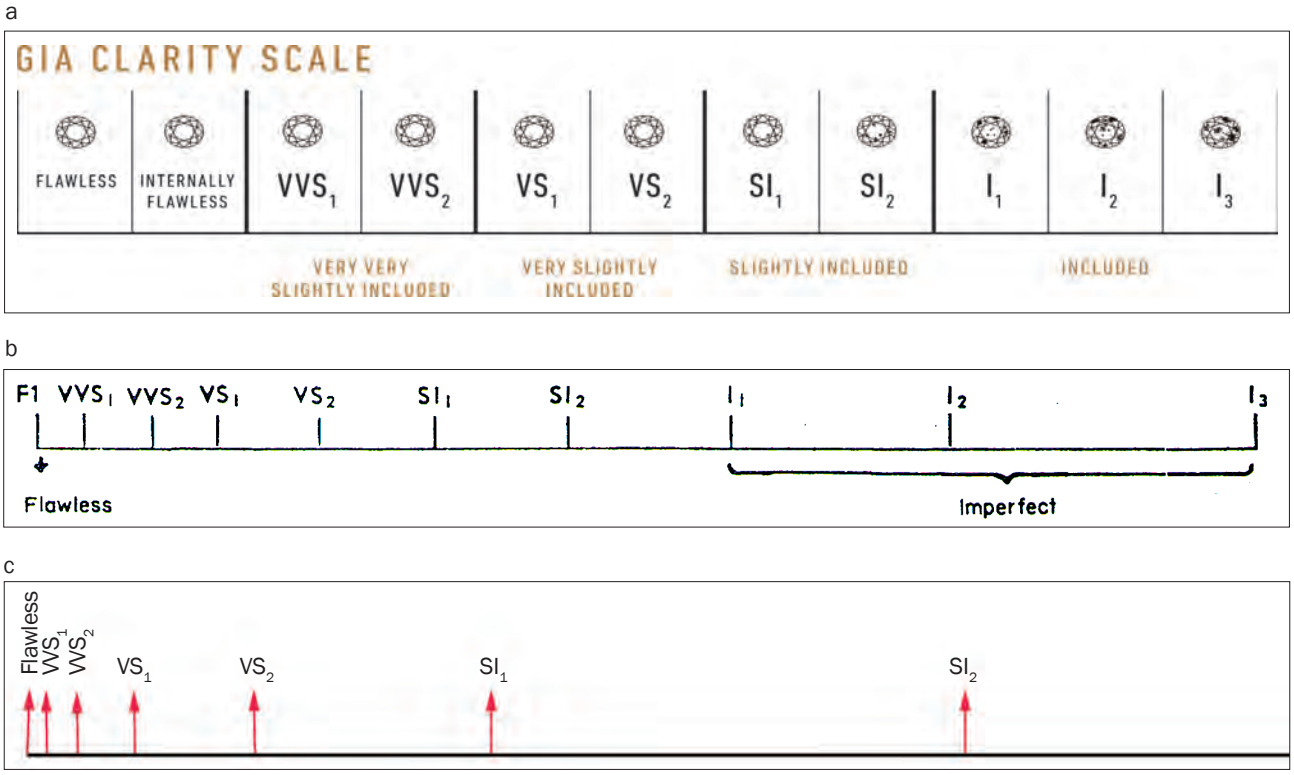

Figure 2: (a) GIA's clarity grading scale consists of 11 grades, ranging from Flawless to Included (formerly Imperfect). (b) This early representation of GIA's clarity scale (GIA, 1969) shows an increase in spacing from higher to lower grades. (c) This diagram shows the actual increase in spacing (and in inclusion dimensions) of a portion of the grading scale, corresponding to a doubling in dimensions of grade-setting inclusions from one grade to the next lower grade.

- Very Very Slightly Included: Minute inclusions that range from extremely difficult (VVS_1) to very difficult (VVS_2) to see.
- Very Slightly Included: Minor inclusions that range from difficult (VS_1) to somewhat easy (VS_2) to see.
- Slightly Included: Noticeable inclusions that are easy (SI_1) or very easy (SI_2) to see with 10× magnification, but usually are not easily noticeable to the unaided eye.
- Included (formerly Imperfect): Obvious inclusions under 10× magnification that are easily eye-visible face-up (I_1, I_2 and I_3); for I_3, they severely affect transparency and brightness, and may threaten durability.

Attaining Accuracy and Consistency in a Subjective Clarity Grading System

The subjective definitions of the clarity grades make it challenging to attain accuracy and consistency with this system. This is particularly the case for the beginning grader, as it is difficult to comprehend what an experienced observer sees as 'extremely difficult', 'very difficult', 'difficult' or 'somewhat easy' to locate under 10× magnification. In addition, GIA's diamond grading course notes that "It is important to remember...that it is impossible to develop a precise description of any clarity grade except flawless….Clarity grading is like appraising a painting...: It is the overall picture that sets the clarity grade. Clarity grading is as much an art as an objective science; becoming really proficient at it takes time, experience, and practice" (GIA, 1994, p. 2).

Observations like these may seem daunting. However, GIA does offer this encouragement: "...most people learn to 'sense' the grade immediately. With a little practice, you will know by a sort of educated gut instinct what grade category a stone falls into, almost at first glance" (GIA, 1994, p. 15).

Developing a 'sense' for the clarity grade is subjective and open to variability in interpretation from grader to grader and from lab to lab. How

is it possible that experienced graders can most often agree on a diamond's clarity grade, at least within a particular lab's system? The not very satisfying answer given in diamond courses is that consistency is only gained over time, through observation of diamonds of all clarities, sizes and shapes with their myriad inclusion variations.

Inclusion Characteristics that Impact Diamond Clarity Grades

Determination of the overall impact that inclusions have on the clarity grade is influenced by up to five factors: *size, number, contrast* (colour and relief), *position* and *nature*. "The nature of a clarity characteristic is based on two general distinctions. Whether it is internal or external is one: Below IF, the clarity grade is almost always set by inclusions; blemishes generally have little or no effect on it. The second is whether a particular characteristic poses any risk to the stone. Most do not" (GIA, 1994, p. 12). Below IF, this most often leaves the combined judgement of the first four of these factors as the determiner of the clarity grade.

The clarity grade of most diamonds is correctly established by assessing the single largest inclusion or a small number of similar major inclusions. Such factors are referred to as the 'grade-makers'. The four main clarity factors (size, number, contrast and position), judged together for the largest grade-maker inclusion(s), most often determine a diamond's clarity grade.

A salient feature among the four clarity factors is *size* which, along with the degree of *contrast* between the inclusion and the surrounding diamond, determines the visibility of a given inclusion. The larger the inclusion and the greater its contrast, the more it stands out and the lower the grade. *Number* comes into consideration when the largest 'grade-maker' inclusions are more numerous than one. Three or four similar grade-maker inclusions are likely to lower the clarity one grade more than would a single similar feature. Multiple grade-maker–size inclusions are effectively handled in most cases by grading them the same as an equivalent inclusion with similar total area. Lastly, consideration is given to the *position* of the grade-maker inclusions within the diamond. Viewed face-up, those under the table (in what is called the 'heart' of the diamond) are most noticeable and are graded most severely. Inclusions touching or near the girdle are least noticeable and are often graded more leniently. Features that are deep enough in the 'heart' often reflect in multiple positions, which may result in a lower grade. Early GIA instruction was to penalize by one grade an inclusion that had a lot of reflections (P. Yantzer, pers. comm., 2014).

To arrive at a clarity grade, the new objective system evaluates the four clarity characteristics together, combining them in a manner that emulates the practice of experienced graders. This is done by utilizing aspects of human perception concerning the noticeability of inclusions. An analysis of early efforts at objective clarity grading (discussed below) leads to two key observations:

1. The grade-defining property of inclusion noticeability is directly related to inclusion area. If inclusion 'grade-makers' have the same area and only differ in their length and width, they are perceived to have similar noticeability and most often will receive the same grade.
2. The increase in inclusion size from one grade to the next is not constant, but approximately follows a doubling of the inclusion's dimensions. That rough dimension doubling, which is a quadrupling in area, is surprisingly consistent from grade to grade across the entire clarity scale.

From Figure 2b it is clear that the range or distances on the GIA clarity grading scale between the lower grades is significantly larger than the distances between the higher grades. However, based on the inclusion size factor indicated in the second key observation mentioned above, the actual increase in distance from grade to grade is even more pronounced, as shown partially in Figure 2c. Surprisingly, an approximate doubling in dimensions of grade-setting inclusions occurs from grade to grade across the entire scale. Because of this doubling in dimension (and therefore an increase in area by about a factor of four), each decrease in clarity grade corresponds to a large multiplicative escalation in inclusion size and noticeability. Figure 3 provides an example of

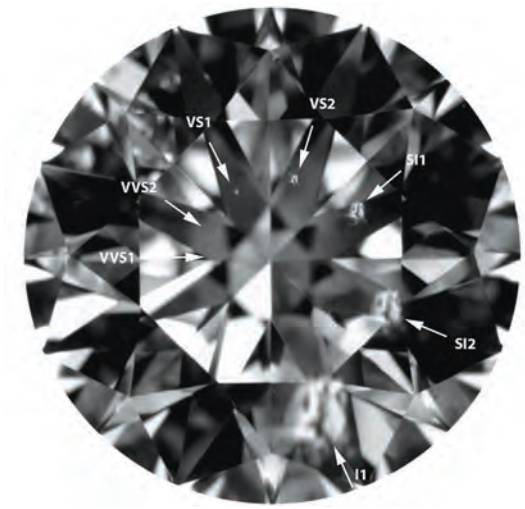

Figure 3: Illustrating the relative increase in inclusion size from grade to grade are these seven inclusions that have been digitally inserted in a 1.11 ct diamond (6.66–6.63 × 4.11 mm). The inclusions are sized according to clarity grades that range from VVS_1 to I_1.

Figure 4: This 1.11 ct diamond (6.66–6.63 × 4.11 mm) contains four SI_1-size inclusions that have different dimensions, but the same area and contrast, and thus similar noticeability. Each has an area determined to be approximately 35,000 μm².

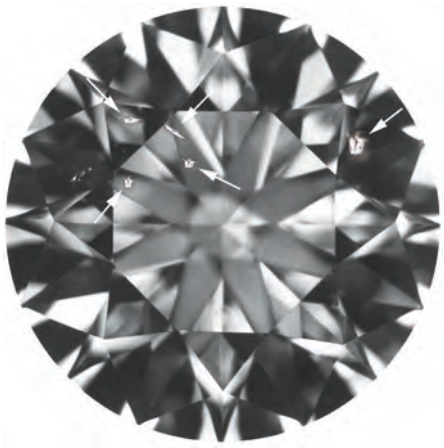

Figure 5: This 0.70 ct diamond (5.74–5.71 × 3.52 mm) contains four VS_2-size inclusions between the 10 and 11 o'clock positions near the table edge. All of these inclusions have the same area and noticeability, despite their varying dimensions.

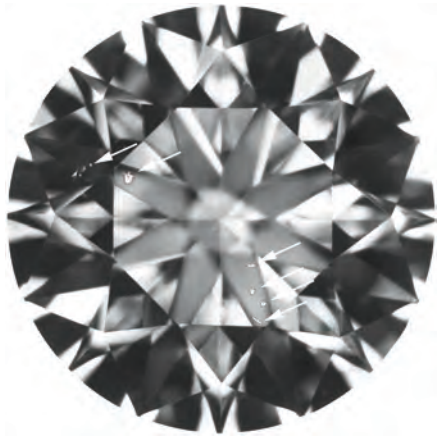

Figure 6: The same 0.70 ct diamond as in Figure 5 is shown here containing four VS_1-size inclusions at 5 o'clock inside the table. Each one has one-quarter the area of the VS_2-size inclusion seen at 10 o'clock. Taken together, the VS_1 inclusions would receive one lower grade of VS_2.

this increase in inclusion size from clarities of VVS_1 to I_1.* To provide visual support for the two key observations listed above, carefully sized inclusions also have been inserted into the darkfield diamond images in Figures 4–6.

In Figure 4, four SI_1-size inclusions in a 1.11 ct diamond have different dimensions but nearly identical area and contrast, and therefore each one has similar noticeability. Individually, each inclusion would be graded identically as SI_1 because each has the same area (roughly 35,000 μm²) and the same contrast (relief).

In Figure 5, the four inclusions between the 10 and 11 o'clock positions in the 0.70 ct diamond are the 'crystals' in Figure 4 reduced to half their dimensions and a quarter of their area (8,800 μm²). This reduces their noticeability and improves the clarity by one grade to VS_2 when

* Unless otherwise noted, all of the diamond images from Figure 3 onward were taken by Jonathan Weingarten and are scaled to show 10× magnification. The original colour photographs were converted by the author to black-and-white images after it was determined that the colours resulting from diamond's high dispersion distracted from finding and judging the noticeability of inclusions.

Figure 7: This 1.11 ct SI_2-graded diamond (6.66–6.63 × 4.11 mm) contains a white crystal and a string of five smaller dark-appearing inclusions, for a combined clarity grade of high SI_2.

Figure 8: Contrast the stone in Figure 7 with this 1.05 ct diamond (6.57–6.59 × 4.03 mm), which received the same SI_2 clarity grade despite having a much larger reflecting crystal inclusion.

they are considered individually. Again, despite their differing dimensions, all four inclusions are individually graded the same because each has the same area and amount of contrast. All four together have the same area as the single SI_1 inclusion seen at the 2 o'clock position in Figure 5. Thus, with similar overall area and impact on noticeability, four VS_2-size grade-maker inclusions evaluated together most often receive the same clarity grade as a single SI_1 grade-maker.

Reducing those four crystals by another factor of two in dimension (and factor of four in area) results in the group of four tiny crystals that are seen at the 5 o'clock position in the 0.70 ct diamond in Figure 6. Individually each of these inclusions is graded VS_1. Evaluated together as a group, they have similar total area and noticeability as the VS_2 inclusion at the 10 o'clock position in Figure 6. Therefore collectively these inclusions would receive one clarity grade lower (VS_2) than when they are considered individually.

An additional example is provided by this diamond's original string of three VS_1-size crystals under the crown main facet at 10 o'clock in both Figures 5 and 6. Considered together, GIA graded these inclusions VS_2.

Since for each successive grade a particular inclusion type increases in dimension by about a factor of two, the range of inclusion dimensions *within* each successive grade also increases by the same factor. For example, an inclusion in a low-borderline SI_2 can be almost twice the dimensions (and about four times the area) of a high borderline SI_2 of similar nature. Compare the large differences in size and noticeability between the identically GIA-graded (SI_2) ~1 ct diamonds in Figures 7 and 8. The SI_2 in Figure 7 should bring a large premium over the SI_2 in Figure 8, but price guides and the market in general currently value them the same. Shouldn't a clarity grading system account for what should be a significant value difference between these two widely different clarity appearances? The current scale lacks sufficient definition for the market in the grades of SI_2 and below. These two identically graded SI_2 diamonds bring to mind Liddicoat's statement "There weren't a large enough number of grades to fit the market.... We had to have more."

With more lower-clarity diamonds entering the market, the relatively large range of SI_2 and the much greater range of I_1 created market demand for an intermediate grade for stones containing inclusions with a combined area that is close to I_1 but that have too good an appearance to be lumped together with typical I_1 diamonds. That need prompted the introduction of an SI_3 grade in 1992, initially by Tom Tashey, then owner of EGL Los Angeles (T. Tashey, pers. comm., 2014). However, attempts to meet this market need have largely been frustrated by misuse. The lack

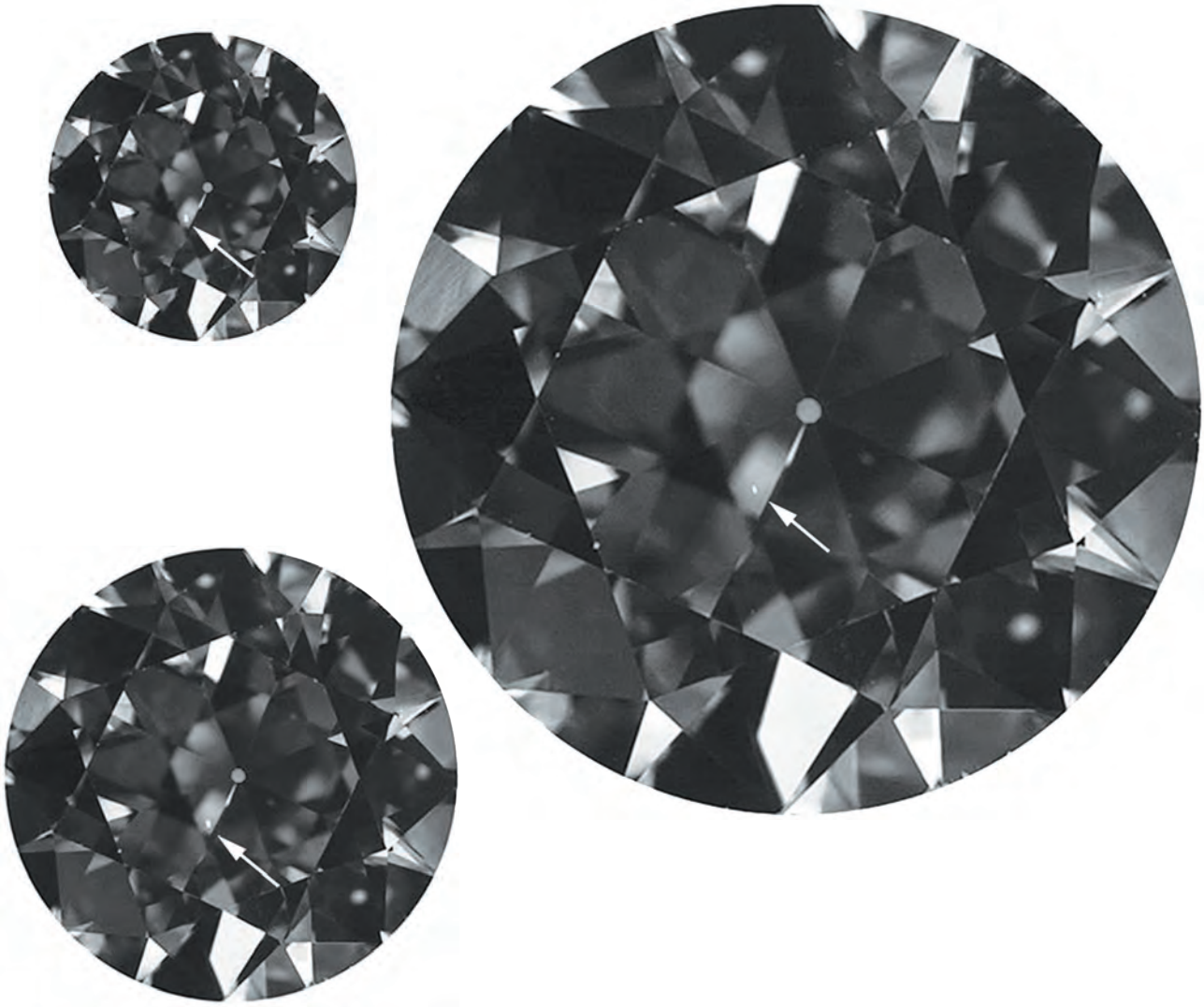

Figure 9: An identical VS_2-size crystal inclusion is shown in these diamond images that have been rescaled to the equivalent of ⅓, 1 and 6 ct. The inclusion has similar noticeability in all three images, and would result in the same grade over this large range of diamond sizes.

of objective grading standards has led to wide discrepancies and an increase in inclusion sizes that are assigned SI_3 grades. In fact, diamonds graded SI_3 often extend well into the GIA I_1 grade. (Note that although many in the diamond trade and some laboratories have adopted the SI_3 designation, it is not recognized by GIA.)

The Relationship of Inclusion Size to Diamond Size

Thus far absolute inclusion size has been addressed, but not inclusion dimension relative to diamond size. In very small diamonds, inclusions that occupy a significant percentage of the diamond's dimensions may be graded more severely. As well, an inclusion in a large diamond may be less noticeable and for that reason may be graded less severely. In general, the system presented here has been found to be accurate independent of diamond size over roughly the range of round diamond diameters from 4.5 mm (⅓ ct) to 11.8 mm (6 ct). This is particularly the case for clarities ranging from VVS_1 to VS_2, as well as most SI_1 diamonds. To illustrate this, the image of a VS_2-size inclusion in a 1.00 ct diamond was copied and pasted into the same location in two images of the same diamond scaled to ⅓ ct and 6 ct (Figure 9). The inclusion in all three diamonds is seen to be of the same category: a 'minor inclusion that is somewhat easy to see under 10× magnification', corresponding to VS_2 over this range of sizes.

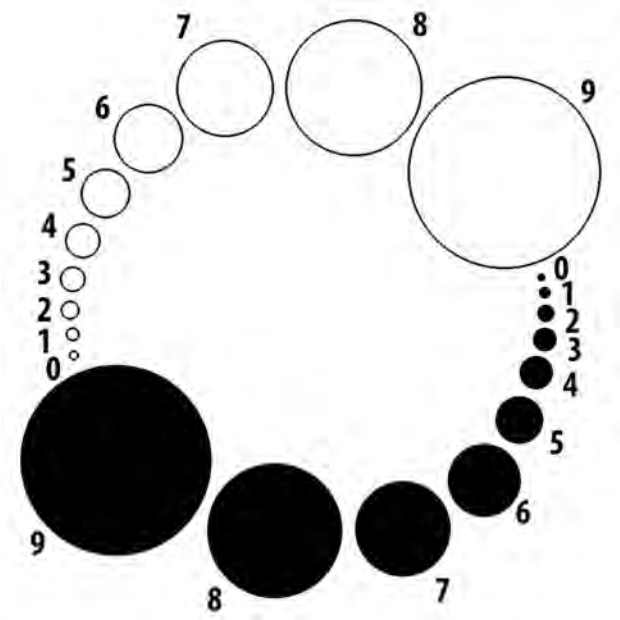

Figure 10: The Porton graticule consists of circle diameters increasing by the factor $\sqrt{2}$. Drawing by M. Cowing.

Previous Objective Clarity Grading Systems

In the 1970s, there were two notable attempts to reduce the subjectivity of diamond clarity grading through objective measurements of inclusion size combined with refinements in the factors of inclusion contrast, number, and location within the stone.

Contributions by Roy Huddlestone and DGL, London

Huddlestone introduced at the Diamond Grading Laboratories (DGL) the use of a Porton graticule to measure diamond inclusions. As mentioned by Bruton (1978), this graticule, a version of which is shown in Figure 10, consists of circles numbered 0 to 9 that increase in diameter by the factor $\sqrt{2}$ (a doubling in area). By fitting an inclusion's length and width to the nearest Porton circles that just enclose each dimension, a measure of inclusion size in Porton numbers is obtained. This transformation from dimensions to circle numbers is a useful and ultimately instructive process. An approximate representation of an inclusion's area (multiplication of length by width) is obtained by simply adding the corresponding circle numbers for its length and width. (Addition in the 'Porton domain' equates to multiplication of length times width, yielding a measure of an inclusion's area.) If the inclusion is rectangular, the area measurement is exact. Irregular or circular features have slightly less area than the product of length and width, but with a little ingenuity they are adequately characterized by this technique. For instance, a tapering inclusion's area is accurately approximated by adding the Porton circle number for its length to that for its average width.

In DGL's system, the total area score, which was obtained in this manner for each significant inclusion, was converted to a 'primary point count' (Burr et al., 1981) that was then adjusted for 'brightness' (the equivalent of contrast or relief) and 'its position in the stone' to arrive at a final point count establishing the clarity grade.

Contributions by Kazumi Okuda

Okuda incorporated his version of the circle graticule into his diamond grading microscope. Having been introduced to DGL's system by Roy Huddlestone (R. Huddlestone, pers. comm., 2014), he used a circle graticule to measure inclusion area in a manner similar to DGL. An important difference is that Okuda's circles increased in diameter not by the factor $\sqrt{2}$ but by a factor of 2. Table I shows Okuda's conversion from micrometre measurement to his circle numbers. As seen in an excerpt of the instruction manual (Figure 11), a representation of inclusion area is obtained by adding the circle numbers that just enclose the inclusion's length and width.

Okuda's most important contribution to objective clarity grading was his clarity conversion table (Figure 12), which converts the area score to a clarity grade. For cases in which no adjustment is needed for contrast or position, such as a grade-

Table I: Okuda's conversion from micrometres to circle number.

Size (µm)	Circle number
10	1
20	2
40	3
80	4
160	5
320	6
640	7
1,280	8
2,560	9
5,120	10

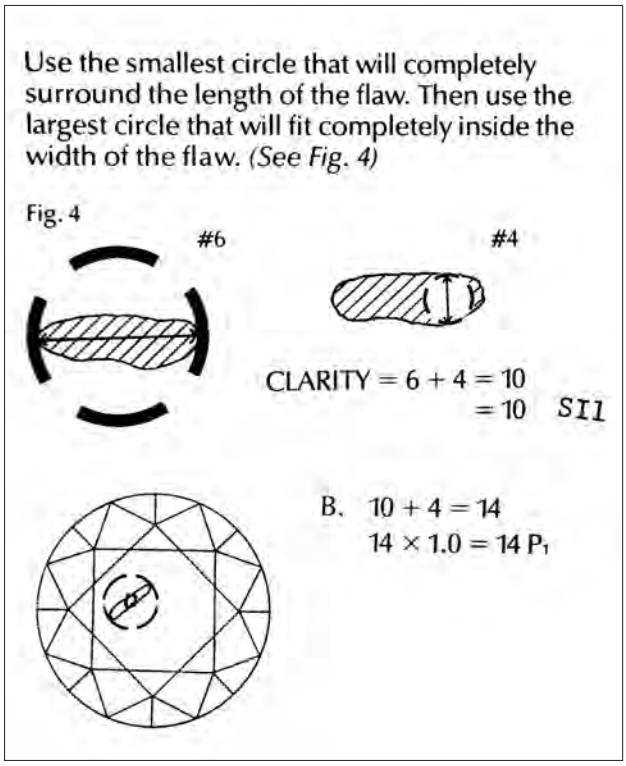

Figure 11: This excerpt from Okuda (1978) illustrates how a measure of inclusion area is obtained by the addition of circle numbers corresponding to their length and width.

Figure 12: The Okuda clarity conversion table shown here converts the area score obtained from the sum of the circle numbers for length and width to a clarity grade. From Okuda (1978).

CLARITY No. (A)	CLARITY No. (B)	CLARITY
0	1	FL
2	3	VVS_1
4	5	VVS_2
6	7	VS_1
8	9	VS_2
10	11	SI_1
12	13	SI_2
14	15	P_1
16	17	P_2
18	19	P_3
20		Rejection

maker crystal or feather inclusions of medium contrast located under the diamond's table, the clarity grade is obtained directly from the conversion table using the area score obtained from the sum of the circle numbers for length and width. However, Okuda's grading system had two shortcomings:

1. It lacked an adjustment for variations in inclusion contrast.
2. Although there was an adjustment for position, it was applied to the area score as a multiplicative factor. As will be seen, this adjustment must be applied additively in the circle number domain in order to mirror GIA grading practice correctly in a uniform fashion throughout the clarity scale.

The New Clarity Grading System

The first step in the new clarity grading system is to measure the inclusion dimensions using 32× to 45× microscope magnification, employing either a vernier caliper or a reticule capable of approximately ±10 µm accuracy. The author recommends today's version of the 6-inch Mitutoyo Digimatic digital calipers that he has employed for over 30 years. The ±10 µm accuracy suffices for typical inclusion sizes of VS_1 and larger. VVS_1- and VVS_2-size inclusions are more easily and accurately measured (using the same digital calipers) from an enlarged photograph.

With insights from the transformation from inclusion dimensions to Porton circle numbers and Okuda's clarity table, the author has developed a new continuous grading scale consisting of a graph with a curve increasing with a $\sqrt{2}$ relationship; it will be included in the author's upcoming ebook (Cowing, in press). The graph is used to provide a transformation of inclusion dimensions to the exponential domain. The sum of the transformed length and width provides an inclusion area score like that obtained using the discrete circles of the Porton graticule. However, the advantage of using this graph over the discrete circles is its continuous nature. It does not require the nonlinear interpolation necessary when measuring an inclusion's length or width that falls between circle sizes.

Table II. Adjustment guidelines due to inclusion contrast.

Scale	1	2	3	4	5
Description	Low-contrast inclusion difficult to observe with overhead lighting; a 'cloud' is a good example	Inclusion with contrast in between a cloud and typical crystals and feathers	Typical contrast of a clear or white crystal or feather as seen with overhead lighting	A more solid white or darker than usual crystal or feather between typical and high contrast	High contrast with overhead lighting, either black on a light background or a bright reflector on a dark background
Adjustment to clarity grade	−2e to −4e (one to two grades higher)	−1e to −2e (one-half to one grade higher)	No adjustment	+0.5e to +1e (one-quarter to one-half grade lower)	+1e to +2e (one-half to one grade lower)

Adjustments to the Area Score due to Inclusion Number, Contrast and Position

After finding the starting clarity grade from the combined total inclusion area score of the grade-maker inclusions, adjustments are made according to inclusion number, contrast and position.

Number: Instances where there are a number of similar grade-maker–size inclusions are effectively handled by summing them to the approximate dimensions of a similar inclusion having the same total area. This commonly results in an adjustment of one grade lower when there are multiple (i.e. about four) similar grade-maker–size inclusions (four times the area of one of them). Note that near-borderline inclusion sizes may drop into the next lower grade with as few as two grade-maker–size inclusions.

Contrast: As taught by GIA, inclusion contrast, which is referred to as 'colour and relief', "can affect visibility as much as size….*Relief* is the contrast between the inclusion and the [surrounding field of the] stone; the greater the relief, the more it will affect the clarity grade" (GIA, 1994, p. 12).

To address the influence of contrast or relief on the clarity grade, the new system employs a simple 1-to-5 scale along with their corresponding adjustments (Table II). Any adjustment is applied additively in the exponential domain. A one-grade-lower clarity adjustment corresponds to an addition of +2e (the 'e' notation refers to an exponential scale).

Needing no adjustment is a medium-contrast crystal or white feather, which would be designated a 3 on the contrast scale. A very high contrast inclusion is 5 on the scale, and most often requires an adjustment of one grade downward (i.e. a +2e adjustment). For example, a black crystal that obviously stands out against the surrounding diamond with overhead lighting would receive a +2e adjustment to the clarity grade. In the other direction, a very low contrast inclusion that barely stands out, such as a cloud, is designated a 1 on the contrast scale and adjusts the initial clarity grade upward by 1–2 grades (a –2e to –4e change). Inclusions requiring intermediate adjustments (i.e. designated 2 or 4 on the contrast scale) may not change the clarity grade if the diamond falls near the middle of a particular grade. However, a borderline grade will probably change.

Position: Adjustments for position are based on observation of GIA practice and are described in Table III. No adjustment is needed for the easiest-to-locate inclusions under the table or just outside

Table III. Adjustment guidelines due to inclusion position.

Position	Inside table or just outside it	VS_2 size or smaller, touching or very near girdle	VS_2 size or smaller, near girdle	SI_1 size, near or touching girdle	SI_2 or larger, anywhere in diamond
Adjustment to clarity grade	No adjustment	−1e to −2e (one-half to one grade higher)	−0.5e to −1e (one-quarter to one-half grade higher)	−0.5e to −1e (one-quarter to one-half grade higher in a large diamond)	No adjustment

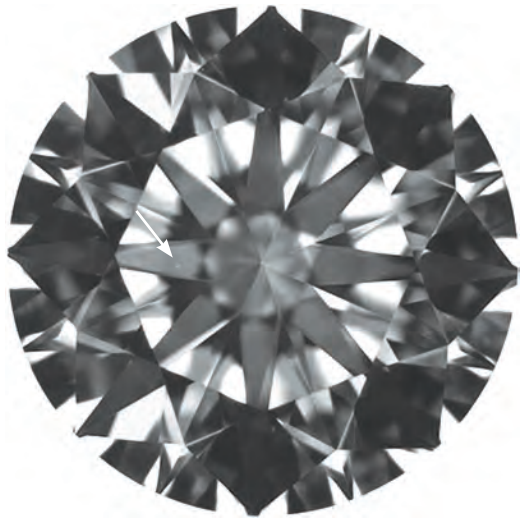

Figure 13: This 1.20 ct VS_1-graded diamond (6.83–6.85 × 4.17 mm) contains a crystal inclusion measuring 90 × 42 µm (under the table at 9 o'clock), which corresponds to a clarity grade of VS_1 using the new system.

it. An adjustment is made for as much as a one grade upward (−1e to −2e) for VS_2 and smaller inclusions that touch the girdle or are just inside it. A position adjustment of one-quarter to one-half grade upward may apply to inclusions outside the table but not very near the girdle. This would only change the clarity grade in borderline cases. Larger inclusions (SI_2 and greater) are unlikely to be adjusted for position because of their obvious nature anywhere in the diamond from girdle to table.

Final Grading Call Considerations

It is important to point out that these inclusion measurements and judgements are all made from a face-up two-dimensional perspective. However, if a grade-maker inclusion extends deeper into the stone than the dimensions of its face-up measurement (so that it appears significantly larger when viewed from the side), consideration must be given to lowering the grade obtained by face-up observation. In most instances, such an adjustment is not more than one grade lower than the face-up call.

It is also important to note that the final clarity grade is made by observation of the overall inclusion visibility in the face-up position under overhead lighting (not darkfield illumination). This is usually accomplished in the laboratory by viewing the diamond with a 10× loupe under the small 7-inch fluorescent-tube light attached to the microscope; diamond traders more commonly use a fluorescent desk lamp.

Objective Clarity Grading Example

Figure 13 provides an example of a single grade-maker crystal inclusion of medium contrast (3 on the contrast scale) located under the table:

1. Measure inclusion length and width (in microns): 90 × 42 µm.
2. Convert length and width from microns to the exponential domain (see Table I): 4.2e + 3.1e.
3. Sum the exponent numbers to obtain the inclusion area score: 7.3e.
4. Make adjustments for contrast and position: In this case there are none, since the inclusion has typical contrast (3) and its position is under the table.
5. Look up the total adjusted clarity grade for 7.3e (see, e.g., Figure 12): VS_1.

Comparison with Clarity Grades Determined by Gem Laboratories

To evaluate numerous laboratory-graded diamonds in conjunction with this study, it was expedient to experiment with grading of inclusions using high-quality photographs. Without the actual diamonds in hand, the question was: Can inclusions, their sizes and their contrast/relief be measured and adequately judged from diamond photographs? With good photographs where the grade-maker inclusions are in focus, the answer is yes. An initial experiment involved grading the diamonds photographed in Roskin (1994). From the darkfield diamond images in that book, a vernier caliper was used to measure the dimensions of each diamond's grade-maker inclusions along with the stone's dimensions. The actual inclusion dimensions were then obtained by scaling according to the ratio of actual diamond diameter divided by the diamond image diameter. Objective grading using inclusion measurements from the images resulted in near-perfect agreement with the stated clarity grades of all the diamonds pictured in the book.

The majority of images in the author's database, and all of those used in this article, were obtained

Figure 14: This 0.92 ct VVS_1-graded diamond (6.22–6.23 × 3.85 mm) contains a VVS_2-size pinpoint. The position of this inclusion near the girdle at 6 o'clock calls for a half-grade adjustment, making the clarity grade a low VVS_1.

from the website for the diamond and jewellery retailer Good Old Gold (www.goodoldgold.com), which lists the company's diamond inventory, commonly with corresponding grading reports from GIA or AGSL. Also available are darkfield images pointing out the grade-maker inclusions, and for some diamonds there are images taken with overhead lighting. Owner Jonathan Weingarten graciously granted the author access to this ready-made database. The inclusion dimensions and other noticeability factors were measured and judged from the available darkfield and overhead lighting images in a manner similar to that employed for 'grading' Roskin's (1994) diamond images. The clarity grades obtained with the new objective system were compared to laboratory-determined grades for more than 100 randomly selected diamonds in Good Old Gold's inventory, over a range of sizes from ⅓ to 6 ct and clarities from VVS_1 to I_2. The grades obtained with the new system accurately reflected laboratory grading in over 90% of the examples. 'Solid' clarity grades (those in the middle half of a grade range) almost always matched those determined by the laboratory. In fact, the author has been employing this objective system's methodology since the early 1980s, and has found throughout this time period a close agreement with the clarity grading calls of both GIA and AGSL. The author continues to augment the current database with GIA-graded diamonds he has examined and photographed (both with darkfield and overhead lighting) and then graded with this new system.

The following examples were selected to show the application of the new system to GIA-graded diamonds with a range of clarities.

VVS_1 Example

The VVS_1 clarity grade is defined by the presence of minute inclusions that are extremely difficult to see with 10× magnification. The question of when an inclusion becomes visible to the experienced observer at 10× magnification is important, as it defines the boundary between Fl or IF and VVS_1. According to Bruton (1978), a possible example of such an inclusion is a white pinpoint of approximately 5 µm that appears bright with very high contrast against a dark background. However, if the pinpoint has medium contrast, then the threshold of 10× visibility doubles to 10 µm. This inclusion area of 10 × 10 µm corresponds to a clarity score of 1e + 1e = 2e, which is the boundary between IF (0e–1.999e) and VVS_1 (2.0e–3.999e).

The 0.92 ct diamond in Figure 14 has a single pinpoint at 6 o'clock near the girdle under a crown half. The inclusion has a diameter of 24 µm for a clarity score of 2.3e + 2.3e = 4.6e, corresponding to an initial grade of VVS_2. The pinpoint's position outside the table near the girdle calls for a half-grade adjustment of 4.6e – 1e = 3.6e, for a final clarity grade of a low VVS_1.

VVS_2 Example

The VVS_2 clarity grade is defined by the presence of minute inclusions that are very difficult to see with 10× magnification. Earlier it was stated that a number of grade-maker–size inclusions are effectively handled by grading them as an equivalent inclusion with similar total area. The presence of about four similar grade-maker inclusions is likely to lower the clarity one grade more than would a single similar feature by itself. An evaluation of the 1.55 ct VVS_2-graded diamond in Figure 15a provides a practical example illustrating both principles. The stone contains five pinpoints (see plot in Figure 15b), but the largest and only one visible at 10× magnification measures 23 × 21 µm = 2.1 + 2.1e = 4.2e, which corresponds to a high borderline VVS_2. Two of the additional pinpoints (visible in

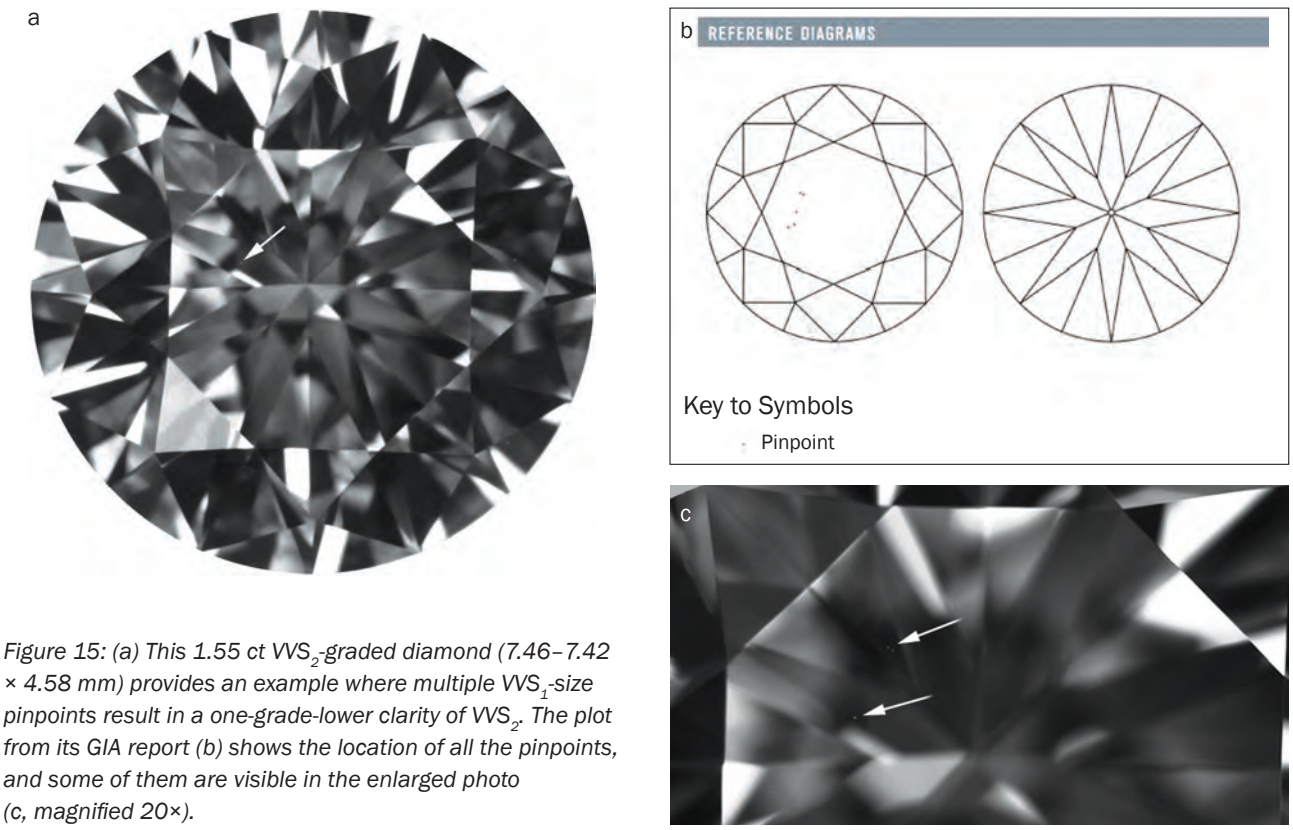

Figure 15: (a) This 1.55 ct VVS_2-graded diamond (7.46–7.42 × 4.58 mm) provides an example where multiple VVS_1-size pinpoints result in a one-grade-lower clarity of VVS_2. The plot from its GIA report (b) shows the location of all the pinpoints, and some of them are visible in the enlarged photo (c, magnified 20×).

Figure 15c) are each 18 × 18 µm = 1.9 + 1.9e = 3.8e (low VVS_1 pinpoints individually) and the other two are even smaller. An inclusion having the combined total area of all five pinpoints would be approximately 70 × 20 µm = 3.8e + 2.0e = 5.8e, which would have a final clarity grade of low VVS_2.

There is an additional way to arrive at the clarity grade for this example. The three pinpoints mentioned above are low-VVS_1 in size, and along with the two additional tiny VVS_1 pinpoints that are not visible in the photos, the group has the equivalent noticeability of four low-VVS_1 grade-makers, bringing the call down one grade from a low VVS_1 to a low VVS_2.

VS_2 Examples

The VS_2 clarity grade is defined by the presence of minor inclusions that are somewhat easy to see with 10× magnification. The 0.90 ct VS_2-

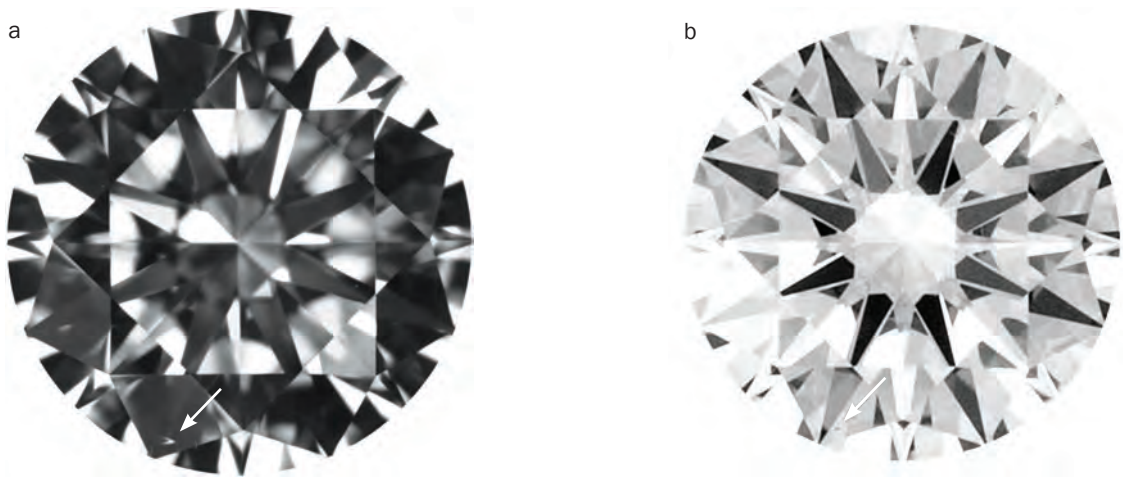

Figure 16: A 0.90 ct VS_2-graded diamond (6.26–6.24 × 3.76 mm) containing an arrowhead-shaped feather located at 7 o'clock is shown with darkfield illumination (a) and overhead lighting (b). This example illustrates how inclusions typically appear less distinct with overhead lighting (where the final clarity grade call is made) than with darkfield.

a

Figure 17: (a) This large VS_2-graded diamond (5.70 ct, 11.48–11.53 × 7.13 mm) contains a string of five tiny crystals that taken together have the combined area of a VS_2. The plot from its GIA report (b) shows the location of all the inclusions, most of which are visible in the enlarged photo (c, magnified 20×).

b

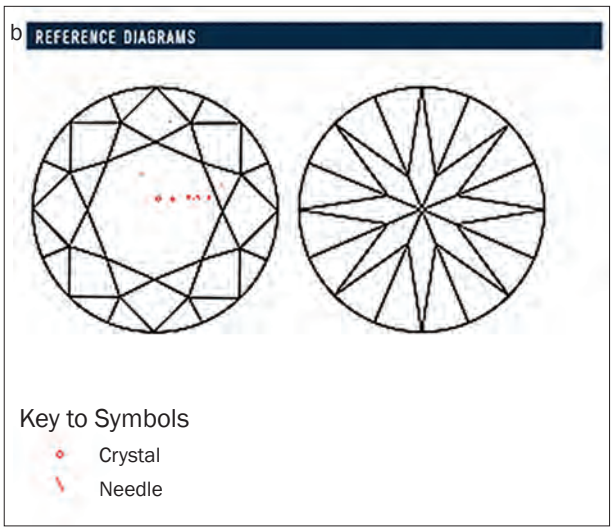

c

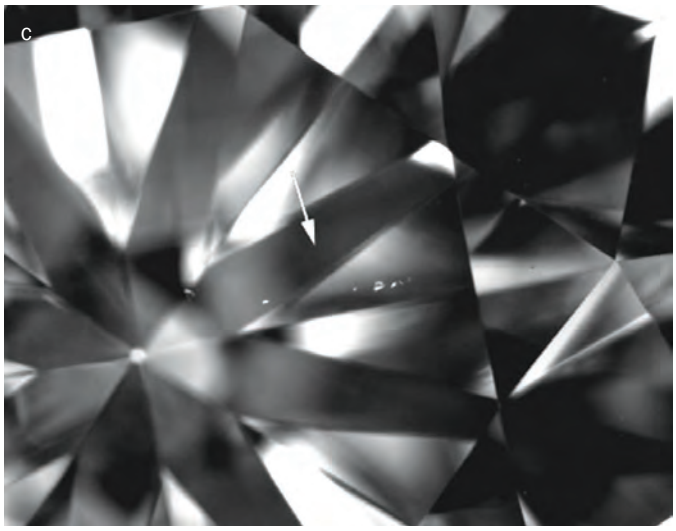

graded round brilliant in Figure 16 contains an arrowhead-shaped feather of medium contrast (3) located under a crown main facet at 7 o'clock. The two images of Figure 16 illustrate the fact that with overhead illumination (where the final clarity grade call is made), inclusions of medium contrast are typically less distinct than they are with darkfield. This is because darkfield illumination is designed to illuminate inclusions by making them appear bright against a dark background. The feather has approximate dimensions of 162 × 65 µm = 5.2e + 3.8e = 9e, which corresponds to an initial call of a solid VS_2. An adjustment is needed due to the feather's location near the girdle; about –0.7e is appropriate, making the final score 8.3e, and the clarity grade a high VS_2.

The 5.70 ct VS_2-graded round brilliant in Figure 17 contains a string of five tiny crystals under the table around 3 o'clock. Together they add up to an equivalent inclusion size of 167 × 83 µm that translates to 5.2e + 4.1e = 9.3e, for a clarity grade of VS_2.

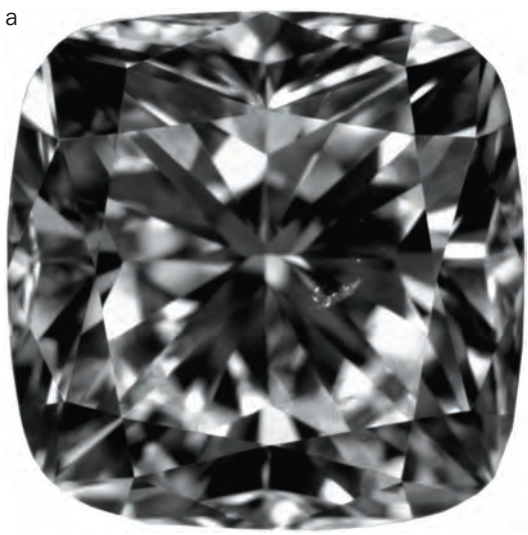

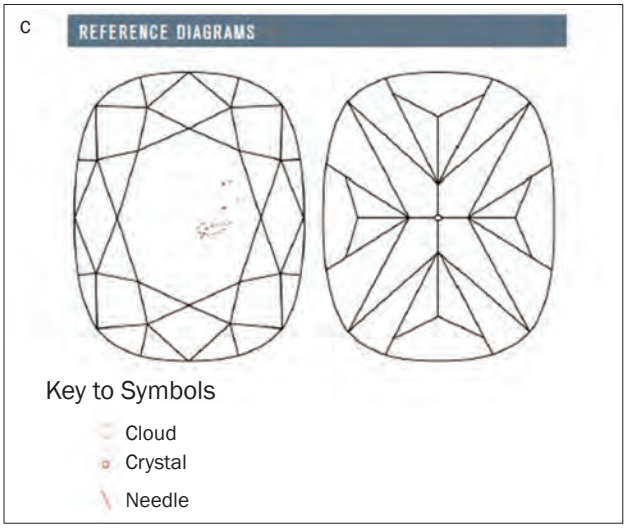

Figure 18: This 1.70 ct SI_1-graded diamond (6.82–6.78 × 4.74 mm) contains a low SI_1-size crystal/cloud combination with low contrast that adjusts the clarity grade to a solid SI_1. It is shown with darkfield illumination (a) and overhead lighting (b), along with a plot of the inclusions from its GIA report (c).

SI_1 Example

The SI_1 clarity grade is defined by the presence of noticeable inclusions that are easy to see with 10× magnification, but usually not easily noticeable to the unaided eye. The 1.70 ct SI_1-graded diamond in Figure 18 contains a grade-maker inclusion group consisting of a crystal/cloud combination under the table at about 3 o'clock. The group of inclusions is of low contrast (2) and has a combined area equivalent to 649 × 130 µm, which translates to 7.1e + 4.6e = 11.7e. After a half-grade adjustment (–1e) for the low contrast of the inclusions, the score is 10.7e, which corresponds to a clarity grade of SI_1.

SI_2 Example

The SI_2 clarity grade is defined by the presence of noticeable inclusions that are very easy to see with 10× magnification, but typically not easily noticeable to the unaided eye. The 0.74 ct SI_2-graded diamond in Figure 19 contains a grade-maker cluster of low-contrast (2) feathers extending deep under the table. Summing the area of each feather yields an approximate inclusion area of 685 × 372 µm = 7e + 6.2e = 13.2e, corresponding to a middle SI_2. An adjustment of one-half grade upward (–1e) for the low inclusion contrast yields a clarity score of 12.2e. However, this diamond provides an unusual case of having features that are not apparent with darkfield illumination but are noticeable with overhead lighting (numerous feather reflections located outside the table). It is challenging to speculate from the photo how apparent these reflections were to the grader. They appear to warrant an adjustment of one-half to one full grade downward (+1e to +2e), yielding a score of 13.2e to 14.2e, corresponding to a low SI_2 bordering on a high I_1. The SI_2 clarity grade received at the laboratory was probably due to the fact that these additional features are reflections that were not very noticeable.

I_1 Example

The I clarity grades are defined by the presence of obvious inclusions with 10× magnification that are eye-visible face-up. The 1.01 ct I_1-graded cushion brilliant cut in Figure 20 contains a large grade-maker inclusion under the table edge at 7 o'clock that shows moderately high relief (4) with overhead illumination. The approximate

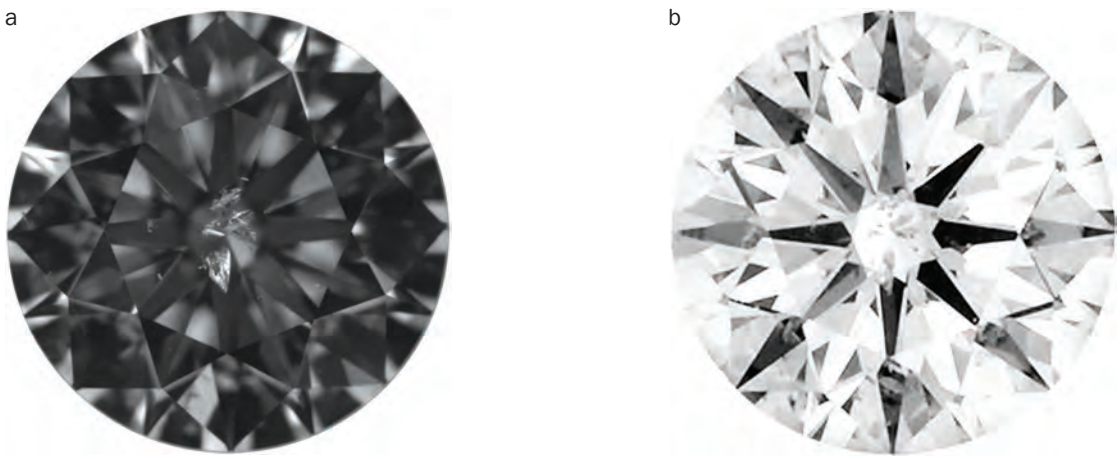

Figure 19: Shown with darkfield illumination (a) and overhead lighting (b), this 0.74 ct SI_2-graded diamond (5.80–5.82 × 3.60 mm) has a grade-maker cluster of feathers with a combined area that sums to SI_2 size. An adjustment for their low contrast is more than offset by the fact that they reflect outside the table. With overhead illumination the reflections outside the table are apparent, leading to a low-borderline SI_2 clarity grade.

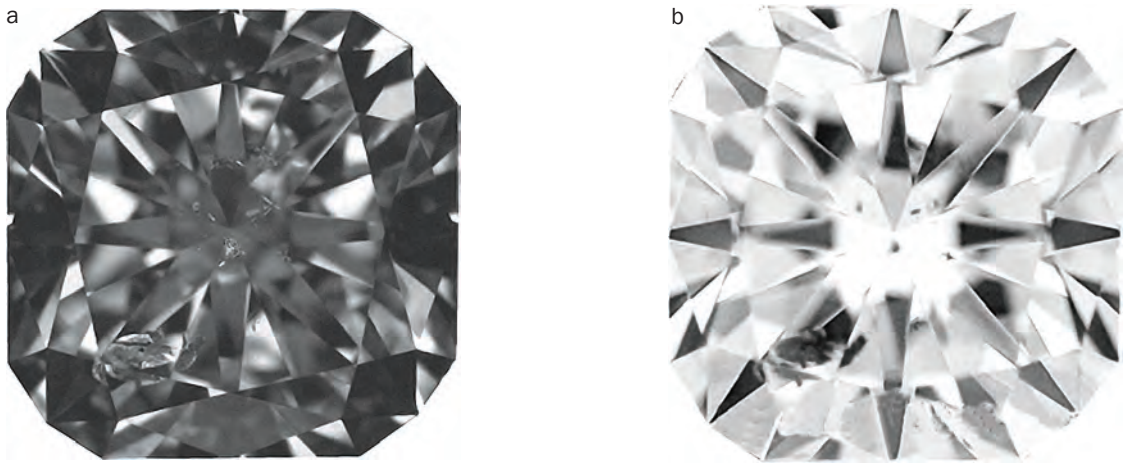

Figure 20: Shown with darkfield illumination (a) and overhead lighting (b), this 1.01 ct I_1-graded diamond (5.85–5.89 × 3.85 mm) contains a large I_1-size inclusion. The high contrast seen with overhead lighting adjusts the grade downward to a low I_1.

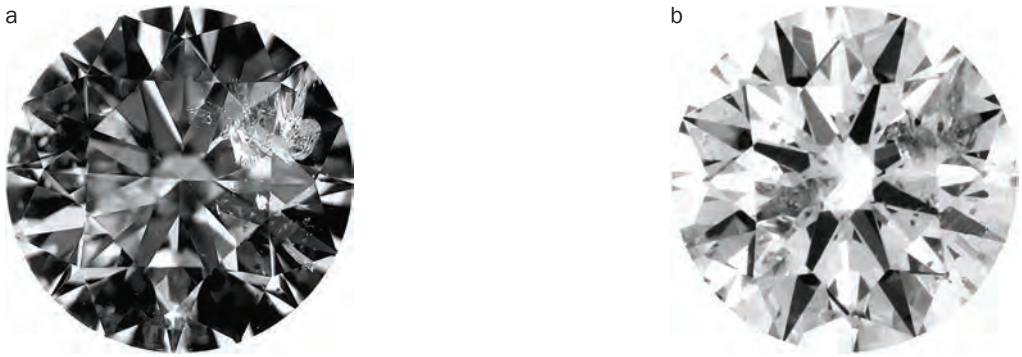

Figure 21: This 0.35 ct I_2-graded diamond (4.55–4.54 × 2.78 mm) contains a large I_1-size fracture that is best seen with darkfield illumination (a). Viewed with overhead lighting (b), a reflection of the fracture causes a doubling of its apparent area, which combined with the relatively small size of the diamond leads to a solid I_2 clarity grade.

dimensions are 1026 × 545 µm = 7.7e + 6.8e = 14.5e, for a clarity grade of high-medium I_1. After adjusting one-half grade downward (+1e) for the moderately high contrast, the final score is 15.5e, corresponding to a low I_1.

I_2 Example

The 0.35 ct I_2-graded round brilliant in Figure 21 contains a large fracture that is best seen and measured using darkfield illumination. It is 1165 × 757 µm = 7.8e + 7.3e = 15.1e, for an initial

clarity grade of middle I_1. When the stone is examined with overhead lighting, the reflection of this fracture requires an adjustment of one-half to one grade downward (+1e to +2e), for a score of 16.1e to 17.1e, corresponding to a high-to-middle I_2. In addition, since the inclusion's appearance constitutes a significant percentage of this rather small diamond, the +2e adjustment is appropriate for a final grade of a solid I_2.

Conclusions

This article introduces a new objective form of clarity grading based on metrics that model the techniques of experienced graders. The system emulates the analysis performed by these graders, who assess the combined factors of inclusion characteristics (size, number, contrast, position and nature) to arrive at the clarity grade.

A small sampling of grading examples are discussed here that compare the results obtained from this new system to photographs of GIA-graded diamonds. They were selected from more than 100 recently documented photographic examples that support the success of this system in matching clarity grades obtained by gem laboratories.

A particularly notable outcome of this study is the approximate but consistent four times increase in inclusion area from grade to grade across the entire GIA clarity scale. This multiplicative relationship resulted from the natural evolution and expansion of the clarity grades and terms used in the diamond trade well before GIA's formalization of the grading scale. It speaks to human perception of the relative noticeability of diamond inclusions.

With the success of this objective system in matching GIA grading, its accuracy and consistency suggests the possibility of its use for improving inter- and intra-laboratory grading consistency.

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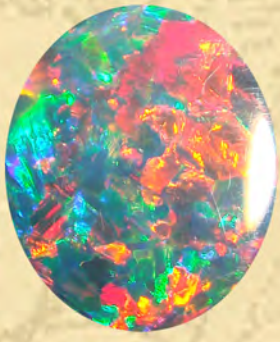

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A Comparison of *R*-line Photoluminescence of Emeralds from Different Origins

D. Brian Thompson, Joshua D. Kidd, Mikko Åström, Alberto Scarani and Christopher P. Smith

A fundamental task for gemmologists is determining whether an emerald is natural or synthetic. Within the laser-excited photoluminescence spectrum of emerald, the peak positions and relative intensities of two emissions in the 680–685 nm range, known as *R* lines, can help identify if a sample is natural, and can also provide information about its geological origin. In particular, the R_1 line of synthetic emerald is positioned at the shortest wavelength, while for natural emeralds with a non-schist origin this line is found at the same or longer wavelengths, and for schist-type emeralds the line peaks at an even longer wavelength. This measurement can supplement origin results obtained from established methods, such as inclusion microscopy, spectroscopy (e.g. ultraviolet-visible–near infrared [UV-Vis-NIR], Fourier-transform infrared [FTIR] and Raman) and trace-element analysis by laser ablation–inductively coupled plasma–mass spectrometry (LA-ICP-MS).

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Introduction

Emerald, the green to bluish green variety of beryl [$Be_3Al_2(SiO_3)_6$], is a beautiful and important gemstone (e.g. Figure 1). Pure beryl does not absorb visible light and therefore appears colourless. The green colour of emerald results from trace amounts of Cr and/or V; Fe may add a yellowish or bluish tinge. A Cr^{3+} ion substituting for Al^{3+} at its crystal site is surrounded by an octahedral arrangement of six oxygen ions. Then six silicon and three beryllium ions, the next-nearest neighbours with which the chromium shares the oxygens, result in a trigonal distortion of this crystal site (Wood, 1965). Crystal field theory explains how the three electrons in a Cr^{3+} ion's *d* orbital, when placed in beryl's octahedral oxygen field, absorb light across the red-orange and blue-violet wavelength ranges, so that emerald only transmits light in the green range (Wood et al., 1963; Wood, 1965; Mitra, 1996; Avram and Brik, 2013).

Chromium is the only emerald chromophore that exhibits photoluminescence (PL); vanadium does not cause PL in emerald. According to

Figure 1: Some of the emeralds studied for this report are shown here. Top row, from left to right: 0.76 ct from Davdar, China; and 0.71 and 0.66 ct from Colombia. Bottom row, from left to right: 1.14 ct synthetic Tairus 'Platinum'; 2.34 ct synthetic Chatham; and 0.37 and 0.23 ct from Kafubu, Zambia. Composite photo by Bilal Mahmood, American Gemological Laboratories.

crystal field theory, there are two possible paths by which Cr^{3+} in an octahedral ligand field may photoluminesce: one path leads to broadband luminescence and the other leads to a pair of narrow luminescence lines (Avram and Brik, 2013). Laser-excited PL spectra demonstrate that emerald displays both types of luminescence (e.g. Figure 2). The broadband structure, peaking at around 710–720 nm, results from a Stokes-shifted reversal of the electron transition that produces emerald's red-orange absorption band (Lai, 1987). Superimposed upon this structure are two narrow lines appearing between 680 and 685 nm that arise from electronic decay of a doublet metastable state (Wood, 1965); these are known as the *R* lines. The longer-wavelength line is denoted R_1 and the shorter-wavelength line is R_2 (Carceller-Pastor et al., 2013).

Moroz et al. (2000) collected Raman and PL spectra from one synthetic and nine natural emeralds of various geological origins. They found that the peak positions of the *R* lines in the PL spectra of schist-origin emeralds showed moderate shifts toward longer wavelengths, as compared to emeralds of non-schist origin and synthetic emeralds. The authors suggested these wavelength shifts may be caused by impurity metal ions substituting at octahedral aluminium sites. *Schist-origin* emeralds have a metamorphic or metasomatic origin in biotite or phlogopite schist; this is the most common emerald deposit type worldwide. *Non-schist origin* describes a few emerald deposits of varying geology. Colombian deposits, where emeralds are hosted by sedimentary black shale, are the primary examples (Groat et al., 2008; Giuliani et al., 2012). Also in this category are Nigerian emeralds, which are hosted by cavities in albitized granite (Groat et al., 2008; Giuliani et al., 2012).

This article provides a preliminary examination of the efficacy of using *R*-line peak shift in emerald PL spectra as an aid for identifying their

Figure 2: Laser-excited PL spectra (E⊥c) of three representative samples are shown: (a) a schist-origin emerald from the Ural Mountains, Russia (no. 9 in Table I); (b) a non-schist-origin emerald from Colombia (no. 19); and (c) a Chatham synthetic emerald (no. 24).

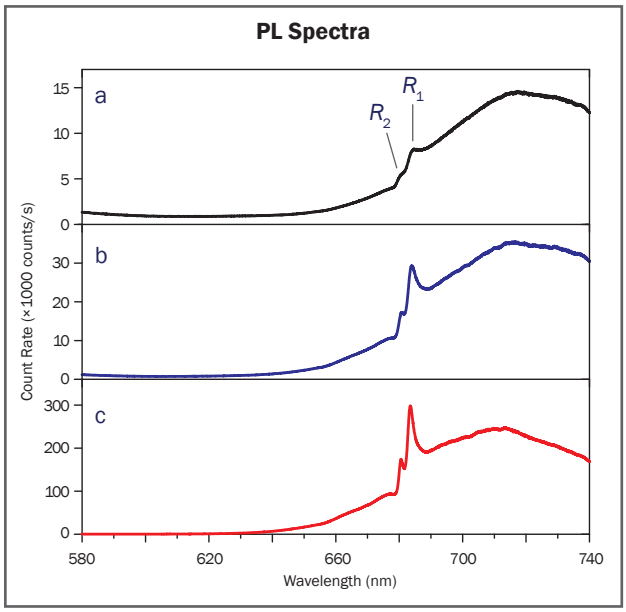

Table I: Emerald samples used in this study and their R *line measurements.*

Sample	Origin	Weight (ct)	Shape	R_2 peak position (nm)	R_1/R_2 peak height ratio	R_1 peak position (nm)	R_1-line FWHM (nm)	R_1/ broadband peak height ratio
Schist Origin								
1	Nova Era, Brazil	0.75	Pear cut	680.73	3.00	684.09	3.39	0.24
2	Nova Era, Brazil	0.58	Pear cut	680.73	2.27	683.95	2.99	0.35
3	Belmont, Brazil	0.31	Emerald cut	680.39	3.42	684.36	3.44	0.03
4	Bahia, Brazil	0.59	Pear cut	680.44	3.29	684.22	3.61	0.12
5	Davdar, China	0.76	Emerald cut	680.51	3.75	684.21	3.53	0.11
6	Mozambique	1.44	Hexagonal prism	680.73	3.10	683.93	3.22	0.30
7	Mozambique	0.96	Hexagonal prism	680.73	3.75	684.16	3.35	0.31
8	Ural Mountains, Russia	0.60	Pear cabochon	680.65	2.73	683.95	3.04	0.15
9	Ural Mountains, Russia	0.42	Oval cabochon	680.44	3.27	684.16	3.57	0.11
10	Lake Manyara, Tanzania	1.13	Hexagonal prism	680.75	3.34	684.04	3.13	0.37
11	Lake Manyara, Tanzania	0.78	Hexagonal prism	680.75	3.54	684.14	3.35	0.26
12	Kafubu, Zambia	0.37	Oval cut	680.48	3.19	684.25	3.61	0.14
13	Kafubu, Zambia	0.23	Oval cut	680.50	3.49	684.26	3.57	0.13
14	Sandawana, Zimbabwe	0.42	Emerald cut	680.31	3.65	684.25	3.66	0.05
15	Sandawana, Zimbabwe	0.46	Teardrop cut	680.23	2.66	684.09	3.76	0.05
Non-schist Origin								
16	Colombia	0.98	Pear cut	680.69	2.74	683.85	2.73	0.51
17	Colombia	0.71	Emerald cut	680.69	2.78	683.75	2.46	0.58
18	Colombia	0.83	Pear cut	680.73	3.16	683.87	2.77	0.48
19	Colombia	0.66	Emerald cut	680.64	3.09	683.85	2.82	0.34
20	Colombia	0.72	Pear cut	680.64	2.63	683.80	2.86	0.31
21	Nigeria	3.78	Hexagonal prism	680.66	2.67	683.58	2.20	0.91
22	Nigeria	4.70	Hexagonal prism	680.64	2.56	683.56	2.28	0.78
23	Nigeria	2.38	Hexagonal prism	680.64	2.80	683.58	2.20	0.83
Synthetic*								
24	Chatham	2.34	Emerald cut	680.59	2.60	683.51	2.29	0.63
25	Chatham	1.19	Emerald cut	680.57	2.60	683.55	2.37	0.58
26	Tairus 'Biron'	1.12	Pear cut	680.67	2.80	683.61	2.15	0.61
27	Tairus 'Biron'	1.07	Emerald cut	680.70	2.60	683.64	2.28	0.52
28	Tairus 'Platinum'	1.25	Emerald cut	680.66	2.60	683.55	2.28	0.61
29	Tairus 'Platinum'	1.14	Emerald cut	680.68	2.30	683.58	2.24	0.67
30	Tairus 'Colombian colour'	1.14	Emerald cut	680.72	2.60	683.65	2.05	0.55
31	A.G. 'Agee'	0.42	Emerald cut	680.70	2.60	683.63	2.23	0.57
32	Malossi	2.07	Emerald cut	680.77	2.40	683.53	2.33	0.38

*The Chatham synthetic emeralds were flux-grown; all the other synthetic emeralds were created by hydrothermal methods.

geological origin. We also investigate the influence of sample type and optic axis orientation on this peak shift, and suggest a mechanism to account for the variations in *R*-line positions.

Materials and Methods

PL spectra were collected at room temperature from 32 rough and cut samples (Table I): 23 natural emeralds from 11 different localities were provided by American Gemological Laboratories, and nine synthetic emeralds were acquired directly from their manufacturers or marketers.

A continuous wave diode-pumped solid-state (DPSS) laser emitting about 100 mW at 532 nm (Laserglow LRS0532) was used as an excitation source.[1] A 500 µm diameter optical fibre with a 25° field-of-view collimating lens aligned perpendicular to the laser beam was used to collect the PL emission from the emeralds. A gem clip was used to position the sample at the intersection of the laser beam and fibre's field of view, such that the beam overlapped the emerald edge closest to the optical fibre. This sampling geometry was chosen to minimize PL emission travelling through non-illuminated emerald before entering the fibre.

The PL emission collected by the fibre entered a CCD-type spectrometer (Ocean Optics USB4000) that dispersed light over the wavelength range 580–740 nm. Discrete-line emissions from Ar and Ne spectral lamps were used to calibrate the spectrometer's wavelength scale. Across the *R*-line wavelength range, the spectrometer had full-width at half-maximum (FWHM) resolution of 0.20 nm, and the width of each spectrometer channel was 0.045 nm. To construct each sample's PL spectrum, 100 accumulated scans were averaged, where typically each scan's integration time was one second. (For a Tairus 'Colombian colour' synthetic emerald with very little Cr, each scan's integration time was 10 seconds.) In a similar manner, with the light source shuttered, a 'dark' spectrum was recorded and the final PL pattern

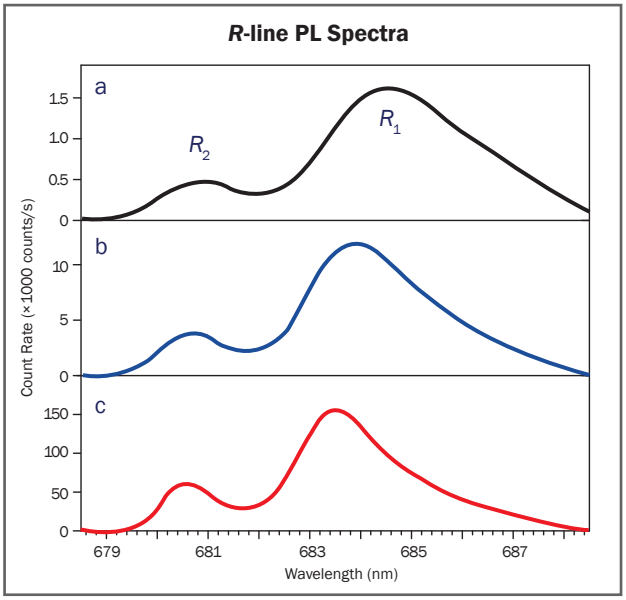

Figure 3: These R-line PL spectra result from performing a baseline subtraction of the spectra in Figure 2(a,b,c).

was created by subtracting this background from the sample spectrum.

Emerald's PL spectrum (e.g. Figure 2) exhibits local minima on either side of the *R* lines. To isolate the *R*-line contribution in each PL spectrum, a baseline was subtracted from the data, and the line's endpoints at 678.5 and 688.5 nm were selected to be close to where these local minima occur. The resulting spectra (e.g. Figure 3) are referred to as *R*-line spectra.

Emerald is optically uniaxial, resulting in differences in PL emission when the excitation laser beam's polarization is perpendicular to the emerald's c-axis (E⊥c) vs. that occurring when the beam is polarized parallel to the c-axis (E||c); both R_1 and R_2 peak positions change, as does the R_1/R_2 peak height ratio (Moroz et al., 2000). To collect orientation-dependent PL spectra from a sample lacking crystal faces, a consistent method is needed for determining E⊥c and E||c. To develop this technique, we first collected a series of spectra from several emerald crystals showing prism faces, beginning with E||c and rotating in 10° intervals to E⊥c. A comparison between spectra (e.g. Figure 4) revealed that the R_1/R_2 peak height ratio was consistently greatest for E⊥c and lowest for E||c. So for all emerald samples listed in Table I, the orientation relative to the laser beam was rotated until the R_1/R_2 peak height ratio reached a maximum value to collect E⊥c spectra; subsequently the sample was rotated until the R_1/

[1] PL spectra of three samples were also collected using each of the three emission wavelengths of an argon-ion laser: 514, 488 and 454 nm. Regardless of the wavelength of the excitation, we observed no change in *R*-line peak wavelength positions or relative heights.

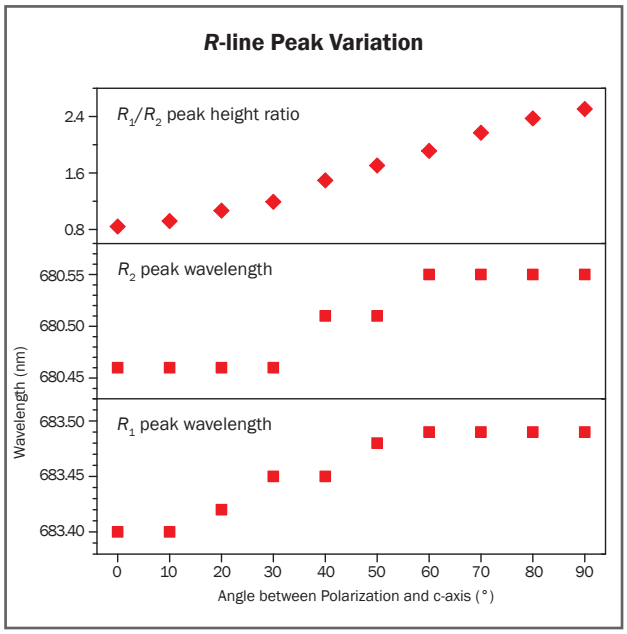

Figure 4: These plots show the angular variation of peak parameters extracted from R-line spectra of a Chatham synthetic emerald crystal with prism faces. The horizontal scale ranges from 0° (E||c) to 90° (E⊥c).

R_2 peak height ratio reached a minimum to collect E||c spectra. Using this method, we found that seven faceted emeralds had their c-axis parallel to the gem's table, six had their c-axis tilted about 45° from perpendicular to the gem's table, and the rest of the cut stones had their c-axis lying within 20° of perpendicular to the gem's table.

After spectral collection and baseline subtraction to create *R*-line spectra, peak-finding software (O'Haver, 2014) was used to extract R_1 and R_2 peak wavelengths and their corresponding relative emission strength, which were used to determine the R_1/R_2 peak height ratio. The R_1 and R_2 peak wavelengths reported in Table I are averages of values extracted from multiple spectral measurements; the uncertainty in peak position was ±0.02 nm or less. For most emeralds, we achieved this uncertainty with a minimum of four separate spectral measurements. However, some samples, such as the Tairus 'Colombian colour' synthetic emerald, required up to 16 measurements to achieve this uncertainty.

Results and Discussion

This study only examines the E⊥c spectra of each emerald, because the E||c spectra were found to show no origin dependence (see end of this section).

While the emeralds were exposed to the laser beam, red PL emission (Figure 5) was visible from all but one sample—the 'Colombian colour' synthetic emerald grown by Tairus. The green colour of this sample occurs without any significant influence of Cr (Schmetzer et al., 2006). Even so, the Cr concentration was high enough to be detected by PL spectroscopy.

Most natural emeralds also exhibit a yellow PL emission, either at spots on the surface or across the entire surface, due to oil or resin coatings used to improve emerald clarity (Johnson et al., 1999). In our samples, this emission appeared in the PL spectra of two natural emeralds (Figure 2a,b) as the non-zero signal between 580 and 620 nm. We saw no evidence of this additional emission disturbing the *R* line structure.

PL Spectral Features

The count rates at the peak of the broadband structure in the PL spectra (Figure 2) are dependent on Cr concentration. For example, the PL spectrum of a Chatham synthetic emerald (Figure 2c), with a reported Cr_2O_3 concentration of 0.35 wt.% (Huong, 2008), had a broadband peak count rate of 250,000 counts/s. In contrast, a Tairus 'Biron' synthetic emerald, with an estimated Cr_2O_3 concentration of 0.25 wt.% (Kane and Liddicoat, 1985; Huong, 2008),

Figure 5: Red PL emission of an emerald is seen here through a colour filter that removes the green excitation light. Photo by Shannon Wells, University of North Alabama.

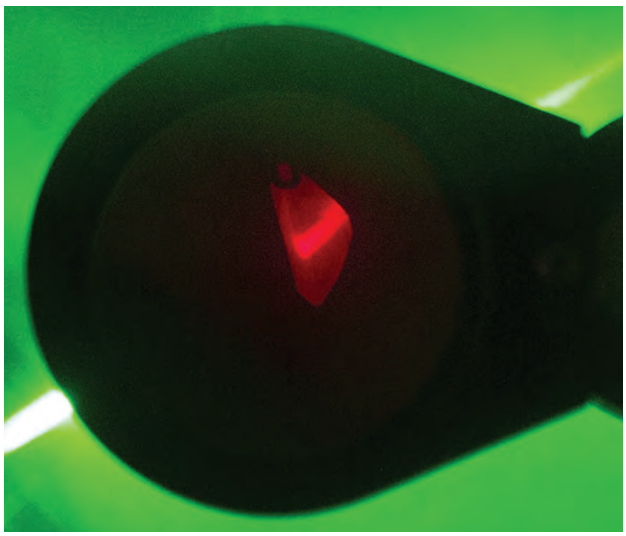

exhibited a peak count rate of 70,000 counts/s. At the other extreme, a peak count rate of only 100 counts/s was observed from the Tairus 'Colombian colour' synthetic emerald with a reported Cr_2O_3 concentration of 0.04 wt.% (Schmetzer et al., 2006). However, due to possible variations from one emerald to another in the luminescence collection volume (defined by the overlap of light beam, emerald and optic fibre field of view), these count rates provide only a qualitative measure of chromium concentration. In addition, some impurities such as iron may quench luminescence. Nevertheless, the broadband peak count rates in the PL spectra of both schist-origin and non-schist-origin emeralds (Figure 2a,b) suggest that they have comparable Cr concentrations.

The *R*-line spectra of the schist-origin, non-schist-origin and synthetic emeralds (e.g. Figure 3) showed two *R* lines with widths and peak separation an order of magnitude larger than the spectrometer's resolution. Besides the two peaks, no other fine structure appeared in any of the spectra collected.

The R_2 line in each spectrum had a Gaussian (bell-shaped) profile, and it peaked at a similar—but not the same—wavelength in each sample. Figure 6 shows a plot of the R_2 peak positions of all the emerald samples (see also Table I). Most of the peak positions occurred within a 0.25 nm-wide range, with the schist-origin emeralds exhibiting somewhat more variation.

The R_1 line in each spectrum had an asymmetric profile with an extended tail along the long-wavelength side. The relative height of each R_1 line was commonly between 2.5 and 3.5 times that of the corresponding R_2 line. Figure 7 presents the R_1/R_2 peak height ratios of all the emerald samples (see also Table I). Although samples from each particular origin exhibited a characteristic range of *R*-line peak height ratios, those from different sources showed significant overlap in some cases.

However, the peak positions of the schist-origin, non-schist-origin and synthetic emeralds' R_1 lines showed clearer trends: those of the synthetic emeralds peaked at the shortest wavelengths, while the R_1 lines of some non-schist emeralds were shifted to longer wavelengths, and those of schist-origin emeralds were present at even longer wavelengths (Figure 8 and Table I). The R_1 line of the schist-origin emeralds was positioned at wavelengths above 683.9 nm, while those of the non-schist-origin and synthetic emeralds peaked at wavelengths below that value. In fact, the R_1 line of all the tested synthetic emeralds peaked at wavelengths below 683.7 nm.

In addition, as R_1-line peak positions were shifted to longer wavelengths, their line-width also increased (as seen in Figure 3) and their height tended to decrease relative to the peak height of the broadband structure (as seen in Figure 2).

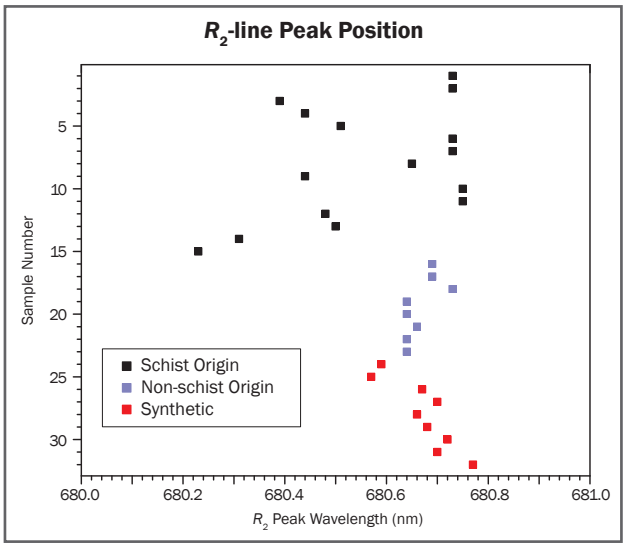

Figure 6: The R_2 *peak positions of the emerald samples showed considerable overlap. The width of the points matches the uncertainty in peak position.*

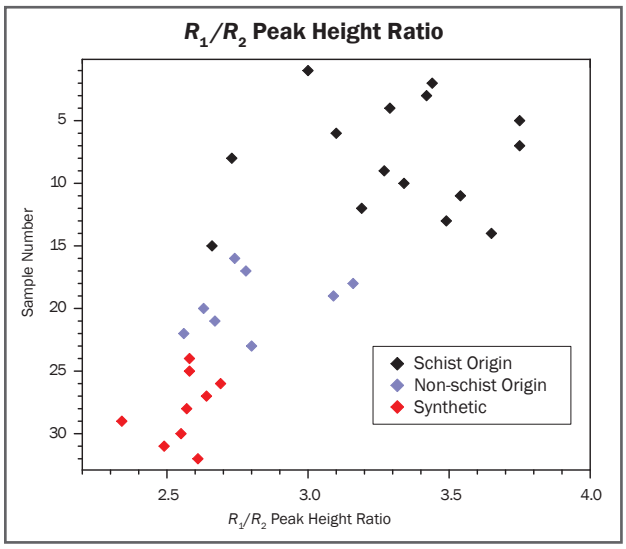

Figure 7: R-line peak height ratios showed some overlap, and were not distinctive enough to separate emerald origin.

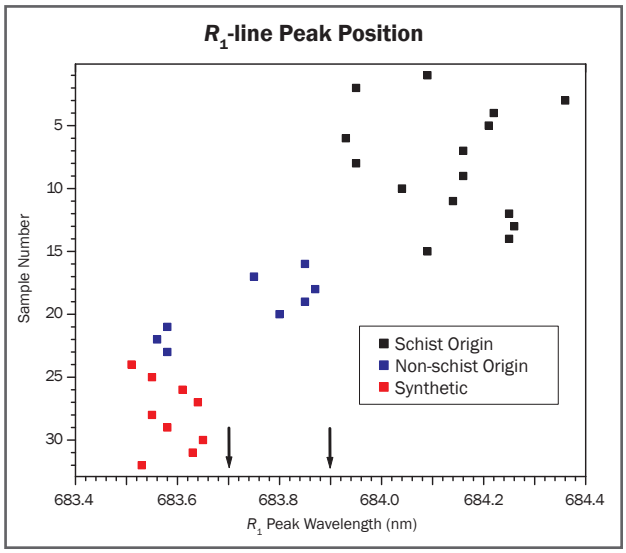

Figure 8: The R_1 peak positions are shown for the analysed samples. The arrows indicate wavelengths mentioned in the text: no R_1 lines of schist-origin emeralds were found to peak at wavelengths shorter than 683.9 nm, and no R_1 lines of synthetic emeralds were measured at wavelengths longer than 683.7 nm.

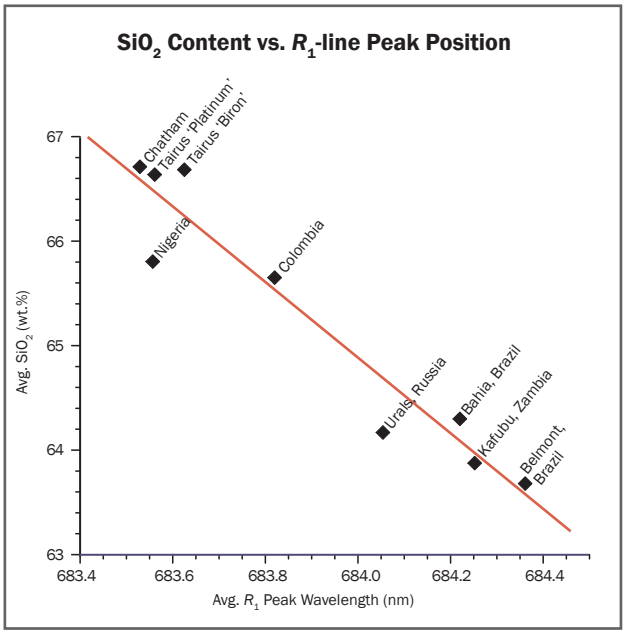

Figure 9: This plot shows average SiO_2 concentrations vs. average R_1 peak position of different emerald samples with the same origins. The SiO_2 values are taken from Huong (2008) and the R_1 peak positions are averages from our measurements. The trend line predicts an R_1 wavelength of 683.41 nm for an ideal beryl with 67 wt.% SiO_2.

The R_1-line FWHM values and R_1/broadband peak height ratios of all samples are listed in Table I, but they are not considered further in the present study.

Cause of PL Spectral Variations

Of the three quantities extracted from the *R*-line spectra and plotted (R_1 peak position, R_2 peak position and R_1/R_2 peak height ratio), the R_1 peak position displayed the strongest variation according to emerald origin. In considering possible reasons for this, we looked for correlation with other emerald properties. Stockton (1984) provided some initial clues for this. Stockton outlined a method for identifying whether or not an emerald is natural based upon measurement of its SiO_2 concentration (where ideal beryl contains 67 wt.% SiO_2). In particular, Stockton found that synthetic emeralds always exceeded 65.7 wt.% SiO_2. A SiO_2 concentration below 65.6 wt.% indicated that an emerald is of natural origin, whereas >65.7 wt.% SiO_2 would require further analysis.

Huong (2008) provided the chemical composition of 36 natural and synthetic emeralds from a variety of sources, and her results for SiO_2 concentration exhibited an origin-specific pattern similar to that of our R_1 peak positions. For synthetic emeralds, the SiO_2 concentration generally approached the value of ideal beryl, whereas non-schist-origin emeralds had lower SiO_2, and schist-origin emeralds had even lower SiO_2 values.

To further investigate these origin-specific patterns, we plotted SiO_2 concentration vs. R_1 peak position (Figure 9). Specifically, we used the average SiO_2 wt.% value of emeralds from various sources (as extracted from Huong's [2008] measurements), and plotted it against the average R_1 peak wavelength measured by us for emeralds from the same origins. The trend line fit to the data has a coefficient of determination $r^2 = 0.91$, with the largest variation arising from the Nigerian data point. Although the data points come from different sets of samples, this fit demonstrates a strong correlation between an emerald's R_1 peak position and its SiO_2 concentration. Thus we propose that an accumulation of vacancy defects or substitutional defects at silicon crystal sites may be responsible for shifts of R_1 peaks to longer wavelengths. The trend line has a slope 3.61 wt.%/nm, and predicts a peak wavelength of 683.41 nm at the 67 wt.% SiO_2 value for ideal beryl.

Stockton (1984) also outlined a method for identifying whether or not an emerald is natural or synthetic based upon its Al_2O_3 concentration.

However the spatial separation between a chromium site and the closest aluminium ion sites is likely too large for an aluminium point defect to exert much influence on *R* values (Lai, 1987). Even so, from Huong's (2008) measurements, Al_2O_3 concentration does show some origin dependence. A plot of this data in a fashion similar to Figure 9 showed much more scatter in the data points. The best-fit trend line had $r^2 = 0.69$, and six of the nine data points showed comparably large variations. Therefore, we consider any correlation between an emerald's R_1 peak position and its Al_2O_3 concentration to be more coincidence than causality.

Having proposed an accumulation of vacancies at silicon crystal sites as the most likely cause of the R_1 line shift, we briefly speculate upon what cations might substitute at these sites. Among trace elements detected by Huong (2000), an isovalent substitution of Ti^{4+} or Mn^{4+} seems most likely. However, her data found that these elemental impurities occur in very low concentrations in emerald; Ti concentration had little origin dependence, and Mn concentration of individual emeralds was not reported. The next most likely choice is an aliovalent substitution of Al^{3+} or Fe^{3+} with charge compensation by alkali ions located at interstitial sites within open channels parallel to the c-axis (Goldman et al., 1978). Indeed, Huong's (2000) data on alkali atom concentration displayed an origin-dependent pattern that parallels the R_1 line shift: namely, synthetics had little to no alkali concentrations, non-schist emeralds had low concentrations, and schist-origin emeralds had high concentrations of alkali impurities.

Recognizing a connection between the R_1 peak position and chromium's next-nearest neighbour silicon ions, we considered whether a similar connection exists between the R_2 line and chromium's other next-nearest neighbours, beryllium ions. Unfortunately we found almost no origin dependence either in our results for R_2 peak positions or in Huong's (2008) reported BeO concentrations. Of course, the fact that both exhibit no origin dependence may be an indication that they are connected.

As mentioned previously, E||c laser-induced PL spectra were also collected for all samples. The average R_1/R_2 peak height ratio in these spectra was 1.45. Along with this decrease in relative height of the R_1 peak compared to E⊥c spectra, these spectra exhibited a significant decrease in the origin-dependent shifts of R_1 peak positions. In particular, peak positions of Colombian emeralds overlapped those of schist-origin emeralds, and there was almost no separation between those and the peak positions of the synthetic and Nigerian emeralds. The spread of R_2 peak positions was also reduced in the E||c spectra and showed no origin dependence.

Implications for Origin Determination

Analysis of gemstone inclusions combined with UV-Vis-NIR, Raman and FTIR spectroscopy and LA-ICP-MS trace-element analysis are the primary methods used to establish an opinion of an emerald's origin. Laser-excited PL spectroscopy can provide an additional tool, and many gemmological laboratories already have suitable instrumentation; an extended-range Raman spectrometer operating at suitable excitation wavelength, when correctly calibrated, is capable of producing similar results.

For example, Colombian emeralds host characteristic three-phase inclusions (Gübelin and Koivula, 2008) that were once thought diagnostic of origin. However, similar inclusions have been observed in emeralds from deposits in Davdar, China (Marshall et al., 2012). The R_1 line of our schist-origin Davdar emerald peaked above 683.90 nm (Figure 8), while those of non-schist-origin Colombian emeralds peaked below that value. This result suggests that R_1 peak position can be used to distinguish between Davdar, China, and Colombian emeralds.

Of course, emeralds from all known deposits were not included in this preliminary study. For example, the characteristic three-phase inclusions also have been observed in emeralds from Panjshir, Afghanistan (Bowersox et al., 1991). Emeralds from this region have been documented in various geological environments, including hydrothermal veins, shear zones, and phlogopite schist reaction zones along the contact between leucogranite and serpentinite (Bowersox, 1985; Bowersox et al., 1991; Groat et al., 2008). Such wide variations suggest that R_1 peak measurements of emeralds from different deposits in Panjshir will show systematic mine-specific variations.

Figure 10: Attractive gem-quality emeralds are sourced from several world localities, and gemmological labs are often asked to identify their origin and separate them from synthetics. R-line PL spectroscopy can help address these challenges. This rough-and-cut pair of emeralds from Colombia show the saturated green colour that is prized for stones from this locality. The crystal, known as El Itoco*, weighs 94.4 g. Composite photo by Bilal Mahmood, American Gemological Laboratories.*

Our results also may be useful for assessing the geological origin of emeralds from new deposits or those of unknown deposit type. The characteristic three-phase inclusions mentioned above also have been found in emeralds from Musakashi, Zambia, which have an uncertain geological origin (Zwaan et al., 2005; Saeseaw et al., 2014). Zwaan et al. (2005) found their Musakashi emerald samples had an average SiO_2 concentration of 66.47 wt.%. Our trend-line fit (Figure 9) predicts that Musakashi emeralds are non-schist origin, with an R_1 line that peaks around 683.55 nm.

As a final example, the R_1 lines of all the synthetic emeralds analysed for this report (Figure 8) peaked at wavelengths below 683.70 nm. Therefore an R_1 line peaking at a wavelength above this value suggests the emerald is natural. Our Nigerian emeralds had R_1 lines that peaked below 683.70 nm, and the R_1 line of emeralds from Musakashi, Zambia, also are predicted to peak below that value. Therefore if an R_1 line peaks below 683.70 nm, further tests are required to determine whether or not the emerald is of natural origin.

Conclusions

Emerald is a beautiful gem material (Figure 10) that is available from several localities and has been synthesized by various manufacturers. From E⊥c laser-excited PL spectra collected from several emerald samples (schist origin, non-schist origin, and synthetic), we isolated the *R*-line contributions (680–685 nm range). We found that locating the peak wavelength position of the R_1 line can help identify natural vs. synthetic origin and also indicate whether a natural emerald comes from a schist or non-schist deposit type. From the literature, measurements of emeralds' SiO_2 concentrations display similar origin dependence. Thus, we suggest that an accumulation of point defects at silicon ion crystal sites may be responsible for shifts of R_1 peaks to longer wavelengths. The correlation between R_1 peak position and SiO_2 concentration has implications for determining an emerald's origin even when only one of these values is known. It is hoped that this preliminary study will encourage further research on more samples from each locality, as well as on emeralds from additional sources.

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Green and Pink Tourmaline from Rwanda

Ulrich Henn and Fabian Schmitz

Green and pink tourmaline is found in granitic pegmatites of the Karagwe-Ankole Belt in south-western Rwanda. The tourmalines studied for this report show typical gemmological properties and consist of elbaite with some rossmanite content. The green colour is caused by Fe^{2+} and the pink by Mn^{3+}, as is common for gem tourmaline.

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Introduction

The most important sources of gem-quality tourmaline in Africa are Nigeria, Mozambique, Namibia, Tanzania and Zambia, as well as Madagascar. During the past several years, some additional countries have joined these producers, such as Malawi (Henn et al., 1990) and the Democratic Republic of Congo (DRC; Laurs et al., 2004; Henn, 2010). Tourmaline-bearing pegmatites in Rwanda have been known for a long time, but gem-quality material has been described only recently (Henn, 2013). The occurrences are located in the Rusizi District of south-western Rwanda. Geologically this area belongs to the Karagwe-Ankole Belt. Numerous granitic pegmatites are worked by artisanal miners in small shallow pits for cassiterite, wolframite and columbite-tantalite (Ngaruye, 2011). Gem tourmaline is produced as a by-product and, although some attractive stones have been faceted (e.g. Figure 1), the majority of the rough contains abundant inclusions and is only suitable for cabochons (e.g. Figure 2). Rwanda is also a source of gem-quality topaz and blue sapphire (Krzemnicki et al., 1996; Milisenda, 2003).

Geology

Rwanda consists of metasedimentary Meso-proterozoic basement rocks on a Palaeoproterozoic shield (Figure 3). About 1 billion years ago the Rhodinian amalgamation influenced the geology in this area (Fernandez-Alonso et al., 2012). During this orogeny, granitic pegmatites

Figure 1: These faceted tourmalines from Rwanda weigh 25.65 ct (left) and 1.26 ct (right). Note the typical fluid inclusions in the pink stone. DGemG Collection; photos by K. Schollenbruch, DGemG.

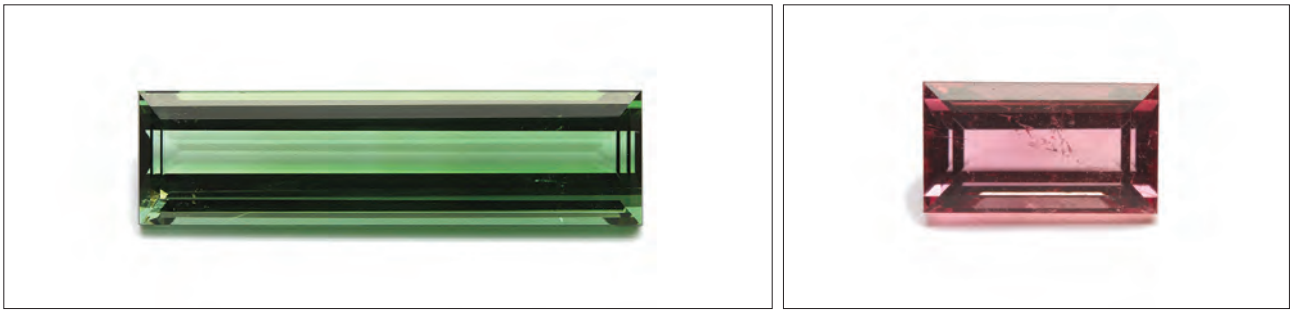

Figure 2: These cabochons were cut from Rwandan tourmaline. The stone on the right weighs 6.40 ct. Photo by K. Schollenbruch, DGemG.

(associated with so-called G4 granites or Kigali granites; Dewaele et al., 2010) with youngest ages of 986 million years intruded the metasediments. These miarolitic pegmatites are the source of the tourmaline found in Rwanda.

In the final stages of crystallization of the pegmatitic melt, the temperature decreased and incompatible elements accumulated to the point that a low-density melt with a high content of fluxing elements exsolved as a second phase. This melt fraction then separated and accumulated, forming the gem-bearing miarolitic cavities (cf. Simmons et al., 2012).

An important occurrence of gem (and non-gem) tourmaline is the M'buye mine in south-eastern Rwanda, near the border with Burundi. Geologically related tourmaline deposits are known from the area around Manono in south-east DRC. In addition, gem-quality green and blue-green tourmaline has been mined in eastern DRC, in North Kivu Province (Virunga area) during the past 15 years (Henn, 2010). In this context it is interesting to note that the well-known tourmaline deposits of Tanzania, Mozambique and Zambia are hosted by pegmatites related to younger granites of the Pan-African orogeny (see, e.g., Keller, 1992; Milisenda et al., 2000).

Materials and Methods

The Rwanda tourmalines examined for this report consist of five faceted stones (e.g. Figure 1), six cabochons (e.g. Figure 2) and 10 crystal sections (e.g. Figure 4). The tourmaline was supplied (as rough material) as an official gift by Rwanda government officials and business representatives

Figure 3: This simplified geological map of central-eastern Africa shows the main units of the Congo and Tanzania Cratons with the Kibara Belt (KIB) and Karagwe-Ankole Belt (KAB). Within these two belts, gem-quality tourmaline has been mined in south-west Rwanda and in south-east and eastern DRC. After Dewaele et al. (2013).

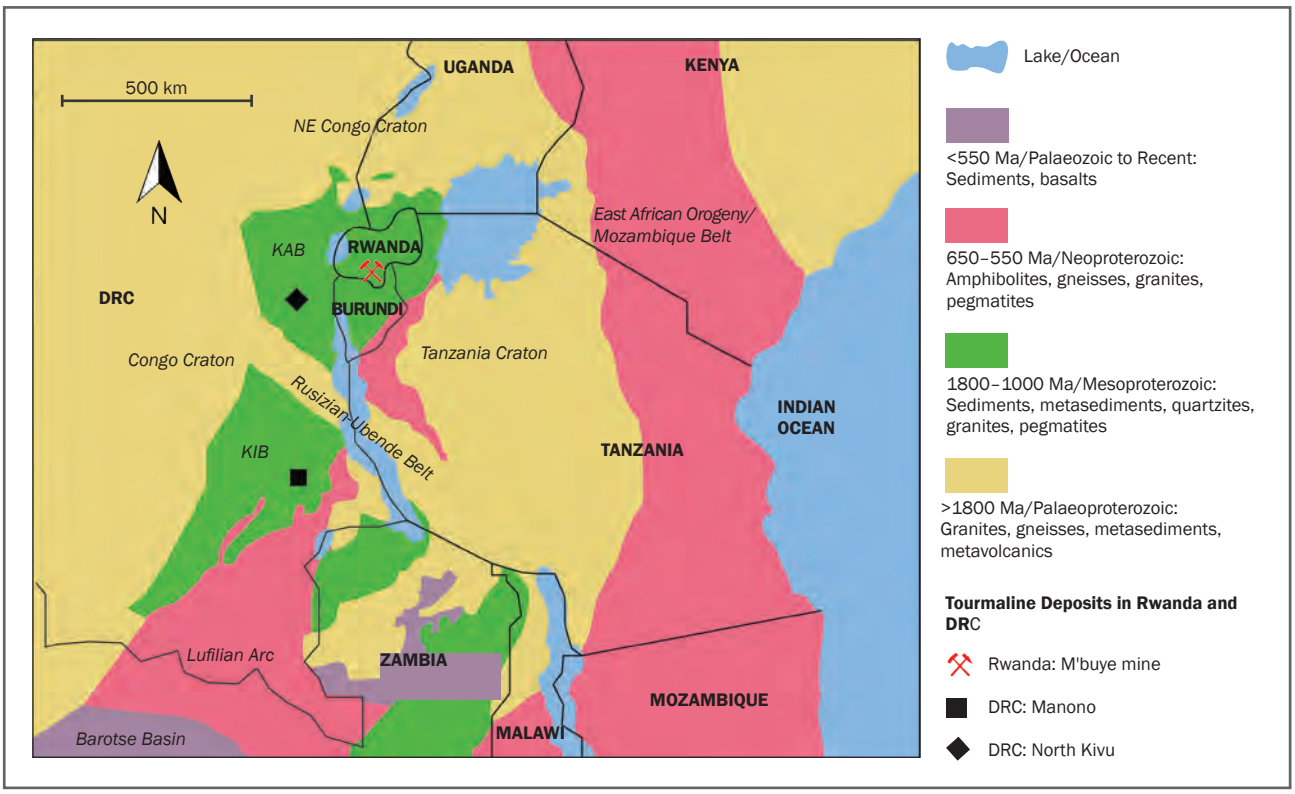

Figure 4: Tourmaline from Rwanda shows typical striations on the prism faces and is commonly colour-zoned in pink and green. The largest crystal in the left image is 22.53 mm long, and the diameter of the bottom crystal section in the right photo is 17.32 mm. Photos by K. Schollenbruch, DGemG.

to the German partner state of Rhineland-Palatinate. In the context of this partnership, the rough material was forwarded to lapidary firms in Idar-Oberstein for cutting and quality assessment.

A small face parallel to the c-axis was polished on the crystals and cabochons. On all samples, refractive indices were measured using a standard gemmological refractometer and specific gravity was determined with a hydrostatic balance. Inclusions were investigated with a gemmological immersion microscope. Visible absorption spectra of five green and five pink samples were measured in the 400–800 nm range with a PerkinElmer Lambda 12 spectrophotometer equipped with a polarization unit. The same samples were also tested for their Fe and Mn contents using a Thermo Scientific ARL QUANT'X energy-dispersive X-ray fluorescence (EDXRF) spectrometer. Complete chemical analyses of two representative samples (one green and one pink; 10 analyses each) were carried out using an electron microprobe at the Institute of Mineralogy and Petrography, University of Hamburg, Germany.

Results and Discussion

Physical and Gemmological Properties

The tourmaline crystals exhibited typical striations on their prism faces. The green samples ranged from yellowish green to light-to-dark green and into pinkish and bluish green. The pink tourmalines showed pinkish red, pink-violet, pure pink and faint 'rose' to brownish 'rose' coloration. Some of the crystals were strongly colour zoned in directions parallel or perpendicular to the c-axis. Examples included faint 'rose' (core) and faint blue (rim) as well as pink (core) and bluish green (rim) combinations.

The most common inclusions consisted of partially healed fractures and hollow tubes (Figure 5), which are characteristic of tourmaline. The partially healed fractures formed thin-planar or irregular fluid-filled areas that were interconnected through vein-like tubes. The hollow tubes were oriented parallel to the c-axis. The following properties were recorded from our samples: RI = 1.619–1.621 (n_e) and 1.639–1.641 (n_o), birefringence = 0.020 and SG = 3.04–3.07. These data fall within the known range for tourmaline.

Visible Absorption Spectroscopy

Figure 5: The most common internal features in tourmaline from Rwanda consist of fluid inclusions and hollow tubes. Photomicrograph by U. Henn; immersion, magnified 40×.

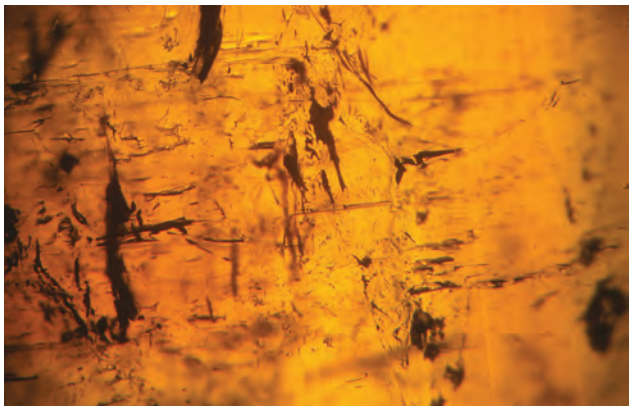

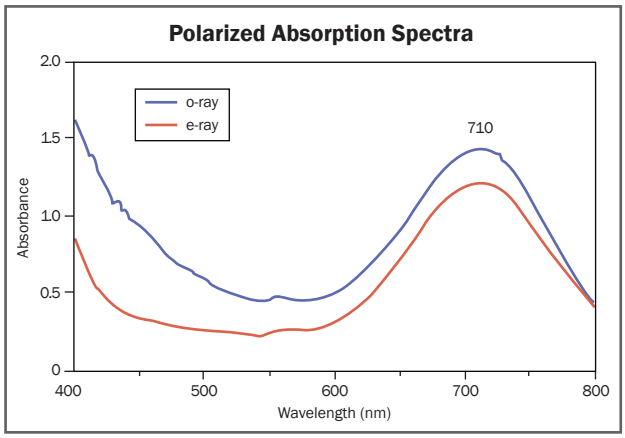

Figure 6: These representative polarized absorption spectra of a green Rwanda tourmaline (beam path length 7.1 mm) show a strongly pleochroic band (o>e) with a maximum at 710 nm that is caused by Fe^{2+}.

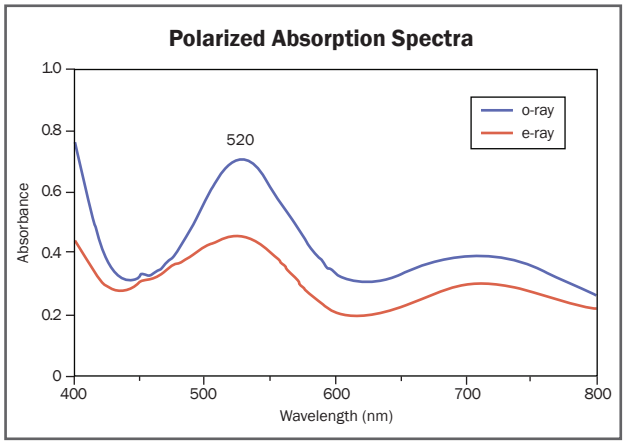

Figure 7: Polarized absorption spectra of pink Rwanda tourmaline (beam path length 3.8 mm) show a strongly pleochroic band (o>e) with a maximum at 520 nm that is caused by Mn^{3+}.

The absorption spectra of the green tourmalines showed a broad band with a maximum at 710 nm (Figure 6). This band was strongly pleochroic, and the spectrum taken with the beam polarized perpendicular to the c-axis (o-ray) showed stronger absorption than the spectrum with the beam polarized parallel to the c-axis (e-ray). The resulting pleochroism was intense green (o-ray) to moderate green (e-ray). According to Smith (1978), the 710 nm band is assigned to Fe^{2+} *d-d* transition and the additional weak absorptions at 560 and 495 nm are due to Fe^{3+}.

The absorption spectra of the pink tourmalines were dominated by an intense pleochroic band (o>e) in the green spectral range with a maximum at 520 nm (Figure 7). According to Manning (1969, 1973), this band is caused by spin-allowed *d-d* electron transitions of Mn^{3+} in octahedral coordination. The pleochroism was pink (o-ray) to light pink (e-ray). In addition, Mn^{3+} was also responsible for a small peak at 460 nm and a broad but weak absorption in the red region of the spectrum.

Chemical Properties

The tourmalines that were analysed by EDXRF contained 0.73–2.17 wt.% FeO (green samples) and 0.14–0.38 wt.% MnO (pink stones). Complete chemical analyses (by electron microprobe) of a representative green tourmaline and pink tourmaline are provided in Table I. The data plot in the elbaite field of alkali tourmalines, with moderate rossmanite and very low liddicoatite components (Figure 8). The green sample contained higher Fe concentration, consistent with its coloration, while the pink tourmaline had Mn as its main chromophoric element. The analyses are representative of the following formulas (Li, B and O/OH calculated stoichiometrically):

Green: $(Na_{0.62}Ca_{0.05}\square_{0.33})(Li_{1.39}Fe_{0.25}Mn_{0.09}Al_{1.28})$
$Al_6B_{3.00}(Si_{5.98}Al_{0.02})O_{27}(OH_{3.55}F_{0.45})$

Pink: $(Na_{0.51}Ca_{0.05}\square_{0.44})(Li_{1.25}Fe_{0.004}Mn_{0.03}Al_{1.72})$
$Al_6B_{3.00}(Si_{5.93}Al_{0.07})O_{27}(OH_{3.69}F_{0.31})$

Figure 8: Both of the Rwanda tourmaline samples analysed by electron microprobe for this report consist of elbaite with a significant rossmanite component, as shown in this compositional diagram (after Selway et al., 1998).

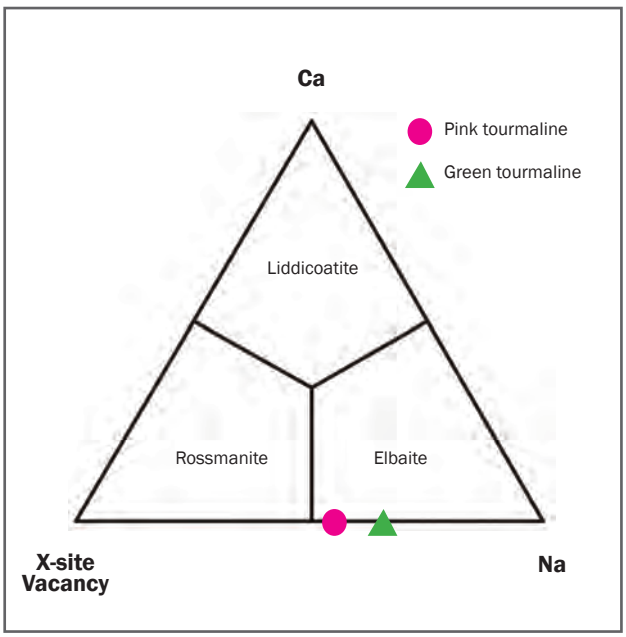

Table I: Chemical composition of green and pink tourmalines from Rwanda.

Sample	Green	Pink
Oxides (wt.%)		
SiO_2	38.27	38.34
TiO_2	0.01	0.01
B_2O_3 calc	11.12	11.24
Al_2O_3	39.66	42.75
FeO	1.89	0.03
MnO	0.66	0.20
CaO	0.29	0.28
Li_2O calc	2.21	2.01
Na_2O	2.06	1.70
K_2O	0.01	0.01
H_2O calc	3.40	3.58
F	0.92	0.63
Subtotal	100.51	100.78
−O=F	0.39	0.27
Total	**100.12**	**100.51**
Ions*		
Si	5.977	5.928
Ti	0.001	0.001
B	2.999	2.999
Al	7.301	7.791
Fe^{2+}	0.247	0.004
Mn	0.087	0.026
Ca	0.049	0.046
Li	1.387	1.250
Na	0.624	0.510
K	0.002	0.002
H	3.546	3.692
F	0.454	0.308
X-site vacancy	0.326	0.442
Ca/Ca+Na	0.072	0.080

*The amounts of elements not determinable by electron microprobe (B, Li, and H) were calculated according to stoichiometry as B=3, Li=3−Y and OH+F=4 (see Simmons et al., 2011).

Conclusion

The studied tourmalines from Rwanda show very similar physical and chemical properties to those from DRC, and also exhibit comparable inclusion characteristics (see Henn, 2010). This can be explained by the similar geological settings of the pegmatites of the Karagwe-Ankole Belt and the Kibara Belt, which extends from DRC to Zambia. These rocks contain metasediments that were intruded by granitic rocks and associated tourmaline-mineralized pegmatites. It seems likely that additional gem-quality tourmaline will be recovered from all of these deposits in the future.

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Conferences

Gem-A Conference 2014

The annual Gem-A Conference and associated events took place 1–4 November in London. Attended by nearly 190 people from 26 countries, the conference featured 13 speakers, four seminars and a tour of the Natural History Museum in London.

Bruce Bridges (Bridges Tsavorite, Tucson Arizona, USA) described the prospecting, mining, processing and marketing of tsavorite from his family's mines in Kenya, as well as the important contributions by his father, Campbell Bridges (see his recent article in *The Journal*, Vol. 34, No. 3, 2014, pages 230–241). At the conclusion of his talk, he announced that the Scorpion mine will be reopened in January 2015.

Edward Boehm (RareSource, Chattanooga, Tennessee, USA) provided numerous tips for analysing gems while in the field. His preferred instruments are the darkfield loupe and the dichroscope, and he emphasized the need to become proficient at using them in a laboratory setting before setting out for the field. When examining inclusions, it is important to observe the whole scene in a stone, rather than just isolated features.

Dr Thomas Hainschwang (GGTL Laboratories, Balzers, Liechtenstein) described the mechanisms for creating green to greenish blue coloration in diamond, and the challenges in identifying the natural vs. artificial origin of the colour. Irradiation using radium salts can result in dangerous amounts of residual radioactivity, whereas neutron-irradiated stones typically remain radioactive for only a couple of hours—although they may contain inclusions that remain 'hot' for a longer period of time.

Figure 1: In Bahia State (Brazil), gem-quality rutilated quartz is extracted from tunnels such as this one at the Pyramid mine, owned by Brian Cook. Photo © Brian Cook.

Alan Hart (Natural History Museum, London) described the history and future plans for the gem and mineral collection at the Natural History Museum. There are currently about 10,000 specimens on display of the ~180,000 samples in the collection; of these, 5,500 of them are gems. During the next 10 years, there are plans to renovate the display in a new Earth and Planetary Sciences wing.

Dr Ulrich Henn (German Gemmological Association, Idar-Oberstein, Germany) compared the properties of moonstone from Sri Lanka, India and Tanzania. The Sri Lankan material is K-feldspar (cryptoperthite), while the Tanzanian moonstone consists of albite. Indian samples typically are K-feldspar, while a 'rainbow' variety is andesine-labradorite.

Brian Cook (Nature's Geometry, Tucson, Arizona, USA) reviewed the history of Paraíba tourmaline from the São Jose da Batalha deposit in Brazil. Mining efforts are currently focused on an area below the hill where the material was originally discovered, and a 3-cm-long crystal of this valuable tourmaline was recently found in the 40-m-deep shaft. Another mine in neighbouring Rio Grande do Norte State (operated by Mineraçao Terra Branca) continues to produce blue Cu-bearing tourmaline in mostly small sizes. Cook also provided an update on gem-quality rutilated quartz from the Novo Horizonte area, Bahia State, Brazil. Miners search for crystal-bearing cavities that are hosted by quartz veins within volcanic rocks (Figure 1). About 15,000 people are affected by the mining and trading of this material, and after nearly a decade of effort to formalize the claims, they are finally being legalized and environmental permits obtained.

Vincent Pardieu (GIA Laboratory, Bangkok, Thailand) reviewed global localities for gem spinel, including Tajikistan, Myanmar, Vietnam, Tanzania, Sri Lanka, Pakistan and Kenya. His presentation highlighted bright red spinel from secondary deposits at Man Sin, near Pyin Pyit in the Mogok area of Myanmar.

Craig Lynch (Ouellet and Lynch, Phoenix, Arizona, USA) described jewellery recovered from the famous RMS Titanic, which sank on 15 April 1912. Of the approximately 6,000 objects recovered from the wreckage during 25 years of salvage operations, 75–85 pieces consist of jewellery and watches. These

represent the Victorian, Edwardian, Art Nouveau and Belle Époque movements. Many of the artefacts are in poor condition after being submerged in saltwater for many decades.

Dr Laurent Cartier (Swiss Gemmological Institute SSEF, Basel, Switzerland) provided an update on worldwide cultured pearl production. He emphasized that for a farm to be profitable, it must attain both high-quality cultured pearl production and low mortality of the host molluscs.

Chris Smith (American Gemological Laboratories Inc., New York, New York, USA) explained his ruby and sapphire source-type classification system. This objective process helps make country-of-origin determinations more consistent by combining both geological and gemmological considerations. Macroscopic and microscopic observations are used to narrow possible origins and are supported by UV-Vis-NIR spectra and chemical data.

Menahem Sevdermish (Gemewizard Inc., Ramat Gan, Israel) described developments of his Gemewizard software package in the areas of digital colour analysis, grading, pricing and trading of gems. A colour converter is now available that gives equivalent terminology for RGB, CMYK, Munsell, CIELAB and GIA colour descriptions.

Terry Coldham (Gemmological Association of Australia, Normanhurst, Australia) described how Thai developments in the late 1960s in using heat treatment to remove the 'silk' and therefore improve the clarity of Australian sapphire resulted in a huge increase of rough exports to Thailand. This material contributed enormously to the growth of the Thai gem processing and cutting industries. Coldham indicated that Thai experience with heating Australian sapphire facilitated their discovery of how to treat Sri Lankan geuda sapphire in 1979.

Richard Hughes (Lotus Gemology Co. Ltd., Bangkok, Thailand) discussed a variety of gemmological misconceptions. He also encouraged experimentation in gemmology, rather than simply observation. Hughes advocated a more 'right-brained' approach to help bring passion back to the trade.

Dr Franz Herzog (Oltingen, Switzerland) provided an informative seminar on portable EDXRF spectroscopy using a Thermo Nitron analyser. Although such devices do not currently provide quantitative data without extensive calibration procedures, they can give trace-element chemical signatures that are useful for geographic origin determination, chromophore evaluation, and natural vs. synthetic vs. treated identifications.

Other seminars covered coloured stone grading and pricing (with **Richard Drucker**, Gemworld International Inc., Glenview, Illinois, USA), gemmological applications of Raman and photoluminescence spectroscopy (with **Mikko Åström** and **Alberto Scarani** of M&A Gemological Instruments, Järvenpää, Finland and Rome, Italy) and ethical challenges in the gem industry (with **Greg Valerio** of Cred Jewellery and Fair Jewellery Action, London; **Vivien Johnston** of Gem-A, London; and **Dana Schorr** of Schorr Marketing, Santa Barbara, California, USA).

Brendan M. Laurs

GSSA Kimberley Diamond Symposium

The second Geological Society of South Africa Kimberley Diamond Symposium & Trade Show was held in Kimberley from 11 to 13 September 2014, seven years after the first one took place in August 2007. It was attended by 270 people, mainly from the Republic of South Africa (RSA) and neighbouring Botswana, Lesotho and Namibia, but also about a dozen each from Canada and Russia, and a few from Australia, Brazil, Germany, UK and USA. The conference was chaired and organized by Drs John Bristow and Mike de Wit. There were 20 oral and 26 poster presentations during the first two days, and visits to several alluvial deposits and two underground mines (Finsch and Kimberley) were made on the third day. A selection of the many interesting talks and posters is provided below.

Dr Mike de Wit (Tsodilo Resources, Toronto, Canada) indicated that most (or all) of the world's easier-to-find large-sized primary diamond deposits have been discovered. He said that geophysical methods will become more important for detecting deposits through superficial strata (i.e. younger than Cretaceous or Eocene) to find additional kimberlites. Thus, target-area selection must be improved, and this was also discussed by **Dr Hielke Jelsma** (De Beers Exploration, Johannesburg), who showed the periodicity of kimberlite intrusion and the formation of cratons and continents. In addition, **Dr Charles Skinner** (De Beers Exploration, Johannesburg) emphasized the importance of correct area selection combined with geographic accessibility, political

stability, and appropriate environmental and transparency regulations. **Dr Barbara Scott Smith** (Scott Smith Petrology, Vancouver, Canada) previewed of a new glossary of descriptive terms for the precise definition of features observed in kimberlites (both in hand specimens and under the microscope), which are grouped into five stages increasing in detail and related to diamond content.

Dr John Bristow (previously of Rockwell Diamonds and now with Incubex Mineral Consultants, Gauteng, RSA) described the geology of the Middle Orange River alluvial diamond deposits. The Early Mesozoic Ghaap Plateau escarpment funnelled the discharge from the Vaal, Harts and Orange Rivers through a wide valley to form the diamond-bearing gravels. The deposits are of low grade but contain many diamonds larger than 100 ct, and Bourevestnik X-ray luminescence equipment (manufactured in Russia) has improved the recovery of large stones. This theme was also discussed by **James Campbell** (Rockwell Diamonds, Johannesburg, RSA), and specific examples of alluvial gravel deposits were presented in three other talks and 11 posters by geologists from Rockwell Diamonds. **Dr Jürgen Jacob** (Namdeb Diamond Corp., Oranjemund, Namibia) described the various forms of beach gravel (linear, pocket and pothole), aeolian and fluvial deposits in Namibia, and concluded that after 106 years of mining there are at least another 50 years of reserves left in this important megaplacer. Four posters by other Namdeb workers described specific examples of various coastal placer deposits.

Hilde Cronwright (MSA Group, Johannesburg) showed that the analysis of microdiamonds at the Karowe mine (AK6 pipe, Botswana) results in a better prediction of the occurrence of large type IIa diamonds than results derived from large drill or bulk samples. **Dr Mike Lynn** (MSA Group, Johannesburg) described the phlogopite-rich, macrocrystic Moteti kimberlite dyke, a new diamond occurrence in Lesotho that may contain 1.5 million tonnes (Mt) of ore at 65 carats per 100 tonnes (cpht), yielding 1 million carats (Mct) of diamonds valued at $62/ct. This presents a new target for diamond exploration in Lesotho (i.e. small size, small volume, medium grade and medium diamond value).

Dr J. P. Donatti-Filho (Lipari Mineração Ltda., Nordestina, Brazil) described the Braúna 3 project, which is destined to become the first kimberlite diamond mine in Brazil. With a surface area of 2 ha, the Braúna 3 pipe is the largest in a 17-km-long zone of 22 occurrences of dykes, 'blows' and small pipes extending south of Nordestina in Bahia State. Estimated reserves (indicated and inferred) are 4.92 Mt with a grade of 53 cpht, yielding 2.57 Mct valued at US$284/ct.

This symposium provided a nice prelude to a diamond/kimberlite session that will be held at the 35th International Geological Conference in Cape Town in mid-2016, and also the 11th International Kimberlite Conference scheduled for June 2017 in Gaborone, Botswana.

A. J. A. (Bram) Janse (archonexpl@iinet.net.au)
Archon Exploration Pty. Ltd., Carine, Western Australia

NAJA Mid-Year Conference 2014

The National Association of Jewelry Appraisers' mid-year conference took place right after the World of Gems Conference (see following report) on 22–23 September in Rosemont, Illinois. There were 150 people in attendance, and Gail Brett Levine and her team put on a great event.

Tammy Cohen (Diamonds International, New York, New York, USA) explained the valuation of the Crown of Light proprietary diamond cut. She and her team shared retail price lists to help with appraisals. The Crown of Light has 90 facets with a domed top and a very small table, like a modified rose cut.

Carl Schutze and his father-in-law **Manuel Marcial de Gomar** of Emeralds International (Key West, Florida, USA) discussed emeralds from the Atocha, a Spanish galleon that sunk off Key West in 1622. The wreck was salvaged by Mel Fisher, who recovered millions in gold, silver, artefacts and emeralds. These 'shipwreck emeralds' are thought to be from the Tequendama mine in the Muzo area of Colombia.

Dr Paul Downing, an author from Fountain Hills, Arizona, USA, hosted an Ethiopian opal workshop, and examples showing various characteristics were available for examination. The hydrophane characteristic of Ethiopian opal can be revealed by its sticky feel when touched with a dampened finger.

Arthur Skuratowicz (Jewelry Training Center, Colorado Springs, Colorado, USA) held a workshop on the identification of non-traditional metals by non-destructive testing. Many cost-effective metals found

in today's market lack accurate markings, creating a challenge for valuers and appraisers. X-ray fluorescence analysis can give an accurate determination of metal composition, but this technique is beyond the reach of most appraisers.

Day two began with what might have been perceived as a dry topic: Internal Revenue Service appraisal rules for charitable contributions of jewellery. **Karin Gross** (IRS, Washington D.C., USA) gave a clear and concise presentation, with references to IRS publications to make the process flow smoothly.

Schutze and **Marcial de Gomar** returned for a second presentation on another treasure found off Key West (and elsewhere in the Caribbean Sea region): the conch pearl. The process of formation within the shell to the finished piece of jewellery was discussed. They stated that only one in 10,000 conch shells may produce a pearl, with no guarantee of quality.

Jeff Ira (Metro Jewelry Appraisers, Medford, Massachusetts, USA) shared 50 ways to energize an appraisal business. He reviewed and introduced timely tips that were broken down into daily organization, quality of life, networking, promoting and perception.

Dr Cigdem Lule and **Stuart Robertson** of Gemworld International (Glenview, Illinois, USA) discussed appraising natural untreated gems. *Natural* in the true sense of the world means nothing has been done to the material besides cutting and fashioning. Value depends not only on visual appearance but on what treatments a stone has undergone. They indicated that an untreated ruby may command a 200–300+% premium in today's market.

Eric W. Fritz (EricFritz@gem-a.com)
Gem-A Regional Manager, North America
Tucson, Arizona, USA

World of Gems Conference IV

This biennial conference was held in Rosemont, Illinois, USA, on 20–21 September 2014. More than 230 people from 12 countries were in attendance. The talks were moderated by **Richard Drucker** (Gemworld International, Glenview, Illinois), who also began the conference with a historical retrospective of the GemGuide publication, as well as a review of current trends in diamonds and coloured stones.

Dr Thomas Hainschwang (GGTL Laboratories, Balzers, Liechtenstein) reported on his doctoral studies of the coloration and defects in type IB diamonds. In addition to showing yellow coloration as expected from their nitrogen content, such diamonds more typically range from orange to 'olive' green (most common) to brown, as well as showing mixtures of these colours.

Dr James Shigley (Gemological Institute of America [GIA], Carlsbad, California, USA) examined diamond fluorescence. He stated that 80% of the diamonds submitted to GIA's laboratories show very faint to no fluorescence, and only 0.1% show very strong fluorescence. Of those diamonds that do luminesce, 97% show blue fluorescence. He also indicated that this blue fluorescence may influence the diamond's face-up colour appearance only in extreme cases. **Richard Drucker** followed with a presentation on the effect of diamond fluorescence on pricing. He pointed out that until the late 1970s (during the diamond investment boom), it was common for observers to prefer some fluorescence, but subsequently it was perceived that fluorescence creates a 'hazy' appearance in a diamond. Prices of fluorescent diamonds continue to be discounted, making them an attractive option for buyers who don't mind fluorescence.

Stuart Robertson of Gemworld International researched the effect of colour modifiers on the pricing of fancy-colour diamonds. By compiling the prices of numerous GIA-graded diamonds (0.5–1.0 ct radiant-cut stones with Fancy colour grades), he found that brown-to-yellow modifiers result in an approximately 20–25% decrease in value, while greenish modifiers of yellow stones correspond to a 100% increase in value.

This author (*Journal of Gemmology*, Gem-A, Encinitas, California, USA) explained the benefits obtained from doing field research of gem deposits. Such expeditions allow one to gain accurate first-hand information on the location, geology, and mining methods at a given deposit, as well as an idea of future reserves. One can also learn about the ore processing techniques and production (gem varieties, quality and quantity), and witness the trading and distribution of the material. Other benefits include obtaining research samples (directly from the mine in some cases) and purchasing hard-to-find maps and publications.

Dr Cigdem Lule of Gemworld International examined the reliability of country-of-origin reports. She stated that origin determinations are an opinion-based practice that relies on scientific data collected by advanced mineralogical testing. Ultimately the locality decision is based on the knowledge and judgement of

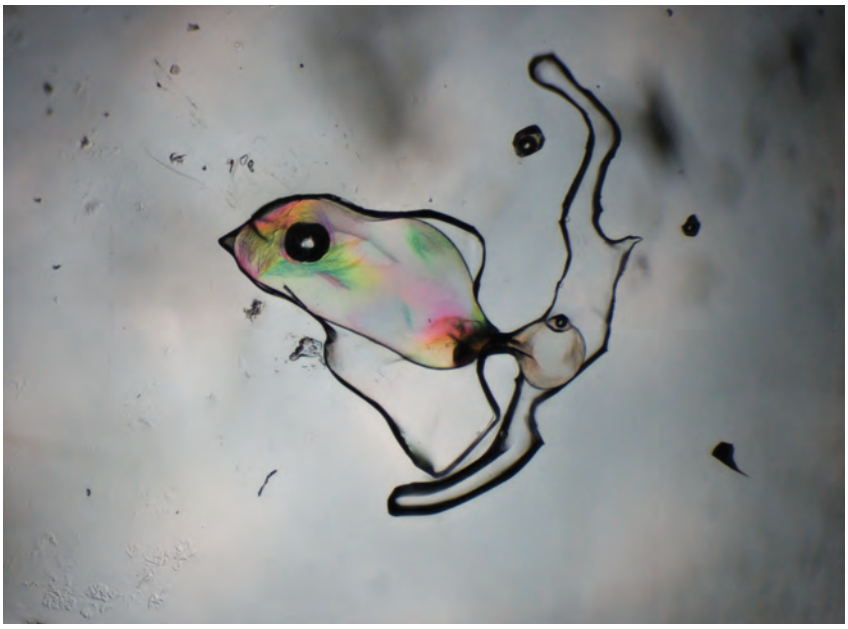

Figure 2: Resembling an abstract fish, this three-phase inclusion in quartz from Bahia, Brazil, was photographed with cross-polarized light to reveal the colourful birefringence in the solid component. A methane gas bubble makes a convincing 'eye' in the petroleum-and-water-filled body. Photomicrograph by Nathan Renfro, © GIA; image width 2.5 mm.

the gemmologist who makes the determination. Due to overlap in the properties of some gems (particularly blue sapphires), the reliability of such determinations would be improved by stating the geologic origin rather than geographic origin, but the latter is preferred by gem merchants.

Eric Braunwart (Columbia Gem House, Vancouver, Washington, USA) highlighted several factors influence the supply and pricing of gems, including: changes in the value of the US dollar; monitoring of gold, diamonds and coloured stones as potential sources of terrorist funding; mine closures due to the global economic recession; the boom in TV/internet sales of gems; China's increased demand for jadeite, as well as diamond, ruby, sapphire and tourmaline, and an increase in the mass production of jewellery in Chinese factories; the prevalence of treated and synthetic gems in coloured stone parcels; and consumers' growing demand for corporate social responsibility in the gem and jewellery industry.

Jeffrey Bergman (Primagem, Bangkok, Thailand) explored trapiche gems in a well-illustrated presentation covering 'true' trapiche stones (e.g. emerald, ruby, sapphire and tourmaline) as well as some gems showing star-like patterns that are not due to a skeletal growth pattern (e.g. garnet, quartz, chalcedony and diamond). In a separate presentation, Bergman described the value factors of star, cat's-eye and trapiche gems: colour, clarity, stone size, and the intensity, sharpness, completeness and centring of the star or eye.

Jon Phillips (Corona Jewellery, Vancouver, British Columbia, Canada) covered recent developments in diamond mining and marketing. He believes that Russia will surpass De Beers' production of rough (by value) in the next five years. He noted that the best-selling shapes of faceted diamonds are pear, round and marquise, and he indicated that branded diamonds may provide better margins—if there is a good story to accompany them.

Dr John Emmett (Crystal Chemistry, Brush Prairie, Washington) and **Stuart Robertson** gave a two-part presentation on how treatments have historically altered the supply and pricing of gem corundum. Dr Emmett reviewed how various heat treatments (with and without added elements) have been critical to boosting the commercial availability of sapphires from localities such as Sri Lanka, Australia, USA (Montana), Madagascar and Tanzania (Songea), as well as rubies from Mong Hsu (Myanmar). Robertson explained that during the past two decades, the proportion of heated corundum in the gem market has grown from approximately 40% to nearly 100%. During this time, the industry has been operating under of the principle of detection, rather than disclosure.

Nathan Renfro (GIA, Carlsbad) illustrated many examples of 'microart' in gems, particularly by using fibre-optic lighting and oblique illumination to highlight interesting inclusion characteristics. With the clever use of a microscope and camera, he showed the beauty associated with gemstone 'imperfections' (e.g. Figure 2).

Gail Brett Levine (National Association of Jewelry Appraisers, Rego Park, New York) described the styles, motifs and pricing of jewellery from the Late Georgian and Victorian movements. She highlighted the variable quality of this jewellery and the fact that some of it is undervalued in today's marketplace.

Brendan M. Laurs

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Gem Identification Report and Gemstone Memo

GIT, The utmost advanced Gem and Precious Metal Testing Laboratory in Thailand, is recognized by CIBJO (The World Jewellery Confederation) and also a member of LMHC and ICA, we are well equipped with the world's most advanced instruments operated by highly experienced gemologists.

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ensuring the authenticity of your valuable gems & jewelry

The Gem and Jewelry Institute of Thailand (Public Organization)
140 ITF Tower, Silom Rd., Bangkok 10500,Thailand
TEL : +66 2634 4999 FAX : +66 2634 4970
http://www.git.or.th E-mail: jewelry.or.th

Gem-A Notices

GEM-A CONFERENCE 2014

The 2014 Gem-A Conference was held on 1–2 November at the Business Design Centre, Islington, London. Originally the Royal Agricultural Hall, the building was the venue for the first Gem-A graduation ceremony in 1913.

A full report of the Conference and events was published in the November/December 2014 issue of *Gems&Jewellery*. Highlights of the presentations are given in the Conferences section, pages 350–351.

Conference Events

Seminars and workshops were presented on 3-4 November at the Gem-A headquarters by Richard Drucker FGA GG, Mikko Åström FGA and Alberto Scarani GG, Dr Franz Herzog, and Greg Valerio, Vivien Johnston and Dana Schorr.

Also on 4 November a guided tour was held of the Mineral Galley at the Natural History Museum hosted by Alan Hart FGA DGA.

Conference Sponsors and Supporters

The Association is most grateful to the following for their support:

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We would also like to thank **DG3 Diversified Global Graphics Group** for sponsoring conference materials.
www.dg3.com

GRADUATION CEREMONY

The Graduation Ceremony and Presentation of Awards was held at Goldsmiths' Hall on 3 November. Gem-A CEO James Riley opened the proceeding by welcoming those present. The guest speaker, Tim Matthews, president of Jewelry Television (JTV), then presented the diplomas and awards.

James Riley announced the special awards. In recognition of their outstanding contributions to the gem and jewellery industry, Dr Gaetano Cavalieri of Bern, Switzerland, and Terry Coldham of Normanhurst, New South Wales, Australia, were each awarded an Honorary Fellowship.

Two members were awarded Fellowship status in recognition of their significant contribution to the field of gemmology for no less than 10 years. They were Edward Boehm of Chatanooga, Tennessee, USA, and Dr Ulrich Henn of Idar-Oberstein, Germany.

Two former members of the Gem-A staff, Dr Jack Ogden and Mary Burland, were awarded Honorary Lifetime Memberships.

Tim Matthews, president of JTV, giving the address. Photo © vips event photography.

The award winners who attended the Graduation Ceremony at Goldsmiths' Hall. From left: Doerte Herold (Diamond Practical Prize), Elie-Anne Caya (Christie's Prize for Gemmology), Ching Man Wong (Deeks Diamond Prize) and Andrea Von Allmen (Bruton Medal). Photo © vips event photography.

Tim Matthews gave the address, congratulating the graduates on their great achievement. He outlined his own career with JTV, before questioning where their careers would take them. He stated: "With your great accomplishment, evidenced by the diplomas conferred this evening, you are now equipped for a great journey in the gemstone business." Tim concluded his address by saying: "I wish you well and trust that your career in the jewellery and gemstone trade will be interesting, exciting and rewarding. Look forward to great destinations and memories of a lifetime. And allow your newfound knowledge and influence to flourish into profound personal leadership to have a positive impact on others in your path."

The ceremony was followed by a reception for graduates and guests in the Drawing Room.

GIFTS TO THE ASSOCIATION

The Association is most grateful to the following for their gifts for research and teaching purposes:

John Bradshaw, Nashua, New Hampshire, USA, for pieces of rough Mexican hyalite opal.

Terry Coldham FGAA FGA, Normanhurst, New South Wales, Australia, for a 0.74 ct natural orange sapphire and six issues of *The Australian Gemmologist* from October 2013 to March 2014.

Brian Davies of Percy Davies Jewellers, Gerrards Cross, Buckinghamshire, for a collection of rough and cut material including emeralds in schist, pegmatite minerals and African gemstones, and photos and negatives from 13 study tours organized by *Retail Jeweller*.

Prof. Dr Henry Hänni FGA, Basel, Switzerland, for fashioned spheres of quartz, olivine and orthoclase.

Bronwen Harman-Jones FGA DGA, Reading, Berkshire, for a selection of faceted diamond simulants including CZ, GGG, quartz, paste, strontium titanate, synthetic corundum, synthetic spinel, YAG and zircon.

Nirijan Khalsa, Beverly Hills, California, USA, for a collection of Oregon sunstones including two large pieces of crystals in matrix, rough stones and oval cabochons, as well as nine fancy-cut stones, each over 10 mm in diameter.

Grenville A. Millington FGA, Knowle, West Midlands, for the 0.03 ct diamond that was used for the winning trigons photograph in the 2014 Gem-A Photographic Competition.

Dominic Mok FGA DGA, Hong Kong, for 35 rough and fashioned gemstones (all showing inclusions), including amber, beryl, corundum, danburite, enstatite, fluorite, garnet, iceland spar, kyanite, moonstone, peridot, phenakite, quartz, scapolite, spinel, topaz, tourmaline and zircon.

Dr John M. Saul, Paris, France, for a copy of his book *The Tale Told in All Lands: The Heavens as Blueprint for Civilization* (2013, Les 3 Colonnes, Paris).

Antonio Silva, London, for approximately 227 g of rough tanzanite (gravel), a blue/green diamond crystal slice and a copy of *Brazil: Paradise of Gemstones* by Jules Roger Sauer (1982, J. R. Sauer, Rio de Janeiro, Brazil).

PHOTOGRAPHIC COMPETITION 2014

Joint Winners

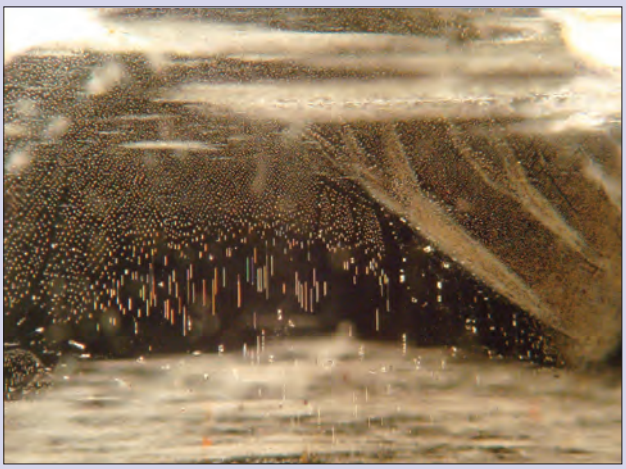

Dayananda Dillimuni FGA. *'Rainy day'. Inclusions in natural beryl, showing flat tabular cavities parallel to basal pinacoid, short tube-like cavities parallel to c-axis and liquid feathers.*

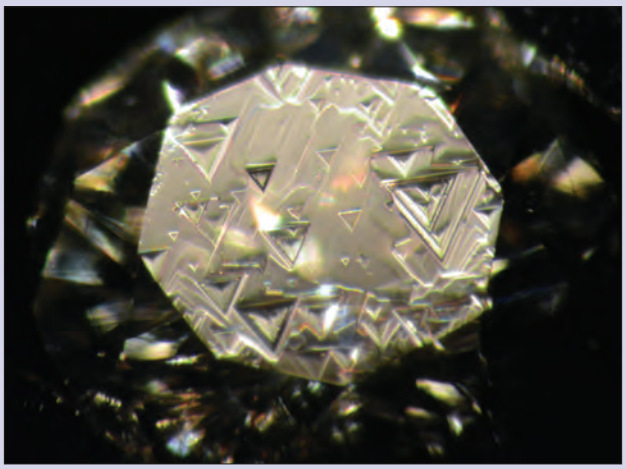

Grenville Millington FGA. *Trigons across the table facet of a 0.03 ct round brilliant diamond (2.01–2.06 × 1.19 mm). Magnification 80×.*

Second Prize

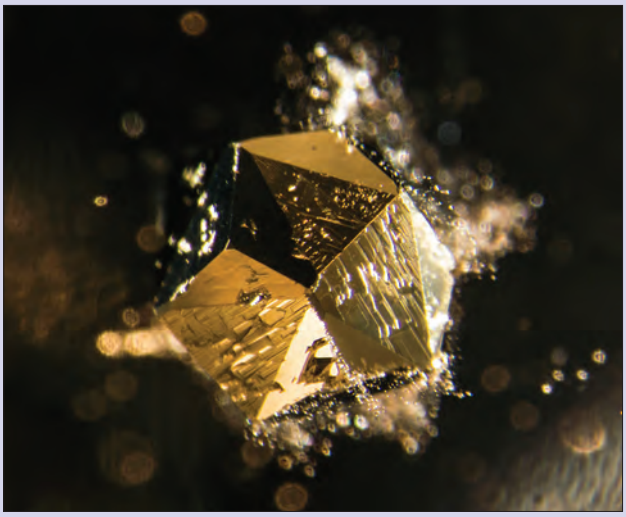

E. Billie Hughes FGA. *Pyrite inclusion in quartz.*

Third Prize

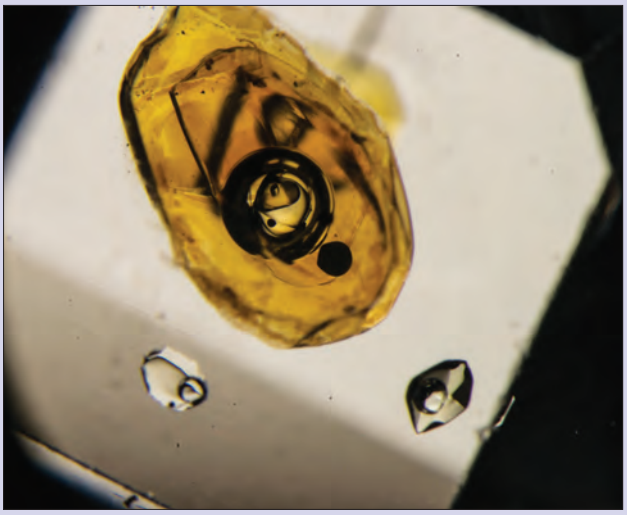

E. Billie Hughes FGA. *Petroleum inclusion in quartz, including a bubble that has the appearance of a 'yin-yang' symbol.*

Honourable Mentions

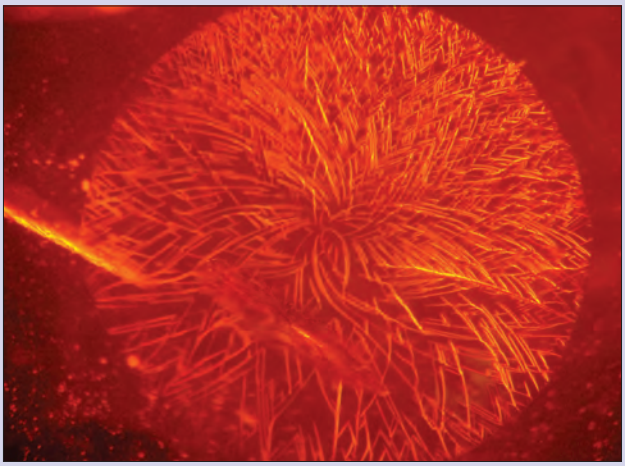

Dayananda Dillimuni FGA. *Sun spangle in amber; the characteristic pattern produced after heat treatment showing curved radiating lines in two directions.*

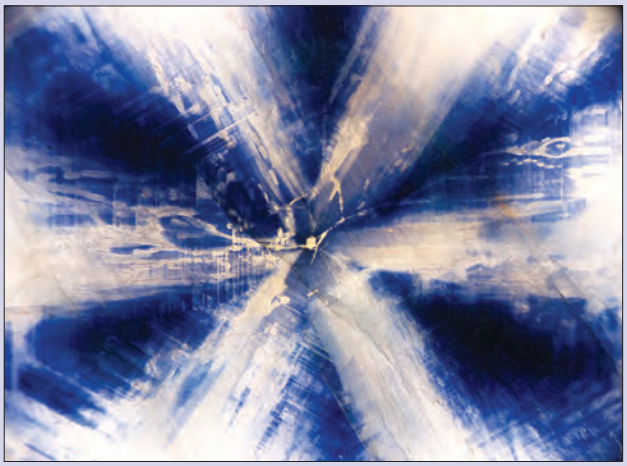

Richard Hughes FGA. *Trapiche sapphire from Mogok, Myanmar. Magnification approximately 7×.*

GEMMOLOGICAL ASSOCIATION OF AUSTRALIA

During the Graduation Ceremony held at Goldsmiths' Hall on 3 November, Gem-A and the Gemmological Association of Australia (GAA) signed an agreement recognizing the equivalent status of the associations' two gemmology diplomas and allowing fully paid-up Fellows of either association to apply for Fellowship of their sister association. The agreement was signed by Gem-A Chairman Jason Williams and President Harry Levy, and GAA President Katrina Marchioni and Patron Terry Coldham. As both organizations are members of CIBJO the agreement was witnessed by CIBJO President Dr Gaetano Cavalieri.

MEMBERSHIP

At a meeting of the Council of the Association held on 3 November 2014, the following were elected to membership:

Fellowship and Diamond Membership (FGA DGA)

Khinvasara, Sunil, *Monroe Township, New Jersey, USA*
Li Man Kit, *Shatin, Hong Kong*
Peshall, Jessica, *Pimlico, London*
Sokkalingam, Visvanathan, *Singapore*
Von Allmen, Andrea, *Münsingen, Switzerland*

Fellowship (FGA)

Carr, Susan, *Thornhaugh, Cambridgeshire*
Chant, Francesca, *Worcester Park, Surrey*
Cheer, Peter, *Somerton, Somerset,*
Elazzouzi, Celine, *Ile de la Réunion, France*
Graff, Elliott, *London*
Griffon, Denise, *Montreal, Quebec, Canada*
Heilio, Saara, *Orpington, Kent*
Kenyon, Janelle, *Auckland, New Zealand*
Kim Dong Hui, *Daegu, South Korea*
Kyle, Jennifer, *Montreal, Quebec, Canada*
Leedham, Laura, *Oldbury, West Midlands*
Lineker-Mobberley, Maryanne, *Bridgnorth, Shropshire*
Liu Hongwei, *Nankai District, Tianjin, P.R. China*
Mustsaers, Gerard, *Dieren, The Netherlands*
Nigam, Pooja, *New Delhi, India*
O'Sullivan Walter, Lauren, *San Francisco, California, USA*
Ramanasse, Anthony, *Paris, France*
Richbourg, Carole, *Los Altos, California, USA*
Roelofse, Frederick, *Bloemfontein, South Africa*
Routledge, Susannah, *Reading, Berkshire*
Schuch-Des Forges, Vanessa, *North Littleton, Worcestershire*
Siritheerakul, Piradee, *Bangkok, Thailand*
Stead, Heather, *Wigginton, North Yorkshire*
Tjioe Ay Djoen, *Montreal, Quebec, Canada*
Tsang, Kim, *Tai Kok Tsui, Hong Kong*

Diamond Membership (DGA)

Acklam, Sharon, *Hull, East Yorkshire*
Fung, Yan Yan, *Yuen Long, Hong Kong*
Hrustic, Ibrahim, *Marieholm, Sweden*
Kuebler-Tesch, Joachim, *Ludwigsburg, Germany*
Lansley, Juliette, *Heathfield, East Sussex*
Lumb, Sarah, *London*
Nadal, Cynthia, *London*
Rice, James, *Hull, East Yorkshire*
Rice, Max, *Hull, East Yorkshire*
Sharpley-Fanner, Harriet, *London*
Wong Yee Wai, *Yuen Long, Hong Kong*

Associate Membership

Appadoo, Vijay, *Croydon, London*
Bohlin, Anne, *Stockholm, Sweden*
Bratton, Tim, *Farnborough, Kent*
Harrison, Peter, *Darlington, County Durham*
Johnson, Mark, *Ryde, Isle of Wight*
McAlpine, Ross, *Liverpool, Merseyside*
McCullough, Lesley-Ann, *Belfast*
McLauchlan, Duncan, *London*
Milliner, Sean, *Scottsdale, Arizona, USA*
Pughe, Marianne, *Corbridge, Northumberland*
Radatzaun, Ramtin, *London*
Risstad Bohlin, Anne, *Stockholm, Sweden*
Rodrigues, Suelle, *Breukeleveen, Utrecht, The Netherlands*
Sathanantharaja, A., *London*
Sergei, Michael, *London*
Sergent, Shelly, *Scottsdale, Arizona, USA*
Shepherd, Drina, *Rude, Isle of White*
Snell, Simon, *Bournemouth, Dorset*
Weerawardana, Sagarika, *Kurunagala, Sri Lanka*

Corporate Gold Membership

Stone Group Laboratories, *Jefferson City, Missouri, USA*
Studley Jewellers, *Wells, Somerset*

Corporate Membership

Fred J Malcolm Ltd, *Belfast*
Serendipity Diamonds, *Ryde, Isle of Wight*
Somewhere in the Rainbow, *Scottsdale, Arizona, USA*

Subscriptions 2015

The Associate, Fellow and Diamond membership subscriptions for 2015 are £135 or £110 if paying by direct debit. Corporate and Corporate Gold Membership subscriptions are £300 or £275 if paying by direct debit.

GEM-A AWARDS

In the Gem-A examinations held in June 2014, 181 students qualified in the Gemmology Diploma examination, including nine with Distinction and 29 with Merit, and in the Foundation Certificate in Gemmology examination 366 qualified. In the Gem Diamond examination 66 qualified, including nine with Distinction and eight with Merit.

In the **Gemmology Diploma** examinations held in January and June 2014, the **Christie's Prize for Gemmology** for the best candidate of the year was awarded to **Elie-Anne Caya** of Quebec City, Canada. The **Anderson Bank Prize** for the best set of theory papers was awarded to **Dilyara Khabrieva** of London. The **Read Practical Prize** for excellence in the practical examination was awarded to **Claire Ito** of Carlsbad, California, USA.

In the **Foundation Certificate in Gemmology** examination, the **Anderson Medal** for the candidate who submitted the best set of answers which, in the opinion of the examiners, were of sufficiently high standard, was awarded to **Andrew Barrett** of Sliema, Malta.

In the **Diamond Diploma** examination, the **Bruton Medal** for the best set of theory answer papers of the year was awarded to **Andrea Von Allmen** of Münsingen, Switzerland.

The **Deeks Diamond Prize** for the best candidate of the year was awarded to **Ching Man Wong** of Discovery Bay, Hong Kong.

The **Diamond Practical Prize** for excellence in the Diamond Practical examination, sponsored by Dominic Mok from AGIL, Hong Kong, was awarded to **Doerte Herold** of Zürich, Switzerland.

The **Tully Medal** was not awarded.

The names of the successful candidates are listed below.

Examinations in Gemmology

Gemmology Diploma

Qualified with Distinction

Jiang Rongxian, *Guangzhou, Guangdong, P.R. China*
Lescuyer, Loic, *Francheville, France*
Li Zhixiang, *Guangzhou, Guangdong, P.R. China*
Liscouet, Marie-Solène, *Saint-Cloud, France*
Platis, Alexandros, *Nafpaktos, Greece*
Wang Jiaying, *Beijing, P.R. China*
Wang Yanjing, *Beijing, P.R. China*
Williams, Kathryn, *Dover, Kent*
Yu Hui, *Beijing, P.R. China*

Qualified with Merit

Borreill, Daniel, *Serralongue, France*
Caya, Elie-Anne, *Quebec City, Quebec, Canada*
Clark, Bryan, *Brooklyn, New York, USA*
Deng Xia, *Beijing, P.R. China*
Dunn, Lauren, *Trowbridge, Wiltshire*
Föge, Kerstin, *Dijon, France*
Fox, Rosanna, *Kennington, London*
Goots, Pauline, *Liège, Belgium*
Lai Cheng, *Guilin, Guangxi, P.R. China*
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Westmoreland, Samantha, *Burntwood, Staffordshire*
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Wong Hiu Moon, *Kowloon, Hong Kong*
Wong Pak Leung, *Tseung Kwan O, Hong Kong*
Wong Tik, *Kwai Chung, Hong Kong*
Wong Yuk Kwo, *North Point, Hong Kong*
Woodfine, Jennifer, *Montreal, Quebec, Canada*
Wu Chia Jung, *Kaohsiung City, Taiwan, R.O. China*
Wu Oi Lam, *Kwai Chung, Hong Kong*
Wu Xuxu, *Beijing, P.R. China*
Wu Yong, *Hangzhou City, Zhejiang, P.R. China*
Xiaorong Jiang, *Guilin, Guangxi, P.R. China*
Xie Danhong, *Enfield, Middlesex*
Xin Wen, *Beijing, P.R. China*
Xu Jian Mei, *Shenzhen, Guangdong, P.R. China*
Xu Qinzi, *Beijing, P.R. China*
Xu Sijia, *London*
Xue Jie, *Ma On Shan, Hong Kong*
Yalin Zhu, *Guilin, Guangxi, P.R. China*
Yan Juan, *Xiamen City, Fujian, P.R. China*
Yan Meng, *Vaughan, Ontario, Canada*
Yan Yan, *Guilin, Guangxi, P.R. China*
Yan Yuxi, *West Vancouver, British Columbia, Canada*
Yanan Fan, *Colombo, Sri Lanka*
Yang Bai, *Colombo, Sri Lanka*
Yang Chen-Yu, *Taipei City, Taiwan, R.O. China*
Yang Dong Wen, *Kowloon, Hong Kong*
Yang Hsiao-Chu, *Taipei City, Taiwan, R.O. China*
Yang Su Fan, *New Taipei City, Taiwan, R.O. China*
Yang Xiao, *Beijing, P.R. China*
Yang Xue-Chang, *New Taipei City, Taiwan, R.O. China*
Yang Yang, *Guilin, Guangxi, P.R. China*
Yang Yong, *Ningbo, Zhejiang, P.R. China*
Yang Yuling, *Beijing, P.R. China*

Ye Run Ling, *Shenzhen, Guangdong, P.R. China*
Ye Shan, *Shanghai, P.R. China*
Yeung Ka Ling, Sophia, *Kennedy Town, Hong Kong*
Yi Nannan, *Beijing, P.R. China*
Yiying Su, *Guilin, Guangxi, P.R. China*
Yong Chenying, *Beijing, P.R. China*
Yoong, Rachel, *Birmingham, West Midlands*
Yoshiaki, Uchida, *Tokyo, Japan*
Yu Hsien-Lung, *New Taipei City, Taiwan, R.O. China*
Yu Menglin, *London*
Yuan Rui Feng, *Shenzhen, Guangdong, P.R. China*
Zerhouni, Yousra, *Montreal, Quebec, Canada*
Zhai Mengqi, *Beijing, P.R. China*
Zhang Lei, *Beijing, P.R. China*
Zhang Lingjie, *Beijing, P.R. China*
Zhang Menglin, *Beijing, P.R. China*
Zhang Nan, *London*
Zhang Peng, *Shanghai, P.R. China*
Zhang Shengdi, *Guangzhou, Guangdong, P.R. China*
Zhang Ting, *Montreal, Quebec, Canada*
Zhang Xiao, *Shanghai, P.R. China*
Zhang Xiaole, *Solihull, West Midlands*
Zhang Yan, *Shanghai, P.R. China*
Zhang Yang, *Shenzhen, Guangdong, P.R. China*
Zhang Yiwen, *Beijing, P.R. China*
Zhao Yi, *Beijing, P.R. China*
Zhao Zhiyang, *Shanghai, P.R. China*
Zhen Wang, *Guilin, Guangxi, P.R. China*
Zheng Bingyu, *Beijing, P.R. China*
Zhong Hua, Anna, *Tsuen Wan, Hong Kong*
Zhou Ziwei, *Beijing, P.R. China*
Zhu Xiaofei, *Shanghai, P.R. China*
Zhu Yuenan, *Hangzhou City, Zhejiang, P.R. China*
Zirogiannis, Athanasios, *Athens, Greece*
Zisis, Vasilis, *Marousi, Greece*
Zou Ran, *Beijing, P.R. China*

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Qualified with Distinction

Dixon, Emily, *London*
Harris, Natalie, *Merstham, Surrey*
Hillcoat, Cathryn, *St. Albans, Hertfordshire*
Khinvasara, Sunil, *Monroe Township, New Jersey, USA*
Marek, Genia, *Putney, London*
Marshall, Angela, *Cambridge, Cambridgeshire*
Pei Yu, *Beijing, P.R. China*
Simonsson, Kim, *Stockholm, Sweden*
Von Allmen, Andrea, *Münsingen, Switzerland*

Qualified with Merit

Arioli, Elena, *London*
Backhouse, Theodora, *Battersea, London*
Bevans-Royston, Aston, *Billericay, Essex*
Hrustic, Ibrahim, *Marieholm, Sweden*
Li Man Kit, *Shatin, Hong Kong*
Liu Huan, *Beijing, P.R. China*
Lumb, Sarah, *London*
Soon, Alexis, *London*

Qualified

An Meilan, *Beijing, P.R. China*
Cai Jing, *North Point, Hong Kong*
Chan Lai Ping, *Tai Po, Hong Kong*
Chan Chi Fung, *Tai Po, Hong Kong*
Chen Xiaoxi, *Brockley, London*
Cheung Ka Yan, Michiele, *Sai Kung, Hong Kong*
Chiu Ying Ying, *Tseung Kwan O, Hong Kong*
Chow Yee Man, *Shatin, Hong Kong*
Coppin, Daisy, *Corsham, Wiltshire*
Doyle, Helen, *London*
Du Yu, *Beijing, P.R. China*
Duan Wei Ju, *Chai Wan, Hong Kong*
Fan Sze Man, Ellie, *North Point, Hong Kong*
Fu Qidi, *Beijing, P.R. China*
Fung Yan Yan, *Yuen Long, Hong Kong*
Hao Yun, *Beijing, P.R. China*
Harper, Kate, *Edgbaston, West Midlands*
Jones, Oliver, *Bern, Switzerland*
Kübler-Tesch, Joachim, *Ludwigsburg, Germany*
Lai Kar Wai, Maria, *North Point, Hong Kong*
Lam Ching Wa, *Kowloon, Hong Kong*
Landmann, Juliana, *London*
Lansley, Juliette Elizabeth, *Heathfield, East Sussex*
Lau King Yiu, *Tuen Mun, Hong Kong*
Lee Hao Wen, *Tuen Mun, Hong Kong*
Leung Po Wa, *Ma On Shan, Hong Kong*
Li Jiahao, *Shantou, Guangdong, P.R. China*
Li Cheuk Lam, *Shau Kei Wan, Hong Kong*
Liu Tong, *Beijing, P.R. China*
Liu Zijing, *Beijing, P.R. China*
Ng Nga Chi, *Kowloon, Hong Kong*
Ng Koon Hang, *Kowloon, Hong Kong*
Scully, Kerryanne, *Birmingham, West Midlands*
Slingsby, Hazel, *Old Coulsdon, Surrey*
Spicer, Gregory, *Hove, East Sussex*
Stenlund, Emelie Maria Christina, *Strangnas, Sweden*
Tang Chung Fu, *Kowloon, Hong Kong*
Tang Kit Shan, *Kowloon, Hong Kong*
Thung Chi Ming, Herbert, *Kowloon, Hong Kong*
Tsang Shek Fai Tsang, *Kwai Fong, Hong Kong*
Tse Chi Kuen, *North Point, Hong Kong*
Valentini-Orme, Francesca, *Wandsworth, London*
Wong Yee Wai, *Yuen Long, Hong Kong*
Wong Nga Sze, Jennifer, *Fotan, Hong Kong*
Woods, Edward, *Hungerford, Berkshire*
Xiao Mingqi, *Beijing, P.R. China*
Xiao Qiyun, *Beijing, P.R. China*
Yeung Chuek Yan, *Kowloon, Hong Kong*
Yeung Chi Nang, *Lam Tin, Hong Kong*

OBITUARIES

Pierre Vuillet á Ciles

Pierre Vuillet á Ciles FGA of Villards d'Heria, France, died on 2 November 2014.

Pierre was born in 1957 in Jura, France and studied in Belfort and Dijon before becoming an engineer working for leading oil and gas companies.

Pierre became interested in gemstones after trips to South America and decided to study gemmology. He qualified in the Gemmology Diploma examination in 1993, gaining the Anderson Bank Prize.

Having taken Spanish lessons in Salamanca, Pierre travelled extensively in Colombia where he managed to establish contacts and develop an emerald business between Colombia and Europe. Always keen to develop new markets, he explored the natural pearl sector, specializing in conch pearls. Meanwhile he played an important role in Gem-A's course development when he discussed various gem education topics in great detail.

He continued to travel extensively, particularly to Asia where the emerging new markets led him.

Pierre was a brilliant mind and willingly shared his impressive knowledge. He will be sorely missed.

Denis M. Gravier

Felix Sydney Cobden FGA (D.1970), Ramat Gan, Israel, died on 22 July 2014.

Monika Grafin Von Francken Sierstorpff FGA (D.1985), Cologne, Germany, died unexpectedly on 28 August 2014.

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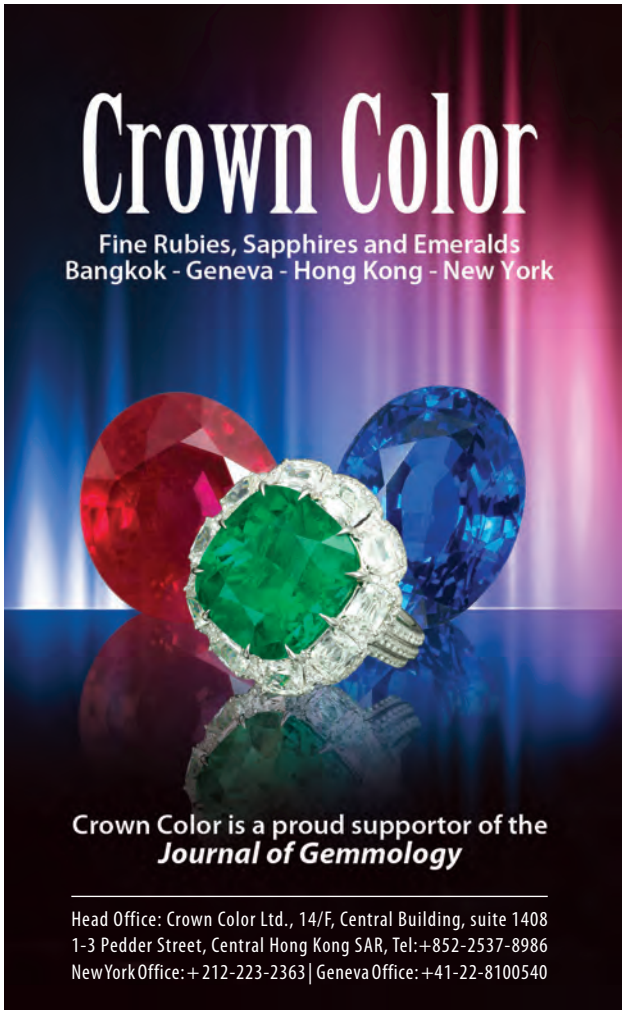
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Learning Opportunities

CONFERENCES AND SEMINARS

NAJA 43rd ACE IT Annual Winter Education Conference
1–2 February 2015
Tucson, Arizona, USA
http://najaappraisers.com/html/conferences.html

AGTA GemFair Tucson 2015
3–8 February 2015
Tucson, Arizona, USA
www.agta.org/tradeshows/gft-seminars.html
Note: Gem-A will be exhibiting at booth 29.

AGA Tucson Conference
4 February 2015
Tucson, Arizona, USA
www.accreditedgemologists.org/currevent.php

2015 Tucson Gem and Mineral Show
12–15 February 2015
Tucson, Arizona, USA
www.tgms.org/show-2015
Notes: (1) Lectures and seminars will follow the show theme 'Minerals of Western Europe'.
(2) Gem-A will be exhibiting for the first time at this show: visit booth 1928–1929.

National Council of Jewellery Valuers Conference
15-21 April 2015
Sydney, Australia
www.ncjv.com.au

Mallorca GemQuest Gemmological Conference
18–20 April 2015
Can Pastilla, Mallorca, Spain
www.mallorcagemquest.com

Swiss Gemmological Society Conference
19-21 April 2015
Meisterschwanden, Switzerland
www.gemmologie.ch

AGS International Conclave
22–25 April 2015
New Orleans, Louisiana, USA
www.americangemsociety.org/conclave-2015

Scottish Gemmological Association Annual Conference
1–4 May 2015
Peebles, Scotland
www.scotgem.co.uk/SGAConference2015

Compiled by Georgina Brown and Brendan Laurs

Association for the Study of Jewelry and Related Arts 10th Annual Conference
2–3 May 2015
Chicago, Illinois, USA
www.asjra.net/event.html

CIBJO Congress 2015
4–6 May 2015
Salvador, Brazil
http://tinyurl.com/n8f9utk

3rd Annual New England Mineral Conference
8–10 May 2015
Newry, Maine, USA
www.nemineralconference.org

ICA Congress
16–19 May 2015
Colombo, Sri Lanka
http://congress.gemstone.org

The Santa Fe Symposium
17–20 May 2015
Albuquerque, New Mexico, USA
www.santafesymposium.org

Society of North American Goldsmiths' 44th Annual Conference
20–23 May 2015
Boston, Massachusetts, USA
www.snagmetalsmith.org/conferences/impact-looking-back-forging-forward

9th International Conference on New Diamond and Nano Carbons
24–28 May 2015
Shizuoka, Japan
www.ndnc2015.org

PEG 2015: 7th International Symposium on Granitic Pegmatites
17–21 June 2015
Lover Silesia, Poland
www.peg2015polandczech.us.edu.pl

Sainte-Marie-Aux-Mines Mineral and Gem Show
25–28 June 2015
Sainte-Marie-Aux-Mines, France
www.sainte-marie-mineral.com
Note: Lectures, workshops and gem/mineral-related films will be offered during the show.

1st Mediterranean Gemmological and Jewellery Conference
27–28 June 2015
Athens, Greece
http://cglworld.ca/education

Jewelry Camp 2015: Antique Jewelry & Art Conference
30–31 July 2015
West Harrison, New York, USA
www.jewelrycamp.org

12th International Congress for Applied Mineralogy
10–12 August 2015
Istanbul, Turkey
http://icam2015.org

Northwest Jewelry Conference 2015
14–16 August 2015
Bellevue, Washington, USA
www.nwgem.com

2015 Dallas Mineral Collecting Symposium
21–22 August 2015
Dallas, Texas, USA
www.dallassymposium.org/2015-symposium

SGA 2015: 13th Biennial Meeting of the Society of Geology Applied to Mineral Deposits
24–27 August 2015
Nancy, France
http://sga2015.blog.univ-lorraine.fr
Session of interest: Gems and Industrial Minerals

26th International Conference on Diamond and Carbon Materials
6–10 September 2015
Bad Homburg, Germany
www.diamond-conference.elsevier.com

5th European Conference on Crystal Growth
9–11 September 2015
Bologna, Italy
www.eccg5.eu

Denver Gem & Mineral Show
18–20 September 2015
Denver, Colorado, USA
www.denvermineralshow.com
Note: Lectures and seminars will follow the show theme 'Minerals of the American Southwest'.

Canadian Gemmological Association Gem Conference 2015
16–18 October
Vancouver, British Columbia, Canada
www.gemconference2015.com

EXHIBITS

Europe

Daily Life—Luxury—Protection. Jewellery in Ancient Egypt
Until 25 January 2015
Neues Museum, Berlin, Germany
www.smb.museum/en/museums-and-institutions/neues-museum/exhibitions

The Treasures of the Fondazione Bucellati
Until 22 February 2015
Museo degli Argenti, Florence, Italy
www.polomuseale.firenze.it/mostre/mostra.php?t=547de14a29644508130000b9

With their Heads Held High—Headgear from All Over the World
Until 8 February 2015
Schmuckmuseum, Pforzheim, Germany
http://klimt02.net/institutions/museums/pforzheim-jewellery-museum-2014

Anton Cepka—Kinetic Jewellery
14 March – 7 June 2015
Pinakothek der Moderne, Munich, Germany
www.pinakothek.de/kalender/2015-03-14/49068/anton-cepka-kinetischer-schmuck

Gold of the Gods from Java
Until 6 April 2015
Wereldmuseum, Rotterdam, Netherlands
www.wereldmuseum.nl/en/tentoonstellingen/goud-der-goden.html

An Adaptable Trade: The Jewellery Quarter at War
Until 27 June 2015
Museum of the Jewellery Quarter, Birmingham
www.birminghammuseums.org.uk/jewellery/whats-on/an-adaptable-trade-the-jewellery-quarter-at-war

Middle East

Urartian Jewellery Collection
Until 31 July 2015
Rezan Has Museum, Istanbul, Turkey
www.rhm.org.tr/en/event/rezan-has-museum-urartian-jewellery-collection

North America

Treasures from India: Jewels from the Al-Thani Collection
Until 25 January 2015
Metropolitan Museum of Art, New York, New York, USA
http://tinyurl.com/kw3qafs

Maker & Muse: Women and Early Twentieth Century Art Jewelry
14 February 2015 – 1 January 2016
The Richard H. Driehaus Museum, Chicago, Illinois, USA
www.driehausmuseum.org/maker-and-muse

Colors of the Universe: Chinese Hardstone Carvings
Until 8 March 2015
Metropolitan Museum of Art, New York, New York, USA
www.metmuseum.org/exhibitions/listings/2013/chinese-carving

Hollywood Glamour: Fashion and Jewelry from the Silver Screen
Until 8 March 2015
Museum of Fine Arts, Boston, Massachusetts, USA
www.mfa.org/exhibitions/hollywood-glamour

Brilliant: Cartier in the 20th Century
Until 15 March 2015
Denver Art Museum, Colorado, USA
www.denverartmuseum.org/exhibitions/brilliant-cartier-20th-century

The Greeks – Agamemnon to Alexander the Great
Until 26 April 2015
Montréal Museum of Archaeology and History, Old Montréal, Québec, Canada
www.pacmusee.qc.ca/en/exhibitions/the-greeks-agamemnon-to-alexander-the-great

Ancient Luxury and the Roman Silver Treasure from Berthouville
Until 17 August 2015
The Getty Villa, Pacific Palisades, California, USA
www.getty.edu/art/exhibitions/ancient_luxury

Glittering World: Navajo Jewelry of the Yazzie Family
Until 10 January 2016
National Museum of the American Indian, New York, New York, USA
http://nmai.si.edu/explore/exhibitions/item/?id=890

Gold and the Gods: Jewels of Ancient Nubia
Until 14 May 2017
Museum of Fine Arts, Boston, Massachusetts, USA
www.mfa.org/exhibitions/gold-and-gods

Bulgari: 130 Years of Masterpieces
On display (closing date to be determined)
Houston Museum of Natural Science, Texas, USA
www.hmns.org/index.php?option=com_content&view=article&id=687&Itemid=722

City of Silver and Gold: From Tiffany to Cartier
On display (closing date to be determined)
Newark Museum, New Jersey, USA
www.newarkmuseum.org/SilverAndGold.html

Fabergé: From a Snowflake to an Iceberg
On display (closing date to be determined)
Houston Museum of Natural Science, Texas, USA
www.hmns.org/index.php?option=com_content&view=article&id=594&Itemid=621

Gemstone Carvings: Crystals Transformed Through Vision & Skill
On display (closing date to be determined)
Houston Museum of Natural Science, Houston, Texas, USA
www.hmns.org/index.php?option=com_content&view=article&id=481&Itemid=502

Australia and New Zealand

Fine Possession: Jewellery & Identity
Until 20 September 2015
Powerhouse Museum, Sydney, Australia
www.powerhousemuseum.com/exhibitions/jewellery

OTHER EDUCATIONAL OPPORTUNITIES

Gem-A Workshops and Courses
Gem-A, London
www.gem-a.com/education/course-prices-and-dates.aspx

Gem-A Trip to Idar-Oberstein
13–20 June 2015
Idar-Oberstein, Germany
www.gem-a.com/news--events/events/idar-oberstein-2015.aspx

Montreal School of Gemmology Gem and Jewellery Appraisal Course
6–29 July 2015 (in English and French)
Montreal, Quebec, Canada
www.ecoledegemmologie.com/en/c/10

Gemstone Safari to Tanzania
13–30 July 2015
Arusha, Merelani and Lake Manyara, Tanzania
www.free-form.ch/tanzania/gemstonesafari.html

New Media

Crystal Mountains

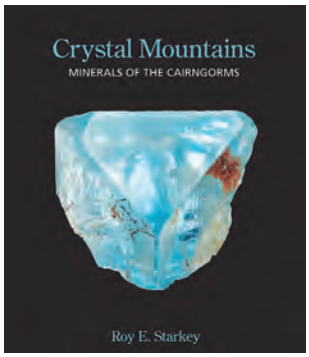

Roy Starkey, 2014. British Mineralogy Publications, Worcestershire, 184 pages, illus., softcover, ISBN 978-0993018213, http://britishmineralogy.com. £25.00.

In this book, the reader is drawn into the granite heights of the Cairngorm Mountains which, rising to over 4,000 feet (1,220 m), host an array of fine crystals and gems. Prominent from this treasure house are the smoky quartz specimens that have traded as 'cairngorm' for some 300 years. The author distinguishes the 1,245 m Cairn Gorm (*blue mountain* in Gaelic) as part of this mountainous terrain known as 'The Cairngorms'.

The area's gems and minerals and their historical background have been assiduously researched by Starkey, and the 184 pages make for an enjoyable journey, without the physical strains the author endured over the years in exploring this wilderness in all types of weather. The reader is treated to some natural history along the way, with mention of the birds (i.e. ptarmigan, capercaillie, dotterel and golden eagle) and red deer that live there.

Starkey has tracked down the earliest reports on the area, such as one from novelist and poet James Hogg who, before Queen Victoria's active interest in the area and its gems, describes "the fields trenched on the height in search of 'Cairngorm Topazes'". The first mention of this famous locality appeared in a jeweller's advertisement in 1769, in the *Aberdeen Journal*, which listed among various gems for sale 'Scots Topazes' and 'Cairngorum seals'.

Topaz continues to be collected from the area, and a 62 g blue crystal is featured on the book's cover (and another one is shown in the book that weighs 164 g). Sadly these are overshadowed today by the tons of blue topaz that occupy the jewellery world's window spaces without a mention of their treated colour.

The reader is further regaled with photos of green and yellow beryls from the region, as well as blue aquamarines. An array of other finds are recorded that extend the gemmological content.

Many Cairngorm gem discoveries came to light in Victorian times, encouraged by the interest of the Queen and her inquisitive consort Albert in all things scientific—a hallmark of the age. The interest intensified after the royal couple's purchase of Balmoral Castle, their Scottish home in the foothills of the Cairngorms. An emerging study of minerals was led by Prof. Matthew Forster Heddle, the defining figure of Scottish mineralogy. This was also the age of Sir David Brewster's discoveries in optics and his enquiries into the multi-phase fluid inclusions in Cairngorm's gems.

The book is overflowing with photos of this alpine massif, deeply scarred by glaciers, which have laid bare the scenery and its mineral delights. Numerous images show gemmy crystal specimens, faceted gems and jewellery, and may tempt the reader to pack a rucksack and head for this Scottish El Dorado. The author achieves a good balance between all the facts assembled and a narrative that takes the reader comfortably to these less accessible parts of Scotland.

The entire area is now the Cairngorms National Park and a Site of Special Scientific Interest with its surrounding remnants of the great Caledonian Forest. All must be treated with respect, and approval to collect gems and minerals should first be sought from landowners or relevant authorities.

Alan Hodgkinson

The Eduard Josef Gübelin Story: The Art and Science of Gems

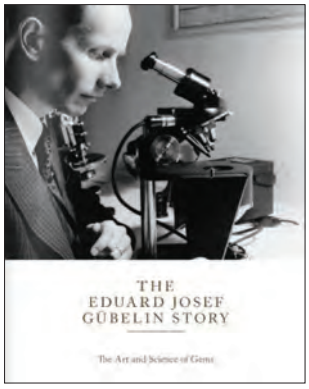

The Gübelin Foundation, 2014. Gübelin Group, Lucerne, and Unicorn Press, London, 306 pages, illus., hardcover, ISBN 978-1910065402, www.guebelin.ch/gemfairhk. £40.00.

"Used to be an Experience meant making you a bit older. This one makes you wider."

– Liner notes to 'Are You Experienced', Jimi Hendrix Experience, 1967

Eduard Gübelin needs little introduction. Arguably the most influential gemmologist of the 20th century, his work spans the transition of the field from 'tradecraft' to a forensic science. But it is actually so much more, as the current book details.

The son of a Swiss watchmaking family, he developed a keen interest in stones at an early age; this was to blossom into a passion for precious stones as

his family's business branched into jewellery. His early scholarly interests were in languages and poetry, but the family eventually steered him towards mineralogy as it was thought this would be more useful in the business. These twin interests in the humanities, fused to exacting science, would give birth to some of the greatest gemmological works in history.

Published 101 years after his birth, *The Eduard Josef Gübelin Story* is a richly illustrated document of this man's amazing life. It is filled with photographs of Gübelin on his various adventures in Burma and Sri Lanka, as well as selections from his vast correspondence, and anecdotes from relatives and colleagues. As such it is a history of gemmology itself and deserves a place on the shelves of anyone wishing to understand the development of the field. It is also studded with photos of his lab and family, which paint a full and personal picture of the man.

The book is divided into logical sections, beginning with the family history. It then continues with Gübelin's early life, his career and accomplishments, with a generous portion devoted to his travels. Completing it is a massive bibliography of Eduard Gübelin's published works and a shorter section on his awards.

This volume is printed on heavy paper and, unlike the *Photoatlas* series, is well bound. An earlier edition (*Enduring Values: In Celebration of Eduard Joseph Gübelin*) appeared briefly in 2013, but had a number of shortcomings. These have been corrected, resulting in a much more professional production. In addition to English, the book is also available in German and Mandarin.

I will close this review with a personal story. When I began my gemmological studies in 1979, a youthful Santpal Singh invited me up to his personal laboratory in Bangkok. I noticed a number of books on gemmology and asked which was his favourite. Without hesitation, he pulled one off the shelf and said: "This." It was Eduard Gübelin's 1973 masterpiece, *Internal World of Gemstones*. Peeking inside, I felt like Harry Potter transported through a brick wall at King's Cross station to a magical world on the other side. This was a work that not only changed my life, but that of virtually all gemmologists who have followed.

In every field, on rare occasions there appears someone with the vision to allow us to see with new eyes. Be it the prose of Morrissey or the guitar of Jimi Hendrix, once heard, nothing is the same. Eduard Gübelin did not simply pass along his experience. He made us wider. We are all better for it.

R. W. Hughes

Gemstones in Victoria

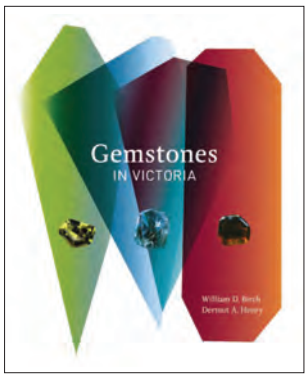

William D. Birch and Dermot A. Henry, 2013. Museum Victoria, Carlton, Victoria, Australia, 232 pages, illus., softcover, ISBN 978-1921833069, http://museumvictoria.com.au/shop. AUS$29.95.

This compilation of gemstone riches from Australia's Victoria State is dedicated to Reverend John Bleasdale (1822–1884), a priest, chemist, mineralogist and former president of the Royal Society of Victoria, who stated in 1868, "…as yet no one country on the broad earth has yielded such an assemblage of varieties of rare and precious gemstones as Victoria".

Following a historic account of gem discoveries in Victoria, the authors launch into specific chapters covering: diamond; sapphire, ruby and zircon; olivine and anorthoclase; topaz, tourmaline and beryl; garnet; quartz; chalcedony and opal; and other gem materials (including banded calcite-ankerite, cassiterite, corundum, chrysoberyl, dumortierite, moonstone, 'selwynite' and turquoise), and round-off each with a brief description of important localities in other Australian states. Each chapter is colour coded to compliment the principal colour of those gemstones, and for easy 'thumbing in' to that section of the book. The chapters each begin with a bold title page and, where available, a historical quotation from the Rev. Bleasdale. For example, on the title page for 'Topaz, Tourmaline & Beryl', he boldly states: "I may venture to say that there is not in the world a stone fit for brooches, of size and fire, and lustre, and suited to both day and candlelight, equal to some of the blue topazes which I have known to be found in Victoria."

The gem photography in the book, credited largely to Museum Victoria staff, is superb both in clarity and detail. The gems are individually photographed or painstakingly arrayed in cascades of colour—loose crystals, fine matrix specimens, or beautiful faceted and polished examples. Each page is adorned with these images plus supporting colour geological locality maps. The layout gives the feel of a fine arts book with strong emphasis placed on its visual presentation; the photos and maps are of ample size, are highlighted by generous white page borders, and are offset by minimal supporting text (printed in a non-distracting neutral grey colour and small font size). The only negative aspect to this presentation, however, was that I found the text somewhat difficult to read under low lighting conditions.

The book is painstakingly comprehensive in its coverage of various Victorian historical occurrences and fossicking localities. To test this, I jumped straight into the 'Sapphires, Rubies & Zircons' chapter, searching under the heading 'Mornington Peninsula and Western Port' for one of my favourite childhood hunting grounds—and there it was, Point Leo, where sapphires and zircons are found 'in a layer about 1 m below the beach' and in 'the matrix of pebble conglomerates at the high-tide level on the beach, and on the rock platform of the point itself'. Following that, I searched the 'Olivine & Anorthoclase' chapter for another favourite, Mt Leura, a 'volcanic complex on the eastern outskirts of Camperdown' where olivine nodules (lherzolite xenoliths) literally fall out at your feet from the walls of the 'scoria and tuff quarries on the northern edge of the volcano'.

Gemstones in Victoria concludes with reference, resource and index sections, conveniently divided into Victorian and other Australian states, as well as a general index, glossary of terms, mineral property data and acknowledgements.

Gemstones in Victoria has been a significant part of the authors' lives for close to two decades now, and no two people could be more fitting to produce such a work than William Birch and Dermott Henry. Birch is curator of minerals, and Henry is manager of the Natural Sciences collections, at Museum Victoria. Both men have worked at the Museum for decades and are avid field collectors of rocks and minerals. They have both spoken to me about countless hours spent on the meticulous collection of gem locality data from museum records, company reports, gem and lapidary club journals and word-of-mouth from prospectors, followed by personal verification of these localities though field visits. This extensive research culminated in the publication of the first edition of *Gemstones in Victoria* in 1997 which, as testimony to its popularity, had completely sold out by 2009, leading Museum Victoria to commission this thoroughly updated second edition.

The publication has been printed in softcover to keep it affordable; however I am pleased to note that a limited run of a hardcover edition was produced and will be considered for future printings depending on demand. The book can be purchased via the internet from Booktopia, Angus & Robertson and CSIRO Publishing, and is available in the Museum Victoria bookshop.

Dr Robert R. Coenraads

Reply to a Review

In response to Jaroslav Hyršl's review of my book *Wonders within Gemstones II* (*Journal of Gemmology*, 2014, **34**(3), 271), I would like to point out a few corrections:

- Regarding the 'silica outcrop' in moldavite on p. 11 of my book, lechatelierite is another word for silica glass. However, I deliberately used the simpler term 'silica outcrop'.
- I have often seen whitish rutile needles in quartz, so why assume the needles shown on p. 54 are tourmaline?
- At least two of the inclusions in the topaz specimen on p. 38 contained several daughter crystals and are indeed multi-phase.

Anthony de Goutière GG, CG
Victoria, British Columbia, Canada
http://anthonydegoutiere.com/the-book

OTHER BOOK TITLES*

Coloured Stones

~~Jadeite: Identification & Price Guide, 4th edn.~~

This book should not have been listed since it deals with glassware and not jadeite gem material.

Rhodochrosite: Crystals of Drama and Nuance
By William S. Logan, 2013. Self-published by Spectrum Minerals, Charlotte, North Carolina, USA, 159 pages. US$78 hardcover, $55 softcover or $10 eBook.

* Compiled by Georgina Brown and Brendan Laurs

Diamond

Beyond the Four C's: What You Should REALLY Know Before You Buy a Diamond
By Joshua Fishman, 2014. CreateSpace Independent Publishing Platform, 138 pages, ISBN 978-1497509962. US$9.39 softcover or $4.29 eBook.

Novel Aspects of Diamond: From Growth to Applications
Ed. by Nianjun Yang, 2014. Springer, Heidelberg, Germany, Topics in Applied Physics 121, 292 pages, ISBN 978-3319098333. US$199.00 hardcover.

Organic Gems

***Pearls of Creation: A-Z of Pearls,* 2nd edn.**
By Marjorie M. Dawson, 2014. Self-published, 332 pages, ISBN 978-0615477640. £22.50 softcover.

Gem Localities

***The Collector's Guide to Herkimer Diamonds* [New York, USA]**
By Michael R. Walter, 2014. Schiffer Publishing Ltd., Atglen, Pennsylvania, USA, 96 pages, ISBN 978-0764347108. US$19.99 softcover.

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Cosmic Debris: Meteorites and Jewellery Objects by Reinhold Ziegler
By Halvor Nordby and André Gali, 2014. Arnoldsche Art Publishers, Stuttgart, Germany, 80 pages, ISBN 978-3897904057. £20.00 hardcover.

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Compiled by Brendan Laurs

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And I saw as it were

a sea of glass

mingled with fire.

— Revelation 15:2

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Aquamarine, Madagascar • 20.36 ct • 14.12 x 14.12 x 9.83 mm

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What's New

INSTRUMENTS AND TECHNIQUES

GL Gem Spectrometer NIR PL405

The GL Gem Spectrometer NIR PL405 is a dual purpose spectrometer for photoluminescence and Vis-NIR spectroscopy (550–1000 nm) that was released by Gemlab Group in December 2014. The spectrometer has a higher resolution but shorter wavelength range than Gemlab's previous GL Gem Spectrometer (300–1000 nm). It is equipped with a long-wave pass filter and is optimized for the NIR range. The unit is simply plugged into a computer's USB port; no additional drivers are necessary. It can be used to identify various gems such as ruby, sapphire, emerald, spinel and alexandrite based on their PL response, and it also may be used for quick diamond testing (to reveal the GR1 and Si centres at room temperature). For more information, visit www.cigem.ca/research-technology/gl-gemspec-nir-pl405.

Photography Accessory Clips

In 2014, Lithographie Ltd. started offering black flexible clips for gem and mineral photography. They are useful for holding reflectors, diffusers, etc., and are available in two sizes: five joints (15.6 cm long) or 10 joints (23.6 cm long). Visit www.lithographie.org/bookshop/five_joint_black_flexible.htm.

Presidium Gem Indicator

The Presidium Gem Indicator was launched at the Hong Kong International Jewellery Show in March 2015. The instrument is an enhanced and more convenient handheld version of the Presidium Gem Tester/Colored Stone Estimator. It distinguishes between diamonds and various other gems using thermal conductivity, and it comes with a changeable probe tip to guard against equipment downtime. The probe consists of two linked thermometers; one is heated electronically while the other is cooled by the stone being tested. The difference in temperature creates an electrical output, which is then amplified and displayed on the LED screen. It features an input function that allows users to select from a range of 12 common gem colours, thereby achieving more accurate results. Visit www.presidium.com.sg/PGI.html.

NEWS AND PUBLICATIONS

Gem Testing Laboratory (Jaipur, India) Newsletter

The latest *Lab Information Circular* (Vol. 71, March 2015), available at www.gtljaipur.info/circulars/LIC_Vol71_March2015_Eng.pdf, describes emeralds with repaired (glued) fractures, a dendritic opal showing play-of-colour, an emerald parcel with imitations consisting of coated beryl and glass, a strongly colour-zoned (green and light brown) synthetic moissanite, a dyed labradorite bead, photochromism and thermochromism displayed by CVD synthetic diamond, and multi-coloured dyed quartz.

GEM TESTING LABORATORY
LAB INFORMATION CIRCULAR
EMERALD - WITH REPAIRED FRACTURE

GGTL Newsletters

In March 2015, GGTL Laboratories released its latest newsletters (Nos. 4 and 5), available at www.ggtl-lab.org/media/newsletter/GGTL_Newsletter_No_4_March_2015_(EN).pdf and www.ggtl-lab.org/media/newsletter/GGTL_Newsletter_ALERT_No_5_March_2015_(EN).pdf. Number 4 reports on a yellow CVD synthetic diamond found in a parcel of melee originating in Hong Kong (see *The Journal,* Vol. 34, No. 4, 2014, pp. 300–302) and also describes the DFI Mid-UV Laser+, an instrument designed and built by GGTL Laboratories for the detection of near-colourless HPHT and CVD synthetic diamonds. Number 5 documents the first colourless melee-sized CVD synthetic detected in a parcel of natural diamonds during the Baselworld (Switzerland) show in March 2015.

GIT Lab Updates

In March 2015, the Gem and Jewelry Institute of Thailand (GIT) issued an 'urgent release' on a new type of glass-filled ruby that is claimed to be toxin-free and marketed under the name 'Organic Ruby' by Spa Gems company in Chanthaburi (see www.git.or.th/2014/eng/testing_center_en/lab_notes_en/glab_en/2015/03/GIT_URGENT_RELEASE.pdf). This lead-glass-filled ruby reportedly has undergone further treatment to remove significant amounts of Pb from the glass filler in the stone. The 'Organic Ruby' name has created controversy among traders who fear that it could be misleading to consumers.

Also in March 2015, GIT released a lab update on a synthetic ruby overgrowth on natural corundum. The properties of the 1.84 ct gem showed that it was similar to material that circulated in the market in the early 2000s. The report can be downloaded at www.git.or.th/2014/eng/testing_center_en/lab_notes_en/glab_en/2015/03/Synthetic_Ruby_Overgrowth.pdf.

Gold Demand Trends 2014

In February 2015, the World Gold Council released their report on 2014 gold demand trends, available at www.gold.org/download/file/3691/GDT_Q4_2014.pdf. Gold jewellery demand was down 10% to 2,152.9 tonnes, but was 5% above its five-year average. Year-on-year declines in jewellery were widespread. A few markets were notable exceptions to the downward trend: India had a particularly good year, topping the 2013 total by 8%.

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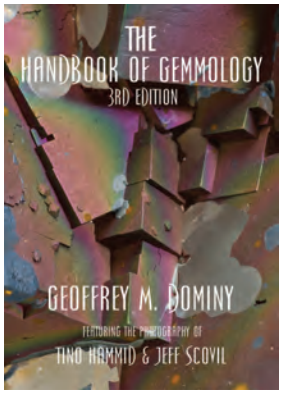

The 3rd edition of this book is now available on DVD or to download (see http://handbookofgemmology.com). Now with 1,056 pages, the book includes updated information on gem magnetism, inclusions, physical and optical properties, opal mining, and a new section titled GEMFACTS that gives comprehensive information on the 15 most common gem species.

ICGL Newsletter

The International Consortium of Gem-Testing Laboratories has released Newsletter No. 1/2015, available at http://icglabs.org. The theme of the newsletter is emerald, and it includes reports on composites of pale green beryl and green glass, hydrothermal synthetic emeralds with filled fractures, and recent developments in 'Soudé Emeralds' (quartz doublets).

Oiled Gems Lab Alert

In April 2015, Lotus Gemology (Bangkok, Thailand) issued a lab alert warning about the prevalence of gems submitted for testing that were fissure filled with oils or resins (see www.lotusgemology.com/index.php/library/articles/315-lotus-gemology-lab-alert-for-oiled-gems). Nearly all of these treated gems were of Burmese origin, consisting of ruby, sapphire, spinel and tourmaline. None of the clients who submitted the stones were aware of the oil/resin filling.

Pink and Blue CVD Synthetic Diamonds

In February 2015, M&A Gemological Instruments released an application note titled 'Large Amount of Pink and Blue CVD-grown Synthetic Diamonds on the Market' by Mikko Åström and Alberto Scarani (PDF available at www.gemmoraman.com/Articles.aspx). The report describes CVD synthetics tested during the 2015 Tucson gem shows, where they were available in relatively large quantities. The blue synthetics have created the most concern because their spectroscopic characteristics at room temperature are similar to those of irradiated blue natural (not synthetic) diamonds and also they are not electrically conductive.

MAGI - M&A GEMOLOGICAL INSTRUMENTS

Large amount of pink and blue CVD-grown synthetic diamonds on the market

World Diamond Magazine

The World Diamond Mark Foundation (WDMF), in close cooperation with the Turkish Jewelry Exporters Association (JTR), has launched a new quarterly periodical called the *World Diamond Magazine*. WDMF was established in 2012 by the World Federation of Diamond Bourses with the global objective to boost consumer demand for diamonds and diamond jewellery. JTR is one of the early adopters of the WDMF and its programs. The *Magazine* publishes WDMF-related articles and its own editorials and news, in addition to carrying a carefully selected choice of articles from the international trade press. It was launched in September 2014, and the latest issue (March 2015) features an article from Gem-A's president, Harry Levy, about diamond grading standards. The magazine is available in print format at major trade shows and conferences, and PDF files of the issues can be downloaded at www.worlddiamondmark.org/world-diamond-magazine. For a free subscription, email communications@worlddiamondmark.org.

Ya'akov Almor
Media Relations Director, WDMA

OTHER RESOURCES

Coloured Gemstone App

Geoffrey Watt of Mayer & Watt (Maysville, Kentucky, USA) recently released an educational coloured gemstone app that is designed to be used by jewellery professionals and consumers. A January–February 2015 update enables users to search by keyword; both iOS and Android devices are supported by this free app. Visit http://mayerandwatt.com/gemipedia/mayer-and-watt-app-instruction.

Erratum

The What's New entry on Historical Facet Designs (Vol. 34, No. 4, 2014, p. 279) should have reported that the website was launched in June 2013 not 2014.

What's New provides announcements of new instruments/technology, publications, online resources and more. Inclusion in What's New does not imply recommendation or endorsement by Gem-A. Entries were prepared by Mary Burland and Brendan Laurs unless otherwise noted.

Colour Grading of Synthetic Moissanite

Mary L. Johnson

Since its introduction to consumers in the 1990s (see Nassau et al., 1997), gem-quality synthetic moissanite has become a popular substitute for diamond. As used in the gem trade, it is generally near-colourless to pale yellow, green or grey, with high lustre and dispersion, and has a hardness greater than corundum; it is typically fashioned in shapes popular for diamonds. So far, all commercial synthetic moissanite diamond substitutes are doubly refractive.

The value of a diamond is determined by the 4Cs: colour, clarity, carat weight and cut. Most grading laboratories use the D-to-Z scale to colour grade near-colourless to yellow diamonds. In such a system, a diamond is compared *face-down* to face-down master stones along the D-to-Z scale. In GIA's laboratory, diamonds with more colour than the D-to-Z scale, or with hues other than yellow, brown or grey, are graded *face-up* using the GIA Fancy Color scale. This scale is applied when such hues first become perceptible (usually at about the H level in the D-to-Z system) for colours such as green, blue and pink. The colour grades are: Faint, Very Light, Light, Fancy Light, Fancy, Fancy Dark, Fancy Deep, Fancy Intense, and Fancy Vivid, with the hue name given after the grade (e.g. Fancy Light orangy yellow: see King et al., 1994).

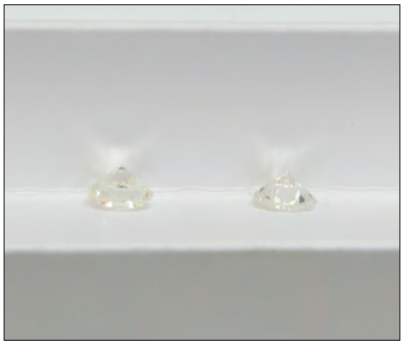

Figure 1: The conventional way to colour grade diamond simulants is as done for D-to-Z diamonds, with both the sample and master stone in the face-down position against a white or light grey background, using daylight-equivalent fluorescent light. Here, a master stone is on the left and a synthetic moissanite is on the right. Each gem is approximately 5 mm in diameter. Photo courtesy of Charles & Colvard Ltd.

During a recent visit to a facility operated by a major synthetic moissanite supplier (Charles & Colvard, Morrisville, North Carolina, USA), this author witnessed experienced gemmologists colour grading near-colourless synthetic moissanites for internal company purposes as if they were grading D-to-Z range diamonds: face-down compared to face-down master stones, on a light-coloured neutral background, with overhead daylight-equivalent fluorescent illumination (Figure 1). Other synthetic moissanite suppliers appear to use a similar technique (e.g. "color grading is done on the bottom half to avoid faceting influencing the color grading": Mira Moissanite – Less Responses, 2011).

It would seem intuitive that near-colourless diamond simulants should be colour graded in the same way as D-to-Z diamonds. However, the face-up colour-grading methodology used for fancy-colour diamonds is more applicable to synthetic moissanite for a simple reason: synthetic moissanite is pleochroic.

Factors in a Gemstone's Colour

Again, let's start with diamonds. There are three aspects that determine the face-up colour appearance of a high-clarity diamond: its body colour, the effect of the cutting style, and the environment in which the diamond is placed (with reference to the observer, lighting and other surroundings). Because diamonds in the D-to-Z range are being evaluated for their rarity and apparent colour purity, the *only* aspect being evaluated is the body colour. (Cut is evaluated separately, and the environment is standardized.) For this reason, diamond is colour graded in the face-down position so that the path of light through the stone,

showing its body colour, does not compete with distracting reflections or dispersion flares.

For fancy-colour diamonds, what matters most is the colour that is manifested face-up; therefore, coloured diamonds are evaluated in this position, and the grade is determined by the apparent face-up colour. This also means that it is sometimes possible to improve the colour grade of a fancy-colour diamond by recutting it. But what about those distracting reflections and/or dispersion flares? To minimize these, the diamond is colour graded within a mostly closed environment (i.e. the Macbeth Judge II viewing booth: see www.xrite.com/judge-ii). Also, the grader must be trained to recognize the *characteristic colour* that creates the overall colour impression of the diamond (again, see King et al., 1994).

Diamond is isotropic, meaning that its optical properties do not change with crystallographic direction. By contrast, gems that are doubly refractive, such as synthetic moissanite, may have different light absorption spectra (and therefore different colour appearances) in different directions—that is, they are pleochroic. Popular examples include tourmaline, ruby, sapphire and emerald. For strongly pleochroic gems, such as green tourmaline and iolite, the orientation of the stone relative to its crystallographic axes is important for determining face-up colour, and the gems are cut accordingly (otherwise, a green tourmaline might appear over dark, and an iolite could look pale or yellowish instead of blue). Partly for this reason, the colour of coloured stones is evaluated in the face-up position.

Synthetic Moissanite Colour-grading Methodology

Synthetic moissanite as a D-to-Z diamond simulant is pleochroic, and it is logical to assume that it is cut in an orientation that minimizes its face-up colour. Because of this, colour grading synthetic moissanite face-down is inappropriate because its face-down colour may not be indicative of its face-up appearance.

Master stones for D-to-Z colour grading (both diamonds and cubic zirconia) are designed to be used in a face-down position, thus minimizing reflections and dispersion flares. Therefore, even though synthetic moissanite should be colour graded in a *face-up position*, it should be graded against *face-down master stones* (Figure 2). A few preliminary experiments known to this author have indicated that this should not be a problem for trained graders, even for fancy shapes. It is important as well to indicate that the colour grade assigned to a synthetic moissanite is not equivalent to that of a D-to-Z (non-fancy-colour) diamond, since such diamonds are graded face-down while synthetic moissanite should be graded face-up. The author recommends terminology such as 'this synthetic moissanite *faces up* F colour.'

Figure 2: Pleochroic diamond simulants such as synthetic moissanite should actually be colour graded in the face-up position (see stone on the right) against face-down master stones (left). Each gem is approximately 5 mm in diameter. Photo courtesy of Charles & Colvard Ltd.

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Gem Notes

COLOURED STONES

Large Kunzite Gem Crystal from Brazil

The granitic pegmatites of Minas Gerais, Brazil, are well known for producing large crystals of gem-quality pink spodumene (kunzite). One such crystal documented by Sinkankas (1962), thought to be the world's largest at the time, measured 31.1 × 15.8 × 9.7 cm and weighed 7.41 kg. Sinkankas (1962, p. 287) also reported that "flawless gems exceeding 300 carats have been cut in Brazil, and the author has cut a number of much larger ones…which, unfortunately, were not entirely flawless."

Figure 1: This enormous gem-quality kunzite crystal weighs almost 30 kg. It was mined in 1998 from the Urucum pegmatite in Brazil. Photo by B. M. Laurs.

An important source of large kunzite crystals in Brazil is the Urucum mine in Minas Gerais State. In 1968, an enormous pocket at this mine reportedly yielded 3,000 kg of gem spodumene, although the largest crystals were modestly sized at just under 2 kg (Cassedanne, 1986). Three decades later, in October 1998, another large kunzite pocket was discovered at Urucum by Dilermando Rodrigues de Melo Filho of Geometa Ltda. (Governador Valadares, Minas Gerais). This cavity reportedly produced over 100 kg of high-quality crystals (Mauthner, 2011). Some of them were exceedingly large, such as the 37.1-cm-tall crystal pictured by Mauthner (2011). However, the largest kunzite crystal from this pocket was not exhibited until recently.

At the 2015 Tucson gem shows, Geometa displayed a gem-quality kunzite recovered from the 1998 pocket that weighed almost 30 kg (Figure 1). The crystal was deeply etched (as is typical of Brazilian kunzite), but had lustrous surfaces and was completely transparent. It was the first time it had been publically displayed outside of Brazil, and to this author's knowledge it is the largest gem-quality kunzite crystal in the world.

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Gem-A Visit to a Marble-hosted Ruby Mine, Mogok, Myanmar

In December 2014, a team from Gem-A visited the gem mining area of Mogok in central Myanmar (for more information, see Laurs, 2015). Guided by Federico Bärlocher (a gem dealer and collector from Switzerland who specializes in top-quality Mogok gems and crystals), the group consisted of CEO James Riley, chairman of the Board of Trustees Jason Williams, and this author. Mogok was closed to foreigners for decades until it was reopened in 2012; a special permit from the Myanmar government is needed to visit there.

Numerous hard-rock (primary) ruby mines explore the 'marble ark' in the mountainous terrain of the Mogok area (Themelis, 2008). We visited one mine in the Bapawdan area, located approximately 5 km northwest of Mogok. The present mine owner has worked the deposit since 2007 in a joint venture with the Myanmar government. The property was initially worked in 2000.

The deposit is mined nearly 24 hours/day in two shifts. Access to the mine is provided by a 100-m-long adit (fitted with track for ore cars; Figure 2) and several shafts. The workings consist of a series of declines that follow a natural karst system in the marble that dips steeply to the south. Ruby mineralization locally occurs along specific horizons in the marble that partially follow the general trend of the natural cave system. A complex network of ladders (e.g. Figure 3) and platforms is used to access both primary and secondary deposits within the underground workings. The miners use pneumatic drills and explosives (e.g. Figure 4) to break up the marble host rock in search of ruby, and they collect

Figure 2: Ore cars are lined up before the entrance to this ruby mine in the Bapawdan area of Mogok, Myanmar. Photo by B. M. Laurs.

Figure 3: A miner descends a steep ladder to the working face where marble is drilled and blasted in search of rubies. The cables on the right are used to hoist the marble to a haulage tunnel, where it is then loaded into ore cars. Photo by B. M. Laurs.

Figure 4: A miner dressed in a longyi *(traditional Burmese skirt) uses a pneumatic drill to prepare the marble for blasting. His assistant in the left foreground holds several sticks of explosives. Photo by B. M. Laurs.*

gravels from the floor of the cave system that have weathered from the marble. According to U San Myo, ruby mineralization is encountered only occasionally in the marble, and it is very rare to see gems in the mine exposures.

The marble pieces broken up by the explosives are immediately placed into heavy-duty bags and secured with a theft-proof tie until they are taken to the surface and processed for any possible rubies. At the processing facility, the marble is passed into a small jaw crusher that reduces it to <2 cm pieces. The crushed marble is washed into a jig using water from a nearby stream. All material that washes over the riffles is hand-sorted for pieces of ruby-bearing marble. At the end of the day, the gravel and rocks trapped in the riffles are placed into sieves (approximately 2 mm mesh size) for additional washing, followed by hand picking. The rubies recovered during this process are placed into a locked steel receptacle. The secondary gravels that are brought up from the mine are washed in the stream using the same sieves. In the brief time that we witnessed the processing of the ore, only one small ruby specimen was recovered (Figure 5), as well as one minute grain each of ruby and red-orange spinel that were sieved from the karst gravels. The secondary deposits reportedly also produce moonstone, apatite and other minerals.

Figure 5: The mine owner displays a small piece of ruby-bearing marble that was just recovered from the processing plant, while Jason Williams looks on. Photo by B. M. Laurs.

We found this mine to be a very well-organized and professionally planned operation. Maps of the geology and mine workings that were displayed in the head office suggested that a considerable portion of the ruby-mineralized layers still remain to be mined in the future.

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Gem-A Visit to a Secondary Gem Deposit in Mogok, Myanmar

Figure 6. This secondary deposit in the Bernardmyo area of Mogok is a source of gem corundum, spinel, topaz, and other minerals. Photo by B. M. Laurs.

In December 2014, a team from Gem-A was led by Federico Bärlocher to visit the gem mining area of Mogok in central Myanmar (see also the preceding Gem Note on the marble-hosted ruby mine). The Mogok Stone Tract is famous for producing a diverse array of gem materials—sometimes of the highest quality—from both primary and secondary deposits (e.g. Themelis, 2008). We visited a secondary gem deposit (Figure 6) located 7.6 km northwest of Mogok, near the village of Ingyauk (or Injauk) in the Bernardmyo area. At the time of the visit, the mine owner had just completed the first year of his three-year lease. He works the mine for six months of the year, during the dry season.

Water cannons are used to wash material from the pit into a sump (Figure 7), and the slurry is then pumped out of the pit to a washing plant (Figure 8). Larger stones (over 1 inch or 2.5 cm) are screened off, and the remainder of the material flows into a jig. The heavier stones (including gems) are caught in the riffles above the jig, and at the end of each day the miners remove the concentrate by hand. Material from the top half of the riffles is discarded, and the heavier gravels in the bottom portion are put into sacks for hand picking off-site. Any gems seen during this process are placed into a metal bowl.

During our visit a rather small amount of gems were extracted from the jig, but they did include one bright pink-red spinel pebble (Figure 9). The remainder consisted of low-quality ruby, sapphire and spinel with some small pieces of pale brown topaz, smoky quartz and black tourmaline. The

Figure 7. A water cannon is used to wash gem-bearing material into a small collecting area, or sump, from where it is pumped out of the pit to a processing plant. Photo by B. M. Laurs.

Figure 8. At the washing plant, rocks larger than 2.5 cm are screened off, and the remaining material is washed into a jig. Photo by B. M. Laurs.

sapphires were mostly colourless to yellow or blue, while the spinel was pink-to-red, purple-grey, yellow, blue or black. The corundum and spinel produced from this mine are only rarely of gem quality, and they typically occur as waterworn broken pieces or less commonly as somewhat rounded tabular pseudohexagonal crystals. By contrast, the topaz is mostly transparent and shows extremely variable degrees of rounding from alluvial transport. Some of the smoky quartz crystals recovered from the operation have sharp crystal faces and attain relatively large sizes (20+ cm long), suggesting that their original source rock was not far away.

The mine owner indicated that several weeks or months may pass with only low-quality production, although one good stone can cover expenses for the entire year. During the 2014 mining season, the best gem he recovered was a 'light' ruby pebble weighing 16 g. He mentioned that after a few months of the mining season have passed, it is common to see local families (especially children) picking tiny grains of gem material from the tailings of the mine. These are cut into melee-sized stones or (mostly) used in gem 'paintings' that are commonly seen in Mogok and in tourist centres throughout Myanmar.

Figure 9. A small assortment of gem material results from cleaning out a portion of the riffles at the end of each day. The inset shows a brightly coloured spinel pebble that is ~1.5 cm long. Photos by B. M. Laurs.

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Pink Play-of-Colour Opal from Idaho

It is well known that opal may be treated by various methods to change its body colour. This is particularly true for porous hydrophane opal, such as the material from Wollo, Ethiopia. Dyeing of this material has produced a variety of hues, especially purple (Renfro and McClure, 2011). Dyed pink play-of-colour opal has also been documented in recent years (e.g. Leelawatanasuk and Susawee, 2013). It was therefore refreshing to see play-of-colour opal showing natural pink body colour at the 2015 Tucson gem shows. Mined in Spencer, eastern Idaho, USA, small amounts of this material

Figure 10: This 14 carat gold pendant features a 2.41 ct pink play-of-colour opal from Spencer, Idaho. It is set together with a diamond and a pink Tanzanian spinel. Photo by Ed Barker.

have been produced for years, but it is not well known in the international opal trade.

A pendant containing a 2.41 ct pink opal from Spencer was shown to this author by Ed Barker (Artistry in Gold, Yountville, California, USA). He purchased the rough material in 1984, and then cut and mounted the cabochon himself. The cabochon showed a noticeable orangy pink body colour along with flashes of green, blue and violet play-of-colour (Figure 10). Barker indicated that such material continues to be produced by Spencer Opal Mines LLC. A visit to their booth in Tucson revealed both rough and cut pink opal showing weak-to-strong play-of-colour. Most of the material was opaque, but some was translucent. According to co-owner Claudia Couture, since early 2012 Spencer Opal Mines has focused on more actively recovering the pink opal, and they have polished several thousand pieces as doublets or solid cabochons ranging from 2–3 ct up to 20+ ct. Couture indicated that the pink opal is only known from certain areas of the mine. Not surprisingly, opal showing the pink body colour is much less common than white opal at this deposit.

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Dumortierite Inclusions in Quartz from Brazil

At the 2015 Tucson gem shows, Luciana Barbosa (Gemological Center, Minas Gerais, Brazil) had an impressive display of various gems with inclusions, including a new find of quartz with dumortierite needles from Brazil. She indicated that the material is from western Bahia State, near the Vaca Morta quarry. She first encountered this quartz in late 2013, and the rough mostly contained very fine hair-like inclusions or blue clouds. Approximately 100 kg of quartz was produced, but most did not have the inclusions. By mid-2014, high demand combined with limited supply resulted in skyrocketing prices for this material. In late 2014 to early 2015, additional production came on the market as slightly larger pieces with inclusions consisting of thicker bluish grey needles. A small number of pieces containing deep blue inclusions were also found at that time. The blue and bluish grey inclusions were subsequently identified by Raman analysis as dumortierite by John Koivula and Nathan Renfro at the Gemological Institute of America in Carlsbad, California. To their knowledge, this is the first time that well-formed, eye-visible crystals of dumortierite have been found in rock crystal quartz (N. Renfro, pers. comm., 2015).

Barbosa reported obtaining a total of ~20 kg of better-quality rough, but only about 20–30% contained desirable inclusions. The dumortierite is usually concentrated on one side of the quartz

Figure 11: A discovery of quartz with dumortierite inclusions recently occurred in Brazil's Bahia State. Shown together with an included quartz crystal are an 11.40 ct cabochon containing bluish grey sprays of dumortierite and a 34.50 ct cabochon with a 'carpet' of deep blue dumortierite inclusions. Courtesy of James Zigras; photo by Jeff Scovil

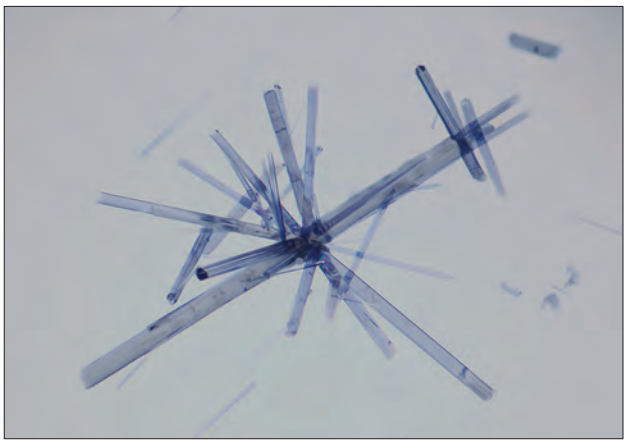

Figure 12: These dumortierite inclusions in quartz form a conspicuous star-shaped cluster. Photomicrograph by Nathan Renfro, © GIA; image width 7.8 mm.

crystal. Therefore, the cabochons are commonly cut so that the adjacent quartz face (on the bottom of the cabochon) is unpolished to preserve as many of the inclusions as possible. The inclusions typically form 'carpets' or radiating clusters in the quartz (Figures 11 and 12); phantom-like clouds of dumortierite are also encountered. Barbosa has cut approximately 200 cabochons of this quartz so far, but most of her stock consists of polished crystals containing the inclusions. She indicated that much of the rough material has been purchased by Chinese buyers. Small quantities of rough continue to be produced from several diggings in western Bahia State.

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Quartz Sphere with Large Well-formed Inclusion

'Crystal balls' or spheres polished from rock crystal quartz are typically cut from material that is very pure in appearance (i.e. free of distracting inclusions). However, it has also become common for quartz spheres to showcase visually pleasing inclusion features. A quick internet search will reveal numerous examples containing a variety of inclusions such as rutile, tourmaline and reflective partially healed fractures, among many others.

At the 2015 Tucson gem shows, Steve Ulatowski (New Era Gems, Grass Valley, California) had an 8.5-cm-diameter quartz sphere containing a remarkably large and well-formed inclusion (Figure 13). The sphere was brought to Tucson by Wiliam M. dos Reis (WR Cut Stone Comércio Ldta., Rio de Janeiro, Brazil), who stated that the rough material was probably mined from Brumado, Bahia, Brazil. The magnesite deposits of Brumado are famous for producing a variety of collectible minerals, including transparent quartz crystals and well-formed rhombohedrons of magnesite and dolomite (e.g. Barbosa et al., 2000). Consideration of the reported locality, rhombohedral morphology and yellow colour of the inclusion suggest that it is dolomite, calcite, or a mineral of the magnesite-siderite series.

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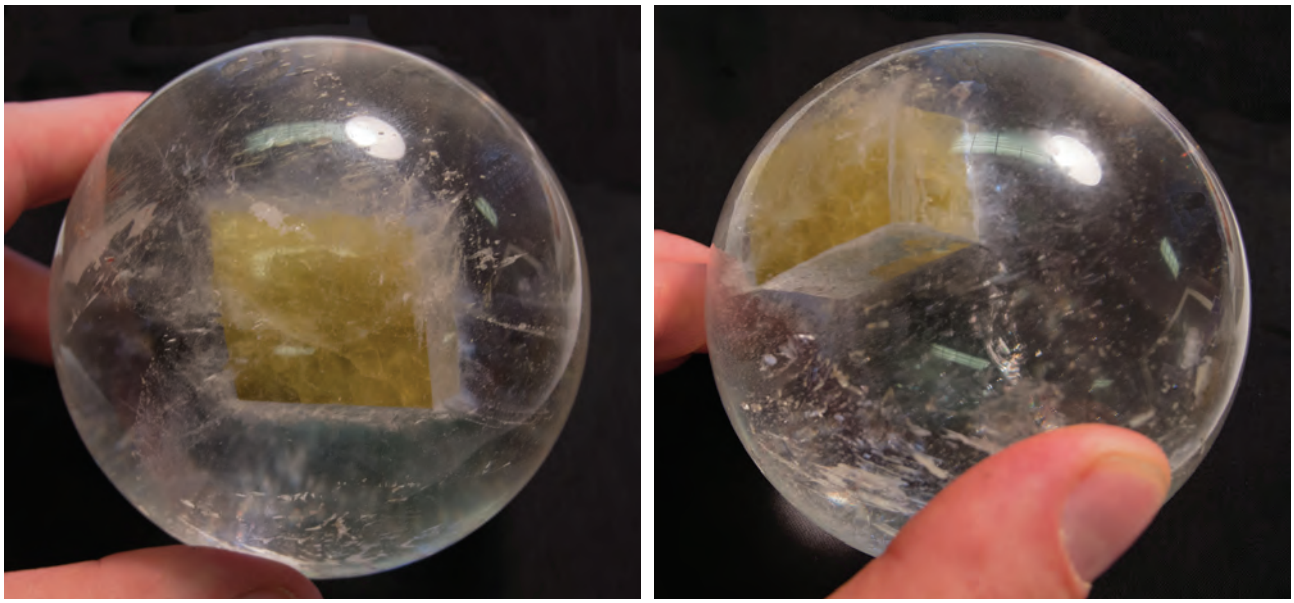

Figure 13: These two views of an 8.5-cm-diameter quartz sphere, reportedly from Brumado, Brazil, show a large well-formed inclusion that has the appearance of a carbonate mineral. Courtesy of James Zigras; photos by B. M. Laurs.

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'Zawadi' Sapphires

During the 2015 Tucson gem shows, Jeffery Bergman (Primagem, Bangkok, Thailand) had some attractive sapphires from a relatively new find in East Africa (most likely eastern Kenya). They were notable for their 'golden' sheen, and in some cases for their intricate network of dark linear patterns (see Figure 14 and the cover of this issue). He was selling them as 'Zawadi' sapphires (after the Swahili word meaning 'gift from the earth'). He indicated that most of the production occurred in early 2013, and his Bangkok-based supplier of the material has reportedly obtained over 20 tonnes of rough.

According to Bergman, about 20,000 carats have been cut so far. Since most of the material is opaque, the gems are typically cut with wide tables (commonly covered by checkerboard facets) and are oriented to best display the sheen. Faceted stones may weigh up to 100+ ct, although most are in the range of 0.50–10 ct with an emphasis on calibrated sizes for volume manufacturers. Numerous cabochons have also been cut in a variety of shapes. The material is reportedly not treated in any way.

Figure 14: The Zawadi sapphires shown here range from 5 to 20 ct. Most exhibit wide tables with checkerboard cuts to emphasize the 'golden' sheen. Photo by Jeffery Bergman.

The sheen displayed by Zawadi sapphire is somewhat reminiscent of black star sapphire from Thailand. However, the Zawadi material only occasionally shows asterism, and it derives its attractive appearance from the sheen combined with the dark patterns caused by fractures and polysynthetic twin planes in the corundum.

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Tourmaline from the Havey Quarry, Maine, USA

During the past few years, activities at the Havey quarry (Poland, Androscoggin County, Maine, USA) by mine owner Jeffrey W. Morrison have yielded significant quantities of high-quality tourmaline crystals and gem rough. Examples of rough and cut stones—mostly bluish green—were seen most recently by this author at the 2015 Tucson gem shows, where the material was offered by Larry Woods (Jewels from the Woods, Blanco, Texas, USA) and displayed by the Smithsonian Institution, as well as by Morrison himself.

The Havey quarry explores a portion of the Berry-Havey pegmatite, which belongs to the Oxford pegmatite field in southern Maine. According to Morrison, the pegmatite first produced gem tourmaline in 1910–1912. It lay mostly idle until 1976, when Terry Szenics produced small amounts of green and 'cinnamon'-coloured tourmaline. It then lay idle again until 2007, when Morrison acquired the property. After completing the necessary preparations for organized mining of the deposit, Morrison found his first tourmaline pocket in late 2009, although it contained mostly smoky quartz. His first significant tourmaline discovery occurred in 2011, and in 2012 he found additional small cavities containing gem tourmaline.

However, 2013 was much more productive, with the discovery of a series of pockets. Detailed accounts of these finds are available at https://crossmainetourmaline.wordpress.com, and several videos of mining and sorting the tourmaline can be viewed at www.crossjewelers.com/video. These finds were important for producing attractive bluish green crystals that contained excellent gem rough for faceting. During the most recent mining season, in 2014, Morrison found several small-to-medium pockets, as well as one significant pocket (Figure 15) with green tourmaline crystals, some showing a 'navy' blue termination.

Figure 15: One of the most recent tourmaline finds (October 2014) at the Havey quarry was the 'Fireworks' pocket. A flashlight illuminates the inside of the excavated cavity. The buckets contain some of the pocket contents. Photo by Jeffrey Morrison.

Figure 16: Tourmaline pockets at the Havey quarry are commonly filled with soft white clay. This 2013 discovery shows a tourmaline crystal that had been broken by natural forces into three pieces. Although the top two sections of this crystal were of fine gem quality (see Figure 17), the remainder of the rough material from this pocket was suitable for cutting only small stones. Photo by Jeffrey Morrison.

Morrison mines the Havey quarry in an open pit that measures approximately 35 × 35 m and 10 m deep. He typically drills holes that are 2½ inches (6.5 cm) in diameter and 12–14 feet (3.7–4.3 m) long that are loaded with explosives. (Shorter and narrower holes are drilled in potentially pocket-bearing zones.) The blasted material is removed from the pit with an excavator and dump truck. The gem pockets are carefully dug by hand. The tourmaline is commonly enclosed in soft white clay (Figure 16) that is washed away with a hose. Most of the tourmaline pockets are football sized or smaller, with varying quantities of gem rough (from a few grams to hundreds of grams). The largest tourmaline pocket was 1.5 × 1.5 m and consisted of two connected chambers. In addition to tourmaline, the pockets may contain smoky

quartz, lepidolite, feldspar, apatite, etched beryl (morganite and goshenite) and several accessory minerals.

Within each pocket the colour of the tourmaline is very consistent. Morrison reported that of all of the Havey tourmaline he has mined, approximately 60% is bluish green (e.g. Figure 17), 10–20% is 'watermelon' (pink/green) and the remainder is pure green. He has also rarely encountered other colours, such as pink, 'fuchsia', grey-blue, etc. Most of the tourmaline cut to date has been faceted by Sean Sweeny (Bar Harbor, Maine), and the majority of the gemstones were then sold to Cross Jewelers (Portland, Maine). Cross has produced an extensive line of jewellery featuring the 'minty green teal' colour of tourmaline that they call 'SparHawk'. Morrison retains the largest gem rough for custom cutting by accomplished faceters such as Sean Sweeny, Larry Woods and Dalan Hargrave (GemStarz Jewelry, Spring Branch, Texas), and stones weighing up to 38 ct have been faceted.

Tourmaline from the Berry-Havey pegmatite was recently studied in detail by Roda-Robles et al. (2015). Samples from the gem pockets mined by Morrison proved to be mainly elbaite with some zones corresponding to rossmanite and darrellhenryite. The latter mineral is a relatively new species of Li-bearing tourmaline that belongs to the oxy-tourmaline series (Novák et al., 2013). Although Roda-Robles et al. (2015) have documented darrellhenryite for the first time in gem quality from the Havey quarry, it is possible that other occurrences exist worldwide but have been misidentified as elbaite.

The Havey quarry is on private property and is closed to the public. However, it will be visited by participants of the 2015 Maine Pegmatite Workshop, which will take place 29 May–6 June in Poland, Maine (http://pegworkshop.com). For more information about the Havey quarry, see Morrison's blog at http://haveymine.blogspot.com, which also provides a list of significant gem pockets.

Figure 17: The Havey tourmaline on the right is the upper section of the crystal shown in Figure 16, and the 23.53 ct stone on the left (now in the Maine Mineral and Gem Museum) was cut from the centre section of this crystal by Sean Sweeney. The ~12.6 g crystal on the right was subsequently cut by Larry Woods into a 30.62 ct stone that is now in the collection of the Smithsonian Institution in Washington D.C., USA. Photo by Jeff Scovil.

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Recent Production of Greenland Tugtupite

In 2014, mining activities by native Greenlandic prospectors yielded additional production of high-quality tugtupite, some of which was shown at the 2015 Tucson gem shows (e.g. Figure 18). The material was produced by two companies, Ice Cold Gems Co. and Red Ice Gem Co., which were also the first to ethically market fair-trade ruby mined and polished by local Greenlanders in that country.

Figure 18: This photo shows some of the recently produced Greenland tugtupite seen at the 2015 Tucson shows. The five gem-quality rough pieces weigh 0.38–0.83 g, and the 1.22 ct marquise-cut gemstone was faceted by Jens Mikkel Fly (Nuuk, Greenland). The pendants were made by Mikael Møller (Nuuk) and feature 26 × 16 mm tugtupite cabochons that are set in silver with caribou antler, in the traditional design of the ulu *(arctic knife). The rock specimen contains a gem-quality tugtupite veinlet 4 cm in width. Photo by Jeff Scovil.*

Tugtupite ($Na_4AlBeSi_4O_{12}Cl$) is an unusual feldspathoid mineral known in gem quality only from the Ilímaussaq intrusive complex in southwest Greenland (Jensen and Petersen, 1982). The initial discoveries occurred between 1957 and 1965, at various sites within an area centred on Tugtup agtâkorfia, also known as Kvanefjeld, in the Narsaq region. The Ilímaussaq igneous complex is known for its extreme enrichment in rare elements, which resulted in the formation of more than 225 different minerals, some indigenous only to this locality (Petersen, 2001). The name *tugtupite* is derived from the Greenlandic Inuit word for reindeer or caribou (*tuktu*). The red and white colour of the rock in the field reminded the traditional hunters of tracking reindeer blood across the snow, considered an auspicious sign.

Tugtupite in Greenland occurs as vitreous, transparent, translucent and opaque masses that most commonly range from white to pink to 'crimson' red. It has a Mohs hardness of 6½, but highly included masses can give artificially low readings of 4 due to contamination by other minerals. Tugtupite is typically found associated with albite, analcime, beryllite, aegirine, neptunite and pyrochlore (Sørensen, 2006). Most tugtupite is microcrystalline and massive; very few well-developed crystals have been found.

Greenland tugtupite displays tenebrescence, also known as reversible photochromism, which is the ability of the mineral to change or intensify in colour when exposed to radiation of a particular wavelength. In darkness or under sustained low light, such as the long arctic night, tugtupite loses its colour and fades to white. But with the bright sunlight of the arctic summer, tugtupite becomes red. Greenland tugtupite is also strongly fluorescent, especially the gem-quality material: it fluoresces bright 'crimson' red to short-wave UV radiation, and a weak 'salmon'-pink to long-wave UV. Even brief illumination of just several minutes with short-wave UV intensifies the tenebrescent red colour in tugtupite.

Gem tugtupite occurs within hydrothermal veins as disseminations, clots and veinlets, in seams measuring up to 4 cm thick and 1–2 m in length and depth (Secher and Johnsen, 2008). The principal surface exposure of the ore zone measures approximately 10 × 50 m, and has been excavated to a depth of up to 5 m. Some half-dozen smaller prospects are known from other locations elsewhere in the district. The tugtupite is gathered by village hunting parties employing simple hand mining methods, and also by small teams of trained prospectors (who are responsible for the recent production) using specialized tools and portable equipment.

The Tucson 2015 delivery of tugtupite was noteworthy for its relatively high transparency, which is unusual for the species. A select amount was suitable for faceting, and stones up to 1.22 ct were on display. Some translucent and semi-translucent material has also been produced, as well as the massive and microcrystalline opaque material traditionally sold as tugtupite. Several kilograms of rough material were included in the Tucson delivery, with about two dozen faceted

stones polished so far. Clean faceted gems are great rarities for tugtupite, yet the important news from Tucson 2015 is that Greenlandic cutters are now producing fine gemstones and cabochons that weigh some 1–4 ct.

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Large Orange Zircon from Myanmar

Recently, a 21.87 ct transparent brownish-reddish orange cushion mixed-cut zircon (Figure 19) was submitted to American Gemological Laboratories for an identification report by Hussain Rezayee (Rare Gems and Minerals, Los Angeles, California, USA). The RI was over the limit of the refractometer (>1.81). The gem readily displayed a uniaxial optic figure in the polariscope, and it fluoresced weak orange to both long- and short-wave UV radiation. Microscopic examination revealed only a few fine needles and lines of reflective pinpoints. As is typical of zircon (e.g. O'Donoghue, 2006), the stone displayed numerous lines in the spectroscope: 432, 484, 521, 537, 562, 589, 660, 662 and 691 nm. Mid-infrared spectroscopy also was consistent with zircon.

Rezayee obtained this stone in July 2014 while visiting Myanmar, and according to his supplier it had not been heated. It is well known in the gemmological community that brown zircon may be heat treated to colourless or blue. This occurs in a reducing environment at approximately 1,000–1,400°C. When, on occasion, off-colours are created via this process, the stones are commonly reheated to approximately 900°C in an oxidizing environment, resulting in colourless, yellow, orange or red colours (see www.gemologyproject.com/wiki/index.php?title=Zircon and Nassau, 1994). To date, there is no definitive way to consistently distinguish between heated and unheated zircon. As a result, all colours of zircon other than brown and green may potentially be the result of a heating process.

Figure 19: This 21.87 ct zircon from Myanmar shows both high transparency and a strong brownish-reddish orange colour. Photo by Bilal Mahmood.

Measuring 16.37 × 12.32 × 10.22 mm, this zircon is very rare for its size, colour and clarity. The dispersion of zircon is close to that of diamond which, combined with the intense colour of the stone, added to its beauty.

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SYNTHETICS AND SIMULANTS

A Convincing Glass Imitation of Emerald

Figure 20: The green gem (12 × 10 mm) in this platinum and diamond ring strongly resembles emerald, but proved to consist of lead glass. Photo by B. Williams.

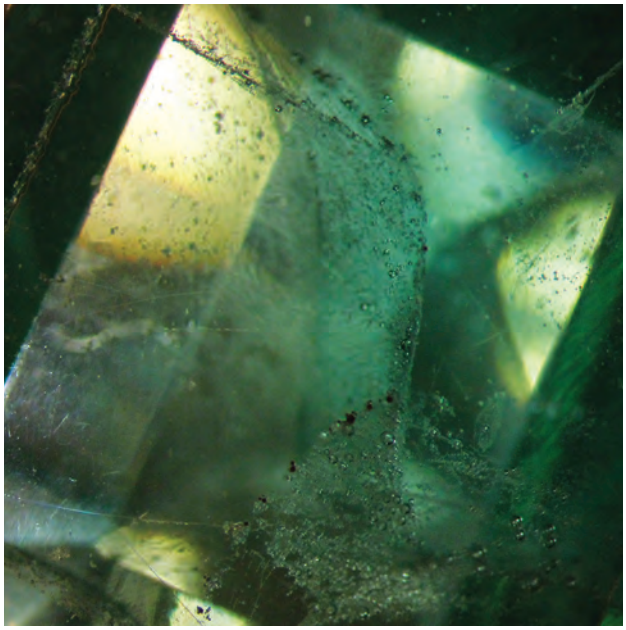

Figure 21: Microscopic examination of the green glass revealed straight and curved planar arrangements of gas bubbles. Photomicrograph by B. Williams; magnified 20×.

Recently submitted to Stone Group Laboratories for identification by Sushil Goyal (Liberty Gems, New York, New York) was a platinum and diamond ballerina-style ring featuring a large green gem (Figure 20). Its general appearance was typical of lighter-coloured Colombian emeralds, and it contained a few eye-visible inclusions. Closer inspection with a loupe revealed what looked like oiled fissures containing numerous minute, rounded gas bubbles (Figure 21).

In some cases, it is more interesting to run laboratory tests in the reverse order of what is typically done, especially when anticipating a certain result based on visual observations. In this case, due to 'something missing' from the gem's colour and its lack of reaction with a Chelsea colour filter, the next test performed was energy-dispersive X-ray fluorescence (EDXRF) spectroscopy to determine the gem's chemical composition and possible chromophores. This showed the unexpected presence of Pb, and since there was no significant Cr or V, further tests were in order. Raman analysis readily identified the gem as glass, but the nature of the strange veins containing tiny trapped gas bubbles remained a mystery. Fourier-transform infrared (FTIR) spectroscopy was performed next, but no polymers were detected. The RI was recorded as 1.52, and we concluded that this gem consisted of a solid piece of green lead glass.

Viewed with the microscope, an experienced eye might sense that there was something unusual about the 'emerald', but the veins of fine bubbles masked many of the properties that would normally indicate glass. The veins did not conform to a typical emerald fissure pattern, yet were not obviously 'wrong' in their appearance. Surface scratches and abrasions were more typical of glass than emerald. When observed with the Chelsea colour filter, the gem remained green despite having the general appearance of a Colombian emerald. Also, the broad table and low crown are not often seen with emerald, nor are they typical of imitation stones. The diamond mounting certainly added credibility to the centre stone.

The process of creating the inclusion features in this glass remains a mystery. Theoretically, cracks could have been induced and then filled with a different high-lead glass. Another possibility is that when the green lead glass was still molten, a wire could have been inserted, twisted and removed, leaving the material laced with gas bubbles.

This was the most recent item seen in a series of unusual and convincing glass imitations that have come through our laboratory in the past few years. These clever imitations are nothing like the more obvious examples commonly seen in gemmological coursework. Glass imitations of tiger's-eye, jadeite, peridot, tourmaline, aquamarine and now emerald have been encountered by these authors, and the tourmaline and aquamarine look-alikes initially fooled even experienced eyes looking for tell-tale signs. Outside of lab testing, the polariscope or refractometer will yield the best initial clues that a material is a glass imitation.

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New Large Black Synthetic Moissanite as a Black Diamond Imitation

Two black, opaque, flat round gems were received at GGTL-Laboratories (Geneva, Switzerland) in October 2014 for certification as black diamonds (Figure 22). The samples weighed approximately 29 and 34 ct, and measured 28.0–28.3 × 3.7 mm and 29.2–29.5 × 4.0 mm, respectively.

Microscopic observation piqued our attention because the gems did not show features consistent with natural black diamond (i.e. an irregular distribution of brown-to-black inclusions of various shapes, dense clouds, etc.), heat-treated black diamond (minute graphite inclusions), or 'classic' black synthetic moissanite (very dark green-to-blue or brown body colour, etc.). Strong fibre-optic illumination revealed a dark grey body colour with an olive tinge (Figure 23), and reflected light showed a very fine-grained homogeneous texture (Figure 24-left). The microtexture was very similar to that of a black ceramic material (boron carbide) imitating black diamond that was described by Choudhary (2013; see Figure 24-right), but was different from the mosaic pattern in black synthetic moissanite described by Moe et al. (2013). Minute interstitial spaces in our samples measured 5–150 µm (mostly ~50 µm).

The two gems were inert to long- and short-wave UV radiation, but showed faint orange fluorescence when exposed to the intense 300–410 nm excitation of the GGTL DFI luminescence microscopy system. Their RI was over the limit

Figure 22: These large black diamond imitations (left, 29 ct and right, 34 ct) consist of very fine-grained synthetic moissanite. Photo by C. Caplan.

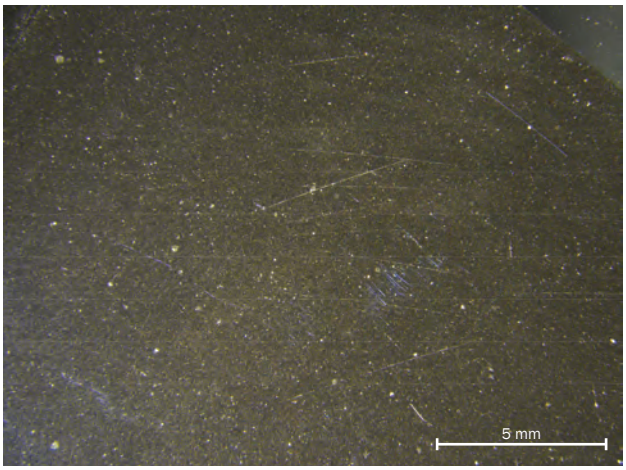

Figure 23: Viewed with the microscope and 250 W fibre-optic illumination, the synthetic moissanite samples showed a dark grey body colour with an olive tinge. Photomicrograph by F. Notari.

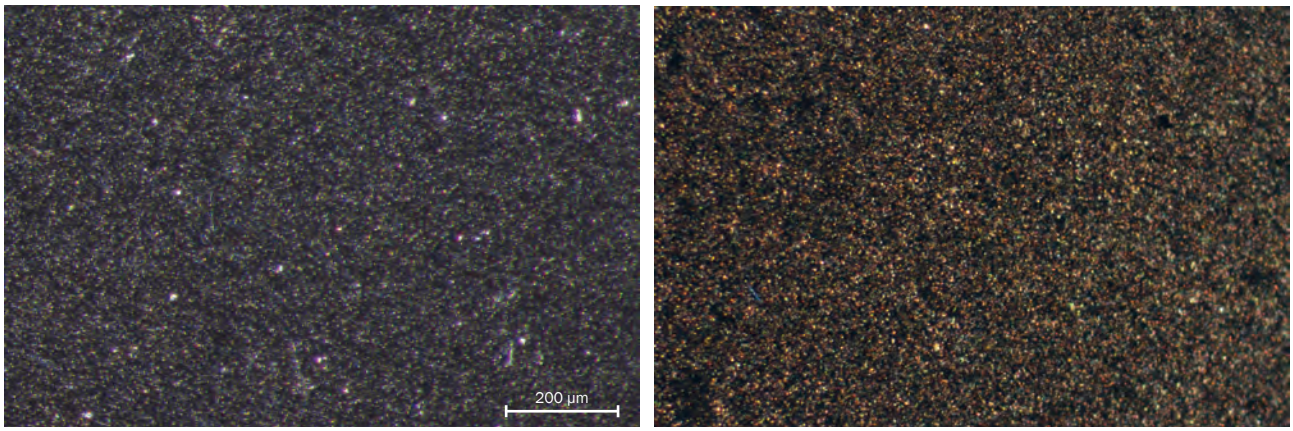

Figure 24: On the left, the 34 ct synthetic moissanite shows a very fine-grained homogeneous texture with minute reflecting particles. A similar texture is shown in the image on the right of a boron carbide black diamond imitation. Photomicrograph on the left by F. Notari, and on the right by Gagan Choudhary (magnified 48×; reprinted with permission from Choudhary, 2013).

of our refractometer (>1.81), and they tested positive for diamond with a thermal conductivity tester. The hydrostatic SG of the two samples was 3.16, and a hardness test showed >9 on the Mohs scale. (Hardness was tested with the client's permission on the girdle at 160× magnification.)

Specular reflectance FTIR spectra were recorded for both gems using a Thermo Nicolet Nexus spectrometer with a DTGS (deuterated triglycine sulphate) detector, by accumulating 20 scans at room temperature at a resolution of 4 cm^{-1}. The spectra showed features corresponding to a reference sample of green synthetic moissanite (Figure 25).

EDXRF chemical analysis was also performed on both gems, using a Thermo Noran QuanX-EC instrument with all available filters (count time of 300 s and beam diameter of 3.5 mm). The analyses showed major amounts of Si and traces of Fe, Cr and Ti. This is consistent with synthetic moissanite, which has a chemical formula of SiC (carbon cannot be detected by this instrument). The Fe, Cr and Ti are likely contained in the impurities that give the black appearance to this material.

Figure 25: The specular reflectance FTIR spectra of the two gems (red lines) provide a close match to the reference sample of green synthetic moissanite (blue line).

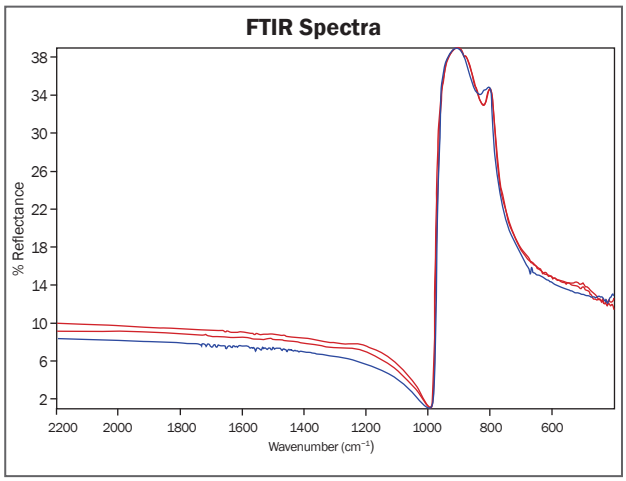

Our analyses indicate that these two gems are opaque black synthetic moissanite with a very fine-grained structure. The SG of 3.16 is helpful for its identification (compared to diamond's 3.54 and boron carbide's 2.40). Monocrystalline synthetic moissanite has a typical SG of 3.22, and the lower value obtained for these samples is probably due to their being some type of sintered product rather than a monocrystalline material. Such sintered dark grey synthetic moissanite is available for industrial applications (e.g. Saddow and Agarwal, 2004). Conclusive identification of this material as synthetic moissanite was shown by specular reflectance FTIR spectroscopy and EDXRF analysis.

This type of black synthetic moissanite is now clearly available in the market as large cut gems. In October 2014 we bought a sample weighing 210.65 ct (diameter ~41 mm) for comparison, and our observations and analyses of this gem were consistent with those described here.

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Peridot-Polymer Composite

Figure 26: This 3.25 ct bead turned out to be a composite, made up of pieces of peridot embedded in a polymer matrix. Photo by G. Choudhary.

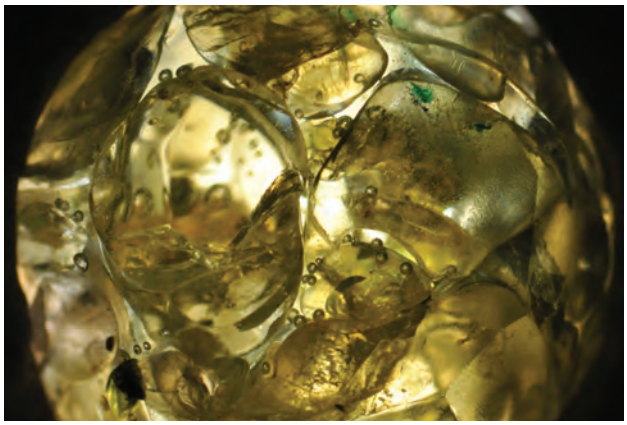

Figure 27: The bead in Figure 26 consisted of several pieces of yellowish green peridot embedded in a pale yellow polymer matrix. Note the presence of gas bubbles confined to the interstitial polymer areas. Photomicrograph by G. Choudhary; magnified 24×.

Figure 28: When viewed through the individual pieces of peridot, doubling of gas bubbles within the polymer matrix was visible. Photomicrograph by G. Choudhary; magnified 48×.

Composites assembled from opaque-to-translucent gem materials such as turquoise, chalcedony, opal and chrysocolla have become popular during the past few years, as evidenced by the number of samples received for identification at the Gem Testing Laboratory in Jaipur, India. We recently examined a translucent yellowish green, round faceted bead (Figure 26) that turned out to be a composite gem featuring peridot.

The bead weighed 3.25 ct and measured 9.09 × 8.91 × 5.36 mm. At first glance, it appeared to be peridot due to its typical colour. However, microscopic observation revealed numerous gas bubbles, which made us think otherwise. Further examination showed that the bead was actually composed of several pieces of yellowish green material that were embedded in a pale yellow matrix containing gas bubbles (Figure 27). This was further confirmed by the difference in surface lustre of the two materials when viewed with reflected light. The individual pieces were transparent with curved and smooth surfaces; although a few of them contained fractures, most were free of inclusions. Looking closely through the individual pieces, we observed doubling of the gas bubbles within the polymer matrix (Figure 28).

Although it was obvious that the bead was a composite, its major component had yet to be

identified. A spot RI of ~1.67 was obtained with a distinct birefringence blink, as expected for the doubling mentioned above. When exposed to long- and short-wave UV radiation, the bead remained largely inert, except for a weak whitish glow overall. The desk-model spectroscope revealed three bands in the blue-green region at ~450, 470 and 490 nm, and these also were recorded with ultraviolet-visible–near infrared spectroscopy. These properties suggested that the individual yellowish green pieces were peridot. Raman spectroscopy confirmed they were peridot and that the matrix was a polymer.

The identification of this bead as a composite was straightforward, and determining the identity of its components was relatively simple using basic gemmological tools. The use of peridot for such a composite is surprising.

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Dyed Quartzite as an Imitation of Bicoloured Tourmaline

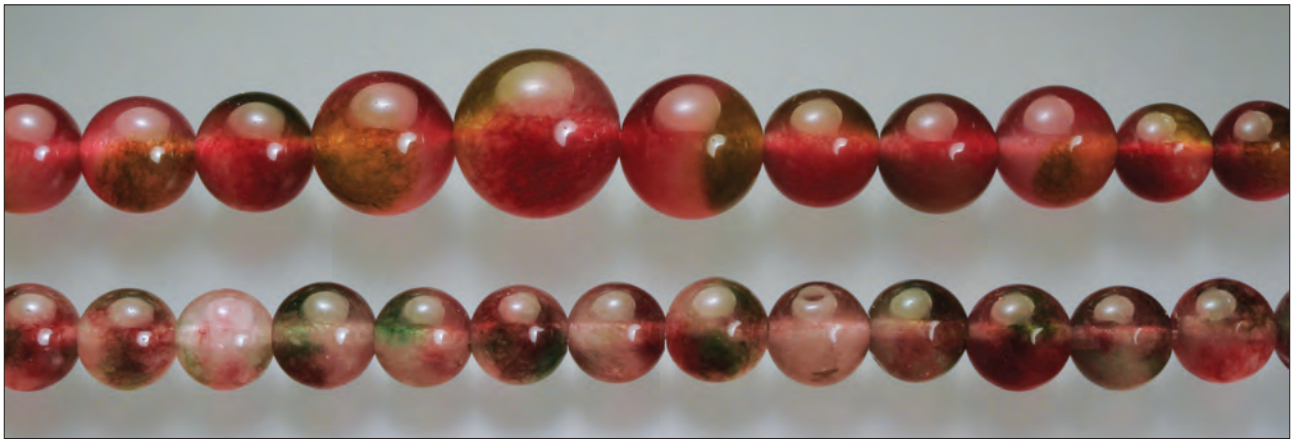

Figure 29: These bead necklaces initially appear to consist of bicoloured tourmaline, but they proved to be dyed quartzite. The largest bead is 14 mm in diameter. Photo by J. Hyršl.

Bicoloured 'watermelon' tourmaline is a popular gem material, but it is becoming rarer and more expensive. Two necklaces recently studied by the author consisted of a clever imitation of bicoloured tourmaline (Figures 29 and 30). They very probably originated from China (as the owner bought them from a Chinese dealer), and they measured 43 and 46 cm long with spherical beads of 6–14 mm in diameter. All of the beads in one necklace were bicoloured, with red prevailing over green. The other necklace contained tricoloured beads, with red, green and colourless portions. At first glance both necklaces looked like typical tourmaline, but a closer look showed that the coloration was concentrated along fractures. The RI measured by the distant vision method was 1.54, indicating that the granular quartz variety, quartzite, was used as the starting material for this imitation. Viewed under both long- and short-wave UV radiation, the red part on both necklaces fluoresced red-orange and yellow, while the other colour(s) appeared inert. The dichroscope is also helpful for revealing such imitations, since tourmaline is strongly dichroic but dyed quartzite shows no pleochroism.

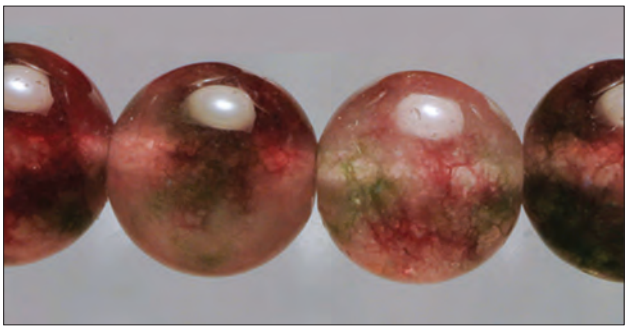

Figure 30: The dyed quartzite beads (here, up to 7 mm in diameter) show obvious colour concentrations along fractures. Photo by J. Hyršl.

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The Potential of a Portable EDXRF Spectrometer for Gemmology

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Energy-dispersive X-ray fluorescence (EDXRF) spectroscopy is an important and well-established technique for the non-destructive chemical analysis of gem materials. The suitability of a portable EDXRF instrument for gemmological use was examined with a Niton XL3t GOLDD+ Analyzer manufactured by Thermo Scientific. Analysis of a variety of gem samples (natural, treated and synthetic) yielded qualitative data in the element range from Na to U that were comparable with results obtained from typical bench-top EDXRF instruments. The spectra measured by the portable unit showed well-resolved peaks, and gemmologically important intensity ratios of various elements were easily obtained. Using different collimators and measuring times, loose as well as mounted gems could be measured qualitatively. Although quantitative chemical data were not obtainable in this study, such results should be feasible using a calibration procedure that is optimized for gem analysis. This portable instrument, in conjunction with the use of an He purge unit for a better signal-to-noise (S/N) ratio when analysing light elements, is deemed very useful for smaller laboratories, as well as for larger laboratories offering off-site testing.

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Introduction

Gemmological laboratories are routinely tasked with establishing the identity of gem samples as well as their natural, treated or synthetic origin. In some cases, the determination of a stone's geographical origin is also requested by the client. Much can be determined by a well-trained gemmologist using standard gemmological instruments, but in many cases it is necessary to perform additional non-destructive analyses. One technique commonly used in gem labs is chemical analysis by EDXRF spectroscopy. The EDXRF spectra provide a quick display of most of the chemical components that may be present, including major (typically >1 wt.%), minor (0.1–1 wt.%) and trace (<0.1 wt.%) elements. While major and minor elements are useful for defining the mineral species, trace elements may indicate whether a gem is natural or synthetic, as well as the presence of some treatments and in some cases a stone's geographical origin. Chemical data are considered *qualitative*

if they are non-quantifiable and simply indicate the presence of an element. In the case of EDXRF spectroscopy, the pattern of a certain element is visually detected through the presence of peaks seen in the X-ray fluorescence spectra. To be *quantitative*, the data must be calibrated against samples of known composition. In that case, the actual concentrations of elements/oxides found in the sample are reported numerically with an inferred accuracy. A limitation of EDXRF analysis is that light elements (atomic mass <11, or lighter than Na) cannot be detected.

Portable instruments for EDXRF spectroscopy have been geared toward a wide range of applications (e.g. Zurfluh et al., 2011; Shugar and Mass, 2012), including archaeology, art conservation, mining exploration, environmental studies and industrial applications (particularly cement and metals). To investigate whether such instrumentation is suitable for gemmology (e.g. Voynick, 2010), the author tested a portable device made by Thermo Scientific (Niton XL3t GOLDD+) on a variety of gem samples (e.g. Figure 1). Although other manufactures have marketed similar instruments (e.g. Bruker, Olympus, Oxford Instruments, Spectro, etc.), these were not tested in this study.

Figure 1: Some of the samples analysed in this study are shown here (clockwise, from top left): an 8.60 ct lapis lazuli slab from Afghanistan (sample 16), an ~100 ct jadeite slab from Myanmar (sample 9), a 20.85 ct zircon from Sri Lanka (sample 15); a 21.65 ct apatite from Madagascar (sample 17); a 3.97 ct Verneuil synthetic spinel (sample 6) and a 1.78 ct spinel from Vietnam (sample 5). The blue spinels were selected to assess testing for the Co chromophore (which is typically not present in detectable amounts using EDXRF), and the other samples were chosen to test for the detection of light (Na to Cl) or heavy (Th and U) elements. Photo by F. A. Herzog.

Figure 2: The portable EDXRF device (Niton XL3t GOLDD+ from Thermo Scientific) tested for this study is shown on the left, together with cables for its power and USB connections. On the right is the He purge unit that is used for light-element analysis. The image scale can be judged from the size of the AC power adapter (6 × 10 cm). Photo by F. A. Herzog.

Materials and Methods

When a sample is analysed by an EDXRF instrument, an X-ray beam is used to excite a unique fluorescent X-ray energy spectrum from each element present in the gem. The simultaneous measurement of various elements in the stone yields a type of compositional 'fingerprint'. With an appropriate calibration procedure, the concentration of most elements can be quantified down to parts-per-million levels. More about EDXRF spectroscopy can be found in, for example, Lachance and Claisse (1995) and Jenkins (1999).

Instrumentation

For this study, a Niton XL3t GOLDD+ Analyzer together with an appropriate stand for the safe handling of gem samples was loaned by Thermo Scientific for two weeks. The instrument is shown in Figures 2 and 3, and some of its parameters are listed in Table I. The device offers four excitation

Figure 3: The EDXRF unit is seen here mounted in a stand used for analysing small samples. The sample chamber (18 × 8 cm) is large enough to accommodate a variety of unmounted samples, but may be too small for bulky jewellery items; larger stands are available. Photo by H. A. Hänni.

ranges (Table II), each with a pre-assigned primary filter that is used to optimize the signal over the background noise in the corresponding energy range. Within each range, a fixed amount of energy excites specific ranges of elements. Due to the X-ray excitation, elements may undergo *K*-, *L*- or *M*-shell ionization, resulting in diagnostic *K*-, *L*- or *M*-lines in the EDXRF spectra.

X-ray devices must follow strict safety protocols, and only those that fulfil country-specific safety regulations can be sold. After buying a Niton Analyzer, user training (including safety aspects) is provided. For small samples (like most gemstones), an appropriate safety-approved enclosure that shields the user from X-rays is mandatory (e.g. Figure 3). Different logins provide various levels of access to the instrument, and the X-rays can only be activated when 'Analyze' is selected and the trigger is pressed (in all other modes, the instrument cannot start operating). Used correctly, the Niton Analyzer is extremely safe.

Table I: Main features of the Niton XL3t GOLDD+ portable EDXRF instrument.

Size	<1.3 kg, 24.4 × 23.0 × 9.5 cm
X-ray tube	Ag anode, 6–50 kV, 0–200 μA
Collimator	8 mm (standard) or 3 mm (optional)
Measurement area	10 mm circle
Primary filters	See Table II
Detector	• Geometrically optimized large-area drift detector (GOLDD) • Si drift detector (SDD), operated at approximately −30°C • Resolution: <185 eV @ 60,000 cps
Connectivity	USB cable for PC connection
Power supply	Two rechargeable Li batteries (8 h each) and AC power adapter
Software	• NDT (Niton Data Transfer) for data transfer between unit and PC • NDTr for remote control of unit
Accessories	• He purge unit, for improved signal/noise for light elements (see Figure 2) • Various stands with interlock mechanism and shielding (e.g. Figure 3)

Table II: Excitation ranges available for the XL3t GOLDD+ device.[a]

Range	Excitation	Element range	Typical energy range (keV)	Primary Filter	Measurement time (sec)[b]
Main	Maximal energy	*K*-lines: Ti to Mo *L*-lines: Ta to Bi	4.0–20.0	Light metal combination	120
Low	Mid-energy	*K*-lines: K to Cr *L*-lines: Ba to Nd *M*-lines: Ir to U	2.5–6.0	Cu	120
High	Maximal energy	Rh to Nd	20.0–44.0	Mo	90
Light	Minimal energy	Na (qualitative) to Cl	1.0–3.0	No filter	150

[a] The current is self-adjusting for optimal 'dead' time, range 0–200 µA.
[b] These times are optimal for the 3 mm collimator, but also were used for the 8 mm collimator.

Analytical Considerations

Although this instrument can be employed in a variety of disciplines, in this study only the 'Mining Cu/Zn' menu was used (in the 'Soils & Minerals' section). The factory calibration for this mode uses a Fundamental Parameter calculation specifically designed for the identification of mineral elements, based on pure elements and mining reference standards.

To operate properly, the device should be 'system checked' at least weekly. This is performed by the user, with a specific menu item on the main display, after the unit has warmed up for at least three minutes. This procedure ensures the energy scale of the system is properly calibrated (i.e. that the Cu($K\alpha$) peak is correctly located at 8.041 keV).

For accurate measurements of gem materials, appropriate sample holders must be used. They should fulfil two conditions:

1. The gem must sit firmly against the Analyzer during the measurement.
2. The sample holder itself should not interfere with the EDXRF spectrum of the gem.

For most analyses, the sample holder consisted of a thin (0.1 mm) transparent polyethylene sheet (as used for overhead projectors) with a hole of 4 mm in diameter (Figure 4, left). For small stones of <5 mm in diameter, an acrylic sample holder was used in addition to the polyethylene sheet (Figure 4, right). The acrylic has only a minute influence on backscattering of the X-rays and its sulphur content can be neglected.

The Niton XL3t GOLDD+ Analyzer itself consists of several components densely packed into its casing, and hence some of these materials show up as peaks when performing a blank test—an analysis done without any sample, but with the sample holder installed—as they are

Figure 4: The sample holder used in this study is shown on the left. It consists of a square sheet of polyethylene with a 4-mm-diameter hole punched in the centre. Scotch tape is used to affix the sheet to the Analyzer. The sample holder on the right consists of an acrylic block with a 10-mm-diameter hole drilled halfway through it, and a smaller hole drilled through the remainder of the block to fit a central, moveable pin (plastic tube from a ballpoint pen) to which the sample is attached with Blu-Tack. This assemblage, which is useful for smaller stones, is then placed over the hole in the polyethylene sheet mentioned above. Photos by F. A. Herzog (left) and H. A. Hänni (right).

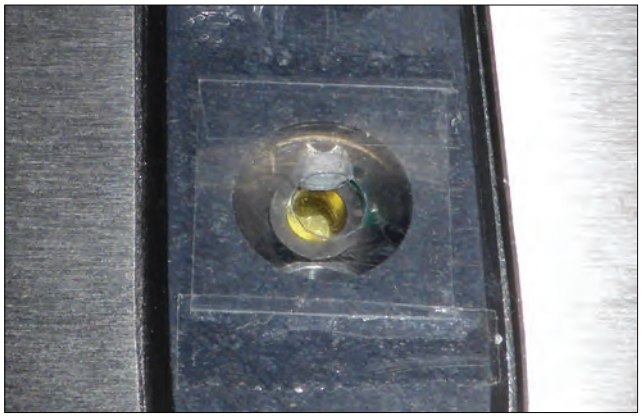

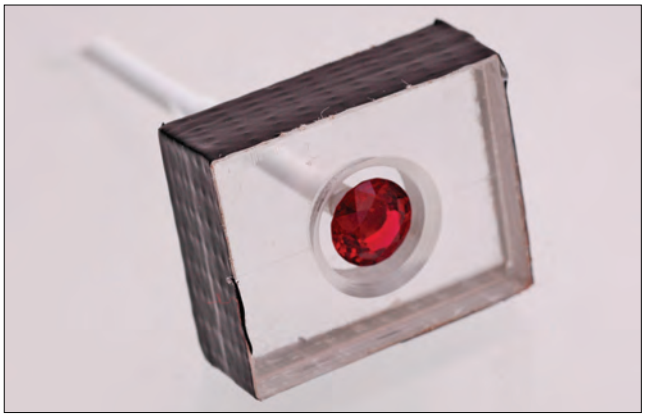

Table III: Elements showing up as system peaks and their excitation range.

Range*	System Peaks
Main	*L*-lines of W from primary excitation beam Ni from contribution of the system in the emerging beam Low Fe from unknown source *L*-lines of Au from detector enclosure, if backscattering occurs
Low	Low Cr from unknown source *L*-lines of Sb
High	Sn from solder in detector Mo from filter Ag from tube
Light	*L*-lines of Ag from tube

* See Table II for range descriptions.

part of the system's chemistry. These *system peaks* (see Table III) should not be mistaken for peaks from the sample. The specific elements appearing as system peaks depend on the energy range that is selected by the excitation energy and the primary filter (Table II). The Ni peak is most significant, as its signal is quite strong and it occurs in an area of high interest for many gem materials—in the vicinity of Fe. Nevertheless, such system peaks are taken into account in the quantitative analysis by an appropriate calibration, and their contributions are subtracted from the chemical data. For qualitative analysis, the system peaks are part of the background spectra (shown as a black curve in the spectra included in this article). The blank spectrum in Figure 5 shows an example of system peaks in the main excitation range. Examples of blank spectra for the other excitation ranges can be downloaded from the online data depository on *The Journal's* website.

In the range of the light elements (Na to Cl), the absorption by air is quite high and hence their signals are attenuated. For many EDXRF instruments this problem is solved by evacuating the sample chamber. However, the necessary vacuum pumps are heavy and power consuming, and therefore are not feasible for battery-operated portable instruments. For the Niton Analyzer, this problem is solved by purging with He gas, where the very small volume between the tube, the outlet window (itself sealed with a very thin piece of foil) and the detector is flushed with He. This provides a very good improvement for the signal-to-noise (S/N) ratio for light elements, and also drastically reduces interfering fluorescence peaks (at 2.95 and 3.19 keV) caused by the presence of Ar in air. The He purge unit (Figure 2) is itself quite portable, although it cannot be transported on commercial airliners due to security regulations.

Figure 5: This 'blank' EDXRF spectrum, taken with an empty sample holder in place, shows the system peaks in the main excitation range. The Ni contribution is most significant, but the count rates are not very high.

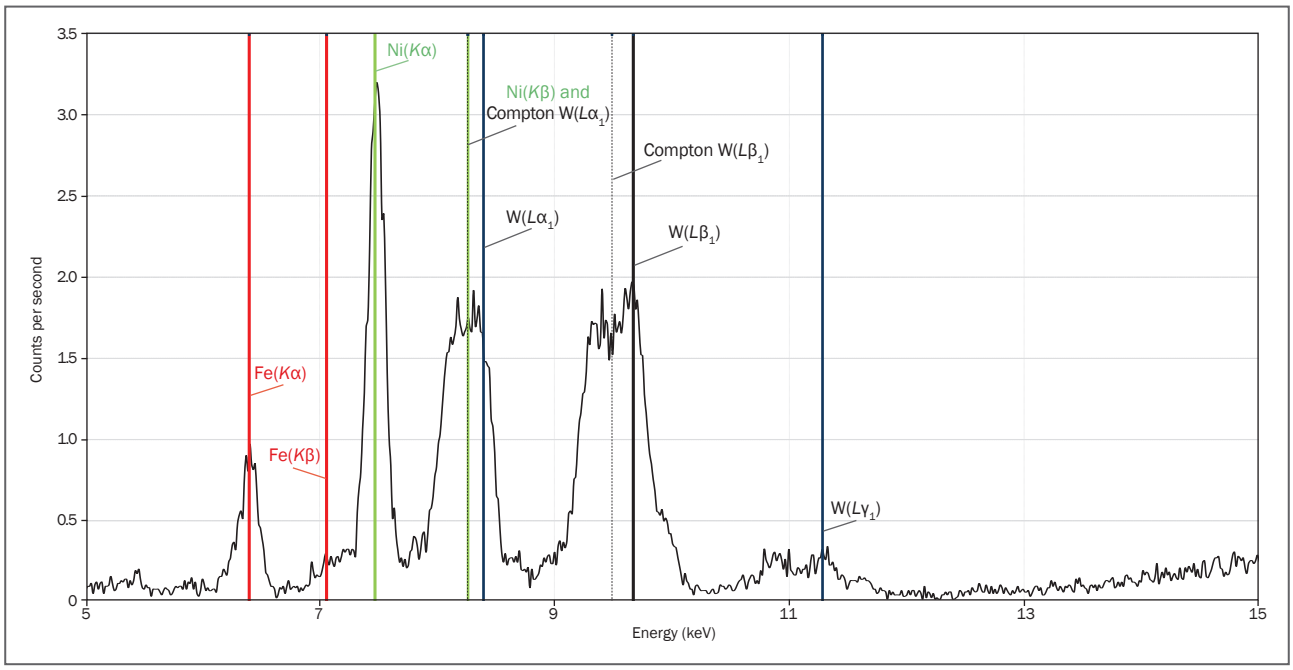

Figure 6: The corundum gems analysed for this study are (clockwise from top left): a 9.10 ct Verneuil synthetic ruby (sample 1), a 4.83 ct ruby with Pb-glass filling (sample 4), a 1.86 ct flux-grown synthetic ruby from Ramaura (sample 2), and a 4.12 ct natural untreated star ruby from Mogok (sample 3). Photo by H. A. Hänni.

Samples and Analytical Procedure

To evaluate the instrument for its suitability in gem testing, a diverse array of materials often found in gem laboratories were analysed (see, e.g., Figures 1, 6, 7 and 8, and Table IV). The analytical procedure was as follows:

- All samples were cleaned with isopropyl alcohol and dried with lint-free paper.
- A 3 mm collimator was used for mounted stones and an 8 mm collimator was employed for loose gems. The device was factory calibrated for both collimators.
- All excitation ranges (main, low, high and light) in the 'Mining Cu/Zn' mode were analysed, and the measurement times for each range are given in Table II.
- After each measurement, spanning all four excitation ranges, the Niton Analyzer automatically provided a 'quantitative' analysis. If a specific calibration is not first set by the user, the standard factory calibration is applied. Since this calibration is not optimized for gemmological samples, such 'quantitative' results cannot be trusted and the data should be considered qualitative.
- All data/spectra were exported to a PC using the Niton Data Transfer (NDT) software supplied with the instrument. Visual evaluation of the spectra was done after they were imported into Microsoft Excel.

Figure 7: The emerald samples analysed in this study consist of (clockwise from top left): a 5 × 4 cm matrix specimen from Panjshir, Afghanistan, with a prismatic 3.0 × 0.3 cm emerald (sample 11); a 9.77 ct loose crystal specimen with pyrite and calcite from La Pita, Colombia (sample 10); a 0.76 ct Chatham flux-grown synthetic emerald (sample 13); and a 2.53 ct Biron hydrothermal synthetic emerald (sample 12). Photo by H. A. Hänni.

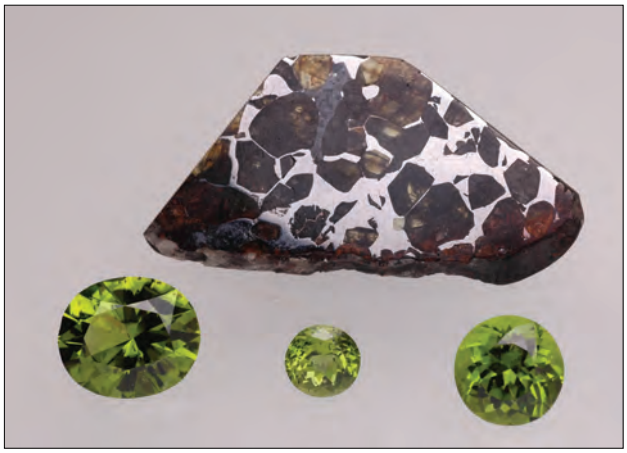

Figure 8: The olivines analysed in this study comprise (clockwise from top): a 67.5 ct Seymchan 1967 pallasitic meteorite slab from Magadan, Russia (sample 8) and a group of terrestrial olivines (sample 7) from Pakistan (11.75 ct), Norway (4.39 ct) and Myanmar (16.72 ct). Photo by H. A. Hänni.

Results

The NDT software used to operate the device and to download data, spectra and images from the Analyzer to the user's PC was clear and straightforward to use. The spectra could be scanned with a cursor, indicating the likely element responsible for a particular peak. All of the spectral lines of a given element were

Table IV: Samples tested for this study.[a]

Sample no.	Mineral	Source	Weight (ct)	Composition	Elements to check
1	Corundum, Verneuil synthetic ruby	Djeva	9.10	Al_2O_3	Low Fe, missing Ga Only colouring agent: Cr
2	Corundum, flux synthetic ruby[b]	Ramaura	1.86	Al_2O_3	Low Fe, missing Ga Only colouring agent: Cr Residues of flux (Pb, Bi, La)
3	Corundum, untreated star ruby	Mogok, Myanmar	4.12	Al_2O_3	V, Cr, Fe, Ga V should be visible, apart from Ti (because of rutile silk); Cr>Fe.
4	Corundum, ruby with Pb-glass filling[b]	Unknown	4.83	Al_2O_3	V, Cr, Fe, Ga, Pb Check the possibility of deconvoluting the Ga peaks below the Pb peaks
5	Spinel, blue	Luc Yen, Vietnam	1.78	$MgAl_2O_4$	Fe, Co, Zn, Ga Co peak, as it is visible in the UV-Vis spectrum
6	Spinel, synthetic blue	Verneuil	3.97	$MgAl_2O_4$	Co Mg deficiency
7	Peridot	Norway Pakistan Myanmar	4.39 11.75 16.72	$(Mg, Fe)_2SiO_4$	Ni
8	Peridot in Fe-Ni meteorite	Extraterrestrial	67.5	$(Mg, Fe)_2SiO_4$	Ni
9	Jadeite	Myanmar	~100	$NaAlSi_2O_6$	Na, as it is quite difficult to detect with EDXRF
10	Beryl, emerald (loose crystal)	La Pita, Colombia	9.77	$Be_3Al_2Si_6O_{18}$	V, Cr, Fe Cr>V, Cr>Fe
11	Beryl, emerald (matrix specimen)	Panjshir, Afghanistan	~200	$Be_3Al_2Si_6O_{18}$	Sc, V, Cr, Fe, Cs, Rb Fe>Cr Possible to see Sc?
12	Beryl, hydrothermal synthetic emerald[b]	Biron	2.53	$Be_3Al_2Si_6O_{18}$	Cl as needed to get Cr into solution
13	Beryl, flux synthetic emerald[b]	Chatham	0.76	$Be_3Al_2Si_6O_{18}$	Residues of flux (Pb, Bi), V, Mo
14	Tourmaline[b]	Paraíba, Brazil	1.32	Complex borosilicate	Among others: Mn, (Fe), Cu, Ga, Bi
15	Zircon	Sri Lanka	20.85	$ZrSiO_4$	U and radioactive decay products (Th, Ra, Bi, Pb)
16	Lapis lazuli	Afghanistan	8.60	Mixture of lazurite, hauynite, sodalite, nosean	Na, Al, Si, S, Cl, Ca Detection possibilities for light elements (Na, S, Cl)
17	Apatite	Madagascar	21.65	$Ca_5(PO_4)_3(OH,Cl,F)$	P, Cl, La, Ce, etc. Detection possibilities for P, Cl and REE
18	Scapolite, yellow	Madagascar	17.89	Al-silicate with additional anions	Check for halogen elements
19	Scapolite, purple	Tanzania	33.52	Al-silicate with additional anions	Compare to sample 18 as the colour is different
20	Tourmaline, magenta	Mozambique	23.28	Complex silicate	Compare results for different collimators
21a	Rhodolite, mounted in ear clip	Montana, USA	0.52	$Mg_3Al_2(SiO_4)_3$	Check usability of the 3 mm collimator; Cr, Fe as chromophores
21b	Andradite, mounted in ear clip	Ural Mountains, Russia	0.51	$Ca_3Fe_2(SiO_4)_3$	Check usability of the 3 mm collimator; Cr, Fe as chromophores

[a] EDXRF spectra for samples 10–21 can be found in *The Journal*'s online data depository.
[b] Loaned by H. A. Hänni.

shown by the software. However, Na was not in the list of elements since it is not considered to be quantifiable with the current version of this instrument (even with the He purge unit). In the 'Overlay' mode, where each curve can be coloured differently, it was easily possible to compare different spectra within the same range (e.g. a natural emerald and a synthetic emerald in the 'low range'). To export the numerical data and the spectra in ASCII format is self-explanatory. Since the NDT software provided only limited reporting capabilities, the spectra were exported to Excel for further analysis. It was then possible to perform more evaluation steps such as drawing the spectra in their respective ranges, peak labelling, peak-fitting routines by use of a solver add-on, etc.

The qualitative analytical results given in subsequent sections of this article were visually derived from the corresponding spectra. The presence or absence of an element was determined by observing the peaks in the spectra, and the intensity ratios of the elements also could be estimated. For example, the Fe/Cr ratio of a Mogok ruby could be compared with that of an East African ruby—and it was clear that for a given Cr content the East African stone contained more Fe than the one from Mogok.

However, when evaluating EDXRF spectra, three important precautions must be taken:

- The identification of an element should be based on as many peaks as possible (deriving from possible *K*-, *L*- and *M*-shell transitions). The shape of the peaks should be symmetric around the energy of its emission. Overlap of peaks from different elements will cause asymmetry. Additional peaks belonging to the same element (possibly even in spectra of other excitation ranges) can help to identify the interfering elements.
- Peaks that cannot be assigned to any element—even after scanning through all of the elements from Mg to U—are suspicious, as they could be diffraction peaks from Bragg reflections of the sample's crystal lattice (see, e.g., Jenkins 1999). Usually diffraction peaks are somewhat broader than fluorescence peaks. In such cases, the sample should be placed in a different orientation (by rotation or tilting) and remeasured. Apart from diffraction peaks, the interpretation of spectra may be complicated by 'sum peaks' as well as 'escape peaks' (see Lachance and Claisse, 1995). Although Thermo Scientific claims that these peak types are automatically removed by the software, any unallocated peak should be checked accordingly.
- For elements that may appear as system peaks, especially Fe and Ni in the main excitation range, any quantitative results have to be checked. Although the factory calibration of the Analyzer is not optimal for gemstones, it nevertheless gives indications for possible contributions of system-peak elements above their detection limit. As part of the underlying calibration process, the system-peak contributions are subtracted (taking into account matrix effects). If there are uncertainties regarding the presence of Fe and/or Ni in a sample, investigating its UV-Vis spectrum may help clarify the situation.

Examples of EDXRF Spectra

A small selection of the spectra obtained during this study is presented below, and several additional examples are provided in *The Journal*'s online data depository; samples of the latter group are shown with a grey screen in Table IV. In all the spectra, the Y-axis shows 'counts per second', which is a measure of the X-ray–induced fluorescence intensity of the various elements. Along the X-axis, the energy of the emitted fluorescence lines is given in units of kiloelectron volts (keV). Element-specific fluorescence peaks are labelled in the form X(*Y*z), where X denotes the element, *Y* refers to the atomic shell (*K*, *L* or *M*) of the fluorescence transition and z is the series name of the transition (α, β, etc.). The background spectra (system peaks of the specified range) are always shown in black. The abbreviation 'LOD' (limit of detection) is the term used within the NDT software; it is equivalent to the more familiar 'bdl' (below detection limit) or 'nd' (not detected).

Ruby: 'Main range' spectra for rubies are shown in Figure 9. In the spectrum of a Mogok star ruby (sample 3), Ga and Cr could be identified by their *K*α and *K*β pair of peaks (for the importance of Ga in natural corundum, see Hänni et al., 1982). The Fe and Ni peaks followed the background

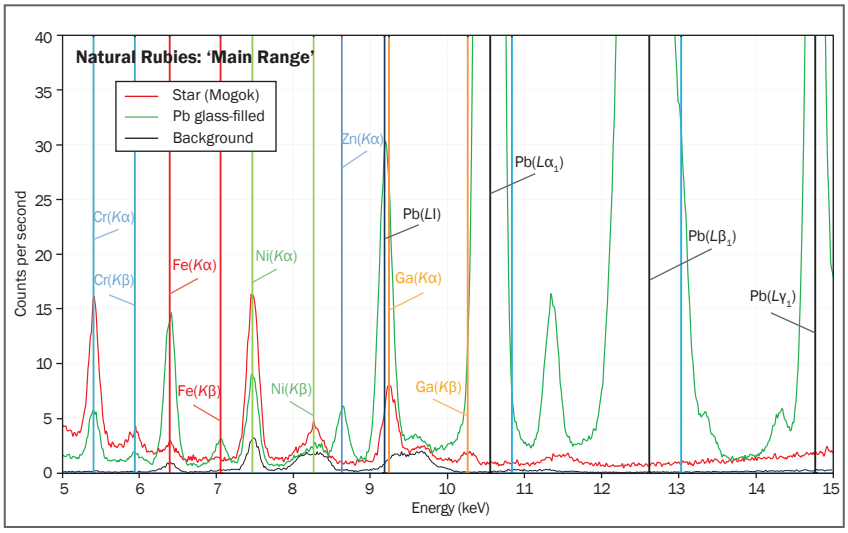

Figure 9: 'Main range' EDXRF spectra are shown for a Mogok star ruby (sample 3) and a Pb glass-filled ruby (sample 4). The star ruby shows the classic Mogok pattern, with low Fe and rather high Cr. Its Ga peak certifies its natural origin. For the Pb glass-filled ruby, a natural origin cannot be determined by its Ga content since the Pb peaks completely overlap the Ga region; its Fe content and visual examination nevertheless indicate its natural origin.

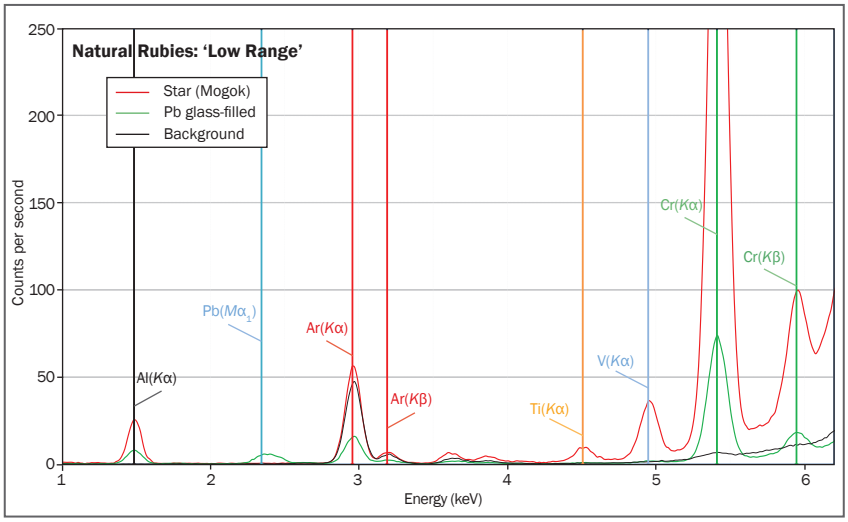

Figure 10: These 'low range' EDXRF spectra are from the same rubies analysed in Figure 9. In the Mogok star ruby, the presence of V supports its claimed origin and the Ti content is consistent with the rutile inclusions that are responsible for its asterism. For the Pb glass-filled ruby, only a small M-line of Pb can be observed in this excitation range.

curve, and therefore these elements do not occur in this ruby, or their concentrations are below the detection limit. A check of the quantitative results indeed showed 'LOD' for both elements in the star ruby. The spectrum of a Pb glass-filled ruby (sample 4) can be recognized as natural (i.e. not synthetic) by its relatively large Fe peak; Ga could not be detected as those peaks were overshadowed by the relatively large peaks of Pb(Ll) and Pb($L\alpha_1$). The Zn peak is somewhat surprising—its origin is not clear, although it could be a constituent of the glass filling.

'Low range' spectra of these same rubies are shown in Figure 10. The V content of the star ruby (sample 3) supported its Burmese origin. The Ti originated from the network of fine rutile inclusions that is responsible for its asterism. In the Pb glass-filled ruby (sample 4), only one peak related to lead, Pb($M\alpha_1$), could be seen in this low-energy spectrum.

'Main range' spectra of two synthetic rubies are shown in Figure 11. For the Verneuil synthetic ruby (sample 1), the only feature was the Cr pair ($K\alpha$, $K\beta$); together with the absence of Fe, Cr is responsible for the bright red colour of this sample. In the flux synthetic ruby (sample 2), apart from the chromophore Cr, the flux-related elements Pb and Bi were visible (cf. Muhlmeister and Devouard, 1991; Muhlmeister et al., 1998). Signals for Fe and Ni were also clearly visible, but they correspond to system peaks that have been enhanced by the corundum matrix. The mechanism of this fluorescence enhancement has not been studied in detail, but such system peaks are subtracted by the instrument's quantitative analysis calculations, and 'LOD' was reported for both Fe and Ni in this flux-grown sample. The absence of Ga peaks is obvious in the case of the Verneuil synthetic. The presence of Ga in the flux synthetic is not clear due to interference from Pb in the Ga($K\alpha$)

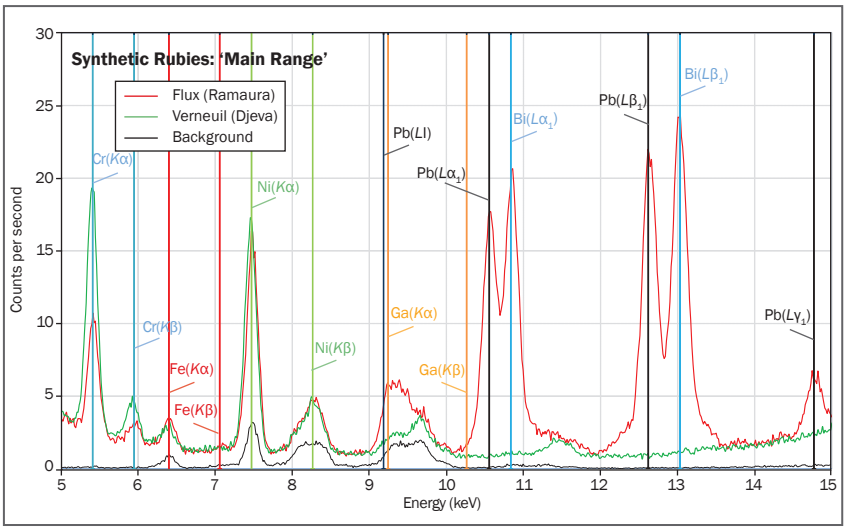

Figure 11: The 'main range' EDXRF spectra are shown for synthetic rubies: Verneuil (flame fusion; sample 1) and Ramaura (flux; sample 2). Both rubies show no Fe and high Cr contents. In the Verneuil sample, Ga is below the detection limit, but this is not so obvious in the Ramaura sample. The flux used for its growth contains Pb (and Bi and La), and the Ga K-lines are hidden by the Pb L-lines—a similar situation as in Figure 9. The Bi lines are also obvious.

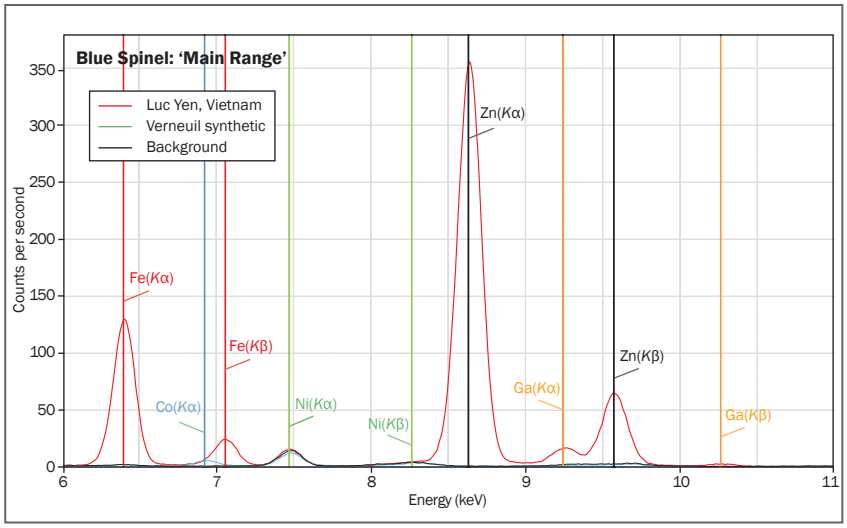

Figure 12: 'Main range' EDXRF spectra of a blue spinel from Vietnam (sample 5) and a Verneuil synthetic blue spinel (sample 6) are shown for comparison. The trace-element pattern of the natural spinel is classic: high Zn with a clear Ga peak and some Fe. All these elements are missing from the synthetic spinel. Only Co (the blue chromophore) is visible for the synthetic spinel.

region. Together with a visual inspection of this sample (which shows multiphase flux residues), the EDXRF spectrum clearly indicated this gem to be a Ramaura flux-grown synthetic ruby (see also Kane, 1983, and Muhlmeister et al., 1998). (In addition, the presence of La, also typical of Ramaura synthetic ruby, could be seen in the low- and high-range spectra.)

Spinel: 'Main range' spectra of one natural and one synthetic blue spinel are shown in Figure 12. The natural origin of the stone from Luc Yen (sample 5) is revealed by the large Zn peak, the clear presence of Ga and an obvious Fe contribution. The Verneuil synthetic spinel (sample 6) contained, apart from its main constituents (not visible in this spectrum), only the chromophore Co. This element could not be detected in the attractively coloured blue gem from Vietnam.

The 'light range' spectra of these natural and synthetic spinels are shown in Figure 13. To improve the S/N ratio, the He purge unit was used for better detection of the light elements. The relative excess Al in the synthetic spinel, as compared to the natural stone, is obvious.

Peridot: 'Main range' spectra of various peridot gems (sample group 7 and sample 8) are shown in Figure 14. As mentioned above and in Figure 5, Ni is a system peak, and this may be problematic in cases where the signal from this element is crucial. The Ni content of terrestrial olivine is higher than for the extraterrestrial counterpart found in pallasites (Shen et al., 2011; Williams and Williams, 2014). The spectra shown in this figure, all measured under exactly the same conditions, clearly confirm these findings (despite the contribution from the Ni system peak). The quantitative results indeed indicated the presence

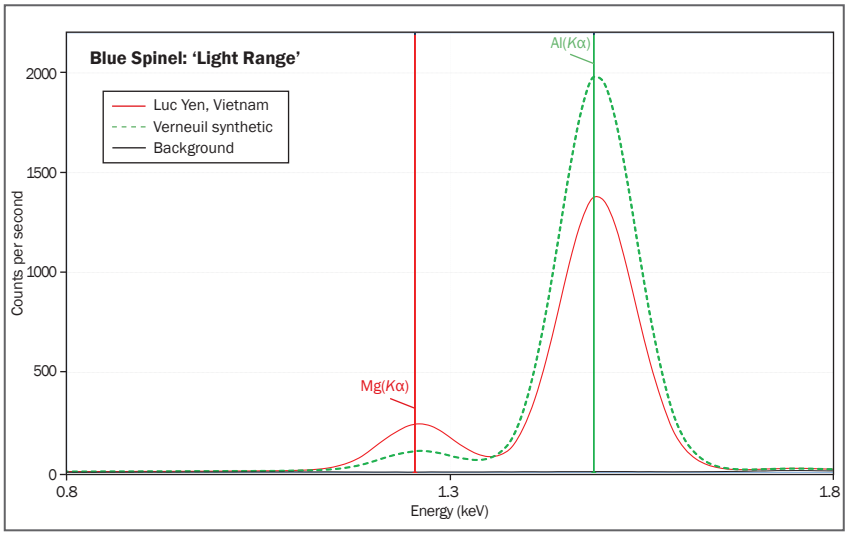

Figure 13: 'Light range' EDXRF spectra are shown for the same samples as in Figure 12. These spectra were recorded with the He purge unit, and they clearly show the relative Al excess in the synthetic spinel.

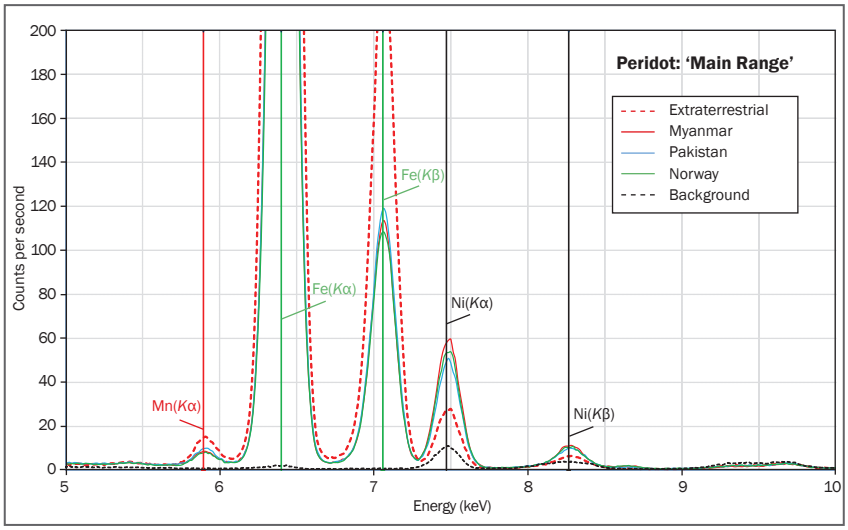

Figure 14: These 'main range' EDXRF spectra of peridot from various origins show lower contents of Ni in the pallasitic gem (sample 8) compared to terrestrial samples (sample group 7) from Myanmar, Pakistan and Norway.

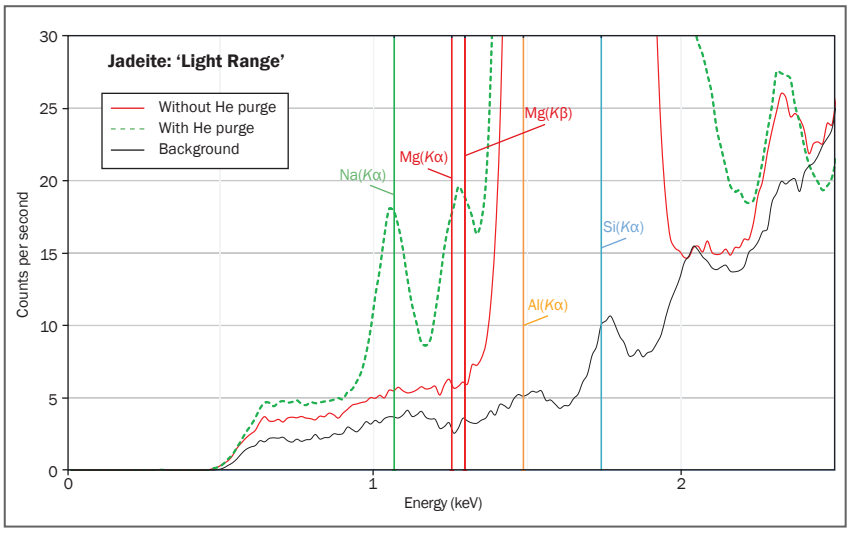

Figure 15: 'Light range' EDXRF spectra of jadeite (sample 9) are shown under normal conditions and with the He purge unit. The presence of Na and Mg can only be seen in the latter spectrum.

of Ni in all the samples, but with a clearly lower value for the pallasitic peridot. The spectra also show that Mn was relatively more abundant in the pallasitic peridot than in the terrestrial samples.

Jadeite: The 'light range' spectrum of jadeite (sample 9) is shown in Figure 15. Using the He purge unit, the important Na signal is obvious, and even a small Mg contribution is observed.

For the following samples, corresponding EDXRF spectra can be found in *The Journal*'s online data depository.

Beryl: Four emerald samples were analysed. The trace-element concentrations of emerald are mainly used for locality determination and/or to establish natural versus synthetic origin. The Colombian stone (sample 10) was characterized by low Fe, higher Cr, substantial V and the absence of alkali elements such as Rb. In the Panjshir emerald (sample 11), Sc could be identified with the help of the 3 mm collimator; the 8 mm collimator measurement sampled too much of the carbonate matrix, and the Ca peak overlapped the Sc signal. The Cr content of this Afghan stone was quite low, but the V peak was surprisingly strong.

For the hydrothermal synthetic emerald (sample 12), the existence of Cl could be demonstrated (cf. Hänni and Kiefert, 1994). Flux residues (Mo) were clearly evident in sample 13, a Chatham synthetic emerald (cf. Nassau, 1980).

Using the He purge unit, it was shown that a natural emerald (sample 10) contained traces of Na and Mg whereas a synthetic stone (sample 12) lacked these elements (cf. Hänni, 1982).

Tourmaline: An elbaite from Paraíba, Brazil (sample 14), showed a small liddicoatite component as indicated by Ca in its 'low range' spectrum. Peaks for Mn and Cu that are characteristic of this tourmaline were obvious in the 'main range' spectrum. The ratio Cu/Mn <1 and the presence of Zn and moderate Bi recorded in the EDXRF spectra may support its Brazilian origin. Nevertheless, origin determination for Cu-bearing tourmaline by means of EDXRF analysis is not rigorous, since quantitative data is required—including for light elements that cannot be detected by EDXRF spectroscopy (Fritsch et al., 1990; Laurs et al., 2008).

Zircon: Sample 15 (see Figure 1) was analysed to test the device's ability to measure heavy elements, such as U and its decay products. In the 'main range' spectrum, these heavy elements may be seen by their *L*-shell fluorescence peaks, whereas Zr shows up with *K*-lines. In sample 15, apart from Zr, the elements Hf, U, Bi and Pb could be identified by at least two peaks—although quite close to the resolution of the instrument. Only one peak for Th was visible, $L\alpha_1$, and to prove the existence of this element at least one more peak should be identified: $L\beta_1$ at 16.215 keV. Since that peak was hidden by the Zr signal, the presence of Th in this zircon was not conclusive.

Lapis Lazuli: Sample 16 (see Figure 1) was chosen for the study of lighter elements such as Na, S and Cl. For this purpose, spectra were recorded with and without the He purge unit. In the 'light range' spectrum, these elements were clearly seen with the He purge unit, but Na was invisible without the purge unit. To prove the existence of Cl within the 'light range', one has to be careful with the nearby Ag system peak [Cl($K\alpha$) = 2.622 keV and Ag($L1$) = 2.634 keV]. There is no filter suppressing the Ag($L1$) line, which originates from the X-ray tube. To confirm the presence of Cl in lapis lazuli, the 'low range' spectrum must be consulted, in which the Cu filter absorbs the Ag($L1$) line.

Apatite: Sample 17, an apatite from Madagascar (see Figure 1), was chosen for its P and rare-earth element (REE) contents, and to check whether it might be a Cl-containing chlorapatite. (However, differentiation between fluorapatite and hydroxylapatite is not possible by EDXRF.) This apatite showed a clear P signal (as apatite is a phosphate), a small Cl contribution, significant Sr (substitution of Ca by Sr), and substantial traces of Y, La, Ce and Nd.

Scapolite: Both analysed samples (18 and 19; see Figure 16) showed clear Cl and Br peaks (cf. Dong, 2005), and their spectra were quite similar with respect to transition-metal elements, even though their colours were quite different (purple and yellow). To properly evaluate the marialite component (Na), the He purge unit should be used.

Comparison of Results from Different Collimators: Sample 20, a tourmaline from Mozambique (see Figure 16), was analysed with both 3 mm and 8 mm collimators, but otherwise under the same conditions (including measurement time). The results clearly showed

Figure 16: Also analysed for this article were the following samples (left to right): a 23.28 ct tourmaline from Mozambique (sample 20), a pair of ear clips with garnets mounted in white gold (sample 21b, a 0.51 ct andradite from Russia, and sample 21a, a 0.52 ct rhodolite from Montana, USA), a yellow 17.89 ct scapolite from Madagascar (sample 18) and a purple 33.52 ct scapolite from Tanzania (sample 19). Photo by F. A. Herzog.

that all elements visible in a certain range could be detected using either collimator. This is very important for the device's use on mounted gems.

Analysing Mounted Gemstones: Two 3-mm-diameter garnets (samples 21a and 21b; see Figure 16) that were mounted in white-gold ear clips were analysed using the 3 mm collimator. Both the rhodolite and andradite could clearly be identified with minimal disturbance from the mounting. The position of each of these stones within their respective garnet series was shown, as well as their colouring trace elements. The spectra were as good as those taken of a loose gem with an 8 mm collimator.

Discussion

The main motivation for this study was to investigate whether a portable EDXRF instrument, widely used in the mining industry and in other fields, can also be useful in gemmology. Analysis of a broad range of gem samples, either loose or mounted in jewellery, was quickly performed in a qualitative manner. Well-resolved spectra for almost all naturally occurring elements (Na to U) can be recorded with this portable EDXRF instrumentation, and trace elements (and their intensity ratios) were effectively revealed that are useful for identifying geographical origin, chromophores and methods of synthesis.

Do we really need quantitative data for the routine analysis of gem materials? Certainly quantitative data are necessary for research purposes, as well as in some gem identification cases (e.g. determining the geographical origin of certain gem varieties). These situations require more sophisticated instrumentation such as an electron microprobe or laser ablation–inductively coupled plasma–mass spectrometry (LA-ICP-MS) equipment (see, e.g., Schmetzer, 2010). By contrast, EDXRF chemical analysis is often performed because the gemmologist wants confirmation of findings derived from standard gem testing techniques. If the interpretation of qualitative results (element ratios, existence of a certain element, etc.) is all that is needed, then EDXRF spectroscopy is sufficient, provided that the spectra are carefully evaluated for (1) peak overlaps, (2) the correct 'fingerprint' for each element and (3) the possibility of escape and sum peaks as well as diffraction peaks.

How does this portable analyzer compare to a typical bench-top EDXRF instrument? On the qualitative level, based on this author's experience with this portable unit and two bench-top EDXRF units (Thermo Fisher ARL Quant'X and Helmut-Fischer Fischerscope XUV 773), spectra from both types of instruments are comparable, even for light elements. An evaluation of quantitative data from this portable unit is beyond the scope of this study (see Box A). Nevertheless, it is certain that the calibration software accompanying bench-top instruments is more advanced; this probably also applies to the software for data quantification, based on the Fundamental Parameter method. However the advantages of the Niton Analyzer are obvious: It is portable, can be operated using a battery for eight hours and has a lower price (the actual price will vary depending on the analytical capabilities and accessories desired by the user).

Conclusions

The portable instrument evaluated for this report would be a great asset to a smaller gemmological laboratory as a principal EDXRF device, and would

Box A: Quantitative Chemical Analysis with the Niton Analyzer

For this study, none of the tested samples was analysed by a quantitative technique such as LA-ICP-MS to obtain a fully quantified concentration profile. Therefore, it is not possible to assess the data quantification process used by the Niton Analyzer when analysing gem samples. Nevertheless, this author suspects that the factory calibration using mining reference standards and pure elements does not produce satisfactory results for gemmological analysis. This raises the question of whether the calibration and hence a quantification can in principle be improved for gem analysis.

Indeed, the calibration for a specific sample's matrix (e.g. corundum) can be done by the user, provided that several measured reference samples of the same species are available. (The process to set up a collection of EDXRF reference samples is complex and is not covered here.) To do this, all the reference samples are analysed with the Niton unit and the results for each element are plotted (e.g. in Excel) against the known values of those elements in the reference samples (see, e.g., the hypothetical example shown in Figure A-1). The resulting slope and intercept parameters can then be entered into the appropriate menu of the device's software. The device allows for concentrations to be given as ppm values of pure elements or as wt.% oxides.

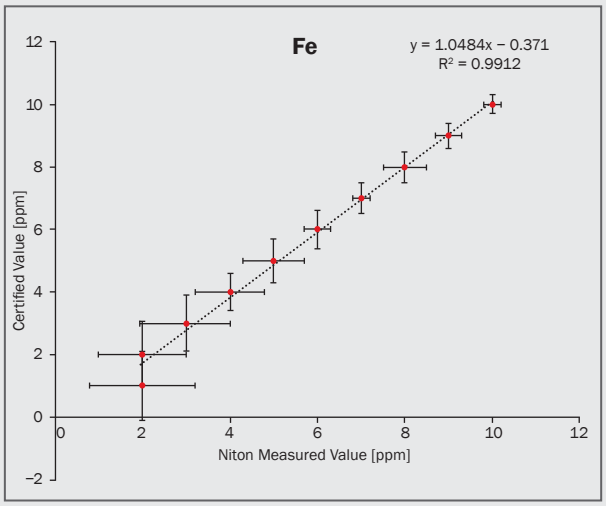

Figure A-1: This hypothetical calibration curve for Fe is shown for 10 reference samples of a given matrix (e.g. corundum). The data measured by the Niton Analyzer are plotted along the X-axis, and the known values (e.g. from LA-ICP-MS) are plotted along the Y-axis. A linear regression analysis calculates the two parameters for the calibration of Fe within the given matrix: slope (1.0484) and intercept (−0.371). These values can be entered into the user-defined cal-factor set of the Niton software for Fe. A similar procedure would have to be applied to all elements of interest to set up the instrument for quantitative analysis of a given gem species.

also be very useful for larger laboratories offering off-site testing. In addition to its portability, the instrument provides good-quality spectra in a simple and rapid way, for all possible sample types that may be submitted to gemmological laboratories. The elements present in a sample can be qualitatively identified (in the Na to U range), whether they are main constituents or present only in trace amounts. In addition, the intensity ratios of various elements are easily visible in the well-resolved spectra. Both of these aspects support the gemmologist in the decision-making path to correctly identifying a sample, including possibly its origin.

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The Fire Within

"For in them you shall see the living fire of the ruby, the glorious purple of the amethyst, the sea-green of the emerald, all glittering together in an incredible mixture of light."

– Roman Elder Pliny, 1st Century AD

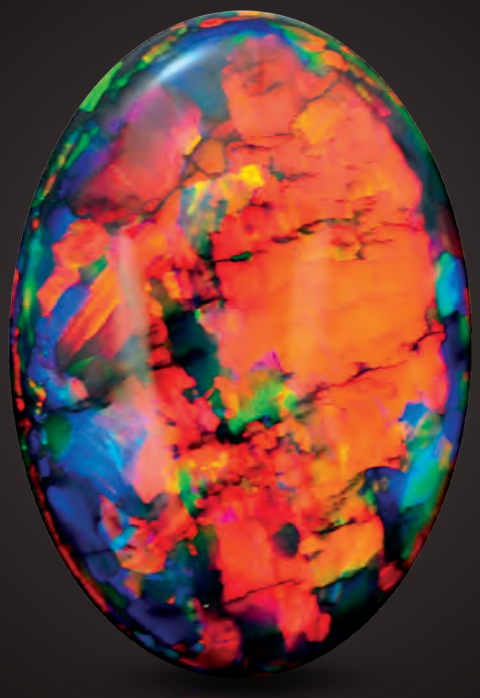

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Green Lead-Glass-Filled Sapphires

Thanong Leelawatanasuk, Namrawee Susawee, Supparat Promwongnan and Nicharee Atsawatanapirom

In April 2014, the Gem and Jewelry Institute of Thailand's Gem Testing Laboratory (GIT-GTL) received several rough and cut samples of green lead-glass-filled sapphire for examination, and in December 2014 the treater invited GIT to tour his facility. These stones show many characteristics similar to those of previously known cobalt-doped lead-glass-filled blue sapphires: orange and blue flash effects and colour concentrations along filled fissures, flattened gas bubbles trapped within the filler, and chalky blue fluorescence of the filler when viewed with the DiamondView instrument. Chemical analysis of the green glass showed mostly Pb with some Si, minor Cu, and traces of Fe and Cr. The latter three elements could possibly be responsible for the green coloration of the glass filler.

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Introduction

Lead-glass-filled corundum was introduced to the gem market in 2004 (see, e.g., Rockwell and Breeding, 2004; Smith et al., 2005). Initially, highly fractured rubies from various sources in East Africa were used as raw material for this treatment, and the finished products were sold under the trade name 'Newly Treated Ruby' in local markets in Bangkok and Chanthaburi, Thailand. Shortly thereafter, the fillers were proven to consist of lead-containing glasses (see references above and McClure et al., 2006; Milisenda et al., 2006). The principle behind this technique of filling fractures was not new, as it had already been applied to diamond (see, e.g., Koivula et al., 1989). However, some modifications were made by using high-temperature furnaces for melting the glass and filling fissures in corundum. Due to the poor durability of the filling material, many problems occurred during jewellery manufacturing/repair and cleaning. The glass filler could be etched by certain acidic or basic solutions, and heat from a jeweller's torch might easily melt the glass.

Although the lead-glass fillers may pose durability problems, there are still certain advantages of these treated products. With proper precautions during jewellery making, repairing and cleaning (e.g. using cold mounting techniques and avoiding contact with acidic or basic solutions), the drawbacks can be avoided. And due to their affordability, mass availability and wide range of quality, these products are still in demand after almost a decade on the market.

In 2012, a new type of blue cobalt-doped lead-glass-filled corundum entered the market (Leelawatanasuk, 2012; Leelawatanasuk et al., 2013). This product showed many identifying features similar to those of the previous lead-glass-filled rubies. Subsequently, Henn et al. (2014) documented additional coloured lead-glass

Figure 1: The five green lead-glass-filled sapphires studied for this report weigh 0.89, 2.79, 5.90, 2.64 and 1.06 ct (from left to right). Photo by N. Atsawatanapirom.

Figure 2: Shown here is an example of the low-quality pale coloured corundum that is used as the starting material for glass filling (bottom right, 3.15 g), together with two fused pieces of corundum and green glass after the treatment process (10.17 and 1.76 g). Photo by N. Atsawatanapirom.

fillings in corundum that were red and pale green. Most recently, in April 2014 GIT-GTL received for examination several rough and cut stones (Figures 1 and 2) that were claimed to be 'the latest lead-glass-treated sapphire'. In December 2014 the owner of the process, Dhiranant Charoenjit (Figure 3), kindly allowed authors NS and SP to visit his facility at Nichima Gems in Chanthaburi Province, eastern Thailand.

According to Charoenjit, the starting material is sorted from low-quality, highly fractured pale-coloured sapphire rough. Some of the corundum shows well-formed hexagonal crystal shapes. The stones are cleaned in an acidic solution to remove impurities from the surface and within the open fissures. After this process, the material appears dull white (Figure 4, left) or is somewhat transparent with many open fissures. The stones are put into an alumina crucible with a sufficient amount of glass powder. The crucible is then heated in an electric furnace to approximately 1,300°C. After treatment, the stones are usually fused together into a glassy mass (e.g. Figure 2). The treatment is reportedly successful on only ~20% of the material, and the remaining 80% is rejected.

Material and Methods

Three pieces of rough and five faceted samples of the treated green sapphire were selected for this study. Standard gemmological equipment was used to obtain refractive indices, hydrostatic specific gravity, pleochroism, and fluorescence to long- and short-wave UV radiation for all of the faceted samples; they also were examined with a gemmological microscope. Chemical analysis by energy-dispersive X-ray fluorescence (EDXRF) spectroscopy was performed on all samples with an Eagle III instrument using an Rh X-ray tube, an accelerating voltage of 30 kV and a beam current of 200 mA. The diameter of the X-ray beam was 2,000 µm, and diffraction artefacts were avoided by sample rotation. Absorption

Figure 3: Dhiranant Charoenjit, managing director of Nichima Gems in Chanthaburi Province, explains the treatment process and shows the material before and after glass filling. Photo by S. Promwongnan.

Figure 4: These images show the corundum starting material after acid cleaning (left), and rough and faceted lead-glass-filled green sapphires after the treatment (centre and right). The rough stones weigh 1–5 g and the faceted samples are 1–3 ct. Photos by S. Promwongnan and N. Susawee.

spectra were recorded on all samples in the mid-infrared range (4000–400 cm^{-1}) with a Thermo Nicolet 6700 Fourier-transform infrared (FTIR) spectrometer equipped with a KBr beam splitter, at a resolution of 4 cm^{-1}. Ultraviolet-visible–near infrared (UV-Vis-NIR) spectra of all samples were recorded in the range 250–800 nm using a PerkinElmer Lambda 950 spectrophotometer with a sampling interval of 3.0 nm and scan speed of 441 nm per minute. X-radiography of all samples was performed using a Softex SFX-100 instrument, and one faceted stone was examined with a DiamondView deep-ultraviolet (<230 nm) luminescence imaging system.

To investigate some of the durability issues associated with lead-glass-filled corundum, preliminary testing was performed on three representative cut stones, which were separately subjected to a soap solution in an ultrasonic cleaning unit, a jewellery torch and a rhodium electroplating agent.

*Table I: Properties of five faceted green lead-glass-filled sapphires.**

Refractive indices	1.760–1.770 (birefringence 0.010)
Polariscope reaction	Doubly refractive
Pleochroism	Slightly dichroic, in greenish yellow to slightly yellowish green
Specific gravity	4.00–4.02
Internal features	Growth tubes, 'fingerprints', lamellar twinning, orange and blue flash effects along filled fissures, green colour concentrations in filled fissures and cavities, flattened gas bubbles trapped in the glass filler
UV fluorescence	
Long-wave	Inert to weak orange
Short-wave	Inert

*Based on the testing of five stones weighing 0.89, 1.06, 2.64, 2.79 and 5.90 ct (see Figure 1).

Gemmological Properties

A distinctive feature of this product is its colour appearance: The faceted stones were yellowish green with low saturation, and the rough samples were a strong green and were coated with deep green glassy material (Figures 1 and 2).

The gemmological properties obtained from the faceted stones (Table I) are consistent with corundum in general. The samples were doubly refractive with RI values of 1.760–1.770. SG was approximately 4.00–4.02. Viewed with a dichroscope, they showed slight dichroism from greenish yellow to slightly yellowish green; the intensity of the green hue remained essentially constant whereas that of the yellow hue varied from pale to almost colourless. Figure 5 shows the differences in dichroism between an untreated green sapphire and this treated material. The dichroism of the treated sapphires suggests that their colour is mainly due to the isotropic green glass filler, and the underlying body colour of the material is likely to be light yellow to almost colourless. The stones were inert to short-wave UV radiation and luminesced weak orange or were inert to long-wave UV.

Microscopic examination proved to be a simple and important method for identifying these treated stones. The five faceted stones all showed features characteristic of natural (i.e. not synthetic) sapphire, such as tube-like features, 'fingerprints' and polysynthetic twinning (Figure 6). In addition, the gems showed many distinct

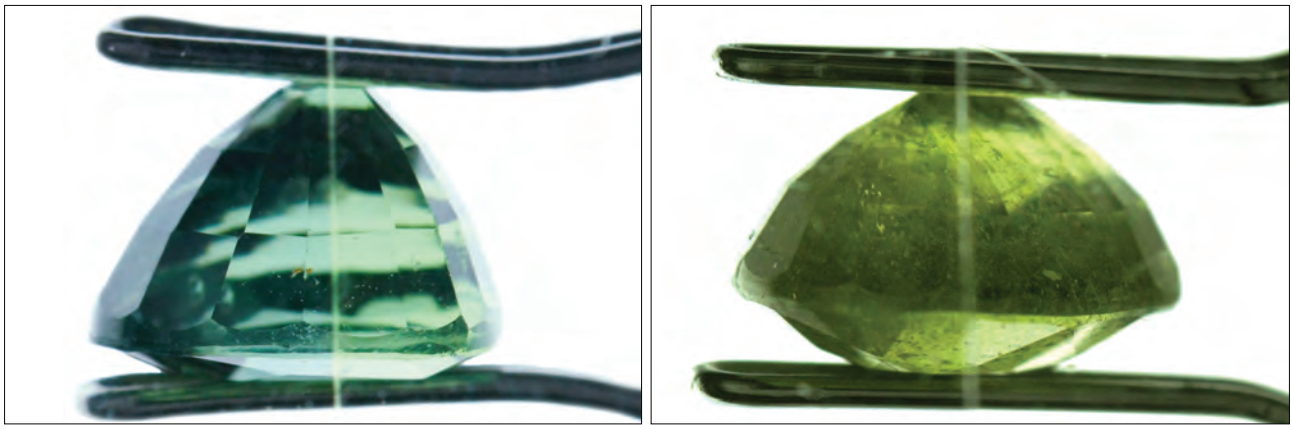

Figure 5: The 2.40 ct untreated green sapphire on the left shows typical bluish green to yellowish green dichroism, in contrast to the 2.79 ct green lead-glass-filled corundum on the right that displays greenish yellow and slightly yellowish green pleochroism. Photos by S. Promwongnan.

microscopic features associated with lead-glass-filled corundum, such as orange and blue flash effects, green colour concentrations along fissures and in cavities, and flattened gas bubbles trapped within filled fissures (Figures 7–9). Reflected light was useful for detecting cavities and fissures that were glass filled, as the surface lustre of the filler was noticeably lower than that of the host sapphire (Figures 9 and 10).

Chemical Composition

Semi-quantitative chemical analysis was performed by EDXRF spectroscopy on the green glassy residue at the surface of a 1.76 g rough sample (see Figure 2) to avoid sampling the host corundum. The analysis showed mostly Pb with some Al (from the corundum) and Si, minor Cu, and traces of Fe and Cr. By contrast, chemical analysis of the cut stones mainly showed the composition of the host sapphire with small amounts of the glassy constituents.

Spectroscopy

The mid-FTIR spectra of the green glass clearly showed strong absorption bands at approximately 3400, 2597 and 2256 cm^{-1} that are related to the glass filler (Figure 11). A UV-Vis-NIR spectrum of the green glass residue protruding from the surface of a rough sample showed strong absorption through almost the entire visible spectrum, except for a transmission window in the green region at ~500–570 nm (Figure 12). This spectral pattern and the presence of Fe, Cu and Cr (measured by EDXRF spectroscopy) suggest that the green coloration

Figure 6: Polysynthetic twinning (left) and tube-like features (right) are characteristics of the natural corundum starting material used for these green lead-glass-filled sapphires. Photomicrographs by N. Atsawatanapirom; magnified 10×.

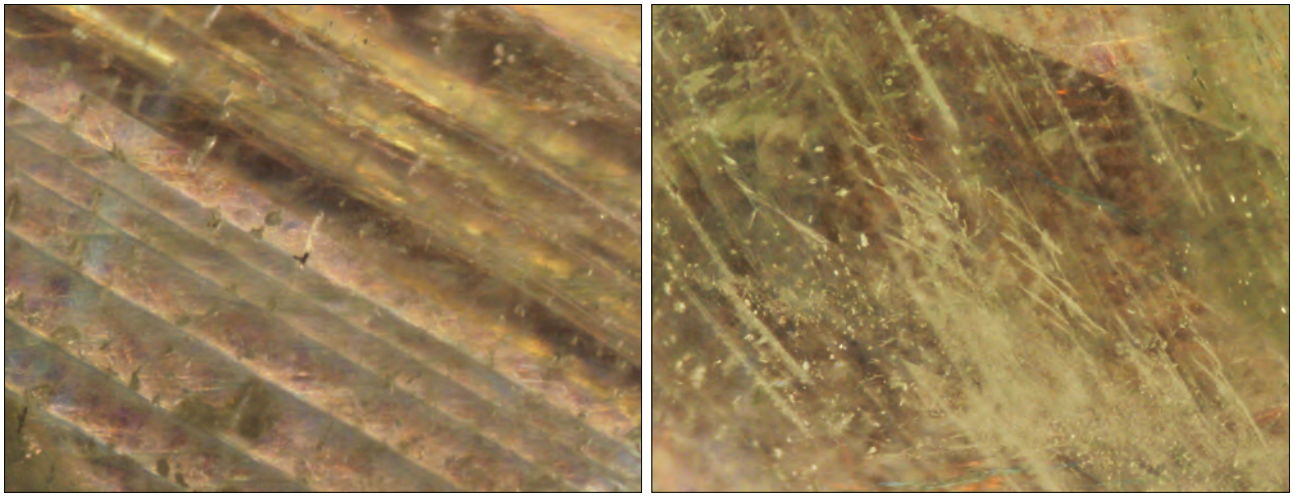

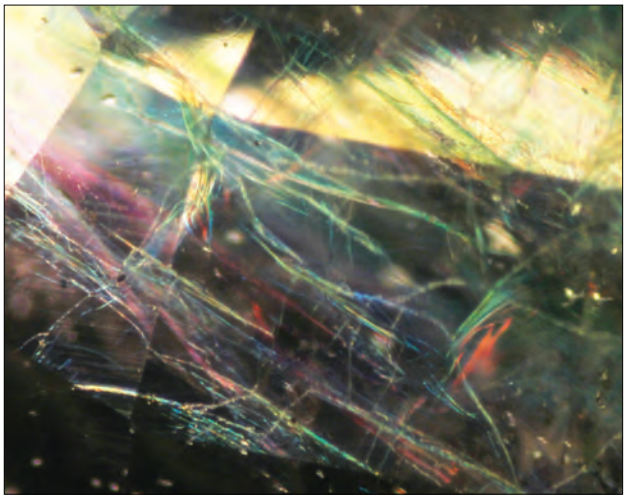

Figure 7: The lead-glass-filled fissures in the corundum show green colour concentrations as well as orange and blue flash effects depending on their orientation to the viewer. Photomicrograph by N. Atsawatanapirom; magnified 16×.

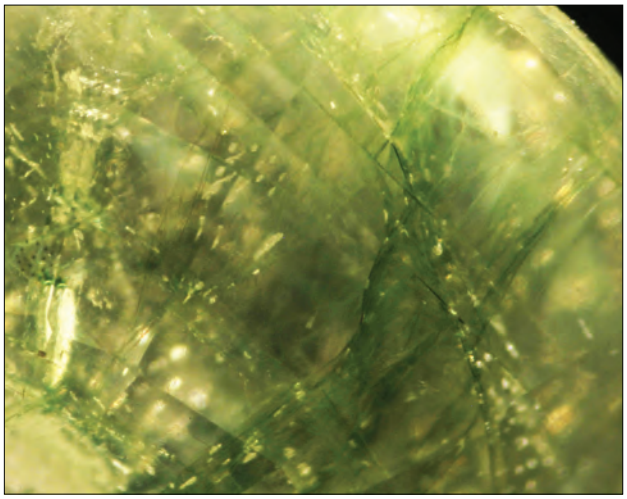

Figure 8: This 2.64 ct lead-glass-filled sapphire exhibits green colour concentrations along fissures that also contain flattened gas bubbles. Photomicrograph by N. Atsawatanapirom; magnified 10×.

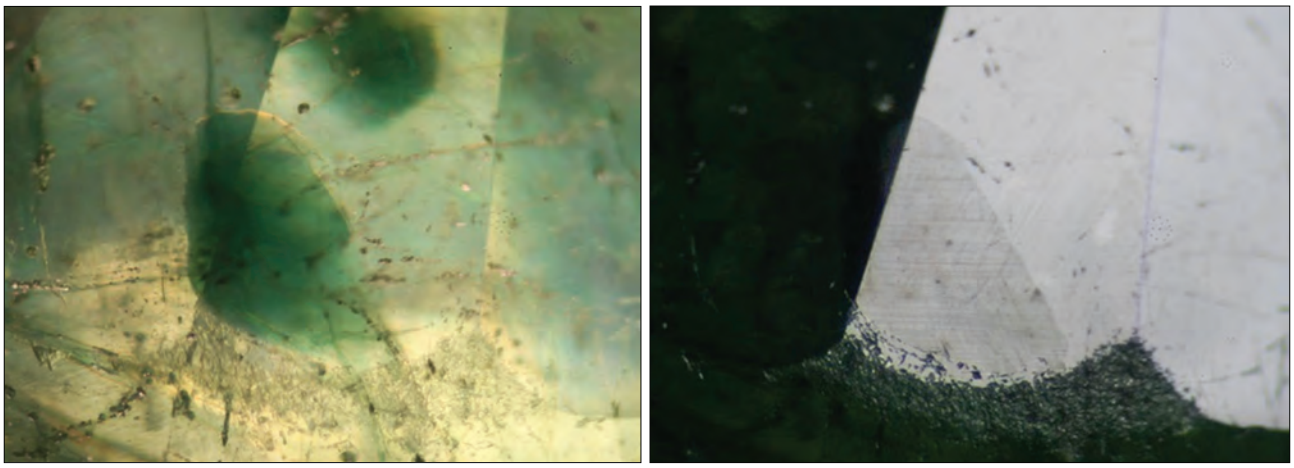

Figure 9: These views show a glass-filled cavity within a treated sapphire in darkfield (left) and reflected light (right). Photomicrographs by N. Susawee; magnified 20×.

Figure 10: Reflected light reveals the lower lustre of the lead-glass filler in fissures (left, magnified 32×) and in a cavity (right, magnified 16×) as compared to the host sapphire. Photomicrographs by N. Atsawatanapirom.

of the glass filler is related to those elements. By comparison, the UV-Vis-NIR absorption spectra of the faceted samples showed strong absorption from around 500 nm toward shorter wavelengths, with a small Fe^{3+}-related peak at ~450 nm and a weak, broad absorption band from ~600 to 800 nm (again, see Figure 12). This pattern is typical of Sri Lankan yellow sapphire (for which the colour is due to the stable colour centres; Pisutha-Arnond et al., 2004) in combination with some absorption contributed by the green glass filler in fissures and/or cavities. This result is consistent with the dichroism observed in the treated material (see Figure 5, right).

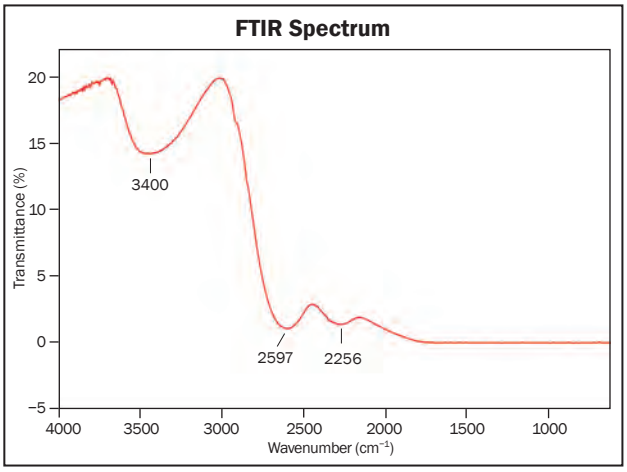

Figure 11: The mid-FTIR spectrum of green glassy residue on the surface of a treated rough sapphire shows strong absorption bands at approximately 3400, 2597 and 2256 cm^{-1}.

X-radiography

As expected, X-radiography of all the samples clearly revealed areas of glass filler within fissures and cavities in the faceted stones (Figure 13) and along the outer surfaces or rims of the rough samples. The filler appears darker than the host sapphire in these positive images; the light and dark patterns correspond to differences in the penetration capability of the X-rays through corundum versus lead glass. Such an appearance is also common for the previous types of lead-glass-filled corundum (e.g. SSEF, 2009).

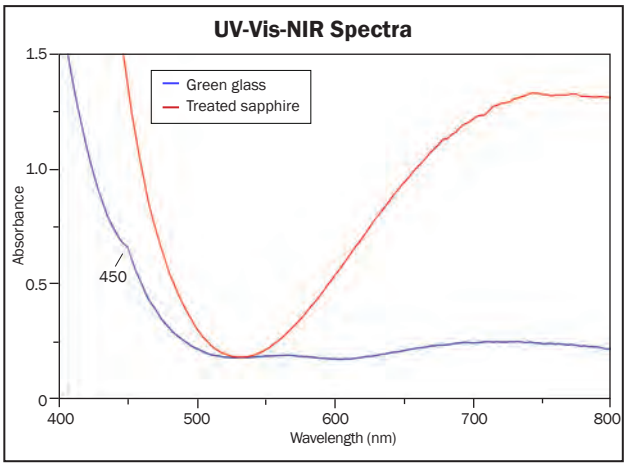

Figure 12: The UV-Vis-NIR spectrum of green glass protruding from a treated rough sapphire shows strong absorption through much of the visible range except for a transmission window in the green region at ~500–570 nm. By contrast, the spectrum of a faceted green lead-glass-filled sapphire shows an absorption edge at ~500 nm extending toward shorter wavelengths, with a small Fe^{3+}-related absorption peak at ~450 nm and a weak, broad absorption band at ~600–800 nm.

DiamondView Imaging

The DiamondView instrument showed intersecting patterns of distinctly chalky blue fluorescence along the glass-filled fissures (Figure 14). Such images can provide valuable information not only for the identification of this type of treatment, but also for giving a rough estimate of the amount of

Figure 13: These X-radiographs of three faceted green glass-filled sapphires (2.64, 5.90 and 2.79 ct, from left to right) show distinct opaque areas along the fractures and cavities. Images by S. Promwongnan.

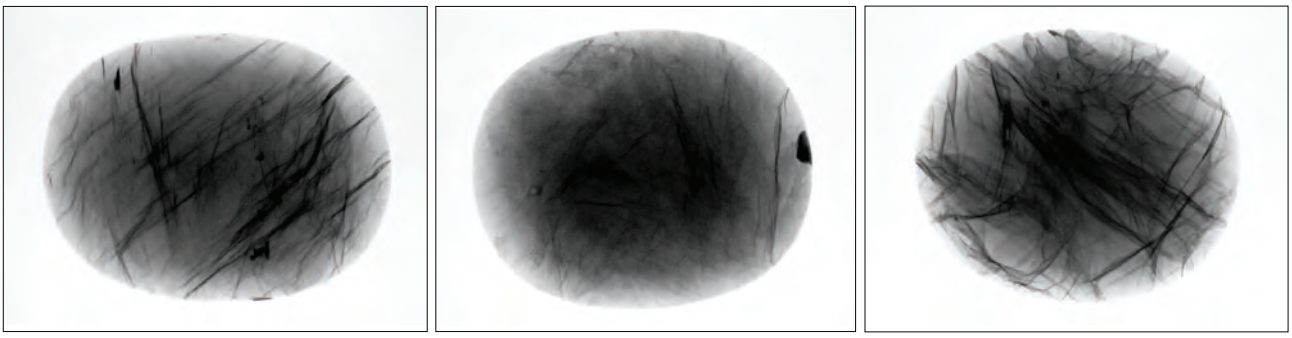

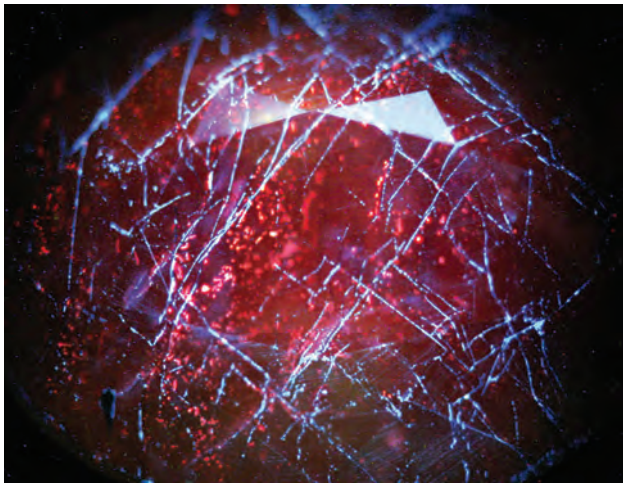

Figure 14: This DiamondView image reveals strong chalky blue fluorescence along the fissures of a 2.64 ct green glass-filled sapphire. Photo by S. Promwongnan.

glass filler that is present in a sample, similar to the X-radiographs.

Preliminary Durability Testing

No damage to the lead-glass filler was observed after ultrasonic cleaning in an ordinary liquid soap solution for 15 minutes.

After exposure to a jewellery torch flame for one minute, some damage was observed on the surface of the lead-glass filler. Subsequent exposure to a strong direct torch flame for 30 seconds caused further damage to the filler.

Immersion in the rhodium electroplating agent for two minutes caused significant damage to the glass filler (Figure 15).

Conclusions

The identification of green lead-glass-filled sapphire is straightforward based on the same criteria used to distinguish previous lead-glass-type treatments. Microscopic observation is probably the simplest method to positively identify such treatments. The most prominent characteristics are orange and blue flash effects and green colour concentrations along fissures, and also flattened gas bubbles trapped within the glass-filled fissures.

EDXRF chemical analyses can reveal the presence of Pb and Si, along with Fe, Cu and Cr that probably act as colouring agents for the green glass filler. Furthermore, FTIR spectroscopy is also useful for proving the existence of a glass filling in such stones. X-radiography can help confirm the presence of lead glass, as well as give a rough estimation of the amount of filling material present in a sample. DiamondView images show chalky blue fluorescence along fissures and cavities, and also can help quantify the degree of filling.

Preliminary durability testing revealed some damage to the glass filler from a jewellery torch and rhodium electroplating solution, similar to results obtained previously for lead-glass-filled corundum (McClure et al., 2006; Leelawatanasuk, 2012; LMHC, 2012; Leelawatanasuk et al., 2013). Thus, we recommend that jewellers and consumers handle these treated stones with the special care that is typically recommended for lead-glass-filled materials.

Figure 15: Lead-glass-filled fractures within the table of a sapphire are shown in reflected light before (left) and after (right) immersion in a rhodium electroplating agent for two minutes. The filler significantly dissolved, leaving many open fractures. Photomicrographs by S. Promwongnan; magnified 15×.

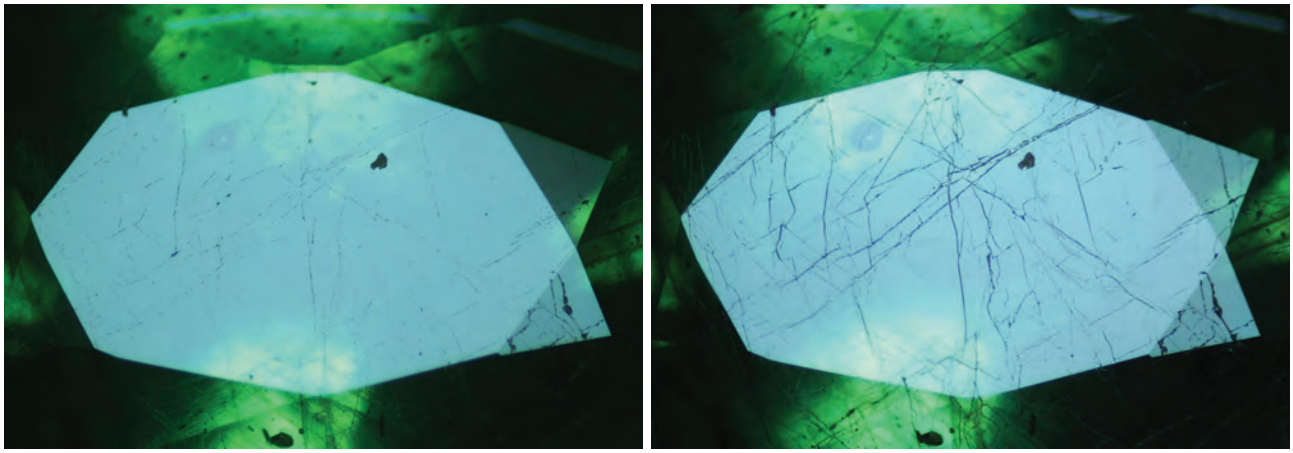

Glass-filled corundum has been circulating in the gem market for many years. With recent developments in this type of treatment, green glass-filled sapphires are now available. There also is the potential for additional colours of glass fillers to be developed in the future.

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Demantoid from Balochistan, Pakistan: Gemmological and Mineralogical Characterization

Ilaria Adamo, Rosangela Bocchio, Valeria Diella, Franca Caucia and Karl Schmetzer

During the past few years, small demantoid crystals, indicated as coming from the Muslim Bagh area of Balochistan Province, have been available occasionally in the gem market in Peshawar, Pakistan. The gemmological properties and chemical data for this material are reported here. These bright green to yellowish green garnets are almost pure andradite (typically ≥98 mol.%, with RI >1.79 and SG = 3.80–3.90). They contain inclusions of serpentine-group minerals, including the well-known fibrous 'horsetails', which are characteristic of a serpentinitic geological origin. Black crystals of Cr-rich magnetite are also common inclusions in demantoid from this relatively new locality. Iron and traces of chromium cause the green colour of these garnets.

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Introduction

Demantoid, the green variety of andradite [$Ca_3Fe_2(SiO_4)_3$], is one of the most appreciated gems of the garnet group (O'Donoghue, 2006). The traditional sources are Russia and Italy, whereas commercially important deposits recently have been found in northern Madagascar, southeast Iran, northern Pakistan (Kaghan Valley) and central Namibia (Philips and Talantsev, 1996; Lind et al., 1998; Quinn, 2005; Du Toit et al., 2006; Adamo et al., 2009, 2011; Pezzotta et al., 2011).

In recent years, gem-quality demantoid crystals have occasionally appeared in Pakistan's Peshawar gem market that are indicated as having come from the Muslim Bagh area of Balochistan, a large province in south-west Pakistan. Brown and orange-brown andradite gems from Balochistan have previously been reported by Fritz and Laurs (2007), whereas recently Palke and Pardieu (2014) also described the occurrence of green samples (demantoid).

The garnets consist of well-formed dodecahedral crystals with an attractive green to yellowish green colour, although they are typically very small, rarely exceeding 1 ct (e.g. Figure 1). Bigger pieces of rough (up to 25 ct) are also available, but they are too included to cut larger stones.

The geology of the Muslim Bagh area locally consists of a nearly complete ophiolite sequence, mainly composed of peridotite (i.e. harzburgite and dunite) that is partially to completely serpentinized, with many outcrops of dunite containing chromite deposits (Kakar et

Figure 1 (above): A small demantoid deposit in Balochistan, Pakistan, is reportedly the source of these fine demantoid crystals (0.78–0.98 ct), which were among those studied for this article. Photo by Stefan Hanken.
Figure 2 (right): These round brilliants (0.05–0.10 ct) are some of the demantoid gems from Balochistan investigated for this study. Photo by Andrea Zullino.

al., 2013). Naeem et al. (2014) briefly mentioned a variety of gems and minerals that are found in this area, including 'tsavorite garnet', but not demantoid.

This study provides a gemmological and mineralogical characterization of demantoid from Balochistan, investigating rough and cut samples by means of standard gemmological methods, as well as electron microprobe and laser ablation–inductively coupled plasma–mass spectroscopy (LA-ICP-MS) chemical analyses.

Materials and Methods

We examined 30 demantoid samples from Balochistan, consisting of 20 pieces of rough (0.18–0.98 ct; e.g. Figure 1) and 10 melee-sized faceted specimens (0.05–0.10 ct; e.g. Figure 2). All of the samples, which were kindly provided by a collector, were examined by standard gemmological methods to determine their optical properties, SG, UV fluorescence and microscopic features.

Quantitative chemical analyses were obtained from polished surfaces of four rough samples by electron microprobe analysis (EMPA) using a JEOL JXA-8200 instrument in wavelength-dispersive mode, with an accelerating voltage of 15 kV, beam current of 15 nA, and count times of 60 s on peaks and 30 s on background. The following elements were measured: Na, Mg, Al, Si, K, Ca, Ti, V, Cr, Mn, Co and Fe. The raw data were corrected for matrix effects using a conventional $\varphi\rho Z$ routine in the JEOL software package.

To compare the composition of these Balochistan samples with demantoid from various localities (see Bocchio et al., 2010), we measured the trace-element composition of five rough samples from Balochistan (including the four analysed by EMPA) by means of LA-ICP-MS. The instrument consisted of a Quantel Brilliant 266 nm Nd:YAG laser coupled to a PerkinElmer DRCe quadrupole ICP-MS. The external calibration standard was NIST-SRM612 glass, and Ca was the internal standard. The spot size was 50 µm. The following elements were analysed: Sc, Ti, V, Cr, Co, Ni, Zn, Sr, Y, Zr, La, Ce, Nd, Sm, Eu, Gd, Tb, Dy, Er, Yb and Lu.

Results and Discussion

Standard Gemmological Properties

The standard gemmological properties of the Balochistan samples are summarized in Table I, and are typical of andradite (cf. O'Donoghue, 2006). All the samples were bright green or yellowish green with low-to-moderate saturation (Figures 1 and 2). The crystals were well formed, with the dodecahedron {110} as the dominant form (Figure 1). A few specimens also showed some intergrown individuals that may be associated with dodecahedral twinning (Figure 3). Nearly all the samples contained fibrous crystalline inclusions, identified as chrysotile by EMPA, in the typical 'horsetail' arrangement (Figure 4). These curved fibres of chrysotile were sometimes associated

with opaque whitish masses, chemically identified as serpentine-group minerals, probably antigorite (Figure 4, right). Opaque black crystalline inclusions, identified by EMPA as Cr-bearing magnetite, were often present (Figure 5). These internal features are characteristic of serpentinite-hosted demantoid, as is also the case for stones from Russia, Italy, Iran and northern Pakistan (Phillips and Talantsev, 1996; Milisenda et al., 2001; Gübelin and Koivula, 2005; Du Toit et al., 2006; Adamo et al., 2009). In particular, the inclusions closely resemble those in demantoid from Val Malenco, Italy (Adamo et al., 2009), whereas the acicular diopsides reported in some demantoid samples from Russia (Krzemnicki, 1999) were not observed in our Balochistan samples.

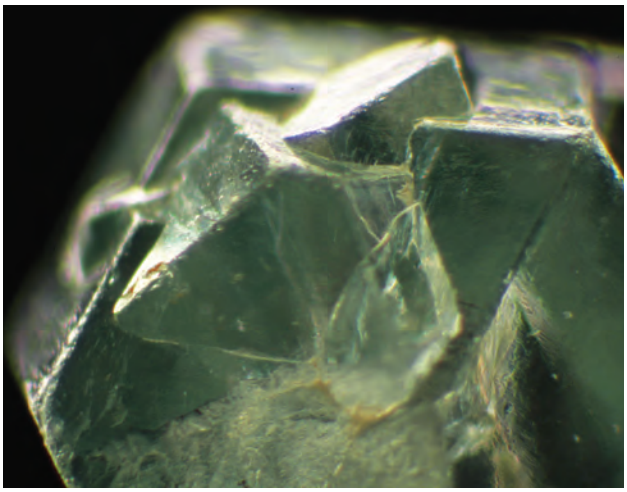

Figure 3: Several intergrown crystals show re-entrant angles that may indicate dodecahedral twinning in this demantoid sample from Balochistan. Photomicrograph by Andrea Zullino; magnified 20×.

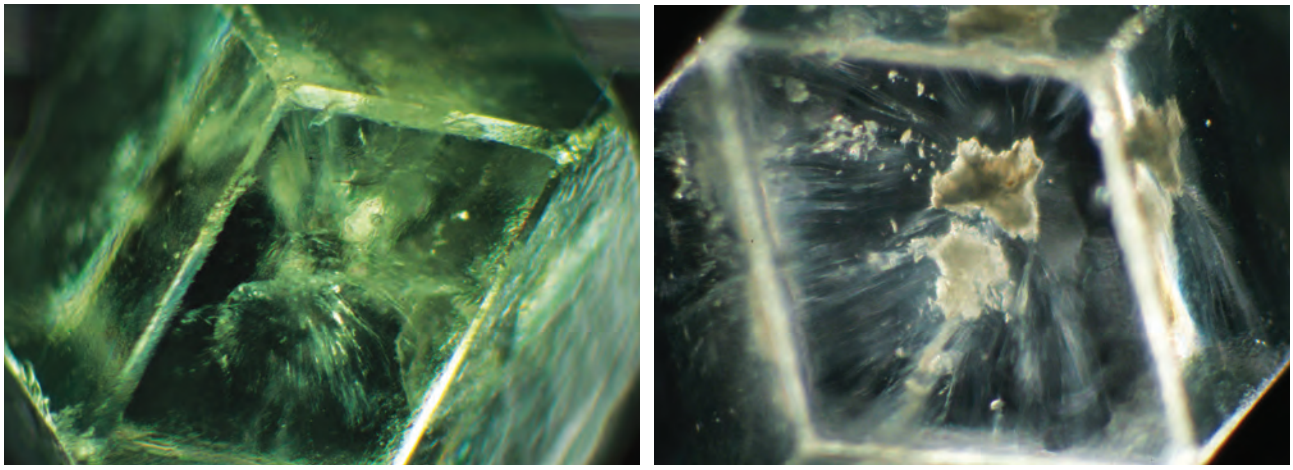

Figure 4: Fibrous (chrysotile; left) and massive (probably antigorite; right) serpentine-group mineral inclusions are seen in these demantoid samples from Balochistan. Photomicrographs by Andrea Zullino; magnified 45×.

Table I: Gemmological properties of demantoid from Balochistan, Pakistan.

Colour	Green to yellowish green
Diaphaneity	Transparent
Optic character	Optically isotropic with moderate to strong anomalous double refraction
RI	Greater than 1.79
SG	3.80–3.90
Fluorescence	Inert to long- and short-wave UV
Internal features	'Horsetail' and fibrous crystalline inclusions (chrysotile), whitish opaque inclusions (probably antigorite), black opaque crystals (Cr-bearing magnetite), growth structures and fractures

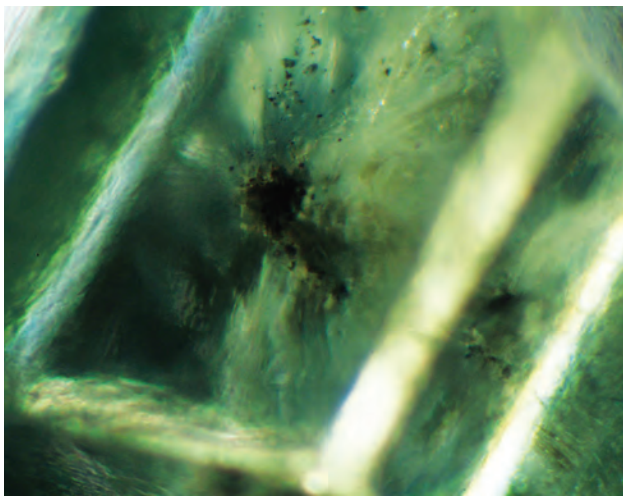

Figure 5: Inclusions of Cr-rich magnetite are present in this demantoid crystal from Balochistan. Photomicrograph by Andrea Zullino; magnified 45×.

Table II: Chemical composition obtained by EMPA of demantoid from Balochistan, Pakistan.[a]

Sample	1	3	4	21	4-5[b]	4-6[b]	4-7[b]	4-2[b]
No. analyses	40	40	60	40	1	1	1	1
Oxides (wt.%)								
SiO_2	35.75	35.73	35.67	35.83	35.42	35.29	34.98	35.45
TiO_2	0.02	0.01	0.02	0.01	0.02	bdl[c]	0.05	bdl
V_2O_3	0.02	0.01	0.01	0.01	0.03	bdl	bdl	bdl
Al_2O_3	0.14	0.18	0.11	0.11	0.08	0.05	0.14	0.04
Cr_2O_3	bdl	bdl	bdl	bdl	0.92	0.21	0.21	0.08
Fe_2O_3 tot	30.79	30.73	30.86	30.91	30.28	31.02	30.44	30.93
MnO	0.02	0.02	0.02	0.02	0.05	0.03	0.03	0.04
MgO	0.21	0.20	0.18	0.18	0.13	0.12	0.12	0.11
CaO	33.40	33.39	33.36	33.37	33.00	33.18	32.93	33.11
Na_2O	0.02	0.01	0.01	0.01	bdl	bdl	bdl	bdl
Total	100.36	100.27	100.22	100.45	99.92	99.90	98.90	99.76
Ions calculated on 12 oxygens								
Si	3.007	3.007	3.006	3.011	2.996	2.989	2.990	3.004
Ti	0.001	0.001	0.001	0.001	0.001	bdl	0.001	bdl
V	0.001	0.001	0.001	0.001	0.002	bdl	bdl	bdl
Al	0.014	0.018	0.011	0.011	0.008	0.005	0.014	0.004
Cr	bdl	bdl	bdl	bdl	0.061	0.014	0.015	0.005
Fe^{3+}	1.948	1.946	1.956	1.954	1.927	1.977	1.958	1.972
Mn	0.001	0.001	0.001	0.001	0.003	0.002	0.002	0.003
Mg	0.027	0.026	0.022	0.022	0.016	0.015	0.016	0.014
Ca	3.010	3.011	3.011	3.004	2.990	3.011	3.016	3.005
Na	0.002	0.001	0.002	0.001	bdl	bdl	bdl	bdl
Mol.% end-members								
Andradite	98.14	98.10	98.50	98.53	95.74	98.49	97.83	98.99
Pyrope	0.88	0.84	0.74	0.73	0.54	0.51	0.52	0.46
Grossular	0.71	0.90	0.54	0.55	0.41	0.24	0.70	0.19
Uvarovite	-	-	-	-	3.05	0.69	0.73	0.27
Others	0.26	0.16	0.22	0.18	0.25	0.07	0.23	0.10

[a] K and Co were analysed for, but not detected.
[b] Analysis points indicated in Figure 6 (left).
[c] Abbreviation: bdl = below detection limit.

Chemical Composition

The chemical compositions obtained by EMPA and LA-ICP-MS of demantoid from Balochistan are reported in Tables II and III, respectively.

Electron microprobe analyses showed that the garnets consist of nearly pure andradite (typically ≥98 mol.%), with the exception of Cr-rich zones of the crystals located close to Cr-bearing magnetite inclusions. This composition is typical of gem-quality demantoid (Bocchio et al., 2010; Adamo et al., 2011). Traces of Mg, Al, Ti, V, Cr and Mn also were measured. In particular, Cr ranged from below the detection limit of the microprobe (0.01 wt.%) up to ~1 wt.% Cr_2O_3 measured adjacent to a Cr-bearing magnetite inclusion that itself contained ~16 wt.% Cr_2O_3 (Figure 6). The Cr content of the garnet decreased with increasing distance from such inclusions, as demonstrated by analyses 4-5 through 4-7 in Table II. Magnetite and Cr-rich magnetite are common in demantoid associated with serpentinites, and their presence has been described in detail by Adamo et al. (2009) in demantoid from Val Malenco.

The trace elements measured by LA-ICP-MS are generally comparable with the contents previously reported for demantoid samples with

*Table III: Trace-element composition obtained by LA-ICP-MS of demantoid from Balochistan, Pakistan.**

Sample	1	3	4	10	21
Trace elements (ppm)					
Sc	2.50	1.62	2.79	1.25	0.93
Ti	12.7	42.1	33.1	13.7	12.6
V	9.54	8.09	9.72	5.81	3.14
Cr	16.1	18.1	23.6	3.85	3.71
Co	0.93	1.03	0.80	1.02	1.07
Ni	0.79	bdl	1.05	0.38	0.35
Zn	bdl	3.26	bdl	3.08	bdl
Sr	0.04	0.04	0.06	0.07	0.04
Y	0.10	0.09	0.03	0.01	0.04
Zr	0.07	0.04	bdl	bdl	0.10
La	2.04	0.87	0.30	1.05	1.34
Ce	0.66	0.32	0.20	0.19	0.58
Nd	0.11	0.05	0.02	0.06	bdl
Sm	bdl	bdl	bdl	0.12	0.11
Eu	1.99	bdl	bdl	bdl	bdl
Gd	bdl	bdl	0.007	bdl	bdl
Tb	bdl	0.54	bdl	bdl	bdl
Dy	bdl	0.17	0.03	bdl	0.11
Er	0.25	bdl	0.01	0.11	bdl
Yb	0.32	0.04	0.03	bdl	0.14
Lu	bdl	bdl	bdl	0.16	0.35
ΣREE	5.36	1.98	0.60	1.70	2.62

* Average of three analyses each. Abbreviation: bdl = below detection limit.

andradite contents of >98 mol.% and related to serpentinitic environments (Bocchio et al., 2010). However, compared to the data of the sample from northern Pakistan (Kaghan Valley) analysed by Bocchio et al. (2010), the Balochistan demantoid appears depleted in all the elements forming the 'first transition series' (i.e. Sc, Ti, V, Cr, Co, Ni and Zn) and also contains lower Y and Zr. This is also in agreement with the data of Milisenda et al. (2001), who found higher amounts of chromium (average 0.15 wt.% Cr_2O_3) in demantoid from the Kaghan Valley.

The content of rare-earth elements (REE) compares well with that of other demantoid samples associated with serpentinites, showing a general light rare-earth (LREE) enrichment and heavy rare-earth (HREE) depletion. Conversely, the LREE/HREE ratio (La/Yb = 4.31–14.42) is higher than that calculated for the Kaghan Valley sample (La/Yb = 0.06). Only two of our analyses exhibited a strong Eu anomaly because this element was otherwise not detected.

Concluding Remarks

Demantoid reportedly from Balochistan, Pakistan, appears occasionally in the Peshawar gem market as crystals rarely exceeding 1 ct that are suitable for faceting melee-sized gems (generally smaller than 0.20 ct). The gemmological properties,

Figure 6: This back-scattered electron image (left) and X-ray map showing Cr concentration (right) depict inclusions of serpentine and Cr-bearing magnetite in a demantoid from Balochistan. The high Cr content of the magnetite grain is clearly indicated in the X-ray map. The numbers in the left image correspond to the analyses points given in Table II.

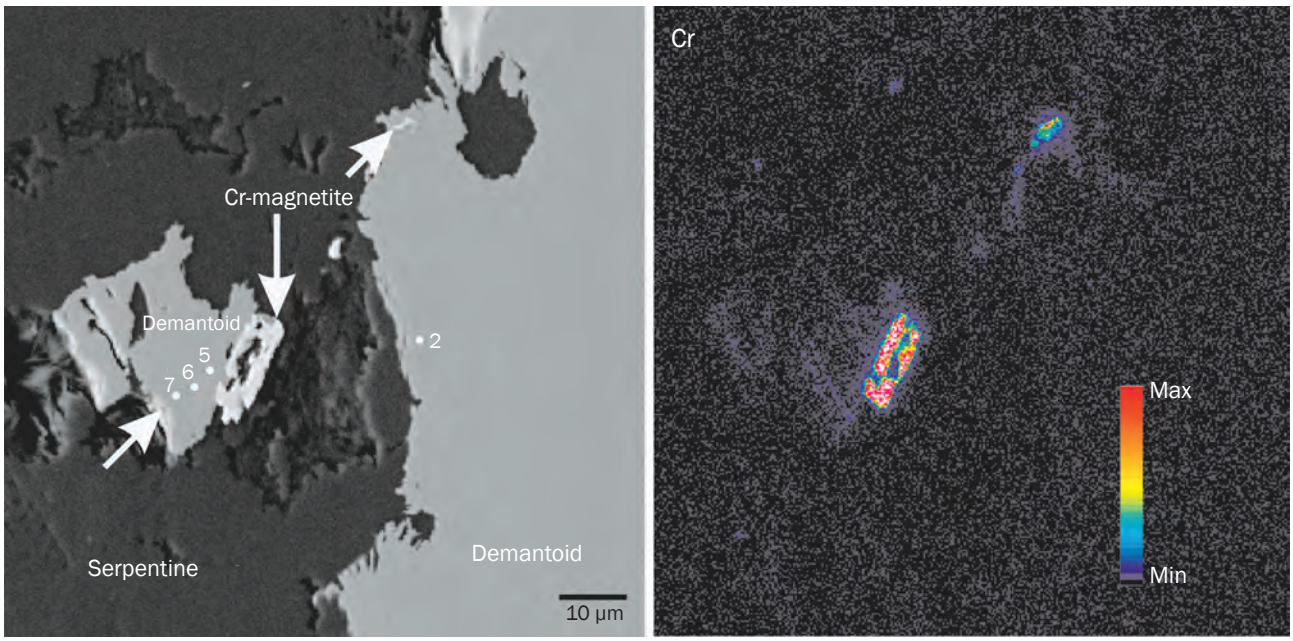

microscopic features and chemical composition of these demantoid gems are consistent with those from other sources associated with serpentinite host rocks. Information about the future potential of the Balochistan deposit is currently unknown.

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Nail-head Spicules as Inclusions in Chrysoberyl from Myanmar

Karl Schmetzer and Michael S. Krzemnicki

Multiphase inclusions developed in the form of nail-head spicules in a colourless chrysoberyl crystal from Myanmar were examined by optical means and by Raman microspectroscopy. The growth tubes of the multiphase inclusions contain CO_2, and the grains attached to the ends of these tubes are most likely chrysoberyl crystals (based on Raman spectra and observation of birefringence), some of which are partially covered with an iron-bearing substance, and possibly also negative crystals.

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Introduction

Nail-head spicules are sometimes found as inclusions in synthetic gem materials (e.g. synthetic emerald or quartz), but occasionally also in natural gems such as sapphire, spinel, tourmaline and quartz (Schmetzer et al., 1999, 2011; Choudhary and Golecha, 2007). Recently, one of the authors (KS) examined a group of rough and faceted, slightly yellow, greenish yellow or colourless chrysoberyls from Myanmar that afforded an opportunity to augment the foregoing list. The samples had been obtained from a collector, who bought them in the trade. The chrysoberyls were said to originate from the Mogok region of Myanmar. One of them contained nail-head spicules, and this note describes that crystal's morphology and its inclusions.

Results

The colourless chrysoberyl (Figure 1a) consisted of a 6.2 × 5.2 mm tabular crystal with broken ends. The main tabular face was determined by optical means (i.e. by the position of both optic axes; see Schmetzer, 2011) as the **b** {010} pinacoid. Because the crystal was broken at both ends, we could determine only two additional forms: a smaller **a** {100} pinacoid and a small **m** {110} prism. Several complete slightly yellow or colourless crystals from the same group showed a similar tabular habit with a dominant **b** pinacoid, and one typical example is depicted in Figure 2.

The subject crystal contained several growth tubes running parallel to the c-axis, with colourless or slightly yellowish brown inclusions at one end of the elongated cavities (Figure 1a,b). One of the two larger growth tubes (labelled A in the figures) was completely trapped within the colourless host, but the second (labelled B) was open at its end to the surface of the broken crystal. With permission from the owner of the crystal, one of the **b** faces was polished to allow better examination of the inclusions. Growth tube A was colourless with a homogeneous, transparent appearance, while tube B was partly filled with an inhomogeneous-appearing yellowish brown fine-grained material (Figure 3).

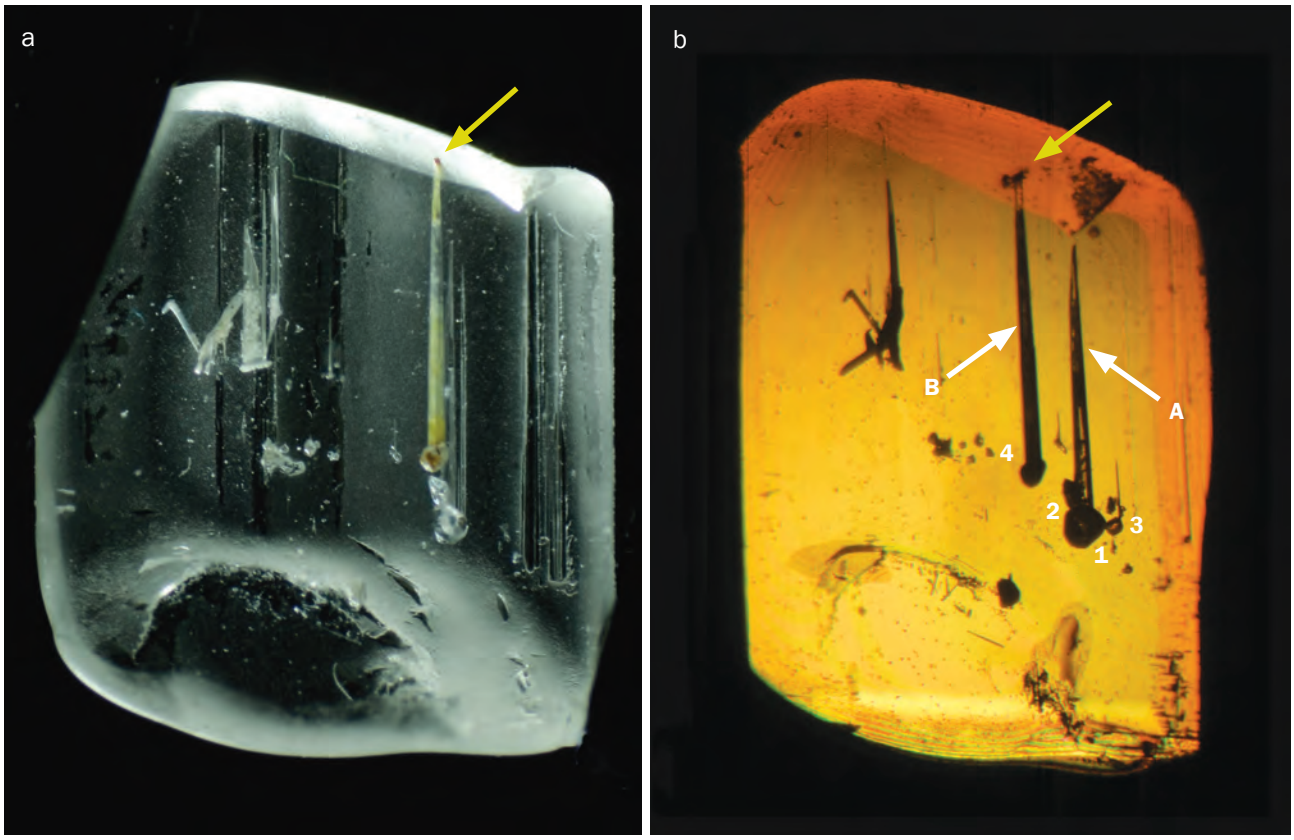

Figure 1: This colourless tabular chrysoberyl crystal (6.2 × 5.2 mm) reportedly from the Mogok area of Myanmar was studied for this report, and is shown in reflected light (a; photomicrograph by M. S. Krzemnicki) and in immersion between crossed polarizers (b; photomicrograph by K. Schmetzer). It contains multiphase inclusions consisting of growth tubes (labelled A and B) with attached grains (labelled 1–4). Growth tube A is completely trapped within the chrysoberyl host, while tube B is open at its end to the broken surface of the host (yellow arrows).

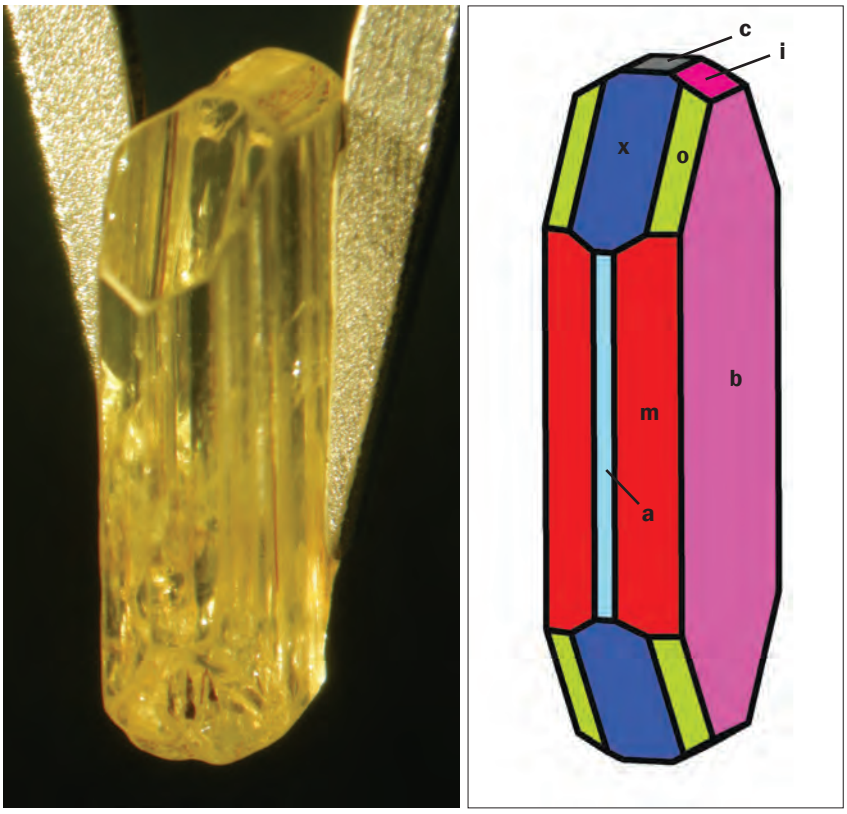

*Figure 2: This yellow chrysoberyl crystal (2.8 × 10.4 mm) reportedly from the Mogok area of Myanmar shows a tabular habit parallel to **b** {010}; similar crystals were frequently seen within the group of samples examined. The crystal forms determined are the pinacoids **a** {100}, **b** {010} and **c** {001}, the prisms **i** {011}, **x** {101} and **m** {110}, as well as the dipyramid **o** {111}. Photomicrograph and crystal drawing by K. Schmetzer.*

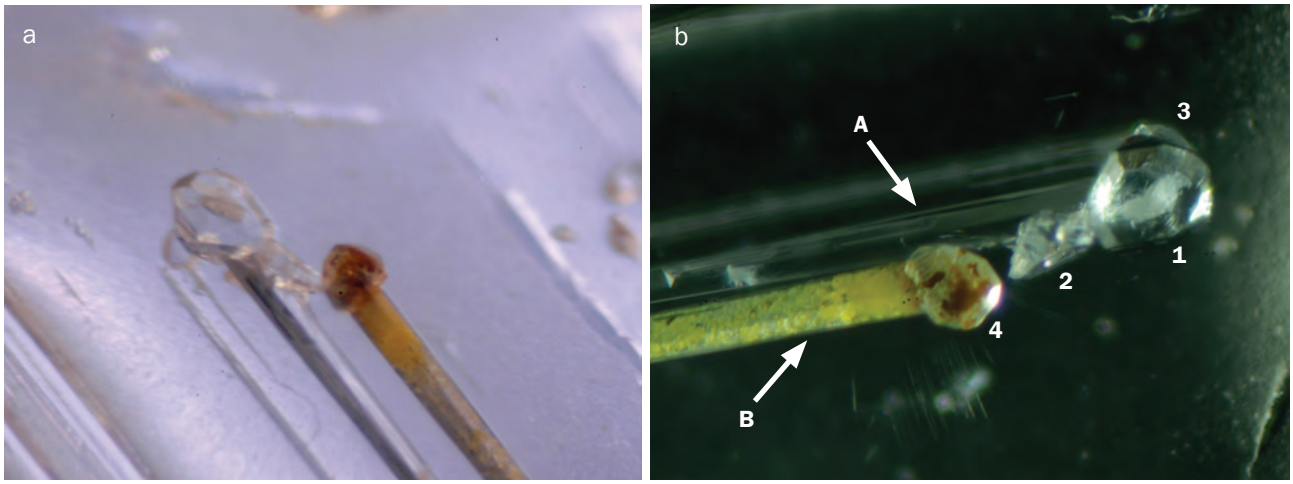

Figure 3: The colourless chrysoberyl crystal contains multiphase inclusions in the form of nail-head spicules. These inclusions consist of growth tubes (A and B) with attached grains showing euhedral crystal forms (1, 3 and 4) or irregular shapes (2). The high-relief appearance of the crystalline inclusions in photo b is due to the use of reflected light with a dark background to obtain the maximum contrast for these tiny colourless inclusions. The field of view of the images is 2.0 × 1.5 mm (a) and 1.8 × 1.3 mm (b); photomicrographs by M. S. Krzemnicki.

Attached to the end of tube A we observed one irregularly shaped colourless inclusion (labelled 2) and one colourless inclusion (labelled 1) with a tabular habit and clearly visible crystal faces (Figure 3). Within the tabular inclusion 1 was a central area that appeared milky white. Close to this assemblage we observed an additional colourless inclusion (labelled 3) attached to a small growth tube (not labelled in the figures).

At the end of tube B, another inclusion (labelled 4) with plane faces was seen, and part of the surface of this inclusion was covered with a yellowish brown phase (Figure 3). Between crossed polarizers (Figure 4), the colourless inclusions (1, 2 and 3) attached to closed growth tubes showed birefringence, but grain 4 attached to growth tube B was opaque.

Figure 4: Viewed between crossed polarizers, the grains at the end of the growth tubes (A and B) show birefringence (1, 2 and 3) or appear dark (4). The image was taken in immersion with a field of view of 2.5 × 1.9 mm; photomicrograph by K. Schmetzer.

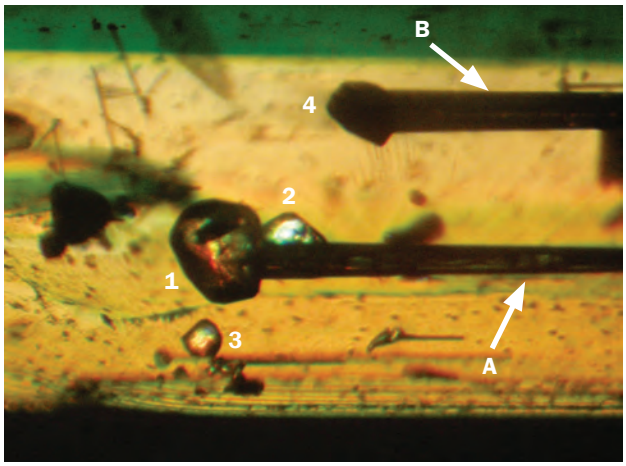

An examination of the inclusions with Raman micro-spectroscopy revealed the presence of CO_2 in growth tube A that was completely trapped within the host chrysoberyl (Figure 5). The various colourless inclusions (1, 2 and 3) at the ends of the enclosed growth tubes showed only the Raman spectra of the chrysoberyl host. Conversely, inclusion 4 at the end of the open tube B, which was at least partly covered with a yellowish brown substance, showed Raman lines for chrysoberyl along with additional peaks corresponding to iron oxides and/or iron hydroxides (Figure 5).

Discussion

Raman spectroscopy of tiny inclusions trapped in a transparent host frequently reveals a spectrum that consists of the characteristic Raman lines of the host with additional lines of the solid or fluid inclusion. If a solid inclusion is identical to the host, Raman spectroscopy cannot separate the two solid phases. Consequently, a Raman spectrum of an inclusion showing only the lines of the host could indicate either a mineral phase identical with the host or a cavity (i.e. a negative crystal). Grains 1, 2 and

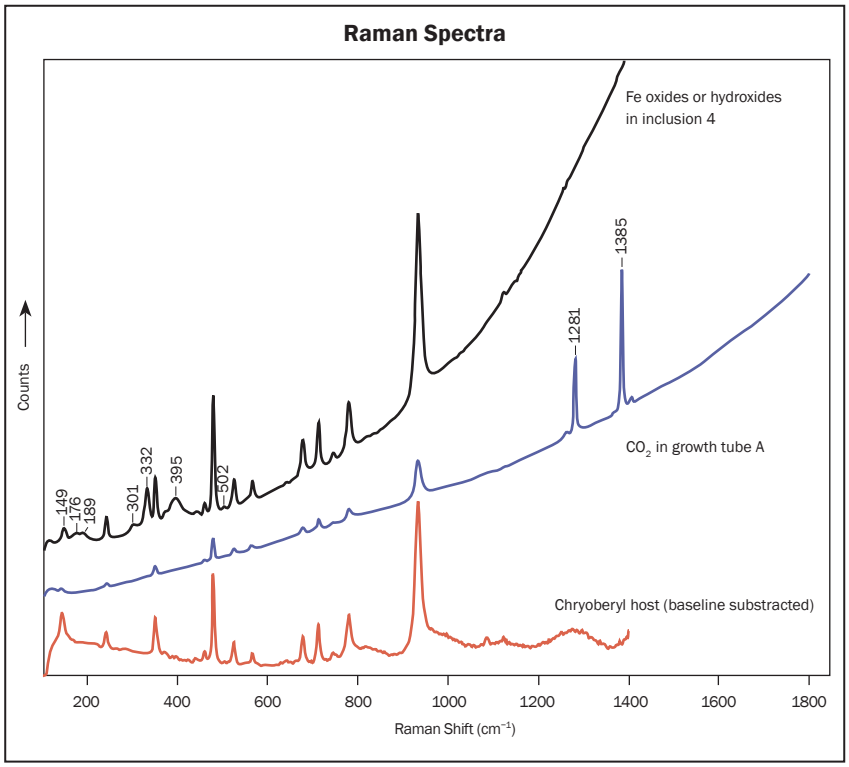

Figure 5: Raman micro-spectroscopy of inclusions in the chrysoberyl showed the presence of iron oxides or hydroxides in the yellowish brown inclusion 4 at the end of the open tube B (top spectrum) as well as the presence of CO_2 in growth tube A (middle spectrum); the bottom spectrum shows only the Raman lines of the host chrysoberyl. Peak labels are provided for the inclusion phases present.

3 showed the Raman spectrum of chrysoberyl and were birefringent. These results indicate that the grains are chrysoberyl. Such inclusions of chrysoberyl in chrysoberyl are rare but have been described occasionally, such as in alexandrite from the Lake Manyara deposit in Tanzania (Schmetzer and Malsy, 2011). In both that alexandrite and the present sample, the orientation of the chrysoberyl inclusions was different from that of the chrysoberyl host.

For grain 4 at the end of tube B that is open to the surface, the Raman spectrum showed lines for chrysoberyl and an additional iron-bearing phase. The microscopic examination did not show birefringence, but this could be due to the low magnification of the gemmological microscope and/or the presence of the iron-bearing material. The yellowish brown substance could cover the surface of a trapped tiny chrysoberyl crystal; could fill, at least partly, the cavity of a negative crystal; or could adhere to the walls of such a negative crystal. However, because a nail-head spicule requires an obstacle during the growth of the host crystal, the first possibility is most likely.

The fine-grained inhomogeneous material in the open tube B may be of secondary origin, a scenario sometimes described as 'iron staining'. This scenario includes the possibility of iron staining of at least a part of the surface of a chrysoberyl crystal trapped at the end of such an open tube.

Although we could confirm the presence of chrysoberyl crystals at the ends of other growth tubes—and although the trapping of a tiny chrysoberyl crystal with iron staining is the most likely scenario—the possibility of a negative crystal terminating the open tube B could not be completely excluded. Only a destructive examination (cutting the host crystal to expose the surface of the inclusion) might afford a definitive explanation.

Conclusion

Colourless chrysoberyl, reportedly from Myanmar, may be added to the list of natural gem materials that have been found to contain multiphase nail-head spicules, consisting in this instance primarily of growth tubes with attached euhedral or irregular chrysoberyl crystals.

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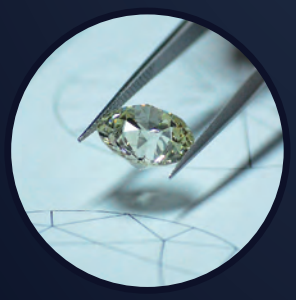

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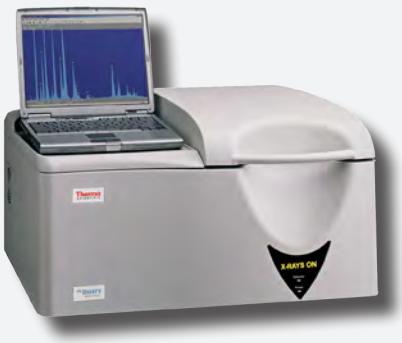

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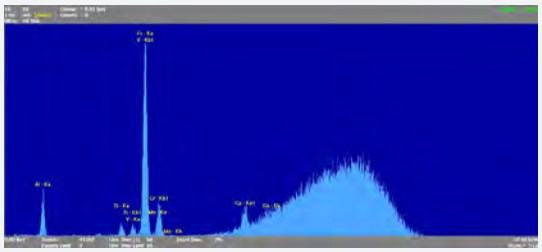

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Letters

Photoluminescence of Emeralds: Sample Orientation Procedure and Correlation of the R_1 Peak Position with SiO_2 Contents

The *Journal* article by Thompson et al. (2014) presented an interesting new contribution to the matter of emerald origin determination. The authors measured polarized laser-induced photoluminescence spectra of emeralds, focusing on the R_1 and R_2 chromium emission lines, and recorded differences in the peak positions and peak height ratios of these lines. The spectra of 32 natural and synthetic emeralds were measured, including both rough and cut samples.

For crystals containing prism faces and, consequently, a known orientation of the c-axis, the authors rotated the samples to obtain spectra with various orientations to the fixed incident laser beam. Because of the known crystallographic orientation, the recorded spectra were easily assigned to E||c and E⊥c, since for E⊥c, the R_1/R_2 peak-height ratio reached a maximum value. For samples without crystal faces and hence with unknown crystallographic orientation, the emeralds were rotated until the R_1/R_2 peak-height ratio reached such a maximum value, and this direction was considered to represent the E⊥c spectrum. Unfortunately, details of this experimental procedure were not given by the authors, and such information also is not available in previous papers (e.g. Moroz et al., 1998, 2000; Carceller-Pastor et al., 2013) that describe the Cr emissions for crystals with known orientation (i.e. with their c-axis oriented parallel or perpendicular to the incident laser beam).

Upon request, Dr Thompson kindly provided the requisite further details that would enable other scientists to replicate the technique and thereby to obtain comparable results. He explained that two rotation axes were employed, aligned at right angles to each other, and that numerous spectra were recorded in each rotation cycle. A detailed description of the method will be published in a forthcoming paper (D. B. Thompson, pers. comm., 2015).

Regrettably, the chemical properties of the samples analyzed by Thompson et al. (2014) are completely unknown. However, in order to explain the cause of the observed differences in the spectra, especially the shift in the position of the R_1 emission line, the authors correlated this position with chemical properties, in particular with SiO_2 weight percentages of emeralds originating from the same locality as the research samples examined by laser photoluminescence. These chemical data were taken from the PhD dissertation of Huong (2008), who presented numerous graphs showing the compositional variation of major and trace elements in emeralds determined by a combination of LA-ICP-MS and electron microprobe analyses. Although it is widely known that emeralds from a given locality exhibit a range of chemical compositions, the approach by Thompson et al. (2014) might be helpful for providing a very rough indication of the chemical features of the examined samples.

Nonetheless, a shortcoming of the just-described correlation flows from the fact that Huong (2008) provided neither a table with complete chemical properties for the samples with the weight percentages of all elements, nor a calculation of the obtained data for 18 oxygen atoms (according to the normal formula unit of beryl, $Be_3Al_2Si_6O_{18}$). Yet despite these deficiencies, Thompson et al. (2014) assigned decreasing SiO_2 weight percentages to increasing vacancies or substitutional defects at the Si site of the beryl lattice and speculated about such defects as the cause of the observed shift in the position of the R_1 emission line.

Beryls are subdivided into two groups with different substitutional schemes, specifically octahedral and tetrahedral (Aurisicchio et al., 1988). In octahedral beryls, two major substitutions are observed for the isomorphic replacement of Al:

$$Al \leftrightarrow Me^{3+} \ (Me^{3+} = V, Cr, Mn, Fe, etc.)$$
$$Al \leftrightarrow Me^{2+} + Me^{1+} \ (Me^{2+} = Mg, Mn, Fe, etc., \text{ and } Me^{1+} = Li, Na, K, Cs, etc.)$$

In the first case, Al is simply replaced by a trivalent atom; in the second case, Al is replaced by a bivalent atom with charge compensation through the incorporation of an alkali atom in channel sites of the beryl structure.

Tetrahedral beryls are characterized by the replacement of Be^{2+} by Li^{1+}, again with charge compensation by alkalis in channel sites. Nevertheless, in the context of natural and synthetic emeralds, we mainly have to consider the effect of the two octahedral replacement schemes, because tetrahedral substitution of beryllium is limited.

The overview of emerald data presented by Groat et al. (2008) indicates through analyses calculated to 18 oxygen atoms per formula unit (apfu) that a small Si deficiency is occasionally present. However, we have on the one hand to realize that only a part of these data represent full analyses, and for many samples light elements (Be and Li) were not determined. On the other hand, it is equally relevant to keep in mind that many samples are chemically zoned and show a variation of the main elements, including Si. For example, for an emerald crystal from Torrington, New South Wales, Australia, a variation of Si from 5.98 to 6.02 apfu was determined from 353 point analyses (Schmetzer and Bernhardt, 1994).

Consequently, it would make sense to consider the effect of octahedral isomorphic replacement and its influence upon the weight percentage of SiO_2 in emerald. This effect is demonstrated by calculating the SiO_2 contents (in wt.%) for emerald in which Al has been replaced by trivalent metal atoms such as Cr and/or Fe. In such a scenario, although the Si sites show no vacancies or deficiencies (Si = 6.0 apfu for all calculations), we observe a distinct decrease in SiO_2 wt.% values (Figure 1). For this calculation, the small weight difference between Fe_2O_3 and Cr_2O_3 is neglected, because it would only generate very slight alteration in the results. Likewise, a water content of 1.5 wt.% H_2O may be assumed, insofar as a different water content would again lead only to a slight shift of the calculated data points.

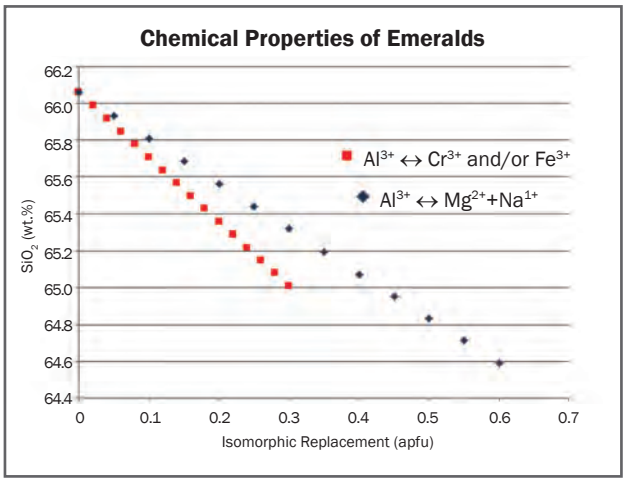

Figure 1: This plot shows the theoretical composition of emeralds with an isomorphic replacement of Al ↔ Fe^{3+} and/or Al ↔ Cr^{3+} or by a coupled substitution of Al ↔ Mg^{2+} + Na^{1+}. The SiO_2 contents were calculated for samples without any silicon vacancies or deficiencies (Si = 6.0 apfu) and for a water content of 1.5 wt.% H_2O. The SiO_2 ranges covered are the variations observed for natural and synthetic emeralds from various sources.

If we calculate the SiO_2 contents, again in wt.%, for the second octahedral replacement scheme involving a coupled substitution of Al by Mg (on Al sites) plus Na (for charge compensation on channel sites), we observe a similar decrease in SiO_2 percentages (Figure 1). These results indicate that for emeralds from different sources, in which both octahedral replacement schemes are always present to a certain degree and with 6 Si atoms per formula unit, the cumulative effects generated by the two isomorphic replacements may cause a reduction in the silicon percentages of up to approximately 2.5 wt.% SiO_2. Thus, decreasing SiO_2 weight percentages found by chemical analyses do not principally represent Si vacancies or defects, but are mainly a consequence of the different weights of Al_2O_3 compared to Cr_2O_3, Fe_2O_3 and MgO plus Na_2O.

Accordingly, a correlation in the shift of the R_1 peak position in emerald PL spectra with analytically determined SiO_2 contents (in wt.%) cannot necessarily be attributed to Si vacancies or defects. Rather, the decrease in SiO_2 contents in emerald is mainly due to the different isomorphic replacement schemes. Such a variation of SiO_2 contents is present in all samples, notwithstanding a theoretical value of Si = 6 apfu.

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Author Reply

We cannot argue with X-ray crystallography measurements showing that defects at Si sites in beryl occur at or below trace-level detection. And so we appreciate Dr Schmetzer's demonstration that variation of SiO_2 wt.% arises from substitutions of heavier metal ions at Al sites. Following that, we are left with the peculiar result that (region-averaged) SiO_2 wt.% is a better indicator than Al_2O_3 wt.% of Al site defects leading to *R*-line peak shifts.

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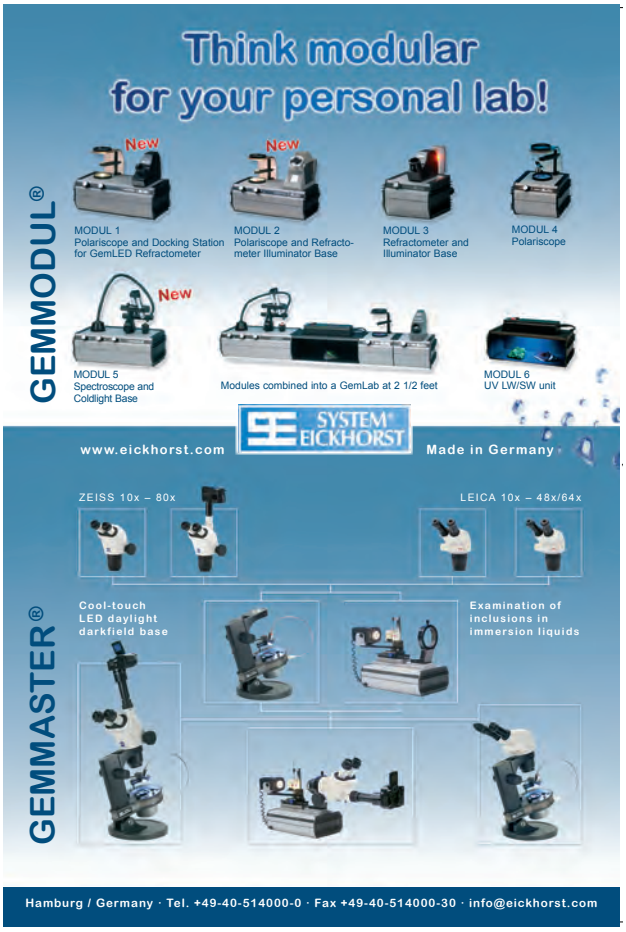

Conferences

AGA Tucson Conference

The 2015 Accredited Gemologists Association Conference in Tucson, Arizona, USA, took place 4 February, with the theme 'Gems – Facets to Micro-Features'.

Christopher Smith (American Gemological Laboratories [AGL], New York, New York) performed experiments on emerald clarity enhancement using three types of fillers: 'traditional' (cedarwood oil, wax, Canada balsam and mineral oil), 'modern' (Excel, Opticon, PermaSafe and Palma) and coloured (Joban oil and green Opticon). Overall, he found that the modern fillers were more efficient at hiding fissures than the traditional products, due to three factors: (1) their refractive index, (2) the quality of the contact at the interface between the filler and fissure walls, and (3) the transparency or translucency of the filler. Coloured fillers were found to improve emerald coloration only in lower-quality material (i.e. containing many large fractures and cavities that are filled with the green substance).

Jeffery Bergman (Primagem, Bangkok, Thailand) reviewed collector gems, and noted that the main sources of these stones include Afghanistan, Brazil, Myanmar, Pakistan, Sri Lanka and Tanzania. The growing popularity of these rarities (e.g. taaffeite, painite, jeremejevite and benitoite) is demonstrated by their presence in mainstream sales outlets such as Jewelry Television and eBay.

Lore Kiefert (Gübelin Gem Lab, Lucerne, Switzerland) described several instances in which gemmologists should use caution when interpreting their results. For example, the energy-dispersive X-ray fluorescence (EDXRF) chemical analysis of waxed jadeite may show traces of Ca from the wax, which could lead to the misidentification of jadeite as omphacite. Kiefert also described her recent research on black opal from a new deposit in Stayish, Ethiopia. Unlike most of the white opal from Wollo, Ethiopia, this black opal shows negligible hydrophaneity. Its coloration is due to organic carbon, like the black opal from Australia.

Victor Tuzlukov (Russian Faceters Guild, Moscow) examined several factors for evaluating the quality of a gemstone's faceting. Ideally, the facets should have perfect flatness, sharp interfacial edges and precise symmetry (if appropriate for the facet design). The faceting should also be executed to avoid undesirable optical effects (e.g. unintended reflections), as well as 'windowing' of the stone.

Dona Mary Dirlam (Gemological Institute of America [GIA], Carlsbad, California) highlighted the GIA library's extensive collection of materials dating from 1496 to the present. She also announced an exciting future project of digitizing GIA's rare book collection using state-of-the art scanning equipment.

Danny Sanchez (Los Angeles, California, USA) provided several tips for digital photomicrography: lens cleaner works well on polished stones as well as lenses; light diffusers can be made from white film canisters, or even tracing paper (if not in the vicinity

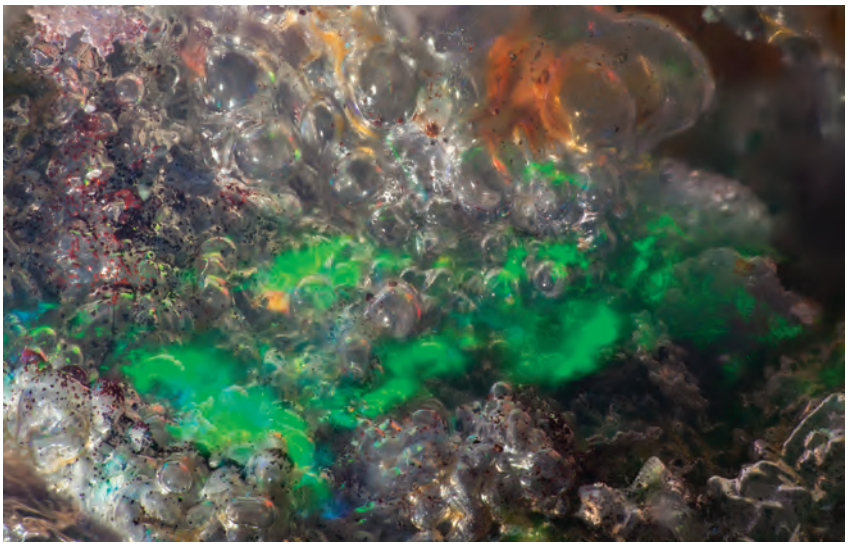

Figure 1: Focus-stacking software was used to capture the globular texture of hyalite in this play-of-colour opal from Magdalena, Jalisco, Mexico. Photomicrograph by Danny Sanchez; image width 4.8 mm.

of hot lights); black foil and mini-reflector cards are useful for manipulating light; and lamps with fans should be placed on a separate surface from the microscope to reduce vibration. He uses Helicon focus-stacking software to blend numerous images (typically around 80) into a single image to show an extreme depth of field (e.g. Figure 1).

In another photomicrography presentation, **Edward Boehm** (RareSource, Chattanooga, Tennessee, USA) described how to take high-quality photos through a microscope with a smart phone. The camera port should be held approximately 1 cm from the microscope's ocular, and darkfield illumination should typically be turned off when using a fibre-optic lamp.

Shane McClure (GIA, Carlsbad) examined three-phase inclusions in emerald and their relationship to country of origin. Jagged three-phase inclusions traditionally have been considered diagnostic of Colombian origin, but very similar inclusions are known in emeralds from Panjshir, Afghanistan, and Musakashi, Zambia. Trace-element analysis can be helpful for separating emeralds from these localities.

The conference was followed by the AGA Gala, where the Antonio C. Bonanno Award for Excellence in Gemology was presented to Thomas Hainschwang and the AGA Lifetime Achievement Award was given to Dona Mary Dirlam.

Brendan M. Laurs

GILC Tucson Conference

The Gemstone Industry & Laboratory Conference took place on 2 February 2015 in Tucson, Arizona.

Shane McClure (GIA, Carlsbad) provided an update on activities by the Laboratory Manual Harmonization Committee (LMHC) during the past year. He indicated that the main function of the LMHC is to come to an agreement on wording on laboratory reports. Two more LMHC information sheets are currently pending, and will be posted at www.lmhc-gemology.org.

In a separate presentation, **McClure** introduced new terminology used on GIA reports for describing the coloration of rubies from Mozambique (and elsewhere) that are attractive but do not have the same appearance as 'pigeon's blood' rubies, which most commonly originate from Mogok, Myanmar. The three new colour categories include 'deep red' (dark red), 'crimson red' (slightly purplish red) and 'scarlet red' (slightly orangy red); the latter two terms cover rubies that would generally be described as 'intense' red.

Christopher Smith (AGL, New York) reviewed the features associated with relatively low-temperature heat treatment of gem corundum. He defined 'relatively low temperature' as below the threshold at which rutile needles begin to dissolve into their corundum host (~1,300°C, depending on various factors). Such temperatures are commonly used to remove a blue colour component (e.g. from ruby and purple sapphire) to produce a purer red/pink coloration, or to decrease or increase yellow colour (to produce colourless sapphire or improve the colour of yellow, orange and padparadscha sapphires). Some microscopic indicators of relatively low-temperature heating include unaltered crystalline inclusions of thermally sensitive minerals such as calcite, diaspore and apatite (but not zircon; Figure 2), and the presence of CO_2-rich fluids in negative crystals.

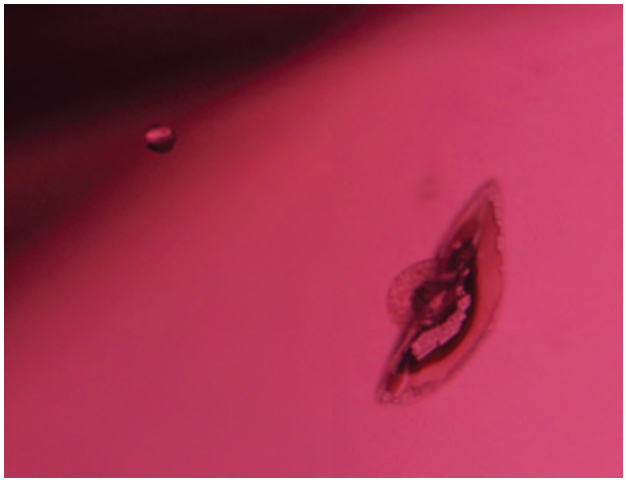

Figure 2: In this pink sapphire from Madagascar, the apatite inclusion on the centre right shows evidence of heat treatment, while the zircon on the upper left does not. Apatite is more thermally sensitive, and therefore such an inclusion scene provides evidence of low-temperature heating. Photomicrograph by Christopher Smith; magnified 40×.

In a presentation based on research conducted by Colombia's national gemmological laboratory, **Gabriel Angarita** (ACODES, Bogotá, Colombia) proposed that residues in emeralds that are left over from the cutting process, such as emerald dust or diamond powder, should not be mentioned in the clarity enhancement section of reports (e.g. 'insignificant' or 'minor'), since these residues are not a result of enhancement.

The formal presentations were followed by a lively 'Open Forum Session', in which attendees brought up a wide diversity of topics for discussion.

Brendan M. Laurs

GIT2014 Conference

The Gem and Jewelry Institute of Thailand (GIT) hosted the 4th International Gem and Jewelry Conference on 8–9 December 2014 in Chiang Mai, Thailand. The event was attended by more than 250 participants and featured six keynote speakers and two parallel oral sessions, as well as a poster session. The oral presentations attended by this author are briefly described below.

Several presentations covered coloured stones. Keynote speaker **Jean Claude Michelou** (International Colored Gemstone Association, New York) reviewed coloured stone sources and markets. He estimated that more than 100,000 artisanal coloured stone miners are currently active worldwide. However, due to the rising technical challenges of mining the deposits, he predicted a decrease in small-scale operators and an increase in activity by large mining companies in the future. He also suggested that green garnets (demantoid and tsavorite) have good potential for future expansion. **Dr Lore Kiefert** (Gübelin Gem Lab, Lucerne) described new black opal from Stayish, Ethiopia, which is located approximately 30 km from the Wollo white opal mines. The black opal deposit is hosted by the same clay-rich volcanic layer that contains the white opals. The Ba content of the black opals determined by EDXRF shows both volcanic and sedimentary signatures. **Dr Taijin Lu** (National Gems & Jewelry Technology Administrative Center, Beijing, China) indicated that there now are more than 25 different materials that are sold as 'jade' in China. Prices are escalating for naturally coloured yellow and red quartzite 'jade', which is mined from more than six quarries in China. The coloration of both materials is due to iron compounds (hematite in the red quartzite, and hematite and goethite in the yellow quartzite). **Dr Miro Ng** (The Hong Kong Institute of Gemmology, Central) summarized the cathodoluminescence (CL) colours and the textures in various types of jadeite and its imitations. Quartzite, maw-sit-sit and amphibole-rich rocks can all be easily separated from jadeite with this technique. The grain size of jadeite correlates to its quality, with finer-grained material showing the highest transparency. **Dr Somruedee Satitkune** (Kasetsart University, Bangkok) studied blue sapphires from Phrae Province in northern Thailand. The secondary deposits are derived from a basaltic flow that is 5.6 million years old, and the sapphires are associated with zircon, black spinel and garnet. Internal features consist of colour zoning, crystalline and fluid inclusions, and minute particles. **Dr Le Thi Thu Huong** (VNU University of Science, Hanoi, Vietnam) described the properties of yellowish brown zircon from Dak Lak in the central highlands of Vietnam. The gems are mined from secondary deposits formed by the weathering of basaltic rocks. EDXRF spectroscopy showed Mg and Al as impurities, and the presence of U^{5+} was revealed by both ultraviolet-visible-near infrared (UV-Vis-NIR) and Fourier-transform infrared spectra. **Jayshree Panjikar** (Panjikar Gem Research & Tech Institute, Pune, India) described aquamarine from Pallapatti village, Karur, Tamil Nadu, India. It shows typical gemmological properties for aquamarine, with internal features consisting of fluid inclusions (two-phase and multiphase) as well as biotite and apatite crystals. **Dr Boontarika Srithai** (Chiang Mai University) used X-ray diffraction (XRD) analysis to determine that the chatoyancy in cat's-eye opal from Tanzania is caused by needle-like particles of goethite. XRD also showed that it is opal-CT with some cristobalite, tridymite and quartz. **Martin Steinbach** (Gems with a Star, Idar-Oberstein, Germany) gave a well-illustrated lecture that reviewed asterism in gems, including very rare examples of star tanzanite (four rays) and star zircon (eight rays, in a pale yellow stone from Sri Lanka).

On diamond topics, keynote speaker **Dr Lutz Nasdala** (University of Vienna, Austria) reviewed advances in the microspectroscopy of diamond. Hyperspectral Raman mapping can quantitatively show specific areas near diamond inclusions corresponding to compressive and dilative stress, which is of interest for interpreting diamond genesis. This technique can also be used to visualize internal growth textures in diamond that are not visible with an optical microscope. **Dr Wuyi Wang** (GIA, New York) described recent investigations of colourless and near-colourless type IIa CVD synthetic diamond using CL and carbon isotopes. Compared to type IIa natural diamond, the CVD products showed very different growth features under CL, and significantly lighter carbon isotope compositions. **Branko Deljanin** (CGL-GRS Swiss Canadian Gemlab, Vancouver, Canada) described criteria for separating Argyle pink and blue diamonds from CVD-grown synthetic diamonds. Compared to the pink CVD synthetics, the blue CVD-grown products are relatively rare in the market. **Dr Katrien De Corte** (HRD Antwerp, Belgium) indicated that the low-pressure, high-temperature treatment of type IIa diamond can be done in 3–15 minutes with desktop equipment at pressure of <1 atmosphere and temperatures of 2,000–2,200°C; hydrogen gas is used to prevent graphitization. The properties of diamonds treated by this technique are similar to those of HPHT-treated stones, since similar temperatures are used.

Figure 3: These sapphires from Nigeria are shown before heating (left, 0.07–0.40 g) and after traditional heat treatment (right, 0.03–0.76 g). Photo by T. Sripoonjan.

Gem treatments were covered in several presentations. **Thanong Leelawatanasuk** (GIT, Bangkok) examined heated and untreated sapphires from the Mambilla area of Nigeria (Figure 3), near the border with Cameroon. The rough material was typical of magmatic-type sapphire derived from secondary deposits. Heated samples showed melted crystalline inclusions with partially healed tension halos, frosted 'fingerprints' and a brownish appearance for dense clouds of microscopic particles. **Boontawee Sriprasert** (GIT, Bangkok) performed further studies of treated 'black' (very dark blue) sapphires that were previously described on GIT's website. He found additional evidence for the Fe-Ti diffusion treatment of these stones, which were submitted to the GIT laboratory in January and August 2014. **Shane McClure** (GIA, Carlsbad) discussed problems associated with describing the degree of emerald clarity enhancement on identification reports: a stone may be treated or re-treated after being submitted for a report, and there are inconsistencies between how various laboratories evaluate the degree of enhancement. **Roman Serov** (MSU Gemmological Center, Lomonosov Moscow State University, Russia) performed heating experiments on Russian demantoid. After heating to 650°C under reducing conditions (stones embedded in charcoal powder) for one hour, the brown colour component decreased and the samples became greener; subsequent heating of those same samples to 650°C under oxidizing conditions (in air) caused them to become browner.

On the topic of pearls, **Shigeru Akamatsu** (Central Gem Laboratory, Tokyo, Japan) highlighted some of the problematic materials being used for bead nuclei in pearl culturing: (1) Giant clam (*Tridacna spp.*) shell easily breaks when it is drilled, and it is also an illegal product included in Appendix II of CITES; (2) beads made from Chinese freshwater mussel shell are commonly treated with toxic chemicals to bleach them white; and (3) glued bead nuclei consisting of three pieces of shell that are cemented together are susceptible to falling apart, even from exposure to hot water.

Dr Seriwat Saminpanya (Srinakharinwirot University, Bangkok, Thailand) studied ancient glass beads from Mae Hong Son, northern Thailand. The beads were recovered from a log coffin burial site dated 12,000 years ago. UV-Vis-NIR spectroscopy showed that copper and iron cause the colours of the blue and green beads, whereas iron is responsible for the colour of the yellow and black beads; some lead was also present.

Business topics presented at the conference varied considerably. Keynote speaker **Prida Tiasuwan** (Pranda Jewelry Group, Bangkok) discussed the business implications for the gem and jewellery industry of the Association of Southeast Asian Nations Economic Community (AEC). The goal of the AEC is regional economic integration of ASEAN nations by the end of 2015 through a single market and a production base that is fully integrated into the global economy. The free flow of goods will be encouraged, and although value-added tax will be paid in the country of sale, there will be no import duty. Keynote speaker **Burak Cakmak** (Swarovski, London) reviewed his company's efforts to embrace corporate social responsibility (CSR). Swarovski has a 120-year history of involvement with CSR, and seeks to balance and maximize three critical aspects of their business: 'Planet, People and Profit'. Keynote speaker **Franco Pianegonda** (Franco Pianegonda, Vicenza, Italy) explained the philosophy behind his jewellery designs. He focuses on the customer who will wear his jewellery, rather than being concerned with innovating fast enough to meet new desires. By contrast, in a presentation titled 'Developing at 10,000 pieces of jewelry per hour', keynote speaker **Thomas Nyborg** (Pandora Production Co., Bangkok) described the policies and procedures that are used by Pandora in their large jewellery manufacturing business. The company is based entirely in Thailand, and employs 7,934 people with an average age of 27. **Kennedy Ho** (AIGS Laboratory, Bangkok) discussed the challenges of doing business in Myanmar. The government offers little protection for investors, so there is a lot of risk, but also an abundance of business opportunities with good potential.

The e-proceedings volume for this conference, and also for prior GIT conferences (2012, 2008 and 2006), can be purchased at www.git.or.th/shopping_cart/e-book.aspx?lang=en.

Brendan M. Laurs

Gem-A Notices

GIFTS TO THE ASSOCIATION

The Association is most grateful to the following for their gifts for research and teaching purposes:

Angelett Gallery, London, for eight pieces of 'highly mineralized ground' from the Salsigne mine, France, and a piece of rock from the goldfields of Western Australia (see *Gems & Jewellery*, Vol. 24, No. 2, 2015, 30–31).

Anura Wijemanne Associates, Colombo, Sri Lanka, for mixed-colour sapphires weighing a total of 29.26 carats.

Than Aung, Mogok, Myanmar, for miscellaneous gem rough and a collection of calcites and ruby in calcite from Mogok.

Jason Baskin Minerals, Flemington, New Jersey, USA, for garnets in graphite schist and faceted garnets from the Red Embers mine, Erving, Massachusetts, USA (see *The Journal*, Vol. 34, No. 4, 2014, 286–287).

John Bradshaw of Coast-to-Coast Rare Stones, Nashua, New Hampshire, USA, for a large selection of rare gemstones.

Eric Braunwart of Columbia Gem House Inc., Vancouver, Washington, USA, for iolite, corundum and kyanite rough from Palmer Canyon, Wyoming, USA.

Pat Daly FGA, London, for two books and 28 magazines.

Richard Eddy, Cheshire, Oregon, USA, for three pieces of opalised wood and three specimens showing the stages of opal treatment.

Sterling Foutz and Mary Hecht of Sterling Opal, Tempe, Arizona, USA, for samples of synthetic opal.

Farooq Hashmi and Michael Puerta of Intimate Gems, Glen Cove, New York, USA, for samples of tourmaline and natrolite from Mwajanga, Tanzania.

Prof. U Tin Hlaing, Shan State, Myanmar, for a bracelet composed of beads of jade-like materials (see *The Journal,* Vol. 34, No. 3, 2014, 197–198).

Syed Iftikhar Hussain of Syed Trading Co., Islamabad, Pakistan, for two peridot crystals, rough pieces of nephrite and spessartine, and an actinolite cabochon (all from Pakistan), and a slab of trapiche quartz from Russia.

Brett and Allyce Kosnar of Kosnar Gem Co., Black Hawk, Colorado, USA, for a piece of rough and three cabochon samples of stabilized shattuckite from DRC.

Milenyum Mining Ltd., Milas, Turkey, for rough and cut Csarite (colour-change diaspore).

U San Myo, Yangon, Myanmar, for samples of spinel, ruby and green apatite, and a selection of marble host rock from Mogok.

Saeko Nagao FGA, Fukushima, Japan, for beryl and rainbow garnet.

Mauro Pantò of The Beauty In The Rocks, Laigueglia, Italy, for the following faceted stones: 'black' axinite (source unknown); quartz from Madagascar (one with lazulite and another with piemontite inclusions); tantalite and columbite from Colorado, USA; fuchsite from the Kola Peninsula, Russia; shungite from New Mexico, USA; and 'liparsite' (manmade glass from Italy).

Denis Pho, for interference figure specimens, jadeite, 11 trapiche cabochons and more than 220 g of spinel crystals.

Hemant Phophaliya of AG Color Inc., New York, New York, USA, for a 19.09 ct tanzanite.

Werner Radl of Mawingu Gems, Liesenfeld, Germany, for two pieces of rough chrysoprase from Kondoa District, Tanzania, and beryl with inclusions from Haneti, Tanzania.

Sein Sein, Mogok, for tourmaline and aquamarine from Pein-pyit and quartz with tourmaline from Leplanha, Myanmar.

U Tin Kyaw Than FGA of the Gemmological Science Centre, Yangon, Myanmar, for a box of miscellaneous faceted gems from Myanmar.

Ian Thompson FGA, Wood Green, London, for a selection of books.

Dominic Turk of G. Turk Ltd., London, for a treated opal.

Wards, Birmingham, West Midlands, for tektites.

MEMBERSHIP

At a meeting of the Council held on 25 February 2015, Alan D. Hart FGA DGA was appointed to serve on the Council. The following were elected to membership:

Fellowship and Diamond Membership (FGA DGA)

Higgo, Emma, *Hindhead, Surrey*
Kwok Men Yee, *Kam Tin, Hong Kong*

Fellowship (FGA)

Clark, Christopher, *Knoxville, Tennessee, USA*
Deng Heng, *Guilin, Guangxi, P.R. China*
Durocher, Beatrice, *Marseille, France*
Huang Jiajun, *Guangzhou, Guangdong, P.R. China*
Hui Wan Man, *North Point, Hong Kong*
Jiamanusorn, Siriwat, *Bangkok, Thailand*
Jin, Apple, *London*
Johansson, Sandra, *Västra Götaland, Sweden*
Kang Zhiyuan, *Shanghai, P.R. China*
Kitching, Laura, *Northampton, Northamptonshire*
Lee Tak Fai, Eric, *Kowloon, Hong Kong*
Lescuyer, Loic, *Francheville, France*
Lloyd, Samantha, *Leicester, Leicestershire*
Marleau, Diane, *Mont-Royal, Quebec, Canada*
Martin-Gutierrez, Francesca, *Bounds Green, London*
Minelli, Adriana, *Toronto, Ontario, Canada*
Ootani, Wakana, *Tokyo, Japan*
Rafalimanana, Laza Andriamizaka, *Antsirabe, Madagascar*
Raherinirina, Haingo, *Antananarivo, Madagascar*
Recchi, Jean-Noel, *Marseille, France*
Rochambeau, David, *Montreal, Quebec, Canada*
Rong Zhen, *Shanghai, P.R. China*
Rykova, Elena, *Paris, France*
Sampson, Suzanne, *Leicester, Leicestershire*
Shi Yang, *Guilin, Guangxi, P.R. China*
So Sau Man, *Tsing Yi, Hong Kong*
Sugawara, Naoyuki, *Saitama, Japan*
Takebayashi, Maya, *Yokohama City, Kanagawa, Japan*
Thompson, Noah, *Chiddingfold, Surrey*
Van Colen, Louise, *Montreal, Quebec, Canada*
Wong Man Ho, *Kowloon, Hong Kong*
Yamazaki, Junichi, *Kambei-gun, Iwate, Japan*
Zhang Shengnan, *Beijing, P.R. China*
Zhu Ying, *Shanghai, P.R. China*

Diamond Membership (DGA)

Arioli, Elena, *London*
Burton, Amy Louise, *London*
Burton, Guy Christopher, *London*
Leung Hang-Fai, Henry, *Kowloon, Hong Kong*
Thung Chi Ming, Herbert, *Kowloon, Hong Kong*
Wong Nga Sze, Jennifer, *Foton, Hong Kong*

Associate Membership

Akgun, Murat, *Mugla, Turkey*
Akgun, Guzide, *Mugla, Turkey*
Alexander, Sheila, *Potters Bar, Hertfordshire*
Auerbach, Roy, *Dallas, Texas, USA*
Campbell, Alan, *Edinburgh*
Colucci, Thomas, *Alexandria, Virginia, USA*
Coquel, Isabelle, *Singapore*
Donn, Nigel, *Manchester, Greater Manchester*
Downes, Claire, *London*
Drammeh, Hamed, *Surutue, Nigeria*
Fujiki, Otoe, *Tokyo, Japan*
Grimwood, Brett, *Nelson, New Zealand*
Hennelly, Jacinta, *Galway, RO Ireland*
Hopkins, Gary, *East Grinstead, West Sussex*
Hughes, Gill, *Chelford, Cheshire*
Ito, Akira, *Tokyo, Japan*
Johnston, Christopher, *Erongo, Namibia*
Kanevskij, Aleksandr, *Antwerp, Belgium*
Lai Yuen Wan, Eva, *Wan Chai, Hong Kong*
Li Jing, *London*
Molliere, Pascal, *Farnborough, Hampshire*
Quinn, Charles, *Varna, Bulgaria*
Tom, Graham, *London*
Watt, Martin, *Belfast, County Antrim*
Weller, Thomas, *Oberwil, Switzerland*
Yamashita, Mei, *Miura City, Kanagawa, Japan*
Zhang Xiaole, *Solihull, West Midlands*

Corporate Membership

Milenyum Mining Ltd., *Milas, Turkey*

At a meeting of the Council held on 25 March 2015, the following were elected to membership:

Fellowship

De Vismes, Raphaele, *Larchmont, New York, USA*
Genet, Julie, *Cagnes-sur-Mer, France*
Swaving, Christine, *The Hague, The Netherlands*

Associate Membership

Bradshaw, John, *Nashua, New Hampshire, USA*
Breitsprecher, Charles, *Sacramento, California, USA*
Finleon, Deborah, *Alexandria, Virginia, USA*

Fitzpatrick, John, *White County, Illinois, USA*
Fogelberg, Kenneth, *Santa Maria, California, USA*
Goldman, Ira, *N. Miami, Florida, USA*
Haindel, Mary Virginia, *Metairie, Louisiana, USA*
Henderson, Corinna, *Shipley, West Yorkshire*
Lindenbergh, Idzarda, *Rotterdam, The Netherlands*
Morrier, Yves, *Montreal, Quebec, Canada*
Morrison, Jeffrey, *Yarmouth, Maine, USA*
Prince, Nick, *Atlanta, Georgia, USA*
Sammon, Christopher, *London*
Smith, Rosalind, *Chelmsford, Essex*

Annual General Meeting

The 2015 Annual General Meeting of The Gemmological Association of Great Britain will be held on Wednesday 24 June (not 17 June as previously notified) at 11:00 a.m. The venue is to be confirmed.

OBITUARY

Dr James Bowman Nelson

1913–2015

Dr Jamie Nelson PhD FGS FInstP FGA (D.1980), of Hampstead, London, died on 17 March 2015 at the age of 101.

Dr Nelson was an ebullient Scottish physicist, X-ray crystallographer, mineralogist, gemmologist and inventor of scientific instruments. His more recent scientific interests centred on gemmology (which he started at an age when most people retire), but his contributions to the scientific world were more wide ranging. As managing director of McCrone Scientific Ltd. (London) his inventions were numerous including the McCrone micronising mill which has received much acclaim from users of X-ray diffraction.

A life-long mineral collector, he has been well-known for only about a quarter of a century in gemmological circles. Jamie was fascinated by the wonders of the behaviour of light. He invented and commissioned various devices to investigate and demonstrate the ways light interacts with gemstones. His laboratory was an Aladdin's cave packed to the ceiling with instruments (most of which he had designed), papers (many of which he had written) and a collection of specimens. He used the latter to demonstrate the principles he always expounded with great enthusiasm. In his late 90s, his ardour, acumen and critical faculties were undiminished and his physical stamina and ability would have done credit to someone several decades younger.

Jamie was born on 7 June 1913 in Stenhousemuir, Scotland. His formal education in Scotland and Canada ended at the age of 14 when he left school to support his mother and sister. However, just before leaving, he was awarded a gold medal for obtaining the highest high school entrance exam marks in the Niagara Falls district. He returned to the UK in the 1930s where he met Doris Holden. They were married in 1942 and for 67 years they were totally devoted to each other.

After working for Cussons Soap Factory, Jamie was employed as chief analytical chemist by Magnesium Elektron in Manchester during most of World War II. In early 1944 he transferred to the coal research establishment BCURA, to take charge of a new X-ray service section. He was based at the Cavendish Laboratory, Cambridge, where he measured the thermal expansion of graphite, obtaining accurate measurements up to 800°C using his own high-temperature X-ray diffraction camera. Graphite was used to slow down the neutrons in nuclear fission electricity generators then under construction in the UK. During all these early years he published many accounts of his own physical analytical methods including UV emission spectroscopy and X-ray diffraction analysis.

Doris discovered a clause in the Cambridge University Admissions Regulations whereby, without formal qualifications, if 'an applicant possessed sufficient background knowledge to profit from a path of instruction leading to a PhD, the enrolment could proceed'. Jamie was made aware of Doris's application on his behalf on the morning of a Viva Voce with three university Fellows. He then received an official letter advising him to seek enrolment at a college and provide himself with cap and gown of Master status. Without Doris's help and her support during his student days at Cambridge, he claims he would have starved. As a couple, they were renowned for their Cambridge parties, a tradition they continued all their lives.

Jamie successfully completed his thesis with Professor Sir Lawrence Bragg as his supervisor. He then regarded himself as a card-carrying crystallographer. Sir Lawrence generously gave Jamie many of the crystal specimens on which Sir Lawrence himself had

Dr Jamie Nelson during his 100th birthday celebration with his good friends Sara Mark (left) and Jean Prentice.

determined the atomic structure over the previous 30 years. Jamie became a Fellow of the Geological Society in 1956 and was by then already a Fellow of the Institute of Physics.

In the 1950s, Jamie transferred to Morgan Crucibles until 1964 when he left to establish McCrone Scientific Ltd. In the early years he was involved in various problem-solving projects and he collaborated with Dr Walter McCrone of McCrone Associates, Chicago, Illinois, USA, providing his X-ray analytical expertise. But Jamie's main love was invention, including the McCrone micronising mill, low-load hardness tester, and wavelength and reflectance standards.

Jamie made a poor start in gemmology. In 1980, after three examination attempts, he achieved only a pass mark. Since then he has more than made up for this inauspicious beginning. Starting in 1984, Jamie published 17 original articles on gemmology, almost all of which were in *The Journal of Gemmology*. In 1988 Jamie and Alan Jobbins were invited by the University of Geosciences in Wuhan, China, to advise on the setting up of gemmological courses and a gem testing laboratory. Subsequently the correspondence courses of the Gemmological Association of Great Britain were translated into Chinese which enabled students in China to access and enrol for the Association's Diploma in Gemmology.

For his seminal work on the explanation of the optical 'flash effect', used to detect glass fracture-filling in diamonds, he was awarded the Gemmological Association's Research Diploma in 1993. Since its inception in 1945 there have been only six recipients of this award.

In 2001, Jamie received the prestigious August Köhler Medal, an award of the State Microscopical Society of Illinois (Chicago), 'for outstanding contributions to optical microscopy'.

Starting in 1994, Jamie was engaged in helping to produce the first comprehensive database of the Raman spectra of minerals, gems and their inclusions. The Renishaw compilation now amounts to over 1,500 mineral species and chemical compounds, all of which have come from his considerable collection. He also developed several gemmological instruments, such as: (1) an accessory for the Renishaw Raman microspectrometer that recorded the low-temperature photoluminescence spectroscopy of diamond, which enabled the distinction of HPHT-treated diamonds from other colourless diamonds, and (2) a compact and inexpensive device for detecting short-wave UV transparency, a helpful pre-screening method for HPHT-treated colourless diamonds. All of Jamie's custom-built products were made and marketed by his one-man company, Nelson Gemmological Instruments.

Jamie will be greatly missed, not just for his scientific abilities but also for his wonderful humour and generous hospitality.

Gwyn Green
Barnt Green, West Midlands

An innovator in gemstone reporting

• Identification of colored gemstones • Country of origin determination • Full quality and color grading analysis

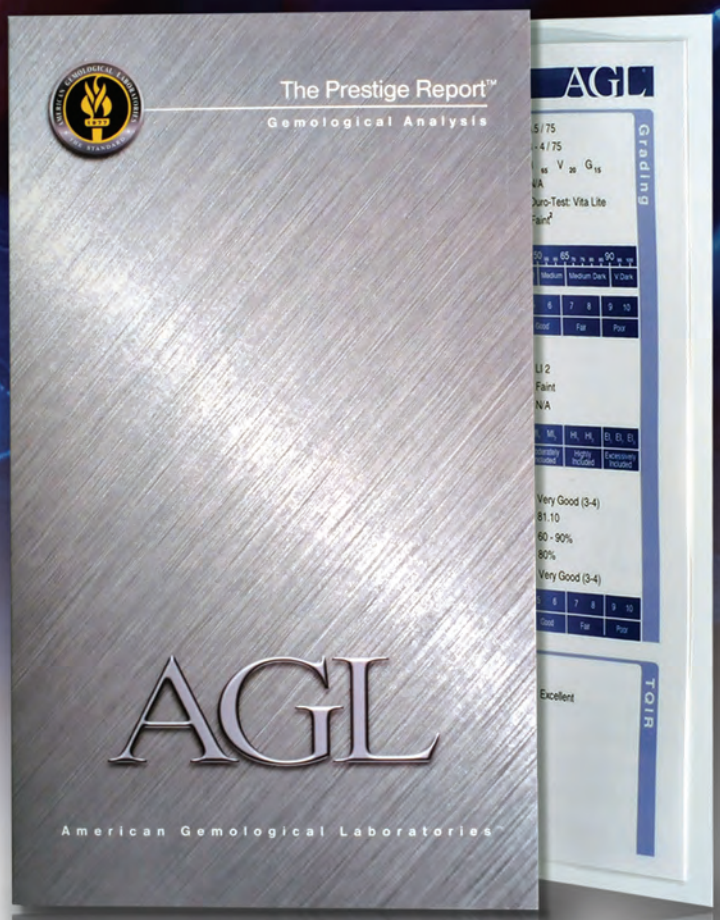

AMERICAN GEMOLOGICAL LABORATORIES AGL

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Learning Opportunities

CONFERENCES AND SEMINARS

CIBJO Congress 2015
4–6 May 2015
Salvador, Brazil
http://congress2015.cibjo.org

3rd Annual New England Mineral Conference
8–10 May 2015
Newry, Maine, USA
www.nemineralconference.org

ICA Congress
16–19 May 2015
Colombo, Sri Lanka
http://congress.gemstone.org

The Santa Fe Symposium
17–20 May 2015
Albuquerque, New Mexico, USA
www.santafesymposium.org

Society of North American Goldsmiths' 44th Annual Conference
20–23 May 2015
Boston, Massachusetts, USA
www.snagmetalsmith.org/conferences/impact-looking-back-forging-forward

9th International Conference on New Diamond and Nano Carbons
24–28 May 2015
Shizuoka, Japan
www.ndnc2015.org

AGA Las Vegas Conference
28 May 2015
Las Vegas, Nevada, USA
http://accreditedgemologists.org/currevent.php

JCK Las Vegas Show
29 May–1 June 2015
Las Vegas, Nevada, USA
http://lasvegas.jckonline.com/Education--Events/Education-Schedule
Notes: Educational lectures and events will take place 28-30 May.

Maine Pegmatite Workshop 2015
29 May–6 June 2015
Poland, Maine, USA
http://pegworkshop.com

Compiled by Georgina Brown and Brendan Laurs

XIVèmes Rendez-Vous Gemmologiques de Paris
8 June 2015
Paris, France
http://tinyurl.com/njx6yu7

PEG 2015: 7th International Symposium on Granitic Pegmatites
17–21 June 2015
Lower Silesia, Poland
www.peg2015polandczech.us.edu.pl

Sainte-Marie-aux-Mines Mineral and Gem Show
25–28 June 2015
Sainte-Marie-aux-Mines, Haut-Rhin, France
www.sainte-marie-mineral.com
Note: Lectures, workshops and gem/mineral-related films will be offered during the show.

1st Mediterranean Gemmological & Jewellery Conference
27–28 June 2015
Athens, Greece
http://gemconference.com

JTV Gem Lovers' Conference
22–24 July 2015
Knoxville, Tennessee, USA
www.jschoolinstitute.com/gem-lovers-conference-2015

Jewelry Camp 2015: Antique Jewelry & Art Conference
30–31 July 2015
West Harrison, New York, USA
www.jewelrycamp.org

NAJA 44th ACE IT Annual Mid-Year Educational Conference
8–11 August 2015
Washington D.C., USA
www.najaappraisers.com/index.html

12th International Congress for Applied Mineralogy
10–12 August 2015
Istanbul, Turkey
http://icam2015.org
Note: One of the congress themes is 'Industrial Minerals, Gems, Ores, and Mineral Exploration'

Northwest Jewelry Conference 2015
14–16 August 2015

Bellevue, Washington, USA
www.nwgem.com

Goldschmidt 2015
16–21 August 2015
Prague, Czech Republic
http://goldschmidt.info/2015
Session of interest: Mantle-Derived Intraplate Magmas, their Xenolith and Diamond Cargo: Processes, Timescales, and Geodynamic Implications

Dallas Mineral Collecting Symposium
21–22 August 2015
Dallas, Texas, USA
www.dallassymposium.org/2015-symposium

International Gemmological Conference (IGC)
23 August–3 September 2015
Vilnius, Lithuania
www.igc-gemmology.net

13th Biennial Meeting of the Society of Geology Applied to Mineral Deposits (SGA 2015)
24–27 August 2015
Nancy, France
http://sga2015.blog.univ-lorraine.fr
Session of interest: Gems and Industrial Minerals

8th International Congress on the Application of Raman Spectroscopy in Art and Archaeology
1–5 September 2015
Wrocław, Poland
http://raa.chem.uni.wroc.pl

26th International Conference on Diamond and Carbon Materials
6–10 September 2015
Bad Homburg, Germany
www.diamond-conference.elsevier.com

8th European Conference on Mineralogy and Spectroscopy (ECMS 2015)
9–11 September 2015
Rome, Italy
www.ecms2015.eu

Institute of Registered Valuers Loughborough Conference
12–14 September 2015
Loughborough
www.jewelleryvaluers.org/Loughborough-Conference

48th Annual Denver Gem & Mineral Show
18–20 September 2015
Denver, Colorado, USA
www.denvermineralshow.com
Note: Lectures and seminars will follow the show theme 'Minerals of the American Southwest'.

Canadian Gemmological Association Gemmology Conference 2015
16–18 October 2015
Vancouver, British Columbia, Canada
www.gemconference2015.com

The Munich Show
30 October–1 November 2015
Munich, Germany
http://munichshow.com/en
Note: The Forum Minerale will offer lectures and films on gems and minerals.

36th Annual New Mexico Mineral Symposium
14–15 November 2015
Socorro, New Mexico, USA
https://geoinfo.nmt.edu/museum/minsymp/home.cfml

Gem-A Conference, incorporating the 18th FEEG Symposium
21–22 November 2015
London
www.gem-a.com

EXHIBITS

Europe

Bellisima—Italy and High Fashion 1945–1968
Until 3 May 2015
MAXXI National Museum of XXI Century Arts, Rome, Italy
www.fondazionemaxxi.it/2014/07/01/bellissima/?lang=en

Anton Cepka—Kinetic jewellery
Until 7 June 2015
Pinakothek der Moderne, Munich, Germany
http://www.pinakothek.de/en/kalender/2015-03-14/49069/anton-cepka-kinetic-jewellery

Déboutonner la mode
Until 19 July 2015
Les Arts Décoratifs, Paris, France
www.lesartsdecoratifs.fr/francais/musees/musee-des-arts-decoratifs/actualites/expositions-en-cours/mode-et-textile/deboutonner-la-mode

Emaux de Bresse…et aujourd'hui?
Until 15 November 2015
Museum of Bresse—Domain Planon, Saint-Cyr-sur-Menthon, France
www.ain.fr/jcms/cd_7944/exposition-temporaire-et-animations-2014-au-musee-departemental-de-la-bresse

130 ans de création joaillière à Bastia: l'atelier Filippi
Until 19 July 2016
Musée Municipal d'Art et d'Histoire, Bastia, Corsica
http://www.musee-bastia.com/musee-bastia/musee.php?nav=16&lang=en

Inspired: Festival of Silver 2015
18–23 May 2015
Goldsmiths' Centre, London
www.thegoldsmiths.co.uk/events/festival-of-silver-2015-

An Adaptable Trade: The Jewellery Quarter at War
14–27 June 2015
Museum of the Jewellery Quarter, Birmingham
www.jewelleryquarter.net/event/first-world-war-centenary-exhibition

Bejewelled Treasures: The Al Thani Collection
21 November 2015–28 March 2016
Victoria and Albert Museum, London
www.vam.ac.uk/content/exhibitions/exhibition-bejewelled-treasures-the-al-thani-collection

Smycken: Jewellery
On display (closing date to be determined)
Nordiska Museet, Stockholm, Sweden
www.nordiskamuseet.se/en/utstallningar/jewellery

Middle East

Urartian Jewellery Collection
Until 31 July 2015
Rezan Has Museum, Istanbul, Turkey
www.rhm.org.tr/en/event/rezan-has-museum-urartian-jewellery-collection

North America

Ancient Luxury and the Roman Silver Treasure from Berthouville
Until 17 August 2015
The Getty Villa, Pacific Palisades, California, USA
www.getty.edu/art/exhibitions/ancient_luxury

Generations of Mastery: Gemstone Carvings by Dreher
Until October 2015
Gemological Institute of America, Carlsbad, California, USA
www.gia.edu/gia-museum-generations-mastery-gemstone-carvings-dreher

Beneath the Surface: Life, Death, and Gold in Ancient Panama
Until 1 November 2015
Penn Museum, Philadelphia, Pennsylvania, USA
www.penn.museum/press-releases/1163-beneath-the-surface.html

Bent, Cast, and Forged: The Jewelry of Harry Bertoia
Until 29 November 2015
Cranbrook Art Museum, Bloomfield Hills, Michigan, USA
www.cranbrookart.edu/museum/CAMec3.html

Fabergé: From a Snowflake to an Iceberg
Until 31 December 2015
Houston Museum of Natural Science, Texas, USA
www.hmns.org/index.php?option=com_content&view=article&id=594&Itemid=621

Maker and Muse: Women and Early Twentieth Century Art Jewelry
Until 3 January 2016
Driehaus Museum, Chicago, Illinois, USA
www.driehausmuseum.org

Glittering World: Navajo Jewelry of the Yazzie Family
Until 10 January 2016
The National Museum of the American Indian, New York, New York, USA
http://nmai.si.edu/explore/exhibitions/item/838

Arts of Islamic Lands: Selections from the al-Sabah Collection, Kuwait
Until 30 January 2016
Museum of Fine Arts, Houston, Texas, USA
www.mfah.org/exhibitions/arts-islamic-lands-selections-al-sabah-collection-

Turquoise, Water, Sky: The Stone and Its Meaning
Until 2 May 2016
Museum of Indian Arts and Culture, Santa Fe, New Mexico, USA
www.indianartsandculture.org/current?&eventID= 1989

Fabergé from the Matilda Geddings Gray Foundation Collection
Until 27 November 2016
Metropolitan Museum of Art, New York, New York, USA
www.metmuseum.org/exhibitions/listings/2011/faberge

Glitterati—Portraits & Jewelry from Colonial Latin America
Until 27 November 2016
Denver Art Museum, Denver, Colorado, USA
http://denverartmuseum.org/exhibitions/glitterati

Gold and the Gods: Jewels of Ancient Nubia
Until 14 May 2017
Museum of Fine Arts, Boston, Massachusetts, USA
www.mfa.org/exhibitions/gold-and-gods

Fabergé: Jeweler to the Tsars
20 June–27 September 2015
Oklahoma City Museum of Art, Oklahoma, USA
www.okcmoa.com/see/exhibitions/faberge/

Gemstone Carvings: Crystals Transformed Through Vision & Skill
On display (closing date to be determined)
Houston Museum of Natural Science, Houston, Texas, USA
www.hmns.org/index.php?option=com_content&view=article&id=481&Itemid=502

City of Silver and Gold: From Tiffany to Cartier
On display (closing date to be determined)
Newark Museum, New Jersey, USA
www.newarkmuseum.org/SilverAndGold.html

Australia and New Zealand

A Fine Possession: Jewellery and Identity
Until 20 September 2015
Powerhouse Museum, Sydney, Australia
www.powerhousemuseum.com/exhibitions/jewellery

OTHER EDUCATIONAL OPPORTUNITIES

Gem-A Workshops and Courses
Gem-A, London
www.gem-a.com/education/course-prices-and-dates.aspx

Antoinette Matlins 'Hands-on' Gem Course
14–17 May 2015
Woodstock, Vermont, USA
www.antoinettematlins.com/seminars_woodstock.html

ASA Course on Recognizing Treated Gems and Origin Issues
16–17 May 2015
Chicago, Illinois, USA
www.appraisers.org/Education/ViewClass?ClassID=3333

The Goldsmiths' Company Assay Office: Hallmarking Information Day
22 May 2015
Goldsmiths' Hall, London
http://tinyurl.com/o2m8tgh

Gem-A Trip to Idar-Oberstein
13–20 June 2015
Idar-Oberstein, Germany
www.gem-a.com/news--events/events/idar-oberstein-2015.aspx

Fakes and Forgeries
14 June 2015
Art Antiques Fair, London
www.societyofjewelleryhistorians.ac.uk/news

Jewels of 'Blacknesse' at the Jacobean Court with Daniel Packer
23 June 2015
Society of Antiquaries of London, Piccadilly, London
www.societyofjewelleryhistorians.ac.uk/current_lectures

Montreal School of Gemmology: Gem and Jewellery Appraisal Course
6–29 July 2015 (in English and French)
Montreal, Quebec, Canada
www.ecoledegemmologie.com/en/c/10

Golden Threads: Filigree in Islamic Jewellery with Michael Spink
22 September 2015
Society of Antiquaries of London, Piccadilly, London
www.societyofjewelleryhistorians.ac.uk/current_lectures

Beauty and Belief: Techniques and Traditions of Omani Jewellery with Aude Mongiatti and Fahmida Suleman
27 October 2015
Society of Antiquaries of London, Piccadilly, London
www.societyofjewelleryhistorians.ac.uk/current_lectures

Digital Tools and New Technologies in Contemporary Jewellery with Dauvit Alexander
24 November 2015
Society of Antiquaries of London, Piccadilly, London
www.societyofjewelleryhistorians.ac.uk/current_lectures

New Media

Amateur Gemstone Faceting

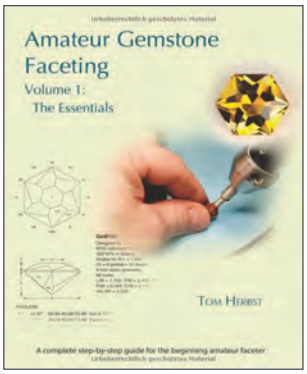

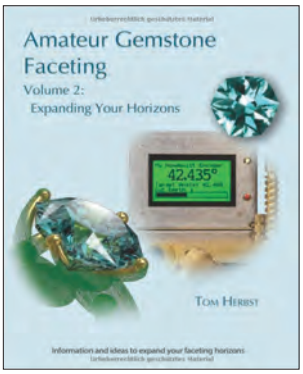

Tom Herbst, 2014.
Vol. 1: *The Essentials,* 428 pages, illus., softcover, ISBN 978-3000474743.
Vol. 2: *Expanding Your Horizons,* 456 pages, illus., softcover, ISBN 978-3000474750.
Self-published by Facetable Books, www.facetingbook.com. US$19.95/volume.

This two-volume book on faceting by Tom Herbst covers a wide range of topics about gem cutting that are of interest to the beginner through master faceter. The word *amateur* in the title might be misleading since a large part of the content is very interesting for professional faceters, as well as for hobbyists with many years of experience. This monumental work, totalling almost 900 pages, is the state-of-the-art publication for this field of knowledge, offering comprehensive information on modern advances and techniques introduced to precision gem faceting during the past few decades.

Volume 1, called *The Essentials*, gives basic information on materials, equipment and techniques involved with gem faceting. A complete review of faceting machines, grinding and polishing laps, and additional equipment is given, together with detailed explanations and tips for gem rough selection, dopping, and cutting and polishing procedures. Elaborate step-by-step instructions for the beginning faceter will guide the reader through the exciting experience of faceting their first stone, with comments on the possible problems encountered at each step and troubleshooting advice.

Volume 2, called *Expanding Your Horizons*, includes valuable information for faceters who want to better understand the science behind cutting gemstones and introduces modern computer-aided techniques related to faceting. The reader will find detailed explanations of gemstone mathematics, geometry and optics, properties of common gem materials, and an explanation of treatments. Computer programs for creating new faceting designs and optical optimization of existing cuts are also explained, together with a case study of creating a new design and a collection of original faceting designs developed by the author. The last chapter invites faceters to improve their equipment with several interesting do-it-yourself projects.

The author provides an explanation of faceting processes from a solid scientific perspective, with information not only regarding how but also why, from the point of view of materials science, optics, mechanics, gemmology and other related fields. Nevertheless, all of the scientific information is presented in easy-to-understand and informal language, with side-bar stories on the history of science and the author's faceting experience that make this book even more enjoyable.

The book is very well illustrated, and has a glossary of faceting terms and a subject index for both volumes. More details and selected pages (as free downloads) are available on the book's website, together with other reader resources and several downloadable items relating to various chapters of the book.

Dr Egor Gavrilenko

Eleventh Annual Sinkankas Symposium—Ruby, rev. edn.

Lisbet Thoresen, Ed., 2014. Pala International, Fallbrook, California, USA, 126 pages, illus., softcover, ISBN 978-0991532001, www.sinkankassymposium.net/order-pubs. US$45.00.

This lavishly illustrated proceedings volume, published in February 2014, commemorates a symposium held in April 2013 at the Gemological Institute of America in Carlsbad, California, that was co-sponsored by the San Diego Mineral & Gem Society. The book contains contributions by 10 authors, some of whom were speakers at the symposium. Not all of the presentations at the conference are represented by articles in this volume.

The book starts with biographies of the speakers and authors, followed by abstracts of the symposium presentations. The bulk of the volume consists of a

series of contributions that cover a broad diversity of topics on ruby: geology and localities (Dr James Shigley); treatments (Shane McClure); a historical account of mining in Mogok, Burma (reprint of a 1907 article by W. G. Fitz-Gerald); a description of a 1996 visit to Mogok (Richard Hughes); Nepalese rubies and sapphires (Elise Skalwold); an update on ruby mining in Afghanistan and Tajikistan (Gary Bowersox); a selected bibliography (Dr James Shigley); a collector's guide to literature on rubies and sapphires (Richard Hughes); mineral illustrations by Gamini Ratnavira and Eberhard Equit (Lisbet Thoresen); and a poem titled 'The Conundrum' (Robert Weldon). The book closes with a series of beautiful photographs of rubies from the collection of William F. Larson.

This eclectic compendium provides useful reference information as well as entertaining reading, and will appeal to a wide audience including hobbyists, collectors, gemmologists, bibliophiles, historians, earth scientists and armchair travellers. It is printed on sturdy paper and the colour reproduction of the photos is excellent. It would have been nice to have dimensions or weights for all specimens pictured (as well as the field-of-view for photomicrographs). Also, it seemed unusual to have the bibliography and literature listing appear in the middle of the volume, rather than at the end. But these are minor issues that do not detract from an otherwise very interesting and informative work on ruby.

Brendan M. Laurs

Geology of Gem Deposits, 2nd edn.

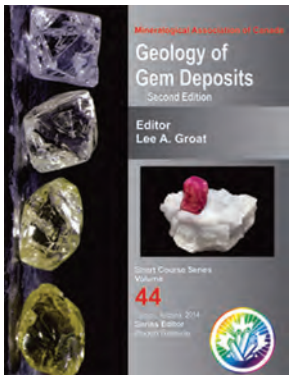

Lee A. Groat, Ed., 2014. Short Course Series Vol. 44, Mineralogical Association of Canada, Ottawa, Ontario, 405 pages, illus., softcover, ISBN 978-0921294542, www.mineralogicalassociation.ca. US$60.00.

This impressive volume accompanied a Mineralogical Association of Canada short course that took place in February 2014 during the Tucson gem shows. This second edition follows the same format as an earlier *Geology of Gem Deposits* volume published in 2007 (now out of print). It has been extensively updated, with the same principal authors for most of the chapters in both editions (i.e. Dr Thomas Stachel, Dr Gaston Giuliani, Dr Lee Groat, David Turner, Dr Daniel Marshall, Dr William 'Skip' Simmons, Dr George Harlow and Bradley Wilson). Chapters are included on the following gem materials: diamond, corundum (ruby and sapphire), emerald, other beryls, chrysoberyl, tanzanite and tsavorite, topaz, gem-bearing pegmatites and jade (jadeite and nephrite). New to the second edition is a chapter on the geology of gems and their geographic origin. This section is quite welcome, although it appears at an odd location between the chapters on gem corundum and emerald, rather than at the end of the volume where it might be expected. In addition, although it provides good summaries of the deposit types for various gems, this chapter is written solely from a geological perspective, so gemmologists will be disappointed by the lack of criteria presented for the origin determination of faceted gem materials. Nevertheless, a thorough synthesis of this subject would require another volume in itself. The final chapter in the book, on coloured gemstones from Canada (which also appeared in the first edition), may at first seem out of place in a volume on the geology of gem deposits. However, the geological setting of the various localities is provided, and considering the Canadian origin of this publication, this chapter must certainly be appreciated by many readers.

The volume contains a wealth of up-to-date information on the localities, geochemistry, geological origin and in some cases exploration criteria for the gem varieties that it covers. Two chapters (on chrysoberyl and topaz) are noticeably shorter than the others. The end of each chapter contains a useful reference list, which is particularly extensive for jade and corundum. This reviewer appreciated that not all of the deposits described in this volume are of economic significance, since much can be learned from studying the geology of minor showings in addition to important localities.

The book is printed on high-quality paper stock and is appropriately illustrated with many colour figures (diagrams as well as specimen photos). Some minor quibbles are that author names are not listed for all of the chapters in the table of contents, and two pages (216 and 256) were left entirely blank, evidently due to the decision to start each chapter on a right-hand page. Dimensions or weights were not included for some of the specimens pictured.

This volume serves as a valuable compendium on the geology of gem deposits, and belongs on the bookshelf of anyone who is involved with gem exploration, mining or origin determination. In addition, the book provides a useful reference for enthusiastic collectors with a desire to know more about the unusual and dynamic forces that have created a wide variety of gem treasures.

Brendan M. Laurs

Twelfth Annual Sinkankas Symposium—Peridot and Uncommon Green Gem Minerals

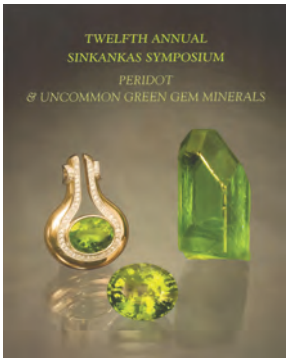

Lisbet Thoresen, Ed., 2014. Pala International, Fallbrook, California, USA, 146 pages, illus., softcover, ISBN 978-0991532018, www.sinkankassymposium.net/order-pubs. US$45.00.

The 12th Annual Sinkankas Symposium, on peridot and uncommon green gem minerals, was held in April 2014 at the Gemological Institute of America in Carlsbad and was co-sponsored by the San Diego Mineral & Gem Society. (See *The Journal,* Vol. 34, No. 2, 2014, pp. 156–157 for a report on this conference.) The format of this proceedings volume is similar to that of the previous symposium's volume on ruby (see review on pp. 457–458), with several contributions by a variety of authors, not all of whom were speakers at the symposium. Some of the presentations given at the conference are not represented by articles in this volume.

The book begins with a listing of the symposium programme, followed by abstracts of the presentations and then biographies of the speakers and authors. There are 12 contributions on peridot (the uncommon green gems covered in the symposium are not included): mineralogy and crystallography (Dr William 'Skip' Simmons); ancient gem peridot from Zabargad Island in Egypt (Dr James A. Harrell); archaeogemmology (Lisbet Thoresen and Dr James A. Harrell); an historical overview of peridot at the Muséum National d'Histoire Naturelle, Paris, France (Dr François Farges); geology (Dr James E. Shigley); worldwide sources (Si and Ann Frazier); peridot from Supat, Pakistan (Pir Dost); peridot from Pyaung-gaung, Mogok Stone Tract, Myanmar (Dr George Harlow and Kyaw Thu); the manufacture of a suite of peridot jewellery (Robert E. Kane); extraterrestrial peridot (Si and Ann Frazier); and a selected bibliography (Dr James E. Shigley). The volume closes with several pages of attractive photos of peridot and other green minerals from the collection of William F. Larson.

To this reviewer's knowledge, this is the only modern volume devoted entirely to peridot. The quality of the printing is very high and the illustrations are outstanding, even capturing the subtle nuances of green coloration in various rough and cut specimens. Unfortunately, dimensions or weights were not included for all specimens pictured, and the ordering of the contributions could have been more logical (i.e. with geology and worldwide localities appearing closer to mineralogy and crystallography). There are also a few typos in the book (e.g. 'pocalities' in the table of contents and an inconsistent spelling of 'Supat' and 'Sapat Gali' in the volume). Nevertheless, these small items are overshadowed by the exceptional amount of interesting and useful information on peridot that has been assembled for this volume, which will appeal to gemmologists, mineralogists, geologists, archaeologists, historians and bibliophiles.

Brendan M. Laurs

OTHER BOOK TITLES*

Diamonds

Research on the Origin of Diamonds under the Kimberley Process Certification Scheme of the United Nations
By Beili Zhang, Hua Chen, Zhili Qiu and others, 2013. Geological Publishing House, Beijing, China, 410 pages, ISBN 978-7116086531 (in Chinese). ¥198.00 hardcover.

Gem Localities

***Gem Trails of Washington,* 2nd edn.**
By Garret Romaine, 2014. Gem Guides Book Co., Upland, California, USA, 248 pages, ISBN 978-1889786537. US$18.95 softcover.

Minéraux de Bretagne
By Louis Chauris, 2014. Les Editions du Piat, Saint-Julien-du-Pinet, France, 336 pages, ISBN 978-2917198223 (in French). €85.00 hardcover.

Namibia—Mineralien und Fundstellen
By various authors, 2014. extraLapis No. 47, Christian Weise Verlag, Munich, Germany, 124 pages (in German). €19.80 softcover.

The Nature of California Guidebook: Gemstones from the Pala Pegmatites
By Ron Schmidtling II, 2015. Self-published, 33 pages, ASIN B00S5OP47M. £6.33 Kindle edition.

General Reference

Beginners Guide to Gem Carving
By Jason Hollis, 2014. Self-published, 24 pages, ASIN B00QOR8032. £6.89 Kindle edition.

* Compiled by Georgina Brown and Brendan Laurs

Gem & Jewelry Pocket Guide: A Traveler's Guide to Buying Diamonds, Colored Gems, Pearls, Gold and Platinum Jewelry
By Renée Newman, 2015. International Jewelry Publications, Columbus, Ohio, USA, 160 pages, ISBN 978-0929975306. US$11.95 softcover or US$4.99 Kindle edition.

Gemstone Tumbling, Cutting & Drilling: A Simple Guide to Finishing & Polishing Rough Stones
By James Magnuson and Val Carver, 2015. Adventure Publications, Cambridge, Minnesota, USA, 128 pages, ISBN 978-1591934608. US$14.95 softcover.

Miller's Field Guide: Silver
By Judith Miller, 2015. Mitchell Beazley, London, 240 pages, ISBN 978-1784720360. £7.99 softcover.

Jewellery and *Objets d'Art*

***Answers to Questions about Old Jewelry, 1840–1950,* 8th edn.**
By C. Jeanenne Bell, 2015. Krause Publications, Iola, Wisconsin, USA, 400 pages, ISBN 978-1440240188. £23.99 softcover.

Anton Cepka: Jewelry and Objects
By The International Design Museum, 2015. Arnoldsche Art Publishers, Stuttgart, Germany, 224 pages, ISBN 978-3897904385. £45.00 hardcover.

Antonio and Piero del Pollaiuolo: "Silver and Gold, Painting and Bronze…"
By Andrea Di Lorenzo and Aldo Galli, 2015. Skira Editore, Milan, Italy, 288 pages, ISBN 978-8857224749. £29.00 hardcover.

Art of the Land of Maharajas: Indian Jewellery and Arms of the XVII–XIX Centuries from Alexander Feldman's Collection
By Eugene Sivachenko and Victoria Bulgakowa, 2015. Hirmer Verlag Publishers, Munich, Germany, 280 pages, ISBN 978-3777422299. £52.33 hardcover.

Cartier Royal: High Jewelry and Precious Objects
By Francois Chaille, 2015. Flammarion, Paris, France, 260 pages, ISBN 978-2080201942. £80.00 hardcover.

Cycles of Life: Rings from the Benjamin Zucker Family Collection
By Sandra Hindman, 2014. Paul Holbertson Publishing, London, 260 pages, ISBN 978-0991517237. £35.00 softcover.

Damiani: Alchemy of Desire. A Story, a Family, and an Italian Passion
By Cristina Morozzi, 2014. Rizzoli International Publications, New York, New York, USA, 240 pages, ISBN 978-0847842834. US$100.00 hardcover.

Eesti Rahvapärased Hõbeehted. Estonian National Silver Jewellery
By Eevi Astel, 2014. Estonian National Museum, Tartu, Estonia, 96 pages, ISBN 978-9949417957. €19.00 hardcover.

Fabergé Eggs by Victor Mayer
By Anne-Barbara Kern, 2015. Arnoldsche Art Publishers, Stuttgart, Germany, 128 pages, ISBN 978-3897904354. £30.00 hardcover.

Inspired by Light and Land: Designers and Makers in Western Australia 1829–1969
By Dorothy Erickson, 2014. Western Australian Museum, Welshpool, Australia, 492 pages, ISBN 978-1920843199. AUS$90.00 hardcover.

Jewellery 1970–2015: Bollmann Collection. Fritz Maierhofer—Retrospective
Karl Bollmann, Graziella Folchini Grassetto, Christoph Thun-Hohenstein and Elisabeth Schmuttermeier, 2015. Arnoldsche Art Publishers, Stuttgart, Germany, 144 pages, ISBN 978-3897904286. US$50.00 hardcover.

Jewels of the Renaissance
By Yvonne Hackenbroch, 2015. Assouline Publishing, London, 200 pages, ISBN 978-1614282037. £120.00 hardcover.

Jewels on Queen
By Anne Schofield, 2014. NewSouth Publishing, Sydney, Australia, 128 pages, ISBN 978-1742231433. £19.99 softcover.

Maker and Muse: Women and Early Twentieth Century Art Jewelry
By Elyse Zorn Karlin, 2015. The Monacelli Press, New York, New York, USA, 256 pages, ISBN 978-1580934046. US$50.00 hardcover.

Non-Figural Designs in Zuni Jewelry
By Toshio Sei, 2015. Schiffer Publishing, Atglen, Pennsylvania, USA, 160 pages, ISBN 978-0764347276. US$24.99 hardcover.

Piaget: Watchmakers and Jewellers Since 1874
By Florence Müller, 2015. Abrams Books, New York, New York, USA, 344 pages, ISBN 978-1419716881. US$85.00 hardcover.

The Rings from the Hashimoto Collection of the National Museum of Western Art
National Museum of Western Art, 2014. National Museum of Western Art, Tokyo, Japan, 318 pages, ISBN 978-4907442040. ¥2,400 hardcover.

Surviving Desires: Making and Selling Native Jewellery in the American Southwest
By Henrietta Lidchi, 2015. University of Oklahoma Press, Norman, Oklahoma, USA, 272 pages, ISBN 978-0806148502. US$34.95 softcover.

***Understanding Jewellery*, 4th edn.**
By David Bennett and Daniela Mascetti, 2015. Antique Collectors' Club, Woodbridge, Suffolk, 526 pages, ISBN 978-1851496976. £45.00 hardcover.

Untamed Encounters: Contemporary Jewelry from Extraordinary Gemstones
By Mimi Lipton, 2014. Thames and Hudson, London, 248 pages, ISBN 978-0500970638. £60.00 hardcover.

Wartski: The First 150 Years
By Geoffrey C. Munn, 2015. Antique Collectors' Club, Woodbridge, Suffolk, 288 pages, ISBN 978-1851497843. £65.00 hardcover.

Mineralogy

Crystals and Crystal Growth
By Wilfred Carter, 2015. Nova Science Publishers, Hauppauge, New York, USA, 108 pages, ISBN 978-1634637916. US$82.00 softcover.

Gold for Collectors
By Scott Werschky, Carles Curto and Joaquim Callén, 2014. Mineral Up Editions, Barcelona, Spain, 288 pages, ISBN 978-8469713464. US$99.99 hardcover.

Lapis Mineralienverzeichnis – Alle Mineralien von A bis Z und ihre Eigenschaften
By Stefan Weiß, 2014. Christian Weise Verlag, Munich, Germany, ISBN 978-3921656808 (in German). €19.80 softcover.

Introducing Mineralogy
By John Mason, 2014. Dunedin Academic Press, Edinburgh, 160 pages, ISBN 978-1780460284. £14.99 softcover.

Social Studies

Most Captivating Diamond Heists of Our Time: A Look at the Worlds Biggest Heists
By Jason Bozzuto, 2014. Self-published, Kobo, Toronto, Canada. US$9.99 eBook.

Erratum

The book *Jadeite: Identification & Price Guide*, 4th edn. should not have been listed in Vol. 34, No. 4, 2014, p. 374, as it deals with glassware and not jadeite gem material.

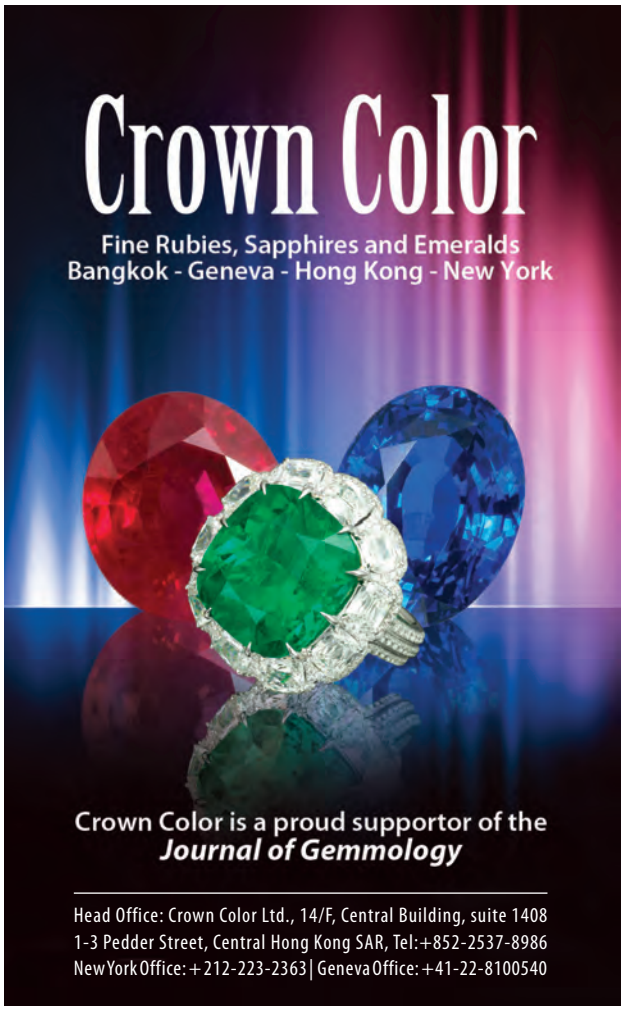

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Cover Photo: The colour appearance of this rough and cut hyalite opal from Zacatecas, Mexico, is due to its green daylight-induced fluorescence. The cut gems weigh 1.34–5.67 ct and were faceted by Michael Gray; the specimen and 5.67 ct stone are courtesy of Kristalle, Laguna Beach, California, USA. Photo by Orasa Weldon.

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Understanding Gems™

What's New

INSTRUMENTS AND TECHNIQUES

Automated Melee Screening (AMS) Device

After several years in development, in early 2015 The De Beers Group of Companies' International Institute of Diamond Grading and Research released their diamond melee screening device to the broad diamond trade. The AMS device automatically tests colourless to near-colourless parcels. The samples are fed from a hopper to a fibre-optic probe that is linked to two spectrometers. The instrument accommodates up to 500 carats of 0.01–0.20 ct round brilliants at a time, and can process 360 samples per hour. The AMS will refer for further testing all synthetics and simulants, and typically ~98% of natural diamonds will 'pass' and require no further examination (type II stones are referred for further testing). It has a 42 × 26 × 23 cm footprint and comes with a compact computer that is used to control the instrument. The cost is US$55,000 plus a three-year software licence, support and warranty contract paid in annual instalments of $10,000. For more information, visit www.iidgr.com/en/services/verification-instruments or email contact@iidgr.com.

Rachelle Grabowski (info@rcopriter.com)

DFI Mid-UV Laser+ Diamond Screening System

In March 2015, GGTL Laboratories announced the commercialisation of their Diamond Fluorescence Imaging (DFI) Mid-UV Laser+ diamond screening system. This instrumentation, which is available to diamond and jewellery manufacturers and dealers, uses a combination of fluorescence microscopy with photoluminescence and Raman spectroscopy. The system employs up to six different UV excitations plus a 405 nm (violet) laser, and contains optical components of the highest quality. It permits the screening of up to 3,000 near-colourless diamonds per hour when used by a well-trained technician. (To guarantee best results, the system is non-automated, and the operator will be able to efficiently screen melee parcels after a brief training period.)

Loose as well as mounted diamonds of any size and shape can be tested, and the results are typically final: natural, synthetic or imitation. Generally there is no need to send questionable stones to a laboratory for further analysis.

Besides the screening of (near-)colourless diamonds, the DFI system can be used for many other gemmological applications, such as the testing of corundum and spinel for synthetics, simulants and treatments. (Users highly experienced in fancy-colour diamond identification can also use it for screening such gems, but this task is far more difficult.) The instrument has a low operational cost of US$1,000 per year (not including electricity) when used eight hours per day.

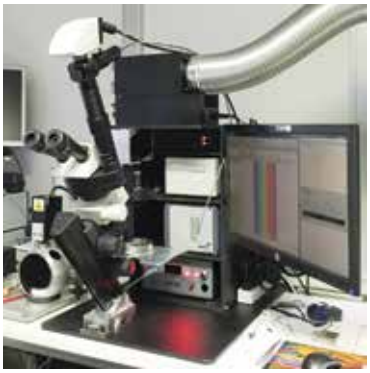

Interested parties can visit the Geneva or Balzers laboratory for a demonstration. For more information, visit www.ggtl-lab.org/science/newsletter (click on GGTL Newsletter No. 4) or email info@ggtl-lab.org.

Dr Thomas Hainschwang FGA and Franck Notari
(thomas.hainschwang@ggtl-lab.org)
GGTL Laboratories
Balzers, Liechtenstein and Geneva, Switzerland

DiaCam360 for Onsite Diamond Photography

Released by Shirtal Diamonds in February 2015 during the International Diamond Week in Ramat Gan, Israel, the DiaCam360 enables portable professional-quality diamond photography using electronic scanning so diamonds can remain on premises. The device can create high-quality photos and 360° interactive videos of diamonds of various shapes weighing up to 20 ct. The scans are customizable, and can accommodate a written description as well as a company logo. DiaCam360 files may be embedded into retailer websites, Rapnet, or other selling platforms.

The DiaCam360 does not require additional camera equipment or special photography skills. The device package includes cloud storage for up to 300 scans, quarterly cleaning/calibration and software updates. Visit www.diacam360.com.

Rachelle Grabowski (info@rcopywriter.com)

GemmoSphere UV-Vis-NIR Spectrometer

In late May 2015, at the JCK jewellery show in Las Vegas, Nevada, USA, M&A Gemological Instruments (MAGI) debuted a prototype of the GemmoSphere. This UV-Vis-NIR spectrometer has a wavelength range of 365–1000 nm with 1 nm resolution. It produces consistent and repeatable readings due to a precisely manufactured integrating sphere/sample chamber. It is specifically designed to fit an accessory for liquid nitrogen immersion of the sample, which is an important capability for diamond analysis. Following MAGI's philosophy of providing the gemmologist with instruments that are simple and straightforward to use, the GemmoSphere comes with software that provides a user interface consistent with both the GemmoRaman532 and GemmoFTIR spectrometers. Orders for the GemmoSphere will be taken starting in August 2015 (approximately €6000) from MAGI's website (www.gemmoraman.com/GemmoSphere.aspx) and from company representatives.

Alberto Scarani and Mikko Åström
(info@gemmoraman.com)
M&A Gemological Instruments
Rome, Italy and Järvenpää, Finland

NEWS AND PUBLICATIONS

Cobalt Diffusion Treatment of Spinel

In May 2015, GRS GemResearch Swisslab issued an alert informing the trade about a new colour enhancement of spinel using cobalt diffusion treatment. The report describes a 5.95 ct very dark blue stone that was obtained from a local market in Beruwala, Sri Lanka. Visit www.gemresearch.ch/news/2015-05-22_Diffusion_Treatment/index.htm.

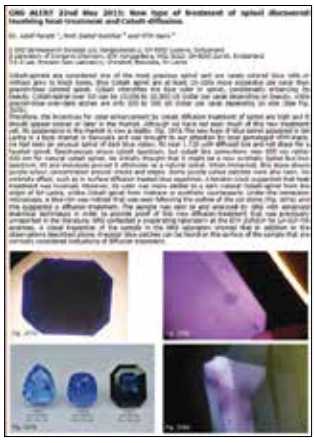

In June 2015, the Gemological Institute of America (GIA) posted a more detailed report on this treatment that describes the properties of 18 samples obtained from a company in Bangkok, Thailand, that reportedly developed the treatment. The samples weighed 0.35–4.99 ct and showed medium to dark blue coloration. The report can be downloaded at www.gia.edu/gia-news-research/cobalt-diffusion-natural-spinel-report.

Diamond-Diamond Doublet Detected in Antwerp

In September 2014, HRD Antwerp issued an online report (www.hrd.be/en/news/a-different-type-of-deception-diamond-diamond-doublet) on a diamond-diamond doublet. As with other doublets, this composite was comprised of two stones cemented together at the girdle. What made this doublet unusual, however, was that both pieces were diamond. Microscopic analysis of the 0.89 ct sample showed unusually strong internal reflections as well as a join line in the middle of the faceted girdle.

The binding material was evidenced by a different RI than the stones, as well as gas bubbles. IR spectroscopy confirmed that both sections of the composite were type IaAB diamond, although tests did not reveal whether they were natural, treated or synthetic.

It is likely that more such diamond-diamond doublets will enter the market; fortunately, their strong internal reflections and join lines make these doublets easy for experienced diamond graders to detect.

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GIA Laboratory Alert for Diamond Colour Treatment

In May 2015, the GIA Laboratory indicated that approximately 500 colourless to near-colourless diamonds that were submitted mainly to their Israel laboratory appeared to have been subjected to a new treatment that temporarily masks the body colour of the stone (see www.gia.edu/gem-lab/laboratory-alert-may-2015). This may improve the apparent colour by up to three grades. The stones ranged from 0.44 to 5.19 ct and were mostly colour-graded E–H. GIA has posted the report numbers for these diamonds on the website above, and has requested that anyone who has such stones resubmit them for review.

ICGL Newsletter

The International Consortium of Gem-Testing Laboratories has released the Summer 2015 issue of their newsletter (No. 2/2015), available at http://icglabs.org. It focuses on tourmaline from Afghanistan, with rarely seen photos of the mines as well as images of exceptional specimens and inclusion features seen in faceted stones.

Low-Temperature Heat Treatment of Mozambique Ruby

In April 2015, the GIA Laboratory posted a report describing the treatment process and identification of red-to-pink corundum that has undergone low-temperature treatment. Experiments were performed on Mozambique ruby in collaboration with heat treaters in Sri Lanka and Thailand (where the temperatures reached approximately 550–750°C). Access the report at www.gia.edu/gia-news-research-low-temperature-heat-treatment-mozambique-ruby.

Microcrystalline Silica Online Lectures

Noted volcanologist Dr Marco Campos-Venuti has developed a comprehensive series of free video lectures on the genesis of microcrystalline silica. The lectures are available at www.agatesandjaspers.com/VIDEO.html, which provides links to the videos on YouTube. Each narrated and illustrated lecture is approximately 15–30 minutes long and covers a unique subtopic related to jasper, agate, or silica. Dr Campos-Venuti starting posting the videos in April 2015, and new lectures are released weekly. Topics include oceanic, volcanic and chemical jaspers, 'thunder eggs', chalcedony, banded agate, lace agate and natural glasses. The entire lecture series comprises 25 videos.

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What's New in the Mineral World?

For years, *Mineralogical Record* has issued free online reports titled *What's New in the Mineral World?* that document new mineral finds as well as old specimens that become available on the market. Although oriented toward mineral collectors, some items of interest to gemmologists that appeared in 2014 include tourmaline from Brazil, Tanzania and Nepal; gem-quality wurtzite and colour-change axinite-(Mg) from Merelani, Tanzania; demantoid from Iran; benitoite from California; and daylight-luminescent hyalite opal from Mexico (as reported in this issue of *The Journal*). In recent years, the reports have been posted in the months of March–April, July–August, and November–December. Visit www.mineralogicalrecord.com/whatsnew.asp.

What's New provides announcements of new instruments/technology, publications, online resources and more. Inclusion in What's New does not imply recommendation or endorsement by Gem-A. Entries are prepared by Brendan Laurs unless otherwise noted.

A Matched Pair of Opals, with a Catch

Alan Hodgkinson

Fine black opals that display the entire spectrum of vivid play-of-colour are seldom encountered. To find such a pair of black opals that match well in shape, colour and pattern is even rarer. The fairly well-matched pair shown in Figure 1 is even more unusual, as one sample is natural and the other is synthetic! Can you tell the difference by looking at the photograph? Admittedly, making this distinction from a photo is more demanding than seeing the samples in the hand. Look first—the answer is revealed below.

The natural stone's identity is well established: it comes from the Lightning Ridge area of New South Wales, Australia, and was probably mined in the late 1920s. Such material found near the surface tends to be stable and not craze, since it has had a long period to acclimatize to the near-surface environment.

The synthetic opal was cut from a parcel of rough that was generously donated to this author for teaching purposes by New York opal dealer Gerry Manning. The specimens covered a range of opal varieties, including milky white material with little play-of-colour, lively 'crystal' opal and semi-black specimens. At the top end of appearance, there emerged after cabochon-cutting a number of attractive black opals—all of which were synthetic. They were produced by Kyocera Co. of Japan, which had bought the patent from the original commercial opal synthesizer: a Frenchman named Pierre Gilson. 'Gilson-created Opal' initially appeared in 1974, two years after his patent was issued, and 10 years after the original breakthrough by Australians P. J. Darragh, A. J. Gaskin and J. V. Sanders (Nassau, 1980).

Figure 1: These two gems show vivid play-of-colour and are fairly well-matched according to their shape, colour and pattern. The 3.00 ct stone on the left is a natural black opal from Lightning Ridge, Australia, while the 2.14 ct sample on the right is a synthetic opal. Photo by A. Hodgkinson.

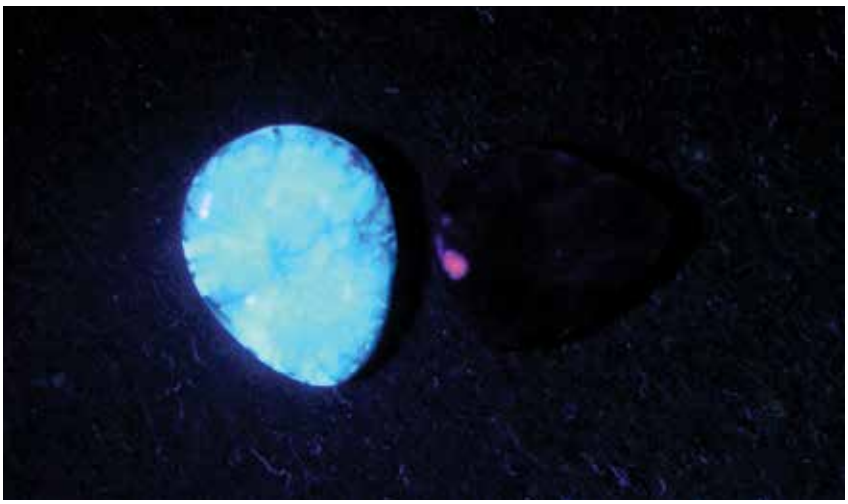

Figure 2: The samples in Figure 1 are shown exposed to 365 nm long-wave UV radiation from an LED lamp. The natural opal fluoresces bright pale blue, while the synthetic is inert (the violet area is a reflection from the lamp on the edge of the cabochon). Photo by A. Hodgkinson.

There appeared to be no telltale 'chicken wire' pattern in the synthetic opal cabochons when viewed superficially with a 10× loupe. However, further examination between crossed polarizers revealed a small area of this pattern in one of the samples. Nevertheless, gemmologists should be careful with using the 'chicken wire' pattern to identify synthetic opal, since in this author's experience a similar structural appearance may be seen in some opals from Virgin Valley, Nevada.

Long-wave UV radiation provides a useful indication of natural opal (i.e. a strong pale blue fluorescence is often seen), but the less-experienced gemmologist may believe this applies only to white or 'crystal' opal. In fact, the natural black opal in Figure 1—seen on the left—showed strong fluorescence (Figure 2). The luminescence shown in the photo was induced by a 365 nm LED lamp. When a traditional long-wave UV lamp was used, the fluorescence was greenish blue and not as strong. While it is known that some synthetic opal does fluoresce a strong bluish white to long-wave UV radiation (e.g. Gunawardene and Mertens, 1984), what clinched the natural identity of this stone was its phosphorescence. After the UV lamp was switched off, the opal continued to emit a dim whitish blue glow for 10 seconds (initially at perhaps 20% of the brightness of the fluorescence). It is interesting to note that the fluorescence pattern mirrored some subtle structural anomalies seen in the play-of-colour of the opal. Short-wave UV radiation at 253 nm also induced similar fluorescence and phosphorescence.

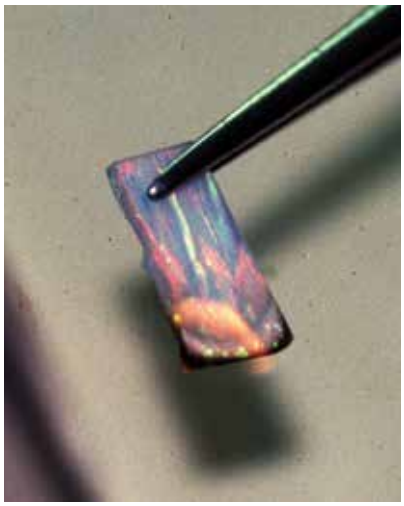

Figure 3: Some reportedly 'synthetic' opals (actually simulants) contain so much plastic stabilizer that they burn when exposed to flame. These simulants are distinct from those that are entirely plastic. Photo by A. Hodgkinson.

For many years, Manning was plagued by companies selling so-called 'Japanese' synthetic opals—under the 'Gilson' name—that contained up to 50+% of a plastic filler. (Such material does fluoresce to long-wave UV radiation, but there is no phosphorescence.) So exasperated was Manning that he delighted in setting fire to the blatant counterfeit material with a cigarette lighter (e.g. Figure 3). Rather than a synthetic, this plastic-rich material is described more accurately as an opal *simulant*. Gilson's material is correctly described as *synthetic*, although some have questioned the use of this terminology for his later production.

Just as for natural opal, the Gilson synthetic shown on the right in Figure 1 would not ignite if combustion tested. However, there is a strong possibility that any opal specimen, whether natural or synthetic, would craze or even crack if so burned. Obviously, observing the fluorescence/phosphorescence of opal is a much better alternative than burning it, which is perhaps the ultimate example of destructive testing.

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Gem Notes

COLOURED STONES

Chrysocolla Chalcedony from Spain

Chrysocolla chalcedony is an attractive green-to-blue material that is commonly marketed as 'gem silica'. At the 2015 gem shows in Tucson, Arizona, USA, Gems in Gems (Seville, Spain) had some chrysocolla chalcedony from a new locality: Rio Tinto in the Seville area of Spain. Sold as 'Sea Stone', the material was gathered in May 2014 from the surface of an old copper mine. Approximately 40 kg of rough material were recovered from a silicified zone of the deposit, which also contained chalcedony pseudomorphs after barite, calcite and other minerals.

Nearly 20 cabochons containing chrysocolla chalcedony have been polished so far, in sizes from 17 × 25 mm to 22 × 38 mm. The material ranges from green (Figure 1) to greenish blue (Figure 2), and forms irregular masses within various amounts of matrix. Particularly common are chrysocolla chalcedony infillings in milky white vein quartz. The diaphaneity of the chrysocolla chalcedony ranges from translucent to semi-transparent. According to Gems in Gems, the material has not been treated in any way.

Figure 1: Spain is the source of this chrysocolla chalcedony (~3.2 cm wide), which formed in association with milky white vein quartz. Courtesy of Gems in Gems.

Recently a new locality in the same area was discovered that contains even thicker veins of chrysocolla chalcedony, so the outlook for future production of high-quality material is quite encouraging.

Acknowledgement: Gems in Gems is thanked for donating to Gem-A the cabochon shown in Figure 2 (left).

Brendan M. Laurs FGA

Figure 2: Cabochons of the Spanish chrysocolla chalcedony (here, containing predominantly greenish blue masses) have been cut with varying amounts of matrix. Photos by B. M. Laurs (left, 3.1 cm tall) and courtesy of Gems in Gems (right, image width 5 cm).

Rhodochrosite from Brazil

Rhodochrosite usually occurs as translucent to opaque, fine-grained aggregates, often showing a banded pattern of white and pink due to the presence of impurities. Less common are transparent gem-quality pink-to-red crystals, known particularly from the Sweet Home mine in Colorado, USA, and also from the Kalahari Desert region in South Africa and from Guangxi, China (e.g. Webster, 1994; Moore et al., 1998; Lees, 2009).

During the 2015 Tucson gem shows, gem dealer Mark Kaufman (Kaufman Enterprises, San Diego, California, USA) had some rough and cut transparent rhodochrosite from another locality: Brazil. He obtained 12 damaged crystals that were reportedly mined several years ago from a pegmatite in Minas Gerais State. Kaufman faceted 15 stones ranging from 0.4 ct to nearly 8 ct, and loaned one cut specimen and one crystal (Figure 3) to this author for examination.

The crystal weighed 16.99 g, and the cushion-shaped faceted stone measured 16.60 × 9.56 × 5.92 mm and weighed 7.78 ct. The crystal showed a somewhat thick tabular habit, with large prismatic and rhombohedral faces. Several shallow cleavage fractures were present just under the crystal's surface, oriented in three directions parallel to the rhombohedral faces (Figure 4, left). The surface itself appeared slightly etched with a matt lustre, but the inner part of the crystal appeared to be completely transparent and very clean.

Figure 3: This crystal and faceted stone of rhodochrosite from Brazil weigh 16.99 g and 7.78 ct, respectively. Photo by Dirk van der Marel.

The faceted stone showed a saturated red-pink colour and high transparency. The stone displayed strong doubling of the facet junctions, consistent with the large double refraction of carbonate minerals such as rhodochrosite. RI readings confirmed this, with one shadow line at a minimum value of 1.603 and a higher value that was above the limit of the refractometer (i.e. greater than ~1.79). The birefringence of rhodochrosite is 0.22 (e.g. Webster, 1994), which means that the higher RI was probably around 1.823. The lower RI of 1.603 stayed constant when the stone was rotated 360° on the hemicylinder. As rhodochrosite is uniaxial negative, this indicates that the table was cut exactly 90° to the c-axis, parallel to a prismatic crystal face.

Moderate dichroism was observed, in pinkish red (red in the crystal) and light pinkish orange.

Figure 4: Near the surface, the rhodochrosite crystal showed perfect cleavage (left, image width 0.9 mm). Needle-like inclusions were present in the otherwise exceptionally clean, faceted rhodochrosite (right, image width 0.5 mm). Photomicrographs by J. C. Zwaan.

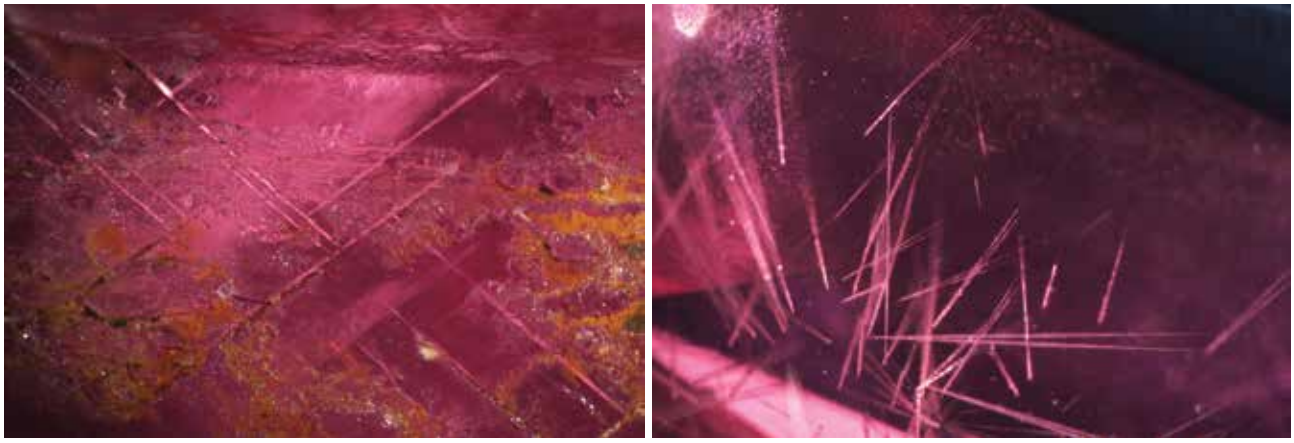

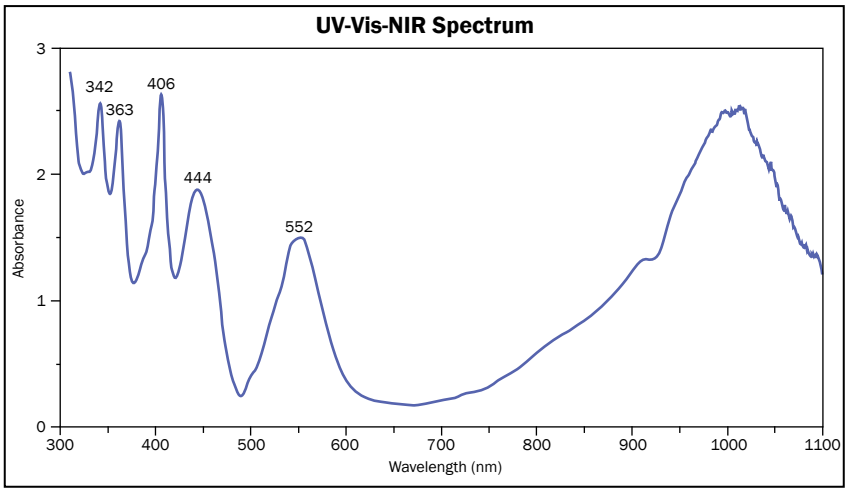

Figure 5: This UV-Vis-NIR spectrum of the Brazilian rhodochrosite crystal, taken parallel to the c-axis, shows absorption peaks on the left side that are due to the presence of Mn^{2+}, and a broad band centred around 1000 nm that is related to Fe^{2+}.

The samples were inert to long-wave UV radiation, but fluoresced a weak red to short-wave UV. A prism-type spectroscope showed a dark band at ~410 nm and weaker bands at ~450 and 550 nm. These properties, and a hydrostatic SG of 3.72, are fairly consistent with those expected for rhodochrosite (with the RI and SG values being the highest known for this mineral; cf. Webster [1994], who reported RIs of 1.600–1.820 and an SG range of 3.45–3.70).

The faceted stone contained needle-like inclusions on one side (Figure 4, right), but was otherwise clean. Raman analysis of these inclusions at the surface of the stone was not conclusive; the weak spectra suggested the presence of barite and mica. The needles were not seen in the crystal fragment, which instead contained small two-phase inclusions. Raman analysis of the stone itself revealed an almost perfect (99%) match with rhodochrosite from the Sweet Home mine in the RRUFF database.

Energy-dispersive X-ray fluorescence spectroscopy (EDXRF) analyses showed mainly Mn and some Fe, with traces of Ca and Mg. Taking into account the presence of CO_2, recalculated values gave 55.6–56.0 wt.% MnO, 5.48–5.74 wt.% FeO, 0.26–0.29 wt.% CaO and ≤0.30 wt.% MgO. Chemical analysis further indicated that the small amount of matrix on one side of the crystal (Figure 3) consisted of K-feldspar and iron sulphide.

Ultraviolet-visible–near infrared (UV-Vis-NIR) absorption spectra (e.g. Figure 5) gave a more detailed picture of what was observed with the spectroscope, with pronounced peaks at ~340, 360 and 410 nm, accompanied by bands at ~440 and 550 nm, and a broad band around 1000 nm, creating a transmission window at around 650–700 nm that is responsible for the pink-red colour. The left part of the spectrum is similar to that of manganese(II) hydrate $[Mn(H_2O)_6]^{2+}$, with all the peaks attributed to the electron transitions related to the presence of Mn^{2+}, while the broad band at around 1000 nm is related to the presence of Fe^{2+} (cf. Jørgensen, 1954).

In light of rhodochrosite's perfect cleavage in three directions, as well as the softness of the material (3½–4 on the Mohs scale), the remarkably clean gemstone of 7.78 ct, which did not show any sign of incipient cleavage, is a true piece of craftsmanship.

Although Kaufman's supplier did not indicate the exact origin of this material within Brazil, a small amount of similar gem-quality

Figure 6: Although not studied for this report, these specimens of rough (5 cm across) and cut (11.97 ct) rhodochrosite also were produced in Brazil, from the Toca da Onça pegmatite in Minas Gerais State. Photo courtesy of Elliott/Fine Minerals International.

rhodochrosite was reportedly found at a granitic pegmatite (Xanda mine) in Minas Gerais in 2013 (www.minfind.com/mineral-203128.html), and rhodochrosite also was recovered prior to May 2014 at the Toca da Onça pegmatite (Virgem da Lapa, Jequitinhonha Valley, Minas Gerais; Figure 6). According to Daniel Trinchillo (Fine Minerals International, Edison, New Jersey, USA), the latter discovery may have produced >500 g of rough material. The Toca da Onça pegmatite has historically been mined for blue tourmaline.

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Tourmaline Mining in the Democratic Republic of the Congo

For many years, the Democratic Republic of Congo (DRC) has been a source of gem tourmaline—particularly the Virunga region in North Kivu, located north of the capital city of Goma (Laurs et al., 2004; Henn, 2010). In April 2014, gem dealer Farooq Hashmi (Intimate Gems, Glen Cove, New York, USA) visited another tourmaline-producing area in DRC: Numbi, in the South Kivu region. Located 40 km (by air) west of Goma, Numbi is reached from Goma by travelling by car for approximately three hours on mostly unpaved roads and then by motorbike for another three to four hours on a rough muddy track.

Hashmi reported that there were two main mining areas for tourmaline near Numbi; at both localities, columbite-tantalite minerals are recovered as a by-product. One area is about 30 minutes' walk from the town, and is situated in a lush valley. The alluvial deposits there were mined from beneath 1–4 m of overburden using simple hand tools (e.g. Figure 7). Small gasoline-powered pumps were used to remove water from the pits. Hashmi witnessed active mining in several pits, and also passed numerous abandoned diggings over a distance of 1–2 km. The second mining area was reached by hiking

Figure 7: This open pit near Numbi, DRC, is being excavated with hand tools to reach an alluvial layer containing gem tourmaline and columbite-tantalite minerals. Photo by Farooq Hashmi.

Figure 8: Tourmaline is also mined from the base of this hillside near Numbi. Photo by Farooq Hashmi.

an additional 1 km, and was located at the base of a hillside (e.g. Figure 8). Here eluvial and possibly some primary deposits were being mined, again using hand tools. Some morganite and pale yellow apatite also were recovered from unspecified deposits in the Numbi area, but the latter was generally not of gem quality.

The miners sold their production to brokers, who then distributed the material to others in Numbi town before it was taken to Goma. Hashmi saw 50–100 kg of tourmaline rough while in Numbi, but most was fractured and suitable only for cutting cabochons. He obtained ~3 kg of clean material (e.g. Figure 9), and the largest clean piece ('peach' coloured) weighed ~20 g. Most of the tourmaline was yellowish green to green (60–70%) and orangy pink to purplish pink (30–40%); blue was rarely seen, unlike from the North Kivu area mentioned above.

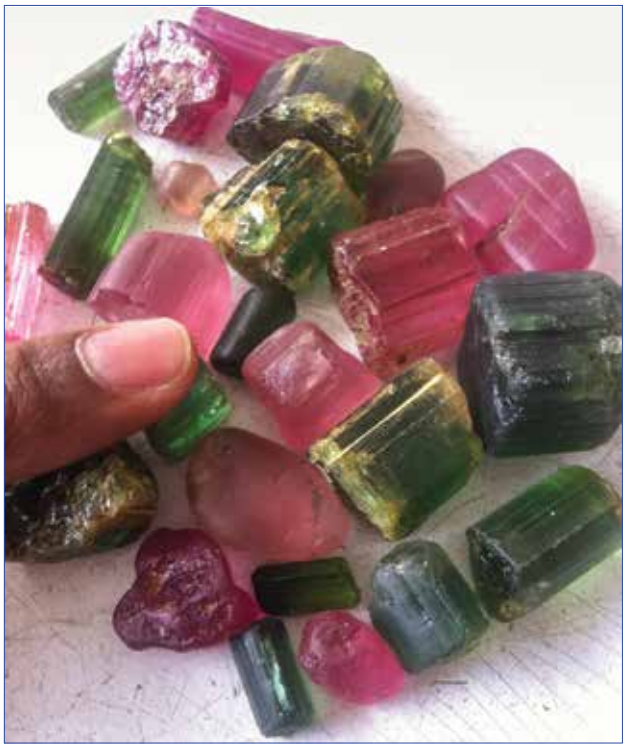

Figure 9: Tourmaline rough from the Numbi area is typically green or pink and shows variable amounts of rounding. Photo by Farooq Hashmi.

The Numbi mining area appears to be quite extensive, and should continue to produce small amounts of gem tourmaline for several years.

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Colour-zoned Cr- and V-bearing Tourmaline from Kenya

Green tourmaline containing Cr and/or V, commonly known as 'chrome tourmaline' in the trade, is an attractive gem variety known mainly from East Africa. During the 2015 Tucson gem shows, gem dealer Dudley Blauwet (Dudley Blauwet Gems, Louisville, Colorado, USA) had some unusual colour-zoned chrome tourmalines that reportedly came from Makuki, Kenya. He first encountered this material in August 2014, when he obtained four gem 'pencils' (6.41 g total weight) from an East African rough dealer. The crystals were colour-zoned perpendicular to the c-axis in shades of light and dark green. Cutting of two of these crystals yielded gems weighing 4.44 and 6.11 ct. Blauwet loaned one crystal and one of the faceted stones to these authors for examination (Figure 10).

The crystal was a well-formed trigonal prism weighing 1.68 g and measuring 21.27 × ~6.7 mm. The faceted stone weighed 6.11 ct and measured

Figure 10: These rough and cut Cr- and V-bearing tourmalines show distinct colour zoning perpendicular to the c-axis. The crystal is ~21 mm long and the cut stone weighs 6.11 ct. Photo by B. Williams.

18.04 × 6.42 × 5.85 mm; it was polished in the classic tourmaline style of a step cut with a long keel oriented parallel to the c-axis. Both samples were similar in colour and also in their colour variations, ranging from a medium-dark green to a light yellowish green with some colour banding. The gems appeared darker when viewed down the c-axis, as expected for tourmaline, but did not exhibit the typical over-dark appearance (or 'closed' c-axis) seen in many tourmalines of comparable saturation.

The faceted sample was eye-clean and exhibited some minor planar growth zoning in the microscope. The crystal exhibited several shallow cracks approximately perpendicular to the c-axis. Viewed through a Chelsea colour filter, both stones displayed shades of red and pink, with the redder reactions corresponding to areas of darker green coloration. RI values varied along the length of the faceted stone: at the darker end they were 1.617 and 1.638 (birefringence 0.021), while the lighter end gave readings of 1.610 and 1.630 (birefringence 0.020). Raman spectroscopy confirmed the stones were tourmaline, with peaks characteristic of elbaite, uvite and dravite. (Quantitative chemical analyses would be necessary to establish the actual tourmaline species present.) Qualitative EDXRF spectroscopy showed a higher Ca content in the darker end of the cut stone. The tourmaline chromophores Ti, V, Cr, Mn and Fe were all present in minor amounts, with much more V in the darker green areas, together with somewhat higher Ti and Cr concentrations.

Dichromatism was observed when a light was shined along the c-axis (Figure 11): both samples showed a red tint when viewed down the longer light paths. This appearance has also been referred to as the *Usambara effect* (e.g. Halvorsen, 2006; Pearson and Hoover, 2014).

Blauwet reported obtaining some additional crystals of Makuki tourmaline from his supplier at the 2015 Tucson gem shows. Most of this later material was not colour zoned, and it was faceted into nine pieces weighing a total of 20.05 carats. It is unclear if more of this tourmaline will become available in the future.

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Figure 11: A red tint is seen when the tourmaline is viewed along the longer light path, down the c-axis. The crystal is ~6.7 mm in diameter. Photo by B. Williams.

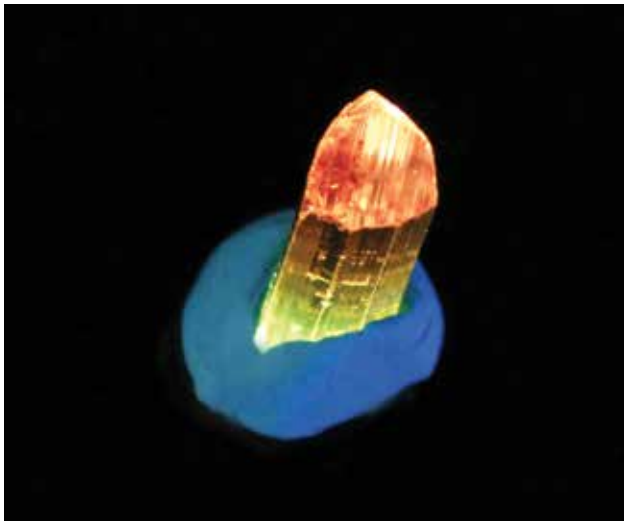

PEARLS

Pearl Marking: An Innovative Non-destructive Method

During the past few years, the gem and jewellery market has increasingly demanded better product knowledge, in particular regarding product origin and traceability. Various worldwide organizations have attempted to address this need with 'best practice' codes and verification systems. The cultured pearl industry also faces issues of traceability, and since the culturing process often uses a bead for nucleation, several projects have focused on the concept of bead marking and related means of recognition (Hänni and Cartier, 2013).

In March 2014, a relatively new technique for pearl tagging called 'Heart of Pearls' (HoP) was presented to the LFG (French Gemmological Laboratory) by Jean-Pierre Le Pollès (Auffargis, France). The technique was designed with the cultured pearl industry in mind, but it may be applied to natural as well as cultured pearls, including those mounted in jewellery.

The HoP concept is very simple: application of a very small label designed not to distract the eye but nevertheless to be quite easy to find with magnification. The microscopic label (e.g. Figure 12) carries a high-resolution holographic image to ensure authenticity, and further security is provided by an embedded invisible coding. (Note: To protect the security of this technique, which is patent pending, the coding specifications are not described here, and the tags shown in this report are samples.) The tag is personalized by an alphanumeric code that is integrated within its structure. In this way, the tag can include relevant data such as the cultured pearl's quality grade, geographical origin, farm name, year of harvest, type of host mollusc, ethics label, ID number, brand and security key. The data on the tag are listed on three lines using a combination of letters or numbers (Figure 13), and can be customized according to local regulations or a customer's request. The label is affixed using a proprietary UV-fluorescent glue, thus enabling the tag to be quickly located (Figure 14). The colour of the glue's fluorescence is controlled by various

Figure 12: This example of the 'Heart of Pearls' marking technique shows an octagonal tag measuring 400 µm across that is glued to the surface of a Pinctada margaritifera *cultured pearl. The tag is inscribed with 'A.BCD', which is clearly visible with a gemmological microscope. The tag is surrounded by a hardened layer of colourless transparent glue. Photomicrograph by O. Segura.*

Key

CK:	Cook Islands ISO 3166-1-alpha-2
14:	2014
XXXX:	ID number and/or pearl grade
PR:	Producer
99:	Security key

Figure 13: Data on the HoP tag may be coded in three lines, as shown in this example for a cultured pearl produced in the Cook Islands in 2014. Courtesy of Jean-Pierre Le Pollès.

Figure 14: When exposed to long- or short-wave UV radiation, the glue used to affix the HoP tag in this prototype example fluoresces blue, while the surrounding cultured pearl is inert, enabling the marker to be easily located. The size of the fluorescent spot is approximately 1 mm in diameter. Photomicrograph by O. Segura.

dopants, and a different luminescence colour can be assigned according to the type of mollusc and/or country of origin. Both the fluorescence and the information on the tag can be observed with an inexpensive pocket microscope equipped with 60× magnification and a UV LED (e.g. Figure 15).

All of the usual laboratory techniques that are used to analyse pearls (X-radiography, spectroscopy, etc.) can be accomplished without the results being disturbed by the tag. If necessary, the tag and its UV-fluorescent glue can be removed using nail polish remover (acetone). Thus, the cultured or natural pearl may be returned to its initial state without any remnants of the tagging process; the final consumer may therefore return it to its pristine state without any damage if they wish to do so.

Figure 15: A pocket microscope can be used to read an HoP tag, and also to view the UV luminescence colour of the glue that is used to affix it. Photo by Jean-Pierre Le Pollès.

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SYNTHETICS AND SIMULANTS

Modern Doublets, Manufactured in Germany and India

At the November 2014 Hong Kong Jewellery and Gem Fair, one of the authors (HAH) noticed some attractive faceted stones in colours resembling popular gem materials (e.g. Figure 16). These samples were actually doublets produced by a German lapidary, Viktor Kämmerling of Idar-Oberstein. They were manufactured using colourless gem materials cemented by an artificial resin that had been dyed to create strikingly realistic gems. Both the crown and pavilion consisted of beryl (for emerald substitutes), topaz (for imitations of spessartine, tanzanite, Paraíba tourmaline and rubellite), tourmaline (for another Paraíba tourmaline substitute) and quartz (for imitations of

Figure 16: These doublets display various colours and optical effects. Samples 1–15 weigh 1.71–8.83 ct, and consist of colourless natural gemstone crowns and pavilions that are glued together with a coloured binder to create the illusion of popular gem varieties. The other samples weigh 2.29–13.79 ct, and display iridescence (no. 18) or contain pieces of foil in the cementing layer that produce different optical effects (nos. 16 and 17). Photo by H. A. Hänni.

peridot, aquamarine, topaz, morganite, amethyst, ametrine, bicoloured tourmaline and prehnite). The gems typically weighed between 2 and 10 ct and were available in calibrated sizes.

Additional high-quality doublets were seen by the authors in February 2015 at the Inhorgenta show in Munich, Germany. A small number of these gems were on display at the booth of Gemstones Corp. (Jaipur, India), which revealed additional colours; some were even bicoloured. They were priced inexpensively and sold as quartz doublets, the majority as oval cuts weighing ~8 ct. Also on display were quartz doublets showing interesting visual effects (again, see Figure 16): red needle-like inclusions (similar to rutilated or tourmalinated quartz), flat metallic inclusions with the appearance of gold and samples showing remarkable iridescence.

The results of our investigations of 18 samples are reported in Table I, and preliminary observations of some of these doublets were given by Hänni (2014). The dye that was used to impart such a realistic colour appearance to those manufactured by Viktor Kämmerling was either dissolved in the binder or consisted of tiny pigment grains suspended in the resin (e.g. Figure 17, left). The desired saturation of the colour was achieved by adjusting the concentration of dye in the resin and the thickness of the glue layer (e.g. Figure 17, right). In the examined samples, this layer varied from about 0.1 mm ('morganite' no. 11) to less than 0.05 mm (centre portion of 'bicoloured tourmaline' no. 14). The character of the colourless parts and the thin coloured glue layer was best observed in immersion (Figure 18, left). The cement typically contained various

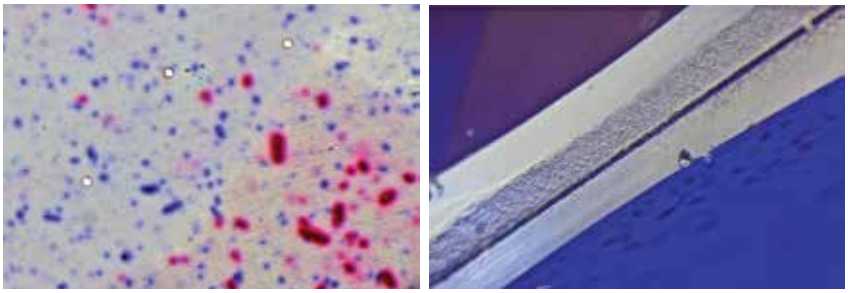

Figure 17: Left: The glue layer in a tanzanite-coloured topaz doublet (no. 7) contains red and blue pigment particles and some gas bubbles (left, image width ~2 mm). Right: The girdle area of the tanzanite imitation displays a coloured glue layer with a thickness of ~0.025 mm. Photomicrographs by H. A. Hänni.

Table I: Properties of some doublets from Viktor Kämmerling and Gemstones Corp.

No.	Colour	Gem imitated	Weight (ct)	Crown/ pavilion*	Internal features	
					In crown and pavilion	In glue layer
1	Green	Emerald	5.35	Beryl/beryl	Clouds, fine tubes	Small gas bubbles
2	Green	Emerald	3.86	Beryl/beryl	Partially healed basal fractures, veils	Small gas bubbles
3	Blue-green	Paraíba tourmaline	1.71	Tourmaline/ tourmaline	Open fissures, fluids	Small gas bubbles
4	Blue-green	Paraíba tourmaline	3.36	Topaz/topaz	Partially healed fractures, two-phase inclusions	Very small pigment particles
5	Red	Rubellite	4.45	Topaz/topaz	None	Distinct pigment particles
6	Orange	Spessartine	4.71	Topaz/topaz	None	Some bubbles, small particles
7	Violet	Tanzanite	4.49	Topaz/topaz	Metallic inclusion	Bubbles, red and blue particles
8	Yellow-green	Peridot	8.83	Quartz/quartz	None	Extended bubble fields
9	Light blue	Aquamarine	7.54	Quartz/quartz	Very small fluid(?) blebs	Dust and some bubbles
10	Light blue	Topaz	8.64	Quartz/quartz	None	Dust and some bubbles
11	Orangey pink	Morganite	8.21	Quartz/quartz	Two-phase negative crystals	Bubbles and pigment particles
12	Violet	Amethyst	8.66	Quartz/quartz	None	Bubbles and pigment particles
13	Violet and yellow	Ametrine	8.30	Quartz/quartz	None	Bubbles and pigment particles
14	Red and green	Bicoloured tourmaline	8.37	Quartz/quartz	None	Bubbles and pigment particles
15	Milky green	Prehnite	8.48	Quartz/quartz	Irregular fine fibres	Bubbles and minor pigment particles
16	Colourless with 'golden' inclusions	Gold-in-quartz	13.79	Quartz/quartz	None	Metallic foils
17	Colourless with narrow foil strips	Rutilated or tourmalinated quartz	2.29	Quartz/quartz	None	Metallic foils
18	Various iridescent	Girasol	4.28	Quartz/quartz	None	Gelatinous appearance

* Identified by Raman spectroscopy using a B&W Tek MiniRam 785 instrument equipped with a >300 mW 785 nm laser.

amounts of gas bubbles. In some gems, the bubbles were sparse and dispersed sporadically, while in others they were more abundant and concentrated near the girdle of the sample (Figure 18, right).

Natural inclusions in the crown and pavilion components of the doublets were seen in only some samples (see Table I). For the quartz samples from Viktor Kämmerling, Fourier-transform infrared (FTIR) spectroscopy with a PerkinElmer Paragon 1000 spectrometer showed typical bands for natural quartz in the 4000–3000 cm^{-1} range, especially the 3595 cm^{-1} band (Zecchini and Smaali, 1999). Both parts of quartz sample no. 15 contained abundant, randomly oriented, fine fibres. Observation of the stone's surface with a scanning electron microscope showed only pits corresponding to these inclusions, which were filled with debris from the tin polishing wheel.

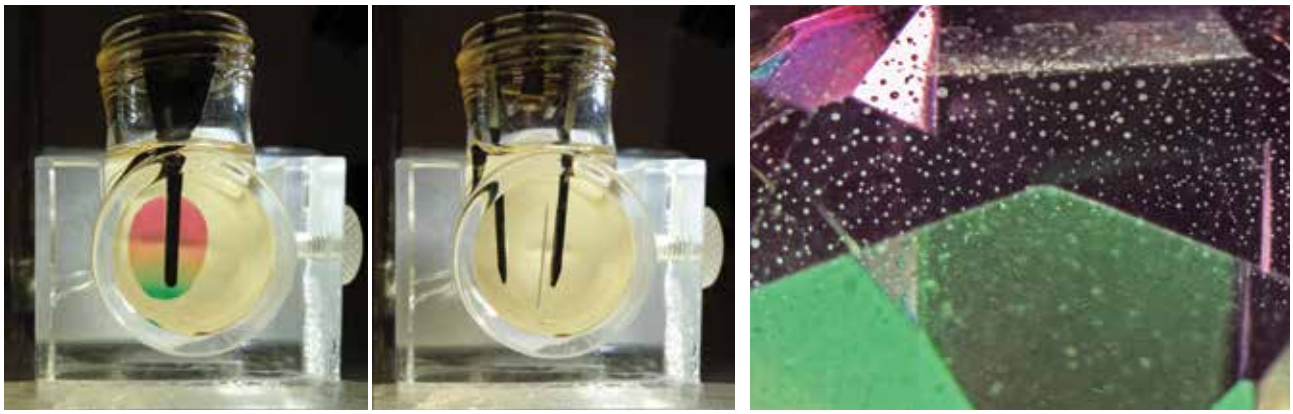

Figure 18: Left: A quartz doublet imitating bicoloured tourmaline (8.37 ct; no. 14) is shown immersed in benzyl benzoate, in views both perpendicular (left side) and parallel (right side) to the girdle plane. Right: The bicoloured tourmaline imitation contains a more concentrated area of gas bubbles near the girdle area (image width ~5 mm). Photos by H. A. Hänni.

Two of the quartz doublets from Gemstones Corp. were found to have thin metallic foils in the cement layer. One of these samples (no. 16) had 'golden'-coloured foil, simulating gold-in-quartz. The other sample (no. 17) revealed narrow foil strips in geometric orientations. The iridescent doublet (no. 18) contained a gelatinous-appearing glue layer that was bright green, yellow or violet depending on the viewing angle when observed in reflected light (e.g. Figure 19). The constituent quartz of these doublets was identified as natural by FTIR spectroscopy, with bands at 3595, 3482 and especially 3379 cm^{-1}. A peak at ~3480 cm^{-1} is typically associated with rock crystal quartz (Choudhary, 2010).

It is not difficult to recognize the composite character of these doublets when they are unmounted and immersed in water or another medium (cf. Henn, 2002). Viewed from the side with a 10× loupe, the girdle plane displays a narrow dark colour band of less than a millimetre. The colourless topaz, beryl or tourmaline used for these doublets may contain inclusions typical for these gem materials, and their conclusive identification as doublets is established by observation of the coloured binder layer. In addition, the doublets will show a peculiar behaviour in the polariscope, with no distinct extinction, which points toward an assembled stone.

Acknowledgements: We thank Viktor Kämmerling and R. K. Jain for providing samples for this study. Daniel Mathis of Zentrum für Mikroskopie ZMB of Basel University is acknowledged for the SEM analysis of sample no. 15.

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Figure 19: The glue layer in the iridescent quartz doublet (no. 18) displays various colours depending on the viewing angle, and contains numerous gas bubbles. Photomicrograph by U. Henn; image width ~10 mm.

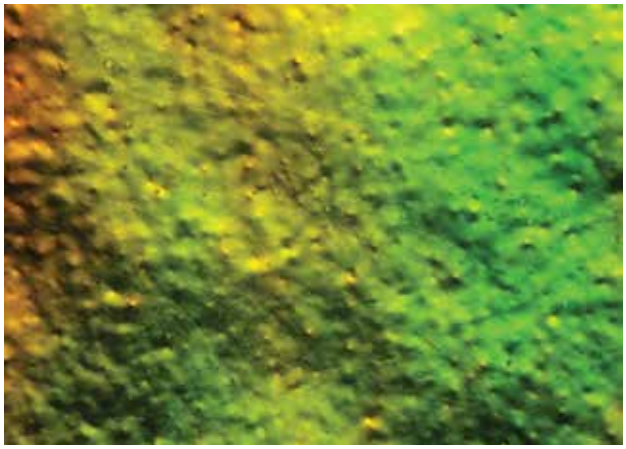

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Fracture-filled Synthetic Emerald, with Synthetic Quartz Inclusions

Recently, the Gem Testing Laboratory, Jaipur, India, received a 1.15 ct, green, oval mixed cut, measuring 8.02 × 5.86 × 4.06 mm (Figure 20). Initial observation with the unaided eye suggested it was emerald. RI values were 1.580–1.587 (birefringence 0.007), the hydrostatic SG was 2.70 and it displayed typical chromium absorption with the desk-model spectroscope. All of these features are consistent with emerald. Viewed with the microscope, however, strong wavy 'chevron' growth features were seen throughout the stone (Figure 21); in addition, some reflective liquid 'fingerprints' were present, mostly in one direction. These features are indicative of a hydrothermal synthetic origin. The gem also contained surface-breaking fractures that displayed blue, green and 'golden' yellow colour flashes (Figure 22)—suggestive of fissures that have been filled with resin—along with a few reflective patches that resulted from incomplete fracture filling.

Microscopic examination also revealed a few colourless crystals in the synthetic emerald. On careful examination, some of these crystals were found to be associated with nail-head spicules (again, see Figure 22), while others formed isolated clusters of elongated inclusions. Closer observation of one of the spicules showed a hemispherical 'head' that appeared to be composed of tiny grains, some of which were granular and frosty (Figure 23, left). The isolated clusters (i.e. without a spicule) consisted of euhedral prismatic bipyramidal crystals (Figure 23, right). The morphology of these crystals, particularly the larger ones, resembled that commonly seen in quartz.

Figure 20: This 1.15 ct oval mixed cut proved to be a fracture-filled hydrothermal synthetic emerald. It was also unusual for its synthetic quartz inclusions. Photo by G. Choudhary.

Raman analysis of the crystals, present as the 'head' of the spicules as well as isolated clusters, using a 532 nm laser, confirmed they were quartz. The spectra showed characteristic major peaks in the 2000–200 cm^{-1} region at ~1157, 1080, 807, 464, 353, 263 and 206 cm^{-1}. FTIR spectroscopy was further used to confirm this emerald as synthetic. The spectra displayed a sharp line at ~5280 cm^{-1}

Figure 21: The strong wavy 'chevron' growth pattern indicates that the synthetic emerald in Figure 20 was grown by a hydrothermal process. Photomicrograph by G. Choudhary; image width 4.2 mm.

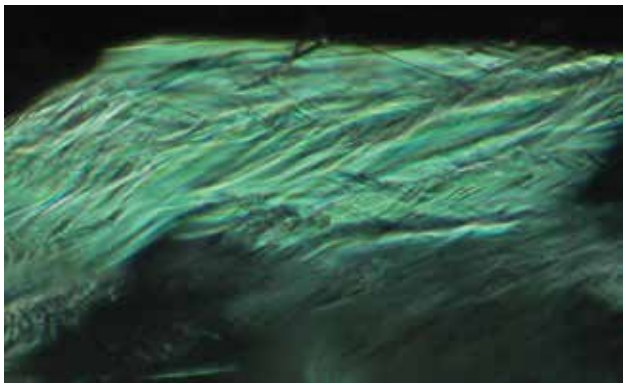

Figure 22: Surface-reaching fissures in the synthetic emerald display flash-effect colours suggestive of fracture filling by a resin, along with some reflective patches of uneven filling. The presence of resin was confirmed by FTIR spectroscopy. Also note the nail-head spicule (centre-right of view), consistent with the synthetic origin. Photomicrograph by G. Choudhary; image width 3.3 mm.

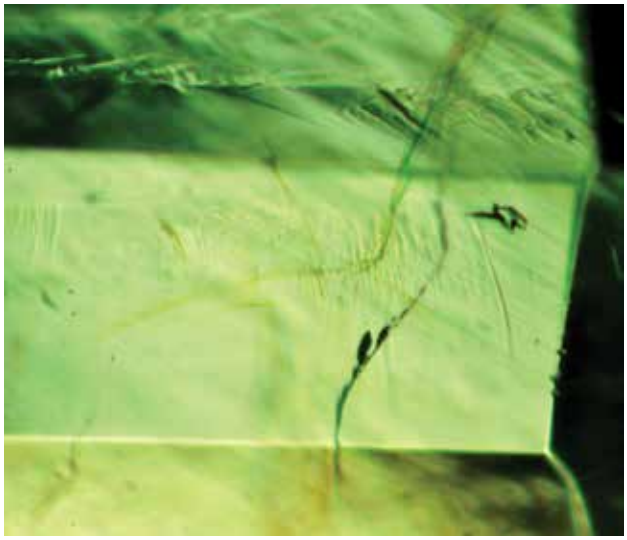

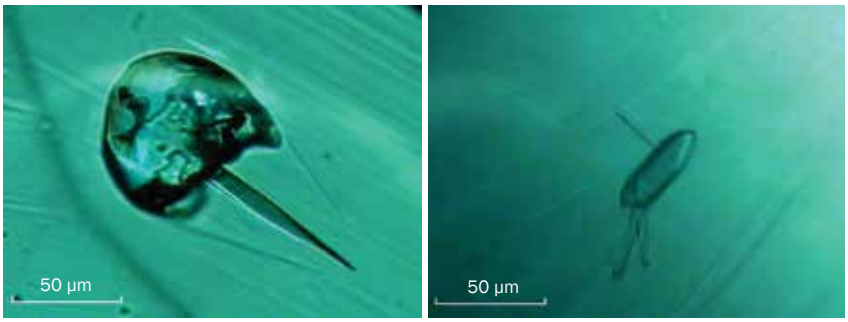

Figure 23: On the left, this spicule in the synthetic emerald consisted of a hemispherical 'head' composed of tiny grains, some of which were granular and frosty. Raman analysis of the 'head' showed the presence of quartz. The photo on the right shows an inclusion cluster of well-formed crystals that also were identified as quartz by Raman spectroscopy. Photomicrographs by G. Choudhary.

(type II water) with side bands for type I water at around 5500–5380 cm^{-1} and 5150–5040 cm^{-1}, an absorption band ranging from 4000 to 3400 cm^{-1} and general absorption below 2100 cm^{-1}. The synthetic origin was revealed by the 2400–2200 cm^{-1} region, with bands at ~2358, 2340 and 2328 cm^{-1}. The CO_2 band at ~2358 cm^{-1} is usually present in association with a feature at 2291 cm^{-1} in natural emerald (not present in this sample) and also the bands at ~2340 and 2328 cm^{-1} are typical of synthetic emerald (Giard et al., 1998). The FTIR spectra additionally displayed features at ~3060, 3032, 2923 and 2871 cm^{-1} that are associated with resin, consistent with the flash effects mentioned above.

The 'head' of the spicules in synthetic emeralds is usually composed of grains of synthetic phenakite, beryl, chrysoberyl, gold or other mineralizers (Choudhary and Golecha, 2007). The presence of synthetic quartz inclusions in synthetic emerald—either as the 'head' of spicules or forming isolated clusters—has not been reported previously to this author's knowledge. In addition, the fracture filling of this synthetic emerald is quite unexpected, and could have occurred when the gem was accidentally mixed into a parcel of natural stones.

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Glass Imitations of Cu-bearing Mozambique Tourmaline

Alluvial deposits in the Mavuco area of north-eastern Mozambique are famous for producing copper-bearing tourmaline in a variety of colours (e.g. Laurs et al., 2008a). At the 2015 Tucson gem shows, Michael Puerta (Intimate Gems, Glen Cove, New York, USA) showed one of these authors (BML) three pebbles that he obtained in Mavuco in June 2014. Although their general appearance was quite convincing for rough alluvial tourmaline (Figure 24), Puerta felt that they did not seem 'right'.

One of the pebbles showed an attractive 'neon' blue colour that is typical of Cu-bearing tourmaline (although not commonly encountered in unheated rough from Mavuco), and another one was a purplish pink that, for Cu-bearing

Figure 24: These pebbles were sold as Cu-bearing tourmaline in Mavuco, Mozambique, but they actually consist of glass. The blue and dark yellow samples are each ~1.4 cm wide. Photo by B. M. Laurs.

tourmaline, is well-known to turn blue after heat treatment. The third sample was a dark yellow that is not typical of Mavuco tourmaline, although similar stones have been mined from the nearby Muva deposit (Laurs et al., 2008b). The first indication that all three pebbles were imitations was revealed when examining them with a loupe. Rather than uniformly smooth waterworn surfaces, they showed randomly oriented tiny chipped areas that produced glassy reflections in bright light. This was suggestive of an artificial tumbling process, commonly done to glass imitations. The rough surface of the pebbles made it impossible to look for gas bubbles or other indications of a glass in their interior. However, hydrostatic SG measurements yielded values of 2.49–2.51, which are within the range of glass and much lower than typical values for this tourmaline (3.01–3.09; Laurs et al., 2008a). Raman analysis gave indistinct patterns that are typical of glass, confirming our suspicion that these pebbles were glass imitations of tourmaline.

Imitations consisting of glass (and other materials such as fluorite and amethyst) are known to occur in parcels of rough tourmaline from Mavuco (Laurs et al., 2008a). When Puerta purchased these samples, the dealer (whom he trusted) stated his absolute belief that they were natural tourmaline. Obviously these imitations were introduced at some point in the supply chain, and they were convincing enough to fool local dealers. The tiny reflective chips on their surface and unexpected colour of the dark yellow pebble provide useful field indications that such pebbles are imitations.

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Quartz Imitation of Star Sapphire

In late 2013, a 7.65 ct oval blue cabochon displaying asterism (Figure 25) was submitted to American Gemological Laboratories for a report. The client believed it was a star sapphire. Initial visual observation showed that the bottom of the cabochon was flat, whereas most star sapphires have a convex bottom (to retain weight, in light of their high value), so this was our first indication that something was amiss. Also, there was no visible parting in the sample, another common feature of star sapphire. Most importantly, the base of the cabochon was coated with a grainy blue material. Observing the stone in profile view showed that it was actually colourless (Figure 26), and the basal coating was the source of its blue colour when viewed face-up.

Visible-range spectroscopy showed cobalt-related features, rather than the standard iron absorption typically seen in blue sapphire. Chemical analyses of the coating with EDXRF spectroscopy detected high concentrations of Pb and traces of Co. Microscopic observation of the colourless dome revealed small colourless

Figure 25: This 7.65 ct imitation resembles a star sapphire, but actually consists of colourless natural star quartz with an amorphous blue coating on the base of the cabochon. Photo by Bilal Mahmood.

Figure 26: In profile view, it became apparent that the cabochon in Figure 25 is actually colourless. The blue colour viewed face-up is due to a coating on the bottom of the cabochon. Photo by Kelly Kramer.

inclusions and/or negative crystals, primary fluid inclusions and tiny, very fine, oriented needles (which caused the asterism). The cabochon was transparent to semi-transparent, and a bull's-eye optic figure was easily detected using a standard polariscope. Together with a spot RI reading of 1.54, the microscopic features and optic figure were consistent with natural star quartz. Mid-IR spectroscopy confirmed this identification.

We concluded that this cabochon consisted of natural, colourless star quartz that had been backed with a lead-based amorphous material that was coloured blue by cobalt. A similar cabochon, consisting of enamel-backed star quartz, was reported by Krzemnicki and Hänni (2001).

The spot RI reading and bull's-eye optic figure, along with the lack of parting and the blue coating on the flat bottom of this cabochon, made this imitation detectable even without advanced testing equipment. This piece serves as a reminder that careful observation and basic gemmological testing remain effective for detecting certain limitations.

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TREATMENTS

Chromium-diffused Corundum

Recently, two stones were submitted to the American Gemological Laboratories that provide a reminder for the potential of old treatments to reappear in the marketplace. The two purple-pink gems weighed 0.83 and 0.95 ct (Figure 27). The client had purchased them as part of a larger acquisition of various gem varieties, from a trader selling old stock that had been in his inventory for more than 20 years.

Microscopic observation of both stones revealed traits consistent with pink sapphires that had been heated (Figure 28), including zones of partially dissolved rutile inclusions, heavily altered crystals and partially healed fissures with a frosted appearance. In addition, their surfaces were heavily pitted (Figure 29). When viewed face-up with the unaided eye, they showed relatively even coloration, yet with magnification they had an atypical patchy appearance. Viewed in immersion, they displayed the distinctive uneven coloration from one facet to another that is associated with diffusion treatment (Figure 30). These observations, coupled with relatively high concentrations of chromium (~2.5 wt.% Cr_2O_3)

Figure 27: These two purple-pink gems (0.83 and 0.95 ct) proved to be Cr-diffused natural corundum. Photo by Bilal Mahmood.

Figure 28: Various thermally altered internal features were present in the Cr-diffused sapphires, confirming their natural (not synthetic) origin. These include lines of stringers composed of fine rutile particles (left), negative crystals with associated partially healed stress fractures (centre) and partially healed fissures with a frosted appearance (right). Photomicrographs by C. P. Smith; magnified 40× (left and centre) and 62× (right).

recorded with EDXRF spectroscopy, confirmed that the two samples consisted of natural corundum that had been subjected to Cr-diffusion treatment. The EDXRF analyses also showed traces of Fe, Ti and Ga in both stones (Table II).

Refractive index readings of both stones revealed uncharacteristically high values (Table II), together with indistinct shadow edges at ~1.76 and 1.77 corresponding to typical corundum values. The high RIs are due to the enriched Cr content near the surface resulting from the diffusion treatment, while the typical values are produced from the underlying corundum where the Cr had not penetrated. Additional gemmological properties collected from these samples are listed in Table II.

Although the client had presumed these sapphires had been heated, he was very surprised to learn that they had been diffusion treated, as he was unaware that Cr-diffusion treatment even existed. It has been many years since Cr-diffused natural corundum was first reported (McClure et al., 1993), and this treatment was short-lived due to the apparent difficulty of diffusing Cr. Further attempts at Cr diffusion resulted in the inadvertent overgrowth of synthetic ruby onto a natural corundum host (Smith, 2002). Although both of these treatment processes were done on a limited basis, a small number of these gems did make their way into the gemstone market.

It has been more than two decades since the author has encountered Cr-diffused natural corundum, and the present stones stand out as a reminder that such uncommon products may be

Figure 29: Due to the very shallow penetration of the Cr-diffused layer, only a light repolishing was performed after the treatment process, leaving remnants of a heavily pitted surface that were evident on the vast majority of the facets. Photomicrograph by C. P. Smith; magnified 38×.

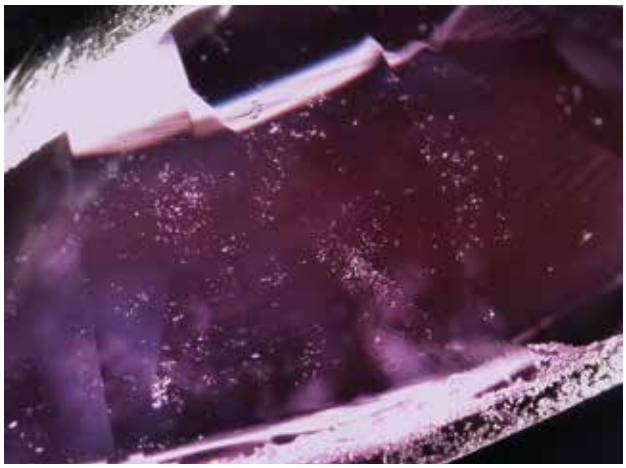

Figure 30: The two sapphires appeared evenly coloured when viewed face-up with the unaided eye, but when immersed in baby oil the patchy uneven coloration associated with Cr-diffused corundum became readily apparent. Photomicrograph by C. P. Smith; magnified 12×.

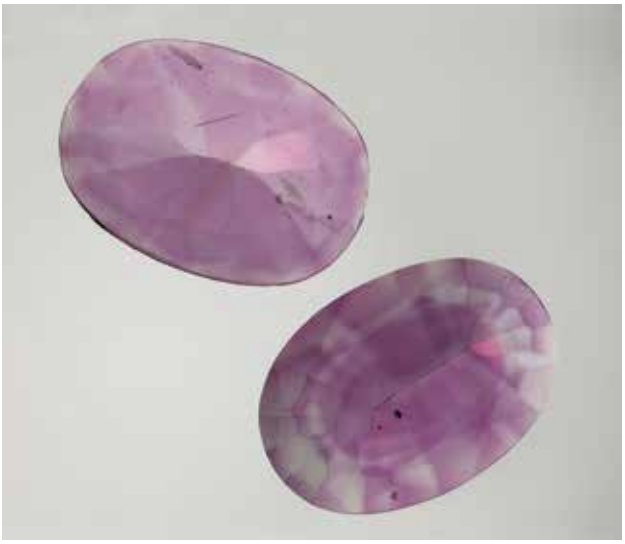

Table II: Gemmological properties of the Cr-diffused natural corundum samples.

Weight	0.95 ct	0.83 ct
Refractive indices (table facet)	Indistinct shadow edges: 1.76 and 1.77	
	More distinct: 1.780 and 1.788	More distinct: 1.772 and 1.780
Optic character	Uniaxial negative	
UV fluorescence Long-wave Short-wave	 Strong red Weak red with chalky blue-white patches	
Visible spectrum	Standard chromium absorption	
Mid-infrared spectroscopy (structurally bonded OH groups)	Weak 3309 cm^{-1}	Weak 3309 cm^{-1} Nominal 3232 cm^{-1}
EDXRF spectroscopy*	Cr: 2.39 Fe: 0.08 Ti: 0.03 Ga: 0.01	Cr: 2.59 Fe: 0.02 Ti: 0.14 Ga: 0.01

* EDXRF values are calculated as approximate wt.% oxides.

recycled back into the gem market at any time. Therefore gemmologists, appraisers and jewellers must remain aware of not only what is currently taking place in terms of treatments and synthetics, but also what has been done in the past.

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Lead-glass-filled Yellow Sapphires

Lead-glass-filled rubies and blue sapphires have been known for several years and have made a big impact on the jewellery market. Some of the treated rubies display an attractive colour and large size, and are priced inexpensively (McClure et al., 2006; Laurs, 2008). Recently, lead-glass-filled yellow sapphires have appeared in the market. This treated material is available in Chanthaburi, Thailand, and it is being sold to dealers at very low cost, by the kilogram.

In February 2015, our laboratory received a large parcel of some 600 faceted pieces (average ~5 ct each) of yellow sapphires for testing and certification. Our client understood that they were glass-filled, but wanted to be sure that the lot was not mixed with synthetic yellow sapphires containing induced flux feathers. We chose 28 pieces showing various shades of yellow and 'golden' yellow coloration for examination (Figure 31). Viewed with the microscope, they exhibited greenish blue, 'golden' yellow and brown colour flashes along glass-filled fractures (Figure 32), which also contained gas bubbles

Figure 31: These yellow to 'golden' yellow lead-glass-filled sapphires (4.05–5.28 ct) were studied for this report. Photo by Aatish Panjikar.

of various sizes and shapes (Figure 33). These features are typical of lead-glass-filled corundum (e.g. McClure et al., 2006). Other inclusions consisted of fine needles, feathers (Figure 32), tabular brown crystals (Figure 33) and lamellar twinning. Unlike the blue colour concentrations in lead-glass-filled blue sapphires, there was no obvious yellow colour concentration in these samples. EDXRF spectroscopy confirmed that the filler was indeed lead glass. For academic interest, the hydrostatic SG for all 28 pieces was found to be in the range of 4.02–4.04.

Our observations confirmed that this parcel consisted entirely of natural corundum that was filled with colourless lead glass. The starting material used for the treatment probably consisted of pale yellow material of very poor transparency.

Figure 32: Greenish blue colour flashes are commonly visible in the yellow lead-glass-filled sapphires, along with feathers. Photomicrograph by Aatish Panjikar; magnified 60×.

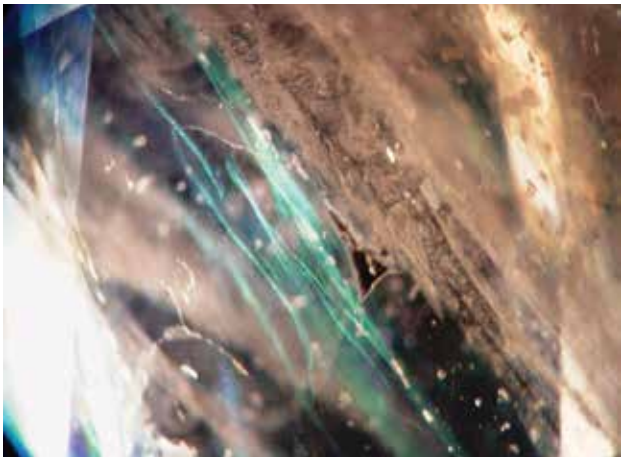

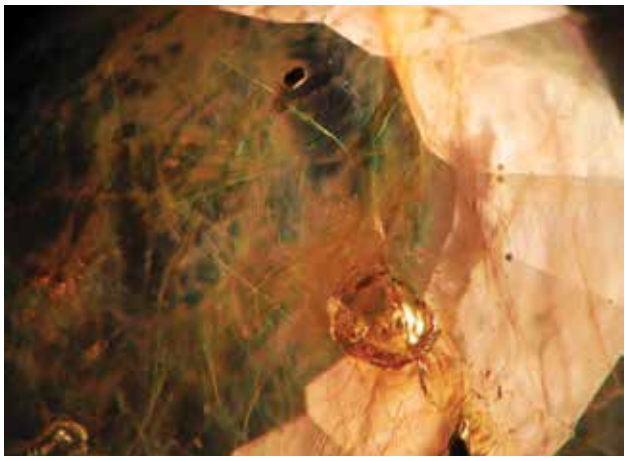

Figure 33: This lead-glass-filled yellow sapphire contains large gas bubbles, colour flashes along some filled fractures, and a tabular brown crystal (top-centre). The lead glass is colourless but reflects the coloration of the host sapphire, making it appear yellow or 'golden' yellow along some filled fractures. Photomicrograph by Aatish Panjikar; magnified 60×.

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Green-Luminescing Hyalite Opal from Zacatecas, Mexico

Emmanuel Fritsch, Peter K. M. Megaw, Tyler L. Spano, Boris Chauviré, Benjamin Rondeau, Michael Gray, Thomas Hainschwang and Nathan Renfro

Green daylight-fluorescing hyalite opal was discovered in Mexico's Zacatecas State in 2013. It occurs as botryoidal coatings commonly up to 1 cm thick along fractures and cavities in a poorly welded rhyolitic tuff. The material possesses spectacular colour behaviour, appearing near-colourless or pale-to-moderate yellow in incandescent light and vivid greenish yellow to yellowish green in indirect sunlight. The daylight-induced green luminescence is related to the presence of trace amounts of the uranyl molecule $(UO_2)^{2+}$. Several dozen high-quality transparent gemstones in the 1–6+ ct range have been faceted from this material so far, in addition to hundreds of smaller stones. The gems typically contain two-phase fluid inclusions and curved deposition marks, and they show bright interference colour patterns between crossed polarizers. This hyalite is not porous, and contains approximately 2.7 wt.% H_2O, which is remarkably low among gem opals. The radioactivity of the opal is within background levels, and does not pose any health concern.

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Introduction

Gems coloured mostly by luminescence are truly rare. Therefore, when a new gem material is discovered that is undoubtedly coloured by luminescence, it attracts a great deal of attention. Such is the case with the daylight-fluorescing, vivid green transparent hyalite that was recently unearthed in Zacatecas, Mexico (Fritsch et al., 2014; see Figure 1 and the cover of this issue). The material was first brought to market in October 2013, when five weathered specimens of rough opal showing moderate green daylight luminescence were given to one of the authors (PKMM) by a well-known importer of mineral specimens and lapidary rough from Mexico. Some of the initial specimens were sold at the February 2014 Tucson gem shows, and they attracted much attention because of their noticeable change from nearly colourless to vivid green in indirect sunlight (Moore, 2014). Reaction to the phenomenon by specimen collectors was very positive, so reconnaissance prospecting was undertaken by author PKMM to help determine the quality and quantity of material available. This initial work showed that the strongly luminescent material is sparsely distributed, but a small amount of facetable opal was recovered. Some of the faceted gems were available at the 2015 Tucson

Figure 1: This matrix specimen (2.5 cm wide) and the cut gemstones (1.34–3.93 ct) show the range of colour appearance resulting from green daylight-induced fluorescence in hyalite from a relatively new deposit in Zacatecas, Mexico. They have been photographed using daylight-equivalent strobe lights (top) and using incandescent modelling lamps within the same strobe fixtures (bottom). The gems were faceted by author MG. Photos by Orasa Weldon.

shows, and were sold as Electric Opal (trademark pending) because of their vivid green colour in daylight. The largest faceted gem weighed almost 6 ct (see cover of this issue), and hundreds of smaller stones were available in calibrated sizes down to 3 mm.

The mining site lies on the top of a steep 250-m-high mesa, so the use of heavy equipment is impractical and all digging has been manual. The difficult access, sparseness of material and reliance on manual labour will probably limit future supply to a small multiple of the production to date. This article documents in detail the geological occurrence and the luminescence phenomenon that makes this opal such an attractive gem material.

Opal Generalities and Classification of Hyalite

The gem species opal—$SiO_2 \cdot nH_2O$—is typically associated with play-of-colour material from Australia and more recently Ethiopia, both of which are abundant in today's market. But the term *opal* more generally refers to a range of hydrated silica materials. In the broadest sense, opal may be divided into microcrystalline and amorphous material (Graetsch, 1994; Gaillou et al., 2008a). The microcrystalline varieties comprise opal-C (rare) and opal-CT (quite common), which are basically poorly crystallized cristobalite (C) with more-or-less tridymite-like (T) stacking. Both cristobalite and tridymite are polymorphs of nominally pure SiO_2. They represent the bulk of 'volcanic' opal, such as fire opal from Mexico (Fritsch et al., 2006) and material from Ethiopian deposits (Rondeau et al., 2010). Amorphous opals are divided into two categories (Langer and Flörke, 1974): opal-AG and opal-AN. Opal-AG is a gel-like (G) aggregate comprised of regularly ordered hydrated silica spheres, often <1 µm in size, with open space between the spheres (e.g. Stephant et al., 2014). It is quite common, often displays play-of-colour caused by diffraction of

light from regularly stacked spheres of similar diameter, and includes material from Australia and Brazil. Opal-AN consists of hydrated silica molecules that are network-forming (N), and therefore it resembles a glass (Flörke et al., 1973). Since opal-AN does not have a regular array of spheres or any specific microstructure, it is always 'common' opal (i.e. does not exhibit play-of-colour). Opal-AN is also known as *hyalite*. It is relatively uncommon in volumes adequate for faceting, and thus is rarely used as a gem material. One of the few examples is botryoidal white opal from Milford, Utah, USA (Johnson and Koivula, 1997).

Green-Fluorescing Hyalite

Most hyalite strongly fluoresces green under both long-wave (LW) and short-wave (SW) UV radiation. In some cases (e.g. from the Erongo Mountains of Namibia, Madagascar and the Thomas Range in Utah, USA; www.mindat.org), hyalite may show a moderate-to-strong yellow-green coloration in daylight, as judged from photographs and unpublished reports, with the green component possibly originating from luminescence (although this has not been confirmed). Strong green fluorescence to *visible light* has not been reported from these localities, however, making the material described in this article quite unusual.

Crowningshield (1985) described one example of a transparent faceted opal with strong green daylight fluorescence that allegedly originated from Mexico. Its properties, general appearance and microtexture closely match those of the present material. Since there was no evidence of older workings in the currently known mining area, that stone may have come from the surface at the current area or from another incidental find, possibly in a similar geological context elsewhere in Mexico.

Other Daylight-Fluorescing Materials

Luminescence probably contributes to the coloration of several gem varieties, but its influence on visual appearance is hard to quantify (Fritsch and Rossman, 1988; Fritsch and Waychunas, 1993). Nevertheless, there are a few well-documented examples with luminescence induced by visible light, and probably the most famous category comprises certain yellow diamonds, such as a stone owned by Pedro II, the last emperor of Brazil (Moses, 1997; Fritsch, 1998; Shigley and Breeding, 2015). Such yellow to yellow-green gems are commonly referred to as 'green transmitters' (although they should really be called green *emitters*), and their coloration comes from the well-known H3 colour centre (Fritsch, 1998). More recently, HPHT-treated brown type Ia diamonds have demonstrated the same optical effect. Some green amber also owes its colour to luminescence, although it is rarer than blue amber (which is also coloured by luminescence; Liu et al., 2015).

Mn^{2+}-doped flame-fusion synthetic spinel often exhibits bright green luminescence, stemming from its dopant, Mn^{2+}, in tetrahedral coordination (Kane and Fritsch, 1991). As a man-made material, it has attracted much less attention for its daylight-induced emission than the present opal. Two other compounds are known for their bright green daylight-induced colour component. The first is 'uranium glass'—also known as 'Uralite glass' (unrelated to the Ural Mountains of Russia)—which usually is a silicate glass doped with traces of uranium. This material was sometimes faceted as a gem, or made into other objects (particularly tableware), and was very popular in the early 20th century. In the USA, its opaque variety is known as 'Vaseline' glass, a popular collectors' item. The second material is 'fluorescein', an organic-based molecule exhibiting strong green daylight luminescence. Fluorescein is used for many monitoring applications, ranging from cell chemistry to tracing underground water flows to highlighting space capsules after splashdown in the ocean. All of these green materials are especially attention-getting because of their daylight fluorescence.

Many gems besides hyalite may have their colour appearance boosted by luminescence emitted in other parts of the visible range. This has been documented for the Tavernier diamond (Liu et al., 1998) and some rare orange diamonds (Titkov et al., 2015). This is also true of ruby, and probably red spinel (Fritsch and Waychunas, 1993). It is likely that the highly sought-after (but poorly defined) 'pigeon-blood' colour of ruby

Figure 2: The opal deposit is located in Zacatecas State in central Mexico.

owes part of its attractiveness to daylight-induced red luminescence caused by chromium.

Location

The hyalite deposit is located in western Zacatecas State, central Mexico (Figure 2). The landowner has requested that more specific information on the location be withheld to minimize unauthorized mining. From the nearest municipality, the area is reached by approximately 40 km of paved road followed by 25 km of dirt tracks that wind through bean and squash fields to the base of a 250-m-high mesa (Figure 3). Then, a rough trail leads 1.5 km up a boulder-strewn and cactus-infested slope to the diggings. The miners have established a camp on site, and return to their homes on weekends to process each week's production.

Geology

Zacatecas State is largely underlain by the Sierra Madre Occidental Volcanic Province (McDowell and Clabaugh, 1979), and the hyalite is hosted by mid-Tertiary (37–28 million year old) rhyolitic rocks that resulted from repeated volcanic eruptions.

To unravel the geological origin of the opal, it is important to understand the formation of its volcanic host rocks, which were deposited by violent eruptions from 'super-volcanoes' similar to Yellowstone in the USA. Instead of erupting though a central vent like familiar conical

Figure 3: This panoramic view (a) and interpretive geological section (b) show the location of the opal deposit in Tertiary volcanic rocks related to an adjacent caldera. The opal-bearing knob protrudes from a long, flat mesa consisting of a vitrophyric welded ash-flow tuff. A ring-fracture fault separates intracaldera unit Tcr from outflow units Tr1, Trv and Tr2. Opal is hosted by poorly welded tuff Teo at the base of the knob held up by Tr2. Photo and drawing by P.K.M. Megaw.

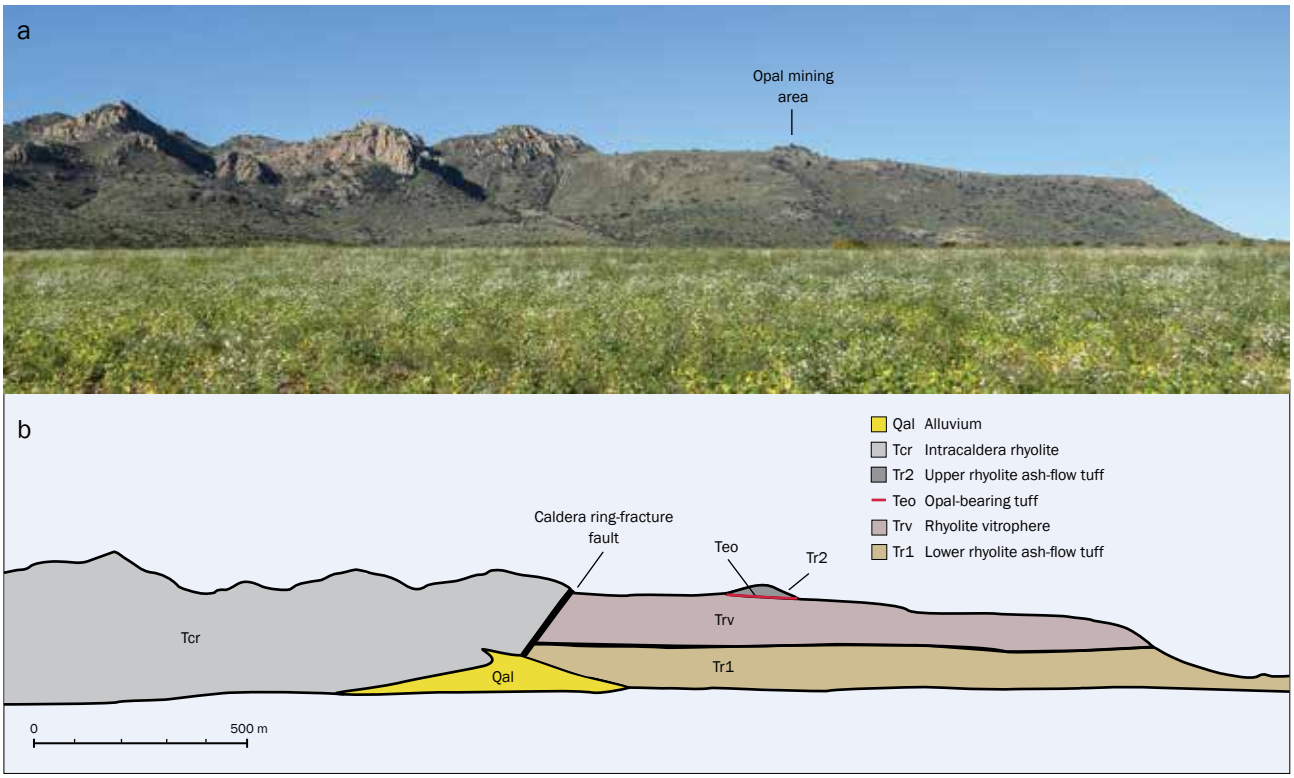

volcanoes (cf. Mount Fuji, Mount Rainier or Mount Vesuvius), these erupt around the circumference of the magma chamber (tens to hundreds of kilometres in diameter) through an annular ring-fracture zone (Smith and Bailey, 1968). During eruption, rocks within the ring-fracture zone settle piston-like into the underlying space left by the erupting magma, creating a circular depression called a *caldera* into which some of the hot ejecta accumulate. Thinner *outflow* facies extend outward from the intracaldera zone. Much of the erupting lava chills instantly into frothy siliceous volcanic glass, which is shattered into myriad tiny shards and pumice fragments that mix with fine volcanic ash to comprise *tuff*. As the eruptive pile cools, settles and compacts, escaping heat and volatiles fuse the ejecta into a hard, compact rock known as *welded ash-flow tuff* or *ignimbrite*. The most densely welded tuffs are compacted into *vitrophere*, a crystal-rich volcanic glass containing rock fragments. The thinner and cooler parts of the eruptive pile escape welding, leaving unconsolidated ash mixed with loosely bound crystals (mostly feldspars and quartz) and rock fragments (i.e. *poorly welded crystal-lithic tuffs*; Smith and Bailey, 1968). In all cases, the volcanic glass that makes up most of the tuff is unstable and decomposes over time. Silica, uranium, iron and other constituents liberated from the decomposing volcanic glass are initially incorporated into vapours emanating from the cooling volcanic pile, which interact with circulating heated groundwaters that emerge as hot springs (Goodell and Waters, 1981; Breit and Hall, 2011). Transformation of glass shards into clays also releases silica and uranium into descending surface waters, and such solutions may redeposit silica as opal, chalcedony or quartz, depending on a number of factors (e.g. Berger et al., 1994; Markússon and Stefánsson, 2011). Uranium and other liberated elements are also deposited, either as discrete mineral species or within the framework structure of the chalcedony or opal.

Within the mining area, the daylight-fluorescent hyalite occurs around the base of a 40 × 125 m elongate knob that protrudes from the top of a 1.3-km-long mesa composed of outflows from a 20-km-diameter caldera. The ring-fracture zone lies approximately 450 m from the hyalite occurrence. The mesa consists of a 90-m-thick section of very densely welded rhyolite vitrophere that overlies 160 m of moderately welded ash-flow units (Figure 3). The hyalite occurs in a 10–15 m thick, poorly welded, crystal-rich rhyolite tuff that sits atop the vitrophere and was protected from erosion by an overlying 30 × 100 m remnant of a younger welded tuff unit (Figure 4). The hyalite-bearing tuff probably once covered the entire mesa but it, and any opal it contained, has long-since been eroded way.

The hyalite-bearing layer is composed of 3–50 mm rhyolite rock fragments mixed with 1–4 mm dipyramidal ß-quartz and limpid sanidine phenocrysts in a weakly welded, porous, siliceous, tuffaceous matrix. Groundwater could have readily percolated through this highly permeable unit, leaching silica and uranium from the devitrifying glass, and precipitating opal and the associated species described below. The hyalite occurs sparsely in voids and in fractures cutting the host tuff unit (Figures 5 and 6). The hyalite locally fills the fractures completely, but more commonly it occurs as isolated blebs and botryoidal coatings up to 3 cm in thickness, in most places covering less than 10% of the surface. The intensity of the opal's fluorescence varies widely within and between fractures and pockets, with less than 10% showing the strongest luminescence. The miners report that the daylight fluorescence is strongest in material found within a metre or so of the surface and drops off rapidly below that, so few fractures have been followed any deeper.

A series of uranium-containing minerals is found on the surface of the veins, and the opal locally formed on top of them. They generally consist of yellow sprays or spherulites of fibrous crystals. The most prominent species were identified by Spano et al. (2015) with X-ray diffraction as meta-autunite ($Ca(UO_2)_2(PO_4)_2 \cdot 6\text{-}8H_2O$), haiweeite ($Ca(UO_2)_2[Si_5O_{12}(OH)_2] \cdot 6H_2O$), uranophane ($Ca(UO_2)_2(HSiO_4) \cdot 5H_2O$), and meta-uranospinite ($Ca(UO_2)_2(AsO_4)_2 \cdot 8H_2O$). The silica that formed the opal probably originated from groundwater-based weathering and dissolution of the glass shards in the tuff, as described above.

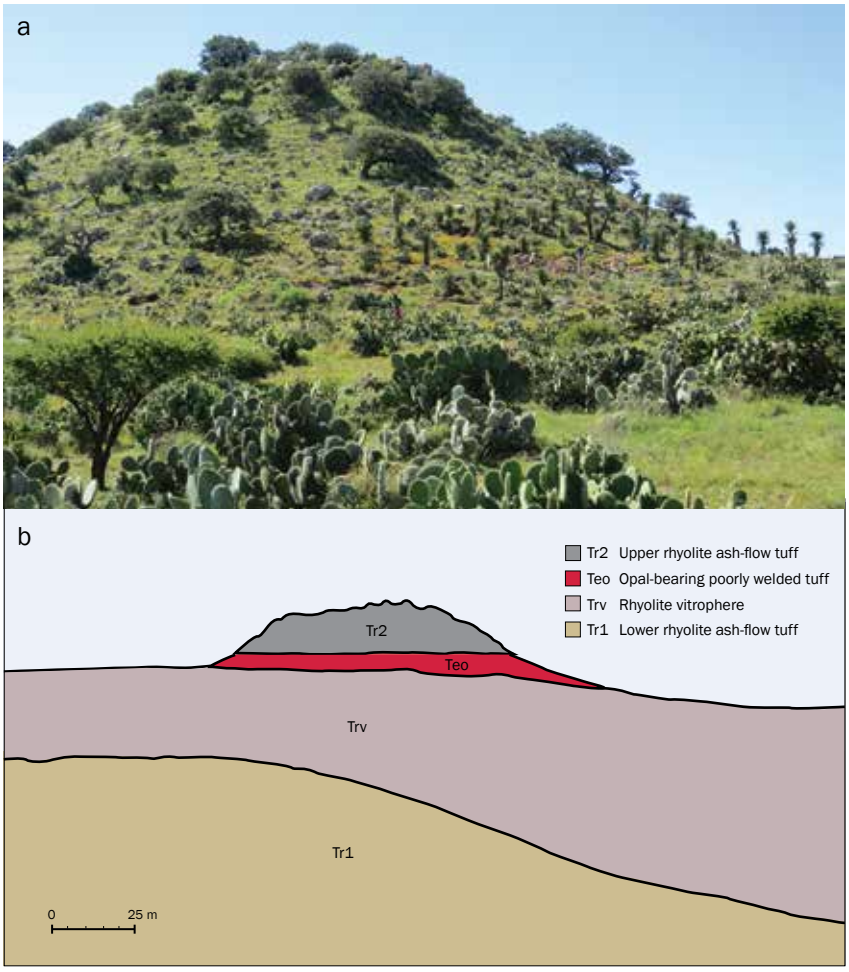

Figure 4: As shown in this photo (a) and interpretive geological section (b) of the mining area, the opal-bearing layer Teo is situated between an overlying welded tuff unit Tr2 and an underlying vitrophere Trv. Note the relatively steep topography and large boulders of Tr2 that protected the Teo layer from erosion. Photo and drawing by P.K.M. Megaw.

Mining and Production

Mining of the hyalite has been done exclusively with pry bars, picks and shovels, and a small gasoline-powered drill. The miners locate and follow iron-oxide stained fractures, and dig until hyalite-bearing voids are encountered. During the rainy season, water collected in earlier excavations is used to wash out the pockets to assist with recognizing the better-coloured opal. During the dry season, the clayey iron-oxide-stained vein fillings fall away to reveal the opal. The voids range from 2 to 20 cm across and each

Figure 5: This view of a trench wall shows hyalite mineralization filling fractures and corrosion voids. Photo by P.K.M. Megaw; image width 26 cm.

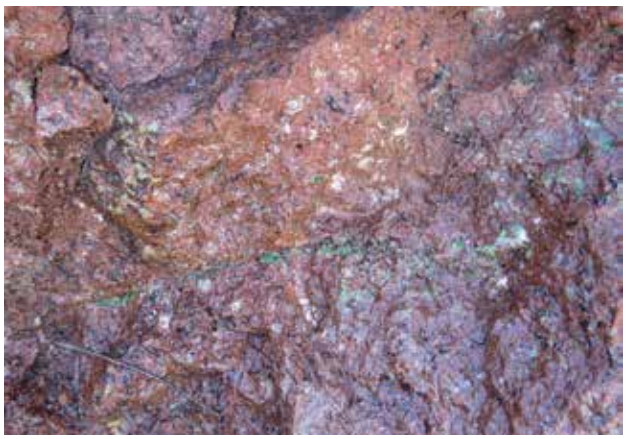

Figure 6: This corrosion pocket is partially coated with hyalite. Several kilograms of good specimens were produced from this pocket. Photo by P.K.M. Megaw; image width 57 cm.

Figure 7. This hyalite specimen (5.6 cm across) contains botryoidal masses of gem-quality material. It is shown under daylight-equivalent strobe lighting (left) and under SW UV radiation (right). P.K.M. Megaw specimen; photos by Mark Mauthner.

typically produces a few kilograms of rough (including matrix). Weekly production ranges from 100 to 200 kg total of opal-bearing rock, of which less than 5% is specimen or cutting quality (e.g. Figures 7 and 8).

Through early 2015, the production totalled approximately 30 kg of top-quality specimens, 10 kg of facet-grade rough and 30 kg of pieces containing areas suitable for cutting good cabochons. Another 150 kg of moderate-quality and 250 kg of low-quality specimen material also were mined. It is difficult to predict future reserves, in part because the depth and lateral extent of the strongly coloured zone of opal mineralization is unknown. Nevertheless, it appears that there is good potential for another 100–250 kg of top-quality specimen and gem rough.

Cutting and Polishing

Most of the larger gems faceted so far have been cut by one of the authors (MG). The grinding and polishing of this opal have presented no unusual problems compared to transparent opal from other localities. The minor heat sensitivity of opal requires the use of a cold dopping method

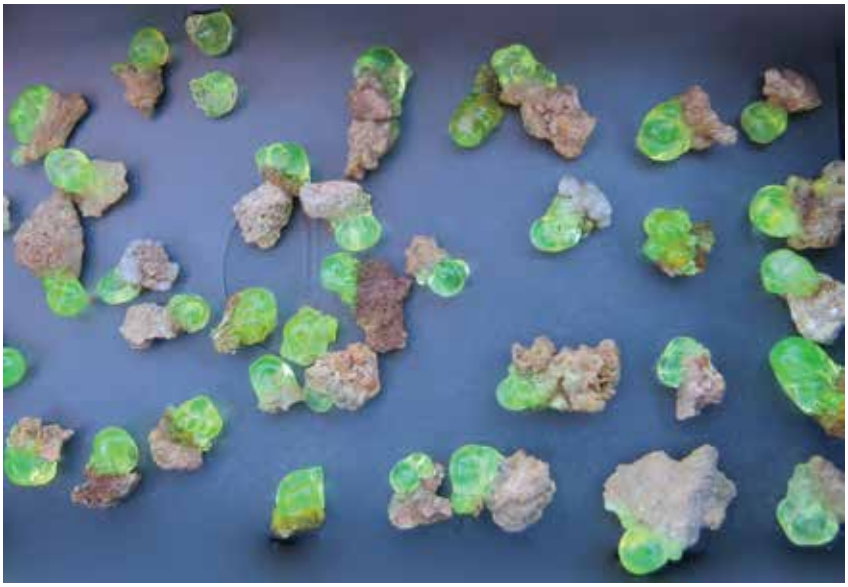

Figure 8: These gem-quality botryoids of hyalite display strong green luminescence in shaded daylight. P.K.M. Megaw specimens and photo; image width 10 cm.

for attaching the stone to the dop stick. The low RI of this opal (1.45–1.46; see below) requires a pavilion angle of at least 45°, as the critical angle is 43.6° (based on the lower RI range). The low SG of opal dictates that it takes more volume to attain a given weight as compared to most other gems. For example, a 1 ct standard round brilliant would measure nearly 8 mm in diameter.

The main problems with cutting the material are the various types of inclusions. Fibrous minerals are commonly associated with hollow tubes in the opal, and voids occur near the remnants of the matrix or at the intersection of botryoidal domains. If opened during the cutting process, these voids fill with debris from the wheel, so they must be either left completely enclosed within the finished gem or entirely ground away.

Materials and Methods

All of the rough samples were obtained by one of the authors (PKMM), either directly from the miners or through his Mexican mineral dealer associate. Three polished pieces were prepared by Jacques Le Quéré (JackyGems, Auray, France) for this research: one round brilliant (1.32 ct), one flat rectangular cabochon (1.81 ct) and one piece with the botryoidal surface kept on one side and a rounded cabochon polished on the other side (0.83 ct). Five matrix specimens were examined, including two on which green-fluorescing pale yellow hyalite formed in continuity with milky white hyalite showing no daylight luminescence.

All rough and cut samples were examined with a binocular Leica MZ6 microscope equipped with a Nossigem gemmological lighting system, and the three polished opals were tested with a GIA Gem Instruments refractometer and a Mettler Toledo XS104 electronic scale (for mass and hydrostatic SG measurements). UV luminescence observations of all samples were done using a VL-215.LC Vilber-Lourmat filtered UV lamp that contained two ~30-cm-long UV tubes of 15 W each: one for 254 nm SW and the other for nominally 365 nm LW UV radiation. For qualitative intensity descriptions, the sample was placed at a fixed distance of 7 cm from the lamp. Fluorescence colour and intensity were judged compared to two reference stones: a flame-fusion synthetic ruby used as a 'very strong' and 'red' reference for both LW and SW, and a colourless flame-fusion synthetic sapphire representing a 'strong' and 'blue' reference in SW (inert in LW). For this specific case of a visible-light luminescing gem material, we used a 405 nm (InGaN) 0.5 mW laser pointer to stimulate emission under violet radiation. (These devices are often incorrectly referred to as 'blue' lasers, and they may be harmful to the eyes, even operating at such low power.) Two additional faceted stones of large size (12.25 and 12.63 ct), which were cut by author MG to show the diversity of their internal features, were examined by one of us (NR) using a Nikon SMZ1500 trinocular microscope fitted with a Nikon DS-Ri2 camera, and selected inclusions were analysed with a Renishaw InVia Raman spectrometer utilizing a 514 nm argon-ion laser.

The identity of purple blocky crystals found within tubes in the hyalite was established as fluorite using single-crystal X-ray diffraction. Crystals suitable for diffraction were manually isolated, and one was selected for unit-cell determination. A matrix of data was collected using a series of 0.3° frames in ω with a collection time of 10 seconds/frame. Data were collected on an Apex II diffractometer with Mo($K\alpha$) X-radiation and a Bruker charge-coupled device (CCD) detector. Unit-cell dimensions were obtained through refinement of 718 reflections using Fast Fourier transform techniques.

Raman spectra of all samples were obtained with a Bruker MultiRAM Fourier-transform Raman spectrometer. Excitation was provided by a 2 W Nd:YAG laser at 1064 nm, in continuous mode, and the data were collected at the standard resolution of 4 cm^{-1}, accumulating 1,000 scans.

Imaging of the opal microstructure in one rough sample was performed using a JEOL 7600 scanning electron microscope (SEM). The opal was fragmented using a mortar, and the pieces were etched in hydrofluoric acid (10% HF by volume) for 30 seconds (a standard etch procedure to reveal opal structure; e.g. Gaillou et al., 2008b). The freshly broken and etched surfaces were coated with platinum to ensure electrical conductivity.

Luminescence emission and excitation spectra as well as 3D block diagrams were obtained for the three fashioned opals and two

of the rough samples using a Horiba Fluorolog spectrofluorometer in conjunction with Fluor-Essence software. Two types of detectors were used: a standard photomultiplier and a Synapse CCD detector coupled to an iHR320 imaging spectrometer. A resolution of <1 nm was obtained by juxtaposing many scans to cover a given spectral domain in several sections. The samples were positioned to maximize the measured emission. For comparison, we analysed a reference specimen of whitish hyalite crust with green UV luminescence from Grimes Sexton Quarry, Inyo County, California, USA. Emission spectra were obtained using 365 nm excitation with a 1 nm bandpass, a sampling interval of 1 nm and a 0.2 second integration time. Excitation spectra were obtained for the 524 nm emission using the photomultiplier with a 3 nm spectral bandwidth; the excitation was scanned with a 1 nm bandpass and sampling interval, and a 0.3 second integration time. In addition, emission spectra of a 0.23 ct round brilliant were recorded on a GGTL-PL6 Raman/photoluminescence system using 405 nm laser excitation, and a high-resolution echelle spectrograph (average resolution of 0.04 nm) by Catalina Scientific equipped with a Peltier-cooled sCMOS camera. The spectra were recorded with the opal at room temperature and also cooled to 77 K by direct immersion in liquid nitrogen.

UV-visible (UV-Vis) absorption spectra were recorded using a Cary 5G spectrophotometer with a resolution of ~1 nm (sampling and spectral bandwidth were each 1 nm). Each point was collected for 0.1–0.5 seconds. The spectrum selected for illustration in this article was obtained from the 1.81 ct flat cabochon sample, and then double-checked on five other rough samples.

Energy-dispersive X-ray fluorescence (EDXRF) analysis of the three polished samples was performed with a Rigaku NEX CG spectrometer (a 'secondary target' or 'Cartesian geometry' instrument), with analytical parameters optimized for four successive energy ranges of secondary X-rays. This provided enhanced sensitivity, intermediate between that of standard EDXRF and ICP-MS techniques. The chemical analyses are reported as if water is not present, since this technique cannot detect water.

Water content was determined with thermogravimetric (TGA) analysis, using a Netzsch Jupiter STA 449 F3 instrument on a 60 mg sample that was powdered in an alumina crucible. The sample was heated from room temperature to 1,000°C (1°C/minute) under a synthetic dry air flow (nitrogen-oxygen mixture with N_2:O_2 = 80:20) of 50 ml/minute.

Figure 9: The measurement geometry used to assess the radioactivity of the hyalite is shown here. The three fashioned samples (0.83–1.81 ct) are positioned face-down on the detector. Photo by Michael Bailly.

The radioactive dose rate of the three polished samples (total weight ~0.8 g; Figure 9) was measured for ~½ hour with the NaI detector of a Canberra InSpector 1000 instrument. The measurements were done with the samples placed face-down and directly on the detector, which is a geometry comparable to wearing the three hyalites directly on the skin. The nature of the radioisotopes was revealed by gamma spectroscopy of the 1.81 ct flat rectangular cabochon, using a high-purity germanium detector (Canberra XtRa) with low background. The efficiency of the detector was defined for each point of the sample chamber, and the volume of the gem was modelled to increase efficiency and precision (hence the choice of the flat cabochon, which was easiest to model). Because of the low levels measured, a count time of 250,000 seconds (almost three days) was used. These data were collected at a laboratory specialized in the measurement of low radioactivity levels (Subatech-SMART) at the Nantes School of Mines, Nantes, France.

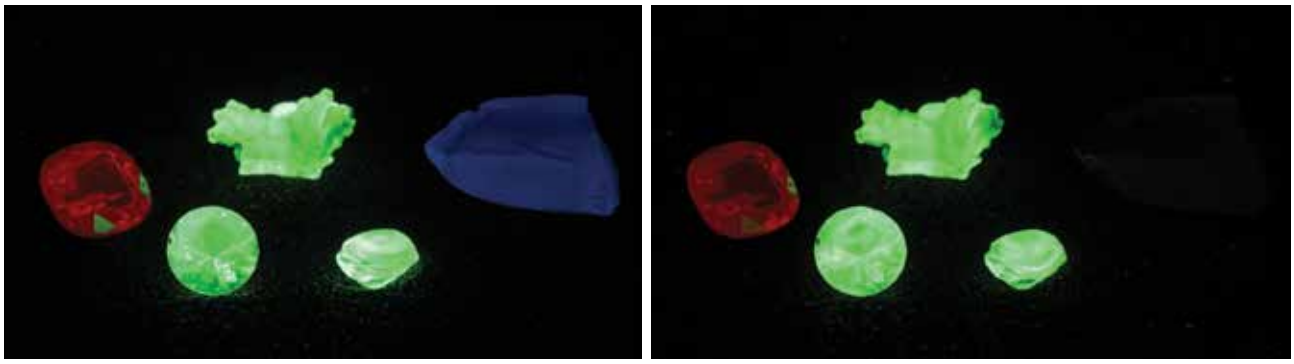

Figure 10: Shown here in SW (left) and LW UV radiation (right), the three hyalite specimens display much more intense luminescence than the fluorescence reference stones: a flame-fusion synthetic ruby with 'very strong' luminescence to both SW and LW, and a colourless flame-fusion synthetic sapphire representing 'strong' emission in SW (inert to LW). Both reference stones appear dimmer than expected since the exposure had to be shortened to avoid overexposing the very bright hyalite. The round-brilliant-cut hyalite weighs 1.32 ct. Photos by B. Chauviré.

Results and Discussion

Visual Observations and Gemmological Properties

The rough specimens showed a botryoidal or concretion-like morphology (e.g. Figures 7 and 8), which is typically associated with hyalite opal (opal-AN) from many localities. Their diaphaneity ranged from transparent to opaque. The colour appearance of the rough and cut material showed a dramatic change from incandescent or fluorescent lighting (colourless to moderate yellow) to shaded sunlight (vivid greenish yellow to yellowish green; e.g. Figure 1 and the cover image). This change arises from visible-light-induced green luminescence. The phenomenon is apparently enhanced by faceting, which provides a longer optical path length for excitation, as well as reflection of the emitted green colour toward the eye as compared to rough specimens. Shaded sunlight is best for viewing the phenomenon, since the brightness of direct sunlight overwhelms the fluorescence.

Exposure of all the samples to the SW UV lamp excited green luminescence that was even more intense than our 'very strong' luminescence reference stone (e.g. Figure 10, left); it was one of the most intense reactions we have documented in a natural gem. All samples, large or small and with or without zoning of diaphaneity, showed an apparently homogeneous luminescence. The fluorescence was only slightly weaker in LW UV, but still much more intense than our 'very strong' reference stone (Figure 10, right). Excitation with a 405 nm laser pointer, emitting in the violet region of the visible spectrum, also spectacularly induced the green coloration (Figure 11).

RI values ranged from 1.45 to 1.46, and 1.455 was measured from a flat polished surface of one faceted stone. SG values spanned from 2.12 to 2.16. These figures are typical of opal in general. No hydrophane effect was noticed while doing the hydrostatic measurements, suggesting that the samples were not porous. Neither did the stone appear to absorb RI contact liquid.

Viewed with the microscope in transmitted light, the botryoidal nature of the opal was easily observed in the faceted stones. Curved growth zoning resulted from slight differences in the index of refraction between the thin successive layers (Figure 12). Yet, we observed no noticeable colour zoning in diffused lighting; this is consistent with Figure 11 of Crowningshield (1985). The curved growth zoning showed

Figure 11: These fashioned hyalites (1.32 and 0.83 ct) display bright green luminescence due to excitation from a 405 nm laser pointer. For the purpose of photography, the laser is directed near the stones, but not at them, to avoid generating 'hot spots' in the samples. Photo by B. Chauviré.

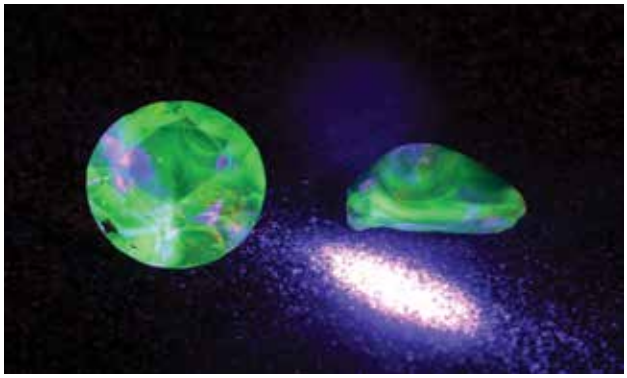

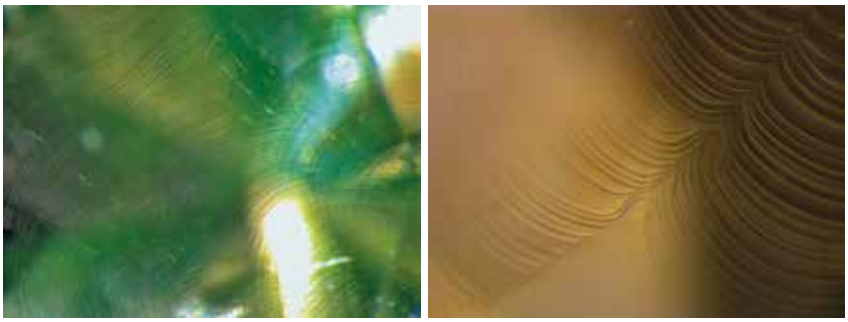

Figure 12: Botryoidal growth zoning is prominent in the faceted hyalite. Photomicrographs by E. Fritsch; image width 3.5 mm (left) and 2.0 mm (right).

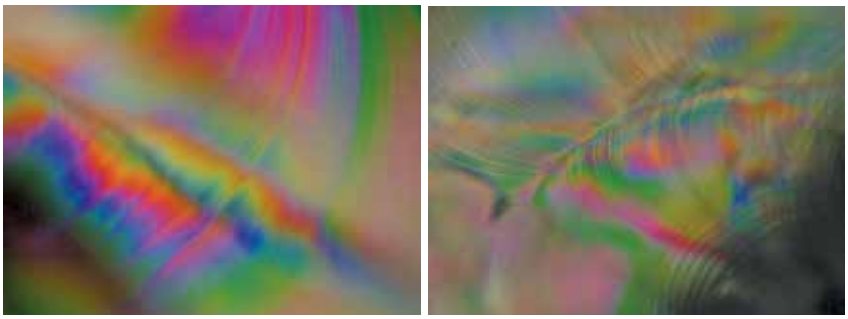

Figure 13: Between crossed polarizers, high-order interference colours are seen following botryoidal growth patterns in the hyalite. Photomicrographs by E. Fritsch; image width 2.1 mm (left) and 2.5 mm (right).

Figure 14: Colourless-to-yellow mineral inclusions in the hyalite were identified as a phosphate mineral by Raman spectroscopy. In the left photo (image width 4.8 mm), some of them are associated with curved fluid inclusions. They also were present as radiating crystal clusters (right, image width 1.5 mm). Photomicrographs by N. Renfro.

corresponding anomalous birefringence when observed between crossed polarizers (Figure 13). Such spectacular high-order interference colours reflecting the depositional layering of the opal are characteristic of hyalite (Graetsch, 1994).

Other internal features in both the rough and cut stones consisted mostly of small rock fragments, fractures (often nearly planar), colourless-to-yellow mineral inclusions (Figure 14), and very small two-phase inclusions containing liquid and a bubble (Figure 15). The fluid inclusions were trapped between curved botryoidal growth zones and as irregular flat planar fluid bodies between depositional layers. The mineral inclusions consisted of prismatic single crystals with a hexagonal cross-section and crystal clusters that were observed scattered throughout the two large faceted stones. Raman analysis confirmed them to be a phosphate. Not seen in our samples, but documented by Spano et al. (2015), were uranyl phosphate minerals contained within transparent silica tubes, which gave an acicular appearance to the normally platy U-phosphates. Elongate tubular voids were locally present in our samples, and may represent areas in which U-bearing inclusions were leached after opal deposition. Some of these tubes, hosted by opal protuberances on some rough samples (Figure 16, left), contained minute blocky purple crystals of fluorite (Figure 16, right) that were identified by X-ray diffraction. The tubular inclusions were common in one of the large cut stones examined. They had blocky outlines and were filled with an amorphous solid material that could not be identified with Raman microspectroscopy.

Identification as Hyalite Opal-AN

This Mexican opal does not display play-of-colour, suggesting that its microstructure probably does not consist of the regular stacking of spheres as in opal-AG (such as typical opal from Australia). Instead, visual observations suggest that the samples are opal-AN. Commonly called *hyalite*, this is probably the rarest variety of gem opal.

Fourier-transform Raman scattering spectroscopy is a reliable method to characterize opal, as

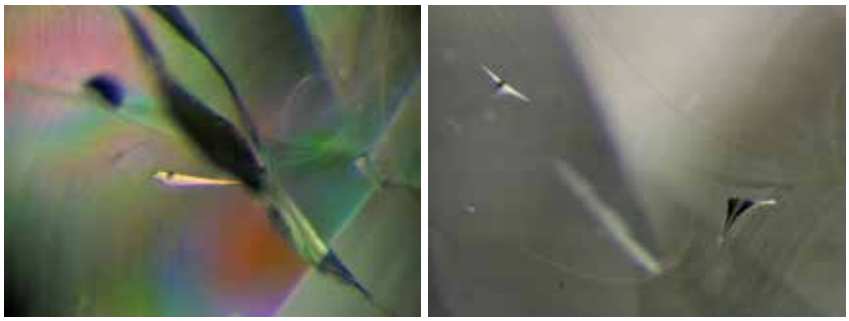

Figure 15: Fluid inclusions in hyalite occur at the intersection of curved botryoidal growth zones. The left image, taken with crossed polarizers, clearly shows a bubble inside the fluid inclusion. On the right, two fluid inclusions adopt the curved surfaces resulting from botryoidal accretion of the host opal. Photomicrographs by E. Fritsch; image width 1.3 mm (left) and 2.3 mm (right).

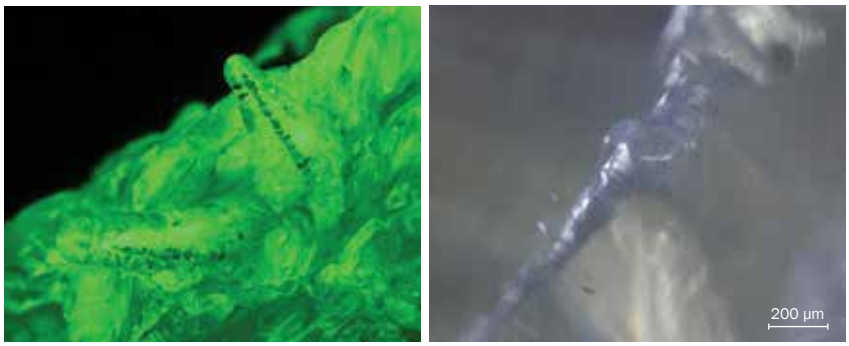

Figure 16: Two of the protuberances on this hyalite specimen contain tubular inclusions (left, image width 12.9 mm) that host minute blocky purple crystals of fluorite (right). Photos by B. Chauviré (left, under LW UV radiation) and B. Rondeau (right).

it avoids many of the challenges caused by opal's strong luminescence (e.g. Smallwood et al., 1997; Ostrooumov et al., 1999; Rondeau et al., 2004). The specimens yielded spectra typical for opal-A (e.g. Figure 17), showing a distinctive broad band with a maximum at ~435 cm^{-1}, and an abrupt drop in Raman scattering at ~500 cm^{-1}. This is different from typical opal-AG, which shows a more Gaussian-like (symmetrical) band centred at ~420 cm^{-1} (Rondeau et al., 2004). Bands also were observed at ~790, 970 and 1075 cm^{-1}, as noted in the publications cited above. A relatively broad band terminating in a sharp peak at about 1550 cm^{-1} seems unique to this Mexican hyalite; it has never been observed in the Raman spectra of other opal-AN specimens studied by the authors, and is not documented in the literature. The broad band with an apparent maximum at 3110–3120 cm^{-1} is related to water, but its intensity was not reproducible with our equipment and thus is not a reliable indicator of water content. Raman scattering therefore established that this hyalite is opal-A, but was not sufficient to establish unambiguously that it is opal-AN.

To establish the exact variety of this opal-A, it was necessary to determine its microstructure through SEM imaging. At all magnifications, the samples showed the characteristics of a glass, with a smooth surface containing no holes or spheres (Figure 18). There were only traces of conchoidal fractures and associated patterns, as in glass. These features identified it as opal-AN (cf. Graetsch, 1994).

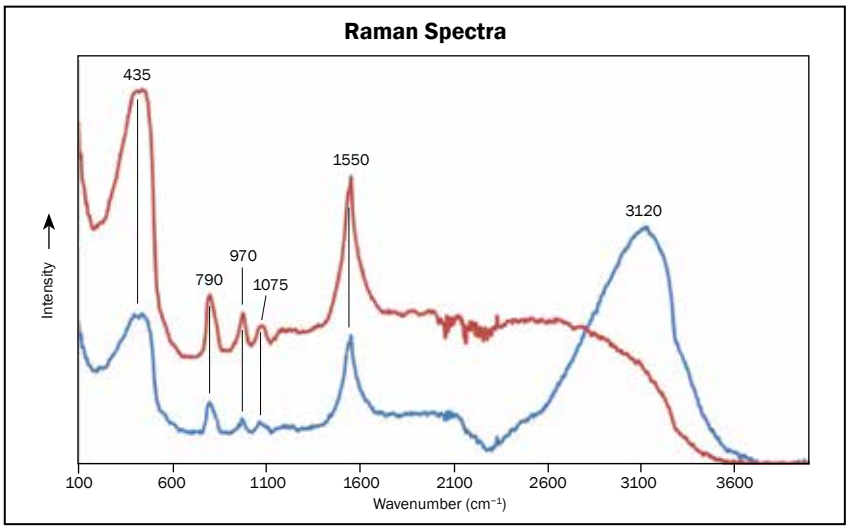

Figure 17: These representative Raman spectra of two different specimens prove that the hyalite is opal-A. They also display a band at ~1550 cm^{-1} that has not been recorded previously in such opals.

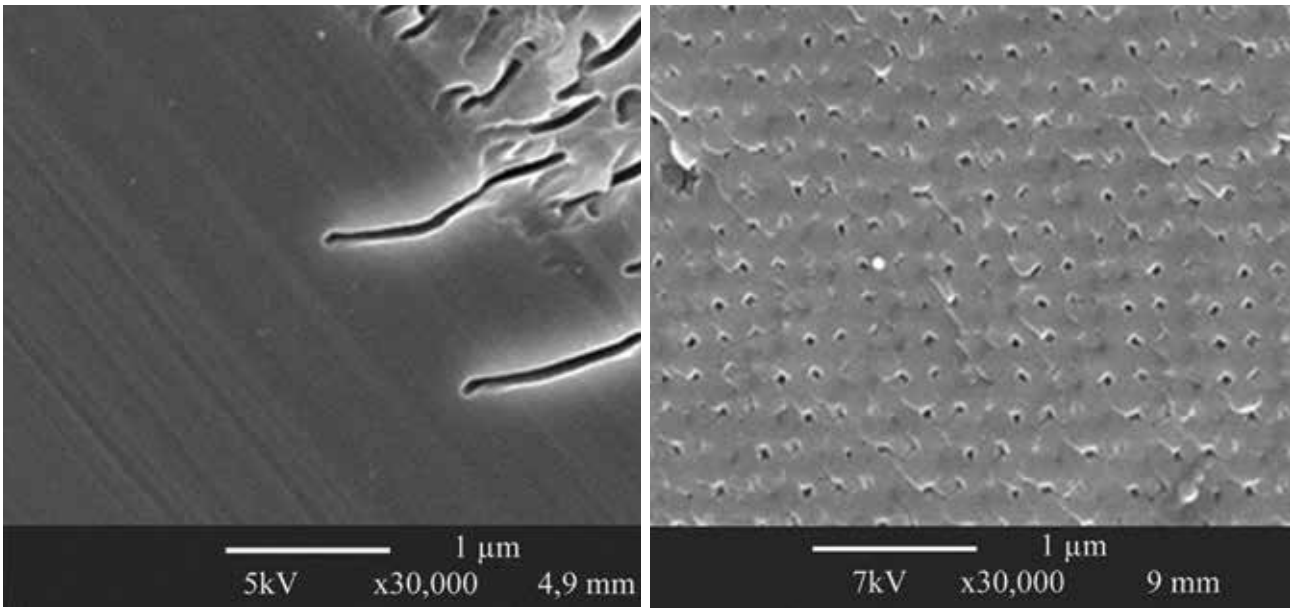

Figure 18: These scanning electron micrographs show the microstructure of the green-fluorescing hyalite from Mexico (left) compared to typical opal-AG (right, a play-of-colour specimen from Australia). The hyalite shows a glass-like structure that proves it is opal-AN, while the play-of-colour sample displays the classic regular stacking of silica spheres (as revealed by a network of holes). The worm-like features in the Mexican sample are related to conchoidal fractures and micro-cracks that were widened by hydrofluoric acid etching. Micrographs by B. Chauviré (left) and Eloise Gaillou (right).

Luminescence and UV-Vis Absorption Spectroscopy

Green UV luminescence of opal is common and well understood. It is usually stronger in SW than in LW UV excitation, and it originates from U^{6+} in the form of the uranyl $(UO_2)^{2+}$ ion (cf. Gaillou et al., 2011). What is striking about this hyalite is that the luminescence is also excited in daylight. To understand this behaviour, we first collected the emission spectrum, which is the spectral composition of the luminescence. The green luminescence of the five samples was identical, and showed typical uranyl emission (e.g. Figure 19), with a wide band extending from about 450 nm (end of the violet range) to almost 700 nm (red region). There were five maxima, at ~504, 524, 546, 572 and 604 nm; the most intense was at 524 nm, in the green region, as expected from the colour of the emission. The emission was the same whether obtained using a standard dispersive spectrometer with 365 nm excitation (Figure 19, left) or using a 405 nm laser (Figure 19, right). At liquid-nitrogen temperature, the emission peaks shifted slightly toward shorter wavelengths.

To understand the cause of a given emission, we collected an excitation spectrum across all excitation wavelengths, measuring the intensity of the green fluorescence excited or induced by each one. In this case, excitation spectra were obtained for the 524 nm emission (the maximum of the emission), for the same five samples (e.g. Figure 20, bottom curve). The results showed several intense bands in the UV, increasing gradually toward the SW range. This explains why the green luminescence was more intense under SW UV radiation. However, an additional, less intense pattern was present in the visible range, extending from about 375 nm (still in the UV) to about 445 nm, covering almost all of the violet range. This feature showed several maxima at ~400, 409, 419 and 432 nm. This pattern of excitation in the violet part of the visible range explains why the green luminescence is excited by visible light, and why daylight, which contains violet radiation, so effectively excites the luminescence. It also explains why 405 nm laser light produces such intense fluorescence.

The UV-Vis absorption spectra (e.g. Figure 20, top curve) were very similar regardless of body colour (which ranged from pale to moderate yellow). Absorption in the violet range explains the yellow body colour. This pattern is well known to be due to uranyl absorption (cf. Gaillou et al., 2011; Smith et al., 2013; Faulques et al., 2015 and references therein).

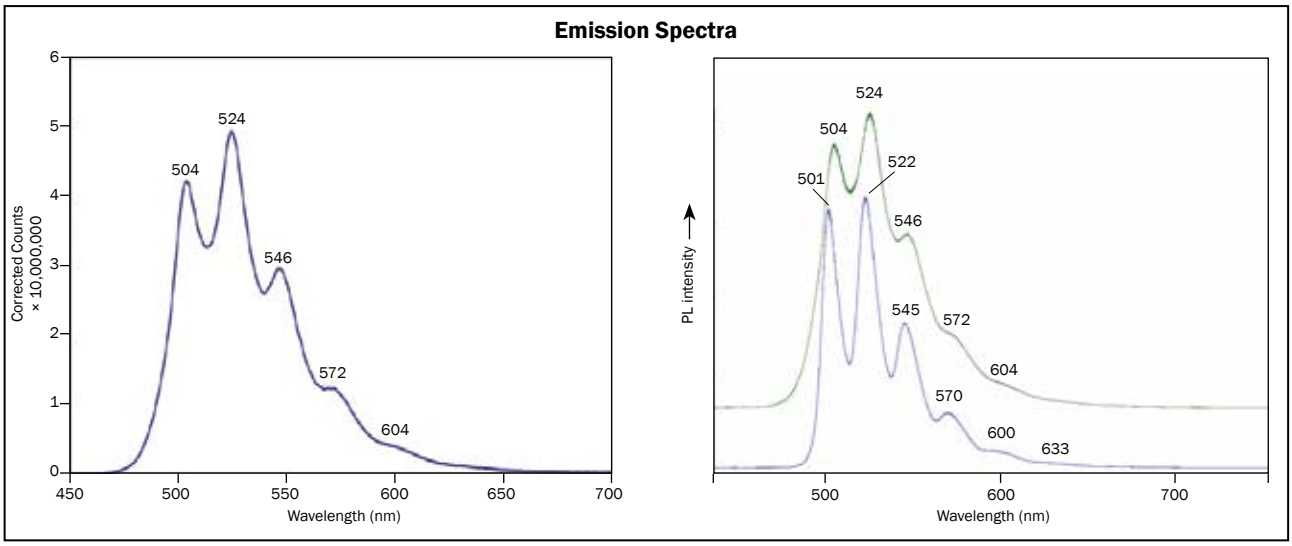

Figure 19: These emission spectra of Mexican hyalite show a characteristic uranyl pattern with five maxima. The left spectrum was taken with standard 365 nm excitation (LW UV) on a 1.32 ct round brilliant. The most intense emission (524 nm) is in the green region of the spectrum, as expected. The spectra on the right are from a 0.23 ct round brilliant excited by a 405 nm (violet) laser photoluminescence system. The top spectrum was collected at room temperature, and is identical to the spectrum on the left. The bottom spectrum, taken at liquid-nitrogen temperature, shows minor shifts. (The stone survived the thermal shock associated with the cryogenic conditions.)

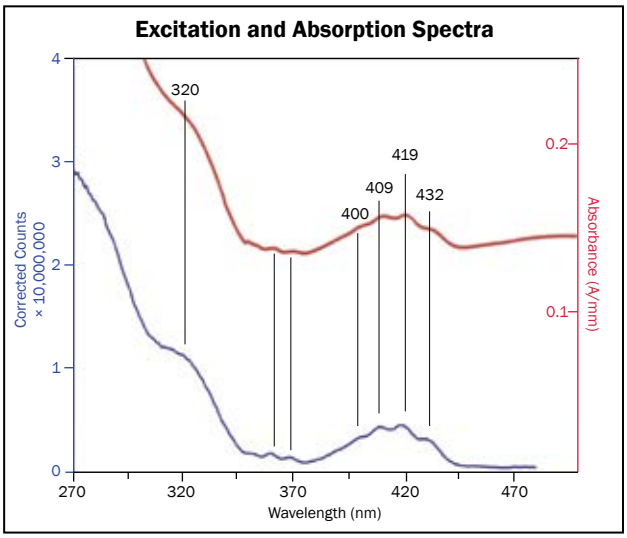

Figure 20: These curves show the excitation versus absorption spectra of the green-fluorescing hyalite from Mexico. The excitation and the absorption patterns are identical, a rare occurrence in natural gems. The path length of the beam used to collect the absorption spectra is ~3 mm.

The almost perfect superposition of the excitation and absorption spectra (again, see Figure 20) is a rare occurrence in natural luminescent materials. It suggests that all the energy absorbed by the uranyl molecule is transformed into green light. This makes the system remarkably efficient (similar to a ruby laser). In addition, this means that there is little to no outside influence on the luminescence/excitation, which is rare in natural systems. Often, for example, one expects $O^{2-} \leftrightarrow Fe^{3+}$ charge transfer to introduce modifications between absorption and actual excitation in natural gem materials (Fritsch and Waychunas, 1993). The broadness of the emission bands in this hyalite is typical of a disordered material, not of a crystalline impurity. This strongly suggests that the uranyl ion is dispersed in the opal matrix.

Another way to view this hyalite luminescence is to plot a 3D block diagram (Figure 21) showing the emission spectra from 500 to 650 nm (red traces) as a function of excitation wavelength from 248 to 490 nm, in 3 nm intervals. The emission spectra show the same shape (with the five maxima described above, in the same relative proportions) within the excitation range that was investigated, which confirms that only one luminescence centre is involved. Only the intensity of the emission varies with excitation. Within the excitation range there are two regions of maximum emission: one is in the UV and the other is in the visible range (centred within the violet). This is consistent with the excitation spectrum noted above. However, because the 3D scan was not obtained using the same detector, and is uncorrected, the overall shape of the excitation curve is different from that described above, especially where it dips in the

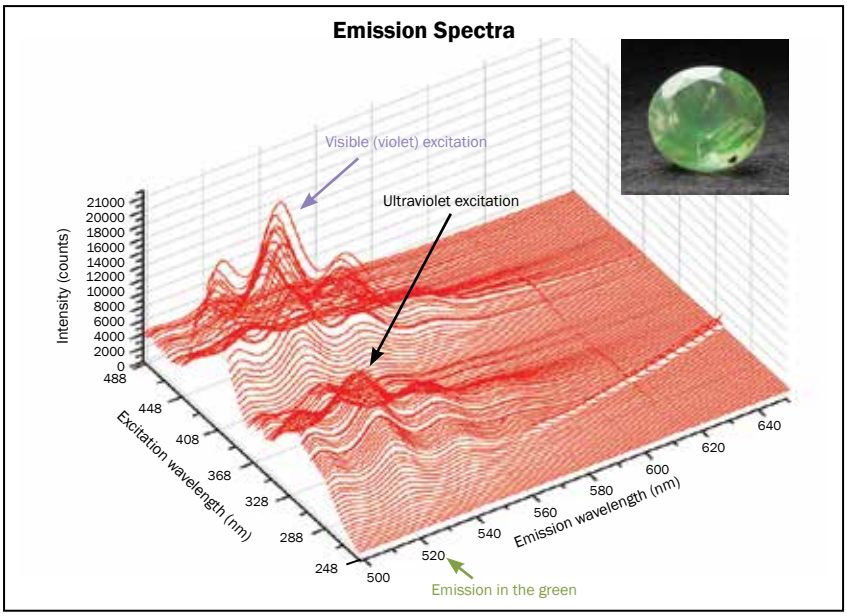

Figure 21: This 3D block diagram of the hyalite luminescence shows emission spectra from 500 to 650 nm that were recorded at excitation wavelengths from 248 to 490 nm (at 3 nm intervals). Four uranyl emission peaks are visible, from ~500 to 600 nm, with the most intense emission in the green region at 524 nm. There are two main excitation regions of the green emission, one in the UV and one in the visible (violet) range. Inset photo of a 1.32 ct opal by B. Chauviré.

UV. Nevertheless, this type of data is useful to visualize the two regions of excitation.

These results were compared to those obtained for our green-luminescing reference hyalite from Inyo County, California. This sample showed the typical behaviour of stronger luminescence in SW than in LW UV radiation, and no emission with daylight illumination. The spectral data were essentially similar in the UV, but there was only a very weak maximum in the visible range. When a 3D block diagram was plotted in a similar fashion to that shown Figure 21, only the UV excitation zone was clearly seen.

Chemical Analysis and Water Content

The EDXRF data should be considered slightly high since the water content of the opal was not taken into account by the instrument. The uranium concentration ranged from approximately 20,600 to 32,400 ppmw UO_2. This is consistent with the value of 22,604 ppmw UO_2 obtained by Spano et al. (2015) using electron microprobe analysis; they also recorded about 94.5% wt.% SiO_2 and 6,384 ppmw CaO. Calcium was also the only other significant impurity we detected (13,300–35,800 ppmw). Spano et al. (2015) proved that U is incorporated into the opal together with Ca. (All the accompanying uranium minerals also contain Ca.) We detected some Fe (<1,000 ppmw), which is much less than the 3,000 ppm necessary to quench green luminescence (Gaillou et al., 2008a). Possible traces of K were noted in all of the analyses, and one sample showed an unquestionable trace of arsenic (~1,000 ppmw).

The water content of the opal determined by TGA analysis was 2.71 ± 0.3 wt.%. This is one of the driest opals we have measured. Added to the chemical analysis determined by Spano et al. (2015), the sum of oxides and water does not quite reach 100% (rather ~97%). This discrepancy is not surprising, considering the very different principles of operation of the two instruments used and that these data originate from different samples.

Radiometry

The ambient background level of radioactivity was 0.052–0.065 µSv/h, and the three opals measured together were in the range of 0.055–0.069 µSv/h. Therefore the radioactivity level of these samples was barely above background. Gamma spectroscopy revealed that only U-related radioisotopes were present above detection limits, despite the long counting time of almost three days. Three decay products of the ^{238}U family were measured: ^{234}Th at 19.4 ± 8.7 Bq/g; ^{214}Pb at 25.3 ± 2.8 Bq/g and ^{210}Pb at 26.5 ± 3.8 Bq/g. (One becquerel per gram means one disintegration per second and per gram of a particular radioisotope.) Our measurements of such low radioactivity levels over an extended period of time showed that this hyalite is not dangerous to wear (or to cut and polish into a gemstone).

Figure 22: This 3.44 ct hyalite from Zacatecas, Mexico, is shown in incandescent light (left) and in shaded daylight (right). Its green colour appearance is due to daylight-induced luminescence. Courtesy of the Smithsonian Institution; photos by Ken Larsen.

In the experience of one of the authors (PKMM), a significant volume of the bulk opal material will set off radiation detectors at the USA-Mexico border. However, this instrumentation is geared toward the detection of the slightest amount of radioactivity, and has been criticized for its inability to distinguish gamma rays originating from nuclear sources versus those "from a large variety of benign cargo types that naturally emit radioactivity, including cat litter, granite, porcelain, stoneware, banana etc." (http://en.wikipedia.org/wiki/Radiation_Portal_Monitor). Other gem materials that likely contain some amount of U-bearing opal—such as some chalcedony, 'crazy lace' agate (or 'laguna lace' agate) and geodes from Las Choyas, Chihuahua State, Mexico—also are known to set off such detectors.

Origin of Daylight-Induced Luminescence

The main interest in this hyalite is its daylight-induced luminescence (e.g., Figure 22). Why is it observed in this opal and in almost no others? It is apparent from our measurements and the literature (in particular, Gaillou, 2006) that most opals luminescing green to UV radiation show very similar excitation spectra to those of this Mexican hyalite (i.e. uranyl absorption in the violet and blue ranges). And indeed, most opals that fluoresce green to UV radiation also will show green luminescence under a 405 nm laser, which is visible light. However, our eyes do not perceive any green emission when these gems are observed in normal daylight. Why?

Several phenomena compete for the perception of a colour: light transmitted (the body colour), light scattered ('haze' in colorimetric terms) and light reflected (gloss) by an object. The most common result of light scattering is seen in milky gems (e.g. white diamond, jade or opal) or the blue adularescence of moonstone, but luminescence is also a scattering phenomenon. The green colour component of the hyalite described in this article belongs to scattered light encountering the eye. One of the matrix specimens examined by the authors was covered by green-luminescing hyalite that abruptly graded into milky white hyalite that showed no daylight luminescence (Figure 23, left). Under UV radiation (or the 405 nm laser), the green luminescence was equally intense over the entire specimen (Figure 23, right). The emission spectra obtained from all of the opal on the specimen were the same, and surprisingly the excitation spectra also were identical. Therefore the entire specimen also should have displayed the same green luminescence in daylight—if this phenomenon could be fully described by spectroscopy alone. Since the visual perception of the specimen was quite different, the daylight luminescence must be dependent upon the interplay of other factors. First, there must be an absence of any sort of luminescence quencher, such as Fe^{3+}. Second, an absence of other forms of scattering besides luminescence is important: for example

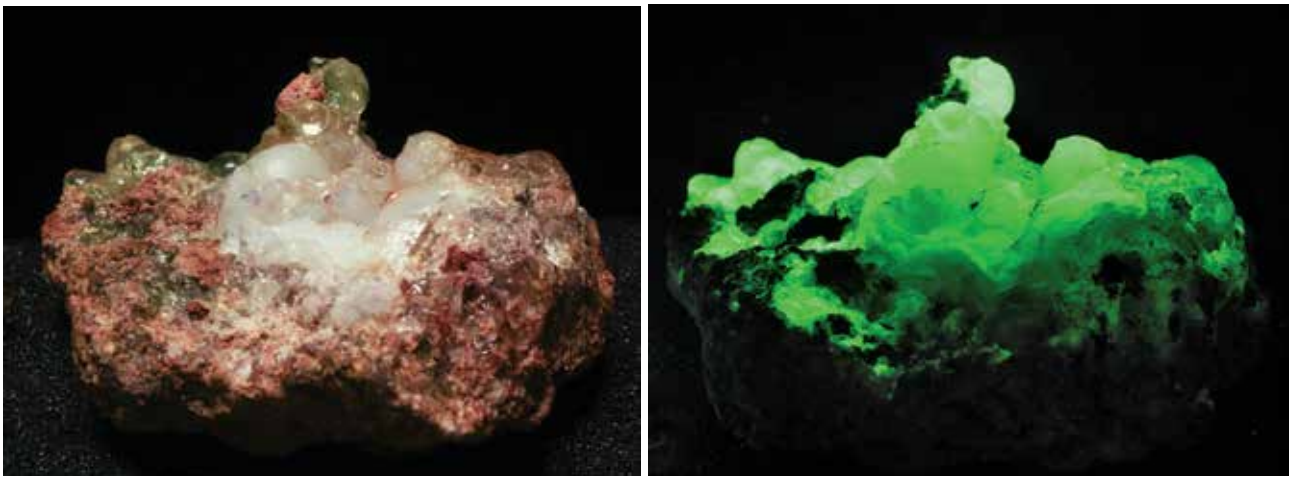

Figure 23: This specimen (~55 mm wide) is covered by hyalite that is milky white, as well as transparent hyalite showing green daylight luminescence (left). When exposed to LW UV radiation, all of the hyalite shows the same intensity of green luminescence (right). Photos by B. Chauviré.

if the sample is milky, it is unlikely that daylight luminescence will be seen. This second condition implies that the gem has to be transparent. Third, the presence of uranyl ions is a prerequisite, probably in a certain range of concentration: if there is not enough, the luminescence will be too weak, and if there is too much, the molecules will absorb one another's emission (a process called *concentration quenching* or *self-quenching*; Fritsch and Waychunas, 1993), reducing the overall luminescence.

The excitation spectrum of the hyalite basically indicates that its luminescence may be excited by visible light, but other conditions, probably not limited to those cited above, are necessary for this rare phenomenon to occur. Obviously, further research is needed to fully understand why certain materials show a luminescence colour in daylight. A comprehensive study of such materials compared to their counterparts that do not have such an emission colour component would be necessary, and should include an investigation into the details of luminescence perception by the human eye.

Conclusions

Green daylight-luminescing opal from Zacatecas, Mexico (e.g. Figure 24), has been identified as hyalite by a combination of its opal-A Raman signal and glassy texture in the scanning electron microscope. It occurs in a volcanic environment, as is usually the case for hyalite. Its luminescence is due to dispersed uranyl ions, with a maximum emission at 524 nm, and excitation in both the UV and the visible range. Although the opal may

Figure 24: The vivid green colour shown by the hyalite in these matrix specimens (left, 2.5–3.1 cm across) and the 4.2 ct gemstone (right) is due to daylight-induced luminescence. The mineral specimens are courtesy of P.K.M. Megaw (photo by Orasa Weldon), and the cut stone was faceted by author MG (photo by Tino Hammid).

contain up to 0.3% wt.% UO_2, detailed radiation measurements recorded only very low levels of emitted radioactivity, so there is no danger in wearing or cutting this gem. Several factors contribute to the daylight luminescence of this opal—in particular its diaphaneity or ability to scatter light—but more research is needed to fully elucidate the factors governing the perception of daylight luminescence.

Perhaps 20 kg of medium-to-top-quality rough material remains to be faceted, and prospecting for more opal sites is in progress at the time of this writing. Whether more such bright green fluorescent hyalite will be discovered remains to be seen, but the geology of the deposit is reasonably well understood, and only the immediate areas around the known deposit are prospective as elsewhere the host unit has been eroded away.

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The Fire Within

"For in them you shall see the living fire of the ruby, the glorious purple of the amethyst, the sea-green of the emerald, all glittering together in an incredible mixture of light."

– Roman Elder Pliny, 1st Century AD

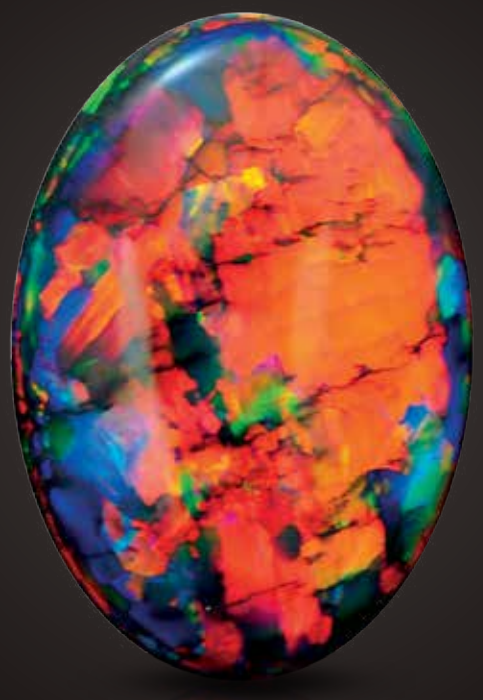

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Raman Spectroscopy of Ancient Beads from Devín Castle near Bratislava and of Four Intaglios from other Archaeological Finds in Slovakia

Magdaléna Kadlečíková, Juraj Breza, Ľubomír Vančo, Miloš Gregor and Igor Bazovský

Raman spectroscopy was used to identify violet and red-to-orange beads from a necklace and bracelet dated from the 11th and 12th centuries that were found in an ancient cemetery at Devín Castle near Bratislava, Slovakia. The violet beads (previously described as amethyst) were identified as fluorite and the red-to-orange beads were determined as quartz (carnelian). In addition, four intaglios (one unmounted and three set in ancient rings) from 2nd–3rd century AD archaeological finds in Slovakia also were analysed by Raman spectroscopy. Two of the gems were identified as carnelian (consisting of a mixture of quartz and the SiO_2 polymorph moganite), while the third stone had Raman bands for hematite and subordinate quartz, suggesting it was jasper. The Raman spectrum of the fourth intaglio corresponded to almandine with some vibrational bands for spessartine.

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Introduction

The use of Raman spectroscopy to study archaeological materials has a long tradition, mainly because it is a non-destructive technique and does not require removal of samples from their mountings. Various materials have been analysed, including gems, pigments, glass and ceramics (e.g. Hänni et al., 1998; Smith and Clark, 2004; Zoppi et al., 2005; Vandenabeele et al., 2007; Colomban, 2012; Katsaros and Ganetsos, 2012). The aim of the present research is to identify the minerals in selected archaeological items from Slovak National Museum collections (beads from the Bratislava City Museum and intaglios from the Archaeological Museum in Bratislava) that had been previously described only on the basis of their macro-appearance. Preliminary results of our analyses were published by Gregor et al. (2013).

Materials

Necklace and Bracelet from Devín Castle

Beads were studied from a necklace and a bracelet that were found in graves from the 11th and

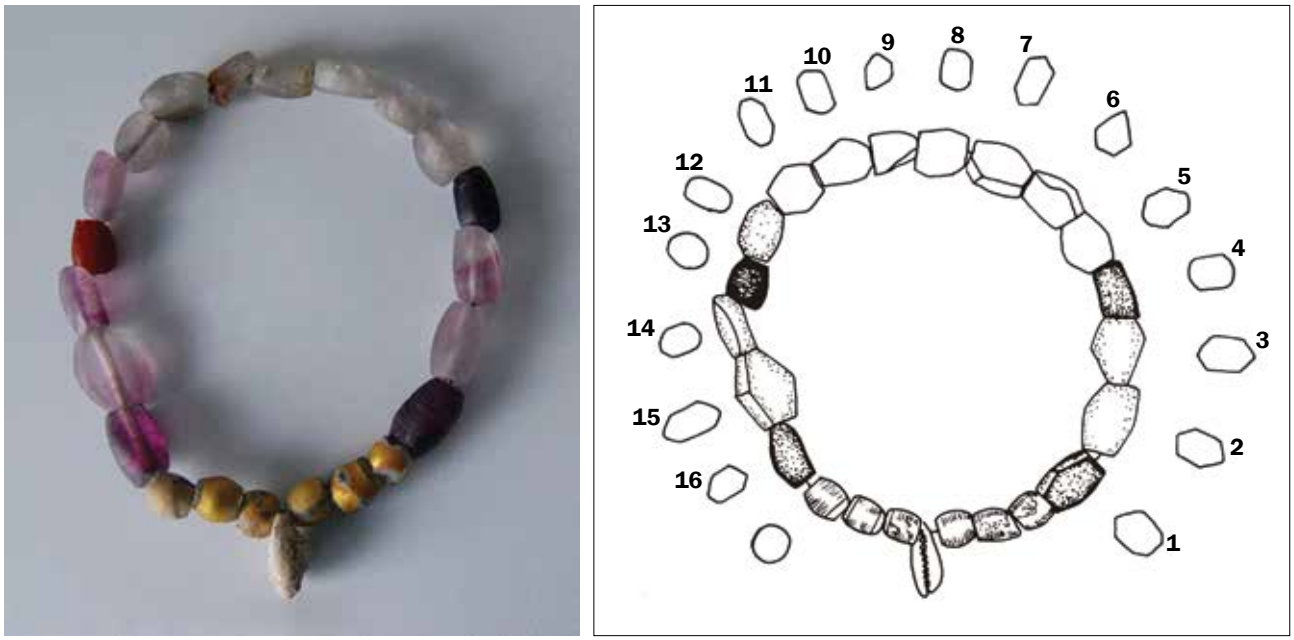

Figure 1: The 23 beads from the necklace found in Devín Castle grave 12/1980 consist of one shell of the cowrie Cypraea moneta *(bottom), 15 faceted fluorites (sample nos. 1—12 and 14—16), one piece of amber (no. 13) and six ball-shaped beads coated with gold foil (non-numbered). The numbered beads range from 11 to 16 mm long. Photo by D. Divileková.*

12th centuries at Devín Castle near Bratislava (Plachá and Divileková, 2012). The necklace, consisting of 23 beads (Figure 1), was found in tomb 12/1980, which contained an incomplete skeleton of a woman. The skull, shoulder blades and lower limbs were preserved in good condition. This grave hosted a rich inventory of artefacts: a silver earring on the left side of the skull, necklace beads between the shoulder blades and a ring at the position expected for the right hand. The bracelet, consisting of six beads (Figure 2), was found in grave 145/1985, in which another woman's skeleton was discovered. The beads were found below the mandible. All the beads are drilled through axially. Selected properties of the beads are summarized in Table I.

Beads from the necklace can be divided into three categories. The first contains only one bead, which is the shell of *Cypraea moneta* (or 'money cowrie', named after the use of this shell as money since ancient times). It was probably positioned as a pendant in the necklace. The second category includes six ball-shaped beads (probably glass) coated with gold foil and typically showing a weathered surface; these beads were studied only macroscopically as they do not correspond to natural gem material. In the third category were 16 roughly faceted oval beads with dull lustre and showing various colours (mostly colourless to dark violet). One of these beads with a dark red colour (no. 13) was previously identified as amber by its macroscopic

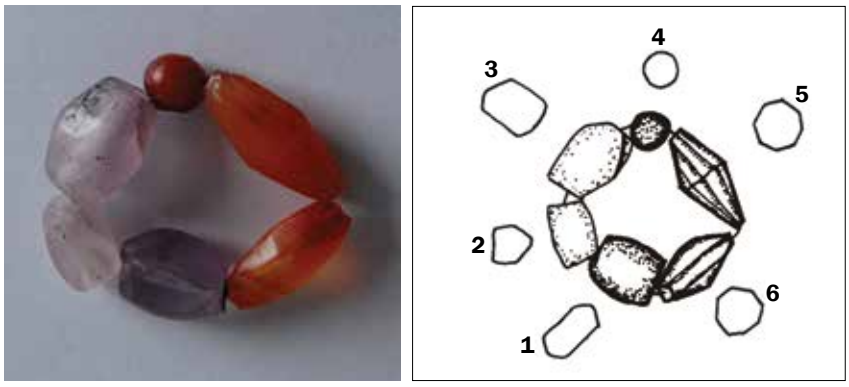

Figure 2: The six beads from the bracelet found in Devín Castle grave 145/1985 were identified as three faceted fluorites (nos. 1–3) and three pieces of carnelian (nos. 4–6). The smallest bead is 7 mm in diameter and the largest is 22 mm long. Photo by D. Divileková.

Table I: Properties of the beads recovered from Devín Castle, Bratislava, Slovakia.

Item	Bead number	Colour	Transparency	Lustre	Material	Long-wave UV fluorescence	Size (mm)	Drill hole diameter (mm)
Necklace beads from grave 12/1980	1	Dark violet	Opaque	Dull	Fluorite	–	16×11×10	3
	2	Light violet	Translucent	Dull	Fluorite	Blue	16×11×10	3
	3	Light violet	Translucent	Dull	Fluorite	Blue	15×13×8	3
	4	Dark violet	Opaque	Dull	Fluorite	Blue	13×10×8	3
	5	Colourless	Translucent	Dull	Fluorite	Blue	12×12×9	3
	6	Colourless	Translucent	Dull	Fluorite	Blue	13×12×9	3
	7	Colourless with green tint	Translucent	Dull	Fluorite	Blue	13×12×7	3
	8	Colourless with green tint	Translucent	Dull	Fluorite	Blue	12×11×7	3
	9	Colourless	Translucent	Dull	Fluorite	Blue	11×10×6	3
	10	Colourless with green tint	Translucent	Dull	Fluorite	Blue	14×12×8	3
	11	Colourless	Translucent	Dull	Fluorite	Blue	12×11×8	3
	12	Light violet	Translucent	Dull	Fluorite	Blue	14×12×7	3
	13	Dark red	Opaque	Waxy	Amber	–	11×8×7	3
	14	Light violet	Translucent	Dull	Fluorite	Blue	15×10×7	3
	15	Light violet	Translucent	Dull	Fluorite	Blue	16×14×8	3
	16	Dark violet	Opaque	Dull	Fluorite	–	16×12×9	3
Bracelet beads from grave 145/1985	1	Colourless with violet tint	Translucent	Dull	Fluorite	Blue	15×12×9	3
	2	Colourless with violet tint	Translucent	Dull	Fluorite	Blue	14×12×6	3
	3	Light violet	Translucent	Dull	Fluorite	Blue	11×8×7	3
	4	Red	Translucent	Vitreous	Carnelian	–	7×7×7	1.5
	5	Orange	Translucent	Vitreous	Carnelian	–	19×8×8	1.5
	6	Orange	Opaque	Vitreous	Carnelian	–	22×9×9	1

properties (lustre, colour, inferred hardness and specific gravity; see Plachá and Divileková, 2012). This amber bead, as well as the shell bead, were not examined for this report.

The bracelet consisted of three colourless-to-light-violet and three red-to-orange beads. The violet beads were similar in shape to the oval beads in the necklace described above, while the red-to-orange ones consisted of a seed-style bead and two roughly faceted bicone beads.

Other Ancient Gems from Slovakia

These samples consisted of three gems set in rings and one unmounted stone. Figure 3a shows a gold ring (AP 44 419) dating to the second half of the 3rd century AD from Castle Hill in Bratislava, above the Church of St Nicholas. It contains a light red oval intaglio that is engraved with a nude human figure holding a helmet in the right hand and another object (perhaps a mace) in the left hand. The metal part of the ring is undecorated. Figure

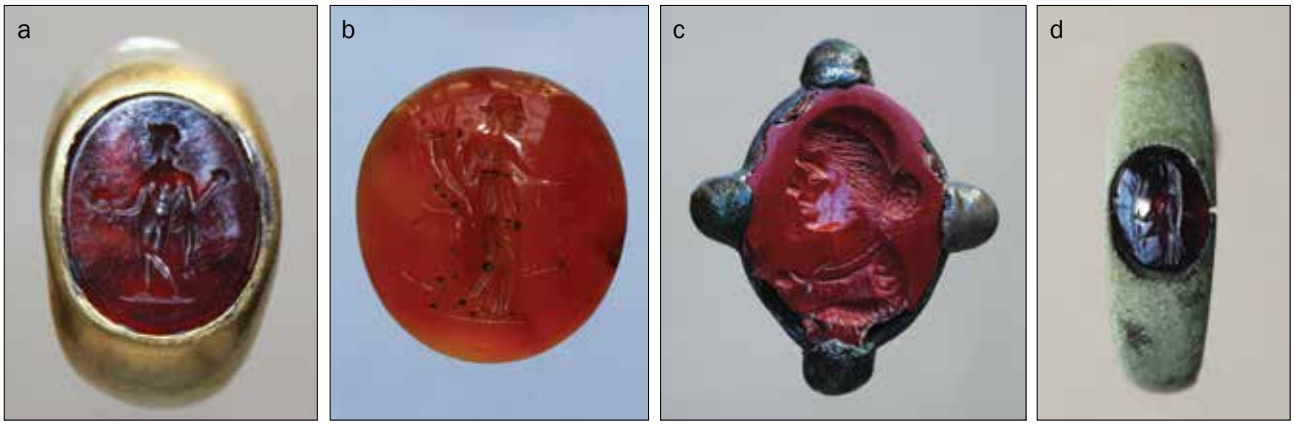

Figure 3: Four ancient gems from various archaeological finds in Slovakia were studied for the report: (a) a gold ring (AP 44 419) containing an intaglio (1.1×1.4 cm) decorated with a human figure, from Castle Hill in Bratislava; (b) an intaglio (AP 44 749; 1.65×1.7 cm) presumably depicting the goddess Fortuna, also from Castle Hill; (c) a ring (AP 17 343) with an intaglio showing a woman's profile (1.8×2.35 cm), from an ancient tomb at Sereď; and (d) a bronze ring (AP 51 487) containing a dark red intaglio (0.56×0.61 cm) with an image of a parrot, from Rusovce near Bratislava. Photos by I. Choma.

3b shows an unmounted orangey red intaglio (AP 44 749) with an image of the goddess Fortuna holding a steer in her left hand and a horn-of-plenty in her right hand. This intaglio is also from Castle Hill (above the Church of St Nicholas), and dates from the middle of the 2nd century AD; it is part of a collection of artefacts from the La Tène culture. Figure 3c shows a ring (AP 17 343) from a tomb at Sereď (located approximately 50 km northeast of Bratislava) that is dated to the 2nd century AD. This ring features a red intaglio that is set in silvery white metal. The opaque stone is decorated by the bust of a woman, viewed from the left profile, holding a round object (probably an apple). Figure 3d shows a bronze ring (AP 51 487) containing a translucent dark red intaglio engraved with a parrot sitting on a sprig. This ring comes from Rusovce (just south of Bratislava) and is dated to the first half of the 2nd century AD.

Methods

The colourless-to-violet and red-to-orange beads from Devín Castle, and all four intaglios from the other archaeological finds in Slovakia, were examined with a binocular visor magnifier and an optical microscope, and their colour, transparency, lustre and UV fluorescence were determined.

The gems selected for analysis by Raman spectroscopy included two violet faceted beads (no. 2 from tomb 12/1980 and no. 3 from grave 145/1985), all three red-to-orange beads (nos. 4–6 from tomb 145/1985) and all four intaglios from the other archaeological finds in Slovakia. The samples were analysed at room temperature without any preparation. Raman spectra were collected with a Dilor–Jobin Yvon–Spex LabRam spectrometer. The samples were placed on the micrometric manipulator of a confocal microscope (Olympus BX-40) and visualized in a video monitor. The excitation source was an He-Ne laser (632.8 nm, 15 mW). The scattered radiation was focused onto the entrance slit of a grid monochromator (1,800 grooves/mm), and the spectral range was up to 4000 cm^{-1}. The spectrometer was equipped with a multichannel CCD detector with a resolution of 1.3 cm^{-1}; it was calibrated to the 520.7 cm^{-1} band of monocrystalline silicon. The focused beam was approximately 2 µm in diameter, and the time of data collection ranged from 20 to 200 seconds depending on the intensity of Raman scattering and fluorescence.

The Raman spectra were processed using the LabSpec software package, and the results were compared to Raman spectral databases (e.g. rruff.info) and with the literature (Loudon, 1964; Ganetsos et al., 2013). The signal-to-noise ratio was sufficient for identifying the Raman bands.

Results and Discussion

Beads from Devín Castle

The colourless-to-violet beads from both the necklace and bracelet were 11–16 mm long

and showed roughly faceted oval shapes with rounded edges. They varied from colourless (sometimes with a violet or green tint) to light violet to dark violet. The colourless and light violet beads were translucent, and some of the latter showed colour zoning. The dark violet beads were opaque, and all showed a dull lustre. Most of the beads fluoresced blue to long-wave UV radiation, with two of the dark violet beads being inert. Some of the beads were broken (e.g. no. 9) and they showed perfect cubic cleavage. No inclusions could be observed through the poorly polished surfaces.

Selected Raman spectra of the violet beads are shown in Figure 4. Both spectra correspond to fluorite. The Raman T_{2g} band at 322 cm^{-1} is a triple-degenerated vibration of the F^- anion sub-lattice with respect to stationary Ca^{2-} cations (Loudon, 1964). Previously, violet or dark violet roughly faceted oval beads from early Medieval cemeteries were commonly believed to be amethyst (e.g. Rejholcová, 1974). However, our visual observations of the beads were not consistent with amethyst, and Raman spectroscopy clearly confirmed that they were fluorite.

The red and orange beads from the bracelet were translucent to opaque and showed a vitreous lustre. They were inert to UV radiation. Raman spectroscopy (Figure 5) identified them as quartz (α-quartz, trigonal SiO_2), confirming that they are carnelian (a variety of chalcedony composed of orange-to-red fibrous microcrystalline quartz). Red bead no. 4 also showed Raman bands for moganite, a monoclinic quartz polymorph. The Raman features corresponding to α-quartz are A_1 bands at 207, 355 and 465 cm^{-1} and E bands at 264, 394 and 401 cm^{-1}. The band at 503 cm^{-1} with E symmetry indicates the presence of moganite and corresponds to Si-O-Si vibrations (Kingma and Hemley, 1994).

Other Ancient Gems from Slovakia

All four intaglios were previously described in museum records as carnelian. Intaglio AP 44 419 was translucent and without any observable inclusions. Its Raman spectrum (Figure 6, top) shows a dominant vibrational band centred at 463 cm^{-1} and additional bands at 128, 207, 264, 353 and

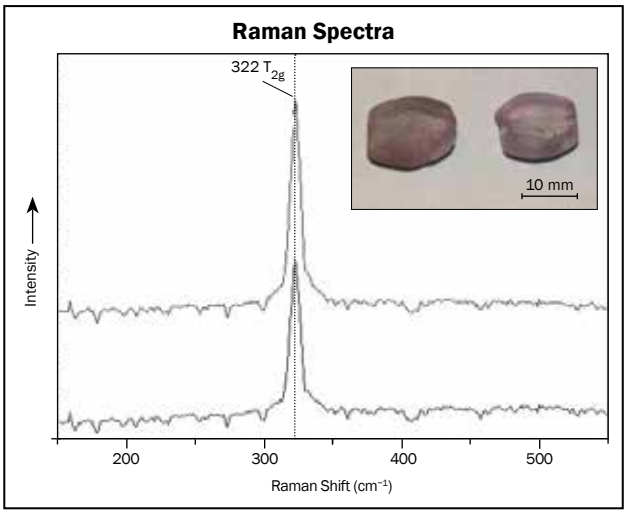

Figure 4: Raman spectra of two violet beads found at Devín Castle correspond to fluorite. These spectra were recorded from two different places on bead no. 3 (shown on the left in the inset) from grave 145/1985. The right bead in the inset is no. 2 from grave 12/1980; it yielded identical Raman spectra. Inset photo by D. Divileková.

393 cm^{-1} that identify it as α-quartz. In addition, a band at 502 cm^{-1} corresponds to moganite. The presence of quartz could be reliably established not only through the dominant band at 463 cm^{-1} but also by the band at 353 cm^{-1} (Kingma and Hemley, 1994). Our visual observations of this intaglio (i.e. red colour and its inferred hardness)

Figure 5: Raman spectra are shown for red bead no. 4 from the bracelet of grave 145/1985, recorded from an area with an inclusion of an unknown brown mineral (a) and from the typical sample surface (b). The better signal-to-noise ratio of the latter spectrum is probably due to stronger absorption of the incident laser radiation. The major phase is α-quartz (trigonal SiO_2), and the weak band at 503 cm^{-1} corresponds to moganite (monoclinic SiO_2). Inset photo by D. Divileková.

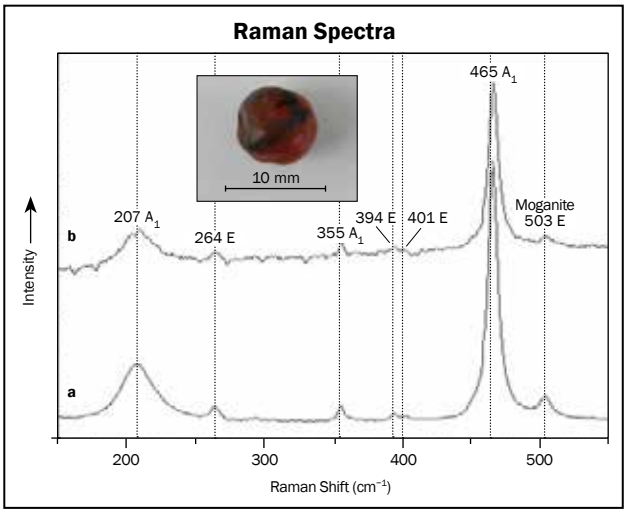

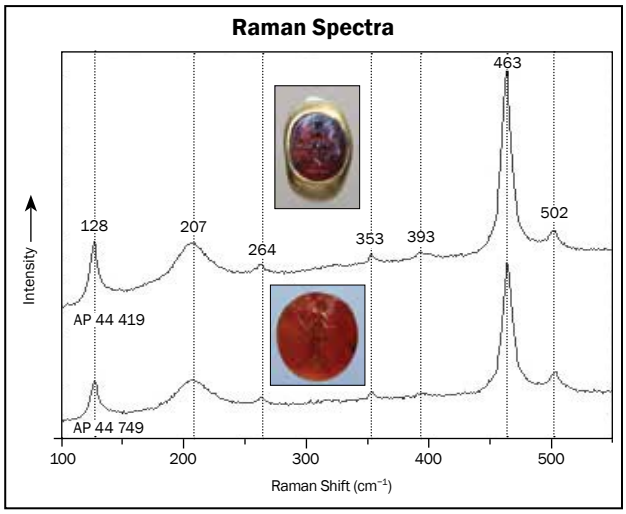

Figure 6: Raman spectra of carnelian intaglios AP 44 419 and AP 44 749 have bands centred at approximately 463 and 502 cm^{-1} that prove the presence of quartz and moganite, respectively. Inset photos by I. Choma.

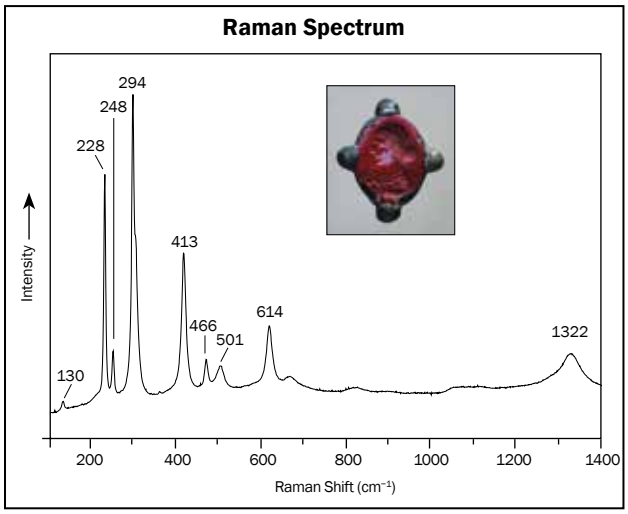

Figure 7: Ring AP 17 343 from the ancient tomb at Sered' contains a jasper intaglio that has a Raman spectrum corresponding to hematite and subordinate quartz. Inset photo by I. Choma.

corresponded to carnelian. Gem AP 44 749 had similar macroscopic characteristics, and its Raman spectrum (Figure 6, bottom) also identified it α-quartz and moganite (i.e. carnelian).

The Raman spectrum of gem AP 17 343 (Figure 7) confirmed the presence of hematite, with vibrational bands centred at 228 (A_{1g}), 248 (E_g), 294 (E_g), 413 (E_g), 501 (A_{1g}), 614 (E_g) and 1322 cm^{-1} (cf. Porto and Krishnan, 1967). The Raman spectrum also contains weak vibrational bands centred at approximately 130 and 466 cm^{-1} that reflect the presence of quartz. The band at 466 cm^{-1} is not expected in hematite using the group theory (de Faria et al., 1997). On the basis of its Raman spectrum and visual macroscopic characteristics (deep red colour, opaqueness, fracture pattern and lustre), we concluded that this gem is jasper.

Gem AP 51 487 in the bronze ring has a distinctly dark red colour and was transparent with a vitreous lustre. Its Raman spectrum (Figure 8) shows bands centred at 171, 217, 347 (subdominant band), 374, 500, 557, 633, 861, 918 (dominant band) and 1028 cm^{-1}, clearly placing it in the garnet structural group. A shift of the band positions can occur as atoms with different masses occupy the cationic sites. Based on data provided by Pinet and Smith (1993), the calcic series uvarovite-grossular-andradite is not a possibility because of differing Raman bands. However, spectra from the aluminian series pyrope-almandine-spessartine fit well with

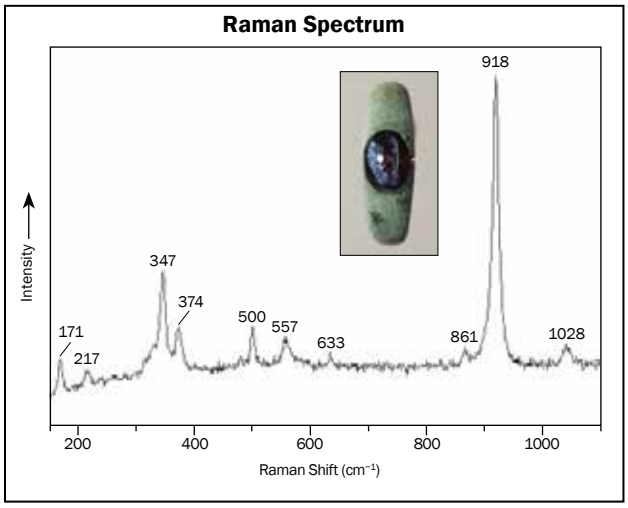

Figure 8: Intaglio AP 51 487 yielded a Raman spectrum with vibrational bands belonging to almandine and subordinate spessartine. Inset photo by I. Choma.

our measured Raman spectrum (cf. Pinet and Smith, 1994). As indicated by the data in Table II, the stone consists of almandine with a spessartine component rather than a pyrope component. Further support for the almandine-dominant composition was obtained by comparing its Raman spectrum with various spectra for almandine (rruff.info/almandine-R040076), spessartine (rruff.info/spessartine-R050063) and pyrope (rruff.info/pyrope-R040159), as well as with the spectra for almandine from Tyrol in Austria and from the historical site of Alabanda in Turkey (Ganetsos et al., 2013).

Table II: Raman bands (cm^{-1}) useful for the identification of garnet intaglio AP 51 487.

Spectral range	Aluminian-series garnets (Pinet and Smith, 1994)			This work	Band symmetry
	Spessartine	Almandine	Pyrope		
1100–750	1030 906 850	1038 915 862	1062 924 867	1028 918 861	T_{2g} T_{2g} T_{2g}
750–450	632 553 503	630 557 499	648 561 511	633 557 500	T_{2g} A_{1g} T_{2g}
450–120	375 352 224 175	370 345 216 168	380 364 208 174	374 347 217 171	T_{2g} A_{1g} T_{2g} T_{2g}

Conclusion

Raman spectroscopy was used to analyse selected beads from a necklace and a bracelet dating from 11th- and 12th-century burials at Devín Castle in Slovakia. The violet beads were previously believed to be amethyst, but our investigations confirmed they are fluorite. In addition, red-to-orange beads from the bracelet were identified as carnelian (confirming their previous identification from visual observations). One of the carnelian beads also showed the presence of moganite (monoclinic SiO_2) in its Raman spectrum. The intergrowth of quartz and moganite polymorphs of SiO_2 is typical for agate structures (Heaney and Davis, 1995).

In addition, four ancient gems (intaglios) from elsewhere in Slovakia were analysed. Two of them were identified as carnelian, showing Raman bands for quartz and moganite. Another intaglio had Raman bands corresponding to hematite and subordinate quartz, suggesting it was jasper. The fourth gem corresponded to almandine with some vibrational bands for spessartine.

Carnelian and jasper are relatively common gems that are known from numerous sources, so the provenance of those ancient beads/intaglios is unknown. The provenance of the almandine-dominant intaglio also is not clear. Garnet with this composition is known from various localities in Zillertal in the Austrian Alps (Grundmann, 1988). Also the classical locality of Alabanda in Turkey should not be excluded (e.g. Rapp, 2002; Ganetsos et al., 2013), as it was known in the Roman age. Clearly, the geographical origin of the ancient almandine-dominant intaglio documented in this article cannot be identified only on the basis of its mineralogical composition.

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The First Undisclosed Colourless CVD Synthetic Diamond Discovered in a Parcel of Natural Melee-Sized Diamonds

Thomas Hainschwang and Franck Notari

During the March 2015 Diamond Show in Basel, Switzerland, a parcel of 6,000 melee-sized colourless diamonds was analysed using the GGTL Diamond Fluorescence Imaging (DFI) Laser+ fluorescence imaging and spectroscopy system. From the entire parcel, one sample stood out clearly with unusual fluorescence colours and distribution, combined with a photoluminescence spectrum that clearly indicated it was a synthetic diamond grown by chemical vapour deposition (CVD).

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Introduction

With the introduction of near-colourless, single-crystal, gem-quality CVD synthetic diamond into the market in recent years, and the enormous progress made in the growth of near-colourless synthetic diamond produced by high-pressure, high-temperature (HPHT) synthesis in the past two years, the gem industry has been very concerned about these synthetics being sold without proper disclosure. One of the main concerns is the mixing of near-colourless melee-sized synthetics into parcels of natural diamond, but so far this has not been confirmed despite many rumours within the trade. The only scientific reports of undeclared melee-sized synthetics detected in parcels of natural diamonds have been HPHT-grown yellow samples (Kitawaki et al., 2008; Hainschwang and Notari, 2012), and recently a single CVD-grown yellow synthetic diamond (Hainschwang, 2014). Until now, near-colourless CVD synthetic diamonds submitted to laboratories were in larger sizes. Since they are straightforward to identify by a well-equipped lab, they have not caused major concern within the trade.

The efficient testing of melee-sized diamonds is a highly specialized task and requires a lot of expertise and specially adapted analytical methods, particularly for fancy-colour diamonds. GGTL Laboratories is one of the few facilities with the expertise and equipment to test large amounts of colourless and fancy-colour melee diamonds for the watch and jewellery industry. After several years of testing such parcels (with several million pieces analysed), GGTL Laboratories recently found the first undisclosed melee-sized colourless CVD synthetic diamond in a parcel of natural diamonds (Hainschwang and Notari, 2015). This article describes the properties of this specimen.

Materials and Methods

A parcel of 6,000 diamonds, each measuring 1.6 mm in diameter, was analysed by GGTL Laboratories during the Diamond Show in Basel in March 2015. The parcel had been purchased

Figure 1: This 1.6-mm-diameter, F-colour, IF-clarity CVD synthetic diamond was found in a parcel of natural melee (left; photo by T. Hainschwang). Its lamellar appearance between crossed polarizing filters (here, shown immersed in methylene iodide) is typical of CVD synthetic diamond (right; photo by F. Notari).

in Mumbai, India, and consisted of high-quality melee (mainly E-F-G colour and IF to VS clarity).

The distinction of natural and synthetic diamonds and imitations with the GGTL DFI Laser+ system is non-automated but very efficient, based on the observation of luminescence colour, distribution and intensity under various excitations, combined with the simultaneous analysis of the photoluminescence (PL) and Raman spectra of the diamonds. The GGTL DFI system uses a suitably filtered 300 W full-spectrum xenon lamp to give six different broadband excitations in the range of 230–420 nm, plus a 250 mW 405 nm laser. Room-temperature PL spectra are collected during luminescence imaging by a single-channel spectrometer (1.5 nm resolution) using a thermoelectrically cooled CCD detector.

The internal features and strain pattern in the synthetic diamond were visualized using a Leica M165C trinocular microscope, equipped with a Leica DFC420 CCD camera with a resolution of 5 megapixels; the strain pattern was observed with the sample immersed in methylene iodide between crossed polarizing filters. Luminescence was observed under 254 nm short-wave (SW) and 365 nm long-wave (LW) UV radiation from a 6 W lamp (model UVP UVSL-26P), and also under broadband UV from the GGTL DFI system using the three different excitations that made the sample luminesce distinctly: 250–350 nm (SW/LW band), 300–410 nm (LW band 1) and 355–375 nm (LW band 2). Luminescence images were acquired with a Leica DFC450 C CCD camera with a resolution of 5 megapixels and the CCD sensor thermoelectrically cooled with a delta of −20°C compared to the surrounding temperature.

The infrared spectra of the sample were recorded with a resolution of 4 cm^{-1} on a PerkinElmer Spectrum 100S Fourier-transform infrared (FTIR) spectrometer equipped with a thermoelectrically cooled DTGS detector. The beam was transmitted through the diamond using a diffuse reflectance accessory as a beam condenser, over a range of 8500–400 cm^{-1}, with 500 scans.

PL spectra were recorded with the GGTL PL-7 system using 405, 473, 532, 635 and 785 nm laser excitations, and a high-resolution echelle spectrograph by Catalina Scientific equipped with an Andor Neo sCMOS camera (resolution of 5 megapixels) that was thermoelectrically cooled to −30°C. The system was set up to record spectra in the range of 350–1150 nm with an average resolution of 0.04 nm. All of these PL spectra were recorded with the sample cooled to 77 K by direct immersion in liquid nitrogen.

Results and Discussion

Gemmological Properties and Initial Detection

The CVD synthetic diamond (Figure 1, left) was detected by its uncommon 'greenish' orange to pink to purple luminescence under the intense broadband UV excitations of the fluorescence imaging system (Figure 2) combined with relatively strong emission from the Si centre, together with distinct luminescence from the NV^0 and 467.7 nm centres (Figure 3). The sample showed no visible luminescence under the standard LW and SW UV lamp.

This CVD synthetic diamond weighed 0.015 ct and was graded F colour and IF clarity (Figure 1, left). Between crossed polarizing filters, in certain orientations it exhibited distinct grey-to-black lamellar extinction, typical for CVD synthetic diamond (Figure 1, right). However, in some orientations the appearance could be confused

Figure 2: The luminescence exhibited by the 1.6-mm-diameter sample under three different broadband UV excitations is highly unusual for a colourless diamond. The 'greenish' orange (under 250–350 nm excitation), pink (355–375 nm excitation) and purple (300–410 nm excitation) luminescence with a slight streakiness are very good indicators of its CVD synthetic origin. Photos by F. Notari (left) and T. Hainschwang (centre and right).

with the so-called tatami strain pattern that is so typical of natural (and HPHT-treated natural) type IIa and low-nitrogen type Ia diamonds.

IR Spectroscopy

To characterize this small CVD synthetic diamond in detail, it was analysed by several spectroscopic techniques. FTIR spectroscopy showed that it was type IIa with no detectable nitrogen, and the spectrum did not exhibit any additional features indicative of a natural vs. synthetic origin: none of the small absorption lines characteristic of CVD synthetic diamond in the near-infrared range were observed (e.g. 7353, 6425 and 5562 cm^{-1}; see, e.g., Wang et al., 2007). Since 'pure' type IIa diamonds in such small sizes are extremely rare (and even far rarer than larger type IIa diamonds), a melee-sized sample that is truly type IIa is very suspect of synthetic origin.

Although this sample showed the expected SW UV transparency for type IIa diamond, in the experience of the authors, the vast majority of SW UV–transparent melee-sized natural diamonds are low-nitrogen type Ia. SW UV transparency is not—as believed by many—a property that changes abruptly from nitrogen-containing to nitrogen-free diamond. Therefore, stones that are low in aggregated nitrogen (easily identified by IR spectroscopy) are SW UV transparent, just like type IIa diamonds. As a result, such low-nitrogen type Ia diamonds are usually erroneously identified as type IIa by SW UV transparency–based methods.

Low-Temperature PL Spectroscopy

The PL spectra recorded with all five laser excitations at 77 K confirmed what was clearly indicated by the GGTL DFI system: that the sample

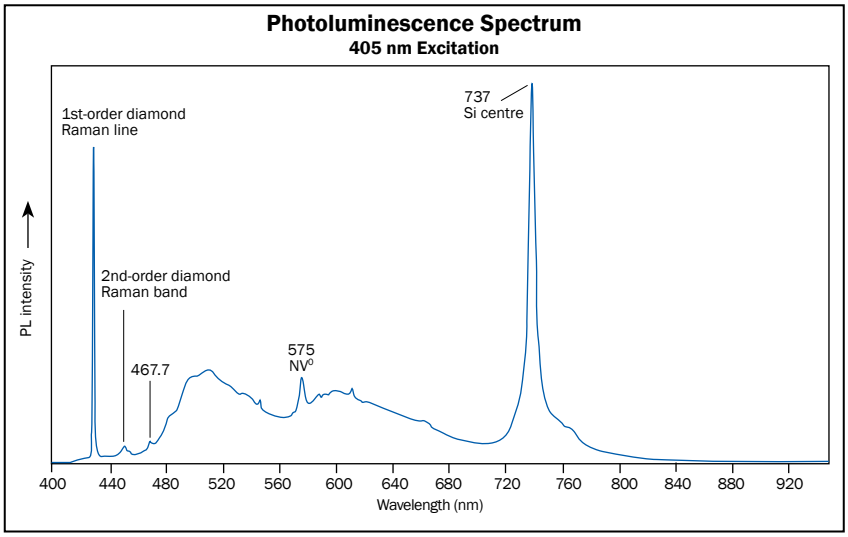

Figure 3: The room-temperature PL spectrum of the sample recorded with the GGTL DFI system shows features characteristic of untreated CVD synthetic diamond, with a strong Raman line diagnostic for diamond and bands from the 467.7 nm centre, the NV^0 centre and the Si centre (which identify it as a CVD synthetic).

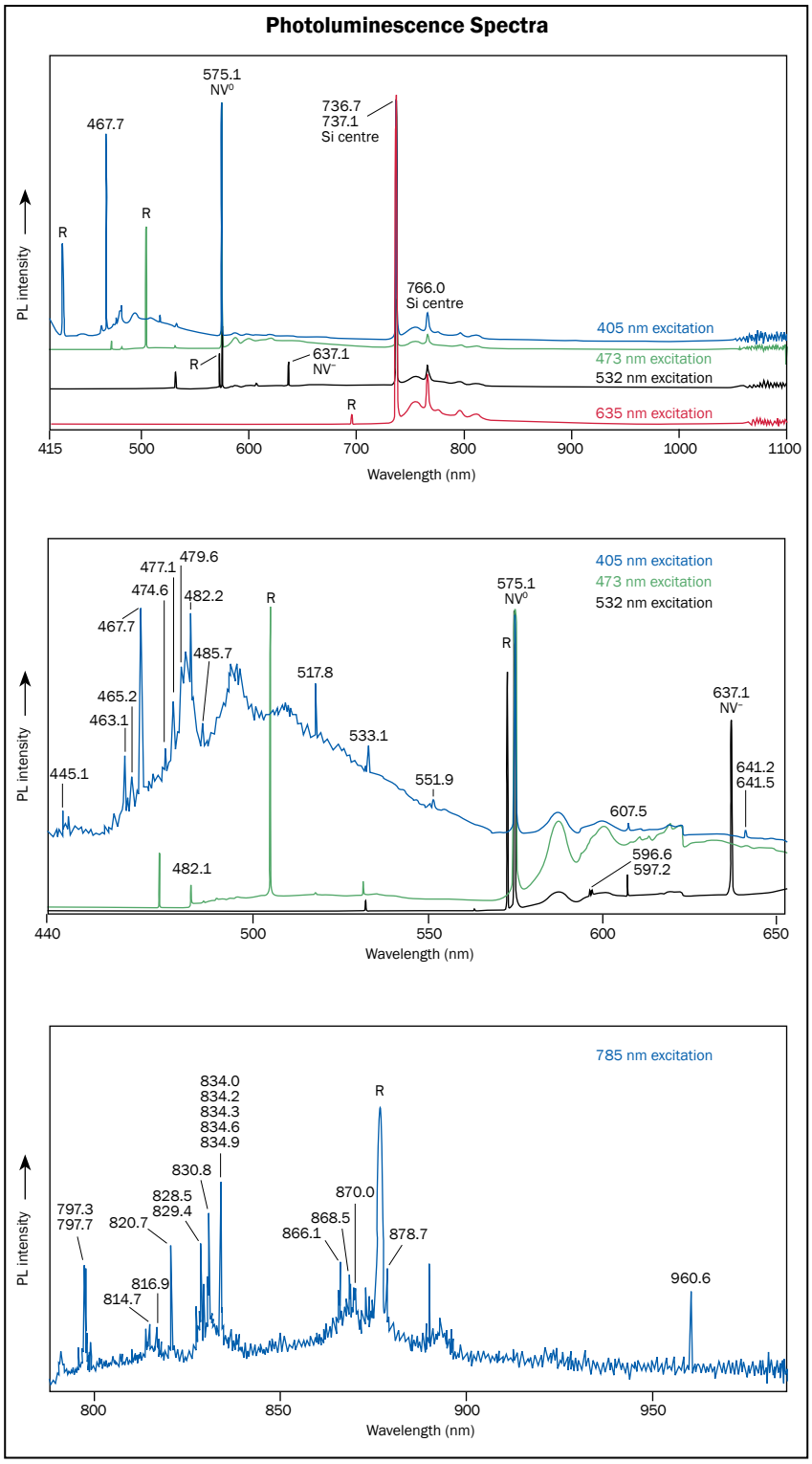

Figure 4: The PL spectra recorded using 405, 473, 532, 635 and 785 nm lasers show many characteristic peaks for CVD synthetic diamond. The well-known doublet at 736.7/737.1 nm is produced by the Si centre, which is the dominant defect recorded with 405, 473, 532 and 635 nm excitations. The 467.7 nm centre is another characteristic feature of CVD synthetic diamond. R = Raman line.

was an as-grown (untreated) CVD synthetic diamond, high in silicon-vacancy defects (Figure 4). The spectra strongly resembled those of violet-grey CVD synthetic diamonds from Orion (PDC) in Hong Kong (Peretti et al., 2013), and also the melee-sized yellow CVD sample recently described by one of the authors (Hainschwang, 2014). Unfortunately the manufacturer of the latter sample is unknown, although the parcel was supplied from Hong Kong, which may point toward the same company mentioned above. The orange/pink/purple luminescence of the sample clearly originates from the NV^0 centre with its zero-phonon line at 575.1 nm, while a green component observed under 405 nm laser excitation originates from the 467.7 nm centre

(Figures 3 and 4). Besides the Si centre—which also can be detected in some HPHT-grown synthetic diamonds (D'Haenens-Johansson et al., 2015) and very rarely in natural type IIa stones (Breeding and Wang, 2008)—the 467.7 nm centre is a characteristic defect in untreated CVD synthetic diamond (Martineau et al., 2004).

In addition to the NV-centre emissions, a large number of very sharp and typically rather weak peaks are evident in the PL spectra, all of which appear to be characteristic of CVD synthetic diamond, and which are—in the experience of the authors—unknown in natural diamond.

Conclusions

This 1.6-mm-diameter sample is the first confirmed melee-sized colourless CVD synthetic diamond discovered by a laboratory in a parcel of natural diamonds submitted by a client for testing and described in a scientific publication. Such CVD synthetics can be identified based on their luminescence under intense UV excitation and their PL spectra.

In the millions of melee-sized diamonds screened by the authors, no other near-colourless synthetic diamonds have been found until now, and therefore the CVD sample described here has the same 'exotic' status as the yellow CVD synthetic diamond discovered in a melee parcel in the latter part of 2014 (Hainschwang, 2014). Until such cases occur repeatedly and in higher percentages than 0.016% (one sample in 6,000), there is no reason to believe that melee-sized colourless CVD synthetic diamonds are currently a major problem in the market.

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The 'Coffee-and-Cream' Effect in Chatoyant Cabochons

Harold Killingback

This article explores the cause of the so-called 'coffee-and-cream' or 'milk-and-honey' effect in chatoyant cabochons. This secondary phenomenon, observed in some cat's-eye gems under oblique lighting, is seen as light and dark halves of the stone located on either side of the bright chatoyant 'eye'. The half nearer to the light source appears dark, while the further side is suffused with a creamy brightness. It is demonstrated that the creaminess is caused by reflections from fibres deeper in the stone than those that cause the 'eye', and that it is impossible for such reflections to reach the observer from the side of the stone that is closer to the light source.

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Introduction

Chatoyant gems contain microscopic parallel-oriented fibrous structures or inclusions that scatter light and produce a cat's-eye effect. The 'eye' is oriented perpendicular to the elongation of these features, and may be seen as a series of bright bands reflecting from appropriately oriented inclusion domains (as in tiger's-eye) or as a single bright band in cabochons when viewed under a point light source (as in alexandrite, apatite, etc.). Cat's-eye chrysoberyl and sillimanite (fibrolite) are particularly prized for their sharp 'eyes', especially when such cabochons also show high transparency. In addition to the cat's-eye appearance in such stones, there is also a secondary effect seen with oblique lighting in cabochons of sufficient transparency: the side nearer to the light source is dark while the further side appears bright and creamy. This is referred to variously as the 'coffee-and-cream' or 'milk-and-honey' effect.

The scattering of light by micron-sized fibres has been described by Birkhoff et al. (1977). The physics of this scattering is complicated, and in the present article such an effect will be simply described as *reflection*. Wüthrich and Weibel (1981) and others have described the manifestation of this phenomenon in chatoyancy and asterism. Yokoi et al. (1986) used an algorithm to model these effects in cabochons. While these studies concentrated on the bright line(s) of the cat's-eye or star, the author is not aware of any explanations in the literature for the coffee-and-cream effect in chatoyant cabochons.

The Coffee-and-Cream Effect

Figure 1 shows four examples of cat's-eye stones, consisting of two chrysoberyls (left) and two sillimanites (right). Figure 2 is a close-up view of one of the sillimanite cabochons, which was lit by a fibre-optic lamp pointing downward from 15° left of vertical. The stone is viewed from directly overhead, and four aspects of the light reflected from it may be noted: 'a' is the bright spot of light to the left of centre; 'b' is the bright vertical arc

Figure 1: These chatoyant cabochons show the coffee-and-cream effect. With the light source located slightly left of vertical, they appear mostly dark on the left side of the 'eye' and show a bright creaminess on the right side. The chrysoberyls on the left weigh 6.76 and 1.05 ct, and the sillimanites on the right are 2.18 and 4.67 ct. Photo by H. Killingback.

to the right of centre (the 'eye'); 'c' is another, but fainter, spot of light further to the right; and 'd' is a general area of creaminess to the right side of effect 'b'. Aspect 'a' is the reflection of the light source from the top surface of the stone; 'c' is the same but from the back surface (not seen in stones that are more opaque or do not have a reflective back); and 'b' is the reflection from shallow parallel fibres oriented parallel to the back of the stone and running horizontally in the photo. This is the cat's-eye effect. But what causes the creaminess shown by 'd'?

Light Paths Through a Chatoyant Cabochon

In this article, the author uses ray-tracing diagrams to demonstrate these four light reflection effects. The diagrams are schematic only, but are based on the sillimanite cat's-eye shown in Figure 2. In particular, the light comes from a direction 15° left of vertical, and an RI value of 1.665 is used for modelling refraction. This number is similar to the RI values for sillimanite (1.658 and 1.675). The RI of the cabochon in Figure 2 (checked by using the remote-vision 'spot' technique) was found to be compatible with the 1.665 value.

Figure 3 shows a cross section, representing the dome of a cabochon, taken on the vertical plane of the minor axis and parallel to the horizontally oriented fibrous inclusions or structure (hereafter termed *fibres*), one of which is indicated by the short black line. One incident ray in the illuminating beam is shown (red line); it meets the stone at a point where the normal to the surface is oriented θ degrees to the right of the vertical axis. In the drawing, θ is +5°. The angle of incidence, i, at this point is therefore θ + 15° = 20°. With the RI of 1.665, the angle of

Figure 2: The 2.18 ct cat's-eye sillimanite is shown with fibre-optic illumination coming from 15° to the left of vertical, and viewed from directly above. The chatoyancy-causing fibres are oriented parallel to the base and to the shorter axis of the cabochon. Photo by H. Killingback. The labels refer to the discussion in the text.

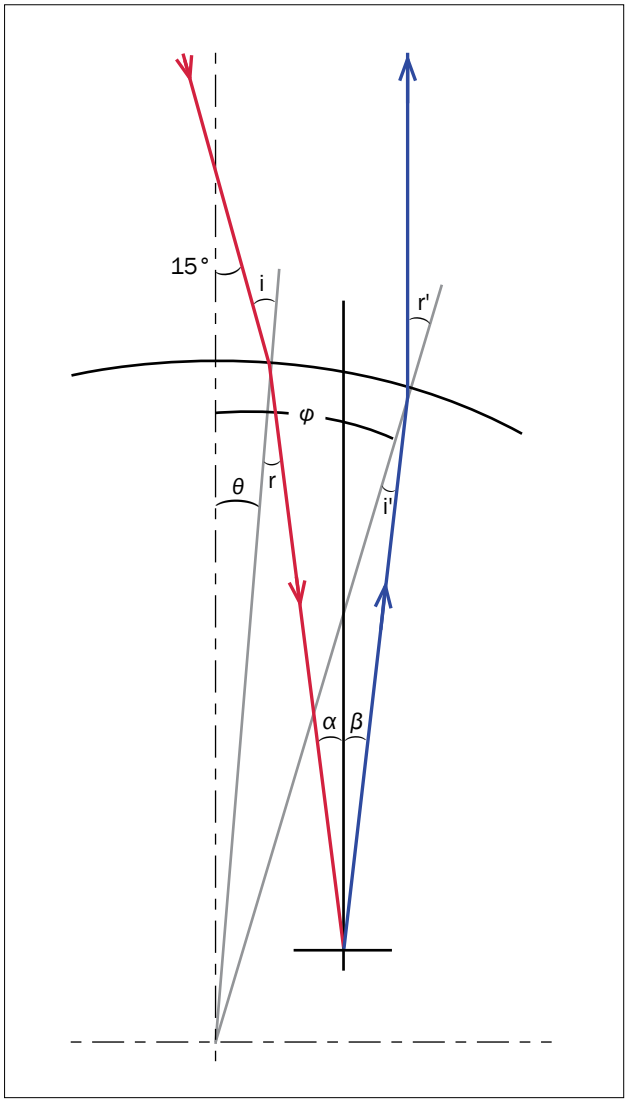

Figure 3: This schematic representation shows a vertical cross section along the minor axis of a cabochon, such as that in Figure 2. An incoming ray (red line) meets the stone at a point where the normal to the surface is θ degrees to the right of the vertical axis (here, θ = +5°). The path of this ray has been calculated to where it meets a horizontal reflecting fibre (short black line). The downward slope of this incoming ray, relative to vertical, is α; on reflection, it would slope upward at −α. Also shown is another ray (blue line) leaving the stone vertically, and so it is visible to the overhead observer. The angle of the normal to the surface at the point of emergence is φ. Tracing this ray back into the stone, it slopes upward from the fibre at angle β. The symbols i and r denote angles of incidence and refraction, respectively. If the blue ray is to join the red ray, as drawn, β must be equal to −α.

refraction, r, calculated by Snell's Law, is 11.8°. The ray in the stone is oriented at angle $\alpha = -(r - \theta) = -6.8°$ relative to vertical, the negative denoting that it slopes down to the right. It is supposed that this downward ray is then reflected by a

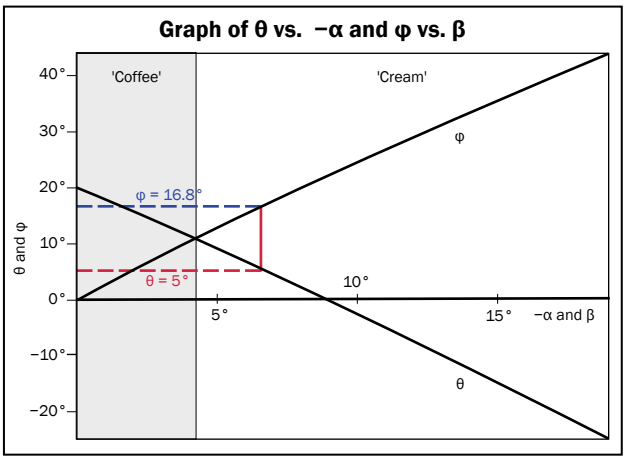

Figure 4: In this graph, θ has been plotted for various values of −α, and φ is shown for various values of β (see Figure 3 for how these angles are defined). For example, for an incoming ray of θ = 5°, the outgoing ray is φ = +16.8°, as indicated by the vertical red line. The position of the 'eye' occurs where the θ and φ angles are the same (i.e. 11°), which is where −α and β are 4.25°.

horizontal surface, whether a fibre or the back of the cabochon. Because α is measured relative to vertical, it is also the angle the ray makes with the normal to the horizontal fibre (i.e. the incident angle here). The ray is then oriented upward at +6.8° since the angle of reflection is equal to the incident angle.

Figure 3 also shows a vertical exit ray (blue line) that would be visible by an observer directly overhead. It is shown leaving the cabochon at a position where the normal to the surface is at φ degrees right of vertical. The angle of refraction as the ray leaves the stone is then also φ. Tracing the ray backwards down into the stone, the corresponding angle of incidence, i', can be calculated. The ray is oriented relative to vertical at angle β, where $\beta = \varphi - i'$. If this exit ray (blue line) is to be the continuation of the entry ray (red line), β must be equal to −α.

While Figure 3 illustrates a particular example, it can be extended for all possible values of θ and φ to show how the cream effect occurs. Calculations were made to establish α for various values of θ, and β for values of φ. Figure 4 is a graph plotting θ against −α and φ against β. As the creaminess occurs for those combinations of θ and φ where −α = β, it is convenient to plot θ and φ on a base of -α and β so that the value of φ for any value of θ can be read from the vertical ordinate for the same −α and β. For the example shown in Figure 3, where θ

Figure 5: The 2.18 ct cat's-eye sillimanite in Figure 2 is photographed here with both the camera and light source located almost directly above the axis of the cabochon. Note the brightness of the 'eye' and the lack of any coffee-and-cream effect in this orientation. Photo by H. Killingback.

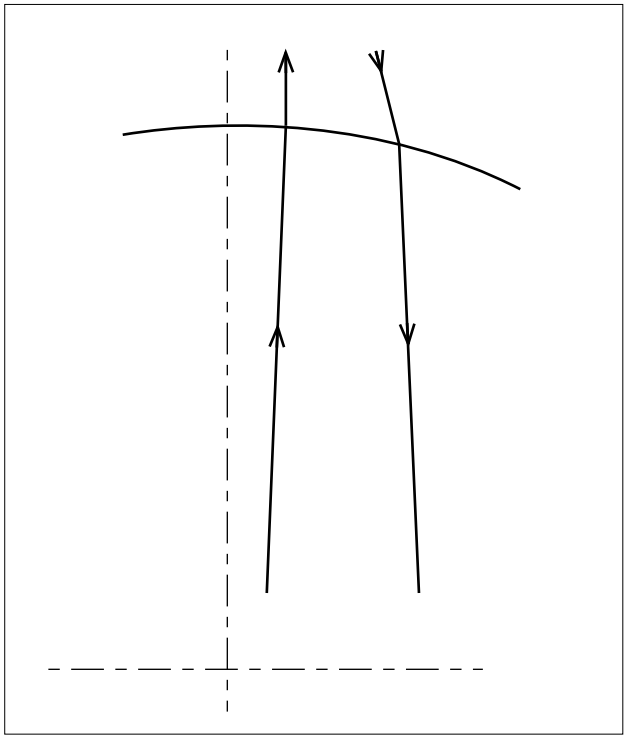

Figure 6: The downward incoming ray cannot join up with the outgoing ray in this configuration, thus showing that the part of the graph in Figure 4 where φ is less than θ represents an area where there can be no reflection reaching the observer. This leads to the conclusion that no creaminess can exist on that side of the 'eye' which is the nearer to the source of illumination.

= 5°, the outgoing ray is at φ = +16.8° (as indicated by the vertical red line).

In the graph of Figure 4, the θ line crosses the φ line where −α and β are 4.25°. At this position, θ and φ are both 11°. This is the position of the cat's-eye. Here the ray is reflected by fibres slightly below the surface. Having a minimum distance to travel within the stone, this reflection of the light source is the least attenuated, and so is the brightest. *Note that the 'eye' is just a special case of the 'cream' effect.* The creaminess gets less bright as the distance from the 'eye' increases around the stone, because the depth of the reflecting fibres increases and the ray paths through the cabochon get longer. In opaque stones, only the 'eye' may be seen. The 'eye' is particularly bright if the direction of illumination comes close to the line of sight, for then all the reflections appear at the 'eye' stripe and there is no other creaminess (e.g. Figure 5).

It was stated above that Figure 3 applies to all *possible* values of θ and φ. What about the situation where φ is less than 11°, which is the 'coffee' area? From Figure 4 it might be deduced that such a situation is possible. To test this, consider the situation where −α = β = 2½°. From the graph, θ is then about +15° and φ is about +5°. Figure 6 shows the incoming and outgoing sections of the hypothetical ray. They do not converge within the stone, but rather toward a point above the cabochon. Such a condition is allowed by the simple model used because it does not specify that the reflecting surface must be *within* the stone. When this condition is applied, the region where θ is greater than φ has no valid meaning, and φ cannot be less than 11°, the position of the 'eye'. The graph in Figure 4 relates to the specified angles of illumination and observation. For different viewpoints or lighting angles, the position of the 'eye' changes, but in all cases no reflected light can escape from the side nearer to the light source. There can be no cream in the coffee there!

Figure 7 shows different rays in the incident beam that illustrate the effects seen in Figure 2. When an incident ray meets the surface, some

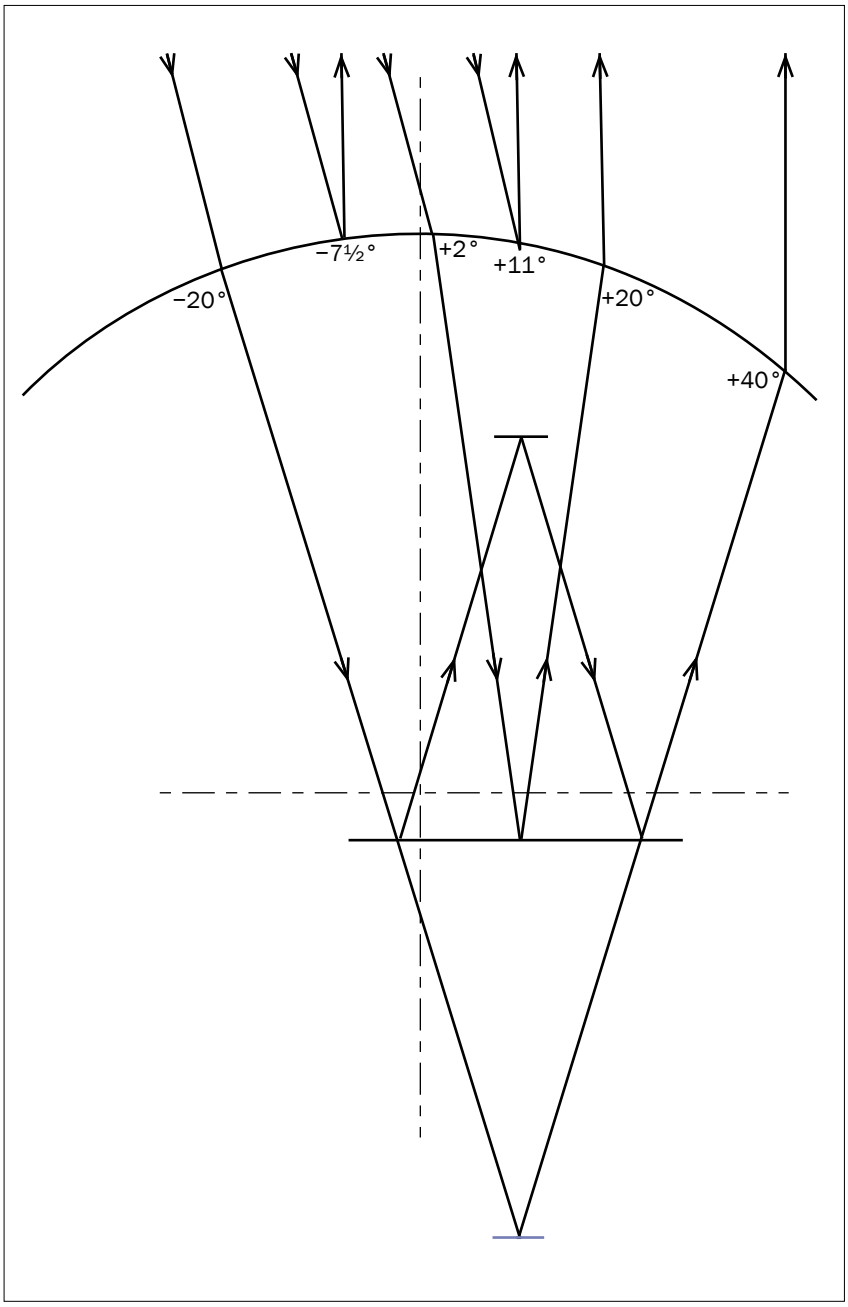

Figure 7: Four additional incident rays are shown in this schematic representation. The ray entering the cabochon at θ = −20° may contribute to the creaminess in a sufficiently transparent stone, either by reflecting from a fibre (short blue line) if the stone were deep enough, or by multiple reflections involving the back of the stone (long black line) and a fibre (short black line). Part of the incident ray approaching the surface at θ = −7½° is reflected by the surface of the cabochon, and part (not shown) enters the stone. The ray entering at θ = +2° reflects from the back of the stone. That entering at about θ = 11° is reflected by fibres near the surface. The shortness of this ray path in the stone results in this being the brightest creaminess, and forms the 'eye'. More ray paths could have been drawn entering anywhere between −20° and +11° to give further examples of the creaminess, but that in Figure 3 is typical.

will be refracted and some reflected but only that portion of relevance to this article is drawn, so as to avoid complexity. It should be emphasized that many ray orientations may contribute to the creaminess (effect 'd' in Figure 2), but some produce greater brightness, either because the ray path is short (effect 'b') or the reflecting surface is more reflective (effect 'c').

The ray entering at θ = −20° can only contribute to the creaminess if the stone is very transparent, because the ray path within the stone is so long—whether due to a single reflection from a deep fibre (short blue line) or multiple reflections involving the back surface (long black line) and a fibre (short black line) in a 'W'-shaped path.

Part of the ray approaching the surface at θ = −7½° reflects off the surface of the stone and is seen by the observer directly overhead. The incident angle is 15° − 7½° = 7½°, and since the angle of reflection is equal to the incident angle, the reflected ray is vertical and is seen by the viewer's eye (effect 'a' in Figure 2). The rest of this ray enters the stone and contributes to the creaminess in the same way as that entering at −20°, so it is not drawn in Figure 7 to avoid overcrowding the diagram. Its path length in the

stone is, however, shorter so the creaminess it can cause is brighter.

The ray entering at $\theta = +2°$ is reflected by the back surface of the stone. If this is a better reflector than the fibres, it will produce a brighter spot of creaminess (effect 'c' in Figure 2), provided the stone is transparent enough to allow such a long ray path.

The ray forming the 'eye' (effect 'b' in Figure 2) is shown entering at $\theta \approx 11°$. It penetrates just under the surface to the nearest reflecting fibre.

It may be noticed from Figures 3 and 7 that the points of upward reflection (or downward where three reflections are involved) are situated along the line-of-sight and below the 'eye'. As the line-of-sight here is vertical, the reflecting fibres are positioned vertically below the 'eye'.

Figure 8 is a chalk drawing interpolated from the upward ray paths shown in Figures 3 and 7. It was made by first projecting and interpolating onto a horizontal screen these upward rays along the minor axis of the cabochon, together with the rest of the rays producing creaminess in this plane. Reflections from the top and back of the stone are from single surfaces, and result in corresponding spots of brightness. The creaminess was then extended in both directions away from the minor axis (to represent the plan view of the entire cabochon) to account for the multitudes of fibres that are capable of reflecting spots of light to the observer. (Only fibres below the 'eye' and along the line of sight can reflect light to the observer.) These spots combine to produce the general creaminess. Because of the increased path length and attenuation within the stone, rays towards the right-hand edge become fainter. The similarity of the appearance of Figure 8 to the photograph in Figure 2 gives confidence in the model used.

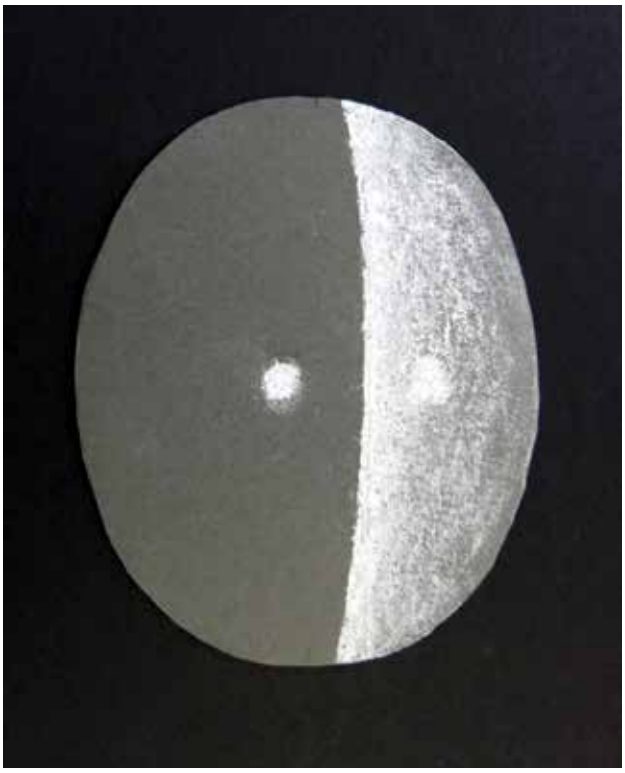

Figure 8: This chalk drawing, based on calculated ray paths, shows a plan view of the cabochon diagrammed in Figures 3 and 7. The width of the cabochon is assumed to be 80% of the diameter of the circular arc that defines its dome. This takes into account the fact that, in most cabochons, the radius of curvature of the top surface decreases sharply toward the edge. The close resemblance of this drawing to the photo in Figure 2 gives confidence in the model used.

Figure 9: This 20.14 ct cat's-eye chrysoberyl provides a fine example of the coffee-and-cream effect. Courtesy of RareSource (Chattanooga, Tennessee, USA) and Palagems .com (Fallbrook, California, USA); photo by Robert Weldon.

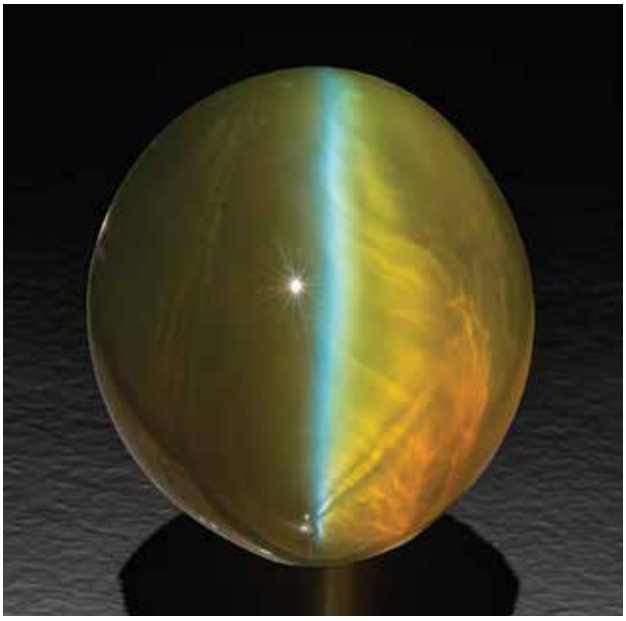

Conclusion

In chatoyant cabochons (e.g. Figure 9), the cat's-eye effect is caused by reflection from fibrous structures or inclusions close to the surface of the stone. With oblique lighting, a creamy brightness may be observed on the side of the 'eye' that is the further from the light source. A simple ray-tracing model has been used to show that the creaminess is due to reflections from fibres deeper in the

stone than those producing the 'eye', and so depends on there being sufficient transparency to allow the longer ray paths to travel through the stone. It has also been demonstrated that no such creaminess can occur on the other side of the 'eye'. The cat can only keep half an eye on the cream!

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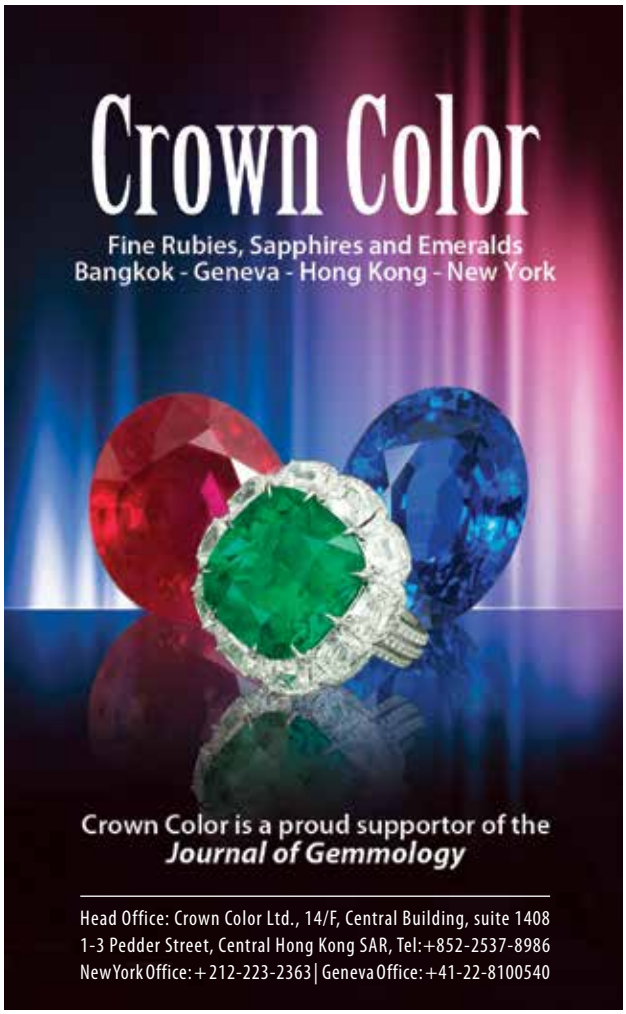

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Conferences

13th Annual Sinkankas Symposium: Opal

On 18 April 2015, this annual symposium in honour of John Sinkankas took place at the Gemological Institute of America (GIA) campus in Carlsbad, California, and was co-sponsored by the San Diego Mineral & Gem Society. The theme of this year's conference was opal, and the sold-out event was attended by approximately 180 people. As in prior years, the conference was flawlessly organized by **Roger Merk** (Merk's Jade, San Diego, California, USA).

Dr Eloïse Gaillou (Musée de Minéralogie, Mines ParisTech, Paris, France) reviewed the geology, coloration and microstructure of gem opals. Their formation involves the circulation of fluids within a silica-rich host rock, and their various body colours—including pink, blue and yellow-orange-red-brown—are all due to inclusions. **Dr George R. Rossman** (California Institute of Technology, Pasadena, USA) explained how play-of-colour in opal is produced by the constructive interference of light that is reflected from layers of silica spheres with a diameter of 250–380 nm.

Andrew Cody (Cody Opal, Melbourne, Victoria, Australia) discussed the history and characteristics of Australian opals. Large deposits were discovered in 1905 (initially of black opal at White Cliffs), and several additional mining areas came online during and after the 1960s, such as Coober Pedy, Andamooka, Lightning Ridge and Mintabie. Value factors include the type of opal; the brilliance, pattern and hues shown by the play-of-colour; transparency (particularly in white opal); thickness of the play-of-colour area; and shape of the polished stone.

Alan Hart (The Natural History Museum, London) highlighted notable opals in the collection of the Natural History Museum. Most of the ~2,300 opal specimens originate from Australia, followed by Hungary, Mexico, UK and USA. Some of the more impressive stones include a 17 ct red fire opal from Turkey, a 131 ct black opal from Lightning Ridge and a 3.4 kg piece of rough from Virgin Valley, Nevada, USA, that was acquired from Ward's in the 1920s for US$20. **Dr Raquel Alonso-Perez** (Harvard University, Cambridge, Massachusetts, USA) described the history and science of opals in the Harvard University collection. Of the 280 specimens from 28 countries, most of them are from the USA (Virgin Valley), Australia and Mexico. Her studies of those from Mexico revealed two main types: fire opal from the Jalisco-Guanajuato area (including Querétaro), and blue and pale brown opals from the Zimapán-Guerrero area.

Renée Newman (International Jewelry Publications, Los Angeles, California, USA) described various types of matrix opal. Such opal is interspersed within the rock in which it formed (rather than occurring in seams, as in typical boulder opal), and may or may not show play-of-colour; the best-known example is boulder matrix opal from Australia, which contains play-of-colour opal hosted by ironstone. **Helen Serras-Herman** (Gem Art Center, Rio Rico, Arizona, USA) reviewed 'common' opals (i.e. those showing no play-of-colour). These underappreciated opals are attractive, colourful (in blue, pink, etc.), take a good polish, may display scenic patterns and are affordable in most cases. They are typically untreated, although some lapidaries may stabilize them with Opticon.

Bill Larson (Palagems.com, Fallbrook, California, USA) provided a collector's perspective on opal. Some of his early acquisitions consisted of fine

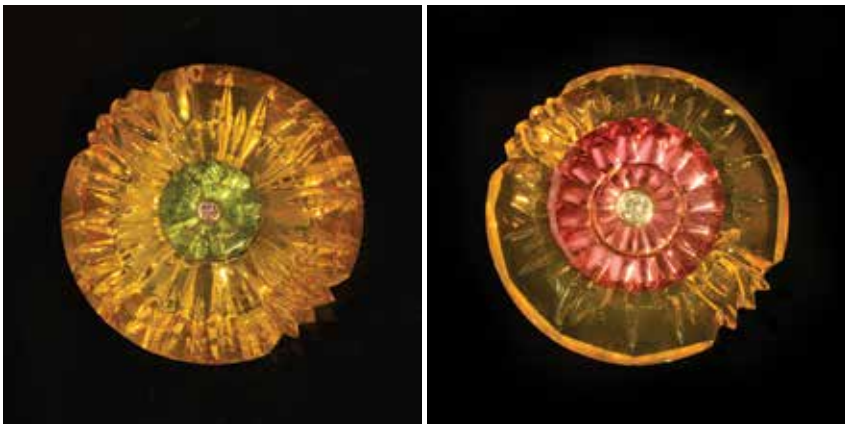

Figure 1: This interesting assemblage by gem artist Glenn Lehrer (Lehrer Designs, Larkspur, California, USA), called 'Parallel Universe', consists of a Torus-cut orange Brazilian opal (~30 ct) with peridot (2.4 ct, front side) and pink tourmaline (~10 ct, reverse side). Diamonds are set in the centre, on both sides of the piece. Courtesy of Palagems.com; photos by Mia Dixon.

Mexican fire opal showing excellent play-of-colour, which he obtained directly from the miners or from antique jewellery. These specimens have not shown any evidence of crazing, even after many years in his collection. Larson also showed some innovative cutting/carving styles for opal (e.g. Figure 1).

Meg Berry (Megagem, Fallbrook, California) provided opal lapidary tips. For carving opal, she employs a spindle equipped with tiny burrs and 240 and 600 grit abrasives. This is followed by a much longer polishing process that uses 'Zircon-Brite' (dental paste of ~50,000 grit). For faceting opal, she cold-dops the stone with superglue or epoxy; final polishing is done using 'French cerium' (cerium oxide) on a tin lap.

Robert Weldon (GIA, Carlsbad) described an innovative technique for photographing play-of-colour opal. The stone is placed in a shallow dark-coloured pan filled with water, and the camera (and lights) are positioned overhead. The immersion reduces surface reflections from the opal, allowing the play-of-colour to show up better. **Nathan Renfro** (GIA, Carlsbad) explored the micro-features of opal through photomicrography, documenting inclusions (e.g. pyrite, amphibole, barite and dendrites) and microstructures (e.g. ignimbrite-related and cellular types). **Jack Hobart** (Los Angeles, California, USA) provided a photographic exploration of Mexican *cantera* opals. These cabochons consist of play-of-colour opal in a rhyolite matrix. The opal shows variations in body colour (orange to colourless or white), structure and transparency, documented in more than 10,000 images he photographed for his database.

A conference proceedings volume is available for US$35 (plus shipping) from Roger Merk (merksjade@cox.net); it contains presentation summaries as well as outside contributions (see review on p. 553 of this issue).

Brendan M. Laurs FGA

Accredited Gemologists Association's 2015 Las Vegas Conference

This educational event took place on 28 May, one day before the start of the JCK Las Vegas Show in Nevada, USA. The conference theme was 'Synthetic Diamonds: The Products, the Perceptions, and the Retailers'. The event was attended by approximately 50 people, and chaired by **Stuart Robertson**, AGA president and vice president of GemWorld International Inc. (Glenview, Illinois, USA). **Gary Roskin** (Roskin Gem News Report, Exton, Pennsylvania, USA) was the conference moderator.

Dr Thomas Hainschwang (GGTL Laboratories, Balzers, Liechtenstein) delivered his presentation remotely (via Skype), and reported that recent developments in growth technology by both high pressure, high temperature (HPHT) and chemical vapour deposition (CVD) technologies have resulted in the production of larger and better-quality synthetic diamonds. He learned recently about the production of a 52 ct piece of HPHT-grown synthetic diamond that may be cuttable into 35 carats of faceted gems. Also, attractive gems up to 3+ ct are now cut from material grown by the CVD technique (typically HPHT treated to remove brown colour). Hainschwang indicated that HPHT-grown synthetics have been showing up in parcels of yellow to yellow-orange melee since 2011, but only recently have synthetics been found in parcels of colourless melee (with only one such example published so far; see pp. 518–522 of this issue).

Eric Franklin (D.NEA, Saline, Michigan, USA) estimated that tens of thousands of carats of synthetic diamonds are now being grown annually, but this remains a very small amount compared to the production of mined diamonds. He noted that the main market for synthetic diamonds is for bridal jewellery sold to customers in their 20s–30s who prefer conflict-free and eco-friendly products and/or appreciate the technology involved with growing synthetic diamonds. Compared to their natural counterparts, he stated, synthetics are priced 20–40% less for colourless gems (and even less for coloured synthetic diamonds).

Alex Grizenko (Lucent Diamonds, Denver, Colorado, USA) indicated that the life cycle for many of the largest diamond mines will end in the near future, while global demand for diamond will continue to increase—particularly from countries with emerging economies. This will create problems with demand, and Grizenko advocated the use of advertising to promote synthetics and make them more desirable.

Tamaz Khikhinashvili (New Diamond Technology, St Petersburg, Russia) reported that in May 2014 his company made significant developments in HPHT technology that allowed them to grow larger, higher-quality synthetic diamonds, including two that were faceted into gems weighing 5.11 ct (K colour, I_1 clarity) and 4.30 ct (D colour, SI_1 clarity). Most

recently, they produced the world's largest faceted synthetic diamond, a 10.02 ct (E colour, VS_1 clarity) square emerald-cut gem that was fashioned from a 32.26 ct piece of rough.

The formal presentations were followed by a panel discussion that included all of the conference speakers (except Dr Hainschwang), as well as **Tom Chatham** (Chatham Created Gems) and **Dr James Shigley** (GIA, Carlsbad). The conference concluded with a hands-on session in which participants were allowed to examine the 10.02 ct synthetic diamond mentioned above, and they also tested a new Presidium Synthetic Diamond Screener that debuted at the 2015 JCK Las Vegas show.

Brendan M. Laurs FGA

Mallorca GemQuest 2015

The inaugural Mallorca GemQuest Gemmological Conference was held on 18–19 April in Palma de Mallorca, Spain, at the Hotel THB El Cid. Situated on the 'Playa de Palma' beach in Can Pastilla, the conference organizers promised 'Sea, Sun, Sand & Gemmology', with a programme that featured eight speakers who delivered 11 one-hour presentations, followed by a round-table discussion. For those who could not attend in person, the conference was accessible via free online streaming and a five-day 'video on demand' access pass that was underwritten by sponsors Gem-A, *The Handbook of Gemmology*, the National Council of Jewellery Valuers, the Canadian Gemmological Association, Instituto Gemológico Español, GemDialogue and GemeWizard. In total, the conference reached more than 800 people from 31 countries through online registrations and physical attendance.

Gemmology has evolved dramatically over the years with the emergence of new treatments, enhancements and lab-created gemstones, particularly in the last 50 years. **James Riley** (Gem-A, London) discussed the history and evolution of gemmology and the equipment that is used for gem identification. **Riley** also gave a presentation on his recent visit to Mogok, Myanmar. Secluded from the world for much of the 20th century, the Mogok area is once again accessible to foreigners with the correct permits.

Alan Hodgkinson (Ayrshire, Scotland) explained and demonstrated 'visual optics', a concept he has pioneered, showing how certain gem characteristics can be assessed in a darkened room using only a light source and a pair of tweezers. While this technique cannot establish if a gem is synthetic or treated, it is very useful in helping to narrow down identification possibilities and can be used on both loose and mounted stones. In a separate presentation, **Hodgkinson** explained various techniques that enable users to maximize the efficiency of the refractometer and overcome the many obstacles that may prevent them from obtaining correct results. Unfortunately, most gemstones are not cut with the determination of RI in mind, and this often causes concern, especially for students who struggle to find the shadow edges, their positions and how they relate to one another.

Today's gem research analyst is required to have a profound knowledge of the gems and pearls tested in the laboratory and also of the instrumentation used to achieve the proper identification of these materials. Gem testing procedures are similar to a crime scene investigation, where every gem presents a new case that must be solved. The solutions for some gems are straightforward, while those for others are complicated and time consuming, and finally there are cases where no solution can be found at all. **Dr Thomas Hainschwang** (GGTL Laboratories, Balzers, Liechtenstein) provided insight into gem identification at the GGTL Laboratories, showing their ambitious instrumental development projects and some interesting examples of day-to-day challenges that are overcome using modern technology. In another presentation, **Dr Hainschwang** discussed the evolution of diamond colour treatments and the techniques used to detect them. He described the use of coatings, radioactive salts, particle accelerators and nuclear reactors (with or without annealing), HPHT treatment, and finally multi-step processing that combines HPHT, irradiation and annealing.

Gemmologist and accomplished gem cutter **Dr Egor Gavrilenko** (Instituto Gemológico Español, Madrid, Spain) was joined by award-winning faceter **Victor Tuzlukov** (Russian Faceters Guild, Moscow) to discuss factors that affect the quality of faceting of coloured gemstones, and also the considerations for producing precision-cut gems including facet design, optimization of angles and proportions based on RI, and the various stages of gem cutting. **Dr Gavrilenko** also delivered a separate presentation that explored the fascinating world of gem inclusions, explaining the various types, how they can assist in gem identification and the techniques used to capture their beauty in photographs.

Figure 2: Deep underground at Lightning Ridge, Australia, miner Fred Mallouck operates a hydraulic excavator in search of black opal. Photo by Tino Hammid.

One of the biggest challenges facing gemmologists, jewellers and appraisers is the grading of coloured gemstones. **This author** looked at the '3 Cs' (clarity, cut and carat weight), discussing the various clarity- and cut-grade classifications, the important carat weight categories and how they impact overall value. Then **Menahem Sevdermish** and **Guy Borenstein** (Gemewizard Ltd., Ramat Gan, Israel) explored the '4th C', colour, using the GemeWizard colour communication system they have pioneered. In particular, they demonstrated how this software can be used for the colour grading of coloured gemstones.

Fresh from his recent trip to Australia, **this author** also gave a presentation on the opal mines of Lightning Ridge (Figure 2), Yowah and Quilpie. The audience learned about not only how opals are formed but also the mining techniques used, the people who mine them, the obstacles they face and the complexities of grading and pricing opals.

The conference concluded with a round-table discussion on valuing and appraising coloured gemstones. Unlike diamonds, coloured gemstones present a myriad of problems because of: the lack of standardization in the industry regarding nomenclature and how they are assessed and described according to colour, clarity and cut; difficulties in finding appropriate comparison stones of similar type and quality for appraisers (especially for opal, jade and top-quality coloured stones); and properly identifying treatments and determining how they affect value. **Adolfo de Basilio, Alberto Scarani, Victor Tuzlukov, Dr Egor Gavrilenko** and **this author** joined moderator **Marian Jaén** in this spirited debate.

A three-DVD set containing all of the presentations given at the conference is available for US$17.50 (plus $10.00 flat-rate shipping) at http://handbookofgemmology.com/shop. Plans are already in the works for Mallorca GemQuest 2016.

Geoff Dominy FGA (geoff@handbookofgemmology.com)
Amazonas Publishing, Palma de Mallorca, Spain

Scottish Gemmological Association Conference

The Scottish Gemmological Association's annual conference was held in Peebles, Scotland, on 1–4 May 2015. Approximately 80 delegates attended from nine countries.

Clare Blatherwick (Bonhams, Edinburgh, Scotland) discussed the use of naturalism in the work of Fabergé, focusing on the firm's experiments in Art Nouveau, as well as animal representations in hardstone carvings and the flower studies that the firm excelled in. She also reviewed naturalistic imagery incorporated into *objets d'art* such as desk seals, caviar dishes, etc.

Dr Emmanuel Fritsch (University of Nantes and Institut des Matériaux Jean Rouxel, Nantes, France) discussed how luminescence can benefit gemmologists. He described how to make meaningful observations with a UV lamp (including knowing the lamp's power and standardizing the distance of observation), and stressed the usefulness of reference stones for both luminescence colour and intensity. In a separate presentation, in collaboration with **Aurélien Delaunay** (LFG, Paris, France) and **Dr Thomas Hainschwang** (GGTL Laboratories, Balzers, Liechtenstein), **Dr Fritsch** presented how the growth history of faceted diamonds can be elucidated with luminescence imaging equipment, especially the DiamondView. The three fundamental growth modes of diamonds are octahedral (typical of gem diamonds), fibrous and cuboid. All of these can be identified with adequate luminescence imaging. Fibrous growth can be dendritic, giving rise to fibrous pseudocubes (sometimes faceted when relatively free of inclusions). Cuboid growth is often present in gem diamonds, but rarely dominates. 'Mixed-growth' diamonds are more common than previously thought, and consist of a succession of octahedral and cuboid growth, often repeated multiple times (e.g. Figure 3). Simultaneous cuboid and octahedral growth may result in reentrant cubes or asteriated diamonds. **Dr Fritsch** also briefly described a relatively new gem material called 'Mustard Jasper', which is more correctly named

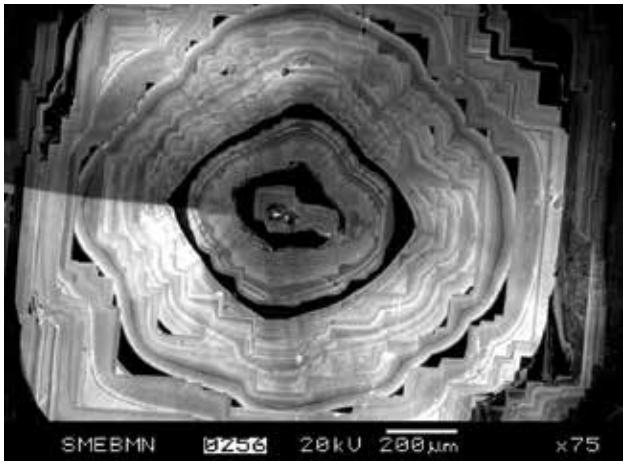

Figure 3: This cathodoluminescence image of an octahedral point of a diamond spectacularly shows the succession of octahedral (straight) and cuboid (curved) growth episodes, repeated over time. Image by Aurélien Delaunay.

'Bumble Bee Stone' because of its contrasting bright yellow, black and white colours. This decorative stone is mined from the base of a volcano in Indonesia, and has a hydrothermal origin with layers of realgar (yellow when fine-grained), pyrite (black when fine-grained) and white calcite.

Dr Keith Barron (Potentate Mining LLC, Toronto, Ontario, Canada) covered the geology, character and origin of sapphires from Rock Creek/Gem Mountain, Montana, USA. The wide array of pastel colours displayed by these sapphires has been known for more than a century, but their geological origin remains enigmatic. More than 62 tons have been recovered to date from short ephemeral drainages mostly within a 25 km^2 area, primarily through hydraulic mining during the period 1900–1930. At first the stones were mined from small-volume alluvials directly in the drainages, but over time activities migrated to the adjacent hillsides (considered perched terraces or 'benches' above the active streams). These deposits are actually mud-matrix supported colluvium produced by landslides or 'mass wasting'. In the drainages the colluvium has been reworked by the streams to produce typical alluvials. The colluvial deposits are widespread and constitute a 2–10 m thick layer of sapphire-bearing material with minimal overburden that can be efficiently mined and processed. Stone populations vary in colour and size across the property. This all suggests multiple proximal undiscovered sources. Potentate Mining LLC has consolidated the district properties and is systematically examining the area geologically and through the use of airborne geophysics, as well as constructing their second gem recovery plant. The company plans to produce 100 kg of rough sapphire in 2015, which will increase after all equipment is acquired and permits secured.

Dominic Mok (Asian Gemmological Institute and Laboratory Ltd., Hong Kong) described the classification of gem-quality jadeite (*fei cui*) into types A, B, C and B+C using FTIR, UV-Vis and Raman spectroscopy. He also outlined how to separate General Electric synthetic jadeite from its natural counterpart by means of FTIR spectroscopy and the Hanneman-Hodgkinson Jade Filter.

Stuart Robertson (Gemworld International Inc., Glenview Illinois, USA) provided an update on the supply, demand and pricing of coloured gemstones. Until ~1960, most of the coloured stones in the world market were sourced from relatively few locations, and the chief determinants of value were rarity and quality. However, during the past few decades the number of gem deposits increased dramatically, producing a broader range of varieties and qualities. Integration of these materials into the market has affected both price and the perception of value. During the past 10 years, no coloured stone has experienced as dramatic a price shift as ruby—particularly of Burmese origin. Today Mozambique is the major producer of gem-quality ruby, and since 2008 its price has doubled and then doubled again. In the sapphire market, fancy colours are perceived as most affordable. Increased interest in many of the lesser-known gem varieties is due at least in part to colour substitution: strong demand for rubellite, spinel and now garnet has benefitted from the high price of ruby. Likewise, Robertson noted a strong relationship between an increase in the price of blue sapphire and the popularity of tanzanite.

Richard Wellander (Historic Scotland, Edinburgh) described The Honours of Scotland (Scotland's crown jewels), consisting of the King's crown, made by Edinburgh Goldsmith John Mosman, and the sceptre and sword, which were gifts from the Pope in Rome. The crown contains Scottish 'river pearls' and gold from Lanarkshire, as well as various gemstones (Figure 4). Although made especially for the marriage ceremony of James V to Mary of Guise in 1540, the first time the crown was used at a monarch's inception was at the coronation of their nine-month-old daughter Mary, as Queen of Scotland in 1543.

Several workshops rounded out the conference (e.g. Figure 5). **Dominic Mok** covered jadeite testing, using a variety of samples including types A, B, C and B+C jadeite; chrome-green cat's-eye nephrite; General Electric synthetic jadeite; and various qualities of jadeite from vivid green to light green ('pea'/'bean' green); lavender, 'icy' and 'glassy' varieties; and omphacite *fei cui* that appeared deep green in transmitted light and black in reflected light. He also explained how to differentiate between various natural and synthetic diamond types, and showed participants synthetic

Figure 4: The Honours of Scotland include the King's crown, which contains Scottish 'river pearls' and various gemstones. Courtesy of the Royal Scottish Museum.

type Ib diamond crystals with metallic inclusions that were attracted by a magnet, faceted CVD synthetic diamonds and natural diamonds treated by HPHT and irradiation. Other workshops were presented by

Figure 5: Participants examine various types of jadeite in this workshop given by Dominic Mok, which took place in the famous Bannockburn room in the Peebles Hotel.

Dr Çiğdem Lule and **Stuart Robertson** (grading and valuing emeralds), **Claire Mitchell** (practical hands-on gem testing), **David Callaghan** (cameos and intaglios, and extraordinary tales behind some pieces of jewellery), and **this author** (gem identification using visual optics).

On the final day of the conference, **Richard Wellander** guided participants on a tour of The Honours of Scotland at Edinburgh Castle.

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Swiss Gemmological Society Conference

On 19–21 April 2015, the Swiss Gemmological Society held its 73rd annual conference. Approximately 82 members and guests (e.g. Figure 6) met at the Seerose Hotel in Meisterschwanden, on the shore of picturesque Lake Hallwil near Zurich. In addition to lectures about the main topics of gem treatments and early 20th century jewellery designs, presentations covered news and market reports for diamonds, coloured stones and cultured pearls. **Michael Hügi**, head of the society's scientific committee, chaired the conference.

Prof. Dr Henry A. Hänni (SSEF, Basel, Switzerland) started the conference with an overview of gem treatments and their detection. He focused on rather sophisticated treatment methods, such as Be diffusion in corundum and the detection of low-temperature heated corundum based on Raman spectroscopy of zircon inclusions. In an additional short lecture, **Prof. Hänni** covered some new types of doublets that strongly resemble natural gems. **Dr Walter Engel** (GRL Inc., Bern, Switzerland) gave insights into the fundamental laws of thermodynamics that are important for successfully heat treating corundum. Crystallization, recrystallization and diffusion processes all follow the rules of thermodynamics. Even the construction of the oven and the different heating and cooling methods require a basic knowledge of thermodynamics. **Jean-Pierre Chalain** (SSEF) presented a historical background on the identification of HPHT-treated diamonds. Collaboration between scientists from different laboratories and organizations was instrumental to providing a reliable method (based on photoluminescence spectroscopy) to detect this treatment, which was originally announced as being undetectable by the treaters. **Dr Thomas Hainschwang** (GGTL Laboratories, Balzers, Liechtenstein) reviewed the irradiation of diamond and described features that may be used to distinguish green diamonds of natural and artificially induced colour. Naturally irradiated green diamonds and those that have been treated by modern methods

Figure 6: Some of the participants of the 2015 annual conference of the Swiss Gemmological Society. Photo by M. Hügi.

(such as electron irradiation) reveal no residual radioactivity. However, diamonds that have been embedded in radium salts are commonly radioactive and may present a considerable safety hazard. **Dr Walter Balmer** (Chulalongkorn University, Bangkok, Thailand) described the heat treatment of blue zircon. Heating to ~900°C in reducing conditions can produce a blue colour, particularly for low-metamict material (i.e. 'high' zircon); such coloration is not seen in untreated zircon. Although the cause of this colour behaviour is not completely understood, UV-visible spectra show a strengthening of the U^{4+} peak after heating, but a decrease in blue colour at temperatures >1,100°C indicates that U^{4+} is not the chromophore. To study the commercial heat treatment of zircon, a traditional charcoal furnace has been constructed in Switzerland and successfully tested. To conclude the topic of gem treatments, **Dr Michael S. Krzemnicki** (SSEF) presented various recommendations (from CIBJO, AGTA and ICA) concerning treatment disclosure and gave examples of laboratory-harmonized terminology (LMHC). Disclosure and correct labelling are an ethical requirement and very important for maintaining consumer confidence. In a second talk, **Dr Krzemnicki** described items studied recently in SSEF's laboratory, such as sapphires from basaltic deposits in Nigeria, low-temperature heated rubies from Mozambique, heated red spinels from Tanzania, a hydrothermal synthetic emerald weighing 67 ct, a star spessartine from Nigeria, and the effect of chemical alteration on conch pearls.

The theme of early 20th-century jewellery designs was kicked off by **Catherine de Vincenti** (CdV Consulting, Lausanne, Switzerland), who described jewellery of the Art Nouveau period. Named after the gallery Maison de l'Art Nouveau in Paris, France, this style was inspired by natural forms and structures. Examples were shown of masterpieces by renowned artists and designers such as René Lalique, Georges Fouquet, Lucien Gaillard and others. A detailed overview of jewellery of the Art Deco period, which was popular between 1920 and about 1940, was given by **Sophie Vantieghem**, curator at the Museum of Fine Arts (Musée des Beaux-Arts) at La Chaux-de-Fonds, France. She explained the development of such jewellery designs in the context of contemporary architecture and interior trends. She also presented typical examples of Art Deco jewellery by artists such as Le Corbusier, Raymond Templier, and Alexander Calder. **Craig Lynch** (Ouellet & Lynch, Phoenix, Arizona, USA) discussed jewellery recovered from the debris field around the wreck of the famous RMS Titanic, which sank in April 1912. About 80 pieces of jewellery and watches were found, many of them from one well-preserved leather bag. While most of the jewellery and watches were strongly corroded, and the pearls partly dissolved, some of the pieces are in pristine condition. The jewellery shows a broad variety of styles, from Edwardian to Art Nouveau.

Other presentations covered a variety of gemmological topics. **Michael Hügi** (Swiss Gemmological Society) took the audience on a photomicrographic journey exploring the boundaries of inorganic and organic origin for different gem materials. The vanadium found as a chromophore of tsavorite and tanzanite was originally accumulated by microorganisms in marine sediments, and subsequent metamorphism of this organic matter resulted in the V-rich graphite that is commonly observed as inclusions in these gems (e.g. Figure 7). The inclusions in moss agate have long been considered as inorganic formations, but many of these filamentous units apparently had an organic origin based on their geometry and structure. In addition, the structure of opal showing play-of-colour is not restricted only to sedimentary processes: SEM images of colour patterns on the carapace of a tropical beetle

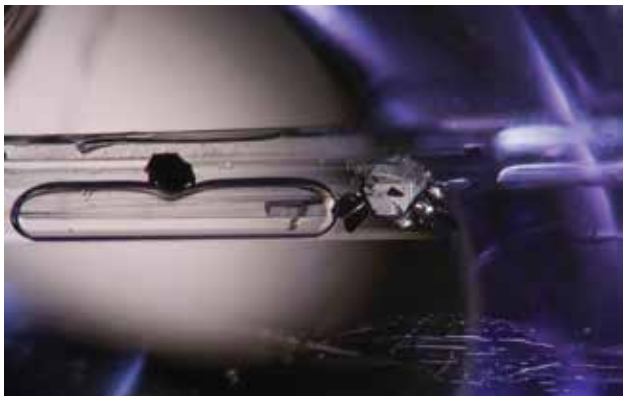

Figure 7: This fluid inclusion in tanzanite hosts a graphite crystal. The V-bearing composition of such inclusions provides evidence for their formation through the metamorphism of organic matter. Photomicrograph by M. Hügi; image width 2.5 mm.

species show exactly the same structure as those opals. **Dr Lore Kiefert** (Gübelin Gem Lab, Lucerne, Switzerland) presented a new find of black opal from the Stayish mine in Ethiopia. The black body colour is due to amorphous organic carbon. Preliminary trace-element analyses show that it is possible to distinguish between two populations of black opal based on their Ba contents: one of volcanic origin, and a second with a sedimentary formation. Some white opals of the Welo (or Wollo) deposit in Ethiopia can be coloured dark brown to black by smoke treatment in order to imitate black opal. This treatment can be detected with the microscope by observing dark spots on the surface and staining of fissures. **Carina Hanser** (University of Freiburg, Germany) presented the results of her Bachelor's thesis on blue cobalt-bearing spinel from Vietnam, carried out under the supervision of Dr M. S. Krzemnicki. Interestingly, part of the analysed blue spinels show a colour change from blue in daylight to bluish purple in incandescent light, which can be explained by the superposition of cobalt and iron absorption bands in the visible part of the absorption spectrum.

Several talks covered marketing and pricing issues. In a short presentation, **Dr Laurent Cartier** (SSEF) gave the current status of various initiatives undertaken recently in ethical sourcing for gems (and gold) by different groups or trade bodies, such as CIBJO (The World Jewellery Confederation), RJC (Responsible Jewellery Council) and UNICRI (United Nations) in collaboration with ICA. He also described how producers of synthetic diamonds address sustainability issues in marketing their products to consumers. **Gilles Walthert** (Edigem AG, Lucerne, Switzerland), provided a market report on diamond. Since mid-2014, the demand for polished colourless diamonds has slowed, resulting in price reductions for finished goods (e.g. Rapaport diamond price list) and by December 2014 also for rough diamonds. This trend was confirmed during the recent Baselworld show, although some dealers had better prices than expected. By contrast, fancy-colour diamonds have seen increasing prices during the past few years, supported by spectacular results at auction for exceptional stones. **Hans Pfister** (Luigitrade S.A., Geneva, Switzerland) gave an overview on the market situation for ruby, sapphire and emerald. Demand for these gems in areas such as China, Southeast Asia, Russia and the Middle East has decreased significantly in recent years, mainly due to political or economic reasons. Nevertheless, prices for important stones and top qualities have skyrocketed in the same period, mainly due to dwindling supplies from traditional sources, such as Myanmar for ruby and sapphire, and the temporary closure of the Muzo emerald mine in Colombia. **Antoinette Starkey** (Exclusive Personal Jewellery & Gemstones, Geneva, Switzerland) described the evolution of coloured gemstone prices in the last decade. She demonstrated that prices of some less popular gem varieties have increased dramatically during this time. The amount of increase is dependent on the hue and size of the stone. For example, the price of a 10 ct spinel of vibrant red colour has increased six-fold since 2005, while a brownish red spinel of the same size saw only a three-fold price increase during the same period. **René Lauper** (Frieden AG, Thun, Switzerland) indicated that the global cultured pearl market is now recovering after the economic crisis that began in 2008. Traditional markets in the USA and Europe show an increasing demand for commercial qualities of cultured pearls, whereas the market for top qualities is still weak in these regions. By contrast, consumers in Asian countries, and especially in China, are looking more and more for top-quality cultured pearls, resulting in a strong demand and consequently higher prices.

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Gem-A Notices

Bachelor of Science with Honours Degree in Gemmology and Jewellery Studies

The BSc (Hons) degree in Gemmology and Jewellery Studies is now being offered at Birmingham City University and as a final-year option through Gem-A in London. This programme is the culmination of three years' development work between these two organizations, and represents a leap forward in the field of gemmological education.

Already, Gem-A's Gemmology Diploma was one of the world's highest level educational qualifications in this field. Now this Diploma, together with the Gem Diamond Diploma, forms part of the requirements for entry into the final year of this BSc programme. Other requirements are that applicants are registered members of Gem-A and have suitable background to apply the advanced techniques covered within the course. The programme consists of six modules, each covering a different area of advanced testing:

- *Advanced Gemmology 1* provides a grounding in crystallography, including symmetry models and crystal lattice points. It also introduces research and presentation skills that will be required for the following modules.
- *Advanced Gemmology 2* builds on Advanced Gemmology 1, and applies the theories learnt to practical applications in real-life scenarios. This involves not only knowing how to operate the equipment (i.e. UV-Vis, FTIR and EDXRF spectrometers), but also which pieces of equipment are used for a particular task, a skill eminently relevant to laboratories today.
- *Advanced Diamonds* brings in the use of advanced testing techniques to analyse diamonds, and the defects that have an effect on the properties of the stone. Advanced use of spectroscopy, and interpretation of the collected data, ensure that the student is well-versed in many areas of diamond analysis, across a range of testing techniques (FTIR, UV-Vis and Raman spectroscopy).
- The *Valuation and Appraisal Theory* module trains students in real-life skills that can be applied in a variety of scenarios. Being able to effectively complete a valuation to an industry-recognized standard is a relevant skill that complements the students' advanced gemmological testing abilities.
- *Geology of Gemstones*, the fifth module, assesses the rock cycle within a gemmological context, and gives advanced study into the geological processes and rock formations that are involved in the formation of gem-bearing deposits.
- The final module covers the *Research Project*, and it is in this area that the students combine all that they have learnt across the various modules to formulate a hypothesis that they are then allowed to research, through existing literature, and then take it forward with the range of testing techniques available to them, before producing a final research document. This is the summation of all other modules, and allows students to demonstrate not only that they know how to use the equipment, but also how to apply it to the furtherance of gemmological knowledge.

The course is assessed on an ongoing basis, with written and practical examinations, course work and presentations all playing a part in the final grading for each module. Upon successful completion of this course, students are awarded a BSc (Hons) qualification.

For further information and details of how to apply for this course, visit www.gem-a.com/education/bsc-in-gemmology-and-jewellery-studies.aspx or contact Miranda Wells at Miranda.Wells@bcu.ac.uk.

Gem-A
THE GEMMOLOGICAL ASSOCIATION OF GREAT BRITAIN

BIRMINGHAM CITY University

GIFTS TO THE ASSOCIATION

The Association is most grateful to the following for their gifts for research and teaching purposes:

Gems in Gems, Seville, Spain, for a cabochon of chrysocolla chalcedony (see page 472).

Melanie Mednuik FGA DGA, Feering, Essex, for faceted quartz and paste, a kyanite cabochon and a 'rainforest' jasper' bead.

Antonio Silva, London, for eight faceted samples of andalusite.

OBITUARY

Catriona Orr McInnes

1938–2015

Catriona McInnes MBE MA FGA was gentle and quiet with a wry sense of humour but also had a stubborn and determined streak when needed.

Catriona grew up in Ayrshire in close contact with her extended family. Her Grandpa Orr was a jeweller, watchmaker and optician, and had a shop in Saltcoats. Catriona's brother Alan was born in 1943 and they enjoyed a close relationship. She also had a very close relationship with her cousins, who lived nearby. Catriona attained the accolade of Dux of the school at Ardrossan Academy, before attending Glasgow University where she graduated with an MA degree in Politics and Economics in 1960. She went on to teacher training school before starting her first job as a secondary school teacher of mathematics in Airdrie.

She joined the Glasgow Geological Society and took a keen interest in geology, eventually going back to University in 1976 to pursue a degree in this subject. That year, on a field trip to Loch Lomondside, she met this author (trip leader); a friendship developed and romance then blossomed. We were married in 1977.

We moved to Edinburgh from Glasgow in 1977, where I had accepted a post with the Institute of Geological Sciences (later to become the British Geological Survey). Holidays were spent self-catering in Mull and Skye, where eventually our children were introduced to mineral collecting and searching for gemstones. (Our collecting trips initially started in the late 1960s at Leadhills, famous for its lead deposits, and over the years we visited many classic localities as described by M. F. Heddle's *The Mineralogy of Scotland*.) We amassed a large collection of Scottish material over some 40 years. The children 'fondly' remember hours of digging in quarries in the horizontal rain, looking for what they called 'rubble' and learning survival techniques in the process, such as lighting fires in caves to get out of the cold and rain! Even the dog gave up.

At Boroughmuir School in Edinburgh, Catriona was given the job of computer teacher when the post became vacant following a colleague's illness. She expanded that role within the school and became involved in the development of the subject throughout Scotland. In collaboration with others, she developed the syllabus for Computer Studies, culminating in the creation and setting of a Higher examination. She also developed a teacher training course in computing at Moray House, later even taking the course herself to get the qualification. Her work was recognized with an MBE in 1997—an award she was going to refuse until I persuaded her to take it. She was asked by a journalist after the ceremony, "What did you get your MBE for?" "I've no idea," she replied. Modest to a fault!

From her early interest in geology, Catriona developed a passion and later, an expertise in gemmology, completing her Gemmology Diploma in 1997 and then teaching the subject at University. She also tutored for Gem-A. Retiring in 1998, she poured her energies into gem collecting and developing her own business, Hyaline. She learned to string beads, and had success selling her own designs and providing stringing services to the trade. We traveled internationally in pursuit of gemstones, often accompanied by Catriona's brother Alan, panning for sapphires in Montana and Australia and gem collecting all over the world, even avoiding mountain lions in Colorado!

With the help of friends, Catriona resurrected the Scottish Branch of the Gemmological Association and took over organization of the annual conference in 1999. The Scottish Gemmological Association was subsequently formed in 2008, and Catriona became

Secretary. Working with others, Catriona helped to establish the SGA Annual Conference as the 'friendliest' gemmological conference in the world. Catriona was meticulous in the organization of conference; it took up much of her life. She wrote her own computerized hotel booking and billing system, and she developed long-term friendships with gemmologists all over the world.

Catriona loved the natural world and got enormous pleasure from the animals, birds, rocks and scenery of Scotland. She was very proud to be Scottish and never lived anywhere else. We have always been interested in birdwatching, and this hobby also developed into a passionate pursuit, taking us all over the world, culminating in a two-week trip to the Brazilian rainforest in 2000.

Catriona was diagnosed with a serious lung condition in 2013. Despite that, her positive attitude shone through and she always approached life looking on the bright side, a smile and sense of fun never far away. She was so well balanced, serene in her nature and above all, very loving to all her family with a sense of humour steeped in observation of life's absurdities.

Catriona will be missed terribly, but her life and our memories of her will be cherished by us all and will remain forever. In addition to myself (her soulmate), Catriona is survived by her children Andrew, Dougal, Eric and Barbara, and her grandchildren Hannah, Ross, Molly, Oscar, Lorcan, Mari and Lucy, with whom she shared much love and laughter. We may have lost our most precious gem, but there is no doubt that Catriona's luminescence and adamantine lustre will continue to light our lives throughout the years ahead.

John McInnes

MEMBERSHIP

At a meeting of the Council held on 13 May 2015, Jason Williams resigned as Chairman. The Council expressed their gratitude for the work he had carried out and his achievements. Jessica Cadzow-Collins was elected to the Chair. The following were elected to membership:

Fellowship and Diamond Membership (FGA DGA)

Chan Kin Chung, *San Po Kon, Hong Kong*

Fellowship (FGA)

Baduza-Sutton, Buyisa, *Birmingham, West Midlands*
Hui Hang-Chung, Marilyn, *Hong Kong*
Lancaster, Sonya, *Sutton, Surrey*
Meissirel, Mathilde, *Canterbury, Kent*
Nijzink-Brandt, Saskia, *Sydney, New South Wales, Australia*
Raguin, Odiane, *Aix-en-Provence, France*
Shaw, Stephanie, *London*
Shen Tao, *Zhuhai City, Guangdong, P.R. China*
Wong Fang, *Singapore*
Zhu Younan, *Beijing, P.R. China*

Associate Membership

Alexandris, Ioannis, *Munich, Germany*
Attie, Edgar, *Monte Carlo, Monaco*
Beckley, Stewart, *Sheffield, South Yorkshire*
Burnett, Mark, *Oslo, Norway*
Delamater, Laurel, *London*
Gozlan, Esther, *Paris, France*
Herries, Jane, *Haugh of Urr, Dumfries and Galloway*
Hoare, Michael, *Witney, Oxfordshire*
Johnston, Patricia, *St Albans, Hertfordshire*
May, Joshua, *London*
May, Steven, *London*
McQuaid, Jessica, *Leeds, West Yorkshire*
Phipps, Joanne, *Abingdon, Oxfordshire*
Sargsyan, Anna, *London*
Taylor, Chris, *Albuquerque, New Mexico, USA*
Valerio, Greg, *Chichester, West Sussex*
Waugh, Anne, *London*

Fellowship of the Gemmological Association of Australia (FGAA) to FGAA FGA

Kovacs, Katherine, *Melbourne, Victoria, Australia*
Smith, Nerrylea, *Maiden Gully, Victoria, Australia*

Corporate Membership

Fairtrade Gemstones Ltd., *London*
Fifi Bijoux Ltd., *St Albans, Hertfordshire*
The Garden Workshop, *London*
May Gems Ltd., London
The Rock Hound, *London*

At a meeting of the Council held on 24 June 2015, it was announced that Steven Collins had resigned from the Council. The following were elected to membership:

Fellowship and Diamond Membership (FGA DGA)

Beard, Thomas, *Eastbourne, East Sussex*
Tang Tiankai, *Zhe Jiang, P.R. China*

Fellowship (FGA)

Arrive, Elodie, *Annecy, France*
Attanayake, Rochana, *Pilimathalawa, Sri Lanka*
Bassil, Sophie-Marie, *Malakoff, France*
Beaumont, Elizabeth, *Montreal, Canada*
Belahlou, Fatima, *Nimes, France*
Blanchard, Alain, *Paris, France*
Boemo, Julien, *Lorraine, France*
Buldanlioglu, Gulgun, *Istanbul, Turkey*
Caplan, Candice, *Monnetier, France*

Carriere, Laurence, *Montreal, Canada*
Chang Cheng-Yi, *Taichung City, Taiwan, R.O. China*
Chen Hsiu-Man, *New Taipei City, Taiwan, R.O. China*
Chen Muyu, *Guilin, P.R. China*
Chen Qiao, *Beijing City, P.R. China*
Chen Ruoxi, *Changsha City, Hunan, P.R. China*
Chen Zhi Sang, *Beijing, P.R. China*
Chiu Ti, *New Taipei City, Taiwan, R.O. China*
Chong Yim Mui, *Tseung Kwan O, Hong Kong*
Chow Hiu Yan, *Central, Hong Kong*
Cornelius, Victoria, *London*
Craig, Deborah, *Sundbyberg, Sweden*
Dai Jun, *Kunshan City, Jiangsu Province, P.R. China*
Dai Xinru, *Wuhan City, Hubei Province, P.R. China*
De Bourgues, Ayena, *Oron-La-Ville, Switzerland*
De Zoysa Jayatilleke, Liyana Gracelyn, *Colombo, Sri Lanka*
Deijen, Stephanie, *Amsterdam, The Netherlands*
Deng Yihong, *Beijing, P.R. China*
Disner, Emilie, *Geneva, Switzerland*
Dong Yiyuan, *Beijing, P.R. China*
Duffy, Alex, *Sutton Coldfield, West Midlands*
Earl, Jeremy, *Kettering, Northamptonshire*
Emanuelli, Odile, *Ivry-sur-Seine, France*
Fan Deng, *Guilin, Guangxi, P.R. China*
Fang Liqun, *Beijing City, P.R. China*
Fauquet, Richard, *Courbevoie, France*
Fong Lap Kit, *Yuen Long, Hong Kong*
Fung Hoi Ching, *Yuen Long, Hong Kong*
Gandhi, Hemang, *Mumbai, India*
Gong Hancheng, *Wuhan City, Hubei, P.R. China*
Gong Qingxu, *Dalian City, Liaoning, P.R. China*
Gui Fu, *Guilin, Guangxi, P.R. China*
Guo Ruizhi, *Beijing, P.R. China*
Guo Yilin, *Beijing, P.R. China*
Gyde, John, *Abingdon, Oxfordshire*
Hall, Claire-Louise, *Newcastle-upon-Tyne, Tyne and Wear*
Han Jiayang, *Beijing, P.R. China*
Hao Haiyan, *Zhanjiang, Guangdong, P.R. China*
He Chin Ju, *Kaohsiung City, Taiwan, R.O. China*
Hein Naing Oo, *Yangon, Myanmar*
Hnin Wutyi Soe, *Yangon, Myanmar*
Hou Yancheng, *Wuhan, Hubei, P.R. China*
Htaik Hay Man Than, *Yangon, Myanmar*
Huang Chanyuan, *Beijing, P.R. China*
Huang I-Ping, *New Taipei City, Taiwan, R.O. China*
Huang Li-Lien, *New Taipei City, Taiwan, R.O. China*
Huang Shu, *Beijing, P.R. China*
Huang Sipei, *Ezhou, Hubei, P.R. China*
Huang Ying, *Beijing, P.R. China*
Huang Yue, *Suzhou, Jiangsu, P.R. China*
Hubley, Kathleen, *Pointe-Claire, Québec, Canada*
Hung Hoo, *Tsuen Wan, Hong Kong*
Ito, Claire, *Carlsbad, California, USA*
Jia Qiong, *Dalian City, Liaoning, P.R. China*
Jiang Dong, *Beijing, P.R. China*
Jiang Haiyan, *Shanghai, P.R. China*
Jiang Xiaowen, *Shanghai, P.R. China*
Jiang Xueqin, *Shanghai, P.R. China*
Jin Xinyu, *Beijing, P.R. China*
Katsurada, Yusuke, *Tokyo, Japan*
Korcia, Sandrine, *Marseille, France*
Lai Hsin Han, *Kaohsiung City, Taiwan, R.O. China*
Lassau, Clothilde, *Cartigny, Switzerland*
Law, Suang See, *Singapore*
Leclerc, Thibault, *Gland, Switzerland*
Li Huan, *Beijing, P.R. China*
Li Rong, *Beijing, P.R. China*
Li Shanshan, *Beijing, P.R. China*
Li Wen, *Beijing, P.R. China*
Li Yikun, *Guilin, Guangxi, P.R. China*
Li Zhechen, *Beijing, P.R. China*
Li Zhen, *Guilin, Guangxi, P.R. China*
Li Zhenjia, *Beijing, P.R. China*
Lin Moqing, *Tseung Kwan O, Hong Kong*
Lin Yu-Jie, *New Taipei City, Taiwan, R.O. China*
Liu Cheng Fang, *Kaosiung City, Taiwan, R.O. China*
Liu, Jia Hong, *Bangkok, Thailand*
Liu Kaichao, *Beijing, P.R. China*
Liu Na, *Shanghai, P.R. China*
Liu Ying, *Shanghai, P.R. China*
Liu Yingying, *Beijing, P.R. China*
Liu Yuli, *Shaoyang, Hunan, P.R. China*
Long Songyun, *Guilin, Guangxi, P.R. China*
Luan Dongqi, *Beijing, P.R. China*
Luk Ka Wa, *Wongtai Sin, Hong Kong*
Luo Jinglang, *Beijing, P.R. China*
Ma Chunao, *Beijing, P.R. China*
Ma Jing, *Beijing, P.R. China*
Mak Ka Wai, *Kowloon, Hong Kong*
May, Eric, *Verbier, Switzerland*
Meidong Zhu, *Guilin, Guangxi, P.R. China*
Meoni, Annabella, *Montreal, Quebec, Canada*
Ming Zeng, *Guilin, Guangxi, P.R. China*
Mouralian, Nicole, *Montreal, Quebec, Canada*
Nacht, Coralie, *Vich, Switzerland*
Nassi, David, *Norwalk, Connecticut, USA*
Nay Hlaing Oo, Y*angon, Myanmar*
Nayak, Asha, *Egham, Surrey*
Nian Bofeng, *Shanghai, P.R. China*
Odake, Shoko, *Tokyo, Japan*
Pan Yanmei, *Beijing, P.R. China*
Parkin, Charlotte, *Caterham, Surrey*
Peng, Mingqiang, *Guilin, Guangxi, P.R. China*
Polly, Teresa, *Knoxville, Tennessee, USA*
Porter, Grace, *Stone, Staffordshire*
Praill, Gregory, *Hockley, Essex*
Price, Amy, *South Darenth, Kent*
Qiao Lei, *Beijing, P.R. China*
Qin Qiaohong, *Guilin, Guangxi, P.R. China*
Quan Xiaoyun, *Beijing, P.R. China*
Redjem, Sihame, *Nanterre, France*
Renfro, Nathan, *Carlsbad, California, USA*
Richard, Genevieve, *Brossard, Quebec, Canada*
Roux, Zongqi, *Le Pontet, France*
Sarson, Gregory, *Toowong, Queensland, Australia*
Senior, Lauren J., *Leeds, West Yorkshire*
Shen Jiamin, *Guilin, Guangxi, P.R. China*
Shen Jingyao, *Beijing, P.R. China*
Shen Rongrong, *Beijing, P.R. China*
Shi Jiaqing, *Beijing, P.R. China*
Shi Shuang, *Beijing, P.R. China*
Shi Shupeng, *Foshan City, Guangdong, P.R. China*
Sit Mei Mei, *Central, Hong Kong*
Soonthorntantikul, Wasura, *Bangkok, Thailand*

Steffens, Hounaida, *Nanterre, France*
Su Yung Chu, *Kaohsiung City, Taiwan, R.O. China*
Su Yung-Han, *Taipei City, Taiwan, R.O. China*
Sun Ziwei, *Fuzhou City, Fujian, P.R. China*
Tan Yongting, *Beijing, P.R. China*
Thiel, Gunyasiree, *London*
Tian Xiufang, *Beijing, P.R. China*
Tint Yin Moe, *Yangon, Myanmar*
Tung Jen-Hao, *Taichung City, Taiwan, R.O. China*
Velickaite, Akvile, *London*
Wang, Dan, *Beijing, P.R. China*
Wang Guohua, *Weifang City, Shandong, P.R. China*
Wang Juan, *Shanghai, P.R. China*
Wang Kailin, *Beijing, P.R. China*
Wang Kang, *Beijing, P.R. China*
Wang Shuang, *Guilin, Guangxi, P.R. China*
Wang Sisi, *Beijing, P.R. China*
Wang Yiying, *Beijing, P.R. China*
Wang Zhilin, *Shenzhen City, Guangdong, P.R. China*
Weng Ruizhi, *Beijing, P.R. China*
Weng Yahui, *Zhengzhou City, Henan, P.R. China*
Wilkinson, Damien, *Danesfort, Co. Kilkenny, R.O. Ireland*
Williamson, Anna, *Hamilton, New Zealand*
Wong Yu Ting, *Tai Po, Hong Kong*
Wright, William, *London*
Wu Wenjie, *Foshan City, Guangdong, P.R. China*
Wu Xuxu, *Beijing, P.R. China*
Xin Wen, *Beijing, P.R. China*
Xu Huanling, *Wuhan City, Hubei, P.R. China*
Xu Lingxiao, *Beijing, P.R. China*
Xu Qinzi, *Beijing, P.R. China*
Yang Hsiao-Chu, *Taipei City, Taiwan, R.O. China*
Yang Xiao, *Beijing, P.R. China*
Yang Xue-Chang, *New Taipei City, Taiwan, R.O. China*
Yang Yang, *Guilin, Guangxi, P.R. China*
Yang Yi-En, *Taipei City, Taiwan, R.O. China*
Yang Yong, *Ningbo, P.R. China*
Yang Yuling, *Beijing, P.R. China*
Yazawa, Emiko, *Woodside, New York, USA*
Yi Nannan, *Beijing, P.R. China*
Yiying Su, *Guilin, Guangxi, P.R. China*
Yong Chenying, *Beijing, P.R. China*
Yuan Wei, *Guilin, Guangxi, P.R. China*
Zhai Mengqi, *Beijing, P.R. China*
Zhang Guifang, *Beijing, P.R. China*
Zhang Hongqing, *Beijing, P.R. China*
Zhang Lingjie, *Beijing, P.R. China*
Zhang Linqi, *Beijing, P.R. China*
Zhang Mingxi, *Chongqing City, P.R. China*
Zhang Peng, *Shanghai, P.R. China*
Zhang Sirong, *Guilin, Guangxi, P.R. China*
Zhang Ting, *Montreal, Quebec, Canada*
Zhang Xiao, *Shanghai, P.R. China*
Zhang Yiwen, *Beijing, P.R. China*
Zhao Chengcheng, *Wuhan City, Hubei, P.R. China*
Zhao Yi, *Beijing, P.R. China*
Zhao Zhiyang, *Shanghai, P.R. China*
Zhen Wang, *Guilin, Guangxi, P.R. China*
Zheng Bingyu, *Beijing, P.R. China*
Zheng Qiong, *Wenling City, Zhejiang, P.R. China*
Zhu Xiaofei, *Shanghai, P.R. China*

Diamond Membership (DGA)

Ball, Gareth, *Letterkenny, Co. Donegal, R.O. Ireland*
Boyce, Georgina Elizabeth, *London*
Bullmore, Elizabeth, *Birmingham, West Midlands,*
Chan Lap Yee, *Shueng Shui, Hong Kong*
Chan Wai Chi, *New Territories, Hong Kong*
Chan Tak Wai, *Shatin, Hong Kong*
Chan Hiu Ching, *New Territories, Hong Kong*
Cheang Chi Ioi, *Macau, P.R. China*
Chen Xiao Qin, *New Territories, Hong Kong*
Cheng Wai Ching, *Kowloon, Hong Kong*
Cheng Wai Lei, *Sai Wan, Hong Kong*
Cheung Wing Yee, *Tsing Yi, Hong Kong*
Choi Sze Man, *Kwun Tong, Hong Kong*
Fu Haitao, *Beijing, P.R. China*
Fu Xinli, *Beijing, P.R. China*
Fung Hang Shun, Jessica, *New Territories, Hong Kong*
Gogarty, Madeleine, *Wimbledon, London*
Ho Pak Ngai, *New Territories, Hong Kong*
Ketcher, Alyce, *Wellington, Somerset*
Kuang, Chuyi, *Beijing, P.R. China*
Kwong Wai Fan, *New Territories, Hong Kong*
Kwong San Fong, Cathy, *Kowloon, Hong Kong*
Lai Ka Man, *London*
Lam Pui Yu, *Ma On Shan, Hong Kong*
Lam Yin Han, *To Kwa Wan, Hong Kong*
Lau Kin Yip, *New Territories, Hong Kong*
Leicester, Keith, *St Helens, Merseyside*
Li Dongyang, *Beijing, P.R. China*
Li Hiu Ying, *Chai Wan, Hong Kong*
Li Man Wah, Irine, *Tseung Kwan O, Hong Kong*
Lo Hau Yin, *Kowloon, Hong Kong*
Marshall, Georgia, *Meopham, Kent*
McLoughlin, Emma, *Rathfarnham, R.O. Ireland*
Milo, Nathan, *London*
Molon, Valentina, *Varese, Italy*
Moorhead, Lisa, *London*
Nash-Wilson, Jake, *Bristol*
Ng Kwok Hung, *Mongkok, Hong Kong*
Niu Tianju, *London*
Rexworthy, Simon, *Market Drayton, Shropshire,*
Saban Makarim, *Taipo, Hong Kong*
Schindler, Leo Joseph Peter, *Kingston-upon-Thames, Surrey*
Shek Sze Wan, *Tuen Mun, Hong Kong*
Tam Ka Hey, *Tuen Mun, Hong Kong*
Tam Suk Han, Sara, *Ma On Shan, Hong Kong*
Ting Evon, *Tsuen Wan, Hong Kong*
Tse Lai Kwan, *Kowloon, Hong Kong*
Tso Hau Yee, Michelle, *Causeway Bay, Hong Kong*
Wang Jinghan, *Beijing, P.R. China*
Wang Yizhu, *Beijing, P.R. China*
Wong Ching Lan, Teresa, *Tuen Mun, Hong Kong*
Wong Hon Lam, Donald, *Kowloon, Hong Kong*
Wong Kay Yee, *Tseung Kwan O, Hong Kong*
Wong Kwan Wai, Alison, *Kennedy Town, Hong Kong*
Wong Kwong Mei, Ice, *Kowloon, Hong Kong*
Wong Sin Yan, *Sai Wan Ho, Hong Kong*
Wong, William, *Kowloon, Hong Kong*
Wu Weiran, *Beijing, P.R. China*
Xie Zhuohong, *Beijing, P.R. China*
Yang Dong Wen, *Kowloon, Hong Kong*
Yang Ning Ning, *Kowloon, Hong Kong*

Yiu King Ting, Eric, *Kowloon, Hong Kong*
Zhang Zhizheng, *Beijing, P.R. China*

Associate Membership

Ball, John, *Hatfield, Hertfordshire*
Chappell, Kathy, *London*
Chib, Phillip, *London*
Clark, Paul, *Penarth, Vale of Glamorgan*
Cook, Brian, *Tucson, Arizona, USA*
Milton, Monica, *Crossgates, Fife*
Rohtert, William, *Phoenix, Arizona, USA*
Sokolov, Pavel, *St Petersburg, Russia*
Wood, Courtney, *New York, New York, USA*

Fellowship of the Gemmological Association of Australia (FGAA) to FGAA FGA

Edwards, Sarah, *Perth, Western Australia, Australia*
Walker, Susan, *Elwood, Victoria, Australia*

Corporate Membership

The Ebor Jetworks, *Whitby, North Yorkshire*

Transfers

From Fellowship (FGA) to Fellowship and Diamond Membership (FGA DGA)

Cheer, Peter, *Somerton, Somerset*
Chui Chun Hin, *Shatin, Hong Kong*
Kolator, Barbara, *London*
Leung Ying, *Tsing Yi, Hong Kong*
Shaw, Stephanie, *London*
Williams, Kathryn, *Dover, Kent*

From Associate Membership to Fellowship (FGA)

Delaye, Aline, *Singapore*
Lusher, Lila, *Whangarei, Northland, New Zealand*
Miller, Mona, *Portland, Oregon, USA*
Reich, Mary, *Albuquerque, New Mexico, USA*

From Associate Membership to Diamond Membership (DGA)

Saleem, Melanie, *Manchester, Lancashire*
Spencer, Sally, *Didcot, Oxfordshire*
Vildiridi, Lilian Venetia, *Knightsbridge, London*

Annual General Meeting

The AGM previously arranged to be held on 24 June was postponed. It is now to be held on 29 July 2015 at 6:00 p.m. at The Crypt, 14 Ely Place, London EC1N 6RY. A full report will appear in the next issue of *The Journal*.

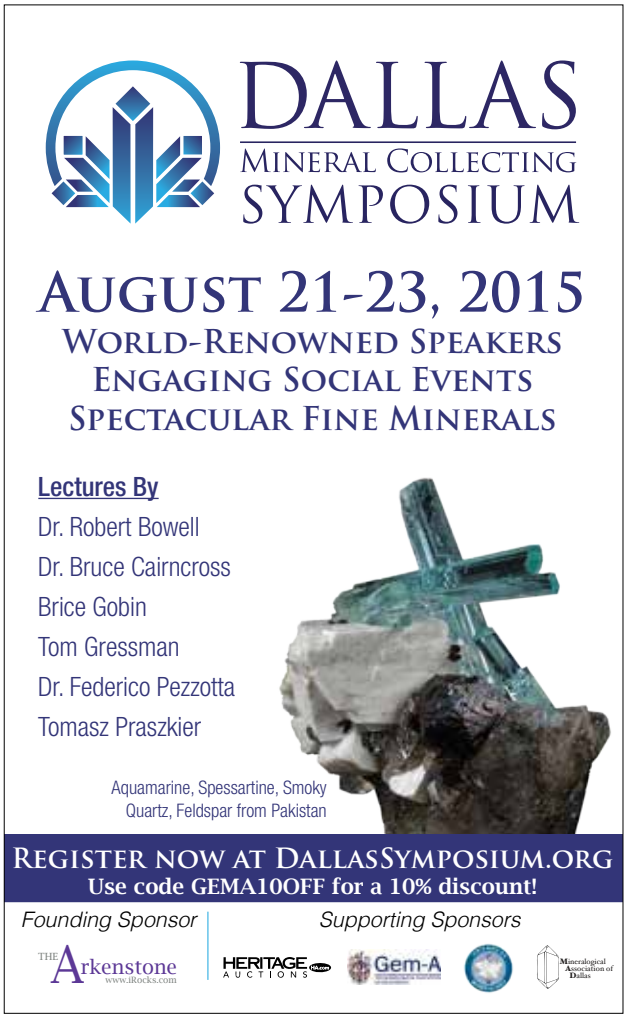

YOUR GLOBAL PARTNER

Gem Identification Report and Gemstone Memo

GIT, The utmost advanced Gem and Precious Metal Testing Laboratory in Thailand, is recognized by CIBJO (The World Jewellery Confederation) and also a member of LMHC and ICA, we are well equipped with the world's most advanced instruments operated by highly experienced gemologists.

LABORATORY SERVICES

ensuring the authenticity of your valuable gems & jewelry

The Gem and Jewelry Institute of Thailand (Public Organization)
140 ITF Tower, Silom Rd., Bangkok 10500,Thailand
TEL : +66 2634 4999 FAX : +66 2634 4970
http://www.git.or.th E-mail: jewelry@git.or.th

Learning Opportunities

CONFERENCES AND SEMINARS

NAJA 44th ACE IT Annual Mid-Year Educational Conference
8–11 August 2015
Washington DC, USA
www.najaappraisers.com/html/conferences.html

Northwest Jewelry Conference 2015
14–16 August 2015
Bellevue, Washington, USA
www.northwestjewelryconference.com

Goldschmidt2015
16–21 August 2015
Prague, Czech Republic
www.goldschmidt.info/2015
Session of Interest: Mantle-Derived Intraplate Magmas, their Xenolith and Diamond Cargo: Processes, Timescales, and Geodynamic Implications

Dallas Mineral Collecting Symposium
21–23 August 2015
Dallas, Texas, USA
www.dallassymposium.org/2015-symposium

1st International Jewelry Industry Forum
21–24 August 2015
Kuala Lumpur, Malaysia
email sumarniparamita@gmail.com

13th Society for Geology Applied to Mineral Deposits Biennial Meeting
24–27 August 2015
Nancy, France
http://sga2015.blog.univ-lorraine.fr
Session of interest: Gems and Industrial Minerals

8th Congress on Application of Raman Spectroscopy in Art and Archaeology
Wrocław, Poland
1–5 September 2015
http://raa.chem.uni.wroc.pl/program

International Jewellery London 2015
6–8 September 2015
Olympia, London, UK
www.jewellerylondon.com/Whats_On/Conferences/#
Note: Includes a programme of seminars

Compiled by Georgina Brown and Brendan Laurs

26th International Conference on Diamond and Carbon Materials
6–10 September 2015
Bad Homburg, Germany
www.diamond-conference.elsevier.com

IRV Loughborough Conference
12–14 September 2015
Loughborough, UK
www.jewelleryvaluers.org/Loughborough-Conference

1st International Emerald Symposium
Bogotá, Colombia
13–15 October 2015
www.worldemeraldsymposium.com

Canadian Gemmological Association Gem Conference 2015
16–18 October 2015
Vancouver, British Columbia, Canada
www.canadiangemmological.com/index.php/about/conference/34-conference/105-gem-conf-2015

American Society of Appraisers International Appraisers Conference
18–21 October 2015
Las Vegas, Nevada, USA
www.appraisers.org/Education/conferences/asa-conference

2015 Geological Society of America Annual Meeting
1–4 November 2015
Baltimore, Maryland, USA
www.geosociety.org/meetings/2015
Session of interest: Gemological Research in the 21st Century – Exploration, Geology, and Characterization of Diamonds and Other Gem Minerals

Gem-A Conference, hosting the 18th International Federation of European Education in Gemmology Symposium
21–22 November 2015
Royal Institute of British Architects, London
www.gem-a.com/news--events/events/gem-a-conference-2015.aspx

2015 China Gems & Jewelry Academic Conference
26 November 2015 (before the Beijing International Gem & Jewelry Fair, 27–30 November)
Beijing, China
email ngtcyjb@ngtc.gov.cn

EXHIBITS

Australia and New Zealand

A Fine Possession: Jewellery and Identity
Until 20 May 2016
Powerhouse Museum, Sydney, Australia
www.powerhousemuseum.com/exhibitions/jewellery/

Europe

Second Hand: Reused Jewellery in Baroque Monstrances
Until 10 August 2015
Dom Quartier, Salzburg, Austria
www.domquartier.at/en/veranstaltung/exhibit-second-hand-reused-jewellery-on-baroque-monstrances-cathedral-museum

#153 – Selected Pieces from the Danish Arts Foundation's Jewellery Collection
Until 16 August 2015
Design Museum Denmark, Copenhagen, Denmark
www.designmuseum.dk/en/udstillinger/153

The Art of Beauty: Jewelry Creations by Gianmaria Buccellati
Until 30 August 2015
Palace of Venaria, Turin, Italy
www.lavenaria.it/web/en/calendar/mostre/details/247-larte-della-bellezza.html

Inside the Victorian Jewellery Box
Until 6 September 2015
The Royal Pump Room Museum, Harrogate, North Yorkshire
www.visitharrogate.co.uk/things-to-do/royal-pump-room-museum-p1203181

Between Nature and Artifice—Jewellery by Daniel Kruger
Until 27 September 2015
Deutsches Goldschmiedehaus Hanau, Hanau, Germany
www.goldschmiedehaus.com/en/daniel-kruger-zwischen-natur-und-kunstlichkeit-schmuck-1974-bis-2014

Hear of Zug – Think of Jewellery. 400 Years of Gold and Silversmithing
Until 27 September 2015
Museum Burg Zug, Zug, Switzerland
www.burgzug.ch/page/en/ausstellungen/sonderausstellung

The Feel of the City—Jewellery from Centres of this World
Until 1 November 2015
Schmuckmuseum, Pforzheim, Germany
www.schmuckmuseum.de/flash/SMP_en.html

Fitting and Befitting—Fibulae and Brooches
20 November 2015–21 February 2016
Shmuckmuseum, Pforzheim, Germany
www.schmuckmuseum.de/flash/SMP_en.html

Bejewelled Treasures: The Al Thani Collection
21 November 2015–28 March 2016
Victoria and Albert Museum, London
www.vam.ac.uk/content/exhibitions/exhibition-bejewelled-treasures-the-al-thani-collection

Colourful World of Quartz Materials Around Us
Until 2016
Moravian Museum, Brno, Czech Republic
www.mzm.cz/en/dietrichstein-palace-exhibitions/colourful-world-of-quartz-materials-around-us

130 Years of Jewellery Creation in Bastia: The Filippi Workshop
Until 19 July 2016
Musée Municipal d'Art et d'Histoire, Bastia, Corsica
www.musee-bastia.com/musee-bastia/musee.php?nav=16&lang=en

Jewellery: From Decorative to Practical
On display (closing date to be determined)
Nordiska Museet, Stockholm, Sweden
www.nordiskamuseet.se/en/utstallningar/jewellery

North America

Fabergé: Jeweler to the Tsars
Until 27 September 2015
Oklahoma City Museum of Art, Oklahoma City, Oklahoma, USA
www.okcmoa.com/see/exhibitions/faberge

Generations of Mastery: Gemstone Carvings by Dreher
Until October 2015
Gemological Institute of America, Carlsbad, California, USA
www.gia.edu/gia-museum-generations-mastery-gemstone-carvings-dreher

Arthur Koby Jewelry: The Creative Eye
Until 5 October 2015
Kent State University Museum, Kent, Ohio, USA
www.kent.edu/file/arthur-koby-jewelry-creative-eyejpg

The Greeks – Agamemnon to Alexander the Great
Until 12 October 2015
Canadian Museum of History, Gatineau, Quebec, Canada
www.historymuseum.ca/thegreeks/

Beneath the Surface: Life, Death, and Gold in Ancient Panama
Until 1 November 2015
Penn Museum, Philadelphia, Pennsylvania, USA
www.penn.museum/press-releases/1163-beneath-the-surface.html

Jeweled Objects of Desire
Until 1 November 2015
Tellus Science Museum, Cartersville, Georgia, USA
http://tellusmuseum.org/galleries-more/special-exhibits/jeweled-objects-desire

Bent, Cast and Forged: The Jewelry of Harry Bertoia
Until 29 November 2015
Cranbrook Art Museum, Bloomfield Hills, Michigan, USA
www.cranbrookart.edu/museum/CAMec3.html

From the Village to Vogue: The Modernist Jewelry of Art Smith
Until 7 December 2015
Dallas Museum of Art, Dallas, Texas, USA
www.dma.org/art/exhibitions/Art-Smith

Fabergé: From a Snowflake to an Iceberg
Until 31 December 2015
Houston Museum of Natural Science, Texas, USA
www.hmns.org/index.php?option=com_content&view=article&id=594&Itemid=621

Maker and Muse: Women and Early 20th Century Art Jewelry
Until 1 January 2016
Driehaus Museum, Chicago, Illinois, USA
www.driehausmuseum.org

Glittering World: Navajo Jewelry of the Yazzie Family
Until 10 January 2016
The National Museum of the American Indian, New York, New York, USA
www.nmai.si.edu/explore/exhibitions/item/838

Turquoise, Water, Sky: The Stone and Its Meaning
Until 2 May 2016
Hillwood Museum and Gardens, Santa Fe, New Mexico, USA
www.indianartsandculture.orgcurrent?&eventID=1989

Fabergé from the Matilda Geddings Gray Foundation Collection
Until 27 November 2016
Metropolitan Museum of Art, New York, New York, USA
www.metmuseum.org/exhibitions/listings/2011/faberge

Glitterati. Portraits & Jewelry from Colonial Latin America
Until 27 November 2016
Denver Art Museum, Denver, Colorado, USA
www.denverartmuseum.org/exhibitions/glitterati

Gold and the Gods: Jewels of Ancient Nubia
Until 14 May 2017
Museum of Fine Arts, Boston, Massachusetts, USA
www.mfa.org/exhibitions/gold-and-gods

City of Silver and Gold from Tiffany to Cartier
On display (closing date to be determined)
Newark Museum, New Jersey, USA
www.newarkmuseum.org/SilverAndGold.html

Crystals Transformed Through Vision & Skill
On display (closing date to be determined)
Houston Museum of Natural Science, Houston, Texas
www.hmns.org/index.php?option=com_content&view=article&id=481&Itemid=502

Mightier than the Sword: The Allure, Beauty and Enduring Power of Beads
On display (closing date to be determined)
Yale Peabody Museum of Natural History, Yale University, New Haven, Connecticut, USA
http://peabody.yale.edu/exhibits/mightier-sword-allure-beauty-and-enduring-power-beads

OTHER EDUCATIONAL OPPORTUNITIES

Gem Central: Maggie Campbell Pedersen Talks Ivory
15 September 2015
Gem-A, London
www.gem-a.com/news--events/events/gem-central---15-september.aspx

2015 Lectures with The Society of Jewellery Historians
Burlington House, London
www.societyofjewelleryhistorians.ac.uk/current_lectures
22 September—'Golden Threads: Filigree in Islamic Jewellery' by Michael Spink
27 October—'Beauty and Belief: Techniques and Traditions of Omani Jewellery' by Aude Mongiatti and Fahmida Suleman
24 November—'Digital Tools and New Technologies in Contemporary Jewellery' by Dauvit Alexander

Gem-A Workshops and Courses
Gem-A, London
www.gem-a.com/education/course-prices-and-dates.aspx

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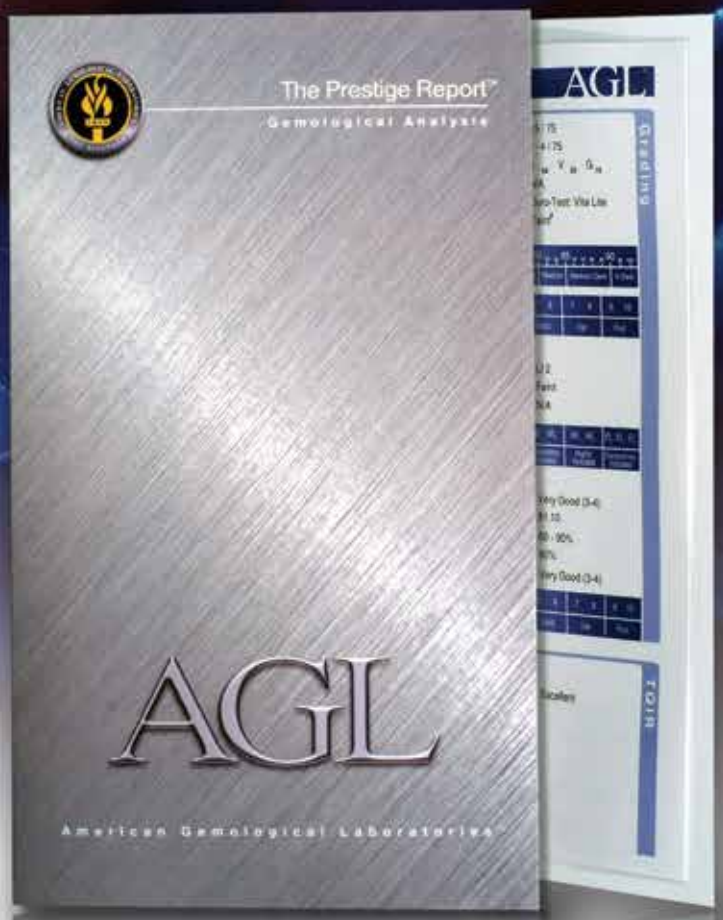

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New Media

The Handbook of Gemmology, 3rd edn.

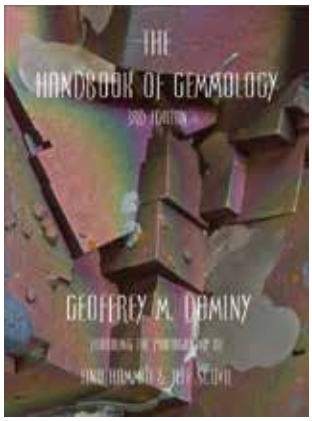

Geoffrey Dominy, 2015. Amazonas Gem Publications, 1,056 pages, illus., ebook, ISBN 978-0991888221, http://handbookofgemmology.com. US$39.95 for single-format download or $49.95 for multiple formats.

The 3rd edition of Geoffrey Dominy's *Handbook of Gemmology* continues in the trend set by the previous two editions (2013 and 2014), only in an extended and enhanced form. When it was first issued, the *Handbook* represented a ground-breaking advancement in portability compared to large and heavy gemmology reference books. The initial concept was to bring the textbook platform into the 21st century by means of portable electronic devices such as tablets and smartphones. This was very successful by way of PDFs, e-reader formats, and the use of 'flipping book' technology. This 3rd edition builds on previous successes, and takes the information to more extensive and in-depth levels. At 1,056 pages, this edition of the *Handbook* sets out to be a 'one-stop' comprehensive resource. The 32 chapters and additional sections cover the physical, chemical and optical properties of gem materials, as well as crystallography.

The 'What Is a Gemstone?' chapter covers the basics of beauty and rarity, but it also goes on to consider mineral and rock definitions, explain rock types (igneous, metamorphic and sedimentary), and introduce the concept of groups, species and varieties as applied to gems. 'The Chemical Nature of Gemstones' provides a good introduction to the world of chemistry and atomic concepts including bonding and electron orbitals. 'Physical, Chemical and Optical Properties' lays the foundation for gemmological testing, giving necessary information on hardness, structure and various optical properties exhibited by gems. 'Basic Crystallography' gives explanations of the seven crystal systems and the concepts that define them (e.g. symmetry, axes and habit). This chapter also explains the underpinnings of the physical and optical properties covered in the previous chapter.

The next several chapters cover gemmological instruments and techniques. 'The Absorption of Light and the Spectroscope' gives an explanation of light and its interaction with gem materials, and is illustrated with numerous images and photographs. Both diffraction-grating and prism-type spectroscopes are covered. In the next chapter, on the '3 Rs', Dominy covers the laws and theory behind—and the practical aspects of—reflection, refraction and the refractometer. In addition to the usual methods, several other techniques are considered. Next, 'Polarised Light and the Polariscope' explains the correct use of the polariscope, along with interpretation of the results. 'Pleochroism, the Dichroscope and Colour Filters' then examines the range of colour filters available on the market today, along with the typical dichroscope and Chelsea Colour Filter. A 'Specific Gravity' chapter covers topics ranging from the basic principles of Archimedes to heavy liquids and the Hanneman direct-reading SG balance. Dominy explains how SG is derived, and how it can be used in gem identification. Then a chapter titled 'Luminescence' explains the basics of UV fluorescence as well as its causes (e.g. crystal defects and impurities). The next chapter, titled 'Magnification and Thermal Conductivity', has a much stronger emphasis on photomicrography than on thermal conductivity. Useful instructions are included on how to turn a smartphone into a microscope, with minimal work.

The next series of chapters covers the important aspects of simulants, synthetics and treatments. 'Imitation and Assembled Stones' reviews major imitations and composites, and is a good reference for both students and qualified gemmologists alike. 'Lab-created Gemstones' provides valuable insights into not only the identification of these gems, but also the historical developments that led to the current market situation. Like some previous chapters, it encompasses numerous photographs (i.e. 52 pages). 'Gemstone Enhancements' also is extensively illustrated and describes the currently available treatments, as well as how to detect them (subject to the limitations provided by non-lab gemmological equipment).

The following chapter, 'Gem Mining', explains how valuable stones are recovered from the earth, with special attention given to Sri Lanka (various alluvial gems), Thailand/Cambodia (ruby and sapphire), Canada (diamond), Australia (opal) and Colombia (emerald). Then, 'Gem Cutting' provides general information on lapidary techniques and

diamond cutting. 'Diamond Grading' outlines the key requirements, techniques and limitations for the successful grading of diamond. Next, 'Colour Gemstone Grading' covers a topic that is becoming more important in gemmology, as several organizations are presently involved in the advancement of colour grading. The systems and properties outlined herein provide a valuable basis for considering colour as a gradable quality of a gemstone, and are backed by photographic examples. The next chapter, 'Gem Identification', will be of particular interest to students, or those starting out in gemmology, as a flow chart is provided that allows users to follow a pre-determined set of tests and, from the results, be able to identify the stone or know which test to perform next.

Chapters 20–29 are organized according to gem colour, and provide background information together with tables helpful for identifying stones of each colour. As with most texts, gemmological knowledge and correct testing methodology are prerequisites for this section, but the layout makes it easy to translate results into successful identifications. These chapters are followed by 'Identifying Phenomenal and Unusual Gemstones', which examines the identification of the more unusual stones, some of which exhibit optical phenomena. Although uncommon, the stones covered are within the range of those that may be seen by a practising gemmologist.

The next chapter, 'Natural, Cultured and Imitation Pearls' is a new addition to the *Handbook*, and covers pearl varieties and identification techniques. Then 'Advanced Gem Testing Techniques' goes beyond the tools available to the average gemmologist, and into the realm of laboratory equipment, covering such techniques as FTIR, EDXRF and Raman spectroscopy, and providing a brief insight into the workings of these instruments.

Before supplying the usual appendix of gem tables and information, the *Handbook* includes a new section titled 'Gemfacts'. For each of the more common gem varieties, a summary of information is provided ranging from coloration through treatments to history. This section alone is of infinite use to students.

In summary, *The Handbook of Gemmology* is lavishly illustrated throughout (with many photographs by Tino Hammid and Jeff Scovil), and provides a wealth of information in an 'at your fingertips' digital format, working on all platforms. This is a valuable resource for any gemmologist, at almost any level, but would be of particular use to modern students familiar with the digital age.

Andrew S. Fellows FGA DGA

Photoatlas of Gemstone Spectra for Gemmology Students

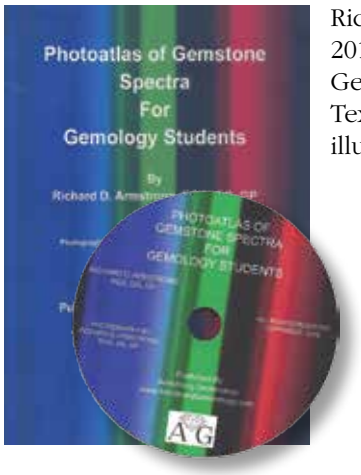

Richard D. Armstrong, 2015. Armstrong Gemmology, Flint, Texas, USA, 78 pages, illus., ebook, ISBN 978-0692298206, www.ArmstrongGemology.com. US$9.95 download or $14.95 on CD (plus p&p).

This book provides a photographic guide and reference for gemmology students, to help them use the handheld spectroscope and develop a visual memory of spectral patterns for the more common gemstones. Containing colour photos of 40 gems with their spectra, this electronic reference book comes on a CD or is available as a downloadable .zip file. The presentation is in a 'flipping book' format that is very user friendly, with turning pages accompanied by the noise of such, giving a more realistic book-like feel.

Chapter 1 covers general tips and techniques for the successful use of the spectroscope, including correct and effective lighting—and how lighting is critical to getting good results. Chapter 2 provides reference spectra for selected gems that students should obtain for initial practice. Chapter 3 covers spectra by elemental source. Chapter 4 deals with spectra for sphalerite, sugilite and glass (red and green).

Each spectrum is comprehensively discussed with good colour illustrations. Another plus is that Armstrong provides spectra taken with varying light sources, including fluorescent, LED, incandescent, halogen and sunlight, each of which may display its own emission spectrum. This helps the student to avoid any possible confusion between features related to the light source and the gem.

To enhance the spectral illustrations, labels for the wavelength endpoints 400 and 700 nm could be added to spectra for ease of reference when additional wavelengths are present. Also, it would be useful if this publication were available in a format compatible with iPad and other tablet/handheld devices.

Although not as comprehensive as the spectroscope coverage in some other gemmology handbooks (both hardcopy and electronic) and websites, this e-book provides a quick and useful reference for those students tackling hand-held spectroscopy for the first time.

Claire Mitchell FGA DGA

Thirteenth Annual Sinkankas Symposium—Opal

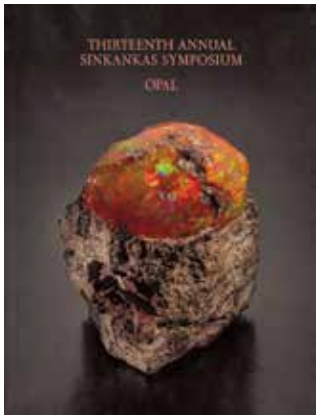

Stuart Overlin, Ed., 2015. Pala International, Fallbrook, California, USA, 121 pages, illus., softcover, ISBN 978-0692416884, email merksjade@cox.net. US$35.00.

This proceedings volume accompanied the 13th Annual Sinkankas Symposium, which was held on 18 April 2015 at the Gemological Institute of America in Carlsbad, California, and was co-sponsored by the San Diego Mineral & Gem Society. (See pp. 532–533 of this issue for a report on this conference.) The format of this volume is similar to that of previous Sinkankas Symposium volumes, with several contributions by a variety of authors, not all of whom were speakers at the symposium. Also, some of the presentations given at the conference are not covered by articles in the volume. The book begins with the symposium programme listing, followed by biographies of the speakers/authors and then abstracts of most of the presentations.

There are 11 contributions on opal in this volume: geology, colour and microstructure (Dr Eloïse Gaillou); opals in the Harvard University collection and research on common opal from Mexico (Dr Raquel Alonso-Perez); collecting opals (Bill Larson); matrix opal (Renée Newman); common opal (separate contributions by Renée Newman and Helen Serras-Herman); opal photography (Robert Weldon); microfeatures in opal (Nathan Renfro); lore (Si and Ann Frazier); a listing of literature in the Frazier opal library (Si and Ann Frazier); and a bibliography of opal localities (Dr James E. Shigley). The volume closes with several pages of attractive photos of opals from the collection of Bill Larson.

The volume is attractively laid-out and lavishly illustrated, with many full-page photos that show the diversity and colourful nature of opal. It is printed on high-quality paper and the colour reproduction is exceedingly good. The information presented is educational and informative, although it would have been nice if dimensions or weights were provided for all specimens pictured. Only one minor technical inaccuracy was noted by this reviewer (X-ray fluorescence, not diffraction, was used to determine the chemical composition of the pink opal mentioned on p. 65). This volume is highly recommended for hobbyists, collectors, gemmologists, mineralogists and anyone interested in opal.

Brendan M. Laurs FGA

The World of Tourmaline – The Gerhard Wagner Collection

Mark Mauthner (photographer), Federico Pezzotta, Daniel Trinchillo, Gerhard Wagner, Jim Walker and Mary Fong-Walker, 2015. Ivy Press, Dallas, Texas, USA, 264 pages, illus., hardcover, ISBN 978-1633510487. US$50.00.

If there ever was a book to capture the eyes and draw someone into the world of minerals this would be it, and what better crystals to do it with than tourmalines. Following a well laid-out introduction in both English and German are 379 stunning colour photographs, all printed on photo-quality paper. Through these images, this book shares with us the passion and eye of Gerhard Wagner in building this extraordinary collection. Like many collectors he was bitten by the 'rock bug' at a young age, and this book demonstrates that his passion for minerals, especially tourmaline, has remained throughout his life.

The images show a broad variety of tourmaline specimens representing colours and localities from around the world, and ranging from dramatic single crystals to specimens containing various combinations of minerals. Some of the most impressive are of near-colourless quartz with vividly coloured tourmaline, which produces a striking contrast, almost like a work of art.

This is an excellent coffee-table book that will appeal to gem and mineral collectors. In fact, anyone unaware of the beauty and hidden treasures of the mineral world cannot help but be drawn in.

Davina Dryland FGA

OTHER BOOK TITLES*

General Reference

British Silver: State Hermitage Museum Catalogue
By Marina Lopato, 2015. Yale University Press, London, 400 pages, ISBN 978-0300213201. £100.00 hardcover.

Gemstone Tumbling, Cutting, Drilling & Cabochon Making
By James Magnuson and Val Carver, 2015. Adventure Publications, Cambridge, Minnesota, USA, 128 pages, ISBN 978-1591934608. US$18.95 softcover.

Mineral Collections in Colorado
Ed. by W. E. Wilson, 2014. Mineralogical Record, Tucson, Arizona, USA, 192 pages. US$25.00 softcover.

Mineral Collections in Texas
Ed. by W. E. Wilson, 2014. Mineralogical Record, Tucson, Arizona, USA, 304 pages. US$25.00 softcover.

Jewellery and *Objets d'Art*

Les Collections de Monsieur, frère de Louis XIV: Orfèvrerie et Objets d'art des Orléans sous l'Ancien Régime
By Paul Micio, 2015. Somogy Éditions d'Art, Paris, France, 360 pages, ISBN 978-2757207802. £61.80 hardcover.

Egyptian Gold Jewellery—With a Catalogue of the Collection of Gold Objects in the Egyptian Department of the National Museum of Antiquities in Leiden
By Mariëlle Bulsink, 2015. Brepols Publishers, Turnhout, Belgium, 220 pages, ISBN 978-2503553672. £73.28 softcover.

Floral Jewels: From the World's Leading Designers
By Carol Woolton and Joel Arthur Rosenthal, 2014. Prestel, New York, New York, USA, 176 pages, ISBN 978-3791381145. US$55.00 hardcover.

Grandi Bigiottieri Italiani: Great Italian Costume Jewellers: Ornella Bijoux
By Bianca Cappello, 2015. Universitas Studiorum, Mantova, Italy, 58 pages, ISBN 978-8897683827. €9 softcover.

I Love Those Earrings: A Popular History from Ancient to Modern
By Jane Merrill with Chris Filstrup, 2014. Schiffer Publishing Ltd., Atglen, Pennsylvania, USA, 224 pages, ISBN 978-0764345166. US$59.99 hardcover.

Jewelry Metals—A Guide to Working with Common Alloys
Ed. by James Binnion, 2015. MJSA Press, Attleboro, Massachusetts, USA, 150 pages, ISBN 978-0979996221. US$34.95 softcover.

Jewels from History
By Rolf McEwan, 2015. CreateSpace Independent Publishing, 76 pages, ISBN 978-1512102048. US$9.95 softcover.

Jewels on Queen
By Anne Schofield, 2015. University of New South Wales Press, Kensington, New South Wales, Australia, 128 pages, ISBN 978-1742231433. £31.95 hardcover.

Little Dreams in Glass and Metal: Enameling in America 1920 to the Present
By Bernard N. Jazzar and Harold B. Nelson, 2015. The University of North Carolina Press, Chapel Hill, North Carolina, USA, 280 pages, ISBN 978-1469626369. US$65.00 hardcover.

Mughal Jewellery: A Sneak Peek of Jewellery Under Mughals
By Nafisa Ali Sayed, 2015. Partridge Publishing, Gurgaon, India, 108 pages, ISBN 978-1482842722. £4.51 softcover or £3.49 Kindle edition.

Petala Aurea: Gold Sheet-work of Byzantine and Lombard Origin from the Rovati Collection
By Marco Sannazaro and Caterina Giostra, 2015. Johan & Levi Editore, Monza, Italy, 240 pages, ISBN 978-8860101563. £22.00 hardcover.

Treasure Box: A Private Collection
By The KK Collection, 2015. Unicorn Press Ltd., London, 450 pages, ISBN 978-1910065181. £500.00 hardcover.

Van Cleef & Arpels: Treasures and Legends
By Vincent Meylan, 2014. Antique Collectors Club, Woodbridge, Suffolk, 344 pages, ISBN 978-1851497706. £55.00 hardcover.

Synthetics and Simulants

Handbook of Crystal Growth, Second Edition: Fundamentals
Ed. by Tatau Nishinaga, 2014. Elsevier, Amsterdam, The Netherlands, 1,214 pages, ISBN 978-0444563699. £280.00 hardcover or £252.70 Kindle edition.

DVD

AGTA GemFair Tucson Seminar DVD
2015. American Gem Trade Association, Dallas, Texas, USA. US$50.00.

* Compiled by Georgina Brown and Brendan Laurs

Literature of Interest

Coloured Stones

La coloration des gemmes par le vanadium trivalent. E. Thoreux, *Revue de Gemmologie*, **191**, 2015, 11–15.

Investigation of hidden periodic structures on SEM images of opal-like materials using FFT and IFFT. N. Stephant, B. Rondeau, J.-P. Gauthier, J. Cody and E. Fritsch, *Scanning,* **36**(5), 2014, 487–500, http://dx.doi.org/10.1002/sca.21144.*

Jadeitites and plate tectonics. G.E. Harlow, T. Tsujimori and S.S. Sorensen, *Annual Review of Earth and Planetary Sciences*, **43**, 2015, 105–138, http://dx.doi.org/10.1146/annurev-earth-060614-105215.

Mineral mysteries: Star rose quartz. J.S. White, *Rocks & Minerals*, **90**(3), 2015, 282–284, http://dx.doi.org/10.1080/00357529.2015.1012960.

Cultural Heritage

Ancient ship treasure confirms Sri Lanka as oldest sapphire source. J. Henricus, *InColor*, **27**, 2015, 34–36.

Un fabuleux saphir de 291 carats redecouvert au MNHN: le "Devonshire-Branicki". F. Farge, *Revue de Gemmologie*, **191**, 2015, 23–29.

Du Turkestan à la Birmanie: la quête du jade dans les sources chinoises, 2nd partie. L. Long, *Revue de Gemmologie*, **191**, 2015, 16–19.

Diamonds

The origin of large irregular gem-quality type II diamonds and the rarity of blue type IIb varieties. A.E. Moore, *South African Journal of Geology*, **117**(2), 2014, 219–236, http://dx.doi.org/10.2113/gssajg.117.2.219.

Visible absorption spectra of colored diamonds. J.E. Shigley and C.M. Breeding, *Gems & Gemology*, **51**(1), 2015, 41–43, http://dx.doi.org/10.5741/gems.51.1.41.*

The world of pink diamonds and identifying them. B. Deljanin and A. Peretti, *InColor*, **28**, 2015, 32–41.

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Amethyst from Boudi, Morocco. F. Troilo, A. El Harfi, S. Mouaddib, E. Bittarello and E. Costa, *Gems & Gemology*, **51**(1), 2015, 32–40, http://dx.doi.org/10.5741/gems.51.1.32.*

Blue spinel from the Luc Yen District of Vietnam. B. Chauviré, B. Rondeau, E. Fritsch, P. Ressigeac and J.-L. Devidal, *Gems & Gemology*, **51**(1), 2015, 2–17, http://dx.doi.org/10.5741/gems.51.1.2.*

Fluid inclusions in ruby from Asian marble deposits: Genetic implications. G. Giuliani, J. Dubessy, D.A. Banks, T. Lhomme and D. Ohnenstetter, *European Journal of Mineralogy*, **27**(3), 2015, 393–404, http://dx.doi.org/10.1127/ejm/2015/0027-2442.

Gem apatite localities. M. Mauthner and T. Ottaway, *Rocks & Minerals*, **90**(3), 2015, 260–269, http://dx.doi.org/10.1080/00357529.2015.1012957.

The geology and gem deposits of Sri Lanka. G. Zoysa, *InColor*, **27**, 2015, 38–41.

Mozambique: A ruby discovery for the 21st century. M. Chapin, V. Pardieu and A. Lucas, *Gems & Gemology*, **51**(1), 2015, 44–54, http://dx.doi.org/10.5741/gems.51.1.44.*

The Pederneira mine, São José da Safira, Minas Gerais, Brazil. D. Trinchillo, F. Pezzotta and A. Dini, *Mineralogical Record*, **46**(1), 2015, 1–138.

The Rock Creek sapphire mine of Montana - A new era. K.M. Barron and W.F. Boyd, *InColor*, **28**, 2015, 46–57.

Sri Lanka's gemstone cutting journey. J. Henricus, *InColor*, **27**, 2015, 58–61.

Star sapphire from Shandong Province. Y. Liu, J. Wang and Y. Wang, *Acta Petrologica et Mineralogica*, **33**(2), 2014, 85–92 (in Chinese with English abstract).

Instruments and Techniques

Application of surface contact angle and surface tension measurements in the identification of gem materials. X. Bao, T. Lu, R. Wei, Y. Zhang, H. Li, H. Chen and J. Ke, *Rock and Mineral Analysis*, **33**(5), 2014, 681–689 (in Chinese with English abstract).

Packing light: Making the most of portable gem instruments. C.L. Horn and A. Lemaire, *InColor*, **28**, 2015, 42–44.

Miscellaneous

Justifying gem testing reports: The way labs can inform their customers. O. Segura, E. Fritsch and A. Droux, *InColor*, **28**, 2015, 24–26.

Compiled by Brendan Laurs

* Article freely available for download, as of press time

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Dominican Republic seeks to improve conditions, prospects for informal larimar mining. *Fox News*, 1 April 2015, www.foxnews.com/world/2015/04/01/dominican-republic-seeks-to-improve-conditions-prospects-for-informal-larimar.*

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Note: The correct year is 2014.

Note: The correct year is 2014.

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Lab Notes. Cobaltocalcite • FTIR spectroscopy of melee diamonds • Irradiated color-change diamonds • Diamond in diamond • *Tridacna* shell in imitation pearls • Large quahog pearl • HPHT synthetic diamond melee in high-end jewelry • Large HPHT synthetic diamonds • Synthetic moissanite melee in colored diamond bracelet. *Gems & Gemology*, **51**(1), 2015, 58–67, www.gia.edu/gems-gemology.*

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ANDRIAMANITRA. The word up until recent times was used in speaking of… anything valuable or wonderful. It is said that the name was so given because while the body might not be seen, there was a fragrancy attending the name.

— Richardson, Malagasy–English Dictionary

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Morganite, Madagascar • 70.58 ct • 30 x 23 x 16 mm
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The Journal of Gemmology

2015 / Volume 34 / No. 7

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Cover Photo: This jewellery suite features red tourmaline from Nigeria that was all cut from the same piece of rough (1.20–9.07 ct; 99.19 carats total weight); see Gem Note on p. 569. Courtesy of Barker & Co., Scottsdale, Arizona; photo by Jeff Scovil.

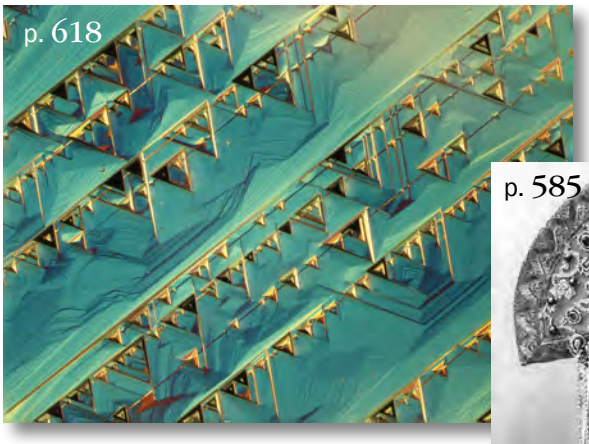

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What's New

INSTRUMENTS AND TECHNIQUES

B&W Tek GemRam Mini

In mid-2015, B&W Tek launched the GemRam Mini handheld Raman spectrometer containing a spectral library of nearly 400 gem species that was assembled by Prof. Dr Henry A. Hänni (GemExpert, Basel, Switzerland). Measuring 19 × 10 × 5 cm and weighing 0.9 kg, the instrument utilizes a touch screen interface, a 785 nm diode laser and a high-resolution spectrometer. Raman data from the instrument can be synchronized to a PC-based database via Wi-Fi or Ethernet to perform additional data analysis. It may be powered by mains electricity or a rechargeable Li-ion battery for >5 hrs of continuous operation. For more information on handheld and portable Raman spectrometers from B&W Tek, visit http://bwtek.com/technology/raman.

OGI DiaPix

In January 2015, OGI Systems launched DiaPix, a technology for capturing high-definition images of diamonds, coloured stones and jewellery. Users can produce videos showing 360° views of an object, which can be uploaded to corporate websites, social networking sites and trade platforms. The instrument weighs 5 kg and measures 46 × 46 × 31.5 cm. Visit www.ogidiapix.com.

NEWS AND PUBLICATIONS

Bursztynisko Amber Newsletter and Baltic Amber Classification

The latest issue of *Bursztynisko* (No. 37, March 2015), the annual bilingual (English/Polish) newsletter of the International Amber Association (IAA), contains articles on the history, mining, certification, and people associated with amber, as well as reports on amber collections, shows, exhibitions and conferences. It also features several short technical articles on fossilized insects and mites in Baltic, Dominican and English amber.

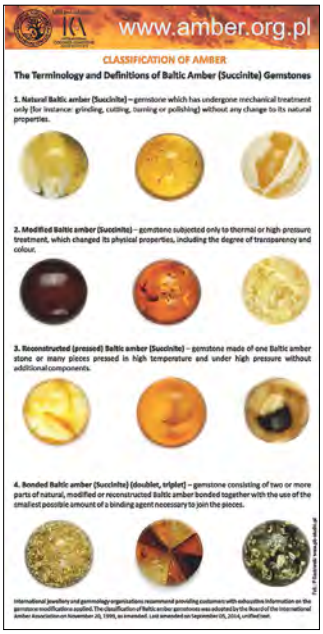

Download the issue at www.amber.org.pl/index.php/download_file/view/460.

In September 2014, the IAA updated their classification of Baltic amber, which provides definitions for Natural, Modified, Reconstructed (pressed) and Bonded (assembled) Baltic amber. Download the illustrated reference card at www.amber.org.pl/index.php/down load_file/view/452.

GTL Newsletter

The latest *Lab Information Circular* (Vol. 72, July 2015) from the Gem Testing Laboratory (Jaipur, India) is available at http://gtljaipur.info/circulars/LIC_Vol72_July2015_English.pdf. It describes resin-filled Cu-bearing tourmaline, fossilized dinosaur bone, banded serpentine, aquamarine with strong dichroism, 'neon' green synthetic sapphire, orthoclase feldspar with abundant hematite inclusions similar to those seen in 'sunstone' plagioclase, and glass with crystalline inclusions.

Gems & Gemology Cumulative PDF

In August 2015, Joseph Gill made available a single searchable PDF file containing all issues of *Gems & Gemology* from January 1934 to Summer 2015 (330 issues covering 81 years in 17,183 pages). Download the file at https://archive.org/details/GemsGemologyOrGGJan.1934Summer2015330Issues17.183Pages81YearsOfGemology.

GIT Lab Update

In July 2015, The Gem and Jewelry Institute of Thailand in Bangkok issued a Lab Update on a yellow lead-glass-filled sapphire. The 10.27 ct oval mixed cut contained fractures and cavities that were filled with lead glass that was coloured yellow by vanadium. Download the report at www.git.or.th/2014/eng/testing_center_en/lab_notes_en/glab_en/2015/07/16/Yellow_Lead-glass_filled_sapphire.pdf.

ICA Congress Presentations

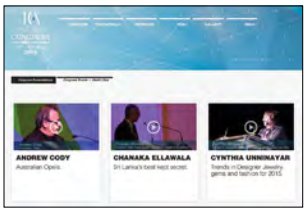

Videos of speaker presentations from the International Colored Gemstone Association Congress that took place in Colombo, Sri Lanka on 16–19 May 2015 are available at www.icacongress.com/videos/congress-presentations.html. There are 13 talks, one panel discussion, and a speech by Paolo Valentini on the history of the ICA.

Ivory Regulations Proposed by the U.S. Fish & Wildlife Service

In July 2015, the U.S. Fish & Wildlife Service proposed ivory regulations intended to curb poaching of African elephants and other species. The regulations would prohibit most U.S. interstate commerce in African elephant ivory and further restrict commercial exports, resulting in a near-total ban on the domestic commercial trade of African elephant ivory. The regulations include specific, limited exceptions for certain pre-existing manufactured items such as musical instruments, furniture pieces, and firearms that contain less than 200 grams of ivory, as well as antiques (as defined by the Endangered Species Act). For more information, visit www.fws.gov/international/pdf/african-elephant-4d-proposed-changes.pdf.

Margaritologia Pearl Newsletter No. 2/3

In June 2015, *Margaritologia* No. 2/3 was released by Elisabeth Strack of Gemmologisches Institut Hamburg, Germany. The issue features an informative 18.5 page report on freshwater

cultured pearls from China—the history of their farming (in 1962–1980, the 1980s, the 1990s and the 2000s, as well as the current situation), production methods and varieties. Details are given of recently developed grafting methods for mantle and gonad implantation using mother-of-pearl beads. The report also contains a short glossary of trade terms for Chinese bead-cultured freshwater pearls. To subscribe to the newsletter, visit www.gemmologisches-institut-hamburg.de.

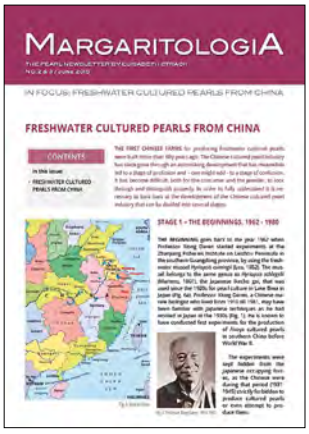

Perettiite-(Y), a New Mineral from Momeik, Myanmar

A new mineral has been discovered as an inclusion in gem-quality phenakite from Momeik, Myanmar. Perettiite-(Y) is named after Dr Adolf Peretti of GRS Gemresearch Swisslab AG. The mineral forms isolated yellow needles in gem-quality crystals of colourless phenakite that were purchased in the Mogok gem market in 2007 and 2014. Visit www.gemresearch.ch/news/2015-08-04_Perettiite/index.htm.

Rough Octahedral Synthetic Diamonds

In July 2015, HRD Antwerp announced encountering some small gem-quality near-colourless synthetic diamond crystals showing octahedral shapes, rather than the cubo-octahedral morphology that is typical of HPHT-grown synthetics. The crystals ranged from 0.01 to 0.04 ct and were produced by Taidiam Technology Co. Ltd., Zhengzhou, Henan, China. View the announcement at www.hrdantwerp.com/en/news/hrd-antwerp-in-focus-rough-octahedral-lab-grown-diamonds-ar.

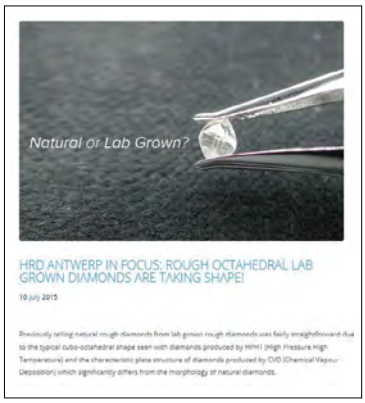

Rubies from Madagascar

In September 2015, Lotus Gemology in Bangkok released a report describing the gemmological characteristics of a new production of rubies from Andilamena, Madagascar. The gems showed properties similar to those of rubies produced in 2005 from the nearby Moramanga area, except that the new stones were larger, with faceted gems ranging from 1.04 to 7.16 ct. Visit www.lotusgemology.com/index.php/library/articles/322-blood-red-rubies-from-madagascar-lotus-gemology.

Silver Institute Publications

In March 2015, the Silver Institute released its '2014 Silver Jewelry Sales Results', which compiles the results of surveying jewellery retailers about silver sales. Download the executive summary at www.silverinstitute.org/site/wp-content/uploads/2011/06/2014SilverJewelrySalesReport.pdf.

More recently, the Silver Institute released its 'World Silver Survey 2015—A Summary', which reported that silver jewellery fabrication rose to a new record level of 215.2 million ounces in 2014, helped by lower silver prices and a strong rebound in Indian demand. Download the report at www.silverinstitute.org/site/wp-content/uploads /2011/06/WSS2015Summary.pdf.

Synthetic Ruby Overgrowth on Corundum

In June 2015, the Gemological Institute of America released a report titled 'Analysis of Synthetic Ruby Overgrowth on Corundum' by S. Saeseaw et al. The paper describes the properties of 10 samples (1.40–2.17 ct) acquired in 2014 through a Bangkok-based supplier, which reportedly consisted of rejects from experiments performed by Duros Company (known for their synthetic rubies) during the early 2000s. The starting material probably consisted of colourless sapphire from Sri Lanka, and may have been provided to Duros after initial Cr-diffusion experiments proved unsuccessful. Download the report at www.gia.edu/gia-news-research/synthetic-ruby-overgrowth-corundum-analysis.

World Diamond Conference Presentations

Reports and videos of some of the presentations at the World Diamond Conference, held 11–12 December 2014 in New Delhi, India, are available at www.gjepc.org/wdc.php. Included is an address by the Prime Minister of India.

World Gold Council Publications

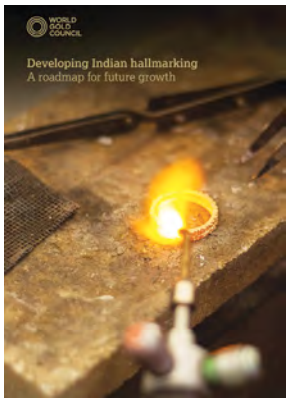

In July 2015, the World Gold Council released a report titled 'Developing Indian Hallmarking' that outlines the importance of quality assurance, assesses the current state of hallmarking in India, considers lessons learned from other countries and establishes a roadmap for the future. Download the report at www.gold.org/download/file/4025/Developing-Indian-hallmarking.pdf.

In August 2015, the World Gold Council issued its 'Gold Demand Trends Second Quarter 2015', which states that gold demand from the jewellery industry dropped 14% to a three-year low of 513.5 tons, mostly due to a downturn in consumer sentiment in India and China. Download the report at www.gold.org/download/file/4107/GDT_Q2_2015.pdf.

MISCELLANEOUS

Gem Museum in Singapore

In June 2015, the Gem Museum opened in Singapore. Founded by the directors of Far East Gem Institute, it is the first and most comprehensive gem and mineral museum in Singapore. The Museum's purpose is to educate

Photo by Huiying Loke

the public and foster an awareness of gemmology to hobbyists and collectors. Various displays focus on aspects ranging from crystals to organic gems, phenomenal stones and even imitation and synthetic gem materials. Workshops are occasionally provided, and the most popular one is the Gem Discovery Series. For more information, visit http://thegemmuseum.gallery or email contact@thegemmuseum.gallery.

Huiying Loke (huiying@gem.com.sg)
Far East Gem Institute, Singapore

What's New provides announcements of new instruments/technology, publications, online resources and more. Inclusion in What's New does not imply recommendation or endorsement by Gem-A. Entries are prepared by Brendan Laurs unless otherwise noted.

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Gem Notes

COLOURED STONES

Buchite from the Eifel Mountains, Germany

The name *buchite* is used for a glassy pyrometamorphic volcanic rock (Callegari and Pertsev, 2007). It originates from the contact of basaltic melts with sandstone, and can be regarded as a glassy sandstone. The name traces back to the famous German geologist Leopold von Buch (1774–1853). Classic occurrences are found in Germany, especially Hohen Hagen near Göttingen, Blaue Kuppe near Eschwege (type locality) and Biebergemünd in the Spessart Mountains.

Recently a faceted transparent green buchite from the Eifel Mountains in Germany was investigated. The specimen (Figure 1) is in the collection of the German Gemmological Association and weighs 0.245 ct. The RI measured with a standard gemmological refractometer was 1.510 and the hydrostatic SG was 2.40. Microscopic examination revealed two types of solid inclusions

Figure 1: This 0.245 ct faceted natural glass (buchite) from the Eifel Mountains, Germany, was investigated for this report. Photo by S. Koch, DSEF.

Figure 2: The inclusions in the buchite consisted of mullite needles (top) and dark crystals of spinel. Photomicrograph by U. Henn, magnified 45×.

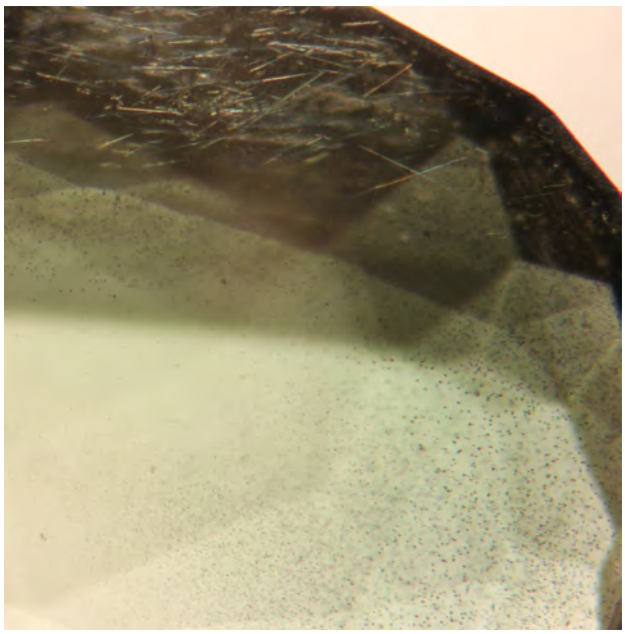

Figure 3: Tabby extinction was seen in the buchite between crossed polarizers. Photomicrograph by K. Schollenbruch, magnified 40×.

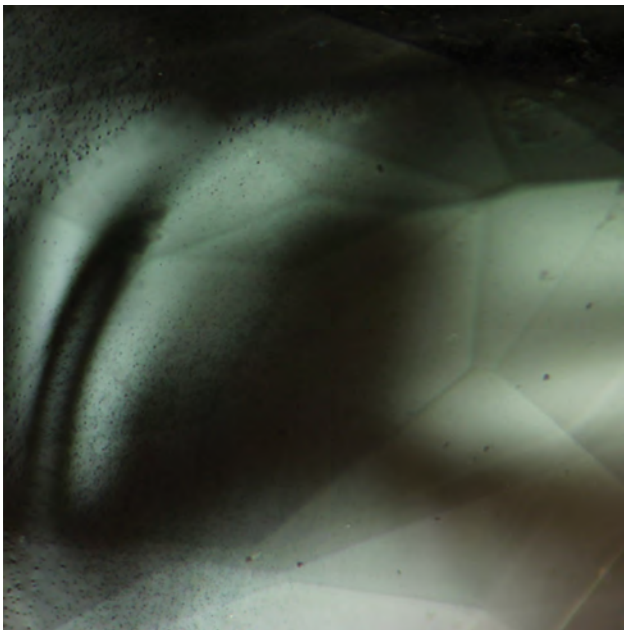

(Figure 2) and a distinct tabby extinction between crossed polarizing filters (Figure 3). The solid inclusions were identified as mullite and spinel using a Renishaw inVia Raman microscope.

The absorption spectrum measured with a Perkin Elmer Lambda 12 spectrometer was characterized by two broad absorption regions in the red and blue-violet range, with no distinct absorption maxima. Chemical analysis carried out by electron microprobe (Jeol JXA 8200 at the Institute for Geosciences, Johannes Gutenberg University of Mainz, Germany) yielded 73.47 wt.% SiO_2, 3.72 wt.% Al_2O_3, 6.68 wt.% Na_2O, 8.59 wt.% K_2O, 3.40 wt.% FeO and 0.64 wt.% MnO.

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Reference

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Colour-zoned Fluorite from Shan and Kayah States, Myanmar

Fluorite in various colours (i.e. purple, violet, green and yellow) has been known from the Mogok Stone Tract in Myanmar for years (Kammerling et al., 1994). More recently, additional localities in east-central Myanmar have produced some multi-coloured fluorite that has been polished into cabochons.

In Shan State, fluorite is known from two localities: Langhko and Pinlaung townships. It was discovered at Langhko (113 km south-east of Taunggyi) in 2012 and mined in 2013 by Shan people during a peace agreement with the Myanmar government. From ~200 rough pieces, about 1,000 cabochons have been cut and polished in mostly oval shapes (average 4 × 3 × 2 mm). Some of these cabochons were worn in rings by top officials from the Shan group. At Pinlaung (80 km south of Taunggyi), fluorite was discovered in 2014 in a banana plantation. The material has been picked up from the surface by local villagers, and no mining has taken place yet. This author obtained a rough piece from the villagers, and a portion of it was subsequently cut into a cabochon of 3.0 × 2.5 × 0.5 mm. It is hoped that good-quality fluorite will be produced from this area in the future.

In Kayah State, fluorite was found in ~2011 in Bawlake township (182 km south of Taunggyi). Only a small quantity of this material has been cut so far, in various sizes and shapes, and it is typically oiled due to the presence of fractures.

Figure 4: From left to right, the Burmese fluorite samples studied for this report were from Langhko in southern Shan State (88.0 and 24.5 ct), Bawlake in Kayah State (35.5 ct) and Pinlaung in Shan State (47.25 ct cabochon and 15.8 g piece of rough). The cabochons appear rather dark in this reflected-light photo. Photo by U T. Hlaing.

Five samples of fluorite from these localities were studied for this report: four cabochons of 24.5–88.0 ct and one rough piece weighing 15.8 g (Figure 4). Viewed with reflected light, all of the cabochons appeared dark with bands or irregular zones of lighter colour. Transmitted light most commonly showed various shades of blue, greenish blue, violet and colourless; rarely present were green or black bands (Figure 5). Energy-dispersive X-ray fluorescence spectroscopy (EDXRF) of the rough piece from Pinlaung (light and dark violet bands) using an Innov-X portable instrument revealed traces of Al, Si, Cl, S, Fe, Cr and Mn (note that the instrument was not set up to detect heavy elements such as rare earths).

Colour-banded fluorite is common from various world localities, typically dominated by violet, yellow or green bands. The fluorite from

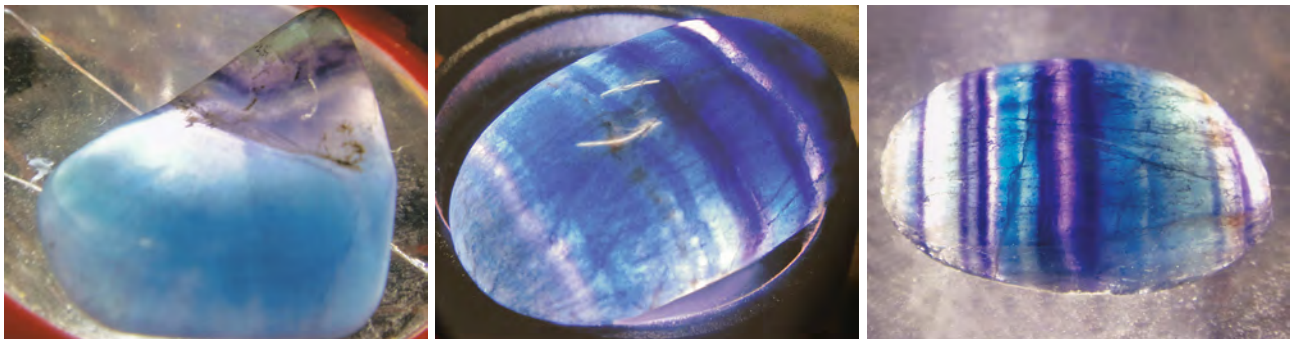

Figure 5: Seen here in transmitted light are the fluorite cabochons from Langhko, Shan State (88.0 ct on the left, and 24.5 ct in the centre) and Bawlake, Kayah State (right, 35.5 ct). Photos by U T. Hlaing.

east-central Myanmar is distinctive for its mostly blue coloration.

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Reference

Kammerling R.C., Scarratt K., Bosshart G., Jobbins E.A., Kane R.E., Gübelin E.J. and Levinson A.A., 1994. Myanmar and its gems—An update. *Journal of Gemmology*, **24**(1), 3–40, http://dx.doi.org/10.15506/jog.1994.24.1.3.

Malachite-Azurite from Peru

Malachite is a popular ornamental stone, but only rarely is it cut as a mixture with chemically similar azurite. An important exception is seen in rare bicoloured malachite-azurite cabochons from Morenci, Arizona, USA, which typically display a sharp border between the two minerals. A new occurrence of malachite-azurite was discovered in 2011 from Moquegua Department in southern Peru. The first specimens were mentioned by Hyršl (2012), but several dozen much better stones were offered for sale during the February 2014 Tucson gem shows.

The polished stones typically consist of rather large flat cabochons that measure up to ~8 cm long. The blue azurite typically forms irregular brecciated masses within the green malachite matrix. An unusual feature displayed by some specimens is a fine banding of both minerals, with regular bands of ~0.5–1 mm wide (e.g. Figure 6). Advanced testing of interstitial areas within the bands using both X-ray diffraction and Raman analysis proved them to be gypsum. In some specimens, white granular calcite is also present.

With standard gemmological testing, the material is easily recognizable by its strong carbonate birefringence blink on the refractometer. Also, the hydrostatic SG is 2.64–2.79, there is no fluorescence to UV radiation, and both malachite and azurite will effervesce when exposed to dilute hydrochloric acid.

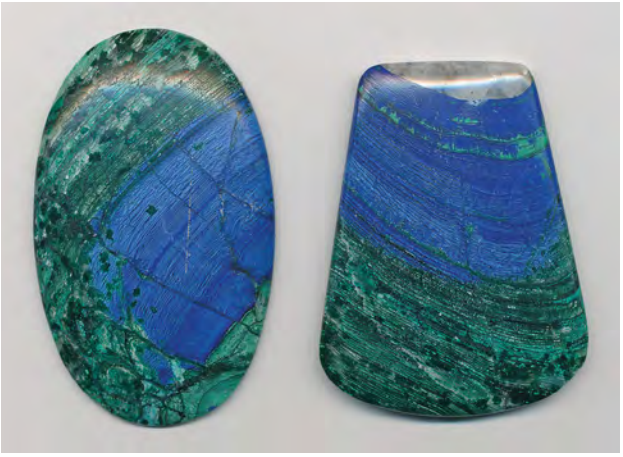

Figure 6: These cabochons of malachite-azurite from Peru (64 and 57 mm long) display an unusual fine banding. Photo by J. Hyršl.

The banded and/or brecciated structure of this material is unique for malachite-azurite, but the amount available on the market is unknown and it may remain a collector's curiosity.

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Reference

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Gem Mosandrite from Russia

Mosandrite is a rare-earth element (REE)-bearing silicate with the formula $(\square,Ca,Na)_3(Ca,REE)_4Ti(Si_2O_7)_2[H_2O,OH,F]_4 \bullet H_2O$, where $\square$ = a vacancy (Sokolova and Hawthorne, 2013). It was named by Axel Joakim Erdmann in 1841 after the Swedish mineralogist Carl Gustav Mosander. Mosandrite has a Mohs hardness of 5, and for several years small quantities of facetable material have been produced only from the Kirovsky apatite mine, Khibiny Massif, Kola Peninsula, Russia. The Khibiny Massif is a famous and unique mineral locality that is composed of a nepheline syenite intrusion rich in a large number of rare minerals. Other locations for mosandrite are Norway and Canada, from which the authors are not aware of any gem-quality material.

A 0.38 ct faceted mosandrite (Figure 7) of brown-orange colour was investigated by standard gemmological methods. The gem was supplied by a colleague in 2014 as Russian mosandrite. The RI values were n_x = 1.650, n_y = 1.653 and n_z = 1.658, with a birefringence of 0.008 and a biaxial positive optic sign. The hydrostatic SG was 3.28. These values fall within reference data for mosandrite reported by Phillips and Griffen (1981): RIs of n_x = 1.643–1.662, n_y = 1.645–1.667 and n_z = 1.651–1.681; birefringence 0.008–0.019; and SG of 2.93–3.50. Examination with a gemmological microscope revealed numerous crystal inclusions (Figure 8, left) and a noticeable roiled appearance (Figure 8, right). The inclusions partly showed an octahedral habit, and analysis with a Zeiss DSM 942 scanning electron microscope at the Institute for Gemstone Research, University of Mainz, Germany, identified them as pyrochlore, $(Ca,Na)_2Nb_2(O,OH,F)_7$.

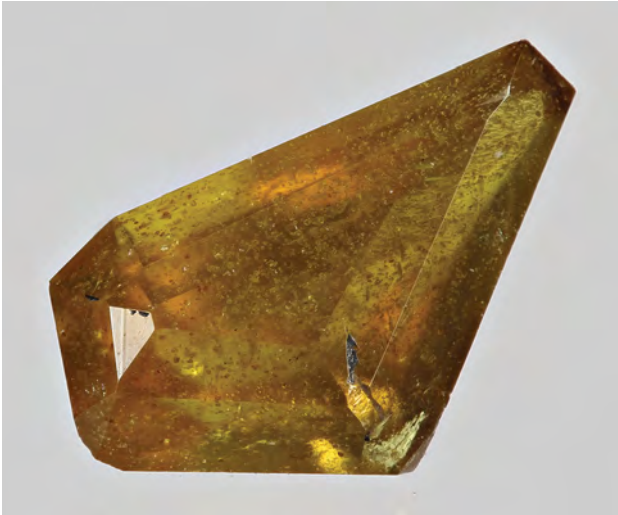

Figure 7: This faceted brown-orange mosandrite (0.38 ct) is from the Kola Peninsula, Russia. Photo by S. Koch, DSEF.

A visible-near infrared absorption spectrum obtained with a Perkin Elmer Lambda 12 spectrometer showed a typical REE spectrum (Figure 9), with maxima at 512, 527, 585, 684,

Figure 8: The mosandrite contained crystal inclusions of partly octahedral habit that were identified as pyrochlore (left, magnified 50×). A roiled appearance was noticeable when the stone was viewed with crossed polarizers (right, magnified 30×). Photos by F. Schmitz.

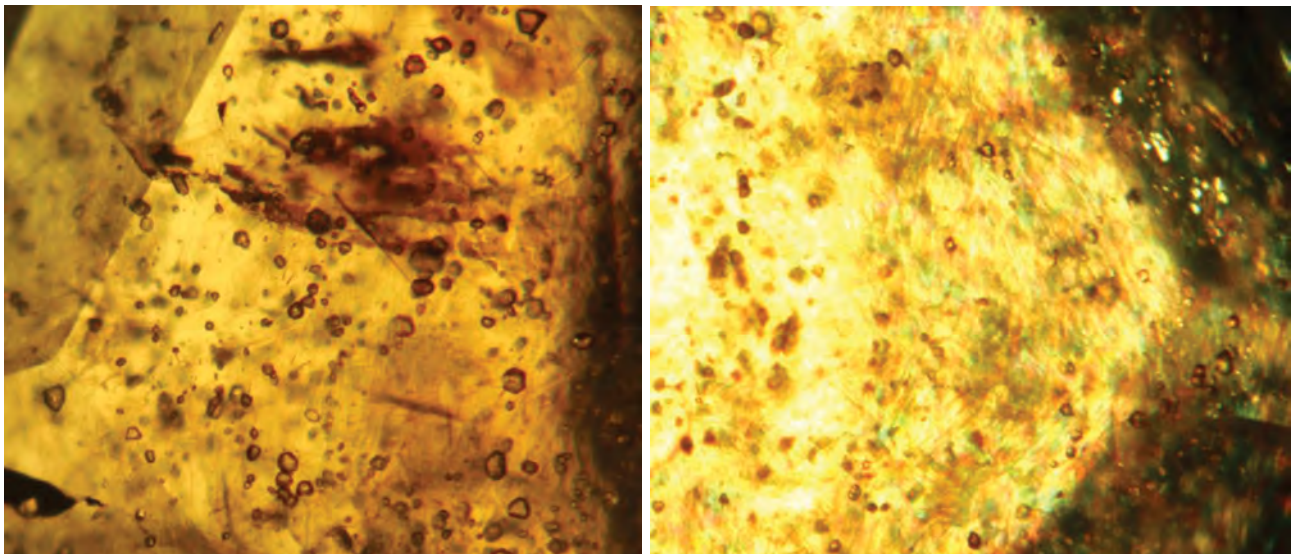

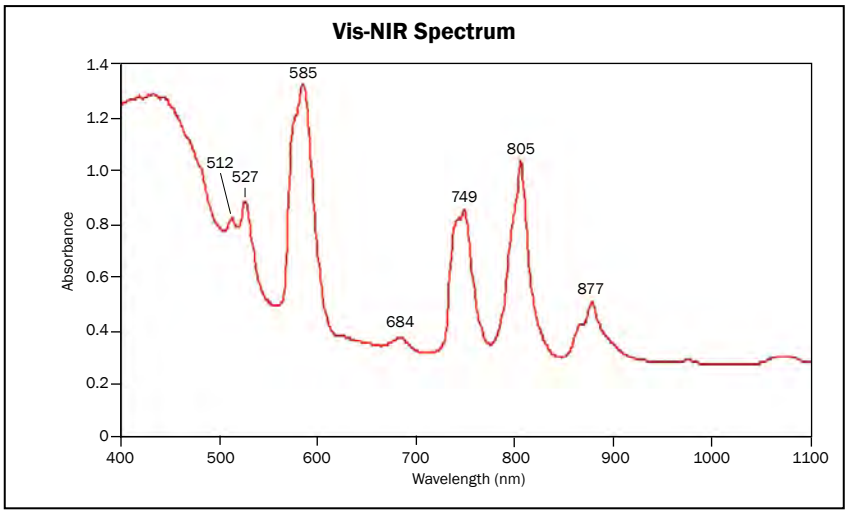

Figure 9: The absorption spectrum of the mosandrite showed several lines corresponding to Nd^{3+}. The path length of the beam was ~2.9 mm.

749, 805 and 877 nm that are due to Nd^{3+} (Wybourne, 1960).

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A Shattuckite Briolette

Recently, the Gem Testing Laboratory, Jaipur, India, received for identification an 8.13 ct intense blue briolette measuring 14.69 × 10.90 × 6.29 mm (Figure 10). On initial observation, it appeared to be composed of azurite and chrysocolla because of its patchy blue coloration and the presence of some green areas (Figure 11, left).

The gemmological refractometer showed a vague shadow edge at ~1.76, while the hydrostatic SG was 3.94. With the desk-model spectroscope, a broad absorption band was visible from the green through red region. Magnification revealed a radiating fibrous pattern that is typical of spherulitic growth (Figure 11, right) and was associated with banding and uneven coloration in the specimen. The RI and SG values ruled out chrysocolla, and although the SG was somewhat higher than expected for azurite (cf. O'Donoghue, 2006), this possibility could not be discarded.

Figure 10: This 8.13 ct intense blue briolette was identified as shattuckite. Photo by G. Choudhary.

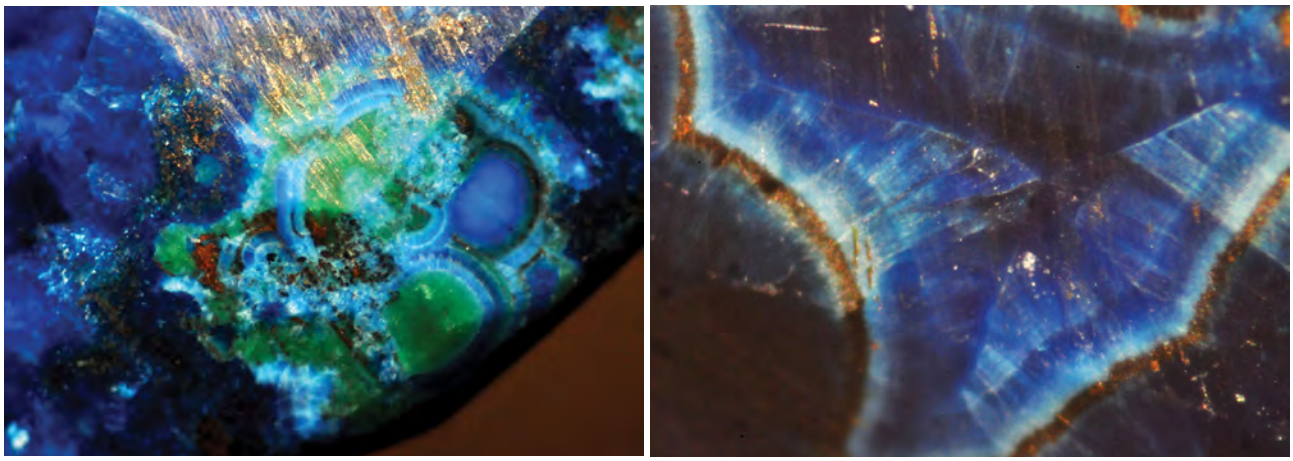

Figure 11: Some green patches of malachite also were present in the shattuckite specimen (left, image width 6.35 mm). The radiating fibrous pattern is typically associated with spherulitic growth (right, image width 5.08 mm). Photomicrographs by G. Choudhary.

Raman spectra in the region 200–2000 cm^{-1} identified the specimen as shattuckite, with characteristic peaks at ~259, 329, 395, 450, 508, 559, 661, 775, 847, 942 and 1069 cm^{-1} (see, e.g., www.rruff.info/doclib/hom/shattuckite.pdf), while the green areas displayed peaks for malachite.

Shattuckite is a hydrous copper silicate, $Cu_5(SiO_3)_4(OH)_2$, which occurs as a secondary mineral in oxidized copper deposits and is commonly associated with chrysocolla, ajoite, malachite and quartz (Anthony et al., 1995). It is known from Bisbee (Shattuck mine), Arizona, USA, as well as Namibia, Democratic Republic of Congo (Overlin, 2014), Chile and elsewhere (Anthony et al., 1995).

This specimen was identified as shattuckite on the basis of Raman spectroscopy, and without this technique it could have been mistaken for azurite. The client was not aware of the sample's identity or origin.

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Saguaro Stone, a New Ornamental Material from Arizona (USA)

During the 2014 Tucson gem shows in Arizona, USA, Warren Boyd FGA (Apache Gems, San Carlos, Arizona) donated to Gem-A a 39.60 ct oval cabochon marketed as *Saguaro Stone*. This new gem material had been recently surface-collected by Charles Vargas on the San Carlos Apache Reservation in Arizona. Boyd indicated that so far 700–800 kg of rough have been stockpiled, and that nearly 1,000 cabochons have been cut and polished in China and the USA, ranging from 10 × 8 mm to 20 × 10 mm, as well as a number of free forms. A few pieces have been sold to local designers, and in the future there are plans to market the material on a larger scale.

For this report, the authors investigated the 39.60 ct oval cabochon (Figure 12) and a few small rough fragments. Viewed with the unaided eye, and particularly with the microscope, it was evident that this new ornamental material consisted of multiple phases that differed in colour and lustre. Standard gemmological testing was inconclusive, so a thin section was cut from one of the rough fragments for detailed mineralogical study. Under the high magnification of a petrographic microscope

Figure 12: This attractive new ornamental material (39.60 ct), called Saguaro Stone *and found on Arizona's San Carlos Apache Reservation, consists mainly of brecciated green volcanic glass and veins of calcite. Gift to Gem-A from Apache Gems; photo © M. S. Krzemnicki, SSEF.*

and assisted by Raman microspectroscopy, it became evident that this material consisted of a volcanic rock, formed mainly by brecciated masses of green volcanic glass. In places it showed wavy flow structures, and also present were a few primary magmatic inclusions such as plagioclase (up to 1.3 mm) and altered greenish brown biotite platelets (0.5–1.6 mm; Figure 13a). Additionally, small vacuoles in the rock (Figure 13b) were filled with fibrous chalcedony and opal (amorphous), and also some zeolites. The greenish colour of the brecciated masses was possibly due to the secondary formation of submicroscopic chlorite.

The Raman analyses further revealed that the whitish veins between the brecciated volcanic glass masses consisted of calcite. Also present were small transparent grey grains (with a distinctly higher lustre) of alkali feldspar that contained tiny metallic hematite flakes and small orange patches, possibly iron hydroxide. When exposed to short-wave UV radiation, the calcite veins fluoresced weak reddish pink, whereas the volcanic glass remained inert (Figure 14). The entire stone was inert to long-wave UV radiation.

EDXRF chemical analysis (with a spot size of ~3 mm in diameter) revealed major amounts of Si, Ca and Al, minor Fe and Mn, and traces of alkalis and alkaline earths (including Sr and Ba). This composition is consistent with a silica-

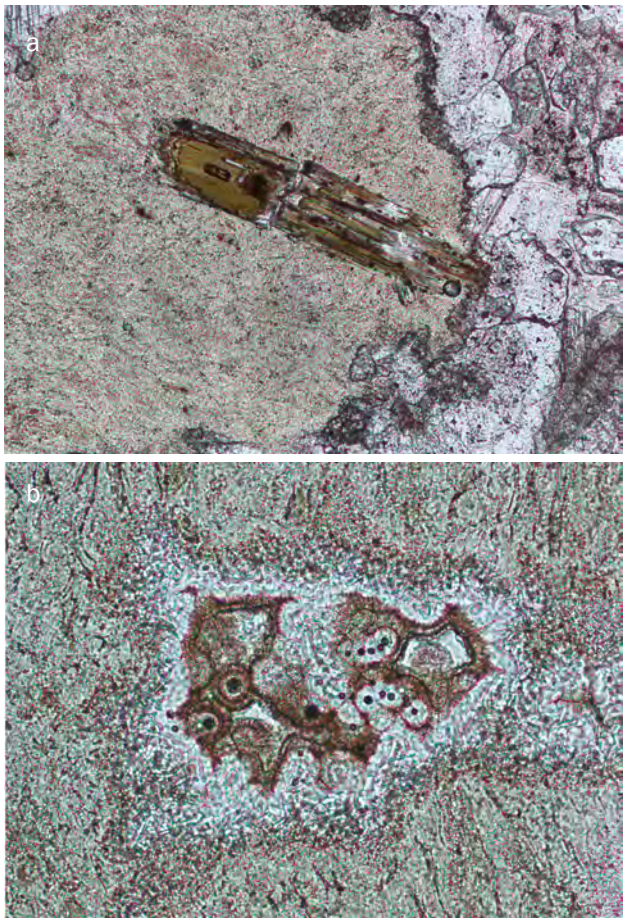

Figure 13: Thin-section examination of the green volcanic rock revealed interesting features. (a) A primary magmatic inclusion of biotite is hosted by a matrix of volcanic glass showing weak flow structures. The colourless grains on the right side correspond to a secondary calcite vein. (b) A small cavity in the rock is filled with acicular chalcedony and amorphous opal. Photos © L. Franz, MPI University of Basel; image width 1.25 mm (a) and 0.56 mm (b).

Figure 14: When the 39.60 ct cabochon is exposed to short-wave UV radiation, the calcite veins in the volcanic rock show a pinkish reaction, whereas the volcanic glass masses remain inert. Photo © M. S. Krzemnicki, SSEF.

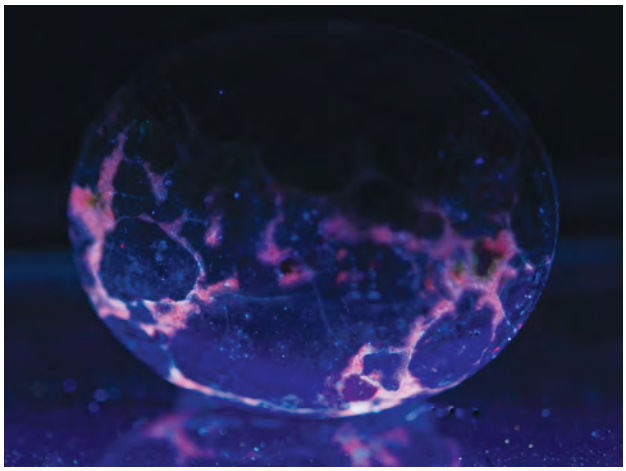

rich volcanic glass containing plagioclase and phyllosilicate inclusions, together with secondary calcite veins.

This ornamental rock makes an attractive addition to the gem market, especially as it is relatively tough and hard, and thus shows a high lustre combined with an attractive colourful brecciated texture.

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'Ruby'-red Tourmaline from Nigeria

During the June 2015 JCK show in Las Vegas, Nevada, USA, Bill Barker (Barker & Co., Scottsdale, Arizona, USA) displayed some red tourmaline from a new discovery at the Oyo Valley deposits in Nigeria, which was notable for its ruby-like coloration. He obtained three large pieces of rough in April 2015 from his supplier in Lagos, Nigeria. Although the rough was dark, it was very red. Cutting of a piece that weighed 8.4 kg yielded 3,973 carats of faceted stones (not including melee from the offcuts) ranging from ~1 to 16 ct each. The final yield of 9.5% was far below the typical yield (13–16%) that Barker has obtained in the past from Oyo Valley Nigerian rubellite, and resulted from his choice to cut smaller stones (especially Portuguese-style rounds) so they would not appear overly dark. Also, only clean faceted stones and no cabochons were cut from the rough.

Barker assembled seven jewellery suites from this material (see, e.g., the cover of this issue), and also offered individual cut stones (Figure 15). They displayed an attractive red colour similar to Thai ruby—so much so that he displayed the rubellite next to Thai ruby at the JCK show (e.g. Figure 16). This coloration is rather distinct from the lighter pink to purplish pink hues that are typically shown by Nigerian tourmaline.

Brendan M. Laurs

Figure 15: These 'ruby'-red tourmalines from Nigeria weigh 4.25–7.25 ct. Photo by Rich Barker.

Figure 16: The Nigerian rubellite on the left (2.71 ct) shows a similar coloration to the Thai ruby on the right (3.14 ct). Both gems were faceted by the same cutter as Portuguese-style rounds. Photo by Rich Barker.

Tremolite from Mwajanga, Tanzania

During the 2015 Tucson Gem shows, gem dealer Werner Radl of Mawingu Gems (Niederwörresbach, Germany) displayed a prismatic gem-quality crystal (Figure 17) that he obtained in Tanzania. It was sold to him as tourmaline, and reportedly came from a new find in the Mwajanga area (Manyara region of north-central Tanzania).

Figure 17: This prismatic crystal is gem-quality tremolite, an amphibole-group mineral. It measures 69.5 mm long and weighs 8.05 g. Photo by J. C. Zwaan.

The elongate crystal was transparent and had a light, slightly greyish, green colour. It weighed 8.05 g and measured approximately 69.5 × 9.37 × 5.48 mm. Both ends of the crystal were broken, and one end also displayed an area with a parallel fibrous structure. The surface of the crystal displayed fine striations along its length, and an incipient cleavage fracture was present in the same orientation. Another fracture positioned in the middle of the crystal was oriented almost perpendicular to the longitudinal direction. Inclusions consisted of parallel growth tubes and partially healed fissures.

One side of the crystal had been polished, but no clear readings could be obtained with the refractometer due to the poor quality of the polish. The hydrostatic SG was 2.99. With the dichroscope, weak trichroism could be observed: colourless, light yellowish green and light green. No fluorescence was observed to long- or short-wave UV radiation. Compared to amphiboles in the tremolite-actinolite-ferroactinolite series (Deer et al., 1997), the overall pale colour, relatively low SG and weak pleochroism corresponded to a member with a low iron content, and therefore suggested tremolite, rather than actinolite, as the identity of this crystal.

Raman analysis taken with 532 nm laser excitation revealed a spectrum that had closest matches to several reference spectra for tremolite in the RRUFF database (www.rruff.info). However, the Raman spectra of actinolite may be very similar, and therefore caution must be exercised when interpreting the spectra (Figure 18). The best match was to a tremolite spectrum that also showed a peak at 120 cm^{-1}. For most of the tremolite and actinolite spectra in the database, spectral features below 150 cm^{-1} were not recorded, and some of those tremolite and actinolite spectra were virtually indistinguishable.

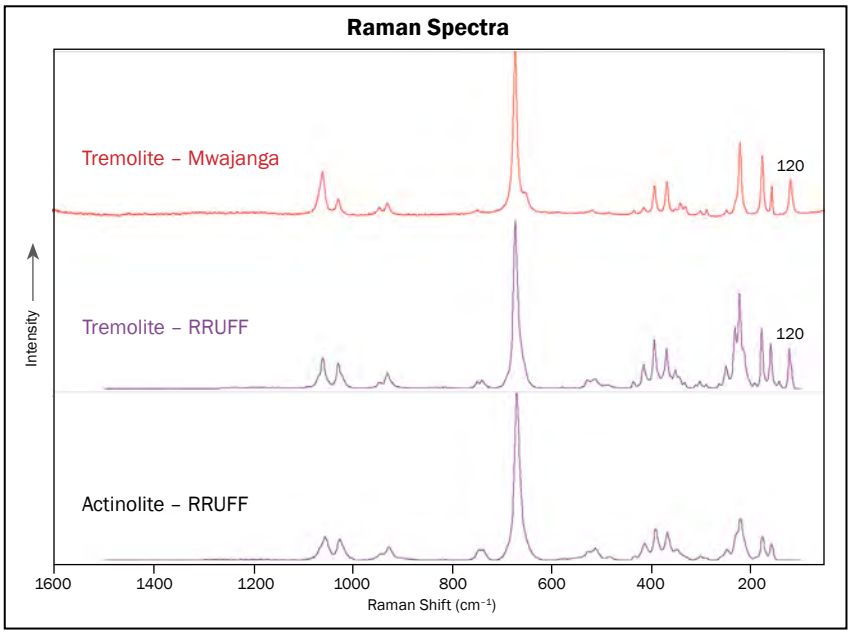

Figure 18: The Raman spectrum of the crystal showed the best match with a tremolite spectrum in the RRUFF database, containing a distinct peak at 120 cm^{-1}. The crystal's spectrum also showed a good match with reference spectra for actinolite (e.g. bottom spectrum). Raman spectra of tremolite and actinolite may be very similar and therefore indistinguishable.

The compositional range of tremolite extends from $\square Ca_2Mg_5Si_8O_{22}(OH)_2$ (where $\square$ = a vacancy) to $\square Ca_2Mg_{4.5}Fe^{2+}_{0.5}Si_8O_{22}(OH)_2$, whereas actinolite extends from $\square Ca_2Mg_{\leq 4.5}Fe^{2+}_{\geq 0.5}Si_8O_{22}(OH)_2$ to $\square Ca_2Mg_{2.5}Fe^{2+}_{2.5}Si_8O_{22}(OH)_2$ (Leake et al., 1997; Hawthorne et al., 2012). Electron microprobe analysis of the crystal by one of the authors (FCH) confirmed that it was indeed tremolite: $(Na_{0.05}K_{0.03})(Ca_{1.94}Na_{0.06})_2(Mg_{4.85}Fe_{0.10}Mn_{0.01}Al_{0.03})_{4.99}Si_{7.99}O_{22}(OH)_{1.92}F_{0.08}$. This formula, with $Mg/(Mg+Fe^{2+}) = 0.98$ (cf. Leake et al., 1997) and with $^{A}(Na+K+2Ca) = 0.08$ and $^{C}(Al+Fe^{3+}+2Ti) = 0.03$ (cf. Hawthorne et al., 2012), shows that the crystal has a composition that is very close to the pure end-member composition of tremolite.

In July 2015, Radl reported that he obtained three more crystals of this tremolite from the same find. Also, his supplier indicated that a few kilograms of the rough tremolite were sold into the market as tourmaline. This is not surprising, given the similar appearance of this tremolite to some of the tourmaline that was recently mined from the Mwajanga area (e.g. www.minrec.org/pdfs/Toms%20Online%20report%2039.pdf).

Radl indicated that he encountered significant amounts of tremolite of the same pale green colour (associated with quartz and purple scapolite) during his first trip to Tanzania in 1995. The only other occurrences of gem-quality tremolite known to these authors are yellowish green material from Merelani, Tanzania (Fritz et al., 2007) and greyish green crystals from Bancroft, Ontario, Canada (www.youtube.com/watch?v=od4OfHsGQbg).

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DIAMONDS

Diamond Horse-head Carving

Sculpting and carving are very intricate and patience-consuming art forms. Numerous examples of sculptures and carvings created from stone and various gem materials are known worldwide, but hand sculpting of diamond is virtually unheard of (e.g. Fryer, 1983; Du Toit, 2009).

In January 2015, this author examined a unique two-headed horse sculpted from natural diamond (Figure 19). It was accompanied by GIA report no. 1209011703, certifying it as a carving weighing 4.07 ct that was made from near-colourless natural diamond. It measured 13.72 × 7.02 × 4.34 mm, and the two horse heads formed a perfect mirror image of one another. The carving was well proportioned with precise symmetry when viewed from any direction. Although designed to stand upright on its base, it was balanced with such precision that it would stand upside-down on the ears without toppling over (see Figure 19, centre). When the sculpture was observed in detail, the illusion of harness straps going across the faces of the horses could be seen.

The sculptor reportedly required more than a full year to plan and execute the carving. A paper

Figure 19: A 4.07 ct diamond horse-head carving is shown in these three views. Photos by Sameer Doshi.

sketch was made first, followed by a wooden prototype, and then the design was marked on the actual diamond rough, which weighed 8.38 ct (Figure 20). Since only a diamond can scratch diamond, to actually carve and sculpt an entire three-dimensional figurine without making use of laser technology required a great amount skill and patience that only a master craftsman would have. The piece was sculpted using subtractive carving techniques, in which material was gradually removed from the diamond rough. Any slight negligence while working could either cleave the diamond or create a misproportioned carving.

One has to give credit to the initiative of the sculptor, as there is no school or institute that provides training in diamond carving. This carving is indeed an extremely rare creation and an amazing piece of art to be treasured.

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Figure 20: The diamond carving started with a paper sketch (left) that was followed by a wooden prototype (centre) before the design was marked on the actual piece of diamond rough, which weighed 8.38 ct (right). Photos by Sameer Doshi.

SYNTHETICS AND SIMULANTS

Gastropod Shell Beads Disguised in a Coral Necklace

The GGTL Laboratories – Gemtechlab in Geneva recently received a coral necklace (e.g. Figure 21) for identification that weighed 100.55 g and consisted of eight round white freshwater cultured pearls and 107 'salmon'-coloured beads (3.3–10.2 mm in diameter). Microscopic examination showed that most of the coloured beads consisted of coral (i.e. *Corallium elatius*: Ridley, 1882). However, the beads present on either side of each freshwater cultured pearl had a distinctly different origin: they were cut from the shell of a gastropod (i.e. *Strombus gigas*:

Figure 21: A portion of a 'coral' necklace containing 'salmon'-coloured beads (3.3–10.2 mm in diameter) and white freshwater cultured pearls is shown here. The two beads adjacent to each cultured pearl in the necklace proved to have been cut from Strombus gigas *shell. Photo by E. Disner.*

Linnaeus, 1758). *Strombus gigas* is the host mollusc for conch pearls, and indeed pink and orange coral beads are occasionally mistaken for conch pearls (Farn, 1986, cited by Fritsch and Misiorowski, 1987).

The discrimination of *Strombus gigas* shell from coral is made by structural observations and may be aided by hydrostatic SG measurements. A diagnostic flame-like structure (Figure 22, left), is exhibited by non-nacreous pearls (and shell material, to a lesser extent) of various gastropods (*Strombus gigas*, *Voluta melo*, etc.). This pattern is caused by domains of stacked aragonite tablets in alternating orientations (Hänni, 2010). In the best specimens, the 'flames' can be seen by microscopic observation as thin lamellae that are almost parallel to one another and are sometimes perpendicular to the axis of pearl, thereby giving rise to a rough chatoyancy (Fritsch and Misiorowski, 1987). By contrast, polished coral beads display banded striations that are much more regular than the flame structures seen in conch pearls and shells. These parallel lines have a spacing of 0.25–0.5 mm, and in cross-section they appear as radiating shapes with very faint concentric lines joining them, in a pattern somewhat resembling a spider web (Figure 22, right), also called a 'tree-ring' structure (Campbell Pedersen, 2004).

Note that the characteristic flame-like and spider-web patterns are not always present or directly seen in these materials. If the flame structure is not visible in a conch pearl with the unaided eye, it is called porcelaneous (Fritsch and Misiorowski, 1987). Also, depending on the location of the drill hole, the spider-web pattern in coral may be invisible. Lack of the radial lines may indicate the presence of shell material. Striations should be easily visible in red coral, but may be harder to discern in lighter coloured coral; a complete lack of structure always raises suspicion (Campbell Pedersen, 2004).

SG measurements may also be effective for differentiating coral from shell material. The SG of 'precious' coral is between 2.6 and 2.7 (Webster, 1994) and is dependent on the porosity of the sample (Karampelas et al., 2009), whereas that of a pink conch pearl is around 2.85 (Webster, 1975). This SG value corresponds to a mixture of about 40% calcite (SG = 2.71) and 60% aragonite (SG = 2.95; Webster, 1975, cited by Fritsch and Misiorowski, 1987). It must be emphasized that

Figure 22: These photos show the flame-like structure in a Strombus gigas *pearl (left) and the typical spider-web structure in coral (right). Photomicrographs by F. Notari.*

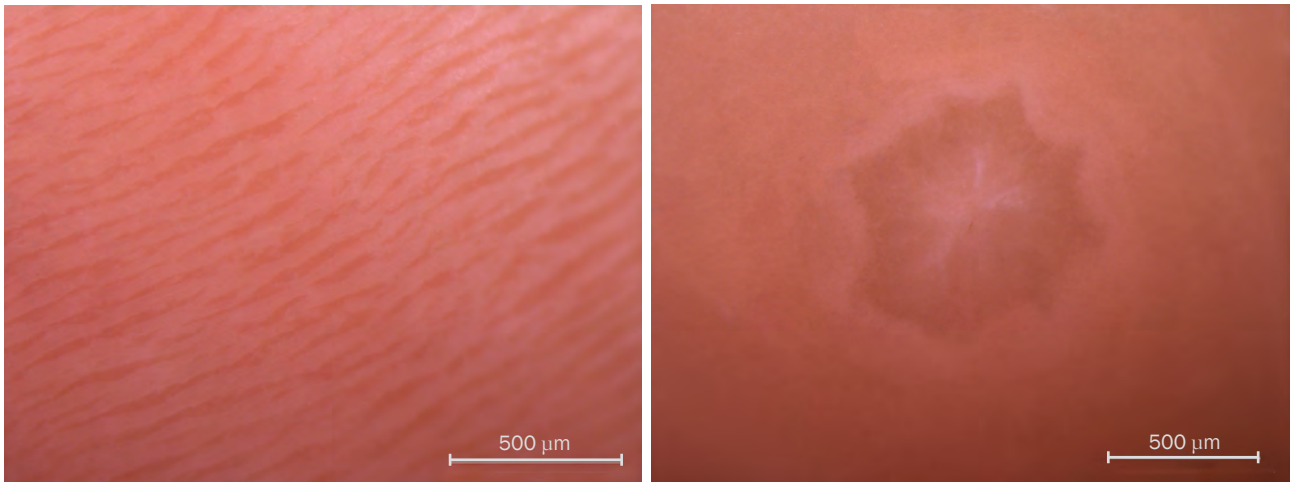

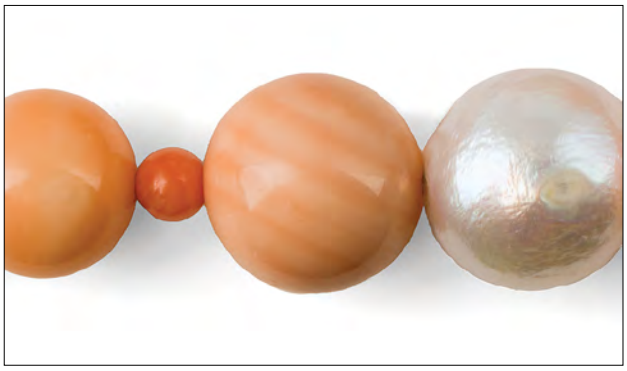

Figure 23: Within the 'coral' necklace, this bead cut from Strombus gigas *shell (10 mm in diameter) displays a layered structure. Photo by E. Disner.*

SG measurements should only be used as an indication, due to the approximate results given by the hydrostatic balance and because coral and conch pearl may have overlapping values.

In general, beads cut from shell material can be distinguished from non-nacreous pearls using only a microscope: Shell beads display a layered structure with an uneven distribution of the flame-like pattern, if any (e.g. Figure 23). This is in contrast to the uniform flame structure that is visible from all directions in those pearls that show this effect (Figure 22, left). In the authors' experience, the distribution of the flame pattern in shell beads is even more irregular than in pearls that have been reshaped.

As demonstrated by the necklace reported here, careful microscopic examination should be systematically done on every sample found within a piece of purportedly coral jewellery.

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TREATMENTS

A Barium-Glass-Filled Ruby

In June 2015, a 3.71 ct oval cabochon-cut ruby (Figure 24) was sent to the Liechtenstein branch of GGTL Laboratories for treatment analysis. Microscopic observation revealed rather obvious glassy residues within fissures, and also some noticeable filled cavities that showed gas bubbles mostly from the shrinking of the glass upon cooling (Figure 25).

To determine the nature of the filler—that is, to separate high-density glass from silica glass residues resulting from flux-assisted heating (typically involving a borax flux that is sometimes combined with quartz during heat treatment)—a high-definition three-dimensional radiograph was recorded, of which one position can be seen in Figure 26 (left). The radiograph showed that the density of the glass filling (white to very light grey portions) is considerably higher than the density of the host ruby. This made us suspect that lead glass was present, although the similarities of the fillings to glassy residues from flux-assisted heating raised suspicion that the stone may have been treated by a combination of these two techniques.

We then analysed the sample with the DFI fluorescence imaging and spectroscopy system,

Figure 24: This 3.71 ct ruby proved to contain fissures and cavities filled with barium glass. Photo by C. Nacht, GGTL Laboratories.

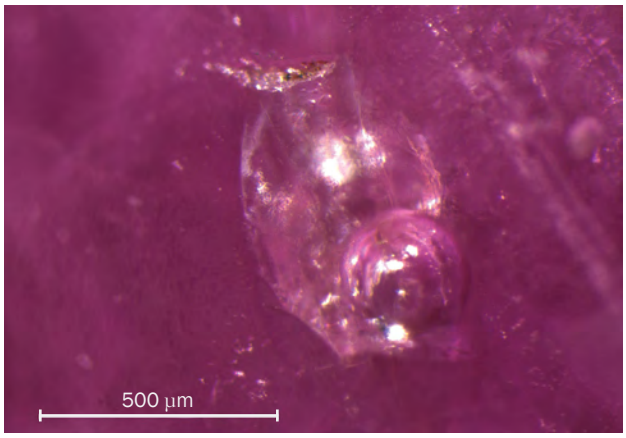

Figure 25: This filled surface-reaching cavity in the ruby contains a large round gas bubble. Photomicrograph by T. Hainschwang.

and all the fissures exhibited blue fluorescence under the deep-UV short-wave excitation (Figure 26, right). The typical reaction of lead glass to the short-wave UV generated by the DFI instrument is a dull and very chalky blue to 'olive' green luminescence that is much fainter than observed for this sample. Glassy residues from flux-assisted heating are generally inert to any type of UV excitation.

Infrared spectroscopy revealed a small 3309 cm^{-1} absorption that is generally a good indicator of heat treatment in ruby, plus a broad band centred at 2640 cm^{-1}. This broad absorption is typically observed in stones that contain significant quantities of glass filling, and is caused by the absorption spectrum of glass overlaying the corundum spectrum. While such a band is seen in most lead-glass-filled rubies, it only very rarely appears in the spectra of flux-assisted heat-treated stones.

To determine the chemical composition of the glass, the stone was analysed by EDXRF spectroscopy. The first spectrum (Figure 27, left) was recorded with an accelerating voltage of 24 kV, typical for the detection of chromophoric elements in corundum (i.e. *K*-lines of lighter elements and *L*-lines of heavier elements). Nothing obviously unusual was detected, only Cr, V, Ga, Fe and Ti appeared to be present, but no Pb or other heavy element; the only curiosities were unusually high Ti and somewhat enriched V. Therefore a second EDXRF analysis was performed with the X-ray tube set to 50 kV to specifically detect heavy elements. This revealed strong barium *K*-lines (Figure 27, right); since these lines are present at energies greater than 24 keV, Ba could not be easily detected with the X-ray tube set at 24 kV. Although the *L*-lines of Ba can be detected at 24 kV, they coincide almost

Figure 26: The light-coloured areas in the radiograph on the left show that the glass-filled fissures and cavities contain far heavier elements than the host ruby. When exposed to the deep-UV short-wave excitation of the DFI fluorescence microscopy and imaging system (right), the glass in the 3.71 ct ruby fluoresces a distinct blue. Images by T. Hainschwang.

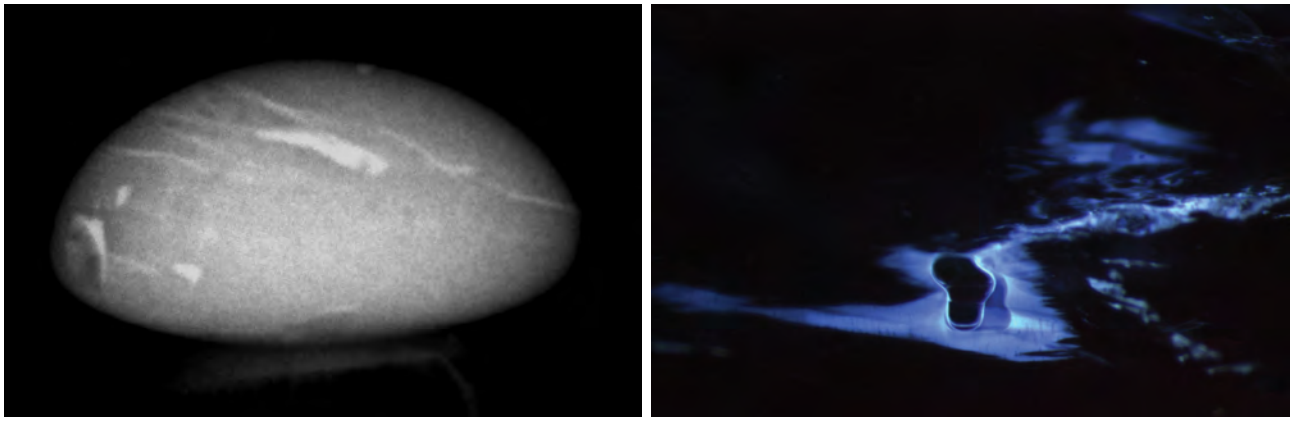

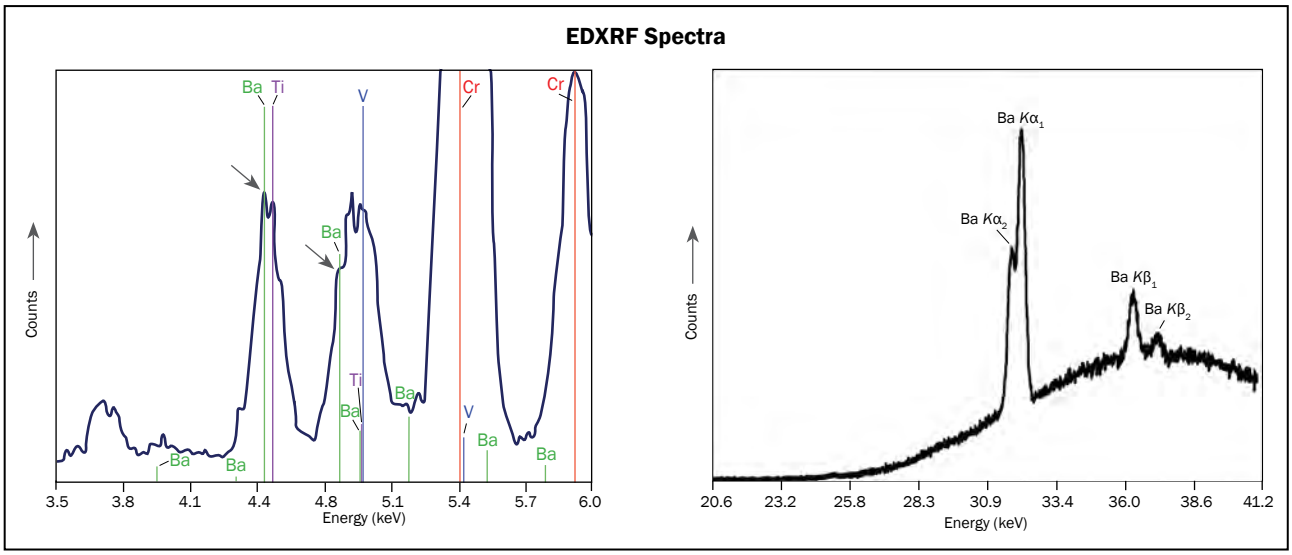

Figure 27: EDXRF spectra of the filled ruby are shown using a voltage of 24 kV (with an Al filter), a setting typically used to see the chromophoric elements in corundum (left), and at 50 kV (with a Pd filter), a setting that revealed the presence of Ba (right). The Ba peaks are difficult to distinguish at the lower energy setting; they are suggested only by an increase in the intensity of the Ti Kα-line by the Ba Lα-line, and a widening of the V Kα-line by the Ba Lβ-line. The Ba Lλ- and Lγ-lines, as well as the small Ba Lα-line, do not substantially modify the spectral appearance at the lower-energy setting of the instrument. Note that in rubies lacking V, the Ba Lβ-line should be detectable and could not be confused with the V Kα-line.

exactly with the Ti and V lines (Figure 27, left). This explains the apparently elevated Ti and V that were shown by the first analysis.

This is the first ruby we have seen in our laboratories that has been filled with a high-refractive-index barium glass. Depending on the Ba content, such glass can have a refractive index above 1.7 (the RI of the glass in this sample could not be determined since the cavities were not large enough to measure it). To identify barium glass with EDXRF spectroscopy, caution is required since Ba may not be detected using standard analytical conditions for lead glass; a higher-energy setting is necessary to properly identify Ba.

According to the client, this stone had been in stock for more than 10 years, which may indicate that it was possibly an experimental treatment product before the more efficient fissure filling procedure was developed using lead glass, starting in 2004.

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Diffusion-induced Blue Colour and Asterism in Sapphire

In April 2015, a client submitted a bright blue star sapphire weighing 13.69 ct and measuring 13.85 × 11.89 × 10.28 mm (Figure 28). The crown was polished into a typical domed cabochon, while the pavilion was faceted so that it reflected light like a faceted stone. This cutting arrangement is only rarely seen in natural star sapphires. The six-rayed star had straight 'arms' that were sharp and bright under a point light source, and the stone exhibited a double star when photographed from an angle.

The crown gave a spot RI reading of 1.76, and the faceted pavilion yielded RIs of 1.760–1.770 (birefringence 0.010). The gem was inert to UV radiation. Viewed with magnification, the stone had small 'fingerprint' inclusions (e.g. Figure 29) that indicated a natural (not synthetic) origin. However, there were no prismatic needle-like inclusions that are typically associated with asterism in sapphire. Instead, at higher magnification (20×–30×), the asterism was seen to be caused by wispy 'silk'

Figure 28: Both the asterism and blue colour of this 13.69 ct sapphire are the result of diffusion treatment. Photo by Tay Thye Sun.

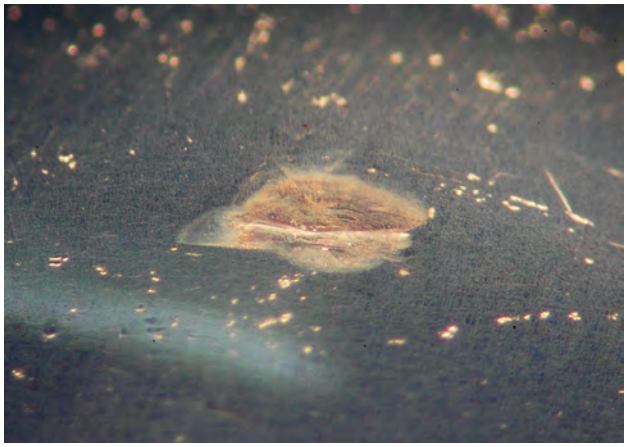

Figure 29: This 'fingerprint' inclusion found under the dome of the star sapphire displays subtle interference colours. Note the hazy appearance of the stone's surface and minute pits that resulted from the diffusion process. Photo by Tay Thye Sun; magnified 35×.

or fine fur-like inclusions that were present just under the surface (Figure 30). Such inclusions have been ascribed to diffusion treatment in synthetic star sapphires (e.g. 'AIGS finds more stars', 1994; Kammerling and Fritsch, 1995; Singbamroong et al., 2015). When the stone was immersed in eucalyptus oil and viewed with diffused lighting, the pavilion showed inconsistent coloration between various facets and colour concentrations along facet junctions (Figure 31), proving that the gem was repolished after diffusion treatment (e.g. Kane et al., 1990).

We concluded that this was a natural sapphire that had been diffused-treated to induce its colour and asterism. Although some previously documented diffusion-induced star sapphires were synthetic in origin ('AIGS finds more stars', 1994; Kammerling and Fritsch, 1995; Singbamroong et al., 2015), gemmologists should remember that natural as well as synthetic starting materials may be used for this type of treatment.

Acknowledgement: The authors thank Mr Yu Xiong for bringing this sapphire to their attention.

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Figure 30: Wispy 'silk' is responsible for the asterism in the sapphire. Photomicrograph by Tay Thye Sun; magnified 30×.

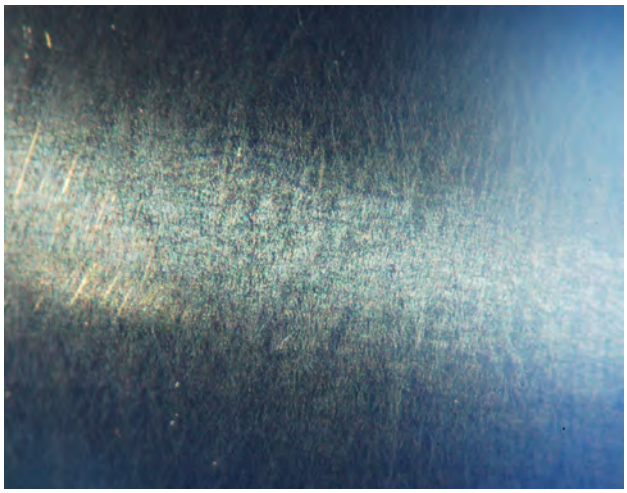

Figure 31: Inconsistent coloration between various facets and colour concentrations along facet junctions of the pavilion prove that the sapphire underwent diffusion treatment and was then repolished. Photo by Tay Thye Sun; magnified 20×.

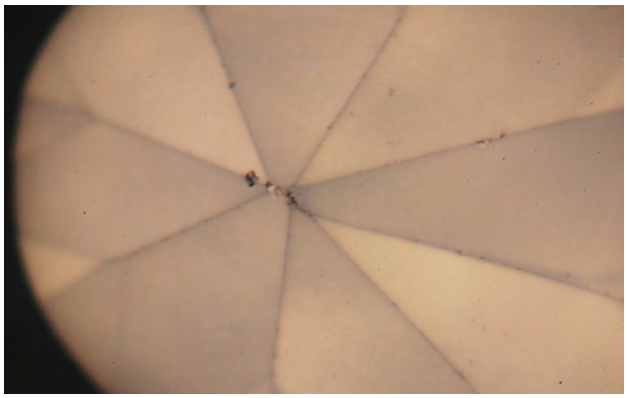

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MISCELLANEOUS

Highlights of the 52nd Gems Emporium in Myanmar

The 52nd Gems Emporium took place in Naypyitaw, Myanmar, on 24 June–6 July 2015. There were 8,943 jadeite lots offered, and 5,843 of them were sold for €938.58 million. Of the 316 gem lots offered, 126 were sold for €5.59 million. The best-quality rubies were supplied by Ruby Dragon Co., and consisted of two rough pieces weighing a total of 79 ct that sold for €801,000. There were 18 lots of rough ruby from Mong Hsu that sold at relatively low prices due to their quality. The highest-quality rough sapphires came from Bawma Mining Co., and consisted of 98 pieces weighing 138 ct that sold for €200,999. In addition, Bawma Mining Co. supplied four lots of cut sapphires, all of which were sold.

Various non-jade materials also were popular, with 18 lots sold. A 6.0 kg piece of green fluorite sold for €23,800 (e.g. Figure 32). Yellow-to-orange quartzite was offered as cabochons (220 pieces weighing 1.5 kg that sold for €1,917; Figure 33, left), and also as discs left over from cutting bangles (not sold; Figure 33, right).

Figure 32: This 6.0 kg piece of green fluorite sold for €23,800 at the 52nd Gems Emporium. Photo by Kaung Naing.

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Figure 33: Yellow-to-orange quartzite was offered at the 52nd Gems Emporium as cabochons (left side, 1.5 kg), and as discs that remained from cutting bangles (right). Photos by Kaung Naing.

The Fire Within

"For in them you shall see the living fire of the ruby, the glorious purple of the amethyst, the sea-green of the emerald, all glittering together in an incredible mixture of light."

– Roman Elder Pliny, 1st Century AD

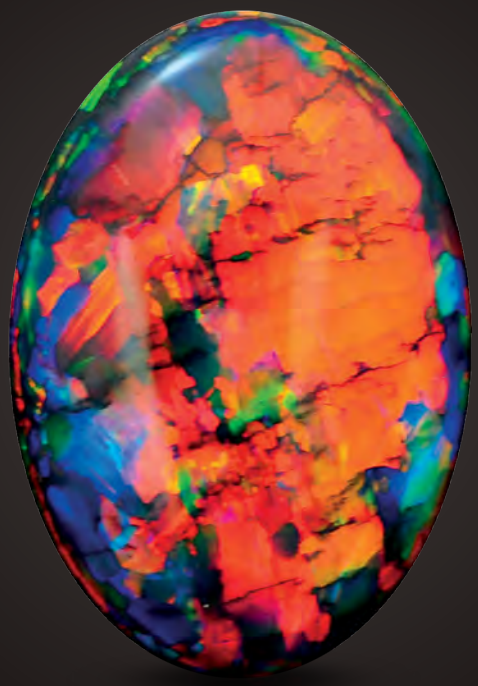

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JOG

European Freshwater Pearls: Part 1—Russia

Elisabeth Strack

Freshwater pearls from *Margaritifera margaritifera* (L., 1758), also called the 'European pearl mussel', are part of European cultural history. The mussels live in cool, clean, oxygenated waters, and formerly ranged from the north-western Iberian Peninsula to north-western Russia. During the last century, populations have largely diminished due to environmental influences, and the species is listed as endangered in the International Union for the Conservation of Nature (IUCN) Red List; harvesting them for pearls is prohibited. In north-western Russia, particularly from the 18th and 19th centuries until 1917, the pearls were commonly incorporated into embroideries, traditional headdresses, jewellery and various objects of religious significance. Interest in pearls waned after the Russian Revolution, and interviews conducted during the 2000s with people in former pearling centres showed an almost complete lack of awareness of pearls.

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Introduction

The freshwater mussel *Margaritifera margaritifera* (L., 1758) has been reported as a source of pearls since antiquity, and eventually became known as the 'European pearl mussel' in popular language. Significant pearl production has occurred in only a few countries, such as parts of Germany (especially Bavaria and Saxony) and Great Britain (especially Scotland). The mussel's population levels have fallen by more than 90% (with few exceptions) during the last century, mainly due to environmental reasons. The species has been listed on the IUCN Red List as endangered since 1996 (www.iucnredlist.org/details/12799/0).

Over the centuries, freshwater pearls from *Margaritifera margaritifera* became part of European cultural history, and this article is the first part of a series that will cover their past and present importance. The focus of this article is Russia, where freshwater pearls were used abundantly for both secular and ecclesiastical purposes, particularly from the 18th and 19th centuries up to the 1917 Revolution. Some secular examples include embroidered dresses, traditional headdresses for women called *kokoshniks* (e.g. Figure 1) and jewellery (e.g. Figure 2). However, visits by the author to north-western Russia in 2001, 2006 and 2008 have shown that local knowledge about pearls has nearly disappeared, and only a few such items were seen at museums in the former pearling centres of Kem in Karelia and Umba on the Kola Peninsula.

The purpose of this article is to describe the history, taxonomy and biology of the *Margaritifera margaritifera* mussel, and then to trace the origins of Russian freshwater pearls, followed by a brief

Figure 1: Russian freshwater pearls (2–4 mm in diameter) are featured in this late-19th-century kokoshnik *(traditional headdress). Courtesy of The Russian Museum of Ethnography, St Petersburg. Photo by E. Strack.*

characterization of their properties. Much of the information in this article is based on what the author observed and was told during her visits to Russia. In addition, general information was taken from Strack (2006).

Historical Context

The pearl mussel was first described by Carl von Linné (or Carolus Linnaeus) as *Mya margaritifera* in the 10th edition of his *Systema Naturae* in 1758. He most probably took the word *Mya* from Pliny the Elder (Gaius Plinius Secundus, AD 24–79), who used it in his *Historia Naturalis* for a small freshwater mussel. In 1816, the Danish scientist Heinrich Christian Friedrich Schumacher recognized the genus *Margaritifera*, which he named *Margaritana* in 1817. In the course of the 19th or early 20th century, the name was changed back to *Margaritifera*; the exact date and reason for this are unknown. *Margaritifera*, taken from *margarita*, the Latin word of Greek origin for *pearl*, indicates 'the pearl-bearing one'.

Pearls from *Margaritifera margaritifera* had been known and worked into jewellery long before von Linné described the mussel in 1758. One of the oldest written testimonies to European pearls is from Gaius Suetonius Tranquillus (AD 75–150), when he refers, in his history of Roman emperors, to the pearls that had made "the divine Julius undertake his conquest of Britain". Before him, both Pliny the Elder and Cornelius Tacitus (AD 55 and AD 116/120) had expressed their disappointment with the lack of beauty shown by British freshwater pearls (Strack, 2006).

From the Middle Ages until about 100–150 years ago, the European freshwater pearl undoubtedly was important as a valuable decorative object. Fine-quality individual pearls or necklaces were extremely rare, and most of them probably were sold into the natural pearl market as being from classical localities such as the Persian Gulf. The majority of European freshwater pearls were used for the decoration of objects of both secular and ecclesiastical use. Some of these items are kept today in churches, monasteries and museums where they serve as a unique witness to the existence of pearls in European cultural history.

Figure 2: These earrings containing Russian freshwater pearls (5–6 mm in diameter) are dated to the late 19th century. Courtesy of The Russian Museum of Ethnography, St Petersburg. Photo by E. Strack.

Freshwater Pearl Mussels

Taxonomy

Freshwater mussels occur worldwide and, along with marine bivalve molluscs, belong to the class Bivalvia. They have two shells, or valves, that are connected by a hinge and a ligament. Their inner soft body has a slightly different, more delicate organization than marine molluscs, and the reproductive cycle of some species is distinctly more complicated (see below).

Pearl production occurs from those mussels within the suborder Schizodonta belonging to the superfamily Unionoidea. Such mussels have been called *najades* in scientific colloquial language. This name dates back to the 18th century, and alludes to the nymphs in Greek mythology that protected rivers and lakes. The superfamily Unionoidea is divided into two families, Unionidae and Margaritiferidae. Both families probably originated from a common freshwater lineage that developed from marine molluscs migrating into freshwater during the Mesozoic Era (Strack, 2006).

The Unionidae family has ~140 genera with more than 1,000 species that occur worldwide. Significant pearl production from Unionidae mussels is known from the eastern half of the United States, specifically the Mississippi River and its tributaries where huge quantities of pearls were fished during the so-called pearl rush in the second half of the 19th and early 20th centuries. Pearl production concentrated on 50–60 species.

The occurrence of the Margaritiferidae family is confined to the northern hemisphere, situated between approximately 40° and 70° north latitude, with the Arctic Circle representing the northern boundary. The Margaritiferidae family was classified in 1929, and until that year the genus *Margaritifera* was seen as belonging to the Unionidae family. Also, some old texts still attribute it to the 'Najade' family. Today's taxonomic classification of the genus is not clearly structured and shows overlaps; it is not described in further detail here. Pearls that were to become known on the world market as 'European freshwater pearls' come from only one species, *Margaritifera margaritifera*. This is considered the youngest species, probably originating about 8 million years ago during the Late Miocene Epoch (Strack, 2006).

Figure 3: Each of these three Margaritifera margaritifera *mussels measures ~8.5 cm long. They typically bury about half of their shell into the ground, while the other half protrudes into the water and is positioned at an oblique angle toward the current. The mussels are usually found growing close to one another with their shells pointing in the same direction. Courtesy of R. Altmüller; photo by E. Strack.*

Biology

Margaritifera margaritifera (e.g. Figure 3) is native to an area comprising parts of the Iberian Peninsula (Portugal and Spain); southern, central and eastern France; Belgium; Luxembourg; northern and central Germany; and eastern Austria and the Czech Republic. It stretches in the north-west to Great Britain and in the north and north-east to Scandinavia and north-western Russia (Figure 4; see also Reis, 2003; Strack, 2006).

Margaritiferidae have the highest life expectancy of all known invertebrates, and may live up to 200+ years (R. Altmüller, pers. comm., 2007). This extraordinary life span is due to the extremely low metabolism that goes hand-in-hand with a slow growth rate of 1.0–1.5 mm per year, dependent on water temperature.

The pearl mussel needs clean, summer-cool waters with temperatures between 4° and 23°C with high oxygen and low nutrient and Ca contents. As the Ca content should not exceed 0.0045–0.0153 grams per litre, the species is regarded as a so-called calcium hater (Strack, 2006). This seems contradictory, since the mussel needs Ca to grow its relatively thick shells. It

apparently compensates for the low amount of available Ca with its slow growth rate.

The pearl mussel prefers a substrate of coarse sand or pebbles consisting of quartz, granite or gneiss. It responds to muddy or fine-grained sandy substrates by becoming smaller and thinner. It generally avoids both stagnant waters and strong currents, and prefers streams but also inhabits rivers and occasionally lakes (Strack, 2006). Mountainous sites are preferred and lowlands are the exception. The ideal water depth is 0.5–2 m, but up to 8 m has been recorded (Strack, 2006).

The shells are made up of two symmetric, oval-shaped convex halves (Figure 3). They can attain a maximum size of ~16 × 6 × 6 cm, while the average length is 10 cm (Strack, 2006). Various localities may show slight morphological differences with regard to shape, size and thickness of the shells.

Margaritifera margaritifera is unique compared to freshwater mussels from the Unionidae family, which have far less demanding life cycles and shorter life expectancies. In particular, this mussel requires for its parasitic glochidial (larval) stage a host fish that is exclusively of the genus *Salmo*; in central Europe the salmonid is the brown trout (*Salmo trutta fario*) and in western and northern Europe it is the Atlantic salmon (*Salmo salar*). The reliance on salmonids goes back to the earliest stages of the pearl mussel's development, when these fish carried the mussel larvae from the Mediterranean area to northern Europe (Strack, 2006).

Margaritifera margaritifera reaches sexual maturity at 15 years and remains fertile for the next 50–70 years. The breeding season starts in early summer, when female mussels transport their eggs from the gonads to special breeding chambers within their gills called marsupia. Fertilization takes place within the marsupia after male mussels from further upstream have released their sperm into the water. Tiny glochidia (larvae) form within four to six weeks. They are kept in the marsupia until July–August when water temperatures rise, and then are released into the water. Each female mussel can hold about 4 million larvae during one breeding season, and can produce about 200 million glochidia during her long active life. Although this is considered one of the highest fertility rates, survival is difficult, and of one million glochidia only about five survive (Strack, 2006).

The glochidia are only 0.07 mm when they are released into the water, but their bivalve shell is already fully developed. It has a hook on the shell rim and a larval thread, which enables several of them to connect into small balls and attach themselves into the gills of a host fish using their strong contractor muscles. New juvenile host fish are required each season, as the fish become immune once they have carried the glochidia. The host fish reacts to the glochidia by secreting a cover around them, and for the next six months the enclosed larvae transform into juvenile mussels. (The relationship between glochidia and host fish can be seen as a type of non-simultaneous symbiosis, in which the host fishes will later benefit from the filtering capacity of adult mussels in keeping the water clean.) In early summer of the following year, the mussels break through the cover secreted by the host fish and fall to the ground. At this time they measure 0.5 mm long and will dig themselves into the substrate where they will spend the next five years. Having attained a size of 1 cm, those that survive this period (about 5%) return above ground where they will spend the rest of their lives (Strack, 2006).

Transportation of glochidia by a host fish enables them to reach the upper regions of a river or stream, and an even wider distribution may occur if birds or other animals feed on the host fish. The complicated growth history of the larvae may also be designed to prevent them from moving downriver and eventually reaching the sea (as saltwater is toxic to freshwater mussels). It is only during the past 50 years that *Margaritifera margaritifera*'s life cycle has been fully understood, thus enabling an appreciation of the mortality factors that are faced by juvenile and adult mussels.

Russian Freshwater Pearls

Pearl Mussel Distribution

Originally, *Margaritifera margaritifera* occurred in a wide area of north-western Russia that stretched from Lithuania in the west to the slopes of the Ural Mountains in the east, and from the tributaries of the Don and Volga Rivers in the south to the White Sea in the north. The mussels formerly were especially abundant in rivers and streams flowing into the White Sea, where the Atlantic salmon served as a host fish (Korago,

Figure 4: The former range of Margaritifera margaritifera *mussels (shown in yellow) extended from the Iberian Peninsula in south-eastern Europe to Finland and north-western Russia. The outlined area refers to the view shown in Figure 5. Modified from http://maps.iucnredlist.org/map.html?id=12799.*

1981; Kaliuzhin, 2004). Today, large Russian populations of *Margaritifera margaritifera* remain only in the Keret River in Karelia and the Varzuga River on the Kola Peninsula (~6 and ~140 million mussels, respectively; see Figure 5; S. P. Kitaev, pers. comm., 2001; Makhrov et al., 2014; Popov and Ostrovsky, 2014). The Varzuga River hosts the largest uninterrupted population in Europe, with mussels living along an approximately 220 km stretch of river within an undisturbed, post-glacial ecosystem that provides adequate nourishment and space for breeding and survival (Ziuganov, 1994; Strack, 2006). Significant stocks have largely disappeared from most other rivers.

Pearl mussels also occurred in various rivers that spilled into Lake Ladoga and Lake Onega (particularly the terminus of the Kumsa, Oster and Vodla Rivers; see Ivanter and Kuznetsov, 1995; S. P. Kitaev, pers. comm., 2001).

In some areas, pearls were also produced from *Anodonta*, the common pond mussel belonging to the Unionidae family. They seem to have come particularly regularly from a lake near the city of Werh-Newinsk, 100 km north of Yekaterinburg in the Ural Mountains (Strack, 2006, p. 206).

Pearl Usage

The use of freshwater pearls for decoration and adornment in north-western Russia goes back to the Middle Ages. Pearls became more generally used towards the end of the 18th century. One might even say that they came into fashion during that time, and this lasted until the end of the Russian empire under the Romanoff dynasty in 1917 (Korago, 1981). Traditional festive linen or silk dresses were embroidered with pearls, which also were used to embellish kokoshniks, the tiara-like headdresses worn in traditional costume

Figure 5: The map shows the main rivers and former pearling centres in Karelia and on the Kola Peninsula in north-western Russia. After Strack (2006).

(Figure 6). Kokoshniks were not only embroidered with pearls, but were decorated in the forehead area with pearl strings in net-like, interwoven and tasselled patterns. Earrings were often made of fine pearl strings that were similarly arranged in a garland or flower pattern (e.g. Figure 2).

Pearling centres developed along the Dvina River and its tributaries near the city of Arkhangelsk, on the Keret and Kem Rivers in Karelia and on the Kola Peninsula (particularly near the Umba and Varzuga Rivers; Figure 5). Apart from the villages, where talented local women did the craftwork, professional workshops for pearl embroideries also opened up in some cities. The city of Kem, founded in 1783 and situated on the White Sea at the mouth of the Kem River, was particularly important, and the string of pearls that is shown on the city's coat of arms (Figure 7) bears witness to this. Another Karelian centre for working with pearls was the small city of Olonez, capital of a governorate with the same name, situated near Lake Ladoga. Olonez was an important and wealthy city in the past, but has fallen into obscurity since then and therefore was not included in the field research described below.

Figure 6: A pearl-bearing kokoshnik is worn by Princess Olga Konstantinovna Orlova as part of a masquerade costume for a ball in 1903. The original photograph measures 50.5 × 36.5 cm and was taken by Elena Mrozovskaya.

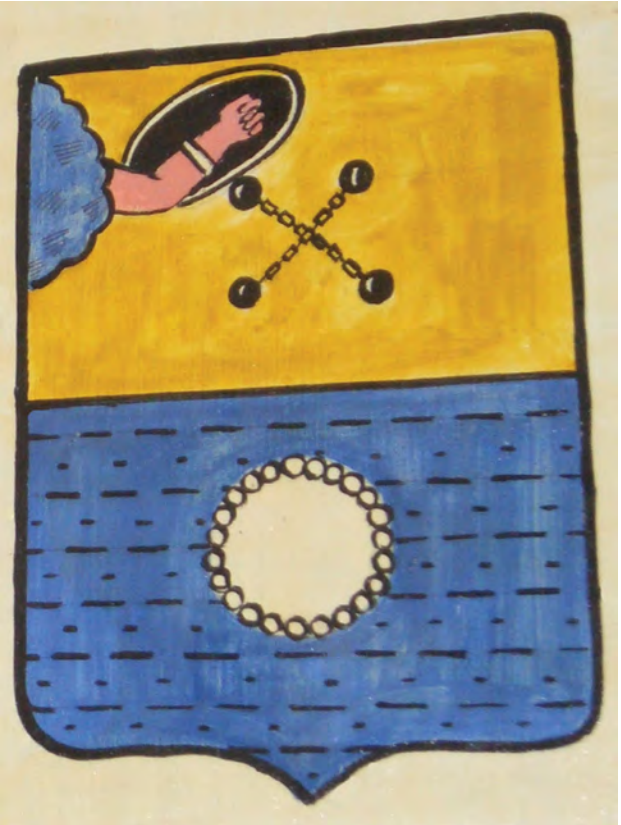

Figure 7: The coat of arms of the city of Kem, a 18th–19th century pearling centre at the mouth of the Kem River on the White Sea, includes a string of pearls in the form of a round necklace. The upper part depicts an arm emerging from a cloud that holds a shield which, together with the cannon balls underneath, alludes to the importance of Kem as a military base in the border region of the Olonez governorate. Courtesy of the Museum of the Coast, Kem, Russia; Photo by E. Strack.

In rural areas, the mussel shells themselves also were worked into buttons or other objects, and a number of small workshops existed along some of the northern rivers until the early Soviet era.

The Russian Museum of Ethnography in St Petersburg houses one of the most exquisite collections of Russian pearl works. The museum not only displays good examples of the quality and status of preservation of pearl-bearing objects prior to the Russian Revolution in 1917, but it also provides an image of traditional village life that has disappeared in modern times. Additional pearl holdings are present in the Armoury Chamber of the Kremlin in Moscow, which focuses on ecclesiastical treasures. The Russian Orthodox Church secured a considerable portion of the pearl riches in north-Russian rivers where it often held fishing rights. Chasubles for priests and antependia (altar-front decorations) were embroidered with pearls since the 10th century, and pearls also were used for devotional works such as chalices, book covers, crosses (so-called *panagia*), mitres and icons. The goldsmiths and silversmiths who created these objects often made lavish use of both pearls and floral designs.

Since 1721, by a decree of Peter the Great, all pearl rights belonged to the czar. This was revised in 1731, although large pearls still had to go to the imperial crown. It is questionable whether this rule was strictly followed by people in the villages. During the 18th and 19th centuries, young lads and women in villages that did laundry in the streams often searched for pearls, mainly using their toes to look for the mussels.

The first two decades of the Soviet era (1922–1991) saw a continuous decline in both the populations of pearl mussels (mostly as a result of pollution by various industries) and pearl production. Even more significant was an increasing lack of interest in pearls that went hand-in-hand with the establishment of the new political system. By this time, those who had used and appreciated pearls in the past—such as the local nobility, well-to-do citizens or the *kulaks* (wealthy village families)—no longer existed. In the aftermath of the revolution, they had left the country, been killed or gone into hiding by integrating themselves into early Soviet society. Also, when religious practices were forbidden after the Russian Revolution, devotional objects that used pearls were no longer produced.

Almost certainly, pearls continued to be found during the first decades after the Russian Revolution, but they are difficult or impossible to trace today. Interest in pearls decreased further in the decades after World War II. In 1966, the Soviet Ministry of Fisheries forbade the harvesting of pearl mussels in a number of rivers, and in 1985 it was completely prohibited (Makhrov et al., 2014). In 1995, *Margaritifera margaritifera* was listed as endangered in the *Red Data Book of Karelia* (Ivanter and Kuznetsov, 1995). In addition, all species of *Margaritifera* are listed as endangered in the *Red Data Book of the Russian Federation* (S. P. Kitaev, pers. comm., 2001).

Today Russian pearls are no longer significant within the country or on the world market, and since they are no longer harvested, they have practically been forgotten.

Field Research

To obtain updated information on Russian freshwater pearls, the author travelled to Karelia and the Kola Peninsula in 2001, 2006 and 2008. Visits were made to the towns of Umba, Kuzomen and Varzuga on the White Sea coast of the Kola Peninsula; the village of Keret and the city of Kem in Karelia; as well as the cities of Arkhangelsk on the coast of the White Sea and Petrozavodsk, the capital of Karelia, situated at Lake Onega. Interviews were conducted with local authorities, scientists and village citizens (approximately 13 people in total). The citizen interviews concentrated on elderly people (between 70 and 80 years old) who had grown up in the 1930s and 1940s. None of those interviewed remembered ever seeing pearls or having searched for them (or knew people who did). All persons agreed that pearls were never spoken about, although there seemed to be some vague collective knowledge among the elderly people interviewed that pearls had been found locally in the past. Not one family in the villages was known to possess local pearls. A retired fisheries inspector in Keret village reported that in 1974 an expedition from Moscow found 415 pearls in the area, but he could not give details, as at the time he was not allowed to ask questions.

Government authorities at the Fisheries Office in Umba and at the Fisheries Cooperative in Varzuga were well informed of the importance of the pearl mussel's symbiosis with local salmon populations (see also Kaliuzhin, 2004). However, all those interviewed agreed that pearls were an item of the past (and they did not seem interested in following up on the matter). Albeit, the head of the salmon cooperative in Varzuga was aware that a considerable number of pearls probably exists among the ~140 million pearl mussels that are thought to inhabit the Varzuga River. It is estimated that about four or five pearls can be harvested from every 1,000 mussels (V. Ziuganov, pers. comm., 1999; Strack, 2006).

Varzuga village, situated about 30 km inland from the mouth of Varzuga River, is an important religious centre for the White Sea coast. A monastery was established there in the second half of the 15th century by monks from the Solovetsky Islands. The monastery no longer exists, but Varzuga still has the oldest wooden church on the Kola Peninsula (built in 1674) and remains a place of religious pilgrimage. The local priest, Mitrofan Badanin, who has been Bishop of the Severomorsk and Umba regions of the Kola Peninsula since 2013, was a highly respected authority in Varzuga. A former high-ranking navy officer and a learned man, he stated that all old treasures and written records on the southern coast of the Kola Peninsula disappeared during the Soviet era when the churches were partially destroyed or used for other purposes. Only a few icons remain in the churches today, and these were made in recent times and decorated with inexpensive Chinese freshwater cultured pearls that seem to find their way to even the remotest corners of the world. Unfortunately, these recent icons have no artistic value.

Varzuga has no museum that traces the area's history, but due to its position as a centre for salmon fishing it is a busy village. Some families rent houses to the few visitors, mainly Russian scientists on summer excursions and a few Scandinavian tourists who come for the fishing. The author was told by her hosts in Varzuga that so far no foreigners have asked questions about pearls or pearl mussels.

Kuzomen village, situated at the mouth of Varzuga River on the White Sea, was once also a local salmon fishing centre (and consequently a source of pearls). The village is now nearly deserted, and is characterized by extreme poverty and desolation. It is connected with Umba by a bus that travels only once a week. An elderly lady, one of the perhaps 100 people still living in Kuzomen and a retired school teacher, indicated that there was no longer any knowledge of pearls in the village. The same opinion was encountered in Keret village, where the few elderly people still living there in partly broken-down houses hardly knew that pearls came from the area in the past. One of the better-kept wooden houses in Keret village belonged to the local fisheries inspector. He was in charge of a government programme for sustaining and restoring mussel populations in the Keret River, which was undertaken for environmental reasons and to secure the salmon population. Timber floating, hydro-engineering construction and industrial pollution have over the decades taken a toll on the salmon population, and thus of the pearl mussel's host fish (Makhrov et al., 2014). The restoration programme has so-far been successful, as the river still hosts about 6 million pearl mussels. Pearls do not seem to be on the governmental agenda.

Figure 8: This late-19th-century kokoshnik is embroidered with small imitation pearls (which also form the tassels) together with larger Russian freshwater pearls. The natural pearls range up to 7 mm, have off-round shapes and are strikingly white. Courtesy of the Museum of History, Culture and Life of Tersky Pomors, Umba, Russia; photo by E. Strack.

The busy town of Umba is situated in the western Tersky coast (i.e. the southern coast of Kola Peninsula) and is connected to Kirov-Apatity by a well-maintained system of roads. The city was once a pearling centre for the Umba River and continues to be a base for salmon fishing. The local fisheries office houses breeding facilities for both pearl mussels and salmon. The most extensive collection of artefacts and objects relating to Russian pearl fishing is found in Umba's Museum of History, Culture and Life of Tersky Pomors. On display are photographs of local pearl fishermen, as well as samples of the equipment (e.g. knives and collecting bags) that they used. Photographs include local village women in their festive dresses, and the museum also owns one kokoshnik that is abundantly decorated with pearls (Figure 8). They were incorporated into the flat top of the kokoshnik, as well as in the ear flaps and within tassel-like rows overhanging the forehead; these features are characteristic of kokoshniks from the Olonez area (Srebrodolski, 1985; Bespalaya et al., 2012).

A similar kokoshnik is owned by the Museum of the Coast in Kem. In addition, the collection includes village costumes and paintings/photographs that show wealthy village women wearing pearl-embroidered kokoshniks and pearl necklaces.

Materials and Methods

Due to the historical and present situation in Russia described above, only a few pearl-bearing items could be located that were available for characterization.

During the author's visit to the museum in Umba, the museum's director kindly allowed the kokoshnik (Figure 8) to be removed from its glass case for closer examination with a loupe and UV lamp equipped with long-wave (366 nm) and short-wave (254 nm) bulbs.

In June 1998, the author had the opportunity to examine a number of pearl objects at The Russian Museum of Ethnography in St Petersburg: several pairs of earrings from around 1800 (e.g. Figure 2), a kokoshnik (Figure 1) and a red velvet belt from the 19th century, and various necklaces from the late 19th century. These pieces were examined with an optical microscope (up to 80× magnification) and the UV lamp mentioned above.

Also in 2008, the author examined a necklace that was taken out of Russia by a Russian family in the 1920s (Figure 9). The pearls may have been harvested in the years before World War I or in

Figure 9: This necklace of Russian freshwater pearls has been owned by a family of Russian origin since the 1920s. The pearls range from 5.0 × 4.5 mm to 8.2 × 7.0 mm and have baroque shapes, are white to light grey and light to dark 'cream', and show distinct growth characteristics. The clasp is a modern addition. Photo by E. Strack.

the 19th century. The necklace was available for a limited amount of time, and only visual observation was possible.

Three additional pearls (Figures 10–12), harvested in the 1990s, were examined in 1999. They were made available by Russian fisheries biologist Valeriy Ziuganov, who obtained them during his studies of the Varzuga River. The pearls were examined using a gemmological microscope and the UV lamp mentioned above, and radiographs were taken with a Kodak 2200 digital X-ray system (60–70 kV, 49 W).

Results

Pearls from the 18th and 19th Centuries

Kokoshnik from the Umba Museum: Examination with a loupe and a UV lamp revealed that the small 'pearls' in this kokoshnik were imitations, and only the larger ones (up to 7 mm) were natural freshwater pearls, present both individually and arranged into rosettes.

Samples from The Russian Museum of Ethnography: The earrings consisted of small pearl strings that were arranged to form drops and rosettes. The kokoshnik and the red velvet belt were decorated with strings of pearls in tulip and rose patterns. The necklaces consisted of multiple strings; the most notable were a four-strand necklace originally attached to a kokoshnik and worn under the chin, and a necklace consisting of 14 rows that were about 40 cm long.

The pearls in these objects averaged 1–4 mm, while the largest measured 7 mm and 9 mm and were present at the centre of the necklaces. Their colours ranged from white and light 'cream' to light grey. A few pearls were greyish brown, brownish orange and brownish purple. Several showed a distinct dividing line in the centre that separated white and brownish grey halves. There were no overtones observed. Lustre was generally dull, with the darker colours showing no lustre at all. Shapes included off-round, flat, barrel, button and baroque. Most of the pearls

Figure 10: A barrel-shaped pearl from Varzuga River, measuring 7.08 × 6.77 × 6.72 mm (2.68 ct), is shown in these three views. This grey pearl has a brown dividing line in the middle (a), a brown spot at one end (b) and an indented area on the other end that is surrounded by cracks (c). Photos by E. Strack.

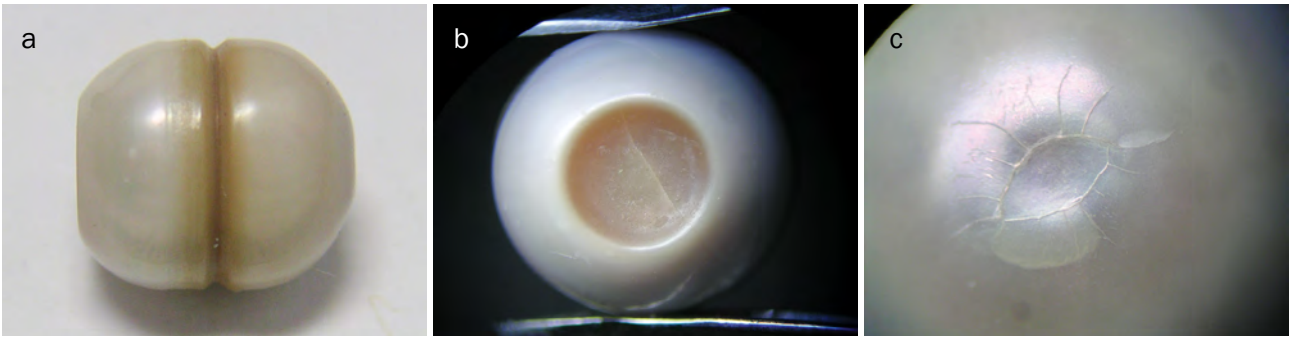

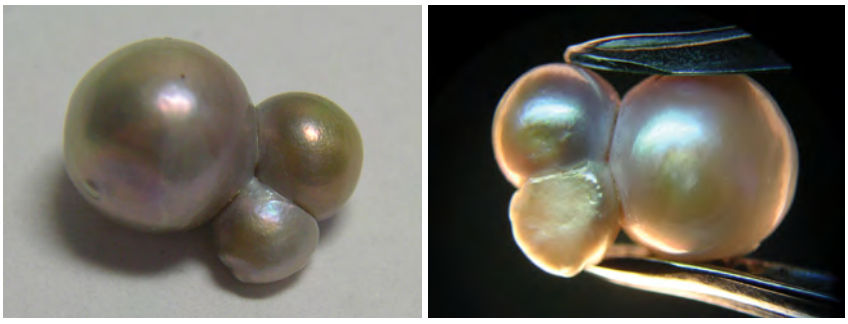

Figure 11: This intergrowth of three Varzuga River pearls measuring 3.18, 3.77 and 5.62 mm each is shown from the front (left photo) and back (right photo). It is greyish purple with 'bronze'-coloured areas and shows good lustre. The flat face on the back of the smallest pearl shows surface wrinkling that is characteristic for pearls of freshwater origin. Photos by E. Strack.

had flat areas with a wrinkled growth pattern on their surfaces.

Microscopic examination of a few of the light grey pearls showed tiny fractures below the surface that may be interpreted as signs of dehydration of originally white pearls. All of the pearls showed an evenly distributed faint blue to whitish blue fluorescence to long-wave UV radiation that was distinctly weaker to short-wave UV.

Nearly all of the items from The Russian Museum of Ethnography consisted entirely of natural freshwater pearls, and only a few small imitation pearls or small mother-of-pearl beads were noted.

Pearls from the 19th/20th Century

Necklace Owned by a Russian Family: This necklace consisted of baroque pearls ranging from 5.0 × 4.5 mm to 8.2 × 7.0 mm. The colours were white to light grey and light to dark 'cream'. Most of the pearls showed distinct growth characteristics, including a characteristic wrinkling on their flat surfaces.

Loose Pearls: The three loose pearls obtained from Valeriy Ziuganov are described as follows:

- A barrel-shaped pearl measured 7.08 × 6.77 × 6.72 mm (2.68 ct), and was grey with a brown dividing line in the middle (Figure 10a, similar to that observed in some pearls from The Russian Museum of Ethnography). One end of the pearl showed a brown spot (Figure 10b), while the other end was indented with associated cracks (Figure 10c). The lustre was dull.
- A sample consisting of three intergrown pearls with diameters of 3.18, 3.77 and 5.62 mm (1.83 ct total) was greyish purple with 'bronze'-coloured areas (Figure 11). The lustre was good. Microscopic examination revealed surface wrinkling on flat areas that is characteristically observed with pearls of freshwater origin.
- A drop-shaped pearl that measured 10.96 × 4.82 × 4.40 mm (1.27 ct) showed a greyish purple coloration similar to that of the triple pearl described above, with a bluish pink overtone and light brown portions (Figure 12a). Surface cracks were present on one side of the pearl (Figure 12b), and an opening on the other side showed a white colour and a surface micro-structure that appeared to consist of tiny rounded points that resembled nail heads (Figure 12c). Lustre was good.

Figure 12: These photos show a drop-shaped pearl from Varzuga River that measures 10.96 × 4.82 × 4.40 mm. It displays a greyish purple colour with a bluish pink overtone and light brown areas (a). (b) The 'bulb' of the pearl shows surface cracks on the front side (b) and a white opening on the underside with a structure made up of tiny rounded points that were visible at higher magnification (c). Photos by E. Strack.

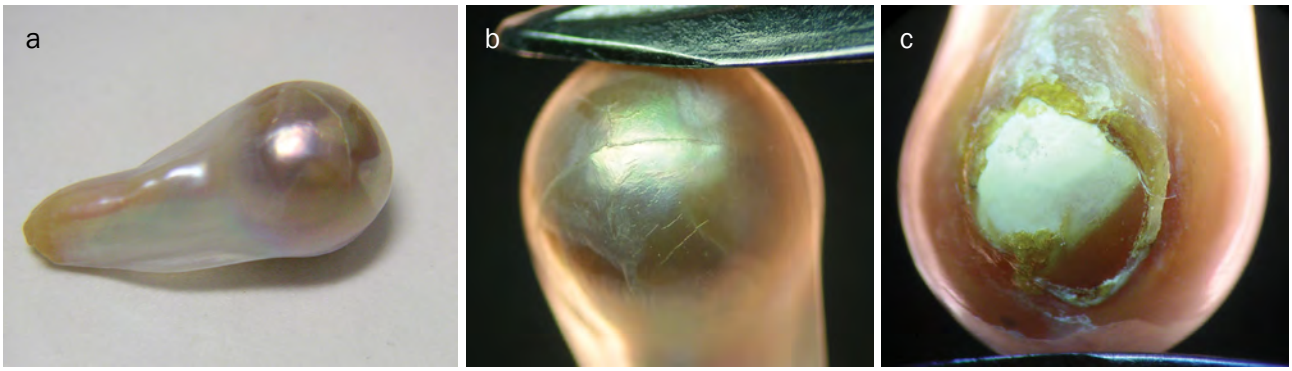

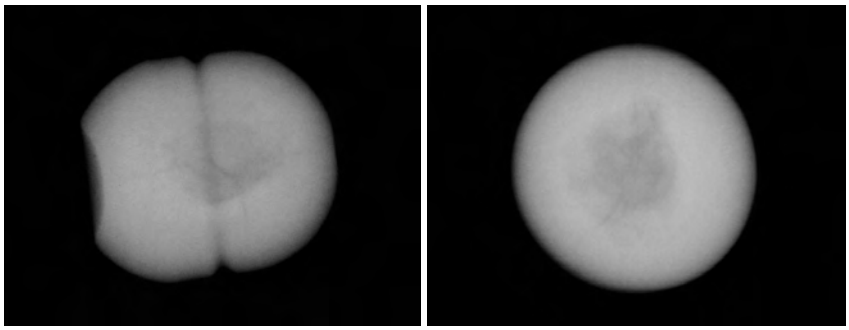

Figure 13: These radiographs of the barrel-shaped pearl in Figure 10 (~7.1 mm long and 6.7 mm in diameter) were taken at orientations parallel to and at right angles to its long axis. They reveal an irregular area of organic substance in the centre of the pearl, which appears dark in the radiographs. Radiographs by E. Strack.

All three pearl specimens showed a weak blue UV fluorescence that was weaker in short-wave than in long-wave UV radiation. Radiographs of the pearls showed irregular and linear deposits of organic substance (Figures 13–15).

Conclusion

The European freshwater pearl mussel *Margaritifera margaritifera* has largely disappeared from its original distribution area in rivers and streams flowing into the White Sea in north-western Russia. Apart from a number of small populations in several rivers, only the Varzuga and Keret Rivers still hold large stocks. The species has been listed as endangered in the IUCN Red List since 1996, and pearl fishing has been prohibited in Russia since 1985, so there has been no significant recent production of these pearls. Moreover, in the decades since the Russian Revolution in 1917, there has been a general lack of local interest and knowledge of pearls.

A limited number of Russian freshwater pearl samples was available for study, including several 18th–19th century objects from museums in St Petersburg and Umba, a necklace from the 1920s and three loose pearls collected from the Varzuga River in the 1990s. The pearls ranged from ~1 to 11 mm and their colours were predominantly white, light 'cream' and light grey; some brownish hues also were present. Their lustre varied from dull to good, and shapes included off-round, flat, barrel, button and baroque. Most of the pearls showed a wrinkled growth pattern on flat surfaces. Varying numbers of imitation pearls (all of small size) were found in the objects studied from the museum collections. X-radiography of the three loose pearls revealed irregular and linear deposits of organic substance.

Figure 14: The radiograph of the pearl intergrowth in Figure 11 shows a circle-shaped, thin linear deposit of organic material that is located just underneath the outer rim of the two larger pearls (~3.9 and 5.6 mm in diameter) and follows their outline. These circular features could initially be interpreted as beads, which obviously is not the case for this natural pearl specimen. In a cultured pearl, the demarcation line of a round bead would not necessarily follow the pearl's outline. Radiograph by E. Strack.

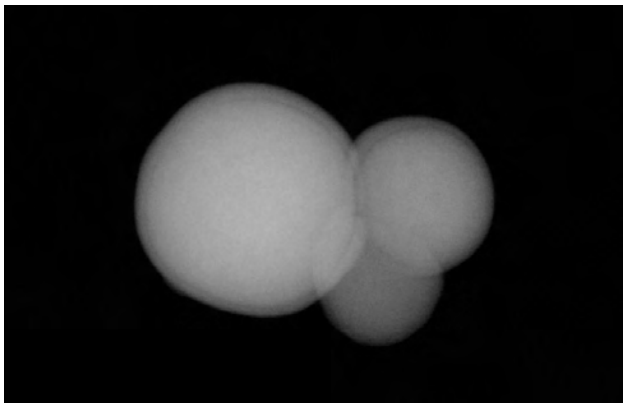

Figure 15: The radiograph of the drop-shaped pearl in Figure 12 (~11 mm long) shows a feature similar to that observed in the triple pearl. Within the 'bulb' is a circle-shaped, thin linear deposit of organic material slightly underneath the outer rim. At the centre of the bulb is a slightly darker core of organic substance. The 'tail' of the pearl has at its centre wavy branch-like extensions of organic material that are arranged parallel to one another along a common line. Radiograph by E. Strack.

Although Russian freshwater pearls are no longer known or encountered on the pearl market, they form an interesting part of European cultural history.

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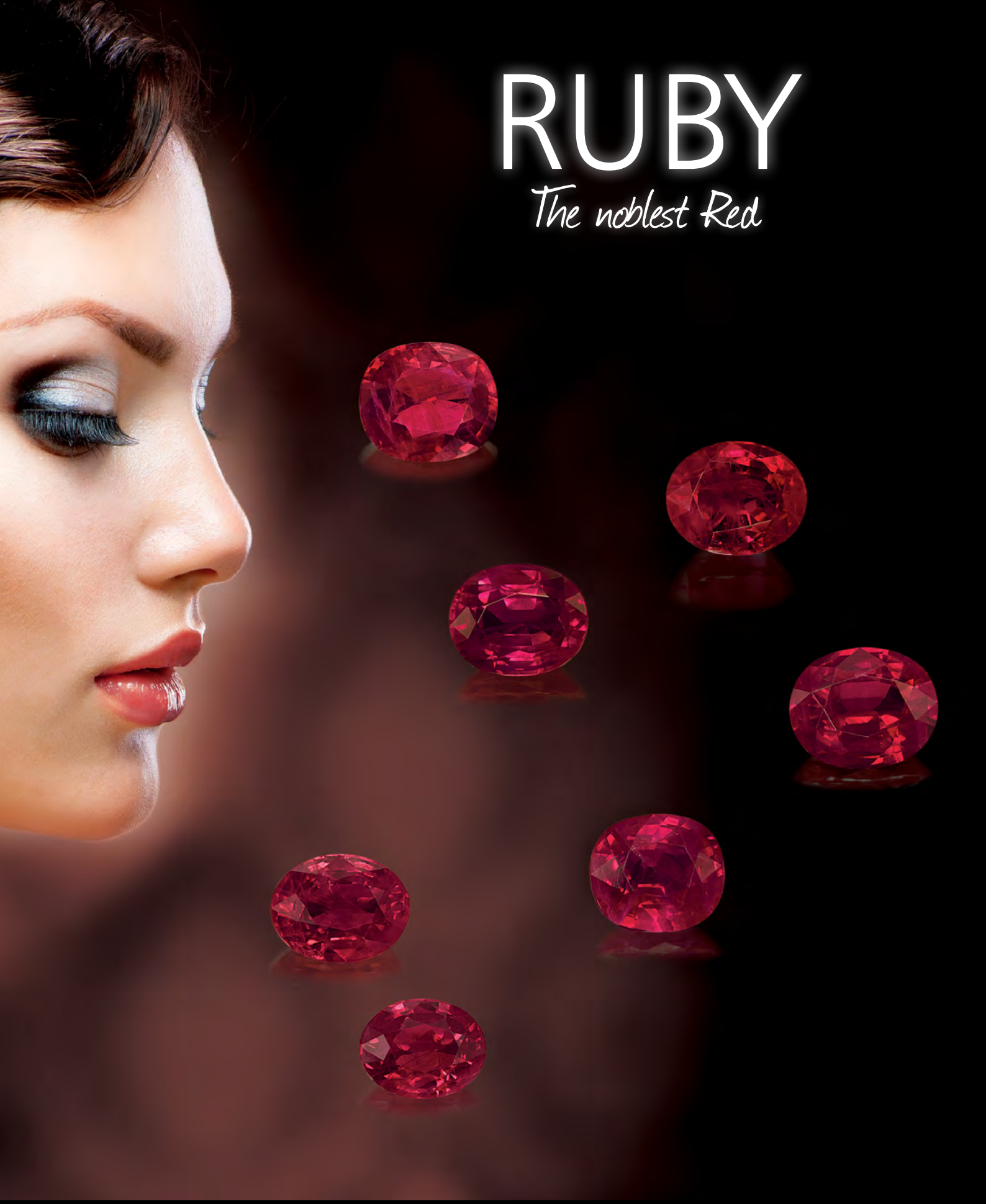

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Type Ib Yellow to Brownish Yellow CVD Synthetic Diamonds Seen at CGL

Hiroshi Kitawaki, Mio Hisanaga, Masahiro Yamamoto and Kentaro Emori

Fifteen yellow type Ib CVD synthetic diamonds were submitted to the Central Gem Laboratory (Tokyo, Japan) without disclosure in October 2014. They weighed between 0.18 and 0.40 ct and were cut as round brilliants. Their colour ranged between very light yellow and light yellow (some with a brownish tint), and they could not be distinguished visually from natural counterparts of similar colour. Infrared spectroscopy revealed isolated substitutional nitrogen in all the samples, which may be the main cause of their yellow colour. In addition, absorptions were recorded at 3032, 2948, ~2905 and ~2873 cm^{-1}, which are due to C-H-related defects and generally are not observed in natural diamonds. These features, together with optical centres such as H3, NV or N3 detected by photoluminescence spectroscopy, indicate that they underwent post-growth HPHT treatment at ~1,900–2,300+°C. The CVD synthetic origin of such gemstones can be identified by detecting the Si-related feature at 737 nm (when present) in low-temperature photoluminescence spectra, and by observing lamellar growth striations in the DiamondView.

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Background

Submission for grading of a large parcel of synthetic diamonds grown by chemical vapour deposition (CVD) was reported by the International Gemological Institute in Antwerp in 2012, and this caused turmoil in the diamond industry (Even-Zohar, 2012). Since then, reports of undisclosed CVD synthetics have emerged from gem testing laboratories in India and China (e.g. Song et al., 2012; D'Haenens-Johansson et al., 2013). The Central Gem Laboratory (CGL) also reported on an undisclosed 1+ ct CVD synthetic diamond (Kitawaki et al., 2013). Gem-quality CVD products have been improving in size and quality year after year, and their range of colours has widened to include pink and blue in addition to (near-) colourless (e.g. Kitawaki et al., 2010; Wang et al., 2010; Peretti et al., 2013). Most of those previously reported were type II. However, recently some yellow CVD synthetic diamonds containing isolated substitutional nitrogen were found in the market (Hainschwang, 2014; Moe et al., 2014). So far, published descriptions of such gemstones have been based only on single samples.

This report provides a comprehensive description of 15 yellow to brownish yellow type Ib CVD synthetic diamonds submitted to CGL without disclosure in October 2014, and diagnostic features to distinguish them from natural diamonds are discussed in detail for the first time.

Figure 1: These type Ib yellow CVD synthetic diamonds (0.18–0.40 ct) were submitted to the Central Gem Laboratory for grading without disclosure. Photo by H. Kitawaki.

Materials and Methods

The 15 samples were submitted to CGL as natural diamonds for standard grading (see Table I). All the samples were loose and faceted as round brilliants; they weighed 0.18–0.40 ct (Figures 1 and 2). Their colour and clarity were graded by experienced diamond graders at CGL in accordance with the GIA grading system. The samples were examined with a Motic GM168 stereo microscope, and Manaslu standard 4-watt long-wave (365 nm) and short-wave (254 nm) UV lamps were used to observe fluorescence reactions in a completely

Figure 2: Twelve of the 15 CVD synthetic diamonds fell in the colour range of very light yellow (below N colour) to light yellow (below S colour), and three were graded as light brownish yellow (below S colour). The samples weigh 0.18–0.40 ct and are shown consecutively from DAG0119 to DAG0133 (left to right). Photo by H. Kitawaki.

Table I: The 15 type Ib yellow CVD synthetic diamonds examined in this study.

Sample no.	Weight (ct)	Colour	Clarity	Fluorescence colour* (DiamondView)	N_s^0 (ppm)	H3/NV^0	IR bands in C-H stretching region (cm^{-1})
DAG0119	0.180	Light yellow	SI_2	Bluish green	4.77	1.65	2907, 2878
DAG0120	0.187	Light yellow	SI_2	Bluish green	5.37	1.03	2903, 2873
DAG0121	0.194	Very light yellow	SI_2	Yellowish green	7.24	1.36	2906, 2874
DAG0122	0.198	Light brownish yellow	SI_1	Str. yellowish green	3.90	0.89	2902, 2872
DAG0123	0.200	Light yellow	SI_1	Yellowish green	4.78	2.36	2908, 2875
DAG0124	0.201	Light yellow	SI_1	Yellowish green	4.12	2.23	2907, 2876,
DAG0125	0.210	Very light yellow	SI_1	Bluish green	1.11	1.77	2908, 2875
DAG0126	0.232	Light yellow	SI_2	Yellowish green	1.47	1.41	2905, 2873
DAG0127	0.237	Light yellow	SI_1	Bluish green	5.68	0.95	2905, 2873
DAG0128	0.268	Light yellow	VS_2	Yellowish green	1.78	0.74	2905, 2873
DAG0129	0.279	Light yellow	SI_1	Yellowish green	3.49	1.54	2905, 2873
DAG0130	0.305	Very light yellow	SI_1	Yellowish green	2.92	1.05	2905, 2874
DAG0131	0.316	Light yellow	VS_2	Yellowish green	3.73	1.01	2905, 2874
DAG0132	0.365	Light brownish yellow	SI_1	Str. yellowish green	2.70	0.64	2902, 2871
DAG0133	0.402	Light brownish yellow	SI_1	Str. yellowish green	1.12	0.93	2902, 2872

* Abbreviation: Str. = strongly.

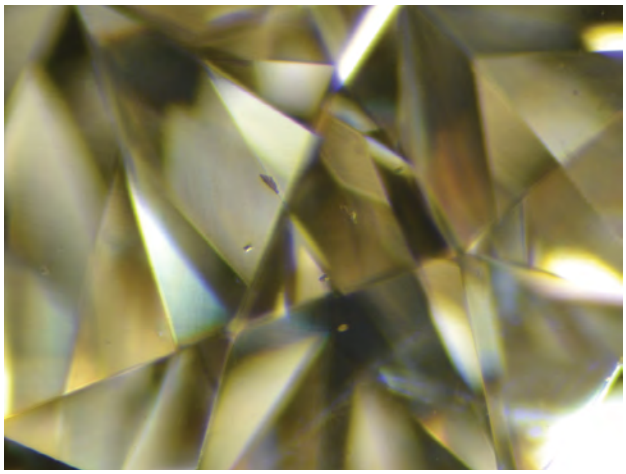

Figure 3: Each of the CVD synthetic diamonds contained irregular-shaped dark brown inclusions, presumably composed of non-diamond carbon. Photo by H. Kitawaki.

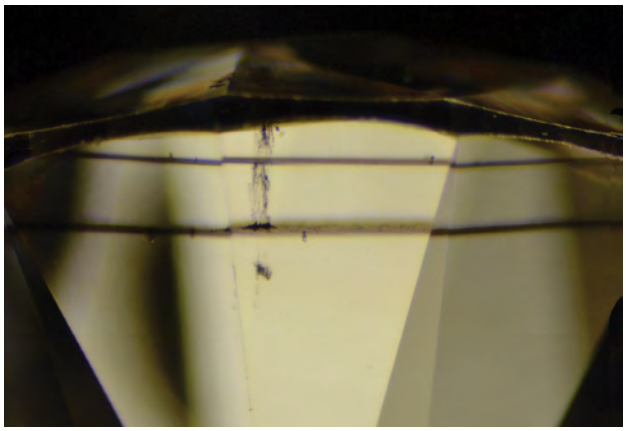

Figure 4: CVD sample DAG0133 shows two subparallel narrow straight bands of colour zoning. Photomicrograph by H. Kitawaki; image width 3.2 mm.

dark room. Ultraviolet-visible-near infrared (UV-Vis-NIR) absorption spectroscopy of all samples was performed at room temperature using a JASCO V-570 spectrometer between 220 and 1100 nm, with a bandwidth of 2.0 nm, resolution of 0.5 nm and scan speed of 400 nm/min. Infrared spectroscopy of all samples was carried out with a JASCO FT/IR-4200 spectrometer in the range 7000–400 cm^{-1} with a resolution of 4.0 cm^{-1} and 20 scans. Photoluminescence (PL) spectroscopy was performed on all samples while they were immersed in liquid nitrogen using a Renishaw Raman System 1000 instrument with several lasers (633, 514, 488 and 325 nm) in conjunction with a Renishaw inVia Raman microscope. All the samples also were tested with a DiamondPlus instrument, and their ultra-short-wave UV luminescence was observed with a DiamondView (both instruments developed by the Diamond Trading Company [DTC]).

Results and Discussion

Colour and Clarity

Of the 15 samples, 12 were in the colour range from very light yellow (below N colour) to light yellow (below S colour), and three were graded as light brownish yellow (below S colour). Two samples were clarity graded as VS_2, nine as SI_1 and four as SI_2. (Note that these are equivalent colour and clarity grades, since in Japan regulations of the Association of Gemmological Laboratories prohibit grading of synthetic diamonds.)

Figure 5: CVD sample DAG0126 contains many pinpoint inclusions arranged in a plane (left, image width 3.4 mm), which individually displayed a quadrilateral shape at higher magnification (right). Photomicrographs by H. Kitawaki.

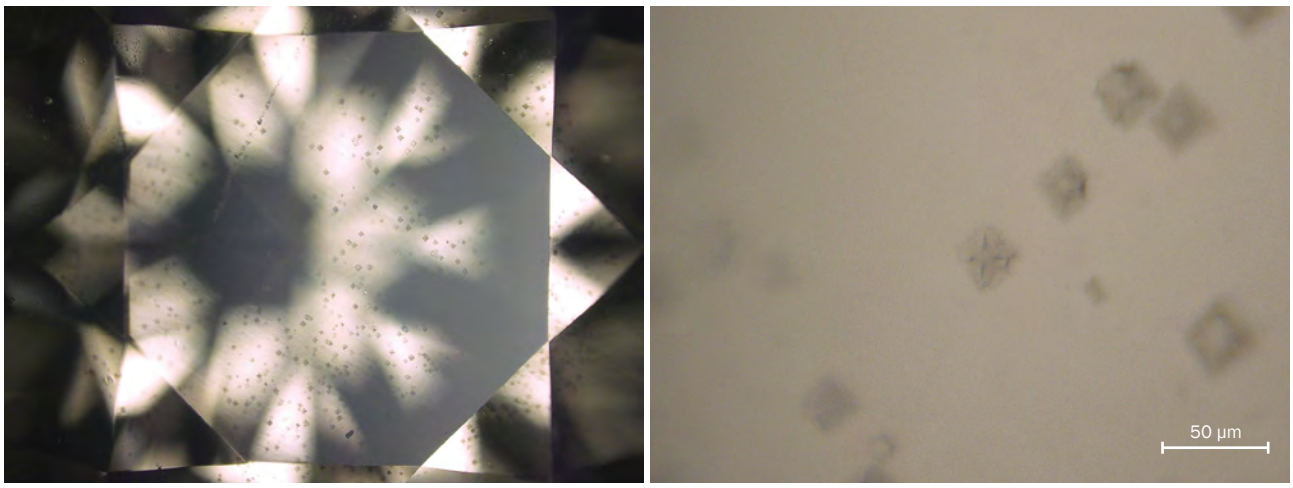

Microscopic Examination

Each sample contained a few pinpoint inclusions that were visible with a 10× loupe, which limited their clarity grade to VS or SI. When further magnified to several dozen times with the microscope, these inclusions appeared irregular shaped with a dark brown colour (Figure 3), and presumably consisted of non-diamond carbon. One sample (DAG0133) showed two narrow, subparallel, straight bands of colour zoning (Figure 4) that probably formed in response to growth from a seed crystal (which was not present). Another sample (DAG0126) contained many pinpoint inclusions arranged in a plane that displayed a quadrilateral shape under magnification (Figure 5). These were probably non-diamond carbon that were arranged in a {100} direction. Some of the samples showed dark areas of graphitization on their girdles (Figure 6). Similar features are seen in diamonds treated by high-pressure, high-temperature (HPHT) conditions (e.g. Moses et al., 1999), which strongly suggests that those samples underwent post-growth HPHT treatment.

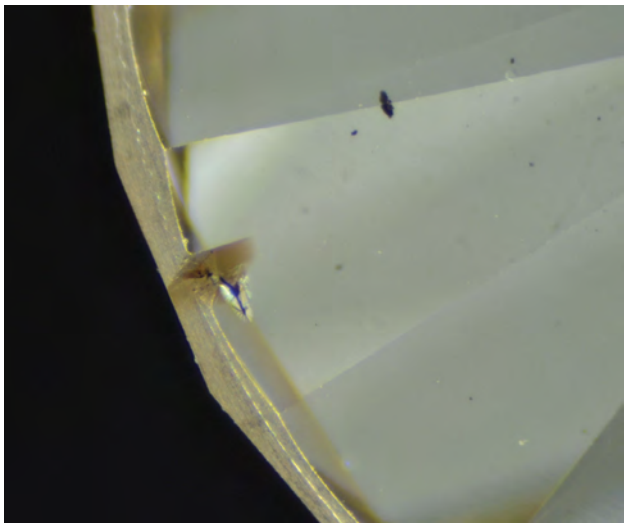

Figure 6: Some of the CVD synthetic diamonds showed dark areas of graphitization on their girdles. Photomicrograph by H. Kitawaki; image width 1.2 mm.

Birefringence

Microscopic examination with crossed polarizers revealed in all the samples a streaked pattern of anomalous double refraction due to strain (low-order black and white interference colours; Figure 7, bottom left). The streaks are interpreted to run parallel to the growth direction of the crystal, and were presumably caused by growth along screw dislocations derived from the interface between the seed crystal and the CVD overgrowth (Figure 7, right; cf. Gaukroger et al., 2008). This type of linear anomalous double refraction pattern is characteristic of CVD synthetic diamond (Martineau et al., 2004).

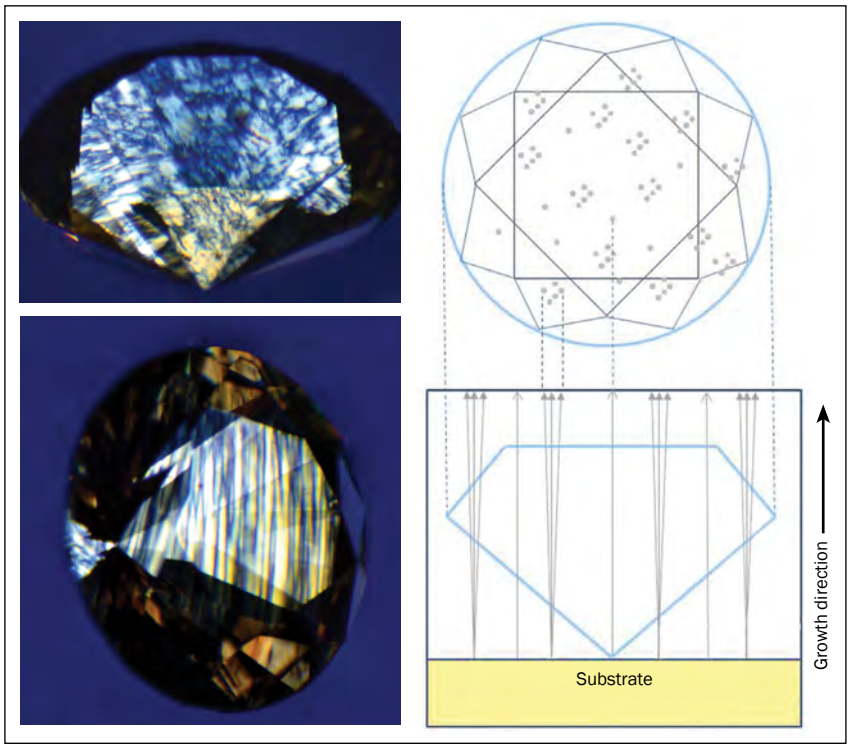

Figure 7: Microscopic observation of the CVD synthetic diamonds with crossed polarizers showed the characteristic streaked pattern of anomalous double refraction due to strain (bottom left). Viewed in certain orientations (top left), it may resemble the 'tatami' structure observed in natural type II diamonds. The schematic diagram shows the orientation of strain in a CVD synthetic diamond. Photos by H. Kitawaki; the diameter of the round brilliant is 4.66 mm.

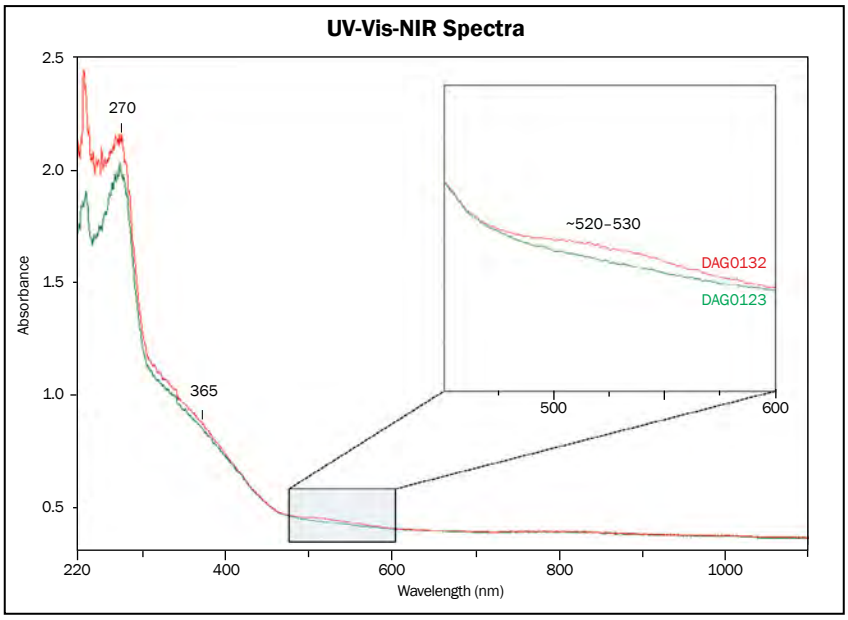

Figure 8: Representative room-temperature UV-Vis-NIR absorption spectra are shown for the light yellow (e.g. DAG0123) and light brownish yellow (e.g. DAG0132) CVD synthetic diamonds. A broad absorption band centred at 270 nm due to isolated nitrogen was observed in all the samples, and a broad band centred at ~520–530 nm was additionally present in only the brownish yellow gemstones.

However, when viewed perpendicular to the growth direction, the birefringence exhibited a fine intersecting mesh pattern (Figure 7, top left), which may resemble the 'tatami' structure observed in natural type II diamonds. Therefore, care should be taken to avoid confusion when observing such birefringence patterns.

UV Fluorescence

All the samples fluoresced yellow-green to both the long- and short-wave UV lamps. Similar-coloured phosphorescence lasting several seconds also was observed. The fluorescence intensity was weak to moderate, with a stronger reaction to short-wave UV.

UV-Vis-NIR Spectroscopy

All the samples showed gradually increasing absorption from the infrared region to near 600 nm in the visible spectrum, and the absorption rapidly increased beyond ~470–480 nm (Figure 8). A broad absorption centred at 270 nm also was observed in all the samples. These features are due to isolated substitutional nitrogen (Dyer et al., 1965). The three samples that had a brownish tint also showed a broad absorption band centred at ~520–530 nm (Figure 8). Martineau et al. (2004) reported that CVD synthetic diamonds synthesized at a high growth rate by doping with nitrogen showed absorptions at 270, 365 and 520 nm, and the latter two features vanished after HPHT treatment. Also, Khan et al. (2010) reported that as-grown brown CVD synthetic diamonds showed absorption bands at 270, 360 and 515 nm, and the band at 515 nm reportedly originated from a neutral complex consisting of nitrogen, a vacancy and hydrogen (NVH^0).

Infrared Spectroscopy

Absorption bands due to isolated substitutional nitrogen were detected at 1344, 1332 and 1130 cm^{-1} in all samples (Figure 9). The bands at 1344 and 1130 cm^{-1} are due to a neutral substitutional nitrogen centre (N_s^0; Collins et al., 1987), and the 1332 cm^{-1} band is associated with a positively charged state (N_s^+; Lawson et al., 1998). From the intensities of these peaks, concentrations of isolated nitrogen were estimated at 1.1–7.2 ppm (see Table I) by the method of Woods et al. (1990). Also, several features between ~3200 and 2800 cm^{-1} that are attributed to C-H-related defects were detected in all the samples. These absorptions were located at 3107, 3032, 2948, ~2905 (varied from 2908 to 2903 in different samples) and ~2873 (varied from 2878 to 2873) cm^{-1} in the 12 samples of yellow colour, while the latter two absorptions were shifted to slightly lower wavelengths (2902 and 2872–2871 cm^{-1}) in the three gemstones showing a brownish tinge (see Table I and Figure 9). Wang et al. (2010) and Kitawaki et al. (2010) reported similar absorption features in pink CVD synthetic diamonds.

PL Spectroscopy

PL spectra obtained with the 633 nm laser are shown in Figure 10. The Si-related feature at 737

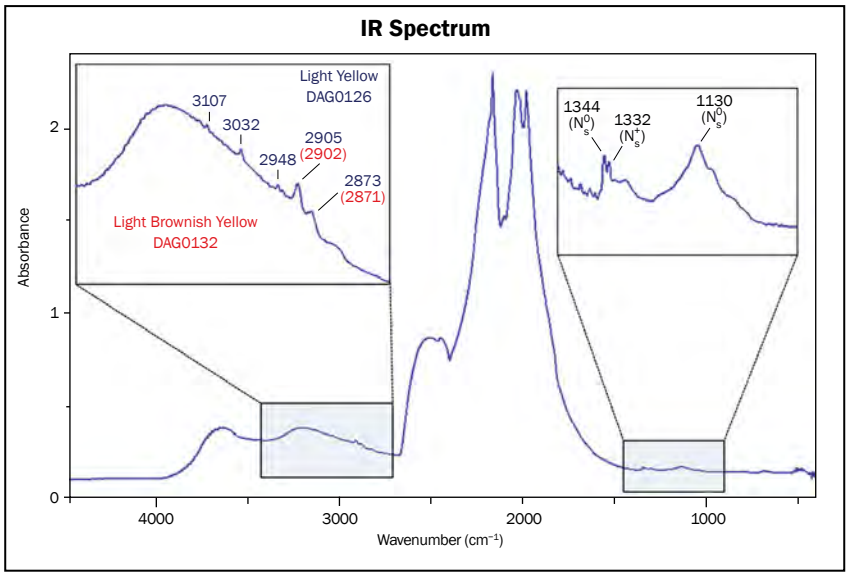

Figure 9: Infrared absorption spectra of the CVD synthetic diamonds (here, for yellow sample DAG0126) show bands due to isolated substitutional nitrogen at 1344, 1332 and 1130 cm^{-1}. In addition, C-H-related features are seen at ~2905 and ~2873 cm^{-1}; these are shifted to 2902 and ~2871 cm^{-1}, respectively, in the brownish yellow gemstones (e.g. DAG0132).

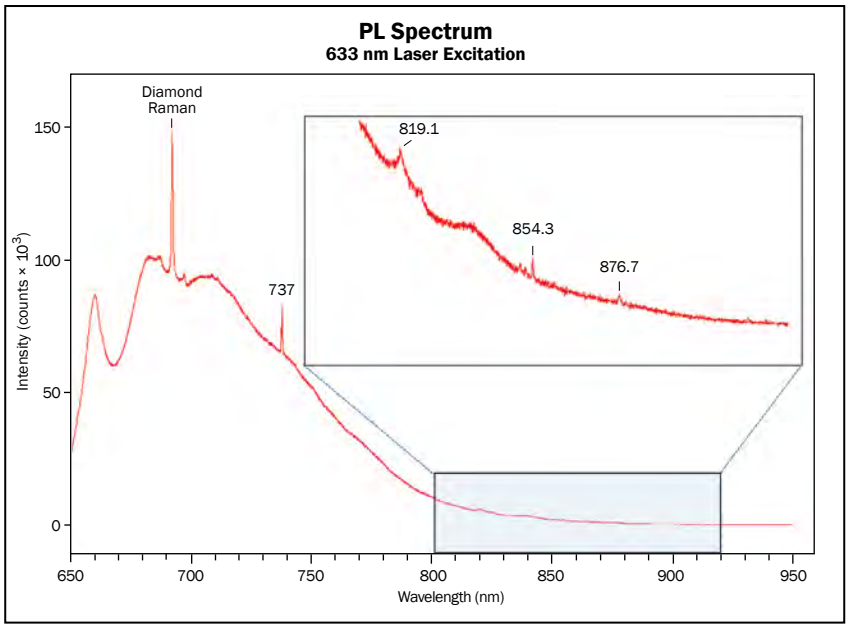

Figure 10: PL spectroscopy using 633 nm laser excitation detected the Si-related feature at 737 nm (actually a 736.4/736.8 doublet) in 13 of the 15 CVD samples, as shown here for sample DAG0120.

nm (actually a 736.4/736.8 doublet, seen when recorded at low temperature) was detected in 13 of the 15 samples (absent from DAG0122 and DAG0125), and this peak was very weak in five of them. Detection of the 737 nm feature in natural diamond is highly unusual, and where present it is accompanied by a series of peaks at 649.4, 651.1 and 714.7 nm (Breeding et al., 2008). The 737 nm feature has been detected in most gem-quality CVD synthetic diamonds previously reported. It is thought to originate from Si that is derived from the growth apparatus, and is regarded as a characteristic feature of CVD synthetic diamonds (e.g. Martineau et al., 2004; Wang et al., 2012). Therefore, although the 737 nm Si-related PL emission was only detected in 13 of the 15 samples studied, when present it is the most important indicator of CVD synthesis. Most of the samples showed small unattributed peaks at 795.8, 819.1, 824.6, 850.2, 851.6, 853.4, 854.3, 876.7 and 908.9 nm (not all of these are shown in Figure 10).

The PL spectra obtained with the 514 nm laser are shown in Figure 11. Very strong peaks at 575 nm (NV^0) and 637 nm (NV^-) were detected in all the samples. However, the 737 nm peak seen with the 633 nm laser was not evident in any of the samples using 514 nm excitation. A pair of peaks at 628.6 and 630.4 nm was detected in nine of the 15 samples. Most of the samples showed small unattributed peaks at 521.4, 524.1, 528.0, 529.1, 532.0, 533.0, 534.9, 536.5, 544.4, 554.0, 555.6 and 565.6 nm (not all of these are shown in Figure 11).

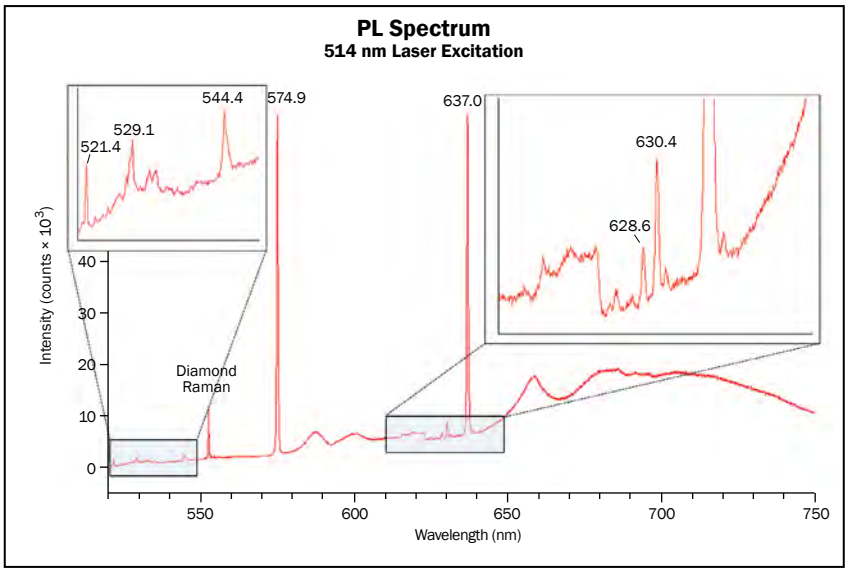

Figure 11: PL spectra obtained with the 514 nm laser show very strong peaks at 575 nm (NV^0) and 637 nm (NV^-). These peaks were seen in all the CVD samples, and are shown here for sample DAG0131.

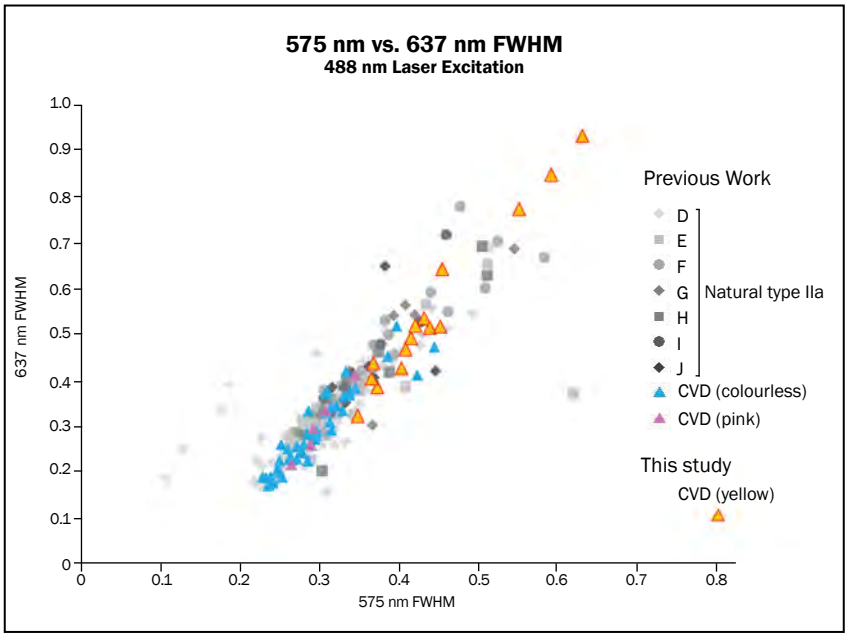

Figure 12: This diagram plots the full width at half maximum (FWHM) for PL data obtained with the 514 nm laser that are due to the 575 nm (NV^0) and 637 nm (NV^-) centres. The CVD synthetic diamonds examined in this study overlap the lower colour grades of natural type IIa diamonds from the authors' unpublished research (colourless and pink CVD synthetic diamonds are also shown for comparison).

The width of the zero-phonon line (ZPL) is known to increase in proportion to localized strain in diamond (Fisher et al., 2006). The full width at half maximum (FWHM) of the peaks at 575 and 637 nm obtained with the 514 nm laser are plotted in Figure 12 for all the samples, together with data for 167 natural type IIa diamonds and 44 CVD synthetic diamonds (of unknown manufacturer). The CVD samples consisted of 39 colourless to near-colourless and five pink samples that were previously analysed by CGL (unpublished data). Among the natural type IIa diamonds, stones with lower colour grades tend to show broader FWHM. Although the yellow CVD synthetic diamonds examined in this study overlap the lower colour grades of natural type IIa diamonds in the diagram, the colourless to near-colourless and pink CVD synthetic diamonds plot in the area of higher colour grades of natural type IIa diamonds.

Representative PL spectra obtained with the 488 nm laser are shown in Figure 13. Strong peaks at 503.2 nm (H3) and 574.9 nm (NV^0) were detected in all the samples. The intensity ratio of H3/NV^0 was between 0.74 and 2.36 for the 12 yellow samples, and was 0.64–0.93 for the three brownish yellow gemstones.

A typical PL spectrum from the 325 nm laser is shown in Figure 14. Other than a series of N3 peaks (ZPL at 415.2 nm, with smaller, relatively

broad peaks at 428.2, 438.8 nm, etc.), several features not seen in natural diamonds were detected (425, 428, 439, 441, 451, 453, 457, 462, 486, 492 and 499 nm; not shown in Figure 14). Martineau et al. (2004) and Wang et al. (2012) reported peaks at ~451–459 nm of unknown origin in CVD synthetic diamonds that had been HPHT treated after synthesis with intentionally doped nitrogen.

DiamondPlus Testing

The DiamondPlus is a compact device developed by DTC to detect HPHT-treated type II diamonds that have been commercially available since 2009. The testing takes 15 seconds per stone, and a 'Pass' result means the diamond is natural and untreated, whereas 'Refer' indicates that the sample requires further laboratory testing. The DiamondPlus is also designed to detect CVD synthetic diamond, and the presence of a 737 nm feature will give the result 'Refer (CVD Synthetic?)' along with its normalized peak intensity.

All 15 samples resulted in 'Refer (CVD Synthetic?)'. However, when re-tested on the device, some samples showed 'Refer' and some of those again produced 'Refer (CVD Synthetic?)' after further re-testing. Such samples had normalized intensities of only 0.057–0.179, and the inconsistent results are presumably due to the weak intensity of the 737 nm feature.

DiamondView Observations

The high-intensity ultra-short-wave UV (<225 nm) radiation of the DiamondView revealed that all the samples had an essentially green luminescence (due to the H3 centre), together with lamellar striations that are characteristic of CVD synthetic diamond (Figure 15). Similar-coloured phosphorescence also was observed in all samples. Three of the gemstones (DAG0122, DAG0132 and DAG0133) showed more yellowish luminescence (Figure 16, left), and four samples (DAG0119, DAG0120, DAG0125 and DAG0127) showed areas with a bluish overtone (Figure 16, right). The former three gemstones correspond to those that were colour graded as light brownish yellow, and their H3/NV^0 intensity ratios were lower than those of most of the other samples (Table I). In the four samples with the bluish overtone, N3 centres were detected by PL analysis.

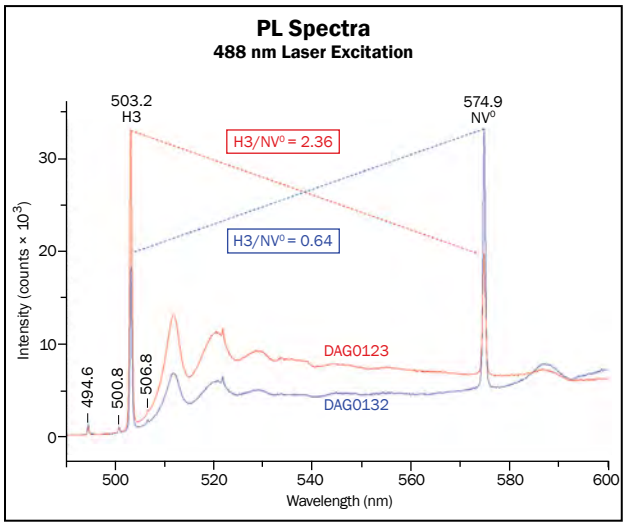

Figure 13: The PL spectra of all the CVD samples obtained with the 488 nm laser showed strong peaks due to H3 and NV centres. In general, the intensity ratio of H3/NV^0 from the yellow samples (here, DAG0123) was much higher than for the brownish yellow gemstones (here, DAG0132).

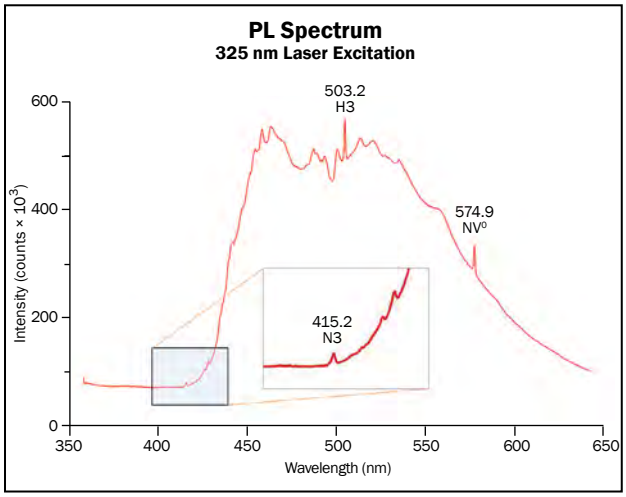

Figure 14: This representative PL spectrum obtained with the 325 nm laser shows weak emission at 415.2 nm from the N3 centre, which was detected in all the CVD samples.

Evidence for Post-growth HPHT Treatment

Most of the colourless to near-colourless CVD synthetic diamonds currently on the market have been intentionally doped with nitrogen to increase the growth rate (Theije et al., 2000). This results in a less attractive brown tint, so the material commonly undergoes post-growth HPHT treatment (Wang et al., 2012). The concentrations of isolated substitutional nitrogen in all the samples in this study confirmed that nitrogen was intentionally added during their growth.

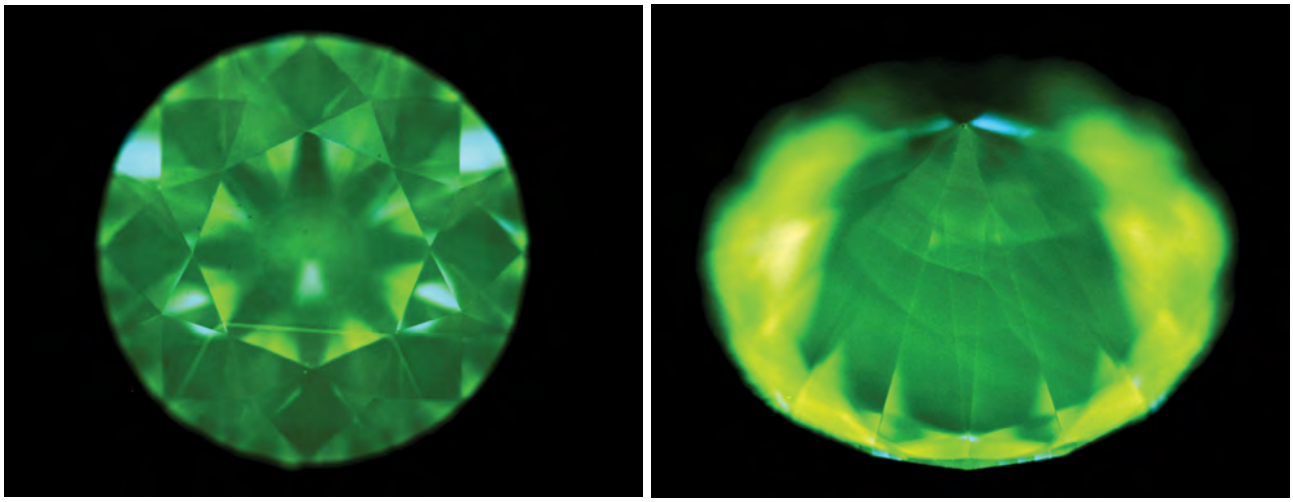

Figure 15: The DiamondView excited green luminescence in all the samples due to the H3 centre (left), together with a lamellar pattern of striations that is characteristic of CVD synthetic diamonds (right). Both images are of sample DAG0131 (0.32 ct). Photos by M. Yamamoto.

UV-Vis-NIR spectroscopy of all the samples showed a broad absorption around 270 nm related to isolated substitutional nitrogen, and a broad absorption centred at ~520–530 nm was present for the three brownish yellow stones. The ~520–530 nm absorption is seen in nitrogen-doped CVD synthetic diamonds, and it is known to be removed by HPHT treatment (Martineau et al., 2004; Meng et al., 2008; Khan et al., 2010). Meng et al. (2008) reported that this absorption is related to NV centres, while Khan et al. (2010) attributed it to NVH^0 centres.

Infrared spectroscopy revealed several bands related to C-H absorptions between 3200 and 2800 cm^{-1} in all samples. These are seen in nitrogen-doped CVD synthetic diamonds that are then HPHT treated (Charles et al., 2004; Meng et al., 2008). According to Charles et al. (2004), bands at 2902 and 2872 cm^{-1} that were detected after HPHT treatment at 1,900°C shifted to 2905 and 2873 cm^{-1}, respectively, after HPHT treatment at 2,200°C. Our unpublished studies of CVD synthetic diamonds before and after HPHT treatment also confirmed that bands at 2902 and 2871 cm^{-1} detected after treatment at 1,600°C shifted to 2907 and 2873 cm^{-1}, respectively, after treatment at 2,300°C. The bands at ~2905 and ~2873 cm^{-1} that were detected in the yellow samples in this study indicate that they may have been HPHT treated at temperatures exceeding 2,300°C. These bands in the three brownish yellow

Figure 16: Three of the CVD synthetic diamonds showed more yellowish luminescence (e.g. left: sample DAG0122; 0.20 ct), and four samples had areas of luminescence with a bluish overtone (e.g. right: DAG0119; 0.18 ct). Photos by M. Yamamoto.

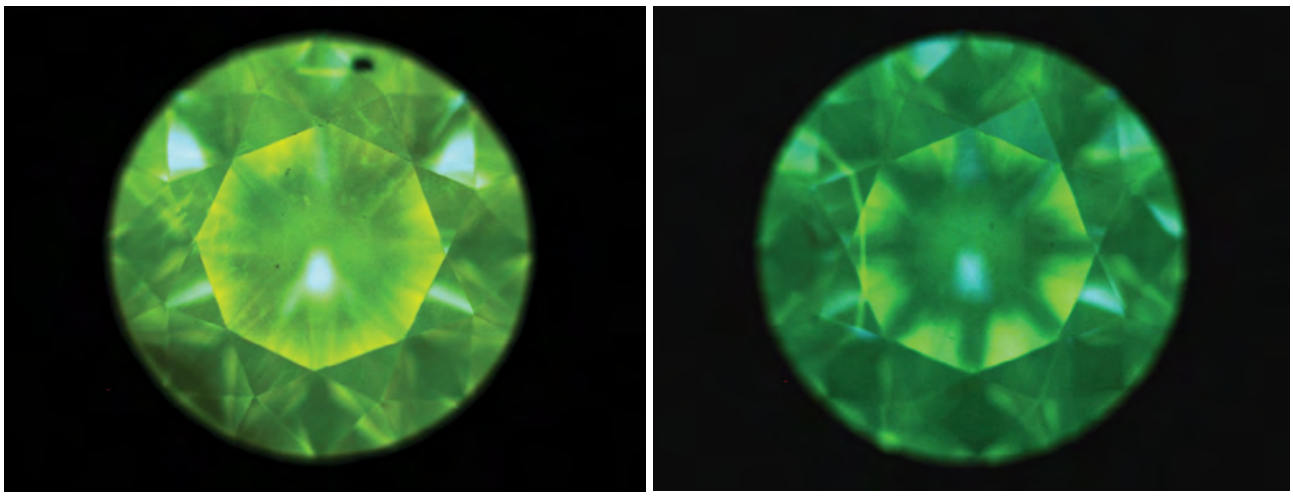

samples were shifted towards lower wavelengths (2902 and 2872–2871 cm^{-1}), and are presumed to have been treated at ~1,900°C.

The H3 centre is not seen in as-grown CVD synthetic diamond, but it can be detected after HPHT treatment (Charles et al., 2004; Meng et al., 2008). Meng et al. (2008) found that the ratio NV^0>H3 after low-pressure, high-temperature treatment at 1,970°C inverted to NV^0<H3 after HPHT treatment at 2,030°C. In our study, only two of the 12 yellow samples and all three brownish yellow samples showed the ratio NV^0>H3, which may indicate they were treated at a lower temperature than the other yellow samples.

The N3 centre has not been detected in as-grown CVD synthetic diamonds; thus it is known that this peak at 415.2 nm is formed by post-growth HPHT treatment (Charles et al., 2004; Martineau et al., 2004). During treatment, the peak intensity becomes stronger with prolonged heating at 2,200°C. In the PL data from this study, the N3 centre in three brownish yellow samples was weaker than in the yellow gemstones. This result also suggests that the brownish yellow samples were HPHT treated at lower temperature than the others.

Conclusion

Fifteen CVD synthetic diamonds in yellow hues were submitted to CGL for grading without disclosure. They proved to be type Ib, containing 1.1–7.2 ppm of isolated substitutional nitrogen. From the presence of the H3 and N3 centres, as well as the H3/NV^0 intensity ratio and the infrared absorption bands due to C-H-related defects, these samples appear to have undergone post-growth HPHT treatment at ~1,900–2,300+°C. The presence of the Si-related feature at 737 nm in the PL spectra (when present) and the lamellar pattern of growth striations observed with the DiamondView are the two most important characteristics for the identification of these CVD synthetic diamonds.

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Letter

Quartz Imitation of Star Sapphire

The Gem Notes section of *The Journal* Vol. 34, No. 6, 2015, pp. 485–486 documented a quartz imitation of star sapphire. Such imitations were manufactured in large quantities in Wembley in the 1940s and sold under the trade name 'Starstones'. They were made by a cousin of my husband, Hermann Stern. The starting material was always rose quartz that was carefully selected to show good asterism. The gems were cut as cabochons and the blue base was affixed under vacuum. Such imitations were mostly set in silver.

Evelyne Stern (evelynestern@btinternet.com)
Harrow, Middlesex

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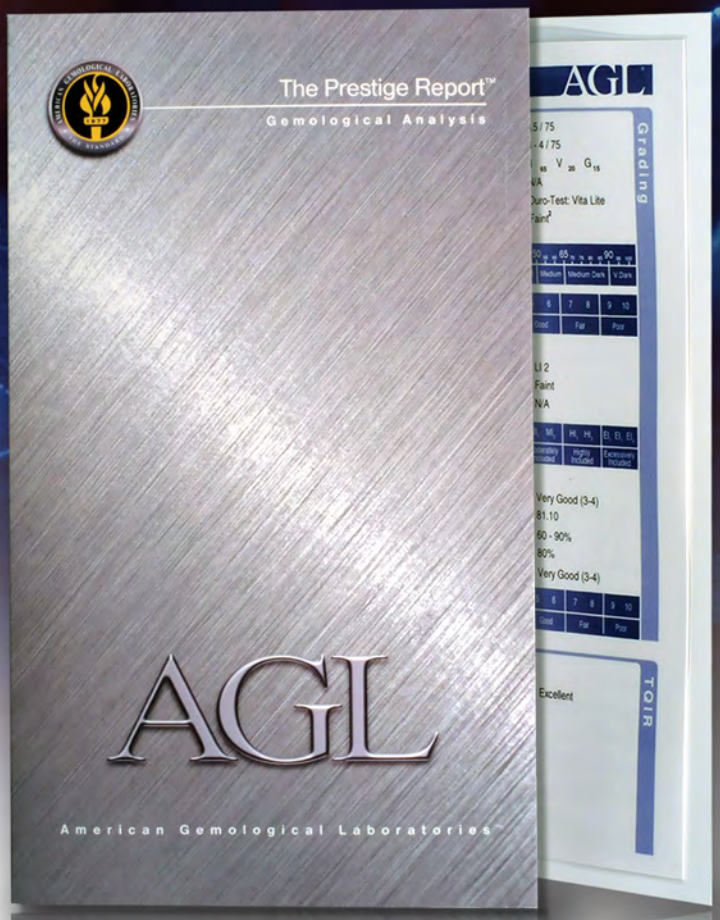

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Burmese Amber from Hti Lin

Tay Thye Sun, Arūnas Kleišmantas, Thet Tin Nyunt, Zheng Minrui, Murali Krishnaswamy and Loke Hui Ying

The main source of Burmese amber is located near Tanai village, Hukawng Valley, Kachin State, northern Myanmar. In 2010–2011, another amber deposit was found about 700 km south of Hukawng Valley near Hti Lin (or Tilin) in Magway Region, central Myanmar. The gemmological properties of material from Hti Lin are consistent with those of amber. Microscopic observation revealed flow marks, flattened gas bubbles, reflective thin-film inclusions, various debris (probably organic material) and included pyrite masses. Hti Lin amber fluoresces a very strong chalky blue to long-wave UV radiation and a weak blue to short-wave UV. FTIR spectroscopy confirmed that the samples were amber (and not copal), whereas no useful Raman data could be collected due to the amber's strong photoluminescence to the 785 nm laser.

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Introduction

Burmese amber or *Burmite* has been commercially exploited for at least two millennia, mainly by the Chinese (Grimaldi, 1996). The history of the use of Burmese amber was reviewed by Webster (1994), Zherikhin and Ross (2000), Grimaldi et al. (2002) and Ross et al. (2010). The main amber-producing area is Hukawng Valley (or Hukawng Basin), Tanai village, Kachin State, northern Myanmar, particularly at Nojie Bum, a hill that rises some 250 m above a broad alluvial plain that lies between two rivers, Idi Hka and Nambyu Hku (Noetling, 1892; Chhibber, 1934; Cruickshank and Ko, 2003; Shi et al., 2012).

A new locality for Burmese amber (e.g. Figure 1) was discovered in 2010–2011 near Hti Lin (or Tilin) township, Gangaw District, Magway Region, central Myanmar (Figure 2). One of the authors (TTS) visited the area in mid-March 2015 with the help of several local contacts. Following an initial report by Tay et al. (2015), this article gives further information on the geology of the area and gemmological properties of the amber.

Geology of the Hti Lin Area

The Hti Lin area lies within the eastern margin of the Indo-Burman Ranges in western Myanmar that extend from the eastern Himalayan syntaxis southward along the eastern side of the Bay of Bengal to the Andaman Sea (Bannert et al., 2011; Figure 3). This mountainous region is composed almost entirely of deep-marine, mostly non-fossiliferous distal turbidite flysch strata—particularly the southern portion, believed to have been deposited into a subducting trench between the Indian and Sunda Plates (Bannert et al., 2011; Win Swe, 2012).

Figure 1: This piece of polished amber from Hti Lin, Myanmar, is partially transparent and contains fractures with dark brown organic matter. The sample measures 72.46 × 45.31 × 24.19 mm and weighs 189.23 ct. Photo by Tay Thye Sun.

The Hti Lin area is underlain by mudstone, shale with coal-bearing layers, some fine-to-medium-grained calcareous sandstone, coarse-grained sandstone with quartz pebbles and conglomerate (Aung Kyi, pers. comm., 2015). These sedimentary layers, which mainly consist of shale intercalated with occasional fine-grained turbidite sandstones, form part of the Late Cretaceous Kabaw Formation (Than Htut, 2015). They strike ~30° and dip ~50° north-east, and are unconformably overlain by the Paunggyi Formation (Win Swe, 2012; Dr A. H. G. Mitchell, pers. comm., 2015). This geological setting is similar to the amber deposits in Hukawng Valley (Noetling, 1892; Chhibber, 1934; Cruickshank and Ko, 2003; Shi et al., 2012).

The specific locality for the Hti Lin amber deposit is known as Kyakhe ('tiger bite' in English), at coordinates N21°41′44.6″, E94°5′47″. At the mines, author TTS saw mostly shale in the tailings piles, occasionally with broken pieces of sub-bituminous coal together with ball-like masses of pyrite and blocks of white calcite. At one of the mining sites were two small vents emitting hot sulphurous fumes, indicative of volcanic activity.

The botanical origin of the amber from Hti Lin has not been studied, but the Cretaceous amber from Hukawng Valley is known to have come from the Araucariaceae family (especially from the genus *Agathis*) and also the Taxodiaceae family (e.g. Poinar and Milki, 2001; Grimaldi et al., 2002). Genera from both families were confirmed by a study of the palynomorphs (i.e. pollen grains, spores, etc.; see Davies, 2001). While it is possible that Hti Lin amber could have a similar botanical origin, further research is needed.

Mining and Production

At the time of author TTS's visit, there were about 100 miners (mostly local farmers) working in an area covering approximately 10 km^2. According to the miners, the amber is hosted by shale layers with a thickness of 30–40 cm. The miners usually look for thin coal seams within the shale, and follow them until they find pieces of amber, typically lying flat along the shale bedding planes. To reach the amber-bearing shale, the miners dig square pits (~1 × 1 m) to a depth of about 15–20 m (Figure 4). Each pit is worked by three to six miners. Author TTS visited two locations that were 1 km apart; one area had about 25 pits while the other had 15 pits. The production of amber from each pit was variable, ranging from a few grams to 1 kg or more after one to two weeks of digging. The pieces ranged from a few grams to a few kilograms each, and nearly all were covered with an opaque black 'skin' that had to be polished off to reveal the quality of the underlying amber.

Materials and Methods

Twenty samples of amber from Hti Lin (e.g. Figure 5) were examined using basic gemmological

Figure 2: The main source of Burmese amber comes from Hukawng Valley in northern Myanmar. The recently discovered deposit in the Hti Lin area is located in eastern-central Myanmar, about 700 km south-east of Hukawng Valley. The different coloured regions refer to the boundaries of Myanmar's states.

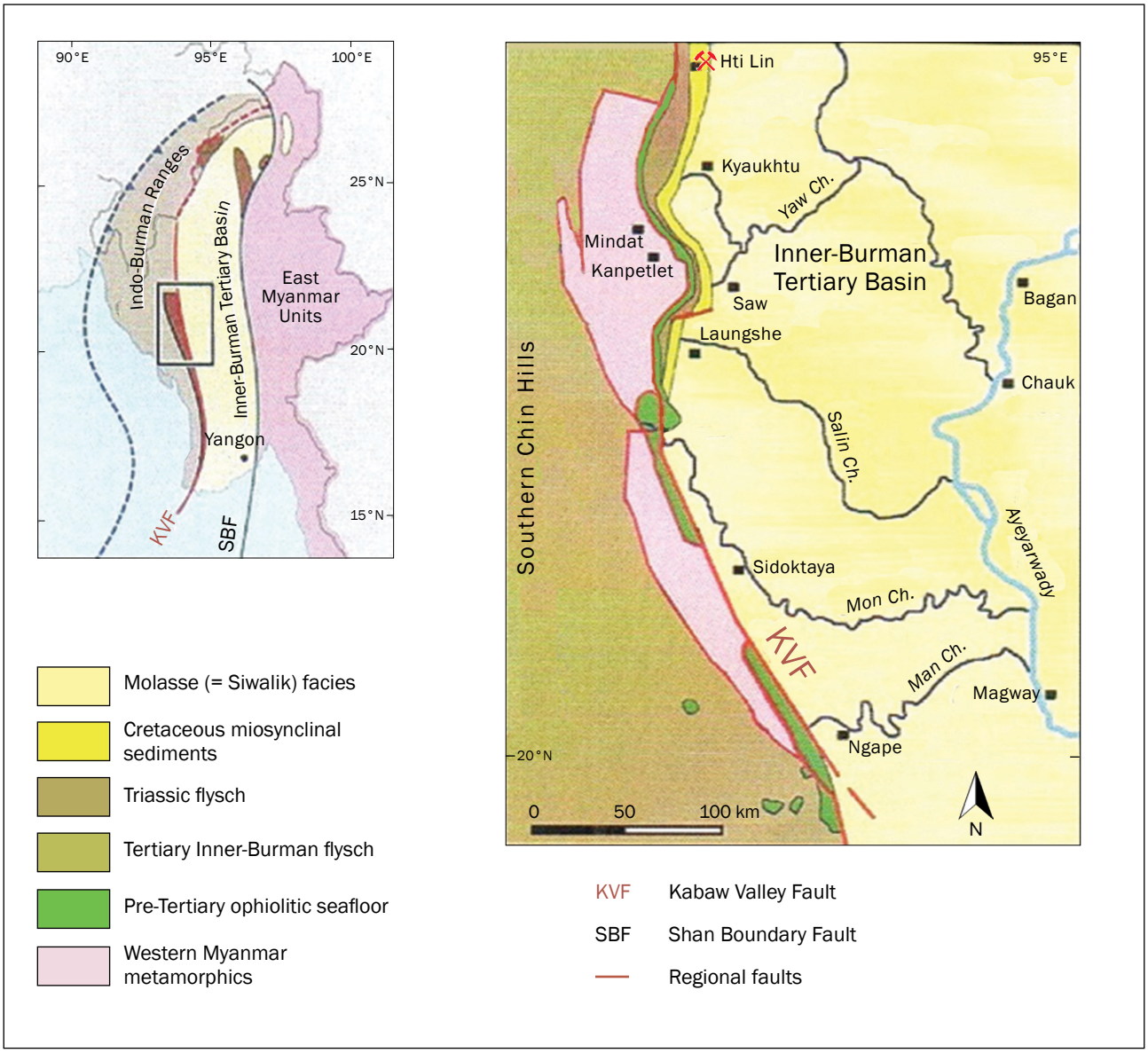

Figure 3: The geological setting of the Hti Lin region is shown here (after Bannert et al., 2011). The amber-mining area is located at the northern edge of the main map.

Figure 4: Pits in the Hti Lin area are typically worked by groups of three to six miners (left). The pit walls are reinforced by timber and bamboo to hold back the soil (right). Photo by Tay Thye Sun.

Figure 5: Some of the rough and polished samples of Hti Lin amber studied for this report are shown here. The disc-like rough piece weighs 45.87 g and measures 87.79 × 88.30 × 14.11 mm, and the large polished sample on the upper right weighs 138.49 ct and measures 88.69 × 59.66 × 12.14 mm. Photo by Tay Thye Sun.

methods. UV fluorescence was observed with a Mineralight UVSL-25 multiband UV 254/365 nm lamp. In addition, five rough amber samples from Hti Lin (0.90, 1.27, 1.66, 2.01 and 5.89 ct) and another five partially polished samples from Hukawng Valley (0.37, 0.40, 0.47, 0.98 and 1.13 ct) were analysed by Fourier-transform infrared (FTIR) and Raman spectroscopy. FTIR data were recorded in transmission mode with a Shimadzu IRPrestige-21 spectrometer in the range of 4000–400 cm^{-1}, with a resolution of 4.0 cm^{-1} and 45 scans. A few milligrams were taken from each sample, crushed into powder, and mixed with KBr to make pellets for analysis. This is a standard method for characterizing amber and its origin and treatments (e.g. Beck et al., 1964; Poinar and Poinar, 1999; Abduriyim et al., 2009; Wolfe et al., 2009) and also for differentiating genuine amber from imitations or forgeries (e.g. Golloch, 1997; Kosmowska-Ceranowicz, 2001). Raman spectroscopy was performed with a Renishaw InVia Raman microscope, using a 785 nm laser in the range of 1768–1400 cm^{-1}. No sample preparation was needed, and this method is also useful for differentiating amber from its imitations (Tay et al., 1998; Shashoua et al., 2006) and determining the country of origin of some ambers (Leelawatanasuk et al., 2013).

Results

Gemmological Data

The colour of the Hti Lin amber ranged from white, yellow and yellowish or reddish brown to dark brown. The diaphaneity was transparent to opaque. The spot RI ranged from 1.54 to 1.55, and the hydrostatic SG was 1.03–1.05. The slightly heavier SG values of the range were probably due to the presence of pyrite inclusions. Most samples fluoresced a very strong chalky blue with white veins to long-wave UV radiation, and a weak chalky blue to short-wave UV. Some of the amber displayed dull green daylight fluorescence.

Viewed with magnification, the samples revealed flattened gas bubbles and groups of thin-film inclusions that were reflective or iridescent under

Figure 6: Flattened gas bubbles and reflective thin-film inclusions are quite common in amber from Hti Lin. Some of them show iridescence when viewed obliquely with fibre-optic lighting (a,b). Groups of these inclusions were folded in some samples (b). The right-hand photo (c) shows masses of reflective thin-film inclusions (right side) and pyrite grains (left side). Photomicrographs by Tay Thye Sun; magnified 15×.

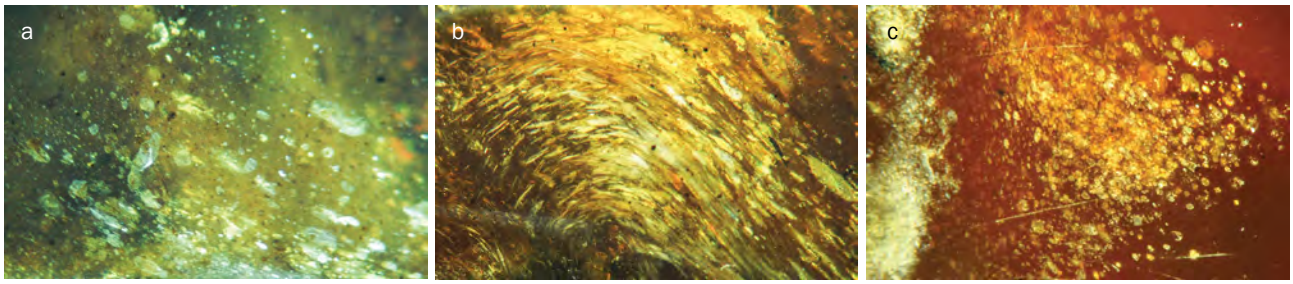

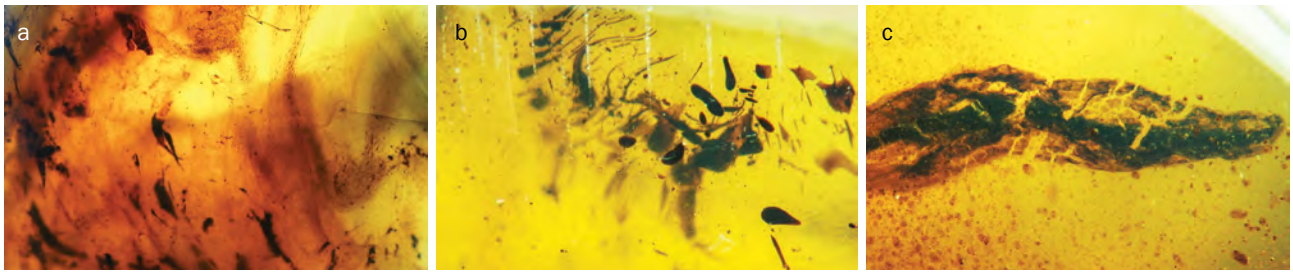

Figure 7: Various types of unidentified debris (probably organic matter) are present in the Hti Lin amber. Some are aligned in the direction of flow marks (a and b, magnified 10× and 15×, respectively). Strange shapes are exhibited by some of these inclusions (c, magnified 10×). Photomicrographs by Tay Thye Sun.

oblique fibre-optic lighting (Figure 6). In addition, various types of unidentifiable (probably organic) debris were noted (Figure 7), sometimes following the direction of flow marks in the amber. Also seen were masses of pyrite (Figures 6c and 8) in some samples that produced gold-like reflections. No insects were present in the pieces examined.

FTIR and Raman Spectroscopy

FTIR spectroscopy of amber from both Hti Lin and Hukawng Valley showed significant bands at approximately 2924, 1724, 1459 and 1376 cm^{-1}, with additional features between 1300 and 1000 cm^{-1} and a weak pair of bands at about 853 and 813 cm^{-1} (Figure 9).

Figure 8: Some of the amber from Hti Lin contains masses of pyrite, as exposed on the surface of this polished sample. Photomicrograph by Tay Thye Sun; magnified 15×.

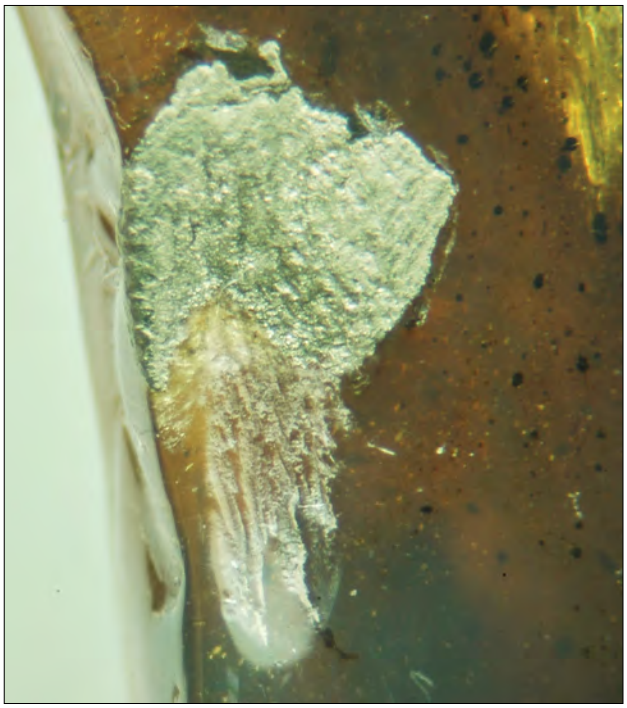

In amber from both localities, the absorption in the C-H stretching region is at wavenumbers below 3000 cm^{-1}, which implies the absence of unsaturated or aromatic compounds. The bands from 3000 to 2850 cm^{-1} are attributed to C-H stretching of sp^3-hybridized C-H bonds of methyl and methylene groups. These are supported by the methylene (CH_2)–bending absorption at ~1458 cm^{-1} and the methyl (CH_3)–bending absorption at ~1375 cm^{-1} (Pavia et al., 2009). The strong band at ~1724 cm^{-1} corresponds to C=O stretching of a carbonyl group. The presence of a second band close to this value in some of the samples could indicate more than one type of carbonyl compound in the amber. The lack of a broad O-H absorption suggests the absence of acid. The complex features between 1300 and 1000 cm^{-1} could be attributed to C-O stretching, and may indicate the presence of an ester (Poulin and Helwig, 2015). Notable is the absence of a 'Baltic shoulder' (i.e. a flat shoulder in the area between 1259 and 1184 cm^{-1}) and an associated feature at 1159 cm^{-1} that has been noted as characteristic of Baltic amber (Beck et al., 1964; Langenheim, 1969). There was no band discerned at 887 cm^{-1} that is characteristic of copal (Guiliano et al., 2007).

No useful Raman spectroscopic data could be collected from samples from either Burmese location because of their strong photoluminescence to the 785 nm laser.

Discussion

Gemmological Data

Amber from Hti Lin is hosted by coal seams within Late Cretaceous shale, in a geological setting that is quite similar to that of Hukawng Valley deposits.

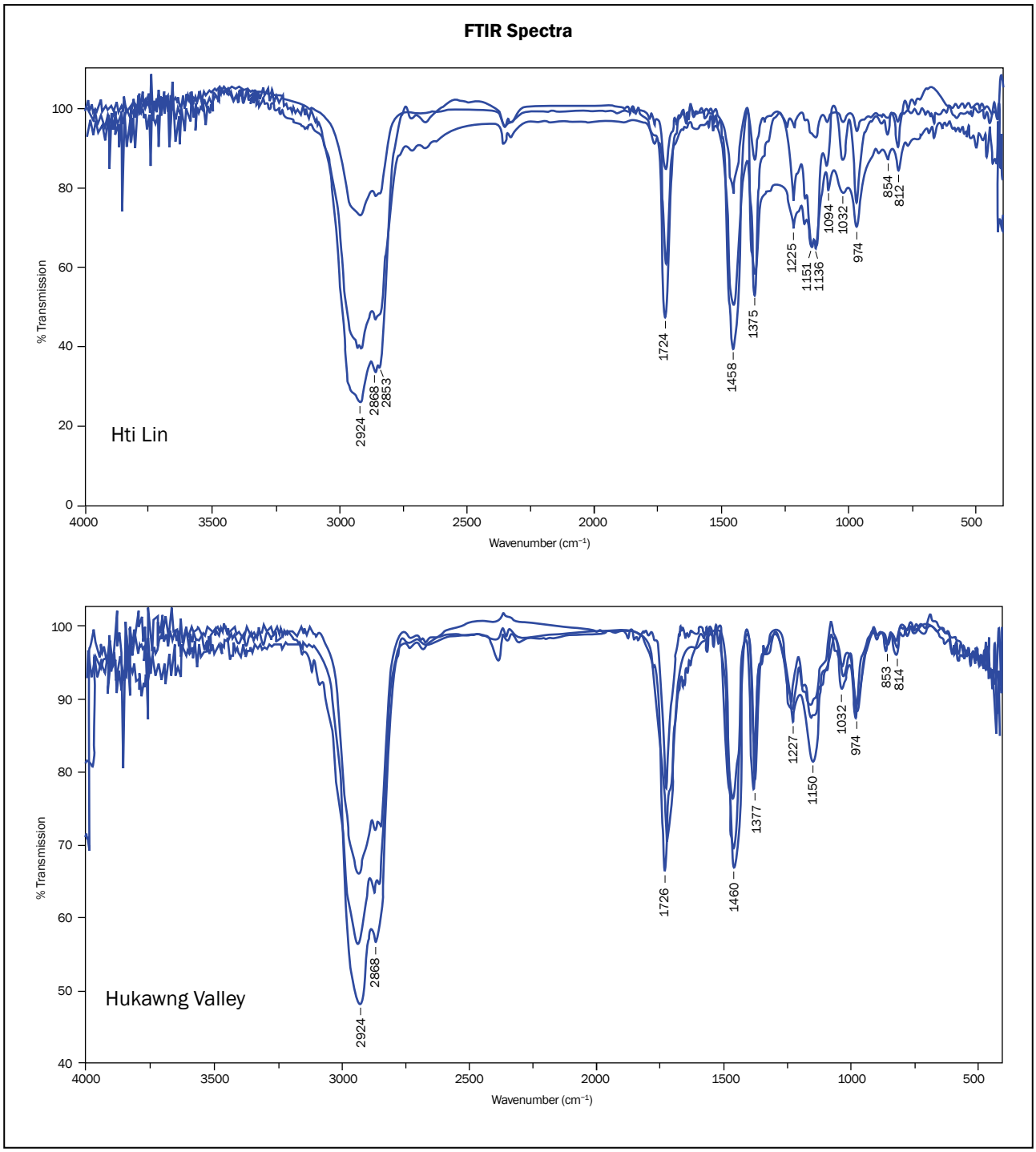

Figure 9: Representative infrared spectra are shown for three amber samples each from Hti Lin and Hukawng Valley.

The gemmological properties of our samples from Hti Lin are typical of amber from other world localities (i.e. RI of 1.54–1.55, SG of 1.03–1.05 and the presence of flow marks, included pyrite masses, and some unidentified [probably organic] debris). Included pyrite masses have been documented in amber from other localities (e.g. from the Baltic area and from New Jersey, USA; Grimaldi, 1996). While Burmese amber from Hukawng Valley is famous for its abundant insect inclusions, the material from Hti Lin had no insects in the limited number of samples examined. The various above-mentioned inclusions are common among amber from other localities around the world, but the flattened and reflective gas bubbles are distinctive for material from Hti Lin.

Considering Hti Lin amber's strong chalky blue fluorescence to long-wave UV radiation, the observed weak chalky blue short-wave UV fluorescence may be due to a 'wavelength bleed' effect that occurs with some dual-wavelength lamps (Williams, 2007).

In daylight, some of the more brownish and reddish brown Hti Lin amber appeared dull green on the surface. Similar colour behaviour has been observed in amber from the Dominican Republic, in which the body colour is yellow and there is a greenish blue surface colour. In addition, amber from Indonesia with a red body colour may show a bluish surface colour. Such colour behaviour has been attributed to UV-stimulated fluorescence together with a variation in colour appearance according to the path length of light through a sample (i.e. the Usambara effect; Liu et al., 2014).

FTIR and Raman Spectroscopy

The IR absorption spectra of the various amber samples from Hukawng Valley and Hti Lin show several common features. The presence of the carbonyl band (1724 cm^{-1}) and the absence of aromatics in the spectra indicate these are likely Class I ambers derived from higher plant resins based primarily on polymers of labdatriene diterpenes (Anderson et al., 1992). The lack of the 'OH' absorption (Pavia et al., 2009), the absence of the 'Baltic shoulder' (Beck et al., 1964; Langenheim, 1969) and a carbonyl stretching vibration at 1724 cm^{-1} that is lower than that of aliphatic esters (Pavia et al., 2009) indicate that this is unlikely to be a Class Ia amber. The classification of the amber into Class Ib or Ic would depend on whether the amber is based on *regular* labdanoids (communic acid, communol and biformenes) or *enantio* labdanoids (ozic acid, ozol and enantio biformene; Anderson, 2001). However, differentiating Class Ib from Ic cannot be ascertained using FTIR spectroscopy alone, and would require further investigation using pyrolysis/gas chromatography/mass spectroscopy. The absence of the 'OH' absorption (Pavia et al., 2009) as well as the lower carbonyl stretching vibration could probably indicate esterification between the labdane alcohol (communol or ozol) and the labdane acid (communic acid or ozic acid) moieties (Poulin and Helwig, 2015).

Previous studies of amber from the Dominican Republic and the Baltic area have attributed bands at 3048, 1642 and 887 cm^{-1} to exocyclic methylene groups of labdanoids, and have drawn conclusions on the maturity of the amber by observing these bands, especially the one at 887 cm^{-1} (Guiliano et al., 2007; Clifford and Hatcher, 1995). The absence of these bands in the Burmese samples indicates a relatively high maturity of the amber (Jehlička, 2012), and confirms that Hukawng Valley and Hti Lin samples are amber and not copal.

Previously, Raman spectroscopy in the 1800–1400 cm^{-1} region was successfully used to differentiate amber from polymer imitations, but this was not possible with the 785 nm laser used in this study due to strong fluorescence from the amber. This photoluminescence is apparently correlative with the very strong blue long-wave UV fluorescence exhibited by the Hti Lin amber. Further investigations using FT-Raman spectroscopy should be undertaken.

Conclusion

Burmese amber from Hti Lin is relatively new to the amber market. Its gemmological properties (i.e. RI, SG and microscopic features) are consistent with those of amber in general. However, it fluoresces a very strong chalky blue to long-wave UV radiation and weak chalky blue to short-wave UV. In daylight, some of the Hti Lin amber exhibits a dull green fluorescence, similar to (but not as strong as) 'blue' amber from the Dominican Republic and Indonesia. Mid-IR spectra of Hti Lin amber show characteristic bands at about 2924, 1724, 1459 and 1376 cm^{-1}, and also between 1300 and 1000 cm^{-1} as well as a weak pair of absorptions at 853 and 813 cm^{-1}. Raman spectroscopy of Hti Lin amber using a 785 nm laser was not effective due to strong photoluminescence, and FT-Raman spectroscopy should be attempted in the future.

In the future, amber mining at Hti Lin is expected to continue, as the amber has become a source of income for the villagers in an otherwise impoverished area. In the opinion of author TTS, it is likely that amber production from Hti Lin will increase in the future with growing demand from the Chinese market.

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The Application of Differential Interference Contrast Microscopy to Gemmology

Nathan Renfro

Episcopic (reflected light) differential interference contrast (DIC) microscopy can reveal information about rough or cut gems that would otherwise be difficult to obtain using standard gemmological optical microscope illumination techniques. Although not widely used in gemmology due to the current expense of the specialized equipment and its limited applications, this type of contrast-enhancing optical microscopy is particularly useful for observing surface features that may help with such tasks as identifying rough gem materials, detecting heat treatment (in stones that have not been repolished) and assessing whether a gemstone was damaged after it was polished. DIC microscopy is valuable for yielding technical information about a gem, as well as for producing informative and often striking images.

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Introduction

The microscope is the gemmologist's most powerful instrument, and in many cases its usefulness is limited only by the experience and knowledge of the user. Several illumination techniques are commonly employed for gemmological observations, and each may reveal particular information about a sample that would otherwise go unnoticed. To obtain the greatest amount of information about a stone, it is important to observe it using as many different lighting conditions as possible.

Differential interference contrast (DIC) microscopy was invented in the 1950s by Georges Nomarski (Nomarski, 1960). It was originally developed for diascopic (transmitted light) illumination, but proved to be quite useful for episcopic (reflected light) applications. This type of illumination has been used occasionally in studies of gem materials (e.g. Sunagawa, 1964; Koivula, 1988, 2000, 2009; Takahashi and Sunagawa, 1998; Horikawa, 2001; Evans et al., 2005). DIC microscopy offers a useful perspective on surface structures that may give clues to a gem's identity and whether or not it has been subjected to heat treatment. Also, this lighting environment can be used to assess whether damage occurred to a gem after it was polished. As an added benefit, the images produced often merge the science and art of gemmology because of the striking results that are possible (e.g. Figure 1).

What is Episcopic Differential Interference Contrast?

Episcopic DIC is an optical microscopy method in which a modified Wollaston prism, also known as a Nomarski prism, is incorporated into the light path of a microscope to significantly enhance contrast, revealing very fine detail that would

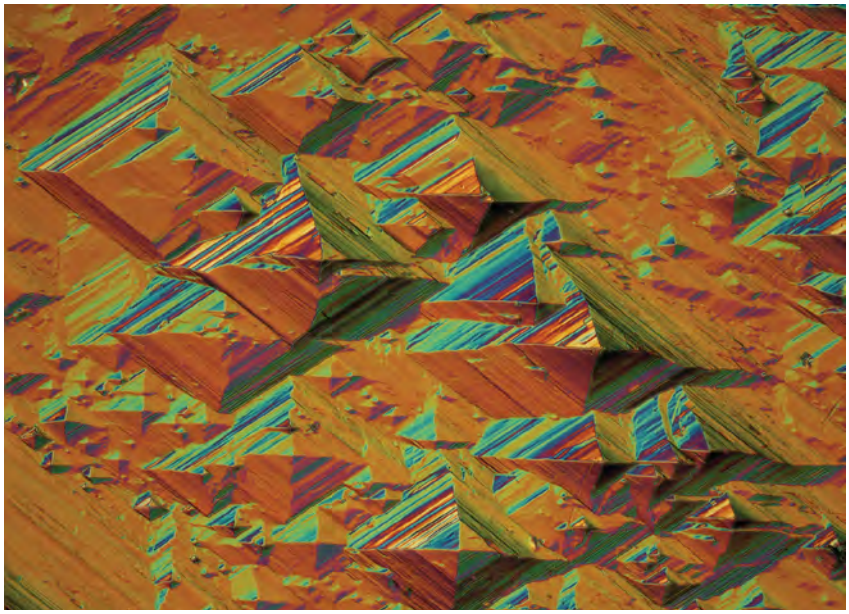

Figure 1: The naturally etched surface of an andradite from Val Malenco, Italy, reveals its isometric morphology in a vibrant display of colour. Photomicrograph by N. Renfro; image width 0.61 mm.

otherwise go unseen. Specimens must be reflective in nature, making polished gemstones and shiny crystals ideal for this type of microscopy. Typically, a compound-type microscope (e.g. Figure 2) is outfitted with a single Nomarski prism located at the rear focal plane of the objective lens. A polarizer and analyser in the optical path are also required components (Brandmaier et al., 2013).

To produce episcopic DIC conditions, an illumination source is polarized by a rotatable filter and directed through the Nomarski prism, where the light is separated into two orthogonally polarized beams. The light then travels through the objective lens where it is focused onto the surface of a sample and reflected back through the objective. The light is then directed back through the Nomarski prism, where the rays are recombined. After exiting the prism, the light travels through an analyser where the orthogonal beams interfere with one another according to variations in path length to produce the interference image that is projected through the oculars. These types of images often display high-order interference colours that can be controlled by the position of the prism in the optical path (Pluta, 1989). This 'optical staining' is not related to the actual coloration of the specimen, but results from the modification of the light used to examine the sample. Even though these types of images may look like they have been artificially produced because of the unnatural-appearing vibrant colour palate, this appearance is what is actually observed in the oculars.

Exploring Surface Features of Rough Gems

Etched gem minerals with their geometric topography provide excellent study subjects for a DIC microscope. Subtle variations of relief can be revealed in a dazzling display of colour and geometry. These etch features can provide clues to a rough gem's identity by revealing symmetry information that corresponds to the crystal system in which the specimen belongs (e.g. Figures 1 and 3). In addition, the surface of a crystal can reveal further information. For example, twin planes that are often seen internally in diamonds are easily observed on the surface of some rough specimens, as evidenced by linear arrangements of trigons (triangular etch features) on octahedral

Figure 2: This Nikon Eclipse LV100 polarizing microscope is equipped with DIC components, and was used to take the photomicrographs in this article. Photo by Kevin Schumacher.

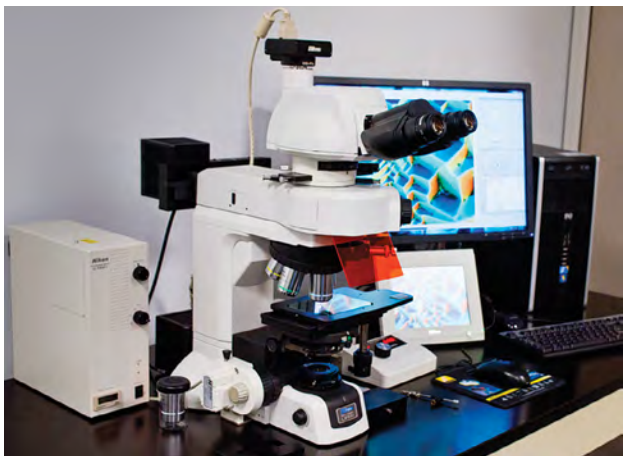

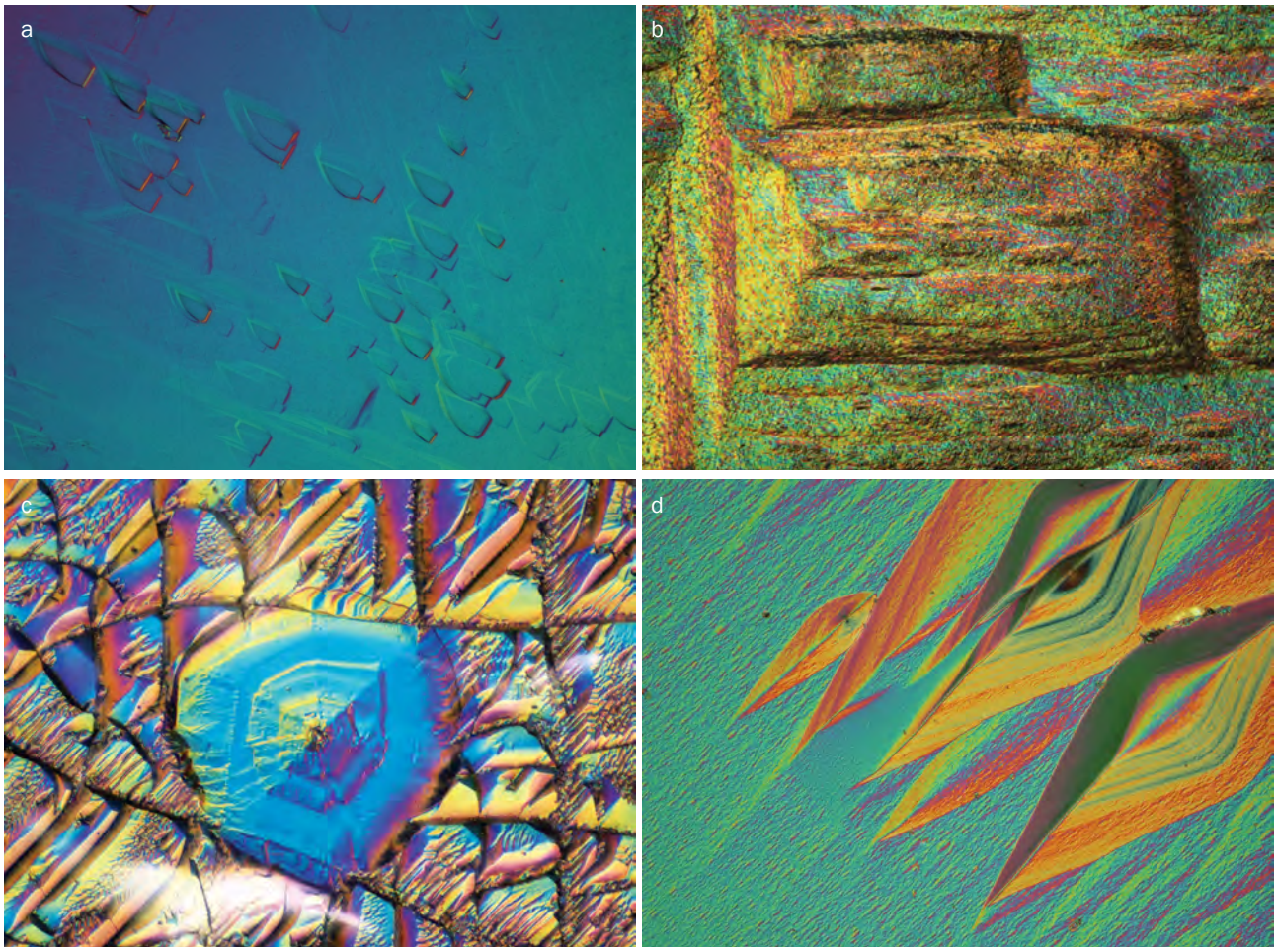

Figure 3: Surface features of gem minerals may provide clues to their identity and crystal structure. (a) These sail-shaped etch features are characteristic of spodumene (image width 0.25 mm). (b) Rectangular etch features are present on the prism faces of a beryl crystal (image width 0.62 mm). (c) The trigonal symmetry of tourmaline is clearly seen in surface etching viewed parallel to the c-axis (image width 0.61 mm). (d) Rhomb-shaped, orthorhombic etching with two-fold symmetry is distinct when looking parallel to the c-axis of this topaz (image width 0.61 mm). Photomicrographs by N. Renfro.

Figure 4: This diamond shows localized areas of higher solubility, as evidenced by the linear arrangement of dissolution trigons along the twin planes. Photomicrograph by N. Renfro; image width 1.24 mm.

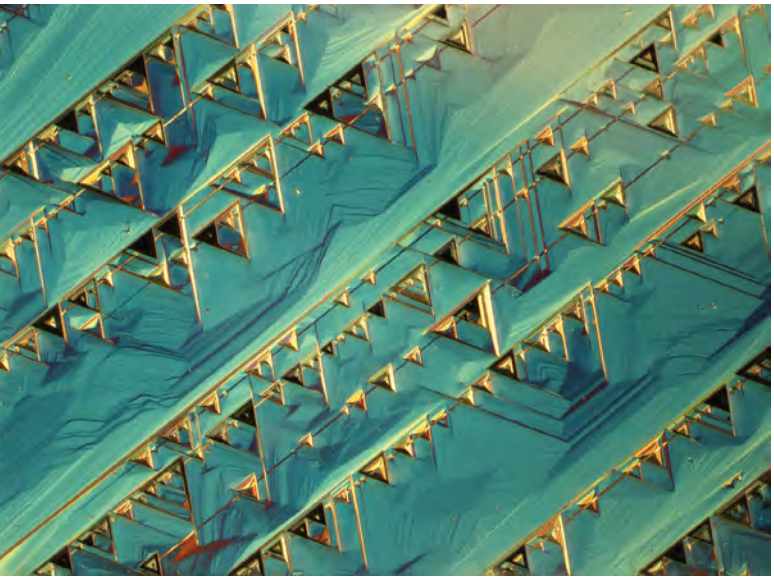

faces (Figure 4). The twinning produces localized areas of high defect concentration that are much more susceptible to etching than areas of pristine structure. As the crystal undergoes dissolution during transport to the earth's surface, the domains with high defect concentration dissolve much faster than the surrounding areas.

Some etch features are also characteristic of certain minerals. For example, sail-shaped, modified triangular etch pits are typical of spodumene (Figure 3a).

Surface features may also give the observer clues about a mineral's genetic environment. Spinel is often hosted by marble, a rock composed of carbonate minerals. The surface morphology of some spinel crystals reveals evidence for carbonate grains in the host rock that interface with the spinel in interesting stepped patterns as the

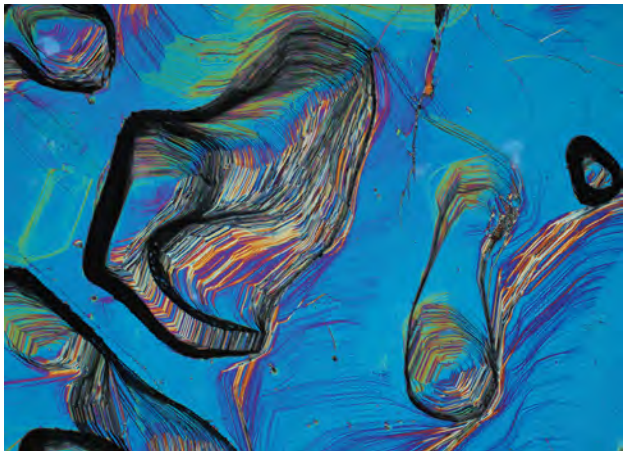

Figure 5: The surface of this Burmese spinel shows stepped patterns corresponding to the interface with carbonate grains in its marble host rock. Photomicrograph by N. Renfro; image width 4.92 mm.

two minerals competed for space in their growth environment (Figure 5).

Heat Treatment Detection

Gems are often treated in ways that leave microscopic evidence. Sometimes this evidence is so subtle that it is difficult to resolve using traditional microscopic illumination. DIC microscopy can help reveal these hidden clues to the observant gemmologist. In particular, heat treatment can cause subtle melt damage on the surface of gems (Gübelin and Koivula, 2008; Koivula, 2009). If a stone does not appear obviously damaged after treatment, then there will be no reason to repolish it, and such evidence may be visible with DIC microscopy.

At the GIA Laboratory in Carlsbad, California, USA, a blue sapphire was recently examined that showed no internal or spectroscopic evidence that it had been heated. However, upon closer inspection using episcopic DIC microscopy, melt damage on the facets of the stone was revealed, proving the sample had been subjected to heating (Figure 6, left). Additionally, when gem corundum is heated, tiny glassy melt droplets are occasionally fused to the surface of the stone. If the gem's surface was not noticeably damaged during the treatment, and therefore not repolished after heating, then viewing these glassy melt droplets with DIC microscopy also provides evidence that the stone has been heated (Figure 6, centre and right).

Damage Assessment

Although diamonds are among the hardest materials known, they are still susceptible to cracking along cleavage planes, should they sustain an impact from certain directions. If a cleavage fracture is observed in a diamond, it can be important to know if the damage was pre-existing or if perhaps it was introduced after polishing. This can help in determining, for example, if a jeweller may be liable for damaging a stone.

Drag lines are polish features that originate from surface imperfections such as graining, pits and cleavage fractures. Their association with a crack proves that the fracture must have existed prior to polishing. However, such drag lines can be extremely difficult, if not impossible, to observe using traditional reflected-light microscopic examination on diamonds that have an excellent or very good polish. Using episcopic DIC, these subtle polish lines can be resolved in high contrast, enabling the microscopist to determine whether a crack existed before the stone was polished (Figure 7, left), or if the gem was damaged after it was cut (Figure 7, right).

Figure 6: Melt damage on the surface of a faceted sapphire (left) is clearly seen using episcopic DIC microscopy, which proves that it was heated after the cutting process. Glassy droplets fused to the surface of a polished sapphire also confirm heat treatment (centre and right). The sharp straight lines are facet junctions. Also apparent in the right-hand image are polish lines that were plastically deformed during heat treatment, taking on an irregular, wavy appearance. Photomicrographs by N. Renfro; image width 1.24 mm (left and right) and 0.62 mm (centre).

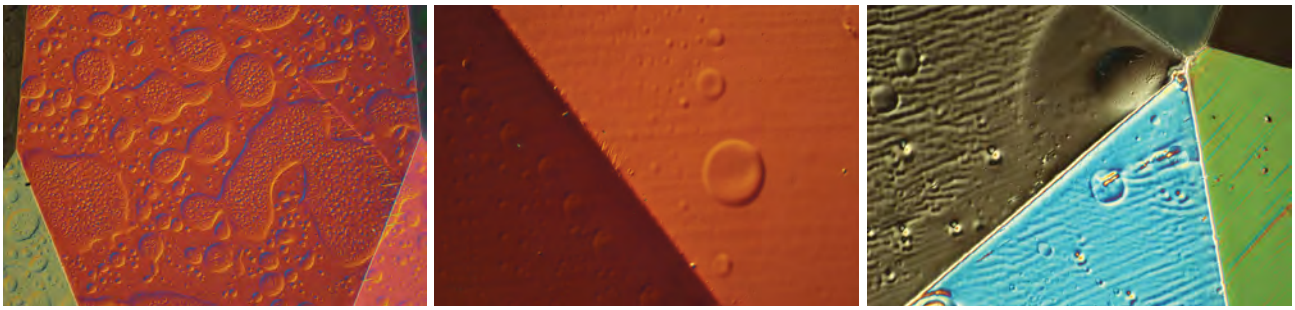

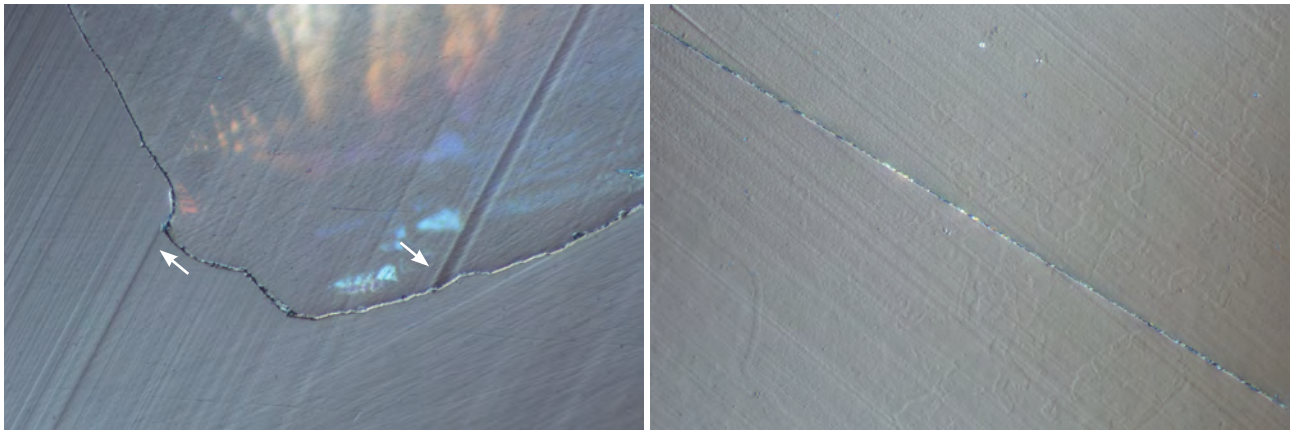

Figure 7: Polish lines that originate from a crack or surface defect can be difficult to see without episcopic DIC microscopy. The left image shows polish lines that stop or start along a fracture in a diamond, proving that the crack was present at the time the stone was polished. By contrast, polish lines that continue across a crack uninterrupted (right) indicate that the diamond was damaged after polishing. Also visible in the right-hand image are subtle irregular surface features known as 'burn marks' that were created from the heat generated while polishing the diamond. Photomicrographs by N. Renfro; image width 0.25 mm.

Conclusion

Episcopic DIC can reveal otherwise unobservable characteristics and information about a gem and is quite useful for certain applications, such as viewing surface features on rough gems, detecting heat treatment in stones that have not been repolished and assessing the timing of damage (fractures) relative to when a diamond was polished. Because of the sharp contrast and spectacular colour palette that is possible, DIC imaging often produces striking artistic photomicrographs where science and art are merged into a single image (Renfro, 2015).

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Conferences

34th International Gemmological Conference

The 34th biennial IGC took place in Vilnius, Lithuania, on 26–30 August 2015. The conference was organized by **Dr Arūnas Kleišmantas** (Vilnius University, Lithuania), **Vilma Misiukonienė** (Infobalt Lithuania, Vilnius) and **Dr Jayshree Panjikar** (PANGEMTECH, Pune, India) in collaboration with Vilnius University and duSafyrai gem laboratory and museum in Vilnius. Approximately 75 delegates, observers and guests gathered for the event (Figure 1), and some of them attended pre- and post-conference field trips. Individual abstracts of the oral and poster presentations, as well as the entire proceedings volume, can be downloaded at www.igc-gemmology.net/proceedings.

Lithuania is a source of Baltic amber, and several presentations focused on amber from this region and elsewhere. **Dr Sigitas Podenas** (Vilnius University, Lithuania) reviewed the broad diversity of crane flies preserved as inclusions in Baltic amber. A total of 160 species representing five genera have been identified, and these lived during the latter part of the Eocene epoch, approximately 54 to 44 million years ago. **Dr Albertas Bitinas** (Klaipeda University, Lithuania) covered the geological origin of amber in the south-east Baltic Sea region. The deposits originated from resin of a *Pinus succinifera* forest and were transported by rivers and then deposited in deltas. Today, amber is known to exist in a 2-m-thick layer of silty sands on the Sambia Peninsula in the Kaliningrad area of Russia, at a depth of 10 m below the present sea level. Erosion of this layer during periods of lower sea level (approximately six million years ago) released some of the amber into the Baltic Sea, where it was

Figure 1: Delegates, observers and guests of the 34th International Gemmological Conference gathered at Trakai Castle in Lithuania for a group photo. Courtesy of B. M. Laurs.

eventually redeposited in offshore spits and lagoons. **Dr Jonas Satkūnas** (Lithuanian Geological Survey, Vilnius) discussed amber production in Lithuania, beginning with the 1858 establishment of Stantien & Becker for gathering amber from the northern part of the Curonian Lagoon. More recently, in 1992–1994, exploration by the Lithuanian Geological Survey near the town of Klaipeda identified an inferred resource of 227 tonnes that could produce an estimated 20–30 tonnes/year of amber, but mining in this area is currently restricted so it is unlikely that the deposits will be exploited. **Willow Wight** (Canadian Museum of Nature, Ottawa) reviewed Canadian amber localities. Although not commercially important, deposits are known at Cedar Lake in Manitoba (Late Cretaceous) and from three sites in the Canadian Arctic (Eocene). **Dr Lore Kiefert** (Gübelin Gem Lab, Lucerne, Switzerland) discussed natural-colour green amber from central Ethiopia, which was discovered in 2010 in Cretaceous sediments that are overlain by Tertiary basalt. It is hypothesized that heat from the basalt flow caused the green coloration of the amber. **Tay Thye Sun** (Far East Gemological Laboratory, Singapore) and co-authors characterized Burmese amber from a relatively new locality near Hti Lin (see article on pp. 606–615 of this issue of *The Journal*).

In diamond presentations, **Dr Thomas Hainschwang** (GGTL Laboratories, Balzers, Liechtenstein) and co-authors examined unusual black diamonds containing inclusions of lonsdaleite (the hexagonal polymorph of diamond) and CO_2. Although such diamonds may be mistakenly identified as synthetic based on the one-phonon region of their infrared spectra, they actually consist of polycrystalline aggregates of natural diamond that are heavily included by non-diamond carbon. **Dr Hiroshi Kitawaki** (Central Gem Laboratory, Tokyo, Japan) and co-authors described type Ib yellow to brownish yellow CVD synthetic diamonds (see article on pp. 594–604 of this issue of *The Journal*). **Dr Joe C. C. Yuan** (Taiwan Gemmological Institute, Taipei; and Solstar Diamond Co. and Taidiam Technology, Zhengzhou, China) predicted that high pressure, high temperature (HPHT)–grown synthetic diamonds produced under even (not gradient) temperature conditions will likely become the most important type of gem-quality synthetic diamonds in the future.

In presentations on gem corundum, **Anette Juul-Nielsen** (Ministry of Mineral Resources, Nuuk, Greenland) provided an update on small-scale mining of rubies and pink sapphires near Fiskenaesset, Greenland. She reported a significant increase in the number of small-scale licences issued, although most activities are focusing on prospecting rather than production at this early stage. **Dr Jayshree Panjikar** and **Aatish Panjikar** investigated the cause of asterism in star ruby from Neriya, Karnataka, India. They attributed the asterism to the presence of rutile needles in addition to micro-inclusions of tialite (Al_2TiO_5, identified by Raman spectroscopy in hazy areas of the gems). **Kentaro Emori** and **Dr Hiroshi Kitawaki** (Central Gem Laboratory, Tokyo, Japan) reported on the geographic origin determination of ruby and blue sapphire based on trace-element analysis using laser ablation–inductively coupled plasma–mass spectrometry (LA-ICP-MS) data in three-dimensional plots. Due to some overlap between localities, they found that such data can help with origin determination but that more analyses are needed from samples of known provenance. **Dr Stefanos Karampelas** (Gübelin Gem Lab, Lucerne, Switzerland) discussed recent research on zircon inclusions in blue sapphires done by **Emilie Elmaleh** (University of Geneva, Switzerland) and their co-authors. Potentially locality-specific characteristics of the zircon inclusions consist of cathodoluminescence zoning features and U-Pb age data, but more research is needed before they can be applied to the origin determination of sapphire. **Dr J. C. (Hanco) Zwaan** (Netherlands Gemmological Laboratory, Leiden) and co-authors performed inclusion and LA-ICP-MS trace-element studies of alluvial sapphires from Montana, USA. Both the inclusion suite and a plot of Fe vs. Ga/Mg supported a metasomatic origin for these sapphires. **E. Gamini Zoysa** (Institute of Gemmological Sciences, Colombo, Sri Lanka) reviewed sapphire deposits of Sri Lanka. He described recent mining at Wellawaya for in-situ corundum, at Getahetta for sapphire 'geodes', at Bogawantalawa for large opaque corundum crystals, and overall gem production from Hasalaka, Elahara and Kolonna. **Dr Karl Schmetzer** (Petershausen, Germany) and co-authors reported on dual-colour double stars in corundum and quartz; these results were recently published in *Gems & Gemology* (Vol. 51, No. 2, 2015, pp. 112–143). **Dr Visut Pisutha-Arnond** and co-authors (Gem and Jewelry Institute of Thailand, Bangkok) performed Be-diffusion experiments on sapphires under reducing and oxidizing conditions. Trapped-hole centres that formed during oxidative heating were inactivated by heating in a reducing atmosphere, and therefore the resulting colour was solely controlled by the Mg/Ti ratio in the sapphires. Further heating under oxidizing conditions reactivated the Be-induced trapped-hole centres. **Dr Walter A.**

Balmer (Swiss Gemmological Institute SSEF, Basel, and Chulalongkorn University, Bangkok, Thailand) and **Dr Michael S. Krzemnicki** provided preliminary results of using Fourier-transform infrared (FTIR) spectroscopy to detect Be diffusion in corundum. The presence of a weak band at 2490 cm^{-1} appears to indicate that a sample was Be diffused, but the absence of this peak is inconclusive. **Dr Pornsawat Wathanakul** (Gem and Jewelry Institute of Thailand, Bangkok) presented the results of an investigation by Thanong Leelawatanasuk and other co-authors on 'surface de-leaded' glass-filled ruby. Lead was reportedly removed from the glass filling near the surface of these stones so that the treatment would be more resistant to the heat of a jeweller's torch. The examined samples showed features consistent with typical glass-filled rubies. Energy-dispersive X-ray fluorescence (EDXRF) spectroscopy of the stones' surfaces appeared to show less Pb than typical glass-filled rubies, but more data is needed since the Pb content recorded by this technique is dependent on the overall amount of glass-filled fractures in the area analysed, as well as on the amount of Pb in the glass. Using photoluminescence spectroscopy, **Dr Ahmadjan Abduriyim** (Gemological Institute of America [GIA], Tokyo Laboratory, Japan) examined the residual pressure distribution of mineral inclusions in sapphires from New England, New South Wales, Australia. The pressure surrounding the inclusions was visualized and quantified, but the technique is only applicable to unheated sapphires and inferring the original crystallization conditions is not possible due to annealing that occurred during magmatic transport of the sapphires to the earth's surface. **This author** reported on mining methods for ruby and other gems in primary and secondary deposits near Mogok, Myanmar (see Gem Notes on pp. 387–390 of *The Journal* Vol. 34, No. 5, 2015).

In other coloured stone topics, **Dr Edward Liu** (Gemmological Association of Hong Kong) and co-authors used variable pressure–scanning electron microscopy–energy dispersive spectroscopy and backscattered electron imaging coupled with a Raman spectroscopy system to perform non-destructive in-situ chemical and structural analyses of jadeite (*fei cui*). The technique was useful for differentiating areas of jadeite and omphacite within compositionally and texturally zoned samples. **Prof. Mimi C. M. Ou Yang** (Hong Kong Institute of Gemmology) and co-authors described the texture of jadeite (*fei cui*). Using cathodoluminescence and microscopic observation of petrographic thin sections, various jadeite varieties could be correlated to different textures according to their grain size and the granoblastic or porphyroblastic size distribution of their mineral constituents. **Shane F. McClure** (GIA Laboratory, Carlsbad, California, USA) described the mining, cutting and gemmological properties of emeralds from the Belmont mine in Brazil. He witnessed the faceting of an unusually large piece of rough (29.8 g) into a fine rectangular step-cut gem weighing 18.17 ct (together with numerous small stones) that was set into a custom diamond ring. **Masaki Furuya** (Japan Germany Gemmological Laboratory, Kofu, Japan) and **Scott Davies** studied the gemmological features of pallasitic peridot from six different meteorites (Admire, Brahin, Esquel, Fukang, Jepara and Seymchan). Peridot from two of the meteorites, Jepara and Seymchan, contained inclusions that were distinctive enough to identify their host bodies. Using a combination of trace-element analysis and FTIR and ultraviolet-visible–near infrared (UV-Vis-NIR) spectroscopy, the meteoritic origin of the various samples could be determined in some cases. Peridot from Esquel and Fukang were the most difficult to separate, and those meteorites may have come from the same origin in space. **Roman Serov** and co-authors (all from the Gemological Center, Lomonosov Moscow State University, Russia) examined the colour origin of Russian demantoid using heating experiments. The optimal heating conditions (up to 650°C in reducing conditions) modified the intensity of the 430 nm cutoff in the UV-Vis spectra, resulting in a less brown and more green coloration; this suggested that the colour was caused by intervalence charge transfer between Fe^{2+} and Ti^{4+} or involving Fe^{3+}. **Dr Andy H. Shen** and co-authors (all from China University of Geosciences, Wuhan) reported on the country-of-origin determination of nephrite jade from East Asia. They developed a statistical method (iterative binary linear discriminant analysis) to process large amounts of trace-element data generated by LA-ICP-MS analyses. Using 22 elements, they were successful in separating samples from eight localities to a high degree of confidence. **Karen E. Fox** (Waterloo, Ontario, Canada) reported on recent visits to Australian opal deposits at Lightening Ridge, Yowah and Coober Pedy, and also discussed opal's stability to crazing. **Dr Emmanuel Fritsch** (Institut des Matériaux Jean Rouxel and University of Nantes, France) and co-authors described green-luminescing hyalite opal from Zacatecas, Mexico (see article on pp. 490–508 of *The Journal* Vol. 34, No. 6, 2015). **Dr Ulrich Henn** (German Gemmological Association, Idar-Oberstein) reported the properties of some rare

gem materials: wurtzite from Merelani, Tanzania; mosandrite from the Kola Peninsula, Russia (see Gem Note on pp. 565–566 of this issue of *The Journal*); and buchite from Eifel, Germany (see Gem Note on pp. 562–563 of this issue of *The Journal*). **Dr Claudio C. Milisenda** (German Gemmological Association, Idar-Oberstein) and co-authors examined some gemstones with photochromism: hackmanite, tugtupite and scapolite. The interesting colour behaviour of these gems is due to S_2^- ions. **Dr Dietmar Schwarz** (Asian Institute of Gemological Sciences Lab Co. Ltd., Bangkok, Thailand) gave an overview of mines and markets for coloured gemstones. He indicated that East Africa is the most promising area for coloured stone production, and some recent trends in the industry include involvement by large mining companies and the importance of ethical mining and marketing.

Several talks focused on pearls. **Prof. Dr Henry A. Hänni** gave a presentation for **Dr Michael S. Krzemnicki** (both from the Swiss Gemmological Institute SSEF, Basel) and co-authors on the imaging of pearls using X-ray phase contrast and X-ray scattering. X-ray analysis with a grating interferometer allows for simultaneous measurement of conventional X-ray absorption, refraction (phase contrast) and scattering, with improved sensitivity to light materials such as soft tissue. The procedure is fast (seconds to minutes) and may be used to analyse an entire necklace at once. Using known natural and non-bead-cultured *Pinctada maxima* pearls, **Nick Sturman** (GIA Laboratory, Bangkok, Thailand) and co-authors illustrated several examples showing the challenges of correctly interpreting structures seen using X-ray computed microtomography. **Sutas Singbamroong** (Dubai Central Laboratory, United Arab Emirates) and co-authors presented observations of natural non-nacreous pearls reportedly from various *Tridacna* clam species. Observations of a large collection of these pearls showed that they were mostly white (some had yellow areas) and semi-translucent to opaque with chalky blue long-wave UV fluorescence. Many had well-developed flame structures that sometimes showed iridescence. SG values typically ranged from 2.81 to 2.85, although some had significantly lower values of 2.63–2.67. X-radiography commonly revealed no internal features, or only dark areas (probably organic material) in the core of those that had the lower SG values. **Dr Jayshree Panjikar** gave a presentation for **Elisabeth Strack** (Gemmologisches Institut Hamburg, Germany) on freshwater pearls from Wisconsin, USA. These pearls were gathered from the 1930s until 1996 (when pearl fishing was banned) and are found in local museums and private collections, in addition to being available from a few local dealers. They are typically white (less commonly pink, purple, blue or green) and range up to 15+ mm, with baroque shapes being most common.

There were two presentations related to instrumentation. **Dr Lutz Nasdala** (University of Vienna, Austria) and co-authors described the search for appropriate gem zircon samples to use as an analytical reference material for age dating using ion microprobes. Large cut gemstones from Ratnapura, Sri Lanka, have shown good potential for such reference material. **Manfred Eickhorst** (System Eickhorst, Hamburg, Germany) recounted technical progress on the use of light-emitting diodes (LEDs) in gemmological instruments. The main benefits of LED lighting are that it is cool to the touch and has versatility with regards to spot vs. diffused beam types and colour temperature/wavelength (from daylight to long-wave UV).

Poster presentations covered diverse topics. **Gagan Choudhary** (Gem Testing Laboratory, Jaipur, India) described emeralds from Jharkhand State, India, which are unusual for being free of any fluid inclusions. **Helmut Pristacz** (University of Vienna, Austria, and University of Tokyo, Japan) and co-authors studied synthetic turquoise from the Natural History Museum in Vienna, Austria, and found that it had an oolitic microstructure composed of a fibrous amorphous phase (related to the high-pressure berlinite structure) together with natural turquoise (presumably used as a starting material) and synthetic turquoise. **Antonello Donini** and co-authors (all from CISGEM Laboratory – Fondazione Gemmologica Italiana, Milan) described some unusual gemmological materials seen in their laboratory, including several ornamental objects made from rhinoceros horn and a necklace composed of ambergris (an intestinal secretion produced by sperm whales). **Dr Emmanuel Fritsch** and **Joel Ivey** characterized 'Mustard Jasper' or 'Bumble Bee Stone' from western Java, Indonesia, which consists of calcite that is coloured yellow to orange by inclusions of pararealgar and realgar (both polymorphs of As_4S_4) and black by pyrite impurities. **Dr John M. Saul** (Oryx, Paris, France) examined the historical use of the word *electrum* for both amber and for the naturally occurring alloy of gold and silver. **Dr Guanghai Shi** (China University of Geoscience, Beijing) and co-authors examined the infrared spectral characteristics of amber from three sources: the Baltic Sea, Dominican Republic and Myanmar. Transmission spectra were obtained by specular reflection using the KBr pellet method, and could be correlated with the ambers' age, plant provenance and geological environment. **Elizabeth Su** (Gemsu Rona, Shanghai,

China) described jadeite markets in China, including wholesale outlets in Guangdong Province (Yangmei, Guangzhou, Pingzhou and Sihui) and Yunnan Province (Ruili, Tengchong and Kunming), as well as retail markets in Beijing and Shanghai. **Thanong Leelawatanasuk** and co-authors (all from The Gem and Jewelry Institute of Thailand, Bangkok) provided an update on their studies of treated 'black' sapphires that appeared in late 2013 and mid-2014. The very dark blue body colour of these gems resulted from the Ti-diffusion treatment of heavily fractured starting material of metamorphic origin. **Supparat Promwongnan** and co-authors (all from The Gem and Jewelry Institute of Thailand, Bangkok) described a synthetic ruby overgrowth on natural corundum encountered in early January 2015. Such material was circulated in the market in the early 2000s and sold under the misleading name 'diffusion ruby'. It can be identified by a sharp contact boundary between the core and the overgrowth seen under immersion, as well as contrasting fluorescence behaviour shown with the DiamondView.

This author also attended the post-conference field trip, which visited amber museums (e.g. Figure 2) and an amber-processing facility in Lithuania (to be reported in the next issue of *The Journal*).

Brendan M. Laurs

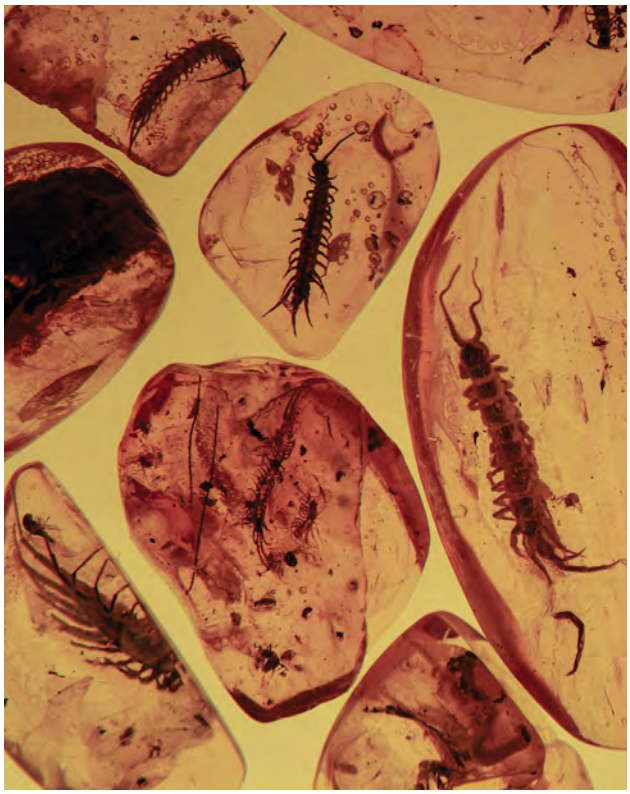

Figure 2: Polished pieces of Baltic amber containing various inclusions (here, millipedes, ~1–2 cm long) were on display at the Amber Queen Museum in Klaipeda, Lithuania. Photo by B. M. Laurs.

1st Mediterranean Gemmological and Jewellery Conference

On 27–28 June 2015, Athens (Greece) was host to the first of a new series of conferences—the Mediterranean Gemmological and Jewellery Conference, organized by the Independent Gemological Laboratory (IGL, Athens, Greece) and CGL-GRS Swiss-Canadian Gemlab (Vancouver, British Columbia, Canada). The event featured an international line-up of speakers and covered a range of topics, including synthetic diamonds, pink diamonds, pearls, rubies and gem treatments. A conference proceedings volume is available from IGL for €10 before 1 February 2016 by emailing iglcert@yahoo.com.

Growing synthetic diamonds using both gradient and even-temperature HPHT methods was addressed by **Dr Joe Yuan** (Taiwan Gemmological Institute, Taipei; and Solstar Diamond Co. and Taidiam Technology, Zhengzhou, China). The latter method produces small octahedral crystals suitable for cutting melee. Samples of colourless rough and cut synthetic diamonds were available for inspection and purchase, along with CVD-grown samples. Dr Yuan described microscopic and spectroscopic characteristics useful for detecting synthetic diamonds, a theme that was continued in detail by **Dr Thomas Hainschwang** from GGTL Laboratories (Balzers, Liechtenstein), who has screened thousands of colourless melee diamonds and to date found only one that was a CVD synthetic. In contrast, his lab has found that all parcels of yellow melee diamonds examined since 2011 were contaminated with synthetics, usually at levels of 1–2% but in one instance as high as 35%. To aid in the detection of synthetic diamonds, instruments have been produced by De Beers, which **Dr Brad Cann** (De Beers Technologies, Maidenhead) described, with special focus on identifying CVD synthetics. A recent optical modification to the DiamondView instrument enhances the visibility of red fluorescence from NV and Si-V centres, indicative of synthetic origin. A late programme change accommodated a talk by **Andre Katrusha**, research adviser for New Diamond Technology (St Petersburg, Russia), on the global synthetic diamond industry and in particular on recent achievements that include producing the world's largest colourless synthetic diamond. The

rough specimen weighed 32 ct, and was polished into a 10.02 ct (E colour, VS_1 clarity) emerald-cut gem that was inspected by many of the conference participants at the end of the day, along with other synthetic diamonds of various colours displayed by Voldstat Diamonds (Seddiner See, Germany). **Heiner Voldstat** from the company presented two posters on growth methods and equipment, including toroid presses.

While much technology has been aimed at colourless diamonds, **Branko Deljanin** (CGL-GRS Swiss-Canadian Gemlab) has directed his research on pink and blue colours. He shared his findings on the birefringence, fluorescence and spectroscopic features that can distinguish Argyle pink and blue diamonds from CVD-grown treated pink and blue synthetics coming from new producers in Asia and USA. His talk was complemented by a presentation by **this author** on pink diamonds from the Argyle mine, covering their history, production, grading and pricing, as well as their colour-change behaviour.

In other presentations, **Dr Thomas Hainschwang** discussed cultured pearls and practices used to disguise their detection, particularly initiating growth with plastic beads or natural pearls, both of which are difficult to detect in X-radiographs. **Wolf Kuehn** (Gemlab Research and Technology, Vancouver, Canada) introduced participants to portable spectrometers and light sources for making absorption, Raman and luminescence spectral measurements, and how the spectra can be used to identify gems. **Andre Huber** (GRS, Switzerland) surprised delegates with price comparisons between Burmese and Mozambican rubies, both of which have enjoyed 300–400% price increases since 2011 and have risen 25% in the past six months. To appreciate the difficulty of mining rubies, a 3D movie was shown of a mine visit in Mogok, Myanmar by **Dr Adolf Peretti** from GRS. The challenges of valuing antique jewellery were highlighted by **Gail Brett Levine** (National Association of Jewelry Appraisers, Rego Park, New York, USA), who stressed the importance of using comparable items, both to help recognize modifications and to understand factors that affect value.

Figure 3: Nikolai Khikhinashvili shows synthetic diamonds to workshop attendees at the Mediterranean Gemmological and Jewellery Conference. Photo by J. G. Chapman.

The day concluded with a 'roundtable' discussion moderated by **this author**, with panellists representing various producers and laboratories. An audience of 65 asked questions about the market for synthetic diamonds, production technologies and melee screening (for details, see https://gemconference.com/round-table-synthetics). Special guest **Nikolai Khikhinashvili** of New Diamond Technology also shared information about the three largest HPHT-grown synthetic diamonds that they produced in the past six months.

The second day of the conference featured a workshop conducted by **Branko Deljanin** that provided hands-on instruction in the detection of synthetic and treated diamonds (Figure 3). The 40 samples that were provided were studied by 30 participants using polariscopes, microscopes and a UV lamp.

The success of the conference has ensured that next year a second Mediterranean Gemmological and Jewellery Conference will take place, and it is scheduled for 7–8 May 2016, in Valencia, Spain. Further details will be available at www.gemconference.com.

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13th Society of Geology Applied to Mineral Deposits Meeting

The Society of Geology Applied to Mineral Deposits (SGA) was founded in 1965 in Heidelberg, Germany, and the 2015 SGA meeting celebrated the 50th anniversary of the Society. The 13th SGA biennial meeting was held in Nancy, France, from 24 to 27 August. The conference theme was Mineral Resources in a Sustainable World, and the meeting included 15 sessions and five symposia. Session 12 was dedicated to Gems and Industrial Materials, and was chaired by Prof. Lee Groat (University of British Columbia, Vancouver, Canada), Dr Daniel Ohnenstetter (Centre de Recherches Pétrographiques et Géochimiques [CRPG], Nancy, France), this author and

Prof. François Martin (University of Toulouse, France). Gem topics were covered in four oral presentations and two posters. Extended abstracts are published in André-Mayer et al. (2015).

Dr Yannick Branquet (University of Orléans, France) discussed the tectono-stratigraphic significance of a regional emerald-bearing evaporitic breccia horizon in the Gachalá-Chivor-Macanal area of Colombia. This horizon contains evidence of sabkha-like evaporitic sediment reworking and destabilization on active sedimentary slopes. Detailed field, petrographic and structural evidence highlighting the role of evaporites in the formation of Colombia's eastern emerald belt were presented. The emerald deposits formed 65 million years ago in local extensional structures related to the initiation of a foreland bulge and associated flexure, via the migration of hot, saline and overpressurized fluids at depths of 5–6 km.

This author investigated the oxygen and hydrogen isotopic compositions of emeralds from the Ianapera deposit at Madagascar. The isotopic data indicate a magmatic-hydrothermal origin for these emeralds. The oxygen isotopic composition of water in equilibrium with emerald coupled with the hydrogen isotopic composition of water in the emerald channels fit with the isotopic water values defined for S-type granitic magmatism.

This author also delivered a presentation for **Dr Jean-Emmanuel Martelat** (University of Lyon 1, France) on the U-Pb ages of zircon and monazite from tsavorite-bearing Neoproterozoic rocks of south-eastern Kenya and the significance of static crystallization of the tsavorite. Detailed field investigations, geochemical studies and U-Pb radiometric dating of various geological formations in the Kasigau and Kurase areas showed that the formation of tsavorite in the Voi region was the result of a metasedimentary sequence preserved from strain but heated by surrounding granulitic rocks between approximately 600 and 595 million years ago.

Albert Gilg (Technische Universität München, Germany) used a variety of non-destructive methods (Raman and UV-Vis spectroscopy, and portable EDXRF analysis) to characterize more than 90 rough and 25 faceted gem-quality pyropes from various localities in Bohemia, and compared their properties to pyrope samples from other significant locations worldwide as well as red Cr-poor magmatic pyropes. This resulted in criteria used for determining the provenance of Cr pyropes in archaeological and historical jewellery (i.e. Merovingian cloisonné jewellery from Bavaria, religious objects of the St Vitus treasure in Prague and Bohemian costume jewellery from the 19th century in Sudetendeutsche Museum in Munich).

Dr Daniel Ohnenstetter delivered a poster on the boron isotopic composition of tourmaline from tsavorite deposits in the Neoproterozoic Mozambique Metamorphic Belt, with a special focus on the mining districts in Kenya. Dravitic tourmalines associated with different types of rock from tsavorite-bearing metasedimentary sequences in Kenya, Tanzania and Madagascar show two ranges of isotopic compositions. The first range is for dravites associated with tsavorite in nodules, which clearly involve continental evaporitic boron material. The second concerns dravites from clastic metasediments, metapegmatite and marbles intercalated in the metasedimentary sequence containing tsavorite nodules, which reflect a magmatic source for clastic dravite and probably an evaporitic one for dravite in marble.

Dr Juan Manuel Garcia presented a poster on the first known occurrence of green quartz related to a polymetallic Cu-Au-Mo porphyry-type deposit in Argentina. The quartz is hosted by a vein-related shear zone and is associated with sulphide, sulphosalt, carbonate and manganese oxide minerals. Preliminary data suggest that the shear-zone-related deformation in the deposit, along with the circulation of hydrothermal fluids and reprecipitation of silica due to pressure dissolution mechanisms, led to the generation of green quartz from the deformation and dissolution of previous smoky quartz. A genesis from a radioactive source is discounted since rocks with high potassium content were not found in the study area.

Reference

André-Mayer A.S., Cathelineau M., Muchez P., Pirard E. and Sindern E., Eds., 2015. *Mineral Resources in a Sustainable World—Proceedings of the 13th Biennial SGA Meeting,* Nancy, France, 24–27 August, six volumes, 2,134 pages (see Vol. 4 for gem-related abstracts).

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Institute of Research for Development at CRPG and University of Lorraine, France

Gem-A Notices

GIFTS TO THE ASSOCIATION

The Association is most grateful to the following for their gifts for research and teaching purposes:

Mattias Haag, Lothar Haag, Idar-Oberstein, Germany, for three emeralds (0.84–0.97 ct) from Brazil, Zambia and Colombia.

Ian Mercer FGA, Chelmsford, Essex, for a copy of *Chinese Jade* by Yu Ming.

Roy Rimington, Bristol, for a rough sample and a polished sphere of plastic imitation ivory.

Antonio Silva, London, for copies of *Jules Sauer – O Caminho Das Pedras* by Mariucha Monero and *The Eras of the Diamond* by Jules Roger Sauer, as well as samples of dendritic agate, howlite, kyanite, opal and various ornamental stones.

Tay Thye Sun FGA, Far East Gemological Laboratory, Singapore, for seven pieces of tumbled amber from Tanai, Hukawng Valley, Myanmar.

ANNUAL GENERAL MEETING

The Gem-A Annual General Meeting was held on 29 July 2015 at The Crypt, 14 Ely Place, London EC1N 8SJ. The meeting was chaired by Nigel Israel, the Chairman of the Council. The Annual Report and Accounts were approved. Hazlems Fenton were re-appointed as auditors for the year.

The AGM was adjourned on the Agenda item 'Election of the Council' until 26 August, when the AGM was reconvened in the Bruton Room at Gem-A, 21 Ely Place, London EC1N 8TD. Jessica Cadzow-Collins and Alan Hart had been appointed to the Council since the previous AGM, and Paul Greer and Richard Slater who retired in rotation, sought re-election to the Council; Paul Greer, Alan Hart and Richard Slater were re-elected. Kathryn Bonanno, Justine Carmody, Kerry Gregory, Alan Hodgkinson, Jack Ogden and Christopher Smith were elected to serve on the Council.

CHIEF EXECUTIVE OFFICER

In July the Association parted company with James Riley, its Chief Executive Officer (CEO), and we thank him for the many good things he did for the Association during his tenure.

MEMBERSHIP

On 23 July 2015, the Council elected the following to membership:

Fellowship and Diamond Membership (FGA DGA)

Smith, Jennifer, *Stourport-on-Severn, Worcestershire*

Fellowship (FGA)

Zerhouni, Yousra, *Montreal, Quebec, Canada*
Zhu Yuenan, *Hangzhou, Zhejiang, P.R. China*
Zuo Tenglong, *Zhengzhou City, P.R. China*

Diamond Membership (DGA)

Li Wenzhuo, *Wuhan, Hubei, P.R. China*
Yeung Yuen Man, *Shatin, Hong Kong*

Associate Membership

King, Rosanna, *Athy, Co. Kildare, Rep. of Ireland*
Lewis, Owen, *Winchester, Hampshire*
McAlister, Diana, *Reading, Berkshire*
Wiser, Fernand, *Luxembourg*

Fellowship of the Gemmological Association of Australia (FGAA) to FGAA FGA

ten Hoedt, Yma, *Beaconsfield, New South Wales, Australia*

At a meeting of the Council held on 11 September 2015, the following were elected to membership:

Fellowship and Diamond Membership (FGA DGA)
Timms, Andrew, *Lancaster, Lancashire*

Fellowship (FGA)
Caya, Elie-Anne, *Quebec, Quebec, Canada*
Fang Xiang, *Shanghai, P.R. China*
Ouahed, Daniel, *Montreal, Quebec, Canada*
Zhou Wei, *Basel, Switzerland*

Diamond Membership (DGA)
Struthers, Rebecca, *Birmingham, West Midlands*

Associate Membership
Alhaider, Ali, *London*
Buckland, John, *Bedlington, Northumberland*
Choudrie, Karina, *London*
Maddock, Jay, *Warrington, Cheshire*
Rodriquez Aguilar, Itzel Montserrat, *Woodinville, Washington, USA*
Szynkier, Diane, *Paris, France*
Walker, Gloria, *Southall, Middlesex*

Fellowship of the Gemmological Association of Australia (FGAA) to FGAA FGA
Murray, Peter, *West Hobart, Tasmania, Australia*

Corporate Membership
Jewellery Quarter Bullion, *Birmingham, West Midlands*

OBITUARIES

Ian Campbell
1931–2015

The gemmological communities in Southern Africa and Europe were devastated at the end of July this year by the loss of one of our stalwarts, Ian Campbell.

An engineering draughtsman by trade, Ian's true passion was gemmology. In 1970 he became a Fellow of the Gemmological Association of Great Britain. He received a Diamond Grading and Evaluation Certificate in 1979, and went on to achieve certification as a Certified Valuator for the Gemmological Association of South Africa in 1988.

But Ian's achievements went far further than this. He enjoyed a lengthy stint in the Northern and Southern Rhodesian Government in the early 1950s, and continued to work in civil service even after he had launched his own gemmology business in 1965. His passion for the craft, his attention to detail and his ongoing commitment to learning saw him become a gemmology consultant in the early to mid-1970s.

Ian founded and managed the Coloured Stones Laboratory for the Jewellery Council of South Africa from 1980 until 1982, when he formed his own business, ICSL (Independent Coloured Stones Laboratory), which he operated until 2000. Ian's reputation for industry excellence spread far and wide, and his gemmological laboratory was recognized by both the Accredited Gemmologists Association in the USA and the International Coloured Gemstone Association. Ian also consulted to the European Gemological Laboratory, before finally retiring in 2010.

Ian was a prolific writer and was always ready to share his wisdom and experience with eager gemmologists, young and old. He published many reports and publications on his area of expertise, and eventually became the editor-in-chief of the *Great South African Gemmologist*, at one time South Africa's foremost gemmology publication.

Ever committed to ethical and accurate gemmology, Ian served as the founder and chairman of the Gemmological Association of Rhodesia and the Matabeleland Gem and Mineral Society. He was also a member of the International Society of Appraisers in the USA, the Accredited Gemmologists of South Africa, and the Micro-mount Society of South Africa.

Ian married Betty Keal at Umzinto, KwaZulu Natal, South Africa, on 11 December 1958. Between them they had three sons and a daughter, and our thoughts are with them at this time of loss. Ian's career and hobbies, which included a passion for fishing, led the family on a life of adventure as they travelled from Livingstone in Northern Rhodesia to Bulawayo in Southern Rhodesia. Ian also loved prospecting, going all over Matabeleland Province in Rhodesia in pursuit of amethyst, rose quartz and agate. When he was 49 years

old, Ian took up karate. Here, as in every aspect of his life, he was dedicated and committed. He achieved his black belt in the early 1990s at the age of 60.

I met Ian in 1985 at a karate training farm in Stilbaai, South Africa. Little did I know then that my life was about to change forever. I was fascinated by his compulsive pebble gathering, and when he explained that he was analysing the iron and minerals in the stones he collected, I was hooked. I sold the photographic equipment I had been collecting for my photography career, and spent every weekend for the next two years at Ian's laboratory. He became a mentor and friend, and set me on the path I walk today.

I owe Ian an enormous debt, as does the gemmological world at large. We are poorer for his passing.

…the river sliding along its banks, darker now than the sky descending a last time to scatter its diamonds into these black waters that contain the day that passed, the night to come.

— Excerpt from the poem
'The Mercy' by Philip Levine

Jeremy Rothon FGA
Kenilworth, Cape Town, South Africa

Tino Hammid

1952–2015

Internationally renowned gem and jewellery photographer Tino Hammid passed away too soon from cancer at the age of 63. His portfolio of work uniquely communicated the beauty of the gem world, in publications ranging from *The Journal of Gemmology* to *Gems & Gemology, Modern Jeweler,* Christie's auction catalogues and numerous trade publications and books including *Coloured Diamonds* (on the Aurora Collection) and *The Handbook of Gemmology*. Tino is survived by his wife Petra, young twins Antonia and Tobias, and adult daughter Evelyn.

The son of Academy Award–winning filmmaker Alexander Hammid, Tino began his career in gem photography at the Gemological Institute of America, where he worked as a staff photographer from 1980 to 1982. Robert Weldon, manager of photography and visual communications for GIA, told *JCK* he "always admired" Tino's work. Of Hammid's photographs, Weldon continued, "They are beautiful because of the attention he paid to detail—the attention he paid to the lighting, the positioning of the stone. His photos are all about the gem. His photography of gemstones has become the definition of excellence in what a gem photograph should be" (www.jckonline.com/2015/07/13/celebrated-gem-photographer-tino-hammid-dies).

In 1983 Tino started his freelance career in gem and jewellery photography, and this began a 25-year association with David Federman in providing images for *Modern Jeweler*'s monthly Gem Profile column. During this period they jointly won two Jesse H. Neal awards. "I always felt Tino was the Richard Avedon of gem photography," Federman told *JCK*. "He didn't take pictures, he took portraits. Colored stones 'sat' for him the way celebrities sat for Avedon." New York gem dealer Alan Bronstein, who worked with

The family: Tino between daughter Evelyn and wife Petra, with twins Antonia and Tobias.

Tino digitally placed these three D-Flawless diamonds (up to ~10 ct) on a background of stars that was taken by the Hubble telescope. Photo © Tino Hammid.

The beauty of the 90.38 ct Briolette of India diamond is captured in this impressive photograph. Courtesy of Christie's; photo © Tino Hammid.

Hammid on two books and on photographing the Aurora Collection, told *JCK* that Tino was "one of the greatest living gem photographers of our time". He continued, "Tino always strived for the purest, cleanest, and most honest photographs of the true color of cut and uncut gemstones. His integrity was unparalleled in his life and his work."

Most recently, in collaboration with author Geoff Dominy, Tino was delighted to contribute a large body of his work to *The Handbook of Gemmology* eBook, where he was able to render his images more accurately and beautifully in this digital medium (using RGB colour) than was possible in print. Of Tino, Dominy says "quite simply he was a genius and had the unique ability to coax the natural beauty out of a stone. He was more than a gem photographer, he was an artist who used the lens to paint the most beautiful pictures".

This author was fortunate to spend 15 years collaborating with and learning from Tino on all aspects of gem photography and digital processing, areas where Tino was always 'ahead of the curve' technically and artistically. He was enthusiastic and giving of his time and knowledge to anyone who asked. Tino had an avid interest in science and its application to his photographic imaging. Most appreciated by this author was his genius in capturing the beauty of colourless diamonds, one of the most challenging of gemstones to photograph well. That beauty, and his interest in astronomy, is apparent in his rendering of three diamonds against a starburst background taken from a Hubble telescope photograph. Equally stunning is his rendering for Christie's of the 90.38 ct Briolette of India, an historically important D-colour, type IIa diamond.

Tino will be missed by all who knew him, but fortunately his work lives on in his photographs.

Michael Cowing
ACA Gemological Laboratory
Crownsville, Maryland, USA

ERRATUM

In the Literature of Interest section of *The Journal* Vol. 34, No. 6, 2015, p. 556, the publication year for two of the articles listed from *Superhard Material Engineering* should have been given as 2014 rather than 2015. The titles of these articles are 'Distinction character of synthetic diamond in jewelry (1)' and 'Distinction character of synthetic diamond in jewelry (2)'.

Learning Opportunities

CONFERENCES AND SEMINARS

1st International Emerald Symposium
Bogotá, Colombia
13–15 October 2015
www.worldemeraldsymposium.com

Canadian Gemmological Association Gem Conference 2015
16–18 October 2015
Vancouver, British Columbia, Canada
www.gemconference2015.com

American Society of Appraisers International Appraisers Conference
18–21 October 2015
Las Vegas, Nevada, USA
www.appraisers.org/Education/conferences/asa-conference

2015 Geological Society of America Annual Meeting
1–4 November 2015
Baltimore, Maryland, USA
www.geosociety.org/meetings/2015
Session of interest: Gemological Research in the 21st Century – Exploration, Geology and Characterization of Diamonds and other Gem Minerals

Jewelry Virtual Expo
10–11 November 2015
Online conference
www.jewelriesexpo.com

36th Annual New Mexico Mineral Symposium
14–15 November 2015
Socorro, New Mexico, USA
www.geoinfo.nmt.edu/museum/minsymp/home.cfml

Gem-A Conference, hosting the 18th FEEG Symposium
21–22 November 2015
London
www.gem-a.com/news--events/events/gem-a-conference-2015.aspx
Note: Register soon for workshops and museum visits.

3rd Annual Jewelry History Series
26–27 January 2016
Miami Beach, Florida, USA
www.originalmiamibeachantiqueshow.com/show/jewelry-series

Compiled by Georgina Brown and Brendan Laurs

45th ACE IT Annual Winter Education Conference
31 January–1 February 2016
Tucson, Arizona, USA
www.najaappraisers.com/html/conferences.html

AGTA Tucson GemFair 2016
2–7 February 2016
Tucson, Arizona, USA
www.agta.org/tradeshows/gemfair-tucson.html
Note: Includes a seminar programme.

Accredited Gemologists Association Conference
3 February 2016
Tucson, Arizona, USA
http://accreditedgemologists.org/currevent.php

PDAC International Convention, Trade Show & Investors Exchange
6–9 March 2016
Toronto, Ontario, Canada
www.pdac.ca/convention
Session of interest: Diamonds

Hasselt Diamond Workshop 2016
9–11 March 2016
Hasselt, Belgium
www.uhasselt.be/UH/SBDD/SBDD-XXI

The Open Forum on Sustainability & Responsible Sourcing in the Jewelry Industry
10–13 March 2016
New York, New York, USA
www.jewelryindustrysummit.com

Amberif—International Fair of Amber, Jewellery and Gemstones
16–19 March 2016
Gdańsk, Poland
www.amberif.amberexpo.pl/title,SEMINAR,pid,1284.html
Note: Includes a seminar programme.

2nd Mediterranean Gem and Jewellery Conference
5–7 May 2016
Valencia, Spain
www.gemconference.com

Society of North American Goldsmiths SNAG^{neXt}
19–21 May 2016
Asheville, North Carolina, USA
www.snagmetalsmith.org/events/snagnext

10th International Conference on New Diamond and Nano Carbons
22–26 May 2016
Xi'an, China
http://ndnc2016.xjtu.edu.cn

12th International GeoRaman Conference
9–15 June 2016
Novosibirsk, Russia
http://georaman2016.igm.nsc.ru

EXHIBITS

Asia

The Art of Bulgari: 130 Years of Italian Masterpieces
Until 29 November 2015
Tokyo National Museum, Tokyo, Japan
www.tnm.jp/modules/r_free_page/index.php?id=1733

Europe

The Munich Show--Mineralientage München
30 October–1 November 2015
Munich, Germany
Note: Includes a seminar programme and special gem-related exhibitions
http://munichshow.com/en/the-munich-show/public-days/highlights-2014/special-exhibitions

The Feel of the City—Jewellery from Centres of this World
Until 1 November 2015
Schmuckmuseum, Pforzheim, Germany
www.schmuckmuseum.de/flash/SMP_en.html

Mademoiselle Privé [Chanel jewellery]
Until 1 November 2015
Saatchi Gallery, London
www.saatchigallery.com/current/mademoiselle_prive.php

Rooted: Swedish Art Jewellery
Until 8 November 2015
Kath Libbert Jewellery Gallery, Bradford, West Yorkshire
www.kathlibbertjewellery.co.uk/rooted/rooted_exhibition.html

Emaux de Bresse…et aujourd'hui?
Until 15 November 2015
Museum of Bresse, Domain Planon, Saint-Cyr-sur-Menthon, France
www.ain.fr/jcms/cd_7944/exposition-temporaire-et-animations-2014-au-musee-departemental-de-la-bresse

A Sense of Jewellery
Until 19 November 2015
The Goldsmiths' Centre, London
www.goldsmiths-centre.org/whats-on/exhibitions/a-sense-of-jewellery

The Art of Beauty—Jewelry Creations by Gianmaria Buccellati
Until 29 November 2015
Palace of Venaria, Turin, Italy
www.lavenaria.it/web/en/calendar/mostre/details/247-larte-della-bellezza.html

Colourful World of Quartz Materials Around Us
Until 2016
Moravian Museum, Brno, Czech Republic
www.mzm.cz/en/dietrichstein-palace-exhibitions/colourful-world-of-quartz-materials-around-us

Urartian Jewellery Collection
Until 31 January 2016
Rezan Has Museum, Istanbul, Turkey
www.rhm.org.tr/en/event/rezan-has-museum-urartian-jewellery-collection

The Silversmith's Art: Made in Britain Today
Until 4 January 2016
National Museum of Scotland, Edinburgh
www.nms.ac.uk/national-museum-of-scotland/whats-on/the-silversmiths-art/

Celts: Art and Identity
Until 31 January 2016
British Museum, London
www.britishmuseum.org/whats_on/exhibitions/celts.aspx

Brilliant! – Jewellery – Photograph – Sound
Until 2 February 2016
The National Museum of Finland, Helsinki, Finland
www.kansallismuseo.fi/en/nationalmuseum/exhibitions/temporary#brilliant_jewelry

Elements: From Actinium to Zirconium
Until 28 February 2016
Ulster Museum, Belfast, Northern Ireland
http://nmni.com/um/What-s-on/Current-Exhibitions/Elements---From-Actinium-to-Zirconium

Take it Personally
Until 1 June 2016
Museum of Cultural History, Oslo, Norway
www.khm.uio.no/english/visit-us/historical-museum/temporary-exhibitions/2015/this-is-personal.html

130 Ans de Création Joaillière à Bastia: l'Atelier Filippi
Until 19 July 2016
Musée Municipal d'Art et d'Histoire, Bastia, Corsica
www.musee-bastia.com/musee-bastia/musee.php?nav=16&lang=en

Fitting and Befitting—Fibulae and Brooches
20 November 2015–21 February 2016
Schmuckmuseum, Pforzheim, Germany
www.schmuckmuseum.de/flash/SMP_en.html

Bejewelled Treasures: The Al Thani Collection
21 November 2015–28 March 2016
Victoria and Albert Museum, London
www.vam.ac.uk/content/exhibitions/exhibition-bejewelled-treasures-the-al-thani-collection
Note: Gem-A is hosting a trip to the see this exhibition as part of the Gem-A Conference 2015. Visit www.gem-a.com/news--events/gem-a-conference-2015.aspx to book your place.

A Motley Crew—New Pieces from the Collection
18 March–12 June 2016
Schmuckmuseum, Pforzheim, Germany
www.schmuckmuseum.de/flash/SMP_en.html

Heavenly Bodies—The Sun, Moon and Stars in Jewellery
8 July–30 October 2016
Schmuckmuseum, Pforzheim, Germany
www.schmuckmuseum.de/flash/SMP_en.html

Smycken: Jewellery. From Decorative to Practical
Ongoing
Nordiska Museet, Stockholm, Sweden
www.nordiskamuseet.se/en/utstallningar/jewellery

North America

Haystack Components: Metals and Jewelry
Until 1 November 2015
Fuller Craft Museum, Brockton, Massachusetts, USA
http://fullercraft.org/event/haystack-components-metals-and-jewelry

Beneath the Surface: Life, Death, and Gold in Ancient Panama
Until 1 November 2015
Penn Museum, Philadelphia, Pennsylvania, USA
www.penn.museum/exhibitions/special-exhibitions/beneath-the-surface

Bent, Cast and Forged: The Jewelry of Harry Bertoia
Until 29 November 2015
Cranbrook Art Museum, Bloomfield Hills, Michigan, USA
www.cranbrookart.edu/museum/CAMec3.html

Fabergé: From A Snowflake to an Iceberg
Until 31 December 2015
Houston Museum of Natural Science, Texas, USA
www.hmns.org/index.php?option=com_content&view=article&id=594&Itemid=621

Maker and Muse: Women and Early 20th Century Art Jewelry
Until 3 January 2016
Driehaus Museum, Chicago, Illinois, USA
www.driehausmuseum.org/maker-and-muse

Out of this World! Jewelry in the Space Age
Until 4 January 2016
Carnegie Museum of Natural History, Pittsburgh, Pennsylvania, USA
www.carnegiemnh.org/exhibitions/event.aspx?id=25727

Glittering World: Navajo Jewelry of the Yazzie Family
Until 10 January 2016
The National Museum of the American Indian, New York, New York, USA
http://nmai.si.edu/explore/exhibitions/item/?id=890

Arts of Islamic Lands: Selections from The al-Sabah Collection, Kuwait
Until 30 January 2016
Museum of Fine Arts, Houston, Texas, USA
www.mfah.org/exhibitions/arts-islamic-lands-selections-al-sabah-collection-

The Glassell Collections of African, Indonesian and Pre-Columbian Gold
Until 30 January 2016
Museum of Fine Arts, Houston, Texas, USA
www.mfah.org/art/collections/Glassell-Gold-Collections

Turquoise, Water, Sky: The Stone and Its Meaning
Until 2 May 2016
Museum of Indian Arts & Culture, Santa Fe, New Mexico, USA
www.indianartsandculture.org/current?&eventID=1989

Variations on a Theme: 25 Years of Design from the AJDC
Until June 2016
Gemological Institute of America, Carlsbad, California
www.gia.edu/gia-museum-variations-theme-25-years-design-AJDC

A Passion for Jade: The Heber Bishop Collection
Until 19 June 2016
The Metropolitan Museum of Art, New York, New York, USA
www.metmuseum.org/exhibitions/listings/2015/passion-for-jade

Thunderbirds: Jewelry of the Santo Domingo Pueblo
Until 5 September 2016
Abby Aldrich Rockefeller Folk Art Museum, Williamsburg, Virginia, USA
www.colonialwilliamsburg.com/do/art-museums/rockefeller-museum/thunderbirds-jewelry

Generations of Mastery: Gemstone Carvings by Dreher
Until mid-November 2015
Gemological Institute of America, Carlsbad, California, USA
www.gia.edu/gia-museum-generations-mastery-gemstone-carvings-dreher

Fabergé from the Matilda Geddings Gray Foundation Collection
Until 27 November 2016
The Metropolitan Museum of Art, New York, New York, USA
www.metmuseum.org/exhibitions/listings/2011/faberge

Glitterati. Portraits & Jewelry from Colonial Latin America
Until 27 November 2016
Denver Art Museum, Denver, Colorado, USA
www.denverartmuseum.org/exhibitions/glitterati

Gold and the Gods: Jewels of Ancient Nubia
Until 14 May 2017
Museum of Fine Arts, Boston, Massachusetts, USA
www.mfa.org/exhibitions/gold-and-gods

Douglas Harling: Residence of the Heart
6 December 2015–6 March 2016
Metal Museum, Memphis, Tennessee, USA
www.metalmuseum.org/upcoming_exhibitions

City of Silver and Gold: From Tiffany to Cartier
Ongoing
Newark Museum, New Jersey, USA
www.newarkmuseum.org/SilverAndGold.html

Crystals Transformed Through Vision & Skill
Ongoing
Houston Museum of Natural Science, Texas, USA
www.hmns.org/index.php?option=com_content&view=article&id=481&Itemid=502

Gilded New York
Ongoing
Museum of the City of New York, New York, USA
www.mcny.org/content/gilded-new-york

Jewelry, from Pearls to Platinum to Plastic
Ongoing
Newark Museum, New Jersey, USA
www.newarkmuseum.org/jewelry

Mightier than the Sword: The Allure, Beauty and Enduring Power of Beads
Ongoing
Yale Peabody Museum of Natural History, Yale University, New Haven, Connecticut, USA
http://peabody.yale.edu/exhibits/mightier-sword-allure-beauty-and-enduring-power-beads

Australia and New Zealand

Wunderrūma: New Zealand Jewellery
Until 1 November 2015
Auckland Art Gallery, Auckland, New Zealand
www.aucklandartgallery.com/whats-on/events/2015/july/wunderruma-new-zealand-jewellery

Opals
Until 14 February 2016
South Australian Museum, Adelaide, South Australia, Australia
www.samuseum.sa.gov.au/explore/exhibitions/opals

A Fine Possession: Jewellery and Identity
Until 22 May 2016
Powerhouse Museum, Sydney, New South Wales, Australia
www.powerhousemuseum.com/exhibitions/jewellery

OTHER EDUCATIONAL OPPORTUNITIES

Gem-A Workshops and Courses
Gem-A, London
www.gem-a.com/education/course-prices-and-dates.aspx

Lectures with The Society of Jewellery Historians
Burlington House, London, UK
www.societyofjewelleryhistorians.ac.uk/current_lectures

27 October—'Beauty and Belief: Techniques and Traditions of Omani Jewellery' by Aude Mongiatti and Fahmida Suleman

24 November—'Digital Tools and New Technologies in Contemporary Jewellery' by Dauvit Alexander

New Media

Gem Testing Techniques

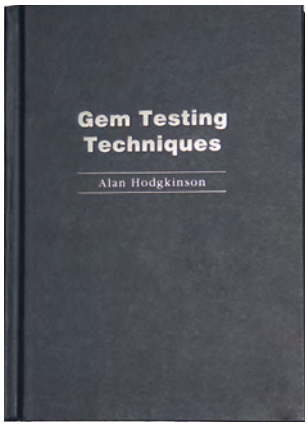

Alan Hodgkinson, 2015. Valerie Hodgkinson, Scotland, 541 pages, illus., hardcover, no ISBN, www.gemtestingtechniques.co.uk. £128.00 United Kingdom, £165.00 Europe, £210.00 Canada, or £185.00 elsewhere.

Gem Testing Techniques is an impressive tome, the culmination of over 40 years of gemmological interest, experimentation, research, and general life-long passion. From his humble beginning as a gemmology student, to working with such visionaries as Eric Bruton and Bill Hanneman, the author has risen through the ranks to become a world-renowned gemmologist, not least in the field of visual optics, an area that he has effectively made his own.

Now, that vast wealth of gemmological knowledge has come together in this much-anticipated book, spanning 15 chapters and 541 pages. Extensively illustrated throughout, the chapters include:

1. Magnification: from the loupe to microscope, includes alternate techniques and filters
2. Polariscope/Conoscope: also describes various mineral accessory plates
3. Refractometer: details different models and methods, with in-depth analysis for proper interpretation of results
4. Spectroscope: comprehensive instruction, with numerous examples of spectra
5. Specific Gravity: examples of and instruction on various methods available
6. Visual Optics: the author's specialty, and one that is overlooked in a great many texts
7. Acid Testing: for opal and resins
8. Electro-conductivity: concise information, mainly in conjunction with diamond
9. Filters: the full range are covered, including those produced by Hanneman and Hanneman/Hodgkinson
10. Hardness: not an often recommended test, this is given due consideration
11. Magnetism: covers diamagnetism, paramagnetism and general magnetic responses
12. Pleochroism: given a new twist with the addition of 'anomalous dichroism'
13. Radiation: brief but useful guide to radioactivity and the needed safety precautions
14. Thermal Testing: not only thermal probes; includes opal, jet, and their simulants
15. Ultraviolet: detailed introduction to UV reactions and how they are useful for gem identification

Within each of these main chapters are various subheadings, which cover the main points of each gemmological aspect in a straightforward and easy-to-follow way. Images and diagrams are sequentially numbered, including reference to the chapter numbers, and are cross-referenced throughout the text. Colour coding of the various chapters provides a useful way of keeping track of important parts of the text.

Some specific aspects worth mentioning include the Spectroscope chapter, which gives detailed instruction on the use of this tool, in all its variants, before providing the reader with 422 full-colour reference spectra, a catalogue that this reviewer believes is unsurpassed in any available standard gemmological text on the market. It is in areas like this that the book comes into its own, providing a unique reference for students and practising gemmologists alike. In addition, the chapter on Visual Optics gives this subject thorough consideration, from both the theoretical side (e.g. how features such as 'primaries' and 'secondaries' occur) and the practical side (e.g. how to view them using very basic gemmological equipment, and in many cases, nothing more advanced than the human eye). Within this section, that author also explains how the concept was used in the creation of the Hodgkinson Refractometer, a large desktop setup that can be created by anyone, and which, with careful practice, can be used to give good results.

Following the extensive main text are equally informative appendices. These provide the usual gemmological constants, but also some welcome additions such as a glossary of gemmological terms and special sections on chrome spinel, feldspar, garnet and ivory. In the appendix on garnet, the author explains the difficulty in identifying the various varieties. By showing a comparison of the constants supplied by various gemmological authorities (Gem-A, GIA, GAA and more), he demonstrates that there is no universally accepted framework for identifying borderline garnet species, and that the situation has

become further complicated by the introduction of varietal names such as rhodolite. Using ternary diagrams, he highlights areas that are still currently not recognized with species names, before going on to include colour and magnetic characteristics in an effort to show the reader the complexities of this mineral group. In the appendix on ivory, the author covers not only elephant and mammoth, but also narwhal, warthog, walrus, hippopotamus and sperm whale ivories, providing a comprehensive breakdown on their uses and identification.

This book offers an easy-to-read, yet informative insight into the world of gemmology, approaching it as Alan Hodgkinson always does, from a light-hearted but accurate viewpoint. This reviewer believes that this book will become a standard text for many future gemmological students.

Andrew Fellows FGA DGA

Ivory

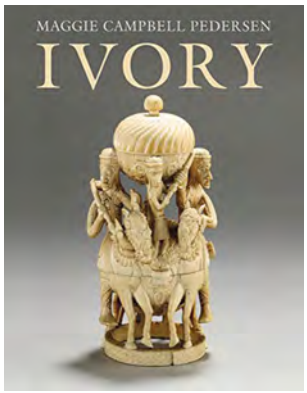

Maggie Campbell Pedersen, 2015. Robert Hale Ltd., London, 240 pages, illus., hardcover, ISBN 978-0719800535, www.maggiecp.co.uk/book.html. £45.00.

Maggie Campbell Pedersen FGA is a well-known organics expert, with ivory being her main area of expertise. This new book provides invaluable information on ivory—its history, sources, composition, imitations, environmental and ethical issues (and resulting legislation) and trade routes.

The book is divided into three chapters. The first one, titled What and Where, covers the occurrence of ivory in nature, beyond the elephant and mammoth varieties, including walrus, hippopotamus, orca (killer whale) and even wild boar. A section for each ivory-bearing animal is included with their facts and features, as well as lore. The ethical and legal aspects and place within our society of this beautiful—but controversial—material is examined and put into context. Differing views exist from country to country, and these have evolved through time. Campbell Pedersen touches on the topic of ivory legislation to prevent elephant poaching, how countries comply with the law, and the consequences for the gem trade. Updated information on banned ivory and the threats to various animals are a must for anyone in the field wanting to understand the ins and outs of the ivory trade.

The second chapter, titled How and What, explores the composition and characterization of ivory. The reader learns how the structure of the dentine can be used to distinguish different types of ivory, and how, according to their structure, each variety is suitable for certain uses such as carvings or beads. Of course, with ivory being such a desirable material, imitations are inevitable. Bone, 'vegetable ivory' and more are presented in detail with their characteristics, localities, principal uses and identification. Also covered are man-made ivory substitutes such as celluloid, casein, elforyn (created specifically to simulate ivory) and others. Visual observation of a sample's structure is most important for proper identification, and UV fluorescence (especially long-wave) is probably the next most helpful non-destructive test; burning (combustion testing) is a useful last resort, but destructive. FTIR and Raman spectroscopy are useful for separating ivory from simulants, and Raman analysis can further distinguish between different types of ivory. Additional (destructive) testing that may be useful for ivory identification includes trace-element and isotopic analyses. Also, carbon-14 dating can be used to establish when the host animal died, although the time that a piece was actually carved cannot be determined. DNA testing can determine species, but sufficient usable material must be extracted and compared to known reference material. The chapter closes with information on the fashioning of ivory and how the general age of a piece can sometimes be established through the carving style. Also explained are carving processes and the final treatments used to finish a piece (e.g. dyeing), as well as methods used to 'age' ivory—possibly in an attempt to circumvent restrictions on some modern varieties.

In the third and final chapter, called Where and When, Campbell Pedersen elaborates on ivory trade routes, and how for thousands of years ivory has been prized by various cultures. Information is provided on the use of mammoth ivory as a tool in prehistoric times, and Campbell Pedersen then progresses through the different types of ivory used in various periods and regions, such as the use of narwhal, sperm whale, orca and walrus ivory in the Arctic. She explains the cultural traditions of the Inuit people and how they relate to ivory, even in the manufacture of toys.

An appendix and glossary are included at the end of this very informative book. *Ivory* is an essential guide for anyone interested in studying this fascinating organic gem material.

Amandine Rongy FGA

Jewelry Appraisal Handbook, 8th edn.

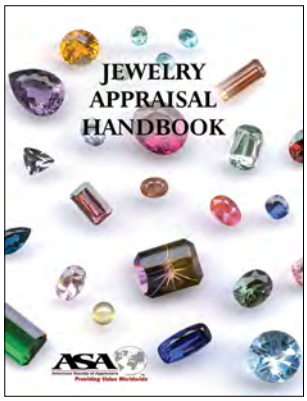

American Society of Appraisers (ASA), 2015. ASA, Reston, Virginia, USA, 50 pages, illus., www.appraisers.org/marketplace. US$112.00 three-ring binder, US$80.00 PDF file or US$152.00 for both.

This 8th edition of the *Jewelry Appraisal Handbook,* a collaborative effort of members of the American Society of Appraisers—Gems and Jewelry (ASA-GJ) discipline, is an essential reference for all who work in the jewellery industry. As one of the most complete resources for the professional jewellery valuer, it contains more than just lists of gemmological properties, useful weight tables and volumetric formulae for common shapes of gemstones. 'Useful', in fact, is the operative word for this publication, which bills itself as a wiki-handbook, in that it is constantly being updated by the ASA-GJ committee.

The first chapter begins with page after page of tables to estimate the weight of mounted diamonds using their measurements, including round, baguette and tapered baguette, marquise, princess, pear and triangle shapes. Accompanying the tables are the formulae upon which they are based, cut-grade parameters for round-cut diamonds and plotting symbols, all courtesy of the Gemological Institute of America (GIA). Following is a coloured stones section with more of the same useful tables and formulae, including GIA nomenclature for the description of colour and clarity types.

Separate informative sections follow for diamonds, coloured stones, pearls, jade, watches, jewellery in general, carvings, beads, phenomenal gems and organic materials. These comprehensively outline descriptive terms and value factors for each of these categories. One page is devoted to a system to estimate the 'condition' of jewellery and watches. There are also more limited sections on unit conversions, jewellery hallmarks and common gold coins.

From Jewelers of America is a page referencing their 2013 Cost of Doing Business report, with data from a survey of retail gross profit margins. Heavy in statistical terminology, the valuer must run the data through several computations to arrive at retail mark-ups. Hopefully in future editions this section will be easier to understand and apply.

Potentially the most useful part of this publication is its Research and Business Web Links Project. This is a compendium of nearly 500 links (and growing) to websites useful to valuers, encompassing topics such as auction houses, suppliers, metals, estate jewellery, diamonds, coloured stones, pearls, watches, coins, hallmarks and trademarks, flatware and hollowware, marketing, appraisers (valuers), laboratories, technical information, insurance, legal and statistical information. This is where the 'wiki' function occurs, as the broader valuation and jewellery communities are encouraged to add to this formidable collection of stored knowledge. For those with the digital (PDF) version, any updates or additions are instantaneous.

The *Jewelry Appraisal Handbook* is a legacy of the late Kirk Root, GG ASG ASA MGA, who began creating and compiling its contents in 1997. The ASA-GJ discipline continues to build the *Handbook* to be as complete a general reference as possible for the jewellery valuation profession.

Charles I. Carmona

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Compiled by Brendan Laurs

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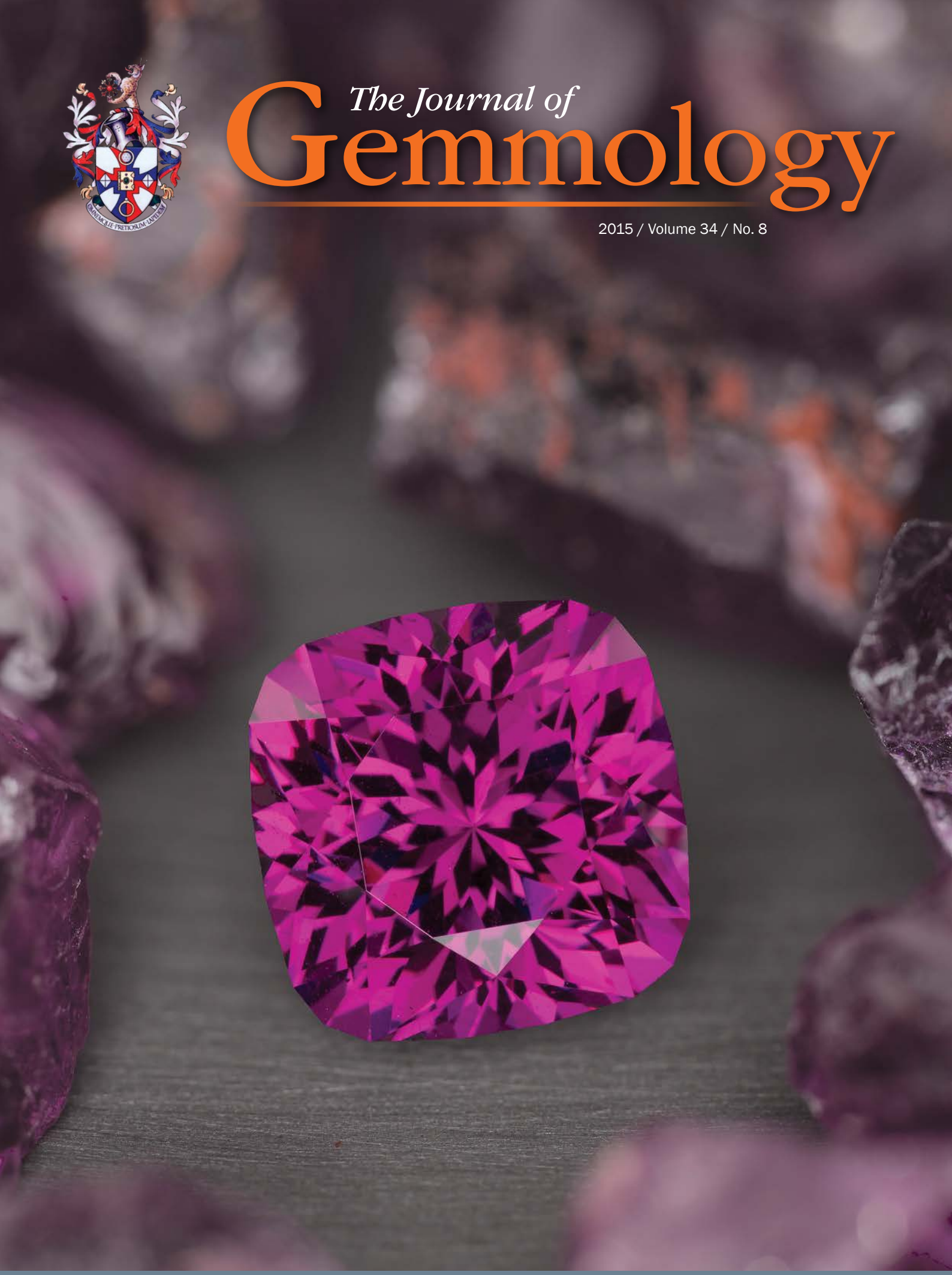

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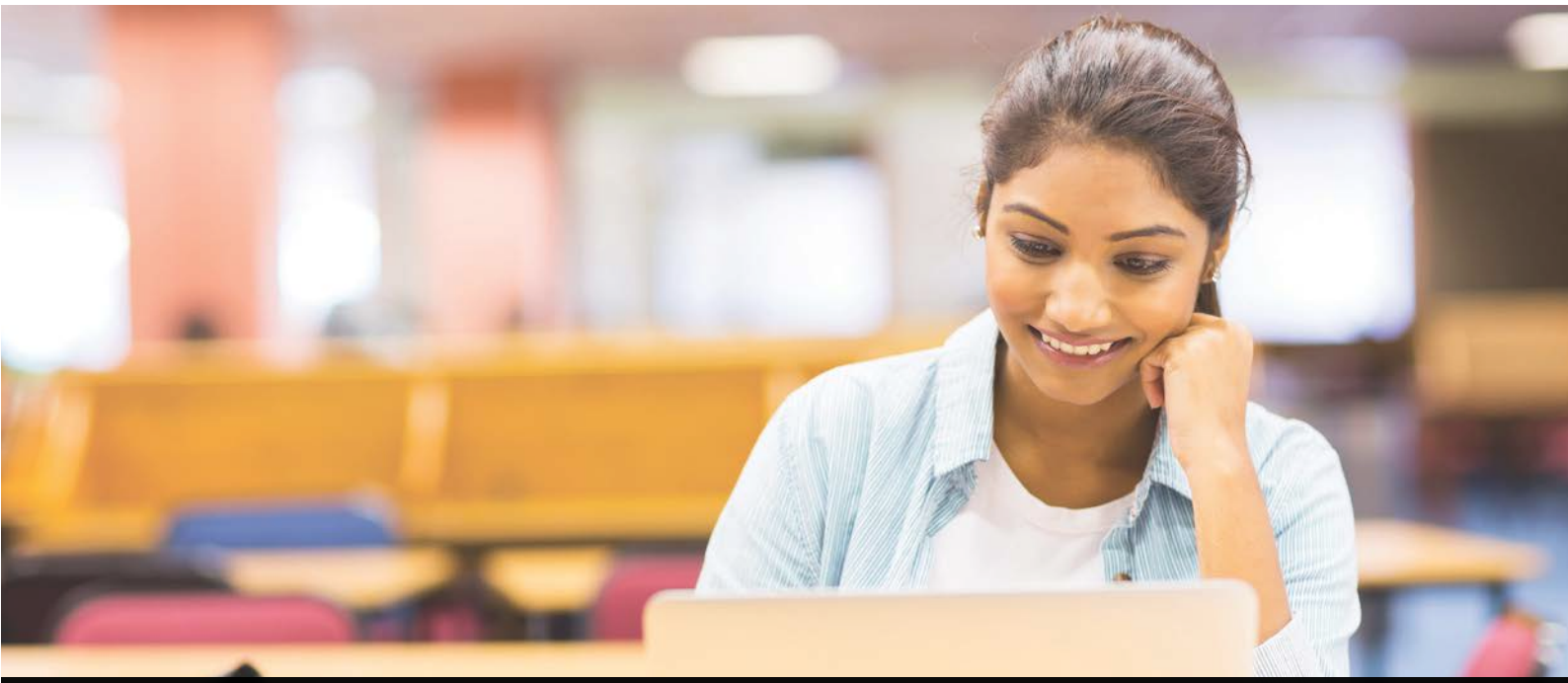

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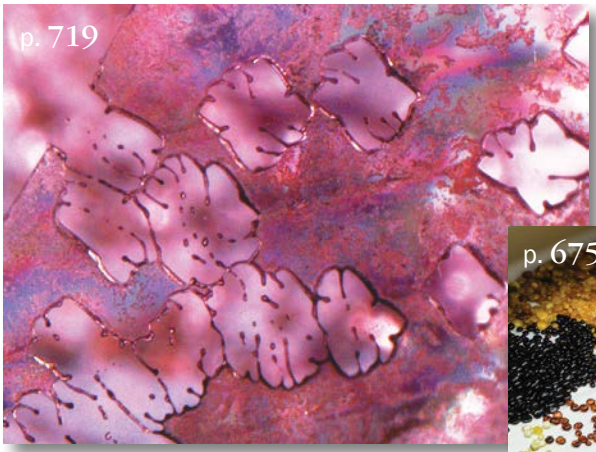

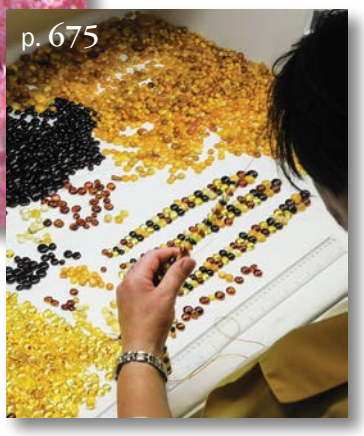

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Cover Photo: This 5.86 ct intense reddish purple garnet was cut by Jeff White from rough material that was mined in Mozambique; see Gem Note on pp. 656–658. Photo by Jeff White.

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I am pleased to report that in November 2015, *The Journal* joined the Web of Science (WoS) when it was accepted into Thomson Reuters' new Emerging Sources Citation Index (ESCI) database. Journals in ESCI are indexed like those in other databases within WoS, but they do not receive an impact factor (a measure of how often recent articles are cited in WoS journals). As *The Journal* continues to be evaluated for Thomson Reuters' impact-factor science database (Science Citation Index Expanded), it should benefit greatly from the exposure provided by ESCI. Additional exposure is provided by *The Journal*'s inclusion in databases that are maintained by other indexing services and journal aggregators (e.g. Scopus, EBSCO, ProQuest and GeoRef) that are commonly subscribed to by university libraries and research institutions worldwide.

The Journal's inclusion in WoS is good for our authors, for our readers and for gemmology in general. *The Journal* will now be in a better position to attract articles from researchers at top universities who are required to publish in WoS journals, and our readers will benefit from this cutting-edge research. In addition, *The Journal*'s coverage by WoS will certainly help raise awareness of gemmology in the global scientific community. Being part of WoS will not change the direction or scope of *The Journal*, as gemmology will continue to be the core foundation of its content.

On another subject, thanks to the efforts by consultant Carol Stockton, I am pleased to announce the completion of *The Journal*'s Cumulative Index that covers all issues from 1947 to 2013 (Volumes 1–33). This index is available as a free downloadable PDF file on *The Journal*'s website, and early in 2016 it will be updated to include all issues through 2015.

Coming soon (also scheduled for early 2016), Gem-A will unveil a new website, and this will give Gem-A members free access to the entire archive of *The Journal* as searchable PDF files. In addition, non-members will be able to purchase PDFs of individual articles/sections, as well as complete issues. The availability of the entire *Journal* archive, combined with the Cumulative Index, will provide a comprehensive gemmological reference tool.

Brendan Laurs
Editor-in-Chief

What's New

INSTRUMENTS AND TECHNIQUES

Gemlogis Taupe Diamond Segregator

Gem laboratories are more commonly receiving mixed parcels of natural and synthetic diamonds for identification. At this author's lab, colourless to near-colourless diamonds weighing >0.50 ct are subjected to advanced testing, while smaller stones (i.e. 0.02–0.49 ct) are segregated using a Gemlogis Taupe Diamond Segregator (www.gemlogisusa.com/gemlogis-taupe-diamond-lab-created-tester.htm), which is manufactured by Jubilee Diamond Instrument Ltd., Hong Kong, and was released in May 2014. The instrument is compact and portable, and has a short-wave UV beam that is focused on the sample. Sensors detect the transmission of the UV beam through the sample to identify type II diamonds, thereby flagging potentially CVD- or HPHT-grown synthetics, or natural diamonds that may have been HPHT treated.

The sample is placed table-down on the instrument and the lid is shut for the analysis. Within seconds of pressing the 'test' button, a green light will indicate the diamond is type I (and therefore probably natural), while a yellow-orange light identifies the need for further testing. An advantage of the instrument is that small diamonds down to 0.02 ct can be segregated. For best results, the instrument should be regularly calibrated using known melee-sized CVD- and HPHT-grown synthetic diamonds.

There is an increasing need for such instruments that are affordable and can segregate small potentially synthetic diamonds from natural ones. Although the instrument does not specifically identify synthetic or HPHT-treated diamonds, it is helpful for separating type II gems for further examination.

Jayshree Panjikar (jayshreepanjikar@gmail.com)
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Pune, India

M-Screen Automatic Melee Screening Device

In September 2015, HRD Antwerp released the M-Screen device, which rapidly screens melee parcels (0.01–0.20 ct) to separate natural from potentially synthetic/treated diamonds and simulants. The desktop instrument automatically feeds, screens and sorts colourless and near-colourless (D–J) round brilliant diamonds at a rate of 2–5 stones per second (7,200–18,000 per hour). Also, starting in November 2015, HRD Antwerp began offering a rapid (24-hour turnaround time) melee screening service using the M-Screen. Visit www.hrdantwerp.com/en/product/m-screen.

Presidium Synthetic Diamond Screener

In September 2015, Presidium debuted a new device for screening colourless and near-colourless (D–J) diamonds and flagging type IIa stones. The instrument measures 13.0 × 10.0 × 6.5 cm, weighs 210 g and can be operated using AAA batteries or via a USB connection. Samples ranging from 0.1 to 10 ct that are loose or mounted (with an open-back setting) can be tested, and the measurement takes approximately 6 seconds. Visit http://presidium.com.sg/psdproduct/synthetic-diamond-screener-sds.

Spekwin32 Spectroscopy Software

In October 2015, Dr Friedrich Menges released an updated version of the spectroscopy software Spekwin32. New capabilities of interest to gemmologists include 'Spectroscope View'—which renders a spectrum collected using a spectrometer

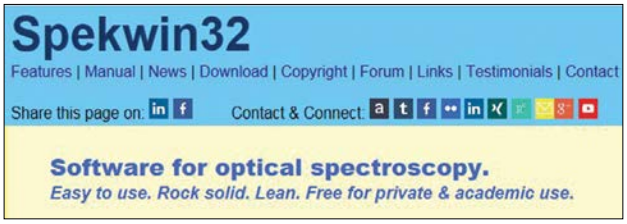

into the visual appearance that would be seen in a hand-held (diffraction grating) spectroscope—and the ability to read file formats from nine additional spectroscopic sources. For more information and to download this free software, visit www.effemm2.de/spekwin/index_en.html.

NEWS AND PUBLICATIONS

CIBJO Coral Book

The newest addition to the line-up of CIBJO Blue Books is *The Coral Book*, released in July 2015. The publication covers the terminology (including definitions) and classification of coral, as well as its treatments and imitations. Various annexes provide a classification flowchart and information on care requirements, normative trade codes, coral species (including those covered in the CITES Appendices), coral sustainability and regulations for harvesting, and a reference list. Download the free publication at www.cibjo.org/download/15-10-01%20Official%20Coral%20Book.pdf.

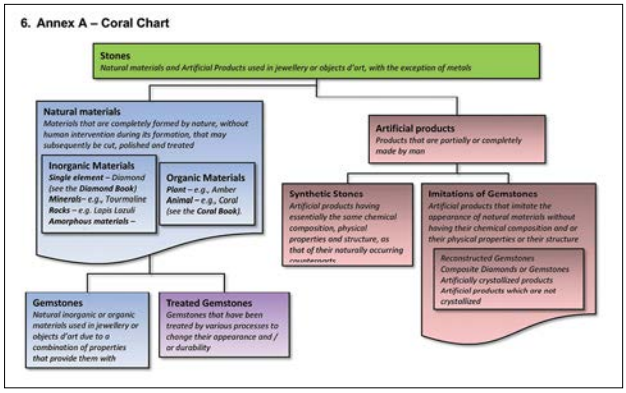

Diamond Industry 2015

The 5th annual report on the global diamond industry prepared by the Antwerp World Diamond Centre and Bain & Company was released in December 2015, titled 'The Global Diamond Industry 2015: Growth Perspectives amid Short-term Challenges'. The paper focuses on long- and short-term drivers of diamond jewellery demand and prices, and concludes by providing an update on the diamond industry outlook through 2030. Download the free report at www.bain.com/Images/FINAL%20bain_diamond_report_2015_01122015.pdf.

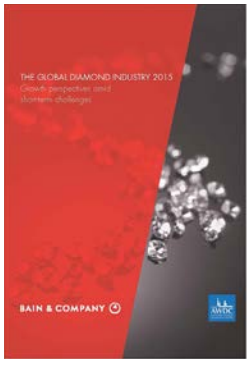

Flux-grown Synthetic Spinel

In September 2015, Gemresearch Swisslab reported on a new line of synthetic spinel manufactured in Russia by Tairus Co. Ltd. The product is available in pinkish red, lavender, colour-change (violet and purplish pink) and violetish blue varieties. Download the report at http://gemresearch.ch/wp/wp-content/uploads/2015/09/2015-09-Spinel_New_Synthetic.pdf.

ICGL Newsletter

The International Consortium of Gem-Testing Laboratories has released the Fall 2015 issue of their newsletter (No. 3/2015), available at http://icglabs.org. It features articles on small HPHT-grown octahedral colourless and blue synthetic diamonds produced using an even-temperature method, heat-treated amber beads, amber in the collection of the Pangem Testing Laboratory (Pune, India) and a proposal to include

certain spectroscopic data on diamond reports to aid in the detection of fraudulent replicas of loose or mounted stones.

ISO Standards for Diamonds

In July 2015, the International Organization for Standardization released a new standard (ISO 18323:2015) for diamond nomenclature: 'Jewellery – Consumer Confidence in the Diamond Industry'. The document is designed to be understood by the consumer, and covers nomenclature and disclosure of diamonds—natural, treated, synthetic, composite and imitation—as well as a glossary. The standard is available for purchase at www.iso.org/iso/catalogue_detail.htm?csnumber=62163.

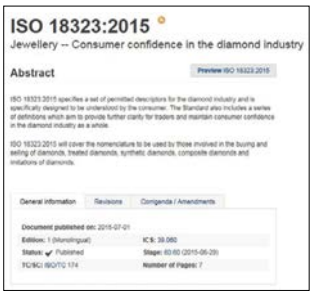

The Journal of Gemmology Cumulative Index

In December 2014, Gem-A released *The Journal*'s Cumulative Index, covering all issues from 1947 to 2013 (Volumes 1–33). In early 2016, it will be updated to include Volume 34 (2014–2015). The contents are listed by subject, and the PDF file is searchable, so entries by specific authors also can be located. The Cumulative Index is available in electronic format only as a free download from *The Journal*'s website at www.gem-a.com/publications/journal-of-gemmology.aspx.

Rare Book Scanning by GIA Library

The Gemological Institute of America's Richard T. Liddicoat Gemological Library and Information Center is in the process of digitizing its collection of rare and historically significant books, and many titles are available for free download at https://archive.org/details/@gia_library. As of 9 December 2015, 101 books had been uploaded, with more being added weekly. Brief descriptions of each item can be seen in list view; most were taken from *Gemology: An Annotated Bibliography* compiled by the late John Sinkankas in 1993.

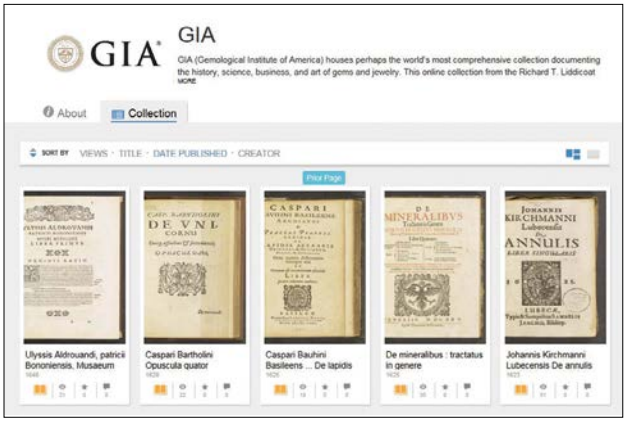

Responsible Business Practices and Jewellery Consumption

A November 2015 presentation delivered at the ESRC Festival of Social Science by Prof. Marylyn Carrigan of Coventry University on preferences by UK jewellery consumers who shop in the Birmingham Jewellery Quarter is available for free download from the National Association of Jewellers' website at http://tinyurl.com/zz6j3qb.

RJC 2015 Progress Report

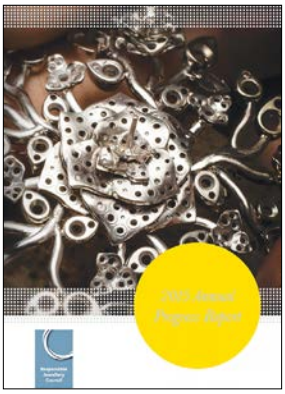

The Responsible Jewellery Council has issued its 2015 annual progress report, which describes the organization's accomplishments in 2014 in areas such as membership growth, certification benchmarks and standards development. Download the free report at www.responsiblejewellery.com/files/RJC-Annual-Report-2015-Web-version.pdf.

What's New provides announcements of new instruments/technology, publications, online resources and more. Inclusion in What's New does not imply recommendation or endorsement by Gem-A. Entries are prepared by Brendan Laurs unless otherwise noted.

The Fire Within

"For in them you shall see the living fire of the ruby, the glorious purple of the amethyst, the sea-green of the emerald, all glittering together in an incredible mixture of light."

– Roman Elder Pliny, 1st Century AD

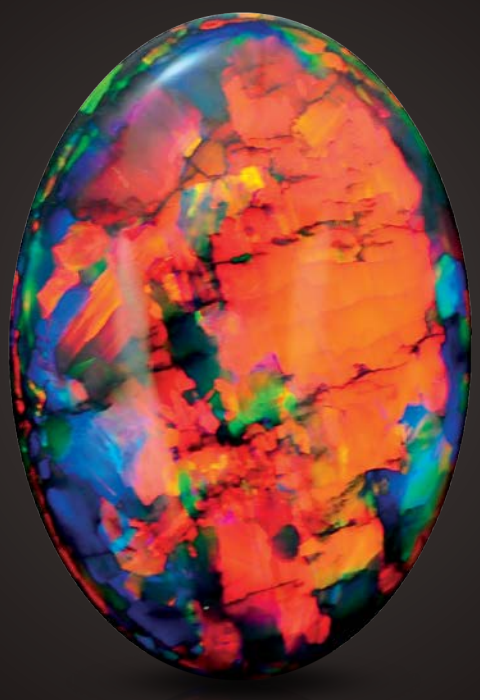

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JOG

The Kerez Effect in Green Tourmaline

Andrew Fellows

The *Kerez effect* refers to an optical behaviour that is very rarely shown by green tourmaline. Since it is so uncommon, it often goes unreported in gemmology textbooks.

Originally discovered by Dr C. J. Kerez (Read, 1982), this optical effect was apparently first described by Mitchell (1967) in two very unusual Brazilian tourmalines. He wrote: "To all outward appearances they are quite normal stones. Refractometer readings, however, reveal the inexplicable fact that the stones each give four distinct shadow edges…the twin ordinary ray readings remain stationary while the other two move as the stone is rotated." Such additional shadow edges, ranging from two to four pairs (four to eight lines in total), also have been referred to as *satellite readings* (Schiffmann, 1972, 1975). The multiple shadow edges can understandably create confusion for gemmologists.

According to everything that this author has been taught, this optical effect should not happen—and this prompted the author's search for such specimens. Eight years (and many tourmalines) later, an elusive multi-RI stone was found. It consisted of a 1.39 ct oval cut (Figure 1) that produced eight individual shadow edges in the refractometer (Figure 2). The two groups of four edges could easily be differentiated using a polarizing filter, giving the four sets of readings that are shown in Table I (which also gives the results from other visually similar green tourmalines that were studied for comparison). Each set of shadow edges corresponded to the ordinary and extraordinary rays, but interestingly they were not equally spaced, although the birefringence was constant for all four sets.

Figure 1: Of the green tourmalines shown here (0.53–2.74 ct), only one (no. 1) showed the Kerez effect in the refractometer. See Table I for RI data corresponding to each stone. Photo by Henry Mesa.

For stones showing the Kerez effect, the 'true' RI values were shown by Schiffmann (1975) to correspond to the lowest reading of each of the sets of shadow edges. He proved this after repolishing such a stone, which resulted in a single set of readings that were normal for tourmaline. Therefore, the correct RI range for the 1.39 ct stone examined by this author

Table I: RI readings of green tourmalines in this study.

Stone	Weight (ct)	Shape	RI readings	Birefringence
1	1.39	Oval	1.622–1.649	0.027
			1.627–1.654	0.027
			1.629–1.656	0.027
			1.634–1.661	0.027
2	0.67	Emerald cut	1.620–1.640	0.020
3	2.74	Emerald cut	1.621–1.638	0.017
4	0.53	Emerald cut	1.618–1.640	0.022
5	0.53	Oval	1.621–1.640	0.019
6	0.54	Oval	1.622–1.641	0.019
7	2.54	Round	1.624–1.642	0.018

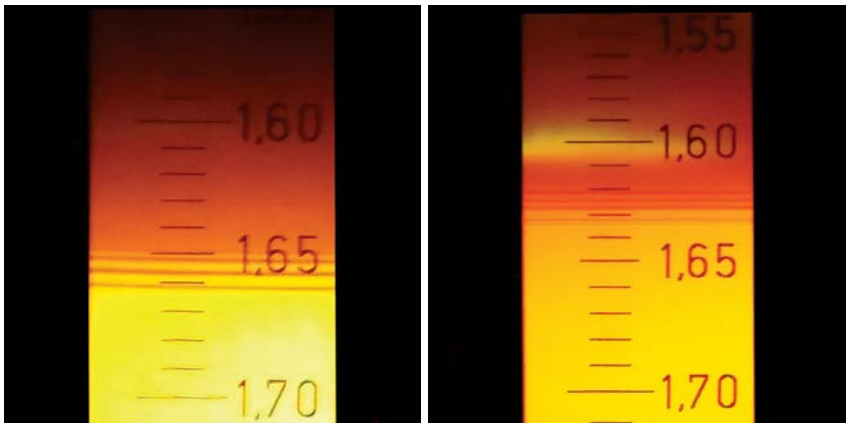

Figure 2: Refractometer readings of the 1.39 ct tourmaline displayed the Kerez effect in four sets of shadow lines corresponding to the ordinary (left) and extraordinary (right) rays. Photos by A. Fellows.

should be inferred as 1.622–1.649.

The Kerez effect is thought to result from the cutting and polishing process, when over-enthusiastic polishing causes a build-up of heat due to friction from the cutting wheel (Schiffmann, 1975). This creates thermal damage that penetrates slightly below the stone's surface.

To check whether the Kerez effect could purposely be created during the cutting process, this author enlisted the help of a fellow gemmologist and local lapidary. Two individual sections of a dark green tourmaline were subjected to heavy polishing, with sufficient speed and pressure used to build up heat within the stones. However, compared to a 'normally' polished section of the same stone, there were no differences seen in the RI readings, and no additional shadow edges were created by the aggressive polishing. It is therefore difficult to see how a lapidary could inadvertently create the Kerez effect, and perhaps there is more than just heat involved.

The exact cause of the Kerez effect, and why it appears restricted to green tourmaline, is still unknown. It is hoped that increasing the awareness of this interesting phenomenon will enable other gemmologists to recognize the effect in tourmalines that they may rarely encounter.

Acknowledgement: The author thanks Sam Lloyd FGA for help with polishing the tourmaline samples, and for independently checking the results.

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Gem Notes

COLOURED STONES

Apatite from Mozambique

In January 2014, gem dealer Dudley Blauwet (Dudley Blauwet Gems, Louisville, Colorado, USA) obtained a 600 g parcel of rough apatite that his African supplier indicated was from Nhamatanda, Mozambique. In July 2014, cutting of six pieces weighing 236.7 g yielded 55 gemstones with a total weight of 264.44 carats. The largest stones (up to 39 ct) contained parallel arrays of eye-visible platelet inclusions, and some also contained fibrous needles. To decrease the visibility of the platelets, the gems were cut so the inclusions were oriented perpendicular to the table facet. Blauwet loaned two apatites to the American Gemological Laboratories (AGL) for examination, and they were characterized by this author: a 3.88 ct triangle and a 10.61 ct cushion (Figure 1).

The yellowish green colour combined with an excellent polish made these stones quite attractive. Standard gemmological testing of both gems revealed RIs of 1.630–1.635 (birefringence 0.004–0.005) and a hydrostatic SG value of 3.17. These properties confirmed the samples were apatite (cf. O'Donoghue, 2006). They were inert to long-wave UV radiation and exhibited a weak yellow fluorescence to short-wave UV.

Microscopic examination revealed various internal features. Parallel star-like oriented cross-hatch inclusions formed one of the most interesting types (Figure 2a). The stones also contained several high-relief disc-like fissures (Figure 2b). Additionally present were parallel growth tubes with reflective platelets and particles (Figure 2c), as well as minute unidentified crystals with parallel needle-like tubes (Figure 2d).

Figure 1: These cushion-cut and triangular gemstones (10.61 and 3.88 ct, respectively) consist of apatite from Mozambique. Photo by Kelly Kramer.

Semi-quantitative chemical analysis using a Thermo Electron Corp. ARL Quant'X energy-dispersive X-ray fluorescence (EDXRF) spectrometer showed the expected major amounts of Ca and P, as well as minor Mg (~0.7 wt.%) and Mn (~0.2 wt.%), and traces of Fe (~0.07 wt.%).

Gem-quality apatite is known from several localities. It is possible that the inclusion assemblage shown by these Mozambique apatites is unique to their specific locality, but more research would be needed to confirm this.

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Reference

O'Donoghue M., Ed., 2006. *Gems*, 6th edn. Butterworth-Heinemann, Oxford, 382–383.

Figure 2: The Mozambique apatites examined for this report contain an interesting assemblage of internal features, including (a) parallel star-like oriented cross-hatch inclusions, (b) high-relief disc-like fissures associated with stringer particles, (c) fine parallel growth tubes with reflective platelets and particles, and (d) tiny unidentified crystals with parallel needle-like tubes. Photomicrographs by M. Chaipaksa; magnified 70×.

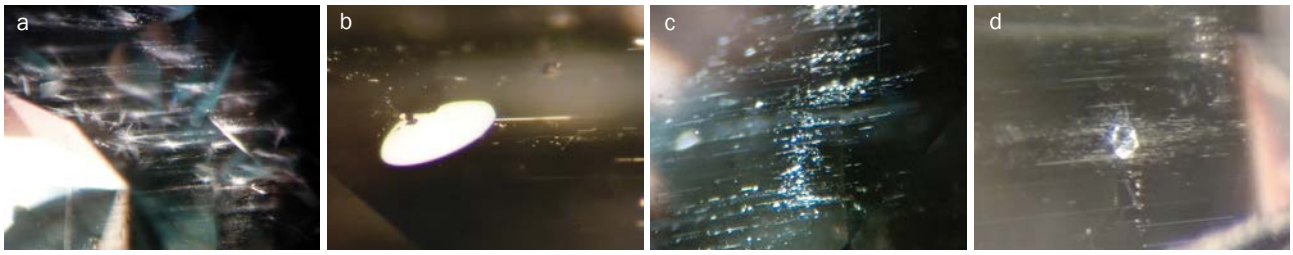

Chondrodite reportedly from Tanga, Tanzania

Chondrodite, $(Mg,Fe^{2+})_5(SiO_4)_2(F,OH)_2$, is an uncommon gem material that is known from various localities, including two places in Tanzania: Sumbawanga in the west-central part of the country (Fritz et al., 2007) and Mahenge in south-central Tanzania (Overton, 2011). A broad range of colour has been documented for Tanzanian chondrodite ('Uncommon minerals as gemstones…', 2007), although the most common colour appears to be 'golden' yellow. In September 2014, gem dealer Dudley Blauwet obtained a parcel of rough from his East African supplier that was represented as chondrodite from a different locality in Tanzania: the Tanga region, in the north-western part of the country. Cutting of 16 pieces of rough weighing 14.78 g yielded 45 gems ranging from 0.15 to 1.96 ct.

Blauwet loaned five of the faceted stones (0.52–1.96 ct; Figure 3) to AGL for examination, and the following gemmological properties were recorded: colour—brownish yellow to yellow, except for one sample that was orangey yellow; no obvious pleochroism; RI—1.592–1.623; birefringence—0.028–0.029; SG—3.12–3.20; fluorescence—inert to long-wave UV and weak-to-moderate yellow to short-wave UV radiation; and no features were visible with the desk-model spectroscope. All of these properties are consistent with data reported for chondrodite by O'Donoghue (2006). Microscopic examination revealed small zones of coarse particles and 'fingerprints' in most of the stones. One sample contained small, parallel needle-like inclusions (Figure 4). EDXRF spectroscopy of the five chondrodite samples showed traces of Al, Mn, Ca, Ti, Na and K, consistent with the results presented by Fritz et al. (2007) for material from Sumbawanga (no chemical data were reported for the chondrodite from Mahenge).

Figure 3: Five chondrodites (0.52–1.96 ct), reportedly from Tanga, Tanzania, were studied for the report. One of them (lower right) was noticeably more orange than the others. Photo by Kelly Kramer.

Figure 4: A parallel array of needle-like inclusions is present within a 'fingerprint' in a chondrodite reportedly from Tanga, Tanzania. Photomicrograph by Christopher P. Smith; magnified 68×.

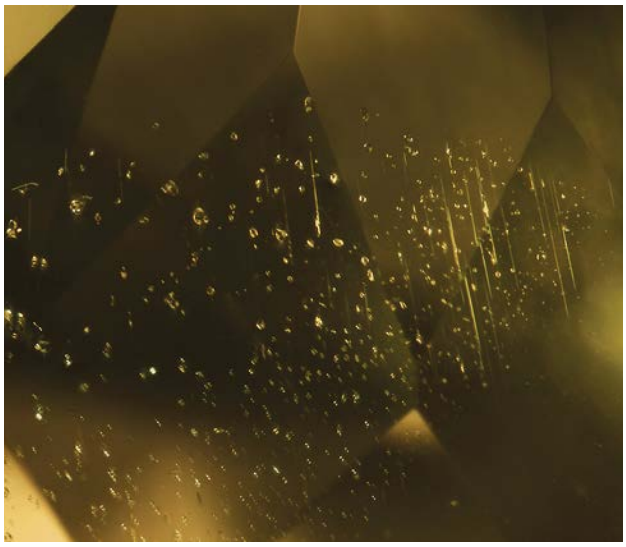

The gemmological properties of these samples are comparable with chondrodite from both Sumbawanga and Mahenge. If the Tanga location can be confirmed, it represents the third location in Tanzania for this unusual gem material.

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Overton T., 2011. Gem News International: Chondrodite from Mahenge, Tanzania. *Gems & Gemology*, **47**(4), 316.

Uncommon minerals as gemstones from Tanzania, 2007. *SSEF Facette*, **14**, 6.

Purple Garnets from East Africa

During the June 2015 JCK gem and jewellery show in Las Vegas, Nevada, USA, news circulated about some attractive new purple garnets from East Africa. Gem dealer Geoffrey Watt (Mayer & Watt, Maysville, Kentucky, USA) had an intense purple 3.87 ct cushion (Figure 5, centre), which was one of two faceted purple garnets that he bought from a Sri Lankan cutter at the 2015 Tucson gem shows. The cutter said he had purchased the rough material in Tanzania. Later, shortly before the JCK show, a 5.86 ct intense purple garnet was faceted by Jeff White (J.L. White Fine Gemstones, Kingsport, Tennessee, USA; see cover of this issue). Subsequently White cut nine more of these garnets, ranging from ~2 ct to 13.31 ct. He purchased the rough from Steve Ulatowski (New Era Gems, Grass Valley, California, USA), who obtained the material in March–April 2015 while on a buying trip to Arusha, Tanzania. His supplier initially told him that the source was Tanzania, but he subsequently confirmed that the material actually came from Catandica, Mozambique. (This also may apply to the origin of Watt's garnet.) Ulatowski noted that the pieces appeared alluvial and were irregularly shaped with a pitted surface texture. After several buying trips to Arusha and Bangkok through October 2015, Ulatowski obtained a total of 1 kg of this garnet (only selecting the better-quality material), commonly in pieces weighing around ½ g each.

Ulatowski also mentioned encountering a different type of purple garnet since December 2014, represented as 'rhodolite' from Salima, Malawi. This material also appeared alluvial but had better shape (like 'gumdrops') and smoother surfaces, and it was available in larger sizes, though stones exceeding 10 g appeared over-dark; he obtained 5–6 kg of this garnet. According to Bill Barker (Barker & Co., Scottsdale, Arizona, USA, the shape of this garnet enables a good cutting yield; he attained 40% from a 1 kg parcel, with individual stones weighing up to 10 ct. Dudley Blauwet also acquired some of the Malawi garnet from an East African supplier, and from 10 pieces of rough weighing 26.4 g, he cut 10 stones (49.96 carats total weight) ranging from 1.47 to 10.60 ct; he loaned two of the more purple gems for examination. They were gemmologically characterized by three of the authors (CW, BW and DH), along with the 3.87 ct cushion from Geoffrey Watt (Figure 5).

Figure 5: Attractive purple garnets were recently produced from East Africa. The cushion-cut gem in the centre (reportedly from Tanzania, but possibly Mozambique) weighs 3.87 ct, and the slightly paler purple stones from Malawi on either side weigh 2.14 ct (left) and 1.47 ct (right). Photo by B. Williams.

The gemmological properties of the three samples are summarized in Table I. They are consistent with those reported for pyralspite garnets by Stockton and Manson (1985), and the RI values of all three samples fall within the ranges expected for both pyrope-almandine (rhodolite) and pyrope-spessartine, with or without some grossular (cf. Jackson, 2006). The magnetic data measured for the 1.47 and 3.87 ct garnets further indicated a pyrope-almandine composition with Pyr>Alm for both gems (cf. Hoover, 2008).

EDXRF spectroscopy using an Amptek X123-SDD instrument with a DP5 preamplifier showed a major amount of Fe, present in approximately equal amounts in all three stones. A small amount of Ca was detected in the three garnets, with slightly more in the 1.47 ct sample; that stone also contained a significant amount of Mn and Cr. (Note: Although Mg was not seen, it is only marginally detectable with this instrumentation.) UV-Vis spectroscopy of the 3.87 and 1.47 ct samples using an Ocean Optics USB4000 instrument showed slightly greater absorption in the ~420 nm region of the 1.47 ct sample. This created a more pronounced transmission window in the violet range for the 3.87 ct stone, corresponding to its more intense purple colour.

Ultraviolet-visible–near infrared (UV-Vis-NIR) absorption spectra also were collected on two

Table I: Properties of the faceted purple garnets from East Africa.[a]

Locality	Tanzania/Mozambique?	Salima, Malawi	
Source	Watt	Blauwet	
Weight (ct)	3.87	2.14	1.47
Colour	Vivid slightly reddish purple	Moderate purplish pink, shifting to a moderate slightly purplish pink in incandescent light	Deep reddish purple, brightening to a vivid reddish purple in incandescent light
RI	1.765	1.749	1.748
SG	3.89[b]	3.75	3.73
Magnetic data[c]	18.01×10^{-4} SI	Not determined	11.76×10^{-4} SI
Internal features	Many parallel needles, some appearing as broken lines and others corresponding to growth tubes	Clusters of small, colourless, iridescent, crumb-like inclusions and a few short needles	A few fine parallel needles

[a] None of the garnets showed any reaction to the Chelsea filter or UV radiation.
[b] A cavity on the pavilion appeared to be filled with a polishing medium, and it is possible that it may have slightly lowered the SG value.
[c] Volume magnetic susceptibility measurements were performed by author DH using the method described in Hoover (2008).

additional samples by one of us (GRR), merging data from three spectrometers: an OceanOptics UV CCD, a silicon-diode array visible spectrometer and a Nicolet iS50 near-infrared unit (Figure 6). Both samples consisted of doubly-polished slabs. Sample 3237 was prepared from a piece of Mozambique rough material supplied by Jeff White (e.g. see border region of cover photo) that was originally obtained from Steve Ulatowski, and sample 3235 was a slightly less intense purple garnet supplied by Ulatowski from a much earlier find that occurred in Tanga, Tanzania. Both pieces had nearly identical spectra, except 3235 showed greater absorption in the violet range (near 400 nm). The more intense purple sample 3237 had less absorption in that region, producing increased transmission. Manganese (Mn^{2+}) is responsible for absorption in the 400–440 nm region of the spectrum (Manning 1967), and chemical analysis (Table II) showed that sample 3235 had >20% more Mn than 3237. The additional manganese absorption in sample 3235 removed more of the violet light, causing it to appear less purple than 3237. An additional factor contributing to the

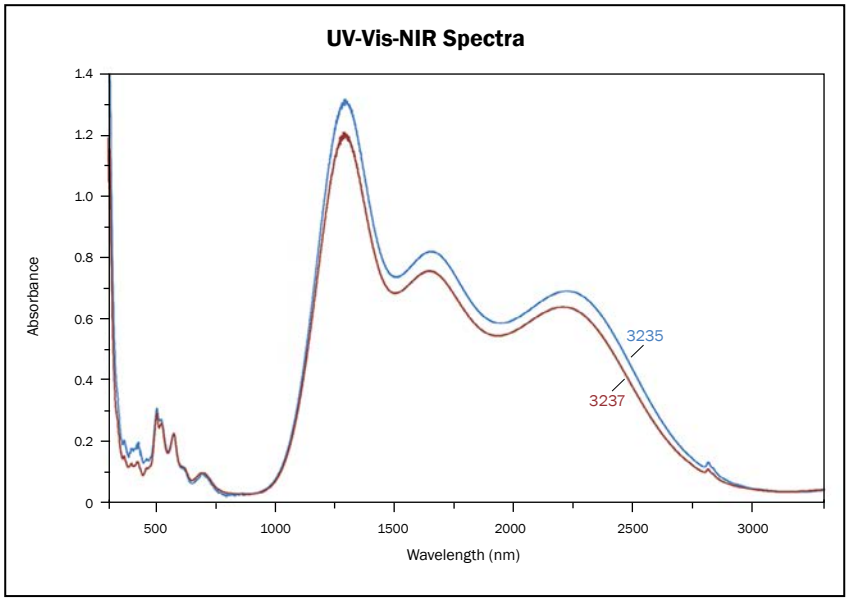

Figure 6: UV-Vis-NIR absorption spectra of two purple garnet slabs from Tanzania (sample 3235) and Mozambique (sample 3237) show nearly identical patterns until the violet range, where 3235 has greater absorption. The more pronounced transmission window in this region for 3237 corresponds to its slightly more intense purple colour. Both samples were scaled to plot as 1.0 mm thick.

colour of 3237 is the absence of Fe^{3+}, that both by itself and through interactions with Fe^{2+} would absorb light in the blue region of the spectrum.

*Table II: Electron microprobe analyses of purple pyrope-almandine garnets from Tanzania and Mozambique.**

Sample no.	3235	3237
Location	Tanga, Tanzania	Catandica, Mozambique
Oxides (wt.%)		
SiO_2	40.40	40.23
Al_2O_3	22.95	23.01
FeO	22.17	24.03
MgO	13.36	12.72
CaO	1.35	0.77
MnO	0.25	0.21
Total	100.48	100.97
Ions per 12 oxygens		
Si	3.002	2.995
Al	2.010	2.019
Fe	1.378	1.496
Mg	1.480	1.412
Ca	0.107	0.061
Mn	0.016	0.013

* Average of five analyses per sample. Cr and Ti were analysed for but not detected. Analyst: Chi Ma. End-member compositions determined by author DH using procedure of Locock (2008):
Sample 3235: $Pyr_{49.00}Alm_{44.29}Gro_{5.10}Sps_{0.52}And_{0.48}$
Sample 3237: $Alm_{48.49}Pyr_{46.81}Gro_{3.57}Sps_{0.44}$

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Green Prase Opal from the Kondoa District, Tanzania

A historically important deposit of chrysoprase and prase opal in Tanzania is located at Haneti, situated north of Dodoma in central Tanzania (Shigley et al., 2009). During the 2015 Tucson gem shows, rough and polished material (e.g. Figure 7) from a new deposit in Tanzania was shown by Werner Radl (Mawingu Gems, Niederwörresbach, Germany). He indicated that mining started in early 2014 near Kwa Mtoro village in the Kondoa District; this is also in the Dodoma region of Tanzania, but further north of Haneti. It is likely that several hundred kilograms of rough material have been produced. Radl obtained ~50 kg of rough, some of which he processed into spheres, cabochons and tumbled pieces.

Radl donated two rough pieces (Figure 8) to Gem-A, and they were analysed by this author. Both were largely bluish green and translucent, with portions containing white opaque material (and also some dark brown matrix in one piece). They measured approximately 21.0 × 20.7 × 11.3 mm and 24.3 × 17.0 × 18.0 mm, and weighed 4.44 and 4.46 g, respectively.

A hydrostatic SG of 2.17 was measured on the larger sample. (The SG of the other piece could not be reliably measured, due to the presence of several cracks and voids.) Both samples appeared green through the Chelsea filter. Their reaction to long-wave UV radiation varied from partly inert to a weak chalky blue-

Figure 7: These polished spheres of prase opal (here, ~1.5–2.5 cm in diameter) are from a new deposit in the Kondoa District of Tanzania. Photo by Brendan M. Laurs.

white fluorescence, whereas they showed a weak yellowish green fluorescence to short-wave UV. No phosphorescence was observed.

The SG value was clearly much lower than the ~2.6 expected for chrysoprase, and instead lies in the range of common opal. Both specimens increased in weight after hydrostatic SG weighing, and after one week they still retained a slightly higher weight, indicating some degree of hydrophane character. Infrared spectroscopy of both fragments (using a Thermo Scientific Nicolet iS50 FT-IR spectrometer) showed a pattern characteristic of opal, with a strong absorption band around 5200 cm^{-1} (Figure 9).

Figure 9: This representative Fourier-transform infrared (FTIR) spectrum of the rough material from the Kondoa District shows a strong absorption at ~5200 cm^{-1} that is characteristic of opal.

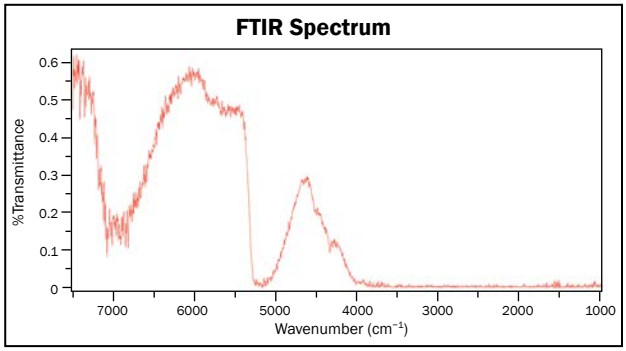

Figure 8: These rough pieces of prase opal (4.44 and 4.46 g) from the Kondoa District were examined for this report. Gift of Mawingu Gems; photo by Dirk van der Marel.

Raman spectroscopy (using a Thermo Scientific DXR Raman microscope with 780 nm laser excitation) produced spectra containing a broad band at ~325 cm^{-1} (the position varied slightly between the two samples), and peaks at 773 and 668 cm^{-1} (Figure 10). The broad band is due to the Raman shift of the O-Si-O bending mode, and its position is characteristic of opal-CT (not totally amorphous, but poorly crystalline cristobalite with some tridymite-like stacking; Fritsch et al., 2012). Moreover, Ilieva et al. (2007) showed that Raman spectra with the most intense (although poorly resolved) band centred near 330–360 cm^{-1} can be considered opal-T, with the proportion of spatial regions containing tridymite-type framework topology being higher than that of cristobalite-type

Figure 10: Raman spectroscopy of the prase opal shows a broad band at 323 cm^{-1}, characterising it as opal-CT or opal-T. A reference spectrum of chrysoprase is shown for comparison; the peak at 465 cm^{-1} indicates the presence of quartz (cryptocrystalline). Both spectra were taken using a 780 nm laser.

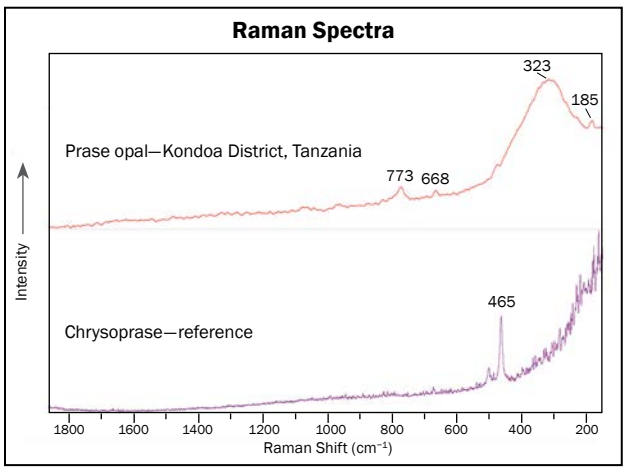

framework typology. The Raman spectra shown in Figure 10 are very similar to the spectra of prase opal presented by Shigley et al. (2009).

EDXRF chemical analyses (with an EDAX Orbis Micro-XRF Analyzer) showed large variations in the Ni content of this prase opal. Analyses of three random spots (300 µm beam diameter) on both samples gave NiO contents of 3.64, 7.36 and 9.72 wt.% for the smaller opal, and 0.73, 3.08 and 5.09 wt.% for the larger piece. On average, the data reflect a relatively high NiO content of slightly below 5 wt.%. Additionally, Fe was not detected, and only traces of Ca were found (0.06–0.26 wt.% CaO).

The high Ni content of this strongly coloured prase opal appears to be consistent with the notion that chrysoprase with a lower degree of crystallinity tends to have greater amounts of Ni and a more intense colour (cf. Gawel et al., 1997), and also with the attribution of the colour to dispersed particles of Ni-containing minerals (cf. Shigley et al., 2009, and references therein).

It is highly likely that this prase opal was found in the same belt of metamorphosed ultramafic rocks that, from Haneti, are aligned in a north-westerly direction along regional shear zones.

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Flower-shaped Trapiche Ruby from Mong Hsu, Myanmar

Trapiche rubies have been known for years from marble-hosted deposits at Mong Hsu, Myanmar. They have been gemmologically characterized by Schmetzer et al. (1996), and their crystal growth mechanisms were studied by Sunagawa (2003). On three separate trips to Myanmar (Yangon in January 2011 and February 2013, and Mogok in December 2013), this author obtained five interesting flower-shaped trapiche rubies (e.g. Figure 11). They were cut and polished perpendicular to the c-axis, and ranged from ~5 to 7 mm in diameter and were 1.0–1.5 mm thick. At first glance, they showed a similar appearance and structure to ordinary trapiche rubies, with hexagonal cores surrounded by six sectors in a star shape that resembles the cogwheels used in sugar mills.

Microscopic examination revealed that they actually consisted of three separate growth layers (Figure 12), making them different from typical trapiche rubies. All five samples had small hexagonal cores that were overgrown by another hexagonal zone, which in turn was overgrown by radiating petals that originated from each prism face of the intermediate zone. The intermediate zone contained six thin arms extending outward from the corners of the core, producing six trapezoidal ruby sectors. The arms continued outward into the final growth layer to separate the six petals in the outer rim. Both the arms and the boundaries between each layer were delineated by thin white or yellow translucent areas. Carbonate mineral inclusions such as calcite and dolomite were documented in trapiche ruby arms by Schmetzer et al. (1996) and Sunagawa (2003).

When the samples were examined with transmitted light, the deep red cores and the six red

Figure 11: These flower-shaped trapiche rubies from Mong Hsu, Myanmar, contain three growth zones, consisting of a hexagonal core and middle layer, and an outer zone consisting of six heart-shaped (left, 7 × 5 mm) or clothes-pin-shaped (right, 7 × 6 mm) petals. Photos by E. Liu.

sectors in the middle layer appeared transparent, while the six petals of the outer rim appeared translucent pinkish red. In the middle and outer layers, the arms widened into branches toward the outer edges of those zones, forming snowflake-like patterns. The outer layer contained extensive elongate tube-like inclusions that were oriented in three directions, perpendicular to the three sets of hexagonal edges of the middle layer. Depending on the amount of weathering of the arms in the outer layer, the radiating patterns in this layer consisted of either six heart-shaped or six clothes-pin-shaped petals (again, see Figure 11).

Sunagawa's (2003, 2005) diagram of trapiche crystal growth (Figure 13) shows how different kinds of growth mechanisms occurred on either smooth or rough interfaces, with the 'driving force' of crystallization (X-axis) plotted as a function of the growth rate (Y-axis). The dendritic growth of the arms and branches of a trapiche ruby are formed under an 'adhesive-type' multi-phase growth mechanism on a rough interface under high-driving-force conditions. The interstitial sectors are formed by a layer-by-layer growth mechanism on a smooth interface and a later infilling process within the interstices between the previously-formed dendritic arms and branches. Disturbances in the crystal growth by tiny fluid blebs or crystalline

Figure 12: With magnification, this trapiche ruby displays a structure formed by three layers with different growth characteristics: a small deep red core, a middle layer with six arms/branches and an outer petal-shaped zone. Photomicrograph by E. Liu; magnified 15×.

inclusions after multi-phase crystallization in the arms and branches (or on boundaries between each layer) led to the formation of the tube-like inclusions in the outer ruby layer.

Chemical analysis by EDXRF revealed that Cr was higher in the core and middle layers than the rim. The variation of Cr contents and crystal morphology between the different growth layers reflects the complicated growth environment in the Mong Hsu region. The multi-phase and multi-stage formation of these trapiche rubies is due to repeated dendritic growth under high-driving-force conditions, followed by an infilling process within the interstices of the arms through a layer-by-layer growth mechanism.

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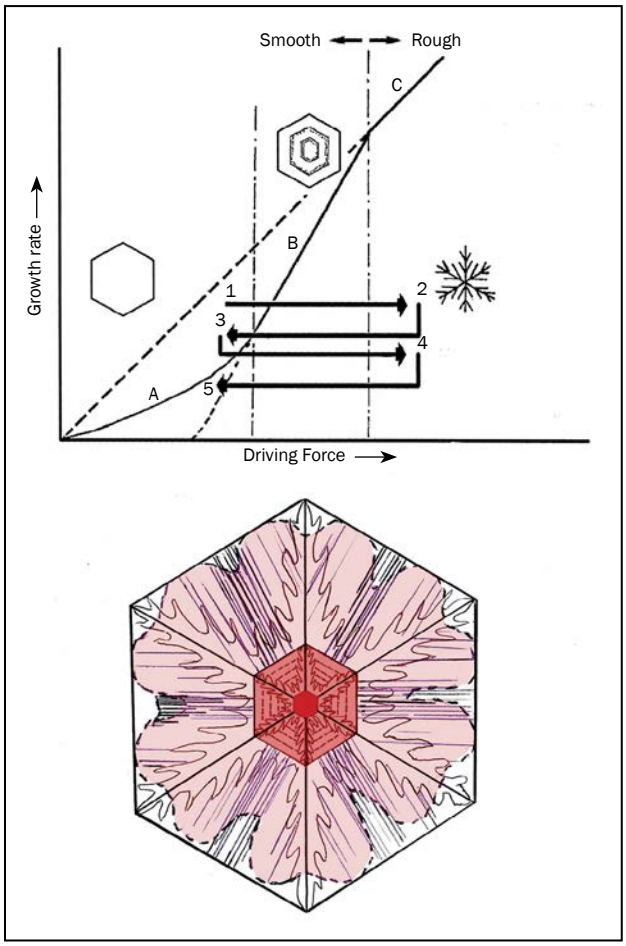

Figure 13: This 'Sunagawa diagram' (top) illustrates the crystal growth mechanisms of a corresponding trapiche specimen (bottom). The favoured growth mechanism is a function of the 'driving force' of crystallization versus the growth rate. The crystal in this example shows a sequence of growth similar to that of the trapiche rubies described in this study. Modified after Sunagawa (2003).

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Sapphires from Kina, Kenya

During the February 2014 Tucson gem and mineral shows, gem dealer Dudley Blauwet obtained from an African supplier a parcel of rough sapphires that reportedly came from Kina in central Kenya, about an hour's drive from Garba Tula. The parcel was particularly notable for its content of bicoloured sapphires, and Blauwet's quick visual comparison with the gem corundum from Kenya's Dusi deposit (near Garba Tula; see, e.g., Simonet et al., 2004) indicated that the present material was somewhat different. From 55 pieces of rough weighing 48.5 g, Blauwet had 57 stones faceted that weighed 83.54 carats and ranged from 0.40 to 2.40 ct. He loaned four samples to AGL for examination (Figure 14).

The three modified cushion cuts and one rectangular emerald cut ranged from 1.03 to 1.94 ct (6.50 × 4.41 × 3.30 mm to 7.85 × 6.36 × 4.23 mm, respectively). Viewed face-up with the naked eye, the stones appeared blue, green, yellow and bicoloured blue-yellow. However, when viewed with diffuse transmitted light in the microscope, they all showed exclusively blue and yellow colour zoning that was both straight and angular.

Visible-range spectroscopy using an S.I. Photonics CCD (charge coupled device)-array

Figure 14: Four sapphires (1.03–1.94 ct) from a relatively new deposit in Kenya were examined for this report: blue, green, yellow (here, appearing greenish yellow due to internal reflections from blue zones) and bicoloured blue-yellow. Photo by Kelly Kramer.

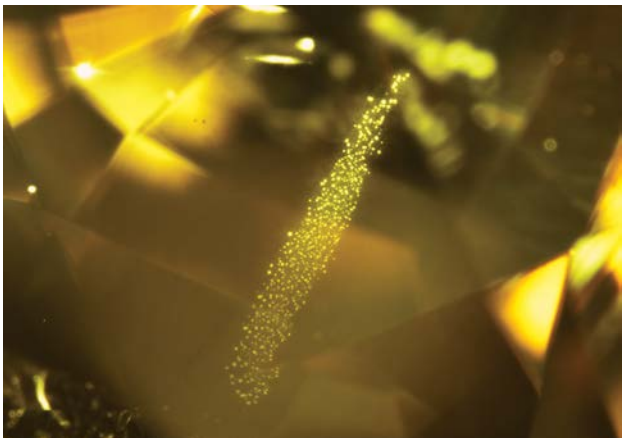

Figure 15: A planar cloud containing whitish, polka dot-like inclusions is seen in the 1.61 ct yellow Kenyan sapphire. Photomicrograph by Christopher P. Smith; magnified 50×.

UV-Vis spectrophotometer showed that all four sapphires were coloured by a combination of Fe^{2+}–Fe^{3+}, Fe^{3+} and Fe^{2+}–Ti^{4+}, and revealed they were of a magmatic-related origin (Smith, 2010), consistent with their overall blue-green-yellow coloration. Mid-infrared spectroscopy of the blue sapphire using a Thermo Scientific Nicolet 6700 FT-IR spectrometer displayed a strong 3309 cm^{-1} series of peaks (strong 3309, 3232 and 3185 cm^{-1}, and nominal 3367 cm^{-1}), while the yellow and green sapphires both showed a nominal 3309 cm^{-1} series (minor 3309 cm^{-1} and extremely small 3232 and 3185 cm^{-1}), while the bicoloured sapphire showed no OH-related features.

Semi-quantitative chemical analysis using a Thermo Scientific ARL Quant'X EDXRF spectrometer showed that all samples contained high amounts of Fe (0.91–1.68 wt.%), which is consistent with their magmatic-related origin. In addition, Ti ranged up to 0.01 wt.%. Neither V nor Cr was detected in any of the stones. Based on their high Fe content, it is not surprising that none of these four sapphires fluoresced to either long- or short-wave UV radiation.

Typical sapphire inclusions were observed in the four stones using a standard gemmological microscope. They consisted of bands of pinpoints (some coarse, some fine), strong straight and angular growth zoning, and a few frosty, whitish, fine-grained 'fingerprints'/healed fissures. Some of the more intriguing inclusion features were found in the yellow sapphire. The largest yellow colour zone in the stone contained an elongate planar cloud consisting of whitish, polka dot-like inclusions, as well as minute spots (Figure 15).

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Stabilized Shattuckite and Bisbeeite from the Democratic Republic of Congo

During the 2015 Tucson gem shows, stabilized slabs and cabochons represented as shattuckite from the Democratic Republic of Congo (DRC) were sold under the trade name *Lunazul* by Brett and Allyce Kosnar (Kosnar Gem Co., Black Hawk, Colorado, USA). The Kosnars obtained approximately 40 kg of the rough material in October 2013 that reportedly came from the Tantara mine in Katanga District. They processed 11 kg of the rough into slabs and 2 kg into

Figure 16: These samples from the DRC, consisting of a mixture of shattuckite and bisbeeite, were examined for this report. The slab weighs 19.91 ct, the flat cabochons are 3.14 and 3.61 ct, and the rough piece weighs 2.58 g. Gift of Kosnar Gem Co.; photo by Dirk van der Marel.

cabochons. Prior to cutting, they stabilized the material with resin at a pressure of 5,000 psi for nearly three weeks. The Kosnars kindly donated to Gem-A one slab (19.91 ct) and two flat cabochons (3.14 and 3.61 ct) along with a piece of unstabilized rough material (2.58 g), and these samples were examined by this author for this report (Figure 16).

All of the stones were opaque and showed pleasing light- and dark-blue colours, with the polished pieces having a slightly darker tone than the rough material. The rough consisted of sprays of radiating fibrous crystals. This same fibrous texture was exhibited by the two cabochons, combined with a locally more granular texture. The slab showed the same textures (Figure 17, left), combined with circular fibrous areas similar to patterns often seen in malachite (Figure 17, right).

Spot RI readings of the polished pieces were ~1.65, and hydrostatic SG values varied between 3.05 (for a cabochon) and 3.16 (for the slab). The stones were mostly inert to long- and short-wave UV radiation, except that the lighter blue parts showed a weak blue fluorescence to long-wave UV.

These properties did not match the known values of shattuckite, $Cu_5(Si_2O_6)_2(OH)_2$, which has RIs of 1.752–1.815 and SG values of 3.80–4.11 (Dedeyne and Quintens, 2007), so further testing was required. Raman analysis (with a Thermo Scientific DXR Raman microscope) identified areas of shattuckite, but also revealed the presence of another mineral showing a close match with reference spectra of bisbeeite ($CuSiO_3 \bullet nH_2O$) in the RRUFF database (Figure 18). The granular areas in the slab consistently gave Raman spectra for shattuckite, regardless of tone (light or dark), and an associated small green-stained area was identified as calcite (Figure 17, right). However, the areas of the slab showing fibrous structure were bisbeeite. The 3.61 ct cabochon also contained a fibrous area of bisbeeite, and an intermediate region with a fibrous/granular structure that showed mixed Raman peaks relating to bisbeeite and shattuckite. For the 3.14 ct sample, shattuckite

Figure 17: Microscopic examination of the slab showed areas of a radiating fibrous texture that were identified as bisbeeite and a more massive, granular structure corresponding to shattuckite (left image). Within the granular areas, small circular fibrous areas showing a malachite-like texture also were identified as shattuckite. Additionally present was a small mass of green-stained calcite (right). Photomicrographs by J. C. Zwaan; image width 15 mm (left) and 8.2 mm (right).

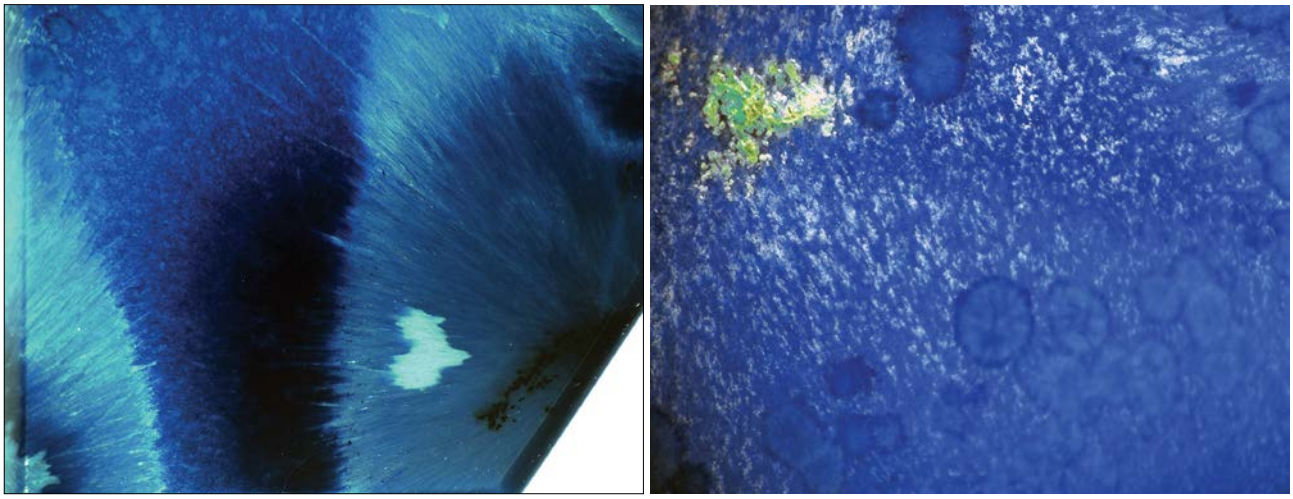

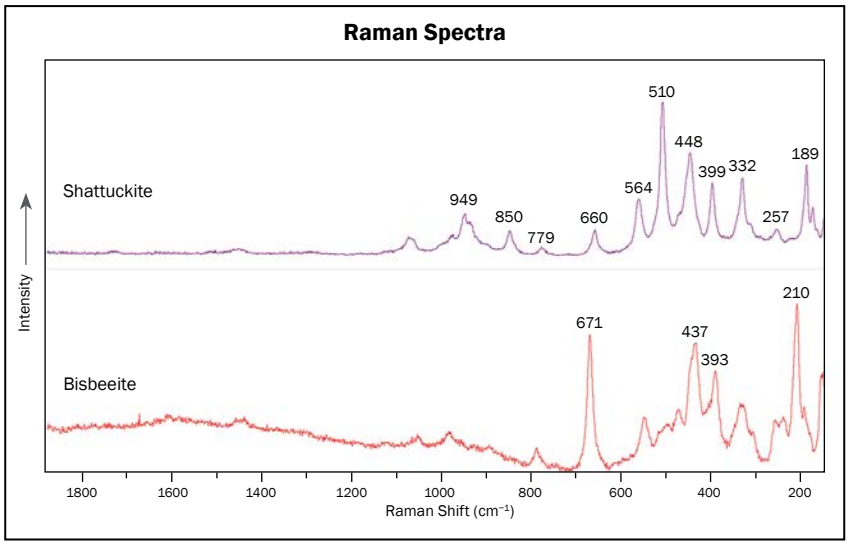

Figure 18: Both shattuckite and bisbeeite were identified by Raman spectroscopy in all three cabochons. Shown here are spectra from the 3.14 ct sample.

was only identified in a small dark spot showing granular texture on one side of the cabochon, while the fibrous areas analysed were bisbeeite. Granular areas on the other side of the stone matched shattuckite, regardless of colour (dark or light blue). A flat fibrous area on the rough sample showed only bisbeeite. Thus it appeared that the fibrous portions of the material consisted of bisbeeite and the more granular parts correlated to shattuckite.

Shattuckite was discovered in Bisbee, Arizona, USA (Shattuck mine) as a pseudomorph after malachite (Schaller, 1915). Bisbeeite is another rare, but poorly defined, secondary copper mineral, which was confirmed by Laurent and Pierrot (1962) as a distinct species. However, Van Oosterwyck-Gastuche (1968) concluded that the validity of bisbeeite was doubtful, and the mineral was discredited by the International Mineralogical Association's Commission of New Minerals and Mineral Names in 1977, when it was considered as a synonym for chrysocolla, $(Cu,Al)_2H_2Si_2O_5(OH)_4 \bullet nH_2O$ (www.mindat.org/min-26553.html). Interestingly, the measured Raman spectra of bisbeeite in the samples we examined showed the best match with RRUFF reference spectra of bisbeeite from Shangulume, Katanga Province, DRC, which showed features significantly different from the spectra of chrysocolla (typically lacking a prominent peak at 211–210 cm^{-1}, and showing a broad band in the 410 cm^{-1} range). Additionally, EDXRF chemical analyses (with an EDAX Orbis Micro-XRF Analyzer) revealed Cu and Si as the main elements in the samples, and did not detect any Al. Fleischer (1972) suggested that bisbeeite could be part chrysocolla and part plancheite, $Cu_8Si_8O_{22}(OH)_4 \bullet H_2O$, but Raman spectra do not support this possibility (cf. Frost and Xi, 2012).

From these preliminary data, as well as the radiating fibrous texture and deep blue colour seen in our samples, it appears that bisbeeite indeed differs from chrysocolla and needs to be better defined. Laurent and Pierrot (1962) gave RIs of 1.613–1.710 for bisbeeite, which explains the spot RI readings of ~1.65. Those values are significantly higher than the RI range for chrysocolla (1.46–1.57). Also, Laurent and Pierrot (1962) reported an SG value for bisbeeite of 3.45 ± 0.05, also higher than the SG of chrysocolla (1.93–2.45), and slightly higher than the SGs of 3.05–3.16 measured for the present samples. These low measured values are apparently due to the stabilized nature of the material.

As expected for the polished samples, which reportedly had been stabilized, Raman spectra showed features in the 3400–1200 cm^{-1} region that are typical of a polymer: main peaks in the 3100–2800 cm^{-1} region due to C-H stretching, a peak at 1725 cm^{-1} due to C=O stretching and a peak at 1457 cm^{-1} (Figure 19; cf. Johnson et al., 1999; Moe et al., 2007). The latter two peaks are similar to those at ~1730 and 1453 cm^{-1} that are characteristic of Norland Optical Adhesive 65, a colourless UV-hardened polymer that is used to stabilize turquoise (Moe et al., 2007). No such polymer-related features were recorded from the rough sample (reportedly untreated), which

also did not show any other visible signs of the presence of a polymer such as filled cavities.

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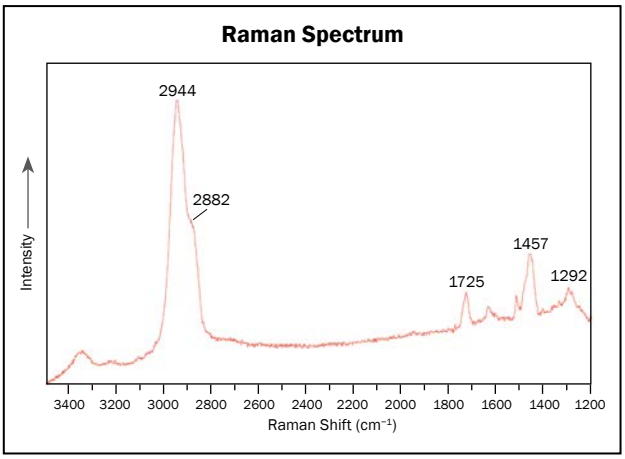

Figure 19: The polished samples of shattuckite/bisbeeite showed features in the 3400–1200 cm^{-1} region of the Raman spectrum that indicate the presence of a stabilizing polymer.

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Purple Tourmaline from Maraca, Mozambique

In the past few years, a relatively new alluvial deposit of tourmaline was found at Maraca, Mozambique. This area is located only ~20 km from the well-known Cu-bearing tourmaline deposits of Mavuco in the Nampula area (e.g. Laurs et al., 2008a). The Maraca area reportedly also has produced Cu-bearing tourmaline, although the stones are smaller and more included.

Two water-worn pebbles from Maraca were loaned for examination by Michael Puerta and Farooq Hashmi (Intimate Gems, Glen Cove, New York, USA). Puerta obtained them during a visit to the nearby village of Iulùti (or Lulùti) in June 2014. The samples were medium purple and dark purple, and weighed 1.73 and 1.75 g, respectively (Figure 20). Their colours resembled those seen in some Cu-bearing tourmaline from Mavuco that is commonly heat-treated to a Paraíba-like blue appearance. The samples showed distinct pleochroism, in orangey yellow and purple, and in slightly greenish yellow and dark purple, respectively. The hydrostatic SG of both pebbles was 3.03. Viewed with a desk-model spectroscope, they showed a doublet at about 450 and 455 nm (with the first line being darker), a broad absorption band between 480 and 560 nm, and gradually decreasing absorption from ~530 to 560 nm; these features are common for purple tourmaline when viewed with a

Figure 20: These two transparent waterworn tourmaline pebbles (1.73 and 1.75 g) are from a new mine at Maraca, Mozambique, which is situated near the Mavuco Cu-bearing elbaite deposit. However, they were found to contain significant Fe and no Cu. Photo by Dirk van der Marel.

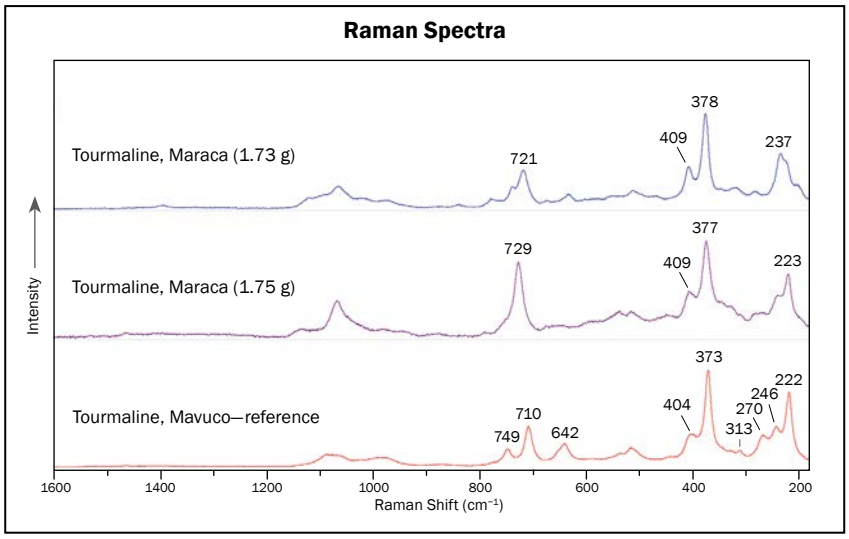

Figure 21: Raman spectra of the tourmaline pebbles from Maraca showed best matches with reference spectra of liddicoatite (for the 1.73 g sample) and liddicoatite/elbaite (for the 1.75 g sample). Shown for comparison is a reference spectrum of Cu-bearing tourmaline (elbaite) from Mavuco.

spectroscope (e.g. GIA, 1995). The stones were inert to long- and short-wave UV radiation.

The Raman spectrum (obtained with a Thermo Scientific DXR Raman microscope) of the 1.73 g sample showed a good fit with spectra of liddicoatite in the RRUFF database, while the 1.75 g piece also showed a best match—although less convincing—with the reference spectra of liddicoatite (in addition, it roughly matched spectra for elbaite). Both samples had Raman spectra that were quite different from that of a slightly reddish purple Cu-bearing tourmaline from Mavuco (no. 510-10, characterized by Laurs et al., 2008a), which best matched elbaite in the RRUFF database (Figure 21).

Semi-quantitative EDXRF chemical analyses (Table III) were obtained from five random spots on each pebble using an EDAX Orbis Micro-XRF Analyzer. The instrument did not detect Cu in either sample, but showed significant amounts of Fe. This is unlike purple Cu-bearing elbaite from Mavuco, which consistently shows extremely low Fe content (again, cf. Laurs et al., 2008a).

Table III. EDXRF analyses (wt.%) of minor and trace elements in Maraca tourmaline.

Sample	1.73 g	1.75 g
Na_2O	0.94–1.0	1.6–2.6
K_2O	0.04–0.13	0.07–0.19
CaO	3.4–3.9	1.0–1.3
MnO	0.07–0.08	0.51–0.66
FeO	0.03–0.96	0.04–0.73
PbO	0.75–1.0	Not detected

The 1.73 g sample showed relative amounts of Ca and Na that would be expected for liddicoatite (although EDXRF spectroscopy is only marginally sensitive to Na). It also contained significant Pb, which is not typical for tourmaline from the Nampula region (cf. Krzemnicki, 2007; Laurs et al., 2008a,b), but has been documented in tourmaline from elsewhere (e.g. Madagascar: Lussier et al., 2006).

The 1.75 g pebble contained Na>Ca, which is not unusual for dark rubellite (cf. Deer et al., 1986). However, the calcium content was still much higher than in purple Cu-bearing elbaite from Mavuco, which typically has very low Ca.

As we analysed only two samples, this study can hardly be seen as representative for tourmaline from Maraca. The alluvial deposit could contain gem rough originating from various sources, and it would not be surprising for Cu-bearing tourmaline to be included among the production of stones from this new locality that is relatively close to Mavuco.

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Tourmaline Slices from Myanmar

Large, colourful tourmaline slices displaying intricate patterns are well-known for liddicoatite from Madagascar (e.g. Dirlam et al., 2002). Recently, this author was surprised to see similar slices that reportedly came from Myanmar, in the collection of Bill Larson (Palagems.com, Fallbrook, California, USA). Larson obtained the two slices from Mark Smith (Thai Lanka Trading Ltd. Part., Bangkok, Thailand), who takes frequent buying trips to Myanmar. In February 2015, Smith encountered these colourful slices with a Burmese dealer who had six pieces that were all cut from the same piece of alluvial rough. The dealer reported that they came from Möng Long (or Maing Lon), which is located about 20 km south of Mogok. Smith purchased the three most attractive slices (Figure 22). In a subsequent trip in October 2015, the same dealer had some additional Möng Long slices, but they displayed an ordinary 'watermelon' concentric pattern with pale coloration. Smith reported that in the past, Möng Long has produced some cabochon- and facet-grade red and green tourmaline, but this is the first time he has seen slices from this locality. The patterns seen in the Möng Long tourmaline are typical of liddicoatite, although these samples have not been chemically analysed to determine the species present. Similar patterns were displayed in a tourmaline slice from Vietnam that proved to consist of Ca-rich elbaite and liddicoatite (Laurs et al., 2002).

Tourmaline slices also have been recently produced from an additional location in Myanmar: Khetchel (or Khetchey, Kat Chay) in the Molo area, Momeik Township, located 75 km north-east of Mogok. The so-called mushroom

Figure 22: These three slices (5.7 × 4.6 cm each) were cut perpendicular to the c-axis from the same tourmaline crystal, which reportedly came from Möng Long, Myanmar. The pair on the left (101.76 and 112.42 ct) is in the collection of Bill Larson; photo by Orasa Weldon. The slice on the right (132.70 ct) is owned by Wing Chiu Li; photo by Mark Smith.

Figure 23: These three slices (11.04, 23.95 and 37.96 ct, from left to right) were cut perpendicular to the c-axis from different crystals of mushroom tourmaline originating from the Molo area of Myanmar. Specimens and photo courtesy of Mark Smith.

tourmalines from this area commonly have a black core and a bulbous triangular top consisting of pink-to-red fibrous elbaite (e.g. Lussier et al., 2008). When sliced perpendicular to the c-axis, they show various concentric patterns in pink-to-red, dark blue/green and black (Figures 23 and 24). They are frequently oiled due to their limited transparency. According to gem and mineral dealer Federico Bärlocher (Como, Italy), who specializes in Burmese stones, the size range of such slices is typically restricted by the relatively small size of the mushroom tourmaline crystals, as compared to the large liddicoatite specimens from Madagascar.

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Figure 24: A single tourmaline crystal from Molo, Myanmar, was cut perpendicular to the c-axis into this series of slices (up to ~6.7 cm in diameter). Specimens and photo courtesy of Federico Bärlocher.

Gem-quality Wurtzite from Tanzania

An interesting discovery of orange-brown gem-quality wurtzite took place in 2012 at the famous tanzanite deposits in the Merelani Hills of northern Tanzania (Hyršl, 2013). The wurtzite came from Block D of the mining area, and was associated with tanzanite or alabandite (a manganese sulphide, MnS). Wurtzite is the hexagonal polymorph of zinc sulphide (ZnS), and was named by the French chemist and mineralogist Charles Friedel (1832–1899) after his

Figure 25: This wurtzite crystal (1.7 × 2.5 cm) from Merelani, Tanzania, shows a typical hexagonal habit. J. Hyršl collection and photo.

Figure 26: Wurtzite from Merelani is rarely facetable and typically suitable for cutting only small gemstones, such as the 0.91 and 0.83 ct samples shown at the bottom of this photo. By contrast, the exceptionally large specimen shown above weighs 76.42 ct. J. Hyršl collection and photo.

tutor Charles Adolphe Wurtz (1817–1884). Well-known occurrences of relatively large crystals are Oruro and Animas in Bolivia, Huanzala in Peru and Talnakh in Russia (Bernard and Hyršl, 2015).

In nature, zinc sulfide generally occurs in the form of the cubic polymorph sphalerite (α-ZnS), which crystallizes under a wide pressure-temperature range. Sphalerite deposits are the most important source of zinc. The crystallization of wurtzite (β-ZnS) is less common, and is typically linked to relatively high temperatures of about 1,020°C (Palache et al., 1944). Metastable formations may occur under lower-temperature conditions (e.g. in acidic solutions or favoured by the presence of cadmium; Okrusch and Matthes, 2014).

The partly translucent to transparent wurtzite crystals from Merelani are generally 2–3 cm in size (e.g. Figure 25), and faceted stones have been documented that weigh 0.30–1.74 ct (Hyršl, 2013) and 3.97 ct (Cooper and Renfro, 2014). More recently, a much larger wurtzite from Merelani was faceted: 76.42 ct (Figure 26).

The two smaller gems in Figure 26 (0.83 and 0.91 ct) were investigated for this report. Viewed with the polariscope, these distinctly fissured stones appeared streaky and exhibited tabby extinction. The high RI of wurtzite cannot be measured on a standard gemmological refractometer, but an approximate value of 2.36 was determined using a so-called digital refractometer (a lustre meter measuring reflectivity). An SG of 3.81 was measured with a hydrostatic balance. These values correspond to reference data for wurtzite (e.g. Phillips and Griffin, 1981).

Quantitative chemical analyses by electron microprobe (Jeol JXA 8200 at the Institute for Geosciences, Johannes Gutenberg-University Mainz, Germany) were obtained for these faceted wurtzite samples (Table IV). The significant Mn and low Cd contents of the two gems characterize

Table IV: Chemical composition of wurtzite from Tanzania (wt.%).

Sample	0.83 ct	0.91 ct
Zn	56.60	56.84
S	33.03	33.27
Mn	9.26	9.19
Cd	0.43	0.41
Fe	0.04	0.10
Cu	0.14	0.10
Ni	0.01	0.01
Total	99.51	99.92

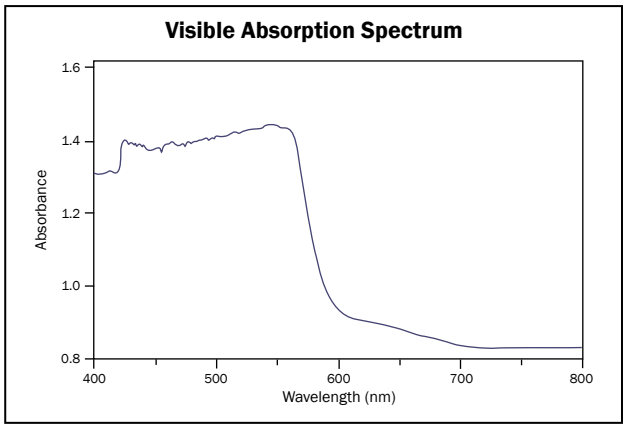

Figure 27: This absorption spectrum of the wurtzite from Merelani shows a flat-topped pattern due to strong reflections, but a broad band in the violet-to-orange spectral range (~400–600 nm) is apparent.

them as the zinc-rich member (wurtzite) of the wurtzite-rambergite-greenockite series (ZnS-MnS-CdS).

Visible absorption spectra (e.g. Figure 27) of the gems were recorded with a PerkinElmer Lambda 12 spectrometer. The spectra were heavily distorted because of strong reflection effects. A broad band in the violet-to-orange spectral range is thought to be caused by an electron transition between a Mn^{2+} *d*-electron level and an unoccupied ZnS energy band (Prof. Dr A. N. Platonov, pers. comm., 2015).

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Zircon Showing Asterism

Zircon ($ZrSiO_4$) is an interesting mineral in gemmology, not only because it is found in attractive colours such as yellow, red, brown, green and even blue (due to heat treatment) combined with a high lustre, but also because it is important as a solid inclusion in numerous other gems. It may be useful for detecting heat treatment of corundum, and also for revealing information about the formation conditions/age and geographical origin of a gemstone.

Gem-quality zircon is typically transparent and cut into faceted gems. Rarely, zircon shows chatoyancy, and such gems have been documented from Sri Lanka (Fryer 1983, 1985; Hänni and Weibel, 1988). Hänni and Weibel described heated zircons containing two sets of tiny cleavage fissures, each responsible for a cat's-eye reflection. However, due to the geometric orientation of these tiny features, they did not produce a star effect.

During the early 2000s, one of the authors (MPS) obtained an attractive asteriated zircon in Ratnapura, Sri Lanka. After years of searching, he has been unable to find any publications mentioning star zircon. He recently loaned the gem to the Swiss Gemmological Institute SSEF for examination, and it was characterized by author MSK. The oval cabochon weighed 13.60 ct, and was light yellowish brown with reduced transparency due to the presence of multiple tiny inclusions. It showed no reaction to long-wave UV radiation, and a weak yellowish fluorescence to short-wave UV. The most notable characteristic of this zircon was the presence of moderate

Figure 28: This 13.60 ct zircon cabochon shows moderate asterism and a bright reflection at the centre of the star. The vertical branch of the star is most prominent, followed by two weaker branches inclined 45° on each side of the vertical band. Additionally there is a very weak and short horizontal branch, thus resulting in a star with a total of eight rays when observed in optimum lighting conditions. Photo © V. Lanzafame, SSEF.

asterism (Figure 28). Two branches of the star were rather weak and by visual observation oriented perpendicular to each other, with a third and more prominent bright band intersecting them with an angle of 45°. Close examination revealed an additional but very weak and short branch that was oriented perpendicular to the most intense band (horizontal in Figure 28). Depending on the observation conditions, this zircon thus revealed a star effect with six or maximum of eight rays. In addition to this, the centre of the star was further pronounced by a bright reflection from the overhead light source.

Microscopic observation of the asteriated zircon revealed three sets of oriented planar features (Figure 29, left), each perpendicular to the weaker branches of the star, combined with a set of very fine short tubes or fissures that were responsible for the distinctly more intense branch (vertical in Figure 28). The bright area at the centre of the star resulted from another set of micro-features (Figure 29, right) that was oriented perpendicular to the inclusions producing the star effect. Due to the highly included nature of

Figure 29: Microscopic observation showed that various micro-features are responsible for the star effect (left) and the central bright reflection (right) in the zircon. Photomicrographs © M. S. Krzemnicki, SSEF; magnified 75×.

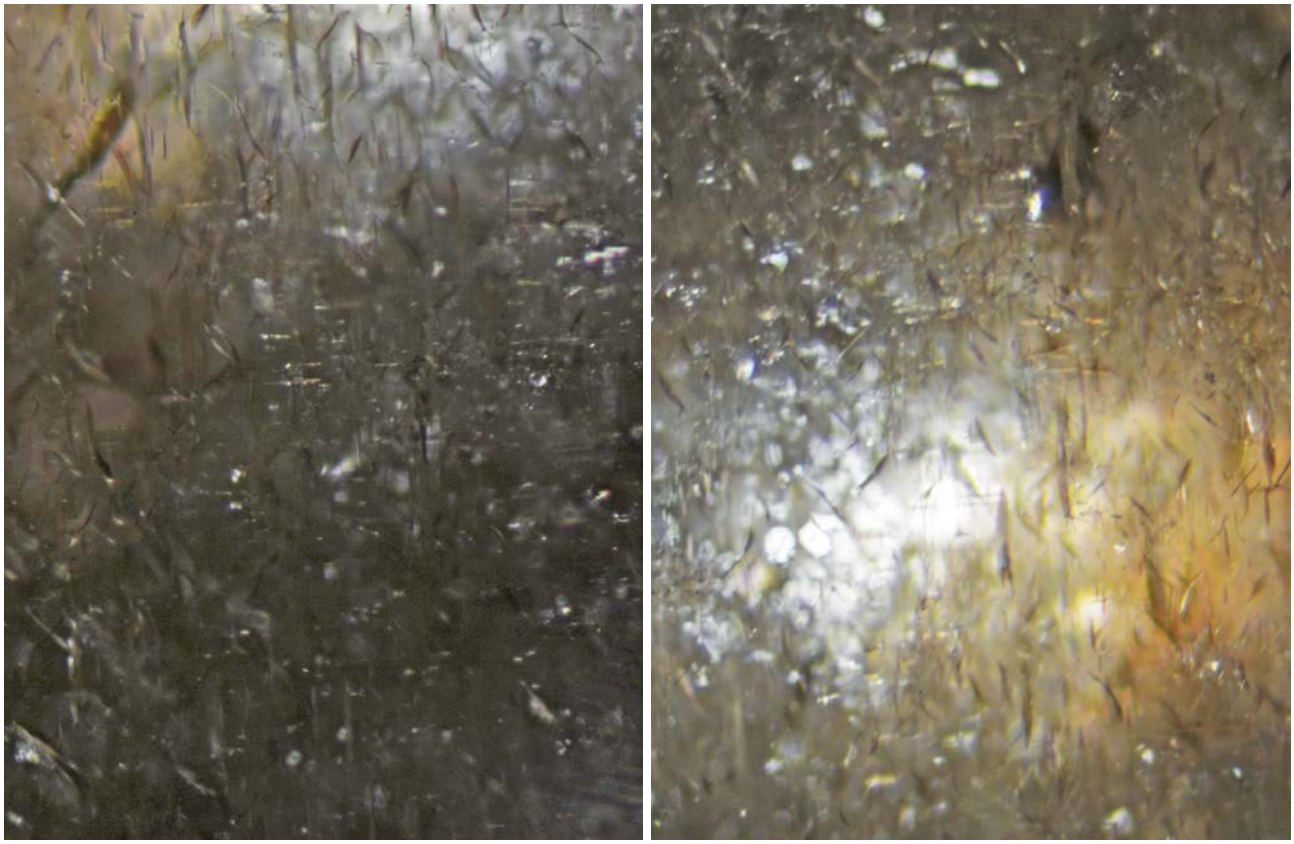

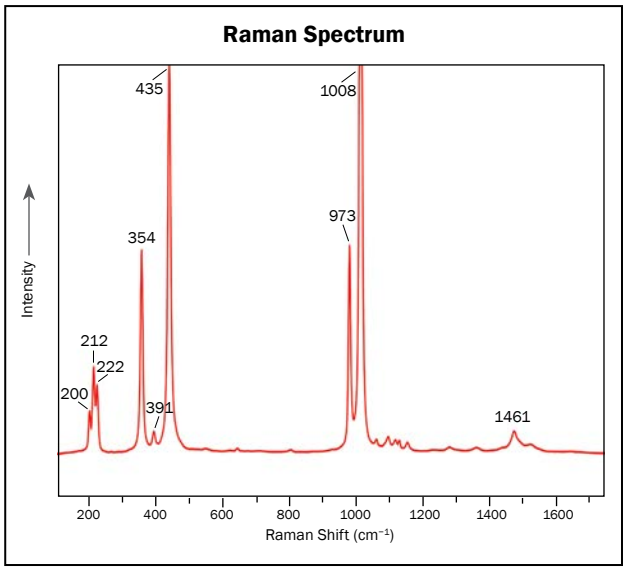

Figure 30: The Raman spectrum of the asteriated zircon shows sharp and pronounced vibrational peaks, characteristic of heat treatment.

the specimen, the crystallographic orientations of the observed micro-structures could not be determined.

Raman micro-spectroscopy of the inclusion features revealed only Raman peaks of zircon, so they are interpreted as micro-fissures along cleavage directions, or another type of micro-structure. Based on the similarity of these complex micro-features to those described by Hänni and Weibel (1988) for heated cat's-eye zircon, it seems probable that the star effect in this specimen is also the result of a heating process. This is supported by the Raman spectrum of this zircon (Figure 30), which is characterised by very sharp and pronounced vibrational peaks, as would be expected in metamict and translucent zircon only after heat treatment (Zhang et al., 2000; Nasdala et al., 2002; Wang et al., 2006; Krzemnicki, 2010) or in well-crystallized (non-metamict) and commonly transparent zircon.

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ORGANIC MATERIALS

Amber Processing in Lithuania

On 1 September 2015, a group of participants from the International Gemmological Conference visited the Amber Queen processing facility in Klaipėda, Lithuania, as part of the post-conference field trip. The tour was led by Sigita Pevceviciute (Figure 31), who explained the various stages of amber processing and acted as an interpreter for our group's questions. The factory employs 150 workers and processes 1.5 tonnes of Baltic amber per month.

The raw amber is initially sorted into transparent material (and rarely, amber containing interesting

Figure 31: At the Amber Queen processing facility, autoclaves (left, with tour leader Sigita Pevceviciute) are used to clarify the raw amber (right). Photos by B. M. Laurs.

inclusions) versus that which needs to be clarified with treatment in an autoclave (Figure 31). We were told that, in general, approximately 20% of the raw amber is of jewellery quality, and the rest undergoes autoclave treatment. To remove bubbles and fractures, the amber is heated to 150–200°C at a pressure of 30 atmospheres in nitrogen gas.

The amber is then worked into pieces of various shapes followed by initial polishing using buffing wheels. Most of the pieces are drilled, either by hand (Figure 32, left) or by machine. Traditionally, drilling is done by men, while polishing is done by women. The beads are drilled from both sides to help prevent breakage and so they slide more smoothly during stringing.

Approximately 90% of raw Baltic amber is pale yellow, and it commonly undergoes a simple heat treatment procedure to darken its colour. The heating is done in air using conventional ovens at various temperatures and durations to create six colour categories ranging from yellow to orange, orangey brown and black. To obtain an attractive yellow colour, the amber is baked at 140°C for three hours, while 'black' amber (actually a black 'skin' on yellow amber) is produced by heating to 200°C for eight hours. Heating at lower temperatures for longer periods (e.g. 100°C for two weeks) is also done to give the amber an 'aged' appearance, to resemble that seen in vintage jewellery (e.g. Figure 32, right).

Figure 32: Hand drilling of amber pieces from both sides requires experience and concentration (left). Either before or after drilling, much of the amber undergoes heat treatment to darken its colour or create an 'aged' appearance (right). Photos by B. M. Laurs.

Figure 33: Amber beads of various colours are strung into necklaces that display repeating patterns. Photo by B. M. Laurs.

Final polishing is done using a two-step process. First the amber pieces are placed into vibra-polishers for 2–3 days together with various mixtures consisting of water, dish soap, ceramic pieces, fine quartz sand and glass balls. Then the amber pieces are put into rotating wooden drums with small pieces of beech wood and polishing powder (for 14 hours) or polishing liquid (for another 14 hours).

The beads are incorporated into a variety of jewellery pieces (necklaces, bracelets, earrings, etc.), and the various colours are often strung into attractive repeating patterns (e.g. Figure 33). Another product made by the factory consists of heat-treated amber cabochons from which the black 'skin' has been polished off the domes and the bases carved to create intricate patterns (Figure 34).

The various amber by-products from the factory (drill filings, powder, dust, etc.) are collected and sold for use in the electronics industry as well as in incense, facial creams and soap, so none of the amber that enters the facility for processing is wasted. No pressed amber products are made at the Amber Queen facility.

The jewellery is sold along with amber souvenirs and *objets d'art* in Amber Queen's shops in Klaipėda and Vilnius (Lithuania) and in Riga, Latvia. Our group visited the main store in Klaipėda, which also hosts an amber museum that displays an impressive private collection of Baltic amber.

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Figure 34: These amber cabochons (approximately 1.5–2.5 cm long) have been carved on their bases to remove the black 'skin' created by heat treatment. Intricate patterns are seen through the polished domes of the cabochons. Photo by B. M. Laurs.

Shungite for Jewellery Use

Recently a client submitted some pieces of a black gem material they called shungite. Initially we thought they were jet, but the gemmological properties were different. According to the literature, shungite is a mineraloid consisting of more than 98% carbon (Mastarlez et al., 2000). A mineraloid is a mineral-like substance that does not have a crystalline structure and possesses

Figure 35: This 4.32 ct piece of shungite has been cut in a freeform shape, and the top surface has been left unpolished to show its conchoidal fracture patterns. Photo by Pangemtech staff.

chemical compositions that vary beyond the generally accepted ranges for specific minerals. Shungite was first described from a deposit near Shunga village, in Karelia, Russia, and it has been reported to contain fullerenes (molecules of carbon in the form of hollow spheres, tubes and other shapes; Reznikov and Polekhovskii, 2000).

The samples submitted by the client consisted of assorted broken fragments and some flat-backed pieces that were cut into various shapes for mounting in jewellery; we tested a 4.32 ct sample (Figure 35). It was opaque black with a vitreous lustre and a surface that showed conchoidal fracture patterns. It was inert to UV radiation and gave a black streak. The sample showed a spot RI value of 1.62 and a hydrostatic SG of 1.86. FTIR spectroscopy recorded an absorption band at ~1578 cm^{-1}. According to information given in Reznikov and Polekhovskii (2000), shungite has an RI of 1.6, SG values between 1.83 and 1.96, and IR absorption between 1580 and 1575 cm^{-1}. The properties we determined for the 4.32 ct sample fell within the range for shungite and not jet (which has SG = 1.20–1.30).

The client explained that shungite is commonly used by crystal healers, and is also being mounted into some unusual designer jewellery (e.g. Figure 36).

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Figure 36: This unusual pendant features a rectangular shungite (upper right, 2.50 × 1.01 cm), a cabochon of spotted coral (4.50 × 2.80 cm) and pear-shaped treated grey-green quartz (1.30 × 0.80 cm). Photo by Pangemtech staff.

PEARLS

Gem-set Cultured Pearls

The past several years have witnessed many creative innovations in modifying cultured pearls for use in jewellery, including carving their surfaces to create interesting patterns or expose an underlying bead made of various materials; embedding them with tags and other devices that can be used to include identifying information or custom-recorded audio, video or image files; and setting them with faceted gemstones (e.g. Hänni and Cartier, 2013; http://galateausa.com). Some new variations in setting gem materials into cultured pearls were recently developed, starting in March 2014, by Hisano Shepherd (little h, Los Angeles, California, USA).

Several cultured pearl varieties are used as starting materials, including both freshwater (soufflé and drop) and saltwater (Tahitian baroque, drop and keshi; golden and white South Sea baroque, drop and keshi; Sea of Cortez keshi; and Vietnamese blue akoya). These are carefully processed using three different methods. For the 'Pearl Geode Collection', they are sliced in half and each side is hollowed out, while for the 'Finestrino Collection' a concave opening is made into the interior of whole cultured pearls, and for the 'Grotto Collection' the cultured pearls are carved to create an opening that goes all the way through them (Figure 37). The interior surfaces of the cultured pearls are polished and then lined with a variety of different melee-sized gem materials (faceted stones or beads), including white and black diamonds, amethyst, ruby, emerald, sapphire and peridot, among others; cultured seed pearls also are used. The rubies and emeralds are commonly 'reclaimed' from old jewellery pieces, and the stone size and shape varies. The gemstones or seed pearls are affixed to the inner walls of the cultured pearls using resin.

The completed gem-set cultured pearls range from 9–10 mm up to 30+ mm, and are set into pendant, earring, ring and necklace designs. Shepherd has made over 300 of these items in her studio and office in Los Angeles. Her inspiration for creating them came from seeing quartz geodes at the Tucson gem shows, and she desired to recreate their geode-like appearance using cultured pearls.

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Figure 37: The earrings on the left are part of the 'little h' Pearl Geode Collection, and feature a pink soufflé cultured freshwater pearl measuring 13 × 20 mm that has been sliced in half and lined with light-to-dark pink sapphires (2.86 carats total weight) and set in 14-carat yellow gold. The Finestrino pendant in the centre is made from a pink soufflé cultured freshwater pearl measuring 30 × 33 mm that has been filled with ruby beads (40+ carats total weight) and set in a 14-carat rose gold necklace. The Grotto pendant on the right features a white soufflé cultured freshwater pearl measuring 20 × 31 mm containing ruby pieces (17.06 carats total weight) with a diamond-set bail in 14-carat white gold. Photos by Katja Bresch (left and right) and Angela Peterman (centre).

From Exsolution to 'Gold Sheen': A New Variety of Corundum

Thanh Nhan Bui, Katerina Deliousi, Tanzim Khan Malik and Katrien De Corte

Sapphires displaying an attractive golden sheen reportedly were discovered in eastern Kenya in late 2009, and were recently brought to market in commercial quantities. The basic gemmological properties of the so-called Gold Sheen sapphires are consistent with typical corundum. Microscopic examination and Raman micro-spectroscopy showed that Fe-Ti oxides (hematite, ilmenite and magnetite) are the main solid inclusions, and they are oriented parallel to crystallographic directions in the basal pinacoid of corundum characterized by a six-fold rotational symmetry. Hematite and ilmenite are present in the form of exsolution intergrowths within platelets or needles. Magnetite typically appears as larger and thicker black platelets. The sheen effect in these sapphires originates from the simultaneous reflection of light from the oriented network of exsolved hematite-ilmenite inclusions.

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Introduction

At the end of 2009, African gem brokers brought a new type of sapphire to the Bangkok gem market. While the rough material appeared dark and opaque overall, it displayed a peculiar weak golden shimmering effect on basal pinacoid surfaces. Author TKM, a gem cutter and dealer for over 25 years, identified a potential business opportunity in this sapphire, and entered into an exclusive selling agreement with the mine owner. The material reportedly was produced from pits measuring a few metres deep in eastern Kenya near the border with Somalia. From 2010 to 2014, the rough material was exported to Thailand. The deposit was subsequently exhausted, with only non-commercial-quality gems extracted during the past two years. About 25 tonnes of rough have been stockpiled in Bangkok, where experiments on cutting and polishing are being conducted to best emphasize the distinctive golden shimmer of this corundum. Its appearance led author TKM to name the stone 'Gold Sheen' sapphire; the gems also have been presented as 'Zawadi' sapphire by some suppliers (e.g. Laurs, 2015).

In this article, we present a detailed gemmological study of the Gold Sheen sapphires and their inclusions, and compare their properties to those of other sheen-displaying gems to further understand their distinctive optical effect.

Samples and Methods

For this study, author TKM supplied 105 samples of Gold Sheen sapphire with a total weight of 675 carats. The stones ranged from 1 to 30 ct.

Figure 1: These Gold Sheen sapphires, faceted into checkerboard cuts or polished as cabochons, weigh up to 30 ct each. The golden sheen, colour zoning and fracture patterns are present in various combinations. Photo by T. K. Malik.

Except for one rough sample, they were cut and polished as cabochons and faceted gemstones of various qualities with regard to the golden sheen effect (e.g. Figure 1). Most of the cabochons were double-sided and displayed a light yellow to golden six-rayed star under a point light source (e.g. Figure 2). The faceted gems were cut into various common and fancy shapes. Due to a lack of transparency in the material, the proportions of the crown and pavilion were optimized for weight rather than for brilliance. Some of the crowns displayed a modified brilliant style, but the majority were fashioned into checkerboard cuts. The cutting and polishing of the rough material was the only processing imposed on the stones. Therefore, the Gold Sheen sapphires and their visual effect are completely natural.

Figure 2: A golden six-rayed star is shown by this 25.06 ct cabochon of Gold Sheen sapphire. Photo by T. K. Malik.

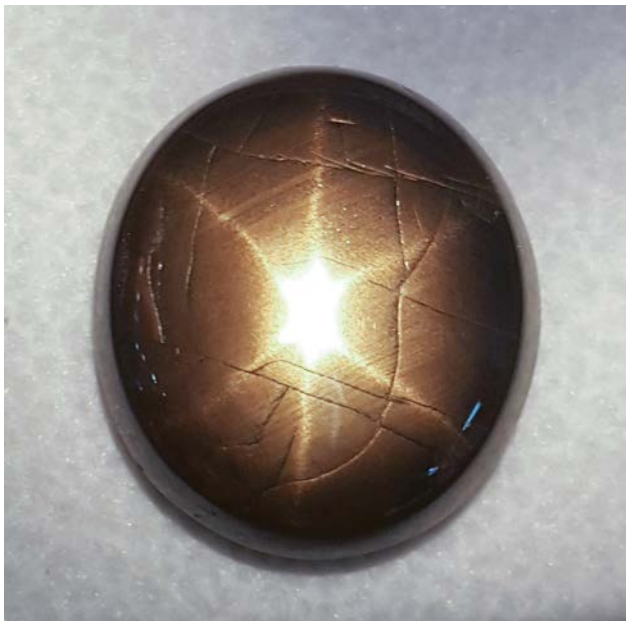

Basic gemmological characterization was performed on 46 samples at HRD Antwerp, and included visual observations, RI and hydrostatic SG measurements, polariscope and dichroscope reactions, hand-held spectroscope absorption spectra, and long- and short-wave UV fluorescence observations. In addition, the samples were studied with the D-Scope gemmological microscope from HRD Antwerp.

Energy-dispersive X-ray fluorescence (EDXRF) spectroscopy was achieved with a PANalytical Epsilon 5 instrument on 29 samples. For primary excitation, the Gd tube anode was operated with a current of 6–24 mA, a voltage of 25–100 kV and a power of 600 W, depending on the nine

secondary targets used for the emission of the different characteristic X-ray lines. The samples were analysed for 10–300 sec, focusing on the analytical X-ray line of each target according to the elements of interest. We used the $K\alpha$ emission lines for most of the light trace elements and the $L\alpha$ emission lines for elements with $K\alpha$ lines greater than 20 keV.

Inclusions were identified in 20 samples using a Horiba LabRAM 800HR micro-Raman spectrometer at the Catholic University of Louvain (Louvain-la-Neuve, Belgium). Calibration was performed on a silicon substrate with a first-order Raman peak located at 520.7 cm^{-1}. A green laser (514 nm) was used to excite the samples, and its power was modulated to between 50% and 100%. The acquisition time for each spectrum ranged from 10 sec to 2 min, and each spectral acquisition was performed twice. Due to the very small size of the inclusions, we used magnifications of 500× and 1,000×. Raman spectra were normalized according to the most intense Raman peak, so as to plot several curves in the same graph. The background was not subtracted from the spectra.

The microstructure of the inclusions in one sample was investigated by a Zeiss Ultra55 field emission scanning electron microscope (SEM). We used a low accelerating voltage (2 keV) and the In-Lens secondary-electron detector with an optimized working distance (~2 mm) to obtain clear micrographs of the girdle profile of the sample where there was a high probability of surface-reaching needles and platelets. These parameters allowed us to resolve the cross-sections of the platelet inclusions to assess their thickness in SEM micrographs. The micrographs were horizontally aligned with the basal pinacoid and vertically aligned parallel to the c-axis of the corundum host.

All of the measurements were performed at ambient pressure and temperature, and none required any sample preparation.

Results

Visual Observations: Colour and Transparency

The body colour of the host sapphires was blue, green and/or yellow, with the latter being the most frequently encountered. The metallic sheen was characterized by a (golden) bronze colour that shimmered when the cabochons and faceted gems were illuminated. As demonstrated below, the shimmer was due to inclusions within the sapphires.

The c-axis of the corundum was oriented perpendicular to the crown/dome of the polished stones. Some samples displayed colour zoning in three orientations at 60°/120°, typical of the six-fold rotational symmetry in the basal plane of the rhombohedral system. Colour zoning in parallel lamellar patterns was created by layers containing various concentrations of inclusions that mechanically coloured those areas. Due to the reflection of light from the inclusions, those bands containing abundant particles appeared light, while the interstitial areas containing few inclusions showed the body colour of the sapphire, which generally appeared dark (especially for sapphires with blue body colour). Intermediate concentrations of inclusions exhibited a mixture of golden sheen and the body colour from the host sapphire.

Within areas showing the golden sheen, we typically observed dark surface-reaching cracks showing random paths. Their full extension was more visible when we observed the samples at an oblique angle to the surface of the stone.

In general, the diaphaneity of the sapphires varied according to the amount of sheen that they displayed. Samples showing less sheen were nearly transparent. Where the sheen was present over a larger area of a gemstone, the diaphaneity was translucent. In areas of darker bronze sheen, the stone could be completely opaque. This suggests that the inclusions responsible for the sheen also cause diminished transparency of the host sapphire.

Physical Properties

As the gemstones were heavily fractured, full of inclusions, typically translucent and not perfectly polished, routine gemmological testing was challenging. The overall results from the 46 samples were: RI—1.76–1.77 (spot reading), birefringence—0.01, SG—3.95–4.05, UV fluorescence—inert to long- and short-wave UV radiation, and spectroscope spectrum—absorption at 450 nm and in some samples a cutoff at ~500 nm. These are typical readings for corundum.

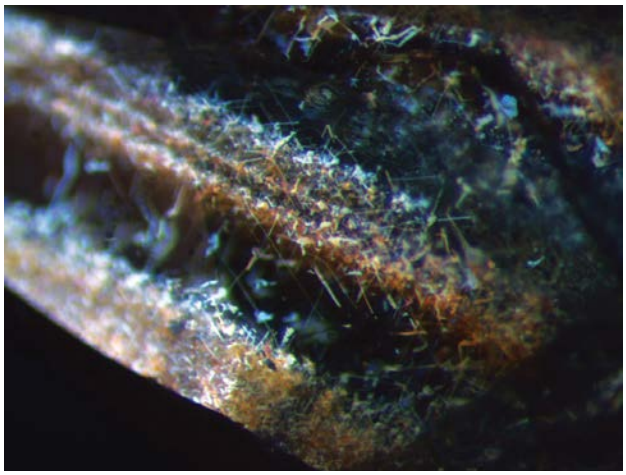

Figure 3: In areas of the sapphires showing sheen, networks of oriented inclusions consisting of needles and platelets lie within the basal pinacoid. Photomicrograph by T. N. Bui using brightfield illumination; magnified 60×, field of view 1.87 × 1.45 mm.

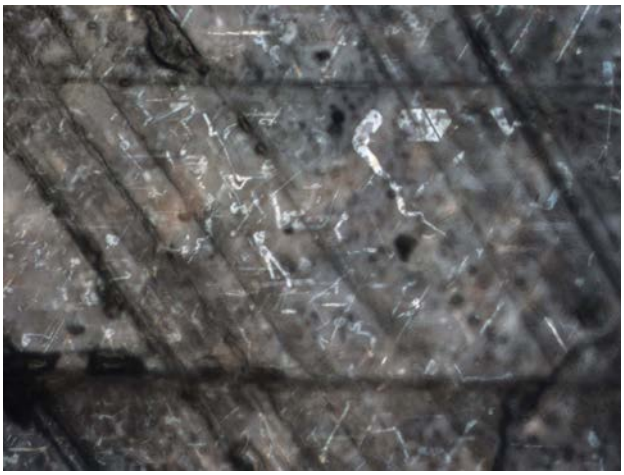

Figure 4: The surface of the basal pinacoid in this particular rough sapphire exhibits growth lines in three directions, parallel to {10$\bar{1}$0}. The needle inclusions below the surface are parallel to these growth lines. Photomicrograph by T. N. Bui using brightfield illumination; magnified 100×, field of view 860 × 635 µm.

Microscopic Characteristics

Under the gemmological range of magnification (10×–80×), we clearly observed hexagonal growth patterns and colour zoning in the sapphires. Furthermore, areas showing the sheen correlated to networks of numerous tiny straight needles and flakes lying within the corundum basal plane (Figure 3). In reflected light, the inclusions were golden metallic, and thus reflections from the inclusion networks created the golden sheen. In transmitted light, the inclusions appeared more orangy brown, and under oblique illumination they exhibited various colours due to thin-film interference (see Figure DD-1 in the Data Depository). The latter observation indicates an inclusion thickness in the nanometre range.

As mentioned above, the inclusions were present in three different orientations intersecting at 60°/120°, typical of the six-fold rotational symmetry in the basal plane of the rhombohedral system. These orientations also were parallel to the corundum growth lines (Figure 4), which are aligned along the first-order hexagonal prism {10$\bar{1}$0} (Hughes, 1997, p. 446). Also present in some samples were larger platelets that contained small dark areas (Figure 5).

Zones in the sapphires consisted of alternating bands of needles and platelets of different concentrations, at various positions along the c-axis (Figure 6). The bands containing inclusions of higher density and closer to the surface produced a golden bronze colour, while those of lower density and deeper inside the host produced a brownish bronze sheen, which resulted from a combination of reflections from the inclusions and the dark body colour of the host sapphire. This is well illustrated by comparing the appearance of a thin sample in reflected vs. transmitted light (again, see Figure 6).

Less abundant, but always present within the inclusion networks in the golden sheen areas, were black plates that were a similar size or larger than the platelets described above (Figure

Figure 5: The platelets in this sapphire contain dark areas and appear to be composed of different minerals. Photomicrograph by T. N. Bui using brightfield illumination; magnified 50×, field of view 1.3 × 1.0 mm.

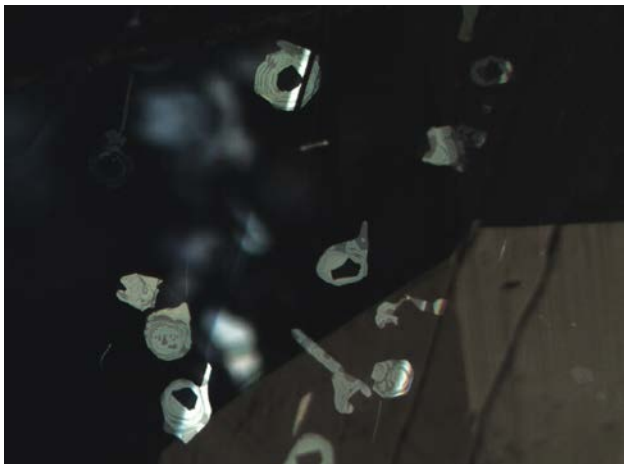

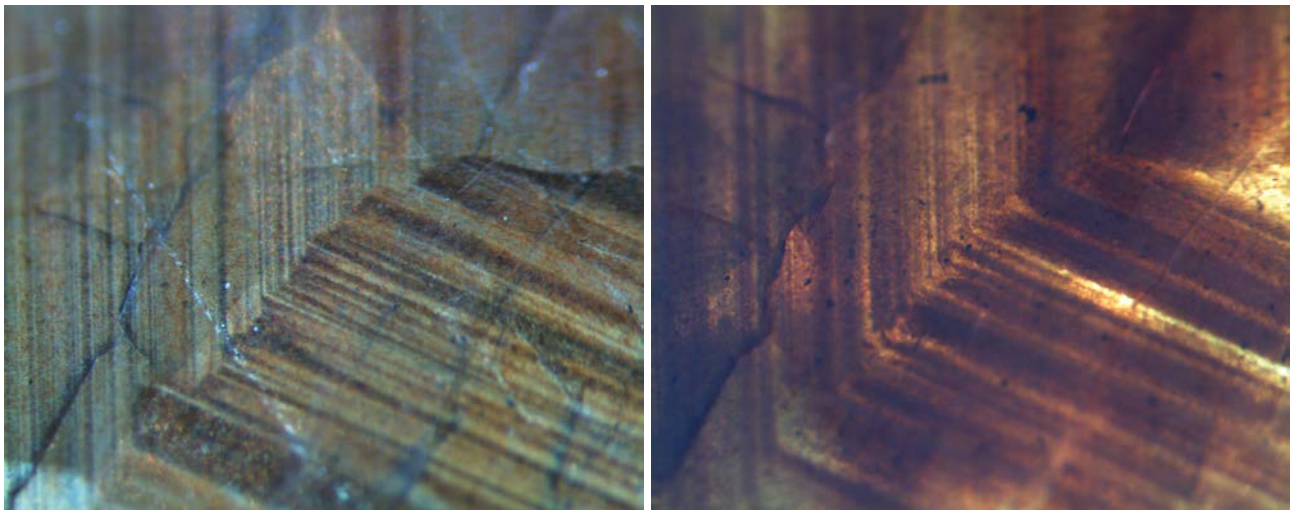

Figure 6: Colour zoning in this sapphire is characterized by different bronze colorations along the crystallographic directions of the corundum host (left, brightfield illumination). With transmitted light, the golden bronze-coloured bands appear dark and the brownish bronze-coloured bands are bright (right). This highlights variations in the concentration of needle and platelet inclusions along the c-axis. Photomicrographs by T. N. Bui; magnified 30×, field of view 4.76 × 3.81 mm.

7). Some of them were so large that they were visible to the naked eye, negatively affecting the appearance of the gemstone. The edges of these hexagonal-shaped inclusions were clearly parallel to the other inclusions and to the colour zoning.

The characteristics of the fractures within the sheen areas became more obvious when viewed with magnification. Their macroscopic 'dark vein' appearance correlated to the absence of inclusions around them. This indicates that these cracks were not created during the cutting of the stones. The absence of inclusions was evident only on one side of the fractures, characterized by a gradual increase in inclusion density away from the fractures. This asymmetry induced a colour gradient on one side leading up to the sharp boundary line of the fracture (Figure 8). This was easily observed with the naked eye in samples containing larger veins. Further microscopic investigations, combining brightfield and darkfield illuminations, showed a correlation between the asymmetry of the dark veins and the pattern of the associated fractures. The side of the dark vein presenting a concentration gradient of inclusions corresponded to the curvature direction

Figure 7: Black plates are present along with the network of needles and platelets in the Gold Sheen sapphires. These plates do not contribute to the sheen. Some of their borders are parallel to the orientation of the needles. Photomicrograph by K. Deliousi using transmitted light; magnified 80×, field of view 1.64 × 1.31 mm.

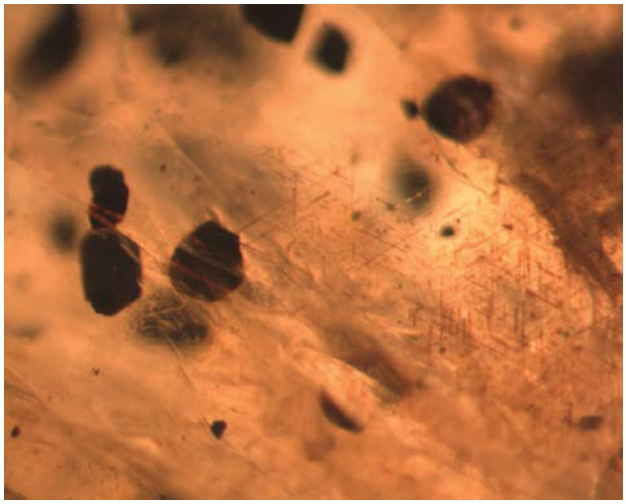

Figure 8: Surface-reaching fractures in the sheen area of the sapphires are characterized by asymmetric dark veins. Photomicrograph by K. Deliousi using brightfield illumination; magnified 25×, field of view 5.67 × 3.85 mm.

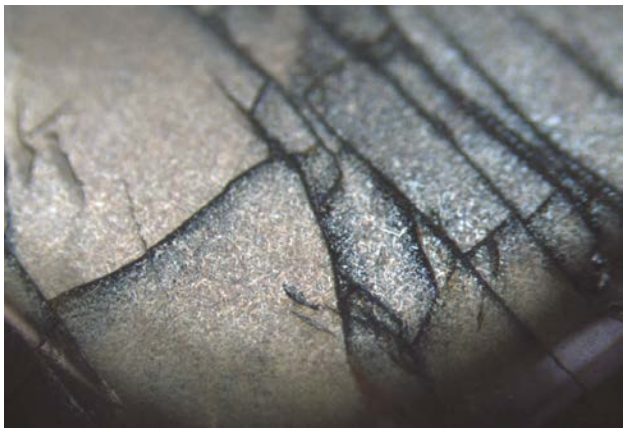

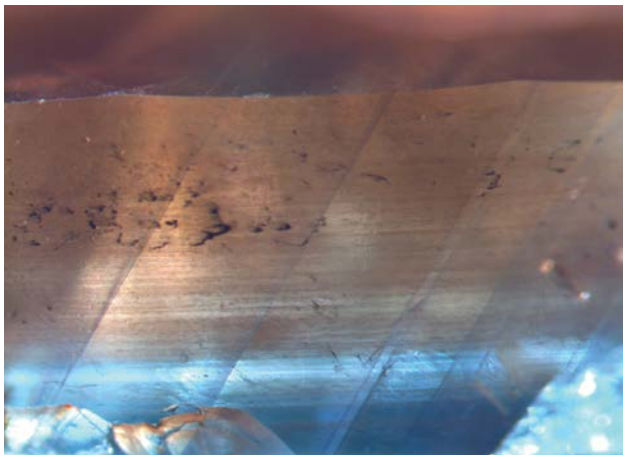

Figure 9: This view of the girdle of a Gold Sheen sapphire shows parallel brownish lines representing networks of needle and platelet inclusions along the basal pinacoid, and also a set of parallel lines (polysynthetic twin planes) oriented at about 58° and 32° to the basal pinacoid and the c-axis, respectively. Photomicrograph by T. N. Bui using darkfield illumination; magnified 30×, field of view 4.76 × 3.35 mm.

of the fracture. The distance along which the gradient extended was proportional to the slope of the fracture curvature. The asymmetric dark veins thus constituted an indirect mapping of the cracks underneath, shadowed by the inclusions.

Some samples showed a series of parallel lines when viewed at certain angles along the girdle profile (in a direction perpendicular to the c-axis). The angle between the lines and the basal pinacoid was 58° and that between the lines and the c-axis was 32° (Figure 9). These parallel lines are attributed to polysynthetic twin planes corresponding to the rhombohedral $\{10\bar{1}1\}$ faces of corundum. We observed parallel long white needles coincident with these twin planes when we looked through the table of the gemstones in a direction close to the c-axis (see Figure DD-2).

Due to the limited transparency of the gems, other solid inclusions were difficult to locate and identify. However, some surface-reaching inclusions in the lower-quality samples are described further below. In addition, planar assemblages of negative crystals corresponding to healed fractures were seen in some samples (e.g. Figures DD-3 and DD-4).

Chemical Composition

Qualitative EDXRF spectroscopy revealed the presence of the following trace elements in all 29 samples analysed: Fe, Ti, V, Cr, Ga, Nb and Ta. A relatively large amount of Fe suggested that this element was probably the main ingredient of the inclusions, especially in the networks of needles and platelets.

There was no obvious correlation between the blue body colour of some of the sapphires and the presence of Ti, as peaks of a similar intensity were also present in samples showing yellow and green body colours. Therefore, Ti could mainly be attributed to the inclusions. Other trace elements that are usually encountered as impurities in corundum include Ga, Nb and Ta; their concentrations varied in our samples.

Some of the sapphires, particularly those of low quality, contained additional trace elements including Zr, S, Ba, Cu, K, Na and Si. These may be attributed to various inclusions other than the metallic-appearing needles and platelets.

Inclusion Observations under High Magnification, and Raman Identification

Raman micro-spectroscopy is a powerful tool for identifying microscopic inclusions that are located at or near the surface of a gemstone (Bersani and Lottici, 2010; Kiefert and Karampelas, 2011). Since some inclusions had lateral dimensions of only a few microns, we used an optical magnification of 1,000× in order to obtain a laser spot of 1 µm. All of the analysed inclusions could be successfully identified by comparing their Raman spectra to those in the RRUFF database.

The high density of the inclusions responsible for the golden sheen makes them suitable for investigation through Raman spectroscopy. In most cases, the networks of needles and platelets reached the surface of the gems, or were less than 5 µm from the surface. Individual needles/platelets had such narrow thicknesses (less than 100 nm) that their surface-reaching cross-sections were extremely small to analyse, so it worked better to look for those that were located just under the surface. The particles selected for analysis had no intervening inclusions between them and the surface, nor ones situated directly below them. Therefore, the Raman spectra consisted exclusively of the superimposition of signals from both the sapphire and the inclusion. Figure 10a shows the spectrum of a host sapphire (α-Al_2O_3

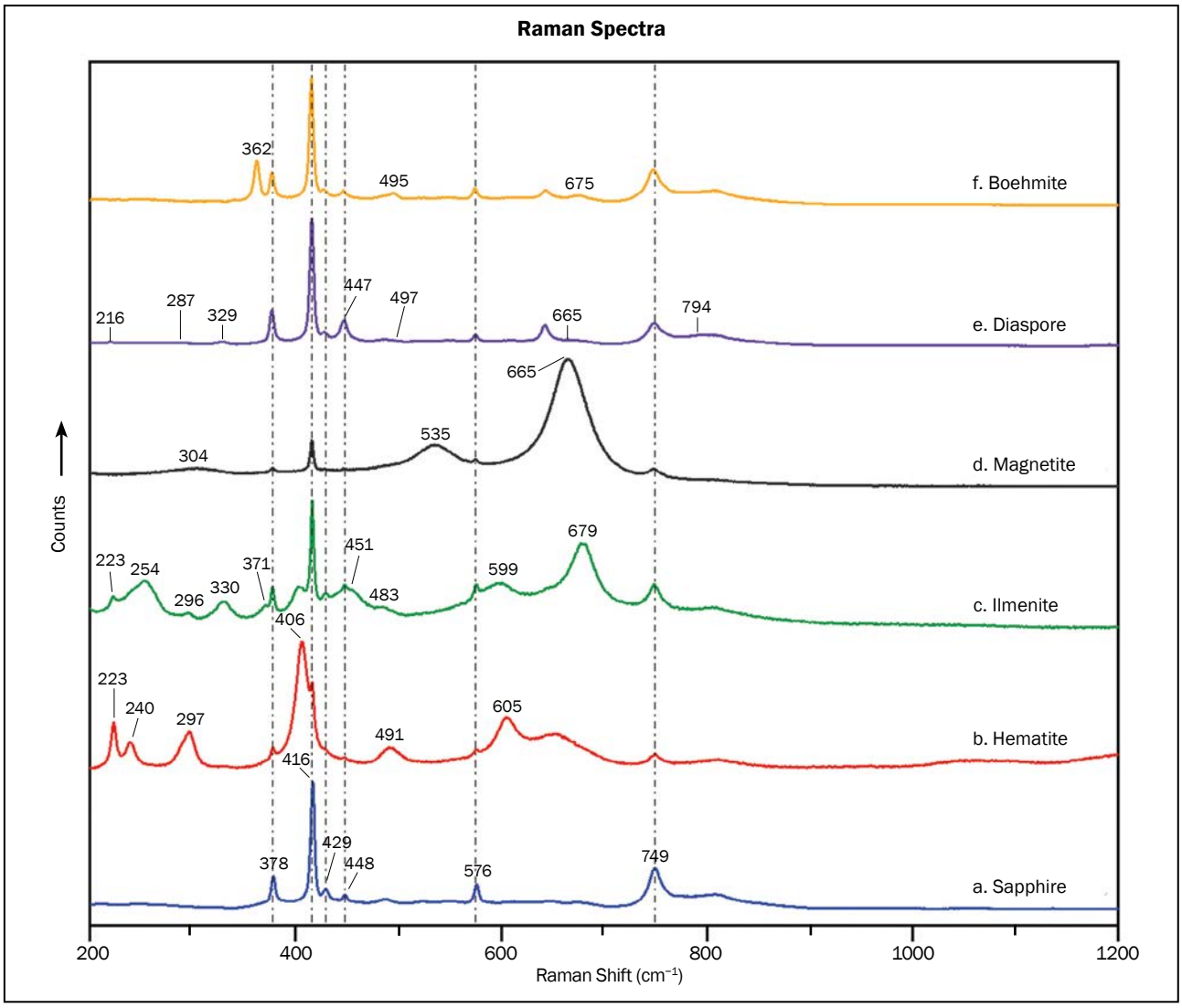

Figure 10: Raman spectra are shown for a host sapphire (a) and for various inclusions (b–f). The vertical dashed lines indicate the Raman peaks of corundum superimposed on those of the analysed inclusions. The two minerals present in the exsolved needles and platelets are hematite and ilmenite. Larger and thicker black plates were identified as magnetite. Diaspore and boehmite are the two polymorphs of AlO(OH) present in long white needles formed along the polysynthetic twin planes. (A peak that is present at 642 cm^{-1} in the spectra of both diaspore and boehmite is due to the A1g vibrational mode of the host corundum. These were the only spectra taken with the laser beam not perpendicular to the basal plane of the corundum.)

corundum), free of inclusions. In agreement with earlier studies (e.g. Xu et al., 1995), it includes peaks at 378, 416, 429, 448, 576 and 749 cm^{-1}.

The built-in optical microscope of the Raman micro-spectrometer, with magnifications from 200× to 1,000×, permitted us to identify some features that were barely distinguishable even when using the highest magnification of a typical gemmological microscope. Examples are provided by the needles and platelets illustrated in Figure 11. Several dark areas of various size and abundance were seen on many of the platelet inclusions. The duality of the colours within each inclusion suggested the presence of two different materials in the platelets. By contrast, in most cases the needles were of uniform colour, so they probably consisted of just one mineral. However, as the thickness of the needles increased, the probability was higher of observing colour inhomogeneities that may correspond to different minerals.

The platelets showed polygonal shapes with some of their edges parallel to the needles and other edges perpendicular to them. These edges were in turn parallel to the faces of the first- and second-order hexagonal prisms, $\{10\bar{1}0\}$ and $\{11\bar{2}0\}$,

Figure 11: The platelets and larger needles in the Gold Sheen sapphire consist of hematite and ilmenite (light and dark, respectively, in reflected light). The lighter areas (hematite) of the inclusions may display various colours due to thin-film interference from the nanometre-scale thickness of the inclusions. Two or more colours may be seen on the same platelet, indicating a variation in thickness (top right and bottom left). The darker areas (ilmenite) may also exhibit colour variations depending on thickness, but they are not as evident. Photomicrographs by T. N. Bui using brightfield illumination; magnified 1,000×, field of view 80 × 60 μm.

of the rhombohedral corundum host. The angles between two edges of the same polygon thus have the following possible values: 30°/150°, 60°/120° and 90°. Depending on the sample, the lateral dimensions of the platelets ranged from just a few to hundreds of micrometres. In SEM images, we observed a series of short white lines parallel to the basal pinacoid, corresponding to the needle-like and platelet inclusions. High magnification (100,000×) revealed the thickness of these inclusions was around 100 nm (Figure 12).

Raman micro-spectroscopy identified the smaller needles and the light-coloured areas of the platelets as hematite (α-Fe_2O_3), with the largest Raman peak at 406 cm^{-1} located near to that of sapphire, and other peaks recorded at 223, 240, 297, 491 and 605 cm^{-1} (Figure 10b). This is in good agreement with previous work on hematite (e.g. de Faria et al., 1997). Raman spectra of the dark areas of the platelets, characterized by a strong band at 679 cm^{-1}, were assigned to ilmenite ($FeTiO_3$); the other vibration modes describing this mineral were 223, 254, 296, 330, 371, 451, 483 and 599 cm^{-1} (Figure 10c). The obtained spectra are in good agreement with natural ilmenite for the main Raman peaks (e.g. Rull et al., 2004, 2007) and with pure synthesized ilmenite for the weaker Raman peaks (e.g. Sharma et al., 2009; Guan et al., 2013).

As mentioned previously, some black plates also were present in the golden sheen areas. The deep boundaries and terraces on the surfaces of these inclusions indicated that they are relatively thick (at the micron scale). Their

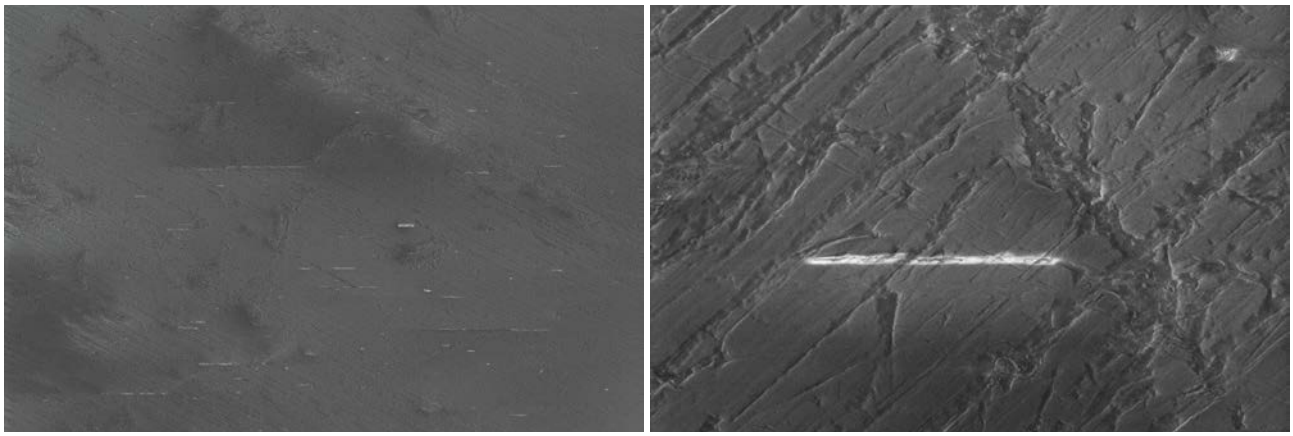

Figure 12: Cross-sections of platelet inclusions are observed in these SEM images taken from the girdle of a Gold Sheen sapphire. They appear as light grey thin parallel lines of various lengths at several levels along the c-axis (left). Closer examination of a single platelet inclusion (right) with the SEM shows that its thickness is 83 nm. Electron micrographs by T. N. Bui; magnified 2,000× (field of view 150 × 100 µm, left side), 20,000× (15 × 10 µm, right side).

lateral dimensions were generally greater than the hematite-ilmenite platelets. Observations with the Raman microscope confirmed their polygonal shape, with edges showing the same orientations as the platelets (Figure 13). Raman micro-spectroscopy identified these black inclusions as magnetite (Fe_3O_4), with three characteristic peaks at 304, 535 and 665 cm^{-1}, the latter being the strongest (Figure 10d). The obtained Raman spectra compared well to previous investigations on magnetite (de Faria et al., 1997).

The long needles lying along the polysynthetic twin planes were seen at high magnification to consist of tiny particles rather than a monocrystalline mineral. The concentration of these particles was higher toward the central core of the needle (Figure 14). Raman spectra obtained from different locations of several needles showed that the particles consisted of two polymorphs of aluminium oxide hydroxide. Most common was diaspore [α-AlO(OH)], with peaks at 216, 287, 329, 447 (strongest), 497, 665, 794 and 1191 cm^{-1} (Figure 10e). Occasionally, we found boehmite [γ-AlO(OH)], characterized by three Raman peaks at 362, 495 and 675 cm^{-1}, the first being the most intense (Figure 10f). All of these Raman features are in good agreement, for example, with a study on naturally occurring diaspore and synthesized boehmite (Ruan et al., 2001).

Several additional surface-reaching minerals were identified that did not contribute to the golden sheen: pyrite, baryte, covellite, zircon, muscovite, albite and K-feldspar. Photomicrographs and/or Raman spectra of these inclusions are provided in the Data Depository (Figures DD-5 to DD-7).

Discussion

Inclusions in the Gold Sheen Sapphires

The physical properties measured for the sapphires were not affected by the presence of their abundant inclusions. The concentration or weight of the inclusions was negligible in regard to the sapphire host, and the SG, RI and birefringence remained consistent with corundum. Optical microscopy highlighted the presence of a network of metallic-appearing needles and platelets and some larger black plates. Raman spectroscopy identified those inclusions as the Fe-Ti oxides hematite, ilmenite and magnetite. The presence of these inclusions in areas showing the golden sheen is consistent with the overall relatively high concentration of Fe (and Ti) in these sapphires.

The alignment of the colour zoning and the networks of hematite-ilmenite needles along the second- and first-order hexagonal prisms, $\{11\bar{2}0\}$ and $\{10\bar{1}0\}$ respectively, is consistent with previous studies of similar inclusions in black sapphires from Australia (Moon and Phillips, 1984). In that article, it was estimated from energy-dispersive spectroscopy that the exsolved inclusions consisted ~50% each of hematite and ilmenite. This is in reasonable agreement with high-magnification observations of the inclusions in our samples, although we noted a slightly higher amount of hematite (e.g. Figure 11).

Figure 13: Black plates in the Gold Sheen sapphires were identified as magnetite. The edges of the inclusions are aligned along the first- and second-order hexagonal prisms. Photomicrographs by T. N. Bui using brightfield illumination; magnified 500× or field of view 175 × 130 μm (top left, top right and bottom left) and 1,000× or 80 × 60 μm (bottom right).

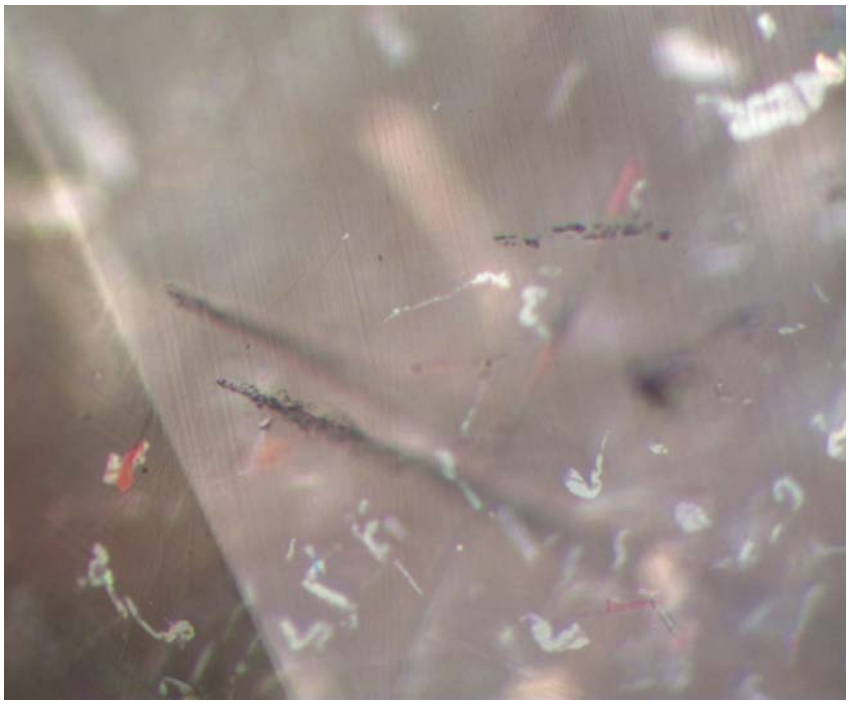

Figure 14: Needle-like inclusions consisting of diaspore and boehmite particles (appearing dark in brightfield illumination) lie along polysynthetic twin planes in the Gold Sheen sapphire. Photomicrograph by T. N. Bui; magnified 200×, field of view 360 × 300 μm.

As observed previously, in contrast to the needles, the edges of the platelets showing polygonal shapes were mostly parallel to both the first- and second-order hexagonal prisms of the host corundum. This difference highlights the preferential growth of the needles along the <10$\bar{1}$0> direction, probably due to the structural mismatch between the Fe-Ti oxides and corundum. The in-plane orientation of the hematite-ilmenite needles and platelets, and the similar crystal structure of hematite and ilmenite to corundum, suggest that the basal pinacoid direction of the inclusions and the host are parallel.

The edges of the magnetite plates had the same orientation as the hematite-ilmenite platelets. As shown in Figure 13, the magnetite plates commonly had triangular and hexagonal shapes. Since magnetite belongs to the spinel group, which crystallizes in the isometric crystal system, these shapes indicate a tetrahedral crystal habit.

Magnetite is known to be the most magnetic naturally occurring mineral. We tested the magnetism of the sapphires with neodymium-iron-boron magnets, and those containing large plates of magnetite were attracted to the magnets when the samples were floated in water (cf. Gumpesberger, 2006). A few low-quality sapphires possessing eye-visible magnetite inclusions were attracted to the magnets even without flotation (see Figure DD-8).

The Fe-Ti oxides and the diaspore-boehmite needles all formed in the sapphire as a result of epigenetic solid exsolution (cf. Hughes, 1997, pp. 93–94). Hematite, ilmenite and magnetite all have different chemical compositions, but they grew according to the crystallographic directions in the basal pinacoid of the host corundum. Such epigenetic inclusions crystallize due to the presence of defects and impurities of Fe and Ti in the host crystal as it cools after its formation (Hughes, 1997, pp. 93–94), forming microscopic needles and plate(let)s. The network of hematite-ilmenite inclusions in these sapphires is responsible for the asterism as well as the golden sheen.

As demonstrated above and verified through optical microscopy, the colour zoning in the sapphires is a consequence of the presence of hematite-ilmenite inclusions grouped into bands parallel to the second-order hexagonal prism {11$\bar{2}$0}. The resulting mechanical colour zoning is therefore linked to exsolution of these particles and also is epigenetic.

The dark-appearing veins following fractures in the Gold Sheen sapphires appear to have formed after the exsolution of Fe-Ti oxides. The exsolved inclusion particles evidently were not stable adjacent to (and on one side of) the fractures.

The presence of the long parallel white needles, identified as diaspore and boehmite, is correlated to the polysynthetic twin planes oriented in rhombohedral {10$\bar{1}$1} directions in the sapphire. In the literature, such inclusions are generally described as boehmite rather than diaspore (White, 1979; Hänni, 1987). Both diaspore and boehmite polymorphs of AlO(OH) were identified in our Raman spectra. They formed by the alteration of corundum at the intersections of two twin planes. Polysynthetic twin planes in corundum are created by mechanical stress after crystallization and are also known as slip twins (Hughes, 1997, p. 97). The angle of 58° between these twin planes and the basal pinacoid and 32° between the twin planes and the c-axis is consistent with the {10$\bar{1}$1} faces of the rhombohedral corundum.

Fe-Ti Oxide Inclusions in Other Gemstones

Plate-like inclusions of hematite and/or ilmenite also exist in other gem minerals. Their highly reflective surfaces produce optical effects such as aventurescence in oligoclase, often called *sunstone* (Gübelin and Koivula, 1986, pp. 165, 279; 2005, pp. 126, 413–415), and in cordierite (Gübelin and Koivula, 1986, pp. 163–164, 269; 2008, pp. 520–521). As in the Gold Sheen sapphires, the plate-like inclusions are parallel to the basal pinacoid. The cutting of the stones is such that the plates are oriented parallel to the girdle profile to highlight the optical effect. The abundance of the inclusions in the host also contributes to the body colour of the stones.

The aventurescence effect produces a kind of iridescence under oblique illumination, inducing various colours due to thin-film interference from the very thin plate-like inclusions. In oligoclase, beryl and cordierite, the inclusions are eye-visible, whereas in the Gold Sheen sapphires they are distinguishable

only with magnification. In the gems displaying aventurescence, the tiny reflective inclusions produce minute sparkles when the stone or the light source is moved. Gold Sheen sapphires display a golden shimmering effect originating from the specular reflections of light from the hematite-ilmenite inclusions. Instead of metallic single glitters, the microscopic network of oriented inclusions reflects light simultaneously, defining the golden sheen area. The smaller dimensions of the inclusions (below 100 µm) and their high concentration in the Gold Sheen sapphires account for the different appearances of the golden sheen and the aventurescence.

Comparison with Black Star Sapphires

Most cabochons of Gold Sheen sapphire display six-rayed asterism, similar to other star corundum. The presence of the asterism is dependent on the presence of oriented networks of hematite-ilmenite needles rather than platelets, and the sharpness of the star is determined by the aspect ratio of those needles. Since the hematite-ilmenite needles are perpendicular to the colour zoning, each ray of the star is, as a result, parallel to the colour zoning and to the second-order hexagonal prism $\{11\bar{2}0\}$. This optical characteristic is the same as that displayed by black star sapphires (Moon and Phillips, 1984; Hughes, 1997, p. 446). Those from Thailand, Australia and Laos are known to have inclusions caused by exsolution of hematite and ilmenite (Hughes, 1997, pp. 297, 380, 447).

In black 12-rayed star sapphires from Thailand, a less intense white six-rayed star is perpendicularly superimposed over a yellow/golden six-rayed star that originates from long, thin rutile needles aligned along the first-order hexagonal prism $\{10\bar{1}0\}$ (Hughes, 1997, p. 447). In our samples of Gold Sheen sapphire, no rutile needles perpendicular to the hematite-ilmenite needles were found by optical microscopy, and so far we have not encountered any 12-rayed stars in these cabochons.

Due to the high concentration of hematite-ilmenite inclusions in black star sapphires, some of these gems show basal parting on their flat base, characterized by a step-like appearance. Fractures due to this basal parting may be filled by residue from the dopping process during cutting (Hughes, 1997, pp. 125, 447). In Gold Sheen sapphires, no basal parting was seen in any of the cabochons. In a few faceted samples showing basal parting, the stones were completely opaque due to the high concentration of inclusions. As most Gold Sheen sapphires are translucent and not opaque, basal parting is not common.

Geological Inferences

Little information is available on the Gold Sheen sapphire deposit. According to the mine owner, it is located in eastern Kenya, near the border with Somalia. This area belongs to Kenya's North Eastern Province and has a low relief with an elevation less than 500 m. The climate is semi-arid, with desert scrub vegetation being most common. The geology of north-east and eastern Kenya is characterized by Mesozoic (Karoo) and Quaternary sedimentary rocks. The former includes Jurassic limestone, shale and gypsum, as well as Cretaceous siltstone, mudstone, limestone and sandstone. The Quaternary sediments are composed of lacustrine and fluvial deposits and gypsum. This entire region of East Africa is located on the Somali Plate, adjacent to the East African Rift and the Nubian Plate. Linear trends in the sedimentary rocks are orientated in relation to the Kenyan Dome (Mathu and Davies, 1996).

Kenya's previously known gem corundum deposits include the John Saul ruby mine located in Mangari (far south) and various other ruby and sapphire localities in the Mangari area, and the Turkana area in the north-western part of the country (Hughes, 1997, pp. 374–379; Shor and Weldon, 2009). To our knowledge, no corundum deposits have been reported in areas near Somalia.

The blue, green and yellow body colours of Gold Sheen sapphires are typical of magmatic-type corundum. Other magmatic deposits containing corundum with similar exsolved inclusions of Fe-Ti oxides are known from Australia (Anakie), Laos (Ban Huai Sai) and Thailand (Chanthaburi). The gemmological properties of black star sapphires from Australia and Thailand most closely resemble those of the Gold Sheen sapphire, including the high Fe content, lack of UV fluorescence, healed fractures and polysynthetic twinning. As there are no volcanic source rocks in the reported mining area for the Gold Sheen sapphires, their geological origin remains enigmatic.

Figure 15: Gold Sheen sapphires may create bold expressions in jewellery. The cabochon in this gold-plated silver pendant weighs 40–50 ct. Photo by T. K. Malik.

Conclusion

This article investigates the recently discovered Gold Sheen sapphires from East Africa, focusing on their peculiar golden sheen effect (e.g. Figure 15). Optical microscopy verified that the sheen is due to the reflection of light from an oriented network of exsolved needles and platelets of Fe-Ti oxides (hematite and ilmenite). The oriented needles also cause asterism (i.e. a six-rayed star) to be seen in cabochons cut from this sapphire.

Black star sapphires may contain similar oriented assemblages of exsolved Fe-Ti oxides. The main difference is the absence of rutile needles from the Gold Sheen sapphires, which explains the lack of 12-rayed asterism. Despite the presence of similar hematite-ilmenite inclusions in both types of sapphire, the large difference in their appearances suggests the need for further investigations into their optical phenomena.

An already-exhausted mine is the only known source of the Gold Sheen sapphires. Cutting of the existing stock of rough material is expected to fulfil market demand for the near future.

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Age Determination of Zircon Inclusions in Faceted Sapphires

Klemens Link

The age determination of zircon inclusions in faceted sapphires by LA-ICP-MS may provide a valuable tool to support geographical origin determination. In this initial study, U-Pb dating of a zircon inclusion in a pink sapphire from Madagascar yielded an age of 650 million years (Ma), suggesting a syngenetic origin (i.e. formed at the same time as the host sapphire) of the zircon. In a greenish blue sapphire from Madagascar, an included zircon yielded a U-Pb age of 1,750 Ma, pre-dating the host sapphire, and therefore indicating the zircon is an inherited inclusion (i.e. it originated from rocks that existed before the host sapphire crystallized). These results are supported by indications provided from conventional methods of geographical origin determination. This article also discusses the potential influence on U-Pb age dating of post-formation metamorphic events, laboratory heat treatment and the possibility of complex zoning in the zircon inclusions.

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Introduction

Laser ablation–inductively coupled plasma–mass spectrometry (LA-ICP-MS) has become an established tool in the past decade for use by prominent well-equipped gemmological laboratories (Breeding et al., 2010). Standard routines have been developed to measure trace-element concentrations in various gem materials to detect treatments and/or determine a stone's geographical origin (e.g. Günther and Kane, 1999; Guillong and Günther, 2001; Abduriyim and Kitawaki, 2006). The geographical origin of high-end coloured stones is seen by the trade as a key value driver, and has developed into one of the main tasks for gem-testing laboratories. Initially LA-ICP-MS was mainly applied to research samples, but with increasing experience and confidence, as well as improved instrumentation, this technique is now routinely used for analysing client-submitted stones. The biggest challenge and the highest priority are to gain meaningful data without damaging or affecting the quality of the stone (i.e. to work quasi-non-destructively).

LA-ICP-MS is a well-established and frequently used method in the geosciences for measuring *in situ* uranium-lead (U-Pb) ages of zircon (e.g. Jackson et al., 2004). Microscopic crystals or grains of zircon can be dated regardless of their host matrix, provided that they reach the surface of the stone and thus can be sampled by the instrument's laser beam.

Zircon inclusions in rough gem-quality corundum have been investigated by numerous researchers using LA-ICP-MS (e.g. Coenraads

Figure 1: These Sri Lanka and Madagascar sapphires are typical candidates for hosting zircon inclusions that could be used for age determination to better characterize their origins. The stones range between 1.4 and 29.7 ct, and are unheated with the exception of the yellow sapphire on the left. Photo by K. Link.

et al., 1990; Sutherland et al., 2008; 2015), and recently the technique was used to perform U-Pb age dating of blue sapphires from Myanmar, Madagascar and Sri Lanka that were sawn and polished to expose zircon inclusions on their surface (Elmaleh et al., 2015). However, determining the age of zircon inclusions in high-quality faceted gemstones such as those commonly submitted to gem labs (e.g. Figure 1) has not been reported until now. Since July 2015, this procedure has been routinely applied to client stones at the Gübelin Gem Lab (GGL) when zircon inclusions are exposed on the surface and age data is particularly helpful for origin determination (e.g. for separating some blue sapphires from Myanmar and Madagascar). It can also provide indications of heat treatment.

Age data for zircon inclusions in sapphires can shed light on the genetic conditions under which the sapphire formed, as well as point to the original host rocks. The latter is particularly important for sedimentary deposits without any connection to their primary host rocks, such as the economically important Ilakaka mining region in south-western Madagascar (Rakotondrazafy et al., 2008).

Materials and Methods

The samples comprised two faceted fancy-colour sapphires (pink and greenish blue; see Figure 2), each weighing ~12 ct, that were submitted to the Gübelin Gem Lab in Lucerne by professional gem traders. Both samples contained zircon inclusions that reached the surface at the girdles, and routine origin determination procedures performed in our laboratory clearly indicated that both stones were from metamorphic-type deposits in Madagascar. The pink sapphire had clusters of small, colourless, rounded anhedral zircon that each measured a maximum 60 µm long and 30 µm wide (Figure 3a). Although heat treatment at relatively low temperatures could not be excluded, the stone clearly had not been exposed to high-temperature heating. The greenish blue sapphire, which was found to be untreated, contained randomly scattered zircon inclusions with subhedral elongated shapes (e.g. Figure 3b,c). The investigated zircon crystal in the greenish blue sapphire was ~90 µm long and 35 µm wide.

To avoid leaving eye-visible traces from LA-ICP-MS analysis, client stones are typically sampled

Figure 2: These pink and greenish blue sapphires (each ~12 ct) were submitted to the Gübelin Gem Lab in 2015. Both sapphires had surface-reaching zircon inclusions on their girdles, so age determination could be conducted. Photos by Janine Meyer, GGL.

Figure 3: (a) In this cluster of zircon inclusions within the pink sapphire, the surface-reaching zircons that were analysed for age determination are circled. (b) Internal features in the greenish blue sapphire consist of isolated zircon crystals (top-centre and top-right), among other inclusions. (c) This zircon inclusion in the greenish blue sapphire was used for in situ *age determination; the circle marks the position and size of the applied laser pit. Photomicrographs (a) and (c) by Klaus Schollenbruch, GGL; (b) is courtesy of Bulgari, image width ~2 mm.*

with the laser only on their girdle (with some exceptions). The pit diameter must not exceed 50–70 µm, and the depth of the pit usually does not exceed its diameter. The resulting pits are not eye visible and have no significant effect on the weight of the stone.

For the U-Pb age dating of zircon inclusions in sapphires, to avoid sampling the corundum host, the LA-ICP-MS signal is carefully controlled for any sudden change in indicative elements such as Si or Zr. Although corundum usually does not contain significant U or Pb, and slightly ablating the host sapphire therefore should not disturb the results, we are sure to avoid any such possible contamination. For both samples described here, the spot diameter of the laser was limited to 30 µm by the size of the outcropping zircon inclusions (Figure 3), and this limited the depth of the pits to ~30 µm as well. The weight loss of the samples after analysis was calculated to be only approximately 0.000004 ct.

The analytical conditions used for this study are listed in Table I. The LA-ICP-MS system at the Gübelin Gem Lab consists of an ESI NWR193^{UC} ArF excimer-based UV laser ablation system with a large-format sample chamber and a flexible cup that collects the ablated material, which is coupled with a PerkinElmer ELAN DRC-e quadrupole ICP mass spectrometer (Figure 4). The laser has a wavelength of 193 nm, which allows precise ablation at the micrometre scale without cracking or splintering the sample. The ablated

Table I: LA-ICP-MS analytical parameters.

Laser	**NWR193^{UC} from ESI**
System	193 nm ArF excimer laser
Sample cell	High-performance two-volume chamber system
Sample carrier gas	1,000 ml/min He
Laser pulse rate	14 Hz
Laser energy	6.3 J/cm^2
ICP-MS	**PerkinElmer ELAN DRC-e quadrupole ICP-MS**
Auxiliary gas	0.66 l/min Ar
Nebulizer gas	0.675 l/min Ar
Plasma gas	16.5 l/min Ar
RF power	1,350 W

Figure 4: The instrumentation at the Gübelin Gem Lab used for this study consists of an ICP-MS (left side) and a laser ablation unit (right side). Photo by K. Link.

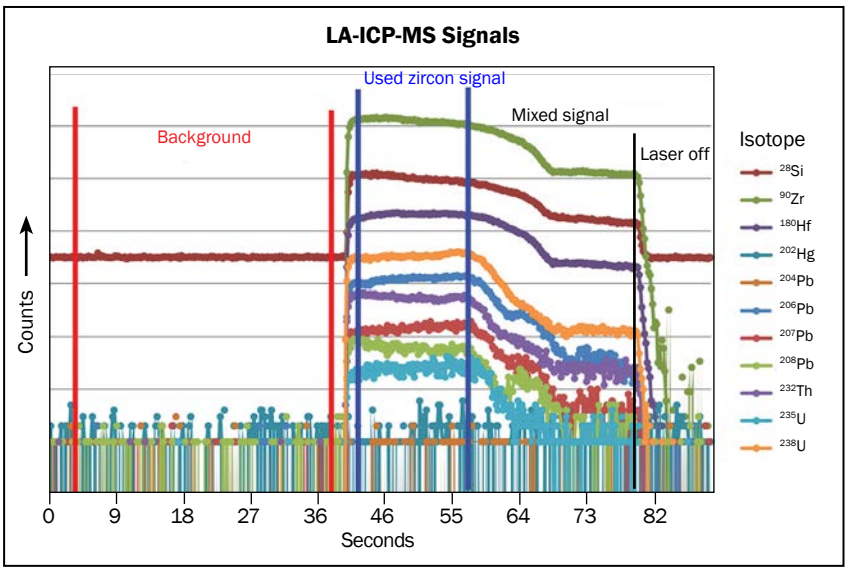

Figure 5: This diagram shows the raw signals for various isotopes obtained during the ablation of the zircon inclusion in the greenish blue sapphire. The portions used for data reduction are marked in red and blue.

material is transported in a flow of He carrier gas to the Ar plasma of the mass spectrometer. Within the plasma, the 60–150 nm-sized particles are disintegrated at ~7,000°C into ions that are selectively detected by the mass spectrometer.

The optimal laser conditions were found by monitoring the U-Pb ratios and searching for the minimum deviation to reduce the errors in age calculations. The dwell times for individual mass scans were 10 milliseconds for all measured isotopes (^{28}Si, ^{90}Zr, ^{180}Hf, ^{202}Hg, ^{204}Pb, ^{206}Pb, ^{207}Pb, ^{208}Pb, ^{232}Th, ^{235}U and ^{238}U). The background was analysed for 40 seconds, and the ablation signal from the zircon was measured until it became unstable after around 15 seconds (Figure 5). Only the area of the signal showing a flat plateau was used for integration. A Plesovice zircon (Sláma et al., 2008) was used for standardization; a GJ zircon (Jackson et al., 2004) and an in-house reference zircon were used for quality control.

For age determination (see Box A and Table II), ^{207}Pb/^{235}U ratios were calculated from the measured ^{206}Pb/^{238}U and ^{207}Pb/^{206}Pb ratios using a constant value for present-day ^{235}U/^{238}U. The ICP-MS was optimized on a daily basis for a maximum sensitivity to heavy elements with minimum (<0.5%) oxide generation (monitored using Th/ThO). Data reduction and the time-dependent laser- and mass spectrometer-induced inter-element mass fractionation (Pb/U) corrections were applied using in-house Microsoft Excel worksheets. Ages, errors (2σ) and concordia diagrams were produced using Isoplot3 macros for Excel (Ludwig, 2003).

Common lead was monitored via non-radiogenic ^{204}Pb, and ^{202}Hg was checked to estimate the interference of ^{204}Hg on ^{204}Pb. For both samples, ^{204}Pb was below the detection limit, so we assumed that no common lead was present.

Results and Discussion

The results of U-Pb age dating of the zircon inclusions are presented in Table II and shown in Figure 6.

Pink Sapphire

The analysed zircon from the inclusion clusters in the pink sapphire yielded a concordant U-Pb age of 652 ± 41 Ma (Figure 6a). From the appearance of the zircon inclusions, they are interpreted as syngenetic with the host sapphire, and are considered to be in equilibrium with the corundum. Thus, the age we obtained should correspond to the formational age of this sapphire. The crystallization ages of the sapphires from Madagascar are not yet well known, but published work (e.g. Rakotondrazafy et al., 2008, and references therein) indicates ages around 560 Ma. Associated granulite- and amphibolite-facies rocks and linked felsic intrusives cluster between 560 and 650 Ma (Kröner et al., 1999). The basement rocks of Madagascar were affected by the Pan-African tectono-metamorphic event (730–550 Ma; Black and Liegeois, 1993), which extended across a broad region that included other sapphire-bearing areas such as East Africa

Box A: Zircon Geochronology

Zircon ($ZrSiO_4$) is a mineral of great benefit for geochronologists. It occurs in nearly all rock types and is very resistant to physical abrasion as well as thermal alteration. In addition, zircon has no or only limited susceptibility to chemical diffusion with its environment under most conditions in the earth's crust. The zirconium cations (Zr^{4+}) in the crystal lattice have an ionic radius that is only about 15% less than uranium ions (U^{4+}), so uranium is somewhat compatible in zircon and can be incorporated up to a few hundred parts per million. Lead cations (Pb^{2+}) are around 50% larger, so that they are far too big for zircon's crystal structure and therefore highly incompatible. Any Pb that may have been incorporated during zircon formation is ideally below the detection limit of LA-ICP-MS.

Starting at the time the zircon is formed, U isotopes undergo radioactive decay to form Pb daughter isotopes ($^{235}U \rightarrow {}^{207}Pb$ and $^{238}U \rightarrow {}^{206}Pb$) according to their decay constants. Measuring the radiogenic Pb allows one to precisely calculate the formation age of the zircon. The two measurable radioactive U isotopes provide two independent radioactive systems ('clocks'). This gives valuable information for determining the plausibility of the calculated ages. If both systems yield the same ages within their errors, the age can be considered as robust or concordant (i.e. it can be assumed that the isotopic system was not disturbed by any chemical or physical process after zircon formation). A good way to visualize and validate U-Pb ages is with a *concordia* diagram, as introduced by Wetherill (1956; see Figure 6 in the text of this article). The concordia diagram plots the isotopic ratios of the two radioactive systems $^{206}Pb/^{238}U$ versus $^{207}Pb/^{235}U$. All possible concordant ages plot along a concordia curve in the centre of the plot. Samples with older ages (higher radiogenic lead and lower radioactive uranium, leading to higher Pb/U ratios) plot further to the top and right on the curve, and younger samples plot toward the bottom left. The different decay constants for the two radioactive systems cause the curved shape. The age including the errors (typically 2σ) is presented as an ellipse in the diagram. The ratios and the sizes of the individual errors define the form, size and orientation of the ellipse. Disturbances of the isotopic system in the zircon corresponding to episodic or continuous Pb diffusion out of the system will cause a sample to plot on a straight *discordia* line. Such values plot below the concordia curve, between the original formational age of the zircon and a younger age-disturbing event.

Using the ratio in the decay constants between ^{238}U and ^{235}U, and assuming that a zircon did not incorporate any common lead during its formation, it is possible to combine the two isotopic U-Pb systems by simply taking the ratio of the two daughter isotopes $^{207}Pb/^{206}Pb$, as this ratio is only a function of time. The Pb-Pb ages can be quite useful since they do not depend on measuring the ratios of two different elements (U and Pb). Besides requiring fewer fractionation corrections, this method allows one to validate the concordance of U-Pb ages and to obtain ages even for disturbed systems, as such processes would affect only the element ratios (U/Pb) and not the isotopic ratios (Pb/Pb). The Pb-Pb ages are particularly important for very old time scales. For extra assurance, Pb-Pb ages are commonly considered minimum ages.

and Sri Lanka, and led to the formation of the so-called Mozambique Belt. More research is needed on Madagascar and other Pan-African-related sapphire age populations before using them as hard criteria for origin determination.

Greenish Blue Sapphire

The zircon analysed in the greenish blue sapphire gave a concordant age of 1,742 ± 70 Ma (Figure 6b). The individual ages given in Table II for the various isotopic pairs ($^{207}Pb/^{235}U$, $^{206}Pb/^{238}U$

Table II: Geochronological results for zircon inclusions in the two sapphires.

Data	$^{207}Pb/^{235}U$	± 1σ	$^{206}Pb/^{238}U$	± 1σ	$^{207}Pb/^{206}Pb$	± 1σ	roh[a]
Pink sapphire	0.9003	0.045	0.1064	0.0056	0.0617	0.0019	0.94
Greenish blue sapphire	4.5779	0.212	0.3144	0.0202	0.1074	0.0051	0.72
Age (Ma)	$^{207}Pb/^{235}U$	± 2σ	$^{206}Pb/^{238}U$	± 2σ	$^{207}Pb/^{206}Pb$	± 2σ	prob[a]
Pink sapphire	651	32	651	34	663	20	0.99
Greenish blue sapphire	1745	80	1762	112	1755	86	0.82

[a] Abbreviations: roh = error correlation between $^{207}Pb/^{235}U$ and $^{206}Pb/^{238}U$ ratios; prob = probability of concordance (taken from Isoplot).

and $^{207}Pb/^{206}Pb$) show a slightly greater variance than those from the pink sapphire, but within their errors they provide good matches with the integrated concordia age, and correspond to an 82% probability of concordance. The reasons for the slightly varying individual ages may be related to post-formation diffusion processes, elemental zoning (see below), or slight differences in the accuracy or precision of measuring the various isotopes.

The ~1,740 Ma age does not coincide with the assumed Pan-African-associated formation of this Madagascar sapphire. Hence, this subhedral zircon is more complicated to interpret (see below).

Influence of Post-Formation Metamorphism on Zircon

Once a zircon has crystallized, very high pressure-temperature conditions are required to destroy it (Watson, 1996). The closure temperature of zircon, which is above 900°C at most geologically relevant time scales (Cherniak and Watson, 2003), marks the condition at which diffusion becomes sufficient to exchange U and/or Pb, and therefore disturb the U-Pb system and thus the age determination. In most cases, temperatures during metamorphism are less than 1,000°C (i.e. combined with high pressures, as with upper granulite facies conditions). Since the Pb content of zircon is preserved through all but the most extreme conditions of metamorphism, its original formation age is usually not disturbed by such events (Watson, 1996). However, depending on the duration of a high-temperature metamorphic event, there may be a severe impact on the zircon (Blackburn et al., 2011). Uranium is rather compatible in the zircon structure, whereas Pb is not (Cherniak and Watson, 2003). Increasing temperatures drive recrystallization processes as well as diffusion rates (Nasdala et al., 2001). This leads to enhanced Pb diffusion toward the outer rim or completely out of the zircon. The loss of

Figure 6: Concordia plots made with Isoplot software (Ludwig, 2003) are shown for the zircon inclusions in the pink sapphire (a) and the greenish blue sapphire (b).

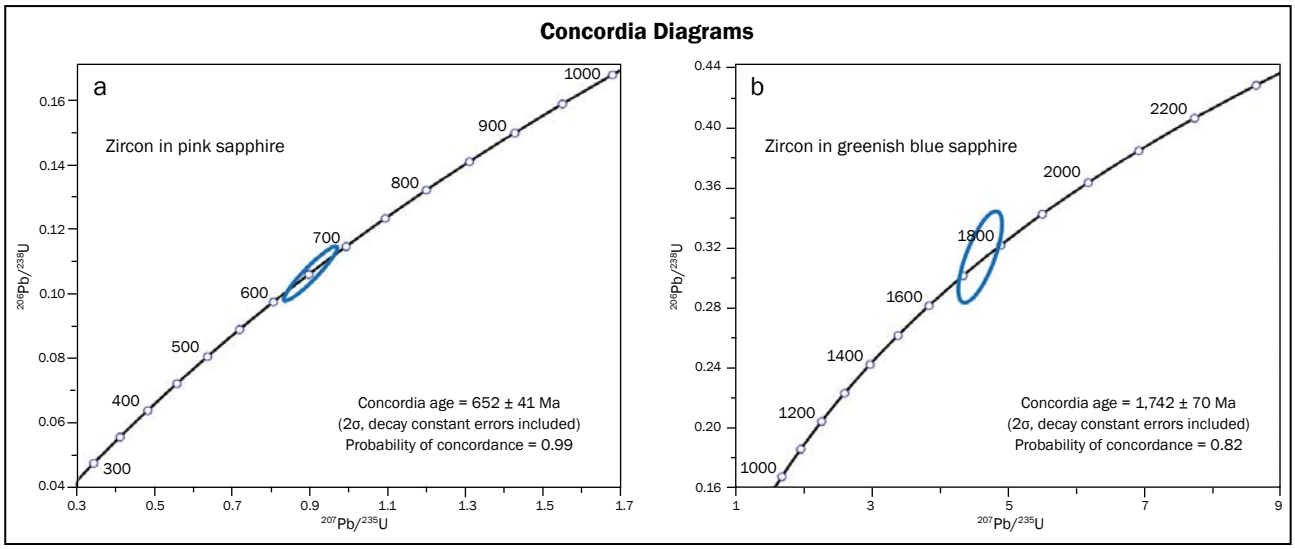

(radiogenic) Pb changes the U/Pb ratio and resets the 'radiogenic clock'. This may be visualized in a concordia diagram (described in Box A), in which the so-called concordia line in the centre of the plot shows the U-Pb ratios for undisturbed, 'closed' systems where all the Pb originates from U decay. Disturbed U-Pb ratios result in combined ratios lying below the concordia on a line called the discordia which leads toward younger ages. In an ideal case, the discordia points to the age of the event that 'opened' the U-Pb system (Dickin, 2005). If the measured U-Pb data plot nicely on the concordia, it can be assumed that the U/Pb ratios were undisturbed by later events such as metamorphism.

Rocks affected by the Pan-African event were tectonically overprinted under amphibolite- to granulite-facies pressure/temperature conditions. Nevertheless, old inherited zircons that preserve the age of the rocks before the intense deformation are well known in the literature (e.g. Kröner et al., 1999). The 1,742 Ma age we obtained for the zircon inclusion in the greenish blue sapphire coincides with the age of zircons possibly derived from granulites found, for example, in southern Madagascar (Kröner et al., 1999). These granulites are interpreted to have formed at 1,740 Ma and to have been later tectonically overprinted during the Pan-African event. The somewhat rounded, resorbed-appearing morphology of the zircon inclusions in this sapphire supports an inherited (protogenetic) origin for these crystals (cf. Corfu et al., 2003). If this is correct, then these zircon inclusions must have been derived from the host rock and trapped in the corundum during its crystallization. Although proving such a scenario is beyond the scope of this article, it does fit well with the Madagascar origin of this sapphire. This is further supported by zircon inclusions in sapphires from Madagascar that have been previously described as ranging around 1,500 Ma (Elmaleh et al., 2015). In addition, the author is not aware of a similar published age for the other potential areas of origin such as Sri Lanka and East Africa.

Potential Effect of Heat Treatment

It is well known that sapphires are commonly heat treated to enhance their appearance. What is the effect of heat treatment on the calculated U-Pb age of their zircon inclusions?

Previous experiments indicate that sapphire heat treatment has an effect on the crystallinity of zircon inclusions—depending on temperature and time—although the extent of this effect is a matter for debate (Nasdala et al., 2001; Wang et al., 2006). Furthermore, it is not clear if or to what extent Pb loss in a diffusive process is measurable for these heated stones. Zircon heating experiments have been done to investigate the amount of Pb loss due to diffusion. Cherniak and Watson (2003) claimed that below 1,200°C, the time to reach 1% Pb loss in an effective 10 µm zone exceeds one year. More relevant is the temperature range between 1,200°C and 1,450°C. At these temperatures, measurable Pb loss can be assumed for heating periods of less than one day (Cherniak and Watson, 2003). Also, the diffusion rate may increase due to strong radiation damage in metamict zircon. Above 1,400°C, zircon ($ZrSiO_4$) becomes unstable and partially melts to form baddeleyite (ZrO_2) and silicate-rich phases (Wang et al., 2006; Váczi et al., 2009). More experiments in the range of 1,200–1,400°C are required to better quantify the diffusive effect on Pb in zircon.

Therefore, sapphire heat treatment may to some extent lead to Pb loss from zircon inclusions. As this does not consider the lifetime of the various U-Pb decay systems, the decay loss must result in an effect similar to natural Pb loss from high-temperature metamorphism. Thus the U-Pb ages of zircon inclusions in heated sapphires would be expected to plot beneath the concordia curve and follow linear trends towards younger ages. Conversely, this implies that concordant-plotting zircons most probably were not exposed to high-temperature heat treatment. U-Pb data that plot discordantly could be the result of exposure to either intense laboratory heat treatment or natural high-temperature metamorphism. Even apparently concordant-plotting zircons may to a minor extent be affected by Pb loss (their error ellipses plot on the concordia line, but the true ages within the ellipses can be slightly discordant). In such cases, the calculated ages represent minimum ages.

With a calculated probability of concordance of 99% (Table II), the zircon in the pink sapphire clearly yielded a concordant age. The age obtained from the zircon in the greenish blue sapphire was 82% concordant, so despite the

high level of confidence there is some possibility of slight discordance. As heat treatment of that sapphire could be excluded, this may be due to tectono-metamorphic events that the zircon was exposed to after its formation and before being trapped in the sapphire.

Highly Zoned Zircons

A potential complication for age dating could be caused by complexly zoned zircons, in which the varying zones represent different times of formation. If the zones with different ages are smaller than the spatial resolution of the laser spot, then mixed ages would result. In the concordia diagram, such results may plot similarly to zircons that have experienced Pb loss. In some cases, different growth zones might be indicated by sudden trace-element concentration changes in the mass spectrum during ablation. If available, cathodoluminescence (CL) imaging is the most powerful tool to identify these zones. The minimum spot size of the LA-ICP-MS instrument (and ion probes such as SIMS or SHRIMP) is around 10–15 µm in diameter, depending on the amount of U and Pb in the zircons, thus dictating the minimum homogeneous zone in a zircon that is required for a 'good' age determination. The zircon inclusions analysed for this article showed no evidence of multiphase mineral formation (i.e. there were no sudden variations in trace-element composition during the analyses).

Conclusions

LA-ICP-MS is effective for determining the age of zircon inclusions, even in valuable faceted stones, without damaging the host sapphire. The limiting conditions are the technical capabilities of the analytical devices on one hand and the characteristics of the zircon inclusions on the other (i.e. the sapphire must contain surface-reaching zircons, preferably on the girdle, that are large enough to analyse and lack fine-scale chemical zoning). The dating methods are applicable to any gemmological laboratory operating a LA-ICP-MS. Age data for zircon inclusions in sapphires provides useful information for origin determination, and can in some cases indicate the crystallization age of the host sapphire. Zircon ages that far exceed the inferred age of the surrounding sapphire can also provide valuable information. Depending on the error ranges, it may be more dependable to consider the data as minimum ages rather than the exact time of formation. This especially applies to those stones where heat treatment cannot be excluded. Although a discordant U-Pb age may be the consequence of a high-temperature (i.e. >1,200°C) heat treatment that was applied for a relatively long period, such discordance might also indicate that a high-grade metamorphic overprint caused loss of Pb and possibly U, or even point to a mixed age from sampling a complexly zoned zircon inclusion.

Although the routine age determination of zircon inclusions in sapphire is not yet frequently accomplished in gemmological laboratories, it is expected that this procedure will become more common in the future as LA-ICP-MS instrumentation becomes more available and better constraints are obtained on the ages of sapphires and their host rocks. It may even become an additional service requested by clients in addition to origin determination.

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Identification of a CVD Synthetic Diamond with a 'Tree Ring' Growth Pattern

Yan Lan, Rong Liang, Taijin Lu, Yong Zhu, Tianyang Zhang, Xuan Wang, Jian Zhang, Hong Ma and Zhonghua Song

The identification of CVD synthetic diamonds has become a challenge for the gem industry. Recently, a faceted 0.61 ct CVD synthetic diamond (VVS_2 clarity and L colour) was submitted to NGTC's Shenzhen Laboratory without disclosure. A bluish green fluorescence pattern similar to the 'tree ring' growth features seen in natural diamonds was observed in the table of the sample with the DiamondView. X-ray topography and Laue diffraction revealed that the crystallographic orientation of the table facet was inclined approximately 20° to the {111} octahedral plane, rather than being oriented in the typical {100} cubic direction. The appearance of this growth pattern could cause confusion, and vigilance is needed to assess the observed pattern in combination with the luminescence colour in differentiating between CVD synthetic and natural diamond. The X-ray topograph and Si-related photoluminescence (PL) doublet at 737.6/737.9 nm clearly indicate a CVD synthetic origin for this sample. The presence of PL peaks at 415 nm (N3) and 503.2 nm (H3), as well as mid-IR absorption at 3107 cm^{-1}, indicate that the sample underwent post-growth high-temperature, high-pressure (HPHT) treatment.

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Introduction

During the last few decades, a considerable number of gem-quality synthetic diamonds produced by chemical vapour deposition (CVD) have entered the market. Most of them have reportedly come from Apollo Diamond Inc., Gemesis Corp. and others (Wang et al., 2003, 2007b, 2012; Martineau et al., 2004; Wang and Moses, 2011). In 2003, the Gemological Institute of America (GIA) laboratory described a near-colourless gem-quality CVD synthetic diamond grown by Apollo Diamond (Wang et al., 2003). Subsequently, Wang et al. (2007b, 2010) reported on colourless, brown and orange-pink gem-quality CVD-grown synthetics from Apollo Diamond. Martineau et al. (2004) presented analytical results from the Diamond Trading Co. (DTC) Research Centre on CVD synthetic

diamond samples grown for research purposes by Element Six; these included as-grown and HPHT-treated nitrogen-doped samples, as well as boron-doped and high-purity CVD synthetic diamonds. Gemesis Corp. announced plans to market CVD-grown synthetics in November 2010, and these were described by GIA in 2011 (Wang and Moses, 2011). Subsequently, Wang et al. (2012) reported additional gemmological and spectroscopic properties of Gemesis CVD synthetic diamonds.

In recent years, greater identification challenges for CVD synthetic diamonds have resulted from refinements in their growth and processing, which have yielded products that are very similar to natural diamond in appearance, with variable properties according to the added impurities or post-growth treatment. In the past few years, undisclosed CVD synthetic diamonds have been submitted to the International Gemological Institute, National Gemstone Testing Centre (NGTC), Tokyo Central Gem Laboratory and others (e.g. Song et al., 2012; Kitawaki et al., 2013, 2015).

NGTC has carried out significant research on CVD synthetic diamonds, and has developed effective identification protocols using ultraviolet-visible–near infrared (UV-Vis-NIR) and infrared absorption spectroscopy, the DiamondView instrument, PL spectroscopy, etc. Of these, DiamondView fluorescence imaging is one of the most useful identification methods, since it reveals the striations associated with the layered growth of CVD synthetics (Martineau et al., 2004; Wang et al., 2010). However, this article documents a 'tree ring' growth pattern seen with the DiamondView in the table of a faceted CVD synthetic diamond that is similar to patterns seen in some natural diamonds. The gemmological characteristics of this sample are presented, and the reason for the unusual appearance of its growth pattern is analysed using X-ray topography and Laue diffraction to determine the crystallographic orientation of the synthetic diamond relative to the table facet.

Materials and Methods

A 0.61 ct round brilliant (Figure 1) was submitted to NGTC's Shenzhen Laboratory for a grading report in February 2015. It was identified as a CVD synthetic diamond, and received a low colour grade (L) but showed good clarity (VVS_2). The following investigations were carried out at NGTC, except for X-ray topography and Laue diffraction, which were carried out at De Beers Technologies in Maidenhead.

Figure 1: This 0.61 ct CVD synthetic diamond was submitted to NGTC without disclosure. Photo by Y. Lan.

The sample's fluorescence and phosphorescence to UV radiation were observed using 254 nm (short-wave) and 365 nm (long-wave) 4-watt UV lamps, and also with the DiamondView deep-UV (<230 nm) imaging system.

Infrared absorption spectra were recorded in the mid-infrared range (6000–400 cm^{-1} and 2 cm^{-1} resolution) at room temperature, with a Nicolet 6700 Fourier-transform infrared (FTIR) spectrometer equipped with a KBr beam splitter. UV-Vis-NIR absorption spectra in the range of 230–1000 nm were collected with an Ocean Optics GEM-3000 Jewel Identifying Instrument at liquid-nitrogen temperature. The sample was also tested using the DTC DiamondSure and DiamondPLus instruments.

Photoluminescence spectra were acquired with four different laser excitations (325, 473, 532 and 785 nm) using a Renishaw InVia Raman confocal micro-spectrometer with the sample cooled to liquid-nitrogen temperature.

X-ray topography (Mo $K\alpha$ radiation, {533} reflection) using a Marconi GX20 rotating anode X-ray generator was done to visualize strain associated with dislocations that formed during the sample's growth. The crystallographic orientation of the

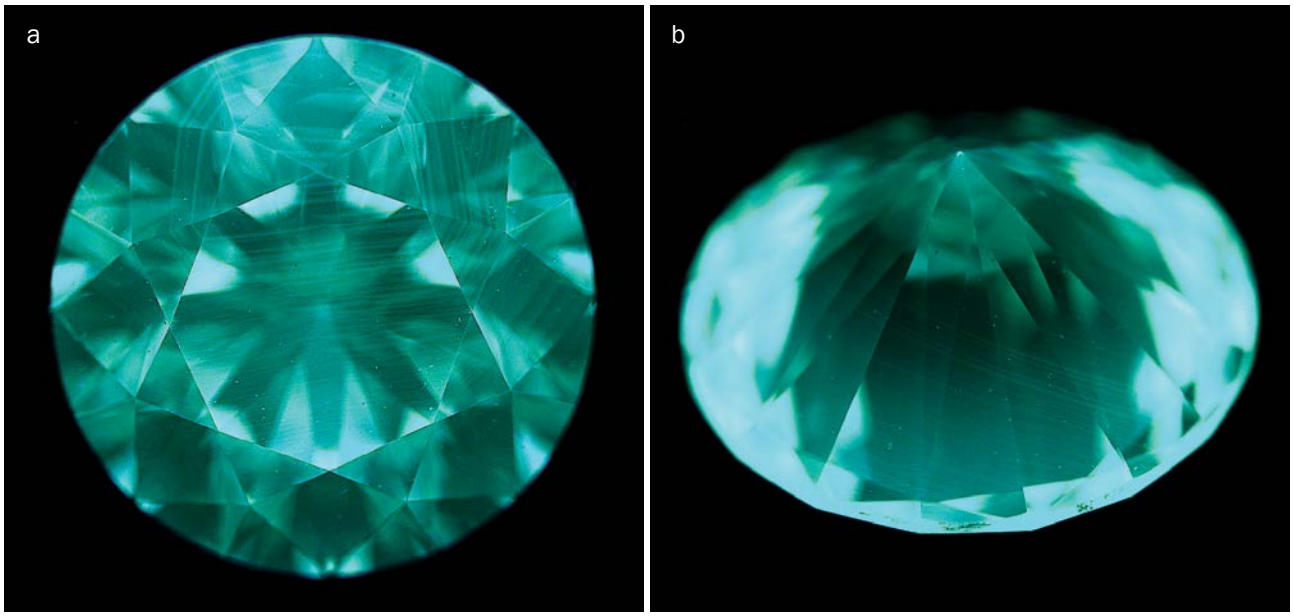

Figure 2: DiamondView images of the 0.61 ct CVD sample show bluish green UV fluorescence patterns with a 'tree ring' growth pattern seen in the table-up orientation (a) and a layered growth pattern viewed through the pavilion (b). Photos by Y. Lan.

table facet was determined by Laue diffraction, using a Bruker SMART 1000 CCD single-crystal diffractometer. Laue diffraction patterns are useful for revealing the crystallographic orientation of a faceted sample. Named after Max von Laue, such images provide a photographic record of the diffraction pattern that is produced when an X-ray beam passes through a crystal (Warren, 1969). The patterns show a regular array of spots on a photographic emulsion resulting from X-rays scattered by certain groups of parallel atomic planes within the crystal. Those X-rays oriented at just the proper angle to a group of atomic planes will combine in-phase to produce intense, regularly spaced spots on the film or plate that indicate the sample's crystallographic orientation relative to the X-ray beam.

Results

Luminescence

The sample was inert to long-wave UV radiation and showed moderate-to-strong green fluorescence to the short-wave UV lamp. No obvious phosphorescence was seen.

In the DiamondView, the sample displayed bluish green fluorescence with layered growth striations (Figure 2). Unlike previously reported CVD synthetic diamonds, when observed table-up the sample showed a 'tree ring' growth pattern, similar to that seen in some type I natural diamonds (Wang et al., 2007a; Sun et al., 2012; see Figure 2a). By contrast, when viewed from the pavilion the sample showed the characteristic parallel layers associated with the growth of CVD synthetic diamond (Figure 2b). As far as we are aware, the 'tree ring' pattern has not been previously reported in CVD synthetic diamond (cf. Martineau et al., 2004; Wang et al., 2007b).

Infrared and UV-Vis-NIR Absorption Spectroscopy

The absorption spectrum in the mid-infrared region (Figure 3) showed that the sample was type IIa, with very weak N-related absorption at 1344 cm^{-1}. Other features included H-related lines at 3107, 3029, 2919, 2880 and 2831 cm^{-1}, and weak bands at 1340, 1332, 1296 and 1128 cm^{-1}. Note that the weak line at 3107 cm^{-1} and the missing 3123 cm^{-1} line (a characteristic H-related feature in CVD synthetic diamond) provide strong evidence that the sample had been HPHT treated (Martineau et al., 2004).

The UV-Vis-NIR absorption spectrum revealed an N-related peak at 270 nm and decreasing absorbance from 300 to 700 nm (Figure 4). Neither the Si-V^--related peak at 737 nm (typical of some CVD synthetic diamonds: Martineau et al., 2004; Wang et al., 2012) nor the N3 absorption at 415 nm (common in natural diamond) were detected.

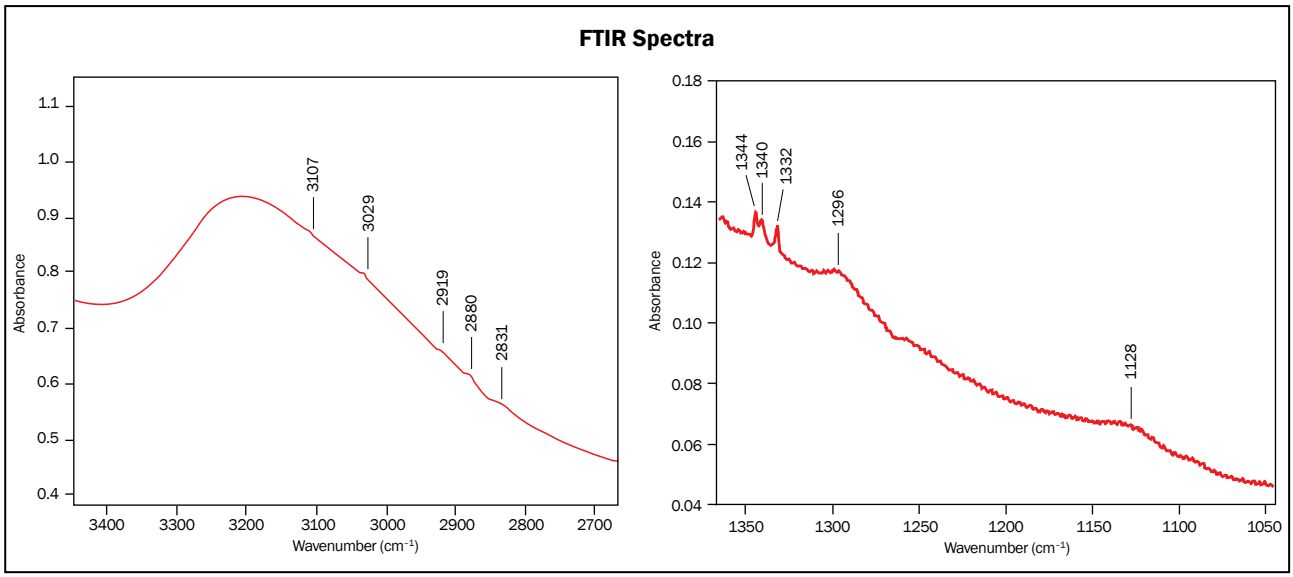

Figure 3: Infrared spectroscopy of the CVD synthetic diamond shows H-related lines at 3107 cm^{-1} etc. (left) and very weak N-related 1344 cm^{-1} absorption (right). The missing CVD-characteristic H-related absorption band at 3123 cm^{-1} reveals that the sample has been HPHT treated.

Verification Instruments

Testing with the DiamondSure resulted in 'refer for further test: type II', and the DiamondPLus indicated 'Refer CVD' from the PL measurement of the 737 nm Si-V$^-$ centre.

Photoluminescence Spectroscopy

325 nm Excitation: A weak PL peak at 415.1 nm was excited by the 325 nm laser (Figure 5). This peak is attributed to the N3 defect (three nitrogen atoms in a {111} plane associated with a vacancy: Davies, 1974; Davies et al., 1978), which usually occurs in cape diamonds. Nitrogen in CVD synthetic diamond is commonly present in the form of single nitrogen, but may be aggregated during HPHT treatment to produce the N3 defect, particularly after prolonged annealing at 2,200°C (Martineau et al., 2004). In addition, a series of weak PL peaks in the 388–503 nm range were detected.

Figure 4: The UV-Vis-NIR absorption spectrum of the CVD synthetic diamond shows a broad absorption band centred at ~270 nm attributed to isolated nitrogen.

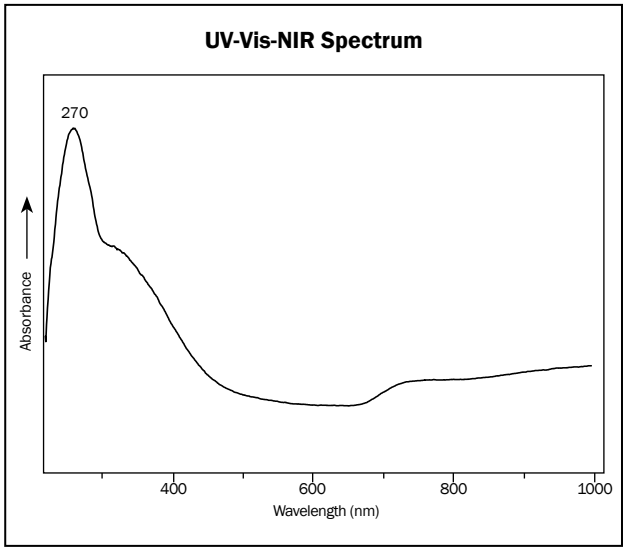

Figure 5: The PL spectrum of the CVD synthetic diamond sample excited by the 325 nm laser at liquid-nitrogen temperature shows a weak emission at 415.1 nm from the N3 optical centre.

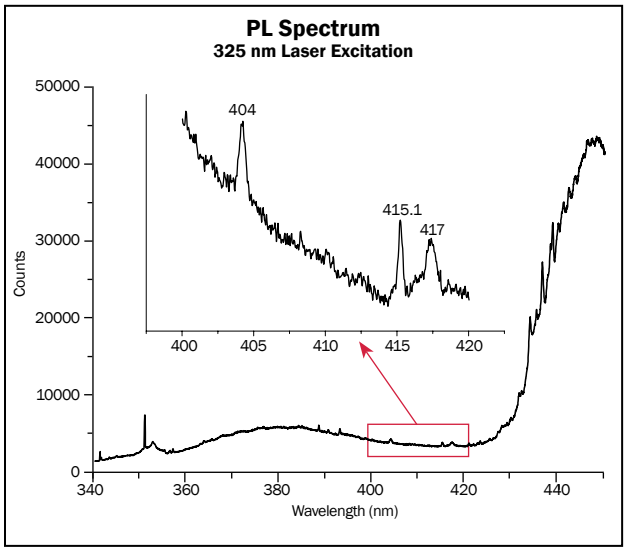

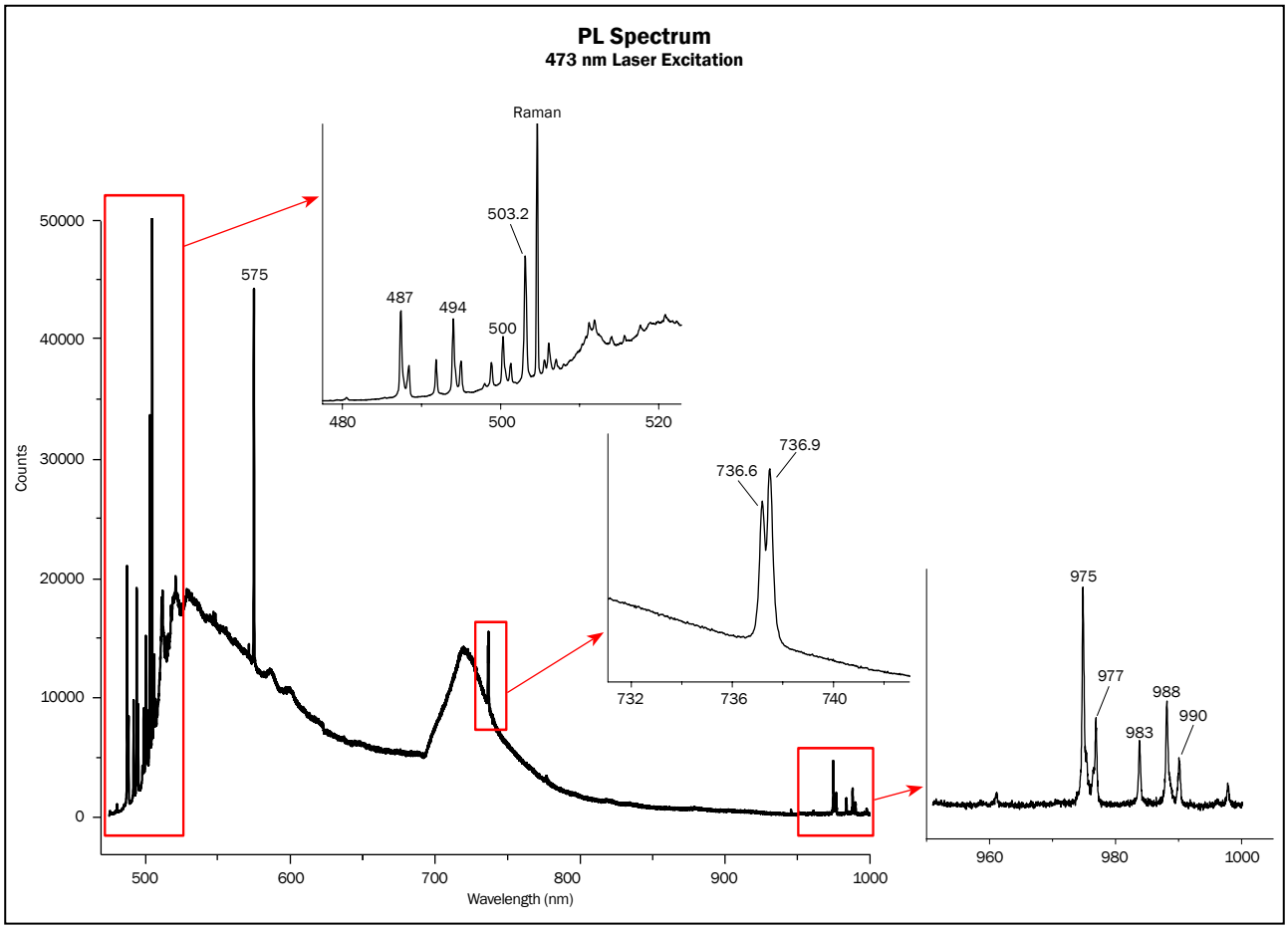

Figure 6: The PL spectrum of the CVD synthetic diamond sample collected with 473 nm laser excitation at liquid-nitrogen temperature shows emissions of H3 (503.2 nm), NV^0 (575 nm) and $Si\text{-}V^-$ (736.6/736.9 nm) centres. Also, numerous sharp peaks were recorded in the 480–520 nm and 960–1000 nm regions.

473 nm Excitation: The PL spectrum excited by the 473 nm (blue-green) laser is shown in Figure 6. The strongest zero-phonon-line (ZPL) emissions were at 575, 503.2 and 736.6/736.9 nm.

The 575 nm emission is from the NV^0 centre, which is commonly detected in CVD synthetic diamond due to the presence of single nitrogen and vacancies that are inevitably introduced during the growth process (Martineau et al., 2004).

The 503.2 nm ZPL is attributed to the H3 defect ($[N\text{-}V\text{-}N]^0$), which can be produced by irradiation in diamond containing aggregated nitrogen, followed by annealing at approximately 800°C. Vacancies are generated during the irradiation and annealing, and are trapped at nitrogen A-aggregates (a nearest-neighbour pair of nitrogen atoms) to form H3 centres. In CVD synthetic diamond, this defect is produced when there is nitrogen and a source of vacancies in the pre-treated material. H3 defects also can be formed by high-temperature annealing without irradiation (Charles et al., 2004; Martineau et al., 2004; Meng et al., 2008). According to Meng et al. (2008), when the annealing temperature exceeds 1,700°C, H3 defects may be observed in CVD synthetic diamond. This defect is responsible for the green fluorescence excited by the short-wave UV lamp and the DiamondView (Wang et al., 2012).

The 736.6/736.9 nm doublet and its corresponding vibronic structure are attributed to the $Si\text{-}V^-$ centre. Silicon is often introduced into CVD synthetic diamond by the etching of Si-containing components forming the reactor (Robins et al., 1989; Barjon et al., 2005; Wang et al., 2012). The defect can exist stably after HPHT treatment (Martineau et al., 2004), and is usually regarded as one of the identification characteristics of CVD synthetic diamond (although not definitive, as a small number of natural diamonds also have this defect: Breeding and Wang, 2008).

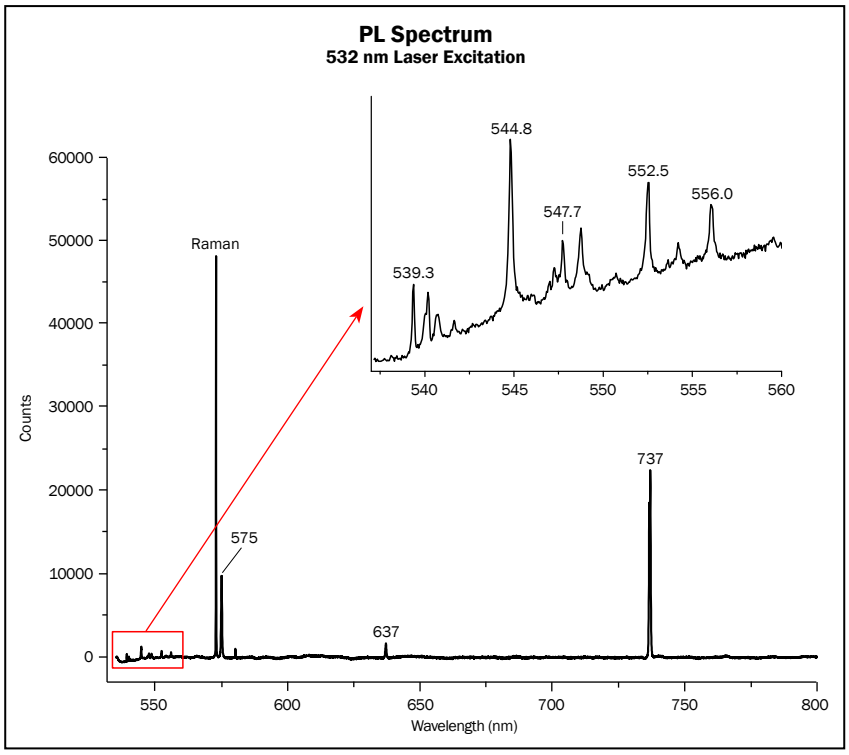

Figure 7: Green laser (532 nm) excitation of the CVD sample produced strong PL emissions at 575 nm (NV^0) and 737 nm ($Si\text{-}V^-$). In addition, numerous weak peaks were recorded in the 535–560 nm region.

The 473 nm laser also excited many unidentified sharp peaks, including those at 487, 488, 494, 495, 500, 501, 506 and 507 nm, as well as those at 975, 977, 983, 988 and 990 nm in the infrared region (not all peaks are shown in Figure 6).

532 nm Excitation: Photoluminescence peaks at 575 nm (NV^0) and 736.6/736.9 nm ($Si\text{-}V^-$) were detected in the sample when excited by the 532 nm laser (Figure 7). In addition, 637 nm emission attributed to the NV^- centre was recorded. Several unattributed emission peaks were detected in the 539–556 nm region, including those at 539.3, 540.1, 540.6, 541.6, 544.8, 547.7, 548.7, 552.5, 554.2 and 556.0 nm (not all peaks are shown in Figure 7).

Figure 8: The PL spectrum of the CVD synthetic diamond excited by the 785 nm laser revealed unidentified weak peaks at 819.3, 824.5, 850.1 and 853.3 nm.

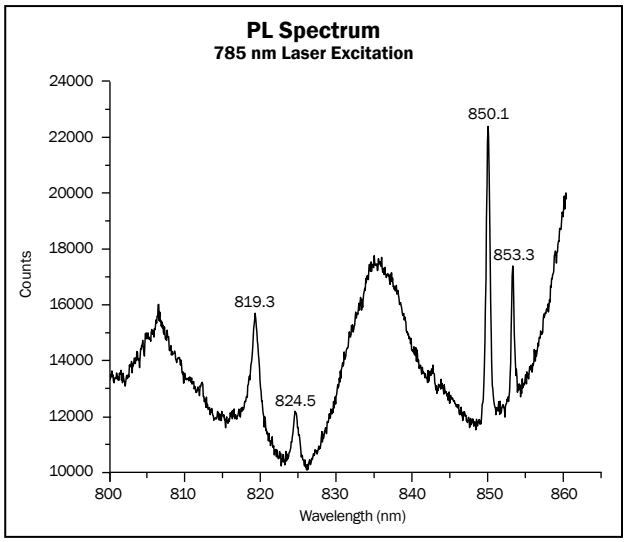

785 nm Excitation: Weak PL peaks at 819.3, 824.5, 850.1 and 853.3 nm were detected in the sample when excited with the 785 nm laser (Figure 8). The defects responsible for these PL peaks have not been identified.

X-ray Topography

The X-ray section topograph of the sample is similar to those previously reported in CVD synthetic diamond (Martineau et al., 2004), showing a columnar texture with linear contrast streaks parallel to the growth direction (Figure 9). This appearance is quite different from that seen in topographs of natural diamonds (cf. Diehl and Herres, 2004). The contrast streaks are believed to be caused by the dislocations produced during the growth process. If the X-ray beam sampled a direction perpendicular to the growth direction, these dislocation bundles would appear as dark spots in the resultant topograph (Martineau et al., 2004). The X-ray topograph shows that the table of the faceted CVD synthetic diamond is oriented at a significant oblique angle to the crystal's growth

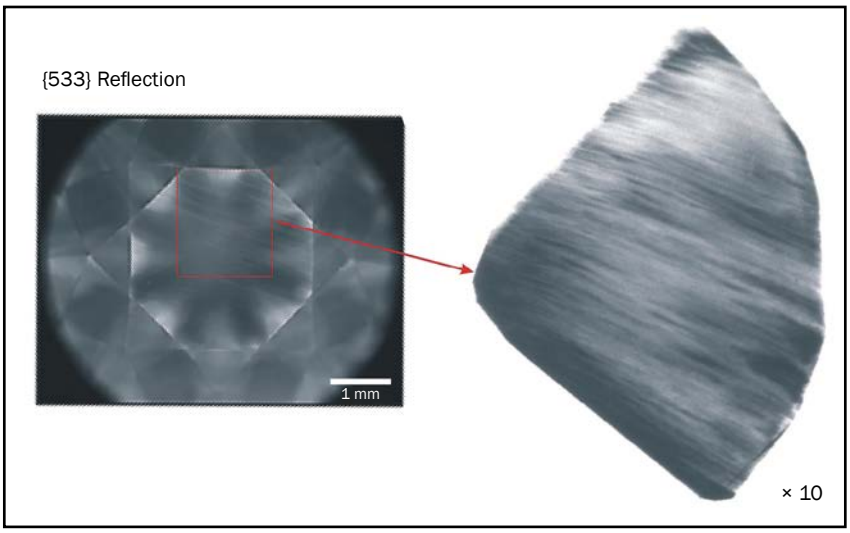

Figure 9: A columnar texture is evident in this X-ray topograph taken through the table facet of the CVD sample, in which a cross-sectional slice parallel to the growth direction was sampled by the X-ray beam. Courtesy of De Beers Technologies.

direction, in contrast to that reported by Martineau et al. (2004) where the table was approximately perpendicular to the growth direction.

Laue Diffraction

A Laue diffraction image taken with the table parallel to the plane of the image (Figure 10) showed that the table facet of the CVD synthetic diamond was oriented approximately 20° to the {111} octahedral plane, in the {100} cubic direction.

Discussion

The angle between the octahedral and cubic planes in diamond is 54.7°. Laue diffraction allows the orientation of the CVD synthetic diamond's table facet to be calculated (Figure 11), showing a deviation from the {100} cubic plane toward the {111} octahedral plane. In general, CVD synthetic diamonds are grown on plates oriented parallel to the {001} plane, producing growth in the <001> direction. The table facet is typically oriented approximately parallel to the seed plate plane (i.e. perpendicular to the growth direction of CVD synthetic diamond) to improve the cutting yield. The Laue diffraction pattern indicates that the 'tree ring' growth pattern observed on the table of the CVD synthetic diamond sample with the DiamondView is due to the orientation of the

Figure 10: Indexing of this X-ray Laue diffraction pattern of the CVD sample revealed that the table facet has an orientation that is inclined approximately 20° to the {111} octahedral plane toward the {100} cubic direction.

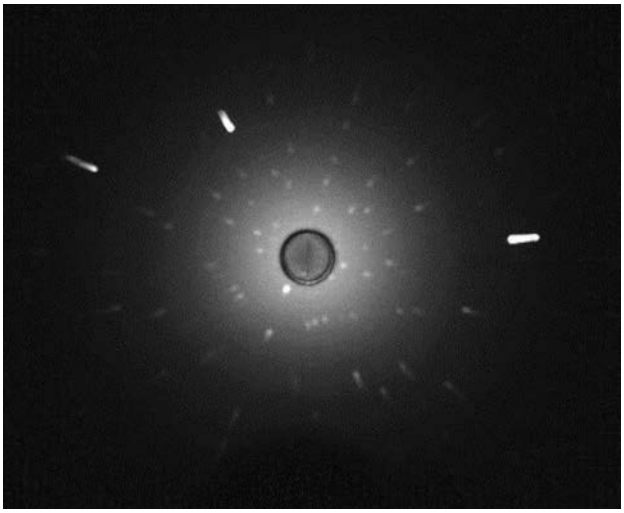

Figure 11: This schematic diagram of the cutting direction of the CVD sample shows that the crystallographic orientation of the table facet deviates from the {100} cubic plane and approaches the {111} octahedral plane. This differs from typical faceted CVD synthetic diamond, in which the table is oriented approximately parallel to the {001} plane.

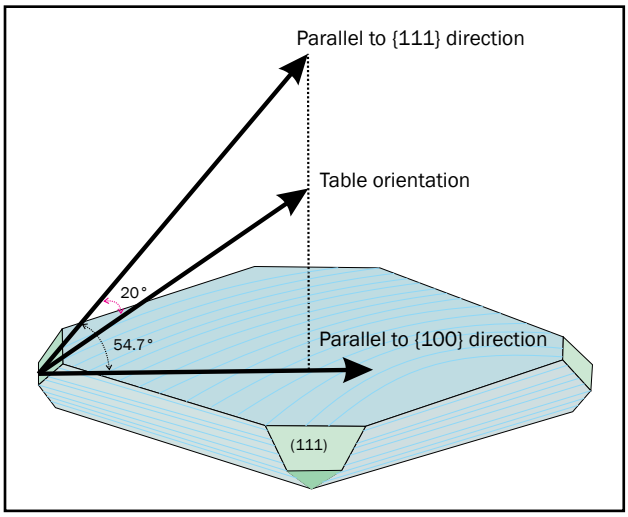

table at just the right angle to the growth direction to produce very shallow angles between the growth planes and the table and crown facets at one position at the edge of the table. This results in the concentric ring-like appearance where the striations intersect the facets.

Conclusion

Refinements in CVD synthetic diamond growth technology, and the resulting increase in crystal size, have resulted in more flexibility regarding the cutting orientation used to facet such products. The 'tree ring' growth structure observed with the DiamondView in the table of a 0.61 ct CVD synthetic diamond is due to the crystallographic orientation of the table facet deviating from the {100} cubic direction toward the {111} octahedral plane to produce very shallow angles between the growth planes and the table and crown facets. This concentric pattern is different from the dislocation and 'mosaic' structures seen in DiamondView images of natural type IIa diamond (Martineau et al., 2004), but may resemble those patterns observed in natural type Ia stones; however, the luminescence of the latter gems shows a blue colour that is very different from that seen in CVD synthetics (Wang et al., 2007a; Sun et al., 2012). Also, compared to the regular striations in CVD synthetics, the growth patterns in natural diamond are more complicated and less orderly because of the complex geological environment of their formation. In addition, the CVD sample showed the Si-V^--related doublet at 737.6/737.9 nm in PL spectra. This defect can be used to identify CVD synthetic diamond but is also seen very occasionally in natural diamond. The columnar texture of the X-ray topograph may be useful as an indicator of CVD synthesis (cf. Diehl and Herres, 2004; Martineau et al., 2004). The presence of the N3 (415 nm) and H3 (503.2 nm) defects, and also the 3107 cm^{-1} absorption seen in the mid-IR spectrum, indicate that the CVD synthetic diamond has been HPHT treated. The 480–524 nm PL peaks excited by the 473 nm laser and the 535–560 nm PL peaks excited by the 532 nm laser have also been detected in other CVD synthetic diamonds that show green fluorescence and characteristics of HPHT treatment, and may be used as further indicators of CVD synthetic diamond.

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Conferences

CGA Conference

The annual conference of the Canadian Gemmological Association took place 17–18 October 2015 in Vancouver, British Columbia, Canada. The 118 people in attendance represented approximately 11 countries.

CGA president **Donna Hawrelko** introduced the conference, which was kicked off with a presentation by **Gary Roskin** (International Colored Gemstone Association, New York, New York, USA) on communicating colour. He asked the audience whether gem laboratory reports should be using scientific colour descriptions (i.e. hue, tone and saturation) or popular colour designations (e.g. 'Pigeon's Blood' red or 'Royal' blue) that gem traders can use as marketing tools. For the latter case, he recommended that labs should be consistent and have well-defined and published ranges for such colour terminology. Next, **Dr Cigdem Lule** (Gemworld International Inc., Glenview, Illinois, USA) warned against the abuse of commercial colour terms for marketing purposes when dealers "sell the report, not the stone". She gave an example of the term 'Pigeon's Blood' appearing on an overly high percentage of ruby reports (90% of some 500+ surveyed), for stones that ranged from $450/ct to $50,000/ct. She, too, emphasized the need to establish clear gemmological nomenclature and be consistent in the way it is applied.

Dr James Shigley (Gemological Institute of America [GIA], Carlsbad, California, USA) provided an update on the identification of synthetic diamonds. He emphasized that only a small number are submitted to the GIA Laboratory (perhaps 10–15/month), and they continue to be readily distinguishable by well-equipped labs. **Richard Drucker** (Gemworld International Inc., Glenview) reviewed the pricing of synthetic and treated diamonds. Synthetic colourless diamonds are generally priced at 50% (up to 65% for larger sizes) of natural stones, except for melee which is ~US$100/ct less than natural diamonds. High-pressure, high-temperature (HPHT)-treated D–G colour diamonds typically are discounted by 40%–55% compared to equivalent untreated natural stones. Drucker also gave pricing data for fancy-colour synthetic and treated-colour natural diamonds in an informative handout. **Alex Grizenko** (Lucent Diamonds Inc., Los Angeles, California, USA) reviewed diamond colour enhancement, with an emphasis on multi-treatments involving HPHT annealing, irradiation, and further heat treatment at lower temperatures. Interestingly, he is asking the same price for both natural and synthetic Imperial Red diamonds (multi-treated type Ia). **Art Samuels** (Vivid Diamonds & Jewelry and EstateBuyers.com, Florida, USA) passed along many diamond-buying tips gleaned throughout his career. For example, he explained how strongly blue-fluorescent stones (which are unnecessarily punished by the trade) and fancy shapes can be great bargains. He also recommended examining a gemstone closely both before and after obtaining a laboratory report to calibrate one's observational skills, and to learn pricing by attending shows and asking questions.

Dr Lee Groat (University of British Columbia, Vancouver, Canada) surveyed Canadian gem localities. Diamond production is planned to begin during the second half of 2016 from the Gahcho Kué deposit in Northwest Territories and the Renard project in Québec, both of which are currently under construction. Canada also hosts significant deposits of nephrite and the world's only commercial occurrence of Ammolite (iridescent fossilized ammonite). Other gems include amethyst from Thunder Bay, Ontario; tourmaline from O'Grady, Northwest Territories; sodalite from Bancroft, Ontario; opal from British Columbia; sapphire from Baffin Island and Revelstoke, British Columbia; emerald from Taylor 2 (Ontario), Anuri (Nunavut) and three additional localities in north-western Canada; aquamarine from the True Blue occurrence in Yukon Territory; green beryl from Mountain River, Northwest Territories; and spinel from Baffin Island. **Simon O'Brien** (De Beers Group of Companies, Toronto, Ontario, Canada) gave an update on De Beers' diamond mining activities in Canada (i.e. Snap Lake, Gahcho Kué and Victor), and then described the evaluation of rough diamonds (e.g. Figure 1). The diamonds are (1) sieved into various

Figure 1: Rough diamonds such as these are evaluated according to numerous criteria including size, shape, clarity and colour. The largest diamond crystal shown here weighs 174.25 ct. Courtesy of De Beers Group of Companies.

sizes; (2) evaluated into sawable and makeable groups followed by sorting according to their shape; (3) separated according to their clarity into gem, near-gem and industrial categories; and (4) assessed for their colour. Further sorting within the various categories leads to a total of 12,000 price points.

Andrew Fagan (True North Gems, Vancouver, Canada) described the geology and gemmology of the Fiskenaesset gem district in Greenland, where his company is preparing to open a ruby and pink sapphire mine at Aappaluttoq. Core drilling (to 220 m depth) and bulk sampling have been used to define the ore zone, and plans call for constructing two open pits up to 65 m deep with a predicted nine-year mine life. The mine economics are modelled on melee-sized material, although some larger stones will be produced. True North will sell the rough to suppliers (initially in 2016), and by 2017 they will be in full production with 20,000–30,000 tonnes/year of ore mined.

Robert Weldon (GIA, Carlsbad) recounted the history of the Chivor emerald mine in Colombia. Many famous emeralds have come from Chivor, and the height of commercial production occurred in the 1930s, when the mine was operated by Peter Rainier.

Dr Edward (Shang-i) Liu (The Hong Kong Institute of Gemmology) described several types of *fei cui* jade, consisting of various amounts of jadeite ± omphacite and kosmochlor. He demonstrated how different minerals can be present in various parts of the same cabochon, leading to challenges in proper identification and nomenclature. For the purposes of the gem trade, he advocated simplifying the terminology to indicate 'natural *fei cui*' on lab reports, with major mineral constituents specified upon the client's request.

Shawn O'Sullivan (Eternity Natural Emeralds, Ridgewood, New Jersey, USA) described the impact of clarity treatment on emerald and tourmaline. He stated that there is generally a 5–10% improvement in appearance after treatment, and that it is difficult for gem laboratories to tell the amount of clarity enhancement because they do not see the stone's appearance after it is cleaned and before its fractures/cavities are filled.

Alan Hodgkinson (Ayrshire, Scotland) highlighted various stones that he encountered at last year's Tucson gem shows, and illustrated how they could be separated or identified using his techniques of 'visual optics'. Ruby and diamond are the only gems that can be specifically identified using visual optics, and otherwise these techniques are good for eliminating possibilities, thus narrowing potential candidates.

Kelly Ross (owner of Ross Inc., Edmonton, Alberta, Canada, and formerly diamond program coordinator for the Royal Canadian Mounted Police) explained why jewellery is so common in 'money laundering', which he defined as the proceeds of a crime that must be sold to obtain cash and real property (i.e. fixed property such as land and buildings). Along with electronics and power tools, jewellery is commonly desired by burglars because (according to the acronym CRAVED) it is concealable, removable, available, valuable, enjoyable and disposable. Jewellers who are approached to buy possible stolen goods can help by reporting suspicious transactions, by keeping good records (of lab reports, etc.), and by getting the seller's identification information.

The conference was preceded by a short-course on the geology of gem deposits and was followed by a jadeite identification and valuation workshop, both of which were filled to capacity.

Brendan M. Laurs

First World Emerald Symposium

'Be Part of the Change' was the theme of the First World Emerald Symposium (WES), held at the Sheraton Convention Center in Bogotá, Colombia, 13–15 October 2015 (Figure 2). The advance registration was capped at 350 participants, and many more tickets were sold at the door (mostly to local Colombians), for a total attendance of 471. The WES was organized by the Colombian government and the Colombian emerald industry umbrella association Fedesmeraldas, an alliance of miners, manufacturers and wholesalers. The two most prominent corporate sponsors were Muzo International (Geneva, Switzerland) and Gemfields (London). Muzo International is the owner of the world-famous Muzo emerald mine, where they first began operations in 2009. Gemfields announced in September 2015 their acquisition of the historic Coscuez mine, some 10 km north of Muzo.

An important message from the WES is that, for the first time in history, Colombia is no longer the number-one producer of emerald in the world. Zambia now leads in annual emerald production by volume and by value. The precipitous drop in Colombia's emerald production is due to the lack of investment by Colombians in their mines.

Zambia's Minister of Mines, **Dr Christopher B. Yaluma**, spoke eloquently on his country's success in the emerald market. Unlike Colombia, where emeralds have been mined continuously for 1,500 years, emeralds were discovered relatively recently (1929) in Zambia. Next, the Vice-Minister of Mines for Colombia, **Dr Maria Isabel Ulloa**, focused on the scourge of 'illegal' emerald mining. By her estimate, half of the small-scale emerald miners in Colombia lack proper title to the land. In the miners' defence, government delays in issuing proper title under the updated mining law of 2012 have led to a three-year backlog in pending reviews and approvals. Minister Ulloa also stated that over 90% of the emerald licences are idle. **Dr Carolina Rojas Hayes** of the Colombian National Mining Agency reported that there were 1,496 exploration permits for some 7,500 prospectors, and another 359 licences for land parcels, with 178 parcels partially certified and another 49 under review. By her count, only two licences have been fully vetted, those of Gemfields and Muzo International.

Principals of coloured gemstone industry organizations discussed and then debated how guild organizations can promote business in a dynamic global market. ICA president **Benjamin Hackman** emphasized the need for full disclosure of treatments, saying: "Synthetic emeralds are better documented than natural emeralds that have been treated and enhanced." **Roland Naftule** with CIBJO highlighted the economic power of the emerging generation of millennials, and contrasted their motivations for buying gemstones and jewellery with those of the 'baby boomer' generation, leading to the creation of new market channels rewarding ample information and social consciousness. **Gerry Manning** with AGTA stressed the importance for national organizations to represent collective interests to both recalcitrant government regulators and hostile media. He said, "Misinformation is pandemic, and clarity is critical to value." Fedesmeraldas president **Oscar Baquero** hoped that the lasting impact of the WES would be closer coordination between Colombians and their international colleagues. Baquero reported officially that the 2014 emerald export for Colombia totalled US$145 million, derived from some 347 licences of which only 10% were active.

Figure 2: The theme of the First World Emerald Symposium was 'Be Part of the Change'. Here, Philippe Scordia discusses emerald selection criteria used by luxury jewellery brands. Photo by W. Rohtert.

International gemstone laboratories were well represented during an afternoon session. In summary, the labs are confident they can distinguish Colombian emeralds from those of other sources, and can differentiate synthetics as well. Admittedly, the cost of testing melee parcels is prohibitive, rendering a risk of blended stock escaping detection. Although technology permits the identification of specific emerald fillers, there is presently no systematic reportage for treatments, nor any plans for such structure. **Dr Thomas Hainschwang** (GGTL Laboratories, Balzers, Liechtenstein) reviewed the standards and protocols for verifying emeralds in gem labs, especially infrared spectroscopy to differentiate fillers and fluorescence

microscopy to map their distribution in a stone. **Kenneth Scarratt** (formerly of the GIA Laboratory in Bangkok, Thailand) spoke on the history of emerald enhancement, elucidating the multiple cycles of cleaning, treating and filling that any emerald might experience, as well as the breakdown over time of some fillers. **Shane McClure** (GIA Laboratory, Carlsbad) addressed the harmonization of reports, protocols and specific wording for emerald documentation. **Ronald Ringsrud**, speaking for Muzo International, focused on residues and other substances mistakenly classified as enhancements in emeralds—especially simple manufacturing residues. Ringsrud also delivered a passionate sermon on the importance of 'romance and glamour' as the driving factors in emerald sales, not scientific certificates. **Dr Dietmar Schwarz** (AIGS Lab, Bangkok) illustrated the many physical and chemical distinctions of Colombian emeralds as compared to those from other sources, notably their high Cr+V content and diagnostic three-phase inclusions, as well as characteristic growth features such as first-order prisms and pinacoids. **Carlos Julio Cedeño** (CDTEC Gemlab, Bogotá) provided insight into some of the unique crystallographic features of Colombian emeralds derived from their growth within open spaces in a hydrothermal environment.

Muzo International president **Charles Burgess** delivered a keynote address focusing on the social responsibility of a modern gem mining company. Burgess said that "six years of positive social transformation has been key to Muzo's commercial success" in Colombia. Corporate social responsibility is a foundation commitment, not an optional extravagance, he claimed. When they arrived at Muzo, they confronted a health-social-cultural crisis that was exacerbated by the modernization and mechanization of an historic mine site. There was a general lack of law and order, a legacy of rampant environmental damage, the constant risk of invasion by squatters and an absence of social services. To succeed, Muzo International assumed a proactive role normally assigned to government in addressing the challenges of unemployment, the need for schools and clinics, and support for the disabled and elderly. Muzo International financed outreach to the community and empowered women by financing local tailors to deliver clothing for miners, and by hiring women to engage in environmental restoration of the riparian environment along the Río Minero. Today, the mine employs over 600 workers and sustains a surrounding community of more than 2,500 people.

ICA director of communications **Jean Claude Michelou** spoke next on the traceability of coloured stones, with an update on ongoing initiatives and a way forward. He emphasized that documentation of provenance was critical to product branding and to building confidence with consumers. **Captain Torres** with the Colombian National Police then spoke on corporate and social traceability, and detailed the considerable capacity of the Colombian police and security forces in Boyacá, the state where the major emerald mines are located. **Jaime Loder** (Aegis Defense Services, London) and **Adam Brown** (Anuera Security, London) addressed private protection forces for the emerald industry in a high-risk environment, where safety originates in the village, and defence ultimately extends internationally to family, friends and business colleagues.

Another block of presentations concentrated mostly on the technical aspects of emeralds. **Dr Gaston Giuliani** (Centre de Recherches Pétrographiques et Géochimiques, Nancy, France) started the session with a review of the geology and gemmology of emerald deposits worldwide, highlighting laboratory determinative techniques for the differentiation of emeralds that are derived, ultimately, from differences in the style of mineralization. **Marcelo Ribeiro**, owner of the Belmont emerald mine in Minas Gerais, Brazil, gave a stunning presentation on their modern, mechanized, surface and underground, emerald mining operations. Belmont is a type example of how to correctly mine emerald deposits in South America, from the use of optic sorters to integration with a national marketing campaign. **Clarissa Maciel** (Brazilian Institute of Gems and Precious Metals, Brazilia) expounded on how her organization—a partnership between the government and private sector—promotes the gem business (including Belmont), nationally and internationally. **Warren Boyd** (R.T. Boyd Ltd., Oakville, Ontario, Canada) provided an interesting review and update on the geology and gemmology of the Malysheva emerald mine in the Ural Mountains of Russia. He noted that the 'seizure' of Malysheva from Canadian-owned Tsar Emerald Corp. coincided with Vladimir Putin's shell companies consolidating control over the remnants of the beryllium industry of the former Soviet Union. Malysheva is Russia's primary source of beryllium for their nuclear industry. Next, **Gary Bowersox** (GeoVision Inc., Honolulu, Hawaii, USA) covered the extensive history of emerald mining in Afghanistan, providing, as always, his own considerable personal experience in south-central Asia. He painted a hopeful picture of the Afghan emerald miners, emerging from decades of war, improving their lives and circumstances, despite difficulties that continue to this day. **This author** spoke next for SRK Consulting (a global mining engineering firm working with diamond, emerald, ruby and sapphire), describing

new mining and recovery tools and technologies useful in the Colombian emerald industry.

Vijay Kedia (Jewelers Association of Jaipur, India) recounted the Indian tradition with emerald of all origins and the market perception of Jaipur as one of the largest buyers and cutters. Left unresolved was the issue of blended melee parcels combined from multiple sources of supply. **Philippe Scordia** (Christian Dior Joaillerie, Paris, France) described the purchasing criteria, selection and certification of suppliers for luxury jewellery brands, and the increasing importance of provenance and social responsibility. Luxury designer **Erica Courtney** (Los Angeles, California, USA) illustrated how social media can be used to promote gems and jewellery, including emerald, to a new generation of media-saturated and techno-savvy buyers.

On the third and final day, **Jaime Rotlewicz** (C.I. Gemtec, Bogotá) began with a demonstration of acoustics and geo-gemmology, using various devices to amplify and record sonic signals, music and noise, from gemstone samples in his lab. **David Lihgtle** (The Wright Brothers, Dayton, Ohio, USA) re-emphasized the importance of global branding for service as well as product. **Gabriel Angarita**, a member of the WES organizing committee and president of the Colombian Association of Emerald Exporters, delivered a resounding review of Colombian emerald branding and lack of branding, ending with a plea for increased cooperation from all elements of the national industry. **Andy Lucas** (GIA, Carlsbad) gave a broadcast-quality still-and-video presentation on educating retailers and the global supply chain from mine to market, using specific examples from Asia and Africa.

Executive director of Gemfields **Sean Gilbertson** recounted the history of his company's activities in the coloured gemstone sector, focusing mainly on exploring and developing the Coscuez emerald district. **Dr Sixtus C. Mulenga** with Zambia's Extractive Industry Transparency Initiative considered the foundations for global gemstone growth to be honest and responsible practices.

Darwin Fortaleche, CDTEC Gemlab's chief gemmologist, presented research into a new emerald enhancement developed in Colombia, where the treatment of emeralds is routine and ever-evolving. **Oded Ben Shmuel** (Sarine Technologies Ltd., Kfar Saba, Israel) gave an update on his company's tools applicable to the emerald trade, borrowing new technology from the electronics and aerospace industries. **Dr Adolf Peretti** (GRS Gemlab, Lucerne, Switzerland) discussed his colour terminology for gem reports, and emphasized its use as a marketing and communication tool. **Hypone-Phyo Kan-Nyunt** (Gübelin Gem Lab Ltd., Hong Kong) detailed the ultra-trace-element analysis of emeralds through a combination of techniques. **Wei Ran** (National Gemstone Testing Center [NGTC], Beijing, China) concluded the WES with a description of emerald investigations underway in the Research Department at NGTC.

A post-conference field trip brought participants to various emerald mines in Colombia. Although the symposium was organized rather quickly, it came together with resounding success.

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Gem-A Conference and FEEG Symposium

incorporating the 18th Federation for European Education Symposium

The annual Gem-A Conference took place in London on 21–22 November 2015, and was attended by 190 people from 20 countries.

The event was introduced by Gem-A's interim CEO **Nick Jones**. Then, **Jörg Gellner** (Gellner, Bochum, Germany) provided a detailed description of pearl quality factors, which he referred to as the '5 S's': size, shape, shade, surface and shine. He gave the typical size ranges of various types of cultured pearls, and for each millimetre above the benchmark size he said the value should be adjusted by +35%. For shape, round is ideal and all other shapes correspond to reductions in value except for matched pairs of drop shapes, which are adjusted by +150%–200%. For shade (colour), different value factors are applied for white or black cultured pearl varieties (e.g. South Sea or Tahitian). Surface is evaluated according to 'spot level', with five categories differing in their value factors by 1.5× (e.g. 100% for no spots and 67% for the next category of lightly spotted). Shine (lustre) is also adjusted by 1.5× between categories, of which there are four (AAA, AA, A and B).

Jean Pierre Chalain (Swiss Gemmological Institute SSEF, Basel, Switzerland) recounted the history of developments surrounding the identification of HPHT-

treated diamonds. After the 1999 announcement by General Electric (GE) and Lazare Kaplan International about their 'undetectable' and 'permanent' diamond decolorization process, a close collaboration between SSEF and researchers from various centres including the University of Nantes and CIBJO laboratories helped develop, one year later, final identification criteria. Additional collaborations with De Beers and the Natural Historic Museum of Vienna later helped in consolidating the identification criteria of HPHT-treated type Ia diamonds.

Adolf Peretti (GRS GemResearch Swisslab Ltd., Lucerne, Switzerland) surveyed some commercially important ruby and sapphire sources, including Myanmar (Mogok and Mong Hsu), Madagascar (Didy and Ilakaka), Sri Lanka (Kataragama), Cameroon, Kashmir, Tanzania (Winza), Vietnam (Luc Yen), Tajikistan and Mozambique. The availability of abundant rough material from Mozambique has allowed the cutting of large ruby suites that were previously very difficult and time consuming to put together. Peretti showed video clips from his visits to some of the mines, and also screened a film that documented the cutting of a notable Mozambique ruby.

Dr Ilaria Adamo (Italian Gemmological Institute, Milan) reviewed the geology and gemmology—including origin determination—of demantoid sources. Serpentine-associated deposits are found in Russia (central Ural Mountains), Italy (Val Malenco), Pakistan (Kaghan Valley and Baluchistan) and Iran (Kerman Province), while skarn-hosted occurrences are in Namibia (Erongo) and Madagascar (Antetezambato). Adamo noted several differences according to the two source types, including their inclusions, reaction to heat treatment and chemical composition.

Dr Paul Rustemeyer (Gundelfingen, Germany) documented colour zoning and growth phenomena in tourmaline crystals. Colourful photographs of slices oriented both perpendicular and parallel to the c-axis showed a wide variety of features, including sequential and face-selective incorporation of chromophore ions, parallel crystal aggregates, re-growth or 'healing', corrosion intervals and delta structures corresponding to the appearance of a second colour phase crystallizing on the same face.

Dr Raquel Alonso-Perez (Harvard Mineralogical & Geological Museum, Cambridge, Massachusetts, USA) examined the historic Hamlin Collection of tourmalines from Mount Mica, Maine, USA. Raman spectra showed four peaks in the 3650–3450 cm^{-1} region (corresponding to OH-stretching vibrations) that could be correlated to the colour of the tourmalines.

Figure 3: Australia's Lightning Ridge mining area is the source of these black opals (~2–70 ct). Courtesy of Cody Opal Australia Pty. Ltd.; photo by Damien Cody.

Andrew Cody (Cody Opal Australia Pty. Ltd., Melbourne, Victoria, Australia) reviewed the global sources of opal, including Australia (e.g. Figure 3), Brazil, Ethiopia, Honduras, Mexico, Indonesia, Slovakia and USA. He indicated that Australia's opal production was formerly worth US$500 million/year, and although many deposits have played out, Australia still supplies 90% of the world's opal by value.

Grant Hamid (Hamid Bros. Gem Merchants, Melbourne) reviewed important historical developments in the sources, supply, treatment and synthesis of gem corundum. He also showed how possessing good gemmological knowledge can be helpful for one's business: he bought a 7.44 ct 'synthetic sapphire' cabochon for $300, and upon examining its inclusions he discovered it was actually a natural Kashmir sapphire.

Richard Drucker (Gemworld International Inc., Glenview) discussed various issues of current interest in the gem trade: coloured stone treatments; nomenclature issues surrounding colour terminology (on lab reports), geographical origin and trade names for gem varieties; and recent developments in synthetic diamond growth and production.

Martin Steinbach (Steinbach – Gems with a Star, Idar-Oberstein, Germany) covered asterism in gems, noting that 50 gem varieties are known to display asterism when cut as cabochons or spheres, and in 90% of the cases the star is due to rutile 'silk'. He described several famous star rubies and sapphires, and also showed examples of rarities as well as asterism resulting from treatments.

Fabian Schmitz (German Gemmological Association, Idar-Oberstein) provided an overview of the coloration and identification of natural and synthetic quartz. The various colours shown by quartz are due to colour centres (natural as well as laboratory-induced) and inclusions. In general, synthetic quartz may show swirl-like colour zoning, 'breadcrumb' inclusions or a seed plate, while natural quartz can display twin structures. Infrared spectroscopy is useful for separating them, but it is important to look at the entire spectrum rather than just one portion of it.

Shane McClure (GIA Laboratory, Carlsbad) described various oddities and scams that he has encountered in the GIA Laboratory over the years. Some standouts include 'rainbow calsilica' from Mexico consisting of dyed colour-banded calcite of an unknown (but clearly manufactured) origin; 'night-glowing pearls' that display strong green fluorescence and phosphorescence due to a coating containing rare-earth elements; various fake mineral specimens and gem crystals; and 'Arabian sand diamonds' consisting of quartz pebbles that were collected in Saudi Arabia by unsuspecting clients and then supplied to a gem cutter, with the resulting 'gems' actually being faceted cubic zirconia.

After the conference, three workshops covered coloured stone grading and pricing, visual optics and pearls, and private museum tours brought participants to the Natural History Museum (gem and mineral collection), the Tower of London (British Crown Jewels) and the Victoria and Albert Museum (Bejewelled Treasures: The Al Thani Collection).

Brendan M. Laurs

GSA 2015

A session on various aspects of research on gem materials was organized by GIA at the 2015 annual meeting of the Geological Society of America (GSA) in Baltimore, Maryland, on 1–4 November 2015. Abstracts of the oral presentations can be viewed at https://gsa.confex.com/gsa/2015AM/webprogram/Session37638.html, and poster session abstracts are available at https://gsa.confex.com/gsa/2015AM/webprogram/Session38771.html.

The talks were led off by **Dr George Harlow** (American Museum of Natural History, New York, New York), who cited three examples where the study of gem minerals has benefited from recent advances in the geological sciences. Occurrences of jadeite jade are related to particular formation conditions that are created by continental subduction. The trace-element study of ruby and sapphire using laser ablation–inductively coupled plasma–mass spectrometry has provided a new approach to understanding the geological environments (igneous and metamorphic) of gem corundum. Large gem-quality forsterite (peridot) crystals appear to grow from hydrous fluids along tension gashes in igneous dunite bodies.

In a presentation made in the absence of a speaker who could not attend the conference, **Dr Wuyi Wang** (GIA Laboratory, New York) described the occurrence of the silicon-vacancy defect in synthetic diamonds, which can be detected by photoluminescence spectroscopy, and which represents one of the most diagnostic features of synthetic diamonds grown by the chemical vapour deposition method.

Dr Karen Smit (GIA Laboratory, New York) and co-authors investigated sulphide inclusions in rare, bright-yellow type Ib diamonds from the Zimmi region of Sierra Leone. Re-Os isotopic compositions of the inclusions give a Pan-African diamond-growth age (~650 million years ago) that correlates with the assembly of the Gondwana supercontinent.

Dr Steven Shirey (Carnegie Institution of Washington, Washington DC, USA) and co-authors described the study of mineral inclusions in diamonds from the Juina area of Brazil, which are rather unique geologically because of their 'superdeep' origin (below the lithosphere from depths of 300–800 km). Such diamonds from the Collier 4 kimberlite are believed to have crystallized from carbonatitic melts derived from the recycling of oceanic lithosphere.

Using an 1851 plaster cast and a modern cubic zirconia replica of the original facet shape of the famous Koh-i-Noor diamond (now a 105.6 ct oval-cut stone in the Coronation Crown of the British Crown Jewels), **Alan Hart** of The Natural History Museum in London described how directional hardness anisotropy was a major constraint to the ancient polishing of the so-called Mogul-cut form of this diamond. Although a centrepiece display of the 1851 Great Exhibition in London, this diamond proved a visual disappointment to many exhibit visitors due to its lack of fire and brilliance, and it was subsequently recut to its present form.

Dr Keal Bryne (Smithsonian Institution, Washington DC) and co-authors investigated the luminescence behaviour of two classes of diamonds that exhibit a colour change when exposed to different

temperatures or light sources. Pink/brown diamonds display luminescence reactions that appear related to optical defects associated with their coloration. So-called chameleon diamonds display a characteristic luminescence peak centred near 560 nm with an intensity that is strongly temperature-sensitive.

The Hamlin Necklace, a unique 19th century jewellery piece containing tourmaline and beryl from Mount Mica in Maine, USA, was investigated by **Dr Raquel Alonso-Perez** (Harvard University, Cambridge, Massachusetts, USA). She used Raman spectroscopy and non-destructive chemical analytical methods to prove that the tourmalines in the necklace are elbaite.

Dr Aaron Palke (GIA Laboratory, Carlsbad) and co-authors documented glassy melt inclusions in alluvial sapphires from Montana. These sapphires are believed to have a metamorphic origin followed by transport to the surface in rhyolitic to dacitic volcanic eruptions. The melt inclusions are hypothesized to be the product of partial melting during high-grade metamorphism of the parent rock, which produced a silica-rich melt and an alumina-rich residue from which the sapphires crystallized.

John Koivula (GIA Laboratory, Carlsbad) and co-authors heated two kinds of synthetic rubies and sapphires in air at temperatures above 1,800°C, and were able to produce partially healed fractures (e.g. Figure 4) and web-like parting planes. These features display a similar appearance to those seen in heat-treated gem corundum that has been interpreted by gemmologists as having been formed during a flux-healing process. The authors conclude that if no contradictory visual evidence exists, synthetic gem corundum containing these visual features could erroneously be mistaken for heat-treated natural gems.

Dr Laurent Cartier (Swiss Gemmological Institute SSEF, Basel) and co-authors discussed the potentially valuable information that DNA testing can reveal about the formation conditions of organic gems such as pearl, coral and ivory that are the result of biomineralization processes. In the case of pearls (cultured or natural), the analytical method has been improved so that it is quasi-non-destructive. This method can provide information on the oyster species, and also geographic origin.

Xiayang Lin and **Dr Peter Heaney** (Pennsylvania State University, University Park, USA) reported on quartz crystals that display natural iridescence from cavities in the Deccan Trap basalts of India. The small iridescent *z* faces exhibit tiny periodic ridges visible with the atomic force microscope, and these ridges act as a diffraction grating for visible light. Non-iridescent *r* faces lack these periodic ridges. The authors interpret the formation of the surface topography of the *z* faces as the result of preferential dissolution.

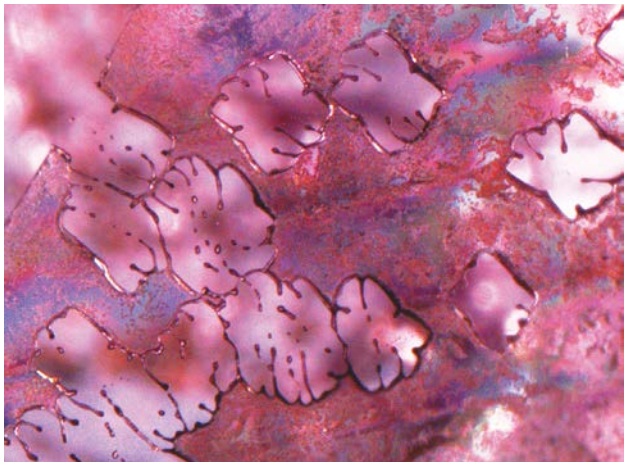

Figure 4: This crack in a Czochralski-pulled pink synthetic sapphire was partially healed by heating the gemstone in air at temperatures exceeding 1,800 °C. Photomicrograph by John I. Koivula/GIA; image width ~0.30 mm.

Yury Klyukin (Virginia Institute of Technology, Blacksburg, USA) and co-authors investigated emeralds from the North American Emerald mine (at the former Rist mine site) near Hiddenite, North Carolina, USA. The gems occur in cavities associated with quartz, muscovite and carbonate minerals. The emeralds have fluid inclusions that contain two fluid phases (CO_2-rich and H_2O-rich). The presence of a CO_2-rich fluid suggests that the emeralds formed in a medium-grade metamorphic environment.

Dr William Simmons (Maine Mineral and Gem Museum, Bethel, USA) and co-authors described gem pollucite from the Mount Mica pegmatite near Oxford, Maine. The dyke is cavity-rich, averaging one pocket about every three metres. Gem-quality pollucite is rare in pegmatites, but one pocket found in 2014 contained a number of strongly-etched crystals measuring 2–3 cm in diameter.

The final oral presentation was made by **Dr Michael Wise** (Smithsonian Institution, Washington DC), who reported on emerald and hiddenite (Cr-bearing spodumene) deposits near Hiddenite, North Carolina. Both minerals occur in quartz-carbonate Alpine-type veins within Precambrian migmatitic schists and gneisses. The gems appear to have been formed from hydrothermal fluids under low-temperature (<250°C) and low-pressure (~1 kbar) conditions. The host rocks are the most likely source of Cr, and local outcrops of granitic rocks provide evidence for the Be needed for emerald mineralization. However, recent discoveries of aquamarine in leucosomes within the migmatite indicate that the latter rocks may provide an alternative source of Be.

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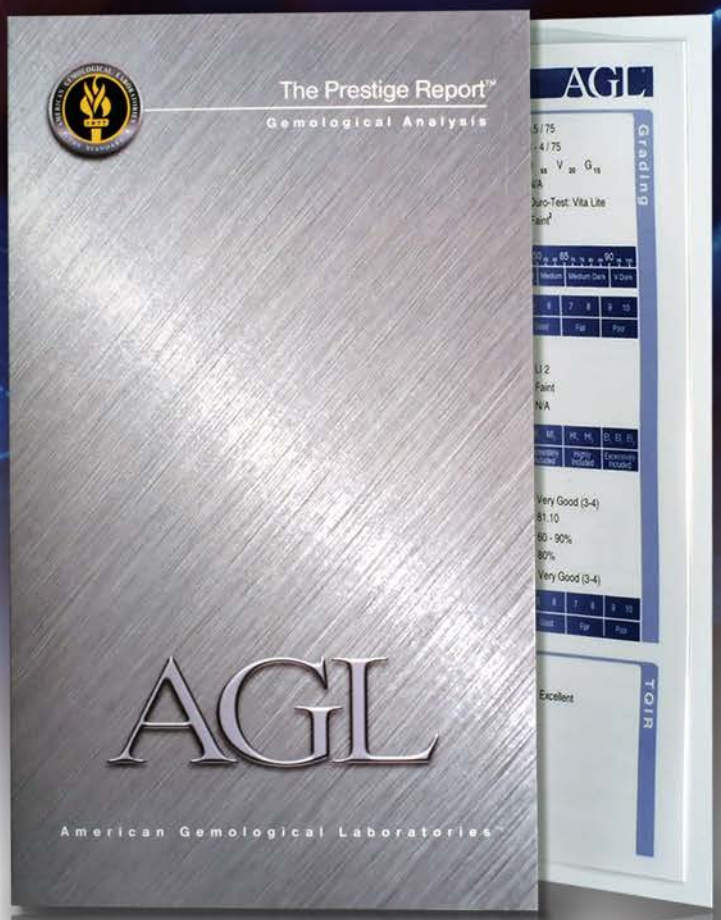

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Gem-A Notices

GEM-A CONFERENCE AND 18th INTERNATIONAL FEEG SYMPOSIUM

The 2015 Gem-A Conference and 18th International Federation for European Education in Gemmology (FEEG) Symposium was held at Royal Institute of British Architects in Portland Place, London, on 21 and 22 November. A full report of the Conference and events was published in the January/February 2016 issue of *Gems&Jewellery*. Highlights of the presentations are given in the Conferences section, pages 716–718.

Seminars and workshops were presented on 23 November at the Gem-A headquarters. Visits were arranged on 24 November to the Victoria and Albert Museum to see 'Bejewelled Treasures: The Al Thani Collection', to the Natural History Museum for a guided tour of the Mineral Gallery, and to the Tower of London for a private viewing of the Crown Jewels.

Conference Sponsors and Supporters

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GRADUATION CEREMONY

The Graduation Ceremony and Presentation of Awards for both Gem-A and FEEG was held at the Mermaid Conference and Events Centre, Puddle Dock, Blackfriars, London, on 23 November.

Nick Jones, Interim Chief Executive Officer of Gem-A, opened the ceremony by welcoming those present. **Kathryn Bonanno** (pictured right), a newly-elected Gem-A Trustee, addressed the graduates before presenting the Gem-A diplomas and awards.

Dr Loredana Prosperi, president of FEEG, introduced the FEEG delegates and presented the diplomas to the FEEG graduates.

Gem-A president **Harry Levy** gave the closing remarks before graduates and guests enjoyed a reception in a room overlooking the River Thames.

GIFTS TO THE ASSOCIATION

The Association is most grateful to the following for their gifts for research and teaching purposes:

John Bradshaw, Coast-to-Coast Rare Stones International, Nashua, New Hampshire, USA, for 21 bags containing part-cut crystals of: apatite (Canada and Mexico), cassiterite (Namibia), celestine (Kansas, USA), cerrusite (Namibia), crocoite (Tasmania, Australia), diaspore (Turkey), oligoclase (Kenya), pollucite (Conneticut, USA), scheelite (Pakistan and Arizona, USA), smithsonite (Namibia), sphalerite (Spain), tourmaline (Maine, USA, and Afghanistan), tugtupite (Greenland), willemite/leucophoenicite (New Jersey, USA) and zincite on calcite (New Jersey); and also for 95 faceted mixed-shape tourmalines, mostly pink, green and blue.

From the estate of **Ingeborg Bratman**, a large collection of rough and fashioned gem materials.

Boris Brianceau, Nantes, France, for large faceted samples of fluorite and amethyst.

Andrew Cody, Cody Opal, Melbourne, Australia, for copies of the book *The Opal Story: A Guidebook* (with DVD) by Andrew and Damien Cody, to sell at the Gem-A Conference, which raised a total of £630.

Roy Duran, Finer Jewelry Inc., Chicago, Illinois, USA, for assorted orange and colour-change sapphires; small Colombian emerald crystals; a carved amethyst; a jadeite bead; cabochons of synthetic ruby, tourmaline and 'white garnet'; and faceted aquamarine, garnet, peridot and sapphire.

Kwong Pui Ho (John Ho), Yangon, Myanmar, for assorted Ammolite, chrome tourmaline, hackmanite, thorite and ruby-in-quartz; rough amber, apatite, corundum, gypsum, jadeite, mica, moonstone, pollucite and tourmaline; crystals of spinel and zircon; cabochons of hematite, kyanite, opal and pargasite; and faceted quartz, spinel and tanzanite.

Alistair Laidlaw and **Christine Marsden**, Fort Augustus, Scotland, for a copy of *Dreams of Diamonds* authored by them.

Bill Larson, Palagems.com, Fallbrook, California, USA, for rough pieces of iridescent andradite from Mexico and a slab of jadeite from Russia.

Claire Mitchell FGA DGA, London, for a reconstituted malachite/azurite, two reconstituted turquoises, two sugilite simulants, and rough and cabochon-cut samples of omphacite jade from Val Pellice-Alpi Cozie, Piemonte-Nord, Italy.

Dominic Mok FGA DGA, AGIL, Hong Kong, for a jadeite colour master set guide.

Saeko Nasao, Fukushima, Japan, for rough opal.

Adolf Peretti FGA, GemResearch Swisslab Ltd., Lucerne, Switzerland, for four issues of his book *Contributions to Gemology* (Nos. 4, 5, 7 and 11) to sell at the Gem-A Conference, which raised a total of £290.

Prof. Chiu Mei Ou Yang FGA, Hong Kong Institute of Gemmology, for a selection of jadeites of various colours and trade names.

Michiko Shimomura FGA, Tokyo, Japan, for a copy of *The Book of the Pearl: The History, Art, Science and Industry of the Queen of Gems* by George Frederick Kunz and Charles Hugh Stevenson.

Tay Thye Sun FGA, Far East Gemological Laboratory, Singapore, for several pieces of tumbled amber.

MEMBERSHIP

At a meeting of the Council held on 9 October 2015, Diploma graduates of the examinations held in June 2015 (included in lists on pages 723–733) were elected or transferred to Fellowship or Diamond Membership as appropriate.

At a meeting of the Council held on 4 November 2015 the following were elected to membership:

Fellowship and Diamond Membership (FGA DGA)

Feng Wei, *Guangzhou, Guangdong, P.R. China*
Pei Yu, *Beijing, P.R. China*

Fellowship (FGA)

Hsu Yen Hsin, *Taipei City, Taiwan, R.O. China*
Reuser, Laetitia, *Amsterdam, The Netherlands*

Diamond Membership (DGA)

Wong Ching Man, *Discovery Bay, Hong Kong*

Associate Membership

Brown, Victoria, *Edinburgh*
Fiebig, Jim, *West Des Moines, Iowa, USA*
Quigg, Gloria, *Tucson, Arizona, USA*

At a meeting of the Council held on 23 November 2015 the following was elected to membership:

Corporate Membership

Fabula, *Thornhaugh, Cambridgeshire*

GEM-A AWARDS

In the Gem-A examinations held in January, February and June 2015, 413 students qualified in the Gemmology Diploma examination, including 36 with Distinction and 51 with Merit, and in the Foundation Certificate in Gemmology examination 606 qualified. In the Gem Diamond examination 135 qualified, including 19 with Distinction and 22 with Merit.

In the **Gemmology Diploma** examinations the **Christie's Prize for Gemmology** for the best candidate of the year was awarded to **Mei Mei Sit** of Central, Hong Kong. The **Anderson Bank Prize** for the best set of theory papers was awarded to **Emilie Disner** of Geneva, Switzerland. The **Read Practical Prize** for excellence in the practical examination was awarded to **Ka Yi Man** of Hong Kong.

In the **Foundation Certificate in Gemmology** examination, the **Anderson Medal** for the candidate who submitted the best set of answers which, in the opinion of the examiners, were of sufficiently high standard, was awarded to **Christina Khoudian** of Colchester, Essex.

In the **Diamond Diploma** examination, the **Bruton Medal** for the best set of theory answer papers of the year was awarded to **Valentina Molon** of Varese, Italy.

The **Deeks Diamond Prize** for the best candidate of the year was awarded to **Kathryn Williams** of Dover, Kent.

The **Diamond Practical Prize** for excellence in the Diamond Practical examination, sponsored by Dominic Mok from AGIL, Hong Kong, was awarded to **Louise Van Colen** of Montreal, Quebec, Canada.

The **Tully Medal** was not awarded.

The names of the successful candidates are listed below.

Examinations in Gemmology

Gemmology Diploma

Qualified with Distinction

Aron-Brunetiere, Patricia, *Raray, France*
Arrive, Elodie Jacquinot, *Annecy, France*
Bai Qing, *Beijing, P.R. China*
Beaumont, Elizabeth, *Montreal, Quebec, Canada*
Chow Hiu Yan Bona, *Central, Hong Kong*
Griziot, David, *Marseille, France*
Guay, Richard, *Saint-Justin, Quebec, Canada*
Herbin, Thomas, *Lésigny, France*
Ito, Claire, *Carlsbad, California, USA*
Jacmain, Irina, *Noisy-le-Sec, France*
Jin Xinyu, *Beijing, P.R. China*
Jonas, Helen C., *Shellingford, Oxfordshire*
Lai Hsin Han, *Kaohsiung City, Taiwan, R.O. China*
Lam Wai Chun, *Tuen Mun, Hong Kong*
Li Huan, *Beijing, P.R. China*
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Quan Xiaoyun, *Beijing, P.R. China*
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Ren Weina, *Beijing, P.R. China*
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Dong Yiyuan, *Beijing, P.R. China*
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Huang Yi, *Beijing, P.R. China*
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Ji Bin, *Rizhao, Shandong, P.R. China*
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Lei Kaixi, *Wuhan, Hubei, P.R. China*
Lei Yunqing, *Heyuan, Guangdong, P.R. China*
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Li Yanbin, *Beijing, P.R. China*

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Tan Yongting, *Beijing, P.R. China*
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Wang Juan, *Shanghai, P.R. China*
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Weng, Mei Han, *Taipei City, Taiwan, R.O. China*
Whittaker, Nicola, *London,*
Win Than Than, *Yangon, Myanmar*
Wong Ho Yin, *Tai Po, Hong Kong*
Wong Hoi Ting, *Tai Po, Hong Kong*
Wong Ka Yan, *Tuen Mum, Hong Kong*
Wong Shing Yan, Sarita, *Shatin, Hong Kong*
Wong Wai Ki, Vikki, *Shatin, Hong Kong*
Wootton, Ashley Gowan, *Great Dunmow, Essex*
Wu Cheng Lung, *New Taipei City, Taiwan, R.O. China*
Wu Chia Jung, *New Taipei City, Taiwan, R.O. China*
Wu Chien Chi, *New Taipei City, Taiwan, R.O. China*
Wu Hsin-Yi, *New Taipei City, Taiwan, R.O. China*
Wu Jeng Long, *Kaohsiung City, Taiwan, R.O. China*
Wu Ruolin, *Beijing, P.R. China*
Wu Shuai, *Beijing, P.R. China*
Wu Yu Chan, *Shenzhen, P.R. China*
Wyrley-Birch, Frederick John, *Hexham, Northumberland*
Xi Nanxia, *Qu Zhou City, Zhejiang, P.R. China*
Xia Mingqi, *Qingzhou City, Shandong, P.R. China*
Xiang Shihui, *Shanghai, P.R. China*
Xie Ziyun, *Beijing, P.R. China*
Xin Meiying, *Dalian City, Liaoning, P.R. China*
Xing Chen, *London*
Xiong Jaikai, *Sheung Wan, Hong Kong*
Xu Fan, *Shanghai, P.R. China*
Xu Jie, *Suzhou, Jiangsu, P.R. China*
Xu Ting, *Shanghai, P.R. China*
Xu Weixuan, *Beijing, P.R. China*
Xu Yan, *Shanghai, P.R. China*
Xu Zihao, *Beijing, P.R. China*
Xue Ru, *Shijiazhuang City, Hebei, P.R. China*
Xue Wenyu, *Shanghai, P.R. China*
Xue Zixuan, *Shanghai, P.R. China*
Yam Man Hung, *Tseung Kwan O, Hong Kong*
Yan Qiuli, *Beijing, P.R. China*
Yang Huey-Wenn, *Taipei City, Taiwan, R.O. China*
Yang Jia-Song, *Guanyin, Taoyuan, Taiwan, R.O. China*
Yang Qin, *Hangzhou, P.R. China*
Yang Wancheng, *Beijing, P.R. China*
Yang Xin, *Guilin, Guangxi, P.R. China*
Yang Yi, *Jinan, Shandong, P.R. China*
Yang Yujiao, *Beijing, P.R. China*
Yang Yunjing, *Montreal, Quebec, Canada*
Ye Hanqi, *Guilin, Guangxi, P.R. China*
Ye Lin, *Beijing, P.R. China*
Yeh Shu Fen, *Kaohsiung City, Taiwan, R.O. China*
Yeung Siau Fung, *New York, New York, USA*

Yeung Woon Ying, Maggie, *Tsing Yi, Hong Kong*
Yin Shihui, *Ningbo City, Zhejiang, P.R. China*
Yin Zhenzhu, *Poissy, France*
Yip Kar Men, *Wan Chai, Hong Kong*
Yoda, Yuko, *Tokyo, Japan*
Yu Ka Man, *Kwai Chung, Hong Kong*
Yu Shin Yang, *Taipei City, Taiwan, R.O. China*
Yu Tzu Fang, *Zhudong, Hsinchu, Taiwan, R.O. China*
Yu Yinglei, *Beijing, P.R. China*
Yuan Hang, *Shanghai, P.R. China*
Yuen, Angel, *Tsuen Wan, Hong Kong*
Yung Yat Kwok, *Yuen Long, Hong Kong*
Zhang Chen, *Shanghai, P.R. China*
Zhang Jie, *Beijing, P.R. China*
Zhang Liang, *Bedford, Bedfordshire*
Zhang Linxue, *Guilin, Guangxi, P.R. China*
Zhang Luqing, *Shenyang City, Liaoning, P.R. China*
Zhang Mei, *Beijing, P.R. China*
Zhang Min Yu, *Shenzhen, Guangdong, P.R. China*
Zhang Shuo, *Beijing, P.R. China*
Zhang Sirong, *Guilin, Guangxi, P.R. China*
Zhang Yan, *Guangzhou, Guangdong, P.R. China*
Zhang Yanling, *Shanghai, P.R. China*
Zhang Yi, *Shanghai, P.R. China*
Zhang Yixuan, *Beijing, P.R. China*
Zhang Yu, *London*
Zhang Zhizheng, *Beijing, P.R. China*
Zhao Wei, *Guilin, Guangxi, P.R. China*
Zhao Xinyi, *Beijing, P.R. China*
Zhao Yanhong, *Shanghai, P.R. China*
Zhao Yuan, *Shanghai, P.R. China*
Zheng Chenyu, *Nagoya City, Aichi, Japan*
Zheng Shuyuan, *Beijing, P.R. China*
Zhong Yuanyuan, *Beijing, P.R. China*
Zhou Baojie, *Dongying City, Shandong, P.R. China*
Zhou Hui, *London*
Zhou Meng, *Beijing, P.R. China*
Zhou Quan, *Beijing, P.R. China*
Zhou Yurui, *Tianjin, P.R. China*
Zhou Zihan, *Beijing, P.R. China*
Zhou Ziyang, *Guangzhou, P.R. China*
Zhu Qianwen, *Shanghai, P.R. China*
Zhu Shichao, *Guilin, Guangxi, P.R. China*
Zhu Yuanhua, *Shanghai, P.R. China*
Zhu Yun You, *Taoyuan City, Taiwan, R.O. China*
Zhu Zihui, *Beijing, P.R. China*
Zhuang Shao Wei, *Qingdao. Shandong Province, P.R. China*
Zwick, Annette, *London*

Diamond Diploma Examination

Qualified with Distinction

Ashri, Atul, *Reading, Berkshire*
Beard, Thomas Whitbread, *Eastbourne, East Sussex*
Chan Hiu Ching, *Shatin, Hong Kong*
Cheer, Peter Richard, *Somerton, Somerset*
Lai Ka Man, *Mayfair, London*
Leung Ying, Evie, *Tsing Yi, Hong Kong*
Li Hiu Ying, *Chai Wan, Hong Kong*
Lineker-Mobberley, Maryanne, *Bridgnorth, Shropshire*
Molon, Valentina, *Varese, Italy*
Moorhead, Lisa, *London*
Newson, John Frederick, *Calne, Wiltshire*
Perry, Fran, *Biggleswade, Bedfordshire*
Ruddie, Elaine, *London*
Saleem, Melanie, *Manchester, Greater Manchester*
Sandum, Mark Antony, *Bexleyheath, Kent*
Shaw, Stephanie Anne, *London*
Williams, Kathryn Ann Jenevora, *Dover, Kent*
Wyer, William, *Wilmslow, Cheshire*
Yiu King Ting, Eric, *Kowloon, Hong Kong*

Qualified with Merit

Boyce, Georgina Elizabeth, *London*
Chu Pui Suen, *Sham Shui, Hong Kong*
Foxwell, Kim, *Twickenham, Middlesex*
Fritz, Eric, *Tucson, Arizona, USA*
Fung Hang Shun Jessica, *Tai Po, Hong Kong*
Gonzalez, Olga, *New York, USA*
Harries, Rebecca, *Long Ditton, Surrey*
Jiang Haijing, *Sai Ying Pun, Hong Kong*
Le, Wai Hang, *Lai Chi Kok, Hong Kong*
Lo Hau Yin, *Kowloon, Hong Kong*
Lo On Ki, *Tsuen Wan, Hong Kong*
Marshall, Georgia Black, *Meopham, Kent,*
Nash-Wilson, Jake, *Bristol*
Rexworthy, Simon Ramsay, *Market Drayton, Shropshire*
Shek Sze Wan, *Tuen Mun, Hong Kong*
Spencer, Sally Jane, *Didcot, Oxfordshire*
Steele, Sarah, *York, Yorkshire*
Tang Tiankai, *Ningbo, Zhejiang, P.R. China*
Velickaite, Akvile, *London*
Walker, Susan, *Elwood, Victoria, Australia*
Wu Weiran, *Beijing, P.R. China*
Yip Pui Sze, *Tai Po, Hong Kong*

Qualfied

Ball, Gareth, *Letterkenny, County Donegal, R.O. Ireland*
Bowkett, Alexandra, *Stroud, Gloucestershire*
Bullmore, Elizabeth Mary, *Birmingham, West Midlands*
Callan, George, *London*
Chan Im Fan, *Central, Hong Kong*
Chan Ka Ling, *Tin Shui Wai, Hong Kong*
Chan Lap Yee, *Shueng Shui, Hong Kong*
Chan Nga Fong, *Macau, P.R. China*
Chan Tak Wai, *Shatin, Hong Kong*
Chan Wai Chi Chilly, *Tin Shui Wai, Hong Kong*
Chau Kam Chi, *Kowloon, Hong Kong*
Cheang Chi Ioi, *Macau, P.R. China*
Chen Xiao Qin, *Kwai Chung, Hong Kong*
Cheng Hei Lam, *Tai Po, Hong Kong*
Cheng Oi Lam, *Yuen Long, Hong Kong*
Cheng Wai Ching, *Kowloon, Hong Kong*

Cheng Wai Lei, *Sai Wan, Hong Kong*
Cheung Wing Yee, *Tsing Yi, Hong Kong*
Chiu Ka Man, *Kwun Tong, Hong Kong*
Cho, Sze Man, *Kwun Tong, Hong Kong*
Chui Chun Hin, *Shatin, Hong Kong*
Donnelly (nee Smith), Yvonne Louise, *Prescot, Merseyside*
Fong Hoi Yip, William, *Kowloon, Hong Kong*
Friar, Harry, *Romford, Essex*
Fu Haitao, *Beijing, P.R. China*
Fu Xinli, *Beijing, P.R. China*
Gill, Harinder, *Southall, Middlesex*
Gogarty, Madeleine, *Wimbledon, London*
Heltzel, Christopher, *Kilkenny, County Kilkenny, R.O. Ireland*
Ho Pak Ngai, *Shatin, Hong Kong*
Jogia, Sonal, *Harrow, Middlesex*
Ketcher, Alyce Janet, *Wellington, Somerset*
Kolator, Barbara, *London*
Kuang Chuyi, *Beijing, P.R. China*
Kwong Tak Chiu, *Tung Chung, Hong Kong*
Kwong Wai Fan, *Tin Shui Wai, Hong Kong*
Kwong San Fong Cathy, *Kowloon, Hong Kong*
Lam Pui Yu, Carol, *Ma On Shan, Hong Kong*
Lam Yin Han Neona, *To Kwa Wan, Hong Kong*
Lam Wai Ting, *Quarry Bay, Hong Kong*
Lau Kin Yip, *Ma On Shan, Hong Kong*
Lau Wai Kin, *Shatin, Hong Kong*
Lee Kwun San, *Shatin, Hong Kong*
Lee Po Yan, *Lam Tin, Hong Kong*
Leicester, Keith, *St Helens, Merseyside*
Li Dongyang, *Beijing, P.R. China*
Li Man Wah Irine, *Tseung Kwan O, Hong Kong*
Li Wenzhuo, *Wuhan, Hubei, P.R. China*
Li Yin Hu, *Hung Ham, Hong Kong*
Liu Man Leong, Vincent, *Kowloon, Hong Kong*
Milo, Nathan Nicholas, *London*
Minns, Russell James, *Northampton*
Ng Kwok Hung, *Mongkok, Hong Kong*
Ng Wing Man, *Tsuen Wan, Hong Kong*
Ng Wing Sze, *Sheung Shui, Hong Kong*
Niu Tianju, *London*
Poon Ka Ben, *Yuen Long, Hong Kong*
Rashid, Attif, *Northampton, Northamptonshire*
Ross, Yvonne, *Grangecon, County Wicklow, R.O. Ireland*
Saban, Makarim, *Taipo, Hong Kong*
Schindler, Leo Joseph Peter, *Kingston-upon-Thames, Surrey*
Spicer, Paul, *Hove, East Sussex*
Sze Cheung, *Tung Chung, Hong Kong*
Tai Pui Man, *Yuen Long, Hong Kong*
Tam Ka Hey, *Tuen Mun, Hong Kong*
Tam Ka Ming, *Shatin, Hong Kong*
Tam Suk Han, Sara, *Ma On Shan, Hong Kong*
Taylor, Elizabeth Anne, *Midhurst, West Sussex*
Ting Evon, *Tsuen Wan, Hong Kong*
Tse Cheuk Kwan, *Yuen Long, Hong Kong*
Tse Lai Kwan, *Kowloon, Hong Kong*
Tso Hau Yee, Michelle, *Causeway Bay, Hong Kong*
Vildiridi, Lilian Venetia, *Knightsbridge, London*
Wan, Jinghan, *Beijing, P.R. China*
Wang Yizhu, *Beijing, P.R. China*
Wehrly, Richard, *Strandhill, Co. Sligo, R.O. Ireland*
Wong Ching Lan, Teresa, *Tuen Mun, Hong Kong*
Wong Hon Lam, Donald, *Kowloon, Hong Kong*
Wong Kwan Wai Alison, *Kennedy Town, Hong Kong*
Wong Kwong Mei Ice, *Kowloon, Hong Kong*
Wong Po Yin, *Tseung Kwan O, Hong Kong*
Wong Sin Yan, *Sai Wan Ho, Hong Kong*
Wong, William, *Kowloon, Hong Kong*
Wong Yee Fan, Angela, *Chai Wan, Hong Kong*
Wong Kay Yee, *Tseung Kwan O, Hong Kong*
Wormack, Michael, *London*
Wu Yee Lee, *Tuen Mun, Hong Kong*
Xie Zhuohong, *Beijing, P.R. China*
Yang Dong Wen, *Kowloon, Hong Kong*
Yang Ning Ning, *Kowloon, Hong Kong*
Yau Chor Suet, *Shatin, Hong Kong*
Yeung Yuen Man, *Shatin, Hong Kong*
Yiu Yan Fong, Winnie, *Wan Chai, Hong Kong*
Zhang Zhizheng, *Beijing, P.R. China*

OBITUARIES

Roger Leon Merk died on 3 November 2015. Roger was one of a kind, an exceptional man, husband and friend. No tragedies stopped his zeal to live his life to the fullest. He lost his father at 6, his grandfather at 10, and his mother at 17. His Aunt Myrtle took him in and created a loving, caring home in San Diego, and helped him to become the educated man he was. Her husband Chuck got him interested in gems and minerals. He took gemmology to another level; he became an icon, educator, collector and mentor, with a particular passion for jade.

Tragedy struck when his heart failed at a young age. He was lucky enough to receive a heart transplant that gave him another 20 years.

Roger organized the annual Sinkankas Symposia (13 in all) in honour of John Sinkankas. These themed events were held at the Gemological Institute of America campus in Carlsbad, California, USA, and were co-sponsored by the San Diego Mineral & Gem Society.

Roger is survived by a wealth of family and friends, his wife, this aunt, another aunt, his brothers, sister, and cousins.

Myrtle PeterSchieck

Douglas Brill FGA (D.1987), Halifax, West Yorkshire, died on 2 August 2015.

Ann P. Sabina Stenson FGA, Ottawa, Ontario, Canada, died recently.

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Learning Opportunities

CONFERENCES AND SEMINARS

3rd Annual Jewelry History Series
26–27 January 2016
Miami Beach, Florida, USA
www.originalmiamibeachantiqueshow.com/show/jewelry-series

45th ACE IT Annual Winter Education Conference
31 January–1 February 2016
Tucson, Arizona, USA
www.najaappraisers.com/html/conferences.html

AGTA Tucson GemFair 2016
2–7 February 2016
Tucson, Arizona, USA
www.agta.org/tradeshows/gft-seminars.html
Note: Includes a seminar programme.

Pueblo Gem & Mineral Show Lecture Series
2 and 5 February 2016
Tucson, Arizona, USA
www.pueblogemshow.com/show-events.aspx

AGA Cutting Edge Conference
3 February 2016
Tucson, Arizona, USA
http://accreditedgemologists.org/currevent.php

Tucson Gem and Mineral Show
11–14 February 2016
Tucson, Arizona, USA
www.tgms.org
Note: Includes a seminar programme.

PDAC International Convention, Trade Show & Investors Exchange
6–9 March 2016
Toronto, Ontario, Canada
www.pdac.ca/convention
Session of interest: Diamonds in Southern Africa: Back to the Beginning

Hasselt Diamond Workshop 2016
9–11 March 2016
Hasselt, Belgium
www.uhasselt.be/sbdd

The Open Forum on Sustainability & Responsible Sourcing in the Jewelry Industry
10–13 March 2016
New York, New York, USA
www.jewelryindustrysummit.com

Amberif—International Fair of Amber, Jewellery and Gemstones
16–19 March 2016
Gdansk, Poland
www.amberif.amberexpo.pl/title,SEMINAR,pid,1284.html
Note: Includes a seminar programme.

AGS Conclave
13–16 April 2016
Washington DC, USA
www.americangemsociety.org/conclave2016

Swiss Gemmological Society Conference
17–19 April 2016
Magglingen, Switzerland
www.gemmologie.ch

Arusha Gem Fair
19–21 April 2016
Arusha, Tanzania
www.arushagemshow.com
Note: Includes a seminar programme.

Scottish Gemmological Association Conference 2016
29 April–2 May 2016
Peebles, Scotland
www.scottishgemmology.org/conference

2nd Mediterranean Gemmological and Jewellery Conference
7–9 May 2016
Valencia, Spain
www.gemconference.com

30th Annual Santa Fe Symposium
15–18 May 2016
Albuquerque, New Mexico, USA
www.santafesymposium.org

SNAG^{neXt}
19–21 May 2016
Asheville, North Carolina, USA
www.snagmetalsmith.org/events/snagnext

10th International Conference on New Diamond and Nano Carbons
22–26 May 2016
Xi'an, China
http://ndnc2016.xjtu.edu.cn

Compiled by Georgina Brown and Brendan Laurs

Northwest Jewelry Conference
12–14 August 2016
Seattle, Washington, USA
www.northwestjewelryconference.com

46th ACE IT Annual Mid-Year Education Conference
13–16 August 2016
Newport Beach, California, USA
www.najaappraisers.com/html/conferences.html

2016 International Appraisers Conference
11–14 September 2016
Boca Raton, Florida, USA
www.appraisers.org/Education/conferences

IRV Loughborough Conference
17–19 September 2016
Loughborough, UK
www.jewelleryvaluers.org/Loughborough-Conference

EXHIBITS

Europe

Celts: Art and Identity
Until 31 January 2016
British Museum, London
www.britishmuseum.org/whats_on/exhibitions/celts.aspx

Urartian Jewellery Collection
Until 31 January 2016
Rezan Has Museum, Istanbul, Turkey
www.rhm.org.tr/en/event/rezan-has-museum-urartian-jewellery-collection

Brilliant! – Jewellery – Photograph – Sound
Until 31 January 2016
The National Museum of Finland, Helsinki, Finland
www.kansallismuseo.fi/en/nationalmuseum/exhibitions/temporary#brilliant_jewelry

Fitting and Befitting—Fibulae and Brooches
Until 21 February 2016
Schmuckmuseum, Pforzheim, Germany
www.schmuckmuseum.de/flash/SMP_en.html

Bejewelled Treasures: The Al Thani Collection
Until 28 March 2016
Victoria and Albert Museum, London
www.vam.ac.uk/content/exhibitions/exhibition-bejewelled-treasures-the-al-thani-collection

Take it Personally [Jewellery and Adornment]
Until 1 June 2016
Museum of Cultural History, Oslo, Norway
www.khm.uio.no/english/visit-us/historical-museum/temporary-exhibitions/2015/this-is-personal.html

Open Space—Mind Maps. Positions in Contemporary Jewellery
11 March 2016–15 May 2016
Nationalmuseum Design, Stockholm, Sweden
www.nationalmuseum.se/sv/English-startpage/Exhibitions/Upcoming-Exhibitions

A Motley Crew—New Pieces from the Collection
18 March 2016–12 June 2016
http://www.museumspass.com/en/Museums2/Pforzheim/Schmuckmuseum-Pforzheim/A-Motley-Crew

Heavenly Bodies—The Sun, Moon and Stars in Jewellery
8 July–30 October 2016
Schmuckmuseum, Pforzheim, Germany
www.schmuckmuseum.de/flash/SMP_en.html

Elements: From Actinium to Zirconium
Until 26 February 2017
Ulster Museum, Belfast, Northern Ireland
http://nmni.com/um/What-s-on/Current-Exhibitions/Elements---From-Actinium-to-Zirconium

North America

The Glassell Collections of African, Indonesian and Pre-Columbian Gold
Until 30 January 2016
Museum of Fine Arts, Houston, Texas, USA
www.mfah.org/art/collections/Glassell-Gold-Collections

Turquoise, Water, Sky: The Stone and Its Meaning
Until 2 May 2016
Museum of Indian Arts & Culture, Santa Fe, New Mexico, USA
www.indianartsandculture.org/current?&eventID=1989

A Passion for Jade: The Heber Bishop Collection
Until 19 June 2016
The Metropolitan Museum of Art, New York, New York, USA
www.metmuseum.org/exhibitions/listings/2015/passion-for-jade

Variations on a Theme: 25 Years of Design from the AJDC
Until July 2016
Gemological Institute of America, Carlsbad, California, USA
www.gia.edu/gia-museum-variations-theme-25-years-design-AJDC

Thunderbirds: Jewelry of the Santo Domingo Pueblo
Until 5 September 2016
Abby Aldrich Rockefeller Folk Art Museum, Williamsburg, Virginia, USA
www.colonialwilliamsburg.com/do/art-museums/rockefeller-museum/thunderbirds-jewelry

Fabergé from the Matilda Geddings Gray Foundation Collection
Until 27 November 2016
The Metropolitan Museum of Art, New York, New York, USA
www.metmuseum.org/exhibitions/listings/2011/faberge

Glitterati. Portraits & Jewelry from Colonial Latin America
Until 27 November 2016
Denver Art Museum, Denver, Colorado, USA
www.denverartmuseum.org/exhibitions/glitterati

Arts of Islamic Lands: Selections from The al-Sabah Collection, Kuwait
Until 29 January 2017
Museum of Fine Arts, Houston, Texas, USA
www.mfah.org/exhibitions/arts-islamic-lands-selections-al-sabah-collection-

Gold and the Gods: Jewels of Ancient Nubia
Until 14 May 2017
Museum of Fine Arts, Boston, Massachusetts, USA
www.mfa.org/exhibitions/gold-and-gods

City of Silver and Gold: From Tiffany to Cartier
Ongoing
Newark Museum, New Jersey, USA
www.newarkmuseum.org/SilverAndGold.html

Fabergé: From a Snowflake to an Iceberg
Ongoing
Houston Museum of Natural Science, Texas, USA
www.hmns.org/exhibits/special-exhibitions/faberge-a-brilliant-vision

Gemstone Carvings
Ongoing
Houston Museum of Natural Science, Texas, USA
www.hmns.org/exhibits/special-exhibitions/gemstone-carvings

Gilded New York
Ongoing
Museum of the City of New York, New York, USA
www.mcny.org/content/gilded-new-york

Jewelry, from Pearls to Platinum to Plastic
Ongoing
Newark Museum, New Jersey, USA
www.newarkmuseum.org/jewelry

Mightier than the Sword: The Allure, Beauty and Enduring Power of Beads
Ongoing
Yale Peabody Museum of Natural History, Yale University, New Haven, Connecticut, USA
http://peabody.yale.edu/exhibits/mightier-sword-allure-beauty-and-enduring-power-beads

Australia

Opals
Until 14 February 2016
South Australian Museum, Adelaide, South Australia
www.samuseum.sa.gov.au/explore/exhibitions/opals

A Fine Possession: Jewellery and Identity
Until 22 May 2016
Powerhouse Museum, Sydney, New South Wales, Australia
www.powerhousemuseum.com/exhibitions/jewellery

OTHER EDUCATIONAL OPPORTUNITIES

Gem-A Workshops and Courses
Gem-A, London
www.gem-a.com/education/course-prices-and-dates.aspx

Lectures with The Society of Jewellery Historians
Burlington House, London, UK
www.societyofjewelleryhistorians.ac.uk/current_lectures

23 February 2016
Jo Whalley—A Journey to India: The Jewellers' Art Revealed

26 April 2016
Henriette Lidchi—Navajo and Pueblo Jewellery of the American Southwest

28 June 2016
Neil Wilkin—Bronze Age Bodily Adornment: How was It Made and Worn

27 September 2016
Galina Korneva—The Grand Duchess Maria Pavlovna's Contacts with Paris Jewellers and her Collection of Treasures

New Media

Tourmaline—Fascinating Crystals with Fantastic Inner Worlds

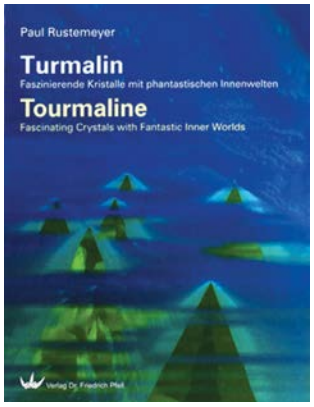

By Paul Rustemeyer, 2015. Verlag Dr. Friedrich Pfeil, Munich, Germany, 272 pages, illus., ISBN 978-3899371949, www.pfeil-verlag.de/06geol/e4_94.php (in English and German). €59.80 hardcover.

In the preface of this impressive book, the author states: "The observer might become meditatively immersed in the tourmaline paintings and may go on imaginative trips into the new landscapes." Indeed the photographs in this book (many of which resemble beautiful paintings) certainly transport the reader to another world—the colourful patterns seen in slices of tourmaline.

The book is printed on high-quality paper, is beautifully designed and laid-out, and the reproduction quality of the photos is excellent. Many of the tourmaline crystals are shown before they were sliced and are accompanied by photographs of the resulting slices (or series of slices). Selected full-page enlargements of some of the more spectacular portions of the slices further reveal amazing colours and patterns that would mostly go unseen without magnification. A black background is used on every page not containing a full-page photo, allowing the images to truly 'pop'. The limited amount of text (always appearing on left-hand pages) is well written and easy to understand for non-specialists. Different font colours are used for English (yellow) and German (white), making it easy for the reader to find their preferred language.

The author has arranged the sections of the book according to the main cause of the dominant patterns shown by the slices:

- 'From Black Crystals to TurmalinArt' presents a series of examples that reveal the inner beauty of black tourmaline crystals when thin sections of them are prepared perpendicular (and in some cases, parallel) to the c-axis. The author explains how he saws the crystals into slices and polishes one side before mounting them on glass slides for final grinding and polishing until the optimal colour appearance is displayed (typically only 0.1–0.01 mm in thickness).
- 'The Structure of Tourmalines' briefly reviews the crystal structure of the mineral to help put the geometric patterns seen in slices into context. Also included are photos of crystal specimens showing myriad variations in colour and morphology.
- 'The Color Palette of the Tourmalines' illustrates the tremendous variety of colours seen in faceted gemstones and in crystals. Simplified explanations of the causes of colour are provided.
- 'The Growth of Tourmaline Crystals' contains many attractive diagrams and photos of tourmaline specimens to illustrate their crystallization process in granitic pegmatites. (Tourmaline formation in metamorphic rocks is not covered.)
- 'The Structures of Crystal Forms' provides an excellent correlation between the various crystal faces and the patterns seen in slices cut perpendicular to the c-axis.
- 'Rim Structures' focuses on features seen within the concentrically zoned portions of slices, which correspond to prism faces.
- 'Oriented Overgrowth' displays the complex mosaic structures seen in slices when a crystal is overgrown by a series of needles and tubes parallel to the c-axis. Also shown are features attributed to skeletal overgrowths.
- 'Delta Structures' portrays a specific type of triangular zoning in tourmaline slices that corresponds to the localized growth of steeper pyramidal faces. The resulting features are particularly reminiscent of landscapes, especially when they are influenced by dislocations in the crystal.
- 'Trigonal Dislocations' provides examples of the complex patterns that result when defects in the lattice of a growing crystal propagate as dislocations.
- 'Division into Parallel Aggregates' shows interesting mosaic networks that result when a growing crystal gradually or abruptly changes into an aggregate structure that is oriented parallel to the c-axis.
- 'The Healing of Broken Tourmalines' records periods of regrowth in 'bent' and broken crystals, including the formation of parallel tubes that may create chatoyancy in cabochons.
- 'Naturally Corroded Tourmaline Crystals' depicts geometrical etch pits and hillocks

resulting from post-grown dissolution, beautifully revealed in photomicrographs taken in reflected light.

- 'Healing of Corroded Tourmalines' shows the results of further crystal growth (often by tourmaline of a different colour) after a period of dissolution.
- 'Healed Corrosion of Cavities' displays some particularly abstract patterns that are produced when irregular areas of dissolution that penetrated deep within a crystal are filled-in by subsequent tourmaline growth.

At the conclusion of the book, the author provides a brief bibliography of tourmaline monographs (with a full listing of tourmaline literature supplied at http://www.pfeil-verlag.de/ef1.html), as well as an index.

While it is easy to become pleasurably absorbed in the richness of the photography, the scientific value of this book should not be overlooked. Through the use of helpful diagrams and photographic comparisons of crystals before and after slicing, as well as neatly arranged series of slices that were obtained from the same crystal, the reader comes away with a much better understanding of the complex crystal growth history of tourmaline.

This reviewer noted only a few very minor errors in the text: p. 42 indicates that the blue colour of Paraíba tourmaline is due to 4% copper, while much lower amounts of Cu are typical (i.e. ~0.5–2 wt.% CuO); p. 44 gives the location of Sweet Home mine rhodochrosite crystals as Utah, rather than Colorado; p. 160 mentions earthquakes as the cause of broken tourmalines that subsequently undergo regrowth in pegmatite pockets, but such breakage is commonly ascribed to pocket rupture due to fluid overpressure; and throughout the book verdelite (green tourmaline) is referred to as 'verdilithe'. In addition, a table-of-contents page would have been helpful for navigating the book.

It is rare to encounter such an effective and inspirational melding of art and science applying to any mineral. This book is sure to please tourmaline aficionados, and also will appeal to many mineralogists, gemmologists, photographers and those who appreciate the beauty of the natural world.

Brendan M. Laurs

Fei Cui Jade—A Stone & a Culture

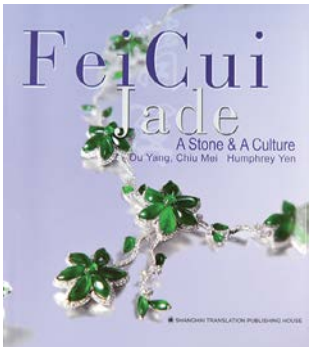

By Chiu Mei Ou Yang and Humphrey Yen, 2015. Shanghai Translation Publishing House, Shanghai, China, 248 pages, illus., ISBN 978-7532764716. HK$480.00.

It is rare in the marketplace to see a comprehensive book on jadeite that is written in English. Both authors have over 30 years of expertise studying jadeite, and they present their information from a Chinese and a gemstone professional point of view.

The reader soon learns that in China what we call *jadeite* is referred to as *fei cui*. This term is said to come from the Chinese name for the kingfisher, as its feathers are so beautiful. The authors repeat the term *fei cui jade* hundreds of times in the book, and this reviewer found this a bit redundant, although it is understandable that the authors wish to promote the terminology used by the Chinese. Many countries have colloquial names for various gem materials. For instance, colourless topaz is often called *gouttes d'eau* in Brazil, alluding to the appearance of drops of water.

The book is well laid out, and includes the following chapters:

1. The Concept and Definition of Jade
2. The Occurrence of Deposits of Fei Cui Jade
3. Color and Other Important Factors in the Valuation of Fei Cui Jade
4. The Varieties of Fei Cui Jade
5. Classification of Rough Fei Cui Jade
6. The Processing Techniques and Classification of Finished Fei Cui Jade Products
7. Jade-like Minerals and Simulants
8. Artificial Treatments of Fei Cui Jade and Their Identification
9. Valuation of Fei Cui Jade
10. The Trending in Marketing of Fei Cui Jade

Each chapter contains a variety of interesting facts and explanations, and many of these will be unfamiliar to most Westerners. For instance, Chapter 3 starts with (1) why jadeite comes in so many colours, and then points out the differences between (2) the primary colouring elements Fe, Cr and Mn, and the secondary colours caused by oxidation and decomposition, and ends with (3) the 'base' or 'fabric' of fei cui jade. This reviewer has not seen such a compilation discussed previously. The authors further provide a classification of six 'bases', and the most amusing is "4) Cooked lotus root: Translucent color like the cooked lotus root used in Chinese cuisine usually with a slight pink or purple color. A cooked lotus root base is not considered very good."

The book contains approximately 380 colour photographs, illustrations and diagrams. The first

10 full-page colour photos are excellent, and in this reviewer's opinion they alone are probably worth the price of the book. Also present are several tasteful advertisements (full-page size and in colour) that are not terribly distracting.

When gem collectors and dealers consider the market value of coloured stones, a comparison with jadeite yields an interesting perspective. The jade market changed in 2006 when the Burmese government brought the first Chinese dealers into the auctions, and jadeite sales went from millions to billions of dollars within a few short years. By comparison, a recent emerald auction held by Gemfields generated US$40 million and made international headlines. When this is compared to the ~US$2.04 billion generated by a recent Burmese jade auction, one realizes this is 50 times the size of that emerald headline. There have been many billion-dollar-plus auctions of Burmese jadeite (see www.palagems.com/gem_news_burma_stats.php), making it the most important coloured stone in terms of sales during the past decade.

William Larson

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* Compiled by Georgina Brown and Brendan Laurs

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Compiled by Brendan Laurs

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Notes on changes from prior subject indexes:
- Author names are no longer listed alphabetically by name within this index, but they continue to be shown in parentheses in this subject index.
- Book reviews and reviews of other media are now listed alphabetically by title under the single heading 'Book and other media reviews', instead of being individually listed throughout the Index.
- The Abstracts section of *The Journal* has been replaced by Literature of Interest.

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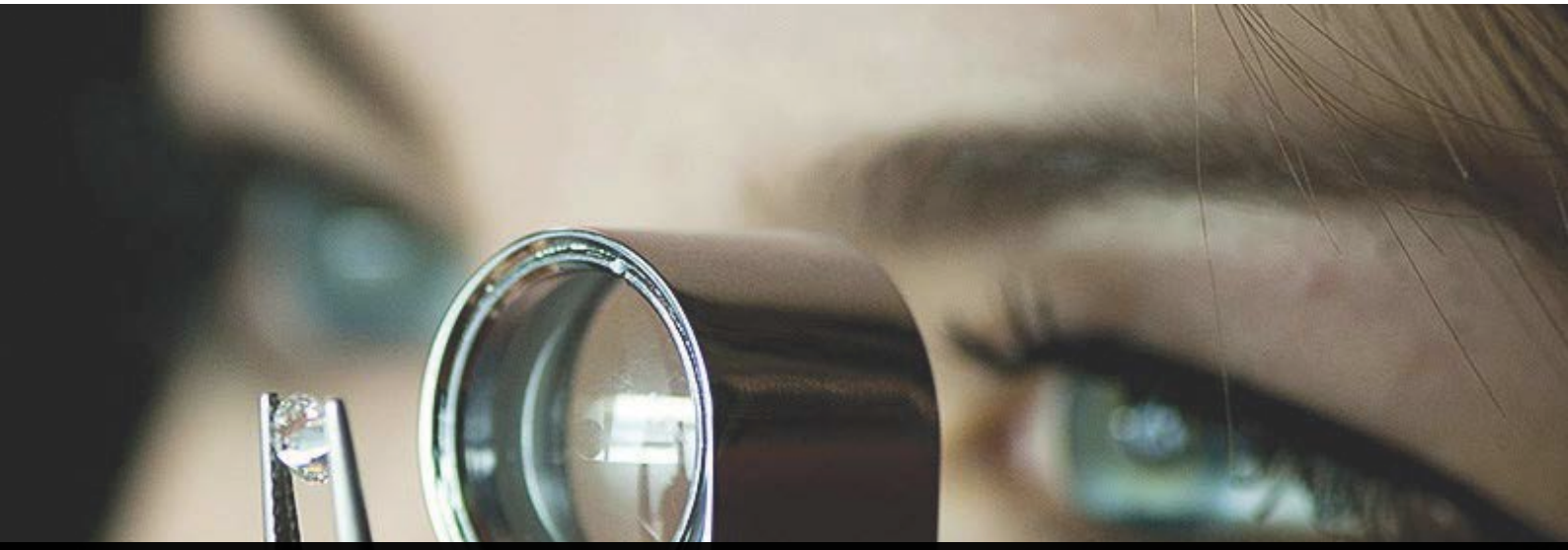

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Little by little,
a little becomes a lot.
— Tanzanian proverb

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Tanzanite, Merelani Hills, Tanzania • 21.79 ct • 16.8 x 16.0 x 1.05 mm
Photo: Mia Dixon

The Journal of Gemmology

Volume 35 / No. 1 / 2016

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The Journal of Gemmology
Volume 35 / No. 1 / 2016

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Cover Photo: Cat's-eye chrysoberyls are shown here in a gold ring (11.71 ct oval), as loose round cabochons (11.00 and 14.09 ct) and mounted in gold cufflinks (6.48–8.89 ct). Courtesy of The Edward Arthur Metzger Gem Collection at the Heasley Museum, Cornell University, Ithaca, New York, USA; composite photo by Jeff Scovil.

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What's New

INSTRUMENTS AND TECHNIQUES

DiamondDect Diamond Identification Instrument

TaiDiam Technology Co. Ltd. (Zhengzhou, China) announced in September 2015 the availability of the DiamondDect portable diamond identification instrument from its associated company Krisdiam. Weighing approximately 8 kg, the instrument includes a polariscope, microscope, fibre-optic illuminator and more, plus a Windows-based computer tablet equipped with identification software to separate CVD and HPHT synthetics from natural diamonds. According to TaiDiam, the instrument can analyse colourless to near-colourless diamonds from 0.01 ct (loose) or 0.03 ct (mounted) up to 10 ct. For additional information, visit http://en.taidiam.com/news_detail/newsId=61.html. A user manual with helpful information on separating natural from synthetic diamonds is available at http://en.taidiam.com/download_detail/&downloadsId=19.html.

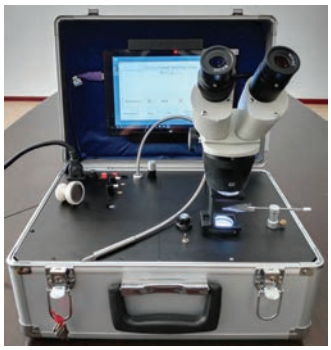

CMS

Triple D Photo Kit

In February 2015, Triple D Experience Ltd. in Israel launched a Photo Kit for gem photography that works with a smartphone. The kit consists of a portable, compact unit that includes a stone holder, light source, background and magnifier that cradles a smartphone, enabling the user to take a high-quality photo or video of a gemstone. The accompanying free smartphone app (for iPhone and Android) enables the user to enter stone data and an identification report, send information to clients, communicate via live chat, and store information for ease of access. To learn more, visit http://tripled-experience.com.

CMS

Upgraded DiamondView Instrument

In June 2015, the De Beers Group of Companies released through its International Institute of Diamond Grading & Research an enhanced version of the DiamondView. The upgraded instrument produces a surface fluorescence image that provides information on a sample's growth history that is useful for separating natural from synthetic diamonds. The upgraded model has changeable filters that are useful for enhancing features shown by some synthetic diamonds, particularly the latest-generation CVD products that show blue fluorescence. The instrument is available in a standard magnification model for stones weighing 0.05–10 ct, and in a high-magnification version for melee-sized goods of 0.01–0.20 ct. A new adapter for the vacuum stone holder allows for the examination of some jewellery items such as stud earrings and simple rings. For more information, visit www.iidgr.com/en/instruments/diamondview.

BML

Variofoc LED Lighting System

In March 2015, System Eickhorst released the Variofoc LED incident lighting system, which features a series of interchangeable LED heads designed for use in a double-gooseneck lamp unit. Three types of LED heads are available: spot, flood and diffuse, each in colour temperatures of neutral white (6,000 K) or daylight (4,000 K). Another interchangeable LED head provides long-wave UV illumination (366 nm). A variety of mountings are available, including a foot plate that allows the unit to be used in conjunction with a gemmological microscope. Visit www.eickhorst.com/en/lamps-lighting/desktop-lights/variofoc-led/merkmale.

BML

NEWS AND PUBLICATIONS

AGTA GemFair Tucson Seminars

The American Gem Trade Association hosted an array of seminars 3–6 February 2016 in Tucson, Arizona, USA. The seminars covered various aspects of gem mining, marketing, industry, identification and jewellery by presenters from around the world. A flash drive containing recordings of 27 of the seminars can be purchased for US$50.00 for non-AGTA members (AGTA members have access through the AGTA eLearning online program). Visit www.agta.org/education/seminars.html for the order form, as well as a summary of the presentations and speakers. *CMS*

Environmental and Social Responsibility for Coloured Stones

The Responsible Ecosystems Sourcing Platform released an International Working Group report on 29 January 2016 titled 'Challenges to Advancing Environmental and Social Responsibility in the Coloured Gems Industry'. Among the 10 major challenges discussed are the importance of tailoring socioeconomic solutions to the unique needs of each geopolitical venue and the lack of basic awareness of environmental principles. For a summary description and a link to the full report, visit http://tinyurl.com/gopvosp. *CMS*

Gold Demand Trends 2015

The World Gold Council released its annual report in February 2016, with a summary web page at www.gold.org/supply-and-demand/gold-demand-trends, where the full report, press report and statistics can be downloaded. Gold demand in the fourth quarter increased to a 10-quarter high of 1,117.7 tonnes. Full-year demand was virtually unchanged, with weakness in the first half offset by strength in the second half. Fourth-quarter growth was driven by central banks and investment, offset by a marginal contraction in jewellery and continued declines in technology. Supply remained constrained: Annual mine production increased by the slowest rate since 2008 (+1%) and recycling dropped to multi-year lows. Total supply declined 4% to 4,258 tonnes, the lowest since 2009. *CMS*

GSJ 2015 Annual Meeting Abstracts

Abstracts of papers presented at the 2015 Annual Meeting of the Gemmological Society of Japan are available at www.jstage.jst.go.jp/browse/gsj. The abstracts are written in Japanese with a brief English summary provided. Abstracts from prior GSJ conferences dating back to 2001 are also available.

CMS

ICGL *Newsletter*

The Winter 2015 issue of the International Consortium of Gem-Testing Laboratories *Newsletter* is now available at http://icglabs.org. Topics include use of a multi-spectral induced luminescence imaging system for screening of near-colourless HPHT synthetic diamond melee in China, identification of dyed golden South Sea cultured pearls and examination of a treated blue diamond. *CMS*

Large CVD synthetic diamond seen by HRD Antwerp

On 28 September 2015, HRD Antwerp posted an article by Ellen Barrie and Ellen Biermans titled

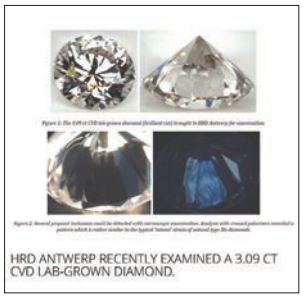

'HRD Antwerp Recently Examined a 3.09 ct CVD Lab-Grown Diamond' at www.hrdantwerp.com/en/news/hrd-antwerp-recently-examined-a-309-ct-cvd-lab-grown-diamon. The report contains a thorough description of the large CVD synthetic, including photomicrographs, DiamondView images, and both UV-Vis and photoluminescence spectra. *CMS*

MAGI Application Note on Diamond Type

The M&A Gemological Instruments website posted 'Application Note: Diamond classification – the diamond types', by Alberto Scarani and Mikko Astrom, on 29 January 2016. It provides a summary of diamond types and impurities as background to a discussion of FTIR spectroscopy and MAGI's GemmoFtir Diamond Type Analysis software. To download the report, visit www.gemmoraman.com/Articles//DiamondTyping.aspx. *CMS*

SSEF *Facette*

The Swiss Gemmological Institute SSEF has released the latest issue of *Facette Magazine* (No. 22, February 2016), which is available at www.ssef.ch/research-publications/facette. It describes: SSEF's new laboratory in Basel; SSEF's criteria for colour terms 'pigeon blood red' and 'royal blue'; rubies from Mozambique (including their low-temperature treatment) and Madagascar (Andilamena); sapphires from Madagascar (Andranondambo), Nigeria and Thailand (Kanchanaburi); REE in danburite; heat treatment of spinel from Mahenge, Tanzania; cobalt diffusion-treated spinel; a challenging Ramaura synthetic ruby; natural diamonds found in a parcel of HPHT synthetic diamonds; analysis of melee-size diamonds and small baguettes with the Lumos micro-FTIR spectrometer; updates concerning the ASDI instrument for analysing melee-size diamonds; pearl analysis with X-ray phase contrast and scattering imaging; pearl structures visualized by neutron scattering; 'ageing' treatment of pearls; a 'historic' necklace containing cultured pearls; carbon-14 dating of pearls from a shipwreck; several exceptional items sold at auction by Christie's and Sotheby's in 2014–2015; examination of iconic rubies from Mozambique; conference reports; recaps of SSEF courses, instrumentation and published research; and more. *BML*

Updated Cumulative Index for *The Journal of Gemmology*

In February 2016, Gem-A released the first update of *The Journal*'s cumulative index, covering all issues from 1947 to 2015 (Volumes 1–34). The contents are listed by subject, but the PDF file also can be searched for specific authors as well as topics. The cumulative index is available only in electronic format for free download from *The Journal*'s website at www.gem-a.com/publications/journal-of-gemmology/indexes.aspx. *CMS*

Wyoming Jades Revisited

In mid-December 2015, Palagems.com posted an article by the late Roger Merk FGA, titled 'Wyoming jades revisited' at http://m.palagems.com/wyoming-jades-revisited. The article is a personal look at the history and types of nephrite from Wyoming, USA, with photos of some exceptional examples of rough, sliced and fashioned specimens that illustrate the range of colours, textures and exterior appearances. *CMS*

OTHER RESOURCES

GemeSquare App and GemePrice5.0

Released in January 2016 by GemeWizard Inc. (Ramat Gan, Israel), the GemeSquare smartphone app is a free colour communication system that allows users to precisely define and describe a particular colour; both iOS and Android devices are supported. In February 2016, GemeWizard released GemePrice5.0, the most recent edition of this online wholesale pricing system for diamonds, coloured stones and jewellery. New to this version are 10 gem varieties that display different textures or optical effects, including turquoise, lapis lazuli, agate and moonstone. The system is available only to gem-industry professionals through subscription at www.gemewizard.com/store-price.php. *CMS*

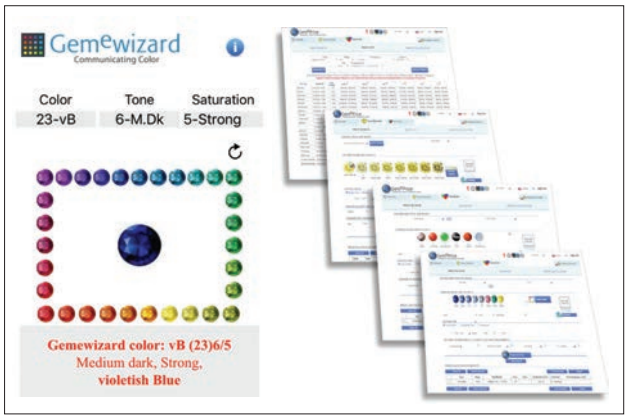

Historical Reading Lists from the GIA Library

The Richard T. Liddicoat Gemological Library at the Gemological Institute of America (Carlsbad, California, USA) recently posted four Historical Reading lists online: 'Diamonds in Arkansas', 'The Koh-i-noor Diamond', 'Pearls from India' and 'Ruby Mines of Burma'. Prepared by Dr James Shigley, each list includes brief descriptions of the references cited, along with information about where to locate the articles. To peruse these lists, visit www.gia.edu/library and click on the links under 'Recommended Reading & Bibliographies'. *CMS*

Hyperion Inclusion Search Engine

In December 2015, Lotus Gemology Co. Ltd. (Bangkok, Thailand) launched Hyperion, an online photographic library of gem inclusions. It includes a search feature that enables the user to look for images based on gem type, origin, enhancement and/or keyword. Gem types include natural and synthetic ruby, sapphire and spinel. Origins include 31 countries and five types of synthetics. Under enhancement, the options are 'none' plus 10 treatment choices. Also available is a useful listing of selected literature on gem inclusions. Use of the service is free at www.lotusgemology.com/index.php/library/inclusion-gallery, but note that the images are copyrighted. *CMS*

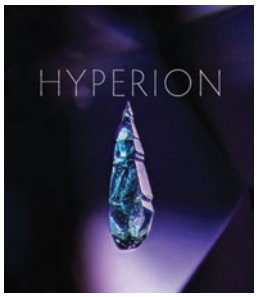

MISCELLANEOUS

Gems from the French Crown Jewels

The MINES ParisTech Mineralogy Museum opened a new permanent exhibit on 5 January 2016 featuring emerald, pink topaz and amethyst from the French Crown Jewels, including gems from the ornaments of Empress Marie-Louise (1791–1847) and the Imperial Crown of Napoléon III (1808–1873). Details are posted at www.musee.mines-paristech.fr/Our-Collections/Exhibits/CrownJewels. *CMS*

What's New provides announcements of new instruments/technology, publications, online resources and more. Inclusion in What's New does not imply recommendation or endorsement by Gem-A. Entries are prepared by Carol M. Stockton (CMS) or Brendan M. Laurs (BML), unless otherwise noted.

Pink Apatite with
Muscovite on Albite
Shah Nassir Peak,
Gilgit, Pakistan

Coming Soon:

The Sisk Gemology Reference

by Jerry Sisk

jtv jewelry a love • jtv.com

Gem Notes

COLOURED STONES

Apatite from Hormuz Island, Iran

During the past two decades, small quantities of gem-quality apatite have been gathered by local mineral enthusiasts on Iran's Hormuz Island in the Persian Gulf. The gems are formed in joints and fractures contained within hematite-goethite iron ores that are associated with deeply altered igneous rocks of variable composition ranging from dacite-trachyte to quartz diorite (Elyasi et al., 1977). The apatite is thought to have a hydrothermal or igin (Padyar et al., 2012). Weathering of the host rocks has dispersed the apatite in areas associated with ochre-coloured soil and salt deposits (Figure 1). The apatite is found as broken pieces and euhedral crystals, typically up to 2–3 cm long, that are somewhat fractured. The gem-quality material is transparent to translucent, and generally ranges from yellow to greenish yellow (Figure 2); less commonly it is green or orangey yellow. It shows various degrees of colour saturation, from very pale to strong. Some samples show colour zoning, with yellower cores and greener outer portions.

Figure 1: Apatite from Hormuz Island, Iran, is found dispersed over the ground from weathering of associated iron-rich ores. Photo by B. Rahimzadeh.

Figure 2: These broken pieces and crystal fragments of apatite from Hormuz Island show a light yellow colour with various degrees of iron staining. The coin is 3 cm in diameter. Photo by B. Rahimzadeh.

Recently, apatite from Hormuz Island was characterized by these authors for this report. The samples consisted of one cabochon, three faceted stones and two freeform carvings weighing 2–4 ct (e.g. Figure 3). They were greenish yellow to green, and RI readings ranged from 1.625 to 1.640 (with small birefringence values) for the faceted stones and were 1.64 (spot readings) for the other samples. An RI of 1.625 is somewhat low for apatite, but the higher measurements were consistent with reported values (1.63–1.64, cf. O'Donoghue, 2006). The hydrostatic SG values were 3.13–3.17, which is somewhat low for apatite (3.17–3.23, cf. O'Donoghue, 2006). The greener samples showed higher SG and lower RI measurements. All of the stones were inert to long- and short-wave UV radiation. Microscopic examination revealed small euhedral hematite inclusions and conchoidal fractures in some samples that were locally iron stained.

Hormuz Island apatite may have significant potential for the gem industry if systematic exploration is undertaken and appropriate methods for cutting and polishing the stone are introduced into the local market. Another source

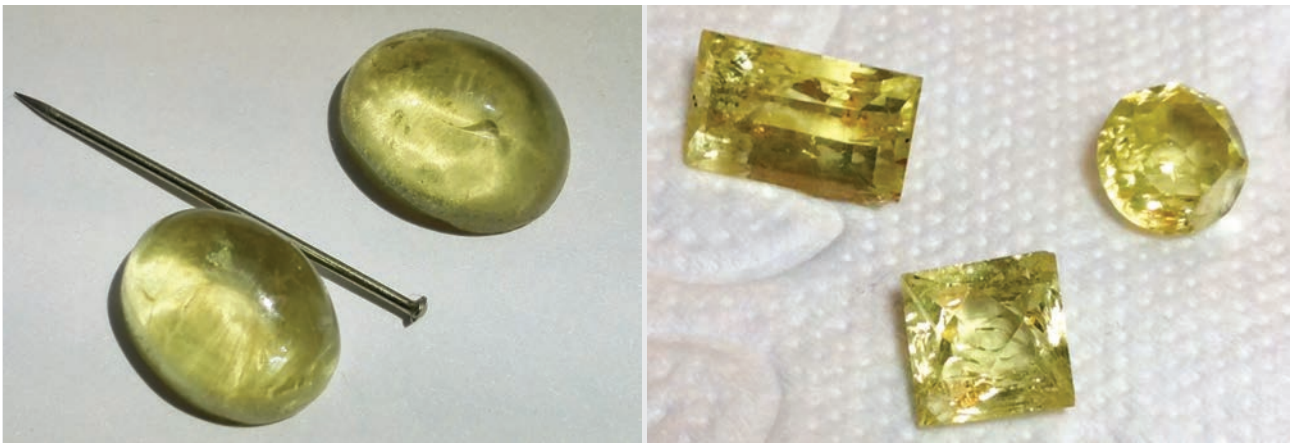

Figure 3: The Hormuz Island apatite samples studied for this report included these slightly greenish yellow cabochons (left, ~4 ct each) and yellow faceted stones (right, ~2–4 ct). Photos by B. Rahimzadeh.

of apatite (some of which is gem quality) is the Sfordi mine in central Iran, where the crystals are hosted by iron-oxide deposits related to alkaline igneous rocks (syenite).

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Purple Apatite from Namibia

Gem-quality apatite is rarely produced from Namibia, and an interesting yellow chatoyant stone was documented fairly recently by one of these authors (Johnston, 2014). During the past few years, apatite in various other colours—including deep purple—also was produced in Namibia. From late 2012 to 2014, one of the authors' (CLJ) suppliers reported finding small amounts of purple apatite on Farm Okatjimukuju, located approximately 20 km south-east of Karibib. The apatite-bearing pockets were associated with quartz, albite and muscovite. The initial finds consisted of moderately purple apatite crystals with a white/green core, but unfortunately the vast majority of the material was recovered as broken pieces that were not transparent. Additional mining produced a few dark purple apatites consisting of well-formed doubly terminated hexagonal prisms (some on matrix). Shortly before mining ceased, approximately 20–30 much better specimens were found that showed a superb deep purple colour (e.g. Figure 4) and relatively good lustre. Individual crystals measured from 1 × ½ cm up to 8 × 6 cm, and some were found on a matrix of transparent quartz crystals. In addition to purple, the apatite colours included white, colourless, pink, green-grey and dark green. The area was reclaimed in 2014, and no additional apatite mining has been allowed by the property owner.

Some of this purple apatite appeared at the September 2015 Hong Kong gem show, and additional material was brought to the October 2015 Munich show. One of these authors (JJB) acquired 500 g of the rough material, which proved challenging to work with due to abundant fractures that required clipping with pliers and some grinding on the cutting wheel to see inside. After this process, only ~100 g of preformed pieces remained that were somewhat clean. Author JJB faceted ~20 stones that ranged from light lavender

Figure 4: Deep purple apatite is associated with quartz and albite on this specimen (14 × 13 cm) from the Karibib area of Namibia. Specimen and photo courtesy of Hans Soltau.

to deep purple; some of them had a slight grey overtone. So far, most of the gems weigh <2 ct (eye clean to very slightly included), and only four eye-clean stones weighing >3 ct have been cut, including a top-colour 3.51 ct oval and a 7.27 ct

Figure 5: Weighing 7.27 ct, this eye-clean cushion brilliant is unusually large for purple apatite from Namibia. Photo by Jeff Scovil.

cushion (Figure 5). In addition, a parcel of small-sized material is being cut overseas.

The purple colour of this apatite is reminiscent of the classic material produced from the Pulsifer Quarry in Maine, USA (e.g. Manchester and Bather, 1918).

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References

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Manchester J.G. and Bather W.T., 1918. Famous mineral localities: Mt. Mica, Mt. Apatite and other localities in Maine. *American Mineralogist*, **3**, 169–174.

Orange-Red to Yellowish Brown Cordierite from Madagascar

Gem-quality cordierite is typically seen as blue material (iolite), showing strong pleochroism in yellow, light blue and dark violet-blue. However, in late 2014 one of the authors (FP) learned about a new occurrence of a much different cordierite, which typically ranged from dark orange-red to yellowish brown. The material is recovered by local miners from weathered residual deposits in southern Madagascar, probably in the Gogogogo area, north of Ampanihy in Tuléar Province. One of the authors (FP) obtained about 120 kg of rough material of mixed quality from the miners over a period of a few months, from which only a few kilograms were suitable for cutting cabochons and faceted stones (e.g. Figures 6 and 7).

Three faceted stones weighing 2.55, 3.17 and 3.63 ct were characterized for this report (Figure 7). They displayed strong pleochroism, in (1) strong orange, (2) greyish purplish (red-) pink and (3) slightly brownish ('straw') yellow. The pleochroism

Figure 6: Cabochons cut from the new Madagascar cordierite show unusual orange-red to yellowish brown coloration. The total weight of the stones shown here is 45.18 ct. Photo by F. Pezzotta.

could clearly be observed with the naked eye, resulting in an overall dark, slightly brownish orange-red or yellowish brown depending on the viewing angle. RI values varied between 1.530 and 1.540, with n_α = 1.530, n_β = 1.533–1.534 and n_γ = 1.540, yielding a birefringence of 0.010. The optic sign was consistently biaxial positive, which differs from the common blue iolite (biaxial negative). Hydrostatic SG values were 2.53–2.55; these are at the low end of the known range for cordierite (2.53–2.78, cf. Deer et al., 1986). All samples were inert to long- and short-wave UV radiation. The stones were moderately included, mostly with partially healed fissures but also with irregularly shaped, breadcrumb-like inclusions and various mineral inclusions. Raman microspectroscopy using a Thermo DXR Raman microscope with 532 nm laser excitation identified the inclusions as follows: rounded and elongated—or thin, long prismatic—crystals of tourmaline; blocky and small rectangular-appearing grains of quartz; rounded crystals of apatite; a small platelet of phlogopite; and minute, parallel-oriented needles and small platelets, possibly rutile. Tiny fractures were seen along partially healed fissures and also adjacent to various mineral inclusions. Chemical analyses of the three samples by energy-dispersive X-ray fluorescence (EDXRF) spectroscopy showed major amounts of Mg, Al and Si, minor amounts of Fe, and traces of Mn. Energy-dispersive spectroscopy on a slab of the cordierite by author GRR using a scanning electron microscope showed similar composition. The optical spectrum showed features of Fe^{2+} found in blue cordierite, plus water-related absorptions in the near-infrared, but also a strong absorption band near 500 nm that is the cause of the unusual orange-red to yellowish brown colour.

Further information on this new cordierite will be reported in a future publication.

Figure 7: These three Madagascar cordierites (2.55–3.63 ct) were analysed for this report. Photo by J. C. Zwaan.

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Reference

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An Unusual Emerald and Pyrite Mixture from Colombia

Emeralds from Colombia are commonly associated with pyrite (for information on the geology of the deposits see, e.g., Pignatelli et al., 2015), and sometimes pyrite is found also as inclusions in the emeralds. In 2015, a new find of emerald from an undisclosed locality in Colombia produced intergrowths of pyrite, emerald and dolomite. Cabochons cut from this material are quite distinctive, and four of them were studied for this report (e.g. Figure 8).

The ratio of pyrite, emerald and dolomite in the samples was highly variable. In two of them, pyrite clearly crystallized first, forming euhedral cubic crystals up to 10 mm. In the other two cabochons, pyrite was present as irregular corroded masses surrounding small grains of emerald (e.g. Figure 9). The green areas of the stones were typically formed by a granular mixture of emerald and dolomite (again, see Figure 9)—except for the marquise-shaped cabochon, in which both minerals occurred separately. (The presence of emerald and dolomite in the cabochons was confirmed by Raman spectroscopy; pyrite does not produce a Raman spectrum with this author's unit.)

Figure 8: These cabochons from Colombia consist of intergrowths of pyrite, emerald and dolomite. The centre stone is 36 mm long. Photo by J. Hyršl.

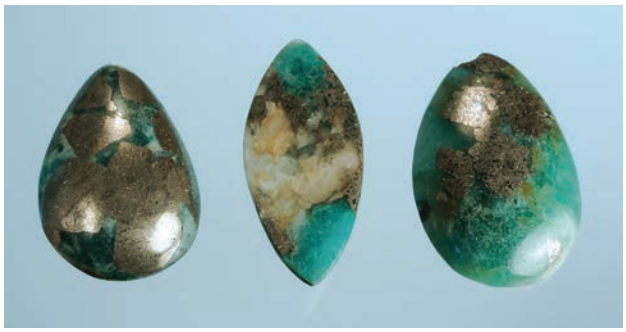

Overall, the polish lustre of the cabochons was mediocre due to the different hardness of the three minerals (Mohs 7½–8 for beryl, 6–6½ for pyrite, 3½ for dolomite). Within the mixed emerald-dolomite areas, the softer grains of dolomite could be easily distinguished with a loupe from the harder emerald by differences in their lustre.

Pyrite is a relatively unstable mineral, especially in humid conditions, and it is very fragile. For this reason, the studied cabochons are not suitable for jewellery use, but they represent interesting collector's objects.

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Reference

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Figure 9: The texture of the various minerals is visible on the base of this cabochon (35 mm long), which shows irregular corroded masses of pyrite and granular intergrowths of emerald and dolomite. Photo by J. Hyršl.

Garnet from Mahenge, Tanzania

The Mahenge area in the Morogoro region of south-central Tanzania is a well-known source of several gem varieties, particularly spinel and ruby. During the 2016 Tucson gem shows, Steve Ulatowski (New Era Gems, Grass Valley, California, USA) had some pink to orangey pink garnets from a new find in this area that he sold as 'Mahenge Malaya'. He obtained the rough material in mid-December 2015 in Arusha, Tanzania. Consisting of clean alluvial pebbles, the garnet ranged from pinkish orange to a saturated 'hot' pink. Most of the production was rather

Figure 10: Weighing 6.79 and 6.84 ct, these faceted garnets from Mahenge, Tanzania, are unusually large for this new find. Courtesy of Evan Caplan; photo by Jeff Scovil.

small sized, although Ulatowski encountered ~1 kg of material consisting of >0.5 g stones, with the largest pieces weighing >3 g. Faceting of two of the largest pieces yielded attractive pink and pinkish orange gemstones weighing 6.79 and 6.84 ct (Figure 10).

Ulatowski loaned a 3.22 ct triangular preform for examination, and the table facet was kindly polished during the show by Todd Wacks (Tucson Todd's Gems, Tucson, Arizona). Its colour was 'fleshy' pink with a faint brown tint (World of Color 2.5R5/6, Brownish Red) under daylight-equivalent lighting. Viewed with incandescent lighting, the brown tint was not evident and the stone appeared slightly more reddish pink (World of Color 2.5R5/10, Moderate Red). This colour behaviour is typical of many so-called Malaya or colour-shift garnets from East Africa. The stone had an RI of 1.751 and a hydrostatic SG of 3.82. Anomalous extinction was observed between crossed polarizers, and the garnet was inert to both long- and short-wave UV excitation. Magnetic susceptibility was not insignificant, with it being picked up by a 9-mm-diameter N-52 REE magnet, and easily dragged by smaller N-52 magnets. The stone appeared eye clean, but microscopic observation revealed several small, scattered, whitish, breadcrumb-like inclusions as well as what appeared to be fine strings of partially dissolved needles.

Figure 11: The visible-range spectrum of a 'fleshy' pink sample of Mahenge garnet showed absorptions related to both almandine and spessartine.

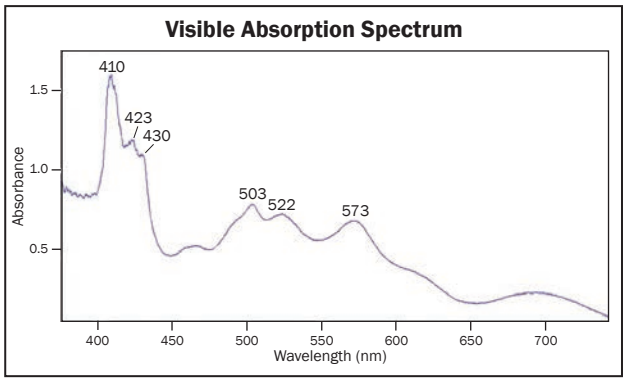

Pink is one of the rarer colours of garnet, and is typically seen in either the hydrogrossular or pyrope-dominant varieties. EDXRF chemical analyses with an Amptek X123-SDD spectrometer revealed major amounts of Mn and Fe, minor Ca, and traces of Cr. Although Mg was below accurate detection levels for this instrument, electron microprobe analysis of five samples of this garnet by John Attard (Attard's Minerals, San Diego, California, USA) revealed major amounts of Mg in all of them. They consisted mainly of pyrope with variable spessartine and almandine, and a very minor grossular component.

Visible-range spectroscopy using an Ocean Optics USB4000 spectrometer with a 7-inch integrating sphere showed weak almandine absorptions at 503, 522 and 573 nm, as well as spessartine absorptions at 410, 423 and 430 nm (Figure 11). Infrared spectroscopy with a PerkinElmer Spectrum100 Fourier-transform infrared (FTIR) instrument revealed a significant water content. The various water-related peaks between 3560 and 3675 cm^{-1} were consistent with OH absorption (Ogasawara et al., 2013).

This attractively coloured garnet is a welcome addition to the gem marketplace.

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Reference

Ogasawara Y., Sakamaki K. and Sato Y., 2013. Water contents of garnets from the Garnet Ridge, northern Arizona: H_2O behavior underneath the Colorado Plateau. American Geophysical Union, Fall Meeting, abstract #V23A-2754, http://adsabs.harvard.edu/abs/2013AGUFM.V23A2754O.

New Production of Grandidierite from Madagascar

Grandidierite, $(Mg, Fe^{2+})(AlFe^{3+})_3(SiO_4)(BO_3)O_2$, is an extremely rare collector's stone that is known in gem quality mainly from Madagascar, and less commonly from Sri Lanka. The material from Madagascar typically lacks transparency: Ostwald (1964) noted that "only massive [rough] material was available for study", and Mitchell (1977) stated that the small number of faceted stones and cabochons that he examined were "semitransparent, due to fissures and inclusions". Schmetzer et al. (2003) documented the first transparent faceted grandidierite (0.29 ct); it was also the first time this gem was reported from Sri Lanka.

During the 2016 Tucson gem shows, Frédéric Gautier (Little Big Stone, Antananarivo, Madagascar) had several pieces of transparent faceted grandidierite from new finds in the Androy region, Tuléar Province, southern Madagascar. The initial production occurred in late 2014, when some low-quality material was found. Better-quality stones were found during early- to mid-2015: approximately 300 kg were produced, with a very small percentage that was transparent. Most of the gem material consisted of small pieces, with some larger fractured pieces weighing 5–10 g. The colour ranged from pale to moderately saturated greenish blue to bluish green, in medium to dark tones. Gautier faceted 40 clean stones weighing 0.10–1.78 ct (e.g. Figure 12). Gemmological properties of a recently produced Malagasy grandidierite were described by Vertreist et al. (2015).

This new production from Madagascar marks the first time that a significant number of clean faceted grandidierites have become available, and also the largest pieces of transparent material ever to be cut. Hand mining of the deposit continues, and it is possible that more gem-quality rough will be produced. Nevertheless, grandidierite remains a very rare gem material.

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Figure 12: Weighing 1.78 ct (left) and 1.08 ct (right), these grandidierites from Madagascar are exceedingly large and transparent for this rare gem material. Photos by Jeff Scovil.

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A Lalique Quartz Pendant, in Polarized Light

Singly polarized or cross-polarized light is often used by gemmologists when testing transparent and translucent rough or cut gem materials. The way the light is modified after passing through the material reveals important characteristics about the crystalline nature of the sample.

In October 2015, GGTL Laboratories in Geneva received for identification a colourless pendant (~37.1 × 34.3 × 5.1 mm; Figure 13) that displayed two human figures engraved in relief. The client indicated that René Lalique made the pendant. Lalique (1860–1945) was a famous designer and well-known for his glassmaking art, but he was also a jeweller who worked with a variety of gem materials (Passos Leite, 2008). At first sight the pendant appeared to be glass, but the cool sensation of the piece on the skin suggested it was quartz. (Glass has a lower thermal conductivity than quartz, and hence feels 'warmer' than quartz.)

Figure 13: This Lalique quartz pendant (~37.1 × 34.3 × 5.1 mm) displays two engraved human figures. Photo by C. Caplan.

Initial gemmological observations were done using a binocular microscope, first in transmitted light and then with crossed polarizers. Bright interference colours indicated the material was anisotropic. When we observed the pendant in the direction of the optic axis with a glass sphere (used as a convergent lens known as a conoscope), we immediately saw a 'bull's-eye' figure that is distinctive for quartz (Figure 14).

Quartz crystallizes in the trigonal system, and the tablet used for this pendant had been cut perpendicular to the optic axis (or three-fold symmetry axis). The common habit of quartz is an elongated prism with rhombohedral terminations, and the crystals are frequently

Figure 14: Viewed with crossed polarizers, the pendant shows a 'bull's-eye' interference figure with the conoscope, as expected for quartz. Distorted Dauphiné twinning interference patterns are visible in the minor rhombohedron at top and left. Photo by C. Caplan; image width ~28 mm.

Figure 15: The quartz pendant (~37.1 × 34.3 mm) shows various interference colours as the analyser is rotated over a stationary polarizer, from the front side (left) and the reverse side (right). Photos by C. Caplan.

twinned (O'Donoghue, 1987). Viewed with crossed polarizers, the quartz showed angular interference colour patterns on the top and left edges of the pendant due to twinning of the minor rhombohedron *z* faces (again, see Figure 14). Consistent with the fact that there was no colourless synthetic quartz available on the market during Lalique's time, the distribution and orientation of the twinning characteristics confirmed it was natural quartz (Notari et al., 2001; Payette, 2013).

This pendant provides a good example of how interference colours are influenced by the thickness of the observed material and by its crystallographic orientation versus the polarization direction of the light. The two groups of photos in Figure 15 show variations in the appearance of the pendant as the analyser was rotated over the stationary polarizer, from the front side (left) and the reverse side (right). The human figures remain colourless in the front view, while they show interference colours in the back view. The colours observed between crossed polarizers are complementary to those seen between parallel polarizers (Figure 15-right, third picture of each line). This appearance is due to a combination of diffusion and diffraction phenomena caused by the curved shape of the engraving. Further, when viewed only with fully crossed polarizers, completely different interference colours are produced as the pendant is rotated (Figure 16).

It is always interesting to examine gem materials with polarized light, and sometimes a simple colourless object can appear complexly beautiful. As shown by this pendant, such examination yields useful information, and may allow one to distinguish natural from synthetic quartz.

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Figure 16: Different interference colours are also produced as the quartz pendant is rotated between crossed polarizers. Photos by C. Caplan; image width ~20 mm.

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Faceted Quartz with Petroleum Inclusions from Baluchistan, Pakistan

Euhedral quartz crystals with petroleum inclusions are well known from Baluchistan Province, western Pakistan (Koivula and Tannous, 2004; Koivula, 2008). These specimens typically have fluid inclusions containing yellow petroleum (with or without a colourless aqueous phase), a methane gas bubble and solid particles of black asphaltite. When exposed to UV radiation (particularly long-wave), the petroleum commonly luminesces a strong yellow or blue (see, e.g., Figure 28 [right] on p. 21).

Koivula and Tannous (2004) indicated that although gems can be cut from this quartz, the heat sensitivity of the inclusions requires caution to avoid fracturing them. It was therefore notable to see some of these faceted gemstones with Mark Kaufman (Kaufman Enterprises, San Diego, California, USA) during the 2016 Tucson gem shows (e.g. Figure 17). From 30 crystals that he purchased at the October 2015 Munich (Germany) show, Kaufman cut six stones weighing ~1–4 ct. He selected the crystals especially to show isolated petroleum inclusions after faceting, but unfortunately most of the inclusions were located too close to the surface of the crystals to avoid intersecting with the cutting wheel, causing the petroleum to leak out. Therefore, the greatest challenge that Kaufman faced while faceting this quartz was the difficulty of cutting around the inclusions without penetrating them.

Figure 17: Faceted Pakistani rock crystal quartz with petroleum inclusions (yellow) is seldom encountered in the marketplace. The stones shown here weigh 2.20–2.29 ct. Photo by Orasa Weldon.

For collectors who appreciate unusual inclusions, these quartz gems will provide interesting samples. *Brendan M. Laurs FGA*

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Quartz Slabs from Inner Mongolia

Quartz crystals are prized by collectors for their transparency and prismatic crystal form, but some specimens are even more interesting when sliced into slabs to show their internal features. Such was the case for quartz tablets from Colombia that were recently described by Krzemnicki and Laurs (2014) as having a radiating fibrous structure.

During the 2016 Tucson gem shows, Luciana Barbosa (Gemological Center, Weaverville, North Carolina, USA) had some interesting quartz

Figure 18: These polished slices of quartz from Inner Mongolia (up to 2.8 cm tall) display various six-fold patterns. Courtesy of Mike and Pat Gray; photo by Jeff Scovil.

slabs from the Huanggang Fe-Sn deposit, Inner Mongolia, China. Polished perpendicular to the c-axis, some of them displayed snowflake-like patterns of dark inclusions, while others had transparent cores that showed complex patterns of interference colours between crossed polarizers (Figures 18 and 19).

Barbosa was told that the quartz was found in 2012. She obtained ~100 slices for the Tucson shows, with an additional ~50 pieces in the process of being slabbed. The slices typically ranged up to 3 cm across, with very few being any larger. Only some portions of the crystals gave attractive patterns when sliced. The dark inclusions have not yet been identified.

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Reference

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Figure 19: Close-up images of the quartz slabs from Inner Mongolia reveal attractive radiating and concentric arrays of dark inclusions (left, 30 × 27 × 2 mm) and complex patterns of interference colours (right, 26 × 25 × 2 mm). Photos by Luciana Barbosa; crossed polarizers.

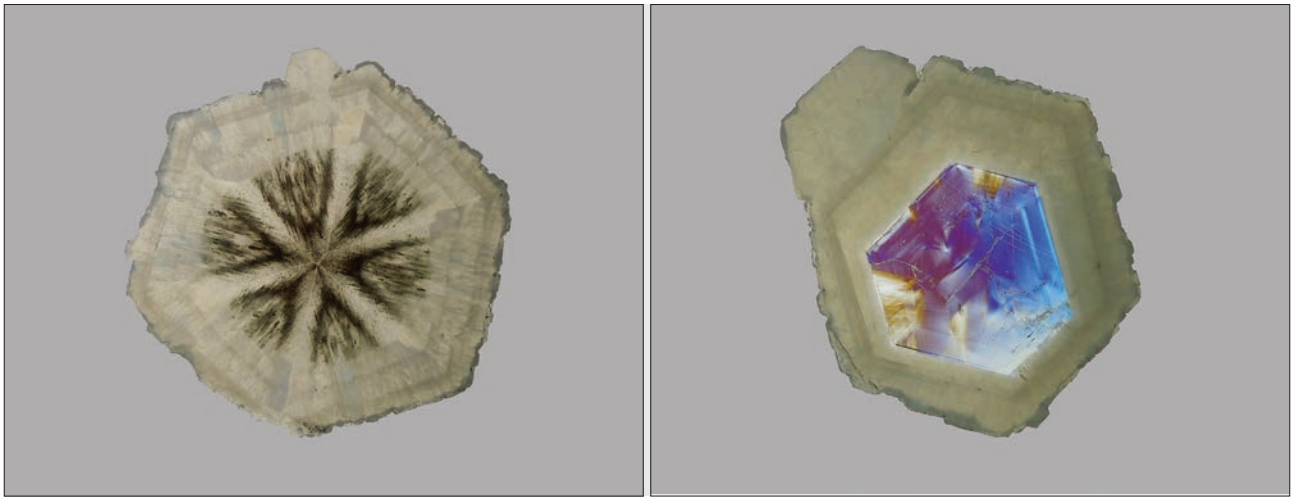

Sphalerite Inclusions in Quartz

During the 2016 Tucson gem shows, rare-stone dealer Luciana Barbosa had some faceted quartz with sphalerite inclusions from a new find in Goiás State, Brazil (e.g. Figure 20). Barbosa reported that about 80 stones were faceted from a single large quartz crystal that was mined in 2015, which contained numerous sphalerite crystals near the surface. The largest gem

Figure 20: This 34.20 ct quartz from a new find in Brazil contains two euhedral inclusions of sphalerite. Courtesy of Luciana Barbosa; photo by Jeff Scovil.

weighed over 100 ct, but most of the stones were <20 ct.

Although sphalerite inclusions have been reported previously in quartz (i.e. from tungsten deposits and various ore veins; Hyršl, 2006), this find is notable for the clarity of the host quartz and the perfection of the sphalerite crystals, some of which even display complex growth patterns on their faces (Figure 21).

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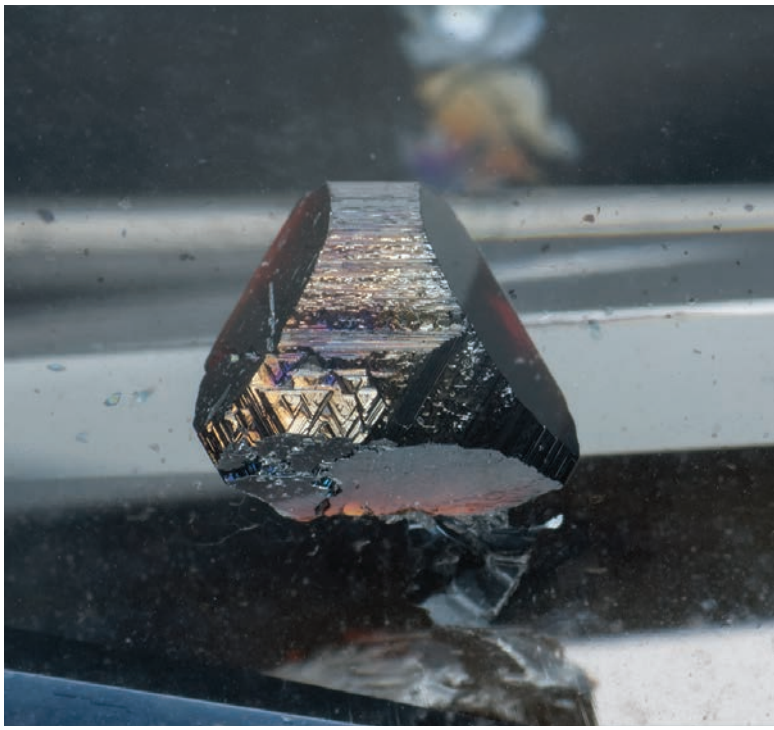

Figure 21: A closer view of the larger sphalerite inclusion (4 mm across) in Figure 20 shows interesting growth patterns on some of its faces. Photo by Jeff Scovil.

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Ruby from Liberia

Ruby from Liberia was reported relatively recently by Kiefert and Douman (2011) as small transparent pinkish red to red pebbles from the Mano River, and larger near-opaque purplish red crystals from Nimba Province near the Guinean border. During the 2015 and 2016 AGTA Tucson gem shows, Eric Braunwart (Columbia Gem House, Vancouver, Washington, USA) displayed ruby from Liberia that was different from either material mentioned above. While not of facet grade, it exhibited an attractive sparkliness in reflected light.

Braunwart loaned the sample in Figure 22 for examination. It consisted of a polished hexagonal plate weighing 3.32 ct and measuring 10.16 × 1.96 mm. It was a dull but saturated dark red (World of Color 2.5R3/6, Dark Red) with slight to moderate

Figure 22: This polished hexagonal plate (3.32 ct) of ruby from Liberia displays abundant sparkles in reflected light that are due to reflections from rutile inclusions and polycrystalline grain boundaries. Photo by B. Williams.

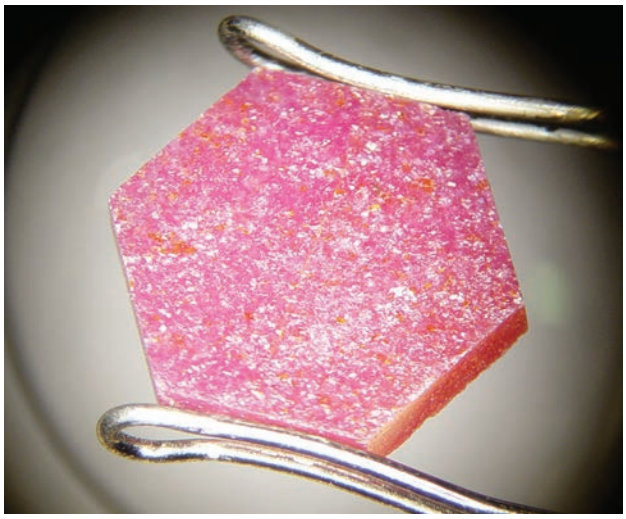

Figure 23: Seen here in oblique lighting, the 3.32 ct ruby shows a granular texture with orangey red domains corresponding to rutile inclusions. Photo by B. Williams.

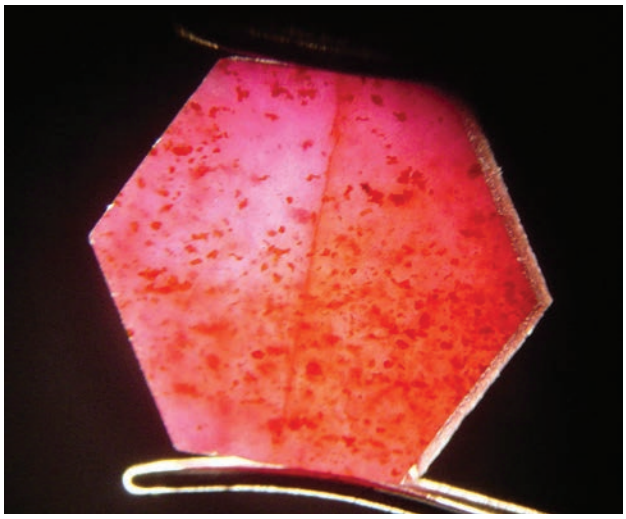

Figure 24: Viewing the 3.32 ct ruby with transmitted light highlights the presence of a partially healed fissure and abundant orangey red inclusions (rutile crystals). Photo by B. Williams.

translucency. Although the hexagonal slice had a shape reminiscent of a cross-section from a corundum crystal, the stone gave a polycrystalline reaction between crossed polarizers, remaining bright throughout a full rotation. Microscopic observation revealed a granular appearance with most individual grains appearing pinkish red, while a few were orangey red (Figure 23). While this might be suggestive of ruby dichroism, the orangey red domains proved to consist of inclusions. Transmitted light revealed numerous translucent, deep orangey red, blocky, crystalline inclusions that were randomly oriented, as well as one partially healed fissure running through the centre of the stone (Figure 24). No other inclusions were observed. RI measurements of the sample yielded a single, weak shadow edge near 1.763. Specific gravity was measured as 3.81; this relatively low value is possibly due to the corundum's polycrystalline structure. The stone was inert to both long- and short-wave UV excitation. Raman analysis with a GemmoRaman-SG instrument confirmed it to be corundum.

It is the sparkly appearance that makes this ruby intriguing. Under magnification, numerous micro-reflections were seen emanating from the polycrystalline grain boundaries, as well as from the inclusions mentioned above. Several of the surface-reaching inclusions were identified as rutile by an Enwave 785 micro-Raman spectrometer. The presence of abundant rutile inclusions is consistent with the elevated Ti content obtained for the sample with an Amptek X123-SDD EDXRF spectrometer. The chemical analysis also revealed the Cr and Fe that are presumed responsible for the red colour of the ruby and lack of fluorescence, respectively.

While ruby with rutile needles is commonly encountered, this material in unusual for having rutile present as reflective grains mixed with polycrystalline ruby.

Cara Williams FGA and Bear Williams FGA

Reference

Kiefert L. and Douman M., 2011. Gem News International: Ruby from Liberia. *Gems & Gemology*, **47**(2), 128.

Yellow Sapphire with Unstable Colour—in Reverse

Irradiated yellow sapphires are rarely encountered in today's market. Although it is possible to irradiate a colourless sapphire to turn it yellow, this treatment is highly unstable and readily fades to colourless upon exposure to light (Nassau and Valente, 1987). We were therefore surprised to learn about a yellow sapphire with unstable colour—in reverse. Harold Dupuy FGA of Stuller

Figure 25: This 1.07 ct sapphire shows an unusual 'reverse' colour change. The more stable yellow state fades to colourless after low-temperature heating, and the yellow colour can be restored by exposure to long-wave UV radiation or daylight. Photos by B. Williams.

Inc., Lafayette, Louisiana, USA, reported that they sold a 1.07 ct white sapphire to a retailer who returned the stone after it turned yellow. The client mounted the white sapphire into a ring, and sold it to a consumer who wore the ring for a few months before returning it to the retailer. Stuller immediately exchanged the stone for another comparable white sapphire, but the question remained of how and why the change in coloration occurred.

The sapphire was sent to Stone Group Laboratories for testing. Upon receipt, the stone was yellow (Figure 25, left). The refractometer showed the expected RI values of 1.76–1.77 and Raman spectroscopy confirmed it was corundum. Detailed microscopic examination and FTIR spectroscopy revealed the absence of thermal enhancement in this metamorphic sapphire. With Dupuy's permission, various experiments were performed to test the colour stability of the stone.

First the sapphire was subjected to low-temperature heating of 260°C for one hour, which rendered it colourless (e.g. Figure 25, right). Then it was exposed to a 4 W long-wave UV lamp for 30 minutes, after which it again appeared light yellow. Reheating as before returned it to colourless. Such reversible coloration is commonly related to energy-induced trapped hole centres, which can vary in their stability (Nassau and Valente, 1987). A reversible colour change also has been observed by the present authors in some blue zircons that exhibit brown-to-green tints upon exposure to strong UV radiation, then revert to their previous (heated) blue colour over a period of days when exposed to a broad-spectrum visible light (cf. Renfro, 2013), or more quickly revert to blue with slight heating.

Jay Boyle (Jay Boyle Co., Fairfield, Iowa, USA), who has been dealing in untreated yellow and white sapphires for 35 years, says he has encountered a small number of yellow stones that exhibited this colour behaviour. He believes it to be observed only in approximately 1 in 3,000 yellow sapphires. In such cases, the yellow colour is more stable, and fades to colourless when exposed to heat (such as during the jewellery-making process), but reverts to the original yellow upon exposure to sunlight for a few days.

In the present sapphire, ultraviolet-visible-near infrared (UV-Vis-NIR) spectroscopy showed a small absorption at 450 nm in both colour states that is indicative of iron (not responsible for the colour phenomenon). The spectra also revealed a very subtle difference between colour states in the form of a broad absorption band in the 460–480 nm range for the yellow state, which was most likely related to the observed change in coloration.

All of the conditions that were found capable of altering the colour of this sapphire are commonly experienced by gem materials in general. Long-wave UV radiation is encountered in the laboratory environment as well as in tanning beds. Of course, sunlight is an even more common source of long-wave UV wavelengths. Heating to a temperature of 260°C is comparatively mild, such that it may be produced by typical kitchen ovens, and jewellery processes can often expose gems to much higher temperatures. Heating of this sapphire to 260°C did not induce a 3309 cm^{-1} band in the FTIR spectra, such as seen in heated corundum. More research is required to understand the coloration of this sapphire, which is best described as containing a rare but unstable energy-activated colour centre.

Cara Williams FGA and Bear Williams FGA

References

Nassau K. and Valente G.K., 1987. The seven types of yellow sapphire and their stability to light. *Gems & Gemology*, **23**(4), 222–231, http://dx.doi.org/10.5741/gems.23.4.222.

Renfro N.D., 2013. Reversible color modification of blue zircon by long wave ultraviolet radiation. *Geological Society of America Abstracts with Programs*, **45**(7), 835.

Petroleum Inclusion in Pink Spinel

Recently, American Gemological Laboratories had the opportunity to examine an unusual 1.69 ct pink spinel that reportedly came from Sri Lanka (Figure 26). Microscopic examination revealed some inclusions commonly seen in spinel, consisting of variously sized octahedral crystals, planar internal growth structures and open fissures. However, most conspicuous was a sizeable two-phase inclusion positioned under the table and in the heart of the stone. The euhedral negative crystal contained a viscous yellow fluid and a spherical bubble (Figure 27, left). As the stone was turned, the bubble slowly moved through the thick yellow fluid. When viewed in a darkened room with long-wave UV radiation (365 nm), the fluid in this inclusion displayed a chalky blue-white reaction underlying the distinct reddish glow of the host spinel (Figure 28, left). Raman analysis could not be used to analyse the fluid due to strong chromium luminescence that swamped the detector. However, focused infrared spectroscopy using a paper mask around the inclusion (Figure 29) identified the fluid as petroleum. The spherical bubble was presumably a gas, although it could have been an immiscible fluid, such as water.

Similar negative crystals are well-known in rock crystal quartz from Baluchistan, Pakistan (see e.g. Koivula, 2008), which contain petroleum and a bubble of methane gas. The petroleum fluid in this spinel has a similar viscous yellow character (see Figure 27, right) and displays the same chalky blue-white long-wave UV reaction (see Figure 28, right) as the petroleum in quartz from Pakistan.

Figure 26: This 1.69 ct pink spinel, reportedly of Sri Lankan origin, contains a unique petroleum-bearing inclusion under the table facet. Photo by Bilal Mahmood.

To the authors' knowledge, this is the first time that a petroleum-bearing inclusion has been documented in spinel.

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and Christopher P. Smith
American Gemological Laboratories
New York, New York, USA

Reference

Koivula J.I., 2008. Lab Notes: Unusual green fluid inclusions in quartz. *Gems & Gemology*, **44**(2), 161.

Figure 27: Left: The large, two-phase negative crystal in the spinel contains a viscous yellow fluid (petroleum) and a spherical bubble consisting of a gas or immiscible fluid. The bubble could be seen to slowly migrate through the petroleum as the stone was turned. Photomicrograph by M. Chaipaksa; magnified 70×. Right: A similar appearance is displayed by petroleum-filled negative crystals in colourless quartz crystals from Baluchistan, Pakistan. Photomicrograph by C. P. Smith; magnified 24×.

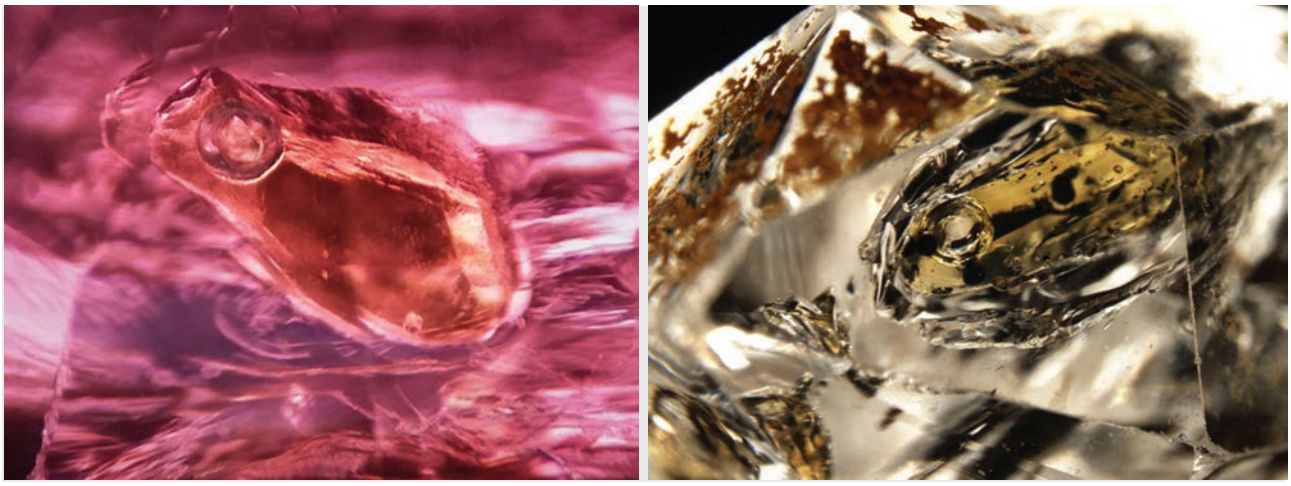

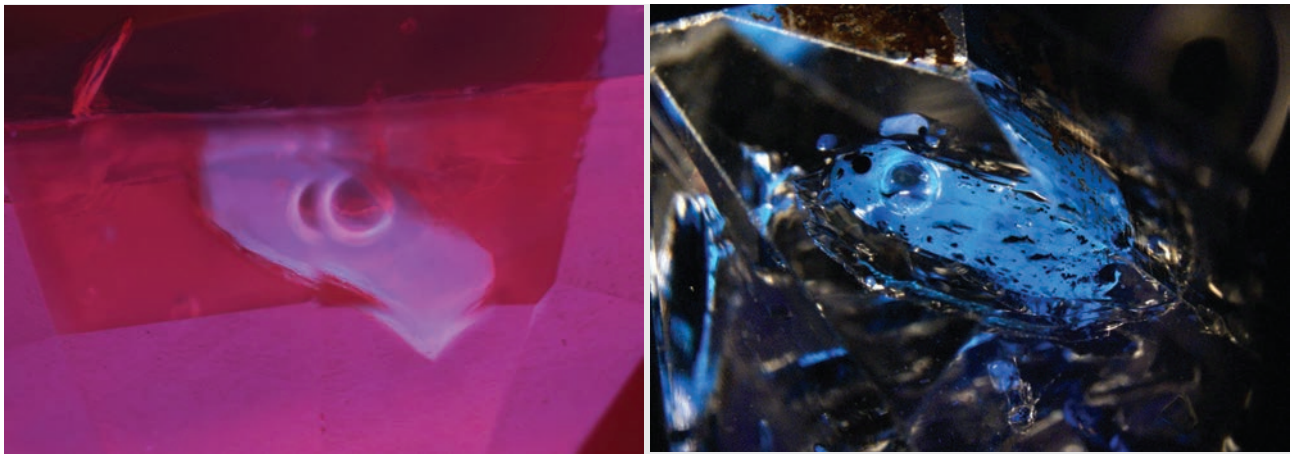

Figure 28: Left: Under long-wave UV radiation (365 nm), the petroleum exhibits a chalky blue-white reaction that was somewhat muted by the dominant red luminescence of the host spinel. Right: Such fluorescence also is displayed by petroleum inclusions in a Pakistani quartz. Photomicrographs by C. P. Smith; magnified 40×.

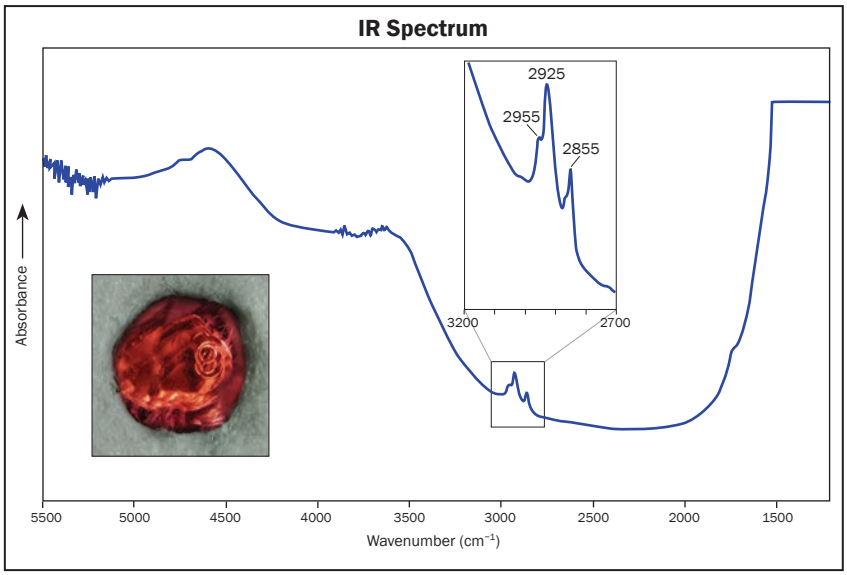

Figure 29: Focused infrared spectroscopy of the negative crystal in the spinel identified the viscous yellow fluid as petroleum, with lines at 2955, 2925 and 2855 cm^{-1}. The inclusion was isolated for the analysis by using a 1.5-mm-wide paper mask (inset photomicrograph by C. P. Smith).

Spurrite from New Mexico, USA

Spurrite is a calc-silicate mineral with the formula $Ca_5(SiO_4)_2(CO_3)$ and a Mohs hardness of 5. It typically forms in contact metamorphic rocks (in particular, skarn deposits) as granular masses ranging from colourless to greyish violet (Bernard and Hyršl, 2004). The mineral has only rarely been used for lapidary purposes (e.g. purple beads and polished slabs or freeform pieces from Mexico and south-western USA; Koivula and Misiorowski, 1986; Wentzell, 2004).

During the 2015 Tucson gem shows, Mauro Pantò (The Beauty in the Rocks, Laigueglia, Italy) had faceted spurrite from Tres Hermanas Mountains, Luna County, New Mexico, USA (cf. Homme and Rosenzweig, 1970). He had 15 pieces that averaged 3 ct each (e.g. Figure 30). Pantò kindly donated one of the spurrites to Gem-A, and the gem was characterized by authors CW and BW.

The following properties were recorded from the 1.86 ct stone: colour—greyish lilac purple; diaphaneity—translucent; RI—approximately 1.67 (indistinct, using the bright line technique); hydrostatic SG—3.00; fluorescence—inert to long- and short-wave UV radiation; polariscope—

aggregate reaction; Chelsea filter—light pinkish red; and no absorption features were visible with a desk-model spectroscope. These properties are consistent with those reported for spurrite in the literature, except that Wentzell (2004) documented faint 'cobalt'-blue long-wave UV luminescence in samples from Mexico. Microscopic examination revealed little other than minor surface-reaching fissures, grain boundaries typical of a polycrystalline material and a few tiny dark masses.

Raman analysis using an Enwave L-Series spectrometer with a 785 nm laser gave a very good match to spurrite in the RRUFF database and in our own reference spectra. EDXRF chemical analyses using an Amptek X123-SDD instrument with a DP5 preamplifier showed that Fe was the main impurity, along with minor-to-trace amounts of Mn, Cr, Zn and Pb. The presence of small amounts of mineral impurities (such as carbonates) was documented by Wentzell (2004) in spurrite from Mexico. Minute amounts of mineral impurities also were present in our sample from New Mexico, as indicated by the anomalous trace elements and the tiny black masses.

Figure 30: These translucent purple gemstones (3.14–5.73 ct) are spurrite from New Mexico, USA. Photo by Mauro Pantò.

Spurrite is dimorphous with paraspurrite, which has mostly overlapping gemmological properties but is known only from Inyo County, California, USA (Bernard and Hyršl, 2004).

Cara Williams FGA, Bear Williams FGA and Brendan M. Laurs FGA

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Bernard J.H. and Hyršl J., 2004. *Minerals and Their Localities*. Granit, Prague, Czech Republic.

Homme F.C. and Rosenzweig A., 1970. Contact metamorphism in the Tres Hermanas Mountains, Luna County, New Mexico. In L.A. Woodward, Ed., *New Mexico Geological Society Fall Field Conference Guidebook – 21: Tyrone–Big Hatchet Mountains–Florida Mountains Region*, 141–145.

Koivula J.I. and Misiorowski E., 1986. Gem News: Tucson 1986. *Gems & Gemology*, **22**(2), 114–115.

Wentzell C.Y., 2004. Lab Notes: Spurrite. *Gems & Gemology*, **40**(1), 63–65.

Update on Tsavorite Mining at the Scorpion Mine, Kenya

The history and mining of tsavorite at Kenya's Scorpion mine and surrounding claims was described by Bridges and Walker (2014), and since then many important developments have occurred. After a six-year hiatus, the operations were reopened in January 2015. This was accomplished after major investments in infrastructure and staffing, improved mining processes and newly implemented safety measures—all in an effort to ramp-up tsavorite production.

Among the infrastructural improvements, access roads to the Scorpion mine and outlying claim areas were upgraded for better access, and a new road to the Green Garnet 3 (GG3) operation was constructed after the old road was destroyed by past rainy seasons. The GG2 site has been renovated to repair most of the damage done by many years of illegal mining. The former 'CW' open pit (where very fine-colour tsavorite and some tourmaline were previously mined) has been reclaimed. Both the main camp and supervisor camp were restored after elephant attacks caused severe damage. The staff quarters also were upgraded to accommodate a labour force that expands to approximately 100 people during the height of the mining season. The main camp has been

Figure 31: Miners sort through waste rock at the working face of Scorpion mine tunnel No. 4. The ceiling in this area has been reinforced with split-sets. Photo by Louis Brunet.

entirely equipped with solar power, and a new workshop has been constructed.

To improve mining efficiency, an 85 kVA generator was installed at the Scorpion mine to power larger fans and two mono-winches that can be used to remove approximately 4–5 tonnes of waste rock per hour. To enable the use of two rock drills simultaneously, a high-pressure compressed air pipe has been installed into both the No. 2 and No. 4 inclines. The existing ventilation system was also upgraded to improve air circulation. Two new airlift pumps were purchased that run on compressed air instead of petrol/diesel, for a safer and cleaner work environment. Six new rock-drilling machines were obtained that are specially designed for operating with water and compressed air. These make drilling much easier and also minimize the drillers' exposure to silica dust. A 40,000 litre water tank has been installed at the Scorpion mine to ensure a continuous water supply, and a water bowser (tanker rig) was built for transporting water to other locations such as GG3. To improve underground safety, split-sets (roof bolts) have replaced the timber and steel girder supports previously utilized in the No. 2 and No. 4 tunnels (e.g. Figure 31). Problematic areas of the tunnels have been reinforced with welded mesh to help retain friable hanging-wall material.

Production of tsavorite from the Scorpion mine (and later from GG2) resumed in mid-July 2015, and several small-to-medium-sized nodules have been encountered so far. Most of the gem rough (e.g. Figure 32) consisted of pieces weighing 0.1–0.5 g, with a small percentage in the 1–20 g range. The colour ranged from a vivid light yellowish green to a vibrant deep bluish green, with some attractive medium green stones produced (e.g. Figure 33). Tsavorite in larger calibrated sizes such as 7 × 5 mm, 8 × 6 mm, 9 × 7 mm, etc. has always been extremely hard to come by. However, the recent production has enabled the creation of complete tsavorite suites (e.g. Figure 34). For the first time in many years, multiple suites of graduated and calibrated tsavorite rounds have been cut, ranging from 2.0 to 8.5 mm. The largest faceted stone from recent production weighed 17.20 ct.

To help ensure future production of tsavorite, several knowledgeable geologists were brought on to assess the mining areas and assist with mapping the local geology and reef zones at Scorpion and GG2. In addition, around Snake Hill and at other tsavorite-bearing locations, approximately 350 cubic metres of earth were removed for bulk sampling.

Unfortunately, activities by illegal miners and bandits remain a problem in the lease areas, and some encroachers have been arrested by the

Figure 32: Recently produced tsavorite rough from the Scorpion mine is in the process of being sorted. Photo by B. Bridges.

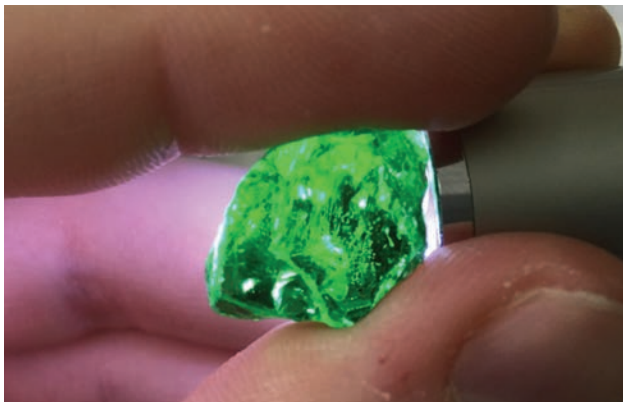

Figure 33: This large (~7 g) piece of tsavorite displays an excellent medium green colour and a good shape for cutting. Photo by B. Bridges.

Kenya Police. There is a strong push by a large Kenyan organized crime syndicate to take over the tsavorite mining region in southern Kenya. Our activities continue to be impacted by threats of violence similar to that which led to the murder of the mine's original owner, Campbell Bridges, in 2009.

With the mine finally in production once more, this represents a new chapter for tsavorite in Kenya, which has contributed to the excitement and optimism the gem industry shares for the future of the Bridges' mining operation. The family is hopeful that they will be able to continue with minimal outside interference and be allowed to further develop their tsavorite reserves.

Bruce Bridges (brucebridges@tsavorite.com)
Bridges Tsavorite, Tucson, Arizona, USA

Reference

Bridges B. and Walker J., 2014. The discoverer of tsavorite—Campbell Bridges—and his Scorpion mine. *Journal of Gemmology*, **34**(3), 230–241, http://dx.doi.org/10.15506/jog.2014.34.3.230.

Figure 34: The graduated and calibrated round brilliants in this tsavorite suite range from 3.5 to 8.5 mm for the necklace stones, and the matched pair has a total weight of 10.76 ct. Photo by Jeff Scovil for Bridges Tsavorite.

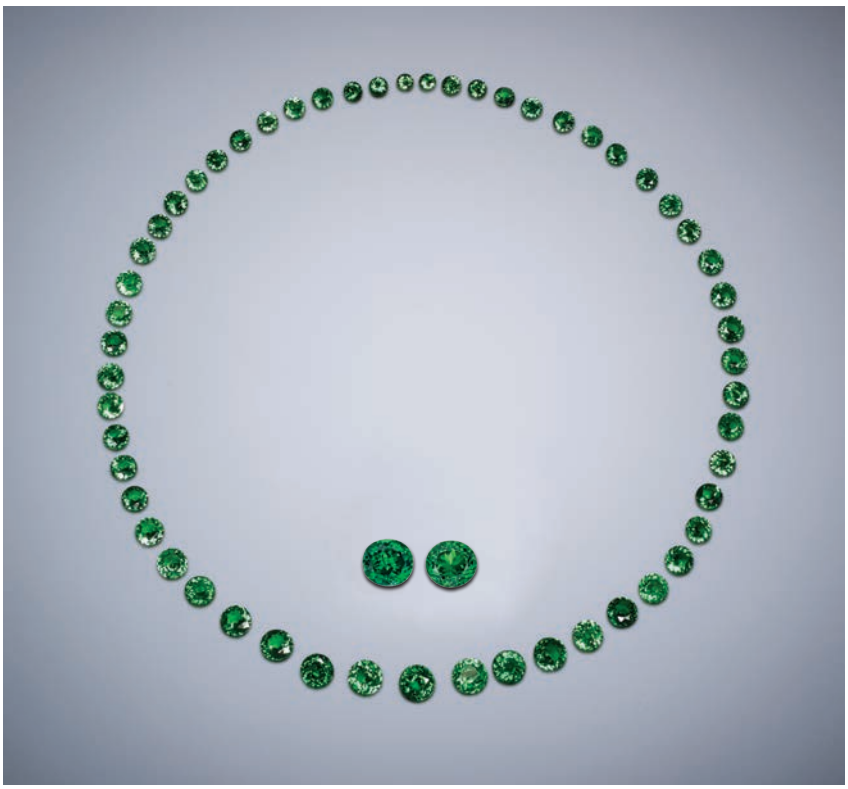

PEARLS

Natural Mussel Pearls from the Philippines

In the Philippines, the brown mussel (*Modiolus philippinarum*) is harvested for food on a subsistence basis, and also has been used as an inexpensive source of aquaculture feed (e.g. Napata and Andalecio, 2011). Natural mussel pearls from *Modiolus philippinarum* are virtually unknown in the gem trade, and it was therefore surprising to see hundreds of them during the 2016 Tucson gem shows with one pearl dealer, K.C. Bell (KCB Natural Pearls, San Francisco, California, USA). Bell reported collecting the pearls from his Philippine supplier for at least 10 years. All of them were drilled and strung, and he divided them into three general varieties (e.g. Figure 35) consisting of the following pieces:

1. Black round
   - Three lines: each ~17.5″ (44.5 cm) long, 1.0–5.3 mm diameter, 65.86 ct total weight
   - Two tassels: each 2″ (5.1 cm) long, 3.0–6.5 mm diameter, 54.75 ct total weight
2. Black baroque
   - Two lines: each ~16″ (40.6 cm) long, 2.0–9.4 mm diameter, 150.76 ct total weight
   - Two tassels: each 2.5″ (6.4 cm) long, 2.0–9.5 mm diameter, 74.00 ct total weight
3. Mauve (mostly baroque)
   - Two lines: each ~18″ (45.7 cm) long, 1.5–6.0 mm diameter, 90.67 ct total weight
   - One graduated line: 4.61″ (11.7 cm) long, 2.0–5.3 mm diameter, 10.62 ct total weight
   - Two tassels: each 2.5″ (6.4 cm) long, 1.5–3.0 mm diameter, 73.72 ct total weight

The 'black' pearls were mostly medium-to-dark purple with some light-coloured pieces (particularly among the rounds) in various purple, blue and golden shades. Overtones of pink and lavender were visible in some of the rounds. The mauve pearls consisted of light-to-medium shades of cream, brown and grey, with silver overtones. Various surface features included dimples and wrinkles; only a few circled pearls were present.

Although *Modiolus philippinarum* pearls are rarely encountered, this collection shows how large numbers can be amassed over a long time.

Brendan M. Laurs FGA

Reference

Napata R.P. and Andalecio M.N., 2011. Exploitation and management of brown mussel (*Modiolus philippinarum*) resources in Iloilo, Philippines. *Philippine Journal of Social Sciences and Humanities*, **16**(2), 22–34.

Figure 35: These are some of the natural pearls (up to 9 mm) collected in the Philippines from the brown mussel Modiolus philippinarum. *From left to right, pearl varieties have been classified into mauve, black round and black baroque. Photo by Jeff Scovil.*

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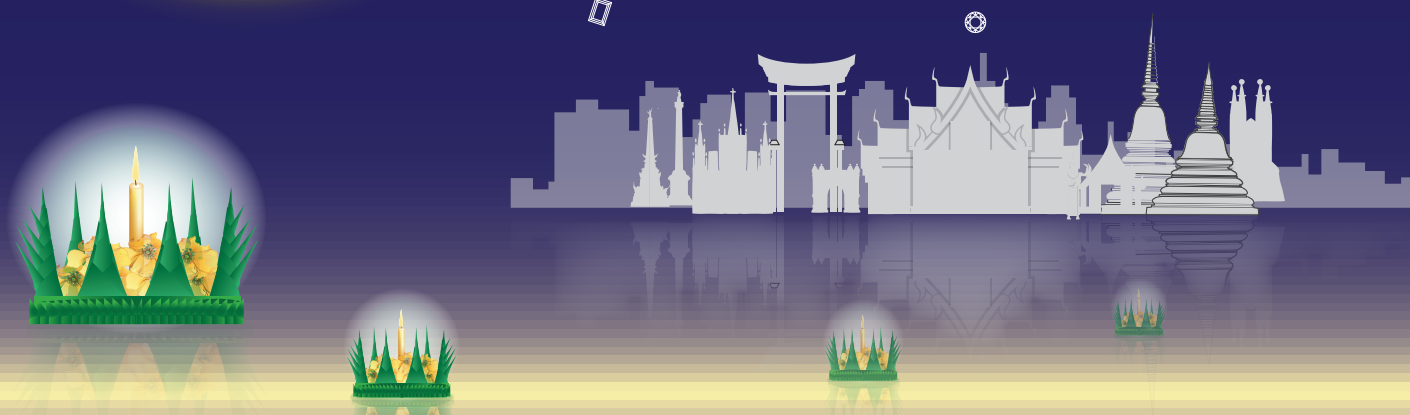

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The Gem and Jewelry Institute of Thailand (Public Organization)

Characterization of Oriented Inclusions in Cat's-eye, Star and Other Chrysoberyls

Karl Schmetzer, Heinz-Jürgen Bernhardt and H. Albert Gilg

Milky-appearing alexandrite samples from Tanzania (Lake Manyara) and India (Kerala) were examined, as were chatoyant and asteriated chrysoberyl/alexandrite from India (Orissa), Brazil, Madagascar and Sri Lanka, and also phenomenal synthetic alexandrite from Kyocera in Japan. Sixteen oriented thin sections were studied by a combination of optical microscopy, micro-Raman spectroscopy, and electron microprobe techniques employing backscattered electron (BSE) imaging, qualitative point analysis and Ti compositional mapping. Rutile was identified as needle-like inclusions and V-shaped platelets in planes perpendicular to the a-axis, elongated parallel to the c-axis, and parallel to symmetry-equivalent <011> directions. Additional structures consisting of rutile needles and/or channels in various samples were oriented parallel to the a-axis. Also observed were single or multiple-intergrown rutile platelets elongated parallel to the a-axis, and rutile platelets showing rectangular, L-shaped or zigzag cross-sections parallel to <012> directions. In a four-rayed star chrysoberyl, elongated ilmenite particles were oriented along the c-axis. Various optical effects such as a whitish appearance, asterism or chatoyancy are caused by, and depend upon, the presence, size and concentration of the combined different types of needle-like or platy inclusions.

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Background

The examination of needle-like mineral inclusions and elongated cavities or channels in gem materials has always been of interest to gemmologists because these features are responsible for chatoyancy and asterism in cabochon-cut samples. Identifying such inclusions, however, has often proved problematic since their dimensions are frequently below the resolution of gemmological microscopes (magnification up to 100×).

By analogy, numerous studies have dealt with the examination and identification of the needle-like precipitates in corundum (specifically Ti-doped synthetic and Fe- and Ti-bearing natural material). The different phases present as acicular inclusions have been characterized via transmission electron microscopy using electron diffraction and/or other micro-analytical techniques. The inclusions often have been described as twinned rutile needles, although the presence of rhombic or monoclinic

Figure 1: This pendant features a cat's-eye alexandrite, presumably from Sri Lanka, and is shown in daylight (left) and incandescent light (right). The stone measures 13.62 × 13.72 × 9.05 mm and weighs 14.52 ct. Courtesy of David Humphrey, Pacific Palisades, California, USA; photo by Erica and Harold Van Pelt.

TiO_2 phases and even the formation of Al_2TiO_5 have been reported as well (Phillips et al., 1980; Langensiepen et al., 1983; Moon and Phillips, 1991; Xiao et al., 1997; Viti and Ferrari, 2006; He et al., 2011).

Oriented structures in chrysoberyl, in contrast, have received less attention. It is evident from the observed optical phenomena that oriented inclusions are present in both cat's-eye (e.g. Figure 1) and star chrysoberyl. The chatoyancy has been ascribed to hollow channels or needle-like mineral inclusions such as rutile (Eppler, 1958), a view broadly repeated in standard gemmological texts. Through examinations involving a large number of samples from sources worldwide, a consistent orientation for these inclusions has been established. The needle-like or channel structures were found to be parallel to the crystallographic a-axis [100], with the single light band of the cat's-eye being observed perpendicular to the needle axis (Schmetzer and Hainschwang, 2012).

With respect to asteriated material, six-rayed natural chrysoberyl is almost unknown and only has been mentioned occasionally (Kumaratilake, 1997; McClure and Koivula, 2001), while four-rayed chrysoberyl is extremely rare, originating mostly from Sri Lanka (Schmetzer, 2010). In the latter material, the two intersecting light bands normally show different intensities, and the needle-like inclusions or channels that cause these bands have not been identified unequivocally.

In a study of cat's-eye and non-phenomenal chrysoberyls from Brazil, precipitates (exsolu-

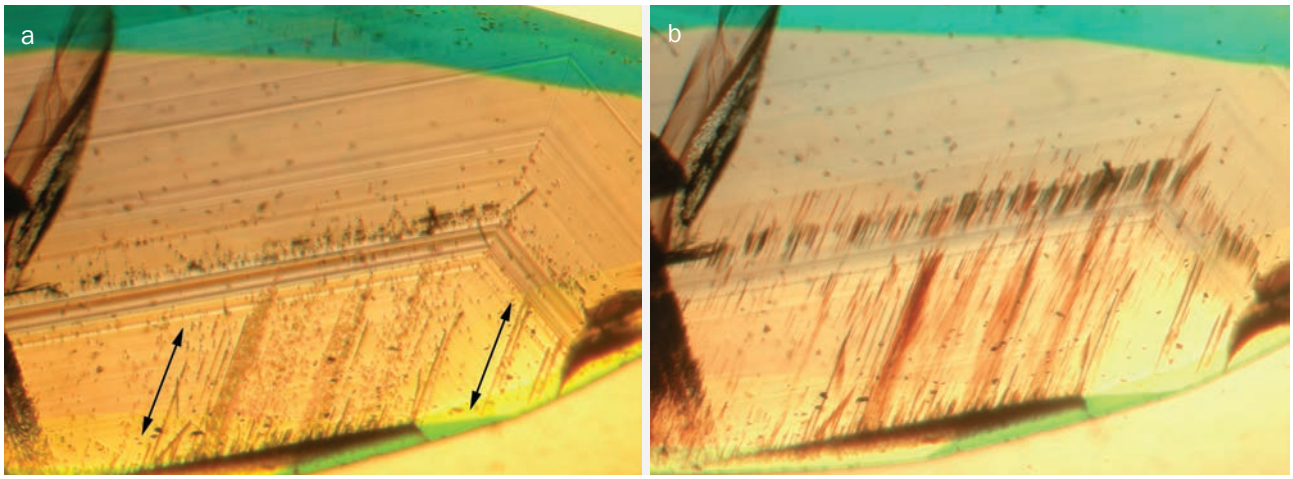

*Figure 2: This alexandrite from Lake Manyara, Tanzania, shows relatively large needle-like inclusions (rutile needles and/or channels) parallel to the a-axis. (a) In a view exactly parallel to the a-axis, the inclusions appear as small rounded dots forming sequences of parallel lines (indicated by arrows), and growth planes parallel to the **i** prism faces appear sharp. (b) In a view inclined to the a-axis, the elongate nature of the inclusions is visible. Immersion, field of view 2.7 × 2.0 mm; photomicrographs by K. Schmetzer.*

tions) of rutile were identified by electron diffraction and micro-analytical techniques in one chatoyant sample (Marder and Mitchell, 1982). The rutile inclusions were described as "elongated plates about 0.1 µm thick", but their orientation was not mentioned. Nonetheless, an analogy between chrysoberyl and corundum was proposed, with the three directions in chrysoberyl parallel to the c-axis [001] and parallel to <011> directions being equivalent to the three directions observed for rutile needles in corundum. (For an explanation of the nomenclature referring to crystallographic directions and their respective axes in chrysoberyl as employed in this article, see Box A.) More recently, two series of oriented inclusions described as rutile precipitates along **k** and **–k** {021} faces were studied by electron diffraction in a chrysoberyl from Brazil (Drev et al., 2015). The equivalent directions of those elongated structures would be <012>, and the maximum length of the precipitates was 0.05 µm. The relationship between the crystal structures of the chrysoberyl host and those of the rutile exsolutions was discussed in detail by Drev et al. (2015), but the dimensions of the precipitates in the direction parallel to the a-axis [100] has not yet been determined (Prof. A. Rečnik [Jožef Stefan Institute, Ljubljana, Slovenia], pers. comm., 2016).

Synthetic alexandrite grown by Kyocera of Japan shows three series of needle-like inclusions (most likely rutile exsolutions) lying in planes perpendicular to the a-axis; within these planes, the inclusions are oriented parallel to the c-axis [001] and to the **i** and **–i** {011} prism faces (Schmetzer et al., 2013), equivalent to orientations parallel to the [001] and <011> directions (see again Box A; for simplicity, this latter nomenclature convention will generally be used herein). Accordingly, the three different series of needles form angles of ~60° with each other.

Authors' Previous Work and the Aim of This Study

In alexandrite from the Lake Manyara deposit in Tanzania, various types of oriented inclusions are observed, mainly in milky-appearing crystals exhibiting pervasive cloudy whiteness throughout the entire piece, or in samples with alternating milky areas and transparent green growth zones. An initial study revealed that the inclusions are developed as needles or channels elongated parallel to the a-axis [100] and as small particles concentrated in planes perpendicular to the a-axis (Schmetzer and Malsy, 2011; see Figures 2 and 3). A polished thin section oriented almost perpendicular to the a-axis showed at high magnification three series of flattened needles or platelets oriented with their flat faces parallel to that plane.

In a subsequent study of a completely milky, translucent alexandrite crystal from Lake

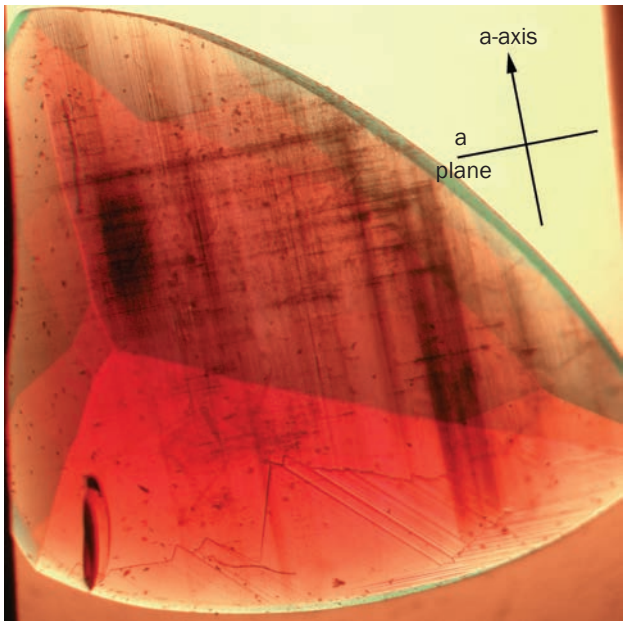

*Figure 3: Alexandrite (shown here) and chrysoberyl from Lake Manyara frequently contain areas with needles or channels oriented parallel to the a-axis, as well as minute inclusions in layers parallel to the **a** plane. View perpendicular to the a-axis, immersion, polarized light, field of view 4.5 × 4.5 mm; photomicrograph by K. Schmetzer.*

Manyara, polished thin sections were prepared in orientations perpendicular to the a-axis and almost perpendicular to the c-axis (Schmetzer and Bernhardt, 2012; Figures 4 and 5). The inclusion pattern observed in the section cut perpendicular to the a-axis (Figure 4) was similar to that described by Schmetzer and Malsy (2011), but like the earlier work, this study did not report the compositional nature of the inclusions.

The current examination was undertaken to further investigate the presence and nature of oriented inclusions in milky-appearing alexandrite from Lake Manyara. Moreover, this study offered an opportunity for wider applicability in understanding similar natural and synthetic materials. For instance, the inclusion pattern described above and pictured in Figure 3 is seen not only in material from Lake Manyara, but also in alexandrite from other localities (e.g. India). Therefore, this study was expanded in an effort to elucidate whether alexandrite/chrysoberyl from other locations might likewise show a pattern of oriented inclusions analogous to that observed in the Lake Manyara material. An example is presented here for semi-transparent samples from the state of Kerala in India.

Yet another opportunity to augment this inclusion study was afforded by chatoyant and asteriated material. As noted above, the elongated inclusions responsible for the chatoyancy in chrysoberyl from various sources were found to be parallel to the a-axis [100] (Schmetzer and Hainschwang, 2012). Additionally, from the orientation of the two intersecting light bands in natural four-rayed star chrysoberyl, presumably from Sri Lanka, it had been concluded that

Figure 4: In a thin section cut perpendicular to the a-axis, this alexandrite from Lake Manyara displays needle-like inclusions oriented in three directions. Intergrowths between two needles commonly form V-shaped angular structures or even triangular platelets. Transmitted light, field of view 120 x 90 µm; photomicrograph by H.-J. Bernhardt.

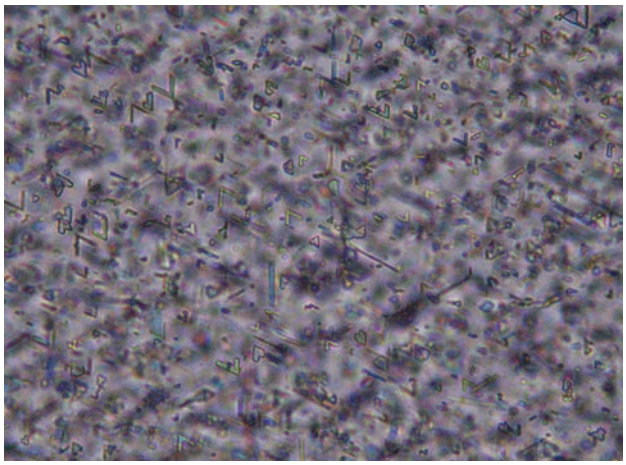

*Figure 5: In this view of a thin section cut approximately perpendicular to the c-axis, a Lake Manyara alexandrite has needle-like inclusions parallel to the a-axis. In some areas, other inclusions are concentrated on **a** (100) planes (perpendicular to the a-axis), and cross-sections of these inclusions are seen in this orientation of the thin section. Transmitted light, field of view 140 × 105 µm; photomicrograph by H.-J. Bernhardt.*

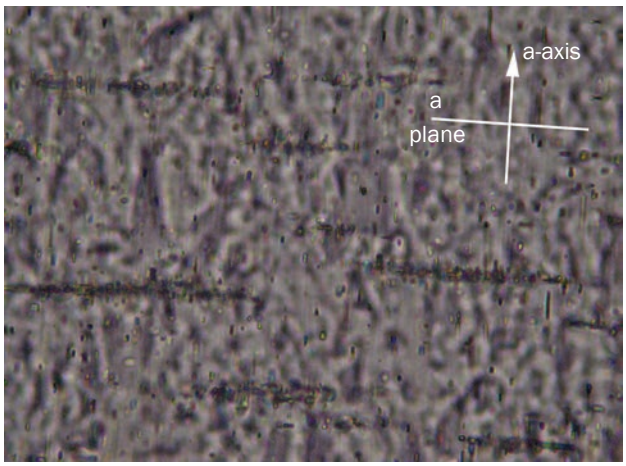

Box A: Nomenclature for Crystal Faces and Crystallographic Directions in Chrysoberyl

To facilitate understanding of the orientation of elongated inclusions (needle-like, channel or platelet structures) in chrysoberyl varieties, and especially to avoid excessive repetition in the text, this box gives a few general points about designating faces and directions in the orthorhombic crystal system.

The three crystallographic axes of chrysoberyl are normally indicated using the simple letters a, b and c. The three crystal faces perpendicular to these axes are correspondingly designated as **a**, **b** and **c**. A more detailed system of notation employing what are referred to as Miller indices in parentheses (hkl) specifies the faces perpendicular to the three axes as (100) for **a**, (010) for **b** and (001) for **c**. A similar notation involving three numbers in brackets [uvw] can be applied to the axes: [100] for the a-axis, [010] for the b-axis and [001] for the c-axis (Table A-1). For purposes of the present paper, cell dimensions of a = 4.42 Å, b = 9.39 Å and c = 5.47 Å were used for the three crystallographic axes.

All symmetry-equivalent faces of a crystal are referred to as a crystal form, and the faces of such a crystal form are symbolized using braces. For example, chrysoberyl has four symmetry-equivalent **i** (011) prism faces, i.e. (011), $(01\bar{1})$, $(0\bar{1}1)$ and $(0\bar{1}\bar{1})$, which are identified by the symbol {011} for the crystal form equivalent to all four such crystal faces (Figure A-1).

Crystallographic directions other than the three crystal axes are also designated with the symbol [uvw]. They commonly represent edges between two crystal faces. There are, for instance, four symmetry-equivalent edges between the four **i** {011} prism faces and the **a** (100) pinacoid. These four edges [011], $[01\bar{1}]$, $[0\bar{1}1]$ and $[0\bar{1}\bar{1}]$ are indicated jointly by the symbol <011>.

Table A-1: Oriented inclusions in chrysoberyl varieties; nomenclature of crystal faces and crystallographic directions.

Crystal Axes and Faces

Crystal axis	Symbol [uvw]	Cell dimensions (Å)	Face perpendicular to the crystal axis	Miller index (hkl)
a-axis	[100]	4.42	Pinacoid **a**	(100)
b-axis	[010]	9.39	Pinacoid **b**	(010)
c-axis	[001]	5.47	Pinacoid **c**	(001)

Needle-like Inclusions or Channels Parallel to Crystal Axes

Orientation	Symbol	Observed in chrysoberyl
‖ a-axis	[100]	Yes
‖ b-axis	[010]	No
‖ c-axis	[001]	Yes

Needle-like Inclusions or Rectangular Cross-Sections Parallel to the Edges Formed by Two Intersecting Crystal Faces

First face	Miller index (hkl)	Second face	Miller index {hkl}	Direction of crystal edges <uvw>	Angles between symmetry-equivalent crystal edges
Pinacoid **a**	(100)	Prism **i**	{011}	<011>	60.44° and 119.56°
Pinacoid **a**	(100)	Prism **k**	{021}	<012>	81.28° and 98.72°

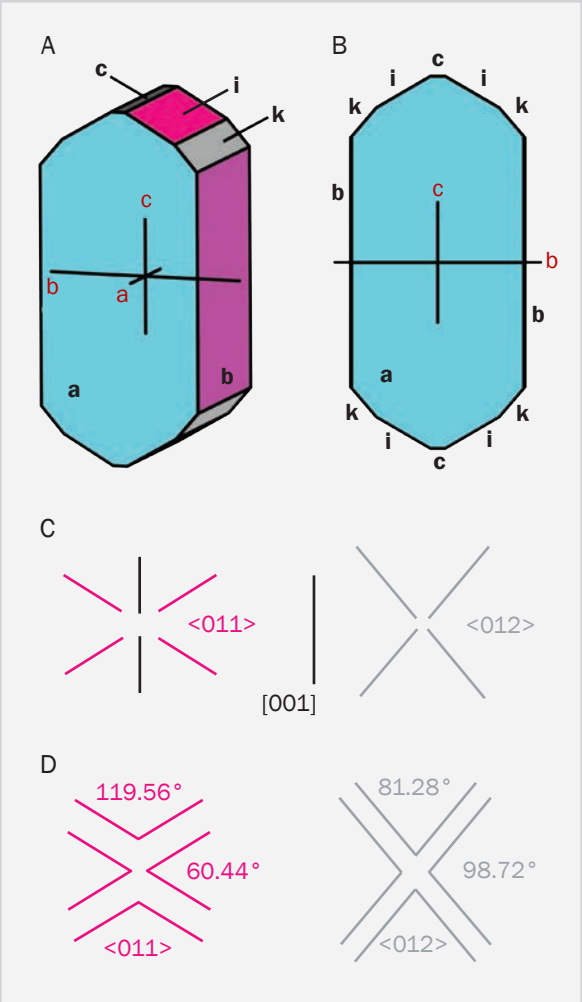

Figure A-1: This diagram shows the morphology of chrysoberyl and alexandrite crystals and the orientations of their acicular inclusions or platelets. Drawing A is an idealized clinographic projection of a crystal formed by the pinacoids **a** *{100},* **b** *{010} and* **c** *{001} in combination with the prisms* **i** *{011} and* **k** *{021}. Drawing B is a view of the same crystal parallel to the a-axis, representing the orientation of thin sections cut perpendicular to the a-axis. Part C displays the orientation of different series of needle-like inclusions in such thin sections, showing needles oriented parallel to the c-axis [001] and to the <011> directions (left), and cross-sections of flattened needles or elongated platelets parallel to the <012> directions (right). Part D depicts the possible orientations of intergrown structures or twins parallel to the <011> and <012> directions, giving the angles formed by the needles parallel to <011> and by the inclusion cross-sections parallel to <012>. All drawings by K. Schmetzer.*

Crystal edges between two faces with Miller indices $(h_1k_1l_1)$ and $(h_2k_2l_2)$ are easily calculated with the formula:

$$u = k_1 \bullet l_2 - l_1 \bullet k_2$$
$$v = l_1 \bullet h_2 - h_1 \bullet l_2$$
$$w = h_1 \bullet k_2 - k_1 \bullet h_2$$

In chrysoberyl, several series of needle-like inclusions, platelets of various shapes, channels and/or cross-sections of such structures are observed. Specifically, needles or channels lie parallel to the a-axis [100], parallel to the c-axis [001], and parallel to the edges between the **a** (100) pinacoid and the **i** {011} prism faces, symbolized by <011>. The cross-sections of flattened needles or narrow platelets elongated in the a-axis [100] direction are parallel to the four edges between the **a** (100) pinacoid and the **k** {021} prism faces, symbolized by <012>. All needles or channels parallel to the directions [001] or <011>, and the inclusion cross-sections parallel to <012>, are located within the **a** (100) plane or are observed in sections parallel to the **a** (100) plane. The various forms of needles, platelets or channels with cross-sections seen parallel to the a-axis [100] extend perpendicular to that plane.

Also in chrysoberyl, symmetry-equivalent needle-like inclusions parallel to <011> may be intergrown or twinned, forming angles of 60.44° and 119.56°. Flattened needles or platelets elongated parallel to the a-axis [100] with cross-sections parallel to <012> may also be intergrown, forming angles of 81.28° and 98.72°.

*Table I: Samples of chrysoberyl varieties containing oriented inclusions.**

Locality	Type	Sample no.	No. polished thin sections	Orientation of thin sections	Notes
Lake Manyara, Tanzania; alexandrite	Crystal	A	1	⊥ a-axis [100]	One Ti map; see also Schmetzer and Malsy (2011)
	Crystal	B	2	⊥ a-axis [100] ≈⊥ c-axis [001]	Two Ti maps; see also Schmetzer and Bernhardt (2012)
Kerala, India; alexandrite	Crystal	C	2	⊥ a-axis [100] ≈⊥ c-axis [001]	Two Ti maps
Kyocera, Japan; synthetic alexandrite (six-rayed star or cat's-eye according to cut orientation)	Cabochon	F	1	⊥ a-axis [100]	See also Schmetzer et al. (2013)
	Cabochon	G	1	⊥ b-axis [010]	
	Cabochon	H	1	⊥ b-axis [010]	
Orissa, India; cat's-eye chrysoberyl	Cabochon	E	2	⊥ a-axis [100] Perpendicular to the other section	
Brazil; cat's-eye chrysoberyl	Cabochon	I	1	⊥ a-axis [100]	
Ilakaka, Madagascar; cat's-eye chrysoberyl	Crystal	J	3	⊥ a-axis [100] ⊥ b-axis [010] ⊥ c-axis [001]	
Sri Lanka; star chrysoberyl (four-rayed)	Cabochon	D	2	≈⊥ b-axis [010] Perpendicular to the other section	Two Ti maps

* Groups of similar samples are highlighted in the same colour. All thin sections were 60 µm thick except for sample A, which was 20 µm thick.

the series of needles or channels causing the somewhat stronger light band was oriented parallel to the a-axis [100], while the second set of needles was found at a right angle to that direction, in the bc-plane (Schmetzer, 2010). Synthetic asteriated alexandrite, on the other hand, shows six rays when cabochons are cut with the base perpendicular to the a-axis (Schmetzer and Hodgkinson, 2011), and the formation of rutile precipitates in such crystals has been described in numerous patent applications (see the overview given by Schmetzer et al., 2013). In commercially available synthetic material grown Kyocera, the light bands of these six-rayed stars are formed by three series of needles in the **a** (100) plane.

Consequently, the present study delves into the apparent differences between cat's-eyes, four-rayed stars, and six-rayed stars, comparing chatoyant and asteriated natural and synthetic alexandrite/chrysoberyl samples.

Materials and Methods

Samples

Table I presents a summary of the samples and the orientation of the corresponding polished thin sections studied for this report. The thin-section orientations were chosen by taking into account the size and morphology of the samples, in combination with information available from the literature (especially from author KS's own studies cited above) on the inclusion directions.

The crystallographic orientation of the crystals, in turn, was determined by considering sample morphology and optical features such as growth structures, position of the optic axes and pleochroism (for alexandrite). The position of the crystallographic axes of the cabochon-cut samples was also established by optical examination, primarily by searching for both optic axes with the immersion microscope. To prepare thin sections of good transparency that

Figure 6: Alexandrite crystals and fragments from Lake Manyara frequently show a somewhat cloudy or milky appearance throughout the complete body of the samples or as alternating milky and transparent green growth zones. The tabular crystal at top-centre measures 9.6 × 6.8 mm. Daylight, photo by K. Schmetzer.

would contain sufficient oriented inclusions, a thickness of 60 µm was selected, which is larger than the sections typically used for petrographic studies (~25 µm).

With the goal of collecting more information about oriented needle-like inclusions in chrysoberyl and alexandrite, the present study started with crystals from Lake Manyara having milky-appearing areas (Figure 6) that were already known to contain such oriented inclusions. Three polished thin sections from two Lake Manyara alexandrites, which were previously prepared and examined by Schmetzer and Malsy (2011) and Schmetzer and Bernhardt (2012), were used. An alexandrite crystal presumably from the Trivandrum District in Kerala, southern India, was then selected for the preparation of two polished thin sections, based on observations of a somewhat similar whitish appearance (Figure 7) and a specific network of inclusions seen with the gemmological microscope. The exact source of this sample within the Trivandrum District is unknown, although alexandrites from various locations in the southern Indian states of Kerala and Tamil Nadu have been briefly mentioned in the literature (Menon et al., 1994; Manimaran et al., 2007; Fernandes and Choudhary, 2010).

Next, again drawing upon prior work that had indicated the existence of relevant oriented inclusions in material grown by the Japan-based company Kyocera, three polished thin sections with two different orientations were added to the present study; these had been prepared earlier for a study of cat's-eye and star synthetic alexandrites (see, e.g., Figure 8; Schmetzer et al., 2013).

Figure 7: These alexandrite crystals and fragments, presumably from the Trivandrum District, Kerala State, southern India, show a somewhat cloudy or milky appearance. The crystal in the upper right measures 8.4 × 4.2 mm. Daylight, photo by K. Schmetzer.

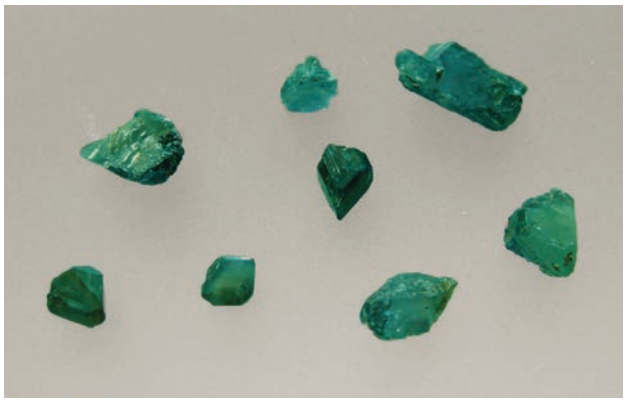

Figure 8: This six-rayed asteriated synthetic alexandrite produced by Kyocera weighs 1.63 ct and measures 8.3 mm in diameter. Daylight, photo by K. Schmetzer.

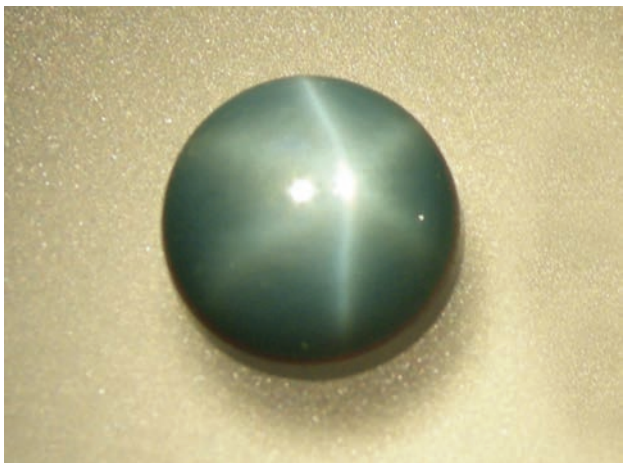

Figure 9: These cat's-eye chrysoberyl cabochons, presumably from Orissa State, India, range from 0.54 to 1.07 ct, and the smallest sample measures 5.0 × 3.7 mm. Incandescent light, photo by K. Schmetzer.

Figure 10: This cat's-eye chrysoberyl from Brazil weighs 1.38 ct and measures 5.9 × 5.8 mm. Incandescent light, photo by K. Schmetzer.

Then, operating on the premise that natural cat's-eye and star chrysoberyl should also contain at least one or two series of needle-like inclusions, a cat's-eye cabochon from a group of chrysoberyls (Figure 9) presumably from the state of Orissa, India (see Fernandes and Choudhary, 2010), was selected for the preparation of two oriented polished thin sections.

To characterize the inclusion pattern of a natural cat's-eye chrysoberyl from a second source, we used a transparent, high-quality cabochon (Figure 10) from one of the numerous Brazilian occurrences (see, e.g., Cassedanne and Roditi, 1993). This sample was sliced parallel to the sharp light band.

Because cat's-eye chrysoberyl is also known from the famous gem mining area of Ilakaka, Madagascar (Milisenda et al., 2001), this study was further supplemented by a milky-appearing, only slightly translucent chrysoberyl crystal from that locality. Oriented thin sections were prepared in all three directions perpendicular to the crystal axes of this sample. Additionally, after the three slices had been removed, the edges of the remaining portion were ground and the surface was polished. The resulting irregularly shaped but rounded sample resembled a tumble-polished pebble, and a strong light band completely encircled its surface.

Finally, the authors were allowed to cut a 1.9-mm-thick slice from a four-rayed star chrysoberyl cabochon from Sri Lanka (top-right sample in Figure 11), despite the fact that such samples are extremely rare and normally not available for destructive examination. The removal of this slice from the base did not influence the visual appearance of the stone after cutting, and the slice was used to prepare two oriented polished thin sections.

Figure 11: In these four-rayed star chrysoberyls, presumably from Sri Lanka, the b-axis of the crystals is almost perpendicular to the base of the cabochons. The weight of the samples ranges from 4.49 to 10.37 ct, and the cabochon at the lower right weighs 6.25 ct and measures 9.6 × 9.3 mm. A slice of the cabochon in the upper right was used for the preparation of two thin sections (sample D). Incandescent light, photo by K. Schmetzer.

Methods

To resolve acicular inclusions and small platelets, all thin sections were examined at higher magnification (up to 1,000×) than normally applied in gemmology, in both reflected and transmitted light, using a Leitz Ortholux II Pol-BK polarizing microscope or a Leica DM LM polarizing microscope.

Because previous work (especially on corundum but also on some natural or synthetic chrysoberyls; see references cited above) suggested that Ti-bearing phases might play an important role in forming acicular inclusions, multiple techniques were employed using a Cameca SX 50 electron microprobe to evaluate the chemical nature of the inclusions. Preliminary qualitative point analyses of individual inclusions, guided by BSE images (which depict differences in mean atomic mass as variations in brightness levels), were performed for several inclusions that were clearly exposed at the surface of the polished thin sections. In addition, X-ray compositional maps for Ti were obtained by scanning seven of the thin sections, to which a carbon coating had been applied. BSE images of certain scanned areas were taken as well. The Ti-mapped areas consisted of 512 × 512 analytical points (pixels) with a step-width (point distance) of 0.119 µm, which resulted in a scanned area of ~61 × 61 µm consisting of 262,144 points for each compositional map. To achieve the greatest possible resolution, the maximum available focus of the electron beam (~1 µm in diameter) was used. The measurement time per pixel was 140 ms, the beam current was 20 nA and the acceleration voltage was 15 kV.

Quantitative microprobe analyses of the host chrysoberyl also were obtained from samples from both localities in India (Kerala and Orissa) to further characterize material obtained from the trade.

The mineral phases forming the Ti-bearing inclusions in all of the samples were analysed by micro-Raman spectroscopy using a Horiba Jobin Yvon XploRA PLUS confocal Raman microscope. The spectrometer was equipped with a frequency-doubled Nd:YAG laser (532 nm, with a maximum power of 22.5 mW) and an Olympus 100× long-working-distance objective with a numerical aperture of 0.9. The measurements were performed with a 1,200 mm^{-1} grating, a 300 µm pinhole and a 100 µm slit. Two accumulations of 5 sec counting time were used for each spectrum.

Results

The numerous Ti-bearing needles, narrow rectangular platelets, V-shaped and triangular platelets, and L-shaped and zigzag clusters examined by micro-Raman spectroscopy in combination with microprobe analysis were identified as rutile, on the basis of four characteristic bands at ~142 cm^{-1} (weak), ~239 cm^{-1} (medium), ~445 cm^{-1} (very strong) and ~611 cm^{-1} (very strong) [Figure 12a; see, e.g., Porto et

Figure 12: Raman spectra are shown for a rutile inclusion in chrysoberyl from Ilakaka, Madagascar (a), and for an ilmenite inclusion in asteriated chrysoberyl from Sri Lanka (b). Spectra from the host chrysoberyl are shown for both samples for comparison.

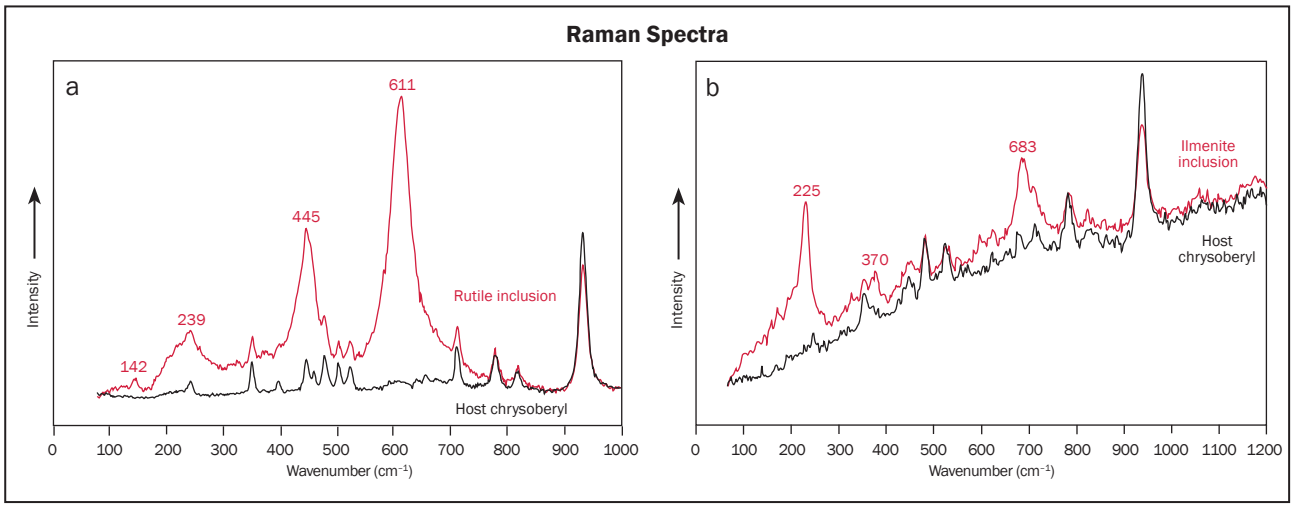

Table II: Oriented needle-like inclusions or platelets in chrysoberyl varieties.[a]

Locality and variety	Sample no.	Orientation of inclusions, optical microscopy						
		Single needles in **a** (100) plane		Single needles, channels or platelets elongated parallel to [100]		Intergrown structures		
		Elongation parallel to [001][b]	Elongation parallel to <011>	Cross-sections parallel to <012>, forming narrow rectangles (single 'stripe')	Cross-sections rounded or rectangular	Elongation parallel to <011>, forming V-shaped or triangular platelets	Elongation parallel to <011> and [001]	Elongation parallel to [100], with cross-sections parallel to <012>, forming L-shaped and zigzag platy clusters (multiple 'stripes')
Lake Manyara, Tanzania; alexandrite	A	Common	Common		Common	Common		
	B	Common	Common		Common	Common		
Kerala, India; alexandrite	C	Rare	Common	Rare	Larger channels	Common		Rare
Kyocera, Japan; synthetic alexandrite (six-rayed star or cat's-eye according to cut orientation)	F, G, H	Common	Common			Common	Rare	
Orissa, India; cat's-eye chrysoberyl	E	Very rare	Rare	Rare		Rare	Very rare	Common
Brazil; cat's-eye chrysoberyl	I	Rare	Rare		Common	Rare		
Ilakaka, Madagascar; cat's-eye chrysoberyl	J	Common	Common	Common		Common		Rare
Sri Lanka; star chrysoberyl (four-rayed)	D	Common			Common			

[a] Dominant inclusions of a similar type are highlighted in the same colour.
[b] Larger growth tubes parallel to the c-axis [001] are occasionally observed in chrysoberyl and alexandrite from various locations, but such channels were not seen in the present samples (see, e.g., Schmetzer and Krzemnicki, 2015).

al., 1967]. Only the inclusions in the four-rayed star chrysoberyl from Sri Lanka were identified as ilmenite needles based on Raman bands at ~225 cm^{-1} (very strong), ~370 cm^{-1} (weak) and ~683 cm^{-1} (very strong) [Figure 12b; cf. Wang et al., 2004].

Other than for the ilmenite, the Raman spectra were all more-or-less identical and indistinguishable from the spectra for rutile available in the literature. No other crystalline TiO_2 phases were detected. Therefore, the Ti-bearing particles, which were also characterized extensively by microscopy in combination with microprobe analysis, are in general designated herein simply as rutile.

Moreover, as a preface to describing observations for different samples in detail, it should be mentioned that additional orientations of needles or platelets or of cross-sections of flattened inclusions were encountered beyond those described below, especially in the sample from Kerala, India. However, we would need to study thin sections cut in different orientations to fully characterize these additional inclusion types.

A summary of the results discussed below is presented in Table II.

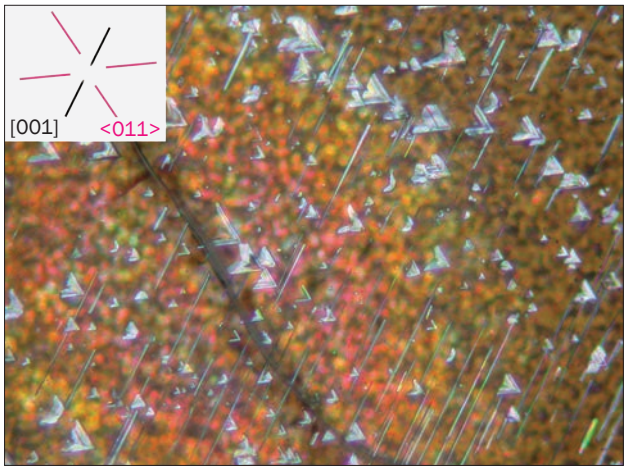

Figure 13: In a thin section cut perpendicular to the a-axis of alexandrite from Lake Manyara (sample B), elongated inclusions are observed in three different orientations parallel to [001] and <011>. Some of the needles or elongated inclusions parallel to <011> meet at one end, forming V-shaped angular structures or triangular platelets. View parallel to the a-axis, reflected light, field of view 140 × 105 µm; photomicrograph by H.-J. Bernhardt.

Alexandrite from Lake Manyara, Tanzania

Alexandrite from Lake Manyara was described in detail by Schmetzer and Malsy (2011), and the oriented inclusions were examined by Schmetzer and Bernhardt (2012). As reported in those publications, both of the polished thin sections cut perpendicular to the a-axis showed needle-like to plate-like structures (Figure 4). In samples A and B, three series of single elongated needles were observed in directions parallel to the c-axis [001] and parallel to <011>, forming angles of ~60° with each other (Figure 13). Frequently, two needles parallel to the <011> directions were intergrown or twinned, forming acute-angled, V-shaped platelets with re-entrant angles measuring ~60°. Due to the differing dimensions and thicknesses of the needles within the **a** (100) plane, the open space between the two sides of these V-shaped structures varied widely. Some exhibited large spaces between the arms; others were essentially triangular platelets with almost no interstitial space. Obtuse-angled structures consisting of two intergrown needles forming angles of ~120° were rare. Intergrown needles comprising crystals elongated parallel to one <011> direction and parallel to the c-axis [001] were not seen in the Lake Manyara material during the investigations to date.

No systematic distribution for these different structures was apparent in the crystals examined. Some areas within the same crystal showed mainly single needle-like features, while other zones contained primarily angular structures of two intergrown or twinned needles/platelets. In still other areas of the crystal, both types of structures were observed together.

Qualitative point analyses of surface-reaching inclusions indicated only Ti as the main element. For the compositional mapping of Ti by the electron microprobe, areas were selected within the thin sections that in transmitted and reflected light showed numerous inclusions, including both single needles and intergrown structures (Figure 14a). The distribution of Ti correlated well with bright spots in BSE images of the same areas; several needles and acute-angled structures were observed within the surrounding chrysoberyl matrix (Figure 14c,e), representing the section perpendicular to the a-axis, sample B). Weaker Ti signals corresponding to several

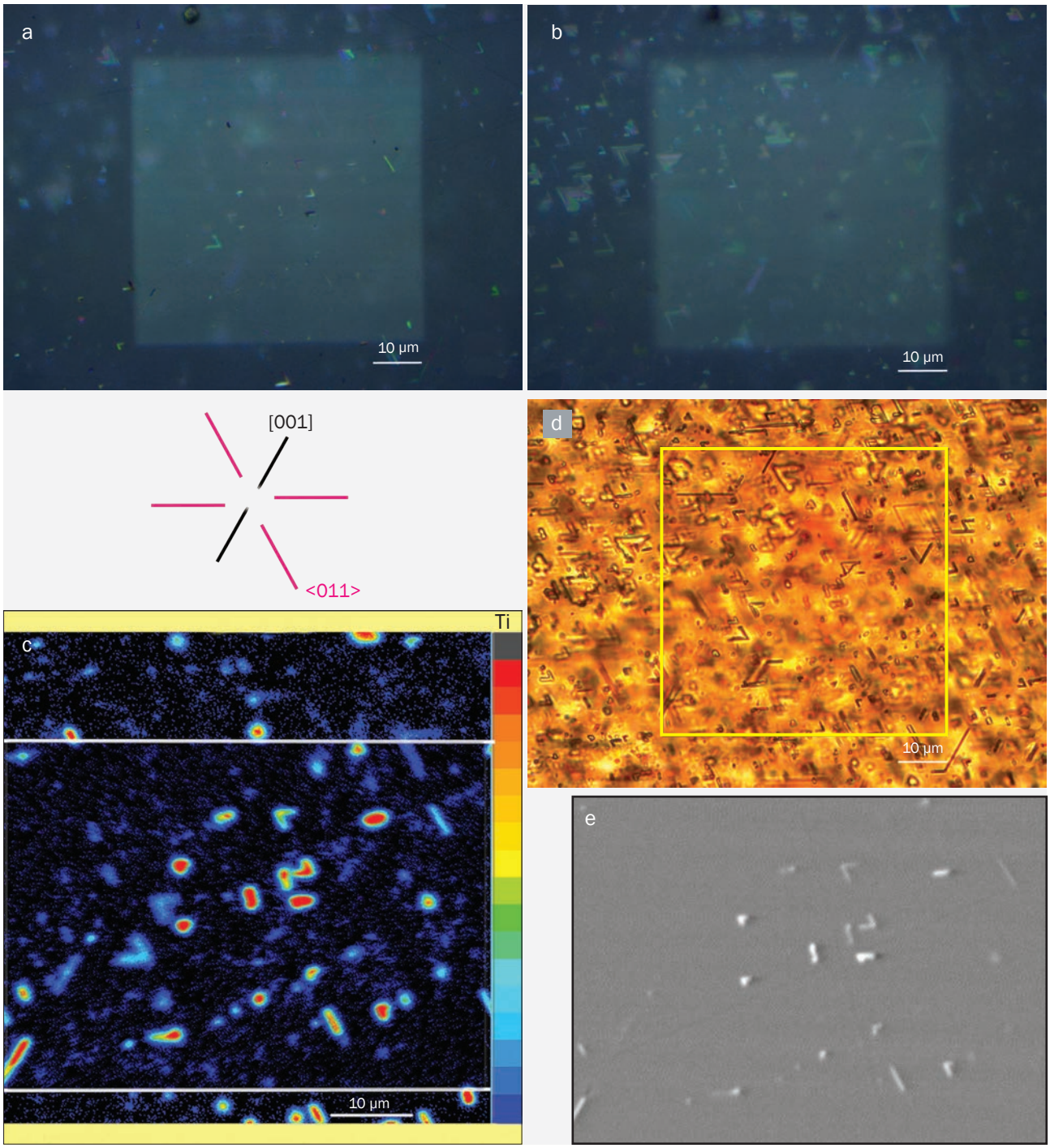

Figure 14: In a thin section cut perpendicular to the a-axis of alexandrite from Lake Manyara (sample B), elongated inclusions are observed in photomicrographs in reflected light (a,b) and in transmitted light (d) compared to a Ti compositional map (c) and a BSE image (e). The scanned area measuring ~61 × 61 µm is clearly seen in reflected light due to the alteration of the carbon coating from the electron beam of the microprobe. In reflected light, the surface of the sample (a) shows rutile needles and V-shaped platelets that are also represented in the Ti compositional map (c). Focusing the optical microscope below the surface of the thin section (b) shows inclusions that generally are not seen in the Ti map. In transmitted light (d), inclusions both at the surface and below are seen. The BSE image (e) shows only rutile needles and V-shaped rutile platelets exposed at the surface of the thin section. The compositional map (c) shows Ti signals corresponding to these inclusions, as well as somewhat weaker Ti signals for inclusions located within the chrysoberyl host, but close to the surface. The scanned area (c) is outlined in (a), (b) and (d); the area of the BSE image (e) is outlined in (c); the intensity of the Ti signal in (c) ranges from weak (blue) to strong (red). Field of view ~112 × 84 µm (a,b,d); photomicrographs and Ti map by H.-J. Bernhardt.

needles and acute-angled structures also were seen within the X-ray map, indicating inclusions not exposed at, but close to, the surface of the chrysoberyl host.

After the Ti compositional mapping was complete, the scanned area remained clearly outlined in the carbon coating in reflected light (Figure 14a,b). It was therefore possible to directly compare the microscopic view in transmitted/reflected light with the BSE image (Figure 14e) and the Ti compositional map (Figure 14c). When the optical microscope was focused on the surface of the sample (Figure 14a), the pattern of inclusions observed in reflected light closely resembled that seen in the BSE image, and these inclusions provided relatively strong Ti signals in the compositional map (Figure 14c). However, if the optical microscope was focused some microns further below the surface, a completely different inclusion picture was revealed in reflected light, consisting of needles and platelets located entirely within the chrysoberyl host (Figure 14b). Most of these inclusions were not indicated in the Ti map. In transmitted light, a denser pattern of inclusions was visible (Figure 14d) that could thus be characterized as an overlap or summation of the inclusions seen in reflected light at various depths within the polished thin section. All these needles or platelets proved to be rutile by Raman analysis, with the individual needles or platelets having—in the direction of the a-axis—a thickness in the range of 1–2 µm or even smaller.

The microscopic features of the thin section of sample B that was cut almost perpendicular to the c-axis revealed two principal types of inclusions: (1) those concentrated in planes perpendicular to the a-axis, and (2) tiny needle-like structures, sometimes slightly flattened, running parallel to the a-axis [100] (Figure 5). For the former type of inclusions, the BSE image depicted numerous single bright spots, and occasionally somewhat elongated points or short lines. The compositional map also showed a high concentration of Ti in these areas. Raman spectroscopy of several highly reflective particles with almost square or rectangular (sometimes slightly rounded) cross-sections yielded clear rutile spectra.

Conversely, the needle-like structures running parallel to the a-axis [100]—the second type of inclusions—were not clearly resolved in the Ti map. However, micro-Raman spectroscopy of numerous tiny needles with this orientation showed rutile spectra for some of them. Others revealed only spectra of the chrysoberyl host, which might indicate that these needles were simply too small for the Raman technique applied or that the structures were channels.

The orientation of the thin section cut almost perpendicular to the c-axis (Figure 5) is a rectangular slice through the section shown in Figures 13 and 14. If rutile needles with a thickness in the micrometre range (see above) are cut in such a way, their representation on the Ti map would be single points. If triangular rutile platelets are cut in this way, the Ti map would show small lines. Both types of reflective structures were identified as rutile by Raman spectroscopy.

The lack of any Ti-related features in the compositional map corresponding to the tiny needle-like structures running parallel to the a-axis [100] indicates either (1) that any Ti signals from these inclusions were below the resolution of the microprobe, if in fact these needles were rutile and exposed to the surface, or (2) that only channels were present. Nonetheless, the Raman examination showed, at least for some of these small needles, that they were indeed rutile. Consequently, the presence of tiny rutile needles parallel to the a-axis [100] was established, but the additional presence of channels in the same direction could not be ruled out.

The observations from optical microscopy, BSE imaging and Ti compositional mapping for sample A from Lake Manyara, obtained from a thin section cut perpendicular to the a-axis, generally showed results similar to those of sample B with the same orientation and therefore are not repeated here. Additionally, in one area of the thin section, cross-sections of needles or channels elongated parallel to the a-axis [100] were observed (Figure 15), appearing in this orientation as parallel lines comprising individual somewhat rounded structures. In reflected light, some of these structures were highly reflective and could be identified as rutile by Raman spectroscopy. However, as with the results just described for sample B, it is possible that channels having the same orientation might also be present.

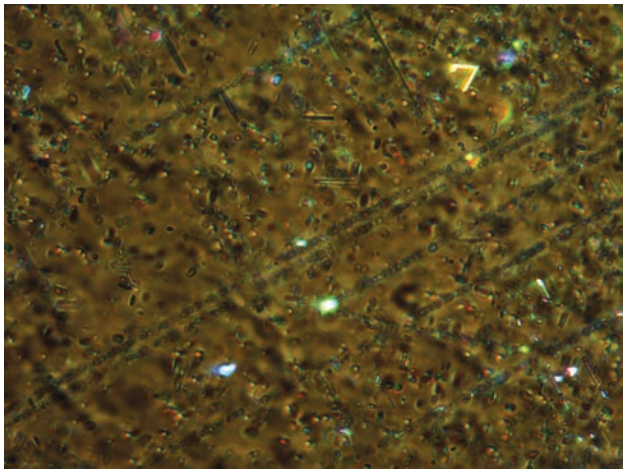

Figure 15: Cross-sections of several sequences of needle-like inclusions are seen in a thin section cut perpendicular to the a-axis, in alexandrite from Lake Manyara (sample A). The individual somewhat rounded cross-sections form numerous parallel lines. Some of these inclusions are highly reflective and were identified as cross-sections of rutile needles. Reflected light, crossed polarizers, field of view 167 × 125 µm; photomicrograph by H.-J. Bernhardt.

Alexandrite from Kerala, India

Alexandrite from Trivandrum in the Kerala State of southern India has been mentioned in the literature, but a detailed description is unknown to the present authors. The material available for this study comprised primarily broken crystal fragments, along with a few complete crystals and some tabular contact twins. Microprobe analyses of six samples of this alexandrite yielded 0.25–0.85 wt.% Cr_2O_3, 0.03–0.05 wt.% V_2O_3 and 0.81–1.35 wt.% Fe_2O_3.

In the gemmological microscope, most samples showed a distinct network of fine needle-like inclusions oriented parallel to the <011> directions (Figure 16). Furthermore, a dense series of needles or channels parallel to the a-axis [100] was present in most samples. A similar inclusion pattern has been described for some alexandrite from Sri Lanka and Madagascar (Schmetzer, 2010).

Examination of the two polished thin sections at higher magnification, in combination with Ti compositional mapping by electron microprobe, showed a number of similarities with the Lake Manyara material. In the thin section oriented perpendicular to the a-axis, Ti-bearing needles or platelets were present, and the inclusion pattern differed substantially depending on whether the focus was at the surface of the thin section (Figure 17a) or slightly below the surface (Figure 17b). The Ti map (Figure 17c), which represented only the surface of the thin section, registered three relatively large rutile needles within the chrysoberyl host. Transmitted light provided a composite view of inclusions at multiple depths within the sample (Figure 17d). Several of these inclusions were identified as rutile by micro-Raman spectroscopy.

Most of the rutile needles were elongated parallel to the <011> directions of the host (Figures 17 and 18). Needles parallel to the c-axis [001] were occasionally present, but less commonly than in the Lake Manyara material. Moreover, the needles and platelets in the sample from Kerala were larger than in material from Lake Manyara, although they, too, were up to 1–2 µm thick in the direction parallel to the a-axis [100]. The pleochroism, as observed in different parts of the rutile platelets or V-shaped rutile crystals (Figures 18 and 19), established that the inclusions consisted of two different parts with different crystallographic orientations.

Figure 16: Observed parallel to the a-axis (as shown by inset), an alexandrite from Kerala State, India, reveals a dense network of needle-like structures parallel to the <011> directions. Immersion, field of view 2.7 × 3.6 mm; photomicrograph by K. Schmetzer.

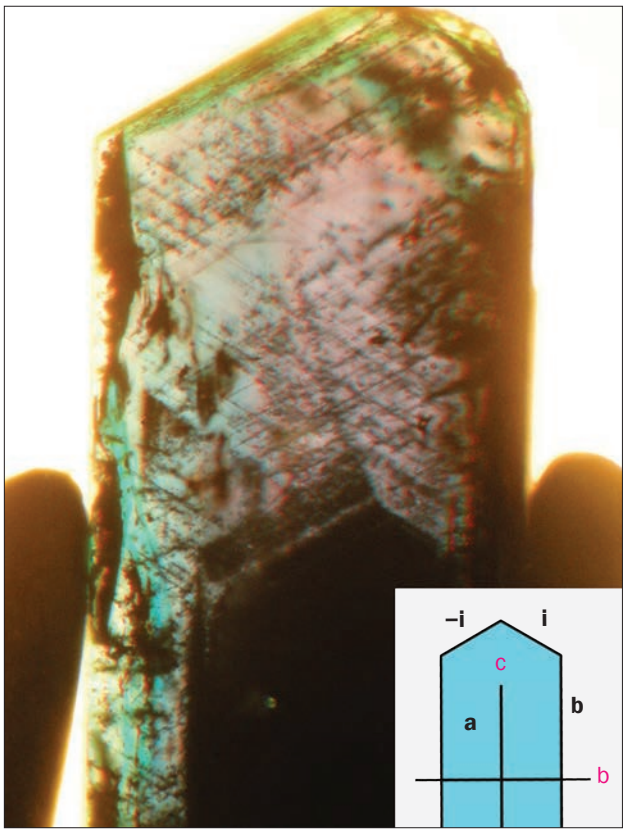

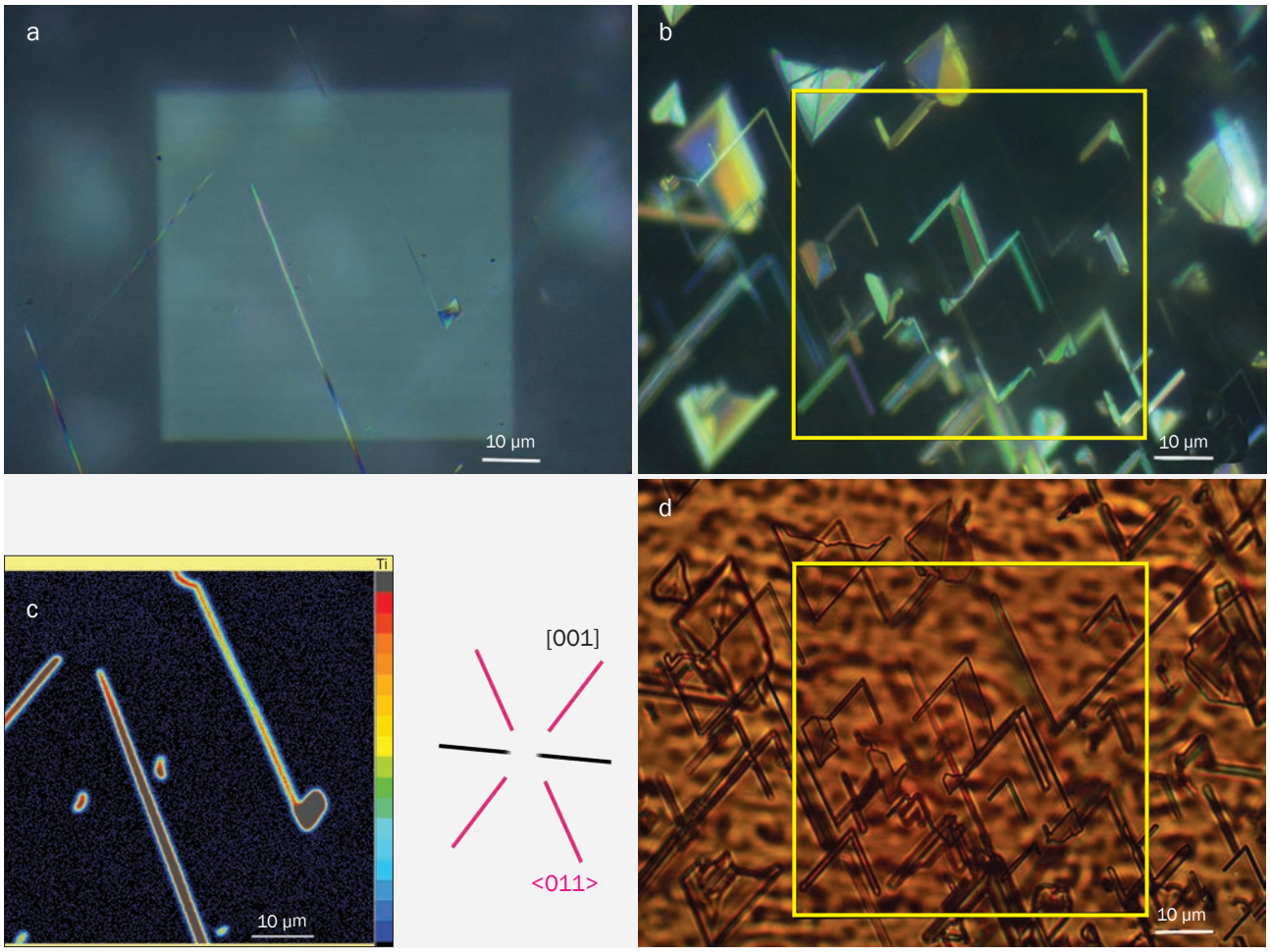

Figure 17: An alexandrite from Kerala (sample C), cut perpendicular to the a-axis, is shown in reflected (a,b) and transmitted light (d) compared to the Ti compositional map (c). In reflected light, the view of the surface of the sample (a) shows the scanned area (measuring ~61 × 61 µm), with rutile needles that are also represented in the Ti distribution map (c). Focusing the optical microscope slightly below the surface of the thin section with crossed polarizers shows inclusions (b) that generally are not observed in the Ti distribution map. In transmitted light (d), inclusions both at the surface and at various depths below the surface are seen. The scanned area (c) is outlined in (a), (b) and (d); the intensity of the Ti signal in (c) ranges from weak (blue) to strong (red). Field of view ~112 × 84 µm; photomicrographs and map by H.-J. Bernhardt.

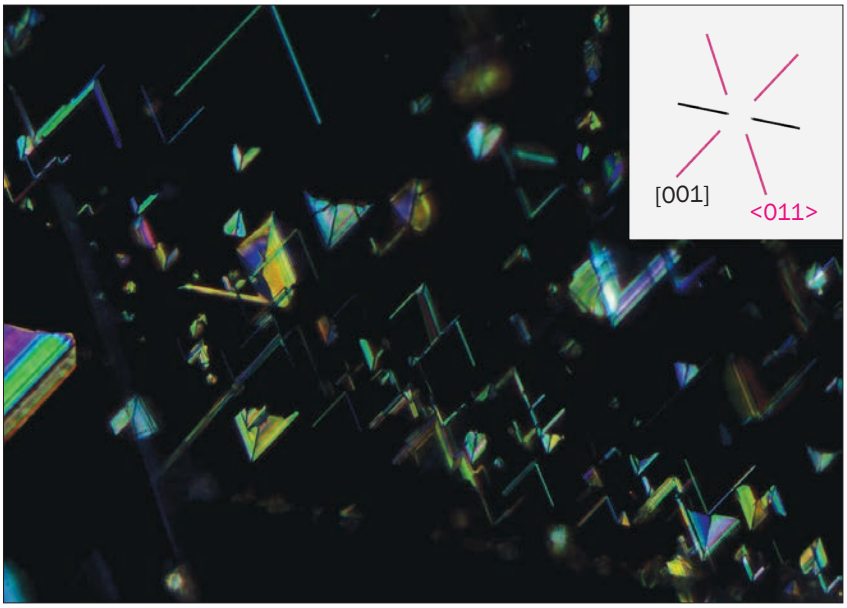

Figure 18: An alexandrite crystal from Kerala, cut perpendicular to the a-axis (sample C), shows elongated rutile inclusions in different orientations parallel to <011>. Some of them meet at one end, forming V-shaped angular structures or platelets; single needles parallel to the c-axis are only rarely seen. View parallel to the a-axis, reflected light, crossed polarizers, field of view 224 × 160 µm; photomicrograph by H.-J. Bernhardt.

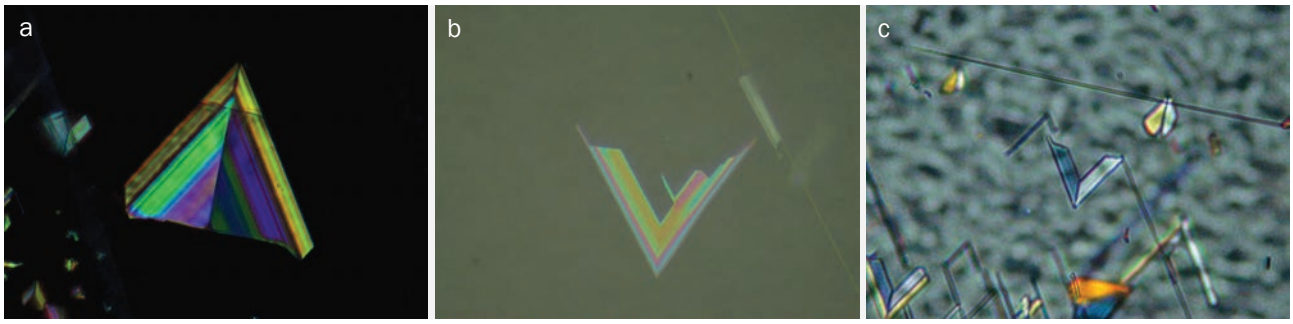

Figure 19: Somewhat larger V-shaped or triangular rutile platelets in the alexandrite from Kerala, cut perpendicular to the a-axis (sample C), are shown in these images (a, b and c). View parallel to the a-axis, reflected light, crossed polarizers, field of view 112 × 84 µm; photomicrographs by H.-J. Bernhardt.

More atypically, in one area of the Kerala thin section cut perpendicular to the a-axis, structures appearing as short lines were observed parallel to the <012> directions of the chrysoberyl host, and were often connected to form L-shaped or zigzag patterns (Figure 20). Such an orientation was recently described in a chrysoberyl from Brazil (Drev et al., 2015). In the Kerala sample, these inclusions also were identified as rutile by Raman spectroscopy. As further explained below in connection with the Orissa material, these structures represented cross-sections of platelets elongated parallel to the a-axis [100].

The other thin section of the alexandrite from Kerala, cut with an orientation almost perpendicular to the c-axis, showed needle-like structures of different lengths, and the compositional map recorded simply Ti-bearing spots or somewhat elongated Ti-rich areas. Again, these are the typical patterns expected if needles or V-shaped platelets such as those depicted in Figures 17–19 are cut at a right angle to the **a** (100) face.

Kyocera Synthetic Alexandrite

Asteriated and chatoyant synthetic alexandrites from Kyocera in Japan were described in detail by Schmetzer and Hodgkinson (2011) and by Schmetzer et al. (2013). The thin section of this Ti-bearing material oriented perpendicular to the a-axis (sample F) showed small elongated particles in three directions, with the three series of needles forming angles of ~60° with each other (Figure 21a). Several intergrown particles were seen, mostly with re-entrant angles of 60° and rarely with angles of 120° (Figure 21b). However, due to the small size of these particles and the dense pattern, it was sometimes difficult to determine if two needles were intergrown or if they were merely exsolved at different depths close to each other and thereby overlapped in the microscopic view of the thin section. The needles were too small for either

Figure 20: In this area of the Kerala alexandrite thin section shown in Figures 18 and 19, cross-sections of elongated inclusions are observed in different orientations parallel to <012>. Some of these structures meet, forming L-shaped or zigzag patterns. View parallel to the a-axis, reflected light (top), reflected light and crossed polarizers (bottom), field of view 112 × 84 µm; photomicrographs by H.-J. Bernhardt.

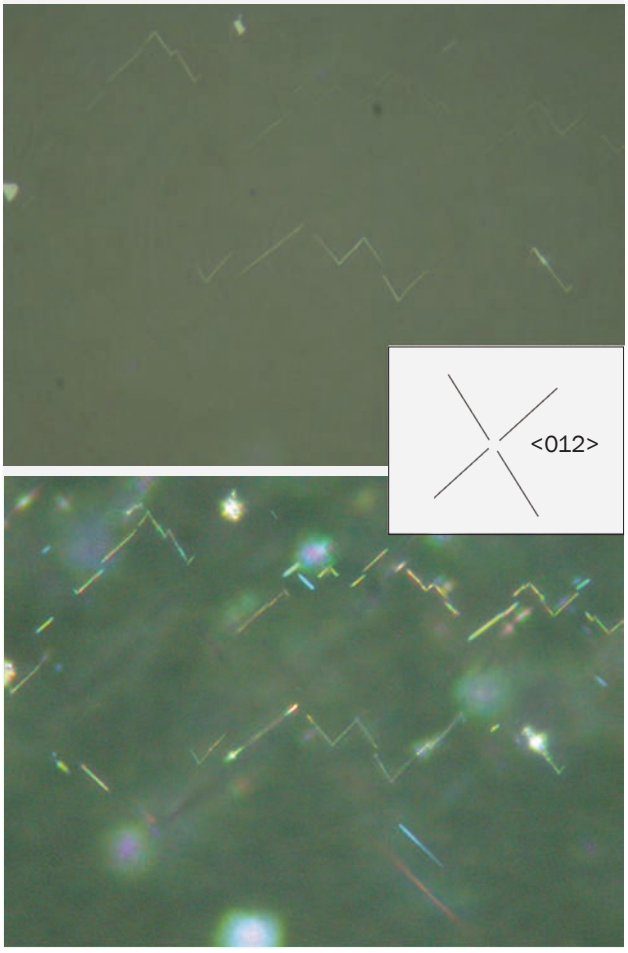

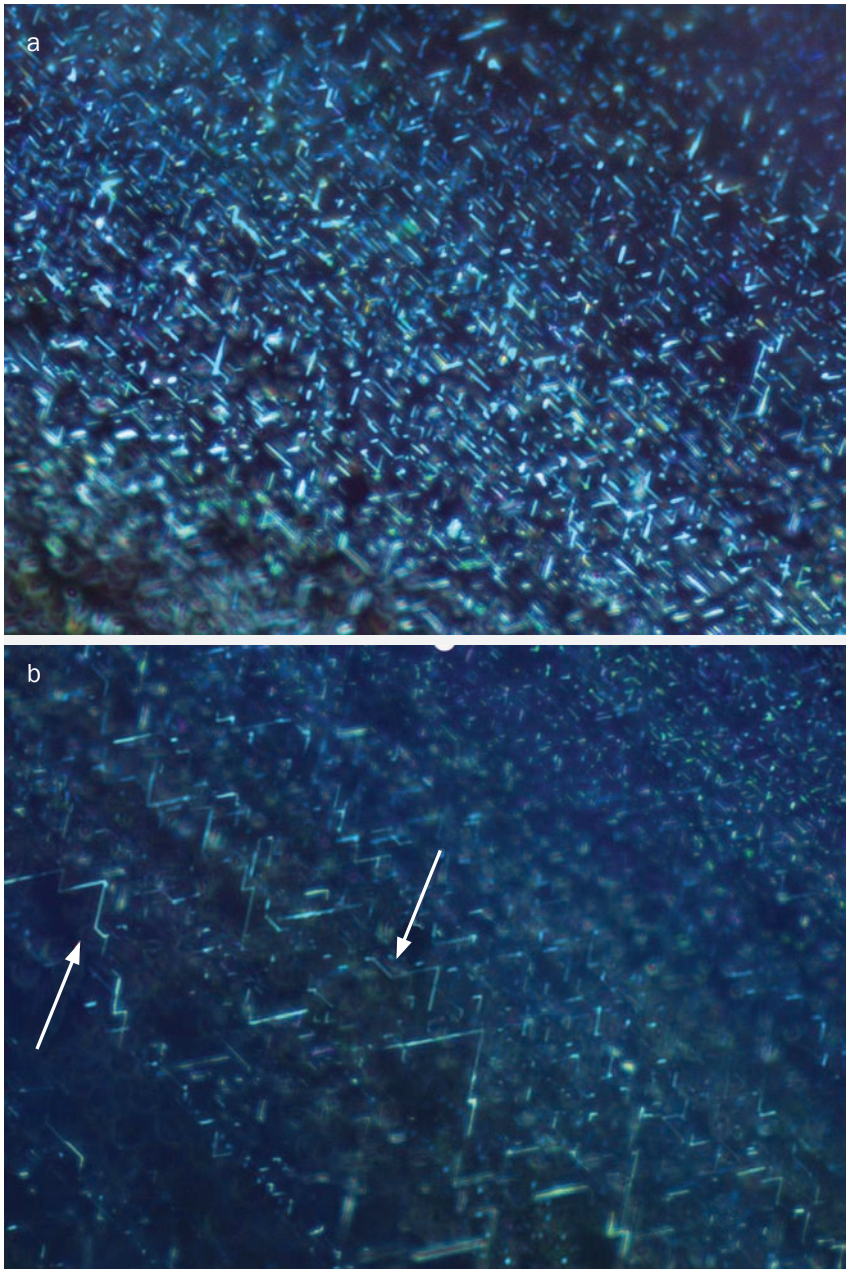

Figure 21: A thin section cut perpendicular to the a-axis of a synthetic asteriated alexandrite grown by Kyocera (sample F) shows a dense network of needles oriented in the <011> and [001] directions. In general, isolated needles or needles that are intergrown forming an angle of ~60° are observed (a), whereas two needles forming an angle of 120° (b, indicated by arrows) are less common. Reflected light, field of view 112 x 84 µm; photomicrographs by H.-J. Bernhardt.

microprobe analyses or micro-Raman spectroscopy. The examination of samples G and H, both cut perpendicular to the b-axis, did not reveal additional information, only corroborating what was learned from sample F. For further details, the reader is referred to the publications cited above.

Chatoyant Chrysoberyl from Orissa, India

Cat's-eye chrysoberyl from Orissa has been known in the trade for several years. The faceted chrysoberyl and alexandrite, as well as their chatoyant varieties, frequently have a low-saturation greenish or a light greyish colour in daylight, with a colour change to grey or light purple, respectively, in incandescent light. In a previous study, some samples described as colour-change chrysoberyl showed low concentrations of both V and Cr in comparable amounts (Schmetzer, 2010).

The chatoyant chrysoberyl selected for the present study (sample E) was chosen from a group of cabochons (e.g. Figure 9) that were slightly greenish grey in daylight and grey in incandescent light. Four samples from the group were analysed by electron microprobe, which recorded 0.05–0.07 wt.% V_2O_3, 0.03–0.05 wt.% Cr_2O_3, and 0.45–0.61 wt.% Fe_2O_3. These measurements are comparable with published data for faceted material from Orissa (Schmetzer, 2010).

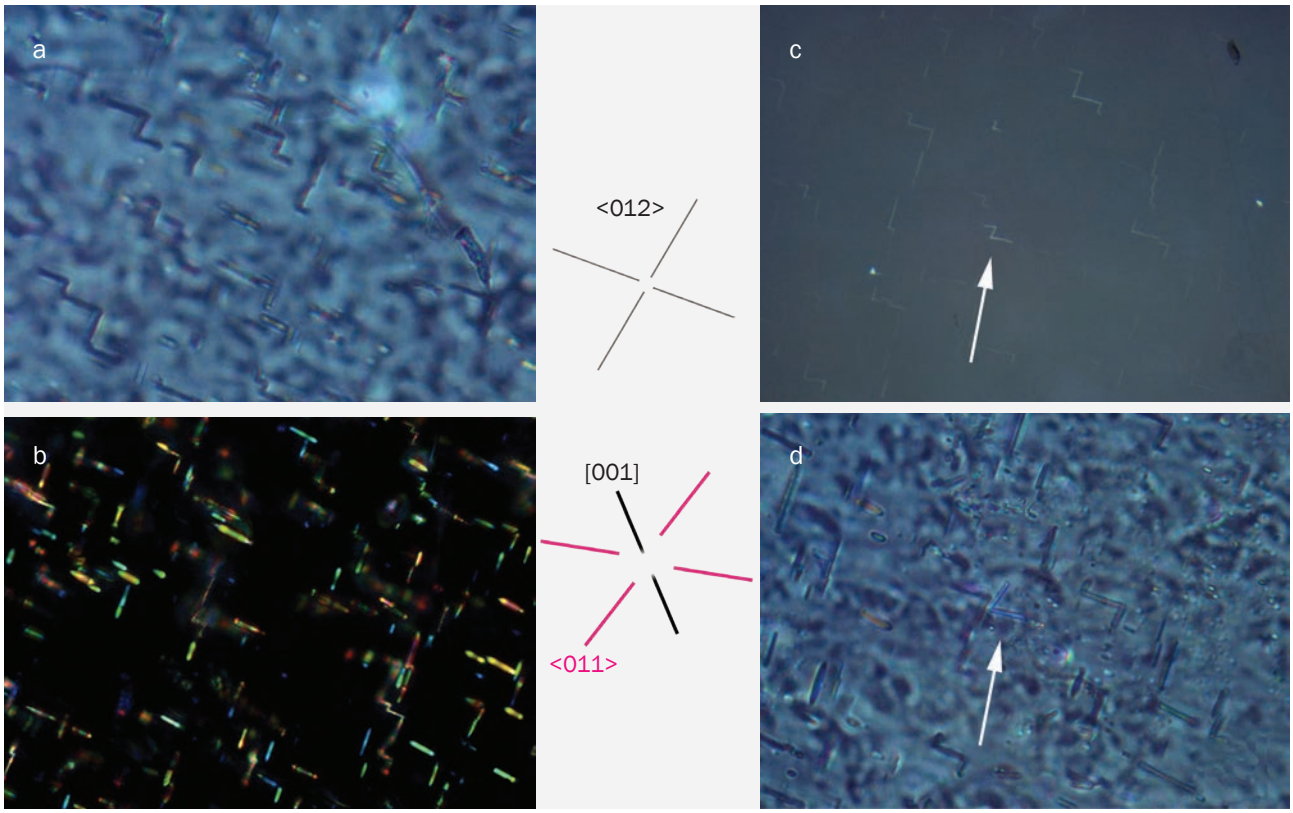

Figure 22: Photomicrographs in reflected light (a,c,d) and in reflected light with crossed polarizers (b) of a thin section cut perpendicular to the a-axis of a cat's-eye chrysoberyl from Orissa (sample E) show a network of L-shaped or zigzag cross-sections of rutile platelets parallel to <012> (a,b). Only a few cross-sections oriented parallel to <011> are observed in one small area of the thin section (c,d; indicated by arrows). Field of view 112 × 84 µm; photomicrographs by H.-J. Bernhardt.

The thin section from sample E (cut perpendicular to the a-axis and parallel to the light band of the cabochon) showed a network of reflective rectangular structures parallel to the <012> directions of the host chrysoberyl (Figure 22a,b). Typically, two, three or even more of these inclusions were linked together, forming an L-shaped or zigzag pattern. In one area of this thin section, similar structures parallel to the <011> directions were also observed (Figure 22c,d). Numerous examples of both types of inclusions revealed Raman spectra for rutile.

The thin section cut perpendicular to that just described showed a dense network of what appeared to be linear structures elongated parallel to the a-axis [100]. This pattern was best seen in transmitted light (Figure 23). Upon detailed inspection, it was observed that typically two or three, but occasionally more, of these linear structures existed within a somewhat larger platy inclusion. The linear structures traversed the larger platelet and gave it the appearance of being comprised of multiple narrow parts, connected by the linear structures. It was further seen that the different narrow parts of these complex platelets came into focus at different depths,

Figure 23: Chrysoberyl cat's-eye from Orissa (sample E) shows a dense network of complex rutile platelets elongated parallel to the a-axis. The platelets are composed of multiple narrow parts or 'stripes' that are inclined to each other and intergrown. Linear junctions connecting these parts or 'stripes' are also oriented parallel to the a-axis. Transmitted light, field of view 225 × 168 µm; photomicrograph by H.-J. Bernhardt.

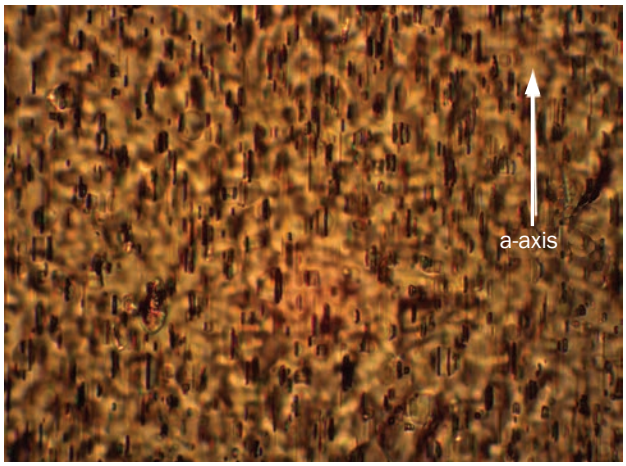

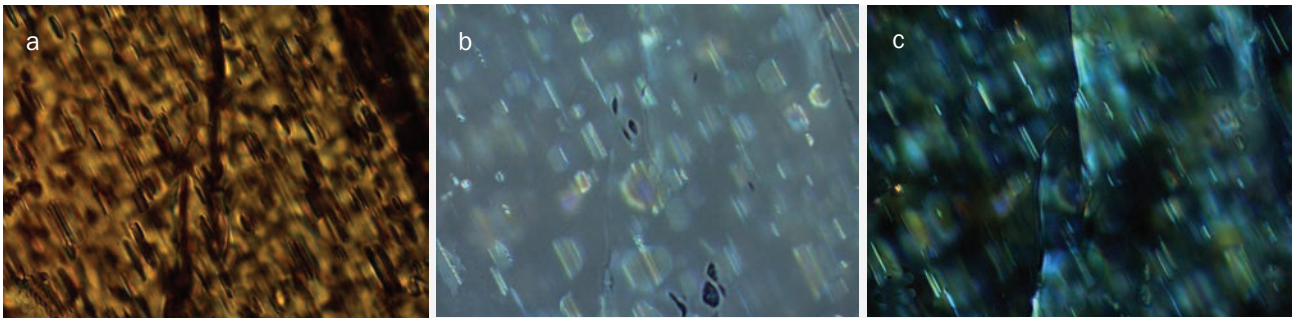

Figure 24: A dense network of complex platelets with internal linear junctions oriented parallel to the a-axis is shown in a cat's-eye chrysoberyl from Orissa (sample E). The small rutile platelets consisting of several parts or 'stripes' each reflect and scatter light. Transmitted light (a), reflected light (b) and reflected light with crossed polarizers (c), field of view 112 × 84 µm; photomicrographs by H.-J. Bernhardt.

indicating that they were inclined to the plane of the polished thin section. Many such platelets were examined by micro-Raman spectroscopy and showed rutile spectra.

Taking into consideration the observations of both the slice cut perpendicular to the a-axis (Figure 22) and the slice cut parallel to the a-axis [100] (Figure 23), it was concluded that the L-shaped and zigzag patterns of rectangular rutile particles along <012> depicted in Figure 22 represented cross-sections of the platy inclusions with internal linear structures elongated parallel to the a-axis [100] depicted in Figure 23. As such, the linear structures along the a-axis [100] and at right angles to the L-shaped and zigzig patterns represented the junctions between the different parts of the larger platy rutile inclusions. Moreover, taking into account the description by Drev et al. (2015) of rectangular structures along <012> as intergrown rutile clusters, it could further be concluded that: (1) the larger platy inclusions or complex platelets described above were rutile clusters, and (2) the linear structures elongated parallel to the a-axis [100] represented the edges or interconnections between the different inclined parts of the platy clusters. In other words, the platy rutile clusters were composed of narrow inclined sections elongated parallel to the a-axis [100] that caused the platelets to appear 'striped' when viewed perpendicular to the a-axis. When viewed in cross-section, two such narrow intergrown 'stripes' formed the L-shaped pattern parallel to the <012> directions of the host, while more than two such 'stripes' formed the zigzag pattern, likewise parallel to the <012> directions.

When lit from above, the different parts or 'stripes' of the platy rutile clusters reflected and scattered the incident illumination (Figure 24). When the chrysoberyl was cut as a cabochon, it was this scattered and reflected light that formed the bright band of the cat's-eye.

Chatoyant Chrysoberyl from Brazil

In the immersion microscope, the transparent cat's-eye chrysoberyl from Brazil revealed a dense pattern of needles with an orientation parallel to the a-axis [100]. These oriented needles visually resembled the inclusion scenario seen in the alexandrite from Lake Manyara in Figure 2. In the polished thin section cut perpendicular to the needle axis, numerous highly reflective cross-sections of such needles could be observed (Figure 25). These were determined to be rutile

Figure 25: Cat's-eye chrysoberyl from Brazil (sample I) is shown here in transmitted light in a thin section cut perpendicular to the a-axis. The photo shows cross-sections of rutile needles elongated parallel to [100], together with a few needles and V-shaped platelets elongated parallel to <011>; some needles along [001] are also observed. Field of view 150 × 112 µm; photomicrograph by H. A. Gilg.

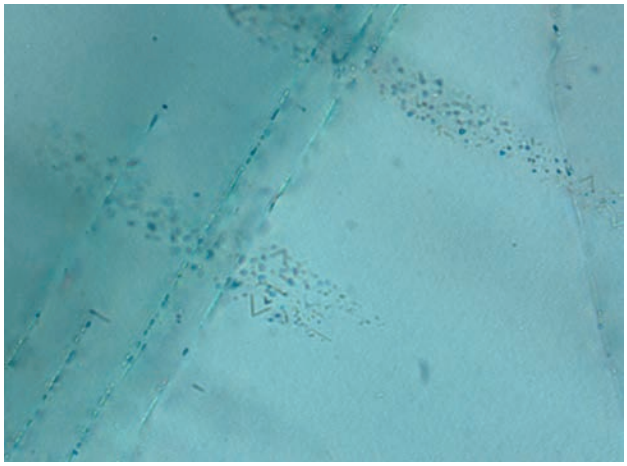

by micro-Raman spectroscopy. Likewise seen were a few needles and V-shaped platelets with an orientation parallel to the a-plane (100), and again Raman examination identified them as rutile.

Chatoyant Chrysoberyl from Ilakaka, Madagascar

Cat's-eye chrysoberyl from Ilakaka is mostly seen in the trade as cabochons prepared from high-quality transparent material; in addition, samples with a milky appearance are known. One such slightly waterworn crystal (sample J), which showed a clear morphology consisting of the pinacoids **a** (100) and **b** (010) in combination with **i** {011} prism faces and **o** {111} dipyramids, was selected for the preparation of three polished thin sections perpendicular to the three crystallographic axes a, b and c. As noted previously, the part of the Ilakaka crystal remaining after removal of these slices was ground and polished into a rounded, irregularly shaped specimen, which displayed a bright, reflective light band encircling the sample.

The thin section cut perpendicular to the a-axis showed an inclusion scene consisting of needles and V-shaped platelets parallel to the a-plane (100) and cross-sections of platelets elongated parallel to the a-axis [100] (Figures 26 and 27). As explained above for the Orissa sample, the narrow platelets elongated parallel to the a-axis [100] had rectangular cross-sections parallel to <012>. In the Madagascar sample, however, only a few of these inclusions were intergrown, and L-shaped cross-sections were rare. Applying the descriptions used for the Orissa sample, the platelets elongated parallel to the a-axis [100] in the Ilakaka stone might be characterized as representing only one narrow part or 'stripe'.

The thin sections cut perpendicular to the b- and c-axes both showed a similar inclusion pattern of narrow platelets elongated parallel to the a-axis [100], consisting of a single part or 'stripe' each, and cross-sections of the needles and platelets oriented parallel to the a-plane (100) (Figure 28). Micro-Raman spectroscopy of numerous inclusions of all the types just mentioned showed spectra for rutile.

Figure 26: This view of a chrysoberyl from Ilakaka, Madagascar (sample J), in a thin section cut perpendicular to the a-axis, shows the inclusion pattern and a cross-cutting healed fracture. The chrysoberyl host shows a high concentration of rutile needles and platelets, whereas the area within the healed fracture is free of rutile particles and shows only some larger fluid inclusions trapped during the healing process. Transmitted light, field of view 300 × 222 µm; photomicrograph by H. A. Gilg.

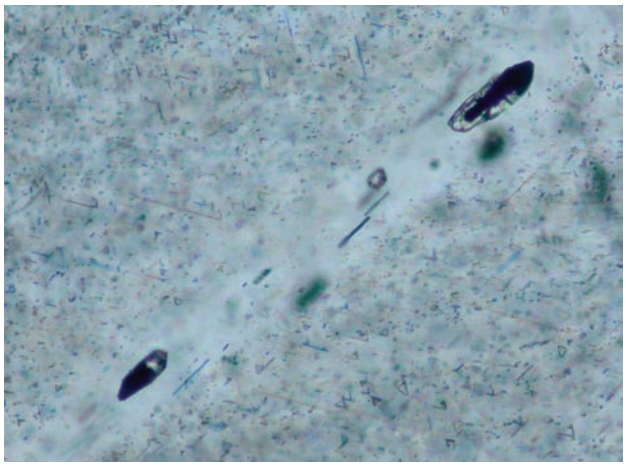

Asteriated Chrysoberyl from Sri Lanka

Star chrysoberyl from Sri Lanka has been mentioned in the gemmological literature as an extremely rare phenomenal gemstone. Subsequent to a previous study dealing with four-rayed chrysoberyl (Schmetzer, 2010), the first author was able to examine six additional four-rayed star samples of varying quality (e.g. Figure 11). Such asteriated chrysoberyls are frequently heavily included and only translucent. However, it was possible by optical examination (correlation of the crystal orientation with the positions of both optic axes) to determine the location of the b-axis [010] in four of these six samples as being more-or-less at the centre of the stars. Together with samples examined previously, this optical orientation in four-rayed star chrysoberyls has now been established for a total of six samples. These results indicate an orientation of two series of needles or channels perpendicular to this axis in the ac-plane.

The slice examined for the present study (sample D) had been cut from, and parallel to, the flat base of such a four-rayed star chrysoberyl (top-right in Figure 11). As stated earlier, two thin sections were prepared from the slice, perpendicular to each other. The slight inclination of the arms of the star was a consequence of

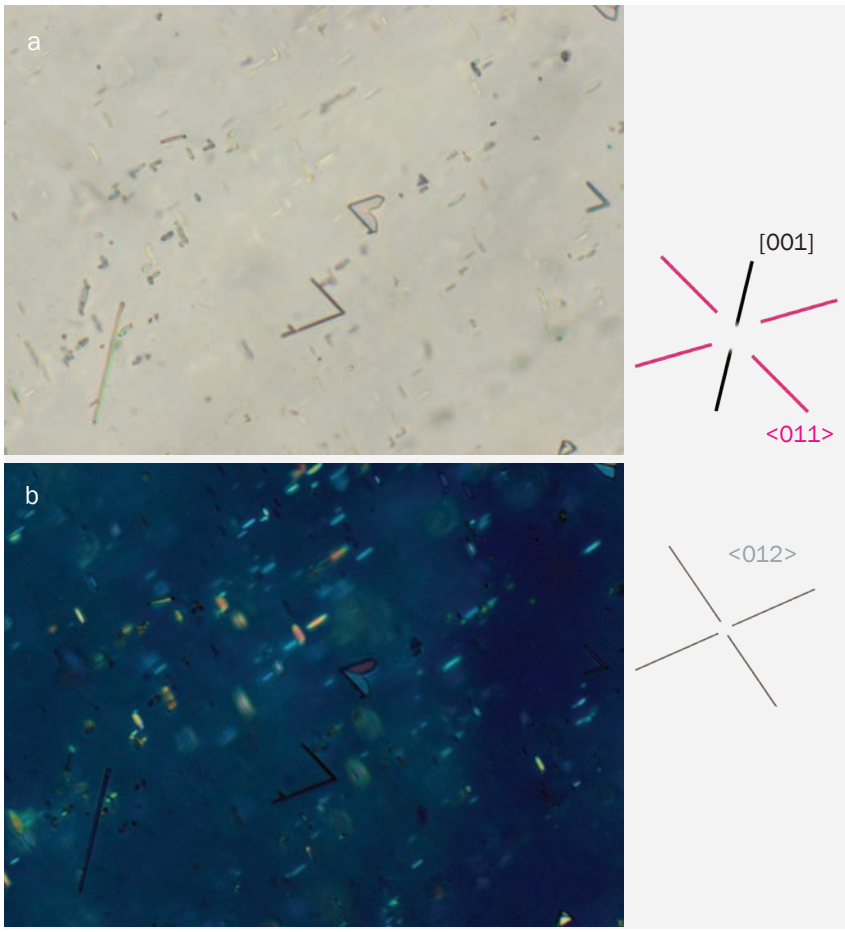

Figure 27: The Ilakaka sample in Figure 26 is shown here in transmitted light (a) and in transmitted light with crossed polarizers (b). Evident is a high concentration of rutile platelet cross-sections elongated parallel to <012>, together with needles and V-shaped platelets elongated parallel to <011>; some needles along [001] are also observed. Field of view 83 × 62 µm; photomicrographs by H. A. Gilg.

the b-axis [010] being inclined by about 30° in relation to the base of the cabochon. Upon tilting the cabochon by approximately that angle, the four-rayed star became orthogonal.

Microscopic examination of the thin section cut parallel to the base of the cabochon showed two series of inclusions oriented parallel to the a-axis [100] and parallel to the c-axis [001] (Figure 29a,b,d). The series parallel to the c-axis [001] was highly reflective and showed Ti signals in the compositional map (Figure 29c). Unexpectedly, micro-Raman spectroscopy of several of these elongated inclusions did not show the pattern for rutile, but instead a spectrum assigned to ilmenite, $FeTiO_3$.

The series of needles or channels parallel to the a-axis [100] was not reflective when viewed in the polarization microscope. If the thin section was rotated so the chrysoberyl appeared dark between crossed polarizers, these elongated particles also invariably appeared dark. Hence, they seemed to show no birefringence. Furthermore, the compositional map (Figure 29c) did not reflect any Ti concentrations for these particles, and the electron microprobe did not record high concentrations of other elements that

Figure 28: In a thin section cut perpendicular to the c-axis, the Ilakaka chrysoberyl (sample J) shows a high concentration of rutile platelets and needles elongated parallel to the a-axis. Most of the platelets consist of only a single part or 'stripe'. Transmitted light, field of view 150 × 112 µm; photomicrograph by H. A. Gilg.

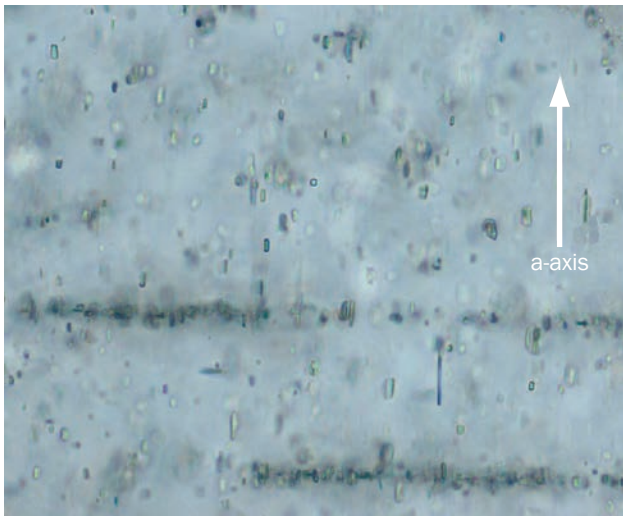

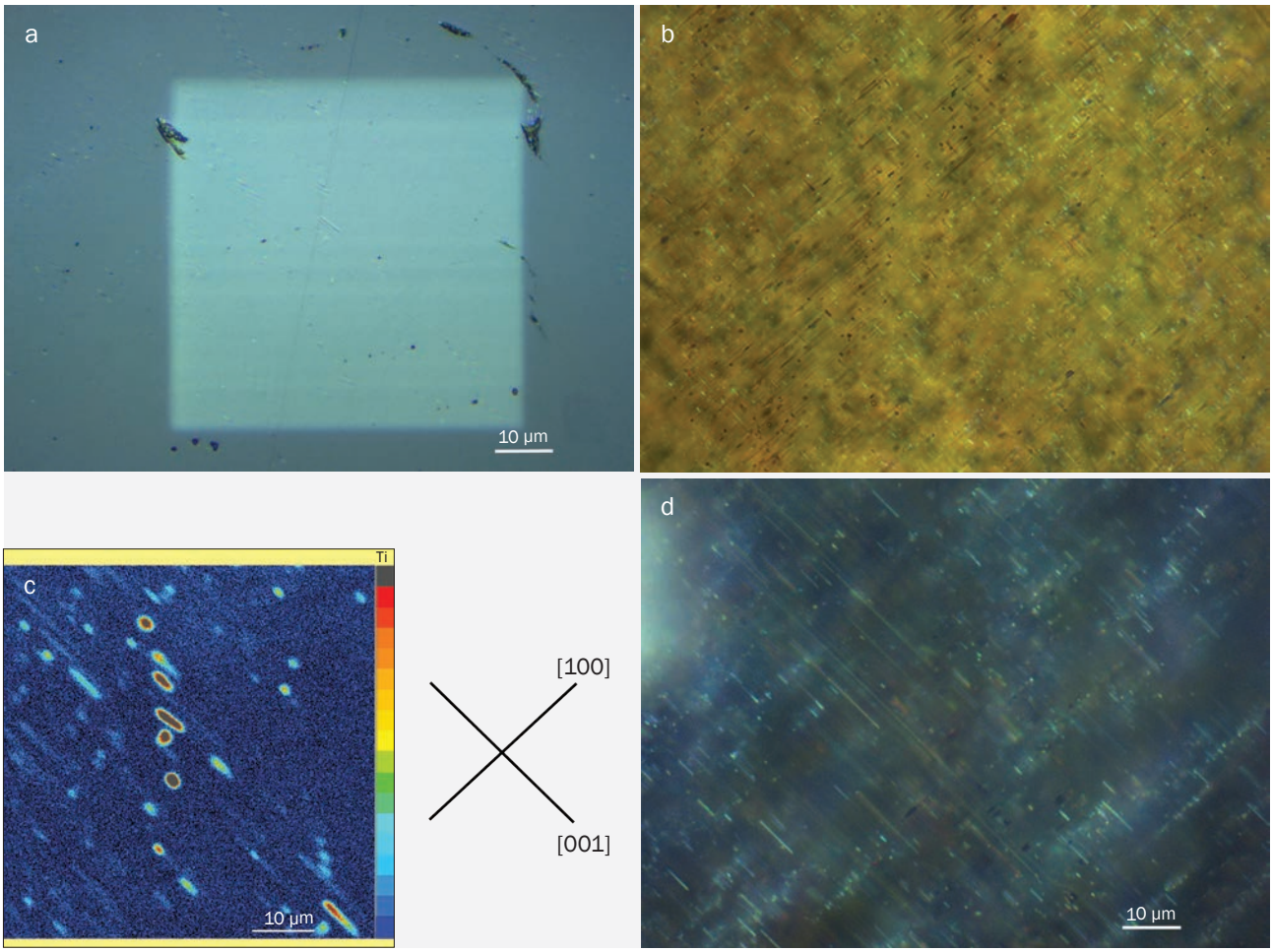

Figure 29: A thin section of an asteriated chrysoberyl from Sri Lanka (sample D), representing a section approximately perpendicular to the b-axis, is shown in reflected light (a) and in reflected light with crossed polarizers (b,d) compared to a Ti compositional map (c). In reflected light, focusing on the surface of the sample (a) shows the scanned area (measuring ~61 × 61 µm), with one series of parallel ilmenite needles that are also represented on the Ti distribution map (c); a second series of needles or channels perpendicular to the first series shows no Ti. The intensity of the Ti signal in (c) ranges from weak (blue) to strong (red). Field of view 112 × 84 µm (a,d) and 224 × 168 µm (b); photomicrographs and map by H.-J. Bernhardt.

could suggest the presence of an alternative type of elongated inclusion. In addition, micro-Raman spectroscopy showed only the Raman lines of the chrysoberyl host. Consequently, these elongated inclusions along the a-axis [100] might represent channels. Nonetheless, given the small size of rutile precipitates in a Brazilian chrysoberyl found by Drev et al. (2015) through use of a transmission electron microscope, there remains the possibility that similarly minute rutile needles might be present in the star chrysoberyl from Sri Lanka that did not generate conclusive signals with our instruments.

The thin section cut perpendicular to the base of the asteriated cabochon revealed only a few highly reflective and somewhat rounded inclusions, which may be understood as the rectangular cross-sections of the ilmenite needles. The compositional map depicted numerous corresponding spots with high Ti concentration. These data confirm the results described above that were obtained from the thin section oriented parallel to the base of the cabochon.

Discussion and Conclusions

The combination of immersion microscopy of gem materials at low magnification, optical microscopy of polished thin sections cut in preferred orientations at high magnification, micro-Raman spectroscopy and electron microprobe techniques (qualitative point analysis, BSE imaging and Ti compositional mapping) showed that two primary groups of rutile inclusions existed in the chrysoberyl and

alexandrite samples examined for this study. Their concentrations varied among the different sources. One group was characterized by needles and platelets on planes perpendicular to the a-axis, whilst the other group consisted of needles and platelets elongated parallel to the a-axis [100]. More specifically:

1. In one group, three different series of needle-like to flat tabular rutile inclusions oriented in planes parallel to the **a** (100) pinacoid were found in natural as well as synthetic samples. These rutile needles were elongated parallel to the c-axis [001] and along symmetry-equivalent <011> directions. Frequently, V-shaped rutile platelets with re-entrant angles of ~60°, rarely ~120°, and/or triangular rutile platelets were formed by such flattened rutile needles and platelets.
2. In the other group, rutile needles and platelets consisting of one or more narrow rectangular parts or 'stripes' elongated in directions parallel to the a-axis [100] were observed. In the optical microscope, the rutile needles showed rectangular, somewhat rounded cross-sections. Rutile platelets consisting of only a single part or 'stripe' showed rectangular cross-sections parallel to the <012> directions of the host. More complex platelets were formed by clusters of intergrown and inclined rutile parts or 'stripes', with internal linear junctions elongated parallel to the a-axis [100] direction. Cross-sections of such complex platelets were oriented along several symmetry-equivalent <012> directions, with re-entrant angles of ~81° or ~99° formed by the different parts of these clusters. These cross-sections displayed an L-shaped or zigzag pattern.

The inclusion pattern seen in any given alexandrite or chrysoberyl, as demonstrated by various samples in this study (see, e.g., Figure 3), may represent both of these groups, that is needles or V-shaped platelets on planes perpendicular to the a-axis, and needles or platelets elongated parallel to the a-axis [100]. These primary groups may also be augmented by further types of inclusions. For instance, in the four-rayed star chrysoberyl, elongated ilmenite particles were seen parallel to the c-axis [001]. Also present were needle-like inclusions parallel to the a-axis [100] that could not be identified as mineral inclusions by the methods applied. This latter type may consist of channels or minute rutile needles.

In samples A and B from Lake Manyara, Tanzania, and in sample C from Kerala, India, the rutile platelets or needles located in the **a** (100) plane were highly reflective and birefringent, and caused the samples to appear whitish in a view parallel to the a-axis [100], i.e. perpendicular to the triangular rutile platelets, flattened rutile needles or V-shaped rutile structures. These small needles or platelets with a thickness in the a-axis [100] direction in the micrometre range (or even smaller) were distributed throughout the completely milky-appearing crystals or within the cloudy areas of zoned samples.

If such inclusions are not exposed at the surface of a crystal or a polished thin section, they still reflect light and are clearly visible in the microscope. They generally do not, however, contribute to the intensity of the Ti signal recorded by the detector of the electron microprobe. As a result, previous studies (Schmetzer and Malsy, 2011; Schmetzer and Bernhardt, 2012) are not inconsistent with the present, more complete work employing multiple techniques.

Although the Ti-bearing needles or platelets in samples from Lake Manyara and Kerala showed a somewhat cloudy, milky appearance in reflected light, no sharp six-rayed asteriated chrysoberyls have been reported to date from these two areas. The presence of both needles and platelets, combined with the relatively large dimensions of these inclusions, prevents such a phenomenon. Conversely, synthetic asteriated alexandrite from Kyocera showed a dense network consisting of three series of distinctly smaller needles in the same orientations as in the Lake Manyara and Kerala examples, but no larger platelets were seen in the synthetic alexandrite. Thus, the Kyocera synthetics, when cut as cabochons with the base parallel to the **a** (100) pinacoid (e.g. sample F in the present study) showed six-rayed asterism. If the base of a synthetic alexandrite cabochon was different from this particular orientation (samples

G and H), only one light band was commonly observed, and such samples are described in the trade as synthetic cat's-eye alexandrite.

Perpendicular to the **a** (100) plane (i.e. parallel to the a-axis [100]), larger channels or needles of sufficient size to be resolved with the magnification of the gemmological microscope were seen in a previous study of samples from Lake Manyara (Figure 2), and now also in the cat's-eye chrysoberyl from Brazil (sample I) and in the alexandrite crystals from Kerala. Smaller elongated particles with the same orientation were found in samples A and B from Lake Manyara and in sample D, the asteriated chrysoberyl from Sri Lanka.

The particles along the a-axis [100] in the four-rayed star chrysoberyl from Sri Lanka could not definitively be identified as rutile by optical examination in combination with electron microprobe analysis and micro-Raman spectroscopy. These inclusions are therefore possibly elongated channels, although it must be considered that very small rutile needles of the size described by Drev et al. (2015) would probably not be seen with the methods applied in the present study.

In contrast, rutile spectra were recorded for numerous tiny needles parallel to the a-axis [100] in samples A and B from Lake Manyara, for both elongated needles (sample B) and cross-sections of needles (sample A). Similar cross-sections of rutile needles also were positively identified in the cat's-eye chrysoberyl from Brazil. Consequently, at least a subset of particles elongated parallel to the a-axis [100] can be characterized as rutile needles.

If a dense concentration of such minute particles (channels and/or rutile needles) elongated along the a-axis [100] is present, these structures cause a light band with an orientation perpendicular to the needle axis. Such a light band formed the chatoyancy in the cat's-eye chrysoberyl from Brazil and was one of the bands observed in four-rayed asteriated chrysoberyl from Sri Lanka (sample D). The second light band in the Sri Lankan star studied here was generated by ilmenite needles along the c-axis [001].

In crystals from Lake Manyara or Kerala, the scattering of light by these elongated inclusions (channels and/or rutile needles) was responsible for the milky appearance of such samples in all directions perpendicular to the a-axis. Given that larger **c** (001) faces are extremely rare in natural chrysoberyl or alexandrite, a whitish appearance is normally visible in a view toward the **b** (010) pinacoid or the **i** {011} prism faces, which are frequently well developed in chrysoberyl.

Complex rutile platelets formed by various narrow intergrown parts or 'stripes' elongated parallel to the a-axis [100], with L-shaped or zigzag cross-sections along the <012> directions, were observed in the cat's-eye chrysoberyl from Orissa, India (sample E). The internal edges or junctions between the inclined parts or 'stripes' likewise ran along the a-axis [100]. These complex platy structures represent a previously undocumented type of inclusion as well as a new mechanism for forming the light band in cat's-eye chrysoberyl. The same type of inclusion also was observed in a small area within the thin section of alexandrite from Kerala, India (sample C). Furthermore, elongated rutile platelets consisting of only one narrow part or 'stripe' each, with simple rectangular cross-sections, were found in high concentration in sample J from Madagascar. The sizes of the rutile inclusions with a similar orientation as described by Drev et al. (2015), for a section perpendicular to the a-axis in one chrysoberyl from Brazil, were much smaller.

In both chrysoberyls with a high concentration of rutile platelets (samples E and J), chatoyancy was observed in the direction perpendicular to the elongation of the platelets. These platelet-derived light bands correspond to those formed by needles in certain other chatoyant chrysoberyls such as sample I from Brazil.

If both types of inclusions are present—that is, rutile platelets or flattened needles in the **a** (100) plane and a dense network of channels and/or rutile needles/platelets elongated in the a-axis [100] direction—then the crystal appears somewhat whitish in most directions, as observed for sample B from Lake Manyara and especially for sample J from Ilakaka, Madagascar. This indicates that a whitish appearance in alexandrite or chrysoberyl is caused by more than one mechanism, and the direction of view parallel or perpendicular to the a-axis allows these mechanisms to be distinguished.

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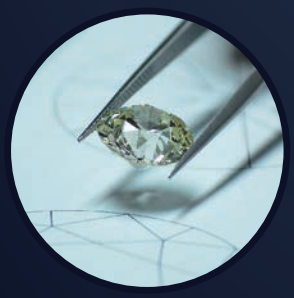

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The Great Mughal and the Orlov: One and the Same Diamond?

Anna Malecka

One of the most famous stones mentioned in the gemmological literature is the so-called Great Mughal diamond, described and depicted in a 17th-century work of Jean-Baptiste Tavernier. According to Tavernier, this specimen weighed ~286 metric carats (upon recalculation from Eastern units); it was not mentioned in later sources referring to the Mughal court. In the 18th century, however, a diamond reminiscent of the Great Mughal appeared on the market—it is known today as the Orlov (189.62 ct). Some researchers have suggested that these specimens could be identical, if not for the fact that the Orlov weighs about 90 ct less than the stone reported by Tavernier. This discrepancy may be explained by the inference that Tavernier never actually examined the stone, but he only described it from accounts given by others. This deduction, together with new evidence showing that the stone actually weighed ~193.5 ct, indicates a high likelihood that the Great Mughal is the same as the Orlov diamond.

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Introduction

In the work of Jean-Baptiste Tavernier (1605–1689), French diamantaire and traveller to India and other exotic locales (Figure 1), there is a description of one of the largest diamonds in the collection of the Mughal emperor Aurangzeb (reigned 1658–1707)—a specimen weighing ~286 ct known as the Great Mughal (or Great Mogul). Most who have written on the history of this diamond do not question the credibility of Tavernier's account (King, 1867; Jagnaux, 1885; Shipley, 1955; Bruton, 1970; Moneta Cavenago-Bignami, 1980; Harlow, 1998; Balfour, 2009). The Frenchman's information regarding this stone is examined further in this article, and its possible relation to the Orlov diamond is explored.

Background

One of the most frequently cited historical European travel writers is Jean-Baptiste Tavernier. This privately active gem merchant made six journeys to the East during the period 1630–1668, visiting among other countries Turkey, Persia and India (e.g. Figure 2). In this last region—the first known source of diamonds—Tavernier was most interested in just these stones, which was reflected in the work he published in 1676, wherein he described the methods used to mine them and problems connected with their trade.

Even though the Frenchman's reports pertaining to these issues are not the only ones from this period, his writings also contain an account of unique value regarding the gems

Figure 1: Jean-Baptiste Tavernier is shown wearing an Oriental costume in this portrait by Nicolas de Largillière. The painting currently resides at Herzog Anton Ulrich Museum, Braunschweig, Germany.

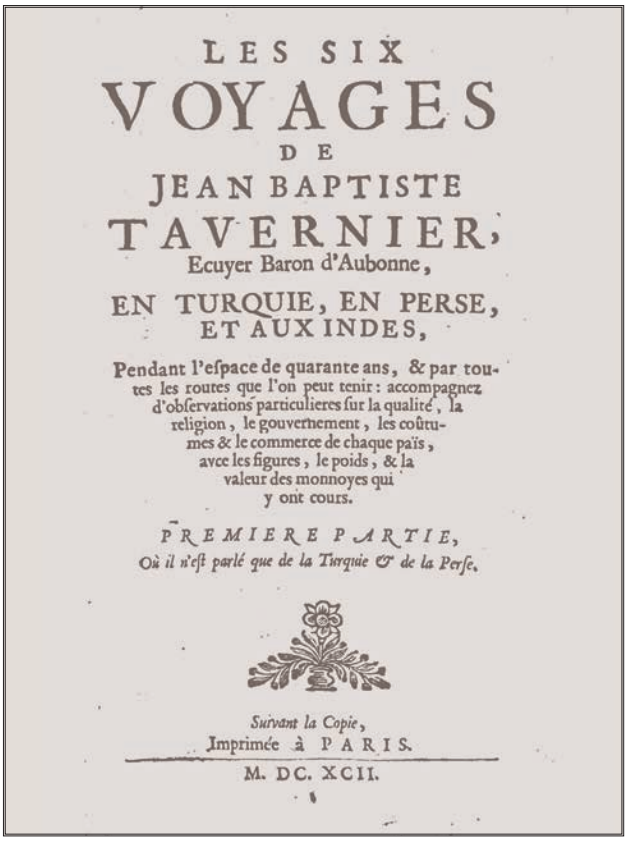

LES SIX
VOYAGES
DE
JEAN BAPTISTE
TAVERNIER,
Ecuyer Baron d'Aubonne,
EN TURQUIE, EN PERSE,
ET AUX INDES,

Pendant l'espace de quarante ans, & par toutes les routes que l'on peut tenir: accompagnez d'observations particulieres sur la qualité, la religion, le gouvernement, les coûtumes & le commerce de chaque païs, avec les figures, le poids, & la valeur des monnoyes qui y ont cours.

PREMIERE PARTIE,
Où il n'est parlé que de la Turquie & de la Perse.

Suivant la Copie,
Imprimée à PARIS.
M. DC. XCII.

Figure 2: Tavernier's travels to the East were recorded in various manuscripts, such as this one from 1692.

of Aurangzeb, the ruler of the Mughal Empire (Howard, 1677; Master, 1911; Moreland, 1931; de Coutre, 1991). Aurangzeb's valuables were shown to Tavernier by the imperial gem keeper, Akel Khan. Most of these were not especially notable by Mughal standards, as they 'only' weighed from several carats to about 60 ct. However, according to Tavernier (1692), there was one exceptional stone (as quoted in and translated by Streeter, 1882, pp. 69–70; see also Balfour, 2009):

> The first piece that Akel Khan placed in my hands was the great diamond, which is rose cut, round and very high on one side. On the lower edge there is a slight crack, and a little flaw in it. Its water is fine, and weighs 319½ ratis [*sic*], which makes 280 of our carats, the rati being ⅞ of a carat.

Tavernier, who included a drawing of this gem in his account (Figure 3), claimed that the keeper allowed him to personally examine and weigh the diamond. He also reported that the original rough stone weighed about 790 carats, and in 1656 it was given as a gift to Aurangzeb's father Emperor Shah Jahan (reigned 1628–1658; Figure 4) by Mir Jumla, previously a dignitary in the court at Golconda, in recognition of his support of the Mughals. The stone was most probably pilfered from one of the temples in Karnataka, India, by soldiers of Mir Jumla during military operations conducted there in 1642–1652 (Gemelli Careri, 1700). The diamond was reportedly cut by a Venetian, Hortensio Borgio, who worked in India

Figure 3: Tavernier's drawing of the Great Mughal diamond appeared in his 1692 monograph.

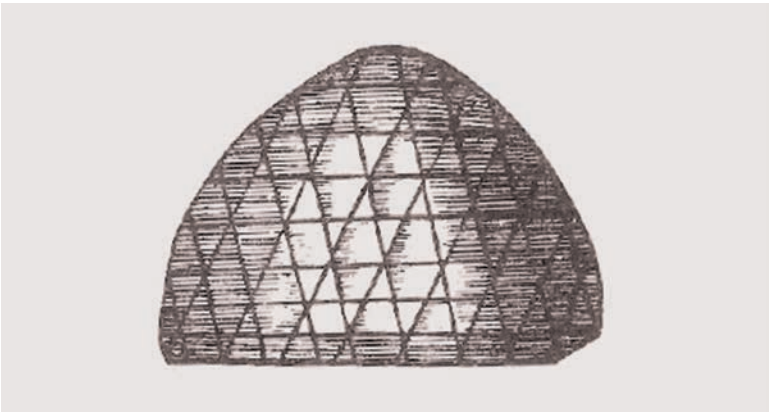

Figure 4: Emperor Shah Jahan is shown on a throne, flanked on the left by his three eldest sons—Dara Shikoh, Shah Shuja and Aurangzeb—while their maternal grandfather, Asaf Khan, stands to the right. The painting dates from the Mughal Period, circa AD 1628. Source: Aga Khan Museum, www.agakhanmuseum.org/collection/artifact/shah-jahan-his-three-sons-and-asaf-khan-akm124.

during the second part of the 17th century. The reported weight of the resulting stone, 319½ rattis—indicated by Tavernier (1692) as being equivalent to 280 'of our carats'—probably is equal to ~286 metric carats (see below).

Figure 5: The 189.62 ct Orlov diamond is shown here in the Imperial Sceptre, part of the Diamond Fund collection of the Moscow Kremlin. Photo © Elkan Wijnberg.

The diamond described by Tavernier has not been mentioned in later sources referring to the Mughal period.

Correlations with the Orlov Diamond

The stone from Tavernier's drawing and description has been noted as being similar to the Mughal-cut Orlov diamond (Figures 5 and 6), which weighs 189.62 ct and is presently kept at the Moscow Kremlin in Russia (Rybakov, 1975; Polynina, 2012; Malecka, 2014b; Shcherbina, 2014). Several legends circulate about the origins of the Orlov diamond. The most popular of them, which can be dated to Europe in the late 18th century, states this gem was taken by a French soldier from an Indian temple in Srirangam in present-day Tamil Nadu State (Dutens, 1783). Another rumour indicated that this stone was to have been an ornament for the throne of Nadir Shah, ruler of Persia, who in 1739 plundered the Mughal treasury (Pallas, 1805; Fersman 1924–25). However, according to documents from Russian archives, during the rule of Nadir Shah (1736–1747), the Orlov was in fact the property of the Persians (although it was not necessarily kept in Persia). We do know for certain that it was taken from the Persian city of Isfahan to Amsterdam by an Armenian merchant. In Amsterdam, it was sold to Catherine II, the empress of Russia (Malecka, 2014b; Malecka, in prep.-b).

Both the Great Mughal and Orlov diamonds have the same type of cut. According to Balfour (2009), "the pattern of facets is not dissimilar" and, even more importantly, there is a small indentation in the Orlov that corresponds to the small crack on the stone described by Tavernier. Even though the similarity of these gems was already noticed in the 19th century by European writers, they were restrained from equating the stones by the information on the weight of the Great Mughal diamond as given by Tavernier. Some writers justified the differences in weight by pointing out Tavernier's probable mistake when weighing Aurangzeb's stone, or that this specimen decreased in size (i.e. through recutting) at a later time (Anonymous, 1853; Schrauf, 1869; Ball, 1889; Fersman, 1922; Fersman 1924–25).

However, Aziz (1942) reported that some Mughal authors pointed to a different weight for this stone than that given by Tavernier (see page 60). He did not correlate the identity of this gem with the Orlov diamond, perhaps because the weight of the Orlov was usually given by older authorities as 185 Amsterdam or Russian carats, whereas Aziz described it as weighing 194.75 ct, similar to that given by some 19th century Russian sources (Anonymous, 1866; Aziz, 1942; Kuznetsova, 2009; Zimin and Sokolov, 2013).

Present Research

Previous writers pondering the correlation between the Great Mughal and Orlov diamonds did not analyse court texts from the Mughal Empire in the Persian language or sources available in the Russian language. The present author's research has been largely based on such material.

A matter of key significance is to determine the Western weight conversions that Tavernier used for the Indian units of the Great Mughal—*rattis*, also known as *surkhs* (Halhed, 1776). Weight units for gems (as weights and measures in general) were quite varied in Asia, Africa and Europe depending on the epoch and geographical location. Normally, the Eastern authors did not specify the local units for the weights of gems they were describing. The weight of identically named units could also differ in reference to gems vs. metals (Lockyer, 1711; Kelly, 1832; Hinz, 1955).

When describing Aurangzeb's diamond, Tavernier's weight conversion was that 1 ratti corresponded to 0.875 of 'our carats' (Tavernier, 1692). Valentine Ball (1889) maintained that the Frenchman converted Eastern weight units for gems into Florentine carats, which were equivalent to about 0.196 g. Ball based his argument on information contained in Tavernier's work pertaining to a diamond weighing 139.5 Florentine carats—the largest diamond in Europe at that time—seen by him in the collection of the Great Prince of Tuscany and known later as the Florentine diamond. The weight of this stone, cited by Tavernier and lost since the times of World War I, was very close to the 137.27 metric carats of The Great Diamond of Tuscany, as it is known from later sources (Ball, 1889; Balfour, 2009).

In fact, it is probable that the weight of the Florentine diamond was reported by Tavernier in local (Florentine) units, as he did sometimes in the case of gems that he saw or heard about during his Eastern voyages (see below; Tavernier, 1692). The present author did not, however, find any information suggesting that the Florentine carat was used universally by Western gem traders at that time. Therefore, one may wonder if this conversion was applied by Tavernier consistently in reference to the various gems mentioned by him. In this author's view, it is more probable that in writing

Figure 6: Various views of the Orlov diamond are shown in this 1767 drawing that was made in Amsterdam by Frans de Bakker. If the Orlov was in fact the same as the Great Mughal diamond, then the image of the rough stone in the upper left must have been conjectural, since the diamond was previously cut in the 17th century. Source: Rijksmuseum, Amsterdam, The Netherlands, www.rijksmuseum.nl/nl/collectie/RP-P-1911-2912.

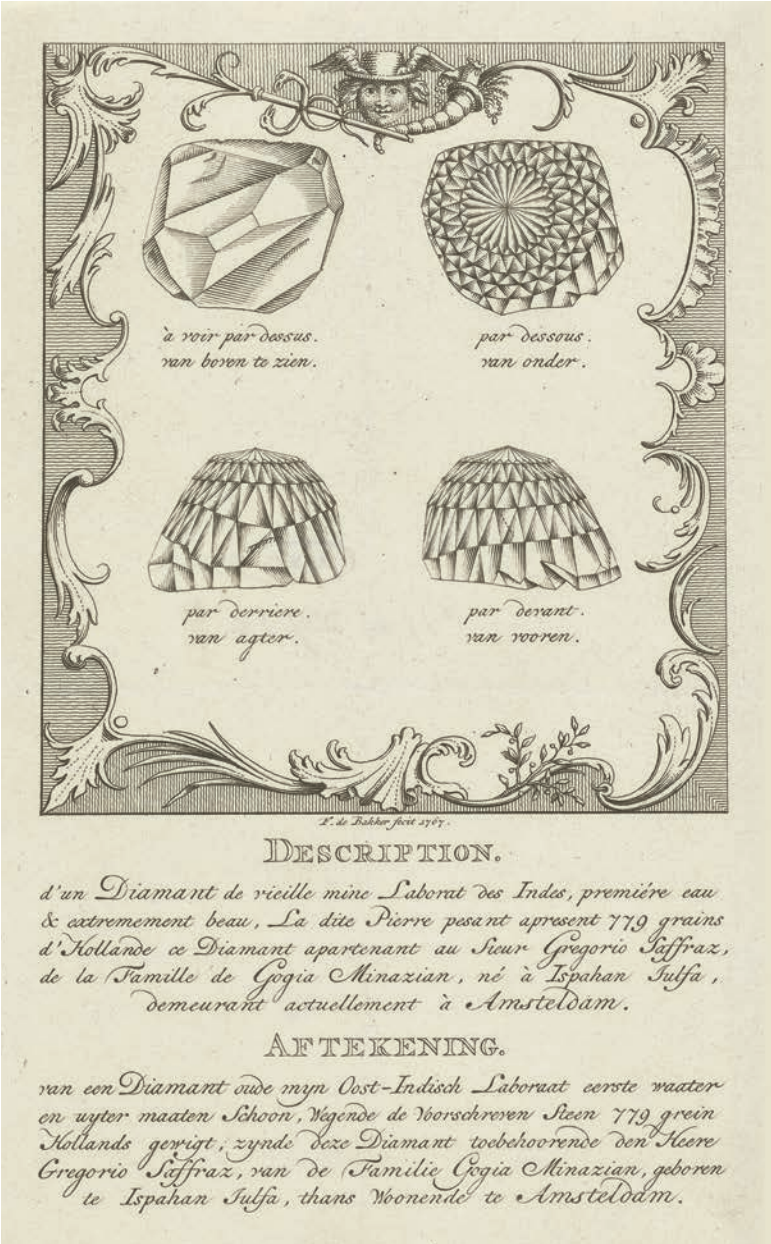

'our carats'—similarly as for French livres, which he described as 'our money'—the famous diamantaire had in mind the French carat commonly used in his home country, the weight of which was about 0.205 g (Tavernier, 1692). In that case, 1 ratti would correspond to about 0.179 g or about 0.896 metric carats, and the 319.5 rattis reported for the Great Mughal Diamond would thus correspond to ~286 ct.

However, according to 17th century Mughal and Deccani chronicles, and most importantly a letter from Shah Jahan (the owner of the stone) to the king of Golconda, the weight of the Great Mughal diamond was 9 *tanks*, which some of these sources indicate is equivalent to 216 rattis or surkhs (e.g. Mīr 'Ālam, AH[1] 1266; Khāfī Khān, 1869; Kanbūh and Yazdani, 1939; Aziz, 1942; Sarkar, 1951; Awranghābādī et al., 1999), rather than the 319.5 rattis reported by Tavernier. A weight of 216 rattis corresponds to ~193.5 ct, if the metric carat conversion suggested above is used. Again, the current weight of the Orlov diamond is 189.62 ct.

Tavernier and the Great Mughal Diamond

If in fact the Great Mughal was actually somewhat over 190 ct, why did Tavernier overstate the weight? For this we are left with conjectures. To the best of this author's knowledge, there are three possible explanations: (1) a mistake in estimating its weight, (2) purposeful deceit or (3) his knowledge of the diamond was gained indirectly, for example, on the basis of accounts given by others.

The possibility that Tavernier made a mistake in estimating the weight of the diamond by nearly 90 ct seems impossible for such an experienced diamantaire (Paxton, 1856). Therefore one might consider that Tavernier deliberately overstated the weight of the diamond, perhaps intending to evoke a stronger impression on those readers who were told since the 16th century about the fabulous riches of the Mughal Empire (Foster, 1921; Keene and Kaoukji, 2001). However, this author feels that the most probable explanation is that Tavernier possessed only indirect knowledge of the Great Mughal diamond. It is known that the Frenchman did in fact include in his work drawings and detailed descriptions of gems that he did not examine personally. Among this group were, for example, gems of the ruler of Bijapur and the Shah of Persia; he most probably gained the information about these during his travels from royal gem keepers or merchants.[2] It is also probable that he obtained knowledge about one of the most famous diamonds of the Muslim world—the Great Table, from which were cut the Nur al-Ayn and Darya-ye Nur stones now found in the treasury of Iran—not by analysing the original gem, as he claims, but by examining a model of the stone (Malecka, 2014a; Malecka, in prep.-a).

The possibility that Tavernier gained information about the Great Mughal diamond from third parties is supported by his drawing of this stone (again, see Figure 3), which was described by one 19th century scholar as 'rough' or 'rude' (Maskelyne, 1860a,b). His drawing could easily have been made on the basis of a description, and therefore not all the details depicted in it should be assumed credible.[3] Indirect knowledge may account for the fact that depictions of other historical diamonds may differ significantly from one another (I'timād al-Salṭanah, AH 1349; Tavakkulī Bazzāz, AH 1380; Diba et al., 1998; Raby, 1999).

If indeed Tavernier obtained information indirectly about the Great Mughal diamond, this certainly does not preclude that the presentation of Aurangzeb's jewels, which he mentioned, actually took place. The showing of valuables from the treasury was often practised in the Muslim world (al-Tanūkhī, AH 1393). It should be underscored, however, that during Tavernier's visit, the most valuable jewels of the Mughal court were not in the possession of Aurangzeb, but rather were kept by his jailed father Shah Jahan, who refused to give them up despite requests from his son (Manucci, 1907; Begley and Desai, 1990). As a connoisseur of gems, Shah Jahan most certainly was attached to his collection of precious objects. It should be emphasized as well that in the Islamic world, the

[1] In reporting the year of ancient scripts, 'AH' means *Anno Hegirae*, or 'in the year of the Hijra'.

[2] Another potential source of Tavernier's information—court inventories—should be excluded, in this author's opinion. First, there is no evidence that the Frenchman had any access to them. Second, a survey of equivalent surviving material from the Islamic world shows that the weight and/or drawings of even large stones was never or rarely noted (Topkapı Sarayı Müzesi Arşivi, AH 1091).

[3] It has also been suggested that the drawings contained in Tavernier's work of the stones he most certainly saw and handled may not be fully credible (Sucher, 2009).

involuntary transfer of valuable stones to another ruler indicated the giver's subservient status; this was particularly the case for diamonds in Mughal India, as their possession was an imperial monopoly (Ferishta, 1829; de Coutre, 1991; Boym, 2009; Malecka, in prep.-b).

It is well worth adding that the most important gems, functioning as regalia, were often worn by the rulers personally. It is also known that Shah Jahan would display a diamond given to him by Mir Jumla by placing it on his turban (Valentijn, 1726; Malecka, in prep.-b). This author finds it doubtful that Shah Jahan would have given a stone of this importance to his son prior to being incarcerated. Such an event would have undoubtedly been noted by court chroniclers scrupulously registering movements of large gems. In view of the above considerations, this author suspects, as did some 19th–20th century authorities, that during Tavernier's visit to the Mughal court, the Great Mughal diamond in fact was in the possession of Shah Jahan, and this excluded the possibility of it being examined by the Frenchman (Maskelyne, 1860a; Aziz, 1942).

Due to large discrepancies regarding the weight of the diamond from Persian-language sources of the epoch as compared to Tavernier's work, the present author deduces that Tavernier did not actually see the Great Mughal diamond. The presumed weight of the Great Mughal, however, both before (~790 ct) and after fashioning (~286 ct), probably was not invented by the Frenchman himself.[4] Tavernier reported the mass of imperial gems by using various units popular in India, which he recalculated into carats only in the case of the diamond in question. It may therefore be supposed that the presumed weights of the Great Mughal both prior to and after polishing were obtained from the imperial treasure keeper, who could have demonstrated the tendency—not at all alien to his profession—to overstate the weight of gems possessed by his master (Brydges Jones, 1833; Meen and Tushingham, 1968; Malecka, in prep.-b). Most likely, this same source also provided Tavernier with information pertaining to the polished stone's appearance.

[4] According to eminent Russian mineralogist Alexander Fersman, one of the few experts who has studied the Orlov, this stone was cut probably from a rough stone weighing ~400 ct (Fersman, 1955). Assuming that the Great Mughal diamond is identical to the Orlov, this provides an additional argument for negating Tavernier's statement that the rough stone from which the Great Mughal was cut weighed ~790 ct.

Conclusions

According to Persian-language sources from the epoch, in 1656 the Great Mughal diamond weighed about 193.5 ct. This is quite close to the 189.62 ct of the Orlov diamond at the Kremlin. The weight difference of ~3.8 ct is very small compared to the sizes of these stones. In fact, various sources from the Great Mughal's time period and cultural circle have indicated that the weight of an important gem could differ by more than a dozen carats (Sāravī Fatḥ Allāh, AH 1371; Sālūr et al., AH 1374; Riḍā' Qulī Khān Hidāyat, AH 1380; Fasā'ī Ḥusainī and Fasā'ī Rastgār, 1988). In this author's opinion, due to similarities in weight, shape, type of cut and flaws, the stone given in 1656 by Mir Jumla to Shah Jahan was in fact the same as the diamond presently known as the Orlov. Since it must have been presented to Shah Jahan in polished form, the abovementioned account by Tavernier about it being cut by Hortensio Borgio cannot be true.

This article provides strong evidence that Tavernier did not see the diamond he described, since during his visit at the Mughal court the stone most probably was in the possession of Shah Jahan. The scene of examination of this stone was then contrived by the Frenchman in order to make the text more attractive and was incorporated into the chapter containing descriptions of Aurangzeb's valuables shown to him.

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A Lead-Glass-Filled Corundum Doublet

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In September 2015, a 1.75 ct pink sapphire was submitted to the Gem and Jewelry Institute of Thailand's Gem Testing Laboratory (GIT-GTL). The stone showed internal features (e.g. flash effects and trapped gas bubbles) that are commonly seen in lead-glass-filled rubies and sapphires. In addition, the sample turned out to be an assembled stone, consisting of a pink sapphire crown and a near-colourless sapphire pavilion. These two portions were joined along a lead-glass-filled contact layer slightly below the girdle that locally contained areas of corundum fragments. We concluded that this stone was a lead-glass-filled corundum doublet.

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Introduction

Lead-glass-filled corundum was first encountered over a decade ago, and has continued to appear in the gem market in various forms (see, e.g., Kitawaki, 2004; Smith et al., 2005; McClure et al., 2006; Milisenda et al., 2006; SSEF, 2009; Henn et al., 2014, Leelawatanasuk et al., 2015; Ounorn and Leelawatanasuk, 2015; Panjikar, 2015). Nowadays such treated stones are widely available, mostly in the low-end jewellery market. The starting material typically consists of low-quality corundum, although a variety of colours and transparencies have been treated by this method (see references above). In September 2015, the GIT-GTL received an unusual lead-glass-filled sapphire that was characterized for this report.

Sample and Methods

The 1.75 ct sample consisted of a pear-shaped modified brilliant measuring 8.32 × 7.21 × 3.81 mm (Figure 1). We used standard gemmological instruments to measure the stone's properties, and its internal features were observed with both a gemmological microscope and an immersion microscope using methylene iodide. In addition, the gem was viewed with a DiamondView instrument. We used a Thermo Nicolet 6700 Fourier-transform infrared (FTIR) spectrometer

Figure 1: This 1.75 ct pear-shaped stone proved to consist of a sapphire doublet containing fissures and cavities filled with lead glass. Photo by S. Saengbuangamlam.

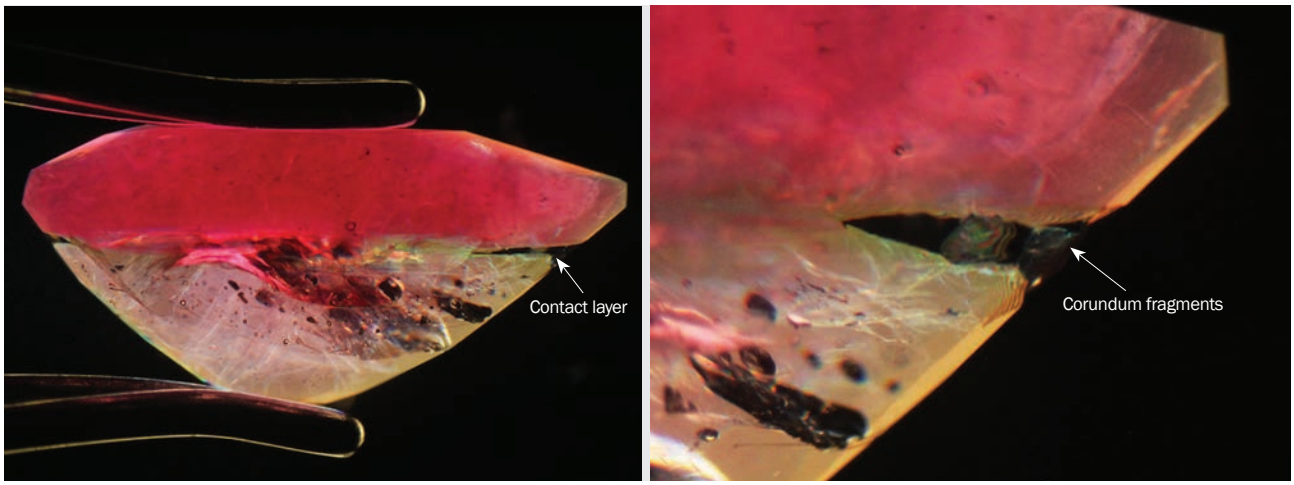

Figure 2: The doublet consists of a pink sapphire crown and a near-colourless sapphire pavilion that are joined along a contact layer located slightly below the girdle (left, image width 6.5 mm). Viewed with higher magnification, the contact layer is seen to locally consist of dark (isotropic) glassy material containing some anisotropic angular fragments of corundum (right, image width 2.2 mm). Photomicrographs by S. Promwongnan, in immersion with cross-polarized light.

to obtain IR transmittance spectra in the range of 4000–400 cm^{-1}. X-radiography was performed with a Softex SFX-100 instrument. Chemical analysis was carried out by energy-dispersive X-ray fluorescence (EDXRF) spectroscopy using an Eagle III system.

Results

Basic Properties

The gemmological properties of this stone were consistent with natural corundum. It had RIs of 1.770–1.761 (measured on the table facet) and a hydrostatic SG of 3.98. The polariscope gave a doubly refractive, uniaxial negative reaction. The stone fluoresced moderate red to long-wave UV radiation, with somewhat weaker luminescence to short-wave UV.

Microscopic Features

When the sample was examined using an immersion microscope between crossed polarizers, it was obvious that it was actually a composite stone (Figure 2, left). It consisted of a doublet formed of two distinctly different pieces: pink sapphire for the crown and near-colourless sapphire for the pavilion. These two pieces were joined together along a contact layer located slightly below the stone's girdle. Higher magnification (Figure 2, right) revealed that the contact layer was filled with glassy material that locally contained randomly oriented fragments of corundum.

Further examination with a standard gemmological microscope at high magnification showed internal features indicative of lead-glass-filled corundum. A blue flash effect associated with filled fractures/fissures was the most prominent characteristic, and was seen in both the pink and near-colourless portions (Figure 3a). Several trapped gas bubbles also were clearly seen in the filled fissures (Figure 3b). Additional inclusions consisted of minute particulates (Figure 3c) and planar 'fingerprints' (Figure 3d), which suggested that the corundum pieces forming both parts of this stone were of natural origin.

In the DiamondView, the relatively low lustre of the glass-filled cavities could be seen easily with reflected light using the instrument's sample chamber illuminator (Figure 4a). When exposed to the DiamondView's deep-UV excitation, the glassy material was inert and appeared as dark areas along the contact layer and in fissures and cavities, in contrast to the strong red fluorescence of the host corundum (Figure 4b,c). In places, the contact layer contained some bright-luminescing angular fragments of corundum embedded in the dark-appearing glassy material.

Mid-Infrared Spectroscopy

The mid-IR spectrum of the sample showed broad absorption features at approximately 3500, 2597 and 2256 cm^{-1} that are commonly present in lead-glass-filled corundum (Figure 5).

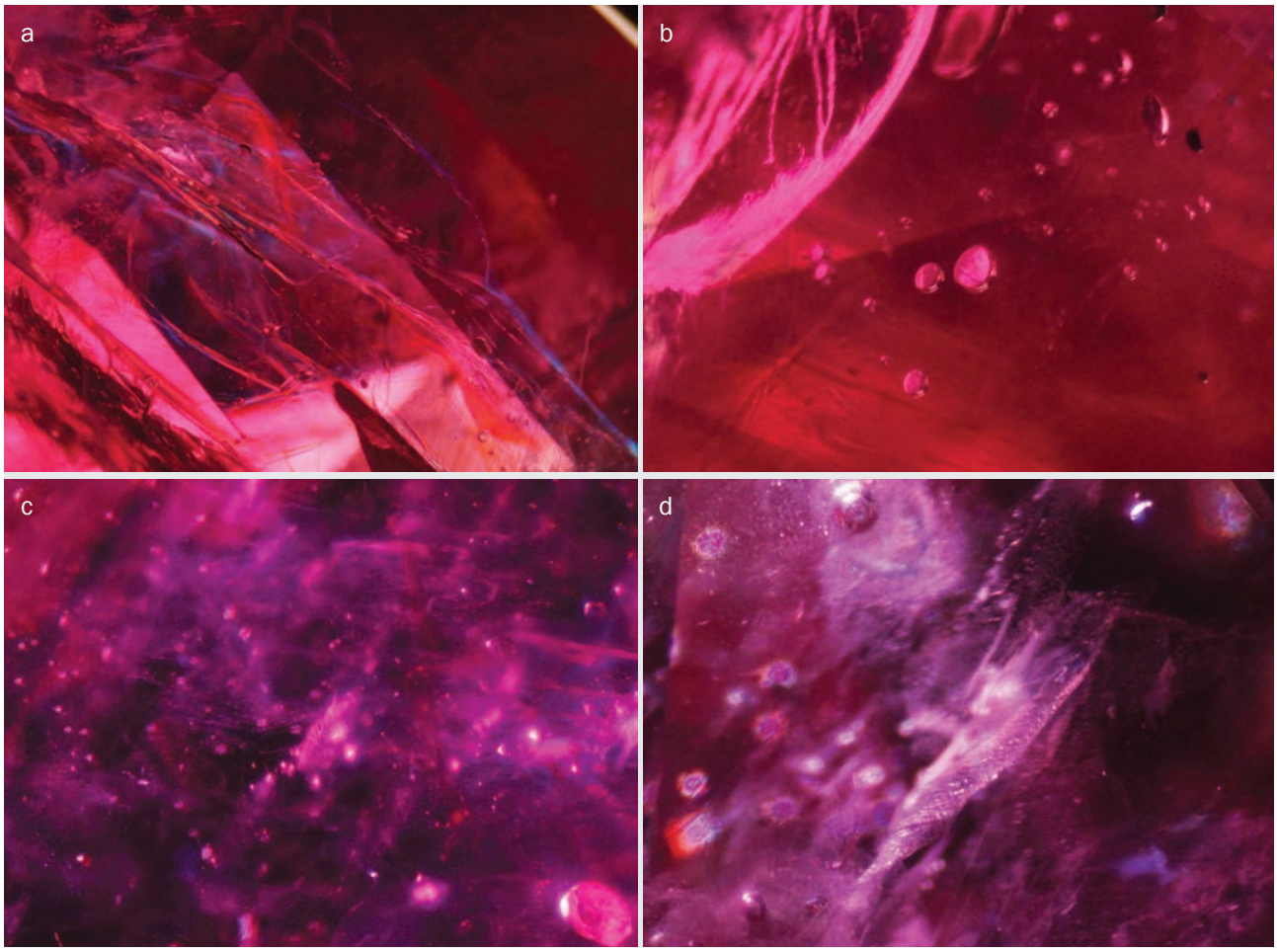

Figure 3: Internal features seen in the lead-glass-filled corundum doublet consist of (a) several filled fractures showing blue flash effects, (b) gas bubbles trapped inside the filler, (c) minute particulates and (d) planar fingerprints. Photomicrographs by S. Promwongnan; image widths 2.1, 1.5, 1.6 and 1.1 mm for photos a–d, respectively.

X-radiography

The X-ray image of the stone (Figure 6, left) revealed that the contact layer consisted of a high-density (dark-appearing) material. Furthermore, high-density material also was present along many fractures inside the host corundum and in cavities on the stone's surface. These results are consistent with the presence of a lead-containing glass filler in fissures and cavities, as well as within the contact layer of this doublet.

Figure 4: These DiamondView images of the 1.75 ct lead-glass-filled corundum doublet show the sample in reflected light from the sample chamber illuminator (a), and exposed to ultra-short-wave UV radiation (b and c). The glass filler has a low lustre in reflected light, and is inert to UV radiation—in contrast to the strong red fluorescence of the host corundum. Note also the presence of some angular fragments of corundum in the glassy material along the contact layer between the crown and pavilion (particularly in image c). Photos by S. Promwongnan.

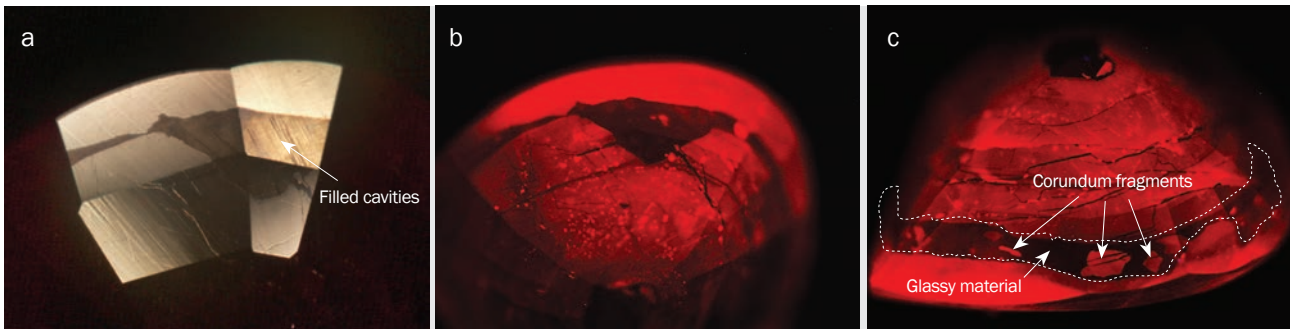

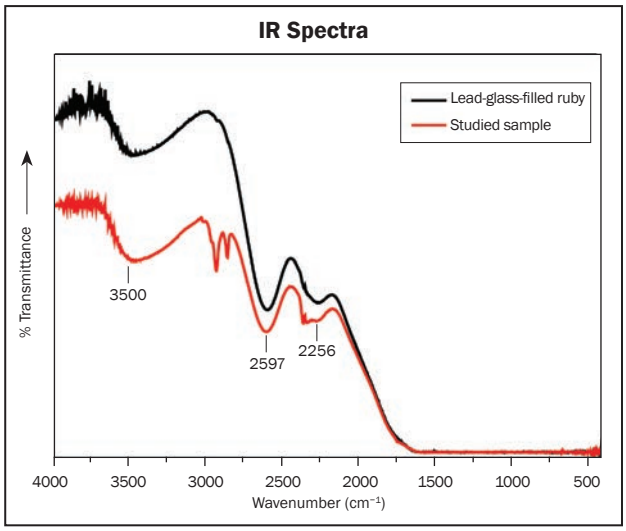

Figure 5: FTIR transmittance spectra are shown here for the tested corundum doublet as compared with a lead-glass-filled ruby reference sample. Both spectra display similar broad bands at approximately 3500, 2597 and 2256 cm^{-1} that are commonly seen in lead-glass filled materials. The bands at approximately 3000–2900 cm^{-1} in the doublet may be due to sample contamination (finger oils, etc.).

Chemical Analysis

EDXRF spectroscopy of the crown and pavilion sides of the corundum doublet showed traces of Ti, V, Cr, and Fe (and Ga in the crown); as expected, the Cr content of the pink sapphire forming the crown side was much higher than that of the near-colourless pavilion (Table I). Also detected were significant amounts of Pb and Si in both portions of the stone, which confirmed that it was lead-glass filled. Much greater quantities of these elements were detected in the pavilion than in the crown, apparently due to a larger amount of glass filling encountered by the beam in that area (i.e. within fractures and/or in the contact layer of the doublet).

Table I: Trace-element contents by EDXRF of the corundum doublet.

Area	TiO_2	V_2O_5	Cr_2O_3	Fe_2O_3	Ga_2O_3	SiO_2	PbO_2
Crown	0.03	0.02	0.57	0.19	0.01	0.36	0.39
Pavilion	0.02	0.02	0.11	0.19	nd*	1.63	7.11

* Abbreviation: nd = not detected.

Discussion and Conclusions

Based on the above evidence, it is clear that this stone was a lead-glass-filled doublet composed of pink and near-colourless sapphire. The presence of small, angular corundum fragments within the glass-filled contact layer suggests that these two pieces could have been accidentally or intentionally brought together during the lead-glass treatment process. Bonding together of their flat surfaces enabled this composite material to be cut into an attractive but deceiving gemstone. Thus, this sample should be referred to as a lead-glass-filled corundum doublet.

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Figure 6: An X-ray image (left) of the lead-glass-filled corundum doublet is shown with a corresponding view taken in immersion with cross-polarized light (right). The X-rays reveal a high-density material that appears as dark areas in fractures and fissures, and along the contact layer between the crown and pavilion. Photos by S. Promwongnan; image width 6.4 mm.

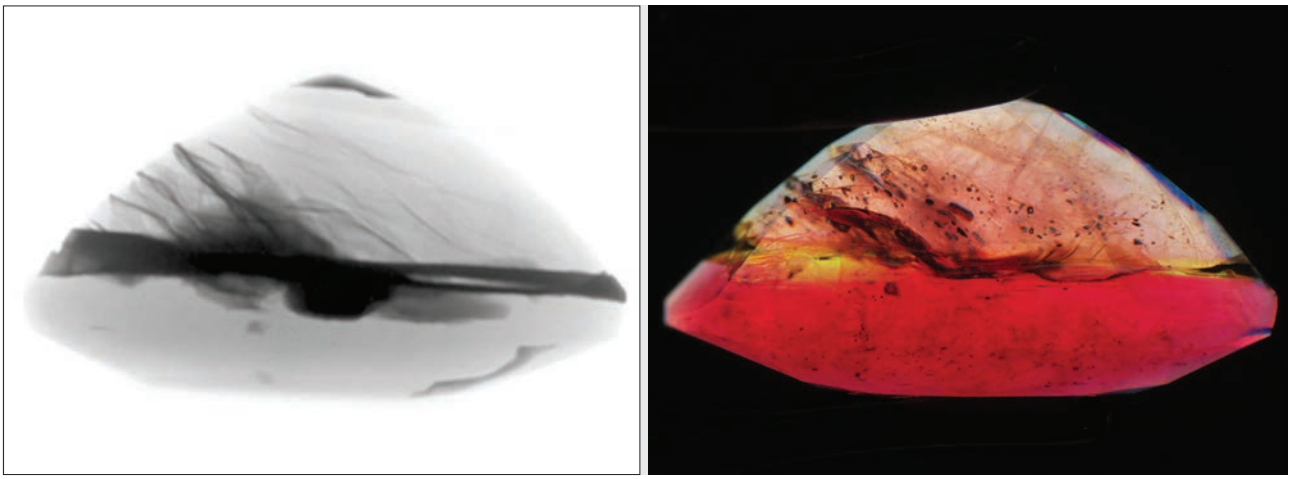

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Conferences

AGA Tucson Conference

The 2016 Accredited Gemologists Association Conference in Tucson, Arizona, USA, took place 3 February, with the theme 'Where in the World?—Origin of Gem Species & More'. Attended by 132 people, the event was moderated by AGA president Stuart Robertson, and featured six speakers.

Andrew Cody (Cody Opal, Melbourne, Australia) began the conference with a presentation on the various types of opal, their attributes and where they have been mined, as well as current pricing trends for fine Australian opal.

Dr Daniel Nyfeler (Gübelin Gem Lab, Lucerne, Switzerland) reviewed 10 years of using laser ablation–inductively coupled plasma–mass spectrometry (LA-ICP-MS) in his gemmological laboratory. The trace-element data provided by this technique is useful for the detection of treatments and synthetics, and also for determining a gem's geographic origin. To obtain meaningful data, it is necessary to employ a highly trained and knowledgeable operator, to have a comprehensive collection of reference samples, and to use appropriate data reduction and processing procedures.

Claire Mitchell (Gem-A, London) described the use of the spectroscope in gemmology. After reviewing the history and development of studying absorption bands in gems and minerals, she explained the differences between prism and diffraction-grating spectroscopes, and gave several tips on how to obtain good spectra (e.g. the use of strong lighting; see Figure 1). She then described the various types and applications of advanced spectroscopic instrumentation.

Figure 1: Gem-A's Claire Mitchell demonstrates the use of strong fibre-optic lighting to obtain a good spectrum of a transparent gemstone with a handheld spectroscope. Photo by Henry Mesa.

Richard Hughes (Lotus Gemology, Bangkok, Thailand) gave a presentation called 'Forests and Trees—Ten Lessons in Gemology' that conveyed some of his experience and research gleaned from decades of working with gems. An overall principle that he emphasized was to beware when things do not make sense and to get more information before making a decision.

Shawn O'Sullivan gave a presentation for **Arthur Groom** (Eternity Natural Emerald, Ridgewood, New Jersey, USA) on the clarity enhancement of emerald. He indicated that it is difficult for gem laboratories to accurately assess the amount or effect of fracture filling because the stones are not seen by the labs before treatment (and after cleaning of the fissures). His company no longer cleans emeralds unless they also perform the enhancement, since some unscrupulous dealers were obtaining laboratory reports on cleaned stones and then having them treated.

Marc Beverly (University of New Mexico, USA) described his experience visiting an enormous cavern containing giant selenite crystals in Naica, Chihuahua State, Mexico. The hot and humid conditions in the cave, combined with the sharp and slippery crystals, created hazardous conditions, but the selenites were awe-inspiring. The expedition has been documented in a National Geographic video that is accessible at www.youtube.com/watch?v=0OLdSJmvcUs.

The conference was followed by the AGA Gala, where The Antonio C. Bonanno Award for Excellence in Gemology was presented to Dr Cigdem Lule (Gemworld International Inc., Glenview, Illinois, USA).

Brendan M. Laurs

GILC Tucson Conference

The Gemstone Industry & Laboratory Conference took place on 1 February 2016 in Tucson, Arizona, USA (Figure 2). The event was moderated by GILC chairman Edward Boehm, and was attended by approximately 80 invitees.

Dr Lore Kiefert (Gübelin Gem Lab, Lucerne, Switzerland) gave a presentation for **Dr Daniel Nyfeler** on the radiogenic age dating of gems. The ages of many gem deposits worldwide are well constrained, particularly for corundum and emerald. At the Gübelin Gem Lab, surface-reaching zircon inclusions in selected client stones are now being analysed by LA-ICP-MS to determine the age of the host sapphire or ruby (for more information, see *The Journal* article by K. Link, 'Age determination of zircon inclusions in faceted sapphires', **34**(8), 2015, 692–700). Combined with other methods, the resulting age information provides a useful piece of data to aid geographic origin determination.

Dr James Shigley (Gemological Institute of America, Carlsbad, California, USA) reviewed GIA's research on the observation and measurement of colour in gems. Faceted gemstones display a complex face-up appearance that is influenced by several factors, including the light source, faceting style, colour (and colour distribution), visual effects (windowing, extinction, etc.), pleochroism and reflections from the observer or viewing environment. To accurately calculate colour coordinates of a gem, these factors must be taken into account, as well as the colour sensitivity of the human eye.

Bruce Bridges (Bridges Tsavorite, Tucson, Arizona, USA) examined the traceability of a gem from the source to the end consumer. He gave examples of some stones that are vertically integrated through some or all stages of mining, processing, cutting and marketing, such as tsavorite from his operation in Kenya, demantoid from the Green Dragon mine in Namibia, emerald from the Belmont mine in Brazil and ruby from True North's project in Greenland. At the end of his presentation, he posed the question, "At what level does traceability start?"

These talks were followed by a general discussion session that provided a lively debate on laboratory terminology for describing colour on reports. The conference concluded with a special announcement by **Ruben Bindra** (president of the American Gem Trade Association) that AGTA had revised its 'Code of Ethics and Principles of Fair Business Practice' to include mine-to-market traceability and transparency source disclosure protocols; the International Colored Gemstone Association adopted the revised code at the ICA Board of Directors meeting on 31 January in Tucson.

Brendan M. Laurs

Figure 2: Attendees of the GILC Conference in Tucson listen to one of the presentations. The topics at this year's event included the age dating of gems, colour measurement and observation, and traceability from the source to the end consumer. Photo by Sherri Graves.

Jewelry Industry Summit

The first Jewelry Industry Summit for Responsible Sourcing was held at the Fashion Institute of Technology in New York, New York, USA, on 10–13 March 2016. The 160 attendees represented all sectors of the industry from mining to retail, including manufacturers, designers and educators, as well as NGOs and personnel from the U.S. Department of State.

The five primary objectives of the summit were as follows:

Figure 3: Participants of the Jewelry Industry Summit joined focus groups to discuss various topics related to socially and environmentally responsible practices in the gem and jewellery industry. Photo by Peggy Jo Donahue.

1. Generate a broad-based awareness of facts related to the jewellery industry supply chain and responsible sourcing, and explore what works and what does not.
2. Create a shared vision that ensures viability of the supply chain and all jewellery businesses as they evolve to meet changing expectations from industry members and the consuming public.
3. Explore the possibility of generating industry-wide goals that all members of the supply chain can reasonably work toward.
4. Begin to develop guiding principles that will help any sector make progress through continuous improvement.
5. Decide if and how to implement and measure the success of any plan resulting from these discussions.

Administration of the summit was coordinated by **Suzan Flamm**, **Cecilia Gardner** and **Sara Yood**, all of the Jewelers Vigilance Committee (New York City). **Cheri Torres** and **Mike Feinson** of Innovation Partners International were hired to facilitate the summit, and they kept ideas flowing by creating focus groups to brainstorm on various topics (e.g. Figure 3) and report back to the larger group. This invited every attendee to be engaged and feel part of the discussion process.

Formal presentations were made by various companies within and outside the jewellery industry to share inspirational stories of success, as well as challenges they faced along the way. The format included a panel of presenters from the jewellery industry that consisted of Eric Braunwart (Columbia Gem House, Vancouver, Washington, USA) on small-scale and artisanal mining, **Jamie McGlinchey** (Melissa Joy Manning, Brooklyn, New York) on socially responsible jewellery creation, **Marcelo Ribeiro** (Belmont, Minas Gerais, Brazil) on socially and environmentally responsible emerald mining in Brazil, and **Stewart Grice** (Hoover & Strong, North Chesterfield, Virginia, USA) on socially and environmentally responsible precious metals refining.

Following the panel discussion, **Eric Jens** (ABN AMRO Bank, Amsterdam, The Netherlands) presented his company's strategy to help its clients generate business opportunities. He also handed out an attractive brochure ('Sustainable Diamond Jewellery Guide') outlining the details of their strategy. Though it was written with diamonds in mind, many of the practices could theoretically be applied to the coloured stone industry as well.

There were two presenters from outside industries. **Maria Gorsuch-Kennedy** (EMC Corp., Boston, Massachusetts, USA) discussed supply-chain sustainability and how EMC applies its environmental and conflict minerals program throughout its computer hardware product lifecycle. **Margo Sfeir** (Elevate Global Ltd., New York City) described the responsible-sourcing management tools that her company has developed to help private-label product companies identify management practices to improve responsible sourcing.

Responsible-sourcing protocols were addressed by **David Bouffard** (Signet Jewelers, Akron, Ohio, USA) and **Andrew Bone** (Responsible Jewellery Council [RJC], London). Bouffard detailed Signet's commitment to maintaining and improving consumer confidence in jewellery products by addressing the social, ethical and environmental risks facing the industry at large. He outlined their recently launched responsible-sourcing protocol for diamonds, which was built on the United Nations' Guiding Principles on Business and Human Rights and the Due Diligence Guidance for Responsible Supply Chains developed by the Organisation for Economic Co-operation and Development (OECD). Bone focused on RJC's independently audited Code of Practices and Chain-of-Custody Certification and how they relate to diamonds, gold and platinum-group

metals. RJC, a not-for-profit organization, currently has over 700 stakeholders.

Inspiring stories were presented by **Anna Bario** (Bario Neal, Philadelphia, Pennsylvania, USA) and **Eduardo Escobedo** (Responsible Ecosystems Sourcing Platform [RESP], Troinex, Switzerland). Bario described the rapid success her company has achieved while focusing on handcrafted jewellery made with reclaimed precious metals, fair-mined gold, ethically sourced gemstones and low-impact environmentally conscious practices. Escobedo explained RESP's mission to create positive environmental, social and economic impacts by fostering change toward the sustainable use of natural resources. A relative newcomer, RESP works with the cosmetics, fashion and jewellery industries; it recently published a report titled 'Challenges to Advancing Environmental and Social Responsibility in the Coloured Gems Industry' (see What's New entry on page 2 of this issue).

Dorothée Gizenga (Diamond Development Initiative [DDI], Ottawa, Ontario, Canada) gave a fascinating presentation on her organization's activities to transform artisanal mining into a source for sustainable development (Figure 4). Through collective small-scale mining groups who meet certain fair-trade protocols, DDI helps the miners sell their rough diamonds to selected buyers. DDI also provides assistance to these miners with housing, education and safer working conditions.

Figure 4: Dorothée Gizenga spoke at the Jewelry Industry Summit about Diamond Development Initiative's efforts to transform artisanal mining into a source for sustainable development for small-scale miners. Photo by Peggy Jo Donahue.

Lynsey Cesca Jones (VF Corp., Greensboro, North Carolina, USA) explained how her company has addressed supply-chain sourcing issues. VF is a lifestyle, footwear and accessories company that owns brands such as North Face, Timberland, Wrangler, Nautica and JanSport. Jones presented real-world scenarios and how her company addressed these challenges through improved responsible sourcing practices.

Hannah Koep-Andrieu (OECD) discussed the OECD Due Diligence Guide for Responsible Supply Chains of Minerals from Conflict-Affected and High-Risk Areas. These guidelines recommend a five-step framework for risk-based due diligence in the mineral supply chain: (1) Establish strong company management systems, (2) identify and assess risk in the supply chain, (3) design and implement a strategy to respond to identified risks, (4) carry out independent third-party audits and (5) report on supply-chain due diligence.

Ideas resulting from the brainstorming sessions that were held during the summit were posted on the walls of the two main meeting rooms. As the days progressed, the ideas were refined to possible goals and initiatives. Attendees were then encouraged to come up with a number of action plans and select those that each wanted to support. Examples included helping miners and gem cutters in developing countries with safety education and using better equipment to avoid health-related issues, educating and conveying responsible-sourcing information to jewellery sales associates, researching consumer attitudes about responsible sourcing and sustainability, and communicating through various media the accomplishments of the industry in these areas.

Finally, volunteers were solicited to steward the summit into its next steps and future meetings. Many industry leaders stepped up to join the new committee.

Interested readers are encouraged to visit the summit's website (www.jewelryindustrysummit.com/new-page-3) to download information sheets related to the responsible sourcing of diamonds, coloured stones, and gold and precious metals, as well as a list of useful links regarding legal requirements, voluntary standards, association and company practices, and sourcing activities by other industries outside the gem and jewellery sector.

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Gem-A Notices

CEO APPOINTED

Alan Hart FGA DGA has been appointed Chief Executive Officer of Gem-A. A former member of the Gem-A Council, Hart is currently Head of Earth Sciences Collections at the Natural History Museum, London. With a wealth of experience in the gem and mineral trade, Hart started his career at the Natural History Museum in 1981 as Assistant Minerals Scientific Officer, and gained a BSc in geology from Birkbeck College, University of London, in 1994. He progressed to his current position of Principle Curator of Gems and Minerals and Head of Earth Sciences Collections in 2012.

Hart will assume his new position at Gem-A on 1 June 2016, and he will remain affiliated with the Museum as Associate Scientist with access to the collections.

GIFTS TO THE ASSOCIATION

The Association is most grateful to the following for their gifts for research and teaching purposes:

Eric Braunwart, Columbia Gem House, Vancouver, Washington, USA, for five pieces of rough hyalite (Guanajuato, Mexico), four faceted iolites (Wyoming, USA) and seven pieces of ruby in mica schist (Wyoming, USA).

Tom Chatham, Chatham Created Gems, San Francisco, California, USA, for a flux-grown synthetic sapphire crystal containing a platinum inclusion.

Anzor Douman, Arzawa Mineralogical Inc., Winchester, Virginia, USA, for specimens of rough sodalite (Afghanistan), turquoise (Iran), demantoid (Iran), a sapphire crystal (Pakistan), and rough and cut Mali garnets.

Zena Haddad for a square plate of Kenyan soapstone called a 'Kisii stone' after the Kisii tribe that lives in the Tabaka Hills in western Kenya; the plate features a giraffe image.

Craig Hazelton, Lafayette, Colorado, USA, for a phenakite crystal (Aquatera claim, Mt. Antero, Colorado, USA).

Dr Jaroslav Hyršl, Prague, Czech Republic, for a rough piece of sekaninaite (Dolní Bory, Moravia, Czech Republic).

Dr Michele Macrì, Rome, Italy, for four faceted chrome diopsides (Brazil).

Marcus McCallum FGA, Hatton Garden, London, for a copy of *Gems&Jewellery*, **1**(4), 1992 (following a Gem-A appeal for that issue).

Mauro Pantò, The Beauty in the Rocks, Laigueglia, Savona, Italy, for faceted specimens of ceruleite (Peru), hyalite (Hungary), agatized coprolite (Utah, USA), stichtite (South Africa), sunstone (Norway) and neptunite (Benitoite Gem mine, California, USA).

Helen Serras-Herman FGA, Gem Art Center, Rio Rico, Arizona, USA, for a slab of 'bumble bee jasper' from Indonesia.

Ashish Sogani, Rakhi Inc., New York, New York, USA, for a mother-of-pearl bead and a glass-filled sapphire, and faceted samples of amethyst, green crackled quartz, rock crystal (faceted bead), tourmalinated quartz, labradorite and 'tiger iron' quartz.

Dr Thet Tin Nyunt, Gemological Science Centre, Yangon, Myanmar, for two rough pieces of colourless beryl (Kuaukse, Mandalay, Myanmar).

Sid Tucker, Homedale, Idaho, USA, for pyrope gem gravel concentrated by ants (Navajo Nation, Arizona, USA).

Dr Marco Campos Venuti, Seville, Spain, for a rough piece of polyhedral agate (Rio Grande do Sul, Brazil) and a cabochon reportedly cut from thomsonite (Portugal).

Bear Williams FGA and **Cara Williams FGA**, Stone Group Labs, Jefferson City, Missouri, USA, for six simulated turquoise beads (dyed and stabilized magnesite) showing various colours and markings.

MEMBERSHIP

At a meeting of the Council held on 11 March 2016, Miranda Wells was appointed as Chair of the Gem-A Council. Wells, Head of Gemmology at Birmingham City University and Course Director of the BSc (Hons) Gemmology & Jewellery Studies degree, has been a member of the Council for four years. The Council also appointed Paul Greer DGA and Kerry Gregory FGA DGA as Vice Chairs. Wells succeeds Nigel Israel FGA DGA, who remains a member of the Council.

The Council of the Association have elected the following to membership:

Fellowship (FGA)

Baptiste, Karen Anne, Panadura, Sri Lanka
Chan Wai Keung, Kowloon, Hong Kong
Davison, Alexander, Southend-on-Sea, Essex
Ji Kaijie, Shanghai, P.R. China
Saksirisamphan Rimml, Phornthip, Näfels, Switzerland
Slootweg, Peter, Nootdorp, Zuid-Holland, The Netherlands

Diamond Membership (DGA)

Belsham, Lesley, Great Dunmow, Essex
Imre, Alexandra Terez Jenssen, Sevenoaks, Kent
Wang Siyu, Beijing, P.R. China

Associate Membership

Armstong, Ceri Louise, Clapham, London
Armstrong, Richard, Flint, Texas, USA
Corkum, John, Niagara Falls, Ontario, Canada
Golden, Scott, Houston, Texas, USA
Hamadi, Sam, Newcastle-upon-Tyne, Tyne & Wear
Kearns, Bobbi, Knoxville, Tennessee, USA
Oakley, Sally, Wombourne, Staffordshire
Van Leeuwen, Suzanne, Amsterdam, The Netherlands
Wheat, Barbara, Astoria, New York, USA

OBITUARY

Leonard Baker
1921–2016

Leonard Alfred Baker FGA (D. 1948), of Ferndown, Dorset, passed away on 21 March 2016. At Gem-A's centenary celebration in 2013, Leonard was honoured with a Lifetime Membership as the longest-standing Fellow of the Association.

Leonard was born in Barnsbury, North London, in March 1921. He entered the Royal Air Force in September 1940 as a mechanic working on Hampden bombers and volunteered on a number of occasions to fly as aircrew (gunner), during one of which he was shot down on a return trip from Hanover, Germany. He was discharged from the RAF in August 1946 with an unblemished record.

He joined his father, George Baker, to be trained as a jeweller before taking a jewellery manufacturing apprenticeship with master craftsman E. A. Wallace (formerly of English Art Works, who supplied Cartier). After attending night school to study gems, in 1948 he qualified in the Gemmology Diploma examination and became a Fellow of the Gemmological Association of Great Britain.

He then formed a manufacturing jewellery company, Leonard A. Baker Ltd. A facsimile of the jewelled peacock inspired by the throne of Titania's Palace earned his company recognition from the Arts Council, and he was awarded a Fellowship of the Royal Society of Arts (FRSA).

After 38 years of manufacturing jewellery for celebrities from around the world, his company gained the distinction of a unique official Post Office address: Messrs Leonard A. Baker Ltd, Oxford Circus, London, England. This was an achievement of which he was justly proud.

Although Leonard retired in 1984, he continued lecturing worldwide on gems and gemmology until 1997.

Leonard leaves his grandson Lee Baker (the author of this obituary), Lee's wife Caroline and great-grandson Luke. He will be sadly missed by close family and friends.

Lee Baker

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Learning Opportunities

CONFERENCES AND SEMINARS

ASJRA's Weekend in Washington: Great Estates, Historic Jewelry, and Decorative Arts
13–14 May 2016
Washington DC, USA
www.jewelryconference.com/sched.html

30th Annual Santa Fe Symposium
15–18 May 2016
Albuquerque, New Mexico, USA
www.santafesymposium.org

37th World Diamond Congress
16–19 May 2016
Dubai, United Arab Emirates
http://diamondcongress2016.com

8th International Conference on Mineralogy and Museums
17–19 May 2016
Changsha, Hunan, China
www.mm8-2016.cn

SNAG^{neXt}
18–21 May 2016
Asheville, North Carolina, USA
www.snagmetalsmith.org/events/snagnext

China (Changsha) Mineral & Gem Show
19–23 May 2016
Changsha, China
www.changsha-show.com/enindex.html
Note: Includes a seminar programme.

10th International Conference on New Diamond and Nano Carbons
22–26 May 2016
Xi'an, China
http://ndnc2016.xjtu.edu.cn

JCK Talks 2016
2–6 June 2016
Las Vegas, Nevada, USA
http://lasvegas.jckonline.com/Education

Maine Pegmatite Workshop 2016
27 May–4 June 2016
Poland, Maine, USA
http://pegworkshop.com

12th International GeoRaman Conference
9–15 June 2016
Novosibirsk, Russia
http://georaman2016.igm.nsc.ru

Compiled by Georgina Brown and Brendan Laurs

15th Rendez-Vous Gemmologiques de Paris
13 June 2016
Paris, France
www.facebook.com/pages/Association-Française-de-Gemmologie

Scandinavian Gem Symposium
18 June 2016
Kisa, Sweden
http://sgs.gemology.se

Sainte-Marie-aux-Mines 53rd Mineral & Gem Show
23–26 June 2016
Sainte-Marie-aux-Mines, France
www.sainte-marie-mineral.com/english/modules/cultural-activities
Note: Includes a seminar programme.

2nd Eugene E. Foord Symposium on Pegmatites
15–19 July 2016
Golden, Colorado, USA
www.colorado.edu/symposium/pegmatite

Northwest Jewelry Conference
12–14 August 2016
Seattle, Washington, USA
www.northwestjewelryconference.com

46th ACE IT Annual Mid-Year Education Conference
13–16 August 2016
Newport Beach, California, USA
www.najaappraisers.com/html/conferences.html

Dallas Mineral Collecting Symposium
19–21 August 2016
Dallas, Texas, USA
www.dallassymposium.org

35th International Geological Congress
27 August–4 September 2016
Cape Town, South Africa
www.35igc.org
Sessions of Interest: Gems: Bringing the World Together; The Dynamic Earth and Its Kimberlite, Cratonic Mantle and Diamond Record Through Time; Diamonds and Crustal Recycling into Deep Mantle

Internationrence on Diamond and Carbon Materials
4–8 September 2016
Le Corum, Montpellier, France
www.diamond-conference.elsevier.com

ASA 2016 International Appraisers Conference
11–14 September 2016
Boca Raton, Florida, USA
www.appraisers.org/Education/conferences/ASA-Conference

2nd European Mineralogical Conference (emc2016)
11–15 September 2016
Rimini, Italy
http://emc2016.socminpet.it
Sessions of Interest: Gem Materials; Inclusions in Minerals as a Record of Geological Processes; New Analysis Methods and Application

IRV Loughborough Conference
17–19 September 2016
Loughborough
www.jewelleryvaluers.org/Loughborough-Conference

49th Annual Denver Gem & Mineral Show
16–18 September 2016
Denver, Colorado, USA
www.denvermineralshow.com
Note: Includes a seminar programme.

42nd Pacific Northwest Chapter Friends of Mineralogy Symposium
14–16 October 2016
Longview, Washington, USA
www.friendsofmineralogy.org/symposia.html

Gem-A Conference
5–8 November 2016
London
www.gem-a.com/news–events/gem-a-conference-2016.aspx

Gem and Jewelry Institute of Thailand Conference (GIT 2016)
14–15 November 2016
Pattaya, Thailand
www.git.or.th/2014/index_en.html

EXHIBITS

Europe

Fabergé – The Tsar's Jeweller and the Connections to the Danish Royal Family
12 May–25 September 2016
Museet på Koldinghus, Kolding, Denmark
www.koldinghus.dk/uk/exhibitions/exhibitions-2016/faberge.html

Open Space—Mind Maps. Positions in Contemporary Jewellery
Until 15 May 2016
Nationalmuseum Design, Stockholm, Sweden
www.nationalmuseum.se/English-startpage/Exhibitions/Open-Space--Mind-Maps

Take it Personally [jewellery and adornment]
Until 1 June 2016
Museum of Cultural History, Oslo, Norway
www.khm.uio.no/english/visit-us/historical-museum/temporary-exhibitions/2015/this-is-personal.html

A Motley Crew—New Pieces from the Collection
Until 12 June 2016
Schmuckmuseum, Pforzheim, Germany
www.schmuckmuseum.de/flash/SMP_en.html

Heavenly Bodies—The Sun, Moon and Stars in Jewellery
8 July–30 October 2016
Schmuckmuseum, Pforzheim, Germany
www.schmuckmuseum.de/flash/SMP_en.html

Elements: From Actinium to Zirconium
Until 26 February 2017
Ulster Museum, Belfast, Northern Ireland
http://nmni.com/um/What-s-on/Elements

Smycken: Jewellery. From Decorative to Practical
Ongoing
Nordiska Museet, Stockholm, Sweden
www.nordiskamuseet.se/en/utstallningar/jewellery

North America

A Passion for Jade: The Heber Bishop Collection
Until 19 June 2016
The Metropolitan Museum of Art, New York, New York, USA
www.metmuseum.org/exhibitions/listings/2015/passion-for-jade

Variations on a Theme: 25 Years of Design from the AJDC
Until July 2016
Gemological Institute of America, Carlsbad, California, USA
www.gia.edu/gia-museum-variations-theme-25-years-design-AJDC

Thunderbirds: Jewelry of the Santo Domingo Pueblo
Until 5 September 2016
Abby Aldrich Rockefeller Folk Art Museum, Williamsburg, Virginia, USA
http://tinyurl.com/zgyd54k

Fabergé from the Matilda Geddings Gray Foundation Collection
Until 27 November 2016
The Metropolitan Museum of Art, New York, New York, USA
www.metmuseum.org/exhibitions/listings/2011/faberge

Glitterati: Portraits & Jewelry from Colonial Latin America
Until 27 November 2016
Denver Art Museum, Denver, Colorado, USA
www.denverartmuseum.org/exhibitions/glitterati

Arts of Islamic Lands: Selections from The al-Sabah Collection, Kuwait
Until 29 January 2017
Museum of Fine Arts, Houston, Texas, USA
www.mfah.org/exhibitions/arts-islamic-lands-selections-al-sabah-collection-

American Mineral Heritage: Harvard Collection
Until February 2017
Flandrau Science Center & Planetarium, Tucson, Arizona, USA
http://flandrau.org/exhibits/harvard

Gold and the Gods: Jewels of Ancient Nubia
Until 14 May 2017
Museum of Fine Arts, Boston, Massachusetts, USA
www.mfa.org/exhibitions/gold-and-gods

Amber Secrets: Feathers from the Age of Dinosaurs
Ongoing
Houston Museum of Natural Science, Texas, USA
www.hmns.org/exhibits/special-exhibitions/amber-secrets-feathers-from-the-age-of-dinosaurs

City of Silver and Gold: From Tiffany to Cartier
Ongoing
Newark Museum, New Jersey, USA
www.newarkmuseum.org/SilverAndGold.html

Fabergé: From a Snowflake to an Iceberg
Ongoing
Houston Museum of Natural Science, Texas, USA
www.hmns.org/exhibits/special-exhibitions/faberge-a-brilliant-vision/

Gemstone Carvings
Ongoing
Houston Museum of Natural Science, Texas, USA
www.hmns.org/exhibits/special-exhibitions/gemstone-carvings

Gilded New York
Ongoing
Museum of the City of New York, New York, USA
www.mcny.org/content/gilded-new-york

Jewelry, from Pearls to Platinum to Plastic
Ongoing
Newark Museum, New Jersey, USA
www.newarkmuseum.org/jewelry

Mightier than the Sword: The Allure, Beauty and Enduring Power of Beads
Ongoing
Yale Peabody Museum of Natural History, Yale University, New Haven, Connecticut, USA
http://peabody.yale.edu/exhibits/mightier-sword-allure-beauty-and-enduring-power-beads

Australia

A Fine Possession: Jewellery & Identity
Until 22 May 2016
Powerhouse Museum, Sydney, New South Wales, Australia
www.powerhousemuseum.com/exhibitions/jewellery

OTHER EDUCATIONAL OPPORTUNITIES

Gem-A Workshops and Courses
Gem-A, London
www.gem-a.com/education/course-prices-and-dates.aspx

Advanced Diamond Program
16 or 17 May 2016
Birmingham
www.naj.co.uk/en/news/events-conferences.cfm/seminar-for-valuers-identifying-synthetic-and-treated-diamonds

Minerals and Gems: Unlocking the Earth's Treasure Chest
21 June–9 August 2016
Harvard University Summer School, Cambridge, Massachusetts, USA
www.summer.harvard.edu/courses/minerals-gems-unlocking-earths-treasure-chest/33384

Gemstone Safari to Tanzania
11–28 July 2016
Morogoro, Umba, Arusha, Longido, Merelani and Lake Manyara, Tanzania
www.free-form.ch/tanzania/gemstonesafari.html

Lectures with The Society of Jewellery Historians
Burlington House, London, UK
www.societyofjewelleryhistorians.ac.uk/current_lectures

28 June 2016
Neil Wilkin—Bronze Age Bodily Adornment: How was It Made and Worn?

27 September 2016
Galina Korneva—The Grand Duchess Maria Pavlovna's Contacts with Paris Jewellers and Her Collection of Treasures

25 October 2016
Robert Baines—Bogus or Real: Jewellery and the Capture of Human Drama

22 November 2016
Kieran McCarthy—Fabergé and London

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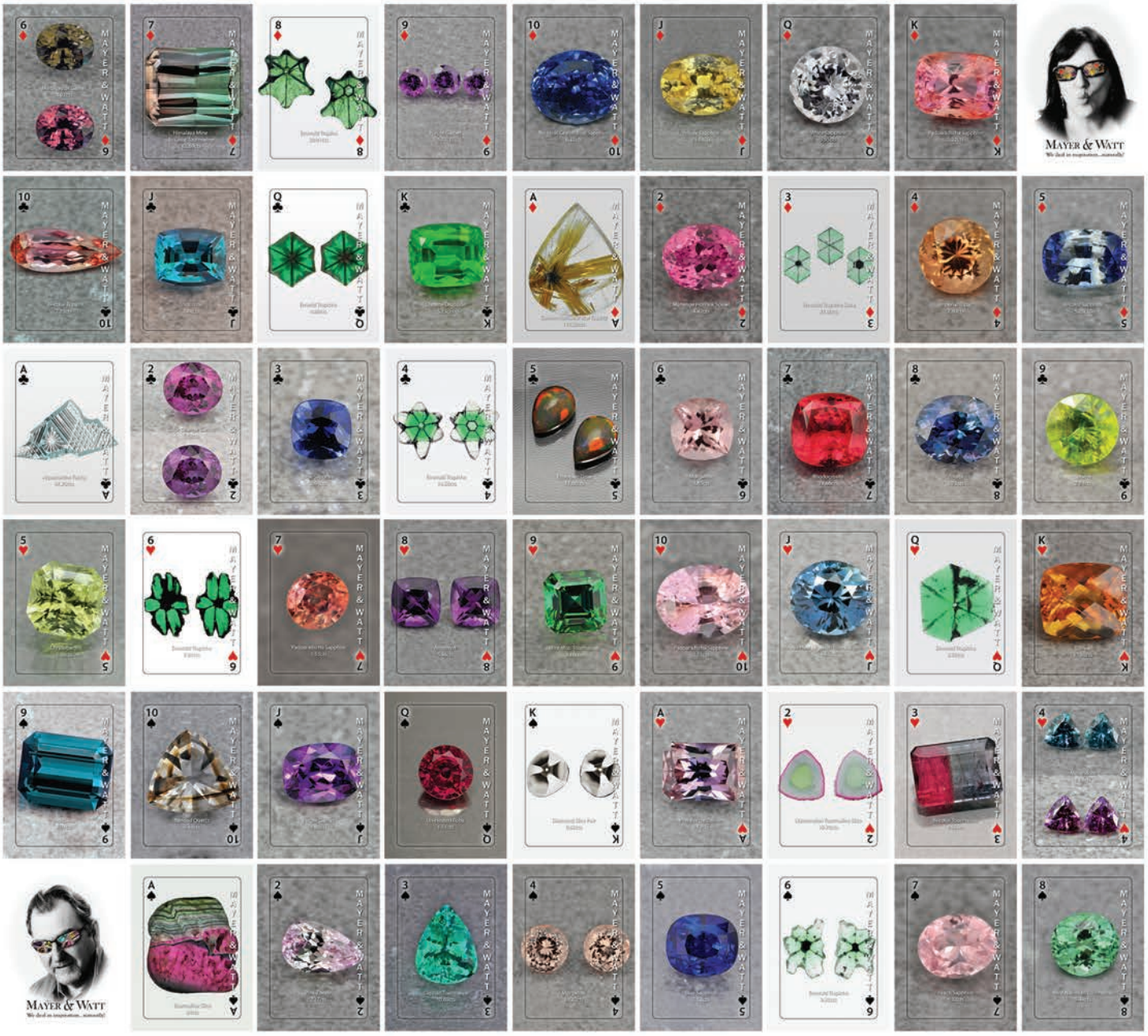

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New Media

Exotic Gems, Vol. 4: How to Identify, Evaluate & Select Jade & Abalone Pearls

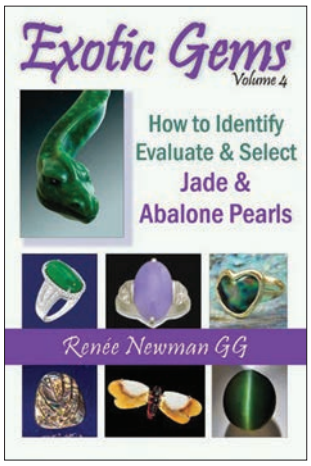

By Renée Newman, 2016. International Jewelry Publications, Los Angeles, California, USA, 136 pages, ISBN 978-0929975504. US$19.95 softcover.

This book is the fourth in a series covering exotic and unusual gems by Renee Newman that explores their history, lore, evaluation, geographic sources and identifying properties. I find these books very readable and highly recommend all of them.

In this Volume 4, *Jade & Abalone Pearls*, a quick perusal of the table of contents shows 12 chapters (116 pages) that are devoted to jade. The final, 13th, chapter dedicates 13 pages to understanding abalone pearls.

Well-written books on jade in the English language are rare. The advantages of this book are that it is inexpensive, understandable and extensively researched. Newman provides answers to most questions that a person with curiosity about gemstones might have. All of the chapters are well illustrated with numerous photographs depicting the corresponding content. Newman also uses tables effectively to illustrate various gemmological points.

The first chapter, 'Why Is Jade so Prized?', briefly covers what makes jade special, with sections titled Durability, Carvability, Color Palette, Auditive Quality, Luster, Rarity, Status Symbol, Therapeutic Virtues, Historical Significance, Investment Appreciation Potential and Spiritual & Mystical Significance. Newman covers these attributes in just four pages, but the reader can find more detailed explanations of some of them in the following chapters. Chapter 2 answers the question 'What Is Jade?' and is followed by Chapter 3, 'Jadeite or Nephrite Jade?' The latter includes a useful table, 'Characteristics of Jadeite Jade Versus Nephrite Jade', which compares and contrasts their various properties (e.g. chemical formulas, RIs, reaction to heat, etc.) according to 19 categories.

Chapters 4 and 5 cover imitations and treatments. Minerals and rocks that look like jade include more than a dozen varieties (e.g. chrysoprase, aventurine, etc.). Many treatments are performed on jade, including waxing, heating, coating and polymer impregnation, among others. These chapters provide a well-researched discussion of these aspects.

Chapter 6 offers a discussion of price factors for jadeite and nephrite, including colour, clarity, cutting style/shape, cut quality, carat weight or stone size, transparency, treatment status and texture. Figure 6.1 shows a magnificent jadeite ring that sold for US$101,400 at Sotheby's in 2004. (*Reviewer's note*: Today it could be valued at perhaps more than 10 times this amount.) Newman mentions that the highest auction price for a piece of jadeite jewellery was attained in 2014 (US$27,440,000 for a necklace sold by Sotheby's Hong Kong); China was the driving force. Several other notable auction pieces are described and pictured in detail. In this chapter Newman includes the Mason-Kay 'Colors of Jade' chart (Figure 6.8), which is one of my personal favourites and was nice to see reproduced here.

Chapters 7 through 12 cover various sources of jade—both nephrite and jadeite—including China, Myanmar (Burma), Guatemala, Canada, USA and other sources. All of these chapters provide interesting reading and anecdotes relating to these various jade localities.

Chapter 13 on abalone pearls gives a brief history of various localities, especially concentrating on North America, including Baja California (Mexico), and California and Oregon (USA). *Pāua* abalone mabe pearl cultivation is briefly mentioned. Identification, pricing and care are also discussed. Numerous photographs accompany the abalone pearl chapter.

The book ends with a bibliography and an index.

William F. Larson
Palagems.com, Fallbrook, California, USA

Gems & Crystals: From One of the World's Great Collections

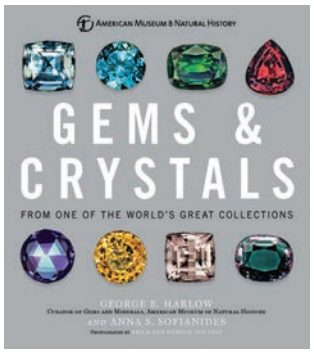

By George E. Harlow and Anna S. Sofianides, 2015. Sterling, New York, New York, USA, 232 pages, ISBN 978-1454917113. US$27.95 hardcover.

The first edition of this lovely picture book was published in 1990. The 2015 edition has been updated in several, but alas not all, subjects.

From One of the World's Great Collections in the title refers to the American Museum of Natural History (AMNH) in New York City, USA, which indeed has a great collection with a storied history. Names such as Dr G. F. Kunz, J. P. Morgan and Tiffany & Co. are associated with its early development; later mineral and gem curators included Herbert Whitlock, Dr Vincent Manson and Dr George Harlow, the present curator and an author of this book. Thus the history given in the book is rather parochial to the AMNH.

Part One describes what a gem is, first from a historical basis and then in terms of its mineralogy and desirable properties. The 'meat' of the book is found in Part Two, titled 'Gallery of Gems and Crystals', in which each important gem material is discussed either alone (e.g. diamond, topaz, opal) or in combination with similar materials (e.g. chrysoberyl with spinel, feldspar group minerals and garnet group minerals).

For each gem material, the description is subdivided into data, properties, historical notes, legends and lore, occurrences, materials that could be confused for the gem, evaluation criteria and, of course, is accompanied by beautiful pictures. The emphasis on history and especially lore is traditional for the AMNH, hearkening back to Kunz's interests. Although the scientific data are generally error-free, it would have been helpful if the authors had included a separate section on synthesis and gem treatments for each material, as this information is often critical in determining a gem's value.

Unfortunately, the information in this book is dated with regard to recent finds and changes in the availability of some gem materials. The section on garnets, for instance, treats 'malaia' as the latest variety, although since then spessartine from Namibia, grandite garnets from Mali and mint-green grossular from Tanzania have been discovered. The garnet section also starts with the old adage that garnets "come in every colour except blue", ignoring the relatively recent production of colour-change garnets that can vary with different illumination from purplish red to violetish blue, blue and greenish blue.

A second example of outdated information is the pearl section's omission of the tremendous availability of Chinese freshwater tissue-nucleated cultured pearls, which are now ubiquitous. Also, the range of colour-treated cultured pearls is much larger than before, and the flamboyantly iridescent abalone pearls are not mentioned. Perhaps the AMNH does not yet have excellent yet representative examples of these missing gem materials.

The authors also indicate that tanzanite is extremely rare, although in the past few decades, fine and commercial tanzanites have been about as available in jewellery stores as rubies, emeralds and sapphires. (Admittedly, this trend may not be permanent, as commercially important deposits of tanzanite are known from only a single source.)

Another problem with this book concerns the colour reproduction of some of the photographs. This is particularly the case for some green gems (e.g. amazonite, serpentine imitation of jade) and for the carved rose quartz *Fu* dog on page 134. Also in some figure captions for images containing more than one gem variety, it is not clear which stone is which material (e.g. the chalcedonies and other gems on page 145).

A last (mineralogical) criticism of this book is that the title is perhaps misleading. The AMNH has many excellent crystals, but with a few exceptions (e.g. amazonite), the only crystals shown are gemmy transparent examples of gem mineral crystals. Should the book instead be titled *Gems & Gemmy Gem Mineral Crystals*?

These issues aside, this is a very good book for understanding the stories and science behind gems, and for appreciating their incredible beauty. It is especially recommended for anyone who does not have the 1990 edition.

Dr Mary L. Johnson
Mary Johnson Consulting
San Diego, California, USA

OTHER BOOK TITLES*

Diamonds

***The Global Diamond Industry: Economics and Development,* Vol. I**
Ed. by Roman Grynberg and Letsema Mbayi, 2015. Palgrave Macmillan, Hampshire, 288 pages, ISBN 978-1137537577. £75.00 hardcover or £75.00 Kindle edition.

***The Global Diamond Industry: Economics and Development,* Vol. II**
Ed. by Roman Grynberg and Letsema Mbayi, 2015. Palgrave Macmillan, Hampshire, 320 pages, ISBN 978-1137537607. £75.00 hardcover or £75.00 Kindle edition.

***Rough Diamonds, a Practical Guide,* 2nd edn.**
By Nizam Peters, 2015. American Institute of Diamond Cutting, Deerfield Beach, Florida, USA, 274 pages, ISBN 978-0966585490. US$165.00 hardcover.

Gem Localities

***Minerals of Ohio*, 2nd edn.**
By Ernest H. Carlson, 2015. Ohio Department of Natural Resources Division of Geological Survey Bulletin 69, Columbus, Ohio, USA, 290 pages. US$30 hardcover.

Minerals of Georgia: Their Properties and Occurrences
By Julian Gray and Robert Cook, 2016. University of Georgia Press, Athens, Georgia, USA, 344 pages, ISBN 978-0820345581. US$32.95 flexibound.

New York Rocks & Minerals: A Field Guide to the Empire State
By Dan R. Lynch and Bob Lynch, 2016. Adventure Publications, Cambridge, Minnesota, USA, 264 pages, ISBN 978-1591935247. US$14.95 softcover.

General Reference

The Collector and His Legacy: Irénée du Pont and the Mineralogical Collection of the University of Delaware
By Sharon Fitzgerald, 2015. Mineralogical Record Inc., Tucson, Arizona, USA, 96 pages. US$15.00 softcover.

Gold: Nature and Culture
By Rebecca Zorach and Michael W. Phillips Jr., 2016. Reaktion Books, Edinburgh, Scotland, 224 pages, ISBN 978-1780235776. £14.95 softcover.

Medieval Jewelry and Burial Assemblages in Croatia (East Central and Eastern Europe in the Middle Ages, 450–1450)
By Vladimir Sokol, 2015. Brill, Leiden, The Netherlands, 268 pages, ISBN 978-900418553. £92.00 softcover.

Mineral Collections in Austria
By Thomas Weiland, 2015. Mineralogical Record Inc., Tucson, Arizona, USA, 96 pages. US$15.00 softcover.

***Minerals: Their Constitution and Origin,* 2nd edn.**
By Hans-Rudolf Wenk and Andrey Bulakh, 2016. Cambridge University Press, Cambridge, 620 pages, ISBN 978-1107514041. £49.99 softcover, £95.00 hardcover or £47.49 Kindle edition.

***Moore's Compendium of Mineral Discoveries 1960–2015,* Vols. I and II**
By Thomas P. Moore, 2016. Mineralogical Record Inc., Tucson, Arizona, USA, 1,644 pages. US$399.00 hardcover.

The Munich Show/Mineralientage München: Theme Book Precious Stones
Ed. by The Munich Show, 2016. Wachholtz Verlag GmbH, 216 pages, ISBN 978-3529054617. €28.00 hardcover.

Jewellery and *Objets d'Art*

Art as Adornment: The Life and Work of Arthur George Smith
By Charles L. Russell, 2015. Outskirts Press, Parker, Colorado, USA, 264 pages, ISBN 978-1478744788. US$64.95 hardcover or US$56.95 softcover.

Asia Imagined: In the Baur and Cartier Collections
By Estelle Niklès van Osselt, 2016. Yale University Press, New Haven, Connecticut, USA, 368 pages, ISBN 978-8874397228. US$90.00 hardcover.

Cartier Dazzling: High Jewelry and Precious Objects
By François Chaille, 2016. Flammarion, Paris, France, 272 pages, ISBN 978-2080202604. €95.00 hardcover.

Pamela Love: Muses and Manifestations
By Pamela Love and Francesco Clemente, 2016. Rizzoli, New York, New York, USA, 176 pages, ISBN 978-0847848195. US$45.00 hardcover.

* Compiled by Georgina Brown and Brendan Laurs

The Fire Within

"For in them you shall see the living fire of the ruby, the glorious purple of the amethyst, the sea-green of the emerald, all glittering together in an incredible mixture of light."

– Roman Elder Pliny, 1st Century AD

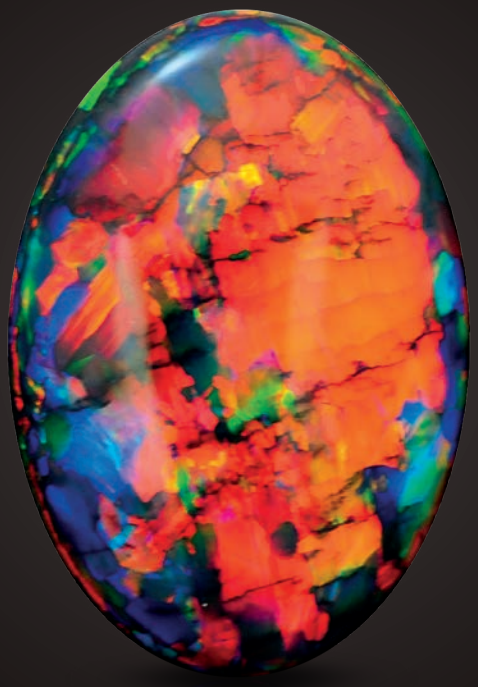

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Literature of Interest

Coloured Stones

Blue minerals: Exploring cause & effect. E.A. Skalwold and W.A. Bassett, *Rocks & Minerals,* **91**(1), 2016, 61–77, http://dx.doi.org/10.1080/00357529.2016.1099136.

Bumble bee 'jasper'. H. Serras-Herman, *Gems&Jewellery,* **24**(6), 2015, 26–28.

Chemistry of opal from Ethiopia. H. Ren and L. Li, *Journal of Gems & Gemmology,* **17**(4), 2015, 23–28 (in Chinese with English abstract).

Colorimetric analysis of green jadeite. D.J. Nie, Y. Zou and X.K. Zhu, in P. Chen (Ed.), *Material Science and Engineering,* Proceedings of the 3rd Annual 2015 International Conference on Material Science and Engineering, CRC Press/Balkema, Leiden, The Netherlands, 2016, 411–414, http://dx.doi.org/10.1201/b21118-87.

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Gemmological characteristic [*sic*] of peridot from Jiaohe, Jilin Province. J. Gu, Q. Zhao, J. Lai, C. Wang and Z. Yin, *Journal of Gems & Gemmology,* **17**(5), 2015, 24–31 (in Chinese with English abstract).

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The history and occurrence of 'Buxton diamonds'. R. Starkey and J. Faithfull, *Journal of the Russell Society,* **18**, 2015, 24–45.

The Hope Chrysoberyl. A. Hart, *Gems&Jewellery,* **25**(1), 2016, 22.

Hope, Hertz and a red spinel. J. Ogden, *Gems&Jewellery,* **24**(6), 2015, 20–21.

Influence of impurities on Cr^{3+} luminescence properties in Brazilian emerald and alexandrite. N. Ollier, Y. Fuchs, O. Cavani, A.H. Horn and S. Rossano, *European Journal of Mineralogy,* **27**(6), 2015, 783–792, http://dx.doi.org/10.1127/ejm/2015/0027-2484.

Les jades, lapidaireries comparatives [The jades, lapidary comparisons]. E. Gonthier and I.-A. Gonthier, *Revue de Gemmologie A.F.G.,* **194**, 2015, 17–28.

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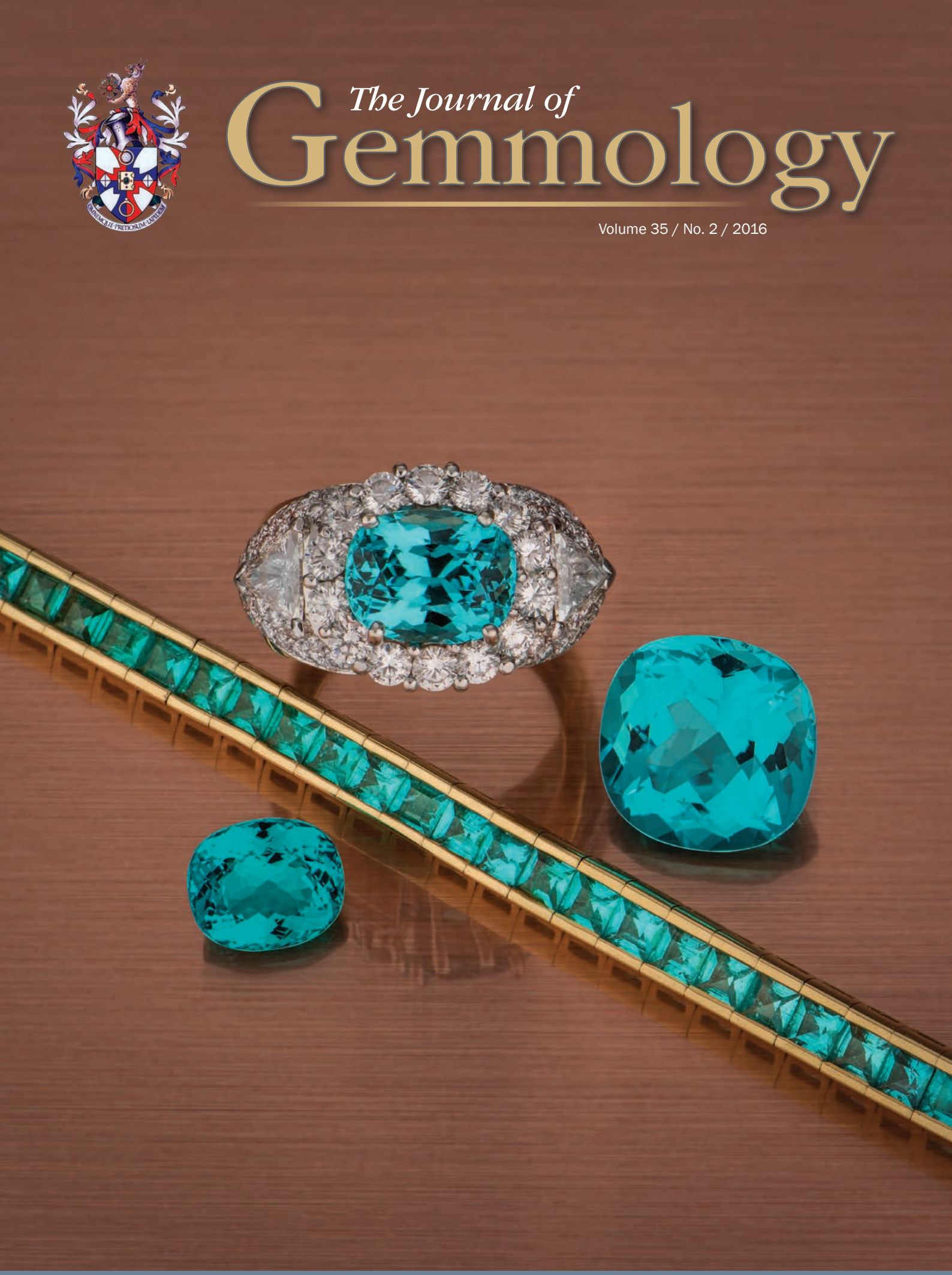

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Cover Photo: These Cu-bearing tourmalines are from Mozambique (13.93 ct cushion and ~5 ct stone in ring) and from Paraíba, Brazil (3.5 mm gems in bracelet and 4.02 ct oval). Courtesy of Collectorfinejewelry.com, Palagems.com (13.93 ct stone) and Leslie Hindman Auctioneers, Chicago, Illinois, USA (4.02 ct gem); photo by Orasa Weldon.

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Understanding Gems™

What's New

INSTRUMENTS AND TECHNIQUES

ASDI Device Updated

In 2015, SSEF twice updated its own Automated Spectral Diamond Inspection (ASDI) device, and these changes will be included on future orders of the instrument. The system is used to rapidly screen colourless round melee for imitations, HPHT-treated diamonds and synthetic (CVD and HPHT) diamonds. More information is available on SSEF's Swiss Analytical Testing Tools website at www.sattgems.com. *CMS*

D-Secure Synthetic Diamond Detection Instrument

From DRC Techno of Gujarat, India, and unveiled in September 2015, D-Secure is designed to be a cost-effective instrument for detecting colourless to near-colourless synthetic diamonds of all shapes, including rough, ranging from 0.003–10 ct (or larger with a special attachment). The 3-inch scan area establishes the parcel size possible for analysis, and also accommodates some mounted diamonds. Visit www.dsecure.com. *CMS*

Dialite MasterGrader

Available since early 2016, the Dialite MasterGrader from System Eickhorst (Hamburg, Germany) was developed jointly with the Natural Color Diamond Association to provide a standardized grading environment especially for fancy-colour diamonds and other coloured gems. The instrument includes standardized daylight illumination (per ISO/PAS and CIBJO), switchable lighting (LED, UV, and incandescent), diffuse illumination for photography and a neutral grey background. The unit measures 34 × 40 × 15 cm, and a voltage converter and adapter plug are available separately for various regions. Visit http://eickhorst.com/en/gemmological-instruments/dialite-mastergrader/features. *CMS*

GemLab Instrument Updates

In May 2016, GemLab (Vancouver, British Columbia, Canada) announced changes to two of its instruments. The 2016/17 model of the GL Gem Raman PL532 features an upgraded spectrometer, a faster processor and version 3.0 of its GLGemSpec software. The unit is available in two models, TEC (5400–100 cm^{-1}) and PL (530–750 nm). Also included is a band-pass filter to suppress fluorescence in Raman mode. The 2016/17 model of the GL Gem Spectrometer also incorporates a new processor and GLGemSpec 3.0 software. The portable UV-Vis-NIR spectrometer can be operated using a Windows laptop via a USB 2.0 connection. The spectral range is 300–1000 nm, in transmission mode with 1.5 nm resolution. The unit measures 17 × 10 × 5 cm and comes with a specimen holder. Optional accessories include a fibre-optic probe, a cosine corrector kit and a Xenon flashlight kit. Visit www.cigem.ca/research-technology/gl-gem-raman and www.cigem.ca/research-technology/gl-gem-spectrometer. *CMS*

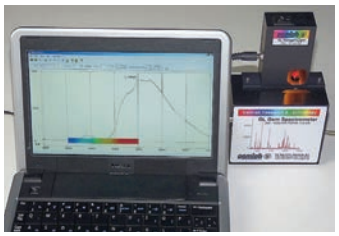

NEWS AND PUBLICATIONS

De Beers' 2015 Diamond Jewellery Demand and Outlook for 2016

Released in April 2016, this De Beers Group report includes statistics on diamond jewellery sales for 2015 compared to 2014. Consumer demand rose 2%, but sales (in US$) declined 2% due to the strength of the US dollar. Growth based on polished wholesale prices was greatest in the USA, followed by China. The report concludes with the outlook for 2016. PDFs and MP4 videos are available for download, along with the online report, at www.debeersgroup.com/en/reports/insight/flash-data/flash-data-Apr2016.html. *CMS*

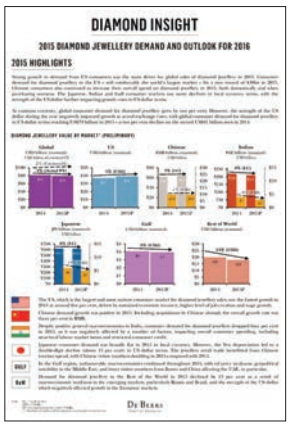

GIT Laboratory Updates

The Gem and Jewelery Institute of Thailand (GIT) released a Lab Update on 1 March 2016 regarding a specimen of 'ruby in marble' containing a polished rod of synthetic ruby embedded in a hole drilled into a piece of marble. After insertion, the exposed portion of the synthetic ruby was polished to create an appearance of natural faces. On 11 May 2016, GIT posted a Gemstone Update on purple garnet from Mozambique that describes the standard gem properties, inclusions and chemical composition of this attractive material. To download these and previous GIT reports, visit www.git.or.th/2014/articles_technic_en.html. *CMS*

GIT Trade Review 2015

Posted in February 2016, this GIT publication reviews Thailand's gem and jewellery import-export performance in 2015. The overall export value

increased 9.27% over 2014, with the main markets being Hong Kong, Switzerland, USA and Cambodia. The import value of gems and jewellery grew 4.38%, with the main sources being Switzerland, Japan, Australia and Hong Kong. Download the report at www.git.or.th/2014/git_trade_publication_en. html. *BML*

IAA Newsletter

The March 2016 issue of *Bursztynisko*, the bilingual (Polish and English) newsletter of the International Amber Association (IAA), can be downloaded at www.amber.org.pl/index.php/download_file/view/474. Articles in this 20th anniversary issue cover the history of IAA, description of the IAA Gallery in Gdańsk, amber classification, amber craft and goldsmiths in 16th–18th century Gdańsk, palaeontological inclusions in amber, mapping of old amber mines in Poland, amber mining in Ukraine, Burmite and recent Baltic amber prices. A report on observations in the IAA Amber Laboratory over the past year describes various simulants seen and methods of testing performed at the lab. *CMS*

ICGL *Newsletter*

Issue 1 for 2016 of the newsletter from the International Consortium of Gem-Testing Laboratories focuses on rubies, with articles on 'blood red' rubies from Madagascar, 'pigeon-blood' coloration and asterism caused by 'tialite' needles in rubies from India. Download the newsletter at http://icglabs.org. *CMS*

IGDA News and Overview of the Lab-Grown Diamond Industry 2015–2016

In February 2016, leading synthetic diamond producers, distributors and retailers formed the International Grown Diamond Association (IGDA).

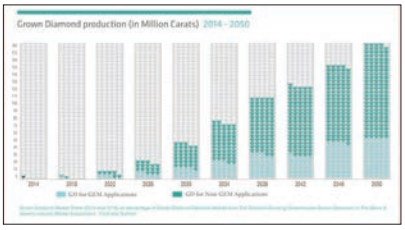

Selected news stories about synthetic diamonds are posted in the Market News section of the IGDA website at http://theigda.org/news, and a report titled 'Overview of the Lab-Grown Diamond Industry in 2015–16' reviews the production of synthetic diamonds beginning in 2014 (around 360,000 carats) and projects growth through 2050 (anticipated to be ~2 million carats). For the full report, visit http://theigda.org/education/an-overview-of-the-grown-diamond-industry-in-2015-16. *CMS*

JGGL *Gem Information*

The latest *Gem Information* (in Japanese, Vol. 43, 2015) from the Japan Germany Gemmological Laboratory in Kofu, Japan, covers demantoid from Pakistan, colour terminology in the gem trade, melee-size synthetic diamonds from India and China, black opal and green amber from Ethiopia, and a report on the 2015 Tucson gem shows. English-language abstracts (posted in December 2015) are available at www.sapphire.co.jp/jggl/978.htm. *CMS*

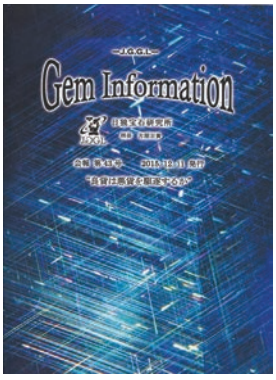

Kyawthuite, a New Mineral from Mogok, Myanmar

A new mineral has been discovered as a faceted gemstone from Mogok, Myanmar. Kyawthuite ($BiSbO_4$) is named after Dr Kyaw Thu of Macle Gem Trade Laboratory, Yangon, Myanmar. The original pebble was recovered in 2010 and suspected to be scheelite. When Dr Thu faceted the 1.61 ct reddish orange gemstone, he recognized it as something unusual. The full description of kyawthuite will be published in an article by A. R. Kampf, G. R. Rossman, C. Ma and P. A. Williams in *Mineralogical Magazine* (download the preprint at www.ingentaconnect.com/content/minsoc/mag/pre-prints/content-minmag-1285). *BML*

G. Rossman

Margaritologia Pearl Newsletter

In December 2015, *Margaritologia* No. 2/3 was released by Gemmologisches Institut Hamburg, Germany. This latest issue features cultured pearls from Lake Kasumigaura, Japan, beginning with the import of mussels from Lake Biwa in 1931. The report covers the history of development, culturing methods, breeding of mussels, marketing, description of the pearls and development of 'Kasumigaura-type' cultured pearls in China. To subscribe to the newsletter, visit www.gemmologisches-institut-hamburg.de. *CMS*

PDAC Diamond Abstracts

Abstracts are available for download from the 2016 conference of the Prospectors & Developers Association of Canada, held in Toronto, Ontario, Canada. A session titled 'Diamonds in Southern Africa: Back to the Beginning' consisted of five presentations: (1) a summary of diamond resources by Mike de Wit of Tsodilo Resources, (2) information on Petra Diamonds by Jim Davidson, (3) the Karowe mine by John Armstrong of Lucara Diamond Corp., (4) the future of the international diamond business by John Bristow of Global Diamond Network and (5) the status of the diamond industry by Chaim Even-Zohar of Tacy Ltd. Download the abstracts at www.pdac.ca/convention/programming/technical-program/sessions/technical-program/diamonds-in-southern-africa-back-to-the-beginning. *CMS*

Photomicrographs of Fossils in Amber

Two articles by Drs David Penney and David Green in *Deposits Magazine* dated 11 and 15 December 2015 focus on 'Biodiversity of fossils in amber' and 'Preparation and study of fossils in amber'. The first lists important amber deposits worldwide with examples of exceptional insect fossils and typical source-identification characteristics. The second article explores how to prepare amber samples to reveal the fossils within, and how to photograph these inclusions using conventional photomicrography and computed tomography. Visit https://depositsmag.com/2015/12/11/biodiversity-of-fossils-in-amber and https://depositsmag.com/2015/12/15/preparation-and-study-of-fossils-in-amber. *CMS*

Precious Stones Multi-Stakeholder Working Group Study

Available online April 2016, a report from the Precious Stones Multi-Stakeholder Working Group dated 16 July 2015 was commissioned by Jewelers of America and authored by members of Sustainable & Responsible Solutions Ltd. and Estelle Levin Ltd.

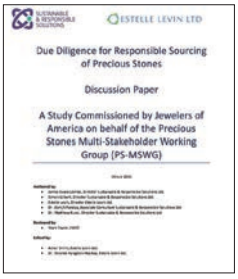

It examines the status of due diligence approaches in the gem industry and addresses the need for future developments within that supply chain. The issues focus on social responsibility based on the UN Guiding Principles on Business and Human Rights, from sourcing of gems through retail practices. Download the report at www.dmia.diamonds/wp-content/uploads/2014/11/PS-MSWG PreciousStonesReportFinal.pdf. *CMS*

Santa Fe Symposium Proceedings

Released in April 2016 are 23 presentations from the

2015 Santa Fe Symposium (held in Albuquerque, New Mexico, USA), with abstracts online and PDFs of the full presentations available for download. Topics include methods of preparing various metals for jewellery making, innovative alloys, manufacturing methods and more. Visit www.santafesymposium.org/2015-santa-fe-symposium-papers/?category=2015. *CMS*

OTHER RESOURCES

AIGS Gem Dictionary App

The Asian Institute of Gemological Sciences (AIGS) updated its searchable Chinese-English Gem Dictionary app in October 2015. Adapted by AIGS from

Akira Chikayama's *Dictionary of Gemstones & Jewelry*, the app is suitable for both amateur and professional gemmologists. Terms can be searched in both English and Chinese, and translations between the two languages are also available. For more information, including links to download iOS and Android versions, visit www.aigsthailand.com/gem_dictionary.aspx. *CMS*

Corporate Social Responsibility Course

In April 2016, CIBJO's World Jewellery Confederation Education Foundation (WJCEF) launched an online educational course titled

'CSR for the Jewellery Professional'. The course consists of six lessons: 'Practical Definitions of CSR', 'Major CSR Issues Affecting the Jewellery Industry', 'The Business Case for CSR', 'Tools and Approaches for Implementing CSR', 'Making "Green" Claims and Consumer Protection Law' and 'Professional CSR Accreditation'. Students who complete the course requirements will receive a Level 1 Certificate of Accreditation from WJCEF. For more information and course registration, go to http://cibjo-csr.btassurance.com. *CMS*

What's New provides announcements of new instruments/technology, publications, online resources and more. Inclusion in What's New does not imply recommendation or endorsement by Gem-A. Entries are prepared by Carol M. Stockton (CMS) or Brendan M. Laurs (BML).

The Fire Within

"For in them you shall see the living fire of the ruby, the glorious purple of the amethyst, the sea-green of the emerald, all glittering together in an incredible mixture of light."

– Roman Elder Pliny, 1st Century AD

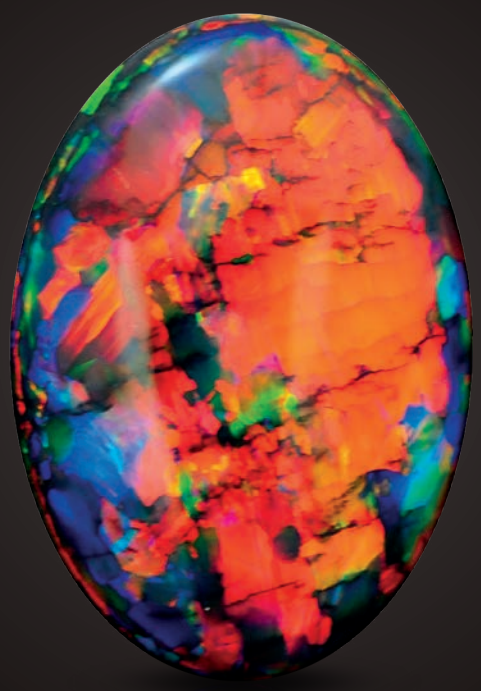

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JOG

Gem Notes

COLOURED STONES

Axinite from Shigar Fort, Northern Pakistan

While on a buying trip to Pakistan in October 2014, one of the authors (DB) saw an old friend in Skardu who had financed a mining venture to work an alpine cleft deposit (series of hydrothermal veins) located above Shigar Fort, a historical site on the outskirts of Shigar town. This area is the gateway to the Shigar Valley, which is famous for producing well-formed crystals of aquamarine, topaz, garnet and other minerals (e.g. Agheem et al., 2014). The dealer had about 3.5 kg of axinite from the Shigar Fort deposit, mostly as broken or poorly formed crystals ranging from 2.5 to 7.0 cm long. Approximately 1 kg of the more transparent pieces were purchased by this author, and many contained silky string-like inclusions that produced a slight schiller effect. Twenty-one pieces weighing 135.4 g were sent to the cutting factory, resulting in 40 faceted stones totalling 25.03 carats (ranging from 0.12 to 3.44 ct each), and two cabochons weighing a total of 12.36 carats. The cutters were instructed to produce clean faceted stones with proper depth, and for the cabochons it was hoped that a cat's-eye effect would result from the silky inclusions. The yield was small due to the presence of fractures and the silky inclusions, as well as the typically thin dimensions of the platy rough material.

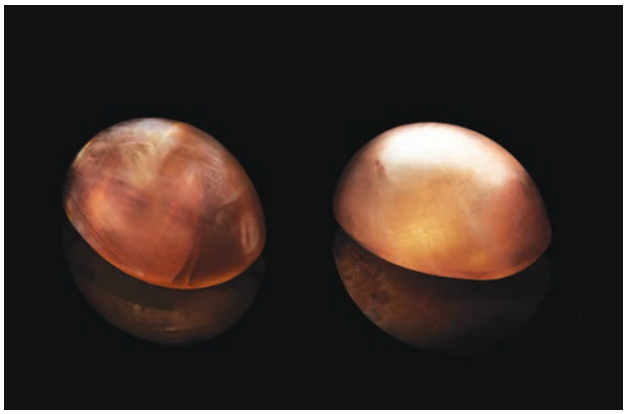

Figure 1: Weighing 6.57 and 5.79 ct, these axinite cabochons are from near the historic Shigar Fort in northern Pakistan. Photo by Bilal Mahmood and Alex Mercado.

Figure 2: Coarse irregular tubules form abundant inclusions in the Pakistan axinite. Photomicrograph by B. Clark; magnified 40×.

The two cabochons (Figure 1) were characterized by one of the authors (BC) for this report. They weighed 6.57 and 5.79 ct, and both were reddish brown, with moderate pleochroism of light brown and purple-brown. The spot RI values of both stones were 1.67–1.69, yielding a birefringence of 0.02. Hydrostatic SG values for the two samples were 3.28 and 3.29. These values are similar to those of axinite from elsewhere in Pakistan (Baluchistan: Fritz et al., 2007), except that the birefringence from these spot readings was somewhat higher. Both stones were inert to long- and short-wave UV radiation. They contained similar inclusion features, consisting of abundant long irregular tubules throughout the stones as well as partially healed fissures and clouds of fine particles (Figure 2).

The identification as axinite was confirmed with Raman spectroscopy using a 514 nm laser. Spectra collected with a multi-channel ultraviolet-visible–near infrared (UV-Vis-NIR) spectrometer revealed weak absorptions at 490 and 515 nm, as well as a broad transmission window at around 780 nm. Energy-dispersive X-ray fluorescence (EDXRF) chemical analysis showed major amounts of Al, as well as traces of Fe, Mn and Mg, consistent with O'Donoghue's (2006) observation that axinite is a mineral group that may contain a combination of the various end members within a single stone (similar to garnet). Agheem et al. (2014) reported an Fe-dominant composition for similar axinites from nearby deposits (Hashupa and Alchuri, located 15–20 km upriver from Shigar Fort), classifying them as ferroaxinite, now called axinite-(Fe).

Axinite is both pyroelectric and piezoelectric, meaning that it will develop a temporary electrical charge when heat or pressure is applied (e.g. Martin, 1931). Although no voltage reading was seen using a basic multimeter when both of the present samples were heated, they were warmed only slightly during this experiment to avoid damaging them.

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Dudley Blauwet
Dudley Blauwet Gems, Louisville, Colorado, USA

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Cat's-eye Diaspore from Turkey

Gem-quality diaspore appeared on the market in the mid-1980s, but its availability remained small and sporadic until a deposit in southwestern Turkey started being mined—mainly for gem rough—in the mid-2000s by Zultanite Gems LLC (Hatipoglu and Chamberlain, 2011). Significant quantities of gem diaspore, commonly showing a somewhat alexandrite-like colour change, became more widely available. The deposit has yielded transparent material suitable for faceted stones, and also some cabochons have been cut, but only rarely have they been mentioned as showing a cat's-eye effect (e.g. Kammerling et al., 1995). Therefore, it was interesting to see several chatoyant diaspore cabochons—some of them quite large—exhibited at the 2016 Tucson gem shows. Gem dealer Leonardo Silva Souto (Gems in Gems, Teófilo Otoni, Brazil) had approximately 50 cabochons weighing up to 335 ct. Most of the gems were yellowish green in daylight and yellowish brown in incandescent light. Some of the smaller gems displaying sharper eyes were purchased by Mauro Pantò (The Beauty in the Rocks, Sassari, Italy), who loaned a 4.60 ct sample for this report (Figure 3).

The sample showed a slight colour change, from greyish yellowish green (in daylight) to pale brown (in incandescent light). The polariscope revealed the stone was biaxial, and spot RI readings of 1.68–1.72 were obtained with the refractometer, yielding a birefringence of 0.04. The hydrostatic SG was 3.28. These properties are comparable to those reported for diaspore by O'Donoghue (2006). The stone was inert to both long- and short-wave UV radiation. Inclusions consisted of numerous coarse tubules throughout the stone (Figure 4), which were responsible for the cat's-eye effect. EDXRF spectroscopy revealed major Al as well as traces of Fe, Ti and Ga. Analysis with a multi-channel UV-Vis-NIR spectrometer revealed absorption bands at 385, 438 and 560 nm, which differed from those at

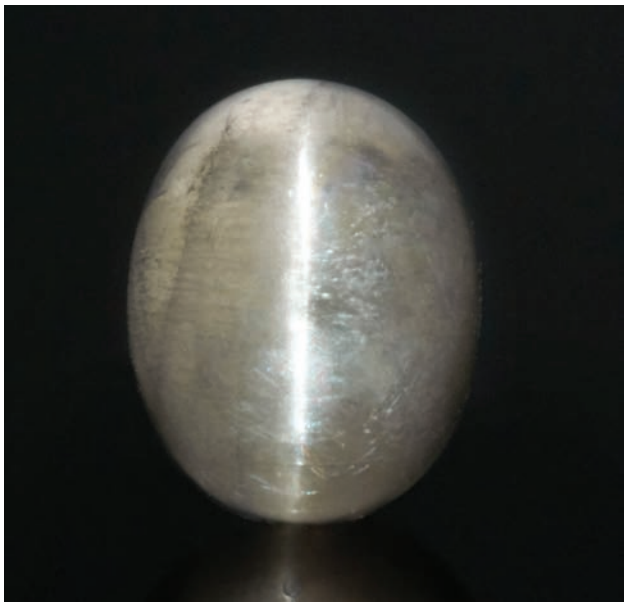

Figure 3: This chatoyant 4.60 ct diaspore from Turkey displays a sharp 'eye'. Photo by Bilal Mahmood.

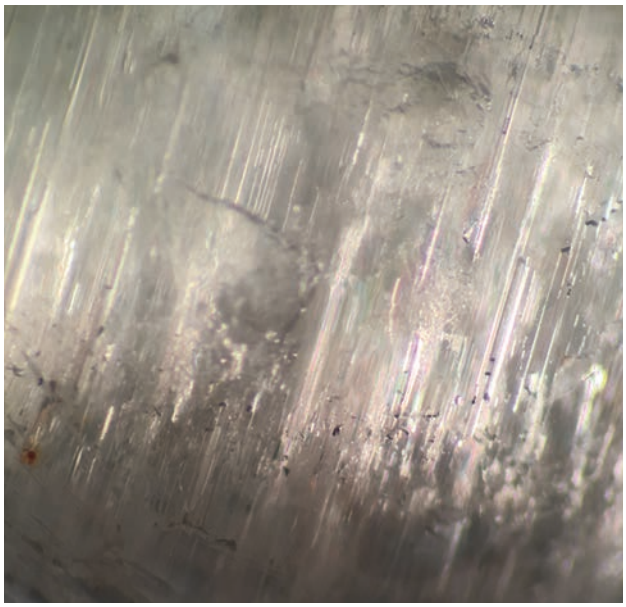

Figure 4: Coarse, parallel growth tubules are responsible for the cat's-eye effect in the diaspore. Photomicrograph by B. Clark; magnified 50×.

454, 463 and 471 nm reported for some diaspore by O'Donoghue (2006).

According to Mauro Pantò, much of the Turkish diaspore he has encountered is heavily included, and some of this material contains abundant tubules that could produce chatoyancy. Therefore it would not be surprising to see more cat's-eye diaspore enter the market in the future.

Bryan Clark

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Polymer-filled Star Enstatite from Norway

Fe-rich enstatite with a brassy brown colour was first called *bronzite* by Karsten (1808); it is part of the enstatite-ferrosilite $(Mg,Fe)_2(Si_2O_6)$ pyroxene solid-solution series. Star enstatite is rare, but has been known for decades. Eppler (1967) described a dark brown, six-rayed star enstatite from southern India, with asterism reportedly caused by thin oriented rutile needles intersecting one another at 51° and 64°. Henn and Bank (1991) documented a brown six-rayed star 'bronzite' that contained oriented hollow channels as the cause of the star effect. Brown enstatite with star and cat's-eye phenomena due to rutile needles and fibrous sillimanite were described in Gübelin and Koivula (2008). This report characterizes star enstatite from a reportedly new find in south-west Norway.

The sample was loaned by Michael Wild (Werner Wild, Idar-Oberstein, Germany), and consisted of a 20.89 ct brassy-brown cabochon showing a weak four-rayed star (Figure 5, left). Also supplied for our research were two slices that were reportedly cut from the same piece of rough as the cabochon. Refractive indices measured on one of the slices were $n_x = 1.685$, $n_y = 1.693$ and $n_z = 1.697$, yielding a birefringence of 0.012. The hydrostatic SG of the cabochon

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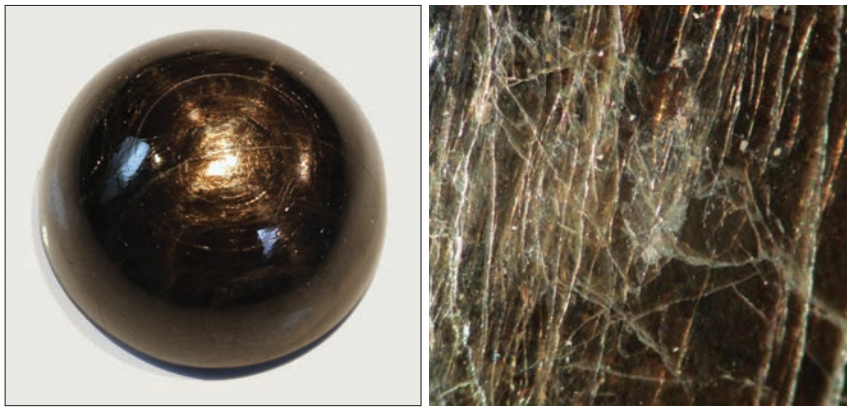

Figure 5: This star enstatite from Norway weighs 20.89 ct (left). Whitish areas in the enstatite cabochon reveal the presence of fractures filled with epoxy resin (right, magnified 30×). Photos by F. Schmitz.

was 3.35. These values are within the expected range for iron-rich enstatite. Chemical analysis of one of the slabs with a Jeol JXA-8200 electron microprobe yielded the formula $(Fe_{0.50}Mg_{1.43}Al_{0.10}Ca_{0.01}Mn_{0.006})(Si_{1.85}Al_{0.15})O_6$.

Examination with a gemmological microscope revealed slightly whitish areas on the surface of the cabochon that corresponded to filled fissures (Figure 5, right). Raman analysis with a Renishaw inVia spectrometer (514 nm laser) showed that the filler consisted of an artificial polymer (epoxy resin), which apparently was used to enhance the surface lustre and stabilize the stone. Microscopic examination also showed oriented inclusions consisting of needles and platelets (Figure 6, left) that apparently were responsible for the star effect. Measured at the top of the cabochon, the inclusions intersected one another at approximately 64°, which also is the angle displayed by the rays of the star when observed from above. This is not consistent with the orthorhombic crystal form of enstatite, but rather a pseudo-hexagonal symmetry that was apparently induced by the cutting orientation. The stone was probably cut slightly oblique to the c-axis, resulting in the appearance of a four-rayed star.

Chemical analysis of the oriented inclusions in one of the slices (using the microprobe's energy-dispersive system) revealed that they were ilmenite. The width of the ilmenite needles and platelets varied between 5 and 50 µm (e.g. Figure 6, right), and they were up to 0.5 mm long. In addition to these inclusions, it is possible that oriented cracks, fissures and/or exsolution areas in the enstatite also contributed to the asterism. Some additional inclusions (not related to the asterism) analysed with the microprobe consisted of rutile and apatite, as well as an unidentified phase. The presence of ilmenite and rutile inclusions in this enstatite is consistent with the existence of titanium deposits in southern Norway (Diot et al., 2003).

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Figure 6: The star enstatite contains oriented needles and platelets that were identified as ilmenite (left, magnified 30×). Backscattered-electron imagery (right) clearly reveals the oriented ilmenite inclusions (bright areas) against the enstatite matrix. Analysis of the medium grey area at the end of the central ilmenite inclusion gave only a carbon signal, suggesting that it may consist of a void filled by the epoxy resin used to treat the stone. Images by F. Schmitz.

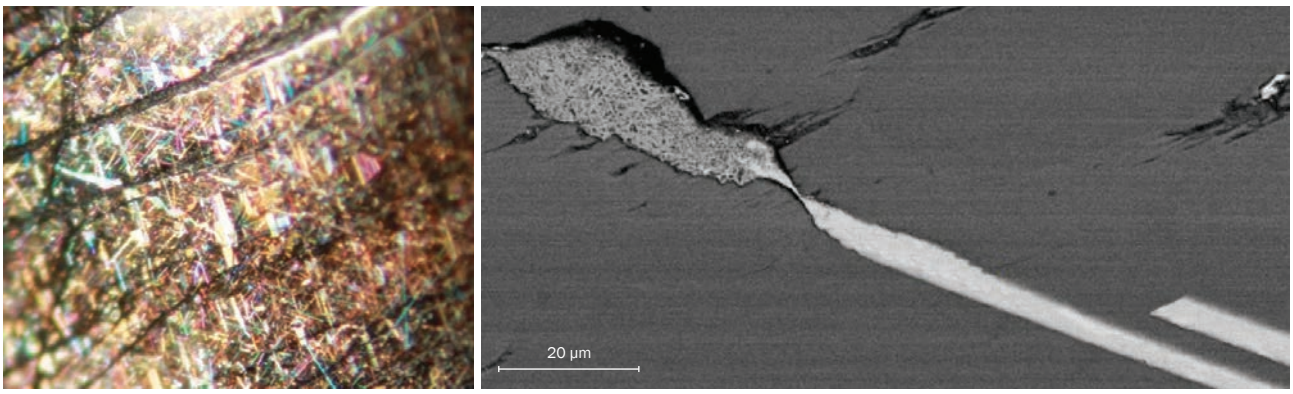

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Garnet Mining near Mahenge, Tanzania

In late 2015, a new alluvial garnet deposit was discovered near Mahenge, Tanzania, that has produced attractive pyrope-almandine-spessartine (Williams and Williams, 2016). For two days in April 2016, rough stone dealer Sir-Faraz 'Farooq' Hashmi (Intimate Gems, Glen Cove, New York, USA) visited the deposit while on a buying trip to Tanzania. He was told that he was the first foreigner to enter the mining area.

The journey was difficult due to wet and muddy conditions caused by the rainy season. From the town of Mahenge, Hashmi was taken by motorcycle to Mbella near the village of Epanko. The ~17 km trip was expected to take 40 minutes, but it actually took one hour and 40 minutes on the narrow rough roads. This was followed by a two-hour walk for 2–3 km on a steeply uphill trail to the mining area. Only a few simple houses were seen during the beginning of the hike in this largely uninhabited area.

The garnets were being mined along a ~2-km-long drainage surrounded by hills that were locally forested (Figure 7). Multiple landowners farm the area where the garnets were discovered, and they sold mining privileges to people who funded digging operations in the valley. Hundreds of pits have been dug in a somewhat chaotic pattern. In each pit, after the garnet-bearing gravel layer was exhausted a new adjacent pit was started. Blue-tarped shelters were constructed by the miners near some of the pits. Hashmi indicated that several dozen people were actively digging during his visit, although he was told that many more miners were present before the start of the

Figure 7: This image (taken in April 2016) shows a portion of the garnet-mining area near Mahenge, Tanzania. Photo by Farooq Hashmi.

rainy season. In addition, several of them recently left the area to try their luck at a new garnet area located about three hours away by foot.

The mines consisted of small hand-dug pits that were filled with various amounts of water (e.g. Figure 8). Hashmi saw only one gasoline-powered pump in operation during his visit. Water from the pump was used to wash the gem-bearing gravels, which were placed into wood-framed screens (Figure 9, right). Most of the gravel washing was done using metal pans, and then the garnets were hand-picked from the screens (e.g. Figure 9, left). Garnet is the only gem found in the gravels; this area has not produced any spinel, tourmaline or other gem minerals known from the Mahenge region.

Hashmi saw only a few of the 'Mahenge malaya' garnets while visiting the mining area, and in Mahenge town he observed ~½ kg of rough material (e.g. Figure 10). The colours ranged from pinkish orange (referred to by the traders as *champagne*) to pink to purple (*rhodolite*). Most of the pieces weighed ~½ g, and Hashmi estimates that the deposit has yielded a total of 30–40 kg of garnet since mining began in November 2015. The largest pieces known to him weighed up to

Figure 8: The garnet-bearing alluvial material is excavated from small water-filled pits using simple hand tools. Photo by Farooq Hashmi.

Figure 9: The mined material is washed with metal pans (left) or with pumped water (right), and then the garnets are hand-picked from the screens. Photos by Farooq Hashmi.

Figure 10: This parcel, seen in Mahenge, shows the colour range of the 'Mahenge malaya' garnet. The pieces range from ~0.5 to 5 g. Photo by Farooq Hashmi.

12 g (pinkish orange) and 15–20 g (purple); most of the larger stones have been sent to Germany for cutting.

Brendan M. Laurs

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Kyanite from Pakistan

During a buying trip to northern Pakistan in June 2015, author DB was shown gem-quality blue kyanite at the home of a local miner in Doko village in the Basha Valley of the Haramosh Mountains. He obtained the entire production at the time—3.78 kg—which consisted of crystals and fragments ranging from 2.5 to 6.0 cm long that were heavily encrusted with iron-stained mica schist. The kyanite deposit is reportedly accessed by climbing 7–8 hours south of Doko village.

Upon returning home, author DB cleaned some of the crystals using a high-pressure water gun, which exposed small transparent areas of the kyanite that ranged from light greyish blue to an attractive violetish blue. He sent 10 pieces weighing 116.1 g to his cutting factory, and instructed them to cut only clean stones. In January 2016, the cutting factory returned 24 stones totalling 15.07 carats; at 0.15–0.85 ct, most of the gems were rather small. More of the kyanite will be cut in the future.

For this report, author WMM characterized a pair of oval modified-brilliant-cut kyanites measuring 6.76 × 4.84 × 3.47 and 6.89 × 5.18 × 3.17 mm; each weighed 0.85 ct. Also examined was a 9.84 g piece of rough material measuring 46.93 × 14.19 × 7.50 mm (Figure 11). Seen in the face-up position with the naked eye, both of the faceted stones were evenly coloured with a bright and pleasant blue hue, and they were transparent with a vitreous lustre. When viewed in the microscope with diffuse transmitted light, both gems showed subtle blue and colourless zoning. The rough was mostly opaque with just a few transparent areas, and displayed colour zoning (in blue and white), local iron staining and a pearly lustre. The RIs of both faceted stones were 1.710–1.728, giving a birefringence of 0.018. Both gems were biaxial positive, which is unusual for kyanite but consistent with material from Nepal (Fritsch, 2002; Henn and Schollenbruch, 2012). The hydrostatic SG value

Figure 11: These faceted (each 0.85 ct) and rough (9.84 g) kyanite samples are from a new deposit in the Haramosh Mountains of Pakistan. Photo by Bilal Mahmood.

of one of the faceted samples was 3.86, well above the typical range for kyanite (e.g. 3.65–3.68: Henn and Schollenbruch, 2012). This may be due to the presence of dark included crystals (one of them was fairly large); similar inclusions in Nepalese kyanite were speculated as ilmenite (SG = 4.7) by Henn and Schollenbruch (2012). The SG of the other faceted sample was 3.54, and although some minute dark inclusions were also present in that stone, this low value was likely caused by a large hollow tube-like inclusion. Other internal features observed in the two faceted stones consisted of parallel whitish growth tubes that were oriented in a single direction, and cleavage fractures evident as several parallel shiny breaks. The rough displayed two directions of white growth tubes (or fibrous inclusions) intersecting at 90°.

All three stones showed identical spectra with a CCD-array UV-Vis spectrophotometer, and the features were consistent with those shown by Nepalese kyanite. Weak peaks at approximately 380 and 385 nm, as well as at 435 and 445 nm, are caused by Fe^{3+} substituting for Al^{3+}, and a broad absorption at approximately 600 nm (the cause of the blue colour) is due to Fe^{2+}–Ti^{4+} intervalence charge transfer (Henn and Schollenbruch, 2012). Small peaks at 690 and 710 nm indicated trace amounts of chromium, which was also the cause of very weak red long-wave UV fluorescence seen in the two gems. It should be noted that the UV-Vis spectra were quite similar to those of blue sapphire, with a subtle shift in the position of the absorption bands that is probably related to differences in the crystal structure of the minerals (corundum is hexagonal, and kyanite is triclinic). Mid-infrared spectroscopy of the two samples using a Thermo Scientific Nicolet 6700 FT-IR produced spectra that were consistent with kyanite.

Although the initial production of this kyanite has been rather small, Pakistan now joins Nepal as a source of facetable blue kyanite from the Himalayan region. Kyanite from the two localities is quite similar, except that stones from Nepal are typically larger. Additional production of the Pakistani kyanite will probably be limited by the rigorous climb to the remote, high-altitude mining area, as well as the relatively low value of the material, making it likely that the local miners will pursue other gem materials in the area.

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Black Star Sapphires from Liberia

Black star sapphires are well-known from Thailand and Australia (e.g. Wüthrich and Weibel, 1981; Moon and Phillips, 1984). During the 2016 Tucson gem shows, Eric Braunwart (Columbia Gem House, Vancouver, Washington, USA) had black star sapphires from a new locality: Liberia. He indicated that this material has been produced since approximately mid-2015, commonly as large crystals (approaching 250 g). The rough is processed by first identifying its crystallographic orientation, then slicing it into slabs, and finally looking for areas that are likely to show asterism when cutting cabochons. Approximately 1,000 cabochons have been cut so far, ranging from 8 × 6 mm to 30 ct (e.g. Figure 12).

Braunwart loaned a 7.01 ct cabochon for examination, and the stone was confirmed as corundum using a GemmoRaman-SG spectrometer. The six-rayed star was slightly off centre and consisted of one strong band and two weaker bands. Its colour appearance was similar to other black star material, and its slightly translucent edges showed a medium greyish 'golden' brown body colour. Magnetic susceptibility was moderately strong, with the sample easily dragged by an N-52 neodymium magnet.

Microscopic observation revealed a consistent cross-hatched texture due to repeated parallel parting planes in two directions. Scattered short, dark stick-like inclusions (Figure 13) were identified as hematite by an Enwave 785 micro-Raman spectrometer. With 40× magnification, fine, short, silvery-gold needles created 'silk' in the stone that was responsible for the asterism. EDXRF spectroscopy with an Amptek X123-SDD unit revealed high contents of Fe and Ti—even higher than in Thai black star sapphires in these authors' experience. Calcium was nearly three times the concentration of the Thai stars, suggesting a possible metamorphic influence.

The back of the cabochon was smooth and well-polished, showing no signs of delaminating parting planes (as is commonly seen in Thai black stars, requiring stabilization with a polymer). As reserves of black star sapphires are depleted, this additional West African source is welcome news. Braunwart is stockpiling additional rough material, and the deposit appears to show good potential for future production.

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Figure 12: This 8.65 ct black star sapphire is representative of material from the new find in Liberia. Photo by Orasa Weldon.

Figure 13: Hematite inclusions are seen here on the base of a black star sapphire cabochon. Photomicrograph by C. Williams; magnified 40×.

New Age Data for Blue Sapphires from Mogok, Myanmar

At the Gübelin Gem Lab, we recently had the opportunity to investigate the age of zircon inclusions in faceted blue sapphires from the Mogok area in Myanmar. To our knowledge, this is the first time that the formational ages of Mogok sapphires have been determined directly. This research not only demonstrates the power of *in-situ* age determination via laser ablation inductively coupled plasma mass spectrometry (LA-ICP-MS) as a tool for origin determination, but it also provides valuable insights into the formation of Burmese sapphires.

Following the methods described in Link (2015), radiometric U-Pb ages were determined quasi-non-destructively by LA-ICP-MS for two high-value blue sapphires weighing 26 and 11 ct (Figure 14) by analysing the zircon inclusions exposed at their girdles. The zircons measured 100–150 × 60–40 µm and were subhedral and stubby in appearance (Figure 15). Some of the zircons included in the larger sapphire were surrounded by radial tension cracks (Figure 15b). Routine laboratory examination indicated that both stones were unheated.

The concordant ages obtained from two zircons in each sample were 26.7 ± 4.2 million years (Ma) for the larger sapphire and 27.5 ± 2.8 Ma for the smaller stone (Figure 16). The crystal shape of the zircon inclusions does not allow a clear interpretation of whether they grew during or before their host sapphires. Nevertheless, a comparison of the determined ages with geochronologic data from the literature for rocks of the Mogok area indicate that the zircons are syngenetic. Therefore, the dates represent the formation ages of the sapphires.

Figure 14: These unheated sapphires (left, 26 ct, and right, 11 ct) from Mogok, Myanmar, contain zircon inclusions that were age dated using LA-ICP-MS. Photos by Janine Meyer.

Figure 15: The zircon inclusions in the 26 ct sapphire (a,b) are surrounded by tension cracks. The laser pits measure 25 µm (a) and 30 µm in diameter (b). Two zircon inclusions are exposed in the partially polished girdle of the 11 ct sapphire (c), and the diameter of the bottom one is about 60 µm. Photomicrographs by Klaus Schollenbruch in darkfield illumination (a,b) and by K. Link in reflected light (c).

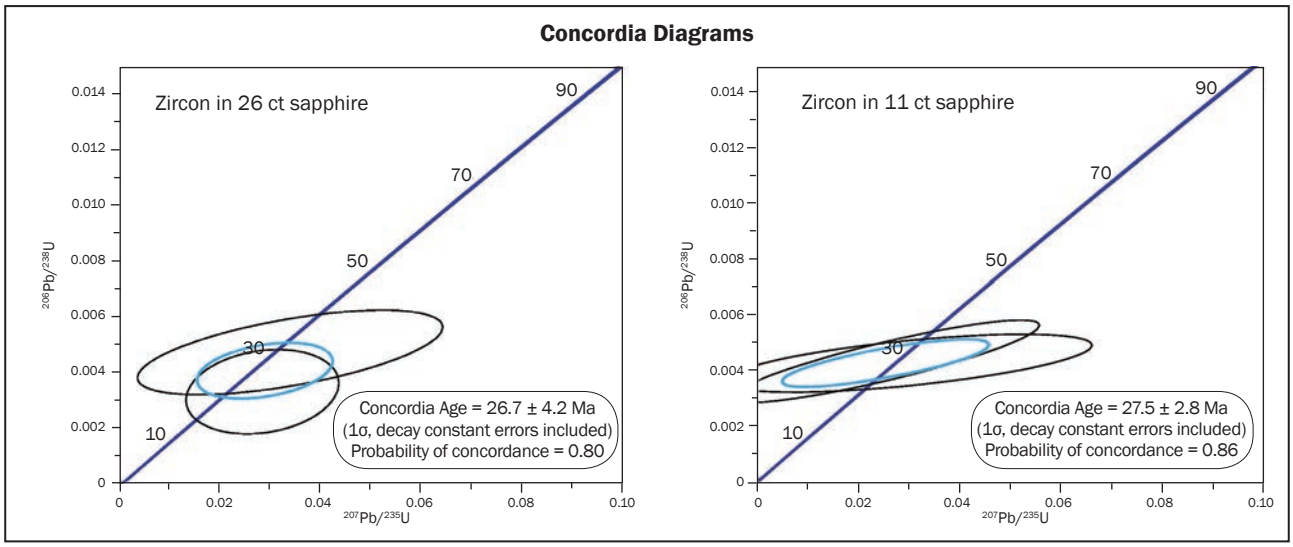

Figure 16: Concordia plots made with Isoplot software (Ludwig, 2003) are shown for the zircon inclusions in the 26 ct (left) and 11 ct (right) sapphires, which yield ages of 26.7 ± 4.2 Ma and 27.5 ± 2.8 Ma, respectively. The black ellipsoids each represent one measurement from a single zircon, and the blue ellipsoids give the resulting weighted mean concordant age and error from the two zircons within each sapphire.

The regional geology of Mogok is dominated by a complex lithological assemblage known as the Mogok Metamorphic Belt, which formed during the 60–50 Ma continental collision between the Indian plate with some micro-plates that at that time formed the southern margin of Eurasia (Searle et al., 2007). The ages of the protoliths (i.e. the original sedimentary and igneous rocks that were subsequently metamorphosed into marbles and gneisses) are suspected to be older than 170 Ma (Barley et al., 2003). During the India-Asia collision, the marbles and gneisses were multiply intruded by various igneous melts. At least one metamorphic episode post-dated the main continental collision, occurring at ~40 to 30 Ma. During this time, syeno-granitic melts began intruding the gneisses (Barley et al., 2003). Finally, at ~23 Ma, leucogranitic melts intruded the Mogok area (Searle et al., 2007). It has been suggested that the sapphires are closely related to these melts (Kan-Nyunt et al., 2013).

Considering the sapphire ages reported here and their error ranges, the formation of these sapphires is constrained to the time between the latest metamorphic event and the initial post-tectonic intrusions. The sapphires appear to be slightly younger than the marble-hosted rubies of Mogok, which formed at 31–32 Ma (see Zaw et al., 2014, and references therein)—although this apparent trend could also be an artefact of the error ranges of the age dates. It is debatable whether the two stones reported here represent the only crystallization age of blue sapphires in Mogok, or whether they indicate a (narrow?) time range of formation within their deposit(s). Significantly for origin determination, these zircon ages are completely different from those of the Pan-African-related gem corundum deposits such as those in Sri Lanka or Madagascar (~750–450 Ma; Giuliani et al., 2014, and references therein).

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Pink Spinel from Mozambique

In November 2015, rough stone dealer Farooq Hashmi was on a buying trip to East Africa when he encountered a new find of pink spinel that was reportedly discovered near the town of Namapa in Cabo Delgado Province, northern Mozambique. Hashmi saw approximately 50 kg of rough material, mostly as pieces weighing less than 3 g each. He loaned two crystals of ~1 g each (5.73 and 5.24 ct) and one faceted stone weighing 1.91 ct to this author for examination (Figure 17).

The samples exhibited a strong pink colour with a hint of purple. The crystals showed typical octahedral morphology with distinct triangular growth hillocks on the octahedral faces (Figure 18). Both crystals appeared slightly waterworn, indicating that the material originated from an eluvial or alluvial deposit not far from where it formed.

The faceted oval had RI = 1.709 and SG = 3.67, while the two crystals had SG values of 3.58 and 3.61, all of which are consistent with those expected for spinel. (Rough material tends to show a slightly lower SG due to surface tension when weighed in water.) The faceted stone exhibited a hazy appearance due to the presence

Figure 17: These rough and cut spinels are from a new find in Mozambique. The faceted gem weighs 1.91 ct and was cut by Marvin M. Wambua (Safigemscutters Ltd., Nairobi, Kenya). Photo by D. Bakker.

Figure 18: This 5.24 ct spinel crystal from Mozambique shows octahedral morphology with triangular growth hillocks, and only slight evidence of erosional transport. Photo by E. Boehm.

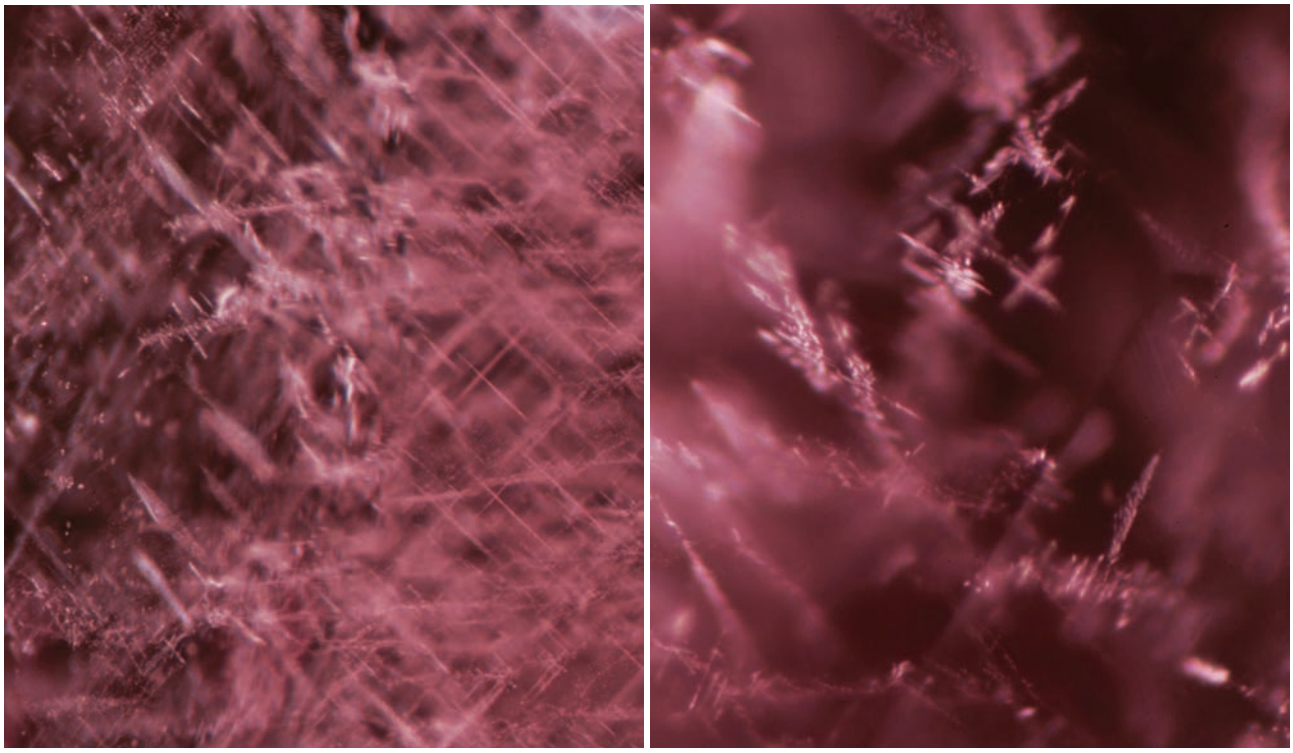

Figure 19: Inclusions in the 1.91 ct Mozambique spinel consisted of intersecting networks (left) and clusters (right) that resemble högbomite in pink spinel from Morogoro, Tanzania. Photomicrographs by E. Boehm; magnified 20× (left) and 40× (right).

Figure 20: Högbomite forms conspicuous parallel inclusions in this 3.34 ct pink spinel from Morogoro, Tanzania. Photomicrographs by E. Boehm; magnified 10× (left) and 40× (right).

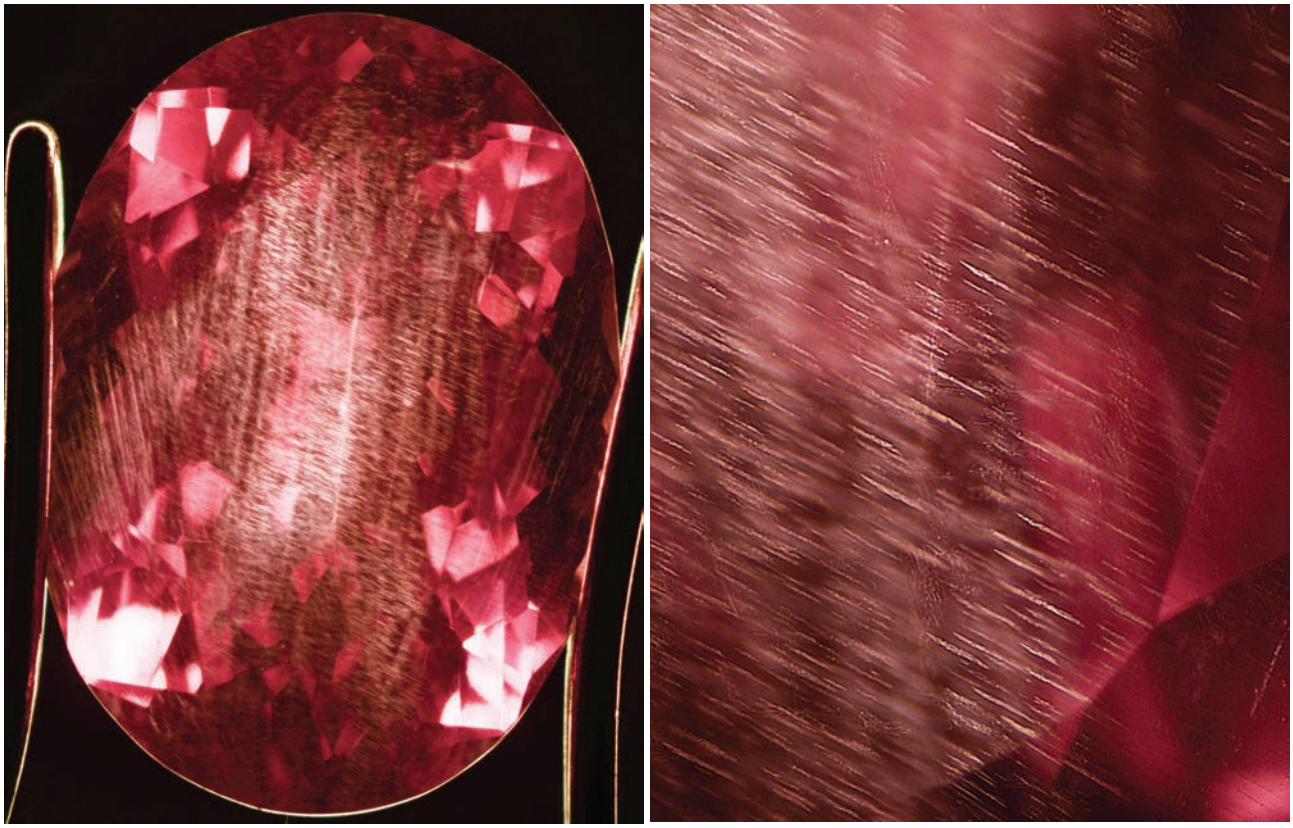

of inclusion networks (Figure 19) that resembled högbomite often seen in pink spinel from the Morogoro region of Tanzania (Figure 20; see also Schmetzer and Berger, 1990, 1992). Högbomite, $(Mg,Fe)_2(Al,Ti)_5O_{10}$, is an Al-rich mineral that typically replaces Fe-Ti-oxide inclusions such as ilmenite and rutile in spinel (Gübelin and Koivula, 2005). The author has also seen such inclusions in pink-to-red spinels from Mahenge, Tanzania. Interestingly, the Tanzanian spinel deposits are located directly north of Namapa and within the same Mozambique Belt.

The samples of spinel from Mozambique exhibited moderate red fluorescence when exposed to long-wave UV radiation, but were inert to short-wave UV. This same reaction is seen in pink spinel from Morogoro. However, pink-to-red stones from Mahenge tend to exhibit strong red fluorescence to long-wave UV and are inert to short-wave UV radiation.

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Tantalite-(Mn) from Grangal, Nuristan, Afghanistan

Manganotantalite—renamed tantalite-(Mn) according to the conventions described by Burke (2008)—is an orthorhombic columbite-group mineral with the formula $MnTa_2O_6$ and a Mohs hardness of 6. Since 2011, one of the authors (DB) has occasionally obtained facetable 'manganotantalite' sourced from granitic pegmatites at Grangal and Watala in Kunar Province, Nuristan, Afghanistan. Although complete crystals are sometimes available, most of the production consists of broken fragments ranging from reddish brown to reddish black; the best is intense 'ruby' red in transmitted light. Most pieces contain only 10%–25% transparent areas that are cuttable; also, the tabular shape of the fragments limits the size of the faceted stones. Most recently, in January 2016, cutting of a parcel containing 29 pieces of rough totalling 86.4 g yielded 28 cut stones (~0.20–2.12 ct) with a total weight of 33.33 carats (7.7% yield). Most of them contained small inclusions visible with magnification. Due to the high specific gravity (see below), the stones had a relatively small size for their carat weight.

Two faceted samples of tantalite-(Mn) were characterized by one of the authors (JCZ): a round mixed cut weighing 1.10 ct (4.65 × 4.69 × 3.31 mm) and an oval mixed cut of 4.66 ct (8.82 × 6.98 × 4.10 mm). Both stones were transparent, and were very dark red with very high lustre (Figure 21). Pleochroism in dark red and dark reddish orange was observed using a calcite dichroscope. As expected for tantalite-(Mn), the RIs were above the limit of the refractometer, and the stones showed strong doubling of the pavilion facets when viewed face-up, consistent with the mineral's high birefringence (cf. RIs 2.19–2.34 and birefringence 0.15: Dedeyne and Quintens, 2007). Average hydrostatic SG values of 7.81 and 7.76 were obtained for the 1.10 and 4.66 ct samples, respectively. The gems were

Figure 21: These samples of tantalite-(Mn) from Afghanistan (4.66 and 1.10 ct) were studied for this report. Photo by Dirk van der Marel.

Figure 22: (a) Both of the tantalite-(Mn) gems contained partially healed fissures, such as those shown here (image width 3.6 mm). (b) The healed fissures are locally marked by larger irregular fluid inclusions that contain gas bubbles (image width 0.6 mm). (c) Crossing trails of partially healed fissures, containing minute two-phase inclusions, are shown in this view (image width 0.6 mm). Photomicrographs by J. C. Zwaan.

inert to long- and short-wave UV fluorescence. The prism spectroscope revealed transmission in the red region, extending only slightly into the orange. The stones were slightly and moderately included, respectively, both containing partially healed fissures (e.g. Figure 22a) that consisted of minute voids and also slightly larger irregular voids, most containing a fluid and a gas bubble (Figure 22b). Some minute voids also contained tiny doubly refractive mineral phases (too small to be identified). In places the partially healed fissures intersected one another, creating interesting patterns (Figure 22c).

UV-Vis spectra, obtained with a Thermo Scientific Evolution 600 spectrometer, showed a steep absorption edge at ~600 nm, with a gradual but rapid decrease in absorption toward 650–700 nm, confirming the observations with the spectroscope.

Raman spectra, collected with a Thermo Scientific DXR Raman microscope with 532 nm laser excitation, revealed a very strong main band at 885 cm^{-1}, and a series of supplementary bands at smaller wavenumbers. The spectra of these two samples appeared to show many more well-resolved peaks than reference spectra of tantalite-(Mn) from Afghanistan, Pakistan and China in the RRUFF database (Figure 23), as well as the spectra of tantalite-(Mn) from north-east Brazil, which contained supplementary bands at 621, 547, 526, 324, 282, 238, 202 and 121 cm^{-1} (Thomas et al., 2011).

EDXRF analyses were performed with an EDAX Orbis Micro-XRF analyser on the tables of

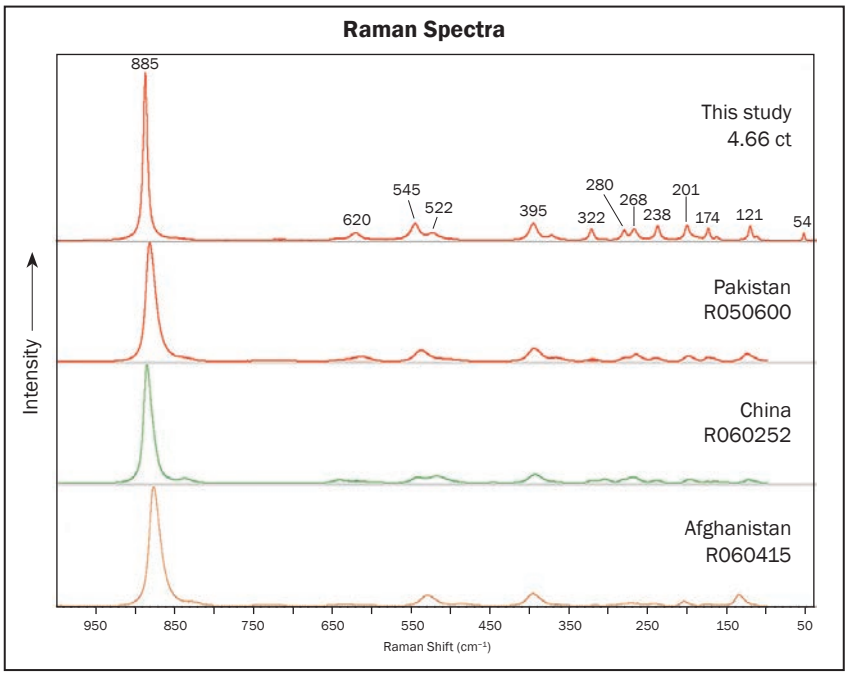

Figure 23: Raman spectra of the analysed samples (here, the 4.66 ct stone) show peaks that are more numerous and well resolved than reference spectra for tantalite-(Mn) from the RRUFF database.

Table I: Chemical analyses and SG values of tantalite-(Mn) from Grangal, Afghanistan.

EDXRF analyses of two faceted stones

Oxides (wt.%)	**1.10 ct** (3 analyses)	**4.66 ct** (4 analyses)
FeO	0.30–0.35	0.70–1.55
MnO	12.5	12.1–12.9
Nb_2O_5	12.3–13.1	14.0–15.7
Ta_2O_5	74.1–74.9	70.8–72.4
SG	7.81	7.76

Representative SEM analyses of four crystal specimens

Oxides (wt.%)	**1**	**2-core**	**2-rim**	**3-core**	**3-rim**	**4**
FeO	0.33	3.58	0.54	2.37	2.02	3.83
MnO	13.81	11.88	13.23	13.07	13.40	13.81
Nb_2O_5	1.39	15.87	1.78	16.04	2.04	29.27
Ta_2O_5	84.47	68.67	84.45	68.52	82.54	53.09
Total	100.00	100.00	100.00	100.00	100.00	100.00
Ions per 6 oxygens						
Fe	0.023	0.231	0.038	0.153	0.142	0.299
Mn	0.989	0.777	0.946	0.854	0.953	0.835
Nb	0.053	0.554	0.068	0.559	0.077	0.944
Ta	1.942	1.442	1.939	1.438	1.885	1.030
TOTAL	3.007	3.005	2.990	3.003	3.057	3.038
Mn/(Mn+Fe)	0.977	0.771	0.961	0.700	0.870	0.785
Ta/(Ta+Nb)	0.973	0.722	0.966	0.720	0.961	0.522
X site	1.012	1.008	0.984	1.005	1.095	1.007
Y site	1.995	1.997	2.006	1.998	1.962	1.997
SG*	8.09	7.48	8.08	7.52	7.91	7.17

*SG values were measured from sample nos. 1 and 4, and were calculated from chemical analyses for nos. 2 and 3 due to the large amount of zoning in those samples. Sample nos. 1 and 4 had no significant chemical zoning in an analytical traverse from core to rim.

the two stones, using a spot size of 300 µm. The results of this semi-quantitative bulk technique (Table I, top) showed that the sample with greater Ta also had a higher SG value, consistent with known trends (Campbell and Parker, 1955).

Additional investigations of the composition and SG were undertaken by author AUF on four crystal specimens (Figure 24). Standard-based energy-dispersive spectroscopy analyses were performed with a Jeol JSM-6400 scanning electron microscope (SEM) using the Iridium Ultra software package by IXRF Systems Inc. The data showed that all specimens were Ta-dominant (Table I, bottom). Tantalum is the major controlling factor in the density of columbite-group minerals, and density (or SG) can be used to estimate Ta_2O_5 content (Campbell and Parker, 1955). The lowest SG of 7.17 was measured for sample no. 4, which corresponds to a calculated Ta_2O_5 content of ~55 wt.%. The slight discrepancy from the measured Ta_2O_5 content of 53 wt.% is probably due to sampling differences (i.e. the bulk sample was used for hydrostatic SG measurement, while only a small volume was analysed by SEM). The geochemically most evolved sample (no. 1) approached end-member tantalite-(Mn) composition, with Ta/(Ta+Nb) = 0.97, and had a measured SG value of 8.09 (corresponding to a calculated Ta_2O_5 content of 86.2 wt.%). Sample nos. 2 and 3 proved to be chemically zoned, with

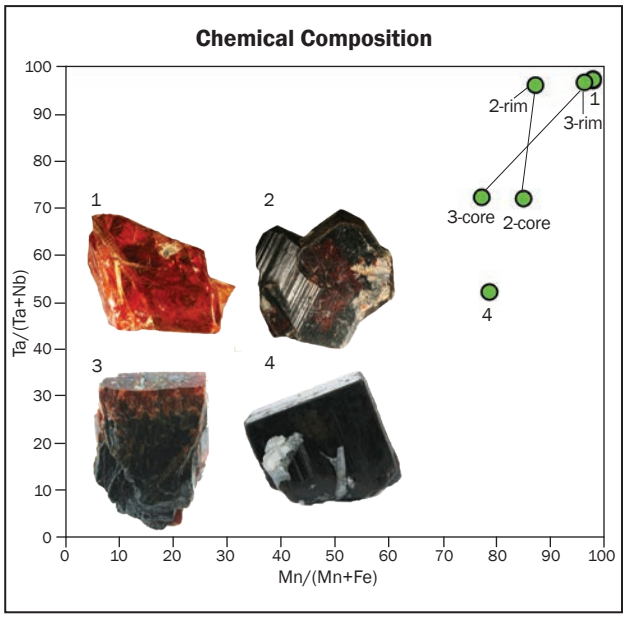

Figure 24: The chemical composition of four crystals of tantalite-(Mn) is summarized in this plot. Analyses of chemically zoned samples are joined by a line. The crystals measure 8, 20, 30 and 40 mm in maximum dimension (nos. 1–4, respectively), and their corresponding SG values are shown in Table I (bottom). Photos by A. Falster.

strong Ta enrichment in their rims compared to their cores (Table I and Figure 24).

The availability of this rare stone will remain limited, with author DB's supplier producing only ~150–200 g of rough per year, typically yielding only about 50–100 carats of faceted stones.

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PEARLS

A Coral Branch 'Pearl' from a Giant Clam

The Laboratoire Français de Gemmologie recently analysed an intriguing sample, submitted as a 'branch of coral' by Croissy Pearls. The client explained that the object was found in a giant clam (*Tridacna gigas*) by an Indonesian fisherman.

Corals are marine invertebrates that form colonies of polyps. Different species are commonly used for jewellery, such as *Corallium rubrum* (red coral from the Mediterranean Sea) or *Corallium elatius* (pink coral, also known as 'angel skin', from the waters around China and Japan). *Corallium spp.* have skeletons consisting of calcium carbonate, while the black corals (order Antipatharia) have skeletons composed of protein and chitin. Corals are often submitted to gemmological laboratories to test for imitations (e.g. glass and plastic) and treatments (e.g. bleaching, dyeing, waxing and plastic or resin impregnation). Some species are protected by the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES), and cannot be imported or exported. These include *C. elatius*, *C. japonicum*, *C. konjoi* and *C. secundum* (from China only), as well as *Heliopora coerulea*, Scleractinia spp., Tubiporidae spp., Antipatharia spp., Milleporidae spp. and Stylasteridae spp. (see www.cites.org/eng/app/appendices.php).

The submitted object weighed 36.8 g and measured 65 × 38 × 29 mm (Figure 25). It had a

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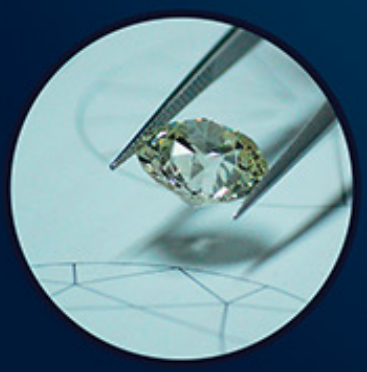

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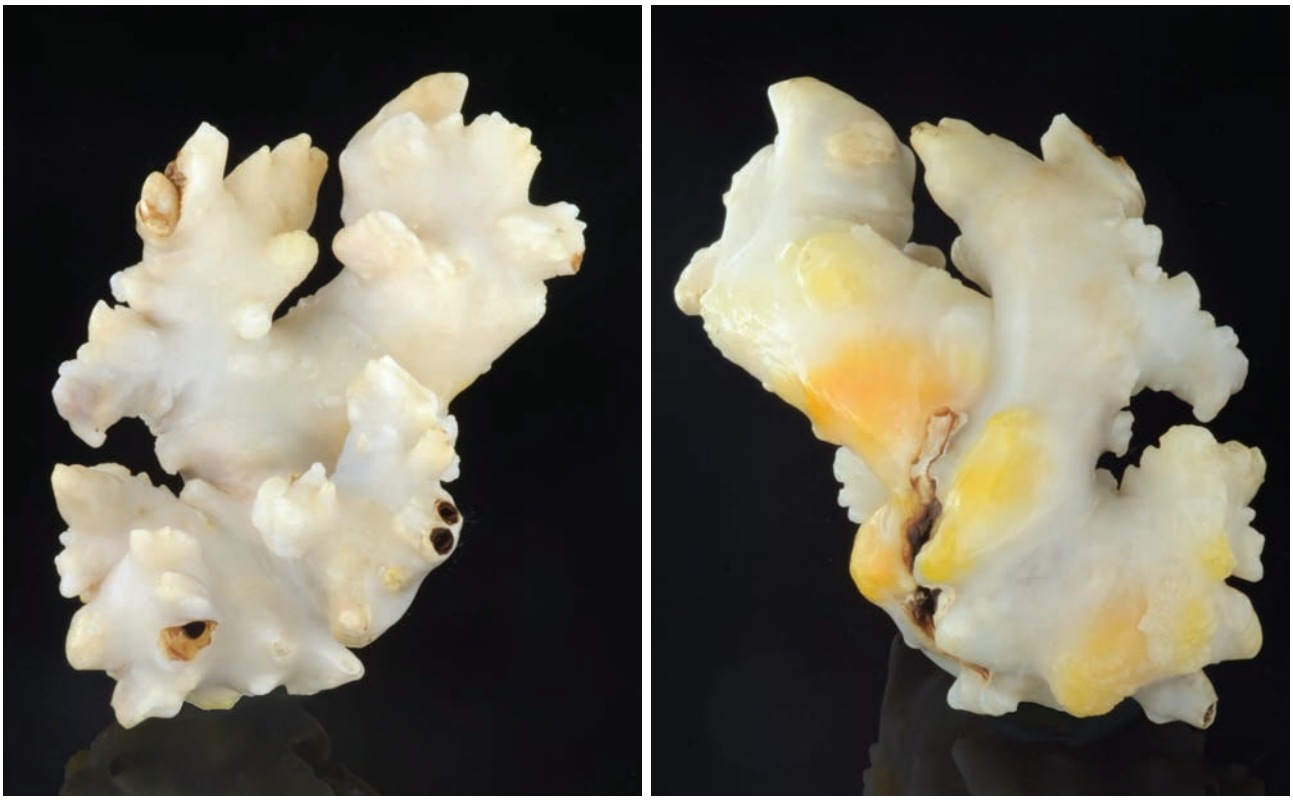

Figure 25: This irregularly shaped object (65 × 38 × 29 mm, shown in front and back views) is inferred to be a Tridacna gigas *'pearl' that formed when a branch of coral was covered by calcium carbonate. Photos by O. Segura.*

typical coral branch shape, but its porcelaneous white appearance (with some yellow areas) was not consistent with coral. Raman spectroscopy confirmed that the material consisted of a calcium carbonate phase; due to abundant luminescence, it was not possible to differentiate between calcite and aragonite. A few holes on the surface (e.g. Figure 26) provided a view into the interior of the object, which consisted of an open void. X-radiography likewise revealed a cavity inside the object (Figure 27). The shape of the hollow area showed a typical branching structure for coral.

These observations are consistent with *Tridacna* biomineralization of a branch of coral. Once inside the giant clam, the coral was covered by numerous layers of calcium carbonate produced

Figure 26: A hole on the surface of the object reveals multiple layers of calcium carbonate that were deposited on a pre-existing coral branch. The inside of the object now consists of a large void. Photomicrograph by O. Segura; magnified 30×.

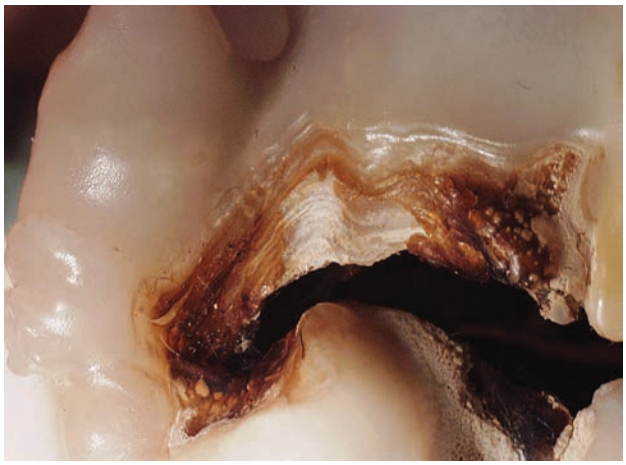

Figure 27: X-radiography of the biomineralized object (65 mm long) shows a dark-appearing void corresponding to a branch of coral that subsequently dissolved. Image by O. Segura.

by the mollusc. Subsequently, the coral branch was apparently dissolved, possibly through the action of enzymes produced by the host clam that entered through the holes in the object's surface, leaving an extraordinary envelope of calcium carbonate.

Technically we could call this object a natural baroque porcelaneous hollow pearl, and its rarity and probable origin make it a real treasure.

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TREATMENTS

Quartz Beads Treated with a Coloured Polymer to Imitate Tourmalinated Quartz

During the February 2016 Tucson gem shows, these authors acquired a strand of unusual beads (Figure 28). The vendor was unsure of their identity, but thought they consisted of quartz that was untreated. At first glance they appeared to be tourmalinated quartz, although the high concentration of greenish blue inclusions in some of the beads would be unusual for tourmaline needles in quartz. The dealer had several hanks of these beads in various sizes (8–12 mm in diameter), and one strand was purchased for testing.

The beads were approximately 10 mm in diameter and showed varying degrees of translucency. The deep greenish blue needle-like inclusions were concentrated in various amounts (Figure 29). Raman analysis with an Enwave 785 micro-Raman spectrometer confirmed the beads were quartz (463 cm^{-1} Raman peak), but the inclusions did not yield a useful signal, even where they reached the surface of the beads. During a prolonged reading, the Raman's 785 nm laser caused smoke to emanate from one such inclusion, suggesting the presence of a hydrocarbon. Using a PerkinElmer Spectrum100 Fourier-transform infrared spectrometer, a coloured polymer substance was confirmed in the inclusions, with bands at 4060, 3055 and 3037 cm^{-1}. Microscopic inspection revealed many of the needles were hollow, with their surfaces coated by the coloured polymer, while the polymer appeared to completely fill the finer tubes (e.g. Figure 30, left). Colour concentrations along fissures in a few of the beads (e.g. Figure

Figure 28 (left): These 'tourmalinated' quartz beads (10 mm in diameter) were studied for this report. Photo by C. Williams.

Figure 29 (below): The quartz beads contain varying amounts of deep greenish blue needle-like inclusions and colour concentrations. Photo by C. Williams.

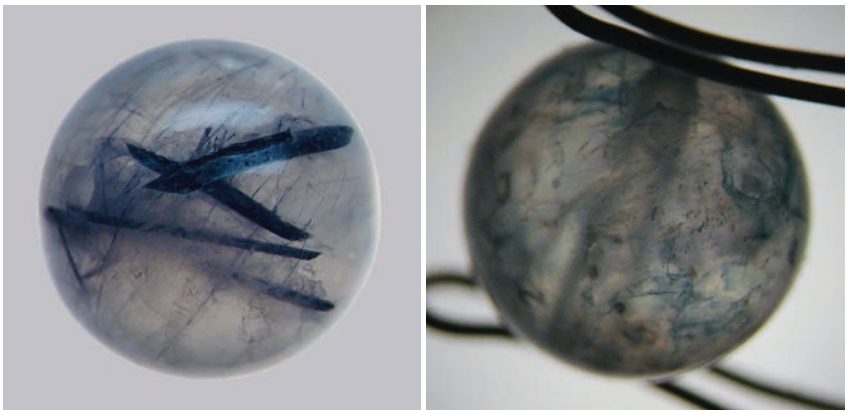

Figure 30: The surface-reaching inclusion in the bead on the left was found to consist of a hollow etch channel that contained coloured resin. In a few of the beads, the coloured polymer also penetrated surface-reaching fissures, as shown on the right. Photos by C. Williams; both beads are 10 mm in diameter.

30, right) also indicated the presence of an artificial dye. In places, air bubbles were visible within the filled fissures when viewed with higher magnification.

We concluded that the beads consisted of quartz with hollow etch channels and fissures that were filled with a deep greenish blue resinous dye.

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Major- and Trace-element Composition of Paraíba-type Tourmaline from Brazil, Mozambique and Nigeria

Martin Okrusch, Andreas Ertl, Ulrich Schüssler, Ekkehart Tillmanns, Helene Brätz and Hermann Bank

Copper-bearing tourmalines are highly prized for their vivid coloration. We analysed the major and trace elements of some gem-quality Cu-bearing tourmalines (e.g. blue, greenish blue, yellowish green, green, violet and pink) from Brazil, Mozambique and Nigeria. Most of them contained significant amounts of Cu, Mn or a combination of both elements. There was no clear-cut correlation of the Cu and Mn contents with coloration. Blue colour was in most cases due to Cu^{2+}. Pink and violet coloration (due to Mn^{3+}) was shown by Mn-bearing tourmalines that contained no significant Fe. Green colour in the Nigerian tourmaline was most probably due to a combination of Mn, Cu and Fe. Some of the green samples from Brazil contained up to 0.6 wt.% V_2O_3. Among the trace elements, remarkable contents of Pb (up to 4,000 ppm) and Bi (up to 2,900 ppm) were detected rarely in samples from all three countries. Based on a comparison of unheated pink and violet samples with data for blue Paraíba-type tourmalines, CuO/MnO_{tot} is usually ≥0.5 for unheated blue samples. Hence, we suggest that blue Cu-bearing tourmalines with CuO/MnO_{tot} <0.5 may have been heat treated to reduce the contribution of the reddish component of Mn^{3+}.

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Introduction

"Tourmaline is unsurpassed by any other gemstone, even corundum, in the range of glorious colours that it displays, and it has risen high in the ranks of jewellery, thanks to the prodigal profusion in which nature has formed it…" (Smith and Phillips, 1972). With its diversity of coloration and moderate Mohs hardness of 7–7½, tourmaline is an excellent gem for pendants, earrings and brooches, and is also commonly used as a ring stone.

Tourmaline's extreme compositional variability is responsible for its multitude of colours. The generalized structural formula is $(X)(Y_3)(Z_6)[T_6O_{18}](BO_3)_3V_3W$, with the individual structural sites occupied (mainly) by the following cations (e.g. Henry et al., 2011, and references therein):

X = Ca, Na, K, □ (vacancy)
Y = Li, Mg, Fe^{2+}, Mn^{2+}, Mn^{3+}, Al, Cr^{3+}, V^{3+}, Fe^{3+}, Zn, Cu
Z = Al, Fe^{3+}, V^{3+}, Cr^{3+}, Mg, Ti^{4+}
T = Si (with minor Al, B)
V = OH^-, O^{2-}
W = OH^-, F^-, Cl^-, O^{2-}

Substitutions at the Y site are more constrained by ionic radius than by valence. Consequently, the variety of cations in this site is larger than at the Z site, where substitutions are more constrained by valence than by size (e.g. Grice and Ercit, 1993). However, many additional crystallochemical constraints are related to interactions between different sites (e.g. the F and X sites; Henry and Dutrow, 1996).

According to the X-site occupancy, three primary tourmaline groups can be distinguished: a calcic group with dominant Ca^{2+}, an alkali group with dominant Na (+K) and an X-vacant group with dominant X-site vacancy. These three primary groups are subdivided based on the respective predominance of Li^{+}, Fe^{2+} or Mg^{2+} on the Y site (leading to, e.g., elbaite, schorl or dravite, respectively, in the alkali group). In addition, W-site occupancy leads to a further subdivision into the three general species hydroxyl-, fluor- and oxy-tourmaline. The combination of these classification aspects results in 32 tourmaline species that are recognized by the International Mineralogical Association (see Hawthorne and Dirlam, 2011; Henry et al., 2011; and for a recent update visit https://en.wikipedia.org/wiki/Tourmaline#Tourmaline_species_and_varieties).

Tourmaline is characterized by a variety of colours, and for gem applications it should not be too light or too dark, with the optimum colour being somewhere intermediate between these extremes. Therefore, gem-quality tourmaline should contain only very small amounts of Fe-rich end members, such as schorl, $NaFe^{2+}{}_3Al_6[Si_6O_{18}](BO_3)_3(OH)_3(OH,F)$, which is an important constituent in most rock-forming tourmalines (e.g. Henry and Dutrow, 1996). Indeed, Epprecht (1953) realized that tourmalines with red, 'rose', green and yellowish green colours are virtually Mg,Fe-free elbaite, $NaLi_{1.5}Al_{1.5}Al_6[Si_6O_{18}](BO_3)_3(OH)_3(OH,F)$, whereas tourmalines of the elbaite-schorl and dravite-schorl series typically range from light brown to brownish black and black with increasing Fe content. The same holds true for the uvite-feruvite series (Dunn et al., 1977). A colourless Mg,Fe-free elbaitic tourmaline revealed 0.33 apfu Mn (Epprecht, 1953; apfu = atoms per formula unit). Consistent with these results and those of other studies (e.g. Deer et al., 1986, and references therein), electron microprobe analyses of Dunn (1975) on zoned elbaite from Maine showed that

Figure 1: This 18 ct white gold ring contains a 3.47 ct heated Mozambique tourmaline that is surrounded by diamonds. Courtesy of collectorfinejewelry.com; ring manufactured by Ilka Bahn and photographed by Wimon Manorotkul.

Fe and Mn contents are highest in dark blue, lower in green and lowest in pink areas of the crystals. Further, the colour intensity of green elbaite was directly proportional to Fe content, and pink elbaite was virtually free of Fe (with the colour being due to small amounts of Mn that were not masked by Fe; Dunn, 1975). Several investigations of the colouring of elbaitic tourmalines (summarized in part by Deer et al., 1986) corroborate that the pink variety contains Mn combined with a low Fe content. This lack of Fe is more important than particularly high values of Mn. Investigations by Ertl et al. (2003) on a yellow-brown to pink Mn-rich tourmaline (~8.5 wt.% MnO_{tot}, ~0.15 wt.% FeO_{tot}) from Austria showed that Mn^{2+} was present in all regions of the crystal, but that Mn^{3+} was higher in the pink regions (where ~8% of the total Mn was Mn^{3+}) than in the yellow-brown areas. They argued, based on a gamma-irradiated crystal fragment, that the natural pink colour in this Mn-rich tourmaline is due to oxidation of the initial Mn^{2+} to Mn^{3+} by natural irradiation. Such a mechanism was initially proposed by Reinitz and Rossman (1988). Green and blue colours in Fe-bearing tourmaline have been attributed to both Fe^{2+}–Fe^{3+} (Mattson and Rossman, 1987) and Fe^{2+}–Ti^{4+} intervalence charge transfer (Mattson, as cited in Dietrich, 1985, p. 129), and yellow-green coloration may be produced by Mn^{2+}–Ti^{4+} (Rossman and Mattson, 1986). The coloration of Cu-bearing elbaite (e.g. Figure 1) is

Figure 2: Thirty-eight tourmaline samples were analysed from Brazil (BRA), Mozambique (MOZ) and Nigeria (NIG). For samples BRA11–BRA14, four samples were chosen at random from the group of stones shown. The red box on NIG2 shows the approximate area covered by the backscattered electron image in Figure 7. Photos by Klaus-Peter Kelber; scale bar in each image is 5 mm.

Figure 3: These gems show the bright coloration of Cu-bearing tourmaline from Brazil. The blue gems on the left weigh 1.87 and 1.49 ct, and the greenish blue to bluish green stones on the right weigh 2.80 ct (centre stone) and 2.51 carats (total weight of matched pair). Courtesy of Palagems.com; photos by Mia Dixon.

summarized in the following section. Many open questions still remain as to the relationships between colour and chemical composition of tourmaline, as they are not always directly correlated (Pezzotta and Laurs, 2011).

As a contribution to this problem, particularly regarding Cu-bearing tourmaline, we have analysed 38 gem-quality samples from Brazil, Mozambique and Nigeria (Figure 2) for major and minor elements using an electron microprobe. In addition, B, Li and several trace elements, including rare-earth elements (REE), were analysed by laser ablation inductively coupled plasma mass spectrometry (LA-ICP-MS) to obtain a comprehensive picture of the composition of these tourmalines. Analytical data on 15 additional, partly unpolished, crystals from Brazil (BRA20–BRA28) and Mozambique (MOZ19–MOZ24) were presented in an article that focused on the structural refinement of these tourmalines (Ertl et al., 2013); they generally show a strong negative correlation between X-site vacancy and Mn+Fe content. Ertl et al. (2013) concluded that the Mn content in such tourmaline depends on the geochemical availability of Mn and the formation temperature, as well as on stereochemical constraints. Because of a very weak correlation between MnO_{tot} and CuO, they argued that the Cu content in tourmaline is essentially dependent on the geochemical availability of Cu and on stereochemical constraints.

Provenance and Characteristics of the Samples

As the investigated tourmalines were purchased on the free market, only the general region of provenance was given. Therefore, the exact localities for the samples are unknown. Moreover, it cannot be excluded that some of the samples may have been initially purple-to-violet but were heat treated to achieve attractive blue coloration.

Brazil

In summer 1987, gem-quality tourmalines of radiant blue-to-green colour (e.g. Figure 3) were discovered in granitic pegmatites near the village of São José da Batalha near Salgadinho, Paraíba State, generating considerable interest of gemmologists and gem traders. Owing to their spectacular 'electric', 'neon' or 'swimming-pool' blue colours, these Paraíba tourmalines rapidly became popular on the gem market and eventually reached prices of US$25,000/carat (Pezzotta and Laurs, 2011) and higher. Their coloration is due to minor amounts of Cu (not previously recorded in tourmaline), partly in combination with Mn (Fritsch et al., 1990; Henn and Bank, 1990; Rossman et al., 1991; Abduriyim et al., 2006; Krzemnicki, 2006; Furuya and Furuya, 2007; Peretti et al., 2008; Shabaga et al., 2010; Beurlen et al., 2011). Interestingly, relatively Fe-rich Cu-Mn elbaite of greyish green colour from São José da Batalha may contain dendritic inclusions of native copper (Brandstätter and Niedermayer, 1993, 1994).

Polarized absorption spectra of dark blue Paraíba tourmaline display strong, pleochroic absorption bands with maxima at ~920 and ~700 nm due to Cu^{2+}, and at ~520 nm due to Mn^{3+}. Both of these cations occur in distorted octahedral coordination. In contrast, spectra of light blue Paraíba tourmaline show only the Cu^{2+} absorptions with no Mn^{3+} band (see Figure 6 in Henn and Bank, 1990). The vivid blue and yellowish green to

Figure 4: These unheated Cu-bearing tourmalines from Mozambique (1.29–2.24 ct) display a wide variety of colour, including green, 'lilac', bluish green, 'magenta', purple and blue. Courtesy of Palagems.com; photo by Mia Dixon.

blue-green colours are due primarily to Cu^{2+} (and varying amounts of Mn^{2+}), but may be influenced by absorption from Mn^{3+} toward violet-blue and violet hues. Heating of such tourmaline leads to a complete disappearance of the 520 nm Mn^{3+} band (e.g. Laurs et al., 2008; Pezzotta and Laurs, 2011).

Similar Cu-Mn-bearing, Paraíba-type tourmalines have been recorded in granitic pegmatites at other Brazilian localities, particularly Quintos de Baixo and Boqueirãozinho, both in the state of Rio Grande do Norte (Karfunkel and Wegner, 1996; Shigley et al., 2001; Milisenda, 2005; Milisenda et al., 2006).

Under the designation 'Brazil', we analysed 13 cut and five rough tourmalines. Most displayed greenish blue, blue or yellowish green colours, typical of Paraíba-type elbaite (Figure 2). Two samples, BRA3 and BRA5, were purple and violet, respectively.

Mozambique

Gem-quality tourmaline, beryl, spodumene and garnet are found in numerous Nb-Ta-Bi-bearing granitic pegmatites, of about 550 million years old, that occur in the crystalline basement of the Alto Ligonha plateau in northern Mozambique (e.g. Hutchinson and Claus, 1956; Simmons et al., 2012). A new occurrence of Cu-bearing elbaite was detected in the mid-2000s in the eastern Alto Ligonha pegmatite province, some 150 km southwest of the city of Nampula (Abduriyim et al., 2006; Krzemnicki, 2006; Milisenda et al., 2006; Laurs et al., 2008; Peretti et al., 2008). The stones are mined from placer deposits, but are presumably derived from pegmatites (Milisenda et al., 2006).

The Cu-bearing tourmalines display a broad spectrum of colours (i.e. violet, pink, purple, blue, greenish blue, yellowish green and green; e.g. Figure 4). Zoned crystals may consist of two (e.g. green–violet) or three (e.g. green–violet–blue) different colours. In blue, bluish green and green specimens, considerable Mn and Cu contents have been revealed by electron microprobe analysis. Heating of purple-to-violet samples to 600°C led to a reduction of the Mn^{3+} absorption bands at 395 and 520 nm, and an increase of the broad Cu^{2+} maxima at 690 and 905 nm. As a result, the colour may be changed to a vivid 'turquoise' blue (Figure 5), typical of Paraíba-type tourmaline (Milisenda and Henn, 2001; Milisenda et al., 2006).

We investigated 15 cut and three rough stones from Mozambique that displayed a large variety of colours (i.e. purple to reddish purple or purplish pink, brownish pink, orangey pink, blue, bluish green, greenish blue, green, yellowish green and yellow brown; Figure 2).

Nigeria

In 2001, green, blue, and blue-violet to amethyst-coloured tourmalines containing Mn^{3+} and Cu^{2+} were discovered at the Edoukou mine near Ilorin in Oyo State (Milisenda, 2001b; Milisenda and Henn, 2001; Smith et al., 2001; Zang et al., 2001; Abduriyim et al., 2006; Krzemnicki, 2006; Furuya

Figure 5: The light greenish blue gems in this 12-piece suite of Mozambique Cu-bearing tourmaline (30.66 carats total weight) have been heated, while the others are unheated. Courtesy of Palagems.com; photo by Mia Dixon.

Figure 6: Weighing up to 4.73 ct, these Cu-bearing tourmalines are from Nigeria. Courtesy of Ekkehard Schneider; photo by Jeff Scovil.

and Furuya, 2007; Peretti et al., 2008). Some of the stones are colour zoned. Upon heating the violet crystals, the ~520 nm absorption band of Mn^{3+} is reduced and the ~700 and ~920 nm absorption bands typical of Cu^{2+} become obvious. Although the resulting colour is blue (e.g. Figure 6), the particularly vivid 'neon blue' typical of Paraíba-type tourmalines has been only rarely encountered. We analysed one blue faceted stone and one rough colour-zoned tourmaline from Nigeria (NIG1 and NIG2, respectively; see Figure 2).

Analytical Techniques

The tourmalines from Brazil (18 samples; Table I), Mozambique (18; Table II) and Nigeria (2; Tables III and IV) were analysed for major, minor and trace elements, including REE, at the Division of Geodynamics and Geomaterial Research, Würzburg University, Germany. Electron microprobe analysis (EMPA) of the faceted stones was carried out on the table facet (which is generally oriented nearly parallel to the optic axis; Smith and Phillips, 1972) while, for laser ablation inductively coupled plasma mass spectrometry (LA-ICP-MS), a pavilion facet on the back of the stone was selected in the majority of cases. On the crystal fragments, a randomly selected surface was polished for analysis.

EMPA was carried out on a Cameca SX50 microprobe with three wavelength-dispersive spectrometers. Analytical conditions were 15 kV accelerating voltage and 15 nA beam current. As F was analysed together with other elements, the beam diameter was 10 µm for all measurements. Counting times were 20 s for most elements, and 30 s for Fe and Mn. Standards consisted of well-characterised natural and synthetic silicate and oxide minerals or pure elements supplied by Cameca. $K\alpha$ radiation was used for the analysis of F, Na, Al, Si, Cl, K, Ca, Ti, V, Mn and Fe, and $L\alpha$ for the analysis of Ba. Special care was taken to account for overlapping peaks, especially V ($K\alpha$) with Ti ($K\beta$). The matrix correction of the EMPA data was done by Cameca's PAP software. Using these analytical conditions, the detection limit was about 0.05 wt.%. The analytical precision was below 1% relative for all major elements except Na (2%), and up to 10% relative for F and the minor elements. In general, 10 or more individual EMPA point analyses were carried out on each sample. From these, average compositions for the tourmalines were calculated. On the colour-zoned sample from Nigeria, a traverse of 82 points were measured, a selection of which are given in Table III.

For all samples, B, Li, REE and some minor-to-trace elements (Mg, Cr, Ni, Cu, Zn, Pb and Bi) were analysed by LA-ICP-MS. The measurements were undertaken using a New Wave Research (Merchantek) 266 nm Nd:YAG laser ablation unit, connected to an Agilent 7500i ICP-MS quadrupole instrument at 1,250 W plasma power. Argon was used as carrier gas (1.28 L/min) as well as plasma gas (14.9 L/min) and auxiliary gas (0.9 L/min). Data acquisition was performed in time-resolved mode with measurements on the maximum peak and 25 ms integration time for all chosen isotopes, except for 10 ms for B and Si. The background was measured for 15 s and the acquisition time also was 15 s. Three spots with a crater size of 40 µm, a repetition rate of 10 Hz and a laser energy of 0.51–0.74 mJ (energy density 43–52 J/cm^2) were ablated on each sample. Data analysis was performed via Glitter software (version 3.0, Macquarie Research Ltd., 2000), using Si as an internal standard (values known from EMPA). Results of the LA-ICP-MS analyses are the mean values of three ablated spots. On the colour-zoned sample from Nigeria, a traverse of six points were measured, and these data are given in Table IV.

Table I: Chemical analyses of tourmaline from Brazil.[a]

Sample no.	BRA1	BRA2	BRA3	BRA4	BRA5	BRA6	BRA7	BRA8	BRA9
Weight (ct)	0.95	0.81	1.10	0.82	0.56	0.38	0.24	0.51	0.34
Max. size (mm)	8.5	7.6	10.8	9.2	7.4	5.2	5.7	5.9	4.5
Colour	Blue	Violetish blue	Purple	Blue	Violet	Yellow-green	Bluish green	Greenish blue	Yellowish green
Oxides (wt.%)									
SiO_2	37.30	36.28	36.94	37.19	36.35	37.01	36.16	36.94	37.47
TiO_2	0.01	bdl	0.01	0.01	0.01	0.07	0.05	0.01	0.01
B_2O_3*	10.80	10.51	10.70	10.77	10.53	10.72	10.47	10.70	10.85
B_2O_3**	9.44	9.39	9.24	9.31	9.98	9.21	9.60	10.67	9.16
Al_2O_3	39.06	40.93	40.15	39.78	42.06	38.99	39.01	40.64	41.27
V_2O_3	0.01	bdl	0.03	0.01	bdl	0.48	0.13	0.01	0.01
MgO	0.01	bdl	0.02	0.01	bdl	0.46	0.13	0.01	0.01
CaO	0.24	0.30	0.11	0.54	0.30	0.25	0.28	0.50	0.53
MnO_{tot}	2.90	1.38	1.91	2.30	0.35	3.66	1.98	2.72	0.55
FeO_{tot}	3.21	0.01	0.06	bdl	0.01	0.28	0.03	bdl	2.43
CuO**	bdl	0.42	0.52	1.07	1.69	1.74	0.89	1.39	bdl
ZnO**	0.07	0.27	1.45	bdl	bdl	1.72	bdl	0.08	0.09
PbO**	bdl	bdl	bdl	0.01	bdl	bdl	0.01	bdl	0.02
BiO**	bdl	bdl	0.01	0.14	0.05	0.03	0.10	0.08	bdl
Li_2O*	1.17	1.12	1.22	1.51	0.83	0.62	1.37	1.00	1.24
Li_2O**	1.47	1.53	1.70	1.87	2.03	1.39	1.76	2.04	1.73
Na_2O	2.67	2.10	2.30	2.31	1.92	2.62	2.48	2.29	2.08
F	1.97	1.39	1.35	2.09	1.14	2.09	1.91	2.02	1.66
H_2O*	2.78	2.84	2.90	2.75	2.90	2.73	2.70	2.74	2.87
-O=F	−0.83	−0.58	−0.57	−0.88	−0.48	−0.88	−0.81	−0.85	−0.70
Sum (EMPA data)	**101.38**	**96.95**	**99.11**	**99.60**	**97.67**	**102.59**	**96.89**	**100.28**	**100.40**
Ions per 31 (O+OH+F)									
Si	6.000	6.000	6.000	6.000	6.000	6.000	6.000	6.000	6.000
B	3.000	3.000	3.000	3.000	3.000	3.000	3.000	3.000	3.000
Al	7.406	7.978	7.684	7.563	8.181	7.451	7.630	7.781	7.788
Mg	0.002	0.000	0.005	0.001	0.000	0.112	0.032	0.002	0.002
Ti^{4+}	0.001	0.000	0.001	0.001	0.001	0.009	0.006	0.001	0.002
V^{3+}	0.002	0.000	0.003	0.001	0.000	0.062	0.018	0.001	0.001
Mn^{2+}	0.395	0.193	0.263	0.315	0.049	0.502	0.278	0.374	0.075
Fe^{2+}	0.432	0.001	0.008	0.000	0.001	0.038	0.004	0.000	0.326
Cu^{2+}	0.000	0.052	0.064	0.131	0.211	0.213	0.112	0.171	0.000
Zn	0.009	0.033	0.174	0.000	0.000	0.206	0.000	0.010	0.010
Li	0.754	0.742	0.797	0.976	0.552	0.404	0.912	0.653	0.795
Sum Y,Z	**9.000**	**9.000**	**8.999**	**8.988**	**8.995**	**8.998**	**8.990**	**8.992**	**8.999**
Ca	0.042	0.052	0.019	0.094	0.053	0.044	0.049	0.087	0.090
Pb	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001
Bi	0.000	0.000	0.001	0.060	0.025	0.001	0.005	0.004	0.000
Na	0.833	0.674	0.723	0.722	0.614	0.823	0.797	0.723	0.647
Vacancy	0.125	0.273	0.258	0.173	0.328	0.131	0.144	0.183	0.262
Sum X	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**
F	1.027	0.743	0.718	1.093	0.608	1.086	1.026	1.054	0.863
OH	0.000	0.128	0.141	0.000	0.196	0.000	0.000	0.000	0.068
O	0.000	0.129	0.141	0.000	0.196	0.000	0.000	0.000	0.069
Sum W	**1.027**	**1.000**	**1.000**	**1.093**	**1.000**	**1.086**	**1.026**	**1.054**	**1.000**
Trace elements (ppm)									
Mg	10.20	3.57	139	0.69	0.32	841	6.13	1.38	84.2
Ni	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl
Cu	2.73	3354	4148	8571	13532	13917	7110	11111	1.84
Zn	601	2179	11670	12.6	17.5	13820	18.9	643	692
La	0.30	bdl	bdl	0.39	4.46	0.18	0.24	1.06	0.79
Ce	0.46	bdl	bdl	0.26	2.72	0.09	0.12	0.56	1.52
Pr	0.04	bdl	bdl	0.03	0.10	bdl	bdl	0.06	0.14
Nd	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	0.40
Sm	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl
Pb	20.2	1.90	6.44	64.5	21.9	26.3	52.2	36.6	168
Bi	0.51	14.2	103	1265	480	252	972	788	bdl
Σ REE	0.80	bdl	bdl	0.67	7.28	0.27	0.37	1.68	2.85

[a] Notes: The V site is completely occupied by OH in all samples. The values B_2O_3*, Li_2O* and H_2O* were calculated (these values were used for the formula calculation; for details, see text). Data for B_2O_3**, CuO**, ZnO**, PbO**, BiO** and Li_2O** are from LA-ICP-MS. Standards used for EMPA measurements were andradite [$Ca_3Fe_2(SiO_4)_3$] for Si and Ca, Al_2O_3 for Al, Fe_2O_3 for Fe, MgO for Mg, albite [$NaAlSi_3O_8$] for Na, $MnTiO_3$ for Mn and Ti, vanadinite [$Pb_5Cl(VO_4)_3$] for V, PbS for Pb, ZnS for Zn, pure elements for Cu and Bi, and LiF for F. Below detection limit in all samples were K, Ba and Cl (EMPA), and Cr, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb and Lu (LA-ICP-MS). For LA-ICP-MS analyses, tourmalines supplied from

BRA10	BRA11	BRA12	BRA13	BRA14	BRA15	BRA16	BRA17	BRA18
8.91	0.03	0.03	0.03	0.03	0.19	0.27	0.38	0.11
13.3	1.7	1.7	1.7	1.7	4.7	5.0	5.3	4.0
Brownish green	Greenish blue	Greenish blue	Greenish blue	Greenish blue	Greenish blue	Greenish blue	Greenish blue	Greenish blue
36.86	37.31	36.54	36.14	38.73	37.93	37.60	37.81	37.40
0.10	0.01	0.02	0.02	0.02	0.01	0.01	bdl	bdl
10.68	10.81	10.59	10.47	11.22	10.99	10.89	10.95	10.83
10.34	9.84	9.71	9.78	9.47	10.64	10.03	10.98	9.97
38.75	41.13	40.45	40.09	41.42	41.43	41.41	42.18	41.80
0.62	bdl	0.01	bdl	0.01	0.02	bdl	bdl	bdl
0.62	bdl	bdl	bdl	bdl	0.01	bdl	0.01	bdl
0.35	0.74	0.76	0.73	0.66	0.69	0.77	0.78	0.60
1.79	0.44	0.49	1.08	2.23	0.40	0.74	0.68	0.29
0.53	0.03	0.04	0.02	0.02	0.02	bdl	0.01	bdl
0.97	1.38	1.06	1.05	1.03	1.22	0.99	1.22	1.03
0.85	0.03	0.02	bdl	0.01	0.04	bdl	bdl	0.02
0.01	0.01	0.01	0.01	bdl	0.01	0.01	0.01	0.43
0.15	0.12	0.09	0.05	0.03	0.07	0.05	0.05	0.06
1.18	1.48	1.45	1.30	1.63	1.66	1.54	1.36	1.40
1.95	1.83	1.94	1.51	1.55	2.17	2.00	2.38	2.04
2.44	2.17	2.11	2.06	2.48	2.07	2.06	2.08	2.00
1.83	1.81	1.69	1.63	1.84	1.86	1.70	1.44	1.89
2.78	2.82	2.79	2.77	2.94	2.86	2.88	2.96	2.81
−0.77	−0.76	−0.71	−0.68	−0.77	−0.78	−0.71	−0.61	−0.80
99.74	**99.50**	**97.38**	**96.71**	**103.48**	**100.48**	**99.91**	**100.93**	**99.77**
6.000	6.000	6.000	6.000	6.000	6.000	6.000	6.000	6.000
3.000	3.000	3.000	3.000	3.000	3.000	3.000	3.000	3.000
7.434	7.796	7.827	7.843	7.562	7.725	7.787	7.888	7.904
0.150	0.000	0.000	0.000	0.000	0.001	0.000	0.002	0.000
0.012	0.001	0.002	0.002	0.002	0.001	0.001	0.000	0.000
0.080	0.000	0.001	0.000	0.001	0.003	0.000	0.000	0.000
0.246	0.059	0.068	0.152	0.292	0.054	0.100	0.091	0.039
0.072	0.004	0.005	0.003	0.002	0.002	0.000	0.001	0.000
0.119	0.168	0.131	0.132	0.120	0.145	0.119	0.146	0.125
0.102	0.004	0.002	0.000	0.001	0.005	0.000	0.000	0.003
0.769	0.958	0.956	0.865	1.016	1.058	0.988	0.868	0.905
8.986	**8.989**	**8.992**	**8.996**	**8.998**	**8.994**	**8.995**	**8.995**	**8.976**
0.061	0.127	0.133	0.130	0.109	0.117	0.131	0.132	0.103
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.019
0.008	0.005	0.004	0.002	0.001	0.003	0.003	0.003	0.003
0.771	0.677	0.673	0.663	0.744	0.633	0.636	0.641	0.621
0.154	0.185	0.186	0.203	0.144	0.244	0.229	0.222	0.252
1.000	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**
0.963	0.940	0.900	0.874	0.927	0.954	0.879	0.742	0.979
0.019	0.030	0.050	0.063	0.037	0.023	0.061	0.129	0.011
0.018	0.030	0.050	0.063	0.036	0.023	0.060	0.129	0.010
1.000	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**
3637	6.13	9.21	2.66	2.68	12.4	1.92	3.42	26.5
bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	3.62
7742	11032	8439	8380	8220	9723	7878	9721	8254
6850	264	138	24.5	84.1	326	11.6	<12	194
0.20	0.51	2.50	1.52	3.62	0.31	3.12	0.64	0.23
0.40	0.52	3.46	1.52	3.54	0.39	3.28	0.44	0.21
bdl	0.03	0.32	0.09	0.19	0.06	0.26	0.08	bdl
bdl	bdl	1.02	0.20	0.35	0.17	0.53	bdl	bdl
bdl	bdl	0.44	bdl	0.19	bdl	bdl	bdl	bdl
65.9	67.4	47.0	47.3	38.4	46.8	55.0	51.5	4002
1433	1105	828	420	249	608	495	495	532
0.60	1.07	7.91	3.33	7.88	0.92	7.19	1.17	0.43

Harvard University (dravite, schorl, elbaite; Dyar et al., 2001) were measured as monitors to check for accuracy; the relative standard deviation for B varied from 3–8%, and for Li 5–17% relative. External calibration was performed via NIST glass standard SRM 610 (nominal 500 ppm) with the values from Pearce et al. (1997); the reproducibility for NIST glass SRM 612 (nominal 50 ppm) was 5–11% relative. Abbreviation: bdl = below detection limit.

Table II: Chemical analyses of tourmaline from Mozambique.[a]

Sample no.	MOZ1	MOZ2	MOZ3	MOZ4	MOZ5	MOZ6	MOZ7	MOZ8	MOZ9
Weight (ct)	6.95	2.78	3.95	2.58	1.59	2.36	2.31	1.41	1.54
Max. size (mm)	17.5	9.7	10.7	11.1	8.7	9.1	9.3	8.8	8.0
Colour	Reddish purple	Brownish pink	Yellowish green	Purple	Blue	Orangey pink	Yellowish green	Reddish purple	Blue
Oxides (wt.%)									
SiO_2	37.07	36.73	36.00	37.06	37.17	37.52	37.46	37.10	36.53
TiO_2	0.03	0.05	0.05	bdl	0.01	0.01	0.01	0.01	0.04
B_2O_3*	10.74	10.64	10.43	10.73	10.77	10.87	10.85	10.75	10.58
B_2O_3**	9.19	8.69	8.52	9.26	9.14	8.96	8.79	8.94	9.51
Al_2O_3	41.44	40.88	40.22	41.94	41.99	43.48	42.45	42.56	40.77
V_2O_3	bdl	bdl	bdl	bdl	bdl	0.01	bdl	bdl	0.01
MgO	bdl	bdl	bdl	0.01	bdl	bdl	0.01	bdl	0.01
CaO	0.10	0.09	0.08	0.08	0.31	0.18	0.89	0.11	0.30
MnO_{tot}	3.03	3.46	4.06	2.69	2.34	1.38	0.32	1.25	3.06
FeO_{tot}	bdl	bdl	bdl	0.01	bdl	0.01	0.01	bdl	bdl
CuO**	0.09	0.17	0.16	0.16	0.35	0.06	0.16	0.13	0.40
ZnO**	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl
PbO**	bdl	bdl	bdl	bdl	bdl	bdl	0.02	bdl	0.01
BiO**	bdl	bdl	bdl	bdl	0.04	0.01	0.24	0.01	0.03
Li_2O*	1.02	0.95	0.74	0.93	0.99	0.94	1.40	1.07	0.94
Li_2O**	1.47	1.44	1.31	1.74	1.45	1.74	2.05	1.65	1.77
Na_2O	2.24	2.28	2.28	2.18	2.08	2.04	1.80	2.07	2.22
F	1.10	1.46	1.31	1.22	1.59	1.32	1.58	1.24	1.72
H_2O*	2.97	2.86	2.83	2.83	2.87	2.96	2.89	2.94	2.78
–O=F	–0.46	–0.61	–0.55	–0.51	–0.67	–0.56	–0.66	–0.52	–0.72
Sum (EMPA data)	**99.38**	**98.96**	**97.62**	**99.32**	**99.85**	**100.23**	**99.41**	**98.72**	**98.66**
Ions per 31 (O+OH+F)									
Si	6.000	6.000	6.000	6.000	6.000	6.000	6.000	6.000	6.000
B	3.000	3.000	3.000	3.000	3.000	3.000	3.000	3.000	3.000
Al	7.905	7.869	7.900	8.003	7.987	8.195	8.012	8.113	7.892
Mg	0.001	0.001	0.001	0.001	0.000	0.001	0.002	0.001	0.001
Ti^{4+}	0.003	0.006	0.006	0.000	0.002	0.002	0.001	0.002	0.005
V^{3+}	0.000	0.000	0.001	0.000	0.001	0.001	0.001	0.000	0.001
Mn^{2+}	0.415	0.478	0.573	0.369	0.320	0.187	0.043	0.171	0.426
Fe^{2+}	0.000	0.000	0.000	0.001	0.000	0.001	0.001	0.001	0.000
Cu^{2+}	0.011	0.021	0.020	0.020	0.042	0.007	0.020	0.016	0.050
Zn	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Li	0.664	0.624	0.498	0.606	0.645	0.606	0.899	0.696	0.623
Sum Y,Z	**9.000**	**9.000**	**9.000**	**9.000**	**8.997**	**9.000**	**8.978**	**8.999**	**8.997**
Ca	0.017	0.016	0.014	0.013	0.053	0.031	0.152	0.018	0.052
Pb	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.000
Bi	0.000	0.000	0.000	0.000	0.001	0.000	0.010	0.001	0.001
Na	0.703	0.722	0.737	0.685	0.651	0.633	0.560	0.649	0.707
Vacancy	0.280	0.262	0.248	0.301	0.293	0.336	0.266	0.332	0.238
Sum X	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**
F	0.580	0.773	0.706	0.642	0.831	0.685	0.817	0.652	0.908
OH	0.210	0.114	0.147	0.179	0.085	0.158	0.091	0.174	0.046
O	0.210	0.113	0.147	0.179	0.084	0.157	0.092	0.174	0.046
Sum W	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**
Trace elements (ppm)									
Mg	0.33	0.35	bdl	bdl	0.54	bdl	0.25	0.19	0.64
Ni	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl
Cu	742	1342	1262	1303	2782	447	1314	1049	3224
Zn	bdl	7.89	14.0	bdl	bdl	4.48	bdl	bdl	19.3
La	bdl	bdl	bdl	bdl	bdl	0.06	bdl	bdl	bdl
Ce	bdl	bdl	bdl	bdl	bdl	0.05	bdl	bdl	bdl
Pr	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl
Nd	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl
Sm	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl
Pb	7.71	8.10	7.28	8.50	39.0	10.7	141	9.11	50.5
Bi	35.3	32.5	28.1	40.6	342	48.8	2324	57.8	253
Σ REE	bdl	bdl	bdl	bdl	bdl	0.11	bdl	bdl	bdl

[a] See notes in Table I. Abbreviation: bdl = below detection limit.

MOZ10	MOZ11	MOZ12	MOZ13	MOZ14	MOZ15	MOZ16	MOZ17	MOZ18
1.23	1.41	1.27	1.13	0.32	1.49	1.53	8.19	7.69
8.0	9.1	8.1	8.0	5.0	8.5	9.4	15.5	12.4
Purplish pink	Orangey pink	Purple	Green	Bluish green	Greenish blue	Yellowish green	Yellow-brown	Bluish grey
37.10	37.49	37.50	35.91	35.62	37.59	36.40	37.24	38.25
bdl	0.01	0.01	0.10	0.07	0.03	0.04	0.01	0.01
10.75	10.86	10.86	10.40	10.32	10.89	10.54	10.79	11.08
9.21	9.25	9.61	9.11	9.19	10.51	9.44	8.89	10.10
42.67	43.56	42.26	39.30	38.91	41.21	40.38	42.19	43.77
0.01	bdl	bdl	bdl	0.02	0.01	0.01	bdl	bdl
bdl	bdl	bdl	bdl	0.02	0.01	0.01	bdl	bdl
0.10	0.20	0.07	0.28	0.37	0.71	0.30	0.11	0.38
1.70	0.60	2.27	4.75	4.37	0.86	3.45	2.67	0.10
bdl	bdl	bdl	bdl	0.01	bdl	bdl	bdl	0.01
0.13	0.04	0.16	0.51	0.42	1.22	0.38	0.08	0.16
bdl	bdl	bdl	bdl	bdl	0.03	bdl	0.01	bdl
bdl	bdl	bdl	bdl	0.01	0.01	bdl	0.01	0.01
0.01	bdl	bdl	0.02	0.04	0.07	0.04	0.03	0.30
0.95	1.08	1.09	0.76	0.85	1.51	0.93	0.94	1.35
1.45	1.88	1.72	1.63	1.50	2.22	1.67	1.81	2.34
2.03	1.99	2.25	2.43	2.39	2.07	2.30	2.21	1.93
1.23	1.10	1.15	1.74	1.71	1.80	1.62	1.32	1.35
2.94	3.01	3.00	2.72	2.70	2.85	2.79	2.94	3.02
−0.52	−0.46	−0.48	−0.73	−0.72	−0.76	−0.68	−0.56	−0.57
99.11	**99.49**	**100.15**	**98.18**	**97.09**	**100.12**	**98.49**	**100.00**	**101.14**
6.000	6.000	6.000	6.000	6.000	6.000	6.000	6.000	6.000
3.000	3.000	3.000	3.000	3.000	3.000	3.000	3.000	3.000
8.133	8.216	7.967	7.739	7.727	7.752	7.845	8.011	8.090
0.001	0.001	0.000	0.000	0.004	0.002	0.002	0.000	0.000
0.000	0.001	0.001	0.013	0.009	0.004	0.005	0.002	0.001
0.001	0.000	0.001	0.000	0.002	0.001	0.001	0.000	0.000
0.233	0.081	0.308	0.672	0.624	0.117	0.481	0.364	0.013
0.000	0.000	0.000	0.000	0.001	0.001	0.000	0.000	0.001
0.016	0.005	0.019	0.064	0.053	0.148	0.047	0.010	0.019
0.000	0.000	0.000	0.000	0.000	0.004	0.000	0.001	0.000
0.615	0.695	0.703	0.509	0.576	0.966	0.615	0.609	0.850
8.999	**9.000**	**9.000**	**8.998**	**8.996**	**8.994**	**8.997**	**8.997**	**8.974**
0.018	0.035	0.013	0.050	0.067	0.122	0.052	0.018	0.063
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.001	0.000	0.000	0.001	0.002	0.003	0.002	0.002	0.013
0.635	0.618	0.697	0.788	0.779	0.641	0.734	0.690	0.586
0.346	0.346	0.290	0.160	0.150	0.231	0.210	0.289	0.324
1.000	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**
0.647	0.570	0.599	0.933	0.929	0.932	0.862	0.692	0.688
0.176	0.215	0.201	0.034	0.036	0.034	0.069	0.154	0.156
0.177	0.215	0.200	0.033	0.035	0.034	0.069	0.154	0.156
1.000	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**
bdl	bdl	bdl	0.28	0.68	2.67	bdl	133	1.01
bdl	bdl	bdl	bdl	bdl	bdl	bdl	0.74	bdl
1071	353	1242	4074	3338	9780	3032	628	1273
bdl	bdl	bdl	23.7	11.6	269	bdl	81	bdl
bdl	bdl	bdl	bdl	bdl	0.39	bdl	3.28	bdl
bdl	bdl	bdl	bdl	bdl	0.35	bdl	5.24	bdl
bdl	bdl	bdl	bdl	bdl	0.04	bdl	0.59	bdl
bdl	bdl	bdl	bdl	bdl	bdl	bdl	1.42	bdl
bdl	bdl	bdl	bdl	bdl	bdl	bdl	0.41	bdl
10.2	7.25	9.31	31.9	53.1	54.6	39.2	60.3	54.9
59.9	39.7	43.8	193	356	675	346	305	2900
bdl	bdl	bdl	bdl	bdl	0.78	bdl	10.94	bdl

Table III: Chemical analyses of tourmaline from Nigeria, measured by EMPA.[a]

Sample no.	NIG1	NIG2								
Weight (ct)	8.20	2.41								
Max. size (mm)	17.1	10.5								
Colour	Greenish blue	Violet		Blue						
Point	–	V1	V2	B1	B2	B3	B4	B5	B6	B7
Oxides (wt.%)										
SiO_2	37.77	37.19	37.07	36.87	36.61	36.97	36.83	36.80	36.99	36.85
TiO_2	bdl	bdl	bdl	bdl	bdl	bdl	bdl	0.06	0.07	bdl
B_2O_3*	10.94	10.78	10.74	10.68	10.61	10.71	10.67	10.66	10.72	10.68
Al_2O_3	41.24	40.69	40.90	40.20	40.16	40.32	39.55	39.11	39.22	40.28
MgO	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl
CaO	0.79	0.09	0.08	0.47	0.43	0.12	0.12	0.13	0.15	0.28
MnO_{tot}	0.98	1.15	1.23	0.55	0.38	0.91	1.63	1.57	1.59	1.00
FeO_{tot}	0.01	bdl	bdl	bdl	bdl	0.06	0.39	0.55	0.49	bdl
CuO	0.27	0.54	0.51	1.61	1.85	0.92	0.90	0.81	0.86	1.32
ZnO	0.01	bdl	bdl	bdl	bdl	bdl	bdl	0.06	0.07	bdl
PbO	0.09	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl
BiO	0.05	bdl	bdl	0.19	0.44	0.41	0.30	0.35	0.26	0.15
Li_2O*	1.73	1.61	1.48	1.54	1.43	1.57	1.53	1.62	1.66	1.47
Na_2O	2.01	1.94	2.04	1.95	1.94	2.00	2.09	2.13	2.11	1.97
F	1.64	0.76	0.60	0.99	1.26	0.86	1.05	1.13	1.00	0.87
H_2O*	2.75	3.06	3.09	2.98	2.89	3.02	2.96	2.94	2.99	3.01
–O=F	–0.69	–0.32	–0.25	–0.42	–0.53	–0.36	–0.44	–0.48	–0.42	–0.36
Sum (EMPA data)	**99.58**	**97.48**	**97.48**	**97.61**	**97.46**	**97.50**	**97.58**	**97.43**	**97.74**	**97.50**
Ions per 31 (O+OH+F)										
Si	6.000	6.000	6.000	6.000	6.000	6.000	6.000	6.000	6.000	6.000
B	3.000	3.000	3.000	3.000	3.000	3.000	3.000	3.000	3.000	3.000
Al	7.721	7.736	7.804	7.710	7.757	7.712	7.595	7.516	7.500	7.729
Mg	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Ti^{4+}	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.007	0.008	0.000
Mn^{2+}	0.415	0.157	0.168	0.076	0.053	0.125	0.225	0.216	0.218	0.138
Fe^{2+}	0.000	0.000	0.000	0.000	0.000	0.008	0.053	0.075	0.066	0.000
Cu^{2+}	0.011	0.066	0.062	0.197	0.229	0.112	0.111	0.100	0.106	0.162
Zn	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.007	0.008	0.000
Li	0.664	1.041	0.965	1.008	0.942	1.025	1.003	1.064	1.083	0.964
Sum Y,Z	**8.992**	**9.000**	**9.000**	**8.992**	**8.981**	**8.982**	**8.987**	**8.985**	**8.989**	**8.994**
Ca	0.134	0.015	0.014	0.082	0.075	0.020	0.021	0.023	0.026	0.048
Pb	0.004	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Bi	0.002	0.000	0.000	0.008	0.019	0.018	0.013	0.015	0.011	0.006
Na	0.618	0.607	0.639	0.615	0.618	0.630	0.662	0.674	0.663	0.621
Vacancy	0.243	0.378	0.347	0.295	0.288	0.332	0.304	0.288	0.300	0.325
Sum X	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**
F	0.848	0.405	0.322	0.530	0.674	0.463	0.563	0.609	0.535	0.465
OH	0.076	0.298	0.339	0.235	0.163	0.268	0.219	0.195	0.233	0.267
O	0.076	0.297	0.339	0.235	0.163	0.269	0.218	0.196	0.232	0.268
Sum W	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**

[a] See notes in Table I regarding the EMPA analyses. V is below detection limit in all measurements. For sample NIG2, representative analyses are given for various zones from the violet core to the dark yellowish green rim. Abbreviation: bdl = below detection limit.

Table IV: Trace elements in tourmaline from Nigeria, measured by LA-ICP-MS.[a]

Sample No.	NIG1	NIG2A	NIG2B	NIG2C	NIG2D	NIG2E	NIG2F
Colour	Greenish blue	Violet	Violet	Violet	Blue	Blue	Yellowish green
Trace elements (ppm)							
Li	9881	7083	9304	8885	8964	9697	7995
B	28623	30472	31371	28634	28505	30723	29772
Mg	0.27	bdl	bdl	0.30	2.18	232	455
Cu	2120	3668	3040	2929	5023	5053	4321
Zn	48.5	bdl	bdl	bdl	49.9	420	1048
La	bdl	bdl	bdl	bdl	bdl	0.87	0.85
Ce	bdl	bdl	bdl	bdl	bdl	1.37	1.65
Pr	bdl	bdl	bdl	bdl	bdl	0.08	0.13
Nd	bdl	bdl	bdl	bdl	bdl	bdl	0.25
Sm	bdl	bdl	bdl	bdl	bdl	bdl	0.33
Pb	859	21.1	15.2	15.5	75.7	24.2	69.3
Bi	431	125	84.1	78.6	2905	2011	2415
Σ REE	bdl	bdl	bdl	bdl	bdl	2.3	3.2

[a] See notes in Table I regarding the LA-ICP-MS analyses. Ni is below detection limit in all samples. Abbreviation: bdl = below detection limit.

NIG2						
2.41						
10.5						
Yellowish green						
G1	G2	G3	G4	G5	G6	G7
36.60	36.48	36.49	36.77	36.69	36.60	36.40
0.12	0.10	0.09	0.06	0.09	0.09	0.07
10.60	10.57	10.57	10.65	10.63	10.60	10.54
39.32	38.89	38.61	39.29	38.86	38.88	38.56
bdl	bdl	bdl	bdl	bdl	bdl	0.06
0.33	0.30	0.33	0.25	0.24	0.31	0.27
2.05	2.40	2.44	2.21	2.26	2.20	2.55
0.69	0.64	0.76	0.64	0.64	0.69	0.66
0.93	0.87	0.81	0.48	0.71	0.84	0.78
0.09	0.06	0.06	0.11	0.05	bdl	bdl
bdl	bdl	bdl	bdl	bdl	0.09	bdl
0.29	0.36	0.29	0.32	0.22	0.29	0.32
1.33	1.36	1.42	1.46	1.51	1.45	1.40
2.10	2.13	2.21	2.13	2.15	2.15	2.26
1.16	1.16	1.01	0.91	1.24	1.01	1.46
2.91	2.90	2.94	2.99	2.90	2.95	2.82
−0.49	−0.49	−0.43	−0.38	−0.52	−0.42	−0.62
98.01	**97.72**	**97.61**	**97.87**	**97.66**	**97.71**	**97.53**
6.000	6.000	6.000	6.000	6.000	6.000	6.000
3.000	3.000	3.000	3.000	3.000	3.000	3.000
7.596	7.538	7.483	7.556	7.490	7.513	7.491
0.000	0.000	0.000	0.000	0.000	0.000	0.014
0.014	0.013	0.011	0.007	0.012	0.011	0.008
0.285	0.334	0.339	0.306	0.313	0.306	0.356
0.094	0.088	0.105	0.087	0.087	0.094	0.092
0.115	0.108	0.101	0.059	0.087	0.103	0.097
0.010	0.007	0.008	0.013	0.006	0.000	0.000
0.874	0.896	0.940	0.958	0.995	0.956	0.928
8.987	**8.984**	**8.987**	**8.986**	**8.990**	**8.984**	**8.986**
0.058	0.052	0.057	0.043	0.042	0.055	0.048
0.000	0.000	0.000	0.000	0.000	0.004	0.000
0.013	0.016	0.013	0.014	0.010	0.013	0.014
0.668	0.680	0.704	0.674	0.681	0.683	0.724
0.261	0.252	0.226	0.269	0.267	0.246	0.214
1.000	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**
0.625	0.627	0.550	0.489	0.669	0.545	0.788
0.187	0.186	0.225	0.256	0.165	0.228	0.106
0.188	0.187	0.225	0.255	0.166	0.227	0.106
1.000	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**

The formula units of tourmaline were calculated by normalising to 31 (O+OH+F) and 15 cations in the tetrahedral and octahedral sites (T+Z+Y). OH and O were calculated by using the empirical formulae OH = 3+(1–F)/2 and O = 31–(F+OH) of Grice and Ercit (1993). Li_2O was calculated based on the assumptions that (1) Si = 6 apfu, (2) Al on the tetrahedral position is negligible (Ertl et al., 2013) and (3) the Y position is completely filled with 3 apfu. Because there is no indication of tetrahedrally coordinated B, the B_2O_3 content was calculated with the assumption that the B site is completely filled with 3 apfu. The Z position will be almost completely occupied by $^{[6]}$Al and perhaps additional small amounts of Ti (Ertl et al., 2012), while the Y position is occupied by the remaining amounts of $^{[6]}$Al, V, Mg, Mn, Fe, Cu, Zn and Li. Calcium, Pb, Bi, Na, K and vacancies are on the X site.

Results

Average chemical analyses and corresponding formulae for each sample are presented in Tables I, II and III/IV for Brazil, Mozambique and Nigeria, respectively. Except for the colour-zoned crystal NIG2, no individual point analyses are presented, although chemical variations within the individual samples may be considerable.

All of the samples show homogeneous coloration except for NIG2, which has a violet core, a blue intermediate zone and a dark yellowish green rim (Figure 2). A backscattered electron (BSE) image of this tourmaline (produced using the electron microprobe) revealed that the core is homogeneous in composition and has a sharp boundary with the adjacent blue zone (Figure 7). The visually more diffuse boundary between that zone and the yellowish green rim is due to the presence of domains of variable composition, as revealed by darker and lighter areas, with the latter corresponding to higher average atomic number. Darker-appearing domains in the BSE image are predominant in the blue zone, whereas the yellowish green rim has darker and lighter domains that are present in similar proportions.

X-site Composition

With average Na_2O values between 1.8 and 2.7 wt.%, Na is by far the most important cation in the X site of the tourmaline samples analysed, whereas K is always below the detection limit of EMPA. CaO never exceeds 1 wt.%. Thus, based on their X-site occupancy, all of the tourmalines belong to the alkali group (Henry et al., 2011; Figure 8a) with 0.56–0.83 apfu Na, up to 0.15 apfu Ca and up to 0.38 apfu vacancies. Within the alkali group, all samples plot in the elbaite field, and most of them are close to the elbaite end member (Figure 8b).

Lithium

Li contents were measured by LA-ICP-MS (Li_2O** in Tables I and II), but calculation of the tourmaline formulas using these values consistently resulted in excessive occupancy of the Y position (=Li+Al+Mn+Cu[+Mg+Fe]), that is, exceeding the

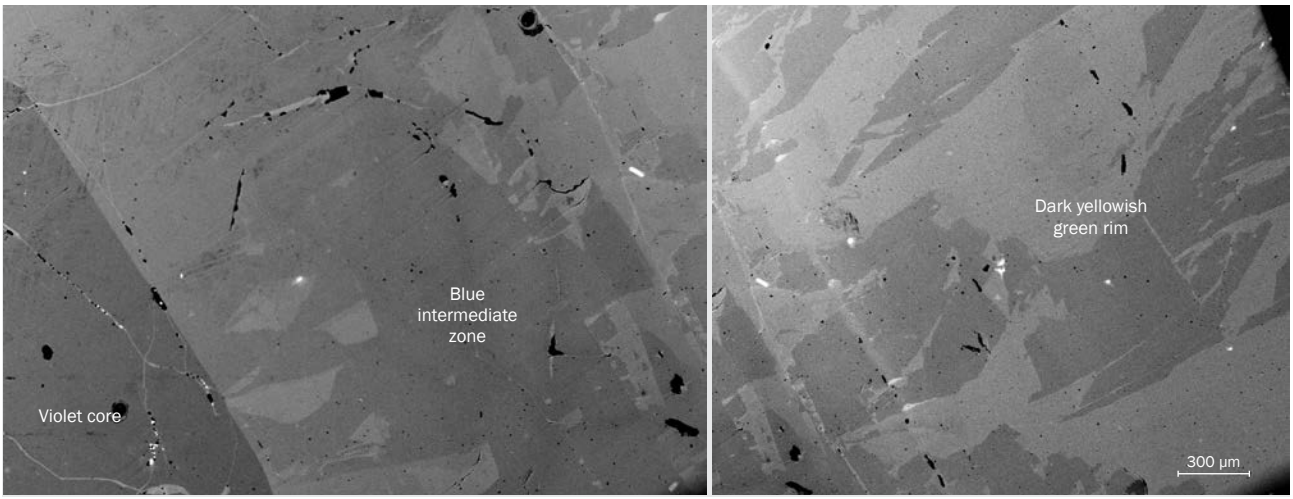

Figure 7: BSE imaging of the zoned tourmaline NIG2 shows a sharp boundary between the compositionally homogeneous violet core and the blue intermediate zone, the latter gradually merging with the dark yellowish green rim. The outer zones are formed by darker- and lighter-appearing domains of different composition. The crystallographic orientation of the section is perpendicular to the c-axis.

maximum possible site occupancy of 3 cations. This discrepancy may be due to problems with the non-routine Li standardization of the LA-ICP-MS analyses. Consequently, the Li contents theoretically calculated for the tourmaline formula at Y = 3 are used in the following considerations and are given as Li_2O* in Tables I–III.

The calculated Li_2O contents fall within a range of 0.62–1.73 wt.% (or 0.40–1.08 apfu). The Li/(Li+^{Y}Al) ratios are in the range of 0.20–0.39 (average of 0.32) for the Brazilian samples and 0.21–0.36 (lower average of 0.25) for those from Mozambique. The unzoned Nigerian tourmaline NIG1 yielded a Li/(Li+^{Y}Al) ratio of 0.39, while the zoned sample provided a range of 0.25–0.42. In general, tourmaline with a relatively low Li/(Li+^{Y}Al) ratio of <0.5 and/or a high amount of vacancies at the X site may have a considerable content of the rossmanite end member □($LiAl_2$)$Al_6(BO_3)_3[Si_6O_{18}](OH)_4$. However, there is only a very indistinct negative correlation between the Li/(Li+^{Y}Al) ratio and X-site vacancies in our samples, which is expected for the substitution $^{X}\square^{Y}$(1.5Li+1.5Al) = ^{X}Na^{Y}(Li+2Al).

Boron

As stated above, the B_2O_3 contents for our tourmalines are calculated for a boron position that is completely filled with 3.0 apfu B (see B_2O_3* in Tables I–III). The B_2O_3 contents determined by LA-ICP-MS vary between 8.52 and 10.98 wt.% (see B_2O_3** in Tables I–II), leading to <3.0 apfu B, with BRA17 as the only exception. We assume that the variability of our B_2O_3** data and a tendency toward an unfilled B position are, at least partly, due to the relatively high analytical uncertainty of the LA-ICP-MS method (which is more suited for trace than for major elements).

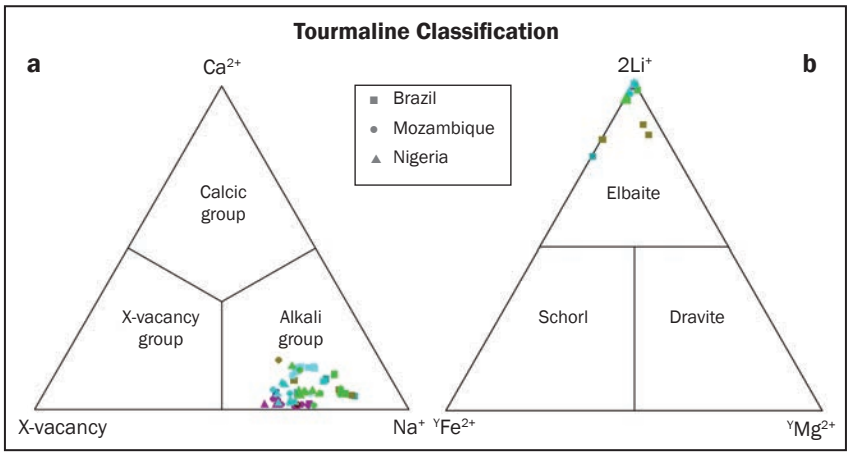

Figure 8: (a) The ternary plot of Ca^{2+}–Na^{+}–X-site vacancy is used to classify the principal groups of tourmaline based on X-site occupancy (Henry et al., 2011). All of the samples belong to the alkali group. (b) The ternary diagram $2Li^{+}$–Mg^{2+}–Fe^{2+} for Y-site occupancy of alkali-group tourmalines indicates that all of the analysed samples are elbaite. The colour of the symbols broadly correlates with the colour of the tourmaline.

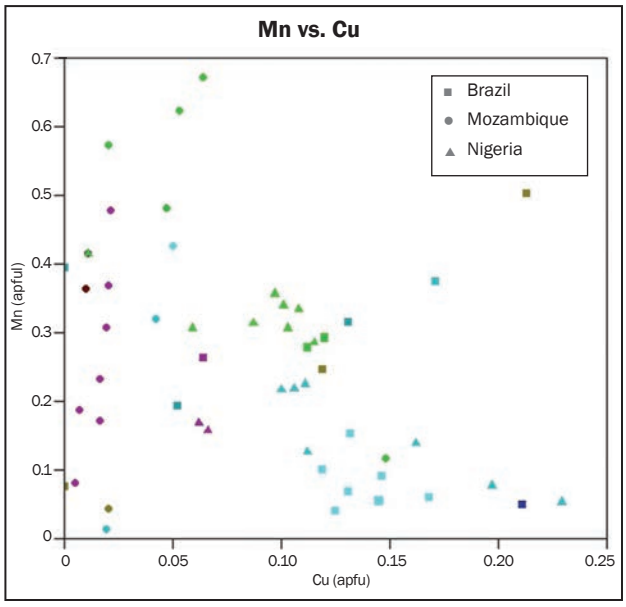

Figure 9: In this plot of Mn vs.Cu, there is no systematic correlation between the contents of these elements and coloration of the tourmalines.

W-site Composition

Fluorine is an important minor constituent in all samples, with average values of 1.1–2.1 wt.% F (0.61–1.09 apfu) for the Brazilian and 1.1–1.8 wt.% F (0.58–0.93 apfu) for the Mozambique tourmalines, while the unzoned Nigerian sample NIG1 contains 1.6 wt.% F and the zoned crystal NIG2 has 0.6–1.5 wt.% F. However, even optically unzoned tourmalines revealed a considerable F variation within individual samples (e.g. 0.6–2.0 wt.% in BRA5 and 1.3–2.3 wt.% in MOZ14). All of the data plot in the field of the 'fluor-' tourmaline subgroup in the ternary diagram F^-–OH^-–O^{2-} for the W-site occupancy (Henry et al., 2011) and, consequently, are assigned to fluor-elbaite. The Brazilian tourmalines are typically richer in F than those from Mozambique. Five of the former reach the theoretical maximum value of F = 1 apfu for W-site occupancy (Cl was below the EMPA detection limit), and thus approach the theoretical fluor-elbaite end member $Na(Li_{1.5}Al_{1.5})Al_6(BO_3)_3[Si_6O_{18}](OH)_3F$. In the zoned Nigerian tourmaline NIG2, the F contents range between 0.32 and 0.85 apfu.

Other Minor and Trace Elements

Manganese is by far the most important minor element in the tourmalines and, consequently, the main substitution on the Y site is $2Mn^{2+} = Li^+ + Al^{3+}$. The content of MnO_{tot} (in wt.%) ranges from 0.1 in MOZ18 to 4.8 in MOZ13, and from 0.3 in BRA18 to 3.7 in BRA6; we noted a tendency for lower Mn contents in the tourmalines from Brazil than in those from Mozambique (Figure 9; Tables I and II). In the zoned crystal NIG2, the MnO_{tot} content is 1.1–1.2 wt.% in the violet core, 0.4–1.6 wt.% in the blue intermediate zone, and increases to 2.1–2.5 wt.% in the dark yellowish green rim (Table III).

Copper also is an important minor element in the samples. Contents of >6,000 ppm Cu were recorded in most of those from Brazil, with a maximum value of 13,917 ppm in yellow-green tourmaline BRA6 (Figure 9; Table I). In contrast, two of the Brazilian samples—BRA1 and BRA9—display exceptionally low Cu contents of only 2–3 ppm and thus do not conform to the definition of Paraíba-type tourmalines. The Mozambique tourmalines show a rather wide variation between 353 and 4,074 ppm Cu, with an exceptionally high value of 9,780 ppm Cu for greenish blue sample MOZ15 (Figure 9; Table II). In the zoned crystal NIG2, the Cu contents are 2,929–3,668 ppm in the violet core, sharply increase to 5,023–5,053 ppm in the blue intermediate zone and decrease to 4,321 ppm in the dark yellowish green rim (Figure 9 and Table IV). Within this sample, Cu shows a roughly negative correlation with Mn and a somewhat positive correlation with Ca (Figure 10).

With rare exception, Fe, Mg and Ti are at or below the detection limit of EMPA (Tables I–III). Only two of the Paraíba-type samples from Brazil revealed slightly higher Fe contents (i.e. BRA6 = 0.3 and BRA10 = 0.5 wt.% FeO_{tot}), corresponding to Y-site occupancies of 0.04 and 0.07 apfu Fe^{2+} (Table I; Figures 8b and 11). Hence these tourmalines contain very little of the schorl end member. In the zoned crystal NIG2, the Fe content increases significantly from the core (below detection limit) to the rim (0.8 wt.% FeO_{tot}; Table III).

In most of the tourmalines, Mg contents are at the ppm level, although with a few significant exceptions. The Brazilian samples exhibit a strong variation between 0.3 and 84 ppm Mg, with distinctly higher contents of 139, 841 and 3,637 ppm in samples BRA3, BRA6 and BRA10, corresponding to 0.02–0.60 wt.% MgO (Table I; Figure 8b). Lower Mg contents were recorded in the Mozambique tourmalines, in which Mg is below the detection limit in seven samples and, for the remaining 11 pieces, only three yielded >1 ppm (i.e. up to 2.7 ppm and an exceptional value of 133 ppm in

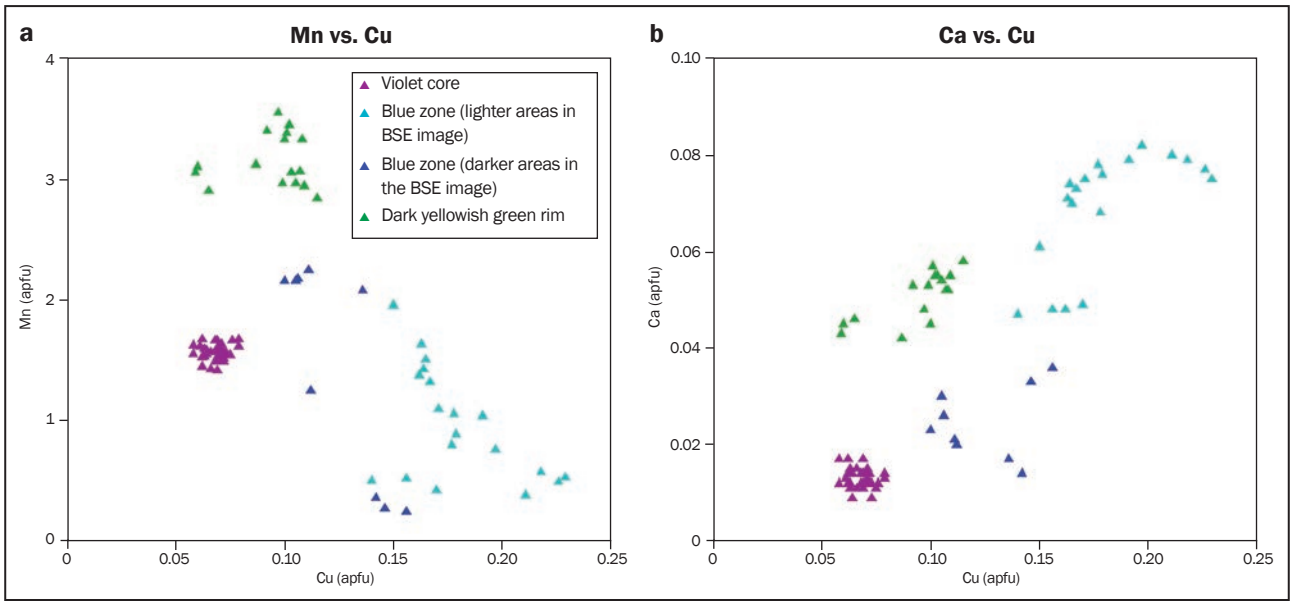

Figure 10: The composition of the zoned tourmaline NIG2 (selected analyses shown in Tables III and IV) is shown in these diagrams of (a) Mn vs. Cu and (b) Ca vs. Cu. The violet core displays a homogeneous composition, whereas the yellowish green rim covers a somewhat broader field of higher Mn and Ca contents. Together with the blue intermediate zone, this field forms a rough compositional trend with a negative correlation of Mn vs. Cu and a positive correlation of Ca vs. Cu.

MOZ17; see Table II). In the zoned crystal NIG2, Mg slightly increases from values below the detection limit in the violet core to 2.2 → 232 → 455 ppm toward the dark yellowish green rim (Table IV).

Among other minor elements frequently present in tourmaline, Cr is below the detection limit, and V is near the detection limit of the EMPA in all samples except BRA6 (0.48 wt.% V_2O_3) and BRA10 (0.62 wt.% V_2O_3). Those tourmalines also contain significant contents of Mg (0.46 and 0.62 wt.% MgO, respectively) and Cu (1.74 and 0.97 wt.% CuO). Such relatively high amounts of Cu, together with V_2O_3 contents up to ~0.6 wt.%, are quite unusual in tourmaline.

Figure 11: The ternary diagram of Al–$Al_{50}Fe_{50}$–$Al_{50}Mg_{50}$ is used to correlate tourmaline composition to host-rock type. As expected, all of the analysed samples plot in the field corresponding to granitic pegmatites. Modified after Henry and Guidotti (1985) and van Hinsberg et al. (2011).

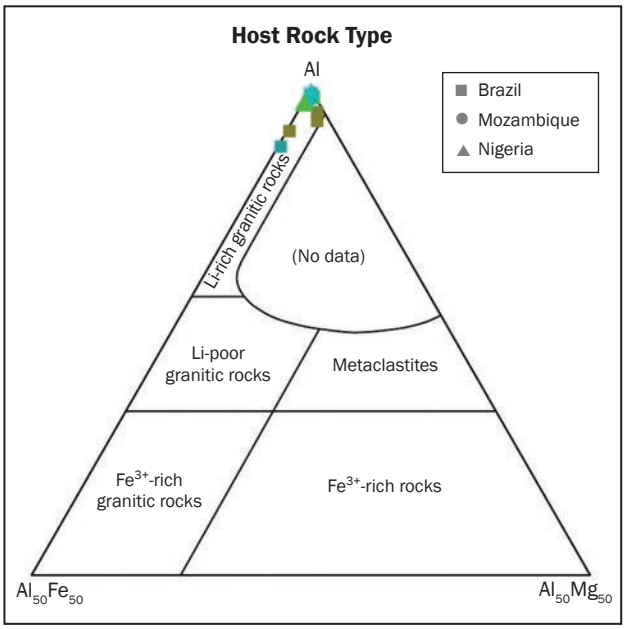

Nickel is below the detection limit of the LA-ICP-MS, except for MOZ17 with 0.74 ppm and BRA18 with 3.6 ppm. For most of the Mozambique tourmalines, Zn values are at the detection limit, although four samples have Zn contents between 4.5 and 24 ppm and MOZ15 and MOZ17 contain 269 and 81 ppm Zn, respectively. In contrast, almost all the Brazilian tourmalines show Zn contents above the detection limit, between 12 and 25 ppm in five samples and from 80 ppm up to 13,820 ppm in 12 samples. Zinc contents in the Nigerian tourmalines are 49 ppm in NIG1 and in NIG2 Zn ranges from below the detection limit in the violet core, up to ~50 → 420 → 1,048 ppm towards the dark yellowish green rim (Table IV).

Lead contents typically range between values close to the detection limit and ~170 ppm. Exceptionally high Pb values were recorded in NIG1 (859 ppm) and BRA18 (4,002 ppm). Bismuth is present in values up to ~2,900 ppm. Whereas Bi is between 84 and 125 ppm in the violet core of

NIG2, values of 2,905 → 2,011 → 2,415 ppm were recorded from the blue zone to the dark yellowish green rim (Table IV).

Rare-earth elements are generally below or near the detection limit in the Mozambique samples, except for MOZ15 and MOZ17 that contain some light REE, with REE totals of 0.8 and 11 ppm, respectively. In the Brazilian tourmalines, trace amounts of the light REE were almost always recorded, particularly La, Ce and Pr. REE totals are between 0.3 and 7.9 ppm except for BRA2 and BRA3, with REE generally below the detection limit. In sample NIG1, all REE are below the detection limit, as well as in the core of NIG2. Near the rim, minor contents of the light REE were measured, with REE totals of 2.3 and 3.2 ppm.

Discussion

Colour and Trace-Element Contents

The contents of Cu measured in the studied tourmalines are similar to those published in the literature. For instance, Abduriyim et al. (2006) analysed 198 stones of various shades of blue and green from Brazil, Mozambique and Nigeria, and obtained Cu ranges of 3,200–20,000, 1,300–25,600 and 3,800–25,500 ppm, respectively.

Although Mn and Cu are important colouring elements in tourmaline, there is no obvious correlation between the contents of these elements and coloration in the investigated samples (Tables I–IV and Figure 9). Even within optically unzoned crystals, considerable variations in MnO_{tot} and Cu were recorded (e.g. 1.6–3.0 wt.% MnO_{tot} in MOZ5 and 10,900–15,300 ppm Cu in BRA5). Nevertheless, certain trends may be observed in the Mn vs. Cu diagram (Figure 9): Most of the green and blue tourmalines from Brazil belong to the high-Cu group (>7,000 ppm Cu), except for one purple and one violetish blue sample (4,148 and 3,354 ppm Cu, respectively). Moreover, one yellowish green and one blue Brazilian tourmaline yielded <3 ppm Cu; the coloration of these non-Paraíba-type stones is mainly due to varying amounts of Fe^{2+} and Fe^{3+}; the green colour can be due to both Fe^{2+} and Fe^{3+} (Mattson and Rossman, 1987) and the blue colour is due to Fe^{2+} (Rossmann, 2016). In the authors' opinion, intervalence charge transfer involving Mn^{2+}–Ti^{4+} (Rossman and Mattson, 1986) probably has only a minor influence (if any) on the greenish coloration of most of the investigated tourmalines, because their Ti contents are very small (usually close to the EMPA detection limit, although some samples have up to ~0.1 wt.% TiO_2).

For the tourmalines from Mozambique, two distinct groups can be distinguished: one group of six blue-to-green samples displays higher Cu contents (>2,500 ppm), whereas the other group with pink-to-violet samples displays lower Cu contents (<1,500 ppm). However, two greenish tourmalines belong to the second group as well, thus blurring the distinction (Figure 9). Colour zonation in NIG2 is matched by variations in Mn and Cu contents (Figure 10a).

The green colour of the three vanadium-bearing Paraíba-type tourmalines (BRA6, BRA7 and BRA10) from Brazil is apparently due to both Cu^{2+} and V^{3+}. Sample BRA7, with the lowest V_2O_3 content (0.13 wt.%), has a greenish blue colour mainly caused by Cu^{2+} (0.89 wt.% CuO; bluish component) with only a minor effect of V^{3+} (greenish component; see also Schmetzer et al., 2007). The tourmalines BRA6 and BRA10 may owe their 'olive' green colour mainly to V^{3+} (0.48 and 0.62 wt.% V_2O_3), whereas Cr is below the detection limit. Spectroscopic features of an Austrian tourmaline with a similar colour and V_2O_3 content strongly testify to V^{3+} (Ertl et al., 2008). Gem tourmalines containing simultaneously significant amounts of V and Cu are quite rare.

It is widely known that Cu- and Mn-bearing, initially purple-to-violet tourmaline may be heat treated to produce the famous Paraíba blue coloration (e.g. Milisenda et al., 2006; Laurs et al., 2008). According to our data, CuO/MnO_{tot} ratios of such heated tourmalines should commonly be low (<0.5), due to low CuO/MnO_{tot} ratios in the original purple-to-violet tourmalines. For example, these values vary between 0.03 and 0.39 (average 0.13) in our purple and violet tourmalines (MOZ1, 2, 4, 6, 8, 10–12 and BRA3). Ratios of CuO/MnO_{tot} within this range (0.04–0.27) also were reported by Laurs et al. (2008) for pink, purple and violet tourmalines from Mozambique. In contrast, CuO/MnO_{tot} ratios in blue to bluish green Cu- and Mn-bearing tourmaline from Brazil usually are higher, ranging between 0.6 and 4.2 (i.e. BRA11–18 and BRA21–25 in Ertl et al., 2013). These samples are assumed to be untreated, and showed an average CuO/MnO_{tot} value of 2.25. Hence, there are indications that blue Cu-bearing tourmaline with CuO/MnO_{tot} <0.5 has been heat treated to

reduce the originally reddish component of Mn^{3+}. This appears to be the case for greenish blue sample NIG1, with a CuO/MnO_{tot} ratio of 0.40. However, more samples should be analysed to test this criterion.

For greenish Cu- and Fe-bearing tourmalines, the cause of colour is more complex. For instance, the blue and yellowish green colours displayed by sample NIG2 are presumably caused by different proportions of the domains richer and poorer in Cu (0.48–1.85 wt.% CuO; Figures 7 and 10) and Fe (up to 0.76 wt.% FeO_{tot}), whereas the Ti contents are generally very low (up to 0.12 wt.%). The Mn contents are distinctly higher in the yellowish green rim (2.05–2.55 wt.% MnO_{tot}) than in the violet core (1.15–1.23 wt.% MnO_{tot}), whereas they are highly variable in the transitional blue zone (0.38–1.63 wt.% MnO_{tot}). This means that the patchy appearance observed in the BSE image of the outer portion of this sample (Figure 7) is mainly due to variations in the Mn, Cu and Fe contents.

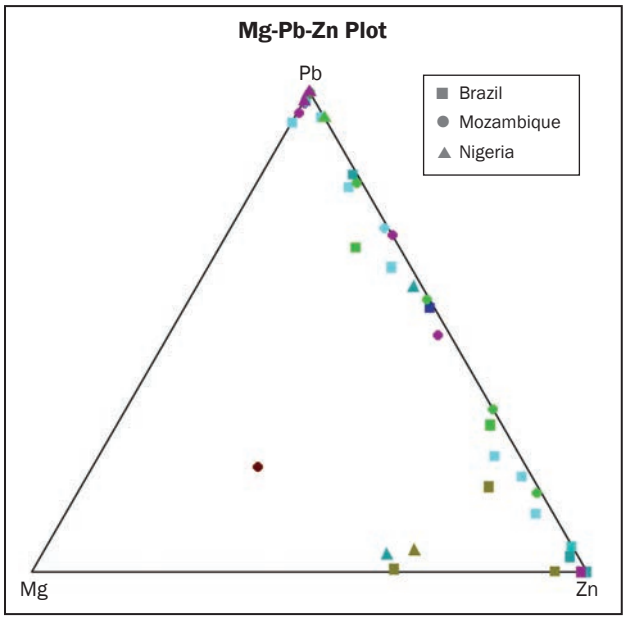

Figure 12: The ternary diagram Pb-Zn-Mg used by Abduriyim et al. (2006) for provenance discrimination does not reveal any systematic differences between the Paraíba-type tourmalines from Brazil, Mozambique and Nigeria that were analysed for this study.

Source Rock and Provenance Criteria

In the ternary diagram Al-Mg-Fe_{tot} for discriminating the host rock of various tourmalines (Figure 11), all of the investigated samples plot at, or near, the Al apex, within the field of Li-rich granitoids or their pegmatites and aplites (Henry and Guidotti, 1985). This is consistent with the known or inferred geological origin of these tourmalines as originating from granitic pegmatites and/or related placer deposits.

As seen in the Mn vs. Cu variation diagram (Figure 9), tourmalines from Brazil and Mozambique display similar ranges of Mn, with maximum values of 3.66 and 4.75 wt.% MnO_{tot}, respectively, but in general show significant differences in their Cu contents. Whereas nearly all samples from Mozambique contained <4,100 ppm Cu, 14 Brazilian stones yielded >7,000 ppm Cu. Notable exceptions are samples BRA2 and BRA3 with intermediate Cu contents, BRA1 and BRA9 with <3 ppm Cu, as well as MOZ15 with nearly 9,800 ppm Cu. However, due to their large variability, contents of Mn, Cu and other elements are not sufficient for a reliable discrimination between the localities.

Based on a ternary plot of Pb-Zn-Mg, Abduriyim et al. (2006) revealed tendencies to distinguish between different provenances of Paraíba-type tourmalines, with Brazilian ones being typically Mg-Zn dominant, Mozambique samples showing Pb dominance and Nigerian tourmalines being Pb-Zn dominant. However, almost all of our samples are poor in Mg and plot unsystematically along the Pb-Zn side of the triangle (Figure 12). The zoned tourmaline from Nigeria NIG2 is lacking Mg and Zn in the inner part, so analyses from the violet and the blue zones therefore plot close to the Zn apex, whereas one analysis from the outer portion of the blue zone and from the green zone have somewhat elevated Zn and Mg contents and plot along the Zn-Mg side.

Milisenda et al. (2006) used a CuO/CaO vs. Pb diagram for the first step of discriminating Cu-bearing tourmalines from Brazil, Mozambique and Nigeria. They defined a Brazilian field by CuO/CaO ratios up to 10 and Pb contents up to 100 ppm. Our tourmalines from Brazil in general plot into this field. The Mozambique tourmalines analysed by Milisenda et al. (2006) defined two fields in the diagram, a first one overlapping the Brazilian field and a second one with CuO/CaO ratios below 1 and Pb contents up to 1,200 ppm. Our Mozambique samples plot into the first field and, therefore, are not distinct from the Brazilian ones. Tourmaline compositions of Milisenda et al. (2006) from Nigeria matched either the first or second field mentioned above (corresponding to type I

Figure 13: This 18 ct white gold and diamond pendant features a 6.98 ct green Cu-bearing tourmaline from Mozambique. Courtesy of collectorfinejewelry.com; photo by Mia Dixon.

and type II, respectively). All analyses of our zoned tourmaline NIG2 display CuO/CaO ratios between 2 and 8 at Pb contents clearly below 100 ppm, thus belonging to Nigeria type I of Milisenda et al. (2006). In contrast, sample NIG1 clearly fits with type 2. For further discriminations, a CuO+MnO versus Pb/Be diagram was used by Milisenda et al. (2006), but this diagram also does not allow for unambiguous provenance assignment of our samples. A third diagram used by Milisenda et al. (2006) involved the Pb/Be ratio, but Be was not analysed in our study. It should be noted that for origin determination the isotope ratios of boron and lithium, $\delta^{11}B$ and $\delta^{7}Li$, are more suitable than trace-element content (e.g. Shabaga et al., 2010; Marschall and Jiang, 2011).

From plate-tectonic considerations, a spatial and temporal connection between the tourmaline-bearing pegmatites in northeast Brazil and Nigeria seems possible (Milisenda, 2001a; Milisenda and Henn, 2001), although precise results from radiometric dating are still needed to prove this possibility.

Conclusions

Paraíba-type tourmaline is prized for its vibrant coloration (e.g. Figure 13), and is currently known from pegmatite provinces in Paraíba and Rio Grande del Norte States, Brazil, from Alto Ligonha, Mozambique and from Oyo State, Nigeria. Chemical analysis by EMPA and LA-ICP-MS of 38 samples from these three countries revealed that they are virtually Mg-free and Fe-poor elbaite (close to the end-member composition). In all samples, F occupied >0.5 apfu in the W site, thus conforming to the fluor-elbaite species. Significant, though highly variable amounts of Cu^{2+} ± Mn^{2+} ± Mn^{3+} are the main chromophores in most of the variably coloured tourmalines, consistent with results previously published in the literature. Our blue-to-green samples from Brazil contain up to 13,920 ppm Cu and 3.7 wt.% MnO_{tot}, and from Mozambique the maximum contents are 9,780 ppm Cu and 4.8 wt.% MnO_{tot}, whereas a zoned crystal from Nigeria yielded up to 5,050 ppm Cu and 2.6 wt.% MnO_{tot}. Some of the green Cu-bearing tourmalines from Brazil may partially owe their colour to V (with up to 0.6 V_2O_3) in rare combination with Cu. Green coloration in the Nigerian tourmalines is probably caused by a combination of Mn, Cu and Fe. We suggest that CuO/MnO_{tot} <0.5 is indicative of heat treatment in blue Cu-bearing tourmaline to reduce the contribution of the reddish component of Mn^{3+}.

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Identification of Colourless HPHT-grown Synthetic Diamonds from Shandong, China

Zhonghua Song, Taijin Lu, Shi Tang, Jie Ke, Jun Su, Bo Gao, Ning Hu, Jun Zhang, Jun Zhou, Lijun Bi and Dufu Wang

Colourless HPHT-grown synthetic diamonds are becoming more common in the marketplace. The authors recently studied 20 samples weighing 0.06–0.67 ct from a producer located in Jinan, Shandong, China. The 10 crystals showed a combination of cubic and octahedral forms, sometimes with small faces corresponding to {110} and {113}, and the 10 round brilliant cuts had colour grades up to D–E and clarity grades up to VS1. Some of the samples were attracted to a magnet due to their metallic inclusions. They showed very weak anomalous birefringence with low-order interference colours between crossed polarizers. UV-Vis spectra recorded a weak absorption at 270 nm, and infrared spectra indicated that all samples contained variable traces of boron, suggesting that they are mixed type Ib and IIb. DiamondView imaging revealed distinct cuboctahedral growth sectors and produced strong greenish blue phosphorescence. These synthetic diamonds can be reliably identified using a combination of FTIR, UV-Vis, microscopy and luminescence imaging techniques.

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Introduction

Since 2014, remarkable progress has been made in the production of colourless high-pressure, high-temperature (HPHT)-grown synthetic diamonds. Companies such as AOTC Group (The Netherlands) and New Diamond Technology (NDT; Russia) have succeeded in growing colourless to near-colourless material for use in jewellery (e.g. D'Haenens-Johansson et al., 2014, 2015). AOTC mainly uses BARS or toroid presses, and NDT employs cubic press technology. In the first half of 2015, several HPHT synthetic diamond companies in China also began producing high-quality colourless synthetic diamonds in large volume, mainly as melee-sized material (Lan et al., 2015). In late 2015, the present authors had the opportunity to study samples produced by Jinan Zhongwu New Materials Co. Ltd. (Jinan, Shandong), and in March 2016 representatives from the National Gemstone Testing Center (NGTC) in Beijing visited the facility to learn about the equipment, growth techniques, production, etc. Recently, Wang and Moses (2016) reported initial observations of 50 colourless gem-quality crystals obtained from the same company.

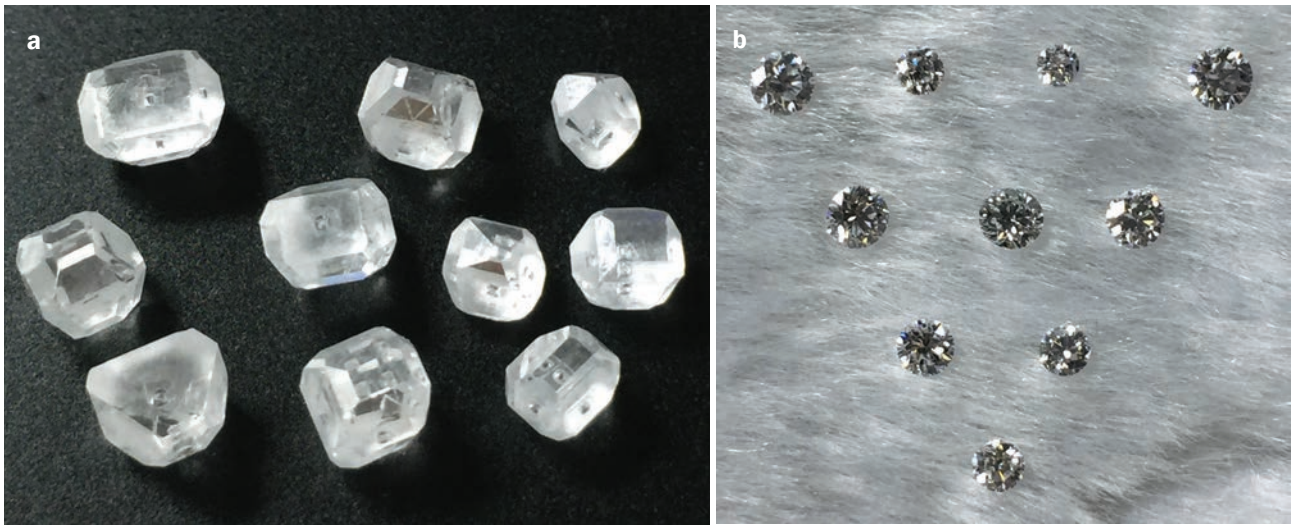

Figure 1: Studied for this report were (a) 10 colourless crystals (0.26–0.67 ct) and (b) 10 colourless faceted HPHT-grown synthetic diamonds (0.06–0.19 ct) from Jinan Zhongwu New Materials in Shangdong, China. Photos by Z. Song.

Jinan Zhongwu New Materials employs domestically made cubic HPHT presses, and there are about 70 of these apparatuses now being used by the company to grow synthetic diamonds. Their synthesis techniques came from a project titled 'Large-sized Synthetic Diamonds Technology Introduction' that was launched in 2011, jointly undertaken by Jinan Zhongwu New Materials and a prominent academic research institution abroad. By combining foreign technology and China's equipment advantages, the company has successfully grown large synthetic diamonds (crystals up to 10 ct). In addition to yellow and blue material, they have produced commercial quantities of colourless synthetic diamonds.

As part of a project to study the characteristics of synthetic diamonds from different producers over time, and to provide updated information to the market and to gem laboratories, the authors characterized a selection of rough and cut colourless HPHT-grown synthetic diamonds from Jinan Zhongwu New Materials for this report.

Materials and Methods

The 10 crystals weighed 0.26–0.67 ct and the 10 faceted synthetics (all round brilliant cuts) were 0.06–0.19 ct (Figure 1). Characterization took place at the NGTC laboratory in Beijing, and all the faceted samples were tested with the methods described below. (The crystals were subjected only to microscopic examination and photoluminescence spectroscopy.) A gemmological microscope was used to observe their inclusions and anomalous birefringence. Fluorescence and phosphorescence were observed with both long-wave (365 nm) and short-wave (253 nm) UV radiation and a DiamondView instrument. Phosphorescence spectra were collected with an Ocean Optics QE Pro spectrometer equipped with an Avantes AvaLight-DH-S deuterium-halogen light source, using the methods described by Eaton-Magaña et al. (2008). Fourier-transform infrared (FTIR) spectroscopy was performed using a Thermo Nicolet 6700 spectrometer in the range of 6000–400 cm^{-1} (128 scans at a resolution of 2 cm^{-1}). A Renishaw InVia Raman microspectrometer was used to collect photoluminescence (PL) spectra of the samples with four laser excitations (325, 473, 532 and 785 nm) at liquid-nitrogen temperature. A Gem-3000 ultraviolet-visible (UV-Vis) spectrometer was used to obtain absorption spectra at room temperature. Chemical analyses were performed with a Thermo Scientific ARL QUANT'X energy-dispersive X-ray fluorescence (EDXRF) spectrometer, with 20 kV voltage, 1.98 mA current and a Pd thin filter for 100 seconds.

About 50 colourless crystals ranging up to 3.50 ct also were examined with a loupe at the factory.

Results

Basic Properties

The crystals showed typical cuboctahedral morphology with well-developed {100} and {111} forms and weakly developed faces corresponding

to {110} and {113}. In some samples, the {110} form was more developed than {113}, while others showed the opposite. All samples contained distinct metallic inclusions, and some could be attracted to a strong magnet.

The details of the weight, colour and clarity grades of the faceted samples are reported in Table I. One sample was colour graded as D and the remaining nine were E colour. Clarity grades ranged from VS_1 to I_2, with most samples containing a few rod-like inclusions (Figure 2a). Some of these inclusions displayed colourful iridescence in reflected light (Figure 2b). Samples with lower clarity grades contained numerous irregular-shaped dark metallic inclusions (Figure 2c). A small square-shaped cloud was present in one of the synthetics (Figure 2d). Those with VS clarity grades were not attracted to the magnet, while the lower grades usually had obvious metallic inclusions and were easily attracted. Sample BST008 was even attracted to magnetized tweezers as a result of the large quantity of metallic inclusions.

Viewed with the microscope between crossed polarizers, all the colourless HPHT synthetic diamonds showed only weak or very weak anomalous birefringence, with low-order interference colours (mostly grey or brown), indicating low levels of strain (Figure 3a). Moreover, weak anomalous birefringence was seen around pinpoint inclusions where the synthetic diamond lattice was possibly distorted. By comparison, noticeable anomalous birefringence is a common optical feature in natural and CVD synthetic diamonds. Normally, the birefringence of natural diamond appears as mottled, banded or cross-hatched ('tatami') patterns (see Figure 3b and Howell, 2012), while CVD synthetic diamond shows linear or grid-like patterns (see Figure 3c and Pinto and Jones, 2009).

Fluorescence and Phosphorescence

The luminescence characteristics of the polished samples are reported in Table I. When exposed to long-wave UV radiation, all samples displayed weak yellow fluorescence and no phosphorescence. The response to short-wave UV radiation, however, was medium-to-strong yellow-green fluorescence with green phosphorescence. Obvious bluish green phosphorescence was seen with the unaided eye after the synthetic diamonds were illuminated with the Avantes AvaLight-DH-S deuterium-halogen light source.

Further observations of the samples' fluorescence and phosphorescence characteristics were conducted using the DiamondView, in which all samples fluoresced greyish blue (Figure 4) and phosphoresced strong greenish blue. The cuboctahedral growth sector could be seen in all samples through the pavilion, but was only visible through the table when the table facet was cut parallel or nearly parallel to the [100] direction.

Phosphorescence spectra showed a band centred at approximately 500 nm (e.g. Figure 5). The 575 nm band reported by D'Haenens-Johansson et al. (2015) in the HPHT-grown synthetic diamonds from NDT was not detected in our samples.

Table I: Properties of faceted HPHT-grown synthetic diamonds from Shandong, China.

Sample no.	Weight (ct)	Colour	Clarity	Magnetic?	EDXRF (Fe?)	Long-wave UV		Short-wave UV	
						Fluorescence	Phosphorescence	Fluorescence	Phosphorescence
BST006	0.19	E	SI_1	No	No	Weak yellow	None	Strong yellow-green	Weak green
BST007	0.08	E	I_1	Yes	Yes	Weak yellow	None	Strong yellow-green	Strong green
BST008	0.06	E	I_2	Yes	Yes	Weak yellow	None	Medium yellow-green	Strong green
BST009	0.19	E	VS_2	No	Weak	Weak yellow	None	Strong yellow-green	Strong green
BST010	0.19	E	VS_1	No	No	Weak yellow	None	Strong yellow-green	Strong green
BST011	0.19	E	SI_2	Yes	Yes	Weak yellow	None	Strong yellow-green	Strong green
BST012	0.14	E	SI_1	Yes	Yes	Weak yellow	None	Medium yellow-green	Medium green
BST013	0.14	E	VS_2	No	No	Weak yellow	None	Medium yellow-green	Medium green
BST014	0.10	D	SI_1	No	No	Weak yellow	None	Strong yellow-green	Strong green
BST015	0.10	E	SI_2	Yes	Yes	Weak yellow	None	Strong yellow-green	Strong green

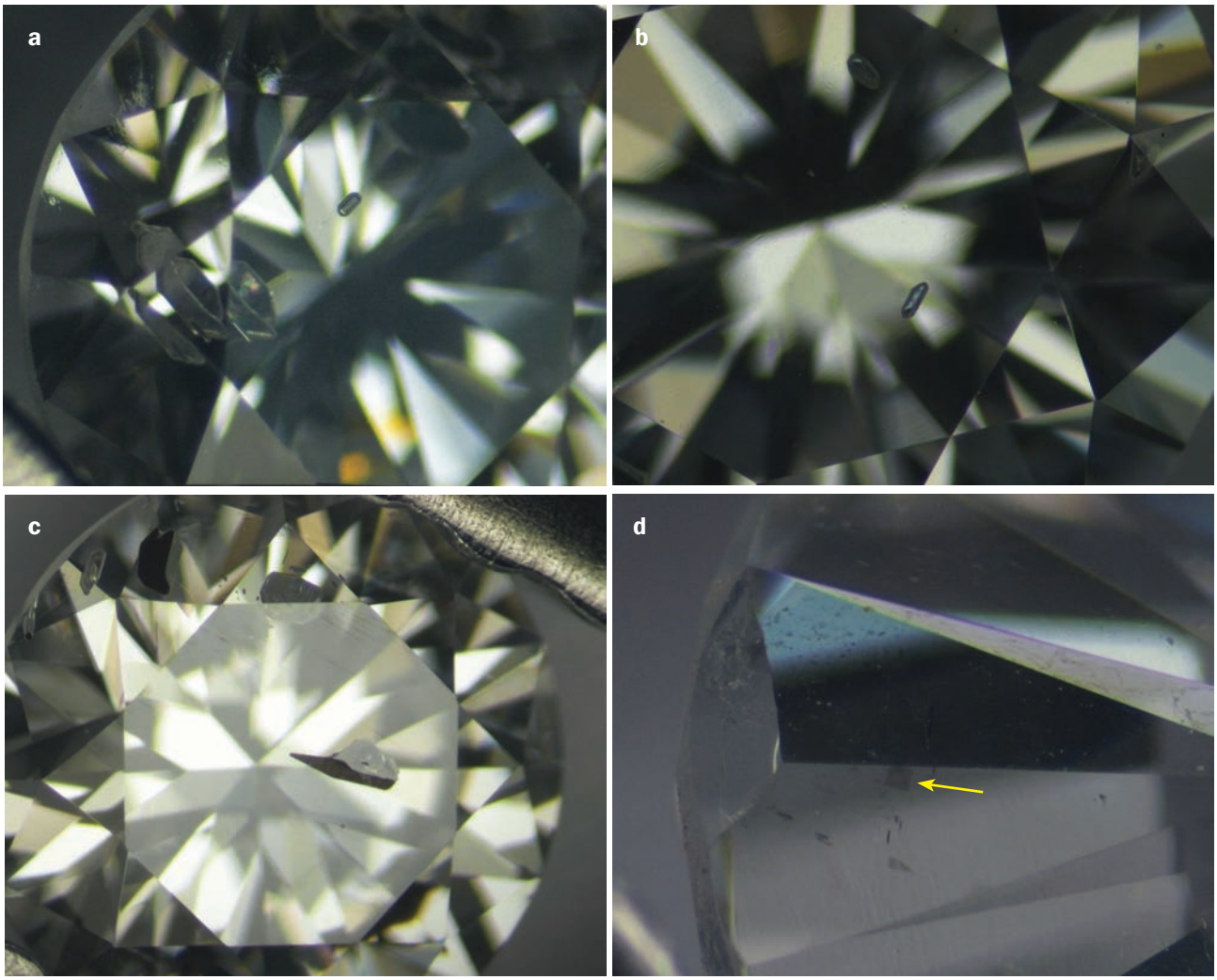

Figure 2: The Shandong HPHT synthetic diamonds commonly contained metallic inclusions, including (a) stubby rod-like shapes (magnified 30×), (b) those showing iridescence in reflected light (magnified 25×) and (c) irregular shapes (magnified 15×). (d) One sample also contained a square-shaped cloud, possibly consisting of metallic particles (see arrow; magnified 45×). Photomicrographs by Z. Song.

Figure 3: Weak birefringence is shown by the Shandong HPHT synthetic diamonds (a; magnified 25×), in contrast to typical patterns displayed by natural diamonds (b; magnified 15×) and CVD synthetic diamonds (c; magnified 15×). Photomicrographs by Z. Song.

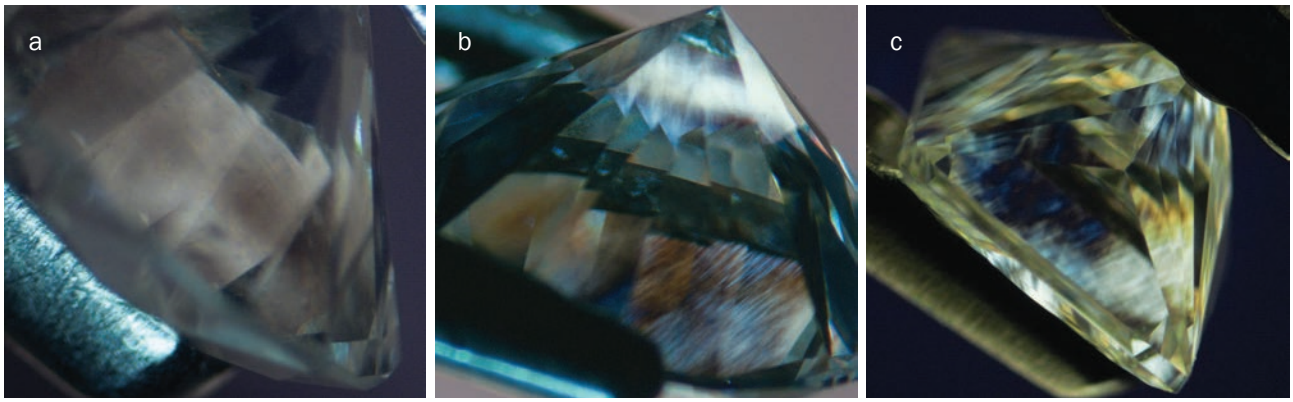

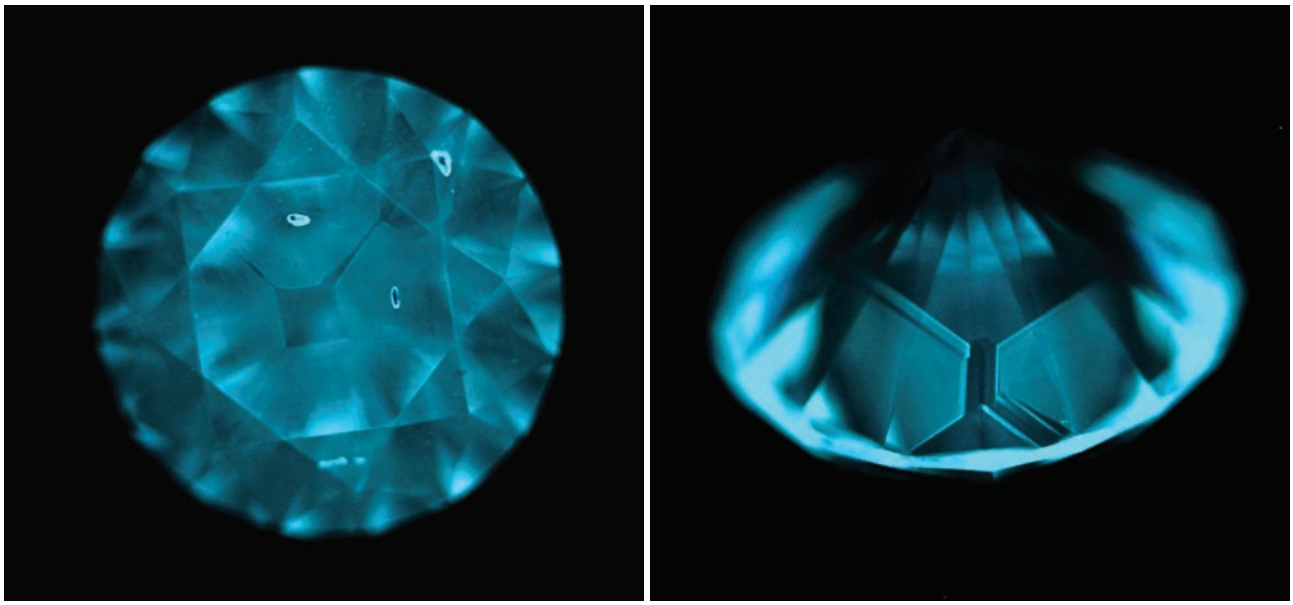

Figure 4: In the DiamondView, the Shandong HPHT synthetic diamonds showed greyish blue fluorescence (here, seen in two views of sample BST012, 0.14 ct). The cuboctahedral growth sector is also evident. Photos by Z. Song.

FTIR Spectra

All samples examined for this article proved to be mixed type Ib and IIb with variable boron content (Figure 6). Boron often concentrates in the {111} growth sector and has absorption features located at 4090, 2800 and 1290 cm^{-1} in FTIR spectra (King et al., 1998). A weak line at 1332 cm^{-1} and bands at 1075 and 960 cm^{-1} also were observed in all samples. The latter two absorptions were stronger (relative to the 1332 cm^{-1} band) than similar bands at 1046 and 950 cm^{-1} shown by Lawson et al. (1998), who assigned the 1332 cm^{-1} band to N^+. We did not detect any isolated nitrogen-related absorption peaks at 1344 and 1130 cm^{-1}. The cause of the 1332 cm^{-1} line is uncertain, although it has been observed in boron-doped synthetic diamonds and in those grown using a Ni-containing solvent/catalyst (Collins et al., 1990; Lawson and Kanda, 1993; Lawson et al., 1998). More samples from Jinan Zhongwu New Materials should be tested to further clarify the existence of the 1075 and 960 cm^{-1} bands.

UV-Vis Spectra

The UV-Vis spectra of the samples (Figure 7) displayed a weak 270 nm absorption associated with isolated nitrogen (Dyer et al., 1965), as well as a weak broad band centred at 350 nm. There was also weak general absorption due to boron in the near-infrared region, but absorption due to boron and nitrogen in the visible region was extremely low, resulting in the samples having a colourless (D–E) grade.

Photoluminescence Spectra

No emissions related to defect impurities (such as N, Ni and Si) were detected in any of the 10 faceted samples when excited with the 325, 473 and 532 nm lasers, but four of them showed a weak Ni-related doublet at 883.2/884.9 nm with the 785 nm laser (Figure 8). In addition, weak 737

Figure 5: These representative phosphorescence spectra of the Shandong HPHT synthetic diamonds show a band centred at approximately 500 nm.

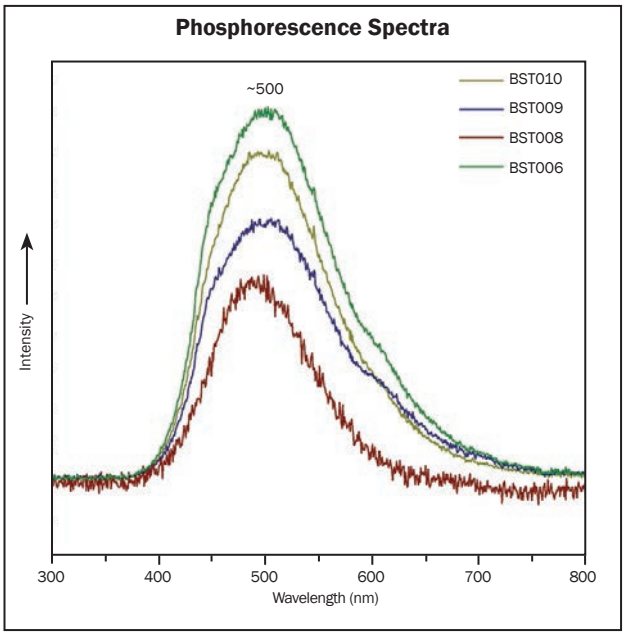

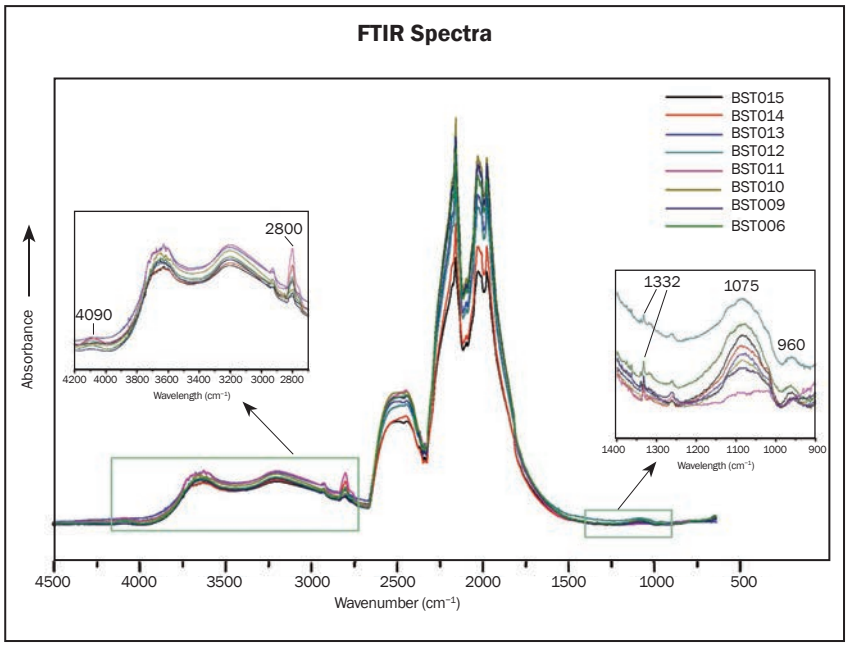

Figure 6: These representative FTIR absorption spectra of the HPHT synthetic diamonds show that they are mixed type Ib and IIb with variable boron content.

and 637 nm emissions were recorded in some of the crystals and a 692/693 nm doublet was detected in all of them with the 532 nm laser. The assignment of the 692/693 nm emission has yet to be determined, and it is not clear why it was present only in the rough samples.

EDXRF Analysis

The only element detected by EDXRF spectroscopy in the samples was Fe (with no Co or Ni). Samples BST007–008, 011–012 and 015 showed considerable amounts of Fe, while only traces were found in BST009, and Fe was not detectable in BST006, 010, 013 or 014. The presence of Fe in these samples is consistent with their inclusion abundance and, as shown in Table I, magnetic behaviour. These results suggest that Fe was likely the dominant solvent/catalyst used during the growth process.

Figure 7: UV-Vis spectra of the Shandong HPHT synthetic diamonds display a weak 270 nm absorption feature.

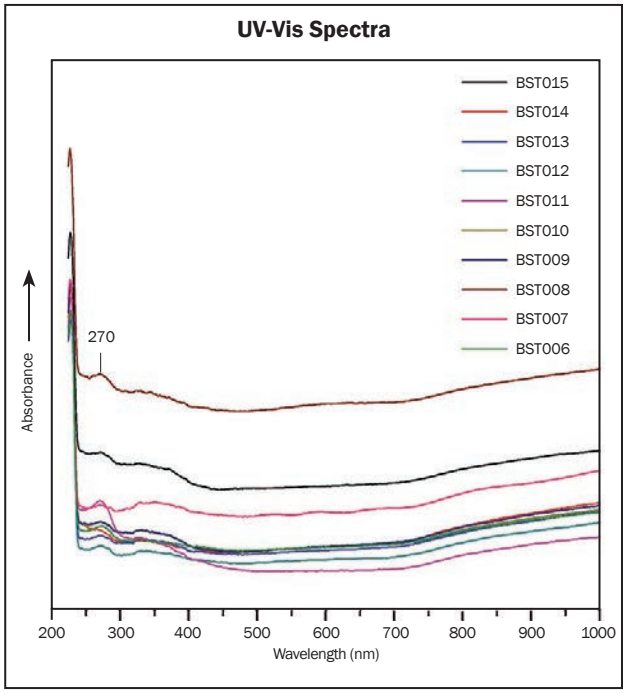

Figure 8: The Shandong HPHT synthetic diamonds generally had featureless PL spectra. Only a few samples showed Ni-related peaks at 883.2 and 884.9 nm that were excited by the 785 nm laser.

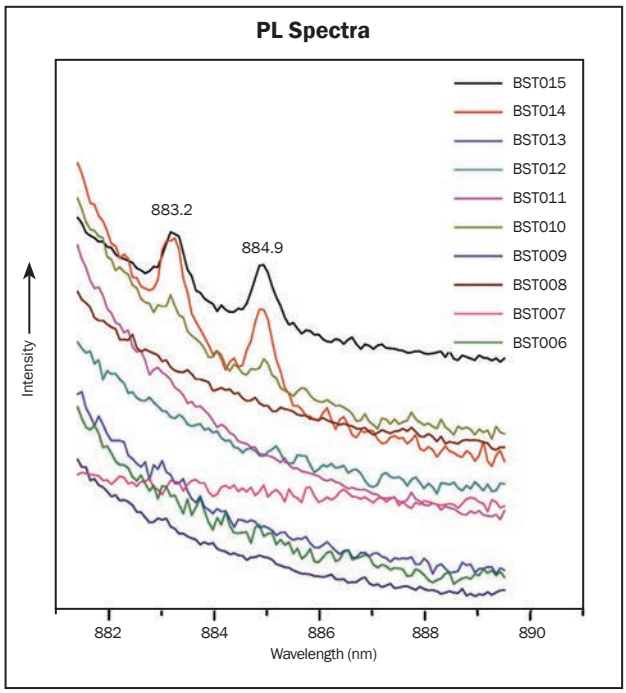

Discussion

With the continued development of synthesis techniques, the characteristics of HPHT- (and CVD-) grown synthetic diamonds are increasingly similar to those of natural diamonds. However, it remains possible to conclusively identify them through a combination of gemmological and spectroscopic observations.

Magnification revealed the common presence of metallic inclusions in our samples, which have not been observed in natural diamonds or in CVD synthetics. The more metallic inclusions present (and thus higher Fe content, as confirmed by EDXRF spectroscopy), the stronger a sample's magnetism.

The cuboctahedral growth sector was distinctly visible in the DiamondView when the samples were thoroughly observed from different directions. Typically this growth sector was more obvious through the pavilion than the table. Moreover, all the samples displayed strong greenish blue phosphorescence in the DiamondView, a characteristic rarely seen in natural diamonds.

Compared to synthetic diamonds from other producers that the authors have tested previously, the 270 nm absorption in the UV-Vis spectra of our samples was generally weaker, as a result of the higher colour grades of these samples. It is known that the 270 nm absorption relates to isolated nitrogen (Dyer et al., 1965), which causes yellow coloration in diamond.

The presence of boron in all samples was indicated by the strong 2800 cm^{-1} and weak 4090 cm^{-1} absorptions in the FTIR spectra. To grow colourless synthetic diamonds, the amount of impurities such as N and B that enter the diamond lattice must be controlled to some extent. To do so, a 'nitrogen getter' is introduced to form compounds with N, thus reducing the amount of this element available to enter the crystallizing synthetic diamond. Also, by controlling the content of B, the resulting weak absorption in the red and near-infrared regions (producing blue coloration) will neutralize the yellow colour caused by isolated nitrogen, thus causing the diamond to appear colourless overall.

Although Raman PL spectroscopy is a useful method for studying the trace impurities in diamond, it was difficult to detect useful emissions in our faceted synthetic diamond samples, regardless of the laser excitation wavelength, even with full power and 10 accumulations. Only a weak 883/885 nm doublet related to Ni was found in a few samples. This may be due to the use of catalysts or growth conditions that are different from other producers. According to D'Haenens-Johansson et al. (2014), synthetic diamonds from AOTC grown with toroid presses also showed few (or weak) PL features, and one exceptionally pure sample did not have any PL-detectable optical centres.

Conclusions

As with CVD lab-grown diamonds, HPHT synthetics can be identified using a combination of gemmological and spectroscopic techniques, as reported here for colourless samples from Shandong, China. Important identification features include metallic inclusions, green to greenish blue phosphoresce after exposure to short-wave (and especially ultra-short-wave) UV radiation and cuboctahedral growth zoning observable with the DiamondView (particularly from the pavilion side), as well as a weak 270 nm absorption and a 2800 cm^{-1} band, consistent with a mixed type Ib and IIb affinity.

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Gem-quality Sekaninaite from the Czech Republic

Radek Hanus, Ivana Kusá and Jana Kasíková

Sekaninaite—the Fe-rich end member of the cordierite-sekaninaite series—was recently found for the first time in gem quality at the type locality of Dolní Bory in the Czech Republic. The mineral is known from several granitic pegmatites in the Hatě area as conical pseudo-hexagonal crystals up to 1 m long that are embedded in feldspar and commonly altered (pinitized). Small unaltered areas of the crystals may show an attractive blue-violet colour and vitreous lustre. Several dozen stones have been faceted that range up to ~11 ct; they have an average weight of ~1 ct. This rare gem-quality sekaninaite can be distinguished from cordierite in some cases by using RI and SG data, although overlap in these measurements may require that additional methods such as X-ray diffraction or quantitative chemical analysis be used to distinguish between the two minerals.

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Introduction

Blue-violet cordierite is an attractive gem material that is available at affordable prices. Cordierite is an end member of the cordierite-sekaninaite series, and the latter mineral is significantly rarer. During the past two years, the type locality of sekaninaite, Dolní Bory in the Czech Republic, has yielded several gem-quality specimens (e.g. Figure 1) as a result of activities by mineral collectors. These gems possess a greyish blue to bluish violet colour with very strong pleochroism, as is commonly seen in cordierite.

To the authors' knowledge, sekaninaite was previously unknown as a gemstone and has not yet been set into jewellery. This article reports on the new production of gem-quality sekaninaite, describes its properties and compares them to cordierite.

Background

The chemical formula of the cordierite-sekaninaite series is $(Mg,Fe^{2+})_2Al_3(AlSi_5O_{18})$–$(Fe^{2+}Mg)_2Al_3(AlSi_5O_{18})$; both minerals are complex cyclosilicates of Mg, Fe and Al crystallizing in the orthorhombic system. There is also a high-temperature hexagonal dimorph of cordierite called indialite, $Mg_2Al_3(AlSi_5O_{18})$, which is isostructural with beryl (Fleischer and Jambor, 1977; Geiger and Voigtländer, 2000; Yakubovich et al., 2004). Sekaninaite from Dolní Bory was approved as a new mineral by the International Mineralogical Association in 1968, and described by J. Staněk and J. Miškovský in 1975; it was named in honour of the Czech mineralogist Dr Josef Sekanina (1901–1986). Another significant occurrence of sekaninaite is Winklarn village in eastern Bavaria, Germany, where it forms within

Figure 1: These rough (~0.5–2 g) and cut (0.22–0.30 ct) samples of sekaninaite are from the Czech Republic. Photo by R. Hanus.

Figure 2: Gem-quality sekaninaite is known only from Dolní Bory in the South Moravian Region, Czech Republic.

pegmatitic veins that are hosted by serpentinite, and is associated with andalusite, chlorite, feldspar and muscovite (Keck et al., 2010). Other localities for sekaninaite include Italy, Russia and the USA (Grapes et al., 2011; Korchak et al., 2011).

Until now, cordierite was the only mineral of the cordierite-sekaninaite series known in gem quality. Named after the French geologist and mineralogist Pierre Cordier, cordierite is also known as *iolite*, and rarely in old literature as *dichroite*. Both names are derived from Greek words—*iolite* for violet, and *dichroite* for a two-coloured stone (although it actually displays trichroism). The authors are also aware of colourless cordierite, although very rare, from Sri Lanka, Tanzania and Madagascar; in addition, Tanzania hosts a bicoloured variety. Chatoyancy may be rarely displayed by cabochons cut from cordierite.

Cordierite is generally not subjected to any treatments. Heat treatment is not viable due to cordierite's low thermal stability. However, one of the authors (RH) has rarely encountered cordierite treated with a surface coating; those stones, which were purchased in Chanthaburi, Thailand, lost much of their attractive blue-violet colour during the recutting/repolishing process.

Location and Geology

The gem-quality sekaninaite was found in the Hatě area, approximately 8 km north of Velké Meziříčí town and 1.5 km west of Dolní Bory village, in the Vysočina area of the South Moravian Region, Czech Republic (Figure 2). The mining area is located in woodland between the Oslava River and Dolní Bory village, south of Babačka Creek. Approximately 20 pegmatites are known in this area of the Moldanubian complex on the northern periphery of the Borsky granulite massif (Staněk, 1991; 2009); however sekaninaite was recovered from only a few veins of the former MKZ feldspar mine (MKZ = Moravské keramické závody or Moravian ceramic plants). The sekaninaite is typically enclosed in orthoclase (and albite), the main resource of the mining operations. The orthoclase was manually sorted and used for the ceramic industry (Duda, 1986). Small-scale pit mining for orthoclase began in 1887, and underground mining commenced after World War II; the final operations ceased in 1972. Since that time, many collectors have visited the deposit and the surrounding area to collect mineral specimens, including crystals of smoky quartz, mica, schorl, secondary uranium minerals and others of aesthetic value (Staněk, 1952a,b; 1991).

The veins from this locality are classified as peraluminous granite pegmatites, of an orthoclase type with weak albitization and secondary rare-element mineralization (Staněk, 2009). The majority of the thicker veins are highly differentiated with a symmetrical-zoned structure from the margins inward: (1) medium- to coarse-grained pegmatite, (2) coarse-grained graphic pegmatite, (3) blocky K-feldspar and quartz and (4) a quartz core. Some areas of

Figure 3: Sekaninaite from the Czech Republic often occurs as conical pseudo-hexagonal crystals (left, 5 cm tall) that commonly break apart into tabular pieces (right, 4 cm diameter). Both specimens are strongly pinitized. Photo by R. Hanus.

the outer edge of the blocky zone underwent metasomatic replacement that is associated with less common minerals. The contacts with the surrounding host rocks are predominantly sharp, and a contact aureole of granitic hornfels is locally present (Staněk, 1952b; 2009). In total, more than 81 mineral species are known from this famous Czech locality (see, e.g., www.mindat.org/loc-787.html), including andalusite, quartz, dumortierite, corundum (sapphire), garnet (almandine-spessartine), albite, 'oyamalite' (REE-P rich variety of zircon), monazite, apatite, augelite, zwieselite, triplite, triphylite, sarcopside, wolframite, ilmenite, löllingite, pyrite, rutile, hematite, marcasite, arsenopyrite, chalcopyrite, sphalerite, dolomite, siderite and less frequently symplesite, autunite, torbernite, cookeite, diaspore, anatase, halotrichite and gypsum (Jaroš, 1936; Němec, 1981; Duda, 1986; Staněk, 1991).

Sekaninaite is fairly abundant in some veins of the Hatě locality. It forms complex parallel twins, often having a conical pseudo-hexagonal form (Figure 3), and can reach 1 m in length. All of the sekaninaite from the Hatě locality has been variably altered (pinitized), which causes the prisms to disintegrate along 1–5 mm-thick layers oriented perpendicular to the c-axis. These parting planes are coated by a film of pale green chlorite/chloritoid that partially replaces the sekaninaite, often with acicular crystals of dark green Fe-amphibole (ferrogedrite). Microscopic assemblages of paragonite and hercynite are also products of the pinitization of sekaninaite (Staněk, 2009).

Based on fluid inclusion studies, the temperature of sekaninaite formation at Dolní Bory is estimated at 530°C; at lower temperatures, Fe-rich chlorite and muscovite are more stable (Staněk, 2009).

Materials and Methods

Seventy-eight faceted sekaninaite samples were studied for this report. They ranged from 0.11 to 11.05 ct (average 1.06 ct). The majority were faceted as octagonal and round brilliant cuts. Approximately 1 kg of rough sekaninaite was also available for testing.

The following tests were done on 50 faceted and 20 rough samples: pleochroism (observed with a calcite dichroscope), hydrostatic SG and fluorescence to standard long-wave (366 nm) and short-wave (254 nm) UV radiation. Refractive indices were measured on the 50 cut samples with a refractometer, and the RI of an additional rough sample was measured with a Freiberger Präzisionmechanik double-wheeled goniometer using the method of minimal deviation in sodium light. The cut gems were examined with a Leica polarizing microscope, a Krüss trinocular microscope and an Optika horizontal immersion microscope.

Identical-appearing inclusions in two samples were identified by optical microscopy (in a faceted stone) and by X-ray diffraction using a Siemens X'Pert Pro diffractometer (in a thin sample plate). The measurement conditions were Cu*K*α radiation, 40 kV, 30 mA and 0.02° step size, under both air-dried and glycolated (with ethylene glycol) conditions. X'Pert HighScore software was used to identify the inclusions from the obtained XRD spectra.

Raman analysis of 10 faceted samples was performed using a GL Gem Raman PL532 instrument with a spectral range of 175–1500 cm^{-1} and a resolution of ~16 cm^{-1} FWHM. Spectra were compared to the RRUFF database (www.rruff.info). Semi-quantitative chemical analyses of the same 10 sekaninaite samples (65 spots total) were obtained with a Tescan MIRA3 GMU scanning electron microscope equipped with an Oxford Instruments EDS microanalytical system.

Ultraviolet-visible–near infrared (UV-Vis-NIR) spectra of 30 faceted samples were collected with a GL Gem Spectrometer in the range 300–1000 nm (optimized for the 400–950 nm range). For comparison, a spectrum also was collected from

one sample of cordierite from the Babati area of the Lake Manyara region in Tanzania.

Results and Discussion

The properties of sekaninaite are summarized and compared to cordierite in Table I. The sekaninaite showed an attractive blue-violet colour and a vitreous lustre where it was unaltered. Like cordierite, sekaninaite displayed strong trichroism (pale yellow to green, violet to blue-violet and light blue). Most of the cut stones were lightly to moderately included (e.g. Figures 1 and 4). The RI values of sekaninaite (n_α = 1.561, n_β = 1.572 and n_γ = 1.576) mostly overlap those of cordierite (typically n_α = 1.527–1.560, n_β = 1.532–1.574 and n_γ = 1.538–1.578). However, the lowest RI value for sekaninaite (n_α = 1.561) is slightly higher than the n_α range for cordierite (1.527–1.560), and is therefore diagnostic for separating the two minerals. The SG measurements of sekaninaite (2.53–2.78) had a wider range than those reported for cordierite (2.53–2.66) and higher values also may be diagnostic in some cases, although SG measurements from both minerals commonly overlap. Therefore, the use of additional methods

Table I: Properties of sekaninaite and cordierite.[a]

Mineral	Sekaninaite	Cordierite
Formula	$(Fe,Mg)_2Al_3(AlSi_5O_{18})$	$(Mg,Fe)_2Al_3(AlSi_5O_{18})$
Crystal system	Orthorhombic	Orthorhombic
Optic sign	Biaxial (−)	Biaxial (+,−)
Type locality	Dolní Bory, Vysočina region, South Moravian Region, Czech Republic	Großer Arber, Bayerisch Eisenstein, Zwiesel, Lower Bavaria, Germany
Year of discovery	1968	1813
Colour	Greyish blue to bluish violet	Grey, blue, blue-violet, greenish, yellowish brown; colourless to very light blue in transmitted light
Pleochroism	*Strong:* *X = c = Pale yellow to green* *Y = a = Violet to blue-violet* *Z = b = Light blue*	Strong: X = c = Pale yellow to green Y = a = Violet to blue-violet Z = b = Light blue
Diaphaneity	Transparent, translucent	Transparent, translucent
Hardness (Mohs)	7½	7–7½
Lustre	Vitreous	Vitreous
Cleavage	{100} good	{100} imperfect/fair, {001} fair and {010} poor
Fracture	Sub-conchoidal	Sub-conchoidal
RIs	n_α = *1.561* n_β = *1.572* n_γ = *1.576*	n_α = 1.527–1.560 n_β = 1.532–1.574 n_γ = 1.538–1.578
Birefringence	*0.015*	0.011–0.018
SG	*2.53–2.78*	2.53–2.66
Fluorescence	None	None
Inclusions	Chloritoid, chlorite, ferrogedrite, quartz, muscovite and orthoclase	Hematite, rutile, apatite, mica, etc. (Henn and Milisenda, 2004)
Absorption spectra[b]	*416, 456, 468, 486, 508, 553 and 627 nm*	426, 436, 456, 492, 535, 585, 593 and 645 nm (O'Donoghue, 2006); *416 and 627 nm also recorded in this study*
Essential elements	Al, Fe, O, Si	Al, Mg, O, Si
Common impurities	*Mg, Mn, Ti, Ca, Na, K,* H_2O[c]	Mn, Fe, Ti, Ca, Na, K

[a] Data in italics indicate the results of our measurements; data not from this study are from www.mindat.org and http://rruff.info/doclib/hom/sekaninaite.pdf, unless otherwise cited.
[b] Absorption spectra vary with pleochroic direction, and in the direction of the violet-blue colour, some bands may be masked by general absorption.
[c] H_2O is from Staněk (2009) and J. Staněk, pers. comm. (2012).

Figure 4: These faceted samples of sekaninaite (left 0.78 ct and right 0.86 ct) show the colour range of the material; both stones are moderately included. Photos by R. Hanus.

such as X-ray diffraction (XRD) or quantitative chemical analysis may be necessary to separate the two minerals.

The alteration (pinitization) of sekaninaite typically follows the abundant fractures in the material, and may even surround entire masses of rough sekaninaite. The inclusions in our faceted samples most commonly consisted of fractures and wispy linear aggregates of microcrystalline chloritoid (Figure 5) and chlorite. Chloritoid was previously documented by Staněk (2009), but the mineral could not be confirmed in the present study because it was not possible to separate a completely 'clean' inclusion for XRD analysis. However, chlorite inclusions were identified in the current study. The chlorite and smectite groups have nearly the same position of the first basal peak measured by XRD. However, expandable structures such as those exhibited by Ca-Mg smectites form intercalates that shift the position of the first basal diffraction peak from 14–15 Å to 17–18 Å. No shift in the first basal peak was observed in the analysed sekaninaite inclusion, confirming it as a chlorite mineral (14.40 Å in spectra of both air-dried and glycolated samples). Other mineral inclusions present in the sekaninaite—identified visually and by their geological association—consisted of ferrogedrite (Figure 5), quartz, muscovite and orthoclase. Also present were minute fluid inclusions. No colour zoning was seen.

Raman Spectroscopy

The Raman spectra of the studied samples showed major peaks at 251.4, 293.8, 560.1 and 665.1 cm^{-1}, with or without additional peaks at 718.2, 901.1, 965.5 and 1006.5 cm^{-1}. These are comparable to spectra of both cordierite and sekaninaite in the RRUFF database (Figure 6). The peak positions were similar, although differences in the spectra were exhibited by the width and intensity of some peaks. These differences were probably due to orientation effects. In addition, sekaninaite and cordierite do not have a fixed chemical composition, as they constitute an isomorphous series. Further deviations may result from admixtures, inclusions or disorders in the crystal lattice. In addition, Raman spectra should be interpreted with respect to the technical limits of the instrumentation (resolution, range, signal/noise ratio, etc.). Therefore, routine Raman spectra cannot be used to distinguish between sekaninaite and cordierite.

Figure 5: Fractures and wispy linear aggregates of microcrystalline chloritoid and/or chlorite form conspicuous inclusions in these sekaninaite gemstones (left magnified 5× and right 3×). The stone on the left also contains ferrogedrite (see arrow). Photomicrographs by R. Hanus.

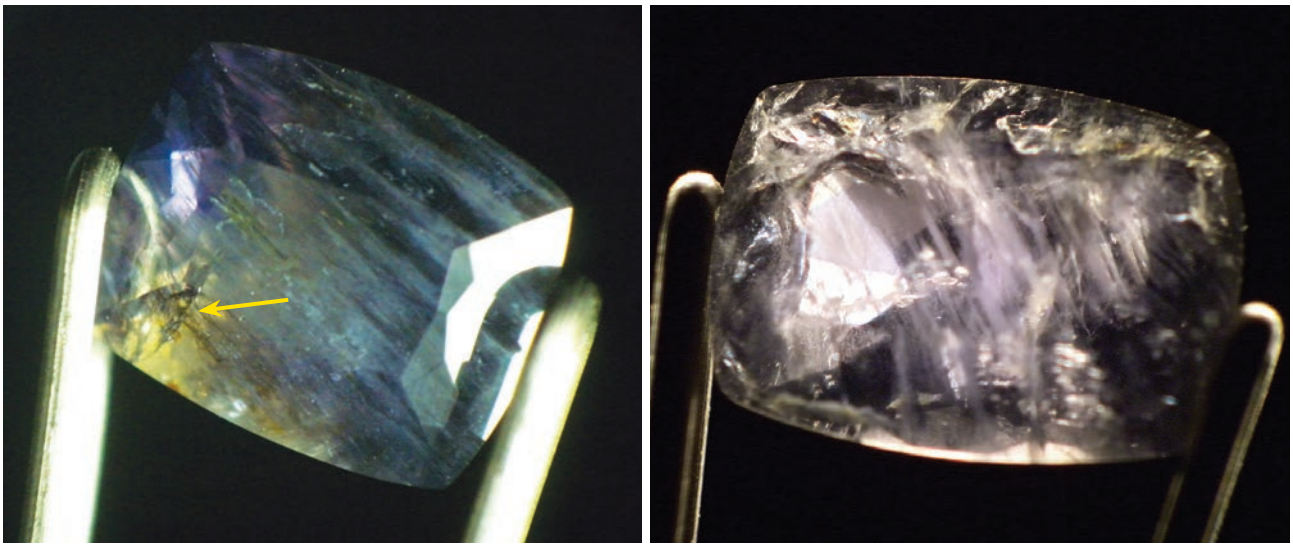

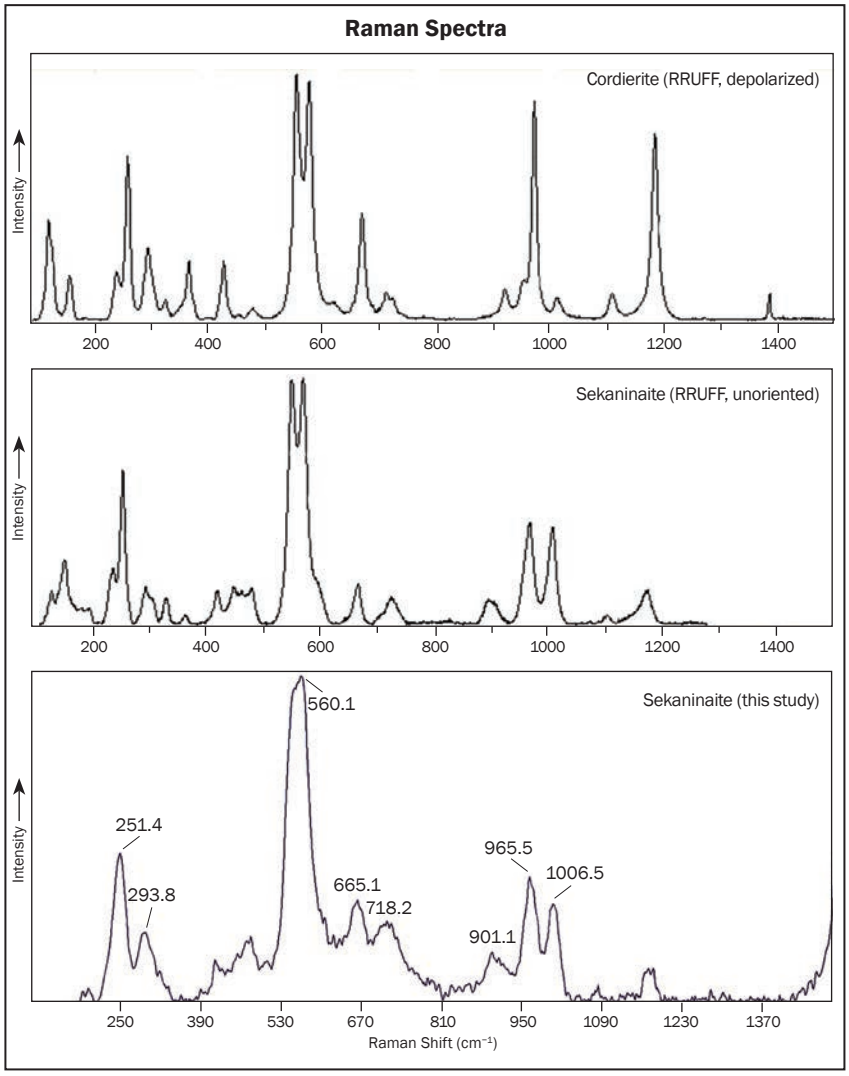

Figure 6: Raman spectra are shown for cordierite and sekaninaite from the RRUFF database, and also for a sekaninaite from this study. The spectra generally have overlapping features, with differences in peak intensities that are probably due mostly to orientation effects.

Chemical Composition

On average, sekaninaite from Dolní Bory contained 16.8 wt.% FeO, 0.8 wt.% MnO and 2.1 wt.% MgO. By comparison, sekaninaite from Winklarn, Germany (as reported by Keck et al., 2010) contained more Fe (average 17.1 wt.% FeO) and Mn (2.5 wt.% MnO), and less Mg (0.2 wt.% MgO). Keck et al. (2010) reported that the Winklarn sekaninaite contained the lowest known Mg concentration, and this remains true. Therefore, the German sekaninaite is slightly closer to end-member composition than the material from Dolní Bory.

UV-Vis-NIR Spectroscopy

The spectra for sekaninaite showed main absorptions at 416, 456, 468, 486, 508, 553 and 627 nm (Figure 7). By comparison, a spectrum for cordierite had main absorptions at 416, 436, 456 and 627 nm. Measured spectra of both sekaninaite and cordierite can vary according to the pleochroic orientation of the sample, with some peaks not occurring in certain orientations.

Figure 7: UV-Vis-NIR spectra of sekaninaite and cordierite show similar absorption features, which may vary according to the pleochroic orientation of the sample.

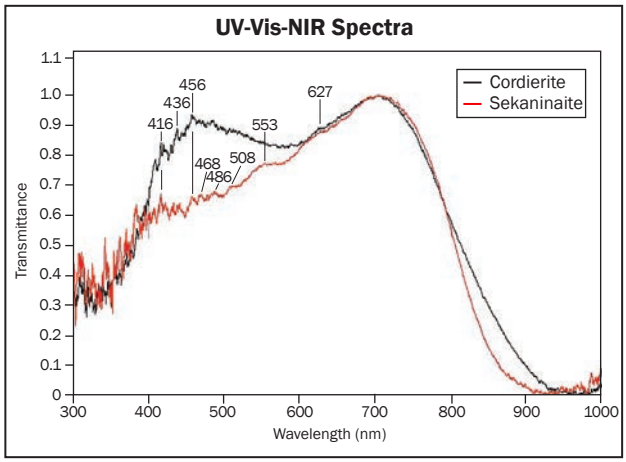

Conclusion

Sekaninaite is a rare collectors' stone that has gemmological properties similar or identical to cordierite, with which it forms a solid-solution series. The two minerals can sometimes be separated by careful RI readings (paying attention to the lowest RI value) and SG measurements, while advanced techniques such as XRD or quantitative chemical analysis will provide a definitive identification.

It is highly unlikely that gem-quality sekaninaite will be produced in a larger scale in the future. Yet, the type locality of Dolní Bory in the Czech Republic will probably continue to yield a limited amount of this attractive gem material.

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An innovator in gemstone reporting

• Identification of colored gemstones • Country of origin determination • Full quality and color grading analysis

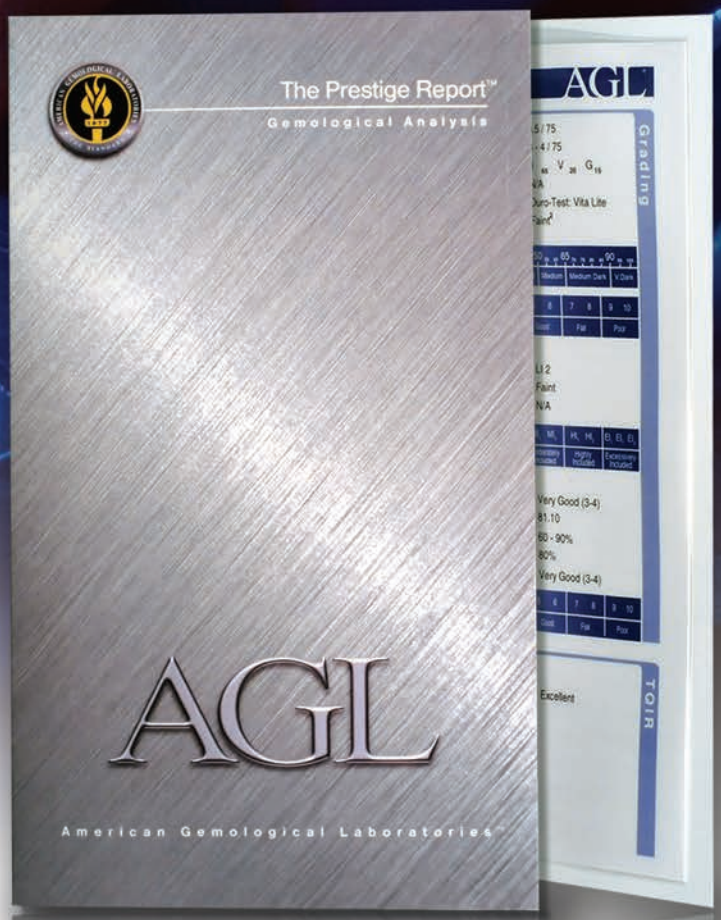

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Phase Transformation of Epigenetic Iron Staining: Indication of Low-Temperature Heat Treatment in Mozambique Ruby

Tasnara Sripoonjan, Bhuwadol Wanthanachaisaeng and Thanong Leelawatanasuk

In the past several years, Mozambique has emerged as one of the world's most important sources of ruby, and unheated stones from this country are in particularly strong demand. Nevertheless, it is common for these rubies to undergo low-temperature heating (~1,000°C or below) to slightly improve their colour. The treated stones may show very subtle or no alteration of internal features (e.g. mineral inclusions, 'fingerprints', needles, 'silk', etc.). However, 'iron-stained' surface-reaching fractures in the rubies commonly display a noticeably more intense colour after heating. Raman and FTIR spectroscopy were used to document a transition from goethite to hematite within stained fractures in samples heated to 500°C and 600°C. The identification of hematite within such fractures provides key evidence for the low-temperature heat treatment of Mozambique ruby.

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Introduction

Mozambique is currently a globally important source of gem-quality ruby (e.g. Figure 1). Since the late 2000s, various ruby deposits have been discovered in the country, particularly around the Montepuez district (e.g. GIT-GTL, 2010). The stones show a range of colours and qualities, from pinkish red to purplish red with low-to-high clarity. The red colour is commonly inhomogeneous, with bluish zoning being commonly visible. Heat treatment is the most commonly used method to improve the colour so that it is acceptable to the gem trade. In late 2014, the Gem and Jewelry Institute of Thailand's Gem Testing Laboratory (GIT-GTL) learned about the low-temperature heat treatment of corundum, particularly of ruby from Mozambique. Low-temperature heating was subsequently documented as effective for improving the appearance of this material and removing bluish overtones (Pardieu et al., 2015). Typically the treatment process involves heating in air to at least 550°C, and then the temperature is increased by 100°C to a maximum of 750°C; however, the temperature at which the colour change occurs is not known to the present authors.

Heat treatment of corundum has been performed for centuries, and initially gem burners used firewood or charcoal as a heat source, sometimes with a blowpipe. Such treatments were performed

Figure 1: Mozambique has emerged as an important ruby source, as shown by these untreated stones (1.02–5.93 ct). Photo by T. Sripoonjan.

at relatively low temperatures compared to some current heating methods, although more recently these low-temperature conditions have been applied using modern electric furnaces. The identification of such treatments by gem laboratories is problematic—particularly for labs that rely only on the appearance of inclusions—resulting in inconsistencies in identification reports. While in some cases careful microscopic observation of inclusions may indicate that a ruby underwent low-temperature heating, the application of Fourier-transform infrared (FTIR) spectroscopy may provide additional proof by detecting the alteration of inclusions such as diaspore (Smith, 1995, 2010). Furthermore, the effects of heating may be detected in weathering-related minerals such as kaolinite (C. Smith, pers. comm., 2016). The systematic study of samples before and after heating is necessary to understand the temperatures under which transformations may occur.

One of the most prominent internal features in both rough and faceted rubies from Mozambique is iron-oxide staining, seen as yellow-to-orange epigenetic residues along surface-reaching fractures. The colour saturation of the iron staining tends to be intensified by heating (Kammerling and Koivula, 1989; de Faria and Lopes, 2007; Koivula, 2013; Pardieu et al., 2015). This study further investigates the changes that occur in iron-stained fractures within Mozambique rubies, and provides criteria for detecting their low-temperature treatment.

Materials and Methods

Ten representative unheated rough samples of ruby from Mozambique (0.11–0.41 g) were used in this study, and all work was carried out at GIT-GTL. Each sample was cut in half, and one piece was used for heating experiments while the other was retained for reference (Figure 2). All

Figure 2: Ten rough ruby samples from Mozambique were sliced in half, and the right-hand portion of each sample was subjected to heating experiments (to 500 °C, and then to 600 °C), while the other half was kept for reference and colour comparison. Photo by T. Sripoonjan.

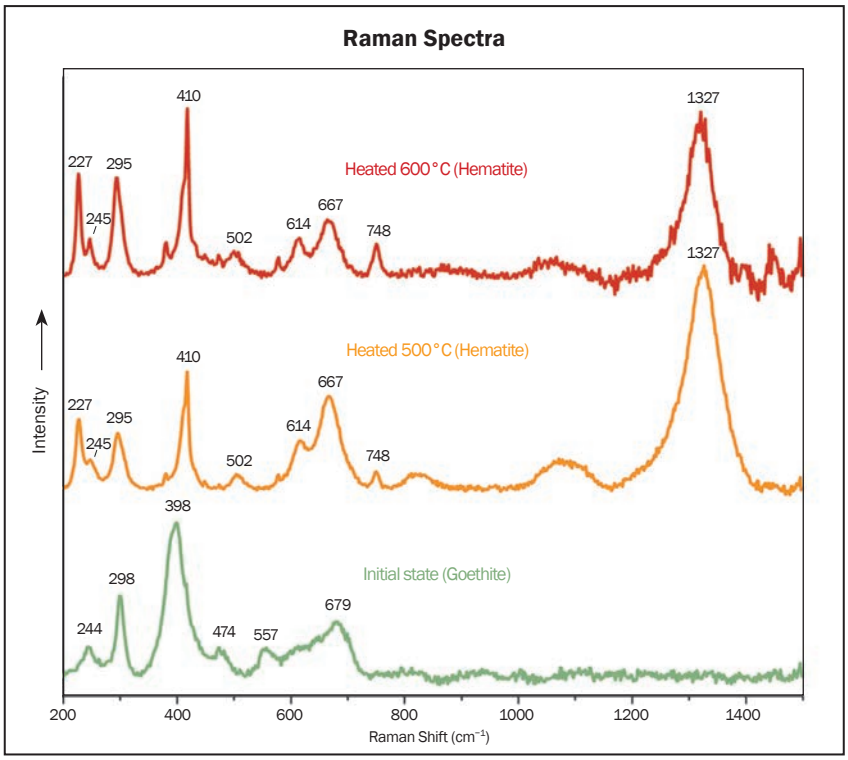

Figure 3: Raman spectra of iron-stained residues within fractures in the Mozambique rubies indicated the presence of goethite in the unheated stones and hematite in samples that were heated to 500 °C and 600 °C.

of the rubies contained prominent iron-stained fractures. The test samples were placed within an alumina crucible in an electric resistance furnace and thermally treated in air for a dwell time of two hours. The samples were initially heated to 500°C and allowed to cool slowly before being analysed. Then they were heated again, to 600°C, and more data were collected.

The iron-stained residues in the unheated reference samples and in the treated rubies were analysed with a Renishaw inVia Raman microscope, and the spectra were compared to GIT-GTL's gemstone and mineral databases and Renishaw's minerals and inorganic material database. In addition, FTIR spectroscopy of all samples was performed with a Thermo Scientific Nicolet 6700 instrument (128 scans, 4 cm^{-1} resolution and 4000-400 cm^{-1} range, using a DTGS detector and KBr beam splitter). The beam was directed through areas of the samples containing iron-stained fractures.

Results and Discussion

Raman spectroscopy of the unheated ruby samples (e.g. Figure 3, bottom) identified the epigenetic iron-stained residues as goethite, α-$Fe^{3+}O(OH)$. This compound precipitated in surface-reaching fractures after iron-bearing groundwater dried out under oxidizing conditions (Kennedy, 1990; Koivula, 2013).

After the samples were heated to 500°C and 600°C, the colour of the iron stains appeared more saturated, as shown in Figures 4 and 5. Raman

Figure 4: The iron-stained fractures in this representative sample of Mozambique ruby display a noticeable increase in orangey red coloration in the heated half (right side) compared to the untreated portion (left side). Photos by Y. Lhongsomboon.

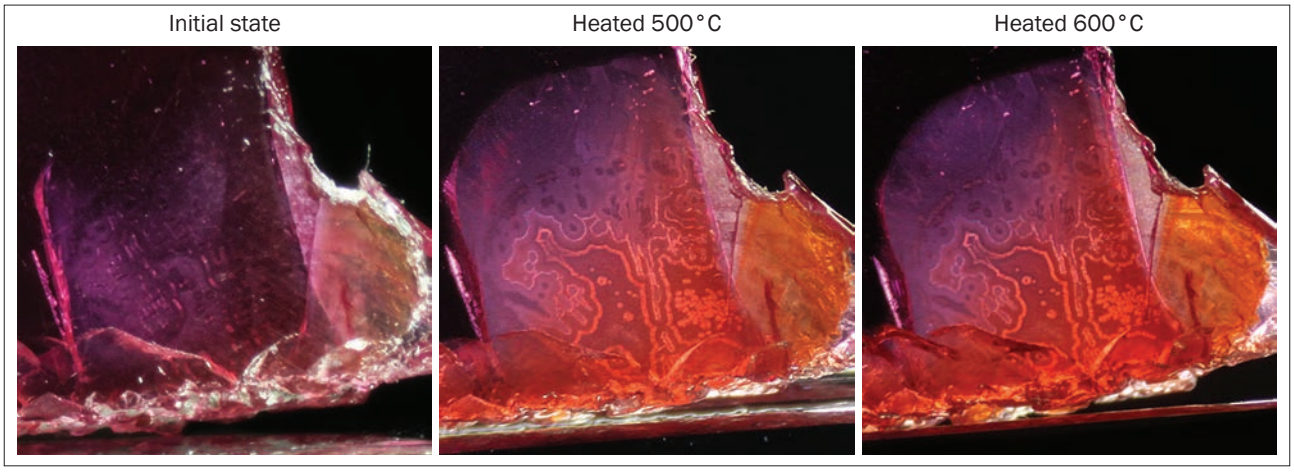

Figure 5: Heating of this Mozambique ruby produced a distinct change in the appearance of epigenetic iron staining within a fracture. Photomicrographs by Y. Lhongsomboon; image width 4.65 mm.

spectra of the iron-stained residues after heating identified them as hematite, Fe_2O_3 (Figure 3, centre and top). The characteristic Raman peaks of hematite at approximately 227, 245, 295 and 410 cm^{-1} were clearly evident after treatment at 500°C. Further heating to 600°C caused the Raman peaks to become slightly narrower, which may be due to increased crystal size and crystallinity of the hematite (Liu et al., 2013). Similar results were found in all samples, indicating that the transformation and dehydration of goethite to hematite in the iron-stained fractures easily occurs below 500°C, as suggested by Koivula (2013) and Liu et al. (2013). The appearance of other internal features (e.g. mineral inclusions) in the samples remained unchanged after heating to both 500°C and 600°C (Figure 6).

Infrared spectroscopy is useful for investigating absorption features related to structural OH groups in rubies, and can reveal trace impurities of diaspore, boehmite and/or kaolinite (Smith, 1995; Beran and Rossman, 2006). The spectra are commonly dominated by O-H stretching frequencies related to boehmite and/or kaolinite impurities, particularly in the 4000–3000 cm^{-1} region (e.g. Figure 7) that is useful for determining if a ruby or sapphire has been heated (Smith, 1995). However, low-temperature heat treatment may not cause boehmite and kaolinite to completely decompose (cf. Glass, 1954; Wanthanachaisaeng,

Figure 6: These inclusion scenes in Mozambique ruby (top: diaspore; bottom: amphibole) show no significant changes in appearance after heating to 500 °C and 600 °C. Photomicrographs by Y. Lhongsomboon; image width 1.8 mm.

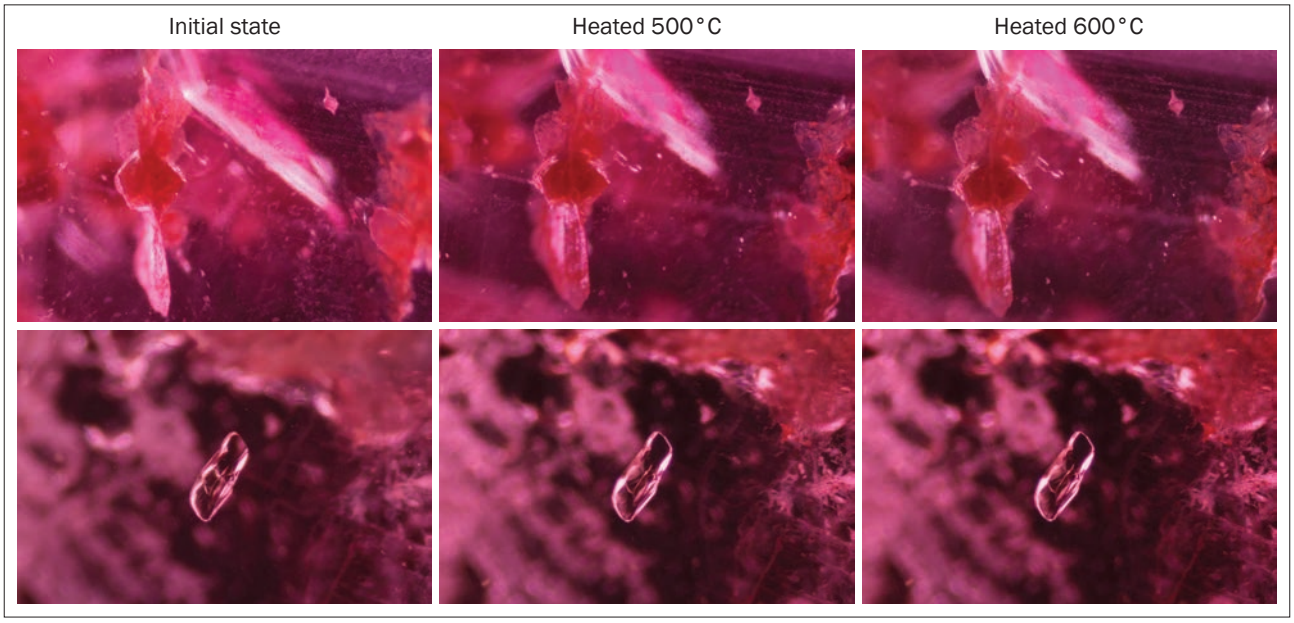

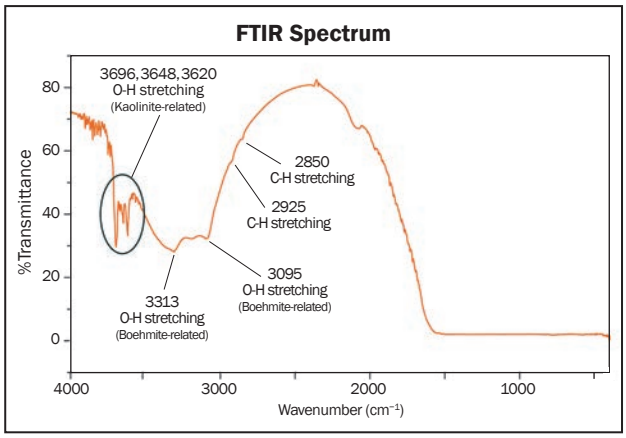

Figure 7: FTIR spectroscopy of OH-related features in ruby and sapphire can help gemmologists determine whether stones have undergone heat treatment. Frequently, the identification of low-temperature heating (i.e. below 600 °C) cannot be precisely achieved because the OH-related features may not have completely decomposed. (The peaks at ~2925 and 2850 cm^{-1} are probably due to contamination from finger oils or cutting residues; Cartier, 2009.)

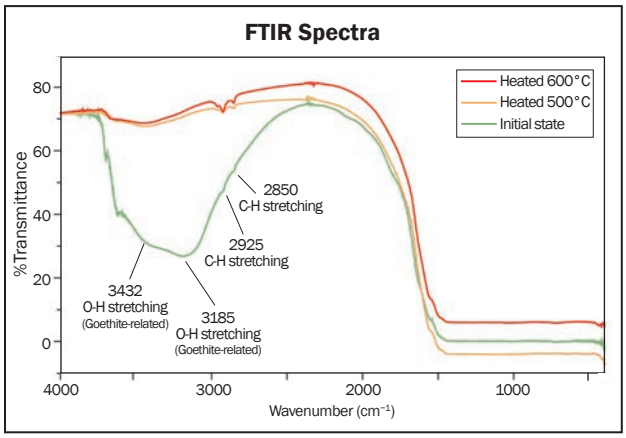

Figure 8: FTIR spectra are shown for a representative sample of Mozambique ruby before treatment and after heating to 500 °C and 600 °C. Goethite-related absorptions in the 3600–3000 cm^{-1} region are evident before heat treatment, but they nearly disappear after treatment.

2007). Unheated samples of Mozambique ruby in this study occasionally showed FTIR absorption bands associated with iron hydroxides (i.e. goethite, as identified by Raman spectroscopy), although only when the ruby samples were analysed in particular directions and positions (cf. Cambier, 1986). In the spectral range of 3600–3000 cm^{-1}, which is important for the detection of hydroxyl bonds (including goethite), the absorption bands in the unheated samples were slightly broadened rather than appearing as sharp peaks. After treatment at 500°C or 600°C, these absorption bands became barely visible due to dehydroxylation and recrystallization of goethite into hematite (Liu et al., 2013; Figure 8). Heating of goethite causes a gradual dehydration that begins at 260°C (Kammerling and Koivula, 1989; de Faria and Lopes, 2007; Koivula, 2013; Liu et al., 2013). It continues with the transformation of the yellow-to-orange goethite (orthorhombic) to dark orange-red hematite (trigonal), through the chemical reaction:

$$\underset{\text{Goethite}}{2\alpha\text{-FeO(OH)}} + \text{Heat} \rightarrow \underset{\text{Hematite}}{\alpha\text{-Fe}_2\text{O}_3} + \underset{\text{Water}}{\text{H}_2\text{O}}$$

Conclusions

Although the low-temperature heating of ruby and sapphire has been conducted for centuries, the detection of such treatment remains difficult. For ruby in particular, low-temperature treatment of material from Myanmar and Vietnam is well known (e.g. Smith, 2010; Wathanakul et al., 2011; Pardieu et al., 2015), but conclusive identification criteria remain elusive in many cases.

In recent years, Mozambique ruby has become important in the gem and jewellery market. Low-temperature heat treatment is successful for improving the colour of this material, but unfortunately many unethical traders have sold these heated stones as untreated. Microscopic observation of inclusions in such rubies is not reliable for identifying this treatment. However, heating intensifies the coloration of epigenetic iron-stained fractures, providing visual evidence of treatment. This change in appearance is due to the transformation of goethite to hematite by a dehydration mechanism that takes place during the heating process. Raman and FTIR spectroscopy are useful for detecting the presence of hematite residues in the iron-stained fractures, which is a key criterion to indicate heat treatment at relatively low temperatures in Mozambique ruby.

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Letters

Digital Manipulation of Gem Photos

I noticed that summaries of papers from *The Journal of Gemmology* are once again being included in *Gems&Jewellery*, and these will enable *Journal* articles to have broader trade exposure.

However, a point niggled me regarding the photo in the summary of *The Journal* article on inclusions in cat's-eye, star and other chrysoberyls that appeared in the current issue of *G&J* (May/June 2016, p. 21); this photo was reprinted from p. 26 of *The Journal* (Vol. 35, No. 1, 2016). It is the matter of showing two photos of the same gem in daylight and in incandescent or other light, which demonstrates a colour change. This particular example illustrates the change in colour of a cat's-eye alexandrite, which according to the caption "... is shown in daylight (left) and incandescent light (right)". Now, the point is, the two photos are one and the same, except one has had the centre gem digitally altered in colour to represent the different lighting environment. From the reflections on the gem, I would say the incandescent one is the actual photo and the daylight one, therefore, is the manipulated one. I suggest that photos manipulated in this way are labelled as such, possibly with 'rendered to simulate daylight appearance'. I know it is often difficult, sometimes impossible, to capture a correct colour (i.e. the photo image does not match what the eye sees), and I am perfectly happy for such manipulation to be carried out in order to represent for us what the photographer was actually seeing. I just want it stated as such, especially in a paper that includes scientific evidence and records of testing.

This subject also arose with *Gems & Gemology* some years ago and they did, finally, admit that such colour manipulation was used and they would alter the description to say so.

It also would help with believability if two photos could be taken, perhaps of slightly differing angles, even if one is then altered.

I hope that this letter will encourage future authors to indicate when photo manipulation has occurred in articles that include such images.

Grenville Millington
Knowle, West Midlands

Reply

Thank you, Mr Millington, for your good suggestion. In the future we will be sure to indicate that such photos are modified to simulate daylight appearance.

Brendan M. Laurs
Editor-in-Chief

Interpretation of Colours Seen Between Crossed Polarizers

I was very interested to read the Gem Note by Candice Caplan and Franck Notari titled "A Lalique quartz pendant, in polarized light" (Vol. 35, No. 1, 2016, pp. 13–15). The accompanying photographs of the lovely quartz pendant dramatically illustrate the beauty of gem materials when viewed in cross-polarized light. However, the reasons stated for some of the optical effects observed by the authors are not completely accurate.

Judging from the interference figure, some of the colours seen in the untwinned areas of the quartz are due to optical activity that results from *rotatory dispersion of light* travelling parallel to the optic axis, and some are due to a *combination of optical activity and interference*. They are not "due to a combination of diffusion and diffraction", nor are they caused by "its crystallographic orientation versus the polarization direction of the light."

Thickness does affect the colours resulting from rotatory dispersion. It also affects the colours due to interference when the optic axis is inclined to the direction the light is travelling,

a condition that seems to be the case in Figure 14, which shows the optic figure slightly askew. And, as stated above, colours can result from a combination of these two phenomena.

Optical activity in quartz is a complicated subject, and because it is rarely treated in any depth in gemmological and mineralogical literature, observations can be easily misconstrued. Clear understanding of the underlying cause of optical activity and its resulting optical effects can be important for interpreting differences in synthetic versus natural quartz, as well as for understanding the nature of quartz itself. For more information on this phenomenon, please see the 2015 booklet by E. A. Skalwold and W. A. Bassett titled *Quartz: A Bull's Eye on Optical Activity*, which is freely available at www.minsocam.org/msa/openaccess_publications/#Skalwold_02. The discussion of optical activity, the nature of the bull's-eye optic figure and, in particular, the quartz monochromator's ability to produce various colours, will give gemmologists a background for interpreting the unique optical effects seen in quartz gems.

Elise A. Skalwold
Ithaca, New York, USA

Authors' Reply

We are thankful to Ms Skalwold for providing the link to her publication and for the explanation regarding the rotatory dispersion of light that we missed including as a possible mechanism. Nevertheless, the purpose of the entry was to draw attention to the differences between the front and back views of the carved figures in the pendant with cross-polarized light, as well as the colours observed during rotation of the object between crossed polarizers, for which we found no explanations in gemmological publications.

Candice Caplan and Franck Notari
GGTL Laboratories, Geneva, Switzerland

Conferences

AGA Las Vegas

The Accredited Gemologists Association's 2016 Las Vegas conference took place on 2 June, just prior to the JCK Las Vegas Show in Nevada, USA. Attended by 62 people, the event was chaired by AGA past-president Donna Hawrelko, and featured seven speakers.

Peter Shemonsky (Peter Jon Shemonsky, San Francisco, California, USA) discussed imitations of high-end jewellery and how to avoid them. Some of the tips he gave were (1) learn variations in hallmarks and signatures, and where to find them on jewellery items; (2) ensure that hallmarks are consistent with the country of manufacture; (3) check for correct assembly, as well as the ease of disassembly for repairs; (4) observe the back of the item, which should be finished as well as the front; and (5) familiarize yourself with the various models that were released over time by some manufacturers.

Art Samuels (Estate Buyers, Miami, Florida, USA) gave examples of various gem and jewellery frauds he has encountered, including a large mounted light blue diamond that was colour-enhanced with a blue substance on the girdle, HPHT-treated diamonds cut to match laboratory grading reports of untreated diamonds and overinflated appraisals used as collateral for money loans.

John King (Gemological Institute of America, New York, New York) reviewed GIA's system for grading coloured diamonds. He stressed that each colour grade represents a range of appearances, and that differences between them are not consistent throughout colour space. Therefore extensive experiments have been done to assess the amount of difference between colour grade boundaries (referred to as 'stepping') throughout the hue circle. Next, **Thomas Gelb** (Natural Color Diamond Association, New York), **José Batista** (Rio Diamond, New York) and **Scott West** (LJ West Diamonds, New York) explored value factors of natural-colour diamonds. Special considerations for these gems include their extreme rarity, high value, fragmented middle market, opaque pricing (with the exception of stones sold at auction) and complex quality grading. In general, the rarer the colour, the less important are the clarity, cut and carat weight in determining their value.

Eric Braunwart (Columbia Gem House, Vancouver, Washington, USA) discussed transparent sourcing of coloured stones (Figure 1). His criteria for fair trade gems include environmental protection, product integrity, fair labour conditions and worker rights, cultural appreciation, supply chain transparency, fair value and full information for consumers. He reported that recent surveys showed that many consumers are willing to pay ~10% more for a fair trade gemstone compared to one with no origin information.

Brendan M. Laurs

Figure 1: Eric Braunwart discusses fair trade gems at the AGA Las Vegas conference. Photo by Ya'akov Almor.

China Gems & Jewelry Academic Exchange Conference

This biannual conference was held on 30 November 2015 in Beijing. It was organized by the National Gems & Jewelry Technology Administrative Center (NGTC, Beijing) and the Gems & Jewelry Trade Association of China (Beijing). About 500 representatives from the UK, USA, Switzerland, Thailand, Poland, Hong Kong, Taiwan, and many Chinese jewellery testing centres, institutes, companies and appraisal agencies attended the conference. Invited presentations were given by 13 speakers (see, e.g., Figure 2 and summaries below). A proceedings volume published by *China Gems* (November–December 2015, 460 pages) contains extended abstracts covering most of the talks, as well as numerous short papers that were not actually presented at the conference.

Dr David Fisher (De Beers Technologies Research Centre, Maidenhead, Berkshire) reported on recent developments in the detection of currently available HPHT- and CVD-grown synthetic diamonds. **Dr Ewa Wagner-Wysiecka** (Gdańsk University of Technology, Poland) discussed the identification of natural and treated ambers using spectroscopic techniques. **Dr Daniel Nyfeler** (Gübelin Gem Lab, Lucerne, Switzerland) reviewed recent applications of LA-ICP-MS to gem testing and dating. **Dr Pornsawat Wathanakul** (Gem and Jewelry Institute of Thailand, Bangkok) described the low-temperature heat treatment of ruby and its detection. **Dr Wuyi Wang** (GIA, New York) explained the application of carbon isotopes for separating CVD and natural type IIa diamonds. **Sterling Foutz** (Sterling Turquoise, Tempe, Arizona, USA) reported on the principles, methods and identification of turquoise enhanced by the Zachery process.

A number of researchers from China also described their research. **Dr Taijin Lu** (NGTC) reported on various instrument development efforts at his laboratory. **Hua Chen** (NGTC) proposed a naming convention for silicic aggregates sold as 'jade' in China (including, but not limited to, quartzite and chalcedony). **Yan Lan** (NGTC) reported progress in the development of various precious metal analytical standards. **Profs. Guanghai Shi** and **Xuemei He** (China University of Geosciences, Beijing) described the origin and appearance of Myanmar jadeite and the coloration of 'Zhangguohong' agate, respectively. **Prof. Lijian Qi** (Tongji University) discussed the characteristics of various colours of sugilite (i.e. light to dark blue and light pink to dark violet) and their associated trade names in the Chinese market. **Author AHS** reported on the geographic origin of nephrite using a novel statistical method involving the LA-ICP-MS analysis of trace elements.

Yilang Huang, Qijuan Wan and
Prof. Andy H. Shen (ahshen1@live.com)
China University of Geosciences, Wuhan

Figure 2: This photo shows some of the invited presenters of the 2015 China Gems & Jewelry Academic Exchange Conference. Photo courtesy of conference staff.

2nd Mediterranean Gemmological & Jewellery Conference

On 6–9 May 2016, the 2nd Mediterranean Gemmological & Jewellery Conference (MGJC) took place in Valencia, Spain. The MGJC is held annually, each time in a different Mediterranean location. The theme of this year's event was diamond treatments, but other topics also were covered. The conference attracted 80 gemmologists, jewellery appraisers and scientists from 20 countries.

Figure 3: The 2nd Mediterranean Gemmological & Jewellery Conference included a panel discussion on diamond treatments moderated by John Chapman (far left) and comprising (from left to right) Branko Deljanin, Gaetano Cavalieri, Gail Brett Levine, Mikko Åström, Sonny Pope and Dusan Simic. Photo by Anastasiya Shramko.

Dr Gaetano Cavalieri (CIBJO, The World Jewellery Confederation, Milan, Italy) delivered the opening address and described the role of his organisation in protecting consumers, as specified in CIBJO's 'Blue Book' series, which defines grading standards and nomenclature. He provided examples of fraudulent and misleading conduct in the gem trade that have been acted upon by CIBJO.

Dr David Fisher (De Beers Technologies Research Centre, Maidenhead) recounted recent research toward understanding colour defects in diamond (particularly brown) and their response to HPHT treatment. Then, **Sonny Pope** (Suncrest Diamonds, Orem, Utah, USA) explained commercial HPHT and irradiation treatments of diamonds done by his company. He emphasized opportunities for transforming low-value brown diamonds into fancy-coloured gems, showing a chart of possible treated colours that depend on the starting colour and nitrogen content coupled with the processing conditions.

Dusan Simic (Analytical Gemology & Jewelry, New York) described instances of laboratories reporting 'natural' for synthetic or treated diamonds. He discussed useful indicators of treatment in FTIR and photoluminescence spectra (e.g. the width of the 741 nm irradiation peak). He also noted that improvements in laboratory techniques and interpretations are lessening instances of misidentification. With analytical tools being a key to detection, **Mikko Åström** (M&A Gemological Instruments, Jarvenpaa, Finland) described the principles and practicalities of IR spectroscopy. He described examples of IR features pertaining to diamonds and coloured stones, including the detection of emerald fillers and synthetic amethyst.

Besides treatments, the source traceability of gemstones is another consumer concern. This was addressed by **Jean Claude Michelou** (International Colored Gemstone Association, New York), who highlighted difficulties in tracing 17 varieties of coloured stones sourced from 47 countries with undeclared or under-declared reports at international borders.

Jeffrey Bergman (Primagem, Bangkok, Thailand) showed examples of how geographic origin and various visible characteristics influence the value of opals, star sapphires and trapiche gems.

Lisa Elser (Custom Cut Gems, Vancouver, British Columbia, Canada) provided her personal experiences of buying gem rough in the field, including offerings of synthetics at mine sites and other deceptive seller tactics.

Independent gemmologist **Dr Rui Galopim de Carvalho** (Lisbon, Portugal) discussed Portuguese jewellery, with examples from the royal collection that demonstrate how exploration of the New World affected the availability of different gems through history and had a strong influence on jewellery design.

The Koh-i-Noor diamond was the topic of a presentation by **Alan Hart** (The Natural History Museum, London). He traced its history using casts of the stone from the Museum's collection, and examined how the polishing anisotropy of diamond had a strong influence on the shape of such Mogul-style cuts. Hart noted the availability for scientific research of more than 1,000 diamonds and almost 5,000 coloured stones in the Museum's collection, all untreated.

The final conference session consisted of a panel discussion on diamond treatments, moderated by **this author** (Figure 3). Experts from various fields explored technologies, detection and consumer aspects of treatments, and the audience offered their questions and viewpoints.

The MGJC also included three workshops on diamonds, during which 85 participants put their learning to the test by identifying synthetics and treatments in 50 samples with the aid of microscopes and UV lamps, while UV-Vis, Raman and FTIR spectrometers provided by M&A Gemological Instruments facilitated further testing.

A conference dinner completed the weekend, and a guided city tour provided visitors with a deeper appreciation of the host city of Valencia. The theme of next year's conference is coloured diamonds, and further details will be announced in due course at www.gemconference.com.

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Scottish Gemmological Association

The 21st Scottish Gemmological Association's annual conference took place from 29 April to 2 May 2016 in Peebles, Scotland. It was attended by approximately 85 delegates and students.

Dr Karl Schmetzer (Petershausen, Germany) gave two presentations as the keynote speaker of the conference. He first recounted synthetic emerald production in Germany between 1911 and 1962. He traced the different companies and production methods involved, and highlighted the use of platinum containers and lithium molybdate and lithium molybdate-vanadate fluxes in certain production processes. His second presentation covered historical garnets spanning 300 BC to 700 AD, and considered their origins based on chemical analyses (e.g. ratios of MgO and CaO).

Dr Thomas Hainschwang (GGTL Laboratories, Balzers, Liechtenstein) described his experiences in testing coloured diamonds and the limited availability of known untreated samples, which requires reliance on historical museum collections with documented provenance. He also highlighted the difficulties and technicalities of transporting a complete lab set-up to the relevant museums to undertake the analyses on-site, usually within a constrained timeframe.

Dr Çiğdem Lüle (Gemworld International, Glenview, Illinois, USA) described the geological occurrence of Turkish diaspore and the cause of its colour-change effect. Gem-quality diaspore is inferred to have formed during a second generation of crystal growth, and contains relatively higher contents of Cr and rare-earth elements.

Dr Rui Galopim de Carvalho (Lisbon, Portugal; Figure 4) reviewed the use of Brazil-sourced gemstones in Portuguese jewellery from the 16th century onward. He also documented a transition from traditional-worked gold styles (in which gems were used to accent the overall design) and engraving to designs showing minimal setting (commonly with foil-backed stones).

Joanna Whalley (Victoria & Albert Museum, London) described a recent V&A exhibition titled 'Bejewelled Treasures: The Al Thani Collection', which featured over 100 items of Mughal jewellery. She explained the difficulties and technical requirements of setting up such an exhibition, and also highlighted the skills of the setters and designers in manufacturing these exquisite pieces.

Figure 4: Dr Rui Galopim de Carvalho answers questions from the audience on the use of Brazil-sourced gemstones in historical Portuguese jewellery during the Scottish Gemmological Association Conference. Photo by A. Fellows.

Clare Dorrell (consultant in fine antiques and jewellery, Edinburgh) discussed the life and works of Scottish gem engraver James Tassie, who perfected the style of resin cameo work that now bears his name, and who was also responsible for producing glass imitations of many carved gem cameos at his workshop in London.

The conference also included the following workshops:

- **Kerry Gregory** (H&T Group, Sutton, Surrey) covered the range of tests available to the practising gemmologist when confronted with mounted gems and the limitations thereof.
- **Dr Çiğdem Lüle** reviewed coatings on gemstones and their detection.
- **Sarah Steele** (Ebor Jetworks, Whitby, North Yorkshire) highlighted the differences between Whitby jet and its alternatives and imitations.
- **Claire Mitchell** (Gem-A, London) reviewed diamond treatments.
- **David Callaghan** (Society of Jewellery Historians, London) highlighted fakes and imitations in the jewellery trade, showing the difference between those created as 'reproductions' and those designed to deceive.

The conference closed with a field trip to the Celts exhibition (National Museum of Scotland, Edinburgh), which features works of art, both jewellery and other, that were created by the Celts in a timeframe spanning over 2,500 years, covering a shared Celtic heritage across ancient Europe.

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Swiss Gemmological Society

On 17–19 April 2016, the Swiss Gemmological Society (SGS) held its 74th annual conference in Magglingen, which is beautifully situated in the Jura Mountains above Lake Biel in western Switzerland. The lectures were attended by 83 SGS members and a few guests. The meeting was chaired by **the authors** and by **Hans Pfister**, SGS president. The main theme of the conference was the specific gemmological challenges and requirements of the Swiss watch industry, although other topics were explored in several presentations.

Jean-Pierre Chalain (Swiss Gemmological Institute SSEF, Basel) introduced his laboratory's testing procedures for the identification and quality control of melee-sized diamonds for the watch industry. In addition to describing in detail the working procedures at SSEF, he also showed how the Automated Spectral Diamond Inspection (ASDI) instrument is used as an efficient tool for diamond identification and sorting.

Cédric Bérruex and **Guillaume Chautru** (Piaget, Geneva, Switzerland) explained the importance of authenticating diamond melee (such as with the ASDI) and of maintaining internal quality control on the stones used in Piaget's gem-set luxury watches and high-end jewellery.

Daniel Haas (Haas Zifferblätter, Pieterlen, Switzerland) focused on how his company follows the highest quality standards during the production of watch dial plates made of ornamental stones for luxury watch brands. He detailed the process from the selection of the raw material (e.g. at the Tucson gem shows, where he is a regular visitor) to the design and high-precision cutting of the stones into watch dial plates. The price for such an exclusive dial plate may easily exceed 10,000 Swiss Francs.

Dr Thomas Hainschwang (GGTL Laboratories, Balzers, Liechtenstein) discussed the challenges and possibilities of sorting synthetic from natural diamonds in parcels of melee using his DFI fluorescence microscopy and spectroscopy system. He explained how synthetic and natural diamonds can be distinguished by photoluminescence and other spectroscopic characteristics, and sometimes also by metallic inclusions and fluorescent growth patterns (i.e. cubic or cuboctahedral sectors being typical for HPHT-grown synthetics).

Figure 5: Dr Walter Balmer demonstrates the heat treatment of zircon using a charcoal furnace during a barbecue at the SGS conference. Photo by M. Hügi.

Edward Johnson, (GIA, London) gave an overview of GIA's international activities and services, focusing on their mission and current infrastructure, with over 3,000 employees worldwide.

Dr Walter Balmer (Chulalongkorn University, Bangkok, Thailand) and **Sebastian Hänsel** (Swiss Gemmological Institute SSEF) gave a detailed report on a field excursion by a group of SGS members to Mogok, Myanmar, in early 2015. With a video and many photos they illustrated how gems are mined in Mogok; the audience was especially impressed by their accounts of underground mining for ruby in karstic marble host rock. In addition, Dr Balmer gave a practical demonstration of the heat treatment of zircon during an evening barbecue social event. Using a charcoal furnace similar to those seen in mining areas in Southeast Asia (Figure 5), he successfully changed the colour of brown Cambodian zircon to an attractive blue by heating the rough material in a reducing atmosphere at approximately 1,000°C for about one hour.

Antoinette Starkey (Exclusive Personal Jewellery & Gemstones, Geneva, Switzerland) gave an overview on the market situation for ruby, sapphire, emerald, spinel and other coloured stones. For more than a year there has been a substantial slowdown in the demand for luxury goods (including gemstones), due to economic and political factors in China, Russia and

the Middle East. The resulting effects on the pricing of gemstones are very different depending on the quality and origin of the material. For example, prices for heat-treated sapphire from Sri Lanka or Madagascar have remained stable or have declined slightly, while those of top-quality unheated Burmese rubies and sapphires have skyrocketed in recent years due to their extreme scarcity.

Dr Claudio Milisenda (German Foundation for Gemstone Research, Idar-Oberstein) gave a detailed report on his visits to ruby, emerald and amethyst mines operated by Gemfields in East Africa. He explained the geology of the deposits, as well as how the gems are mined and quality-sorted prior to being offered at Gemfields' auctions (in the case of ruby and emerald). The Montepuez ruby mine in northern Mozambique was discovered in 2009 and is probably the most consistent-producing source of ruby today.

Dumortierite is typically known to the gemmologist as a blue ornamental stone, often forming fine-grained intergrowths with quartz. **Author MH** presented other aspects of this boron silicate, for example its occurrence as nano-sized fibres responsible for the colour of rose quartz. Also, at the Vaca Morta quarry in Brazil's Bahia State, attractive blue dumortierite quartzite (sold as Azul Macaubas) is cut into large slabs for architectural applications and interior design. Near this quarry, a relatively new discovery has yielded specimens of rock crystal with inclusions of dumortierite providing a beautiful micro-world of transparent, idiomorphic blue crystals.

Willy Bieri (GRS Gemresearch Swisslab AG, Lucerne) presented the current status of emerald mining in Colombia, such as at the famous Muzo mine and the nearby Cunas mine, as well in Chivor. His presentation also showed possibilities for the use of new technologies in field exploration, including aerial surveys of the mining area made with a drone.

In his first talk, **author MK** discussed new non-destructive methods for pearl analysis: X-ray phase contrast and X-ray scattering (dark field) imaging, and neutron radiography and tomography. These techniques are complementary to traditional X-radiography and tomography, and provide new and additional insights into the inner structure of pearls. His second talk provided an annual update of news from the SSEF laboratory, ranging from challenging analytical problems to exceptional or amusing items that the lab has encountered. These specimens included the 'Sleeping Lion pearl', a fake 'Imperial Chinese pearl necklace', exceptional rubies from Mozambique (i.e. the Rhino ruby and a matched pair called Eyes of the Dragon), and a 16 ct musgravite and 10 ct taaffeite.

René Lauper (Frieden AG Creative Design, Thun, Switzerland) provided his annual report on the cultured pearl market. The pearl industry still has not recovered from the challenges of the recent years, particularly because of China's economic difficulties. Nevertheless, today's market offers a much broader variety of qualities and prices of cultured pearls than ever before. Whereas the prices of commercial qualities of cultured pearls have remained stable or weakened in certain ranges, prices for the top qualities are expected to rise due to relatively strong demand, especially for Akoya and high-end round freshwater cultured pearls.

Klemens Link (Gübelin Gem Lab, Lucerne) presented 10 years' experience with the gemmological application of LA-ICP-MS at his laboratory. The main advantages of this sophisticated method of chemical analysis are the large range of elements that can be measured and the low detection limit for trace-element concentrations. The data are particularly useful for origin determination of coloured stones, and in some cases it is even possible to determine the age of surface-reaching zircon inclusions by measuring the isotope ratios of uranium and lead.

Dr Laurent Cartier (Swiss Gemmological Institute SSEF) reviewed the use of corals in the gem trade. He described the species that are economically important and how they are incorporated into jewellery. With photos from a recent visit to Taiwan, he showed the importance of coral as a gem material in the Far East and in many other cultures since antiquity. He also addressed the significance and application of the Convention on International Trading in Endangered Species (CITES) regulations when trading coral internationally.

Karl Vogler (Gemtrade AG, Hergiswil, Switzerland) gave a short overview about the diamond market. The diamond trade is currently going through a difficult period due to political and economic factors in major producing and consuming countries.

Helen Molesworth (Gübelin Academy, Lucerne) reviewed the historical significance and iconography of gems. She traced mankind's knowledge about coloured stones throughout history, the sources of this knowledge and the psychology of adornment. Gems from ancient burials and hoards were discussed, ranging from ancient Egypt to Britain in the 17th century, and she also examined more modern glamorous and royal collections to illustrate the value and status of wearing jewels.

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Dr Michael S. Krzemnicki
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Basel, Switzerland

Gem-A Notices

GIFTS TO THE ASSOCIATION

The Association is most grateful to the following for their gifts for research and teaching purposes:

Brian Cook, Tucson, Arizona, USA, for 17 rough untreated Paraíba tourmalines from the Batalha mine, São José da Batalha, Paraíba, Brazil; and 22 garnets consisting of spessartine from the Alto Mirador mine, Rio Grande do Norte, Brazil, and chrome pyrope from the Navajo reservation, Arizona.

John Garsow, Murrieta, California, USA, for two parcels of rough amethyst from Rwanda.

Mohamed Fahmy Mohamed Hilmy, Harrow, Middlesex, for a rough and a faceted sample of ruby from Greenland.

E. Alan Jobbins FGA, Caterham, Surrey, for over 4,000 slides depicting gemstones, photomicrography and gemmological trips, and copies of *The Mirror of Stones* by Camillus Leonardus, published in 1750, and *Glossary of Geology* (2011).

A. D. Moth, High Wycombe, Buckinghamshire, for an impregnated red and white coral cabochon.

Mark Olm, Tucson, Arizona, USA, for two samples of rough amber weighing 70.11 g in total.

Patricia Stoecklein FGA, Trafalgar, Indiana, USA, for danburite crystals from San Luis Potosí, Mexico.

Jason Williams FGA DGA, G. F. Williams & Co., London, for three carved garnets and five cubic zirconia briolettes.

MEMBERSHIP

The Council of the Association have elected the following to membership:

Associate Membership

Achikalova, Anna, *Kowloon, Hong Kong*
Hann, Janet, *Dubai, UAE*
Hughes, Billie, *Bangkok, Thailand*
Lee, Vanessa Hena, *London*
Luca, Alexander, *Göttingen, Germany*
Ozdil, Ozlem, *Enfield, Middlesex*
Poulson, Majken, *Nuuk, Greenland*
Segura, Olivier, *Paris, France*
Van Maris Dijk, Michele, *Oxshott, Surrey*

GENERAL MEETINGS

The Annual General Meeting of the Gemmological Association of Great Britain will be held on Friday 9 September 2016. The venue is to be announced.

A report of the Extraordinary General Meeting scheduled for 30 June 2016 will be published in the next issue of *The Journal*.

OBITUARIES

It is with great sadness that we announce the death of **Michael J. O'Donoghue FGA,** Sevenoaks, Kent. Michael died on 16 June 2016 and a full tribute will be published in the next issue of *The Journal*.

June Ive FGA, Waltham Abbey, Essex, died on 5 June 2016. June qualified for her Gemmology Diploma in 1966 and has been a Fellow of the Association ever since.

Learning Opportunities

CONFERENCES AND SEMINARS

2nd Eugene E. Foord Symposium on Pegmatites
15–19 July 2016
Golden, Colorado, USA
www.colorado.edu/symposium/pegmatite

Northwest Jewelry Conference
12–14 August 2016
Seattle, Washington, USA
www.northwestjewelryconference.com

46th ACE IT Annual Mid-Year Education Conference
13–16 August 2016
Newport Beach, California, USA
www.najaappraisers.com/html/conferences.html

Dallas Mineral Collecting Symposium
19–21 August 2016
Dallas, Texas, USA
www.dallassymposium.org

35th International Geological Congress
27 August–4 September 2016
Cape Town, South Africa
www.35igc.org
Sessions of Interest: Gems: Bringing the World Together; The Dynamic Earth and Its Kimberlite, Cratonic Mantle and Diamond Record Through Time; Diamonds and Crustal Recycling into Deep Mantle

International Conference on Diamond and Carbon Materials
4–8 September 2016
Le Corum, Montpellier, France
www.diamond-conference.elsevier.com

ASA 2016 International Appraisers Conference
11–14 September 2016
Boca Raton, Florida, USA
www.appraisers.org/Education/conferences/asa-conference
Session of interest: Gems & Jewelry

2nd European Mineralogical Conference (emc2016)
11–15 September 2016
Rimini, Italy
http://emc2016.socminpet.it
Sessions of Interest: Gem Materials; Inclusions in Minerals as a Record of Geological Processes; New Analysis Methods and Application

Compiled by Georgina Brown and Brendan Laurs

49th Annual Denver Gem & Mineral Show
16–18 September 2016
Denver, Colorado, USA
www.denvermineralshow.com
Note: Includes a seminar programme.

IRV Loughborough Conference
17–19 September 2016
Loughborough
www.jewelleryvaluers.org/Loughborough-Conference

Geological Society of America Annual Meeting & Exposition
25–28 September 2016
Denver, Colorado, USA
http://community.geosociety.org/gsa2016/home
Session of interest: Gemological Research in the 21st Century: Characterization, Exploration, and Geological Significance of Diamonds and other Gem Minerals

42nd Pacific Northwest Chapter Friends of Mineralogy Symposium
14–16 October 2016
Longview, Washington, USA
www.friendsofmineralogy.org/symposia.html

CIBJO Congress 2016
26–28 October 2016
Yerevan, Armenia
www.cibjo.org/congress2016

The Munich Show
28–30 October 2016
Munich, Germany
www.mineralientage.de
Note: Includes a seminar programme.

MJSA ConFab
30 October 2016
Fashion Institute of Technology, New York, New York, USA
www.mjsa.org/eventsprograms/mjsa_confab

The Wonder of Fabergé: A Study of the McFerrin Collection
3–4 November 2016
Houston Museum of Natural Science, Texas, USA
www.hmns.org/education/adults/faberge-symposium

Gem-A Conference
5–8 November 2016
London, UK
www.gem-a.com/news--events/gem-a-conference-2016.aspx

37th Annual New Mexico Mineral Symposium
12–13 November 2016
Socorro, New Mexico, USA
https://geoinfo.nmt.edu/museum/minsymp/home.cfml

Gem and Jewelry Institute of Thailand Conference (GIT 2016)
14–15 November 2016
Pattaya, Thailand
www.git.or.th/2014/index_en.html

3rd European Congress on Jewellery: The Jewel in Art and Art in Jewel
17–18 November 2016
Barcelona, Spain
www.museunacional.cat/en/jewel-art-and-art-jewellery

AGA Tucson Conference
1 February 2017
Tucson, Arizona, USA
http://accreditedgemologists.org

Amberif International Fair of Amber, Jewellery and Gemstones
22–25 March 2017
Gdańsk, Poland
www.amberif.amberexpo.pl/title,Jezyk,lang,2.html
Note: Includes a seminar programme.

14th Annual Sinkankas Symposium (Sapphire)
8 April 2017
Carlsbad, California, USA
www.sinkankassymposium.net

11th International Conference on New Diamond and Nano Carbons
28 May–2 June 2017
Cairns, Queensland, Australia
http://ndnc2017.org

Swiss Gemmological Society Conference
8–11 June 2017
Zermatt, Switzerland
www.gemmologie.ch

11th International Kimberlite Conference
18–22 September 2017
Gaborone, Botswana
www.11ikc.com
Note: Pre- and post-conference field trips will visit diamond deposits in Botswana and neighbouring countries.

EXHIBITS

Asia

Van Cleef & Arpels, the Art and Science of Gems
Until 14 August 2016
ArtScience Museum, Marina Bay Sands, Singapore
www.marinabaysands.com/museum/van-cleef-and-arpels.html

Europe

Charlotte De Syllas
Until 22 July 2016
Goldsmiths' Hall, London
www.thegoldsmiths.co.uk/company/today/events/2016/charlotte-de-syllas-exhibition

Une Education Sentimentale
Until 24 September 2016
Le Musée Ephémère of Chaumet, Paris, France
www.chaumet.com/news/the-musee-ephemere-of-chaumet-presents-une-education-sentimentale

Celts
Until 25 September 2016
National Museum of Scotland, Edinburgh
www.nms.ac.uk/national-museum-of-scotland/whats-on/celts

Fabergé—The Tsar's Jeweller and the Connections to the Danish Royal Family
Until 25 September 2016
Museet på Koldinghus, Kolding, Denmark
www.koldinghus.dk/uk/exhibitions/exhibitions-2016/faberge.html

Heavenly Bodies—The Sun, Moon and Stars in Jewellery
Until 30 October 2016
Schmuckmuseum, Pforzheim, Germany
www.schmuckmuseum.de/flash/SMP_en.html

Elements: From Actinium to Zirconium
Until 26 February 2017
Ulster Museum, Belfast, Northern Ireland
http://nmni.com/um/What-s-on/Elements

Smycken: Jewellery. From Decorative to Practical
Ongoing
Nordiska Museet, Stockholm, Sweden
www.nordiskamuseet.se/en/utstallningar/jewellery

North America

Tourmaline Treasures
Until 1 September 2016
Houston Museum of Natural Science, Texas, USA
www.hmns.org/exhibits/special-exhibitions/tourmaline-treasures

Thunderbirds: Jewelry of the Santo Domingo Pueblo
Until 5 September 2016
Abby Aldrich Rockefeller Folk Art Museum, Williamsburg, Virginia, USA
http://tinyurl.com/zgyd54k

Fabergé from the Matilda Geddings Gray Foundation Collection
Until 27 November 2016
The Metropolitan Museum of Art, New York, New York, USA
www.metmuseum.org/exhibitions/listings/2011/faberge

Glitterati: Portraits & Jewelry from Colonial Latin America
Until 27 November 2016
Denver Art Museum, Denver, Colorado, USA
www.denverartmuseum.org/exhibitions/glitterati

Jewelry, from Pearls to Platinum to Plastic
Until 1 January 2017
Newark Museum, Newark, New Jersey, USA
www.newarkmuseum.org/jewelry

Arts of Islamic Lands: Selections from The al-Sabah Collection, Kuwait
Until 29 January 2017
Museum of Fine Arts, Houston, Texas, USA
www.mfah.org/exhibitions/arts-islamic-lands-selections-al-sabah-collection-/

American Mineral Heritage: Harvard Collection
Until February 2017
Flandrau Science Center & Planetarium, Tucson, Arizona, USA
http://flandrau.org/exhibits/harvard

Gold and the Gods: Jewels of Ancient Nubia
Until 8 January 2017
Museum of Fine Arts, Boston, Massachusetts, USA
www.mfa.org/exhibitions/gold-and-gods

Amber Secrets: Feathers from the Age of Dinosaurs
Ongoing
Houston Museum of Natural Science, Texas, USA
www.hmns.org/exhibits/special-exhibitions/amber-secrets-feathers-from-the-age-of-dinosaurs

City of Silver and Gold: From Tiffany to Cartier
Ongoing
Newark Museum, New Jersey, USA
www.newarkmuseum.org/SilverAndGold.html

Fabergé: From a Snowflake to an Iceberg
Ongoing
Houston Museum of Natural Science, Texas, USA
www.hmns.org/exhibits/special-exhibitions/faberge-a-brilliant-vision

Gemstone Carvings
Ongoing
Houston Museum of Natural Science, Texas, USA
www.hmns.org/exhibits/special-exhibitions/gemstone-carvings

Gilded New York
Ongoing
Museum of the City of New York, New York, USA
www.mcny.org/content/gilded-new-york

Mightier than the Sword: The Allure, Beauty and Enduring Power of Beads
Ongoing
Yale Peabody Museum of Natural History, Yale University, New Haven, Connecticut, USA
http://peabody.yale.edu/exhibits/mightier-sword-allure-beauty-and-enduring-power-beads

OTHER EDUCATIONAL OPPORTUNITIES

Gem-A Workshops and Courses
Gem-A, London
www.gem-a.com/education/course-prices-and-dates.aspx

Gemstone Safari to Tanzania
11–28 July 2016
Morogoro, Umba, Arusha, Longido, Merelani and Lake Manyara, Tanzania
www.free-form.ch/tanzania/gemstonesafari.html

American Society of Appraisers and Shanghai BETTER Institute of Gemology's Advanced Gemological Appraisal Course
19–30 September 2016
Shanghai, China
http://tinyurl.com/j5dh4lk

Lectures with The Society of Jewellery Historians
Society of Antiquaries of London, Burlington House, London
www.societyofjewelleryhistorians.ac.uk/current_lectures

27 September 2016
Galina Korneva—The Grand Duchess Maria Pavlovna's Contacts with Paris Jewellers and Her Collection of Treasures

25 October
Robert Baines—Bogus or Real: Jewellery and the Capture of Human Drama

22 November
Kieran McCarthy—Fabergé and London

New Media

Rough Diamonds, a Practical Guide

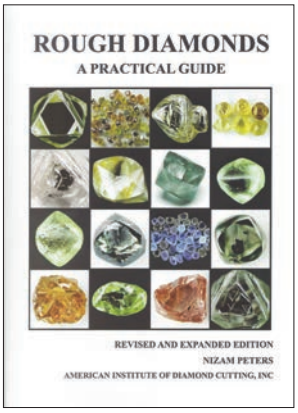

By Nizam Peters, 2016. American Institute of Diamond Cutting, Deerfield Beach, Florida, USA, 274 pages, ISBN 978-0966585490, http://diamondschool.com/books. US$165.00 hardcover.

This book is a revised and expanded edition of the previous version published in 1998. My first impression was that the book is for those who know little about diamonds and want to get involved in rough diamond trading and/or cutting. This assumption was validated by the final sentence in the introduction: "The author's intention is to keep this work free from cumbersome technical language and present an educational format that will be easily understood by anyone."

Chapter 1 is titled 'Overview of the Rough Diamond Market', but it actually deals with a variety of subjects like mining, deposit types, prospecting, recovery, classification and production. These are all valid topics, but they are somewhat incoherent and misplaced in this section.

Chapter 2 covers 'Rough Diamond Structure, Shape and Orientation'. Noticeably absent in this chapter is any mention or illustration of the atomic structure of diamond and its crystallography. The images of the various crystal shapes are, on the other hand, of high photographic quality, and are varied enough to allow the reader to get a good idea of what rough diamonds look like. The captions 'Elongated Irregular' and 'Irregular Diamond' for elongated dodecahedra are, however, vague at best. The images of twinned crystals and macles are comprehensive. The portion on 'orienting the rough for weight retention and yield' seems out of place, as it forms part of cutting and polishing (covered in Chapter 7).

Chapter 3 comprehensively reviews the surface features of diamonds. This reviewer noted one surface feature is missing: the flattened or inverted cube faces seen on some diamonds.

Chapter 4 deals with the internal characteristics of diamonds. The images are of high quality and informative, although colour photomicrographs of mineral inclusions would have added more depth to the chapter. The author also digresses by including content on twinned and multiply twinned crystals that should have appeared in Chapter 2. The portion on 'stress and strain' lacks any reference to the detection of stress using a polariscope, which is vital in the planning and marking process.

The title of Chapter 5, 'Fundamentals of Rough Diamond Proportions', is misleading since it only covers polished diamonds and not rough material. The chapter is, however, informative for those who want to learn about polished diamonds.

Chapter 6 includes some very interesting high-quality images showing diamond colour, colour zoning and colour saturation.

The content of Chapter 7 on 'Manufacturing Rough Diamonds' is somewhat dated, but still relevant. Technology changes constantly and staying up to date is a challenge to any author. This reviewer found it interesting to read about the author's concept of a 'Master Diamond Cutter', which was described but not defined. There is no academy where a person can get a master's degree in diamond cutting. The title 'Master Diamond Cutter' is indeed earned and reflects the title holder's ability to purchase, plan, cut and polish as well as grade the finished diamond to the highest standards.

Chapter 8, 'Introduction on Valuing Rough Diamonds', deals with the ability of a buyer to determine an appropriate dollar value by measuring and determining the projected colour, clarity, size and shape of the finished diamond(s).

Chapter 9 provides an introduction to alluvial diamond mining with some relevant images. It also covers the Kimberley Process scheme that is designed to monitor the movement of rough diamonds between countries.

Chapter 10 is a bonus chapter that provides many high-quality images of rough and polished diamonds

The author succeeds in using language that is easily understandable, particularly to those who have done or are familiar with diamond cutting. Despite the need for an editor, there is some good content in the book for persons who want to 'wet their toes' by getting an understanding of rough diamonds, mining and recovery, and cutting and polishing as well as the diamond industry in general.

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Photo: Mia Dixon

The Journal of Gemmology

Volume 35 / No. 3 / 2016

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John Dyer
The science and the art of gem cutting

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In Peter Rainier's footsteps: journey to the Chivor emerald mine

SUNDAY PROGRAMME

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The history of gemstones

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Cover Photo: New technologies, such as laser ablation inductively coupled plasma time-of-flight mass spectrometry (see article on pp. 212–223), are helping gem labs make more accurate geographic origin determinations on high-end stones such as these Kashmir sapphires (~7.3 and 8.5 ct). Photo by Julien Xaysongkham/SSEF.

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What's New

INSTRUMENTS AND TECHNIQUES

FourPro Photo Studio

Announced in late 2015, this Italian-made modular photography system helps with taking professional-quality photos of jewellery without shadows and unwanted reflections. The components are sold separately and can be purchased in almost any configuration: light box (with or without light fixtures), holder with rotating arm and camera/lens adapter, remote-controllable Canon Reflex EOS camera, robotic kit for 3D animation, and various software for use with a computer or tablet (Android or iPad). The system will accommodate the user's own camera. For more information, visit www.fourpro.com. *CMS*

Gemax Pro Digital Microscope

Introduced in 2015, this portable high-definition digital microscope includes an approximately 9 cm LCD screen with 3.5 megapixel image-capture capability, a diffused LED lighting system and 20×–220× optical magnification. The unit comes with its own software, in 12 languages, and is both PC- and Mac-compatible. Weighing just 1,250 g and measuring 23.2 cm high, 14.9 cm long and 10.6 cm wide, the microscope is truly portable. For additional information, visit www.amazon.com/Gemax-Pro-Digital-Microscope/dp/B01FN08OPY, but note that the microscope is available from numerous retail sources worldwide. *CMS*

GemoLog Color Stone Gem Tester

Released in June 2016 from U.S.-based Tri Electronics Inc., this testing unit includes an optical pen connected to a handheld controller with a digital readout. It reportedly can be used on loose or mounted faceted samples to separate natural ruby, sapphire, emerald, garnet, alexandrite and spinel from synthetics and imitations. Although no information is available on the manufacturer's website (http://trielectronics.com), a limited description can be found at www.kassoy.com/prodcat/gemstone-testers.asp. *CMS*

PhosView

During the September 2016 Hong Kong Jewellery & Gem Fair, the International Institute of Diamond Grading & Research (part of The De Beers Group of Companies, London) released PhosView for screening parcels of polished colourless or near-colourless diamonds for potential HPHT-grown synthetics. The compact device can accept loose stones weighing 0.3 points to 1 ct, as well as some jewellery items. The user can manually separate potential HPHT synthetics for further testing using built-in manipulator arms. PhosView cannot identify CVD synthetics, diamond simulants or treated natural diamonds. For more information, visit www.iidgr.com/instruments/Phos_View. *BML*

NEWS AND PUBLICATIONS

Diamond Literature Compilations

Since September 2015, reference compilations of scientific diamond literature prepared by Patricia Sheahan (honorary research associate at the University of British Columbia, Canada) have been posted in the education section of Kaiser Research Online at https://secure.kaiserresearch.com/s2/Education.asp. Annual listings are available from 2005 to the present and include the following fields: author, title, source, region and keywords. In addition, Sheahan's diamond reference compilations are listed by author or media/corporate name for all years. It is also possible to directly receive free monthly diamond literature reference compil-ations by emailing Patricia Sheahan at konsult@compuserve.com and indicating the subscription request in the subject line. *BML*

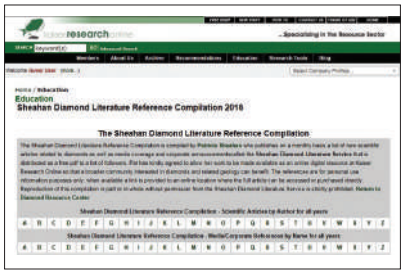

GRS Alert: Phosphorescent Pebbles are Synthetic Aggregates

In April 2016, Gemresearch Swisslab AG (Lucerne, Switzerland) warned the gem trade about a number of manufactured fluorescent pebbles that have been sold for high prices and submitted to their laboratories since 2014. Marketed as natural rounded pebbles, but also seen as carved specimens, the material fluoresces green under strong light and patchy blue-to-green to long-wave UV radiation, with strong green phosphorescence to both. The material proved to be a synthesized aggregate of Sr-Al oxides with traces of Dy and other rare-earth elements. The online report (http://gemresearch.ch/phosphorescent-synthetic-aggregate) includes an informative video. *CMS*

Gem Testing Laboratory *Lab Information Circular*

The July 2016 issue of the Gem Testing Laboratory (Jaipur, India) *Lab Information Circular* includes reports on polymer-treated hessonite; yellow-green translucent opal; a large 'coppery'-coloured star sapphire; unusual fluorescence in mounted, light greyish brown CVD synthetic diamonds; dyed, stabilized alunite sold as gaspeite; a brightly coloured, banded assembled material made with dyed, powdered limestone in polymer and sold as 'rainbow calsilica'; and a plastic bead showing the flame-like structure seen in conch pearls. Download the newsletter from http://gtljaipur.info/ProjectUpload/labDownLoad/LIC_Vol73_July2016_Eng.pdf. *CMS*

ICGL Summer 2016 *Newsletter*

The 2016 No. 2 issue of the International Consortium Gem-Testing Laboratories' *Newsletter* contains four reports on synthetic and treated diamonds: irradiated melee-sized CVD synthetics that might test as natural with a Gemologis instrument, the detection of fracture-filled diamonds, characteristics and identification of nano-coated 'Ice Pink' diamonds from Lotus Colors Inc., and a brief description of a mounted 'pink' diamond showing a partially worn pavilion coating responsible for its pink appearance. Download the *Newsletter* from http://icglabs.org. *CMS*

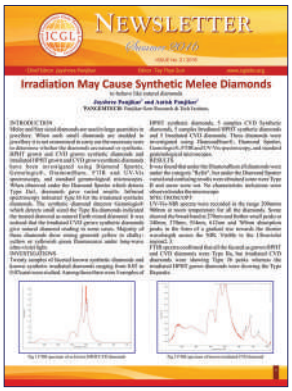

What's New provides announcements of new instruments/technology, publications, online resources and more. Inclusion in What's New does not imply recommendation or endorsement by Gem-A. Entries were prepared by Carol M. Stockton (CMS) or Brendan M. Laurs (BML), unless otherwise noted.

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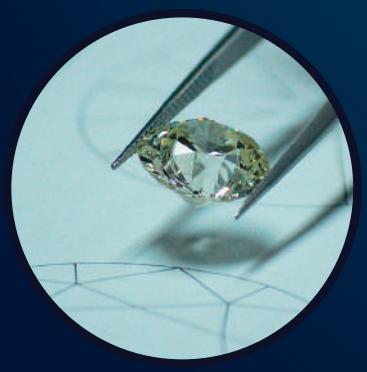

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Gem Notes

COLOURED STONES

Almandine from Negev, Israel

In 2013, some dark red crystals were found in the southern mountains of the Negev Desert region near Eilat, Israel. This area is known to be rich in granite- and quartz-bearing rocks. Around 500 g of samples were collected during a two-month period, and a few were fashioned as cabochons, the biggest weighing 1.54 ct.

Gemmological testing was performed on seven rough samples and on one partially polished piece. They ranged from 0.38 to 0.67 g, averaging slightly over 0.4 g and measuring 4.3–7.8 mm in maximum dimension. All of the crystals exhibited a slightly flattened dodecahedral crystal form with shallow surface striations. They displayed a very dark, highly saturated, red colour with a distinct brownish tint, typical of some garnet (Figure 1). The samples were highly included, and microscopic examination revealed dark irregular-shaped crystals and an abundance of fluid inclusions with some fissures. The RI of the partially polished piece was above the limit of a standard gemmological refractometer (1.80). Most of the samples had hydrostatic SG values from 4.13 to 4.15, with a maximum value of 4.17 and the minimum of 4.10. These properties are consistent with almandine with some spessartine component.

Energy-dispersive X-ray fluorescence (EDXRF) chemical analysis with an Amptek X123-SDD spectrometer confirmed the anticipated high Fe content and a minor Mn component. A very minor amount of Ca also was detected. Absorption spectra recorded with a Unicam UV540 spectrophotometer revealed a classic almandine spectrum (peaks at 507 and 526 nm and a doublet at 573/578 nm) with weak spessartine features (409, 417, 421, 426 and 431 nm). Raman analysis with an Enwave 789 spectrometer yielded a consistent Raman shift of 915 cm^{-1}, and a comparison to the RRUFF database confirmed the garnet to be predominantly almandine.

Figure 1: These dark brownish red crystals and cabochons (0.60–1.54 ct) of almandine originate from the Negev Desert of Israel. Photo by G. Borenstein.

Due to their small size and the abundance of inclusions, these garnets are unlikely to be of commercial interest. However, based on their geographic origin, they may be related to the ancient Nofekh gem that is mentioned in the breastplate of the high priest of the Israelites. Commentaries by Philo Judaeus (Yonge, 1855) and Flavius Josephus (Court, 1770), and a passage in the *Targum Pseudo-Jonathan* (McNamara and Maher, 1994), have all pointed toward a precious stone resembling a burning coal in this breastplate, which might have been garnet.

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- "Gem Corundum Deposits with Regards to Their Geological Origin"
  Gaston Giuliani
- "HPHT - Treated Sapphire: Before and After"
  Hyunmin Choi
- "Purple Garnet from a New Deposit in Mozambique"
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Faceted Anatase from Pakistan

Anatase (TiO_2) is polymorphous with rutile and brookite. Faceted anatase is rarely encountered, although gemmy material has been reported from Switzerland, Russia and Brazil (O'Donoghue, 2006). Recently, gem dealer Dudley Blauwet (Dudley Blauwet Gems, Louisville, Colorado, USA) obtained faceted anatase from another locality: Kharan, Baluchistan, Pakistan. He first encountered this anatase while on a buying trip to Peshawar, Pakistan, in approximately 2000. Almost all of the initial production consisted of opaque crystals on matrix, as well as some loose pieces that had fallen off matrix. More recently, in October 2014, Blauwet obtained ~30 g of crystals that measured up to 2 cm and contained small areas that were transparent enough to facet. In May 2016 he received eight gems from his cutting factory that weighed 0.10–1.56 ct. The smaller stones contained fewer inclusions, and he loaned three of them to American Gemological Laboratories for examination.

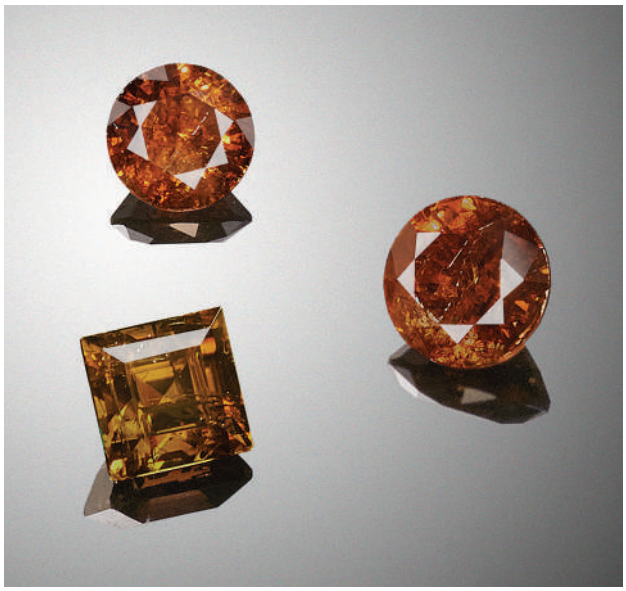

Figure 2: These faceted anatase gemstones (0.10–0.17 ct) are from Baluchistan, Pakistan. Photo by Bilal Mahmood and Kelly Kramer.

The samples weighed 0.10–0.17 ct and were brownish orange to yellowish brown (Figure 2). They were confirmed as anatase with Raman spectroscopy using a 514 nm laser. Refractive indices were over the limit of a standard refractometer, and when viewed in the polariscope all the samples 'blinked' upon rotation, consistent with the uniaxial nature of anatase. Hydrostatic SG values ranged from 3.83 to 3.87. Qualitative chemical analysis using EDXRF spectroscopy showed major amounts of Ti and no trace elements. A multi-channel ultraviolet-visible-near infrared (UV-Vis-NIR) spectrometer recorded no absorption features. Microscopic examination revealed a series of iridescent thin films along cleavage planes in each sample (e.g. Figure 3). Additionally, short, fine tubules and fine particles were visible.

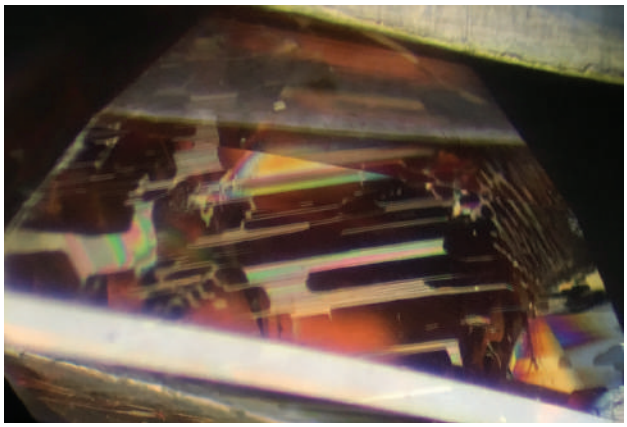

Figure 3: Iridescent thin films are seen along cleavage planes in this 0.16 ct anatase. Photomicrograph by B. Clark.

Anatase may appear visually similar to rutile, but the latter mineral is easily differentiated by its higher SG value (4.23 vs. 3.82–3.95; O'Donoghue, 2006).

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Large Cat's-eye Apatite from Madagascar

For many years, Madagascar has been a source of small quantities of gem-quality apatite that is notable for its bright blue coloration, similar to Paraíba-type tourmaline. Rarely, this material shows chatoyancy (Kammerling et al., 1995). Recently, gem dealer Dudley Blauwet brought to

Figure 4: This cat's-eye apatite from Madagascar weighs 584.22 ct, and is shown here in incandescent light. Photo by J. Rakovan.

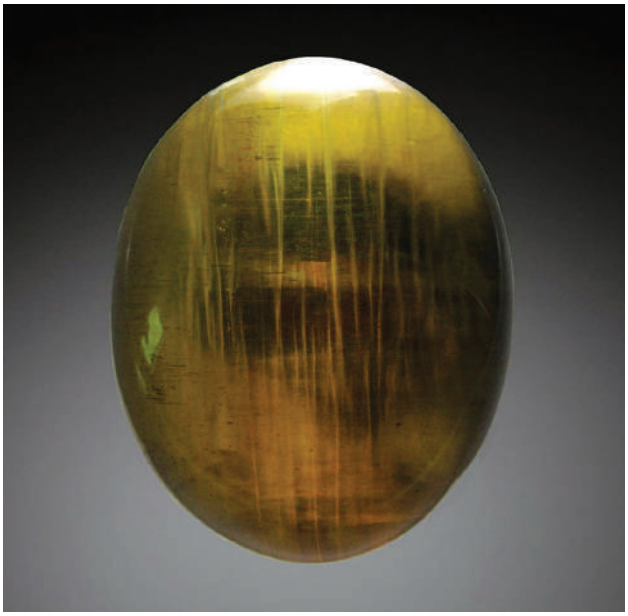

Figure 5: Elongate planar veils traverse the length of the 584.22 ct apatite, as shown here in transmitted daylight-equivalent illumination. The c-axis is oriented perpendicular to these veils. Photo by J. Rakovan.

our attention a cat's-eye apatite from Madagascar of a different colour that was notable for its large size (Figures 4 and 5). He obtained the 584.22 ct cabochon in April 2016 while on a buying trip to Ratnapura, Sri Lanka. The merchant who sold him the stone specialized in acquiring rough sphene (titanite) from the Darren mine located near Ambilobé in the Vohemar District of northern Madagascar. This supplier stated that the rough apatite used to cut this stone also was found at the Darren mine. This is generally consistent with a report by Pezzotta (1999), who documented apatite crystals up to 7 cm long associated with sphene, quartz and other minerals in alpine clefts of the Vohemar-Ambilobé region.

The apatite cabochon was examined by one of the authors (JR) for this report. It measured 4.9 × 3.85 × 3.2 cm, and exhibited a colour shift from reddish brown in incandescent light to greenish yellow-brown in daylight-equivalent illumination (again, see Figures 4 and 5). A well-defined chatoyant 'eye' ran the length of the stone when it was viewed with reflected pinpoint illumination. Transmitted lighting revealed elongate planar veils of fluid inclusions that also traversed the length of the stone (Figure 5). Examination of the stone with a polariscope showed that these veils were generally oriented perpendicular to the c-axis. Microscopic examination revealed abundant growth channels parallel to the c-axis that were responsible for the chatoyancy (Figure 6a). At higher magnification, some of these growth tubes were seen to be partially filled with black or red solid phases (Figure 6b).

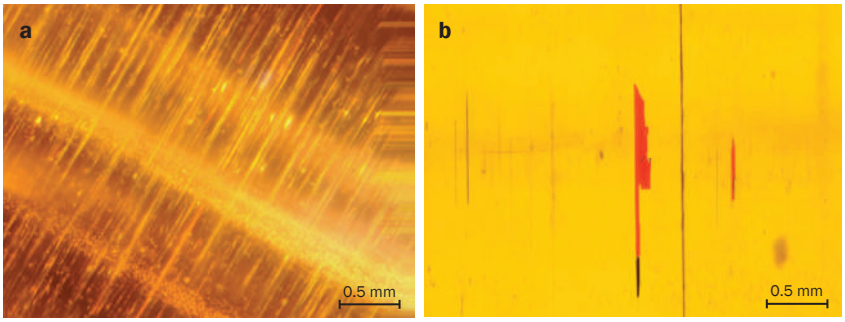

Figure 6: (a) Oblique transmitted lighting shows abundant growth tubes oriented parallel to the c-axis that are responsible for the apatite's chatoyancy. Perpendicular to these are thick planar veils of fluid inclusions (here, viewed edge-on). (b) Higher magnification reveals that some of the growth tubes are filled with black or red solid phases. Photomicrographs by J. Rakovan.

Confocal Raman spectroscopy using a 785 nm laser with a Renishaw InVia Raman microscope confirmed that the host gem was fluorapatite, but the solid phases in the inclusions could not be identified due to a high fluorescence background in the 500–200 cm^{-1} region and especially above 1000 cm^{-1}. Confocal Raman analysis with a 633 nm laser also produced strong fluorescence. Based on the inclusions' coloration and geological environment of formation, the red phase is probably hematite or lepidocrocite and the black material is likely a manganese oxide mineral.

The alpine clefts of northern Madagascar are known for producing large and fine specimens of sphene and quartz, and these are now joined by chatoyant apatite.

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Unusual Aquamarine from Pakistan

For decades, Pakistan has been an important producer of aquamarine and other pegmatitic minerals. In June 2015, gem dealer Dudley Blauwet obtained an unusual broken crystal of aquamarine while on a buying trip to northern Pakistan. His supplier stated that it came from Shah Nassir peak, near the village of Nyet in the Braldu Valley. The crystal locally contained conspicuous aggregates of green inclusions and also showed some chatoyant areas. In May 2016, four cabochons were cut from the 86.1 g crystal: The two largest (101.39 and 97.43 ct; e.g. Figure 7) were pale bluish green and had areas of weak chatoyancy along with patches of the green inclusions, while the two smaller gems (24.64 and 20.00 ct; e.g. Figure 8) were greenish blue and displayed a sharp cat's-eye but contained no green inclusions.

Blauwet loaned the 97.43 ct cabochon to the American Gemological Laboratories for examination. The stone had RIs of 1.573–1.581 (birefringence 0.008) and a hydrostatic SG of 2.71, consistent with beryl. Confirmation of its identity was obtained by Raman analysis using a 514 nm laser. EDXRF chemical analysis of the sample showed the expected major amounts of Si and Al for beryl,

Figure 7: This 97.43 ct aquamarine cabochon from Pakistan contains conspicuous aggregates of green inclusions. Photo by Kelly Kramer and Bilal Mahmood.

Figure 8: This cat's-eye aquamarine (24.64 ct) was cut from the same piece of rough as the stone in Figure 7. Photo by Orasa Weldon.

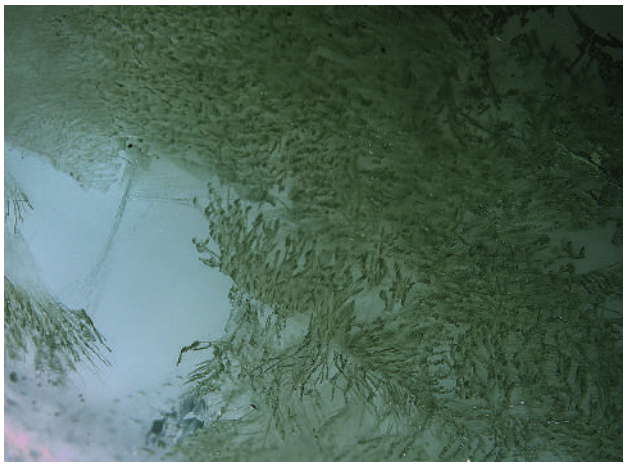

Figure 9: An ocean-like scene of monazite-Ce inclusions is present within the aquamarine cabochon shown in Figure 7. Photomicrograph by Christopher P. Smith; magnified 30×.

as well as traces of Fe, Na and Mn. UV-Vis-NIR spectra collected with a multi-channel spectrometer showed typical aquamarine absorption features at 370 and 427 nm.

The cabochon revealed an extremely faint 'eye' when viewed with a concentrated fibre-optic light source in certain directions. More interesting were the dense zones of yellowish green inclusions that created an ocean-like atmosphere (Figure 9); these were identified using Raman microspectroscopy (by comparison with the RRUFF database) as monazite-Ce. Gübelin and Koivula (2005) also documented yellowish green monazite inclusions in a beryl from Pakistan, but those in the present stone had a much finer texture. Additionally, the 97.43 ct cabochon contained small aggregates of greyish green and black zircon, as well as 'fingerprints' and very fine particles.

Blauwet reported that he has occasionally encountered similar specimens of aquamarine (only as one or two pieces at a time) since the early 2000s during various visits to northern Pakistan.

Bryan Clark

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Chrome Chalcedony from Tanzania

Chrome chalcedony is a rare variety of chalcedony that is typically dark green or 'olive' green, and is known from just a few localities worldwide: Zimbabwe ('mtorolite'), Bolivia, Turkey and Australia (Hyršl, 1999; Willing, 2003). It can be mistaken for similar-appearing chrysoprase, which is coloured by nickel. Like chrysoprase, chrome chalcedony occurs only in weathered ultramafic rocks.

Figure 10: Chrome chalcedony from Tanzania (left, 42 mm long) has a similar colour appearance to gem silica from the Lily mine in Peru (right). Photo by J. Hyršl.

A new material sold as 'gem silica' (Figure 10) appeared in 2016 from an unknown locality in Tanzania. While visiting Idar-Oberstein, Germany, this author saw approximately 20 polished cabochons that were up to about 5 cm in maximum dimension. Gem silica, also known as chrysocolla chalcedony (Frazier and Frazier, 1999), is another rare variety of chalcedony, which is coloured by microscopic inclusions of copper silicates. The colour of the new material showed obvious inhomogeneities consisting of 'turquoise' blue and near-colourless areas. The coloured portions were very similar to gem silica from Arizona, Peru or Namibia (see, e.g., Figure 10). The RI of the material was 1.537, and it remained bright upon rotation in a polariscope (i.e. aggregate reaction). When exposed to short-wave UV radiation, the colourless areas displayed strong yellow-green fluorescence and the blue parts luminesced light yellow-green, while in long-wave UV both areas fluoresced milky white. Viewed with a Chelsea filter, the blue areas appeared pink. UV-Vis-NIR

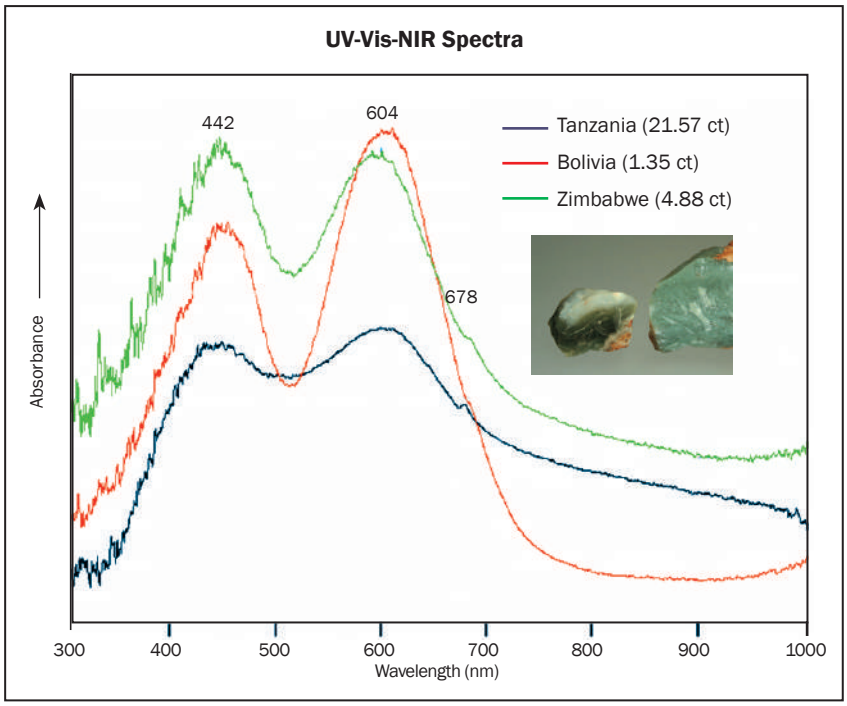

Figure 11: UV-Vis-NIR spectra for chrome chalcedony from Tanzania, Bolivia and Zimbabwe show chromium-related absorption features at 442, 604 and 678 nm. The inset shows the tested samples from Bolivia (left, 26 mm long) and from Zimbabwe (right); photo by J. Hyršl.

spectroscopy of the blue areas revealed chromium as the chromophore (Figure 11; see also Henn et al., 2016), so the correct description of this material is chrome chalcedony.

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Yellow Dravite from Tanzania

During the 2016 Tucson gem shows, Todd Wacks (Tucson Todd's Gems, Tucson, Arizona, USA) showed author BML a yellow 11.13 ct tourmaline that he faceted from a piece of rough recently obtained on a buying trip to Tanzania by Sir-Faraz Ahmad (Farooq) Hashmi (Intimate Gems, Glen Cove, New York, USA). The rough material was reportedly found in October–November 2015 in the Landanai region of north-eastern Tanzania, in an area that is known for producing green 'chrome' tourmaline. The rough consisted of a round 'nodule' that showed a few crystal faces (Figure 12, left). In faceting the gemsone, Wacks cut a small table and a deep pavilion to maximize the colour appearance (Figure 12, right).

Landanai is located in the same region of East Africa that produces 'golden' yellow tourmaline, particularly in the Taita-Taveta District of southern Kenya (see Simonet, 2000, and references therein). The tourmaline from this area is commonly dravite with a minor uvite component. Since the slightly orangey yellow coloration of the present tourmaline was somewhat different from the typical 'golden' tourmaline, we decided to examine the stone in more detail.

Refractive indices measured by author BML were typical for tourmaline: 1.620–1.639 (birefringence 0.019). Microscopic examination revealed a few minor 'fingerprints' and a single colourless mineral inclusion. Additional testing

Figure 12: The tourmaline gem nodule from Tanzania on the left was faceted into the 11.13 ct stone on the right. Photos by Todd Wacks (left) and Orasa Weldon (right).

was performed by author GRR at the California Institute of Technology. The composition of the sample was determined by energy-dispersive X-ray analysis using a Zeiss 1550 VP field-emission scanning electron microscope (SEM) with an Oxford Instruments X-MaxN SDD energy-dispersive spectroscopy (EDS) analysis system. A square-shaped area (155 µm wide) on the table of the stone was analysed. Because the sample was not carbon coated to conduct away electrons from the SEM beam, the analysis was run in variable-pressure mode. The X-ray spectrum (Figure 13) indicated that the stone was dominantly a Na,Mg-aluminosilicate. Minor amounts of Ca, Fe and Ti (but no Mn) also were detected. Detailed analysis of the X-ray spectrum with Oxford Instruments AZtec software showed that a significant amount of boron was present in addition to the other elements mentioned above. The data confirmed that the tourmaline was dravite, with Fe and Ti most likely responsible for its colour.

The slightly orangey yellow colour of the dravite showed moderate dichroism such that the E⊥c direction had the more intense colour. Compared to many dravites of similar size, which are commonly brown, this sample showed a low intensity of colour and a high degree of transparency. To confirm the cause of colour, Vis-NIR spectroscopy was performed. Absorption spectra (Figure 14) were obtained through the girdle of

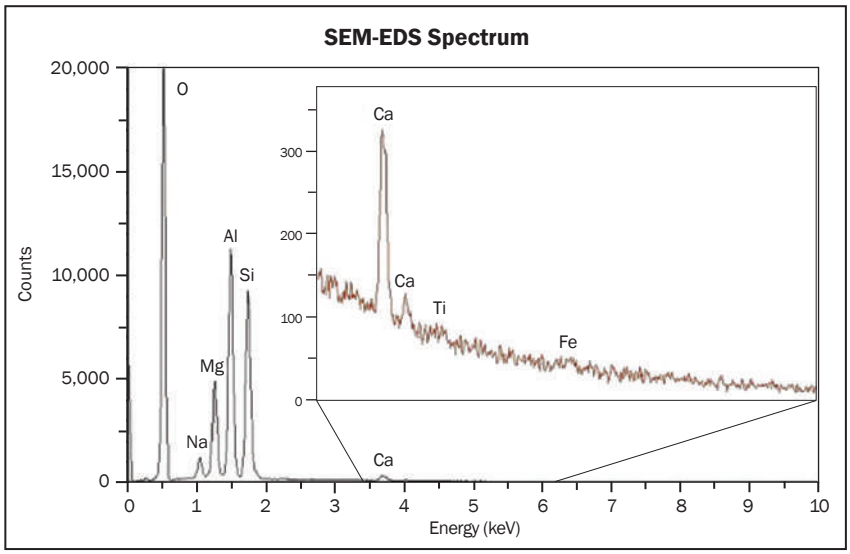

Figure 13: SEM-EDS chemical analysis shows that the tourmaline in Figure 12 is Mg-rich with some Na and minor Ca, corresponding to a dravite composition. Also present are traces of Fe and Ti.

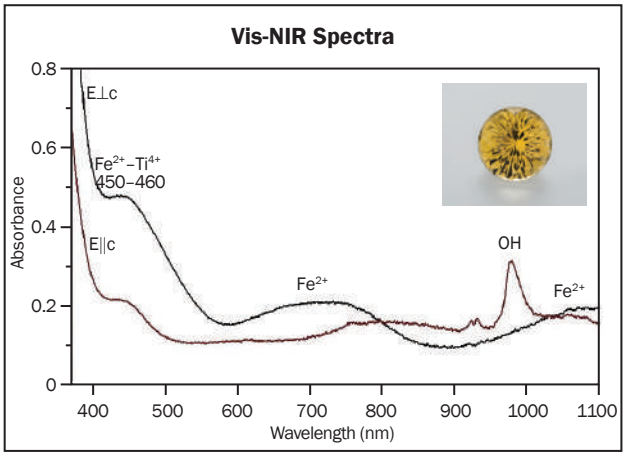

Figure 14: Polarized Vis-NIR absorption spectra of the yellow dravite show a dominant feature in the 450–460 nm region that is caused by Fe^{2+}–Ti^{4+} intervalence charge transfer. The spectrum is plotted for a 10.0 mm sample thickness.

the stone with the beam polarized both parallel and perpendicular to the girdle direction, corresponding to the E⊥c direction and approximately to E||c, respectively. A prominent absorption feature was recorded in the 450–460 nm region, and this is also an important characteristic of brown dravite such as the material from Yinnietharra, Australia. It arises from Fe^{2+}–Ti^{4+} intervalence charge transfer (Mattson and Rossman, 1988), and is the dominant cause of colour in this dravite. Fe^{2+}-related features occurred near 700 and 1100 nm, and narrower peaks in the 900–1000 nm region were overtones of OH absorptions in the infrared.

This attractive yellow dravite is much lighter coloured than typical brown dravite because of its low Fe and Ti contents. Its spectrum is similar to that of the golden dravite from Kenya (cf. Simonet, 2000), except that the broad absorption band in that material was centred at 435 nm rather than in the 450–460 nm region.

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New Garnets from East Africa

During a buying trip to Arusha, Tanzania, from late May to early June 2016, rough stone dealer Farooq Hashmi encountered some new garnet rough that was reported to be from north-eastern Tanzania or south-eastern Kenya. Several kilograms were available as pebbles and fractured pieces ranging up to ~10 g. The garnet was sold by local dealers as rhodolite. The colour of the material showed some variation, and Hashmi purchased only the lighter material (with a more purple colour in daylight), which he has marketed as 'Rhodolaya'.

Hashmi loaned three faceted stones (e.g. Figure 15) and 18 rough samples to authors CW and BW for examination. The cut stones weighed 3.24, 3.36 and 3.89 ct, and measured up to 9.4 × 8.2 ×

Figure 15: These two specimens (3.24 and 3.89 ct) are representative of some of the new garnet production from East Africa. The stones were faceted by Marvin M. Wambua, Safigemscutters Ltd., Nairobi, Kenya; photo by B. Williams.

Figure 16: These rough garnets (2.1–5.4 g) appear strongly bluish purple in daylight (left) and slightly orangey red in incandescent light (right). Photos by B. Williams.

6.2 mm. The rough material weighed a total of 50.1 g and the piece with the longest dimension measured 21.3 mm. The faceted stones appeared moderate purplish red (typical of rhodolite) under daylight-type illumination, and changed to a slightly orangey red (as commonly seen in malaya garnet) in incandescent light. However, in these authors' opinion, there was not enough of a shift to label it colour-change garnet. The rough stones appeared slightly orangey red in incandescent light and displayed a strong bluish purple in transmitted daylight (Figure 16), but the latter colour was not evident in the faceted stones, possibly due to dichromatism as a result of their smaller size and therefore shorter path length of light.

Refractive indices varied slightly from 1.743 to 1.749, and the hydrostatic SG value of all three cut stones was 3.82; these data are consistent with pyralspite garnet. The faceted samples exhibited various appearances between crossed polarizers, with one showing no strain and remaining dark during rotation, one behaving like an anisotropic stone and blinking four times during a complete rotation, and one showing patchy anomalous birefringence. Some of the rough material also displayed patchy birefringence. All of the faceted stones were eye-clean, but the microscope revealed a 'fingerprint', a fine colourless needle and a dark reflective crystalline inclusion surrounded by tension fractures (Figure 17). UV-Vis spectroscopy showed mainly almandine-related absorptions at 505, 527 and 575 nm. Raman analysis yielded a pattern expected for pyralspite garnets, and the samples showed moderate magnetic susceptibility.

Chemical data for the three faceted stones was obtained by author AUF via standard-based SEM-EDS analysis using a Jeol JSM-6400 instrument with the Iridium Ultra software package by IXRF Systems Inc. The data showed a similar composition for all three samples (Table I), consisting mainly of the pyrope component (58.9–62.2 mol%) with ma-

Figure 17: The faceted garnet samples were found to contain a 'fingerprint' (left), a colourless needle (centre) and a crystalline inclusion (centre and right). Photomicrographs by C. Williams; magnified 40× (left and right) and ~15x (centre).

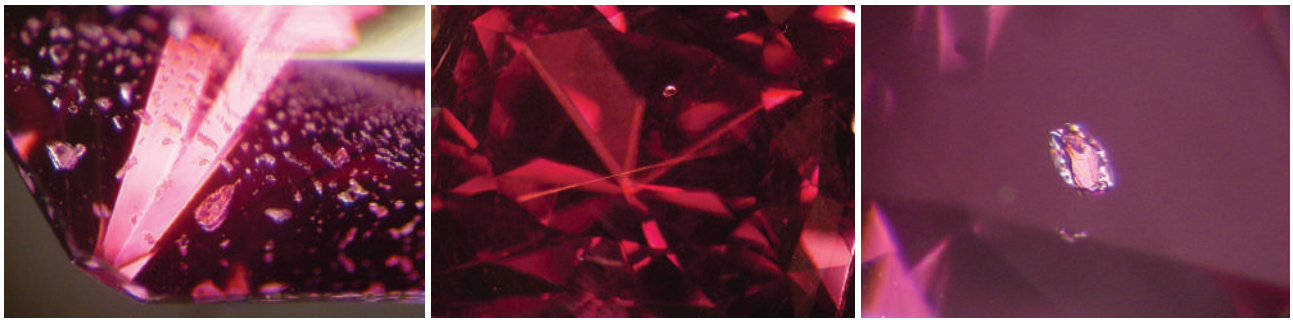

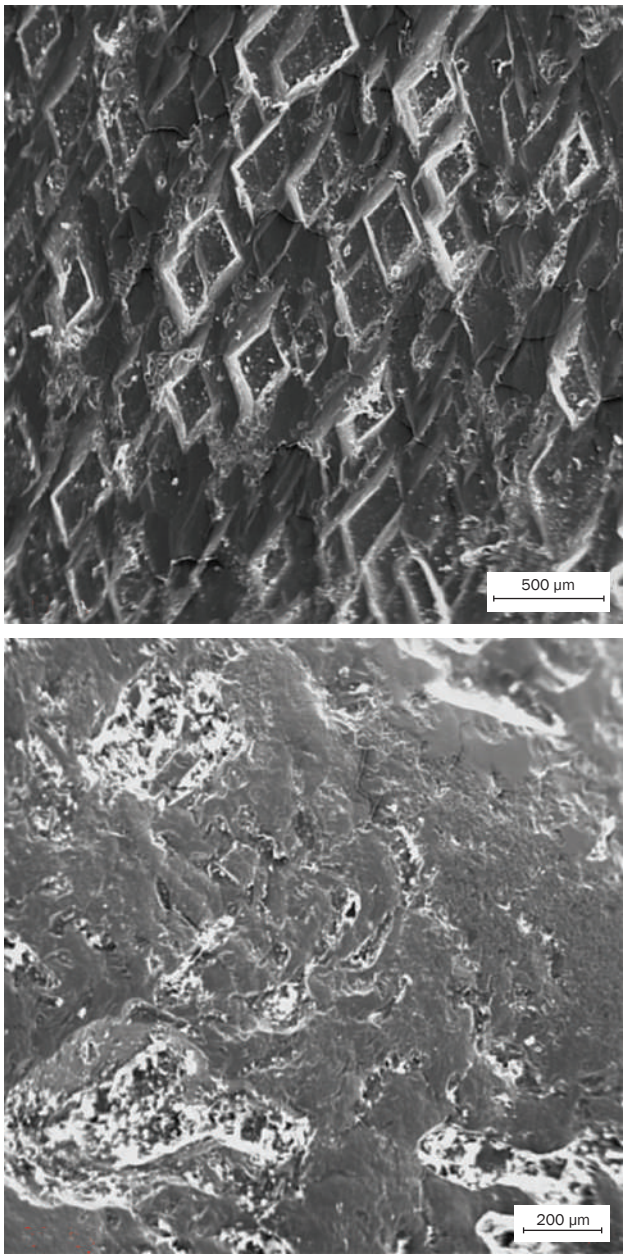

Figure 18: These SEM images of the surface features of two garnet pebbles show evidence of chemical etching (top) and the effects of mechanical abrasion from alluvial transport (bottom). Images by A. U. Falster.

*Table I: Representative SEM-EDS analyses of three new garnets from East Africa.**

Composition	Trilliant	Round	Cushion
Oxide (wt.%)			
SiO_2	40.89	41.03	41.01
TiO_2	0.15	0.17	0.11
Al_2O_3	23.04	23.02	22.98
Cr_2O_3	0.15	0.15	0.20
V_2O_3	0.26	0.24	0.05
FeO	12.41	11.89	13.98
MnO	4.71	4.20	3.35
MgO	16.15	17.30	16.32
CaO	2.24	2.00	2.00
Total	**100.00**	**100.00**	**100.00**
Ions based on 12 oxygens			
Si	2.990	2.985	2.999
Ti	0.008	0.009	0.006
Al	1.986	1.975	1.981
Cr^{3+}	0.009	0.009	0.012
Bi^{3+}	0.000	0.000	0.000
V^{3+}	0.015	0.014	0.003
Fe^{2+}	0.759	0.724	0.855
Mn	0.292	0.259	0.207
Mg	1.761	1.876	1.778
Ca	0.175	0.156	0.157
Mol% end members			
Pyrope	58.9	62.2	59.4
Almandine	25.4	24.0	28.5
Spessartine	9.8	8.6	6.9
Grossular	5.9	5.2	5.2

* Data are auto-normalized by the software, and therefore the sum of the oxides is 100 wt.%.

jor almandine (24.0–28.5 mol%), and much lower spessartine (6.9–9.8 mol%) and grossular (5.2–5.9 mol%) components. Minor amounts of V, Cr and Ti also were present in all samples. This combination is commonly seen in garnets of the rhodolite and malaya varieties. Interestingly, SEM images of the surface of the rough samples showed evidence of both chemical etching and mechanical abrasion from alluvial transport (Figure 18).

East Africa continues to be an important source of gem-quality pyralspite garnets, as shown by this attractive new material.

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Quartz Cubes from Volodarsk-Volynski, Ukraine

The Volynian granitic pegmatite deposits in western Ukraine are historic sources of superb gem-quality beryl, topaz and smoky quartz (Lyckberg et al., 2009). Quartz was the main target for min-

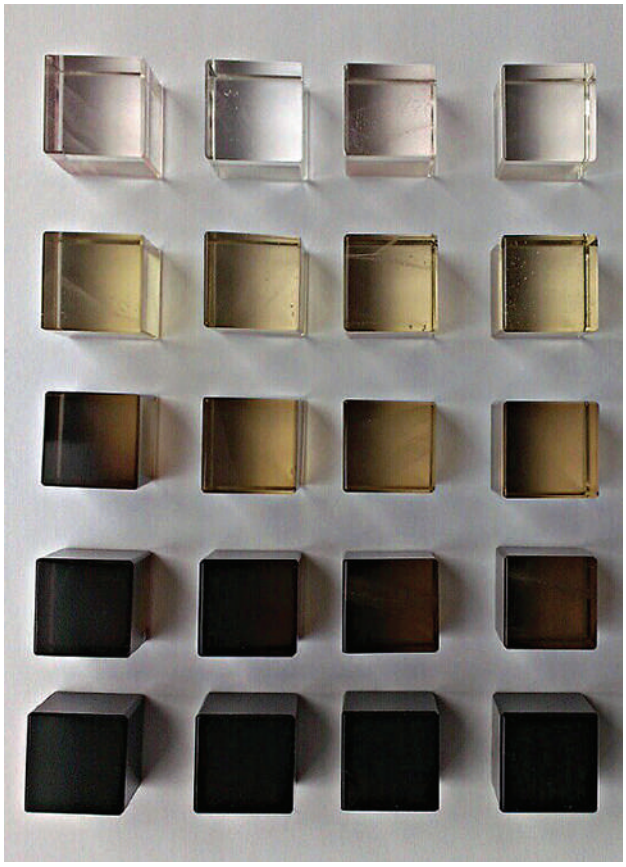

Figure 19: These polished quartz cubes from Volodarsk-Volynski, Ukraine, show various amounts of smoky coloration, ranging from black (untreated) to near-colourless (heated to 340–350°C). Each cube measures 2 cm wide. Photo by Dr Rostyslav Kyrii, mine manager.

ing back in the Soviet era due to its piezoelectric properties. Since approximately 2012, the three major mines in the area have been under the control of PJSC Kvartssamotvit (Volodarsk-Volynski, Zhitomir Oblast, Ukraine), with this author being a consultant since March 2016. The company mines only one deposit at a time due to ongoing flooding by groundwater that requires pumping on a 24-hour basis. The two main levels of the mines are at approximately 60 and 120 m depth. Large quartz crystals have been found in all of the mines and at all levels. Due to the large size of the gem-bearing 'pockets' or cavities—typically several metres in dimension, making them some of the largest in the world—only one pocket at a time is mined by the current full-time operation.

Due to natural radiation within the pegmatite, most of the quartz is so smoky that it appears black (morion). The radiation damage can be reversed by heating the quartz to temperatures up to 350°C. The fading of the smoky colour is carefully controlled according to the heating temperature, yielding a full range from dark smoky to near-colourless. The temperature range needed to produce a given colour is not always consistent; because the various pockets have different radiation histories, the quartz from each behaves slightly differently.

The heating process is done by placing the quartz (rough pieces or entire crystals) within sand in an oven. The sand helps provide even heating and reduces fracturing due to thermal expansion and contraction. Approximately 40 minutes to one hour is taken to bring the quartz up to the chosen temperature, and it is held there for one hour. The temperature is then slowly reduced over a period of about 12 hours. Starting with morion, the temperatures used to produce the various colours are as follows: dark brown—270–290°C, light brown—290–300°C, pale smoky to citrine—310–320°C, and near-colourless—340–350°C.

After heat treatment, the quartz is processed into sets of polished cubes (e.g. Figure 19) at the company's cutting centre in Volodarsk-Volynski for use in modern jewellery designs. Each colour set consists of five cubes that measure 2 cm wide. In addition, some smaller cube sets are being created for earrings (4 and 6 mm) and pendants (8 mm), and beads also are being cut. These quartz products are presently being produced from six cutting lines (three automated). Several dozen prototype cube sets have been manufactured, and the company is currently starting full production.

The cubes typically contain veils and feathers that add interest to the quartz by forming various three-dimensional inclusion patterns. The sets also provide an educational example of the effect of annealing a naturally irradiated gem material.

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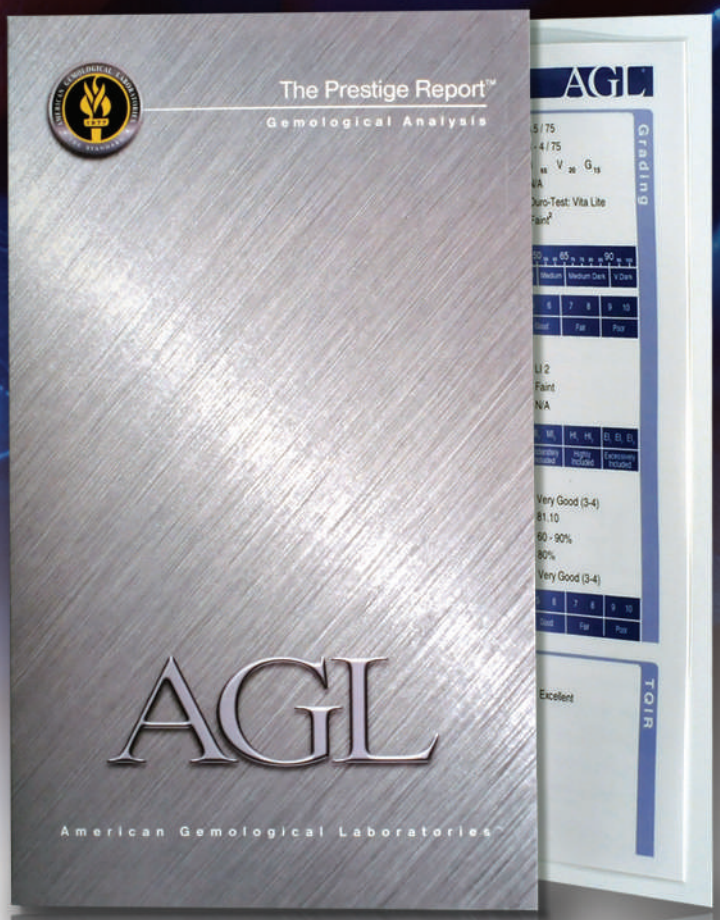

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Star Sapphire Showing a Variable Number of Rays

This article documents an unusual nine-rayed star sapphire that weighs 8.47 ct (11.89 × 10.16 × 6.06 mm) and originated in Myanmar according to its owner. The stone is accompanied by a report from GRS GemResearch Swisslab that is dated 2007. A nine-rayed star is observed when the cabochon is illuminated at its centre with a pinpoint light (Figure 20a). The asterism consists of a complete six-rayed star of white-coloured rays that is bisected on its right side by a three-rayed star of pale brown colour. However, when moving the light source along the stone, the number of rays does not stay constant: a white six-rayed star is observed on one end of the cabochon (Figure 20b) and a 12-rayed star composed of both pale brown and white rays is seen on the opposite end (Figure 20c). This suggests an inhomogeneity of the inclusions that produce the asterism in the host sapphire, thus motivating further investigations.

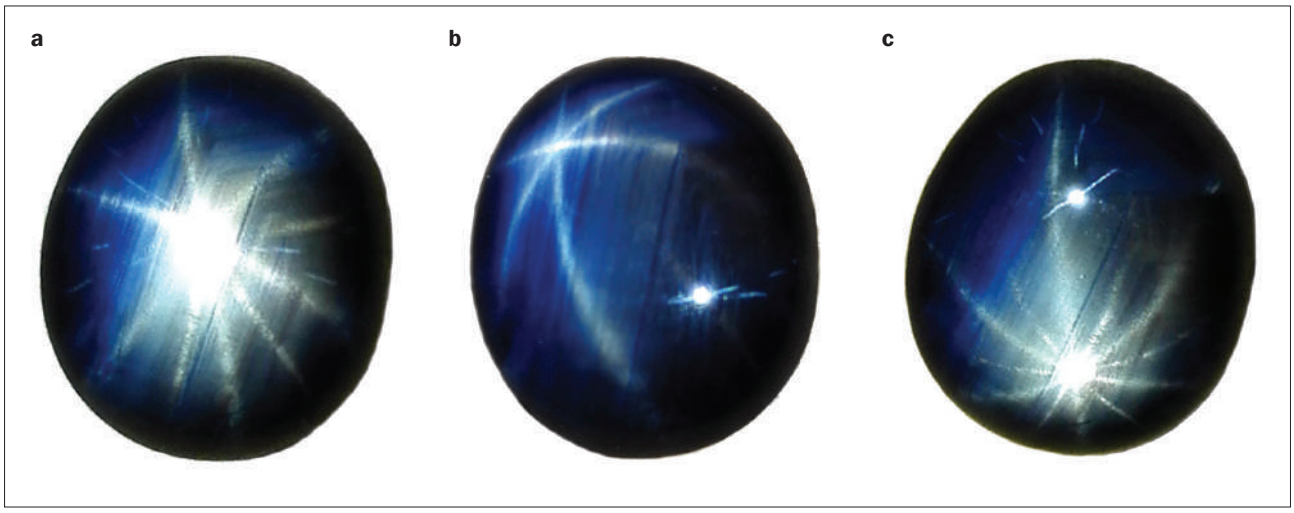

Figure 20: Depending on how this 8.47 ct sapphire cabochon is illuminated, it displays (a) a nine-rayed star, (b) a six-rayed star or (c) a 12-rayed star. The pinpoint light source is positioned over the centre, bottom right and top-centre of the stone, respectively. Photos by T. N. Bui.

The body colour of the sapphire was blue and its overall diaphaneity ranged from transparent to slightly translucent. Growth zoning was observable as banding along the crystallographic directions of the corundum host. Two different areas of the cabochon could be distinguished (Figure 21, left): a transparent area with narrow whitish and blue growth zoning (corresponding to the area showing the six-rayed star) and a translucent-to-opaque portion with broad brownish bands and a higher density of inclusions (corresponding to the area showing the 12-rayed star). The latter bands were quite similar to those seen in 'Gold Sheen' sapphires from Kenya (Bui et al., 2015). Observed with transmitted light (Figure 21, right), the whitish and brownish bands appeared darker, while the blue bands were lighter. This highlights the presence of mechanical coloration by inclusions constituting the whitish and brownish bands of the blue sapphire.

The white six-rayed star in Figure 20 has branches that are oriented perpendicular to or at ±30° from the growth zoning bands. A pale brown six-rayed star, partly visible within the nine-rayed star of Figure 20a and complete in the 12-rayed star of Figure 20c, is perpendicular to the former so its branches are parallel to or at ±60° from the growth zoning bands. These observations suggest that the white six-rayed star is formed by rutile-type inclusions and the pale brown one by hematite/ilmenite-type inclusions (cf. Hughes, 1997, p. 446).

Close inspection of the inclusions at high magnification revealed some details about the microstructure of the whitish and brownish bands. On the end of the cabochon showing the six-rayed star, the density of the acicular inclusions on the surface was weak. Networks of needles, in three different orientations and intersecting

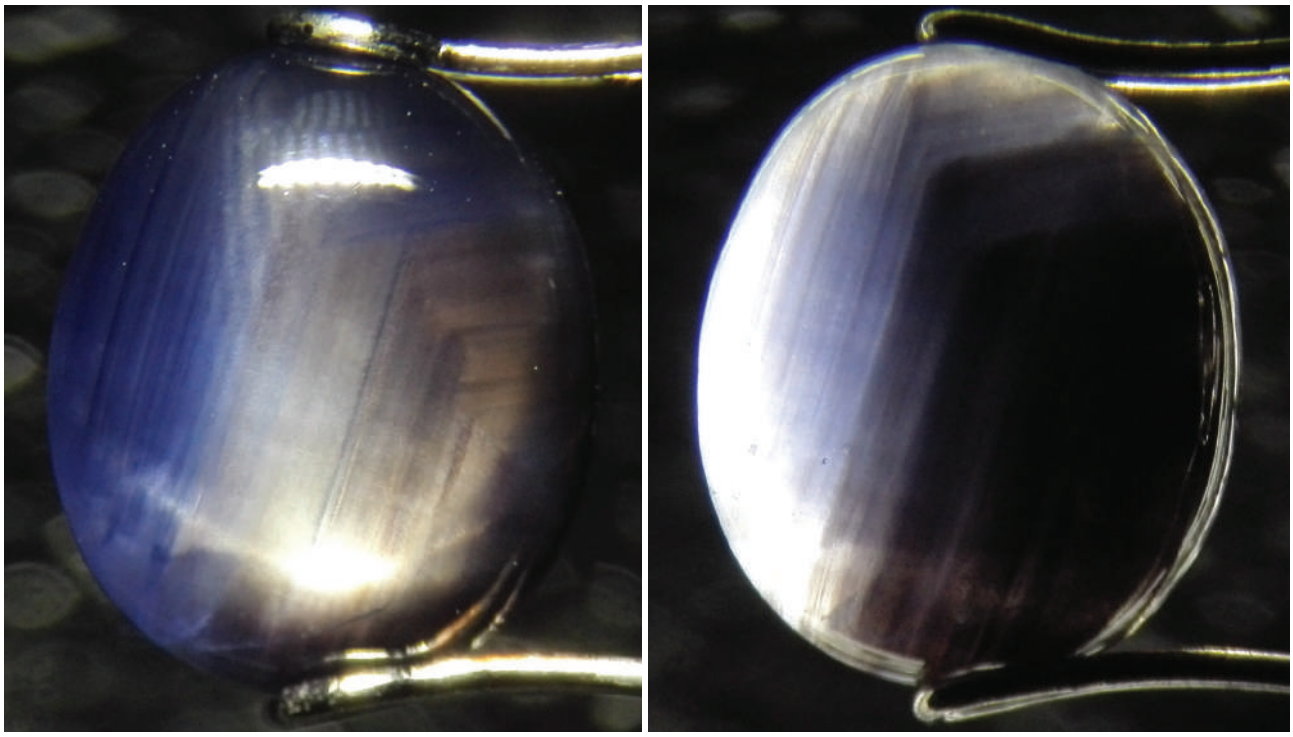

Figure 21: As seen in the left photo in brightfield illumination, colour and growth zoning in the 8.47 ct star sapphire are characterized by white (left portion) and brown-bronze (right portion) bands along the crystallographic directions of the corundum host. Transmitted light (right photo) reveals the mechanical coloration by the inclusions constituting the growth bands. Photomicrographs by T. N. Bui.

at 120° typical of the three-fold rotational symmetry, were present within the basal pinacoid. These needles were oriented parallel to the corundum growth bands. Two similar networks of needles and platelets were present on the other end of the stone showing the 12-rayed star. The needles were parallel to the growth bands, while the platelets were perpendicular to it. The density of the inclusions in the latter network was quite high. Both networks appeared to overlap, but in fact they grew in alternating layers along the c-axis (Figure 22).

Raman spectra of the inclusions (Figure 23) gave results that were quite similar to previous studies (e.g. Palanza et al., 2008; Bui et al., 2015). The needles on the end of the cabochon showing the six-rayed star were identified as rutile, while both rutile and ilmenite were present on the other end, producing the 12-rayed star.

By analysing the pattern of the growth zoning in this Burmese sapphire, we deduce that crystal growth began from the bottom side of the brownish area. The initial input of fluids rich in Ti and Fe resulted in abundant exsolved phases of epigenetic inclusions in the host sapphire. Sharp changes in the concentrations of Ti and Fe at each growth step produced the oscillating broad brownish bands along the crystallographic directions in the basal pinacoid.

Figure 22: Networks of oriented inclusions consisting of needles and/or platelets lie within the basal pinacoid of the sapphire, where they form alternating layers. Both rutile (blue arrow) and ilmenite (red arrow) inclusions were identified in the brownish growth bands of the cabochon. Photomicrograph by T. N. Bui, brightfield illumination; field of view 330 × 250 μm.

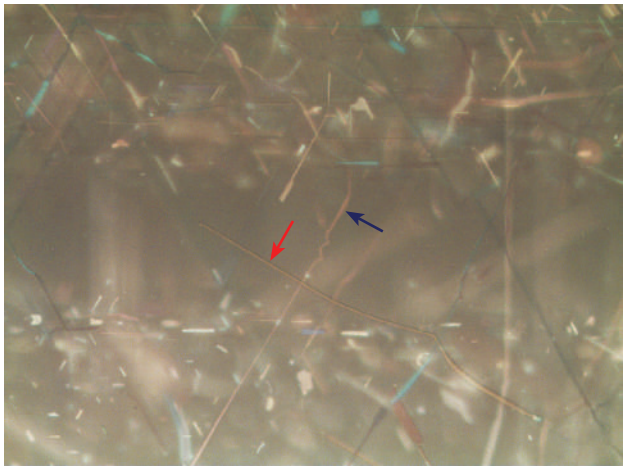

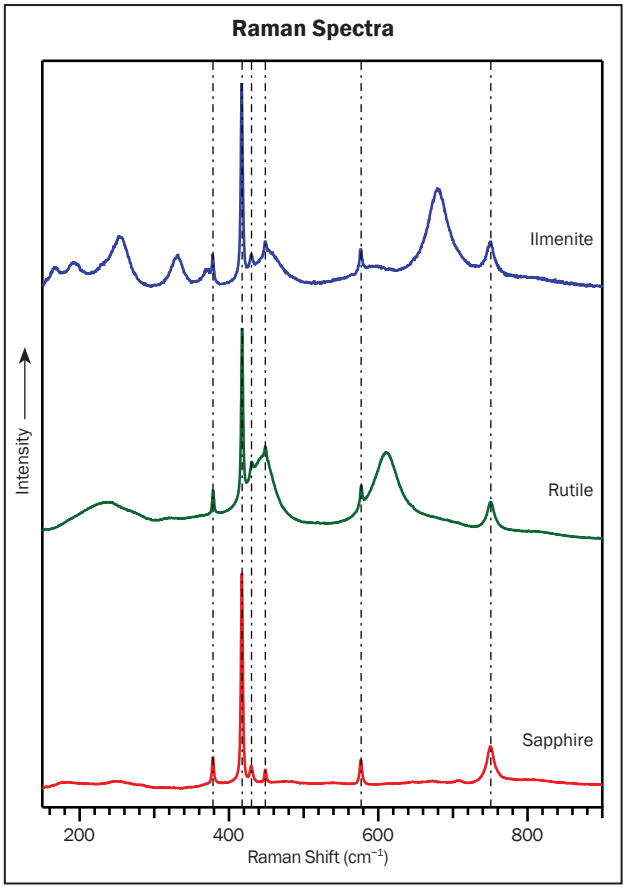

Figure 23: Raman spectra are shown for the host sapphire and for the inclusions responsible for the whitish and the brownish growth zoning, respectively—identified as rutile and both rutile and ilmenite needles and/or platelets. The vertical dashed lines indicate the Raman peaks of corundum superimposed on those of the analysed inclusions.

Microscopic observation of the inclusions in the brownish area at different positions along the c-axis (not shown here) revealed that inclusions of the same type were co-planar. This suggests that a fluctuation of Ti- and especially Fe-rich fluids occurred during crystal growth along the c-axis. Assuming a constant Ti input, Fe-poor fluids lead to rutile and Fe-rich to ilmenite. Subsequently, the input of Fe-rich fluids drastically decreased, generating only exsolution of rutile during further growth of the crystal in the basal plane. This explains the six- and 12-rayed stars that were produced, respectively, by exsolutions of rutile and both rutile and ilmenite.

Nature's decision to vary the seasoning of Fe-rich fluids during the formation of the corundum crystal—combined with a controlled or fortuitous cutting orientation of the rough so that the border between the two regions was located at the centre of the cabochon—are simultaneously responsible for the unusual nine-rayed asterism visible only when the stone is illuminated at its centre.

Acknowledgements: This work was partially funded by Almini Beijing Trading Co. Ltd. (亚米尼北京贸易有限公司), China. We are grateful to Tanzim Khan Malik for supplying the sample. Our gratitude goes to Yiannis Karvelis for proof-reading the English text.

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Unusual Star Sapphire from Tanzania

In this study, we document an interesting Tanzanian star sapphire that is set in a gold ring. Called 'Zebra Star', the stone resides in author PE's collection. Rather than displaying uniform blue coloration, the background consists of a series of striated parallel bands of various widths that range from white to dark blue (Figure 24). Such a thick-banded zonal structure is unusual

Figure 24: The asteriated Tanzanian sapphire (~13 × 9 mm) in this ring displays large and distinct colour bands that are oriented perpendicular to the vertical branch of the star. Photo by J.-P. Gauthier.

in sapphire, although it was reported by Fritsch and Lulzac (2004) in the case of a slightly asteriated stone, without any reference to the country of origin.

The cabochon measured approximately 13 × 9 × 6 mm. It was first observed with a Leica S8 APO binocular microscope (up to 80×), and then with a Leica DM4000 B for higher magnification (up to 400×). To avoid removing the stone from the ring, we examined it by lighting the front side with a regular desk lamp and the back with a special illuminator. Reflected light (Figure 25, left) showed broad and narrow bands of alternating dark and light hues. The opacity of the stone prevented focusing the microscope inside the white bands. Transmitted light (Figure 25, right) produced an inversion of the band hues, while confirming the opacity of the white bands and conversely demonstrating the transparency of the dark bands.

On the vertical branch of the star oriented perpendicular to the colour bands, it was possible to detect the presence of thin white acicular inclusions (Figure 26, top). These inclusions, oriented parallel to the colour banding, accounted for the chatoyancy of the corresponding branch of the star. Their relative orientation with respect to the bands, their aspect ratio and their colour suggested they are rutile needles (cf. Sahama, 1982; Hughes, 1997, pp. 94 and 446). The high density of these inclusions 'mechanically' colours the white zones (cf. Hughes, 1997, p. 447), whereas the depleted zones showed significant transparency and therefore appeared dark.

Viewing the same area of the stone with the star branch at 60° from the colour banding showed another set of reflective needles that was oriented perpendicular to that branch (Figure 26, bottom). A similar observation was made for the third branch of the star at 120°. In each case, the

Figure 25: The ~13 × 9 mm star sapphire is shown here in reflected light (left) and in transmitted illumination (right). The banding displays a reversal of shades between the two images. Also visible in the left image are 'fingerprint' inclusions (red arrows). Since it was challenging to produce homogeneous transmitted lighting, the reversal of band hues is less evident on the left side of the stone in that photo. Both images have been edited to show the stone without the surrounding mounting. Photos by J.-P. Gauthier.

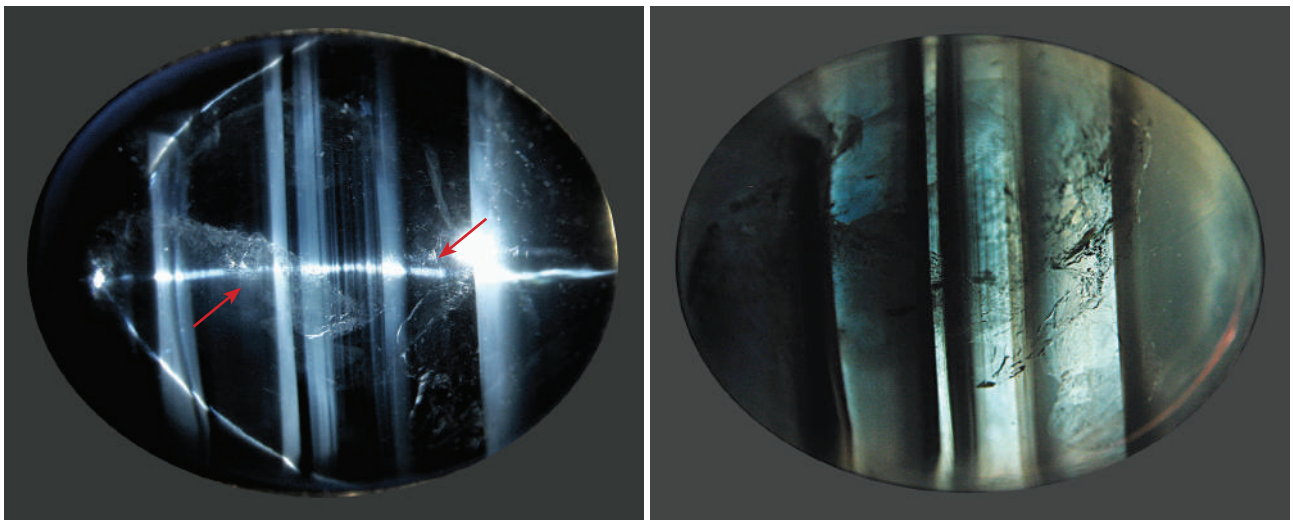

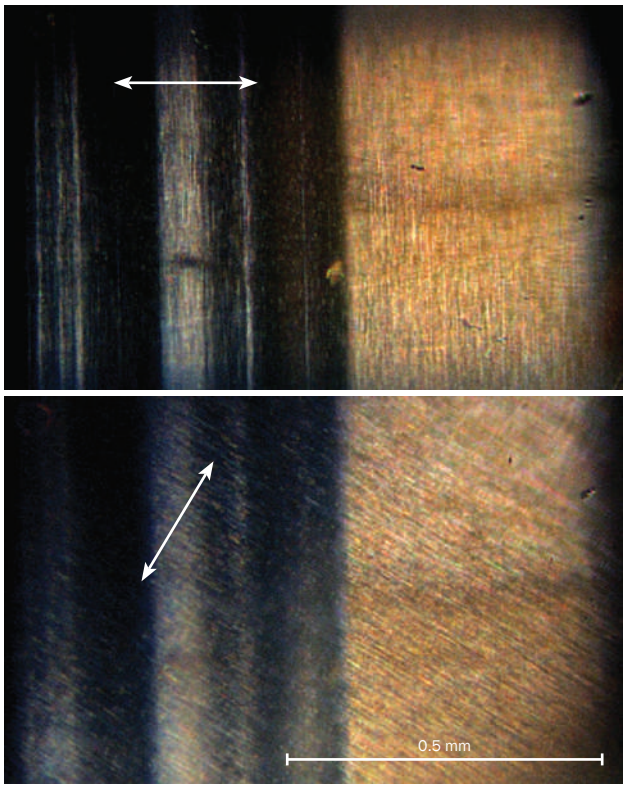

Figure 26: These two images, taken at the same position of the star sapphire, show the orientation of needle inclusions according to the direction of the particular star branch (indicated by arrows) that is illuminated. The top photo shows the main branch of the star, perpendicular to the colour banding, while the bottom image illuminates the star branch at 60° from the previous one. The visible needles are, in each case, those oriented perpendicular to the corresponding star branch. Photomicrographs by J.-P. Gauthier.

density of needles was higher in the white zones and lower in the darker ones. At high magnification, the rutile needles were seen to have widths in the micron range (Figure 27).

The sharp change in rutile-needle concentration among the thick bands oriented in a single direction gives this sapphire its unusual and appealing striped appearance. By contrast, in most asteriated gem corundum, considered as 'homo-geneous', each of the three needle systems is distributed uniformly without any preferential localization, resulting in a star that is seen over a uniform body colour. It is also common to see growth zoning defined by concentric hexagonal patterns that are generally formed by narrow zones (e.g. Gübelin and Koivula, 2008, pp. 222–223, 226), which are quite different from the banded effect described here.

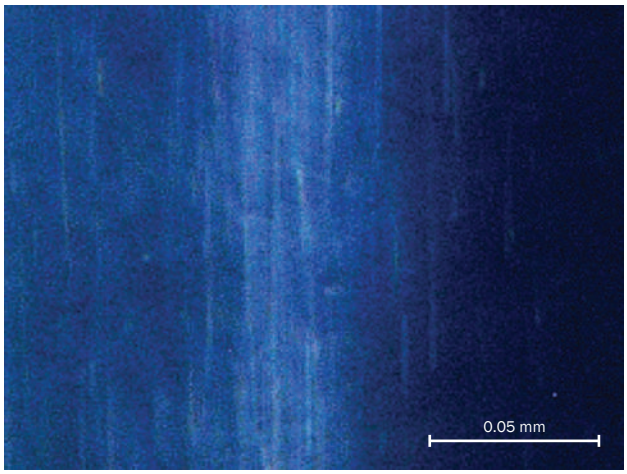

Figure 27: At high magnification, the needles in the star sapphire (oriented vertically in this image) exhibit widths in the micron range. Photomicrograph by J.-P. Gauthier.

The banded zoning in this sapphire is apparently due to fluctuating inputs, during crystallization, of fluids rich and poor in minor elements (i.e. Ti for rutile), followed by exsolution of rutile inclusions in amounts corresponding to the sharp changes in impurity concentration within each growth step. Thus, the formation of this Tanzanian star sapphire was controlled by particular circumstances, specifically during fluid inputs, which created highly contrasting broad bands that are rich or poor in acicular inclusions. The single direction of the striations in the sapphire may be explained by the cutter's decision to use just one segment of the hexagonal growth pattern that was present in the original rough stone.

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Scapolite from Tanzania with Magnetite Inclusions

During the February 2016 Tucson gem shows, gem dealer Dudley Blauwet bought a 48.06 g scapolite crystal that contained numerous black inclusions. It appeared light yellow when viewed down the c-axis and greyish tan down the a- and b-axes. His East African supplier indicated that the stone came from an unspecified deposit in Tanzania, but not from the previously known scapolite mines in the Dodoma area. The crystal was faceted into two stones (weighing a total of ~87 carats), rather than one, to avoid a fracture in the centre and also to show the best colour by cutting the table perpendicular to the c-axis.

Blauwet loaned one of the stones, a 31.44 ct light brown cushion cut (Figure 28), to American Gemological Laboratories for examination. Standard gemmological testing was consistent with scapolite, and the RIs of 1.542–1.560 (birefringence 0.018) indicated an intermediate composition between the Na-rich end-member marialite and the Ca-rich end-member meionite, though somewhat closer to marialite (cf. Deer et al., 1963). The hydrostatic SG was 2.66. The stone fluoresced moderate purplish pink to long-wave UV radiation and moderate orangey red to short-wave UV. The black platelet inclusions were conspicuous to the unaided eye. Microscopic examination showed the platelets were both discoid and irregular in shape (Figure 29), and were randomly oriented throughout the stone. The inclusions were identified as magnetite with Raman spectroscopy using a 514 nm laser.

Magnetite inclusions have been documented previously in brown cat's-eye meionite from the Dodoma area (Mayerson et al., 2003). However, their distribution and appearance—oriented fine needles, elongated platelets and flat dendrites—were much different than the magnetite inclusions in the present sample.

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Figure 28: This 31.44 ct scapolite from Tanzania contains many black inclusions that are visible to the unaided eye. Photo by Alex Mercado and Kelly Kramer.

Figure 29: The inclusions in the scapolite consist of discoid and irregular-shaped black platelets that were identified as magnetite. Photomicrograph by Christopher P. Smith; magnified 32×.

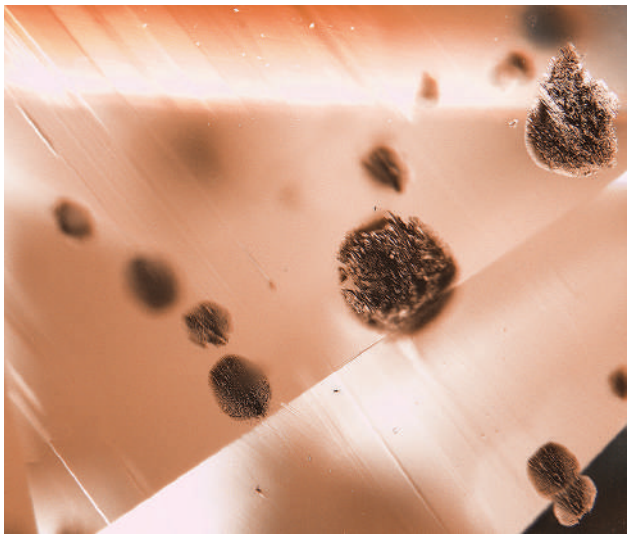

The Fire Within

"For in them you shall see the living fire of the ruby, the glorious purple of the amethyst, the sea-green of the emerald, all glittering together in an incredible mixture of light."

– Roman Elder Pliny, 1st Century AD

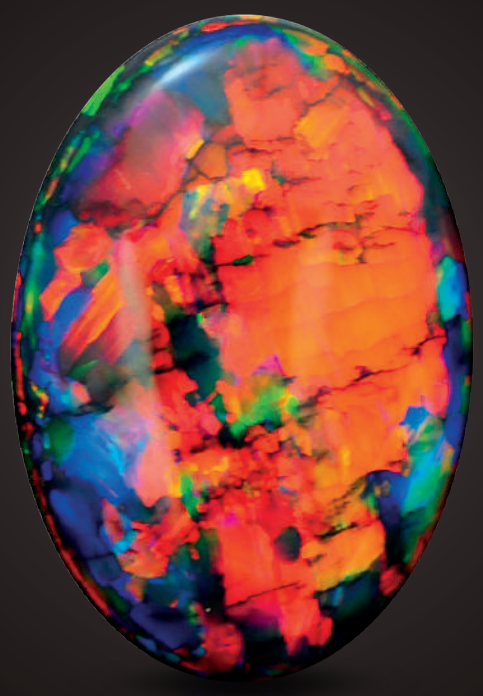

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PEARLS

A Gastropod Shell as the Core of a Natural Pearl

As a pearl-testing laboratory, the LFG (French Gemmological Laboratory, in Paris) examines numerous natural pearls every day. Therefore we are accustomed to seeing the typical structures of natural pearls, such as calcitic cores surrounded by aragonitic growth rings. But once in a lifetime, we have the opportunity to discover a pearl such as the one we describe here.

A half-drilled brown nacreous pearl weighing 9.84 grains (2.46 ct) and measuring 6.86–6.96 × 7.31 mm (Figure 30) was recently submitted for examination. The usual procedure to identify the natural or cultured origin of a pearl relies on X-radiography to visualize its inner structure. For example, the presence of a bead or graft residue in the centre reveals a cultured origin. X-radiography (Figure 31) of the present sample was performed with an RX Solutions DeskTom 130 micro-tomography system, and further examination with UV-Vis and Raman spectrometry and chemical analysis indicated that it was of saltwater origin and that the colour was natural.

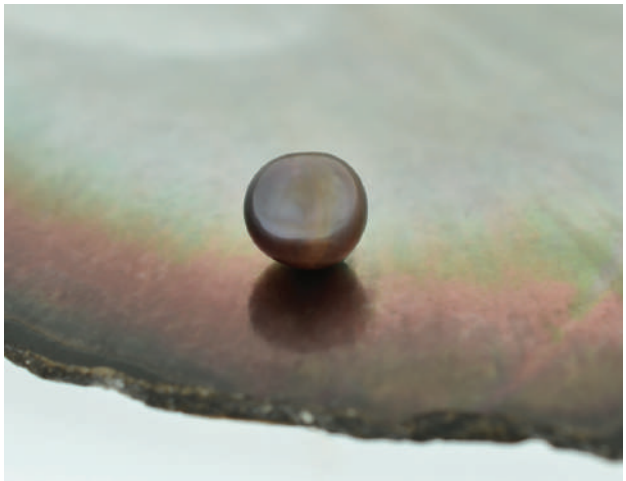

Figure 30: This natural brown pearl (9.84 grains; 6.86–6.96 × 7.31 mm) proved to contain a very unusual shell core. Photo by O. Segura.

When reviewing the X-radiography, we noticed what appeared to be an unusual void in the centre of the pearl that showed some strange round structures. Because a radiograph is a two-dimensional projection of a three-dimensional structure, analysing such a pattern can be quite difficult. In this case, we were able to perform X-ray tomography with the same device, allowing us to visualize digitally reconstructed slices of the pearl to reveal its internal structure in more detail (Figure 32). This clearly showed a gastropod seashell as the origin of the pearl's growth. Seashell cores in pearls are described extremely rarely, and to our knowledge, only one such X-radiograph has been published (Bari and Lam, 2009). The concentric fissures seen around the seashell are typical of natural pearls, and have been described as growth patterns.

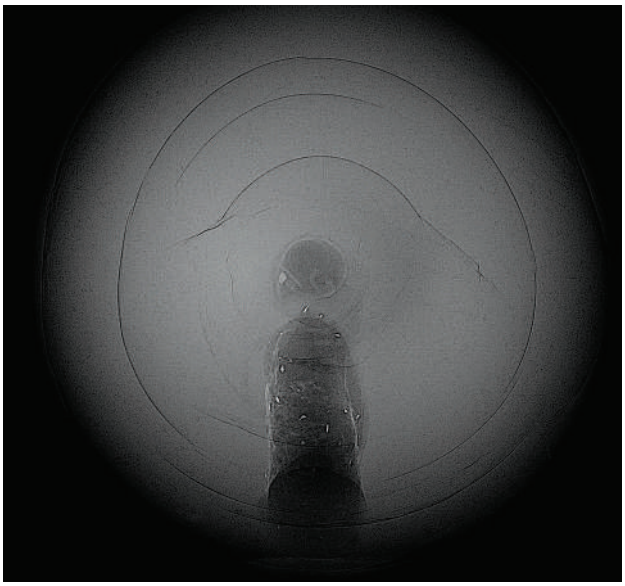

Figure 31: X-radiography of the pearl shows an unusual structure (approximately 1.3 mm long) in the centre, close to the end of the drill hole. Image by O. Segura.

With the help of reconstruction software (thanks to Solène Valton and the RX Solutions team), it was possible to digitally 'extract' the seashell from the pearl (Figure 33). The shell measured only 1.28 × 0.78 mm wide, and a slab could be seen in its opening that may be a remnant of the mollusc's operculum. The three-dimensional

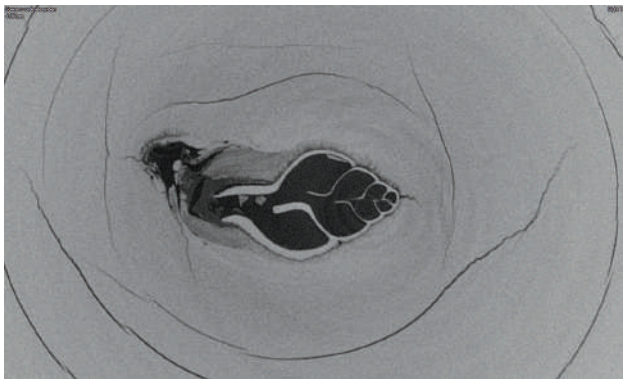

Figure 32: This X-ray tomography reconstruction clearly reveals the tiny shell (approximately 1.3 mm long) responsible for the pearl's growth. Image by O. Segura.

image and corresponding slices showed a small depression in the shell's largest whorl due to the drilling process. Although the drill hole did not actually reach the inner seashell core, this slight damage evidently occurred when the surrounding layers of the pearl were compressed by the drill bit. Fortunately the pearl was only half drilled, preserving this unique evidence of its formation.

All the structures of the seashell were visible, enabling us to distinguish the first four smooth spirals determining the protoconch. The anatomy of this shell—including the shoulders on the body whorl, the central axis (columella) and the siphonal canal structures—are interesting details that permit us to identify this marine mollusc (Gastropoda class, Neogastropoda, Buccinoidea, Fasciolariidae).

The improvement of analytical methods such as X-radiography and X-ray tomography,

Figure 33: Image processing was used to create this three-dimensional reconstruction of the shell in the pearl's core. Image by O. Segura.

and the high quality and precision of the resulting images, provide the specialist with a great quantity of structural information. As shown here, this new imagery may allow the user to establish a thorough—and at times remarkable—conclusion.

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SYNTHETICS AND SIMULANTS

A New Peridot Imitation—Yttrium Aluminosilicate Glass

Peridot has become increasingly popular in the Chinese market. Within China, there are two famous peridot deposits: Jiaohe in Jilin Province and Zhangjiakou in Hebei Province. Various materials have been used to imitate peridot, such as barium-zirconium glass or lead-oxide silica glass (McClure and Reinitz, 1999; Hainschwang, 2009).

Recently, the National Gemstone Testing Center Laboratory in Beijing received a green oval modified brilliant for identification (Figure 34). The client purchased the sample as Chinese peridot; it weighed 6.08 ct and measured 13 × 11 × 6 mm. Visually it resembled peridot, except for a lack of doubling of the facet junctions, and it was free of inclusions under 40× magnification.

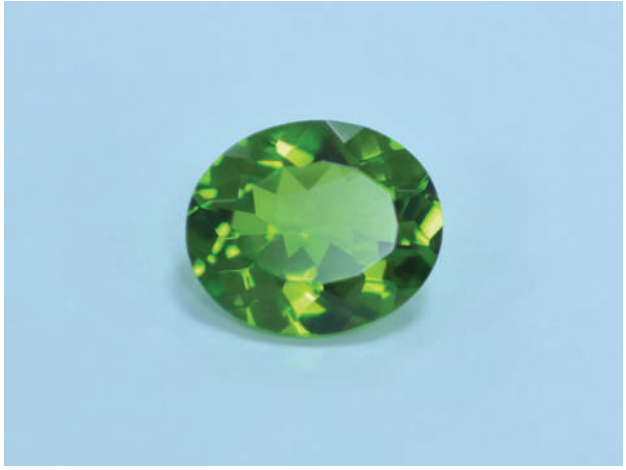

Figure 34: This faceted 6.08 ct sample was identified as a new imitation of peridot: yttrium aluminosilicate glass. Photo by W. Han.

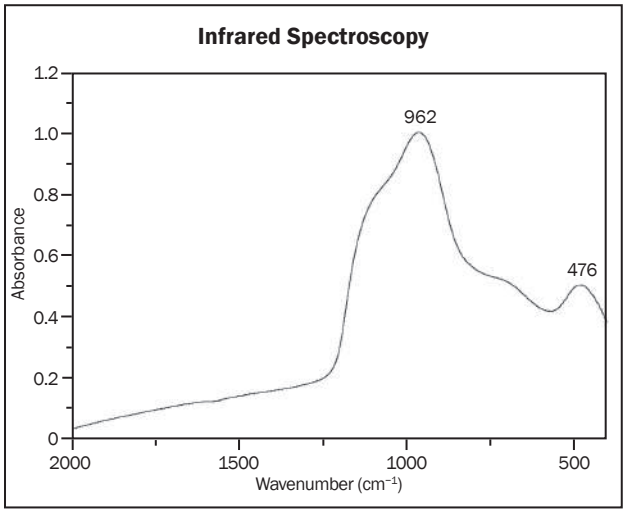

Figure 35: Infrared reflectance spectroscopy of the peridot imitation reveals bands at 962 and 476 cm^{-1} that are not typical of ordinary silica glass.

Its hydrostatic SG value was 3.37, and the refractometer showed a single RI of 1.661, which ruled out peridot. It exhibited a 'Maltese cross' pattern in the polariscope, and was inert to both long- and short-wave UV radiation.

Infrared reflectance spectroscopy revealed two bands at 962 and 476 cm^{-1} (Figure 35), which do not correspond to the spectrum of ordinary silica glass. Semi-quantitative EDXRF chemical analysis revealed mainly Y, Si, Pr and Al, along with minor Mg and traces of Fe, S, Mn, Cr, K, Ca, Cu and Zn. UV-Vis spectroscopy showed main absorption bands at 440 and 590 nm (Figure 36), which are caused by internal f-f transitions of Pr^{3+} (Zhang et al., 2009), resulting in the attractive green colour of the sample.

We identified this peridot imitation as a Pr^{3+}-coloured yttrium aluminosilicate glass. Glass has been used to imitate gemstones for centuries. However, this is the first instance we have encountered of yttrium aluminosilicate glass being used to imitate Chinese peridot. Customers should be aware of this imitation when buying peridot in the marketplace.

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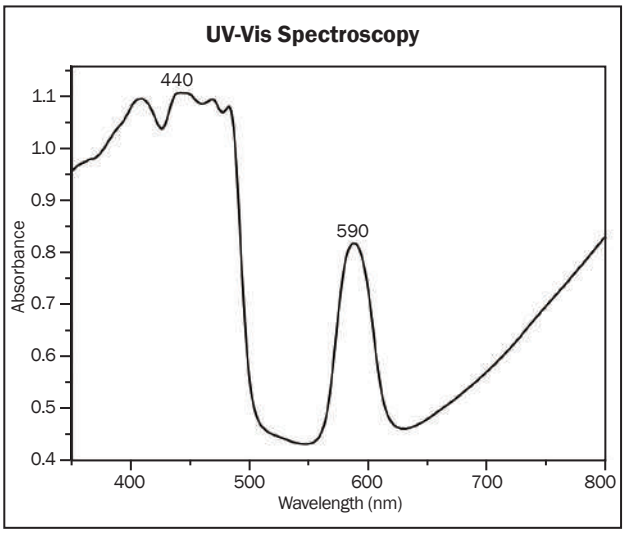

Figure 36: UV-Vis spectroscopy of the peridot imitation shows absorptions at 440 and 590 nm that are attributed to Pr^{3+}.

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TREATMENTS

HPHT-Treated Blue Sapphire: An Update

Since 2014, reports have circulated about blue sapphires being treated by a Korean company using a high-pressure, high-temperature (HPHT) technique (see Choi et al., 2014a,b; Song et al., 2015; e.g. Figure 37). According to the treater, the starting material consists of pale blue sapphire from Sri Lanka, and there is no addition of any chemical component except for a small quantity of water during the treatment process. The main advantage in applying HPHT treatment is that the technique may help avoid fracturing due to differential thermal expansion of solid or fluid inclusions, as well as help minimize thermal decomposition of some mineral inclusions. HPHT-treated blue sapphires have entered the gem market during the past few years, but to the authors' knowledge the treatment has not yet been applied to other colour varieties of corundum.

Initial research on samples before and after treatment showed that Fourier-transform infrared (FTIR) spectroscopy is useful for distinguishing the HPHT-processed samples from standard heat-treated sapphire; the presence of a strong absorption band centred at 3047 cm^{-1} with a shoulder at 2627 cm^{-1} was evident in the stones after HPHT treatment (Choi et al., 2014a,b). Surprisingly, however, a subsequent study by another group of researchers who HPHT-treated their own samples did not find any strong absorption features in the 3050–3040 cm^{-1} region after treatment (Song et al., 2015).

The present study provides an update on HPHT-treated blue sapphires that have been seen at The Gem and Jewelry Institute of Thailand's (GIT) laboratory, and reports some of the gemmological properties of these sapphires for the first time. Since 2013, more than 40 blue sapphires suspected of being HPHT treated were submitted by various clients. The stones weighed 1.91–15.21 ct, and all showed the strong diagnostic absorption band in the 3050–3040 cm^{-1} region of the FTIR spectra. Basic properties were measured by standard gemmological instruments, and spectroscopic data were collected at GIT using an Eagle III micro-EDXRF unit, a PerkinElmer Lambda 950 UV-Vis-NIR spectrophotometer and a Thermo Nicolet 6700 FTIR spectrometer.

The sapphires were a moderate to intense blue, and had RIs of 1.759–1.770 (birefringence 0.008–0.010) and hydrostatic SG values of 3.97–4.00. Stones tested with the polariscope showed a doubly refractive, uniaxial, single-crystal reaction. Fluorescence ranged from inert to moderate red in long-wave UV radiation and inert to weak red in short-wave UV. These properties are consistent

Figure 37: This 1.19 ct sapphire is shown before (left) and after (right) HPHT treatment. Photomicrographs by Youngsoo Chung; magnified 10×.

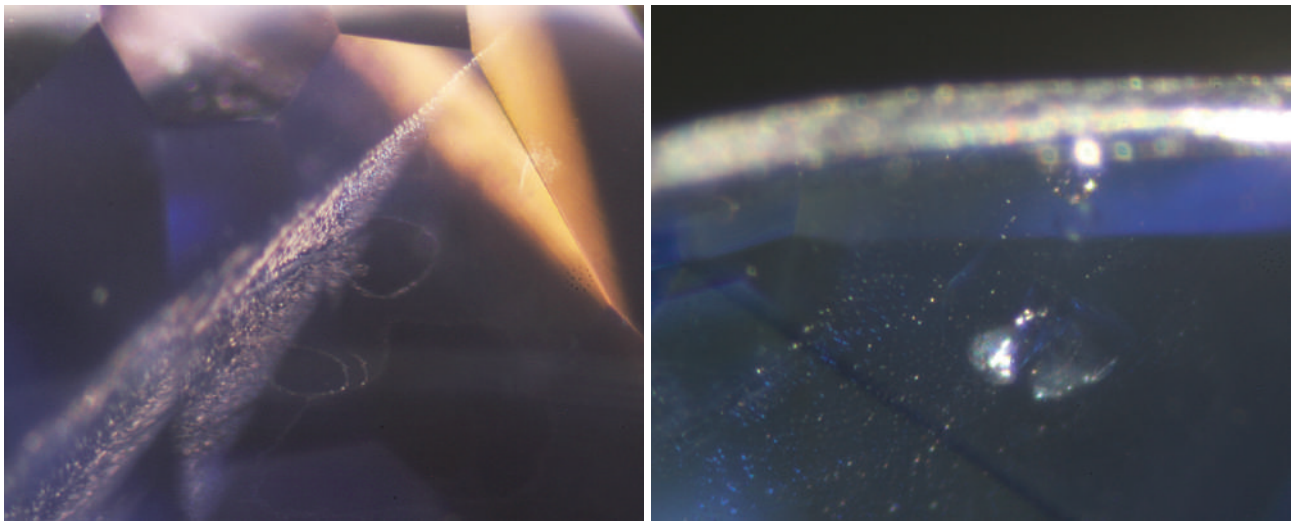

Figure 38: Inclusion scenes in HPHT-treated sapphires may consist of 'fingerprint' inclusions accompanied by slightly healed thin-film tension cracks (left), or clusters of thermally altered 'snowball' inclusions with fuzzy tension halos, as well as trails of pinpoint inclusions and clouds of minute particles (right). Photomicrographs by N. Atsawatanapirom (left) and J. Jakkawanvibul (right); magnified 40×.

with those of gem corundum. Observation with the gemmological microscope revealed various internal features, including 'fingerprints' that were often accompanied by peculiar thin-film tension cracks (Figure 38, left) and clusters of altered mineral inclusions ('snowballs') with fuzzy tension halos (Figure 38, right). Trails of pinpoint inclusions and clouds of minute particles also were seen. Most of the inclusion features are similar to those of conventionally heated sapphires, except for the healed tension fractures that looked hazy rather than forming the tiny droplets that are typically seen in normally heated stones.

As expected, EDXRF chemical analysis of the blue sapphires (Table II) showed relatively low-to-moderate Fe contents (0.05–0.23 wt.% Fe_2O_3) and traces of Ga (0.01–0.02 wt.% Ga_2O_3). Visible spectra (e.g. Figure 39) showed a typical dominant absorption band due to Fe^{2+}–Ti^{4+} intervalence charge transfer (IVCT) that is responsible for their blue coloration. The mid-IR spectra recorded a strong absorption band centred at 3047 cm^{-1} with a shoulder at 2627 cm^{-1}; by comparison, untreated blue sapphires occasionally show a weak OH-related band at 3310 cm^{-1} (Figure 40).

Based on these examinations of client stones that were suspected of being HPHT treated (i.e. showing the strong absorption band at 3047 cm^{-1}), we concluded that the general appearance, basic gemmological properties, microscopic features, trace-element composition and visible-range spectra were quite similar to those found in conven-

*Table II: Trace-element contents of HPHT-treated sapphires by EDXRF spectroscopy.**

Oxide	Range (wt.%)
TiO_2	0.01–0.04
V_2O_5	0.003–0.02
Cr_2O_3	0.003–0.01
Fe_2O_3	0.05–0.23
Ga_2O_3	0.01–0.02

* Data from the analysis of 11 selected samples.

Figure 39: This non-polarized visible absorption spectrum of a blue sapphire suspected of HPHT treatment shows a typical Fe^{2+}–Ti^{4+} IVCT absorption band. Minor absorption due to Fe^{3+} also is present at 450 nm.

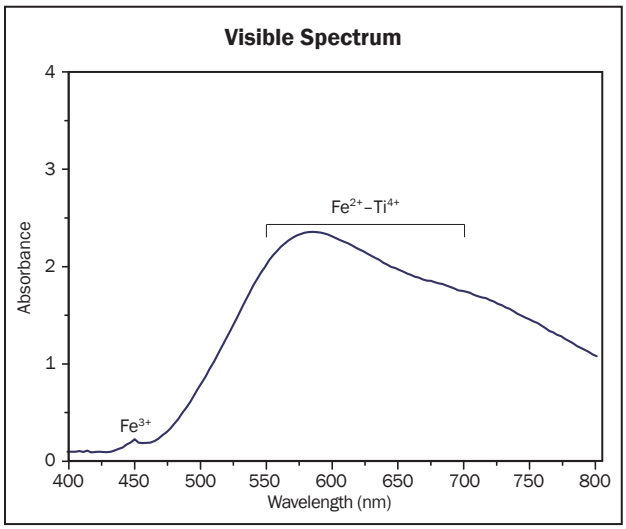

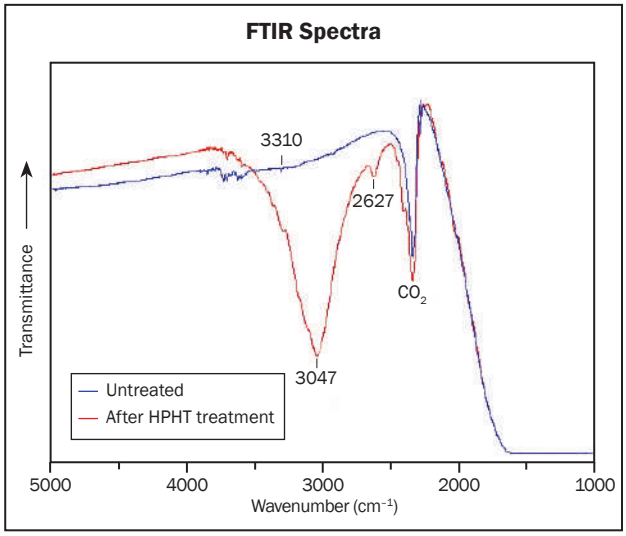

Figure 40: FTIR spectra are shown for blue sapphires that are untreated (blue) and HPHT-processed (red). The treated stone shows a strong absorption band centred at 3047 cm^{-1} with a shoulder at 2627 cm^{-1}.

tionally heated sapphires. In the FTIR spectra, it is likely that the occurrence of the strong absorption band at 3050–3040 cm^{-1} (Choi et al., 2014a,b) is related to another type of structural OH group that developed as a result of water that was reportedly added during the HPHT treatment.

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MISCELLANEOUS

Myanmar Gems Emporium

The 53rd Myanma Jade, Gems & Pearl Emporium took place 24 June–6 July 2016 in Nay Pyi Taw, Myanmar. Under the new government of Aung San Suu Kyi, the Emporium was organized by the Ministry of Natural Resources & Environmental Conservation (a combination of the former Ministry of Mines and Ministry of Forestry and Environmental Conservation). An illustrated catalogue was provided to attendees that listed the programme of events and showed the layout of the Emporium building.

The jade tender consisted of 3,947 lots, with total sales of €527.08 million. In addition to rough material, there were 43 lots of bangles, 20 lots of beads, seven lots of carvings and three lots of cabochons. Highlights included three bangles (190 g total weight) in lot no. 727 with a floor price of €136,000 and two cabochons (35 carats total weight) in lot no. 815 with a floor price of €100,000. The 'gems' tender contained 60 lots with sales of €3.15 million, and the cultured pearl tender consisted of 312 lots that realized €3.2 million.

Attendees came from China (813 companies with 1,866 buyers) and Hong Kong (82 companies with 150 merchants), as well as Australia, India, Japan and Singapore (combined 919 companies with 2,069 buyers). Relatively low sales at this Emporium are blamed on the low turnout of Chinese buyers, as well as the overall lack of high-quality gem material.

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Simultaneous High Sensitivity Trace-Element and Isotopic Analysis of Gemstones Using Laser Ablation Inductively Coupled Plasma Time-of-Flight Mass Spectrometry

Hao A. O. Wang, Michael S. Krzemnicki, Jean-Pierre Chalain, Pierre Lefèvre, Wei Zhou and Laurent E. Cartier

GemTOF, installed at the Swiss Gemmological Institute SSEF, is a next-generation chemical analysis technique for gemmology: laser ablation inductively coupled plasma time-of-flight mass spectrometry (LA-ICP-TOF-MS). The system enables full elemental mass-spectrum acquisition at an ultra-high acquisition speed. Nearly all elements in the periodic table can be simultaneously acquired with low limits of detection. Major-to-trace (and even ultra-trace) element compositions can be accurately quantified, and slight concentration differences can be distinguished. The data can be processed with multivariate statistical analysis, thereby increasing the reliability of origin determination as well as the detection of potentially new diffusion treatments. Additionally, higher precision for isotopic analysis is expected than with sequential-acquisition LA-ICP-quadrupole-MS (LA-ICP-Q-MS), especially for short transient signals. Novel research directions in gemstone age dating, analysis of inclusions and chemical zoning will benefit from the advantages of this system.

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Introduction

In the past several decades, gem testing has evolved from a rather basic characterization of physical properties (e.g. RI, SG, absorption and fluorescence) into advanced materials science, using sophisticated instrumental technologies for detailed chemical and structural analyses. As gemmology is primarily an applied science, this analytical evolution was driven by challenging issues confronting the gem trade rather than by fundamental research. From the use of X-ray radiography and X-ray diffraction to detect beaded cultured pearls in the early 20th century (Anderson, 1932), additional technological innovations in gemmology include the chemical characterization of synthetic coloured stones by

Figure 1: Six blue sapphires (various client stones weighing approximately 2–36 ct) are shown on an historical map of the famous gem locality of Mogok, Myanmar. Quantitative chemical data can be helpful for determining the geographic origin of sapphires. Map from Gordon (1888); photo by L. E. Cartier and Julien Xaysongkham, SSEF.

energy-dispersive X-ray fluorescence (EDXRF; Stern and Hänni, 1982; Muhlmeister et al., 1998) and the detection of fissure-filling treatments using Fourier-transform infrared (FTIR) spectroscopy and micro-Raman spectroscopy (Kiefert et al., 1999). Subsequently, the undisclosed appearance of Be-diffusion-treated sapphires, high-pressure, high-temperature (HPHT)-treated diamonds and beadless cultured pearls at the turn of the millennium had major impacts on the evolution of analytical methods in gem laboratories. New and highly sensitive methods have proven very helpful for gemstone and pearl testing, many of them applied for the first time or in a very early stage in the field of gemmology and in actual testing cases. These techniques include photoluminescence spectroscopy at liquid-nitrogen temperature (–196°C) of HPHT-treated diamonds (Chalain et al., 1999; Fisher and Spits, 2000), atomic force microscopy of pearl surfaces (Gutmannsbauer and Hänni, 1994), laser-induced breakdown spectroscopy (LIBS) of Be-diffused corundum (Krzemnicki et al., 2004), X-ray computed microtomography of pearls (Wehrmeister et al., 2008; Krzemnicki et al., 2010), age dating of pearls using accelerator mass spectrometry (Hainschwang et al., 2010; Krzemnicki and Hajdas, 2013), DNA-fingerprinting of pearl species (Meyer et al., 2013), X-ray phase contrast and X-ray scattering imaging of pearls (Krzemnicki et al., 2015; Revol et al., 2016) and neutron imaging of gemstones and pearls (Hanser, 2015; Mannes et al., 2016).

Throughout this period, the chemical analysis of gem materials has been very important not only for material identification (e.g. to identify species within the garnet-group solid solution), but also for identifying synthetics and treatments (e.g. Ti-diffusion of corundum). The main driving force for detailed trace-element analysis of gem materials, however, has been the demand from the trade for laboratories to deliver a scientifically based opinion of geographic origin, particularly for higher-end stones (see, e.g., Figure 1 and the cover of this issue). The demand has resulted from value factors attributed to certain origins (e.g. sapphires from Kashmir), but also from the growing need for traceability of gems due to political (trade bans) or ethical (fair trade) reasons (Dickinson DeLeon, 2008; Cartier, 2010).

Semi-quantitative to quantitative chemical analysis of trace elements in gem materials is typically performed using EDXRF spectroscopy. For the past 15 years, LA-ICP-MS has proven to be a very sensitive and versatile method for trace-element analysis of gem materials (Guillong and Günther, 2001), despite being only quasi-non-destructive. This technique provides access not only to a distinctly wider range of elements than traditional XRF methods, but also to much lower detection limits (especially for light elements such as Li, Be, B and Na) and to different isotopes of the same element. During the past several years, various publications have focused on the chemical characterization of gems from different origins (Giuliani et al., 2000; Rankin et al., 2003; Abduriyim

Figure 2: This LA-ICP-TOF-MS system, named GemTOF, was installed at SSEF in July 2016. The ICP-TOF-MS instrumentation is on the left and the LA unit is on the right. Photo by Vito Lanzafame, SSEF.

and Kitawaki, 2006; Sutherland et al., 2009; Halicki, 2013).

Recently, a novel analytical technique, LA-ICP-TOF-MS, was introduced into the market. In late 2015, the SSEF laboratory in Basel, Switzerland, initiated an evaluation project with three leading companies focusing on implementing such a system for gemstone analysis. The final instrumentation was installed at SSEF in July 2016 (Figure 2) and will be fully operational in winter 2016. This article discusses the capabilities of LA-ICP-TOF-MS compared to conventional ICP-Q-MS. Various potential applications of this new instrumentation are described, and a preliminary case study of sapphire origin determination is briefly presented.

Introduction to LA-ICP-TOF-MS

In general, LA-ICP-MS is a well-known and versatile analytical method for major- to trace-elemental analysis of solids. It consists of a material sampling part (LA) and a chemical analysis part (ICP-MS). The gemstone is placed within a sealed sample chamber in the LA instrument, with no need for sample preparation. Then a high-power pulsed UV laser is focused on the surface of the gem (normally on the girdle). The high laser energy accumulates on a tiny spot, and the ablated particles are instantaneously ejected into the sealed chamber. The resulting crater is too small (commonly less than 100 µm in diameter) to be visible to the naked eye and too shallow (e.g. 18 µm for a 30 s ablation on sapphire; Guillong and Günther, 2001) to produce any significant weight loss. The released particles are transported in a flow of He gas into the plasma source. Inductively coupled plasma (ICP), created from Ar gas, is a robust ionization source. The temperature of this plasma is comparable with the surface temperature of the sun, causing almost all fine particles to become dissociated, atomized and finally ionized. The stream of ions is then extracted into the mass spectrometer (MS), which separates them based on their mass-to-charge ratio (m/Q). Most ions measured by ICP-MS have a charge of +1, and therefore m/Q is of equal value to mass m. A detector separately registers the intensities of ions with different m/Q values. External calibration is performed using standard reference materials, through which quantitative results for various elements can be calculated. The capability to precisely quantify multiple elements in a wide range of concentrations is the key benefit of LA-ICP-MS.

Commonly, LA instruments are equipped with either a 213 nm solid-state Nd:YAG laser or a 193 nm ArF excimer laser. An excimer laser is preferred for universal applications because finer particles are produced during ablation (Guillong et al., 2003).

There are several types of ICP-MS instruments based on different mass-separation schemes. The quadrupole type is one of the most popular, and is typically used for gemstone research. In such instrumentation, only one selected m/Q is collected by the detector at a time, while others are deflected and lost. To measure several isotopes, the mass spectrometer has to jump from one selected m/Q (isotope) to another.

ICP-TOF-MS is one of the latest and most advanced technologies in the ICP-MS family. The key difference between TOF and quadrupole setups is the mass-separation scheme. TOF uses the principle that the 'flight' duration for one ion passing through a fixed flight tube is related to its m/Q. Lighter ions take less time to travel the same distance compared to their heavier counterparts with the same charge, provided they have identical kinetic energy; hence mass separation is achieved. The flight time difference between the lightest and the heaviest ions travelling to the detector is so minimal that one may even consider them to arrive at almost the same time (i.e. simultaneously) at the detector. Benefiting from recent developments in ultra-fast electronics and optimized ion optics, ICP-TOF-MS acquires spectra from the lightest to the heaviest isotopes at a

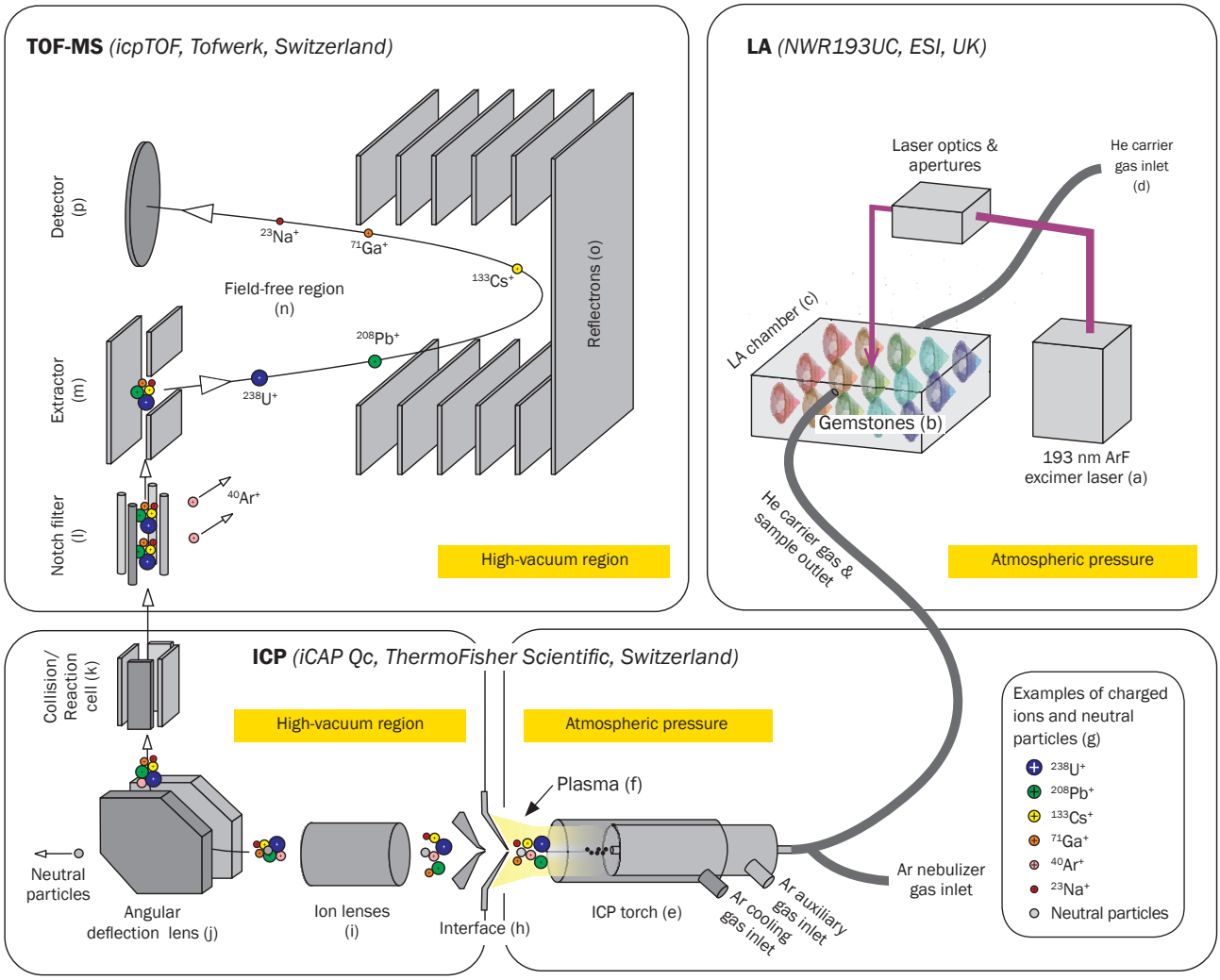

Figure 3: This schematic diagram shows a typical LA-ICP-TOF-MS setup (e.g. GemTOF at SSEF). The beam from a 193 nm ArF excimer laser (a) is focused on the gemstone or pearl (b) that is sealed in a sample chamber (c). The LA chamber is flushed by He gas (d), which transports the ablated particles to the ICP torch (e). The plasma (f) dissociates, atomizes and ionizes the particles into preferably singly-charged ions (g), which are sampled at an interface (h) from atmospheric pressure to a high-vacuum region. The stream of ions is extracted through a series of ion lenses (i), and neutral particles are separated from ions by an angular deflection lens (j). A collision/reaction cell (k) can be used to reduce interferences. At the entrance to the TOF-MS, a notch filter (l) first rejects selected dominant ions (e.g. Ar^+) from the ion stream, and then the extractor (m) pushes the ions orthogonally at a high frequency into the field-free time-of-flight region (n). The ions are mirrored by reflectrons (o) and finally registered at a detector (p).

higher speed as well as achieving a better resolving power (or higher mass resolution) than conventional Q-MS (see www.tofwerk.com/icp). A schematic diagram showing the components and procedures of the LA-ICP-TOF-MS instrumentation at SSEF is shown in Figure 3.

Key Features of LA-ICP-TOF-MS

Full Mass-Spectrum Acquisition

Argon ICP has a high ionization potential, so almost all elements can be ionized efficiently. But to detect all these elements, an adequate mass spectrometer should be employed. Conventional Q-MS has limitations. Because of sequential acquisition, it measures the intensity of one m/Q during a certain dwell time (integration time) before jumping to the next one. Although Q-MS is able to scan the full mass range by hopping through the entire spectrum, it is time consuming. Therefore, in practice, elements from Li to U (Figure 4) are commonly measured using only a selected number of isotopes within a limited measurement time. After measurement, if the selection of isotopes needs to be readjusted, the sample has to be re-ablated.

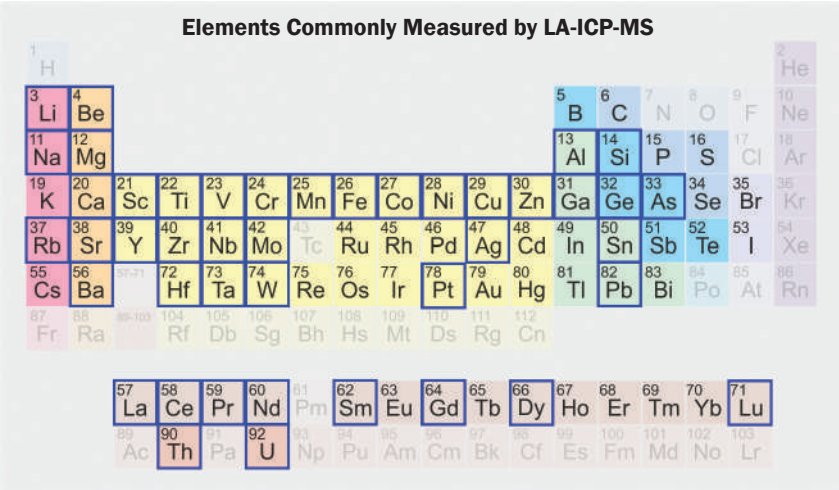

Figure 4: ICP-MS can measure most of the elements in the periodic table (shown in solid colours, with the atomic number indicated in the top-left corner for each element). The greyed-out elements are difficult to ionize, have strong interferences and high backgrounds, or are not commonly seen in geological samples. For LA-ICP-Q-MS measurements, only some of the elements (e.g. those with blue outlines) are selected using one of the isotopes from each element. By contrast, LA-ICP-TOF-MS measurements not only analyse all of the (solid coloured) elements simultaneously, but also almost all isotopes of those elements.

By comparison, LA-ICP-TOF-MS 'snaps pictures' of the full and continuous mass spectrum without the need to assign isotopes of interest (e.g. an 'averaged picture' from a 20 s ablation signal is shown in Figure 5a). Details of the 'picture' can be revisited at any time, and the isotopes of interest also can be changed, even after the measurement has been completed. Such a spectrum reveals almost the full elemental composition, reaping the benefits of the robust plasma source. As a further consequence of this 'picture snapping', it is possible to considerably reduce the amount of ablated material required from the sample, thus creating a smaller and shallower crater on the analysed gemstone. In contrast to commonly used quadrupole mass spectrometers, there is no risk of needing to re-ablate the stone due to an incomplete or 'badly' chosen predefined list of isotopes, because the full mass spectrum is registered.

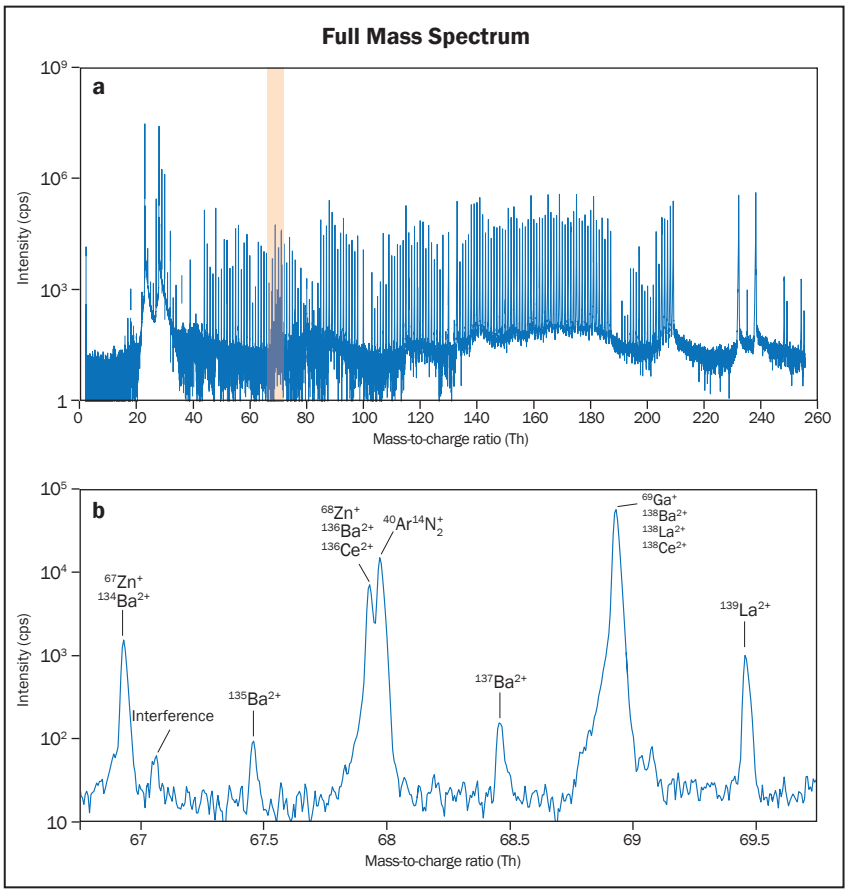

Figure 5: (a) An averaged full elemental mass spectrum is shown from a 20 second LA-ICP-TOF-MS measurement of NIST610, a silicate standard reference material. Mass-to-charge ratios (in units of Thomson) through the entire elemental range were acquired simultaneously. (b) Details of the orange region in (a) illustrate the mass resolving power of TOF-MS ($m/\Delta m \approx 3{,}000$), which is better than quadrupole MS (normally $m/\Delta m \approx 300$) in resolving some interferences.

Due to technical limitations, the ICP-TOF-MS model described in this article cannot measure light isotopes (e.g. ^{7}Li, ^{9}Be, ^{10}B, ^{11}B, etc.) while maintaining a high sensitivity for heavy isotopes (e.g. ^{232}Th and ^{238}U, etc.). In these situations where access to a low m/Q range is required, another set of ion optic voltage settings can be applied. Since the parameters can be pre-set and changed quickly, it is hence feasible to complete the full elemental analysis from Li to U with two measurements (each focused on either low or high m/Q). Taking advantage of simultaneous acquisition, this limitation may not necessarily increase measurement time or have more impact on a sample compared to sequential LA-ICP-Q-MS.

High Mass-Resolving Power

As depicted in Figure 5b, the full mass spectrum 'picture' is taken at a high mass-resolving power (i.e. $m/\Delta m \approx 3{,}000$, where m is the nominal mass of the peak and Δm defines the mass difference between two resolved peaks), and this may help with potential interference problems. For example, when analysing $^{68}Zn^{+}$, the polyatomic ion $^{40}Ar^{14}N_2^{+}$ at nominal m/Q = 68 as well as doubly charged ions $^{135}Ba^{2+}$ and $^{137}Ba^{2+}$ present at m/Q = 67.5 and 68.5 cause interference when using Q-MS (resolving power $m/\Delta m \approx 300$). The higher resolving power of TOF-MS separates $^{40}Ar^{14}N_2^{+}$ from $^{68}Zn^{+}$. The doubly-charged species are, however, close in mass to $^{68}Zn^{+}$, and their separation requires higher resolving power or the application of various mathematical correction models.

High-Speed Mass Spectrum Acquisition

ICP-TOF-MS is capable of 'snapping' a full elemental mass spectrum at a maximum speed of 33,000 'pictures' per second, but the data transfer speed from instrument to computer is limited. Therefore, the 'pictures' are commonly averaged and downloaded to a computer at a maximum speed of ~1,000 'averaged pictures' per second. By contrast, Q-MS commonly measures only 2–5 sweeps per second (i.e. complete analysis over the list of predetermined isotopes, analogous to 'averaged pictures'). The fast 'frame rate picture snapping' from TOF-MS can capture more details of a continuous change of sample concentration (e.g. local chemical zoning in gems), and any instantaneous short-signal events (e.g. tiny inclusion, nanoparticle, etc.) also can be resolved.

It is worth mentioning that not all ions from the continuous mass spectrum are eventually detected due to the discrete sampling nature of TOF. The detection efficiency of ICP-TOF-MS is less than 100%, but generally higher than Q-MS (Borovinskaya et al., 2013).

Limit of Detection (LOD)

The LOD is a figure of merit when describing the detection capability of an analytical instrument. During routine LA-ICP-MS analyses, LOD is often given in the unit of parts per million (ppm) or parts per billion (ppb), indicating the lowest concentration of analyte that is sufficient to provide a significant signal above background. There are two major factors for determining LOD: the sensitivity of the instrument and its background signal level. In general, higher sensitivity and lower background noise are necessary for a better LOD. As a result of recent instrumental developments, LA-ICP-TOF-MS has an improved multi-element sensitivity. While benefiting also from lower background noise, it provides better LOD than Q-MS (Borovinskaya et al., 2013).

As summarized in Figure 6, the LOD values of LA-ICP-TOF-MS, calculated using a widely accepted method (Pettke et al., 2012), range from single-digit ppb for heavy elements to low ppm for light elements. Although this is satisfactory for most gemmological studies, a larger laser spot size or a higher laser repetition rate can further boost the sensitivity, thereby further improving LOD values. Specifically for GemTOF at SSEF, it is possible to enlarge the spot size up to 150 µm in diameter and increase the laser repetition rate up to 200 Hz (theoretically giving one to two orders of magnitude better LOD). This will, however, produce a larger and deeper crater on the girdle of the gem. In case both minimized ablation impact and improved LODs are required, then collision/reaction cell technology can be used (e.g. QCell by ThermoFisher Scientific; see 'k' in Figure 3). A QCell is an inert or reactive gas-flushed container that is installed on the ICP-TOF-MS. When ions fly though this device, they collide and/or react with gas molecules. In collision mode, polyatomic ions (which may cause interferences) run into inert gas molecules and lose energy more efficiently than the elemental ions of interest; then they can be removed from the beam by using energy filtering. Moreover, less-energetic ions also improve the

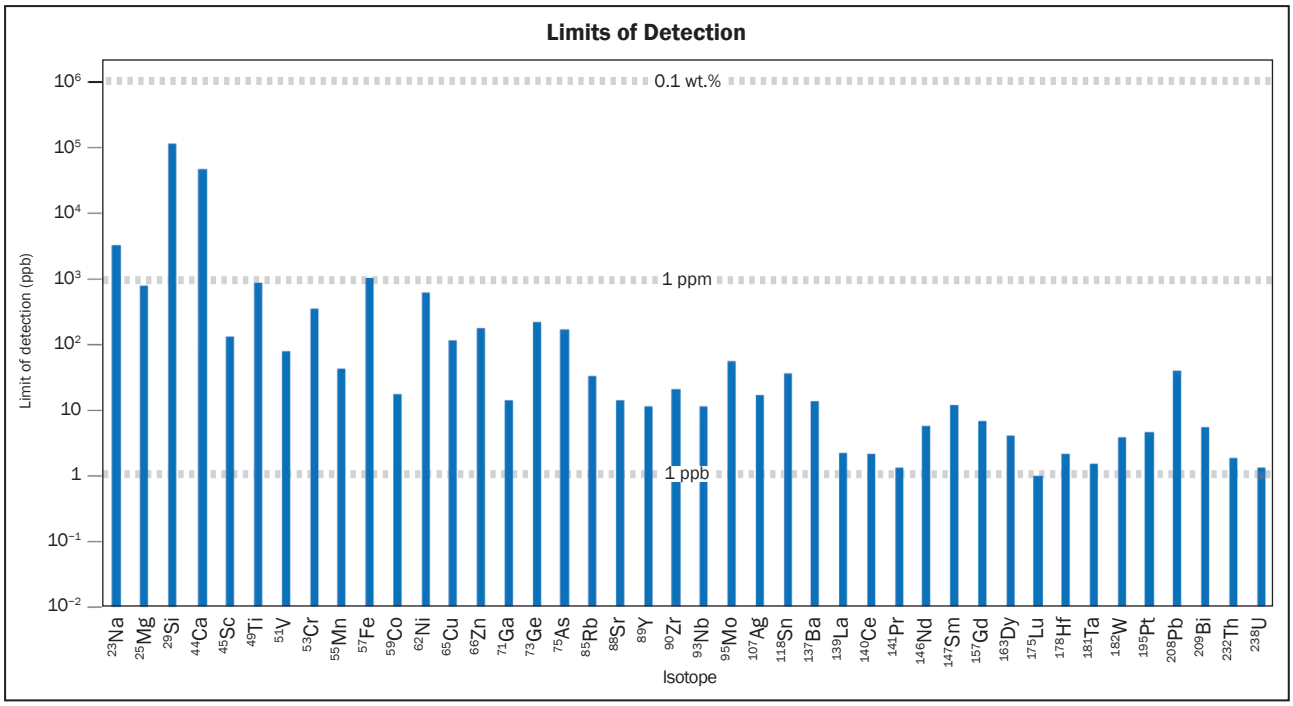

Figure 6: Limits of detection are shown for the LA-ICP-TOF-MS measurement of NIST610 reference material (most elements are ~450 ppm in concentration) in Figure 5 using a 40 µm diameter laser spot size and a 20 Hz laser repetition rate. Only a selected list of isotopes are displayed in the figure.

mass-resolving power of ICP-TOF-MS. Alternatively, interferences may selectively react with gas molecules (e.g. H_2) and disassociate to neutral particles or ions of a different m/Q.

Isotopic Analysis

Isotopes of an element differ in their masses but are naturally present at constant ratios of abundance. Considering fast-varying transient signals, especially from tiny inclusions or from a small area on a gemstone in chemical imaging analysis, it is highly likely that isotope ratios analysed at different sequential time intervals with Q-MS will have high uncertainty. The measurement of isotopic ratios using simultaneous acquisition of TOF-MS is thus expected to be better than that using Q-MS.

Isobaric interferences (isotopes appearing at the same nominal mass) create difficulties for determining the actual contribution of an isotope of interest. Intrinsically with TOF-MS, all other isotopes of the same elements of interest and interference are collected at the same time. Based on their constant natural abundance, mathematical corrections can be applied in order to improve accuracy of the trace-element quantification.

However, slight differences in isotopic ratios may result from the unique natural formation/production history of gemstones and pearls. This uniqueness could help to answer the question of carbon source for diamonds (e.g. Cartigny, 2005), to determine a gem's origin (e.g. Coenraads et al., 1990) or to separate synthetic from natural gemstones. Again, high-precision isotopic ratio determination is mandatory for such applications.

Methodology

The GemTOF system used at SSEF includes a high-performance 193 nm laser ablation unit (model NWR193UC from ESI, Huntingdon, UK) and an ICP-TOF-MS (model icpTOF from Tofwerk AG, Thun, Switzerland) upgraded from an optimized ICP-Q-MS unit (model iCAP Qc from ThermoFisher Scientific, Reinach/Basel, Switzerland). Due to installation limitations at the instrument demonstration site, it was not possible to test a combined setup of a NWR193UC laser ablation unit and ICP-TOF-MS. The results summarized in this article used a NWR213 LA system (from ESI) operating at 213 nm wavelength and an ICP-TOF-MS (same model as GemTOF). SSEF conducted a separate

Figure 7: These four sapphires (1.40–3.06 ct) were analysed by LA-ICP-TOF-MS. From left to right, their documented origins are Kashmir (LABc_126), Sri Lanka (LABc_899 and LABc_906) and Myanmar (LABc_926). All samples are from the H. A. Hänni collection at SSEF. Photo by Vito Lanzafame, SSEF.

evaluation of the NWR193UC system and found it to be more suitable for gemstone analysis than the NWR213 unit. Given the focus of the current research on the mass spectrometer, the comparison of different laser wavelengths is not included in this article, and related information can be found elsewhere (Guillong et al., 2003). Notably, these two laser-ablation instruments do not change the qualitative picture of the key points highlighted.

For the experiments described in this article, the 213 nm laser was focused into a 40-µm-diameter spot, ablating in single-hole-drilling mode at a repetition rate of 20 Hz. The laser fluence was set to 15 J/cm^2. Helium was used as the carrier gas, with a flow rate of 1.0 L/min. Before each measurement, five pre-ablation shots were done to clean any surface contamination from the sample. In all measurements, the first 30 s were recorded as background without ablation, and then the sample was ablated for 20 s.

The ICP-TOF-MS unit was operated at a power of 1,400 W. Argon was used as the nebulizer gas at a flow rate of 0.8 L/min. Without losing key information, the TOF detector collected 10,000 spectra and then reported one averaged spectrum (3.3 spectra per second, maximum 1,000 spectra per second). Though demonstrated in 'slow' acquisition mode, the importance of being able to acquire full spectra at the highest speed will be discussed below in the 'Analysis of Inclusions' and 'Imaging of Chemical Zoning for Gem Research' sections.

NIST610 standard reference material was used for external calibration and Al was used as an internal standard for sapphire quantification. Element concentrations and LOD values were calculated using the methods of Longerich et al. (1996) and Pettke et al. (2012), respectively.

The settings described above are comparable with routine LA-ICP-Q-MS measurements.

Applications of LA-ICP-TOF-MS

Gemstone Origin Determination: A Preliminary Case Study

The main application of LA-ICP-MS in gemmology is the chemical characterization of gems from various origins according to their major, trace and even ultra-trace elemental composition. The acquired chemical information can be displayed in a binary diagram, ternary plot or 3D plot in order to categorize the data into groups (i.e. geographic origins).

In a preliminary case study using LA-ICP-TOF-MS, we recorded full-mass spectra of four sapphires of documented provenance (Kashmir LABc_126, Sri Lanka LABc_899 and 906, and Myanmar LABc_926; Figure 7) from the H. A. Hänni collection at SSEF. The quantitative results for the trace elements Mg, Fe and Ga were plotted in a three-dimensional scatter plot (Figure 8) together with data from a previous study (Halicki, 2013) that used LA-ICP-Q-MS to analyse sapphires from Kashmir, Sri Lanka and Myanmar in the SSEF reference collection with various colour saturations. The scatter plot reveals that the reference sapphires (circles in Figure 8) plot in separate areas according to their three origins. The four sapphires analysed by TOF-MS (triangles in Figure 8) fit well into the expected plotting areas for the Kashmir, Sri Lanka and Myanmar origins. A drawback of this three-dimensional scatter plot is that only a limited number of trace elements (three in this 3D plot) can be displayed.

By using additional multivariate statistical approaches—such as principle component analysis and linear discrimination analysis—we can in principle take further advantage of the multi-element (multidimensional) information from LA-ICP-TOF-MS and reduce the amount of data to fewer dimensions while maintaining data-set variations in the plot.

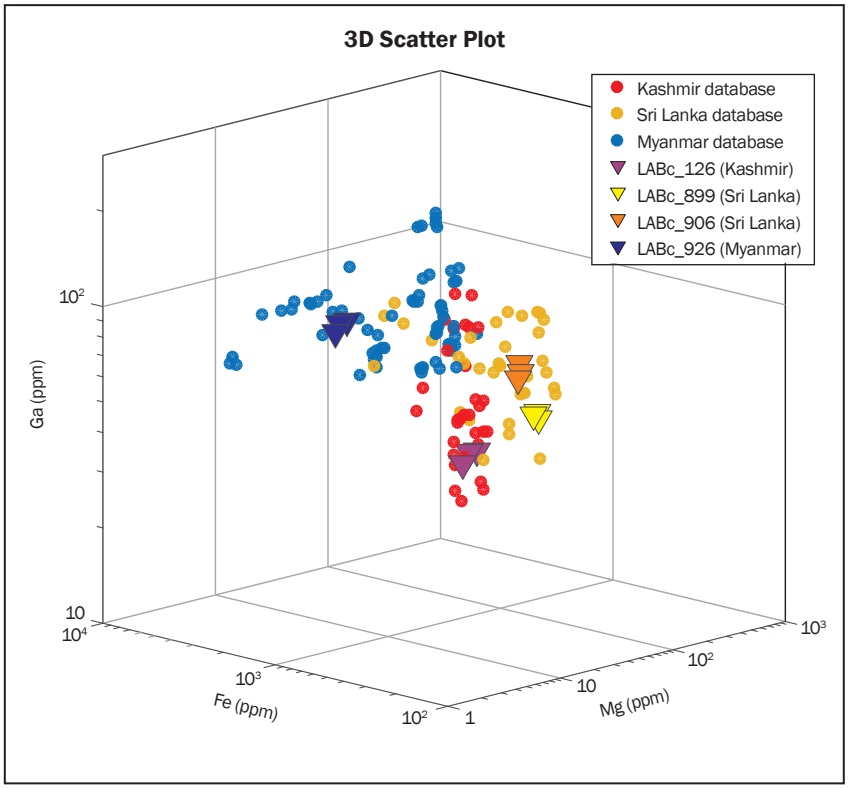

Figure 8: This three-dimensional scatter plot shows quantitative LA-ICP-TOF-MS results for the sapphires in Figure 7, together with data for SSEF reference sapphires from Kashmir, Sri Lanka and Myanmar. Trace-element concentrations of Mg, Fe and Ga are displayed using logarithmic scales. Additional plots of this data, seen from different directions, are available in the online data depository on The Journal's *website.*

Detecting Diffusion Treatments or Coatings

LA-ICP-Q-MS measures a set of preselected elements/isotopes of interest, and ignores all others. This involves choosing the elements/isotopes prior to analysis, and thus one may—by lack of knowledge—omit a crucial element, especially in the case of a previously unknown diffusion treatment or coating. However, LA-ICP-TOF-MS collects all information in the full mass spectrum with no information loss. It is therefore perfectly adapted to detect new and undisclosed chemical treatments. And thus it may help avoid an unprepared situation for gem laboratories such as when Be diffusion-treated corundum entered the market (Emmett et al., 2003).

Analysis of Inclusions

Most gemstones contain various types of inclusions, which may provide key information about the formation conditions of the sample in a minute volume. If the laser is used to analyse a surface-reaching inclusion or to ablate through a shallow surface layer of the host gem to reach an inclusion, such information can be registered by the ICP-MS. The sampling of inclusions by the laser usually lasts for only a very short time (ranging from less than a second to a few seconds of ablation time), as inclusions are commonly very small. The short signal interval often is too brief for complete sequential acquisition of all isotopes of interest with one sweep using Q-MS. However, since TOF-MS offers simultaneous acquisition at a very high speed, hundreds of full-mass spectra can be collected from a tiny inclusion with only <0.5 s of ablation time. Consequently, TOF-MS provides more accurate concentrations for specific elements and a more reproducible multi-element quantification of the chemical composition of a tiny inclusion in a complex matrix such as a gemstone.

Geological Age Dating

Some elements in nature have constant ratios for their isotopes (only stable isotopes), while others have one or more radiogenic isotopes, which results in a steady change of their isotopic ratios over time due to the radioactive decay from parent to daughter isotopes. The decay process is related to the half-life of the parent radiogenic isotope. By measuring the ratio of the daughter-to-parent isotopes, the elapsed time or age can be calculated using the known half-life constant for the radiogenic pair.

The widely used U-Pb dating system ('geological clock') uses daughter-parent radiogenic pairs of $^{206}Pb/^{238}U$ and $^{207}Pb/^{235}U$. Zircon is by far the most useful mineral for age dating, as it contains U but no Pb when it forms, with limited contami-

nation from host rocks after formation. Age dating of surface or near-surface zircon inclusions in gem corundum (so far mostly sapphires) has been studied (Coenraads et al., 1990; Sutherland et al., 2002, 2008; Graham et al., 2008). More recently, age dating of zircon inclusions analysed by LA-ICP-Q-MS was performed on faceted sapphires from highly relevant origins to the gem trade (e.g. Link, 2015). These studies show that age dating can be used as a valuable tool for origin determination in gemmological testing, reflecting different formation times for sapphires from particular geological contexts. However, to precisely determine geological age, ratios of parent and daughter isotopes need to be measured at a high reproducibility. At the same time, interfering isotopes from the geological background of a given sample must be monitored and used to correct the ratio of radiogenic isotopes. As discussed previously, higher-precision isotopic ratios are expected when possible interfering isotopes are measured simultaneously by LA-ICP-TOF-MS. Therefore, this technique can be quite suitable for age dating, especially when the zircon inclusions are minute.

Besides a sensitive mass spectrometer, precise age dating relies on proper standard reference materials as well as corrections for laser ablation artefacts (e.g. fractionation). This must be addressed regardless of whether TOF-MS or Q-MS is used.

Imaging of Chemical Zoning for Gem Research

The formation of gem materials is a complex process both spatially and temporally. Chemical (and colour) zoning is common, caused by intrinsic (e.g. oscillatory growth zoning) or extrinsic (e.g. change of rock chemistry due to fluid infiltration) factors. Detailed mapping of elemental distribution may provide valuable information about formation kinetics that cannot be readily perceived based on just a few analytical spots. Quantitative imaging of trace-element distribution thus can be a powerful tool, particularly at high spatial resolution, such as from using homogenized 10 µm (or even smaller) laser spots. The amount of ablated material from such a tiny laser spot is minute and provides a brief transient signal. By controlling the ablation process, it is possible to gain two-dimensional or even three-dimensional elemental distribution images (Burger et al., 2015). Hence LA-ICP-TOF-MS is preferred for chemical mapping at high spatial resolution.

Conclusion and Outlook

The Swiss Gemmological Institute SSEF recently installed an LA-ICP-TOF-MS system, named GemTOF. This system is equipped with a 193 nm LA unit and an ICP-TOF-MS instrument.

LA-ICP-TOF-MS is a relatively new and highly sensitive technique for the chemical analysis of gemstones and pearls. This article discusses the advantages, compared to LA-ICP-Q-MS, as well as limitations of this technique. The main advantage is the simultaneous acquisition of full elemental mass spectra with high mass-resolving power and ultra-high acquisition speed. ICP-TOF-MS does not jump from one mass to the next through a series of preselected isotopes, as Q-MS does. Therefore, it is not necessary to preselect isotopes of interest, which requires assumptions about the trace-element composition of a sample and careful consideration of possible peak interferences before the measurement is performed. Since a full mass spectrum is recorded, TOF-MS allows adjustments for the isotope of interest, even after ablation and analysis, in contrast to Q-MS where re-ablation would be needed.

LA-ICP-TOF-MS yields high-quality elemental analyses, produces multidimensional data and feeds the database for statistical analysis. The combination of improved sensitivity and low background noise guarantees a superior limit of detection for heavy elements in single-digit ppb and for light elements in low ppm concentrations. In addition to routine measurements, this new and sophisticated analytical method complements other gemmological testing instruments. This will enhance applications such as trace-element characterization of gemstones and pearls for origin determination and treatment detection, and will open new research opportunities for age dating, inclusion studies and high-spatial-resolution chemical mapping of gems.

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Synthetic Emeralds Grown by IG Farben: Historical Development and Properties Related to Growth Technology

Karl Schmetzer, H. Albert Gilg and Elisabeth Vaupel

Developments in emerald synthesis occurred over a period of nearly five decades (1911–1958) at a facility in Bitterfeld, Germany, operated primarily under the name IG Farben. Initial experiments involving the flux method of growth performed by H. Wild in Idar-Oberstein led to collaborations with Bitterfeld scientist O. Dreibrodt in the 1910s and 1920s. Almost two decades of research then ensued, culminating in a breakthrough by H. Espig of IG Farben in 1929 that permitted the growth of larger synthetic emerald crystals. A standard synthesis process was developed between 1930 and 1935, and production on a limited scale lasted until 1942. Although the possibility of restarting production was explored in the 1950s, those initiatives were abandoned without further operations. The evolution of the company's flux-growth technology from the first trials before 1914 through the standardized production after 1935 is recorded in variations in the properties of the resulting synthetic emeralds. While Cr was always present as a colour-causing trace element, in later eras Ni was added as well. Growth was performed in platinum crucibles with the nutrient at the bottom, seeds centrally located in a molybdate melt and silica plates floating on top of the melt. To create a barrier between the seeds and the silica plates, a platinum net was originally employed but was subsequently replaced by a platinum baffle. Natural beryl seeds were used in the early years, followed by flat synthetic emerald plates. As a consequence, the morphology of the synthetic emerald crystals changed from prismatic to thick tabular or short prismatic.

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Introduction

In February 1935, the trade press first announced that scientists at Interessen-Gemeinschaft Farbenindustrie Aktiengesellschaft, known as IG Farben AG, in Bitterfeld, Germany, had succeeded in growing synthetic emeralds of facetable size and quality (e.g. Figure 1), denominated 'Igmerald' (for **IG** Farben synthetic e**merald**; Anonymous, 1935a). The first gemmological and mineralogical descriptions were published by M. Jaeger, the director of the IG Farben plant at Bitterfeld, and H. Espig, the technical leader of synthetic gemstone production at the company, which mainly grew rubies, sapphires and spinels by

the Verneuil technique (Espig, 1935; Jaeger and Espig, 1935).[1] These initial descriptions were soon followed by additional studies by a few gemmologists or mineralogists who were able to obtain samples for scientific research (Anderson, 1935; Eppler, 1935, 1936; Schiebold, 1935). A general summary, with short contributions by K. Schlossmacher, B. W. Anderson and G. O. Wild, also was published by the Gemological Institute of America (Anonymous, 1935b).

Jaeger and Espig (1935) further indicated that commercialization of the growth process through the release of the synthetic emeralds freely to the trade was not intended at that time. Rather, they indicated that samples would be given to a limited number of highly qualified goldsmiths for production of a small quantity of special jewellery items. In reality, it appears that samples were received only by K. B. Berthold, who published a note in *Deutsche Goldschmiede-Zeitung* (German Goldsmiths' Journal) describing the extraordinary "beauty, quality and value" of the synthetic emeralds (Berthold, 1935). Such statements could certainly support use of the new synthetic material exclusively for advertisement and public relations purposes (see Metzger, 2000).

In the early works cited above, as well as in subsequent reports discussing ways to distinguish natural and synthetic emeralds, the growth method used at Bitterfeld was not mentioned even in general terms. Instead, it was simply assumed through the 1950s that a hydrothermal technique had been used (Webster, 1952, 1955, 1958; for an overview of methods applied for emerald synthesis, see also Fischer, 1955; Cannawurf, 1964; Nassau, 1976a,b; Diehl, 1977; Schmetzer, 2002). Only in the 1960s did a series of publications by Espig (1960, 1961, 1962) correct the record, detailing flux growth in lithium molybdate. An analogous flux-growth process had already been used by French scientists in the 19th century (Hautefeuille and Perrey, 1888, 1890), but the resulting synthetic emerald crystals were heavily included and only in the millimetre range or below.

Figure 1: This cluster consisting of five synthetic emerald crystals (type 3) was produced by IG Farben at Bitterfeld, and is from the collection of the Museum für Naturkunde, Berlin. The size of the crystal group is approximately 19.3 × 15.4 mm, and it weighs 15.54 ct; the largest crystal measures 13.8 mm long, with a diameter of 9.3 mm. Photo courtesy of R.-T. Schmitt.

Based upon the descriptions given by Espig (1960, 1961, 1962), the growth technique for synthetic emeralds applied at Bitterfeld was more recently depicted schematically (Recker, 1973; Schmetzer and Kiefert, 1998). The 'secret ingredient' alluded to by Espig as the means for obtaining a more desirable slightly yellowish green colour was also identified as a Ni-bearing compound by X-ray fluorescence and absorption spectroscopy (Schmetzer and Kiefert, 1998).

Yet much about the development and history of emerald synthesis at Bitterfeld has remained a mystery. Although Espig (1960, 1961, 1962) indicated that efforts began as early as 1911,

[1] Verneuil synthesis of ruby and sapphire in Bitterfeld commenced in 1910 at Elektrochemische Werke Bitterfeld (see footnote 2). The initial attempts at growing synthetic emerald by this company can be traced back to around 1911 and, later, to the work of O. Dreibrodt beginning in ~1913–1914 (see footnotes 4–6). In 1925, this company, including the plant for producing synthetic gem materials, was incorporated into the IG Farben group of companies. Later, under communist rule, the state-owned entity VEB Elektrochemisches Kombinat Bitterfeld took control of synthetic ruby, sapphire and spinel production at Bitterfeld. Business files from all three periods are preserved in the Landesarchiv Sachsen-Anhalt (LASA), Abteilung Merseburg (archives of the German federal state Saxony-Anhalt, Department Merseburg) and at Kreismuseum Bitterfeld. In Merseburg, the documents attributed to Elektrochemische Werke Bitterfeld and IG Farben Bitterfeld are filed as LASA, MER, I 506; the documents attributed to VEB Elektrochemisches Kombinat Bitterfeld are filed as LASA, MER, I 507; and a mixed file containing documents from different eras is filed as LASA, MER, I 509. The documents collected at Kreismuseum Bitterfeld are filed as SE (**s**ynthetische **E**delsteine = synthetic gemstones).

until now our knowledge has been restricted to those facts that he decided to publish in the early 1960s. Almost nothing is known about work prior to the 1930s, and equally absent is information about possible developments after production at Bitterfeld was terminated in 1942 because of World War II. Also limiting is the fact that the modern analytical examinations undertaken by Schmetzer and Kiefert (1998) were performed using only a small number of samples from a single collection (i.e. that of the late E. Gübelin, Lucerne, Switzerland).

However, the foregoing dearth of available information was recently altered when, during research by one of the authors into the industrial history of Verneuil synthesis at Bitterfeld (see footnote 1 and Vaupel, 2015), some internal IG Farben reports and related documents were discovered pertaining to emerald synthesis. Additional samples were then located and obtained from the museum of the Technische Universität Bergakademie (University of Mining and Technology) in Freiberg, Saxony, Germany; from the Museum für Naturkunde (Natural History Museum) in Berlin (Figure 1); from the Naturhistorisches Museum (Museum of Natural History) in Vienna, Austria; from the reference collection of the German Gemmological Association in Idar-Oberstein, Germany; and from private collections (e.g. from S. Fordemann, the granddaughter of Berthold). Thus, with these samples and the new documents, the present study was undertaken to fill historical gaps regarding emerald production in Germany and to add further gemmological and mineralogical data about the synthetic emeralds grown primarily in connection with the Bitterfeld operations.

Figure 2: Hermann Wild began producing synthetic rubies and sapphires by the Verneuil technique in Idar-Oberstein in 1906, and the operations were transferred to Bitterfeld in 1910. Wild also experimented with emerald synthesis and submitted some small crystals he produced to R. Brauns in 1912. Photo taken ~1900; courtesy of D. Jerusalem.

History

Emerald Synthesis by H. Wild (~1912)

Hermann Wild[2], a gem merchant from Idar-Oberstein (Figure 2), was the first to grow synthetic rubies and sapphires by the Verneuil method in Germany, beginning in 1906 (Miethe, 1908; Bauer, 1909; Doelter, 1909; Mitteilungen der Wiener Mineralogischen Gesellschaft, 1909). He cooperated with Elektrochemische Werke Bitterfeld in these efforts from 1907 until 1909, when his synthetic corundum operations were acquired by that company. In 1910 the synthetic corundum production was transferred from Idar-Oberstein to Bitterfeld, but Wild continued to collaborate with Elektrochemische Werke Bitterfeld by giving technical advice, observing the market, and distributing the synthetic materials grown by them (for further details see Vaupel, 2015). Also in 1910, Wild discussed emerald synthesis experiments with F. Rothe

[2] Hermann Wild (1859–1938) developed technology for growing Verneuil synthetic rubies together with Dr Adolf Miethe (1862–1927), professor at the Technical University of Berlin-Charlottenburg, Germany (Conradt, 1959). They first grew synthetic rubies in 1906 and developed recipes for producing synthetic sapphires of various colours in the following years. Samples grown on an experimental basis were cut in Idar-Oberstein and put on the market. Beginning in 1907, Wild and Miethe collaborated with Elektrochemische Werke Bitterfeld, then a subsidiary of Allgemeine Elektricitäts-Gesellschaft AEG (General Electricity Company), one of the major producers of electrical equipment in Germany at that time. In 1909, Wild's gem trading company, including the equipment for experimental corundum synthesis, became a subsidiary of Elektrochemische Werke Bitterfeld, and the new joint enterprise worked under the designation Deutsche Edelsteingesellschaft (DEG; German Gemstone Company).

Figure 3: Hermann Espig joined Elektrochemische Werke Bitterfeld in 1921 and from 1924 onwards was involved in experiments related to emerald synthesis. After a breakthrough in 1929 enabled the growth of larger crystals, he developed the final production technique between 1930 and 1935. Photo taken in the 1950s; courtesy of K.-D. Heinrich.

and H. Röhler, leading representatives from Bitterfeld (file LASA, MER, I 506, No. 96). This corresponds with the dates given by Espig (1945, 1960), who mentioned the years 1910 and 1911 in connection with the start of experimental studies on emerald synthesis at Bitterfeld. While maintaining his own emerald-growth operations in Idar-Oberstein, Wild additionally became privy to details regarding the experiments at Bitterfeld, such as learning in 1915 about the use of Otto Dreibrodt's[3] apparatus in the early years of experimental mineral synthesis (see below).

In August 1912, Wild submitted a number of small synthetic emerald crystals to R. Brauns, professor of mineralogy at the University of Bonn, Germany. Brauns published a short note about this synthetic gem material in 1913, and a more detailed study followed in 1936. The full text of that study, including the three original figures, was later republished in the *Zeitschrift der Deutschen Gesellschaft für Edelsteinkunde* (Journal of the German Gemmological Association), together with general notes and comments by H. Bank (1965).[4] The synthetic emeralds produced by Wild also were briefly mentioned in Doelter (1913) and in Michel (1914, 1915), and some of the material was used for a luminescence study (Michel and Riedl, 1925). Nevertheless, none of the works divulged anything about Wild's production technique.

Emerald Synthesis at Bitterfeld by O. Dreibrodt (~1913–1926) and H. Espig (~1924–1928)

As noted above, in describing the method for emerald synthesis invented at Bitterfeld, Hermann Espig (1960, 1961, 1962; Figure 3) dated the first experiments in that endeavour as early as 1910–1911. It is likely that such comments also referred to the collaboration with and early experiments by Wild, because experiments in Bitterfeld, as performed by Dreibrodt and described below, are documented only from 1913 or even somewhat later.

In 1913, Otto Dreibrodt (Figure 4), a young mineralogist, was hired by Elektrochemische Werke Bitterfeld, which in turn became part of IG Farben in 1925. Prior to this employment, Dreibrodt had already invented an apparatus for crystal growth in solutions or melts, and in his new position he

[3] Dr Otto Dreibrodt (1887–1941) studied mathematics and mineralogy at the Universities of Halle and Leipzig, Germany, graduating from the latter in 1912. Dreibrodt joined Elektrochemische Werke Bitterfeld in August 1913. Numerous German and international patents by Dreibrodt and assigned to Elektrochemische Werke Bitterfeld dealt with developments and improvements in the Verneuil technique, such as for producing sapphires and spinels of various colours, as well as for chemical technology not related to gem synthesis. He became the technical leader for synthetic gemstone production at Elektrochemische Werke Bitterfeld in 1919 but left the company at the end of 1926. His personnel records still exist (files LASA, MER, I 506, Nos. 1068 and 1069), but no grounds for his departure were disclosed. Several Verneuil boules from his work remain with the family, having been left by his daughter L. Dreibrodt at her death, but no synthetic emerald samples are included (E. Schlatter, pers. comm., 2015).

[4] In his comments, H. Bank (1965) mentioned that he borrowed the samples produced by H. Wild and described by R. Brauns from the mineralogical collection at the University of Bonn, Germany, and he announced the forthcoming publication of his own study. Unfortunately, this paper was never published, and the samples can no longer be located in the mineralogical collection at the University of Bonn (A. Zacke, pers. comm., 2015).

was tasked with developing novel techniques for crystal growth and with applying known methods to new materials, including synthetic emerald. Elektrochemische Werke Bitterfeld also applied for German and international patents covering the apparatus previously invented by Dreibrodt, after rights to the device had been transferred to the company by contract.[5] A German patent was granted in 1914, and the corresponding U.S. patent was published in 1920. The U.S. patent for Dreibrodt's apparatus was apparently considered worthy of attention, as it was reviewed briefly in the *American Mineralogist* (Hunt, 1921)—not a common practice at that time.

In that device, called a 'rotation apparatus' (Figure 5a), a solution or melt was placed in a vessel with the nutrient at the bottom and a seed ('k' in Figure 5a) in an upper crystallizing chamber (f). A temperature gradient was created between the seed and nutrient by an external heat source. An outer tube (b) was suspended over the crystallizing chamber and connected by special holders to an inner tube (g), which terminated in a T-piece (h). When the bottom portion of the apparatus containing the nutrient was heated and the outer and inner tubes were rotated (with the T-piece), hotter solution or melt was drawn up through the outer tube, thereby transporting dissolved nutrient to the cooler seed. To work with a melt and not only with hydrous solutions, the apparatus was constructed of platinum and used, at least temporarily, in Bitterfeld for emerald synthesis experiments (file LASA, MER, I 506, No. 475, dated 1915; see footnote 1 for an explanation of LASA references).

Figure 4: Otto Dreibrodt worked from August 1913 to December 1926 for Elektrochemische Werke Bitterfeld and was involved in the first experiments dealing with emerald synthesis. His projects also encompassed the growth of synthetic rubies, sapphires and spinels by the Verneuil technique. Photo taken about 1913; Landesarchiv Sachsen-Anhalt, Merseburg, file LASA, MER, I 506, No. 1068; reproduced by permission.

However, problems with oversaturation of the melt and spontaneous nucleation of tiny synthetic emerald crystals or aggregates could not be solved, and no samples of facetable size were obtained from the experiments.

Hermann Espig[6] (see again Figure 3) was involved in experiments dealing with emerald synthesis at Bitterfeld beginning in 1924. In an internal report, Espig (1930) presented a short summary of the work before 1929. He described the problem of oversaturation and mentioned another apparatus, also made of platinum, that was developed to obtain synthetic emerald

[5] The rights to use and to file national and international patent applications for the apparatus Dreibrodt invented for crystal growth were sold to Elektrochemische Werke Bitterfeld for 3,000 Reichsmark. Dreibrodt was hired by the company at a monthly wage of 300 Reichsmark in 1913 (file LASA, MER, I 506, No. 1068).

[6] Dr Hermann Espig (1895–1969) studied mathematics and natural sciences, primarily mineralogy, chemistry and physics, from 1916 to 1920 at the University of Leipzig. He graduated in 1920 with a thesis addressing X-ray diffraction patterns of silicon carbide, prepared under the academic supervision of F. Rinne and E. Schiebold (archives of the University of Leipzig). Espig joined Elektrochemische Werke Bitterfeld in March 1921 and became O. Dreibrodt's assistant in 1922. During his early years with the firm, Espig was also tasked with carrying out experiments suggested by A. Miethe (see footnote 2). After Dreibrodt left the company at the end of 1926, Espig became the leader of synthetic gemstone production at Bitterfeld. (Espig's personnel file is available in Merseburg, LASA, MER, I 506, No. 1064.) The cooperation between Espig and Dreibrodt in the early 1920s is evidenced by German patents 385 374 (granted 1923) and 390 794 (granted 1924). Both applications, which dealt with the production of green synthetic sapphires, were filed in December 1922 and listed Dreibrodt, Espig and D. Strauss as the inventors.

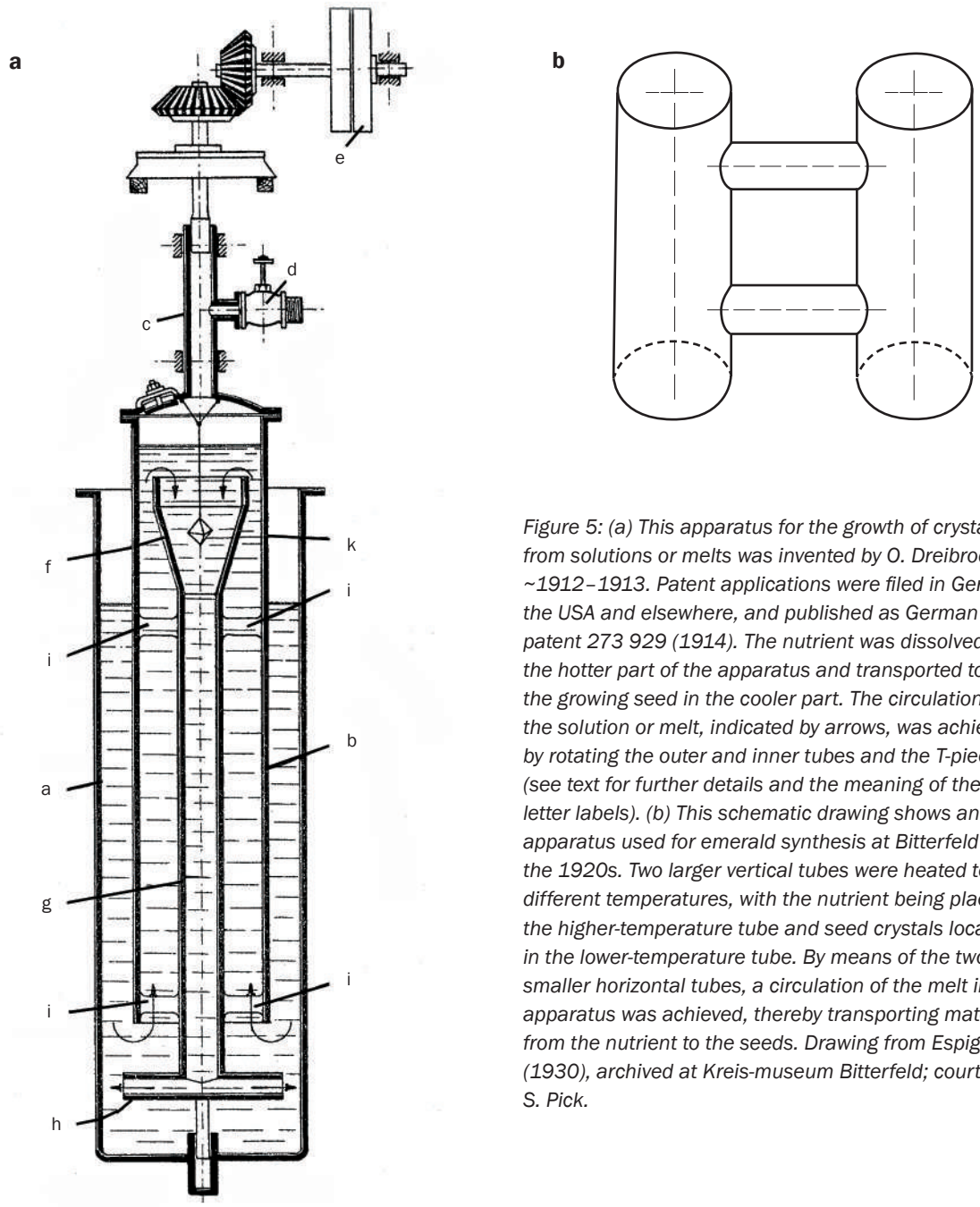

Figure 5: (a) This apparatus for the growth of crystals from solutions or melts was invented by O. Dreibrodt in ~1912–1913. Patent applications were filed in Germany, the USA and elsewhere, and published as German patent 273 929 (1914). The nutrient was dissolved in the hotter part of the apparatus and transported to the growing seed in the cooler part. The circulation of the solution or melt, indicated by arrows, was achieved by rotating the outer and inner tubes and the T-piece (see text for further details and the meaning of the letter labels). (b) This schematic drawing shows an apparatus used for emerald synthesis at Bitterfeld in the 1920s. Two larger vertical tubes were heated to different temperatures, with the nutrient being placed in the higher-temperature tube and seed crystals located in the lower-temperature tube. By means of the two smaller horizontal tubes, a circulation of the melt in the apparatus was achieved, thereby transporting material from the nutrient to the seeds. Drawing from Espig (1930), archived at Kreis-museum Bitterfeld; courtesy of S. Pick.

crystals of larger sizes. A simple schematic drawing showed two larger vertical tubes that were connected by two smaller horizontal tubes (Figure 5b). By heating one of the vertical tubes to 600°C and the second to 800°C, a temperature gradient and a circulation of the melt could be established, with the nutrient being added to the higher-temperature tube. Nonetheless, the experiments performed with that equipment likewise did not succeed in growing larger crystals.

Obviously, the small synthetic emerald crystals produced by Elektrochemische Werke Bitterfeld/ IG Farben Bitterfeld before 1929 were not distributed on a significant scale. Only a few short descriptions of the small hexagonal prisms are found in the literature (Michel, 1927; Doermer, 1929; see Figure 6).

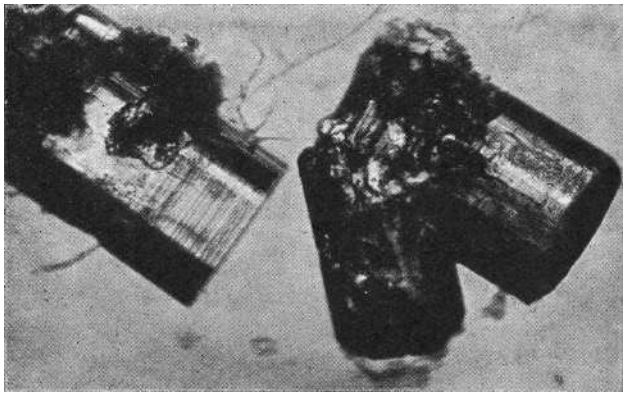

Figure 6: Small synthetic emerald crystals were grown in various experiments at the Bitterfeld facility in the 1920s. The diameter of the crystals is about 0.5 mm. From Doermer (1929).

Breakthrough by H. Espig (1929) and Efforts Toward Commercial Production (1930–1935)

Espig (1930) described an experiment in which two of the components of beryl, Al_2O_3 and BeO, were separated from SiO_2 powder in a platinum dish. That experiment, performed in February 1929, led to the growth of synthetic emerald crystals that were larger than those obtained before. Additional developments resulted in the Al_2O_3 and BeO being placed on the bottom of a crucible with silica plates (composed of quartz or vitreous silica) being floated on top of the molten flux. The silica was dissolved by the flux to supply the SiO_2 component for synthetic emerald growth. With that arrangement, however, small synthetic emerald crystals were found to grow on the silica plates.

Next, in an attempt to avoid nucleation on the silica plates, a platinum net was placed in the crucible, with beryl seeds below the net. The disadvantage was that the synthetic emerald crystals tended to adhere to and grow on both sides of the platinum net (Figure 7). They consequently had to be sawn into pieces to separate them from the net. This was addressed by replacing the platinum net with a platinum baffle (disc) punctured by small holes to allow circulation of the SiO_2-bearing flux. Finally, to ensure that crystal growth would not need to be interrupted every 2–3 days due to consumption of the initial nutrient, a platinum tube was placed in the centre of the crucible to allow nutrient to be added to the bottom as the growth process continued (Figure 8). After a growth period of about 20 days, the synthetic emeralds were removed from the flux and inspected visually. Any extremely impure layers were removed and the synthetic emeralds so prepared were used for further growth cycles. Facetable-sized crystals were obtained after a total period of about one year (for further details, see Schmetzer and Kiefert, 1998).

Additional information regarding the seeding technique, which influenced the properties of the final product, is found in some of Espig's later works (1960, 1962). During the early years, after the clusters or druses were sawn from the

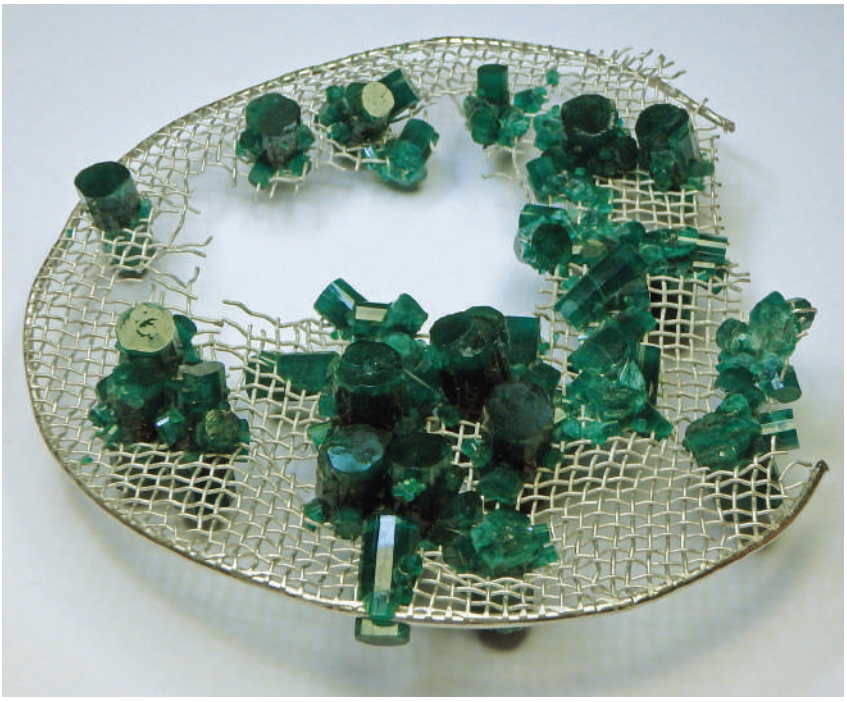

Figure 7: Multiple IG Farben synthetic emerald crystals and crystal clusters are shown attached to a platinum net. The size of the item is approximately 11 × 9 cm, and it is part of the collection of the Museum für Naturkunde, Berlin. Photo courtesy of R.-T. Schmitt.

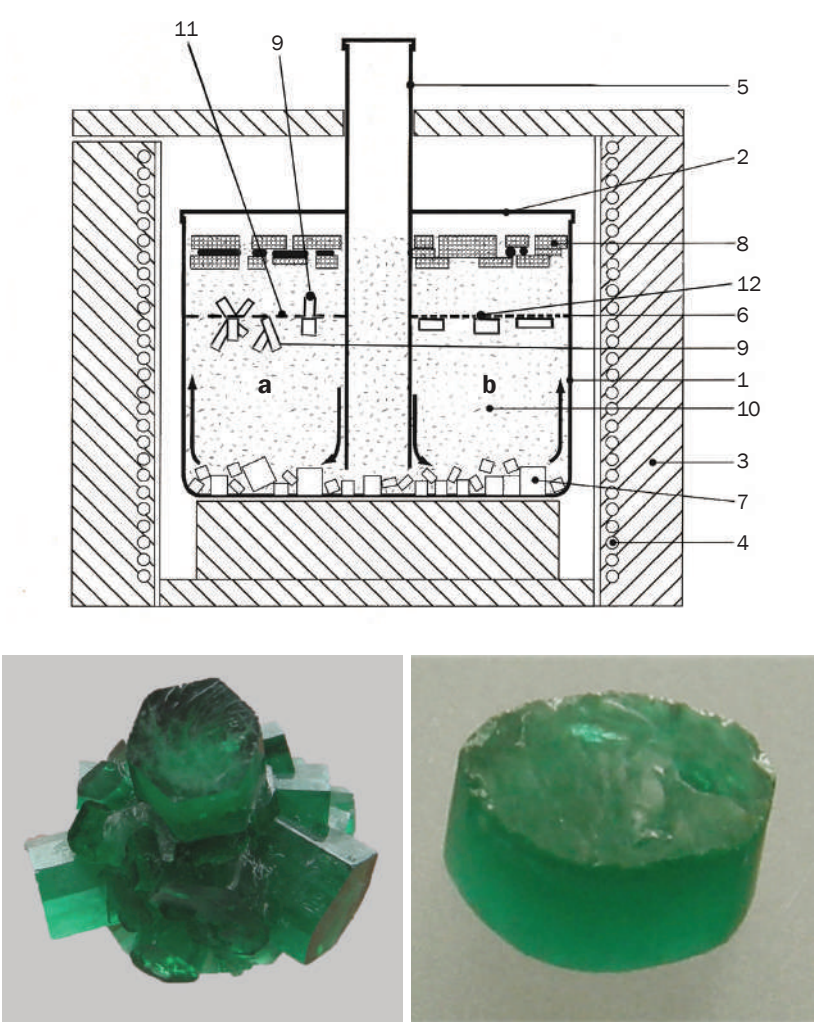

Figure 8: In this schematic diagram for the flux growth of synthetic emerald by IG Farben at Bitterfeld from 1929 to 1942, (a) represents the earlier method using a platinum net to separate seeds of natural beryl or synthetic emerald from silica plates floating on the melt, and (b) represents the later method using platinum baffles to separate seeds of synthetic emerald from the silica plates. For (a), the synthetic emerald crystals and crystal clusters grew on both sides of the net, while in (b) single crystals grew only on one side of the baffle. 1—platinum crucible, 2—platinum lid, 3—insulation, 4—heating system, 5—central platinum tube for the addition of nutrient material, 6—platinum baffle, 7—nutrient, 8—silica plates, 9—growing prismatic synthetic emerald crystals, 10—lithium molybdate flux, 11—platinum net, 12—growing tabular synthetic emerald crystals (adapted from Schmetzer and Kiefert, 1998). The photos show a crystal cluster (left, approximately 20.4 × 17.3 × 13.6 mm) and a single crystal with short columnar habit (right, approximately 13.8 × 12.9 × 6.3 mm), representing typical products grown with the two variants drawn schematically above. Photos by K. Schmetzer.

platinum nets, they were used to create synthetic seeds. Specifically, the ends of the larger crystals within the clusters were cut perpendicular to the c-axis. These short prismatic seeds were then placed in the melt for further crystal growth, and this practice continued after the platinum net was replaced by a platinum baffle. The morphology of the resulting single crystals was described by Espig (1962) as prismatic to thick tabular.

Overall, many details given in the above-cited early internal report prepared by Espig (1930) are consistent with later data published in the early 1960s. Obvious examples include a BeO-Al_2O_3-SiO_2 phase diagram and a description of the various mineral phases and their stability fields in a triangular diagram, which are identical across the sources. Conversely, one notable aspect of the history found only in Espig's 1930 report is the filing of two patent applications, the first in October 1929 and a second shortly thereafter. Espig stated that both applications had already received positive reports from the examiner at the German patent office in Berlin responsible for inorganic synthesis technologies and were awaiting publication. However, given that those patents were never published, it can be concluded that they were abandoned by the applicant, likely to avoid having the processes for emerald synthesis made publicly available. Other internal IG Farben documents dated between 1931 and 1942 confirm this presumption (see below).[7]

[7] Two documents preserved in the archives of Bayer AG at Leverkusen, Germany (dated 1931 and 1935, in file 186/9) and one document archived at Merseburg (dated 1942, in file LASA, MER, I 506, No. 9580) record statements by IG Farben managers and by staff members of the patent department about filing patent applications dealing with emerald synthesis. (From 1925 onwards, Bayer AG was one of the larger companies within the IG Farben group.) Together with the internal report by Espig (1930), these documents show that at least three patent applications were filed and then subsequently withdrawn to avoid publication.

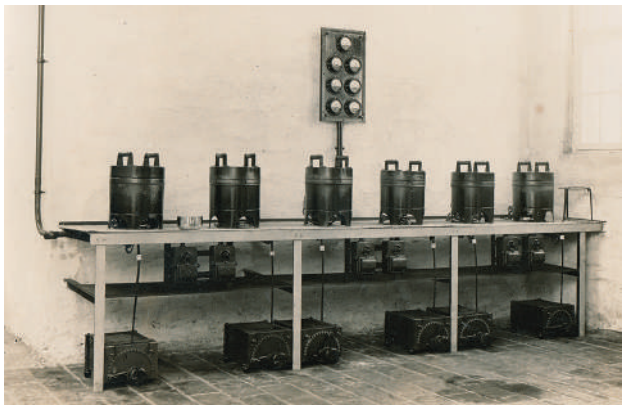

Figure 9: The production facility at the IG Farben plant in Bitterfeld for growing synthetic emeralds in 1930 is shown here. Six apparatus are seen, each corresponding to the assembly shown schematically in Figure 8. Photo from Espig (1930), archived at Kreismuseum Bitterfeld; courtesy of S. Pick.

The use of a Ni-bearing compound together with yttrium oxide (see below)—in addition to Cr—as the cause of colour was not mentioned in Espig's 1930 report. This may indicate that the "hundreds of experiments to establish the desired slightly yellowish green coloration of the synthetic emeralds", as described by Espig in his papers of the early 1960s, were performed between 1930 and 1935. As noted at the outset, 1935 was the year that IG Farben announced the successful development of a process for Igmerald synthesis and made available to the public a limited number of samples, especially for gemmological examination.

IG Farben in the 1930s

Although the IG Farben board of directors in 1935 proudly announced their company's work as a breakthrough in synthetic emerald production, the result achieved actually fell short of the goal underlying the more than two decades of effort that preceded the announcement. The aim had been to develop a process for cheap mass production of synthetic emerald (comparable with the Verneuil synthesis of ruby and sapphire) that could meet the demand of the jewellery industry for a green gem material. However, the high production cost, the required growth time of one year or more in total and the relatively low yield failed to meet the vision of IG Farben leadership.

Various calculations of the production cost, based upon different assumptions, exist in the historical documents from 1937 (50 or 60 Reichsmark per carat of faceted material) and from 1940 (100 Reichsmark per carat of faceted material).[8] The production capacity from the established facility (Figure 9) was given in a 1938 document as only 200 carats per year. The consequent high cost of production resulted in a selling price in the trade of at least ~100 Reichsmark per carat for smaller gems and ~140 Reichsmark per carat for larger ones.[8] At those prices, distribution via the established German gem trade in Idar-Oberstein would have been uneconomical. Moreover, none of the companies dealing in faceted natural emeralds wanted to offer synthetics for sale, in addition to their established product range of natural stones. Such facts led the IG Farben board of directors to consider using the Igmeralds for public relations purposes,[9] as opposed to releasing them for sale. However, the officially stated reason offered in 1934 for the company's decision not to engage in commercial production was that IG Farben sought to protect the trade in natural stones.[10] Nonetheless, several efforts to explore placing the synthetic material into the trade are documented to have taken place in the years after 1935.

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[8] The various estimations or calculations of production cost for 1937 and 1940 are found in file LASA, MER, I 509, No. 9850. The production capacity and possible selling prices are mentioned in the same files. For comparison, the monthly wage of an average worker in Germany in 1937 was about 150 Reichsmark, and the average monthly income of a university professor was approximately 800 Reichsmark.

[9] A contract between IG Farben and goldsmith Prof. Karl Borromäus Berthold (1889–1975) for the supply of synthetic emeralds is dated January 1935, and Berthold produced several jewellery pieces containing Igmerald. Some of the pieces were displayed at major exhibitions, such as the 1937 world exposition in Paris. Others were ultimately donated to high-ranking officials within the German government. For example, one item called the 'Golden Shrine', which incorporated 161 Igmeralds, was presented to A. Hitler on the occasion of his 50th birthday (1939) by the city of Cologne. See files LASA, MER, I 506, No. 2547 and LASA, MER, I 509, No. 9580; several items also were depicted and described in detail by Metzger (2000).

[10] A short note was published in 1952 by C. Rühle, editor of *Deutsche Goldschmiede-Zeitung* from 1922 to 1953. Rühle mentioned that he had been told in 1934 by several people involved in Igmerald production that the primary rationale for limiting output was to avoid causing a drop in the prices for natural emerald. The market for ruby and sapphires had seen such a drop with the introduction of Verneuil-grown synthetics in the first decades of the 20th century.

This ambiguity between official statements and proprietary activities was also reflected in the patent policy of the company (again see footnote 7). As indicated previously, Espig's June 1930 internal report referenced two patent applications filed in the German patent office, the first one in October 1929, and a possible application in the USA also was considered. Both German applications were abandoned by the company, and at least one further application, filed about 1934, also was abandoned in 1935. The rationale behind these abandonments is suggested in the minutes from a meeting of IG Farben management in 1931: The company leaders were afraid that it would be impossible to control the worldwide use of the growth technology and especially to prevent possible patent infringement. Several letters dated after 1935 evidence consent amongst management regarding these policies.

IG Farben After 1942

According to all available information, the synthesis technique as established by 1935 remained essentially unchanged, and production continued on a limited scale until being terminated in 1942 because of World War II. Although Espig (1960, 1961, 1962) published that production of synthetic emeralds did not resume after 1942, two noteworthy events after 1945 should be mentioned for completeness.

Archived at Kreismuseum Bitterfeld is an internal report by Espig (1946) that recounted an experiment for growing synthetic emeralds. Specifically, a description of the growth process had been prepared in October 1945 for the Russian commander of the synthetic gemstone plant at Bitterfeld, and a practical demonstration also was required by the Russians. The February 1946 document reported that the original platinum apparatus used in emerald synthesis had ceased to be available. Therefore, at least one platinum crucible had to be manufactured from some residual sheet material. The experiment was performed successfully in January 1946 with a growth period of approximately one month. Most interestingly, the recipe for the various ingredients was given, and that recipe included nickel carbonate, the 'secret' ingredient not otherwise disclosed until the late 1990s (Schmetzer and Kiefert, 1998). Surprisingly, the list of ingredients also contained yttrium oxide, an Igmerald component not previously recognized. As a consequence of these activities, Espig would later remark in a letter dated 1952 that the production technology for synthetic emerald was no longer secret because his 1946 report had been sent to Moscow.

In a further internal report, which was recently obtained by the authors from K.-D. Heinrich (the final director of the Bitterfeld plant before its closure in 1990), Espig (1945) stated that the yttrium oxide mentioned above was used in addition to lithium chromate and nickel carbonate as a colour-causing trace element to obtain the desired slightly yellowish green coloration of the synthetic emeralds.

In the Landesarchiv Sachsen-Anhalt, Abteilung Merseburg, a series of documents dated March 1954 to December 1958 revealed several exploratory efforts toward restarting synthetic emerald production after 1945. Included in them were calculations regarding the profitability of a small production of synthetic emerald comprising about 15–20 carats of faceted material per month (i.e. close to the yield obtained in the late 1930s), with an estimated production expense of 200 DM per carat (using the currency of the German Democratic Republic) and a selling price that was equivalent to that of Chatham synthetic emeralds at the time. The investment for the apparatus, including 15 kg of platinum,[11] was computed by Espig in 1955 to be about 118,500 DM.

Obviously, Espig never succeeded in obtaining permission for such a restart. However, samples of the remaining pre-1942 production (an inventory from 1951 mentioned 159 faceted pieces totalling 15.1 carats and 623 crystals totalling 3,124.7 carats) were used as state gifts for important visitors to the German Democratic Republic, mostly from the Soviet Union and other socialist countries.

Materials and Methods

The present study involved flux-grown synthetic emerald samples grown by four early producers. The oldest were some small crystals produced in the late 19th century from a lithium molybdate

[11] Espig listed 15 kg of platinum as well as several ingredients (beryllium oxide, lithium carbonate and yttrium oxide) that had to be purchased from foreign countries using Western currencies. Such complications in the supply chain, the high investment required and the minimal production output of only 15–20 carats per month culminated to suggest only a small possible profit. The combined disadvantages may explain why Espig was never successful in obtaining permission to restart synthetic emerald production. See file LASA, MER, I 507, No. 591, dated 1950s.

Table I: Properties of some early flux-grown synthetic emeralds.

Samples prepared by	P. G. Hautefeuille and A. J. E. Perrey, Paris, late 19th century	H. Wild, Idar-Oberstein, ~1912	K. A. Hofmann, Berlin, ~1926
Source of samples	Naturhistorisches Museum, Vienna	German Gemmological Association, Idar-Oberstein	Museum für Naturkunde, Berlin; Inv. No. 2015 00055
Description	Minute crystals or clusters, embedded between two glass slides	5 minute crystals or clusters, loose	Numerous minute crystals or clusters, loose
Crystal morphology	Short prismatic single crystals or clusters	Long prismatic single crystals or clusters	Long prismatic single crystals or clusters
Size	Up to ~0.5 mm	Up to ~1 mm	Up to ~1 mm
Growth zoning	Very impure, heavily included cores, clearer rims	None	None
Inclusions	Residual flux in various forms	Residual flux in various forms	Residual flux in various forms
Cause of colour	(Analysis not possible because embedded between glass slides)	Cr, minor Fe	Cr, minor Fe
Element(s) related to flux		Mo	Mo

flux by P. G. Hautefeuille[12] and A. J. E. Perrey in Paris, France. These were examined principally for comparison purposes and came from the Naturhistorisches Museum in Vienna. Five small crystals grown by Wild around 1912 were made available from the reference collection of the German Gemmological Association, Idar-Oberstein. Several synthetic emerald crystals produced in the 1920s by K. A. Hofmann,[13] professor at the Technical University of Berlin-Charlottenburg, were provided by the Museum für Naturkunde in Berlin (Inv. No. 2015 00055). An overview of these three groups is presented in Table I.

The fourth group consisted of rough and faceted Igmeralds that were obtained from six different sources. The German Gemmological Association loaned two crystals and one faceted sample, and from the private collections of C. Weise, Munich, and E. Gübelin, Lucerne, came one crystal cluster and one faceted sample, respectively. The Museum für Naturkunde in Berlin offered one crystal and one cluster submitted by Espig in 1962 (e.g. Figure 1), plus a platinum net with multiple attached synthetic emerald crystals and clusters (Figure 7). The Technische Universität Bergakademie Freiberg provided 10 faceted samples and 10 rough crystals, which had been bequeathed by an individual involved in the production at Bitterfeld during the 1960s and 1970s. Five faceted Igmeralds set in jewellery by Berthold in the 1930s were made available by his granddaughter S. Fordemann of Herford, Germany. Thus, in summary and without counting the samples attached to the platinum net, the authors were able to examine 15 crystals or crystal clusters and 17 faceted synthetic emeralds produced by IG Farben.

All of the rough and faceted Igmeralds were examined with a gemmological microscope (magnification up to 100×), both with and without immersion. The early flux-grown synthetic emeralds were examined without immersion. All of the samples also were examined at higher magnification (up to 1,000×) using a Leica DM LM polarizing microscope with a transmitted light source. For photo documentation, we used an Olympus DP25 digital camera with Olympus Stream Motion software 1.6.1. For all faceted samples,

[12] Dr Paul Gabriel Hautefeuille (1836–1902) was a French mineralogist and chemist. In 1865 he earned doctorates in physical sciences and medicine. From 1870 to 1885, he then served as co-director of the chemical laboratory at the École Normale Supérieure in Paris. He was appointed professor of mineralogy at the Faculté des Sciences in Paris in 1885 and, during the same year, was named director of the mineralogical laboratory at the École des Hautes Études. He published a number of papers that dealt with mineral synthesis, often in collaboration with the *ingenieur* Adolphe Jean Edme Perrey, vice-director of the laboratory at the École des Hautes Études (see Wisniak, 2014). Modern analytical and spectroscopic data for synthetic emeralds grown by Hautefeuille and Perrey were published by Bellatreccia et al. (2008).

[13] Dr Karl Andreas Hofmann (1870–1940) was professor of inorganic chemistry at the Technical University of Berlin-Charlottenburg, Germany. He worked at the same university as A. Miethe (see footnote 2), so it is likely that the two scientists interacted. Additionally, Hofmann was in contact in the 1920s with staff members at the Bitterfeld production facility, discussing various aspects of mineral synthesis (including diamond).

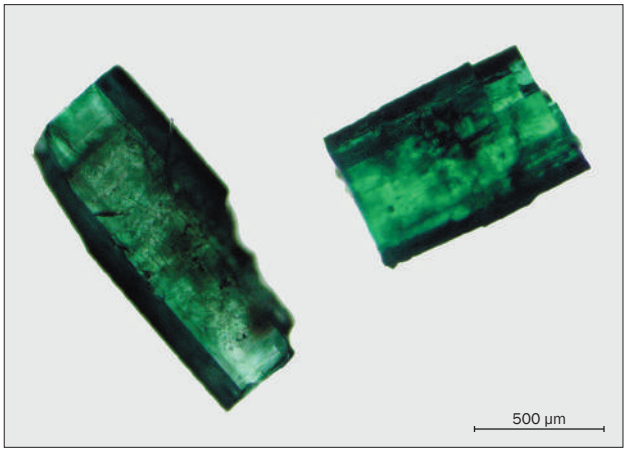

Figure 10: These tiny crystals from the synthesis experiments of H. Wild, about 1912, are kept in the reference collection of the German Gemmological Association, Idar-Oberstein. These single crystals contain dark inclusions of residual flux. (The dark edges along the prism faces are due to internal reflections.) Transmitted light; photomicrograph by H. A. Gilg.

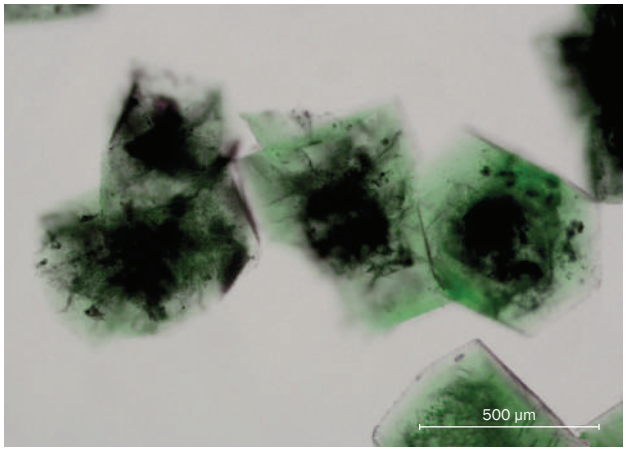

Figure 11: These tiny crystals from the synthesis experiments of P. G. Hautefeuille and A. J. E. Perry, late 19th century, are kept in the collection of the Naturhistorisches Museum, Vienna. The single crystals and crystal aggregates contain inclusions of residual flux, especially in the centre of each crystal. Transmitted light; photomicrograph by H. A. Gilg.

refractive indices were measured; in addition, hydrostatic specific gravity was determined for samples without natural seed plates.

The 32 rough and faceted Igmeralds were examined by energy-dispersive X-ray fluorescence (EDXRF) spectroscopy using a Bruker Tracer III-SD mobile unit, as were the five synthetic emeralds grown by Wild and a similar number of tiny synthetic emerald crystals grown by Hofmann.

The platinum net with the attached crystals was not allowed to leave the Museum für Naturkunde in Berlin. Therefore, some of the crystals attached to the platinum net, as well as the single synthetic emerald crystal and the cluster from the same museum (which were also among the 32 samples mentioned above), were analysed by L. Hecht in Berlin using a Bruker Nano Tracer IV-SD EDXRF unit.

Results

Early Flux-grown Synthetic Emeralds

The basic properties of the early flux-grown synthetic emeralds are summarized in Table I.

Brauns (1936) described and depicted samples that were obtained from Wild in 1912. Strong zoning within the tiny prismatic crystals was highlighted, with a heavily included core and a transparent, almost clear rim. Conversely, the five samples grown by Wild available for the present study (e.g. Figure 10) lacked such distinct zoning. Instead, only the synthetic emeralds grown by Hautefeuille and Perrey displayed pronounced zoning, with heavily included, almost opaque cores and clear rims, combined with a short prismatic morphology (Figure 11). The morphology and microscopic inclusion scene of the Wild samples instead paralleled the features seen in the Hofmann samples (Figure 12). In addition to the absence of zoning or of heavily included cores, both the Wild and Hofmann samples showed longer prismatic habits. Overall, their visual appearance was similar to that of material produced in Bitterfeld in the mid-1920s (see Figure 6).

The Hofmann material is recorded as having been produced through the same method used by

Figure 12: These tiny crystals from the synthesis experiments of K. A. Hofmann, mid-1920s, are kept in the collection of the Museum für Naturkunde, Berlin. The single crystals contain some inclusions of residual flux. Transmitted light; photomicrograph by H. A. Gilg.

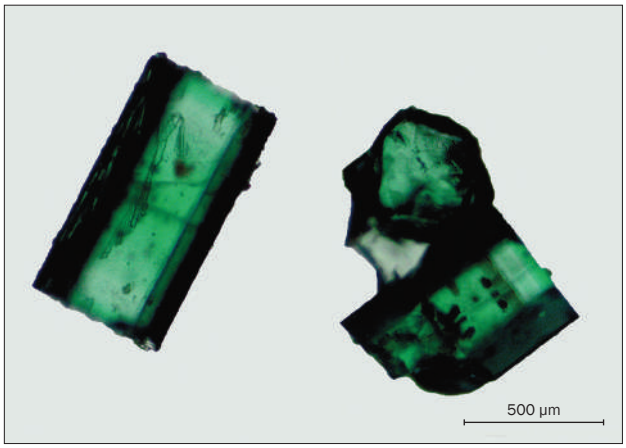

Hautefeuille and Perrey—flux growth in lithium molybdate. Consistent therewith, the Hofmann samples gave a clear signal for Mo in the EXDRF spectrum. A likewise clear Mo spectrum also was obtained for the Wild material. Unfortunately, the samples produced by Hautefeuille and Perrey could not be analysed by EDXRF because they were embedded between two glass slides.

The foregoing results indicate that the synthetic emeralds grown by Wild in the early 20th century were produced by a variant of the method applied by French scientists in the late 19th century. The samples grown by Wild and also by Hofmann demonstrated that it was possible to produce small synthetic emerald crystals without intensely zoned areas of inclusions. Similar unzoned samples produced by the method of Hautefeuille and Perrey were described by Eppler (1961).

Thus, it is possible that Brauns (1936) had received samples from Wild that simply represented a different production run than those crystals available for the present study. Nonetheless, it is equally conceivable that Brauns just selected the samples with the most interesting zoning for description.

Igmerald

The Igmerald samples, based on their respective features, were subdivided into four different types (Table II). These types demonstrate the development of the growth technology at Bitterfeld between 1929 and 1935 (types 1–3) and ultimately represented the last step of the developmental process and the standardized production from 1935 to 1942 (type 4). Samples of types 1 and 4 are depicted in Figure 13.

Table II: Properties of IG Farben flux-grown synthetic emeralds (Igmeralds, ~1929–1942).

Classification		Type 1	Type 2	Type 3	Type 4
Samples		1 cluster of 18 crystals[a]; 1 crystal[b]	1 faceted sample[b]	1 platinum net with numerous attached clusters, 1 cluster of 5 crystals and 1 single crystal[c]	1 crystal[b]; 10 crystals and 10 faceted samples[d]; 1 faceted sample[e]; 5 faceted samples, set in jewellery by K. B. Berthold[f]
Crystal morphology		Long prismatic (cluster) or short prismatic (crystal), first- and second-order hexagonal prism plus basal faces	(Not applicable)	Long prismatic, first- and second-order hexagonal prism plus basal faces	Tabular or short prismatic
Seed		Irregularly shaped colourless natural beryl seed (crystal)	Colourless natural beryl seed with prism faces	Synthetic emerald seed	Synthetic emerald seed
Growth zoning		Layers parallel to the surface of the seed and parallel to prism faces (crystal)	Layers parallel to the first- and second-order hexagonal prism, in the seed zoning parallel to the basal faces	Layers parallel to prism and basal faces	Layers parallel to the first- and second-order hexagonal prism plus basal faces
Colour zoning		Strong zoning parallel to all crystal faces	Strong zoning parallel to all crystal faces	Strong zoning parallel to all crystal faces	Strong zoning parallel to all crystal faces
Inclusions	Growth tubes with nail-heads	Present (crystal)	None	None	None
	Isolated beryl crystals	Present	Present	Present	Frequently present
	Residual flux in various forms	Present	Present	Present	Always present
Element(s) related to flux		Mo	Mo	Mo ± Y	Mo
Cause of colour		Cr, minor V and Fe	Cr, Ni, minor Fe	Cr, Ni, minor Fe	Cr, Ni, minor Fe

Sources of samples:
[a] C. Weise, Munich
[b] German Gemmological Association, Idar-Oberstein
[c] Museum für Naturkunde, Berlin; Inv. Nos. 2011 04554 and 2015 00054
[d] Technische Universität Bergakademie Freiberg
[e] E. Gübelin, Lucerne (obtained by author KS in the late 1990s)
[f] S. Fordemann, Herford

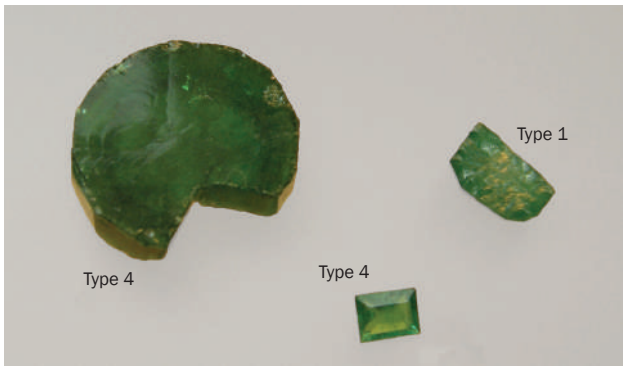

Figure 13: Shown here are rough synthetic emeralds of types 1 and 4 from the reference collection of the German Gemmological Association, as well as a type 4 faceted synthetic emerald from the collection of the late E. Gübelin. The crystal on the left measures 14.0 mm in diameter, with a thickness of 3.5 mm, and weighs 6.05 ct. Photo by K. Schmetzer.

Figure 14: This cluster of type 1 synthetic emerald crystals (20.4 × 17.3 × 13.6 mm) was produced by IG Farben without the addition of a Ni-bearing compound and is from the collection of C. Weise, Munich. Photo by K. Schmetzer.

In the present study, types 1 and 2 were represented by only a few samples. However, when considered together with the more abundant samples of types 3 and 4, a progression became evident that closely paralleled the developments indicated by Espig's descriptions and the IG Farben internal notes. Thus, while it remains highly probable that samples with properties intermediate between these four types were grown as the experiments proceeded, the classification into four types was used to facilitate general chronological understanding of the available samples. The intent was not to strictly circumscribe different categories or types of Igmeralds.

Type 1: Type 1 synthetic emeralds were grown from Mo-bearing fluxes. The two samples found to be of type 1 included a short prismatic crystal (Figure 13, upper right) and a cluster of 18 prismatic synthetic emeralds (Figure 14). With respect to the primary cause of the green colour, Cr-bearing compounds had been added to the nutrient, but Ni-bearing compounds were absent (i.e. not detected by EDXRF spectroscopy; Figure 15). Along with Cr, both samples also contained traces of V and Ga. It is unknown if the small amounts of V might have come from impurities present in chemicals used in the growth process or, alternatively, if V might have been intentionally added to the nutrient to induce colour. The traces

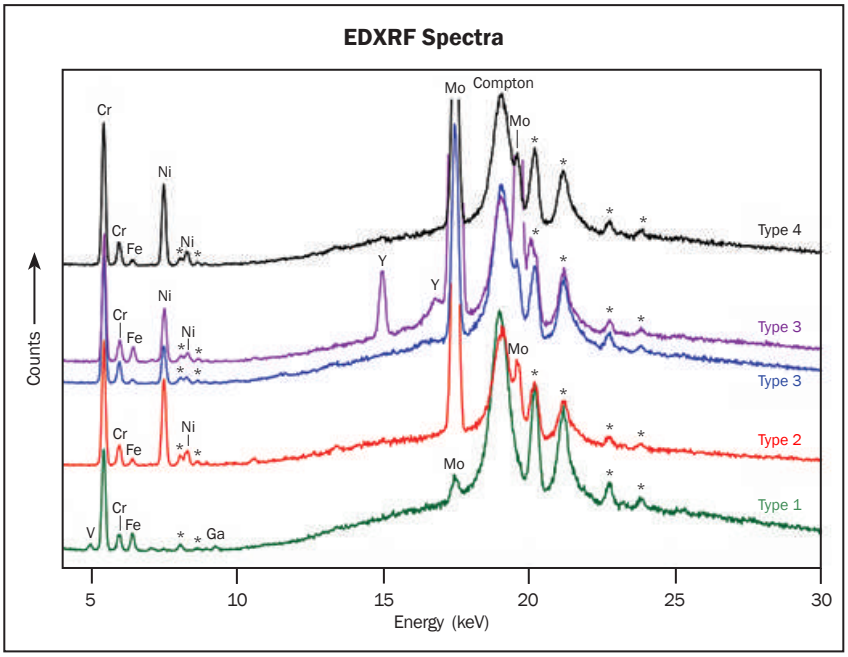

Figure 15: EDXRF spectra of type 1–4 synthetic emeralds produced in Bitterfeld show Cr and Ni as the main colour-causing trace elements and Mo as the main component of the flux. Small amounts of V (but no significant Ni) are present in the spectrum of the type 1 sample. A Y-bearing compound is also demonstrated as an ingredient of the flux used for crystal growth in one type 3 sample. The peaks labelled with an asterisk are related to the X-ray tube (Rh) or to interactions with the instrument (Pd, Cu, Zn); Compton refers to the inelastic scattering of the incident radiation.

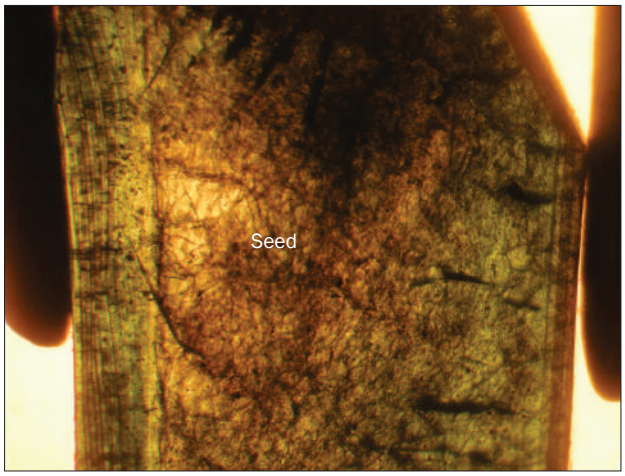

Figure 16: A crystal of type 1 synthetic emerald grown in Bitterfeld shows a natural colourless seed that is overgrown by synthetic emerald. Growth and colour zoning are seen parallel to the boundary between the seed and the synthetic emerald overgrowth. Immersion, field of view 4.6 × 3.5 mm; photomicrograph by K. Schmetzer.

of Ga most likely originated from somewhat impure chemicals (e.g. from traces of Ga in the aluminium oxide).

The individual crystal contained a colourless, somewhat irregularly shaped seed, and growth zoning was observed parallel to the boundary between the seed and the overgrowth (Figure 16). Amongst the inclusions seen, along with residual flux, were isolated synthetic beryl crystals, occasionally attached to growth tubes (i.e. 'nail-head spicules'; Figure 17).

Type 2: The one type 2 synthetic emerald studied for this report was produced with the addition of a Ni-bearing compound to the nutrient (see Figure 15). In the immersion microscope, a colourless core with a boundary parallel to various prism faces was observed (Figure 18). The overgrowth displayed intense growth and colour zoning, likewise generally parallel to prism faces. However, in some parts of the crystal, the boundaries between growth zones were inclined to the otherwise typical prism planes. This indicated that the sample had been cut and repolished for subsequent growth runs, most likely to remove impure portions. Besides various forms of residual flux, inclusions of synthetic beryl in an orientation different from that of the host synthetic emerald were seen (Figure 19). Those tiny included synthetic emerald crystals were generated by spontaneous nucleation and, in turn, contained numerous inclusions in their respective cores.

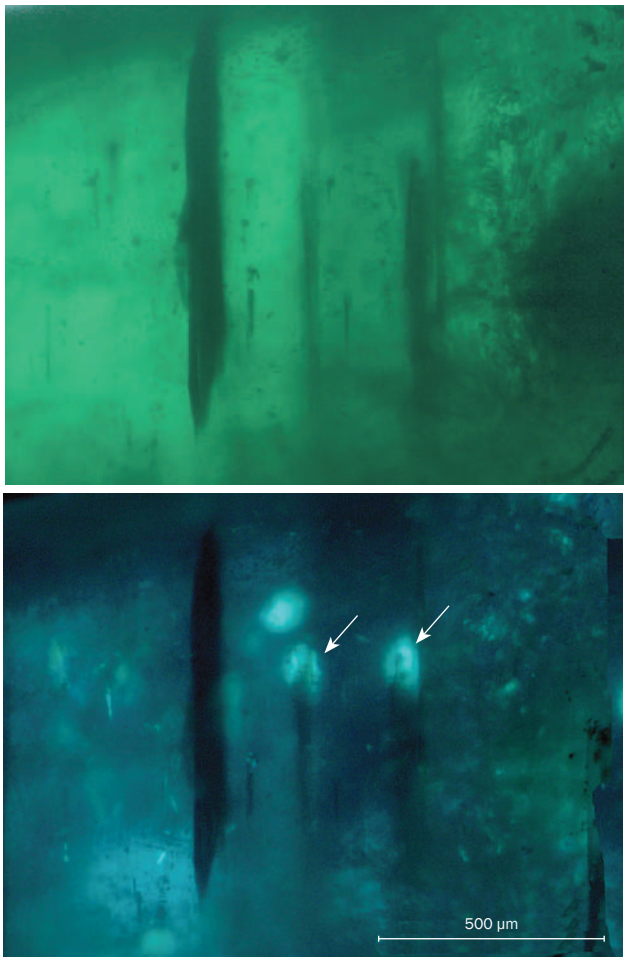

Figure 17: At higher magnification, the type 1 synthetic emerald depicted in Figure 16 shows growth tubes with small birefringent synthetic emerald crystals attached to the wider ends of the channels (see arrows). Top: transmitted light; bottom: transmitted light with crossed polarizers; photomicrographs by H. A. Gilg.

Type 3: The samples assigned to type 3 were grown with seeds having been placed below a platinum net in the crucible. As a consequence of such arrangement, the developing synthetic emerald crystals adhered to the net, even growing through the net (Figure 7). One cluster of five crystals (Figure 1) had been removed from the net and consequently exhibited a planar sawn surface. A single crystal of this type (Figure 20, left) contained residual platinum wires from the net. The prismatic morphology of the crystals (Figure 20, right) typically consisted of first- and second-order hexagonal prism faces **m** $(10\bar{1}0)$ and **a** $(11\bar{2}0)$, in combination with the basal pinacoid **c** (0001). The single crystal displayed a green seed in the centre, with growth planes parallel to the basal and prism faces (Figure 21). These

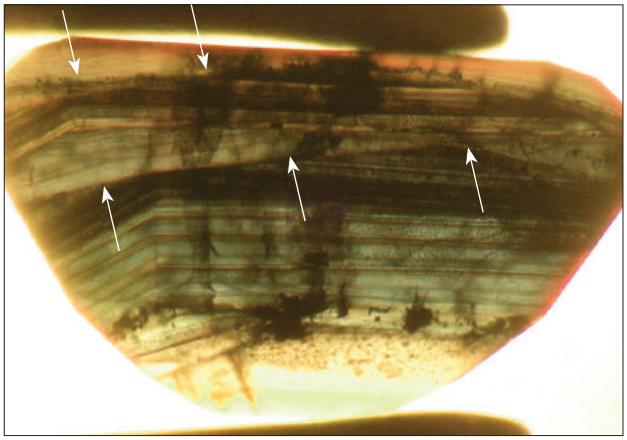

Figure 18: A faceted type 2 synthetic emerald grown in Bitterfeld shows a natural colourless seed (bottom) and multiple layers of synthetic emerald. Growth and colour zoning are seen parallel to prism faces. Between different growth cycles, impure material was removed and a new surface was prepared for subsequent crystal growth. Such surfaces, indicated by arrows, do not exactly follow the morphology of the synthetic emerald crystal. Immersion, field of view 4.2 × 3.1 mm; photomicrograph by K. Schmetzer.

results demonstrated that the crystal grew freely in different directions before becoming attached to the platinum net.

EDXRF chemical analyses performed in Berlin of samples still attached to the platinum net revealed the primary colour-causing elements, Cr and Ni, and the main component of the flux, Mo. The characteristic X-ray lines for Y also were evident in those samples. Analyses of the crystal cluster in Munich and Berlin gave identical results (Figure 15). Surprisingly, the single crystal showing identical habit and with wires of the platinum net still attached did not show any Y signal (again, see Figure 15).

Figure 19: At higher magnification, the type 2 synthetic emerald shown in Figure 18 displays inclusions of small birefringent synthetic emerald crystals. These inclusions were generated by spontaneous nucleation and are heavily included with various forms of residual flux. Top—transmitted light; bottom—transmitted light with crossed polarizers; photomicrographs by H. A. Gilg.

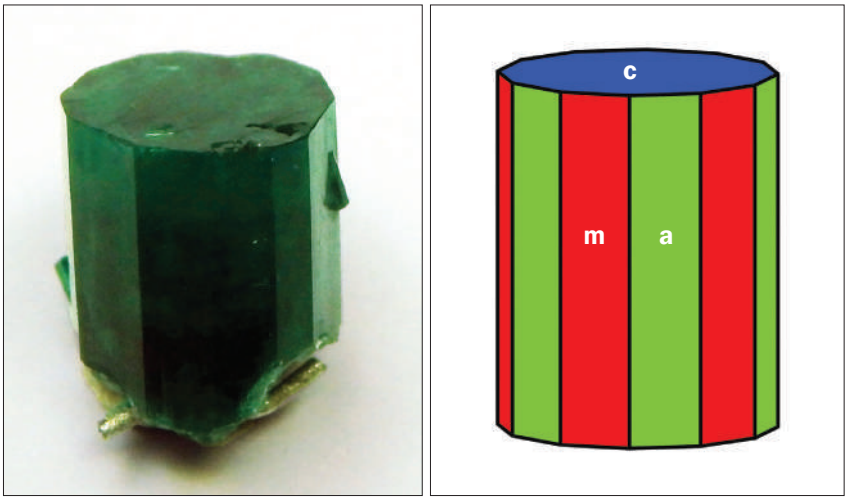

*Figure 20: On the left, this type 3 synthetic emerald crystal (8.4 × 7.2 × 6.8 mm; 3.68 ct) was produced by IG Farben at Bitterfeld and is from the collection of the Museum für Naturkunde, Berlin. At the lower end, two included residual wires from a platinum net are seen. Photo courtesy of R.-T. Schmitt. On the right, a clinographic projection shows the typical crystal habit of the synthetic emeralds grown from Mo-bearing fluxes by IG Farben in Bitterfeld. The idealized drawing shows two hexagonal prism faces, **m** and **a**, as well as the basal pinacoid **c**. Drawing by K. Schmetzer.*

Type 4: Refractive indices of the faceted samples were n_o = 1.562–1.566 and n_e = 1.558–1.561, yielding a birefringence of 0.004–0.005. Specific gravity was 2.64–2.66. These data are consistent with values given by Schmetzer and Kiefert (1998) for Igmerald, as well as with information generally reported for flux-grown synthetic emerald from various producers (see, e.g., Flanigen et al., 1967; Sinkankas, 1981; Henn, 1995).

Type 4 samples proved to be most prevalent amongst the research material. The 10 crystals from the Technische Universität Bergakademie Freiberg consisted of thick tabular plates or short hexagonal columns formed by a 12-sided prism and the basal faces (Figure 22). The one tabular crystal from the reference collection of the German Gemmological Association had a similar appearance (Figure 13, left). The basal faces were either rough (i.e. having remained unpolished after the last growth cycle) or polished. The polishing was likely undertaken to select samples either for further growth runs or for cutting. The faceted samples from the Technische Universität Bergakademie Freiberg, the Gübelin collection and the Berthold jewellery had all been cut with the c-axis perpendicular to the table facet and showed, in that direction of view, homogeneous colour with only small variations (Figure 22).

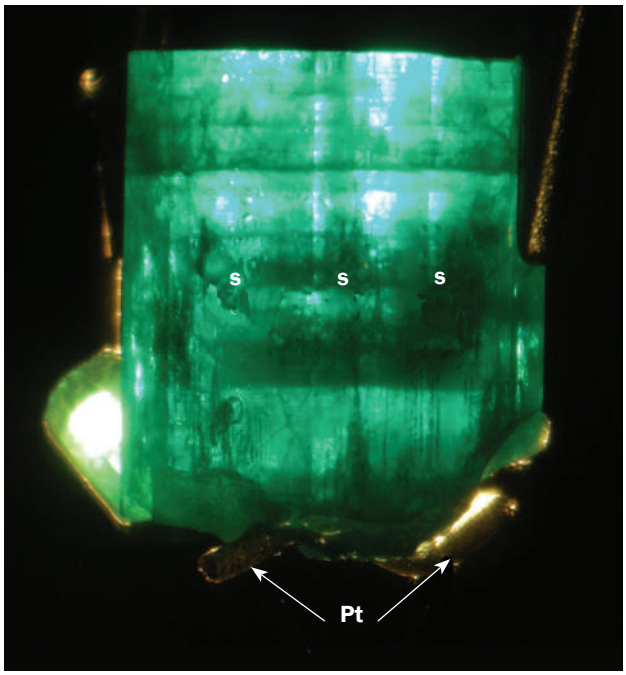

Figure 21: The type 3 synthetic emerald crystal depicted in Figure 20 (left) shows growth zoning parallel to the basal pinacoid and parallel to prism faces. In the centre of the crystal, a seed (s) of synthetic emerald is visible. The crystal was removed from the platinum net on which it grew, and residual wires (Pt) can be seen at the base of the sample. View perpendicular to the c-axis in transmitted fibre-optic light; photomicrograph by K. Schmetzer.

Figure 22: These photos show some of the samples of type 4 Cr- and Ni-bearing synthetic emerald studied from the collection of the Technische Universität Bergakademie Freiberg. Top: Tabular plates or short prismatic crystals—the crystal in the upper row, centre, measures 8.6 × 5.7 × 3.8 mm and weighs 1.62 ct. Bottom: Faceted samples; the largest at the upper left measures 13.5 × 7.6 mm and weighs 4.04 ct; shown for comparison is a Cr-bearing synthetic emerald crystal at the lower left from the early Chatham production measuring 5.2 × 3.6 mm and weighing 0.40 ct. The use of Ni in addition to Cr caused a somewhat more yellowish green coloration for the synthetic emeralds produced by IG Farben. Photos by K. Schmetzer.

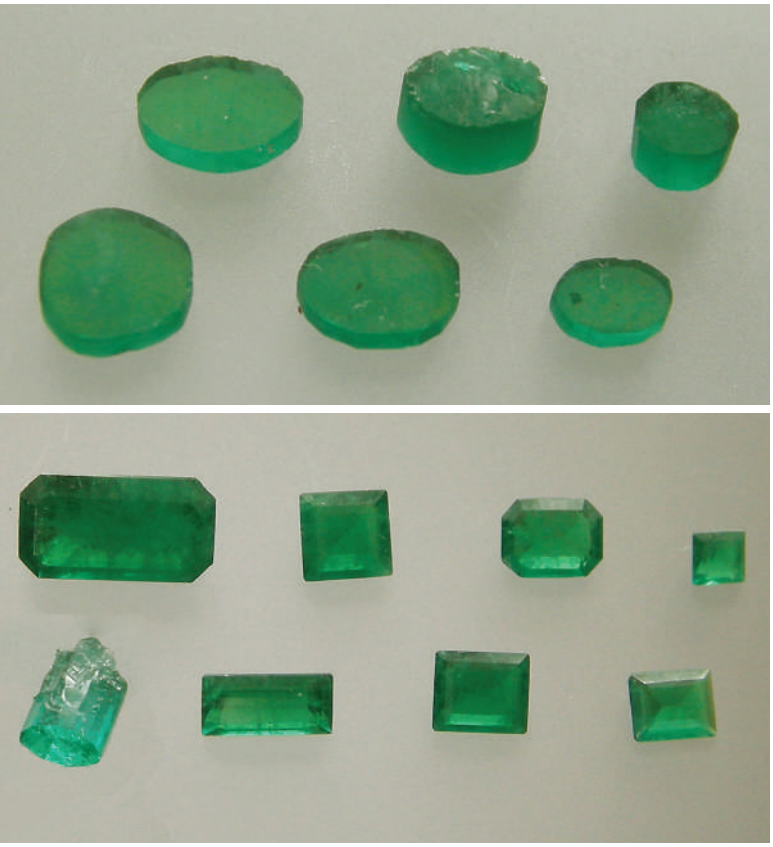

EDXRF chemical analyses obtained in Munich showed almost identical spectra in 18 of the 20 samples obtained from the Freiberg collection (Figure 15). One piece with a somewhat more intense green coloration gave a slightly higher Cr concentration, while one sample with a more yellowish green colour showed an increased Ni signal. Such consistency indicated that these Igmeralds were produced by means of a well-established growth process using a standard recipe for the composition of the flux and the ingredients of the nutrient. Compared to other synthetic emeralds without Ni, these faceted

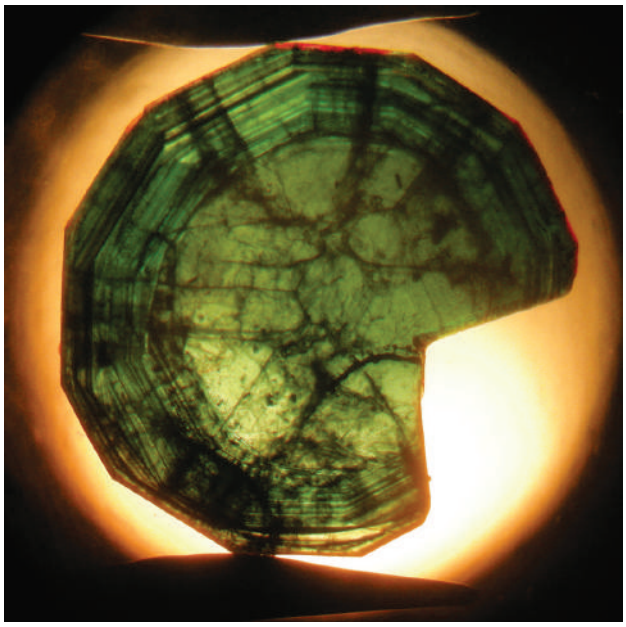

Figure 23: Growth zoning combined with colour zoning in a type 4 synthetic emerald crystal produced in Bitterfeld is seen parallel to first- and second-order prism faces. The diameter of the sample is approximately 14 mm. Immersion, view parallel to the c-axis in transmitted light; photomicrograph by K. Schmetzer.

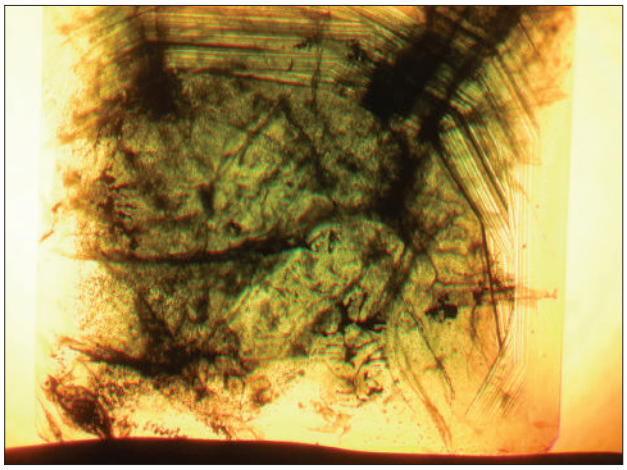

Figure 24: Growth zoning combined with colour zoning in a faceted type 4 synthetic emerald produced in Bitterfeld is seen parallel to first- and second-order prism faces. The sample was cut and polished between different growth cycles to remove impure areas. Immersion, view parallel to the c-axis in transmitted light, field of view 7.6 × 5.7 mm; photomicrograph by K. Schmetzer.

Igmeralds were slightly more yellowish green and less bluish (Figure 22).

When viewed parallel to the c-axis, most rough and faceted type 4 samples showed primarily residual flux (see below), and only a few samples had growth structures parallel to the prism faces (Figure 23). The prismatic growth pattern clearly reflected the morphology of the rough samples, comprised of first- and second-order hexagonal prism faces (see Figure 20, right), but such prismatic growth zoning was seen only in one faceted sample (Figure 24). The results thereby demonstrated that growth zones related to prism faces were mostly removed between the different growth cycles.

Viewed perpendicular to the c-axis, growth sectors parallel to the basal faces showed very intense growth and colour zoning with numerous layers. This was best seen in faceted samples in a view perpendicular to the table facet, since the preferred cutting style oriented the table at a right angle to the c-axis. The perpendicular view also revealed the distinct pleochroism of the samples, which was bluish green parallel to the c-axis and yellowish green perpendicular to the c-axis (Figure 25).

Most type 4 samples contained a few included synthetic emerald crystals that were oriented

Figure 25: Growth zoning combined with colour zoning in a type 4 synthetic emerald produced in Bitterfeld is seen parallel to the basal pinacoid. Pleochroism is observed in plane-polarized light parallel (left) and perpendicular (right) to the c-axis. The sample was cut and polished between different growth cycles to remove impure areas. Immersion, view perpendicular to the c-axis, field of view 3.6 × 2.7 mm; photomicrographs by K. Schmetzer.

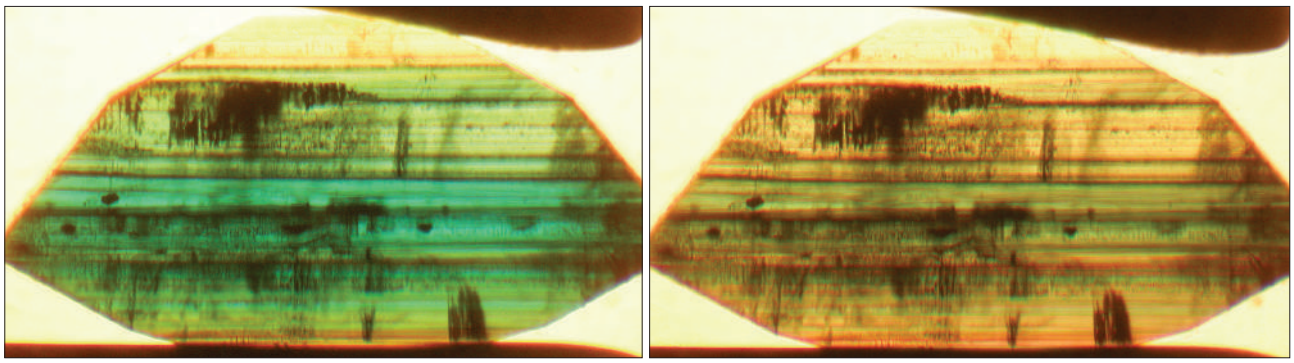

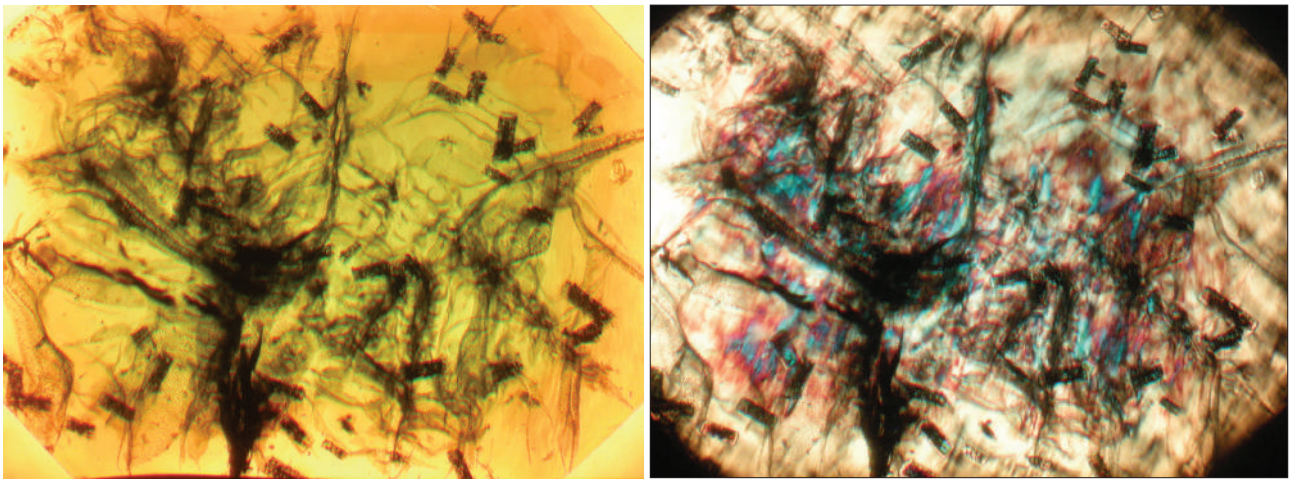

Figure 26: Numerous inclusions of tiny synthetic emerald crystals, grown by spontaneous nucleation, are present in this type 4 synthetic emerald grown in Bitterfeld (left); they are particularly evident under crossed polarizers (right). Immersion, view parallel to the c-axis, field of view 6.7 × 5.0 mm; photomicrographs by K. Schmetzer.

differently from the host. As noted above, such small prismatic crystals were formed by spontaneous nucleation. One sample in particular showed many of these tiny inclusions, which were best seen between crossed polarizers (Figure 26).

Small inclusions of birefringent phenakite crystals were occasionally seen. Such inclusions were identified by micro-Raman spectroscopy in a previous study (Schmetzer and Kiefert, 1998).

Residual flux was always present, mostly in the form of wispy veils, but occasionally as straight lines made up of numerous tiny particles (Figure 27). There were also instances where a cellular pattern of almost hexagonal structures could be seen (Figure 23). The different forms of residual flux showed net-like, interconnected structures or isolated particles of various shapes. Likewise frequent were phase boundaries between different components of the flux, as well as contraction bubbles (Figure 28). At higher magnification, the multiphase nature of the residual flux inclusions was clearly visible (Figure 29).

Discussion and Conclusions

The IG Farben internal documents, archived primarily in the Landesarchiv Sachsen-Anhalt, Abteilung Merseburg and at Kreismuseum Bitterfeld, disclosed various steps undertaken to develop emerald synthesis at the Bitterfeld facility. They also reflected the discrepancy between the intentions of IG Farben management, who hoped to create a process for cheap mass production, and the limitations of the synthesis technology ultimately realized.

Equally apparent was the divergence of opinion between factions within IG Farben. Among managers and scientists were many who wanted to commercialize production with a process protected by patent applications, while on the IG Farben board were a number of directors who decided that the synthetic emeralds should be used only for public relations activities. These various opinions arose because the process for synthesizing emerald by the flux technique applied at Bitterfeld was extremely

Figure 27: Various forms of residual flux are commonly seen in type 4 synthetic emeralds from Bitterfeld. Occasionally flux particles are concentrated along straight lines, forming a three-dimensional net-like or cellular pattern. Immersion, transmitted light, field of view 6.0 × 4.5 mm (left and centre) and 4.1 × 3.1 mm (right); photomicrographs by K. Schmetzer.

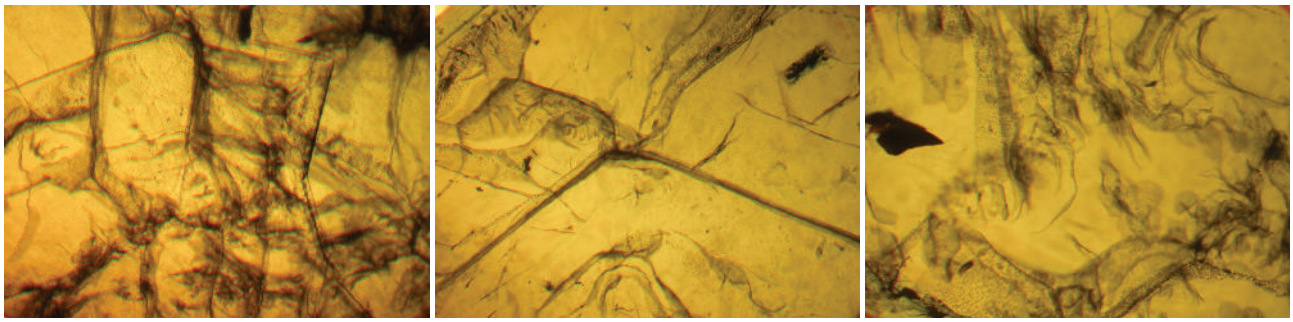

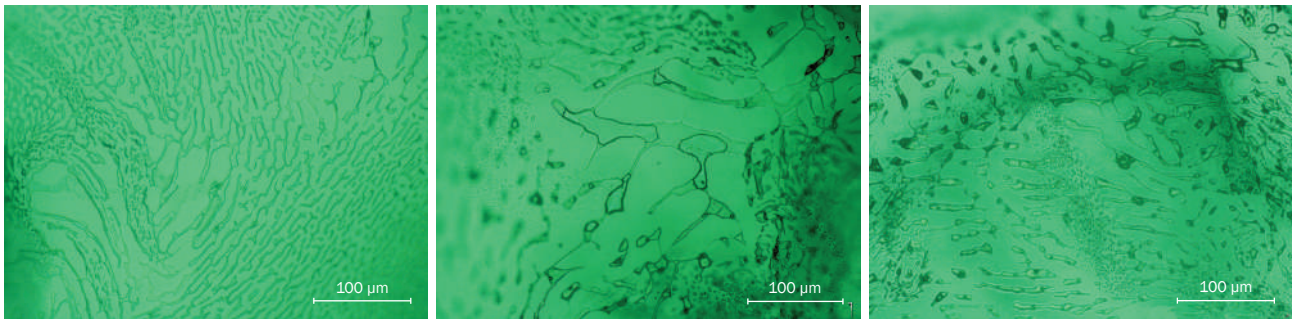

Figure 28: Residual flux in type 4 synthetic emeralds grown in Bitterfeld forms net-like patterns or isolated single dots. Transmitted light; photomicrographs by H. A. Gilg.

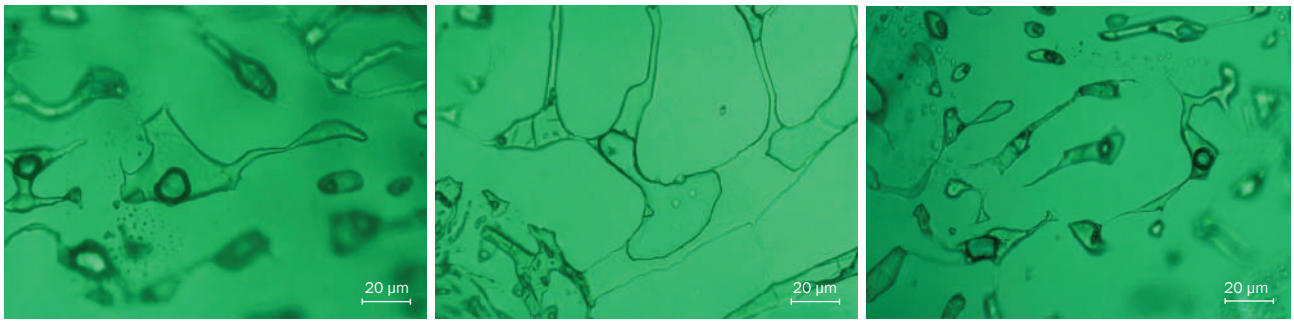

Figure 29: At higher magnification, residual flux inclusions in type 4 synthetic emeralds grown in Bitterfeld are seen as mostly multiphase inclusions consisting of different components of the flux and contraction bubbles. Transmitted light; photomicrographs by H. A. Gilg.

expensive, with lengthy production times (in the range of at least one year) required to grow crystals of facetable size. The resultant relatively high production cost and low monthly yield (~20 carats of faceted material) meant that the wholesale price to the trade would be substantial, yet the retail price for a synthetic material would need to be comparatively low. Traders had little incentive to place a product on the market with such minimal profitability.

Chemical analyses of samples grown by Wild around 1912 established that the crystals were produced in a Mo-bearing flux. That, in turn, indicated a growth method identical or similar to the technique applied by French scientists in the late 19th century. The synthetic emeralds grown by Hofmann in Berlin in the 1920s also were produced from a molybdate melt, and they bore many similarities with the small crystals obtained in Bitterfeld in the 1920s (see Figure 6).

The different types of synthetic emeralds (Table II) grown in Bitterfeld after the technological breakthrough in 1929 demonstrated the progressive development and improvement of seeding and production techniques. Colourless natural seeds used in early years were later replaced by tabular plates of synthetic emerald. Separation between the seeds and the silica plates floating on top of the molybdate melt was first accomplished with a platinum net and then by a platinum baffle (see again Figure 8). With these changes in synthesis technology, the long prismatic habit of the synthetic emerald crystals (Figures 1, 7 and 20) changed to short prismatic or thick tabular (Figure 22). At the culmination, only single crystals were grown, eliminating both clusters of synthetic emeralds and attachment of the crystals to the platinum net.

Only the initial samples were grown with Cr as the sole colour-causing trace element; later samples always contained two transition metals, Cr and Ni. The chemistry of the latter thus parallels the data presented by Schmetzer and Kiefert (1998). However, it is worth mentioning that Espig added hexavalent chromium in the form of lithium chromate to the flux, and Cr needs to be trivalent to be incorporated into the beryl lattice and cause the desired green coloration of emerald. Thus, a change of the valence state of Cr in the complex flux system was necessary.

Chemical analysis also demonstrated use of yttrium oxide as a component of the nutrient in several synthetic emeralds (i.e. some from the collection of the Museum für Naturkunde in Berlin and one from the group examined by author KS

in the 1990s[14]). This addition of yttrium oxide finds historical corroboration both in Espig's 1946 list of ingredients and in his 1950s list of chemicals that would have to be purchased to re-start synthetic emerald production after World War II (see footnote 11).

Furthermore, the advantage to be gained by employing this additional ingredient as a colour-causing trace element was mentioned by Espig (1945). Nevertheless, a comparison of the samples obtained for this study that contained Y with those in which Y was not detected by EDXRF spectroscopy showed no colour difference. Therefore, the direct effect (if any) of Y on the colour of these synthetic emeralds is not clear.

Internal growth structures observed in the synthetic emeralds from different eras reflected the seeding technique applied and also showed—for faceted samples—the part of the crystal from which the synthetic gemstone was cut. In most faceted samples produced after the growth process was standardized in 1935, distinct growth and colour zoning was seen only parallel to the basal plane. Further growth planes parallel to the first- and second-order prism faces were present in just a small fraction of the samples examined.

Small prismatic synthetic emeralds were the most typical crystalline inclusion, consistent with previous descriptions (see, e.g., Eppler 1958a,b; Schmetzer and Kiefert, 1998). These inclusions were best seen between crossed polarizers. Birefringent phenakite crystals were another solid phase seen both in the present samples and in prior works.

In the current study, growth tubes—some with tiny birefringent crystals attached to their wider ends, so-called nail-head spicules—were found in only one sample with an irregularly shaped colourless seed.

Various forms of flux were present in all samples, frequently as multiphase inclusions containing contraction bubbles. Raman spectroscopy was used previously to identify these inclusions as components of the flux (e.g. polymolybdate and molybdenum trioxide; Schmetzer and Kiefert, 1998). Due to multiple devitrification processes and chemical variability, residual flux in synthetic emerald can be complex and show numerous vitreous and crystalline constituents (Schmetzer et al., 1999).

IG Farben synthetic emeralds (Igmeralds) were the first synthetic emeralds to be produced in facetable sizes and released to the public. They became publicly known in 1935, and the history of their development, which spanned five decades of the 20th century during various political and economic conditions, is fascinating. At present, such synthetics are found as extreme rarities in a few private, public and university collections, as well as in reference and teaching collections of gemmological laboratories and associations. So, the possibility of encountering an Igmerald as an unknown sample for testing will be limited, but the description provided by this article—especially of the inclusions and chemical features—will help identify such samples.

[14] A re-examination of the X-ray fluorescence diagrams for Igmerald recorded in the late 1990s by Schmetzer and Kiefert (1998) showed that one of the faceted synthetic emeralds (0.48 ct) from the collection of the late E. Gübelin displayed the characteristic Y line in the 15 keV range (see Figure 15).

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A Diamond with a Transient 2804 cm^{-1} Absorption Peak

Jianjun Li, Chengxing Fan, Shuxiang Chen and Guihua Li

The National Gold & Diamond Testing Center (NGDTC) in Shandong, China, recently encountered a colourless 0.08 ct diamond with strong greenish blue phosphorescence in the DiamondView. Such phosphorescence is often found in HPHT-grown synthetic diamonds from Russia and China. However, the sample proved to be a near-type-IIa natural diamond with weak A and B centres and a subtle type IIb component detectable in the infrared spectrum. The DiamondPLus indicated 'Pass', confirming it was an untreated natural diamond. Notably, while the diamond phosphoresced, the infrared spectrum displayed a transient ~2804 cm^{-1} absorption peak associated with boron. This is the first evidence of charge transfer at boron acceptors being directly linked to phosphorescence in diamond.

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Introduction

In recent years, synthetic diamonds grown by chemical vapour deposition (CVD) and high-pressure, high-temperature (HPHT) techniques have been more commonly encountered in gem testing laboratories. Especially in the last two years, a considerable number of melee-size (less than 0.20 ct) synthetic diamonds have entered the Chinese market, and most are HPHT synthetics from China and Russia. Nearly all show greenish blue phosphorescence that is similar in colour to Sleeping Beauty turquoise. Therefore, when a parcel of melee diamonds undergoes screening at NGDTC, the first step is to separate for further testing those specimens showing this phosphorescence.

Phosphorescence is rare in most natural diamonds, although it is frequently observed in type IIb stones, as well as in some that do not show the type IIb-related absorption at ~2800 cm^{-1} in their infrared spectra. For the latter diamonds, the boron concentration is below the level of detection, so they are nominally type IIa diamonds (see, e.g., Eaton-Magaña and Lu, 2011).

Recently during routine testing, the NGDTC laboratory encountered a natural diamond with strong greenish blue phosphorescence. Further analysis demonstrated that this unique diamond showed different infrared spectral features before and after the disappearance of its phosphorescence.

Methods

The 0.08 ct round brilliant diamond was tested and graded by standard gemmological methods. Testing also was performed on the DiamondSure, DiamondView and DiamondPLus verification

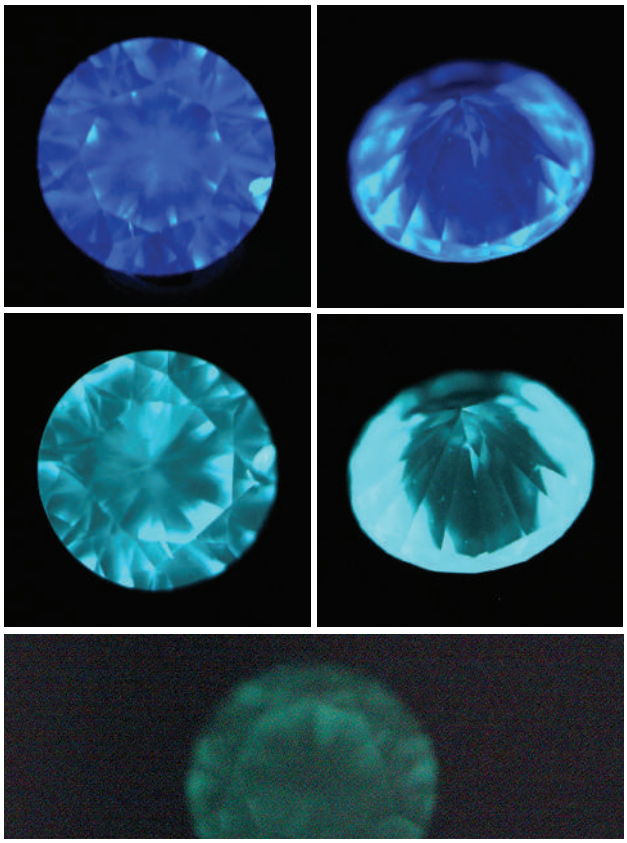

Figure 1: In the DiamondView, the 0.08 ct diamond displays vivid blue fluorescence (top) and strong slightly greenish blue phosphorescence (centre, as captured with the DiamondView's imaging system). When the hatch of the DiamondView was opened, greenish phosphorescence was visible to the naked eye (bottom). Images by Li Jianjun.

instruments manufactured by the International Institute of Diamond Grading & Research (IIDGR; De Beers Group of Companies). Ultra-violet-visible-near infrared (UV-Vis-NIR) spectroscopy was performed using a GEM-3000 instrument made by Biaoqi Scientific (China) Corp., and an integrating sphere was used to collect the internal reflectance spectra. (The incident light on the crown of a round brilliant diamond is internally reflected back through the crown by the pavilion facets, so the internal reflectance spectrum is a combination of reflection and transmission signals.) Fourier-transform infrared (FTIR) transmission spectra were collected using a Nicolet iS5 spectrometer with a Pike Technologies UpIR diffuse reflectance accessory, both during phosphorescence and after it disappeared. The spectra were scanned cumulatively four times while the diamond displayed phosphorescence and 32 times after the phosphorescence disappeared, and the resolution was set to 8 cm^{-1}.

Results

Standard Testing

The 0.08 ct diamond had a colour grade of F and clarity grade of SI_1 (due to a small brown feather). In addition, a small colourless transparent inclusion was visible at about 30×–40× magnification. The sample was inert to both long- and short-wave UV radiation.

Reactions to Verification Instruments

The DiamondSure indicated the sample was a type II diamond and referred it for further testing. The DiamondPLus showed 'Pass' when the sample was tested in liquid nitrogen.

In the DiamondView, the sample showed vivid blue fluorescence and strong phosphorescence in slightly greenish blue, but no strain pattern was visible (Figure 1). The phosphorescence lasted for a few seconds after the radiation source was turned off. Slightly greenish blue phosphorescence is often observed in synthetic diamonds in the DiamondView (D'Haenens-Johansson et al., 2015), so the sample was tested further to rule out a lab-grown origin.

UV-Vis-NIR Spectroscopy

The UV-Vis-NIR spectrum (Figure 2) displayed no significant absorption from 250 to 1000 nm, but it did show the strong 225 nm feature caused by the diamond energy bandgap at 5.47

Figure 2: The UV-Vis-NIR spectrum of the diamond shows strong absorption at 225 nm initiated by the diamond energy bandgap at 5.47 eV. The weak, broad absorption at 350 nm is likely an instrumental artefact.

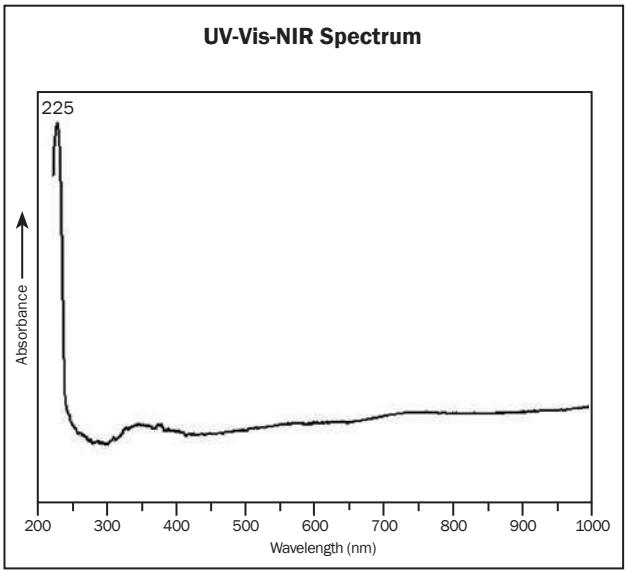

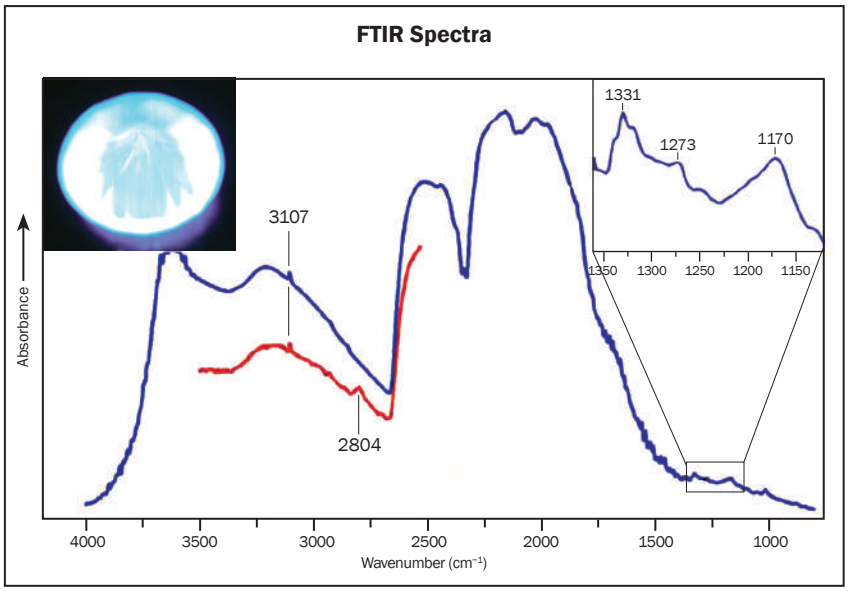

Figure 3: FTIR spectroscopy shows that the diamond is near type IIa with a 3107 cm^{-1} feature due to hydrogen; the weak bands at 1331, 1273 and 1170 cm^{-1} (see inset) indicate the diamond also contains A and B centres and possibly N_s^+ (blue line). After the sample was excited using the DiamondView, it displayed strong greenish blue phosphorescence, and the resulting spectrum (red trace) shows an absorption peak at ~2804 cm^{-1} related to neutral substitutional boron.

eV. A broad, weak absorption band centred at 350 nm may have been an instrumental artefact. There was no 270 nm absorption related to single nitrogen (Zaitsev, 2001). The absence of significant extrinsic absorption in the visible and ultraviolet regions suggested that the diamond is type IIa.

FTIR Spectroscopy

FTIR spectroscopy (Figure 3) confirmed that the sample was a near-type-IIa diamond. The spectra showed a sharp, weak band at 3107 cm^{-1} related to hydrogen (Woods and Collins, 1983; Field, 1992; Kiflawi et al., 1996; Goss et al., 2014). In the 1400–1100 cm^{-1} range (see Figure 3, inset), absorption bands were recorded at 1330/1331, 1273 and 1170 cm^{-1}. These bands (and the 2804 cm^{-1} feature mentioned below) are usually reported as occurring at 1332, 1282, 1175 and 2803 cm^{-1}, respectively. As all these bands are very weak in this sample, the presence of noise might explain the apparent shift in the peak positions.

The absorption feature at 1273 cm^{-1} correlates to nearest-neighbour substitutional pairs of nitrogen (A centres), and the 1170 cm^{-1} band is attributed to nitrogen aggregates (B centres), that is, four nitrogen atoms symmetrically surrounding a vacancy. These spectral characteristics show that the diamond is natural in origin. The 1331 cm^{-1} peak is mostly related to B-centres (see, e.g., Breeding and Shigley, 2009) and/or might also indicate the diamond contains the positively charged state of the single substitutional nitrogen centre (N_S^+). Therefore, the sample may be classified as near type IIa with a low IaAB component. Combined with the results of the DiamondPLus and the UV-Vis-NIR spectrum, the sample was confirmed as untreated natural diamond.

It is notable that while the diamond displayed phosphorescence, it showed a ~2804 cm^{-1} absorption feature related to neutral substitutional boron (i.e. uncompensated boron: Collins and Williams, 1971; Fisher et al., 2009; Gaillou et al., 2012; D'Haenens-Johansson et al., 2014). To verify this phenomenon, we scanned the sample in the region 3500–2500 cm^{-1} after exciting it in the DiamondView until it displayed strong greenish blue phosphorescence. After the sample was removed from the DiamondView, the absorption spectrum was quickly measured using the diffuse reflectance accessory (Figure 3, red trace) while we could still see significant phosphorescence. According to the Omnic software, the scanning time was 3.95 seconds.

To obtain a higher signal-to-noise ratio, we attempted to accumulate eight scans of the phosphorescing diamond (Omnic software recorded a scanning time of 7.90 seconds), but we found that the ~2804 cm^{-1} absorption feature had disappeared after about six or seven scans.

Repeated testing as described above (i.e. exciting the sample in the DiamondView and then collecting the FTIR spectrum by accumulating four to eight scans) confirmed that the ~2804 cm^{-1} feature only lasted for a few seconds; as the phosphorescence disappeared, the absorption

band became extinct. Thus, the ~2804 cm^{-1} feature was only recorded while the diamond phosphoresced (i.e. for about 4–8 seconds).

The current understanding of the phosphorescence process in diamond is in terms of a charge transfer between the boron acceptor and a deep donor (Watanabe et al., 1997), changing the charge state of boron from compensated to uncompensated and back again. There are other instances in which a short-lived charge-transfer effect has been observed in diamond, such as $SiV^{-/0}$ in highly silicon-doped CVD synthetic diamond (D'Haenens-Johansson et al., 2011). To our knowledge, however, this is the first record of a transient ~2804 cm^{-1} absorption peak observable only during the process of phosphorescence. Compared with the 2803 cm^{-1} peak in the spectra of diamonds containing more boron, this is the most direct evidence of charge transfer at boron acceptors being immediately linked to phosphorescence in diamond.

Conclusions

A 0.08 ct round brilliant displaying greenish blue phosphorescence in the DiamondView was verified as a near-type-IIa natural untreated diamond of a mixed type that contained a low IaAB component and a IIb boron content near the detection limit of infrared spectroscopy. Infrared spectra recorded while the diamond phosphoresced displayed an absorption feature at ~2804 cm^{-1} related to boron. This is the first instance of UV radiation inducing a characteristic IR absorption feature during phosphorescence in diamond. The specimen provides evidence that charge transfer (from negative to neutral) at boron acceptors is directly linked to phosphorescence in diamond.

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Conferences

Arizona Geological Society Presentations

On 3 May 2016, the Arizona Geological Society hosted two presentations in Tucson, Arizona, USA, that were of interest to gemmologists. **Dr Pete Modreski** of the U.S. Geological Survey in Denver, Colorado, USA, spoke on Colorado diamonds and gem-bearing pegmatites.

Colorado kimberlites are numerous, but only two have been commercially viable for diamond. First noted in the early 1900s as 'serpentine-olivine' intrusions, they were identified as diamond-bearing kimberlites in the 1960s by geologist Malcolm McCallum. While preparing thin sections of the rock, he noticed that the polishing wheel became gouged. Kelsey Lake became the best-known mine, operating between 1994 and 1997 as an open pit. Of particular note was a 28.3 ct rough diamond yielding a 5.39 ct yellow pear shape that reportedly sold for US$100,000 in December 1996. The Sloan I and II kimberlites also were a source of gem-quality diamonds. Sloan I was mined as an open pit where the kimberlite broke the earth's surface, and Sloan II explored the pipe underground. A processing mill was built on site utilizing heavy mineral separation, X-ray luminescence and a grease table to collect the diamonds. Diamond yield was 1/100 to 1/10 ct per tonne of ore.

Gem-bearing pegmatites are known for their large, well-formed crystals. In Modreski's home state of Colorado, the pegmatites of the Pikes Peak area commonly host amazonite, and this bluish green feldspar is sought primarily for mineral specimens. From adjacent areas in Colorado, aquamarine and topaz are mined for specimens and gem rough (e.g. Figure 1). Gem-quality tourmaline is rare in the state due to a lack of boron in the pegmatites. In general, from an economic standpoint, pegmatites rich in Li are important for commercial mining. Traditional scientific thought was that the large crystals in pegmatite dykes formed over many years or centuries. It is now believed that gem-bearing 'pockets' or cavities crystallize in a matter of days or weeks.

Eric W. Fritz (EricFritz@gem-a.com)
Gem-A, Tucson, Arizona, USA

Figure 1: Fine aquamarine and topaz crystals have been mined from pegmatites in Colorado, USA. The aquamarine cluster on the left is part of a larger matrix specimen with feldspar and smoky quartz from 'Diane's Pocket' at Mt Antero. The largest crystal is approximately 4 cm long, and the specimen (94 × 64 cm) is on display at the Denver Museum of Nature and Science. The topaz crystal on the right (approximately 6 cm wide) is from the 'Tribute Pocket' in the Pikes Peak area, and was collected by Rich Freterd and Jean Cowman. Photos by Pete Modreski.

35th International Geological Congress

This large quadrennial conference took place in Cape Town, South Africa, from 27 August to 4 September 2016, and attracted over 4,200 delegates from 115 countries. The programme included a session titled 'Gems: Bringing the World Together', and some additional gem-related presentations took place in other sessions. Gemmologically relevant talks and posters that were seen by the author are summarized below. Several field excursions took place before and after the Congress, including one trip to various alluvial diamond deposits in South Africa (to be covered in a future issue of *The Journal).*

Considering the conference's location in South Africa, it is not surprising that diamonds were well re-

Figure 2: This thin slice of a Marange diamond (5.8 mm across) cut parallel to a cubic direction shows curved growth zones revealed by abundant graphite micro-inclusions in the cuboid sectors. Photo by Joshua Balduf/GIA.

presented in the programme. **Prof. Paolo Nimis** (University of Padova, Italy) described the pitfalls of using conventional two-phase thermobarometry of mineral inclusions to elucidate the pressure and temperature conditions of diamond formation, since the inclusions might not be in equilibrium with one another. He indicated that future developments in thermobarometric methods will allow scientists to refine their models of the vertical distribution of diamond formation in the sub-cratonic lithosphere. In another presentation, Nimis and co-authors documented for the first time hydrous silicic fluid films at the interface between solid inclusions and their gem-quality diamond hosts. These thin films were found around all types of mineral inclusions in both peridotitic and eclogitic diamonds, and suggest that they commonly form in the presence of H_2O-rich fluids. **Dr Alexander Proyer** (University of Botswana, Gaborone) proposed a mechanism for diamond formation in deep and relatively cool cratonic roots in which exsolution of Ti minerals (rutile or ilmenite) might create a localized reducing environment where oxidized carbon could undergo reduction and crystallize into diamond. **Dr Herwart Helmstaedt** (Queen's University, Kingston, Ontario, Canada) examined the interaction of diamond tectonic history and geotectonics during the formation of the earth's oldest diamonds in the Archean Eon. Peridotitic diamonds formed first (3.5–3.2 billion years ago) with the establishment of continental lithospheric roots, and subsequently eclogitic diamonds initially formed during the amalgamation and breakup of early continental nuclei (3.0–2.5 billion years ago). **Dr Katie Smart** (University of the Witwatersrand, Wits, South Africa) and co-authors proposed that the oldest known diamonds—controversially inferred to have formed as early as 3.5 billion years ago, and recovered as a by-product of gold mining in the Witwatersrand Supergroup of South Africa—record an early Archean onset of plate tectonics.

Alluvial diamond deposits were the focus of various presentations. **Lyndon De Meillon** (Paleostone Mineral Consultants, Kimberley, South Africa) and his co-author described those along the Orange and Riet Rivers in the vicinity of Douglas, Northern Cape Province, South Africa. These areas are known for producing large high-value gem diamonds (generally US$1,200–$7,000 per carat) but have ultra-low grades. Strategies for the successful exploration of such deposits include detailed geological modelling and selective mining based on the geological controls of each specific occurrence. **Dr Mike C. J. de Wit** (University of Pretoria, South Africa, and Tsodilo Resources Ltd., Toronto, Ontario, Canada) reported recent research on alluvial diamond 'runs' in the Lichtenburg-Ventersdorp area of North West Province, South Africa. It is inferred that the diamonds originated from local sources and were redeposited in the alluvial runs by proximal eskers (glacial tunnels) that were active during the final stages of the Carboniferous-age Dwyka glaciation. The same deposits also were described by **Pieter Bosch** (Council for Geoscience, Pretoria, South Africa), who noted that the gravel runs are associated with karstic features in the dolomite basement rock, and that Dwyka glacial tillite sediments are closely associated with the diamondiferous gravels. **Dr Gabriele Schneider** (Namibian Uranium Institute, Swakopmund) chronicled the history of diamond mining in Namibia, from the April 1908 discovery of a diamond near Kolmanskop in the Namib Desert to modern marine operations exploiting offshore deposits using large and sophisticated mining vessels.

Other presentations focused on the properties and characteristics of diamonds. **Dr Karen Smit** (Gemological Institute of America, New York, New York, USA) and co-authors examined the preservation of unaggregated nitrogen (C centres) in yellow type Ib diamonds from the Zimmi alluvial deposit in Sierra Leone. Multiple lines of evidence suggest that after their formation in the root of the West African craton, the diamonds were rapidly exhumed to shallower depths by tectonic uplift following continental collision associated with the assembly of Gondwana. In another talk, Smit and co-authors described mixed-habit (octahedral and cuboid) diamonds from Marange in eastern Zimbabwe. The crystals contain abundant micro-inclusions of methane within the cuboid sectors, along with graphite micro-inclusions that reveal the curved growth zones in

transmitted light (e.g. Figure 2). Isotopic analyses suggest that diamond growth occurred under non-redox (reduction–oxidation reaction) conditions from cooling CH_4-CO_2 hydrous fluids. **Susan Foulkes** (Mintek, Randburg, South Africa) and her co-author studied nine diamond parcels from two different alluvial mining areas in the Central African Republic. LA-ICP-MS trace-element analysis and Fourier-transform infrared spectroscopy enabled them to tentatively separate the diamonds from the two localities, although more samples need to be analysed to make the database more robust. **Aparajita Bhattacharya** (Geological Survey of India, Kolkata) and co-authors examined diamonds from Panna belt in Madhya Pradesh, India. Morphological and Raman spectroscopic characteristics were consistent with an eclogitic affinity for some of the diamonds and a deep mantle origin for others.

Presentations related to coloured stones covered a wide range of gem materials. **Prof. Bruce Cairncross** (University of Johannesburg, South Africa) reviewed gems from the southern Africa subcontinent: amethyst, aquamarine, chrysoberyl (including alexandrite), diamond, emerald, hydrogrossular, jeremejevite, several quartz gem varieties, spessartine, tiger's-eye, topaz and tourmaline (e.g. Figure 3). **Stephen Harris** (University of New South Wales, Sydney, Australia) and co-authors studied an alluvial ruby-sapphire suite from the New England gem field, New South Wales, Australia. The unusual presence of rubies in this assemblage may be explained by magmatic interactions with Cr-bearing mafic-ultramafic rocks during corundum formation at depth, prior to transport of the xenocrysts to the earth's surface in alkali basalts. In another presentation, Harris and co-authors examined the origin of alluvial sapphires from the Orosmayo region, Sierra de Rinconada, Jujuy Province, north-west Argentina. The small transparent pebbles of colourless to blue sapphire contain a bimodal inclusion suite, suggesting that they formed through metasomatic exchange between a carbonatitic and an evolved felsic source. The sapphires were then transported to the surface as xenocrysts in lamprophyre dykes. **Kandy Wang** (University of New South Wales, Sydney, Australia) and co-authors reported on cabochon-quality rubies hosted by actinolite schist in the Paranesti region of north-eastern Greece. Oxygen isotope values of the rubies are extremely low ($\delta^{18}O$ ~1%), identical to seawater, suggesting a potential subduction zone genetic environment. **The author** (BML)described modern mining of primary and secondary gem deposits in Mogok, Myanmar (see Gem Notes in *The Journal*, **34**(5), 2015, 387–390). **Jullieta Lum** (University of Johannesburg, South Africa) and co-authors obtained chemical analyses of beryls of various colours (blue to green, yellow and colourless) from miarolitic cavities in the Erongo Mountains of Namibia. In general, the samples had major- and trace-element contents similar to those of aquamarine from worldwide localities, with no distinctive locality-specific characteristics. **Dr Le Huong** (Vietnam National University Hanoi) and co-authors performed femtosecond LA-ICP-MS analysis of danburite from Tanzania (dark yellow), Mexico (colourless) and Vietnam (light yellow). Samples from the three localities could be separated by various trace elements (i.e. Be, Ti, Mn, Ni, As, Sr and Y), and the content of light rare-earth elements was greatest in the dark yellow danburite. **Dr Ian Graham** (University of New South Wales, Sydney, Australia) and co-authors studied deep green cabochon-quality viridine (Mn-andalusite) from Thassos Island in northern Greece. The viridine is associated with piemontite and other Mn-bearing silicates of the epidote group. **Sonwabile Rasmeni** (Mintek, Randburg, South Africa) and co-authors described the mining and beneficiation of gem materials in the Northern Cape Province of South Africa. The various resources include 'red aventurine' (quartzite with pink Mn- and Fe-rich muscovite) from Pella, rose quartz from Riemvasmaak and Kakamas, tiger's-eye from Prieska, and green fluorite from Riemvasmaak. **Dr João Reynolds Marques** (Gondwana – Exploration and Mining Consultants Ltd., Maputo, Mozambique) and co-authors examined the regional distribution of granitic pegmatites in the Zambézia Province of Mozambique. The most important pegmatites for gem production include LCT (lithium, cesium,

Figure 3: Southern Africa is an important source of various gem varieties, such as those shown here that were faceted by Massimo Leone. Top row: citrine from Zambia (11.06 and 16.88 ct). Next row: greenish blue tourmaline (8.72 ct), aquamarine (8.62 ct) and pink tourmaline (8.72 ct) from Mozambique. Next row: greenish yellow tourmaline (2.21 ct) and spessartine (3.74 ct) from Zambia, and greenish blue tourmaline (1.73 ct), purplish pink tourmaline (1.70 ct) and greyish green tourmaline (2.85 ct) from Mozambique. Bottom row: spessartine from Namibia (1.81 and 1.64 ct). Photo by Bruce Cairncross.

tantalum)-type dykes in the Alto Ligonha District for tourmaline, and NYF (niobium, yttrium, fluorine)-type bodies of the Nampula Complex for dark blue aquamarine. **Prof. Olugbenga Okunlola** (University of Ibadan, Nigeria) and co-authors mapped Precambrian rare-metal (Ta-Nb-Sn) granitic pegmatites in southwestern Nigeria, some of which contain gem mineralization. They designated 10 pegmatite subfields, and geochemical data from muscovite suggests that those of Lema-Ndeji show the highest potential for economically significant rare-metal mineralization.

There were two talks related to instrumentation. **Dr Anton Du Plessis** (Stellenbosch University, South Africa) and co-authors reported applications of X-ray computed microtomography for faceted diamonds and coloured stones. The method can be used to visualize internal and external features of gemstones, and the full three-dimensional dataset is recordable to provide a unique identifier for insurance purposes. **Nicolaas Steenkamp** (geological consultant, Pretoria, South Africa) and his co-author investigated the use of electric pulsed-power disaggregation using a Russian-made selFrag instrument to break down massive pegmatite, potentially liberating gem-quality garnet and tourmaline. Pegmatite samples from the Limpopo Province of South Africa were submerged in water and subjected to high-voltage discharges, causing them to be fragmented along pre-existing fractures as well as mineral grain boundaries. Due to the fractured nature of the minerals in the pegmatite, the experiments produced ~30% grains measuring <1 mm (i.e. powder), while ~70% consisted of >1 mm pieces that were not completely liberated along the grain boundaries.

The next International Geological Congress will take place in March 2020 in Delhi, India.

Brendan M. Laurs

Letters

Digital Manipulation of Gem Photos—Author's Reply

In *The Journal of Gemmology* (Vol. 35, No. 2, 2016, p. 162), a letter by Grenville Millington addressed the caption of the lead figure that appeared in my article 'Oriented Inclusions in Cat's-eye, Star and Other Chrysoberyls' published in *The Journal* (Vol. 35, No. 1, 2016, pp. 28–54). In summary, Mr Millington concluded that any "manipulation" of digital photos should be indicated in the corresponding figure caption. I disagree with this statement.

When photos of gems are taken with modern digital cameras, certain types of stones (e.g. rubies or sapphires) frequently yield images that closely approximate the visual appearance of the gem to the human eye. This stands in stark contrast to the results of digital photography involving colour-change gemstones such as alexandrites or some garnets, even if the camera has been calibrated against a white standard for the actual lighting used. For such stones showing a different colour appearance in daylight and incandescent light, what is obtained in the digital photo most often does not match the visual impression of the sample. After many attempts, I have been fortunate on occasion to have the photo of a colour-change stone under one of the two relevant light sources appear close to what is actually seen with the eye, but rarely can this be achieved for both light sources. In most cases the results of such efforts, or at least some results, are highly disappointing.

Thus, I normally select the photo 'closest' in appearance to the actual gemstone and then adjust this digital image to attain as nearly as possible the real impression of the stone, having the sample, the computer screen and different light sources available on my desk. For my alexandrite book (*Russian Alexandrites*, 2010), a pre-print of all photos representing colour and colour change of 'critical' samples was even prepared in a paper version, enabling the colour of the paper pre-print to be corrected against the real gem. Such a procedure is, however, as a practical matter infeasible for articles in gemmological journals, simply for cost reasons.

I had the chance to examine in Germany some years ago the cat's-eye alexandrite mentioned above and depicted in *The Journal* (Vol. 35, No. 1, 2016, p. 29). The photo of that stone in its jewellery setting taken by Erica and Harold Van Pelt reportedly was carefully adjusted in the USA by modern digital techniques to match the actual impression of the gem in daylight and incandescent light. I consider such colour adjustment to be not a "manipulation" but rather a normal part of modern digital photography or digital processing of existing photos, what I would call 'state of the art' in modern publication technology. Therefore, I do not think that it is necessary to mention such colour adjustment in figure captions. Rather, digital adjustment should be indicated only if the appearance of a sample in the photo has been shifted toward a colour ('beautified') which, for whatever reason, is not consistent with the true coloration and visual appearance of the gemstone.

Dr Karl Schmetzer
Petershausen, Germany

Gem-A Notices

ANNUAL GENERAL MEETING

The Annual General Meeting of the Gemmological Association of Great Britain was held on 9 September 2016 at the Goldsmiths' Centre, 42 Britton Street, London EC1M 5AD. Nigel Israel chaired the meeting and welcomed those present.

Hazlems Fenton were re-appointed auditors for the year.

The Council had nominated the international organics expert Maggie Campbell Pedersen for the office of President and the nomination was unanimously carried. The outgoing President, Harry Levy (who could not be present), was thanked for his support and commitment to Gem-A during his four years in office.

Kathryn Bonanno and Nigel Israel retired from the Council in rotation and being eligible offered themselves for re-election. Nominations also were received from Ronnie Bauer and Starla Turner. There were only two places vacant on the Council and following a poll vote Kathryn Bonanno and Nigel Israel were re-elected. Mary Burland retired in rotation and did not seek re-election.

The meeting was followed by a brief address from the new CEO Alan Hart who spoke of his Natural History Museum background, his long association with, and support for, Gem-A, and his initial thoughts on the Association's growth and development.

The newly elected President, Maggie Campbell Pedersen.

MEMBERSHIP

At a meeting of the Council held on 30 June 2016, the following were elected to membership. Also Diploma graduates of the examinations held in January 2016 (to be published in the **35**(4) 2016 issue of *The Journal*) were elected or transferred to Fellowship and/or Diamond Membership as appropriate.

Fellowship

Hou Fei-Feng, *Taipei, Taiwan, R.O. China*
Khabrieva, Dilyara, *London*
Li Meng, *Montreal, Quebec, Canada*
Qin Yu Song, *Changyi, Jilin, P.R. China*
Tan Yu, *Ningbo, Zhejiang, P.R. China*
Xu Qian, *Huainan, Anhui, P.R. China*
Zhang Rui, *Beijing, P.R. China*

Associate Membership

Fairclough, Philippa, *Swindon, Wiltshire*
Gagnon, Luc, *Lasalle, Quebec, Canada*
Nasim-Brittan, Natalie, *Canterbury, Kent*
Sapora, Raul, *Velletri, Rome, Italy*
Vahman, Sarira, *Oxford, Oxfordshire*

At a meeting of the Council held on 9 September 2016, the following were elected to membership:

Fellowship

Woodmansterne, Chloë, *St Albans, Hertfordshire*

Associate Membership

Khourie, Kaylan, *Guateng, South Africa*
Vasseur, Chantal, *Rixensart, Belgium*
Durand, Jennifer, *Burton-on-Trent, Staffordshire*
Pulese Aulehla, Herbert, *London*

GIFT TO THE ASSOCIATION

The Association is most grateful to the following for his gift for research and teaching purposes:

Valerio Zancanella of Cavalese, Trentino, Italy, for a faceted hyalite opal from Mexico weighing 0.16 ct.

EXTRAORDINARY GENERAL MEETING

On Thursday 30 June 2016 at Gem-A, 21 Ely Place, London EC1N 6TD, an Extraordinary General Meeting was held for the purpose of considering the following Special Resolution to amend the Articles of Association (changes and additions in *italics*):

Termination of Membership

4 Membership is terminated if:

(3) any sum due from the member to the Charity is not paid in full within six months of it falling due, *except that the Council may by Bylaw(s) establish the period, not less than two months of it falling due, that a Member may be in subscription arrear before being deemed to have resigned from Membership.*

Notice of general meetings

7 (1) The minimum periods of notice required to hold a general meeting of the Charity are:

- *eighty-four* clear days *for the date of* an Annual General Meeting

Directors

20 *Unless determined otherwise by ordinary resolution:*

(1) The number of Elected or Co-opted Directors shall be not less than four [see Articles 26, 27 and 29(1)] and the number of Appointed Directors, who need not be members of the Charity, shall not be more than three [see Article 29(2)].

(2) The total number of all Directors shall not exceed twelve.

Retirement

24 At the first Annual General Meeting all the Council must retire from office unless by the close of the meeting the members have failed to elect sufficient Council to hold a quorate meeting of the Council. At each subsequent Annual General Meeting one-third of the *elected* Council or, if their number is not three or a multiple of three, the number nearest to one third must retire from office.

(1) The *elected* Directors to retire by rotation shall be those who have been longest in office since their last *election*. If any Directors became or were appointed Directors on the same day, those to retire shall (unless they otherwise agree among themselves) be determined by lot.

(2) *Elected Directors shall normally serve no more than three consecutive three-year terms, but may serve further terms upon recommendation of the Council.*

(3) If a Director is required to retire at an Annual General Meeting by a provision of these articles, the retirement shall take effect upon the conclusion of the meeting.

The *Election* of Directors

26 The Charity may by ordinary resolution in any general meeting:

- *elect* a person who is willing to act as a Director providing he is recommended by the Council, and

27 No person other than a Director retiring by rotation may be *elected* a Director at any general meeting unless:

(1) He is recommended for election by the Council;

(2) If not recommended by the Council then at an Annual General Meeting only providing that: *Not less than forty-two clear days or more than seventy clear days before the date of the meeting, the Charity is given notice in writing that: A Fellow (FGA) and/or Diamond Member (DGA) who has been an FGA and/or DGA in good standing for a minimum of the two most recent whole subscription years has been nominated for election to the Council, by two nominators who both have been either Fellows and/or Diamond Members in good standing for a minimum of the most recent whole subscription year, or Associate Members in good standing for the two most recent whole subscription years.*

The written nomination must:

(a) be signed by the *Nominators;*

(b) state the *Nominators'* intention to propose the *election* of a person as a Director;

(c) contain the details that, if the person were to be *elected*, the Charity would have to file at Companies House; and

(d) be signed by the person who is to be proposed to show his willingness to be appointed.

28 All members who are entitled to receive notice of a general meeting must be given not less than seven *or* more than twenty-eight clear days' notice of any resolution to be put to the meeting to *elect* a Director other than a Director who is to retire by rotation.

29 (1) *The Council may co-opt a person who is a Member of the association to fill a casual vacancy or an extra Director who is willing to act as a Director, subject to the maximum number of Directors allowed. Co-opted members shall be appointed by Council and shall retire at the first General Meeting of the Association thereafter, but may offer themselves as candidates for election at that Annual General Meeting and shall not be taken into account in determining the Directors who are to retire by rotation.*

(2) *In order that the Council may have an appropriate range of skills, it may, by resolution of two thirds of elected/co-opted Directors, appoint up to a further three Directors who need*

not be members of the Association. They shall serve a term up to the fourth Annual General Meeting following their appointment (or the third Annual General Meeting if appointed at an Annual General Meeting). They may serve further terms of three years at the request of the Council.

(3) Appointed Directors may be removed by resolution of two thirds of elected/co-opted Directors.

(4) Nothing in these Rules shall require any person who is a Director at the date of adoption of these Rules to resign as a Trustee, or shall prevent such person offering themselves, if eligible, for re-election if retiring by rotation at an Annual General Meeting.

30 *No election, co-option or appointment* of Directors may cause the number of Directors to exceed the number fixed as the maximum number of Directors.

Disqualification and removal of Directors

31 A Director shall cease to hold office if he:

- ceases to be a Director by virtue of any provision in the Act or is prohibited by law from being a director;
- is disqualified from acting as a Trustee by virtue of the Charities Acts;
- *ceases to be a member of the Charity unless an Appointed Director*;
- becomes incapable by reason of mental disorder, illness or injury of managing and administering his own affairs;
- resigns as a Director by notice to the Charity (but only if at least two *elected* Directors will remain in office when the notice of resignation is to take effect); or
- is absent without the permission of the Council from three consecutive meetings and the Council resolves that his office be vacated.

Proceedings of the Council

33 (1) *The Directors shall meet together for the despatch of business, adjourn, and otherwise regulate their meetings as they think fit, subject to the provision of the Articles. Such meetings may be held with one or more or all Directors participating by electronic communication if all the Directors so agree.*

34 (2) The quorum shall be *four elected or co-opted Directors*, or such larger number as may be decided from time to time by the Council.

President

52 On the nomination of the Council, the President shall be elected by the members of the Charity at a General Meeting. *The term of Office of the President shall run from the election at an Annual General Meeting until such President's re-election or a successor is elected at the second Annual General Meeting thereafter; if elected at a General Meeting not an Annual General Meeting, then until the third Annual General Meeting thereafter.* Subject to the discretion of the Council and the membership, a President would not normally be re-elected more than once. The President shall, ex officio, be entitled to attend meetings of the Council but shall not be entitled to vote unless he is also a member of the Council.

The motion was accepted with two abstentions.

A full version of the updated Memorandum and Articles of Association is available on Gem-A's website at www.gem-a.com/index.php/membership/resources/applications-articles/memorandum.

OBITUARY

Michael J. O'Donoghue FGA
1934–2016

The worldwide Gemmological community has been greatly saddened to hear of the passing of Michael O'Donoghue on 16 June 2016.

Michael did his National Service in the RAF, but, in spite of being offered a commission, he went to Selwyn College, Cambridge, graduating in 1959 with a degree in English Literature.

He became a librarian, working in Cambridge University Library, the National Library of Scotland and then in 1962, the British Museum Library. Initially he worked in the State Paper Room, but then moved to the Scientific and Technological Section where he became curator of Earth Sciences. He retired from the then renamed British Library ca. 1998. Being a curator of a major earth science collection of printed material obviously stirred his interest in gem materials. He became an FGA in 1968, and began teaching the same year at Sir John Cass College.

I studied my gemmology preliminary in 1976–77, and while walking along Cass corridors often passed the open doors of two classrooms where the Gemmology Diploma was being studied. In one of the rooms there were always about 40 students, heads down continually taking notes by dictation. There were considerably fewer in the other room, but far from taking notes, they seemed to be having a lively vocal relationship with their lecturer: Michael, of course! When I selected my Diploma lecturer I had

no hesitation in choosing Michael, a decision I still have much to be thankful for. Michael had a happy knack of transferring his immense enthusiasm to his students. I remember well how impatient we all were for his classes to start, wondering each week what exciting gems and books he would bring to show us.

Michael was a truly inspirational teacher, and the considerable number of his past students that I have recently talked to about him have all stressed that. He continued teaching until ca. 2009, becoming the College's Head of Gemmology.

Knowing that, like him, I was a keen collector of historic gemmological literature, he persuaded me to give my first-ever lecture during a day event at the Library. I remember using covers and pages of books photocopied onto overhead projection transparencies; how times have changed! He visited me regularly to look at my latest purchases, but food and wine were equally important on those occasions.

Michael wrote or edited about 20 books on gemstones, and led gemmological trips to far-flung places. He was, in 1991, the first editor of *Gem & Jewellery News*, then the joint newsletter of Gem-A and The Society of Jewellery Historians that was later to become *Gems&Jewellery*. Michael also produced abstracts of gemmological journals and reviewed books for *The Journal of Gemmology* from 1972, and in 1997 was appointed an Assistant Editor, a post he held until he died. In addition, Michael was made a Vice President of Gem-A in 2009.

I would not like anyone to think, however, that Michael was a one-subject enthusiast. He had many other varied interests. He was an accomplished church organist, having started to learn when he was nine. He was also passionate about the railways (his father was a railway executive), and apparently visited at least 110 signal boxes. He was an exceptionally kind man, and for some time was a Samaritans' volunteer.

Michael leaves a wife, Annie, three children and five grandchildren. Michael's past students, Gem-A and, indeed, the whole world of gemmology, owe him a massive debt. He is sorely missed, but his gemmological legacy will continue into the far future.

Nigel Israel

Michael O'Donoghue's talents stretched far beyond gemmology, but it was as a gemmologist that I knew him. My background was not in the gem trade—I had a photographic studio specializing in jewellery, and was simply curious to know more about the gems. Thanks largely to Michael's inspirational and challenging method of teaching in my Diploma year, I became so engrossed in the subject that I considered switching careers. The evening study group, which was started by Michael (today called 'Gem Central' but to which we affectionately referred as 'The Playgroup'), clinched it for me. We brought our dogs along, we ate chocolate biscuits (both of which Michael enjoyed), and we worked hard for a couple of hours under his guidance. It brought gemmology to life and was fun. That weekly opportunity to study gemstones from his wonderful collection and to share views and experiences pointed me firmly in the direction which I then followed.

Michael did not encourage note-taking during class. He himself provided notes the following week on what we had studied, but in class he wanted his students to listen and give their full attention to what they were hearing. There was of course a certain amount of surreptitious note-taking, especially by some of the students for whom English was not their first language. Michael had a dry sense of humour, and he was fond of explaining things by use of analogy. Though I now forget what he was describing at the time, I well remember a rather bewildered foreign gentleman leaning over to me in class and whispering, 'How do you spell Kit Kat?'

Michael was never afraid of being challenged himself. He was delighted to be confronted with an unusual specimen or with new information. Often—to use an analogy myself—we would come into class a bit like puppies, full of enthusiasm and proudly wag-

ging our tails at some new-found knowledge, only to find that Michael already knew all about it, and could elaborate on it and teach us a lot more. He was always pleased when we showed initiative, and he made us feel good about our discoveries, encouraging us to go out and investigate further. He wanted us to think for ourselves.

Personally, I owe Michael such a lot. He was very special, and he is greatly missed.

Maggie Campbell Pedersen

Ralph Ellis McRae Blacklock FGA (D.1967), Darlington, Co. Durham, died on 22 August 2016 following a short illness.

Born on 9 October 1946, Ralph started his career in 1965 in Birmingham with Bernard Lowe stone dealers sorting and selling gems. In 1966 he joined the family fine jewellery business, Blacklocks, in Sunderland. He was awarded his Gemmology Diploma in 1967, completing the course within one year.

Ralph worked with his father Ellis from 1966 until 1986. In that time the business grew with the opening of a second shop in Durham. In the early 1990s Ralph opened a third shop in Newcastle. In 2000 he sold the business and set up independently as a jewellery designer. From 2000 until 2016 he used his gemmological knowledge and design skills to create bespoke pieces, sourcing and identifying fine diamonds and gemstones to set within them, selling through a website. In 2009 he was joined by his son Christopher, who was the sixth generation to work in the family business, now entirely online.

By the time of his death, Ralph had designed multiple collections and fulfilled hundreds of bespoke orders.

Ralph was a founding director of the Company of Master Jewellers in 1981, served on the Board of the then National Association of Goldsmiths in 1997 and was a director of the Houlden Buying Group from 1998 to 2001.

Ralph leaves wife Roz, sons Chris and Mark, and three grandchildren. *Christopher Blacklock*

Adi Inskeep (née Redman) FGA (D.1959 with Distinction), Oxford, died at home on 5 April 2016. Adi attended Witwatersrand University, Johannesburg, South Africa, from 1947, completing her BSc in Geology and Botany followed by BSc (Hons) in Economic Geology in 1952. At the age of 22 Adi was appointed a curator at the University's Geological Museum, where she constructed many new exciting exhibits, acquiring outstanding material and brought enthusiasm and life to what had previously become a dormant museum. Adi worked at the museum for 12 years, until 1965. She then pursued her interest in human artefacts. *Hugh Underhill*

Individual Membership is changing...

Renew your Individual Membership before 1 January 2017 and pay just £110 — Individual Membership will be £135 for all renewals after this date.

Contact membership@gem-a.com for more information or to renew your Membership for 2017.

Learning Opportunities

CONFERENCES AND SEMINARS

CIBJO Congress 2016
26–28 October 2016
Yerevan, Armenia
www.cibjo.org/congress2016

The Munich Show
28–30 October 2016
Munich, Germany
www.mineralientage.de/en
Note: Includes a seminar programme.

MJSA ConFab
30 October 2016
New York, New York, USA
www.mjsa.org/eventsprograms/mjsa_confab

CGA Grad Gemmology Conference
29 October 2016
Vancouver, British Columbia, Canada
www.canadiangemmological.com

Fabergé Symposium – The Wonder of Fabergé
3–4 November 2016
Houston, Texas, USA
www.hmns.org/education/adults/faberge-symposium

Gem-A Conference
5–6 November 2016
London
www.gem-a.com/event/conference/conference-2016

The New Mexico Mineral Symposium
12–13 November 2016
Socorro, New Mexico, USA
https://geoinfo.nmt.edu/museum/minsymp

5th GIT International Gem and Jewelry Conference (GIT 2016)
14–15 November 2016
Pattaya, Thailand
www.git2016.com

3rd European Congress on Jewellery: The Jewel in Art and Art in Jewell
17–18 November 2016
Barcelona, Spain
www.museunacional.cat/en/jewel-art-and-art-jewellery

AGA Tucson Conference
1 February 2017
Tucson, Arizona, USA
https://accreditedgemologists.org

Compiled by Georgina Brown and Brendan Laurs

The 38th Annual Tucson Mineral Symposium: Mineral Treasures of the Midwest
11 February 2017
Tucson, Arizona, USA
www.friendsofmineralogy.org/symposia.html

Hasselt Diamond Workshop 2017 (SBDD XXII)
9–11 March 2017
Hasselt, Belgium
www.uhasselt.be/sbdd

Amberif International Fair of Amber, Jewellery and Gemstones
22–25 March 2017
Gdańsk, Poland
www.amberif.amberexpo.pl
Note: Includes a seminar programme.

American Gem Society International Conclave
5–8 April 2017
Hollywood, California, USA
www.americangemsociety.org/Content/uploads/Conclave2017RFP.pdf

14th Annual Sinkankas Symposium – Sapphire
8 April 2017
Carlsbad, California, USA
www.sinkankassymposium.net

The Santa Fe Symposium
21–24 May 2017
Albuquerque, New Mexico, USA
www.santafesymposium.org

Swiss Gemmological Society Conference and European Gemmological Symposium 2017
8–11 June 2017
Zermatt, Switzerland
www.gemmologie.ch

2017 Society of North American Goldsmiths (SNAG) Conference
24–27 May 2017
New Orleans, Louisiana, USA
www.snagmetalsmith.org/events/nexus-2017

11th International Conference on New Diamond and Nano Carbons
28 May–1 June 2017
Cairns, Australia
http://ndnc2017.org

Association for the Study of Jewelry and Related Arts (ASJRA) Annual Conference
9–10 June 2017

Boston, Massachusetts, USA
www.jewelryconference.com

PEG2017 – 8th International Symposium on Granitic Pegmatites
13–15 June 2017
Kristiansand, Norway
www.nhm.uio.no/forskning/aktuelt/arrangementer/konferanser-seminarer/peg2017

11th International Kimberlite Conference
18–22 September 2017
Gaborone, Botswana
www.11ikc.com
Note: Pre- and post-conference field trips will visit diamond deposits in Botswana and neighbouring countries.

World of Gems Conference V
23–24 September 2017
Rosemont, Illinois, USA
http://gemguide.com/events/world-of-gems-conference

35th International Gemmological Conference
11–15 October 2017
Windhoek, Namibia
www.igc-gemmology.org/igc-2017-programme/4592655130
Note: Pre- and post-conference field trips will visit diamond and coloured stone deposits in Nambia.

EXHIBITIONS

Australia

Lustre: Pearling and Australia
Until 22 January 2017
Immigration Museum, Melbourne, Victoria, Australia
http://tinyurl.com/hcrhscq

Europe

Heavenly Bodies—The Sun, Moon and Stars in Jewellery
Until 30 October 2016
Schmuckmuseum, Pforzheim, Germany
www.schmuckmuseum.de/flash/SMP_en.html

Eggs-travagant—Ostereier aus Edelsteinen
Until 2 November 2016
Edelsteinmuseum, Idar-Oberstein, Germany
www.edelsteinmuseum.de/ausstellungen-deutsches-edelsteinmuseum/sonderausstellungen.html

Enamoured
Until 18 November 2016
The Goldsmiths' Centre, London
www.goldsmiths-centre.org/whats-on/exhibitions/enamoured

Eva's Beauty Case: Schmuck und Styling im Spiegel der Zeiten (Jewelry and Styling Through the Ages)
Until 22 January 2017
LVR-LandesMuseum Bonn, Bonn, Germany
www.landesmuseum-bonn.lvr.de/de/ausstellungen/evas_bauty_case/evas_beauty_case.html

Elements: From Actinium to Zirconium
Until 26 February 2017
Ulster Museum, Belfast, Northern Ireland
http://nmni.com/um/What-s-on/Elements

Warrior Treasures: Saxon Gold from the Staffordshire Hoard
Until 23 April 2017
Bristol Museum & Art Gallery, Bristol
www.bristolmuseums.org.uk/bristol-museum-and-art-gallery/whats-on/warrior-treasures

Must-Haves—Jewellery Created by Greats of the Craft and **Must-Sees—Jewellery in the Arts**
21 May–10 September 2017
Schmuckmuseum, Pforzheim, Germany
www.schmuckmuseum.de/flash/SMP_en.html

Authentically Inauthentic?—Jewellery from Pforzheim's Industrial Production
28 May–10 September 2017
Municipal Museum, Pforzheim, Germany
www.schmuckmuseum.de/flash/SMP_en.html

Smycken: Jewellery. From Decorative to Practical
Ongoing
Nordiska Museet, Stockholm, Sweden
www.nordiskamuseet.se/en/utstallningar/jewellery

North America

Fabergé from the Matilda Geddings Gray Foundation Collection
Until 27 November 2016
The Metropolitan Museum of Art, New York, New York, USA
www.metmuseum.org/exhibitions/listings/2011/faberge

Glitterati: Portraits & Jewelry from Colonial Latin America
Until 27 November 2016
Denver Art Museum, Denver, Colorado, USA
www.denverartmuseum.org/exhibitions/glitterati

Jewelry, from Pearls to Platinum to Plastic
Until 1 January 2017
Newark Museum, Newark, New Jersey, USA
www.newarkmuseum.org/jewelry

All That Sparkles...20th Century Artists' Jewelry
Until 8 January 2017
The Bechtler Museum of Modern Art, Charlotte, North Carolina, USA
http://bechtler.org/Collection/All-that-sparkles

Gold and the Gods: Jewels of Ancient Nubia
Until 8 January 2017
Museum of Fine Arts, Boston, Massachusetts, USA
www.mfa.org/exhibitions/gold-and-gods

Arts of Islamic Lands: Selections from The al-Sabah Collection, Kuwait
Until 29 January 2017
Museum of Fine Arts, Houston, Texas, USA
www.mfah.org/exhibitions/arts-islamic-lands-selections-al-sabah-collection-

American Mineral Heritage: Harvard Collection
Until February 2017
Flandrau Science Center & Planetarium, Tucson, Arizona, USA
http://flandrau.org/exhibits/harvard

Beyond Bling: Jewelry from the Lois Boardman Collection
Until 5 February 2017
Los Angeles County Museum of Art, California, USA
www.lacma.org/art/exhibition/beyond-bling

Bijoux Parisiens: French Jewelry from the Petit Palais, Paris
11 February–14 May 2017
Taft Museum of Art, Cincinnati, Ohio, USA
www.taftmuseum.org/upcoming-exhibitions-draft

Spectacular! Gems and Jewelry from the Merriweather Post Collection
10 June 2017–14 January 2018
Hillwood Estate, Museum & Gardens, Washington DC, USA
www.hillwoodmuseum.org/Spectacular-Gems-and-Jewelry

Amber Secrets: Feathers from the Age of Dinosaurs
Ongoing
Houston Museum of Natural Science, Texas, USA
www.hmns.org/exhibits/special-exhibitions/amber-secrets-feathers-from-the-age-of-dinosaurs

City of Silver and Gold: From Tiffany to Cartier
Ongoing
Newark Museum, New Jersey, USA
www.newarkmuseum.org/SilverAndGold.html

Fabergé: From a Snowflake to an Iceberg
Ongoing
Houston Museum of Natural Science, Texas, USA
www.hmns.org/exhibits/special-exhibitions/faberge-a-brilliant-vision

Gemstone Carvings
Ongoing
Houston Museum of Natural Science, Texas, USA
www.hmns.org/exhibits/special-exhibitions/gemstone-carvings

Gilded New York
Ongoing
Museum of the City of New York, New York, USA
www.mcny.org/content/gilded-new-york

Mightier than the Sword: The Allure, Beauty and Enduring Power of Beads
Ongoing
Yale Peabody Museum of Natural History, New Haven, Connecticut, USA
http://peabody.yale.edu/exhibits/mightier-sword-allure-beauty-and-enduring-power-beads

OTHER EDUCATIONAL OPPORTUNITIES

Gem-A Workshops and Courses
Gem-A, London
www.gem-a.com/education/courses/workshops

Lectures with The Society of Jewellery Historians
Society of Antiquaries of London, Burlington House, London
www.societyofjewelleryhistorians.ac.uk/current_lectures

- 25 October 2016
  Robert Baines—Bogus or Real: Jewellery and the Capture of Human Drama
- 22 November 2016
  Kieran McCarthy—Fabergé and London
- 24 January 2017
  Noël Adams—Gold and Garnet Cloisonné Jewellery: Recent Discoveries and New Perspectives
- 28 February 2017
  David Callaghan—(To be announced)
- 28 March 2017
  Marjan Unger—My Jewellery Collection: Confessions of an Art Historian

New Media

Gemstone Buying Guide, 3rd Edn.

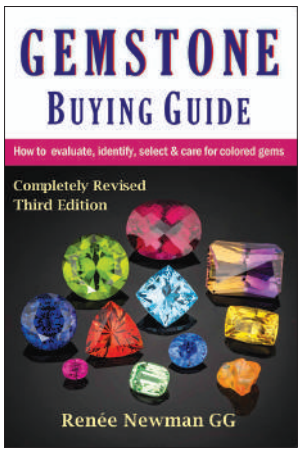

By Renée Newman, 2016. International Jewelry Publications, Los Angeles, California, USA, 156 pages, ISBN 978-0929975511. US$19.95 softcover.

This third edition is a completely revised version of the *Gemstone Buying Guide*, and it has been updated with well-rounded information that is organized into 12 chapters:

- Chapter 1 explains coloured gemstone pricing factors.
- Chapters 2–6 explain how to examine a stone according to the '4 Cs' (cut, carat, colour and clarity).
- Chapter 7 is a short section on cat's-eye and star stones.
- Chapters 8–9 cover various treatment processes and the identification features useful for distinguishing between natural and synthetic gemstones.
- Chapter 10 warns the reader about practices done with the intent to deceive the gemstone buyer.
- Chapter 11 provides 77 pages describing the history, characteristics and sources of the more important gem varieties on the market, organized alphabetically.
- Chapter 12 concludes with a short but nonetheless important section on how to care for your gems.

The final pages contain a tabulation of birthstones and anniversary stones, followed by a list of gem varieties in order of descending Mohs hardness.

The book includes several new gem varieties that were not covered in previous editions. It is also a 'feast for the eye', with 356 colour images by a variety of photographers. Newman once again included several of my photos, which I greatly appreciate. She has also conveyed captivating historical information on the gems that she profiles.

The book is an excellent tool for the novice, as well as for knowledgeable members of the gem and jewel-lery trade. I recommend Newman's book to anybody buying or selling gemstones.

Mia Dixon
Palagems.com, Fallbrook, California, USA

Pederneira – A Rainbow of Colors (DVD)

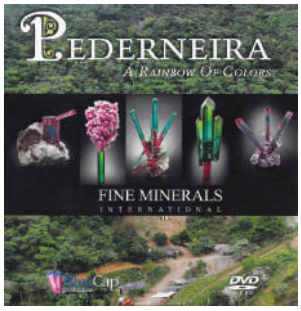

By Fine Minerals International, 2014 (released 2016). Produced by Blue Cap Productions, Honolulu, Hawaii, 1 hour 28 minutes playing time, www.shop.bluecapproductions.com. US$19.99.

In the world of tourmaline, few mines of the modern era have yielded more of the stunning beauty and variety of gem crystals than the Pederneira mine, located near São José da Safira, Minas Gerais, Brazil. This film was prepared to accompany an extensive article on this famous deposit that was published by *Mineralogical Record* (Vol. 46, No. 1, January–February 2015, 1–138). It takes the viewer on a journey from the 1940s to 2014, from the transformation of coffee plantation to mine, and chronicles several incredibly productive eras, ending with an exploration programme to (hopefully) expand the mine in the future. The scene selection is divided into 21 topics, of which 14 are dedicated to individual gem 'pockets' (i.e. cavities in the pegmatite hosting tourmaline crystals).

The video is passionately narrated by various key players in Pederneira's development, such as Daniel Trinchillo (mine co-owner and mineral dealer), José Menezes de Souza (mine partner, also known as 'Ze') and Dr Federico Pezzotta (pegmatite geologist). Each individual adds fascinating personal stories of his involvement, with a particularly memorable one by Ze who recounted the discovery of the Rocket Pocket in 2001: Ze received a call from the mine workers stating that they had broken into a new cavity showing gemmy tourmaline. He instructed them to stop work and wait for him to arrive the following morning. How-

ever, when he arrived he discovered, to his horror, that the miners conducted further blasting that ultimately caused considerable damage to the material; in Ze's words, "I almost cried." Although the colour and quality of the crystals were spectacular, only a very few matrix specimens could be salvaged. Since the same crystals still attached to their host matrix could have yielded "5 to 6 times" the selling price, Ze and the Pederneira team quickly learned an expensive lesson in gem and mineral mining. Fortunately, the team moved on from this misstep and subsequent pockets were handled more diligently.

The narration is accompanied by video footage of amazing tourmalines as they are slowly rotated, including famous named specimens such as the 'Rocket' and the 'Big Blue' (the latter being a perfect 15-cm-diameter, 23-cm-tall blue-green tourmaline crystal perched upon a 'soccer ball'-sized piece of white albite matrix). The film is full of such visual treats.

For those interested in the Pederneira locality, or tourmaline in general, this is a must-watch video. However, gemmologists will find little discussion of gem rough and faceted material, as they are not the subject of focus. Some of the narrators' English pronunciation is challenging to understand, but this actually adds to the authenticity of the story. The audio and video are both of excellent quality, and most of the video was filmed on location at Pederneira. The film truly captures the spectacular beauty of Pederneira tourmaline, and hopefully we will see similar video treatments of additional world-class gem and mineral localities in the future.

Keith Mychaluk
Calgary, Alberta, Canada

Pigeon Blood Valley—On the Trail of Mogok's Famed Burmese Ruby

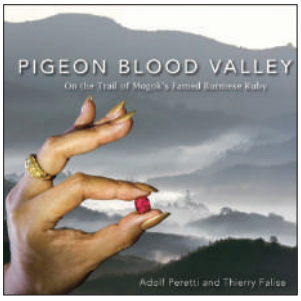

By Adolf Peretti and Thierry Falise, 2016. GRS GemResearch Swisslab AG, Lucerne, Switzerland, 237 pages, ISBN 978-952386774, www.mogok.com. Fundraiser edition, US$200.00 hardcover.

In the foreword of this attractive book, the authors explain that this is a personal journey through the history of this fascinating locality for vivid red rubies (commonly called *pigeon blood* red by gem traders). They divide the book into 12 chapters. The text is minimal (only 1–2 pages per chapter), but well written and concise. The authors prefer to let the photographs and captions tell much of their story.

The first four chapters focus on some of the famous old-time ruby dealers, as well as on Burmese kings and British colonization, before shifting to more modern history. The photos show the local people, places, mines and, of course, wonderful jewels. There are numerous spectacular full-page colour images supplied by auction houses Sotheby's and Christie's, as well as by a plethora of famous jewellers including Cartier, Graf, Van Cleef & Arpels, Harry Winston and Bulgari, to name a few. These photos show the reader exactly why Mogok is so famous for pigeon-blood rubies, with examples of modern and vintage necklaces, bracelets, rings, watches and earrings. The authors also include comprehensive historic maps, reproductions of original photos from the late 1800s, and antique letters and stamps from the famous collection of Santpal Sinchawla of Bangkok. These help the reader to better understand this amazing and complicated valley.

In Chapter 5 the authors introduce the reader to the 'Men Who Mine', covering many modern-day deposits and the miners who work them. Chapter 6, 'Till the Last Crumb', is a tribute to an old tradition of allowing village women and children to go through the mine tailings and keep whatever they find. Chapter 7, 'Ruby Royalty', covers some present-day local gem dealers, followed by 'Warlords and Smugglers' in Chapter 8. The latter characters are an age-old problem in Mogok, as well as in most gem-producing areas throughout history. Chapter 9 covers the 'Subcontinent Influence' of the many Indians and Nepalese who have become strong players in the Mogok gem business. Chapter 10, 'The Final Cut', describes how Mogok locals skilfully transform rough material into beautiful gems, often using techniques passed down from their grandfathers' time.

Chapter 11, 'The Soul of the City', shows how Mogok is focused completely on gemstones. The authors start with quotations from older books on Mogok that point out the fantasy and charm of this fabled place, and illustrate the chapter with photographs that confirm the beauty and mystique that visitors feel there. The final chapter, 'A Future between Gloom and Hope', tackles social and environmental issues in a realistic dialogue. The chapter ends with the author's statement that "only when the river is no longer red will Mogok be finished".

The last few pages focus on 'Specialist Doctor Wanted', as one of the overriding purposes of this book is to help the AIDS victims of the Mogok District.

For any gemmologist interested in classic Burmese gemstones, especially ruby, I recommend this book. The hundreds of photographs will give you a new understanding of the Mogok area, and you will gain an appreciation of just how rare and beautiful gemstones from this fabled valley are.

William F. Larson
Palagems.com, Fallbrook, California, USA

OTHER BOOK TITLES

General Reference

***Collecting Rocks, Gems and Minerals: Identification, Values, Lapidary Uses*, 3rd edn.**
By Patti Polk, 2016. Krause Publications, Fort Collins, Colorado, USA, 352 pages, ISBN 978-1440246159. US$19.99 softcover.

***Gem Identification Made Easy*, 6th edn.**
By Antoinette Matlins, 2016. Gemstone Press, Nashville, Tennessee, USA, 400 pages, ISBN 978-0997014556. US$38.99 hardcover.

Gemstones: A Complete Color Reference for Precious and Semiprecious Stones of the World
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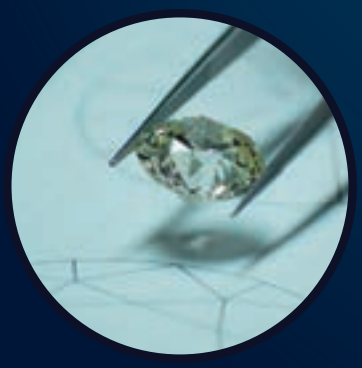

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Cover Photo: Greenland is poised to become a significant producer of rubies and pink sapphires. These rubies recovered from the Aappaluttoq deposit weigh 0.29–2.53 ct and were characterized for an article appearing in this issue (see pp. 294–306). Photo by Bilal Mahmood, AGL.

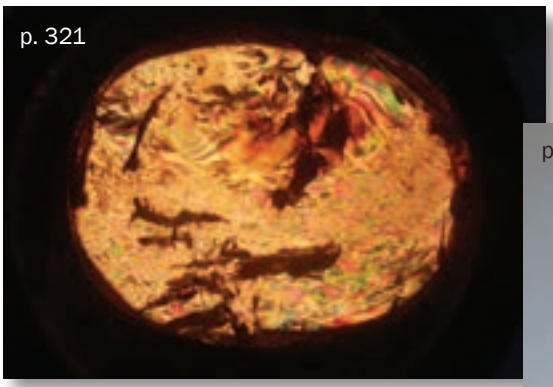
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Understanding Gems™

What's New

INSTRUMENTATION

DiaPix Jewelry Imaging System

In March 2016, OGI Systems Ltd. (Ramat Gan, Israel) released DiaPix Jewelry, an "all in one video imaging machine" that captures high-definition images and 360° videos of loose gemstones as well as jewellery of any size. The unit measures 42 × 24 × 37 cm, and the system includes video editing tools that allow the user to rapidly upload interactive videos to the internet. Visit www.ogisystems.com/diapixjewel.html. *CMS*

DiaTrue Diamond Screening System

Released by OGI Systems Ltd. in September 2016, the DiaTrue is designed to screen colourless natural diamonds, HPHT synthetic diamonds and HPHT-treated CVD synthetic diamonds. Both mounted and unmounted samples can be tested, the latter including parcels and individual gems from 0.01 to ~20 ct. The system reportedly operates by detecting weak phosphorescence of catalyst residues from the HPHT process, and suspect gems must be confirmed by additional laboratory testing. The unit weighs approximately 8.5 kg and measures 28 × 25 × 50 cm. Visit www.ogisystems.com/diatrue.html. *CMS*

GemTrue Experior Tester

The GemTrue Multi Experior DK9000, released by DiKai Industrial (Shenzhen, China) in April 2016, is a pen-style thermoelectric probe that reportedly can identify diamond, synthetic moissanite and cubic zirconia, as well as help distinguish natural from synthetic ruby and sapphire. Both mounted and loose gems can be tested. Measuring 150 × 33 × 23 mm and weighing 42 g, it is highly portable. Visit www.dikaitools.com/en/Diamond_Testers_Moissanite_Testers/20160404/432.html. *CMS*

GLIS-3000 GEM Luminous Imaging System

Released in October 2015 by Biaoqi Guangzhou Electronic Science Technology Co. Ltd. (Guangzhou, China), the GLIS-3000 GEM Luminous Imaging System is designed to quickly test batches of loose diamonds (rough or cut, including melee), as well as mounted stones. The instrument contains a UV spectrometer and excites diamond luminescence to produce fluorescence and phosphorescence images that allow the user to refer certain samples for further testing to confirm natural or synthetic (HPHT and CVD) origin. Visit www.gzbiaoqi.com/ProductShow.asp?ArticleID=393. *CMS*

J-Secure Synthetic Diamond Detector

As a follow-up to the D-Secure instrument (see What's New section, **35**(2), 91), J-Secure was released by DRC Techno (Gujarat, India) in October 2016 to identify synthetic dia-

monds in jewellery. The instrument is available in two versions: the J-Secure, which is for use only with jewellery, and the J-Secure Plus, which can be used with both mounted and loose diamonds. For details, including video demonstrations, visit www.jsecure.in. *CMS*

Solico Diamond-Cutting Machine

Announced in June 2016, the Solico Diamond Robotics Process from OGI Systems Ltd. is a fully automated system for cutting diamonds. The machine first analyses the rough (including CVD synthetic diamond shapes) to determine which of nine shapes will yield maximum profit. It will then block, brute, table-saw and polish to within 90% of the finished product. Visit www.ogisystems.com/solico.html. *CMS*

Synova Diamond-Cutting Machines

Synova Advanced Laser Systems (Synova SA, Lausanne, Switzerland) announced in May 2016 the release of three models of diamond-cutting machines. The different units are optimized for cutting specific size ranges, and all of them use Synova's Laser MicroJet technology that combines a 532 nm laser with a thin water jet. Three-axis and five-axis versions are available for a range of capabilities. Information about each model is available at www.synova.ch/products/diamond-cutting-systems.html. *CMS*

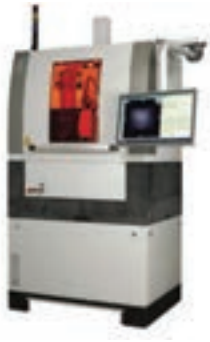

NEWS AND PUBLICATIONS

CIBJO Congress 2016 Presentations and Special Reports

Five of the presentations from this year's CIBJO Congress, held 26–28 October in Yerevan, Armenia, are available at www.cibjo.org/congress2016/presentations. They include talks by Andrew Bone about the Responsible Jewellery Council; Eduardo Escobedo on the Responsible Ecosystems Sourcing Platform; Ian Harebottle about Gemfields as a coloured stone supplier; and Dr Michael Krzemnicki on laboratory standards for the coloration of 'pigeon-blood' ruby and 'royal blue' sapphire. Special Reports released prior to the Congress from the commissions on pearls, gemmology, precious metals, coloured stones, diamonds, ethics, and marketing and education are also available for download at www.cibjo.org/congress2016/special-reports-2. *CMS*

GIT Lab Updates

In September 2016, the Gem and Jewelry Institute of Thailand released two Lab Updates: 'Cymrite: An unusual jade imitation' and 'Some uncommon features in a heat-treated fancy sapphire'. To download these and other reports, including some GIT-authored abstracts from the GIT 2016 conference, visit www.git.or.th/2014/articles_technic_en.html. *CMS*

USA Lifts Ban on Burmese Ruby and Jadeite

On 7 October 2016, President Obama signed an Executive Order terminating the Burma Sanctions programme that for more than a decade has banned the importation into the USA of Burmese ruby and jadeite (rough, cut and mounted). For in-depth information and related

resources, visit www.treasury.gov/resource-center/sanctions/programs/pages/burma.aspx. *CMS*

***Margaritologia* Pearl Newsletter No. 5/6**

Margaritologia No. 5/6 was released in August 2016 and includes reports on the history of the pearling trade as presented at the International Maritime Economic History Association's 7th International Congress of Maritime History; 'The Art

and Science of Gems' exhibition at the ArtScience-Musum in Singapore; and pearling icon Bill Reed's autobiographical book *The Long Road to Broome*. To subscribe to the newsletter, visit www.gemmologisches-institut-hamburg.de. *CMS*

MISCELLANEOUS

David Friend Hall at the Yale Peabody Museum

October 2016 marked the opening of the David Friend Hall, to coincide with the 150th anniversary of the Yale Peabody Museum (New Haven, Connecticut, USA). This new gallery displays more than 150 gem and mineral specimens in dramatic fashion, including many notable specimens (e.g. a large tanzanite crystal, a 77 ct yellow diamond and a 75 ct sapphire). Some are permanent exhibits, while others are on loan from private collections. Under development is an accompanying mobile app that visitors can download to their smartphone or tablet to enhance their visit. To learn more, read this pre-opening article: http://news.yale.edu/2016/10/17/peabody-museum-s-new-mineral-gallery-will-knock-your-socks. *CMS*

Harvard Museum Virtual Tour

Take a virtual tour of some of the gems and minerals at Harvard University's Mineralogical and Geological Museum (Cambridge, Massachusetts, USA) through Google Arts & Culture, which presents images from more than 1,000 partner museums and archives. At the time of writing, three Harvard exhibits were available: 'Opals', 'Albert Burrage and His Rare Golds' and 'The Hamlin Collection' (featuring tourmaline from Mount Mica, Maine, USA). These online exhibits include high-resolution photos of notable pieces along with descriptive text and historical material. Also pictured are various additional specimen photos and a profile of the museum, which is headed by Dr Raquel Alonso-Perez FGA. Take the tour at www.google.com/culturalinstitute/beta/partner/mineralogical-and-geological-museum-harvard-university. *CMS*

Jades for Life and Death Online

In October 2016, the Smithsonian's Freer Gallery of Art and Arthur M. Sackler Gallery (Washington DC, USA) launched the first part of their five-volume online digital catalogue, 'Jades for Life and Death'. It features more than 250 ancient Chinese jades from the extensive Freer and Sackler collections dating from the Chinese Stone Age (ca. 5000–1700 BC) through the Han Dynasty (206 BC–220 AD), along with essays on the history of the collection, related scientific studies and an archaeological survey of the Neolithic Liangzhu culture. The searchable catalogue is available at www.asia.si.edu/publications/jades/default.php. *CMS*

What's New provides announcements of new instruments/technology, publications, online resources and more. Inclusion in What's New does not imply recommendation or endorsement by Gem-A. Entries were prepared by Carol M. Stockton (CMS) or Brendan M. Laurs (BML), unless otherwise noted.

Anomalous Behaviour of a Sumitomo Synthetic Diamond on the Reflectance Meter

Alan Hodgkinson

Gemmological surprises sometimes come when least expected. At the September 2016 Registered Valuer conference in Loughborough, I ran three 'Yellow Gemstone' workshops. Thirty-four gems were available for 'hands-on' access, accompanied by a list of the instruments that were available to probe further into their identity.

A fine 'canary' diamond (Bruton, 1970; Cunningham, 2011) was included among the study samples (Figure 1, left) along with its definition: no absorption features are visible with a hand-held spectroscope, and the identity of such a type Ib diamond is further clinched by bright yellow fluorescence to long- and short-wave UV radiation, with the long-wave UV producing the stronger fluorescence. The yellow colour of 'canary' diamonds is due to dispersed single (unaggregated) nitrogen atoms. This contrasts with the majority (98%) of natural yellow diamonds, which are type Ia with the nitrogen in aggregated form, and with a characteristic 415 nm absorption system commonly seen (referred to as the *cape series*) with a hand-held spectroscope.

Also available to the delegates was a yellow synthetic diamond grown by Sumitomo in Japan (Figure 1, right); such crystals were first introduced in 1985. Yellow synthetic diamonds are type Ib with no absorption seen in the visible range, like their natural type Ib equivalent. However, the yellow UV fluorescence of the Sumitomo product is stronger to short-wave than to long-wave UV. This behaviour is often observed in synthetic diamonds but is most unusual in their natural counterparts. Another interesting feature of the Sumitomo synthetic diamonds is their distorted cross-shaped pattern of strain birefringence seen between crossed polarizers (Figure 2). Bear in mind that samples cut from larger crystals (Sumitomo synthetics over 10 ct have been reported) may only yield a portion of such a pattern, which would not be so obviously diagnostic.

Among the tools available to the delegates were some Hanneman Diamond Eye reflectance meters (Figure 3). Also called

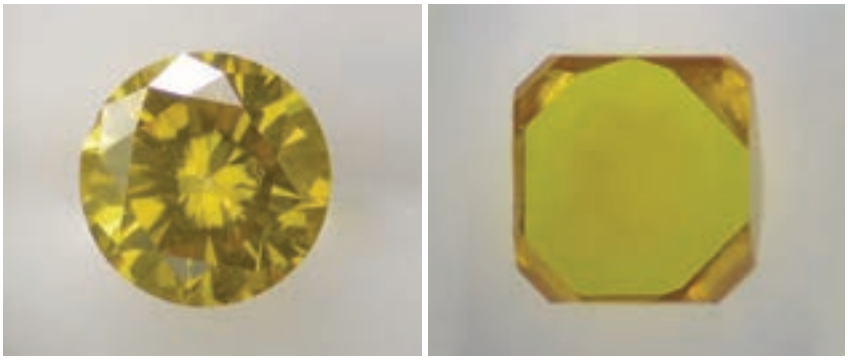

Figure 1: The natural 'canary' diamond on the left weighs 0.50 ct, and the Sumitomo crystal on the right is 5 mm in dimension. Photos by A. Hodgkinson.

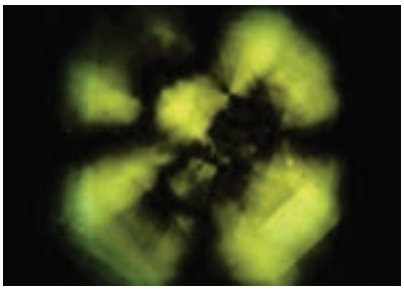

Figure 2: A distorted cross-shaped strain pattern is seen between crossed polarizers in the 5 mm Sumitomo synthetic diamond crystal. Photomicrograph by A. Hodgkinson; magnified 10x.

Figure 3: The Hanneman Diamond Eye reflectance meter is a useful tool for checking the comparative RIs of diamond and its various simulants. Photo by A. Hodgkinson.

'lustre meters', such instruments are quite useful to the gemmologist, as they require no contact liquid and can record reflection (and its comparative sequence level of refraction) to cope with any level of RI. Before measuring an unknown specimen, it is essential to set the instrument against a control sample. One of the delegates, Rupert Huddy, duly did this with a control cubic zirconia. However, on testing the Sumitomo synthetic diamond, the indicator needle raced across the scale beyond 'diamond' to the extremity of the instrument. He drew my attention to this, and I proceeded to check his finding. Care was taken to set the meter twice against a control sample of natural diamond, but each time the erratic behaviour was repeated by the Sumitomo specimen. The results were further checked using three other Hanneman reflectance meters, including a desk model that gives a more controlled reflection response across a wide 5-inch screen.

Gemmologists should be aware of the possibility for such anomalous behaviour when testing Sumitomo synthetic diamonds. It would be interesting to have readers with access to Sumitomo specimens repeat this procedure on any reflectance meter.

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Bruton E., 1970. *Diamonds*. N.A.G. Press, London (see pp. 315, 328).

Cunningham D., 2011. *The Diamond Compendium*. N.A.G. Press, London (see p. 340).

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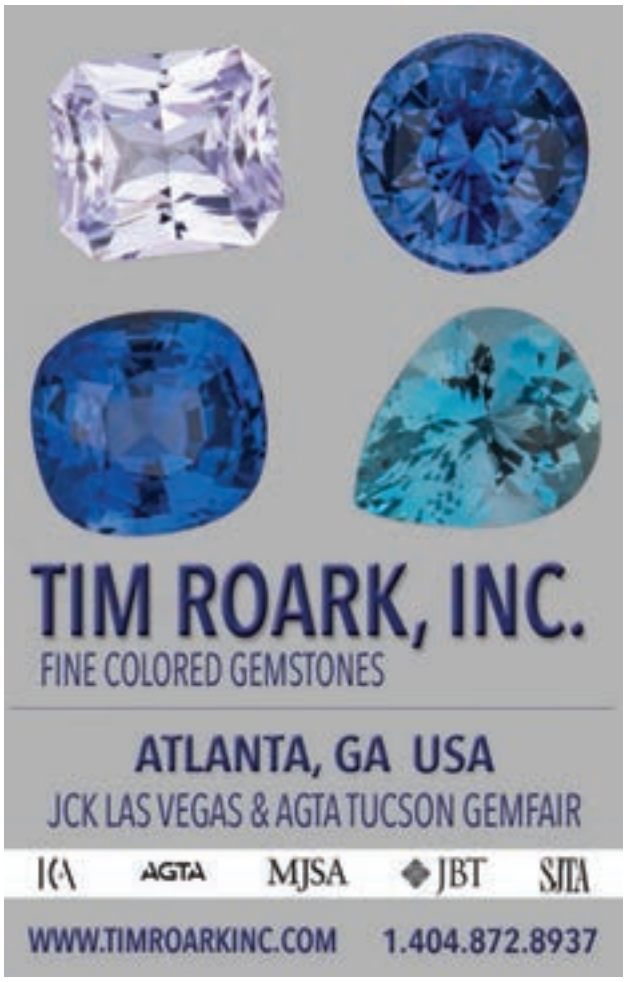

Gem Notes

COLOURED STONES

Antigorite Serpentine from North-West Pakistan

During the 2015 Tucson gem shows in Arizona, USA, one of the authors (BML) was informed about some recently produced translucent green gem materials from north-west Pakistan by two different dealers. Syed Iftikhar Hussain (Syed Trading Co., Peshawar, Pakistan) donated to Gem-A a weakly chatoyant cabochon (16.77 ct) and a piece of rough material that were thought to be actinolite, as well as a cobble that was sold to him as nephrite, while Anzor Douman (Arzawa Mineralogical Inc., Winchester, Virginia, USA) had a sample of chatoyant material that resembled nephrite upon initial inspection. Later, during the following year's Tucson gem shows, Sir Ahmad (Farooq) Hashmi of Intimate Gems (Glen Cove, New York, USA) loaned one faceted stone (3.71 ct) and three oval cabochons (6.29–8.59 ct) consisting of an unidentified green material that was reportedly mined from north-west Pakistan. The overall appearance of all the samples (i.e. the semi-transparent to translucent diaphaneity and the 'olive' green colour; e.g. Figure 1) were typical of some nephrite showing good transparency.

The 'actinolite' samples from Hussain and the 'unknowns' from Hashmi were examined by authors CW and BW, and analysis with a GemmoRaman-532SG spectrometer identified all of them as antigorite serpentine, $Mg_3(Si_2O_5)(OH)_4$. Fourier-transform infrared (FTIR) spectroscopy with a PerkinElmer Spectrum100 unit revealed the expected high amounts of OH and H_2O associated with serpentine minerals, and none of the samples showed any indications of polymer-type treatment.

Further testing of the polished stones revealed spot RI values of approximately 1.56, and hydrostatic SG measurements ranged from 2.59 to 2.60, typical of serpentine. The lustre of the gems ranged from sub-vitreous to silky, which is consistent with the variable low Mohs hardness of antigorite (2½–4, rarely up to 6; Gaines et al., 1997). The samples were inert to long- and short-wave UV radiation, and visible-to-near-infrared (Vis-NIR) spectra with an Ocean Optics USB4000 spectrometer showed a strong absorption peak at 460 nm, a weak 493 nm feature and a broad band centred at 715 nm that extended from the red region into the infrared. Energy-dispersive X-ray fluorescence (EDXRF) spectroscopy showed a chemical composition that was consistent with antigorite for the elements detectable by our Amptek X123-SDD instrument (i.e. Si), as well as significant Ni, minor Cr and Mn, and traces of V and Zn. All samples contained numerous parallel, near-colourless linear features (e.g. Figure 2) that showed a fibrous, feathery effect in some cases. The weak chatoyancy exhibited by the 16.77 ct cabochon was caused by a relatively large amount of these inclusions. Also present in some samples were opaque black dendritic and crumb-like masses (Figure 3).

Figure 1: These green gems (3.71–16.77 ct), reportedly from a relatively new deposit in Pakistan, proved to be antigorite serpentine. The largest stone shows a faint cat's-eye effect. Photo by B. Williams.

The antigorite described in this report shows some similarities to a cat's-eye serpentine from an unspecified origin documented by Choudhary (2009), except that stone fluoresced weak yellow

Figure 2: Abundant parallel linear inclusions are present in this 6.29 ct antigorite cabochon. Photo by C. Williams.

to long-wave UV radiation, and the desk-model spectroscope recorded only weak bands in the green and blue regions of the spectrum. Also, it contained fewer trace elements (Cr, Fe and Ni) than the material described here. Although this antigorite may be offered in the market as actinolite or nephrite, it can easily be identified by its lower RI and SG values. It also has a lower hardness, and the parallel linear features present in the samples examined for this report are not seen in nephrite, although antigorite does not always contain such inclusions.

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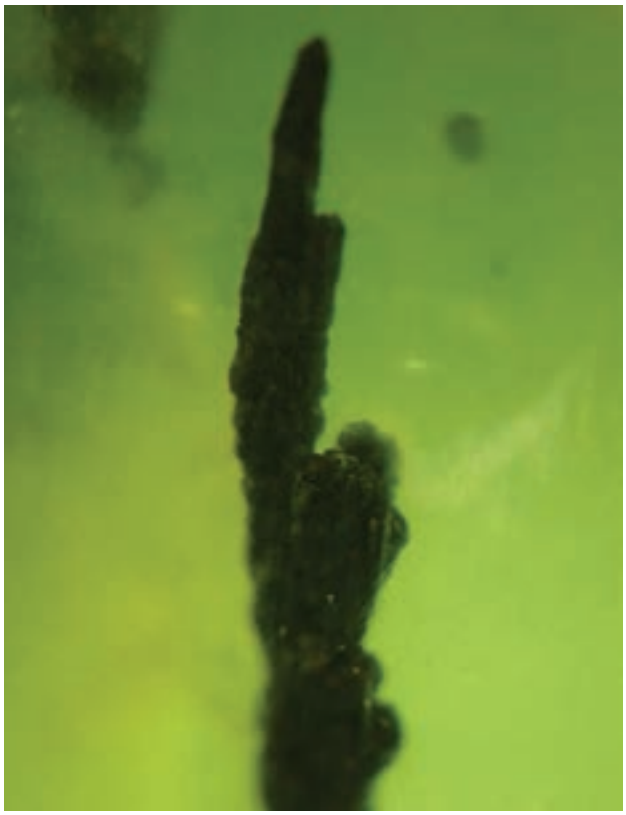

Figure 3: Some of the antigorite samples contained opaque black dendritic inclusions, such as those seen here. Photomicrograph by C. Williams; magnified 30×.

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Choudhary G., 2009. Gem News International: Serpentine cat's-eye. *Gems & Gemology*, **45**(2), 151–152.

Gaines R.V., Skinner H.C.W., Foord E.E., Mason B. and Rosenzweig A., 1997. *Dana's New Mineralogy*, 8th edn. John Wiley & Sons, New York, New York, USA, 1872 pp. (see pp. 1415–1417).

'Black' Axinite

Axinite is a rather unusual gem material that is most commonly encountered as the species axinite-(Fe), $Ca_2Fe^{2+}Al_2BSi_4O_{15}OH$, which typically shows an overall dark purplish brown coloration. However, at the February 2015 Tucson gem shows, some faceted examples of 'black' axinite were displayed by Mauro Pantò (The Beauty in the Rocks, Sassari, Italy). Pantò cut approximately 10 stones from a single large axinite crystal of unknown origin that his supplier suspected to be from Russia. The dark colour and translucent diaphaneity of the gems both appeared to be caused by abundant inclusions (Figure 4). Pantò mentioned that

Figure 4: These samples of 'black' axinite (5.04–12.87 ct) are coloured by abundant clinochlore inclusions. Photo by Mauro Pantò.

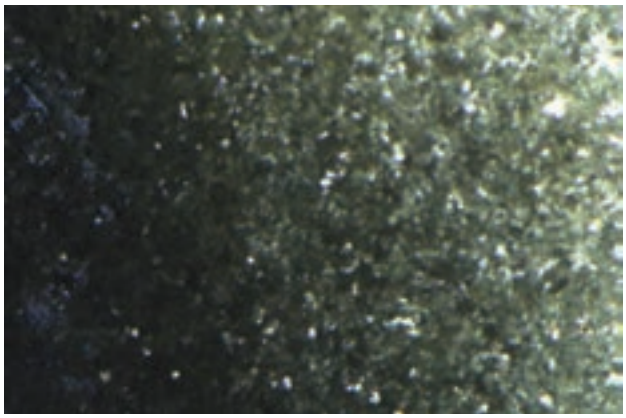

Figure 5: Clinochlore forms randomly oriented flakes in the 'black' axinite. Photomicrograph by N. Renfro, © GIA; image width 1.8 mm.

in an area of one stone containing a lower density of inclusions, the axinite appeared reddish purple.

Pantò kindly donated a 4.03 ct sample to Gem-A, which was examined by author NR. Viewed with the microscope, the sample contained a dense aggregation of randomly oriented greenish grey flakes (Figure 5); the abundant inclusions absorbed light and made the axinite appear black. Raman analysis of the inclusions with a Renishaw InVia instrument identified them as clinochlore. Gaines et al. (1997) reported that axinite-(Fe) may rarely be replaced by clinochlore-chamosite, but in this case the inclusions were syngenetic with the host.

Similar-appearing 'black' axinite crystals are known from Dal'negorsk, Primorskiy Kray, Far-Eastern Region, Russia, and also from Medel Valley, Grischun, Switzerland (www.mindat.org/gm/29239).

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Reference

Gaines R.V., Skinner H.C.W., Foord E.E., Mason B. and Rosenzweig A., 1997. *Dana's New Mineralogy*, 8th edn. John Wiley & Sons, New York, New York, USA, 1872 pp. (see p. 1154).

Beryl from Tanzania with Phenakite Inclusions

Gemmologists typically associate phenakite inclusions in beryl with so-called nail-head spicules in hydrothermal- and flux-grown synthetic emerald (e.g. Choudhary and Golecha, 2007). These synthetics may host elongate spindle-shaped two-phase (liquid and gas) inclusions that appear to have formed when a tiny crystalline inclusion (such as synthetic phenakite) locally interrupted the growth of the host synthetic emerald.

Figure 6: These 14.05 and 11.02 ct samples of beryl from Tanzania contain abundant colourless mineral inclusions that proved to be phenakite. Photo by Robison McMurtry, © GIA.

We were therefore interested to encounter inclusions of phenakite in two natural beryls. The tumble-polished 11.02 and 14.05 ct colourless beryls (goshenite; Figure 6) were donated to Gem-A by gem and mineral dealer Werner Radl (Mawingu Gems, Niederwörresbach, Germany) during the 2015 Tucson gem shows. According to his Tanzanian supplier, the beryl was mined from a claim owned by a Mr Madinga in the Haneti area of the Dodoma region in central Tanzania. All of the beryl showed diminished transparency due to abundant colourless inclusions.

Microscopic examination of both stones by one of us (NR) revealed numerous low-relief, colourless, blocky inclusions (Figure 7). Raman micro-spectroscopy with a Renishaw InVia instrument identified them as phenakite. Some of the phenakite inclusions were associated with tiny black grains that were too small to be identified with Raman analysis.

Phenakite has been reported previously in emerald from Madagascar (Gübelin and Koivula, 2008), but this is the first time to these authors' knowledge that it has been documented in any other beryl va-

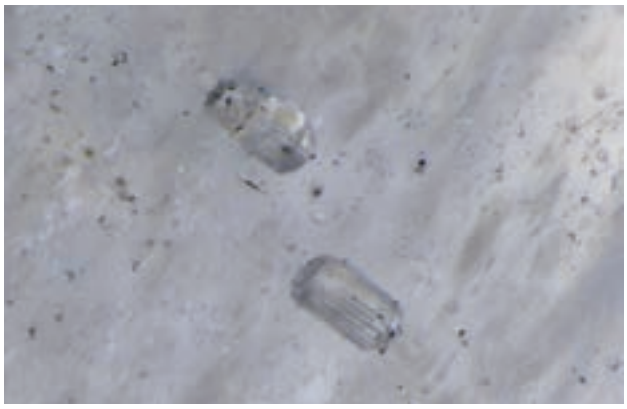

Figure 7: The phenakite inclusions in the Tanzanian beryl occur as colourless euhedral-to-subhedral crystals. Photomicrograph by N. Renfro, © GIA; image width 2.6 mm.

riety. Although the Dodoma area is not known as a source of beryl, there are reports of Li-bearing pegmatites in this region (e.g. www.aspecthuntley.com.au/asxdata/20160819/pdf/01768945.pdf). The potential for additional production of this goshenite is not known at this time.

Brendan M. Laurs and Nathan Renfro

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Clinohumite from Vietnam

The Cổng Trời mine in northern Vietnam is a well-known producer of various colours of spinels that are occasionally associated with orange clinohumite (e.g. Huong et al., 2012). This marble-hosted deposit is located ~3 km from An Phú in the Lục Yên District of Yên Bái Province. On separate buying trips to Lục Yên in 2013 and 2014, gem dealer Dudley Blauwet (Dudley Blauwet Gems, Louisville, Colorado, USA) obtained a single piece of facetable clinohumite (both of which were presented to him as chondrodite) from one of his regular suppliers of spinel crystals from Cổng Trời. One of the two pieces was cut into a single gem weighing >1 ct and the other one was faceted into five stones totalling 1.05 carats. The latter faceted pieces were received from the cutting factory in November 2014, and during the February 2016 Tucson gem shows, Blauwet loaned two of them for examination (Figure 8).

The stones consisted of a round brilliant and a cushion modified brilliant that weighed 0.32 and 0.54 ct, and measured 4.37–4.38 × 2.76 mm and 5.72 × 4.26 × 3.05 mm, respectively. RI readings of the two gems gave 1.635–1.670 and 1.639–1.670, yielding birefringence values of 0.035 and 0.031, respectively. Both were biaxial positive, and for the 0.32 ct stone, the RI of the β vibration direction could be seen as 1.640. Average hydrostatic SG values of 3.19 and 3.20 were obtained for the 0.32 and 0.54 ct samples, respectively. Strong orange and yellow pleochroism was observed in both stones using a calcite dichroscope. The gems were inert to long-wave UV radiation, but

Figure 8: These samples of clinohumite from Vietnam (0.32 and 0.54 ct) were studied for this report. Photo by Dirk van der Marel.

they fluoresced weak orange to the short-wave UV lamp.

The RIs were consistent with clinohumite, which has values between 1.623 and 1.674, and n_β = 1.636–1.643 (i.e. for a low-Fe composition; cf. Dedeyne and Quintens, 2007; Deer et al., 1982). By contrast, the RIs were higher than those reported for chondrodite (another mineral of the humite group), which typically are between 1.592 and 1.646 (n_β = 1.602–1.627). Also, the stones' reaction to short-wave UV radiation was typical for clinohumite, whereas chondrodite would remain inert (e.g. Fryer, 1986; Zwaan and Zoysa, 2002; Dedeyne and Quintens, 2007).

Both gems were only slightly included. Apart from partially healed fissures that consisted of minute voids, they contained rounded-to-euhedral transparent crystals (Figure 9) that were identified as apatite by Raman spectroscopy (with the closest match to fluorapatite).

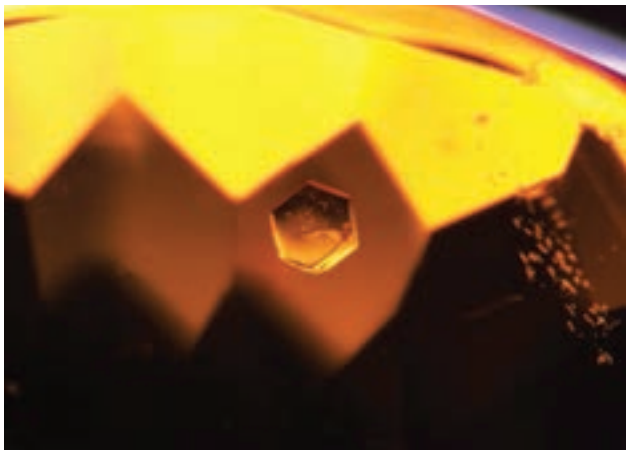

Figure 9: Both of the clinohumite study samples contained transparent apatite inclusions, which were mostly rounded. This particular apatite displays a hexagonal outline when viewed along the c-axis. Photomicrograph by J. C. Zwaan; image width 2.1 mm.

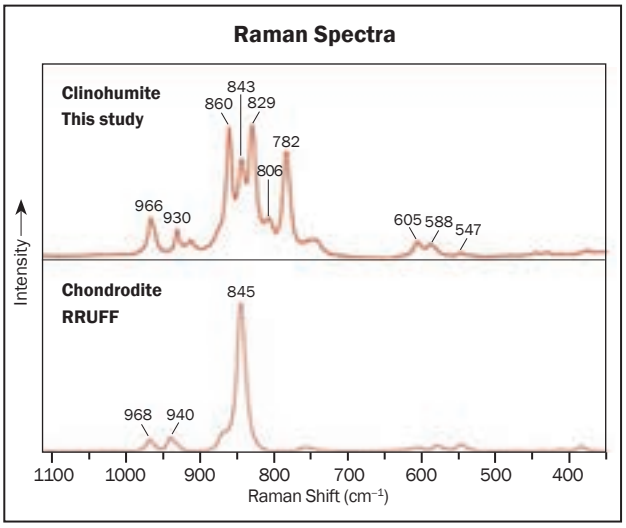

Figure 10: Raman spectra of the analysed samples (here, the 0.32 ct stone) show an excellent match with those of clinohumite, but differ greatly from chondrodite spectra in the RRUFF database.

Chemical analyses were obtained by EDXRF spectroscopy with an EDAX Orbis Micro-XRF Analyzer on the tables of the two stones, using a spot size of 300 µm. Apart from the main elements Mg and Si, the analyses showed low Fe (0.20–0.25 wt.% FeO) and considerable Ti (1.8–2.0 wt.% TiO_2).

As expected, both samples showed identical Raman spectra, which were collected with a Thermo Scientific DXR Raman microscope using 532 nm laser excitation. The spectra gave an excellent match with those for clinohumite in the RRUFF database (http://rruff.info)—and differed significantly from the spectra of chondrodite in the RRUFF database and those published by Frost et al. (2007), especially in the 1000–350 cm^{-1} region (Figure 10). Humite-group minerals are composed of silicate layers with the structure of olivine (Mg_2SiO_4) and brucite ($Mg[OH]_2$). The number of silicate layers varies depending on the mineral. The Raman spectra in the 1000–800 cm^{-1} region show a characteristic pattern that is attributed to stretching vibrations of the layered olivine $(SiO_4)^{4-}$ structural units. The Raman spectrum of chondrodite (a two-silicate-layered mineral) shows two or three bands depending on the chemical composition, while the spectra for clinohumite (a four-silicate-layered mineral) shows increased complexity in this region. The bands in the 750–500 cm^{-1} region correspond to the bending vibrations of the $(SiO_4)^{4-}$ units. A number of bands between 790 and 740 cm^{-1} are ascribed to MgOH and other $M^{2+}OH$ (M^{2+} = Mg, Ca, Mn, Fe, Co) deformations (Frost et al., 2007).

Vietnamese clinohumite will likely remain a rarity in the marketplace. According to Blauwet, it is typically poorly crystallized and heavily fractured, and only rarely are there clean areas suitable for cutting small gemstones. Although the orange material from Cổng Trời is commonly sold as chondrodite in Vietnam, this study confirms information from the literature that it is clinohumite.

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Lace Opal from Utah

The western USA is a source of both 'common' and play-of-colour varieties of opal. Recently these authors had the opportunity to examine some colourful banded samples marketed as 'Utah Lace Opal' (e.g. Figure 11). They were submitted to two of the authors (CW and BW) for identification and analysis by Larry and Joyce Wright of Aspen Rock and Gem, Cedaredge, Colorado, USA. They have been mining this material since 2008 in Milford County, south-central Utah, but it has yet to be gemmologically characterized.

Three pieces of rough, four polished slabs and three cabochons were examined. Most areas of the samples were opaque to slightly translucent, although some transparent bands were present that were colourless with a crackled appearance. Overall, white-to-grey areas were most common in the samples, and these alternated with purple to orangey red bands, as well as pink and 'mustard'-yellow layers (see Figures 11 and 12). A few of the specimens contained bluish grey bands. According to Mr Wright, the colour range of the material changes every few feet along the vein.

Several areas of each sample were analysed by FTIR spectroscopy (with a PerkinElmer Spectrum100 instrument) and Raman spectroscopy (GemmoRaman-532SG), which revealed that they consisted primarily of opal. Some of the colourless areas showed a 500 cm^{-1} Raman peak indicative of moganite. On two polished samples, spot

Figure 11: Left: These rough (up to ~11 × 7 cm) and cut (58.72 ct cabochon) samples of Utah Lace Opal show a range of colours and patterns. Right: These cabochons of Utah Lace Opal measure 41.4 × 28.61 × 7.14 mm (44.63 ct) and 31.7 × 23.73 × 7.15 mm (29.67 ct). Photos by B. Williams.

Figure 12: Left: Bands consisting mostly of colourless, white, purple and orangey red form well-defined layers in this Utah Lace Opal. Right: The purple band contains clusters of Fe-oxide inclusions within the colourless opal matrix. Photomicrographs by A. U. Falster; image width 3 mm (left) and 0.8 mm (right).

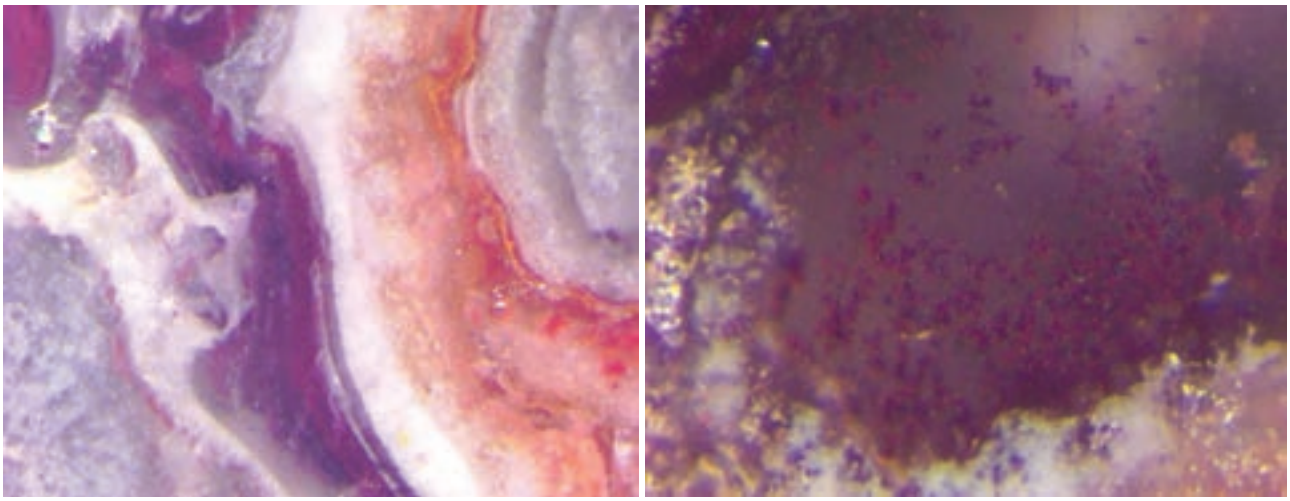

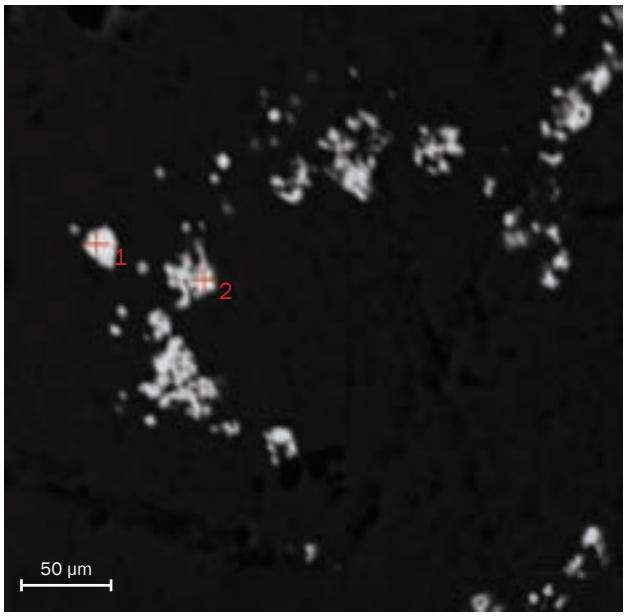

Figure 13: Backscattered-electron imaging of a polished surface of Utah Lace Opal shows bright-appearing sulfide inclusions. Approximately 20% of them consisted of an unidentified antimony thallium sulfide (e.g. spots 1 and 2), and the remainder were pyrite or marcasite. Image by A. U. Falster.

RI readings of 1.43 and 1.44 were obtained, and hydrostatic SG was measured as 2.08. Chemical analysis with an Amptek X123-SDD EDXRF spectrometer indicated the main impurities consisted of Fe, Mn, Ti, Ca and K. Iron was present in the red and yellow areas, and Mn in the black areas. The Ca and K are presumed to be present in the form of feldspar inclusions (see below). Trace amounts of Ni, Zn and Cu also were present.

A JEOL JSM-6400 scanning electron microscope was used to further investigate the composition of one piece of rough and two polished slabs by authors AUF and WBS. Backscattered-electron imaging and energy-dispersive spectroscopy (EDS) were used to analyse various inclusions, including Fe oxides (Figure 12, right), Fe sulphides (pyrite or marcasite; Figure 13) and alkali feldspar. Perhaps the most interesting were blebs of an antimony thallium sulphide (Figure 13). The only mineral species known with this combination of elements is weissbergite, $TlSbS_2$. However, the EDS spectrum indicated that Tl was not present in sufficient amounts, and more work is needed to confirm the identity of these inclusions. Nevertheless, Sb- and Tl-sulfide mineralization is common in a low-temperature hydrothermal environment, consistent with the formation of opal.

Areas of porosity were evident in some of the rough pieces, and the polished samples were brittle and easily broken along their edges. For these reasons, Wright stated that some of the cut material is treated by polymer stabilization, but none of the submitted samples showed indications of any treatment.

The name 'Utah Lace Opal' seems appropriate for this material, as it closely resembles the colourful, intricate, banded appearance seen in so-called lace agates, but tests primarily as common opal.

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Pollucite from Pakistan with Polylithionite Inclusions

Pollucite, $(Cs,Na)_2(Al_2Si_4O_{12})\cdot 2H_2O$, is an uncommon cesium mineral that is typically colourless or white. It has a Mohs hardness of 6½ but is rarely faceted as a collector's stone since it is very brittle and typically not very transparent. For approximately two decades, the granitic pegmatites in northern Pakistan—particularly in the Shengus area (Blauwet et al., 1997)—have been a source of fine pollucite crystals that are highly valued by mineral collectors.

At the 2015 Tucson gem shows, Dr Marco Campos Venuti (Gems in Gems, Seville, Spain) had faceted pollucite from northern Pakistan that contained interesting clusters of colourless inclusions (e.g. Figure 14). Approximately 0.5 kg of the rough material was obtained in early 2013, and 300–400 carats of stones were faceted that weighed up to ~60 ct (the largest stone present in Tucson weighed 14.31 ct). In November 2014, the inclusions in two samples were analysed by Raman micro-spectroscopy at Geospectra Scientific Solutions (Torrejón del Rey, Spain) and identified as polylithionite, $KLi_2Al(Si_4O_{10})(F,OH)_2$, a lithium-rich mica. The association of Li-rich mi-

Figure 14: This 1.20 ct pollucite from Pakistan contains inclusions of polylithionite. Photo by Robison McMurtry, © GIA.

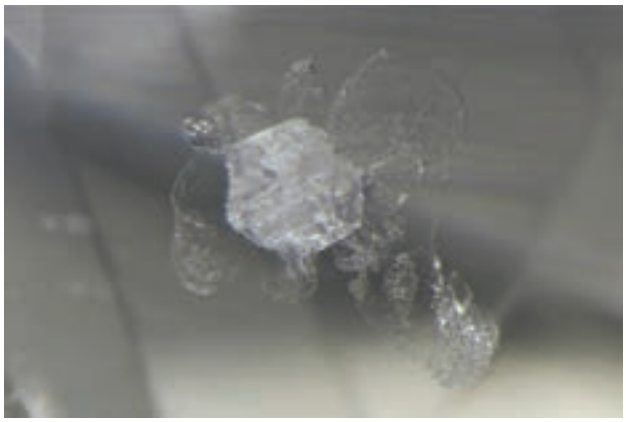

Figure 15: The polylithionite inclusions form clusters of subhedral crystals in the pollucite host. Photomicrograph by N. Renfro, © GIA; image width 2.0 mm.

cas with pollucite is known to occur in highly evolved granites and pegmatites (e.g. Wang et al., 2004), in which such micas are commonly called 'lepidolite', a discredited species that falls near or within the polylithionite-trilithionite series.

Dr Campos Venuti kindly donated a 1.20 ct oval cut to Gem-A, and microscopic examination by author NR showed the polylithionite inclusions forming in platy groups that were colourless to white and were mostly subhedral (Figure 15). As expected, Raman analysis (with a Renishaw InVia Raman instrument instrument) gave a close match to polylithionite in the RRUFF database. Interestingly, the inclusions displayed pale yellow fluorescence to short-wave UV radiation.

Gem-quality pollucite is quite rare, and these polylithionite inclusions make these gemstones even more interesting for collectors.

Brendan M. Laurs and Nathan Renfro

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Large Ruby Matrix Specimen from Lục Yên, Vietnam

In the Lục Yên region of northern Vietnam, gem mining activity—mainly for ruby and sapphire—boomed in the mid-1990s, but since the late 2000s facet-grade gem corundum has become rare (Huong et al., 2012). This is apparently due to the lack of access to appropriate technology and expertise, and mining is now typically restricted to small-scale diggings at easily worked secondary deposits near the surface. One of the main primary sources for ruby and sapphire in the area is marble, and only a few such hard-rock deposits have been exploited so far. The production from these mines typically consists of small matrix pieces of ruby/sapphire in marble that are commonly offered as collectors' samples in the local market.

Occasionally quite large matrix specimens are produced, and during a field excursion to the Lục Yên area that took place after the International Gemmological Conference in October 2013, a two-tonne marble specimen containing purple/violet corundum crystals was shown to participants by a local miner. The corundum crystals in that specimen ranged up to 20 cm long. It reportedly was recovered in spring 2013 from the Mây Thượng mine in the An Phú area. Interestingly, on the opposite side of the mountain from Mây Thượng is a well-known source of spinel, the Cổng Trời mine.

More recently, during a subsequent excursion to Lục Yên in March 2015, this author was shown by another local miner (Van Khiem Vu) several

Figure 16: This 400 kg specimen of ruby-bearing marble was recovered from the Mây Thượng mine in 2014 by Van Khiem Vu (pictured), who has worked the deposit for more than a decade. Photo by L. T.-T. Huong.

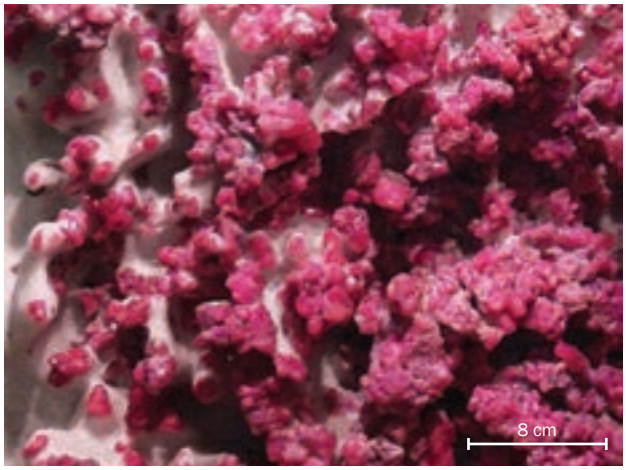

Figure 17: A closer view of the specimen in Figure 16 shows dense clusters of ruby crystals that have been carefully exposed from the marble. Photo by Lutz Nasdala.

large marble specimens containing ruby crystals that also were extracted from Mây Thượng. The most impressive specimen (Figure 16) weighed about 400 kg, and was carved from a two-tonne block of marble that was found in 2014. It contained dense clusters of ruby crystals, several of which possessed good transparency and were up to 4–5 cm long (Figure 17). According to Vu, he and his two brothers have worked the mine for approximately 10 years, and several tonnes of corundum-bearing marble have been extracted during that time. The quarrying is done by drilling and blasting, and then the corundum crystals are carefully exposed from the marble using simple tools such as a hammer, chisel and rasp. It took more than two months to prepare the specimen shown in Figure 16. Other large pieces that Vu and his team have produced weighed 300–700 kg after processing. Such specimens are prepared for sale as a single piece rather than being broken down into gem rough, because the price for such impressive mineral specimens is higher than the gem value they contain.

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Scapolite from Badakhshan, Afghanistan

While on a buying trip to Pakistan in June 2015, gem dealer Dudley Blauwet obtained a parcel of colourless-to-grey rough material that was represented as zoisite. According to his regular Afghan supplier, the stones came from Lajuar Madan, Kokcha Valley, Badakhshan, Afghanistan. The etched crystals showed a strong resemblance to the zoisite from the well-known Alchuri deposit in northern Pakistan, and some of them contained parallel inclusion features that would likely produce chatoyancy. Blauwet selected 80 pieces totalling 27.6 g for cutting, and in September 2015 he received from his factory 60 faceted stones weighing a total of 18.57 carats, as well as 18 cat's-eye cabochons weighing 8.94 carats.

During the 2016 Tucson gem shows, Blauwet loaned two samples to this author for examina-

Figure 18: Afghanistan is the source of these samples of colourless transparent and dark grey cat's-eye scapolite (0.76 and 1.06 ct, respectively). Photo by Dirk van der Marel.

tion: a colourless transparent emerald cut (6.76 × 4.77 × 3.70 mm) that weighed 0.76 ct, and a dark grey translucent cabochon (6.22–6.28 × 3.73 mm) that weighed 1.06 ct and showed a sharp cat's-eye (Figure 18). The cabochon's dark grey colour and translucency were caused by abundant inclusions; it was otherwise transparent and colourless, like the emerald-cut sample.

The RI values of the faceted stone were 1.548–1.570, yielding a birefringence of 0.022, and it was uniaxial negative. The cabochon gave a spot-RI reading of around 1.55. Average hydrostatic SG values of 2.70 and 2.68 were obtained for the faceted stone and the cabochon, respectively. The emerald-cut gem was practically inert to long-wave UV radiation, but under completely dark conditions it showed a very weak yellowish fluorescence, whereas the cabochon remained inert. Both stones showed weak red fluorescence to short-wave UV radiation.

The analysed properties are consistent with those of scapolite (cf. Deer et al., 2004; Dedeyne and Quintens, 2007); zoisite would show significantly higher RI and SG values. Raman analysis with a Thermo Scientific DXR Raman microscope, using 532 nm laser excitation, showed a closest match with the spectra of marialite (the Na-rich scapolite end member) in the RRUFF database. However, the RI and SG values indicated an intermediate composition between marialite, $Na_4Al_3Si_9O_{24}Cl$, and meionite, $Ca_4Al_6Si_6O_{24}CO_3$ (cf. Deer et al., 2004). EDXRF analysis (performed with an EDAX Orbis Micro-XRF Analyzer, using a spot size of 300 µm) confirmed an intermediate composition, with approximately equal amounts of Na and Ca (~7 wt.% oxide).

Both stones showed parallel-oriented growth tubes that were partially filled with opaque material and/or dendritic opaque minerals (Figure 19). The high abundance of these inclusions in the cabochon created the cat's-eye effect under pinpoint lighting. The many opaque inclusions also caused the overall dark grey colour of the stone. The faceted sample additionally hosted some multiphase inclusions that contained a gas bubble with opaque and transparent phases (Figure 20). Raman analysis of the inclusions was hampered by the rather strong fluorescence of the host scapolite. Attempts to analyse the opaque phases along the growth tubes and within the multiphase inclusions consistently yielded the spectrum of scapolite with an additional band at ~660 cm^{-1}. This position corresponds to the main vibration band of pyrolusite, suggesting the presence of manganese oxide(s). In addition, calcite was identified in a multiphase inclusion.

This scapolite is much different from the colourless material reported previously from the Lajuar Madan area in Afghanistan, which showed yellow UV fluorescence, had lower RI and SG

Figure 19: Parallel growth tubes containing opaque material are present in both the faceted stone (left) and the chatoyant cabochon (right) of scapolite. Photomicrographs by J. C. Zwaan; image width 1.4 mm.

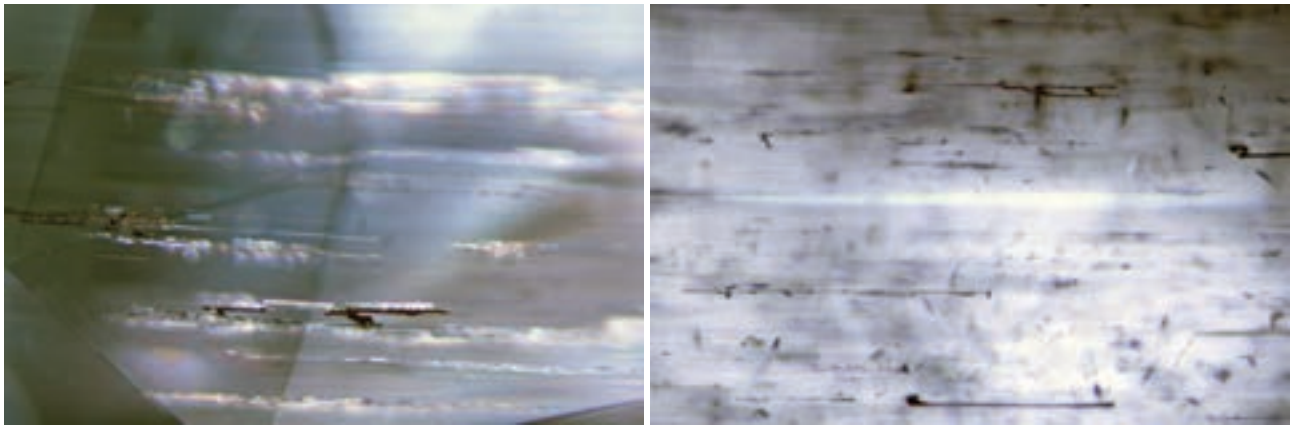

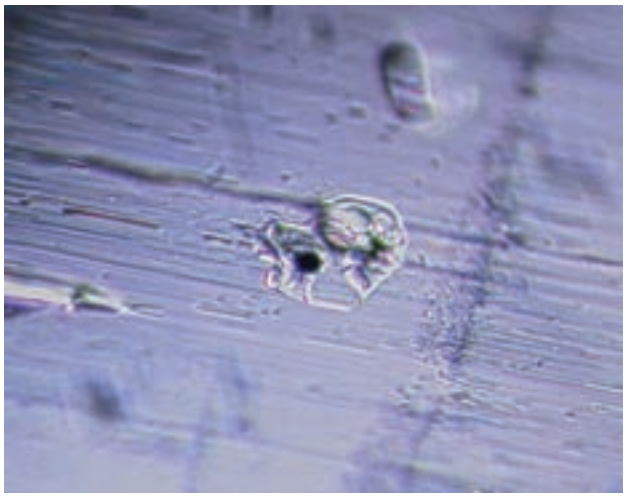

Figure 20: The faceted scapolite also contained multiphase inclusions, here consisting of a bubble in the upper part with an opaque grain (probably Mn oxide) and some colourless crystals. The crystal below the opaque mineral was identified as calcite; the other phases could not be identified. Photomicrograph by J. C. Zwaan; image width 0.3 mm.

values (corresponding to marialite), and contained inclusions of lazurite and apatite (Shen, 2011). In addition, it is distinct from the violet cat's-eye scapolite that has been documented from near the Papra (or Paprok) tourmaline mine in Afghanistan (Milisenda and Wehr, 2009).

Dr J. C. (Hanco) Zwaan

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Tourmaline from Ife, Osun State, Nigeria

For approximately the past three decades, Oyo State in south-west Nigeria has been known as a source of gem-quality pink, green and bicoloured tourmaline. In 2015, a new gem tourmaline occurrence was discovered in neighbouring Osun State, near the town of Ife (or Ilé-Ifẹ̀). Alluvial deposits of tourmaline and aquamarine in Osun State were reported by Ajeigbe et al. (2014), and the new tourmaline mine near Ife was briefly mentioned by Nwadique (2015).

During the 2016 Tucson gem shows, gem dealer Dudley Blauwet obtained approximately 35 bicoloured pink-green tourmaline crystals (total weight ~350 g) from Ife that showed good colour saturation, as well as sharp crystal faces with no evidence of alluvial transport. Most were sold as mineral specimens, although Blauwet had some broken pieces polished into cabochons (e.g. Figure 21). He loaned two stones to this author for examination that weighed 14.30 and 23.00 ct, and both of them displayed chatoyancy in their green portions. The most conspicuous inclusions consisted of partially healed fractures composed of typical 'trichite' fluid inclusions, which were particularly abundant in the pink portions of the stones, and elongate growth tubes oriented parallel to the c-axis (mostly in the green portions; Figure 22). Tiny birefringent colourless mineral inclusions were visible at the ends

Figure 21: This crystal (4.2 cm long) and cabochon (14.30 ct) of bicoloured tourmaline are from a new deposit in Osun State, Nigeria. The cabochon displays chatoyancy in its green portion. Photo by Orasa Weldon.

of some of the tubes. The tubes were responsible for the cat's-eye effect exhibited by the green portion of the cabochons.

It remains to be seen whether Osun State will become a significant source of gem-quality tourmaline in the future.

Brendan M. Laurs

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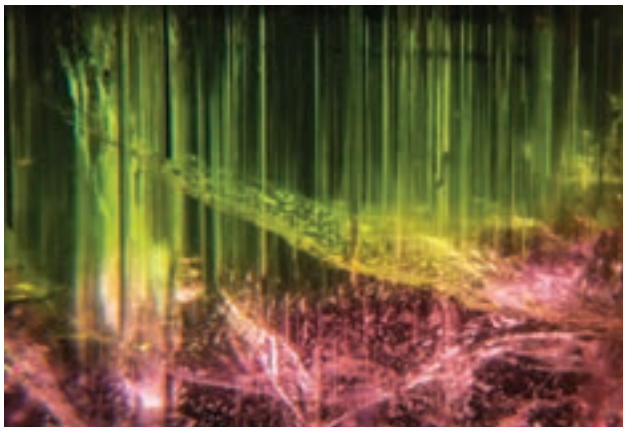

Figure 22: Parallel growth tubes are responsible for the chatoyancy of the green side of the Nigerian tourmaline cabochon in Figure 21, while the pink portion contains abundant partially healed fractures. Photomicrograph by Orasa Weldon; magnified ~45×.

Cat's-eye Väyrynenite from Pakistan

Väyrynenite, $MnBe(PO_4)(OH,F)$, is a rare phosphate mineral that is known in gem quality only from granitic pegmatites in Pakistan and Afghanistan (Laurs and Fritz, 2006a,b). During a buying trip to Skardu, Pakistan, in June 2014, gem dealer Dudley Blauwet obtained a small parcel of väyrynenite, with some pieces having a silky appearance. The parcel was sourced from a miner who was active in the Sabsar and Khargulook areas, located ~10 km east of Shengus in northern Pakistan. Blauwet sent 11 pieces weighing 3.8 g to his cutting factory, and when the order was returned in 2015, he found that one of the silky pieces was polished into a 0.62 ct cabochon that showed chatoyancy.

Figure 23: This 0.62 ct väyrynenite from northern Pakistan shows a weak cat's-eye, making it an extremely rare example of this unusual mineral. Photo by Dirk van der Marel.

The sample was transparent, slightly orangey pink, and had a weak cat's-eye (Figure 23). It measured 4.53–4.60 × 3.55 mm and weighed 0.62 ct. A spot-RI reading of ~1.64 and an average hydrostatic SG value of 3.22 were obtained. These data are consistent with those reported previously for faceted väyrynenite (Laurs and Fritz, 2006a,b) and correspond to the known values for the mineral: RIs of 1.638–1.667 (birefringence 0.026–0.028; biaxial negative) and SG of 3.23 (cf. Dedeyne and Quintens, 2007).

The stone showed distinct pleochroism in pink and 'straw' yellow, and was inert to both long- and short-wave UV radiation. The most notable inclusions were partially healed fissures that contained two-phase inclusions (Figure 24). Also present were some parallel-oriented very fine tubes or needles, although not in the abundance that normally would be expected in a chatoyant gem. However, many elongated voids in the partially healed fissures lined up parallel to these needles, possibly adding to the reflection of light, and thus contributing to the rather weak cat's-eye.

Raman analysis was carried out with a Thermo Scientific DXR Raman microscope using 532 nm laser excitation. The obtained spectrum showed an excellent match with a reference spectrum in the RRUFF database for väyrynenite, also from

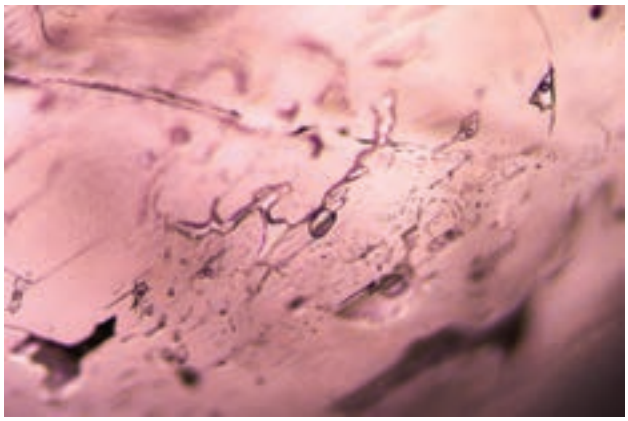

Figure 24: Partially healed fissures containing two-phase inclusions are prominent features in the cat's-eye väyrynenite. Photomicrograph by J. C. Zwaan; image width 1.4 mm.

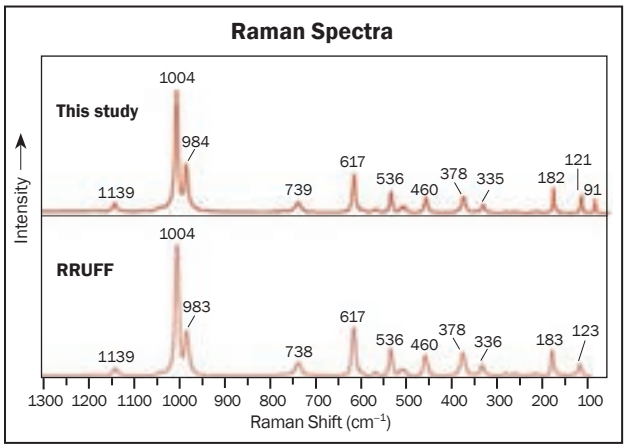

Figure 25: The Raman spectrum of the cat's-eye stone provides a good match to väyrynenite in the RRUFF database that is from Shengus in northern Pakistan.

northern Pakistan (Figure 25). The main peak at 1004 cm^{-1} and the strong band at 984 cm^{-1} are attributed to the PO_4^{3-} ν_1 symmetric stretching mode, while peaks between 800 and 300 cm^{-1} are due to PO_4^{3-} bending modes and vibrations of POH units (Frost et al., 2014). Additionally, in the 3800–2600 cm^{-1} region (not shown in Figure 25), a strong band was present at 3219 cm^{-1} that is assigned to the OH stretching vibration (Frost et al., 2014). Note that Raman spectra of väyrynenite from different localities (e.g. from Finland and Pakistan) may show significant differences, and these appear to be related to variations in chemical composition (Frost et al., 2014).

EDXRF analyses were performed with an EDAX Orbis Micro-XRF Analyzer, using a spot size of 300 µm. As expected, the main elements Mn and P were found (Be cannot be detected with this technique). Minor Fe and traces of Ca also were present, and these are consistent with electron microprobe analyses of väyrynenite reportedly from Gilgit, Pakistan (Falster et al., 2012).

This cat's-eye väyrynenite is extremely rare, and is the only example of this stone that Blauwet has seen after decades of dealing in gem material from Pakistan and Afghanistan.

Dr J. C. (Hanco) Zwaan

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SIMULANTS

Quartzite and Calcite Bangles, Resembling Jadeite

Recently submitted by an appraiser for identification were five bangle bracelets that were all represented as jade when sold to their client. Among them were obvious examples of agate and typical B-jade (bleached and polymer impregnated), but also some unexpected imitations.

One bangle appeared near-colourless but was actually very pale yellowish green (seen

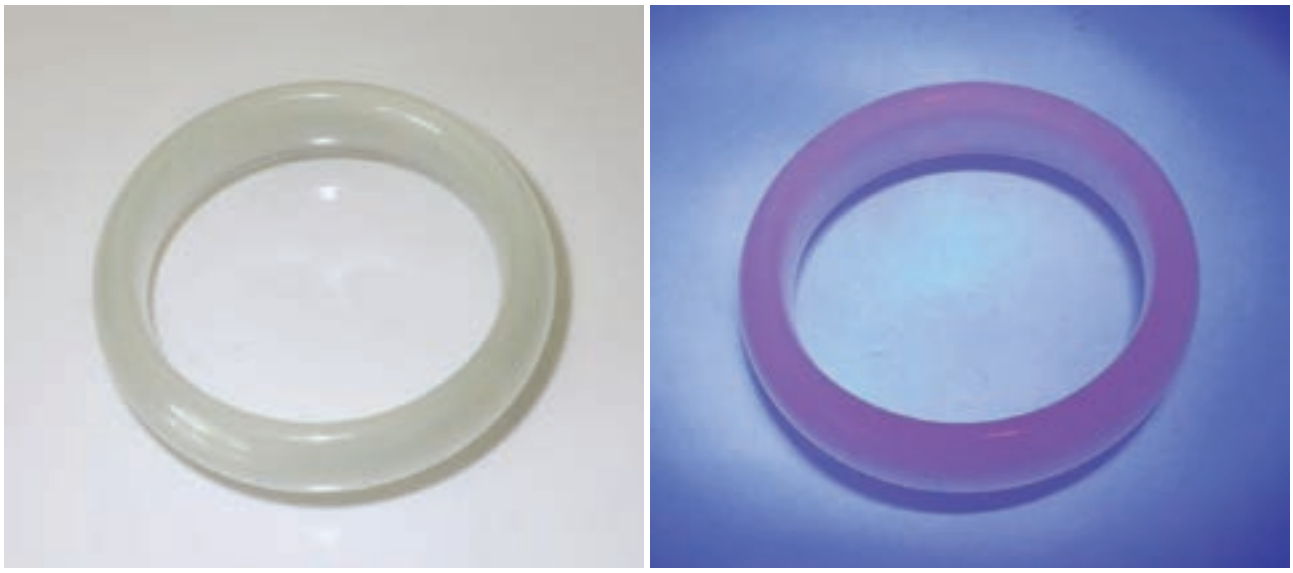

Figure 26: This 16.5-mm-diameter bangle resembling 'ice jade' proved to consist of calcite (left). It displays pink fluorescence to long-wave UV radiation (right). Photos by B. Williams.

only when placed on a white background). It exhibited the watery translucency typical of finer 'ice jade' (Figure 26, left), but Raman analysis with a GemmoRaman-532SG instrument identified it as calcite. Weighing 63.79 g, it was 16.5 mm in diameter and had an average thickness of 9.1 mm—which was somewhat thicker than a typical stone bangle. Close examination with a 10× loupe revealed an even pattern of colourless parallel banding throughout the piece, which created a weak, billowy cat's-eye effect along the entire circumference of the bangle. Viewed with the microscope, the banding was resolved as lamellar twinning together with numerous microscopic incipient cleavage cracks. Due to the twinning, the polariscope showed no 'blink' (i.e. the bangle remained light when it was rotated between crossed polarizers). No polymers or dyes were detected, either by microscopic observation or by FTIR spectroscopy with a PerkinElmer Spectrum100 unit. EDXRF chemical analysis with an Amptek X123-SDD spectrometer revealed a relatively high Mn content, and the bangle showed a uniform moderate pink fluorescence to long-wave UV radiation (Figure 26, right).

Another bangle appeared to be an imitation of 'moss-on-snow' jadeite (Figure 27, left), a variety that exhibits small areas of vivid green coloration in a white base. The bangle weighed 66.27 g and was 16.9 mm in diameter with an average thickness of 8.6 mm. It was highly trans-

Figure 27: Although appearing like 'moss-on-snow' jadeite, this 16.9-mm-diameter bangle consists of dyed quartzite (left). The green areas of the bangle exhibit strong green fluorescence to long-wave UV radiation (right). Photos by B. Williams.

lucent and mostly milky white, with three areas that were mottled in deep bluish green. Microscopic observation revealed the typical translucent graininess of quartzite, and the coloured areas showed green dye concentrations along grain boundaries. Raman analysis identified the bangle as quartz, confirming that it was quartzite. FTIR spectroscopy revealed the presence of a polymer in the coloured areas, which is the presumed method of delivering the dye. The green areas fluoresced a strong green under long-wave UV radiation (Figure 27, right).

While B-jade continues to be prevalent in the market, gemmologists should also be wary of other convincing jadeite imitations such as these.

Cara Williams FGA and Bear Williams FGA

TREATMENTS

Large Pink Sapphire with Diffusion-Induced Star

In August 2016, a large, semi-transparent to translucent, oval pink star cabochon mounted in a white metal ring with several diamonds was submitted for testing to the American Gemological Laboratories in New York (Figure 28). The client indicated that the cabochon weighed 56.47 ct before it was set in the ring. Measuring approximately 25.10 × 22.07 × 9.68 mm, the stone was quite impressive for its size, and visible-range spectroscopy using an S.I. Photonics CCD (charged coupled device)-array UV-Vis spectrophotometer showed that its attractive pink colour was caused by Cr^{3+}.

Figure 28: Measuring approximately 25 × 22 mm, the oval pink cabochon in this ring proved to be a heat-treated pink sapphire with a Ti-diffusion-induced star. Photo by Kelly Kramer.

Mid-infrared spectroscopy of the cabochon using a Thermo Nicolet 6700 FTIR spectrometer identified it as a sapphire. It also showed extremely weak lines at 3309 and 3232 cm^{-1}, which are part of a series of absorptions (3309, 3232 and 3185 cm^{-1}) that are indicative of heat treatment in metamorphic-related sapphires (Smith, 2010). Microscopic examination revealed numerous thermally-altered 'fingerprints' (partially healed fissures) that had a melted and drippy appearance. Coupled with sheets of heating residues that also were prevalent in the stone, heat treatment was evident. Fibre-optic lighting revealed an extremely shallow, sub-surface milky sheen/layer all over the stone (Figure 29). At 60× magnification, extremely minute needles could be discerned in this layer. In the absence of

Figure 29: The thin, sub-surface milky sheen/layer seen in the sapphire using fibre-optic lighting is an indication that the star is the result of a diffusion process. As shown here at 60× magnification, minute needles can be discerned. A thermally altered partially-healed fissure with a melted/drippy appearance can be seen at the lower left. The three prominent straight lines are parting planes. Photomicrograph by Christopher P. Smith.

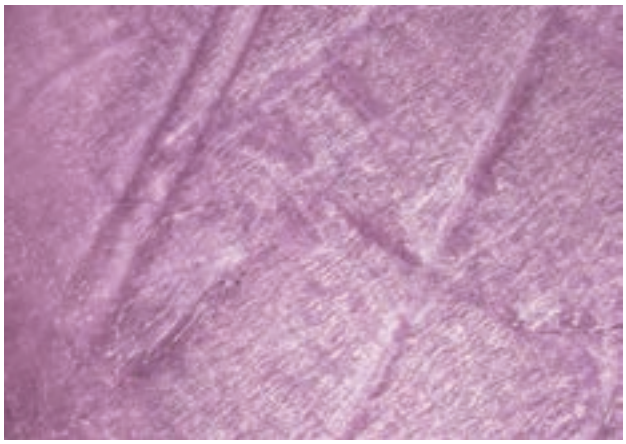

the typical three directions of rutile 'silk', it was evident that the stone's asterism was caused by this sub-surface layer. Semi-quantitative chemical analysis using a Thermo Scientific ARL Quant'X EDXRF spectrometer showed a relatively high amount of Ti (0.2 wt.%), which proved the star was not natural, but rather induced, by the diffusion of Ti.

Gemmologists should always be wary of a star stone that is missing the asterism-causing oriented needles. In sapphire, these needles consist of rutile (TiO_2) and they are resorbed into the corundum during the standard heating process, so a heated sapphire showing a star should arouse suspicion. For this particular pink sapphire, the absence of 'silk' combined with the sub-surface sheen provided telling evidence that the star is the result of a diffusion treatment process.

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MISCELLANEOUS

Mid-Year 2016 Myanma Jade & Gems Emporium

Figure 30: This is one of several warehouses containing jade lots at the recent Mid-Year 2016 Emporium. Photo by T. Hlaing.

On 20–29 November 2016, the Mid-Year 2016 Myanma Jade & Gems Emporium took place in Nay Pyi Taw, Myanmar. The opening day was marked by a visit from Myanmar's vice president, U Henry Van Thio, and this author also attended the Emporium on the same day. Some of the gem merchants there were seen with interpreters, and those buyers reportedly came from Guangdong, China, to attend the event. On offer were nearly 6,000 jade lots and 439 'gems' lots (e.g. rough or faceted ruby, sapphire, peridot, danburite, etc.). In addition to the main building, there were 15 warehouses containing various 'jade' lots (e.g. Figure 30), including those labelled as bowenite, amphibole, quartzite, albite and idocrase (e.g. Figure 31).

The Emporium was attended by 1,796 foreign and 1,746 local merchants. A total of €327.9 million were obtained from the sale of 4,041 jade lots, and €1.6 million came from 44 'gems' lots. Revenues were down compared to the previous Emporium, in which jade lots sold for €527.08 million and 'gems' lots brought in €3.15 million (see Gem Notes section, **35**(3), 210).

At next year's Emporium, scheduled for November 2017, sales are planned to take place in dollars rather than euros, since the USA's sanctions against Burmese jadeite and ruby from Myanmar have been lifted.

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Figure 31: The 'jade' lots at the Emporium included boulders of various materials, such as those labelled amphibole, quartzite and idocrase. Photos by T. Hlaing.

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Ruby and Pink Sapphire from Aappaluttoq, Greenland

Christopher P. Smith, Andrew J. Fagan and Bryan Clark

Since 1966, rubies and pink sapphires have been recovered from the southwest coastal region of Greenland. Until recently, only minor amounts of gem material were produced by local people using small-scale artisanal mining techniques. In 2014, True North Gems Inc. (Vancouver, British Columbia, Canada) completed mine permitting, and an exploitation licence for the extraction of gem corundum was issued for the area around the Aappaluttoq deposit. The property changed ownership in November 2016, and the first sale of its rubies and pink sapphires is expected to take place in 2017. The mineralization is hosted by the Fiskenæsset Anorthosite Complex, primarily within a phlogopite-bearing metasomatic rock. Standard gemmological properties are consistent with metamorphic-metasomatic-type rubies and pink sapphires from other world deposits. Typical inclusion features consist of coarse particles and fine needles of rutile, as well as inclusions of mica, talc, pargasite, cordierite, sillimanite, plagioclase and boehmite. The chemical composition of the Greenland rubies and pink sapphires is characterized by relatively high Fe contents and comparatively low concentrations of Ti, V and Ga.

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Introduction

Little attention has been paid to the gem corundum localities of Greenland since their discovery in the 1960s. However, during the past several years, True North Gems Inc. applied detailed geological mapping, geophysics, drilling (more than 6,000 m of core), geochemical and heavy mineral concentrate sampling, and mini-bulk and bulk sampling techniques to characterize and define a minable reserve at their Aappaluttoq deposit (Weston, 2009; Reggin and Horan, 2015). In 2014, True North received an exploitation licence after undergoing strict environmental and social permitting that accompanied extensive baseline surveys of the local ecology and villages. However, in September 2016, True North Gems Greenland, the operating subsidiary of True North Gems Inc., was unable to raise sufficient working capital to put the mine into production, and the project was taken over by LNS Group of Norway, which continues to work towards production and sales in 2017.

With the development of the Aappaluttoq deposit, Greenland is poised to become a significant producer of ruby and pink sapphire (e.g. Figure 1). The deposit has the potential to make an important contribution to the global supply of ruby and pink sapphire for many years. This article provides an update on the geology of the Aappaluttoq deposit and gives a comprehensive gemmological description of its rubies and pink sapphires.

Figure 1: A range of colour and clarity is shown by these rubies and pink sapphires (0.61–2.37 ct) from Greenland's Aappaluttoq deposit. Photo by Bilal Mahmood.

Location and Access

The gem corundum deposits of south-west Greenland are located approximately 200 km south of Greenland's capital city, Nuuk (Figure 2). From there, the mine is accessible by either a 45 minute helicopter flight or a five hour speedboat trip; there are no roads nearby. The area receives significant snowfall during the winter, when the average temperatures range from −10°C to +10°C (Statistics Greenland, 2016). Compared to the climate of the diamond mines in northern Canada, it is easier to conduct a mining operation in the more temperate environment of south-west Greenland.

The coast of western Greenland is mountainous with deeply incised fjords that run from the Davis Straight (between Canada and Greenland) inland toward the permanent ice sheet. At Aappaluttoq, only the local fjords (and not the open sea) freeze during the winter, so the mine is considered to have year-round sea access—a major logistical advantage. The vast majority of the labour required for the mine can be sourced from local towns and villages; this ensures that staff is well accustomed to working through the winter and also throughout the long days of summer.

Figure 2: The Aappaluttoq deposit is located south of Greenland's capital city, Nuuk. This satellite image of the Fiskenæsset gem district shows the approximate outline of the area where True North has concentrated its exploration efforts since 2006. The prospective ruby and pink sapphire deposits include Aappaluttoq, Siggartartulik and Kigutilik. Base photo courtesy of True North Gems Inc.

Geology and Gem Formation

The geology of the Aappaluttoq deposit has been summarized in several papers and conference abstracts (Appel, 1995; Weston, 2009; Reggin and Chow, 2011; Fagan and Groat, 2014a,b; Giuliani et al., 2014; Fagan, 2015; Reggin and Horan, 2015), and is still being actively researched by a team of company and academic geologists.

The rocks at Aappaluttoq have been subjected to high-pressure, high-temperature metamorphism and are very old (Mesoarchean); recent research suggests an age of approximately 2.9 billion years (Polat et al., 2010). Research is ongoing to define the actual age of the gem mineralization; the gems probably are significantly younger than their host rocks, related to later regional metamorphism and metasomatism. Nevertheless, Aappaluttoq still may be one of the oldest coloured stone deposits in the world (Krebs et al., 2016).

Greenland's gem corundum deposits are hosted by the Fiskenæsset Anorthosite Complex (FAC; see, e.g., Herd et al., 1969; Myers, 1975, 1985). The mineralization at Aappaluttoq is hosted by a reaction zone that formed from metasomatic interactions between ultramafic rock (peridotite) and mafic rock (leucogabbro). The peridotite forms a small lens or layer within the FAC and is composed of olivine, clinopyroxene, orthopyroxene, green spinel, amphibole and ilmenite, with minor apatite, magnesite, pyrrhotite and chalcopyrite. This ultramafic rock has low SiO_2 (<45 wt.%) and contains various chromophore elements (particularly Cr, and also V, Fe and Ti) that are important for the formation of an economically significant gem corundum deposit. The leucogabbro is a large and well-defined layer within the FAC. It has an Al-rich composition and comprises varying amounts of plagioclase, amphiboles (mostly hornblende and pargasite) and micas (biotite and phlogopite) with minor quartz. Although both the peridotite and leucogabbro have been regionally metamorphosed, most of their original igneous layering and textures are preserved.

In the metasomatized reaction zone, the ultramafic rock is rich in phlogopite (and is therefore called a *phlogopitite*; Figure 3) and consists of a steeply dipping layer approximately 2–5 m thick that extends to a depth of more than 90 m. It is composed of phlogopite-biotite (~80%), corundum (~10%), plagioclase (~5%) and oxide minerals (~5%) with minor amounts of amphiboles (pargasite, hornblende and gedrite). Adjacent to the phlogopitite reaction zone, the peridotite has been altered to a sapphirine-gedrite-hornblende assemblage. The metasomatized leucogabbro hosts some corundum mineralization, but since it does not contain as much Cr as the peridotite, it contains pink sapphire rather than ruby.

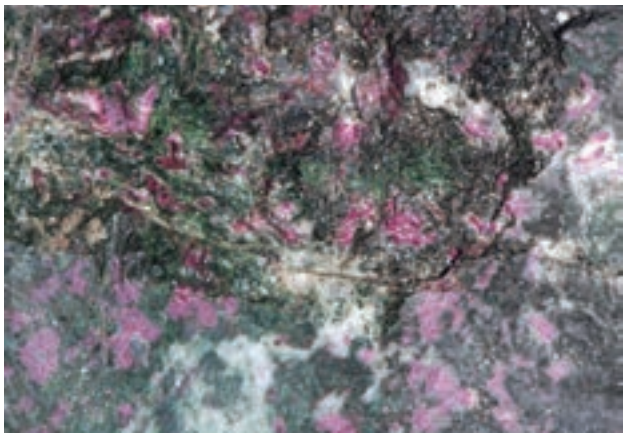

Figure 3: This unusually coarse-grained and high-grade corundum ore from Aappaluttoq consists of a phlogopitite rock that contains brown phlogopite-biotite, white plagioclase, dark green pargasite and pink-to-red corundum crystals up to 4 cm long. The lower part of the sample has been sawn, while the top part is a broken surface. Photo courtesy of True North Gems Inc.

Geochemical interactions between the differing rocks are thought to be responsible for forming the gem corundum. Although the general mechanism was suggested decades ago (Herd et al., 1969), new ideas regarding the geochemistry and timing have only recently been presented (Fagan and Groat, 2014a,b; Fagan et al., 2014; Krebs et al., 2016). According to these models, during regional metamorphism, fluid interactions between the two differing rock types created a metasomatic reaction zone encompassing part of the peridotite, the leucogabbro and the contact zone between the two units. Within this zone, silica was leached from the leucogabbro and the chromophoric elements were removed from the peridotite (Fagan and Groat, 2014). Upon regional cooling, the reaction zone formed significant volumes of stable phlogopite with corundum. Alumina (Al_2O_3), the main component of corundum, is believed to have remained stable in the residue of the altered leucogabbro. The concentration of Al in the reaction zone was high, and the availability of Cr from the adjacent peridotite

Figure 4: This aerial photo shows the construction of the processing plant and main workshop at the Aappaluttoq deposit, well underway. The processing plant will employ dense media and magnetic separation, as well as advanced optical sorting technology to extract the corundum. Since this image was taken in October 2015, the plant building has been completed. Photo courtesy of True North Gems Inc.

allowed the substitution of Cr^{3+} for Al^{3+} in the corundum, producing its pink-to-red coloration.

An examination of rough gem corundum derived from the 200 tonnes of rock extracted by True North from Aappaluttoq since 2006 reveals several crystal morphologies. The primary form for both ruby and pink sapphire is the hexagonal tablet, with crystals commonly ranging from 1.7 to 20 mm in dimension. These tablets formed between the layers of mica (phlogopite and biotite) in the main phlogopitite host rock. The morphology is not linked to coloration, with the tablets exhibiting all colours from deep red to 'lilac' pink. Within the altered leucogabbro, the dominant morphology consists of hexagonal prisms with pinacoidal terminations, in slightly larger sizes than those observed within the phlogopitite ore. In addition, hexagonal dipyramidal crystals up to 4 cm long rarely have been recovered from exploration samples.

Figure 5: Processing of ore from Aappaluttoq resulted in this rough concentrate of <4.6 mm-sized material. The pink-to-red corundum in this material will then be further separated with an optical sorter. Photo courtesy of True North Gems Inc.

Mining and Recovery

The Aappaluttoq deposit is being developed into one of the most advanced coloured stone mines in the world (Figure 4). Modern mining techniques are planned to maximize production, minimize cost and limit the opportunity for theft.

The extraction process is planned to begin with blocks of ore being quarried with large commercial wire saws—a technique borrowed from the dimension stone industry. These blocks will weigh approximately 20 tonnes each, and 5–8 of them will be produced each day. Each block will be transported to a processing facility, where it will be crushed into small pieces (initially 20 mm and processed down to 1.7 mm). Iterative crushing and recovery will ensure that the largest corundum stones are liberated rather than crushed. The material will be transported on closed conveyor belts to the Aappaluttoq Gem Recovery plant for further processing using dense media and magnetic separation followed by optical sorting technology to produce a corundum concentrate (e.g. Figure 5). This material will be sent to a separate facility in Greenland where the remaining host rock (approximately 25–30%) will be removed using a 24-hour hydrofluoric acid wash. The corundum will then be graded according to a customized sort matrix. After the opaque material is removed, the gem corundum (Figure 6) will be prepared for valuation and export. More

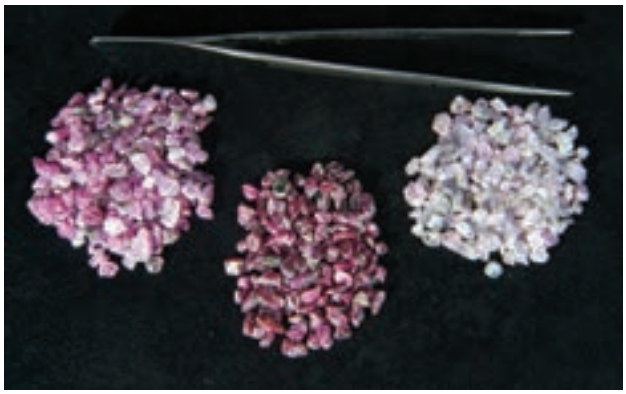

Figure 6: Initial sorting experiments of the rough gem corundum yielded these categories (from left to right) of 'medium pink', 'red' and 'lilac pink'. Photo courtesy of True North Gems Inc.

details on the ore processing and corundum recovery procedures are provided by Reggin and Horan (2015).

Production, Quality and Size

The use of modern exploration techniques at Aappaluttoq allows for a high degree of predictability in the grade and volume of gem corundum recovered from each mined block over the entire life-of-mine. This is unusual for a coloured gemstone deposit and should enable a dependable supply of rough material to the market.

Figure 7: These sapphires from Greenland range from light to intense pink; some also exhibit a subtle purplish colour modifier. The stones are eye-clean to moderately included and weigh 0.42–1.43 ct. Photo by Bilal Mahmood.

From the outset, True North Gems modelled the mine economics using only melee-sized (<4 mm) rough gem material. Although geological sampling has shown that larger stones are present within the deposit, their recovery is highly difficult to predict. The focus on melee-sized material will enable a steady supply of rough to partners in the marketplace, rather than relying on auctions that take place a few times per year. This improves mine cash flow and avoids 'peaks and surges' of gem corundum production. Although this strategy has led some to believe that Aappaluttoq will only produce small stones, this actually is not the case. Numerous faceted gemstones of >1 ct are held by the company in inventory recovered from exploration bulk samples; some of those gems were made available for this study (e.g. see the cover of this issue and Figure 7). The largest piece of corundum recovered to date is the carved opaque 440 ct Kitaa Ruby (see www.diamonds.net/News/NewsItem.aspx?ArticleID=15699).

The exploration bulk samples obtained during the early phases of the project have been processed for 'test-polishing' exercises, in which several kilograms of rough material were faceted to assess the quality of the material. The resulting sample inventory includes approximately 15,000 carats of polished material, ranging from cabochon-quality to extra-fine faceted material, in various colours, sizes and shapes. Pink sapphire makes up approximately 60–80% of this production, with ruby making up the balance. This colour proportion is in line with other deposits of this type, such as the Montepuez ruby mine in Mozambique (Roberts and Beare, 2015). For the highest quality polished stones from Aappaluttoq, valuations reached US$3,200/ct for intense pink sapphires and US$6,000/ct for deep red rubies.

Production from Aappaluttoq is expected to last for a minimum of nine years, and the deposit currently has defined minable reserves of 59.2 million grams of corundum, with an additional 21.8 million grams as inferred resources (i.e. exploration targets that could prolong the life-of-mine once they have been investigated further; see Reggin and Horan, 2015). Approximately 70% of the corundum is allocated to the non-gem 'opaque' category, 20–25% is 'near-gem' and 5–10% is 'gem'. These percentages are consist-

ent with other large gem corundum deposits (e.g. Roberts and Beare, 2015).

Materials and Methods

Nineteen faceted samples were provided by True North Gems to American Gemological Laboratories for this study. These consisted of 10 rubies (0.29–2.53 ct; see cover of this issue) and nine pink sapphires (0.42–1.43 ct; Figure 7).

Standard gemmological instrumentation was used to record pleochroism, RI, birefringence, optic character, hydrostatic SG, UV fluorescence (with a 4 W combination 365 nm long-wave and 254 nm short-wave lamp) and optical absorption spectra (with a prism-type desk-model spectroscope) for all samples. A binocular microscope, incorporating fibre-optic and other lighting techniques, was used to document internal features in the stones.

Identification of mineral inclusions was performed using a Renishaw 2000 Raman microscope. Additionally, we utilized a Thermo Scientific Nicolet 6700 Fourier-transform infrared (FTIR) spectrometer to record the absorption of all samples in the near- to mid-IR region of the spectrum (7000–400 cm^{-1}). Polarized ultraviolet-visible-near infrared (UV-Vis-NIR) spectra in the range of 250–850 nm were recorded on four of the stones with a PerkinElmer Lambda 950 spectrometer. A Thermo Scientific ARL Quant'X energy-dispersive X-ray fluorescence spectrometer (EDXRF) was used to determine the semi-quantitative chemical composition of all samples.

Results and Discussion

Gemmological Characteristics

Colour and Visual Appearance: Ten of the samples possessed a richly saturated, pure red coloration that classified them as ruby (see, e.g., the cover of this issue). The remaining nine pink sapphires ranged from a light pastel pink to an intense pink face-up appearance (Figure 7). Several of the pink sapphires displayed a subtle purplish colour modifier. No eye-visible colour zoning was observed. The majority of the samples were transparent, while several trended towards semi-transparent due to the nature and number of their inclusions.

All samples exhibited moderate-to-strong dichroism when viewed perpendicular to the c-axis with a dichroscope. Yellowish orange to orangey red or pink coloration was seen parallel to the c-axis, and reddish purple to purple-red (for rubies) or purplish pink to purple-pink (for pink sapphires) was observed perpendicular to the c-axis.

Gemmological Properties: The standard gemmological properties were consistent with corundum in general, and also with past research on rubies and pink sapphires from Greenland (Thirangoon, 2009): RI—n_ω = 1.769–1.700 and n_ε = 1.760–1.762, birefringence—0.008–0.009, optic character—uniaxial negative and SG—3.98–4.01. In general, the ruby samples displayed moderate-to-strong red fluorescence when exposed to long-wave UV radiation, whereas the pink sapphires displayed a weak-to-moderate red reaction. All samples showed weaker red fluorescence to short-wave radiation, ranging from weak to none. Four of the samples contained unidentifiable inclusions that fluoresced bright orange when exposed to both long-wave and short-wave UV radiation.

Internal Features: A rich diversity of features were noted in the rubies and pink sapphires from Greenland. In addition to twinning (see below), the most commonly observed internal features were clouds of minute rutile particles (i.e. 'silk', see Figure 8), as well as some fine rutile needles and arrowhead-shaped platelets (Figure 9). Generally speaking, few additional mineral inclusions were observed. Of these, we identified whitish inclusions of talc (Figure 10), whitish to

Figure 8: Clouds of fine rutile particles are one of the most common inclusion features observed in the rubies and pink sapphires from Greenland. Photomicrograph by C. P. Smith; magnified 55×.

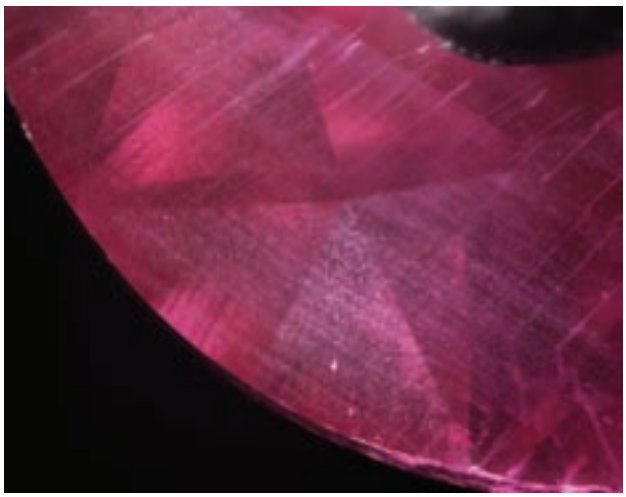

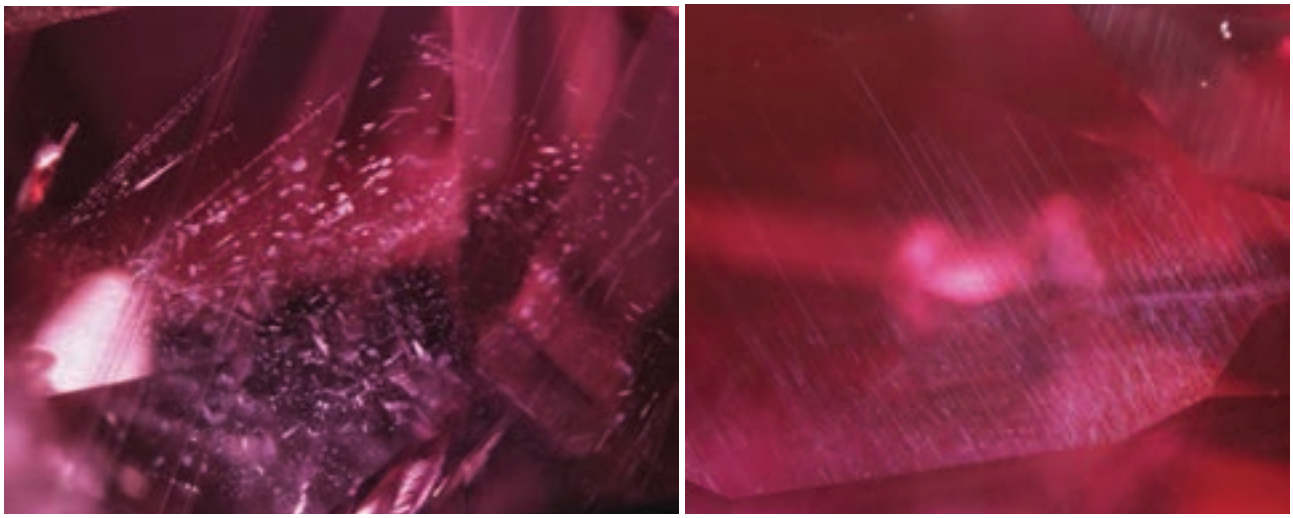

Figure 9: Fine exsolutions of rutile needles and platelets (sometimes arrowhead shaped) also are commonly encountered in Greenland gem corundum. Photomicrographs by C. P. Smith; magnified 58× (left) and 75× (right).

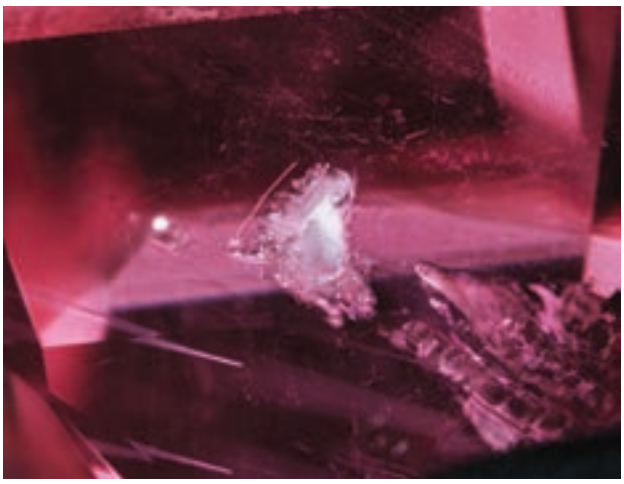

Figure 10: Of the various mineral inclusions identified, translucent, whitish inclusions of talc were the most commonly observed in the rubies and pink sapphires from Greenland. Photomicrograph by C. P. Smith; magnified 58×.

Figure 11: Mica is another of the more common mineral inclusions identified in Greenland rubies and pink sapphires. Photomicrograph by C. P. Smith; magnified 60×.

brownish crystals of mica (Figure 11), as well as cordierite, sillimanite, plagioclase and columnar crystals of pargasite (Figure 12). Additionally, we observed several rounded-to-oblong, colourless crystals that could not be identified with Raman spectroscopy (because Cr luminescence from the host gemstone swamped the Raman detector and resulted in a poor analysis); their appearance resembled apatite and zircon (Figure 13). Also present at the polished surface of some samples were inclusion assemblages composed of a variety of minerals, including talc, plagioclase, sillimanite and others.

We noted various patterns of partially healed fissures that were composed primarily of isolated (not interconnected) negative crystals (Figure 14).

Figure 12: Pargasite is not commonly found in rubies and sapphires, although a few samples in this study possessed columnar euhedral crystals of this amphibole-group mineral. Photomicrograph by C. P. Smith; magnified 62×.

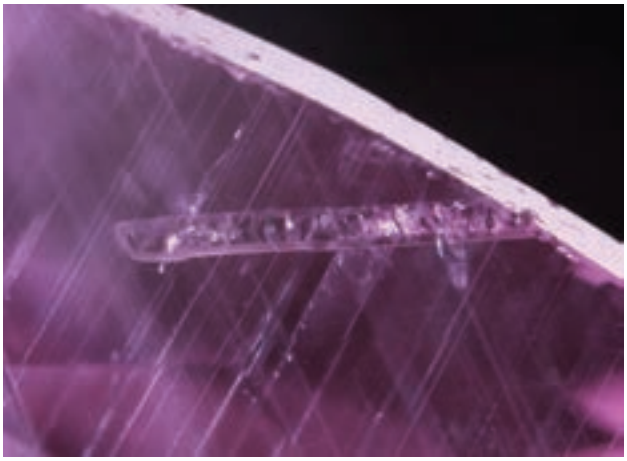

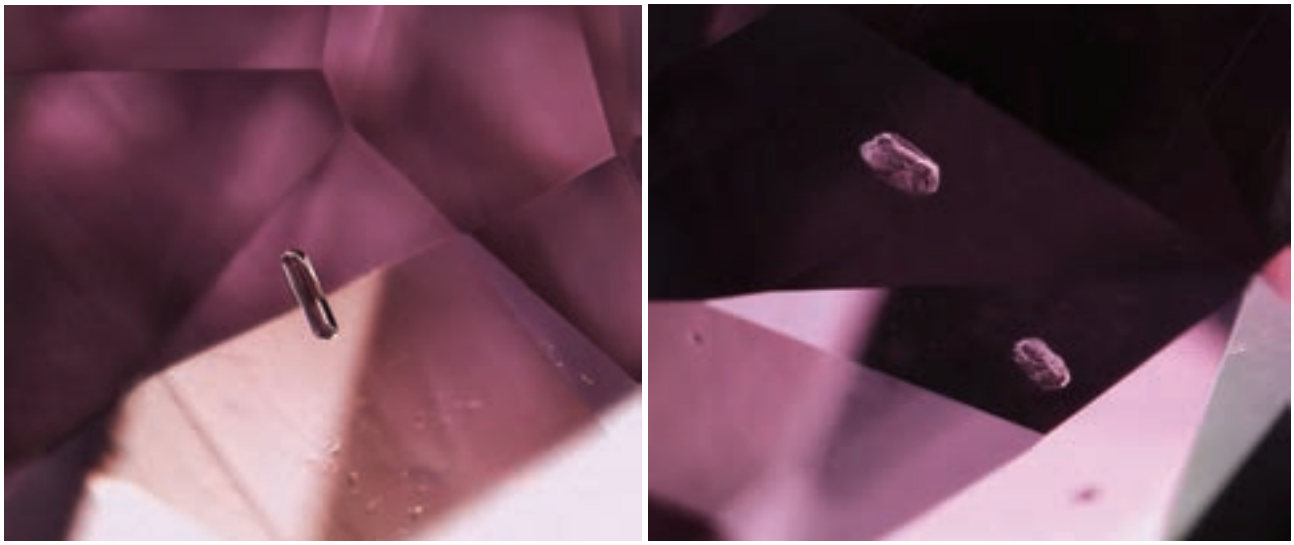

Figure 13: These inclusions could not be identified in this study, although they resemble zircon and/or apatite. Photomicrographs by C. P. Smith; magnified 60×.

In addition, one sample possessed basal-oriented thin films associated with negative crystals (Figure 15). The partially healed fissures and negative crystals seen in these samples interestingly did not trap any fluid phase. Also, the necking-down process of fissure healing typical of rubies and pink sapphires from most other deposits was not observed in these samples, and only tiny negative crystals were seen. It is possible that fluid may be present in these minute negative crystals but was too small to be recognized. It is also possible that there was not much fluid present under the high temperature and pressure conditions that the gems formed (i.e. near granulite metamorphic conditions).

Boehmite (identified by mid-IR spectroscopy) commonly formed an alteration product along a series of coarse, whitish intersection tubules occurring at the intersection of two or three twinning/parting planes (Figure 16). Open fissures also were commonly observed, and often they were lined by epigenetic minerals such as boehmite, kaolinite, goethite and other weathering minerals.

Additional mineral inclusions of catapleiite, chlorite, cosalite, dolomite, magnesite, margarite, pyroxene and sapphirine have been identified in

Figure 14: Partially healed fissures composed of groups of isolated negative crystals are a common feature in Greenland rubies and pink sapphires. Photomicrograph by C. P. Smith; magnified 55×.

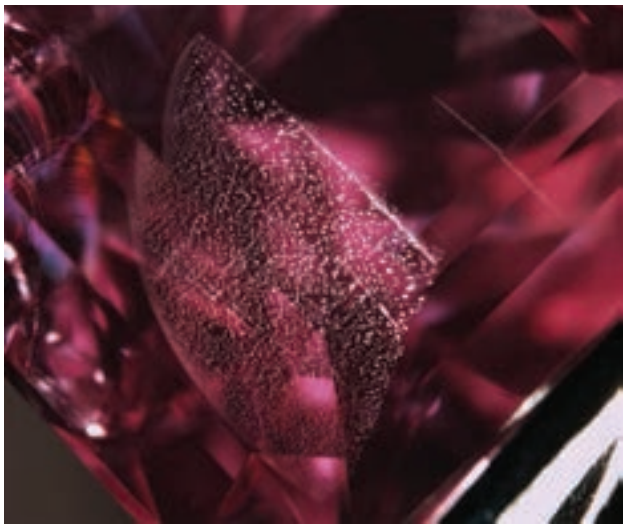

Figure 15: A series of fine, platy negative crystals and thin films are oriented along the basal growth planes in this pink sapphire. Photomicrograph by C. P. Smith; magnified 50×.

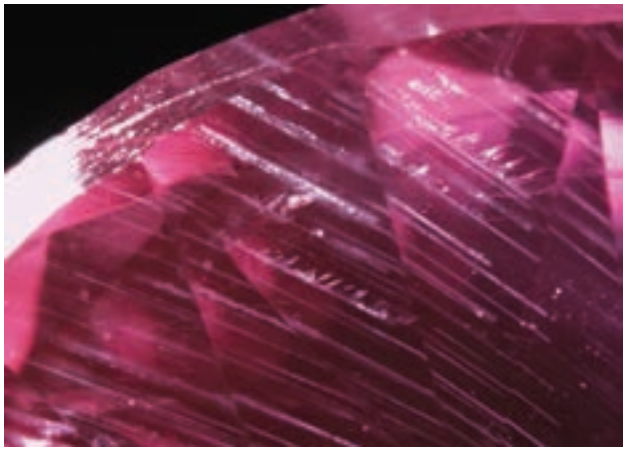

Figure 16: Boehmite is found along intersection tubules that commonly occurred at the crossing of twinning (and sometimes parting) planes in the rubies and pink sapphires. Also visible are a series of stress fractures along the length of some of the tubules. Photomicrograph by C. P. Smith; magnified 60×.

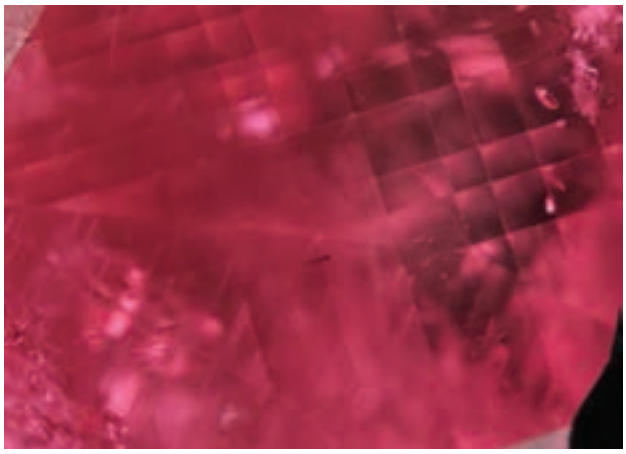

Figure 17: Intersecting twinning along different directions of the positive rhombohedron r {10$\bar{1}$1} create a checkerboard pattern in this ruby. Photomicrograph by C. P. Smith; magnified 42×.

Greenland rubies and pink sapphires by other researchers (e.g. Thirangoon, 2009).

Internal Growth Structures, Colour Zoning and Twinning: Generally, the samples contained rare-to-no internal growth structures, and their colour was homogeneous. A few showed subtle planar growth structures, and weak-to-distinct pink-to-red colour zones were rarely noted.

Several of the stones displayed twinning parallel to the positive rhombohedron *r* {10$\bar{1}$1}. Typically we noted only one direction of laminated twinning, parallel to a single series of *r* planes. Occasionally, however, there were as many as three directions of twinning parallel to additional *r* planes. Parting parallel to *r* also was prominent in a few samples. The intersections of twinning and/or parting planes created a checkerboard pattern (Figure 17).

Visible and UV-Vis-NIR Spectroscopy

All spectra were dominated by chromium absorption features. The strength of the absorption bands varied with the intensity of the pink-to-red colour of the gems.

Desk-model Spectroscope: In the visible range, a general absorption to approximately 450 nm was apparent, along with weak-to-distinct lines at 468 nm and at 475/476 nm (doublet). A broad absorption band was observed from approximately 525 to 585 nm; its width depended on the saturation of pink-to-red colour. We also noted faint lines at 659 and 668 nm, plus two strong lines at 692 and 694 nm (which appeared as a bright emission line at 693 nm).

UV-Vis-NIR Polarized Spectroscopy: Two broad bands, centred at approximately 405 and 550 nm, as well as weak-to-distinct sharp peaks recorded at 468, 475, 476, 659, 668, 692 and 694 nm, are

*Table I: Semi-quantitative EDXRF chemical analyses of rubies and pink sapphires from Greenland.**

Variety	Ruby (sample no.)									
Element	**1681**	**1889**	**1945**	**1952**	**2165**	**2236**	**2309**	**2311**	**3403**	**3426**
Al	99.27	99.43	99.33	99.24	99.09	99.30	99.46	99.39	98.88	99.44
Ti	228	1227	141	95	112	124	81	139	128	156
V	72	46	64	67	62	72	83	36	38	44
Cr	4552	2701	4353	5242	6860	5084	3358	3086	8387	2754
Fe	2261	2686	1999	2058	1837	1624	1728	2706	2435	2507
Ga	49	49	55	54	53	54	56	41	52	42

* Data are in wt.% for Al and in parts per million by weight (ppmw) for all other elements. Approximate detection limits are Ti = 22, V = 20, Cr = 18, Fe = 11 and Ga = 7 ppmw.

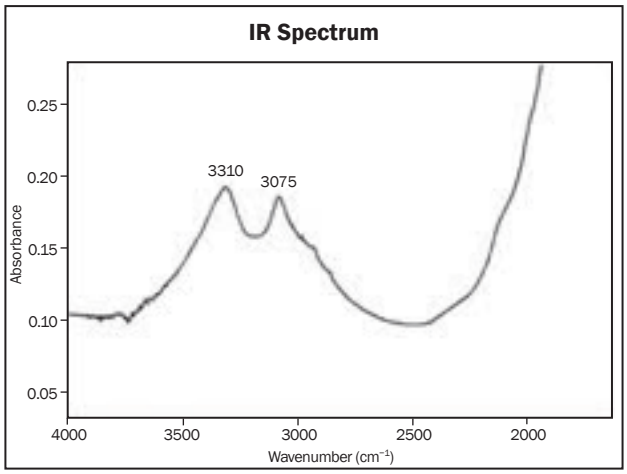

Figure 18: In the mid-infrared region of the spectrum, some rubies and pink sapphires from Greenland showed distinct bands at approximately 3310 and 3075 cm^{-1} (and weak bands at approximately 2100 and 1980 cm^{-1}). These features indicate the presence of boehmite, which was mostly concentrated along intersection tubules related to twinning and/or parting planes. Such absorption characteristics are helpful not only for identifying the presence of foreign mineral phases, but also for proving that a gem has not been heated.

all ascribed to Cr^{3+}. A weak band was also occasionally observed at 450 nm, attributed to Fe^{3+} pair transition.

FTIR Spectroscopy

In addition to the dominant IR absorption characteristics of corundum between 1000 and 400 cm^{-1} (i.e. approximately 760, 642, 602 and 450 cm^{-1}: Wefers and Bell, 1972), the rubies and pink sapphires in this study commonly had weak-to-very strong absorptions related to structurally bonded OH groups and foreign minerals. A nominal, sharp band was recorded at 3310 cm^{-1} in several samples. Additionally, a weak series of absorptions with the dominant feature at 3161 cm^{-1} was found in one stone. These are all associated with structurally bonded OH groups (Smith and van der Bogert, 2006). Also common were two dominant bands positioned at approximately 3310 and 3075 cm^{-1} (Figure 18), with an additional pair of weak bands at approximately 2100 and 1980 cm^{-1}. These features are related to OH-stretching frequencies associated with boehmite, an aluminium hydroxide mineral (Farmer, 1974; Wefers and Misra, 1987; Smith et al., 1997). Several samples had additional absorptions in this region that further signalled the presence of kaolinite, goethite and other weathering minerals (cf. Smith and van der Bogert, 2006). The specific mineral phase could not be identified in all instances.

The presence of boehmite was generally traced to locations along parting planes, interpenetrating intersection tubules and open fissures, whereas the presence of kaolinite, goethite, etc. was generally attributed to epigenetic staining present in surface-reaching fissures.

Chemical Analyses

The most significant minor- to trace-element variations were recorded in Cr concentrations, which again correlated to the intensity of the red-to-pink colour. Ti and Fe were the next most significant trace elements, followed by very small amounts of V and Ga (Table I). Although higher Ti contents were recorded previously by Thirangoon (2009), other elements (Cr, V, Fe and Ga) were consistent with that study. Mg was below the detection limit of EDXRF spectroscopy in all samples. Although Keulen and Kalvig (2013) also analysed corundum from Greenland, a direct comparison to their dataset is impossible due to their use of normalized data and the absence of any verifiably comparable gem-quality

Pink Sapphire (sample no.)								
1512	**1519**	**1849**	**1888**	**1891**	**1894**	**1895**	**1896**	**1897**
99.73	99.80	99.71	99.56	99.64	99.63	99.69	99.74	99.74
141	149	128	81	56	130	143	108	139
94	42	32	69	82	38	40	37	67
561	869	750	2269	1524	1070	1058	775	298
1784	886	1919	1895	1788	2407	1705	1580	1997
40	31	57	50	63	58	63	42	60

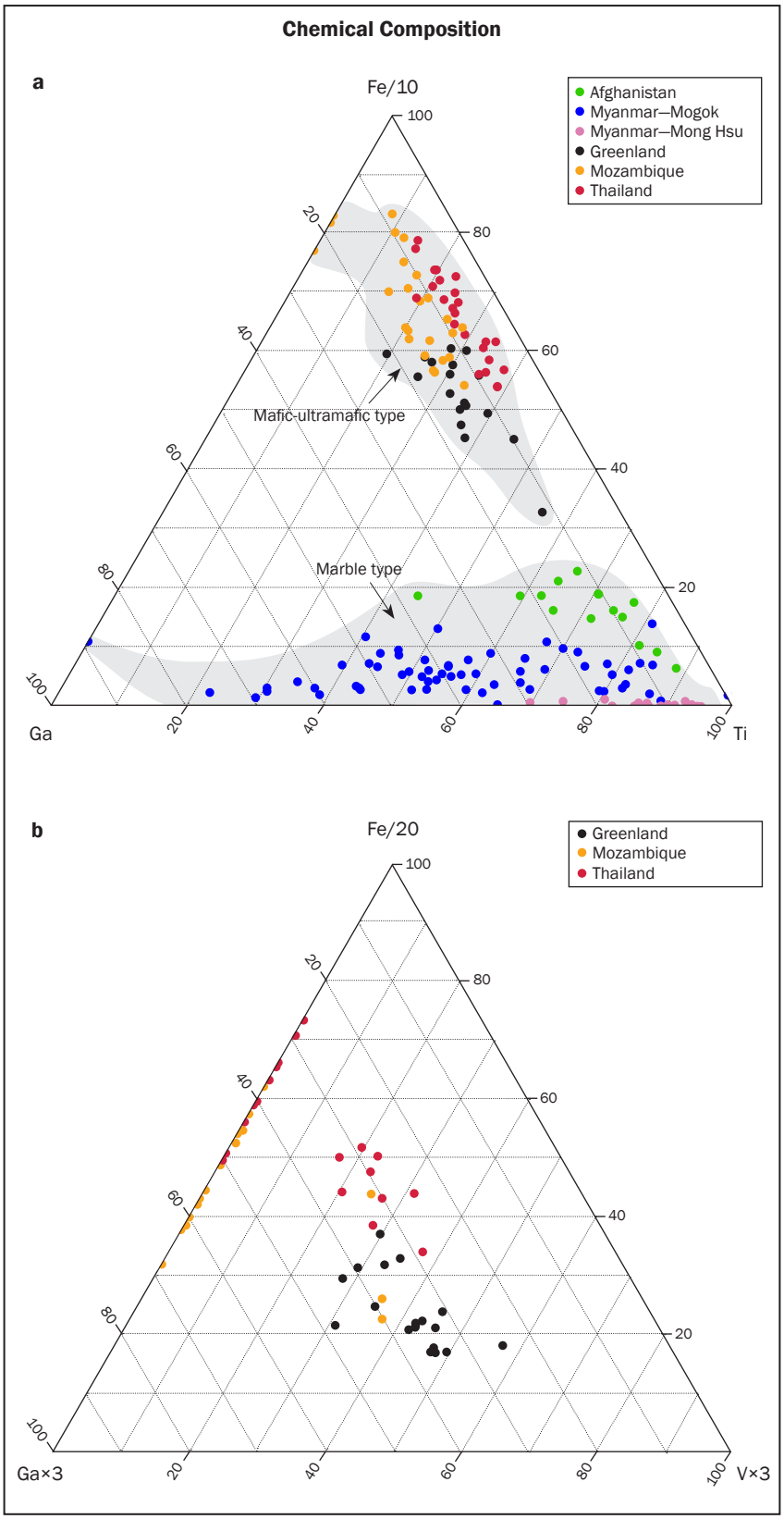

Figure 19: (a) The concentrations of Fe, Ti and Ga are plotted for the rubies and pink sapphires from Greenland as compared to some other major world sources, including marble-type deposits from Afghanistan (Jegdalek) and Myanmar (Mogok and Mong Hsu), mafic metamorphic-metasomatic rocks from Mozambique (Montepuez) and alkali basalts from Thailand (Chanthaburi and Trat). The relatively higher Fe contents of the mafic-ultramafic-derived gems from Greenland, Mozambique and Thailand readily separate these sources from marble-type deposits. (b) Further correlations of these and other elements such as V help to separate the relatively higher-Fe sources from those of Greenland, although there is some overlap—particularly with stones from Mozambique.

samples from the same deposit. In the present authors' opinion, the analyses of opaque material in a geographic origin study do not normally compare well to those of the high-quality stones that are routinely submitted to gemmological laboratories.

Figure 19 illustrates how the composition of the rubies from Greenland compares to that of rubies from some other major deposits. Further geochemical and isotopic work is ongoing in association with the University of Alberta (Krebs et al., 2016) and the University of British Columbia.

Geographic Origin Determination

There are a number of features that may help gemmologists recognize a ruby or pink sapphire from Greenland. Their relatively high Fe content separates them from the majority of stones from marble-type deposits, such as those in Afghanistan, Myanmar, Nepal, Pakistan and Vietnam, as well as plumasites (i.e. Mangare, Kenya) and metasomatized mafic dykes in marble (i.e. Mahenge and Matombo in Tanzania). For pink sapphires, this also includes the placer deposits of Sri Lanka and Madagascar (Ilakaka).

Rubies and pink sapphires from basalt-related deposits also contain relatively high Fe, although correlations between other trace elements can help to separate them from those of Greenland (again, see Figure 19). In addition, the typical inclusion features of thin films oriented along basal growth zoning and associated with doubly truncated negative crystals, such as those found in the basalt-related deposits of Thailand, Cambodia and Kenya (Lake Baringo), were not encountered in our Greenland samples. The Fe content of our Greenland stones was similar to that of some rubies and pink sapphires from East Africa (Madagascar, Mozambique, Tanzania and Malawi). Further work on the trace-element and isotopic composition of the Greenlandic material is ongoing and should prove helpful for origin fingerprinting (Fagan and Groat, 2014a,b; Krebs et. al., 2016).

Some typical microscopic properties of Greenland gem corundum include the relative fineness of the rutile silk as compared to the typically coarser rutile particles observed in a number of the East African deposits. In addition, certain mineral inclusions such as cordierite, cosalite and catapleiite that have been identified in previous studies (Thirangoon, 2009) may also point to a Greenland origin.

It should be noted that none of the rubies and pink sapphires included in this study were heat treated, and this is one of the current marketing points of the Greenland gem corundum. However, and the majority of the rubies and pink sapphires sold in the market have been heat treated, it should be expected that heated Greenland gems will also become available (directly or indirectly) at some point. Once a stone has been heated, geographic origin determination becomes more difficult, as key identification features such as rutile patterns and other mineral inclusions become altered.

Conclusions

In the near future, it is expected that rubies and pink sapphires from Greenland will become a significant new addition to the gem and jewellery market. Although gem corundum was first discovered there in the 1960s, a full mineral exploration study was not completed until 2011. Since then, the Aappaluttoq deposit has gone through the mine permitting process, and an exploitation licence was issued in 2014. Once fully financed and constructed, large-scale mining activities will commence.

Mineral inclusions in these rubies and pink sapphires are consistent with the metamorphosed and metasomatized mafic-ultramafic host rocks. Inclusions of mica (mostly brown phlogopite-biotite), feldspar (plagioclase) and pargasite are typical minerals of the phlogopitite and leucogabbro host rocks. Inclusions of talc are consistent with the alteration of ultramafic rocks, and boehmite also may be attributed to a retrograde metamorphic alteration of the host corundum. The presence of sillimanite and cordierite inclusions is consistent with the pressure-temperature conditions expected for the Aappaluttoq stones. Other researchers have also identified catapleiite, chlorite, cosalite, dolomite, magnesite, margarite, pyroxene and sapphirine inclusions in rough ruby and pink sapphire samples from Greenland (Thirangoon, 2009). The minor-to-trace-element composition of the Greenland gem corundum revealed relatively high Fe with comparatively low Ti, V and Ga.

By taking into account the complete array of gemmological characteristics and chemical data, we found that it is possible to separate the gem-quality Greenland rubies and pink sapphires from those of the more commercially important deposits in Myanmar, Thailand, Madagascar, Mozambique, Kenya, Vietnam and elsewhere.

Despite the poor mining finance climate that currently exists, it is likely that Aappaluttoq will go into production in 2017. Thus the gem and jewellery trade should expect an influx of Greenland rubies and pink sapphires in the near future.

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Geology, Gemmological Properties and Preliminary Heat Treatment of Gem-Quality Zircon from the Central Highlands of Vietnam

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Gem-quality brown zircon occurs in alluvial deposits derived from Neogene–Quaternary alkali basalts in the Central Highlands of Vietnam. Rough and cut samples were characterized using standard gemmological methods, chemical analysis (electron microprobe and LA-ICP-MS), and Raman, FTIR and UV-Vis-NIR spectroscopy. Among the internal features observed were colour zoning and various mineral inclusions, such as apatite, ilmenite, hematite and iron hydroxide. The analysed samples contained up to 1.14 wt.% HfO_2 and 0.08 wt.% total REE oxides. Darker brown stones contained greater amounts of Hf than the lighter-coloured ones. Raman and FTIR spectroscopy showed that the zircon is high-type (i.e. has high crystallinity). As with the famous Ratanakiri zircon of neighbouring Cambodia, heat treatments can be applied to dark-coloured samples to lighten the coloration in an oxidizing atmosphere or induce blue colour in reducing conditions.

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Introduction

Zircon ($ZrSiO_4$) crystallizes in the tetragonal system and is a common and widely distributed accessory mineral in most types of igneous and metamorphic rocks. Zircon of gem quality has been reported from various localities, including Australia, Cambodia, Thailand, Myanmar, Sri Lanka, China and Tanzania (Shigley et al., 2010; Yu et al., 2010; Chen et al., 2011; Sutherland et al., 2016). In the Central Highlands of Vietnam, gem-quality brown zircon (e.g. Figure 1) has been exploited—usually together with sapphire—in basalt-related alluvial deposits (Garnier et al., 2005; Huong et al., 2012).

In general, zircon comes in a variety of colours, and most gem material falls into one of two colour series (Gastil et al., 1967): (1) a common pink series that is highly metamict (radiation damaged) and ranges from pink to 'rose', red, purple ('hyacinth') and green to black; and (2) a

Figure 1: Vietnamese zircon commonly ranges from reddish to orangey brown, as shown by these 3.25–6.70 ct gemstones. Photo by N. T. M. Thuyet.

less-common yellow series of highly crystalline to moderately radiation-damaged zircon that ranges from pale yellow to 'straw' or 'honey' yellow to brown. In general, the coloration of zircon is affected by its trace-element composition (i.e. transition metals and rare-earth elements [REEs]) and also by radiation damage (i.e. radiation-induced colour centres; Wanthanachaisaeng et al., 2014).

Typically, traces of REEs are incorporated into zircon through the substitution $REE^{3+} + P^{5+} \rightarrow Si^{4+} + Zr^{4+}$ (Hanchar et al., 2001). Other trivalent elements can substitute in Zr^{4+} sites in the form $M^{3+} + H^{+} \rightarrow Zr^{4+}$, accompanied by H^{+} as well as OH^{-}, where H^{+} may bond with a nearby oxygen atom (Woodhead et al., 1991b). Hafnium as well as radioactive elements such as U^{4+} and Th^{4+} can substitute for Zr^{4+} in dodecahedral coordination; the resulting radiation damage to the structure results in metamict zircon (Finch et al., 2001). In extreme cases, the radiation damage increases the distance between atoms and decreases the degree of lattice ordering, forming amorphous zircon as a final end-product of metamictization. Vibration frequencies corresponding to lattice ordering and bond length in the zircon structure can be characterized by Fourier-transform infrared (FTIR) and Raman spectroscopy. Both FTIR and Raman modes of the $[SiO_4]^{4-}$ group show intense and sharp bands in crystalline zircon, weakened bands in radiation-damaged samples and the absence of these bands in highly metamict zircon (Woodhead et al., 1991a; Nasdala et al., 1995).

This article presents the gemmological and physical properties of brown zircon from the Central Highlands of Vietnam, together with its chemical composition (major and trace elements, including total REE and the radioactive elements Th and U), as well as Raman, FTIR and ultraviolet-visible-near infrared (UV-Vis-NIR) spectroscopic features. Also described are preliminary heat-treatment experiments. The results show that zircon from the Central Highlands has similar properties and heat-treatment behaviours to those of zircon from Ratanakiri, Cambodia (cf. Khoi et al., 2012; Huong et al., 2012, 2014).

Geology and Occurrence

In Southeast Asia and the adjacent Pacific region, gem-quality zircon has been brought to the earth's surface in basalts that formed as a result of diffused mantle magmatic activity. Particularly important are alkali basalts that commonly contain mantle xenoliths as well as sapphire and zircon xenocrysts, such as those in the Central Highlands of Vietnam (Hoang and Flower, 1998; Sutherland et al., 2016). These zircon occurrences are hosted by the Kon Tum (or Kontum) block, one of five structural terranes of Vietnam (Nam, 1995; see Figure 2). This block forms the earliest continental part of Vietnam, as the first granitization process took place 2.3 billion years ago. The Kon Tum massif has been stable since the Late Proterozoic, with only thin platform cover formation and virtually no Paleozoic rocks (Nam, 1995). In the Neogene–Quaternary Periods, mantle melting took place under a vast region of Southeast Asia, including central and southern Vietnam as well as adjacent Cambodia and Laos. This resulted in a large basalt plateau that formed during the age range of 0.8–17.6 million years (see Rangin et al., 1995; Hoang et al., 1998; Garnier et al., 2005; Sutherland et al., 2016). Two distinct basaltic suites are recognized in the region: tholeiitic (without xenocrysts) and alkaline (containing mantle and lower-crustal xenocrysts, including gems such as sapphire, zircon and olivine; Hoang and Flower, 1998; Garnier et al., 2005; Izokh et al., 2010; Thuyet et al., 2016). Several zircon occurrences related to these basalts have been discovered, among them the famous Ratanakiri deposit in Cambodia (e.g. Payette and Pearson, 2011). Significant zircon deposits also are located in Vietnam, including the Kon Tum, Gia Lai, Đắk Lắk, Đắk Nông, Lâm Đồng and Bình

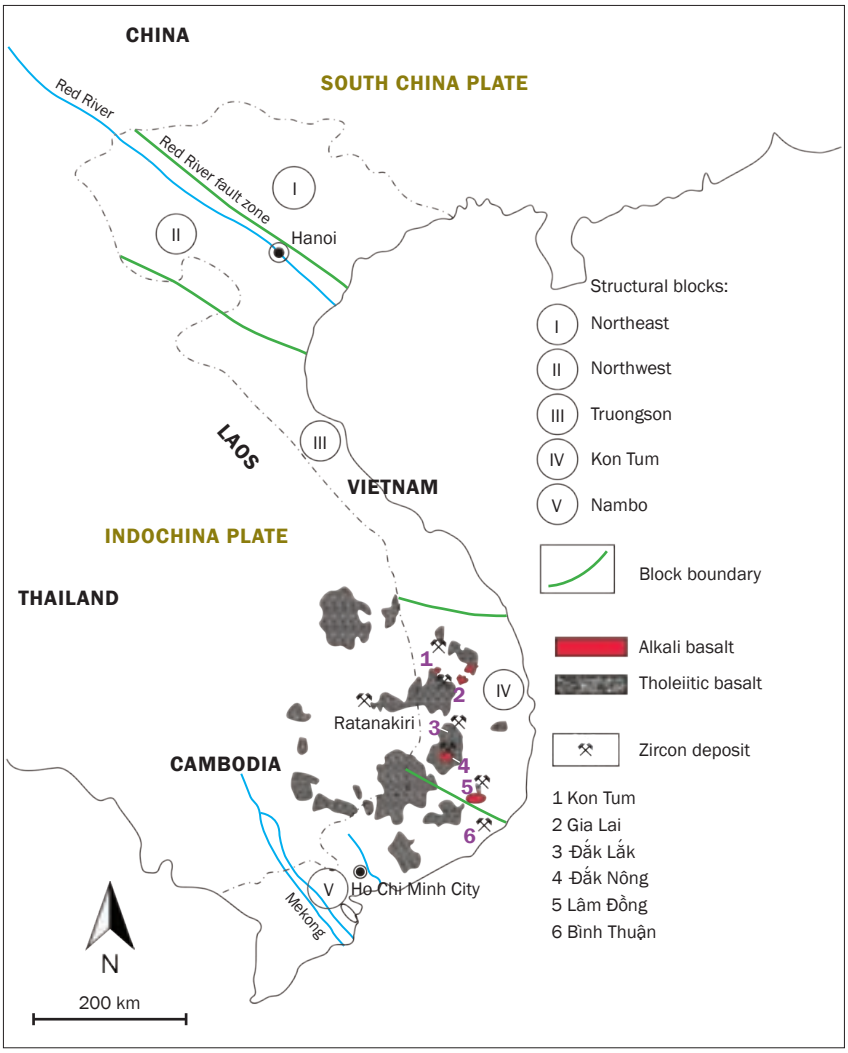

Figure 2: Alluvial deposits of brown zircon in Southeast Asia are related to basaltic magmatism. Most of the zircon mines in Vietnam are located within the Kon Tum block. The famous zircon deposit of Ratanakiri, Cambodia, is located about 150 km from the closest zircon mine in Vietnam (in Gia Lai Province).

Thuận Provinces. The formation ages of basalts containing gem zircon are in the range of 0.8–1.6 million years (Ma) at Ratanakiri, which is comparable with the ages of the Gia Lai (0.8–4.3 Ma), Đắk Nông (1.1–7.1 Ma) and Đắk Lắk basalts (1.1–5.8 Ma; Hoang and Flower, 1998; Garnier et al., 2005; Sutherland et al., 2016).

The Vietnamese zircon deposits have been known since the late 1980s, and during the past two decades sporadic mining activities have taken place at numerous small workings. All deposits have been exploited by informal surface digging by local people, who extract the gems by hand after washing the alluvial material. As reported by local miners, monthly production from each site varies from 200 kg to some hundreds of kilograms (Huong et al., 2012). Although widespread in its occurrence in the region, the zircon commonly shows a similar reddish brown coloration (e.g. Figure 3) from the various deposits, including Ratanakiri. Overall, the colour ranges from very light brown (near-colourless) to orangey or yellowish brown to very dark reddish brown (Figure 4). Zircon samples from various locations in the Central Highlands were briefly described by Khoi et al. (2012) and Huong et al. (2014).

Samples and Methods

For this article, we investigated the gemmological, chemical and spectroscopic features of 20 rough zircon samples (up to 1 cm in dimension; again, see Figure 4) from the Gia Lai and Đắk Nông deposits, and six faceted samples (3.25–6.70 ct; see, e.g., Figure 1) from unspecified localities in the Central Highlands. The rough samples were collected by the authors from the field or bought from miners after they finished washing the soil; they ranged from very light brown (near-colourless) to orangey, reddish and dark reddish brown. The faceted stones, purchased from a

Figure 3: Vietnamese zircon typically consists of short, stubby or elongated prismatic crystals and fragments ranging from very light brown to orangey, reddish and dark reddish brown. Photo by L. T.-T. Huong.

trusted local dealer in Đắk Lắk, were dark reddish brown (4), reddish brown (1) and orangey brown (1). All samples were tested with a dichroscope, a hydrostatic Shimadzu balance (for specific gravity), a UV lamp, a desk-model prism-type spectroscope and a Schneider immersion microscope with Zeiss optics. Eight rough samples representing the four different colour categories—very light brown (near-colourless) and orangey, reddish and dark reddish brown (two samples per category)—were selected for quantitative chemical analysis by electron microprobe and laser ablation inductively coupled plasma mass spectrometry (LA-ICP-MS) and also for Raman, FTIR and UV-Vis-NIR spectroscopy.

Electron microprobe analysis was performed with a JEOL JXA-8900RL instrument equipped with wavelength-dispersive spectrometers, using 20 kV acceleration voltage and 20 nA filament current. Only the Si content of the samples was analysed by microprobe, and wollastonite was used as a standard. The trace elements were measured with an LA-ICP-MS system (ESI NWR193 laser ablation unit and Agilent 7500 ICP-MS) at the Central Lab for Water, Minerals and Rocks, NAWI Graz Geocentre, Graz, Austria. The samples were ablated using a 193 nm laser pulsed at 9 Hz, with a 75 µm spot size and an energy of ~8 J/cm^2. Helium was used as the carrier gas (flow of ~0.7 l/min), and data were acquired in time-resolved mode. For each analysis, a gas blank was obtained for background correction. The laser was active for 60 seconds followed by 30 seconds of washout time. The glasses

Figure 4: These rough samples of Vietnamese zircon were studied for this report. They are divided into four different colour groups: very light brown, orangey brown, reddish brown and dark reddish brown. Photo by N. T. M. Thuyet.

NIST610 or NIST612 were routinely analysed for standardization and drift correction, while zircon standard 91500 and basalt standard BCR-2 were analysed as unknowns to monitor the accuracy of the measurements. Both standards could be reproduced to within ±10% of the certified values. Silicon was used as an internal standard.

Raman spectra were collected with a Horiba Jobin Yvon LabRAM HR800 spectrometer coupled with an Olympus BX41 optical microscope and a Si-based charge-coupled device (CCD) detector; samples were excited by a 633 nm red He-Ne laser. Raman micro-spectroscopy of inclusions was performed in confocal mode, facilitating analysis at the micron scale (2–5 µm). Infrared spectra were collected in the 4000–400 cm^{-1} range with 64 scans and 4 cm^{-1} resolution, using a Thermo Scientific Nicolet 6700 FTIR spectrometer equipped with an optimized beam condenser. The analyses were done on powder ground from inclusion-free areas of the zircon samples. The measurements were carried out in transmittance mode, and the spectra were converted from transmittance to absorbance (so that bands in the 3800–3400 cm^{-1} range were more obvious). UV-Vis-NIR absorption spectra were recorded in the 200–1600 nm range with 20 scans using a Zeiss Axio Imager.A2m microscope that was connected to two spectrometers from J&M Analytik AG: a TIDAS S with a diode-array CCD detector (200–980 nm range with 0.75 nm resolution) and a TIDAS S 900 with an InGaAs detector (900–1600 nm range with 2.8 nm resolution).

Heat-treatment experiments were done with a Nabertherm L9/SH furnace, under both oxidizing (one faceted and 20 rough samples) and reducing (24 pieces of rough) conditions. After annealing at the target temperature (200–1,000°C for two hours), the furnace was slowly cooled to room temperature before the samples were removed. After heat treatment, the samples were analysed with Raman spectroscopy to check their structural state.

Results and Discussion

Visual Appearance and Physical Properties

The rough zircon samples consisted of short, stubby or elongated prismatic crystals (again, see Figures 3 and 4). Irregularly shaped fragments were common, but some well-formed tetragonal prisms also were present. Diaphaneity varied from translucent to transparent. The samples ranged from almost colourless to orangey brown to dark reddish brown. Viewed with the dichroscope, they showed weak-to-distinct pleochroism in purplish brown and brownish yellow. Hydrostatic SG ranged from 4.10 to 4.60; transparent samples usually had higher SG values than translucent ones. All samples were inert to long- and short-wave UV radiation. Absorption spectra could be observed only for the transparent, near-colourless to light-coloured samples, which showed typical REE-related features.

Internal Features

Microscopic observation revealed straight and angular growth zoning consisting of different shades of yellow, orange or brown (e.g. Figure 5a). Tension cracks and partially healed fissures also were quite common. In some samples, dark, elongated, euhedral inclusions identified by Raman micro-spectroscopy as apatite were observed (Figure 5b). We also identified hematite, red iron hydroxide (Figure 5c) and ilmenite (Figure 5d). Rare inclusions of baddeleyite, tourmaline and jadeite were reported in another study (Izokh et al., 2010).

Chemical Composition

The average chemical composition of the different-coloured zircon groups is presented in Table I. The results show generally low contents of non-formula elements. The most abundant chemical substitution was Hf, with an oxide concentration of 0.60–1.14 wt.%. The concentration of Hf was significantly higher in the darker samples than in the lighter ones. The total REE-oxide concentrations were 0.03–0.08 wt.%. (For more specific data on REEs in Vietnamese zircon, see Khoi et al., 2012, which included REE plots of samples from Ma Lâm, Đá Bàn [Bình Thuận] and Đắk Ton [Đắk Nông].) The concentrations of Th and U were low (average 10–85 ppm and 24–105 ppm, respectively), and varied among sample groups and even within a group. The Th:U ratio was >0.2 for all samples, which is typical for zircon of magmatic origin (Williams and Claesson, 1987; Rubatto and Gebauer, 2000). Other significant trace elements included Y, P, Al and Ca; the average Y concentration ranged up to 469 ppm in reddish brown samples.

The chemical properties of our Vietnamese zircon samples were similar to those from Ra-

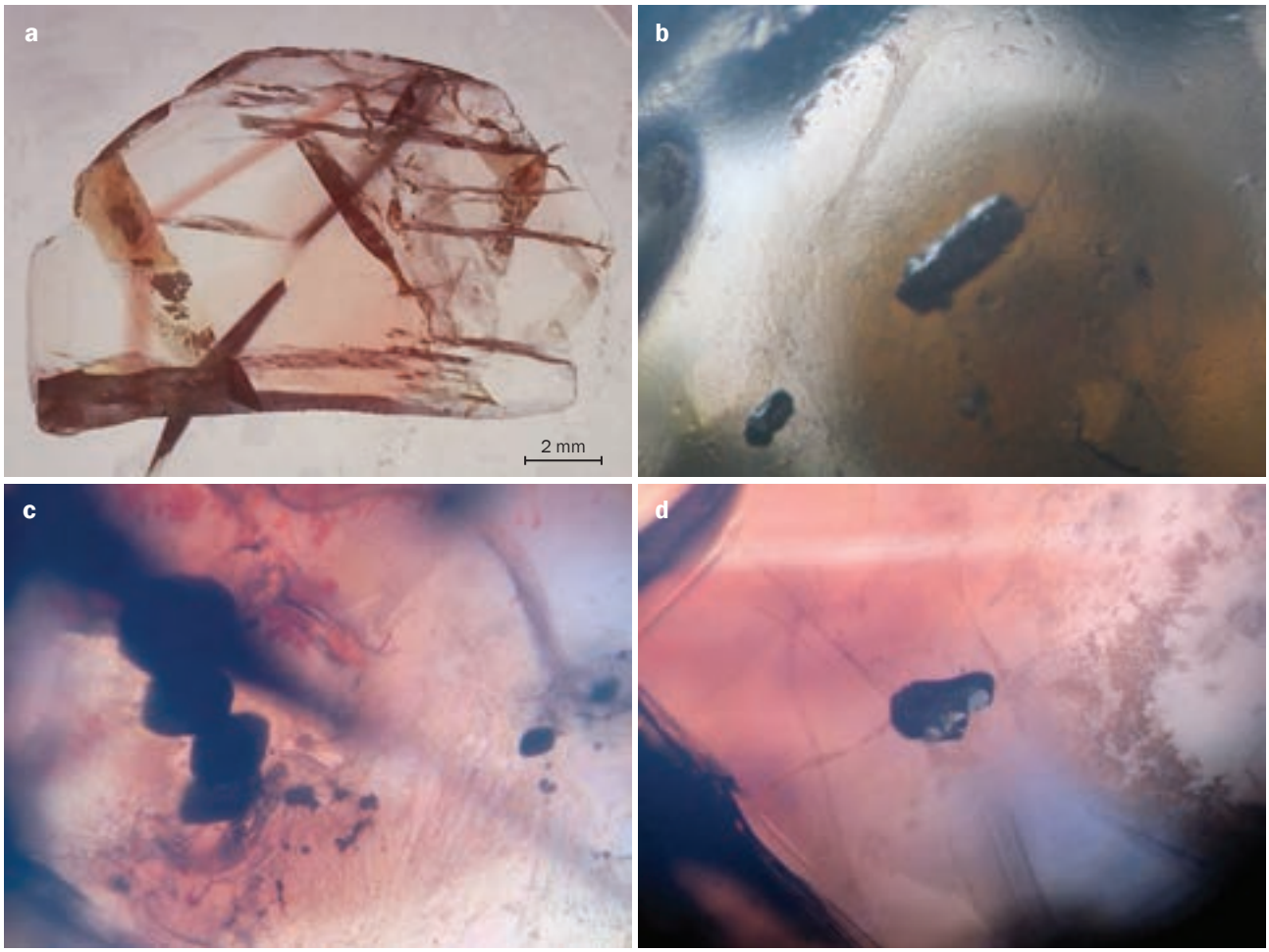

Figure 5: Typical internal features observed in Vietnamese zircon include (a) colour zoning (seen here in a fragment that has been mounted in epoxy and polished), (b) apatite crystals (magnified 20×), (c) masses of opaque hematite and red iron hydroxide (magnified 20×) and (d) ilmenite crystals (magnified 10×). Photomicrographs by N. T. M. Thuyet and L. T.-T. Huong.

tanakiri, which also contain low trace-element contents (i.e. an average of 0.7 wt.% HfO_2, and 40–240 ppm U and 10–270 ppm Th; see Wittwer et al., 2013).

Raman Spectroscopy

Raman spectra of all sample categories showed similar patterns and band values. The dominant peaks were at 1008, 975, 437, 392, 355, 225, 214 and 202 cm^{-1} (Figure 6). According to Dawson et al. (1971), the bands in the 230–200 cm^{-1} range are generated by intense external lattice (inter-tetrahedral) vibrations, while the strongest bands in the 450–350 cm^{-1} range and around 1000 cm^{-1} are due to internal (intra-tetrahedral) vibrations of SiO_4 tetrahedra. Metamictization increases the distance between the atoms in the zircon structure, resulting in decreased vibration frequency of inter-tetrahedra and intra-tetrahedra (Nasdala et al., 1995). The width of the Raman bands broadens, and the peaks shift toward lower wavenumbers. Nasdala et al. (1995) reported that in medium-to-high-degree metamict zircon, the three vibrational bands of inter-tetrahedra in the range 230–200 cm^{-1} broaden and shift to form a single broad, weak band at 200 cm^{-1}. In completely metamict samples, the zircon structure is mostly destroyed and these bands can be absent. Special attention should be paid to the most intense intra-tetrahedral vibrational band at 1008 cm^{-1}, which Nasdala et al. (1995) showed is best suited to quantify the degree of metamictization. Crystalline (high-type) zircon shows a full width at half maximum (FWHM) value of ≤ 5 cm^{-1} for this peak, while amorphous (low-type) samples have the values >30 cm^{-1}. The Raman data of Vietnamese zircon have FWHM values in the 2–3 cm^{-1} range, which show a good match to those of Ratanakiri zircon (cf. Wittwer et al., 2013).

*Table I: Average chemical composition of Vietnamese zircon.**

Chemical composition	Very light brown		Orangey brown		Reddish brown		Dark reddish brown	
	Average	SD	Average	SD	Average	SD	Average	SD
Oxides (wt.%)								
SiO_2	31.91	0.11	32.08	0.09	32.32	0.16	32.36	0.20
ZrO_2	65.91	0.43	65.68	0.18	65.87	0.37	65.75	0.27
HfO_2	0.60	0.02	0.61	0.01	1.02	0.09	1.14	0.01
REE_2O_3	0.03	0.02	0.08	0.01	0.05	0.03	0.07	0.02
Total	98.45	--	98.45	--	99.26	--	99.32	--
Trace elements (ppm)								
Li	<0.05	--	0.10	0.04	0.45	0.31	0.10	0.03
Be	<0.05	--	0.68	0.02	0.15	0.08	0.23	0.04
Al	41.9	4.35	11.8	1.26	22.1	10.2	32.2	2.99
P	77.8	2.32	72.1	16.4	44.4	13.0	71.1	8.85
Ca	7.79	3.88	8.24	2.52	39.4	10.5	14.0	3.67
Ti	1.27	0.07	4.28	0.31	5.31	1.49	6.96	0.51
Cr	0.42	0.03	0.45	0.08	0.50	0.05	0.42	0.09
Mn	0.06	0.01	0.77	0.10	1.31	0.50	<0.06	--
Ni	0.57	0.09	0.19	0.04	1.44	1.08	<0.05	--
Cu	<0.01	--	<0.01	--	0.54	0.40	<0.01	--
As	0.16	0.01	0.18	0.02	0.20	0.07	0.20	0.05
Rb	0.03	0.01	0.08	0.03	0.11	0.04	0.09	0.03
Sr	0.06	0.01	0.11	0.04	0.55	0.34	0.13	0.02
Y	107	23.9	444	126	469	120	333	88.5
Nb	0.69	0.19	3.14	1.10	5.45	2.12	3.29	1.00
Mo	0.56	0.17	0.48	0.04	0.49	0.03	0.46	0.04
Sn	0.07	0.01	0.12	0.04	0.11	0.02	0.09	0.02
Ta	0.57	0.15	1.55	0.49	4.48	2.17	5.99	1.35
W	0.05	0.02	0.16	0.07	0.17	0.04	0.13	0.05
Th	10.6	3.34	36.6	18.3	79.5	37.6	84.5	70.2
U	24.0	2.53	78.7	28.5	105	80.2	101	76.3

* Concentrations of V, Co, Zn and ^{208}Pb were below the detection limits (0.05, 0.01, 0.01 and 0.10 ppm, respectively) in all samples. SiO_2 was analysed by electron microprobe (five spots per sample) and other elements by LA-ICP-MS (three spots per sample); ZrO_2, HfO_2 and REE_2O_3 values were calculated from LA-ICP-MS data. Abbreviation: SD = standard deviation.

FTIR Spectroscopy

FTIR spectra displayed three sharp, intense bands in the 1100–400 cm^{-1} range at 854, 609 and 430 cm^{-1} (Figure 7). The intense band around 854 cm^{-1} (and shoulder at 970 cm^{-1}) is due to internal stretching vibrations of SiO_4 tetrahedra; this band weakens and broadens in metamict zircon. The band at 609 cm^{-1} (due to internal bending vibrations of SiO_4 tetrahedra) and the band at 430 cm^{-1} (due to the external or lattice vibration mode) may also weaken and broaden with metamictization, and they are nearly absent from highly metamict samples (Woodhead et al., 1991a).

FTIR spectroscopy of the Vietnamese zircon confirms the results of the Raman spectra showing that the samples are well crystallized. In addition to the SiO_4-related bands, other weak bands were observed between 3800 and 3400 cm^{-1} that correspond to hydrous components (OH^- and/or H_2O). The broadening of the bands in this range can be explained by the band overlap of OH^- in different sites of the zircon structure, as well as the $(SiO_4)^{4-}$ internal vibrations. The presence of OH^- in crystalline zircon has been explained by the substitutions $M^{3+} + H^+ \rightarrow Zr^{4+}$ and/or $4(OH)^- \rightarrow (SiO_4)^{4-}$ (Woodhead et al., 1991b).

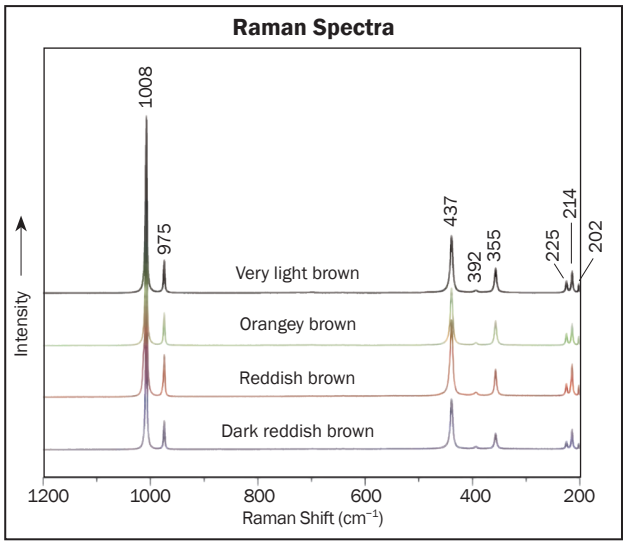

Figure 6: Raman spectra of representative samples from the four colour groups of Vietnamese zircon all show bands in the 230–200 cm^{-1} range generated by intense external lattice (inter-tetrahedral) vibrations, as well as bands in the 450–350 cm^{-1} range and at around 1000 cm^{-1} due to internal (intra-tetrahedral) vibrations of SiO_4 tetrahedra. Spectra are offset vertically for clarity.

UV-Vis-NIR Spectroscopy

UV-Vis-NIR absorption spectra for the zircon samples of the four colour categories are shown in Figure 8. The spectra of the two reddish brown categories show a similar continuous increase in absorption toward the UV region, in particular between 400 and 600 nm with a shoulder at around 500 nm, giving an absorption window toward the red end of the spectrum. As a result, those samples show red-orange-yellow colour components. The spectra of the very light brown and orangey brown categories have a shoulder of very low intensity. Similar absorption patterns have been reported for reddish brown and brownish red zircon from other localities, including Ratanakiri and Muling (China). Those samples are believed to owe their colour to radiation damage (Chen et al., 2011).

Heat Treatment

Under oxidizing conditions, most brown Vietnamese zircon becomes lighter coloured with heat treatment. Figure 9 shows a dark reddish brown sample before and after being heated to 200–600°C under oxidizing conditions. From 200°C to 500°C, the stone became lighter with a more obvious orangey red component. However, the treated colour was unstable and reverted to its original appearance after less than one hour of exposure to light (i.e. in a combination of reflected sunlight and fluorescent lighting). Only when heated to 600°C did the resulting colour stabilize, after much of the orange and red components disappeared, resulting in a pale brown coloration after heat treatment.

Under reducing conditions, the brown Vietnamese zircon began turning light blue at 800°C. The blue colour intensified upon heating the zircon to 1,000°C (Figure 10). The treated blue colour was stable, and its intensity depended on the shade of the original brown colour: the browner the sample, the deeper blue after treatment.

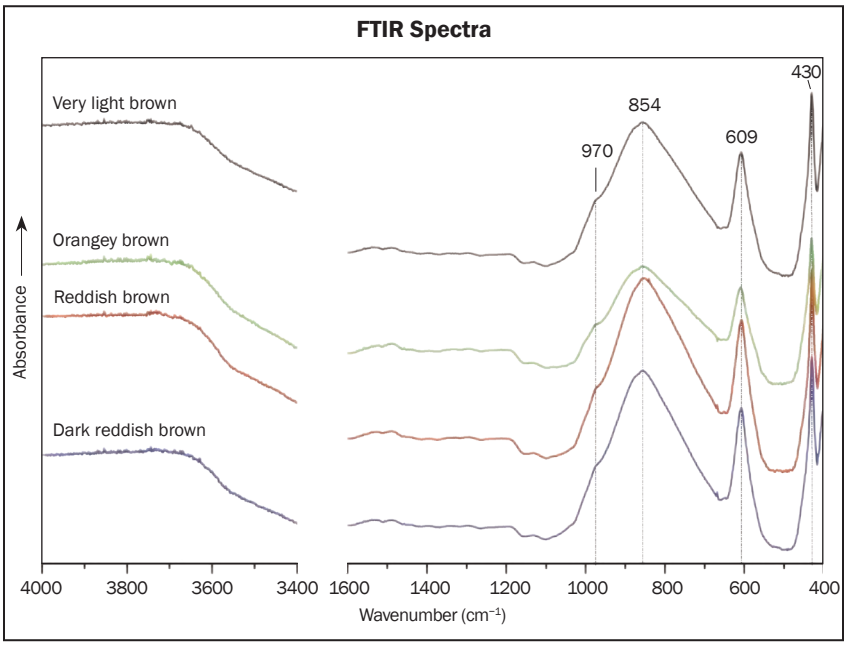

Figure 7: FTIR spectra for the four colour groups of Vietnamese zircon all display intense bands at around 854 and 609 cm^{-1} due to internal vibrations of SiO_4 tetrahedra. The band at 430 cm^{-1} belongs to external (lattice) vibrations. Other weak bands between 3800 and 3400 cm^{-1} are due to hydrous components. Spectra are offset vertically for clarity.

The colour of blue zircon that is grown synthetically is apparently due to U^{4+} (cf. Richman et al., 1967), whereas the blue colour in heat-treated natural zircon may be due to a composite of features including the transition of U^{5+} to U^{4+} (Satitkune et al., 2013) and others of unknown origin (Wittwer et al., 2013). Interestingly, not every brown zircon—even from the same mine—turns blue after heat treatment at the same conditions.

Raman spectroscopy of the heat-treated zircon in this study showed no change in structural state; the FWHM value of the 1008 cm^{-1} peak remained the same.

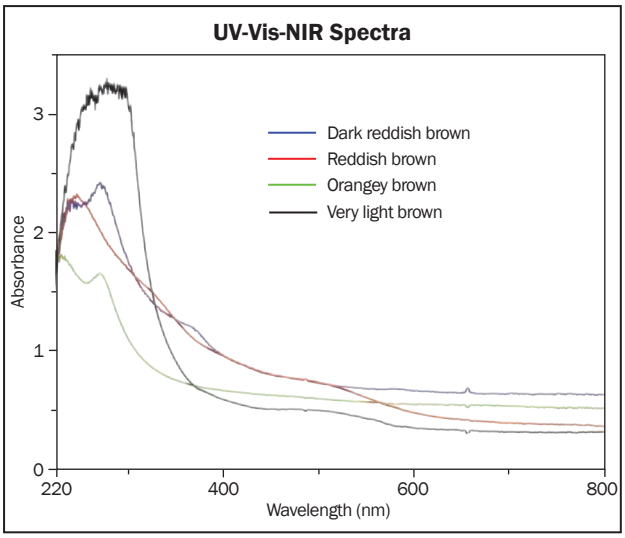

Figure 8: The UV-Vis-NIR absorption spectra of dark brown and reddish brown samples of Vietnamese zircon show a similar continuous increase in absorption toward the UV region (see text for discussion).

Conclusions

Alluvial deposits in the Central Highlands of Vietnam host gem-quality zircon ranging from very light brown to orangey or reddish brown to dark reddish brown. Common internal features include straight and angular growth zoning as well as inclusions of apatite and iron-oxide and iron-titanium-oxide minerals. The main chemical difference between the dark and light brown zircon is the Hf concentration, which is higher in the darker stones. All the samples contained low amounts of Th and U, and the Th:U ratios are consistent with a magmatic origin (and subsequent transport to the earth's surface in alkali basalts). Raman and FTIR spectroscopy indicate that the zircons are high type (highly crystalline). Heat treatment under oxidizing conditions produced a lighter but unstable brownish orange colour in the range of 200–500°C and a stable pale brown colour after heating to 600°C, whereas treatment under reducing conditions yielded a stable blue colour after heating to 800–1,000°C.

Figure 9: Heat treatment of a 6.70 ct dark reddish brown zircon (a) in an oxidizing atmosphere produced an unstable lighter brownish orange coloration after exposure to 200°C (b), 400°C (c) and 500°C (d), and a stable pale brown colour after heating to 600°C (e). Photos by L. T.-T. Huong.

Figure 10: Reddish brown Vietnamese zircon is shown before (top) and after (bottom) heat treatment under reducing conditions at 1,000°C, resulting in a stable blue colour. Photo by L. T.-T. Huong.

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Identification of Reconstructed Amber from Different Periods

Haibo Li, Jie Liang, Taijin Lu, Jun Zhang and Jun Zhou

Recently, reconstructed amber has been more commonly encountered in the Chinese jewellery market. Some of the newer (post-2009) material presents a serious identification challenge for gemmological laboratories. This article divides reconstructed ambers into two categories—early and current—corresponding to their properties and the approximate time period that they were manufactured. By comparing the structure of reconstructed amber from either category with that of natural amber, it is generally possible to differentiate it using microscopic features. In addition, the distinctive structure of reconstructed amber can sometimes be seen using cross-polarized light and UV fluorescence imaging with a standard UV lamp or with the DiamondView instrument.

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Introduction

Reconstructed amber (also known as 'pressed amber'; Zhang, 2006, 2010a) consists of small amber fragments or scraps that have been reformed into larger amber pieces under heat and pressure (e.g. Figure 1). In this article, we classify reconstructed amber into two categories: early (pre-2009) and current (i.e. from ~2009–2010 to the present time). Most previous studies on identifying reconstructed amber were limited to early-stage material. Those samples are relatively easy to identify—even distinguishable with the unaided eye in some cases—as they have obvious structural characteristics. Current reconstructed amber is more difficult to identify, and the authors are not aware of any previous systematic research being done on it.

Based on the documentation of reconstructed amber in the literature (Koivula et al., 1993; Hänni, 2005; Qi et al., 2005; Ma, 2007; Zhu and Xing, 2008; Campbell Pedersen and Williams, 2011; Zhou and Yang, 2011; Wang et al., 2012), along with the present authors' examination using multiple instruments and lighting techniques to analyse reconstructed amber from various periods of time, this article summarizes the identification criteria for early and current reconstructed ambers. Our initial observations were published (in Chinese) in Li et al. (2012).

Materials and Methods

The study is based on ~100,000 documented samples that were encountered in the National Gemstone Testing Center's Beijing laboratory during approximately the past decade. We summarized all those records and classified a selection of typical cases for this article. The samples included various loose beads, strung beads, cabochons, rough material, carved pieces and more.

Standard gemmological testing was carried out on all the samples, including examination with a microscope, polariscope and UV lamp. Observations were made with brightfield and darkfield

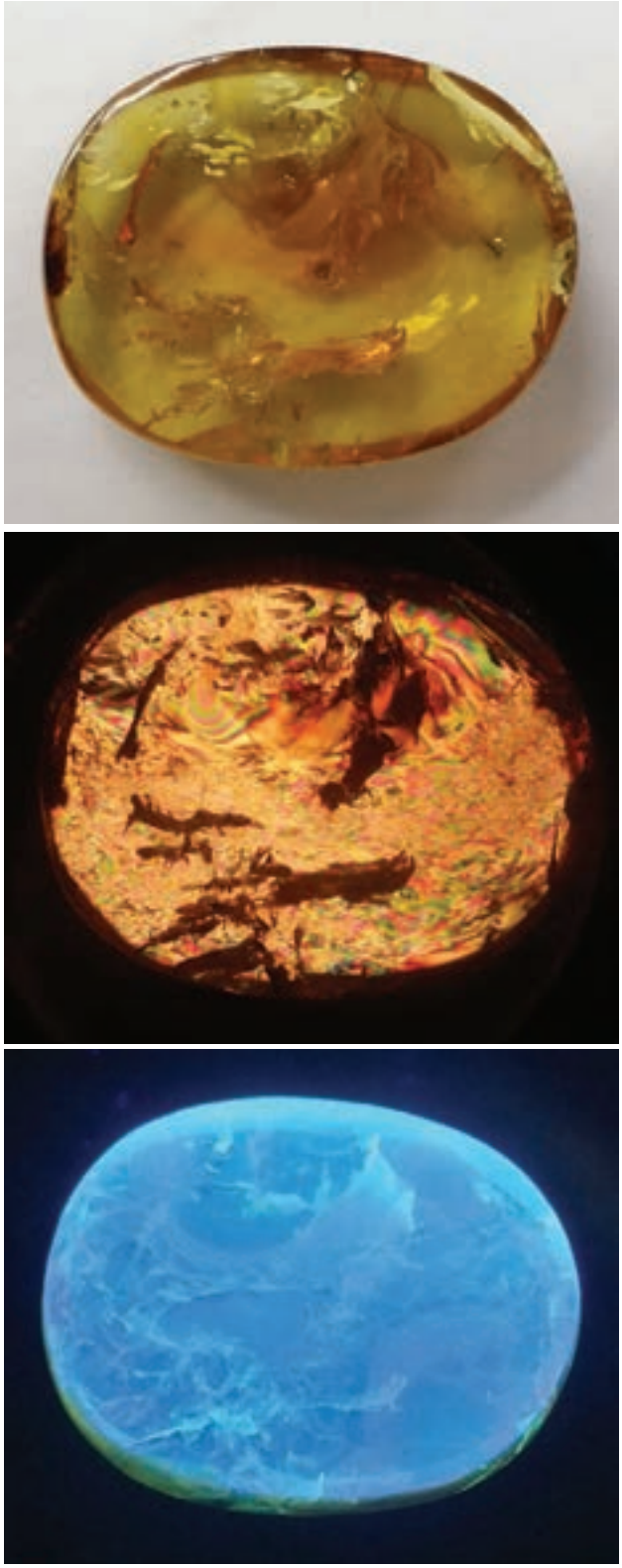

Figure 1: This cabochon of current-stage reconstructed amber (6 × 4 mm) does not show an obvious fragmental or 'blood streak' structure to the unaided eye (top), but examination with a polariscope (in cross-polarized light) reveals a mylonitic pattern of extinction accompanied by interference colours (centre), and long-wave UV fluorescence shows a mosaic texture (bottom) indicative of its reconstructed origin. Photos by H. Li.

illumination, as well as with additional lighting such as a fibre-optic illuminator. In addition, a DiamondView instrument was used to observe details of the samples' ultra-short-wave UV fluorescence. Fourier-transform infrared (FTIR) spectra of all samples were recorded with a Nicolet 6700 spectrometer in the 4000–400 cm^{-1} region, at a resolution of 4.0 cm^{-1} and 8–64 scans. Several points were analysed on some samples to confirm the identity of the constituent material(s). All FTIR analyses were performed non-destructively by specular reflection, and a Kramers-Kronig transformation was performed to remove distortions in the spectra (e.g. Zhang, 2006, pp. 120–121).

Constituents of Reconstructed Amber

As Baltic material is the main amber variety sold in the market, reconstructed amber is commonly manufactured from pieces of this material. The samples submitted to the authors' laboratory were therefore suspected as being made from Baltic amber, and this origin was confirmed by the presence of a 'Baltic shoulder' (e.g. Beck et al., 1964) in most of their FTIR spectra.

According to the process used, there are two main types of reconstructed amber typically seen in the market. Type 1 is made without the addition of any substances to the amber fragments, while type 2 contains foreign substances (e.g. natural or artificial resins) that are added to make the material more solid and durable. If the artificial material is too abundant, then the resulting sample may no longer be called 'amber', but rather an amber imitation. For cases where FTIR spectroscopy can easily detect different areas of a reconstructed sample consisting of amber and a foreign substance, then more tests are needed to assess the proportion of the constituents and determine the proper nomenclature (i.e. reconstructed amber or imitation amber).

On the other hand, when there is little or no foreign substance present, the FTIR spectra of reconstructed amber may look quite similar to that of natural amber, and additional examinations using a microscope, polariscope and UV lamp should be performed to make the proper identification.

In the authors' experience, both types 1 and 2 can be found from various time periods (i.e. early and current). However, most samples encountered in our laboratory have been type 1.

Figure 2: Left: These 13-mm-diameter beads, sold as 'African amber', proved to be early reconstructed amber that also contains foreign substances. Right: The beads show uneven fluorescence to long-wave UV radiation, with an obvious fragmental structure. The cementing agents surrounding the amber fragments exhibit two different fluorescence reactions: blue and inert (the latter appearing dark/black in contrast with the adjacent amber luminescence). Photos by H. Li.

Identification of Early Reconstructed Amber

Microscopic Features

Processing of early reconstructed amber involved the use of relatively high temperature and pressure conditions in air (i.e. the amber fragments being fully in contact with oxygen). The resulting material often displays a relatively dark body colour, poor transparency with a muddy-looking interior, and a diagnostic fragmental or mosaic structure (e.g. Figure 2). It can be identified by visual observation; the boundaries between fragments have darker (oxidized) edges that appear translucent brown or red (Figure 3). The boundaries show various three-dimensional patterns corresponding to the different shapes and sizes of the amber fragments used in the reconstruction process. This fragmental or mosaic structure in reconstructed amber is also known as 'blood streak' in Chinese because it may resemble blood vessels in colour and distribution. In addition, some early-stage reconstructed amber may display uneven surface lustre due to different hardness characteristics of the partially melted amber fragments (Figure 4).

In early reconstructed amber, the 'blood streak' structure is usually obvious, making it easy to distinguish from natural amber, although an inexperienced gemmologist could confuse it with heat-enhanced amber (Zhang, 2010a,b) contain-

Figure 3: These samples of early reconstructed amber contain some unmelted amber fragments that show dark oxidized boundaries. Photomicrograph by H. Li; magnified 10×.

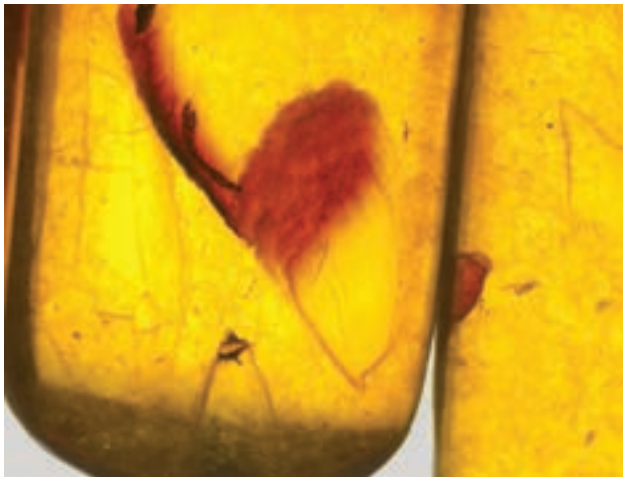

Figure 4: Viewed in reflected light, the surface of this early reconstructed amber sample shows uneven polish lustre due to the different hardnesses of the constituent amber fragments. Photomicrograph by H. Li; magnified 10×.

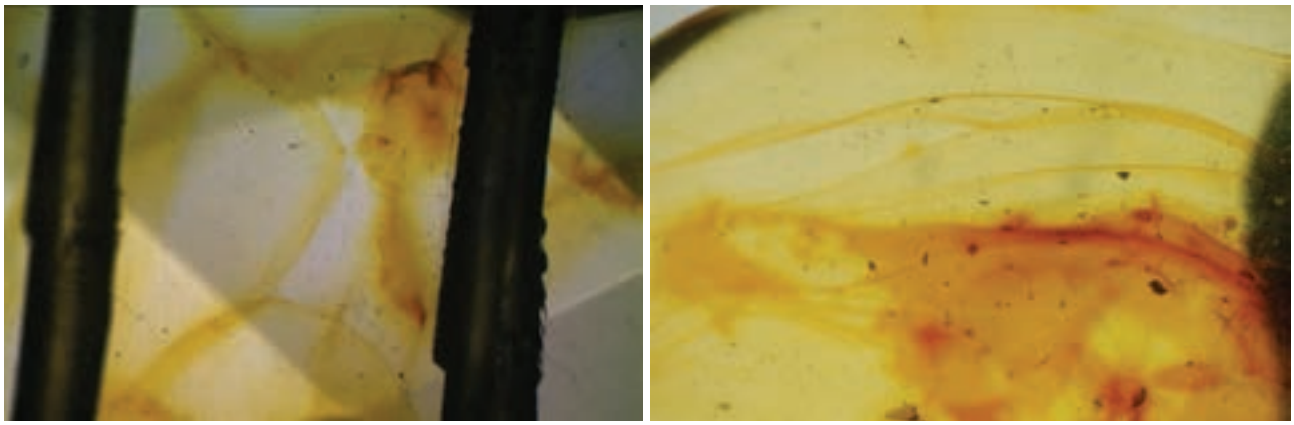

Figure 5: Left: A three-dimensional mosaic (or 'blood streak') structure in early reconstructed amber shows a network of angular boundaries that completely enclose the fragments. Right: By contrast, heat-enhanced amber displays brownish red flow lines that do not interconnect. Photomicrographs by H. Li; magnified 10×.

ing brownish flow lines. These flow lines result from the oxidation of pre-existing cracks that are healed during enhancement at low temperature and pressure to solidify the raw material and help avoid future cracking. (Because raw amber commonly has a layered structure that is accompanied by cracks, it can be difficult to carve and manufacture without this enhancement. According to the Chinese standard for amber, since this process does not change the basic component of the amber raw material, it should be recorded as an 'enhancement' rather than a treatment. By contrast, reconstructed amber is an artificial product, although it is produced using fragments of natural material [Zhang, 2010a].) In reconstructed amber, the coloured boundaries defining the fragmental structure of the material form interconnected networks that completely enclose the grains, while in heat-enhanced natural amber the flow lines are not commonly interconnected (Figure 5).

Figure 6: Viewed between crossed polarizers in a polariscope, this 7-mm-long carved piece of natural amber shows anomalous double refraction with snake-like and wavy extinction patterns. Photo by H. Li.

Appearance in the Polariscope

Natural amber is amorphous and often shows anomalous double refraction in the polariscope, sometimes displaying snake-like, wavy or patchy extinction patterns (Figure 6). By contrast, early-stage reconstructed amber shows patchy grainy extinction with clear grain boundaries and often exhibits interference colours. If the fragments in the sample are small, then it may show distorted mylonitic patterns (Figure 7, left), while samples with larger unmelted fragments commonly show snake-like extinction and interference colours within the individual pieces (Figure 7, right).

Fluorescence

Natural amber usually displays even fluorescence, regardless of whether it is viewed with a UV lamp (long- and short-wave) or in the DiamondView instrument. While darker-coloured early-stage reconstructed amber may not show diagnostic fluorescence, pale-coloured material commonly shows uneven luminescence with a fragmental or granular structure (Figures 8 and 9). Depending on the size of the fragments in the sample, it may be necessary to adjust the magnification of the DiamondView to properly observe the grain boundaries. However, it is not always possible to examine amber samples in the DiamondView due to the size limitations of the instrument.

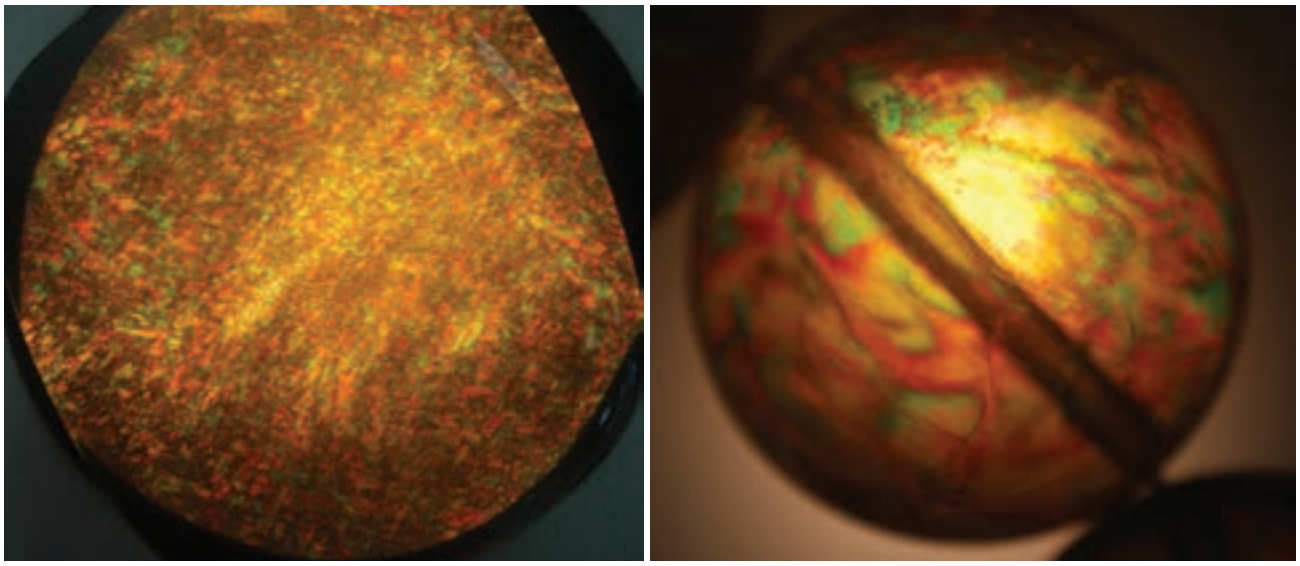

Figure 7: Left: Distorted mylonitic extinction patterns accompanied by interference colours are seen with the polariscope in this reconstructed amber that was manufactured from tiny grains of raw material (magnified 10×). Right: A coarse pattern of wavy extinction and bright interference colours is visible with the polariscope in this 12-mm-diameter bead of reconstructed amber that was made from larger fragments of raw material. Photomicrographs by H. Li.

Identification of Current Reconstructed Amber

As the techniques for reconstructing amber have evolved, the characteristics used for identifying this material also have needed refinement. Compared to early reconstructed amber, the authors believe that current-stage reconstructed amber is manufactured under relatively higher temperatures and pressures in an oxygen-free environment. Also, current reconstructed amber is often subjected to post-processing treatments that are designed to conceal any identifying features. These include inducing internal and surface cracks (by heating and cooling), polishing with coarse grit to create a matt appearance (usually represented as an unpolished surface), darkening the surface colour (by baking), carving complex patterns and applying coloured coatings. Although these processes make identification more difficult, they do not completely hide the internal evidence of the reconstruction process.

Figure 8: Long-wave UV fluorescence reveals various fragmental patterns in these early reconstructed amber samples consisting of larger (left) and smaller (right) amber fragments. The carving on the left is 8 cm tall and the piece on the right is 13 cm wide. Photos by H. Li.

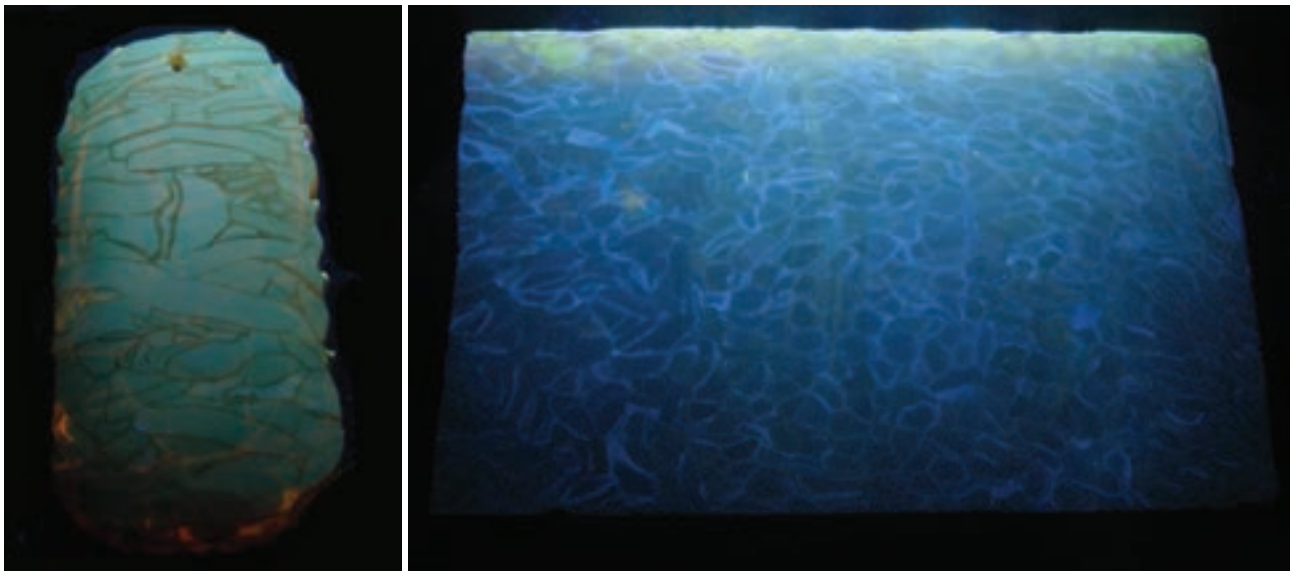

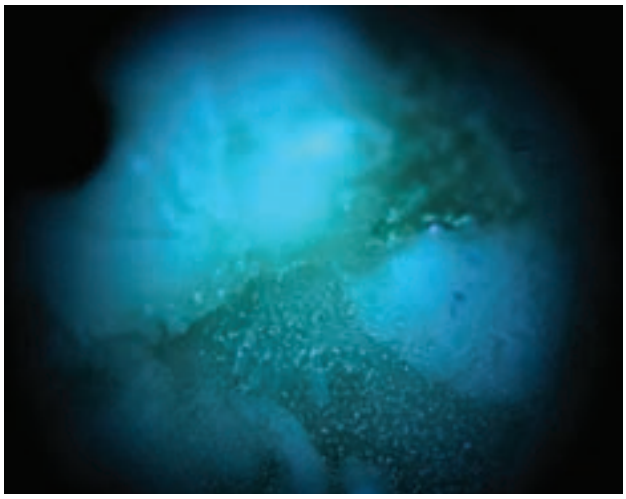

Figure 9: With the DiamondView, an early reconstructed amber bead shows angular grain boundaries. Photomicrograph by H. Li; magnified ~8×.

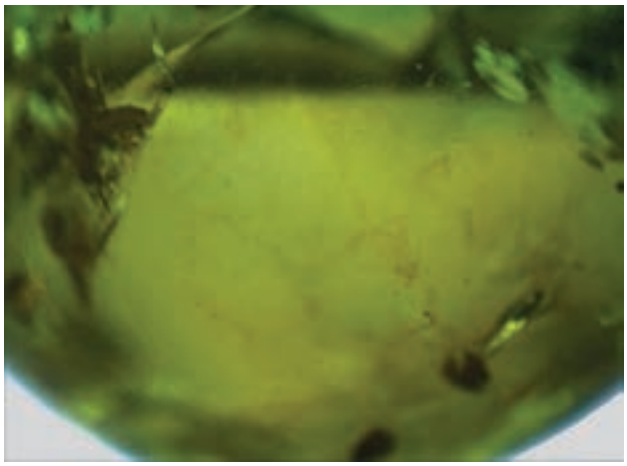

Figure 10: The fragmental structure of current reconstructed amber commonly shows subtle boundaries between grains. Here, the boundaries are pale reddish brown with a dot-like appearance. Photomicrograph by H. Li; magnified 16×.

Microscopic Features

Current reconstructed amber can often be identified by carefully observing the sample with the microscope using a strong light source. Rather than coarse amber fragments, finer grains are typically used as the raw material for current reconstructed amber. As a result, it usually shows a more subtle and fine-grained fragmental structure consisting of areas with pale colour that are enclosed by dot-like edges (Figure 10). However, in some current reconstructed amber, the dark-coloured grain boundaries are nearly absent, or are quite fuzzy and only can be seen with careful observation; thus the 'blood streak' structure is not apparent (Figure 11). In addition, current reconstructed ambers made from tiny grains of raw material may not show an apparent fragmental structure, although they sometimes exhibit a granulated sugar-like texture, with or without a flowed appearance (Figure 12).

Careful examination of samples with transmitted illumination using a strong light source is helpful for revealing the interconnected mosaic pattern or angular grain boundaries in current reconstructed amber subjected to various post-processing treatments. Heat treatment (followed by abrupt cooling)

Figure 11: Left: Viewed with a strong transmitted light source, this opaque reconstructed amber bead exhibits no 'blood streak' structure, although the angular fragments are still quite apparent. Right: Two beads in an amber bracelet consist of natural amber (left side) and current reconstructed amber (right side) that displays fuzzy grain boundaries with no 'blood streak' structure. The presence of small grains with angular boundaries is the key identification factor for the reconstructed amber bead. Photomicrographs by H. Li; magnified 16× (left) and 12.5× (right).

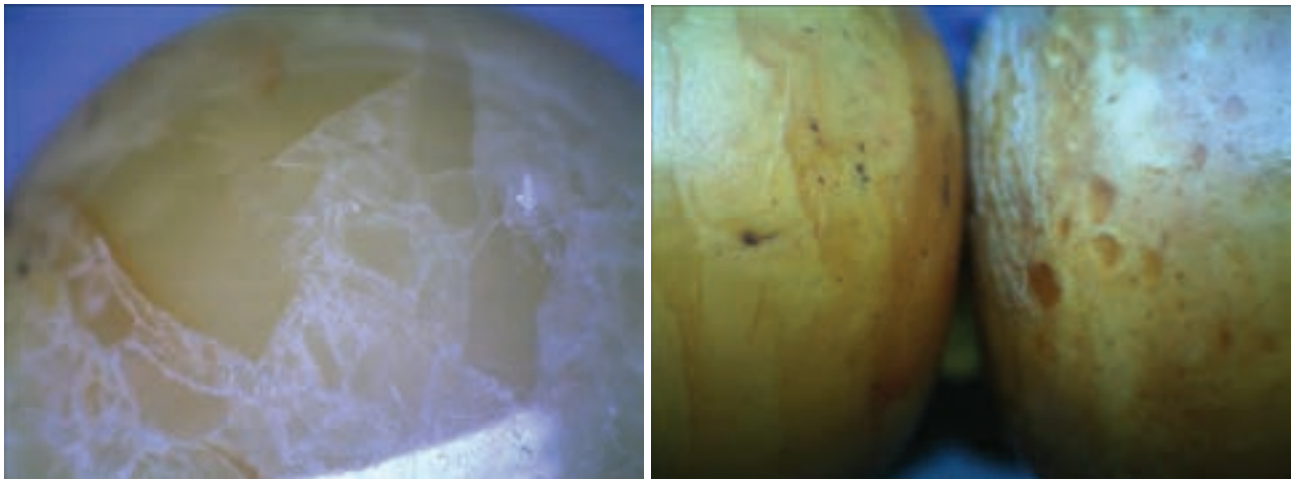

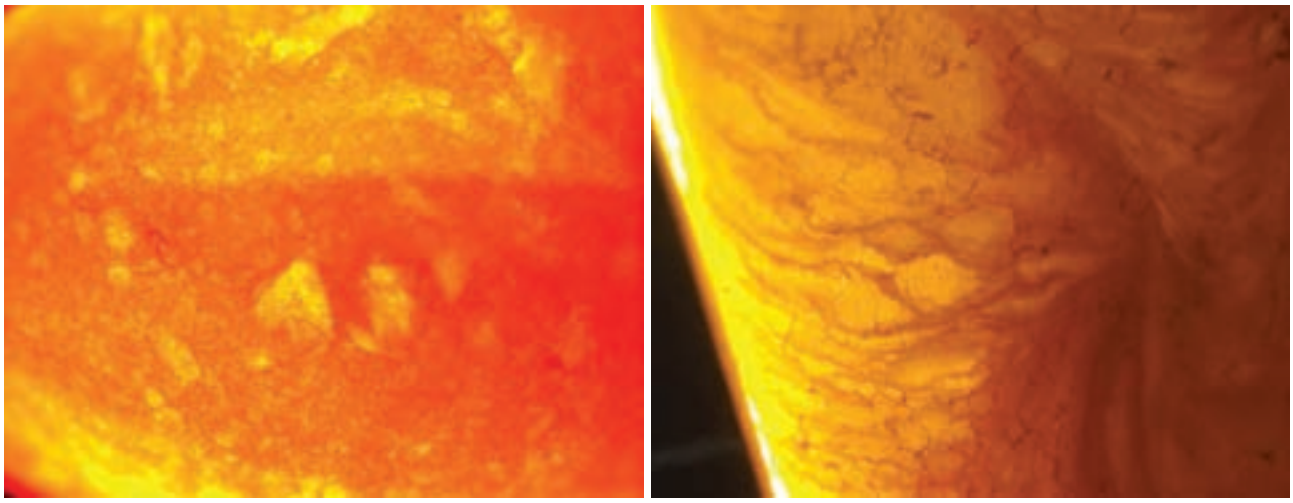

Figure 12: Left: A grainy 'sugar-like' texture is seen with strong transmitted light in a colour-coated sample of current reconstructed amber. Right: Current reconstructed amber made from somewhat larger grains exhibits a granulated structure with a flowed appearance when viewed with strong transmitted light. Photomicrographs by H. Li; magnified 32× (left) and 8× (right).

of reconstructed amber may create scattered flaky internal fractures or a network of surface cracks, which can obscure the diagnostic mosaic structure (Figure 13). Care must also be exercised when identifying reconstructed amber submitted to other post-processing treatments (e.g. Figures 14 and 15).

Polariscope and UV Fluorescence

The post-processing treatments mentioned above often obscure the diagnostic features of current reconstructed amber in the polariscope and when observed for fluorescence with a UV lamp or the DiamondView. Therefore, these tests frequently cannot be used to reliably separate current reconstructed amber from natural amber.

Discussion and Conclusions

Previous research on reconstructed amber has shown that variations in RI readings and the height of infrared absorption peaks at ~2930 and ~1735 cm^{-1} can confirm that a sample has been heat treated and, further, suggest that it might be reconstructed (Zhu et al., 2009; Wang et al., 2012). During the heating process, the surface of the amber becomes oxidized, which also changes the RI and infrared spectral readings. The higher the temperature used, the higher the RI value will be, up to a maximum of 1.60 (distant-vision or 'spot' reading). Exposure to greater temperatures may cause the FTIR features to change: the ~1735

Figure 13: Left: Evidence of post-processing heat treatment in current reconstructed amber can be seen in the flaky internal cracks that are partially distributed along the fragmental structure. Right: Heating also may induce surface cracking, partially obscuring the fragmental structure of the reconstructed amber. Photomicrographs by H. Li; magnified 10× (left) and 12.5× (right).

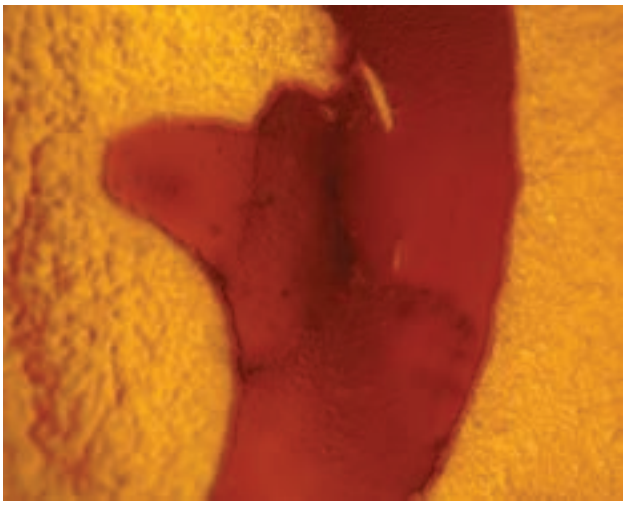

Figure 14: This current reconstructed amber sample was baked to develop a much deeper brown-red surface colour, and then carved into a complex pattern that was finished with a matte surface. These features conceal the internal structure and makes identification difficult. Viewed with a strong transmitted light source, an unusual pattern can be seen under the smooth, transparent part of the surface—a pattern similar to the Chinese character '人' (meaning people)—corresponding to be the junction of three pieces of the amber raw material. Photomicrograph H. Li; magnified 20×.

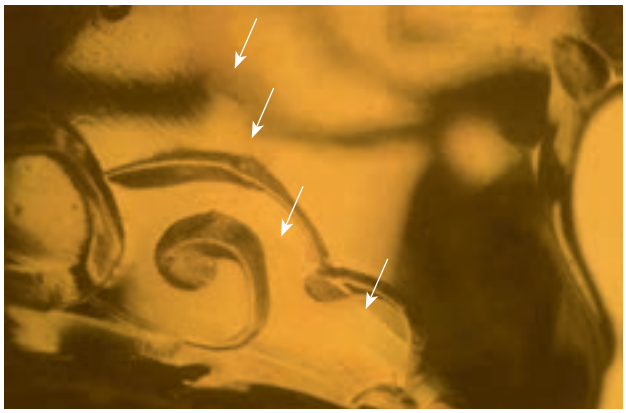

Figure 15: This transparent hand-carved sample of current reconstructed amber shows subtle angular boundaries intersecting at an angle of about 145° (see arrows). The carved surface decorations make the internal texture details very easy to overlook. Photomicrograph by H. Li; magnified 20×.

cm^{-1} absorption band shifts to lower wavenumbers (down to 1716 cm^{-1}), and the ~1157 cm^{-1} absorption band moves to higher wavenumbers (up to 1175 cm^{-1}). In addition, the intensity of the ~2930 cm^{-1} feature decreases and the ~1735 cm^{-1} band increases (Figure 16). These variations in RI and infrared spectra indicate that an amber specimen has been heated, but they do not provide conclusive evidence of reconstruction. While it is normal for the infrared spectra of reconstructed amber to show indications of heating, this does not prove that a sample has been reconstructed. For example, most of the 'blood amber' (named for its brownish red to red surface colour) currently on the market is the result of heating light yellow or yellow starting material. Variations in the RI values and infrared spectral characteristics of these ambers are similar to those seen in reconstructed ambers. However, 'blood amber' does not show the distinctive internal structures exhibited by reconstructed amber, and no other evidence points to these ambers having been reconstructed. Moreover, some reconstructed ambers have the same RI and infrared spectral features as natural untreated amber, so these are not reliable distinguishing characteristics (e.g. Figure 17). However, such samples can be revealed as reconstructed by careful microscopic observation of the internal fragmental/grainy textures.

In summary, the most effective method for identifying reconstructed amber is microscopy with the use of various lighting techniques to observe the internal microstructure. Observations with the polariscope and the UV lamp or DiamondView are useful auxiliary methods for the identification of reconstructed amber. Despite

Figure 16: Infrared spectra (after Kramers-Kronig transformation) are shown for natural Baltic amber, reconstructed amber and heated natural amber that was enhanced to produce a darker surface appearance. Analysis of the intensity of the absorption bands at ~2930 and 1735 cm^{-1} reveals that the temperature used for creating a darker surface colour was much higher than that used to produce reconstructed amber. Therefore, it is problematic to use infrared spectroscopy for determining whether or not an amber sample is reconstructed.

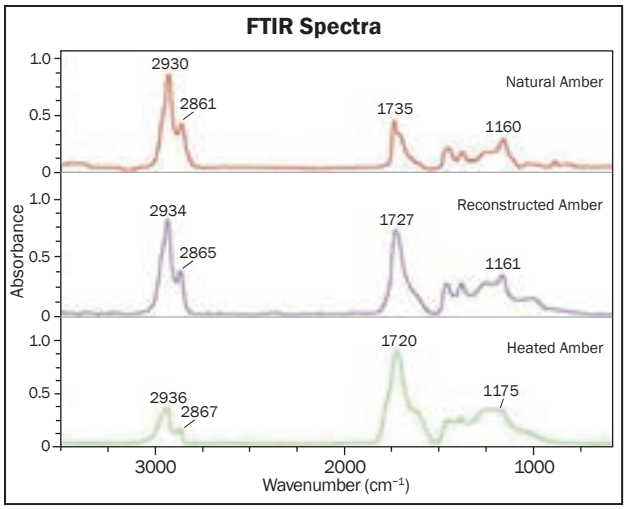

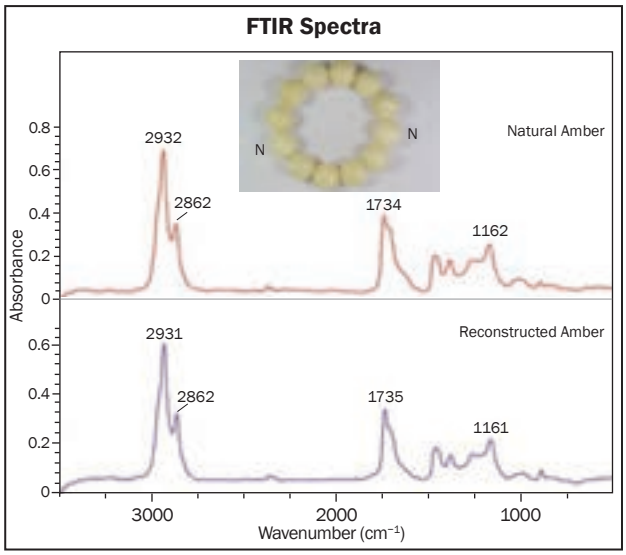

Figure 17: Gemmological examination of a bead bracelet submitted by a client (see inset; photo by H. Li) showed that two of the beads were natural amber ('N'), while the rest were reconstructed amber. Infrared spectra (after Kramers-Kronig transformation) of all beads in the sample presented the same absorption features, consistent with their identity as Baltic amber, regardless of natural or reconstructed origin.

recent improvements in amber reconstruction manufacturing techniques and post-processing treatments, in almost all cases there are clues remaining that allow reconstructed amber to be distinguished from natural amber.

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Violet-to-Blue 'Nuummite' from Simiuttat, Greenland: Origin of Colour Appearance and Conditions of Formation

Leander Franz, Tay Thye Sun, Richard Wirth, Christian de Capitani and Loke Hui Ying

Iridescent orthoamphibole rock ('Nuummite') from the Nuuk District in south-west Greenland is an unusual gem material known in the trade since 1983. Unlike most Nuummite that shows a 'golden' brown iridescence, some specimens from Simiuttat in the Buksefjorden Archipelago display a violet-to-blue colour similar to that seen in some labradorite. The rock is a biotite-cordierite-anthophyllite granofels that formed in the Late Archean and subsequently experienced a polymetamorphic overprint, with peak metamorphism at amphibolite-facies conditions. While electron microprobe analyses and Raman spectroscopy classify the orthoamphibole as an Al-rich anthophyllite without any inhomogeneities on a micrometre scale, transmission electron microscopy revealed sub-microscopic exsolution lamellae of anthophyllite and gedrite parallel to (010). The periodic lamellae have an average spacing of 124–133 nm, which generates the violet-to-blue diffraction coloration. This study shows that the colour appearance of Nuummite is not due to chemical variations from grain to grain, but to the spacing of exsolution lamellae in orthoamphibole.

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Introduction

Iridescent orthoamphibole (anthophyllite-gedrite) has been reported from New Hampshire and Massachusetts in the USA (Robinson et al., 1971), south-west Greenland (Appel and Jensen, 1987; Rodgers et al., 1996; Champness and Rodgers, 2000) and Mauritania (Kobayashi, 2009; Renfro, 2011); the gem-quality material from Greenland is commonly marketed as 'Nuummite'. In most cases, a golden brown iridescence colour is observed (Bøggild, 1905, 1924; Appel and Jensen, 1987), although yellow-green and blue colours also occur (Champness and Rodgers, 2000; Renfro, 2011).

This study focuses on violet-to-blue-appearing orthoamphibole from Greenland (e.g. Figure 1). (Note that although the body colour of this material is dark grey, in this article the 'violet-to-blue' description refers to the coloration shown by the diffraction of light from suitably-oriented cleavages in the amphiboles constituting the rock.) Ac-

cording to geologists at the Geological Survey of Denmark and Greenland (N. Keulen, K. Secher and P. Appel, pers. comm., 2016), this material is known to occur on Simiuttat Island in the Buksefjorden Archipelago near Nuuk, the capital of Greenland (Figure 2). The Nuummite is hosted by a sequence of Precambrian polymetamorphic rocks (mainly quartz-cordierite gneisses) called the Malene supracrustals (McGregor, 1969; Dymek and Smith, 1990) with an average age of 2,732 ± 10 million years old (Rodgers et al., 1996). Nuummite occurs as thin bands and lenses up to 1 m wide along the strike of the rock sequence (Appel and Jensen, 1987). It consists almost exclusively of orthoamphibole with minor amounts of gahnite, magnetite, pyrrhotite, chalcopyrite and molybdenite. The orthoamphiboles form a solid-solution series between the end members anthophyllite $(Mg,Fe^{2+})_7[Si_8O_{22}](OH)_2$ and gedrite $(Mg,Fe^{2+})_5Al_2[Al_2Si_6O_{22}](OH)_2$ (Robinson et al., 1971; Spear, 1980).

The iridescence of Nuummite is due to the interference of light reflected from sub-microscopic, alternating gedrite and anthophyllite exsolution lamellae (Rodgers et al., 1996; Champness and Rodgers, 2000). While golden brown iridescence is typical, subordinate occurrences showing violet-to-blue coloration also are found (Ap-

Figure 1: This checkerboard-cut Nuummite gemstone (57.73 ct; 47.04 × 28.62 × 4.86 mm) shows long, thin, violet-to-blue prisms. Photo by Tay Thye Sun.

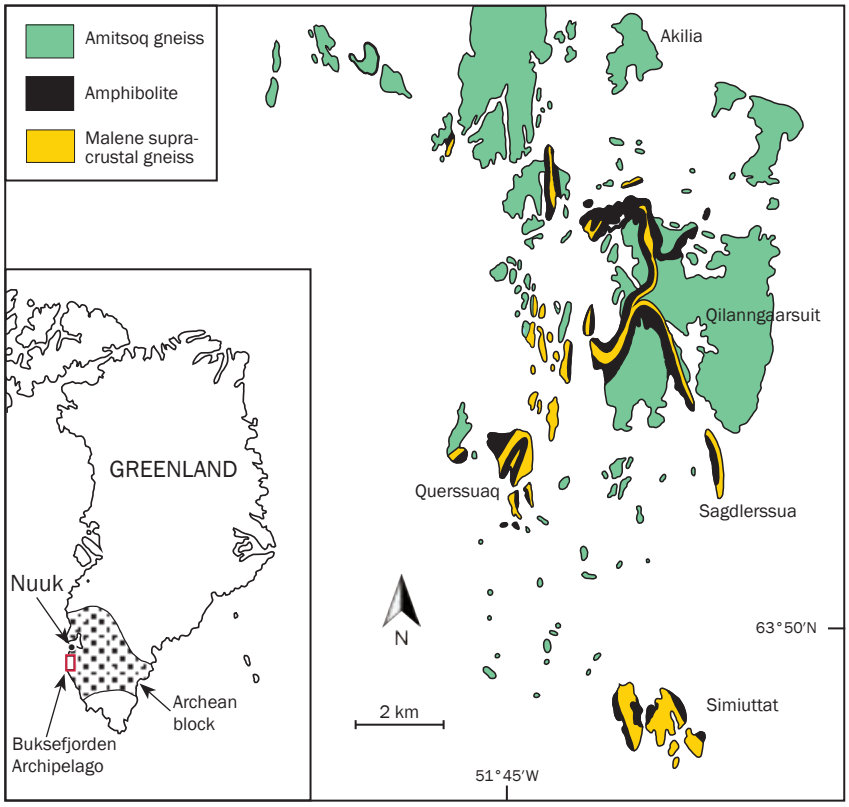

Figure 2: The Nuummite investigated in this study came from Simiuttat Island in Greenland's Buksefjorden Archipelago, where it is hosted by Precambrian Malene supracrustal gneiss. The inset shows the capital Nuuk and the position of the Buksefjorden region in the Archean block of Greenland. Modified after Beech and Chadwick (1980).

Figure 3: These Nuummite slabs (5.1 and 4.7 g) show rather subtle violet-to-blue coloration because they are only roughly polished. Photo by Tay Thye Sun.

pel, 1983; Appel and Jensen, 1987). This study investigates the mechanism for the violet-to-blue diffraction coloration of the Simiuttat Nuummite, provides a petrological description of the rock and highlights the metamorphic pressure-temperature (PT) conditions of its formation.

Materials and Methods

A sizable rough sample of Nuummite showing violet-to-blue coloration was provided by author TTS's client Rex Guo. In addition, Guo supplied two triangular slabs that were cut and partially polished from the same piece of rough; one of them weighed 5.1 g (42.00 × 15.76 × 5.57 mm) and the other was 4.7 g (30.73 × 19.24 × 5.69 mm; Figure 3). From these two samples, a polished slice and a polished thin section were prepared for further analysis.

Mineral abbreviations used in this article are after Spear (1993).

Gemmological and Petrographic Methods

The polished slice was visually examined with a Keyence VHX-1000 digital microscope, and its RI values were determined with a Gem-A refractometer. The slice also was used for hydrostatic SG measurements and was examined with a UV lamp and a desk-model prism spectroscope. The mineralogy and micro-texture of the thin section were studied using a Leica DMRX polarized-light microscope.

Electron Microprobe Analysis (EMPA)

The composition of rock-forming minerals in the thin section was quantitatively measured by EMPA using a JEOL JXA-8600 instrument at the University of Basel, Switzerland. The instrument was equipped with an UltraDry silicon energy-dispersive X-ray detector (Noran System 7 spectral imaging system by Thermo Scientific). The accelerating voltage was 15 kV and beam current was 20 nA, and we used a peak counting time of 30 seconds for all elements. Data correction was performed using the Proza (ϕρZ) method. To avoid volatilization of Na we chose a spot size of 10 µm. As the analyses were performed without the use of standards, an overall error of 2% is assumed. Backscattered electron (BSE) imaging was done at a relatively low magnification in the microprobe to investigate the mineralogical composition of the phases.

Raman Spectroscopy

Confocal Raman micro-spectroscopy was used to non-destructively identify the minerals and especially to characterize the composition of the orthoamphiboles in the polished slice. We used a dispersive Bruker Senterra Raman microscope equipped with a 532 nm laser. The high spatial resolution of this method (measurement of spots with diameters of 1–3 µm is possible) may even allow the identification of complex mineral intergrowths, zoning and exsolution lamellae. Measurements were performed at 20 mW (on the sample) with a 50 second counting time; we used objective lenses with 50× and 100× magnification and an aperture of 25 µm. Spectral matching was performed using the RRUFF database (Downs, 2006) and our own Raman database at the Mineralogical Institute in Basel.

Transmission Electron Microscopy (TEM) and Analytical Electron Microscopy (AEM)

Two slices taken from the {210} cleavage surface of orthoamphibole showing violet-to-blue coloration were investigated. Both TEM and AEM were carried out using a FEI Tecnai F20 X-Twin transmission electron microscope with a Schottky field emitter as an electron source. The accelerating voltage was 200 kV. The TEM was equipped with a Gatan imaging filter, a Fischione high-angle annular dark field detector for Z-contrast imaging, and an EDAX X-ray analyser. Electron diffraction patterns were acquired on image plates.

Calculated PT Conditions

Phase diagram calculations for the PT formation conditions of Nuummite were performed with

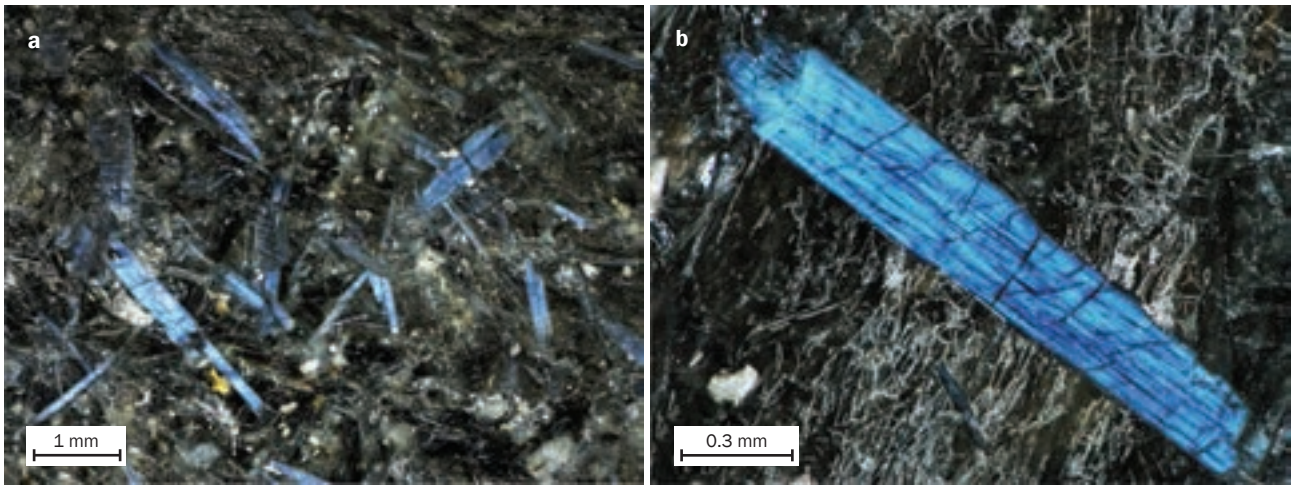

Figure 4: Keyence digital microscope photos (in reflected light) of a polished slice of Nuummite show (a) criss-crossing orthoamphibole prisms in a dark matrix of cordierite and biotite, and (b) an orthoamphibole prism displaying violet-to-blue coloration. Photomicrographs by L. Franz.

the Theriak/Domino program of de Capitani and Brown (1987; see also de Capitani and Petrakakis, 2010) in the model system TiO_2-CaO-K_2O-FeO-MgO-Al_2O_3-SiO_2-H_2O using the JUN92.bs dataset of Berman (1988) with an ideal model for anthophyllite (JUN92ANTH). A synthetic bulk-rock composition was derived from EMPA data for the equilibrium mineral assemblage and from the modal proportions of the individual phases.

Results and Discussion

Gemmological and Petrological Properties

While the rough sample was uniformly dark and hardly revealed any coloration, the roughly polished samples showed a few subtle bluish shimmers (Figure 3). By contrast, the highly polished gemstone in Figure 1 (seen previously by author TTS) displayed distinct violet-to-blue colour from mm-sized prisms over a dark grey body colour. The RIs of the polished slice were 1.650–1.660, with a second shadow edge at approximately 1.54. Hydrostatic SG measurements were 3.09 ± 0.01, and the material was inert to long- and short-wave UV radiation. No absorption features were seen with the spectroscope.

Observation of the polished slice with the Keyence digital microscope showed laths of orthoamphiboles criss-crossing one another (Figure 4a). The crystals displayed blue-to-violet flashes, which were only visible on {210} cleavages (e.g. Figure 4b). The colours vanished when the crystal was tilted to an angle of 5–15° depending on the tilting axis, indicating a strong geometric control on the colouring phenomenon. The blue-to-violet coloration was not evident on fractures and on other cleavage planes.

Polarized microscopy of the thin section revealed a close intergrowth of prismatic orthoamphibole, granular cordierite (with weak pinitization) and brown, strongly pleochroic biotite flakes (Figure 5). All minerals displayed a random orientation, although biotite may have had a weak foliation. With the use of a point counter, the mineral content of the thin section was estimated at 60 vol.% orthoamphibole, 31 vol.% cordierite, 8 vol.% biotite and 1 vol.% accessory minerals (mainly ilmenite with tiny inclusions of relic rutile and subordinate apatite and chlorite). The presence of amphibole-, biotite- and cordierite-rich areas explains the different refractometer readings, with values of about 1.66 being typical for orthoamphibole while the additional shadow edge of 1.54 originated from cordierite. Due to the lack of any significant foliation or banding, and considering the abundance of the observed minerals, the petrographic name of the rock was determined as biotite-cordierite-anthophyllite granofels. A granofels is a metamorphic rock with prevailing granular-textured minerals lacking any alignment (Schmid et al., 2007).

Orthoamphibole prisms in the thin section showed a weak pleochroism from pale yellow (α) to brownish yellow (β) to greyish brown (γ), and displayed no violet-to-blue coloration with either crossed or parallel polarizers. The prisms

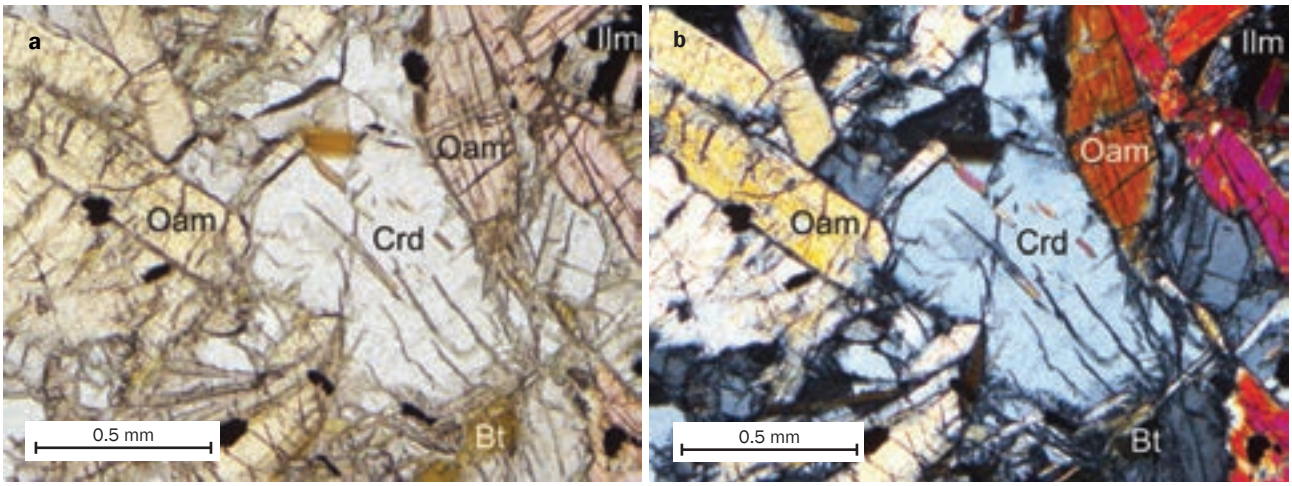

Figure 5: The mineral composition in a thin section of Nuummite is shown with (a) parallel and (b) crossed polarizers, revealing randomly oriented orthoamphibole (Oam), cordierite (Crd), biotite (Bt) and accessory ilmenite (Ilm). Photomicrographs by L. Franz.

were up to 4 mm long and had a length-to-width ratio ranging from 4:1 to 20:1. Raman spectroscopy of the orthoamphibole showed great similarities to gedrite in the RRUFF database (Downs, 2006) and to anthophyllite 75296E in our own database (Figure 6).

Selected EMPA data are shown in Table I, and all of the analyses can be found in Tables DD-1–DD-5 of the *Journal*'s data depository. The data indicated that the orthoamphibole is Al-rich anthophyllite using the classification of Hawthorne et al. (2012). All of the minerals in the rock were unzoned and had similar composition throughout the thin section. Backscattered-electron imaging, EMPA, and Raman profiles across the orthoamphibole crystals did not reveal any evidence of zonation or exsolution lamellae in the micrometre or larger scale; the same applied to the other rock-forming minerals. The cordierite was Mg-rich with X_{Mg} values [Mg/(Mg+Fe^{2+})] of 0.80–0.83, while biotite had X_{Mg} values of 0.70–0.75 with TiO_2 contents of 1.0–1.7 wt.%. Biotite and cordierite were intergrown with pale green chlorite (ripidolite/sheridanite with X_{Mg} values of 0.79–0.81).

TEM and AEM

TEM images (e.g. Figure 7a) showed a continuous succession of alternating exsolution lamellae of anthophyllite (wide, dark grey bands) and gedrite (narrow, light grey lamellae), which also were revealed by AEM chemical analyses (Table I). The electron diffraction pattern (Figure 7b) of the orthoamphibole showed that the exsolu-

Figure 6: Raman spectra of the violet-to-blue orthoamphibole from the Simiuttat Nuummite (a) had many similarities to the spectra of the gedrite and anthophyllite reference standards (b and c).

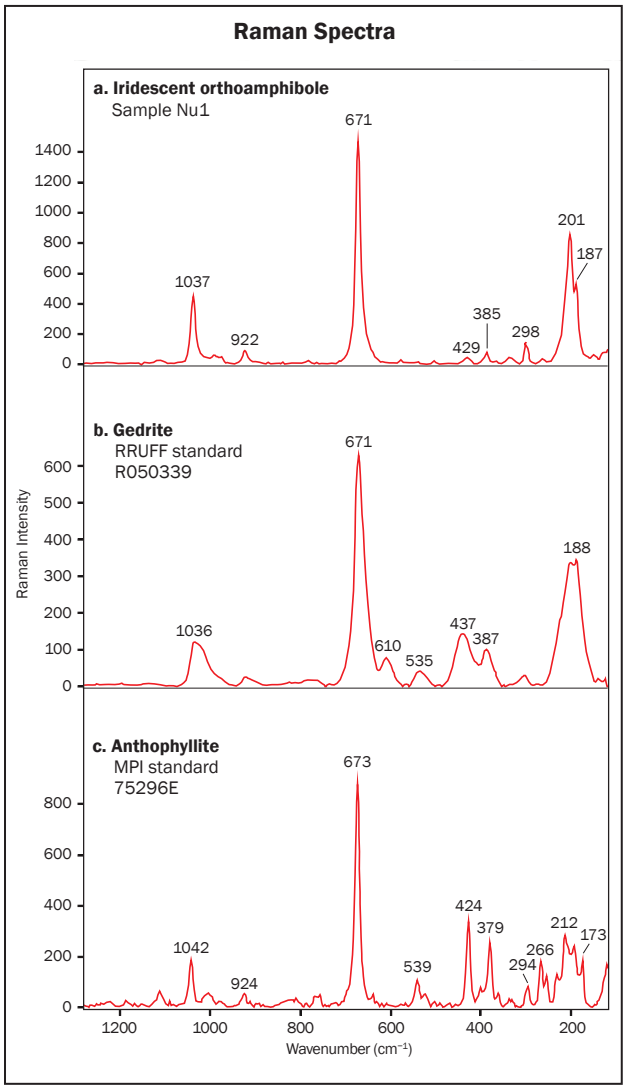

*Table I: EMPA and AEM data of rock-forming minerals in iridescent violet-to-blue Nuummite from Simiuttat, Greenland.**

Mineral	Orthoamphibole						Cordierite	Biotite	Chlorite
Technique	EMPA	EMPA	EMPA	EMPA	AEM	AEM	EMPA	EMPA	EMPA
Point	F1 core	F1 rim	F5 core	F5 rim	A2 Ged	A2 Ath	Average	Average	Average
Oxides (wt.%)									
SiO_2	53.02	52.49	51.49	52.95	43.14	52.44	50.22	38.81	28.15
TiO_2	0.16	bdl	bdl	0.04	bdl	bdl	bdl	1.25	bdl
Al_2O_3	6.11	6.91	6.78	5.65	17.84	1.95	33.18	17.76	22.58
Fe_2O_3	1.27	1.70	2.47	1.19	bdl	bdl	nd	nd	0.38
Cr_2O_3	bdl	bdl	bdl	bdl	bdl	bdl	nd	bdl	nd
MgO	19.96	19.99	19.69	20.49	24.88	31.61	11.61	18.08	25.24
CaO	0.43	0.42	0.46	0.52	0.53	0.21	bdl	bdl	bdl
MnO	0.26	bdl	0.11	0.33	bdl	bdl	0.13	0.22	0.40
FeO	16.13	15.86	16.66	16.54	13.58	13.78	4.60	11.57	11.29
Na_2O	0.78	0.80	0.59	0.40	nd	nd	0.26	0.39	bdl
K_2O	bdl	bdl	bdl	bdl	bdl	bdl	bdl	7.75	bdl
Total	98.13	98.17	98.25	98.12	99.97	99.99	100.00	95.83	88.05
Cations	per 23 oxygens						per 18 oxygens	per 12 oxygens	per 28 oxygens
Si	7.472	7.388	7.301	7.476	5.947	7.214	5.005	2.790	5.471
Ti	0.017	bdl	bdl	0.004	bdl	bdl	bdl	0.067	bdl
Al	1.014	1.146	1.133	0.941	2.899	0.316	3.897	1.505	5.172
Fe^{3+}	0.135	0.180	0.264	0.127	bdl	bdl	nd	nd	0.056
Cr	bdl	bdl	bdl	bdl	bdl	bdl	nd	bdl	nd
Mg	4.194	4.195	4.162	4.313	5.113	6.482	1.725	1.937	7.313
Ca	0.065	0.064	0.070	0.079	0.078	0.031	bdl	bdl	bdl
Mn	0.032	bdl	0.013	0.040	bdl	bdl	0.011	0.014	0.066
Fe^{2+}	1.901	1.867	1.976	1.953	1.566	1.585	0.383	0.695	1.836
Na	0.214	0.219	0.162	0.110	nd	nd	0.050	0.054	bdl
K	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl
Total	15.044	15.059	15.081	15.041	15.603	15.628	11.072	7.773	19.915

* Estimates of Fe^{3+} in the EMPA data of orthoamphibole were done with the min-max method of Leake et al. (1997) using the intermediate value of Fe^{3+}. Na could not be determined with AEM due to an overlap of the Na(*K*α) line with the Ga(*L*α) line; consequently, an estimate of Fe^{3+} for those analyses was not performed. Fe^{3+} in chlorite was estimated using the method of Laird and Albee (1981). Abbreviations: bdl = below detection limit; nd = not determined.

tion of the lamellae occurred parallel to (010)—that is, (010) anthophyllite || (010) gedrite—as previously observed by Gittos et al. (1976). Our images showed close correspondence with the observations of Champness and Rodgers (2000) and with atomic force microscopy images of Rodgers et al. (1996) on golden brown iridescent orthoamphibole. The main difference between our results and those previous studies is a variation in the thickness of the gedrite-anthophyllite lamellae pairs. While the mean thickness of the lamellar pairs in our sample was 124–133 nm, Champness and Rodgers (2000) observed a mean of ~180 nm, while Rodgers et al. (1996) found 190–350 nm.

Due to the difference in RI values between the anthophyllite and gedrite lamellae (0.035 for n_z), the wavelength of the observed colour for incident light on the lamellar interfaces can be calculated with the Bragg equation, $\lambda = 2nd\sin\Theta$, where n is the mean RI of the two phases, d is the mean thickness of the lamellar pairs and Θ is the angle of incidence of the light on the lamellar interface (cf. Laves et al., 1965). Assuming an RI value of 1.66 (average for the anthophyllite-gedrite solid solution; cf. Champness and Rodgers, 2000) and an angle of 80° for Θ, the Bragg equation yields a wavelength of 405–435 nm (i.e. violet-to-blue light). This shows that the observed lamellar spacing of 124–133 nm is consistent with

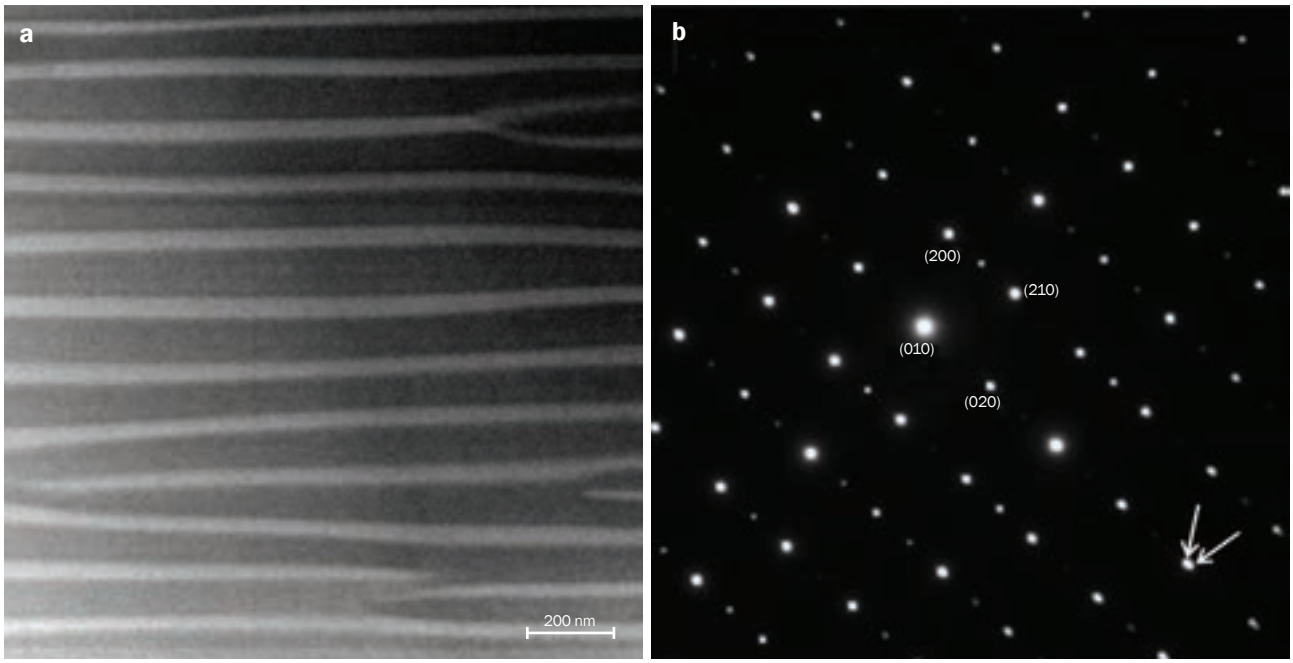

Figure 7: (a) The TEM image of violet-to-blue orthoamphibole shows alternating lamellae of anthophyllite (dark grey; major phase) and gedrite (light grey; minor phase) with a spacing of ~133 nm, seen parallel to (010). (b) In the electron diffraction pattern from the orthoamphibole in (a), each spot along the crystallographic b-direction is split (e.g. see arrows). The splitting is due to different lattice parameters and is very small. It is only visible at higher-order reflections such as those from (020) to (080), and indicates that there are two contiguous phases with analogous structures visible at higher-order reflections of {0k0}. Images by R. Wirth.

the violet-to-blue diffraction coloration observed in this Nuummite.

PT Formation Conditions

Phase diagram calculations with the Theriak/Domino program (Figure 8) clearly show the stability field for the mineral assemblage anthophyllite-cordierite-biotite-chlorite-ilmenite-H_2O at temperatures of 505–660°C and pressures below 6.4 kbar, corresponding to upper greenschist to amphibolite-facies conditions at low-to-moderate pressures (see yellow field in Figure 8). The EMPA data of the orthoamphibole crystals from our Nuummite samples plot at 590–600°C (±25°C) in the T–Al^{IV} solvus diagram of Spear (1980; see Figure 9), constraining the minimum metamorphic temperature experienced by the rock. Due to the polymetamorphic history of the Nuummite, however, it is not possible to infer the timing of the exsolution in the orthoamphibole.

Figure DD-1 in *The Journal's* data depository shows a phase diagram including mineral reactions and activity models used, and all mineral reactions are listed in Table DD-6 of the data depository.

Conclusions

Iridescent orthoamphibole has been reported from various locations, such as New Hampshire and Massachusetts (Robinson et al., 1971), south-west Greenland (Appel and Jensen, 1987; Rodgers et al. 1996; Champness and Rodgers, 2000) and Mauritania (Kobayashi, 2009; Renfro, 2011). In most cases, these orthoamphiboles show a golden brown iridescence with greenish and bluish colours being subordinate (Rodgers et al., 1996; Renfro, 2011). As shown by Rodgers et al. (1996) and Champness and Rodgers (2000), the iridescence of Nuummite results from sub-microscopic, alternating lamellar exsolution of gedrite and anthophyllite. Champness and Rodgers (2000) proved that the periodic lamellae had an average spacing of ~180 nm, which gives rise to a yellow iridescence. For our samples from Simiuttat, we found distinctly smaller spacings of 124–133 nm, resulting in violet-to-blue coloration. By comparison, Nuummite from Mauritania contains blades of orthoamphibole showing bluish coloration in the outer zones shifting to a yellowish green in the centre, which was ascribed to possible chemical

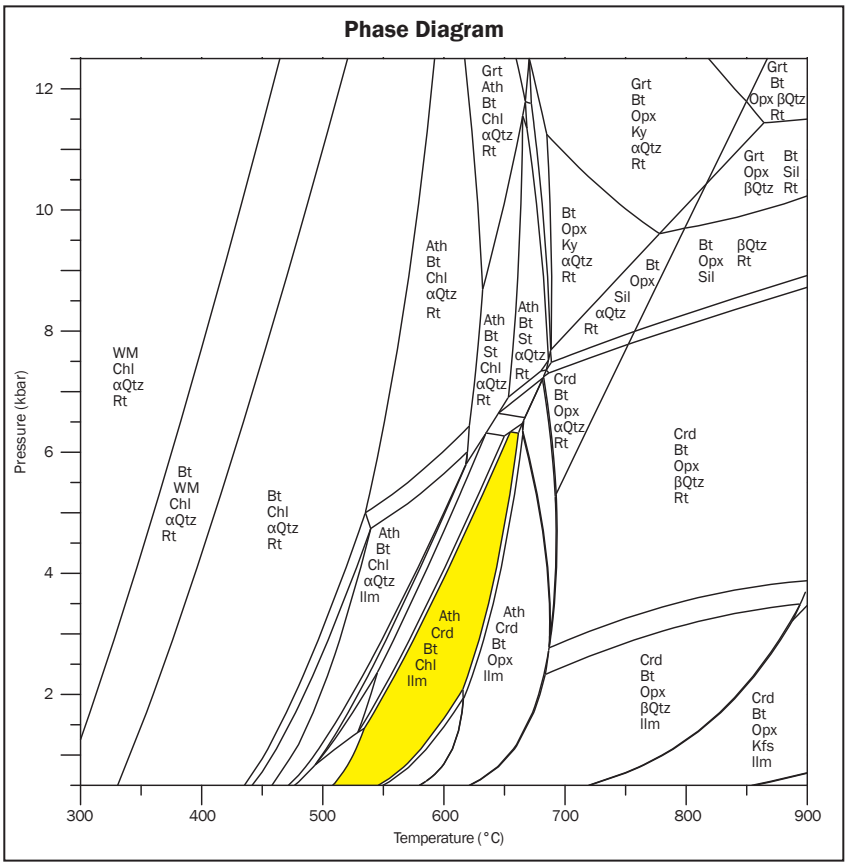

Figure 8: This equilibrium phase diagram for the Simiuttat Nuummite was calculated with the Theriak/Domino program of de Capitani and Brown (1987) and the JUN92ANTH dataset for the most important mineral assemblages and H_2O in excess. The molar bulk-rock composition is 3.612 Si, 0.04 Ti, 1.228 Al, 0.853 Fe, 1.872 Mg, 0.054 K, 50 H and 36.898 O. The stability field of the observed assemblage anthophyllite-cordierite-biotite-chlorite-ilmenite is shaded in yellow, and corresponds to temperatures of 505–660 °C and pressures below 6.4 kbar.

variation within the crystals (Renfro, 2011). The present study, as well as former investigations (see Rodgers et al., 1996; Champness and Rodgers, 2000), prove that such differences in the colour are not due to chemical variations from grain to grain but rather are due to the spacing of the exsolution lamellae in the orthoamphibole. While Appel and Jensen (1987) ascribed Nuummite iridescence to internal reflections from alternating gedrite and anthophyllite exsolution lamellae (see also Champness and Rodgers, 2000), Rodgers et al. (1996) postulated that the surface topography of the {210} cleavages (as an expression of the underlying lamellae) might act as a diffraction grating that could contribute to the iridescence. To definitively assign the iridescence to one of these phenomena, further investigations (including ultraviolet-visible reflectance spectroscopy) would need to be performed, but these are beyond the scope of the present investigation.

Polarized microscopy showed that the correct petrographic name of the investigated Nuummite is biotite-cordierite-anthophyllite granofels, following the suggestions of Schmid et al. (2007). This investigation also confirmed that the second RI shadow edge at approximately 1.54 is due to cordierite. As shown by phase diagram calculations using the Theriak/Domino program of de Capitani and Brown (1987), the rock experienced a metamorphic overprint at low-to-moderate pressures and upper greenschist to amphibolite-facies conditions. Minimum metamorphic temperatures of 590–600°C (±25°C) were estimated using the T–Al^{IV} solvus diagram for orthoamphibole of Spear (1980), constraining amphibolite-facies conditions. According to Rodgers et al.

Figure 9: EMPA data for the orthoamphiboles in this study are plotted on the T–Al^{IV} solvus diagram of Spear (1980), indicating minimum temperatures of formation of 590–600 °C. The error of the diagram is ±25 °C.

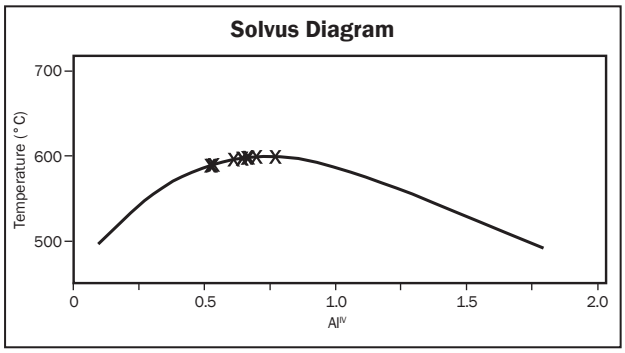

(1996), the average age range for this metamorphic overprint (using $^{207}Pb/^{206}Pb$ ages of monazite and zircon) is 2,707–2,732 (±10–12) million years. The exsolution lamellae in the orthoamphibole may have formed during cooling after peak metamorphism, during reheating processes in the course of the intrusion of the Qôrqut granite complex (~2,500 million years ago) or during a later Proterozoic metamorphic overprint (Rodgers et al., 1996).

Small amounts of violet-to-blue Nuummite from Greenland will likely continue to be available on the market in the future.

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– Roman Elder Pliny, 1st Century AD

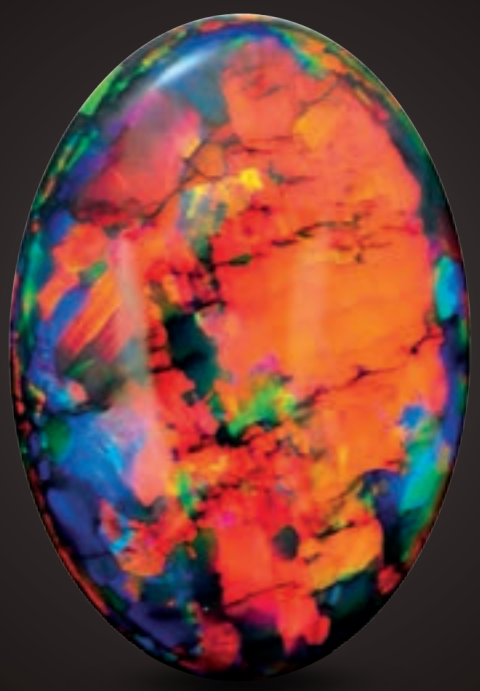

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Conferences

2nd European Mineralogical Conference (emc2016)

This relatively new conference took place in Rimini, on the north-east coast of Italy, on 11–15 September 2016 and attracted approximately 700 attendees. A session titled 'Gem Materials' offered 23 contributions (15 talks and eight posters), and the conference also included sessions on 'Diamonds: Open Windows to the Earth's Mantle' and 'Inclusions in Minerals as Record of Geological Processes'. Gemmologically relevant talks and posters that were seen by these authors in the Gem Materials and the Diamonds sessions are summarized below.

The session on Gem Materials opened with keynote speaker **Dr Dan Marshall** (Simon Fraser University, Burnaby, British Columbia, Canada), who revisited the convoluted topic of emerald deposit models and classifications. He reviewed various past efforts and approaches, emphasizing how specific localities can be hard to put into only one deposit type. He proposed a simplified classification with just three types: magmatic (pegmatites without schist), metamorphic (schist without pegmatite) and sedimentary (black shales with veins and breccias).

Dr Emmanuel Fritsch (University of Nantes, France) presented the growth factors involved in obtaining gem-quality crystals. A small number of nuclei ensure that only a few crystals will form, which generally grow via spiral dislocations to generate gem-quality crystals (e.g. Figure 1). A small number of gems grow much faster in fibres or dendrites (e.g. *gota de aceite* emeralds and some tourmalines and diamonds). Surface instability during growth induces the capture of inclusions, so optimum growth conditions must be maintained for a relatively short period of time, from a few weeks to a few months at most.

Dr Peter Bacik (Comenius University, Bratislava, Slovakia) followed with an overview of selected Cr- and V-bearing gem minerals and materials and their spectroscopic properties in the visible range. He reviewed the influence of bond strength on absorptions related to crystal field transitions of these important colour-causing elements. Differences in crystal structures lead to variations in positions and intensities of the absorptions, and therefore different colours perceived by the human eye.

Dr Isabella Pignatelli (CRPG, Vandoeuvre-lès-Nancy, France) presented her investigations of the trapiche-like growth textures in euclase from Colombia. She systematically showed through various avenues of investigation (including X-ray tomography) that although there are similarities in the origins of these textures for emerald and euclase, the term *trapiche* should not be applied to euclase.

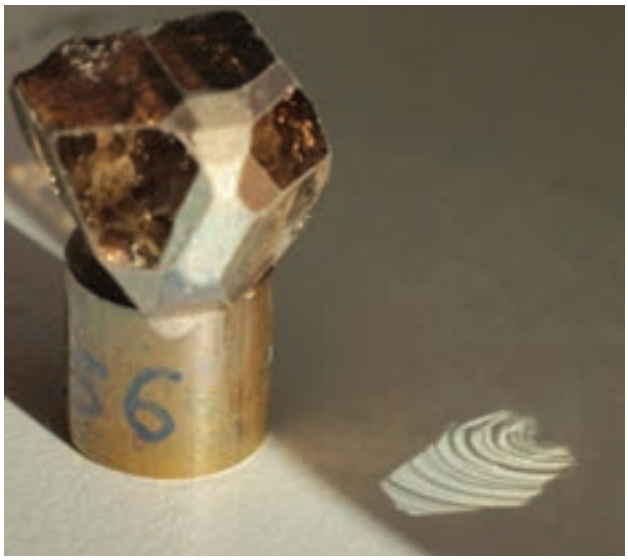

Figure 1: The reflection from a face of this natural topaz crystal (~2 × 2 × 1 cm) from Pakistan highlights a spiral-shaped growth hillock. Most gems grow via such a spiral dislocation mechanism, visible on their crystal faces. Photo by Benjamin Rondeau.

Dr Dan Marshall presented again on emeralds, with new information on mineralization at Poona in Western Australia. Particular attention was given to fluid inclusions and stable isotopes to show that the distinctly zoned crystals have origins that can be tied to alternating crystallization in igneous and metamorphic hydrothermal fluids.

Dr Gaston Giuliani (CRPG, Vandoeuvre-lès-Nancy) enthusiastically reviewed his team's ongoing work on marble-hosted pink and red spinel. In particular, he presented oxygen isotope data of spinel from many localities, showing a wide range in values but with three main clusters based on the current dataset. This isotopic data, combined with trace- and minor-element composition (e.g. V, Cr, Fe and Zn), form the beginnings of a database for determining the geographic origin of gem-quality spinel.

Dr Stefanos Karampelas (GRS Gemresearch Swisslab AG, Lucerne, Switzerland) provided new

data on the detection of heat treatment in tanzanite. Previous criteria have been refined, and attention is being paid to several absorptions in the ultraviolet-visible region that are not attributable to any specific ion or defect presently known.

Dr Aaron Palke (Gemological Institute of America [GIA], Carlsbad, California) presented his research on melt inclusions within sapphire from Yogo Gulch, Montana, USA. The melt inclusions are postulated to be the medium from which the sapphires crystallized; however, their bulk chemistry is distinctly different from the ouachitite dyke that hosts the sapphires and is more akin to remnant leucocratic ocelli that are also found in the dyke. This evidence supports the hypothesis by Dahy (1991) in which the lamprophyre has entrained the sapphires as xenocrysts.

Dr David Turner (University of British Columbia, Vancouver, Canada) discussed the application of near-field hyperspectral imaging to gem corundum exploration, using the marble-hosted Beluga sapphire occurrence at Nunavut, Canada, as an example. Indicator minerals for corundum mineralization were shown to be detectable by this technique, and the work also revealed additional spectrally active minerals that are genetically related to corundum mineralization. Potential exists to conduct airborne exploration surveys by drone in areas with decent outcrop exposure.

Dr Benjamin Rondeau (University of Nantes, France) presented the discovery of a probable new phosphate mineral species as inclusions in quartzite from Mt Ibity, Madagascar. Often referred to as 'blue quartz', it contains the largest-known diversity of inclusions in quartz (over 20 different species), among which lazulite dominates and causes its blue colour. The apparently new mineral is very light pinkish brown and could have a formula corresponding to $Mg_3(Ca,Sr)_2(Al,Fe^{3+})_3(PO_4)_6F$. Only five crystals were found, and the material is awaiting final characterization by X-ray diffraction analysis.

Dr Ilaria Adamo (International Gemological Institute, Milan, Italy) discussed the characterization of purplish blue banded chalcedony from Yozgat Province, Turkey. The presence of moganite, a rare variety of silica, is inferred from Raman spectroscopy, and scanning electron microscopy showed an uneven, somewhat porous structure. Both could contribute to light scattering, to which the blue component of the colour is attributed. As Fe is the only impurity found at concentrations above 10 ppm in this material, the authors wonder if it may cause a minor amethyst colour component.

Dr Boris Chauviré (University of Nantes, France) developed a model for the formation of opal at Wegel Tena, Ethiopia, now a major producer of this gem. New evidence from field research (16 mines documented) and laboratory studies reinforces the view that the opal formed in a soil. All fossils found in the opal are roots, rather than any other part of plants or other organisms. Oxygen isotope measurements also favour a low-temperature precipitation. Finally, the zoning often seen in the opal—showing a cloudy white rim and a transparent orange centre—has been reproduced in the laboratory. When gem fire opal was soaked in oxalic acid (a reasonable proxy to complex humic acids found in soils) for a few weeks, the same zoning was produced.

Dr William 'Skip' Simmons (University of New Orleans, Louisiana, USA) enthusiastically described the new Maine Mineral and Gem Museum in Bethel, Maine, USA. This museum is devoted to the preservation of Maine minerals, gems and historical mining material from this renowned gem pegmatite region. Two major contributors helped assemble the collection with old and newly mined material, sometimes negotiated from other museums and collections outside Maine. Many spectacular gems and mineral specimens are on display, including vividly coloured tourmalines. As an aside, some remarkable meteorite specimens are also on display.

Ann Pizzorusso (New York, New York, USA) delved into the historical aspect of gemstones. She took the audience through a series of examples of how gems were represented in ancient texts and what that could reveal about societal values of the time. For example, Dante was shown to have weaved both the mythology and physical properties of gems into some of his texts through both allusions and direct references.

Dr Valeria Diella (CNR-IDPA, Milan, Italy) studied massive pink epidote ('clinothulite') from the Val Malenco region in northern Italy (Figure 2). There are two occurrences: the main one at Pizzo Tremoge and

Figure 2: This pink massive epidote, also known as 'clinothulite', comes from the famous Val Malenco area in northern Italy. The beads in the necklace on the right have a diameter of ~1 cm. Photo by Pietro Nana.

one of lesser-quality material at Pra Isio, Valtellina, about 10 km away. Both are at high altitude and difficult to reach, but prospecting suggests good potential. The stone occurs in various shades of pink. Its RI is about 1.69, SG is 3.10–3.52, and it is inert to UV radiation. Its pink colour is attributed to traces of manganese.

M. G. Reid and **Dr Alan Anderson** (St Francis Xavier University, Antigonish, Nova Scotia, Canada) investigated melting and crystallization in the system $LiAlSi_4O_{10}$–H_2O to provide insights into the crystallization of gem-bearing cavities in granitic pegmatites, which are generally believed to have formed from a volatile-saturated melt in the late stages of pegmatite crystallization. Using video footage from their experiments, they showed *in situ* crystallization in the silicate melt, the aqueous fluid or in both. Some of the crystals that initially grew in the silicate melt continued to grow beyond the melt-fluid interface by the transfer of melt material in the aqueous fluid. Thus they propose that the cavity minerals form in a low-density fluid by rapid diffusion of ions from the residual silicate melt to the growing crystal faces.

In the Diamond session, several communications were of interest to gemmologists. **Dr Hélène Bureau** (Paris-Sorbonne University, France) proposed that the presence of small discrete or isolated volumes of water in carbonate-rich fluids are necessary to grow fibrous, cloudy and coated diamonds in peridotitic or eclogitic environments. She conducted synthetic diamond growth experiments employing mixtures of carbonates, graphite and silicates together with diamond seeds, in the presence of water or saline fluids (H_2O-NaCl) between 6–7 GPa at 1,300–1,675°C, for 6 to 30 hours. Water promoted faster diamond growth, which is favourable for the formation of inclusions, as seen in nature. Diamond isotopic signatures near the inclusions corresponded with those of the starting carbonates, indicating that the carbon source for such diamond growth must be carbonates.

Dr Ingrid Chinn (De Beers Group Exploration, Johannesburg, South Africa) pointed out two major shortcomings of previous isotopic studies of diamond. Based on a detailed documentation of 198 microdiamonds from Orapa, Botswana, she demonstrated considerable zoning within a single stone: from –24.03‰ in the core to –6.21‰ $\delta^{13}C$ in the rim, and from 40 to 3,196 atomic ppm N in another crystal. Hence, the bulk analyses that comprise the majority of the global isotopic datasets are inappropriate. Furthermore, she established that the carbon isotopic data from inclusion-bearing diamonds is quite different from that of inclusion-free crystals. However, most carbon isotope data come from inclusion-bearing stones and are thus not representative of the entire diamond populations. Clearly, detailed and spatially controlled stable isotopic analyses and fully representative samples are required if the complex origins of diamonds in the mantle are to be understood.

Dr Paolo Nimis (University of Padova, Italy) provided the first direct evidence of the common presence of a hydrous silicic fluid surrounding typical eclogitic and peridotitic mineral inclusions (e.g. olivine) in gem-quality diamonds. The fluid film (up to 1.5 µm thick) contains $Si_2O(OH)_6$, $Si(OH)_4$ and molecular H_2O. This observation strongly suggests that gem-quality lithospheric diamonds grow in the presence of a water-rich fluid, an idea echoed by several other presentations.

J. Rudloff-Grund, a PhD student from the Goethe University Frankfurt, Germany, presented an ongoing study of the inclusions in milky diamonds from Juina, Brazil. The milky areas are filled with octahedral nanoinclusions, appearing optically empty. However, infrared spectroscopy suggests that these voids are actually filled with ammonia.

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HRD Antwerp Symposium

The annual HRD Antwerp Symposium was held on 26 September 2016 at Elzenveld in Antwerp, Belgium. About 90 people attended the conference, which was themed 'Inspired by Nature'. **Dr Katrien De Corte**, chief officer of Education & Industry at HRD Antwerp, chaired the event. HRD Antwerp acknowledged the contributions of **Sergey Panchekhin**, managing director of Arcos Belgium, by awarding him the 2016 Certificate of Appreciation. Also, HRD Antwerp celebrates 35 years of education this year, and **Mark Van Bockstael** and **Eddy Vleeschdrager** were honoured for being its founders.

Figure 3: Dr Ewa Wagner-Wysiecka discusses Baltic amber at the HRD Antwerp Symposium. Photo by Stijn Beckers.

Prof. Pierre Cartigny (CNRS, Institut de Physique du Globe de Paris, France) analysed the 'DNA' of diamonds by using stable isotopes. He illustrated how C and N isotopes can be used to help fingerprint the geological origin of diamond.

Frederik Degryse (Dominion Diamond Corp., Toronto, Ontario, Canada) documented the challenges of mining diamonds in Canada's Northwest Territories, and described the sustainable mining practices in use there. He also indicated that the CanadaMark hallmark programme can be used as a verification of Canadian-origin diamonds.

Dr Ewa Wagner-Wysiecka (Gdańsk University of Technology, Gdańsk, Poland) summarized the origin, deposits and properties of Baltic amber (Figure 3). She also pointed out the differences between amber (succinite), copal and other resins. In addition, she classified the different types of Baltic amber and mentioned various amber imitations in today's market.

Thanh Nhan Bui (Louvain School of Engineering, Université catholique de Louvain, Belgium) described 'gold sheen' sapphire from East Africa. He outlined the exsolution of hematite and ilmenite inclusions to form the sheen in these sapphires and compared them with similar black star sapphires.

Hans Smellinckx (Artoos|Hayez, Antwerp) discussed changes in the high-end jewellery industry as a result of the accelerating pace of life that is shaking up the way of doing business and influencing marketing strategies and branding.

Elke De Greef (Ibriz, Bellingen, Belgium) explained how to choose the right shape and style of jewellery according to the outline of one's face and the effect the designer aims to achieve.

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Geological Society of America Annual Meeting

This large geoscience conference took place in Denver, Colorado, USA, on 26–28 September 2016. Approximately 7,100 people attended from 48 countries. A session of interest to gemmologists was titled 'Gemological Research in the 21st Century: Characterization, Exploration, and Geological Significance of Diamonds and other Gem Minerals', and was organized/advocated by Dr James Shigley, Dona Dirlam, Dr Wuyi Wang, Dr Barbara Dutrow, Dr Jeffrey Post, Dr Steven Shirey, Dr William 'Skip' Simmons and Dr John Valley. The session was attended by about 220 people, and abstracts are available at https://gsa.confex.com/gsa/2016AM/webprogram/Session40327.html (oral presentations) and at https://gsa.confex.com/gsa/2016AM/webprogram/Session41331.html (posters).

Dr Jeffrey Post (National Museum of Natural History, Smithsonian Institution, Washington DC, USA) and co-authors reviewed investigations into the luminescence properties and composition of coloured diamonds. Post emphasized the importance of having access to these rare samples for research via museum collections, such as at the Smithsonian Institution. Some of the notable coloured diamonds that his team has studied include the Hope, the Wittelsbach-Graff, the DeYoung Pink and those in the Cullinan Blue Diamond Necklace.

In a well-illustrated talk, **Dr Christopher 'Mike' Breeding** (GIA, Carlsbad, California, USA) examined the artistic and scientific aspects of diamond fluorescence using DiamondView images. In addition to often being quite attractive in their patterns and colours, such images also reveal the growth history, morphology, defect distribution, and migration of these defects in natural and synthetic diamonds.

Dr Karen Smit (GIA, New York, New York, USA) and co-authors described the unusual geologic history of rare bright yellow type Ib diamonds from Sierra Leone. Their research suggests that these diamonds formed via closed-system growth from methane-rich fluids approximately 650 million years ago, and that the presence of unaggregated single nitrogen atoms (the cause of their yellow colour) points to rapid exhumation rates after an extended residence time at temperatures below 700°C.

D. Graham Pearson (University of Alberta, Edmonton, Canada) and his co-author studied the composition of fluids trapped as inclusions in diamonds from

the Ekati and Diavik mines in Canada, and postulated that saline fluids were key to the enrichment of the base of the lithosphere and the formation of those peridotitic diamonds. The source of the saline fluids appears to be the subducting plate under western North America, prior to the Mesozoic kimberlite eruptions that brought the diamonds to the surface.

Dr Evan Smith (GIA, New York) and co-authors characterized the mineral inclusions that rarely occur in a special subgroup of type II diamonds that they termed 'CLIPPIR' (Cullinan-like, large, inclusion-poor, pure [type II], irregular-shaped, resorbed). From a sample set of 73 type IIa diamonds (faceted gemstones and offcuts), they categorized 52 as CLIPPIR stones, and of those, 37 contained metallic inclusions. The most common inclusions consisted of a multiphase assemblage of Fe-carbonate, an Fe-Ni alloy and sulphide segregations. They also identified inclusions of perovskite and majoritic garnet, which suggest ultra-deep formation depths for these diamonds of >360 km, within the mantle transition zone.

Dr Emmanuel Fritsch (University of Nantes, France) highlighted the rising number of near-colourless synthetic diamonds in today's market (as melee and larger stones) and also noted that the reliability of melee-sorting machines for separating synthetic diamonds is not well known. He then reviewed various methods that may be helpful toward identifying near-colourless synthetic diamonds, including UV transparency (to separate type IIa samples), short-wave UV phosphorescence (more typical of synthetics), anomalous double refraction (natural diamonds show more strain than synthetics), luminescence patterns (although the differences between natural and synthetic diamonds are becoming more subtle) and photoluminescence spectroscopy (although ultrapure diamonds—whether natural or synthetic—may show no PL features).

Jullieta Enone Lum (University of Johannesburg, South Africa) and co-authors geochemically characterized aquamarine from the Erongo Mountains in Namibia and emerald from the Gravelotte-Leydsdorp area in South Africa. Compared to the aquamarines, the emeralds contained greater amounts of Ti, Cr, Sc, Mg and Na.

Yury Klyukin and his co-author (Virginia Tech, Blacksburg, USA) reviewed the occurrence of fluid and melt inclusions in gem minerals. Using examples from emerald, diamond, ruby and sapphire, they showed how such inclusions may be useful for identifying natural vs. synthetic origin, indicating heat treatment, differentiating genetic type and giving provenance information.

Dr Peter Heaney (Penn State University, University Park, Pennsylvania, USA) and co-authors reported on their study of iridescent specular hematite aggregates from the Andrade mine in Minas Gerais, Brazil (frequently marketed as 'rainbow hematite'). Using a combination of microanalytical techniques, they found that spindle-shaped nanocrystals of hematite comprise a highly porous framework with distances between adjacent crystals of 280–400 nm. This creates a diffraction grating that causes the iridescence.

Mandy Krebs (University of Alberta, Edmonton, Canada) and co-authors characterized rubies from Mozambique and Greenland (e.g. Figure 4). They used a new offline LA-ICP-MS technique to obtain a wider range of quantitative trace-element data, and found that rubies from the two deposits showed systematic differences in composition (i.e. plots of Th/Yb vs. Nb/Yb and Zr vs. Ti; see Figure 4). In addition, Sr isotopic values of rubies from the two deposits were distinct, and Pb-Pb age dating of the Green-

Figure 4: Rubies from Mozambique and Greenland have a similar regional metamorphic-metasomatic origin, but these plots reveal significant variations in some of their trace elements. The dashed lines separate the geochemical fields for each locality, although there is minor overlap in the data.

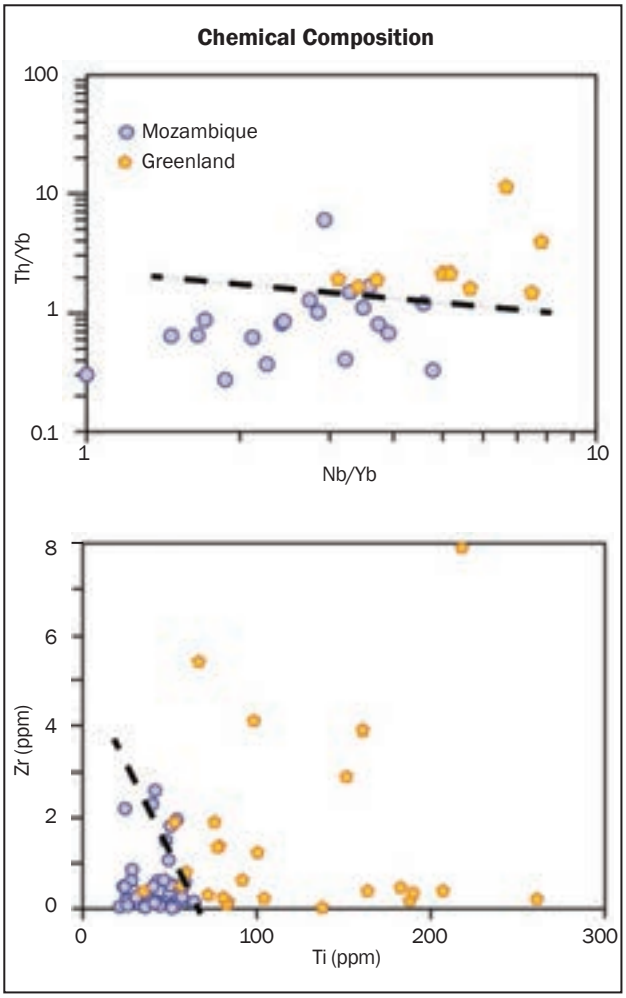

land rubies yielded 2,676 ± 40 million years, which is much older than the Pan-African age assumed for Mozambique rubies.

Dr Raquel Alonso-Perez (Harvard University, Cambridge, Massachusetts, USA) and her co-author studied a cabochon-quality emerald deposit (Gilles mine) at Irondro in the Mananjary area of Madagascar. Field and analytical studies show that the emeralds formed in a 'blackwall' alteration zone (amphibolite-phlogopite-rich rocks) situated between a felsic gneiss and a talc-serpentine schist.

Dr David London and co-authors (University of Oklahoma, Norman, Oklahoma, USA) reviewed the nature and origins of internal zonation within granitic pegmatites. Understanding the formation of such zonation may aid in the exploration for gem minerals that are hosted by cavities or 'pockets' within such pegmatites. *Brendan M. Laurs*

Gem-A Conference

The annual Gem-A Conference took place 5–6 November 2016 at the Royal Institute of British Architects in London and was attended by approximately 200 people from 27 countries.

The event was introduced by Gem-A's CEO **Alan Hart**. Then **Ian Harebottle** (Gemfields, London) gave a provocative presentation on the evolution of coloured stones in jewellery design. Although coloured stones are among the first recorded luxury goods, he indicated that they have been trapped in a sector that has shown little meaningful growth in more than 500 years. Using Gemfields' mining projects for emerald, ruby and amethyst as examples, he described efforts to enhance demand for coloured stones through marketing and providing a stable and large enough supply to meet the needs of the industry.

Jim Clanin (JC Mining, Bethel, Maine, USA) described his experiences with mining coloured gemstones and mineral specimens at various world localities. He emphasized that each deposit is different and successful exploitation depends on customizing the mining methods for each situation (e.g. surface or underground workings, type of machinery and blasting techniques used). An exciting new development in blasting technology recently became available. Called Autostem, when detonated it causes less damage to the surrounding area (including nearby gem and mineral specimens) and it does not produce any hazardous gases.

Dr David Fisher (De Beers Group of Companies, Maidenhead) reviewed the detection of diamond treatments. The need to solve more complex problems has prompted the use of more advanced instrumentation. De Beers is currently investigating a new technique called confocal luminescence depth profiling to scan the intensity of luminescence through the entire thickness of a diamond sample to help with detecting natural irradiation vs laboratory irradiation.

John Dyer (John Dyer & Co., Edina, Minnesota, USA) examined the art and science of gem cutting, using photos and video footage to illustrate case studies of successful and unsuccessful outcomes. When evaluating the cut quality of coloured stones, one should beware of rounded or misshapen facets; a girdle that is wavy, too sharp or of variable thickness; lack of facet symmetry or shape; poor polish; and windowed stones. A well-cut gem should show lots of brilliance, but also an attractive contrast pattern that displays a pleasing balance of light and dark areas along with good colour saturation.

Robert Weldon (GIA, Carlsbad, California, USA) took the audience on a virtual journey to the Chivor emerald mine, in the footsteps of Peter W. Rainier. Author of the book *Green Fire*, Rainier managed operations at the Chivor mine during some of its most productive times from 1926 to 1931. Some of the famous stones that were produced during Chivor's long history include the Angel of the Andes (987 ct crystal) and the Patricia emerald (632 ct crystal).

Helen Molesworth (Gübelin Academy, Lucerne, Switzerland) explored the history of gemstones using various sources of information, including textual (written records), visual (paintings and other pictorial evidence) and physical (artefacts). The earliest use of gems can be traced back to 100,000 BC (shells), while fakes were first used around 400 BC. Later, from the 3rd century BC to the 3rd century AD, there was an increase in the availability and diversity of gem materials that corresponded with the rise of Alexander the Great's empire and the establishment of the Silk Road network of trade routes.

Dr Michael Wise (National Museum of Natural History, Smithsonian Institution, Washington DC, USA) described the hiddenite and emerald deposits of North Carolina. At the North American Emerald mine in Hiddenite, both gems occur within hydrothermal veins in the same mining area, but they are never found together in the same cavity. Exploration guides for emerald mineralization include cavities containing limonite (altered siderite) and red (not black) rutile, as well as more complex mineral assemblages than in the hiddenite-bearing cavities.

Figure 5: Danny Sanchez discusses inclusion photomicrography at the Gem-A Conference. Photo by B. M. Laurs.

In a multimedia presentation, **Danny Sanchez** (Los Angeles, California) described how he takes dramatic photomicrographs of inclusions in gem materials (e.g. Figure 5). Using a Wild microscope on a vibration reduction table, he employs various lighting accessories (e.g. black foil, reflectors and diffusers) together with fibre-optic lamps that are positioned with the help of friction arms. He generally shoots photos with a 3-mm-wide field of view, and uses image-stacking software to obtain sharp details despite the sometimes large depth of field.

Pat Daly (Gem-A, London) described various techniques that are useful for identifying gems and detecting treatments. For example, using a loupe within a polariscope can aid in seeing inclusions and extinction patterns in gems. In addition, a polariscope can be set on the stage of a microscope to help reveal inclusions and even to check their pleochroism.

Bill Larson (Palagems.com, Fallbrook, California) chronicled his extensive experience with mining and collecting gems and minerals from pegmatites in San Diego County, California, USA. Within this region, he has worked 14 mines and driven over 36,000 feet (10,970 m) of tunnels for various minerals such as tourmaline, beryl, spodumene and garnet, but he considered only three of the projects successful (i.e. no money lost). Several of these, including the Himalaya mine in Mesa Grande, had been operated since the early 1900s. The Himalaya mine is the largest producer of tourmaline in North America, and of the ~90 tonnes extracted from there, Larson mined ~2.5 tonnes from more than 1,000 pockets in the period 1980–1998.

At the end of the conference, Gem-A president **Maggie Campbell Pedersen** provided an insightful recap of the extensive information presented during the two days.

On 7 November, two workshops were held at Gem-A's headquarters, one on coloured stone grading and pricing (hosted by **Richard Drucker**, Gemworld International Inc., Glenview, Illinois, USA) and the other on visual optics (presented by **Alan Hodgkinson**, Ayrshire, Scotland). That evening marked Gem-A's graduation ceremony and presentation of awards at The Royal College of Surgeons in London.

On 8 November, two separate field trips took attendees for private viewings of the British Crown Jewels and of the Natural History Museum's mineral collection.

Brendan M. Laurs

Gem-A Notices

GEM-A CONFERENCE

The 2016 Gem-A Conference was held again at Royal Institute of British Architects in Portland Place, London, on 5 and 6 November. A full report of the Conference and events was published in the November/December 2016 issue of *Gems&Jewellery*. Highlights of the presentations are given in the Conferences section of this issue of *The Journal of Gemmology*, pages 347–348.

Seminars and workshops were presented on 7 November at the Gem-A headquarters. Visits were arranged on 8 November to the Mineral Gallery at the Natural History Museum for a guided tour by Gem-A Chief Executive Officer Alan Hart, and to the Tower of London for a private viewing of the Crown Jewels.

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GRADUATION CEREMONY

The Graduation Ceremony, sponsored by Gemfields, was held at the Royal College of Surgeons, Lincolns Inn Fields, London, on 7 November.

Alan Hart, CEO of Gem-A, opened the ceremony by welcoming those present. Maggie Campbell Pedersen, President of the Association, gave graduates an inspiring talk before presenting the Gem-A diplomas. Richard Lake, Chair of the Examiners, then announced the winners of the special prizes and awards.

Jack Cunningham, Sustainability Manager of Gemfields, addressed the graduates.

Alan Hart gave the closing remarks before graduates and guests enjoyed a reception in the Hunterian Museum and Surgeons Library at the Royal College of Surgeons.

Prize winners Héloïse Collin-Randoux, Peter Sandberg, Daisy Welford-Ranson, Kate Flitcroft and Emma Testill, in the Hunterian Museum.

GIFTS TO THE ASSOCIATION

The Association is most grateful to the following for their gifts for research and teaching purposes:

John Bradshaw, Coast-to-Coast Rare Stones, Nashua, New Hampshire, USA, for rough and offcut samples of adamite from Mexico; amber; anhydrite from Balmat, New York, USA; purple apatite from Karibib, Namibia; aquamarine from Mozambique; axinite from Plumas Co., California, USA, and from Baja California, Mexico; baryte from Silverbond mine, Westmoreland, Stoneham, Colorado, USA, and Namibia; bastnaesite from Pakistan; celestite from Ontario, Canada; cobaltocalcite; datolite from Lanes quarry, Westfield, Massachusetts, USA; hemimorphite from Santa Eulalia, Mexico; hexagonite from New York, USA; hodgkinsonite; kyanite from Brazil; legrandite from Mexico; leucite from Italy; morganite from Nigeria; powellite from Inca de Oro, Chile; prehnite from Australia, Mali and unspecified localities; preobrazhenskite from Kazakhstan; probertite from Germany; sanbornite from Esquire No. 1 mine, Rush Creek, California, USA; senarmontite from Algeria; shomiokite-(Y); siderite; smithsonite from Namibia; sphalerite from Spain; spodumene; tourmaline from Afghanistan and unspecified localities; vesuvianite from Magadi, Kenya; and willemite/leucophoenicite. Faceted samples included purple apatite from Karibib, Namibia; chrome diopside from Russia; oval kornerupine from Tanzania; sapphire in a range of colours from Montana, USA; and xenotime from Zagi Mountain, Pakistan. Also donated were a broken piece of apatite from Madagascar, a cerussite preform from Namibia, diaspore crystal slices from Turkey, as well as synthetic samples of a flux-grown GGG crystal, black moissanite, willemite (hydrothermal) and zincite.

Jim Clanin, JC Mining, Bethel, Maine, USA, for a copy of his book *The Fundamentals of Mining for Gemstones and Mineral Specimens*.

Charles Evans FGA DGA, London, for three examples of vegetable ivory from *Hyphaene petersiana* (lala palm) from Shingwedzi River, Limpopo Province, South Africa.

Institut de Gemmologie de Madagascar, Antananarivo, Madagascar, for a large specimen of epidote crystals on calcite matrix from Andapa, Madagascar.

Mark Joias, Joias, Shepton Mallet, Somerset, for 11 jadeite cabochons and one piece of maw-sit-sit.

Brett Kosnar, Kosnar Gem Co., Black Hawk, Colorado, USA, for 19 samples of gem rhodochrosite from various localities including rough from N'Chwaning mines, Kuruman, Northern Cape, South Africa; Sweet Home mine, Mount Bross, Colorado, USA; Sunnyside mine group, Gladstone, Colorado, USA; Uchucchacua mine, Oyon, Peru; and Pederneira mine, São José da Safira, Minas Gerais, Brazil. The samples also include cabochons from Capillitas mine, Andalgalá Department, Catamarca, Argentina, and faceted stones from Wutong mine, Guangxi, Zhuang, China.

Antonio Silva, London, for a copy of *Emeralds Around the World* by Jules Roger Sauer.

Anne van der Meulen Cunningham FGA DGA, Chicago, Illinois, USA, for faceted samples consisting of an amethyst, 13 emeralds, two bicoloured quartzes (smoky–rock crystal), a ruby, a sapphire, a greenish blue spinel, a pale blue synthetic spinel and three blue topazes. Also donated were a pink tourmaline carving, a ruby cabochon and a rough white opal showing play-of-colour, as well as fragments of aquamarine, malaya garnet, rhodolite, blue and yellow sapphire, heated and unheated tanzanite, tourmaline and chrome tourmaline, and tsavorite.

Beth West, Bucklebury Common, Berkshire, for a collection of 32 ivory beads and four bone beads.

GEM-A AWARDS

In the Gem-A examinations held in January and June 2016, 487 students qualified in the Gemmology Diploma examination, including 41 with Distinction and 52 with Merit, and 590 qualified in the Foundation Certificate in Gemmology examination. In the Gem Diamond examination 126 qualified, including 16 with Distinction and 25 with Merit.

The **Tully Medal** is awarded to the candidate who submits the best set of answers in the Gemmology Diploma examinations which, in the opinion of the examiners, are of sufficiently high standard. **Héloïse Collin-Randoux** of Garches, France, was awarded the **Tully Medal**, the **Christie's Prize for Gemmology** for the best candidate of the year, and

the **Anderson Bank Prize** for the best set of theory papers.

The **Read Practical Prize** for excellence in the practical examination was awarded to **Daisy Welford-Ranson** of Tadley, Hampshire.

In the Foundation Certificate in Gemmology examination, the **Anderson Medal** for the candidate who submitted the best set of answers which, in the opinion of the examiners, were of sufficiently high standard, was awarded to **Kate Flitcroft** of London.

In the **Diamond Diploma** examination, the **Bruton Medal** for the best set of answers which, in the opinion of the examiners, were of sufficiently high standard, was awarded to **Rachel Bailey** of Edinburgh.

The **Deeks Diamond Prize** for the best set of theory answer papers of the year was awarded to **Emma Testill** of Cannock, Staffordshire.

The **Mok Diamond Practical Prize** for excellence in the Diamond Practical examination, sponsored by Dominic Mok of AGIL, Hong Kong, was awarded to **Peter Sandberg** of Stockholm, Sweden.

The names of the successful candidates are listed below.

Examinations in Gemmology

Gemmology Diploma

Qualified with Distinction

Beauséjour, Joanie, *Longueuil, Quebec, Canada*
Bu Di, *Beijing, P.R. China*
Chedid, Karine, *Paris, France*
Chen Wanzhu, *Beijing, P.R. China*
Collin-Randoux, Héloïse, *Garches, France*
Du Jie, *Beijing, P.R. China*
Du Mingyue, *Beijing, P.R. China*
Dzikowski, Tashia, *Freiburg, Germany*
Fung Chun Yan, *New Territories, Hong Kong*
Hou Yitong, *Beijing, P.R. China*
Hu Zhe, *Beijing, P.R. China*
Khoudian, Christina, *Luton, Bedfordshire*
Li Zi Tian, *Beijing, P.R. China*
Liang Huan, *Beijing, P.R. China*
Liang Lin, *Beijing, P.R. China*
Liu Congyi, *Beijing, P.R. China*
Liu Hao, *Beijing, P.R. China*
Liu Mingyue, *Beijing, P.R. China*
Man Ka Yi, *Wong Tai Sin, Hong Kong*
Peng Jingxin, *Beijing, P.R. China*
Shi Jingzhe, *Beijing, P.R. China*
Thomas, Isaac Matthew David, *Bristol*
Tian Lu, *Beijing, P.R. China*
Viala, Martin, *Montreal, Quebec, Canada*
Vicente, Elisabeth, *Paris, France*
Viguier, Murielle, *Pontault-Combault, France*
Wainer, Stephane, *Singapore*
Wang Ying Ying, *Shanghai, P.R. China*
Wang Yuwei, *Beijing, P.R. China*
Wei Jiarong, *Tangshan, Hebei, P.R. China*
Wu Muyun, *Beijing, P.R. China*
Xu Chang, *Beijing, P.R. China*
Yang Chiyu, *Beijing, P.R. China*
Zhang Cheng, *Beijing, P.R. China*
Zhang Shangqi, *Beijing, P.R. China*
Zhang Zheng, *Beijing, P.R. China*
Zhong Yuanyuan, *Beijing, P.R. China*
Zhou Yan, *Shanghai, P.R. China*
Zhu Jingran, Beijing, P.R. China
Zhu Mengchen, Beijing, P.R. China
Zhu Yun You, *Taoyuan, Taiwan, R.O. China*

Qualified with Merit

Chan Wing Chi, *Tsuen Wan, Hong Kong*
Chen Suni, *Fuzhou, Fujian, P.R. China*
Chen Yanran, *Beijing, P.R. China*
Chin Chun-Yu, *Taipei City, Taiwan, R.O. China*
Ding Dong, *Beijing, P.R. China*
Feng Jie, *Beijing, P.R. China*
Fujii, Yuko, *Tokyo, Japan*
Haddad, Zena, *London*
Haniel, Louisa, *London*
Hao Yue, *Beijing, P.R. China*
Hu Wai Ping, *Tin Shui Wai, Hong Kong*
Huang Ying-Yun, *Kaohsiung City, Taiwan, R.O. China*
Lavoie Ste-Marie, Bénédicte, *Montreal, Quebec, Canada*
Lebrun, Amelie, *Bagnolet, France*
Li Dianhui, *Beijing, P.R. China*
Li Jingting, *Beijing, P.R. China*
Li Ying, *Beijing, P.R. China*
Lin Yian-Ting, *Kaohsiung City, Taiwan, R.O. China*
Lin Yucheng, *New Taipei City, Taiwan, R.O. China*
Liu Dan, *Guangzhou, Guangdong, P.R. China*
Liu Di, *Beijing, P.R. China*
Liu Meiying, *Beijing, P.R. China*
Liu Shengpeng, *Beijing, P.R. China*
Nijem, Karmel, *Lézignan-Corbières, France*
Ning Zhenhua, *Beijing, P.R. China*
Pavula, Nathalie, *Châtillon, France*
Petit, Fabienne, *Versailles, France*
Qu Hongting, *Beijing, P.R. China*
Ren Baichen, *Beijing, P.R. China*
Ruan Chentao, *Beijing, P.R. China*
Schintu, Emanuele, *Bologna, Italy*
Somsa-Ard, Nanthaporn, *Bangkok, Thailand*
Sun Ying, *Beijing, P.R. China*
Tai Tianjiao, *Beijing, P.R. China*
Taiclet, Alexia, *Paris, France*
Toche, Claire, *Aubagne, France*
Tsai Tzu-Yin, *New Taipei City, Taiwan, R.O. China*
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Wang Han, *Shanghai, P.R. China*
Wu Linjie, *Beijing, P.R. China*
Xu Nan, *Shanghai, P.R. China*
Xu Nijie, *Beijing, P.R. China*

Xu Su, *Chengdu, Sichuan, P.R. China*
Xue Ru, *Shijiazhuang, Hebei, P.R. China*
Yam Man Hung, *Tseung Kwan O, Hong Kong*
Yan Qiu Li, *Beijing, P.R. China*
Yang Jiwen, *Wuhan, Hubei, P.R. China*
Yang Yujiao, *Beijing, P.R. China*
Yuan Zelu, *Beijing, P.R. China*
Yuen Angel, *Tsuen Wan, Hong Kong*
Zhang Chuanzheng, *Liaocheng, Shandong, P.R. China*
Zheng Shuyuan, *Beijing, P.R. China*
Zhou Jin, *Beijing, P.R. China*

Qualified

Addeo, Juanita, *Heathrow, Florida, USA*
Ahmed, Fazlul, *Kandy, Sri Lanka*
Aiken, Juliette, *London*
Akiyama, Kayo, *Fukuoka, Japan*
Alonso-Perez, Raquel, *Arlington, Massachusetts, USA*
Armengaud, Anne Florence, *Carcassonne, France*
Arredondo, Gabriel, *Geneva, Switzerland*
Arrive, Raphael, *Annecy, France*
Ashri, Atul, *Reading, Berkshire*
Balmer, Isabel, *Derby, Derbyshire*
Barrault, Mathilde, *Angers, France*
Bastien, Ellyn, *Palaiseau, France*
Beardmore, Lindsay Ann, *Walsall, West Midlands*
Bejarano Prieto, Fernando Jose, *Lima, Peru*
Bergamin, Irene, *Zurich, Switzerland*
Bhattarai, Amikar, *Yangon, Myanmar*
Brown, Gareth, *Bristol*
Bu Zhao, *Beijing, P.R. China*
Bullock, Emily, *Birmingham, West Midlands*
Cai Haoyu, *Beijing, P.R. China*
Cai Yiming, *Beijing, P.R. China*
Caldicott, Gary, *Rowley Regis, West Midlands*
Cani Mazin, Sandra, *London*
Cao Han, *Beijing, P.R. China*
Cao Yunyu, *Beijing, P.R. China*
Chan Ching Ching, Hilary, *New Territories, Hong Kong*
Chan Shih, Sally, *Flushing, New York, USA*
Chang Chia-Yu, *Taichung City, Taiwan, R.O. China*
Chang Hui Min, *Taipei City, Taiwan, R.O. China*
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Chen Zhiying, *Linhai, Taizhou, Zhejiang, P.R. China*
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Fattal, Nancy, *London*
Finnemore, Hannah, *Norwich, Norfolk*
Frandgie, Marushka Tehani Sidney, *Wandsworth, London*
Fronczak-Jabbal, Joanna Natalia, *Birmingham, West Midlands*
Geng Meng, *Beijing, P.R. China*
Herries, Jane Denise, *Castle Douglas, Kirkcudbrightshire*
Ho Chin Ching, *Tai Kok Tsui, Hong Kong*
Ivanov, Andra Raluca, *London*
Ktisti, Nicole, *Palmers Green, London*
Lam Ching Fei, *Shatin, Hong Kong*
Lam Hou Kai, *Macau SAR*
Lau Po Chi, *Tuen Mun, Hong Kong*
Law Hoi Ying, *Tai Po, Hong Kong*
Layton, Janina Sarah, *London*
Lee, Fiola, *Zürich, Switzerland*
Leung Lai Man, *Hung Hom, Hong Kong*
Liu Sui Chung, *Sheung Shui, Hong Kong*
Liu Yuqian, *Beijing, P.R. China*
Lo Shuk Ching, *Sham Shiu Po, Hong Kong*
Ma Jing, *Beijing, P.R. China*
Ma Kwan Yu, *Shatin, Hong Kong*
Ma Suk Fong, Cecilia, *Shatin, Hong Kong*
Ma Suk Yan, Suanne, *Tuen Mun, Hong Kong*
Ma Tsing Ping, *Ngau Tau Kok, Hong Kong*
Mak King Man, *Aberdeen, Hong Kong*
Man Ka Yi, *Wong Tai Sin, Hong Kong*
Morath-Gibbs, Raymond, *London*
Pan Haixia, *Beijing, P.R. China*
Parks, Guy Sonny, *Brighton, East Sussex*
Poulsom, Ben, *Farnham, Surrey*
Rice, Jennifer, *Hull, East Yorkshire*
Robino Rizet, Maria Bruna, *London*
Shevlin, Heather Jane, *Stone, Staffordshire*
Sicolo, Emma, *Bristol*
Sit Shan Na, *Tseung Kwan O, Hong Kong*
So Lok Wai, Winnie, *Kowloon, Hong Kong*
Springe, Karl, *Sollentuna, Sweden*
Springham, Melvin, *Berlin, Germany*
Sze Ching Man, Suki, *Shatin, Hong Kong*
Tan, Gabriel, *Singapore*
Tang Yeung, *Fanling, Hong Kong*
Taylor, Emily, *London*
Togores Romeu, Covadonga, *Galicia, Spain*
Tsang Hon Wah, *Hong Kong*
Tse Ying Kit, *Fanling, Hong Kong*
Tu En, *Taipei City, Taiwan, R.O. China*
Waters, Renee, *Wembley Downs, Western Australia, Australia*
Wolff, Caitlin, *Flagstaff, Arizona, USA*
Wong Hong Kit, *Yau Ma Tei, Hong Kong*
Wong Shu Hung, *Chai Wan, Hong Kong*
Wong Tsz Yan, *Shawkiwan, Hong Kong*
Wong Nga Wai, *Kwai Fong, Hong Kong*
Wu Chun-Lin, *Taoyuan City, Taiwan, R.O. China*
Wu Hiu Yan, Daisy, *Sai Ying Pun, Hong Kong*
Xue Jie, *Shatin, Hong Kong*
Yim Mei See, Maisy, *Tuen Mun, Hong Kong*
Zhan Shiyu, *London*
Zhang Le, *Beijing, P.R. China*
Zhao He, *Beijing, P.R. China*
Zisis, Vasileios, *London*

MEMBERSHIP

At a meeting of the Council held on 7 September 2016, Justine Carmody was elected Chair of the Council. The following were elected to membership:

Fellowship and Diamond Membership

Woodmansterne, Chloë Elinor, *St Albans, Hertfordshire*

Associate Membership

Durand, Jennifer, *Burton upon Trent, Staffordshire*
Khourie, Kaylan, *Johannesburg, South Africa*
Pulese Aulehla, Herbert, *London*
Vasseur, Chantal, *Rixensart, Belgium*

At a meeting of the Council held on 7 November 2016, the following were elected to membership. Also Diploma graduates of the examinations held in June 2016 (included in the lists on pages 351–361) were elected or transferred to Fellowship and/or Diamond Membership as appropriate.

Associate Membership

Bosack, Carol, *London*
Bubber, Karan, *Derby, Derbyshire*
Cullinan, Mark, *Monte Carlo, Monaco*
Gilbert, Denise, *Lowestoft, Suffolk*
Johnston, Wothaya Esther, *Middleton, Milton Keynes, Buckinghamshire*
Karnon, Jude, *Leighton Buzzard, Bedfordshire*
Keighley, Kimberly, *Round Rock, Texas, USA*
Kiefel, Philipp, *Sant Cugat del Vallès, Spain*
Kielbinska, Karina, *London*
Madivila, Kasun, *Beruwala, Sri Lanka*
Sun Ziyin, *San Diego, California, USA*

OBITUARY

Sheila O. Greatwood
1946–2016

It is with deep regret that we announce the death of Sheila Greatwood FGA (D. 1982), Mitcham, Surrey, on 27 September 2016. Sheila had been a Gemmology Foundation examiner since 2004. Following are two tributes to her.

It came as a huge shock to hear from Sheila's husband John that she had died suddenly while playing table tennis with him. They had enjoyed 49 years of an exceptionally happy marriage.

I first met Sheila and John in the early 1980s when they started coming to Alan Jobbins' Post Diploma Class at John Cass—far more a club than a class!

I (and I think everyone) was immediately struck by their huge enthusiasm for gemmology. Enthusiasm was normal for the members of the class, but they coupled it, considerably more than most of us, with the practical application of their knowledge. They both frequented gem markets, and there are many legendary tales of their extraordinary talent for spotting interesting and rare stones that the vendors had no idea about.

Sheila and John were licensed dealers and breeders of reptiles, and I think all who were part of the class with them will remember the lizards and snakes that would occasionally appear out of Sheila's handbag. I well remember being persuaded, admittedly very reluctantly, to stroke the head of a snake that Sheila was holding. To my great surprise it was cool and dry, and really quite pleasant.

They both became part of the Jobbins gemmological social scene, and came on the famous (or perhaps now infamous) trip to Idar-Oberstein arranged by Alan and Evelyne Stern.

Both Sheila and John went on to become Gem-A examiners, a role from which Sheila, with her great practical experience, will now be sorely missed. We all do hope that John will continue as an examiner for many years.

Outside gemmology, Sheila only retired last year (I am told at the third attempt) from a full-time job in NHS family planning. She continued her lifelong passion for cycling (their tandem was famous, although I never discovered which of them pedalled most), and was for very many years secretary of the local cycling association. She was a keen horse rider and owned a horse, Magic, that John gave her, who was part of the family for 20 years. Like everything she did, she took riding seriously and even competed in dressage in the hallowed arena at Hickstead. Magic was eventually succeeded by a new horse, Diamond.

In the last 15 years both Sheila and John practised freediving, an extreme sport that I will not describe, as even thinking about it makes me feel queasy.

Sheila and John had two sons, and it is a mystery how, amongst all her other activities (and there were many that I haven't mentioned) she had time to be a mother. She also leaves four much-loved grandchildren.

Sheila was truly an exceptional character, and the world will be the lesser without her, but all of us will remember her and feel privileged to have been able to call her a friend.

Nigel Israel

Although I had known Sheila for a long time, I really only got to know her well when she became a Foundation examiner. She very rapidly took to this and, despite her own deep knowledge of practical gemmology, she could always see the questions from the point of view of the inexperienced student. She was more saddened than exasperated when students lost marks for careless mistakes. Sheila willingly gave up her only day off to attend meetings to set the questions for the next year's papers. At these meetings, which can be quite tedious, she was unfailingly cheerful and always ready with new suggestions for questions, but at the end of a long day she was always keen to get home to see her horse, and John of course.

Her fellow examiners will greatly miss her wise counsel and her friendship. Sheila was truly a delight to work with. We shall not forget her.

Tony Allnutt
Chief Examiner

Thank You, Guest Reviewers

The following individuals served as guest reviewers during the past publication year. The editors extend their special thanks to all of them for lending their expertise to reviewing manuscripts submitted to *The Journal*. Together with the Associate Editors, these individuals have enhanced the quality of *The Journal* through their knowledge and professionalism.

Dr Ahmadjan Abduriyim
Gemological Institute of America, Tokyo, Japan

Dr Christopher 'Mike' Breeding
Gemological Institute of America, Carlsbad, California, USA

Maggie Campbell Pedersen
Organic Gems, London

Jean-Pierre A. Chalain
Swiss Gemmological Institute SSEF, Basel, Switzerland

Dr Ulrika D'Haenens-Johansson
Gemological Institute of America, New York, New York, USA

Dr Barbara L. Dutrow
Louisiana State University, Baton Rouge, Louisiana, USA

Dr Ian C. Freestone
UCL Institute of Archaeology, London

Dr Gaston Giuliani
Centre de Recherches Pétrographiques et Géochimiques, Vandoeuvre-lès-Nancy, France

Dr Christoph Hauzenberger
University of Graz, Austria

Richard W. Hughes
Lotus Gemology Co. Ltd., Bangkok, Thailand

Dr Mary Johnson
Mary Johnson Consulting, San Diego, California, USA

Anette Juul-Nielsen
Ministry of Mineral Resources, Nuuk, Greenland

Dr Çiğdem Lüle
Gemworld International Inc., Glenview, Illinois, USA

Dr Sally Eaton-Magaña
Gemological Institute of America, Carlsbad, California, USA

Franck Notari
GGTL Laboratories, Geneva, Switzerland

Dr Benjamin Rondeau
Centre National de la Recherche Scientific, University of Nantes, France

Dr Andy Shen
China University of Geosciences, Wuhan, China

Sutas Singbamroong
Dubai Gemstone Laboratory, United Arab Emirates

Dr Frederick L. Sutherland
Port Macquarie, Australia

Dr Dedo von Kerssenbrock-Krosigk
Glasmuseum Hentrich, Museum Kunstpalast, Düsseldorf, Germany

Dr Markus Wälle
ETH Zürich, Switzerland

Learning Opportunities

CONFERENCES AND SEMINARS

Jewelry Industry Summit
29–30 January 2017
Tucson, Arizona, USA
www.jewelryindustrysummit.com

Somewhere In The Rainbow's 'A Modern Gem & Jewellery Collection'
31 January 2017–January 2018
Tucson, Arizona, USA
Email shelly@somewhereintherainbow.com
Note: Contains a selection of historical gemmological instruments from Gem-A's collection.

AGTA Gemfair
31 January–5 February 2017
Tucson, Arizona, USA
www.agta.org/tradeshows/gft-seminars.html
Note: Includes a seminar programme.

AGA Tucson Conference
1 February 2017
Tucson, Arizona, USA
www.accreditedgemologists.org/currevent.php

The 38th Annual Tucson Mineral Symposium: Mineral Treasures of the Midwest
11 February 2017
Tucson, Arizona, USA
www.friendsofmineralogy.org/symposia.html

Hasselt Diamond Workshop 2017 (SBDD XXII)
8–10 March 2017
Hasselt, Belgium
www.uhasselt.be/sbdd

Amberif International Fair of Amber, Jewellery and Gemstones
22–25 March 2017
Gdańsk, Poland
www.amberif.amberexpo.pl/title,PROGRAMME,pid,3275.html
Note: Includes a seminar programme.

American Gem Society International Conclave
5–8 April 2017
Hollywood, California, USA
www.americangemsociety.org/Content/uploads/Conclave2017RFP.pdf

14th Annual Sinkankas Symposium—Sapphire
8 April 2017
Carlsbad, California, USA
www.sinkankassymposium.net

Scottish Gemmological Association Conference
28 April–1 May 2017
Stirling, Scotland
www.scottishgemmology.org/conference

Compiled by Angharad Kolator Baldwin and Brendan Laurs

3rd Mediterranean Gemological and Jewellery Conference
11–14 May 2017
Syracuse, Italy
www.gemconference.com
Note: The conference theme is coloured diamonds, and the program will include several speakers, a round table discussion, pre-conference workshops, and a poster competition.

The 31st Annual Santa Fe Symposium
21–24 May 2017
Albuquerque, New Mexico, USA
www.santafesymposium.org

2017 Society of North American Goldsmiths (SNAG) Conference
24–27 May 2017
New Orleans, Louisiana, USA
www.snagmetalsmith.org/events/nexus-2017

11th International Conference on New Diamond and Nano Carbons
28 May–1 June 2017
Cairns, Australia
http://ndnc2017.org

JCK Las Vegas
5–8 June 2017
Las Vegas, Nevada, USA
http://lasvegas.jckonline.com/Events/Education/Education
Note: Includes a seminar programme.

Association for the Study of Jewelry and Related Arts (ASJRA) Annual Conference
9–10 June 2017
Boston, Massachusetts, USA
www.jewelryconference.com

PEG2017—8th International Symposium on Granitic Pegmatites
13–15 June 2017
Kristiansand, Norway
www.nhm.uio.no/forskning/aktuelt/arrangementer/konferanser-seminarer/peg2017

Scandinavian Gem Symposium 2017
17–18 June 2017
Kisa, Sweden
http://sgs.gemology.se/#home

Sainte-Marie-aux-Mines Mineral & Gem Show
22–25 June 2017
St Marie, France
www.sainte-marie-mineral.com/english/modules/cultural-activities
Note: Includes a seminar programme.

Tourmaline 2017
23–28 June 2017
Nové Město na Moravě, Czech Republic
www.tourmaline2017.cz

Swiss Gemmological Society Conference and European Gemmological Symposium 2017
29 June–1 July 2017
Zermatt, Switzerland
www.gemmologie.ch

Northwest Jewelry Conference
11–13 August 2017
Seattle, Washington, USA
www.nwjcon.com

28th International Conference on Diamond and Carbon Materials (DCM 2017)
3–7 September 2017
Göteborg, Sweden
www.diamond-conference.elsevier.com

Hong Kong Jewellery & Gem Fair
13–19 September 2017
Hong Kong
http://tinyurl.com/hbn8y56
Note: Includes several seminar programmes.

11th International Kimberlite Conference
18–22 September 2017
Gaborone, Botswana
www.11ikc.com
Note: Pre- and post-conference field trips will visit diamond deposits in Botswana and neighbouring countries.

World of Gems Conference V
23–24 September 2017
Rosemont, Illinois, USA
gemguide.com/events/world-of-gems-conference
Note: Will include a poster session.

EXHIBITIONS

Europe

The Spectacular Second Empire, 1852–1870
[includes Mellerio dits Meller jewellery]
Until 15 January 2017
Musée d'Orsay, Paris, France
http://tinyurl.com/jxp82x5

Eva's Beauty Case: Schmuck und Styling im Spiegel der Zeiten (Jewelry and Styling Through the Ages)
Until 22 January 2017
LVR–LandesMuseum Bonn, Germany
www.landesmuseum-bonn.lvr.de/de/ausstellungen/evas_bauty_case/evas_beauty_case.html

Illuminations—Earth to Jewel
Until 1 February 2017
Musée de Minéralogie MINES ParisTech, Paris, France
www.musee.mines-paristech.fr/Events/TempExhibit/Illuminations

Elements: From Actinium to Zirconium
Until 26 February 2017
Ulster Museum, Belfast, Northern Ireland
nmni.com/um/What-s-on/Elements

Across Art and Fashion
Until 7 April 2017
Museo Salvatore Ferragamo, Florence, Italy
www.ferragamo.com/museo/en/usa/exhibitions

Warrior Treasures: Saxon Gold from the Staffordshire Hoard
Until 23 April 2017
Bristol Museum & Art Gallery, Bristol
www.bristolmuseums.org.uk/bristol-museum-and-art-gallery/whats-on/warrior-treasures

Must-haves—Jewellery Created by Greats of the Craft and **Must-Sees—Jewellery in the Arts**
21 May–10 September 2017
Schmuckmuseum, Prorzheim, Germany
www.schmuckmuseum.de/flash/SMP_en.html

Authentically Inauthentic?—Jewellery from Pforzheim's Industrial Production
28 May–10 September 2017
Municipal Museum, Pforzheim, Germany
www.schmuckmuseum.de/flash/SMP_en.html

Smycken: Jewellery—From Decorative to Practical
Ongoing
Nordiska Museet, Stockholm, Sweden
www.nordiskamuseet.se/en/utstallningar/jewellery

North America

Gold and the Gods: Jewels of Ancient Nubia
Until 8 January 2017
Museum of Fine Arts, Boston, Massachusetts, USA
www.mfa.org/exhibitions/gold-and-gods

Gold Rush!—El Dorado in British Columbia
Until 15 January 2017
Canadian Museum of History, Gatineau, Quebec, Canada
www.historymuseum.ca/goldrush

Giant Gems of the Smithsonian
Until 17 January 2017
Perot Museum of Nature and Science, Dallas, Texas, USA
www.perotmuseum.org/explore-the-museum/traveling-exhibits/2016-giant-gems/index.html

Arts of Islamic Lands: Selections from The al-Sabah Collection, Kuwait
Until 29 January 2017
Museum of Fine Arts, Houston, Texas, USA
www.mfah.org/exhibitions/arts-islamic-lands-selections-al-sabah-collection-

American Mineral Heritage: Harvard Collection
Until February 2017
Flandrau Science Center & Planetarium, Tucson, Arizona, USA
flandrau.org/exhibits/harvard

Beyond Bling: Jewelry from the Lois Boardman Collection
Until 5 February 2017
Los Angeles County Museum of Art, California, USA
www.lacma.org/art/exhibition/beyond-bling

Bijoux Parisiens: French Jewelry from the Petit Palais, Paris
11 February–14 May 2017
The Taft Museum of Art, Cincinnati, Ohio, USA
www.taftmuseum.org/upcoming-exhibitions-draft

Variations on a Theme: 25 Years of Design from the AJDC
Until 1 March 2017
Gemological Institute of America, Carlsbad, California, USA
www.gia.edu/gia-museum-variations-theme-25-years-design-AJDC

Spectacular! Gems and Jewelry from the Merriweather Post Collection
10 June 2017–14 January 2018
Hillwood Estate, Museum & Gardens, Washington DC, USA
www.hillwoodmuseum.org/Spectacular-Gems-and-Jewelry

Australia and New Zealand

Lustre: Pearling and Australia
Until 22 January 2017
Immigration Museum, Melbourne, Victoria, Australia
www.thatsmelbourne.com.au/Whatson/Exhibitions/HistoryandHeritage/Pages/7e193464-ada5-4a57-911c-70b792d4d5ba.aspx

The Art of Adornment: Greek Jewellery of the 17th–19th Centuries
Ongoing
Hellenic Museum, Melbourne, Victoria, Australia
www.hellenic.org.au/the-art-of-adornment

OTHER EDUCATIONAL OPPORTUNITIES

Gem-A Workshops and Courses
Gem-A, London
www.gem-a.com/education/courses

Gem-A Midlands Branch
Fellows Auctioneers, Birmingham
Email georgina@fellows.co.uk

- 24 February 2017
  Gwyn Green—Treatments and Imitations of Gemstones
- 28 April 2017
  Elizabeth Goring—Suffragette Jewellery

ASA Appraising Gems and Jewelry Courses
6–10 March 2017
Carlsbad, California, USA
www.appraisers.org/Education/View-Class?ClassID=3688 and www.appraisers.org/Education/View-Class?ClassID=3689.

Gemstone Safari to Tanzania
10–27 July 2017
Morogoro, Umba, Arusha, Longido, Merelani and Lake Manyara, Tanzania
www.free-form.ch/tanzania/gemstonesafari.html
Note: Includes options for a lapidary class and/or a private trip to visit ruby mines near Morogoro and Mpwapwa (including Winza).

Lectures with The Society of Jewellery Historians
Society of Antiquaries of London, Burlington House, London
www.societyofjewelleryhistorians.ac.uk/current_lectures

- 24 January 2017
  Noël Adams—Gold and Garnet Cloisonné Jewellery: Recent Discoveries and New Perspectives
- 28 February 2017
  David Callaghan—(To be announced)
- 28 March 2017
  Marjan Unger—My Jewellery Collection: Confessions of an Art Historian
- 24 October 2017
  Lynne Bartlett—The Rise and Fall of the Chatelaine
- 28 November 2017
  Judy Rudoe—Cartier Gold Boxes: A Visionary Patron and a Bet with Ian Fleming

New Media

A Guide to the Spectroscope

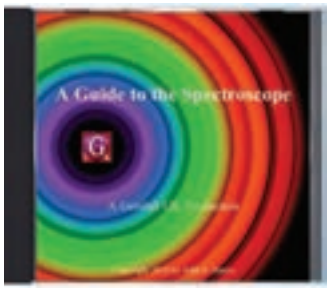

By John S. Harris, 2016. Self-published, www.gemlab.co.uk. US$25.00 CD.

This CD is formatted as an animated Microsoft PowerPoint presentation containing 23 slides that provide concise information, diagrams and photos on using the spectroscope for practical gem testing. The format allows for interactive animation with the viewer, and the slides can easily be reversed so that a sequence of the animated images may be repeated whenever necessary.

The presentation consists of three main parts: (1) the prism spectroscope, (2) the diffraction grating spectroscope and (3) observation techniques. The author starts with a review of the interaction of light with glass prisms to help the user to better understand the basic principles of this most useful and diagnostic of gem testing instruments. Then, parts 1 and 2 include comprehensive information on diffraction and prism spectroscopes, the construction of each type of instrument and also the differences in the spectra they produce. The direct visual comparison of these spectra is most informative and useful, thus enabling users to choose the best type of spectroscope for their requirements. Part 3 offers advice on observation techniques, which are of primary importance for achieving good readings. The final slides in this section (16–23) provide a comprehensive range of gem spectra that are categorized by colour. Each spectrum is accompanied by a nanometre scale and an image of the stone itself along with its colouring element, making this part of the presentation an excellent resource. Transmitted- and reflected-light techniques also are shown, with the advantages of each being described, as well as good practices for successfully viewing spectra by avoiding factors such as glare from unwanted surface reflections. The author's demonstrations of the differences between good and bad techniques are most informative.

Overall, this reviewer found this CD to be educational and intuitive to use and navigate. The information is provided in an interesting, informative and engaging way, making this CD an excellent reference/resource for tutors, students, appraisers and hobbyists or enthusiasts alike.

Claire Mitchell FGA DGA
Gem-A, London

Ruby, Sapphire & Spinel: An Archaeological, Textual and Cultural Study

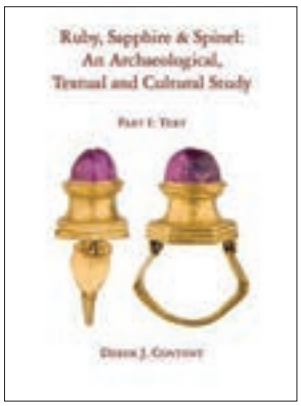

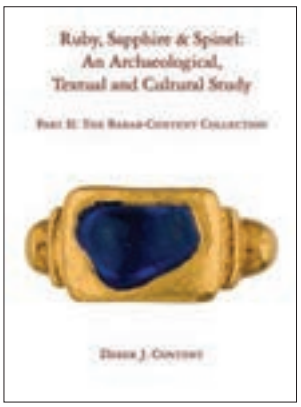

By Derek J. Content, 2016. Brepols Publishers, Turnhout, Belgium, www.brepols.net, 452 pages, illus., ISBN 978-2503568089. €150.00 hardcover.

While ruby, sapphire and spinel find occasional mention in books on engraved gems, no comprehensive text focusing on the history of these gems has been previously written. Thus the current work is welcome on that score alone. That it is the product of two true experts on antique gems—Derek Content and Riaz Babar—makes it all the more important.

Ruby, Sapphire & Spinel: An Archaeological, Textual and Cultural Study is split into two volumes. 'Part I: Text' is 191 pages long and gives a detailed historical description of these gems, from ancient times to the modern era. Following the Introduction are seven chapters. Chapters I and II cover the early history up through modern times (with the period after about 1830 AD being something of an afterthought). Chapter III deals with early mining technology, while Chapter IV covers fashioning methods. The remaining chapters cover usage, properties and nomenclature. Part I finishes with an epilogue, a comprehensive bibliography and a detailed index.

'Part II: The Babar-Content Collection' is 261 pages long and almost entirely composed of colour photographs (by Gonzalo Salcedo) and descriptions of 99 pieces in the combined collections of Riaz Babar and Derek Content. The photographs of each piece are excellent, and in the case of the many engraved pieces, wax replicas of the mostly Arabic inscriptions are also included, along with English translations. Approximate dates are given for each piece, increasing the value to scholars and appraisers alike.

As someone who has long been involved in researching these gems, this reviewer was extremely impressed by the high level of scholarship brought to bear on the subject. *Ruby, Sapphire & Spinel* is clearly aimed at an academic audience and is written with that in mind. Citations from the literature are both detailed and pertinent, with the original authors' words quoted rather than paraphrased. Almost every page reveals a fascinating tidbit or three, not just about these gems, but also about life, society and culture in early times. More importantly, this book gathers together an astonishing amount of information from disparate fields and sources and places it into a modern gemmological and historical context, correcting many of the errors of previous authors, who often lacked gemmological training.

This is an extremely important book on the history of gems and jewellery. If there are any flaws, they are that Part I is completely devoid of illustrations, and not a single map appears anywhere in the entire set. While scholars in the field will know the location of many of the places named in the text, adding maps and other illustrations would have enriched the reading experience for more casual readers. But these are small quibbles when one takes into account the decades of work in both collecting and research that *Ruby, Sapphire & Spinel* represents. Not only would I highly recommend this book to gemmologists, but would suggest it is a must-buy for appraisers and jewellery historians.

Richard W. Hughes
Lotus Gemology, Bangkok, Thailand

Understanding the Gem Minerals: A Practical Guide

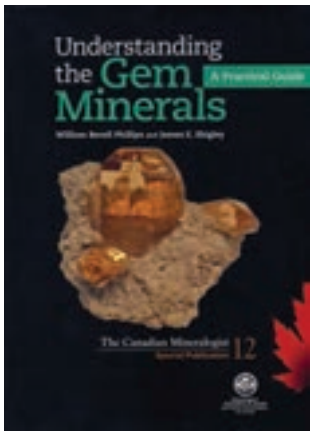

By William Revell Phillips and James E. Shigley, 2016. Canadian Mineralogist Special Publication 12, Mineralogical Association of Canada, Quebec, Canada, 259 pages, illus., ISBN 978-0921294580. US$70.00 softcover.

In the Preface to this work, the first author states: "I can only pray that this volume never falls into the hands of an expert, for he [sic] will pick it apart for its over simplification and broad generalizations…" Well, alas, this reviewer is probably what would be considered an expert; but rather than picking apart this useful guide, I will instead praise it (mostly).

Why are gems valuable? The usual criteria for a gemstone are that it be beautiful, durable and rare. After introducing the concepts of atoms, elements and crystal structures, necessary for understanding what a mineral is, the authors have arranged topics on the basis of these gem criteria.

Why is a gem beautiful? Because of the ways it interacts with light. The gem splits light into rays of different polarization; it bends light that comes in at a non-perpendicular angle, thus defining its index (or indices) of refraction; and it absorbs (and sometimes re-transmits) light, which leads to its colour. The reader is cautioned that in order to understand how light is used to distinguish among gem minerals, it will be necessary to visualize the uniaxial and biaxial indicatrices, which are, respectively, oblate and/or prolate spheroids (for uniaxial minerals), and spheroids that have been squashed or stretched in the third dimension (for biaxial minerals). Fortunately, there are many illustrations to help with this visualization.

Why is a gem durable? Well, that depends on the way its atoms are connected to each other by electron interactions. Non-directional charge interactions lead to (weak) ionic bonds; directional charge interactions lead to (strong) covalent bonds; and atomic nuclei that swim in a sea of electrons are characteristic of metals (which are sometimes weak with respect to scratching, but also malleable, or loathe to be broken apart).

Why is a gem rare? Many gem minerals require a specific history to form within the earth. For example, corundum needs a starting material from which Si is leached or under-available relative to Al; it helps if the Mg content is low as well (to avoid crystallizing spinel). If the right trace elements are present in the right abundance, it may be a ruby, a blue sapphire, or a fancy-coloured sapphire. But if it embraces too much of its history, in the form of inclusions, clouds, fissures or stains, it will not be gemmy. Then, after its formation, it must finally be brought to the surface of the earth where it can be mined.

This book is profusely illustrated, with the captions expansively explanatory, which brings me to my main quibble with this book: its design. Often, the captions are too big to fit on the same or facing page as the illustration. Also, not only are concepts explained the same way in the text as in the captions, but sometimes these explanations are only a few lines apart.

Less significantly, there are a few notable errata. An attempt to explain refractive indices in uniaxial minerals in the caption of figure 3-16C, on page 76, leads to two different meanings of n_ε in the same sentence (n_ε is "some value between n_ε and n_ω"). On page 81, figures 3-21B and C are reversed in the caption. Yet, on the other hand, figure 5-4 on p. 106, illustrating how interference colours come about, is both beautiful and self-explanatory, and for the most part the figures are more helpful than confusing.

Of course knowledge is always increasing, and some exotic gems or treatments may go beyond the lessons in this book. One should always be suspicious—or at least curious—about new gem substances and locations, and strange gem appearances. Still, with careful attention to the text and figures, it should in principle be possible for the reader to gain a good education on the basic mineralogy of gems using this book alone.

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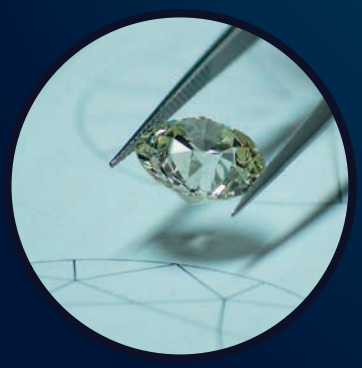

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Cover Photo:

High-quality rubies, sapphires and emeralds are typically accompanied by geographical origin reports from gemmological laboratories, as discussed on pp. 416–423 of this issue. Shown in this composite photo are matched pairs of Colombian emeralds, Kashmir sapphires and Burmese rubies (total weights approximately 10, 7 and 4 ct, respectively). Courtesy of Joseph Ambalu, Amba Gem Corp., New York, New York, USA.

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Understanding Gems™

What's New

INSTRUMENTATION

Multi-Colour-Temperature Lamp

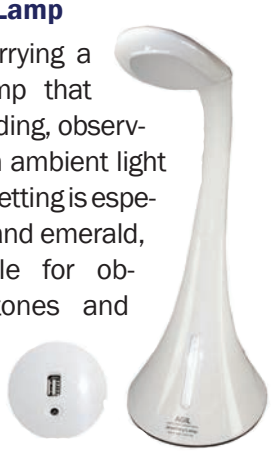

The Gem-A Shop is now carrying a multi-colour-temperature lamp that can be used for diamond grading, observing colour change, and as an ambient light source. The 3,700–3,900 K setting is especially useful for viewing jade and emerald, 4,200–4,500 K is suitable for observing most coloured stones and 5,000–5,500 K is ideal for diamonds and blue sapphires. The lamp has eight levels of brightness controlled by a touch-sensitive slide. The flexible head folds for storage. The unit comes with a 100/240 V adaptor and a USB-powered connector. To order, email instruments@gem-a.com. *CMS*

PL-Inspector

Gemetrix Pty Ltd released its new PL-Inspector instrument in May 2016 at the Mediterranean Gem and Jewellery Conference in Spain. It contains a portable UV light source, weighing only 300 g, that provides both short-wave (255 nm) and long-wave (365 nm) radiation for the observation of fluorescence and phosphorescence in gems (particularly diamond). An optional battery pack makes the unit suitable for travel. Visit http://gemetrix.thediamondpages.com/PLinspector.html; for North American orders, go to www.gemconference.com/store and for European orders visit www.iglcert.gr. *CMS*

NEWS AND PUBLICATIONS

AGTA Report on Myanmar Gem Sector

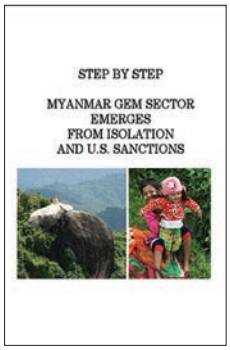

In October 2016, the American Gem Trade Association led a visit to Myanmar that included a delegation of American gem industry representatives. In January 2017, AGTA released a white paper titled 'Step by Step: Myanmar Gem Sector Emerges from Isolation and U.S. Sanctions' that gives the background and outcome of that visit. The report describes several mines visited and the local supply chain, along with recommendations for the ethical support of the gem sector of Myanmar. To download the report, go to http://agta.org/info/docs/burmawhitepaper2016.pdf. *CMS*

ASEAN Gem & Jewelry Review

Issue 1, 2017, of this English-language gem and jewellery trade publication for the Association of Southeast Asian Nations (ASEAN) focuses on the coloured stone trade between Thailand and Myanmar, e-commerce opportunities in Thailand and ASEAN, the jewellery manufacturing industry in Vietnam, major sources of gems and precious metals in ASEAN, and more. To download the issue, go to www.git.or.th/2014/thai/info_center/trade_review/2017/2017_ASEAN_Gem_Review.pdf. *CMS*

Atypical Pearl Culturing Experiments in *P. maxima*

In February 2017, GIA's online Research News section posted a report titled 'Atypical "Beading" in the Production of Cultured Pearls from Australian *Pinctada maxima*'. It describes experiments using low-quality natural pearls and other materials as beads for producing cultured pearls in

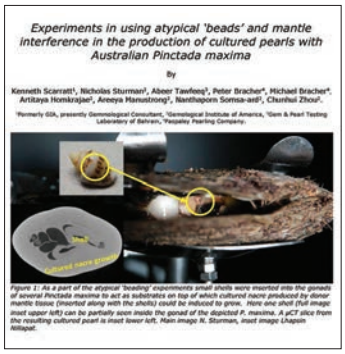
Experiments in using atypical 'beads' and mantle interference in the production of cultured pearls with Australian Pinctada maxima

By

Kenneth Scarratt[1], Nicholas Sturman[2], Abeer Tawfeeq[3], Peter Bracher[4], Michael Bracher[4], Artitaya Homkrajae[5], Areeya Manustrong[5], Nanthaporn Somsa-ard[5], Chunhui Zhou[6].

[1]Formerly GIA, presently Gemmological Consultant, [2]Gemological Institute of America, [3]Gem & Pearl Testing Laboratory of Bahrain, [4]Kapalky Pearling Company.

Figure 1: As a part of the atypical 'beading' experiments small shells were inserted into the gonads of several Pinctada maxima to act as substrates on top of which cultured nacre produced by donor mantle tissue (inserted along with the shells) could be induced to grow. Here one shell (full image inset upper left) can be partially seen inside the gonad of the depicted P. maxima. A µCT slice from the resulting cultured pearl is inset lower left. Main image N. Sturman, inset image Lhapsin Anilapat.

P. maxima. Most of the resulting bead-cultured pearls could be readily identified using either real-time X-ray imaging or X-ray computed micro tomography. Download the report at www.gia.edu/gia-news-research/atypical-beading-production-cultured-pearls-australian-pinctada-maxima. *CMS*

Conflict Diamonds and Cameroon

Partnership Africa Canada released its report 'From Conflict to Illicit: Mapping the Diamond Trade from Central African Republic to Cameroon' in December 2016. It describes the failure of the Kimberley Process to prevent conflict diamonds from CAR from reaching the international diamond market via adjacent Cameroon. The report includes recommendations to the Kimberley Process, the government of Cameroon and the diamond industry to control the flow of conflict diamonds from CAR. Download the report at http://pacweb.org/images/PUBLICATIONS/from-conflict-to-ilicit-eng-web.pdf. *CMS*

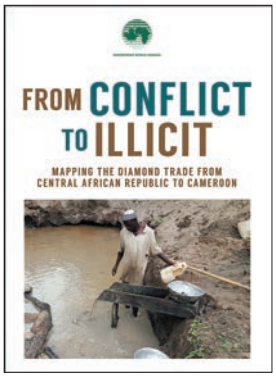

Fluorescence as a Tool for Diamond Origin Identification—a Guide

In January 2017, this 19-page booklet was released by Gemetrix Pty Ltd, CGL-GRS Swiss Canadian Gemlab Inc. and Independent Gemological Laboratory to provide a photographic reference for the luminescence behaviour of colourless and coloured diamonds. Numerous images show typical fluorescence (to long- and short-wave UV radiation) and phosphorescence reactions for untreated and treated natural and synthetic diamonds. Also included is a brief review of diamond type classification, causes of colour, treatments, and synthetics and their detection. The booklet closes with a short article, 'Identification of CVD-Grown Diamonds on the Greek/EU Market with Standard and Advanced Gem Instruments', by G. Spyromilios, B. Deljanin, M. Åström and J. Chapman, followed by a reading list. The booklet is available for US$25.00 plus shipping and handling from www.gemconference.com/store/books/fluorescence-as-a-tool-for-diamond-origin-identification-a-guide. *BML*

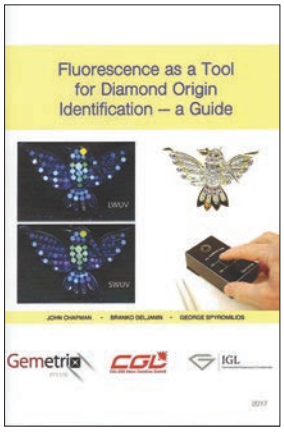

Global Diamond Industry 2016

Released in December 2016, the 6th annual report on the global diamond industry prepared by the Antwerp World Diamond Centre and Bain & Company is titled 'The Global Diamond Industry 2016: The Enduring Allure of Timeless Gems'. The paper reviews recent developments in the diamond industry and then describes rough diamond production, the cutting and polishing industry, retail jewellery sales and how the 'millennial generation' perceives diamonds and diamond jewellery. It concludes with discussions of the current challenges to the industry and an updated model of supply and demand. Download the report at www.bain.com/Images/bain_diamond_report_2016.pdf. *CMS*

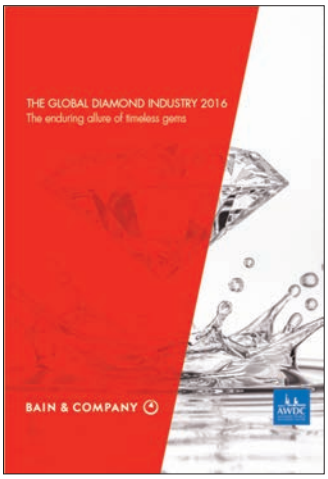

ICGL Fall 2016 *Newsletter*

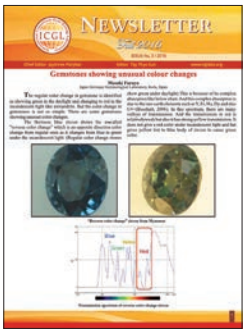

The International Consortium of Gem-Testing Laboratories' Fall *Newsletter* (No. 3, 2016) was released in December 2016, and features gems with unusual colour changes, similar-appearing serendibite and sapphirine gems, a new ornamental material from

Pakistan called 'Sannan Skarn' and sphene from India. Visit http://icglabs.org to download this and previous issues. *CMS*

Journal of the Gemmological Society of Japan Online

All issues of this journal, published from 1974 (Vol. 1) through 2016 (Vol. 32), were made available online in January 2017. Most of the content is in Japanese, but articles commonly contain an English abstract. PDF files are freely downloadable for all but the most recent issue, **32**(1–4), for which access to articles and short notes requires a subscriber login. Visit www.jstage.jst.go.jp/browse/gsjapan. *CMS*

Raman Spectrometer Sensitivity

In November 2016, TSI Inc. posted online an application note titled 'Simple Method for Sensitivity Comparison of Raman Spectroscopic

Instruments', which describes a technique using the 1082 cm^{-1} feature of a calcium carbonate standard to measure the sensitivity of Raman spectrometers. Download the three page report at http://tinyurl.com/zqlfq9s. *CMS*

World Gold Council's Gold Demand Trends 2016

This annual report on the gold industry was released in February 2017 and includes extensive data analysis of changes in demand for the year 2016 compared with previous years. Due to high gold prices, annual jewellery demand for gold declined to a seven-year low. The report can be viewed online at www.gold.org/supply-and-demand/gold-demand-trends/back-issues/gold-demand-trends-full-year-2016, which also has links to download the complete report, data spreadsheets and charts, and infographics. *CMS*

OTHER RESOURCES

2016 Agate Expo DVDs

Released in September 2016, this set of four DVDs contains extensive information from the 2016 Agate Expo held 8–10 July 2016 in Cedarburg, Wisconsin, USA. Included on the DVDs are all 12 symposium presentations, 10 additional speaker presentations, the opening ceremony, highlights from the 128 show displays, vendor interviews and more. To order the set, visit https://thegemshop.com/collections/publications-1/products/2016-agate-expo-dvd-complete-set-pre-order. *CMS*

AGTA 2017 Tucson Seminars

Held from 31 January to 5 February 2017, the American Gem Trade Association (AGTA) GemFair in Tucson, Arizona, USA, featured numerous educational presentations covering a broad range of gem, jewellery and industry topics. Approximately 26 of the seminars are available (as audio synchronized with the presenters' PowerPoint slides) on a flash drive that is available to AGTA non-members for US$50.00. (AGTA members can freely access the seminars through AGTA's eLearning online program.) To view a list of topics/presenters and place an order, visit www.agta.org/education/seminars.html. *CMS*

ColorCodex Color Referencing System

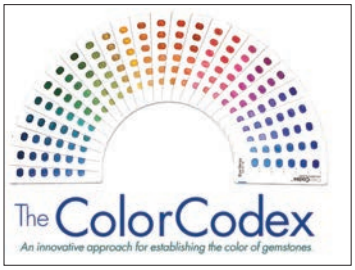

Released in early 2017, the ColorCodex is a set of colour-range cards designed for gem colour description. Each card has six textured colour images for a specific hue that range from lighter to darker and more saturated, with even numbers (to permit communication of interpolated appearances) that correspond to each image. The system is designed for use with both mounted and unmounted gems. Visit www.color-codex.com. *CMS*

GemeSquare and MyGemewizard Apps

Released in February 2017 by Gemewizard Ltd., the free GemeSquare and MyGemewizard apps make it possible to use a smartphone or tablet to communicate gem colours. The GemeSquare app enables users to select the gem's colour from a base palette of 31 master hues modified by tone and saturation, and translate it into other colour coordinates such as Munsell, CIE L*a*b* and CMYK. The MyGemewizard app enables users to save records of gems of interest (e.g. at shows or in suppliers' offices), enabling them to capture their images, analyse and record their colours and save other information, such as their properties, prices, vendor information and more. The apps can then be used to share the gem's information via email and social media. Visit www.gemeapps.com for additional information and links to download iOS and Android versions. *CMS*

Gemewizard Monitor Colour Calibration Kit

In February 2017, Gemewizard Ltd. released a specially designed kit enabling users to calibrate their computer monitor to display accurate gem colours. The kit contains a row of six faceted pieces of terbium glass representing all of the hues needed for calibrating an LCD/LED screen: blue, red, magenta, green, cyan and yellow. The kit is placed under a standard 6,500 K (D65) fluorescent lamp next to the monitor displaying the Gemewizard calibration page at www.gemewizard.com/calibration, and the user adjusts the monitor settings until the colours most closely resemble those shown by the glass samples. The kit will soon be available for US$10.00, and will be included at no extra charge with subscriptions to GemePrice. To order, email sales@gemewizard.com. *BML*

MISCELLANEOUS

Fabergé Online

The Virginia Museum of Fine Arts in Richmond, Virginia, USA, possesses one of the world's outstanding collections of Fabergé works, including five Imperial Easter Eggs and more than 170 additional pieces, donated in 1947 by Lillian Thomas Pratt. VMFA now offers the ability to search the collection online, as well as a website dedicated to the story of the collection, and an app for iOS and Android smartphones and tablets that was launched in October 2016. Visit https://vmfa.museum/collections/faberge. *CMS*

Reopening of The Lapworth Museum of Geology

In September 2016, the University of Birmingham opened its extensively redeveloped Lapworth Museum of Geology. The Museum's exhibits cover 3.5 billion years, including rocks, fossils and dinosaurs. The mineralogy collection contains approximately 12,000 specimens, many from British mining areas that are now closed, as well as historical displays about famous British mineralogists and collectors. For more information about the Museum and its collections, visit www.birmingham.ac.uk/facilities/lapworth-museum/index.aspx. *CMS*

What's New provides announcements of new instruments/technology, publications, online resources and more. Inclusion in What's New does not imply recommendation or endorsement by Gem-A. Entries were prepared by Carol M. Stockton (CMS) or Brendan M. Laurs (BML), unless otherwise noted.

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Journal of Gemmology

Moonstone Mystery

Alan Hodgkinson

The three cabochons in Figure 1a each show an aspect that may be seen in moonstone: chatoyancy, asterism and adularescence (from left to right). The stones on the left and right are in fact moonstones, easily confirmed by their spot RI of 1.53 and their biaxial interference figure (e.g. Figure 2). However, no such figure was obtainable with a polariscope from the cabochon in the centre. It was handed to the author at the 2016 Scottish Gemmological Association conference by a regular Norwegian attendee, Stig Sundin, with the question, "Just what exactly is the identity?"

Exposure of the three samples to short-wave UV radiation revealed the faintest pinkish red luminescence in the two moonstones, but striking 'sky'-blue fluorescence in the other cabochon (Figure 1b). The mystery sample also exhibited various combinations of asterism depending on the angle of light and viewing, ranging from four, five, six or even seven rays as the cabochon was manoeuvred (e.g. Figure 3). Lapidary Martin Donoghue polished the base of the cabochon, and this enabled a clear single RI reading of 1.727 on an Eickhorst refractometer. The test results confirmed synthetic spinel, but what was the mechanism that formed the stars?

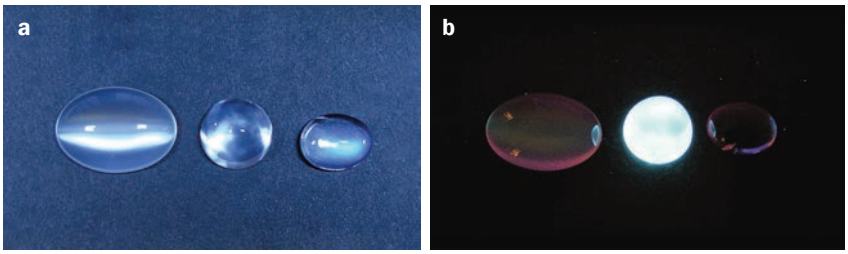

Figure 1: (a) The moonstone on the left (6.14 ct) displays chatoyancy, while the moonstone on the right (2.40 ct) shows bluish adularescence. The moonstone simulant in the centre (6.08 ct), which proved to consist of heat-treated synthetic spinel, exhibits asterism with various numbers of rays depending on the orientations of the light source and the cabochon. (b) Exposure of these cabochons to short-wave UV radiation revealed faint pinkish red fluorescence in the two moonstones, whereas bright 'sky'-blue luminescence is shown by the synthetic spinel. Photos by A. Hodgkinson.

Cross-polarized light revealed the 'tortured' interior of the cabochon as a random birefringence pattern (Figure 4), which could be due to strain or the exsolution of a second phase. This suggested that this moonstone simulant was originally grown as a Verneuil colourless synthetic spinel that was then subjected to heat treatment. The heating caused a segregation or exsolution within the structure of this flame-fusion synthetic spinel (Eppler, 1943; Saalfeld and Jagodzinski, 1957). Unlike corundum, since it is difficult to grow synthetic spinel by the Verneuil technique, the alumina-to-magnesia ratio was increased by as much as five times of that contained in natural spinel to facilitate growth of a product with minimal internal stress (Nassau, 1980).

The high temperature may have caused lamellae of aluminium oxide to partially segregate, with the resultant appearance of an adularescent moonstone. Such cabochons were in fact posed as star moonstone simulants, but there was little market for such products when moonstones themselves from Sri Lanka cost very

Figure 2: A biaxial interference figure in the polariscope is useful for confirming the identity of moonstone. Photo by A. Hodgkinson.

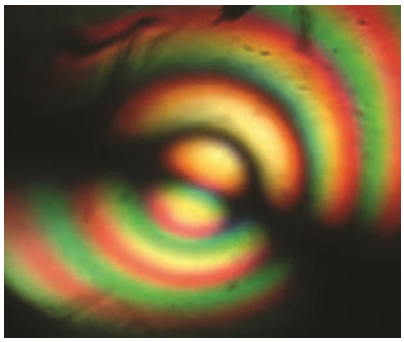

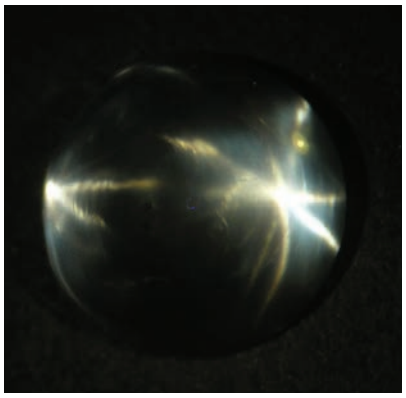

Figure 3: Various numbers of rays are shown by the asterism in the 6.08 ct heat-treated synthetic spinel. Photo by A. Hodgkinson.

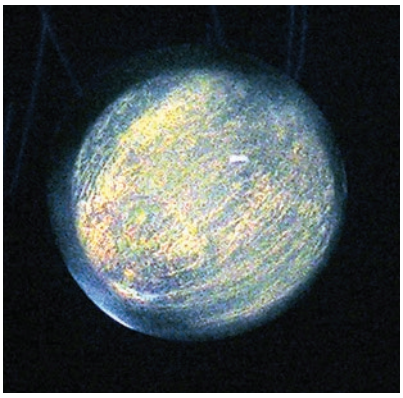

Figure 4: A random birefringence pattern, possibly due to strain or the exsolution of a second phase, is seen when the 6.08 ct synthetic spinel cabochon is viewed with cross-polarized light. Photo by A. Hodgkinson.

little during that period in the late 1940s–50s.

The variable-ray stars in such products may be the result of the exsolved lamellae of an aluminium-rich phase within the synthetic spinel host. This created multi-random reflective mechanisms, and so, as the light source and/or specimen is manoeuvred, the light paths within the specimen will reflect. The cabochon cut then acts as a convex lens to focus the reflections in various directions to the dome surface, hence the random and unpredictable nature of the star formations.

Readers may wonder why valuable crystal-growth resources would be targeted toward simulating such an inexpensive gem as moonstone. During World War II, Germany was nearly starved of the crucial commodity of industrial diamond, essential to keep the wheels of war turning. The friction obstacle found in all bearings—especially those deployed in aircraft—required very hard and tough materials to offset wear and abrasion. This resulted in much effort and expense that was funded primarily by the German Luftwaffe (air force). Central to the German effort, Prof. W. Eppler at the University of Strasbourg experimented with heat/annealing processes to increase the wear resistance of both synthetic spinel and synthetic sapphire (Steindorff, 1947). To test this, he devised a sandblast wear-resistance and hardness test, based on loss of weight of a standard polished sample. Incredibly, in some cases he was able to increase the wear resistance of synthetic spinel to a greater factor than that of synthetic sapphire. The benefit of this to Germany was immense, as it minimized the need for industrial diamond powder.

The point of interest here is that the experiments involved controlled heating sequences. Apart from the successes of such work, there would have been experiments that did not yield the desired results for hardening the heated material, and it is fair to assume that such items would be rejected. By chance, Prof. Eppler was also head of the Technical Gem Cutting School at Idar-Oberstein, and it is therefore understandable that such reject material would find its way onto their faceting laps and, in the case of cabochons, the by-product had a moonstone appearance with the bonus of also having asterism.

To put this article in some perspective, it should be mentioned that one of the two factories charged with growing such synthetic spinels, Wiedes Carbidwerk at Freyung, produced 4,000,000 carats of synthetic spinel per month (Anonymous, 1948). It is little wonder that such moonstone imitations should now turn up on occasion! However, they are straightforward to identify with standard gemmological instruments—and a knowledge of their existence.

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Gem Notes

COLOURED STONES

Red Beryl in Matrix, Cut as Cabochons

It is always interesting to see innovative uses of gemstone raw materials, particularly for high-value gem varieties. During the 2017 Tucson gem shows, this author saw one such example—for red beryl from the Wah Wah Mountains of southwest Utah, USA. The Ruby Violet mine was the only commercial source of gem-quality red beryl, but it closed several years ago, making this very rare beryl variety even rarer.

Figure 1: These cabochons (8 × 6 mm each) are cut from red beryl interspersed with its associated altered rhyolite matrix. Photo by Jeff Scovil.

At the booth of Robert and Patricia Van Wagoner (Beija-flor Wholesale, Haiku, Hawaii, USA), there were dozens of calibrated cabochons cut from red beryl in matrix (e.g. Figure 1). Various patterns were displayed by the light-coloured, altered rhyolite matrix against the deep red-to-pink beryl, ranging from random-appearing intergrowths to linear patterns that resulted from the crystallization of the red beryl along thin veinlets in the host rock (see, e.g., Figure 9 of Shigley et al., 2003). The cabochons were cut in various shapes (round, pear and oval), and ranged from 4 mm in diameter to 9 × 7 mm. Although it is common for red beryl to be clarity enhanced, these cabochons reportedly were untreated.

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Ceruleite from Chile

Ceruleite is a blue hydrous copper aluminium arsenate, $Cu_2Al_7(AsO_4)_4(OH)_{13} \cdot 12(H_2O)$, that is rarely encountered as a gemstone. Although originally described in 1900 from Chile, gem-quality ceruleite was first documented from Bolivia by Schmetzer et al. (1978). Subsequently, gem-quality material from Chile was mentioned by Schmetzer et al. (1983). Like turquoise, ceruleite is typically polished as cabochons. At the 2016 Tucson gem shows, we encountered ceruleite from Chile that was faceted and contained various impurities. The stones were offered by Mauro Pantò (The Beauty in the Rocks, Sassari, Italy), who had approximately 20 pieces weighing 1.0–2.5 ct. Pantò indicated the rough material came from Mina El Guanaco in the Taltal area of the Antofagasta Region, Chile. He kindly donated a 1.45 ct stone to Gem-A, and it was examined by authors CW and BW.

The gem was cut in a modified octagonal shape and measured 7.15 × 6.90 × 5.02 mm (Figure 2). It was opaque and showed an overall intense blue colour (World of Color 5B 7/8), with some dark brown, white and green areas corresponding to impurities. The RIs could not be obtained, probably due to the stone's poor polish. The hydrostatic SG was 2.69, which is lower than the value of 2.80

Figure 2: This 1.45 ct stone consists of intense blue ceruleite with dark brown, white and green impurities. Gift of Mauro Pantò; photo by B. Williams.

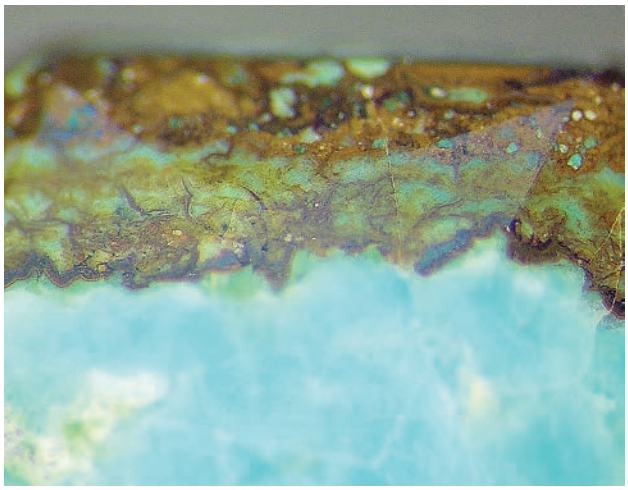

Figure 3: This closer view of the pavilion side of the stone in Figure 2 shows the veined appearance of the iron staining and associated matrix material, as well as the green and white impurities in the ceruleite. Photomicrograph by C. Williams; magnified 50×.

typically reported for ceruleite, but is similar to the SG of 2.70 determined by Schmetzer et al. (1978) on polycrystalline mater-ial. The blue areas of the sample were confirmed as ceruleite using an Enwave 785 Raman spectrometer, by comparing the spectra to the RRUFF database.

Microscopic observation of the blue areas revealed a polycrystalline texture, while the dark brown areas showed vein-like patterns (e.g. Figure 3) that resembled the iron-stained matrix commonly seen in turquoise and the white areas locally contained tiny open vugs. According to analytical work done by German mineralogist Gunnar Farber, the green inclusions consist of schlossmacherite, a sulphate mineral of the alunite group with the formula $(H_3O)Al_3(SO_4)_2(OH)_6$.

The reported hardness of 5–6 on the Mohs scale makes ceruleite sufficiently durable for cutting and use in jewellery. Like turquoise, however, it may be sufficiently porous to require stabilization. Schmetzer at al. (1983) documented plastic-impregnated ceruleite, which was easily identified because its SG was distinctly lower (2.58) than that of untreated material, and infrared spectroscopy showed a diagnostic absorption band at 1725 cm^{-1}, as seen in stabilized turquoise.

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Yellow Danburite from Namalulu, Tanzania: Gemmological Properties and Chemical Composition

Danburite is a calcium borosilicate $[CaB_2(SiO_4)_2]$ that is an uncommon collector's stone. It typically ranges from colourless to light brown or light yellow, although less commonly it can exhibit intense yellow coloration. In early 2008, significant amounts of gem-quality yellow danburite entered the market, mined from granitic pegmatites in the Morogoro region of central Tanzania (Chadwick and Laurs, 2008). A few years later, another deposit of yellow danburite was discovered near

Figure 4: These two vivid yellow danburites (8.72 and 7.86 ct) are from the Namalulu area of north-east Tanzania. Courtesy of the Somewhere In The Rainbow Collection; photo by Bilal Mahmood, AGL.

Namalulu village in north-east Tanzania. According to a Tanzanian supplier of this material to gem dealer Werner Radl (Mawingu Gems, Niederwörresbach, Germany), mining of the Namalulu deposit began in 2012, and production consisted of hundreds of kilograms of mainly tumble- and cabochon-grade material, as well as several kilograms of facet-grade rough.

Since 2014, one of the authors (CPS) has examined a number of the vivid yellow danburites from Namalulu, ranging from less than 1 ct to more than 18 ct (e.g. Figure 4). Their standard gemmological properties were: RIs—n_α = 1.628–1.629, n_β = 1.631–1.634 and n_γ = 1.634–1.637; birefringence—0.006–0.008; hydrostatic SG—2.97–3.01; and fluorescence—inert to both long- and short-wave UV radiation. These data for Namalulu danburite are consistent with the material from Morogoro reported by Chadwick and Laurs (2008). Microscopic features consisted of small colourless crystals, pinpoint particles, series of fine etch tubules, open fractures with a frosted surface appearance and partially healed fissures. (The absorption spectra and colour stability of Namalulu danburite are described in the following Gem Note entry.)

We measured the chemical composition of three samples of faceted yellow danburite from Namalulu, as well as three faceted yellow danburites from Myanmar for comparison. Energy-dispersive X-ray fluorescence (EDXRF) spectroscopy was performed on one sample each from Tanzania and Myanmar with a Thermo Scientific Quant'X instrument, using a series of seven excitation energies from 4 to 50 kV (SSEF silicate routine). Laser ablation inductively coupled plasma mass spectroscopy (LA-ICP-MS) was performed on all samples with a GeoLas 193 nm excimer laser, coupled with a PerkinElmer Elan 6100 DRC mass spectrometer (see Table I footnote for details of the procedure).

EDXRF spectroscopy revealed the expected major elements Si and Ca; B could not be measured due to limitations of the technique for detecting light elements. In addition, low concentrations of Sr were detected in samples from both Tanzania and Myanmar. The trace-element data obtained by LA-ICP-MS are shown in Table I; overall, the analysed specimens had similar compositions. Rare-earth elements (REE) were present in all the samples, with a general enrichment of light REEs (La, Ce, Pr, Nd and Sm), as also found by Huong et al. (2016) in danburite samples from Tanzania, Vietnam and Mexico. Our data for the Namalulu danburites were similar to the selected elements reported by Chadwick and Laurs (2008). However, our Tanzanian danburites contained higher concentrations of heavy REEs (including Y) compared to the samples from Myanmar.

Due to the fact that elements with even atomic numbers are naturally more abundant than those with odd atomic numbers (so-called Oddo-Harkins rule), REE data are often plotted in a diagram normalized to a chondrite standard (stony meteorite; data from Anders and Grevesse, 1989). This diagram for our samples clearly shows the higher abundance of heavy REEs in danburite from Tanzania compared to the Burmese samples (Figure 5). The so-called europium anomaly, a deficiency or enrichment of Eu relative to the other REEs^{3+}, is a common feature in minerals and rocks, and is linked to the fact that this element can be found in two valence states: Eu^{3+} and Eu^{2+} (Weill and Drake, 1973). The danburites from Tanzania were characterized by a distinct negative Eu anomaly, whereas two of the three Burmese samples showed no such anomaly. However, the presence of an Eu anomaly in one of the Burmese samples precludes the use of this element for separating danburites from these two localities.

*Table I: Average trace-element concentrations in danburite analysed by LA-ICP-MS.**

Origin	Tanzania			Myanmar		
Weight	**2.10 ct**	**2.93 ct**	**3.01 ct**	**1.50 ct**	**1.60 ct**	**1.70 ct**
Element						
Be	188 (5)	169 (4)	136 (1)	81.3 (22.3)	29.8 (4.2)	202 (11)
Na	11.8 (0.2)	13.5 (0.1)	10.1 (0.4)	164 (56)	24.2 (1.4)	156 (8)
Mg	4.56 (0.43)	5.55 (0.58)	4.60 (0.22)	5.38 (0.32)	4.91 (0.18)	4.98 (0.46)
Al	178.8 (0.6)	129.3 (0.4)	146.9 (1.0)	89.6 (20.5)	474 (53)	82.9 (1.4)
P	29.3 (5.0)	36.8 (3.0)	28.2 (0.7)	39.8 (0.9)	31.3 (5.0)	36.5 (6.2)
K	<2.0	<1.4	<1.5	1.60 (0.12)	<2.5	5.5 (0.9)
Sc	0.66 (0.08)	0.78 (0.04)	0.39 (0.12)	0.80 (0.12)	0.68 (0.10)	0.49 (0.03)
Ti	<18	<6.0	14.8 (1.5)	<6.3	<20	<19
Mn	1.35 (0.19)	0.50 (0.08)	<0.6	<0.45	1.56 (0.12)	<0.8
Fe	25.7 (3.8)	26.5 (2.1)	21.3 (3.0)	31.3 (3.4)	23.1 (3.2)	25.2 (3.9)
Ga	5.89 (0.62)	10.07 (0.22)	4.07 (0.38)	2.19 (0.27)	4.60 (0.12)	5.08 (0.70)
Ge	7.38 (0.24)	6.75 (0.46)	7.07 (0.17)	2.14 (0.17)	3.42 (0.28)	2.48 (0.31)
Sr	343 (2)	203 (1)	181 (2)	612 (38)	226 (20)	1037 (12)
Y	19.2 (0.3)	13.04 (0.09)	14.68 (0.23)	1.48 (0.14)	5.99 (0.81)	2.11 (0.03)
Sn	2.05 (0.15)	1.63 (0.13)	2.00 (0.14)	1.44 (0.26)	2.33 (0.60)	2.01 (0.09)
Ba	<0.22	<0.14	<0.20	1.75 (0.32)	<0.25	9.89 (0.74)
La	192 (3)	333 (1)	99 (2)	84 (6)	157 (26)	234 (5)
Ce	297 (4)	475 (1)	203 (3)	95 (8)	229 (19)	266 (4)
Nd	68.6 (0.8)	91.0 (0.3)	62.4 (0.6)	24.7 (1.6)	42.7 (1.7)	57.4 (2.3)
Eu	0.84 (0.03)	0.61 (0.02)	0.56 (0.03)	0.74 (0.13)	0.26 (0.01)	1.32 (0.03)
Gd	7.33 (0.20)	6.00 (0.12)	5.91 (0.14)	1.19 (0.21)	2.47 (0.32)	2.10 (0.07)
Dy	3.17 (0.04)	2.16 (0.08)	2.58 (0.09)	0.40 (0.01)	1.00 (0.10)	0.55 (0.07)
Er	0.96 (0.09)	0.65 (0.01)	0.83 (0.01)	0.077 (0.002)	0.32 (0.04)	0.10 (0.01)
Yb	0.50 (0.09)	0.32 (0.02)	0.52 (0.03)	<0.08	0.12 (0.03)	<0.14
Lu	0.055 (0.003)	0.035 (0.004)	0.062 (0.007)	<0.01	<0.02	<0.02
Pb	8.34 (0.11)	11.04 (0.09)	19.16 (0.46)	6.12 (0.51)	7.26 (0.27)	5.82 (0.06)
Th	1.39 (0.08)	0.438 (0.012)	0.54 (0.015)	0.009 (0.004)	<0.007	0.024 (0.003)

* Three analyses were done on the polished girdle of each sample, using a 60 µm spot size. Values are shown in parts per million by weight, and standard deviations are given in parentheses. The raw data were standardized using NIST 610 glass as an external standard and Si as an internal standard. Before each analysis, a short pre-ablation was performed with the laser to avoid surface contamination effects. The concentration calculation of the transient LA-ICP-MS signals was carried out with SILLS data reduction software (Guillong et al., 2008). The isotopes were carefully selected to ensure there were no interferences, and special care was taken in the data processing to correct for any artefact (spike) or contamination (surface or inclusions). The following elements were analysed but were below the detection limits: Li, V, Cr, Co, Ni, Cu, Zn, Rb, Zr, Nb, Mo, Sb, Hf, Ta, W, Bi and U; not analysed were the REEs Pr, Sm, Tb, Ho and Tm.

Nevertheless, the analysed samples from Myanmar and Tanzania could be effectively distinguished by plotting the concentrations of the elements Gd, Dy and Ge (Figure 6).

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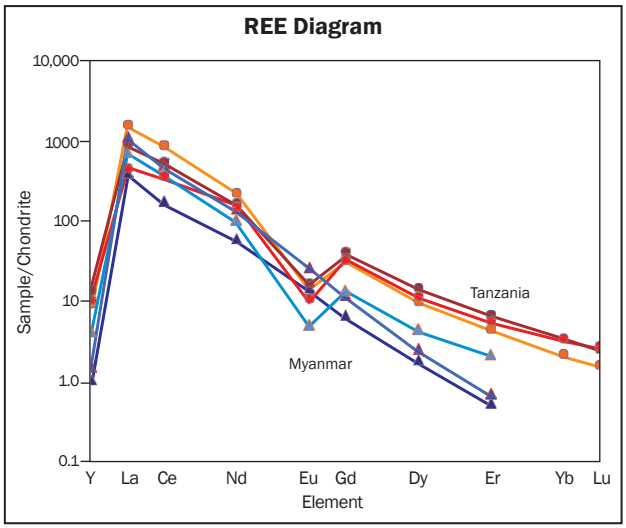

Figure 5: This chondrite-normalized REE diagram of the danburite samples analysed by LA-ICP-MS reveals their general enrichment in light REEs (La to Sm). The three specimens from Tanzania show distinctly higher amounts of heavy REEs (Gd to Lu) than the Burmese samples. All but two of the samples (from Myanmar) show a negative Eu anomaly.

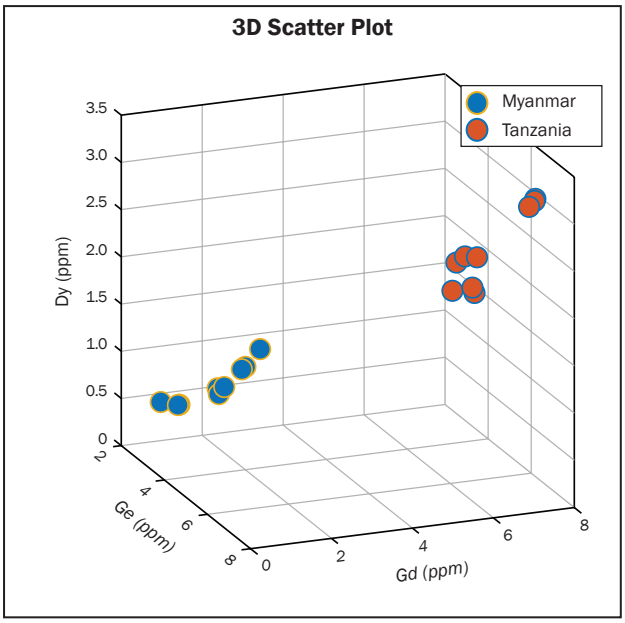

Figure 6: The analysed danburites from Myanmar and Tanzania are clearly distinguished in this three-dimensional scatterplot of germanium, gadolinium and dysprosium.

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Yellow Danburite from Namalulu, Tanzania, and Myanmar: Origin of Colour and Its Stability

The origin of the yellow colour in danburite is not fully known. However, some researchers have speculated that it may be due to didymium, a name referring to a mixture of light REEs including praseodymium (Pr) and neodymium (Nd), and sometimes cerium (Ce). These and other REEs can replace Ca^{2+}.

When viewed with a desk-model spectroscope, typically no absorption features were observed for yellow danburites from Tanzania and Myanmar (see preceding Gem Note for sample descriptions). However, in the larger and more intensely coloured samples, a very faint line at approximately 584 nm could be seen. Using a Perkin-Elmer Lambda 950 spectrometer, several weak bands were recorded in the visible region at approximately 525, 567, 577, 584, 732, 744 and 792 nm, as well as two dominant bands in the UV region positioned at approximately 275 and 315 nm (Figure 7).

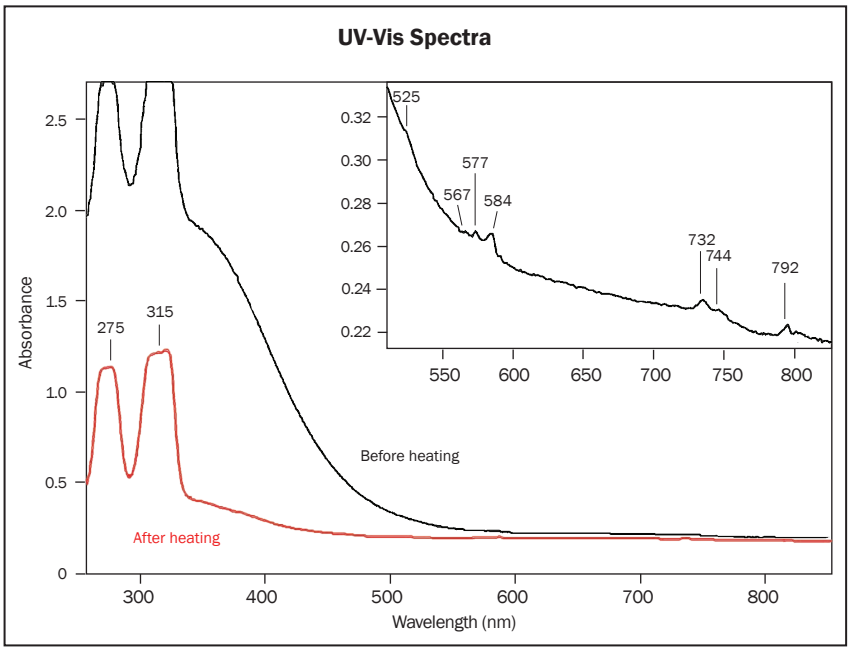

Figure 7: UV-Vis-NIR spectra (5.4 mm path length) are shown for a rough sample of Namalulu danburite, before and after heating. The spectrum before heating shows a general increase in absorption beginning just below 600 nm, as well as two dominant bands in the UV region positioned at approximately 275 and 315 nm. After heating, the yellow sample became colourless with a corresponding decrease in absorption from the visible to the UV region of the spectrum; the bands in the UV region remained unchanged. A series of weak absorption bands positioned at approximately 525, 567, 577, 584, 732, 744 and 792 nm (see inset) appeared to be unaffected by heating.

Although we assume that lanthanides (REE with atomic numbers 57–71) are responsible for the colour of these danburites, we could not find a direct correlation between the yellow colour saturation and the REE concentration in the studied samples from Tanzania and Myanmar. The colour intensity may therefore be linked to variable ratios of the valence states of certain lanthanides (e.g. Ce^{2+}, Ce^{3+}, Ce^{4+}), in addition to their concentration.

To test the colour stability of yellow danburite, one of the authors (CPS) heated one rough sample each from Tanzania (Figure 8a) and Myanmar to 500°C for four hours, and both showed a complete loss of colour (e.g. Figure 8b). The samples were then heated further to 950°C for a period of 24 hours, but they remained colourless. Ultraviolet-visible-near infrared (UV-Vis-NIR) absorption spectroscopy was performed on the samples before and after heating. In their unheated state, the yellow danburites showed a significant rise in general absorption from roughly 550 nm leading into the UV region of the spectrum (again, see Figure 7). After heating, this absorption was greatly reduced. The mid-infrared spectra (taken with a Thermo Scientific Nicolet 6700 spectrometer) were virtually unaffected by heating, although a band at 3588 cm^{-1} did appear slightly diminished. Additionally, no apparent changes were noted in Raman or photoluminescence spectra (recorded with a Renishaw InVia spectrometer equipped with a 514 nm Ar-ion laser) in the samples after heating.

We did not perform experiments specifically to restore the yellow colour in the danburite

Figure 8: A rough yellow danburite from Namalulu, Tanzania, (a) was heated to 500°C for four hours, resulting in a complete loss of colour, and the sample remained colourless after further heating to 950°C for 24 hours (b). For another test, one bead of Namalulu danburite was kept as a reference sample, while another bead was exposed to a tensor lamp for eight hours (c, left and right samples, respectively). After three hours, the bead exposed to the lamp darkened and became more brownish. Photos by Bilal Mahmood (a, b) and C. P. Smith (c).

samples, but exposure of Burmese danburite to X-rays is known to induce a yellow or 'golden' brown colour (Webster, 1953); the stability of the induced colour was not reported.

Gem dealers who have handled danburite from the two localities in Tanzania (Morogoro and Namalulu) have noted a significant difference in their colour stability to sunlight. While the Morogoro material appears stable, Namalulu danburite develops a darker brownish yellow coloration after exposure to sunlight (Werner Radl and Menahem Sevdermish, pers. comm., 2016). To test this, author CPS exposed a yellow danburite from Namalulu to a tensor lamp (positioned 15 cm from the stone) for eight hours and checked hourly for any changes in colour. After approximately three hours, its colour had become slightly more saturated, yet distinctly more brownish (Figure 8c). After the full eight hours, its colour did not change further. No experiments were performed in an attempt to restore the original coloration, but according to Radl this change in colour is permanent and irreversible under normal conditions of display or wear. He added that mining for the Namalulu danburite has stopped in recent years due to lack of commercial interest as a result of the susceptibility to develop a brownish coloration.

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New Production of Emerald from Ethiopia

Ethiopia has been known as a source of emerald for many years, but recently it produced some high-quality material (see, e.g., Figure 9 and Renfro et al., 2017) and some fine stones were displayed by various dealers during the 2017 Tucson gem shows. One vendor, Mahesh Agarwal (Stone International, Jaipur, India), reportedly obtained approximately 1,000 carats of faceted stones (150–200 pieces) that ranged up to 21.70 ct. The emeralds were cut from selected pieces of a parcel weighing several kilograms that was mined since September 2016 in the Shakiso region of southern Ethiopia. In addition, Agarwal has obtained ~300 kg of low-to-medium quality rough material. He indicated that the faceted stones were untreated except for light oiling (with mineral oil), as is typically done for coloured stones after they are cut in Jaipur.

Figure 9: These emeralds (total weight 23.60 carats) reportedly were produced recently from Ethiopia and were on display at one of the 2017 Tucson gem shows. Courtesy of Mahesh Agarwal; photo by B. M. Laurs.

Figure 10: A miner searches for emeralds in a narrow shaft in the Kenticha area of Ethiopia. Photo by Dr Klaus Schollenbruch, © Gübelin Gem Lab.

According to gem dealer Hussain Rezayee (Rare Gems & Minerals, Los Angeles, California, USA), the recent emerald production took place in the Kenticha area, which is located approximately 40 km south of Shakiso. A series of shallow pits and shafts (up to a few metres deep; e.g. Figure 10) have been dug by about 500 miners in search of emerald. Production from the area

Figure 11: Amde Zewdalem holds a large emerald crystal that he indicated was mined recently in Ethiopia. The sample was previously sliced in two places to extract facetable areas, so the original crystal was somewhat longer. Photo by B. M. Laurs.

has averaged 30–40 kg of mine-run emerald per week, and about 5% of it is gem quality.

The gemmological and chemical properties of these schist-hosted emeralds were described by Renfro et al. (2017), who reported that they could be separated from those of Zambia and Brazil by their trace-element contents (i.e. Cs, Li, Rb, Sc and Rb, analysed by LA-ICP-MS). In addition, Cevallos et al. (2012) documented the gemmological and chemical properties of earlier Ethiopian emerald production, reportedly from the Dubuluk' area, which is ~70 km south-west of Kenticha. Cevallos et al. (2012) mentioned that during a buying trip to Ethiopia in 2011, gem dealer Farooq Hashmi (Intimate Gems, Glen Cove, New York) was told that the Dubuluk' area has produced emeralds for a few years. More recently, in September 2013, Hussain Rezayee informed one of us (BML) about some additional production of emeralds from the Shakiso region, including some large crystals—although they contained only small areas that were transparent enough for faceting. During the 2017 Tucson gem shows, Amde Zewdalem, an Ethiopian gem dealer living in Jacksonville, Florida, USA, indicated that some large stones likewise have been produced during the most recent mining (i.e. Figure 11).

The area hosting emerald deposits in southern Ethiopia appears quite extensive, and it seems likely that additional commercially significant production will take place there in the future.

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Vivid Purplish Pink Fluorite from Illinois, USA

The Illinois-Kentucky Fluorspar District in the east-central USA was a famous producer of beautiful specimens of fluorite and associated minerals from the early 1800s until 1995, when the last operating mine was closed (Goldstein, 1997). Fluorite from this area shows a wide variety of colours, with the most common being purple, yellow and colourless (often as zoned crystals); blue and green are less common, and pink is rare (Smath, 2010).

It was surprising, therefore, to encounter vivid purplish pink fluorite from Illinois (e.g. Figure 12) at the 2017 Tucson gem shows. The stones were offered by Paul Cory (Iteco Inc., Powell, Ohio, USA), who had 90 gems cut from a single large piece of rough that was mined some years ago near Cave-In-Rock, Hardin Co., Illinois. They ranged from 4 mm in diameter up to ~150 ct, with ~20 stones weighing >1 ct. Although the largest stone was rather included, the next

largest (52.85 ct; Figure 12) was relatively clean, with few eye-visible inclusions. Cory plans to have two more larger-size stones cut from the remaining rough material.

While pink is an unusual colour for fluorite from this famous mining area, such a vivid purplish pink coloration is notable for fluorite from any locality. Cory decided to have the stones cut on occasion of the theme of the 2017 Tucson Gem and Mineral Show®, which was 'Mineral Treasures of the Midwest'; Illinois is one of the states in the American Midwest.

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Figure 12: This 52.85 ct fluorite from Illinois, USA, is notable for its saturated purplish pink colour. It was faceted by Jay Medici (Fredericktown, Ohio). Photo by Jeff Scovil.

Colourless Forsterite from Vietnam

Gem-quality colourless fosterite (the Mg-rich end member of the olivine group) was recently found in the Luc Yen region in northern Vietnam. Previously, colourless forsterite was described in gem quality only from the Pyaung Gaung (Themelis, 2008) and Dattaw (Krzemnicki and Groenenboom, 2008) mining areas of Myanmar, and from Kukh-i-Lal in the south-western Pamir Mountains of Tajikistan (Kondo, 2008); it is also known from the Embilipitiya region of Sri Lanka (Gamini Zoysa, pers. comm., 2016).

The Vietnamese forsterite occurrence was discovered in July 2016 by a local miner and author RH at the Cong Troi mine near the village of An Phu. This region was influenced by the tectonic movements of South-East Asia during the closing of the Palaeo-Tethys ocean and subsequent Himalayan orogeny. The area consists mainly of metamorphic rocks, including mica schist, marble and granulite gneiss. The marble layers in the Luc Yen area are quite thick (up to 500 m), and locally contain pargasite, sulphides, chlorite minerals and gem-quality spinels of various colours (Chauviré et al., 2015), which are mined from both primary and secondary deposits.

The colourless forsterite described here was found in coarse-grained white marble together with clinohumite, pink spinel, green pargasite and mica. Two pieces of transparent forsterite were separated from the rock and faceted into oval cuts with dimensions of 5.44 × 4.68 × 3.64 mm (0.54 ct) and 5.17 × 4.61 × 3.27 mm (0.44 ct; Figure 13). They had RIs of 1.638–1.670, a birefringence of 0.032 and a hydrostatic SG of 3.25. The identity of both samples was confirmed by Raman spectroscopy (with peaks at 964, 917, 856, 824, 752, 591, 542, 430, 410, 372, 328, 304 and 226 cm^{-1}). Microscopic examination revealed tiny fluid inclusions and two white anisotropic solid inclusions (probably carbonates) in one of the

Figure 13: Weighing 0.44 and 0.54 ct, these colourless forsterites are from Cong Troi in the Luc Yen region of northern Vietnam. Photo by R. Hanus and J. Štubňa.

samples (Figure 14). Both stones were inert to long-wave UV radiation and fluoresced weak violet to short-wave UV.

The typical green-yellow colour of peridot (a solid solution between the end members forsterite [Mg_2SiO_4] and fayalite [Fe_2SiO_4]) is caused by Fe^{2+} in octahedral coordination. The colourless appearance of the present forsterite gems is consistent with its Mg-rich end-member composition, which is also indicated by the RI and SG values (cf. Deer et al., 1982). UV-Vis-NIR spectroscopy revealed absorption bands at 645, 668 and 740 nm (Figure 15). By comparison, the typical absorption spectrum of green peridot shows three distinct bands due to iron in the blue region of the spectrum at 453, 473 and 493 nm (O'Donoghue, 2006), which were absent from the colourless forsterite.

This is the first documented occurrence of colourless forsterite in the Luc Yen area of northern Vietnam that is known to the authors. It is possible that such forsterite may have been inadvertently sold on the local gem market as microcline, topaz, colourless spinel or quartz. It seems likely that more of this colourless forsterite will be mined in the future.

Figure 14: The 0.44 ct forsterite contains colourless crystals and fluid inclusions. Photomicrograph by R. Hanus and J. Štubňa; magnified 90×.

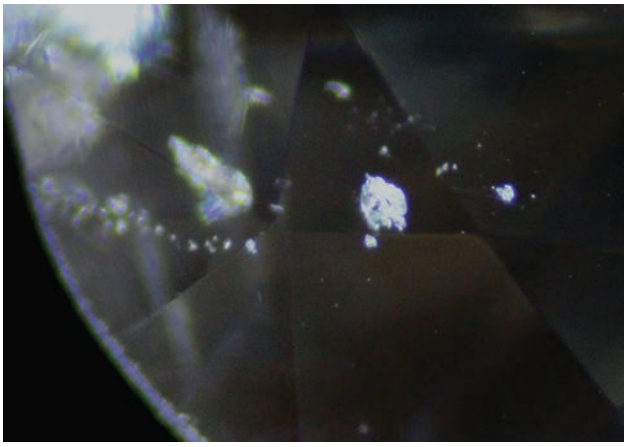

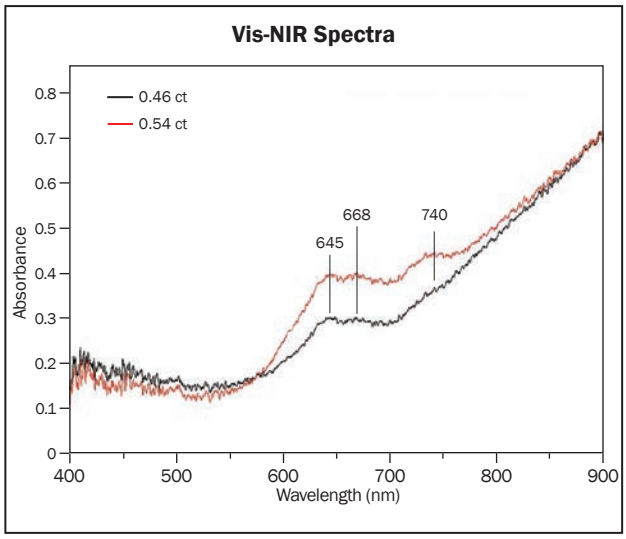

Figure 15: UV-Vis-NIR spectra of the two Vietnamese forsterite samples show absorptions at 645, 668 and 740 nm, but lack the features typically seen in green peridot at 453, 473 and 493 nm.

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New Sapphires from Ambatondrazaka, Madagascar

Madagascar, an island of many gem treasures, saw in recent months another gem 'rush' after the discovery of a new sapphire deposit at Bemainty, located about 35 km east of the small town of Ambatondrazaka (Perkins and Pardieu, 2017). With about 50,000 artisanal miners working the gravels of this alluvial deposit, this new site has so far reportedly produced an impressive amount of mainly blue sapphires, including some large stones up to 30 g of exceptional quality and additionally some orangey pink sapphires. These stones are currently arriving in the gem market in significant quantities, and some of them have been heated to improve their colour and clarity.

SSEF recently analysed a number of sapphires reportedly from this new source ranging from 1.3 ct to 34 ct (Figure 16). Most of the stones showed a rather pure moderately strong to strong blue colour, sometimes with a slight greyish to greenish tint. UV-Vis spectroscopy (Figure 17) showed that they can be separated into two categories, both of metamorphic origin. One group exhibited only small features due to Fe^{3+} that are reminiscent of sapphires from Sri Lanka and Kashmir with slight turbidity. The other group consisted of mostly dark, saturated blue stones with rather distinct Fe^{3+}-related absorption features, as also seen in Burmese sapphires.

Many of the studied specimens exhibited a slight to marked milkiness due to sub-microscopic fine particles in zones and bands (Figure 18a), but only occasionally did they have small rutile needles. Some of these sapphires also showed patches and crossed stripes of coarser particles and very fine kinked dust lines (Figure 18b), somehow reminiscent of Kashmir sapphires. We also observed characteristics found in gem-quality sapphires from other metamorphic-related deposits in

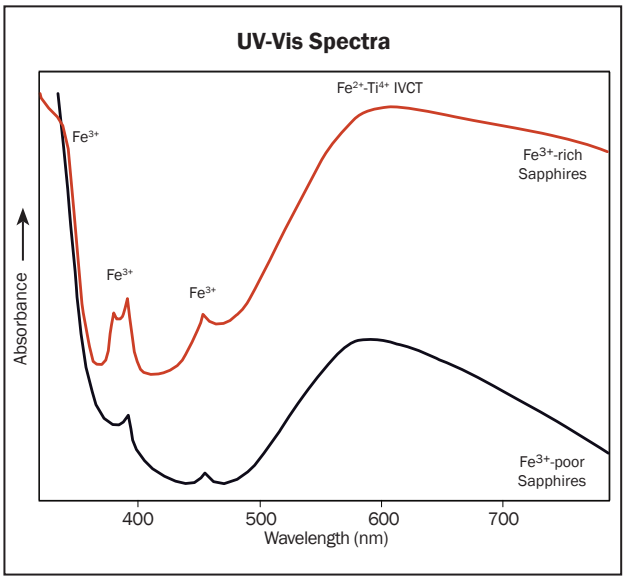

Figure 17: Absorption spectra are shown for the o-ray (i.e. beam oriented perpendicular to the c-axis) of blue sapphires from the new Ambatondrazaka deposit. The spectra were recorded with a portable UV-Vis spectrometer developed by SSEF.

Figure 16: These blue (~1.3–34 ct) and orangey pink (~30 ct) sapphires are representative of some of the stones that were recently studied by SSEF from a new deposit near Ambatondrazaka in Madagascar. Photo by Julien Xaysongkham, SSEF.

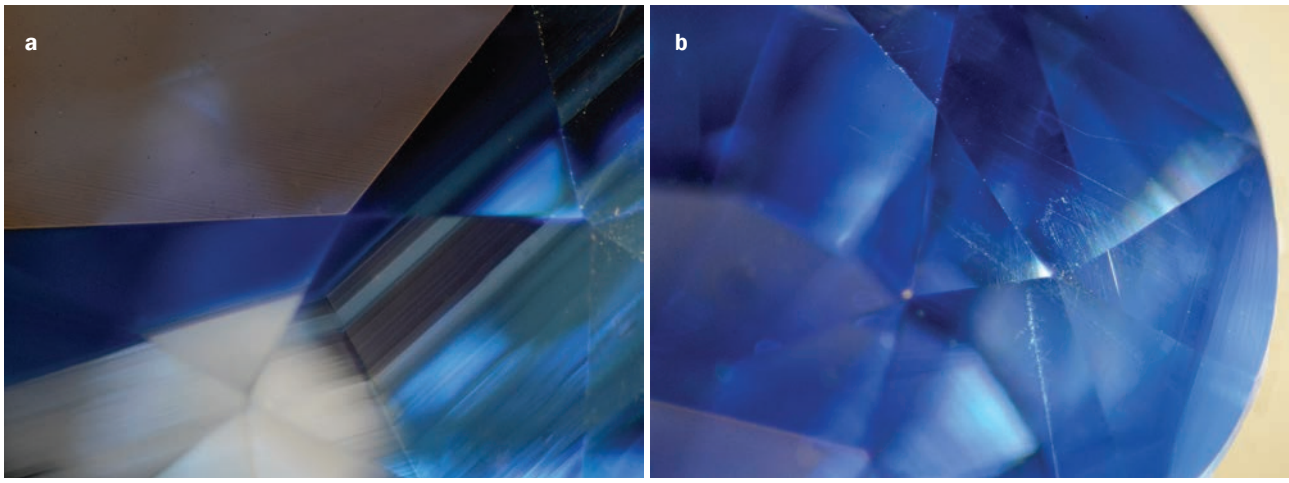

Figure 18: These sapphires from the Ambatondrazaka area contain fine milky banding due to minute particles (a, magnified 35×), as well as crossed stripes of coarser particles and very fine kinked dust lines (b, magnified 45×). Photomicrographs by M. S. Krzemnicki.

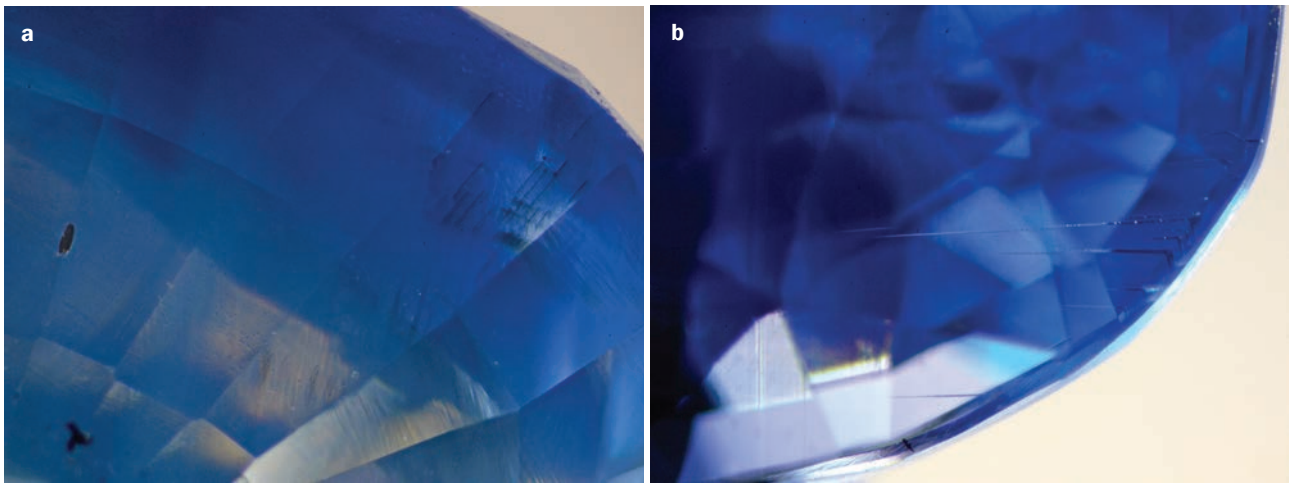

Figure 19: Also seen in the Ambatondrazaka sapphires are: a dense 'chaotic' pattern of growth lines with greyish colour effects (a, magnified 30×) and fine etched hollow channels that emanate from a stone's girdle (b, magnified 50×). Photomicrographs by M. S. Krzemnicki.

Madagascar (e.g. Andranondambo and Ilakaka), such as distinct and narrow growth zoning. This zoning also can produce a 'chaotic' three-dimensional pattern, occasionally showing brownish or greyish colour effects when viewed with transmitted light (seen with brightfield illumination, due to slight variations in refractive index; Figure 19a). A few samples also contained hollow channels that appeared to be etched (Figure 19b). Other features consisted of small colourless prismatic zircon inclusions surrounded by tension fissures and a black flake (presumably graphite) with small comet-like dust trails.

Although the visual appearance of some of these sapphires may resemble those from Kashmir, we did not find in our samples any of the highly characteristic inclusions of Kashmir sapphires, such as pargasite needles, short-prismatic tourmaline and corroded long-prismatic zircon. The dark sapphires rich in Fe^{3+} from this new source were often quite clean, sometimes with zones of short rutile needles associated with irregular platelets. Many of the dark blue sapphires we examined also showed small milky bands and zones, in contrast to Burmese sapphires that typically contain no such features.

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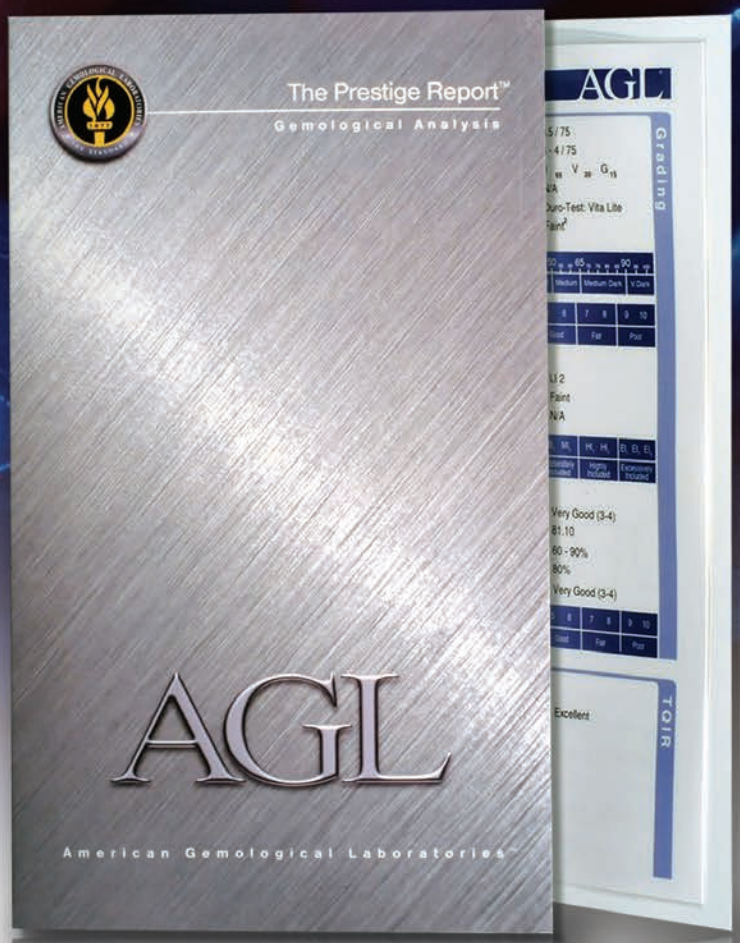

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Colour-Change Scorodite from Tsumeb, Namibia

Scorodite is a hydrous iron arsenate with the formula $Fe^{3+}AsO_4 \cdot 2H_2O$. The mineral was first described by Breithaupt (1818), who named it after the Greek word 'scorodion', which means 'garlic' because of the smell of the arsenic vapours produced when heating or grinding the material. The type locality of scorodite is the Asser pit in Langenberg, Saxonia, Germany. Scorodite is a secondary mineral originating from the weathering of arsenopyrite and other arsenic minerals. A significant source of scorodite is the Tsumeb mine in Namibia. This deposit is well-known to geologists, mineralogists and mineral collectors, and of the 288 minerals known from there, it is the type locality for 72 of them (www.mindat.org/loc-2428.html). Mining of the deposit began in 1907, primarily for Cu-Pb-Zn-Ag-Ge-Cd ores. In 1996, when the mine closed, a final depth of 1,000 m had been reached.

Facetable scorodite from Tsumeb was described by Gübelin (1976). Scorodite has a Mohs hardness of only 3½–4 and is rarely found in gem quality, so it is typically considered a collector's stone. In addition, scorodite loses all of its water upon heating to 200–220°C (Gübelin, 1976), which could cause unintended colour and/or stability alterations. Furthermore, the mineral is soluble in various strong acids and in some weak basic solutions (Weiß, 2000).

The authors investigated a translucent, faceted scorodite (6.99–7.07 × 4.36 mm; 1.41 ct), from Tsumeb that attracted attention because of its unusual colour behaviour, which has not been described previously in a faceted sample. Viewed with a daylight-equivalent lamp (6,774 K), the stone appeared dark green (Figure 20a), but it changed to dark greenish blue under a 3,400 K halogen lamp (Figure 20b). With an incandescent lamp or candlelight, the colour changed to violetish red. This change appeared strongest with transmitted incandescent light (Figure 20d). For comparison, Figure 20c shows the greenish blue appearance of the stone in transmitted light from the halogen lamp.

The SG was determined with a hydrostatic balance as 3.29. This is consistent with literature data for scorodite (3.29–3.31). The refractive indices of scorodite are reported as n_x = 1.738–1.786, n_y = 1.742–1.796 and n_z = 1.765–1.814, with a biaxial positive optic character (cf. Henn, 2012). However, it was not possible to determine the RIs of the investigated sample with a standard refractometer because of poor surface polish attributed to its low hardness. Therefore, the identity of the stone was confirmed by Raman spectroscopy. Microscopic observation revealed fissures, partially healed fractures and colourless doubly-refractive mineral inclusions. Qualitative chemical analysis by EDXRF spectroscopy revealed the major elements Fe and As, as well as traces of Al.

In general, the absorption spectra of colour-change minerals show two transmission minima around 476–507 and 625–666 nm, as well as a strong absorption maximum in the 561–578 nm region. Stones that are green in daylight usually change to red in artificial light, while bluish green and blue ones typically change to reddish violet (Schmetzer et al., 1980). An unpolarized absorption spectrum of the 1.41 ct scorodite was recorded with a MAGI GemmoSphere spectrometer. The visible-range spectrum (Figure 21) was characterized by three absorption bands at ~430, 570 and 800 nm caused by Fe^{3+} (Lehmann, 1978); the 430 nm band is not completely visible in Figure 21 because the signal overwhelmed the detector. The 570 nm band is responsible for the colour change; transmission windows on either side of this strong band (located at 480 and 688 nm) correlate to the sample's colour (Figure 20b–d), depending on the spectral composition of the light source. When measured with the daylight-equivalent lamp as the light source, the transmission window located at 480 nm shifted

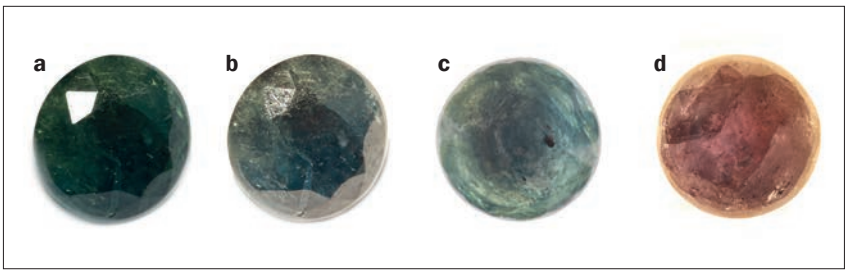

Figure 20: This 1.41 ct scorodite displays different colours in (a) artificial daylight-equivalent light (6,774 K), (b) halogen light (3,400 K), (c) transmitted halogen and (d) transmitted incandescent light (the yellowish hue close to the girdle is an artefact of the light source). Photos by T. Stephan.

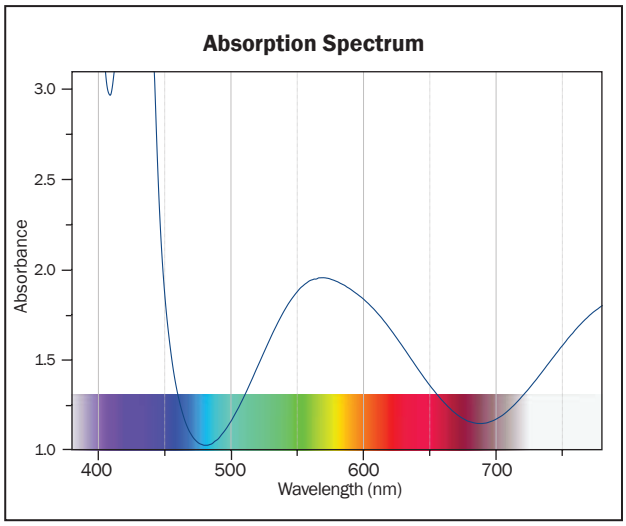

Figure 21: The visible-range absorption spectrum of the investigated scorodite (here, illuminated with an approximately 3,400 K light source) displays distinct transmission windows at 480 and 688 nm that account for the colour change.

to 500 nm, causing the dark green colour shown in Figure 20a.

Usually Cr^{3+} and V^{3+} (and less commonly REEs) are described in the literature as the causes of a colour change in gems (e.g. Schmetzer et al., 1980; Hänni, 1983). The scorodite described here revealed no traces of Cr^{3+} or V^{3+} in EDXRF analyses; also no bands associated with these elements were recorded in the absorption spectrum. Therefore, it appears that Fe^{3+} (and its associated strong absorption band at 570 nm) is the sole cause of the colour change in this scorodite.

Gebhard (1999) also mentioned colour-change scorodite from Tsumeb, and Weiß (2000) described it from Hemerdon in south-west England. Gebhard (1999) described the colour change as greenish blue to blue-green, while the samples documented by Weiß (2000) changed from intense blue in sunlight to grey-blue or grey-yellow in 'artificial' light, pale green in 'neon' light and bright yellowish green in the light of an 'energy-saving' lamp.

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Stichtite as a Gem Material

Stichtite, $Mg_6Cr_2CO_3(OH)_{16} \cdot 4H_2O$, is an attractive purplish pink to purple mineral of the hydrotalcite group that is very soft, with a Mohs hardness of just 1½–2. Nevertheless, because of its attractive colour, this material is sometimes polished as a collector's stone. Such gems commonly are sourced from Tasmania, Australia, and typically consist of compact aggregates of stichtite that form in association with serpentinite, producing striking colour combinations of purple and yellow-green (e.g. Laurs, 2012). Less frequently encountered are nearly monomineralic stichtite gems (e.g. Koivula et al., 2003).

At the 2016 Tucson gem shows, rare-stone dealer Mauro Pantò had approximately 50 nearly monomineralic faceted stichtites (~1.0–2.5 ct) from South Africa. Two regions in South Africa are known to produce stichtite, in Limpopo

and Mpumalanga Provinces (www.mindat.org/min-3784.html); the particular origin of Pantò's stones is unknown. He kindly donated to Gem-A a 1.70 ct faceted hexagon (Figure 22), and it was characterized for this report by authors CW and BW.

The stone was opaque with a pinkish purple colour and a waxy lustre. A faint RI was recorded at approximately 1.54 and SG was measured hydrostatically as 2.11; these values are similar to those reported by Koivula et al. (2003). The sample was inert to both long- and short-wave UV radiation. Microscopic observation revealed a polycrystalline oolitic structure with tiny pearlescent cleavage reflections similar to those commonly seen in amazonite. In addition, small black inclusions were distributed throughout the stone.

Raman analysis with an Enwave spectrometer (789 nm laser) confirmed its identity as stichtite. Chemical analysis with an Amptek X123-SDD EDXRF spectrometer showed major amounts of Cr and also some Fe (possibly present within the dark inclusions). Raman analysis of areas containing the dark inclusions was inconclusive, but the presence of Fe combined with the stone's significant magnetic susceptibility suggested magnetite or chromite; similar-appearing inclusions were identified as chromite in the sample examined by Koivula et al. (2003).

While the low hardness of stichtite does not allow for its common use in jewellery, when cut as a cabochon it may be suitable for pendants and other items that receive gentle wear. Such a pendant was submitted to Stone Group Laboratories in mid-2016, in which stichtite was set with various quartz gems (Figure 23).

Figure 22: This stichtite (1.70 ct) was faceted from material that was mined in South Africa. The low lustre and rounded facet junctions visible at the lower right are consistent with the low hardness of stichtite. Gift of Mauro Pantò; photo by C. Williams.

Figure 23: This pendant containing a 13 × 18 mm-wide cabochon of stichtite was submitted to Stone Group Laboratories in mid-2016. It also is set with pale amethyst, CVD-coated colourless quartz and black onyx, in sterling silver. Photo by B. Williams.

Cara Williams FGA, Bear Williams FGA and Brendan M. Laurs FGA

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DIAMONDS

A Zoned Type IaB/IIa Diamond of Probable 'Superdeep' Origin

Few zoned-type diamonds have been documented, and most are type IIa/IIb (see, e.g., Reinitz and Moses, 1993; Hall and Moses, 2000; Breeding, 2005; Chadwick, 2008). Sunagawa (2001) illustrated a positive image of micro-diamonds on a photographic plate exposed to 253.7 nm (short-wave UV) radiation, and reported that the black-appearing stones corresponded to type IaA diamond (opaque to SWUV), the transparent ones to type II (transparent to SWUV) and the grey samples to mixed types I and II. However, no additional spectroscopic investigations were done on those zoned-type diamonds to confirm their nature.

The Laboratoire Français de Gemmologie (LFG) in Paris recently examined a notable zoned-type 7.28 ct round brilliant diamond. It was graded K colour and VS_2 clarity due to clouds that extended through two-thirds of the stone (Figure 24). The portion that was free of clouds was situated near the culet. Observation of the diamond between crossed polarizing filters revealed parallel graining in most of the sample (Figure 25), while a 'tatami' pattern was seen in the area near the culet. The latter pattern is specific to type II diamonds. The two portions of the sample also differed in luminescence with the DiamondView. A dislocation network typical of type II diamond was visible near the culet, while yellow-emitting graining was seen on a background of blue luminescence in the rest of the stone. The difference in plasticity between the two zones could be seen near their contact (Figure 26); the absence of graining in the type II portion caused it to appear less 'rigid' than its counterpart.

The infrared spectrum taken in transmission through the girdle of the stone showed the presence of type IaB diamond with hydrogen. Photoluminescence spectra taken with 325 and 514 nm excitations at liquid-nitrogen temperature showed marked differences between the two zones (Figure 27). The type IIa zone contained more N-V and GR1 defects than the type IaB zone. In addition, the IaB zone contained 536 and 576 nm defects, which are linked to B-aggregates. The 491 nm centre was detected in the same region, and is often observed in plastically deformed diamonds with the 406 and 423 nm centres (also present here; cf. Collins, 2001; Nadolinny et al., 2009).

This is the first time that a diamond composed of a mixture of types I and II has been documented at LFG. However, Dr Ulrika D'Haenens-Johansson of the Gemological Institute of Amer-

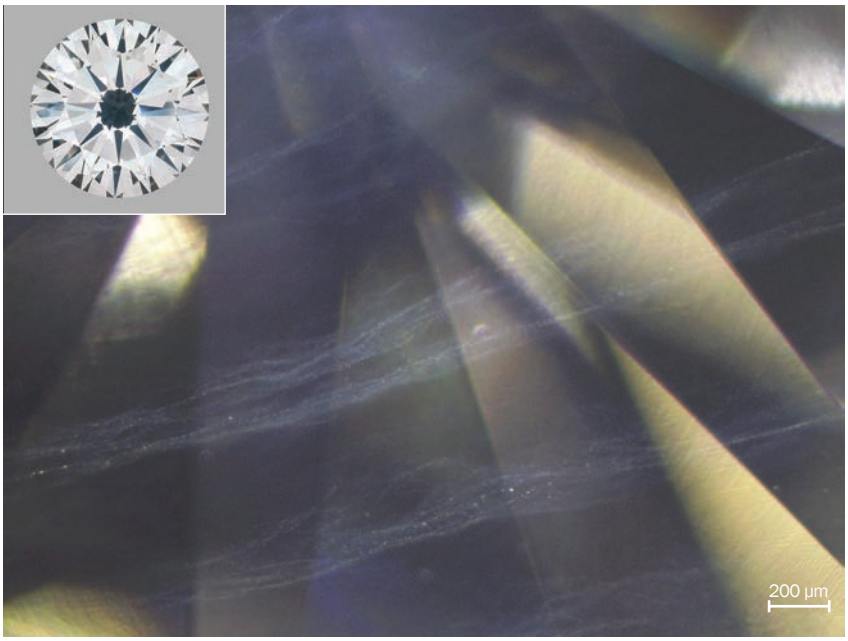

Figure 24: The 7.28 ct diamond (see inset) contains clouds that account for its VS_2 clarity; they are restricted to the type IaB zone of the stone. Photomicrograph by A. Delaunay, © Laboratoire Français de Gemmologie.

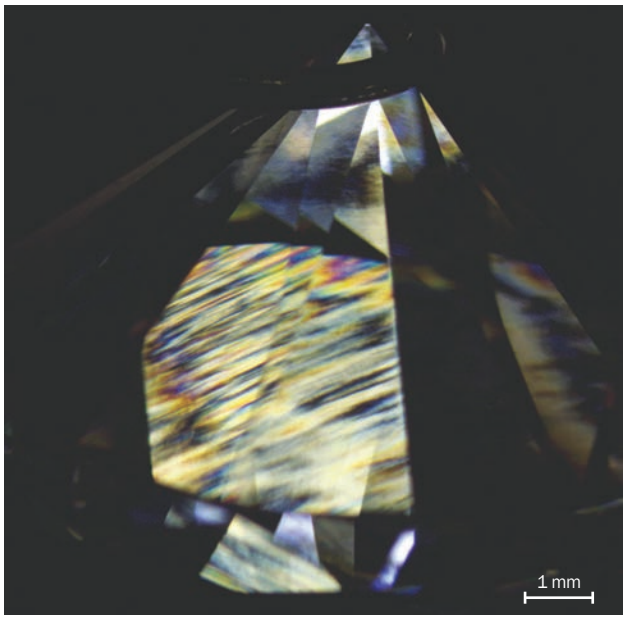

Figure 25: A sharp contrast in anomalous birefringence is seen between the main portion of the diamond, which exhibits parallel graining, and the culet area of the stone. Photomicrograph by A. Delaunay, © Laboratoire Français de Gemmologie.

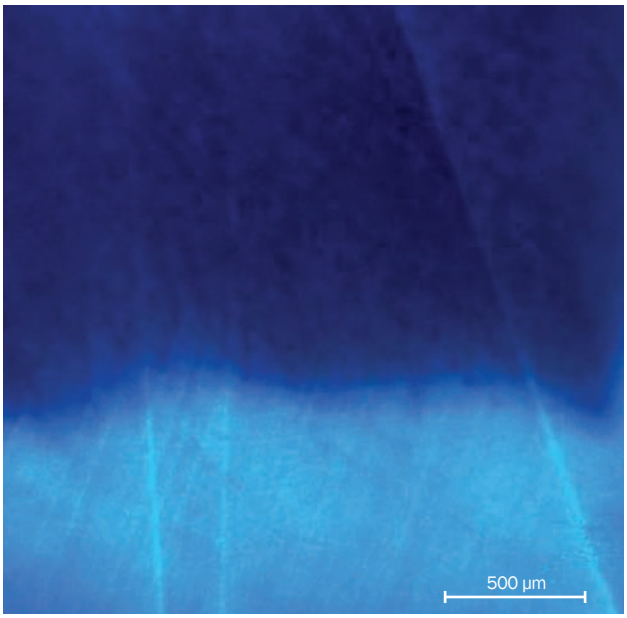

Figure 26: The DiamondView image of the contact between the type IaB and IIa zones of the diamond illustrates how the graining seen in the type IaB portion (bottom) seems to dissolve into the type IIa zone (top). Image by A. Delaunay, © Laboratoire Français de Gemmologie.

ica's New York laboratory indicated to these authors that she has encountered such zoning two or three times (pers. comm., October 2016), but since they were client stones, there was no time for a detailed study. The presence of such zoning proves that the formation conditions of type IIa and IaB diamonds may be similar, such that they can occur in a single crystal. This is also consistent with correlations in the behaviour of type IIa and IaB diamonds, for example, in terms of UV transparency and high-pressure, high-temperature treatment (the rare type IaB diamonds are transparent to SWUV and can be HPHT treated to improve their colour; Deljanin and Fritsch, 2001). Furthermore, the association of type IaB diamond with low-nitrogen type IIa

Figure 27: Liquid-nitrogen temperature photoluminescence spectra of the two zones of the diamond with 325 and 514 nm laser excitation show that the type IaB zone contains numerous defects, such as the 406.2 nm, N3 (415 nm), 491 nm, H4 (496.1 nm), 536 nm, 576 nm, 612 nm and a very weak GR1 (741 nm) centre, whereas the type IIa zone contains only very weak emissions of the N3, H4 and H3 (503.3 nm) centres, a trace of the GR1 (741.3 nm) defect, weaker emissions of the 536 and 612 nm centres, and N-V$^-$ and N-V^0 features (637 and 575 nm, respectively).

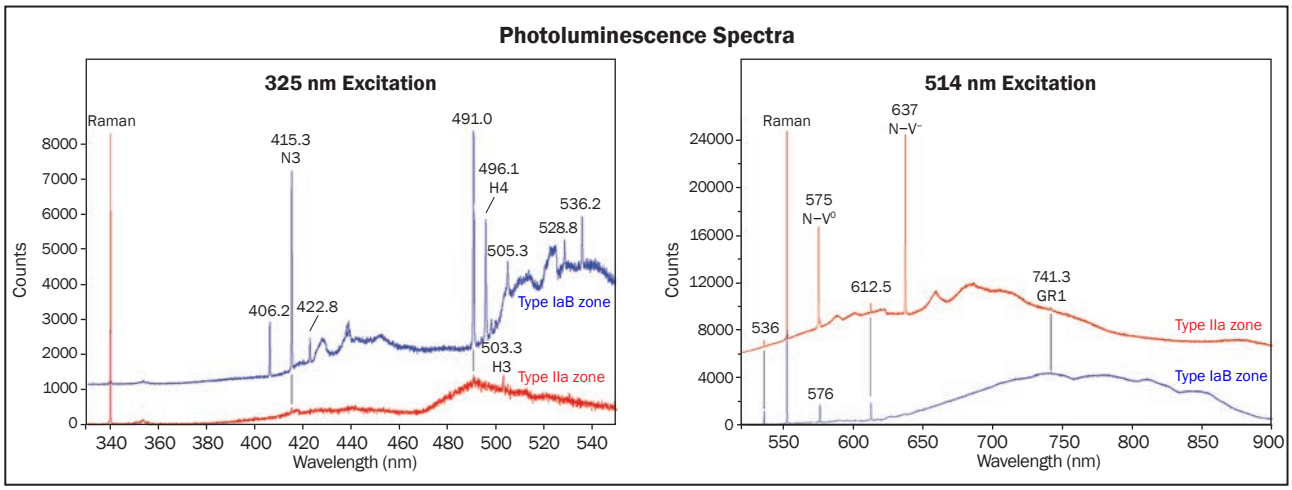

diamond showing a high level of nitrogen aggregation, formed under high pressure and temperature conditions, is consistent with 'super-deep' diamonds—those derived from the base of the lithosphere down to about 600 km (see, e.g., Burnham et al., 2016)—rather than about 150 km, where most diamonds form.

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SYNTHETICS

Synthetic Star Ruby with an Unusual Production History

The process for manufacturing synthetic asteriated ruby and sapphire was invented by researchers J. N. Burdick and J. W. Glenn in the late 1940s and was patented by the Linde Air Products Company (Schmetzer et al., 2015). Grown by the Verneuil technique, early samples frequently showed—after annealing to form rutile precipitates—an inhomogeneous distribution of colour and inclusions between the cores and the rims of the boules. In such samples, this zoning of colour and rutile precipitates often caused the resulting six-rayed stars on their surface to appear broken or partially absent in areas where the zoning had depleted the cabochon of titanium (Schmetzer et al., 2015).

In examining historical samples of synthetic asteriated corundum from various collections, one of the authors (KS) recently observed a synthetic star ruby that likewise displayed pronounced zoning but which differed from the more common scenario just described. The sample had been kept in the teaching and reference collection of author LR for several decades, but the original producer is unknown. The cabochon, weighing 4.20 ct, was examined with fibre-optic illumination and in immersion in transmitted light using a gemmological microscope (up to 100× magnification), and at higher magnification (up to 1,000×) with a Leitz Ortholux II Pol-BK polarizing microscope.

In reflected light, the sample showed a typical six-rayed star on its surface and displayed a rather milky appearance (Figure 28a). Conversely, the base of the cabochon consisted entirely of transparent synthetic ruby material, without any milkiness (Figure 28b). Between crossed polarizers and in a view parallel to the optic axis (i.e. approximately perpendicular to the base of the cabochon), the

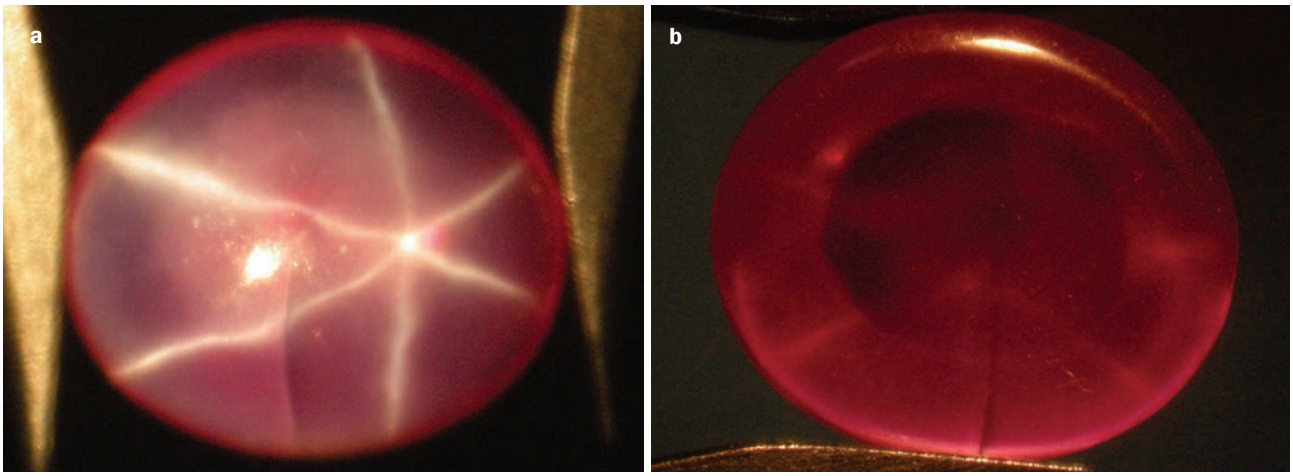

Figure 28: This 4.20 ct synthetic star ruby is shown in two views: (a) toward the milky, translucent dome of the cabochon, and (b) toward the transparent base of the cabochon. The photo of the dome side is focused slightly above the cabochon's surface, where the star appears sharpest. Fibre-optic illumination; photos by K. Schmetzer.

sample showed a series of parallel striations, referred to as 'Plato lines' in gemmological literature (Figure 29). These striations represent glide planes parallel to the second-order hexagonal prism $\{11\bar{2}0\}$ and are caused by internal stress generated during the Verneuil process used for crystal growth.

In views nearly parallel to the base of the cabochon, it became apparent that the sample consisted of two principal parts. The outer portion, comprising the dome of the cabochon, showed a curved structure of sequential shell-like layers. These layers generally followed the external form of the dome. In contrast, the central part of the cabochon, including the central part of the base, revealed curved growth striations that were oblique to the boundary between the core and rim of the sample (Figure 30). Within the rim, but close to the core of the sample, an almost opaque zone with a high concentration of inclusions, mostly in the form of non-transparent, irregularly shaped particles, was present. A further inclusion feature was a fracture that extended through the cabochon from the base to the dome.

At higher magnification, three sets of needle-like precipitates, forming angles of 60° with one another, were visible in the milky rim (Figure 31). The transparent red core was free of such needles.

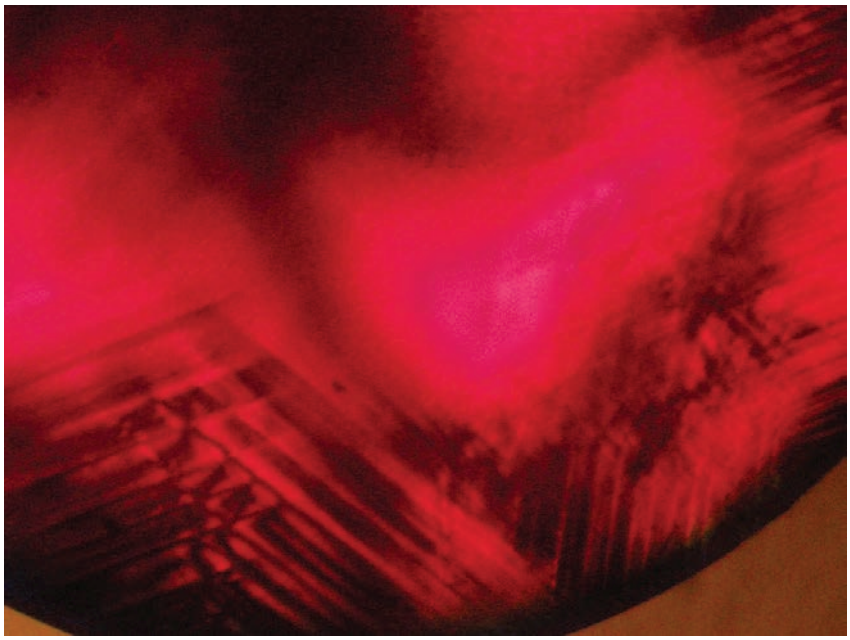

Figure 29: Between crossed polarizers, three series of parallel striations are visible in a view parallel to the optic axis of the synthetic star ruby. These striations (Plato lines) represent glide planes parallel to the second-order hexagonal prism. Immersion, field of view 4.6 × 3.4 mm; photomicrograph by K. Schmetzer.

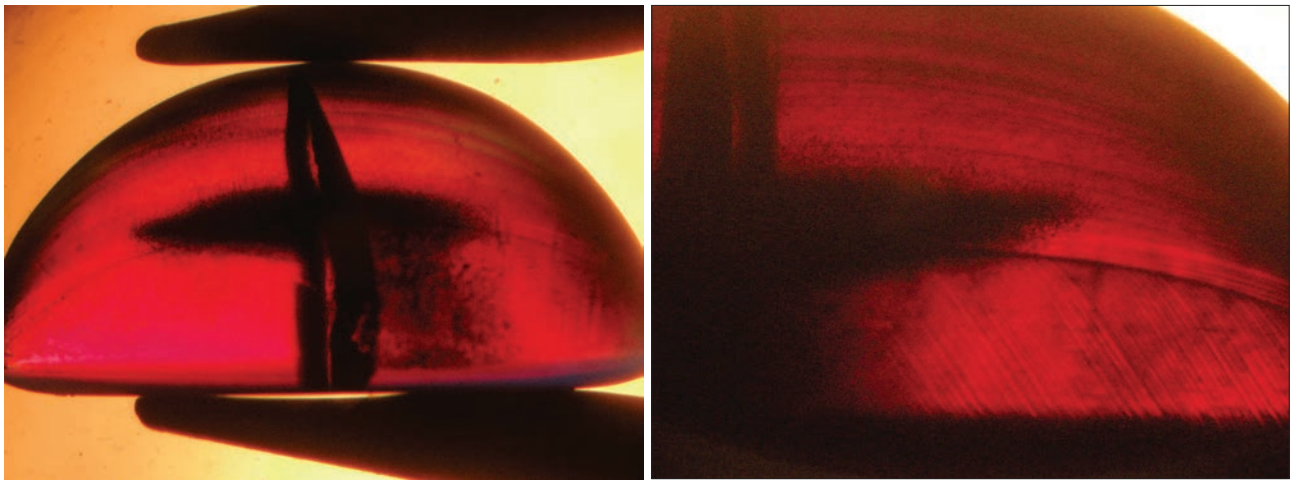

Figure 30: In these views nearly parallel to the base of the synthetic ruby cabochon, the sample can be seen to consist of two principal parts: a Verneuil-grown core of transparent synthetic ruby without rutile needles, and a Verneuil-grown somewhat milky rim of synthetic ruby containing rutile precipitates. In the rim, shell-like layers approximately follow the external form of the cabochon; in the core, curved Verneuil striations are oriented obliquely to the core-rim boundary. Within the rim, close to the core, an almost opaque zone with a high concentration of inclusions is seen. In addition, a fracture runs vertically through the stone. Immersion, field of view 8.8 × 6.5 mm (left) and 7.8 × 5.9 mm (right); photomicrographs by K. Schmetzer.

The foregoing observations thus established that production of this star sample began from a cabochon of transparent Verneuil-grown ruby. That cabochon was used as a seed for the growth of a Verneuil crystal with high Ti concentration, thereby enabling formation of rutile precipitates upon subsequent annealing. Such an approach is analogous to the classical method for manufacturing star corundum, but normally small seeds of oriented natural or synthetic ruby or sapphire are used. The small seeds are then removed when asteriated cabochons were cut for jewellery purposes.

Figure 31: Three sets of rutile needles in the synthetic star ruby cabochon are responsible for the reflection and scattering of light that generates asterism. Reflected light, oil immersion, field of view 92 × 69 µm; photomicrograph by H.-J. Bernhardt.

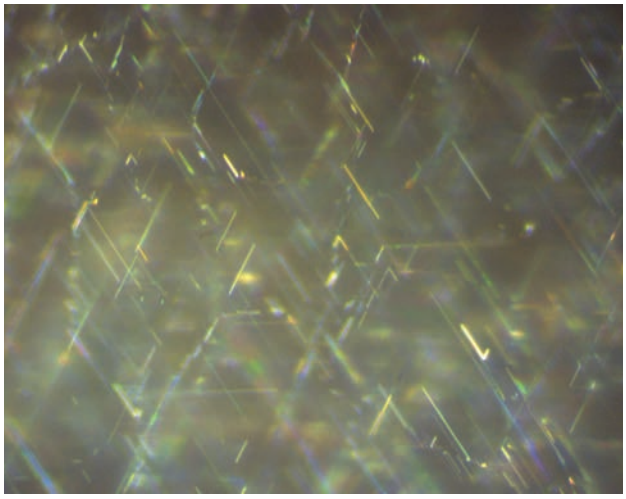

Oriented seeds are necessary for control of crystal orientation in the Verneuil process, a particularly important factor when the aim is to produce star material. This technique was invented independently in Germany and in the United States in the 1940s (see again, Schmetzer et al., 2015). Without such oriented seeds, the orientation of the Verneuil-grown synthetic ruby and sapphire crystals is unpredictable, and consequently, each crystal must be individually examined to find the optic axis for cutting cabochons with well-centred stars.

In the present case, use of a synthetic ruby cabochon for the seed also explained the high concentration of non-transparent, irregularly shaped inclusions near the boundary between the core and rim portions. These inclusions were trapped at the dome of the seed cabochon at the beginning of crystal growth, before more stable growth conditions were achieved.

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Synthetic Emeralds Grown by W. Zerfass: Historical Account, Growth Technology and Properties

Karl Schmetzer, H. Albert Gilg and Elisabeth Vaupel

Rough and faceted synthetic emeralds were produced by W. Zerfass in Idar-Oberstein, Germany, between 1963 and 1973. The synthesis process was developed in cooperation with the chemist G. H. Jaeger; experiments started in 1952 and led to samples of facetable size in the early 1960s. Microscopic examination and chemical analysis of rough and cut Zerfass samples indicate that crystal growth took place on oriented seed plates cut from synthetic emerald crystals within a molybdate melt. Only chromium was added to the nutrient as a colour-causing trace element. Although the growth method was similar to that developed by H. Espig in the 1930s and applied by the IG Farben company, the process used by Zerfass and Jaeger was developed independently and, contrary to certain statements in the gemmological literature, did not involve anyone who had formerly worked with Espig at the IG Farben plant in Bitterfeld, Germany.

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Introduction

In 1963, a new synthetic emerald grown by W. Zerfass in Idar-Oberstein, Germany, was introduced to the market. The production technique, however, was not disclosed. Several descriptions of the material followed shortly after its introduction (Schlossmacher, 1963; Eppler, 1964; Gübelin, 1964a,b). Schlossmacher mentioned that the samples, especially in small sizes, were of high quality, resembling Colombian emeralds in colour (e.g. Figure 1). No information was offered regarding the chemical compounds used for crystal growth, and he did not speculate as to the production technology. The latter topic was instead taken up by subsequent writers. Eppler concluded, based on the form and distribution of inclusions, that the synthetic emeralds were grown through a flux-melt process. In contrast, Gübelin assumed a hydrothermal origin, deduced from the presence of inclusions formed by tapered conical channels with small crystals attached to their wider ends (commonly called 'nail-head spicules'). Further work by E. M. Flanigen and colleagues at the Linde division of Union Carbide Corp. (Flanigen et al., 1965, 1967) then considered the available evidence, but without the benefit of directly examining samples produced by Zerfass. Comparing different types of hydrothermal and flux-grown synthetic emeralds, they noted that nail-head spicules could be formed by both growth methods,

Figure 1: Shown here are faceted and rough synthetic emeralds grown by W. Zerfass in Idar-Oberstein, Germany, in the 1960s. The faceted samples weigh 0.24–1.02 ct, and the crystals are 0.23 and 0.40 g; the faceted sample on the upper left measures 6.4 × 6.4 mm and weighs 1.02 ct. Photo by K. Schmetzer.

provided the seed plates used had been cut at an incline to the beryl crystal faces. Therefore, taking into account the relatively low SG and RI values (as reported by previous researchers), they concluded that the Zerfass synthetic emeralds had been created through flux-melt growth. However, in the absence of any published chemical data, the production method remained a matter of discussion (O'Donoghue, 1980).

In addition to the foregoing focus on the production technique, and despite the relative rarity of the material in the marketplace (see Crowningshield, 1970), details about the individuals involved were also of continuing interest. In the early papers describing the new synthetic emerald, an unnamed 'inventor' or 'co-worker' was mentioned along with Zerfass (Schlossmacher, 1963; Eppler, 1964). Later, Nassau (1976a,b) offered the following based upon an unpublished interview with Zerfass conducted by R. Crowningshield: "The Zerfass emeralds were grown for a time in small quantities by one of Espig's I.G.-Farben co-workers after he left the firm and worked for Walter Zerfass of Idar-Oberstein, Germany, from about 1964 on, undoubtedly using the I.G.-Farben process."

Given the apparent logic, the explanation offered by Nassau was widely accepted (see, e.g., Sinkankas, 1981; O'Donoghue, 2005, 2006). In addition to H. Espig, the inventor of the process for growing IG Farben AG synthetic emerald (Igmerald), there would have been a number of people involved in the routine production of Igmerald in Bitterfeld, Germany, from 1935 to 1942. Such individuals, in turn, would have had internal knowledge of the process and could have moved to West Germany after World War II.

During a recent re-evaluation of the growth process applied by IG Farben at Bitterfeld and of the properties of Igmeralds (Schmetzer et al., 2016a), the present authors also examined synthetic emeralds grown by R. Nacken in the 1920s (Schmetzer et al., 2016b) and by Zerfass. These investigations were prompted by reports that the Nacken and Zerfass material had been grown by processes similar to those used for Igmeralds and/or that various people or companies involved might have collaborated. Thus, efforts were undertaken to delve into historical facts and to correlate the properties of faceted and rough samples with knowledge about the growth techniques applied.

Collaboration by W. Zerfass and Dr G. H. Jaeger

Walter Zerfass[1] (Figure 2) was a gem cutter in Idar-Oberstein leading a small, independently owned company. His son, chemist Dr Torsten Zer-

[1] W. Zerfass (1911–1995) was trained as an agate cutter and worked in that profession in the 1920s and 1930s. He was employed first in the family firm and later, in the 1930s, founded his own company in Hintertiefenbach, now part of Idar-Oberstein, Germany. After World War II, he augmented his work by cutting and polishing hard materials for technical applications, such as jewel bearings for watches or water meters. Subsequently, in the early 1950s, he developed processes for manufacturing layered glasses used as a substitute for banded agate, leading to German patents published in 1951 and 1952. Also, in the early 1950s, Zerfass met G. H. Jaeger (see footnote 2), and the two collaborated on several projects during that era. For instance, they cooperated in developing cutting and polishing methods for technical ceramic products, an endeavour related to Jaeger's work at that time for Degussa AG. They similarly began in the early 1950s to partner on experiments for synthetic emerald growth at Hintertiefenbach. After implementing their own production process, in 1963 they presented the first synthetic emeralds resulting from these long-running efforts to the public. Other activities by Zerfass included cutting and polishing hard metal tools (e.g. knives for microtomes).

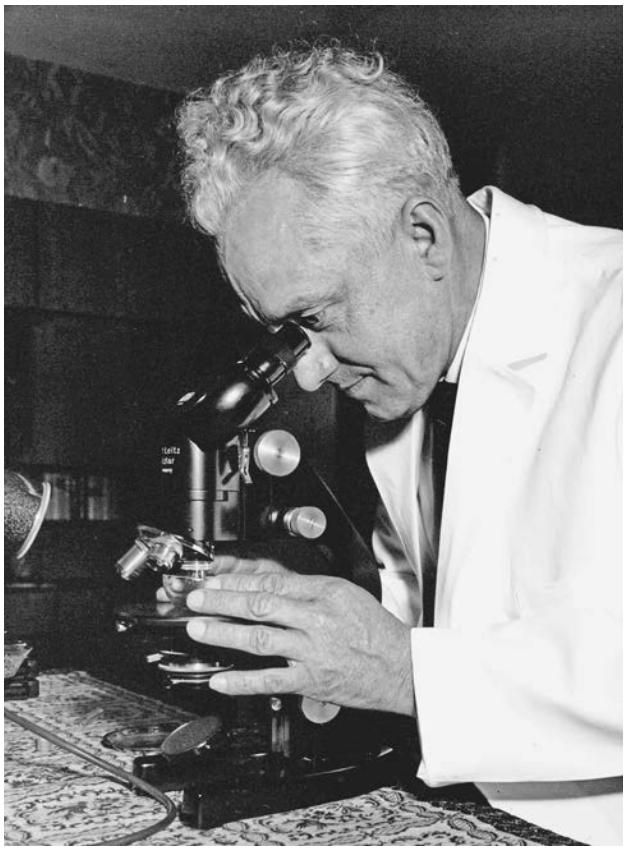

Figure 2: W. Zerfass developed a method for emerald synthesis over the course of a decade, from approximately 1952 to 1962, and presented his first faceted synthetic emeralds to the public in 1963. Production of Zerfass synthetic emeralds continued in the 1960s and early 1970s on a small scale. Photo taken in approximately 1970; courtesy of T. Zerfass.

Figure 3: Dr G. H. Jaeger, who worked with W. Zerfass in developing a synthesis technique for emerald, was an inorganic chemist involved in the 1930s with beryllium ore processing and metallurgy. Later he focused on the development and production of oxide ceramics for Degussa AG, now part of Evonik Industries AG. Photo taken in approximately 1953–1954; © Evonik Industries AG.

fass (hereinafter T. Zerfass), continues to reside in Idar-Oberstein and was interviewed by one of the authors (KS) in the course of this study. T. Zerfass identified his father's partner in developing the emerald synthesis technique as Dr Gustav Heinrich Jaeger[2] (Figure 3). Jaeger was a chemist living in Neu-Isenburg, near Frankfurt, Germany.

Zerfass and Jaeger met by chance and thereafter cooperated for approximately two decades (1952–1973) in the synthetic emerald project. Zerfass was the practical partner, building the different devices used in the experiments. Jaeger was the scientist, developing the various recipes for the fluxes and nutrients used to grow the synthetic emeralds (T. Zerfass, pers. comm., 2015, 2016).

Corroborating this association, an internal document from the Walter Zerfass gem-cutting company, dated 1971, also named Jaeger as a partner in developing the process for synthetic emerald growth (D. Jerusalem, pers. comm., 2015).

[2] G. H. Jaeger (1901–1974) studied natural sciences, especially chemistry, at the University of Frankfurt, Germany, from 1920 until graduating in 1924 with a dissertation on the analytical chemistry of nitrogen-bearing compounds. In the curriculum vitae accompanying his thesis, he mentioned R. Nacken as one of his academic advisors. Nacken and Jaeger also collaborated in the mid-1920s in Frankfurt, and filed a patent application dealing with improvements to gemstone synthesis by the Verneuil technique. Based on this invention, German and British patent documents by Nacken et al. were published in 1926 and 1927. Jaeger joined Degussa AG (**De**utsche **G**old- **u**nd **S**ilber-**S**cheide**a**nstalt, now part of Evonik Industries AG) in Frankfurt in 1928, and eventually he left the company in 1959 because of health problems. From 1932 to 1938, he led operations at the branch of the company responsible for beryllium metallurgy and technology. Later he headed production at Degussa of various technical ceramics, such as the so-called 'Degussit'. Numerous German and international patents involving beryllium refinement and technology, dated in the 1930s and 1940s, named Jaeger as the inventor. From his involvement with Degussa, he developed extensive expertise in the fields of beryllium chemistry and the processing of Be minerals.

Materials and Methods

The present study is based on the examination of five faceted samples (0.24–1.02 ct) and two crystals (0.23 and 0.40 g) of Zerfass synthetic emeralds. Four samples came from the reference collection of the German Gemmological Association, Idar-Oberstein, and three were loaned by T. Zerfass.

Refractive indices were measured on the faceted synthetic emeralds using a Topcon refractometer, and the SG values of all seven rough and faceted samples (e.g. Figure 1) were measured hydrostatically. All samples were examined with a gemmological microscope (magnification up to 100×), with and without immersion; also used was a Leica DM LM polarizing microscope, with a transmitted light source and magnification up to 1,000×. Photographic documentation of inclusions at high magnification was accomplished with an Olympus DP25 digital camera with Olympus Stream Motion software (version 1.6.1).

All seven Zerfass synthetic emeralds were chemically analysed by energy-dispersive X-ray fluorescence (EDXRF) spectroscopy using a Bruker Tracer III-SD portable unit equipped with an Rh anode (40 kV, 30 µA), a yellow filter (12 mil Al + 1 mil Ti) and a 10 mm² peltier-cooled XFlash SDD system. The counting time was 30 s.

Results

Crystal Morphology

Of the two crystals examined (Figure 4), the larger one showed a short prismatic to thick tabular habit consisting of a 12-sided prism and two basal faces. First- and second-order hexagonal prisms **m** $\{10\bar{1}0\}$ and **a** $\{11\bar{2}0\}$ were present in combination with the basal pinacoid **c** {0001}. Tiny polycrystalline material, most likely small synthetic emerald crystals grown by spontaneous nucleation, covered the prism faces. A groove traversed all prism faces, encircling the crystal (Figures 4 and 5).

The smaller crystal also had a short prismatic form, with six dominant prism faces and one basal pinacoid. The six-sided prism also showed some smaller additional prism faces that would correspond to a 12-sided prism if fully developed. The prism faces were again covered with small prismatic synthetic emerald crystals (Figure 6), but these were somewhat larger than those seen on the other rough sample. Likewise present was a deep groove surrounding the crystal, as also seen in the larger crystal (see again Figure 4). The smaller sample, however, had been sawn at a short distance from the groove, presumably to remove half of the piece for cutting.

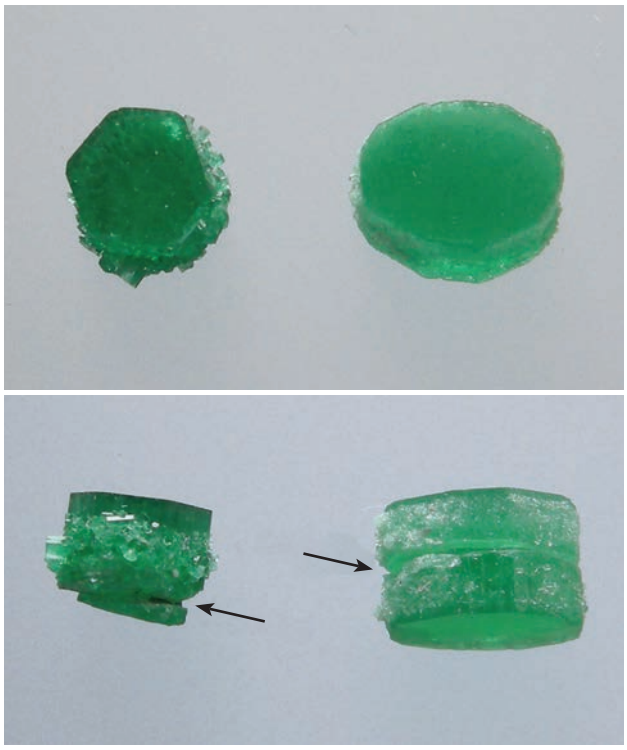

Figure 4: These two Zerfass synthetic emerald crystals were grown using small seed plates of synthetic emerald that were suspended with gold wires in a special holder within a lithium molybdate flux. After the gold wires were removed from the crystals, grooves where the wires originally rested remained on the surface of the crystals (see arrows); the lower half of the left crystal was sawn off for cutting purposes. Views are shown almost parallel to the c-axis of the crystals (above) and almost perpendicular to the c-axis (below). The left crystal measures approximately 6.0 mm in diameter on the basal face and 4.6 mm along the c-axis, and it weighs 0.23 g; the right crystal measures about 6.8 × 5.7 mm on the basal face and 4.8 mm along the c-axis, and it weighs 0.40 g. Photos by K. Schmetzer.

Gemmological Properties

The synthetic emeralds were slightly bluish green in colour, displaying pleochroism of blue-green parallel to the c-axis and green to slightly yellowish green perpendicular to the c-axis. The RIs of the faceted samples ranged from 1.558 to 1.559 for n_e and from 1.562 to 1.563 for n_o, with a birefringence of 0.004. The SG values were between 2.65 and 2.66. These data are consistent with information generally reported for flux-grown synthetic emerald from various produc-

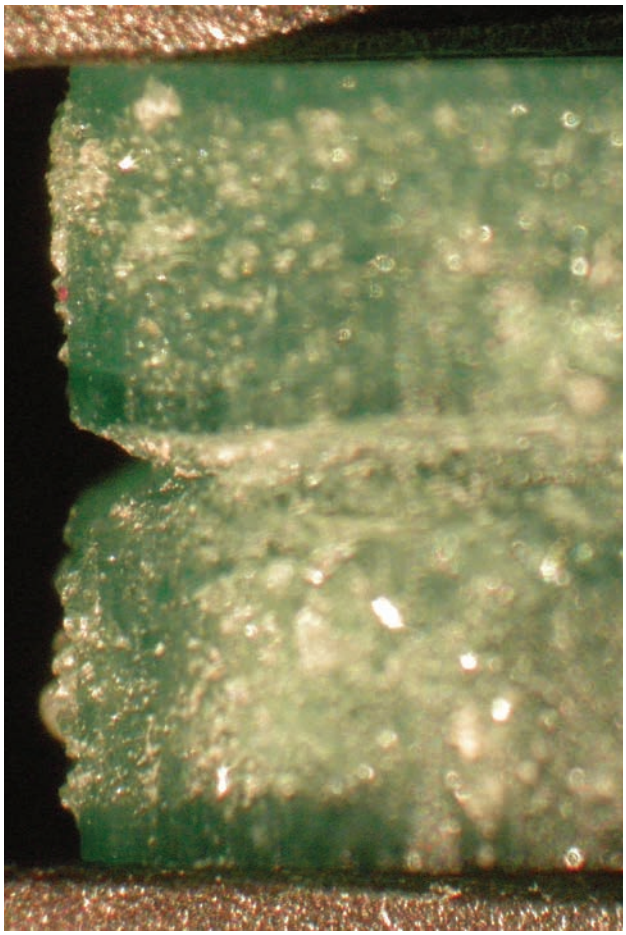

Figure 5: The larger Zerfass synthetic emerald crystal is viewed here perpendicular to the c-axis. The prism faces are covered with tiny synthetic emerald crystals. The groove in the centre circumscribing the prism faces was left by a gold wire; the wire had been used to suspend a small seed plate of synthetic emerald in the lithium molybdate flux. The c-axis runs vertically, and the length of the crystal along the c-axis is 4.8 mm. Photomicrograph by K. Schmetzer.

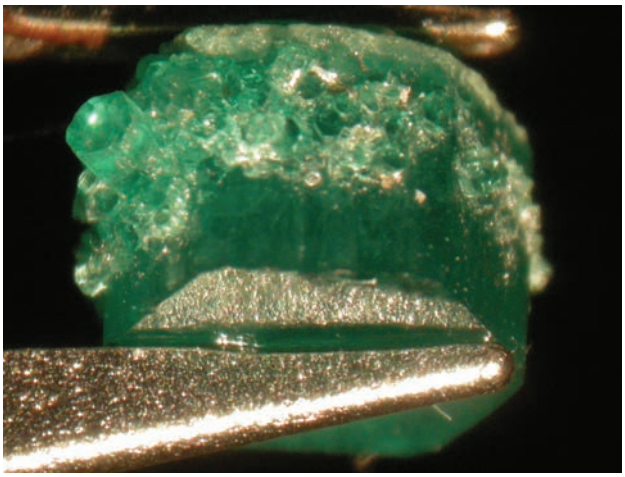

Figure 6: The smaller Zerfass synthetic emerald crystal is viewed here almost perpendicular to the c-axis. The prism faces are covered with small prismatic synthetic emerald crystals. The c-axis is almost vertical, and the length of the crystal along the c-axis is 4.6 mm. Photomicrograph by K. Schmetzer.

ers (see, e.g., Flanigen et al., 1967; Sinkankas, 1981; Henn, 1995).

When the crystals and cut samples were viewed parallel to the c-axis with a microscope, a cellular pattern of residual flux was observed (e.g. Figure 7). This created a honeycomb-like structure formed by residual flux concentrated along planes running through the synthetic emeralds in a direction parallel to the c-axis. When examined in immersion (Figure 8), the three-dimensional extension of the honeycomb pattern was evident. The individual cells of the pattern varied from nearly hexagonal to completely ir-

Figure 7: A cellular web-like pattern of residual flux is seen parallel to the c-axis of the Zerfass synthetic emerald crystals. The samples have diameters of approximately (a) 6.0 mm and (b) 6.8 × 5.7 mm. Photomicrographs by K. Schmetzer.

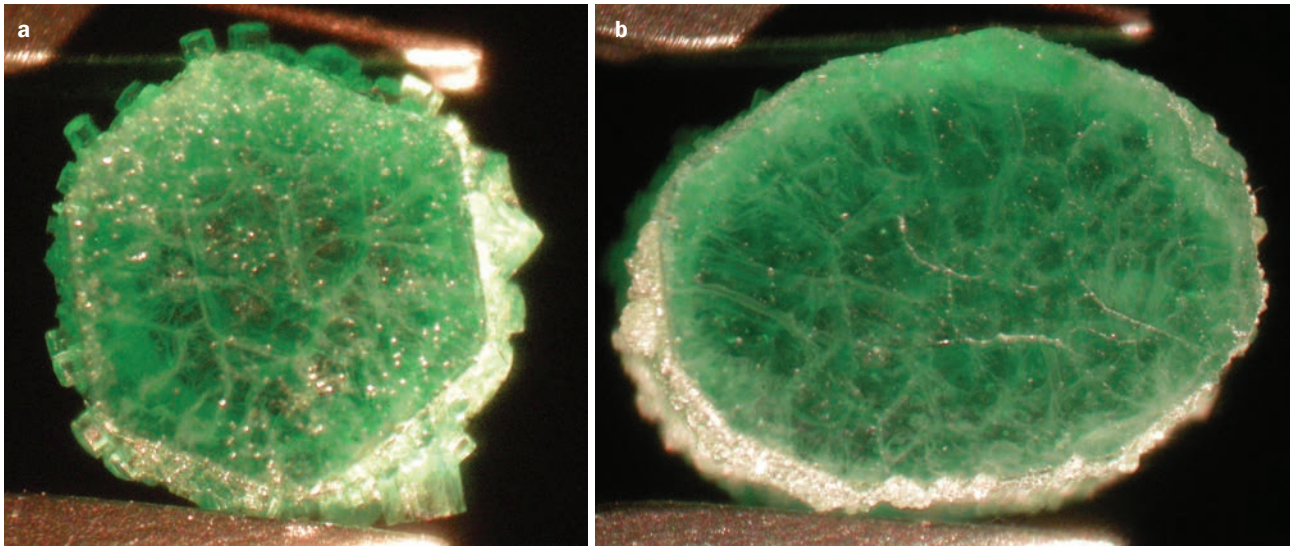

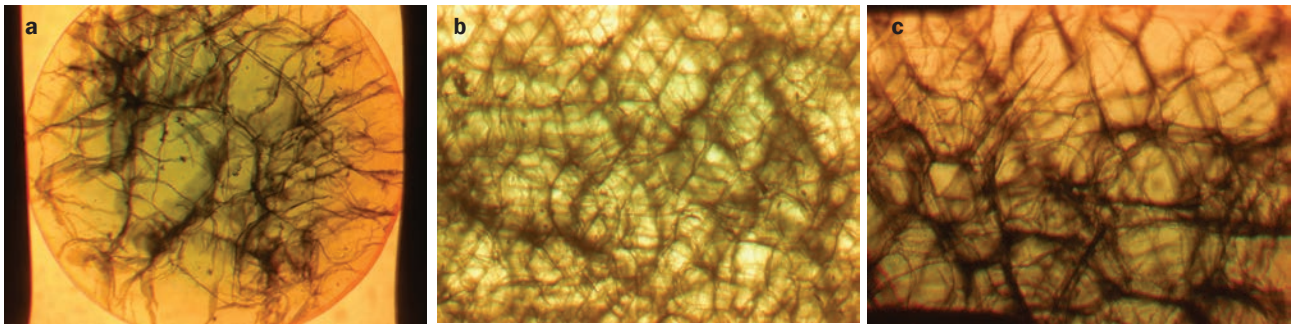

Figure 8: Cellular honeycomb-like structures are formed by residual flux concentrated on planes traversing the synthetic emeralds in a direction parallel to the c-axis. Such structures were seen in all the faceted Zerfass synthetic emeralds, with the cells forming patterns that show a variety of sizes and shapes. Immersion; view parallel to the c-axis; field of view (a) 4.6 × 3.5 mm, (b) 3.5 × 2.6 mm and (c) 3.2 × 2.4 mm; photomicrographs by K. Schmetzer.

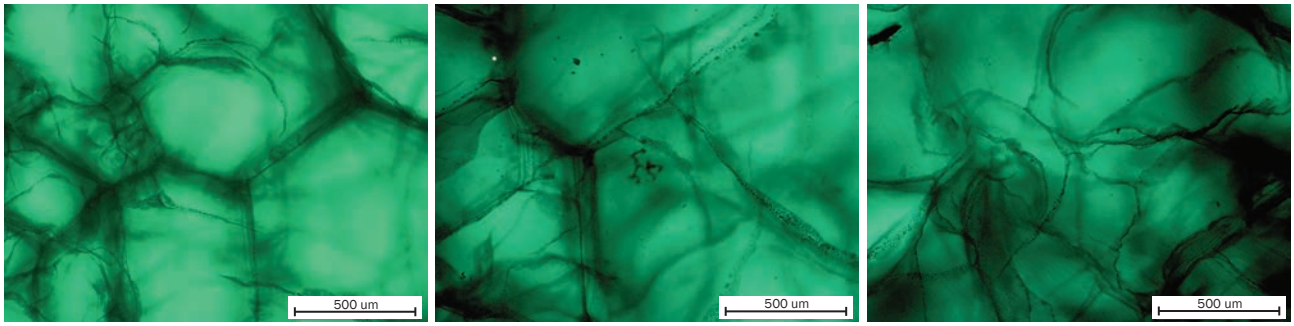

Figure 9: These images show details of the honeycomb-like structures observed in the Zerfass synthetic emeralds. These patterns are formed by tiny flux particles concentrated in various forms, ranging from almost planar faces running parallel to the c-axis to wispy veils with an entirely irregular arrangement. Transmitted light; view parallel to the c-axis; photomicrographs by H. A. Gilg.

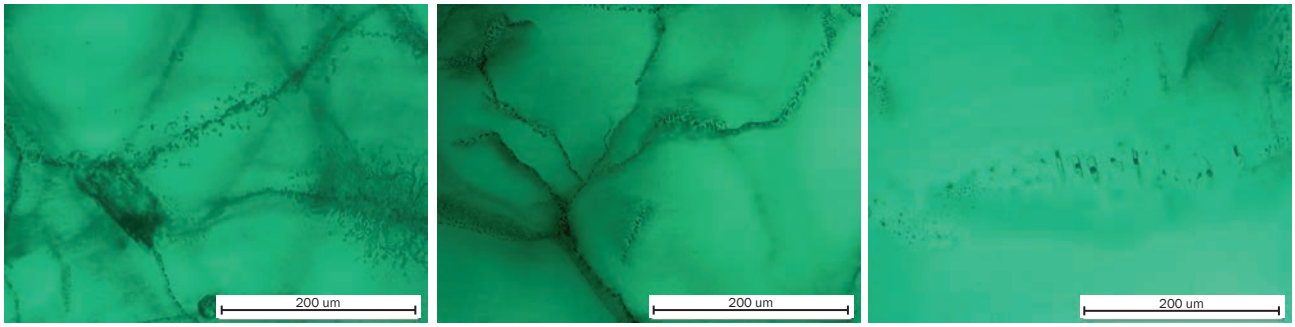

Figure 10: At higher magnification, the tiny particles of residual flux in the Zerfass synthetic emeralds are shown to be formed by two-phase inclusions consisting of contraction bubbles and various components of the flux. Transmitted light; photomicrographs by H. A. Gilg.

regular in shape (Figure 9). At higher magnification, the tiny particles of residual flux that formed the pattern could be resolved (Figure 10), and minute two-phase inclusions (residual flux with contraction bubbles) were frequently apparent.

When the rough and faceted samples were viewed perpendicular to the c-axis, a layered structure was observed with distinct boundaries that were more-or-less parallel to the basal plane (Figure 11). The boundaries were not always exactly planar and could even be slightly inclined to one another. Strong colour zoning was observed between the different growth layers. The honeycomb pattern of six-sided to irregularly shaped cells formed by particles of residual flux caused the two crystals and some of the faceted samples to appear only translucent when viewed perpendicular to the c-axis (again, see Figure 11), notwithstanding their rather good transparency when viewed parallel to the c-axis.

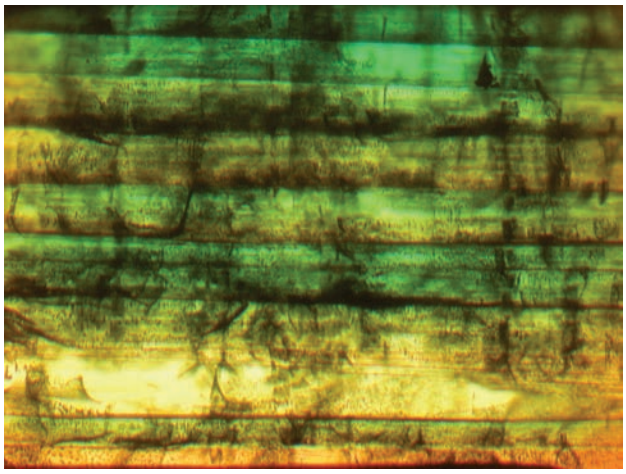

Figure 11: Growth zoning combined with colour zoning is seen parallel to the basal pinacoid in a faceted Zerfass synthetic emerald. Immersion; view perpendicular to the c-axis, with the c-axis vertical; field of view 3.9 × 2.9 mm; photomicrograph by K. Schmetzer.

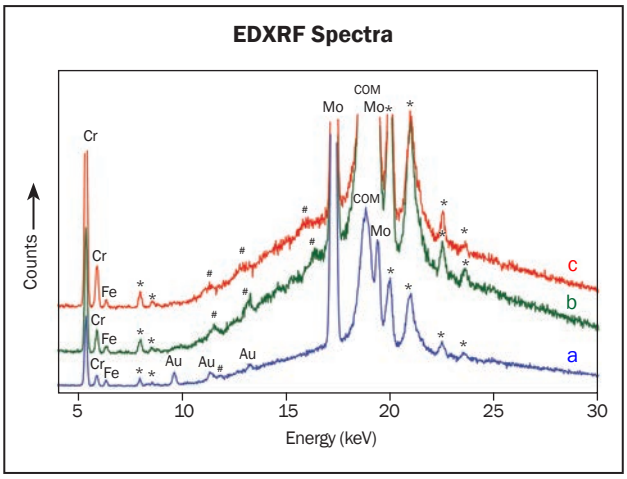

Figure 12: EDXRF spectra of Zerfass synthetic emeralds are shown for: (a) a crystal with the X-ray beam directed toward the prism faces, (b) the same crystal with the X-ray beam directed toward a basal face and (c) a faceted sample. The spectra indicate Cr as the main colour-causing trace element, with traces of Fe, and also Mo as the main component of the flux. In addition, the lower spectrum (a) shows signals for Au, derived from a gold wire (now removed) that was originally used to suspend the seed plate for crystal growth. The peaks labelled with an asterisk (*) are related to the X-ray tube (Rh) or to interactions with the instrument (Pd, Cu and Zn). Diffraction peaks are labelled #, and COM refers to the inelastic scattering of the incident radiation (Compton scattering).

Chemical and Spectroscopic Properties

The trace elements revealed by EDXRF spectroscopy showed a homogeneous pattern in all seven samples (e.g. Figure 12). Chromium was the main colour-causing trace element, with small traces of Fe also present. No V or Ni was detected.

Molybdenum peaks in the EDXRF spectra indicate that the synthetic emeralds were grown from a Mo-bearing flux. Unexpectedly, characteristic X-ray lines for Au were recorded for both rough samples, but only when analysed with the X-ray beam aimed toward the prism faces and incorporating the surface grooves. Gold was not detected when the beam was directed toward the basal faces of the two crystals, nor was it found in any of the faceted samples.

Ultraviolet-visible absorption spectra of several previously examined Zerfass synthetic emeralds (unpublished data of author KS) showed the typical Cr^{3+} spectrum of emerald without any remarkable features. This is consistent with chemical data of the present study, showing Cr as the dominant colour-causing trace element.

Discussion and Conclusions

Connections Between IG Farben and Zerfass

Although similarities might exist between the process used by IG Farben for growing synthetic emerald and the method later employed by Zerfass and Jaeger, all historical evidence indicates that technical developments made by the latter team occurred independently. No person from the IG Farben staff involved either in developing the Igmerald growth process (from 1929 to 1935) or in subsequently producing Igmeralds at Bitterfeld (from 1935 to 1942) could be identified as a potential co-worker of Zerfass. While documentation does show that G. H. Jaeger had contact with Nacken during his years in Frankfurt in the 1920s, no such connections to IG Farben staff members at Bitterfeld have been demonstrated.

Nonetheless, consideration of the existing facts suggests a possible explanation for the erroneous information published by Nassau (1976a,b): It appears that Nassau might have misinterpreted what was said in the interview of Zerfass by Crowningshield. In the 1930s, when the breakthrough in emerald synthesis at Bitterfeld was announced (see Jaeger and Espig, 1935), Dr Max Jaeger was the director of the IG Farben chemical plant, including the gemstone branch at Bitterfeld. The first description of the 'German synthetic emerald' by the Gemological Institute of America (Anonymous, 1935) likewise mentioned the names 'Jaeger' and 'Espig'. Thus, operating on the premise that the name Jaeger was given correctly

by Zerfass to Crowningshield, we might conclude that a conflation of family names could have led to the now largely discredited assumptions.[3]

Production Technology

From the results described above, it can be concluded that the production process applied by Zerfass in Idar-Oberstein, which he developed between 1952 and 1963 together with Jaeger, was based on flux-growth technology. Given the outcome of our examinations, we could establish that synthetic emerald plates sliced parallel to the basal face were used as seeds and suspended in a Mo-bearing flux for crystal growth. The combination of the grooves seen traversing the prism faces of the crystals and the traces of gold detected by EDXRF spectroscopy indicate that circumscribing gold wires were used to suspend the seed plates in the flux. With that technique, the crystals could grow freely in both directions parallel to the c-axis of the crystal, but only limited growth was observed perpendicular to the c-axis. The only colour-causing trace element identified was chromium. The growth zoning parallel to the basal face suggests that several interruptions took place in the growth process.

All of the foregoing conclusions drawn from observations of the rough and faceted samples were confirmed by T. Zerfass, who has in-depth knowledge about the growth technology applied by his father and developed together with Jaeger. T. Zerfass also added further details about the growth process, as revealed in the following paragraphs, many of which were not deducible directly from the samples themselves.

Similar to the IG Farben process, crystal growth was performed in platinum crucibles, with the nutrient subdivided into two parts. Compounds of Al, Be and Cr were placed in the bottom of the crucible, and natural quartz crystals floated on top of the lithium molybdate melt. No colour-causing trace elements other than Cr (such as V or Ni) were ever added by Zerfass and Jaeger to the nutrient. The method did not involve the use of a temperature gradient within the crucible. The first experiments, performed in about 1952–1953, started by reproducing the emerald synthesis described by French scientists in the late 19th century (Hautefeuille and Perrey, 1888, 1890). By 1956, Zerfass and Jaeger had altered their process to one that involved using seed plates and separating the nutrient into two components, with quartz floating on top of the lithium-molybdate melt. Notably, they made these adjustments independently of other scientists dealing with emerald synthesis who adopted similar approaches, such as those formerly at IG Farben in Bitterfeld.[4]

A special holder for the suspended seed plates was placed between the ingredients at the bottom of the crucible and the quartz floating on top of the melt. During early experiments, natural aquamarine or natural emerald was used to make seed plates. Such samples were not examined in the present study, but a Zerfass synthetic emerald described by Gübelin (1964a,b) containing nailhead spicules may represent this early work. The primary production of the 1960s and 1970s, however, was performed using oriented seeds cut from synthetic emerald crystals obtained in the earlier growth experiments. With the crucible arrangement mentioned, especially the orientation and suspension of seed plates, crystal growth was mainly in a direction parallel to the c-axis. A special furnace was used that was able to heat several platinum crucibles at the same time.

In contrast to the IG Farben process, in which nutrient was added to the bottom of the crucible every 2–3 days, the Zerfass process was performed without interruption for a period of about 2–3 weeks. Only then were the synthetic emeralds temporarily removed, and another run with additional flux and nutrient was prepared. This separation of the growth process into 2- to 3-week intervals was reflected in the zoning of the synthetic

[3] Since Dr M. Jaeger (1869–1938) and Dr G. H. Jaeger (1901–1974) were both born in the city of Frankfurt on the Main, the authors initially wondered whether they could be related (e.g. father and son or uncle and nephew). However, investigations of various birth registers preserved at the Institut für Stadtgeschichte in Frankfurt failed to reveal any such familial relationship. Thus, there remains no proven connection, either professional or familial, between these two chemists involved in the development of emerald synthesis.

[4] Because Zerfass and Jaeger started their work by following the techniques described by Hautefeuille and Perrey (1888, 1890), rather than by undertaking experiments based on the successful work by Nacken (T. Zerfass, pers. comm., 2016), it is unlikely that Jaeger had obtained any information regarding Nacken's emerald synthesis experiments of the mid-1920s. Nonetheless, it is possible that Nacken could have shown Jaeger examples of those flux-grown crystals. (For more details about Nacken's work, see Schmetzer et al., 2016b.)

emeralds parallel to the basal faces. A proprietary technique was used to avoid variable concentrations of Cr in the melt within a single growth cycle. In the final years of their partnership, Zerfass and Jaeger also performed experiments aimed at reducing the concentration of trapped flux particles and obtaining larger and cleaner material.

Hence, the chronological history of the Zerfass production can be summarized as follows. Experiments in crystal growth took place from approximately 1952 to 1962, and the first faceted synthetic emeralds were presented to the public in 1963. Production continued on a small scale during the 1960s and early 1970s, and then terminated in ~1973.

Comparison of the Processes Used for Emerald Synthesis by Nacken, Espig (IG Farben) and Zerfass

The historical development of flux-grown synthetic emerald in Germany occurred over the course of six decades and involved three principal producers: Nacken , IG Farben and Zerfass. The story can be traced from about 1910 or 1911, when a precursor company of IG Farben performed the first experiments in Bitterfeld, to 1973, when Zerfass ceased production in Idar-Oberstein.

Sources of direct information (i.e. provided by the producers) evidencing these developments is varied but limited. Certain aspects of IG Farben's process for Igmerald production were published by Espig in the early 1960s, and further information was contained in internal IG Farben reports dated 1930, 1945 and 1946, likewise penned by Espig, that have recently come to light (for details, see Schmetzer et al., 2016a). Nacken himself never published regarding his emerald synthesis, and only fragmentary accounts can be found in Allied government documents generated from 'interviews' with German scientists in 1945 and 1946 by American and British investigators after World War II (for details, see Schmetzer et al., 2016b). Zerfass also did not formally document his work, but unpublished information was disclosed to his son T. Zerfass (reported in this article).

Insights into growth technologies derived from the foregoing sources proved to be consistent with the examination of respective synthetic emerald samples. Results of the authors'

*Table I: Growth of synthetic emeralds by R. Nacken, IG Farben and W. Zerfass.**

Production	Nacken Type 1	Nacken Type 2	IG Farben	Zerfass
Reference	Schmetzer et al. (2016b)		Schmetzer et al. (2016a)	This paper
Time of production	Mid-1920s		1935–1942	1963–1973
Flux	Molybdate	Molybdate-vanadate	Molybdate	
Crucible	Gold		Platinum	
Nutrient for SiO_2	Quartz pieces, distributed in the melt		Silica plates, floating on the melt	Quartz plates, floating on the melt
Nutrients for BeO and Al_2O_3	Distributed in the melt		At the bottom of the crucible	
Chromophore(s)	Cr-bearing compound		Cr- and Ni-bearing compounds, alleged yttrium oxide	Cr-bearing compound
Type of seed	Irregularly shaped natural beryl		Synthetic emerald plate, cut parallel to the basal face	
Suspension of seed plate	No suspension, seed freely distributed in the melt		Seeds placed below platinum baffles	Seeds suspended in the melt with gold wires and an additional holder
Growth cycles	Several growth cycles		Several growth cycles of about 1 month with addition of nutrient every 2–3 days	Several growth cycles of 2–3 weeks each without addition of nutrient during the cycle

* Only the primary variants of the processes as finally developed are given. All of the techniques used a homogeneous temperature (no temperature gradient).

work on rough and faceted synthetic emeralds from all three producers are summarized in Table I. On a conceptual level, each producer employed a process for growing synthetic emerald based upon dividing the nutrient into two components. Specifically, BeO, Al_2O_3 and colour-causing ingredients were added to the melt separately from SiO_2 (quartz or vitreous silica).

All three producers started with employing natural colourless beryl as seed material, but only IG Farben and Zerfass transitioned to using synthetic emerald plates for seeds. The seeds were suspended in a molybdate or molybdate-vanadate flux, primarily in gold or platinum crucibles. For all three manufacturers, growth then proceeded through multiple cycles. In the IG Farben process, additional nutrient was added to the bottom of the crucible every 2–3 days. This method, however, had the disadvantage of frequently interrupting the process and causing different equilibria and concentrations of nutrient within the melt. Further developments instigated by Zerfass avoided this problem, but the details of the technique have not been disclosed by his son to the present authors.

Nacken and Zerfass used only Cr-bearing compounds as colour-causing trace elements. Espig, in contrast, added nickel carbonate to the melt, and this component was responsible for the desired slightly yellowish green colour of the Igmeralds, as compared to natural and synthetic emeralds without Ni. Although yttrium oxide was also added by Espig as a purported colour-causing ingredient, any potential influence on colour remains unclear; samples showing traces of Y by EDXRF spectroscopy and those without any detectable Y did not display any noticeable difference in colour. For those Nacken synthetic emeralds grown from vanadate-molybdate fluxes, V may make a small contribution to the otherwise Cr-based colour, similar to that exhibited by natural emeralds from various sources, such as those from Colombia.

With IG Farben's announcement in 1935, it became public knowledge that growing synthetic emeralds of facetable size was possible. Although details of the growth technology used by IG Farben were not disclosed until the early 1960s, the mere presentation of these first faceted samples may have stimulated interest within the research community. A similar effect was created some years later by the presentation of the first faceted synthetic emeralds produced in the USA by Chatham in the early 1940s, and any such interest would have been augmented by various discussions after 1945 involving Nacken's experiments in emerald synthesis.

These various announcements may have encouraged other researchers, such as the team working at Linde's research and development department, to grow synthetic emeralds. Being informed in principle about the success in emerald growth by IG Farben and Nacken in Germany and the production by Chatham in the USA, Zerfass and Jaeger can be seen as following the same tradition.

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The Fire Within

"For in them you shall see the living fire of the ruby, the glorious purple of the amethyst, the sea-green of the emerald, all glittering together in an incredible mixture of light."

– Roman Elder Pliny, 1st Century AD

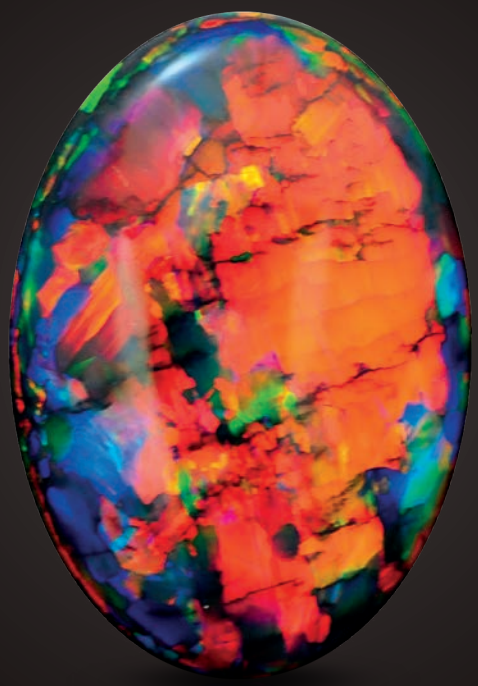

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Rethinking Laboratory Reports for the Geographical Origin of Gems

Jack M. Ogden

The proliferation of gemmological laboratory reports and the need for transparency to best protect against litigation suggest that some gem-testing laboratories should consider changes in the wording and content of their geographical origin reports. Based on the author's recent broader study of the legal aspects of the opinions provided by experts in the field of art and antiques, the main proposals presented here are that statements of opinion rather than fact should be clearly expressed as such where they are presented on a report, rather than relegating all mention of 'opinion' to the 'terms and conditions', and that the basic nature of the observational or analytical evidence on which any opinions are based should be noted. In addition, a laboratory might usefully provide some indication of the level of confidence in its opinion.

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Introduction

In a recent law journal article, the present author considered opinions in the art and antique world from a legal perspective and suggested how the rather woolly concept of 'opinions' might be made more objective and therefore more useful to those who rely on them, including the courts (Ogden, 2016). This article looks more briefly at opinions provided in gemmological testing and grading reports, and proposes some ways to improve their helpfulness and transparency. This is written from the point of view of someone with recent experience in art law[1], and who has had a long association with gem labs as an observer—from being on the committee overseeing the lab run by the Diamond, Pearl and Precious Stone Section of the London Chamber of Commerce (the forerunner of the Gem-A laboratory) in the early 1970s to being in the unenviable position of having to action the closing of Gem-A's lab in 2008 when he was CEO of Gem-A. Those wanting more of the legal background are directed to Ogden (2016).

Numerous authors in the past have considered the challenges that confront gemmological laboratories issuing reports and their need to balance scientific prudence with the demands of the gem trade, particularly with regard to geographical origin determination (e.g. Hänni, 1994; Nyfeler, 2006; Krzemnicki, 2007; Rossman, 2009). In addition, the actual processes and procedures of gem testing within a laboratory have been described at length in this and in other gemmological journals.

Origin reports have become a prominent part of the gem trade, particularly for high-end stones (e.g. cover of this issue and Figure 1). They aim to provide support for the seller and reassurance for the buyer, and, as is often observed, some gems seem to be sold as much on the basis of their accompanying paperwork as on their appearance (Figure 2). Against this background, it is timely

[1] The author has had a long-term interest in art law and was awarded a Diploma in Art Profession Law and Ethics (with distinction) by the Institute of Art Law, London, in 2014.

Figure 1: This ring with a 30.08 ct sapphire was sold at auction (Bonhams, London, 30 April 2014, lot 186) and was accompanied by three lab reports that gave two different geographical origin opinions—Sri Lanka and Burma (Myanmar). Photo © Bonhams, used with permission.

to consider whether the uncertainty often inherent in such reports is always presented clearly enough to those who rely on them. This is particularly important with 'origin' reports, which can have a huge impact on prices. Some laboratories are scrupulously cautious here with their wording and its prominent placing; others are less so.

This article discusses the nature of opinions on geographical origin reports, the objective and subjective factors leading to an expression of opinion of origin—and the levels of confidence in that opinion—and then considers extended liability and trade expectations before giving recommendations for initial steps toward improving the transparency and usefulness of such reports by proposing changes in their wording and content.

The Nature of Opinions

Gemmological laboratories are usually careful to state that their reports present opinions. This provides a level of protection against litigation for the lab but can be of limited comfort to the user of the report because of the lack of precision. There has been some education of laboratory users about the way in which labs reach their conclusions, such as SSEF's *Standards & Applications for Diamond Report/Gemstone Report/Test Report* (1998), but little to help the user gauge how much confidence the laboratory might have in its report. A laboratory report offering the opinion that a particular sapphire is from Kashmir (e.g. Figure 3), say, could imply anything from the lab's absolute conviction that it is from that cherished source to a consensus among lab employees that on balance it is more likely to be Kashmir than not (e.g. Hänni, 1990). A consensus approach such as this is not unusual, particularly with diamond grading. If two employees in a lab have slightly different views, they will typically ask a third for their opinion and go with the majority. It is essential that the nature of a lab report as an opinion must be made absolutely clear to all who are likely to rely on it, but if we accept that laboratories would be delusional to assert that they were equally confident in all their opinions, do the users of their reports have some right to know how convinced those labs are about their opinion?

Opinions presented in gem-testing reports are of course nothing more nor less than educated guesses or a consensus of educated guesses. If they were more than educated guesses they would be facts. Referring to details on gem lab reports, particularly origin statements, as educated guesses is not a new thing; a previous example is mentioned in an editorial in *Gems & Gemology* (Liddicoat, 1990). The education for the guesses is provided by a range of factors—from precise and replicable scientific analysis to experience and even gut feelings—and so, if the report presents an opinion rather than a provable fact, it will be based on a combination of objective and subjective elements. For as long as there is a subjective element, then report conclusions necessarily will not be constant from one laboratory to another. This is not a new observation. For example, Hainschwang and Notari (2015) pointed out that where lab reports are based to some extent on "the opinion of the analyst and not only on scientific evidence…the results of a specific stone may vary to a certain degree from laboratory to laboratory".

Objective and Subjective Elements

In the interests of transparency for the user of the report and for protection against litigation for its issuer, it is reasonable to suggest that the

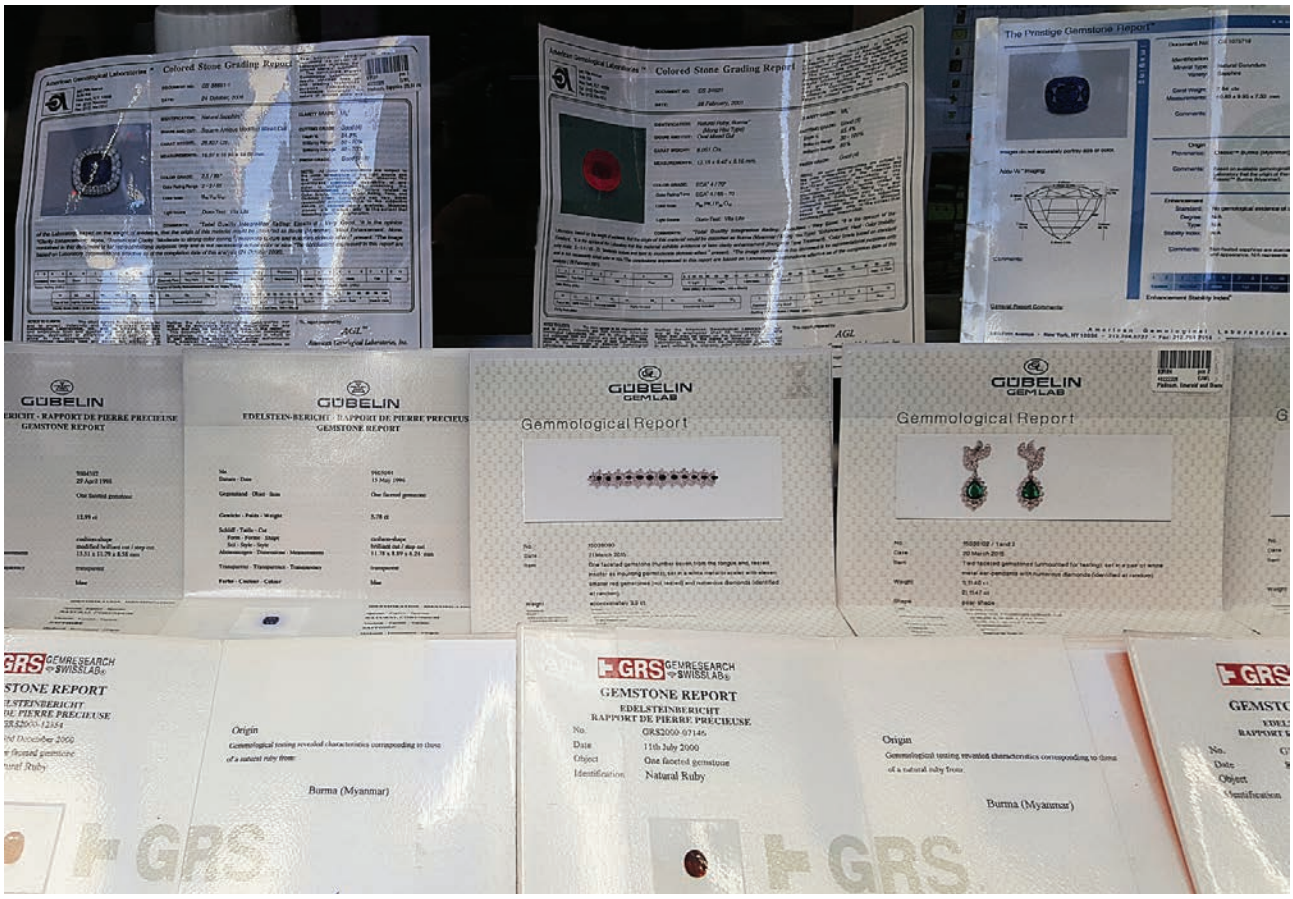

Figure 2: A shop window in New York's jewellery district demonstrates the significance currently given to lab reports. Photo by J. M. Ogden, November 2016.

objective facts and the subjective interpretations derived from them should be distinguished in the report. Even this is not as simple as it sounds. Some aspects are obviously facts, such as the weight and shape of a gem, but even here names of shapes or the classifications of girdle thicknesses, say, are not standardized any more than is colour terminology. The treatment of a gem may be an observable fact (a visible laser drill hole in a diamond, for example) or a subjective inference based on observation or analysis. Nevertheless, it should be possible to distinguish between the objective aspects that could be checked and replicated by another laboratory, and the deductions by the laboratory from observation or inferred on the basis of past experience or defined using non-standardized terminology.

Figure 3: Two examples are shown of the sections on 'Origin' on gemmological laboratory reports, for a 10.33 ct sapphire sold by Christie's in Hong Kong in 2015. The Christie's catalogue described both reports as "stating that the 10.33 carat sapphire is of Kashmir origin". The sapphire fetched $2.5 million.

Origin	Gemmological testing revealed characteristics consistent with those of sapphires originating from: Kashmir
Condition	No indications of heating (NTE).
Comments	See Information Sheet(s). Important notes and limitations on the reverse.

Comments:	The analysed properties confirm the authenticity of this transparent sapphire. No indications of heating. Origin: Kashmir

This suggestion of a distinction between the objective and the subjective is not a novel proposal; it is already laid down for the handful of gemmological laboratories that are accredited under International Standard ISO/IEC 17025 (2005). International Standards lack legal weight in most jurisdictions, but they would usually be taken to represent best practice. This particular standard is aimed primarily at testing laboratories where the data collected are measurable facts, but it recognizes that reports may include opinions based on those facts, and so in Section 5.10.5 it states that "Opinions and interpretations shall be clearly marked as such in a test report." It goes on to

say that "When opinions and interpretations are included [in a report], the laboratory shall document the basis upon which the opinions and interpretations have been made." It could be argued that this latter clause means that the laboratory should retain this documentation in its files and not necessarily pass it on to the client, but in the interest of transparency there are good reasons to suggest that in addition to distinguishing between the analyses or measurements a laboratory has made on a gem and the deductions it has derived from these, it should provide some indication on the report of how the latter were inferred from the former.

Indeed, in the UK at least, we can find some legal support for this. In a very different sort of context, Lord Justice Stuart-Smith stated: "I do not think guesswork, educated or otherwise, is sufficient to discharge the burden of proof, especially when he [the expert] does not indicate what evidence he relies upon as educating his guess" (Vernon v Bosley, 1996). As things stand, a sapphire might be sold at a very high price as 'Kashmir' on the basis of evidence less persuasive than would be needed to convict someone of stealing it. This practice of including the data on which the opinion is based in a laboratory report has been termed a "justified report" (Segura et al., 2015). Justification in this way, as defined in the International Standard 17025 cited above, is particularly applicable to opinions of origin for gems where, in the words of Bui et al. (2012), "origin determination is sometimes more akin to branding than science", although they ignore the point that 'science' is itself a combination of experiment, observation, interpretation and theory.

Clear Expression of Opinion

In the spirit of International Standard 17025, and thus again arguably best practice, it would make things clearer if all gem labs clearly stated that opinions are simply opinions where they are presented in a report, and not relegated to some generality about it all being an opinion in the typically small print of the 'terms and conditions', sometimes even on the reverse of the report. This means stating something like, 'Based on the chemical constituents of the sapphire, the measured spectral features and its internal characteristics, it is this laboratory's opinion that it comes from Kashmir', rather than simply saying 'Origin: Kashmir' with a generalized disclaimer about 'opinions' tucked away on the side or back. One only needs to leaf through the files of photocopies of lab reports at any major jewellery auction preview, viewed by public as well as trade buyers, to realize that it is time for more up-front—literally—transparency and honesty. We can note that in its recent formal request for public views on 'terms and conditions' relating to consumer products, the UK government has expressed its view that the key terms in such conditions should be 'upfront and bold' (Department for Business Innovation & Skills, 2016). One cannot argue that the 'opinion' nature of a lab report is not a key aspect.

It is growing practice for gemmological laboratories to accompany a report on an important gem with supplementary documentation that can range from a letter to a glossy book. Such an offering about an emerald, say, might praise its size, quality and Colombian origin, but among the glossy photos of sunsets over Muzo, comparisons with the green in a Renoir painting and stories of Cleopatra and conquistadors, there might be little sign of a clear statement that the Colombian origin of the gem in question is merely an opinion. As a side note, this author repeats a plea made before (Ogden 2012a): that labs should apply the same level of academic rigour to these glossy dossiers as they would to the publication of their gemmological research.

Levels of Confidence

Even if lab reports start becoming more open about the opinions they provide, along the lines of the wording proposed for the Kashmir sapphire example above, they still will not have solved the problem of the inherent fuzziness of the word 'opinion'. Some gems are trickier than others to characterize and some easier, all for a wide variety of reasons: from the individual nature of the gem, to laboratory experience or rigour of the stone reference database, to fortuitous availability of up-to-date published research. So, would it be reasonable for the user of a report to have some indication as to how much confidence a laboratory has in its opinion? From the report user's point of view—or the lawyer's, if a dispute ever came to court—a useful question to the report's signatory would be, "Are you personally convinced that the gem is from Kashmir (say) or merely believe that it is probably so?"

Quantification of overall confidence that the sapphire is from Kashmir is problematic. Courts must often undertake such assessment to apportion blame or damages on the balance of

probability, sometimes quoted as a percentage, when confronted by conflicting evidence with no means of determining the truth. Court pragmatism is different from market reality, however, and besides, laboratories could not consistently calculate overall likelihood. But just because numerical quantification of a lab's overall confidence in an opinion is unrealistic, it does not mean that all quantification is unwarranted. When there is clear, objective data from a gem, such as trace-element ratios and a large and robust database of comparisons, deductions can be made. Plotted charts can give a graphical indication of groupings and overlaps (e.g. Figure 8 of Wang et al., 2016, at www.gem-a.com/component/edocman/3233-wang-additional-plots-to-accompany-figure-8/download?Itemid=), although these are commonly constrained to two dimensions with two or three variables, while multivariate statistics can generate probabilities expressed in percentages with definable margins of error.

There is a good parallel here with the Antique Plate Committee of the Worshipful Company of Goldsmiths, London, which has been operating for nearly 80 years. A piece of antique silver submitted to this committee for verification is analysed, the results are compared with a huge database of analyses, and the likelihood of a certain date range is expressed as percentages. Thus, the computations might show that a purported Georgian silver coffee pot has an 84% likelihood of being pre-circa 1830, an 11% likelihood of being between 1830 and 1899, and a 5% chance of being 20th century or later. No one pays top price for a Georgian coffee pot with a 16% chance it is fake, so the Antique Plate Committee mulls over the analysis implications in the light of their expertise and experience regarding style, technique, patina and so on, and then states its overall opinion—alongside noting the 84% probability as generated by the statistical calculations of the analysis results.

This author is not aware of published information about multivariate statistics being used this way in gem labs, although it is hard to imagine they are not. This would be ideal where the results of chemical analysis could be compared with a robust database of reference material. There are good arguments for statistical results, whether expressed numerically or graphically, to be noted on a gem report as part of the supporting evidence for a stated opinion.[2] If the trace-element ratios indicate an 85% chance that a sapphire is from Kashmir, it seems fair—and certainly in the spirit of International Standard 17025—for the end-user to be told. It helps explain one of the criteria by which the lab justifies its final opinion. Chemical analysis is seldom the sole criterion; various internal characteristics will help identify origin, sometimes fairly conclusively, and often colour will give clues. A combined approach will typically provide a more certain indication of origin than chemical analysis alone, but even so can the user of a report claim a right to be told if the objective analytical data, in effect, showed a 15% chance that the gem was not from Kashmir (see Ogden, 2012b)?

Of course, there is a further layer here: the confidence a laboratory has in the database or reference collection upon which it relies. The Gemological Institute of America (GIA) classifies its laboratory reference collection according to the confidence it has in the given origin, ranging from certainty with gems collected in the mine by their own employees to the far less reliability of the stated origin of gems purchased in the market (Pardieu, 2009). Only a few laboratories, however, have the resources to build rigorous sample databases. 'Objective' statistics based on factors such as trace-element ratios are only as reliable as the comparative data to which the lab has access.

Extended Liability

The growing profusion of supplementary documentation aimed at the ultimate buyer says a lot about who the labs see as their end-user, even though reports might state that they are solely for the commissioning client—usually a gem dealer, auction house or jeweller. Labs know that consumers often rely on reports and, in a wider context, might work with consumer protection agencies to help safeguard the public. They also have some legal responsibilities further down the line, certainly in the UK. If the lab knows or should reasonably be expected to know that their report will be relied upon by a third party, their liability will generally extend to that party. There is UK case law on this, although nothing specific to

[2] The challenge of providing useful information in reports without disclosing intellectual property has been noted by the author (Ogden, 2016). There can be a balance, noting sufficient background to show due diligence without revealing proprietary methods. The situation if a dispute comes to court can be more problematic, especially since those best able to gauge the validity of an approach are the very competitors from whom a lab may wish to hide it.

gems, but for equivalent situations such as property surveys and company valuations (Ogden, 2016). Labs are potentially liable to third parties or classes of third party that they know, or should reasonably expect, are likely to rely on their report. Whatever the original intention of lab reports, labs now know full well that their reports often will play a significant role in both marketing and purchasing decisions. Some of the dossiers and other supplementary documents issued by gem labs are so blatantly an endorsement for a gem that this author wonders if they might even be subject to advertising legislation.

We have talked about the evidence that suggests what a gem is. What about contrary evidence? There is legal support, in the UK anyway, to the view that if the seller is aware of any significant negative opinions about a gem, the buyer should be advised of this. (For a case involving negative opinions on antique porphyry vases, see Thomson v. Christie Manson & Woods Ltd and others, 2005.) This probably means that if the laboratory is aware of negative or less-than-wholly-supportive aspects of their opinion, the user of the report might have a right to be told. On this basis, the user of the report probably has a right to know if the data or observations leading to a 'Burma' origin for a sapphire left room for significant doubt, or if two of the gemmologists in the lab thought it was from Myanmar but another indicated Sri Lanka.

Also, the not-uncommon practice for a dealer to get more than one lab report for the origin of a sapphire, say, and retain any that say Kashmir and dispose of the rest, is likely to be illegal rather than just unethical. This selective presentation of lab reports in the trade has been countered by the growing practice for major auction houses to list the findings of different gem labs in their catalogues, even if they disagree. For example, an auction of fine jewellery held in London in 2014 included a ring set with an important sapphire weighing 30.08 ct (again, see Figure 1; Bonhams, 2014). It was accompanied by reports from SSEF and The Precious Stone Laboratory (London) giving a Sri Lankan origin, as well as a report from the Gübelin Gem Lab expressing the opinion that it was from Burma. This openness in providing all three reports is the result of legal advice and an indication of the sort of transparency, realism and honesty that buyers should be able to expect from all in the trade. How buyers might be expected to know how much confidence they can place in the individual laboratories is a problem and a matter for ongoing discussion. Labs differ in the equipment and experience they have, and one might be far more accomplished with one type of gem than another.

Trade Expectations

The gem trade's use of lab reports brings us back to the practicalities. There is no scientific reason not to be more open and transparent about lab reports being an educated guess, and likewise there is no reason for them not to include something about the data and reasoning that formed the basis of the stated opinion. There are strong ethical and probably even legal reasons why they should. The main obstacle is the trade. Those who commission the reports ideally want black-and-white answers: the origin of the sapphire, say, stated as unequivocally as possible. Just consider the indignation, even anger, that can greet an 'undeterminable' lab verdict on a stone. However, if a lab is to be genuinely independent and aware of its responsibilities to all who are likely to rely on the report, it should not let its scientific principles be subverted by the unrealistic expectations of the gem trade. Modern gemmology is deeply complex and must attempt to keep its head above the waters of the flood of gem treatments, synthetics and origin challenges.

But laboratories tread a difficult path. As one former lab director has said, if gem laboratories are too cautious in their reports, they lose customers; if they are overconfident, they lose credibility (H. A. Hänni, pers. comm., 2017). Labs are businesses and costly to run, so there must be a balance, but the overriding factor must surely be the best interests of those who rely on the reports. The boards that run the labs might also be warier about expressing uncertainty than those working in them, but times are changing.

Every industry today is awash with the need for laboratory reports, from contaminants in baby powder to ancient Greek gold wreaths. In the art and antique world, perhaps closest in concept to gem lab reports, it is increasingly normal for reports to include tables of analyses, details of methods of manufacture and signs of age, often with photomicrographs and, of course, the relevant expert's overall view, which necessarily includes the input of his or her 'experienced eye'. With a carefully thought-out workflow, the addition of analytical data and photos (e.g. Figure 4) does not greatly increase the time taken to pro-

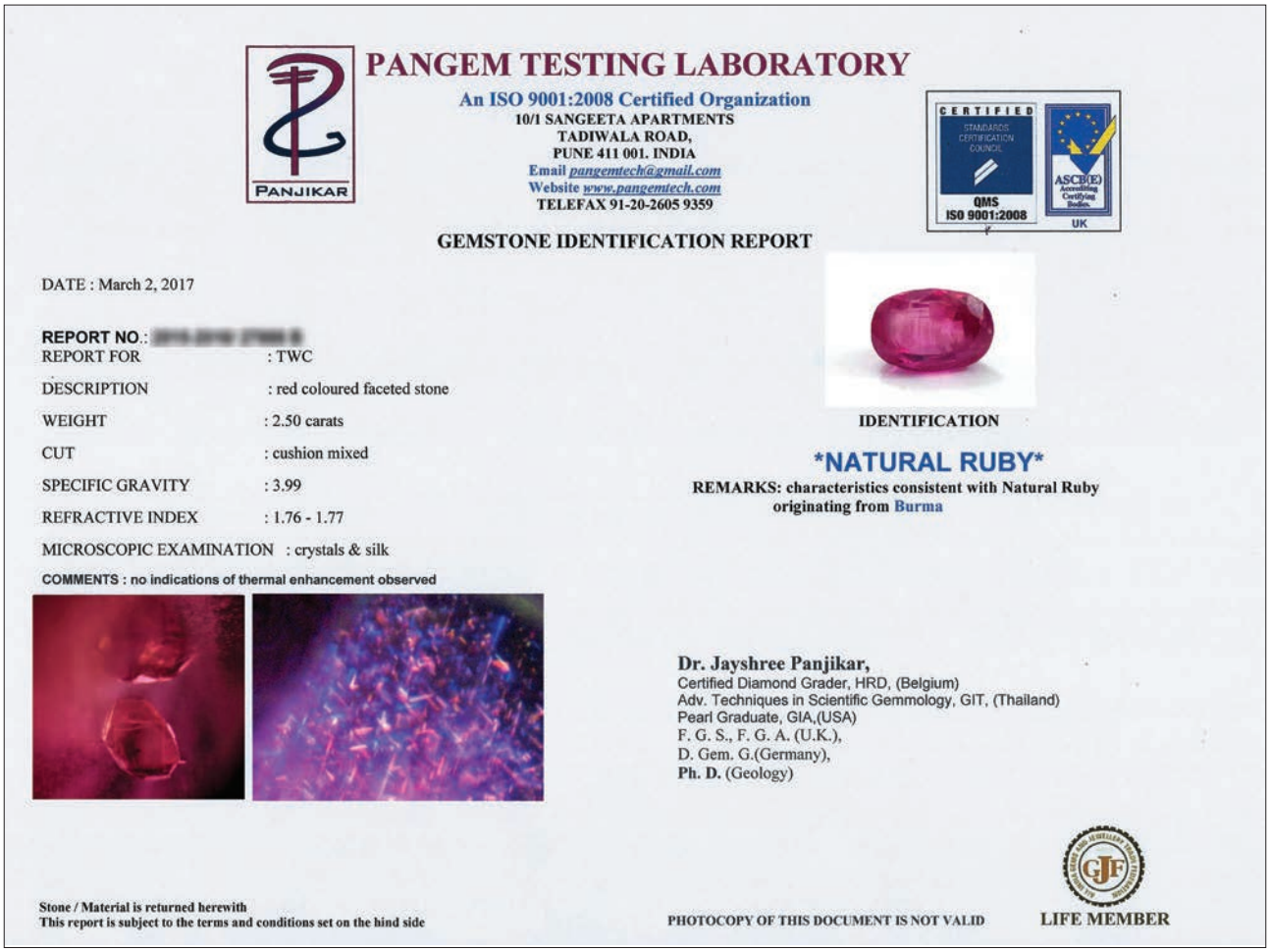

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GEMSTONE IDENTIFICATION REPORT

DATE : March 2, 2017

REPORT NO.:
REPORT FOR : TWC
DESCRIPTION : red coloured faceted stone
WEIGHT : 2.50 carats
CUT : cushion mixed
SPECIFIC GRAVITY : 3.99
REFRACTIVE INDEX : 1.76 - 1.77
MICROSCOPIC EXAMINATION : crystals & silk
COMMENTS : no indications of thermal enhancement observed

IDENTIFICATION
NATURAL RUBY
REMARKS: characteristics consistent with Natural Ruby originating from Burma

Dr. Jayshree Panjikar,
Certified Diamond Grader, HRD, (Belgium)
Adv. Techniques in Scientific Gemmology, GIT, (Thailand)
Pearl Graduate, GIA,(USA)
F. G. S., F. G. A. (U.K.),
D. Gem. G.(Germany),
Ph. D. (Geology)

Stone / Material is returned herewith
This report is subject to the terms and conditions set on the hind side
PHOTOCOPY OF THIS DOCUMENT IS NOT VALID
LIFE MEMBER

Figure 4: This lab report provides an example of including photomicrographs to support an opinion of a stone's geographical origin—in this case, a Burmese ruby. Courtesy of Dr Jayshree Panjikar.

duce a report. After all, the lab is keeping these records anyway.

However, with a more 'justified' gem lab report, this author is not suggesting documenting every inclusion, say, but rather providing an overview of the range of observations or tests that were significant in reaching the conclusions presented, along with a statistical representation of data where relevant. This sort of report will not necessarily give sufficient detail for the reader to gauge how much confidence he or she should place in the report, but it should be worded in a way to indicate broadly how confident the lab is in its opinion. More justified laboratory reports might not reduce the issuing of conflicting reports by different labs, but they might better allow the users of those reports to understand why different conclusions were reached.

Conclusions

A serious discussion of a way forward in the context of gemmological lab reports, and their value for and impact on the trade is long overdue. There are various industry bodies that could spearhead this, and even a new International Standard is perhaps not unrealistic. With the growing use of reports and the legal liabilities of labs, such discussions are surely essential. This author suggests two initial steps:

- When conclusions presented in a lab report are opinions, not facts, they should be clearly expressed as such at the point where they are presented.
- Reports should briefly explain the nature of the observations and analyses on which their conclusions are based, where possible including relevant photomicrographs, analyses or statistical information.

Another step would be to realize that use of the word 'probably' in a report can be a sign of wisdom rather than weakness.

It might well be that some gemmological laboratories decide their future is best served as the marketing arm of the gem trade. That is their

choice; there is nothing wrong with the gemmologist as poet, but they cannot then pretend to the trade, and the trade cannot pretend to their customers, that they represent an independent, detached service. If all gem lab reports become more open about the inherent uncertainties behind many opinions, fine gems might begin again to be sold on the basis of their beauty and individuality rather than on the basis of paper. A wider and more realistic understanding of the subjective content of lab reports would mean also an understanding that labs should be able to change their opinions without this being viewed as a sign of incompetence or ignorance. Information, experience and technology develop. As the 18th century moralist Joseph Joubert said: "Those who never retract their opinions love themselves more than they love truth."

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Fake Pearls Made from *Tridacna gigas* Shells

Michael S. Krzemnicki and Laurent E. Cartier

Five non-nacreous 'pearls' that allegedly came from *Tridacna gigas* (giant clams) were studied for this report. Our observations revealed that none of them were pearls, but instead they had been manufactured from *Tridacna* clam shell. The identification of such imitations is in most cases straightforward, and is mainly based on their characteristic layered structure observed in reflected light and with transmitted fibre-optic illumination. Our results are compared with recent reports of other such fake pearls that are often wrongly described as being genuine natural pearls.

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Introduction

Pearls inspire the imagination of mankind, as they have represented status, good fortune and wealth since historic times. Therefore, it is no surprise that, even today, exceptionally large pearls attract much interest among the public (even though they are not nacreous). Occasionally reports on such objects appear in popular news media, in which they are commonly and correctly described as formations from the *Tridacna* clam (e.g. *Tridacna gigas*). A single account from a local newspaper may be multiplied by press agencies, so that a story based on just one pearl is then covered in many newspapers and websites, thus making its way into worldwide headlines.

Due to such recent media coverage, the authors' laboratory is being confronted with numerous requests to analyse similar non-nacreous 'giant pearls'. This article documents the results of our testing on five such items at SSEF (Figure 1), all of which proved to be fake pearls that had been cut and polished from *Tridacna* clam shell.

Tridacna Clams and Their Pearls

Tridacna clams (Tridacninae subfamily) are among the largest living bivalve molluscs, with a shell diameter up to 110 cm (Sarasin, 1904; Rosewater, 1965). Inhabiting shallow coastal waters of the Indo-Pacific region (Rosewater, 1965), these species are nowadays among the most endangered clams and are protected by the Convention on International Trade in Endangered Species (CITES, 2016). Their white shell is massive and thick, and shows a characteristic and attractive wave-like cross-section. As such, the shell has been used for adornment in native cultures and historically as fonts (vessels containing holy water) in Catholic churches throughout Europe (e.g. Saint Sulprice in Paris, France: Figuier, 1868, p. 148; Kunz and Stevenson, 1908, p. 76).

The presence of symbiotic single-celled dinoflagellate algae (zooxanthellae) in the mantle tissue of *Tridacna* clams not only results in a colourful appearance of the living animal, but also is regarded as the reason for the growth of the

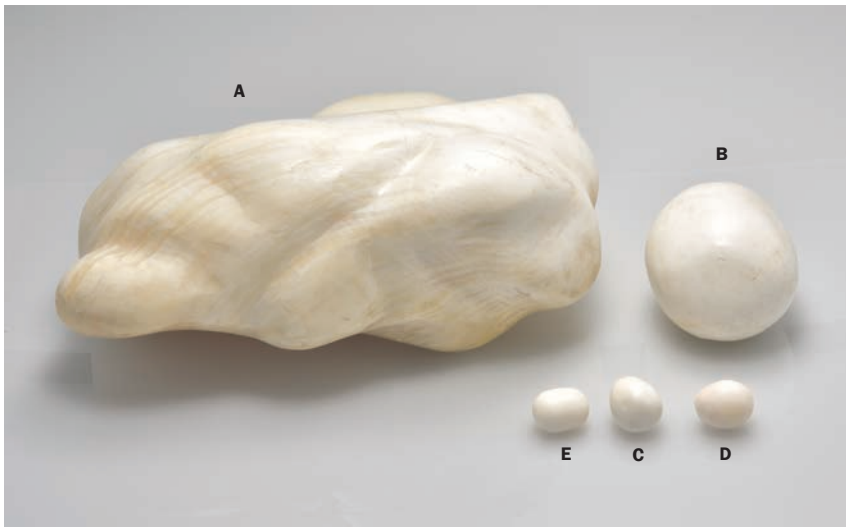

Figure 1: These five fake pearls (samples A–E), all cut from the shell of giant clams, were studied for this report. The largest item is 27 cm in diameter and weighs 6.8 kg. Photo by V. Lanzafame, © SSEF.

massive calcium carbonate shells of these species (Dame, 2011).

Pearls, blister pearls (i.e. those attached to the inner wall of a shell) and blisters (i.e. internal protuberances of the shell caused by the intrusion of foreign bodies between the mantle and the shell) from *Tridacna* clams are known in the trade (e.g. Kunz and Stevenson, 1908; Bari and Lam, 2010; Singbamroong et al., 2015; see also www.pearl-guide.com/forum/content.php?76), but due to their often rather dull whitish appearance and baroque shape (e.g. Figure 2) they have not gained much interest so far, except among a few pearl collectors. The shell material of *Tridacna* clams consists of regularly and densely interwoven aragonite fibres, similar to *Strombus gigas* (queen conch: Osuna-Mascaró et al., 2014) and many other gastropods. This partially results in fine 'flame structures' when viewed in reflected light (Hänni, 2010). As a consequence, both natural pearls and polished shell pieces from *Tridacna* clams often show such flame structures on their surface. However, not all non-nacreous white natural pearls claimed to be from *Tridacna* clams (Lai, 2014; Singbamroong et al., 2015) necessarily originate from the Tridacninae subfamily. They may also be the beautiful products of other mollusc species—misnamed as *Tridacna* clam pearls, since there is currently no method for the species identification of such non-nacreous white pearls. This is very much in contrast to nacreous pearls, which currently can be separated genetically (Meyer et al., 2013), and also in some cases by UV-Vis-NIR reflectance and Raman spectroscopy.

Samples and Methods

For this study, we investigated five samples (specimens A–E, Figure 1) submitted to SSEF by one client who reported them to be *Tridacna* pearls originating from Palawan, an island in the eastern Philippines. The samples ranged in weight from 6.8 kg (A) to 18.4 g (E) and in maximum length from approximately 27 to 2.6 cm. The large size and weight of some of the samples precluded our normal pearl testing procedure, so we based our conclusions mostly on careful observation of surface textures with the unaided eye and the microscope (Eickhorst LED Leica Gemmaster). In addition, for sample E we performed Raman spectroscopy with a Renishaw InVia microscope and chemical analysis by energy-dispersive X-ray fluorescence (EDXRF) spectroscopy using a Thermo

*Figure 2: A large hollow natural blister is shown attached to the inside of a giant clam shell (*Tridacna gigas*). A loupe is shown for scale; the shell measures approximately 26 cm wide. Photo by Luc Phan, © SSEF.*

Scientific Quant'X instrument. Also, X-radiography was performed on the three smaller samples (C, D and E) using a Yxlon Cougar digital X-ray setup.

Visual and Microscopic Observations

We divided the study specimens into two categories according to their shape (again, see Figure 1). The largest sample (A) displayed a baroque shape, visually somewhat reminiscent of the wave-like form of *Tridacna* shell. The remaining specimens (B–E) were oval to slightly baroque, and thus were more typical of the shapes exhibited by pearls.

Viewed with reflected light, all five specimens showed distinct curved, layered structures across their entire surfaces. These structures had no direct correlation to the shapes of the specimens, but were consistent with the undulating layered structures of *Tridacna* clam shell. Sample B exhibited a complex curved and folded structure (Figure 3) that appeared to represent the hinge of the clam; this area possesses the thickest accumulation of calcium carbonate in *Tridacna* shells.

Close examination of all the samples further revealed distinct polish marks in random orientations (e.g. Figure 4), as would be expected from items worked into a roundish shape. The low-quality polish, suggesting a rushed 'production' of these items, contrasts with the highly polished specimens of manufactured shell material that have been previously examined at SSEF (e.g. Krzemnicki, 2006).

Figure 3: The surface of specimen B (8.6 cm long), cut and polished from Tridacna *shell, exhibits distinct curved lines representing seasonal growth layers. Photo by V. Lanzafame, © SSEF.*

Using a strong transmitted fibre-optic light source, it was possible to investigate the internal structure of the five study samples. All showed distinct and sharply defined internal layering (Figure 5), representing the seasonal calcium carbonate precipitation layers of the shell in *Tridacna* species. Such features are not commonly observed in pearls, which form by precipitation of concentric spherical layers within the pearl sac of a mollusc.

Although surface- or subsurface-related striae in genuine *Tridacna* pearls might occasionally produce a somewhat layered appearance with transmitted fibre-optic illumination (Lai, 2014),

Figure 4: Distinct polish marks on the surface of fake pearl sample C result in a low-quality polish. Photo by M. S. Krzemnicki, © SSEF; image width 10 mm.

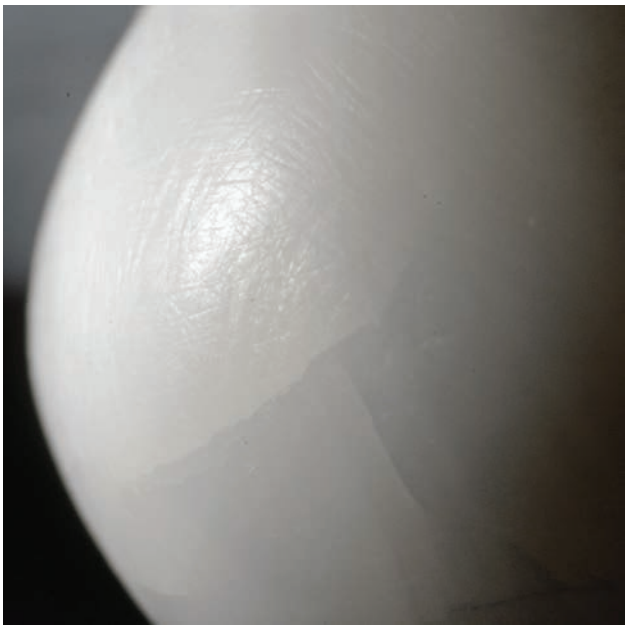

Figure 5: Viewed with transmitted fibre-optic illumination, this close-up of specimen D (22.5 g) reveals the layered structure of the Tridacna *shell from which it was cut. Photo by M. S. Krzemnicki, © SSEF; image width 11 mm.*

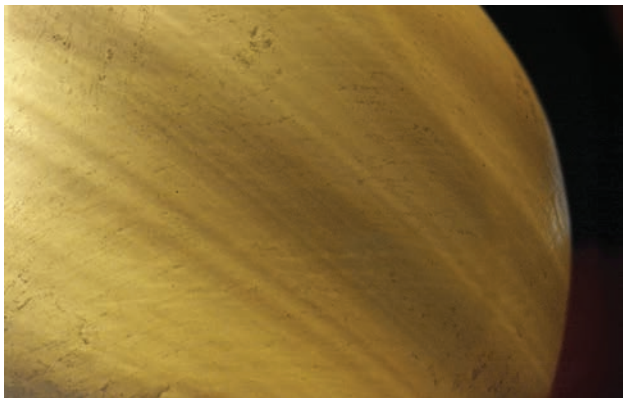

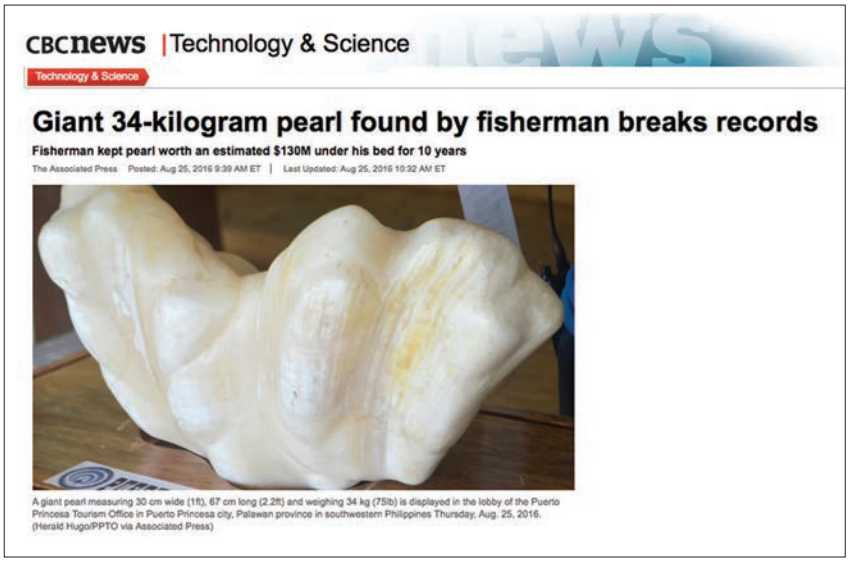
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Giant 34-kilogram pearl found by fisherman breaks records

Fisherman kept pearl worth an estimated $130M under his bed for 10 years

The Associated Press Posted: Aug 25, 2016 9:39 AM ET | Last Updated: Aug 25, 2016 10:32 AM ET

A giant pearl measuring 30 cm wide (1ft), 67 cm long (2.2ft) and weighing 34 kg (75lb) is displayed in the lobby of the Puerto Princesa Tourism Office in Puerto Princesa city, Palawan province in southwestern Philippines Thursday, Aug. 25, 2016. (Herald Hugo/PPTO via Associated Press)

Figure 6: A reported 'giant pearl' weighing 34 kg provides a recent example of a fake pearl that made its way into worldwide headlines via the Associated Press in August 2016. The shape, layered structure and poor surface polish provide strong combined evidence that this object has been manufactured from Tridacna *shell.*

the present samples did not show any such striae, but rather only a badly polished surface.

The complex and sharp banding exhibited by the present samples (e.g. Figures 3 and 5) is also very different from the weak circling bands occasionally observed in non-nacreous white pearls from various molluscs, such as *Spondylus* spp. (Ho and Zhou, 2015) and *Fusinus* spp. (Bari and Lam, 2010, p. 75). These circles (seen as parallel bands when viewed from the side) are due to growth heterogeneities aligned by the rotation of the pearl during its formation (Gueguen et al., 2015). Typically these bands are rather broad and diffuse, and are visible either as a sub-surface effect when illuminated with a strong light source or at the surface (i.e. in nacreous pearls), where they may negatively affect the quality of a pearl. Such pearls commonly show a distinct rotational shape (button to long-prismatic oval) and occasionally reveal distinct flame structures radially emanating from rotational axis points at their top and bottom.

Viewed with the microscope, some of the five study samples revealed weak and fine flame structures perpendicular to the layering, similar to those described by Hänni (2010), but no flame structures were seen radially emanating from a distinct (rotational axis) point.

Based on these observations, we concluded that all five study specimens were fake pearls that had been cut and polished from the massive shells of *Tridacna* clams. Such imitations—typically of rather small size—have been manufactured since historic times (mostly then from *Unio* freshwater mussel shells) and have been described in detail by Kunz and Stevenson (1908, pp. 361, 494 and 497).

Advanced Testing

Raman spectroscopy of sample E revealed that it consisted of aragonite, as expected for *Tridacna* clams (Hänni, 2010). EDXRF analysis of this sample showed the expected major amounts of Ca along with traces of Sr (0.25 wt.% $SrCO_3$), but with Mn below the detection limit, clearly supporting a formation of the biogenic calcium carbonate in marine waters. X-radiography of samples C, D and E revealed no discernible internal structures such as layers or internal cavities in any of these specimens. This result is very common for non-nacreous pearls or shells (or beads made from such shells) that consist completely of densely interwoven aragonite fibres.

Further Cases of Fake Pearls from *Tridacna* Clams

From time to time, the authors' laboratory is asked to analyse 'giant pearls', and these objects are often accompanied by dubious identification and appraisal documents. Since the international media highlighted such a 'giant pearl' in August 2016 (e.g. Figure 6), the number of such requests has increased steadily. Although the authors have not personally studied the 'giant pearls' claimed to originate from *Tridacna* clams that have recently appeared in the media, we are convinced that most—if not all—of them are in fact fakes that were manufactured from the shell of *Tridacna* clams. This opinion is based on their apparent similarity in shape, layered structure and surface polish to the study samples we described above.

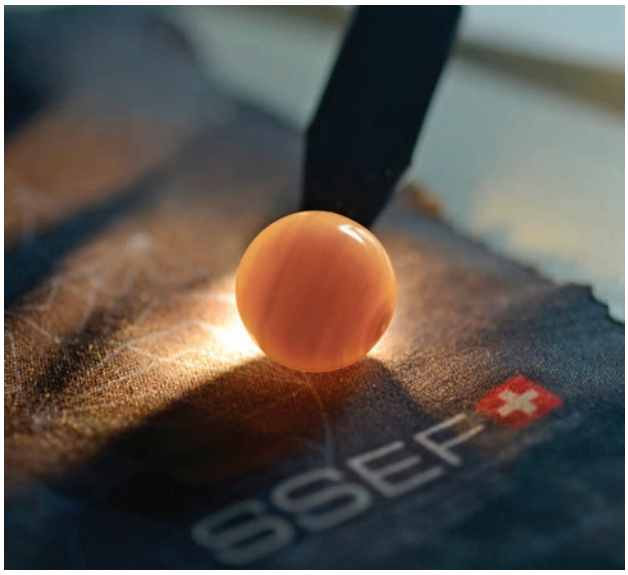

Figure 7: This 'pearl' (18.6 mm in diameter) is actually a bead cut from Tridacna *shell. The shell layers are distinctly visible when illuminated with fibre-optic lighting. Photo by M. S. Krzemnicki, © SSEF.*

Figure 8: This polished Tridacna *shell bead (~23 × 16 mm or 63 ct) was dyed to imitate a Melo pearl. Note the well-developed flame structure, as would be expected for a genuine Melo pearl. Photo by M. S. Krzemnicki, © SSEF.*

Still, the media hype about such 'giant pearls' is worth highlighting, as it reveals the context in which modern urban myths are presented to the general public. For those who have read about several such 'giant pearl' discoveries, the themes sound very familiar. The stories include emotions such as greed and tragedy (a diver dies as he is trying to remove the 'pearl' from the giant clam but is stuck in the closing shell), unexpected discoveries but ignorance of their value (a poor fisherman finds the 'pearl' and keeps it as a personal item without knowing its 'true' value) and fairy-tale endings that involve achieving wealth and fortune and, hopefully, happiness (finally the 'giant pearl' is appraised by some unknown source as being of enormous value—for example, US$100 million—with an open ending as to how much money the poor fisherman will actually obtain). Although such stories may be entertaining and intriguing, the same themes have been used and repeated with great detail since historic times (Kunz and Stevenson, 1908, p. 144), mostly to create illusion and interest in such exotic 'oddities'.

Unnoticed by the media, but occasionally encountered in the laboratory and reported in the gemmological literature, are smaller fake pearls that most probably have been cut and polished from *Tridacna* clams (Disner and Notari, 2015). In the past few years, SSEF has analysed a few such specimens, cut into roundish shapes and sizes typical for gastropod pearls (e.g. Figure 7). They were polished with great care to display their fine flame structure and perfectly shaped to fit into jewellery. As such, they have been mistakenly bought as non-nacreous natural pearls, even by knowledgeable pearl dealers. Moreover, these manufactured 'pearls' may be dyed orange to imitate Melo pearls (Wentzell, 2006; Sturman et al., 2011; Figure 8). Raman spectroscopy of one such Melo imitation showed no peaks at 1134 and 1527 cm^{-1} characteristic of the natural-colour pigment in Melo (and conch) pearls, but did reveal three broad features at 1519, 1499 and 1363 cm^{-1} that closely matched the broad Raman peaks of organic dye (possibly red eosin; Krzemnicki, 2006).

Conclusions

Based on our observations and analyses, the five specimens submitted as 'pearls' reportedly originating from giant clams were identified unambiguously as beads cut and polished from *Tridacna* shell. The main criterion for the detection of all these fake pearls was the presence of distinctly discernible shell layers (sometimes overprinted by fine flame structures).

Considering the similarity of these specimens to numerous other items on the Internet or in pictures sent to us, we assume that most of these others also are fakes, and as such have essentially no commercial value. This is very much in contradiction to media reports or dubious appraisal documents, which unfortu-

nately are too often reproduced and relinked by reputed news sources without question.

It is also important to reiterate that *Tridacna* clams are endangered species listed in Appendix II of CITES (2016) and therefore are protected. Any international trade of shells or pearls from *Tridacna* requires an official permit before export. As such, trade organizations actively have banned the use of *Tridacna* shell beads in jewellery or as beads for pearl cultivation in recent years (Zhou and Zhou, 2015).

And, finally, this study reminds us of the ingenuity of mankind to create illusion and garnish fraud with an appealing myth. The authors hope that with this article, the chapter on the so-called 'giant pearls' from *Tridacna* clams can be closed, at least in the gemmological community.

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Large 12-Rayed Black Star Sapphire from Sri Lanka with Asterism Caused by Ilmenite Inclusions

Thanh Nhan Bui, Pascal Entremont and Jean-Pierre Gauthier

A large (112.64 ct) black star sapphire of probable Sri Lankan origin that exhibits 12-rayed asterism was studied for this report. As in other 12-rayed star sapphires, its phenomenal appearance is due to the presence of oriented needle-like inclusions that produce two superimposed six-rayed stars that are rotated 30° relative to one another. However, Raman spectroscopy combined with optical microscopy unexpectedly revealed that the inclusions responsible for both stars consist of the same mineral, ilmenite. By contrast, 12-rayed star sapphires from Thailand typically contain separate inclusion sets of rutile and hematite-ilmenite series minerals corresponding to the two six-rayed stars.

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Introduction

Asterism is an optical phenomenon that occurs in gemstones containing oriented needle-shaped inclusions. In corundum, due to the three-fold rotational symmetry of the basal pinacoid, networks of needles are oriented in three different crystallographic directions that intersect at 120°. As a consequence, typical asterism in corundum consists of a six-rayed star composed of three intersecting branches. The exsolved acicular inclusions, with the same rotational symmetry, may be oriented along two different hexagonal prisms of the host crystal. As a general rule, rutile needles are oriented parallel to the growth zoning and the second-order hexagonal prism of the host corundum, while needles of hematite-ilmenite series minerals are oriented perpendicular to these features (Hughes, 1997, p. 94). When both orientations of acicular inclusions are present in the same corundum host, they result in a 12-rayed star.

In the gemmological literature, there is a lack of systematic identification of minerals leading to asterism in corundum and, more generally, in asteriated gemstones. In this article, we use Raman spectroscopy to analyse both networks of needle inclusions in a large 12-rayed black star sapphire reportedly from Sri Lanka, as well as in smaller samples from the same source and from Thailand for comparison.

Materials and Methods

The large star sapphire (Figure 1) weighs 112.64 ct and was purchased in Colombo, Sri Lanka, by author PE in approximately 1985. No information concerning the exact origin of the stone was available. Named 'Ceylon Stars', it is the largest 12-rayed star sapphire from Sri Lanka that is known to the authors. It resembles another large 12-rayed star sapphire (70.79 ct), also from Sri Lanka, that is very dark blue and mounted in a ring in the National

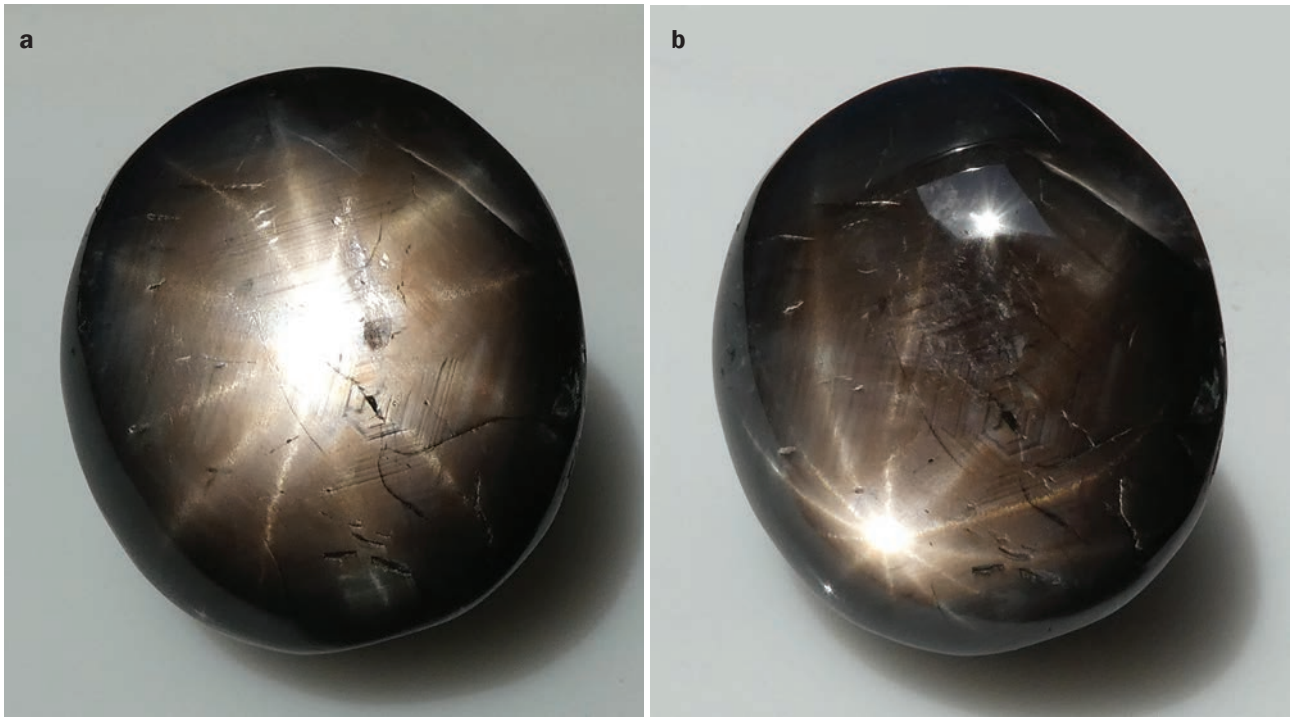

Figure 1: The 112.64 ct 'Ceylon Stars' sapphire, from the collection of P. Entremont, displays 12-rayed asterism, as shown here with pinpoint illumination positioned (a) over its centre and (b) obliquely. Photos by P. Entremont.

Gem Collection of the Smithsonian National Museum of Natural History (http://geogallery.si.edu/index.php/10002721).

For comparison, five other 12-rayed star sapphires from Sri Lanka (Figure 2A–E)—all weighing less than 5 ct and obtained by author PE at the same time as the 112.64 ct stone—also were examined, as well as a 12-rayed star sapphire from Thailand (Figure 2F) weighing 8.05 ct that was recently obtained by author TNB in Chanthaburi, Thailand.

All samples were observed with a binocular microscope in reflected light at magnifications of 15×–1,000× to examine their acicular inclusions. The inclusions in all samples were then identified using a Horiba LabRAM 800HR micro-Raman spectrometer. Calibration was performed on a silicon substrate (first-order Raman peak of 520.7 cm^{-1}). A green laser (514 nm) was used to excite the samples, and the power (6.6 mW) was modulated at 50% and 100%. The acquisition time for each spectrum ranged from 1 to 2 minutes, and each spectral acquisition was performed twice. Due to the very small size of the inclusions (a few micrometres wide), we used an optical magnification of 1,000×. In order to plot several curves in the same graph, the spectra were normalized according to the most intense Raman peak. The background was not subtracted from the spectra.

Results and Discussion

Large Sri Lankan Black Star Sapphire

When illuminating the cabochon at its centre (Figure 1a) or obliquely (Figure 1b) with pinpoint illumination, we readily observed the 12-rayed star. Growth zoning was seen as bands along three crystallographic directions in the basal plane of the pinacoid of the corundum host. The hexagonal growth bands were off-centre relative to the dome of the cabochon. This is probably due to weight optimisation during cutting, as supported by the backside of the cabochon being kept in its rough state. The body colour of the sapphire was difficult to discern due to the dense concentration of acicular inclusions. Nevertheless, strong transmitted illumination revealed that its body colour was mainly dark blue with some areas showing a more violet hue.

The 12-rayed star was composed of two six-rayed stars rotated 30° relative to one another. This seems consistent with the usual exsolution of inclusions in this type of corundum, in which one set of needles (perpendicular to the growth bands in the corundum) consists of hematite-ilmenite minerals, and the other set (parallel to the growth bands) consists of rutile (cf. Bui et al., 2016). These latter inclusions typically appear white and are thinner in dimension, producing

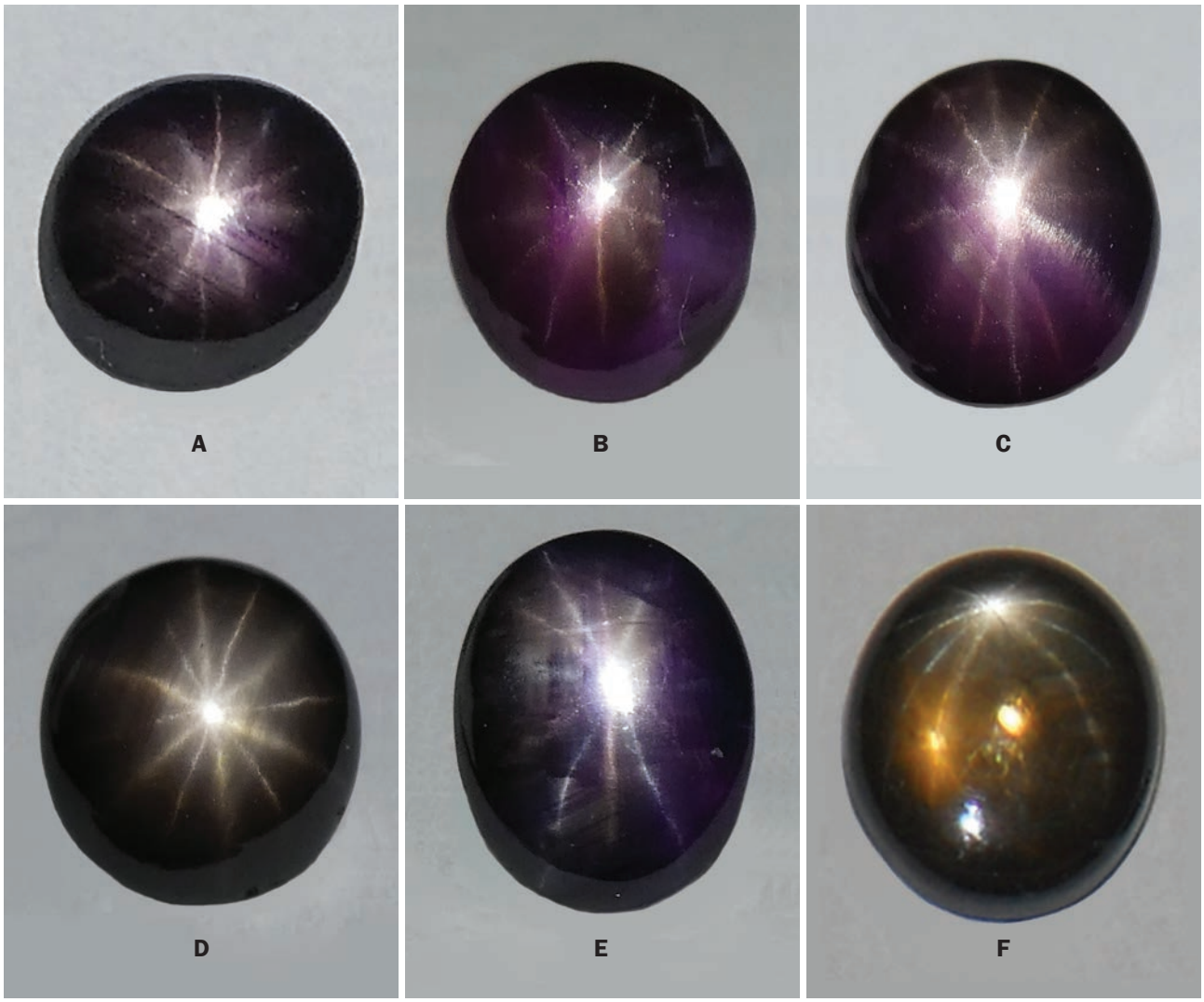

Figure 2: Several additional 12-rayed star sapphires were studied for comparison, including five others from Sri Lanka (A–E; 1.53–4.19 ct) and one from Thailand (F; 8.05 ct). The Sri Lankan samples range from purple to violet, except one that can be considered black (D). The Thai stone (F) is also a black star sapphire. In samples A–D, all rays of the stars are brownish, while samples E and F have both brownish and whitish rays corresponding to differences in the inclusions responsible for their stars. Photos by T. N. Bui (A–E) and J.-P. Gauthier (F).

sharp asterism, whereas the former are darker and wider, giving broader rays. However, in the present stone, the needles of the two stars were similar in colour. For this reason, we decided to examine this 12-rayed sapphire more carefully to determine the exact nature of its inclusions.

Close inspection by optical microscopy at high magnification near the surface of the cabochon revealed some details about the microstructure of the growth bands. Networks of oriented needles and platelets—in three different orientations intersecting at 60°/120°, typical of the three-fold rotational symmetry of corundum—were present within the basal plane. Compared to the growth bands, most of the acicular inclusions were oriented perpendicular and oblique at 30° (e.g. Figure 3a), or parallel and oblique at 60° (e.g. Figure 3b). From these relative orientations of the acicular inclusions compared to the growth bands, we expected to attribute the inclusions in Figure 3a to the hematite-ilmenite series and those in Figure 3b to rutile. However, the density and the width of inclusions varied in different areas of the stone. Also, the average width of the inclusions oriented perpendicular to the growth bands of the host corundum was narrower than the inclusions oriented parallel to the growth bands. This explains the difference in sharpness between the two six-rayed stars constituting the 12-rayed asterism.

Figure 4a illustrates a dark-coloured region that was depleted of acicular inclusions. Instead, it contained a lower density of somewhat larger

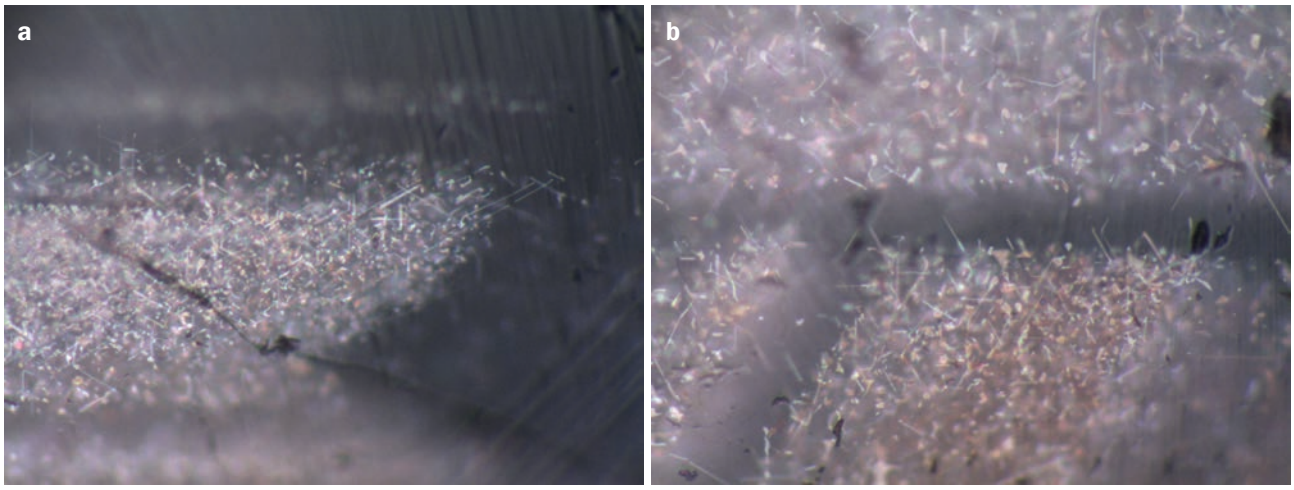

Figure 3: Two networks of needles constitute the growth zoning in the large 12-rayed sapphire, oriented perpendicular (a) and parallel (b) to the growth bands in the host corundum. The corundum growth bands are horizontal in both of these images. Photomicrographs by T. N. Bui in brightfield illumination; field of view 400 × 300 µm.

black inclusions. High magnification revealed their plate-like shape (Figure 4b), with edges parallel or perpendicular to the acicular inclusions. Their appearance was similar to the magnetite inclusions found in 'Gold Sheen' sapphires (see Figure 13 in Bui et al., 2015). In the present case, however, these black inclusions were isolated from the networks of acicular inclusions.

In agreement with previous studies (e.g. Palanza et al., 2008; Bui et al., 2015), Raman spectra of the inclusions consisted of superimposed signals from both the host sapphire and the tiny inclusions. Figure 5a illustrates the spectrum of sapphire (α-Al_2O_3 corundum), including peaks at 379, 418, 430, 449, 576 and 750 cm^{-1}. Surprisingly, both networks of acicular inclusions, as well as the black inclusions, were identified as ilmenite ($FeTiO_3$); no hematite or rutile inclusions were found. Typical Raman spectra for the ilmenite inclusions were characterized by a strong band at 678 cm^{-1}, as depicted in Figure 5 (spectra b–d). The other vibration modes for ilmenite were 162, 194, 221, 256, 291, 329, 374, 451 and 597 cm^{-1}. The obtained spectra are in good agreement with natural ilmenite (e.g. Rull et al., 2004, 2007; Bui et al., 2015) and pure synthesized ilmenite (e.g. Sharma et al., 2009; Guan et al., 2013).

Thai Black Star Sapphires

Black star sapphires, including those displaying 12 rays, are usually attributed to the Ban Kha Cha

Figure 4: Near the surface of the large sapphire is an area that is free of inclusions that contribute to the asterism; this area appears dark and contains black inclusions (a: field of view 3.25 × 2.60 mm). A closer view of the black inclusions reveals their plate-like shape with edges that are parallel or perpendicular to the acicular inclusions (b: field of view 400 × 300 µm). Photomicrographs by T. N. Bui in brightfield illumination.

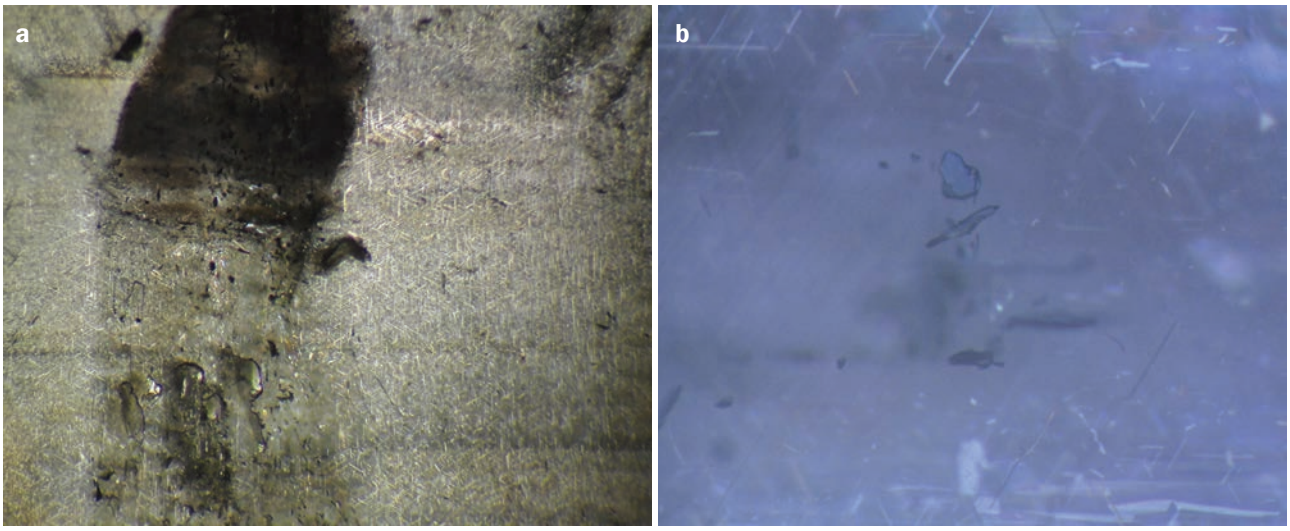

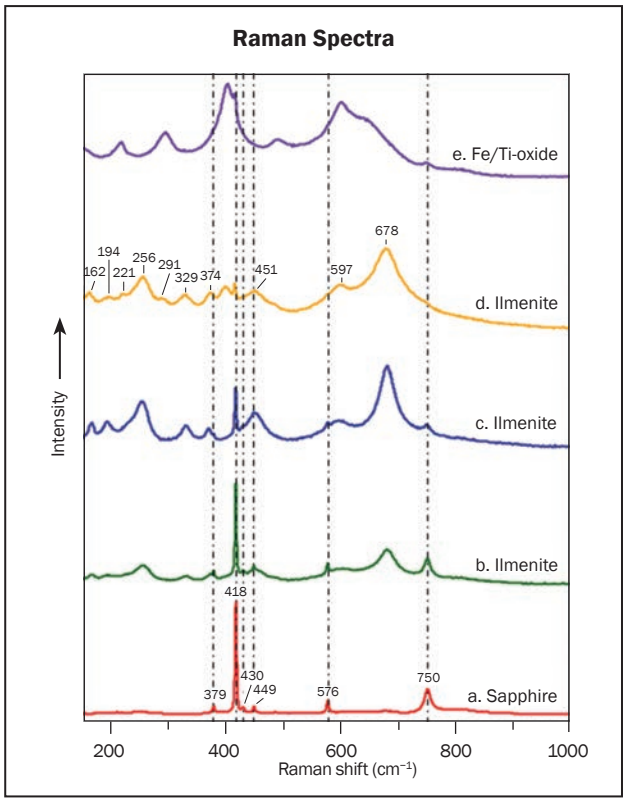

Figure 5: For the large sapphire, Raman spectra are shown for the host corundum (a); the inclusions responsible for the 12-rayed star, identified as ilmenite, present as narrow (b) and thick (c) needles and/or platelets; and for black inclusions of ilmenite that are not related to the asterism (d). The ilmenite spectra are distinct from those of Fe/Ti-rich oxide acicular inclusions in black star sapphires from Thailand (e). The vertical dashed lines indicate the Raman peaks of corundum superimposed on those of the analysed inclusions.

mine in Thailand, based on their physical and chemical characteristics. The acicular inclusions forming the classic six-rayed black star sapphires have been reported as an exsolution of hematite (Weibel and Wessicken, 1981) or both hematite and ilmenite (Gübelin and Koivula, 2008, p. 214). It was later demonstrated by scanning electron microscopy with energy-dispersive X-ray spectroscopy (Moon and Phillips, 1984) and by electron microprobe analysis (Saminpanya, 2001) that the inclusion exsolution is of the same chemical composition (Fe/Ti-rich oxides) but not pure hematite or pure ilmenite. In 12-rayed star sapphires from Thailand, the additional network of needles—parallel to the second hexagonal prism of the corundum host and producing the second six-rayed star at 30° with respect to the first one—is typically attributed only to rutile (Schmetzer and Glas, 2001). To our knowledge, there are no reports in the literature containing Raman spectra of Fe/Ti-rich oxides from acicular inclusions in black star sapphires, and therefore no identification of their exact mineralogy.

Figure 5 demonstrates the difference between a typical Raman spectrum of Fe/Ti-rich oxide inclusions in our 12-rayed black star sapphire from Thailand (Figure 2F) and those found in the large Sri Lankan gem (Figure 1). Further characterization of the mineralogical nature of the Fe/Ti-rich oxide acicular inclusions in the Thai sample is beyond the scope of the present study. We also confirmed the presence of rutile inclusions in this stone by Raman spectroscopy (not plotted in Figure 5).

Our 12-rayed black star sapphire from Thailand (Figure 2F) had the same appearance as the one reported by Schmetzer and Glas (2001). While one six-rayed star was brownish, the other was whitish, which was not the case for the large Sri Lankan sample in this study. Moreover, the branches of the whitish star in 12-rayed black star sapphires from Thailand were sharper than those of the brownish star, due to the narrower width of the rutile needles. In the large Sri Lankan sample, the six-rayed star parallel to the growth zoning was sharper than the other rays seen in this stone. The fact that it contains only ilmenite inclusions is consistent with its Sri Lankan origin, which is distinctive from the inclusion assemblage found in Thai stones.

Sri Lankan Star Sapphires

The smaller 12-rayed star sapphires that were studied for comparison had body colours ranging from purple to violet (Figures 2A–C and 2E) and black (Figure 2D). In each sample, the acicular inclusions parallel to the first-order hexagonal prism were identified by Raman spectroscopy as ilmenite. Ilmenite also constituted the second set of acicular inclusions—as for the 112.64 ct stone—except for one sample (Figure 2E), in which the second network consisted exclusively of rutile needles, which was consistent with the whitish colour of its corresponding six-rayed star.

Twelve-rayed stars are quite rare among Sri Lankan sapphires (Hughes, 1997, p. 406). By analysing the pattern of the growth zoning (formed by exsolved inclusions of epigenetic ilmenite) in our samples, we can deduce a relatively constant input of fluids rich in Ti and Fe during crystal growth. The lack of notable variation in fluid composition was suitable for ilmenite growth along both the first- and second-order hexagonal prisms in all but one of our samples. Microscopic observation of all the Sri Lankan samples demonstrated that the width of acicular ilmenite inclusions was narrower

for those oriented perpendicular to the growth bands in the corundum. This explains the sharpness difference between the two six-rayed stars constituting the 12-rayed asterism. In addition, the presence of the same mineral—ilmenite—causing both six-rayed stars in all but one Sri Lankan sample is consistent with the uniform brownish colour observed in all 12 rays of those samples (Figures 1 and 2A–D). However, both a brownish and whitish appearance of the rays may be shown by some Sri Lankan 12-rayed star sapphires (see Figure 2E and http://geogallery.si.edu/index.php/10002721/corundum-var-star-sapphire) and also in 12-rayed black star sapphires from Thailand (Schmetzer and Glas, 2001; Figure 2F), which contain inclusion networks of both the hematite-ilmenite series and rutile.

Conclusion

The presence of a single mineral—ilmenite—as the cause of 12-rayed asterism in sapphire was documented here for the first time in the largest such gem known to the authors, a 112.64 ct black star sapphire of probable Sri Lankan origin. For comparison, we examined five smaller star sapphires from Sri Lanka and one star sapphire from Thailand, all of which displayed 12-rayed asterism. Visual observation and optical microscopy showed a similar appearance for both networks of inclusions (i.e. both perpendicular and parallel to the growth bands of the host corundum). Raman spectroscopy confirmed that both sets of inclusion networks in all but one of the Sri Lankan sapphires consisted of ilmenite, which caused both six-rayed stars that constitute the 12-rayed asterism. By contrast, the 12-rayed asterism in Thai star sapphires is attributed to separate networks of hematite-ilmenite minerals and rutile. In addition, separate networks of ilmenite and rutile were confirmed in one of our Sri Lankan samples.

The identity of the mineral(s) causing the asterism in 12-rayed star sapphires can be inferred from the colour of the branches of each six-rayed star: ilmenite corresponds to brownish rays, and rutile produces whitish rays. The sharpness of the rays correlates to the width of the inclusions, regardless of the identity of the mineral that causes them.

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GIT 2016 Pre-Conference Field Trip to Mogok, Myanmar

November 2016

Tasnara Sripoonjan, Saengthip Saengbuangamlam and Thanong Leelawatanasuk

The Gem and Jewelry Institute of Thailand (GIT) organized a field trip to Mogok, Myanmar, to accompany the 5th GIT International Gem and Jewelry Conference, which was held 14–15 November 2016 (see report on pp. 445–447 of this issue). This 9–13 November pre-conference excursion was attended by 15 overseas participants from various fields related to gems and jewellery (i.e. gemmologist, mineralogist, journalist, gem retailer, gem wholesaler, gem collector and retail jeweller): Marcelo E. Souza (Brazil), Dr Geng Li (China), Ioannis Alexandris (Germany), Arent and Helene Heilmann (Greenland), Mary Ng (Hong Kong), Meenu Brijesh Vyas (India), Kentaro Emori (Japan), Yoko Okubo (Japan), William Wold (Netherlands), Sang Phil Oh (South Korea), Young Soo Chung (South Korea), Yuanchan Chaiyawat (Thailand), Chen Shen (USA) and Cynthia Unninayar (USA). The group was led by Aung Naing Thun, a representative of the Myanmar Gem and Jewellery Entrepreneurs Association, as well as three GIT gemmologists (the authors).

The goal of the five-day trip was to examine gem deposits, active mining operations and stone trading in Mogok. Participants had many opportunities to learn about the geology, mining and recovery techniques, as well as ruby and sapphire production. Other attractions included visits to educational facilities, gem markets and several historical pagoda sites.

***En Route* to Mogok:** The group flew from Bangkok to Mandalay and then boarded a van. Our first stop was the Werawsana Jade Pagoda near Amarapura Township, about 20 km from the airport. The pagoda is decorated with several varieties of jadeite jade, including 'ice', green and lavender types. We then visited a gemmological laboratory and school in Mandalay, where we stayed overnight before proceeding to Mogok early the next morning.

Our route followed the Mandalay–Myitkyina highway, passing through an immigration checkpoint near Pyin Oo Lwin in the

Editor's note: This report gives a description of the Mogok area just before it was closed to foreigners by Myanmar's government in December 2016. For two previous Excursions reports on Mogok, see *The Journal*, **34**(1), 2014, 55–67.

A panoramic view of 'Ruby Land' greets visitors to the Mogok valley. Photo by T. Sripoonjan.

Shan Highland, some 67 km east of Mandalay. The trip to Mogok took around six hours on good pavement alternating with dirt road, often quite winding. Upon our arrival, we checked into the King Bridge Hotel and then visited a viewpoint on the main road to the east of the gem mining region. It provided a panoramic vista of the Mogok Valley with numerous villages flanked by forested mountains.

Mogok Monasteries: We visited three pagodas in the Mogok area. At the Phaung Daw Oo temple, a white marble Buddha is flanked on both sides by sacred gilded Buddhas. The Buddhas are brought out for worship and placed on gem-studded, gold-and-silver plinths for one day each year. The plinths are decorated with various gemstones, including ruby, sapphire, jadeite and others. The stones were mainly donated by gem dealers and local people, notably a former governor, and kept as one of the secret treasures of Mogok. Our group was fortunate to see these plinths, which are rarely displayed for visitors.

Chan Thar Gyi is another famous temple in Mogok. It is situated on the hill of Minn Phaya in Shansu Quarter. Like Phaung Daw Oo, this temple contains white marble Buddhas, along with cabinets displaying innumerable gemstones donated by local people. The gems and jewellery on display there are a sign of the cultural affluence and respect for the Buddha by the Burmese people.

The Daw Nan Kyi temple is located in a spectacular setting at around 1,520 m (5,000 ft) elevation, above the western side of Mogok. From there, we could see the town of Kyat Pyin and surrounding hillsides comprising the Mogok Stone Tract.

EN ROUTE *TO MOGOK*

(A) The beautiful Werawsana Jade Pagoda near Amarapura is decorated with jadeite of various colours. (B) Thousands of tons of jadeite slabs are cemented to the surface of the pagoda. (C) U Tommy Thein (left) introduces his gemmological school in Mandalay. Photos by T. Sripoonjan (A–B) and S. Saengbuangamlam (C).

MONASTERIES IN MOGOK

(A) The former governor of Mogok and his son showed us treasures of the Phaung Daw Oo temple. (B) Chan Thar Gyi temple contains a collection of valuable gemstones and antique jewellery. (C) The Daw Nan Kyi Monastery affords an excellent view of the Mogok Stone Tract. Photos by T. Sripoonjan.

Bernardmyo Peridot Deposits: Fine peridot is mined from the Pyaunggaung area near Bernardmyo, located in the northwest part of Mogok. The deposits in this area are well-known for producing peridot from veinlets and pockets within a fine-grained peridotite rock. Although many of the mines are run by the government, we visited a private operation owned by Purify Co. The authors climbed down a shaft on traditional wooden ladders, where we saw active drilling using pneumatic hammers. There also was a small shaft used to transport equipment and mined material. Near this peridot mine is a military station and sanatorium established after the Third Anglo-Burmese War. A cemetery there dates back more than 120 years, based on the years 1888–1898 that were inscribed on headstones of British soldiers.

Baw Mar Sapphire Mine: Located northwest of Kyat Pyin Township, about 18 km west of Mogok, is a well-known blue sapphire mine called Baw Mar. We accessed the site in four-wheel-drive pickup trucks provided by the mine owners. The geology of the area is complex, consisting mainly of regionally metamorphosed rocks, especially calc-silicates and graphitic marble, often with weathered gneiss, and is locally intruded by syenite or pegmatite veins. The mine is operated with heavy machinery, and excavators initially remove up to 20 m of overburden to reach secondary deposits containing the sapphires. The miners use water cannons to wash the gravels from the pit, and the material is then routed to a washing plant.

We had an opportunity to discuss the mine operation with the owners at their home. Our hosts gave us a warm welcome and took our group to view the gem-sorting process. The mine recently has produced blue sapphire in relatively large siz-

PYAUNGGAUNG PERIDOT MINING AREA

(A) The entrance of the Purify Company's peridot mine is located in the mountains of the Bernardmyo area. (B–C) The Purify mine is accessed by a traditional wooden ladder, and a rope is attached to a winch for transporting mining equipment. (D) This view shows the typical underground workings in the Purify peridot mine. (E) Graves of British soldiers from the late 19th century are located near the peridot mines. Photos by T. Sripoonjan.

BAW MAR MINE

(A) The large open pit at Baw Mar is mined for blue sapphire. (B) Miners use water cannons to mobilize gravels in the pit. (C) Sorting of rough blue sapphires is done on-site. (D) U Ye Min Tun (left), one of the owners of the Baw Mar mine, displays some rough and faceted blue sapphires. Photos by T. Sripoonjan (A–B) and S. Saengbuangamlam (C–D).

es (up to 3+ cm in diameter) in low-to-moderate qualities. Fine gem-quality sapphire is occasionally found, and additional production consists of spinel of various colours.

Yadana Shin Ruby Mine: One of the most famous ruby mines of Mogok, Yadana Shin, is located approximately 4 km north-west of the town of Mogok. Yadana Shin is a relatively modern operation that is exploited underground as well as in open pits. Miners access the underground workings using a series of ladders. Ruby mineralization is hosted by fine-grained marble with some brown mica. The ruby-bearing marble pieces are placed in secure bags and transported to the surface using a cable pulley system. All the material then passes into jaw crushers, and the fragments are washed into jigs using water jets. The jigs are hand-picked for ruby, spinel and other gems, and the rejected material is further sorted by workers with metal blades before it is transported to the tailings pile outside the mine, where local people are allowed to go through it. Most of the mine's ruby production is not of high quality, but only a few good stones are needed to make the operation viable.

Ruby Dragon Mine: This mine is located near Yadana Shin in the Bawpadan area. Operated by Ruby Dragon Jade and Gems in a joint venture with the Myanmar government, this is one of the largest ruby mines in the Mogok area. The best overall ruby production occurred in 2012, yielding approximately 450,000 carats. By comparison, in 2016 the mine produced around 100,000 carats of ruby. At the time we visited, mining took place almost 400 m below the surface in a complex network of tunnels following the ruby-bearing marble layers. However, most of the ruby-rich layers were found at around 90 m depth. The mine manager used a scale model of the workings to explain the sophisticated operation. The manager also took us to visit the mine entrance, but unfortunately visitors were prohibited from entering. The gem material (faceted pieces averaging 2–3 ct; exceptionally up to 10 ct) is sorted on-site into various qualities, and the least transparent stones are reportedly heated to improve their clarity.

YADANA SHIN MINE

(A) Yadana Shin is one of the most well-known ruby mines in Mogok. (B) The mine workings are accessed by shafts, (C) which contain wooden ladders and timbering. (D) The mined material is passed through jaw crushers and then into jigs. (E) Workers sort the crushed rock by hand to recover the rubies. Photos by S. Saengbuangamlam (A, C) and T. Sripoonjan (B, D–E).

RUBY DRAGON MINE

(A) The Ruby Dragon mine is surrounded by steep, forested slopes. (B) An elevator is used to access this Ruby Dragon shaft. (C) The mine manager shows a scale model of the underground workings. (D) The air in the shaft is hazy from the mining activities below. (E) Ore carts are used to bring the mined material to the surface. Photos by T. Sripoonjan (A–D) and S. Saengbuangamlam (E).

MOGOK GEM MARKETS

(A) Many kinds of rough samples, faceted stones and some jewellery are offered at the Cinema Lane market. (B) This old cinema gives the gem market its name. (C) Gem traders enthusiastically offer their stones to prospective buyers. (D) A strong torch is an indispensable tool for gem trading. (E–F) Faceted rubies and peridots were available during our visit to Mogok. (G) The gem-trading atmosphere is busy at the so-called blue umbrella market. Photos by T. Sripoonjan.

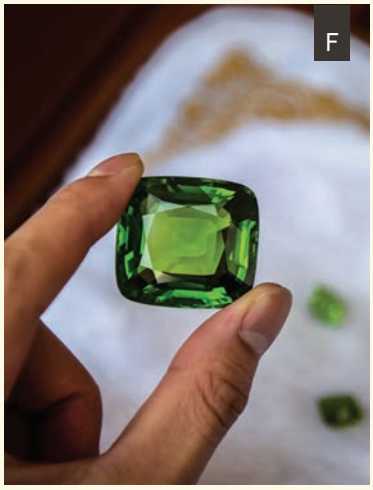

Our international group of participants gathered together at the Mogok Valley viewpoint. Photo courtesy of T. Sripoonjan.

Gem Markets in Mogok: There are two notable gem markets in the town of Mogok, as well as several smaller markets scattered throughout the Mogok area. At these open-air markets, mostly low- to medium-quality rough and cut rubies, sapphires and other gems are traded among the locals. The Yoke Shin Yone gem market (also known as the 'crystal market', or Cinema Lane since it is located within sight of the old cinema) operates daily in the morning. It occupies both sides of the street for about 100 m. Some of the minerals and rough gem parcels there were reasonably priced. Also present were ornamental rocks and less-common specimens, including shells and fossils. A small amount of imitations and synthetics was noted at this market.

We then visited the Panchan (or 'blue umbrella') gem market, the largest in Mogok, which opens from 1:00 pm to around 4:00 pm. In addition to Burmese traders, it is frequented by people of Indian, Chinese and other ethnic backgrounds, along with some Thais. The buyers sit at tables under numerous blue umbrellas and are offered gems by local dealers or brokers. We saw energetic dealers buying and selling gemstones enthusiastically. Interestingly, we encountered some of the same dealers that we saw at the morning gem market, offering us the same stones. The sellers especially focused on foreigners once anyone showed interest in buying, and negotiating the prices was a long, painstaking process. We saw various qualities of ruby, sapphire, spinel and peridot, particularly as rough stones. Nevertheless, the prices seemed relatively high. We were not offered any obvious synthetics or imitations in this market.

Conclusions: The gem town of Mogok has retained its charm as one of the most desirable places for gem enthusiasts to visit. There are several active mining operations in the area, mainly for ruby and sapphire, and mechanized techniques are commonly used. However, the production of fine-quality ruby and sapphire is scarce. We hope that Mogok will once again be open to visits by foreigners in the future.

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Conferences

AGA Tucson Conference

The 2017 Accredited Gemologists Association Conference in Tucson, Arizona, USA, took place 1 February, with the theme 'Cutting Edge Gemology to Keep You in the Loupe'. Attended by 125 people, the event was moderated by AGA president Stuart Robertson and featured eight presentations.

Christopher Smith (American Gemological Laboratories Inc., New York, New York, USA) reviewed various systems for communicating colour in gemmology (i.e. Gem Dialogue, Color Scan, Color Master, GemSet, Gemewizard and World of Color), and then introduced his ColorCodex Color Referencing System (Figure 1). Consisting of a set of colour-range cards, each with six textured foils for a specific hue that range from lighter to darker and more saturated, the ColorCodex provides an intuitive, observer-based system for referencing (not grading) colour in loose or mounted gems.

Elise A. Skalwold (Cornell University, Ithaca, New York, USA) gave two presentations. Her first one reviewed her work, together with Dr William Bassett (retired professor of geology, Department of Earth and Atmospheric Sciences, Cornell University), on various mineralogical and gemmological projects involving mineral physics. Perhaps most intriguing was an investigation to identify a blue inclusion in a macle-twinned diamond that turned out to be olivine; the reason for its anomalous colour is still unknown. Skalwold's second presentation examined the possible use of iolite or calcite as navigation aids by Viking seafarers. Referred to as 'sunstones', the Vikings purportedly looked though them to find the location of the sun through the fog that commonly blanketed the cold seas in the Scandinavian region.

Warren Boyd (R.T. Boyd Ltd, Oakville, Ontario, Canada) profiled two gem materials from the western USA: Montana sapphires and 'Apache Blue stone' from Arizona. A mechanized mining operation by Potentate Mining LLC at the West Fork of Rock Creek in Montana is producing sapphires in a variety of hues, and most are heat-treated to improve their colour and clarity. Apache Blue stone has a turquoise-like appearance and was recovered recently in cooperation with a copper-mining company at a deposit located <1 km from the Sleeping Beauty turquoise deposit near San Carlos, Arizona. It appears to be primarily composed of chrysocolla, along with multiple minerals that formed through supergene processes; most of the material is stabilized before cutting by impregnating it with resin.

Yianni Melas (Limassol, Cyprus) described 'Aquaprase', a relatively new bluish green chalcedony from Africa. The rough material is hand-mined from an open pit, and approximately 80% is processed locally. Chemical analysis has revealed traces of various chromophoric elements in Aquaprase, including Cr, Ni and Cu.

Gary Roskin (International Colored Gemstone Association [ICA], New York, New York) provided some interesting background information on ICA, and then noted various trends in coloured stones that he had

Figure 1: Christopher Smith discusses the fundamentals of colour space before introducing his ColorCodex Color Referencing System. Photo by B. M. Laurs.

seen during the previous few days at the 2017 Tucson gem shows. Among the items he mentioned were irradiated and heated morganite showing brownish pink to orangey pink coloration that was available in relatively large sizes (10–40 ct), blue sapphires from a new deposit in Madagascar (see pp. 391–392 of this issue for more on this material) and an abundance of Cu-bearing tourmaline from Mozambique that showed good colour saturation but was fairly included.

Art Samuels (EstateBuyers.com and Vivid Diamonds & Jewelry, Miami, Florida, USA) described how gemmological knowledge has helped make him money when dealing with diamonds, including faceting the girdle of a 6.4 ct round brilliant to improve its colour grade from H to G; buying brown type IIa diamonds that can be decolourized through high-pressure, high-temperature treatment, so they can be sold (with disclosure) for more money; and requesting that a laboratory recheck a diamond that had received a borderline I_1 clarity grade, resulting in a considerably more valuable SI_2 grade.

Dr Jeffrey Post (Smithsonian Institution, Washington DC, USA) chronicled the history of the Hope diamond, a 45.52 ct type IIb blue diamond at the Smithsonian Institution, and then described his scientific research on this famous gem. Although it shows no fluorescence to UV radiation, it displays long-lasting intense orange phosphorescence (for approximately one minute). Recent analysis of the diamond with time-of-flight laser ablation inductively coupled plasma mass spectrometry showed that it contains an average of only 0.5 ppm boron, which is enough to produce its deep blue colour.

The conference ended with the announcement of a new Hanneman Award for contributions to the literature of gemmology. **William Hanneman** (Monterey, California, USA) announced that the award is being given to two recipients, **John I. Koivula** (Gemological Institute of America [GIA], Carlsbad, California) and **Alan Hodgkinson** (Ayrshire, Scotland). The AGA Gala took place later that evening, where The Antonio C. Bonanno Award for Excellence in Gemology was presented to **Al Gilbertson** (GIA, Carlsbad). This honour recognized Gilbertson's many contributions to gemmology, which included authoring the book titled *American Cut—The First 100 Years*. Published in 2007, it recently became available for free download at https://archive.org/details/AmericanCut--theFirst100YearsTheEvolutionOfTheAmericanCutDiamond.

Brendan M. Laurs FGA

GIT 2016

The Gem and Jewelry Institute of Thailand's 5th International Gem and Jewelry Conference, GIT 2016, was held in Pattaya, Thailand, 14–15 November 2016. It included a pre-conference field trip to Mogok, Myanmar (see report on pp. 436–443 of this issue), and a post-conference excursion to the Chanthaburi-Trat area of Thailand. The conference was well attended, with 306 participants that included 185 Thai nationals and 121 others from 33 countries. There were 84 presenters (e.g. Figure 2) consisting of four keynote speakers, four invited speakers and 30 others who delivered oral presentations over two days in two parallel sessions, as well as 46 poster presenters. Those oral presentations that the authors attended are reported here, and abstracts of all the presentations are available in the conference proceedings volume, which can be downloaded at www.git.or.th/download/GIT2016.pdf.

GIT's Chairman of the Board of Directors **Siripol Yodmuangcharoen** and Director **Dr Pornsawat Wathanakul** delivered brief welcoming speeches to open the conference. Gem-cutting specialist **Victor Tuzlukov** (Moscow, Russia) gave the first keynote

Figure 2: GIT 2016 conference organizers and presenters gather for a group photo. Courtesy of GIT.

speech, titled 'The fourth "C": Today and tomorrow', in which he described changes in the gem-cutting market. Modern gem-cutting techniques are becoming more and more precise (down to the micrometre). Tuzlukov described in detail the judging criteria of the United States Faceters Guild and showed photos of beautifully faceted topaz, spessartine, amber, kunzite, tanzanite and a 219 ct amethyst with 705 facets. **Cynthia Unninayar** (*Jewelry Showcase Magazine*, New York, New York, USA) gave the second keynote lecture titled 'The dozen dominant design directions for fine jewelry in 2017', in which she described the trending design directions as: Mesmerizing Multicolors, Nature's Glory, Lusciously Lacy, All About Anglez, Circular Momentum, Gothic Chic, Evolving Earwear, Fun Finger Fashion, Trendy Tassels & Fringe, Wristeria, Long & Layered and Eco-Jewels. She also discussed Pantone's prediction of 2017 fashion colours and the corresponding gem varieties. For the third keynote lecture, **Dr Gaston Giuliani** (Institute of Research for Development, Vandœuvre-lès-Nancy, France) gave detailed information about the geological environment, timing and geographical distribution (in terms of paleogeography and modern geography) for the most important ruby and sapphire deposits. This fundamental research provides important background knowledge for country-of-origin determinations. The fourth keynote speech was delivered by **Rupak Sen** (Gemfields, Mumbai, India), who provided a detailed historical account of a shift in popularity from diamonds to coloured stones and the passion for them in Asian countries. He emphasized the fact that not only are celebrities taking the lead in this change, but people are now saying 'I do' with coloured stones. He then updated the delegates on Gemfields' projects and initiatives around the globe, including an ethical mining and marketing policy to help ensure the future of the coloured stone industry.

Among the invited speakers, **Didier Giard** (Association Française de Gemmologie, Paris, France) described a shift in the paradigm of the gem and jewellery trade from being more production oriented toward an emphasis on sustainable development. He also proposed an idea for a United Nations 'International day for the sustainable management of the gem mines and pearl farms', which would focus on the traceability of products, energy efficiency and mining regulation. He continued with three more proposals, for the establishment of a 'rainbow passport', an international platform for exchange, as well as possible financial actions. **Francis Errera** (Francis Errera Ltd., Hong Kong) summarized the pricing and marketing of coloured diamonds from the 1970s to 2010s. In 1976, coloured diamonds were cheaper than colourless diamonds. The market changed after 1986 when the Argyle mine in Australia started production. Certainly, consumer awareness also propelled the value of coloured diamonds over the past 40 years. **George Lu** (CIBJO Coral Commission and Chii Lih Coral Co., Taipei, Taiwan) pointed out that the coral used as a gem material is not the same as the coral reefs where most people go snorkelling. The gem corals come from much deeper waters, ranging from several hundred metres to 1,800 m. He went on to describe the taxonomy of corals from various localities and included some amazing images of coral carvings and jewellery from various cultures around the world. **Dr Pornsawat Wathanakul** described GIT's many years of research on the colour grading of ruby and sapphire. She presented GIT's Masterstone sets for 'pigeon's blood' ruby, 'royal blue' sapphire and 'cornflower blue' sapphire in terms of the Munsell system, as well as displaying the Masterstone sets on site during the conference. She also described the importance of a standard lighting system used in the colour-grading environment.

The contributed papers were organized into six sessions: Gem Deposits and Identification; Diamonds; Corundum and Others; Pearls and Others, Innovation and Instrumentation; and Jewelry Trend and Design. **Dr Lore Kiefert** (Gübelin Gem Lab, Lucerne, Switzerland) described the results of her lab's country-of-origin study on demantoid. She specified the two major geological environments in which these garnets formed: serpentinite-related and skarn-related. She went on to characterize the corresponding differences in inclusions, spectral features and chemical composition, and provided further details about demantoid from specific localities, as well as the heat treatment of Russian material. **Tasnara Sripoonjan** (GIT) reported on purple rhodolite from Mozambique, including inclusion features, spectral characteristics and the cause of colour. **Adesoji Adesugba** (Gemstones Miners and Marketers Association of Nigeria, Abuja) described the gem deposits and investment incentives in Nigeria. **Dr Ahmadjan Abduriyim** (Tokyo Gem Science and Kyoto University, Japan) highlighted jadeite from Itoigawa, Japan, and reported the textural, chemical and spectral characteristics in comparison with jadeite from Myanmar, Guatemala and Russia. **Prof. Guanghai Shi** (China University of Geosciences, Beijing) described the geology of placer nephrite deposits in the southern Xinjiang area. He then compared the 'shan' (primary) material and 'zi' (placer) material in terms of the appearance and the price of the finished products. **Dr Visut Pisutha-Arnond** (GIT) gave a presentation for **Dr Henry Hänni** (GemExpert, Basel, Switzerland) on the gemmological properties of 'Sannan Skarn' from Pakistan, a relatively new gem material that resembles mawsit-sit. **Arent Heilmann** (Ministry of Mineral Resources, Nuuk, Greenland) explained the occurrence, colour

and tenebrescence, fluorescence and mining of tugtupite from Greenland. **Dr Jayshree Panjikar** (Panjikar Gem Research & Tech Institute, Pune, India) reported her study of sphene from Mettur Taluk, southern India.

John Chapman (Gemetrix, Perth, Australia) examined how the details of lighting, viewing angle, cutting and colour zoning can affect the colour grading of coloured diamonds. **Seung Kwon Lee** and **Jo Eun Ok** (Wooshin Gemological Institute of Korea, Seoul, South Korea) reported their research on coated-colour diamonds and identification techniques for near-colourless melee-sized synthetic diamonds.

Dr Dietmar Schwarz (Federated International GemLab, Bangkok) and **Saengthip Saengbuangamlam** (GIT) both provided insights into determining the geographic origin determination of blue sapphires. **Thanong Leelawatanasuk** (GIT) described 'golden sheen' and non-sheen sapphires from Kenya, highlighting the gemmological characteristics and microscopic features. **Nguyen Ngoc Khoi** (Hanoi University of Science, Vietnam) provided an update on ruby and sapphire from Vietnam, and classified them into marble, gneiss and basalt types. **Hyunmin Choi** (Hanmi Gemological Institute & Laboratory, Seoul) described blue sapphires before and after high-pressure, high-temperature enhancement, as well as the use of Fourier-transform infrared spectroscopy for identifying this treatment. **Thitikorn Na Nan** (Chiang Mai University, Thailand) described blue lead-glass-filled sapphires. **Dr Tobias Häger** (Centre for Gemstone Research, Johannes Gutenberg-University of Mainz, Germany), characterized strontium aluminate that shows strong phosphorescence and has been sold as apatite.

Nicholas Sturman (GIA, Bangkok) used real-time X-ray microradiography and X-ray computed microtomography to characterize non-bead cultured pearls from the Mergui Archipelago of Myanmar. **Kook Whee Kwak** (Wooshin Gemological Institute of Korea) described the identification of dyed golden South Sea cultured pearls using ultraviolet-visible and photoluminescence spectroscopy. **Geng Li** (School of Gems, China University of Geosciences, Beijing) explained the cultivation and the market for Chinese freshwater cultured pearls, covering both historic and current production. **Sutas Singbamroong** and **Aisha Rashid Almazrooei** (Gemstone and Precious Metal Laboratory, Dubai Central Laboratory, United Arab Emirates) presented the microradiographic structures of natural non-nacreous pearls from *Tridacna* species.

Dr Andreas Burkhardt (Zollikon-Zürich, Switzerland) covered state-of-the-art energy-dispersive X-ray fluorescence instruments and techniques for chemical analysis. **Dr Ewa Wagner-Wysiecka** (Gdansk University of Technology, Poland; Figure 3) reviewed infrared spectral features that can help separate copal from amber. **Dr Nirawat Thammajak** (Synchrotron Light Research Institute, Nakhon Ratchasima, Thailand) covered the radiation treatment of cultured pearls and the use of synchrotron X-ray absorption spectroscopy for gemmological applications. **Dr Chatree Saiyasombat** (Synchrotron Light Research Institute) described a multiple-X-ray-techniques beamline that he is developing for gemmological research applications.

Figure 3: Dr Ewa Wagner-Wysiecka discusses how infrared spectral features can help separate copal from amber. Courtesy of GIT.

Although presentations from the poster session are not covered here, three posters received special recognition in a poster competition: (1) **Meenu Brijesh Vyas** (Gem Testing Laboratory, Jaipur, India) described green spinel from Afghanistan, (2) **Sungjae Kim** (Hanyang University, Seoul) presented a colour-origin study of various beryls and (3) **Charuwan Khowpong** (GIA, Bangkok, Thailand) described the diversity of rubies from Kenya.

Conference attendees celebrated the Festival of Loy Krathong, where prayers and wishes were set afloat in 'krathongs' made with banana leaves and decorated with flowers, candles and incense. The celebration took place on the night of the 'super moon', the closest full moon to Earth since 1948, which was the inspiration for the conference theme of 'The Fullmoon of GEMUnity'.

Prof. Andy H. Shen (ahshen1@live.com)
Gemmological Institute, China University of Geosciences, Wuhan, China

Miro Ng
Guild Gem Laboratories, Hong Kong

Barbara Wheat
Asian Institute of Gemological Sciences
Bangkok, Thailand

Jewelry Industry Summit 2017

The second Jewelry Industry Summit—The Open Forum on Sustainability & Responsible Sourcing in the Jewelry Industry was held in Tucson, Arizona, USA, 29–30 January 2017, just prior to the AGTA GemFair. This year's conference brought together 125 attendees (Figure 4) from many industry groups, including miners, gem dealers, designers, appraisers, retailers, gemmological educators, laboratory personnel, government representatives and members of non-governmental organizations. Holding the Summit just prior to the Tucson gem shows allowed for a diverse representation from many sectors of the industry.

A vision was developed at the first Jewelry Industry Summit (held in March 2016; see *The Journal,* **35**(1), 71–73) that merged ideas from all the participants, and can be summarized into four categories:

1. Procure products in a manner that protects and sustains the environment and respects and benefits the people and communities where these products are found.
2. Use business methods and engage in actions designed to promote and sustain growth and development of the people and communities where products are sourced, manufactured, traded and sold.
3. Continue to take affirmative steps towards ensuring legal compliance, transparency and open and legitimate business practises by actively engaging in and managing everyday actions through the business supply chain.
4. Commit to existing international standards including the *UN Guiding Principles on Human Rights* and *OECD Guidelines for Multinational Enterprises*.

The primary objective of the second summit was to continue to collaborate and collectively engage with members of all sectors of the industry to help further the vision principles outlined above. The four main goals were:

1. Generate broad-based awareness of facts related to the jewellery industry supply chain and responsible sourcing, and explore what works and what does not.
2. Learn about and review progress on current industry-wide initiatives and developments related to sustainable business practises and responsible sourcing.
3. Develop shared visions for key segments of the jewellery-industry supply chain that support the broader industry vision for sustainable business and responsible sourcing.
4. Design prototypes of tools and strategies that enable businesses in the supply chain to make progress through continuous improvement.

To effectively explore and reach the objectives, the firm Innovation Partners International was hired to help guide participants. After an initial interview session, attendees were asked to form groups to discuss what they felt was working and gather examples within or outside our industry that may be beneficial for others to hear. The next task was to identify the biggest challenges each segment of our industry faces regarding sustainability and responsible sourcing. Finally, participants were asked what they could do within their control that would have a ripple effect on their personal segment of the industry.

Throughout the Summit, several speakers provided tangible examples of efforts other industries were employing to address sustainability and corporate responsibility. **Lisa Manley** (Cone Communications, Boston, Massachusetts, USA), who served six years as global sustainability communications director for The Coca-Cola Company, described her work as a sustainability consultant for clients such as Converse, CVS, Hilton, Mars, Quaker, Target, Timberland, U.S. Bank, Wrigley and others. She emphasized that it is okay for businesses to take an advocacy stance, and millennials expect companies to adhere to ethical business practices.

Figure 4: The second Jewelry Industry Summit brought together 125 attendees from various industry groups. Photo by Mariana Photiou.

She cited sustainable business trends such as transparency, collaboration, human rights initiatives, recycling, etc. She challenges her clients to be conscientious, connected to communities where they source and sell, and be radically inclusive and inspiring. Tangible examples include water stewardship, sustainable packaging, climate protection and supporting sustainable communities through women's economic empowerment and active, healthy living. **Thea Polancic** (Clear Space, Chicago, Illinois, USA) gave a passionate presentation on 'Conscious Capitalism' to relay the power of business to create prosperity, beauty and happiness in the world. The Conscious Capitalism movement was popularized by John Mackey, CEO of Whole Foods, and is dedicated to elevating humanity through business. This movement has gained ground rapidly, and Polancic runs the Chicago chapter, which has grown to 1,100 members in 18 months. The main tenets of the movement are to focus on a higher purpose, create value for all stakeholders, encourage caring and passionate leadership, and create healthy and value-based cultures.

Participants were then asked to gather in small groups to create compelling visions for the future of our industry and to identify real actions we could take to bring those visions to fruition (e.g. Figure 5). Each group then presented their visions to the entire audience. The end of the first day concluded with a cocktail reception and poster session, which featured more than 20 presenters.

The second day of the Summit began with a presentation by **Bob Mitchell** (Electronic Industry Citizenship Coalition [EICC], Alexandria, Virginia, USA). Mitchell is a 16-year veteran of Hewlett Packard with more than 10 years in sustainability. He was most recently the Director of Global Social & Environmental Responsibility at Hewlett Packard Enterprise, where he led a team of professionals in human rights, supply-chain responsibility and conflict minerals. Mitchell shared examples of his experiences at Hewlett Packard and the EICC mission and values of a responsible global electronics supply chain. The EICC consists of more than 100 electronics companies, has a combined revenue of more than US$4.75 trillion and directly employs more than 6 million people. Their primary focus is on ethical and conflict-free sourcing of raw materials and labour.

The attendees were then asked to identify action possibilities that they could personally explore and implement. The author's group was inspired by one of the poster presentations—by **Dr Girma Woldestinsae** (Ministry of Mines, Petroleum and Natural Gas, Addis Ababa, Ethiopia)—to provide basic resources and education to students in rural areas, in order to help them learn about and identify potential local natural resources. In his presentation, Dr Woldestinsae enthusiastically shared his experiences educating and encouraging rural school children to look for minerals and gems on their way to and from school. Teachers are asked to form science and coloured-stone clubs through which they can integrate their teaching curricula to educate their students about the characteristics and properties of the rocks and minerals they find. They also focus on stories that encourage thinking about creating added value and turning raw materials into useful products. To assist his project, we proposed providing gemmological training and instrumentation, as well as translating into local languages the Gemological Institute of America's new guide to gem rough booklet that has already been introduced to rural mining communities in Tanzania.

Figure 5: Summit participants broke into small groups to discuss visions for the future of the jewellery industry and to identify actionable tasks to bring those visions to reality. Here, Dr Girma Woldestinsae and Anna Barker review notes from their group. Photo by E. Boehm.

Along with new ideas, a number of initiatives initially introduced at the first Summit were reintroduced for update and further review. For example, **Eric Braunwart** (Columbia Gem House, Vancouver, Washington, USA) and his committee shared developments on eliminating silicosis. His initiative proposes education and use of equipment designed to reduce exposure to ultra-fine particulates from mining and cutting that are known to cause silicosis. His committee presented several possible technological developments that would reduce exposure during the cutting and polishing of beads. Another initiative from the first Summit focuses on mining of rutilated quartz in a remote region of Bahia, Brazil. This responsible sourcing initiative aims to create a model artisanal and small-scale (ASM) mining community that would serve as a guide for other ASM communities. **Brian Cook** (Nature's Geometry, Tucson) proposed empowering the rural rutilated-quartz-mining community by constructing a processing warehouse and lapidary school. He also plans to help the miners and their families create greater food security through the development of organic farming.

Five new initiatives were introduced along with the eight initiatives from the first Summit, so participants divided into 13 teams. Attendees were encouraged to migrate to the initiatives that interested them most to hear their goals and provide input. Group leaders gave brief presentations and conducted discussions with teammates and those who joined in. Participants were encouraged to visit as many different groups as possible and focus on how to overcome challenges and obstacles. This process allowed further refinement of each initiative's goals and helped each group gain additional support and create a prototype that the group could confidently present to the entire Summit. The initiatives and their descriptions, progress, next steps, challenges and resources needed, will be shared via the Jewelry Industry Summit's website www.jewelryindustrysummit.com, Facebook page jewelryindustrysummit and on Instagram at #ResponsibleJewelryStories.

Edward Boehm FGA (edward@raresource.com)
RareSource, Chattanooga, Tennessee, USA

Letters

Comment on the Apparent Anomalous Reflectance of a Sumitomo Synthetic Diamond

In the previous issue of *The Journal*, Hodgkinson (2016) reported observations that he and a colleague had made on a Sumitomo high-pressure, high-temperature (HPHT) synthetic diamond using a Hanneman Diamond Eye reflectance meter. The reading obtained from that sample was much higher than that obtained from a control sample of natural diamond. We show below that this 'anomalous behaviour' has its origin in the different geometries of the natural and synthetic diamonds used in that investigation. The former was faceted as a round brilliant, whereas the Sumitomo sample was a thin polished plate.

The reflectance R in air from the polished surface of an optical material is approximately given by $R = (n - 1)^2/(n + 1)^2$, where n is the refractive index of the material. For diamond $R = 0.172$ at the 'sodium D' wavelength (589.3 nm). Consider a thin pencil of light incident normally on the table of a round brilliant. Approximately 17% of the light is reflected back along the path defined by the incident illumination. The rest of the light enters the diamond where it is refracted and reflected in numerous directions. Very little, if any, of that light travels back along the path defined by the incident illumination.

For a thin plate of diamond, with near-parallel polished top and bottom faces, approximately 17% of the incident illumination is reflected from the top surface. The rest of the light enters the diamond, and about 17% of the light that reaches the rear surface is also reflected. The reflected light from both the top and bottom faces travels back along the path defined by the incident illumination. For a colourless diamond, the total intensity of the reflected light is about 29% of the incident intensity. (This value is obtained by taking into account the multiple reflections that occur within the diamond plate.) If the diamond is coloured, as with the HPHT synthetic studied by Hodgkinson (2016), some light will be absorbed internally, and there is a smaller contribution from the rear surface; however, the total intensity of the reflected light will still be much greater than that observed from the table of a round brilliant. That is why, in Hodgkinson's investigation, "the indicator needle [of the Hanneman reflectance meter] raced across the scale beyond 'diamond' to the extremity of the instrument".

Prof. Alan T. Collins
Department of Physics, King's College London

Reference

Hodgkinson A., 2016. Anomalous behaviour of a Sumitomo synthetic diamond on the reflectance meter. *Journal of Gemmology*, **35**(4), 274–275, https://doi.org/10.15506/jog.2016.35.4.274.

Gem-A Notices

GIFTS TO THE ASSOCIATION

The Association is most grateful to the following for their gifts and donations for research and teaching purposes:

Meg Berry, Fallbrook, California, USA, for pieces of green garnet from Ethiopia.

Guy Borenstein FGA, Gemewizard, Ramat Gan, Israel, for Gemewizard monitor calibration kit containing six faceted pieces of terbium glass.

Dr Marco Campos Venuti, Seville, Spain, for a faceted pollucite with polylithionite inclusions from Pakistan.

Jeffrey Bergman, Primagem, Bangkok, Thailand for two trapiche ruby specimens from India consisting of a hexagonal flat cabochon and a crystal.

Farooq Hashmi, Glen Cove, New York, USA, for two antigorite cabochons from Pakistan.

Syed Iftikhar Hussain, Syed Trading Co., Peshawar, Pakistan, for four chrysoprase cabochons from Australia, and a faceted quartz with actinolite needles from Pakistan.

Marc Jobin, New York, New York, USA, for three spheres of rainbow moonstone from Madagascar.

Mona Khan, Vista Gems, Skillman, New Jersey, USA, for a cabochon of 'Passion amethyst' from Minas Gerais, Brazil.

National Association of Jewellers, London, for a box of paste replicas of famous diamonds, three sets of fashion diamond imitations displaying different shapes and sizes, and four teaching sets of NAJ education stones containing more than 200 various rough and cut specimens.

Mauro Pantò, The Beauty in the Rocks, Sassari, Italy, for a buff-top quartz with chlorite inclusions from Brazil.

Werner Radl, Mawingu Gems, Niederwörresbach, Germany, for one quartz sphere with inclusions from Kongwa District, Tanzania.

Helen Serras-Herman FGA, Gem Art Center, Rio Rico, Arizona, USA, for a 'Mohave Purple turquoise' composite stone.

Leonardo Silva Souto, Cosmos Gems, Minas Gerais, Brazil, for a quartz cabochon with pyrite inclusions from Minas Gerais, Brazil.

Steve Ulatowski, New Era Gems, Grass Valley, California, USA, for a Cr-bearing dravite crystal from Tanzania.

Charles Vargas, Apache Gems, San Carlos, Arizona, USA, for three pieces of rough 'Apache Blue stone' from the Apache Nation, Arizona.

Tak Yi Yung FGA, Shau Kei Wan, Hong Kong, for a monetary donation.

OBITUARY

Evelyn (Eve) Rosemary Symes FGA DGA (D.2002 and 2007), Bath, Somerset, passed away on 6 December 2016. Eve was Treasurer of the South West Branch of Gem-A for a number of years.

Learning Opportunities

CONFERENCES AND SEMINARS

44th Rochester Mineralogical Symposium
20–23 April 2017
Rochester, New York, USA
www.rasny.org/minsymp

Scottish Gemmological Association Conference
28 April–1 May 2017
Stirling, Scotland
www.scottishgemmology.org/conference

3rd Mediterranean Gemmological and Jewellery Conference
11–14 May 2017
Syracuse, Italy
www.gemconference.com
Note: The conference theme is coloured diamonds, and the programme will include several speakers, a round table discussion, pre-conference workshops and a poster competition.

5th Annual New England Mineral Conference
12–14 May 2017
Newry, Maine, USA
www.nemineralconference.org/nema

The 31st Annual Santa Fe Symposium
21–24 May 2017
Albuquerque, New Mexico, USA
www.santafesymposium.org

2017 Society of North American Goldsmiths Conference
24–27 May 2017
New Orleans, Louisiana, USA
www.snagmetalsmith.org/events/conferences

11th International Conference on New Diamond and Nano Carbons
28 May–1 June 2017
Cairns, Queensland, Australia
http://ndnc2017.org

JCK Las Vegas
5–8 June 2017
Las Vegas, Nevada, USA
http://lasvegas.jckonline.com/en/Events/Education
Note: Includes a seminar programme.

Association for the Study of Jewelry and Related Arts (ASJRA) Annual Conference
9–10 June 2017
Boston, Massachusetts, USA
www.jewelryconference.com

Compiled by Angharad Kolator Baldwin and Brendan Laurs

The Gemmological Society of Japan Conference
10–11 June 2017
Tokyo, Japan
www.gakkai.ac/gsj/english

XVIèmes Rendez-Vous Gemmologiques de Paris
12 June 2017
Paris, France
www.afgems-paris.com/rdv-gemmologique

PEG2017—8th International Symposium on Granitic Pegmatites
13–15 June 2017
Kristiansand, Norway
www.nhm.uio.no/forskning/aktuelt/arrangementer/konferanser-seminarer/peg2017/

Scandinavian Gem Symposium 2017
17–18 June 2017
Kisa, Sweden
http://sgs.gemology.se

Sainte-Marie-aux-Mines 54th Mineral & Gem Show
22–25 June 2017
Sainte-Marie-aux-Mines, France
www.sainte-marie-mineral.com/english/modules/cultural-activities
Note: Includes a symposium and lectures.

Tourmaline 2017
23–28 June 2017
Nové Město na Moravě, Czech Republic
www.tourmaline2017.cz

Swiss Gemmological Society Conference and European Gemmological Symposium 2017
29 June–1 July 2017
Zermatt, Switzerland
http://gemmologie.ch/en/current/messages/central-course-egs-2017.php

Northwest Jewelry Conference
11–13 August 2017
Seattle, Washington, USA
www.nwjcon.com

48th ACE© IT Annual Mid-Year Conference
12–15 August 2017
Indianapolis, Indiana, USA
www.najaappraisers.com/html/conferences.html

Dallas Mineral Collecting Symposium
25–27 August 2017
Dallas, Texas, USA
www.dallassymposium.org

28th International Conference on Diamond and Carbon Materials (DCM 2017)
3–7 September 2017
Gothenburg, Sweden
www.diamond-conference.elsevier.com

Hong Kong Jewellery & Gem Fair
13–19 September 2017
Hong Kong
http://tinyurl.com/hbn8y56
Note: Includes a seminar programme.

Denver Gem & Mineral Show
15–17 September 2017
Denver, Colorado, USA
www.denvermineralshow.com
Note: Includes a seminar programme.

IRV Loughborough Conference
16–18 September 2017
Loughborough
www.jewelleryvaluers.org/Loughborough-Conference

11th International Kimberlite Conference
18–22 September 2017
Gaborone, Botswana
www.11ikc.com
Note: Pre- and post-conference field trips will visit diamond deposits in Botswana and neighbouring countries.

World of Gems Conference V
23–24 September 2017
Rosemont, Illinois, USA
http://gemguide.com/events/world-of-gems-conference
Note: Includes a poster session, and pre- and post-conference workshops.

ASA 2017 International Appraisers Conference
7–10 October 2017
Houston, Texas, USA
www.appraisers.org/education/conferences

200th Anniversary Meeting of the Russian Mineralogical Society
10–13 October 2017
Saint Petersburg, Russia
www.minsoc.ru/2017
Session of interest: Natural Stone in History of Civilization (Including Gemology)

Friends of Mineralogy Pacific Northwest Chapter 43rd Annual Symposium: Minerals of the Pacific Northwest
13–15 October 2017
Kelso, Washington, USA
www.pnwfm.org/symposium

Canadian Gemmological Association Conference
20–22 October 2017
Toronto, Canada
www.canadiangemmological.com/index.php/com-virtuemart-menu-configuration/conferences-and-special-events

ICA Congress
21–24 October 2017
Jaipur, India
www.gemstone.org (to be announced on new website)

Geological Society of America Annual Meeting
22–25 October 2017
Seattle, Washington, USA
www.geosociety.org/GSA/events/GSA2017
Session of interest: Gemological Research in the 21st Century: Characterization, Exploration, and Geological Significance of Diamonds and Other Gem Minerals.

9th International Congress on the Application of Raman Spectroscopy in Art and Archaeology
24–28 October 2017
Évora, Portugal
www.raa2017.uevora.pt

The Munich Show
27–29 October 2017
Munich, Germany
www.munichshow.com/en
Note: Includes a seminar programme.

Gem-A Conference
4–5 November 2017
London
www.gem-a.com

EXHIBITIONS

Asia

Treasures of the Natural World: Best of London's Natural History Museum
Until 11 June 2017
National Museum of Nature and Science, Tokyo, Japan
http://treasures2017.jp/outline/english_index.php

Mastery of an Art: Van Cleef & Arpels: High Jewelry and Japanese Crafts
29 April–6 August 2017
National Museum of Modern Art, Kyoto, Japan
http://highjewelry.exhn.jp

Europe

Across Art and Fashion
Until 7 April 2017
Museo Salvatore Ferragamo, Florence, Italy
www.ferragamo.com/museo/en/usa/exhibitions

De Vroomen: Harmony in Colour and Form
12 April–26 July 2017
Goldsmiths' Hall, London
www.thegoldsmiths.co.uk/company/today/events/2017/de-vroomen-harmony-colour-and-form

Warrior Treasures: Saxon Gold from the Staffordshire Hoard
Until 23 April 2017
Bristol Museum & Art Gallery, Bristol
www.bristolmuseums.org.uk/bristol-museum-and-art-gallery/whats-on/warrior-treasures

Authentically Inauthentic?—Jewellery from Pforzheim's Industrial Production
21 May–10 September 2017
Municipal Museum, Pforzheim, Germany
www.schmuckmuseum.de/flash/SMP_en.html

Must-haves—Jewellery Created by Greats of the Craft and **Must-sees—Jewellery in the Arts**
21 May–10 September 2017
Schmuckmuseum, Pforzheim, Germany
www.schmuckmuseum.de/flash/SMP_en.html

Tone Vigeland. Jewelry–Object–Sculpture
Until 11 June 2017
The Design Museum, Munich, Germany
http://dnstdm.de/en/tone-vigeland-schmuck-objekt-skulptur-2

Stone of Heaven. HRH Prince Henrik's Collection of Oriental Jade
Until 27 August 2017
Museet på Koldinghus, Kolding, Denmark
www.koldinghus.dk/uk/exhibitions-2017/stone-of-heaven.html

Vanity: Stories of Jewelry in the Cyclades
Until September 2017
Archaeological Museum of Mykonos, Mykonos, Greece
http://odysseus.culture.gr/h/4/eh41.jsp?obj_id=23576

Jewellery—From Decorative to Practical
Ongoing
Nordiska Museet, Stockholm, Sweden
www.nordiskamuseet.se/en/utstallningar/jewellery

North America

Bijoux Parisiens: French Jewelry from the Petit Palais, Paris
Until 14 May 2017
The Taft Museum of Art, Cincinnati, Ohio, USA
www.taftmuseum.org/cur_exhib

Playa Made: The Jewelry of Burning Man
Until 4 June 2017
Fuller Craft Museum, Brockton, Massachusetts, USA
http://fullercraft.org/event/playa-made-burning-man-jewelry

Spectacular! Gems and Jewelry from the Merriweather Post Collection
10 June 2017–1 January 2018
Hillwood Estate, Museum & Gardens, Washington DC, USA
www.hillwoodmus eum.org/Spectacular-Gems-and-Jewelry

Past Is Present: Revival Jewelry
Until 19 August 2019
Museum of Fine Arts, Boston, Massachusetts, USA
www.mfa.org/exhibitions/past-is-present-revival-jewelry

The Wonderful World of Opals
Until December 2017
New Mexico Museum of Natural History & Science, Albuquerque, New Mexico, USA
www.nmnaturalhistory.org/exhibits/temporary-exhibits/wonderful-world-opals

Gilded New York
Ongoing
Museum of the City of New York, New York, USA
www.mcny.org/exhibition/gilded-new-york

Mightier than the Sword: The Allure, Beauty and Enduring Power of Beads
Ongoing
Yale Peabody Museum of Natural History, New Haven, Connecticut, USA
http://peabody.yale.edu/exhibits/mightier-sword-allure-beauty-and-enduring-power-beads

Australia and New Zealand

Australian Opal Exhibition
3–4 August 2017
Surfers Paradise, Queensland, Australia
www.austopalexpo.com.au

The House of Dior: Seventy Years of Haute Couture
27 August–7 November 2017
The National Gallery of Victoria, Melbourne, Australia
www.ngv.vic.gov.au/exhibition/the-house-of-dior

OTHER EDUCATIONAL OPPORTUNITIES

Gem-A Workshops and Courses
Gem-A, London
www.gem-a.com/education/courses

Gem-A Midlands Branch
Fellows Auctioneers, Birmingham
Email Georgina@fellows.co.uk

- 21 April 2017 (*please note the change in date*)
  Elizabeth Goring—Suffragette Jewellery

DUG Advanced Gemology Program (in English)
6 November–8 December 2017
Nantes, France
www.gemnantes.fr/en

Gemstone Safari to Tanzania
8–25 January 2018
Morogoro, Umba, Arusha, Longido, Merelani and Lake Manyara, Tanzania
www.free-form.ch/tanzania/gemstonesafari.html
Note: Includes options for a lapidary class and/or a private trip to visit ruby mines near Morogoro and Mpwapwa (including Winza).

Lectures with The Society of Jewellery Historians
Society of Antiquaries of London, Burlington House, London
www.societyofjewelleryhistorians.ac.uk/current_lectures

- 27 June 2017
  Andrew Prince—Sparkling Times and My Work So Far
- 26 September 2017
  (*40th Anniversary Lecture*)
  Paulus Rainer—Benvenuto Cellini's Salt Cellar: Some New Thoughts, Some New Discoveries
- 24 October 2017
  Lynne Bartlett—The Rise and Fall of the Chatelaine
- 28 November 2017
  Judy Rudoe—Cartier Gold Boxes: A Visionary Patron and a Bet with Ian Fleming

Gem-A
THE GEMMOLOGICAL ASSOCIATION OF GREAT BRITAIN

The Gem-A blog is live!

- Full of up-to-date information on the latest news and trends
- Exclusive features
- Regular reports from gemmology insiders
- Highlights from our printed publications
- Behind the scenes at Gem-A and industry events

Our top performing blog post from last month?
The Journal Digest from Volume 35/No.4/2016
'Ruby and Pink Sapphire from Aappaluttoq, Greenland'.

www.gem-a.com

Gem-A

THE GEMMOLOGICAL ASSOCIATION OF GREAT BRITAIN

SAVE THE DATE

Gem-A Conference 2017

Saturday 4 and Sunday 5 November

etc.venues County Hall, Westminster Bridge, London

4TH 5TH

New Media

Gem—The Definitive Visual Guide

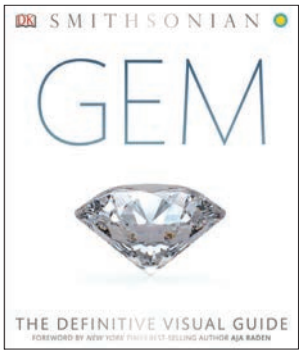

2016. Dorling Kindersley Ltd, London, in connection with Smithsonian Books, Washington DC, USA, www.dk.com/us/9781465453563-gem, 440 pages, illus., ISBN 978-1465453563. £25.00 hardcover.

Beware of a book with multiple editors and no recognized authors. (Five contributors, listed in the acknowledgments, are presumably responsible for the text of this large volume; but the masthead lists 13 editors, exclusive of additional editor named on the cover.) With no single person responsible, but many people 'in charge', facts and meanings can get lost.

In a book review, it is traditional to indicate whether the reviewer liked or disliked the book. I wanted to like this book, but it pains me to note that this guide to gems, while beautiful, is by no means definitive. Instead, it is fraught with errors and mischaracterizations.

There are three main aspects to such a guide book: its organization, its words and its images. All three have problems, as well as some positive aspects.

I have several comments on the book's organization. The book alternates gem characterization pages (or two-page spreads) with descriptive pages about jewellery history or specific jewels. This is a strong positive feature, since the jewellery pages are anything but boring and are profusely illustrated. As jewellery and its history are not areas of my expertise, I am not competent to find errors on these pages and they read very well for me. The characterization pages, however, tended to catch my eye for their errors, inconsistencies or odd placement. These pages are divided into the following categories: Native Elements, Gemstones, Organic Gems, and Rock Gems and Rocks. This is an unfortunate way to slice up the 'gem universe', since the only non-metallic native element considered is diamond, and the ordering scheme (which follows the Dana system) does not start with the most important gems, but with rather insignificant ones. (If you were looking in a gem book for the characteristics of diamond, would you look after copper and before pyrite?) Minerals are defined by their chemical compositions *and their structures*. The book neglects even the mention of structure, so the reason for organizing gem minerals by the Dana system—by anions and not cations, rather than, say, considering all copper minerals together—is not obvious. There are also errors with how some minerals are categorized. For example, variscite, an aluminium phosphate, is listed out of order on page 104 with the carbonates.

Regarding the book's words, these are found in several blocks on the characterization pages: main text, characterization box, figure captions, figure labels and a pithy quote. Among my issues with the words:

- Regarding the treatments mentioned on page 31, laser drill holes in diamonds are much likelier to be filled with a high-RI glass than with epoxy resin.
- Page 23: Absorption spectra depend not only on specific (chromophore) elements, but also their local environment (chromium causes different spectra in ruby, red spinel and red garnet, not to mention green emerald). And there are other causes for absorption besides chromophores, such as the structural defects in pink diamonds.
- Pages 44 and 48: For some reason, RI values are given for platinum and copper. Since metals are opaque (except in very thin sections), it would be more meaningful to provide reflectivity, or to omit such values entirely.
- Page 71: Sapphire does not have adamantine lustre, but rather vitreous.
- Page 88: Cassiterite localities are listed in two places and the lists do not match.
- It is unlikely that synthetic topaz was used in the restoration of the Patiala Necklace (page 91), as this was not yet a commercially significant material in gem quality, and natural (and treated) topaz was both plentiful and inexpensive.
- Page 98: When stating, "Calcite has the largest number of different crystal structures of any mineral…", it should say crystal *habits* here. Calcite has only one crystal structure.
- There is an error in transcribing ancient Greek on page 117: 'γονια' (*gonia*) means angle, not 'gouia'.
- Page 157: 'Black onyx' is not onyx, which is striped; it is instead heat-treated porous chalcedony.

The publisher DK has done its usual excellent job of finding images. However, I have some issues with the figures (mainly their captions and labels), among them:

- The size (or at least weight) of most objects in the images is not indicated.

- If a gem is photographed in diffuse lighting, it will generally not display 'fire' (which instead is seen when the edge of a light ray is partly refracted, leading to a flash of spectral colour). The caption for a colourless 'cut taaffeite gemstone' on page 87 asserts that fire is visible, but none is seen in the photograph.
- The causes of 'fire' should be discussed. Double refraction is not the primary cause of fire, although it can help. The same is true of a high RI. The main cause of fire in gemstones is *dispersion*, the tendency of rays at the opposite end of the visual spectrum—i.e. red and blue/violet—to take different paths through a gem because of their different refractive indices.
- Page 14: The example provided for carbonates is chrysocolla (a silicate, not a carbonate), with a label pointing to chrysocolla and saying it is 'blue azurite'. There is azurite (a carbonate) on the specimen, but it looks black, not blue, here.
- Page 21: Unless African orange sapphires are included in the term 'padparadscha', I question whether these gemstones are as affordable as indicated on the figure.
- Pages 24–25: This list of sources for the various gem varieties, while helpful, is not exhaustive.
- Page 66: The 'modified crystals' of pyrite show cube and pyritohedral faces, not cube and octahedral faces.
- On page 72, the bipyramidal 'colourless rough' crystal is described as having prismatic shape. And the so-called padparadscha looks instead like a pink sapphire, possibly with some rust staining.
- The Timur Ruby is not discernible in the famous portrait of Queen Elizabeth II on page 78.
- Page 88: The example labelled 'Specular Hematite | Rough' does not show specular hematite, which forms in flat plates.
- On page 114, lapis lazuli is given as the anniversary gem for both the 9th year (caption title) and the 7th year (text of caption).
- The 'traditional triangular step cut' on page 116 has a four-sided profile, not a three-sided one. I would call it a lozenge shape instead.
- In the amethyst images/text on page 136, an apparent flaw is visible in the upper left corner of the 'internally flawless' step cut, and colour zoning is still visible in the mixed cut, which was supposedly fashioned to minimize this effect.

Various additional examples of mistakes or mischaracterization have not been mentioned here. So, why these many problems? As alluded to above, this book has no single responsible author and more than a dozen editors. But with a 'critical mass' of editors, the result can be a massive game of 'telephone'. An urgent deadline and easy access to the Internet may lead the unwary to create a product that is 'good enough'…but not, in this case, definitive.

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Gemstones—Terra Connoisseur

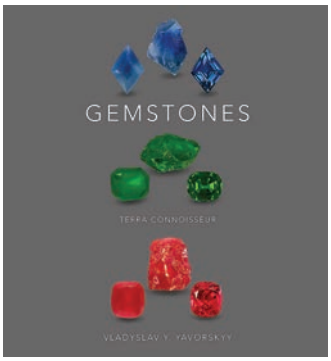

By Vladyslav Y. Yavorskyy, 2017. Yavorskyy Co. Ltd, New York, New York, USA, http://ivynewyork.com/gemstonesbook, 235 pages, illus., ISBN 978-0692784990. US$88.00 hardcover.

This is the third book in the *Terra* series, after spinel and garnet, and it follows the style of previous *Terra* works: colourful and beautiful. They have been created by a true artist: Yavorskyy loves nature, is a fine photographer and has travelled the world in search of his passion—rough gem materials.

There is very little text in *Gemstones*, with most pages being full of colour. Like a kaleidoscope, photos are often practically stacked upon each other, creating a somewhat different look from the usual gem book. The pages often show ethereal photos from the area of the gem being featured, with mining shots, miners, rough stones and finished gems telling a story within that page. Maps have been used throughout from antique prints, with colourful groups of gems and rough on each corner (which, as an antiquarian map lover, I found a bit unnecessary).

The book's contents are highlighted on pages 7–8, and even these two pages have gem photos peeking out. Portions of the text are listed that have been authored by various experts and friends. The first 40 pages cover several topics, including the author's forward, the history of gemstones, gem cutting and lighting. The history section, while succinct in its eight pages, hit many highlights with photos reproduced from various museums that are credited. The gem cutting section is basic, but well done in 10 pages, mostly consisting of photos of gems and a few lapidaries shown cutting as well as the related machinery. I particularly liked this statement: "...so the essence of the craft lies in the preforming stage; this is when the destiny of a gem is shaped". The lighting chapter consists of two pages showing the different looks achieved in white vs. somewhat yellow light, with tips that might be use-

ful for interested readers trying their hand at gem photography.

The next 44 sections cover specific gemstones that Yavorskyy has been involved with, ranging from diamond to fluorite in no particular order. His stated favourite gemstone is spinel, which is covered in seven of the 44 sections (categorized as: rare, blue, mauve, grey, lavender, red and pink). This gives the author many pages to feature various stories from Sri Lanka, Tanzania, Burma and Vietnam. Most of these are two pages long, but the red spinel chapter is 20 pages! Each of the gem sections show extraordinary cut stones, photos of nearby areas (often at sunset) and the local people involved with gems. The hundreds of gems photographed—most with their carat weight listed—may seem a bit like a fancy catalogue of the author's inventory, but with that said the gems are beauties. Repeated on most of these pages featuring the cut stones is printed "all [gem name] in these pages are natural and untreated". Although a bit redundant, it highlights the importance to the author of untreated gems.

The final dozen pages briefly cover other gem materials and gem properties, how to be successful in the gem business, gem shows and gemstones of the future, with an index of gem varieties on the final page.

The inside front and back covers are the same: a group photo of several hundred gemstones. Many are used throughout the book in various places, and some are seen more often than others.

In this reviewer's opinion, most anyone interested in gems will enjoy this book. Several friends saw the book as I was reviewing it, and expressed interest in acquiring a copy. They felt it was a good 'coffee table' book to page through with an abundance of beautiful colour photos that anyone would enjoy. Not all gem books are this beautiful.

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OTHER BOOK TITLES

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Asterism—Gems with a Star
By Martin P. Steinbach, 2017. Self-published, 900 pages, ISBN 978-3000504945. US$199.00 hardcover.

Ruby & Sapphire: A Gemologist's Guide
By Richard W. Hughes, 2017. Lotus Publishing, Bangkok, Thailand, 816 pages, ISBN 978-0964509719. US$200.00 hardcover.

Diamond

Botswana Diamond Jewellery
By Michael C. Brook, 2016. Self-published, 136 pages, ISBN 978-9996804182. US$75.00 hardcover.

Diamond—The Ultimate Gemstone (MINERAL Monograph No. 19)
Ed. by Jeff W. Harris and Gloria A. Staebler, 2017. Lithographie Ltd, Arvada, Colorado, USA, 152 pages, ISBN 978-0983632351. US$40.00 softcover.

Fancy Color Diamonds: The Pricing Architecture
By Eden Rachminov, 2016. Self-published, 200 pages. US$240.00 hardcover.

Kohinoor: The Story of the World's Most Infamous Diamond
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Compiled by Angharad Kolator Baldwin and Brendan Laurs

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Silver, Freiberg, Erzgebirge, Saxony, Germany
Specimen courtesy of Collector's Edge Minerals, Inc.

Coming Soon:

The Sisk Gemology Reference

by Jerry Sisk

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The owl is small,
but its voice is loud.

— Tamil proverb

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Padparadscha Sapphires from Sri Lanka • 4.04 ct, 10.08 x 7.55 x 5.72 mm • 2.66 ct, 7.77 x 7.5 x 5.3 mm
Blooms from Pala International Grounds • Photo: Mia Dixon

The Journal of Gemmology

Volume 35 / No. 6 / 2017

Gem-A
THE GEMMOLOGICAL ASSOCIATION OF GREAT BRITAIN

The Gemmological Association of Great Britain

SSEF
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The Sisk Gemology Reference
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Cover Photo:

A new approach for microscopically distinguishing natural from synthetic ametrine is described on pp. 506–529 of this issue. Shown in this composite photo are three custom-faceted natural ametrines: a 19.87 ct round StarBrite cut, a 20.35 ct cushion ZigZag cut and a 13.69 ct square StarBrite cut. Courtesy of John Dyer Gems, Edina, Minnesota, USA; photos by Ozzie Campos.

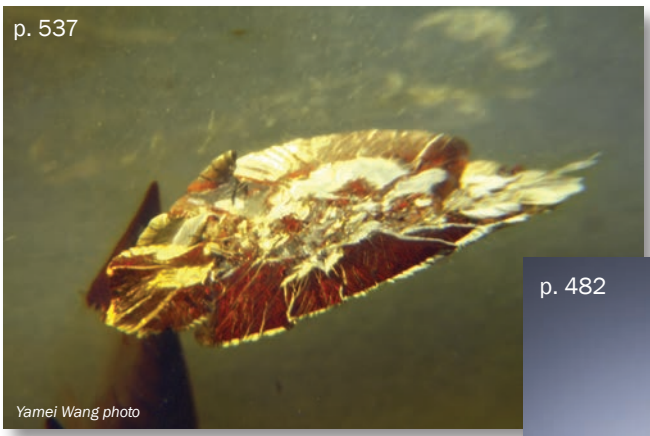

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Understanding Gems™

Research Tools at Your Fingertips

The core foundations of the Gemmological Association of Great Britain are gemmological knowledge and education, which are furthered through Gem-A's courses, publications, website and annual conference, as well as by the tools and books that are available through the Association's instruments division. Gem-A's leadership role in disseminating high-quality gemmological knowledge is exemplified by its flagship scholarly publication, *The Journal of Gemmology*, which has published ground-breaking technical articles from researchers worldwide since its inception in 1947.

I am pleased to announce that as of April 2017, the entire 70-year archive of *The Journal* has been posted online. This collection of PDF files (currently numbering 259 issues) is accessible by visiting *The Journal*'s website at https://gem-a.com/news-publications/publications/journal-of-gemmology. The most recent issues continue to be accessible only to Gem-A members in the 'Latest Issues' section of the website, while the rest of the collection is freely available to anyone via '*The Journal* Archive'. And there is more good news: Also available online is the full archive of Gem-A's trade publication, *Gems&Jewellery*—and its predecessor, *Gem & Jewellery News*, going back to its inception in 1991—through *G&J*'s home page at https://gem-a.com/news-publications/publications/gems-jewellery.

While *The Journal*'s archive is clearly a valuable storehouse of gemmological information, how do you go about finding what you are looking for? The answer lies in *The Journal*'s cumulative index, which also can be downloaded as a PDF file from *The Journal*'s website. This index was recently updated to include all issues through 2016, and it is our intention to continue to update it annually, so separate volume indexes will no longer be prepared. The index can be searched for any keyword or author that you are looking for, and the combination of this resource with access to the full archive of back issues puts all of the research published in *The Journal* at your fingertips.

For those wishing to dive even deeper into research published in *The Journal*, I invite you to visit the Data Depository, which is freely available online at https://gem-a.com/news-publications/publications/journal-of-gemmology/data-depository. There you will find supplemental data, diagrams, photos and videos that accompany some of the recent articles that have appeared in *The Journal*.

Gem-A is pleased to make these valuable resources available to help with your research and continuing education. Please use and enjoy them!

Brendan M. Laurs
Editor-in-Chief

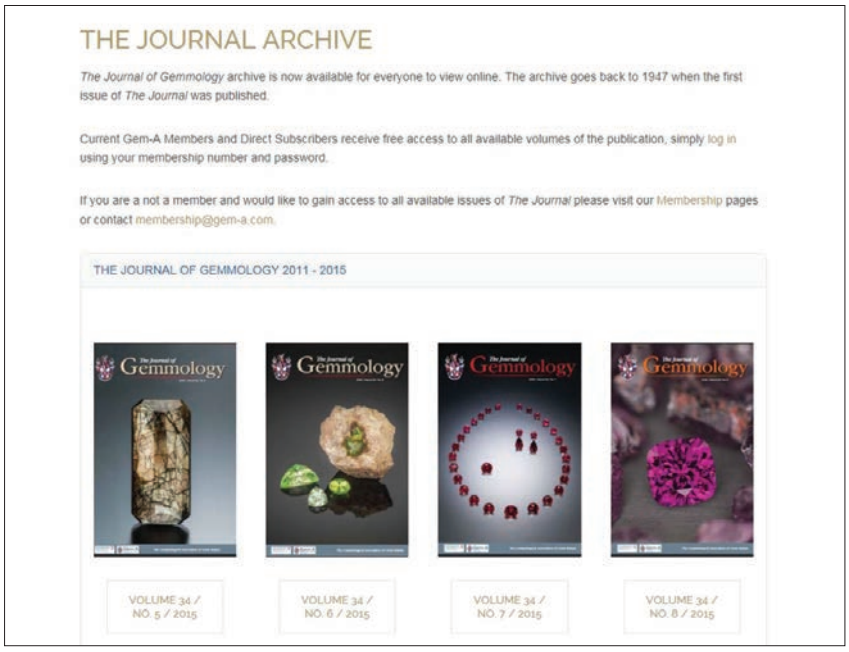

The full Journal *archive is now available online.* Journal *issues that were published before 2005 (i.e. without currently accessible digital files) were scanned and processed using character-recognition software to make them fully searchable. All illustrations were scanned using settings that were optimized to maintain a good balance between file size and resolution, keeping download times as short as reasonably possible.*

What's New

INSTRUMENTATION

Gemchrom EOS Diamond Colorimeter

The EOS Diamond Colorimeter from Italy-based Gemchrom was released in January 2016. The compact instrumentation determines the colour grade of unmounted polished diamonds of 0.10–20.00 ct in the D–M colour range with a clarity grade of at least VS_2. The grading time is less than 20 seconds per stone, and results can be reported according to GIA, HRD and IGI grading systems. The unit is self-calibrating, with a built-in centring device and an LED lighting system that has a lamp life of 6,000 hours. The unit weighs 4 kg and measures 17.7 × 21.2 × 29.3 cm, and comes with a separate label printer. For more information and a demonstration video, visit www.gemchrom.com. *CMS*

GoSpectro Smartphone-based Spectrometer

In September 2016, ALPhANOV of Talence, France, released the GoSpectro device, a visible-range (380–750 nm) spectrometer that works with a camera-equipped smartphone or tablet. Spectral resolution is 10 nm with 1 nm accuracy. Weighing just 30 g (55 × 20 × 20 mm), it is highly portable and works with Apple iOS and Android apps, enabling the user to save and email spectra. The software also can perform baseline correction and spectral subtraction, and compare spectra with external databases. The unit is priced at €300. Visit www.alphanov.com/223-news-gospectro—the-power-of-spectroscopy-at-your-fingertips.html. *CMS*

OGI Systems DiaTrue Mobile

In April 2017, OGI Systems Ltd. (Ramat Gan, Israel) launched a new synthetic diamond detector called DiaTrue Mobile. This portable device follows the development of the previous desktop models (DiaTrue and DiaTrue XL). It rapidly scans both single stones and parcels (0.001 ct or larger), and the analysis can then be shared using a mobile device via WhatsApp and email. The unit weighs 1.3 kg and measures 9.5 × 6.8 × 20.0 cm. Visit www.ogisystems.com/diatruemobile.html. *BML*

SSEF PearlScan

In March 2017, the Swiss Gemmological Institute SSEF released PearlScan, which is designed to quickly count and measure the dimensions of large quantities of strung pearls. The system consists of an A4 scanner, computer and software, and produces images and a detailed report of the number, diameter and roundness factor of each pearl. PearlScan is sold through SSEF's subsidiary SATT Gems in Basel, Switzerland. Visit www.sattgems.ch/pearlscan. *CMS*

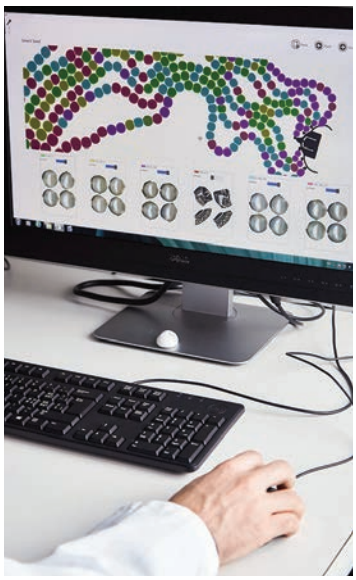

NEWS AND PUBLICATIONS

CIBJO Blue Books Updated

In February 2017, the latest editions of several CIBJO Blue Books (Diamond, Gemstone, Pearl, Coral and Gemmological Laboratory) became available for download from www.cibjo.org/introduction-to-the-blue-books. The Blue Books provide definitive grading standards and nomenclature, and are periodically updated by CIBJO commissions that include representatives of gem trade organizations and laboratories. PDF downloads are free to CIBJO members and to those belonging to a CIBJO-member organization, and otherwise cost CHF9.90 for each Blue Book or CHF49.90 for a set of all six books (i.e. those mentioned above, as well as the 2012 Precious Metals Book). *CMS*

Gemmological Society of Japan 2016 Conference Abstracts

In August 2016, extended abstracts from 16 lectures given at the Annual Meeting of the Gemmological Society of Japan, held from 28 June to 2 July 2016, became available at www.jstage.jst.go.jp/browse/gsj. The documents are in Japanese with English summaries or keywords, and cover a range of topics including melee-sized synthetic diamonds, new technologies, pearls and more. *CMS*

GIA News from Research: Sapphires from Baw Mar, Myanmar

In February 2017, a report titled 'An in-depth gemological study of blue sapphires from the Baw Mar mine (Mogok, Myanmar)' was posted by the Gemological Institute of America at www.gia.edu/gia-news-research/blue-sapphires-baw-mar-mine-mogok-myanmar. The Baw Mar mine has recently produced a significant amount of fine blue sapphires with gemmological properties somewhat different from those typically recovered in the Mogok area. The blue colour of stones from the northern part of the mine is medium to dark, while material from the southern portion is lighter blue. All of the sapphires have a trace-element composition similar to those from metamorphic-type deposits, such as those from Sri Lanka and some sources in Madagascar. *CMS*

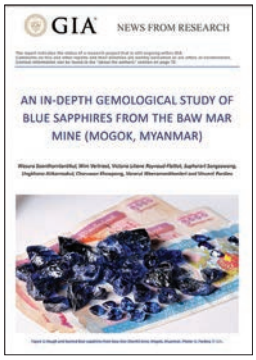

GIA News from Research: Sapphires from Bemainty, Madagascar

In February 2017, GIA posted a report titled 'Sapphires from the gem rush Bemainty area, Ambatondrazaka (Madagascar)' at www.gia.edu/gia-news-research/sapphires-gem-rush-bemainty-ambatondrazaka-madagascar. It provides a description of the Bemainty area (near Ambatondrazaka) and other gem corundum sources in north-eastern Madagascar, as well as the gemmological features of 38 sapphire samples (mostly blue but also some pinkish orange). The report concludes that these sapphires will be difficult to distinguish from those of other metamorphic-type deposits. *CMS*

GIA News from Research: Sapphires from Chanthaburi, Thailand

Posted online by GIA in February 2017, 'A study of sapphire from Chanthaburi, Thailand and its gemological characteristics' presents the results of research on 59 blue to greenish blue samples from the Khao Ploy Waen area of Chanthaburi. The study sam-

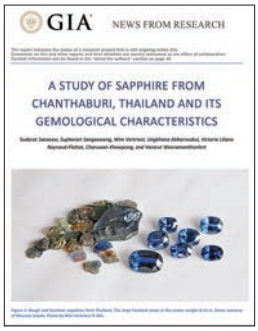

ples revealed features similar to those of sapphires from other basalt-related origins. Nevertheless, they are distinguishable from magmatic-type sapphires mined in Cambodia and Nigeria. Visit www.gia.edu/gia-news-research/sapphire-chanthaburi-thailand-gemological-characteristics. *CMS*

GIT Lab Update: Grandidierite from Madagascar

In March 2017, The Gem and Jewelry Institute of Thailand in Bangkok released a report titled 'Gem-quality grandidierite from Madagascar'. It describes six rough samples received in September 2016. The report suggests that the depth of their bluish green colour could be related to iron content. Download this and previous GIT reports at www.git.or.th/articles_technic_en.html. *BML*

LAB UPDATE

"GEM-QUALITY GRANDIDIERITE FROM MADAGASCAR"

The Goldsmiths' Company *Technical Journal*

Issue 16 (Summer 2016) of this journal is now available at http://technical-journal.thegoldsmiths.co.uk/wp-content/uploads/2016/07/Technical-Journal-Issue-16.pdf. It features an update from the Assay Office; a profile of The National Association of Jewellers; an introduction to modelling, moulding, and other methods of creating precious-metal *objets d'art*; a report on the 2016 Goldsmiths' Craft & Design Council Awards; a feature on Baird & Co, UK's largest gold refiner and the sole producer of rhodium bars; a report on the 29th Santa Fe Symposium on Jewelry Manufacturing Technology; and a description of a new micro-pavé setting technique. *CMS*

PDAC Diamond Abstracts

Abstracts are available from the March 2017 conference of the Prospectors & Developers Association of Canada, held in Toronto, Ontario. A session titled 'Diamonds in Africa: Part 2—The rest of the story' consisted of six presentations on diamonds from Angola, Lesotho (Letseng), West Africa (Sierra Leone, Guinea and Liberia), Zimbabwe and Namibia, as well as techniques for diamond resource evaluation. Download the abstracts at www.pdac.ca/convention/programming/technical-program/sessions/technical-program/diamonds-in-africa-part-2-the-rest-of-the-story. *BML*

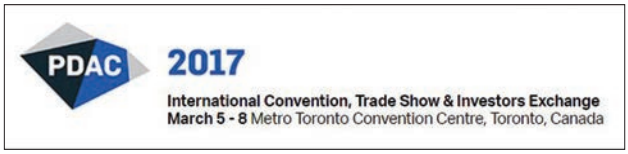

SSEF *Facette*

In February 2017, the Swiss Gemmological Institute SSEF released *Facette Magazine* No. 23 at www.ssef.ch/fileadmin/Documents/PDF/640_Facette/SSEF-Facette-23.pdf. This issue covers emerald fissure filling and cleaning; rare and unusual stones (such as pezzottaite, musgravite and taaffeite) seen recently at SSEF; neutron and X-ray tomography of emeralds; a description of the historic 'Sleeping Lion Pearl'; purple garnets from Mozambique; blue sapphires from Bemainty, Madagascar; oiled rubies; time-of-flight mass spectrometry; opalized dinosaur bone; fake *Tridacna* pearls; exceptional jadeite; an eskolaite inclusion in synthetic ruby; treatment of and research on golden cultured pearls; blue colour in type IIb diamonds; an Umba ruby with a zircon spectrum; heated pink sapphire in antique jewellery; gibbsite as a coral imitation; age dating of pearls offered as a lab service; testing and sorting colourless diamond melee; SSEF news and instruments; and more. *CMS*

SSEF Trade Alert: 'Kashmir-like' Sapphires from Madagascar

SSEF
TRADE ALERT
Kashmir-like' sapphires from Madagascar entering the gem trade in large sizes and quantities

In early 2017, the Swiss Gemmological Institute SSEF studied a 'significant number' of sapphires from the new deposit at Bemainty, Madagascar. This trade alert focuses on those samples with a 'Kashmir-like' appearance, including a velvety blue colour appearance, and how to distinguish them from Kashmir sapphires. Typical features of Bemainty sapphires include exceptional clarity (even in large-sized stones), narrow growth zones, and the lack of pargasite and tourmaline inclusions that are characteristic of Kashmir sapphires. In addition, the sapphires from the two localities can be separated by their trace-element composition. Download the March 2017 report at http://tinyurl.com/mwctgfh. *CMS*

World Bank Report: Ethiopia's Coloured Gemstone Industry

An Analysis of the Commercial Potential of Ethiopia's Coloured Gemstone Industry
WORLD BANK GROUP

The World Bank recently commissioned a study of Ethiopia's coloured stone industry to learn more about the state of the industry in terms of commercial and social development. The resulting June 2016 report, 'An analysis of the commercial potential of Ethiopia's coloured gemstone industry', reveals factors that are contributing to and limiting its commercial success in light of lessons learned from other gem-producing nations, including Afghanistan, Australia, Brazil, Madagascar, Nigeria, Sri Lanka and Tanzania. Visit http://documents.worldbank.org/curated/en/386891474020338559/An-analysis-of-the-commercial-potential-of-Ethiopia-s-coloured-gemstone-industry. *CMS*

OTHER RESOURCES

Gemstone Knowledge Hub

Launched in April 2017, this new resource contains science-based information on various aspects of coloured gemstones, with the goal of enhancing sustainability efforts and providing education and training for the coloured-stone supply chain. Topics include coloured stone varieties, mining and geology, processing and manufacturing, environmental/social/gender issues, and economic development impacts. The hub is a collaboration of the University of Delaware's Department of Geography, the University of Queensland's Center for Social Responsibility in Mining and the University of Lausanne's Faculty of Geosciences, and is supported by the Tiffany & Co. Foundation. Visit the hub at www.sustainablegemstones.org. *BML*

What's New provides announcements of instruments, technology, publications, online resources and more. Inclusion in What's New does not imply recommendation or endorsement by Gem-A. Entries were prepared by Carol M. Stockton (CMS) or Brendan M. Laurs (BML), unless otherwise noted.

Gem Notes

COLOURED STONES

Amethyst from Brazil with Interesting Inclusion Patterns

During the FIPP 2016 International Gemstone Show in Teófilo Otoni, Brazil, that took place in August, a new find of amethyst debuted with interesting zoned patterns created by inclusions. The deposit was discovered in November 2016 in Minas Gerais, Brazil, and from approximately 10 kg of rough material (e.g. Figure 1), about 4,000–5,000 carats were cut and polished as cabochons and tablets in a variety of shapes (e.g. oval, pear and marquise), including a large number of matched pairs (e.g. Figure 2). These stones were marketed as 'Passion Amethyst' (due to their red and purple coloration) at the February 2017 gem shows in Tucson, Arizona, USA, where they were exhibited by gem dealer Mona Khan (Vista Gems, Skillman, New Jersey, USA). One of the polished tablets was kindly donated to Gem-A by Khan, and was examined for this report.

Figure 1: Two crystals of amethyst from Brazil (up to 2.7 cm long) show layers of inclusions along 'phantom' growth faces. The c-axis of both crystals is approximately vertical. Courtesy of Michele Macrì; photo by B. M. Laurs.

The attractive colour patterning is caused by layered assemblages of inclusions (i.e. 'phantoms') that crystallized at distinct intervals on the growing rhombohedral faces of the amethyst. Although the inclusions were not analysed to confirm their identification for this report,

Figure 2: Various patterns created by inclusions are visible in these rough and cut amethyst specimens. The largest polished sample measures 24 × 19 mm. Photo by Jeff Scovil.

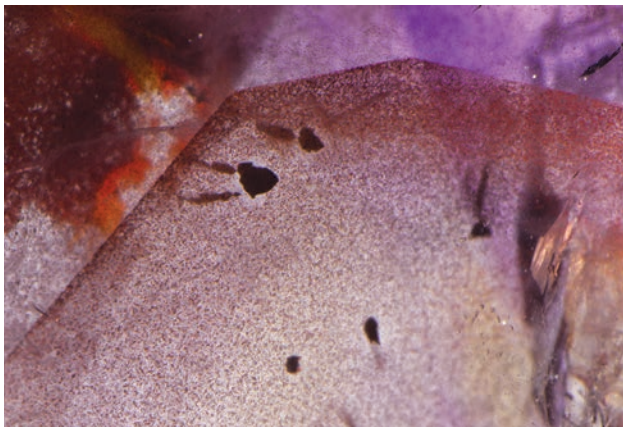

Figure 3: A phantom layer of what appear to be hematite particles is shown here in 'Passion Amethyst' from Brazil. Photomicrograph by N. D. Renfro; image width 5.6 mm.

they appeared typical for quartz, most probably consisting of orangey red to yellow brown iron oxides/hydroxides (i.e. hematite and goethite) and dark greenish grey chlorite. During crystallization of the amethyst, the typical sequence of the phantoms started with particles of hematite (Figure 3) followed by particles of chlorite and finally by local brush-like bundles of hematite/goethite that were oriented perpendicular to the crystal faces. Cutting and polishing brought out various inclusion-related patterns and colours that were superimposed over the pale purple body colour of the host amethyst, creating an unusual appearance.

Brendan M. Laurs FGA and Nathan D. Renfro

Beryllonite from Pakistan

Beryllonite ($NaBePO_4$) is an uncommon mineral that is more typically seen as a mineral specimen than as a faceted gemstone. Nevertheless, its hardness of 5½–6 on the Mohs scale makes it suitable for faceting and use in gently worn jewellery. Both chatoyant cabochons and transparent faceted gems are sold as collector's stones, but they have seldom been documented in the gemmological literature (e.g. Koivula and Kammerling, 1991; Muyal and Sun, 2016).

Figure 4: Pakistan is the source of this beryllonite, which weighs 14.79 ct and is completely colourless. Photo by Dean Brennan.

During the February 2017 Tucson gem shows, Dudley Blauwet (Dudley Blauwet Gems, Louisville, Colorado, USA) showed one of the authors (BML) a faceted 14.79 ct beryllonite from northern Pakistan (Figure 4). He purchased the rough material 15–20 years ago in Chhappu village in Pakistan's Braldu Valley. The crystal was large (338.1 g), but Blauwet hesitated to send it to his cutting factory because he could not determine how much gem material was inside. In March 2016 he finally sent it for cutting, and the factory returned 102 pieces weighing 176.94 carats. The largest gem weighed ~28 ct, while the two largest clean stones were between approximately 9.7 and 8.6 ct, with the majority less than 3 ct including numerous melee-sized stones.

Blauwet loaned the 14.79 ct beryllonite to authors CW and BW for examination. It measured 17.81 × 14.56 × 10.28 mm and was so colourless that it appeared silver-white. The RIs were 1.551–1.560 (birefringence 0.009) and the hydrostatic SG was 2.81. It was inert to UV radiation. These properties are consistent with those reported for beryllonite, and the identification was confirmed by Raman analysis with a GemmoRaman-532SG instrument. Energy-dispersive X-ray fluorescence (EDXRF) chemical analysis with an Amptek X123-SDD instrument revealed only the expected major amount of P and no significant trace elements.

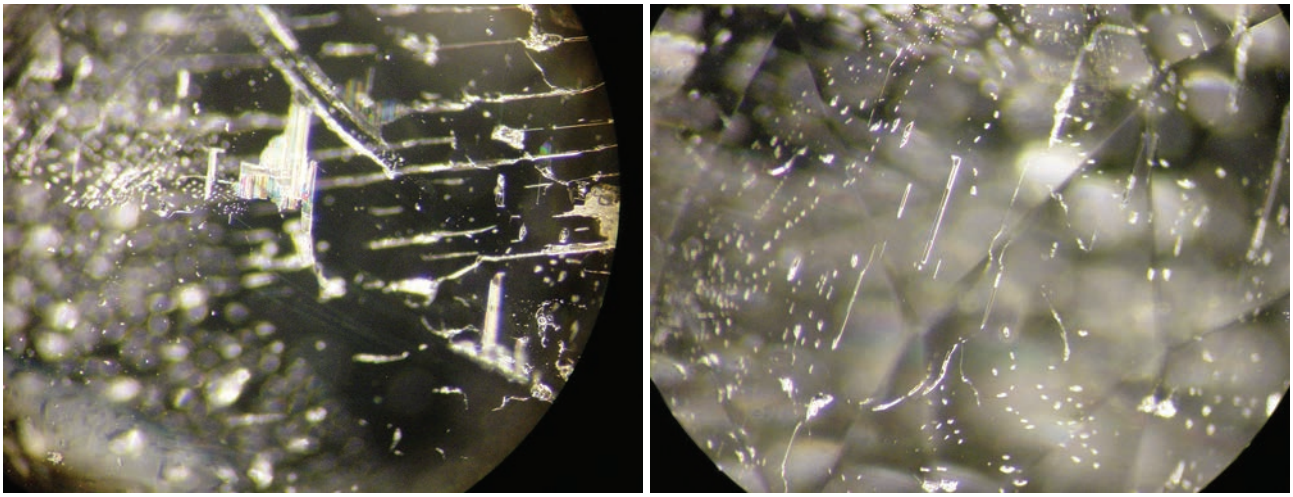

Figure 5: Internal features in the beryllonite consisted of iridescent planar fluid inclusions (left) and variably shaped two-phase inclusions (right). Photomicrographs by C. Williams; magnified 40×.

Numerous small inclusions were evident upon close examination of the stone without magnification. Microscopic observation with darkfield illumination revealed fluid-filled partially healed fissures, including one geometric-shaped iridescent inclusion that appeared to follow a cleavage plane (Figure 5, left). Also present were two-phase (fluid-gas) inclusions containing tiny bubbles (Figure 5, right).

Gem-quality beryllonite is known mainly from Afghanistan and Brazil, although Pakistan is also an occasional source of this rare gem material, as seen in this report.

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Apache Blue Stone (Chrysocolla) from Arizona, USA

The south-western USA is a well-known source of colourful secondary copper minerals such as malachite, azurite, chrysocolla, turquoise, etc. In 2013, a temporary partnership between a copper-mining company and Apache Way LLC (Chiricahua Apache Nde Nation, San Carlos Apache Reservation, Arizona) produced several tonnes of bright blue rough material from a large open pit located approximately 1 km from the now-inactive Sleeping Beauty turquoise mine. The appearance of the material varies from uniformly coloured to showing substantial amounts of matrix. Approximately 225 kg have been stabilized by polymer impregnation, and this material is being sold as Apache Blue Stone. More than 400 gems of various sizes and shapes have been cut and polished on the San Carlos Apache Reservation, with some contract cutting also being done overseas. In addition, silver- and gold-mounted jewellery and *objets d'art* are being manufactured and sold with Apache Blue Stone in indigenous and American heritage-inspired designs.

During the February 2017 Tucson gem shows, three pieces of rough were donated to Gem-A, and five cut-and-polished pieces were loaned for examination, by Charles Vargas and Warren Boyd (Apache Gems, San Carlos, Arizona). The rough material (Figure 6) was untreated, while the polished stones (Figure 7) had been stabilized by different polymer impregnation processes.

The samples were characterized by authors CW and BW. The rough stones were vibrant blue

Figure 6: These untreated rough pieces of Apache Blue Stone range from 4.4 g (~2 × 2 cm) to 90.3 g (~6 cm in maximum dimension). Gift of Charles Vargas; photo by Dean Brennan.

Figure 7: These polished samples consist of Apache Blue Stone that has been stabilized by polymer impregnation. The pieces on top (23.4 × 5.6 mm) were treated by the currently used stabilization method, while those on the bottom (drop shapes of 22.0 × 14.0 mm and an oval cut of 12.3 × 9.4 mm) were treated by an older polymer impregnation technique that partially darkened their colour. Photo by Dean Brennan.

to greenish blue. One rough sample appeared to consist of a brecciated rock with blue colour running in veins and along areas of the surface. The other pieces appeared more homogeneous, with translucent colourless areas of quartz. All of them had a chalky texture. Standard-based scanning electron microscopy–energy-dispersive spectroscopy (SEM-EDS) chemical analysis (Figure 8) of a rough sample by author AUF (using a Jeol JSM-6400 instrument with the Iridium Ultra software package by IXRF Systems Inc.) revealed major amounts of Si and high Cu contents (40.03–40.79 wt.% CuO). There also was minor Ca (~1 wt.% CaO) and traces of Mg, Fe and Mn. This composition is consistent with chrysocolla, and the identification was confirmed by Raman spectroscopy with a GemmoRaman-532SG instrument.

Figure 8: SEM-EDS imaging of the rough Apache Blue Stone showed features consistent with chrysocolla that is veined with quartz. The backscattered electron image on the left shows variations in overall atomic number (with darker areas corresponding to lower values, and vice versa), and the X-ray map on the right of the same area has been colourized according to contents of Cu (green) and Si (red). Images by A. U. Falster.

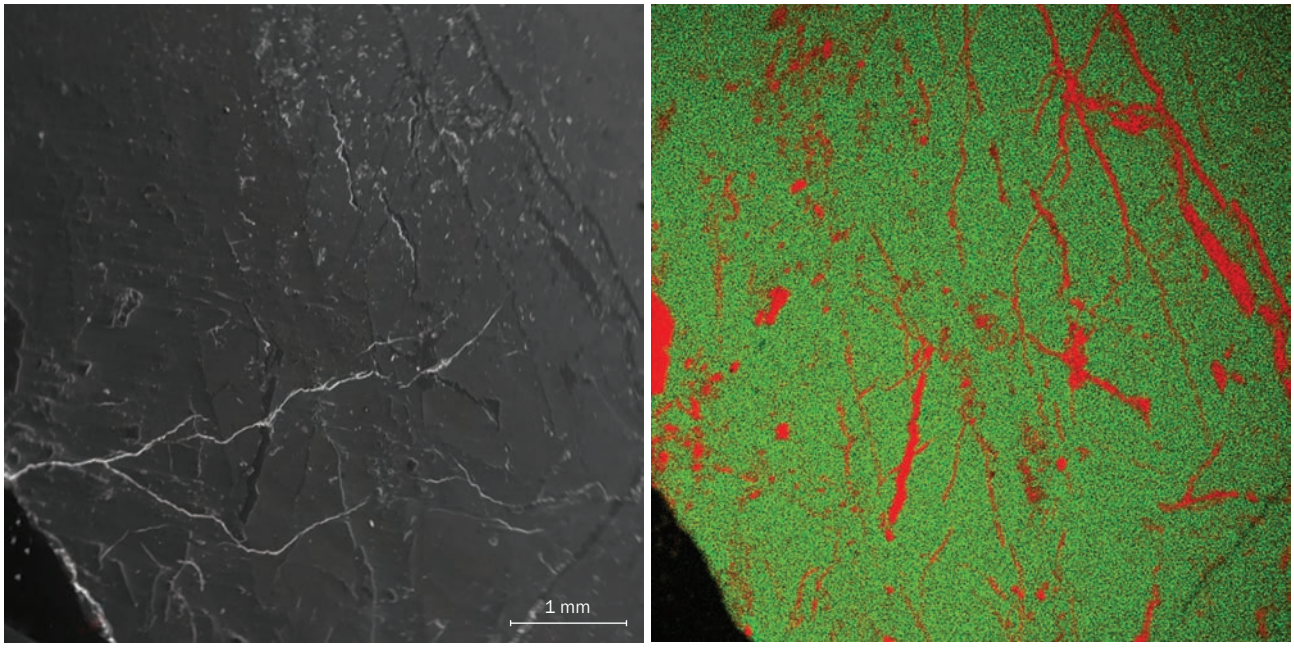

Of the five polished samples examined, three were treated using an older, now-discontinued process, and they showed areas of darker and lighter blue to greenish blue. Raman analysis identified the samples as chrysocolla, regardless of colour intensity. In addition, Fourier-transform infrared (FTIR) spectroscopy revealed bands associated with serpentine in some areas of these stones, as well as the expected presence of artificial resin that was used for stabilizing the material. EDXRF spectroscopy showed traces of K in these three samples, which may be due to mineral impurities. The other two polished samples were treated by the currently used stabilization method, and they displayed a lighter shade of blue (similar to the rough material) and contained quartz veining with some brown matrix. FTIR spectroscopy revealed artificial resin associated with the stabilization, but no K was detected with EDXRF analysis. Although RI readings could not be obtained from most of the samples, one of them yielded an approximate spot RI of 1.53. Hydrostatic SG was not measured due to the porosity of the material (rough) or the presence of polymer impregnation (polished samples).

Although Apache Blue Stone was reportedly mined within sight of the Sleeping Beauty mine, it is not related to turquoise other than exhibiting a similar colour and appearance. Due to overlapping values of RI and SG, and complications caused by the common presence of impregnation treatment, the identification of turquoise vs. chrysocolla is best determined by a well-equipped gemmological laboratory.

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Tianhuang, an Unusual Yellow Stone: Dickite or Nacrite?

In a collection of family heirloom jewellery that a client brought in for appraisal, we encountered an unusual yellow stone carving that we initially thought to be talc because of its soft and soapy feel. The yellow translucent stone—finely carved with a stylized lion—weighed 28.90 g and measured 44.90 × 26.58 × 12.19 mm (Figure 9). The object was typical for a Chinese stone seal, but its base was not yet engraved. It was slightly chipped due to wear and tear, and the softness of the material also was demonstrated by the presence of polishing marks and in the corresponding blurry reading on the refractometer caused by the poor polish. A faint shadow edge ranged from

Figure 9: Left: This yellow stone carving (44.90 × 26.58 × 12.19 mm) was found to be a material known as Tianhuang in China, which may consist of the kaolinite-group minerals dickite and/or nacrite. Right: In this view, the main flat side of the carving displays whitish vein-like patterns. Photos by Tay Thye Sun.

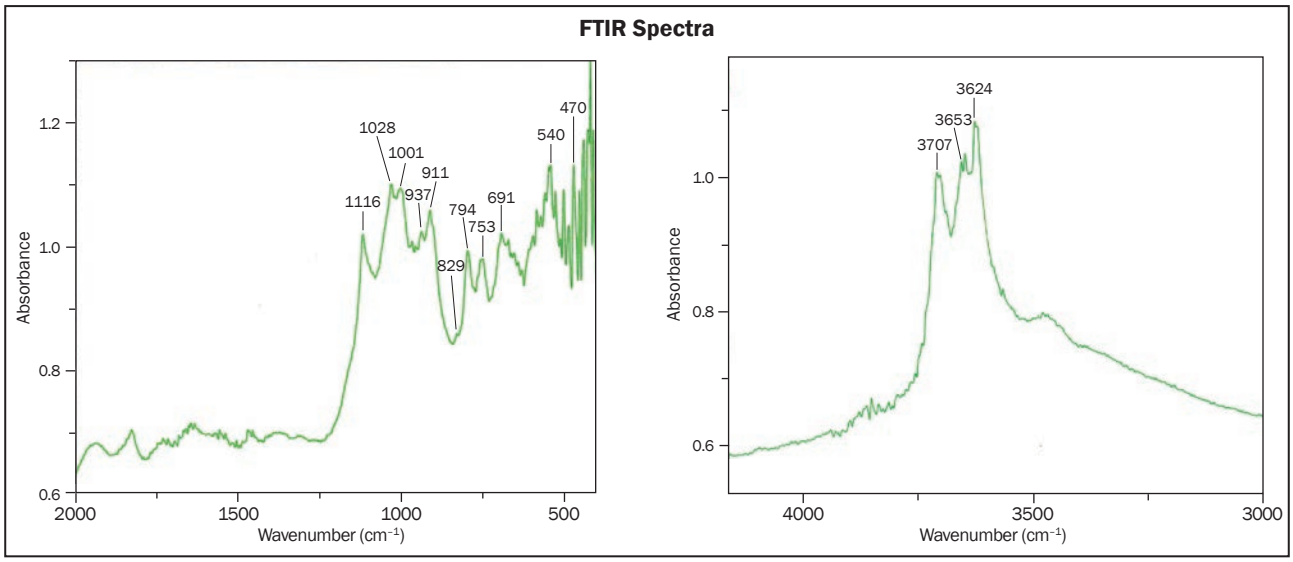

Figure 10: FTIR spectroscopy of the yellow stone carving revealed several absorption bands in the low-wavenumber region that point to a kaolinite-group mineral (left), while the three hydroxyl-related bands at 3707, 3653 and 3624 cm^{-1} in the high-wavenumber region correspond to dickite (right).

approximately 1.55 to 1.58, which is typical for clay minerals. Close examination of some areas of the object showed whitish vein-like markings (e.g. Figure 9, right).

To identify the material, a very minute amount of powder was extracted from the chipped corner. Infrared spectroscopy was performed using a Jasco FT/IR-4100 with a single beam and resolution of 4.0 cm^{-1}. Absorption bands were recorded at 1116, 1028, 1001, 937, 911, 829, 794, 753, 691, 540 and 470 cm^{-1} in the low-wavenumber region (Figure 10, left), and at 3707, 3653 and 3624 cm^{-1} in the high-wavenumber range (Figure 10, right). These features identify the material as a kaolinite-group mineral (cf. Farmer, 1964; Johnston et al., 1990), and the three sharp bands in the high-wavenumber region are characteristic of dickite (van der Marel and Krohmer, 1969). There are four types of non-equivalent OH in the crystal structure of kaolinite minerals, of which 3707 cm^{-1} belongs to the telescopic vibrations of ordered hydroxyl-OH_3. It is evident that the sample has a high degree of order; the 3653 and 3624 cm^{-1} bands are attributed to the inner-surface hydroxyl of OH_4 (Balan et al., 2005).

The same powder sample was analysed by Raman spectroscopy using a Bruker Senterra spectrometer, equipped with a red laser (785 nm) with a power of 100 mW; the measurement time was 100 seconds. The Raman spectra of dickite and nacrite are quite similar in the range 915–120 cm^{-1}, and the main distinction is the presence of peaks between 1120 and 1050 cm^{-1} that are typical of dickite (Figure 11).

The properties of this stone carving are consistent with those of Tianhuang, which consists of clay related to the kaolinite group of minerals, in which dickite and nacrite are among the rarer polymorphs (Deer et al., 1992). *Tianhuang* means 'field' and 'yellow', and is known to occur in rice paddy fields along the Shoushan stream in the northern suburbs of Fuzhou, the capital of Fujian Province in south-east China (Liu and Chen, 2012). It has been valued since ancient times—an ounce of Tianhuang was once reportedly worth an ounce of gold—and was treasured by various Chinese emperors for making stone seals. Yellow Tianhuang is more desirable than other colours such as red, white, black and grey.

Our investigation showed that a combination of infrared and Raman spectroscopy can identify a specific clay mineral, and in this case, our analysis of the yellow stone carving revealed that it was composed of dickite.

Acknowledgements: Many thanks to Dr Lo Wai Kit and family for allowing the yellow stone to be analysed, and to Dr Eugene Huang for assistance with English translation.

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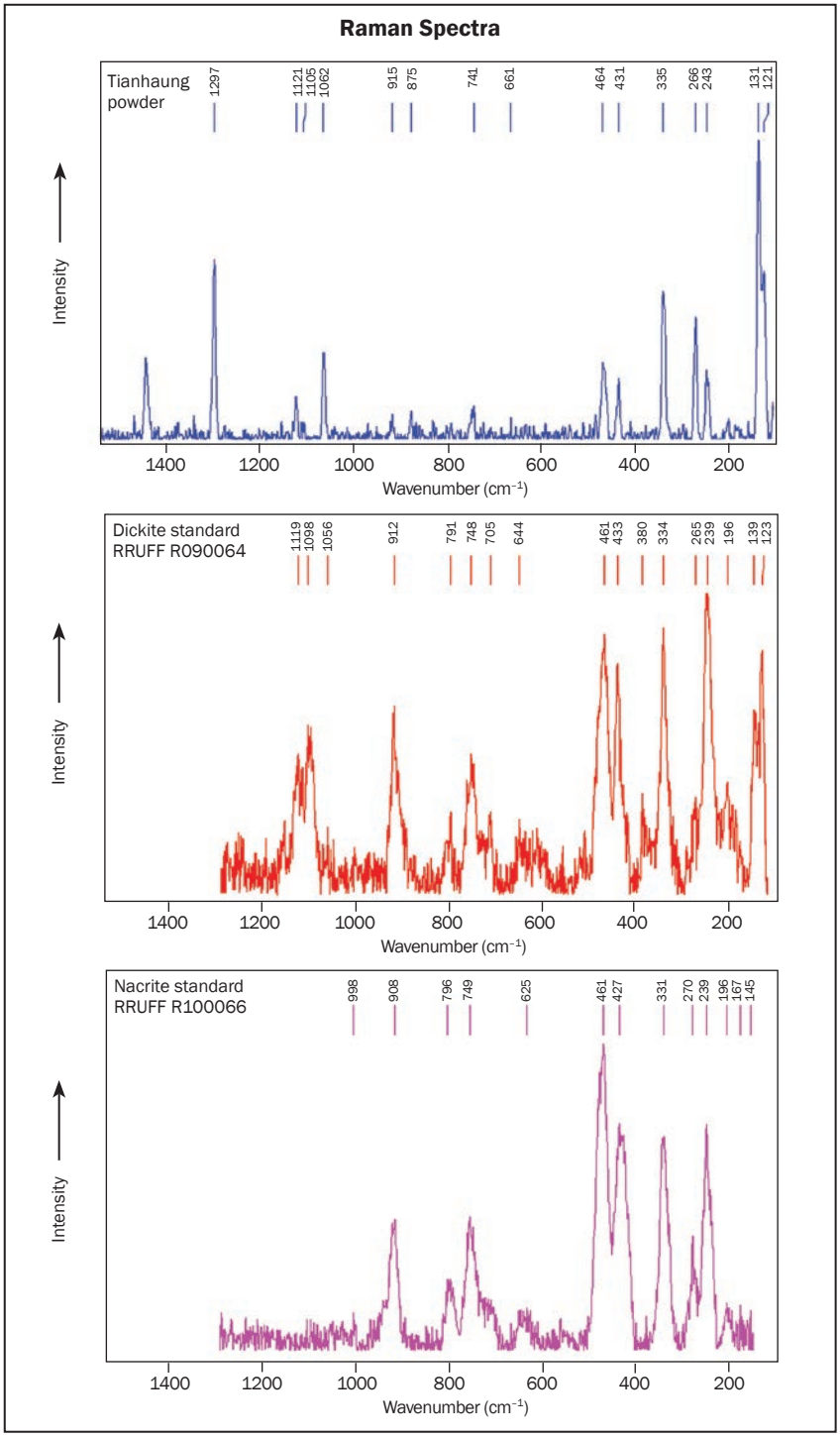

Figure 11: The Raman spectrum from the yellow carving displays features corresponding to both dickite and nacrite from the RRUFF database (http://rruff.info). Peaks between 1120 and 1050 cm^{-1} are typical of dickite.

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Copper-Stained Quartzite from Badakhshan, Afghanistan

Badakhshan Province in north-eastern Afghanistan is a source of various gem materials and is especially well known as the world's oldest locality for lapis lazuli. A new material appeared in the summer of 2016 that reportedly originated from the Tushkan District of Badakhshan, and has been sold as 'Tushkan jade' because of its green colour and translucency. More than 100 kg of rough have been sent to Europe, and additional production is expected. However, the deposit is situated in high mountains, so the mining season is limited.

Rough specimens show green to blue-green areas within white rock (Figure 12), and the material can be cut as cabochons or faceted (Figure 13). The greenish areas often contain metallic grains up to 15 mm in dimension that display various colours (Figures 12 and 14). Mineralogical analysis of a rough sample by powder X-ray diffraction revealed quartz as the main component and, because of its granular structure, it is therefore called quartzite. The metallic grains consisted of three different copper sulphides: bornite (dark purple), chalcocite (grey) and chalcopyrite (yellow). The overall green to blue-green colour of the material is caused by copper as a secondary mineral, very probably malachite, which forms an extremely thin coating between quartz grains.

Figure 12: These two rough pieces of copper-stained quartzite are from Badakhshan, Afghanistan. The specimen on the right is ~8 cm across. F. Naubahar collection; photo by J. Hyršl.

Figure 13: The copper-stained quartzite is available as cabochons (left, up to 17.26 ct) and faceted stones (right, up to 18.77 ct). F. Naubahar collection; photos by J. Hyršl.

Figure 14: Areas of bornite (dark purple) and chalcopyrite (yellow) add interest to these cabochons of copper-stained quartzite. The larger stone weighs 29.29 ct. J. Hyršl collection and photo.

The gemmological properties of the material were typical for quartzite. The spot RI of the cabochons was approximately 1.54 and the hydrostatic SG was 2.64 (for samples not containing sulphides). All of the samples were translucent and they appeared green under the Chelsea filter. Visible-near infrared (Vis-NIR) spectroscopy showed a broad absorption band centred at 660 nm (Figure 15). The spectrum was rather similar to that of gem silica (copper-bearing chalcedony) from Peru, but in the latter material the band is shifted to centre at 720 nm.

Quartzite is quite durable but malachite is easily soluble in acids, so jewellery containing this copper-stained quartzite should not be cleaned in acid.

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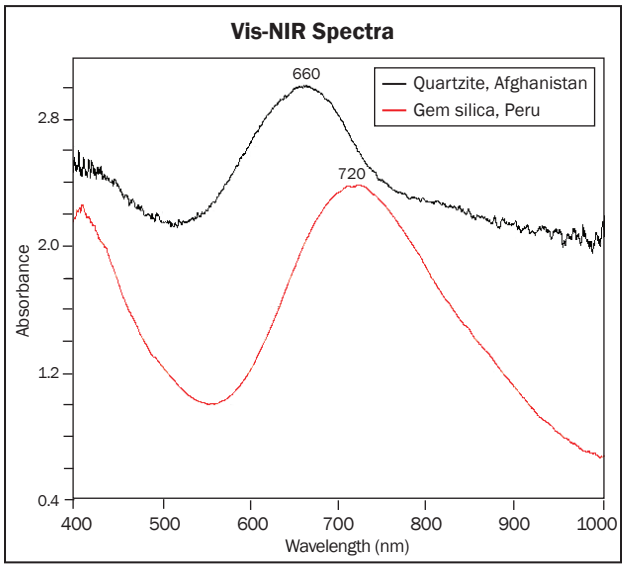

Figure 15: A broad absorption band centred at 660 nm is seen in the Vis-NIR spectrum of the copper-stained quartzite. By comparison, the absorption band for gem silica (copper-bearing chalcedony) from Peru is centred at 720 nm.

Sapphires from Canada—An Update

Corundum from Ontario, Canada, was first discovered in the 1870s by Henry Robillard. The large primary deposit was mined in the early 1900s and resulted in the development of the town of Craigmont. At this time, the corundum (mostly of brown colour) was primarily used as an abrasive, and was shipped all around the world (Adams and Barlow, 1910). A fire in February 1913 destroyed the mining mill, which ultimately turned Craigmont into a ghost town and halted mining (Barlow, 1915).

With the growing demand for unique faceted material, Canadian corundum is experiencing a slow-but-steady revival. However, rough material remains hard to come by, as no commercial mining has taken place since the 1920s, and most of the mine sites are overgrown by bush. Nevertheless, new initiatives are focused on cutting Canadian sapphires, and the stones are being featured in some interesting jewellery. So far, approximately 134 gemstones (about 656 carats total) have been faceted primarily as checkerboard cuts in round, oval and cushion shapes (Figure 16). They have been cut to accommodate the manufacture of comfortable-sized rings, ranging from 7 to 12 mm for cushion cuts and 9 to 13 mm for round stones. In February 2017, the first 'Snowflake Cut' (Lurie, 2000) Canadian sapphire was faceted by Rudi and Ralph Wobito (Wobito Gems, Stouffville, Ontario; again, see Figure 16). Also being produced are some rare large slices that weigh up to 134.5 ct (58.5 × 36.0 × 4.4 mm). These slices provide the preforms from which the best faceted stones are cut. They also have been used to make large, one-of-a-kind, reversible pendants that are polished on one side to show the beautiful growth pattern and left unpolished on the other side to display the natural surface (Figure 17). In addition, some of the sapphires are being carved and incorporated into *objets d'art* such as butterflies and fish (Figure 18).

One of the rarest Canadian sapphire varieties shows a greyish blue colour. A very few of these stones have been found by rock and mineral col-

Figure 16: This selection of Canadian (Ontario) sapphires features: a large rough crystal (top centre); two sapphire-and-diamond halo rings set in 14-carat yellow gold, together with three corundum crystals (right side); an ~14 ct checkerboard-cut greyish blue sapphire set in a 14-carat white gold diamond halo ring, sitting on a piece of rough (left); and a 14-carat yellow gold pendant set with a freeform-cut sapphire and diamonds, which is sitting next to a loose 3.90 ct 'Snowflake Cut' sapphire (centre). The other stones consist of various checkerboard-cut sapphires in oval, round and cushion shapes. The brown stones are from the Craigmont area and the greyish blue gem is from Sharbot Lake. Photo by R. Schroetter.

lectors at Sharbot Lake in Ontario (Barlow, 1915; see geological map no. 1023, p. 57), and also pale blue/white and yellow sapphires are known from the Cabonga Reservoir terrane of Québec (Hudon et al., 2006; see, e.g., Figure 19). Of particular note is a 14+ ct greyish blue checkerboard cut from Sharbot Lake that is set with diamonds in 14-carat white gold (Figure 16).

The production of such faceted stones, jewellery and *objets d'art* will remain quite limited, but

Figure 17: The freeform slice of Canadian brown sapphire in this 10- and 14-carat yellow and white gold pendant measures approximately 50 × 35 mm. The stone has been polished on one side (left) and shows its natural surface on the other side (right). Pendant and photo by R. Schroetter.

Figure 18: The butterfly wings (approximately 69 × 30 mm) in this objet d'art *are carved from Canadian brown sapphire; the body is 10-carat yellow gold, and the base consists of a stilbite mineral specimen from India.* Objet d'art *and photo by R. Schroetter.*

these recent initiatives will nonetheless expand the availability of these Canadian sapphires.

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Figure 19: The four cushion-cut yellow and pale blue/white sapphires in the centre are from Québec, and the surrounding stones are from Sharbot Lake in Ontario. The 13 checkerboard-cut sapphires have a total weight of ~78 carats and range from 8.9 mm rounds to 14.5 × 14.0 mm cushions. Photo by R. Schroetter.

New Sapphire Deposit in Northern Ethiopia

In December 2016, a large alluvial sapphire deposit was discovered in the Tigray region of northern Ethiopia. According to gem dealer Hussain Rezayee (Rare Gems & Minerals, Los Angeles, California, USA), who visited Ethiopia in April 2017, the deposit is located in the Axum (or Aksum) area of Rama District, near the town of Chila. The mining area (e.g. Figure 20) appears to be quite large, extending north of Axum toward the border with Eritrea and west toward the Sudan border for 100+ km. Although foreigners are not allowed to visit the mining area, he was told that there are 10,000–12,000 people working there. According to Rezayee, only about 10% of the stones are of moderate-to-good gem quality. The sapphires range from pure blue to blue-green, grey-blue, and yellow to golden yellow, and some of them are quite large (e.g. Figures 21 and 22). Numerous local stone dealers

Figure 20: Local diggers mine alluvial sediments for sapphires in northern Ethiopia. Photo courtesy of Hussain Rezayee.

Figure 21: These rough sapphires from northern Ethiopia consist of a large milky colour-zoned pebble (left, 61.2 g), a transparent water-worn crystal (centre, 2.6 g) and a dark blue stone (20.0 g). Courtesy of Hussain Rezayee; photo by Orasa Weldon.

Figure 22: The sapphires in Figure 21 are illuminated from below or from the side with strong lighting to show their body colours. The geuda-type stone on the left appears more yellow when viewed here with transmitted light (see Figure 21 for comparison). Photos by B. M. Laurs.

Figure 23: Northern Ethiopia is also the source of this trapiche sapphire. Photo by Farooq Hashmi.

have opened offices near the mining area and also in the capital city, Addis Ababa. Most of the buyers are Sri Lankan, as well as some Thais and also wealthy Ethiopians who buy the gems for investment.

In May 2017, rough stone dealer Sir-Faraz Ahmad (Farooq) Hashmi (Intimate Gems, Glen Cove, New York, USA) spent several days in northern Ethiopia, and reported seeing 3–5 kg of the rough sapphires in the market in Axum. Although many large stones were commonly available (20–70 g), they tended to be overly dark, and the best material for cutting gemstones weighed 2–10 g. The most attractive colour displayed by the rough material was pure blue, while the lower-quality stones appeared 'inky' or had grey banding. In addition, some trapiche sapphires were available (Figure 23). Hashmi found the prices of the rough to be quite high, regardless of the colour and clarity characteristics of the stones.

The colour appearance of sapphires from this deposit is consistent with typical magmatic corundum. Compared to the magmatic sapphires reported from Yabelo in southern Ethiopia (Beaton, 2011), stones from the Axum area are more blue (commonly without a green tint or yellow coloration), available in larger sizes, and they are hosted by a much larger deposit. The presence of magmatic sapphires in the Axum area is consistent with the abundance of Cenozoic alkali basalts that underlie this part of northern Ethiopia (Hagos et al., 2010).

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Tourmaline from Mwajanga, Tanzania

A new deposit of tourmaline was discovered in mid-2014 near Mwajanga village, in the Komolo area of the Manyara Region of north-eastern Tanzania. The initial production—some of which was shown at the East Coast Gem, Mineral & Fossil Show in Springfield, Massachusetts, USA, in August 2014—consisted mostly of pale yellow-to-colourless crystals with pale brown, blue and

Figure 24: (a) This dravite from Mwajanga, Tanzania, is 2.3 cm tall and has a white chatoyant zone at the top of the crystal; courtesy of Dr Alexander Schauss, photo by Jeff Scovil. (b) Multicoloured tourmaline crystals such as this one were produced from Mwajanga in March 2015. Photo by Steve Ulatowski.

pink areas (Polityka, 2014). Crystals up to 10 cm long were available, and although they were well formed, they tended to have dull lustre. In addition, only small areas were transparent enough for faceting. Further production from Mwajanga in 2014 yielded deeper yellowish-to-orangey brown (e.g. Figure 24a) and pale green crystals, some of which were quite gemmy and possessed high lustre; they have been referred to as dravite (Moore, 2014). Some of the brown crystals contained sharply defined white chatoyant zones, or displayed evidence of multiple breakage and regrowth events, producing the appearance of bent crystals. Such tourmalines were seen by author BML at the February 2015 Tucson gem shows, with rough stone dealers Steve Ulatowski (New Era Gems, Grass Valley, California, USA) and Farooq Hashmi/Michael Puerta (Intimate Gems, Glen Cove, New York, USA). Also on display were colourless prismatic crystals of natrolite up to nearly 4 cm long that reportedly were found at the same deposit as the tourmaline. Additional production in March 2015 consisted of multicoloured tourmaline crystals that ranged from black to orangey brown, yellowish green and bright pink (e.g. Figure 24b).

Most of the Mwajanga tourmaline has been sold as crystals to mineral collectors, and until recently these authors were unaware of any faceted material. However, in July 2016 gem dealer Dudley Blauwet had some pale brownish yellow and greenish brown faceted gems that ranged from 0.20 to 0.82 ct. The 42 stones (17.43 carats) were cut from 36 pieces weighing a total of 15.1 g. He obtained the rough material during the February 2016 Tucson gem shows from a stone dealer who purchased the tourmaline in Mwajanga. The rough consisted mostly of gem nodules, as well as some 'flawless' complexly formed crystals.

Figure 25: These pale brownish yellow and greenish brown tourmalines (0.56–0.82 ct) were found to consist of dravite with a minor uvite component. Photo by Orasa Weldon.

Blauwet loaned four of the cut stones for examination (Figure 25), and authors AUF and WBS performed standard-based SEM-EDS chemical analysis using a Jeol JSM-6400 instrument with the Iridium Ultra software package by IXRF Systems Inc. The results showed that all four samples had a very similar composition that consisted of dravite with a minor uvite component (0.90–0.96 wt.% CaO). Consistent with the pale coloration, there were few minor and trace elements; MnO and FeO were present in very low amounts (0.01–0.02 wt.%), V_2O_3 was only slightly above the detection limit (0.01 wt.%) and TiO_2 and Cr_2O_3 were not detectable.

Most recently, in April 2017, Ulatowski reported obtained some matrix specimens of translucent Mwajanga tourmaline that were mostly colourless but with deep blue terminations. The future potential of the deposit is unknown, but clearly it has already produced a variety of colours of tourmaline as attractive crystals and also a limited amount of rough material suitable for faceting.

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Tourmaline (Dravite) from Simanjiro District, Tanzania

'Chrome tourmaline' is well known from East Africa (e.g. Sun et al., 2015), and in mid-2016 a significant new discovery occurred at the Commander mine in Simanjiro District, Manyara Region, north-eastern Tanzania. These tourmaline crystals first appeared on the market at the October 2016 Munich Show (Moore, 2017), and additional material was offered at the February 2017 Tucson gem shows. According to rough stone dealer Steve Ulatowski, the mine is located about 14 km from Nadonjukin village and was initially explored in 1997, but was soon abandoned. In late August 2016, a local miner referred to as 'Commander' reopened the deposit. He extended the previous workings by hand digging and blasting to ~12 m depth, where he found a large pocket that produced ~5 kg of mixed-grade crystals. A subsequent pocket was recovered that yielded an additional ~3 kg of tourmaline. The crystals were well formed with lustrous faces and ranged up to 10+ cm long. They typically were bicoloured with yellowish to orangey brown bases and green terminations (e.g. Figure 26). A few of the tourmalines were recovered on a matrix of blocky white crystals (probably calcite or dolomite), but most of them had been broken off the matrix by the miners.

Most of the tourmaline production has been sold as crystals, with only a limited amount of gem rough available. Ulatowski faceted four stones ranging from ~0.7 to 1.1 ct; two of them were bicoloured and two were pure green (again, see Figure 26). He donated a crystal fragment and loaned one of the green gems (1.09 ct) for examination. The faceted stone was characterized by authors CW and BW. It displayed an overall lively deep green colour and yellowish green/bluish dichroism. The RIs were 1.620–1.638 (birefringence 0.018) and the hydrostatic SG was 3.06. These data are very similar to those reported for 'chrome tourmaline' by Sun et al. (2015). The stone was inert to a standard long- and short-wave UV lamp, but emitted a red glow when exposed to 405 nm excitation from a hand-held laser. It ap-

Figure 26: These faceted stones (1.09 and 0.70 ct) and crystal (4.7 cm tall) consist of dravite that was recently produced from Simanjiro District in Tanzania. Photo by Jeff Scovil.

peared red under a Chelsea colour filter. Microscopic observation revealed two small fractures and also a long, needle-like growth mark (Figure 27). Raman analysis with a GemmoRaman-532SG instrument provided a good match to reference spectra for dravite.

Standard-based SEM-EDS chemical analysis of the crystal fragment was performed by author AUF using a Jeol JSM-6400 instrument with the Iridium Ultra software package by IXRF Systems Inc. In addition, Na was analysed by a direct-coupled plasma spectrometer to check the results. These data confirmed the tourmaline is dravite with a lesser uvite component. Analyses of green and brown portions of the crystal fragment yielded a fairly similar composition, with the following chromophoric elements: 0.71–1.12 wt.% TiO_2, 0.11–0.27 wt.% V_2O_3, 0.03–0.11 wt.% Cr_2O_3, 0.04–0.07 wt.% FeO and 0.04–0.07 wt.% MnO. These elements also were detected in the faceted stone by authors CW and BW using an

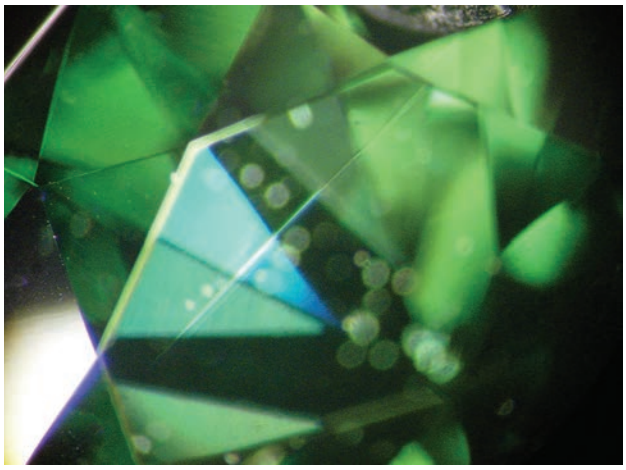

Figure 27: This microscopic view of the 1.09 ct dravite in Figure 26 shows a needle-like growth mark. Photomicrograph by C. Williams; magnified 40×.

Amptek X123-SDD EDXRF. A similar composition was reported for Cr- and V-bearing tourmaline from Kenya (Williams and Williams, 2015).

Due to the common presence of inclusions in this tourmaline and the fact that the well-formed crystals are sold as mineral specimens, it is unlikely that many gemstones will be cut from this dravite. In May 2017, gem dealer Dudley Blauwet received 34 faceted stones weighing 21.38 carats from his cutting factory; they were cut from a parcel of this dravite that he purchased at the 2017 Tucson gem shows that consisted of 31 pcs of rough weighing 17.8 g. The gems ranged from 0.10 to 1.62 ct, and from a fine light yellowish 'mint' green to brownish green to deep 'chrome' green.

A small amount of the Commander mine dravite contained abundant growth tubes oriented parallel to the c-axis that could produce chatoyancy if cut as cabochons.

Cara Williams FGA, Bear Williams FGA, Brendan M. Laurs FGA, Alexander U. Falster and Dr William 'Skip' B. Simmons

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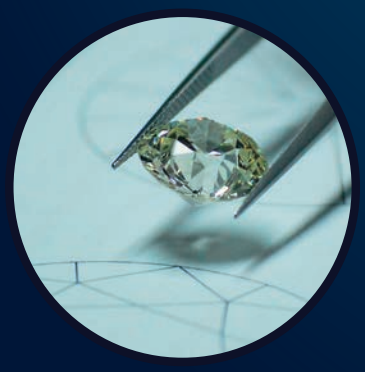

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DIAMONDS

Recent Alluvial Diamond Mining in South Africa

In August 2016, this author joined a five-day pre-conference field trip associated with the 35th International Geological Congress (held in Cape Town, South Africa) that visited many historical and currently active alluvial diamond deposits in South Africa. The excursion was led by Dr Mike C. J. De Wit (Tsodilo Resources Ltd. and University of Pretoria, South Africa) and was attended by 26 participants from at least six countries. This report focuses on the three largest active mining areas that we visited: Tirisano and London Run in the North West Province, and Saxendrift on the Middle Orange River.

The Tirisano mine is located in the Lichtenburg–Ventersdorp Field (26° 5.218' S; 26° 47.121' E) and has been worked most recently (since 2012) by Badenhorst Diamante. The deposit has produced a total of ~100,000 carats, with a current average value of US$400–$500/ct and an overall grade of 1–2 carats per hundred tonnes (CPHT). At the time of our visit, the operation employed 50 people and included seven trucks and two excavators. Two open pits were being mined in a series of benches (e.g. Figure 28). The gravels were trucked to a washing plant (Figure 29), where they were screened to remove +100 mm clasts and then passed into a scrubber or trommel for sizing to 2–32 mm. This gravel fraction was then fed into rotary washing pans, and the heavy material that concentrated along the outer edge of the pans was routed into a secure area for X-ray and hand sorting. Most of the Tirisano diamonds are near-colourless (typically H colour), and daily production is usually around 5 carats, but may range up to 300 carats; approximately 60% are of gem quality. The largest diamond was found in June 2016 and weighed ~100 ct; the second largest weighed 68 ct, and some additional significant stones weighed 13–30 ct. The diamonds are sold at a monthly tender in Johannesburg.

The London Run deposit (27° 20.380' S; 25° 25.662' E), mined by Namakwa Diamonds Ltd., is located near the town of Bloemhof, and forms part of the Southern Field of alluvial diamond deposits in South Africa. The gravels are 200–400 m wide and generally 5 m thick (Figure 30), but the upper 3–4 m are commonly cemented by calcrete

Figure 28: An excavator and dump trucks are used to mine this open pit at the Tirisano deposit. Photo by B. M. Laurs.

Figure 29: This view of the processing plant at the Tirisano mine shows vibrating screens (centre-background), a scrubber (right) and rotary washing pans (left). Photo by B. M. Laurs.

Figure 30: Field trip participants survey one of the mining trenches at the London Run deposit. The light-coloured sediments in the pit walls are diamond bearing, and they are overlain by a dark-coloured soil horizon and previously mined material. Photo by B. M. Laurs.

and must be blasted in places. The best diamond production comes from the bottom portion, so in most cases only the lower 2–3 m of the gravel unit is mined. The deposit typically produces diamonds averaging 0.8–0.9 ct with a value of slightly below US$1,000/ct (e.g. Figure 31). Grades are fairly constant at 0.8–1+ CPHT. The largest stone produced in the past year weighed 62 ct. Other notable stones include a 27 ct diamond and a flat-shaped 55 ct type II stone that was recovered in early 2015. Although very rarely, the area produces a significant number of fancy-coloured diamonds (i.e. yellow, pink, purple, orange, blue). Our group visited one of the several small operations that mine the deposit in partnership with Namakwa Diamonds Ltd. It had 12 employees and produced some 300–400 carats per month. The processing plant used two vibrating screens (to size the material to 2–32 mm) and two rotary washing pans, with a throughput of 4,000 tonnes in a 24-hour period. The plant produced 4 tonnes of concentrate in each 12-hour shift. The concentrate was taken to a nearby privately operated facility for further processing (dense media separation and X-ray sorting). The diamonds are sold at tender in Kimberley, South Africa.

Figure 31: This parcel of London Run diamonds weighs a total of 24.32 carats and consists of '3 grainers' (stones weighing ¾ ct). Courtesy of John Ward, Namakwa Diamonds Ltd.

The Middle Orange River deposits are located between the towns of Douglas and Prieska (e.g. 29° 19.308' S; 23° 15.257' E), and have yielded many large diamonds over 100 ct and several over 200 ct. The fluvial-alluvial gravels are developed on terraces along the banks of the present Orange River, in a sequence comprising basal gravels 2–4 m thick that are overlain by <5 m of variably calcreted sands and silts. At the time of our visit, Rockwell Diamonds was processing tailings piles that had been stockpiled from the upper gravels at the Saxendrift mine by the previous company, Trans Hex Group. They also were preparing for a new mining operation at a nearby deposit called Wouterspan. Rockwell uses trommels to remove oversized material, and then mobile screening equipment is employed for de-sanding, and magnets remove clasts of banded iron formation (which forms most of the concentrate as it has a higher density than diamond) before the remainder is processed through washing pans. The resulting concentrate is passed through X-ray sorting machines. During the past five years, more than 10 diamonds weighing in excess of 100 ct have been recovered by Rockwell from newly mined gravels and tailings. The overall grade varies from 0.3 to 2 carats per hundred cubic meters, with better grades from the lower gravel layers. Despite the low grade, the deposit has a high diamond value of $1,800–$2,000/ct. About 70–80% of the value of the deposit lies in 10–20+ ct stones, so relatively large-sized material (5–36 mm) is processed. The diamonds are sent to Johannesburg, where most of the production is sold in sights that are held every two weeks; large diamonds (10+ ct, referred to as 'specials') are sold separately.

Brendan M. Laurs FGA

INCLUSIONS IN GEMS

Quartz from Brazil with Colourful Epigenetic Inclusions

Epigenetic fracture fillings of hematite and goethite in quartz are quite common, but occasionally they create attractive displays of colour and pattern that are noteworthy, particularly when viewed with different types of lighting (see, e.g., Koivula, 2003, p. 16). Recently, a significant amount of such quartz was produced in Brazil and made its way to the February 2017 Tucson gem shows.

According to Leonardo Silva Souto (Cosmos Gems, Teófilo Otoni, Brazil), the included quartz was mined from a granitic pegmatite in the Governador Valadares area, where similar material was initially found about 15 years ago. The recent production was notable for the size of some of the pieces (e.g. Figure 32) and the vibrant inclusion displays. According to Silva Souto, cutting the quartz to display the colourful inclusions has been challenging since the coloured areas are present in only small areas of large crystals, and they usually are accompanied by an abundance of typical colourless inclusions (i.e. fluids and feathers) that reduce the transparency of the surrounding quartz. Most of the quartz has been cut as polished tablets to show off the inclusions, and dealer Luciana Barbosa (Gemological Center, Weaverville, North Carolina, USA) had approximately 1,000 carats that ranged from about 5 to 30 ct each, as well as two pieces in the 100 ct range (e.g. Figure 33).

The vast majority of the inclusions in the material seen in Tucson were orange to orangey red, typ-

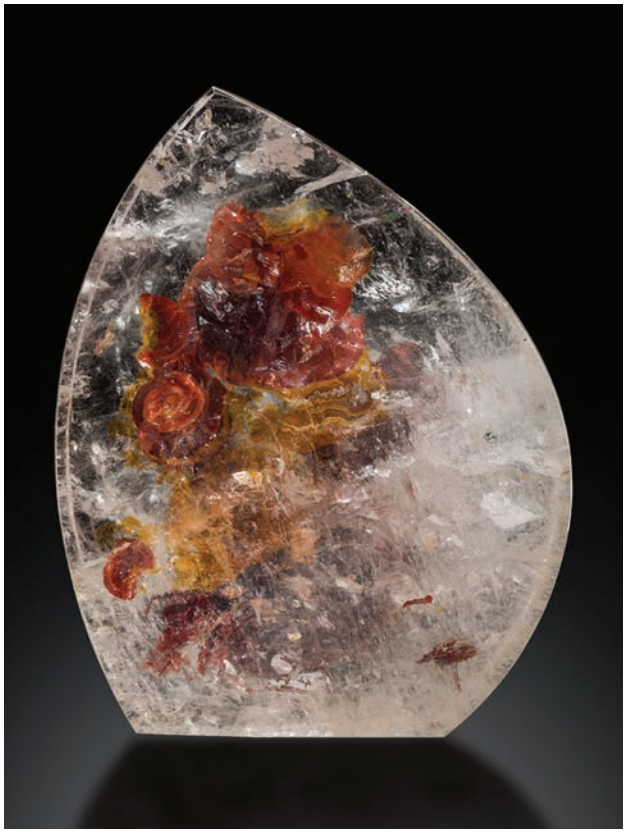

Figure 32: This large display specimen (14.9 cm tall) consists of recently produced quartz with colourful fractures that most likely are filled by hematite and goethite. Courtesy of Leonardo Silva Souto; photo by Jeff Scovil.

Figure 33: This quartz specimen (weighing 102 ct and measuring 46 × 29 mm) is shown under normal lighting (top) and in a polariscope (bottom). The cross-polarized light reveals radial crystallization textures in the hematite inclusions. Specimen and photos courtesy of Luciana Barbosa.

Figure 34: The red and yellow inclusion assemblage in the quartz on the left (~19 ct) probably consists of hematite and goethite, respectively. Dendritic patterns are seen in the hematite inclusions within the quartz on the right (4.68 ct). Specimens and photos courtesy of Luciana Barbosa.

ical of epigenetic hematite, although some pieces contained yellow areas that are probably goethite (e.g. Figure 34, left). Radial inclusion formations were quite common, and dendritic patterns were displayed by a few pieces (Figure 34, right).

This quartz demonstrates that even common materials (quartz and iron oxide/hydroxide) can come together to create specimens that are quite attractive. *Brendan M. Laurs FGA*

Reference

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Quartz from Brazil with Pyrite Inclusions

Well-formed crystals of pyrite are known to occur as inclusions in quartz, particularly from Brazil (e.g. Koivula and Laurs, 2007). At the February 2017 Tucson gem shows, a new production of pyrite-included quartz was displayed by gem dealer Leonardo Silva Souto. The deposit was discovered at an old mine site in early 2016, while being prospected for aquamarine in Brazil's Tocantins State. Although no aquamarine was found, the work did yield a fairly large quantity of quartz that contained an abundance of pyrite inclusions. Approximately 400 kg of quartz were produced, with most of the inclusions concentrated on only a single layer in the quartz. Although one large piece was polished (Figure 35), most of the quartz was sliced along the pyrite-rich layers so that smaller gems could be cut to showcase the inclusions (e.g. Figure 36). The polished stones consisted of cabochons and freeform tablets that ranged from 11 × 9 to 65 × 50 mm. In addition to pyrite, the gems commonly

Figure 35: Leonardo Silva Souto displays a large (~10 kg) polished piece of quartz, which contains a layer of pyrite inclusions that follow the rhombohedral faces of the host quartz. Isolated pyrite inclusions are also present further inside the quartz, along with some iron-stained fractures. Photos by B. M. Laurs.

contained fractures that were locally iron stained, which provide splashes of colour within the arrays of pyrite crystals.

Brendan M. Laurs FGA

Reference

Koivula J.I. and Laurs B.M., 2007. Gem News International: Citrine with pyrite inclusions. *Gems & Gemology*, **43**(2), 166–167.

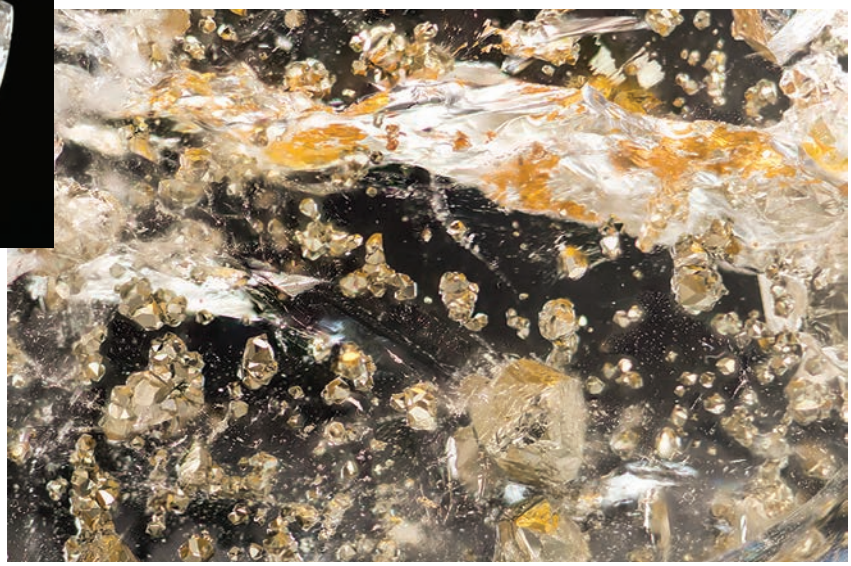

Figure 36: Numerous pyrite crystals and some fractures that are locally iron stained decorate this quartz specimen (above, 26 × 17 mm; gift of Leonardo Silva Souto). A closer view (right, image width 1.5 mm) shows that the pyrite inclusions consist of combinations of the cube and octahedron. Photos by Jeff Scovil, with image stacking for the photomicrograph by Lucas Fassari.

The Fire Within

"For in them you shall see the living fire of the ruby, the glorious purple of the amethyst, the sea-green of the emerald, all glittering together in an incredible mixture of light."

– Roman Elder Pliny, 1st Century AD

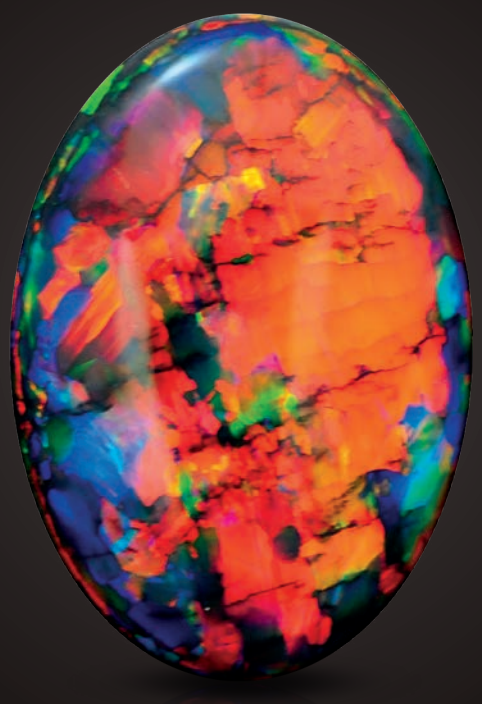

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Quartz from Brazil with Rhodochrosite Inclusions

Gem-quality rhodochrosite from granitic pegmatites in Minas Gerais, Brazil, was recently described in *The Journal* (Zwaan, 2015). During the February 2017 Tucson gem shows, the present author encountered rhodochrosite as inclusions in quartz from one of the localities mentioned in that report—Virgem da Lapa. The 230 ct stone was displayed by gem dealer Luciana Barbosa, and consisted of a faceted light smoky quartz containing a cluster of pink rhodochrosite crystals, which were surrounded by fluid inclusions and planar feathers (Figure 37). Barbosa indicated she cut a total of three stones containing such inclusions, with one being slightly larger than 230 ct and the other weighing ~25 ct. The rough material was produced in mid-2015 and was associated with loose crystals of rhodochrosite in addition to the included quartz specimens.

Although rhodochrosite inclusions in quartz have been previously reported from tungsten deposits (Hyršl, 2006), this is the first time to this author's knowledge that they have been encountered from a granitic pegmatite. Considering the rarity of rhodochrosite in these pegmatites, it is unlikely that there will be significant additional production of such specimens in the future.

Brendan M. Laurs FGA

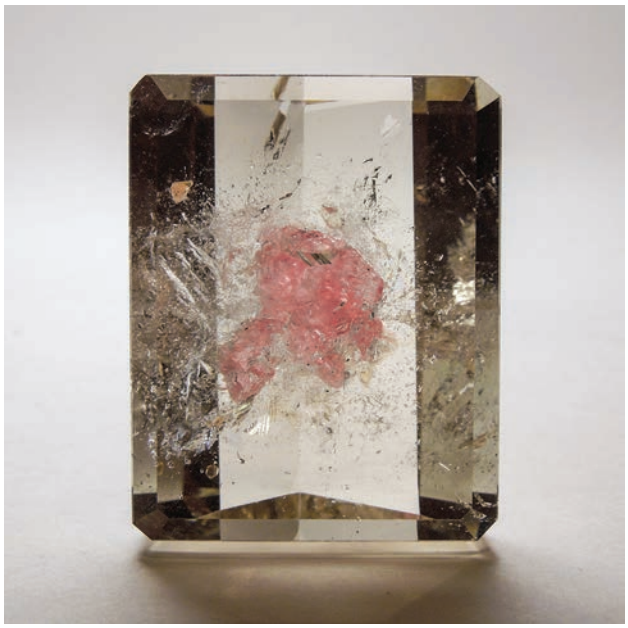

Figure 37: Weighing 230 ct (40 × 32 mm), this smoky quartz contains a cluster of rhodochrosite crystals. Photo by Luciana Barbosa.

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Hyršl J., 2006. Genetic classification of mineral inclusions in quartz. *Gems & Gemology*, **42**(3), 97–98.

Zwaan J.C., 2015. Gem Notes: Rhodochrosite from Brazil. *Journal of Gemmology*, **34**(6), 473–475.

Some Inclusions in Quartz from Pakistan

For decades, Pakistan has been an important source of a variety of mineral specimens and gem materials, particularly from granitic pegmatites and Alpine-type hydrothermal veins. During the February 2017 Tucson gem shows, Syed Iftikhar Hussain (Syed Trading Co., Peshawar, Pakistan) showed one of the authors (BML) some quartz specimens containing inclusions from both of these genetic environments, and he kindly donated one of them to Gem-A.

The 53.36 ct smoky quartz in Figure 38 was mined from pegmatites in the Skardu area of northern Pakistan, and contained numerous randomly oriented pale brown flakes. Raman analysis identified them as biotite. The interface between the quartz and the biotite inclusions locally showed reflective mirror-like areas that displayed thin-film interference colours (Figure 39).

Conspicuous bluish green needles were present in a 5.70 ct quartz (Figure 40) from Zagi Mountain, which is located in Khyber Pakhtunkhwa (formerly North-West Frontier Province), approximately 40 km north-west of Peshawar. At this famous mineral deposit, Alpine-type veins are hosted by alkaline granite gneiss of the Warsak igneous complex (Obodda and Leavens, 2004). Raman analysis confirmed the needles in this quartz (Figure 41) to be an amphibole, and it provided a good match to reference spectra for actinolite. Interestingly, similar amphibole inclusions in mineral specimens of quartz from Zagi Mountain have been referred to as riebeckite

Figure 38: Numerous inclusions of biotite decorate the interior of this 53.36 ct smoky quartz from Skardu, Pakistan. Photo by Robison McMurtry, © GIA.

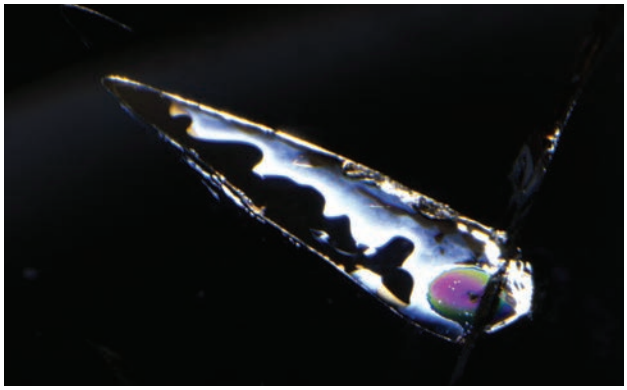

Figure 39: This biotite inclusion in quartz showed a highly reflective mirror-like interface and a circular area of thin-film interference colours. Photomicrograph by N. D. Renfro, © GIA; image width 4.7 mm.

Figure 40: This 5.70 ct oval modified brilliant from Zagi Mountain, Pakistan, consists of quartz with abundant actinolite needles. Gift of Syed Iftikhar Hussain; photo by Robison McMurtry, © GIA.

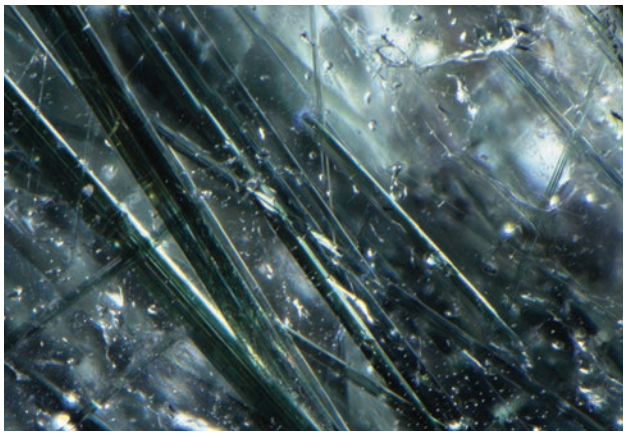

Figure 41: Actinolite forms locally dense networks of needles in this quartz. Photomicrograph by N. D. Renfro, © GIA; image width 2.7 mm.

(http://tinyurl.com/lbx5btz), but the Raman spectrum of these particular inclusions did not match the reference spectra for riebeckite.

Brendan M. Laurs FGA and Nathan D. Renfro

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Obodda H.P. and Leavens P.B., 2004. Zagi Mountain—Northwest Frontier Province, Pakistan. *Mineralogical Record*, **35**(3), 205–220.

SYNTHETICS AND SIMULANTS

A Research Facility in The Netherlands for the HPHT Growth of Synthetic Diamonds and HPHT Treatment

In 2008, AOTC Group B.V. (Advanced Optical Technologies Corporation) established a research-and-development site in Westknollendam (Zaanstad), The Netherlands. While AOTC does not commercially produce synthetic diamonds at this particular facility, they do perform research on how to improve the growth process using single-axis presses with a modified Bridgman-type (toroid) high-pressure apparatus. During a visit in May 2016, the authors were shown old and new systems that were in operation.

Figure 42: At the AOTC research facility in The Netherlands, two older presses, each weighing 17 tonnes, are still in use. Co-author Branko Deljanin poses for scale. Photo by J. C. Zwaan.

In addition to two older 17-tonne presses (Figure 42), the facility includes two new 5.5-tonne presses (e.g. Figure 43). These employ improved hydraulic, heating and control systems that are much more efficient, and a cooling system that exactly matches the ambient temperature at the air-conditioned facility. The repeatability of experiments has greatly improved as a result of these developments. In addition, the new presses have lower running costs, less maintenance, and can be manufactured on demand. The old presses are no longer readily available for purchase.

The new Bridgman-type apparatus is capable of producing pressures up to 10 GPa (100 kbar) and temperatures as high as 2,300°C (Choudhary and Bellare, 2000) in a reasonably large working volume, which is important for the commercial growth of high-pressure, high-temperature (HPHT) synthetic diamonds. By comparison, the two main types of devices that have been traditionally used are 'belt' and multi-anvil presses (also known as BARS or cubic presses), and both of them can reliably generate pressures up to 6 GPa.

The Bridgman-type apparatus (Figure 44) consists of a frame, a hydraulic cylinder, a high-pressure component within three plates on each outer side (not depicted in Figure 44), backing

Figure 43: New Bridgman-type presses such as this one (front and back) provide significant advances in the efficiency of growing synthetic diamonds. Photos by J. C. Zwaan.

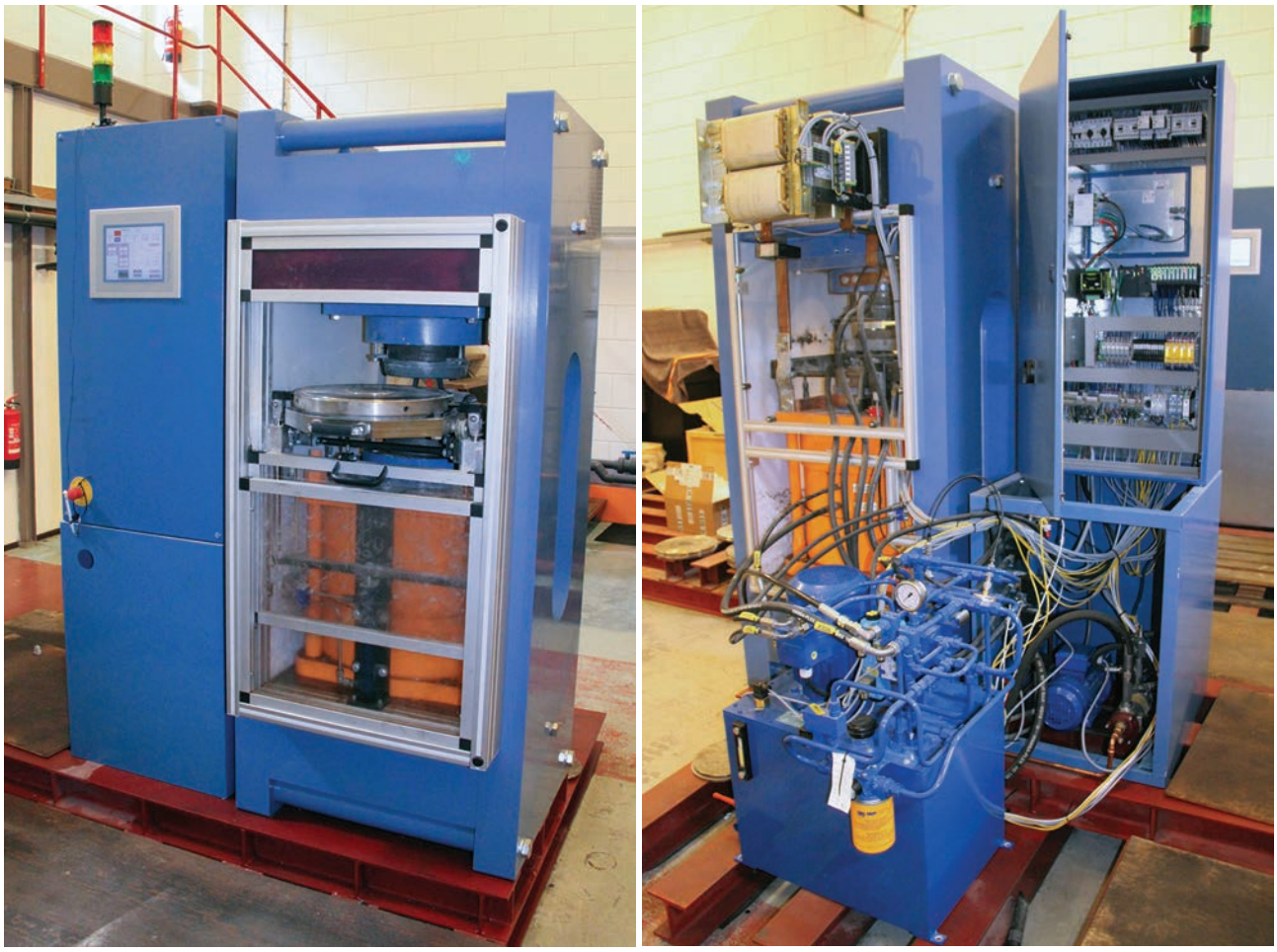

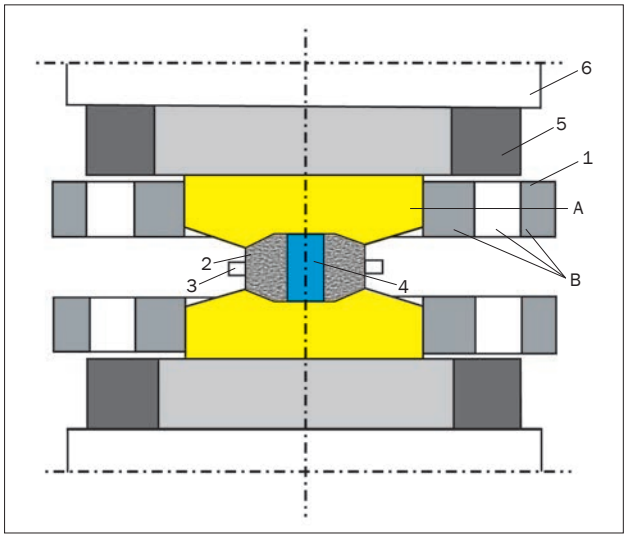

Figure 44: The Bridgman-type, toroidal HPHT apparatus is shown in this diagram: 1 – anvil (A – central part made of sintered carbides and B – supporting steel rings); 2 – ceramic container; 3 – pyrophyllite gasket; 4 – growth cell; 5 – backing plate; 6 – supporting plate. Diagram courtesy of AOTC.

and support plates, and cooling rings. The central high-pressure apparatus consists of shrunk-fit steel-alloy rings and tungsten-carbide anvils supporting a ceramic container and a cell for growing synthetic diamond crystals on a seed by a temperature-gradient method. The critical components of the high-pressure apparatus are the compressible gasket/container and the growth cell. The gasket, made from pyrophyllite, permits compressive movements of the conical piston and helps distribute the loading between the chamber and the piston. When the pyrophyllite gasket is compressed between opposed anvils, the outward flow of pyrophyllite from the central region is stopped by the inward flow of gasket material from the toroidal region, creating ultra-high pressure in the reaction cell (Choudhary and Bellare, 2000).

One synthesis cycle typically is completed in six days when growing yellow synthetic diamonds, but a cycle might be more than eight days to grow blue synthetics and more than two weeks to produce colourless material (D'Haenens-Johansson et al., 2014). During the growth process, a mixture of carbon and catalyst metal (in this case, iron) is heated high enough for the carbon to dissolve in the molten catalyst; the temperature of 1,500°C is generated with 2,000 watts of power. A pressure of ~5.5 GPa (55 kbar) is applied so that the system is thermodynamically stable for diamond formation. Under these conditions, a temperature gradient of 25°C (between 1,475°C and 1,500°C) causes diffusion of carbon atoms through molten iron, resulting in the crystallization of synthetic diamond. The growth cell has a diameter of 40 mm, allowing production of single-crystal synthetic diamonds weighing up to 8 ct. Typically, however, three smaller crystals of <1 ct are produced in each run. A single crystal of 3 ct (Figure 45) can be faceted into a polished synthetic diamond of ~1 ct. To extract the synthetic diamond(s) after growth, the researchers use 'royal acid' (a mixture of nitric and hydrochloric acid, optimally in a molar ratio of 1:3) to dissolve the metals at 245°C for a period of more than three hours.

Due to their improved properties and relative portability, the new toroid presses manufactured in The Netherlands by AOTC also are used worldwide for the HPHT treatment of type IIa natural diamonds and CVD-grown synthetics. Temperatures of more than 2,200°C and pressures above 5.5 GPa provide conditions at which the colour of light brown type IIa natural diamonds and off-colour CVD-grown synthetics can be improved to colourless (D–F range) and consequently increased in value (Pope et al., 2016).

Gemmologists very rarely have an opportunity to visit research facilities where equipment is designed to perform HPHT growth and treatment of diamond, and to observe results of actual experiments. AOTC is one of the few producers of synthetic diamonds that have been very open in the past 10 years to share samples and information on growth technology. They were even willing to show us their research facility in The Netherlands.

Figure 45: Typically, three crystals of synthetic diamonds (each less than 1 ct) are produced during each growth cycle, but single crystals up to 3 ct (as shown here) and occasionally up to 8 ct have been produced. Photo by J. C. Zwaan.

Acknowledgements: We thank Alexei Zarakhani, CEO of AOTC, Canada, for supplying Figure 44 and for useful comments. Alexander Lisenkov is thanked for organizing our visit to the AOTC research facility in The Netherlands.

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Borosilicate Glass Resembling Gem Crystals

At the February 2017 Tucson gem shows, authors LK and BML encountered some interesting objects that were handcrafted from borosilicate glass to recreate the aesthetic appearance of natural gem crystals. They were created by glass artist Jeremy Sinkus of Artisan Made Gemstones, Massachusetts, USA. On display in his booth and in his case at the Tucson Gem and Mineral Show were items resembling variously coloured tourmaline (including crystals, slices, cutting rough and faceted pieces), as well as replicas of aquamarine, crystal clusters (simulating rock crystal and fluorite, tourmaline, etc.) and fossils (ammonites). Also present were various soda-lime glass items such as drinking glasses, vases and lamps with crystal-themed motifs (e.g. Figure 46).

Sinkus is a former mineral collector who first displayed his gem crystal simulants at the August 2016 East Coast Gem, Mineral & Fossil Show in Springfield, Massachusetts. He then brought several hundred pieces to Tucson, including some of his newest creations, resembling kunzite, pur-

Figure 46: A variety of borosilicate glass objects were on display at the Tucson Gem and Mineral Show, including many pieces that imitated tourmaline as variously coloured crystals, slices and faceted pieces (left). Also shown (right) are replicas of aquamarine crystals and an ammonite, as well as artistic soda-lime-type drinking glasses that resembled colour-zoned tourmaline crystals. The largest 'crystal' in the left photo measures ~7 cm tall, and the 'ammonite' in the right photo is ~4 cm long. Photos by B. M. Laurs.

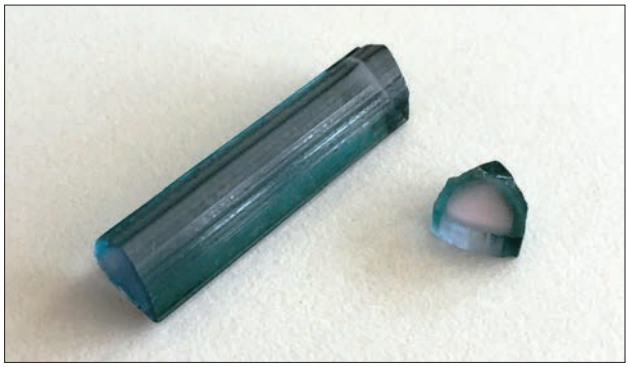

Figure 47: This sample of borosilicate glass was sliced into two pieces and examined for this report. The length of the larger piece is 30 mm. Photo by Lore Kiefert.

ple apatite and pale pink or blue danburite. The overall shape/form of the pieces, as well as surface details such as striations and growth marks, are imparted during the glassmaking process, and then the crystal models are finished by hand-lapping flat faces for their terminations. The different colours of the glass are controlled by the addition of various substances, along with the temperature and time they are held in the kiln. Due to the high heat needed to work borosilicate glass (typically around 1,650°C), the size of the pieces is limited by the amount of glass that can be heated by torches to attain the working temperature; Sinkus' largest multi-coloured tourmaline 'crystal' measures 6.3 × 15.2 cm.

The Gübelin Gem Lab acquired a dark greenish blue 'crystal' that weighed 15 ct and sliced it into two pieces for analysis (Figure 47). It possessed a trigonal-shaped cross-section and had fine parallel striations along its length, as commonly seen on tourmaline crystals. In cross-section, it had a pink core and a dark greenish blue rim. The RI value was 1.480 and the average hydrostatic SG was 2.27. It was inert to long- and short-wave UV radiation. Microscopic observation showed swirly and uneven features within both colours of the glass, and along the boundary between them, which gave an artificial impression (Figure 48a,b). Also seen were multiple tube-like inclusions that were arranged parallel to the length of the piece (Figure 48c); with higher magnification, these could be identified as elongated bubbles.

A cross-section of one of the slices was analysed by laser ablation inductively coupled plasma mass spectrometry (LA-ICP-MS), and Table I gives the chemical concentrations of the most relevant elements in the core and rim of the specimen.

*Table I: Representative LA-ICP-MS trace-element analyses (in ppmw) of the borosilicate glass imitation of tourmaline in Figure 47.**

Element	Rim 1	Rim 2	Core 1	Core 2
Li	21	10	21	15
B	31713	31287	30506	30379
Na	29893	28561	26674	27128
Mg	96	210	119	124
Al	19518	18331	17621	16983
K	1106	1212	1162	888
Ti	95	75	23	33
V	5.2	10	2.5	3.1
Cr	500	433	31	14
Mn	19	15	9.4	13
Fe	314	488	135	95
Co	272	259	3.38	1.90
Rb	2.3	3.2	33	31
Sr	11	8.4	5.0	7.3
Y	5.4	5.6	7.1	5.3
Zr	1552	541	595	517
Cs	2.0	3.6	1.8	2.6
Ba	13	12	21	19
La	2.3	1.5	0.9	1.2
Ce	14	13	10	8.6
Nd	174	162	4.9	3.5
Er	27	29	26055	25492
Tm	<0.79	<1.0	3.3	2.6
Hf	36	13	15	13
W	1.7	<2.1	16	13
Pb	0.55	<0.82	1.1	0.80
Bi	2.0	<1.0	2.4	1.0
Th	2.5	1.2	1.4	<0.58

* Data are from laser spots of 100 µm in diameter, with a laser energy of 3 J/cm^2 and a 20 Hz pulse rate. Helium was the carrier gas and argon was the plasma and cooling gas. All values are normalized against NIST 610 glass using Al as an internal standard.

The glass was found to be composed mainly of Si, together with B, Na and Al. Compared to the pink core, the greenish blue rim comprised significantly greater values of Cr, Co, Fe, Ti and Nd. The pink core was enriched in Er, and also contained slightly higher Rb, Tm and W. Fairly constant values in both zones were measured for trace elements such as Ce, Hf and Ba; these were most probably related to the basic glass material.

The sharp border between the rim and core sections is clearly evident in the LA-ICP-MS line scan shown in Figure 49. The abrupt change in

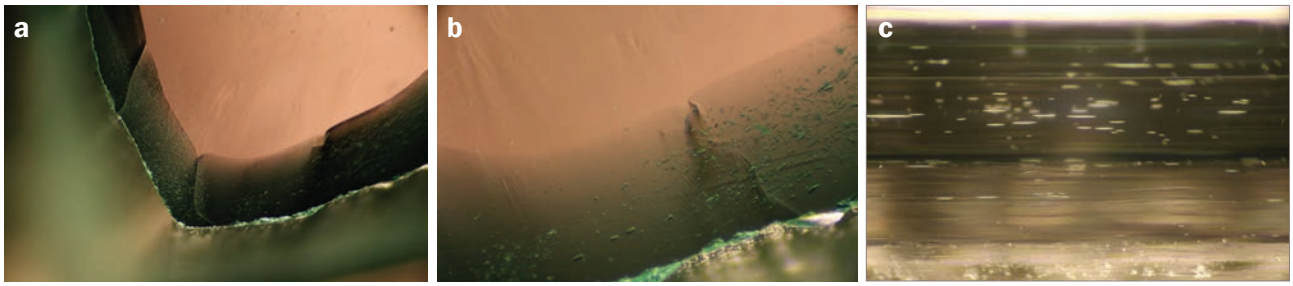

Figure 48: Colour swirls are seen in both the pink and greenish blue areas of the glass, and the colour boundary shows uneven curved surfaces that would not be seen in natural tourmaline (a,b). Tube-like inclusions with tapered pointy ends are arranged parallel to the length of the sample (c). Photomicrographs by B. Huber; magnified 50× (a), 65× (b) and 40× (c).

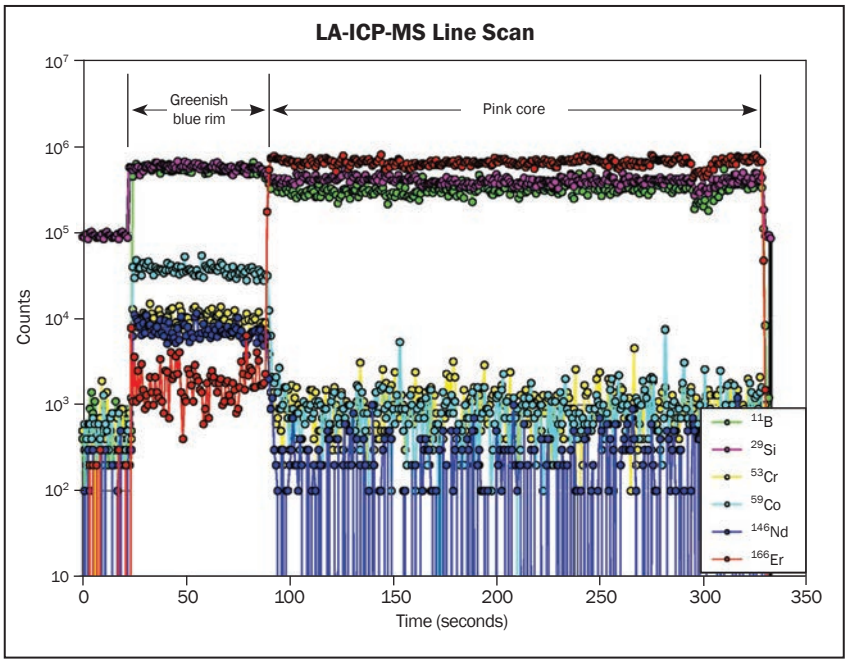

Figure 49: This LA-ICP-MS line scan across a slice of the glass tourmaline replica starts on the greenish blue rim and ends in the pink core. During the analysis, the laser traversed the sample at a speed of 11 microns per second (total length 3.4 mm) with a pulse rate of 30 Hz. (The first 20 seconds represent the background before turning on the laser.) This method is useful for visualizing chemical differences between the colour zones for several elements according to the counts obtained, which can then be converted to chemical concentrations, as partially reported in Table I.

composition between the two colour zones could point to a two-step manufacturing process in which the pink core was made first, and then in a later step after cooling and hardening the greenish blue rim was applied as a second layer.

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Synthetic Ruby Resembling Burmese Ruby

Synthetic corundum displaying a natural-like sheen has been known in the trade for years (e.g. Choudhary, 2009), although it is not encountered very often. In addition, there have been reports of a few treated (e.g. fracture-filled) synthetics that are particularly reminiscent in appearance of natural stones (e.g. Choudhary, 2008). Recently this author received for identification another such example—a 6.20 ct bright purplish red synthetic ruby with a strong sheen effect and eye-visible orange-stained fractures (Figure 50).

Identification of the specimen as ruby was straightforward by its standard gemmological properties, and at first glimpse it appeared natural because of the strong sheen, surface-reaching orange-stained fractures (consistent with iron staining) and the cutting style. The pavilion of the sample was not properly faceted, and had a large

Figure 50: Left: This 6.20 ct bright purplish red oval cut with pronounced orange fractures was identified as a synthetic ruby. Note also the subtle milkiness throughout the sample. Right: The pavilion of the synthetic ruby exhibits a large cavity instead of a culet, which is a common cutting style in 'old' stones originating from Burma (Myanmar). Also visible is a strong sheen effect in some areas. With this combination of features, this synthetic could easily be mistaken for a natural ruby. Photos by G. Choudhary.

cavity instead of a culet (Figure 50, right)—a cutting style that is commonly seen in 'old' stones originating from Burma (Myanmar). The presence of the sheen made this presumption stronger.

When observed with a microscope, the sheen effect appeared to be caused by fine particles (pinpoints) and short needles (Figure 51), mainly restricted near the surface, forming subtle zones. These pinpoints and needles had a diffused appearance, so their orientations could not be discerned. Such an inclusion pattern has been seen previously in synthetic star corundum and in natural corundum with asterism induced by the diffusion of titanium oxide (e.g. Mayerson, 2001). Surface-reaching fractures displayed thick, granular orange material not commonly associated with natural iron-stained films. These two features were sufficient to raise doubt about a natural origin for this sample. Careful observation with transmitted light revealed curved growth lines as well as curved zones of minute particles (Figure 52), as commonly seen in Verneuil synthetics. Interestingly, some planes consisting of minute droplets reminiscent of 'fingerprint' inclusions also were present (Figure 53), as were some elongated or 'bomb-shaped' gas bubbles.

For the record, the specimen glowed bright red under long-wave UV radiation, while short-wave UV yielded a chalky blue fluorescence mainly restricted to the surface, with an internal red glow.

Figure 51: Minute particles and short needles cause the sheen effect in the synthetic ruby. Also note the subtle zoning (see arrows). Photomicrograph by G. Choudhary; image width 5.5 mm.

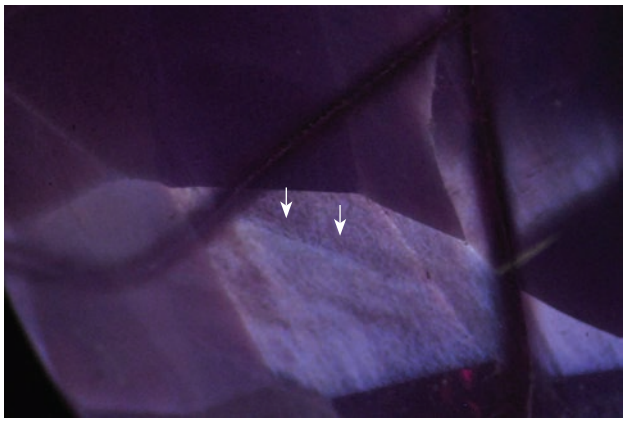

Figure 52: Curved growth lines and curved zones of minute particles confirmed the 6.20 ct sample as Verneuil synthetic ruby. Photomicrograph by G. Choudhary; image width 5.1 mm.

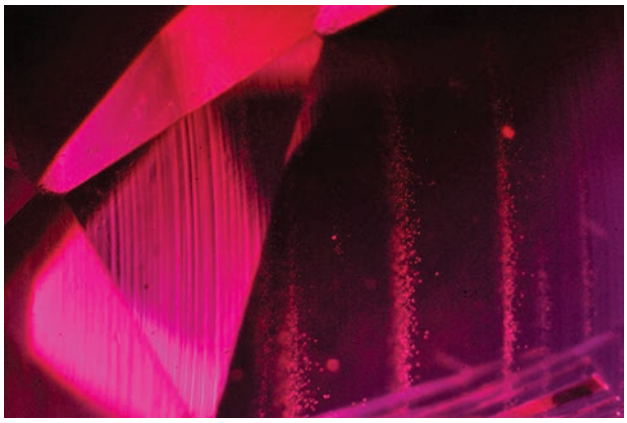

The overall features suggest that this synthetic ruby had undergone multiple treatment processes: first to induce sheen-causing titanium oxide inclusions, followed by quench crackling and impregnation with an orange substance. Further, this specimen also reminds us that synthetics can still be very tricky to identify—not only for novice gemmologists, but also for experienced gem dealers—making a buying decision much more challenging, especially in situations where only limited gem-testing tools are available.

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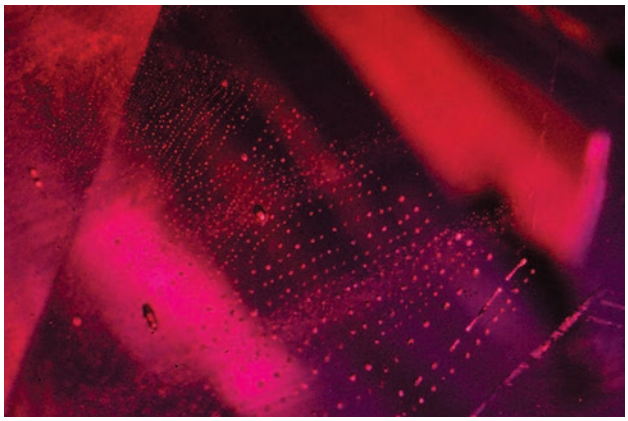

Figure 53: A plane of droplets reminiscent of a 'fingerprint' inclusion was present in the synthetic ruby. Photomicrograph by G. Choudhary; image width 5.1 mm.

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'Sea Sediment Jasper', a Dyed Composite Material

In January 2016, author FS acquired a pendant of so-called 'Sea Sediment Jasper' (Figure 54) while visiting New Zealand. Equivalent material has been offered on the Internet under this and other trade names such as 'Emperor Jasper' for years. Observed with the unaided eye, this sample consists of a composite of coloured fragments in a reflective metallic matrix. The disc in the present pendant was offered and described as follows: "Pyrite and coloured Sea Sediment Jasper make up these totally unique stones….We know that it is a jasper material from Africa but no one in the market knows what exactly to call it yet…."

The hydrostatic SG of the sample was determined as 2.45, and the spot RI reading of the most readable surfaces yielded a value of around 1.53–1.56. Microscopic observation showed that the sample was held together by a matrix of colourless material, into which fragments of pyrite (identified by Raman spectroscopy) were embedded (Figure 55). Each of the main colourful pieces showed a heterogeneous colour distribution and resembled marble or some other sedimentary rock that evidently had been dyed. The colour was concentrated in fractures and around the edges of the fragments, and was dispersed throughout each piece to varying degrees depending on the texture of the material, indicating the presence of an artificial dye.

Figure 54: This pendant, marketed as 'Sea Sediment Jasper', consists of a flat, slightly curved round piece that is polished on one side, with a diameter of 4 cm and a thickness of 7 mm. Courtesy of the German Gemmological Association.

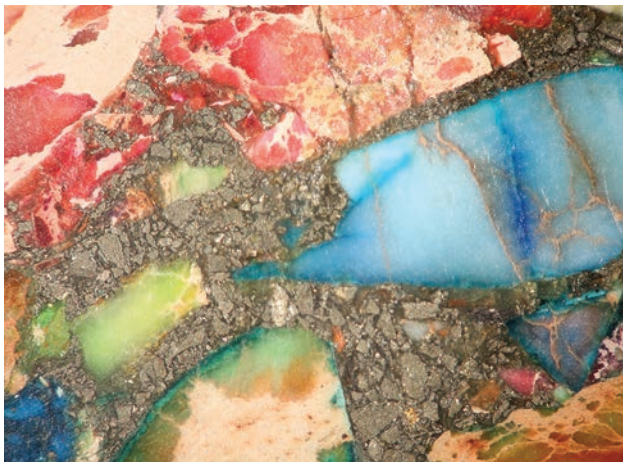

Figure 55: Microscopic observation of the surface of the sample in Figure 54 shows differently coloured areas with heterogeneous colour distribution, including some fragments that appear to be partially without colouring. The reflective metallic matrix consists of a colourless substance embedded with fragments of pyrite. Photomicrograph by F. Schmitz; magnified 30×.

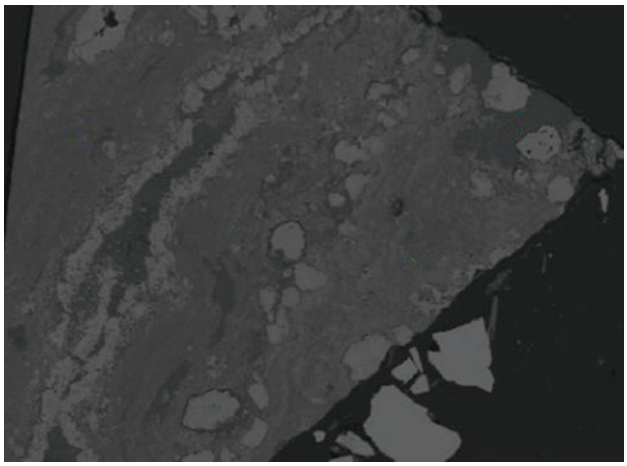

Figure 57: This backscattered-electron image obtained with an electron microprobe reveals the compositional differences of various fragments in the 'Sea Sediment Jasper', as shown by different grey tones. The brightest areas in the lower right consist of pyrite, and the darkest area on the left is the polymer binding agent. Magnified 45×.

To characterize the coloured components, X-ray diffraction was conducted on a small powdered sample with a Seifert XRD 3000 TT instrument using RayfleX ScanX software. The results showed a mixture of several clay minerals: illite, tosudite, taeniolite, halloysite and montmorillonite (Figure 56). Therefore, the coloured fragments consist of clay rocks with a high percentage of layered silicates (Brinkmann et al., 1967), and this was confirmed with infrared spectroscopy (Oinuma and Hayashi, 1965; Farmer, 1974). Such material might best be called mudstone (with no carbonate content, as it did not react to hydrochloric acid). Backscattered-electron imaging of the coloured fragments with a Jeol JXA-8200 electron microprobe showed greyscale variations corresponding to differences in composition, and further revealed details of the texture of the material (Figure 57). In addition, microprobe analysis showed greater amounts of Ti in the more colourful parts of the sample, suggest a Ti-containing colourant.

Raman spectroscopy revealed an artificial polymer as the colourless binding agent holding together the fragments. The pyrite pieces evidently

Figure 56: X-ray diffraction analysis of the main coloured components of the 'Sea Sediment Jasper' revealed several clay minerals.

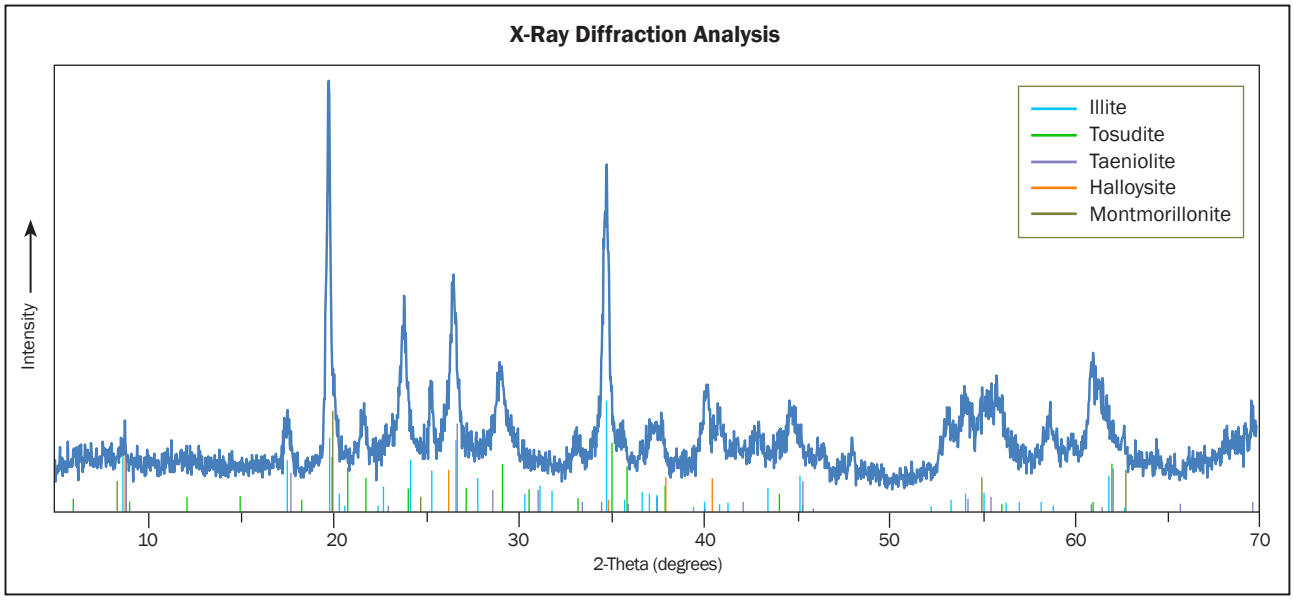

were added to the polymer to create a metallic lustre in the matrix.

The name 'Sea Sediment Jasper' is deceptive, as this is a dyed composite material that does not contain any microcrystalline quartz but only clay minerals. By comparison, a reference sample of natural 'porcellanite' in our collection consists of clays and other minerals such as feldspar and quartz.

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An Unusual Blue Synthetic Star Spinel

In late 2016, the Gem and Jewelry Institute of Thailand's (GIT) laboratory encountered an unusual 28.21 ct blue synthetic spinel that displayed a six-rayed star (Figure 58). Although various synthetic spinels have been reported previously in the literature (e.g. Nassau, 1980), this sample merited a more in-depth study due to the uncommon presence of its asterism.

We measured a spot RI value of ~1.72 and a hydrostatic SG of approximately 3.59. The sample displayed obvious cross-hatched anomalous double refraction (ADR) in the polariscope, and also exhibited strong pinkish red fluorescence to long-wave UV radiation and strong chalky blue luminescence to short-wave UV. Such ADR and fluorescence behaviours are commonly displayed by blue flame-fusion synthetic spinel (Schwarz, 1981; Webster, 1994), whereas natural blue spinel displays a singly refractive polariscope reaction and is inert to UV radiation.

Figure 58: This 28.21 ct blue synthetic star spinel (18.6 × 17.5 × 9.3 mm) was sent to GIT's laboratory for an identification report. Photo by C. Onlaor.

Observation with a gemmological microscope revealed various internal features indicative of a synthetic origin, such as a group of tiny gas bubbles (Figure 59, left) and dispersed stream-like minute inclusions (Figure 59, right) that were observed by using reflected light together with an oblique fibre-optic illuminator. These clouds of reflective inclusions were probably responsible for its asterism. Similar features have been documented (Nassau, 1981) near the surface of shallowly diffused star sapphires that create asterism by the exsolution of minute rutile needles, which are seen as stream-like clouds. The sample showed no evidence of oriented surface scratches that might have been applied to induce asterism.

The photoluminescence (PL) spectrum (obtained with a Renishaw inVia Raman spectrometer with 532 nm laser excitation) gave a broad emission band at ~689 nm that was similar to that of a reference sample of Co-bearing blue flame-fusion synthetic spinel. In contrast, the PL spectrum of our natural Co-blue spinel reference sample displayed a sharp Cr-related peak at 685 nm (Figure 60). The Vis-NIR spectrum (obtained with a PerkinElmer Lambda 950 spectrometer) of the cabochon displayed clear Co-related absorp-

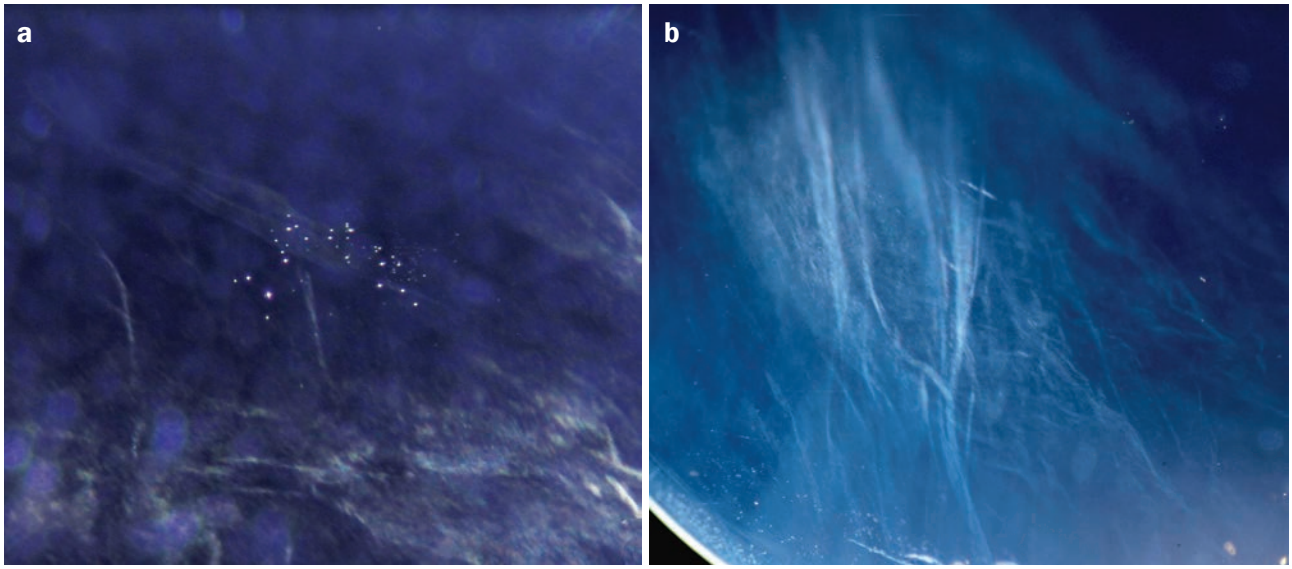

Figure 59: Internal features in the synthetic star spinel consist of a group of very tiny gas bubbles (left, image width 3.3 mm) and unusual stream-like minute inclusions when closely observed using reflected light combined with oblique fibre-optic illumination (right, image width 6.2 mm). These inclusions indicate a synthetic origin. Photomicrographs by S. Promwongnan.

tions at ~545, 580 and 625 nm (Muhlmeister et al., 1993), similar to those of our synthetic reference sample, while our natural blue spinel showed these Co features as well as an Fe-related peak at around 460 nm (Figure 61).

Semi-quantitative chemical analysis of the cabochon by EDXRF spectroscopy using an Eagle III system showed major amounts of Al and Mg with minor-to-trace levels of Si, Fe and Ga. As compared to the composition of our reference samples of natural and synthetic blue spinels, the relatively low contents of Mg, Zn and Ga confirm its synthetic origin (Table II).

The gemmological properties (ADR and UV fluorescence), inclusion aspects, PL and absorption spectra, and chemical composition of the cabochon clearly indicate its synthetic origin. While asterism is not commonly seen in synthetic spinel, it may have resulted from post-growth heat treatment by inducing the partial exsolution

Figure 60: PL spectra are shown for the synthetic star spinel cabochon, together with our blue flame-fusion synthetic spinel and natural Co-blue spinel reference samples.

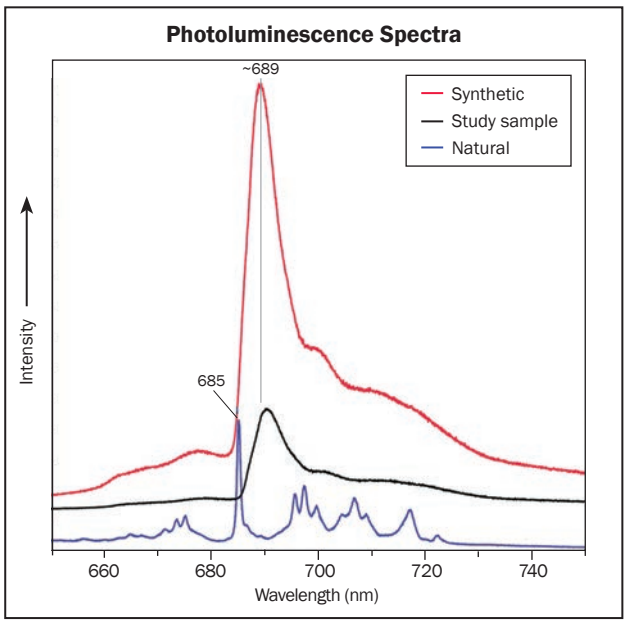

Figure 61: Vis-NIR spectra of the synthetic star spinel cabochon and our reference samples of blue flame-fusion synthetic spinel and natural Co-blue spinel display absorption bands at ~545, 580 and 625 nm due to cobalt, which produces their blue coloration. The natural sample also shows Fe-related features at around 460 nm.

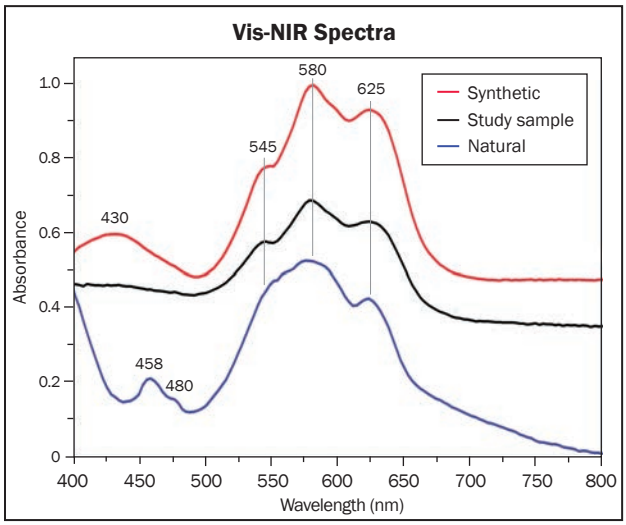

of aluminium oxide, which could produce the reflective irregular stream-like minute particles (Webster, 1994; Steinbach, 2016; Hodgkinson, 2017). Such a process is known to create an adularescent-like or star effect in colourless synthetic spinel to imitate moonstone. Thus, a similar post-growth treatment may have been applied to this sample.

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*Table II: Chemical composition obtained by EDXRF of the blue synthetic star spinel, a reference synthetic spinel and a natural Co-blue spinel.**

Oxide (wt.%)	Synthetic star cabochon	Synthetic reference	Natural reference
MgO	9.03	11.67	23.86
Al_2O_3	89.49	87.89	73.07
SiO_2	1.43	0.28	0.37
Fe_2O_3	0.02	0.01	2.49
CoO	bdl	0.13	0.04
ZnO	bdl	0.01	0.12
Ga_2O_3	0.01	bdl	0.03

* Abbreviation: bdl = below detection limit.

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MISCELLANEOUS

The Gemstone Collection of the Natural History Museum in London

For more than 260 years, minerals, gemstones, gem materials and worked objects have been purposefully gathered to form one of the world's most outstanding mineralogical collections, housed at the Natural History Museum (NHM) in London. This report provides a brief overview of the gem collection at the NHM, as a prelude to a series of future Gem Notes and articles in *The Journal* about noteworthy specimens in the collection.

The collection contains around 185,000 specimens, of which some 5,000 are gemstones or worked objects. A number of the gems are on display in the historic systematic Mineral Gallery, unchanged since 1881, and additional highlights are visible to the public in 'The Vault' and as sparkling arrays of colour in the Earth's Treasury permanent exhibitions (e.g. Figure 62).

The collections of the NHM have their foundations with Sir Hans Sloane (1660–1753). As a physician to royalty, he had the resources to both travel and collect widely. During his time, the sciences were in their infancy and collections were about exotic curiosities—flora, fauna, coins, books and minerals. At the time of Sloane's death his collection numbered 71,000 items, more than half of which were books. Sloane's will allowed Parliament to buy his collection for the undervalued sum of £20,000, and it was opened to the public in 1759 as the British Museum. It has since gone on to be separated into the British Library, the NHM and the British Museum. Sloane did not have a great interest in minerals, but we can trace certain gemstones and worked objects such as cameos, bowls and archers' rings back to his collection, dating them prior to 1753. Particularly notable is a 31.5 ct rose-cut blue sapphire set in a Mogul button.

As knowledge of mineralogy and crystallography progressed, the diversity of the NHM's

Figure 62: This image shows a small portion of one of the glittering arrays of gemstones on display in the Earth's Treasury gallery at the Natural History Museum. Courtesy of NHM London, © The Trustees of the Natural History Museum, London.

gem and mineral collections steadily increased. The strength of the gem collection is in its historic depth, and highlights include a wealth of early gem materials preserved from Ceylon/Sri Lanka and Burma/Myanmar, alluvial diamonds from the earliest discoveries in Brazil, opals from the then-new colony of Australia and some of the first diamonds from South Africa.

As a scientific institute, research by the mineralogical staff has led to many significant discoveries, including some of gemmological interest. The first specimens of sinhalite were discovered in the collection, erroneously documented as peridot, and significant donations facilitated by research have included the first specimens of taaffeite and the first two crystals of painite (once considered the world's rarest gem). Other important specimens or collections include:

- A range of gemstones obtained between 1906 and 1933 from Edward Hopkins, including a 598 ct morganite from Madagascar, obtained in 1913, which to our knowledge is the largest flawless faceted morganite in the world.
- A collection of gemstones set in rings from Lady Church, wife of chemist Sir Arthur H. Church, who was fascinated by their chemical and physical properties as well as their colours.
- Several Australian gemstones from Prof. Archibald Liversidge, acquired in 1927.
- An array of coloured diamonds and a 27 ct Mexican fire opal from T. B. Thornhill in 1934.
- A significant collection of both rare and fine gemstones from the Mogok region of Myanmar, including a 130 ct peridot, from Dr A. C. D. Pain.
- A choice collection of 268 fine gemstones, including at least 40 from Myanmar, from C. R. Mathews, obtained in 1993.

Perhaps the most significant development, adding some 1,500 gemstones, occurred when the gem and mineral collections of the Geological Museum were merged with the NHM in the 1980s. Highlights include a pale blue Brazilian topaz of 2,982 ct (the largest cut gemstone in the NHM collection), a 424 ct Brazilian kunzite, a 20 ct sillimanite from Myanmar (Figure 63), a 146 ct peridot from St John's Island in the Red Sea, a 57 ct padparadscha sapphire from Sri Lanka (Figure 64) and a diamond-studded gold snuff box given in 1867 to Sir Roderick Impey Murchison by Tsar Alexander II in recognition of his geological exploration of Russia (Figure 65).

The gemstone holdings of the NHM are amongst the most historically important preserved in any museum, and combined with one of the world's

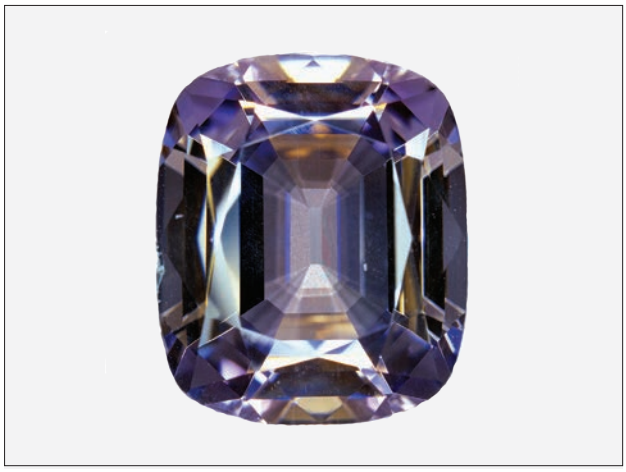

Figure 63: Among the numerous highlights of the gemstone collection at the Natural History Museum is this 20 ct sillimanite from Myanmar (BM.1985,MI29639). Courtesy of NHM London, © The Trustees of the Natural History Museum, London.

most extensive mineral collections, provide an impressive scientific, historical and cultural resource. In our most recent phase of strategic collection building, we are looking to expand representative examples of new finds and modern simulants, synthetics and treatments to continue to develop and provide a complete scientific resource to serve the gemmological and mineralogical community for education, inspiration and research.

Figure 64: The Natural History Museum's 57 ct padparadscha sapphire from Sri Lanka (BM.1985,MI33163) is shown here with a 9.35 ct pink sapphire (BM.54811). Photo by Robert Weldon; courtesy of the Trustees of the Natural History Museum, London.

Figure 65: In 1867, this diamond-studded gold snuff box (~10 cm tall, BM.1935,1219) was given to Sir Roderick Impey Murchison by Tsar Alexander II, Emperor of Russia. It features an enamel portrait of the tsar. Courtesy of NHM London, © The Trustees of the Natural History Museum, London.

The public is welcome to browse the beta version of our collections catalogue at http://data.nhm.ac.uk by clicking 'Mineralogy', then 'Configure fields & filters', and then filtering the 'Specimen' field as 'Collection Kind' = 'Gems'.

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DITP
Department of International Trade Promotion
Ministry of Commerce, Royal Thai Government

GIT

AIGS
Asian Institute of Gemological Sciences

A. F. G.

Distinction of Natural and Synthetic Ametrine by Microscopic Examination—A Practical Approach

Karl Schmetzer

Rough and faceted ametrine samples from the Anahí mine, Bolivia, were studied and compared with synthetic samples grown hydrothermally using seeds cut with various orientations and elongated in different directions. Examination with an immersion microscope yielded sufficient diagnostic features to allow differentiation between natural versus synthetic origin. Specifically, it was found that a combination of features could be used to distinguish natural from synthetic ametrine; these include the interference patterns caused by twinning, the orientation of violet/yellow colour boundaries, the orientation of growth striations and the appearance of the fluid inclusions.

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Introduction

Ametrine is a quartz variety that contains both amethyst (violet to purplish violet or purple; hereafter, referred to simply as 'violet') and citrine (yellow to brownish yellow or yellow-orange; hereafter 'yellow') sectors within the same stone (e.g. Figure 1). Such colour-zoned violet/yellow natural quartz is available primarily from the Anahí mine in Bolivia (Koivula, 1980; Collyer et al., 1994; Vasconcelos et al., 1994; Laurs, 2001; Weldon, 2009). The synthetic counterpart is grown hydrothermally from iron-bearing solutions. Commercial production employs seed material consisting mainly of basal quartz plates (Balitsky et al., 1999, 2000, 2001). Iron is incorporated in different forms into the synthetics, resulting in yellow and colourless growth zones in the as-grown crystals. Irradiation then develops the desired bicoloured ametrine appearance, with yellow basal **c** growth sectors and violet rhombohedral **r** and **z** sectors (Balitsky and Balitskaya, 1986, 2005, 2009). Additionally, it is possible in some cases to produce heat-treated ametrine using natural amethyst from specific localities. The treatment may lighten intense violet **r** growth zones and turn light violet **z** growth zones to light yellow (Neumann and Schmetzer, 1984).

Although infrared spectroscopy can be an effective tool for distinguishing natural and synthetic amethyst and ametrine (see, e.g., Kitawaki, 2002; Balitsky et al., 2004; Karampelas et al., 2005, 2011; and various references therein), microscopic examination will reveal information about twinning, colour zoning and occasionally also about inclusions—features that differ in natural versus synthetic ametrine (Crowningshield et al., 1986; Lu and Shigley, 1998; Balitsky et al., 1999; Notari et al., 2001; Hainschwang, 2009). Because it is a widespread practice in the trade to mix synthetic quartz into parcels of natural amethyst, citrine and ametrine, a simple method for separating these natural quartz varieties from their synthetic counterparts

Figure 1: Set in a gold ring, this ametrine from Bolivia weighs approximately 7 ct. Photo courtesy of Udo Reimann.

is commercially warranted. Furthermore, for such relatively low-priced goods, a cheap method for mass screening is highly desirable.

Within the past few years, a simple technique was suggested for discriminating between natural and synthetic ametrine, using standard gemmological tools such as the refractometer and polariscope (Payette, 2013). The method relied on the presence or absence of twinning in combination with the orientation of the violet/yellow boundary in faceted samples. Useful results were yielded by this method, provided the table facet had been cut at an appropriate orientation relative to the crystal structure. However, difficulties could occur with samples displaying other orientations, complex colour zoning and/or twin structures. Thus, the present study was undertaken to evaluate if efforts at separation might be advanced by additional characteristic growth-related properties that could be easily seen in an immersion microscope, similar to the approach previously described in detail for natural and synthetic amethyst and heat-treated amethyst, the latter of which is transformed to citrine by the annealing process (Schmetzer, 1986, 1989; Kiefert and Schmetzer, 1991a,b,c). In so doing, it also became apparent that an investigation of the different seeding techniques used for producing the synthetic crystals would be key to understanding such diagnostic growth-related properties.

Natural Ametrine

The Anahí mine, which lies in the tropical rainforest of south-eastern Bolivia, is the only known commercial source of bicoloured amethyst-citrine quartz (i.e. natural ametrine; see again Figure 1). The mine has been operated since the early 1990s by Minerales y Metales del Oriente. Comprehensive descriptions of the mining operation were published by Collyer et al. (1994) and Vasconcelos et al. (1994), and Weldon (2013) provided a detailed update. Biste and Burgoa (2002) discussed the formation of ametrine at the Anahí mine.

Although open-pit mining is performed on a small scale, the main recovery of amethyst, ametrine and citrine at Anahí occurs underground via a system of shafts and tunnels. The unearthed material then undergoes initial sorting and washing before being transported to the company's processing facility (Figure 2) in the city of Santa Cruz.

Figure 2: These crystal clusters occupy the storage room of the company Minerales y Metales del Oriente in Santa Cruz, Bolivia. Only small portions of the crystals are of facetable quality. Photo taken in 1997; courtesy of Udo Reimann.

Figure 3: Quartz crystals from the Anahí mine are sawn and/or cobbed at the processing plant of the company Minerales y Metales del Oriente. Photo taken in 1997, courtesy of Udo Reimann. This process leaves irregularly shaped pieces of quartz (here, 5.7–9.3 g) that commonly exhibit a distinct colour boundary (inset photo by K. Schmetzer).

Most of the crystals are heavily included, with only a small percentage being gem grade. Extensive sawing and cobbing (hammering) is thus required to extract the clear gem-quality areas (Figure 3). Such operations are frequently begun on-site at the mine to reduce weight before transporting the goods to Santa Cruz. The clean material, estimated at several thousand kilograms per year, may be pre-shaped or cut in Bolivia. A significant percentage of the facetable gem material, however, is sold and cut elsewhere, mostly in Asia.

The combination of amethyst and citrine colours in natural ametrine from the Anahí mine has been attributed to colour zoning that differentiates rhombohedral **r** (violet) and **z** (yellow) growth sectors (Vasconcelos et al., 1994; Notari et al., 2001; Payette, 2013). However, in larger natural crystals, a sharp colour boundary is difficult to observe (Figure 4). Although the colouring mechanism is not completely understood, there are definite differences in Fe content between various growth sectors, with higher amounts in the yellow portions (Vasconcelos et al., 1994, 2002).

Synthetic Ametrine

A method for growing synthetic ametrine crystals was developed by Prof. V. Balitsky and his co-workers in the late 1980s at the research facilities of the USSR Academy of Sciences in Chernogolovka and Alexandrov, Russia. Detailed descriptions of the hydrothermal method employed and the properties of the resulting synthetics were given in multiple publications (Balitsky and Balitskaya, 1986, 2005, 2009; Balitsky et al., 1999, 2000, 2001, 2004). The synthetic material has been commercially available since the mid-1990s (Johnson and Koivula, 1998).

A number of seeding techniques can be applied for ametrine synthesis, but commercial crystal growth is typically performed using rectangular colourless synthetic quartz seed plates cut perpendicular to the c-axis. Production with such seeds leads to a varied incorporation of colour-causing

Figure 4: Ametrine crystals from the Anahí mine can be rather large, as shown by this specimen, which measures approximately 7.5 cm in diameter and weighs 312 g. The violet/yellow colour boundary is not easily seen. Photo by K. Schmetzer.

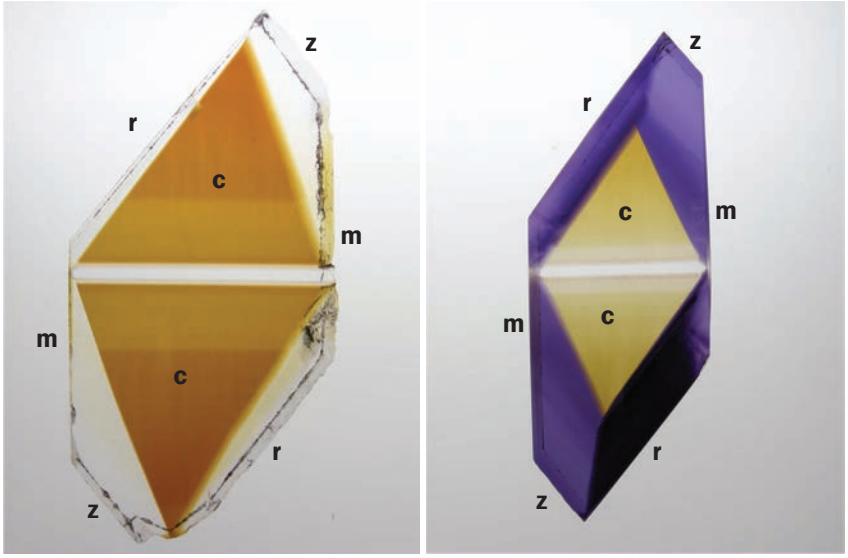

Figure 5: These slices of synthetic quartz show the colour zoning in as-grown crystals (left, 76 × 37 × 10 mm) and after irradiation (right, 63 × 22 × 10 mm). During irradiation, violet (amethyst) colour centres develop in the colourless **r** *and* **z** *growth sectors, but the yellow citrine colour of basal* **c** *growth sectors remains almost unchanged. Photos by K. Schmetzer.*

trace elements, mostly forms of iron, in different growth sectors. Growth rates of the crystal faces depend on temperature gradients in the autoclave. After crystal growth, all sectors of the as-grown crystals are either colourless or yellow to yellowish orange of variable intensity. The violet-to-purplish violet (amethyst) colour of certain sectors is then generated through irradiation, while the existing yellow (citrine) colour centres in general remain unaffected (Figure 5).

At slower growth rates, precursors of the amethyst colour centres (violet after irradiation) are incorporated in **r** and **z** growth sectors, and yellow colour centres are incorporated only in basal **c** sectors. However, with increasing growth rates, yellow colour centres are also developed in **r** and **z** sectors, along with a decreasing concentration of violet colour centres. The colours obtained are detailed by Balitsky and Balitskaya (1986), and a schematic drawing of colour intensity versus growth rates for **r** and **z** sectors is shown in Balitsky et al. (1999, 2000, 2001). As the growth rate increases (on a scale from 1 to 4, with 1 being the slowest and 4 the fastest), the resulting colour centres produce the colours after irradiation that are indicated in Table I.

Table I: Coloration of various sectors in synthetic ametrine according to growth rate.

Growth rate	r sector	z sector	c sector
1	Pale violet	Very pale violet	Yellow
2	Purplish violet	Violet	Yellow-orange
3	Brownish violet	Deep violet	Yellow-orange
4	Yellow	Brownish violet	Yellow-orange

To achieve the best yield for cutting attractive synthetic ametrine, growth rate 2 is selected for its ability to create intense violet **r** and **z** growth sectors along with deep yellow-orange **c** sectors. With growth rate 1, the colours of the **r** and **z** sectors are lighter. At growth rates 3 and 4, yellow colour centres develop in the **r** and **z** sectors, with a simultaneous decrease in violet colour intensity, thus leading to less desirable results.

The author was unable to obtain a complete picture regarding either which companies (e.g. in Russia, China and/or Japan) have ever produced or are presently growing synthetic ametrine (with or without also cutting), and/or which companies were or are only purchasing crystals and cutting this material for distribution through the Internet or at trade fairs. Nonetheless, it became clear that a portion of the purported 'Chinese' synthetic ametrine offered previously in the trade was grown in Russia and faceted in China.

Materials and Methods

The present study is based on a range of natural and synthetic ametrine material from multiple sources:

- faceted natural and synthetic ametrine obtained directly from the trade
- complete crystals and cobbed portions of natural ametrine from various collections
- slices of natural ametrine obtained by a German dealer directly at the mine in Bolivia and at the mine's office in Santa Cruz

- complete crystals and slices of synthetic ametrine (grown with a variety of seeding techniques) from various collections. Some of these crystals and slices were donated by Prof. V. Balitsky to colleagues or friends, while other slices were cut from larger crystals grown commercially.

In summary, and in terms of quantities, the following materials were examined:

- natural ametrine: three complete crystals, nine cobbed gem-quality rough samples, 11 slices cut perpendicular to the c-axis and 68 faceted gemstones
- synthetic ametrine: nine complete crystals, 25 slices cut in various orientations and 25 faceted samples

The morphology, colour zoning and growth zoning of the crystals and oriented slices of natural and synthetic ametrine were examined visually with the naked eye or a loupe, as well as with a microscope in transmitted light.

In addition, the cobbed rough and the slices of natural ametrine, the smaller slices of synthetic ametrine, and all the faceted natural and synthetic samples were examined in a horizontal immersion microscope using benzyl benzoate as the immersion liquid. The techniques employed, particularly the use of a special sample holder with two rotation axes, were described in detail by Schmetzer (1986) and by Kiefert and Schmetzer (1991a,b,c). Note that some of the larger samples could not be examined in this way because their sizes precluded the use of an immersion cell.

Moreover, as a preface to the discussions that follow, it should be emphasized that, *in the opinion of the author, the use of an immersion cell and the application of crossed polarizers are necessary to recognize the diagnostic patterns described in this work*. Additional, more specialized equipment can be of assistance but is not mandatory. For example, use of a sample holder with both horizontally and vertically oriented rotation axes is helpful, but all examinations also can be performed with a 'normal' sample holder having only a single vertically oriented rotation axis. Likewise, employing various tools to determine angles between different growth structures can aid in *understanding* the features observed, but such measurement tools are not essential to *distinguish* natural and synthetic ametrine.

Results

Natural Ametrine—Cobbed Rough and Slices

Visual Appearance: As mentioned above, the violet/yellow (amethyst/citrine) colour boundaries can be difficult to observe in larger natural crystals, and this held true for a 312 g sample studied here (see again Figure 4). Its morphology was typical for such crystals, which normally show faces of the positive rhombohedron **r** $\{10\bar{1}1\}$ and the negative rhombohedron **z** $\{01\bar{1}1\}$, occasionally with small prism faces **m** $\{10\bar{1}0\}$. After such crystals have been sawn and/or cobbed to remove heavily included areas, the remaining facet-quality rough readily displays straight colour boundaries (Figures 3 inset and 6).

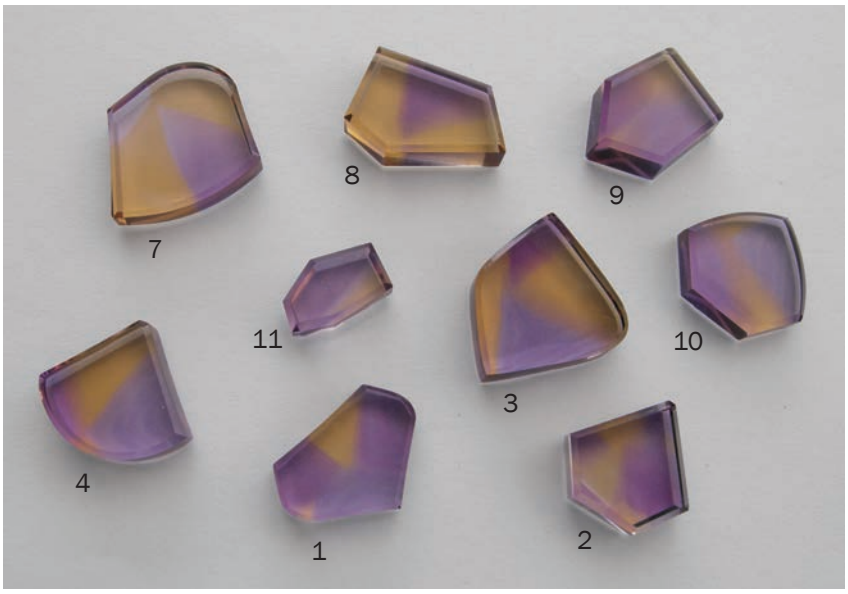

*Figure 6: Slices of natural ametrine viewed parallel or almost parallel to the c-axis show variable colour distribution between violet **r** and yellow **z** growth sectors. In some of the samples, the **r** sectors include a range of hues from violet to purple. The samples weigh from 6.31 to 21.39 ct (sample 7, 20.3 × 19.5 × 5.4 mm). Photo by K. Schmetzer.*

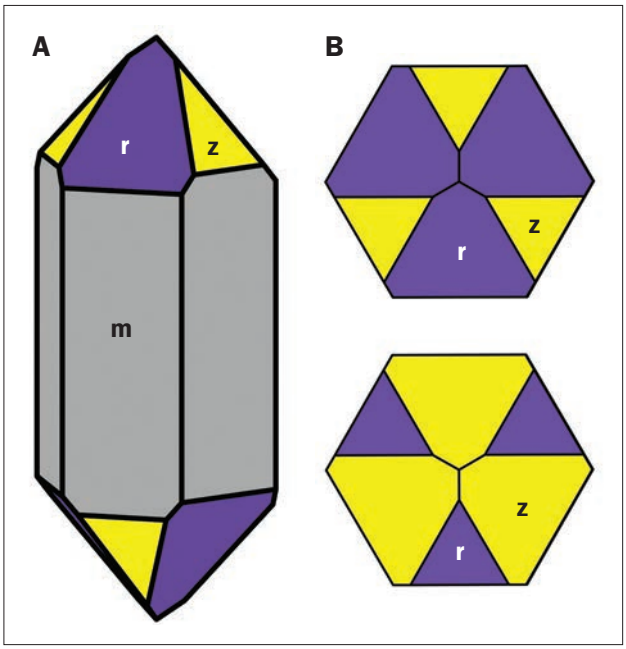

*Figure 7: (A) This idealized natural quartz crystal with prismatic habit (clinographic projection) consists of **m** prism faces in combination with **r** and **z** rhombohedra. (B) Two examples of the colour distribution between violet **r** and yellow **z** growth sectors of different sizes are shown for such crystals when viewed parallel to the c-axis. The top one corresponds to the size of the rhombohedral faces in drawing A. Drawings by K. Schmetzer.*

In idealized crystals such as depicted in Figure 7A, sectorial colour zoning with three-fold symmetry would be apparent, with variable sizes for the two rhombohedral **r** and **z** growth sectors (Figure 7B). However, most natural crystals are somewhat distorted and frequently reveal more complex patterns of growth and colour zoning when viewed as slices cut approximately perpendicular to the c-axis. Such slices studied here exemplified this situation, showing irregularities in both the size and the shape of the violet **r** and the yellow **z** growth sectors (Figure 6). Moreover, even within a single slice, the **r** growth sectors may exhibit a range of hues, with some appearing more violet and others more purplish violet or purple. Lighter and darker coloured stripes within **r** growth sectors, often with triangular shapes, could also be observed with the unaided eye in some samples.

Microscopic Examination: The immersion microscope was used to look for twinning features, to establish the orientation of the violet/yellow colour boundaries and the direction of growth striations relative to these boundaries, and to observe any characteristic inclusions.

Between crossed polarizers, especially after orienting the samples to a view exactly perpendicular to the c-axis, so-called Brewster fringes were visible in the violet **r** growth sectors of all samples (Figure 8). This interference pattern results from Brazil-law twinning in these sectors of the ametrine crystals. It is generally accepted that such areas consist of polysynthetically twinned lamellae of alternating right-handed and left-handed quartz. The fringes appear black because light travelling along the optic axis passes through almost equal distances (light paths) of right-handed and left-handed quartz. Hence, for purposes of the following discussion, and particularly when describing rotations and angles, the c-axis of a sample is assumed to be oriented parallel to the microscope tube if the Brewster fringes appear sharp and black between crossed polarizers.

In slices where darker violet stripes within the **r** growth sectors were visible even to the unaided eye in normal lighting, the Brewster fringes proved to be coincident with this colour zoning. The convoluted patterns observed demonstrated the complexity of the violet and yellow colour zoning present in these highly distorted samples (see again Figure 6).

The violet/yellow colour boundaries between the **r** and **z** sectors ran more-or-less parallel to the c-axis and parallel to the **m** prism faces, with a maximum deviation of up to 10°. As the samples were rotated about various axes, growth striations could be seen repeatedly in the violet parts in certain orientations, but none were found within the yellow areas. The striations in the violet growth zones were parallel to the rhombohedral **r** faces and inclined to the violet/yellow colour boundary (Figure 9). However, it should be noted that in the directions of view revealing the striations, the violet/yellow boundary was not an exact plane but fluctuated somewhat within the crystals, especially from the centre to the rim.

With the violet/yellow colour boundary oriented east–west in the microscope and using a north–south rotation axis (i.e. parallel to the main vertical axis of the sample holder and perpendicular to the colour boundary), it was possible to more specifically establish the orientations in which the growth striations in the violet sectors could be seen, as follows. Starting with a view oriented parallel to the c-axis (Figure 10, top), in which the Brewster fringes were visible, the **r** growth striations became evident after rotating the sample through an angle of about 40°. This

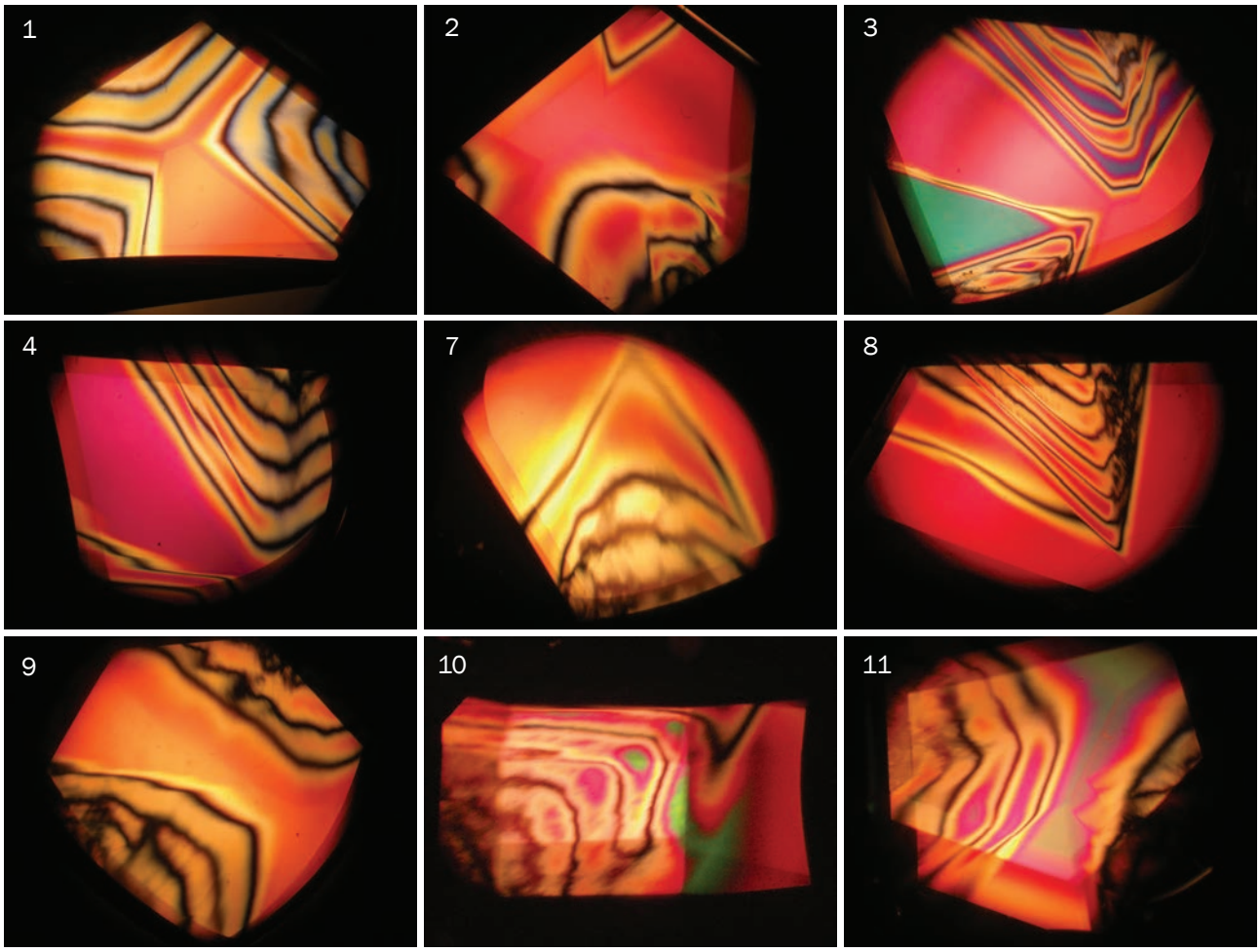

*Figure 8: Between crossed polarizers, the samples depicted in Figure 6 show interference patterns (Brewster fringes) that indicate Brazil-law polysynthetic twinning of the violet **r** growth sectors. Photomicrographs by K. Schmetzer, in immersion.*

*Figure 9: In natural ametrine, the colour boundary between the violet **r** and yellow **z** growth zones more-or-less follows a prismatic **m** crystal face but is not exactly planar. In addition, growth striations are present in the violet **r** sectors, and they are parallel to an external **r** face and inclined to the violet/yellow boundary. The angle between the growth striations and the colour boundary measures approximately (A) 67° or (B) 38°. Photomicrographs by K. Schmetzer, in immersion; field of view (A) 7.5 × 10.0 mm and (B) 9.5 × 7.1 mm.*

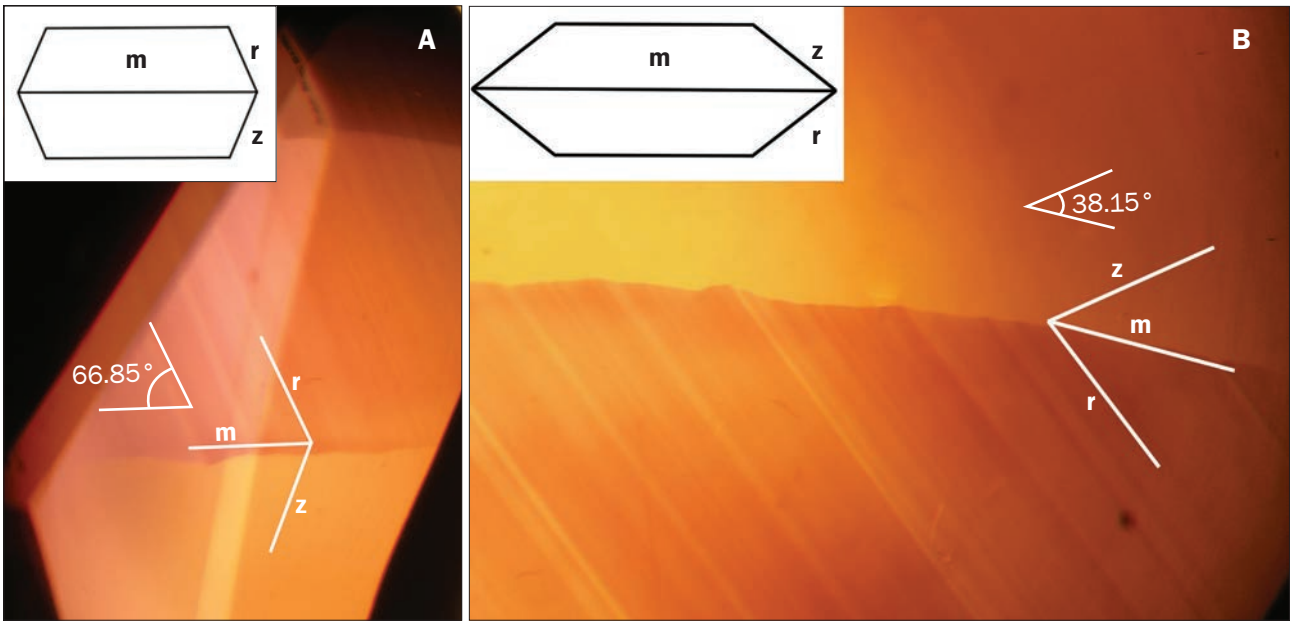

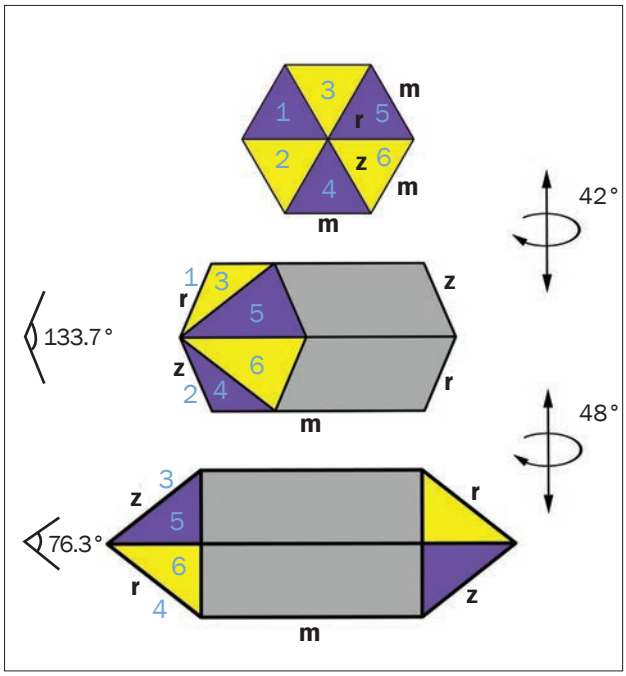

*Figure 10: Three views of an idealized natural ametrine crystal are shown in this diagram: parallel to the c-axis (top), after rotation through an angle of 42° (centre), and after further rotation through an additional angle of 48° (bottom). The orientation shown at the top exhibits differently coloured **r** and **z** growth sectors, and crossed polarizers will reveal Brewster fringes caused by polysynthetic twinning on the Brazil law, as seen in Figure 8. After rotation through an angle of 42° (centre), the **r** and **z** faces labelled 1 and 2 are parallel to the direction of view, as seen in Figure 9A. After further rotation through an additional angle of 48° (bottom), the **r** and **z** faces labelled 4 and 3 are parallel to the direction of view, as seen in Figure 9B. Drawings by K. Schmetzer.*

situation is drawn schematically in Figure 10-centre. The **m** prism faces were then oriented east-west, and adjacent **r** and **z** planes of the crystal (labelled 1 and 2) were parallel to the direction of view (Figure 9A). These rhombohedral faces formed an angle of 133.7° with each other, and the exact rotation angle was calculated as 42.2°. Half of the 133.7° angle (i.e. 66.85°) was measured between these growth striations and the dominant violet/yellow colour boundary.

After further rotation through an additional angle of 47.8° (for a total rotation of 90°), a view exactly perpendicular to the c-axis was obtained. At that point, other **r** and **z** faces (labelled 4 and 3, respectively) were oriented parallel to the direction of view, and striations were again potentially visible in the microscope (e.g. Figure 9B). This situation is represented in Figure 10 (bottom). The angle between the **r** and **z** planes in this orientation measured 76.3°. Half of the 76.3° angle (i.e. 38.15°) was measured between these growth striations and the dominant violet/yellow colour boundary.

The inclusions in the slices consisted only of fluid inclusions, as described below for the faceted samples.

Natural Ametrine—Faceted Samples

Visual Appearance: Commercial ametrine gemstones seen in the trade are normally faceted in a direction and shape which shows a single colour boundary across the table facet, as were most of the samples studied here (Figure 11). Only in a small percentage of samples were two colour boundaries observed. The colour boundaries were frequently more obvious when viewed from the pavilion side. Zoned faceted quartz from the same mine in Bolivia with very light yellow to near-colourless and more intense yellow portions are described in Box A.

Microscopic Examination: The optical properties of the faceted samples were consistent with those described above for the oriented slices. When the optic axis was oriented exactly parallel to the light path of the microscope, complex interference patterns were observed with Brewster fringes corresponding to the violet sectors of the stones (Figure 12). Upon then turning the stones with the colour boundary oriented perpendicular to the rotation axis of the sample holder, growth striations appeared at certain intervals (Figure 13). More specifically, and as already detailed for the natural ametrine slices, rotating a faceted sample about an axis perpendicular to the colour zoning led to orientations revealing two particular features: interference patterns with Brewster fringes in a view parallel to the c-axis (Figure 12) and, after a rotation of 42.2°, growth striations parallel to rhombohedral **r** faces (Figure 13A; see again Figure 10-centre).

However, in contrast to the situation typically apparent for the slices, continuing to rotate a faceted stone without removal from the sample holder did not, in general, unveil any additional growth striations. Their absence can be explained by the fact that these faceted ametrines consisted only of two of the six rhombohedral **r** and **z** growth sectors (labelled 1 and 2 in Figure 10). Consequently, because the other sectors (labelled 3 to 6 in Figure 10) were not present in most

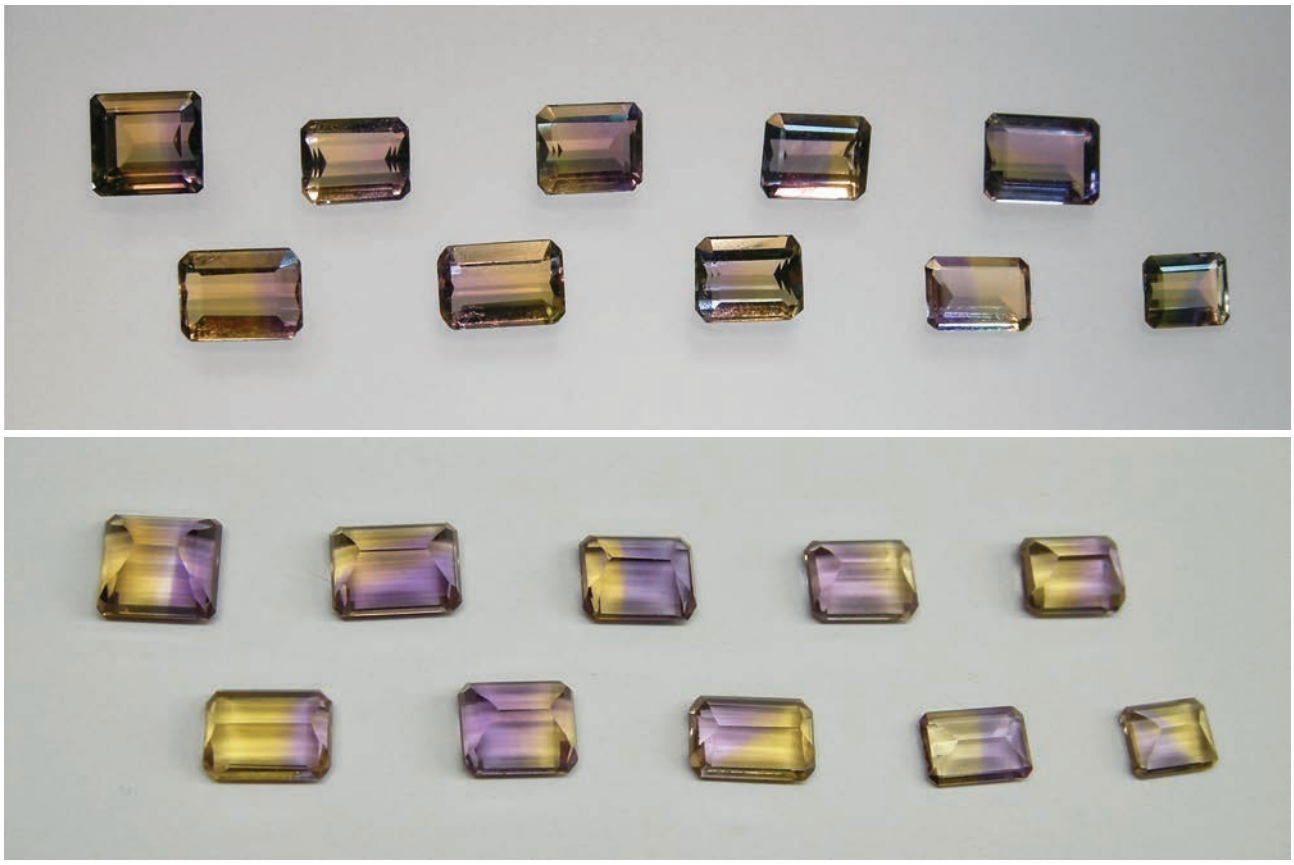

Figure 11: Faceted natural ametrine gemstones from Bolivia typically display only two colour zones, as seen here viewed toward the table facets (top) and toward the pavilions of the same samples (bottom). The stones weigh from 2.45 to 7.45 ct (upper left, 11.7 × 10.8 mm). Photos by K. Schmetzer.

faceted samples, the growth striations in such sectors could not be seen. Nonetheless, in less common faceted samples such as those with two violet/yellow growth boundaries, the possibility remained for locating further growth striations in a view perpendicular to the c-axis, as described for the slices (Figure 13B, see again Figure 10, bottom). Likewise, it should be emphasized that the foregoing applies to a rotational sequence starting from an orientation in which Brewster fringes are observed, but with other starting orientations and/or other rotation axes a different scenario of observations could unfold.

Most of the faceted ametrines obtained from the trade were generally free of inclusions. However, negative crystals in the form of two-phase inclusions were seen occasionally (Figure 14A). Somewhat more common were partially healed fractures, sometimes consisting of elongated fluid inclusions (Figure 14B). The shapes and orientations of the liquid and two-phase inclusions trapped in the partially healed fractures reflected the internal structure of the polysynthetically twinned crystals and their lamellar microstructure. In particular, a specific parquet-like zigzag pattern of fluid trapped in elongated voids revealed the complex polysynthetic twinning of the violet areas on the Brazil law (Figure 14C). An analogous scenario was previously described for inclusions in natural amethyst (Schmetzer, 1987), and a similar pattern has been seen after etching polished amethyst surfaces (Lu and Sunagawa, 1990; Lu et al., 1990).

Synthetic Ametrine—Crystals and Slices

Variations in Seed Plates, Crystal Morphology and Colour Zoning: Synthetic ametrine is grown by the hydrothermal technique using seeds cut with various orientations and elongations, as described below. Consequently, multiple types of samples must be investigated in any effort to determine whether it is possible to distinguish natural from synthetic ametrine based on, for instance, the orientation of the violet/yellow boundary. In Figure 15A and B, an idealized synthetic crystal with five dominant faces is drawn as

Box A: 'Luna y Sol' Quartz

During the course of the present study involving bicoloured quartz of the traditional violet/yellow variety, the opportunity also arose to examine two faceted samples exhibiting a more unusual bicoloured appearance. These consisted of quartz with very light yellow to near-colourless and more intense yellow portions, referred to in the trade as 'Luna y Sol' (moon and sun) or 'Lunasol' (Figure A-1). They had been obtained by a German dealer at the headquarters of the Anahí mine in Santa Cruz, Bolivia. Such faceted samples have been depicted in earlier publications, and it also has been mentioned that slices of ametrine from Anahí may consist of violet (amethyst), yellow (citrine) and nearly colourless zones (Vasconcelos et al., 1994).

The two samples examined by the author showed a planar boundary between the light yellow zone and the more intense yellow portion. The boundary was oriented parallel to the c-axis, thus corresponding to the violet/yellow boundary in natural ametrine. The stones were optically untwinned single crystals in which neither zone showed a specific interference pattern or any Brewster fringes under crossed polarizers. No growth striations were observed in either part.

Similar bicoloured near-colourless and yellow quartz was mentioned by Henn and Schultz-Güttler (2012). These authors noted that the material can be produced by heat treatment of colour-zoned amethyst from Bolivia or Brazil. However, after a transformation of amethyst to citrine by heat treatment, the typical polysynthetic twin pattern of amethyst is not removed (Schmetzer, 1989). Thus, the lack of twinning in the two samples described in the present study indicates that they are unheated and may consist of two citrine growth zones (i.e. nearly colourless/yellow zones of different colour intensities, cut from an ametrine crystal). It might be possible to learn additional details about the relation of these zones within the complete ametrine crystals if slices made from rough containing such near-colourless zones, along with violet and intense yellow areas, should become available in the future.

Figure A-1: Faceted colour-zoned quartz consisting of a lighter yellow, almost colourless, zone and a more intense yellow zone is referred to as 'Luna y Sol' or 'Lunasol' in the trade. These examples weigh 3.17 ct (left, 10.0 × 8.0 mm) and 2.14 ct (right). Photo by K. Schmetzer.

a clinographic projection and in a view parallel to the c-axis, respectively. The faces shown are the basal pinacoid **c** {0001}, the prism faces **m** $\{10\bar{1}0\}$ and **x** $\{11\bar{2}0\}$, the positive rhombohedron **r** $\{10\bar{1}1\}$ and the negative rhombohedron **z** $\{01\bar{1}1\}$.

For purposes of the following discussion, the present study will use the generally accepted nomenclature established by Prof. V. Balitsky and his co-workers (see references mentioned in the introduction). Small discrepancies in terminology and/or in details describing the synthetics between various publications, which are potentially attributable to inconsistent translations from Russian into English, will not be addressed at any length, provided the intended meanings are obvious.

Seed plates used in producing synthetic ametrine are frequently cut perpendicular to the c-axis (Z-cut). The simplest way to obtain a Z-cut seed plate is to slice a natural quartz crystal with six **m** prism faces perpendicular to its c-axis (Figure 15C). However, Z-cut seeds also may be elongated either parallel to an **x** prism face (parallel to the Y direction; Figure 15D) or parallel to an **m** prism face (parallel to the X direction; Figure 15E).

Commercial ametrine is often grown on Z-cut seed plates elongated parallel to the X direction (parallel to one of the **m** prism faces; Figure 15E). A complete crystal produced with such seed orientation and elongation is depicted in Figure 16.

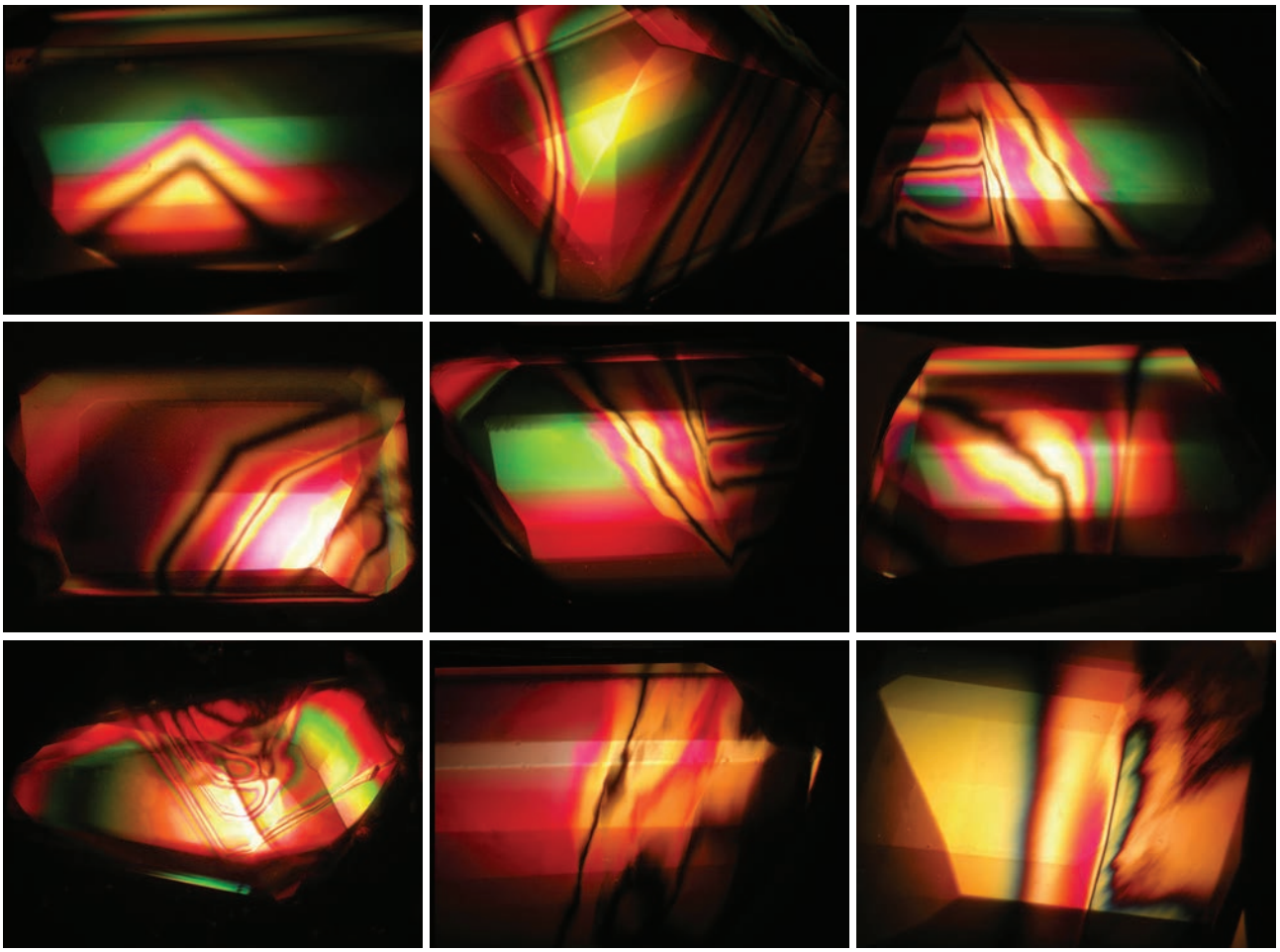

*Figure 12: Between crossed polarizers, faceted natural ametrine shows interference patterns (Brewster fringes) when viewed parallel to the c-axis, indicating polysynthetic twinning of the violet **r** growth sectors. The samples shown here were chosen from the faceted ametrines depicted in Figure 11. Photomicrographs by K. Schmetzer, in immersion; field of view ranges from 8 × 6 mm to 12 × 9 mm.*

*Figure 13: The growth boundary between violet **r** and yellow **z** growth zones in natural ametrine is not exactly planar, as shown in these two faceted examples. In addition, growth striations parallel to an external **r** face and inclined to the violet/yellow boundary are observed in the violet **r** sector (forming angles with the violet/yellow boundary of ~67° in A and ~38° in B). Photomicrographs by K. Schmetzer, in immersion; field of view (A) 6.3 × 4.7 mm and (B) 9.5 × 7.1 mm.*

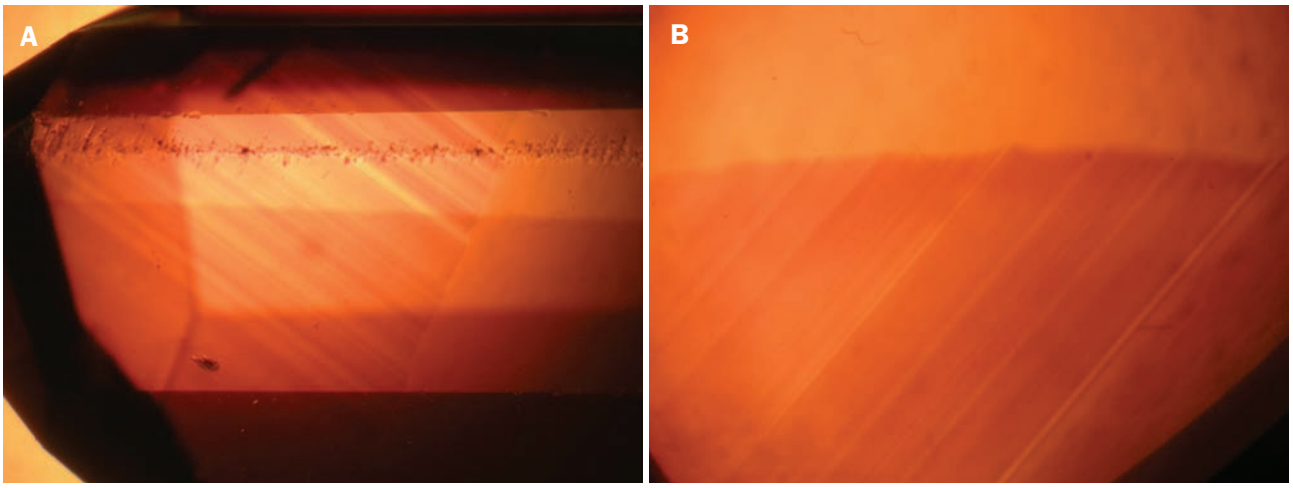

*Figure 14: Various forms of fluid inclusions are occasionally seen in faceted natural ametrine, such as (A) negative crystals with two-phase fillings and (B) partially healed fractures with elongated cavities. (C) A parquet-like zigzag pattern of elongated fluid inclusions follows the complex polysynthetic twinning of the violet **r** growth sectors on the Brazil law. Photomicrographs by K. Schmetzer, in immersion; field of view (A) 4.5 × 3.4 mm, (B) 3.1 × 2.3 mm and (C) 2.2 × 1.7 mm.*

*Figure 15: (A) This clinographic projection of an idealized synthetic quartz crystal with prismatic habit consists of **m** and **x** prism faces in combination with **r** and **z** rhombohedra and basal **c** faces. (B) A view of the same crystal parallel to the c-axis shows the colour distribution between violet **r** and **z** growth sectors and yellow basal growth zones. For crystal growth, seeds are frequently cut perpendicular to the c-axis, also described as Z-cut seeds. These seeds can display (C) a hexagonal outline consisting of six prismatic **m** faces, or they can be elongated (D) parallel to the Y direction or (E) parallel to the X direction. Drawings by K. Schmetzer.*

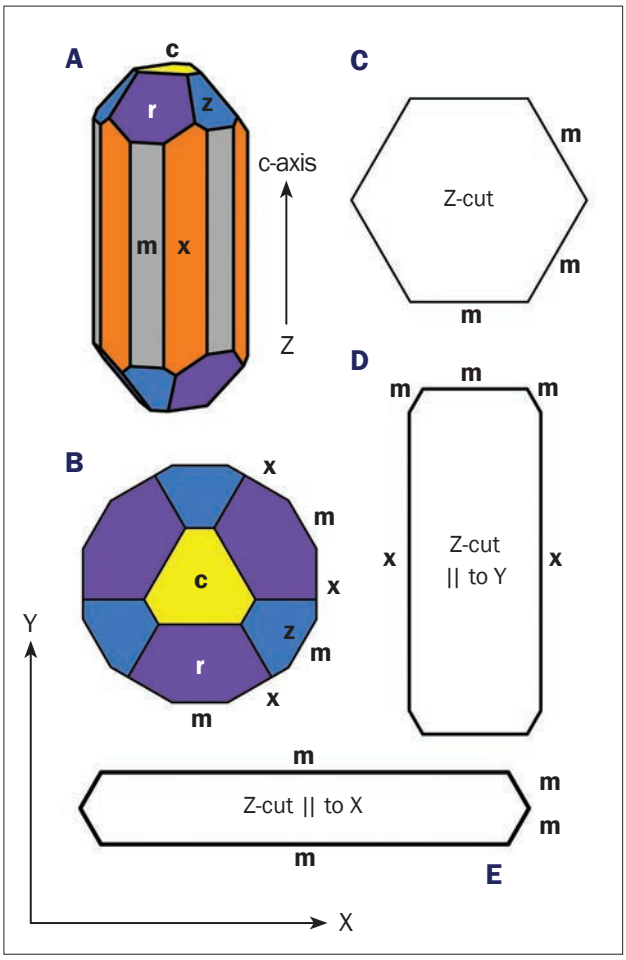

*Figure 16: Commercial growth of synthetic ametrine is frequently performed with Z-cut seed plates elongated parallel to the X direction. (Top) This complete crystal, weighing 306 g (161 × 46 mm), was grown by this method. (Centre) A clinographic projection of the same crystal shows a habit of **m** prism faces combined with **r** and **z** rhombohedra. (Bottom) This view parallel to the c-axis depicts the orientation of the Z-cut seed plate elongated parallel to the X direction and the orientation of the slices shown in Figure 17A,B. Photo and drawings by K. Schmetzer.*

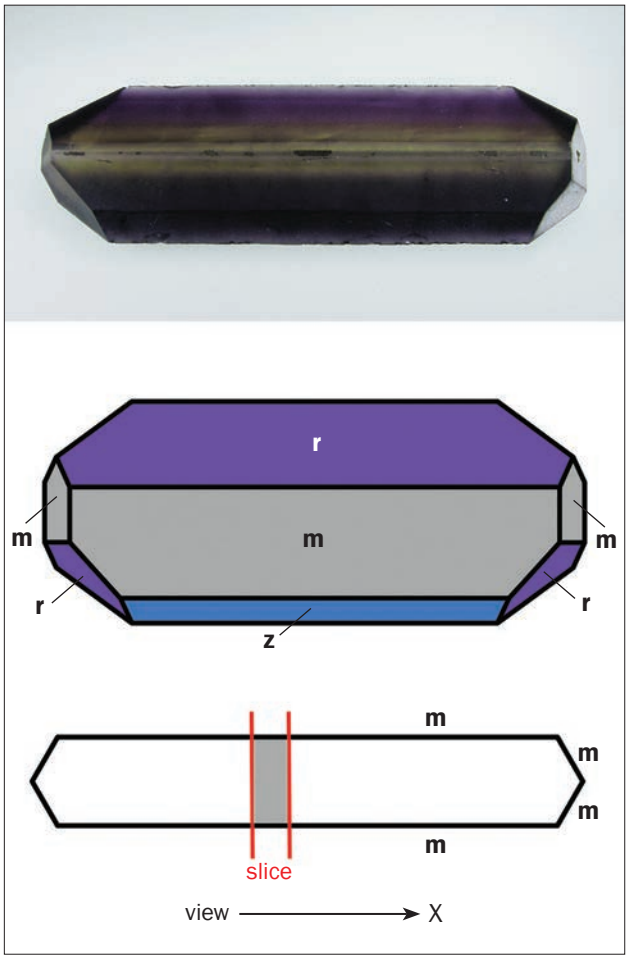

The crystal has two elongated **m** faces as well as two elongated **r** and **z** faces, together with four smaller **m** and four smaller **r** faces. Colour zoning in crystals so grown was seen best in slices cut perpendicular to the two elongated **m** faces, viewed perpendicular to the cut (Figure 17A,B). In crystals grown with seed plates having the same elongation but cut at an incline of about 30° to the c-axis, the morphology of the crystals obtained was almost identical (Figure 17C).

In both cases, the crystals had yellow to yellow-orange basal **c** growth sectors along with violet **r** and **z** growth zones. For the examples seen in Figure 17A and C, the **r** and **z** growth sectors were purely violet, and the colour of the **r** sectors was somewhat more intense. For the example portrayed in Figure 17B, more iron had been incorporated into the crystal, so the **r** zones began to exhibit a degree of brownish colour admixed with the intense violet.

With these samples, and regardless of whether the seed had been cut parallel to the basal **c** face or angled by about 30°, the inclination of **r** and **z** rhombohedral faces to the c-axis was always constant at 38.2°. The boundary between basal yellow growth sectors and intense violet **r** zones was parallel or nearly parallel to the external **r** faces, with only a small deviation. In contrast, the boundary between basal yellow growth sectors and lighter violet **z** zones was not parallel to the external **z** faces (Figure 17A–C). The angle between this boundary and the c-axis varied mostly between 20° and 30°, and only in one sample was an angle of 35° measured.

However, in crystals grown with seed plates elongated parallel to the X direction but cut parallel to a rhombodedral **z** face, the morphology changed substantially. Alternating violet and brown striations parallel to the seed and the external **z** faces were observed, with small brown **r** growth sectors (Figure 17D); note that the brown areas in this crystal would be yellow or yellow-orange if less iron had been incorporated during crystal growth (see Table I and text on page 511). A related sample with an unusual orientation of the seed plate and the resulting colour zoning thereof is described in Box B.

Synthetic ametrine has also been grown on Z-cut seeds elongated parallel to the Y direction (parallel to one of the **x** prism faces; Figure 18). External crystal faces of such samples studied here were parallel to the **m** and **x** prism faces and the **r** and **z** rhombohedral faces. Slices cut from such synthetic ametrine crystals showed yellow basal **c** growth sectors, intense yellow-orange ('amber'-coloured) **x** growth sectors, and violet **r** and **z** growth zones. In samples with this seed

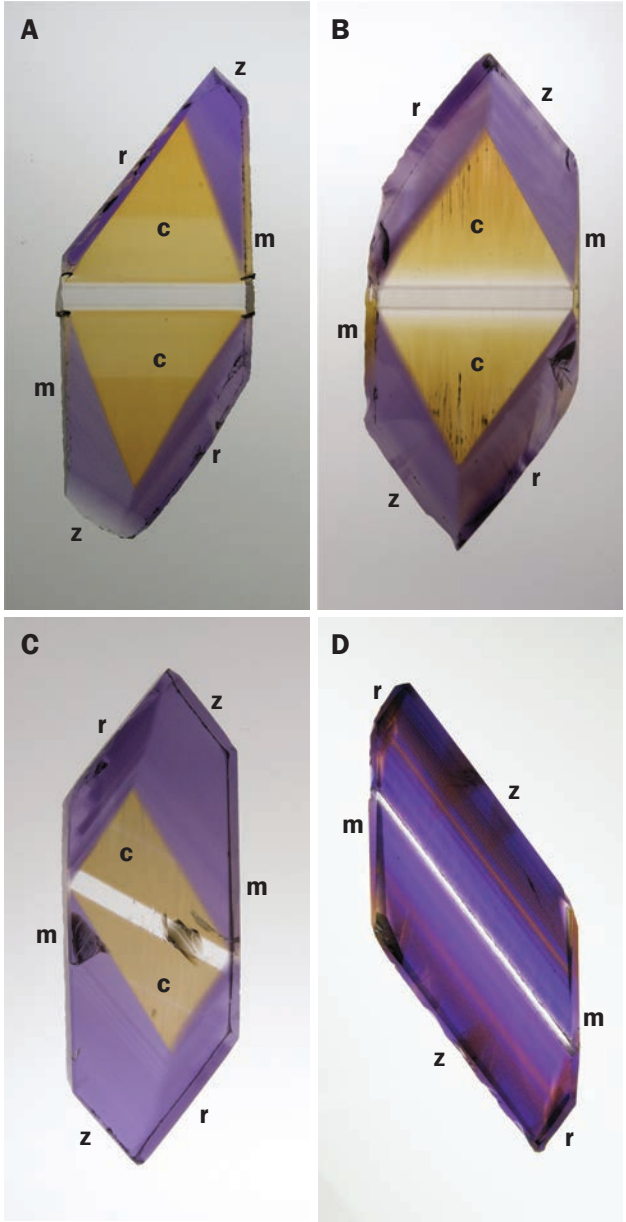

*Figure 17: These slices of synthetic ametrine were grown on seed plates elongated parallel to the X direction and were sawn perpendicular to the long **m** prism faces. The seed plates were cut at various orientations: (A,B) perpendicular to the Z direction (i.e. parallel to the basal **c** face), (C) inclined about 30° to the basal face and (D) parallel to the rhombohedral **z** face. The habit of the samples shows prismatic **m** faces in combination with **r** and **z** rhombohedra; the colour distribution within the different growth zones also can be seen. The samples measure (A) 61 × 24 × 5 mm, (B) 71 × 30 × 9 mm, (C) 61 × 22 × 7 mm and (D) 75 × 31 × 14 mm. Photos by K. Schmetzer.*

Box B: Synthetic Ametrine with Violet and Yellow z Growth Zones

A unique synthetic ametrine sample was obtained in 2015 from the trade in Moscow, Russia. The crystal had been grown using a seed plate cut parallel to a rhombohedral **z** face. The seed could be seen in the slice, together with rhombohedral **r** and **z**, prismatic **m** and small basal **c** faces (Figure B-1). Violet and yellow areas were observed within the main **z** growth zones, with striations parallel to the **z** seed plate visible in both the violet and yellow areas. These growth striations appeared sharp in the immersion microscope.

If such a synthetic ametrine crystal were to be faceted, the cut specimen would contain growth striations parallel to the **z** seed in the violet region, but possibly also in the yellow portion. In addition, the violet/yellow boundary would be parallel to the seed. However, since the seed plate is inclined 38° to the c-axis, such faceted material would be easily identified by the microscopic techniques described in this article.

No direct information about the production of this material is available, and the growth conditions for achieving this type of colour zoning in synthetic ametrine are unknown. It is probable that the temperature (and/or the temperature gradient) within the autoclave changed during crystal growth, and this was responsible for incorporation of the different violet and yellow colour centres in the **z** growth sector.

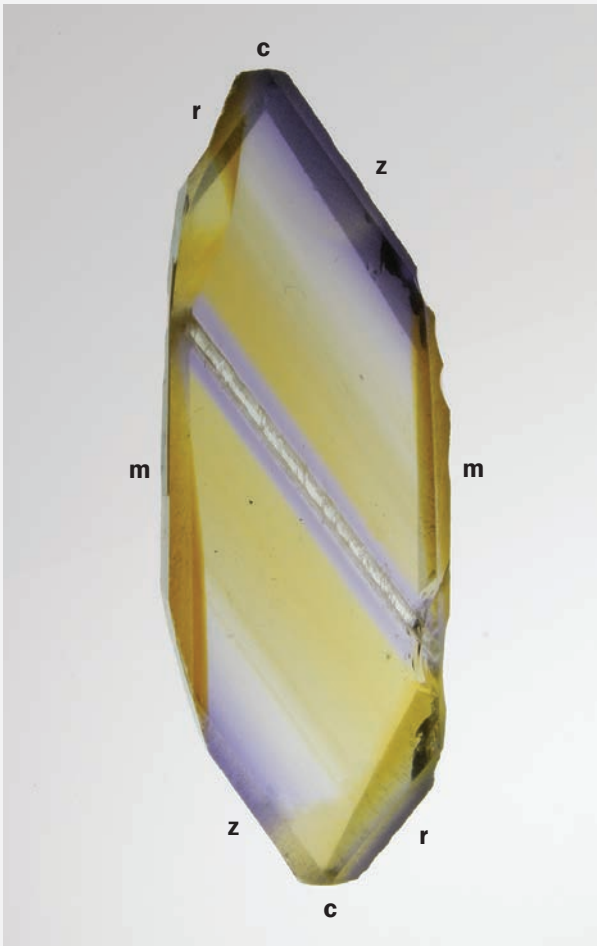

*Figure B-1: This synthetic ametrine was grown on a seed plate cut parallel to the rhombohedral **z** face. Parallel to the seed, colour zoning is visible within various violet and yellow areas. The slice measures 61 × 21 × 10 mm. Photo by K. Schmetzer.*

configuration, the growth zones adjacent to the seed were either yellow (basal **c** zones) or amber-coloured (prismatic **x** growth zones). This seed-related colour scheme was readily observed in slices cut perpendicular to the Y direction (Figure 18C), but was also visible in a crystal with large cobbled basal **c** faces parallel to the seed (Figure 19). The various growth zones in this latter crystal were all either yellow or amber-coloured, and no violet zones had developed adjacent to **r** and **z** faces. From this morphology, it can therefore be concluded that the growth time in the autoclave for the synthetic quartz pictured in Figure 19 with large basal faces was comparatively shorter than that employed for samples such as in Figure 18C with small or no basal faces.

The boundaries between yellow basal growth zones and violet **r** sectors were parallel or almost parallel to the external **r** faces and, consequently, inclined approximately 38° to the c-axis. Most of the boundaries between **c** sectors and **z** zones were somewhat less inclined to the c-axis, forming angles of 20–30° (Figure 18C,D). The boundaries between intense yellow-orange (amber-coloured) **x** growth zones and violet rhombohedral **r** and **z** sectors were only slightly inclined to the c-axis (see below).

In a variation of the situation described above, in some instances steel pins were incorporated during the process of growing synthetic ametrine on Z-cut seeds elongated parallel to the Y direction (parallel to one of the **x** prism faces). The

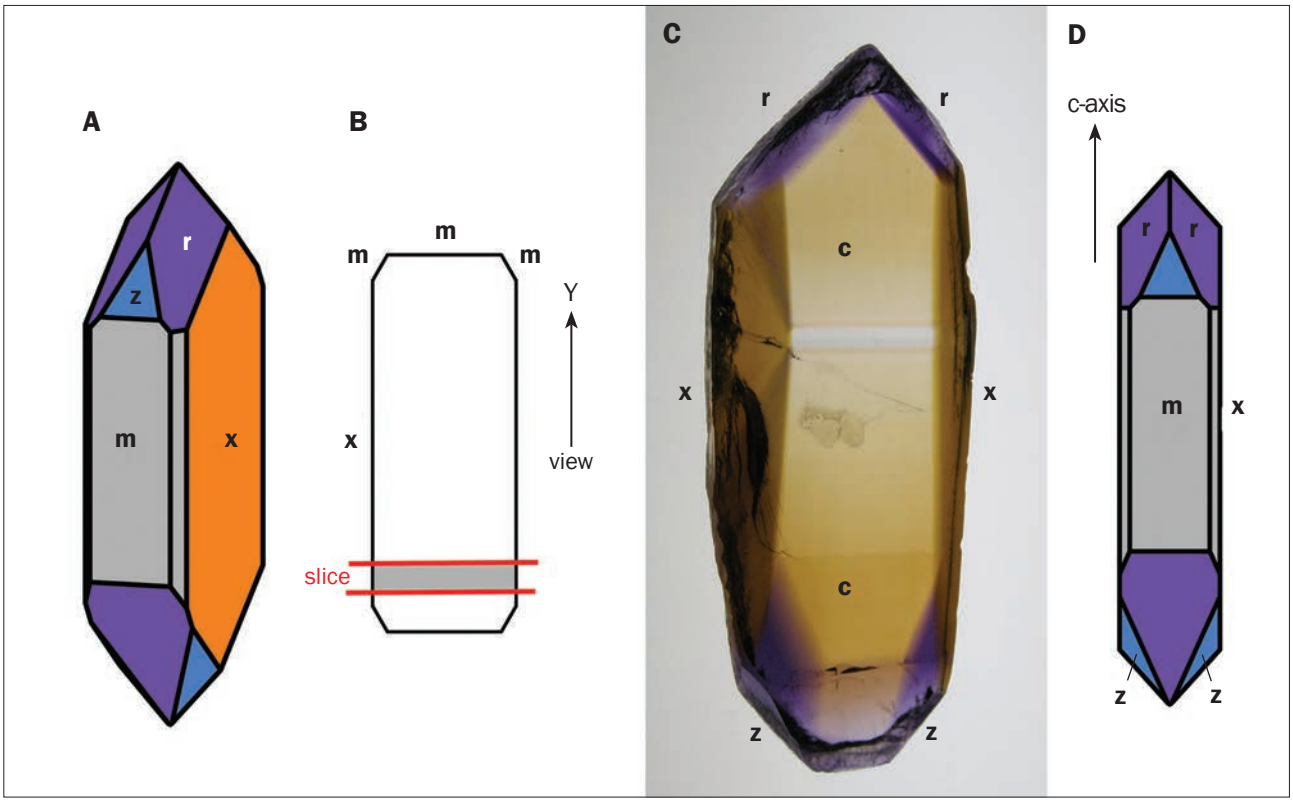

*Figure 18: (A) This clinographic projection shows the crystal habit resulting from growth of synthetic ametrine on Z-cut seed plates elongated parallel to the Y direction. The crystals consist of **m** and **x** prism faces combined with **r** and **z** rhombohedra. (B) A view parallel to the c-axis depicts the orientation of the Z-cut seed plate elongated parallel to the Y direction and the orientation of the slice shown in C. (C) This slice of synthetic ametrine cut perpendicular to the Y direction (i.e. perpendicular to the long **x** prism faces) measures 83 × 30 × 6 mm. (D) A clinographic projection, corresponding to the orientation of the slice in C, shows the crystal in a view parallel to the **x** faces. Photo and drawings by K. Schmetzer.*

pins served to interrupt crystal growth and resulted in samples comprising several identically oriented crystals, with dominant **m**, **r** and **z** faces (Figure 20). The **r** and **z** growth sectors influenced by the steel pins were highly distorted, with alternating violet, purplish violet, yellow and brown growth lamellae (Figures 20 and 21). Some of these crystals contained essentially planar boundaries between the **r** and **z** sectors and the yellow central areas, but in others the boundaries between **r** and **c** growth sectors were bent or curved. More precisely, the boundaries between the **z** and **c** growth sectors were inclined 20°–25° to the c-axis, and the boundaries between the **r** and **c** growth sectors were primarily inclined 30°–35° to the c-axis, except that the bent/curved

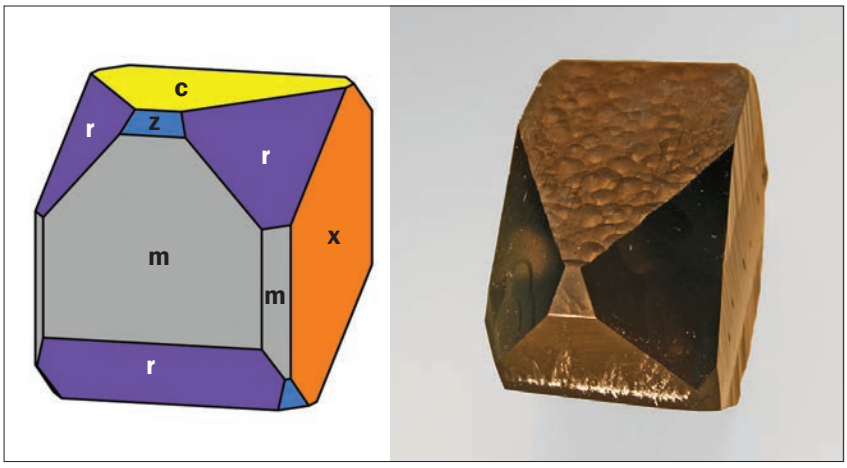

*Figure 19: (Left) This clinographic projection of a synthetic ametrine crystal grown with a Z-cut seed elongated parallel to the Y direction shows a habit consisting of **m** and **x** prism faces combined with **r** and **z** rhombohedra and a large basal face **c**. (Right) This corresponding synthetic ametrine crystal exhibits a large basal face with a cobbled surface, a texture frequently seen in hydrothermal synthetic quartz. The crystal weighs 103 g (49 × 29 mm, and 33 mm along the c-axis). Photo and drawing by K. Schmetzer.*

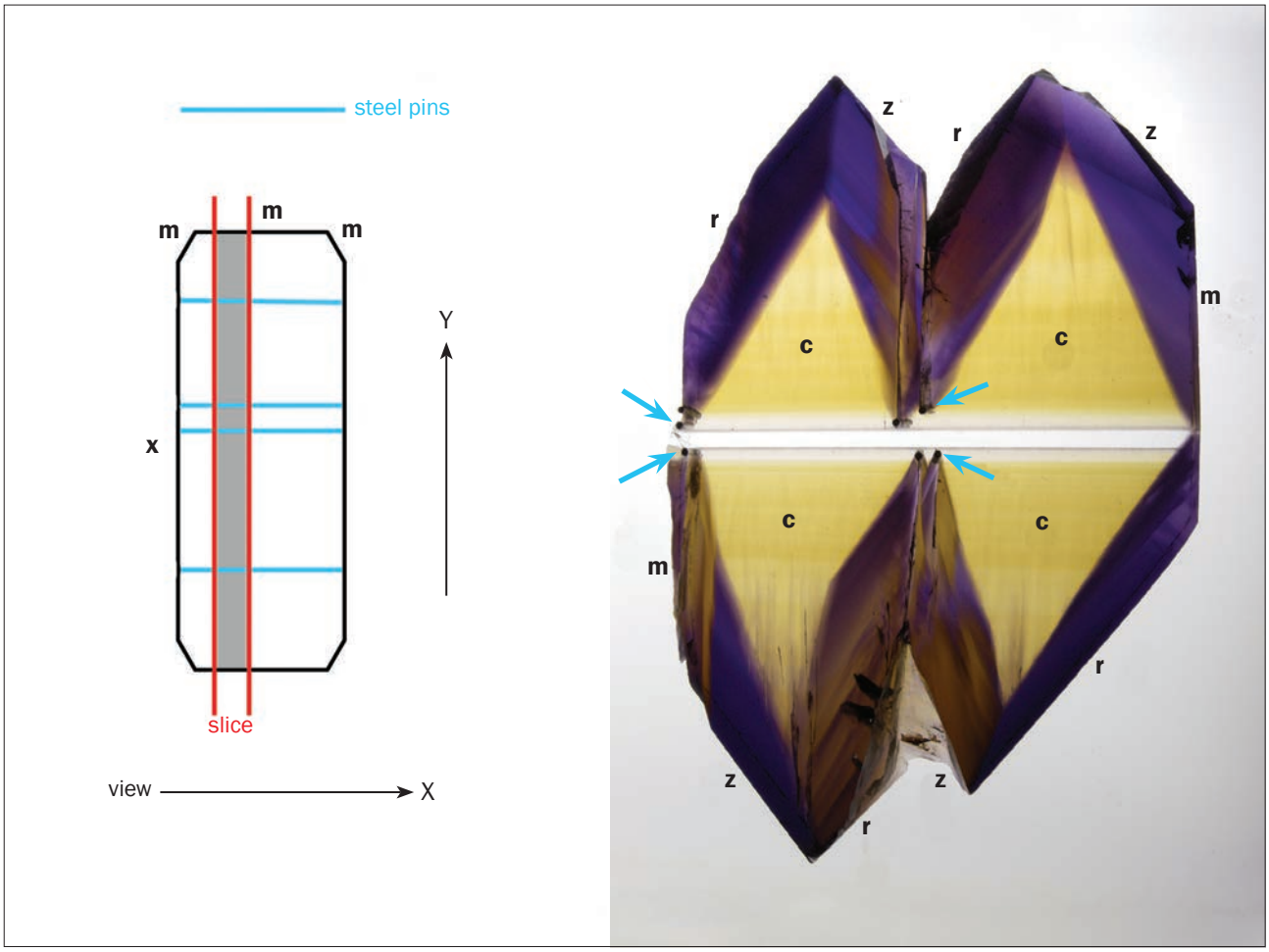

*Figure 20: Growth of synthetic ametrine is also performed with Z-cut seed plates elongated parallel to the Y direction but with steel pins interrupting crystal growth. (Above, left) This drawing of a view parallel to the c-axis shows the orientation of the seed plate and the steel pins, as well as the position of the slice shown on the right. (Above, right) This slice of such a synthetic ametrine crystal was cut parallel to the Y direction (i.e. parallel to the long **x** prism faces); it measures 93 × 59 × 10 mm. The slice consists of two ametrine subindividuals with parallel orientation; steel pins are indicated with blue arrows. The colour distribution within basal **c** and rhombohedral **r** and **z** growth sectors can be seen; some boundaries between basal yellow growth sectors and adjacent violet-to-brown **r** growth zones are bent. Photo and drawing by K. Schmetzer.*

*Figure 21: An enlarged partial view of the synthetic ametrine slice in Figure 20 is shown here. Due to the influence of steel pins interrupting crystal growth, the **r** and **z** growth sectors are highly distorted, with alternating violet, purplish violet, yellow and brown growth zones, most seen as lamellae. The steel pins are indicated with blue arrows. Photo by K. Schmetzer; field of view 40 × 30 mm.*

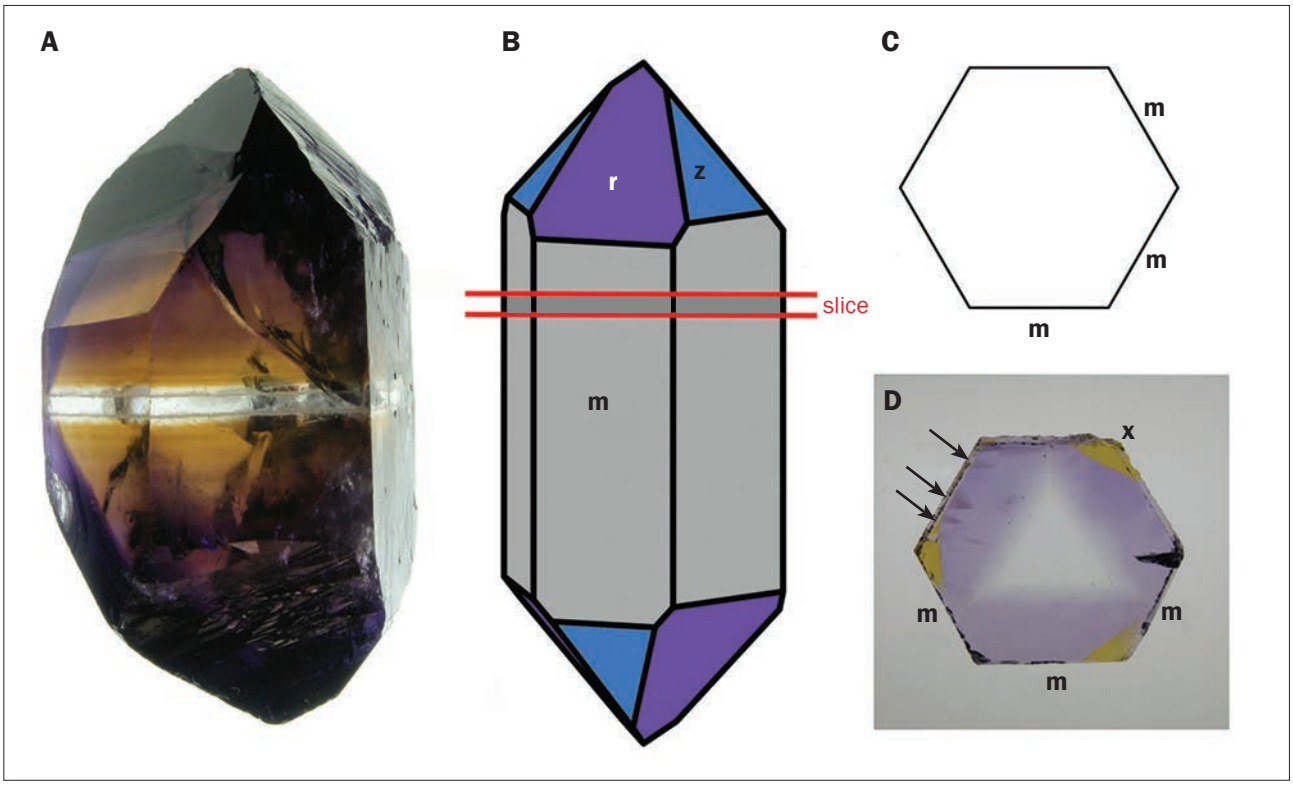

*Figure 22: Synthetic ametrine crystals resembling natural quartz in morphology are grown from Z-cut hexagonally shaped seed plates. The colour distribution within such crystals, however, differs from that of natural ametrine. (A) This complete crystal shows prismatic **m** and rhombohedral **r** and **z** faces; diameter 26 mm, length 52 mm and weight 49 g. (B) The clinographic projection shows the crystal habit, consisting of **m** prism faces combined with **r** and **z** rhombohedra. (C) The seed plate is bounded by **m** faces. (D) This slice perpendicular to the c-axis shows a light yellow, almost colourless **c** growth sector, three violet rhombohedral sectors and three small amber-coloured **x** growth zones. The arrows point to twinning features. The slice has a diameter of 26 mm and a thickness of 5 mm. Photos and drawings by K. Schmetzer.*

areas (close to the tips of the yellow triangles) showed an inclination of about 20°.

When Z-cut seed plates with hexagonal outlines were chosen for crystal growth, synthetic ametrine with a morphology resembling that of natural quartz crystals could be obtained (Figure 22). The dominant external faces were the prism **m** and three larger rhombohedral faces. In addition, some smaller rhombohedral faces could be seen. The central basal **c** growth sectors were yellow (Figure 22A) or very light yellow, almost colourless (Figure 22D). The boundaries between violet rhombohedral growth sectors and yellow basal growth areas were parallel or nearly parallel to the larger external rhombohedral faces. Small intense yellow (amber-coloured) sectors could be seen in one slice cut perpendicular to the c-axis and were presumably related to prismatic **x** growth zones (Figure 22D).

The growth boundaries between intense yellow-orange **x** growth sectors and violet rhombohedral sectors in synthetic ametrine with Z-cut hexagonally shaped seed planes (Figure 22D) were only slightly inclined and almost parallel to the c-axis, as was the case above with Z-cut seed plates elongated in the Y direction (Figure 18). This growth feature is detailed in Figure 23 and should be taken into consideration if faceted samples of unknown origin are examined with the microscope.

Twinning, Growth Striations and Inclusions: Twinning in synthetic ametrine has been mentioned only briefly in the literature—as Brazil-law twinning in violet **r** sectors and Dauphiné twinning in violet **z** sectors (Balitsky et al., 1999, 2000), and therefore details reported for synthetic amethyst can help explain the properties of synthetic ametrine.

In synthetic amethyst, two different types of twinning have been described for rhombohedral **r** and **z** growth sectors, but no twins have been observed in basal **c** growth zones. More specifically, **z** growth sectors display twinning on the Dauphiné law, while **r** growth zones exhibit twinning on both the Dauphiné and Brazil laws.

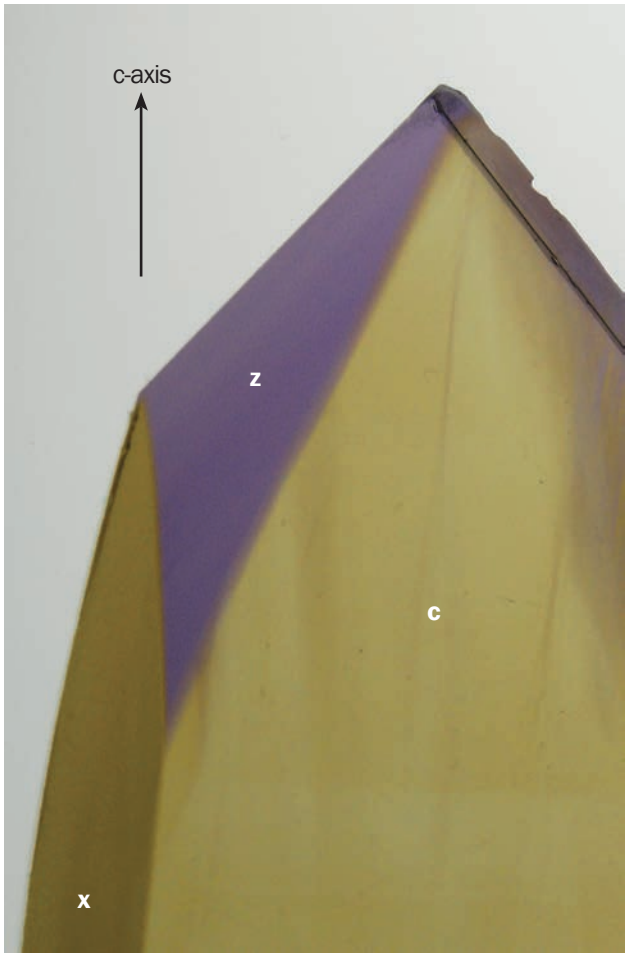

*Figure 23: Growth boundaries in synthetic ametrine with amber-coloured **x** growth sectors and violet rhombohedral growth zones frequently run almost parallel to the c-axis of the crystals. This slice is oriented parallel to the c-axis and is 4.4 mm thick. Photo by K. Schmetzer; field of view 14.7 × 19.6 mm.*

Dauphiné twinning is developed as irregularly shaped, somewhat conical or tapered domains with irregular composition planes, and Brazil twinning is manifested as lamellae with rhombohedral composition planes. Dauphiné twins in **z** growth sectors are equivalent to **r** growth sectors, and vice versa. Furthermore, because Dauphiné twins in **z** growth zones are equivalent to **r** growth zones, these Dauphiné twin domains sometimes contain lamellae of Brazil twins (Lu et al., 1990; Sunagawa et al., 1990; Balitsky et al., 2004; Balitsky and Balitskaya, 2009).

Twinning was observed in four of the 25 slices of synthetic ametrine available for the present study (e.g. Figures 17D, 22D and 24). Such twinning was easily recognized in the form of variously shaped small growth sectors showing darker colour within the lighter area of the surrounding host. In **r** growth sectors, single Brazil-twin lamellae were seen (Figure 24B), with composition planes running parallel to another rhombohedral **r** face (indicated as **r'** in Figure 24A). In **z** growth sectors, somewhat tapered, conically shaped darker colour zones were found (Figure 24C) that correspond to Dauphiné twins.

On the surface of the **r** face representing the **r** growth zone with lamellar twins, a series of dense striations was seen. In contrast, the **z** face showed irregular depressions corresponding to the conical domains of the Dauphiné twins. In the immersion microscope, these tapered domains within the Dauphiné twins themselves showed interference patterns of lamellar twinning on the Brazil law (Figure 25). The depressions formed by the **r** Dauphiné twins in the **z** growth zones result from the fact that **r** faces are relatively slower growing.

*Figure 24: Twinning in synthetic ametrine is occasionally observed in the form of comparatively darker violet lamellae or tapered domains within lighter coloured **r** and **z** growth sectors. (A) This slice from a crystal grown with a Z-cut seed plate elongated parallel to the Y direction was cut perpendicular to the elongated **x** prism face; 96 × 38 × 8 mm. (B) An enlarged partial view of the sample shows planar dark violet lamellae within the rhombohedral **r** growth zone. The lamellae run parallel to a second rhombohedral face, indicated as **r'** in A. (C) This enlarged partial view of the sample shows dark violet tapered domains within the rhombohedral **z** growth zone. Photos by K. Schmetzer.*

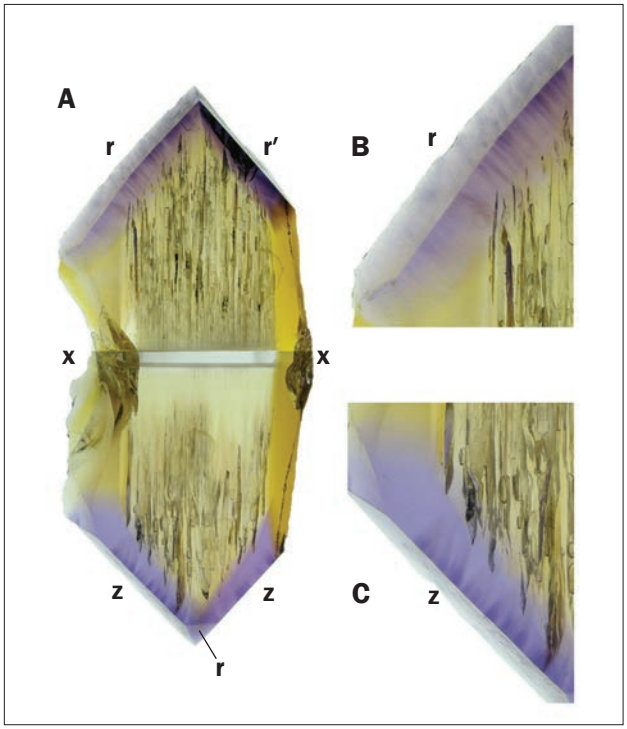

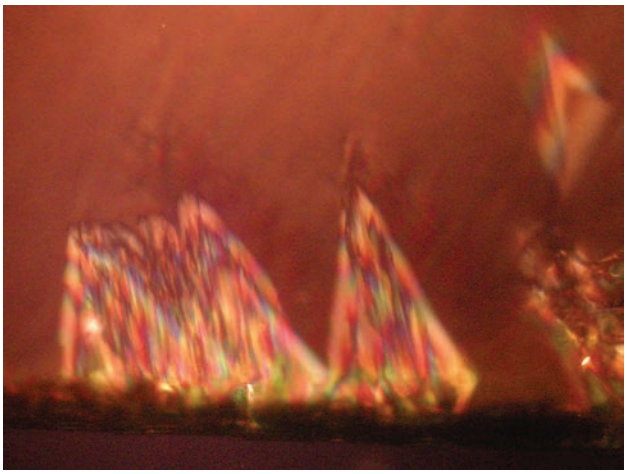

Figure 25: Viewed with crossed polarizers, interference patterns are seen within tapered domains in violet rhombohedral growth zones of synthetic ametrine. These conical domains represent Dauphiné twins that are internally twinned on the Brazil law. Photomicrograph by K. Schmetzer, in immersion; field of view 6.7 × 5.0 mm.

Growth striations in the yellow sectors of synthetic ametrine were in general extremely weak and always parallel to the basal **c** face. Occasionally the **c** growth zone appeared to be subdivided into lighter and darker yellow portions. Growth striations in the violet **r** and **z** sectors were consistently parallel to the external crystal faces. In certain instances, such growth striations in **r** zones were more pronounced than those in **z** sectors (Figure 26A,B), but it was also possible to find **z** sectors showing intense growth striations (Figure 26C). As compared to the violet/yellow boundary, the inclinations of the growth striations in **r** and **z** zones may be summarized as follows:

- In **r** zones, striations mostly tended to be parallel or almost parallel to the colour boundary, with angles smaller than 8° (Figure 26A,B), and only in samples grown with seeds interrupted by steel pins might this angle reach up to 18°.
- In **z** sectors, striations exhibited a broader range of angles, from slightly inclined to a maximum angle of 18° (i.e. in samples for which the angle between the violet/yellow boundary and the c-axis measured 20°; Figure 26C).

In some slices, fluid inclusions were observed that were elongated parallel to the c-axis and typically contained two-phase fillings (Figure 26B).

Synthetic Ametrine—Faceted Samples

Visual Appearance: The faceted synthetic ametrine samples studied here were typically cut to show a single colour boundary across the table of the gem (Figure 27), in keeping with normal trade practices. The colour boundary often appeared more pronounced when viewed from the pavilion side. In general, the colours displayed by the synthetics were of greater saturation than those exhibited by natural ametrine.

*Figure 26: Growth striations in the rhombohedral **r** and **z** growth sectors of synthetic ametrine are always parallel to the external **r** and **z** crystal faces. In **r** growth zones, these striations are parallel or almost parallel to the violet/yellow colour boundary (A,B). In **z** growth zones, the striations are sometimes parallel or almost parallel to the violet/yellow boundary (B), but they also may be inclined up to 18° to this boundary (C). Note also the elongate two-phase inclusions in B. Photos by K. Schmetzer; (A) slice 25 × 16 × 3 mm, (B) field of view 20 × 15 mm and slice thickness 9 mm and (C) field of view 18.1 × 13.6 mm and slice thickness 10 mm.*

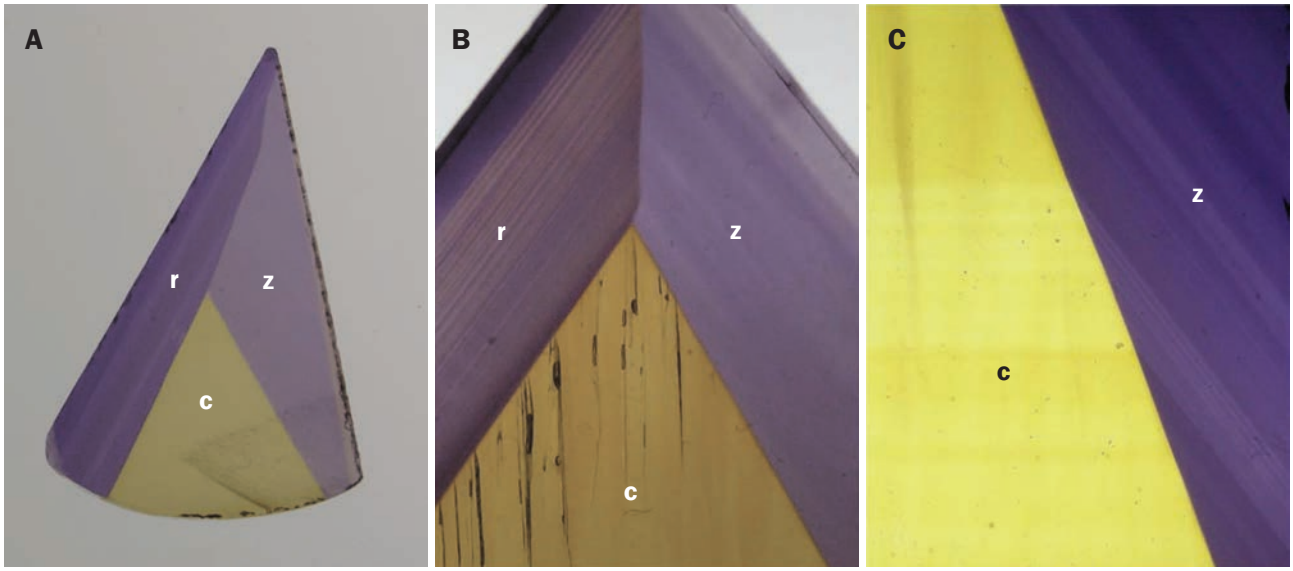

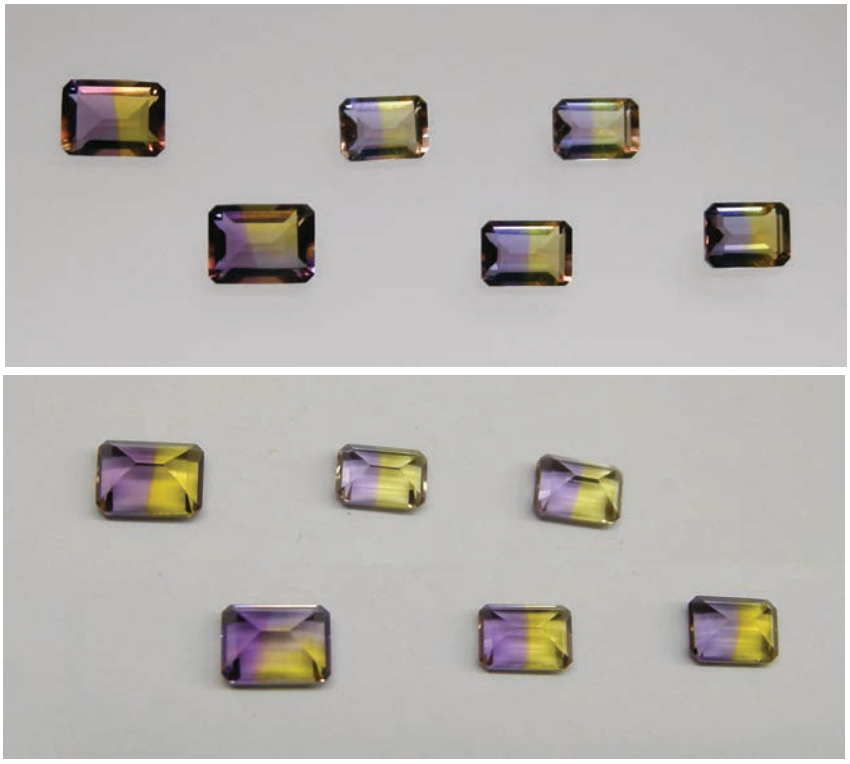

Figure 27: These faceted synthetic ametrines weigh from 1.67 ct (lower left, 8.1 × 6.1 mm) to 0.93 ct. They are viewed toward the table facets (top) and toward the pavilions of the same samples (bottom). Photos by K. Schmetzer.

Microscopic Examination: The optical properties of the faceted synthetics were consistent with those just described for complete crystals and oriented slices. Most faceted samples were untwinned single crystals. They showed a simple interference pattern that consisted of coloured interference rings that moved toward the centre when the sample was tilted so that the optic axis was parallel to the microscope tube (Figure 28A). In addition, the rings were occasionally disturbed by triangular sectors twinned on the Brazil law (Figure 28B). The visual impression of these twinned areas, showing a so-called 'flame structure' appearance (Figure 28C,D), was quite distinctive and thus distinguishable from the various forms of Brewster fringes observed in natural samples (see again Figure 12). Rather, the appearance was consistent with the pattern observed for Dauphiné twins containing twin lamellae on the Brazil law (as described above for the slices; see again Figures 24C and 25).

The boundaries between violet and yellow growth zones were inclined to the c-axis by angles of 20°–38°. This range is analogous to that measured for the synthetic ametrine slices. Growth striations in the violet zones were observed in approximately half of the faceted samples. They were parallel or only slightly inclined to the violet/yellow boundary (Figure 29). Larger inclinations (up to 18°) for such striations, as seen in some oriented slices, were not found in the faceted synthetics from the trade. For faceted material, orienting the rotation axis of the sample holder perpendicular to the colour zoning did not lead to a position enabling a view in the direction of the optic axis. Consequently, the typical interference pattern of an untwinned crystal could not be located using this orientation, on account of the angle of the violet/yellow boundary versus the c-axis in the synthetic samples.

Fluid inclusions were generally not observed in the faceted synthetic ametrines from the trade.

Discussion and Conclusions: Application of Optical Properties to Distinguish Between Natural and Synthetic Ametrine

Prior works have suggested distinguishing natural from synthetic ametrine based on two criteria: (1) the presence or absence of twinning and (2) the orientation of the violet/yellow boundary (Balitsky et al., 1999; Notari et al., 2001; Payette, 2013). The present study, in turn, has now yielded a third criterion: (3) the orientation of growth striations. In addition, it has revealed a more effective and practical approach for examining a sample of un-

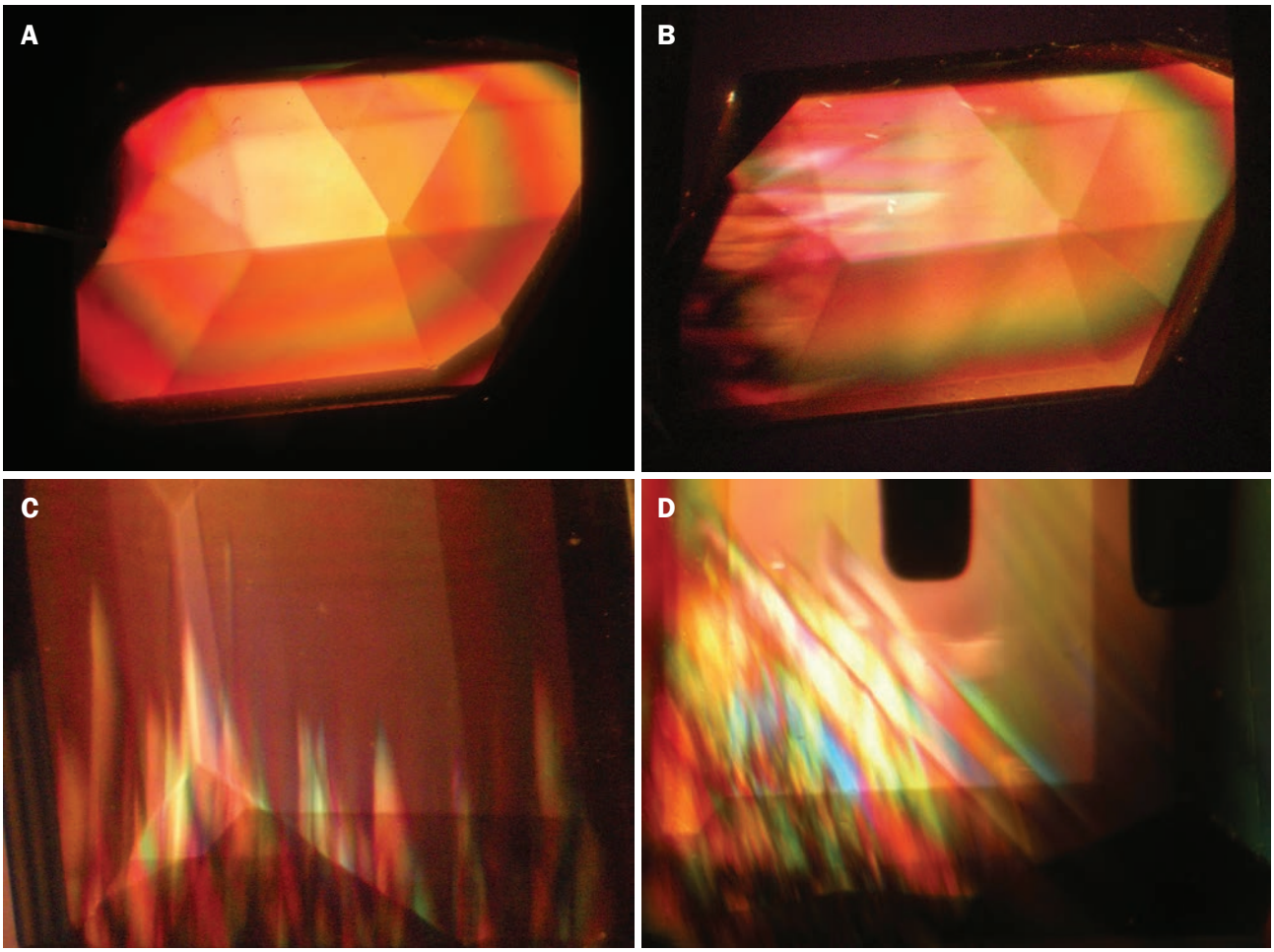

Figure 28: (A,B) In cross-polarized light, the interference patterns in faceted synthetic ametrine generally consist of interference rings, the sizes of which increase or decrease in diameter as the sample is tilted in the immersion microscope. (B–D) If the sample contains twinned areas, interference patterns related to twinning on the Brazil and Dauphiné laws are observed. Photomicrographs by K. Schmetzer, in immersion with crossed polarizers; field of view (A,B) 7.0 × 5.2 mm, (C) 4.7 × 3.5 mm and (D) 5.7 × 4.3 mm.

Figure 29: Growth striations are frequently seen in the violet zones of faceted synthetic ametrine. These striations are parallel or only slightly inclined to the violet/yellow boundary. Photomicrograph by K. Schmetzer; field of view 5.8 × 4.4 mm.

known origin in search of these three criteria. A microscopic observation procedure can be used in lieu of the previously employed combination of only refractometer and polariscope for determining the orientation of the growth boundaries. Doing so can reduce the uncertainty and risk for misinterpretation when faced with cut samples having an unfavourable orientation of the optic axis versus the table facet and with synthetic samples having a small inclination (only 20°) between the colour boundary and the c-axis. Furthermore, an erroneous interpretation of atypical twin patterns (interference patterns) can be avoided.

Table II provides an overview of the microscopic features seen with an immersion microscope for distinguishing between natural and synthetic ametrine.

Table II: Diagnostic features of natural and synthetic ametrine, seen with an immersion microscope.

Optical feature	Natural		Synthetic	
	Description	Relevant figures	Description	Relevant figures
Twinning	Violet growth sectors are intensely twinned on the Brazil law, showing various forms of Brewster fringes with crossed polarizers; yellow growth sectors are not polysynthetically twinned	8, 12	Violet and yellow growth sectors are primarily untwinned; small areas within the violet growth sectors may be twinned on the Dauphiné and/or the Brazil law	17D, 22D, 24, 25, 28B,C,D
Violet/yellow colour boundaries	Mostly parallel to the c-axis or only slightly inclined to the c-axis (up to about 10°)	6, 9, 13	Inclined between 20° and 38° to the c-axis	17, 18, 20, 21, 23, 24, 26, 29, B1
Growth striations	Violet growth sectors: inclined at about 67° or 38° to the violet/yellow boundary; yellow growth sectors: none observed	9, 13	Violet growth sectors: parallel or almost parallel to the violet/yellow boundary, mostly inclined at angles between 0° and 8°, with a maximum inclination of 18°; yellow growth sectors: very weak striations parallel to the basal face	26, 29
Fluid inclusions	Rare fluid inclusions, occasionally reflecting the polysynthetic twin pattern of the violet growth zones	14	Rare two-phase (liquid and gas) inclusions elongated parallel to the c-axis	24, 26B

First, with respect to twinning, as is well documented in the existing literature, the violet growth sectors of natural ametrine are polysynthetically twinned on the Brazil law and show Brewster fringes between crossed polarizers. In contrast, synthetic ametrine is typically untwinned, although it occasionally contains small conical twinned areas.

Second, pertaining to the dominant violet/yellow colour boundary, in natural ametrine it is approximately parallel to prism faces (i.e. parallel or almost parallel to the c-axis). In synthetic ametrine, the colour boundary varies at angles of 20°–38° relative to the optic axis, regardless of the cut orientation and elongation of the seed plate (amongst those currently known) used for growth. Note that the inclination angle of about 51° between the violet/yellow boundary and the c-axis mentioned by Balitsky et al. (1999) most likely refers to the complementary angle (38° + 51° ≈ 90°).

Third, growth striations in natural ametrine form two different angles of approximately 67° or 38° with the violet/yellow colour boundary. This contrasts markedly with the striations in synthetic ametrine, which are parallel to the dominant colour boundary or only slightly inclined, mostly at angles of up to 8° (rarely up to 18°).

In rare cases, the presence of typical inclusions might support a decision based upon the three main criteria described above.

Ametrine produced from natural amethyst by heat treatment (which is possible for samples from certain locations but, to the author's knowledge, not performed commercially) would show the same characteristic features of twinning, growth boundaries and growth striations described for natural unheated ametrine.

The microscopic procedure for identifying these key features can be summarized as follows. The examination of a faceted sample of unknown origin should begin by orienting the dominant colour boundary perpendicular to the rotation axis of the sample holder. If the stone is natural, the typical interference pattern with Brewster fringes will be revealed upon rotation of the sample. Furthermore, growth striations inclined at relatively large angles to the colour boundary will be observed in the violet portion of the stone after a rotation of about 40° versus the c-axis. If the sample is synthetic, rotating the sample generally will not bring the optic axis into view, and violet growth striations parallel or at a small angle to the violet/yellow colour boundary frequently will be present. It is possible to find the optic axis in a synthetic sample by moving

it to other orientations within the sample holder, in which case an untwinned interference figure normally will be seen.

Thus the present study demonstrates that parcels of faceted ametrine can be screened quickly to distinguish between natural and synthetic samples through use of an immersion microscope and the application of three criteria in combination (see again Table II):

- presence or absence of twinning
- orientation of the violet/yellow colour boundary
- orientation of growth striations relative to this colour boundary

To perform a full examination for all the criteria mentioned, unmounted samples are always preferred. Nonetheless, the examination process can be employed at least in part with mounted samples (e.g. Figure 1), revealing in jewellery pieces some of the noted properties.

The use of a standard gemmological microscope for such examinations is possible, but the observation of structural properties such as twinning and growth zoning, or optical phenomena such as interference patterns (e.g. details of Brewster fringes), is always limited and even finding the location of the optic axis might be problematic. Thus, the various patterns or structures observed without immersion often are of less diagnostic value.

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Gemmological and Spectroscopic Features of Untreated vs. Heated Amber

Yamei Wang, Mingxing Yang, Shufang Nie and Fen Liu

Detailed testing of amber samples before and after heat treatment (i.e. clarifying, baking, decrepitating and 'beeswax ageing') was performed using standard gemmological instruments, as well as Fourier-transform infrared (FTIR) and FT-Raman spectroscopy. In general, the heated ambers were characterized by: (1) an increase in RI and a decrease in fluorescence; (2) the presence of discoidal stress fractures and red flow striations in the interior of some samples, as well as oxidation cracks, septarian cracks and ripples on the surface of amber treated by certain processes; (3) a significantly enhanced absorption in FTIR spectra of the carbonyl (C=O) stretching vibrations at 1732 and 1702 cm^{-1}, and of the C–O stretching vibration at 1260–1160 cm^{-1}; and (4) an intensity ratio $I = 2932\ cm^{-1}/I = 1732\ cm^{-1}$ in FTIR spectra of >1.78 for untreated amber vs. ≤1.54 for clarified (golden) amber and ≤0.50 for baked (red) amber; intensity ratios of ~1.5–1.9 are not considered diagnostic.

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Introduction

Amber is a fossilized organic gem material derived from Cretaceous–Tertiary ancient plant resin that has undergone devolatilization, polymerization and hardening through various geological processes. Because of its moderate price and warm colour appearance, and its status as one of the seven jewels embraced by Buddhists, amber is popular with many people and has profound cultural connotations. In recent years, the amber market has expanded rapidly in China. However, because heat-treated amber comprises a significant share of the market (e.g. Figure 1), distinguishing untreated from heat-treated amber has become a priority for some gem-testing institutions. The identification of heat-treated amber has been difficult, in part because knowledge of the heat-treatment processes and techniques used have long been kept confidential.

The main purposes of amber heat treatment are to improve or alter the colour, enhance the clarity and produce inclusions that have an appealing visual effect. Methods include clarifying, baking (oxidation), decrepitating and 'beeswax ageing'; see Wang et al. (2014) for a detailed description of the various processes and conditions used for each type of treatment. Clarification (or 'purification') removes bubbles from amber by heating it in an inert atmosphere under autoclave-controlled temperature and pressure. Baking involves adding an appropriate amount of oxygen gas to the autoclave to oxidize the amber surface and form a thin red to dark red layer, thus changing its colour appearance. Decrepitation involves the rapid release of gas from the autoclave after heating and pressurizing; this alters the pressure equilibrium of bubbles in amber so the internal pressure is greater than the external pressure, causing the

Figure 1: Various types of heat-treated amber are commonly encountered in the marketplace. Shown here are a golden amber pendant (upper left, 36.65 g), a bicoloured fire amber pendant (upper right, 22.59 g), a red amber necklace (96.27 g) and an aged beeswax bracelet (45.31 g). Photo by Y. Wang.

bubbles to expand and decrepitate into discoidal stress fractures. The purpose of decrepitation is to produce attractive inclusions called 'sun spangles' or 'sun sparks'. In the beeswax ageing process, amber with low clarity (i.e. *beeswax* amber, which is sub-translucent or opaque due to abundant microscopic gas bubbles) is given an aged and darkened appearance by prolonged slow oxidation under low temperature at constant pressure, so that it resembles antique beeswax.

This article provides a detailed characterization of the amber samples that were treated in experiments by Wang et al. (2014). We used standard gemmological instruments and FTIR and Raman spectroscopy to document changes in the physical, optical and spectroscopic properties of the amber samples before and after heat treatment. The formation mechanisms of the features seen in heat-treated amber are discussed, and criteria for identifying heat-treated amber are presented.

Materials and Methods

Six blocks of Baltic amber originating from Kaliningrad, Russia, were sliced into pieces and subjected to heating experiments that were inferred to be representative of those performed by commercial treatment facilities; the treatment conditions and their outcomes were described by Wang et al. (2014). The samples from the six blocks are designated JA, JB, JC, JD, JE and JF (Figure 2), and they ranged from opaque to transparent, including some with a beeswax appearance (i.e. JC, JD, JE and JF). Of the 32 slices, one piece from each block was retained as an untreated reference sample (JA-1, JB-3, JC-5, JD-1, JE-1 and JF-4), three were preserved for future studies and the remaining 23 slices underwent clarifying, baking, decrepitating and/or beeswax-ageing experiments, depending on the features present in each sample (see Figure 3 and Table I). The sawn surfaces of each sample were polished before any treatments were performed. After treatment, samples JA-5, JC-3, JC-4, JE-3 and JE-4 were repolished and JE-5 was partially repolished.

Detailed observations and testing of colour and clarity, RI, long-wave UV fluorescence and internal features were carried out on the samples before and after heat treatment using standard gemmological instruments, including a refractometer (GI-RZ6), UV lamp (GI-UVB) and microscope (GI-MPV), all manufactured by Shenzhen Baoguang Scientific Instruments Co. Ltd. In addition, SG was measured hydrostatically for all samples, but the values were all nearly identical (1.065–1.069) and therefore are not discussed further in this article.

A Bruker Tensor 27 FTIR spectrometer was used with a reflectance accessory to acquire FTIR absorption spectra of the samples before and after heat treatment, in the range of 4000–400 cm^{-1} with 32 scans at a resolution of 4 cm^{-1}. Analyses were performed at a temperature of 19°C and a relative humidity of 35%. Because specular reflectance FTIR was used to non-destructively analyse the samples, all the acquired spectra were subjected to a Kramers–Kronig transformation and baseline correction using OPUS software to eliminate the distortion of spectra caused by dispersion. FTIR spectroscopy was performed on the six untreated reference samples, as well as on all the other ambers before treatment. After heat treatment, FTIR spectra were collected on six golden ambers, one pearly beeswax sample, three golden fire ambers, three red fire ambers, seven red ambers, one bicoloured amber and two aged beeswax samples, and also on selected samples (JA-4, JB-4, JC-1,

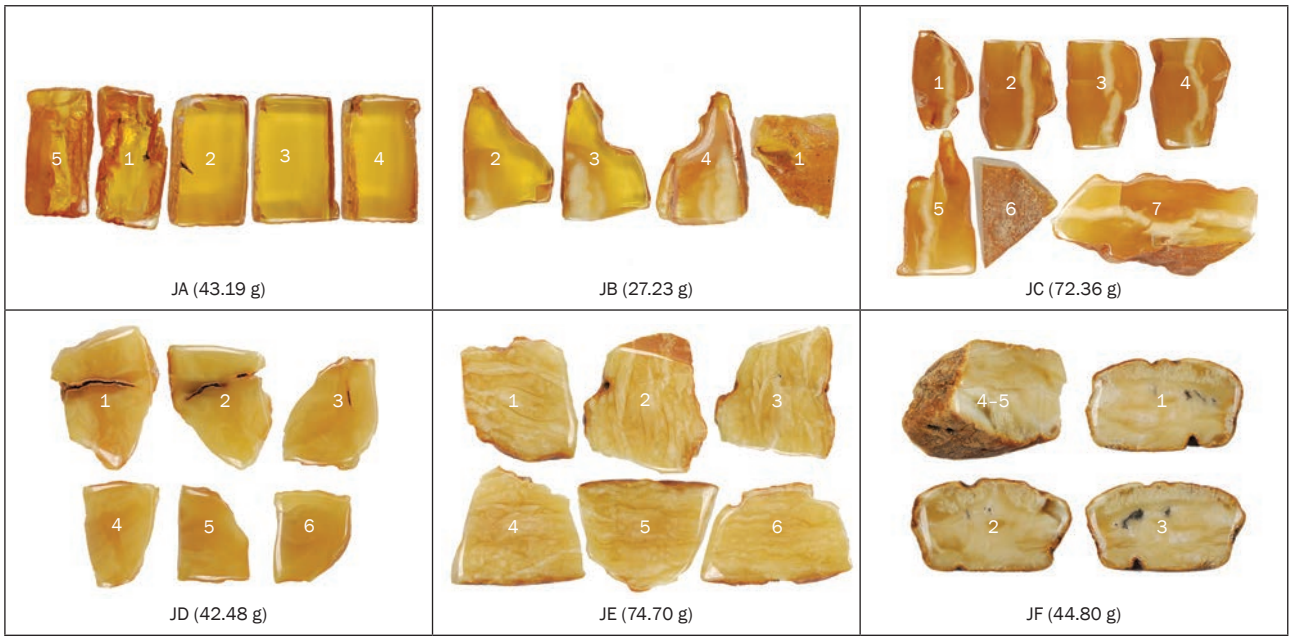

Figure 2: Untreated amber specimens from Kaliningrad, Russia, were sliced into multiple pieces for heating experiments. Each sample number is shown with the total weight of all the slices. Photos by Y. Wang.

JC-2, JD-6, JF-1 and JF-3) after clarifying and/or baking.

A Bruker Vertex 70 FT-Raman spectrometer was used to acquire Raman reflectance spectra with an excitation wavelength of 1064 nm, laser energy of 150 mW and 64 scans at a resolution of 4 cm^{-1}, at a temperature of 25°C and a relative humidity of 46%. Raman spectroscopy was performed on four representative untreated ambers (JA-1, JD-1, JE-1 and JF-4) and on three heated samples (bicoloured JA-5, golden JD-3 and red JD-6).

All spectroscopic measurements were performed on smooth flat faces that had been polished before heat treatment, except for those samples listed above that were repolished after treatment.

Results and Discussion

The colour and clarity, RI values, long-wave UV fluorescence and internal features of the amber samples before and after heat treatment are shown in Table I.

Colour and Clarity

Heat treatment effectively altered the colour and clarity of the amber. Yellow or light yellow beeswax amber was transformed into golden yellow, red or dark red-appearing material. The clarity of the entire sample changed in most cases from opaque or translucent to transparent, although a few of the treated ambers displayed a transparent surface and an opaque interior (e.g. the pearly beeswax sample JC-7).

Refractive Index

The RI of all samples was measured on flat-polished surfaces, and for each piece the refractometer displayed the shadow edge with a fairly clear boundary, so we consider the RI values to be accurate to two decimal places.

Table I and Figure 4 show that heat treatment increased the RI of the samples in most cases, and that variations in RI were closely related to heat treatment time and the amount of oxidation. Specifically, we found that: (1) the clarifying and baking processes increased the RI value; (2) the longer the clarifying time, the greater the increase in refractive index (e.g. the RI of sample JD-3 changed from 1.54 to 1.56 after three clarifying cycles); (3) the greater the oxidation amount (darker colour), the larger the increase in RI (e.g. sample JC-2 was oxidized to red in one baking cycle, yielding an RI of 1.56, while sample JC-1 underwent three baking cycles to turn dark red, with a resulting RI of 1.58); (4) prolonged (60–100 days) beeswax ageing at low temperature (60°C) did not significantly alter the refractive index (e.g. samples JD-2 and JE-6 had unchanged RIs of 1.54 before and after treatment); and (5) the increase in RI was limited to the near-surface, as no change in measurements compared to untreated amber was noted in practically all heated samples after they were repolished (e.g. samples JA-3, JC-4, JD-4, JE-5 and JF-2 underwent clarifying, decrepitating and/or baking followed by repolishing, and their measured RI values remained 1.54 before and after treatment).

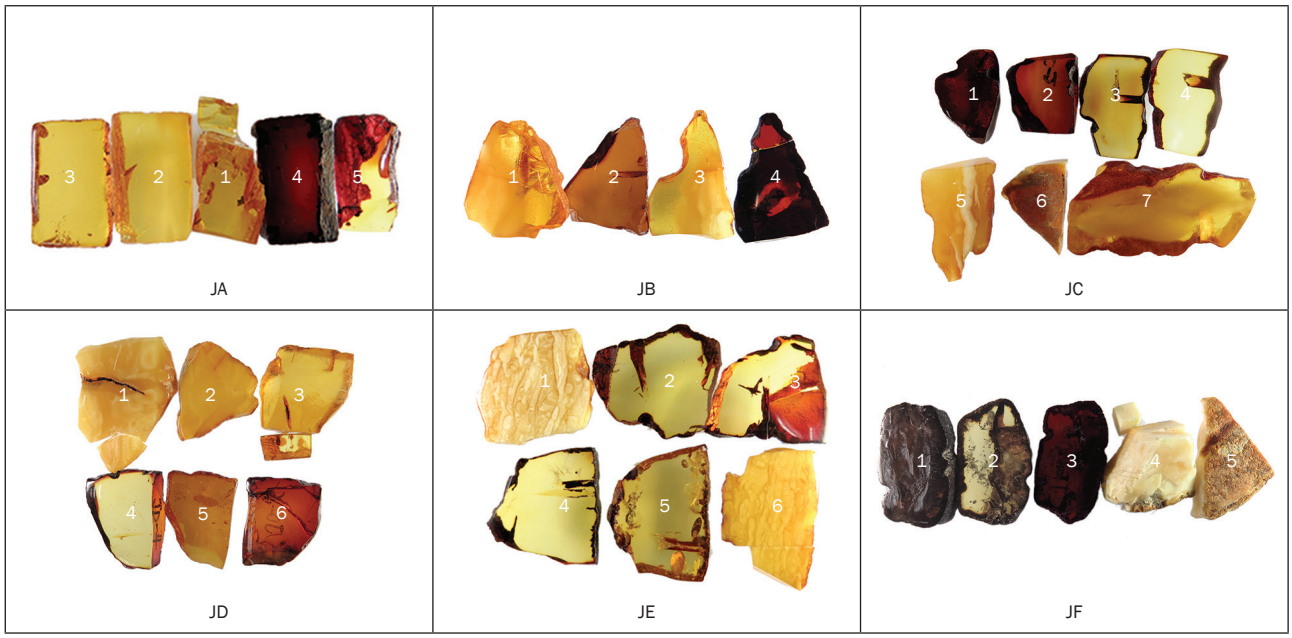

Figure 3: Pictured here are the same amber specimens in Figure 2 following various treatment processes, as described in the text and in Table I. Photos by Y. Wang.

Long-wave UV Fluorescence

Before treatment, all the samples showed similar moderate-to-strong yellow to yellowish white fluorescence (Table I), and their luminescence patterns mimicked the internal structure of the amber (e.g. flowed clouds of gaseous inclusions). Heat treatment significantly altered the UV fluorescence features of the amber, and the intensity, uniformity and colour of the luminescence closely corresponded with the heat-treatment process. Figure 5 shows the fluorescence of representative samples under long-wave UV radiation, including untreated amber, clarified golden amber and baked red amber.

Figure 4: Compared to untreated samples, RI values were higher for some of the tested heat-treated golden ambers and all of the red ambers. While the golden ambers were clarified in an inert gas, the red ambers underwent oxidation during the baking process that was used to induce their surface coloration.

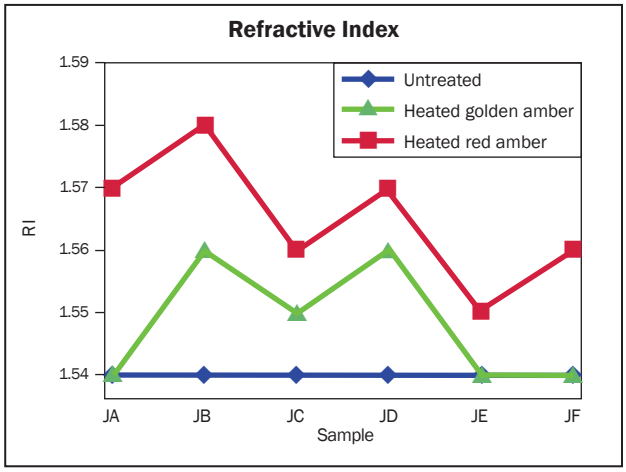

Our results indicate that: (1) the fluorescence intensity of our clarified golden amber samples decreased somewhat, exhibiting weak-to-moderate dull yellow or yellowish white fluorescence that was typically uniform in appearance; and (2) the fluorescence strength of our baked red ambers diminished significantly, becoming inert or showing only weak dull yellow fluorescence (with the exception of those samples that were repolished after treatment, which displayed moderate yellow or yellowish white luminescence). Therefore, such luminescence quenching provides important evidence of heat treatment.

The clarity of opaque Baltic amber can be improved with heat treatment under pressure. As supported by our experiments, an increased concentration of the carbonyl group (C=O; described below) acts as a chromophore because its n-π* transition absorbs visible light, leading to a darkened and reddened coloration and a quenching of fluorescence after heat treatment (Wu and Chen, 2000).

Internal Features

Discoidal Stress Fractures: After the beeswax-type samples were decrepitated, discoidal stress fractures appeared (i.e. 'sun-spangle' inclusions), and two varieties were noted. 'Golden fire' amber—containing golden yellow-coloured sun-spangle inclusions—resulted from decrepitation in an anaerobic environment (e.g. JE-5; Figure 6a), while

Table I: Gemmological properties of amber samples before and after heat treatment.[a]

Treatment method(s)[a]	Type	Sample no.	Treatment parameters	Colour		Clarity	
				Before	After	Before	After
Clarifying	Golden amber	JB-2	200°C, 5 MPa, 5 hours, inert gas (N_2)	Golden yellow–milky white	Brownish yellow	Transparent surface and opaque interior	Transparent
		JD-3	210°C, 5.5 MPa, 5.5 hours, inert gas (N_2)	Yellow	Brownish yellow	Translucent	Transparent
		JD-4	200°C, 3 MPa, 3 hours, inert gas (N_2)	Yellow	Bright yellow	Translucent	Transparent
		JE-2	210°C, 5.5 MPa, 6 hours, inert gas (N_2)	Yellow and light yellow	Bright golden yellow	Opaque	Transparent
		JF-2	200°C, 5 MPa, 5 hours, inert gas (N_2)	Milky white and yellow	Golden yellow	Opaque	Transparent
		JC-4	210°C, 5.5 MPa, 6 hours, inert gas (N_2)	Yellow and white	Bright yellow	Translucent	Transparent
	Pearly beeswax	JC-7	200°C, 4.5 MPa, 5 hours, inert gas (N_2)	Yellow and white	Yellow	Translucent	Transparent–translucent
Clarifying + baking	Red amber	JA-4	210°C, 4.5 MPa, 3 hours, N_2+O_2 gas	Golden yellow	Dark red	Transparent	Transparent
		JB-4	210°C, 4.5 MPa, 3 hours, N_2+O_2 gas	Yellow–milky white	Dark red	Transparent surface and opaque interior	Transparent
		JC-1	210°C, 5.5 MPa, 6 hours, inert gas (N_2) with residual air	Yellow and white	Dark red	Translucent	Transparent
		JC-2	210°C, 4.5 MPa, 3 hours, N_2+O_2 gas	Yellow and white	Red	Translucent	Transparent
		JD-6	210°C, 4.5 MPa, 3 hours, N_2+O_2 gas	Yellow	Orangey red	Translucent	Transparent
		JF-1	210°C, 5.5 MPa, 6 hours, inert gas (N_2) with residual air	Milky white	Dark red	Opaque	Translucent
		JF-3	210°C, 4.5 MPa, 3 hours, N_2+O_2 gas	Milky white	Dark red	Opaque	Transparent
	Bicoloured amber	***JA-5***	210°C, 4.5 MPa, 3 hours, N_2+O_2 gas	Golden yellow	Yellow and red	Transparent	Transparent
Clarifying + decrepitating	Golden fire amber[b]	JA-3	200°C, 3 MPa, 2.5 hours, inert gas (N_2) with residual air	Golden yellow	Golden yellow	Transparent	Transparent
		JD-5	200°C, 3 MPa, 2.5 hours, inert gas (N_2)	Yellow	Brownish yellow	Translucent	Transparent
		JE-5	200°C, 3 MPa, 2.5 hours, inert gas (N_2)	Yellow and light yellow	Golden yellow	Opaque	Transparent
Clarifying + decrepitating + baking	Red fire amber[b]	***JC-3***	200°C, 3 MPa, 3 hours, N_2+O_2 gas	Yellow and white	Yellow	Translucent	Transparent
		JE-3	200°C, 4 MPa, 3 hours, N_2+O_2 gas	Yellow and light yellow	Golden yellow and red	Opaque	Transparent
		JE-4	200°C, 4 MPa, 3 hours, N_2+O_2 gas	Yellow and light yellow	Yellow	Opaque	Transparent
Beeswax ageing	Aged beeswax[c]	JD-2	60°C, ambient pressure, 60 days, in air	Yellow	Brownish yellow	Translucent	Translucent
		JE-6	60°C, ambient pressure, 90 days, in air	Yellow and light yellow	Brownish yellow	Opaque	Opaque

[a] For detailed heat treatment procedures and results, see Wang et al. (2014). Samples shown in bold italics were repolished or partially polished after treatment.
[b] 'Golden' and 'red' fire ambers are transparent and have golden and red discoidal fractures ('sun spangles'), respectively.
[c] 'Aged beeswax' amber is slowly oxidized to show an aged and darkened-yellow appearance similar to antique beeswax.

RI		Long-wave UV fluorescence		Internal features	
Before	After	Before	After	Before	After
1.54	1.56	Moderate yellow to intense yellowish white	Weak orange	Flowed clouds of gaseous inclusions, bubbles, local cracks	Local red cracks
1.54	1.56	Strong yellow	Weak dull yellow	Flowed clouds of gaseous inclusions, small fissures	Small fissures
1.54	1.54	Strong yellow	Moderate yellowish white	Flowed clouds of gaseous inclusions	Small red striations
1.54	1.54	Strong yellowish white	Moderate-to-weak yellowish white	Flowed clouds of gaseous inclusions	Red cracks
1.54	1.54	Strong yellowish white	Moderate yellowish white	White flowed clouds of gaseous inclusions	Partial flowed clouds of gaseous inclusions
1.54	1.54	Strong yellowish white	Moderate yellow	Flowed clouds of gaseous inclusions	Clear with red microfissures on the rim
1.54	1.55	Strong yellowish white	Moderate dull yellow	Flowed clouds of gaseous inclusions	Flowed clouds of gaseous inclusions in the centre
1.54	1.57	Moderate yellowish white	Inert	Thin flowed clouds of gaseous inclusions	None
1.54	1.55	Strong yellowish white	Inert	Flowed clouds of gaseous inclusions	None
1.54	1.58	Strong yellowish white	Inert	Flowed clouds of gaseous inclusions	Partial flowed clouds of gaseous inclusions
1.54	1.56	Strong yellow to white	Inert	Flowed clouds of gaseous inclusions	Partial flowed clouds of gaseous inclusions
1.54	1.57	Strong yellow	Inert	Flowed clouds of gaseous inclusions	None
1.54	1.56	Strong yellowish white	Inert	Flowed clouds of gaseous inclusions	Red flow striations
1.54	1.56	Strong yellowish white	Inert	Flowed clouds of gaseous inclusions	Impurities and small fissures
1.54	Yellow: 1.54 Red: 1.56	Moderate yellowish white	Moderate yellowish white (yellow area) and inert (red area)	Thin flowed clouds of gaseous inclusions	None
1.54	1.54	Moderate yellowish white	Weak dull yellow	Bubbles, flowed clouds of gaseous inclusions	Golden and red discoidal stress fractures
1.54	1.55	Strong yellow	Weak dull yellow	Flowed clouds of gaseous inclusions	Golden discoidal stress fractures of variable size
1.54	1.54	Strong yellowish white	Weak yellow before repolishing; moderate yellowish white after repolishing	Flowed clouds of gaseous inclusions	Golden discoidal stress fractures
1.54	1.54	Strong yellow to white	Inert before repolishing; moderate yellow after repolishing	Flowed clouds of gaseous inclusions	Red discoidal stress fractures
1.54	Yellow: 1.54 Red: 1.55	Strong yellowish white	Inert before repolishing; moderate yellowish white after repolishing	Flowed clouds of gaseous inclusions	Red discoidal stress fractures
1.54	1.54	Strong yellowish white	Weak brownish yellow before repolishing; moderate yellowish white after repolishing	Flowed clouds of gaseous inclusions	Red discoidal stress fractures
1.54	1.54	Strong yellow	Moderate brownish yellow	Flowed clouds of gaseous inclusions, large cracks	Flowed clouds of gaseous inclusions
1.54	1.54	Strong yellowish white	Moderate yellow	Flowed clouds of gaseous inclusions	Flowed clouds of gaseous inclusions

	Untreated	Clarified golden amber	Baked red amber
JA	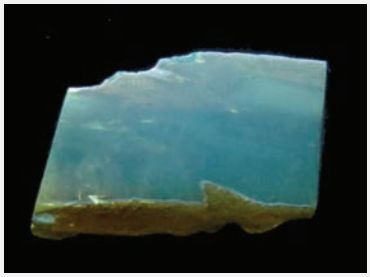 JA-1 (6.65 g): Moderate yellowish white	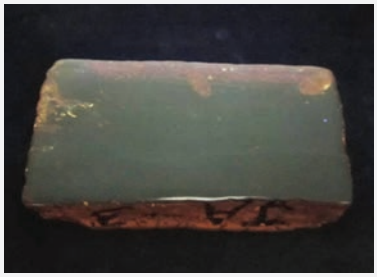 JA-3 (9.44 g): Weak dull yellow	JA-4 (8.94 g): Inert
JB	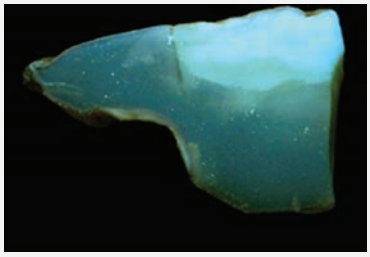 JB-3 (6.25 g): Moderate yellow to intense yellowish white	JB-2 (6.83 g): Weak orange	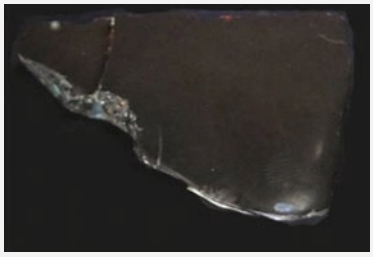 JB-4 (5.42 g): Inert
JE	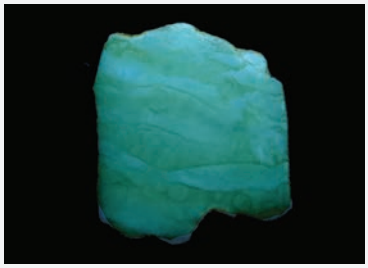 JE-1 (13.54 g): Strong yellowish white	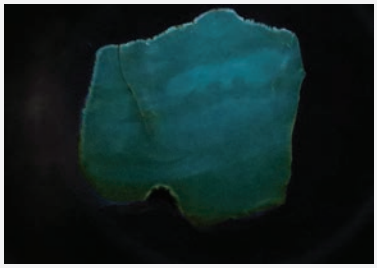 JE-2 (11.50 g): Moderate-to-weak yellowish white	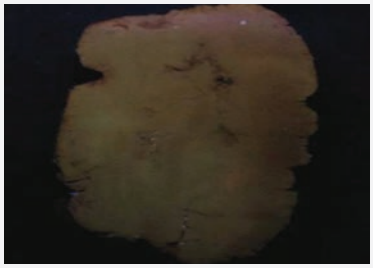 JE-4 (13.87 g): Weak brownish yellow (before repolishing)

Figure 5: These images illustrate the typical long-wave UV fluorescence of the amber samples before and after heat treatment. The bluish hue seen in some of the images is a photographic artefact from the UV lamp. Photos by Y. Wang.

'red fire' amber showed sun-spangle inclusions that were red, ascribed to products of decrepitation combined with oxidation of the fissures (e.g. JC-3; Figure 6b).

Sun spangle-type inclusions are very rarely encountered within untreated amber, owing to the equilibrium of temperature and pressure during fossilization. In heat-treated amber, the discoidal stress fractures are produced by expansion and decrepitation after the pressure equilibrium of the bubbles within the amber has been abruptly broken (i.e. internal pressure exceeds external pressure). Therefore, the presence of large and numerous sun spangles within amber provides immediate evidence of heat treatment.

Red Flow Striations: Red flow striations were sometimes visible within heat-treated golden or red amber samples (e.g. Figure 7). These striations were well defined, with a natural and fluid-like appearance, reflecting the primary textural features of beeswax amber. The original flow striations in the amber apparently were preferentially oxidized along the flow boundaries during heat treatment.

Surface Features

Various surface features were seen on the samples that had not undergone repolishing after treatment.

Oxidation Cracks: Narrow red oxidation cracks often were visible along fissures and defects in aged beeswax amber. The centrelines of such fissures were unoxidized with a light yellow colour, and both sides of the fissures were dark red with only minor 'bleeding' of colour (Figure 8a). This is dramatically different from the appearance of cracks that have undergone slow natural oxida-

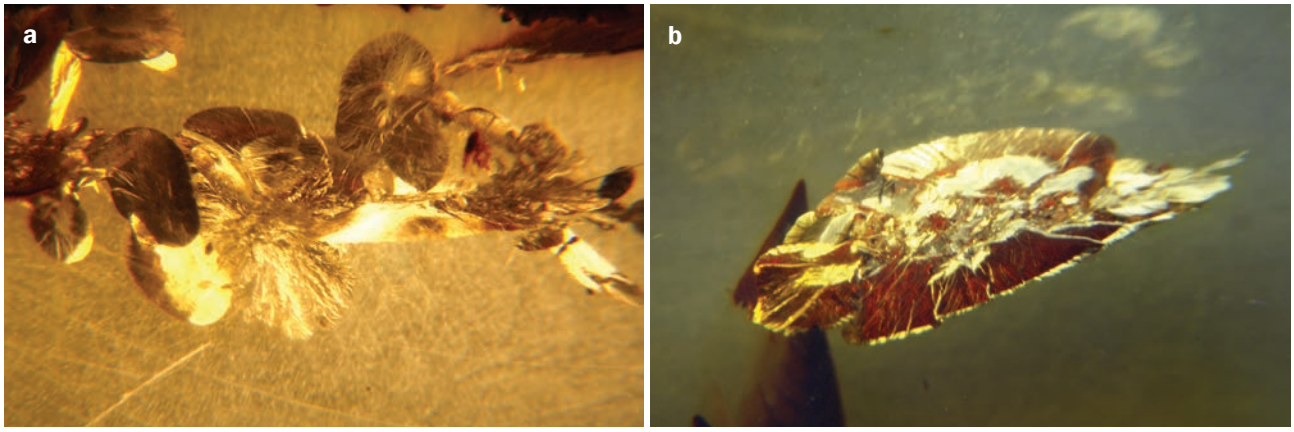

Figure 6: 'Sun spangles', or discoidal stress fractures, were exhibited by heat-treated amber samples that underwent decrepitation. They are shown here within: (a) golden fire amber JE-5 (magnified 15×) and (b) red fire amber JC-3 (20×; the red colour of this particular discoid fracture is partially obscured by yellow reflections from the surrounding amber). Photomicrographs by Y. Wang.

Figure 7: Red flow striations are seen within baked amber sample JF-1. Photomicrograph by Y. Wang; magnified 10×.

tion during geological weathering; they have dark centrelines and show progressively lighter coloration outward from the cracks (Figure 8b).

Septarian Cracks: Irregular networks of microcracks showing a mosaic-like appearance (i.e. 'septarian cracks') often were seen on the surface of red amber samples (Figure 9). They provide another indication of heat-treated amber, and appear to be caused by uneven contraction of the amber surface through rapid devolatilization resulting from improper temperature control during the heating process.

Surface Ripples: Wavy surface ripples were seen on some of the amber samples that had undergone treatment in an autoclave (e.g. Figure 10). These ripples probably formed when the surface of amber placed in the upper part of the autoclave softened during heat treatment and was slightly deformed by gas currents.

Figure 8: (a) Surface features of aged beeswax amber may include oxidation cracks, as shown here on sample JD-2; note the unoxidized centrelines and only minor 'bleeding' of adjacent colour. (b) By contrast, cracks formed in beeswax amber during natural weathering have dark centrelines with more extensive 'bleeding' of colour, as seen here on untreated amber JB-3. Photomicrographs by Y. Wang; magnified 20×.

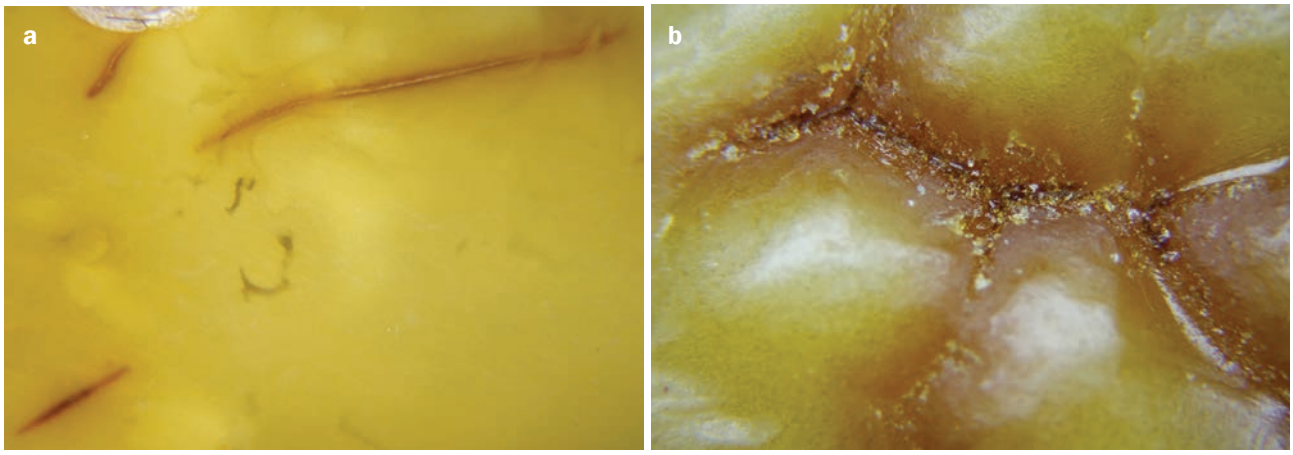

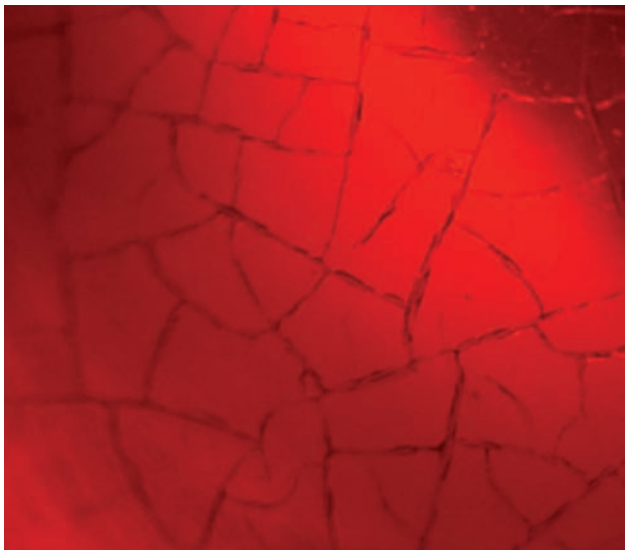

Figure 9: Septarian cracks (here, on the surface of red amber JA-4) display a mosaic-like appearance. Photomicrograph by Y. Wang; magnified 15×.

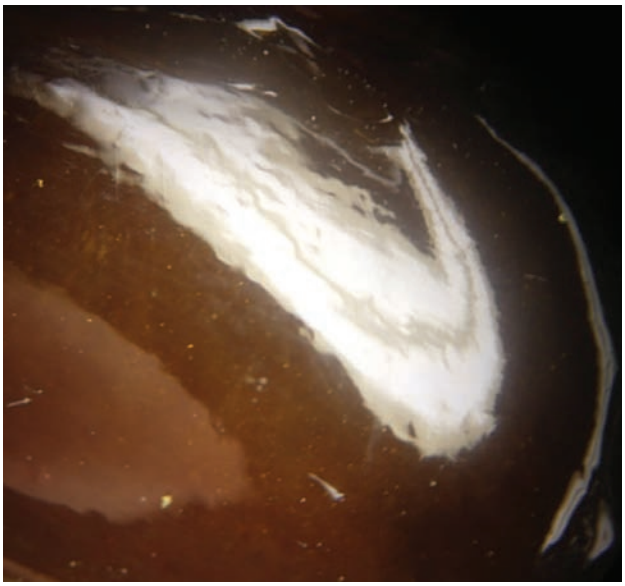

Figure 10: Ripples are seen on the surface of baked amber JF-1. Photomicrograph by Y. Wang; magnified 10×.

FTIR Spectra

Before Heat Treatment: FTIR spectroscopy of all 32 amber samples before treatment yielded largely the same results (see, e.g., the spectra of samples JA-4, JB-4 and JD-6 in Figure 11a). Strong IR absorption bands at 2932 and 2867 cm^{-1} corresponded to the asymmetric stretching vibration of the C–H saturated bond, and a pair of IR absorptions at 1732 and 1702 cm^{-1} resulted from the carbonyl stretching vibration ν(C=O) (Abduriyim et al., 2009). Moderately strong IR absorptions from the $\delta(CH_2–CH_3)$ bending vibration occurred at 1452 and 1378 cm^{-1}, indicating that the basic structure of the amber is aliphatic (Qi et al., 2003; Guiliano et al., 2007). In addition, broad absorptions in the range 1260–1160 cm^{-1} are assigned to C–O stretching vibration; these features (known as the 'Baltic shoulder') are specific to Baltic amber and are related to the presence of succinic acid and succinate (Brody et al., 2001). (The features in the ~2300 cm^{-1} region are attributed to H_2O and CO_2 in the air.)

It is worth noting that almost all of our untreated Kaliningrad samples displayed absorptions at 1645 cm^{-1} related to unsaturated C=C double bonds and at 888 cm^{-1} due to C–H out-of-plane bending vibration of the exocyclic methylene group. These features also occur in other Baltic ambers from Poland, Ukraine and Lithuania, as well as in Dominican amber, as we have discovered during our routine analysis of amber. A previous study (Yang and Wang, 2010) also showed that, with natural resin polymerization and volatilization, the out-of-ring bonds (grouped absorptions at 3078, 1645 and 888 cm^{-1}) of unsaturated terpenoids existing in fossilized resin gradually broke down, and their relative intensities became weaker until they vanished. Nonetheless, weak absorptions at 1645 and 888 cm^{-1} suggest the presence of a small amount of terpenoid volatiles remaining in our amber samples. This is also one of the reasons why Baltic amber, after being rubbed or processed, gives off a more intense rosin smell than ambers from other localities.

After Heat Treatment: The FTIR spectra of the amber samples after heat treatment varied significantly with clarification and degree of oxidation (Figure 11b,c). Table II summarizes the intensity ratios of the two major bands—2932 cm^{-1} (ν[CH_2]) and 1732 cm^{-1} (ν[C=O])—in the FTIR spectra of samples before and after heating and at different stages of treatment. The intensity ratio of these bands for golden amber ranged within 0.62–1.74, while the intensity ratio for red amber was <0.5. As seen in Figure 11, the intensity ratio exhibits a distinct progressively decreasing trend from before heat treatment to clarification to oxidation.

The following FTIR spectral information of heat-treated amber can be obtained from Table II and Figure 11:

1. The intensities of the IR absorptions at 2932 and 2867 cm^{-1}—owing to the asymmetric stretching vibration of ν(CH_2)—tend to decrease progressively with clarification and oxidation, whereas the intensities of the bands at 1732 and 1702 cm^{-1}—owing to the carbonyl stretching vibra-

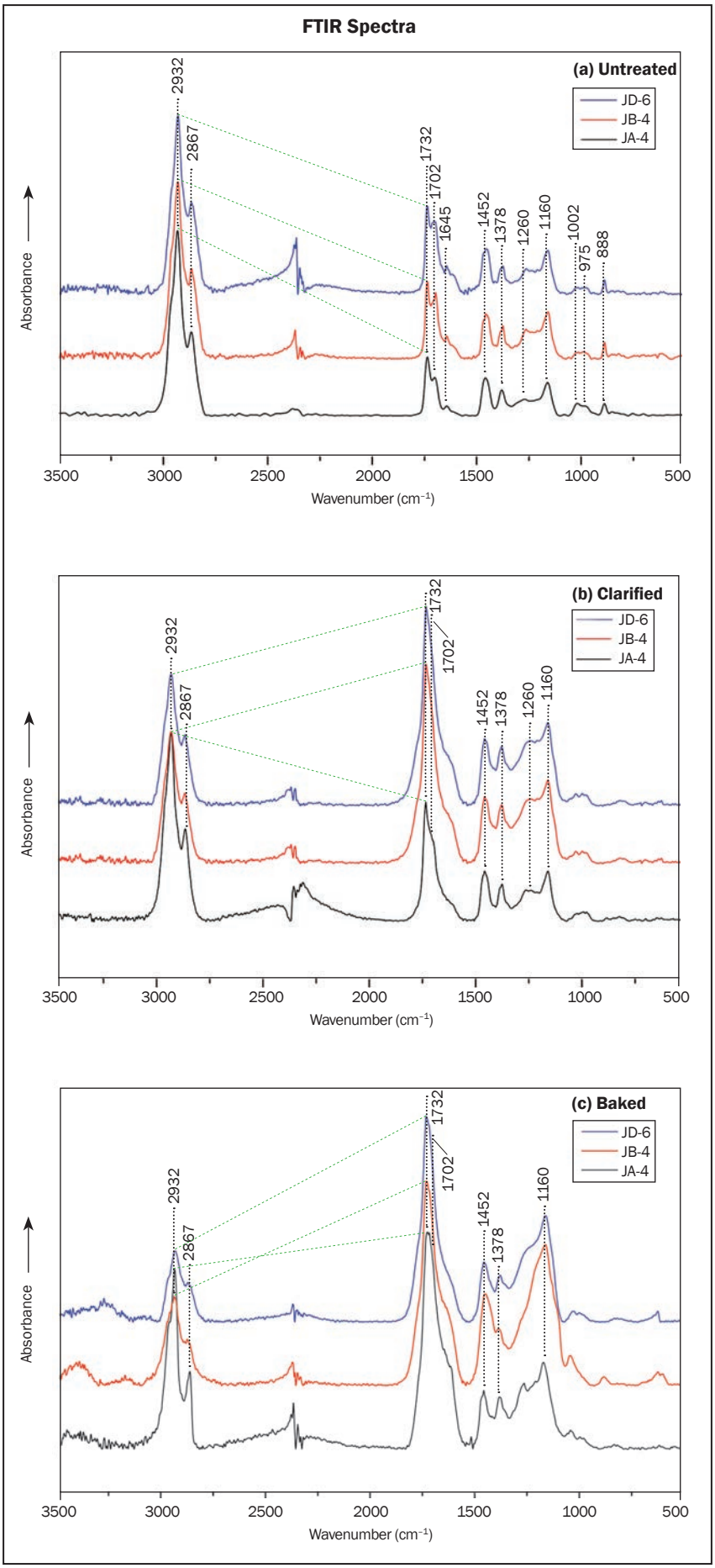

Figure 11: FTIR spectra of amber samples JA-4, JB-4 and JD-6 are shown (a) before heat treatment, (b) after clarification and (c) after oxidation. The clarification process increased the 1732 cm^{-1} band in all three samples, although somewhat less in JA-4, probably because it was clarified only once whereas JB-4 and JD-6 were clarified twice.

*Table II: Intensity ratios (I = 2932 cm^{-1}/I = 1732 cm^{-1}) in the FTIR spectra of the amber samples before and after heat treatment.**

Sample no.	Untreated	Heat treated		
		Golden amber and fire amber	Red amber	Aged beeswax
JA-3	2.94	1.00	–	–
JA-4	3.13	1.74	0.32	–
JB-2	2.28	0.62	–	–
JB-4	2.41	0.72	0.49	–
JC-1	2.41	0.82	0.50	–
JC-2	2.43	0.75	0.32	–
JC-3	2.08	0.92	–	–
JC-4	2.13	1.54	–	–
JC-7	2.05	0.92	–	–
JD-2	2.08	–	–	0.43
JD-3	2.15	0.79	–	–
JD-4	2.26	1.57	–	–
JD-5	2.52	0.72	–	–
JD-6	2.00	0.65	0.33	–
JE-2	2.00	1.21	–	–
JE-3	1.92	1.48	–	–
JE-4	1.96	1.26	–	–
JE-5	1.92	1.09	–	–
JE-6	1.94	–	–	0.48
JF-1	1.89	–	0.40	–
JF-2	1.78	1.08	–	–
JF-3	1.82	–	0.39	–

* Samples shown in bold italics were analysed on surfaces that were repolished after treatment.

tion of ν(C=O)—tend to increase progressively with the overall peak shape, becoming sharper and steeper. In our samples, an intensity ratio of ≤1.54 for the 2932 and 1732 cm^{-1} bands is indicative of clarified amber, while ≤0.50 correlates to baked amber and the range of ~1.5–1.9 is not considered diagnostic.

2. During heat treatment, the weak absorptions at 1645 cm^{-1} (related to unsaturated C=C double bonds of the exocylic methylene group) and at 888 cm^{-1} (related to C–H vibrations linked with the exocyclic methylene group) diminish until they disappear.
3. The relative intensity of the C–O stretching vibration features (Baltic shoulder at 1260–1160 cm^{-1}) generally increases progressively with clarification and oxidation.
4. With increasing absorption intensity of the carbonyl stretching vibration ν(C=O), the appearance of heat-treated amber gradually darkens until it turns dark red. Therefore, it can be postulated that the carbonyl group is a chromophore that reddens amber.
5. Repolishing may remove the heat-treated surface, which has a higher degree of oxidation than the interior, and thus may change the intensity of IR features. For example JC-4, JE-3, JE-4 and JE-5 have relatively high ratios of I = 2932 cm^{-1}/I = 1732 cm^{-1} (i.e. 1.09–1.54). Depending on the extent of the treatment and the depth of repolishing, the intensity ratio may or may not be diagnostic.

A previous study (Abduriyim et al., 2009) also reported the diminishment of the unsaturated bonds at 3076 cm^{-1}, 1643 cm^{-1} (corresponding to 1645 cm^{-1} in this study) and 887 cm^{-1} (corresponding to 888 cm^{-1} in this study), and the increase of C=O carbonyl stretching vibration at 1732 cm^{-1} in Baltic amber during heat treatment. By combining the results of previous research with the conclusions of this study, we surmise that such variations in the FTIR spectra of amber represent proportional thermal oxidation. A decrease in the absorption of the major band at 2932 cm^{-1} suggests that the saturated C–H bond was broken down by heating. An increase in intensity of the absorption at 1732 cm^{-1} suggests that oxygen involvement enables a higher concentration of the C=O functional group. And the extinction of weak absorptions at 1645 and 888 cm^{-1} corresponds with the breaking of the unsaturated C=C double bond of the exocyclic methylene group. In summary, heat treatment eventually leads to fewer saturated C–H bonds and unsaturated C=C double bonds in amber, in correlation with more oxygen-bearing functional groups and a higher degree of polymerization.

Raman Spectroscopy

Before Heat Treatment: The untreated samples had a very strong fluorescent background, so a Fourier-transform technique was employed in this study to collect the signal followed by multiple accumulations to improve the signal-to-noise ratio. Samples also were illuminated by a near-IR laser at 1064 nm, which greatly mitigated the fluorescent background, and the spectra were baseline corrected.

Of the four untreated samples that were analysed, JA-1 was transparent whereas JD-1, JE-1 and JF-4 consisted of opaque beeswax types. Compared to the FTIR spectra, the FT-Raman spectra were simpler. As seen in Figure 12, they mainly consist of three regions:

1. Within the 3000–2800 cm^{-1} range is a group of multiple characteristic peaks related to the stretching vibration of the saturated C–H bond (Brody et al., 2001; Edwards et al., 2007), with the strongest Raman peak at around 2932 cm^{-1}.

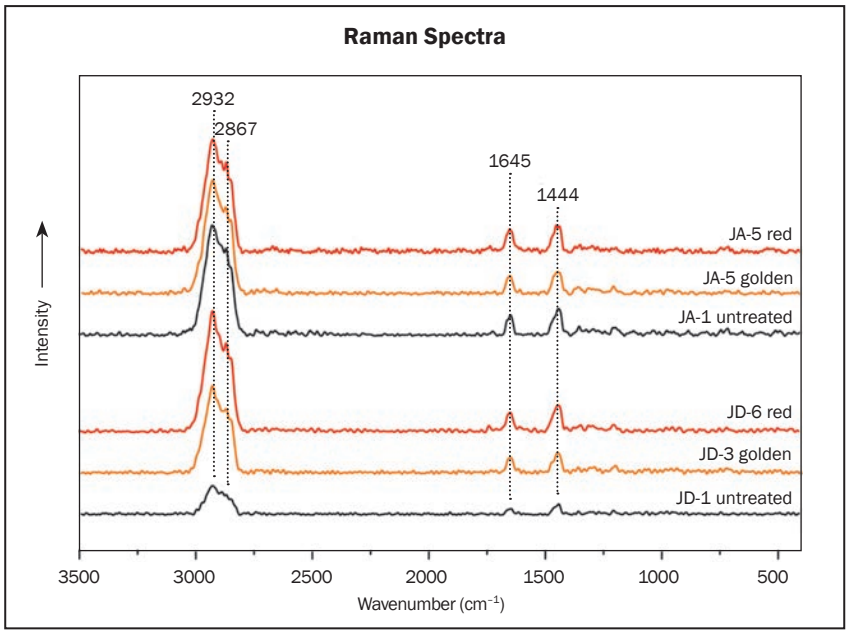

Figure 12: Representative FT-Raman spectra are shown for sample groups JA and JD, both before and after heat treatment.

2. The peak at ~1444 cm^{-1} is due to the bending vibration of the C–H bond (Brody et al., 2001; Edwards et al., 2007). The peaks in the 3000–2800 cm^{-1} range and at 1444 cm^{-1} indicate the presence of a saturated aliphatic structure, which is consistent with the features shown by the FTIR spectra.
3. Significantly different from the FTIR spectra, the FT-Raman spectra had a strong peak at ~1645 cm^{-1} related to the stretching vibration of the unsaturated C=C double bond (Brody et al., 2001; Edwards et al., 2007), whereas the feature at 1645 cm^{-1} in the FTIR spectrum resulting from the stretching vibration of the C=C double bond was extremely weak. This is related to the intense Raman activity of this group.

After Heat Treatment: Samples derived from the same original block of amber showed little variation in their Raman spectra before and after heat treatment (Figure 12). Previous Raman spectral studies of amber mainly focused on the intensity ratio $\nu(C{=}C)/\delta(CH_2)$, or I = 1645 cm^{-1}/I = 1444 cm^{-1}, because during amber formation, as resin maturity increases, polymerization continuously alters unsaturated C=C double bonds into single bonds. As a result, the absorption intensity at 1645 cm^{-1} dwindles whereas that at 1444 cm^{-1} increases gradually, so the relative intensities of these two Raman peaks have been used to postulate the degree of amber polymerization (Brody et al., 2001; Vandenabeele et al., 2003; Guiliano et al., 2007). Table III reports these intensity ratios for samples JA-1, JA-5, JD-1, JD-3 and JD-6 obtained through computation with the OPUS software.

Careful comparison indicated that: (1) for heat-treated amber, the Raman intensity ratios were still <1, which is consistent with the ratio before treatment, and (2) after the samples had been heat treated, this ratio was slightly greater than before heat treatment. However, these minor changes are not considered diagnostic for heat treatment, and more data are needed for verification. Such changes might be related to oxidation during heat treatment, indicating that the number of saturated C–H bonds consumed by oxidation is more than that of unsaturated C=C double bonds consumed by oxidation.

Conclusions

Based on our experimental study of the heat treatment of amber (Wang et al., 2014), we performed a systematic comparison of the changes in gemmological features, FTIR spectra and FT-Raman spectra of samples before and after heating. We reached the following conclusions:

1. Heat treatment can alter the appearance of amber, clarifying inclusions and producing discoidal stress fractures and red flow striations internally as well as a red coloration (on baked amber) and cracking/ripples on the surface.
2. Heat treatment may cause the RI to increase according to the amount of clarification and oxidation. In this study, the RI of untreated

Table III: Intensity ratios (I = 1645 cm^{-1}/I = 1444 cm^{-1}) of FT-Raman spectra of amber before and after heat treatment.

Sample no.	Untreated	Heat treated	
		Golden amber	Red amber
JA-1	0.72	–	–
JA-5	–	0.81 (yellow zone)	0.93 (red zone)
JD-1	0.50	–	–
JD-3	–	0.78	–
JD-6	–	–	0.92

amber was 1.54, while that of clarified golden ambers ranged from 1.54 to 1.56 and oxidized red ambers yielded RIs of 1.55–1.58.

3. Heat treatment weakened or completely quenched the long-wave UV fluorescence. The clarified golden ambers usually showed weak or moderate yellow-white or yellow fluorescence, while all the oxidized red ambers were inert.
4. In FTIR spectra, the intensity ratio I = 2932 cm^{-1}/I = 1732 cm^{-1} was >1.78 for untreated amber, compared to ≤1.54 for clarified amber and ≤0.50 for baked amber. The significant increase in absorption intensities of the C=O carbonyl stretching vibration at 1732 and 1702 cm^{-1}, and the C–O stretching vibration at 1260–1160 cm^{-1}, indicate the oxidation of the surface of heat-treated amber. An increase in carbonyl concentration is presumed to be the main cause of both the reddening of amber colour and the quenching of UV fluorescence in baked amber. In addition, thermal treatment promotes the decay or even extinction of the weak absorptions at 1645 cm^{-1} (related to unsaturated C=C double bonds of the exocylic methylene group) and at 888 cm^{-1} (related to C–H out-of-plane bending vibrations linked with the exocyclic methylene group). Although the above-mentioned changes in the FTIR spectra of heat-treated amber are limited to only a thin layer, in most cases they should still be diagnostic for identifying heat treatment in amber that has been repolished after heating.
5. FT-Raman spectra indicate that the number of saturated C–H bonds (1444 cm^{-1}) consumed by oxidation during amber heat treatment is greater than that of unsaturated C=C double bonds (1645 cm^{-1}) consumed during this process, and thus higher intensity ratios (I = 1645 cm^{-1}/I = 1444 cm^{-1}) indicate a greater degree of oxidation. However, the minor changes recorded for this intensity ratio were not confirmed as being diagnostic for identifying heat treatment.

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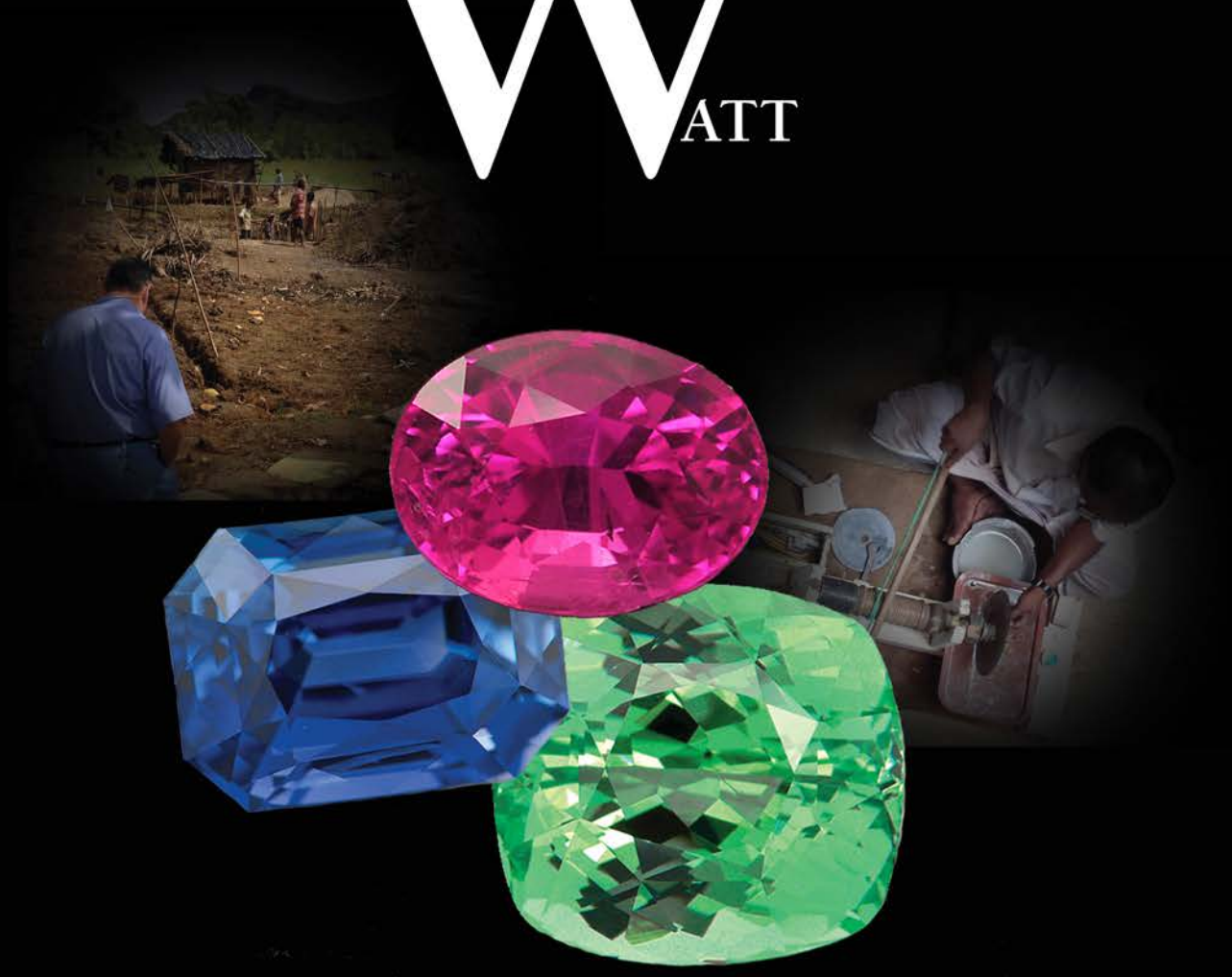

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Sassolite- and CO_2-H_2O-bearing Fluid Inclusions in Yellow Danburite from Luc Yen, Vietnam

Le Thi-Thu Huong, Kurt Krenn and Christoph Hauzenberger

In 2015, gem-quality yellow danburite was discovered in placers of the Luc Yen mining area in northern Vietnam. Microscopic observations revealed 'fingerprints', hollow tubes and two types of fluid inclusions (two-phase and multiphase). Micro-Raman spectroscopy indicated that the two-phase inclusions consisted of CO_2 vapour and pure water, while the multiphase inclusions usually contained one or more crystalline phases in addition to CO_2 and H_2O. Most of the solid phases in the latter fluid inclusions were identified as sassolite (H_3BO_3) and, less commonly, calcite. The presence of sassolite associated with low-density CO_2-bearing fluid inclusions indicates a granitic pegmatite origin for Luc Yen danburite.

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Introduction

Danburite is a calcium borosilicate, $CaB_2Si_2O_8$, belonging to the orthorhombic crystal system. It is genetically associated with rocks of magmatic (granitic pegmatite), metasomatic (skarn) and sedimentary (evaporite) origins (Kurshakova, 1982; Anovitz and Grew, 1996). Gem-quality yellow danburite is known mainly from Tanzania, Madagascar and Myanmar (Kiefert, 2007; Chadwick and Laurs, 2008; Smith and Krzemnicki, 2017; Smith et al., 2017). In mid-2015, several gem-quality pieces of yellow danburite (1.0–2.5 cm) were discovered in the Bai Cat alluvial deposit, near An Phu in the Luc Yen mining area of northern Vietnam. The gemmological, chemical and spectroscopic properties, as well as inclusion characteristics, for this danburite were recently reported (Huong et al., 2016a). However, the original host-rock source remains unknown. The geology of Luc Yen is dominated by metamorphic rocks—mainly granulitic gneiss, mica schist, and marble—that are locally intruded by granitic and pegmatitic dykes (Garnier et al., 2005; Huong et al., 2016a). The pieces of danburite were recovered together with minerals corresponding to both metamorphic (ruby, sapphire and spinel) and pegmatitic (tourmaline and topaz) host rocks.

Two-phase (liquid and gas) and 'fingerprint' inclusions were reported as the main internal features in Vietnamese danburite (Huong et al., 2016a), and similar inclusions also have been documented in yellow danburite from Tanzania and Myanmar (Kiefert, 2007; Chadwick and Laurs, 2008; Smith et al., 2017). In December 2015, a large broken piece of yellow danburite was recovered from the Bai Cat mine (Figure 1), and various types of liquid inclusions were present in the specimen. From a study of this and other recently found samples of Vietnamese danburite, the authors here provide an updated description of the inclusions in danburite from Luc Yen, which were characterized by opti-

Figure 1: This 31.6 g danburite specimen from the Bai Cat alluvial deposit in the Luc Yen mining area shows eye-visible hollow tubes and overlapping 'fingerprint' inclusions. Photo by L.T.-T. Huong.

cal means and by micro-Raman spectroscopy. The original source rock type for this alluvial danburite is then proposed, according to information provided by our study of the inclusions.

Materials and Methods

The large specimen (31.6 g) and four additional crystal fragments (0.7–1.0 g) of Vietnamese danburite were partially polished for optical observations and Raman measurements. Raman spectra of the inclusions were collected in confocal mode using a Jobin Yvon LabRAM HR800 spectrometer equipped with an Olympus BX41 optical microscope and an Si-based CCD (charged-coupled device) detector in the department of Petrology and Geochemistry, at the NAWI Graz Geocentre, University of Graz. The ability of micro-Raman spectroscopy to acquire data from aqueous solutions, together with the high spatial resolution of the Raman microprobe, make it well suited for non-destructive analysis of gas, liquid and solid phases within small (≥5 µm) fluid inclusions. The instrumentation used a 100 mW Nd-YAG laser (532 nm emission), a grating of 1,800 grooves/millimetre

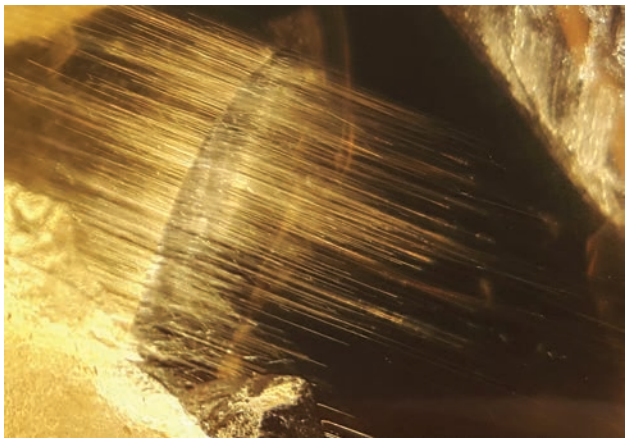

Figure 2: The hollow tubes in the danburite specimen shown in Figure 1 attain a length of 2.5 cm, and some of them nearly cross the host crystal. Photomicrograph by L.T.-T. Huong; field of view 2.5 cm.

and a slit width of 100 µm. The spectral acquisition time was set to 20 seconds for all measurements in the range 150–4000 cm^{-1}. Peak analysis of CO_2 was performed with OriginLab software (OriginPro 9); peak-fitting used a Gauss-Lorentz function.

Results and Discussion

Optical Observations

Without magnification, the 31.6 g danburite specimen showed obvious hollow tubes and multiple overlapping fingerprint inclusions (Figure 1). The hollow tubes were up to 2.5 cm long and some of them crossed almost the entire specimen. With magnification, the tubes did not appear to be filled with any liquid or solid phases (Figure 2). The fingerprints appeared to contain liquid (one- or two-phase) inclusions. In addition, within the other danburite samples, primary fluid inclusions formed singly or were arranged along linear trails (Figure 3a) that were oriented both parallel and perpendicular to the c-axis of the host crystal. The individual fluid inclusions varied from <1 µm to several hundred micrometres in size, and were composed of two-phase and multiphase assemblages (Figure 3a,b). The two-phase inclusions were typically composed of a liquid and a vapour bubble that showed various proportions, suggesting heterogeneous entrapment of the dominant fluid during crystal growth (Figure 3b). Most of the multiphase inclusions contained several crystals, a liquid phase and a vapour bubble (Figure 3c,d). In some cases, two vapour bubbles were seen (Figure 3e). The crystals in the multiphase inclusions

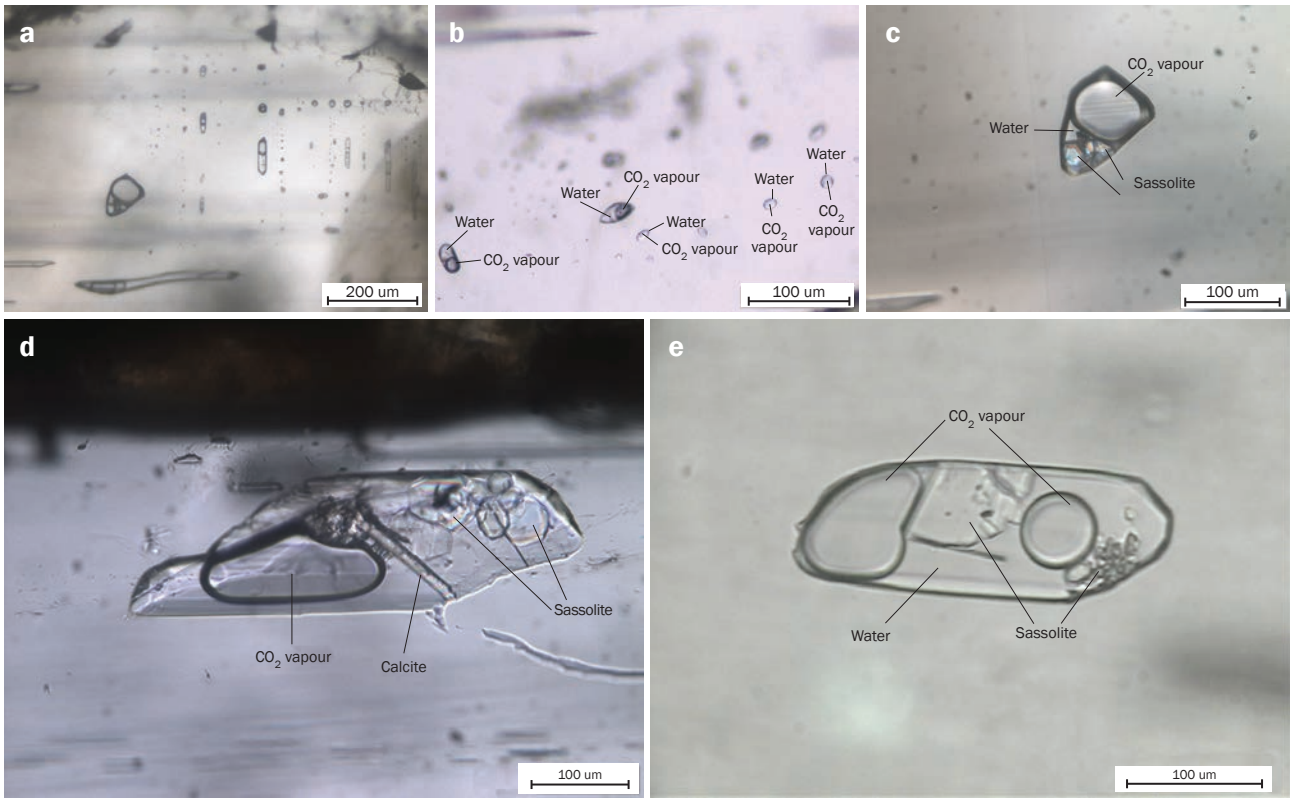

Figure 3: (a) Primary multiphase inclusions occur singly or are arranged along trails, both parallel and perpendicular to the c-axis of the host danburite crystal. (b) The CO_2 vapour bubbles in the two-phase inclusions vary in size, and in some cases only a thin layer of liquid is present along the inclusion walls. (c) Sassolite crystals in the multiphase inclusions appear as colourless, pseudohexagonal plates—sometimes displaying interference colours—with more-or-less perfect crystal faces. (d) Calcite crystals are occasionally associated with the sassolite plates in the multiphase inclusions. (e) This fluid inclusion contains multiple sassolite crystals accompanying two CO_2 vapour bubbles and a liquid (H_2O). Photomicrographs by K. Krenn.

typically formed colourless euhedral pseudohexagonal plates that varied from 5 to 50 µm in dimension; some of them displayed interference colours (again, see Figure 3c,d).

Micro-Raman Spectroscopy

Raman spectroscopy of the multiphase inclusions in all five samples revealed that most of the crystals were sassolite with occasional crystals of calcite (Figure 3d). The liquid and vapour phases were identified by Raman spectroscopy as H_2O and CO_2, respectively. All of these phases were unambiguously identified, as each one showed distinctive Raman bands. In the range 150–1500 cm^{-1}, we oberved Raman bands of the host danburite in addition to characteristic bands of sassolite, calcite and CO_2 vapour (Figure 4a). Higher wavenumbers (1500–3000 cm^{-1}) yielded no evidence of additional gas phases, such as N_2 and/or CH_4, but only luminescence signals of the host danburite (Figure 4b). Between 3000 and 3800 cm^{-1} were characteristic peaks for H_2O and sassolite (Figure 4c).

The sassolite showed two distinct bands at 500 and 880 cm^{-1} (Figure 4a) and two additional bands at 3165 and 3247 cm^{-1} (Figure 4c). The 500 and 880 cm^{-1} bands are assigned to $\nu_s B^{[3]}$-O species, where $B^{[3]}$-O denotes three-coordinated boron (Janda and Heller, 1980; Thomas, 2002).

The calcite was characterized by two strong bands at 1088 and 283 cm^{-1} and a less-intense band at 714 cm^{-1} (Figure 4a). The doublet at 270–300 cm^{-1} in the Raman spectrum of the calcite might result from a combination of the intense calcite band at 283 cm^{-1} with the two nearby danburite bands (~281 and 296 cm^{-1}).

Raman spectroscopy of the liquid phase gave no hint of the presence of organic matter, and showed only the characteristic peaks of the host danburite and some weakly resolved bands due to H_2O in the 3000–3800 cm^{-1} range (Figure 4c). Some of the bands seen in the spectra of both sassolite and H_2O (i.e. above 3600 cm^{-1}) were probably generated by the luminescence of the host danburite.

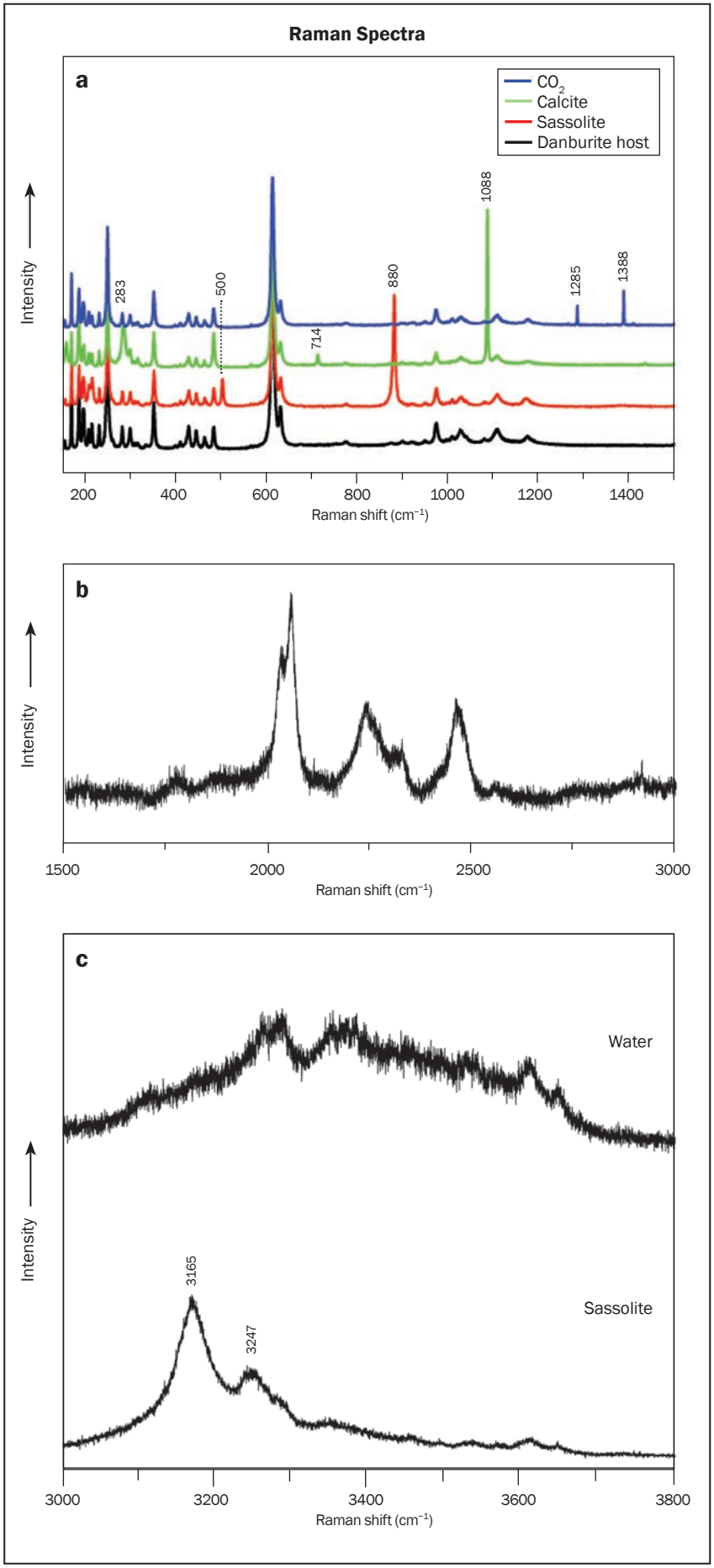

Figure 4: (a) Micro-Raman spectroscopy of the danburite fluid inclusions in the 150–1500 cm^{-1} range shows the presence of sassolite, calcite and CO_2 vapour. The black trace shows only the bands of the host danburite. Labelled peaks are from the inclusion phases present. (b) Raman spectroscopy of the fluid inclusions in the 1500–3000 cm^{-1} range shows no bands from additional gas phases (e.g. N_2 and/or CH_4), but only luminescence signals of the host. (c) In the 3000–3800 cm^{-1} range, Raman spectroscopy of the fluid inclusions shows additional bands for sassolite (at 3165 and 3247 cm^{-1}) and characteristic bands of water.

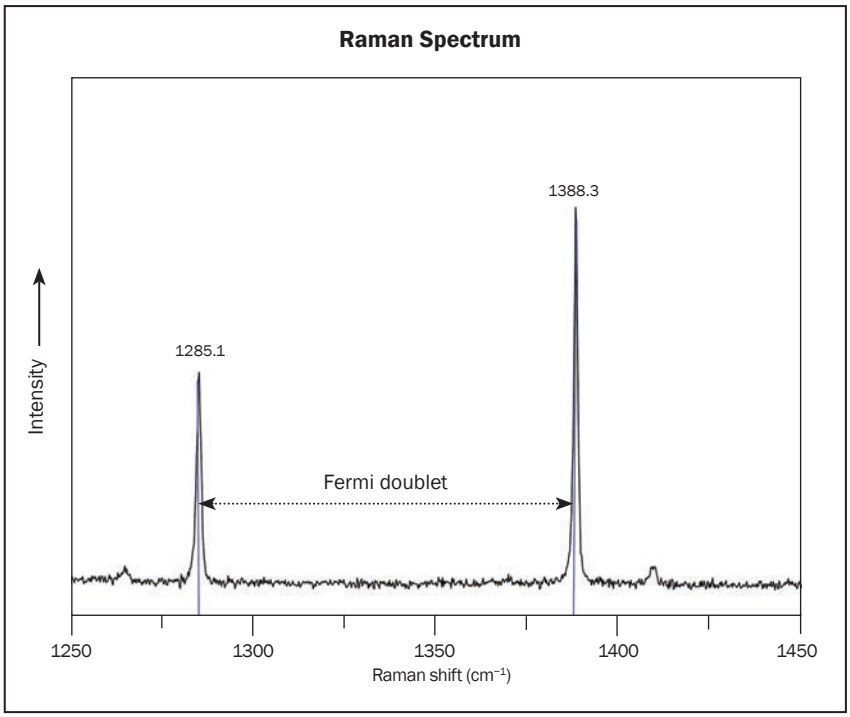

Figure 5: This representative Raman spectrum of CO_2 in the danburite fluid inclusions shows two diad peaks positioned at 1285.1 and 1388.3 cm^{-1}. The diad split (known as the Fermi doublet) corresponds to low-density values, which points to a granitic pegmatite source rock for the danburite.

The Raman spectrum of CO_2 in the fluid inclusions showed two main bands at ~1388 and 1285 cm^{-1}, which are known as the Fermi diad (Gordon and McCubbin, 1966; see Figure 5). The separation between the Fermi diad bands (Fermi doublet Δ) is a function of CO_2 density in fluid inclusions, whereby the separation increases with increasing density of CO_2 (Song et al., 2009; Wang et al., 2011; Kobayashi et al., 2012). Thus, the density of CO_2 in primary-trapped inclusions is an excellent indicator for the formation conditions of the host mineral (i.e. lithostatic pressure, therefore providing an estimate of the depth of crystallization: Sirbescu and Nabelek, 2003; Yamamoto et al., 2007). According to Raman data for CO_2 in the Vietnamese danburite (Figure 5), Δ values fall in the range 102.7–103.1 cm^{-1}, which correspond to densities lower than 0.3 g/cm^3 (Wang et al., 2011). The density of CO_2 in liquid inclusions in pegmatitic minerals (i.e. plagioclase, tourmaline and quartz) has been reported up to 0.65 g/cm^3 (Smerekanicz and Dudás, 1999; Bakker and Schilli, 2016), whereas the CO_2 density in liquid inclusions in garnet of metamorphic origin is reportedly much higher: up to 1.13 g/cm^3 (Santosh and Tsunogae, 2003; Lamadrid et al., 2014).

Origin of Luc Yen Danburite

The identification of sassolite in the fluid inclusions points to a pegmatite origin (cf. Anovitz and Grew, 1996) for the Luc Yen danburite, and this is confirmed by the low-density values of the CO_2 (0.3 g/cm^3) in the multiphase inclusions. Sassolite is a characteristic component of fluid inclusions in minerals from the majority of tourmaline-bearing and topaz-beryl miarolitic pegmatites worldwide (Peretyazhko et al., 1999, 2000; Smirnov et al., 2000; Bakker and Schilli, 2016).

Some pegmatites in the Luc Yen area of Vietnam have been exploited for tourmaline, green feldspar, topaz and lepidolite. These granitic pegmatites are of the relatively shallow miarolitic type, and are of Oligocene age (i.e. 30.58 million years according to K/Ar data for K-feldspar: Huong et al., 2016b). The presence of tourmaline and topaz with danburite in the alluvial sediments, combined with the inclusion data described above, suggests that the Luc Yen danburite is related to these pegmatites.

Conclusions

Internal features in Vietnamese danburite consist of fingerprints, hollow tubes, and two-phase and multiphase fluid inclusions. Micro-Raman spectroscopy was used to identify the various constituents of the multiphase inclusions. The solid phases consisted of sassolite—which was present in all of the analysed inclusions—and occasional calcite. The various proportions of a carbonic vapour phase (CO_2) compared to a liquid phase (H_2O) indicate a heterogeneous entrapment of

the fluid inclusions. This suggests that the associated sassolite and calcite precipitated as a result of decreasing temperature through hydration reactions with the host danburite. The presence of sassolite together with low-density H_2O–CO_2 fluid inclusions indicates the Luc Yen danburite originated from a granitic pegmatite source rock.

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Conferences

Fourteenth Annual Sinkankas Symposium—Sapphire

This sold-out conference was held on 8 April 2017 at the Gemological Institute of America (GIA) in Carlsbad, California, and was co-hosted by the Gemological Society of San Diego (GSSD). (See pp. 560–561 of this issue for a review of the accompanying proceedings volume.) The 12 speakers (Figure 1) covered a variety of topics related to sapphire, and a beautiful array of sapphire crystal specimens and polished stones was displayed during the event by Pala International of Fallbrook, California (Figure 2).

The symposium opened with brief introductions by **Donna Beers** of GSSD and **Robert Weldon** of GIA. Then **Richard Hughes** (Lotus Gemology, Bangkok, Thailand) gave a multimedia presentation that reviewed world sources and quality factors for blue and fancy-colour sapphires. He also looked at pricing and showed that, even though blue and padparadscha sapphires are the most valuable colours of sapphire, they are still much less expensive than ruby.

Alan Hart (Gem-A, London) reviewed sapphires in the British Crown Jewels, covering 1,200 years of history of the regalia, which is used particularly for coronation ceremonies. Interestingly, many of the sapphires and other gems mounted in various objects (e.g. crowns) were recycled into new versions of those pieces that were made for successive generations of kings and queens.

Nathan Renfro (GIA, Carlsbad) examined the microscopic internal and external features of sapphires. His attractive photomicrographs showed various mineral inclusions (rutile as silk and skeletal crystals, ilmenite, uraninite, zircon, apatite, spinel and metal sulphides) as well as colour zoning, thin films, fractures with epigenetic staining, negative crystals (with bubbles that appeared/disappeared upon cooling/heating) and surface textures.

Dr George Harlow and Rachelle Turnier (American Museum of Natural History, New York, New York) discussed syenite-hosted sapphires from the Baw Mar mine in Mogok, Myanmar, and compared their composition and oxygen isotope values to syenite-hosted sapphires from other localities. He concluded that there is no uniform formation environment for such sapphires, and that they are brought to the earth's surface as xenocrysts rather than phenocrysts.

Glenn Lehrer (Glenn Lehrer Designs, Larkspur, California) gave numerous tips for faceting and carv-

Figure 1: Sinkankas Symposium presenters and organizers gather for a group photo around a statue of Richard T. Liddicoat. From left to right: Edward Boehm, Lisbet Thoresen, Dr George Harlow, Richard Hughes, Dona Dirlam, Carl Larson, Robert Weldon (kneeling), Dr William 'Skip' Simmons, Glenn Lehrer (kneeling), Shane McClure, Dr George Rossman, Alan Hart, Nathan Renfro and Dr John Emmett. Photo by Jim Parrish.

Figure 2: This photo shows a few of the sapphire specimens that were displayed during the Sinkankas Symposium. Courtesy of Pala International; photo by Jim Parrish.

ing sapphire, as well as improving traditional-cut stones. In general, sapphires that contain 'silk' can benefit from fewer facets of larger size, while those that are free of silk should have numerous small facets. Also, he showed that when recutting the table and crown to improve a sapphire's appearance, dramatic results may be obtained with very little weight loss (only a few tenths of a point in some cases).

Dr John Emmett (Crystal Chemistry, Brush Prairie, Washington, USA) and co-authors covered the coloration mechanisms of sapphire, examining the strength of the chromophores (Cr^{3+}, Fe^{2+}–Ti^{4+}, V^{3+}, Fe^{3+} and trapped hole centres involving various ions) and how different combinations of them produce various colours. While the presence of Cr^{3+} alone causes pink coloration, it is the combination of Cr^{3+} with a trapped hole centre involving Cr^{3+} that causes the red colour of ruby (only about 1 ppm of trapped holes is needed).

Dr William 'Skip' Simmons (Maine Mineral & Gem Museum, Bethel, Maine, USA) reviewed the crystallography and mineralogy of sapphire. Although corundum is a trigonal mineral, its crystal structure is characterized by hexagonal close packing. It is commonly associated with spinel, phlogopite, calcite and olivine (in marbles); kyanite and sillimanite (in schists); and nepheline (in syenite).

Shane McClure (GIA, Carlsbad) provided a review of sapphire treatments, particularly heating. It has been estimated that 90–95% of sapphire on the market has undergone heat treatment, which takes place at temperatures ranging from ~800°C to 1,800°C and for periods of 1 hour to 3+ weeks. The main goals of heat treatment are to remove the blue tint from pink sapphires, deepen the colour of yellow sapphires, and create blue colour (while improving the transparency) of geuda material.

Carl Larson (Pala International, Fallbrook, California) discussed collecting sapphire crystals and gemstones from worldwide localities. Generally it is best to have a particular focus when collecting; examples include locality, colour, crystal form or gemstone shape, and phenomena (e.g. star stones). Cut stones are more easily understood by consumers to have high value. Done correctly, collecting sapphires can be a good investment.

Lisbet Thoresen (Temecula, California) reviewed the archaeogemmology of sapphire, starting with the Hellenistic Era (323 BC). Studies of glyptic (carved or engraved) gems have shown that there are generally two categories of sapphires: small, heavily zoned dark blue stones and larger, lighter-coloured gems. All available evidence suggests that Sri Lanka (Ceylon) was the source of sapphires from the 3rd through the 6th century AD.

Edward Boehm (RareSource, Chattanooga, Tennessee, USA) explored the evolution of laboratory services for gemstones, which has shifted from basic gem identification to high-tech geographic origin determination—particularly for sapphires and other high-value coloured stones. Besides influencing a stone's pricing, origin reports are also important for traceability (e.g. separating gems associated with conflict from those that are mined sustainably).

Dr George Rossman (California Institute of Technology, Pasadena) performed experiments on a blue sapphire and a ruby to observe whether their colours are stable at temperatures that are at least as high as their formation conditions. The sapphire and ruby samples each were colourless when they were observed at high temperature (1,000°C), due to broadening of their absorption bands that occurred during the heating process. Therefore, Rossman postulated that sapphire and ruby are actually colourless when they crystallize, and only develop their colour upon cooling.

Brendan M. Laurs FGA

Presentations in Tucson, Arizona, USA

In April 2017, two presentations of interest to gemmologists took place in Tucson.

On 13 April, at the University of Arizona, **Prof. Lutz Nasdala** (University of Vienna, Austria) gave a presentation on new advances in Raman micro-spectroscopy. He described four case studies, two of which pertained to gemmology. The first study looked at natural radiation damage in gem-quality ekanite ($Ca_2ThSi_8O_{20}$), which occurs due to the decay of radioactive isotopes of Th and U. The resulting damage to the crystal structure may cause it to appear amorphous with no Raman peaks. Heat treatment of the metamict material causes recrystallization and the corresponding appearance of diagnostic Raman peaks. For the second case study, Nasdala explained that zircon samples for use as analytical reference material are best obtained from high-quality facetable material in pieces that are larger than 10 ct. The samples should be sliced into 100-µm-thick wafers and monitored for long periods of time to look for metamictization. Metamict gems with abundant radiation damage behave as amorphous material, and may not show the doubling of back facets that is commonly shown by faceted zircon. Annealing of zircon removes traces of helium, so analysis for He may provide a useful criterion for identifying heat treatment.

On 22 April, the Mineral Enthusiasts of the Tucson Area hosted **Mike Clow** (LightSource Industries, Sedona, Arizona), who discussed LED lighting for gem and mineral displays. LEDs are becoming the standard light sources for home, industry and now gem and mineral cases, as well as retail displays. Clow shared a few key facts we might not realize. For example, there is no such thing as a 'white' LED. Instead, apparent white light is achieved with a blue bulb that is coated with a yellow phosphor. Another example is that LEDs emit 50% of their energy as light and the remainder as heat; by comparison, incandescent bulbs produce 95% heat and only 5% light. Most gem and mineral displays respond well to having a mixture of 'warm' and 'cool' LEDs. Diamond merchants commonly prefer a colour temperature of 6,500 K because this cool light helps offset the slight yellow tint that can be seen in many diamonds. Overall, proper display lighting is dependent on the presence of other light sources as well as the background of a display. Black moves an object to the forefront while white gives more depth. Glare is never good, whereas side lighting can show textures effectively. Ultimately, proper lighting is subjective: What looks good, works.

Eric Fritz
Gem-A, Tucson, Arizona

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Gem-A Notices

GIFTS TO THE ASSOCIATION

The Association is most grateful to the following for their gifts and donations for research and teaching purposes:

Gina Barnes, School of Oriental & African Studies, University of London, for for two jade and jasper pebbles and a jasper fragment from Itoigawa, Niigata Prefecture, Japan.

Meg Berry, Megagem, Fallbrook, California, USA, for some fragments of tsavorite from Ethiopia.

Peter Dwyer-Hickey FGA DGA, South Croydon, Surrey, for copies of the following books: *The Diamond Underworld* by F. Kamil; *English Medieval Lapidaries* by J. Evans and M. Serjeantson; *Gems, Minerals and Rocks in Southern Africa* by J. R. McIver; *Jewellery* by the National Museum of Ireland; *Gold* by S. La Niece/British Museum; and *Medieval Goldsmiths* by J. Cherry/British Museum.

Melvyn Gallagher, Upminster, Essex, for a scrapbook of diamond sales at Debenhams Store Auction House, 1871–1872.

William Hasselrot, Stockhom, Sweden, for a monetary donation.

Marcus McCallum FGA, Hatton Garden, London, for a monetary donation.

Antony Shih, Taipei City, Taiwan, RO China, for one large piece of rough 'blue' amber and a carved 'blue' amber Buddha.

Beth West, Reading, Berkshire, for a large cubic zirconia set in a ring.

ANNUAL GENERAL MEETING

The 2017 Gem-A Annual General Meeting will be held on 27 July at 18:30 at The Goldsmiths' Centre, London.

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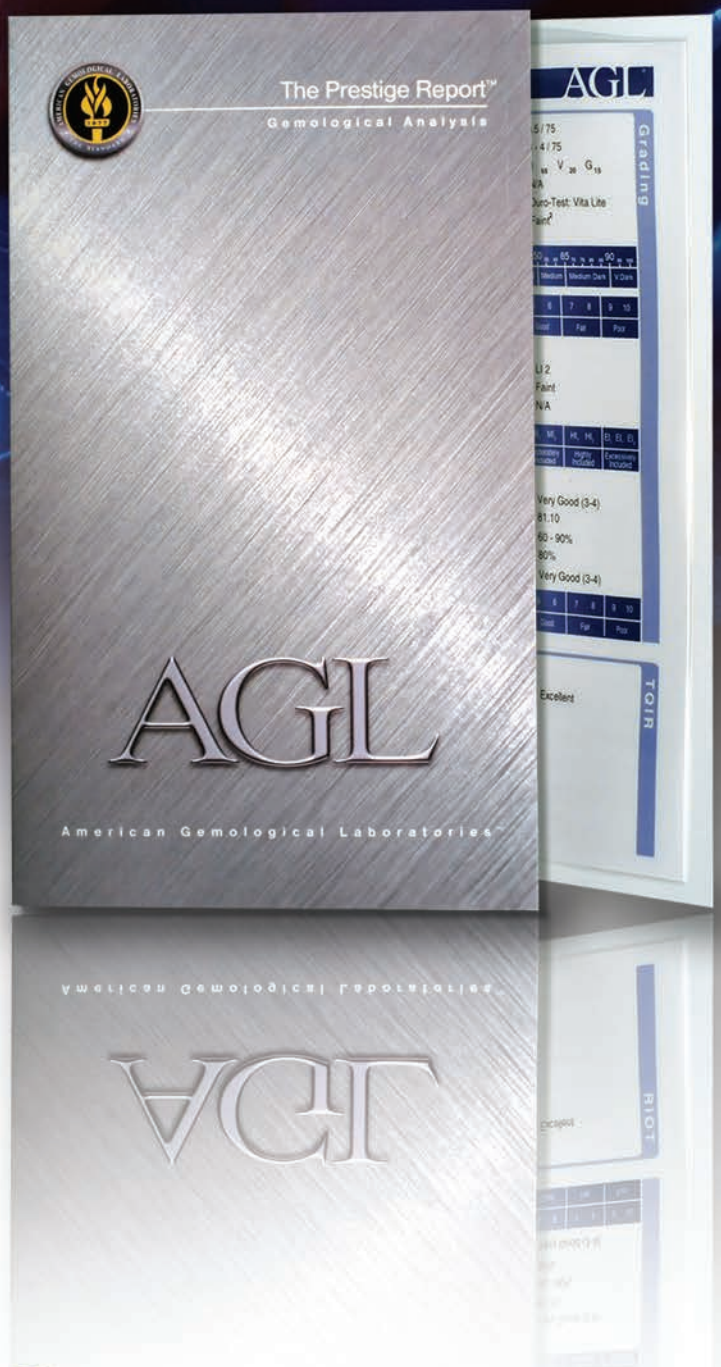

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Learning Opportunities

CONFERENCES AND SEMINARS

Swiss Gemmological Society Conference and European Gemmological Symposium 2017
29 June–1 July 2017
Zermatt, Switzerland
http://gemmologie.ch/en

International Conference in Geology, Mining, Mineral and Groundwater Resources of the Sub-Saharan Africa
11–13 July 2017
Livingstone, Zambia
www.mines.unza.zm/conference
Theme of interest: Gemstones Mining

East Coast Gem, Mineral & Fossil Show
11–13 August 2017
West Springfield, Massachusetts, USA
www.mzexpos.com/east-coast-show
Note: Includes a seminar programme.

Northwest Jewelry Conference
11–13 August 2017
Seattle, Washington, USA
www.nwjcon.com

48th ACE© IT Annual Mid-Year Conference
12–15 August 2017
Indianapolis, Indiana, USA
www.najaappraisers.com/html/conferences.html

Dallas Mineral Collecting Symposium
25–27 August 2017
Dallas, Texas, USA
www.dallassymposium.org

28th International Conference on Diamond and Carbon Materials (DCM 2017)
3–7 September 2017
Gothenburg, Sweden
www.diamond-conference.elsevier.com

Hong Kong Jewellery & Gem Fair
13–19 September 2017
Hong Kong
www.tinyurl.com/hbn8y56
Note: Includes a seminar programme.

Denver Gem & Mineral Show
15–17 September 2017
Denver, Colorado, USA
www.denvermineralshow.com
Note: Includes a seminar programme.

IRV Loughborough Conference
16–18 September 2017
Loughborough
www.jewelleryvaluers.org/Loughborough-Conference

11th International Kimberlite Conference
18–22 September 2017
Gaborone, Botswana
www.11ikc.com
Note: Pre- and post-conference field trips will visit diamond deposits in Botswana and neighbouring countries.

World of Gems Conference V
23–24 September 2017
Rosemont, Illinois, USA
http://gemguide.com/events/world-of-gems-conference
Note: Will include a poster session.

ASA 2017 International Appraisers Conference
7–10 October 2017
Houston, Texas, USA
www.appraisers.org/education/conferences/asa-joint-conferences

35th International Gemmological Conference
11–15 October 2017
Windhoek, Namibia
www.igc-gemmology.org

200th Anniversary Meeting of the Russian Mineralogical Society
10–13 October 2017
Saint Petersburg, Russia
www.minsoc.ru/2017
Session of interest: Natural Stone in History of Civilization (Including Gemology)

Friends of Mineralogy Pacific Northwest Chapter 43rd Annual Symposium: Minerals of the Pacific Northwest
13–15 October 2017
Kelso, Washington, USA
www.pnwfm.org/symposium

Canadian Gemmological Association Conference
20–22 October 2017
Toronto, Ontario, Canada
www.canadiangemmological.com/index.php/com-virtuemart-menu-configuration/conferences-and-special-events

ICA Congress
21–24 October 2017
Jaipur, India
www.gemstone.org/events/2017-congress

Compiled by Angharad Kolator Baldwin and Brendan Laurs

Geological Society of America Annual Meeting
22–25 October 2017
Seattle, Washington, USA
http://community.geosociety.org/gsa2017/home
Session of interest: Gemological Research in the 21st Century: Characterization, Exploration, and Geological Significance of Diamonds and Other Gem Minerals

9th International Congress on the Application of Raman Spectroscopy in Art and Archaeology
24–28 October 2017
Évora, Portugal
www.raa2017.uevora.pt

The Munich Show
27–29 October 2017
Munich, Germany
www.munichshow.com/en
Note: Includes a seminar programme.

Inaugural Conference on Applied Earth Sciences in Myanmar and Neighboring Regions
2–3 November 2017
Yangon, Myanmar
www.maesa.org/info.html
Session of interest: Applied Mineralogy and Gem Deposits

World Ruby Forum 2017
4 November 2017
Bangkok, Thailand
www.worldrubyforum.com

Gem-A Conference
4–5 November 2017
London
www.gem-a.com

CIBJO Congress 2017
5–7 November 2017
Bangkok, Thailand
www.cibjo.org/2017-cibjo-congress-take-place-bangkok-thailand-november-5-7

Swiss Geoscience Meeting
17–18 November 2017
Davos, Switzerland
https://geoscience-meeting.ch/sgm2017
Session of interest: Gemmology

EXHIBITIONS

Asia

Imperial Splendours: The Art of Jewellery Since the 18th Century
Until 2 July 2017
The Palace Museum, Beijing, China
http://en.dpm.org.cn/exhibitions/current/2017-03-02/2602.html

Europe

Stone of Heaven. HRH Prince Henrik's Collection of Oriental Jade
Until 27 August 2017
Musee på Koldinghus, Kolding, Denmark
www.koldinghus.dk/uk/exhibitions-2017/stone-of-heaven.aspx

Authentically Inauthentic?—Jewellery from Pforzheim's Industrial Production
Until 10 September 2017
Municipal Museum, Pforzheim, Germany
www.schmuckmuseum.de/flash/SMP_en.html

Must-haves—Jewellery Created by Greats of the Craft and **Must-Sees—Jewellery in the Arts**
Until 10 September 2017
Schmuckmuseum, Pforzheim, Germany
www.schmuckmuseum.de/flash/SMP_en.html

Amber and Form
Amber Room in Saint Petersburg
Jewels of the Baltic in Novo Mesto
Until 30 September 2017
Dolenjski muzej Novo mesto, Slovenia
www.dolenjskimuzej.si/en/amber

Liv Blåvarp: Jewellery
Until 29 October 2017
Lillehammer Kunstmuseum, Lillehammer, Norway
http://lillehammerartmuseum.com/utstilling/liv-blavarp-smykker-17-juni-24-september-2017/?lang=en

Jewellery—Materials Craft Art
Until 22 October 2017
Swiss National Museum, Landesmuseum Zürich, Switzerland
www.nationalmuseum.ch/e/microsites/2017/Zuerich/Schmuck.php

Vanity: Stories of Jewelry in the Cyclades
Until 31 October 2017
Archaeological Museum of Mykonos, Greece
http://news.gtp.gr/2016/08/18/ancient-cyclades-jewelry-mykonos

Pretty on Pink—Éminences Grises in Jewellery
27 October–mid-February 2018
Schmuckmuseum, Pforzheim, Germany
www.schmuckmuseum.de/flash/SMP_en.html

Smycken: Jewellery—From Decorative to Practical
Ongoing
Nordiska Museet, Stockholm, Sweden
www.nordiskamuseet.se/en/utstallningar/jewellery

North America

Jeweled Splendors of the Art Deco Era: The Prince and Princess Sadruddin Aga Khan Collection
Until 27 August 2017
Cooper Hewitt, New York, New York, USA
www.cooperhewitt.org/events/current-exhibitions/jeweled-splendors

Linda MacNeil: Jewels of Glass
Until 1 October 2017
Museum of Glass, Tacoma, Washington, USA
https://museumofglass.org/mog/exhibition/linda-macneil-jewels-of-glass

Spectacular! Gems and Jewelry from the Merriweather Post Collection
Until 1 January 2018
Hillwood Estate, Museum & Gardens, Washington DC, USA
www.hillwoodmuseum.org/Spectacular-Gems-and-Jewelry

Past is Present: Revival Jewelry
Until 19 August 2018
Museum of Fine Arts, Boston, Massachusetts, USA
www.mfa.org/news/past-is-present-revival-jewelry

Australasia

Australian Opal Exhibition
3–4 August 2017
Surfers Paradise, Queensland, Australia
www.austopalexpo.com.au

The House of Dior: Seventy Years of Haute Couture
27 August–7 November 2017
The National Gallery of Victoria, Melbourne, Australia
www.ngv.vic.gov.au/exhibition/the-house-of-dior

OTHER EDUCATIONAL OPPORTUNITIES

Gem-A Workshops and Courses
Gem-A, London
www.gem-a.com/education/courses

Sri Lanka Trip with Gem-A and The National Association of Jewellers
16–30 October 2017
Visit mines, markets and cutting centres in Sri Lanka
http://tinyurl.com/kujwh72
Note: Open to members of Gem-A and NAJ.

DUG Advanced Gemology Program (in English)
6 November–8 December 2017
Nantes, France
www.gemnantes.fr/en

Gemstone Safari to Tanzania
8–25 January 2018
Visit Morogoro, Umba, Arusha, Longido, Merelani and Lake Manyara in Tanzania
www.free-form.ch/tanzania/gemstonesafari.html
Note: Includes options for a lapidary class and/or a private trip to visit ruby mines near Morogoro and Mpwapwa (including Winza).

Lectures with Gem-A's Midlands Branch
Fellows Auctioneers, Birmingham
Email Georgina@fellows.co.uk

- 29 September 2017
  Geoff Whitefield—Valuation Practice
- 27 October 2017
  Stephen Alabaster—The History of Alabaster & Wilson

Lectures with The Society of Jewellery Historians
Society of Antiquaries of London, Burlington House, London
www.societyofjewelleryhistorians.ac.uk/current_lectures

- 26 September 2017
  (40th Anniversary Lecture)
  Mag. Paulus Rainer—Benvenuto Cellini's Salt Cellar: Some New Thoughts, Some New Discoveries
- 3 October 2017
  Raymond Sancroft-Baker—Hidden Gems – Jewellery Stories from the Salesroom
- 24 October 2017
  Lynne Bartlett—The Rise and Fall of the Chatelaine
- 28 November 2017
  Judy Rudoe—Cartier Gold Boxes: A Visionary Patron and a Bet with Ian Fleming

New Media

Diamond—The Ultimate Gemstone

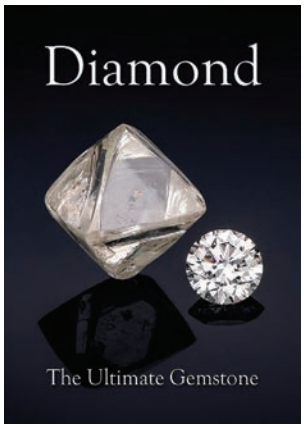

Ed. by Jeff W. Harris and Gloria A. Staebler, 2017. MINERAL Monograph No. 19, Lithographie Ltd., Arvada, Colorado, USA, www.lithographie.org/bookshop/diamond__the_ultimate.htm, 152 pages, illus., ISBN 978-0983632351. US$40.00 softcover.

Did you know that the first experiments to 'vaporize' diamond with focused sunlight were conducted in 1694 in Florence, Italy, by Giuseppe Averani and Cipriano Targioni, and in 1772 Antoine Lavoisier was able to prove that diamonds consisted of carbon? And did you know that the impact of the huge meteorite that created the Nördlinger Ries crater in Bavaria, Germany, also turned a nearby graphite deposit into the rock suevite, which contains about 72,000 tonnes of tiny (less than 0.2 mm) impact-origin diamonds? And that the largest CVD-grown synthetic diamond identified by the GIA laboratory so far (2016) is a J-VS_2 cushion cut of 5.19 ct? Or that the production of HPHT-grown synthetic diamonds currently exceeds 300 tonnes per year? These and many more facts can be found in this volume.

The editors have brought together a group of authors who are well-known experts in their fields, and their papers comprise a wide range of topics. 'Lands Immemorial' by G. A. Staebler and C. Mitchell summarizes the history of diamonds from the oldest known jewels of Roman times to the discovery of diamonds in South Africa, their mining and trade, and their role as symbols of wealth and power. India and Brazil are treated in more detail. As an example of a historic Indian stone, B. Janse briefly depicts the history of the Hope Diamond from its discovery to its current home in the Smithsonian Institution.

Janse is also the author of the chapter 'Geology of Diamond'. The geological conditions of diamond formation are described comprehensibly, as are the classification, distribution and prospection of diamondiferous rocks and indicator minerals; secondary deposits (alluvial and marine); the age dating and world production of diamonds; and where diamond prospecting is taking place today.

In 'The Magnificent Mineralogy of Diamond', J. A. Jaszczak and K. Dunnell first explain the differences between the structures of diamond and graphite. Then they describe the most interesting aspects of diamond morphology (e.g. for monocrystalline, twinned and fibrous diamonds), surface features, lustre, refraction, dispersion, inclusions, hardness and thermal conductivity. The chapter closes with a description of diamond types based on the presence/absence of nitrogen and boron.

'Diamond Studies' is mainly an abbreviated version of an article by the late M. Glas published in *extraLapis* No. 18 (2000). Glas presents diamond crystal drawings from Fersman and Goldschmidt's *Der Diamant, eine Studie* (1911), and also the detailed drawings of a complicated multiple diamond twin made in 1942 by Berend George Escher, the half-brother of the famous graphic artist M. C. Escher. In a separate box, J. Rakovan, A. G. Schauss and R. P. Richards discuss 'The Puzzle of Re-Entrant Cube Morphology'.

With the title 'On the Beauty of Defects', E. Gaillou and G. R. Rossman do not refer to the clarity of diamond, but to various 'imperfections' that cause the different colours, such as trace elements (e.g. nitrogen, boron and hydrogen), effects of radiation, lattice defects, etc. Then they discuss the specific causes for each colour, as well as for phenomena such as luminescence and 'chameleon' colour behaviour.

In 'Diamond: Intimate Portraits', J. I. Koivula and E. A. Skalwold offer a gallery of breathtakingly beautiful photomicrographs of structures and inclusions. They also give accompanying explanations, but frankly speaking, you may also skip them and just enjoy the beauty of the incredible images.

J. Shigley then covers 'Diamonds as Gemstones'. Starting with quality criteria for faceted diamonds (the famous 4Cs), he describes modern gem diamond manufacturing, in which computers play an ever-increasing role, and the identification of diamond treatments, synthetics and simulants, in which high-tech analytical methods are needed where the naked eye and loupe are not sufficient. In a separate box, Robert M. Shipley Sr. (1887–1978) is portrayed as one of the fathers of modern gemmology.

The following five chapters deal with selected diamond sources, ranging from a continent to a single pipe. 'Diamonds in Africa – A Tribute to Tom Clifford', by N. Norman, gives a comprehensive description of the African diamond industry since the discovery of the first diamonds in South Africa in the 19th century, with a focus on this part of the continent. This is followed by a brief review of 10 major diamond-producing countries in Africa.

In 'Crater of Diamonds—The Natural State's Gem of a Park', M. Howard traces the history of this unique deposit in Arkansas, USA, from its discovery in 1906 and several failed attempts to operate a mine, to 1972, when it became a state park. The chapter not only contains images of some of the named diamonds from this source, but also a table of the 24 largest diamonds.

Diamonds were discovered in Russia on 4 July 1829 when 14-year-old Pavel Popov found a 0.52 ct stone while panning for gold in the Ural Mountains. In 'Diamonds in Russia', V. K. Garanin and G. Y. Kriulina give a comprehensive historical outline from this discovery to the prospecting efforts that led to the discovery of numerous deposits in Siberia and more recently in the Arkhangelsk region, and the development of the Russian diamond industry.

In 'Argyle Diamonds', J. Chapman describes the geology and future prospects of the Argyle mine and the extraordinary diamonds it produces.

T. C. Wallace Jr. relates the history of 'Colorado Diamonds'. A series of kimberlites, some of them diamondiferous, are known along the Front Range, but only a little mining has taken place, and with little success. The most important enterprise was the Kelsey Lake mine, which was operated in the 1990s and yielded the 28.3 ct yellow Colorado Diamond, the largest found in that state.

'Laboratory-Grown Diamonds' by J. E. Butler and B. N. Feigelson is the most technical chapter in this monograph. The authors give a detailed description of the problems of diamond synthesis and how they were solved through the development of various HPHT and CVD methods. To conclude, they describe the different applications and uses of both techniques and their growing importance, including in the gem industry.

In 'Diamonds in the Sky', E. Bullock shows that diamonds are not only created deep in the earth, but also near its surface by meteorite impacts. And there are also extraterrestrial diamonds that are hosted by meteorites. Conditions favourable for diamond growth may be found on Jupiter, Saturn, Uranus and Neptune. Some researchers believe that certain planets in other solar systems may even be completely composed of diamond.

In the last chapter of this volume, T. Funk discusses some of the most spectacular 'Diamond Heists', mainly in this century, and why diamonds and jewels are so attractive to thieves. A box in this chapter (by J. H. Betts) briefly outlines 'The Kimberley Process for Collectors'.

All texts in this volume are well written, concise and offer an abundance of up-to-date information. The monograph contains a number of maps, graphics and tables, and is lavishly illustrated. The only flaw I found is on page 80, where the diamond production of Sierra Leone is given as "roughly 300,000 carats per annum (…) more than either Brazil or Australia". While this is possibly true for Brazil, Australia produced 13,570,000 carats in 2015 (see table on page 20).

Considering the vastness of the field, the choice of topics is necessarily incomplete. There is little, for example, about the history of diamond cutting or about the role of diamonds in jewellery throughout history, and one might also desire a description of additional source countries such as Canada. Nevertheless, one can say that the subjects chosen for this volume provide a good survey of all important aspects.

All in all, reading *Diamond—The Ultimate Gemstone* was pleasant and informative, and if it was to be certified like a real diamond, it would certainly get a very good colour grade and VVS_1 clarity.

Dr Rolf Tatje
Duisburg, Germany

Fourteenth Annual Sinkankas Symposium—Sapphire

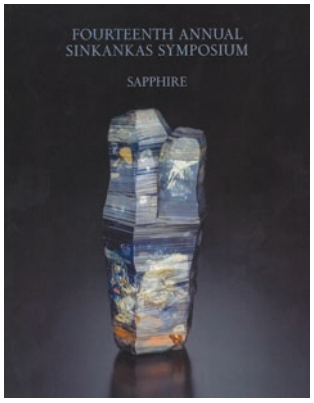

Ed. by Stuart Overlin, 2017. Pala International, Fallbrook, California, USA, 136 pages, illus., ISBN 978-0991532025. US$45.00 softcover.

The Fourteenth Annual Sinkankas Symposium, featuring sapphire, was held in April 2017 at the Gemological Institute of America in Carlsbad and was co-hosted by the Gemological Society of San Diego (see pp. 551–552 of this issue for a report on this conference). As for other Sinkankas Symposia, each attendee received a copy of an attractive proceedings volume that serves as a record of the conference, as well as a detailed reference on the various topics covered by most of the speakers.

The volume begins with a listing of the symposium programme, speaker biographies and abstracts. These are followed by speaker contributions covering a range of topics pertaining to sapphire: world sources and quality factors (Richard Hughes); microscopic features (Nathan Renfro); geochemistry and oxygen isotope values of syenite-hosted sapphires from the Baw Mar mine in Mogok, Myanmar, compared to those from other localities (Rachelle Turnier and Dr George Harlow); the art and science of faceting and

carving sapphire, as well as improving traditional-cut stones and the process of developing the TorusRing cut (Glenn Lehrer); coloration mechanisms, focusing on the chromophores Cr^{3+}, Fe^{2+}–Ti^{4+}, V^{3+}, Fe^{3+} and trapped hole centres involving various ions (Dr John Emmet and Emily V. Dubinsky, with Richard Hughes); mineralogy and crystallography (Dr William 'Skip' Simmons); archaeogemmology (Lisbet Thoresen); collecting rough and cut stones from worldwide localities (Carl Larson); treatments and their detection (Shane McClure); evolution of laboratory services, culminating in origin determination (Edward Boehm); and a bibliography covering both rubies and sapphires (Richard Hughes).

The volume is attractively laid out, with many colour images and even a full-page photo to mark the beginning of each article. The various diagrams and spectra have mostly been redrafted into a consistent and easy-to-read format, although headings are missing from some of them and one heading is incorrect (the spectrum on p. 53 refers to the Fe^{2+}–Ti^{4+} chromophore, rather than Cr^{3+}).

Every sapphire enthusiast should have this volume in his or her library. Not only does it provide useful reviews of several important aspects of sapphire, but in some cases the information is not available anywhere else in the literature.

Brendan M. Laurs FGA

Ruby & Sapphire—A Gemologist's Guide

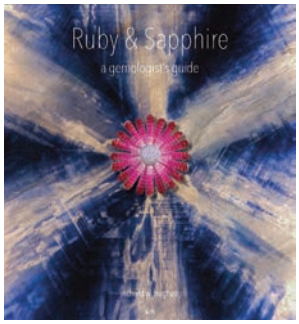

By Richard Hughes with Wimon Manorotkul and E. Billie Hughes, 2017. RWH Publishing/Lotus Publishing, Bangkok, Thailand, www.lotusgemology.com, 816 pages, illus., ISBN 978-0964509719. US$200.00 hardcover.

In the 20 years since Richard Hughes' book *Ruby & Sapphire* was published, many new mines have been discovered and different treatments have appeared, requiring an extensive update. Together with his wife Wimon Manorotkul and daughter E. Billie Hughes, he has managed this task in a grand way, with hundreds of pages that are packed with information. While working on a book chapter of my own about gem treatments and synthetics, I referred to Hughes' book numerous times and never failed to get an answer.

The book starts with some personal information about the author, as well as an exhaustive list of people who helped him during the compilation of this work. This is followed by Chapter 1, a 20-page historical outline, starting with ancient China, moving west to ancient India, and then on to the Arab world and into Europe.

Chapter 2 covers chemical and crystallographic data, including two pages of trace-element contents for corundum from all important origins (compiled by K. Scarratt), as well as a useful table giving the angles between crystal faces of corundum, drawings of known crystal shapes and listings of the major morphologies for different deposits. This is followed by Chapter 3 on physical and optical properties and phenomena, including cleavage/parting/fracture, hardness, thermal properties, melting point, density, electrical and optical properties, lustre, asterism, colour change and trapiche corundum.

At nearly 60 pages, Chapter 4 covers colour, spectra and luminescence, and is co-authored by J. L. Emmett, E. V. Dubinsky and K. Scarratt. The authors go into detail about colour causes from trace elements, charge-transfer effects, band gaps, hole defects, impurity effects, and absorption and transmission. This is accompanied by explanatory graphs and spectra. All colours of corundum are covered, not only taking into consideration the colours themselves but also the connection to their geological origin. A sub-section is dedicated to FTIR spectra, which gives information about the presence or absence of contaminants or treatments. Another important aspect which is covered brilliantly in this chapter is luminescence and fluorescence, with many illustrations and explanations of how these properties can be used to determine origin and treatment. The chapter ends with some observations about pleochroism.

Chapter 5 is dedicated to inclusions and photomicrography. In addition to a multitude of beautiful images, the chapter covers the history of inclusion photography, explains how these inclusions formed, and provides an extensive listing of inclusions observed in corundum.

Chapter 6, with co-authors J. L. Emmett and T. R. Douthit, covers corundum treatments, reaching as far back as 2,000 years. Heat treatment is covered in great detail, from traditional heating to modern high-temperature methodology. The chapter gives information on furnaces, the gases used during heating and the resulting effects on corundum coloration (summarized in a table). Flux-healing of fractures, Ti-diffusion and Be-diffusion are described, as well as fissure and cavity filling. Inclusion photos give detailed information about ways to detect such treatments. The chapter ends with the description of irradiation effects on corundum, as well as oiling and dyeing.

Chapter 7 provides a thorough review of synthetic corundum, starting from the first attempts in the mid-1800s, to the Verneuil, Czochralski and floating-zone

processes, as well as hydrothermal and flux-grown synthetic rubies from various producers. The chapter outlines the history of the methods, but also gives tables with properties of the various synthetics available. Images of inclusions help identify such synthetics. The chapter also shows how synthetics can be treated to induce asterism or make them appear more natural. This is followed by a chapter describing assembled stones such as various doublets and triplets, as well as coatings and foiling.

The next two chapters are valuable tools mostly for buyers and appraisers, but they are interesting for gemmologists as well. Chapter 9 gives a short summary of cutting styles and what to look for when buying stones, while Chapter 10 is about judging the quality of corundum, including colour, inclusions and facet geometry, leading us back to the chapter on gem cutting. Hughes summarizes how these factors influence prices, and then goes into other properties that are sometimes even more important than cut and colour. For example, he lists the most sought-after geographic origins for ruby and sapphire, with an explanation why they are so much more valued than others, and includes guidelines for how to judge star, trapiche, colour-change and fancy-colour corundum. Also provided is a summary of market tastes according to various nations all over the world, and a description of colour types. This is followed by an extensive section covering famous rubies and sapphires (including spinel, which was often mistaken for ruby) with historical background information, lists of significant rubies and sapphires with prices obtained for them at auction, and notable rough and carved stones.

Chapter 11 is dedicated to the geological formation of corundum, starting with a short introduction about the formation of the earth and its components before going into specific geological settings. Hughes, together with R. M. Allen, divide these into igneous, metamorphic and sedimentary deposits, followed by case studies of the most important corundum deposits and their mining methods. A useful table of all deposits lists the mode of occurrence as well as the colours found at each location.

The last chapter, on world sources, is most exhaustive (over 270 pages), describing ruby and sapphire from nearly every known deposit according to geological setting, history and gemmological characteristics (providing that Hughes had study samples available). Maps, mining photos, and images of stones and their inclusions are complemented by tables summarizing the properties of corundum from the described areas. Beautiful images of the countryside and its people are also included. This aspect makes it a pleasure just to scan through, and is a welcome addition to all the information collected and compiled in this chapter. The amount of information for each of the deposits in 52 countries is related to their importance, allowing Burmese rubies and sapphires the most coverage with about 40 pages. Great effort is also spent describing the Kashmir deposit as well as those of Afghanistan, Tajikistan, Madagascar, Kenya, Mozambique, Tanzania, Malawi, Sri Lanka, Australia and Thailand/Cambodia.

The book is completed by two appendices. Appendix A is a reprint of portions of Tagore's *Ma<u>n</u>i-Málá* (1879, 1881). Appendix B is a pricing chart, compiled together with R. Drucker, along with identification flow charts for ruby and sapphire. The last pages contain a very complete and helpful subject index.

Worth highlighting is the extensive bibliography compiled by Hughes: The 3,500 references go back 2,000 years and span all centuries up to the newest literature from 2015. These references are invaluable for every gemmologist. They are listed at the end of each chapter (for those from 1 to 11), and also at the end of each description of the various localities in Chapter 12. While I usually prefer to have all references in one place, I appreciate the ease of finding relevant literature according to the subject covered by the corresponding chapter.

Of course, in such a fundamental work there is always room for criticism, and I have two. The first one is the sheer volume and weight of the book (nearly 10 lb or 4.5 kg), which makes it hard to handle in everyday work. The second one concerns errors in the Table of Contents. The introduction starts on page 35, not on page 39 as stated in the Contents. This inconsistency continues all the way to Chapter 4 (which indeed starts at page 107). The problem happens again with the geology chapter, which starts on page 403 (rather than page 383 as given in the Contents), and this shifts all subsequent page numbers so that the reader needs to search a little bit unless the Index is used, where page numbers are correct. Fortunately, readers can download a corrected version of the Contents (along with a listing of several errata) at www.lotusgemology.com/files/pdf/RS-Errata.pdf.

In summary, this book is a must for all gemmologists working in laboratories or as appraisers. It also contains helpful information for those dealing in ruby and sapphire. It is the most comprehensive reference on corundum that I have seen, but also a great source of information for anyone interested in gems. Although some may find the many quotes unnecessary, they do brighten the text. The beautiful images are a delight for the eyes. This is a very well-balanced work that offers the reader both beauty and valuable information.

Dr Lore Kiefert FGA
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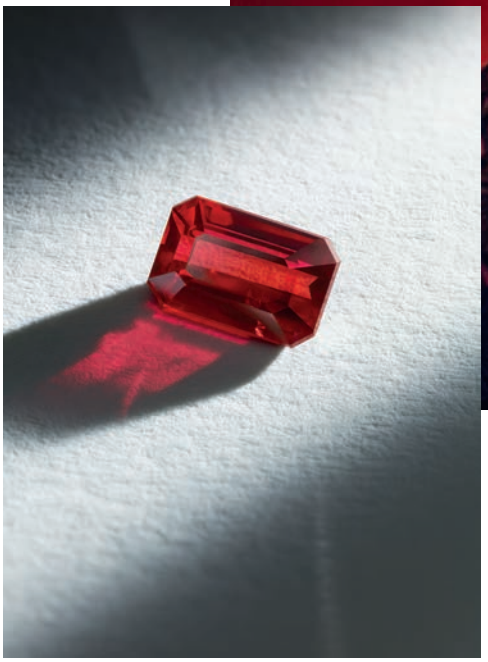

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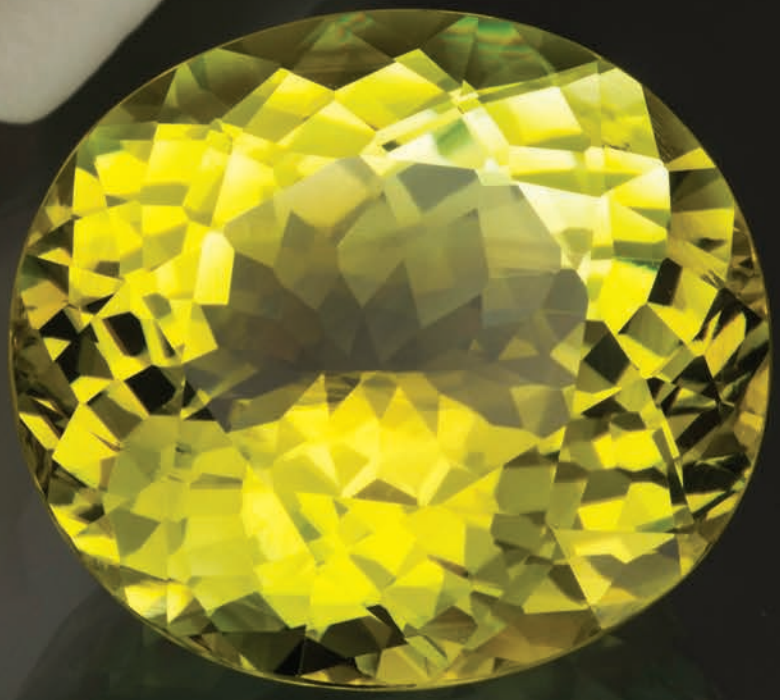

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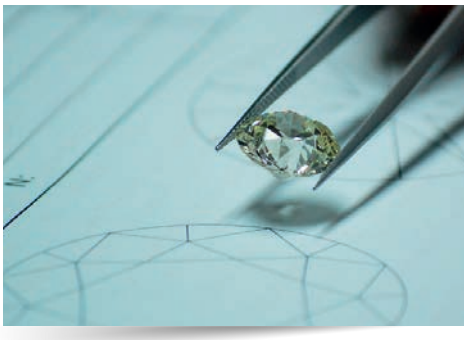

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Cover Photo:

This cloisonné-style disc brooch (5.75 cm in diameter, from Unterhaching, near Munich, Germany) is set with thin, doubly polished garnet plates of up to 2.8 cm long and 1 mm thick. The origin of such garnets in early medieval European jewellery is widely debated and often attributed to India. A provenance study focusing on Indian garnet beads appears on pages 598–627 of this issue. Photo by M. Eberle, © Archäologische Staatssammlung, Munich, Germany.

S. Bruce-Lockhart photo

Thanh Nhan Bui photo

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What's New

INSTRUMENTATION

AMS2 Automated Melee Testing Instrument

In August 2017, De Beers' International Institute of Diamond Grading & Research (IIDGR) released the next-generation Automated Melee Testing instrument, called AMS2, for the separation of potential synthetics and simulants from natural diamond melee. This instrument uses a new measurement technique that enables significantly lower referral rates for natural diamonds. Compared to the first-generation AMS, the AMS2 is designed to be faster, more accurate and more affordable, with the ability to process smaller sizes and all polished shapes. Like its predecessor, AMS2 is designed to screen colourless to near-colourless diamonds. The instrumentation includes the AMS2 device and computer with proprietary software in a single desktop unit. For more information, visit www.iidgr.com/innovation/automated-melee-testing2-ams2. *CMS*

MiNi 360° Photography System

Version 4.0 of the Vision360 MiNi diamond photography system was released in June 2017 at the JCK show in Las Vegas, Nevada, USA. This version—B2B—offers a reduced device size without image deterioration, as well as more advanced colour correction and customizable colour background. The system generates still images and 360° videos of diamonds ranging from 50 to 0.10 ct (and smaller, with an additional lens), along with table-to-culet and 'hearts and arrows' imaging. The unit is approximately 61 cm long and weighs about 7 kg. A vacuum-based stone holder permits up to 99% of a polished diamond to be displayed. Visit https://v360.in/b2bmini.aspx. *CMS*

Spectra Diamond Colorimeter

Released in May 2017, the Spectra portable diamond colorimeter from OGI Systems Ltd. is designed to colour-grade polished diamonds weighing 0.30–100 ct of any shape in the D-to-M range, using GIA and other grading systems. It also measures and grades fluorescence. The unit's dimensions are approximately 15.0 × 10.2 × 10.5 cm and it operates for 15 hours on rechargeable batteries. Visit www.ogisystems.com/spectra.html. *CMS*

NEWS AND PUBLICATIONS

Gem Testing Laboratory (Jaipur, India) Newsletter

Volume 74 (June 2017) of the *Lab Information Circular* of the Gem Testing Laboratory, Jaipur, is now available at http://gtljaipur.info/ProjectUpload/labDownLoad/LIC%2074%20_June2017.pdf. This issue features informative reports on cobalt-diffused blue spinel, gem-quality grandidierite seen in the past year, convincing synthetic ruby rough sold as natural in mining areas in Mozambique, plastic imitation 'play-of-colour opal', californite (cryptocrystalline vesuvianite) as a jade imitation and silicified siltstone marketed as pink opal from Australia. *CMS*

Gemmological Society of Japan Abstracts

Abstracts of lectures from the 2017 Annual Meeting of the Gemmological Society of Japan, held 23–26 January, were released in June 2017 at www.jstage.jst.go.jp/browse/gsj. The topics of the 22 lectures include new analytical methods, CVD synthetic diamond, photoluminescence of type IIa natural pink diamond, emerald coloration, opal, chalcedony, agate, 'Herkimer diamond', liddicoatite, ruby, sapphire, spinel and pearls. The abstracts are in Japanese and often also in English, and those from previous meetings dating back to 2001 are available as well. *CMS*

GIA News from Research: Bead-Cultured Blister Pearls from *Pinctada maculata*

In April 2017, the Gemological Institute of America (GIA) reported on cultured blister pearls originating from Penrhyn Island, the northernmost atoll of the Cook Islands in the Pacific Ocean. *P. maculata* is the smallest of the *Pinctada* molluscs, and the natural 'pipi' pearls it produces are usually 4–5 mm in diameter and can occur in various colours. The cultured blister pearls are produced by inserting a near-spherical freshwater shell bead between the inner shell surface and the overlying mantle tissue. Download the report at www.gia.edu/gia-news-research/pinctada-maculata-bead-cultured-blister-pearls-shells. *CMS*

GIA News from Research: Rubies from Cambodia and Thailand

Posted in August 2017, this report from GIA describes a study of 41 rubies of known provenance from Pailin, Cambodia, and Chanthaburi-Trat, Thailand. Characterization with optical microscopy, Raman spectroscopy, LA-ICP-MS chemical analysis, and UV-Vis-NIR and FTIR spectroscopy revealed features that can readily separate these stones from similar-appearing rubies of basaltic origin from Kenya, as well as those from amphibolite-related deposits. Download the report at www.gia.edu/gia-news-research/study-rubies-cambodia-thailand. *CMS*

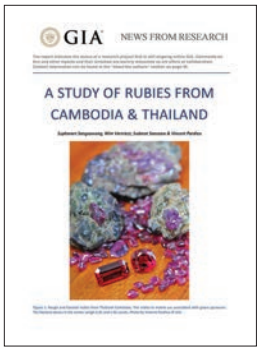

The Goldsmiths' Review 2016–2017

The most recent Goldsmiths' Company annual review publication is now available at www.thegoldsmiths.co.uk/company/today/news/2017/07/28/goldsmiths-company-review-2017. It includes a description of the previous year's activities, introduces the new Prime Warden, profiles contemporary jewellery and galleries in the UK, features women involved in the Goldsmiths' Company, and explores various current and historical facets of precious metals in the UK, from Shakespeare and sovereigns to miniatures and memberships. *CMS*

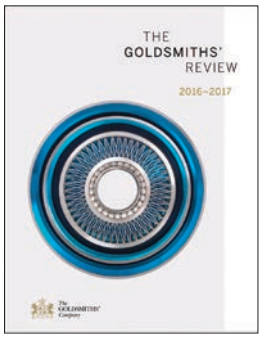

Polished Topaz and Synthetic Moissanite Imitating Rough Diamonds

In July and August 2017, HRD Antwerp reported on two pieces each of polished topaz (38.18 and 50.08 ct) and synthetic moissanite (5.01 and 7.14 ct) that were submitted as rough diamonds. The octahedral-like shapes of the samples were typical of diamond, which strongly suggests that these specimens were created with the intent to deceive. Visit www.hrdantwerp.com/en/news/polished-topaz-imitating-rough-diamonds and www.hrdantwerp.com/en/news/yet-another-rough-diamond-imitation-analyzed-by-our-research. *CMS*

Santa Fe Symposium Proceedings

Papers associated with 22 presentations delivered at the 2016 Santa Fe Symposium (held in Albuquerque, New Mexico, USA) are available for download, on topics including innovative alloys, new technologies,

manufacturing techniques and more. Visit www.santafesymposium.org/papers to obtain PDF files of the 2016 papers, as well as those from earlier symposia dating back to 2000. *BML*

Colour-Change Glass Sold as Garnet Rough

In July 2017, Jeffery Bergman (Primagem, Bangkok, Thailand) distributed a trade alert on two water-worn pebbles represented as colour-change garnet from Mahenge, Tanzania. Their colours were yellowish green in fluorescent illumination and orange in incandescent lighting. The RI of 1.66 and SG of 3.48 matched those of colour-change sinhalite from Sri Lanka and Tanzania, except that only a single RI reading was observed. The visible-range spectra revealed a match with the artificial colour-change glass-ceramic called Nanosital. To read the full report, visit www.academia.edu/33940879/TRADE_ALERT_Color-Change_Glass_Sold_As_Natural_Garnet_Rough?auto=download. *CMS*

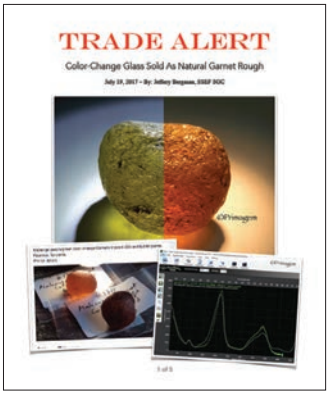

MISCELLANEOUS

M2M Diamond-Origin Tracking Service

GIA announced its new M2M (Mine to Market) programme at the June 2017 JCK show in Las Vegas. The goal of the programme is to track the complete history of a polished diamond from mine to retailer. The service requires that a manufacturer submit appropriately documented rough to GIA's laboratory, which then collects detailed data on each diamond (morphology, spectroscopy and growth structure) and assigns it a serial number. The rough is returned to the manufacturer for cutting, and the polished stones are then sent to GIA for further documentation and matching. It should be possible to verify approximately 90% of the polished stones for which the history has been recorded. A consumer-oriented app, available for iOS and Android devices, will then enable retailers to access an individual diamond's history. Currently it is free to submit rough to GIA, but retailers must pay to access the complete information via the app. To learn more, visit www.gia.edu/gia-news-press/jck-las-vegas-2017. A video with additional information is also available at www.youtube.com/watch?v=n6RUoYZJRvg. *CMS*

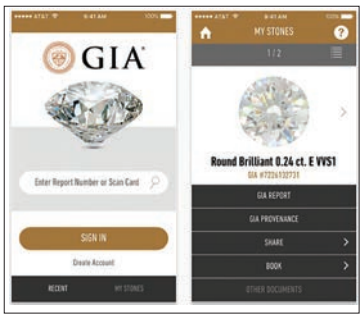

More Historical Reading Lists

GIA's Richard T. Liddicoat Gemological Library recently added four new topics to its 'Historical Reading' lists of articles and books that are available in the Library's holdings: Ancient Emerald Mines of Egypt, Baltic Amber, California Gold Rush and Diamond Fields of South Africa. The ancient Egyptian emerald listing includes 22 articles and books dating from 1817 to 2008. The Baltic amber list encompasses 83 articles and books from 1809 to 2012. The California Gold Rush list begins with a *Scientific American* article published in 1848 (just six months after the discovery) and continues with 98 more articles through 1998. The South African diamond fields listings are divided into Part 1 (1868–1893) and Part 2 (1893–2014), and include 239 holdings. Access the lists at www.gia.edu/library. *CMS*

What's New provides announcements of instruments, technology, publications, online resources and more. Inclusion in What's New does not imply recommendation or endorsement by Gem-A. Entries were prepared by Carol M. Stockton (CMS) or Brendan M. Laurs (BML), unless otherwise noted.

Gem Notes

COLOURED STONES

Cat's-eye Aquamarine from Meru, Kenya

For more than two decades, small amounts of aquamarine have been mined from granitic pegmatites in central Kenya, mostly in the Embu-Meru (Tharaka) and Isiolo areas (Simonet et al., 2000). According to gem dealer Dudley Blauwet (Dudley Blauwet Gems, Louisville, Colorado, USA), the stones are typically medium to light blue and facetable in modest sizes, with generally small parcels (i.e. <250 g) being sporadically available. The mines are reportedly worked with hand tools (and no explosives), and the gem rough is typically 'frozen' within massive quartz, making it difficult to extract. The rough material is commonly somewhat hazy in appearance.

In August 2016, Blauwet obtained a 'silky' piece of rough aquamarine from the Meru area weighing 4.75 g, and it yielded an 11.09 ct cabochon (Figure 1). The chatoyancy was caused by abundant parallel needles and platelets that were oriented parallel to the c-axis (Figure 2). Raman analysis of these features only yielded spectra for the host beryl. Considering their orientation parallel to the c-axis, they are likely fluid-filled tubes resulting from growth blockages.

Similar inclusions were documented in a cat's-eye aquamarine from Embu, Kenya, by Barot et al. (1995). Its chatoyancy was ascribed to abundant parallel, hair-like tubes (pictured in Figure 4 of their article); they also reported the presence of laminae and platelets of biotite and muscovite. In addition, Barot et al. (1995) mentioned a cat's-eye beryl from the Meru area that displayed 'sea-green' and 'yellowish' pleochroism and contained parallel tubes that contained hematite impurities.

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Figure 1: These aquamarines are from Meru, Kenya. The chatoyant cabochon is 11.09 ct, and the faceted gems weigh 0.81–1.24 ct. Photo by Robison McMurtry, © GIA.

Figure 2: Abundant parallel needles and platelets are the cause of the chatoyancy in the cat's-eye aquamarine. Photomicrograph by N. D. Renfro using oblique fibre-optic illumination, © GIA; image width 2.8 mm.

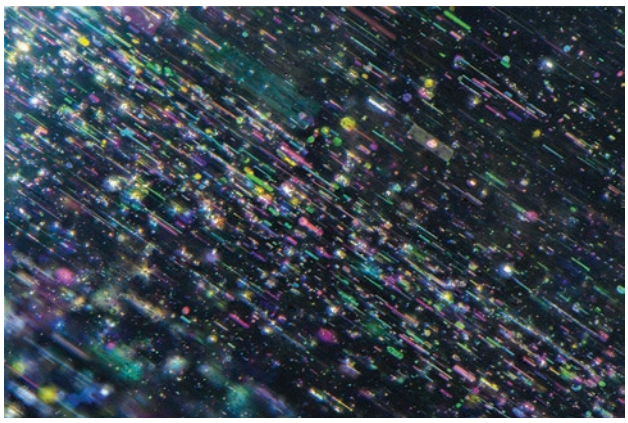

Colour-zoned Green Beryl from Pakistan

During a buying trip to Pakistan in June 2016, gem dealer Dudley Blauwet obtained ~500 g of colourless beryl that showed distinctive green banding from a local miner/dealer. The beryl reportedly came from the Shandu Fangma mine, located on the ridge between Haiderabad and Baha, east of the Braldu River, in the Shigar Valley area of northern Pakistan. The crystals were hosted by a friable mica schist that fell apart when handled. Blauwet retained 25 of the best crystals to sell to mineral collectors, and assembled five parcels of rough material (totalling 297 pieces and weighing 199.5 g) to send to his cutting factory. He instructed the lapidaries to cut the various lots in different styles, including step cuts and elongate matched pairs to accentuate the colour zoning. He also had them facet some radiant emerald cuts to blend the colour zones into a more uniform pale emerald-green colour, and some cabochons to obtain cat's-eye gems from somewhat silky pieces. These latter two efforts did not prove successful, however, since the radiant cuts turned out pale blue with only slight green coloration, and the cabochons did not show chatoyancy. In total, the gems that were returned from the cutting factory totalled 434 pieces weighing 247.18 carats, and ranged from approximately 0.10 to 4.97 ct.

Blauwet loaned three faceted samples (0.83–4.97 ct) to authors CW and BW for examination (Figure 3). All of them were near-colourless with bluish green banding perpendicular to the length of the stones. The RIs were 1.572–1.579 (birefringence 0.007) and the SG was 2.68 (measured on the 4.97 ct stone), consistent with beryl. The samples were inert to standard long- and short-wave UV lamps (i.e. 365 and 254 nm, respectively); however, the bluish green bands did fluoresce moderate pink to 375 nm LED illumination (Figure 4). No reaction was observed with the Chelsea colour filter. The polariscope revealed that the optic axis of all the stones was oriented parallel to their length, and therefore the colour banding was parallel to the basal pinacoid. Viewed with the dichroscope, the green bands showed bluish green and yellowish green pleochroism, while the near-colourless areas appeared very pale blue and yellow.

Microscopic examination revealed growth tubes oriented parallel to the c-axis in all three stones (Figure 5). Some of the tubes appeared flattened with a feathery texture (Figure 5, left). While some tubes were colourless, others were filled with a dark substance; those that were open to the surface of the stones contained polishing residues with a different appearance than the dark matter mentioned above. Most of the growth tubes had abrupt terminations, in some instances where they encountered minute colourless mineral inclusions (Figure 5, right).

Figure 3: These beryls from Pakistan (0.83–4.97 ct) show distinct colour bands oriented parallel to the basal pinacoid. Photo by C. Williams.

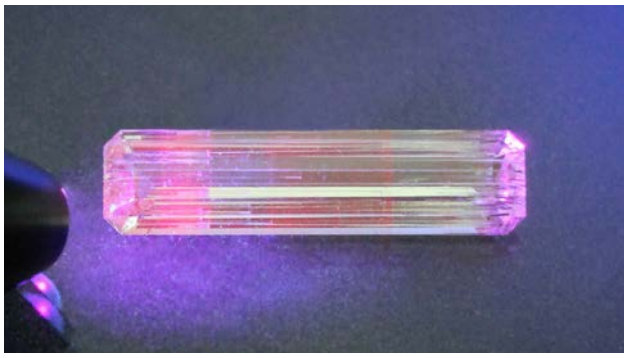

Figure 4: Moderate pink fluorescence is displayed by the bluish green colour bands in the 4.97 ct beryl when illuminated with a 375 nm LED torch. Photo by Dean Brennan.

Energy-dispersive X-ray fluorescence (EDXRF) spectroscopy with an Amptek X123-SDD instrument showed significant Fe, minor Cr and Cs, and a trace of V; relatively higher amounts of these elements were found in the bluish green bands as compared to the near-colourless areas. In addition, standard-based chemical analysis done with scanning electron microscopy-energy dispersive spectroscopy of another sample of this beryl was performed by authors AUF and WBS using a JEOL JSM-6400 instrument with the Iridium Ultra software package by IXRF Systems Inc. The rough sample was ground down slightly and

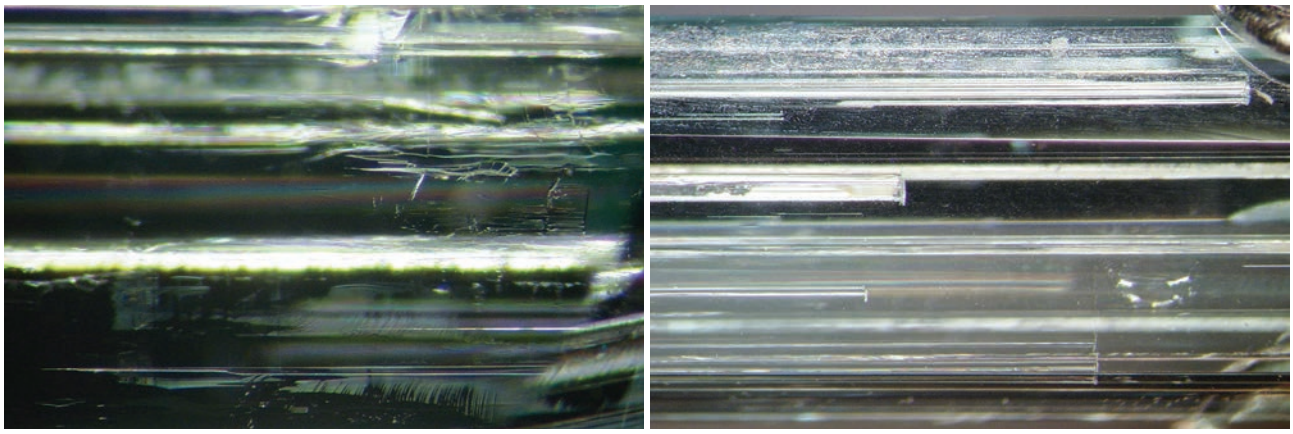

Figure 5: Growth tubes form conspicuous inclusions in the Pakistan beryls. Some of them show a feathery appearance (left, magnified 20×), and the tubes commonly terminate at colourless mineral inclusions (right, magnified 35×). Photomicrographs by C. Williams.

then polished before the analysis. Overall, it contained 0.3–0.6 wt.% FeO, 0.22–0.31 wt.% MgO and 0.14–0.20 wt.% Na_2O. In addition, contents of V_2O_5 ranged from below the detection limit up to 0.02 wt.%, with no relation to colour, whereas Cr_2O_3 was undetectable in the near-colourless areas and up to 0.05 wt.% in the darker green zones.

Blauwet has occasionally encountered limited quantities of this beryl in Pakistan since approximately mid-2011, and it was commonly offered to him as 'emerald'. Its colour banding and growth tubes are similar to those shown by colour-zoned beryl from Torrington and Emmaville in eastern Australia (e.g. Brown, 1998). However, the Australian beryls contained less Fe, and more Cr and V, than the Pakistan stones documented here.

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Coloration of Green Dravite from the Commander Mine, Tanzania

A recent Gem Note by Williams et al. (2017) documented green/brown dravite from the Commander mine, Simanjiro District, north-eastern Tanzania. A crystal fragment that was studied for that report was subsequently analysed further by the present author to investigate the nature of its green coloration.

The green portion of the sample was sliced into a piece measuring 3 mm thick that was slightly darker at the rim and lighter in the interior. The dichroic colours of the rim were very light bluish green (E∥c) and greenish yellow (E⊥c), while the inner region was pale yellow (E∥c) to light yellow (E⊥c).

Visible-near infrared (Vis-NIR) spectroscopy with a silicon-diode array microspectrometer showed absorption bands at ~444 nm (more intense in the E∥c direction) and at ~606 nm (more intense in the E⊥c direction; Figure 6). An overtone of the OH bands occurred at 979 nm in the E∥c direction. These spectra are very similar to those of the V-Cr tourmalines (olenite, uvite and dravite) reported by Ertl et al. (2008). In addition, there is a close resemblance to the spectrum of green dravite from Tanzania (GRR 1719 with V>Cr) available at http://minerals.gps.caltech.edu/manuscripts/2008/V_Olenite/Index.html. The primary difference is the lack of a spin-forbidden

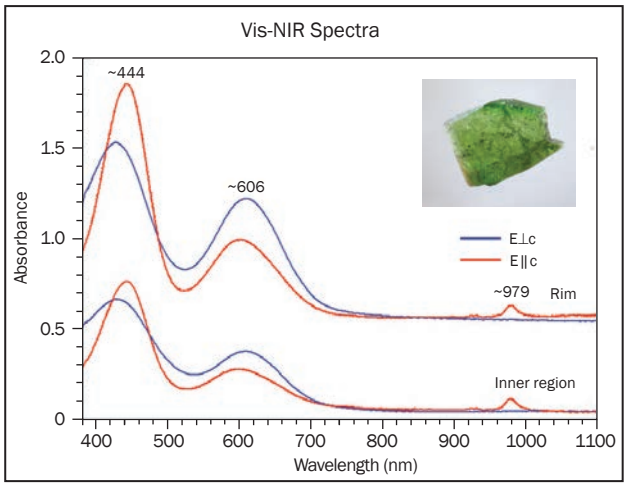

Figure 6: Polarized Vis-NIR spectra of the green dravite recorded absorption bands at ~444 and ~606 nm that are related to vanadium. In addition, an overtone of the OH bands occurred at 979 nm in the E∥c direction. The spectra for the rim are offset vertically for clarity. Inset photo by G. R. Rossman.

chromium band near 700 nm in the Commander mine sample, suggesting a lower Cr content.

This was corroborated by EDXRF chemical analysis using an INAM Expert 3 instrument, which indicated that vanadium is the primary chromophore. The outer darker green rim contained 0.25 wt.% V, 0.044 wt.% Cr and 190 ppm Fe, while the inner, more yellow region had 0.17 wt.% V, 0.036 wt.% Cr and 122 ppm Fe. In addition, both zones contained ~0.40 wt.% Ti.

From Figure 4 in Ertl et al. (2008), the position of the lowest-energy electronic absorption band at 606 nm corresponds to a ratio of V/(V+Cr) of approximately 82% for the darker green rim. This provides good agreement with the EDXRF analyses, which gave V/(V+Cr) ratios of 86% for the rim and 83% for the inner region of the sample. These results clearly indicate that this sample is coloured primarily by vanadium, as is typically the case for 'Cr-tourmaline' from East Africa (Schmetzer and Bank, 1979).

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Enstatite from Emali, Kenya

In September 2014, gem dealer Dudley Blauwet obtained a parcel of rough yellowish green enstatite from an East African supplier. The material reportedly came from the Emali area, located ~160 km northwest of the Taita Hills in southern Kenya. The parcel contained 65 pieces weighing a total of 45.7 g, and some of the stones had a black 'skin' on their surface, which the cutters were instructed to remove before faceting. Due to this, and the irregular shape of the rough, the cutting yield was relatively low: 82 faceted stones weighing a total of 29.4 carats were returned from Blauwet's cutting factory in April 2015. Blauwet loaned the author four faceted samples of this enstatite (Figure 7) for examination.

The stones consisted of one cushion and three oval cuts that weighed 1.18–1.49 ct. The cushion and one of the oval cuts (left two stones in Figure 7) showed saturated colours: respectively a dark strong green and a medium dark, moderately strong, slightly yellowish green. The other two stones were a very dark, slightly greyish, slightly yellowish green; abundant inclusions reduced their transparency.

Figure 7: These enstatites from Emali, Kenya (1.18–1.49 ct), range from a well-saturated green to a dark 'olive' green. Photo by J. C. Zwaan.

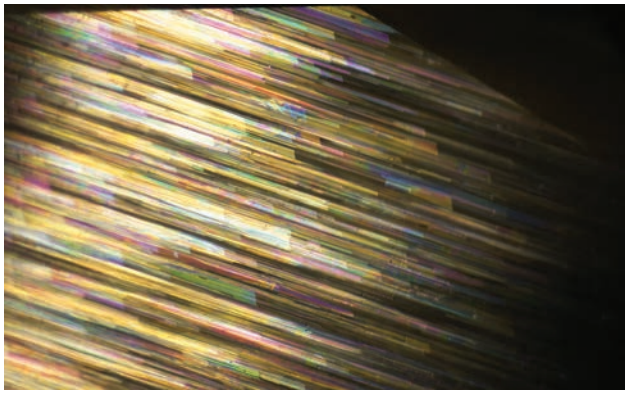

Figure 8: Viewed face-up with the microscope, iridescent colours were seen in one dark enstatite (1.49 ct), related to the presence of dense, parallel needles. Photomicrograph by J. C. Zwaan, oblique fibre-optic lighting; image width 3.7 mm.

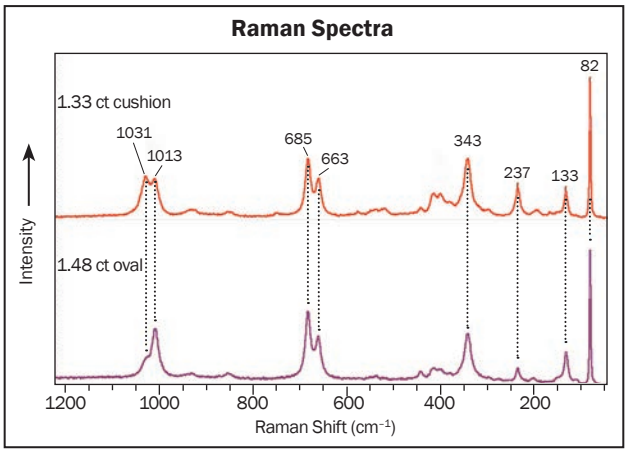

Figure 9: Representative unpolarized spectra taken at random orientations on two of the stones show the diagnostic Raman bands for orthoenstatite at 685 (Si-O-Si bending vibrations), 663 and 82 cm^{-1}, and also demonstrate that the intensity of the Si-O stretching vibrations at wavenumbers greater than 1000 cm^{-1} (here, at 1031 and 1013 cm^{-1}) are sensitive to orientation.

RIs varied from 1.661 to 1.672, yielding birefringence values of 0.008–0.011. The optic character was biaxial positive. Average hydrostatic SG values were 3.26–3.29. Using a calcite dichroscope, green and yellow-green pleochroism was observed in the lighter samples, while the very dark stones showed yellowish green and brown, or green and yellowish brown pleochroism. The prism spectroscope revealed two absorption lines at approximately 505 nm (clearly visible) and 550 nm (weak to very weak) in all four stones. The gems were inert to both long- and short-wave UV radiation.

The described properties are consistent with enstatite. Hypersthene, an orthopyroxene with intermediate composition between the end-members enstatite ($MgSiO_3$) and ferrosilite ($FeSiO_3$), need not be confused with enstatite, because hypersthene is biaxial negative and has higher RI values, between 1.686 and 1.772, with a greater birefringence of 0.015–0.017. It also has a higher SG of around 3.45 (cf. Deer et al., 1992; Dedeyne and Quintens, 2007).

The dark green cushion-shaped stone was relatively clean; it showed subparallel very fine needle-like inclusions or growth tubes, some of which appeared to be filled and thus looked like multiphase inclusions. It also contained a small liquid feather near the girdle. In the yellowish green oval stone, the fine parallel needles locally caused a slight silkiness, while in the very dark stones, the abundance of these needles not only imparted silkiness but also reduced their transparency. In one of those samples, dense parallel needles produced iridescent colours when viewed with oblique fibre-optic illumination (Figure 8).

Chemical analyses were obtained by EDXRF spectroscopy with an EDAX Orbis Micro-XRF Analyzer on the tables of the four stones, using a spot size of 300 µm. Apart from the main elements Mg and Si, the analyses showed 2.6–3.0 wt.% FeO and 0.30–0.57 wt.% CaO.

All four stones showed similar Raman spectra (e.g. Figure 9), which were collected with a Thermo Fisher Scientific DXR Raman microscope using 532 nm laser excitation. The Si-O-Si bending doublet at 685–663 cm^{-1} and the lowest-lying mode at 82 cm^{-1} confirmed the identity of these stones as orthoenstatite, easily distinguished from two other common polymorphs of enstatite: low-clinoenstatite (lowest mode at 118 cm^{-1}) and protoenstatite (high-temperature polymorph with no doublet but a single peak at 673 cm^{-1}; cf. Reynard et al., 2008). The intensities of the Si-O stretching vibrations above 1000 cm^{-1} are sensitive to orientation, while the intensities of the diagnostic peaks at 685 and 663 cm^{-1} are not (Reynard et al., 2008).

Similar yellowish green enstatite from an alluvial deposit in the Mairimba Hill region of southern Kenya, located south of the Taita Hills, was described by Schmetzer and Krupp (1982). However, that enstatite had lower RI (1.652–1.662) and SG (3.23) values, and its colour was attributed to a combination of iron and chromium, whereas no Cr was detected in this Emali enstatite.

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Grossular from Tanga, Tanzania

Grossular—particularly the yellow-orange to brownish orange variety known as hessonite—commonly displays a roiled graining appearance in the microscope called 'treacle' (O'Donoghue, 2006, p. 215). Recently we encountered two examples of slightly brownish yellow grossular that showed this effect, but that also contained other interesting features. Both stones were loaned for examination by gem dealer Dudley Blauwet, who obtained the rough material at the February 2017 Tucson gem shows in Arizona, USA. According to his East African supplier, the two alluvial pebbles came from Tanga, Tanzania. Faceting of the 7.43 and 5.81 g pieces yielded an 11.75 ct cushion cut and a 10.13 ct pear cut (Figure 10).

Figure 10: These grossular gemstones from Tanga, Tanzania, show interesting features resulting from an intense treacle effect (left, 11.75 ct) and from dark green colour patches (right, 10.13 ct). Photo by Robison McMurtry, © GIA.

The larger stone displayed a particularly intense treacle effect (Figure 11), so pronounced that it made the stone appear oily. The treacle appearance was much less pronounced in the smaller stone, which was notable for containing two dark green patches, located on either end of the pear cut. Microscopic examination by author NDR revealed that the green areas were associated with inclusion clusters characterized by transparent, dark coloured, irregular spots that had an RI similar to that of the host garnet (Figure 12). Also present were irregular transparent colourless birefringent crystals with a lower RI

Figure 11: The strong treacle effect displayed by the 11.75 ct grossular is shown here, and is superimposed over the facet pattern of the stone's pavilion. Photomicrograph by N. D. Renfro, © GIA; image width 5.8 mm.

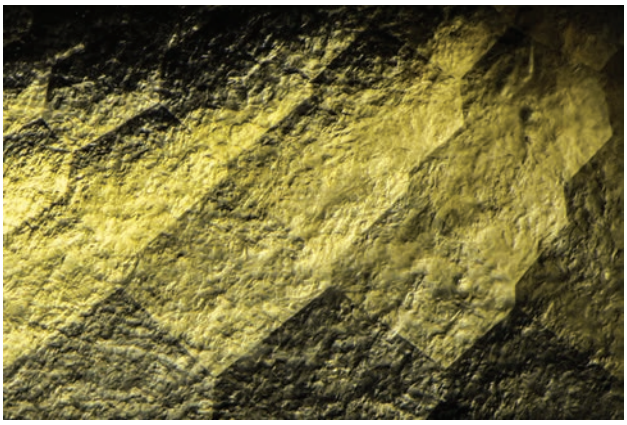

Figure 12: This green colour patch in the 10.13 ct grossular is associated with a cluster of colourless and dark inclusions. Photomicrograph by N. D. Renfro, © GIA; image width 4.1 mm.

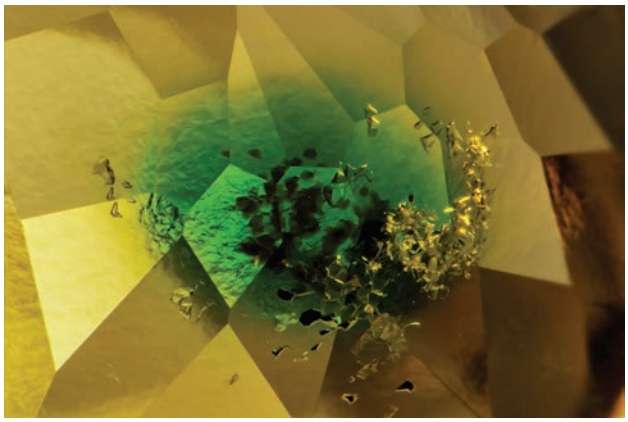

than that of the host garnet. Raman spectroscopy of the inclusions yielded poor-quality spectra that we could not conclusively match with any in our database. The origin of the V and/or Cr that is inferred to have caused the tsavorite-like green patches in this grossular is unknown. The coloration might result from V- and/or Cr-bearing inclusions that subsequently underwent alteration, releasing the chromophores into the surrounding grossular.

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Natrolite from Portugal

Natrolite ($Na_2Al_2Si_3O_{10} \cdot 2H_2O$) is a zeolite mineral with a Mohs hardness of 5–5½ that commonly forms compact radial aggregates of fine needles. Natrolite crystals are rarely thick and transparent enough for faceting, although rare colourless gems weighing up to 8.70 ct have been reported (e.g. Wight, 1996).

At the February 2016 Tucson gem shows, Dr Marco Campos Venuti (Seville, Spain) had cabochons composed of radial aggregates of natrolite from Portugal. In June 2015, he obtained ~2 kg of rough material from Spanish mineral dealer Alberto Ledo Lopez, who reported the source as a basalt quarry near Sintra on Portugal's west coast. Zeolites and other minerals are well-known from quarries in this area (Ináçio Martins, 2013).

Figure 13: These natrolite veins from Portugal (up to 9.7 cm long) have been partially sawn away from their basalt matrix in preparation for cutting. Photo by M. Campos Venuti.

The rough pieces consisted of vein fillings 1–2 cm thick and up to 20–40 cm long (e.g. Figure 13). Campos Venuti cut ~50 cabochons that were oriented perpendicular to the width of the veins, which displayed interesting cellular patterns that were created by the radiating crystal clusters. The cabochons ranged from ~2 to 10 cm in maximum dimension (e.g. Figure 14); smaller pieces did not show enough of the pattern and were discarded. Campos Venuti noted

Figure 14: The cellular pattern in this natrolite cabochon is accentuated after it has been soaked in water for 10 seconds. In addition, its weight has increased from 229.21 to 231.85 ct. Photos by M. Campos Venuti.

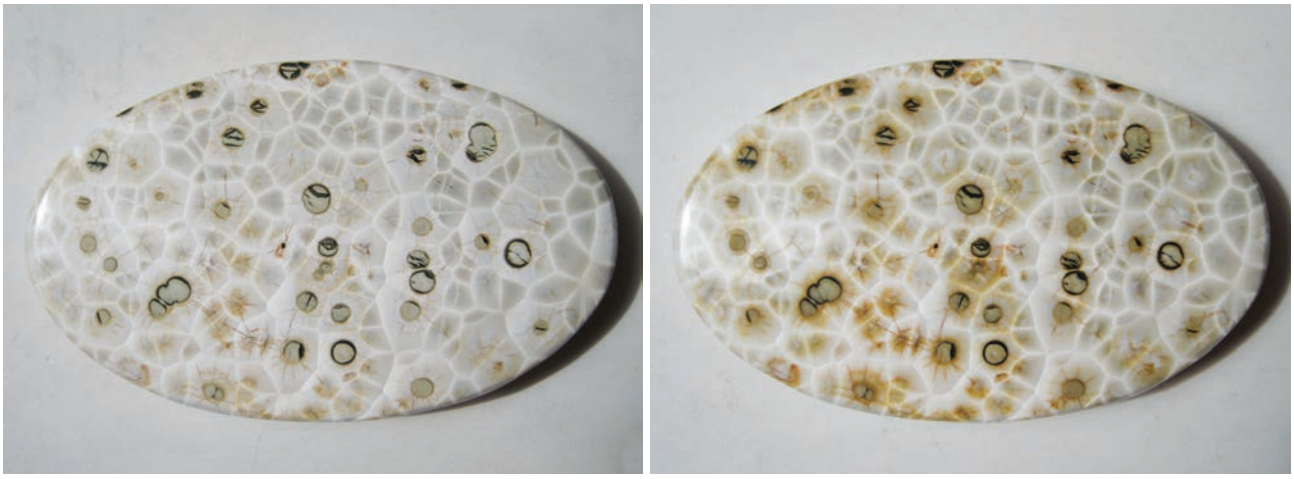

that the pattern becomes darker and more accentuated after the cabochons are soaked in water (again, see Figure 14).

Campos Venuti kindly donated one natrolite cabochon (2.8 × 2.0 cm) to Gem-A. Microscopic examination by one of the authors (NDR) showed distinct colour zoning in some of the radial aggregates (Figure 15), but Raman analysis revealed only the presence of natrolite, regardless of the area that was analysed. This suggests that the darker cores are due to staining, perhaps originating from the adjacent matrix material that was removed before cutting.

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Figure 15: The radial aggregates in this natrolite cabochon (gift of Marco Campos Venuti) contain yellowish brown cores. Photomicrograph by N. Renfro, © GIA; image width 11.05 mm.

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Large Matrix Opal Carving

In April 2017, L. Troy Hatch (Galaxy Gems Brazil, Newcastle, Washington, USA) showed this author a carved matrix opal from Andamooka, Australia, which was significant for its large size (Figure 16). Weighing 8.15 kg and measuring 38.1 cm long and 20.3 cm tall, the piece was carved on both sides and exhibited play-of-colour in red, orange, yellow, green and violet. The intensity of the colours shifted with changes in the viewing angle to the piece. The carving was done over a period of 11 days in March 2017 by Dalan Hargrave (GemStarz Jewelry, Spring Branch, Texas, USA). After the carving process was complete, the piece was 'sugar-treated' and then coated with a thin layer of resin to increase its lustre. Several Chinese-themed motifs are displayed on the piece: two cranes (left side), a penjing tree (centre), butterflies (top), lotus flowers (bottom left), cherry blossoms (upper right), the Great Wall of China (top edge) and

Figure 16: This carved matrix opal from Andamooka, Australia, measures 38.1 cm long and 20.3 cm tall. Photo by B. M. Laurs.

Figure 17: Orange, red and violet play-of-colour mingle with various elements of the carved matrix opal. Photo by B. M. Laurs; image width ~11 cm.

a dragon (back side). Figure 17 shows a closer view of some of the butterfly and cherry blossom motifs.

It is unusual to encounter large pieces of matrix opal that show play-of-colour over a widespread area, and carved pieces of this material commonly range up to just a few centimetres in maximum dimension (e.g. Brown, 1991). The large size and wide distribution of the play-of-colour make this matrix opal carving quite unusual.

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Update on Sapphires from Tigray, Northern Ethiopia

Following the discovery of sapphires in the Chila area of Tigray Province in late 2016 (Laurs, 2017; Vertriest et al., 2017), mining and trading activities in northern Ethiopia are now well underway. In collaboration with Ethiopia's Ministry of Mines, this author visited the sapphire mines and markets in the Tigray region for one week in late May to early June 2017.

Sapphire mining was actively taking place in the region surrounding the town of Chila (Figure 18), which is also a focal point for sapphire trading. The deposits are all alluvial (Figure 19) and extend north of the town of Aksum (or Axum) toward the Eritrean border. The original sapphire discovery occurred near Chila (14°16'23.94"N, 38°38'4.26"E), and a second mining area was subsequently discovered several kilometres west-north-west of Chila (14°19'58.48"N, 38°36'4.86"E). Additional deposits were then found east toward the town of Rama and also to the west of Chila. In June 2017, new finds of higher-quality material were made southeast of Chila toward Aksum University.

According to a geological map published by the Geological Survey of Ethiopia (1999), the region hosting the sapphire deposits is underlain mostly by Neoproterozoic basement rocks. They are locally covered to the south by Paleozoic to Mesozoic sediments as well as Tertiary volcanic rocks—particularly in the Aksum area but also locally around Chila (again, see Figure 18). The Tertiary units consist of stratified basaltic rocks that have been mapped as the Koyetsa Volcanics, as well as the Adwa Trachyte and Phonolite. Their presence as isolated hills in the region indicates that they erupted over a larger area before being eroded (Tadesse, 1999). Since the sapphires have properties consistent with a magmatic origin, it seems likely that these alluvial deposits are associated with the weathering of the Tertiary volcanic rocks of the Aksum area. Geochemically, some of these rocks are correlative with volcanic suites in central and south-eastern Eritrea (Hagos et al., 2010).

As reported previously (Laurs, 2017), only a small proportion of the Tigray sapphires are of gem quality. Their coloration falls within the typical dark-toned blue-yellow-green series that is commonly associated with basaltic-origin sapphires with relatively high Fe content (Figure 20a,b). In addition, a small amount (approximately 5%) of the gem-quality production appears lighter in colour and is therefore inferred to contain relatively less Fe. Such stones display a pleasing intense medium blue colour, and they are keenly sought after by international rough sapphire buyers.

Since the rough material typically has a slightly pale green dichroism, it has to be carefully oriented during faceting to yield the most attractive pure blue coloration. In general, the darker blue sapphires tend to occur in larger sizes, while the lighter ones are smaller (i.e. typically up to 4–5 g). Interestingly, stones from the new 'University Block' area near Aksum often show a desirable

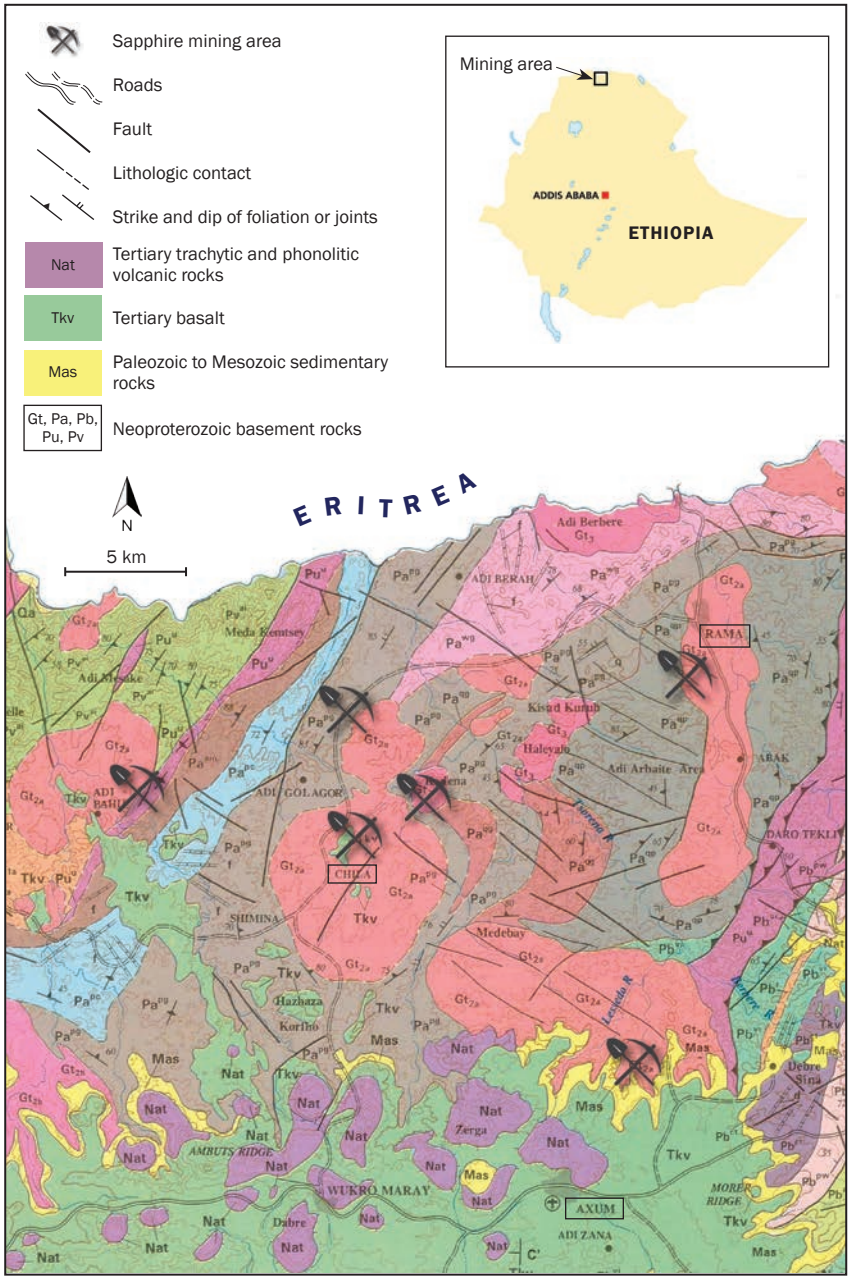

Figure 18: Sapphire mining areas in Tigray Province, northern Ethiopia, are shown on a portion of a geological map produced by the Geological Survey of Ethiopia (1999). Various Neoproterozoic basement rocks (mainly granitoids [Gt], metamorphic rocks [Pa, Pb and Pv] and mafic intrusives [Pu]) are overlain in the southern portion of the map area by Paleozoic to Mesozoic sediments (Mas) and Tertiary volcanic rocks (Tkv and Nat). Boxes surround the names of towns mentioned in the text.

blue colour without the greenish dichroism, and they commonly occur in cleaner pieces than typical Tigray sapphires (Figure 20c).

The heat treatment of Tigray sapphires has met with mixed success. While some of the material can be successfully lightened with high-temperature heat treatment, a portion of the darker material behaves unpredictably, and several treatment facilities in Chanthaburi (Thailand) took considerable financial losses exploring its viability as a commercial product. Generally, those facilities having longstanding experience with basaltic-type sapphires from Australia, Diego Suarez (Madagascar), Shandong (China) and Nigeria are

Figure 19: The sapphires are hosted by alluvial deposits along active or formerly active watercourses. The miners dig shallow pits with simple hand tools. Photo by S. Bruce-Lockhart.

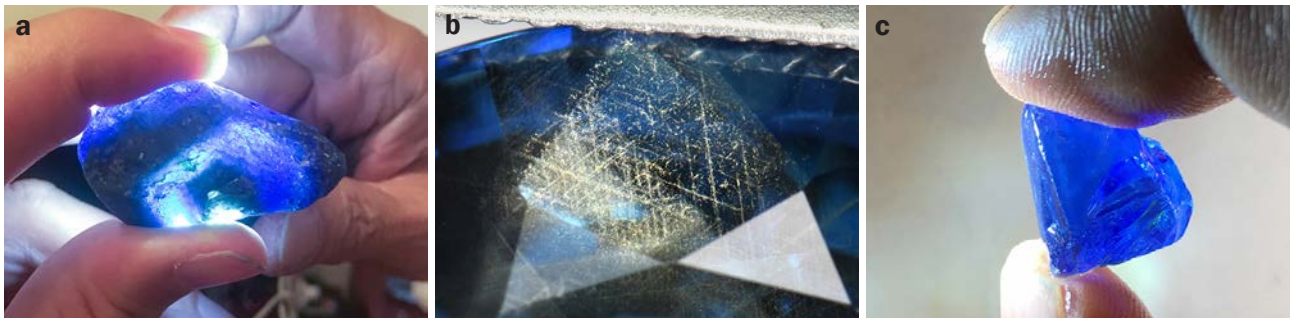

Figure 20: Shown here are some examples of different types of unheated Tigray sapphires: (a) an ~50 g very dark stone that is strongly backlit to show zones containing abundant black silk, (b) a relatively dark 18.56 ct faceted sapphire with 'golden'-coloured silk and (c) a lighter 4.85 g sapphire (which has been oiled) showing the particularly attractive blue colour of fine stones from the 'University Block' area near Aksum. Photos by S. Bruce-Lockhart.

enjoying the most success with Tigray sapphires. The main challenges are avoiding an increase in undesirable greenish coloration during the heating process and removing dense clouds of rutile 'silk'. The Thai heaters have had to deploy specific processes for each of the three types of silk present in these Ethiopian sapphires, which consist of: (1) silk that will disappear with heating; (2) denser silk that can be heated only to produce semi-transparent or opaque star stones; and (3) dark, very dense silk known locally as *MaaHin* (e.g. Figure 20a), which, when heated, will result in valueless, dark, almost opaque corundum. The very dense silk is cut away from the stones before heating to prevent the darkness from spreading into adjacent gem-quality areas.

Unlike other gem rushes in Africa, the Tigray sapphire mines have not received a huge influx of migrant workers from other regions of Ethiopia or other countries. No hastily constructed shanty towns were seen around the mines, as the diggers consist of local farmers who commute to the mines daily from their homes. Labour shortages inevitably lead to production declines when the local population is engaged with agricultural obligations during various times of the year (e.g. most recently during the first half of July).

Figure 21: These stones (~3–10 ct) show the typical colour range of the heated darker blue sapphires from the Tigray region of northern Ethiopia. Photo by S. Bruce-Lockhart.

According to a senior Ministry of Mines official, about 35 kg of sapphires were exported in June 2017. Compared to the official export figure of 0.03 kg for November 2016, this represents a considerable increase. The Tigray sapphires have made their way from Ethiopia to the gem-heating centres of Thailand and Sri Lanka, and from there have entered the global faceted-sapphire markets (Figure 21). Many gem labs have knowingly or unknowingly encountered these sapphires, and their potential as a commercially important gem material is starting to be understood by treaters and lapidaries.

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Gem-quality Whewellite from the Czech Republic

Two mineral species that are suitable for faceting can be found in coal basins of the northwestern Czech Republic. One of them is marcasite, from which rose cuts were made at the beginning of 20th century, mostly for silver jewels. The other is whewellite, a monoclinic calcium oxalate ($CaC_2O_4 \cdot H_2O$) with a Mohs hardness of 2½–3.

The first whewellite samples were discovered in 1897 during excavation work at the Venuše mine in Konobrže, near the city of Most. Grey-white samples in the form of radial aggregates were found in clay layers at 110–120 m depth (Becke, 1898). Significantly better-quality whewellite was recovered after 1899 from the Julius II mine in Kopisty (~2 km from the Venuše mine). Smaller crystals also were found after 1910 in the closed Guttmann mine near Most (Ježek, 1911). A large amount of yellow whewellite, in aggregates or crystals up to 6 mm, was recovered from septarian nodules at the Bílina mine between 1987 and 2000. Most recently, in 1996–2008, whewellite of facetable quality was discovered at the Ležáky mine in Kopisty (e.g. Figure 22). This locality has been mined out and was flooded by a lake during restoration, so no additional production is expected from there in the future.

The gem-quality whewellite was recovered from pelosiderite cavities within septarian nodules that ranged from 20 cm to 1 m in maximum dimension. (Pelosiderite consists of siderite contaminated with an admixture of clay.) The pelosiderite nodules mostly occurred in pelitic sediments near coal banks. Whewellite formed after sedimentation (i.e. during diagenesis), in cracks and cavities where various minerals crystallized from residual fluids, and also within the nodules during the final phases of diagenesis. The crystals are often mistaken for calcite or other carbonates showing irregular crystal growth. The whewellite crystals typically do not exceed 2 cm, although specimens ranging up to 4 cm rarely have been found. Whewellite often forms acicular or radial aggregates (Dvořák et al., 2012), rather than blocky crystals that could be faceted. The presence of dickite reduces the transparency of the crystals and imparts a grey colour. At the Ležáky mine, the crystals are commonly twinned, and this causes problems during faceting. Brittleness also makes faceting difficult.

Thirty faceted specimens of whewellite (0.05–2.21 ct, e.g. Figure 23) from the Ležáky mine were characterized by the author for this report, and the following properties were obtained: colour—colourless to slightly yellow; RI—1.489–1.649; birefringence—0.160; hydrostatic SG—2.21–2.23; fluorescence—intense white to long-wave and very weak whitish to short-wave UV radiation; phosphorescence—white after exposure to long-wave UV; and no absorption features visible with a desk-model spectroscope. Microscopic examination revealed

Figure 22: These two specimens of pale yellow whewellite on dolomite crystals are from the Ležáky mine at Kopisty, near Most, Czech Republic. The crystal on the left is 8 mm wide, and the one on the right is 3 mm in longest dimension. Photos by P. Fuchs.

Figure 23: These faceted whewellites, weighing 0.81 and 0.66 ct (left) and 2.21 ct (right), are also from the Ležáky mine. Photos by R. Hanus.

fractures as well as fluid inclusions along partially healed cleavage planes (Figure 24).

Whewellite has a special position among collector's stones because it was formed by biogenic processes.

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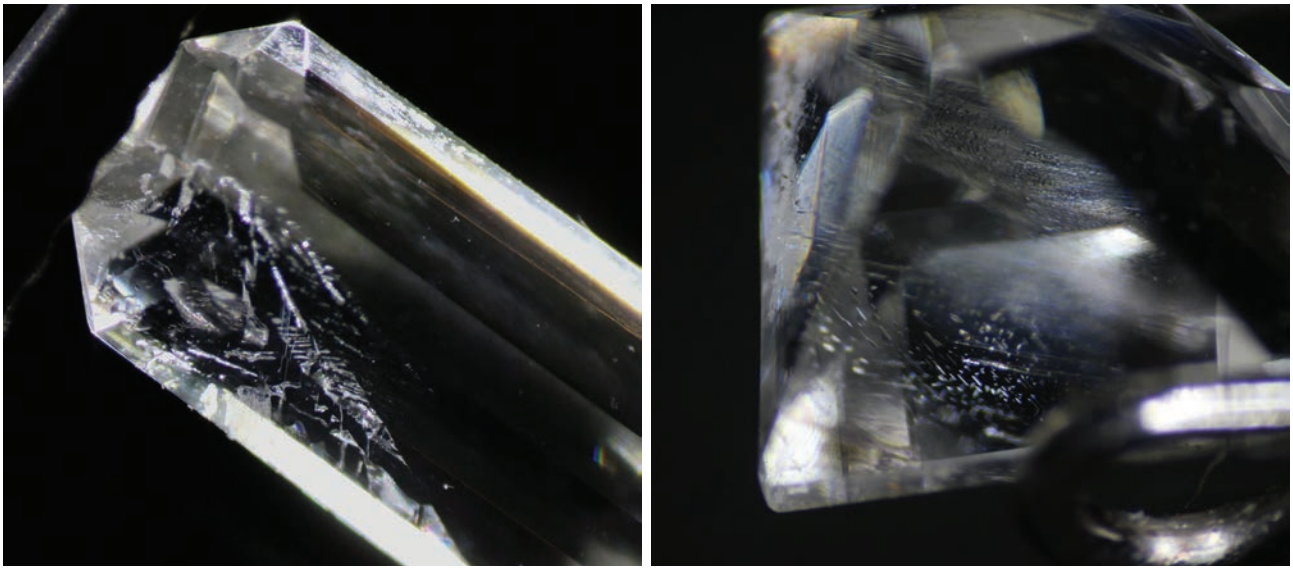

Figure 24: The whewellite on the left contains fractures that demonstrate the material's very good cleavage. The sample on the right contains fluid inclusions along partially healed cleavages. Photomicrographs by R. Hanus; magnified 40× (left) and 20× (right).

INCLUSIONS IN GEMS

Inclusions in Sunstone Feldspar from Norway

Aventurescent feldspar, commonly called *sunstone* in the gem trade, is known from various localities, mainly Tanzania and India (oligoclase with hematite inclusions) and Oregon, USA (labradorite with copper inclusions), although various other occurrences have been reported (O'Donoghue, 2006,

Figure 25: This sawn piece of rough sunstone from Norway (32 × 30 × 23 mm) displays attractive schiller and is bordered by dark layers of biotite-rich gneiss. Photo by Mauro Pantò.

Figure 26: This 0.62 ct sunstone from Norway contains a noticeable cluster of black inclusions that were identified as biotite. Gift of Mauro Pantò; photo by Robison McMurtry, © GIA.

pp. 277–281). Southern Norway may be the first-known sunstone locality (Weibye, 1848), and although deposits in this area have not yielded large quantities of material for the gem trade, the oligoclase sunstone has been extensively characterized mineralogically (e.g. Copley and Gay, 1978, 1979).

Today it is rare to encounter Norwegian sunstone in the gem trade, but during the February 2016 Tucson gem shows, Mauro Pantò (The Beauty in the Rocks, Sassari, Italy) had several cut stones. He reported that the rough material (e.g. Figure 25) came from the original Norwegian sunstone locality (Østerådalen, Østerå, Tvedestrand, Aust-Agder), and about 75% of it displayed schiller. However, the pieces were heavily fractured, so it was difficult to facet large stones without cracks. He cut approximately 15 gems ranging from ~1 to 3 ct each.

Pantò kindly donated one of the faceted sunstones to Gem-A (Figure 26), and microscopic examination by author NDR showed a locally dense network of orange platy inclusions (Figure 27). As expected, Raman analysis identified these platelets as hematite. In addition, a group of conspicuous dark inclusions in the stone were identified as biotite. The presence of biotite in this sunstone is not surprising, since the rough material is associated with a biotite-bearing gneissic host rock that commonly envelops the sunstone (again, see Figure 25).

Figure 27: The interior of the 0.62 ct Norwegian sunstone is dominated by an oriented network of hematite inclusions. Photomicrograph by N. D. Renfro using oblique fibre-optic illumination, © GIA; image width 3.8 mm.

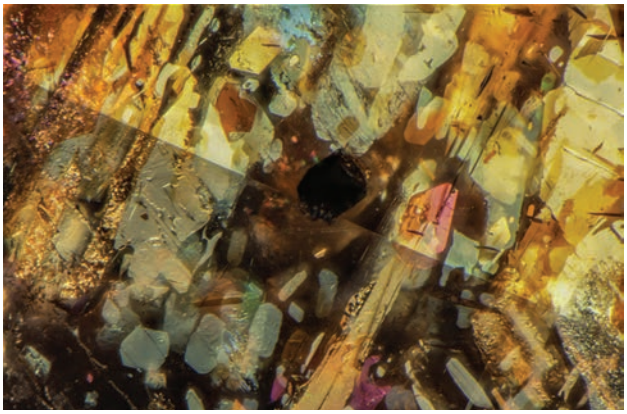

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Nathan D. Renfro FGA

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Quartz with Outstanding Black Tourmaline 'Pinwheel' Inclusion

Although inclusions in transparent gemstones are generally avoided, some of them are highly prized due to their attractive appearance or interesting nature (e.g. insects in amber, 'horsetail' inclusions in demantoid, etc.).

Inclusions of black tourmaline (schorl) in quartz are commonly encountered as aggregates of needles (e.g. Gübelin and Koivula, 2005, pp. 639–640). Rough material containing a single isolated needle of tourmaline (or another conspicuous acicular inclusion) may be carefully faceted with the inclusion extending from the culet to the centre of the table, so that when viewed face-up, the stone displays multiple reflections of the inclusion that create a spoke-like appearance (e.g. Koivula, 1986; Gübelin and Koivula, 2005, p. 549; and www.palagems.com/inclusions). Such gems are commonly referred to as having a 'pinwheel' or 'wagon-wheel' appearance.

An excellent example of this phenomenon is shown by the 50.55 ct rock crystal quartz from Madagascar in Figure 28. The stone measures 22.6 mm in diameter and has a total height of 19.6 mm; it contains a single needle of black tourmaline that is reflected with 12-fold rotational symmetry. The gem was faceted to have three steps of crown fac-

Figure 28: The 50.55 ct 'Time Quartz', cut by Y. Guazzini and from the collection of P. Entremont, contains a single black tourmaline needle that is perfectly oriented perpendicularly from the centre of the table to the culet, so that it reflects uniformly in the gemstone with 12-fold rotational symmetry. The photos show the stone from the side (a), obliquely from the top (b), directly from the top (c) and from the back (d). Photos by T. N. Bui.

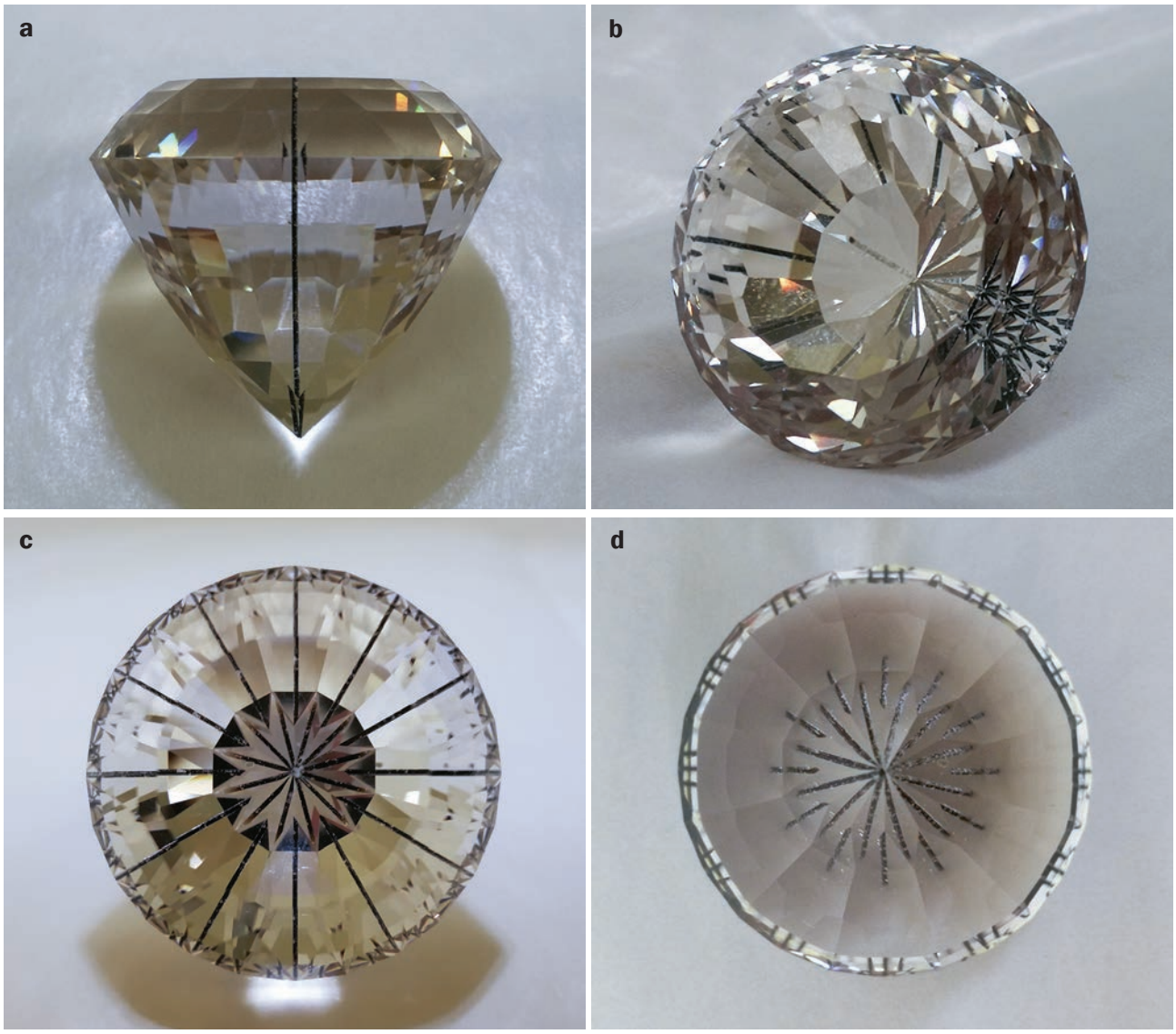

ets consisting of one row of 12 mains and two rows of 24 break facets near the girdle (which is also faceted). The pavilion has three steps composed of 12 main facets, 12 star facets and 24 break facets at the girdle. In total, there are 157 facets. The gem is referred to by its owner (author PE) as 'Time Quartz', in reference to the 12-fold symmetry of the reflection pattern.

When the stone is viewed face-up (Figure 28c), the schorl reflections appear discontinuous from the centre to the girdle due to the positioning of the pavilion star facets, which are angularly shifted from all the main facets by 15°. The outer reflections of the schorl extending to the girdle are created by the crown and pavilion mains that are cut in the three rows. The gradual step angles forming the main facets in the crown and pavilion induce an overlap of the schorl reflections, resulting in the appearance that each 'needle' is continuous along its length. The triple duplication of the culet seen through the crown when the stone is viewed obliquely (Figure 28b) confirms this assertion.

When the gemstone is observed through the pavilion, the tourmaline needle is reflected only by the pavilion star facets and the first two rows of the pavilion mains (Figure 28d). The end of the reflected schorl, located at the second row of the pavilion mains, corresponds physically to the needle's intersection with the table. The discontinuous reflected image of the schorl is then virtually 'compressed' by the quartz medium.

Creating such a pinwheel appearance in gemstones is not limited to schorl in quartz, but the black colour of the inclusion does offer good contrast against the colourless quartz. This 'Time Quartz' gemstone is a demonstration of the high cutting skill achievable by lapidaries. Such pieces will likely remain uncommon, not only because of the cutting expertise needed to produce them, but also due to the rarity of finding suitable rough material (i.e. a large clean piece of transparent quartz containing only one isolated acicular schorl crystal), since tourmalinated quartz generally hosts aggregates of such needles, as well as other inclusions and fractures.

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Illuminating Different Sets of Acicular Inclusions in 12-rayed Star Sapphires

Star sapphires with 12 rays are somewhat rare or very rare in most of the world's known deposits (Hughes, 2017, Chapter 12). Asterism in corundum (and in other minerals) is caused by the presence of oriented acicular inclusions. If one type of needle exists in one crystallographic direction in the basal pinacoid, it also will be found in the other two equivalent directions due to the ternary axial symmetry of the host corundum, leading to a six-rayed star. When observing the regularly spaced arms forming a 12-rayed star, one must conclude that this appearance is due to the presence of two sets of needles angularly rotated by 30° to one another. The authors' recent research (see below) has focused on whether these inclusions are of the same or a different nature.

What is already known about acicular inclusions in natural star sapphires? As early as 1878, Tschermak suggested that rutile was responsible for the asterism. In 1982, Sahama confirmed this. But rutile is not the only mineral that can form acicular inclusions in sapphire. In black star sapphires from Thailand, Weibel and Wessicken (1981) found the presence of hematite, but Saminpanya (2001) leant rather toward a phase of the hematite-ilmenite series. In 'Gold Sheen' sapphires from Kenya, Bui et al. (2015) identified the acicular inclusions as an intergrowth of hematite and ilmenite. In a 12-rayed black star sapphire from Ban Kha Cha, Thailand, Schmetzer and Glas (2001) noted a colour difference in the two stars turned by 30°, one bluish white due to rutile inclusions and the other 'golden' yellow due to an undetermined phase close to hematite. In similar Thai sapphires, Bui et al. (2017b) showed that rutile also might cause the six-rayed star in

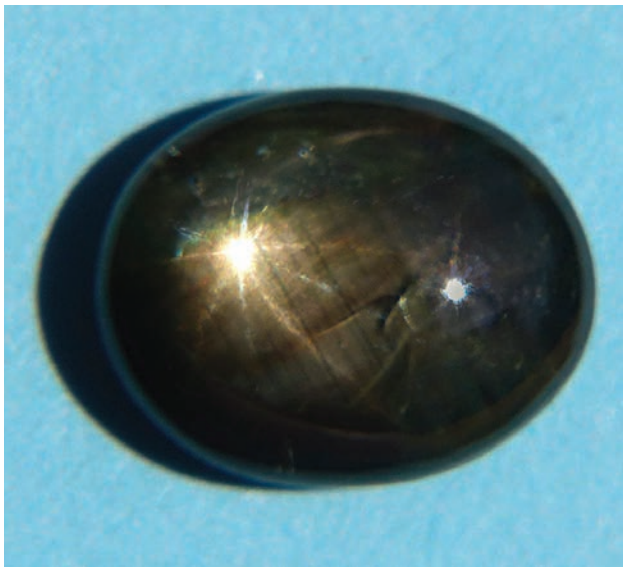

Figure 29: This 1.60 ct black star sapphire from Ban Kha Cha, Thailand, displays 12-rayed asterism and was studied for this report. Photo by J.-P. Gauthier.

one domain, whereas adjacent needles could be of the hematite-ilmenite series, yielding another six-rayed star turned by 30°. In a 12-rayed star sapphire from Sri Lanka, Bui et al. (2017a) identified both domains of acicular inclusions as ilmenite. Pearson (1990) analysed a 12-rayed Australian sapphire and found two kinds of needles: rutile and a 'ferrilmenite'-type phase.

We recently examined a few dozen 12-rayed black star sapphires from Ban Kha Cha (e.g. Figure 29) with an optical microscope at relatively high magnification (initially around 250×). Although they all displayed 12-rayed asterism, we could observe only three sets of opaque, relatively short needles perpendicular to growth zones, and these are inferred to be of the hematite-ilmenite type owing to their orientation, 'golden' brown colour and shortness compared to rutile needles (Figure 30a). Rutile inclusions seemed to be absent, un-

Figure 30: The sapphire in Figure 29 displays various acicular inclusions, as shown in these four images of the same area within the sample. (a) Transmitted lighting reveals only the opaque inclusions of hematite-ilmenite. (b,c,d) Reflected lighting oriented tangential to the surface of the cabochon in different directions shows three sets of rutile inclusions that are illuminated in succession. The arrows point to each set of rutile inclusions and show the lighting directions used to illuminate them. Photomicrographs by J.-P. Gauthier.

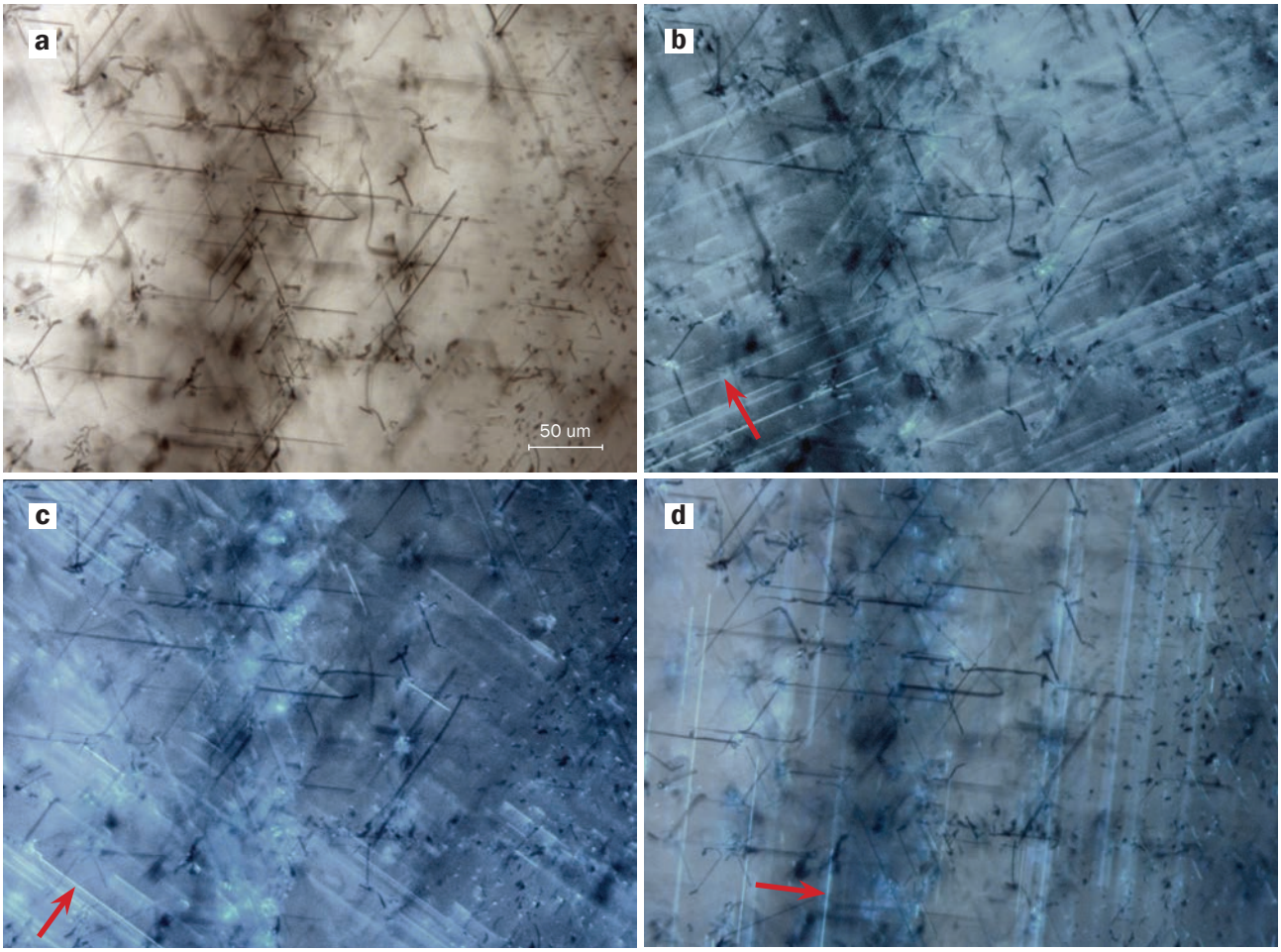

like in other star sapphires, such as those from Sri Lanka (Gübelin and Koivula, 2008a, p. 350 and 2008b, p. 287) or Myanmar (Hughes, 2017, p. 182), in which the rutile needles are visible within the range of magnification typically used in gemmology. In the present stones, it turns out that due to the transparency of the rutile needles in the corundum matrix and their very narrow dimension, they were not visible with our setup using transmitted lighting. We therefore tried different illumination directions, although we could not light the sample from directly overhead because the microscope objective was positioned too close to the cabochon. Instead, we used a penlight to provide reflected illumination tangentially. Thus, by orienting the light beam from various oblique directions, different sets of rutile needles were successively revealed. When directing the lamp parallel to one set of hematite-ilmenite needles, only the rutile needles perpendicular to this set were visible (Figure 30b). By changing the light azimuth by 120° and 240°, the second and third sets of rutile needles were illuminated in succession (Figure 30c,d).

Optical microscopy at higher magnification (500×; not pictured) revealed that the diameter of the rutile needles was approximately 1 µm, while that of the hematite-ilmenite needles was two to three times broader. Thus the diameter of the highlighted rutile inclusions was of the same order of magnitude as the hematite-ilmenite needles, but they were much longer (by several times). Because of the low density of the rutile inclusions, the branches of the star they caused were much less intense than those due to hematite-ilmenite.

This selective lighting method, previously used on an unusual six-rayed blue star sapphire from Tanzania (Entremont et al., 2016), is here shown to be particularly valuable for distinguishing both types of inclusions in 12-rayed star sapphires.

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Topaz from Sri Lanka with an Interesting Inclusion

Topaz may host a variety of interesting internal features, but recently these authors encountered an unusual inclusion that we believe was unlike those reported previously. The 4.79 ct very light brown topaz was purchased in July 2015 by gem dealer Dudley Blauwet in the local market at Ratnapura, Sri Lanka. It was reportedly cut from rough material found in Sri Lanka, and it contained a rather large pyramid-shaped inclusion that was readily visible through the table of the stone (Figure 31). Closer

Figure 31: This 4.79 ct topaz from Sri Lanka contains a pyramid-shaped inclusion under the table that was identified as fluorite. Photo by Robison McMurtry, © GIA.

examination showed that the inclusion formed a half-octahedron and was locally surrounded by narrow tension fractures (Figure 32). Raman analysis by author NDR identified the inclusion as fluorite.

Fluorite inclusions are well-known in topaz, particularly from Nigeria, in which they typically show various forms such as the cube and octahedron or a combination of these and/or the rhombic dodecahedron (Hornytzkyj, 1982). In the present case, it appears that only half of the fluorite octahedron crystallized.

Brendan M. Laurs FGA and Nathan D. Renfro FGA

Reference

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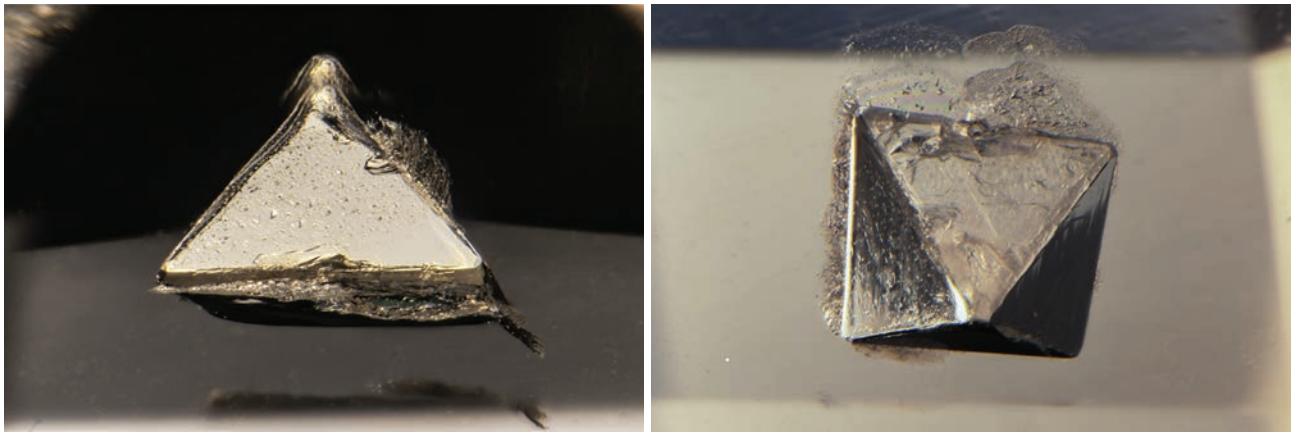

Figure 32: Two views of the fluorite inclusion reveal its pyramidal or half-octahedron shape. The inclusion is surrounded in places by small tension fractures. Photomicrographs by N. D. Renfro, © GIA; image width 3.0 mm (left) and 3.8 mm (right).

PEARLS

Black Non-Nacreous Natural Pearls from *Pteria* sp.

The Bahrain Institute for Pearls & Gemstones (DANAT), Manama, recently received a 5.70 ct black pearl (9.49–9.51 × 8.75 mm) and an 11.84 ct black and brown pearl (13.63–13.71 × 9.55 mm), both of button shape (Figure 33). Viewed with the microscope, the samples showed hexagonal-like cellular patterns linked with calcite columnar structures, similar to those observed on non-nacreous pearls of similar colour (Sturman et al., 2014). The brown part of the larger sample showed a nacreous appearance. EDXRF chemical spectroscopy revealed Sr/Mn>>12, characteristic of saltwater pearls.

Digital X-microradiographs of the samples in three orientations, taken perpendicular to one another, are shown in Figure 34. Lighter tones indicate materials with higher density such as calcium carbonate, and darker tones represent lower-density materials such as organic matter or cracks. Both samples presented radial structures, as well as concentric structures pronounced toward the rim and a darker centre (mainly observed in the larger sample; see middle and right radiographs at the bottom row of Figure 34), characteristic of natural pearls. The fully non-

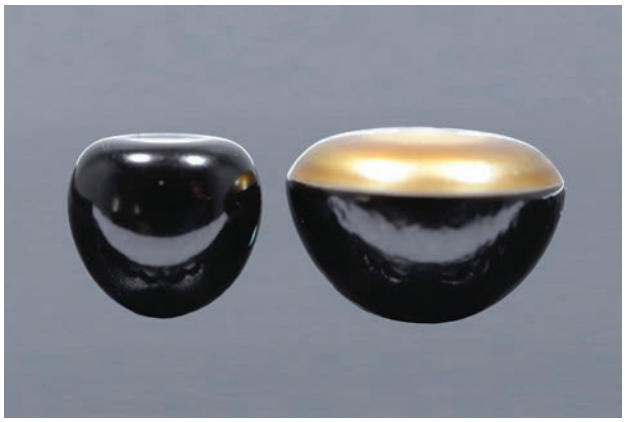

Figure 33: A 5.70 ct black pearl (left; 9.49–9.51 × 8.75 mm) and a 11.84 ct black and brown pearl (right; 13.63–13.71 × 9.55 mm) were recently examined at DANAT. Both pearls are of button shape, with the one on the left being non-nacreous and the one on the right showing areas that are non-nacreous (black part) and nacreous (brown part). Photo by H. Abdulla, © DANAT.

nacreous pearl also showed some cracks, mainly visible in the radiograph taken along the longest dimension (Figure 34a). Small cracks also were visible in the centre of the other sample (Figure 34d). It is worth noting that cracks in non-nacreous calcitic pearls are commonly observed along their columnar structures.

Under long-wave UV radiation (365 nm, 6 watt), both samples exhibited orangey red fluorescence (Figure 35), similar to that observed in pearls from *Pteria* sp. (Kiefert et al., 2004). Under short-wave UV radiation (254 nm, 6 watt), both samples luminesced a very weak yellowish green. A similar fluorescence reaction, which is linked with a kind of porphyrin, was observed for a partially non-nacreous and nacreous pearl from a *Pteria penguin* bivalve when viewed with the microscope using 300–410 nm excitation (Hainschwang et al., 2013). A porphyrin-type pigment also has been identified in natural and cultured pearls from other molluscs (e.g. *Pinctada margaritifera*); however, samples from *Pteria* sp. present orange-red fluorescence to long-wave UV. Thus, even though black-coloured non-nacreous pearls are found in different molluscs (e.g. from the Pinnidae family, also known as pen shells, which commonly show chalky yellow fluorescence to long-wave UV; Sturman et al., 2014), the fluorescence of these two samples leads us to the conclusion that they originated from *Pteria* sp.

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Figure 34: Digital X-radiographs are shown in three different directions for the 5.70 ct sample (top row) and the 11.84 ct sample (bottom row). The contrast has been adjusted to reveal features that the authors consider most insightful. Depending on the contrast used, the X-radiographs showed subtle features characteristic of natural pearls, including radial and concentric structures with a darker centre (note that these features may only be visible in the original hardcopy of this issue, and not in the PDF version).

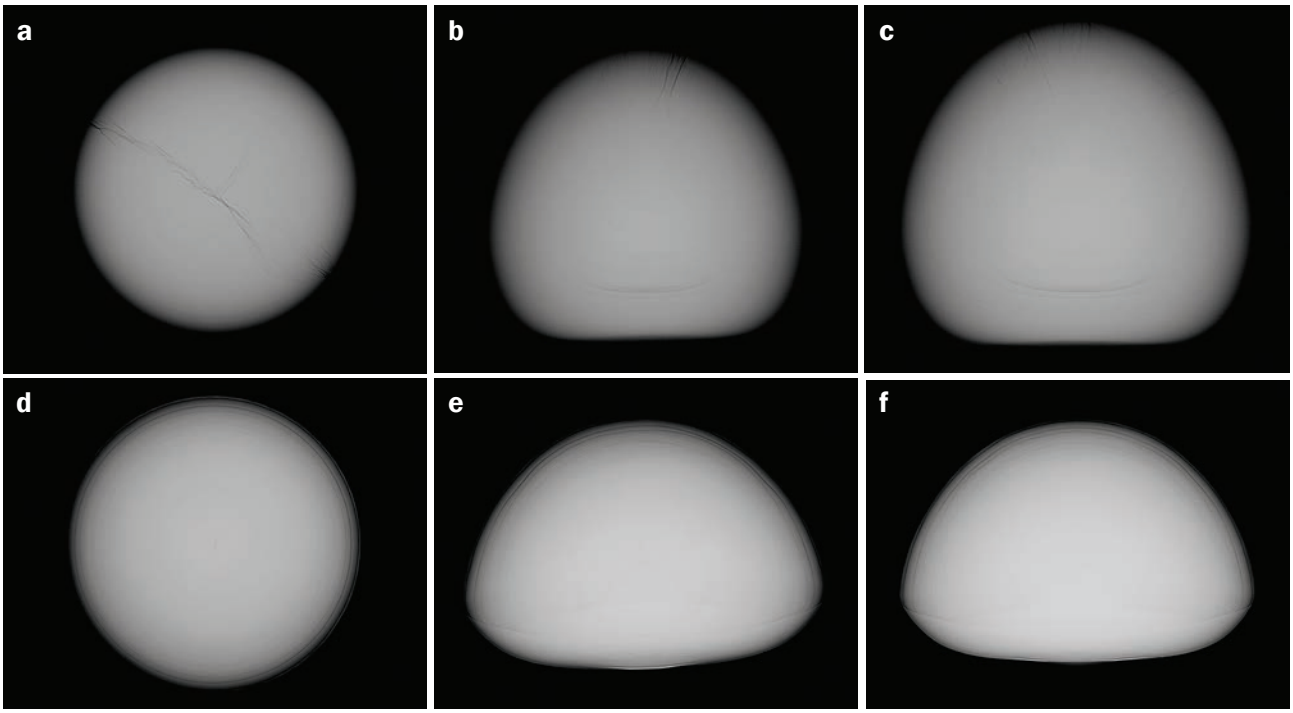

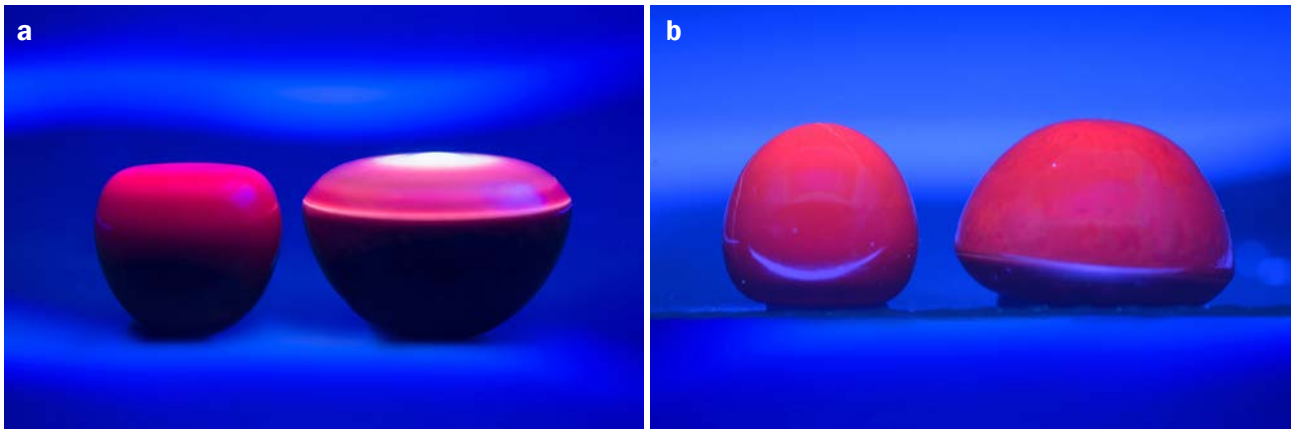

Figure 35: The samples show orangey red luminescence to long-wave UV radiation, on both their top and bottom sides, as is characteristic of pearls from Pteria *sp. Photos by H. Abdulla, © DANAT.*

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SYNTHETICS AND SIMULANTS

Pink Synthetic Spinel with an Unusually Large Negative Crystal

Recently, a pink octagonal step cut weighing 12.56 ct (Figure 36) was submitted for identification to the Gem Testing Laboratory, Jaipur, which drew attention for various reasons. First, it had an unusually large elongated tubular inclusion; second, this elongated inclusion contained a bend; and third, it hosted a group of parallel 'bomb-shaped' gas bubbles—all visible to the unaided eye. Since bomb-shaped gas bubbles are typically associated with synthetic gems grown by the flame-fusion process (e.g. Gübelin and Koivula, 1997, pp. 476–477, 501, 515), their presence, along with the large bent elongated tubular inclusion, also with different orientation, was intriguing.

Figure 36: This 12.56 ct pink flame-fusion synthetic spinel coloured by iron is unusual for its large bent tubular inclusion (negative crystal/bubble), which is visible to the unaided eye in the lower right here. Also note the group of parallel 'bomb-shaped' gas bubbles in the upper portion of the gem, which are oriented in a different direction than the large inclusion. Photo by G. Choudhary.

The large elongated inclusion also appeared to be a bomb-shaped gas bubble or a negative crystal (terms used interchangeably in synthetics; again see, e.g., Gübelin and Koivula, 1997, p. 515). It displayed complex growth consisting of several sections: a main tubular body, a tail, a pseudo-hexagonal head and a pyramidal top (Figure 37). Pseudo-hexagonal negative crystals in flame-fusion synthetics have been reported by the above-mentioned authors as well as by Kiefert (2003). The head and its top were bent at ap-

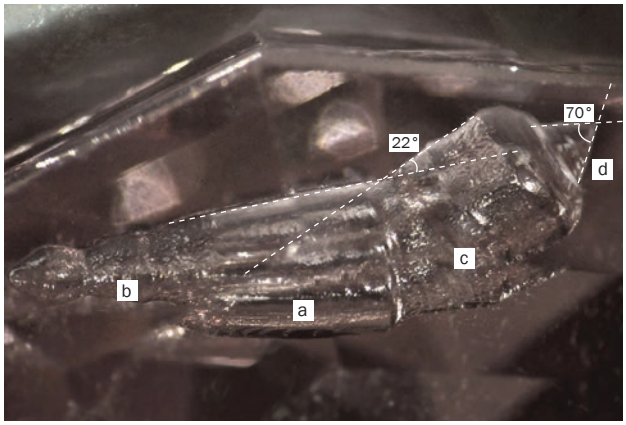

Figure 37: The large negative crystal or bomb-shaped bubble has a complex growth structure consisting of a main tubular body (a), a tail (b), a pseudo-hexagonal head (c) and a pyramidal top (d). As suggested by the interfacial angle of ~70°, the faces of the pyramidal top appear to be following octahedral directions. Photomicrograph by G. Choudhary; image width 8.0 mm.

proximately 22° from the main tubular section, while the faces of the pyramidal top intersected at approximately 70°; all these sections displayed different patterns of growth markings, controlled by the growth and symmetry of the host crystal. The main tubular body displayed striations or growth planes in two directions (Figure 38, left), giving the impression of pyramidal faces, intersecting each other at approximately 70°/110°. The pseudo-hexagonal head displayed a highly complex pattern of striations that could not be resolved properly, while the pyramidal top displayed triangular features suggesting three-fold symmetry, such as that associated with octahedral and rhombohedral faces (Figure 38, right).

Standard gemmological testing revealed a single RI value of ~1.727 and a hydrostatic SG of 3.57. Between crossed polarizers, strong anomalous birefringence (strain) was visible. Weak absorption features were seen in the blue-green and yellow-orange regions with a desk-model spectroscope, and the sample was inert to long- and short-wave UV radiation. The RI value and strong anomalous birefringence suggest synthetic spinel, although the SG value was relatively low (possibly due to the presence of the large negative crystal). Further, as compared to typical pink spinel coloured by chromium (in our reference collection as well as given in the literature, e.g. O'Donoghue, 2006, pp. 171–172), this specimen displayed neither any UV reaction nor Cr-related absorption lines in the desk-model spectroscope. Interestingly, qualitative EDXRF chemical analysis revealed traces of only Fe; no V, Cr, Co, Zn or Ga was detected. The ultraviolet-visible absorption spectrum displayed a broad band at ~553 nm with an associated weak shoulder

Figure 38: The main tubular body displays growth striations or planes in two directions, giving the impression of pyramidal faces intersecting each other at approximately 70°/110° (left). However, the angle also suggests their alignment with octahedral faces. The pyramidal top shows triangular features or hillocks (right), as commonly seen on octahedral faces of natural spinel. Photomicrographs by G. Choudhary; image width 4.6 mm for each.

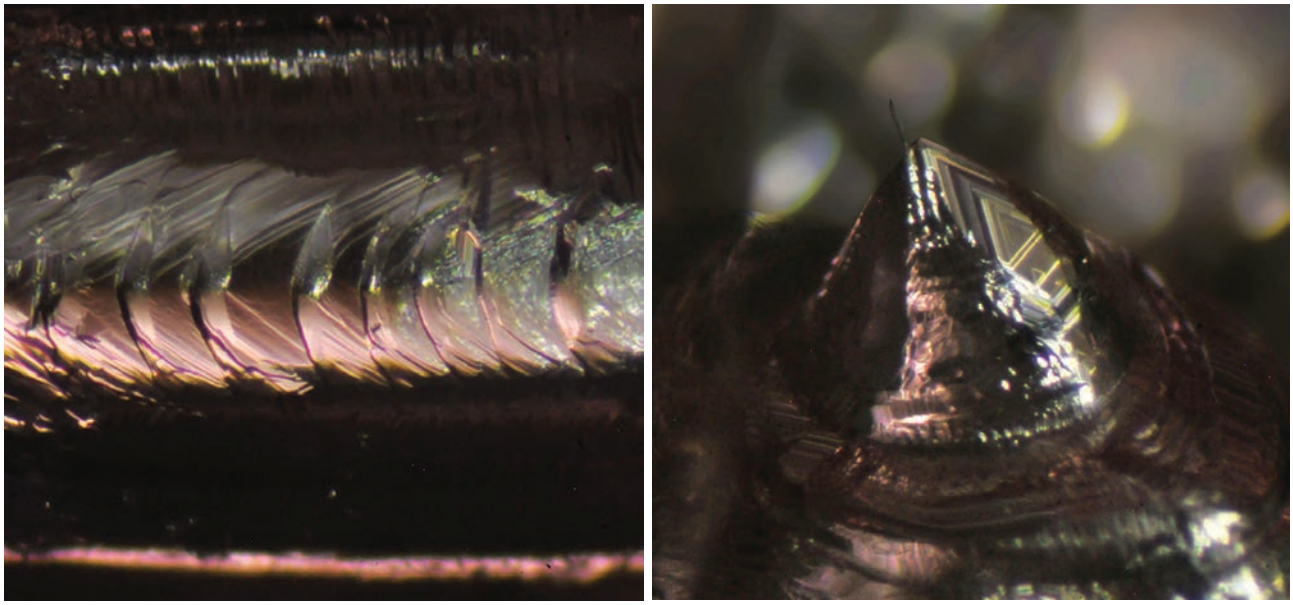

at 525 nm; weak absorptions at ~442, 473 and 615 nm; and a cut-off at 400 nm. The overall properties are consistent with those reported by Krzemnicki and Lefèvre (2007) for a pink flame-fusion synthetic spinel coloured by iron.

This is the first time that our laboratory has encountered such a synthetic spinel. We could not find any reports of a synthetic gem containing negative crystals or bomb-shaped gas bubbles that display a bend or a series of complex growth markings. The growth markings on the main tubular inclusion can be related to the octahedral faces, as the angle of their intersection, as well as that of the faces of the 'pyramidal' top, is approximately 70°, which is quite close to that of the interfacial angle of octahedral faces at 70°31'44" (e.g. Ford, 2005). While the bend appears to have formed as a result of disturbances during growth, determining its exact cause would just be speculation at this stage. Any insights on this from the readers are welcome.

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TREATMENTS

Filled Phosphosiderite

Recently 13 pendants of purple 'jade' (Figure 39) were submitted to the National Gemstone Testing Center Laboratory in Beijing, China. The samples' spot RIs (ranging from 1.69 to 1.71), SG (approximately 2.76), and infrared and Raman spectra confirmed their identity as phosphosiderite, $FePO_4 \cdot 2H_2O$ (Wang et al., 1987; Pei et al., 2012).

The samples were observed using Gemolite microscopes with magnifications ranging up to 40× and with various illuminations. With diffused light and a fibre-optic illuminator, we could see white spots on the surfaces of all the samples. Brightfield lighting showed the samples' coarse granular texture. With reflected lighting, the cracks and pits on the surfaces of 11 of the samples were seen to be filled with a material that obviously had a different lustre than the phosphosiderite; the other two samples did not show this characteristic.

Diffuse-reflectance Fourier-transform infrared (FTIR) spectroscopy of all samples was performed with a Nicolet 6700 spectrometer in the 4000–400 cm^{-1} range, at a resolution of 4.0 cm^{-1} and 32 scans. We applied a Kramers-Kronig transformation to remove distortions in the spectra (Zhang, 2006, pp. 120–121). In addition to identifying the samples as phosphosiderite (Wen, 1989), the FTIR spectra of the suspected filled samples showed a line at 1510 cm^{-1} (Figure 40a). Significantly, 1510 cm^{-1} is the major band of epoxy resin (González et al., 2012). To confirm that these samples had been filled with artificial resin, we carried out more detailed testing. With the client's permission, a minute amount of powder was scraped from each sample, and attenuated total reflectance (ATR) infrared spectroscopy showed a result consistent

Figure 39: These 13 samples of purple 'jade' (from 14 x 13 mm to 31 x 14 mm) were found to be phosphosiderite. All but two of them (at the lower right) were filled with an epoxy resin. Photo by X. Feng.

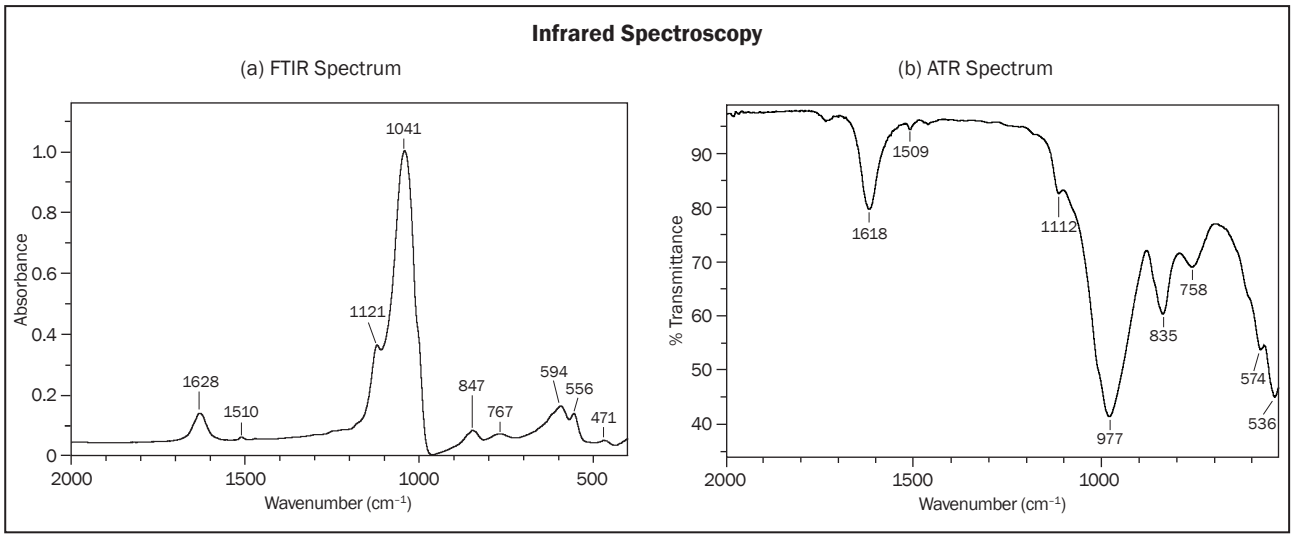

Figure 40: (a) FTIR spectroscopy (after Kramers-Kronig transformation) of the purple 'jade' pendants revealed features typical of phosphosiderite, plus a line at 1510 cm^{-1} in the filled samples that is indicative of epoxy resin. (b) ATR spectroscopy confirmed the FTIR results, including the epoxy resin feature at 1509 cm^{-1} in the filled samples.

with the diffuse-reflectance FTIR spectra: While all the samples had the characteristic bands of phosphosiderite, the filled ones had an extra line at 1509 cm^{-1} (Figure 40b).

Raman spectra of all samples were obtained at liquid-nitrogen temperature using a Renishaw In-Via Reflex laser Raman spectrometer with 532 nm excitation in the range 4000–400 cm^{-1} (at a resolution of 2.0 cm^{-1} and one scan). As expected, the main Raman peaks (1004, 984, 846, 489 and 456 cm^{-1}) confirmed that the purple 'jade' was phosphosiderite (Xi et al., 1984). The filled samples had several additional peaks at 3068, 1608, 1184 and 1110 cm^{-1} (Figure 41) that are mainly attributed to epoxy resin (Yu et al., 2004).

On the basis of microscopic observation combined with infrared and Raman spectroscopy, we concluded that 11 of the phosphosiderite samples were filled, while two of them were untreated. Although phosphosiderite is relatively common on the Chinese market today, filled phosphosiderite is much rarer.

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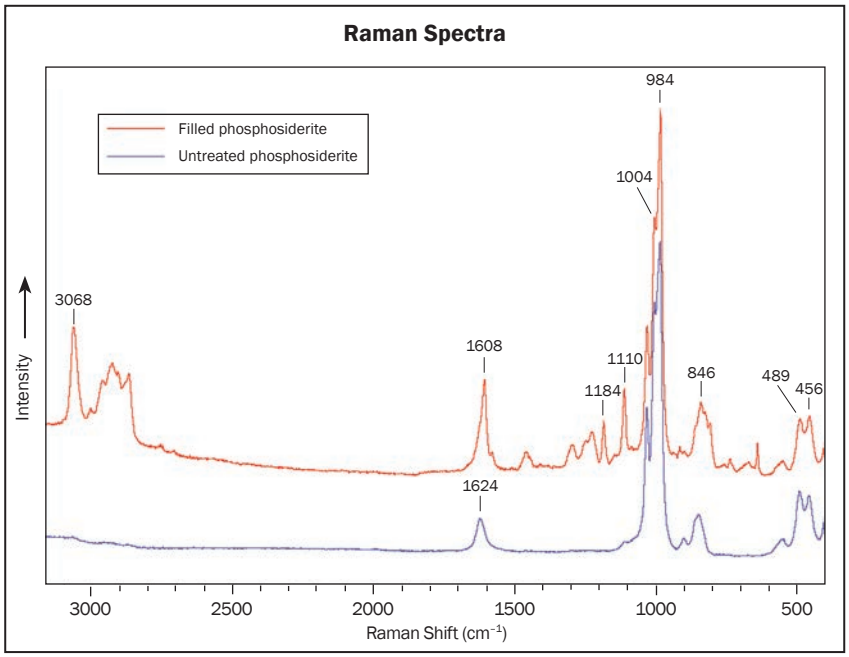

Figure 41: Raman spectra representative of the filled samples are compared to the untreated phosphosiderite. The features shown by the filled sample at 3068, 1608, 1184 and 1110 cm^{-1} are typical of epoxy resin.

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MISCELLANEOUS

54th Myanmar Jade and Gems Emporium

On 2–11 August 2017, the 54th Myanmar Jade and Gems Emporium took place in Nay Pyi Taw. This author visited on opening day, when a large crowd gathered inside and outside of the facility due to a visit by Myanmar's vice president, U Henry Van Thio. This year's Emporium occurred in grand style with lots of security and many gem and jewellery shops open for business. In addition, the inaugural Gems and Jewellery Day was celebrated on 3 August.

Open tender bidding took place 5–10 August, and was attended by 3,466 foreign merchants and 1,845 local buyers. Of the 326 Gems lots that were offered, 105 of them sold for a total of US$3,643,809. Of the 5,500 Jade lots offered, 4,282 sold for a total of US$535,920,497.

This year the author was pleased to see good-quality rubies and sapphires, as well as some rare stones such as johachidolite, jeremejevite, serendibite, edenite and danburite. In addition, some noteworthy pieces consisted of: (1) lot no. 78, a 7.1 ct faceted ruby with a reserve price of €2,600,000; (2) lot no. 89, a 42 ct sapphire pendant set with diamonds that had a reserve price of €12,900,000; and (3) lot no. 243, an 11.82 ct pale bluish green johachidolite with a reserve price of €50,000. In total, the rubies on offer included 96 rough lots, 20 cut lots and 22 rough parcels (of Mong Hsu material), while the sapphires consisted of 30 rough lots and 58 cut lots.

Figure 42: Various colours of jadeite decorate these three beds that were offered at the 54th Emporium. Photo by T. Hlaing.

The most unusual offering at this year's Emporium consisted of three beds decorated with jadeite (Figure 42). Variously coloured jadeite tiles were used to embellish the headboards, footboards and sides of the beds, and jadeite beads were sewn together to create the bedspreads and pillowcases.

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The Fire Within

"For in them you shall see the living fire of the ruby, the glorious purple of the amethyst, the sea-green of the emerald, all glittering together in an incredible mixture of light."

– Roman Elder Pliny, 1st Century AD

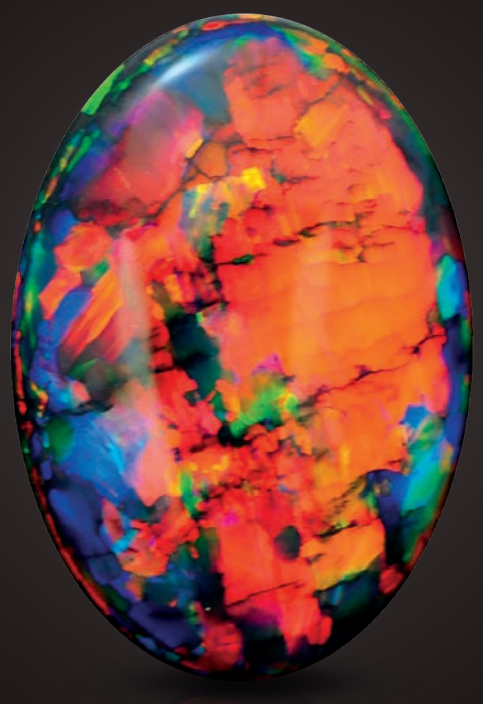

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JOG

The Linkage Between Garnets Found in India at the Arikamedu Archaeological Site and Their Source at the Garibpet Deposit

Karl Schmetzer, H. Albert Gilg, Ulrich Schüssler, Jayshree Panjikar, Thomas Calligaro and Patrick Périn

The archaeological site of Arikamedu, located in Tamil Nadu State on the east coast of India, was the centre for many centuries of a significant bead-producing industry. Beads were made of both glass and stone, including garnet, but the source of the garnet rough material has not been confirmed. To probe this question, garnet beads found at Arikamedu were compared with rough material from the Garibpet deposit, located approximately 640 km away in Telangana State, east of the city of Hyderabad, India. Samples from the two localities exhibited substantial correlation with respect to average composition, trace-element contents, chemical zoning of major and minor elements, inclusion assemblages and zoning of inclusions between the rims and cores of the crystals. Chemically, the stones were almandine rich (averaging 81.0% almandine, 11.5% pyrope, 3.3% spessartine and 1.5% grossular), with pronounced zoning for Mn and Mg. Zoning of trace elements also was observed, especially for Y, P and Zn. The most characteristic aspects of the inclusion pattern were sillimanite fibres that were concentrated in a zone between an inclusion-rich core and an inclusion-poor rim. In combination, the microscopic observations, identification of the inclusion assemblage, and chemical analyses established that the rough material used historically in the Arikamedu area to produce garnet beads originated from the Garibpet deposit. Furthermore, the results suggest that existing schemes for classifying historical garnets require additional refinement.

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Introduction

During the Hellenistic and Roman eras, garnets in the red-to-purple colour varieties were one of the most appreciated and expensive gem minerals. Principal uses spanned from functional to aesthetic: They were both engraved as seals and set in jewellery pieces. In the ancient world, the extensive use of garnet—*anthrax* in Greek; *carbunculus* in Latin—can be traced from approximately 300 BC to the end of the western Roman Empire (5th century AD). Usage continued in the Early Middle Ages (5th–7th century AD or even

Table I: Various nomenclature schemes used for classifying historical garnets.

Calligaro et al., 2002	Type I	Type II	—	—	Type III	Type IV	Type V
Gilg et al., 2010; Gilg and Gast, 2012	Cluster B	Cluster A	Cluster C	Cluster Z	Group X	Cluster D	Cluster E
Chemical characteristics	Mn-, Cr- and Y-poor almandine	Mn-, Cr- and Y-rich almandine	Ca- and Mg-rich almandine	Ca-rich, Mg-poor almandine	Intermediate pyrope-almandine	Cr-poor pyrope	Cr-rich pyrope

somewhat later, e.g. in Scandinavia), with garnet becoming the dominant gem mineral in jewellery. The setting of flat, doubly polished garnet plates into a metal framework (see photo on the cover of this issue) is one form of the so-called cloisonné work used in the past (*cloisonné* is French for 'partitioned'). In central Europe, the extensive use of garnets in personal jewellery then decreased throughout the course of the 6th century AD and disappeared almost entirely in the 7th century, a period associated with a suspected closure of sea routes to India by the Sasanians and later by the Muslim Arab invasion (Rupp, 1937; Whitehouse and Williamson, 1973; Roth, 1980; Sidebotham, 1991; von Freeden et al., 2000; Lennartz, 2001). The causative relationship, however, has been questioned, and other factors—including changes in fashion and/or burial habits concomitant with Christianization—may have contributed to the decline in garnet use (Calligaro et al., 2006–2007; Gilg et al., 2010; Drauschke, 2011; Sorg, 2011). Summarizing the various periods in which garnet played an important role in glyptic and jewellery, Adams (2011) referred to the span from 300 BC to AD 700 as the 'garnet millennium'.

The origin of the primary garnet material used in the ancient world and the Early Middle Ages, and correlation with information found in texts penned by the authors of classical antiquity (primarily Theophrastus and Pliny the Elder), was a matter of largely unsupported speculation for decades. The initial examinations used physical and structural properties (e.g. SG, RI or unit cell dimensions obtained by X-ray diffraction analysis), but interpretations were highly ambiguous in the absence of chemical data. A major step forward was achieved when scientists began to apply non-destructive analytical techniques that measured the complete chemical composition of garnet samples found in early medieval jewellery or excavated at historical sites. Moreover, such results could then be compared with data obtained for garnets from modern sources (e.g. Löfgren, 1973; Rösch et al., 1997; Farges, 1998; Greiff, 1998; Quast and Schüssler, 2000; Calligaro et al., 2002).

Classification Schemes for Historical Garnets

Building on the advancements mentioned above, Calligaro et al. (2002) subdivided early medieval garnets into five different types primarily by means of major- and trace-element composition, with a smaller contribution coming from the identification of inclusions in a limited number of samples. As shown in Table I, these subdivisions comprised two types of almandine with different Mn, Ca, Cr and Y contents (Types I and II), two types of pyrope with different Cr levels (Types IV and V) and one intermediate pyrope-almandine type with variable composition (Type III). Further studies refined the five types (Calligaro et al., 2006–2007; Périn and Calligaro, 2007; Calligaro et al., 2009; Gast et al., 2013; Bugoi et al., 2016), and the scheme was applied, in general, to additional groups of early and even late medieval garnets by other researchers (e.g. Mathis et al., 2008; Greiff, 2010; Horváth and Bendö, 2011; Šmit et al., 2014).

Nonetheless, despite the foregoing progress, problems remain in any attempt to assign historical garnets to various types or groups. As noted, Calligaro et al. (2002) performed the main subdivision of garnets into different types by means of spot chemical analysis, and for a small number of samples inclusions also were identified by micro-Raman spectroscopy. Because pyropes are largely free of diagnostic inclusions, the 2002 study identified mineral inclusions in just five samples (one Type I almandine and four Type II almandines). Hence, although the large chemical data set of Calligaro et al. (2002)—as expanded in follow-up studies using the AGLAE proton probe at the Louvre in Paris, France (see references cited

above)—continues to be the best resource on garnet chemistry available to date, only a statistically insignificant amount of information on inclusions was provided by these studies. Consequently, the assignment of garnets to different types is at present still based mainly on chemical data, and no 'typical' inclusion patterns derived from a similarly large number of examined samples have been offered to assist in classifying Type I to Type V garnets. Furthermore, these studies did not indicate the number of stones that could not be definitely assigned to a specific type of garnet.

Such drawbacks were highlighted when Gilg et al. (2010) observed that the two types of almandines showed fairly consistent inclusion characteristics, and the intermediate pyrope-almandines (Type III) had extremely variable inclusion assemblages. Thus, the latter could not be considered a 'type', but rather were a group of different types. Gilg et al. (2010) therefore used a somewhat different nomenclature, subdividing the samples into Clusters A through E and Group X (again, see Table I). Four of the clusters paralleled four of Calligaro's types, and one, Cluster C, incorporated a new chemically distinct group for Scandinavian stones as characterized in previous studies (Löfgren, 1973; Mannerstand and Lundqvist, 2003). The remaining garnets formed the larger intermediate Group X, which corresponded broadly to Calligaro's pyrope-almandine type but likely included multiple more discrete types or clusters.

Thoresen and Schmetzer (2013) then compiled and compared properties of 37 garnets from the ancient Greek and Roman eras with those of early medieval samples. In that study, garnets were found with compositions close to four of Calligaro's types: the two different types of early medieval almandines (Type I/Cluster B and Type II/Cluster A), Cr-poor pyrope (Type IV/Cluster D) and the large group of intermediate pyrope-almandine (Type III/Group X). Conversely, no Cr-rich pyropes were discovered. In addition, the investigations identified, among the Greek and Roman samples, a third type of almandine that to date has not been seen in early medieval jewellery. These almandines were distinguished by their high Ca and Mn but very low Mg contents. A small group of Greek and Roman stones yielding a similar composition already had been denominated Cluster Z by Gilg and Gast (2012; see Table I). Still, notwithstanding such work, the statistical data set for Greek and Roman jewellery has remained small, and information about inclusions or trace-element contents was not available for all of these samples.

Thus, in summary, no clear and fully supported boundaries for the different types or clusters of historical garnets have yet been published. In most studies, only average chemical compositions and standard deviations for the types and groups, or hand-drawn compositional fields in binary plots, were provided for characterization. Ideally, data dealing with major-, minor- and trace-element compositions; with solid and fluid inclusion assemblages; and with zoning of such chemical components and inclusions—all taken from a sufficiently large number of samples—should be utilized to define a type or cluster. Such complete data sets, however, do not yet exist or have not yet been published. Consequently, for samples with overlapping chemical compositions, the need persists to find additional well-defined criteria or establish definite inclusion patterns, in order to support and better define the classification of historical garnets into types, clusters or groups. In the process, for each group of examined samples, the number of stones which cannot be definitively assigned to a specific type of garnet should be indicated.

Determining Geographic Origin of Historical Garnets

Shortcomings also affect efforts to take the next step beyond type classification and to correlate garnet types with supposed geographic origins. Many studies have pointed to large countries (India, Sri Lanka), Indian states (Rajasthan, Orissa) or regions (Bohemia) as the possible or probable source of a certain garnet type, cluster or group. Such assignments often have been based only on similarities in chemical composition and have not considered or presented adequate comparative inclusion data. Moreover, a detailed discussion of other geologically related and thus chemically similar occurrences has rarely been offered. For example, gem-quality Cr-poor pyropes with chemical compositions identical to those assigned to Type IV/Cluster D garnets have been mentioned from at least three places that were accessible in ancient and medieval times (Monte Suimo, Portugal; possibly the Jos Plateau, Nigeria [Garamantic garnets]; and Elie Ness, Scotland), the first two of which

Figure 1: These faceted garnet beads were collected by local farmers from the Arikamedu site. The samples constitute some of those studied for this report (i.e. group B1) and measure ~4.5–5.5 mm in diameter. Photo by K. Schmetzer.

apparently even relate to sources mentioned in ancient texts (Gilg et al. 2010). A further occurrence of pyrope (Mount Carmel, Israel; Mittlefehldt, 1986) has, to the knowledge of the present authors, been considered as a possible source of historical garnets only briefly by Gilg et al. (2010).

Such challenges are magnified in the case of India, where, aside from the basic problem that a specific source might have been completely exhausted and thus be presently unknown as a gem locality, the pertinent time span can be extensive and poorly documented. More than a millennium stretched between the last written record in late antiquity and the beginning of mineralogical research in India in the first part of the 19th century. Yet available recent summaries of gem garnet localities in India that might have supplied raw material for ornamental or jewellery purposes mostly repeat older references and do not provide primary data (e.g. Brown and Dey, 1955; Wadia, 1966; Jyotsna, 2000). Likewise, recent summaries of possible trade routes in antiquity (see, e.g., Borell-Seidel, 2017; Larios, 2017; Seland, 2017; Thoresen, 2017) present only generalized overviews, without referring to specific localities in detail.

Consequently, the most promising strategy, and the one employed here, is to take a more comprehensive approach: After considering the potential sources mentioned in the literature, gem-quality material is obtained from likely localities for examination and comparison with properties of the historical garnets in question, incorporating a large number of samples and multiple criteria.

The current study presents for the first time a thorough chemical and mineralogical characterization of garnets found at the Arikamedu archaeological site in southern India (e.g. Figure 1), using high-quality major- and trace-element data in conjunction with detailed inclusion studies. The authors then demonstrate a remarkable correlation with recently mined garnets from Garibpet in Telangana State, India—approximately 640 km away or 760 km distant by road—as the source of origin. Potential relationships of the Arikamedu and Garibpet garnets to those excavated at additional localities and to engraved samples, as well as a discussion of possible trade routes, will be the subjects of future publications.

Background

The Arikamedu Site and Its Connection to Garnet Beads

Arikamedu is a highly significant historical location in India and has sparked great interest within the archaeological community. The site is situated on the banks of the Ariyankuppam River, approximately 4 km south of the town of Pondicherry (Puducherry), in the state of Tamil Nadu in southeast India (Figure 2). Arikamedu was discovered in the 1930s and was excavated by British-Indian (R. E. M. Wheeler, campaign of 1945), French (J.-M. Casal, campaigns of 1947–1950) and American-Indian archaeological teams (V. Begley, campaigns of 1989–1992). These excavations unearthed numerous archaeological artefacts of Roman origin and led to Arikamedu being initially portrayed as a Roman settlement (Wheeler et al., 1946; Casal 1949; Wheeler, 1954). Continued research, however, has shifted modern theories toward interpreting Arikamedu as an important Indian trading centre and harbour, connecting the east coast of India with the Western world from the 1st century BC to the 7th century AD (Begley, 1983, 1993; Begley et al., 1996, 2004). Various trade routes from the Indian east coast (Coromandel Coast) to the west coast (Malabar Coast) have been established. These included both land routes using the Palghat Gap and sea routes via the Palk Strait between India and Sri Lanka with smaller vessels or, later, circumnavigating Sri Lanka with larger craft. The Indian west coast was then linked with Mediterranean society by means of major harbours, for example Muziris (Ray, 1994; Smith, 2002; Deloche, 2010; Rajan, 2011; Gurukkal, 2013).

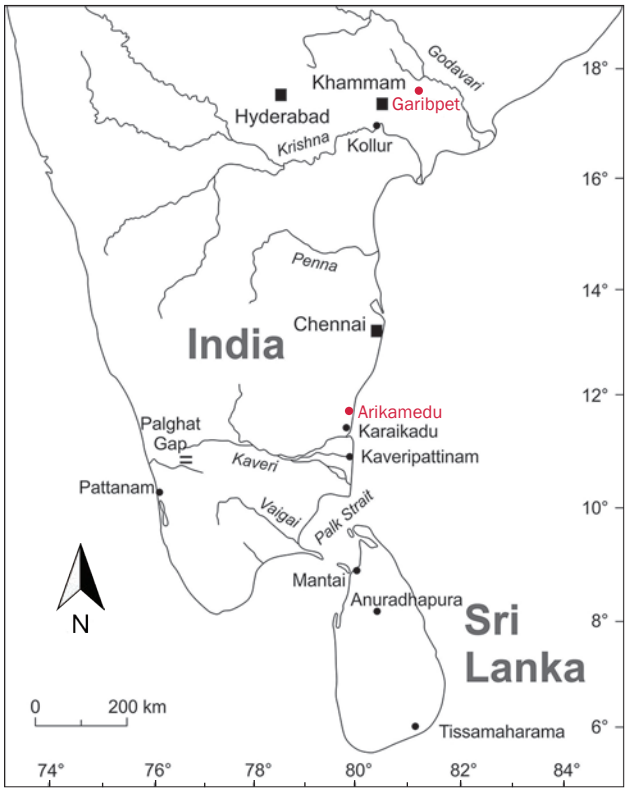

Figure 2: This map of southern India shows the locations of Arikamedu and Garibpet on the subcontinent. The Arikamedu site is located adjacent to the Ariyankuppam River, near the town of Pondicherry (neither of which are shown at the scale of this map).

Arikamedu has been equated with the harbour of Podouke (Podukê) mentioned in the *Periplus Maris Erythraei* (Periplus of the Erythraean Sea), a sailing guide written by an anonymous author in the 1st century AD (Raman, 1991). Another important ancient harbour also located on the Coromandel Coast, south of Arikamedu, was named Kaveripattinam (Rao, 1991a,b; Gaur and Sundaresh, 2006; Sundaresh and Gaur, 2011). The Kaveripattinam port has been associated with the Kaberis Emporium cited by Ptolemy (Raman, 1991) and with a locality denominated 'Caber' in a text by the traveller and merchant Cosmas Indicopleustes, written in the mid-6th century and known as *Christian Topography* (Banaji, 2015; see also Winstedt, 1909 and Schneider, 2011). It has been speculated that the text mentioning "Caber which exports alabandenum" refers to shipment of almandine garnet (Roth, 1980; Kessler 2001). After the decline in trade with the West, Arikamedu trading activities focused on the East, as demonstrated by the Chinese ceramics excavated at the site (Begley et al., 1996, 2004). In the 19th and 20th centuries, even after the archaeological importance of the site had been recognized, Arikamedu and surrounding regions continued to be used for agriculture. Only in 2006 was the land purchased by the government from private landowners and designated a protected historical site (Suresh, 2007).

In addition to its functions as port and trading centre, Arikamedu served as one of the main bead-producing localities in India. The unearthing of several thousand stone and glass beads during the archaeological excavations attests to this fact. Wheeler et al. (1946) mentioned "more than two hundred beads of various materials found in the excavations" but did not refer specifically to garnets. Casal (1949) depicted a limited number of garnets along with other beads. Detailed information describing the material excavated by Begley and her team in the 1989–1992 campaigns was published by Francis (2002, 2004), who had joined in the archaeological work. It was noted that garnets were the second-most prevalent among the stone beads after the quartz varieties. Francis (2004) listed about 3,500 pieces of glass beads and bead-making waste that were excavated in the 1989–1992 campaigns together with 200 stone beads, including 29 garnets. Numerous unworked garnet pebbles were mentioned as well, exceeding the number of finished beads.

The Pondicherry Museum houses 50,000 beads of multiple kinds, catalogued in a 'bead census' by Francis (1986). This enormous number far surpasses the several hundred beads excavated by Wheeler and Casal. Francis (1987) surmised that "the material was picked up on the surface over the last 200 years or so" by villagers living near Arikamedu. Garnet beads account for 10.1% of the Pondicherry Museum holdings of stone beads (Francis, 2002). Francis (1991, 2001, 2004) assumed that beads were produced in Arikamedu for over 2,000 years. Bead production remained on-going in the region for centuries and was only abandoned in the early 17th century. A period when the site was uninhabited followed thereafter for some time, with the area then seeing agricultural use in the 19th and 20th centuries (S. Suresh, pers. comm., 2017). Francis (1993) indicated that "the almandine garnets at Arikamedu were doubtless from lower Andhra Pradesh", but he offered no definitive proof for this conclusion.

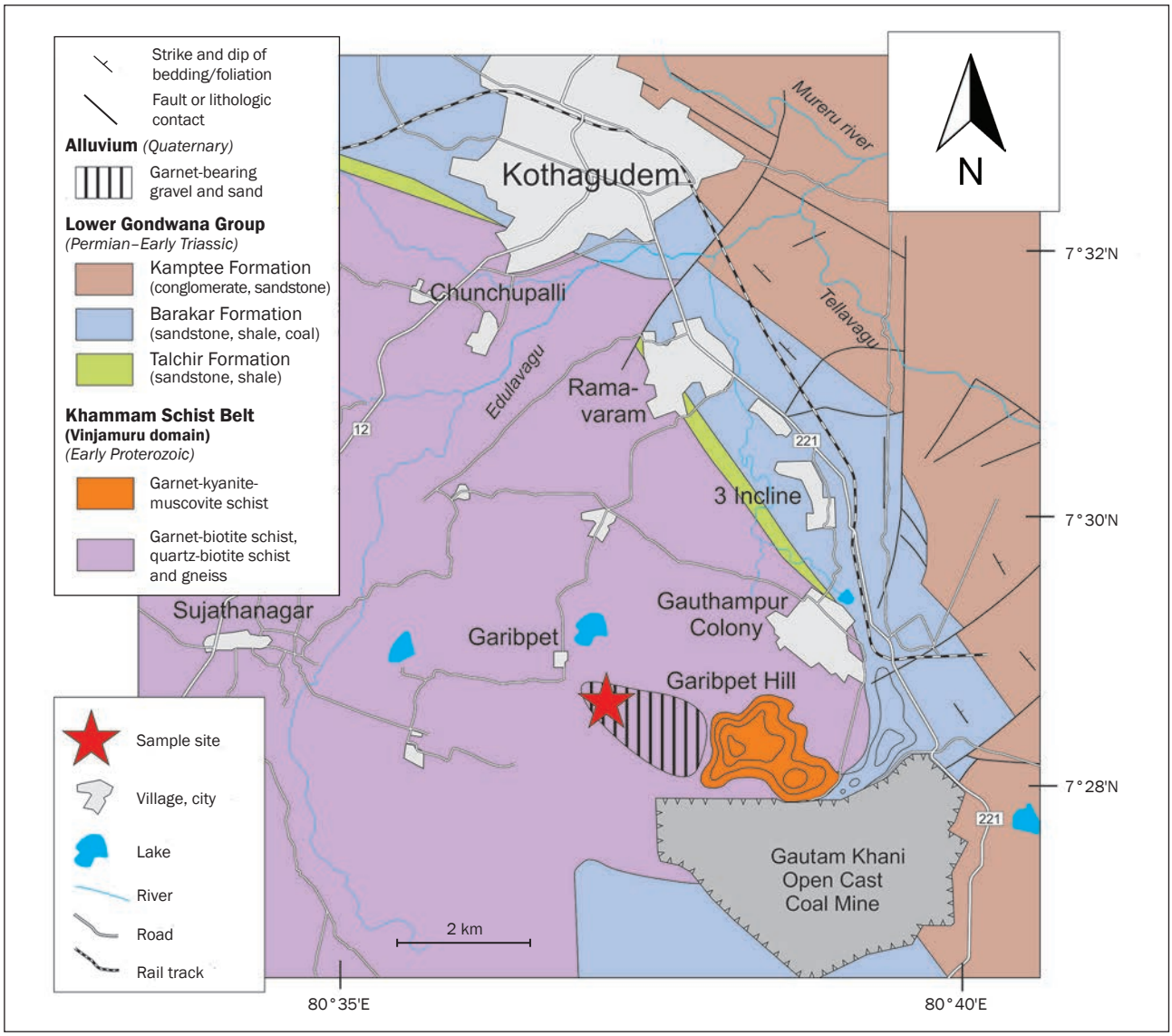

Figure 3: The locations of Garibpet Hill and Garibpet village can be seen in this geological map, south of the municipality of Kothagudem in the Khammam District, Telangana State, India. The Garibpet samples characterized in this study came from the alluvial garnet deposit associated with Garibpet Hill. After Phani (2014b).

Although stone beads were mentioned in all major excavation reports for Arikamedu (Wheeler et al., 1946; Casal, 1949; Wheeler, 1954; Begley et al., 1996, 2004), only very limited information about the garnet mineral species and composition is available. The sole source of chemical data exists in the form of a summary published twice by Francis (2002, p. 240; 2004, p. 480) of a microprobe analysis performed by C. Rösch at the University of Würzburg, Germany. The garnet, a surface find from Francis's collection, was determined to be composed of 83% almandine and 12% pyrope, with spessartine and grossular being subordinate. Unfortunately, the full analytical data underlying the summary are no longer available (C. Weinfurter, née Rösch, pers. comm., 2014). Thus, with the possibilities offered by modern scientific instruments and methods, further investigation of Arikamedu garnets may help answer heretofore unresolved questions of historical significance. In particular, correlating Arikamedu samples with medieval garnets could corroborate or disprove origin theories and could confirm ancient trade routes, as hinted at by the suggested association of the 'alabandenum' from Caber with almandine.

Garibpet—History and Geology

Garibpet Hill is located south of the modern city of Kothagudem in the Khammam District, Telangana State, and southeast of the village of Garibpet (Figures 2 and 3; see also Master Plans India, 2014). *Garibpet*, *Gharibpeth*, *Gharibpet*, *Gareeb-*

pet and several other variants of the name are mentioned in the literature. Sometimes the locality is also referred to as *Palunsha* or *Paloncha*, now part of the modern city of Palvoncha, situated northeast of Kothagudem. Telangana State was separated in 2014 from the neighbouring Indian state of Andhra Pradesh.

The Garibpet locality was first described as a secondary deposit and garnet mine by Voysey (1833), the 'Father of Indian Geology' (Murty, 1982). Many subsequent studies referred to this short note by Voysey (e.g. Walker, 1841; Newbold, 1843), and Walker also indicated that the material was cut in Hyderabad. Bauer (1896) mentioned Garibpet as a secondary occurrence of better-quality gem garnets. Mirza (1937) then reported production figures covering the period from 1910 to 1929. In addition to discussing primary sources, Mirza observed that "precious garnets are also reported in the water courses draining the hills composed of garnetiferous rocks" (see again Figure 3). The production figures reflect that the most extensive mining activity during this period evidently occurred from 1915 to 1919, as follows (converted from pounds to kilograms): 6,205 kg from 1910 to 1914, 105,513 kg from 1915 to 1919, 28,358 kg from 1920 to 1924, and 12,902 kg from 1925 to 1929.

Researchers of the current era still recognize the productive nature of the geology, with a recent publication remarking that garnet-bearing schist "constitutes an entire hill at Garibpet, in the Khammam district" of Telangana State (Phani, 2014a). Phani (2014a) further stated that in the Kothagudem area "crystals of transparent to translucent almandine variety of garnet occur in situ as well as float ore". The garnets have been used both as an abrasive and as a gem material (Kothagudem City, 2014). An analysis of Kothagudem garnet revealed a composition of 85.0% almandine, 9.5% pyrope and 0.9% spessartine (Kumar et al., 1992).

Garibpet is situated in the western part of the Proterozoic Eastern Ghats Belt, close to the north-west–south-east trending Permo-Triassic Godavari Rift (Subbaraju, 1976; Phani, 2014b). The Eastern Ghats Belt experienced two orogenic episodes as a result of collisions between the Archean Dharwar, Bhandara (Bastar) and Singhbum cratons in the west and cratonic areas of Antarctica in the east. The late Paleoproterozoic Krishna orogeny (~1.65 to 1.55 billion years [Ga]) occurred during the formation of the Columbia supercontinent (Zhao et al., 2002), while the late Mesoproterozoic to Neoproterozoic Grenvillian orogeny started ~1.1 Ga during the assembly of Rodinia (e.g. Dobmeier and Raith, 2003; Mukhopadhyay and Basak, 2009; Dasgupta et al., 2013). The Paleoproterozoic metamorphism prevails in the western part of the Eastern Ghats Belt, the so-called Krishna Province that is subdivided into the western Nellore-Khammam schist belt and the eastern granulite-facies Ongole domain (Dobmeier and Raith, 2003). The Nellore-Khammam schist belt comprises the upper, low-grade Udayagiri domain and the lower, moderate-grade Vinjamuru domain. The Kothagudem-Garibpet area is located in the Vinjamuru domain of the Khammam schist belt and consists of Paleoproterozoic moderate-grade (and partly migmatitized) metasediments and metavolcanics with minor mafic and granitic intrusives (Subbaraju, 1976).

Figure 4: (a) Shallow pits mark the locations of artisanal mining activities in this secondary deposit of garnet-bearing gravel in the Garibpet area. Garibpet Hill is visible in the background. Photo by P. Périn, 2012. (b) The gravels consist mainly of garnet pebbles (mostly ~0.5-1.5 cm in diameter). Photo by T. Calligaro, 2012.

Figure 5: This schematic map of the Arikamedu archaeological site indicates where garnet beads in the form of faceted bicones, typically broken, were found. The arrow indicates the location of the site shown in Figure 6. The inset shows a sign marking the boundary of the Arikamedu site. Photo by J. Panjikar; map after Begley et al. (1996).

The conspicuous Garibpet Hill is formed of garnet-kyanite-muscovite schist and is surrounded by biotite schist and gneiss. The adjacent Godavari Rift hosts clastic rocks composed of Lower Gondwana sediments, including the Early Permian terrestrial Talchir and Barakar Formations and the Late Permian to Early Triassic Kamptee Formation. The upper part of the Barakar Formation contains significant coal seams that make up the Kothagudem Coal Field, with several underground workings and the large Gautam Khani (or Goutham Khani) open-cast mine located to the south of Garibpet Hill (Figure 3).

The alluvial gem quality garnet-bearing gravels occur on the west-north-western side of Garibpet Hill and are derived from the weathering of the garnet-bearing schist (again, see Figure 3). The gravels are less than 1 m thick and consist mostly of garnet pebbles (Figure 4). They continue to be worked by local artisanal miners.

Figure 6: Various types of beads, including garnets, were found on the surface at the Arikamedu archaeological site. Many beads were discovered in the roots of trees and along the banks of the Ariyankuppam River. Photo by J. Panjikar, 2014.

Materials and Methods

Sample Collection

In March 2014 one of the authors (JP) visited Arikamedu, together with a local guide (Panjikar, 2014). During a walk across the site, beginning at the 'French mission house', the guide found various beads on the surface at several places. The locations of these surface finds are shown in Figure 5. Some beads were found in the roots of fallen trees (e.g. Figure 6), while others were seen in the sand along the banks of the Ariyankuppam River. A preliminary examination at the Pangem

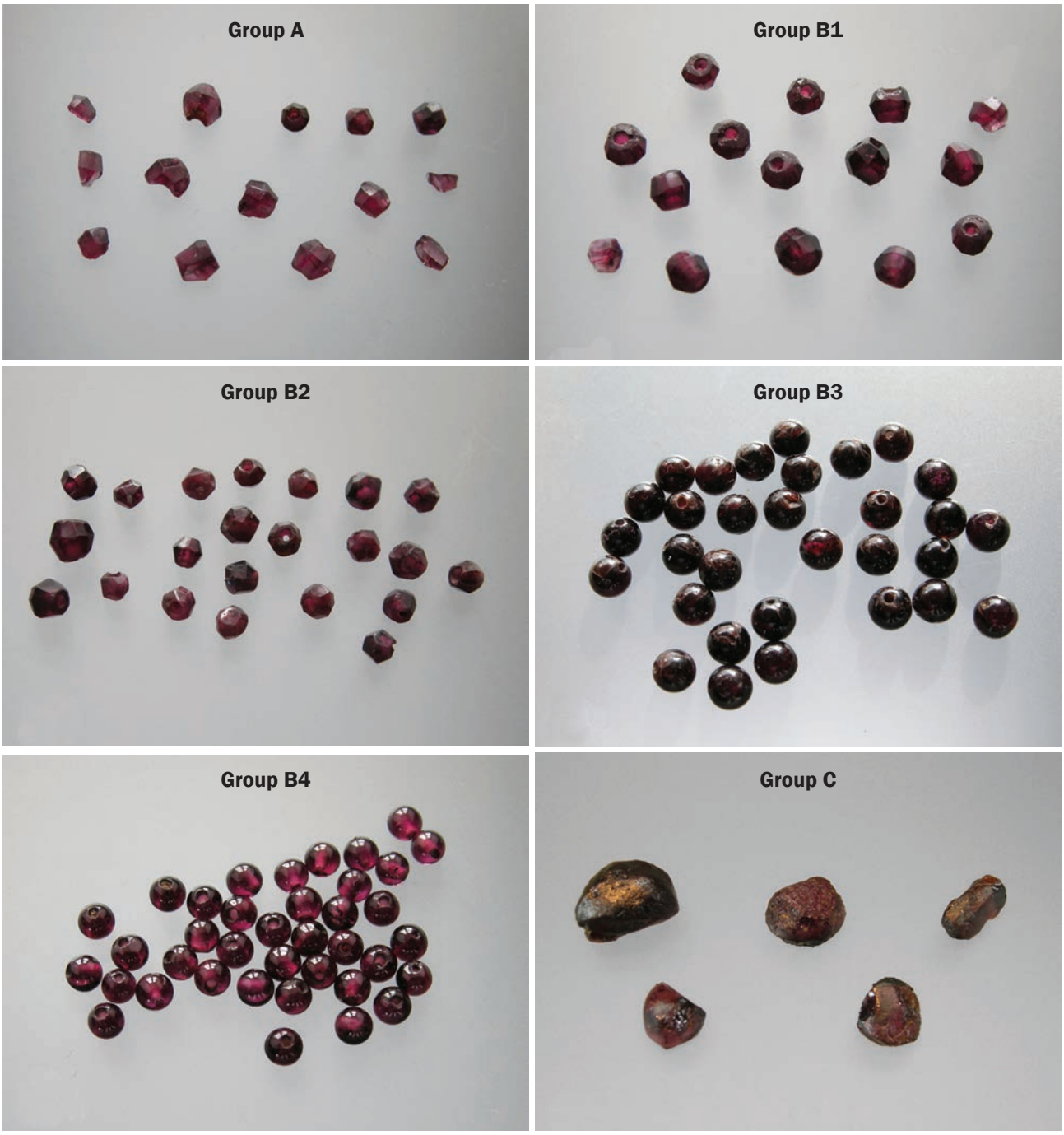

Figure 7: These photos show the garnet samples from Arikamedu that were assembled for the present study and from which selected samples were characterized. Group A: faceted bicones found at the archaeological site in 2014, with the largest measuring ~4 mm in diameter. Groups B1 and B2: transparent faceted bicones collected by local farmers, with B1 samples measuring ~4.5–5.5 mm in diameter and B2 samples being ~2.8–3.2 mm in diameter. Groups B3 and B4: translucent and transparent spherical beads collected by local farmers, with B3 samples measuring ~5.2 mm in diameter and B4 samples being ~3.2 mm in diameter. Group C: garnet fragments collected by P. Francis and archived at the American Museum of Natural History, New York, USA, with the sample at top left measuring 9.0 × 6.8 mm. Photos by K. Schmetzer.

Testing Laboratory in Pune, India, revealed that four different kinds of beads had been collected: blue glass, green glass, red to brownish red glass and garnet. The garnet beads consisted of broken and complete faceted samples, and 22 of these were sent to Germany for further examination. All garnets of this group, designated group A in the following text, were faceted in the form of barrel-shaped bicone beads and were mainly broken (Figure 7, upper left).

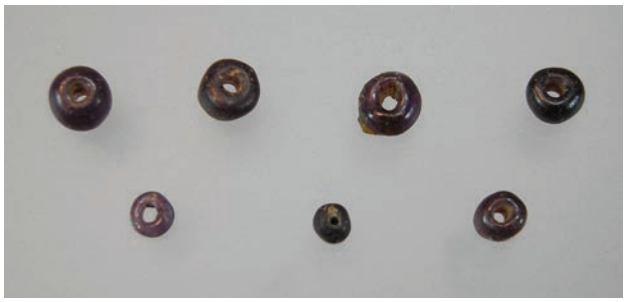

Figure 8: These red-to-purple glass beads from Arikamedu were collected by P. Francis and archived at the American Museum of Natural History, New York, USA. The sample at top left measures 3.6 mm in diameter. Photo by K. Schmetzer.

Figure 9: These garnet pebbles (~0.5–1.5 cm in diameter and coated by a weathered crust) were recovered from a secondary deposit in the Garibpet area. Photo by T. Calligaro, 2012.

During her visit to Arikamedu, author JP was informed by her guide that members of his family possessed numerous similar beads that had been unearthed in past decades during agricultural work at or near the fenced archaeological site, and a particularly substantial find had been made when local farmers were digging a well. A portion of the garnets so discovered had been kept within the guide's family for at least two generations. Ultimately, 314 such beads were obtained from the family members and supplied for examination. They are here designated group B (Figure 7) and were visually sorted into four subgroups: faceted barrel-shaped bicones (groups B1 and B2, identical in appearance to group A) and smooth spherical beads (groups B3 and B4). Group B1 consisted of 69 larger bicones ranging from ~4.5 to 5.5 mm, and group B2 contained 55 smaller bicones of ~2.8–3.2 mm. Group B3 consisted of 60 larger translucent spherical beads with a diameter of ~5.2 mm, and group B4 comprised 130 smaller transparent spherical beads of ~3.2 mm in diameter.

Although garnet samples from the Pondicherry Museum were not available for non-destructive analyses and microscopic examination, the authors were nonetheless able to obtain access through an alternate channel to material that had been collected by Peter Francis Jr. at Arikamedu. After his death in 2002, bead research materials remaining in Francis's possession in the USA were donated to the American Museum of Natural History in New York (see www.TheBeadSite.com). Upon request, all samples in the red-to-violet colour range within the container labelled 'Arikamedu', and thus potentially consisting of garnets, were made available for study. In total, 31 samples were examined. Of those, 22 were red-to-purple glass beads (e.g. Figure 8), one was an amethyst and eight were garnets. The eight garnets, designated group C for this project (Figure 7), were all rough, primarily irregularly shaped pieces without drill holes. As for the glass beads, their visual appearance was such that, without thorough gemmological examination, some could be mistaken for garnets.

For comparative purposes, the study also incorporated rough material recently obtained from the known garnet locality in Garibpet, India. Because initial research suggested that the properties of such samples correlated extremely well with those of Arikamedu material, data on Garibpet stones was obtained to investigate the possibility of this deposit being a source of garnets for the Arikamedu bead-making enterprise. The garnet samples were collected in 2012 by two of the authors (TC and PP) from a secondary deposit in the Kothagudem-Garibpet area (again, see Figure 4) and are here designated group E. These water-worn pebbles had somewhat rounded and irregularly shaped surfaces, and were generally covered by a weathered crust (Figures 9 and 10). Although some of the samples were transparent (group E1), most were only translucent at best (group E2).

Sample Selection, Preparation and Analytical Techniques

The garnets were initially examined with an immersion microscope to provide information on internal features and to guide selection of samples for more thorough investigation and analysis.

Figure 10: Among the garnet pebbles from the secondary deposits in the Garibpet area, it is possible to find transparent samples of facetable quality. The pebbles range up to ~1.5 cm in diameter. Photo by T. Calligaro, 2012.

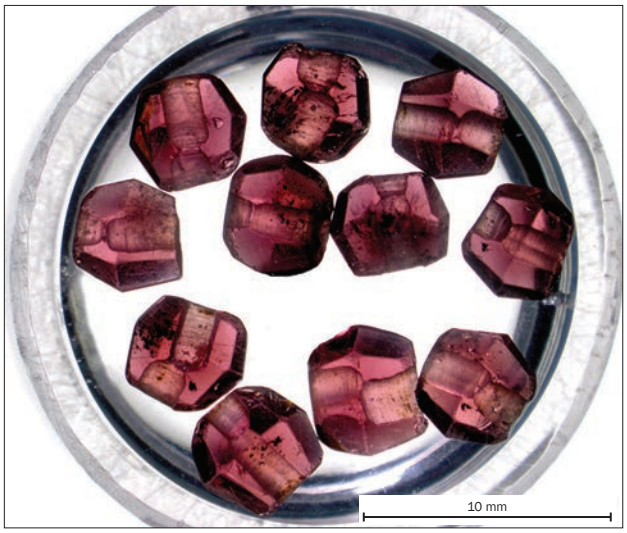

Figure 11: Faceted garnet bicones from Arikamedu were cut in half and polished for microprobe analysis. Two drill holes meet approximately in the centre of each sample. Photo by H. A. Gilg.

From the transparent Arikamedu beads (groups A, B1, B2 and B4; see Figure 7), 41 were chosen for electron microprobe analyses and detailed inclusion examination, including identification by micro-Raman spectroscopy. These examples covered all the different types of inclusion patterns seen in the various beads. For the primarily broken bicones (group A), smaller faceted bicones (group B2) and smaller transparent spherical beads (group B4), a single flat face was polished on each sample for microprobe analysis. From the larger faceted bicones (group B1), 11 beads were cut in half using a diamond wire saw, and the sawn surfaces of both halves were polished for analysis (Figure 11). The same sawing procedure was employed for five translucent spherical beads that contained opaque veinlets of foreign material (group B3). Six irregularly shaped samples from the Francis collection at the American Museum of Natural History (group C) were analysed on a suitable rough surface without preparatory cutting or polishing. A similar method had previously been used successfully for the garnet beads excavated at Tissamaharama, Sri Lanka (Schüssler et al., 2001). From the water-worn pebbles collected at Garibpet, 15 samples were sliced in half, and both resultant surfaces were polished. Seven of these garnets (group E1) were comparable with the transparent samples from Arikamedu (groups A, B1, B2, B4 and C), and the other eight (group E2) contained opaque polycrystalline seams or veinlets comparable with the translucent Arikamedu samples (group B3). The analysed garnets of the different groups are listed in Table II.

Electron microprobe analysis was carried out using a JEOL JXA 8800L instrument equipped with wavelength-dispersive spectrometers. Analytical conditions were as follows: 15 kV accelerating voltage, 20 nA beam current, 1 µm beam diameter and counting times of 20 s for peak positions and 20 s for background. Natural and synthetic silicate and oxide mineral standards or pure-element standards supplied by Cameca were used for calibration (i.e. andradite for Si and Ca, hematite for Fe, Cr_2O_3 for Cr, corundum for Al, $MnTiO_3$ for Mn and Ti, and MgO for Mg). *K*α radiation was utilized in the process, and matrix correction was performed by a ZAF procedure. Under these conditions, the detection limit was ~0.05 wt.% for most elements, and the analytical precision was better than 1% relative for all major elements.

For all samples from Arikamedu with the exception of the garnets from group C, from four to 12 single point analyses were performed on their cut/polished surfaces. Appropriate locations were selected on the rough fragments of group C for a similar number of single point analyses per stone. Additionally, for two faceted beads (group B1) and two spherical beads (group B3), detailed line-scans consisting of 29–49 point analyses per scan were obtained. For the samples from Garibpet (without drill holes), complete line-scans were performed across the cut and polished surfaces of all 15 garnets, consisting of 12–53 point analyses within a single scan. In summary, a total

Table II: Samples and techniques for microprobe analyses of garnets from Arikamedu and Garibpet, India.

Designation	Description	No. of drill-holes	No. of analysed samples	Cut and/or polished for analysis	Analysis technique[a]	No. of point analyses
Arikamedu Group A	Faceted transparent bicones, mostly broken	2	10	Yes	1	60
Arikamedu Group B1	Larger faceted transparent bicones	2	11	Yes	1, 3 (for two samples)	123[b] + 60[c]
Arikamedu Group B2	Smaller faceted transparent bicones	2	4	Yes	1	24
Arikamedu Group B3	Larger translucent spherical beads	1	5	Yes	1, 3 (for two samples)	58[b] + 80[c]
Arikamedu Group B4	Smaller transparent spherical beads	1	16	Yes	1	96
Arikamedu Group C	Irregularly shaped fragments, transparent	None	6	No	2	24
Garibpet Group E1	Irregularly shaped water-worn transparent pebbles	None	7	Yes	3 (for all samples)	192
Garibpet Group E2	Irregularly shaped water-worn translucent pebbles	None	8	Yes	3 (for all samples)	137

[a] 1 = several point analyses on a cut and/or polished face; 2 = several point analyses on a flat rough surface; 3 = continuous scans across a cut and polished face.
[b] Number of individual point analyses.
[c] Number of point analyses within continuous scans across cut and polished faces.

of 854 point analyses were acquired from the Arikamedu and Garibpet samples for this study (see again Table II).

Trace elements in the garnets were analysed by laser ablation inductively coupled plasma mass spectrometry (LA-ICP-MS) using a short-pulsed (<4 ns) UP193Fx argon-fluoride fast-excimer laser ablation system (New Wave Research Inc.) inductively coupled to an Agilent 7300c plasma quadrupole mass spectrometer system with an He-Ar carrier gas mixture. Single-spot ablation (30–50 µm spot size) was conducted with a laser frequency of 20 Hz, an irradiance of 0.69 GW/cm² and a fluence of 3.41 J/cm². Data reduction was carried out using Glitter 4.4.4 software, with Si measured by the electron microprobe as an internal standard. The glass standard NIST SRM 612 (Pearce et al., 1997) was used for external calibration. Four large faceted bicones and two larger spherical beads from Arikamedu (groups B1 and B3) and seven garnets from Garibpet (groups E1 and E2) were selected for scans consisting of three to eight spot analyses from centre to rim.

A Leica DM LM polarising microscope with transmitted and reflected light sources and an Olympus DX stereomicroscope, both equipped with an Olympus DP25 digital camera and Olympus Stream Motion software, were used for microscopic investigation and documentation of inclusions. All mineral phases were additionally identified by micro-Raman spectroscopy by means of a Horiba Jobin Yvon XploRA PLUS confocal Raman microscope. The spectrometer was equipped with a frequency-doubled Nd:YAG laser (532 nm, with a maximum power of 22.5 mW) and an Olympus 100× long working-distance objective with a numerical aperture of 0.9.

Results

Arikamedu Garnets—Visual Appearance

The garnets from Arikamedu comprised both beads (groups A, B1, B2, B3 and B4) and irregularly shaped fragments (group C). The beads were either faceted bicones or smooth spheres. The bicones, all transparent, showed two parallel planar facets, on opposite ends, into which the holes through the beads had been drilled (Figures 12 and 13). The holes had been made from each end, meeting approximately in the centres of the bicones, and were cylindrical in shape (Figures 11 and 14). The bead surfaces sloped outward from each flat end, creating a rounded

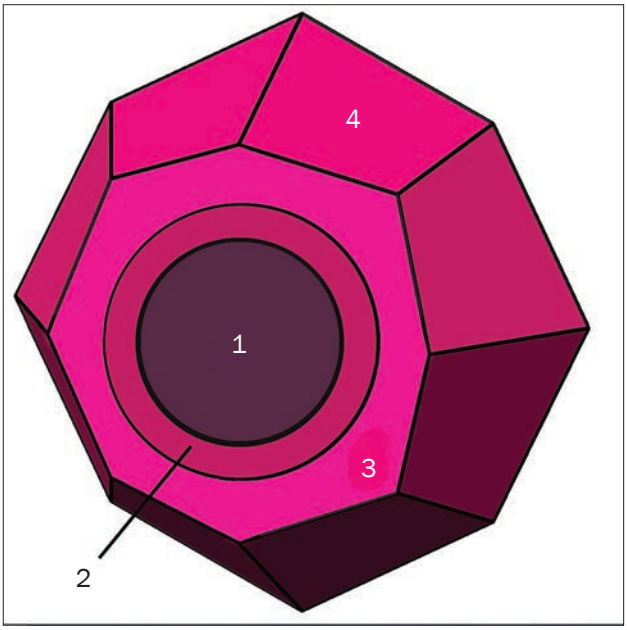

Figure 12: This schematic drawing of a faceted bicone from Arikamedu shows various features: (1) drill hole, (2) planar unpolished facet used as a base for the drill hole, (3) somewhat rounded area and (4) polished facet. Drawing by K. Schmetzer.

area, followed by two rows of facets around the sides. The two angled rows of facets intersected to form the widest diameter of the bicone beads. Measurements at these widest points versus those between the drilled planar facets reflected ratios such as 5.0/4.2 mm, 4.1/3.6 mm or 3.4/3.1 mm.

The number of polished facets in each of the two rows ranged from between 8 and 10 on the larger beads to between 7 and 9 on the smaller beads (Figure 13). Typically, the total count of facets per row for any particular bead was identical (e.g. 9/9 or 8/8), but some beads exhibited different numbers of facets within their two rows (e.g. 7/8 or 7/9). The alignment of facets within the two rows could be mirrored across the centre junction, forming a more-or-less straight sequence of edges around the cross-sections of the beads. Conversely, where the facets in the two rows varied in position or number, a zigzag pattern of edges was seen around the centre circumference (again, see Figure 13).

The spherical beads comprised either smaller transparent stones (Figure 14) or larger translucent samples (Figure 15). In detail, the larger garnets contained some transparent areas interspersed with opaque polycrystalline veins of foreign materials (Figure 15). Both the smaller and the larger spherical beads showed only a single, conically shaped drill hole.

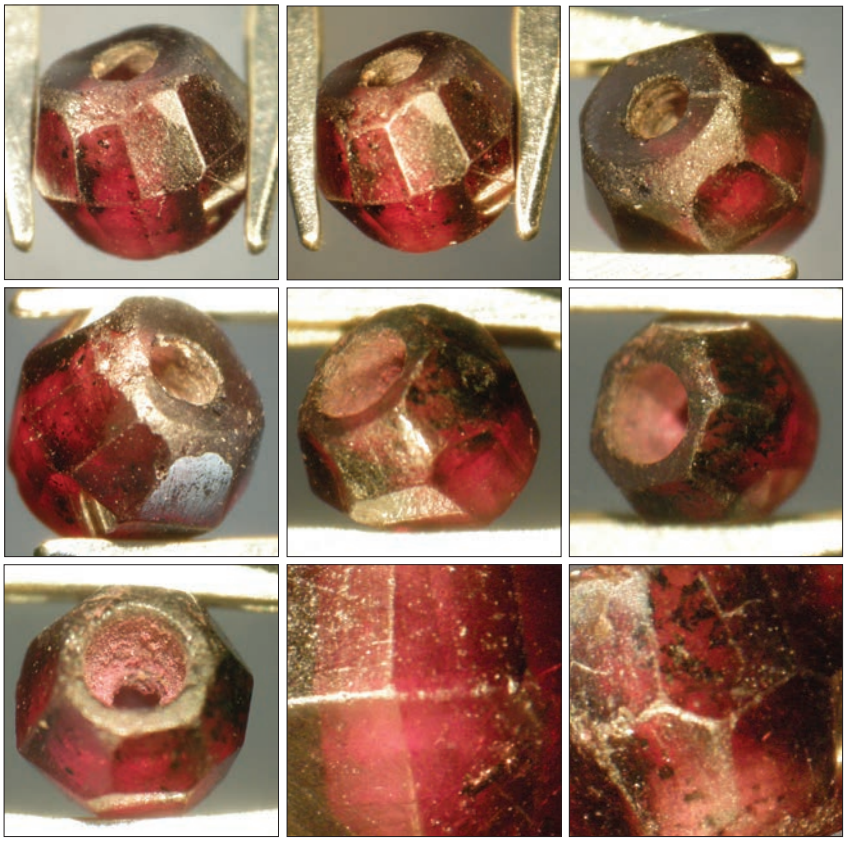

Figure 13: Shown here are various faceted bicones from Arikamedu. Each sample has planar unpolished facets serving as a base for the drill holes, and a somewhat rounded area between these planar surfaces and the rows of polished facets. If the alignment of facets in the two rows is mirrored across the centre junction, a straight sequence of edges is formed around the bicones (bottom row, centre); if the alignment or the number of facets in the two rows differs, a zigzag pattern of edges is found around the circumference (bottom row, right). The beads measure 2.8–5.5 mm in diameter. Photos by K. Schmetzer.

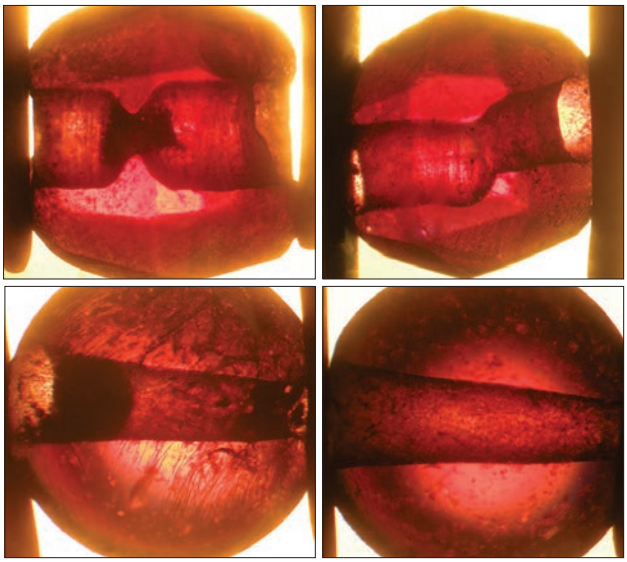

Figure 14: All faceted garnet beads from Arikamedu show two cylindrical drill holes meeting approximately at the centre (top row, ~5 mm in diameter). In contrast, spherical garnet beads from Arikamedu show only a single slightly tapered drill hole (bottom row, ~3.2 mm in diameter). Photos by K. Schmetzer.

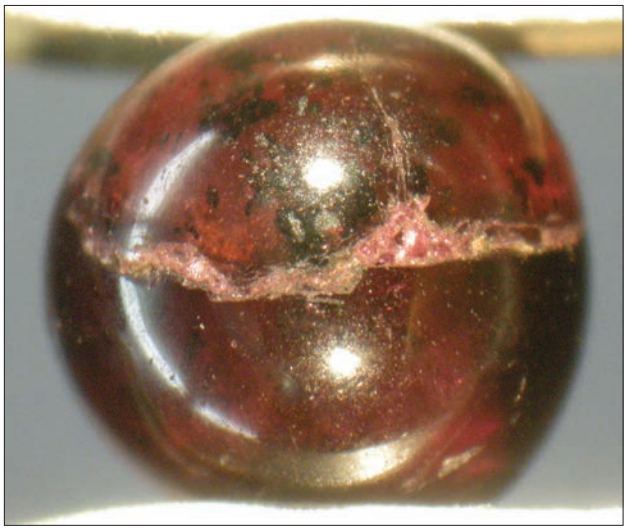

Figure 15: An irregular fracture is present in this translucent spherical garnet bead from Arikamedu. The sample measures ~5.2 mm in diameter. Photo by K. Schmetzer.

The contrast shown by the drill holes within the faceted bicones versus the spherical beads indicated different drilling techniques. According to Gwinnett and Gorelick (1987) and Gorelick and Gwinnett (1988), conically shaped drill holes are commonly observed in Asian material and are made by various simple tools. Cylindrically shaped drill holes, on the other hand, are produced by diamond drills, most likely by the so-called twin diamond drills. Analogous observations with respect to drilling methods have also previously been made in connection with an Arikamedu sample (Gwinnett and Gorelick, 1988), thus supporting the proposed manufacturing techniques.

The remaining samples from Arikamedu consisted of rough, irregularly shaped pieces without drill holes. The fragments were primarily transparent. In visual appearance, they resembled the excavated garnets depicted by Casal (1949).

All samples from Arikamedu, regardless of group, were homogeneous purplish red to reddish purple, occasionally with a slightly brownish modifier, and without any colour zoning discernible to the unaided eye.

Garibpet Garnets—Visual Appearance

The material from Garibpet (groups E1 and E2) consisted of waterworn pebbles covered by a weathered crust and, prior to preparation for testing, had not undergone further processing or fashioning. After being cleaned or polished on the surface, the diaphaneity of the gem-quality samples examined varied from translucent to fully transparent. Their colour appeared identical to that of the garnets from Arikamedu, and no colour zoning was observed with the unaided eye.

Chemical Properties

Compositional Fields and End-Member Percentages: The great majority of analysed samples from Arikamedu, including both beads and fragments (groups A, B and C), and the rough stones from Garibpet (group E) proved to be garnets with high almandine content. Microprobe data revealed almandine in the range of 77–84 mol%, with minor components of pyrope, spessartine and grossular. Calculations based on some of the 854 point analyses indicated the presence of a small andradite (Fe^{3+}) component of up to 2.0%; other garnet end members were negligible. Table III summarizes the results of the chemical analyses by electron microprobe.

A ternary plot of the molecular percentages of the garnet end members pyrope and almandine and the sum of spessartine + grossular showed that the studied garnets plotted within a relatively small compositional range (Figure 16a). This outcome was seen even more clearly when only a small portion of the full ternary diagram was drawn with an extended scale (Figure 16b). Various binary diagrams representing the

Table III: Microprobe analyses of garnets from Arikamedu and Garibpet, India.[a]

Locality	Arikamedu			Garibpet	
Group	A, B1, B2, B4	B3	C	E1	E2
Description	Transparent faceted bicones or spherical beads	Translucent spherical beads	Transparent irregularly shaped fragments	Transparent pebbles	Translucent pebbles
Composition (wt.%)					
SiO_2	35.42–37.03	35.96–37.28	34.58–37.79	34.74–36.84	35.18–36.72
TiO_2	nd–0.05	nd–0.05	nd–0.05	nd–0.06	nd–0.07
Al_2O_3	21.02–22.28	21.66–22.22	21.46–22.75	20.55–22.24	21.10–21.97
Cr_2O_3	nd–0.08	nd–0.08	nd–0.05	nd–0.08	nd–0.09
Fe_2O_3[b]	0.29–3.25	0.59–2.73	0.29–4.64	0.42–3.48	0.45–2.91
MnO	0.41–2.32	0.75–1.43	0.59–1.37	0.50–2.38	0.51–2.58
MgO	2.52–3.37	2.83–3.57	2.96–3.27	2.42–2.99	2.37–2.99
CaO	0.34–0.90	0.60–0.93	0.47–0.82	0.47–0.73	0.48–0.73
FeO[b]	34.50–37.20	35.05–36.90	34.08–37.33	34.05–37.20	0.45–2.91
FeO_{total}	36.38–38.76	36.41–38.33	36.92–39.03	36.39–38.88	36.30–39.21
Mol% end members[c]					
Almandine	77.6–83.5	77.7–82.3	77.4–81.9	79.4–83.4	79.2–84.0
Pyrope	10.2–14.2	11.3–14.1	11.8–13.0	9.8–12.0	9.6–12.0
Spessartine	0.9–5.3	1.7–3.2	1.3–3.1	1.1–5.5	1.2–5.9
Grossular	0.9–2.5	1.6–2.5	1.3–2.5	0.6–2.1	1.1–2.1

[a] The composition of two anomalous samples from Arikamedu (see Figure 16a) are not included here, since they apparently represent garnets from different primary sources. Abbreviation: nd = not detected.
[b] FeO and Fe_2O_3 were calculated from FeO_{total} by stoichiometry.
[c] Small andradite contents (up to 2.0 mol%) are not included.

main cations replacing one another within the solid-solution series pyrope-almandine-spessartine-grossular (i.e. Mg-Fe-Mn-Ca; Figure 17) also were helpful in elucidating the relatively small compositional range and the overlap of chemical properties for samples from Arikamedu and Garibpet.

The compositional fields for all but one of the transparent Arikamedu samples obtained by author JP at the archaeological site and from local residents (groups A, B1, B2 and B4) showed a complete overlap and, hence, are not reported separately. The compositions of the larger translucent garnet beads from Arikamedu containing veinlets of iron oxides and hydroxides as weathering products (group B3) were found to be in the same range, as were five of the six analysed garnets from the Francis collection (group C). The samples from Garibpet, both transparent (group E1) and translucent (group E2), likewise evidenced substantial overlap in compositional fields. No differences in chemical composition were found between 'clean' samples and those with veins filled by secondary weathering and oxidation processes, regardless of whether the material was from Arikamedu or Garibpet.

Thus, the compositional fields for the two major groups considered here (i.e. samples from Arikamedu and Garibpet) were in close proximity and overlapped to a large extent, as demonstrated in Figures 16 and 17. Neglecting the small andradite percentages, the compositional ranges for the two localities were:

- Arikamedu: 77.4–83.5% almandine, 10.2–14.2% pyrope, 0.9–5.3% spessartine, 0.9–2.5% grossular
- Garibpet: 79.2–84.0% almandine, 9.6–12.0% pyrope, 1.1–5.9% spessartine, 0.6–2.1% grossular

Notably, these almandine contents are in the upper range or even slightly above the values typically observed for gem-quality almandine from other modern localities (Stockton and Manson, 1985).

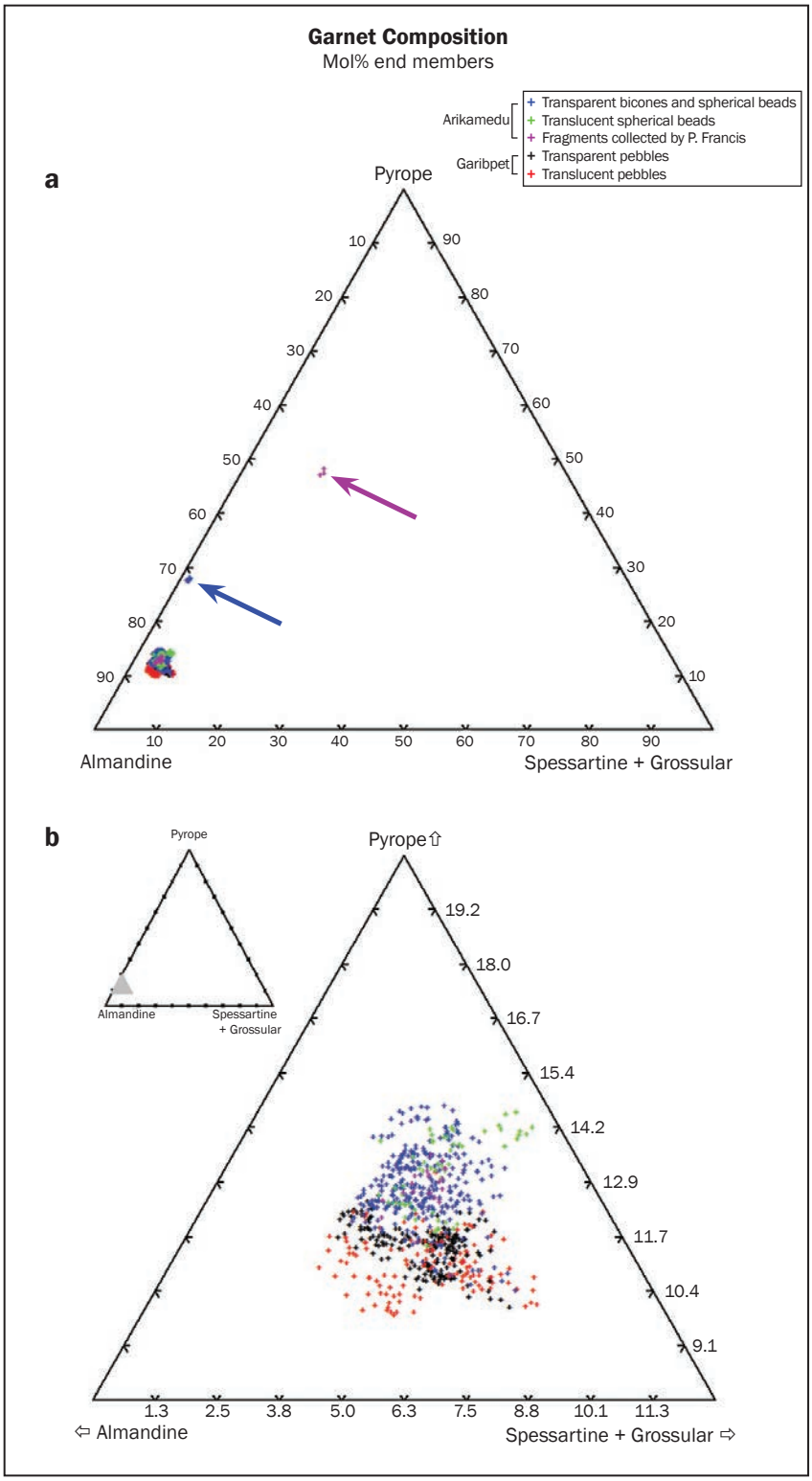

Figure 16: (a) This ternary diagram shows the chemical composition of garnets from Arikamedu and Garibpet calculated for the molecular end-members pyrope, almandine and spessartine + grossular. The compositions plot in a concentrated area, except for two anomalous Arikamedu samples (blue and purple arrows) that fall outside the main compositional field, which are inferred to be from different sources. (b) An enlarged detail of the main compositional field for the Arikamedu and Garibpet garnets corresponds to the area defined by the grey triangle in the inset. Note the extensive overlap in the composition of garnets from Arikamedu and Garibpet.

Oxide weight percentages further revealed that the average MgO content in Arikamedu samples was slightly higher than in Garibpet garnets (Figure 17a–c). The average CaO value was also slightly higher for garnets from Arikamedu (Figure 17a). In contrast, the average MnO content was slightly greater in Garibpet samples and slightly lower in garnets from Arikamedu (Figure 17b,d). Nonetheless, it should be emphasized that, although the average compositions were slightly different, samples from Arikamedu and Garibpet cannot be separated using a single point analysis, due to the wide overlap in the compositional ranges for both groups.

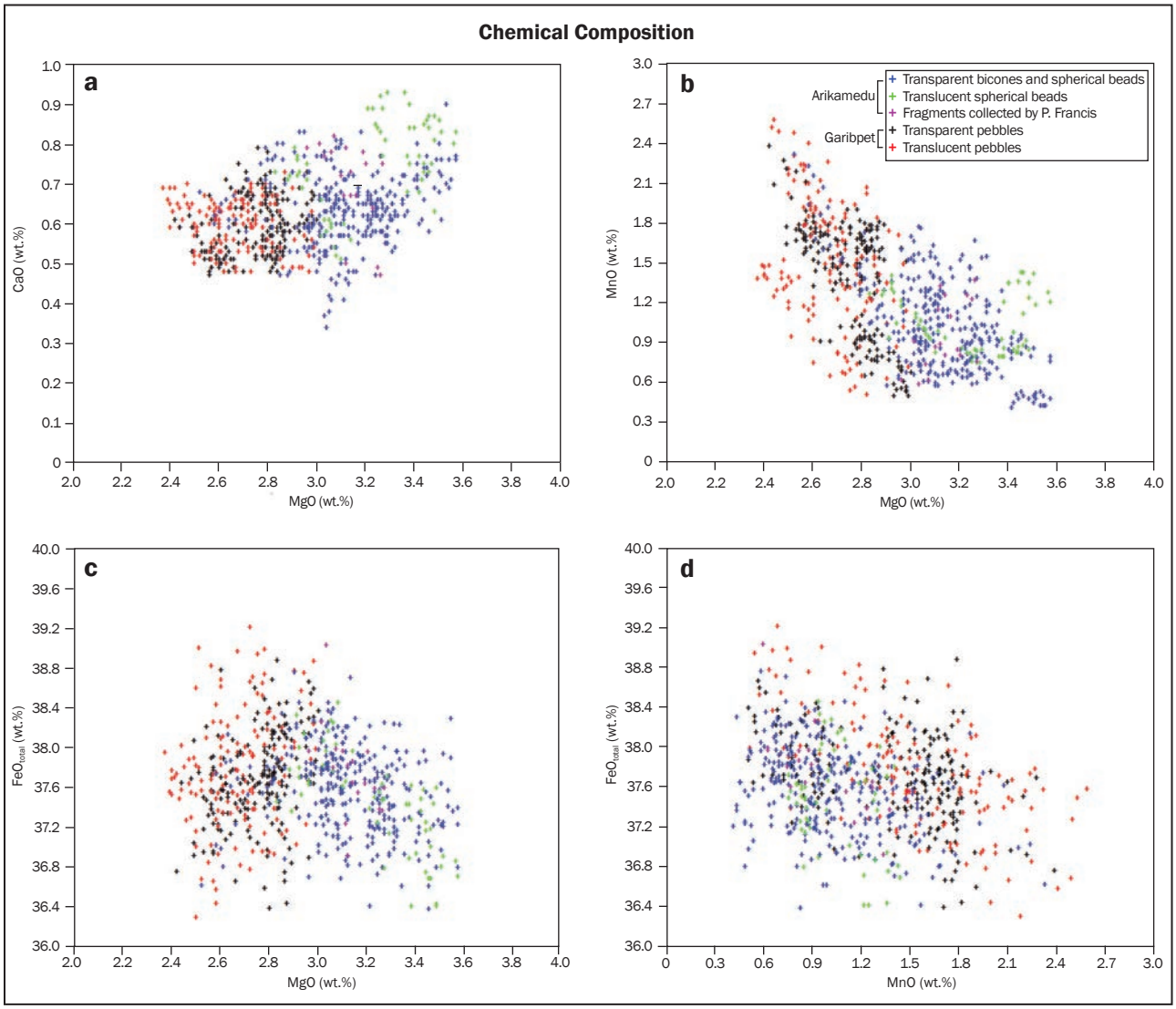

Figure 17: Various binary plots show the chemical composition of Arikamedu and Garibpet garnets, calculated as MgO, CaO, MnO and FeO weight percentages. Again, the plots show extensive overlap in the compositions for garnets from Arikamedu and Garibpet.

There were also two exceptions to the above typical composition, and they were found amongst the samples from Arikamedu (see Figure 16a). One of the beads from group A consisted of 68.4% almandine, 27.1% pyrope, 0.5% spessartine and 1.1% grossular, and one garnet from the Francis collection showed 38.9% almandine, 45.8% pyrope, 2.5% spessartine and 10.4% grossular. Given the notable divergence from the compositional ranges for the vast majority of the Arikamedu and Garibpet stones, these two garnets most likely represent samples from other primary sources, and they presumably came to Arikamedu from localities other than Garibpet.

For general interest, some of the 22 purplish red glass beads from Arikamedu that had been collected by Francis were analysed as well. These samples contained unusually high manganese contents in the range of 4.5 wt.% MnO and relatively low iron percentages of 0.9 wt.% FeO.

Chemical Zoning of Major and Minor Elements: Additional chemical detail was obtained from analytical traverses across the undrilled water-worn pebbles from Garibpet. All of these line-scans showed a decrease in Mn from core to rim of the garnet crystals, which correlated with an increase in Mg (Figure 18). Prominent Mn zonation is characteristic of prograde garnet growth (e.g. Spear, 1995), and such zoning has been reported from several locations (e.g. Lanzirotti, 1995; Borghi et al., 2000). Calcium zoning was less pronounced but still frequently observed. Calcium levels decreased slightly from the core

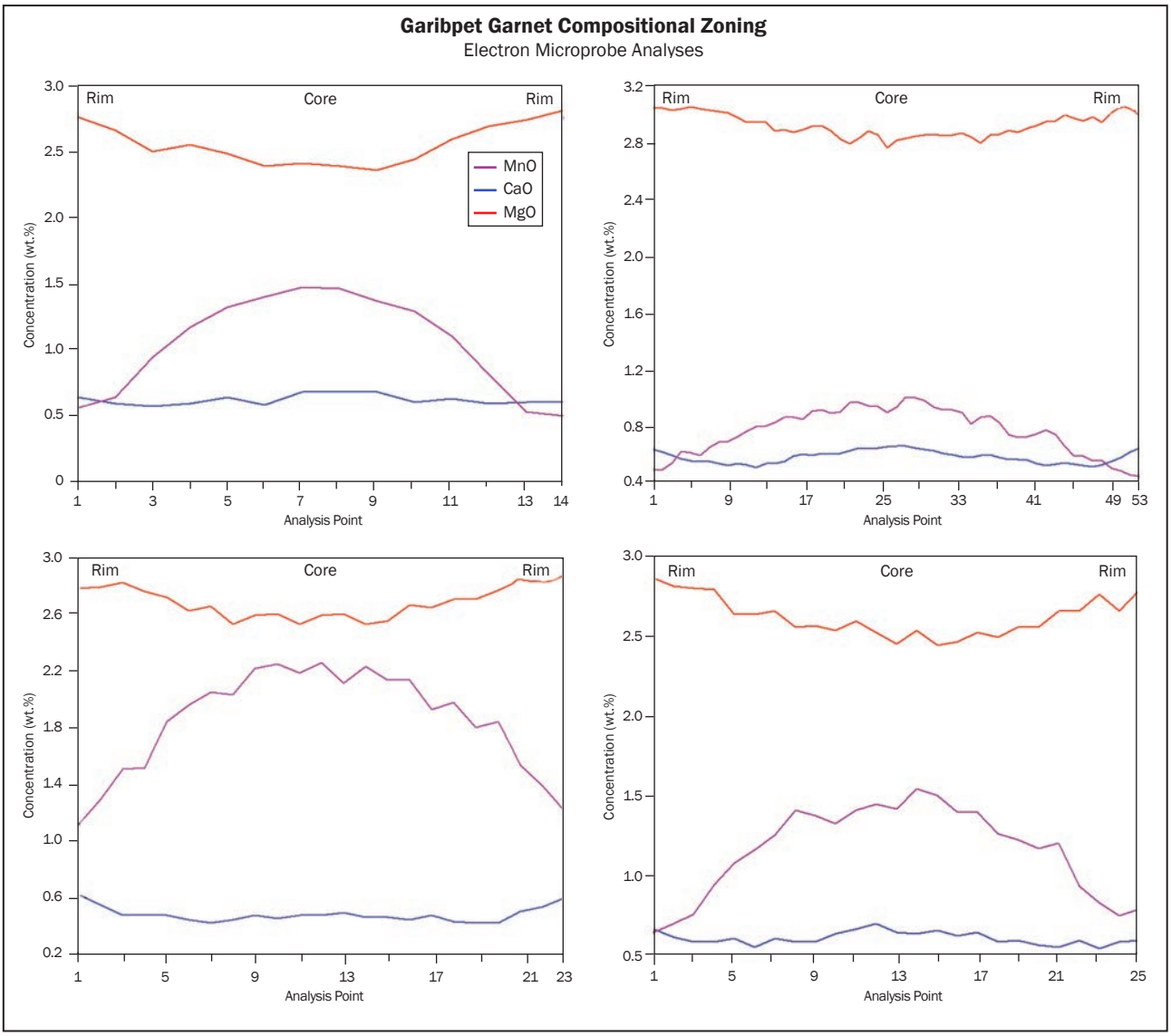

Figure 18: Line-scans by electron microprobe across four garnet samples from Garibpet show chemical zoning of MnO, CaO and MgO. From the core to the rim, MnO decreases and MgO increases; CaO exhibits a subtle but more complex pattern.

outwards and, after a minimum, then reversed direction to increase slightly toward the outermost rim (again, see Figure 18). In some scans, only a portion of the patterns depicted in Figure 18 was apparent, as expected when examining samples derived from secondary deposits in the form of water-worn pebbles, since some of the crystals were broken or abraded and did not represent the complete as-grown garnets.

The four line-scans performed across samples from Arikamedu (two faceted bicones and two spherical beads) revealed the same basic chemical zoning as the Garibpet samples. Again, however, because these beads consisted of only a part of the original as-grown crystals, the scans corresponded merely to a portion of the full area from core to rim and back. More specifically, the scans across the two spherical beads represented an area that could be described as the core plus inner rim, while the scan across one faceted bicone represented an area from core to rim and the scan across the other bicone represented an area from the rim to the core and then to the inner rim.

Crystal Chemistry: Upon plotting the atomic proportions of the main bivalent cations Mg (representing pyrope), Fe (representing almandine), Mn (representing spessartine) and Ca (representing grossular), an inverse correlation between Mg and Mn (Figure 19a) and between Mg and Fe (Figure 19b) was observed. Again, comparing the samples from Garibpet and Arikamedu, slightly

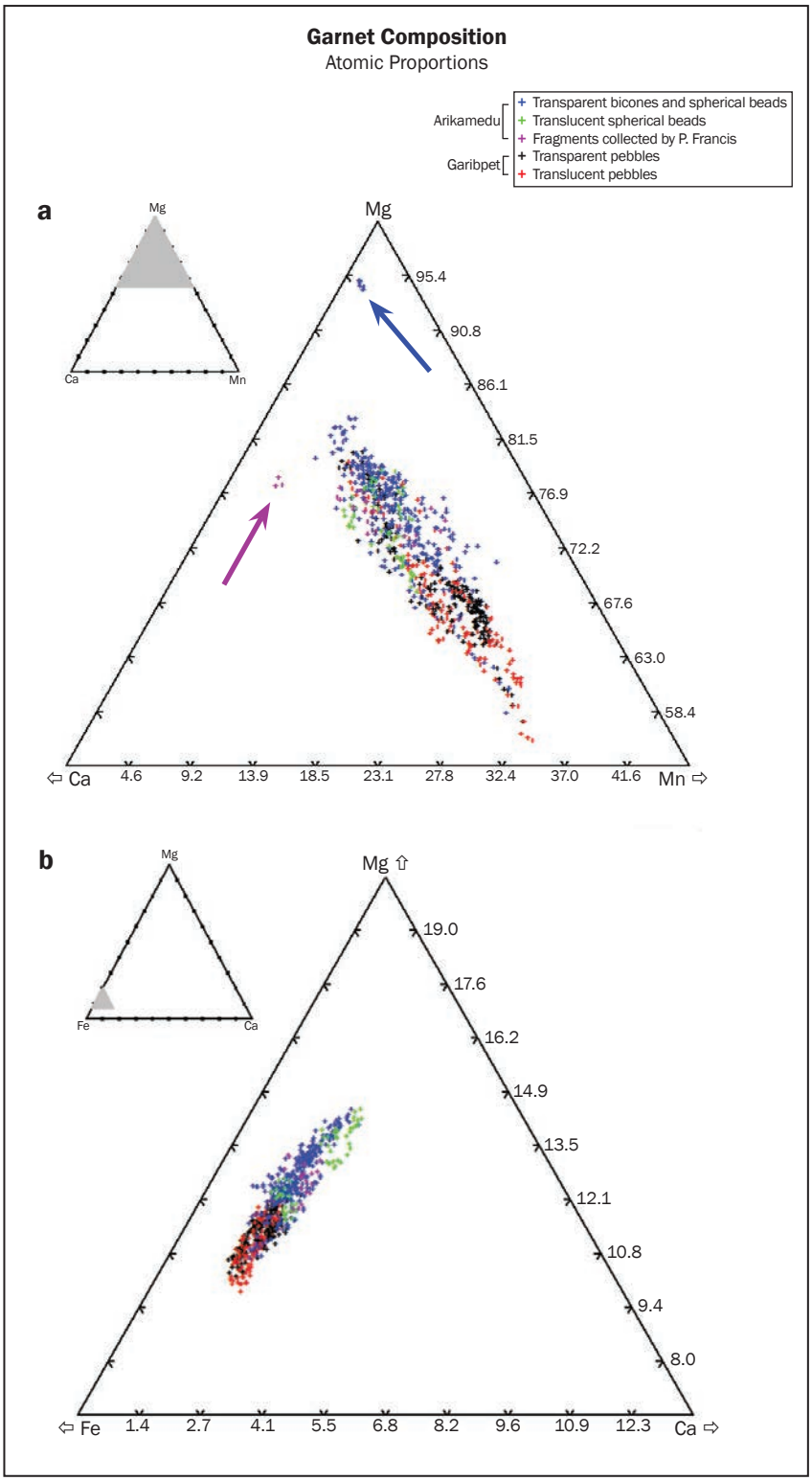

Figure 19: These ternary diagrams show the chemical composition of garnets from Arikamedu and Garibpet, calculated according to atomic proportions for: (a) Mg, Ca and Mn; and (b) Mg, Fe and Ca. Both plots display enlarged details of the full triangular diagrams, as shown by the grey triangles in the insets. The data show an inverse correlation between Mg and Mn (a) and between Mg and Fe (b).

elevated Mg (pyrope) contents were found in Arikamedu garnets, with higher Fe (almandine) and Mn (spessartine) proportions seen in garnets from Garibpet. As previously noted, the compositional ranges for the Arikamedu samples obtained on author JP's visit and those from the Francis collection were substantially equivalent, and the overlap with the Garibpet garnet chemistry was extensive. The results exhibited for both the Arikamedu and the Garibpet garnets were consistent with an isomorphic replacement of Mg by Mn, which was dominant, and a replacement of Mg by Fe, which was subordinate. This isomorphic substitution can be represented by the gen-

Table IV: LA-ICP-MS analyses of garnets from Arikamedu and Garibpet, India.

Locality	Arikamedu			Garibpet		
No. samples	6			7		
No. analyses	30			31		
Element (ppmw)	Mean	Minimum	Maximum	Mean	Minimum	Maximum
Li	22	16	27	22	15	28
P	232	154	371	227	122	313
Ca	3454	2652	4414	3308	2746	5055
Sc	95	74	125	79	55	112
Ti	39	17	61	38	18	55
V	29	19	43	28	17	44
Cr	64	28	198	55	25	255
Mn	8747	3422	17456	11494	3451	19494
Co	33	23	56	33	19	41
Ni	0.5	0.3	1.0	0.6	0.3	1.1
Zn	129	88	159	107	77	129
Y	261	88	548	213	45	401
Zr	6	1	17	4	1	11

eral scheme Mg ↔ (Mn, Fe), applicable to all of the Arikamedu and Garibpet samples. For crystal chemistry considerations, Ca was correlated with Mn in the core of the samples and with Mg in the rim (Figure 18). This leads to a replacement scheme of Mg ↔ (Mn, Fe, Ca) for the core and (Mg, Ca) ↔ (Mn, Fe) for the rim of the garnets. Thus, in general, the small changes in Ca values representing slightly different grossular components were negligible.

Trace Elements: Trace-element contents yielded by LA-ICP-MS are summarized in Table IV. Both the compositional averages and the ranges demonstrated by the analyses were nearly identical for the Arikamedu and Garibpet garnets. A similar relationship was noted for lanthanide rare-earth elements (not shown in Table IV). Several samples from Arikamedu and Garibpet also showed chemical zoning for some trace elements, such as Y, P and Zn. Levels of certain other trace elements were nearly constant within the scans.

Considering in detail both trace and other elements as measured by LA-ICP-MS, chemical zoning between core and rim was strong for Mn and significant for Ca, largely consistent with the results of microprobe analyses. The continuously decreasing Mn contents within scans from core to rim correlated with an increase in Ca and Zn and a systematic decrease in P. Yttrium levels varied but typically in a random way, displaying only minor, and often no, systematic variation between core and rim (Figure 20). The relatively high Y concentrations in the Arikamedu and Garibpet garnets are indicative of a temperature range of ~550–600°C during formation, if buffered by xenotime (Pyle and Spear, 2000). Titanium levels were low (17–61 ppm) and showed a moderate decrease from core to rim.

Inclusions

Insofar as all investigated garnets from Arikamedu had inclusion characteristics identical to those seen in the Garibpet samples, the results are presented together here. The garnets exhibited a very typical zonation with an inclusion-rich core and a rather inclusion-poor rim (Figures 21a,b and 22). The cores reached a diameter of ~2–3 mm, while the rims had a maximum width of ~3–4 mm. Consequently, the small beads and fragments sometimes displayed inclusion features corresponding only to the core or the rim, but not both. The proto- to syngenetic inclusions in the cores comprised, with decreasing abundance: apatite, quartz, ilmenite, rutile, monazite, zircon, graphite and fluid inclusions. The elongated inclusions at times showed a preferential orientation, marking in part a wavy schistosity inherited

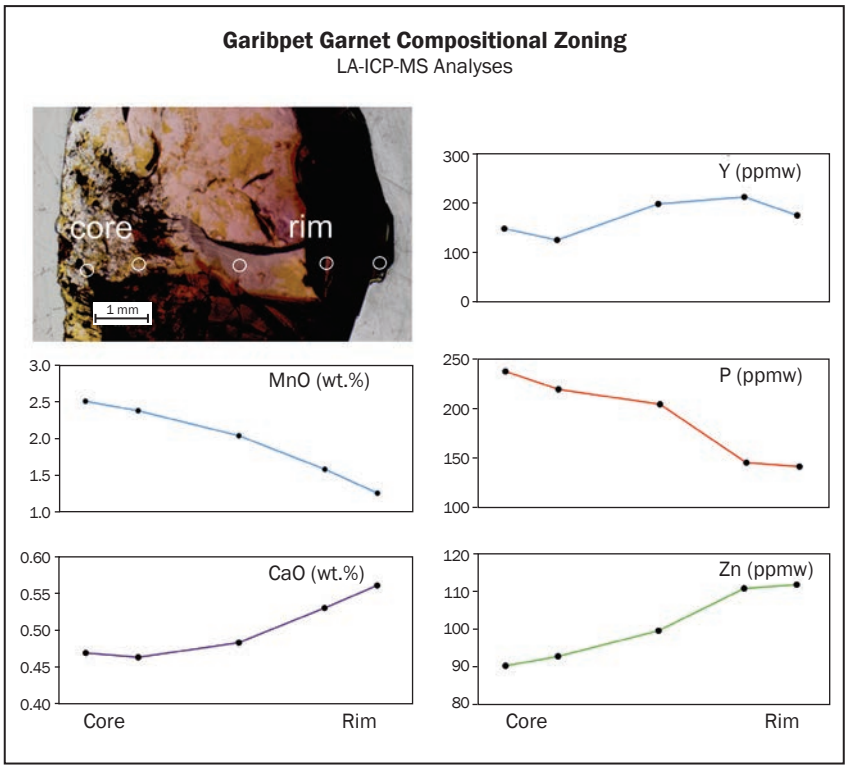

Figure 20: LA-ICP-MS analyses show chemical zoning between the core and rim in a garnet from Garibpet. Variations are seen in two primary garnet compositional elements, Mn and Ca (left), and in the trace elements Y, P and Zn (right). The analysis points are shown by the circles on the photo of the sample. Photomicrograph by H. A. Gilg.

from the metamorphic host rock. At the core-rim boundary, a very characteristic layer of fibrous sillimanite bundles was observed. The sillimanite fibres in some instances reached far into the inclusion-poor rims. Isolated zircon, monazite and quartz crystals also were found occasionally in the rims. The garnets were often cut by brownish-yellowish fractures coated by various generations of goethite or other iron oxides-hydroxides.

Apatite (Figure 21c,d) occurred as elongated, sometimes segmented, euhedral prismatic crystals up to 600 µm long and 60 µm in diameter, with subrounded tips. The apatite was colourless and contained characteristic flaky rounded opaque inclusions up to 20 µm in diameter that Raman microspectroscopy identified as graphite. Apatite was not observed in the inclusion-poor rims of the garnets.

Quartz (Figure 21e,f) was found as rounded to subrounded isometric and elongate transparent grains, as well as occasional polycrystalline aggregates with straight grain boundaries. The aggregates were more common in the inclusion-poor rims and were up to 1 mm long. Also observed was an unusual ring-shaped quartz inclusion.

Sillimanite (Figure 21g,h) was mainly seen at the core-rim boundaries. The fibrous curved aggregates of colourless needles exhibited a diameter of less than 10–30 µm (Figure 23) but reached a length of more than 1 mm. Some acicular sillimanite crystals also continued to grow into the inclusion-poor rims of the garnets (Figure 24).

Monazite (Figure 25a,b) was observed as short prismatic crystals, easily recognizable by their brownish halos, rounded shapes and inclusion-rich nature. The inclusions consisted of opaque phases, identified by Raman analyses as graphite, as well as high-relief colourless rutile crystals. Anhedral monazites up to 60 µm were seen. The monazite inclusions only exceptionally induced fractures in the host garnets.

Zircon (Figure 25c,d) was found as euhedral prismatic crystals and was primarily colourless. In contrast to the monazite inclusions, zircon almost always produced tension fractures.

Ilmenite (Figure 25e,f) often formed rounded, or more rarely subhedral, opaque flakes of up to 300 µm in diameter. These flakes occurred within the cores of the garnet crystals in groups frequently recognizable with the unaided eye. In rare cases, highly irregular shapes were found. With reflected light (Figure 25g,h), the internal structure of the opaque flakes was visible on cut surfaces and showed many rounded inclusions up to 20 µm in diameter. Raman spectroscopy identified these inclusions as quartz.

Rutile (Figure 26a,b) occurred mostly in the form of a three-dimensional network of extreme-

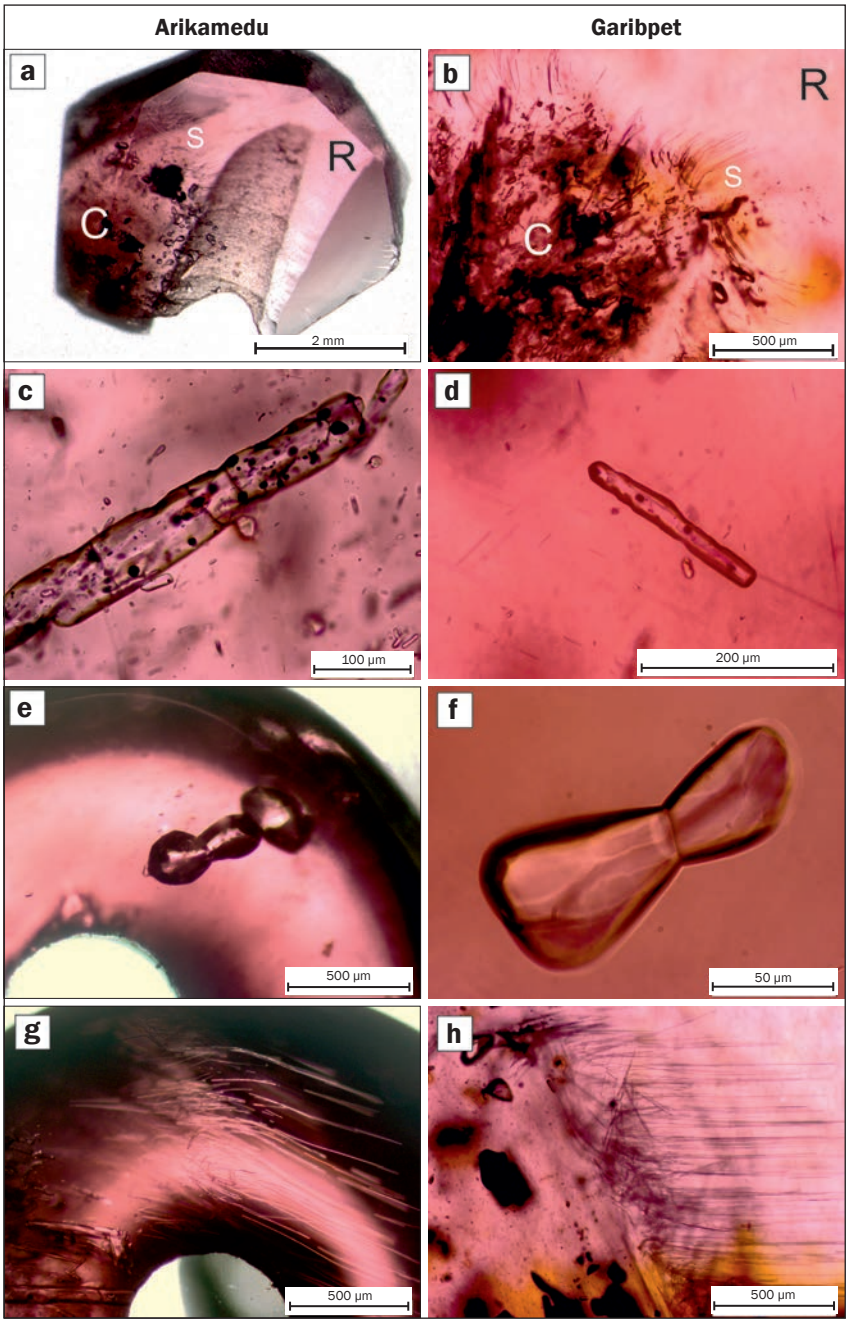

Figure 21: A comparison of the inclusion pattern found in garnets from Arikamedu (left) and Garibpet (right) revealed very similar features which include: (a,b) zoning of inclusions in the core 'C' and rim 'R' of the samples, with 's' representing a zone enriched in tiny sillimanite fibres; (c,d) apatite; (e,f) quartz; and (g,h) sillimanite fibres. Photomicrographs by H. A. Gilg.

ly thin needles oriented along [110] or [111] directions of the host, found exclusively in the cores of the zoned garnets. The distribution of the oriented needles was, however, quite patchy, and many inclusion-rich cores lacked such a rutile network. More rarely a second type of rutile was found as brownish translucent euhedral overgrowth rims on opaque ilmenite cores (Figure 26c,d).

Fluid inclusions (Figure 26e,f) were present in planar arrays along healed fractures, thus indicating their secondary nature. They always displayed a very rugged, irregular surface. Their visual aspect suggested either textural re-equilibration or retrograde reactions with the host, synchronous to the formation of colourless Fe-rich chlorite crystals. Some fractures appeared to have monophase inclusions without vapour bubbles, while others exhibited a vapour bubble filling approximately 40% of the inclusion's volume.

Secondary fractures (Figure 26g,h) were filled with polycrystalline material. Raman microspectroscopy identified them as primarily iron oxides and hydroxides (see also Figure 15).

The complete inclusion pattern just demonstrated has not yet been described for any historical garnet. However, it should be emphasized

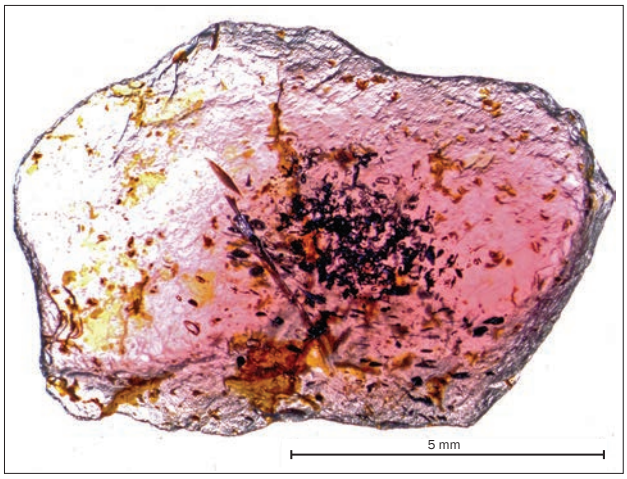

Figure 22: Zoning of inclusions in a garnet pebble from Garibpet shows a heavily included core and a more transparent rim. In the transition area is a zone enriched with a high concentration of tiny sillimanite fibres (visible at higher magnification; see, e.g., Figure 23). Photomicrograph by H. A. Gilg.

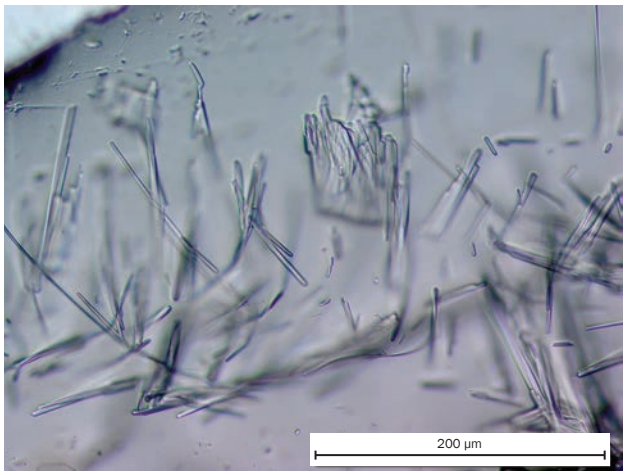

Figure 23: Tiny sillimanite fibres are shown here at high magnification in a transparent garnet bead from Arikamedu. Black-and-white photomicrograph by H. A. Gilg.

that the most characteristic feature—the zone of fine sillimanite fibres—while rare among garnets in general, is not unique. A similar rim of sillimanite fibres surrounding a core with numerous inclusions such as biotite, ilmenite and rutile was described recently from north-eastern Connecticut, USA (Axler and Ague, 2015).

Discussion and Conclusions

Garnets found at Arikamedu, historically one of the most important bead-producing locations in India, were characterized and compared to samples collected from an alluvial deposit in the Garibpet area, located approximately 640 km north of Arikamedu. In particular, six criteria were considered to evaluate whether the Arikamedu garnets were originally sourced from Garibpet:

1. Chemical composition, namely in terms of the percentage of garnet end members
2. Chemical zoning for major and minor elements within the crystals from core to rim
3. Trace-element contents
4. Zoning of trace elements from core to rim
5. General inclusion assemblage
6. Distribution and zoning of inclusions

The authors suggest that such criteria are key in any endeavour to establish a common source for groups of gem samples, including historical material. In applying these criteria to garnets from Arikamedu and Garibpet, the following results were obtained:

a. Broad overlap in the population fields for the chemical composition of samples from both localities, with a nearly identical average and only small differences
b. An identical scheme of chemical zoning from core to rim for major and minor elements
c. The same group of trace elements in essentially identical percentage ranges
d. A consistent situation with respect to zoning of trace elements with insignificant variability for most elements and distinct zoning for some others (e.g. Y, P and Zn in several samples)
e. The same general assemblage of inclusions, incorporating numerous specific minerals (mainly apatite, quartz, ilmenite, rutile, monazite, zircon and sillimanite)

Figure 24: Coarse acicular sillimanite needles were observed in a small number of the garnets from Arikamedu. Photomicrograph by H. A. Gilg.

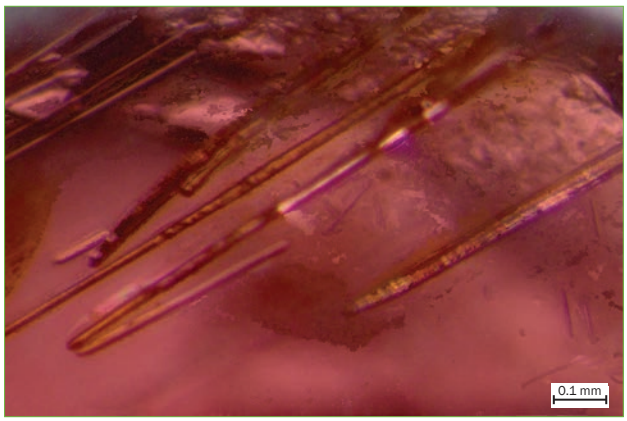

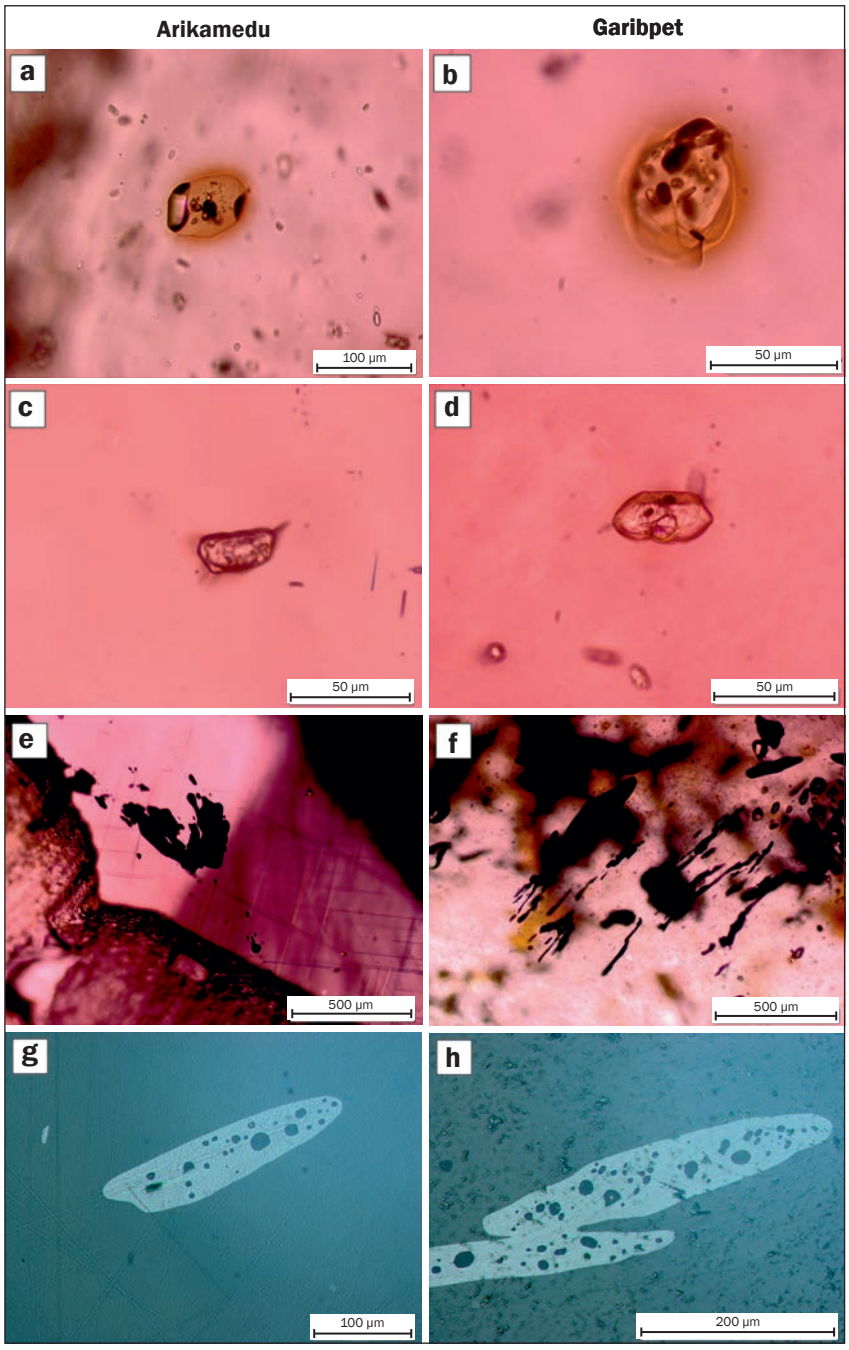

Figure 25: Very similar inclusion patterns are seen in garnets from Arikamedu (left) and Garibpet (right), including: (a,b) monazite with graphite and rutile inclusions; (c,d) zircon with tension cracks; (e,f) ilmenite flakes; and (g,h) ilmenite flakes with quartz inclusions. Photomicrographs by H. A. Gilg in transmitted light (a–f) and reflected light (g,h).

f. A consistent zoning of inclusions between core and rim, with the boundary separating these two zones being enriched with fibrous sillimanite needles

Given the detailed consistency of features listed above for the chemical criteria 2, 3 and 4, and very similar properties related to end-member composition populations (criterion 1), the authors are convinced that the garnets worked at the bead-making site of Arikamedu originated from the Garibpet area. The small differences observed in the average chemical compositions can probably be explained by the fact that the Garibpet samples were collected from one secondary source within a large garnet-bearing area (which includes the primary source of Garibpet Hill) and, therefore, are not entirely representative of the Garibpet rough material used for bead production at Arikamedu. However, neither detailed data for garnets collected at various places within the extensive Garibpet area, nor a comparison of samples found within the secondary garnet-bearing gravels and the primary garnet-bearing host rock, is presently available.

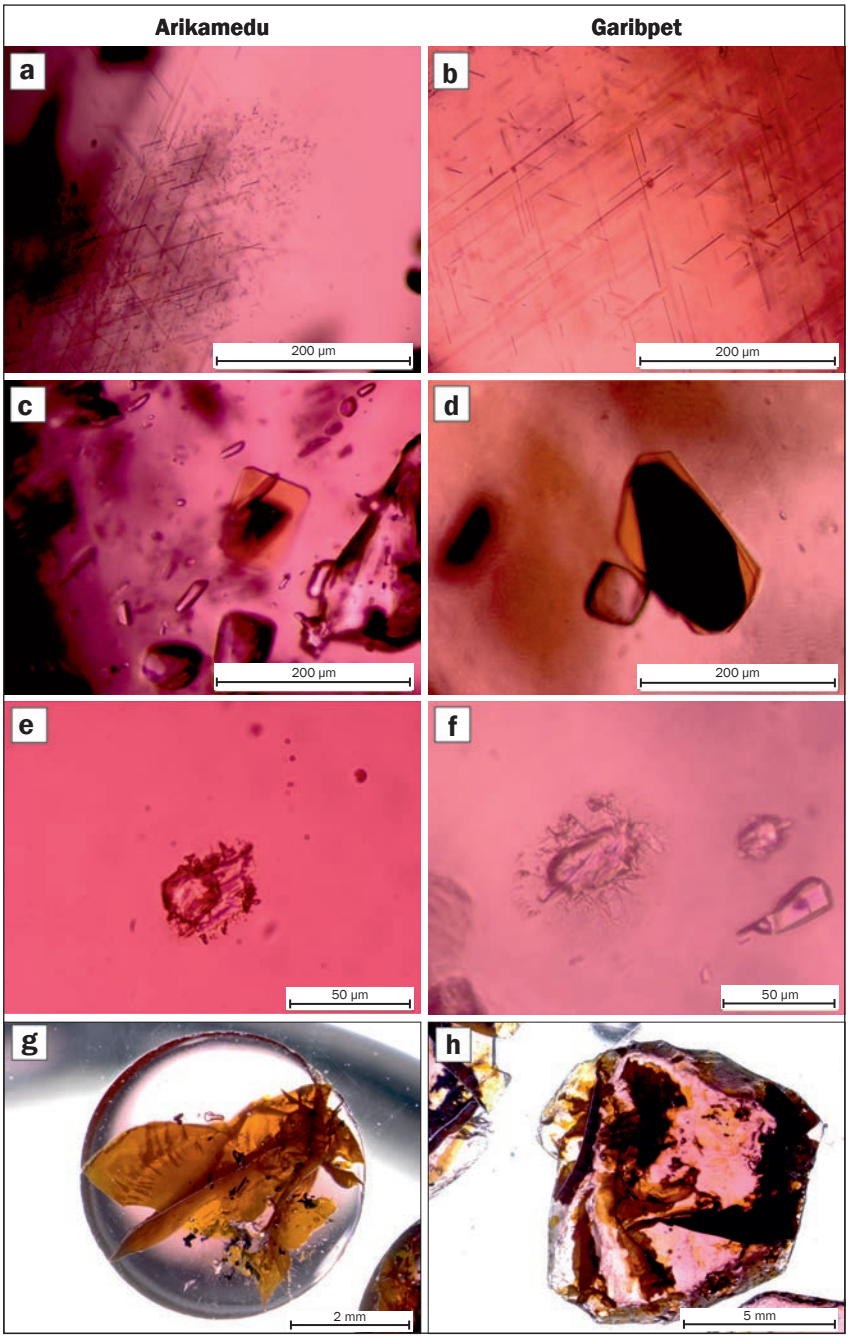

Figure 26: Additional characteristic inclusion patterns in garnets from Arikamedu (left) and Garibpet (right) include: (a,b) networks of rutile needles; (c,d) transparent rutile overgrowth on opaque ilmenite crystals; (e,f) fluid inclusions; and (g,h) secondary fractures filled with polycrystalline material, primarily iron oxides and hydroxides. Photomicrographs by H. A. Gilg.

The Arikamedu-Garibpet garnets characterized in this study plot—according to chemical composition and depending on the type of plot and the elements selected—within or close to one of the major types or clusters of garnets established for early medieval samples, namely within Type I of Calligaro et al. (2006–2007) or Cluster B of Gilg et al. (2010). However, they are distinguishable by their higher Mn, Cr and Y concentrations. This scenario suggests a potential problem of excessive breadth in the existing definitions circumscribing the types or clusters. Such breadth, in turn, calls into question the usefulness of these categories, not only for understanding relationships amongst historical and/or contemporary samples but also for guiding origin determination. The overlap is mostly due to the poor quality of some (but not all) chemical analyses (H. A. Gilg, unpublished research). Indeed, by considering only good-quality analyses (i.e. those with a garnet composition and formula close to ideal or at least acceptable garnet stoichiometry), there is a reduction in overlap and a better definition of garnet types or clusters.

With respect to the general inclusion assemblage and inclusion zoning (criteria 5 and 6), the data for the Arikamedu and Garibpet samples are

quite consistent, thereby supporting the relationship indicated by their composition. Conversely, no inclusion pattern similar to that described for the Arikamedu/Garibpet samples has been seen by the authors to date in garnets from numerous recent productive localities in India and Sri Lanka.

Again, however, it must be emphasized that a particular group of inclusions alone should not be relied upon as sufficient for origin determination. For instance, samples excavated in Unterhaching, Bavaria, which plot chemically in the Type II/Cluster A compositional field, display an inclusion pattern consisting of rutile needles, zircon, quartz, sillimanite and ilmenite (Gast et al., 2013). This clearly demonstrates the possibility of similar and partly overlapping inclusion assemblages among garnets from different origins and dictates that all features of such inclusion patterns should be considered. To give an illustrative example, the characteristic graphite-bearing apatite inclusions found in Garibpet and Arikamedu garnets are absent from Type II/Cluster A garnets.

Hence, the authors suggest that the results of the present study should prompt a re-evaluation, at least partly, of the established types or clusters. On a general level, it has become apparent that some of the types or clusters might consist of several subgroups and should be split accordingly. More specifically, in doing so, the methodology should perhaps be refined beyond a simple narrowing of compositional ranges. Because it remains possible, and even likely, that there will be samples from different origins with overlapping or similar chemical compositions, regardless of the ranges chosen, the following two queries should be considered. First, how many criteria should be used to define the types or clusters? Second, how many such criteria would any given sample need to fulfil before being assigned to a particular type or cluster? In some cases, it may be feasible only to offer probabilities of assignments.

The authors are of the opinion that the traditional practice of using mainly chemical composition, occasionally supplemented by identification of a few inclusions (not a complete pattern incorporating any possible zoning), is deficient. As one example of the shortcomings of the current method, two garnets set in a Hellenistic gold earring described by Gartzke (2004) plot within the same compositional field as the Arikamedu-Garibpet samples (for further details, see Thoresen and Schmetzer, 2013). Without considering multiple additional features, however, it is clear that such information offers only minimal support for drawing any conclusions regarding the provenance of these two Hellenistic garnets. Thus, we feel that a more detailed correlation of properties is necessary to assign a sample to an established type or cluster of garnets. Stated otherwise, only samples which fulfil more than one, or preferably more than two, criteria (taking into account the concentrations of all measured main, minor and trace elements as well as the type, shape and distribution of inclusions) should be assigned to a particular garnet type or cluster. Conversely, any proposed assignment of samples that correspond only in one feature (e.g. in chemical composition) should be indicated as not assigned with certainty.

Some of the early medieval garnets classified as Type I/Cluster B, with the underlying analyses derived mostly from excavated jewellery pieces, overlap in chemical composition with the range determined for the Arikamedu-Garibpet samples. Other criteria pertaining to the early medieval samples, however, are unavailable or vague. Hence, at a minimum, further detailed inclusion studies would be necessary to establish whether the same inclusion assemblage, and especially the zoning of inclusions with a sillimanite-enriched boundary, is present in the medieval garnets. Such examinations could go far in proving or disproving whether stones from the Garibpet deposit were used for early medieval cloisonné metalwork jewellery.

In forthcoming studies, the results described in this article will be compared with those derived for garnets from other excavations—such as stones from Tissamaharama, Sri Lanka—and with properties of engraved early medieval samples. As a harbinger of such future work, the authors would highlight that a Byzantine garnet, engraved with a Christian motif and dated to the end of the 6th or beginning of the 7th century AD, has shown consistency with the Garibpet material in average chemical composition, chemical zoning, inclusion assemblage and inclusion zoning. This, in turn, could have significant implications for establishing whether the text of Cosmas Indicopleustes (see Banaji, 2015), written in the mid-6th century AD, refers to the shipment of Garibpet garnets from harbours located on the Coromandel Coast at or close to Arikamedu.

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Simultaneous X-Radiography, Phase-Contrast and Darkfield Imaging to Separate Natural from Cultured Pearls

Michael S. Krzemnicki, Carina S. Hanser and Vincent Revol

The separation of natural from cultured pearls is mainly based on the interpretation of their internal structures, which traditionally have been visualized by X-radiography and more recently by X-ray computed microtomography (micro-CT). In this study, the authors present a new analytical approach using a grating interferometer, which simultaneously generates an X-radiograph, a phase-contrast image and a small-scale scattering or darkfield image. The latter two additional images provided by this technique offer detailed and complementary information, as they are especially sensitive for visualizing tiny material inhomogeneities in pearls such as fissures, organic layers and cavity structures. Using seven selected natural and cultured pearl samples and a strand of non-beaded freshwater cultured pearls, the authors demonstrate that this new analytical approach offers versatile and rapid pearl identification possibilities, especially as it is possible to analyse not only single loose pearls but also entire strands and necklaces. Compared to micro-focus digital radiography and micro-CT, certain limitations in resolution still remain with the described prototype setups, and as such this new methodology should be considered a helpful complementary technique to the classical radiography of pearls.

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Introduction

One of the main duties of gemmological laboratories working for the pearl trade is to distinguish natural (Figure 1) from cultured pearls. This separation, as well as the identification of pearl treatments, is commonly based on a combination of testing methods, among them visual (microscopic) observation, ultraviolet-visible reflectance spectroscopy (Elen, 2002; Karampelas et al., 2011), Raman spectroscopy (Barnard and de Waal, 2006; Karampelas et al., 2007), X-ray luminescence (Hänni et al., 2005), X-ray diffraction (i.e. Lauegrams; Hänni, 1983) and trace-element analysis (e.g. energy-dispersive X-ray fluorescence [EDXRF] spectroscopy; Gutmannsbauer and Hänni, 1994).

However, for decades by far the most important approach to identifying natural and cultured pearls has been X-radiography and, in more recent years, micro-CT (Anderson, 1932; Farn, 1986; Kennedy, 1998; Scarratt et al., 2000; Schlüter et al., 2005; Hänni, 2006; Strack, 2006; Wehrmeister et al., 2008; Sturman, 2009; Karampelas et al., 2010;

Figure 1: This seven-strand pearl necklace contains 543 saltwater natural pearls (4.55–9.90 mm in diameter) of exceptionally matching shape and lustre. The length of the strands varies from approximately 43.5 to 57.0 cm (including the clasp), and the total declared weight of the pearls is 1,006 ct. The necklace is from the Hussein Alfardan pearl collection and was tested and analysed at the Swiss Gemmological Institute SSEF. Photo by Luc Phan, SSEF.

Krzemnicki et al., 2010; Cartier and Krzemnicki, 2013; Rosc et al., 2016). Both methods enable the visualization and interpretation of internal features in pearls such as cavities, ring structures, dehydration fissures and bead structures.

Here the authors describe a new and promising complementary method to visualize internal structures in pearls: simultaneous X-ray differential phase-contrast imaging and small-angle scattering (or darkfield imaging). The technique was initially presented by Krzemnicki et al. (2015), and the current article provides a gemmological description and interpretation of analysed pearl structures for a range of natural and cultured samples. As such, it follows a more general introduction into phase-contrast and darkfield imaging for pearl testing by Revol et al. (2016). Initially developed using synchrotron light (David et al., 2002; Momose et al., 2003), this imaging technology is nowadays usable with standard X-ray tubes (Pfeiffer et al., 2006) and—coupled with an improved design of X-ray interferometers—is characterized by a considerably enlarged field of view and range of usable X-ray energies (Revol et al., 2011). Phase-contrast imaging and darkfield imaging are based on the interaction of X-rays with pearls, similar to classical radiography, but they offer additional information and/or sensitivity to minute internal features. This technology is especially useful for detecting small structural inhomogeneities such as organic matter in the calcium carbonate matrix of a pearl. Both single pearls and entire strands can be analysed, and the technique is thus capable of rapid and versatile non-destructive pearl characterization.

Figure 2: The X-ray phase contrast and darkfield imaging prototype EVITA, developed and installed at the CSEM research facility in Switzerland, was one of the instruments used in this study. Photo © V. Revol, CSEM Switzerland.

Principles of X-ray Phase-Contrast and Darkfield Imaging

Classical radiography is based on the attenuation (decrease of intensity via absorption and scattering) of X-rays passing through an object. This happens as the X-rays interact with the electrons of the atoms in the specimen. The amount of attenuation correlates to the atomic weight of the elements present (i.e. their atomic number), thus heavier elements will absorb X-rays more effectively. As a consequence, dense calcium carbonate appears light, whereas organic matter and voids within pearls appear dark in X-radiographs.

Phase-contrast imaging relies on the phase shift of radiation (e.g. X-rays) propagating through an object. For our study, a grating interferometer was used (e.g. Figure 2), which enabled us to transform the phase shift caused by the sample

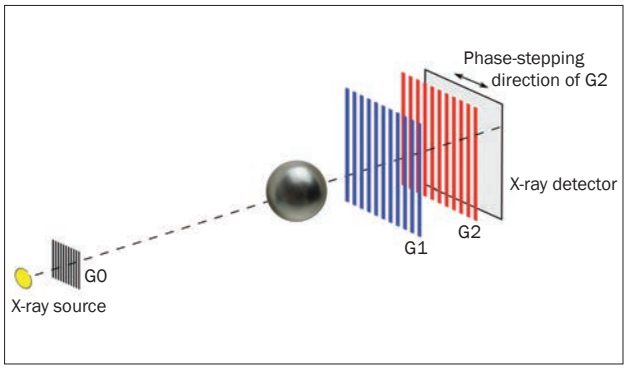

Figure 3: In this schematic diagram of the grating interferometer, the pearl sample is placed between the gratings G0 and G1, while grating G2 is moved in a direction perpendicular to the X-ray beam while recording the resulting intensity with the detector. After Revol et al. (2016).

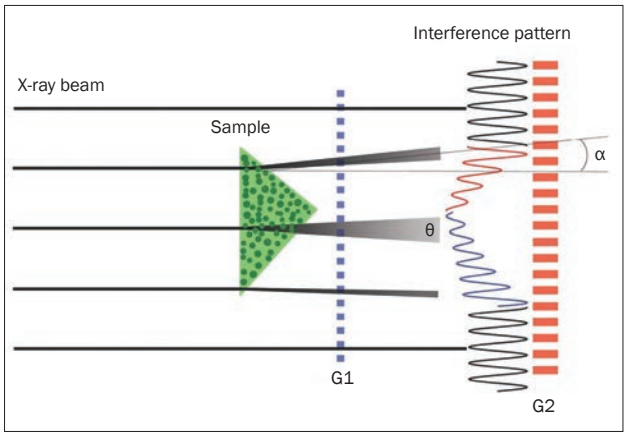

Figure 4: This diagram shows the principle of the X-ray grating interferometer for measuring a differential phase-contrast image (angular deflection α) and a darkfield image (scattering power θ). Depending on the gradient of the index of refraction, α changes from a positive to a negative angle, as illustrated by the red and blue sections of the interference pattern.

into variations in intensity, which could then be recorded by a conventional digital X-ray detector. The principle of the grating interferometer is explained extensively in the literature (Pfeiffer et al., 2008; Revol et al., 2010). As illustrated in Figure 3, the radiation emitted from an X-ray tube first passes through a source grating (G0), which is an aperture mask with transmitting slits that create an array of X-ray 'line sources' that are directed toward the sample. The phase grating (G1) behind the sample splits the beam array by imprinting periodic phase modulations, resulting in interference (intensity modulations) of the split rays in the plane of the final analyser grating (G2) through the Talbot effect (Weitkamp et al., 2005; Pfeiffer et al., 2008; Zhu et al., 2010). In the presence of a sample, the phase front is distorted, which leads to a change in the intensity, position and amplitude of the interferences, as illustrated in Figure 4. The change in the interferences can be recovered by using the phase-stepping approach presented in Weitkamp et al. (2005). It consists of moving one of the grids (e.g. G2 in our setup) perpendicular to the beam while recording the intensity with the detector. For each pixel, the resulting intensity variations are compared to a reference measurement made without a sample to extract the average intensity, position and amplitude of the interferences (Pfeiffer et al., 2008; Zhu et al., 2010).

The method allows the simultaneous generation (using the same instrumental parameters) of three images: a conventional X-ray absorption image (radiograph), a differential phase-contrast image and a darkfield image. As illustrated in Figure 4, the phase-contrast image is related to the deflection angle by the gradient of the phase shift. The darkfield image is a measurement of the ultra-small-angle scattering of the beam induced by inhomogeneities in the sample at the microscopic scale. This method thus gathers otherwise inaccessible structural information below the resolution limit of the X-ray detector. (For more on the experimental setup, see Revol et al., 2011.)

Pearls are especially suitable for this type of analysis because the organic matter and void/cavity/fissure features within their carbonate matrix provide inhomogeneities that can result in strong phase contrasts compared to conventional attenuation-based imaging (Revol et al., 2016).

Materials and Methods

To illustrate both the capabilities and limitations of X-ray phase-contrast and darkfield imaging, we selected seven natural and cultured pearls (Table I) from the molluscs *Pinctada maxima, P. margaritifera, P. radiata, Hyriopsis cumingii* and *Strombus gigas*, ranging from 3.68 to 25.30 ct. These specimens included three natural pearls (saltwater) and four cultured pearls (one non-beaded freshwater cultured pearl, one non-beaded saltwater cultured pearl and two beaded saltwater cultured pearls). In addition, we analysed an entire strand of 44 colour-treated (by silver salt) non-beaded freshwater cultured pearls. Previously, we had fully characterized all of these

Table I: Natural and cultured pearl samples analysed for this study.

Sample no.	Type	Species	Origin	Weight (ct)	Size (mm)	Colour
NP-2e	Saltwater natural pearl	*P. radiata*	Bahrain	6.49	10.3	Light cream
P14-11	Saltwater natural pearl	*P. maxima*	Northern Australia	3.68	8.2	White
NP-2j	Natural conch pearl	*Strombus gigas*	Caribbean Sea	6.58	14.3	Light pink
CP-2d	Beaded saltwater cultured pearl	*P. maxima*	Indonesia	25.30	15.4	Yellow
CP-2e2	Beaded saltwater cultured pearl	*P. margaritifera*	French Polynesia	12.76	12.1	Black
CP-2m	'Keshi' non-beaded saltwater cultured pearl	*P. margaritifera*	French Polynesia	8.14	13.9	Black
CP-1b	Non-beaded freshwater cultured pearl	*Hyriopsis cumingii*	China	9.92	13.0	White
CP-54	Non-beaded freshwater cultured pearl strand (44)	*Hyriopsis cumingii*	China	~3.5 each	~7.5 each	Dark grey (silver treated)

samples (and confirmed their species identification) using X-ray luminescence, radiography, micro-CT (except for the cultured pearl strand) and EDXRF (including three selected cultured pearls in the strand), among other techniques.

We used two different grating interferometer setups: a research prototype (S50-4) and, in a second round, an improved prototype (EVITA), both installed at the Centre Suisse d'Electronique et de Microtechnique (CSEM) research facilities in Switzerland. This instrumentation is currently under commercial development and is not yet available for purchase. The characteristics of each setup and the corresponding measurement parameters are listed in Table II. The X-ray gratings were produced at CSEM from 100 or 150 mm-diameter silicon wafers by photolithography, wet etching and electroplating. The sample holder could accommodate up to ~30 loose pearls, or a complete pearl strand/necklace. Further details of the setup and analytical conditions are described in Hanser (2015) and Revol et al. (2016).

The images were reconstructed with the help of the phase-stepping approach using the translation of the G2 grating (Weitkamp et al., 2005) by employing proprietary algorithms developed at CSEM. For pearls, the phase-contrast image results in a virtual surface topography, with highly absorbing zones appearing slightly elevated and the sample virtually illuminated from the side

Table II: Characteristics of the grating interferometers used in this study.

Parameter	S50-4 setup	EVITA setup
Design energy	50 keV	40 keV
X-ray source	60 kVp, 16.65 mA, focal spot 1 × 1 mm^2, 0.8 mm beryllium window	60 kVp, 10 mA, focal spot 0.4 × 0.4 mm^2, 0.8 mm beryllium window
Filter	No filtering	No filtering
Detector	2048 × 1024, 48 µm pixel size	3072 × 1944, 75 µm pixel size
Distance G0–G1	161.3 cm	107.5 cm
Distance G1–G2	40.3 cm	21.5 cm
Grating size	7 × 5 cm	10 × 10 cm
Magnification	1.3	1.4
Effective pixel size in the image	37 µm	54 µm
Number of phase steps	9	19
Exposure time per phase step	6 s	0.7 s
Averaging	10	10
Total exposure time	9.0 min	2.2 min

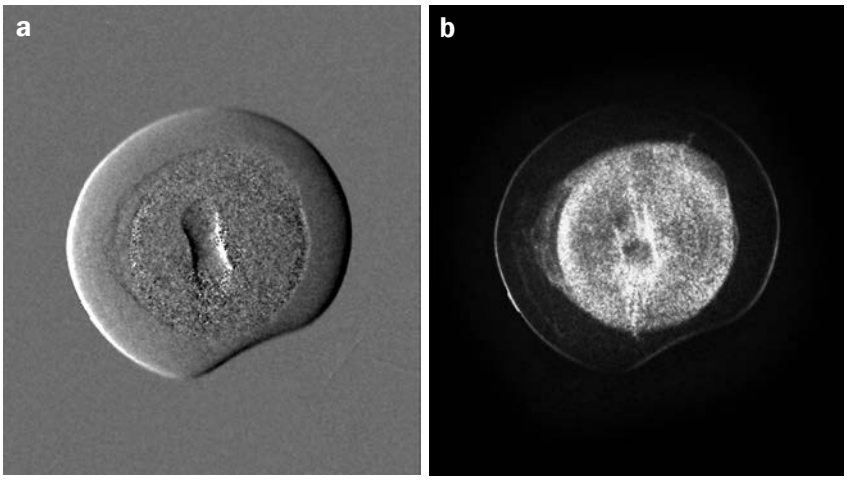

Figure 5: (a) Differential phase-contrast imaging of a natural pearl (9.5 mm in diameter) reveals an enriched amount of organic material in its core (pixelated with lower relief) as compared to its nacre rim, which appears to be slightly elevated. (b) Darkfield imaging of the same pearl shows a high amount of small-angle scattering in the organic-rich core (appearing bright); the outline of the pearl is also marked by a bright line as a result of scattering at the pearl's surface. The distinct columnar structure in the centre of each image corresponds to the slightly inclined drill hole. Images by V. Revol.

(Figure 5a). Zones of intense inhomogeneities (and scattering) appear strongly pixelated. The darkfield image is more similar to a classical X-radiograph, but it displays bright areas and streaks in the zones where small-angle scattering at material inhomogeneities occurs in great number. As such, the organic-rich heterogeneous zones in pearls (e.g. the core zone in particular) usually appear brighter than the very densely packed layers of nacre, which is contrary to the appearance of an X-radiograph. The outline of the investigated sample is also displayed, as small-angle scattering occurs at the pearl/air interface (Figure 5b). To improve such images, a built-in bandpass filter using ImageJ software was used uniformly to filter out structures larger than 10 pixels (equivalent to 577 µm). Some of the images were further enhanced by applying Adobe Photoshop functions such as gamma correction, exposure, line sharpening and colouring.

Results

The samples in this study were selected for the presence of internal features commonly encountered in natural and cultured pearls. The interpretation of their structures is based on both the presented images and detailed analyses by micro-CT. For each of the following five examples, we present X-radiographs, phase-contrast images and darkfield images, all obtained simultaneously with the EVITA setup (see Table II).

Natural Pearl with a Core Enriched in Organic Matter

The X-radiograph of saltwater natural pearl NP-2e (*P. radiata*, Figure 6a) is characterized by a grey nacre layer of ~3 mm thickness surrounding a darker grey core consisting of radially arranged calcite prisms interlayered with organic matter (Figure 6b). The outermost part of the core appears distinctly darker as a result of an enrich-

*Figure 6: A sequence of images is shown for saltwater natural pearl NP-2e (*P. radiata *from Bahrain), which weighs 6.49 ct and measures 10.3 mm in diameter. The photograph (a) was taken from the side, while the radiograph (b), phase-contrast (c) and darkfield (d) images were taken from above. This pearl is characterized by an organic-rich core of radially arranged calcite prims surrounded by an approximately 3 mm-thick nacre layer. The prominent structure in the centre of images b–d corresponds to the drill hole. Pearl photo by Carina Hanser and other images by V. Revol.*

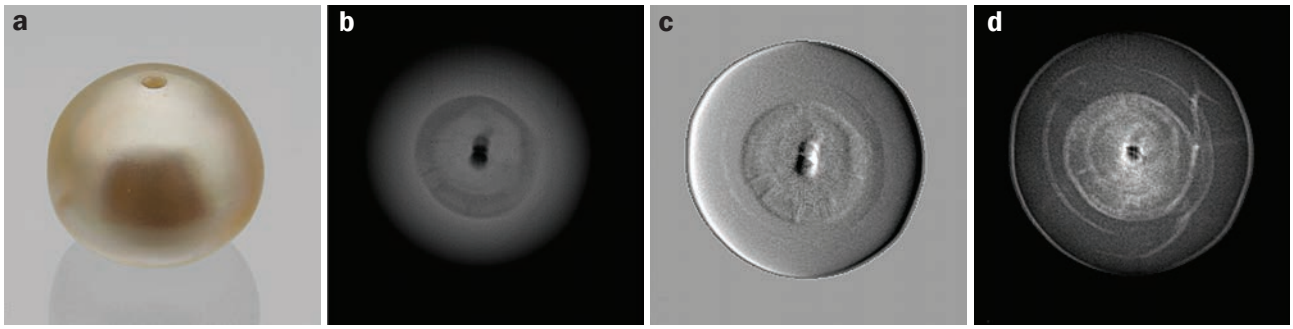

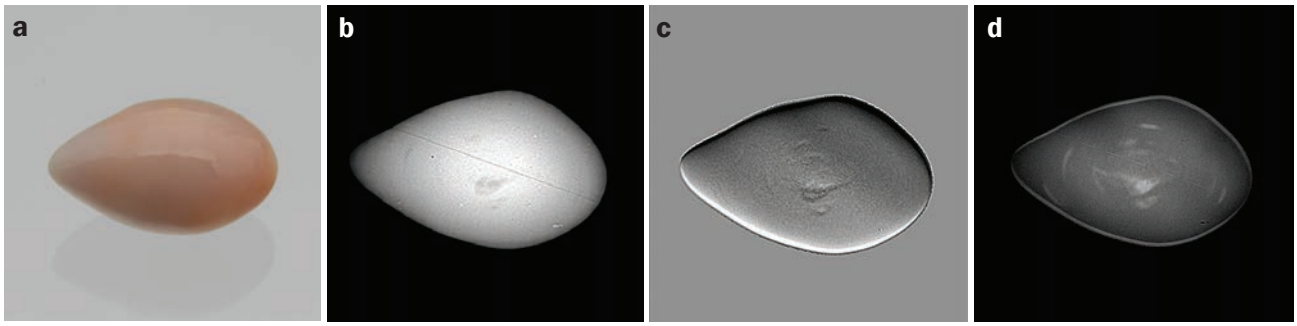

Figure 7: (a) This natural pearl (sample NP-2j from the H. A. Hänni reference collection at SSEF) is from the queen conch Strombus gigas *and was collected from the Caribbean Sea in the early 1990s; it weighs 6.58 ct and is 14.3 mm long. The radiograph (b), phase-contrast (c) and darkfield (d) images reveal an irregularly shaped cavity structure, not to be mistaken as an indication of cultured origin. The diagonal line (which is particularly visible in the radiograph) is an instrumental artefact. Pearl photo by Carina Hanser and other images by V. Revol.*

ment of organic matter. The phase-contrast image (Figure 6c) of the same pearl shows a marked contrast between the organic-rich core and the quasi-uniform rim of nacre, apparent as a 'quasi'-surface topography. Within the nacre are weak ring structures typical of nacre layers in pearls. The organic-rich outer portion of the core shows a number of radial fractures. In the darkfield image (Figure 6d), the core appears distinctly brighter because of an increased amount of small-angle scattering in this calcium-carbonate (calcite) zone enriched in organic matter. The darkfield image further reveals the complex structures of fine fissures and cracks in the nacre layer, which were not discernible or only barely visible in the radiograph and phase-contrast images.

Natural Conch Pearl with Cavity Structure

Conch pearls from marine gastropods such as *Strombus gigas* (e.g. sample NP-2j; Figure 7a) often show no to very weak internal structures in radiographs (Figure 7b). The irregularly shaped cavity and additional weak surrounding growth rings in this natural conch pearl are evident in the phase-contrast and darkfield images (Figure 7c,d). Such cavity structures are occasionally seen in natural pearls from marine gastropods and should not, or only cautiously, be interpreted as an indication of a cultured formation without additional evidence such as a bead structure. This is in contrast to pearls from bivalve molluscs, where similar cavities are commonly encountered, especially in non-beaded cultured pearls (e.g. from *P. maxima* or *Hyriopsis cumingii*), and as such provide a strong indication of cultivation (see below).

Beaded Saltwater Cultured Pearl

The beaded saltwater cultured pearl CP-2d (*P. maxima*, Figure 8a) reveals rather weak structures in the radiograph, indicating a small bead (~5 mm) surrounded by a thick and nearly unstructured nacre layer (Figure 8b). As a result of

*Figure 8: (a) This beaded saltwater cultured pearl CP-2d (*P. maxima *from Indonesia; side view) weighs 25.30 ct and is 15.4 mm in diameter. The radiograph (b), phase-contrast (c) and darkfield (d) images were taken from above. It contains a rather small bead overgrown by a thick layer of nacre (about 5 mm), best seen in the phase-contrast and darkfield images. The columnar structure in the centre of each image corresponds to the slightly inclined drill hole. Pearl photo by Carina Hanser and other images by V. Revol.*

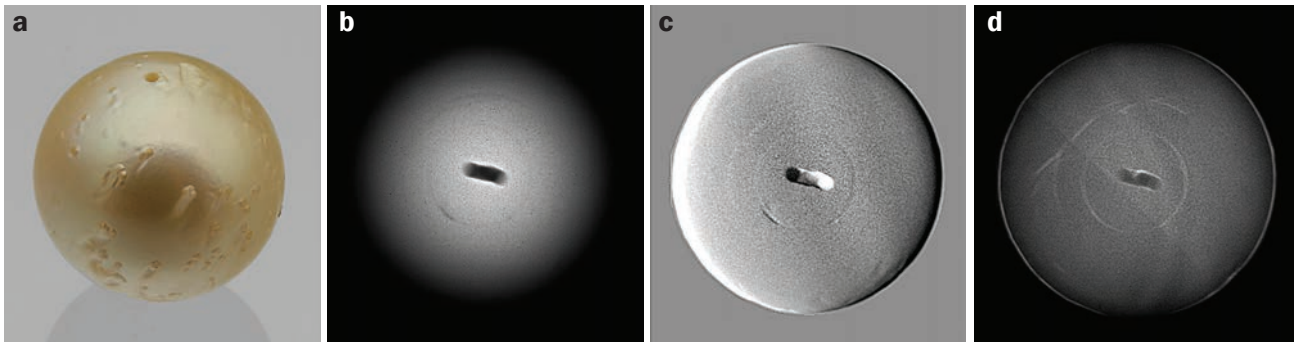

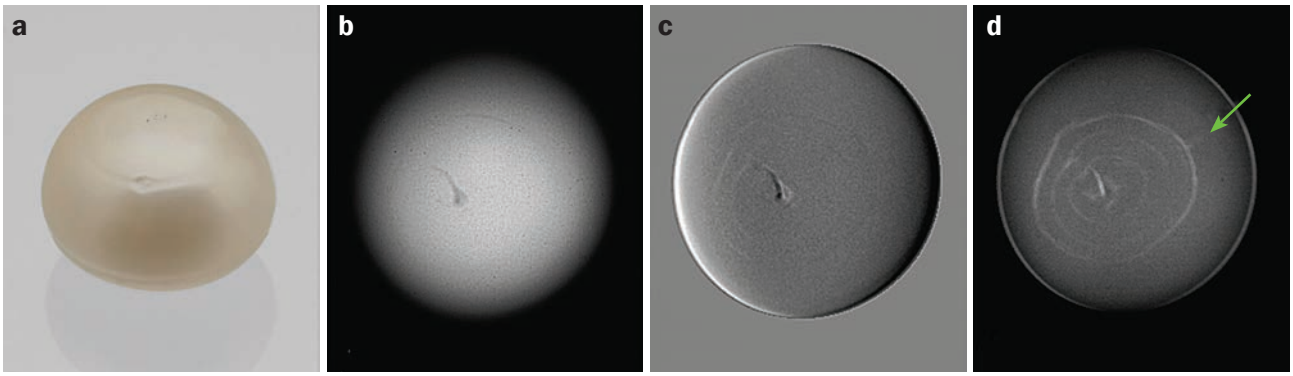

*Figure 9: (a) This non-beaded freshwater cultured pearl CP-1b (*Hyriopsis cumingii *from China; side view) weighs 9.92 ct and is 13.0 mm in diameter. The radiograph (b), phase-contrast (c) and darkfield (d) images were taken from above. It reveals a small irregular (comma-shaped) cavity surrounded by ring structures and a small crack (green arrow) that is only seen in the darkfield image. Pearl photo by Carina Hanser and other images by V. Revol.*

the thick nacre overgrowth, the commonly observed difference in brightness between the bead (made from a freshwater shell) and the nacre overgrowth (slightly more transparent to X-rays and thus slightly darker) is barely visible in the radiograph. In the phase-contrast image and, especially, in the darkfield image (Figure 8c,d), the perfectly round bead is more discernible, as are growth circles and dehydration fissures in the nacre overgrowth. Both features were also observed in micro-CT images of this sample.

Non-Beaded Freshwater Cultured Pearl

The non-beaded freshwater cultured pearl CP-1b (*Hyriopsis cumingii*, Figure 9a) exhibits a small central cavity structure in the X-radiograph (Figure 9b), highly characteristic for this type of cultured pearl. The phase-contrast and darkfield images (Figure 9c,d) add even more detail to the internal structures, with additional fine growth rings and a small crack only seen in the darkfield image. This crack was not visible in micro-CT images of this sample.

'Keshi' Non-Beaded Saltwater Cultured Pearl

The non-beaded saltwater cultured pearl CP-2m (*P. margaritifera*, Figure 10a) has a baroque shape, characteristic of cultured pearls formed within a collapsing pearl sac after ejection of the bead that had been inserted for second-generation cultured pearl production. This is also known as a second-generation 'keshi' cultured pearl. The complex structure of the large organic-rich cavity can be observed equally well in the X-radiograph, phase-contrast and darkfield images (Figure 10a–c). The darkfield image again delivers the most detailed insight, strongly highlighting the complexly folded internal structure of the sample (compare with Figure 15 of Sturman, 2009). This is due to the small-angle scattering effects (appearing bright in the darkfield image) at these material inhomogeneities.

Entire Strand of Cultured Pearls

Because of the large field of view afforded by the instrumentation, it is possible to analyse entire

*Figure 10: (a) This 'keshi' non-beaded saltwater cultured pearl CP-2m (*P. margaritifera *from French Polynesia) weighs 8.14 ct and is 13.9 mm in diameter. The complex spatial structure of the large cavity in its core is discernible in great detail in the radiograph (b), phase-contrast (c) and darkfield (d) images. Pearl photo by Carina Hanser and other images by V. Revol.*

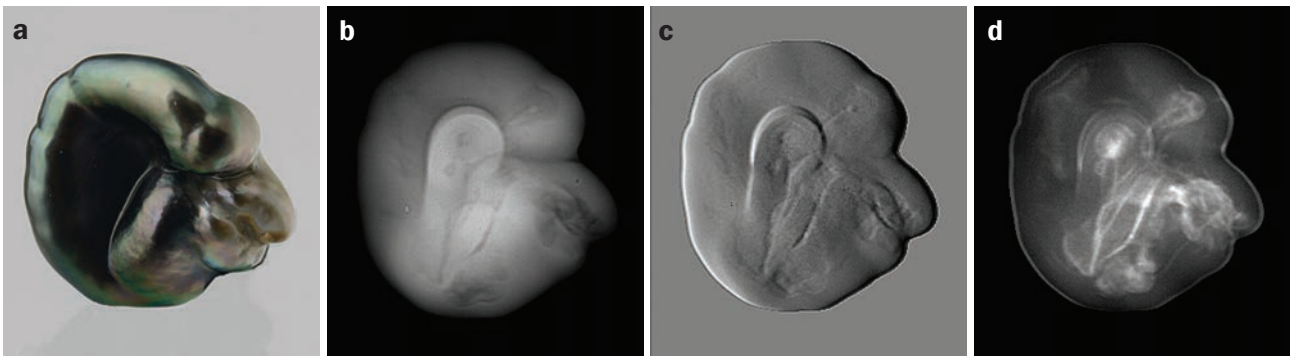

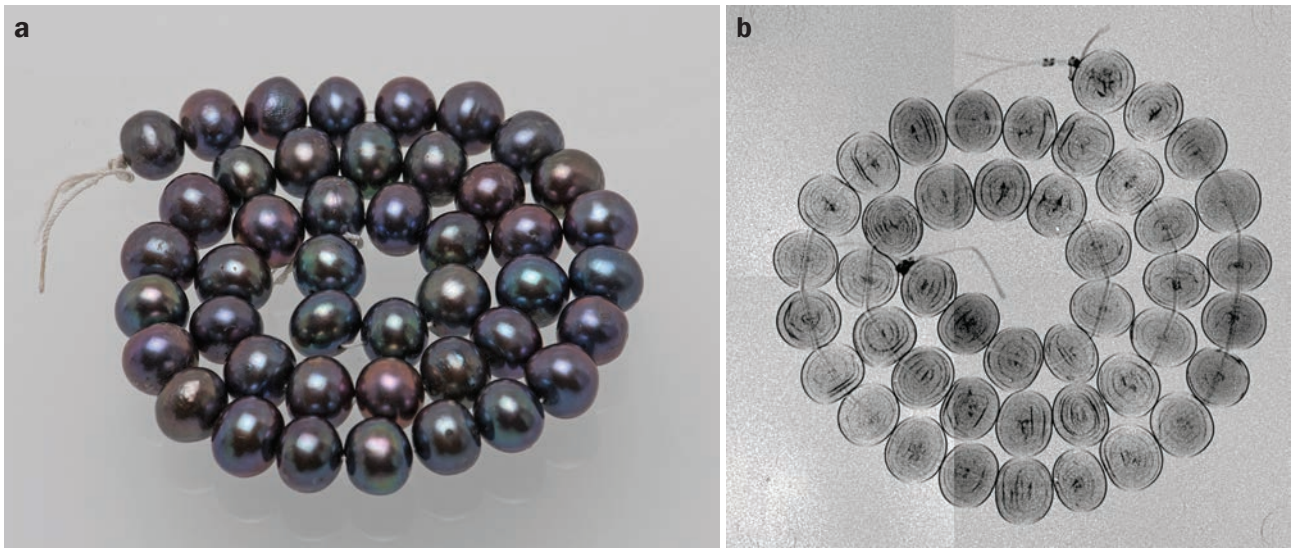

Figure 11: A strand of dyed non-beaded freshwater cultured pearls from China (sample CP-54, ~7.5 mm in diameter each) is shown in a photograph (a; photo by Vito Lanzamfame, SSEF) and in an inversed darkfield image (b; image by V. Revol). The latter view shows a central cavity structure in each pearl that is characteristic of culturing; these features are readily displayed in greater detail than with traditional radiography.

strands/necklaces at once, a prerequisite for rapid and reliable routine analysis in a gemmological laboratory. The darkfield image of the strand of non-beaded freshwater cultured pearls in Figure 11a was acquired with the S50-4 setup (see Table II). Owing to the relatively limited field of view of this setup, four images were stitched together to obtain the final image displayed in Figure 11b. As also shown by Figure 11b, the black-and-white tones in darkfield images can be inverted for a more straightforward comparison with conventional X-radiographs.

Discussion

As described above, X-ray phase-contrast and darkfield imaging offer simultaneous complementary information to 'classical' radiography, all in one analytical run. However, it should be noted that the current setup and instrumental limitations provide X-radiographs at lower resolution and contrast than state-of-the-art digital radiography units (e.g. Yxlon Cougar). Figure 12 compares such X-radiographs. This drawback is compensated by the additional information simultaneously delivered by phase-contrast and darkfield imaging. However, this makes it a complementary analytical approach rather than a full replacement of 'classical' radiography at this time.

By using a rotating sample stage, it is also possible to obtain three-dimensional tomographic reconstructions of a pearl with the grating interferometer setup. This is shown for natural pearl P14-11, which is characterized by several dehydration fissures along the nacre growth rings and

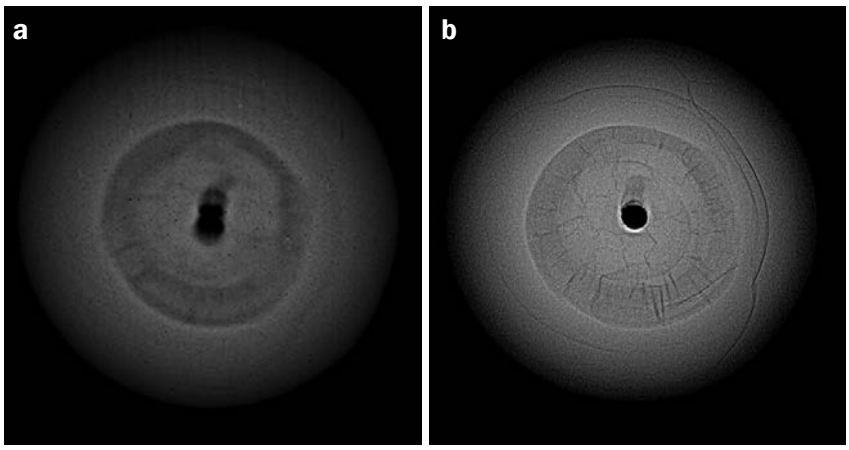

Figure 12: A significant difference in resolution is seen here in the X-radiographs of natural pearl NP-2e (10.3 mm in diameter) that were obtained with a grating interferometer (left, image by V. Revol) and a Yxlon Cougar micro-focus X-ray inspection system (right, image by J. Braun, SSEF).

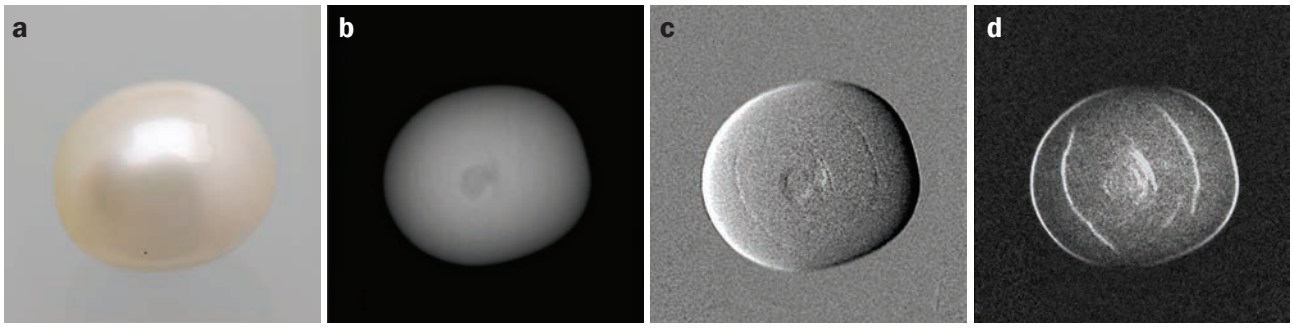

*Figure 13: (a) This saltwater natural pearl P14-11 (*P. maxima *from northern Australia) weighs 3.68 ct and measures 8.2 mm in diameter. The radiograph (b), phase-contrast (c) and darkfield (d) images reveal its internal features. Pearl photo by Carina Hanser and other images by V. Revol.*

a roundish centre zone slightly enriched in organic matter (Figures 13 and 14). These internal structures are best illustrated by darkfield tomography, and the three-dimensional reconstruction offers insights into the shell-like shape of the fissures on each side of the pearl, together with the spherical outline of the organic-rich core.

Additional possibilities with these digitally registered images are to study internal features along a line-scan (see, e.g., Revol et al., 2016), or to overlay X-radiographs with the simultaneously registered phase-contrast and darkfield images for better visualization (see, e.g., Hanser, 2015).

As demonstrated with the natural and cultured pearls studied here, X-ray phase-contrast imaging is useful for visualizing aspects such as cores containing an enrichment of organic matter. Darkfield imaging is particularly powerful, as it offers valuable and complementary information to traditional radiography. The small-angle scattering in darkfield images reveals even tiny and thin material inhomogeneities at high contrast, such as fine fissures within the bead of a cultured pearl (Figure 15) or small central cavity structures that are especially characteristic of non-beaded freshwater cultured pearls from China.

The authors did not observe any colour modification of the samples after imaging them with either analytical setup. Although the possibility that such colour changes may occur in rare cases cannot be excluded completely, the same applies to classical radiography (which has a similar range of exposure time and energy).

The main disadvantage of this new analytical technique at this stage is the low resolution of the simultaneously registered X-radiograph compared with state-of-the-art digital radiography (and micro-CT). The authors are currently working on this aspect with the aim to considerably improve the resolution of the X-radiographs in the near future.

Conclusion

The separation of natural from cultured pearls greatly relies on the interpretation of their internal structures. This study shows that X-ray differential phase-contrast imaging and X-ray darkfield imaging provide detailed information for pearl analysis that is complementary to traditional X-radiography. By using a grating interferometer coupled with a standard industrial micro-focus X-ray tube, it is possible to simultaneously generate

Figure 14: A sequence of video still images shows a full rotation of a darkfield tomographic reconstruction of saltwater natural pearl P14-11. Its internal features consist of an interlocked and shell-like arrangement of dehydration fissures (red arrows) in the nacre layer and a spherical organic-rich zone in the core (yellow arrow). The orientation of the pearl is rotated by 90° compared to that shown in Figure 13. Images by V. Revol.

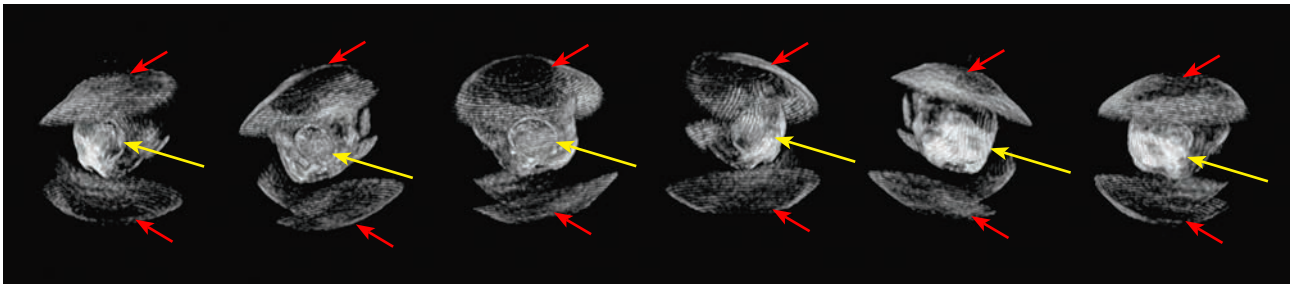

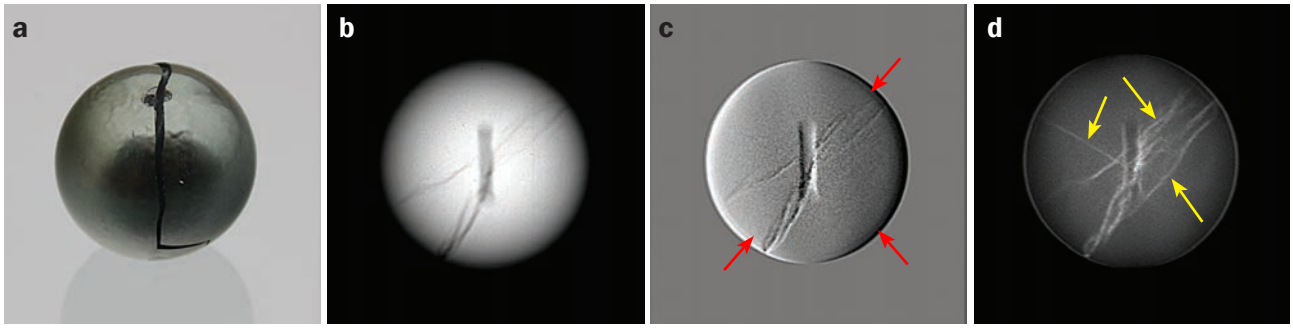

Figure 15: Fissures that develop in the bead of a cultured pearl during the drilling process are a major problem for both pearl farmers and the trade, as they can result in cracking of the pearl—as happened here for sample CP-2e2 during analytical manipulation (a; 12.1 mm in diameter). Compared to the radiograph (b), phase-contrast (c) and darkfield (d) imaging are both very useful for visualizing such fine structures of fracturing (yellow arrows), even at an incipient stage. The sample only has a thin layer of nacre over the large bead; the red arrows mark the boundary between the bead and the nacre overgrowth. Pearl photo by Carina Hanser and other images by V. Revol.

X-radiographs along with differential phase-contrast and darkfield images of pearls within a few minutes. There is no need to sequentially analyse a sample to obtain these three complementary images. Moreover, the ability to analyse not only single pearls but entire strands and necklaces makes this a rapid and versatile new approach, which in the authors' opinion has great potential for pearl characterization in the near future.

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Camels, Courts and Financing the French Blue Diamond: Tavernier's Sixth Voyage

Jack Ogden

The memoirs of the French gem merchant and traveller Jean-Baptiste Tavernier (1605–1689) are well known and shed much light on the European gem trade with India during the 17th century. A surviving factum (a submitted summary of a legal case) provides some supplementary information, as it details a claim made by Tavernier against the children and heirs of Parisian jeweller Daniel Chardin following his sixth trip to the East. We learn something of Tavernier's practical problems regarding extortionate Ottoman customs-duty demands and how he financed his trade. The diamonds he purchased in India were bought and sold by him on behalf of a syndicate of French merchants and investors, all of whom received a share of the profits. The royal goldsmith Jean Pitan (or Pitau), who received a brokerage fee for their sale, was a close relative by marriage to Tavernier. One of the stones brought back to France by Tavernier on this sixth and final voyage was a large blue diamond of slightly over 115 metric carats, which he sold to King Louis XIV in 1669. It was recut in 1673 as 'the blue diamond of the crown' or French Blue, and ultimately became what we know as the Hope Diamond in the Smithsonian National Museum of Natural History, Washington DC, USA. A letter dated early 1668 between British diplomats in the region provides a tantalizing hint that Tavernier might have purchased this large blue diamond in Isfahan, Persia, for the equivalent then of £7,000, and also sheds some light on Tavernier's competitor, David Bazu.

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Introduction

Jean-Baptiste Tavernier's memoires, *Les Six Voyages de J. B. Tavernier*, first published in Paris in 1676, are perhaps the best-known historical record of a gem dealer (Tavernier, 1676a,b). They recount in detail his six journeys to the East in the mid-1600s and provide a wealth of information, from the mining of diamonds to the trade routes to the Mughal court. The title page of the 1678 Amsterdam edition of Tavernier's *Voyages* in Figure 1 shows Tavernier buying diamonds at a mine in India (Tavernier, 1678). Extracts of his work are quoted in almost every study relating to the gem trade in the past, and the *Voyages* even form

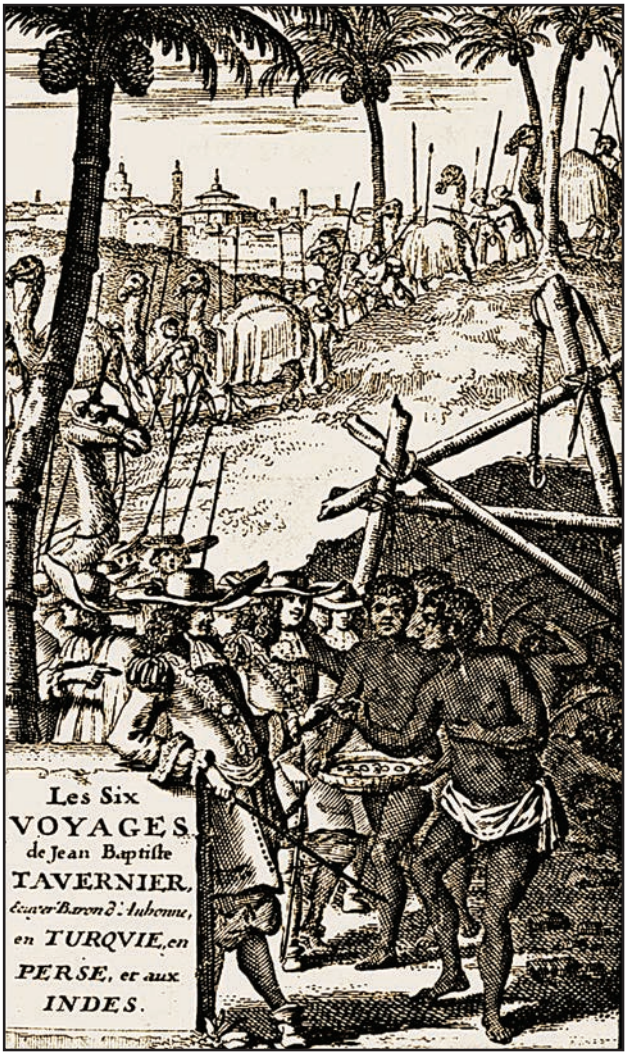

Figure 1: The title page of the 1678 Amsterdam edition of Tavernier's Voyages *shows him being offered diamonds at a mine site in India, with a caravan of camels in the background.*

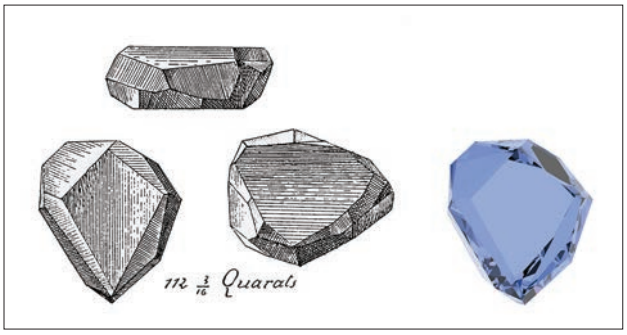

Figure 2: A drawing of three views of Tavernier's large blue diamond, as published in most editions of his Voyages, *is shown together with a modern three-dimensional computer rendering of the stone prepared by the author.*

Figure 3: This CZ replica of the French Blue diamond was faceted by Scott Sucher (The Stonecutter, Tijeras, New Mexico, USA), and represents the stone as it was cut by Pitan. Photo by Scott Sucher.

the basis of an engaging historical novel (Wise, 2009). Tavernier provides us with information on the diamond trade in India in the 1600s and on some of the renowned diamonds mined there, including what was perhaps the Koh-i-Noor and the Great Mughal, the latter probably equivalent to the Orlov (Malecka, 2016).

However, the stone that Tavernier is best associated with is a large blue diamond of 112$^{3}/_{16}$ old carats (115.28 metric carats) that he obtained on his sixth trip (Figure 2) and sold to the French King Louis XIV. It had been roughly cut, perhaps as what we would term a preform to best show off its colour. It was soon recut for the king into what we know as the French Blue (cf. Figure 3), a kite-shaped brilliant of 67$^{1}/_{8}$ old carats (68.9 metric carats) according to the 1691 inventory of the king's jewels (Bapst, 1889, p. 374). The French Blue was confiscated and then stolen during the French Revolution, only to turn up, recut to 44.5 old carats (45.7 metric carats), for sale in London in 1812, where it was described and accurately drawn by the mineralogist James Sowerby (Ogden, in prep.). It passed into the gem collection of Henry Philip Hope and has retained the name 'The Hope Diamond' in the Smithsonian National Museum of Natural History, now weighing 45.52 ct. The meticulous research to prove that the Hope Diamond is indeed the French Blue recut, and a summary of its history, appears in Farges et al. (2009).

Despite Tavernier's extensive writing, we know little of the business and monetary aspects of his dealings, such as prices, how he was financed and his customers. This is understandable; few gem

dealers today would wish to publish such information. Supplementary documentation to fill these gaps is sadly sparse, but there is some to be found in various archives. Of his customers in Europe, we know of only two major ones by name: Louis XIV, of course, and Louis' younger brother the Duke of Orleans. We learn of the latter from a 1668 letter from Benjamin Lannoy of the British Consul in Aleppo, Syria, to Sir Heneage Finch, Third Earl of Winchilsea, Charles II's Ambassador to the Ottoman Empire in Constantinople (modern Istanbul), where Tavernier is described as "a person who hath often bin sent [to India] by the Duke of Orleans and others to gather rarities for them" (Finch, 1913, p. 439).

Most informative about Tavernier's financing is a document of which at least three copies survive, although they are not well known: a *factum*, or summary of a legal case, prepared by Tavernier's legal advisor Procurator Marpon.[1] It is a claim against the children and heirs of French jeweller Daniel Chardin and his wife, and although its text sheds considerable light on Tavernier's dealings and although it has been mentioned by some writers in the context of Chardin's travels in the East (e.g. van der Cruysse, 1998), it seems little known in the gem world. The first page of this four-page factum is shown in Figure 4.

Factums were an interesting feature of the old French legal system. Cases were played out in written submissions and judgements rather than being debated in court. The factum discussed here gives some unique insights into the trade in diamonds in the 1600s, and it links three well-known figures in jewellery history: Jean-Baptiste Tavernier, Daniel Chardin (the Parisian jeweller mentioned above) and Jean Pitan (or Pitau), the court jeweller to King Louis XIV who is best known for recutting the large blue diamond into the French Blue.[2]

Background

Prior to Tavernier's departure on his sixth voyage to the East in 1663, he learned that there was animosity between Daniel Chardin and Jean Pitan. Pitan owed Chardin 20,000 livres[3], as well as several years' interest. Chardin had goods as security from Pitan and was threatening to sell these and anything else of his he could get his hands on. Pitan approached Tavernier and begged him to help, assistance which Tavernier felt obliged to offer because of what the factum calls his 'new alliance' with Pitan. This alliance was one of marriage. In 1662, in his late fifties, Tavernier had married Madeleine Goisse, the daughter of another Parisian jeweller, Jean Goisse, and his wife Elisabeth, formerly Elisabeth Pitan. The anonymous author of the introduction to the 1713 Paris edition of Tavernier's *Voyages* (and some subsequent editions) notes that he accepted Madeleine as wife in gratitude for the many services rendered to him by her father, a "jeweller-diamond cutter" (translated from Tavernier, 1713, Foreword). He added that he didn't look so good but had many merits, and that she was too old and could not give him an heir. She is sometimes referred to as Jeanne-Madeleine Goisse. This was not the only association of the families; Tavernier's older brother Melchior had married a Pitan (Joret, 1886, p. 161), and as early as 1619 Melchior was described as a brother-in-law at the time he and Jean Pitan were among the witnesses of an inventory made when Jean's brother, the painter Géral Pitan, died (Guiffrey, 1915, p. 103). So royal jeweller Jean Pitan—who cut the French Blue—was the brother of Tavernier's mother-in-law.

The factum explains that Pitan promised that, if Tavernier arranged to have the goods on pledge

[1] The three copies of this factum of which this author is aware are all in the Bibliothèque nationale de France (BnF): Two copies are bound together in BnF manuscript Clairambault 1182 and the third is BnF manuscript Z THOISY-87 (f. 249). The latter can be obtained online at http://gallica.bnf.fr/ark:/12148/bpt6k3120071/f1.item.zoom. These are also the only three versions of this factum that are noted in Corda (1902, p. 27).

[2] Mentions of this diamond's recutting usually give the cutter's family name as Pitau, although it is clearly shown as Pitan in the factum. In 17th-century French handwriting, such as in a document relating to the recutting of the blue diamond by Pitan (described later in this article), the letters 'u' and 'n' are often indistinguishable, but this is probably not the root of the discrepancy. Jean was originally from a Flemish family, and it seems likely that Pitan (sometimes spelled Pittan, e.g. Guiffrey, 1872, p. 165) was the Flemish spelling. The spelling changed to how it sounded in French—'Pitau'—as he and his family assimilated into Parisian society. Certainly, when his son Nicolas, an artist, engraved a portrait of Louis XIV in 1670 it included the printed legend: *N. Pitau sculpsit 1670*. Since Tavernier, also from a Flemish family, refers to the royal jeweller as Jean Pitan, this is the spelling used in this article.

[3] It is not easy to suggest a modern equivalent value, but in Tavernier's time there were approximately 10 livres to the British pound and each livre was equal to around 12 g of silver. The debt of 20,000 livres was thus about £2,000, the equivalent of 240 kg of silver then (or £100,000 at current silver prices).

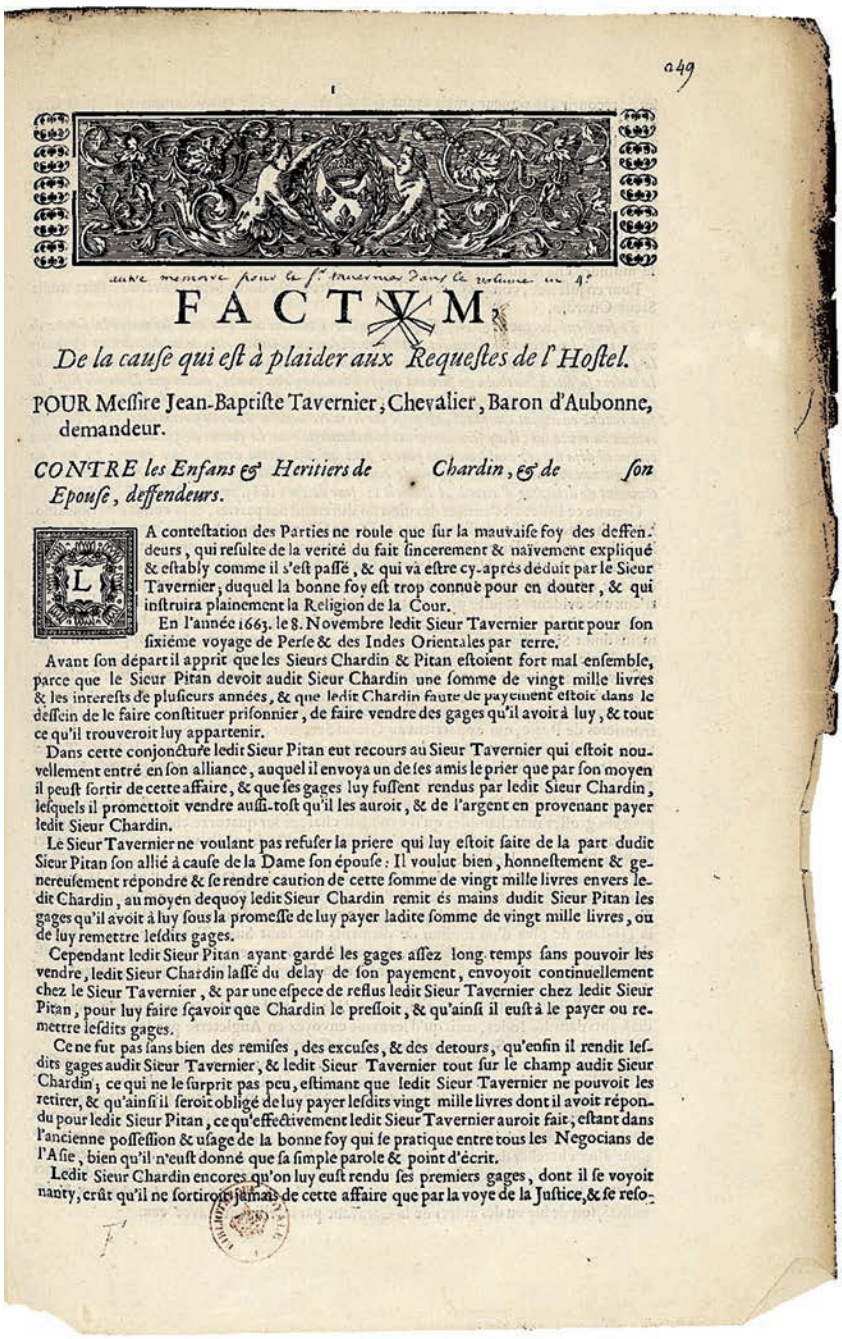

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FACTVM

De la cause qui est à plaider aux Requestes de l'Hostel.

POUR Messire Jean-Baptiste Tavernier, Chevalier, Baron d'Aubonne, demandeur.

CONTRE les Enfans & Heritiers de Chardin, & de son Epouse, deffendeurs.

LA contestation des Parties ne roule que sur la mauvaise foy des deffendeurs, qui resulte de la verité du fait sincerement & naïvement expliqué & estably comme il s'est passé, & qui va estre cy-aprés déduit par le Sieur Tavernier; duquel la bonne foy est trop connuë pour en douter, & qui instruira plainement la Religion de la Cour.

En l'année 1663. le 8. Novembre ledit Sieur Tavernier partit pour son sixiéme voyage de Perse & des Indes Orientales par terre.

Avant son départ il apprit que les Sieurs Chardin & Pitan estoient fort mal ensemble, parce que le Sieur Pitan devoit audit Sieur Chardin une somme de vingt mille livres & les interests de plusieurs années, & que ledit Chardin faute de payement estoit dans le dessein de le faire constituer prisonnier, de faire vendre des gages qu'il avoit à luy, & tout ce qu'il trouveroit luy appartenir.

Dans cette conjoncture ledit Sieur Pitan eut recours au Sieur Tavernier qui estoit nouvellement entré en son alliance, auquel il envoya un de ses amis le prier que par son moyen il peust sortir de cette affaire, & que ses gages luy fussent rendus par ledit Sieur Chardin, lesquels il promettoit vendre aussi-tost qu'il les auroit, & de l'argent en provenant payer ledit Sieur Chardin.

Le Sieur Tavernier ne voulant pas refuser la priere qui luy estoit faite de la part dudit Sieur Pitan son allié à cause de la Dame son épouse: Il voulut bien, honnestement & genereusement répondre & se rendre caution de cette somme de vingt mille livres envers ledit Chardin, au moyen dequoy ledit Sieur Chardin remit és mains dudit Sieur Pitan les gages qu'il avoit à luy sous la promesse de luy payer ladite somme de vingt mille livres, ou de luy remettre lesdits gages.

Cependant ledit Sieur Pitan ayant gardé les gages assez long-temps sans pouvoir les vendre, ledit Sieur Chardin lassé du delay de son payement, envoyoit continuellement chez le Sieur Tavernier, & par une espece de reflus ledit Sieur Tavernier chez ledit Sieur Pitan, pour luy faire sçavoir que Chardin le pressoit, & qu'ainsi il eust à le payer ou remettre lesdits gages.

Ce ne fut pas sans bien des remises, des excuses, & des detours, qu'enfin il rendit lesdits gages audit Sieur Tavernier, & ledit Sieur Tavernier tout sur le champ audit Sieur Chardin; ce qui ne le surprit pas peu, estimant que ledit Sieur Tavernier ne pouvoit les retirer, & qu'ainsi il seroit obligé de luy payer lesdits vingt mille livres dont il avoit répondu pour ledit Sieur Pitan, ce qu'effectivement ledit Sieur Tavernier auroit fait; estant dans l'ancienne possession & usage de la bonne foy qui se pratique entre tous les Negocians de l'Asie, bien qu'il n'eust donné que sa simple parole & point d'écrit.

Ledit Sieur Chardin encores qu'on luy eust rendu ses premiers gages, dont il se voyoit nanty, crût qu'il ne sortiroit jamais de cette affaire que par la voye de la Justice, & se reso-

Figure 4: Shown here is the first page of the factum describing Jean-Baptiste Tavernier's case against the children and heirs of Daniel Chardin. Bibliothèque nationale de France, manuscript Z THOISY-87; © BnF.

returned to him, he could sell them quickly and pay Chardin back. So Tavernier "plainly and generously" (translated from p. 1 of the factum) acted as guarantor for the 20,000 livres Pitan owed Chardin, received back the goods and gave them to Pitan to sell. Unfortunately, Pitan had been overly optimistic and was unable to sell them quickly, but Chardin was impatient for his money. To resolve things, Tavernier volunteered to take the goods with him on his upcoming sixth voyage to the East, sell them in Persia or India, and on his return, give the proceeds to Chardin "without taking any profit or interest therein for his pains" (p. 2). Tavernier would take the merchandise to the value of 20,000 livres from Chardin and bring him back 35,000 livres in cash or diamonds, whichever Chardin preferred. There was also a specific clause in the agreement that all the risks involved would fall to Chardin. This was fair and "the least thing that Sieur Tavernier could ask" (p. 2), but it caused problems later, as we will see.

The agreement, signed by Tavernier on 12 June 1663, is quoted in the factum, as shown in Figure 5. We know little specific information about the nature of the goods that Tavernier carried east, other than he had some diamonds with him (Tav-

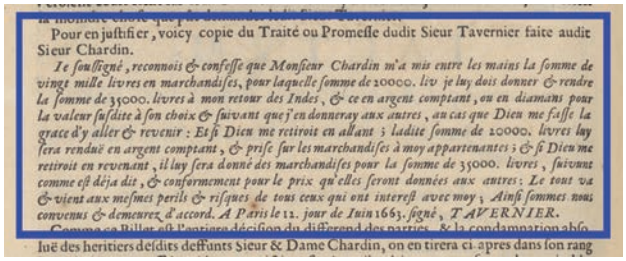
Pour en justifier, voicy copie du Traité ou Promesse dudit Sieur Tavernier faite audit Sieur Chardin.

Je soussigné, reconnois & confesse que Monsieur Chardin m'a mis entre les mains la somme de vingt mille livres en marchandises, pour laquelle somme de 20000. liv je luy dois donner & rendre la somme de 35000. livres à mon retour des Indes, & ce en argent comptant, ou en diamans pour la valeur susdite à son choix & suivant que j'en donneray aux autres, au cas que Dieu me fasse la grace d'y aller & revenir: Et si Dieu me retiroit en allant; ladite somme de 20000. livres luy sera renduë en argent comptant, & prise sur les marchandises à moy appartenantes; & si Dieu me retiroit en revenant, il luy sera donné des marchandises pour la somme de 35000. livres, suivant comme est déja dit, & conformement pour le prix qu'elles seront données aux autres: Le tout va & vient aux mesmes perils & risques de tous ceux qui ont interest avec moy; Ainsi sommes nous convenus & demeurez d'accord. A Paris le 12. jour de Iuin 1663. signé, TAVERNIER.

Iuë des heritiers desdits deffunts Sieur & Dame Chardin, on en tirera ci-apres dans son rang

Figure 5: This section of the factum cites the 12 June 1663 agreement between Chardin and Tavernier. It includes the former's agreement to cover the cost of the involved "perils and risks" of his expedition to the East. Bibliothèque nationale de France, manuscript Z THOISY-87; © BnF.

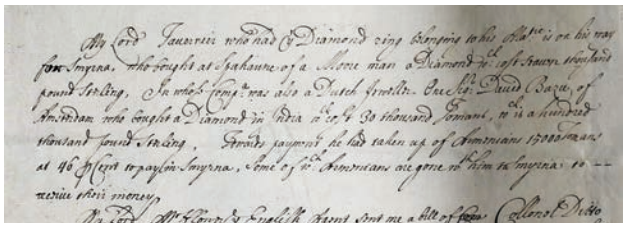

Figure 6: This portion of a 1668 letter from Consul Lannoy in Aleppo to the Earl of Winchilsea in Constantinople explains that Tavernier, then in a caravan heading to Smyrna, had bought a diamond in Isfahan in Persia for £7,000. Source: The Record Office for Leicestershire, Leicester & Rutland, Finch MSS p. 493/1.

ernier, 1676a, p. 96), as well as a gold ring set with a diamond engraved with the coat-of-arms of the King of England (Tavernier, 1676a, p. 484). Letters from Consul Lannoy in Aleppo to the Earl of Winchilsea in Constantinople and from the Earl of Winchilsea to Lord Arlington, who was then in charge of foreign affairs for Charles II, also refer to this engraved diamond (summarized in Finch, 1913, pp. 477, 482, 493, 509). Part of the original text of one of these letters is shown in Figure 6, which describes it as the "Diamond ring belonging to his Ma[jesty". George Kunz, however, argues that this cannot have been the British monarch's ring because there were later documents of the king that were impressed with this seal (Kunz, 1917, p. 154).

The Journey

Having obtained Chardin's agreement to the details, Tavernier set out on his sixth trip. The factum says he left Paris on 8 November 1663, yet the date given in Tavernier's *Voyages* is 27 November (Tavernier, 1676a, p. 253). The reason for the date discrepancy is unknown. He went via Lyon, down to Livorno in Italy and then sailed to Smyrna (modern Izmir) in Turkey, where he waited for more than a month to join a caravan. He then set off to Yerevan in Armenia and down to Isfahan in Persia, where he arrived on 14 December 1664 after more than a year of travelling. He took with him gems, goldwork and other objects totalling 400,000 livres in value to sell to the Persian Shah and the Indian Mughal emperor (Tavernier, 1676a, p. 253). This selling of precious objects brought from Europe to the Persian Shah is corroborated in various sources. A letter written from Bandar Abbas in Persia to the East India Company in Surat, India, dated 10 April 1665, notes that Tavernier was on his way, sailing to Surat "having sold the King [the Shah] to the value of 4000 tomands and upwards in jewells and other rarities brought with him out of Europe" (Foster, 1925, p. 16). The *toman* was the Persian currency, and the 1668 letter in Figure 6 conveniently tells us that 30,000 tomans were then the equivalent of £100,000. So Tavernier's sale to the Persian Shah was for the equivalent of just over £13,000. If we link this to current gold prices, it represents about £5 million today.

Tavernier arrived in Surat on 2 May 1665 (Foster, 1925, p. 15), with three or four Dutchmen, en route to the Mughal Court to sell the rest of his goods on which he had "allready made extraordinary proffit" (Foster, 1925, p. 16). It is unclear who these Dutch were. They did not include Tavernier's competitor from Amsterdam, David Bazu (see below), who arrived in Surat on the following ship (Foster, 1925, p. 16). Tavernier does tell us in his *Voyages* that he left Paris with eight companions with useful professional skills (Tavernier, 1676a, p. 253). The first edition of the *Voyages* does not name or describe these people, but we know one was a surgeon who is mentioned several times elsewhere in the work (e.g. Tavernier, 1676a, p. 20). Another was probably the young painter whose many engravings of 'courtesans' proved popular (Tavernier, 1676a, p. 151), and there were two described as a horologist and a goldsmith who died during the trip (Tavernier, 1676a, p. 267).

In the 'Corrections and Notes' at the end of the 1713 French edition of the *Voyages* we find information that was supposedly brought to light

after the rest of the volume had been printed (Tavernier, 1713). This includes a description of Tavernier's eight companions: his nephew; an Armenian valet named Antoine; Destremeau, a surgeon; Kernel, a Dutch diamantaire; Pitan, Tavernier's 'parent' and a goldsmith; Calvet, a goldsmith from Castres in southern France; Bizot, an horologist; and Deslandes, who was "the only Catholic among the Huguenots". It is unclear from where this more complete list was compiled or how reliable it is. With regards to Pitan, the term 'parent' had a slightly wider meaning than just father. The goldsmith who died from a disease on the trip must have been Calvet and not Pitan, judging from Tavernier's fleeting mention of this tragic event. Nor can Pitan the goldsmith have been Jean Pitan himself unless he travelled only part of the way, because just a year after they all set off Jean Pitan is recorded as selling a gem-encrusted sword to the French king for 264,566 livres (Bapst, 1889, pp. 357 and 396). That the list of companions in the 1713 edition of the *Voyages* is not completely fanciful is shown by the presence among them of Deslandes. This was André Daulier Deslandes (1621–1715) who later, in his own report, expressed his disappointment that Tavernier sold a major part of the goods brought from Paris to Shah ʿAbbās II in Isfahan without involving him in the negotiations (Deslandes, 1673; Yarshater, 1996). Tavernier describes his dealings with the Shah in Book 4, Chapter 15 of his *Voyages* (Tavernier, 1676a, pp. 464–476).

Customs Demands

Having explained the background, the factum fast-forwards to Tavernier's homeward journey from the East in 1667–1668. After leaving Surat he travelled to 'Urzeron' (Erzurum), a large city in what is now eastern Turkey. Erzurum was an important Ottoman centre on the frontier with Persia, and the place where merchants paid the customs duties on goods they brought into the Ottoman Empire from the East, although in his *Voyages* Tavernier is not very flattering about the city itself (Tavernier, 1676a, p. 17). Tavernier and his caravan remained in Erzurum for three weeks, so that the relevant duties could be paid and provisions obtained for the onward journey. Tavernier paid the customs duties required for the merchandise, which he had loaded on to 14 camels.[4] The factum notes that if a traveller there had no merchandise to declare, he would be taken for a spy and mistreated.

Then, three days before the caravan set off again, two men approached Tavernier—one on behalf of the governor of the city, who took a share of the customs revenues, and the other a customs official. They placed him under house arrest where he was staying, demanding 30,000 piastres[5] in customs duties on more than a million piastres worth of diamonds. These diamonds, they said, had been brought from India by Tavernier; they had learned of them from a Dutchman called 'Bazur', who claimed to have made the purchases. This was David Bazu, a diamond merchant and cutter who Tavernier says cleaved a large but flawed diamond that no other dealer in India would risk money on and made a loss. Bazu was travelling in the same caravan as Tavernier and inadvertently or deliberately let the officials know about the diamonds. In his edition of Tavernier's *Voyages in India*, Valentine Ball notes that on his return to Europe, Bazu "sold a number of diamonds and pearls to Louis XIV" (Ball, 1889, p. 99). This is something of an understatement: Shortly after Tavernier sold his diamonds to Louis XIV, Bazu also sold the king diamonds and other objects for more than 500,000 livres, including one large Indian-cut diamond of 70 old carats which represented 110,000 livres, half the price of the French Blue (BnF MS Mèlanges de Colbert, Vol. 281, f. 14). Once recut, this might have been the cushion-shaped brilliant later set in Louis XV's Golden Fleece ornament, above the French Blue (Morel, 1988, pp. 223–224; Farges et al., 2009, p. 6).

Tavernier explained to the two Ottoman officials that he had bought many diamonds in India but had sent them by sea from Surat to England aboard an English ship. The officials were sceptical. 'Bazur', they said, had revealed that when the caravan had recently passed through Isfahan, the Persian king had wanted to buy a good number of Tavernier's diamonds, which supposedly was

[4] A camel load is about 200 kg, so Tavernier's 14 camels must have been carrying something in addition to his own belongings, most likely Indian textiles, a major French import.

[5] The fineness and purity of the Ottoman silver currency varied during the 17th century, but the officials' demand of 30,000 piastres was then the equivalent of about 450 kg of fine silver.

proof that he had them with him. The problem was that the Ottoman officials did not relish the thought of having to search through the merchandise on the "two thousand camels and four or five hundred horses and mules" (p. 2 of the factum) that comprised the entire caravan. This shows the huge size of such caravans, more particulars of which are detailed by Tavernier in Chapter 10 of the first book of his *Voyages* (Tavernier, 1676a). In the background of the title page of a 1678 edition (Figure 1), one can see a section of such a caravan (Tavernier, 1678). Tavernier's protestations that he had sent the diamonds by sea might have been true, and it was perhaps a safer way to transport his merchandise to Europe, but a letter dated 20 October 1667 from Lannoy in Aleppo, to the Earl of Winchilsea in Constantinople, after noting that Tavernier was travelling with a silk caravan, quoted a report from India that he and the Dutchmen in his company "had bought up in those parts vast quantities of jewelles, which they carry with them for Christendome" (Finch, 1913, p. 482).

The Turkish and Armenian merchants in the caravan supported Tavernier—the factum righteously explains that this was because "justice was wholly on the side of the said Sieur Tavernier" (p. 3 of the factum)—and they told the governor's functionary and customs official that no merchant should have to pay duty on goods he didn't have and which could not be found. This made little impression on the officials, and so the merchants appealed to the local Islamic scholars. These experts in Islamic jurisprudence decided that the officials were indeed wrong: The Koran expressly said that no rights shall be taken of things not made by man's hands, and thus customs duties could not be levied on diamonds, gems, gold, silver and other minerals that are found in the ground. In the face of this ruling, and the clamour from the other merchants, Tavernier was released on payment of 10,000 piastres rather than the 30,000 they originally had demanded. The factum describes this payment as an *avania*—the tax or fee, typically an extortionate one, imposed on foreigners by the Ottomans.

The factum notes that this outcome was actually a great favour for Tavernier because it is "constant and true" that the more one tries to avoid paying tax, the more it costs, and "reason has no place" (p. 3). But as the factum also points out, merchants returned from the East with goods, not money, so for Tavernier to raise this sum in cash was complex and expensive. When he finally reached Constantinople, and with the help of the French ambassador's interpreter and 800 piastres paid for 'presents' for the provincial governor and other officers, it was agreed that the money he had paid in Erzurum should be returned to him. But to achieve this he would have to go back to Erzurum accompanied by two members of the Ottoman cavalry and a representative of the Grand Vizier (the prime minister of the Ottoman Sultan), paying them for their services as well as the costs of the trip. The extra delay in his return to France would add considerably to his time and costs. Besides, the French ambassador confided that it might be unwise to trust the three Ottomans who would accompany him. Tavernier decided that his best option was to return home.

The Sale to the King

Back in France, Tavernier paid those who had put up goods for his voyage their capital investments and shares of the considerable profits. The factum specifically notes that these profits included the amount made on the diamonds sold to King Louis XIV. The investors also gave their word that, as per their original agreements, they would repay Tavernier their share of the unforeseen and unfortunate *avania* and associated costs once the calculations of this total amount, with relevant exchange rates, had been completed. This sum was found to be more than 48,000 livres in total, which we are told worked out that each of his investors was liable for 8% of their investment. This would suggest that the original investment was in excess of 600,000 livres, although Tavernier stated that he took goods worth 400,000 livres on his trip. The explanation for this discrepancy is unclear. In any case, all of the investors paid up apart from Daniel Chardin.

Tavernier could see no reason why Chardin should escape his obligations and requested payment many times, sometimes with witnesses present. The Chardins had the funds to pay and did not deny that the sum was due, but they thought it should be paid by Pitan. Their argument presumably was that they should not have to defray the costs involved in being paid back what was owed to them. Chardin fell ill and died while Tavernier himself was gravely ill for a long time and was in no state to press his case. Then, as one

accident typically follows another (as the factum sagely notes on page 4), Chardin's widow with whom Tavernier had taken up the case also died. So he had to turn to Chardin's children to get the refund of the *avania* and, mentioned now for the first time, 1½ percent extra for what we are told was the brokerage fee paid to Pitan on the sale of the diamonds. From this we might infer that Pitan, as the royal jeweller, played a facilitating role in the sale of the French Blue and the other diamonds to the king. The factum notes that the other investors had covered their shares of this brokerage. The Pitan heirs seemed to deny any involvement; the 35,000 livres debt had been paid back to Chardin, but not via their father, so they considered that they had no further liabilities or responsibilities. Recourse to the courts, and thus the drafting of the factum, was the only option left to Tavernier.

Tavernier was sure that if the record books of Chardin's business were made available (something he had often requested), the payments and the original agreement would be seen. This would provide clarification for the court, which would understand that it was not right for the Chardin heirs to take advantage of Tavernier's goodness and readiness to help, as had their father and mother. The factum concludes with the plea that the court will judge in his favour, not forgetting interest and expenses.

The Case

The factum is undated, but it must date to after 1675, since it was taken out against Chardin's children and heirs, and Pitan's heirs are also mentioned. Chardin died in 1672; the date of his wife's death is unknown. Jean Pitan, noted in the factum as deceased, died in 1675; he was described as goldsmith to the king and "one of the first who executed these presents so rich and so varied which Louis XIV presented to foreign ambassadors and to his entourage" (translated from Maze-Sencier, 1885, p. 63). The factum leaves a blank space for the first names of Chardin and his wife. It is hardly likely that Tavernier didn't know their names, so it suggests Tavernier had not given this information to his legal representative and was not readily available to furnish it. Possibly this means that the factum was not issued until after 1689 when Tavernier left France, but that would mean an extraordinarily long delay. The factum has the signatory 'Marpon, Proc'—i.e. Procureur (prosecutor) Philibert Marpon.

The detailed recounting of the Erzurum incident in the factum, even describing the number of camels in the caravan and the intervention of Islamic legal scholars, seems unnecessary in a French legal deposition, and one is tempted to think that this was partly intended to entertain the court and thus get it on Tavernier's side. The factum does, however, argue that it was unfair of Chardin and his heirs to deny him payment after he had undertaken "labours and risks which few people are capable of undertaking, and still less able to withstand and overcome" (p. 4). The copious details of the problems in Erzurum would provide the court with a clear idea of the perils involved in a business such as Tavernier's.

To date, the present author has not located court records that reveal whether Tavernier ever received his money from Chardin's heirs. Daniel Chardin and his wife Jeanne had several children. These included Jean, born in 1643, and Daniel, born in 1649. Jean worked with his father in the jewellery business and also travelled to the East. It has been suggested that he became a diamond dealer and travelled East as a replacement for Tavernier after the latter's business relationship with Danial Chardin "soured" (Baghdiantz McCabe, 2008, p. 108). However, Jean first travelled East while Tavernier was on his sixth trip, thus before the matter of non-payment of the *avania* arose, and the factum does not imply any bad feeling between Tavernier and Daniel Chardin before this. Jean Chardin settled in England after the persecution of Protestants in France began, becoming Crown Jeweller there, and was knighted as Sir John Chardin. Daniel Chardin the younger became a merchant in Madras (now Chennai), India, and a business partner to Jean. There were three other sons, two of whom had died, and one recorded sister.

We should be grateful for Jean Pitan's non-payment of his debt to Chardin, without which the factum and its insights into Tavernier's business and challenges would not exist. Pitan might have been an excellent goldsmith, but he seems to have been poor at managing his finances. In 1699 his heirs were acquitted of another of Pitan's debts dating back to 1673 (Guiffrey, 1896, col. 306)—proof that slow payment is not a preserve of the modern gem industry.

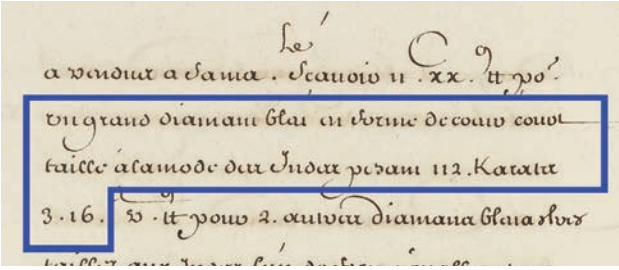

Figure 7: In this record of the 1669 payment to Tavernier for diamonds, the first stone listed is the large blue one. A translation of the outlined text says, "a large blue diamond in the form of a short heart cut in the Indian fashion weighing 112 3/16 carats". Detail of BnF MS Mèlanges de Colbert, Vol. 281, f. 14; © BnF.

The French Blue

The factum refers to the sale of diamonds, including the large blue one, to King Louis XIV, but it does not describe any of them individually or give the date of the sale. Nor does Tavernier say anything about the origin or purchase of the large blue diamond in his *Voyages*. The only possible clue to where he obtained it, of which this author is aware, is the letter of 31 January 1668 from Lannoy in Aleppo to the Earl of Winchilsea in Constantinople (Figure 6). This states that Tavernier, then on the way from Aleppo to Smyrna with the caravan, and travelling with "a Dutch jeweller One Sig[nor] David Bazu of Amsterdam", had purchased a diamond for the huge sum of £7,000 on his trip "at Spahaune [Isfahan] of a Moore man [i.e. an Arab merchant]" (Figure 6; also summarized by Finch, 1913, p. 493). The amount of £7,000 would have been around 70,000 livres. That is exactly the sort of price we might expect him to have paid for the large blue diamond that he sold to Louis XIV for 220,000 livres, according to its record of the payment, which survives today in the Bibliothèque nationale de France (BnF) in Paris among the collection documents of Jean-Baptiste Colbert, French Minister of Finance from 1665 to 1683 (Figure 7; BnF MS Mèlanges de Colbert, Vol. 281, f. 14). Of the other diamonds that he sold the king, the only one that would have shown a good profit on 70,000 livres was the third on his invoice, one of just over 51 old carats that he sold for 180,000 livres. On his invoice to the king he describes this rather lumpy table cut, and several others, as "cut in India", whereas the large blue diamond he describes more enigmatically as "cut in the Indian fashion"—not a description he applied to any of the others (Figure 7). The original invoice was quoted in full by Germain Bapst (1889, 403–405).

The possibility that Tavernier's large blue stone, now the Hope diamond, was the one purchased from an Arab merchant in Iran is intriguing, but it is impossible to corroborate unless further archive documentation comes to light. But if nothing else, the 1668 letter does reinforce the view that despite what Tavernier had told the officials in Erzurum, he took some diamonds with him on his journey home; not all had been sent off by sea.

There have been some suggestions over the years that Tavernier might actually have purchased his large blue diamond on an earlier trip, but it is unlikely that he would tie up significant capital for so long (Morel, 1988, p. 158). That it was one of the diamonds purchased on his sixth trip is also shown by his drawing of the 20 most important stones he sold to the king, which appeared in most editions of his *Voyages* and of which Figure 2 is a detail. In the first edition of his *Voyages*, this drawing is clearly described as the "representation of twenty diamonds which the author sold to the king on the return from his last [i.e. sixth] voyage to India" (translated from Tavernier, 1676b; see p. 336 and adjoining plate). The drawing was probably made around the time of the sale in 1669 and certainly seems to have been in circulation by 1670. When the London diamond merchant John Cholmley wrote to his brother Nathaniel in India in December 1670, he enclosed "the prints for the great Dyamond hee [Tavernier] brought with him the last time from India" (Cholmley and Cholmley, 1664–1693, f. 0147). It seems probable that this refers to the Tavernier drawing.[6]

With Tavernier making no comment about where he purchased the diamond, India would be the natural assumption. The date of the sale can be placed with some certainty to 1669, soon after his return from his final trip and the year he was able to purchase the Seigneury (feudal lordship) of Aubonne near Geneva, an honour granted to him by the king on account of his services. A margin note in the handwritten record of Tavernier's sale of the diamonds to the king—just

[6] The "Representation of a considerable number of excellent Diamonds, sold by one Monsieur Tavernier to his King" was also noted in Anonymous (1674). This author noted that the drawing had come into his hands 'some while since'.

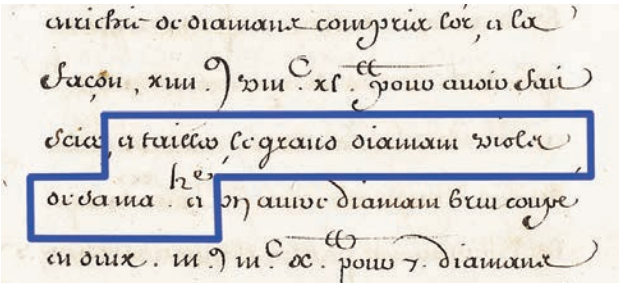

Figure 8: This shows a record of the payment to Jean Pitan for cutting the large blue diamond—"le grand diamant violet de sa ma[jesté]". Detail of BnF MS Mèlanges de Colbert, Vol. 291, f. 341; © BnF.

off to the side of the excerpt in Figure 7—confuses the issue because it places the purchase by the king in the year 1666. However, this annotation is in a later hand, and little reliance should be placed on it. This document, a copy of the invoice from Tavernier, lists all the diamonds with their sizes, prices paid and sometimes a description of their shape or cut. Thus, it provides us with the total price paid: 898,731 livres. The large blue stone is described as "a large blue diamond in the form of a short heart cut in the Indian fashion weighing 112$^{3}/_{16}$ carats" (Figure 7), and its price is given as 220,000 livres. At today's silver prices these would represent about £4.5 million and £1 million, respectively (considerably more if relative gold values are used).

The 1668 letter in Figure 6 also tells us that David Bazu of Amsterdam, then on his way with Tavernier from Aleppo to Smyrna, had "bought a Diamond in India wh[ich] cost 30 thousand Tomans, wh[ich] is a hundred thousand pounds Sterling" (also summarized in Finch, 1913, p. 493). He had raised 15,000 tomans of this by borrowing from Armenians at 46% interest, noting that "Some of wh[ich] Armenians are gone with him to Smyrna to receive their money" (again, see Figure 6). If this report is accurate, this diamond must have been truly exceptional—it was worth more than all the other diamonds that Tavernier sold to Louis XIV added together.

The Colbert documents also record the payment to Jean Pitan for cutting "the large violet diamond of his Majesty" (Figure 8; text translated from BnF MS Mèlanges de Colbert, Vol. 291, f. 341). In 1673 Pitan reduced it into a kite shape that was essentially a brilliant, a very early example of the form. It was listed second and described in an extensive 1691 inventory of the French Crown jewels as a "very large violet diamond very thick, cut in facets in the fashion of two sides, formed as a short heart of eight sides, very lively water and clear" (translated from Bapst, 1889, p. 374). At that time it weighed 67$^{1}/_{8}$ old carats, was set in a pin of gold with enamelled reverse and was estimated to be worth 400,000 livres. The first diamond listed in the inventory was the Sancy—weighing less at 53¾ old carats, but valued more at 600,000 livres. As John Fryer, a surgeon with the East India Company, observed just a few years later, a diamond "of a Blue, Brown, or Yellow Water, is not worth half the Price of a perfect Stone of a White Water" (Fryer, 1698, p. 213). Coloured diamonds at that time were clearly not held in high esteem.

Conclusion

The detail in the factum, along with other archive documents, adds to our understanding of the complexities and perils that impacted the gem trade in the 1600s and on Tavernier in particular. It also shows that even after his five previous trips, Tavernier remained reliant on fellow French merchants to provide the precious objects which he could sell in the East to finance his purchases. In particular, it indicates that his purchase of the French Blue and other diamonds was funded by selling jewelled objects in Persia and India that had been provided by a syndicate of French merchants and investors. The original value of the goods supplied by this syndicate was stated to be 400,000 livres—perhaps 600,000 livres, as noted above. If, as implied by the factum, the diamonds he sold to Louis XIV were all the diamonds he brought back, the profit was some 300,000–500,000 livres less the *avania* costs, Pitan's brokerage or commission fee ('courtage') and perhaps other expenses. That was a huge amount of money, but we do not know how large Tavernier's stakeholding was in this business, although his profit no doubt covered the 60,000 livres he paid for the Seigneury of Aubonne in 1669, when he became Baron Tavernier. The possibility that Tavernier purchased the large blue diamond that was to become the French Blue—eventually the Hope—at Isfahan in Persia from an Arab merchant adds a tantalizing new angle to the history of this celebrated gem, but it is for now just supposition.

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Counterfeiting Gems in the 16th Century: Giovan Battista Della Porta on Glass 'Gem' Making

Annibale Mottana

Glass simulants of gemstones were long produced with little or no prejudice against their use. However, their making is poorly documented due to the secretiveness imposed by glassmaking guilds, despite the presence of some late medieval manuscripts that have recently appeared. They reveal glass composition and fabrication recipes in accordance with the trend launched by 16th-century 'writers of secrets', who revealed technological developments to the public. Giovan Battista Della Porta was the first to publish in print recipes for making glass simulants of gems, in addition to information on the enhancement of natural gem materials. His *Magiae Naturalis* (1558), originally written in Latin to appeal to upper-class amateurs, enjoyed vernacular translations in several European languages. The second, vastly improved edition (Della Porta, 1589), again in Latin, did not enjoy the same popularity—possibly because the first one had saturated the market or, alternatively, because the Catholic Church had enforced rules that made alchemy a forbidden practice, and even the title *Magiae* became suspect. In spite of such restrictions, both editions contributed to making glass 'gems' popular decorative objects and to increasing their trade. During Baroque times, interest in glass 'gem' making reached an acme, and Della Porta's treatise was even translated into English in 1658.

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Introduction

Opening the 37th book of his *Naturalis Historia* (Natural History), Pliny the Elder stated in the 1st century AD that people admire gemstones and seek after them more passionately than anything else: "*...gemmae supersunt et in artum coacta rerum naturae maiestas, multis nulla parte mirabilior*" (Corso et al., 1988, 37.1). However, they also may make them factitiously, and "no kind of fraud is practised by which larger profits are made" ("*neque enim est ulla fraus vitae lucrosior*"; Corso et al., 1988, 37.197). With such concise but highly poignant words, Pliny summarized almost two millennia of vitreous paste and glassmaking with the goal of simulating gemstones, starting from Mesopotamian and Egyptian times to his own era. He

did not refrain from stressing the negative implications of such activities, and concluded with a statement that he would avoid describing the full glass-making methodology. To further stress his disdain, he pointed out that Romans used such glass gem simulants only for the rings of lowest-class people: "*fit et ipsum e creta admixtis vitreis gemmis e volgi anulis*" (Corso et al., 1988, 35.48).[1] Yet the majority opinion was never as severe as Pliny's, as long as the simulants possessed properties that would make them attractive as 'gems'. High-quality natural stones occur too rarely and are thus too valuable as not to induce unscrupulous dealers from faking them. While the most common fraud was (and perhaps still is) swindling the customer with an imitation composed of a natural stone but of a cheaper type, gem simulants were also commonly made from glass. Even the elite would tolerate the manufacture of glass gem imitations as being a sound practice; indeed, there was a widespread understanding among cultivated people that producing something which had properties either very close or at times even superseding the natural version was a triumph for technology. Nevertheless, such activities were mostly severely repressed, exposing the forger to a penalty that could bring him as far as to death.[2]

The state of gem trading through Roman times and the Middle Ages has been widely studied and will not be repeated here (see, e.g., Zwierlein-Diehl, 2007). By contrast, glass 'gems' (e.g. Figure 1) have been the subjects of lesser studies, although they too have a long tradition with roots in late Roman imperial times. The availability of the information related to such glass objects has recently increased significantly due to thorough investigations of miscellaneous medieval codices preserved in library archives (e.g. Beretta, 2004, 2009; Cannella, 2006; Tosatti, 2006; Baroni et al., 2013). This was particularly the case for the 15th and 16th centuries, when Europe left the Dark Ages and entered Humanism and the Renaissance.

Renaissance scholars enjoyed wearing gemstones just as much as any other men of their time, despite being aware that they could be either enhanced or counterfeited. They could draw such information from sources spanning from late antiquity to the late Middle Ages.[3] However, only one author gave reliable information on glass gem simulants made in Roman times. This was Heraclius, who wrote when late Greco-Roman techniques were still alive. Heraclius' treatise *De Coloribus et Artibus Romanorum* consists of two parts. The first two books, which are in verse, were written in Italy during the 8th century, while the third is a prose paraphrase of the first two with many added explanations, written in northern France by a pseudo-Heraclius of the 12th century (Garzya Romano, 1996, p. xxi; Tosatti,

Figure 1: These 'emerald' and 'amethyst' glass eardrops in the Renaissance style were presumably assembled in the second half of the 16th century. The mounting is partially silvered copper. The green glass 'gems' are 6 mm in diameter. Courtesy of a private collection near Rome, Italy; photo by Carlotta Cardana.

[1] Properly, this refers to an artificial white (candidum) pigment used to colour plaster and added with ground glass splinters to obtain pleasant sparkling effects.

[2] In 1488, a forger named Zocolino, who had cheated the king of England by selling him a doublet at a very high price, was submitted by the duke of Milan to *debito supplicio* (i.e. put to death; Cardano, 1560, p. 642). However, later the same year, the duke had to relax his hold, as he realized that his revenues included substantial excise taxes from dealers of *contrafacte* (counterfeit) gems (Venturelli, 1996, p. 53).

[3] The oldest Latin recipes for making coloured glass derive from Greek and Oriental sources that date back to Pliny, or even older. They are reported in *Mappae Clavicula* (also known as *Compositiones lucentes*), a compilation resulting from an intricate process of addition and accumulation with contributions from various sources which developed from the 8th to the 12th centuries AD at various monastic sites (Baroni et al., 2013, pp. 27–35).

2006, pp. 37–46). In verse I.13 (i.e. in the oldest section), Heraclius recommends carving a hole in a lump of clay with the shape of the gemstone one wants to imitate, and filling it with ground glass of the appropriate colour. Then the clay block is fired so that the glass powder melts and completely fills the pre-shaped hole, thus obtaining a defect-free glass 'gem' of the right size and shape (Garzya Romano, 1996, pp. 5–63). Such a production technique continued to be used in many scattered places.[4] Implicitly, Heraclius points out that the most important aspects of a gemstone's appearance are its shape and colour; these two properties are directly determined by nature but can be duplicated by art. Therefore, the technical challenges to those creating gem simulants shifted from imitating gems[5] to glassmaking activities.

At that time, one could take advantage of various sources on glassmaking (see works by Beretta, 2004, 2009; Tosatti, 2006; Baroni et al., 2013). However, only one describes the technology in full: "*Le traité de Théophile reste à bien des regards atypique*" (Boulanger, 2004, p. 14). This unique source is the celebrated *De Diversis Artibus* written by 'Theophilus presbyter'.[6] His book is rooted in long tradition and its content ranges from very basic data on how to build a kiln to some final touches such as repairing broken vases. In between, Theophilus specifies how to make vitreous gems and polish them so that they shine. He instructs that 'gem' glass will become as shiny as rock crystal after rubbing and polishing ("*Lapides quoque eodem modo vitrei, quo cristallum, fricantur et poliuntur*"; Caffaro, 2000, Book III, Chapter 95, p. 416) using *tenax*, a concoction that was nothing more than brick powder mixed with pitch and wax.[7]

Three centuries later, in the technical environment preceding the Renaissance, a few new treatises appeared that referred to artificial 'gems' made of coloured glass according to a preparation method essentially following Theophilus' one. The best-known text is by Jean d'Outremeuse[8], written ca. 1390–1400 to inform high-class people of the Bourgogne court, but he also included what he had learned from old masters and had used successfully for a long time. This is why he wrote in vernacular French and did not spare practical details, mentioning both the good results and the bad ones.

In fact, all through the late Middle Ages glass had been used occasionally to simulate gems, but it was mostly in the form of polished shards (scrap from the window panes decorating cathedrals) and relics picked up among the debris of Roman towns (including mosaic *tesserae*) or in buried treasures. The glass 'gems' thus obtained did not have the required shape, but they had the appropriate colours, so that polishing, which was almost the only enhancement applied, made them bright and lustrous. Most of the genuine gemstones during this time consisted of crude 'cabochons', as the simplest cleavage cuts were then at their beginning.[9]

Short descriptions of glassmaking, mostly dealing with kiln operations but also with scattered information on the possibility of producing glass 'gems', are found in metallurgical treatises by Biringuccio[10] and Agricola.[11] They dealt with glass near the end of their descriptions of ore-dressing methods to extract met-

[4] It was still described in the *Sedacina*, an alchemical treaty by the Catalan monk Guillem Sedacer, who died ca. 1382–1383. A translation with extensive comments was given by Barthélemy (2002).

[5] A prominent example of imitating gems occurred in 1347, when during the manufacture of the Bohemian royal crown the artist inserted a rubellite to imitate the largest ruby.

[6] Possibly the pen name of the Benedictine monk Roger from Helmarshausen, who also operated as a goldsmith ca. 1140–1160 in the Cologne and Liège regions (Tosatti, 2006, p. 77), located in present-day Germany and Belgium.

[7] The texts mentioned in this and the two previous paragraphs represent the antigraphs for the entire science of glassmaking that developed in Europe during the early Middle Ages. Such sources might appear to be few, but consider that there were scattered recipes in even older books (e.g. *Mappae Clavicula*; see footnote 3). These recipes were repeatedly copied in more than 400 manuscripts, although in bits and pieces (Boulanger, 2004, p. 12; Cannella, 2006, pp. 72–103; Baroni et al., 2013, p. 134).

[8] Born 1338 in Liège, he was an officer in the court of the dukes of Bourgogne. He wrote *Trésorier de philosophie naturelle des pierres précieuses*, the fourth book of which is dedicated entirely to gems, both natural and fictitious (Cannella, 2006). He died in Liège in 1400.

[9] The first written information on cut diamonds ('rose cuts') dates to a note in the 1413 inventory of Jean de Berry, the brother of the king of France. A late example of this kind of enhancement is the Lyte Jewel, in which four large 'Burgundian-style' rose-cut diamonds surround the IR monogram (for Iacobus Rex) of King James Stuart VI of Scotland, made probably 1605–1610 after his accession as King James I of England and Ireland. However, shaping glass by grinding with emery dust and selling it as diamond was practised long before.

Figure 2: This portrait of Giovan Battista Della Porta at the age of 50 is from the title plate of the 1589 edition of his Magiae Naturalis.

als, because glass (which melts under fire) was considered by both to be a transparent and fragile kind of metal. Additional information on glass 'gems' appears in Cardano's *De Subtilitate* (1560)[12], whose entire Book VII concerns minerals, rocks and gem materials. At the end of Book VII, Cardano even proposed a practical method to distinguish a true gem from a glass one by using their reflective properties.

It was not until the full development of the Renaissance, in the mid-1500s, that a writer purposely gave the tedious details of the entire process of glass 'gem' making.[13] This author was Giovan Battista Della Porta.[14]

Della Porta's Contribution to Disclosing Gem Counterfeiting

Della Porta (1535–1615; Figure 2) was a Neapolitan polymath and a major representative of the 'writers of secrets'—those who, from around 1550 onward, made agreements with greedy printers to make public numerous practices and techniques long since kept secret by the artisan guilds and alchemists of the Middle Ages. Most of them wrote in Italian, as their target was the largest possible number of common people across Italy[15], but their teachings spread through translations into most European vernacular languages. Only a small number of them, including Della Porta, chose to write and print their books in Latin.[16] These authors had as their target not only the Italian cultivated class, which they considered to be fairly well informed on matters of natural science, but also well-to-do people from other countries, since Latin was the *lingua franca* of Europe.

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[10] *De la Pirotechnia* (On the Firing Art, 1540) by Vannoccio Biringuccio (1480–1537), a mine engineer from Siena, Italy, is the first book on the matter in Italian and the first treatise published about the fire treatment of metal-bearing ores. It has only a few pages on gems. Moreover, *De la Pirotechnia* was the first Renaissance book to provide printed information on glass imitations of gem materials.

[11] Georg Pawer or Bauer (1499–1554; a German physician and mining scientist whose name was Latinised as Agricola) wrote in Latin and published his classification of minerals and rocks in *De Natura Fossilium* (On the Nature of Minerals; 1546), after which he prepared his major treatise, *De Re Metallica* (On Mining; 1556), in which he established mining and metallurgy on a solid scientific basis.

[12] Girolamo Cardano (1501–1576) was a polymath: inventor, mathematician, philosopher and astrologist. He wrote in Latin and first published *De Subtilitate* (On Subtlety) in 1550, almost doubled its size in 1554, and further enlarged it in 1560 (Cardano, 1560). His five-fold division of the mineral world was clearly influenced by Agricola, but he also introduced novel concepts and ideas.

[13] The thorough review of the Venetian Renaissance glass-making techniques and innovations by Marco Verità states precisely (and unfortunately) that "lead silica glass for the production of imitation gemstones, (is) not discussed in this paper" (Verità, 2014, p. 53, note 1).

[14] Della Porta is the name and surname given to him in the National Edition of all his works (currently in preparation). In the past, a variety of names and surnames have been used for him: Giambattista Porta was most common, and is reflected in the English translation as John Baptist(a) Porta.

[15] Their actual target was the *paterfamilias* (literally, 'family father'), so that he could be educated enough to face all the problems arising when managing his household. Indeed, most 'secrets' concerned how to cure sickness by concocting herbal medicines and also dealt with other health issues. Such works enjoyed almost numberless printings. The most famous one, written originally by a 'reverendo donno Alessio Piemontese' (pen name of Girolamo Ruscelli, 1518–1566), was published only three years before Della Porta's book and reprinted more than a hundred times (Eamon, 1984; Eamon, 1994, pp. 352–417).

[16] Della Porta was also a prolific author in Italian. He wrote poems, dramas and comedies, besides translating his own Latin books (Clubb, 1965).

Della Porta disclosed recipes that were mostly related to artisans' practical arts and experiments having affinity with alchemy.[17] Spreading information of this sort (which was not entirely new, as it was already available in the closed circles of craftsmen and of members of alchemical unions) contributed to the general development of science, because carrying out tests and experiments by hand was no longer considered a demeaning practice for gentlemen and other open-minded seekers of new information. Della Porta's most significant work was his *Magiae Naturalis* (Natural Magic, 1558). He translated it into Italian, using a pen name to avoid losing authority (since it was inconceivable at the time for a Neapolitan nobleman to write about scientific topics in a language other than Latin), and within a century of its original publication there were 58 printings: 16 in the Latin original, 25 in French, 14 in Italian, two in Dutch and one in German (Balbiani, 1999, p. 280; see also Orlandi, 2013).[18]

Della Porta never stated where he drew his 'secrets' from, but it is likely that he gathered most of them from craftsmen who did not refrain from sharing their practical knowledge with a young nobleman[19] who showed as much an appreciation for their empirical approach as he did for his own scholarly readings. Indeed, Della Porta's *modus operandi* was well known. For every secret he learned, he first checked for other possible sources by reading books by old masters, after which he tested the results by performing experiments in his home laboratory. He also took discreet advantage of the guidance from such alchemists as Leonardo Fioravanti and Domenico Pizzimenti when they stayed in Naples, as well as from clever local apothecaries such as Ferrante Imperato.[20]

Glassmaking was one process that could be performed with a rather simple apparatus (a kiln). Ordinary cloudy glass was widely available and, when broken, was often repaired by re-melting. By contrast, the preparation of certain special glasses (e.g. coloured ones suitable for simulating gems) involved knowledge that had been an artisan secret until it was released by Della Porta in his original 1558 edition of *Magiae Naturalis*. He also described glassmaking and glass 'gems' in a later edition that he published in 1589.

Magiae Naturalis *Edition of 1558*

In Book III of *Magiae Naturalis*, 1558, Della Porta wrote three chapters (16–18, pp. 136–140) related to glass that followed the descriptions of other chemical operations[21], such as sublimation, distillation, purification and melting, plus miscellaneous recipes on how to repair broken corals, pearls and gemstones. Then he added recipes on how to clean these gems using etching liquids and organic additives. Clearly, what he delivered as a 'secret' was a mixture of alchemical and artisanal craft. As for gems, it is worth stressing that he did not care to deal with how to make ordinary glass, but he proceeded directly to release the technicalities on how to prepare the special colourless glass that would be suitable for making coloured glass, so as to imitate gem materials.[22] In Chapter 16 he summarized the preliminaries, recommending the use of very finely ground silica mixed with fluxes such as tartar juice, salt or dried egg white[23], or even

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[17] Alchemy—that is, the process by which man tried to reproduce natural wealth—was officially repressed (particularly by the church), but widely tolerated and even supported by some of the highest authorities, clerical as well as lay, at least as long it would not appear that their alchemists were incapable of reaching satisfactory results (Pereira, 2006; Principe, 2013).

[18] Della Porta (1589, Foreword) mentions a Spanish translation and another in Arabic, but neither one appeared in Balbiani's (1999) survey of the books preserved in European libraries, or in Orlandi's (2013) commented list.

[19] In the 'Praefatio ad lectores' (foreword to the readers) of his 1589 *Magiae Naturalis*, Della Porta claims that he wrote the original 1558 version when he was a youth, "*vix tum quintum & decimum annum agente*" (only 15 years old). However, this should be interpreted as the age when he started compiling information, since the edition was actually published when he was 23 years old.

[20] Della Porta's research practices as a youth were reported by Neapolitan writer Pompeo Sarnelli (1649–1724), who wrote Della Porta's biography (Sarnelli, 1677) and translated some of his Latin works to Italian. For additional information, see Eamon (1984, 1994), Fulco (1987, p. 113) and Perfetti (1997, pp. 173–176).

[21] "*Experimenta (…) quae vulgus vocat chymica*" (Procœmium section of Book III). In fact, most of the recipes were of the alchemical type, but even at this early date Della Porta avoided mentioning alchemy openly.

[22] He called it "*pro adulterandis gemmis vitrum fictitium*" (Chapter 16, p. 136).

[23] "*Multa ovorum albumina simul exagitabis (…), ac diu coqui sinas, detrahe, & per multos dies resiccare curabis (…) ut in vitri duritiem transeat*" (Chapter 16, p. 136). To the present author's knowledge, nobody else specified this flux material, nor did Della Porta mention it again except in the Italian translation of his book, which he released in 1560.

ash. In Chapter 17 he made a digression aimed at explaining how natural gem materials acquire their colours and shifted to recipes on enhancing colour by using various natural pigments ('black lead' [i.e. galena], orpiment, curcuma root, iron filings, etc.), by slowly diffusing them from the surface to the bulk of the gem under the slow action of fire. Then he returned to recipes intended to add weight to glass without modifying its hardness. In particular, he recommended adding lead to the already prepared colourless glass only while it melts, so as to increase its brilliance and weight. After another digression, he ended Chapter 18 with a series of explanations on how to obtain attractive 'gem' glass by carefully mixing colourless glass with pigments while it melts (the colouring agents being burnt copper, minium, tin and 'white lead'). The resulting gem simulants would resemble diamond, emerald, sapphire, pyrope, topaz, olivine, chalcedony, etc. The final recommendation was that the crucible containing the molten mix should be kept under close supervision, as excess heating would make the colour fade away.

Della Porta's description flowed rapidly, with little care for detail, as if the reader already might be familiar with the subject. Most likely, these few chapters are a summary of alchemical recipes that he had learned quickly and not investigated sufficiently. Nevertheless, the subject was such as to arouse a wide interest, so that the entire text was promptly translated into Italian, Spanish and French, and some years later, Dutch and German.[24] Moreover, the original Latin edition was widely read and taken into account in England, where the Elizabethan court was just as interested in jewels as any other royal court in Europe.[25]

Magiae Naturalis *Edition of 1589*

In 1589, Della Porta, by now a mature scientist, reworked his *Magiae Naturalis*, expanding it from four books to 20 (Figure 3). This overall increase transformed his work into a very curious treatise, comprising a mixture of useful recipes, half-told half-truths, observations and experiments by both the author and his fellow investigators[26], as well as quotations from classical writers who, however, were often in disagreement. The in-folio sized text dealing with gems grew from five ordinary pages to a complete Book VI encompassing 10 dense pages (117–126) and distributed over 13 chapters.[27] Actually, only Chapters 1 to 5 concern glass gem simulants (pp. 118–120), because Chapter 6 (p. 121) is on abstruse alchemical matters[28] and Chapters 7 to 13 (pp. 121–126) mostly concern the enhancement of gem materials. Everything is described in much greater detail than in the previous edition. Although the approach to the subject did not change substantially, a systematic decrease in fancy alchemical recipes[29] and a corresponding increase in technology are immediately appar-

[24] "*Italicam nempe, Gallicam, Hispanicam, & Arabicam*" (1589, Foreword). As for the translation into Arabic, there is no known trace of it (Balbiani, 1999, pp. 280–281).

[25] The most influential divulger of gemstone enhancement techniques during Elizabethan times was Hugh Plat (1552–1608), himself a 'writer of secrets'. His book *The Jewell House of Art and Nature* (1594) draws information of all sorts from two books by Alessio Piemontese (1555, 1567) as well as from Della Porta, including some on glass 'gems'. However, for the latter, he copied from the 1589 edition of *Magiae Naturalis* rather than the 1558 one.

[26] Della Porta twice organized in Naples groups of researchers on natural matters who formed academies called *Accademia dei Secreti* (secret) and *Accademia degli Otiosi* (lazy), the latter meaning that they had time to spend enjoying apparently useless experiments. One after the other, both academies were dissolved (in 1580 and 1584) by the Spanish authorities running Naples at that time, because their founder had been admonished by Pope Gregory XIII (Sarnelli, 1677; Valente, 1999). In 1610 Della Porta joined the *Accademia dei Lincei*, founded in 1604 by Federico Cesi in Rome, as its fifth member and the leader-to-be of a section to be established in Naples (Carutti, 1883, p. 24; Paolella, 2002, p. 514).

[27] The title of Book VI is "*Gemmas adulterare nititur*" (p. 117), which translates as "one makes efforts to adulterate gems". Therefore, the full aim was not only counterfeiting gemstones, but enhancing them too.

[28] Not only does he refer (p. 121) to a recipe by which rock crystal can be made using the decapitated head of a rooster with its neck and comb ("*crista galli capiatur, & intercisa galea, caput, & collum seruato…*"), but he also proposes a riddle regarding the philosopher's stone ("*philosophorum lapidem inde habeas*"). Thus, Price (1958, p. 2) was not entirely correct when, in editing the reprint of the English translation on the occasion of the book's 300-year anniversary, he wrote that "the full and expanded version of his book…includes much new material of a real scientific character and omits from the 1558 version some of the more blatant marvels."

[29] The exception is the abstruse 6th chapter; it comes as a real surprise and interrupts the regular flow of technical descriptions.

ent. The word *alchemy* is nowhere mentioned[30], and yet several alchemical practices survived, although disguised and spread throughout the text so as not to be conspicuous.[31]

Fluxes: After the introduction ('proœmium') to Book VI (p. 117), where Pliny's words are recalled—but his advice not to enter deeply into such a shameful practice is ignored—Della Porta began Chapter 1 (p. 118) with a careful description of the preparation of reagents for glass gem making, beginning with two fluxes. For the first one, the ashes of *kali herba*[32] are burned and then boiled with water for four hours in a copper cauldron, the ratio being one pound (0.45 kg) of ash to one firkin (4.9 L) of water. When the liquid decreases to one-third, the cauldron is withdrawn from the fire and the liquid is allowed to settle for 12 hours to become clear; then it is filtered through cloth and placed aside. This process is repeated three times and finally the concentrated liquid is placed in an earthen vase, warmed again and condensed first to a thick liquid and then to a dry salt, which has to be skimmed with an iron spoon. The output from five pounds of 'herb' was said to be one pound of pure salt; too much, possibly, such that this result implies some contamination by unknown impurities.

The second flux to be prepared is tartar ("*tartarum vocatur vulgò*"; p. 118). One collects old wine dregs and dries them in a reverberant hot oven. They will whiten and must be turned over using iron tongs until they stop fuming and the entire mass is calcined. The broken bits are quenched in water and ground to a powder, which is settled in water in a large jar until it is clear; then it is filtered through felt into another jar while the first jar is filled again with water and the operation is repeated three or four times. All the filtered waters are then transferred to a glass vase, which is warmed with charcoal until all the water evaporates and the dry salt deposits. Such a salt must be kept in a dry place; otherwise it absorbs moisture and alters into a kind of oil.

Silica Raw Material and Glassmaking: Della Porta begins Chapter 2 (p. 118) by recalling that silica is the main constituent of any glass gem. The raw silica can be either crystal or flint, or even round pebbles, the best of which are said to be those gathered from the river Thames.[33] Cobbles are first set into a reverberant oven where the flame is most intense. When red hot, they are taken out, fractured by dropping them into water, dried and then ground with a bronze mortar until reduced to a light powder. The powder is transferred to a large basin full of water, which is shaken by hand so that the finest part will float and can be transferred to another basin. The coarser part is shaken repeatedly until the bottom portion looks like a mud. This will contain any dirt and, in particular, the metal particles scraped off the mortar and the mill; these would contaminate the gem simulant and should be washed away. The finest powder is skimmed off by a spoon and set into clear water until it dries completely and can be stored away.

At this point, Della Porta proceeds to teach the reader how to "cook" *pastilli* (pastilles): "*His peractis docere decet quomodo pastilli coquantur*"

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[30] Because of the word *Magiae* in the title and of some contents of the book that could be interpreted as affected by alchemy, in 1574 and 1580 Della Porta was summoned to Rome for questioning, his books were suspended *donec expurgantur* (till being cleared from what was wrong) and he himself was warned not to publish anything before receiving clearance by church authorities. He avoided a heavier punishment only because he could convince the Inquisition that his teaching contained no trace of the errors and superstitions inherent in *magia nera* (black magic), i.e. inspired by the devil (cf. Amabile, 1892; Valente, 1999). However, despite its preliminary expurgation, the 1589 edition of *Magiae Naturalis* was on the 1593 *Index Librorum Prohibitorum* (Index of Prohibited Books) at the suggestion of the French philosopher Jean Bodin (1530–1596).

[31] A full translation into English of the 1589 edition appeared in 1658 under the title *Natural Magick*. It is now freely available online at https://archive.org/details/naturalmagick00port. Here the present author attempts to give a summary translation that goes directly to the point and disregards the useless digressions and fancy descriptions so common in many texts of that era.

[32] "*Kali herbam in cinerem versam, sodam appellat vulgus*" (p. 118). The herb is likely *Salsola kali L.*, which is a common bush along the Italian coastline, particularly from Venice to Trieste, where long since it had been picked up to supply Murano glass works. Its ashes are rich in potassium carbonate, indistinguishable from sodium carbonate ("soda" *sensu stricto*) at that time.

[33] Stated as "*rotundi fluminum calculi, principem enim locum tenent, qui ad Temesim amnem albi, perspicui, ovi magnitudine*", translated as "those are the best which are taken up by the river Thames, white, clear, and of the bigness of an egge". This translation appeared in the 1658 English edition (p. 179) of Della Porta's 1589 *Magiae Naturalis*. The present author could not find any reference to the river Thames in Biringuccio's or Agricola's treatises, but the Latin name of the river occurs in several medieval church documents (e.g. Guardo, 2008).

ASPICIT ET INSPICIT

IO. BAPT. PORTAE
NEAPOLITANI
MAGIAE NATVRALIS
LIBRI XX.
Ab ipso authore expurgati, & superaucti, in quibus scientiarum Naturalium diuitiæ, & delitiæ demonstrantur

I De mirabilium rerum causis.
II De varijs animalibus gignendis.
III De nouis plantis producendis.
IIII De augenda supellectili.
V De metallorum transmutatione
VI De gemmarum adulterijs.
VII De miraculis magnetis.
VIII De portentosis medelis.
IX De mulierum cosmetice.
X De extrahendis rerum essentijs.
XI De myropœia.
XII De incendiarijs ignibus.
XIII De raris ferri temperaturis.
XIIII De miro conuiuiorum apparatu.
XV De capiendis manu feris.
XVI De inuisibilibus literarum notis.
XVII De catoptricis imaginibus.
XVIII De staticis experimentis.
XIX De pneumaticis.
XX Chaos.

CVM PRIVILEGIO.
NEAPOLI, Apud Horatium Saluianum. D. D. LXXXVIIII.

Figure 3: The title page of Magiae Naturalis Libri XX, *1589 edition, shows the titles of all 20 books composing this volume.*

(p. 118). The ingredients are tartar, soda and silica in the ratio 5:5:20. They are mixed very well, and wetted to make a paste lump, which is sun-dried first and then set in a reverberant oven for six hours while increasing the heat slowly until the lump becomes red hot. However, it should not be allowed to melt, and therefore it is recommended not to use bellows. After such pastilles cool down, they should be so hard as almost not to break under a hammer.

After describing the preparation of the main mixture, Della Porta takes great pains to describe in detail the furnace and the instruments to be used (Chapter 3). A furnace for making gem simulants (p. 119) is similar to the ordinary one used by glassmakers, but smaller. It is 2.4 m high and narrow on top but with a vent 30 cm wide, and two chambers. The lower chamber has walls about 37 cm thick and one small opening to add wood, while the upper chamber has several large openings on every wall to let workers insert the open crucibles[34], which should lay on top of the furnace divide. Slow heating under continuous control requires six hours to reach

[34] To properly describe these crucibles, Della Porta used two words—*catini* (Latin) and *padella* (Italian)—to make it clear that they must be low and wide (basins). He also specifies that they be made with clay from Valencia (Spain), which stands up best to a hot fire.

the required temperature. Then the pastilles, which were previously crushed to pieces the size of a walnut, are set one by one into the crucibles using iron tongs. Several pastilles are added to each crucible. When they reach the melting temperature, they release air and tend to swell, and the worker must prick them with iron forks to deflate them and prevent the glass from flowing over the rim. One day of work will fill each crucible with molten glass, which must be sampled and tested for brightness and transparency. When the glass is ready, the crucibles are first extracted and cooled in water, and then the glass is brought back to the furnace for two days, so that the final glass becomes free of air bubbles generated by the fluxes. As a further precaution, at the end certain artisans add some 'white lead'[35], which first turns to red and then, when fully dissolved, makes the glass become colourless and transparent. The bubble-free and transparent glass is now ready to acquire the various colours.

Pigment Preparation and the Glass Coloration Process: Chapter 4 teaches how to prepare pigments, taking advantage of the two idle days during which the colourless glass[36] matures in the furnace (p. 119). The first colour to be made is orange-red (*crocus*[37]), obtained from iron filings washed in a large basin to skim off any intermingled wood shavings coming from the bottom chamber. The iron filings are first dried and then transferred into a large glazed jar that is filled with strong vinegar, in the ratio of three or four pounds of filings to three or four firkins of vinegar.[38] The chemical reaction should go on for three or four weeks, and every day the mass should be stirred seven or eight times using an iron rod. After the mixture has settled somewhat, the supernatant liquid is transferred to a pan, and fresh vinegar is added to the jar to renew the reaction as many times as needed to consume all of the iron-rich mud-like deposit. The solution in the pan is set in the warm side of the furnace and evaporated until it becomes a dry dust: this is the *crocus*. It may also be prepared by scraping filings from red-hot iron nails and quenching them into a pot of vinegar, and by repeating this operation three or four times, after which the vinegar is evaporated and the *crocus* resting at the bottom of the pot is collected.

A blue pigment is made by converting *zaphara*[39] into powder, by using a case (probably made of clay) measuring one foot wide that is built over a small window on a side of the furnace. The fire enters through a hole and opposite it is another hole with a shutter, which is just large enough for the hand of the artisan. The case containing the *zaphara* is set inside and the shutter closed for six hours, after which it is taken out and quenched in water so that it breaks apart. Finally the *zaphara* is dried and milled to a very fine powder.

A pigment called *aes* was used for making aquamarine and olivine imitations, and it was derived from burning copper. The copper is first filed smooth and then mixed with salt in a ceramic pot and exposed to fire for a full day while being turned over every two or three hours with an iron rod so that it is strongly heated throughout. It is then removed from the furnace and divided into two portions: one is stored away, and the other is mixed with salt again and exposed to fire for half a day, and so on for three or four times to be sure that all is completely changed into powder. The fire must be hot but the copper should not be allowed to melt; it should only show a black crust.

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[35] "*In catinos tantundem cerussae addunt, nam rubescit illico, max liquescit cum vitro, & perspicuum redditur*" (p. 119). It was known from Roman times that the addition of lead would produce a transparent glass. Della Porta's innovation was to specify when to add lead and in what form. Indeed, white lead (*cerussa*) is $(Pb[CO_3])_2 \cdot Pb(OH)_2$. At high temperature, it first turns into red lead Pb_3O_4 (minium), which then dissolves completely into the melt, increasing its density and refractive index. The cerussa was produced artificially by exposing metallic lead in a closed pot to fumes arising from warm vinegar.

[36] Here he calls such a glass *crystallum*, a name then in use in Venice (Verità, 2014, p. 57, Figure 1).

[37] Properly, the colour of *Crocus sativus L.* (i.e. saffron), a common flower in Italy's Apennine Mountains.

[38] In modern terms, ~2 kg of metallic iron should be reacted with ~160 L of vinegar.

[39] The *zaphara*, also called *zaphara figlinorum* (p. 120)—in English *zaffer* or *zaffre*—was a deep blue pigment obtained by sublimation of the fumes arising while roasting silver- and cobalt-bearing lead sulphide ores to extract silver in the Saxon-Bohemian ore district. It consists of impure, partly amorphous varieties of either cobalt oxide Co_3O_4 or cobalt arsenate $Co_3[AsO_4]_2$. It was imported to Italy as a raw powder, which, when wetted, was appropriate to paint pottery and glaze it to a vitreous coating during the final firing.

Table I: Recipes for making glass 'gems', from the 1589 edition of Magiae Naturalis.

Glass 'gem'	Pigment(s)	Ratio pigment : glass*	Experimental details
Sapphirus (sapphire)	*Zaphara* (zaffre: impure cobalt)	2 *dragma* : 1 *libra*	6 hours' duration
Aqua marina (aquamarine)	*Aes* (burnt copper)	Indifferent (best 1 *dragma* : 1 *libra*)	None given
Amethystinus (amethyst)	*Manganese* (manganese oxide)	1 *dragma* : 1 *libra*	None given
Topacium (topaz)	*Crocus* + *minium* (saffron + 'red lead')	3 *uncia* 'red lead' + ¼ *uncia* saffron : 1 *libra*	Add 'red lead' first
Chrysolitus (chrysolite or olivine)	*Aes* (burnt copper)	*Pulvisculum* (dusting)	Use the topaz-type glass instead of colourless glass
Smaragdum (emerald)	*Crocus* (saffron)	Add ¼ *uncia* to the aquamarine glass and let it season for 6 hours, then add ⅛ uncia and season, and so on until the desired colour is attained.	

* In Renaissance Naples, *dragma* was a weighing unit for drugstores equivalent to 2.64 g, and *libra* was 320.76 g. An *uncia* is roughly equivalent to one ounce.

Chapter 5 is the core of the entire process. Indeed, it is titled "How gems are coloured" ("*Quomodo gemmae colorentur*"; p. 120). The pigments described above are blended with the previously prepared colourless glass while it is molten, so that they mix homogeneously. The recipes are summarized in Table I. There were no particular instructions given here, but Della Porta thought it best to add a series of tedious recommendations based on his own observations of glassmaker practices. For example, the glass used for a sapphire simulant should be coloured first, and as soon as the proper colour is reached it should be quickly removed from the fire, as otherwise the colour would fade and the glass turn clear. The addition of *zaphara* requires strong stirring from the bottom to top of the crucible using an iron rod; a little glass should be tested to check if the correct colour is reached. He also added some information not given previously: (1) The blue glass 'gem' called 'aquamarine'[40] is a variety of sapphire (*sic*) and, as in natural stones, may be either dark or light in colour; (2) the colour of amethyst-type glass is obtained by adding manganese[41]; (3) adding 'red lead' will enhance the brightness of topaz-type glass; and (4) the glass made to imitate topaz can be further used to simulate chrysolite (olivine), because the latter gem has a similar colour except that it ranges into a shade of green.

The recipe for glass used to simulate emerald is given last, because this preparation requires a long exposure to fire, as the burnt copper which dyes the glass has a tendency to sink into the crucible, leaving on top a glass too poorly coloured. The best way to produce emerald-coloured glass (e.g. Figure 1) is to start with the aquamarine-type glass (containing burnt copper) and add *crocus*, so that the ratio of *crocus*:copper is 2:1, and then let the mix season until the glass becomes homogeneous and transparent, reabsorbing any coloured clouds that might form inside.

The list ends with the recommendation of decreasing the fire slowly until the furnace has cooled down enough to safely extract the pots. Finally, when the pots are cool, they are broken and the "fictitious precious stones" ("*confrac-*

[40] "*Cyaneam gemmam colorare. Quam vulgus aquam marinam vocat, speciem sapphiri*" (p. 120).

[41] The first mention of manganese was by Biringuccio (1540, c. 36v). To him it was not a metal, but a *mezzo minerale* (semi-mineral), rust-like in colour, which was imported from Germany for use by glassmakers. He pointed out that the same material could also be found in lower Tuscany and upper Latium, where, indeed, occurrences of oxides and hydroxides of manganese are widespread. Notice that, in Venice, to make glass clear and transparent, people had been adding (probably without knowing it) some imported Mn-bearing mineral powder to the melt since 1290 (Verità, 2014, p. 56). Pliny mentions *magnesium* added for the same purpose, but this name had lost its specificity during the Middle Ages and certainly did not refer to black ore.

taeque (ollulae) ementitos preciosos lapides largientur"; p. 120) can be easily taken out.

Della Porta begins Chapter 6 (p. 121) by saying that he knows other ways of making gem simulants that are even better than the ancient ones found in the ruins of Pozzuoli or, occasionally, in the nearby shore sands. Then, rather suddenly, he goes astray into the mysteries of alchemy (see above). The following chapters describe various enhancements of natural gem materials (in particular quartz), and then move on to enamels, coloured metal sheets for reflection, etc.[42] Della Porta ends Book VI, Chapter 13, with the short but factual statement: "This is all that we experimented on gems so far" ("*Haec sunt quae hoc tempore de gemmis experti sumus*"; p. 126).

Discussion and Conclusion

Comparing the two editions of Della Porta's *Magiae Naturalis* contributes to understanding their audience: The slender 1558 edition, with its few precise recipes accompanied by alchemical suggestions, is intended to stir the interest of cultivated people and induce them to experiment. The large and somewhat confusing 1589 version provides details that enable experiments to be made to the best of the contemporaneous abilities, and it avoids alchemical tracts, or separates them from the bulk of the description of technical recipes. The 1589 version enjoyed fewer editions and translations than the 1558 one did.[43] The local vernacular translations of the 1558 edition continued to be preferred all over Europe, with the exception of Germany.

Implications for English Glassmaking: In England, Della Porta's 1589 *Magiae Naturalis* Latin edition was cursorily quoted by Thomas Nicols in 1652 in the "first independent gemological book written or published by a British author"[44], but only to mention the existence of various enhancement methods to colour quartz, rather than for his description of making glass gem simulants. In fact, Nicols (1652) appears to draw from Della Porta's treatise only once (pp. 25–26), in a concise reference (14 lines), as partially given here:

> …foyls, are made either *ex foliis æris, auri, vel argenti*, then they are wont to prepare these by hanging them in threads in a furnace made for the same purpose; that so they may be tinctured with the vapour of that which being burned in the lower part of the furnace, doth ascend for that purpose.

Unfortunately, the reference is incorrect: nowhere does Della Porta suggest mixing the pigments into the wood fire in the lower part of the furnace, and the method itself applies to enhancing the surface colour of natural gemstones rather than making glass 'gems'. Yet, Nicols' book enjoyed two reissues, in 1653 and 1659, until it was superseded by Robert Boyle's *Essay* (1672).

In 1658, the English translation of Della Porta's 1589 *Magiae Naturalis* was made anonymously. The title plate (Figure 4) shows only the name of the engraver, "R. Gaywood"[45], and nothing of the essential publishing data, which appear instead in the frontispiece that follows, printed in two colours (Figure 5). This book is now exceedingly rare, both in its first printing and in its reissue (1669); the few soiled copies remaining testify that they apparently were used and worn out by practical men operating on a laboratory bench, rather than by scholars preserving them almost untouched on a library shelf. Most probably, the actual readers were high-class people who felt experimenting to be an interesting, albeit unusual activity, or practical men who tried methods first in their laboratories before exposing themselves to a new venture.

The second half of the 17th century in England was characterized by an economic revival with increasing interest for science in general, including those books penned by 'writers of secrets' (i.e. those treatises that described technical undertakings). Della Porta's was among the

[42] Such treatments were studied and carefully described by Nassau (1994).

[43] Balbiani (1999, p. 281) stated that the 1589 enlarged edition had 'only' 35 printings, mostly in the Latin original text. In Germany this became the reference tome, so that it was translated to German only as late as 1680, by Christian Knorr von Rosenroth.

[44] This statement was made by John Sinkankas in his authoritative annotated gemstone bibliography (1993, p. 755b).

[45] Richard Gaywood (active 1650–1680) was a pupil of the British-naturalized Bohemian engraver Wenceslaus Hollar (cf. *Dictionary of National Biography*, Smith, Elder & Co., London, 1885–1900). He worked in London, and the bulk of his work consisted of portraits and frontispieces to books, several of which related to natural science, including Della Porta's *Natural Magick* (1658).

Figure 4: Shown here is the title plate of the first English translation of Natural Magick, *published in London in 1658. Note the profile of Della Porta taken from the 1589 Neapolitan edition surrounded by images engraved by Richard Gaywood of the subjects covered in the volume.*

very first translations printed and used most. This is apparent not only from the faded state of the volumes but also from a comparison with Christopher Merret's translation, issued in 1662, of Antonio Neri's *Arte Vetraria* (Glass Art; 1612), originally published in Florence in Italian but never extensively applied in Tuscany.[46] Notably, both books were translated and published during the Protectorate, when the primary aim was to restore England's national economy after 30 years of disastrous civil wars. This trend continued after the Restoration, which, in particular, took advantage of the newly founded Royal Society (1663) to scout and translate all books written in foreign languages that could stimulate the country's economy.[47]

[46] In his translation of Neri's *Arte Vetraria* (in which Florentine glass knowledge is summarized), Christopher Merret (1614–1695) supplemented the original treatise with 176 pages of comments and new information he had probably deduced from the Venetian glassmaking tradition (cf. Verità, 2014, p. 62).

[47] This project, clearly and repeatedly mentioned by Thomas Sprat and Henry Oldenburg (both secretaries of the Royal Society), was reviewed recently by Henderson (2013).

Indeed, the English glassmaking industry benefited greatly from such translations. In 1674 George Ravenscroft (1632–1684)[48] filed for a glassmaking patent of his own (MacLeod, 1987). He had been in Venice as a youth and had become acquainted with the essentials of Murano glassmaking techniques. When he returned to London, he attempted the production of similar glass with the help of two Murano glassmakers he had convinced to follow him.[49] As primary ore he used the local Thames flint-rich grey sands.[50] The results were not satisfying, but he persisted and, following a suggestion by Robert Plot[51], he moved his kiln upstream to Henley-on-Thames, where the river sands contain white flint similar to that of the Po River delta that the Venetian glassmakers had always exploited. Actually, the success of the enterprise did not depend upon the flint used for silica, but upon the flux. Ravenscroft used a potassic-alkali flux with added lead oxide such as that suggested by Della Porta. The mix produced brilliant, heavy 'crystal' glass easy to mould and, moreover, did not suffer 'crizzling' (i.e. it did not become cloudy with age due to the formation of numerous microscopic internal cracks). Furthermore, his factory used coal from the nearby mines, thus bringing the kiln to higher temperatures at lower cost.

The practice of publishing 'secrets', although unwelcome to many, contributed to the development of both science and the economy. In particular, it is significant that Della Porta's *Magiae Naturalis*, intended for completely different purposes and contributing only poorly to the 'scientific revolution' because of its still rather alchemical bent, eventually helped speed up the English industrial revolution.

[48] During his youth, Ravenscroft travelled throughout Europe and established an import-export network, with bases located in Venice and London.

[49] This was against Venetian law, as it would deprive Venice of essential knowledge and manpower for its (fading) monopoly on high-quality glass.

[50] This is a precise recollection of Della Porta's mention of the river, which can be found only in the 1589 edition (p. 118).

[51] A fellow of the Royal Society (1640–1696), Plot was the first professor of chemistry at Oxford University and the first keeper of the Ashmolean Museum. He knew very well the geology of Oxfordshire and Staffordshire, where flint, coal and lead ores were present together in exploitable quantities, and published a detailed record of this (cf. *Dictionary of National Biography*, Smith, Elder & Co., London, 1885–1900).

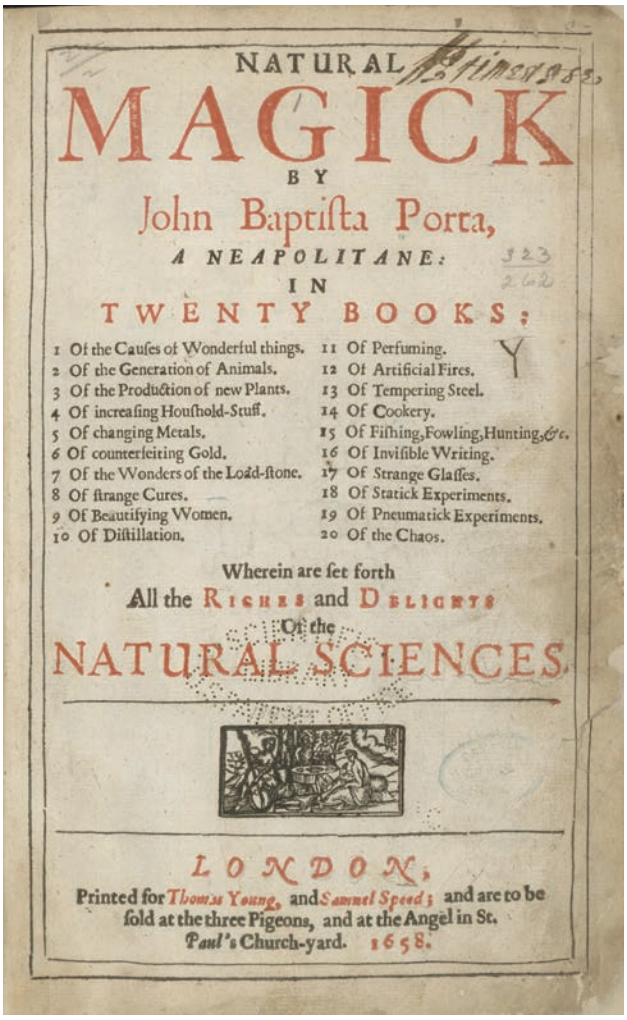
NATURAL
MAGICK
BY
John Baptista Porta,
A NEAPOLITANE:
IN
TWENTY BOOKS;

1 Of the Causes of Wonderful things.
2 Of the Generation of Animals.
3 Of the Production of new Plants.
4 Of increasing Houshold-Stuff.
5 of changing Metals.
6 Of counterfeiting Gold.
7 Of the Wonders of the Load-stone.
8 Of strange Cures.
9 Of Beautifying Women.
10 Of Distillation.
11 Of Perfuming.
12 Of Artificial Fires.
13 Of Tempering Steel.
14 Of Cookery.
15 Of Fishing, Fowling, Hunting, &c.
16 Of Invisible Writing.
17 Of Strange Glasses.
18 Of Statick Experiments.
19 Of Pneumatick Experiments.
20 Of the Chaos.

Wherein are set forth
All the RICHES and DELIGHTS
Of the
NATURAL SCIENCES.

LONDON,
Printed for Thomas Young, and Samuel Speed; and are to be sold at the three Pigeons, and at the Angel in St. Paul's Church-yard. 1658.

Figure 5: Shown here is the frontispiece of the first English translation of Natural Magic, *as printed in London in 1658. Note that there is an error in the title of Chapter 6; inside the book on p. 178 is the correct translation: 'Of Counterfeiting Precious Stones'.*

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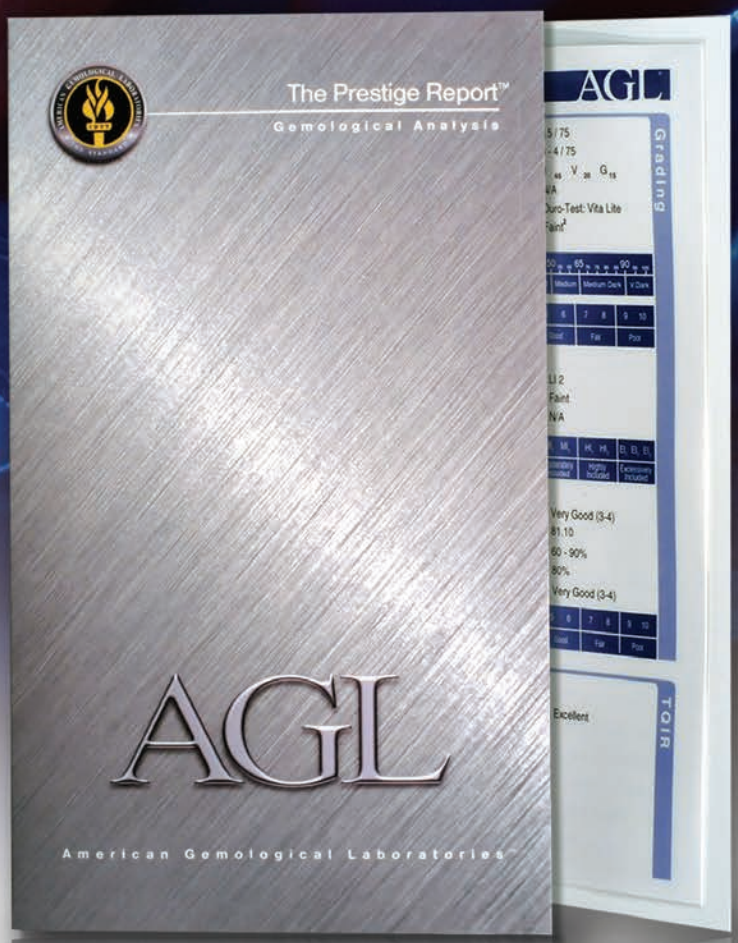

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Conferences

3rd Mediterranean Gem and Jewellery Conference

The sunny Mediterranean lured gemmologists, jewellers and appraisers (Figure 1) from 15 countries to the 3rd Mediterranean Gem and Jewellery Conference (MGJC), this year in Syracuse, Italy, with a view of Mount Etna in the distance. The theme of the conference was coloured diamonds, which formed the basis of most of the talks and also workshops before and after the 11–14 May 2017 conference.

A pre-conference morning workshop on the use of the handheld spectroscope for testing gems and coloured diamonds was instructed by Gem-A's **Claire Mitchell**. After her presentation on various techniques for using a spectroscope and the features to look for, the 12 participants practised on sample gems, while Mitchell was at hand to provide viewing tips and answer queries.

In the afternoon, 30 participants filled the room to attend a workshop on identifying synthetic diamonds, both loose and mounted in jewellery. The focus was on small diamonds (including melee), which are a growing concern in the industry. The workshop started with a presentation by conference co-organiser **Branko Deljanin** (CGL-GRS Swiss Canadian Gemlab Inc., Vancouver, British Columbia, Canada), who reviewed synthetic diamond production techniques and characteristics that distinguish them from natural diamonds. Identification techniques included the use of crossed polarisers and observation of luminescence behaviour. The greater part of the workshop was taken with participants examining up to 50 samples of synthetic and natural diamonds with the help of conference co-organizer **George Spyromilios** (Independent Gemological Laboratory, Athens, Greece). He brought new samples that included rings and earrings set with natural and both HPHT-grown and CVD-grown synthetic diamonds. Participants had the opportunity to use a PL Inspector, which provides short- and long-wave UV excitation to examine a sample's fluorescence colour, intensity and, importantly, any phosphorescence, which is a key identifying feature of HPHT synthetic diamonds. The instrument was designed by **this author**, who assisted and demonstrated the use of a smartphone to better view the luminescence reactions. Conference sponsors System Eickhorst and M&A Gemological Instruments brought various lighting devices and instruments (including UV-Vis-NIR, FTIR and PL spectrometers) so participants had access to a mobile gem lab.

The second day of the conference was more formal, with speakers delivering talks on a variety of topics. **Alan Bronstein** (Aurora Gems, and president of Natural Color Diamond Association, New York, New York, USA) related the story of polishing the 'Blue Moon' diamond. He recounted the stone's journey from its origin in South Africa in early 2014 to its transformation into a 12.03 ct Vivid Blue, Internally Flawless diamond that achieved a record $4 million/carat at auction three years later. Grading fancy-coloured

Figure 1: Conference attendees gather at this year's MGJC for a group photo. Photo by J. G. Chapman.

diamonds has been a mystery to some, even those in the trade, so it was instructive to hear from **Thomas Gelb** (Natural Color Diamond Association), who once worked in GIA's diamond colour-grading department, outline the methods and terminology of fancy-colour grading, including viewing geometry, colour space and the concept of 'characteristic colour'. **Dr Katrien De Corte** (HRD Antwerp, Belgium) delivered a more technical discussion on natural and synthetic type II diamonds. She outlined some of the spectroscopic testing HRD does to detect synthetics when stones are submitted for grading. **This author** followed by describing how technology can be applied to grading coloured diamonds and fluorescence intensity using digital cameras and image-processing techniques. While body colour is one of the prime factors in determining the value of a diamond, provenance is also playing an increasing role, particularly with regard to pink diamonds. **Branko Deljanin** described a new service being offered by CGL-GRS of grading colour to finer resolution (11 rather than five grades) and also identifying whether a pink or blue diamond is from the Argyle mine in Australia. Pink diamonds from Argyle were the main topic of a talk by **Kym Hughes** (Symmetry Jewellery Valuation Specialists, Nerang, Queensland, Australia), who covered pricing factors for coloured diamonds and pitfalls in valuations for jewellery in which mountings can complicate the determination of a diamond's true colour appearance.

A buffet lunch break overlooking the Mediterranean Sea allowed delegates to discuss some of the morning's issues with one another before returning to hear more presentations. The importance of sponsors cannot be underestimated for the viability of conferences and, in exchange, sponsors can promote their businesses. Russia's mining giant—Alrosa—was a major sponsor, and **Alexey Useinov** (Technological Institute for Superhard and Novel Carbon Materials, Moscow, Russia, on behalf of Alrosa) introduced the Alrosa Diamond Inspector for screening both loose and mounted synthetic diamonds. **Marco Pocaterra**, from sponsor Diamond Love Bond (Milan, Italy), also took the podium to highlight the investment market for diamonds in Italy.

Although diamonds dominated the conference theme, other gems also were covered. **Ilaria Adamo** (Italian Gemmological Institute, Milan) introduced conference participants to the world of demantoid, covering their sources and geological origins—serpentinite- and skarn-related—for which distinctive inclusions are associated. Then **Victor Tuzlukov** (Russian Faceters Guild, Moscow, Russia) and **Alicia de Vildósola** (Tasarjoyas, Madrid, Spain) together discussed unconventional cuts and how they should be judged and valued. With jewellery as another topic of the conference, the audience

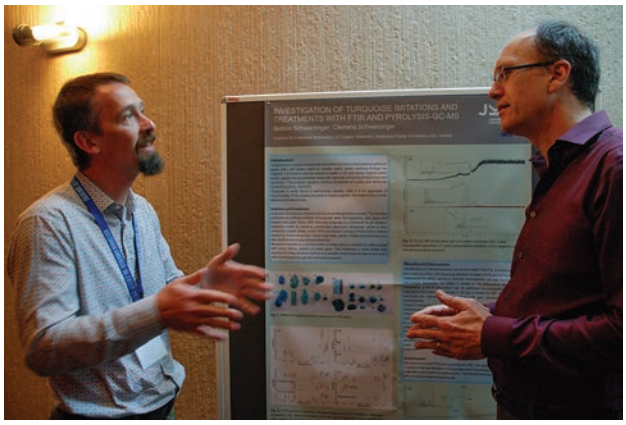

Figure 2: Clemens Schwarzinger discusses his MGJC poster presentation on turquoise imitations and treatments with Branko Deljanin. Photo by J. G. Chapman.

was entranced by examples of the exquisite work of Italian jewellery designer Gainmaria Buccellati, as told by **Larry French** (Gianmaria Buccellati Foundation, Milan), who also described Buccellati's techniques that involved mostly their 'Tulle' and 'Honeycomb' styles. **Manfred Eickhorst** (System Eickhorst, Hamburg, Germany) gave a short presentation on the importance of lighting in examining and grading diamonds and coloured stones, and offered some practical solutions.

A round-table session ended the day with a panel comprising **Thomas Gelb**, **Katrien de Corte**, **Alan Bronstein**, **Branko Deljanin** and **Kym Hughes**, moderated by **this author**, which covered coloured-diamond grading methods and reports. Members of the panel and the audience voiced their opinions on such matters as the reliability of reports for trading and valuation. A second part of the round table addressed fluorescence in diamonds, particularly its impact on appearance and whether discounts applied to strongly fluorescing diamonds are justified. In light of historical accounts of price premiums for fluorescence and its desirability to consumers, it was generally considered that the time is right for revisiting the impact of fluorescence on diamond grade and the appropriate discount (or premium) to be applied.

The day finished with a conference dinner, taking advantage of the al fresco conditions of Sicily, with some delegates passing the time beforehand browsing the posters. The poster presentations included one by **Dr Brad Cann** (De Beers, Maidenhead, Berkshire) on a thermometer for the HPHT treatment of CVD synthetic diamond. **Dr Clemens and Bettina Schwarzinger** (Johannes Kepler University, Linz, Austria) presented a poster on how to identify turquoise imitations and treatments using FTIR spectroscopy and pyrolysis mass spectroscopy (Figure 2). Asterism in gems was the subject of a poster by **Martin Stein-**

bach (Steinbach – Gems with a Star, Idar-Oberstein, Germany), and **Nick del Re** (independent gemmologist, New York) provided an insight into a smartphone accessory for recording digital spectra.

The third day of the conference returned to the workshop format, and was attended by 40 participants eager to learn how to distinguish natural from synthetic or treated coloured diamonds using the techniques mentioned above for the pre-conference workshop, as well as more advanced instrumentation such as UV-Vis-NIR, FTIR and PL spectrometers supplied by M&A Gemological Instruments. A second part of the day's workshop had participants learning how GIA grades colour in fancy-colour diamonds and what other labs such as GRS and CGL-GRS are offering as alternatives. A wide range of coloured diamonds were available for examination in a new Eickhorst grading cabinet, using Munsell colour chips for grading. Lectures were offered by **Branko Deljanin** and **Thomas Gelb** and assisted by **George Spyromilios**, **Elena Deljanin** and **this author**.

The following day provided an excursion to the historical part of Syracuse, where delegates could marvel at ancient ruins, enjoy the atmosphere of a food market and explore the narrow streets.

Every fourth year, the MGJC will 'travel' to a large country or market, and the 2018 conference will be held in Russia this summer with the theme 'Diamonds in 21st Century'. In addition, the 2019 MGJC is being planned for Israel. Further details on the conferences can be found at www.gemconference.com.

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75th Anniversary Congress of the Swiss Gemmological Society/ European Gemmological Symposium

From 29 June to 2 July 2017, the Swiss Gemmological Society (SGS) celebrated its 75th anniversary in conjunction with the European Gemmological Symposium. The congress and jubilee events took place at the Grand Hotel Zermatterhof in the alpine resort village of Zermatt, Switzerland, and were attended by approximately 120 SGS members and guests (Figure 3). Former Swiss prime minister, **Adolf Ogi**, and president of SGS, **Hans Pfister**, gave commemorative speeches at the anniversary gala dinner. **Dr Thomas Hainschwang** (GGTL Laboratories, Balzers, Liechtenstein) and **Dr Michael Krzemnicki** (Swiss Gemmological Institute SSEF, Basel, Switzerland) received SGS Excellence Awards for their contributions to the field of gemmology (Figure 4). The conference concluded on Sunday with a field excursion to the Gornergrat,

Figure 3: Conference participants recently gathered at the Swiss Gemmological Society Congress and European Gemmological Symposium in Zermatt, Switzerland. In the centre of the first row is honorary guest Adolph Ogi, who is the former Swiss prime minister. Photo by M. Hügi.

Figure 4: The SGS Excellence Award is presented to Dr Thomas Hainschwang (left) and to Dr Michael Krzemnicki (centre-left) by SGS president Hans Pfister (right) and SGS director Michael Hügi (centre-right). Photo by D. Bellandi.

where **Prof. Dr Kurt Bucher** (University of Freiburg im Breisgau, Germany) gave an overview of the geology of the Zermatt region. **Dr Walter Balmer** (SGS scientific committee) and **the authors of this report** chaired the conference, which covered a broad variety of topics.

Martin Rapaport (Rapaport Diamond Corp., New York, New York, USA) focused his keynote lecture on the importance of gemmology to the diamond market. To maintain consumer confidence in the jewellery industry, there is a strong need now and in the future for well-trained people who are able to assess the different certifications and declarations of a gem's quality, especially in view of the emerging Internet trade. **Dr Thomas Hainschwang** provided an overview of the development of diamond treatments from the early simple methods of irradiation and annealing to the modern complex combinations of HPHT processing with irradiation and annealing, which allow a broad variety of diamond colours to be produced. To increase the knowledge of current diamond treatments, GGTL Laboratories have launched a study on the effects of different treatments on lattice defects in diamond. **Dr Wuyi Wang** (Gemological Institute of America, New York) presented the principles and current status of diamond synthesis. Although it is possible for laboratories to easily distinguish natural from synthetic diamonds, retailers and jewellers often reach the limits of their capabilities. For such cases, GIA is developing an easy-to-handle device to indicate samples that require further testing for separating between natural or synthetic origin. **Dr Andrey Katrusha** (New Diamond Technology Ltd., St Petersburg, Russia) presented his achievements in the production of large type IIa synthetic diamonds. In the near future, he predicted that it will be possible to produce ultra-large (>100 ct) synthetic diamond crystals exhibiting excellent structural perfection. High-quality colourless crystals in the range 10–20 ct could enter the market in large quantities within the next few years. **Alan Hart** (Gem-A, London) illustrated the history and meticulous reconstruction of the original cut of the Koh-i-Noor diamond through the analysis of a rediscovered plaster model and subsequent modelling of a CZ replica. His findings enhance our knowledge of the cutting of other so-called Mogul-cut diamonds such as the Orlov and Taj-e-Mah. **Guillaume Chautru** (Piaget, Paris, France) presented the point of view of the watch industry concerning melee-sized synthetic diamonds. The integration of a reliable testing routine within short production cycles is a difficult but crucial quest.

Author MSK highlighted how the combination of mineral inclusion studies and sophisticated scientific instrumentation is advancing gem treatment and origin research. This work has focused on inclusions such as zircon and amphibole, which can be found in various gem materials of different origins. Understanding the formation and properties of these inclusions offers great clues toward how and where a gem formed. **Dr Daniel Nyfeler** (Gübelin Gem Lab, Lucerne, Switzerland) focused on his lab's development of a new system for the traceability of gemstones from the mine to the consumer. This system is based on nanoparticles containing DNA, which are introduced into the rough gem material at the mine and cannot be removed even by cleaning and cutting processes. With this technology, trade organisations, jewellers and customers can determine the provenance of a cut stone at any time. **Helen Molesworth** (Gübelin Academy, Lucerne) gave an overview of the historical perspective of the gem market. When comparing historical prices of rubies corrected with the purchasing power of currency at the time, a 1 ct stone had a value that corresponded to a soldier's salary for a period of several years. Against this background, the current record prices for rubies and sapphires at auction can be explained by strong driving forces such as scarcity and the emotional value of certain gems.

Willy Bieri (GRS Gemresearch Swisslab AG, Meggen, Switzerland) gave an overview of the recently discovered sapphire deposits near Bemainty in the Ambatondrazaka region of Madagascar. This mining area has produced important and very beautiful sapphires, including 'royal' to 'cornflower' blue colours. Kashmir-like sapphires from this area can be distinguished from those of Kashmir by studying specific inclusions. **Vincent Pardieu** (VP Consulting, Manama,

Bahrain) reported on the gem deposits of East Africa. Beginning with the discovery of major sapphire deposits in Madagascar in the 1990s—especially those of the Ilakaka area—there have been many new mining areas found on this island. The most recent sapphire discoveries near Bemainty lay within a protected forest area, and mining of these deposits might trigger serious criticism from NGOs, which in turn might affect the jewellery industry in the future. **Dr Hanco Zwaan** (Netherlands Gemmological Laboratory, Naturalis, Leiden, The Netherlands) described the complex metamorphic processes that led to the formation of sapphire crystals in a primary deposit at Wellawaya, Sri Lanka. The gem sapphire growth is metasomatic, promoted by ultra-high-temperature metamorphism, in proximity to a tectonic contact and fluid/melt transfer associated with a pegmatite. **Franck Notari** (GGTL Laboratories, Geneva, Switzerland; lecture given by Dr T. Hainschwang) showed that the linear structures along the intersections of twin lamellae in corundum are not boehmite, as frequently described in the gemmological literature. Rather than mineral inclusions, they seem to consist of linear void structures that result from the crystallography of corundum.

Author LC shared insights on the history of emeralds, the meanings and uses of these stones, and their various geographic origins. Developments in emerald treatments and the discovery of new deposits in recent decades (most recently, Ethiopia) have provided challenges for gem laboratories. This has fuelled the need for extensive gemmological research on treatment detection and origin determination. **Klemens Link** (Gübelin Gem Lab, Lucerne) discussed the age determination of gem-quality emeralds by Rb-Sr geochronological analysis. The recently acquired triple-quadrupole LA-ICP-MS instrumentation at his laboratory allows the chemical separation of Rb and Sr isotopes and the subsequent mass-spectrometric measurement in one step. This technology will enable better origin determination of emerald as well as aquamarine. **Dr Raquel Alonso-Perez** (Mineralogical & Geological Museum, Harvard University, Cambridge, Massachusetts, USA) showed that the emerald deposit at Irondro, eastern Madagascar, formed from a combination of different geological processes and tectonic conditions. Her study contributes to the refining of the genetic classification of emerald deposits and might help enhance the economic assessment of such deposits in the future.

The history of tsavorite from the first discoveries to the present time was the theme of a presentation by **Bruce Bridges** (Bridges Tsavorite, Tucson, Arizona, USA). His father, Campbell Bridges, discovered the new green garnet variety in 1967, and subsequently developed the famous Scorpion mine. Today, the Bridges company activities cover the full production cycle from mining of the rough material to the marketing and sale of cut stones. **Alan Hodgkinson** (Whinhurst, West Kilbride) gave an overview of the occurrences and treatments of zircon, focusing on the effects of metamictization on optical properties. He showed that visual optics alone can provide important information. By the observation and measurement of dispersion and birefringence, it is possible to distinguish between a high and low zircon. The discovery of 'Sannan-Skarn', a new ornamental stone resembling maw-sit-sit, was the topic of a lecture by **Prof. Dr Henry Hänni** (GemExpert GmbH, Basel, Switzerland). This new material, mined in western Pakistan, is a dense, green granular rock consisting of up to 10 minerals including hydrogrossular, diopside, aegirine and pectolite.

Dr Ulrich Henn (German Gemmological Association, Idar-Oberstein, Germany) gave an overview of the gem deposits in western Namibia. Numerous pegmatites in the areas surrounding granitic plutons of the Erongo massif, the Spitzkoppe and Brandberg have provided high-quality gems, mostly blue-to-green, red and pink elbaite tourmaline. **Author MFH** provided an overview of Swiss gem deposits. Due to the complex geological structure of the Alps, there is a broad variety of gem minerals, mostly consisting of ornamental and collector stones. Only large transparent quartz crystals from alpine fissures deposits have enjoyed significant economic importance in history, as they were used as raw material for the lapidary industry in Italy and in Prague, which produced outstanding works of art in the past.

Dr Joseph Taylor (PT Cenada Indopearls, Denpasar, Bali, Indonesia) discussed the effects of technology transfer on marine pearl farming. The introduction of modern selective breeding practices based on genetic knowledge can lessen the reliance on wild pearl oysters. The application of these techniques has enhanced cultured pearl production and created new opportunities for the communities in islands where they are farmed.

Bernhard Berger (Cartier Tradition, Geneva, Switzerland) described Cartier's historic collection. Founded by Eric Nussbaum in 1973, the Cartier Collection manages a systematic search for the masterpieces of the company in order to establish a Cartier Museum showing the great eras and influence on jewellery design that members of the famous jeweller family have had.

Jeff Scovil (Scovil Photography, Phoenix, Arizona, USA) conveyed the techniques of aesthetic scientific photography. It takes a lot of experience and patience

to depict crystals and gemstones according to the different types and intensities of reflections, as well as to establish a fitting background. Even with the aid of digital image processing such as image stacking and combining different illuminations, the making of an aesthetic gem or mineral photograph remains an artistic endeavour.

Michael F. Hügi FGA
Swiss Gemmological Society SGS
Bern, Switzerland

Drs Michael S. Krzemnicki FGA
and Laurent Cartier FGA
Swiss Gemmological Institute SSEF
Basel, Switzerland

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Gem-A Notices

GIFTS TO THE ASSOCIATION

The Association is most grateful to the following for their gifts and donations for research and teaching purposes:

Roy (Basil) Duran, Chicago, Illinois, USA, for various gem materials, including two faceted citrines, a broken faceted round brilliant diamond, baguette melee diamonds, a blue melee diamond, cultured pearls, small faceted rubies, a soudé emerald and a synthetic star sapphire.

Charles Evans FGA DGA, Gem-A, London, for two large rough salt crystals from Devil's Golf Course, Death Valley, California, USA.

Marcus McCallum FGA, Hatton Garden, London, for a twinned alexandrite crystal slice from near Masvingo, Zimbabwe.

'Keke' Saint-Clair Fonseca Junior, BC Gemas do Brasil, Governador Valadares, Brazil, for several sawn fragments and preforms of yellow tourmaline from Mavuco, Mozambique.

Susan Stocklmayer FGA, Perth, Western Australia, Australia, for a copy of her book *Gemstones of Western Australia* 2nd edn. and an olivine lamproite tuff from Ellendale Diamond Pipe #9, Western Australia.

ANNUAL GENERAL MEETING

The Annual General Meeting of the Gemmological Association of Great Britain was held on 27 July 2017 at the Goldsmiths' Centre, Britton Street, London. The meeting was chaired by Justine Carmody.

Kerry Gregory FGA DGA retired in rotation and was re-elected to serve on the Council. Two new members had been nominated for election, Joanna Hardy FGA DGA and Philip Sadler FGA DGA, both of whom were elected. Alan Hodgkinson FGA DGA and Richard Slater FGA DGA retired in rotation and did not seek re-election.

Hazlems Fenton were re-appointed auditors for the year.

Gem-A
THE GEMMOLOGICAL ASSOCIATION OF GREAT BRITAIN

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Gem-A Conference attendee 2016

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Learning Opportunities

CONFERENCES AND SEMINARS

ASA International Appraisers Conference
7–10 October 2017
Houston, Texas, USA
www.appraisers.org/education/conferences/asa-joint-conferences

200th Anniversary Meeting of the Russian Mineralogical Society
10–13 October 2017
Saint Petersburg, Russia
www.minsoc.ru/2017
Session of interest: Natural Stone in History of Civilization (Including Gemology)

35th International Gemmological Conference
11–15 October 2017
Windhoek, Namibia
www.igc-gemmology.org (requires log-in to access information)

Chicago Responsible Jewellery Conference
13–14 October 2017
Chicago, Illinois, USA
www.chiresponsiblejewelryconference.com

Friends of Mineralogy Pacific Northwest Chapter 43rd Annual Symposium: Minerals of the Pacific Northwest
13–15 October 2017
Kelso, Washington, USA
www.pnwfm.org/symposium

Canadian Gemmological Association Conference
20–22 October 2017
Toronto, Ontario, Canada
www.canadiangemmological.com/index.php/com-virtuemart-menu-configuration/conferences-and-special-events

ICA Congress
21–24 October 2017
Jaipur, India
www.gemstone.org/events/2017-congress

Geological Society of America Annual Meeting
22–25 October 2017
Seattle, Washington, USA
http://community.geosociety.org/gsa2017/home
Session of interest: Gemological Research in the 21st Century: Characterization, Exploration, and Geological Significance of Diamonds and Other Gem Minerals

Compiled by Sarah Salmon and Brendan Laurs

9th International Congress on the Application of Raman Spectroscopy in Art and Archaeology
24–28 October 2017
Évora, Portugal
www.raa2017.uevora.pt

The Munich Show
27–29 October 2017
Munich, Germany
www.munichshow.com/en
Note: Includes a seminar programme.

Inaugural Conference on Applied Earth Sciences in Myanmar and Neighboring Regions
2–3 November 2017
Yangon, Myanmar
www.maesa.org/info.html
Session of interest: Applied Mineralogy and Gem Deposits

World Ruby Forum 2017
4 November 2017
Bangkok, Thailand
www.worldrubyforum.com

Gem-A Conference
4–5 November 2017
London
https://gem-a.com/event/conference

MJSA ConFab
5 November 2017
New York, New York, USA
www.mjsa.org/eventsprograms/mjsa_confab

CIBJO Congress 2017
5–7 November 2017
Bangkok, Thailand
www.cibjo.org/congress2017

Jewellery Matters. Context and Material Research
15–17 November 2017
Amsterdam, The Netherlands
www.rijksmuseum.nl/en/jewellery-matters

15th Swiss Geoscience Meeting
17–18 November 2017
Davos, Switzerland
https://geoscience-meeting.ch/sgm2017
Session of interest: Gemmology

Kenya Mining Forum
4–5 December 2017
Nairobi, Kenya
www.kenyaminingforum.com
Session of interest: Gemstone Industry: A Sector Sure to Shine in Time

AGTA Gemfair
30 January–4 February 2018
Tucson, Arizona, USA
www.agta.org/tradeshows/gft-seminars.html
Note: Includes a seminar programme.

AGA Tucson Conference
31 January 2018
Tucson, Arizona, USA
www.accreditedgemologists.org/currevent.php

2018 Tucson Gem and Mineral Show: Crystals and Crystal Forms
8–11 February 2018
Tucson, Arizona, USA
www.tgms.org/show
Note: Includes a seminar programme.

Amberif International Fair of Amber, Jewellery and Gemstones
21–24 March 2018
Gdańsk, Poland
www.amberif.amberexpo.pl/title,PROGRAMME,pid,3275.html
Note: Includes a seminar programme.

45th Rochester Mineralogical Symposium
19–22 April 2018
Rochester, New York, USA
www.rasny.org/minsymp

American Gem Society Conclave
23–26 April 2018
Nashville, Tennessee, USA
www.americangemsociety.org/page/conclave2018

The 32nd Annual Santa Fe Symposium
20–23 May 2018
Albuquerque, New Mexico, USA
www.santafesymposium.org

Society of North American Goldsmiths' 47th Annual Conference
23–26 May 2018
Portland, Oregon, USA
www.snagmetalsmith.org/conferences/made

JCK Las Vegas
1–4 June 2018
Las Vegas, Nevada, USA
http://lasvegas.jckonline.com/en/Events/Education
Note: Includes a seminar programme.

22nd Meeting of the International Mineralogical Association
13–17 August 2018
Melbourne, Victoria, Australia
www.ima2018.com
Sessions of interest:
- Recent Advances in our Understanding of Gem Minerals
- Sciences Behind Gemstone Treatments
- Mantle Xenoliths, Kimberlites and Related Magmas: The Diamond Trilogy

EXHIBITIONS

Europe

A Ring is a Ring is a Ring
Until 6 October 2017
London Design Festival, London
www.londondesignfestival.com/events/ring-ring-ring

Showstoppers Silver Centrepieces
Until 15 October 2017
Temple Newsam House, Leeds, West Yorkshire
www.leeds.gov.uk/museumsandgalleries/Pages/templenewsamhouse/Silver-Centrepieces.aspx

Jewellery—Materials Craft Art
Until 22 October 2017
Swiss National Museum, Landesmuseum Zürich, Switzerland
www.nationalmuseum.ch/e/microsites/2017/Zuerich/Schmuck.php

Wiener Werkstätte 1903–1932: The Luxury of Beauty
26 October 2017–29 January 2018
Neue Galerie, New York, New York, USA
www.neuegalerie.org/content/wiener-werkst%C3%A4tte-1903-1932-luxury-beauty

Pretty on Pink—Éminences Grises in Jewellery
27 October 2017–25 February 2018
Schmuckmuseum, Pforzheim, Germany
www.schmuckmuseum.de/flash/SMP_en.html

Liv Blåvarp: Jewellery
Until 29 October 2017
Lillehammer Kunstmuseum, Lillehammer, Norway
http://lillehammerartmuseum.com/exhibitions/?lang=en

Vanity: Stories of Jewelry in the Cyclades
Until 31 October 2017
Archaeological Museum of Mykonos, Greece
http://www.mymykonosapp.com/articles/the-exhibition-to-see-in-mykonos-vanity-stories-of-jewelry-in-the-cyclades

Jewellery: Designs in Print and Drawing
Until 26 November 2017
Rijksmuseum, Amsterdam, The Netherlands
www.rijksmuseum.nl/en/jewellery-designs-in-print-and-drawing

North America

Linda MacNeil: Jewels of Glass
Until 1 October 2017
Museum of Glass, Tacoma, Washington, USA
https://museumofglass.org/mog/exhibition/linda-macneil-jewels-of-glass

Colors of the Universe: Chinese Hardstone Carvings
Until 9 October 2017
The Met Fifth Avenue, New York, New York, USA
www.metmuseum.org/exhibitions/listings/2016/colors-of-the-universe

Spectacular Gems and Jewelry from the Merriweather Post Collection
Until 7 January 2018
Hillwood Estate, Museum & Gardens, Washington DC, USA
www.hillwoodmuseum.org/Spectacular-Gems-and-Jewelry

Past is Present: Revival Jewelry
Until 19 August 2018
Museum of Fine Arts, Boston, Massachusetts, USA
www.mfa.org/news/past-is-present-revival-jewelry

Gemstone Carvings: The Masterworks of Harold Van Pelt
Ongoing
Bowers Museum, Santa Ana, California, USA
www.bowers.org/index.php/exhibitions/upcoming-exhibitions/484-gemstone-carvings-masterworks-by-harold-van-pelt

Australasia

The House of Dior: Seventy Years of Haute Couture
Until 7 November 2017
The National Gallery of Victoria, Melbourne, Australia
www.ngv.vic.gov.au/exhibition/the-house-of-dior

OTHER EDUCATIONAL OPPORTUNITIES

Gem-A Workshops and Courses
Gem-A, London
www.gem-a.com/education/courses

Sri Lanka Trip with Gem-A and The National Association of Jewellers
16–30 October 2017
Visit mines, markets and cutting centres in Sri Lanka
http://tinyurl.com/kujwh72
Note: Open to members of Gem-A and NAJ.

DUG Advanced Gemology Program (in English)
6 November–8 December 2017
Nantes, France
www.gemnantes.fr/en

Gemstone Safari to Tanzania
8–25 January 2018
Visit Morogoro, Umba, Arusha, Longido, Merelani and Lake Manyara in Tanzania
www.free-form.ch/tanzania/gemstonesafari.html
Note: Includes options for a lapidary class and/or a private trip to visit ruby mines near Morogoro and Mpwapwa (including Winza).

Lectures with Gem-A's Midlands Branch
Fellows Auctioneers, Birmingham
Email Georgina@fellows.co.uk

- 29 September 2017
  Geoff Whitefield—Valuation Practice
- 27 October 2017
  Stephen Alabaster—The History of Alabaster & Wilson

Lectures with The Society of Jewellery Historians
Society of Antiquaries of London, Burlington House, London
www.societyofjewelleryhistorians.ac.uk/current_lectures

- 3 October 2017
  Raymond Sancroft-Baker—Hidden Gems – Jewellery Stories from the Salesroom
- 24 October 2017
  Lynne Bartlett—The Rise and Fall of the Chatelaine
- 28 November 2017
  Judy Rudoe—Cartier Gold Boxes: A Visionary Patron and a Bet with Ian Fleming

New Media

Asterism: Gems with a Star

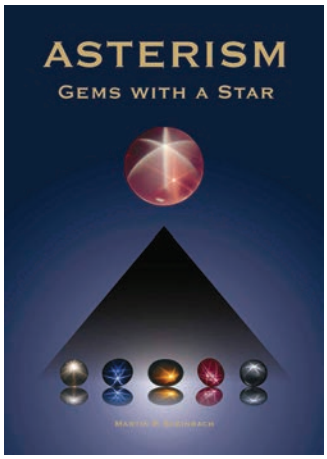

By Martin Steinbach, 2016. MPS Publishing and Media, Idar-Oberstein, Germany, 896 pages, illus., ISBN 978-3000504945. US$199.00 hardcover or $399.00 VIP edn.

Martin Steinbach has masterfully compiled the most comprehensive treatise on gems displaying asterism. His passion for star gems is evident in each chapter, in which he covers topics such as history, famous stars, scientific aspects, treatments, synthetics, imitations, all known star varieties, types of stars and stars in art. To whet the reader's palate for what follows, the first few pages of this compendium feature the largest-known and most famous star rubies and sapphires. Steinbach has devoted 20 years to creating this book, which features over a thousand photos depicting more than 60 varieties of gems with stars.

The first chapter, on asterism throughout history, begins with a focus on Greco-Roman references to stars (*asterius-asteria*) from ancient history, then continues into the Middle Ages, and culminates with early modern times to the present. Steinbach also includes translations from Latin, French and German references that are particularly enjoyable because so many famous European mineralogists and gemmologists were studying and writing about gem materials during the European Renaissance. One interesting reference from Anselmus Boëtius de Boodt's book, *Gemmarum et Lapidum Historia* (1609), mentions that Germans commonly referred to star stones as Siegstein (victory stone).

The second chapter focuses almost exclusively on notable star rubies and sapphires. While most of the star stones mentioned in this chapter are deserving of their place, some that lack accompanying photos or exact weights could have been left out and replaced by notable stars of other gem species. This chapter provides an invaluable reference to the sizes, qualities and origins of many of the most important corundum stars that are known, and includes where many of them currently reside.

The third chapter, on the scientific aspects of asterism, explains how the orientation of the inclusions combined with the cutting of the gem material into a cabochon is responsible for the optical phenomenon of asterism. This reviewer found the addition of diagrams by Fischer and the charts by Eppler particularly informative and useful. The various inclusions that commonly cause asterism are described and characterized according to when they formed in relation to the host gem. Steinbach provides concise descriptions of the basic optical properties of gems, as well as a section that defines and compares various colour phenomena in gems with asterism. This reviewer also found the section on crystallography and symmetry easy to understand, beautifully illustrated and appropriately focused on its relation to asterism. However, the basic gemmology and geology described in the rest of this chapter could have been left out, perhaps to focus more on the optical mechanisms producing asterism.

The chapter on treatments of star gems covers all the major processes, including heating, irradiation, diffusion, fracture filling etc. Iron and titanium diffusion treatment is of highest concern in relation to star stones because this process can simultaneously alter the colour and create a star. Fracture filling is another treatment that is commonly applied and often missed by unsuspecting buyers. Lead-glass filling, frequently employed to treat corundum, also is being used to enhance star rubies and sapphires. One of the more interesting photos is of an irradiated greenish yellow 8-rayed star quartz from Brazil.

Synthetic star gems, manufactured by companies such as Djeva and Linde, were immensely popular from the mid-1940s to the mid-1970s. Chapter 5 focuses on these virtually perfect stars and their creators. Examples of synthetic star alexandrite, opal, spinel and even zincite also are included.

Imitations, including assembled and artificial products, are covered in Chapter 6. Scratching the surface of a cabochon is one of the most common ways to create a fake star, and an unscrupulous seller can employ this treatment method with minimal effort and skill. Doublets and triplets, as well as coatings and foil-backs, are shown in numerous colours and gem varieties.

The reverence that Steinbach gives to every gem displaying asterism is evident in the largest chapter, devoted to all known star varieties from andalusite to zircon. The fact that it starts with a photo of a cat's-eye andalusite reflects the equal importance Steinbach places on chatoyant gems as compared to star stones. (In this reviewer's opinion, he could have placed equal focus on both chatoyancy and asterism throughout the entire book.) For each gem, he includes a detailed

chart of its chemical, physical and optical properties, and occurrences. Some of the rarities featured are a 6-rayed star apatite, 4- and 6-rayed star emeralds, a 4-rayed star rhodochrosite, an 8-rayed star moonstone, a 12-rayed star rose quartz, and a unique 6-rayed star tourmaline. Along with numerous photos, Steinbach includes full-page charts of the countries and regions producing star rubies and star sapphires, followed by a brief description of each source. Charts of record auction results for many famous stars also are included in this section.

Steinbach concludes the book with an interesting finale of 'dream stars' (such as 14- and 24-rayed stars and trapiche gems), 'stars-n-art' featuring artful photos, and several interesting annexes. A list of famous 'fantasy stars' is useful from an historical standpoint for anyone studying or writing about the more well-known star gems. An annex featuring a star grading scale provides photos of Steinbach's black star sapphire master stones, and his star rating system could be useful to educators and appraisers for comparing star quality. Finally, a comprehensive list of scientific institutions provides an excellent resource for those seeking information, further education or laboratory services.

At 896 pages, the physically heavy and large size of the book limits its portability and ease of use. However, Martin Steinbach's obsessive passion and attention to detail has resulted in the most complete work on star gems that will likely be published for many decades to come. Any collector or hopeful connoisseur of star gems should definitely add this passionate ode to stars to their gemmological library.

Edward Boehm FGA
RareSource, Chattanooga, Tennessee, USA

Gemstones in the First Millennium AD—Mines, Trade, Workshops and Symbolism

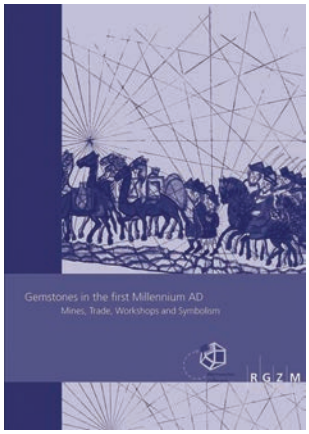

Ed. by Alexandra Hilgner, Susanne Greiff and Dieter Quast, 2017. Römisch-Germanisches Zentralmuseum, Mainz, Germany, RGZM-Conferences, Vol. 30, 332 pages, illus., ISBN 978-3884672716. €44.00 softcover.

Enthusiasts of ancient gems and jewellery will be pleased to know that the German Federal Ministry of Education and Research has sponsored a project called 'Weltweites Zellwerk/International Framework', which examines changes in the cultural significance of early medieval gemstone jewellery against the background of economic history and the transfer of ideas and technologies. The project led to an international conference titled *Gemstones of the First Millennium* AD, held in Mainz, Germany, in October 2015. An impressive group of international researchers participated, with backgrounds in archaeology, history and natural sciences, and their findings were published in the proceedings volume being reviewed here. The researchers focused on trade activities, production methods and interpreting cross-cultural dynamics through gem materials—garnet in particular—during the first millennium AD.

This substantial volume demonstrates the intricate modern research methods used in the interpretation of ancient gems. The chapters, by various authors, are presented in three main sections: (1) Mines and Trade, (2) Gemstone Working and (3) The Value and the Symbolic Meaning(s) of Gemstones, as well as an additional Poster Session section.

The Mines and Trade section consists of six chapters presenting studies on the intensive trade of raw and finished products, including gems, between Ancient Rome and the South Sea China region through seafarers, as well as overland to the Indian sub-continent via the Punjab area, the Hindu Kush mountains and the Arabian Peninsula. The researchers discuss the possibilities of cultural exchange along these routes and the various types of exotic goods such as garnet, amber and beaver fur. Considering the popularity of cloisonné work of the era, garnet was a desirable gem material, and the Europeans might have reached out to deposits in the East as well as local sources. It is compelling to see how the authors studied particular gem and mineral products to understand the trade dynamics and cultural exchange of the first millennium AD.

The Gemstone Working section consists of five chapters and presents studies of the era's gem-cutting workshops, mining regions, trade routes of raw materials and manufacturing techniques. These subjects are presented through garnet and rock crystal research in different regions including Sweden, East Africa (Kenya to Madagascar), Egypt and Germany.

The section titled The Value and the Symbolic Meaning(s) of Gemstones contains six chapters. Following the more evidential and practical study of trade routes, exotic goods and manufacture of gemstones, the authors discuss the value and meaning of gemstones (incorporating religious and magical symbolism) in the context of the first millennium AD. Traditionally, researchers interpret ancient writings and

therefore rely on textual evidence to explain the aforementioned concepts. These texts include religious and mythical scripture as well as translations from different eras. Hence the interpretations of the meaning and value of the ancient objects might not be clear to the modern world. However, today's technology allows scientists to use more solid evidence for establishing gemstone identity and determining origin beyond speculation. This section also addresses the issue of gem identification and terminology, as most archaeologists rely on information in the translated ancient texts rather than taking advantage of modern identification and classification techniques. The symbolism of gemstones in different religions such as Hinduism, Christianity and Islam of the first millennium AD is also discussed with specific examples in different chapters of this section.

The section covering the Poster Session includes six studies, mainly focusing on garnet jewellery of the era, and provides informative images.

The International Framework project, and this accompanying publication, provide a rare and inspirational example of multidisciplinary work pertaining to gemmology. Reading this volume makes the modern gemmologist realize that the nomenclature issues we face on a daily basis are also engrained in the historical studies, and it will take time for some scientists to embrace modern gemmological terminology. The volume should appeal not only to gem historians but also to archaeologists, art historians, gemmologists and archaeometry researchers. It is refreshing to see the growing interest in multidisciplinary sciences incorporating gemmology.

Dr Çiğdem Lüle FGA DGA GG
Kybele LLC, Buffalo Grove, Illinois, USA

Objective Diamond Clarity Grading

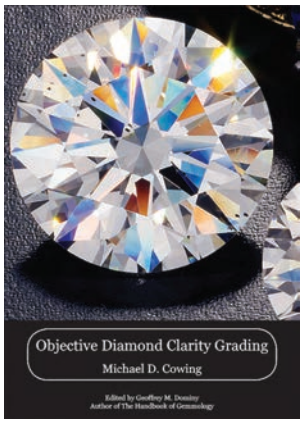

By Michael D. Cowing, 2017. Amazonas Gem Publications, Mallorca, Spain, 138 pages, illus., ISBN 978-0998483702. US$19.95 ebook.

The author of this book, Michael D. Cowing, has been studying diamond design, light performance analysis and grading for a long time. This book expands on his article published in *The Journal* (Cowing, 2014), and explains an objective methodology for diamond clarity grading using more than 100 examples accompanied by magnified images and clarity diagrams. As an ebook, it is available in various formats for computer, smartphone or tablet, and allows the user to highlight text or insert memos, as well as zoom in on photos and bookmark pages.

Cowing's objective diamond clarity grading system is based on concepts proposed by Roy Huddlestone and Kazumi Okuda, and includes aspects of GIA clarity grading gathered through interviews with authorities who were involved with GIA's laboratory. According to Cowing, the system yields results that have a high degree of consistency with clarity grades determined by GIA or AGS. In this book, the author demonstrates that anyone, regardless of their degree of expertise, can use this system to obtain a diamond clarity grade that is very close to that determined by these laboratories.

Chapter 1 describes how grade-maker inclusions (e.g. a single large inclusion or a small number of similar major inclusions) often determine a diamond's clarity grade. Such inclusions are evaluated by assessing five factors: size, number, contrast (colour and relief), position and nature. Among these, size is the main factor that determines the visibility of a given inclusion; therefore, the size of a grade-maker inclusion plays a key role in determining the initial grading call in this system.

Chapter 2 examines the clarity characteristics that experienced graders use to arrive at a clarity grade. Each decrease in clarity grade corresponds to a large (2×) multiplicative increase in inclusion size and visibility. Also discussed is the influence of a larger inclusion of consistent size on the clarity grade of different-sized diamonds.

Chapter 3 explains an orderly sequence of steps that are followed to reach the initial clarity call based on inclusion size, using graphs and diagrams. The influence of the various factors mentioned above is considered, as evaluated at GIA's laboratories. The system also includes adjustments for the reflection or appearance of an inclusion (or multiple inclusions) from the sides or pavilion of a stone, as well as the visibility of an inclusion under overhead lighting, consistent with the viewing environment used at GIA for determining a final clarity grade.

Starting with Chapter 4, the book then illustrates examples of each clarity grade using photos and clarity diagrams of a large number of diamonds graded by GIA or AGS. In these chapters, the reader can take advantage of the ability of the digital format to zoom in on the photos and diagrams while referring to the text. This is particularly useful to confirm VVS_1-class inclusions, and provides a higher level of understanding of all the clarity grades.

I believe that readers will want to use Cowing's system because it provides a standardized method to give more consistent clarity grading results. The system shows how the relationship of increasing inclusion size (by a factor of two in dimension and a factor

of four in area) varies almost consistently from grade to grade across the entire scale. Furthermore, adjustments for the number, contrast and position of inclusions that influence a clarity grade can be quantified. These features suggest that diamond clarity grading could be automated in the future.

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Yoichi Horikawa FGA
Central Gem Laboratory, Tokyo, Japan

Secrets of the Gem Trade, 2nd edn.

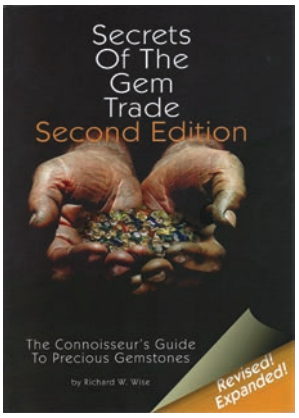

By Richard W. Wise, 2016. Brunswick House Press, Lenox, Massachusetts, USA, 404 pages, illus., ISBN 978-0972822329. US$99.95 hardcover.

Why publish a second edition of the successful *Secrets of the Gem Trade*? Wise perhaps explains it best in his preface: "This second edition has been enlarged and largely rewritten. Five new introductory essays and 10 new chapters have been added together with numerous photographs." The new volume has 64 chapters and covers 45 gems that Wise believes "should be included in any contemporary list of precious gemstones". He has added 11 more gems in this second edition. He also notes "that the essays in this edition assume that the reader has studied and understands" the principles in his first edition.

The table of contents covers four pages, and is followed by a five-page preface titled 'Lifting the Veil', which personalizes Wise's experience learning the secrets of the trade, followed by an introduction written by Vincent Pardieu and a foreword penned by Benjamin Zucker, both well-known authors who praise this second edition.

The book is then divided into Parts 1 and 2. Each chapter starts off with a relevant quotation, often by historic gem authors—a nice touch. In Part 1, the first seven chapters (90 pages) cover gemmology, history, connoisseurship, enhancement and new sources. Wise redefines the 'Four Cs' (colour, cut, clarity and carat weight) by adding a fifth C: 'crystal'. He often uses this term 'crystal' instead of referring to a gemstone as being transparent or diaphanous in his descriptions of the individual gem materials. This reviewer thinks this term belongs together with the concept of clarity—perhaps as a top clarity.

Part 2 is titled 'A New List of Precious Gemstones'. It starts with Chapter 8, on page 91, with alexandrite and continues to page 361, Chapter 54, on cobalt-blue spinel. Throughout these chapters are numerous images of historic subjects, gem mining areas, gemstones and fine jewellery pieces. Notable photographers are given credits throughout.

The book ends with a good glossary, a five-page bibliography and an extensive 16-page index to make finding information easy.

Both editions of *Secrets of the Gem Trade* showcase Wise's passion for the gemstone world. This reviewer recommends this book to amateurs and professionals alike.

William F. Larson FGA
Palagems.com, Fallbrook, California, USA

OTHER BOOK TITLES*

Coloured Stones

Collector's Guide to Silicates: Orthosilicates (Silicate Mineralogy)
By Robert Lauf, 2017. Schiffer Publishing Ltd, Atglen, Pennsylvania, USA, 240 pages, ISBN 978-0764352867. US$45.00 hardcover.

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DITP Department of International Trade Promotion Ministry of Commerce, Royal Thai Government

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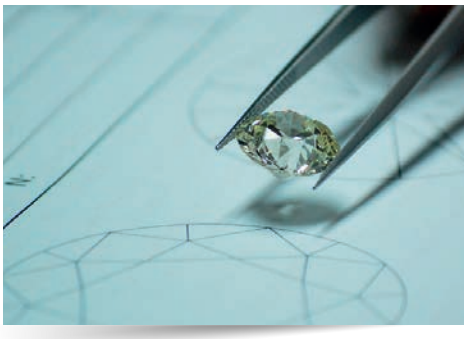

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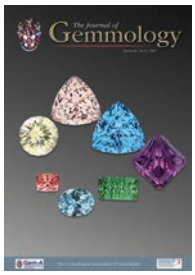

Brazil is the source of a variety of coloured stones, as described in the article by A. Reys on pp. 708–726 of this issue. Shown here are several custom-cut Brazilian gems consisting of a 9.69 ct morganite, 12.73 ct Swiss Blue topaz, 7.99 ct amethyst, 3.29 ct tourmaline, 2.40 ct aquamarine, 1.12 ct Imperial topaz and 4.84 ct golden beryl. Courtesy of John Dyer Gems; composite photo by Ozzie Campos.

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Understanding Gems™

What's New

INSTRUMENTATION

D-Scope+ Microscope

Introduced in September 2017, the D-Scope+ microscope from HRD Antwerp is specially designed for use with diamonds. Improvements on HRD's original D-Scope include its illumination, ease of use, and ergonomics. The user can choose from three colours of darkfield lighting: yellowish, white daylight, and strong white light. The controls to manipulate a stone have been redesigned to improve comfort, and the manipulation table can be moved up and down to achieve proper focus. For additional information, visit www.hrdantwerp.com/en/product/new-d-scope. *CMS*

EXA Spectrometer

In November 2017, Magilabs released the EXA, a standalone spectrometer unit able to quickly identify natural diamonds and other gems by their fluorescence spectra. A coaxial fibre optic bundle collects spectra on both loose and mounted stones. EXA operates in two different modes: diamond testing and advanced. The first delivers a pass or refer message within a second of analysing a diamond (as small as 0.005 ct), referring possible CVD and HPHT synthetics and diamond simulants for further testing. The advanced mode is designed for gem identification, and displays a sample's fluorescence spectrum on a 7-inch (18-cm) touchscreen. Examples for which EXA can provide identification include pink diamonds (natural, synthetic and treated), spinel, corundum, alexandrite, tanzanite, zircon, Imperial topaz and emerald (and its most common fillers). The unit measures 23 × 21 × 13 cm, weighs 3.3 kg and can be upgraded for additional applications. For more information, visit www.gemmoraman.com/Products/EXA.aspx.

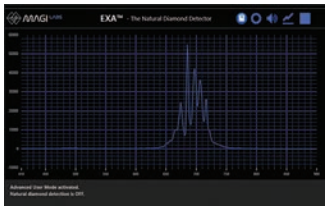

Alberto Scarani and Mikko Åström
Magilabs, Helsinki, Finland and Rome, Italy

GIA iD100 Gem Testing Device

In April 2017, the Gemological Institute of America announced a new spectroscopy-based desktop instrument for the screening of natural diamonds from simulants and synthetic (HPHT and CVD) or treated diamonds. Stones 0.9 mm in diameter (approximately 0.005 ct) or greater, either loose or mounted, can be tested by pointing the probe at the sample. Within two seconds, the device displays either 'Pass' (i.e. natural diamond) or 'Refer' (for further testing). For additional information, visit www.gia.edu/id100. *CMS*

Melee Inspector

New in August 2017 from Gemetrix Pty. Ltd. (Perth, Western Australia), the Melee Inspector is a shortwave (255 nm) UV unit designed to screen HPHT synthetic diamonds based on phosphorescence that can be captured with a smartphone camera. It is suited for use with rough and polished diamonds, loose (including parcels) or mounted, within a 45 × 45 mm viewing area. The unit also can operate on a 9V battery for portability. For additional information and a brief video demonstrating how to use the unit, visit www.gemetrix.com.au/melee.html. *CMS*

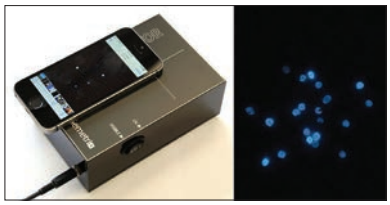

Presidium Synthetic Diamond Screener II

Released in September 2017, the Synthetic Diamond Screener II from Presidium uses UV transparency to distinguish colourless type IIa from type Ia diamonds. Type IIa diamonds are more likely to be synthetic (CVD or HPHT) and require additional testing. The instrument delivers a result within two seconds and can be used on diamonds of 0.02–10 ct and D–J colour, either loose or mounted in an open-back setting. The unit measures 130 × 100 × 65 mm and operates on a variety of power sources, including battery, making it readily portable. To order, contact Gem-A Instruments (email instruments@gem-a.com); for more information see page 751 of this issue of *The Journal.* *CMS*

SYNTHdetect Mounted Diamond Screening Device

In June 2017, De Beers' International Institute of Diamond Grading & Research unveiled its SYNTHdetect device for screening diamonds that are loose or mounted in jewellery. The instrument became available for delivery in September 2017 and uses a patented time-resolved photoluminescence technology to screen colourless to near-colourless samples with no lower size limit. With a very low referral rate, the unit reportedly reduces the need for additional off-site testing. For more information, visit www.iidgr.com. *CMS*

NEWS AND PUBLICATIONS

CIBJO Special Reports from 2017 Congress

Reports from eight commissions—Coral, Pearl, Gemmological, Ethics, Coloured Stone, Diamond, Precious Metals and Marketing & Education—prepared for the 5–7 November 2017 CIBJO Congress are available at www.cibjo.org/congress2017/special-reports. The reports were prepared before the conference to review issues for discussion by the various commissions. In addition, several news entries review the outcome of the conference sessions (click the News button). *CMS*

Diamonds in Canada: 25th Anniversary

In November 2016, the 25th anniversary of the discovery of diamonds in Canada was marked by a special issue of *Mining North* magazine with the theme '25 Years of Diamonds'. The issue can be downloaded from www.miningnorth.com/25-years-of-diamonds, which also offers links to slide shows and oral presentations from a 'Diamond Gala' celebration of the 25th anniversary held in conjunction with the 2016 Yellowknife Geoscience Forum in Yellowknife, Northwest Territories. *BML*

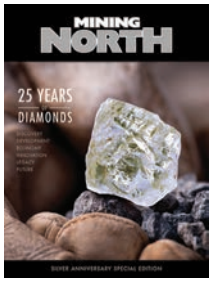

GRS Colour Terms Defined

In December 2017, GemResearch Swisslab AG (GRS) released *GRS Color Terms Go Global*, a 63-page online booklet that illustrates and describes "the most popular GRS color descriptions that have been used by GRS and the global gemstone community over the past two decades". The colour terms are pigeon blood ruby, royal blue and cornflower sapphire, old mine/Muzo green emerald, sunrise and sunset padparadscha sapphire, honey-colour chrysoberyl and Paraíba-colour tourmaline. Each includes a definition, history, research, and related publications, as well as major geographical sources. The publication is bilingual in English and Chinese. To view or download the booklet, visit http://gemresearch.ch/grs-color-terms-go-global. *CMS*

GSA Gem Session Abstracts

Abstracts from the 22–25 October 2017 annual meeting of the Geological Society of America are available online. Of particular interest to gemmologists are the oral and poster presentations from the session 'Gemological Research in the 21st Century—Characterization, Exploration, and Geological Significance of Diamonds and other Gem Minerals', which can be viewed at https://gsa.confex.com/gsa/2017AM/meetingapp.cgi/Session/43031 and https://gsa.confex.com/gsa/2017AM/meetingapp.cgi/Session/44100, respectively. The abstracts cover a wide range of gemmological topics, including diamond, tourmaline, demantoid, spinel, emerald, corundum and instrumentation. *CMS*

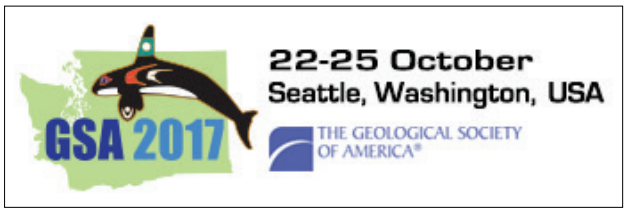

Margaritologia Pearl Newsletter Nos. 7/8/9

In May–November 2017, the Gemmologisches Institut Hamburg, Germany, released issues 7, 8 and 9 of *Margaritologia*. Issue No. 7 focuses on the history of pearl culturing in Japan and China in recognition of the 100-year anniversary of the 'regular

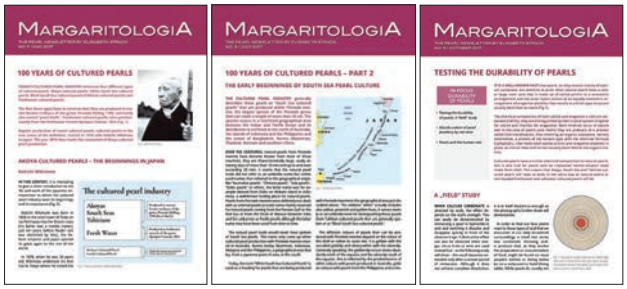

production of round [Akoya] cultured pearls' by Kokichi Mikimoto. No. 8 continues the history with South Sea pearl culturing. Issue No. 9 features three articles: testing the durability of pearls when exposed to a variety of household products, discoloration of pearls by red wine, and how human skin affects pearls. To subscribe to the newsletter, visit www.margaritologia.de. *CMS*

Santa Fe Symposium Proceedings

Papers from 22 presentations delivered at the 2017 Santa Fe Symposium (held in Albuquerque, New Mexico, USA, 21–24 May) are available for download, on topics such as metallurgy of precious metals, jeweller apprenticeships, manufacturing methods, digital innovations in the jewellery industry and more. Visit www.santafesymposium.org/papers to obtain PDF files of these papers, as well as those from earlier symposia dating back to 2000. *CMS*

Standard Methods for Testing Fei Cui for Hong Kong

In February 2016, the Gemmological Association of Hong Kong (GAHK) issued its working group's recommendations for standardized gemmological methods to be used for testing *fei cui* (jadeite, omphacite and kosmochlor jades). The document includes gemmological descriptions of these three minerals—often intergrown—and reviews jade treatments. 'Standard' test methods are

outlined for shape and cut description; measurement of dimensions and weight; identification of transparency and colour; polariscope examination; determination of RI and SG; examination using a UV lamp, Chelsea filter, spectroscope and microscope; and infrared spectroscopy (for detection of resin impregnation). Download the publication at www.gahk.org/attachment/feicui/HKSM%20FCT-2016%20(20170327).pdf. *CMS*

What's New provides announcements of instruments, technology, publications, online resources and more. Inclusion in What's New does not imply recommendation or endorsement by Gem-A. Entries were prepared by Carol M. Stockton (CMS) or Brendan M. Laurs (BML), unless otherwise noted.

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Gem Notes

COLOURED STONES

Baryte from South Dakota, USA

Baryte (or barite) is an orthorhombic sulphate mineral that is sometimes found as well-formed crystals that are prized by collectors. One area in particular has yielded fine transparent baryte crystals that are colourless and yellow to yellowish brown (commonly referred to as 'golden'): Elk Creek in Meade County, South Dakota, USA (Campbell et al., 1987; see also https://collectorsedge.com/pages/elk-creek-barite-meade-county-south-dakota). Although these deposits have been known since at least 1891 and abundant mineral specimens have been mined there, it is rare to encounter gems faceted from this material. Therefore we were interested to examine three faceted South Dakota barytes (Figure 1) that were loaned by gem dealer Dudley Blauwet (Dudley Blauwet Gems, Louisville, Colorado, USA). The stones were cut from a 139 g parcel of rough that he obtained in January 2016, which contained pieces that were too broken to be sold as crystals. His cutting factory produced 25 stones weighing a total of 69.62 carats and ranging from ~1.2 to 8.30 ct; the yield was rather small due to fractures and cleavage issues.

The examined barytes weighed 2.27–7.90 ct and were very pale brownish yellow, medium brownish yellow and a cognac-like orangey brown. The RIs of all three stones were 1.634–1.647, yielding a birefringence of 0.013 (comparable with the 0.012 stated in the literature). The hydrostatic SG value of each sample was 4.49. The stones fluoresced a moderate-to-strong yellowish white to long-wave UV radiation (Figure 2) and a very faint yellowish white to short-wave UV. Microscopic observation revealed only minor cleavage effects and twinning planes. Analysis with a GemmoRaman-532SG confirmed the identification as baryte, and energy-dispersive X-ray fluorescence (EDXRF) spectroscopy with an Amptek X123-SDD instrument revealed the expected major amounts of Ba and S; there were no significant chromophores detected, even when comparing these differently coloured stones. This is consistent with the fact that radiation-damage centres commonly cause colour in baryte (Bartoshinsky et al., 1991).

Baryte occurs as transparent material and in various colours, but its status as a collector's stone is due to its low hardness (3 on the Mohs scale) and perfect cleavage, making it generally unsuitable for use in jewellery.

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Stone Group Laboratories
Jefferson City, Missouri, USA

Brendan M. Laurs FGA

Figure 1: These rare faceted barytes (2.27–7.90 ct) show the range of colour of material from South Dakota. Photo by Dean Brennan for Stone Group Labs.

Figure 2: All three of the barytes in Figure 1 fluoresce yellowish white to long-wave UV radiation. Photo by B. Williams.

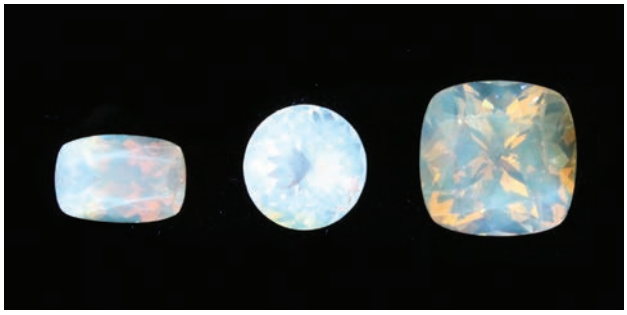

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Campbell T.J., Campbell D.R. and Roberts W.L., 1987. Famous mineral localities: Elk Creek, South Dakota. *Mineralogical Record*, **18**, 125–130.

Gems from the Mong Long Area, Myanmar

For more than a century, the area near the town of Mong Long in Myanmar has been a source of gem-quality ruby, sapphire, tourmaline, spessartine and chrysoberyl, as well as other gem minerals. The mining area is situated in the Kyaukme District of northern Shan State, approximately 18 km south-east of Mogok (Figure 3). The region is mainly underlain by the Mong Long mica schist (La Touche, 1913), which lies adjacent to the Mogok Stone Tract of Iyer (1953) or the Mogok Belt of Searle and Haq (1964). According to recent field research done by one of the authors (Theint, 2017), the mining area encompasses the south-eastern part of the Mong Long mica schist and extends into the north-western part of the Mogok gneiss; the rocks are mainly composed of metasedimentary and igneous units such as mica schist, garnet-biotite gneiss and tourmaline-bearing muscovite-biotite granite. Mong Long hosts two main gem-mining areas: alluvial deposits in Namseka Valley and both primary and secondary deposits in Mong Pai Valley.

The Namseka deposit is located west of Mong Long near Nam Pai Stream, which is fed by Yeni Stream from the Mogok Valley, so it is possible that the alluvial gems mined there originally formed in the Mogok area. The gems are recovered as a by-product of alluvial gold mining. The rubies are light-to-medium purplish red (Figure 4a), and most of them are quite waterworn and irregularly shaped, although they are sometimes found as prismatic crystals terminated by rhombohedral faces and a pinacoid. The sapphires are medium violetish blue, light yellow, light pink and medium purple (again, see Figure 4a), and they mostly consist of waterworn subhedral crystals showing the hexagonal pyramid and a pinacoid. The rubies and sapphires typically measure 0.3–15 mm long. Other gems recovered from these deposits include spinel (Figure 4b), spessartine (Figure 4c), almandine, quartz, zircon, apatite, topaz, sillimanite, fluorite, chrysoberyl, chal-

Figure 3: The Mong Long area is located south-east of Mogok, in central Myanmar.

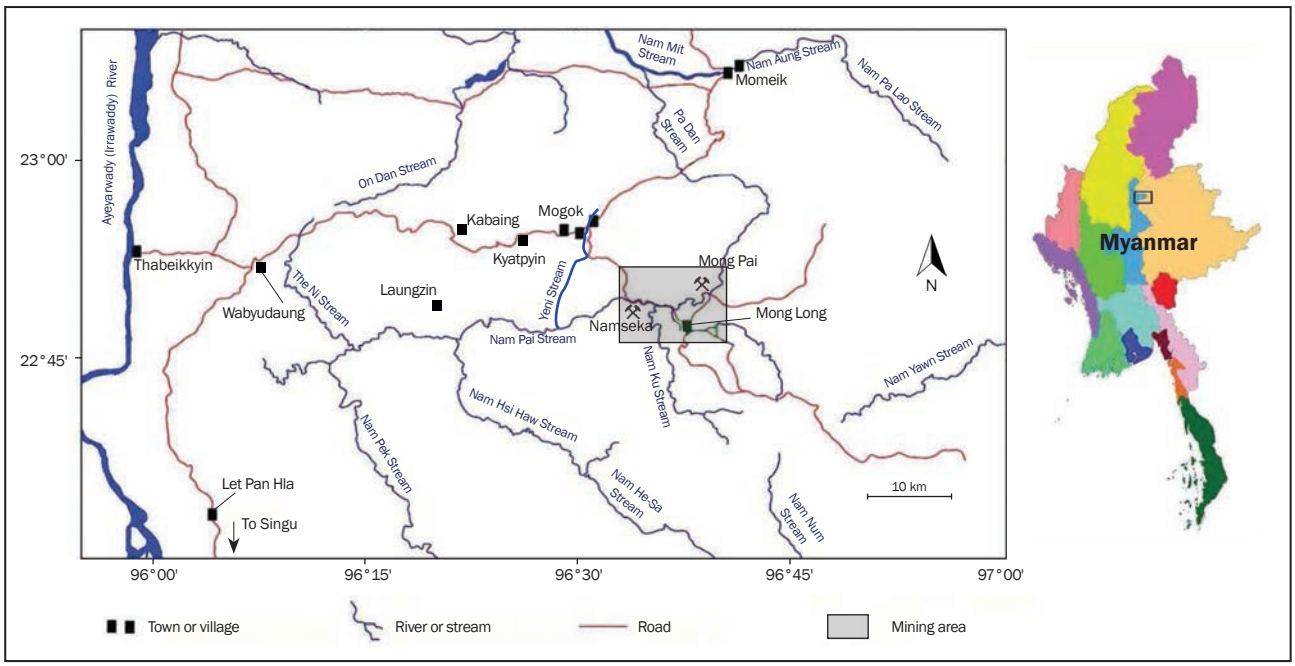

Figure 4: Several gem varieties are mined in the Mong Long area, including: (a) ruby and sapphire from Namseka Valley (here, 0.97–1.38 ct faceted); (b) spinel from Namseka Valley (1.25–1.46 ct); (c) spessartine from Namseka Valley (1.62–2.19 ct); and (d) tourmaline from Mong Pai Valley (0.84–1.56 ct faceted). Photos courtesy of M. T. Theint.

cedony (agate), danburite, scapolite, moonstone and kornerupine.

In Mong Pai Valley, which is located a few kilometres north-east of Mong Long, gems such as tourmaline (Figure 4d), aquamarine, spessartine, quartz, topaz, zircon and phenakite are mined. Tourmaline is recovered in various colours from both primary deposits (i.e. elbaite from the Legyi and Kyauktalon pegmatites) and secondary deposits (elbaite and dravite). Also, the Kyauktalon pegmatites are a source of beautiful 'sky' blue aquamarine crystals.

Six tourmaline samples from Mong Pai were sent to the Swiss Gemmological Institute SSEF, in Basel, Switzerland, for chemical analysis by laser ablation inductively coupled plasma mass spectrometry (LA-ICP-MS). The samples consisted of green, 'olive' green and pink crystals from the Legyi pegmatite, and some dark brown pieces from alluvial deposits. In addition to their constituent elements Si, Al and B, all of them contained the following: Li, Be, Na, Mg, K, Ca, Sc, Ti, V, Mn, Fe, Cu, Zn, Ga, Ge, Pb and Bi. Additional trace elements—such as Sr, Nb, Sn and Sb—were above the detection limits in some specimens. Relatively high Fe (up to 9,700 ppm) and Mn (up to 10,600 ppm) with significant Ti (725 ppm) were present in the green tourmaline, while the 'olive' green sample had less Fe (up to 2,550 ppm) and more Mn (up to 38,900 ppm) and Ti (880 ppm). Conversely, the pink stone contained very low Fe (up to only 16.4 ppm) and less Mn (1,980 ppm) than the green samples. Elevated Ti (up to 9,300 ppm) and low Mn (up to 29.5 ppm) were present in the dark brown samples. Enriched Mg (up to 101,500 ppm) also was measured in the dark brown samples, consistent with dravite. By contrast, the green, 'olive' green and pink tourmalines only contained traces of Mg and were characterized by higher amounts of Na (15,570–18,930 ppm) than Ca (930 to 3,080 ppm), consistent with elbaite. The possible presence of rossmanite was not considered since this is best assessed with electron microprobe data for calculating the amount of vacancies in the X site.

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Pyrite and Other Sulphides for Jewellery Use, from Peru

Pyrite has been used in jewellery for a long time, most commonly as small faceted stones sold as 'marcasite'. The source of much of this pyrite is the Huanzala mine in west-central Peru, which has probably yielded thousands of tonnes of specimens and rough material. Recently, a completely new type of pyrite for jewellery use emerged from another Peruvian deposit: the Quiruvilca mine in northern Peru. The as-mined specimens typically consist of flat druses of pyrite crystals with a pentagonal-dodecahedral form. The individual crystals are usually between 5 and 20 mm. For jewellery use, the druses are polished on the bottom and then cut as ovals or free-form pieces up to ~4 cm long (Figure 5). Together with pyrite, several additional sulphides from Quiruvilca have been prepared in the same way (Figure 6), although they are quite rare. These include black sphalerite, lead-grey tetrahedrite, silvery arsenopyrite and even very rare hutchinsonite as shiny black prisms on sphalerite.

Of course, pyrite is not an ideal jewellery stone because it is quite heavy. It also should not be washed with water because it is susceptible to corrosion; brushing or wiping off the surface or cleaning with alcohol is safer. Nevertheless, according to dealers in Lima, several thousands of pieces already have been sold to dealers in the USA and elsewhere. With proper care, the pieces can make an interesting addition to one-of-a-kind jewellery.

Dr Jaroslav Hyršl (hyrsl@hotmail.com)
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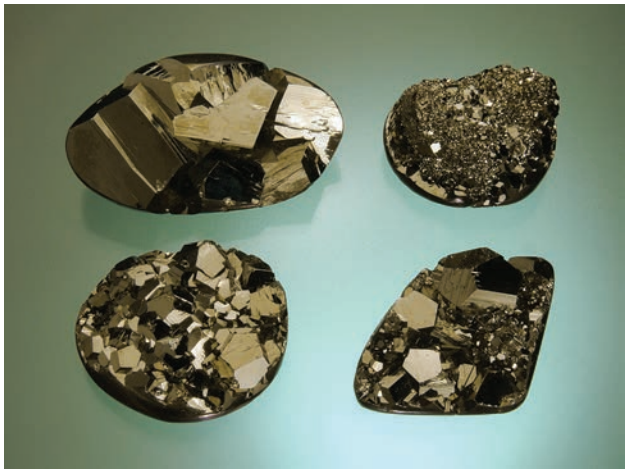

Figure 5: These four pieces of pyrite from the Quiruvilca mine in Peru (up to 4.3 cm long) have been fashioned for use in jewellery. Photo by J. Hyršl.

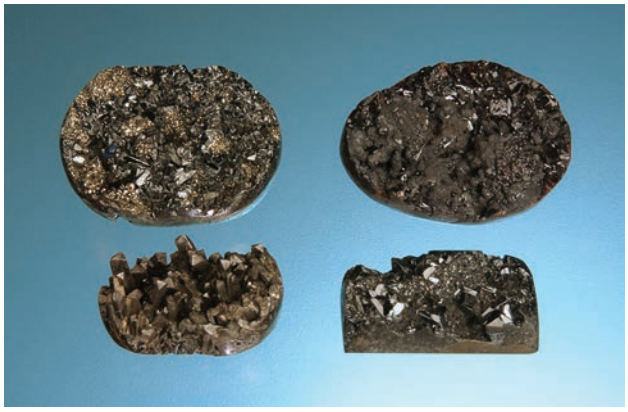

Figure 6: Additional sulphides from the Quiruvilca mine besides pyrite have been similarly fashioned for mounting in jewellery. Shown here are pieces ranging up to 2.8 cm long that consist mostly of (clockwise from the upper left) sphalerite, hutchinsonite, tetrahedrite and arsenopyrite. Photo by J. Hyršl.

Purple Spinel from Badakhshan, Afghanistan

The Badakhshan area of Afghanistan adjacent to Tajikistan is famous for its production of large pink to red spinels (Hughes, 1994). Recently, a new find of attractive purple spinel occurred in Badakhshan. According to rough stone dealer Sir-Faraz Ahmad (Farooq) Hashmi (Intimate Gems, Glen Cove, New York, USA), the material was initially thought by some dealers to be amethyst. The first parcel that Hashmi learned about (through videos sent by his supplier) weighed ~1 kg and contained clean pieces weighing more than 50 g. Some of the spinel occurred in crystals with well-developed octahedral form, indicative of a primary deposit. Gem dealer Dudley Blauwet first learned about this new spinel in early November 2016, and in late March 2017 he obtained a 56 g parcel at the gem and mineral market in Peshawar, Pakistan. From this he had three larger gems faceted in Sri Lanka that were characterized for this report, and subsequently his cutting factory produced 46 smaller stones weighing up to 2.99 ct from 41.7 g of rough. Another rough parcel made its way to the market in Bangkok, Thailand, in early 2017 and reportedly yielded stones weighing up to 5–9 ct, with one exceptional gem of

The Fire Within

"For in them you shall see the living fire of the ruby, the glorious purple of the amethyst, the sea-green of the emerald, all glittering together in an incredible mixture of light."

– Roman Elder Pliny, 1st Century AD

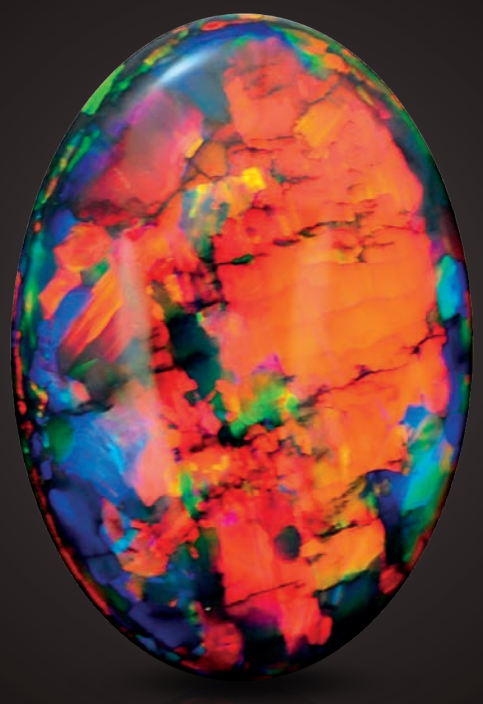

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Figure 7: These purple spinels (4.01–6.71 ct) are reportedly from Badakhshan, Afghanistan. Photo by D. Bakker.

15+ ct. Blauwet was told by his suppliers that the spinel came from the Parawara mine near the lapis deposits at Lajuar Madan in the Kokcha Valley. This is consistent with information on mindat.org (see www.mindat.org/loc-256247.html).

Blauwet loaned some rough and cut samples to this author for characterization. The faceted gems weighed 4.01, 5.01 and 6.71 ct (Figure 7), and the rough stone was 0.76 g. The samples all exhibited a strong purple colour with a hint of blue, and none showed any noticeable colour change between daylight and incandescent light. The RI and SG values of all four pieces were characteristic of those for natural spinel. All were inert to long- and short-wave UV radiation, and they did not change colour under the Chelsea filter. The broken piece of rough showed three distinct octahedral faces that were etched and slightly abraded. Microscopic examination revealed inclusions that resembled clusters and booklets of colourless mica (Figure 8); they were seen in one of the cut stones and in the rough sample. Similar mica inclusions also have been documented in pink spinel from Mahenge in the Morogoro region of Tanzania (Gübelin and Koivula, 2005, p. 682).

This new production of purple spinel from Badakhshan, Afghanistan, is a welcome addition to the gem trade, and hopefully more of this material will become available in the future. However, according to Hashmi the mine is located in a politically unstable area, and digging activities ceased in mid-2017. Blauwet also reported that, with few exceptions, since April 2017 only heavily included and/or small-sized rough material has been available in the market. It is unclear whether there will be additional production of high-quality spinel from this deposit.

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Figure 8: Inclusions with the appearance of mica are observed in the 5.01 ct purple spinel from Afghanistan, as shown here with darkfield lighting (left) and oblique fibre-optic illumination (right). Photomicrographs by E. Boehm; magnified 40×.

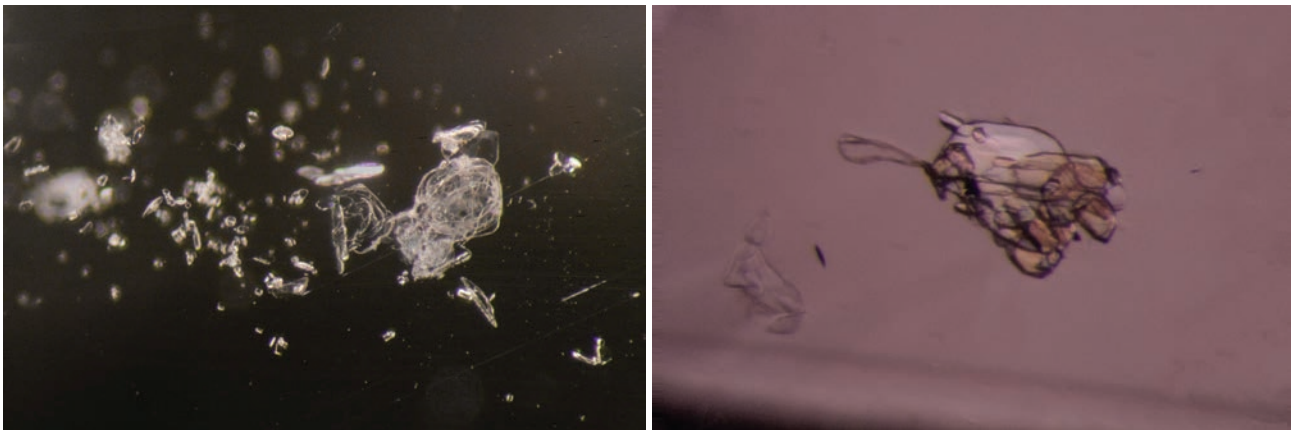

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Windmill-cut Topaz from Namibia

Klein Spitzkoppe in west-central Namibia is a source of colourless or 'silver' topaz, as well as rare pale blue and pale yellow topaz (e.g. Cairncross et al., 1998). The crystals are typically mined by local Damara women and offered for sale to tourists and mineral collectors. During the 12–13 October 2017 Namibian Coloured Gemstone & Jewellery Showcase in Windhoek, Namibia, this author encountered an innovative faceting style that was developed specifically for colourless topaz from Klein Spitzkoppe. Called the *Windmill Cut*, it was displayed by Mike Thygesen (Desert Gems/Bead World, Swakopmund, Namibia). Although Thygesen initially developed this faceting style in the mid-1990s, this was the first time it has been actively promoted, with several hundred stones available in sizes ranging from 6 to 22 mm in diameter.

The Windmill cut is a variation of a single-cut round brilliant. The windmill-like appearance is created by alternating pavilion facets that have a matte finish, which provide a contrasting appearance with the adjacent highly polished pavilion facets (Figure 9). When viewed through the table, a pleasing spoke-like appearance is visible. By using a minimal number of crown and pavilion facets, the pattern is easy to see and is not broken up by multiple reflections. The effect is best seen in larger stones (i.e. those that are at least 6 mm in diameter). According to Thygesen, it is important to cut the topaz according to its critical angle because of the loss of some light return from the matte facets.

The goal of the Windmill cut is to benefit the local Damara women who mine the topaz by creating demand for the gem material. All of the Windmill-cut topaz is faceted from rough material that is purchased directly from these women, and the faceted stones are sold loose or mounted into creative windmill-themed jewellery designs.

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Reference

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Figure 9: Windmill-cut topaz displays a spoke-like pattern created by alternating pavilion facets that have a matte finish, as shown in these top and oblique views of a 24.80 ct stone. Photos by Adam Smaruj, Windhoek.

Tourmaline from Masisi, Democratic Republic of the Congo

For almost the past two decades, the Democratic Republic of Congo (DRC) has been a source of gem-quality tourmaline (Laurs et al., 2004, Henn, 2010; Laurs 2015). It typically has been recovered as a by-product of mining for industrial minerals—in alluvial, eluvial and primary (granitic pegmatite) deposits—although recently some of the miners have focused on gem tourmaline. Rough stone dealer Farooq Hashmi recently shared some information on tourmaline mining that has taken place in two areas of eastern DRC: Rwangara and Rubaya, which are both located in the Masisi region of North Kivu Province. Although Hashmi has not visited the mines, in late 2016 and in 2017 he went to the city of Giseni in Rwanda, which is on the border with DRC (adjacent to Goma) and is located ~50 km south-east of the Masisi area.

Hashmi reported that gem tourmaline has been mined in the Rwangara area since approximately 2004. Several tonnes of greenish blue tourmaline were reportedly recovered there, and most of it was sent to China and Hong Kong since the vast majority was bead/cabochon grade. In recent years, some near-colourless to pale brownish pink to brownish red material was produced from Rwangara. Efforts to irradiate the lighter-coloured material resulted in an unattractive brownish yellowish hue, and subsequently the mining activities at Rwangara have mostly ceased. Nevertheless, some greenish blue to pale green stones (mostly cabochon grade) were produced there in 2016.

The other mining area in the Masisi region, called Rubaya, has been worked for the past few years. Hashmi estimated that initially a few kilograms of cabochon- and facet-quality rough were sporadically recovered as a by-product of mining the pegmatites for industrial minerals. However, since mid-2017 some new mining ventures have specifically targeted gem tourmaline (e.g. Figure 10), resulting in the production of more and better-quality tourmaline from the Rubaya area. The initial output took place in June, and consisted of several kilograms of crystals that were commonly tricoloured (green, pale yellow and brownish pink) or bicoloured (light and dark green). From late June to August, additional tricoloured crystals were produced (Figure 11, left), as well as some bluish green tourmaline. Some tens of kilograms were produced, and many crystals possessed excellent transparency, with the largest clean pieces weighing ~100 g. In September, the colour of most of the tourmaline production shifted to a 'peachy' or brownish pink (Figure 11, right) and pale brownish green. Most recently, in October, the mines yielded similar but darker material. Of the several kilograms of this tourmaline that were mined in September–October, much of it was facet-grade with clean pieces weighing up to ~100+ g. Although the colours were not as desirable for cutting gemstones, some fine crystal specimens were produced.

Figure 10: Gem tourmaline recently has been mined from narrow hand-dug tunnels such as this one in the Rubaya area of DRC. Photo by a local miner and courtesy of Farooq Hashmi.

Some of the Masisi tourmaline that Hashmi obtained in 2016 was faceted for this report, and

Figure 11: These tourmalines were mined in the Rubaya area of DRC in 2017. Photos by Farooq Hashmi.

rough and cut samples were investigated by authors AUF and WBS with standard-based scanning electron microscopy–energy-dispersive spectroscopy (SEM-EDS) chemical analysis using a JEOL JSM-6400 instrument equipped with the Iridium Ultra software package by IXRF Systems Inc. Initial EDS scanning of two samples from Rubaya (both blue-green; e.g. Figure 12, left) showed a likely Ca-bearing elbaite composition with Fe as the main chromophore. No Cu was detected in either sample. More-detailed analysis of several samples from Rwangara (Figure 12, right) showed that all of them were elbaite with some liddicoatite component. The content

Figure 12: These DRC tourmalines were chemically analysed for this report. The 2.20 ct stone on the left is from the Rubaya area and was faceted by Jason Doubrava (Poway, California, USA). The faceted and cabochon-cut tourmalines on the right (0.46–7.33 ct) are from the Rwangara area and were cut by Todd Wacks (Tucson Todd's Gems, Tucson, Arizona, USA). Photos by Jason Doubrava (left) and Orasa Weldon (right).

Table I: Content of chromophore elements in tourmaline from Rwangara, DRC.

Oxide (wt.%)	Pink to red	Yellow-green	Light green	Blue
FeO	nd*–0.05	1.8–1.9	1.8–2.1	2.5–4.0
MnO	0.2–0.4	0.9–1.2	0.9–1.2	1.0–1.2
TiO_2	nd	0.01–0.03	nd–0.01	0.03–0.04

* Abbreviation: nd = not detected

of chromophore elements is summarized for the various colours in Table I; none of the samples contained any detectable Cu. A similar range of chromophore elements was obtained previously for several pieces of DRC tourmaline that were pink and yellowish green to blue (Laurs et al., 2004). However, those samples ranged from elbaite to liddicoatite and rarely rossmanite, in contrast to the elbaite composition of the present tourmalines.

The production of tourmaline from the Rubaya area of DRC is expected to continue, both as a by-product of mining for industrial minerals and from activities specifically aimed at recovering gem- and specimen-grade material.

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Yellow Tourmaline from Mavuco, Mozambique

The Mavuco area of Mozambique is famous for producing Cu-bearing (Paraíba-type) tourmaline in a variety of colours (e.g. Laurs et al., 2008), which are sourced from alluvial deposits. In addition, aquamarine has been produced from granitic pegmatites in the area, such as in the northwest portion of Mozambique Gems' claim (Laurs, 2012). In late 2014, Mozambique Gems mined one of these pegmatites to a depth of approximately 60 m, and found three pockets containing tourmaline. The crystals mostly had cores that were dark brownish yellow or green with narrow pink rims. The overall dark tone was quite different from the lighter hues typically shown by the Cu-bearing tourmaline from this area. Heat treatment experiments were performed by 'Keké' Saint-Clair Fonseca Junior (BC Gemas do Brasil, Governador Valadares, Brazil), and heating to 500°C in air was successful in changing the brownish yellow tourmaline to light yellow (Figure 13).

Mozambique Gems donated the sawn fragments and preforms in Figure 13 to Gem-A, and these were sent to authors AF and WBS for standard-based SEM-EDS chemical analysis using a JEOL JSM-6400 instrument with the Iridium Ultra software package by IXRF Systems Inc. Although

Figure 13: These tourmaline pre-forms were cut from material that was mined from a primary deposit at Mavuco, Mozambique. The brownish yellow colour shown by the stones on the left and centre changed to light yellow with heat treatment, as seen in the pieces on the right. No copper was detected in the samples, which have a total weight of 63.45 carats; the largest piece (which has been partially polished) weighs 21.12 ct and the smallest is 0.86 ct. Gift of Mozambique Gems; photo by B. M. Laurs.

no Cu was detected by this technique (or by EDXRF spectroscopy), the analyses revealed relatively high Mn and Ti, significant Ca and very low Fe (i.e. 3.90–5.80 wt.% MnO, 0.30–0.46 wt.% TiO_2, 1.35–1.57 wt.% CaO and 0.03–0.08 wt.% FeO). Overall, the composition was similar to yellow tourmaline that these authors have analysed previously from Mozambique (Muva), Russia (Malkhan District), Madagascar (Tsilaisina) and Nepal. The Ca contents were higher than in yellow tourmaline from certain localities such as Zambia (Canary mine), Italy (Elba) and the USA (Himalaya mine in San Diego County, California). Nevertheless, the Mavuco material still plotted well inside the elbaite field, corresponding to a ratio of approximately 3:1 for elbaite:liddicoatite.

Although yellow Cu-bearing tourmaline is known—although uncommon—from Mozambique (see the 43.40 ct stone in 'Pala's Featured Stones' section of www.palagems.com/gem-news-2017-02#featured-stones), the lack of Cu in this production of brownish yellow material from Mavuco is consistent with previous reports that the mineralization in the pegmatites there is unrelated to the adjacent alluvial deposits that have been mined for Paraíba-type tourmaline. The original primary source of the Cu-bearing tourmaline remains unknown.

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More Tremolite from Tanzania

A recent report in *The Journal* (Zwaan, 2015) described facet-grade tremolite from Mwajanga, Tanzania, which was encountered at the February 2015 gem shows in Tucson, Arizona, USA. Since gem-quality tremolite is uncommon, we were surprised to learn from gem dealer Dudley Blauwet about some additional tremolite from Tanzania that was somewhat different from the material described by Zwaan (2015). Blauwet first encountered it during the 2015 Tucson shows, when he was shown a parcel of rough material that his East African supplier thought was diopside. While some of the pieces appeared to be diopside, others had a flattened shape with cleavages that were characteristic of an amphibole mineral. Blauwet purchased 76.6 g of the amphibole-like material, and sent 26 pieces totalling 33.5 g to his cutting factory. Due to the brittle nature and well-developed cleavage, the cutting process yielded only 14 faceted stones ranging from 0.40 to 1.80 ct, with a total weight of 11.10 carats. During the 2016 Tucson shows, Blauwet's supplier showed him some more of this material, and stated that it came from the Merelani area (though presumably not from the tanzanite mines). Interestingly, a recent find of some dark green crystal clusters of tremolite was reported by Moore (2017) as coming from near the town of Mpwapwa in the Dodoma region of central Tanzania.

Figure 14: This tremolite from Tanzania consists of a 1.80 ct faceted stone and four cleavage fragments weighing 0.81–1.01 g. Photo by Dean Brennan.

Blauwet loaned one oval faceted stone and four rough samples to authors CW and BW for examination (Figure 14). The faceted stone weighed 1.80 ct, measured 7.82 × 7.03 × 5.38 mm and was a moderate, slightly greyish, yellowish green. The rough weighed 0.81–1.01 g and consisted of wedge-shaped cleavage fragments that were up to 15.86 mm long. The colour of the rough appeared slightly deeper green with more

grey compared to the cut stone. The RIs of the faceted stone were 1.609–1.631, and the SG of the largest crystal was measured hydrostatically as 3.01. These values are consistent with the calcic amphiboles tremolite-actinolite, and the RIs correspond to a tremolite-rich composition (cf. Nesse, 1986). The faceted sample contained no visible inclusions when examined with the gemmological microscope; the rough pieces also had good clarity and contained only incipient cleavages. The GemmoRaman-532SG and the Enwave 789 nm Raman spectrometer both confirmed the identification as tremolite, based on comparisons with the RRUFF database. Chemical analysis with an Amptek X123-SDD EDXRF unit revealed the expected significant Ca and Fe contents, as well as traces of Cu, Ti and Cr. Although the presence of Fe suggests the actinolite end of this isomorphous series, Mg is only marginally detectable with this EDXRF unit, so the chemical composition obtained with this instrumentation was not entirely consistent with tremolite.

To confirm the identification as tremolite, electron microprobe analysis by authors FCH and MD yielded the following composition: $(Na_{0.38}K_{0.04})_{0.42}(Ca_{1.58}Na_{0.32}Fe^{2+}_{0.10})_2(Mg_{4.69}Al_{0.18}Fe^{2+}_{0.10}Ti_{0.03})_5(Si_{7.68}Al_{0.32})_8O_{22}(OH_{1.69}F_{0.28}Cl_{0.03})_2$. This composition corresponds to that of tremolite (Hawthorne et al., 2012).

The colour of this tremolite is similar to that documented by Zwaan (2015) from Mwajanga, although the latter had a somewhat lighter tone and was available as well-formed prismatic crystals, unlike the cleavage fragments shown by the present material.

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Tsavorite Reportedly from Ethiopia

Tsavorite, the green grossular garnet originally found in the Tsavo area of Kenya, today comes mainly from various mines situated in the East Africa region, including Kenya, Tanzania and Madagascar; additional occurrences are known in Pakistan and eastern Antarctica (Feneyrol et al., 2014). However, a new mining area reportedly in Ethiopia recently has produced gem-grade tsavorite, and some of the authors acquired samples from various sources for analysis. The Bahrain Institute for Pearls & Gemstones (DANAT) received three rough samples (0.2–1.4 g; Figure 15, top) from Simon-Bruce Lockhart (Chanthaburi, Thailand), and Stone Group Laboratories received three faceted samples from Jason Doubrava (Poway, California, USA) and seven faceted samples from Meg Berry (Megagem, Fallbrook, California). The faceted samples weighed 0.25–3.56 ct, and were cut from several pieces of rough obtained by Steve Ulatowski (New Era Gems, Grass Valley, California, USA; see, e.g., Figure 15, bottom). The

Figure 15: These crystal fragments and broken pieces of Ethiopian tsavorite weigh 0.2–1.4 g (top) and 1.4–4.5 g (bottom). Samples courtesy of Simon-Bruce Lockhart (top) and New Era Gems (bottom); photos by Hasan Abdulla © DANAT (top) and Jordan Wilkins (bottom).

garnets ranged from yellow-green to deep green, sometimes resembling the colour of tsavorite from other sources (Figures 15 and 16).

The RI of the Ethiopian samples fell within a narrow range of 1.740–1.745, and their hydrostatic SG values were 3.62–3.65. All were inert to long- and short-wave UV radiation, and they did not change colour under the Chelsea filter. Semi-quantitative EDXRF analysis revealed Ca, Al and Si as major elements and confirmed the samples as grossular. Compared to tsavorite from other localities, these Ethiopian samples contained very low V (<200 ppm) and relatively high Fe (up to 2%). Preliminary ultraviolet-visible–near infrared (UV-Vis-NIR) spectroscopy showed that their green colour is mainly due Cr^{3+}, with absorption bands situated at ~430 and 600 nm. An absorption peak at ~370 nm also was observed and has been linked to Fe^{3+} (Schmetzer and Bank, 1982). In addition, a continuum of unknown origin that gradually increased in absorption from the UV to the NIR region was responsible for a yellowish hue in some samples. The exact role of iron in the coloration of the samples is still under discussion. The Raman spectra of our samples were consistent with tsavorite from Kenya (Figure 17) and Tanzania in our reference collections.

Some yellowish green to green grossular (tsavorite) with relatively high iron (up to 8%) has been found in Mali (Johnson et al., 1995). However, those stones contained a relatively large andradite component, as well as higher RI and SG values, compared to those from Ethiopia. The Ethiopian samples have similar characteristics (chemical composition, RI and SG) to green grossular from the Jeffrey mine (Quebec, Canada; Wight and Grice, 1982), although lower Ti.

Figure 16: The three faceted gemstones in the top photo are all Ethiopian tsavorite (1.66–3.55 ct). In the bottom image, the stone on the left is a 0.60 ct Ethiopian tsavorite, and is shown for comparison with a 1.10 ct tsavorite from Kenya. Photos by Orasa Weldon (top) and B. Williams (bottom); the Ethiopian samples were faceted by Meg Berry.

Figure 17: The Raman spectra of tsavorite from Ethiopia and Kenya are very similar.

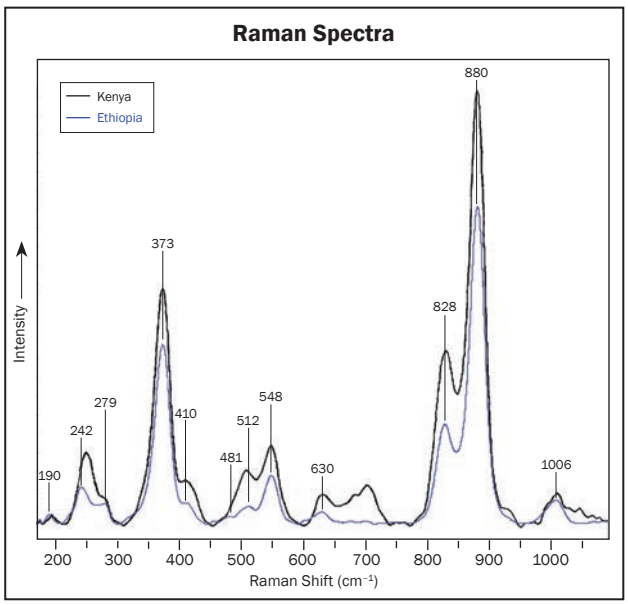

It appears likely that the geological environment of Ethiopian tsavorite differs from that of the 'classic' tsavorite deposits in East Africa. More research is needed to better understand the geological origin and spectroscopic features of the Ethiopian tsavorite.

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SYNTHETICS AND SIMULANTS

Black Star Cubic Zirconia Sold as Natural Star Rutile

In August 2017, a Canadian collector bought from a U.S. dealer a 10.67 ct black cabochon showing asterism (Figure 18) for US$900. The gem was purchased as a natural star rutile from Sri Lanka, and submitted to CGL-GRS Swiss Canadian Gemlab for testing and a possible appraisal report.

The star displayed eight rays, and the cabochon was black in daylight but appeared translucent brownish red when viewed with strong illumination (Figure 19). Routine testing revealed that its RI was over the limit of the refractometer (consistent with its highly metallic lustre), its hydrostatic SG was very high (5.97) and it was inert to long- and short-wave UV radiation. By comparison, natural star rutile has a lower SG (4.20–4.30) and has been documented only as very rare four-rayed stones (Steinbach, 2016, pp. 667–670). Microscopic examination showed numerous highly reflective rounded gas bubbles (Figure 19), indicating a manufactured material.

Figure 18: This 10.67 ct black star CZ was recently sold as natural star rutile. Photo by Matthias Alessandri.

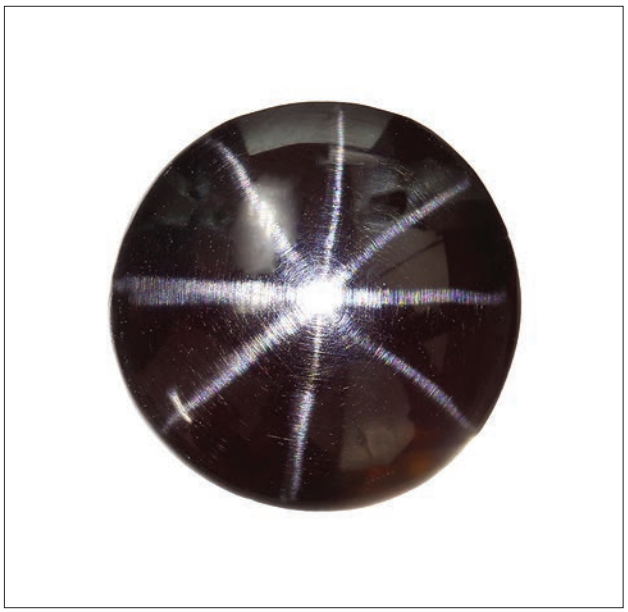

Vis-NIR spectroscopy was recorded with an SAS 2000 instrument (range 400–1000 nm, resolution 1 nm). The spectrum (Figure 20) matched that of cubic zirconia in our database, with a series of rare-earth element (REE) absorptions in the 730–900 nm range (cf. Turner et al., 2015).

Most CZs on the market are transparent and near colourless to imitate diamond, but it is known that CZ is manufactured in a wide range of colours. It is interesting to note that this black star CZ was 5% heavier than typical CZ (SG ~5.7). Nevertheless, Günther (1988) reported that some CZ (e.g. Zirkonia, Fianit) may have SG values up to 5.9 due to doping with Y, making it heavier than CZ containing Ca (SG of 5.6–5.7). Both Y and Ca have been used to stabilize CZ, and a study of three black (non-phenomenal) Russian-grown specimens doped with Y gave SG values of 5.93–5.94 (Kammerling et al., 1991), approaching the 5.97 value obtained for the present specimen.

Figure 19: Numerous rounded gas bubbles are present in the star CZ, which appears brownish red under strong illumination. Photomicrograph by B. Deljanin; magnified 30×.

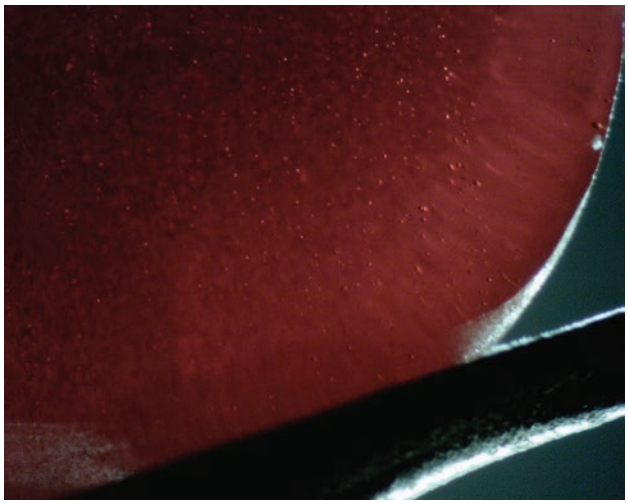

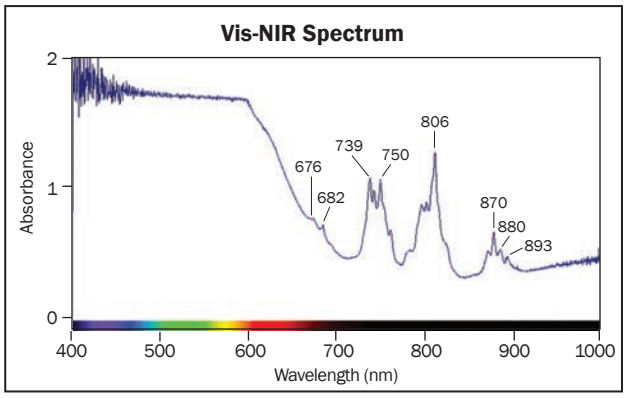

Figure 20: The Vis-NIR absorption spectrum of the black star CZ displays a series of REE-related peaks.

To further document this new synthetic material, additional advanced testing was performed by Matthias Alessandri at the GRS laboratory in Hong Kong. Energy-dispersive X-ray fluorescence analysis with a Skyray Instrument EDXRF spectrometer (45 kV for 40 seconds) showed a large amount of Zr and Y. Raman spectroscopy with a GemmoRaman-532SG instrument showed the best match for CZ in the database.

The origin of the asterism in this black CZ was not established, since there were no obvious oriented elongate features seen with the gemmological microscope. It is known that the presence of an inadequate amount of stabilizer (for example, 5–6 wt.% instead of the usual 15–65 wt.% Y_2O_3) results in a material containing a multitude of tetragonal zirconia needles (ZrO_2) within a cubic zirconia matrix (Kammerling et al., 1991). A 'tweed-like' structure has been observed with very high magnification in material stabilized with 5 wt.% Y_2O_3 (Ingel, 1982), and reduced transparency also may be caused by light scattering from these tetragonal needles. We assume that such needles—too small to be resolved with a gemmological microscope—may be the cause of the asterism in the present cabochon.

To our knowledge, this is the first report of star CZ imitating a rare natural star stone (in this case rutile). The amount of such material on the market is unknown, but a similar specimen was recently encountered by Alberto Scarani (Magilabs, Rome, Italy). The 8.77 ct reddish brown cabochon displayed a six-rayed star (Figure 21) and was sold at the 2017 Facets Show in Sri Lanka; however, testing with a portable GemmoFTIR identified it as CZ (A. Scarani, pers. comm., October 2017). This particular cabochon contained a large fracture, but

Figure 21: A similar, 8.77 ct reddish brown star CZ showing six-rayed asterism was recently encountered. A large fracture is present on the upper-left portion of the cabochon. The sample displayed no obvious internal features to account for the asterism when viewed with a gemmological microscope. Photo by Alberto Scarani.

no other internal features or gas bubbles were visible with the gemmological microscope.

The presence of this star CZ on the market provides a good reminder that gemmological testing is prudent to confirm the identity of any stone offered as a very rare gem material.

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MISCELLANEOUS

Two Interesting Cameos in the Collection of the Natural History Museum, London

The collections of the Natural History Museum (NHM), London, include minerals, gemstones, worked objects and carvings. This author recently had the pleasure to study two chalcedony/agate cameos that were fascinating for their gemmological, mineralogical and historical interest. What made both so delightful was that they had been carved onto the exterior of geodes. Both were purchased from gem carver Wilhelm Schmidt by the Geological Museum of the British Geological Survey in the late 1800s; the specimens then became part of the NHM collection in 1985.

Wilhelm Schmidt (1845–1938) was born in Idar (now part of Idar-Oberstein, Germany). At the age of 15 he was sent to Paris as an apprentice to learn the craft of gem engraving, under the masterful eye of cameo cutter Arsène. He was trained in the neo-classical style, but stone cameos were going out of fashion when he graduated in the 1860s. Although Romanticism brought in new trends of Renaissance subjects for cameos, Schmidt's interest waned and he returned to Germany. Following the Franco-Prussia War in 1870 and subsequent events, Wilhelm moved to England with his brother Louis, where he changed his name to William. The brothers set up a business in Hatton Garden that ran from 1872 to 1915 (Seidmann, 1988). During this time William regularly sold cameos, intaglios and carvings to the Geological Museum. His work was of interest because he utilized more unusual materials such as labradorite, moonstone and opal.

Figure 22: In the late 1800s, Wilhelm Schmidt carved this cameo of a Roman figure into chalcedony adjacent to amethyst crystals that originally formed part of a geode. This composite image shows four sides of the object, which measures 78 × 66 × 38 mm. Specimen BM.1985,MI5547; courtesy of NHM London, © The Trustees of the Natural History Museum, London.

Figure 23: This cameo (55 × 38 × 27 mm), also by Wilhelm Schmidt, depicts the head of Jupiter and is carved on the exterior of an agate geode, with the rear interior lined by quartz crystals. The raw material originated from Idar-Oberstein, Germany. Specimen BM.1985,MI6225; courtesy of NHM London, © The Trustees of the Natural History Museum, London.

Of the two cameos documented here, the first specimen (Figure 22) is BM.1985,MI5547, described in the museum's handwritten register as "Cameo in Agate-Jasper on Amethyst". Depicting a Roman man with a wreath on his head, Schmidt carved the layer just beneath the amethyst druse, which consisted of pale orangey pink chalcedony containing fine crisscrossing dark veinlets and a few thin linear arrays of red iron-oxide spots. The layer of chalcedony continues into the background of the carving, giving a halo effect. The amethyst creates a simple dark backdrop, and it is a surprise to most viewers to find the centimetre-sized amethyst crystals on the back-side of the piece. The terminations of many of the crystals have been ground away, presumably to give the cameo a more even surface. The object measures 78 × 66 × 38 mm and was purchased from Schmidt on 23 December 1886 for £8. Although no location is given for the source of the raw material, it is likely to have been Rio Grande do Sul in Brazil, well known for its amethyst, agate and jasper, as well as its connections with Idar-Oberstein in the 1800s. [*Editor's note*: See the article by A. Reys on pp. 708–726 of this issue for more on this connection.]

The second cameo (Figure 23), BM.1985, MI6225, is described in the museum's register as "Head of Jupiter (after the antique) cut on the exterior of a hollow Agate from Oberstein". It is carved as the head of the Roman god Jupiter, with long flowing hair and beard. The agate is very pale purple to light beige and locally contains small, dark, translucent, angular areas. It also has very fine red veinlets and tiny spots with an iron-oxide appearance. On the rear, a fine layering of the agate can be seen around the edges of a hollow geode lined by a druse of sparkling quartz crystals up to 3 mm in size that range from colourless to an ever-so-slight hint of pale amethyst. The carving measures 55 × 38 × 27 mm, and was purchased by the Geological Museum on 25 March 1891 for £10.

Roman figures were a common theme for Schmidt, and the NHM collection includes other cameos that he carved with the head of Mars, several of Minerva and Julius Caesar, and a bust of Britannicus.

The beauty of these pieces—in the workmanship, in the gem materials used, and in the clever utilization of the geodes and adjacent chalcedony/agate—makes these two specimens a fascinating part of the NHM collection.

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Coloured Stone Mining and Trade in Brazil: A Brief History and Current Status

Aurélien Reys

Coloured stones from Brazil have been sought after since the European discovery of the Americas more than 500 years ago. Numerous deposits have been explored, and gem cutting and trading activities also have emerged. As a result, Brazil is one of the world's most important gem suppliers. Although production continues, significant changes in the world market have greatly impacted Brazil's coloured stone industry, local miners and tradespeople. In addition to recounting the history of gem mining and trade in Brazil, this article provides a review of Brazil's proven and potential deposits of coloured stones.

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Introduction

Brazil has been one of the world's major suppliers of coloured stones for decades. Deposits of emerald, aquamarine, tourmaline (e.g. Figure 1), topaz, chrysoberyl and quartz are widespread, and some of the mines have been explored extensively for centuries. Other gem materials, such as morganite, heliodor, amazonite, opal, kunzite, iolite, apatite, jasper and garnet, also have been found in abundance. According to both the Brazilian Ministry of Development, Industry and Foreign Trade (MDIC) and the United Nations, from 2011 until recently official exports of coloured stones from Brazil reached more than US$150 million annually (AliceWeb, 2016; UN ComTrade, 2016). This is twice as much as was documented during the previous decade, and is one of the highest reported export values for countries engaged in coloured stone mining (and the highest with regard to rough material). Based on the same sources, this figure also represents about 20 times more than all reported diamonds exported from Brazil. Moreover, the volume of gems illegally smuggled abroad likely represents a significant addition to the official exports and overall mining production. Because such data for Brazil and elsewhere often are unreliable, it is generally accepted that some countries, especially in Africa, have higher production than is reflected by official exports.

This article presents an updated overview of the Brazilian coloured stone industry based on results of field research undertaken by the author during several visits in 2011–2013, as well as access to various more recent Brazilian databases. In addition to chronicling the development of activities linked to gem exploration and mining, this article examines the effects of China's emergence as a consumer market on Brazil's gem industry. Furthermore, recent information on Brazilian gem occurrences is presented from data compiled by the Brazilian National Department of Mineral Production (DNPM) and other resources.

Historical Review

Although gold and diamonds played an important economic role in Brazil's early history, emeralds were the resource that truly captivated the early pioneers (Reys, 2014b). Their discovery in Colombia during the 16th century convinced explorers that other emerald riches were hidden in the interior of Brazil's vast territory (Rocha Pombo, 1919).

Colonial Period (16th–18th Centuries)

The history of Brazilian gemstones began with the early colonization period, when the *bandeirantes*—private slave-hunting expeditions with a secondary goal of locating potential mining areas—ventured into unknown territories (Weldon, 2012). The first of these raids was initiated in 1554, only a few decades after Brazil was claimed for Portugal by Pedro Álvares Cabral in 1500. Led by an explorer and a Jesuit priest, the raiders sailed up the Rio Mucuri to penetrate a heavily forested mountain range (Delaney, 1996; Castañeda et al., 2001). Then they continued overland to the modern-day town of Diamantina (Cornejo and Bartorelli, 2010). While the expedition opened new routes for other incursions in subsequent years, it failed to make any gem discoveries.

Indeed, no gem deposits were found until 1573, during an expedition led by Sebastião Fernandes Tourinho. Following the Rio Doce, Tourinho reached the legendary *Serra das Esmeraldas*, or 'mountain range of emeralds' (Saint-Adolphe, 1885). According to Cornejo and Bartorelli (2010), and based on information provided four centuries ago by the explorer Gabriel Soares de Sousa, the reported emeralds were discovered in the present-day Governador Valadares area, about 80 km north of the junction of the Doce and Suaçuí rivers (Soares de Sousa, 1938). However, since emeralds subsequently could not be verified in this region, the gems are now considered by most experts to have been green tourmaline (Saint-Hilaire, 1833b; Proctor, 1984; Cornejo and Bartorelli, 2010). Nevertheless, an emerald mine does exist in the area indicated by Gabriel Soares de Sousa and reportedly was later exploited for at least a decade until the 1990s.[1] This reopens the original hypothesis that emeralds could have been found in Brazil in the early years of colonization and not just in the 20th century. This also could explain why the *bandeirante* incursions continued in the region for over a century, even if most of them returned with only a few beryls or tourmalines of little value (Mauro, 1977).

Figure 1: Multi-coloured tourmaline is emblematic of Brazil's gem production. These rough and cut examples are from the Cruzeiro mine in Minas Gerais State; the crystal is 6 cm tall and the gemstone measures 13 × 28 mm. Courtesy of Scott Rudolph; photo by Jeff Scovil.

Although these early expeditions sought emeralds, in the late 17th century they found instead the legendary gold mines of Sabarabussu, located to the east of the present city of Belo Horizonte. The ensuing rush then expanded north, unearthing the first diamond deposits a few decades later near the town that would become Diamantina, located about 200 km from Sabara-

[1] This mine was partially owned by a gem dealer from Governador Valadares who confirmed a rumour brought to the author's attention by local gem brokers in the town square of Teófilo Otoni. One of these brokers had worked at the mine in question. The site was located in the municipality of Agua Boa, ~5 km from the Cruzeiro tourmaline mine in São José da Safira. (This is ~120 km north-east of the Itatiaia emerald deposit in the Conselheiro Pena area.)

Figure 2: The mining town of Ouro Preto was also the capital of Minas Gerais until the late 18th century. Photo by A. Reys.

bussu (Saint-Adolphe, 1885; Barbosa, 1991). The settlements that sprang up from these discoveries led to the consolidation of territories and the present-day state of Minas Gerais, an important step for Brazil (Rocha Pombo, 1919). The exploration for gold and diamonds overshadowed other gem mining activities until the 19th century, apart from the Imperial topaz deposits found nearby in the old Minas Gerais capital city of Ouro Preto (Figure 2; Machado, 2003). Yet the 18th century still can be considered the foundation of Brazilian gem mining culture. For example, it was during this time that the term *garimpeiro* emerged; this word comes from the French *grimper*, meaning 'to climb' (Pimenta, 2002). Originally referring to the lookouts for diamond smugglers who took refuge in the steep mountains, watching for the approach of Portuguese soldiers (Saint-Hilaire, 1833a), the term is still used to refer to independent miners.

Post-Independence (19th to Mid-20th Centuries)

After Brazil's independence from Portugal in 1822, the new emperor Dom Pedro I opened the border to immigration with the goal of populating and consolidating this massive territory. Among the new arrivals were Germans, who concentrated in the present-day state of Rio Grande do Sul and initiated the first stage of development for the modern Brazilian coloured stone industry (Proctor, 1984; DNPM, 1998). Most of these immigrants working in the gem industry were from the town of Idar-Oberstein, an agate-mining community in Germany that remains an important commercial centre for gems. During this period, Idar-Oberstein was experiencing economic troubles, as the production from its agate mines dwindled. As a result, many residents left in search of other opportunities. Some travelled as far as southern Brazil, bringing their cutting and polishing techniques to the newly discovered agate and amethyst mines in Rio Grande do Sul (DNPM, 1998; Nadur, 2009). Thanks to their established trading networks, these immigrants played an important role in connecting local gem deposits with the world market. German immigrants also went to the north-eastern part of Minas Gerais, starting around the mid-19th century (Proctor, 1984; Castañeda et al., 2001; Figure 3). Within a few years, the region became Brazil's most important mining area, and the town of Teófilo Otoni was widely considered the main trading centre for gems in Brazil (Rocha Pombo, 1919).

The rise of the Brazilian gem industry also was fostered by an abundance of discoveries. Many occurred in north-eastern Minas Gerais (Gorceix, 1885). Among the most notable early finds was the 110.5 kg *Papamel* aquamarine, discovered in 1910 in the Marambaia Valley, as well as numerous emerald deposits. The first emerald site in modern times was discovered in 1912, 16 km

Figure 3: German immigrants from Idar-Oberstein initially went to Rio Grande do Sul State and later established gem-related businesses in Minas Gerais. Shown here in Minas Gerais from left to right are Viktor Bohrer-Borges, Hermann Kaucher, Herbert Wild, August Leyser, Stolley (a Brazilian dealer) and Karl Bank, circa 1907. They are holding small 'finger' bananas, a rather exotic fruit to them at the time. Courtesy of Paul Wild.

Figure 4: The bright coloration shown by Paraíba tourmaline (here, 5.73 ct) as well as its rarity have contributed to its high value. Photo and stone courtesy of Paul Wild.

from the town of Brumado in the deep south of Bahia State. Other emerald discoveries followed in the early 20th century at Sant'Anna dos Ferros (1919), later named Ferros, in Minas Gerais; at Itaberaí in the state of Goiás (1920); and at Anagé (1939) in Bahia (Delaney, 1996). Beryl, tourmaline, chrysoberyl and quartz also were found in abundance in those states. In the 1930s–40s, opal deposits were found near the town of Dom Pedro II in Piauí State, which at one point boasted the only explored opal deposits outside Australia (Delaney, 1996; Milanez and Puppim, 2009).

On the eve of World War II, gem-related activities in Brazil were mainly limited to mining. Although trade skills had been introduced by German immigrants a century before (Cornejo and Bartorelli, 2010), there is little evidence of a relevant coloured-stone cutting industry outside the south—at least this is what the available sources suggest (Barbosa, 1991; Nadur, 2009)—and until the 1940s diamond cutters outnumbered all other lapidaries. Most areas that are currently engaged in gem commerce were already established by this time, with the possible exception of Governador Valadares. This mid-size city was engaged in mining for industrial beryl and mica, which were used in metal alloy and insulation, respectively. Both commodities were much more profitable than gems during this period, and their global consumption peaked during World War II due to military applications (Castañeda et al., 2001).

The Contemporary Era

The end of World War II, along with the advent of new synthetic materials, led to the widespread closure of industrial mineral mines in Minas Gerais. As a consequence, unemployment rose dramatically. Because tourmaline and other gems were usually found in the same pegmatite deposits as the industrial minerals, many of these mines turned exclusively to gem production (Proctor, 1984; Delaney, 1996; Castañeda et al., 2001). Accordingly, local lapidary and other trade activities grew dramatically. Within a decade, Governador Valadares became one of the most influential gem commerce centres, behind Teófilo Otoni.

The latter half of the 20th century also was marked by the emergence of a Brazilian jewellery industry and the creation of the country's two largest companies in this sector, H. Stern and Amsterdam Sauer (Nadur, 2009). Both founders, Hans Stern and Jules Roger Sauer, were Jewish immigrants fleeing Nazi persecution. In northern Minas Gerais they contributed to the rising demand for gems and even invested in some mining operations, such as the Cruzeiro tourmaline mine (Douglas Neves, pers. comm., 2013).

New deposits, often found near established mines, played an important role in the geography of gem cutting and trade. In 1954, a 34 kg aquamarine of 60% clarity, named *Martha Rocha* in tribute to the deep blue eyes of that year's Miss Brazil, was unearthed north of Teófilo Otoni. Over the next few decades, several new emerald deposits were discovered: at Itabira (1977) and Nova Era (1988) in Minas Gerais; at Santa Terezinha de Goiás (1981) in Goiás; and in the Serra de Carnaíba region (1983) of Bahia (Delaney, 1996). Alexandrite deposits also were located in the early 1980s in the municipalities of Malacacheta and Antônio Dias in Minas Gerais. Perhaps the most important discovery of the 20th century—for its singularity and its profitability—became known as Paraíba tourmaline. Uncovered for the first time in 1987 in the São José da Batalha district of Paraíba, this tourmaline's unique 'neon' blue-to-green coloration contributed to making it one of the most valuable coloured stones on the global market (Figure 4; Cornejo and Bartorelli, 2010).

Thanks to these discoveries, among other factors, Brazil emerged as one of the world's major gem exporters, creating jobs for local popula-

tions and enhancing the standing of Minas Gerais in the areas of gem production, cutting and trading. While some sources noted a slowdown in the 1970s (Proctor, 1984), others maintained that, to the contrary, numerous discoveries during this period provided a steady output into the late 1980s (Weldon, 1995; and several interviews with miners and traders). At the beginning of the 1990s, there were more than 2,700 lapidary shops in Teófilo Otoni alone, with hundreds of large, medium and small independent brokers frequenting the town centre (Robson de Andrade, pers. comm., 2013). The number of participants in Brazil's coloured stone industry then significantly decreased in the following years, especially cutters of lower-value stones such as quartz and garnet. This decline accelerated during the 2000s and seriously affected local employment in the gem industry (Reys, 2014a, 2015).

Recent Factors Affecting Brazil's Gem Industry

What can explain the decline in production of a country as rich in gem deposits as Brazil, which has been actively engaged in the exploitation of these deposits for decades? According to official figures, Brazil remains one of the major producers of coloured stones (Reys, 2012). They even show that Brazilian exports might have increased recently, although its principal trade partners have changed during the last couple of decades (AliceWeb, 2016; UN ComTrade, 2016).

The Increase of Exports to Asia

In the late 1990s, Brazilian gems were mainly exported to the United States, Europe and Japan. While the United States and Europe remain important trade partners, especially for cut gemstones, Japanese buyers practically disappeared in the 2000s. The biggest change, however, was the emergence of other Asian countries. Although Hong Kong and India have been important economic partners for Brazil, and gem exports to these countries have increased since the 1990s, they were joined by another major player: China. While China's international gem trade was negligible until the mid-1990s, the country has become one of the most important gem importers and, in 2011, the main partner in Brazil's gem commerce. In 2013, Brazil exported 60% by weight, or 25% by value, of its output to China (up to 50% by value if Hong Kong is included). Although exports to China have slightly decreased, they still represented 15% of Brazil's total output by value and 60% by weight in 2016 (AliceWeb, 2016; UN ComTrade, 2016). Indeed, the increase in exports of rough gem material to Asia has become very significant, and for a time most of it was being cut and polished in India and China. Although China has recently decreased its activities in the purchasing and cutting of coloured stones, India and Thailand furthered their positions, so Asian countries still remain at the heart of the gem industry.

Such developments have had a significant impact on the nature of local gem production in Brazil. Areas engaged with mining large quantities of quartz have benefited from the partnership with China. According to Brazilian tradespeople, the Chinese brokers began to arrive in the quartz-producing areas at the beginning of the 2000s. These brokers bought most of the cheaper gems and minerals available, especially rough mine-run quartz, contributing heavily to the rise in mining activities in areas such as Novo Horizonte in Bahia, and Curvelo and Corinto in Minas Gerais. Through the years, the Chinese dealers acquired a greater variety of stones, showing a preference for tourmaline, especially rubellite.

The Fall of Brazil's Lapidary Industry

An unfortunate consequence of the increase in the trade with China has been the collapse of Brazil's domestic gemstone cutting and polishing industry for low-value materials (e.g. Figure 5), which has been unable to compete with cheaper labour in China and India. Some stones, especially quartz, were sent to China to be made into jewellery and then returned to Brazil to be sold (Figure 6). The negative effect on local economies is particularly apparent in northeastern Minas Gerais, which has traditionally specialized in handcrafted gems. In Teófilo Otoni, of the 2,700 lapidary businesses operating in 1993, only 360 remained in 2005 (GEA and IEL, 2005), and there have probably been further declines since then (Robson de Andrade, pers. comm., 2013). At least 90% of those operations had fewer than six employees and remained undeclared in the mid-2000s, indicating that the sector was still dominated by small businesses. Similar declines have been noted in Governador Valadares, as well as in larger cities such as Belo Horizonte and São Paulo.

However, gem cutting is a value-added activity and, according to Hécliton Santini Henriques, former president of the Instituto Brasileiro dos Gemas e Metais Preciosos, it should be possible to domestically process up to 80% of the gem material mined in Brazil (SEBRAE, 2006). Theoretically, this could produce more than US$50 million and also create thousands of additional lapidary jobs (SEBRAE, 2006). However, the situation has not evolved much since 2006, even if Brazil still remains significant for cutting higher-value gemstones. But since both the inexpensive and more valuable gems are included in the same statistical category, it is difficult to analyse the situation through the data usually provided (AliceWeb, 2016; UN ComTrade, 2016). In light of their differences in value, it might even be pertinent to ask whether a single 'coloured-stone' category is still relevant. For a better understanding of the geography of international trade, quartz and other lower-value stones could be grouped apart from more valuable gems such as aquamarine, tourmaline, kunzite and morganite.

Figure 5: A lapidary facets a citrine in Governador Valadares. Photo by A. Reys.

Gem Business and Trading Centres

Despite their recent difficulties, Teófilo Otoni and Governador Valadares remain the major gem cutting and trading centres in Brazil (Reys, 2015), followed by the city of Belo Horizonte (the capital of Minas Gerais State). Soledade, a town in Rio Grande do Sul State, specializes in the trade of ornamental and rough agate, amethyst and other quartz varieties. The three mid-sized towns compete with, or even surpass in both cutting and trade, Brazil's three main metropolitan cities (São Paulo, Rio de Janeiro and Belo Horizonte), where jewellery businesses seem to dominate the gem-related activities. Low-cost jewellery industries are also located in São Paulo's outlying cities, such as Limeira and São José do Rio Preto (PORMIN, 2008; AliceWeb, 2016;

Figure 6: These bead necklaces, seen in Teófilo Otoni, were manufactured in China from Brazilian rough material and then shipped back to Brazil for sale. The largest beads are approximately 8 mm in diameter. Photo by A. Reys.

see also www.telelistas.net). However, the Brazilian gem industry remains limited in capacity on a global scale because of, notably, low Asian labour costs, high domestic taxes and bureaucracy.

Various urban centres engaged in some level of gem business host the country's main gem fairs, which are small venues compared with other international shows such as those in Tucson, Hong Kong, Bangkok, Basel and Munich. The *Feninjer Brazilian Gems and Jewellery Show* has taken place in São Paulo since the 1950s and remains a jewellery-focused event. Other exhibitions occur annually near the main mining areas. The largest of these is the *Feira Internacional de Pedras Preciosas* (FIPP) in Teófilo Otoni, which marked its 27th year in 2017. Other major gem fairs include the *Exposol* in Soledade and the *Feira de Pedras Preciosas e Semipreciosas* in Curvelo, both showcasing mainly quartz specimens, spheres and other ornamental quartz gems. The *Brazilian Gem Show*, which was marketed as the country's most important specialized fine-gems exhibition, has not taken place or has run only sporadically since the beginning of the 2010s, reportedly due to lack of interest and support from local agents and authorities.

Figure 7: A gem broker in Teófilo Otoni waits for customers, who are becoming increasingly scarce. Photo by A. Reys.

An important factor to note is the informal trading of gems. Several hundred individuals travel around the country and acquire rough material to sell later in the metropolitan areas, particularly in Teófilo Otoni (Figure 7) and Governador Valadares. In Teófilo Otoni, a gallery of about 25 shops associated with a local brokers' association was established at the beginning of the 1990s near the main town square and supported by local authorities in an effort to legalize gem trading practices. Other shops also can be found throughout the town, and they act as headquarters for regional companies engaged in mining in the surrounding areas.

While Teófilo Otoni remains the main centre for gem trading, other areas such as Peçanha and Afonso Pena streets in Governador Valadares and Praça Sete in Belo Horizonte also conduct trade activities. As noted above, additional centres exist, notably Soledade in Rio Grande do Sul. Smaller towns with trading centres include Ouro Preto, Curvelo, Itabira and Nova Era in Minas Gerais; Ametista do Sul and Lajeado in Rio Grande do Sul; Campo Formoso, Brejinho das Ametistas and Novo Horizonte in Bahia; Santa Terezinha de Goiás, Caldas Novas and Cristalina in Goiás; and Dom Pedro II in Piauí (PORMIN, 2008). The widespread adoption of modern technology such as the Internet and digital cameras has revolutionized traditional methods of trading over the past decade, making middlemen somewhat obsolete. In addition, a decline in business also might be due to the erosion of informal mining activities.

Status of Mining Operations

It can be challenging to judge the legality of a mining operation in Brazil, as even a legally registered one might use an undeclared labour force or might illegally export its production. Nevertheless, a mine remains technically legal as long as it is declared to the DNPM, so most smaller-scale operations (e.g. Figure 8) are therefore considered illegal, as they do not appear in official statistics. Although these small mines are important to the local gem industry, their number has fallen significantly during the last couple of decades, and local labour forces, gem merchants and associations assert that the number of *garimpeiros* has declined anywhere from 50% to 90% in Minas Gerais since the end of the 1980s (Reys, 2015).

Figure 8: Garimpeiros *dig for aquamarine in Catuji, located in the Marambaia Valley. This type of open-pit mine is called* cata *('pick off') by locals. Photo by A. Reys.*

Such declines are usually blamed on local authorities who support progressive measures to limit unauthorized mining. Yet several recent aspects have called this reasoning into question, besides the geographical and logistical difficulties in tracking down illegal mines. Mining regulations are expensive and difficult to enforce, and there are insufficient resources to accomplish such a mission. In Teófilo Otoni, for instance, there are only four agents assigned to an area of 8,100 km², and only one squad from DNPM is available for the entire north-eastern Minas Gerais region, where gem mining operations are scattered over a 100,000 km² area. Some places in the far west and north, near the Amazon rainforest, are extremely difficult to reach. Roads in such regions are rare or in poor condition, and furthermore, DNPM agents admit that they often avoid closing down illegal operations because the miners have no other employment opportunities in these poor rural areas. In addition, according to the present author's research, the impacts of the Brazilian Institute of Environment (IBAMA) and its fight against illegal small-scale gem mining are often overestimated. Contrary to popular belief, actions carried out by the Brazilian authorities so far have not been very effective. In northern Minas Gerais, for instance, there are still hundreds of illegal gem mines operating, sometimes quite close to the main roads.

Other factors are linked to diminishing Brazilian gem production, such as the evolution of the international market. Many African countries now produce a larger variety and quantity of gems than they did a couple of decades ago, and those stones usually are sold at somewhat lower prices than those from Brazil. However, the effects of this on the Brazilian market have been tempered by a rise in demand caused by the new middle class in emerging countries. Nevertheless, the author's research has linked the reduction in Brazilian gem mining activities with economic growth and improved living conditions. Indeed, in the past few years, several rural regions have experienced significant economic development, which has led to social improvements. With an increasingly stable political atmosphere followed by economic growth, the living standards of the most modest regions of Brazil have improved. Economic progress has provided new investment opportunities that carry less financial risk than gem prospecting. The growth of the economy also has had positive effects on employment: Workers are able to choose less-dangerous and less-exhausting jobs for comparable wages to mining. Most workers engaged in mining are more than 40 years old and want a different future for their children; and for their part, the younger generation seems to aspire to a more modern and comfortable lifestyle (Reys, 2104a, 2015).

The high cost of mining—because most of the current deposits require deeper tunneling since the easier-to-obtain gems have already been exploited—is another reason for the recent decline in mining and production.

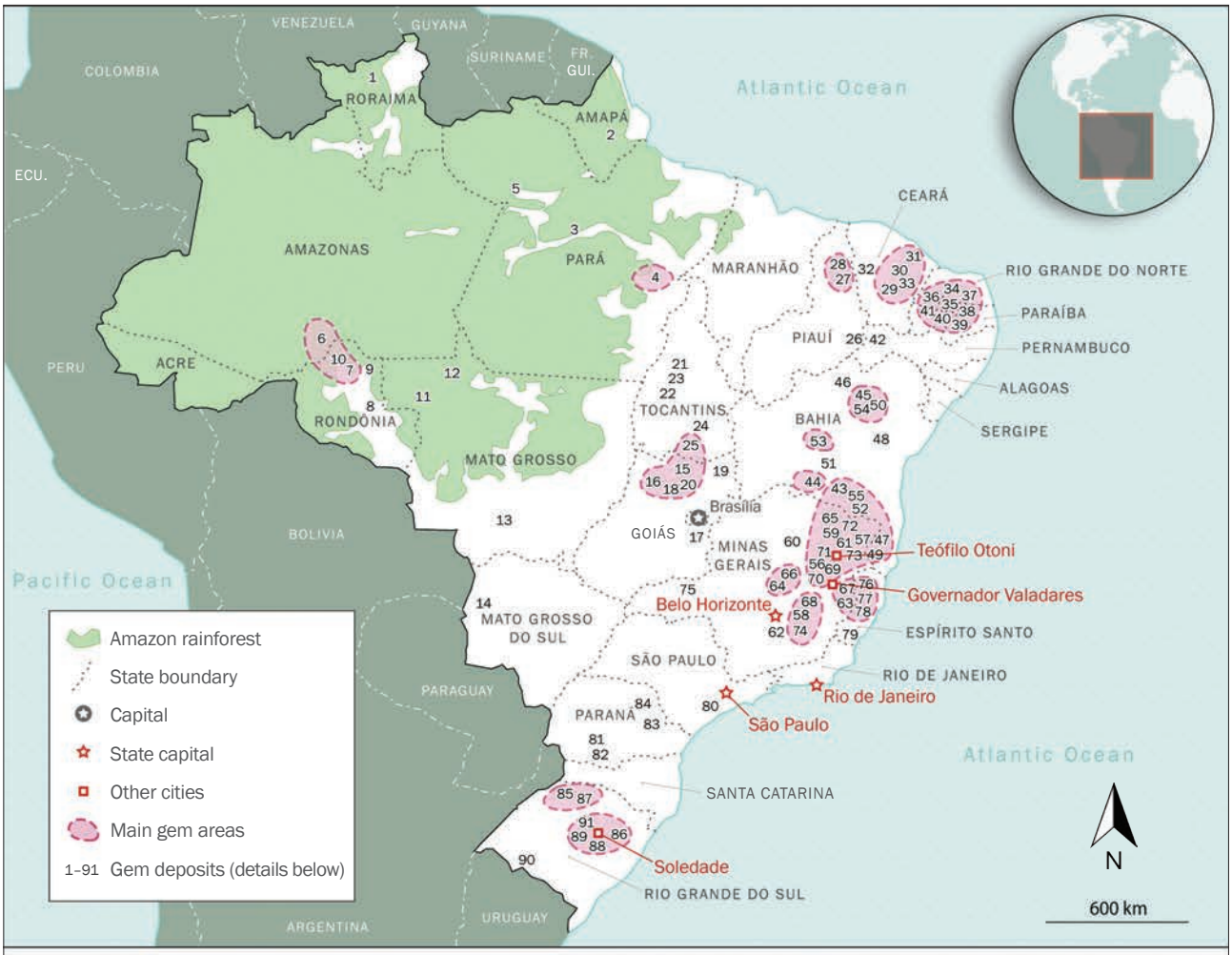

◆ RORAIMA
1. Amajari (Am)

◆ AMAPÁ
2. Porto Grande (Tta)

◆ PARÁ
3. Brasil Novo, Medicilândia (Am)
4. Marabá (Am, Qz)
5. Oriximiná, Óbidos (Col)

◆ AMAZONAS
6. Lábrea (Am, Tp)

◆ RONDÔNIA
7. Alto Paraíso, Ariquemes (Tp)
8. Ji-Paraná (Am, Qz)
9. Machadinho d'Oeste (Op, Qz)
10. Porto Velho (Am, Tp, Tu)

◆ MATO GROSSO
11. Aripuanã (Am)
12. Colniza, Cotriguaçu (Tu)
13. Cuiabá, Várzea Grande (Qz)

◆ MATO GROSSO DO SUL
14. Bodoquena, Corumbá (Am)

◆ GOIÁS
15. Campinaçu, Campinorte, Minaçu (Be)
16. Campos Verdes, Santa Terezinha de Goiás (Em)
17. Cristalina (Qz)
18. Crixás, Uruaçu (Am)
19. Monte Alegre de Goiás (Qz)
20. Niquelândia (Qz)

◆ TOCANTINS
21. Barrolândia (Be)
22. Cristalândia (Qz)
23. Monte Santo do Tocantins (Be, Em, Tu)
24. Peixe, Pindorama do Tocantins (Gr, Qz)
25. São Salvador do Tocantins, Palmeirópolis (Be, Tu)

◆ PIAUÍ
26. Betânia do Piauí (Be)
27. Buriti dos Montes (Op)
28. Pedro II (Op)

◆ CEARÁ
29. Acopiara, Piquet Carneiro (Am, Qz)
30. Banabuiú, Quixeramobim (Am, Be, Gr, Qz, Tta, Tu)
31. Beberibe (Am, Qz)
32. Crateús (Am, Qz)
33. Milhã, Solonópole (Be, Gr, Tu, Qz)

◆ RIO GRANDE DO NORTE
34. Acari, Currais Novos, Jardim do Seridó, Santana do Matos (Be, Gr)
35. Carnaúba dos Dantas, Equador, Parelhas (Ap, Be, Eu, Gr, Qz, Tu)
36. Tenente Ananias (Be, Tu)
37. Lajes, São Tomé (Be, Em)

◆ PARAÍBA
38. Assunção, Juazeirinho, Taperoá (Be, Qz, Tta, Tu)
39. Frei Martinho, Pedra Lavrada (Gr, Qz, Tta, Tu)
40. Salgadinho (Em, Tu)
41. Santa Cruz, São Francisco (Be, Qz, Tu)

◆ PERNAMBUCO
42. Ouricuri, Santa Filomena (Alx)

◆ BAHIA
43. Brumado, Anagé (Em)
44. Caetité (Am, Gr, Qz)
45. Campo Formoso (Alx, Em, Qz)
46. Casa Nova, Sento Sé (Am, Be, Gr, Qz)
47. Guaratinga (Alx, Be, Cb)
48. Ipirá (Ap, Be, Dio, Qz)
49. Itamaraju, Itanhém (Be, Cb)
50. Itiúba (Az)
51. Livramento de Nossa Senhora (Am, Qz)
52. Macarani, Maiquinique, Encruzilhada (Be, Qz, Tu)
53. Novo Horizonte, Oliveira dos Brejinhos (Qz)
54. Saúde, Pindobaçu (Cb, Em)
55. Vitória da Conquista, Itambé (Be, Eu, Gr, Qz, Tp)

◆ MINAS GERAIS
56. Água Boa, Santa Maria do Suaçuí, São José da Safira (Be, Gr, Qz, Tu)
57. Almenara, Itaobim, Joaíma (Be, Qz, Tu)
58. Antônio Dias, Itabira, Nova Era (Alx, Be, Em, Qz, Tp)
59. Araçuaí, Itinga (Am, An, Be, Bz, Qz, Tp, Tu)
60. Bocaiúva, Montes Claros, Botumirim (Qz)
61. Caraí, Catuji, Padre Paraíso (Be, Cb, Qz, Tp, Tu)
62. Conselheiro Lafaiete (Gr)
63. Conselheiro Pena, Galiléia, Resplendor (Ap, Be, Em, Eu, Gr, Qz, Spd, Tu)
64. Corinto, Curvelo (Qz)
65. Coronel Murta, Salinas, Virgem da Lapa (Be, Qz, Tp, Tu)
66. Diamantina (Qz)
67. Divino das Laranjeiras (Am, Be, Bz, Qz, Tu)
68. Ferros, Santa Maria de Itabira (Alx, Az, Be, Eu, Em, Qz)
69. Franciscópolis, Itambacuri (Qz, Tu)
70. Governador Valadares, Tarumirim (Be, Gr, Qz, Tu)
71. Malacacheta (Alx, An, Be, Qz, Sa, Tu)
72. Medina, Pedra Azul (Be, Tp)
73. Novo Oriente de Minas, Teófilo Otoni (Be, Qz, Tp, Tu)
74. Ouro Preto (Eu, Tp)
75. Tupaciguara, Uberlândia (Am, Qz)

◆ ESPÍRITO SANTO
76. Água Doce do Norte, Barra de São Francisco (Be, Qz, Tu)
77. Colatina, Itaguaçu, Pancas (Be, Cb)
78. Mimoso do Sul, Muqui (Be, Tp, Tu)
79. Santa Teresa (An, Be, Cb, Qz)

◆ SÃO PAULO
80. Itariri (Qz)

◆ PARANÁ
81. Chopinzinho (Am, Qz)
82. Clevelândia, Coronel Vivida (Am)
83. Cerro Azul, Jaguariaíva (Dio)
84. Congonhinhas, Ibaiti, Tibagi (Sa)

◆ RIO GRANDE DO SUL
85. Ametista do Sul, Frederico Westphalen, Iraí (Ag, Am, Cac)
86. Caxias do Sul (Am, Qz)
87. Cristal do Sul, Rodeio Bonito (Ag, Am, Cac)
88. Progresso (Ag, Am, Qz)
89. Salto do Jacuí, Estrela Velha (Ag, Am, Op, Qz)
90. Santana do Livramento (Ag, Am, Qz)
91. Soledade (Ag, Am, Qz)

ABBREVIATIONS

Ag: agate	Dio: diopside
Alx: alexandrite	Em: emerald
Am: amethyst	Eu: euclase
An: andalusite	Gr: garnet
Ap: apatite	Op: opal
Az: amazonite	Qz: quartz
Be: beryl	Sa: sapphire
Bz: brazilianite	Spd: spodumene
Cac: calcite	Tp: topaz
Cb: chrysoberyl	Tta: tantalite
Col: columbite	Tu: tourmaline

Figure 10: Weighing 6.11 ct, this emerald is unusually large for clean material from Brazil. Courtesy of Paul Wild; photo by Jordan Wilkins.

Figure 11: This 22.93 ct aquamarine is from Santa Maria in Minas Gerais. Courtesy of Paul Wild; photo by Jordan Wilkins.

Current Gem Deposits and Occurrences

Despite the above-mentioned forces, mining for various commodities remains the backbone of the Brazilian gem industry, and a wide variety of gems is still found throughout the country. According to DNPM, there were 2,294 gem occurrences in 401 different municipalities as of 2013, with 49.3% of them in Minas Gerais and 19% in Rio Grande do Sul (DNPM, 2013; Reys, 2015). The occurrences in the north-eastern part of the country have surely been underestimated, as it is a poorer and usually less regulated area. Emerald and other beryls, tourmaline, topaz and all types of quartz are the most widely mined coloured stone resources nationwide (see Figure 9 and Table I).

Emerald

Since the 2000s, Brazil was usually ranked third among the world's leading emerald producers (e.g. Figure 10), behind Colombia and Zambia (Yager et al., 2008; UN ComTrade, 2016). Unlike Colombian emeralds, which have a hydrothermal origin, Brazilian emeralds occur in schist-type deposits, formed by the reaction of pegmatitic veins with ultramafic host rocks (Giuliani et al., 2013). Brazilian emerald production has occurred in three states—Goiás, Bahia, Minas Gerais—and mining operations are usually conducted by people originally from the state of Bahia. In recent years, output from Goiás has drastically slowed as the depths required have made commercial mining unprofitable. In Bahia, most of the production is in the vicinity of Campo Formoso in the Carnaíba region, while in Minas Gerais exploitation is run by the company Belmont in Itabira and by a cooperative in the neighbouring town of Nova Era. The Itabira emerald belt also includes Conta Galo, São Domingues da Prata, Piteiras and Rocha. Emeralds from Minas Gerais are deemed to have a higher purity and clarity than those found in Bahia, which are typically a deeper green.

An emerald deposit was discovered relatively recently in the Rio Doce Valley of Minas Gerais. Located at the Itatiaia mine in Conselheiro Pena, the area is being explored by Geometa, a company based in Governador Valadares. Geologist Jurgen Schnellrath from the Mineral Technology Center (CTM) in Rio de Janeiro believes that higher quality emeralds might be produced as mining continues (J. Schnellrath, pers. comm., 2013; see also Schnellrath et al., 2013). Additional locations in Tocantins and Rio Grande do Norte States also host emerald deposits (Johnson and Koivula, 1998; Zwaan et al., 2012). Other areas previously claimed by locals to produce emeralds, such as in Malacacheta or Novo Cruzeiro, in reality do not. Specimens extracted from these areas are usually Cr/V deficient and therefore too light coloured to be considered emerald.

Other Beryls

Apart from emerald, beryl production is dominated by light to medium-dark blue aquamarine (e.g. Figure 11), of which Brazil may be one of the largest exporters. Historically, these gems came from deposits near Teófilo Otoni, within

Figure 9: The distribution of Brazil's current gem occurrences is shown in this map. Minas Gerais accounts for almost half of the deposits.

Table I: Current coloured stone deposits of Brazil.
Sources: DNPM (2013); locations not listed by DNPM (shown in italics) are documented by bibliographic references, and the ones underlined are sites visited by the author during fieldwork. Locations are listed by states (in capital letters) followed by municipalities. Not all of the deposits listed here are shown in Figure 9 due to lack of space.

Amazonite	BAHIA: Itiúba, Macarani MINAS GERAIS: *Araçuaí, Ferros, Jaguaraçu, Salinas, Santa Maria de Itabira*
Andalusite	ESPÍRITO SANTO: *Santa Teresa* MINAS GERAIS: *Araçuaí, Itinga, Malacacheta, Minas Novas*
Apatite	BAHIA: *Capim Grosso, Ipirá, Senhor do Bonfim* MINAS GERAIS: *Conselheiro Pena, São José da Safira* RIO GRANDE DO NORTE: *Equador, Parelhas*
Beryl (aquamarine, goshenite, heliodor, morganite)	BAHIA: *Alcobaça,* Anagé, Cândido Sales, *Caravelas,* Casa Nova, Encruzilhada, Eunápolis, *Guaratinga*, Ipirá, *Itamaraju*, Itambé, *Itanhém, Itapetinga,* Macarani, *Maiquinique,* Maraú, Pilão Arcado, Piripá, Sento Sé, Vitória da Conquista CEARÁ: Banabuiú, Independência, *Jaguaribe,* Milhã, Ocara, Russas, Solonópole ESPÍRITO SANTO: Afonso Cláudio, Água Doce do Norte, Aracruz, *Baixo Guandu,* Barra de São Francisco, *Castelo,* Domingos Martins, *Fundão,* Ibitirama, *Itaguaçu, Mimoso do Sul, Muqui,* Pancas, *Santa Teresa* GOIÁS: Campinaçu, Campinorte, Formoso, Minaçu MINAS GERAIS: Água Boa, Águas Formosas, Aimorés, Almenara, Alpercata, Alvarenga, Antônio Dias, Araçaí, Araçuaí, Aricanduva, Ataléia, Barão de Cocais, Barão de Monte Alto, Bom Jesus do Amparo, Capelinha, Caraí, Carangola, Caratinga, Cataguases, Catuji, Chapada do Norte, Cipotânea, Conceição do Mato Dentro, Conselheiro Pena, Cordisburgo, Coronel Murta, Dionísio, Divino, Divino das Laranjeiras, Dom Silvério, Espera Feliz, Ferros, Franciscópolis, Frei Inocêncio, Galiléia, Goiabeira, Governador Valadares, Inhapim, Ipanema, Itabira, Itaipé, Itanhomi, Itaobim, Itinga, Jampruca, Jenipapo de Minas, *Jequitinhonha,* Joaíma, Jordânia, Malacacheta, Marilac, Marliéria, *Mata Verde,* Mathias Lobato, Medina, Mendes Pimentel, Minas Novas, Muriaé, Nanuque, Ninheira, Nova Era, Novo Cruzeiro, Novo Oriente de Minas, Padre Paraíso, Pavão, Peçanha, *Pedra Azul,* Piranga, Pocrane, Poté, Raul Soares, Resplendor, Rubelita, Sabinópolis, Salinas, Santa Bárbara do Leste, Santa Maria de Itabira, Santa Maria do Suaçuí, Santa Rita de Minas, Santana do Paraíso, Santo Antônio do Itambé, São Domingos do Prata, São Geraldo do Baixio, São Gonçalo do Rio Abaixo, São José da Safira, São José do Mantimento, São Sebastião do Maranhão, Serro, Simonésia, Sobrália, Tarumirim, Teófilo Otoni, Virgem da Lapa PARAÍBA: Alagoa Grande, Alagoa Nova, Areia, Assunção, Barra de Santa Rosa, Bom Jesus, Cacimbas, Cajazeiras, Juazeirinho, Junco do Seridó, Pedra Lavrada, Picuí, Santa Cruz, Santa Luzia, São Francisco, São José de Espinharas, São José dos Cordeiros, *São Mamede,* Seridó, *Serra Branca,* Sossêgo, Sumé, Taperoá PERNAMBUCO: Dormentes, Santa Cruz do Capibaribe, Santa Filomena PIAUÍ: Betânia do Piauí RIO DE JANEIRO: Laje do Muriaé RIO GRANDE DO NORTE: *Acari,* Caiçara do Rio do Vento, Carnaúba dos Dantas, Cerro Corá, Currais Novos, *Equador,* Jardim de Angicos, Jardim do Seridó, Lagoa Nova, Lajes, Lajes Pintadas, Luís Gomes, Parelhas, Santana do Matos, *São João do Sabugi,* São Tomé, Tenente Ananias TOCANTINS: Barrolândia, Jaú do Tocantins, Monte Santo do Tocantins, Palmeirópolis, Presidente Kennedy, São Salvador do Tocantins
Beryl (emerald)	BAHIA: Anagé, *Brumado,* Campo Formoso, Mirangaba, Pilão Arcado, Pindobaçu, Saúde, *Vitória da Conquista* GOIÁS: Campos Verdes, *Pirenópolis,* Santa Terezinha de Goiás MINAS GERAIS: *Água Boa,* Antônio Dias, Bela Vista de Minas, *Conselheiro Pena,* Ferros, Itabira, Nova Era, São Domingos do Prata PARAÍBA: Juazeirinho, Salgadinho RIO GRANDE DO NORTE: Caiçara do Rio do Vento, Lajes, São Tomé TOCANTINS: Monte Santo do Tocantins, *Paraíso do Tocantins,* Presidente Kennedy
Brazilianite	MINAS GERAIS: *Divino das Laranjeiras, Itinga*
Calcite	RIO GRANDE DO NORTE: *Currais Novos* RIO GRANDE DO SUL: Ametista do Sul, Cristal do Sul, Frederico Westphalen, Iraí, Planalto, Rodeio Bonito, Trindade do Sul

Chrysoberyl	BAHIA: *Alcobaça, Caravelas, Encruzilhada, Guaratinga, Itamaraju, Mucuri, Pindobaçu, Prado, Teixeira de Freitas* ESPÍRITO SANTO: *Colatina, Cachoeiro do Itapemirim, Itaguaçu, Pancas, Santa Teresa, Sooretama* MINAS GERAIS: *Araçuaí, Caraí, Catuji, Itabira, Itambacuri, Jequitinhonha, Malacacheta, Minas Novas,* Padre Paraíso, *Pavão, Serro, Teófilo Otoni* SÃO PAULO: *Itapecerica da Serra, Patrocínio Paulista*
Chrysoberyl (alexandrite)	BAHIA: *Campo Formoso, Guaratinga* GOIÁS: *Minaçu* MINAS GERAIS: Antônio Dias, Ladainha, Malacacheta, *Manhuaçu,* Nova Era, Santa Maria de Itabira, Setubinha PERNAMBUCO: Ouricuri, Santa Filomena
Columbite	BAHIA: *Encruzilhada, Itambé* PARÁ: Óbidos, Oriximiná RONDÔNIA: Itapuã do Oeste
Cordierite (iolite)	BAHIA: *Nova Itarana, Teixeira de Freitas*
Corundum (ruby)	BAHIA: *Ponto Novo*
Corundum (sapphire)	BAHIA: *Itaetê* MINAS GERAIS: Canápolis, *Caratinga,* Ituiutaba, Ladainha, *Malacacheta, Manhuaçu* PARANÁ: Congonhinhas, Ibaiti, Tibagi
Diopside	BAHIA: Castro Alves, Ipirá, Rafael Jambeiro, Santa Teresinha MINAS GERAIS: Capelinha PARANÁ: Cerro Azul, Doutor Ulysses, Jaguariaíva, Sengés
Euclase	BAHIA: *Vitória da Conquista* ESPÍRITO SANTO: *Cachoeiro de Itapemirim* MINAS GERAIS: *Conseilheiro Pena, Ouro Preto, Santa Maria de Itabira, São Sebastião do Maranhão* RIO GRANDE DO NORTE: *Carnaúba dos Dantas, Equador, Parelhas*
Garnet (almandine, pyrope, spessartine)	BAHIA: *Andaraí,* Caetité, *Curaçá,* Casa Nova, *Itambé, Mucugê, Vitória da Conquista* CEARÁ: Banabuiú, *Orós, Quixeramobim, Solonópole* ESPÍRITO SANTO: *Colatina, Guarapari, Santa Teresa* GOIÁS: Ipameri MINAS GERAIS: *Barbacena, Conceição do Mato Dentro,* Conselheiro Pena, *Galiléia, Governador Valadares, Itamarandiba, Resplendor, Santa Maria do Suaçui,* São José da Safira, Tarumirim, *Viçosa* PARAÍBA: Frei Martinho, *Pedra Branca,* Pedra Lavrada, *Santa Luzia, Seridó* RIO GRANDE DO NORTE: *Acari,* Carnaúba dos Dantas, *Currais Novos, Jardim do Seridó, Parelhas, São João do Sabugi, Várzea* TOCANTINS: Peixe, Pindorama do Tocantins, São Salvador do Tocantins, São Valério da Natividade
Kyanite	MINAS GERAIS: *Coronel Murta,* Frei Lagonegro, Itamarandiba, São Sebastião do Maranhão
Opal	CEARÁ: Várzea Alegre PARÁ: *São Geraldo do Araguaia* PIAUÍ: Buriti dos Montes, Pedro II RONDÔNIA: Machadinho d'Oeste RIO GRANDE DO SUL: Estrela Velha, Fontoura Xavier, Lagoão, Salto do Jacuí
Quartz (agate, chalcedony)	MARANHÃO: São João dos Patos PARÁ: São Félix do Xingu RIO GRANDE DO SUL: Ametista do Sul, Boqueirão do Leão, Ciríaco, Cristal do Sul, Espumoso, Estrela Velha, Frederico Westphalen, Iraí, Júlio de Castilhos, Lagoão, Nova Prata, Planalto, Pinhal da Serra, Progresso, Rodeio Bonito, Salto do Jacuí, Santana do Livramento, Segredo, Soledade, Trindade do Sul
Quartz (amethyst, citrine)	AMAZONAS: Japurá, Lábrea, Novo Aripuanã, Presidente Figueiredo BAHIA: Botuporã, Caetité, Casa Nova, Condeúba, Gentio do Ouro, Ibiassucê, *Itambé, Jacobina, Licínio de Almeida, Livramento de Nossa Senhora,* Presidente Jânio Quadros, Sento Sé

Quartz (amethyst, citrine) (continued)	CEARÁ: Banabuiú, Beberibe, Crateús, Deputado Irapuan Pinheiro, Milhã, Novo Oriente, Piquet Carneiro, Quixeramobim GOIÁS: Cavalcante, Crixás, Nova Iguaçu de Goiás, Uruaçu MATO GROSSO DO SUL: Bodoquena, Corumbá MATO GROSSO: Aripuanã MINAS GERAIS: *Araçuaí,* Araporã, *Ataléia, Coronel Murta, Divino das Laranjeiras, Galiléia, Itinga, Montezuma, Ouro Verde de Minas,* Palma, Recreio, *São Geraldo do Baixio, São Miguel do Anta,* Senhora do Porto, Tupaciguara PARÁ: Almeirim, Aveiro, Brasil Novo, Marabá, Medicilândia PARAÍBA: *Santana da Mangueira, Juazeirinho* PARANÁ: Chopinzinho, Clevelândia, Coronel Vivida, São João, São Jorge d'Oeste PIAUÍ: Cocal RIO GRANDE DO SUL: *Alpestre,* Ametista do Sul, Barros Cassal, Boqueirão do Leão, Caxias do Sul, Coqueiro Baixo, Cristal do Sul, Espumoso, Estrela Velha, Fontoura Xavier, Frederico Westphalen, *Gramado dos Loureiros,* Guaporé, Iraí, Júlio de Castilhos, Lagoão, Nova Boa Vista, Nova Bréscia, Nova Prata, Pinhal da Serra, Planalto, Pouso Novo, Progresso, Putinga, Relvado, Rodeio Bonito, Salto do Jacuí, Santana do Livramento, São José do Herval, São Martinho da Serra, Segredo, Soledade, Trindade do Sul RONDÔNIA: Campo Novo de Rondônia, Costa Marques, Ji-Paraná, Nova Mamoré, Porto Velho RORAIMA: Amajari SÃO PAULO: Santo Antônio do Jardim TOCANTINS: Chapada da Natividade, Gurupi
Quartz (rose quartz, smoky quartz, rock crystal)	BAHIA: Belo Campo, *Boninal,* Brotas de Macaúbas, *Brumado, Caetité, Campo Formoso,* Casa Nova, Condeúba, Contendas do Sincorá, *Encruzilhada,* Ibipitanga, *Ibitiara,* Ibotirama, Ipirá, Ipupiara, Itaju do Colônia, *Itambé,* Ituaçu, *Livramento de Nossa Senhora,* Macarani, *Maiquinique,* Novo Horizonte, Oliveira dos Brejinhos, Paramirim, Pau Brasil, Piripá, Rio do Pires, *Saude,* Sento Sé, Tanhaçu, *Vitória da Conquista* CEARÁ: Acopiara, *Alto Santo,* Banabuiú, *Beberibe,* Cariús, *Crateús,* Deputado Irapuan Pinheiro, *Independência,* Itapiúna, Milhã, *Morada Nova, Nova Olinda, Novo Oriente,* Parambu, Piquet Carneiro, Quixeramobim, *Santa Quitéria, Solonópole,* Tamboril, Várzea Alegre ESPÍRITO SANTO: Afonso Cláudio, Água Doce do Norte, Barra de São Francisco, João Neiva, Santa Leopoldina, Santa Teresa GOIÁS: Campinaçu, Cristalina, Monte Alegre de Goiás, Niquelândia, Nova Roma, Teresina de Goiás, Trombas MATO GROSSO: Cuiabá, Nova Monte Verde, Poconé, Várzea Grande MINAS GERAIS: Açucena, Água Boa, Águas Formosas, Aimorés, Almenara, Alpercata, Alvarenga, Araçuaí, Araguari, Araporã, Aricanduva, Ataléia, Bandeira, Barão de Monte Alto, Belmiro Braga, Bocaiúva, Botumirim, Buenópolis, Capelinha, Caraí, Caratinga, Carbonita, Carmésia, Catuji, Chapada do Norte, Cláudio, Conceição do Mato Dentro, Congonhas do Norte, Conselheiro Pena, *Corinto,* Coroaci, Coronel Murta, Couto de Magalhães de Minas, Crisólita, Curvelo, Diamantina, Divino das Laranjeiras, Dom Joaquim, Entre Folhas, Espera Feliz, Ferros, Formiga, Francisco Dumont, Francisco Sá, Franciscópolis, Frei Inocêncio, Fronteira, Galiléia, Gouveia, Governador Valadares, Inhapim, Itaipé, Itamarandiba, Itambacuri, Itanhomi, Itaobim, Itinga, Jampruca, Jenipapo de Minas, Jequitaí, Joaíma, Jordânia, Ladainha, Limeira do Oeste, Malacacheta, Mata Verde, Mathias Lobato, Matias Barbosa, Mendes Pimentel, Minas Novas, Monte Alegre de Minas, *Montes Claros,* Muriaé, Nacip Raydan, Nanuque, Naque, Nova Era, Nova Módica, Nova Serrana, Novo Cruzeiro, Novo Oriente de Minas, Padre Paraíso, Patrocínio do Muriaé, Pavão, Peçanha, Periquito, Poté, Presidente Kubitschek, Raul Soares, Resplendor, Rubelita, Sabinópolis, Salinas, Santa Maria de Itabira, Santa Maria do Suaçuí, Santa Rita de Jacutinga,Santa Rita de Minas, Santana do Paraíso, São Domingos do Prata, São Félix de Minas, São Geraldo do Baixio, São João da Lagoa, *São João do Paraíso,* São José da Safira, São Sebastião do Maranhão, Senador Modestino Gonçalves, Senhora do Porto, Setubinha, Sobrália, Tarumirim, Teófilo Otoni, Tupaciguara, Uberlândia, Vargem Alegre, Virgem da Lapa, Virgolândia PARÁ: Eldorado dos Carajás, Marabá, São João do Araguaia PARAÍBA: Assunção, Barra de Santa Rosa, Bom Jesus, Cabaceiras, Cacimbas, Cajazeiras, Junco do Seridó, Monteiro, Pedra Lavrada, Santa Cruz, São Francisco, São João do Cariri, Sossêgo, Sumé, Taperoá PARANÁ: Chopinzinho RIO GRANDE DO NORTE: *Carnaúba dos Dantas, Equador*, Parelhas, São Miguel

Quartz (rose quartz, smoky quartz, rock crystal) (continued)	RIO GRANDE DO SUL: Barros Cassal, Boqueirão do Leão, Caxias do Sul, Ciríaco, Espumoso, Estrela Velha, Fontoura Xavier, Jacuizinho, Júlio de Castilhos, Lagoão, Nova Prata, Pinhal da Serra, Progresso, Putinga, Salto do Jacuí, Santana do Livramento, Segredo, Soledade RONDÔNIA: *Ji-Paraná*, Machadinho d'Oeste SÃO PAULO: Icém, Itariri TOCANTINS: Cristalândia, Dueré, Peixe, Pequizeiro, Pindorama do Tocantins, Santa Rita do Tocantins
Rhodonite	BAHIA: *Encruzilhada, Urandi* MINAS GERAIS: *Conselheiro Lafaiete*
Spodumene (hiddenite, kunzite)	MINAS GERAIS: *Araçuaí*, Conselheiro Pena, *Galiléia*, *Novo Cruzeiro, Resplendor*
Tantalite	AMAPÁ: Mazagão, Pedra Branca do Amapari, Porto Grande, Serra do Navio CEARÁ: Banabuiú PARAÍBA: Frei Martinho, Juazeirinho, Nova Palmeira, Picuí, Seridó
Titanite (sphene)	MINAS GERAIS: Capelinha
Topaz	AMAZONAS: Lábrea, Manicoré BAHIA: *Belmonte, Itambé, Vitória da Conquista* ESPÍRITO SANTO: *Mimoso do Sul* MINAS GERAIS: *Araçuaí, Caraí,* Catuji, Galiléia, Goiabeira, *Itabira,* Itaipé, *Itinga, Medina,* Nova Era, Novo Oriente de Minas, Ouro Branco, Ouro Preto, Padre Paraíso, Pavão, *Pedra Azul, Salinas,* São Domingos do Prata, Teófilo Otoni, *Virgem de Lapa* RONDÔNIA: Alto Paraíso, Ariquemes, Itapuã do Oeste, Monte Negro, Porto Velho, Rio Crespo
Tourmaline	BAHIA: Brumado, Condeúba, *Encruzilhada,* Macarani, *Maiquinique,* Nordestina, Queimadas, *Vitória da Conquista* CEARÁ: Apuiarés, Banabuiú, *Canindé, Itapiúna,* Jaguaretama, Milhã, Quixeramobim, Solonópole ESPÍRITO SANTO: Água Doce do Norte, Barra de São Francisco, Ecoporanga, *Mimoso do Sul* GOIÁS: Campinaçu, Montividiu do Norte MATO GROSSO: Alta Floresta, Castanheira, Colniza, Cotriguaçu MINAS GERAIS: Açucena, Água Boa, Águas Formosas, Aimorés, Almenara, Alpercata, Alvarenga, Araçuaí, Aricanduva, Ataléia, Bandeira, Barão de Monte Alto, Bela Vista de Minas, Capelinha, Caraí, Caratinga, Catuji, Chapada do Norte, Conselheiro Pena, Coroaci, Coronel Murta, Crisólita, Divino das Laranjeiras, Entre Folhas, Francisco Sá, Franciscópolis, Frei Inocêncio, Galiléia, Goiabeira, Governador Valadares, Inhapim, Itambacuri, Itanhomi, Itaobim, Itinga, Jampruca, Jenipapo de Minas, Joaíma, Jordânia, Ladainha, Malacacheta, *Mantena, Marilac,* Mata Verde, Mathias Lobato, Mendes Pimentel, Minas Novas, Muriaé, Nacip Raydan, Nanuque, Naque, Ninheira, Nova Era, Nova Módica, Novo Cruzeiro, Novo Oriente de Minas, Padre Paraíso, Patrocínio do Muriaé, Pavão, Peçanha, Periquito, Poté, Raul Soares, Resplendor, Rubelita, Sabinópolis, Salinas, Santa Maria do Suaçuí, Santa Rita de Minas, Santana do Paraíso, São Félix de Minas, São Geraldo do Baixio, São José da Safira, São Sebastião do Maranhão, Setubinha, Sobrália, Tarumirim, Teófilo Otoni, Vargem Alegre, Virgem da Lapa, Virgolândia PARAÍBA: Assunção, Barra de Santa Rosa, Cacimbas, *Frei Martinho*, Juazeirinho, Junco do Seridó, *Pedra Lavrada*, Salgadinho, Santa Cruz, Santa Luzia, São Francisco, São José do Sabugi, São José dos Cordeiros, Sumé, Taperoá, RIO GRANDE DO NORTE: Currais Novos, Equador, Parelhas, Santana do Seridó, São Tomé, *Tenente Ananias* RONDÔNIA: Porto Velho TOCANTINS: Chapada da Natividade, Jaú do Tocantins, Monte Santo do Tocantins, Palmeirópolis, São Salvador do Tocantins

the Marambaia Valley in the Padre Paraíso, Caraí and Catuji areas. Aquamarine production subsequently extended north toward Medina and Pedra Azul, and further east into Bahia and Espírito Santo States, as well as close to the Minas Gerais border. Other sites can be found in various regions around the country, especially within Tenente Ananias in Rio Grande do Norte, but as indicated by data from DNPM and local travelling gem brokers around the country, there are many additional deposits to be explored throughout the north-eastern region.

Other Brazilian beryls include heliodor from Padre Paraíso, morganite from around Araçuaí

Figure 12: This suite of morganite (16.69–22.22 ct) was cut from Brazilian rough. The gems were fashioned into various custom cuts, including (from upper left to lower right) Concave, Super Trillion, Deep Concave and StarBrite. Courtesy of John Dyer; composite photo by Ozzie Campos.

and in São José da Safira (Figure 12), and greenish and brownish beryl, also found in quantity in the north-eastern part of Minas Gerais.

Tourmaline

Brazil is one of the most important world producers of tourmaline, although in some recent years it has become more difficult to find on the market, as Chinese brokers have purchased it in large quantities. Prices escalated significantly in 2012–2014 in response to Chinese demand, which reduced the supply. However, since 2015 Chinese demand for all kinds of gems has dropped dramatically, which has considerably reduced the price of tourmaline to near-historic levels. Deep blue tourmaline can be found near Governador Valadares, while black tourmaline is very common in many areas. Green and multicoloured (e.g. Figure 13) specimens are available from Itambacuri and elsewhere. The Cruzeiro mine, located in São José da Safira, claims to be the major producer of pink-to-red tourmaline (Figure 14; Douglas Neves, pers. comm., 2013). Other important sources are found near Conselheiro Pena and in the region from Araçuaí to Coronel Murta (Barra de Salinas district) in the far north of Minas Gerais. There are also various tourmaline deposits still underexploited in the states of Rio Grande do Norte and Paraíba. Production of the famous 'neon'-coloured Paraíba tourmaline has dwindled in recent years.

Figure 13: This large colour-zoned tourmaline from Brazil weighs 144.75 ct. Courtesy of Paul Wild; photo by Jordan Wilkins.

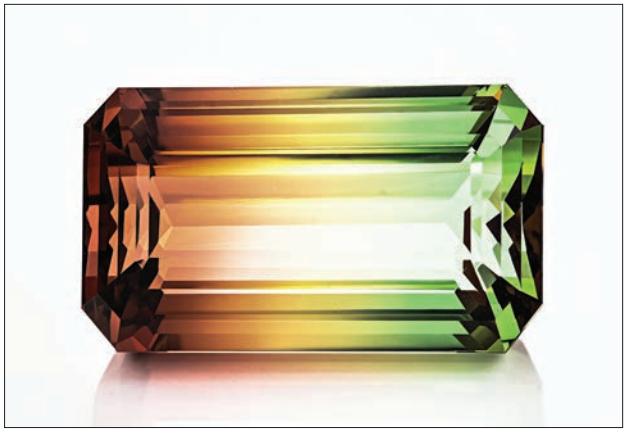

Figure 14: The Cruzeiro mine in Minas Gerais is known for producing fine pink-to-red tourmaline, such as this 9.00 ct rubellite. Courtesy of E. Schneider; photo by Jeff Scovil.

Quartz Gems

China has created strong demand for quartz for the past decade, and Chinese buyers have established a presence near the main extraction areas in order to have first choice of the rough material. Stunning crystal clusters appreciated by collectors come from hydrothermal veins found in the Curvelo and Corinto areas of Minas Gerais. Rose quartz is found in pegmatites in the north-eastern part of Minas Gerais, most notably at Itinga and Joaíma, but also in central Bahia, where huge smoky quartz crystals also occur. Rutilated quartz also has been produced (Figure 15), mainly in the Novo Horizonte District of Bahia State, which formerly belonged to the Ibitiara municipality.

Quartz deposits also are worked in the far south of the country, primarily in Rio Grande do Sul. Huge amethyst geodes and most of the agates of the country have been mined in abundance in the interior of this state; these deposits have been worked for more than 150 years. Amethyst also is produced elsewhere throughout Brazil. The Brejinho das Ametistas District in the Caetité municipality of Bahia and the Marabá site near the historic gold mine of Serra Pelada in Pará State are both significant sources. Other sites exist where gem exploration otherwise is negligible, such as in Rondônia and Ceará States. Citrine is found in Rio Grande do Sul and around Araçuaí, but it is mainly brownish yellow (Figure 16); material from Bahia usually has a lighter yellowish colour. However, most of the citrine produced and exported from Brazil is actually heat-treated amethyst.

Figure 15: An attractive radiating pattern is displayed by this Brazilian rutilated quartz cabochon, which measures 26 × 30 mm and weighs 34.35 ct. Photo by Jeff Scovil.

Topaz

Brazil accounts for much of the world's topaz production. Most is colourless or tinged very light blue, and laboratory irradiation creates the bright blue colour appreciated by jewellers (Figure 17).

Figure 16: Brazil is a significant source of citrine, as shown here from left to right by a 10.20 ct Super Trillion cut, a 34.42 ct StarBrite cut and 25.16 ct StarBrite cut. Courtesy of John Dyer; composite photo by Ozzie Campos.

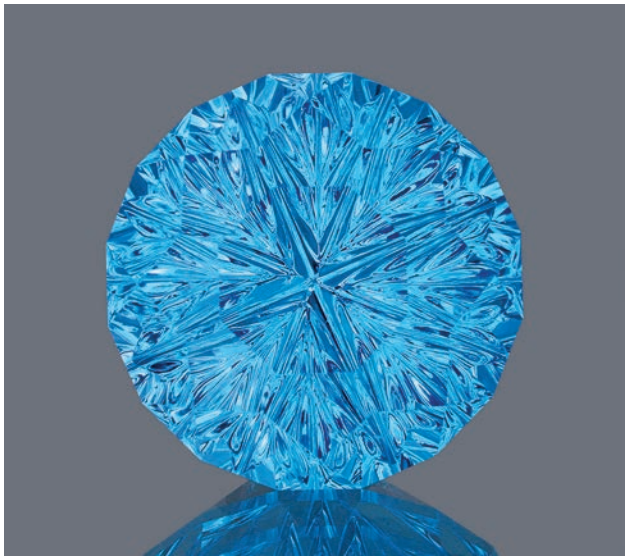

Figure 17: The colour of this Swiss Blue topaz (13.73 ct, StarBrite cut) was produced by laboratory irradiation, using colourless or pale blue starting material from Brazil. Courtesy of John Dyer; photo by Ozzie Campos.

Figure 18: Brazilian Imperial topaz is appreciated for its orange to orangey pink colour. This orange pear-shaped gemstone weighs 25.47 ct. Courtesy of Paul Wild.

Colourless topaz comes mainly from the northern region of Teófilo Otoni, but an increasing supply comes from further north-west, from both sides of the border between Amazonas and Rondônia States. The rare and famous orange to orangey pink Imperial topaz is still being produced from the Capão, Vermelhão and Antônio Pereira mines, as from other deposits near Ouro Preto in Minas Gerais, although production is greatly diminished and good-quality material (e.g. Figure 18) is particularly scarce on the local market.

Chrysoberyl and Alexandrite

Chrysoberyl production seems to have seriously declined during the past decade and, as a consequence, good-quality material has become harder to find locally. Most production of chrysoberyl is still located in Minas Gerais and Bahia; the Padre Paraíso deposit in Minas Gerais was recently explored by a company based in Teófilo Otoni. Other sites are usually found near established emerald-extraction areas. Alexandrite production from Malacacheta has slowed during the last few years, as the greater depths required have made it a risky investment. Campo Formoso in Bahia and Hematita in the Antônio Dias municipality of Minas Gerais are still producing small quantities of alexandrite, with most of the output from the latter being exported to Asia.

Other Gems

Many other gems and minerals are found throughout Brazil, and Minas Gerais hosts the greatest diversity of them. Kunzite is found in the Conselheiro Pena and Galiléia regions. Production of brazilianite continues in Divino das Laranjeiras and Itinga, although the material is becoming harder to find on the local market. Additional mining activity is taking place for sphene (titanite) in the municipality of Capelinha; andalusite at Itinga, near Araçuaí; and rhodonite at Conselheiro Lafaiete. Iolite, blue apatite and amazonite are all found in Bahia, while green diopside comes from Rio Grande do Sul.

Conclusion

Coloured stones (e.g. Figure 19) have been mined for centuries in Brazil, and significant changes have recently affected the national industry, as the vast majority of gems extracted are directly exported abroad. New relationships with international partners, economic growth and improved living conditions in Brazilian rural areas have led to an evolution of the workforce, which is becoming less interested in and reliant upon mining via illicit operations.

Nevertheless, official data show that Brazilian gem exports remain robust (AliceWeb, 2016; UN ComTrade, 2016), although this might also be due to more mines becoming legalized and

Figure 19: This gold necklace features a 2.11 ct tourmaline from Minas Gerais. Courtesy of Beau Soleil; photo by Jeff Scovil.

the higher prices for gem material, rather than greater production. Progressively, gem mining in Brazil is seeing a shift toward bigger and more professional companies, and a national gem and jewellery industry strategy is being developed with the help of public and private institutions (Pobozzon Palma et al., 2014; Lourenção and Giraldi, 2015). Furthermore, the quantity of mining areas remains substantial and, probably, to a large extent underexplored. Yet the future of the Brazilian gem industry may not be determined by geological factors. Rather it may depend more on social issues, global market trends and an ability to establish efficient trade relationships.

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Radiocarbon Age Dating of 1,000-Year-Old Pearls from the Cirebon Shipwreck (Java, Indonesia)

Michael S. Krzemnicki, Laurent E. Cartier and Irka Hajdas

The 10th-century Cirebon shipwreck was discovered in 2003 in Indonesian waters. The excavation yielded an incredible array of archaeological finds, which included pearls and jewellery. Radiocarbon dating of the pearls agrees with the age of the shipwreck, which previously was inferred using recovered coins and ceramics. As such, these are some of the oldest pearls ever to be discovered. Based on this example, the present article shows how radiocarbon age dating can be adapted to the testing of historic pearls. The authors have further developed their sampling method so that radiocarbon age dating can be considered quasi-non-destructive, which is particularly important for future studies on pearls (and other biogenic gem materials) of significance to archaeology and cultural heritage.

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Introduction

The discovery of the Cirebon (or Nan-Han) shipwreck in the Java Sea in 2003 marks one of the most important archaeological finds in Southeast Asia in recent years (Hall, 2010; Liebner, 2014; Stargardt, 2014). Apart from ceramics, glassware and Chinese coins dating from the 10th century AD, the excavation of this ancient merchant vessel also produced a number of carved gastropod shells (presumably ritual objects, from *Turbinella pyrum*), jewellery (e.g. earrings with diamonds and sapphires), loose gemstones (e.g. sapphires, red garnet beads and rock crystal carvings) and a rather large number of small pearls (Tan, 2007; Liebner, 2010, 2014; Henricus, 2014). Of the more than 12,000 pearls that were recovered, most were less than a few millimetres in diameter (e.g. Figure 1).

Fishermen discovered the wreckage site accidentally in 2003, at depths greater than 50 m (Liebner, 2010) off the northern coast of Java, Indonesia, near the city of Cirebon (Figure 2). Excavation efforts were complicated due to legal uncertainties as to which companies/entities should be permitted to excavate the site, unfortunately leading to a period in which looting of the wreck occurred. Administrative, legal and diplomatic problems pertaining to the excavation, storage and ownership of recovered items continued in the following years (Tjoa-Bonatz, 2016).

The exact route of the ship is still disputed in academic circles (Liebner, 2014), but there is ample evidence of strong trading ties between China and western Asia, which are supported by shipping routes along the Strait of Malacca between the Malay Peninsula and the Indonesian

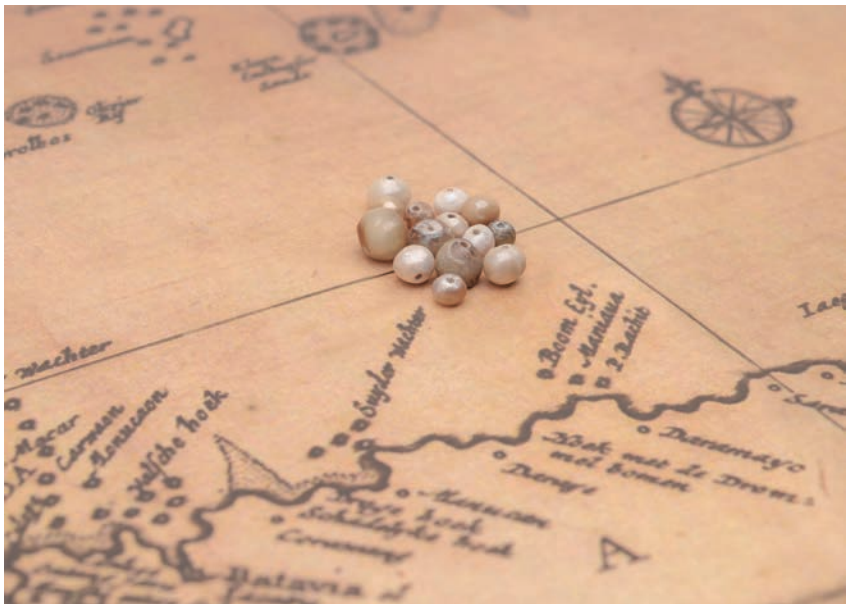

Figure 1: A small selection of pearls (approximately 2–8 mm diameter) from the Cirebon shipwreck was investigated for this study. The pearls are shown on a historic map of the Java Sea, where the shipwreck was discovered. Photo by Luc Phan, SSEF.

island of Sumatra in the 8th–10th century AD (Stargardt, 2014; Manguin, 2017; Shen, 2017). The recovery and study of artefacts from the Cirebon shipwreck offer a rare glimpse into trading practices of that period. It is thought that the trade in Yue ceramics (Chinese stoneware) peaked in the 10th century (Liebner, 2010), and they were a major export commodity during the Tang dynasty (Flecker, 2000). The form and decorations (including motifs) on Yue ceramics recovered from the wreck suggest a 10th-century period of manufacture and are complemented by potters' marks indicating 968 AD (Liebner, 2014). Furthermore, of nearly 5,000 individual coins recovered from the Cirebon shipwreck, eight were identified as "*Zhou Yuan tong bao*, a 955/6 issue by Shizong, emperor of the Later Zhou, mainly fashioned from confiscated 'Buddhist statuary of bronze [that] was mandated for recasting as coin' (Ouyang 2004: 115)" (Liebner, 2014, p. 197). Therefore, the coins and other recovered artefacts provided good evidence for a 10th-century age of the shipwreck. This time period corresponds to an era of upheaval in China called the 'Five Dynasties and Ten Kingdoms' during approximately 907–960 AD (Lorge, 2011); it was preceded by the Tang dynasty and succeeded by the Song dynasty (960–1127 AD). The pearls dated in this article yield further evidence documenting the 10th-century age of the shipwreck, and this provides an opportunity to better understand the rich history of this period in time.

Figure 2: The 10th-century Cirebon shipwreck is situated in the Java Sea, north of the city of Cirebon on the island of Java. The yellow areas correspond to Indonesia.

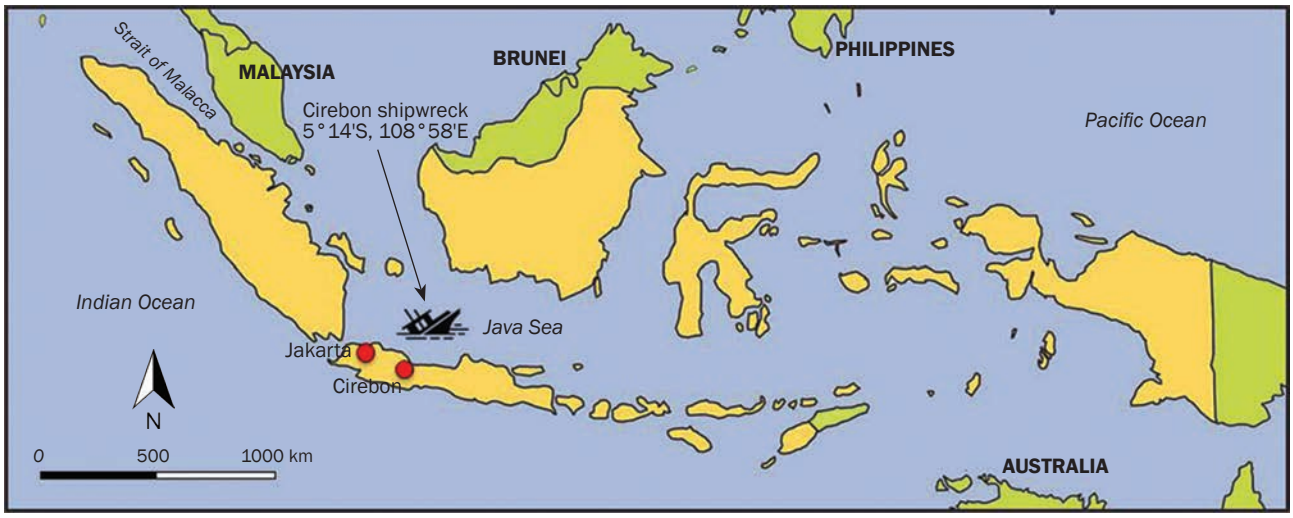

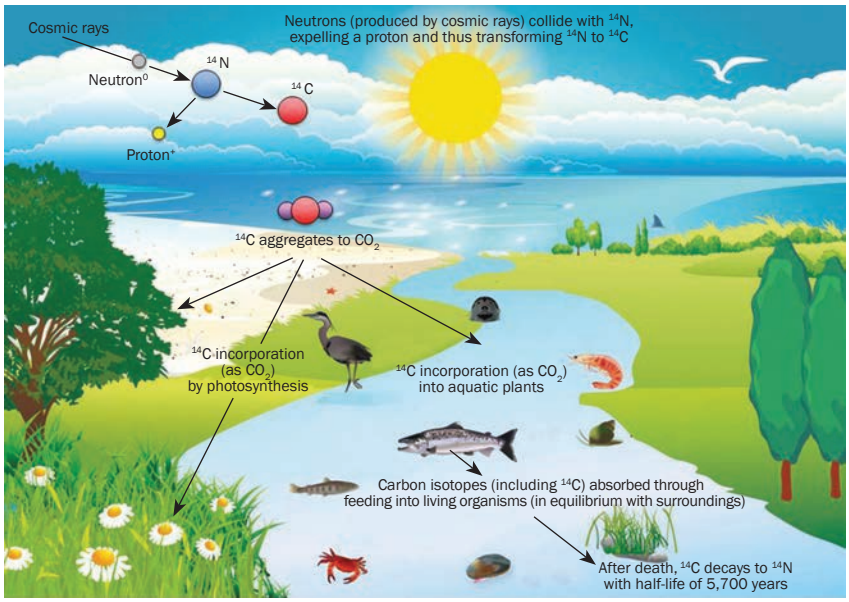

Figure 3: As shown in this schematic diagram of the radiocarbon cycle, radiogenic ^{14}C is produced in the atmosphere by the collision of high-speed neutrons (produced by cosmic radiation) with nitrogen (^{14}N). The traces of ^{14}C are in-corporated into carbon dioxide, which is assimilated into plants by photosynthesis and into animals (e.g. shells of molluscs) via respiratory and metabolic pathways. After death, the lifelong exchange of carbon with the environment suddenly stops, resulting in slow radioactive decay of ^{14}C, making it possible to determine the age of materials by radiocarbon dating. Illustration by M. S. Krzemnicki, using an artwork template from Inland Fisheries Ireland (www.somethingfishy.ie/resources/image_resources/image_estuary_food_web.jpg).

So far, the world's oldest dated pearl was recovered in the Middle East, and the stratigraphic layer in which it was found was attributed by Charpentier et al. (2012) to be around 7,500 years old. Szabo et al. (2015) dated the material surrounding a pearl found in Australia to more than 2,000 years old. In both cases, the pearl itself was not dated, and in recent years there have been only a few studies on radiocarbon age dating of historic pearls. For example, Krzemnicki and Hajdas (2013) performed age dating on historic and modern pearls. Recently, Zhou et al. (2017) obtained radiocarbon ages in the 16th century for pearls that reportedly came from the Venezuelan island of Cubagua in the Caribbean Sea, which supported the pre- to early Columbian era assumed for these pearls. Advances in testing and future archaeological finds will contribute to this area of pearl research by providing further evidence for the fishing and trade of pearls since ancient times in diverse regions of the globe (Kunz and Stevenson, 1908; Donkin, 1998).

Radiocarbon Age Dating

The underlying principle of the radiocarbon method is the constant production of radiogenic ^{14}C in the atmosphere by the interaction of secondary cosmic rays with nitrogen. The collision of high-speed neutrons produced by cosmic radiation with the nucleus of nitrogen results in the capture of a neutron and the expulsion of a proton, thus transforming the ^{14}N isotope into the radionuclide ^{14}C. The radiocarbon, present only in trace amounts in the atmosphere (about 1 atom per 1,012 atoms of carbon) combines with atmospheric oxygen and forms radioactive carbon dioxide (Figure 3), which is then incorporated into plants by photosynthesis and subsequently into animals via respiratory and metabolic pathways (Bowman, 1990; McConnaughey et al., 1997; Hajdas, 2008). As a consequence, the radiogenic ^{14}C is incorporated into the endo- or exoskeletons (e.g. bones or shell structures) of animals (Hajdas, 2008; Douka et al., 2010).

After death, the lifelong exchange of carbon with the environment suddenly stops, resulting in a slow radioactive decay of ^{14}C in the dead plants and animals. By measuring the ratio of radiogenic and stable carbon isotopes ($^{14}C/^{12}C$), it is thus possible to determine their age. The so-called half-life of ^{14}C (that is, the time at which only half of the original ^{14}C still is present in a sample and, as such, represents the constant rate of decay over time) is about 5,700 ± 40 years (Godwin, 1962). As a consequence, the maximum age dating reliably possible with this method is up to approximately 50,000 years before present (BP).

The radiocarbon age dating method, first described by Nobel laureate Willard Libby in the 1940s (Libby, 1946; Arnold and Libby, 1949) has been applied since then as a standard tool in numerous scientific disciplines and has gained much interest of the public, especially in relation with archaeological studies of Egyptian pharaohs and the prehistoric mummy 'Ötzi' from Austria (Bonani et al., 1994). Although it is applicable to only a very short period in geological terms, the

Figure 4: These 14 pearl samples (71742_A–N; approximately 2–8 mm diameter) from the Cirebon shipwreck were examined for this study. They are partially abraded around their drill holes and show some brown to grey colour alterations. Photo by Luc Phan, SSEF.

method has proven quite useful for dating organic matter (trees, tissues, etc.) and carbonaceous materials such as charcoal and biomineralization products, including corals (Adkins et al., 2002), shells (Berger et al., 1966; Hänni, 2008; Douka et al., 2010; Hainschwang et al., 2010) and pearls (Krzemnicki et al., 2009; Krzemnicki and Hajdas, 2013; Zhou et al., 2017).

A pearl is a calcium carbonate ($CaCO_3$) concretion formed by biomineralization processes in a mollusc—very much the same processes as for shell (exoskeleton) formation. As such, pearls (and shells) contain carbon, mainly the stable isotope ^{12}C (as well as ^{13}C) but also a small fraction of radiogenic ^{14}C. The carbon used for the biomineralization of pearls and shells mainly originates from two very different carbon pools: (1) oceanic dissolved inorganic carbon; and (2) respiratory CO_2, mainly stemming from food metabolism (Tanaka et al., 1986; Gillikin et al., 2007; Douka et al., 2010). As such, the so-called marine reservoir age effect may distinctly affect the resulting ^{14}C ages of shells and pearls, especially in areas with upwelling of 'old' water. Hence, a correction is required to take into account the geographic location of the sample. For a more detailed discussion of this issue, see Rick et al. (2005), McConnaughey and Gillikin (2008), Douka et al. (2010), Krzemnicki and Hajdas (2013) and references therein.

Samples and Methods

For this study, we investigated 14 pearls (nos. 71742_A–71742_N) from the Cirebon shipwreck (Figures 1 and 4) that weighed 0.14–0.85 ct and measured approximately 2–8 mm in diameter. They were round to button-shaped and baroque, and all showed a drill hole, indicating that they were originally at least partially strung on strands. This is further supported by the presence of abrasion marks around the drill holes, characteristic for pearls strung tightly in a row. The colour of the pearls ranged from white to light cream, some with brownish and greyish alterations (Figure 4) presumably due to oxidation of adjacent metallic material. Even after a prolonged period on the ocean floor, most of the pearls showed at least partially a soft nacreous lustre with some white dull weathered spots and patches.

All 14 pearls were analysed routinely by X-radiography (Faxitron unit) and X-ray luminescence (cf. Hänni et al., 2005), as well as by energy-dispersive X-ray fluorescence spectroscopy using a Thermo Quant'X instrument. We then selected four pearls (71742_A, B, I and J) for X-ray computed microtomography (micro-CT) analysis using a Scanco µCT-40 scanner. For radiocarbon age dating, we chose the three smallest pearls (71742_L, M and N). From each sample, ~8 mg of calcium carbonate was extracted either by abrading or chipping off nacre fragments from the pearls, which was facilitated by their slightly altered surface condition. However, based on this and more recent experiments, we now can perform quasi-non-destructive radiocarbon age dating with as little as ~2 mg (0.01 ct) of nacre taken from the drill hole, thus not affecting the outer surface of the pearl (Krzemnicki, 2017).

The calcium carbonate samples were washed in ultrapure water and leached to remove the surface layers (Hajdas et al., 2004). After the leaching of about 20% (by weight) of the original sample, approximately 6.4 mg of pearl material was placed in a gas bench tube and flushed with a flow of helium gas, then dissolved in concentrated phos-

Table I: Results of ^{14}C analyses of three saltwater pearls from the Cirebon shipwreck in the Java Sea.[a]

Sample	^{14}C age (BP, ±1σ)	$\delta^{13}C$ (‰)[b]	$F^{14}C$ (±1σ)[c]	Calendar age (calAD)	
				68.2% prob.	95.4% prob.
71742_L	1,529 ± 25	–0.7 ± 1.0	0.8267 ± 0.0026	878–1042	780–1130
71742_M	1,493 ± 25	–1.9 ± 1.0	0.8304 ± 0.0026	902–1072	816–1170
71742_N	1,508 ± 25	–3.2 ± 1.0	0.8288 ± 0.0026	894–1058	804–1156

[a] Abbreviations: BP = before present; prob. = probability.
[b] The isotopic signature $\delta^{13}C$ is a measure of the ratio of stable isotopes $^{13}C/^{12}C$, and is reported in parts per thousand (per mil, ‰).
[c] The fraction of modern radiocarbon ($F^{14}C$) is the conventional way of displaying the so-called 'bomb peak' in a radiocarbon vs. known age diagram for post-1955 events.

phoric acid (85%) and transferred to a graphitization system (Wacker et al., 2013). The graphite was then pressed into targets (cathodes), and the $^{14}C/^{12}C$ ratio was measured using the Mini Carbon Dating System (MICADAS; see Synal et al., 2007) at the Swiss Federal Institute of Technology, ETH Zürich, Switzerland. This optimized accelerator mass spectrometer (AMS) is characterized by a high yield and superior stability, thus enabling radiocarbon measurements at highest precision. Different from other mass spectrometer designs, the ions formed in the AMS ion source are negative, thereby filtering out ^{14}N, which is an isobar of ^{14}C. Then the ions are accelerated, reaching very high kinetic energies and resulting in a high resolving power for separating a rare isotope from an abundant neighbouring mass, such as ^{14}C from ^{12}C. Moreover, a suppression of molecular isobars (e.g. ^{13}CH and $^{12}CH_2$) is achieved by passing the beam through a stripper gas. Finally, the ^{14}C atoms are detected by a gas ionization system (Synal et al., 2007).

After correction for blank values and fractionation ($\delta^{13}C$), the measured $^{14}C/^{12}C$ concentration was used to calculate conventional ^{14}C ages (Stuiver and Polach, 2016). For all samples, the calculated ^{14}C age BP was corrected by applying a marine reservoir correction (delta R = 89 ± 70) that was based on values for the Java Sea location (Reimer and Reimer, 2001, and references therein). These were estimated (weighted mean) based on 10 data points in the vicinity of the sampling site. The corrected ^{14}C ages were then calibrated using the Marine13 curve of Reimer et al. (2013).

Results and Discussion

Based on their X-radiographs, trace-element composition (cf. Gutmannsbauer and Hänni, 1994) and lack of luminescence to X-rays (cf. Hänni et al., 2005), the samples studied for this report were all saltwater natural pearls. The radiography and micro-CT scans (on pearls 71742_A, B, I and J) further revealed that their internal structure mainly consisted of fine ring structures typical of natural pearls.

Table I summarizes the results of radiocarbon age dating of the three pearls (71742_L, M and N). They all show very consistent ^{14}C ages and similar calibrated ages of 780–1170 AD (95.4% probability) or 878–1072 AD (68.2% probability) using the Marine13 curve (Reimer et al., 2013; Figures 5 and 6). The more precise mean value of 1,510 ± 15 BP results in a calendar age of 806–1151 AD (Figure 7). This relatively wide range in calendar age is due to uncertainty for the reservoir age correction.

The calculated age of the pearls, corresponding approximately to the end of the 10th century, correlates well with the age stipulated for the coins, pottery and other artefacts found in the shipwreck (Liebner, 2014). It places the sinking of the historic merchant vessel at the time of upheaval in China

Figure 5: The three investigated pearls (71742_L, M and N) from the Cirebon shipwreck all show very similar calibrated ages corresponding to the late 10th century AD. The bracketed ranges represent 68.2% and 95.4% probabilities for the pearls' ages.

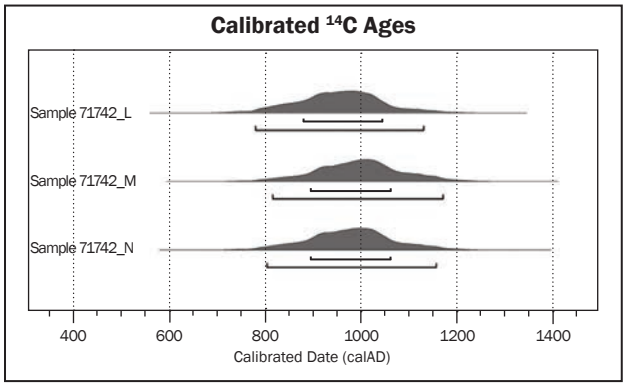

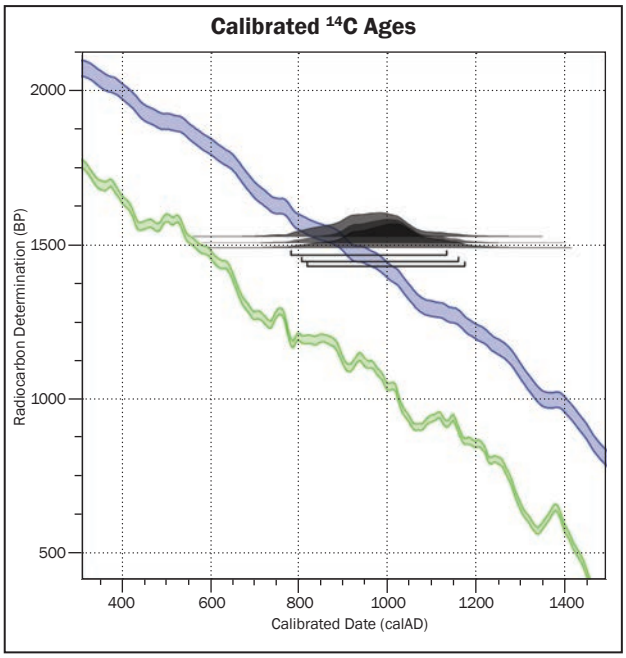

Figure 6: The calibrated ages of the three investigated pearls from the Cirebon shipwreck were derived from the radiocarbon ages using OxCal 4.2 software (Ramsey and Lee, 2013). The purple band is the marine calibration curve (Marine13, Reimer et al., 2013), and the green band is the atmospheric curve (IntCal13, Reimer et al., 2013).

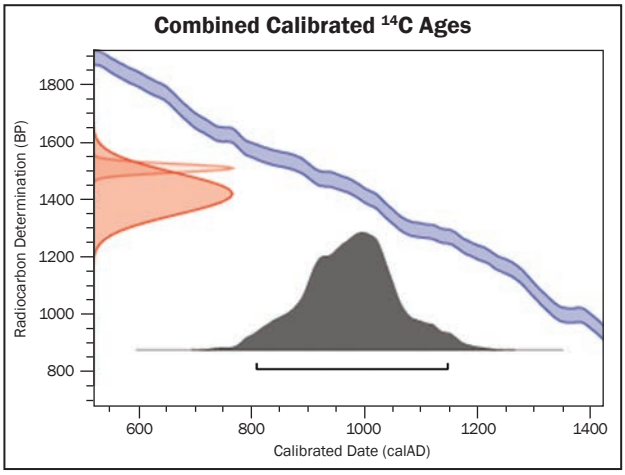

Figure 7: The combined calibrated ages obtained from the three Cirebon pearls yield a range of 806–1151 AD at 95.4% probability. The red peaks represent the uncalibrated radiocarbon age (as measured and corrected for regional reservoir age) and the dark grey peak shows the distribution of calendar ages.

called the 'Five Dynasties and Ten Kingdoms' (ca. 907–960 AD), which was also a time of extensive maritime trade in Southeast Asia.

These pearls likely originated from the Persian Gulf or the Gulf of Mannar (between India and Sri Lanka), both known since ancient times as sources of saltwater natural pearls (from *Pinctada radiata*; see Hornell, 1905; Carter, 2005). This assumption is mostly related to their size, bearing in mind that other molluscs also produced (larger) nacreous pearls during the same period (e.g. *P. margaritifera* in the Red Sea and *P. maxima* in Southeast Asia; Southgate and Lucas, 2008). The thousands of glass fragments and several unbroken blue and green glass objects found in the Cirebon shipwreck undoubtedly originated from the Islamic Middle East (present day Iran or Iraq and Syria; H. Bari, pers. comm., 2017). This indicates extensive trade in Southeast Asia along maritime routes (or a 'maritime silk route') at that time (Liebner, 2014; Manguin, 2017), of which the Cirebon merchant vessel was a part. This also supports a Persian Gulf origin for the pearls (H. Bari, pers. comm., 2017).

The partly abraded and brown-to-grey alterations around the drill holes of these pearls (Figure 8) suggest that they might have been in use for some time, strung on strands or set with metal linings in jewellery before they sank in the vessel with the rest of its cargo, including Sri Lankan sapphires (Henricus, 2014) and other gems (e.g. red garnet and quartz) of probable Sri Lankan, East African or Malagasy origin (H. Bari, pers. comm., 2017).

Figure 8: Pearl 71742_A (0.85 ct) shows brownish colour alteration around its drill hole (visible on the right side), as would be expected from a setting with a metal lining that has oxidized. The abrasion features adjacent to the drill hole are consistent with wear marks commonly encountered on pearls that are tightly strung on wire or fibre strands. Photo by M. S. Krzemnicki, SSEF.

Conclusions

This study is the first to document radiocarbon age dating, along with gemmological testing, carried out directly on historic pearls dating back to the 10th century. Previous research on historic pearls, including the 2,000-year-old Brremangurey pearl from Western Australia (Szabo et al., 2015) or the 7,500-year-old Umm al-Quwain pearl from UAE (Charpentier et al., 2012), derived their ages by using associated materials found at the archaeological sites, rather than directly dating the pearls themselves.

By using the highly sensitive MICADAS system at the Ion Beam Physics Laboratory at ETH Zürich, it was possible to analyse very minute portions of the Cirebon pearls. The radiometric age dating of the three samples gave homogeneous results corresponding approximately to the end of the 10th century, closely matching the age stipulated for the shipwreck based on Chinese pottery and coins.

This study, and further age-dating experiments on pearls, also have resulted in a refined sampling process that allows us to work with tiny amounts of nacre powder (~2 mg) taken from the drill hole without any damage to the outer surface of a pearl. Thus, radiocarbon age dating can be considered a quasi-non-destructive test when following our sampling protocol. This has opened up new possibilities for research on historical biogenic objects and artefacts of significance to archaeology and cultural heritage.

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Naming of the Koh-i-Noor and the Origin of Mughal-Cut Diamonds

Anna Malecka

For centuries, the Koh-i-Noor, or Mountain of Light, has been a diamond of exceptional renown in the East as well as in the West. Several legends circulate regarding this stone, and among these are tales of its origin and the way it received its name. This article attempts to verify the authenticity of these accounts and shows that the true origin of the diamond's name is connected to its appearance achieved through the faceting style known today as the Mughal cut. Although the provenance of this cut has thus far not been determined, this article proposes that it possibly originated in the 16th century in Goa, India, through the Gujaratis and under the influence of European diamond cutters. Various lines of evidence suggest that the Koh-i-Noor may have been worked in the 16th century by an Indian specialist in the Vijayanagara Empire.

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Introduction

One of the world's most famous diamonds is the Koh-i-Noor, or *Mountain of Light* as it translates from Persian, the language of the Mughal court. The diamond originated in the treasury of the Great Mughals, and is currently mounted in the crown of the Queen Mother (wife of George VI and mother of Elizabeth II), which is kept in the Tower of London. It has the form of an oval brilliant and weighs 102.8125 English carats or 105.59 metric carats (Tennant, 1854b). The original Mughal-cut stone (cf. Figure 1) weighed 589.82 troy grains, corresponding to 186.0625 English carats, which is equivalent to about 191.09 metric carats (Tennant, 1854b; Story-Maskelyne, 1860) or 191.03 ct (Carriere and Sucher, 2008). It reached the United Kingdom in 1850 from India, where it was confiscated by the British from the last maharaja of the Sikh Empire, Dulip Singh (r. 1843–1849). For more background on this important stone, see Mīrzā ʿAṭā Muḥammad (1952–1953 (AH 1331), Bukhārī (1958 [AH 1337]), Howarth (1980), Gill (1982), Amini (1994), ʿAyn al-Salṭanah, (1995–2000), Shirazi and Muḥaddiṯ (2000) and Dalrymple and Anand (2016).

Several legends have circulated on the topic of the Koh-i-Noor, including a commonly cited story of how its name originated. According to contemporary gem writers, its name was assigned in Delhi, at the court of the Mughal emperor Muhammad Shah (r. 1719–1748); the person instrumental in giving the stone its name was the king of Iran, Nadir Shah (r. 1736–1747). The Shah of Persia invaded the Mughal capital in March 1739, after the battle at Karnal in which he overpowered the Indian armies. Although Nadir Shah did not deprive Muhammad Shah of the throne, he also did not refrain from confiscating his legendary treasures (Astarabadi and Rashad, 1994). The conqueror's interest was piqued by the huge diamond in the Mughal emperor's possession. The existence of this gem was told to the invader, it is said, by a woman from the Mughal's harem.

She was said to have revealed that her lord had a habit of carrying the stone in the folds of his turban. In order to take the gem while maintaining the appearance of respect for the conquered royal, Nadir Shah developed a ploy in which he proposed to the Indian emperor an exchange of headdresses, which symbolized friendship. The Mughal could do nothing else but hand over his turban, which contained the gem inside. Upon seeing its glow, Nadir Shah exclaimed "Koh-i-Noor", thus giving the diamond its name (Streeter, 1882; Amini, 1994; Balfour, 2009).

Although the authenticity of this legend has recently been questioned (Dalrymple and Anand, 2016), contemporary writers have not researched, to the present author's knowledge, the true origin of the name *Koh-i-Noor*.[1] In the present author's view, the name refers to the appearance of the diamond's faceting style, known today as the Mughal cut. Based on the analysis of gemmological material, researchers do not state unequivocally if this cut, widespread in Indian territory, was indigenous or created under Western influence. This article analyses primary literature sources from the 15th to the 17th centuries, as well as iconographic material, to investigate this matter and the validity of the stories about the naming of the Koh-i-Noor.

Figure 1: This glass replica of the Koh-i-Noor diamond, as it appeared when it reached Great Britain in 1850, resides at the Corning Museum of Glass in Corning, New York, USA. It was made in 1851 by Falcon Glassworks of Apsley Pellatt & Co., London. More information is available at www.cmog.org/artwork/replica-koh-i-noor-diamond; courtesy of the Corning Museum of Glass.

Investigating the Tale of Koh-i-Noor's Name

The meeting of Nadir Shah and the defeated Mughal emperor did in fact take place, and the conqueror of Delhi did receive diamonds at that time (Malecka, in preparation). Analysis of sources from the epoch, however, indicates that the Koh-i-Noor could not have been one of them (Anonymous, 1866–1867 [AH 1283]). According to Nadir Shah's chronicler, a diamond called the Koh-i-Noor was indeed among jewels confiscated by his lord from the Mughal emperor, but it had been placed in the famous Peacock Throne of the Mughals—and not in the folds of the monarch's turban—as a decoration on the head of the eponymous bird adorning it. The historiographer of the king of Iran is a credible source, in the present author's view, because he saw the Peacock Throne in the Afghan city of Herat, to which it was transported from Delhi upon the order of the conqueror (Marvī et al., 1991; see also Tihrani and Sha'bāni, 1990 [AH 1369]). Since it follows that the name *Koh-i-Noor* already was used in the Mughal court in reference to this diamond, the name could not have been assigned by Nadir Shah.

How, then, did the story arise that Nadir Shah conferred the name on this diamond? None of the Persian sources from the time of Nadir Shah, to the present author's knowledge, cite this story. It appeared for the first time in the tale of the Koh-i-Noor written in 1850 by Theophilus Metcalfe, a functionary of the East India Company who, upon the order of the Governor-General of India, gathered stories circulating in Delhi on

[1] An author from the Indian subcontinent who was active at the end of the 19th century stated, without justifying his opinion, that the episode wherein the Koh-i-Noor was gained by exchange of turbans was untrue (Latif, 1956).

the topic of this stone (Singh and Singh, 1985; Kinsey, 2012; Dalrymple and Anand, 2016).[2] Metcalfe's report was not published. In printed form, one of the earliest English-language publications of this story was the catalogue of the Great Exhibition of 1851, at which the Mountain of Light was presented to the public (Ellis, 1851).

It also should be mentioned that, with regard to the Koh-i-Noor, the tale of the exchange of turbans did appear in Persian-language sources, but for a different owner of the stone: Ranjit Singh, the father of Dulip Singh. In 1813, this monarch forced the ex-king of Afghanistan, Shah Shuja Durrani, who at that time possessed the stone, to surrender it in order to close an agreement of friendship with him. To seal this pact, as Durrani himself affirmed in his memoirs, Ranjit Singh exchanged headdresses with him, and after this ceremony came the presentation of the stone (Shuja Shah, 1914/1915 [AH 1333]).

It is probable that this event had an impact on the development of the story about the acquisition of the Koh-i-Noor by Nadir Shah. It should be emphasized, however, that tales of the exchange of headdresses as a means to swindle gems had been circulating in India in earlier times. For example, a 19th-century researcher mentioned, on the basis of unpublished family annals of the rulers of the Chota Nagpur in India, that a similar event had taken place in 1772 (Dalton, 1872). According to this account, a British officer wished to acquire diamonds that the rajah of Chota Nagpur carried in his turban, and proposed to the ruler the exchange of headdresses as a gesture of eternal friendship, claiming this custom also was practised in Great Britain.

It should be underlined that the authors who saw the Koh-i-Noor in the court of Ranjit Singh do not refer to exchanging headdresses while mentioning its acquisition by Nadir Shah (Osborne, 1840; Hügel, 1848). It seems that this story gained popularity in the 1840s, both as a result of the wheedling tales that circulated in India during the Mughal epoch, as well as the actual turban exchange that accompanied the earlier transfer of the Koh-i-Noor in 1813.

Connection Between the Koh-i-Noor's Name and Its Appearance

Researchers have been unable to explain how the Koh-i-Noor was originally included among the several hundred large diamonds in the Mughal treasury that were confiscated by Nadir Shah. In the present author's view, the stone was already in the possession of these rulers in the 1500s. It is known that a diamond weighing about 190 ct had been the property of Emperor Akbar (r. 1556–1605; AMIDRF, 1740; Malecka, in preparation). Even though Akbar's stone was the only diamond of such weight in the possession of the Mughals mentioned in 16th-century sources, we cannot simply assume it to be identical with the Koh-i-Noor on the basis of its approximate weight.[3] A mention of its shape allows a greater probability of identifying it as the Koh-i-Noor. Akbar's diamond was described by an author from the epoch (Malecka, in preparation) as having the form of a pyramid, which does correspond to the shape of the original Koh-i-Noor (Figures 1 and 2, left). Considering such factors as weight, shape and Mughal provenance, the identification of Akbar's stone as the Koh-i-Noor seems justified.

It is probable that Akbar had obtained the stone from the Vijayanagara Empire (1336–1646) in the southern part of the Indian subcontinent, which abounded in diamond mines.[4] Sources from the turn of the 16th/17th centuries mention a diamond of fabulous value purchased by the Great Mughal from the ruler of Vijayanagara.[5] In the present author's opinion, it is probable that the Koh-i-Noor remained in the Mughal treasury continuously from around 1600 to 1739, when it was looted by Nadir Shah. This is supported by the fact that Jahangir (r. 1605–1627), the son of

[2] Mention of the mythical history of the Koh-i-Noor did, however, appear in the British press in earlier years (Anonymous, 1849).

[3] Sixteenth-century sources also mention the so-called Babur's diamond. Some contemporary authors infer it to be identical with the Koh-i-Noor on the basis of its alleged weight of about 186 carats (Beveridge, 1899). In reality, Babur's diamond weighed significantly less than the Koh-i-Noor, and most probably it also was a rough stone (Malecka, in preparation).

[4] After the battle at Talikota in 1565 between the Vijayanagara Empire and a coalition of Muslim kingdoms of the Deccan, the mines gradually passed under the rule of Golconda, contributing to building the fame of the sultanate as the global diamond capital at the time. The mines were famous for producing exceptionally large stones, as attested by the following comparison: In the Mughal Empire, rough stones weighing as little as 2.5 ct automatically passed to ownership by the emperor, while in Vijayanagara the weight of diamonds subject to the monopoly of the king was set above 20–30 ct (Orta, 1891; Lopes, 1897; Foster, 1921; Vassallo e Silva, 1989). See also footnote 12.

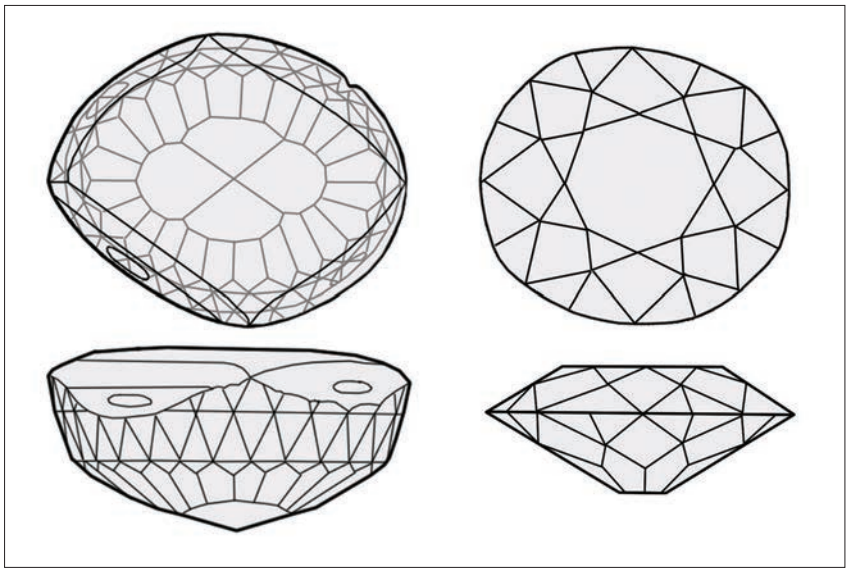

Figure 2: These line drawings prepared by Al Gilbertson compare the appearance of the Koh-i-Noor before (left) and after re-cutting (right) in 1852. The cuts are shown from the top and side views.

Akbar, was in possession of a diamond of similar weight (Malecka, in preparation).

The Koh-i-Noor was presumably wheel cut into a 169-facet stone measuring 40.85 × 32.57 × 16.18 mm (Carriere and Sucher, 2008).[6] It had a high-domed crown and flat base, with predominantly triangular and pentagonal facets (resembling rectangles with triangular pinnacles) covering its surface (Figure 2, left). It seems most probable that the Koh-i-Noor received its name because of the shape it was given during this 'rough fashioning', which was reminiscent of a mountain (Younghusband and Davenport, 1919).[7] It was common in the East to give names to gems that referred to their appearance, and particularly large stones were sometimes described as 'mountains'. Other important gems with names alluding to mountains include the Koh-i-Toor (or Sinai Mountain diamond), as well as al-Jabal (or Mountain), a huge red stone that was the property of the Abbasid caliphs (Ibn al-Zubayr et al., 1959; Ibn al-Athir, 1995; Malecka, in preparation). According to mistaken suppositions by some researchers, the full name of this last stone was Jabal al-Noor, or Mountain of Light, arising supposedly from translation of the Persian words *Koh-i-Noor* (Herzfeld, 1948). Islamic sources also mention other precious stones having the name of 'Mountain' (Farmān-Farmāyān, 1962; Malecka, in preparation).

The second part of the Koh-i-Noor's name has a connection to radiance. Names of large stones held by the Mughals often contained allusions to brilliance by including such words as *sun, moon* or *light* (Linschoten et al., 1885; Manucci and Irvine, 1907). Radiance was of key importance to the Islamic monarchy, because it was believed to embody the invisible perfection of God. Radiance attested to the connection between God and the ruler, who governed in His name on Earth (Bedik,

[5] A discussion of sources referring to this diamond is presented in Malecka (in preparation). Even though rulers in the East unwillingly parted with exceptional diamonds, a stone of 190 ct would certainly not have been deemed unique by Vijayanagara rulers, as their diamond treasury contained specimens weighing several hundreds of carats. In the 15th century, before the Mughal emperor Shah Jahan ordered construction of the Peacock Throne, similar fame was attributed in the East to the diamond throne of Vijayanagara, which was described as priceless (Sousa, 1666; Goes, 1749; Malecka, in preparation). It is probable that the reason the Koh-i-Noor (assuming it was identical to the diamond purchased from the Vijayanagara ruler) was sold to the Mughal was that it contained some blemishes (see below). It is known that Vijayanagara royals would sell large imperfect diamonds that they considered inauspicious (Malecka, 2018).

[6] Scott Sucher, an American cutter specializing in making replicas of historical stones on the basis of computer modelling, informed this author that analysis of a Koh-i-Noor model shows that it must have been wheel cut: "I can't imagine it being cut being hand-held. The laser scan data also supports this. There is facet rounding, as to be expected by the wheels of the time, but based on my best gem cutting experience (4+ decades), hand holding would have made the rounding far more pronounced."

[7] According to Metcalfe's unpublished report mentioned above, the stone was obtained thousands of years previously from the Koh-i-Noor mine, situated a four-day journey north-west from Masulipatnam, on the banks of the Godavari River (Dalrymple and Anand, 2016). However, this statement could not have been true. The Persian name would not have been used in reference to an ancient Indian mine; moreover, analysis of primary sources does not allow for the assumption that a mine had ever existed under this name.

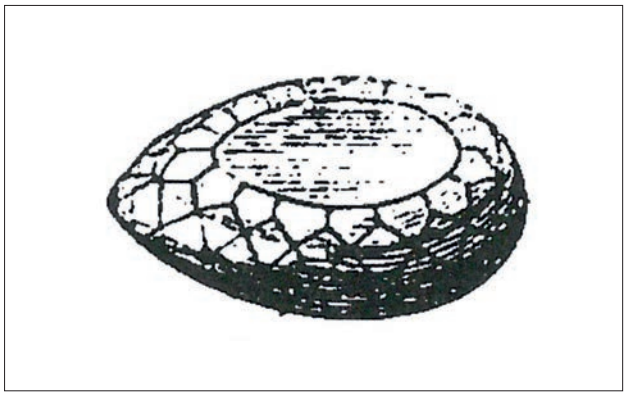

Figure 3: This illustration of a 'Flat Mughal'-cut diamond appears in various editions of Tavernier's 1692 Les Six Voyages..., *Vol. 2.*

1676; Termezi et al., 1971; Soudavar, 2003). In early Islamic texts, the pearl was the quintessence of lustre, but after the 15th century—most certainly related to popularization in the East of European-cut stones—its place in Muslim literature was taken over by diamonds (Dankoff, 1991; Malecka, in preparation).

The Koh-i-Noor owed its radiance to its facet arrangement, known today as the Mughal cut. This term was introduced in the 1960s for stones of "rather lumpy form with a broad, often asymmetrical base, an upper termination consisting of a set of usually shallow facets or a table, and two or more zones of strip facets parallel to the base and oriented vertically" (Tillander, 1995, p. 64; see also Waite, 1968). The Mughal cut occurred in two versions. As a rule, it was rather flat, with the table usually surrounded by a number of smaller facets. The other version was topped with several facets and usually covered by a large number of small facets. The present author refers to the first of these as 'Flat Mughals' (Figure 3) and the second as 'High Mughals'; the Koh-i-Noor is assigned to the latter (Figure 2).

Cutting History of the Koh-i-Noor

The original artisans who worked the Koh-i-Noor into the Mughal cut, as well as the place where the stone was cut and polished, are not known. In India, diamonds were worked by locals, as well as by European, Jewish and Armenian cutters, who were employed to fashion diamonds in the European way. During the 16th century, such European-cut stones reached prices several hundred percent higher on the Indian subcontinent than in the West, even compared to larger Mughal-cut diamonds (Malecka, in preparation). Given this, it seems likely that the expert who fashioned the Koh-i-Noor came from India.[8] According to a contemporary researcher whose analysis of a replica of the stone revealed that its facet corners met precisely at a point (Ogden, 2013), the Koh-i-Noor was polished with the greatest precision, so this specialist must have been a highly skilled professional. He also might have used a Western-type wheel in his work (Ogden, 2013).[9] As a rule, the most outstanding experts were employed for the royals. Assuming the Koh-i-Noor was the same as the diamond purchased by Akbar in Vijayanagara, it may have been fashioned in the 16th century in the large diamond centre of Vijayanagara by cutters and polishers working for the local ruler.

Mughal-cut diamonds were popular in India because this cut allowed for removal of small flaws, while retaining the greatest possible amount of material and simultaneously giving the diamond the desired brilliance (Haidar and Sardar, 2015). Due to high demand, on the Indian subcontinent such stones were the most expensive among the traditional cuts (Malecka, in preparation). However, this author has not found any evidence that diamonds of this cut were popular in the Near East where, as a rule, Western-cut stones were preferred (Malecka, in preparation; see also Bilirgen and Murat 2001). In the West, diamonds cut in this way were not considered worthy of attention until the second half of the 20th century. As a result, such diamonds were often either subjected to re-cutting upon their arrival in Europe or returned to India for sale (Burton, 1869; Hoey, 1880; Tillander, 1995).

[8] The widespread declaration that it was the Venetian Hortensio Borgio who worked the Mughal-cut diamond known as the Great Mughal is not true (Malecka, 2016).

[9] Even though precious stones were worked in India on wheels at the latest in the 13th–14th centuries, such equipment was not used that early for diamonds, for which polishing by hand was preferred (Malecka, in preparation). It is logical to assume that on the Indian subcontinent wheels were first applied to diamonds under Western influence, most certainly in the 16th century (see below). In contrast to Europe, where artisans used iron discs that did not need removal from the base, workers in 17th-century India used steel wheels that had to be taken off daily to be rubbed with emery. The result of these repeated relocations was the uneven run of the polishing tools, which made it impossible to produce diamonds with the high quality characteristic of Westerners' work (Tavernier, 1692). Such steel equipment was still in use by the Indians in the 19th century, although some used iron discs by that time (Newbold, 1843; Hoey, 1880).

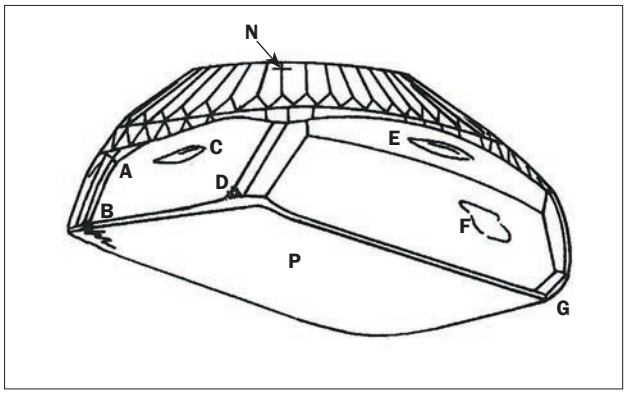

Figure 4: According to Tennant (1854a, p. 136), "The flaws in the Koh-i-noor are...F...a large cleavage plane, produced by a fracture...(that) had not been polished...A...a flaw...most skilfully ground nearly out before any of the facets were cut. This flaw seems to proceed from a fracture B...C and E were little notches cut...for the purpose of holding the diamond in its original setting...N, a small flaw...almost required a glass to see it...D, a fracture from a blow or fall, showing at its base a cleavage plane." Image from Tennant (1854a).

The Koh-i-Noor was received with just such disappointment in Great Britain (Hamlin, 1884). Although Hatleberg (2006) inferred that the Mughal-cut stone was actually a "very brilliant and highly dispersive" diamond, both the British royals and the public who viewed the Mountain of Light at the Great Exhibition of 1851 deemed it not radiant enough (Kinsey, 2009; Roberts, 2012), as they were accustomed to the appearance of brilliant-cut diamonds. In London, the Mughal way of working the diamond was described as so 'unskillfully executed that its appearance scarcely surpassed that of cut crystal'; other undesirable elements included its irregular egg form, 'grooves in the sides', and 'a small split near the top' (Figure 4; Anonymous, 1856, p. 221).[10]

To eliminate these flaws and make the diamond attractive to the Western public, the stone was re-faceted into a brilliant cut. This enhanced its brilliance, as reflected in its name 'Noor', but paradoxically it also lost its 'mountainous' shape (and 43% of its weight), thus making the name 'Koh' inappropriate (Hatleberg, 2006).

Indians' Views on Cutting Diamonds and Creation of the Mughal Cut

In literature on the subject, there is no conclusive answer to the question of whether the Mughal cut, as well as diamond cutting in general, were initiated in India independently or under Western influence (King, 1870; Tillander, 1995; Bari, 2001; Klein, 2005). Diamonds were worked on the subcontinent before the Europeans began to cut them towards the end of the 14th century (Tillander, 1995). However, this author could find no texts to support the assertion that these early Indian operations involved processes other than polishing, even though pre-Mughal sources report that hard stones were worked on the subcontinent with the use of various types of specialized tools (Malecka, in preparation). Since the value of diamonds depended on their weight, gem cutters of the Indian subcontinent were probably reluctant to radically diminish them (Malecka, in preparation).

The motivation for cutting diamonds in India was related to concerns about potentially breaking or damaging them. According to Hindu beliefs, gems that were broken, chipped, or had cavities and cracks, as well as those that were flawed or had a particularly coarse surface, were detrimental to the owner, and the amount paid for such stones was of course significantly lower than for good-quality specimens. Thus, the flaws were removed by polishing. Occasionally, this would make the edges of the diamonds less sharp or more even (Garbe, 1882; Varāhamihira and Ramakrishna Bhat, 1982; Shastri and Bhatt, 2008; Tiruttakkatevar and Ryan, 2012). However, at least until the 16th century, it seems that even diamonds without flaws but showing evidence of being worked (i.e. indications of their previous imperfections) brought a lower price in In-

[10] Scott Sucher, who analysed a plaster-cast model of the Koh-i-Noor, informed this author that the 'split near the top' could be one of several gashes 2–3 mm deep (three of which, in his view, were man-made) that were present on the stone (Figure 4). According to a British gem expert who examined the Koh-i-Noor in the middle of the 19th century, two of these cavities helped keep the stone in its setting (i.e. C and E in Figure 4; Tennant, 1854a; Malecka, 2018). Although they most certainly were used in this way, in the present author's view it is doubtful that in India an unblemished specimen would be purposefully defaced by engraving such cavities in it. (See below for the Indians' views on working diamonds.) According to traditional Indian criteria, such cavities would be counted among diamond flaws described as *gara* or holes on the surface, which could arise during the mining process or from removing inclusions that affected the price of a specimen to a greater degree than would the cavities (Tagore, 1879; Malecka, in preparation). Two of the Koh-i-Noor's cavities could have resulted from removing flaws, with both being worked in a similar orientation to provide the added benefit of being used to help keep the stone in its setting (Malecka, 2018; see also Brewster, 1863).

Figure 5: A faceting style reminiscent of the Mughal cut is displayed by the garnet in this 6th-century Byzantine ring. Photo © Les Enluminures.

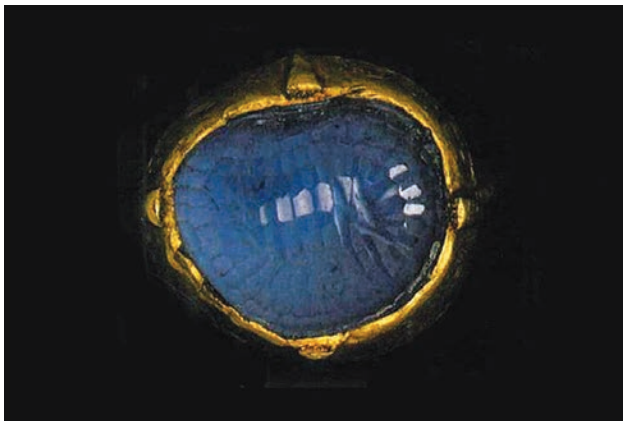

Figure 6: This Mamluk ring from the 13th–14th centuries is mounted with a sapphire cut in a style similar to the Mughal cut. Reproduced with permission from Content (1987); © Derek Content.

dia, and perhaps also in the Near East, than the unblemished, untouched-by-tradesmen rough termed 'virgins' (Linschoten et al., 1885; Shammā' and Tawfīq, 1999; Shcherbina, 2014).

Assuming the Koh-i-Noor was purchased in Vijayanagara by the Great Mughal, it is reasonable to conclude that diamonds were worked in the Mughal cut in India at the latest by the end of the 16th century. So if this cut had appeared on the Indian subcontinent at this time, what were the sources of its inspiration, and where was it most likely created?

In the Near East, cutting of minerals was deemed an Occidental art, at the latest in the 12th century. In a treatise on gems, and as part of a discussion of mounting diamonds in jewellery, an Iranian author of the time mentioned that cutting and polishing were practised in Europe, although exclusively on rubies and emeralds (Nīshābūrī, 2004). A gem expert active around the first quarter of the 16th century in Mughal India denounced the cutting of diamonds as an art of the "Franks" that "did not bring good results"; however, he also admitted that no one was more proficient in this trade than those "immoral infidels" (Rustamdari, 1852 [AH 1268]). A similar view also was held by an Arab gemmologist active at the turn of the 15th/16th centuries, as well as by a Persian-language author from the 15th century who nevertheless maintained that "within the last quarter of the century" it was the Europeans who had best mastered this art (Binesh, 1964; Shammā' and Tawfīq, 1999).

Such remarks suggest that, in the East in the 15th century, there were known 'Frankish' types of cuts. The table cut and the flat-bottomed Gothic rose cut were widespread in the West at that time, so it is logical to assume that remarks by the Eastern authors pertained to these cuts (Tillander, 1995). In the present author's view, it also is doubtful that diamonds cut by Westerners would be admired by Indian specialists if Mughal cuts were in use on the subcontinent before this time.

It should be noted that faceting styles reminiscent of the Mughal cut had been done on gems other than diamonds since ancient times. Examples of such stones include an early Byzantine garnet and several sapphires covered with numerous small facets, cavities or 'dimples' from about the 10th–14th centuries in India, Vietnam and Egypt (Content, 1987, 2016; Spier, 2012; see Figures 5 and 6). Similarly, as for the Mughal cuts, cavities covering most or all of their exposed surfaces were situated not merely to remove impurities, but also to show the gems to maximum advantage (Content, 2016). However, the present author has not found proof that this type of work—in the case of coloured stones, still appearing in India at least in the 17th century—constituted a direct inspiration for the creation of the Mughal cut for diamonds (Shcherbina, 2014).

In this author's view, the European cuts admired on the subcontinent were the direct inspiration for Mughal-cut diamonds. The earliest surviving examples this author has found of Mughal-cut diamonds in jewellery that can be dated come from the beginning of the 17th century, while in the West, diamonds reminiscent of the Flat Mughals were worked as early as the first quarter of the

16th century (Keene and Kaoukji, 2001).[11] One such stone decorates the hat ornament in a 1519 portrait of Anna Jagellonica (1503–1547), the wife of Holy Roman Emperor Ferdinand I Habsburg (Belozerskaya, 2005; see also Zimerman, 1887). Even though such diamonds theoretically could have had an impact on the origins of the Mughal cut, there is no evidence that they had reached the subcontinent by the early 1500s. Rather, it seems more likely that inspiration for Mughal-cut diamonds came from table- and rose-cut diamonds (see Tillander, 1995, and Galopim de Carvalho, 2014, for illustrations of these cuts). Such stones, including large exceptional ones, were available on the subcontinent at least by the first half of the 16th century; they were exported from Europe or fashioned locally by valued and usually well-paid Westerners (Castañeda, 1554; Vassallo e Silva, 1989; Malecka, in preparation). Among such experts were, for example, Francisco Pereira and Master Pedro, who were both present in the diamond-trading centre of Vijayanagara circa 1548 (Teles e Cunha, 2001).[12]

Most certainly at this time, Indian specialists already were engaged not only in polishing but also in cutting diamonds in Vijayanagara. A description of a mythical city patterned after the capital of the Vijayanagara Empire, written in about 1550 in the Canarese language, includes many gem traders active in its local bazaar, including diamond experts who had their own stalls, where they were engaged in polishing and cutting diamonds into various shapes and sizes (Dallapiccola, 2003). This text unfortunately does not contain information on whether the polishing and cutting were done by the same persons or, as was the case in the West, by different persons.

Evidence that Indians were engaged in diamond cutting under Western influence is found in a Portuguese treatise composed during about 1560–1580 or perhaps a bit earlier. The anonymous author of this work reported that "recently diamonds in India are worked as in our land" and added, in a tone of regret, that Indians "polish them in their own way" (Vassallo e Silva, 1989, p. 137). It is most probable that these remarks referred to early attempts at preparing the Mughal cut.[13] Information in the work of a Dutch author present on the subcontinent during 1583–1588 also must have pertained to Mughal-cut diamonds. He mentioned that diamonds prepared at that time in India were "pointed with three corners, h(e)arts, and such like sorts thereby to hide their fault()s…made in that sort to hold (their) greatness and w(e)ight" (Linschoten et al., 1885, p. 153).

Even though the Mughal cut was effective for retaining the greatest possible amount of the weight, early efforts to prepare such stones apparently were not especially successful, from the point of view of Indian market requirements. The author of the Portuguese treatise stated that, as a result of the Indians' actions, a rough stone would sometimes lose about 30% and even (as was often the case for Western cuts) 50% of its weight (Vassallo e Silva, 1989).[14]

Westerners considered such stones to be badly worked, having "too much thickness underneath" and undoubtedly requiring re-cutting, as both Portuguese and Dutch writers stated that it was not economical for Europeans to buy them (Lin-

[11] In the 17th century, Mughal-cut diamonds were especially favoured among Indian Muslims (Ovington, 1690). However, their popularity on the subcontinent started to decline in the 19th century, and by about 1950 finding buyers for Mughal cuts became difficult (Christie's, 1997; Malecka, in preparation).

[12] Vijayanagara was at that time one of the most important global centres of diamond trade, where stones from elsewhere in India were brought for sale. Other gems also were traded in this centre (Schurhammer and Voretzsch, 1928). For information on European diamond specialists working in Vijayanagara, see Kömmerling-Fitzler (1968).

[13] It is rather doubtful, in the present author's view, that cuts prepared then by the Indians were Western-style roses or tables. As mentioned earlier, the market for these unusually costly and exotic stones was not large on the subcontinent at that time; it was most certainly limited to court circles. The wealthy Indians preferred to import such stones from Europe, send rough to be worked in the West or take advantage of the services of European cutters active in India (Malecka, in preparation).

[14] Perhaps the initial attempts by the Indians at working diamonds were not very successful due not only to a lack of capability and proper equipment, but also to the scarcity of specialists with a distinct knowledge of cutting or polishing on the subcontinent. Islamic texts mention two terms describing gem workers: *hakkak*—now usually rendered as a gem engraver, lapidary, or polisher—and *tarash*, or cutter. In the present author's view, both terms could have been used interchangeably in historical texts as general descriptions of gem workers. The specialists themselves possibly used *hakkak* specifically for a polisher and *tarash* for a cutter, although the meaning of either term may differ depending on the region (Çelebi, 1896; Kāshānī and Afshār, 1966/1967 [AH 1345]).

schoten et al., 1885, p. 153; Vassallo e Silva, 1989). The Portuguese writer maintained that it was more beneficial to buy 'developed and cleaned' diamonds from 'Moors' (most probably Muslims active in India), whose stones could be recut without losing much of their weight. Such diamonds probably were already polished in the mining areas according to the Indian custom of removing flaws (Vassallo e Silva, 1989, pp. 136–137; Malecka, in preparation).

What factors contributed to the rise of the Mughal cut? It is known that in India, hundreds of years before Europeans arrived there, diamonds with smooth polished edges were popular and considered auspicious (Hultzsch et al., 1916; Malecka, in preparation). As a result of these polishing activities, specimens with big tables probably existed already, although surviving examples of such stones are impossible to date earlier than Mughal times (Ivanov et al., 1984; Keene and Kaoukji, 2001; Tān, 2002). Although pre-Mughal Indian diamond experts were probably familiar with diamonds with tables, we have no evidence to support the placement of triangular facets in a regular pattern around the tables prior to Western influence. On some Mughal-cut diamonds, the first row of facets around the table was composed of trapezoids or rectangles, possibly inspired by Western table cuts. In the case of the High Mughals, the table was replaced by a small number of facets, which brings to mind early rose cuts (Tillander, 1995). Of course, the final form of the stone was determined by several factors: size and shape of the rough, type and positioning of flaws and directional hardness anisotropy, which in consideration of the primitive tools used at the time, was the greatest challenge for the cutters (Hart, 2015).

The Mughal cut was considered to be a local, Indian version of the rose cut. Prior to the 20th century, Mughal-cut diamonds (now described simply as 'Indian' or 'worked on in India') were described in Europe as 'roses' or 'Indian roses' (Ujfalvy-Bourdon, 1885; Nasiri, 1945 [AH 1364]; Copeland, 1960; Rybakov, 1975; see also Tarshis, 2000). It should be mentioned that the Mughal cut had 'flowery' connotations on the subcontinent. In conversations with this author, Indian gem merchants described High Mughals with the term *kanwal*, which in the Hindustani language means 'water lily'.[15] In reference to Flat Mughals, the present author's interlocutors used the term *parab* ('flat diamond' in Hindustani; see also Bala Krishnan and Ramamrutham, 2001). In the literature, the stones described today as Mughal cuts appear under the names *villandi* or *bullandi* (Persian 'buland' or 'high'), as well as *polki*, which is also used on the subcontinent to refer to rose cuts (Untracht, 1997; Shcherbina, 2014; Shor, 2016). It is possible that the same terms were used in somewhat different ways for the various methods of working in different areas of the Indian subcontinent at varying times.

Determining where in India the Mughal cut could have originated is not an easy task. It most likely happened in one of the centres in which European gem experts stayed: the above-mentioned Vijayanagara; Calicut, in which gem experts from the West already were present at the end of the 15th century; Cochin, the main seat of Portuguese India in 1503–1530; or Goa, which was conquered by the Portuguese in 1510. Through this last city, Western goldsmithing techniques reached the subcontinent, imported by Europeans as well as by Indians who travelled to Lisbon as early as the first quarter of the 16th century (Alves, 1935; Matos, 1989; see also Pissurlencar, 1936). Western diamond cuts appeared in Goa as imports, and also through the actions of the European workers operating in this city, among whom the Flemish and Portuguese distinguished themselves (Linschoten et al., 1885; see also Vassallo e Silva, 1995, 2004). Given this, it is logical to assume that around the middle of the 16th century diamonds were worked in Goa. In the present author's view, it is most likely that Goa is where the Mughal cut was created, as an example of Indo-Western syncretism typical of the artistic creativity in that city.

It is tempting to suggest that the Indian community of diamond workers were instrumental to

[15] It is interesting that the term 'water lily diamonds' might have been used in other parts of the Islamic world to describe rose cuts. It is known, for example, that stones fashioned in the shape of a water lily were ordered in the 1660s from the Dutch by a certain Sumatran royal (Chijs, 1893). In the Malay world at that time, the rose cut was considered exotic and was ordered from Western cutters, so it is highly probable that those 'water lily diamonds' were the same as roses. Diamonds described as *nilüferi* or water lily also were mentioned in an Ottoman text (Malecka, in preparation).

the rise of the Mughal cut, and in the present author's view the most probable candidates are the Gujaratis who were present in Portuguese Goa in the 16th century. It is known that the Gujaratis, who had already played an important role in the diamond trade for many centuries, had been moving between Goa and the diamondiferous Deccan area during the Mughal era (Orta, 1891; Malecka, in preparation). In view of the Gujaratis' presence in this centre in which Europeans were active, it is possible that the experts belonging to this community created the Mughal cut, modelling on the work of their Western colleagues but bearing in mind the aesthetic and material needs of the Indians. The above-mentioned pentagonal facets, which resemble rectangles with triangular pinnacles, and gave the stone a flower-like appearance, evoke a motif known from 16th-century Gujarati decorative art: a central medallion surrounded by rectangular, sharply finished 'petals' (Vassallo e Silva, 2001).

Conclusion

Various versions of a story regarding Nadir Shah's acquisition of the Koh-i-Noor diamond and his naming of this stone gradually became established during the 19th century, in India as well as probably in Great Britain. The name *Koh-i-Noor*, in keeping with Eastern tradition, was directly related to the appearance of the stone (i.e. its radiance and shape), as displayed by its Mughal cutting style. Assuming the Koh-i-Noor to be Emperor Akbar's stone, it is logical to conclude that cutting and polishing of this diamond took place in the 16th century by an Indian specialist. It also is possible that the diamond was worked in the kingdom of Vijayanagara, where it might have originated.

In the present author's view, Mughal-cut diamonds appeared on the Indian subcontinent under the influence of European table and rose cuts. The Mughal cut was created most certainly before 1550, possibly in Goa through the Gujaratis. The largest market for diamonds worked in this way, at least prior to 1565, was probably Vijayanagara. This cutting style facilitated the removal of flaws that disfigured a diamond or made it susceptible to breakage, while simultaneously maintaining the greatest volume of material.

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Characterization of Mexican Amber from the Yi Kwan Tsang Collection

Vittoria L. Villani, Franca Caucia, Luigi Marinoni, Alberto Leone, Maura Brusoni, Riccardo Groppali, Federica Corana, Elena Ferrari and Cinzia Galli

Twenty-seven amber samples from an important collection of 115 specimens from Chiapas, Mexico, were subjected to gemmological analysis, microscopy of the inclusions (including taxonomic classification), infrared spectro-scopy, X-ray powder diffraction (XRD) and mass spectrometry. Some of the data were compared to those obtained from amber samples from the Baltic Sea and the Dominican Republic. All the ambers had the same RI (1.54), but the Mexican samples showed slightly lower SG values (1.03) than the Dominican (1.05) and Baltic (1.06) ones. Mexican amber is notable for hosting a large variety of beautiful organic inclusions, in particular flower petals and leaflets of the extinct species *Hymenaea mexicana*, as well as a planthopper of the extinct species *Nogodina chiapaneca*, which dates back to the Middle Miocene and has been found only in amber from Chiapas. XRD analysis of samples from all three localities showed the expected amorphous pattern accompanied by traces of refikite and hartite, as well as calcite in the Mexican samples. Infrared spectroscopy was useful for identifying amber from each of the three localities. Mass spectrometry of the Mexican (and Dominican) amber showed that it lacked succinic acid and can therefore be classified as a resinite of Class IC (i.e. resinites with ozic acid and/or zanzibaric acid derived from the *Hymenaea* genus).

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Introduction

Amber is like a screenshot of the past, when ecosystems were much different than presently known. A peculiarity of amber is that it may perfectly preserve an organism in its original life position. Amber is an amorphous and organic solid substance, characterized by a complex mixture of terpenoid compounds (aromatic hydrocarbons), alcohols, acids and water (Alekseeva and Samarina, 1966). It derives from fossilized resins produced by prehistoric trees, and is usually associated with coal or terrigenous deposits (Langenheim, 1966, 1969; Langenheim et al., 1967; Poinar, 1992; Rao et al., 2013). Such resins are produced by plants in response to certain circumstances, such as defence against insect pests or protection of wounds (Anderson and Crelling, 1995; Langenheim, 1995, 2003; Anderson, 1996).

The most important resin-producing plant families are classified among the gymnosperms (conifers) and the angiosperms (flowering plants). Conifers and their progenitors appeared earlier than angiosperms in the geological record (Hurd et al., 1962; Poinar, 1992; Anderson and Crelling, 1995; Poinar and Poinar, 1999).

Amber deposits are present worldwide; the oldest date back to the Carboniferous Period (~360–300 Ma [million years]; Grimaldi, 1996), but they still have not been investigated in detail. Important studied amber deposits (see Table I) date back to the Mesozoic Era—such as those from the Dolomites in Italy, Kachin and Magwe States in Myanmar, New Jersey in the USA and Manitoba in Canada—and also the Cenozoic Era—such as those from China, the Baltic Sea region, the Dominican Republic, Chiapas in Mexico and Sicily in Italy. The majority of Mexican amber comes from Late Oligocene/Early Miocene deposits in Chiapas State (e.g. Figure 1), although Late Cretaceous deposits are known in Baja California and Coahuila States (Riquelme et al., 2014).

Ambers are typically classified according to two criteria: their place of origin (Poinar, 1992) and their chemical composition (Anderson and Crelling, 1995). The latter classification considers

Figure 1: This necklace from the Yi Kwan Tsang Collection contains amber beads from the San Cristóbal de las Casas area of Chiapas, Mexico, and was made by Francesca Montanelli (Lutezia Jewels, Stradella, Italy). Photo by Francesca Montanelli.

Table I: Age, origin and chemical classification of amber (based on succinic acid content) from selected deposits.

Deposit	Age	Paleobotanical origin	Chemical classification	Reference
Sicily, Italy	Miocene (22.5–6 Ma)	Angiosperm	Resinite	Beck and Hartnett (1993); van der Werf et al. (2016)
Chiapas, Mexico	Late Oligocene/Early Miocene (23–13 Ma)	Angiosperm	Resinite	Riquelme et al. (2014)
Dominican Republic	Middle Oligocene/Early Miocene (30–22.5 Ma)	Angiosperm	Resinite	Larsson (1978); Grimaldi (1995)
Baltic Sea, Europe	Eocene (40–35 Ma)	Coniferous	Succinite	Poinar (1992)
Fushun, Liaoning Province, China	Eocene	Coniferous	Succinite	Wang et al. (2014)
Cedar Lake, Manitoba, Canada	Late Cretaceous (Campanian, 78 Ma)	Coniferous	Resinite	Poulin and Helwig (2016)
New Jersey, USA	Late Cretaceous (Cenomanian, 94–90 Ma)	Coniferous	Resinite	Azar et al. (2015)
Hukawng Valley, Kachin State, Myanmar	Late Cretaceous (Cenomanian, 94–90 Ma)	Coniferous	Resinite	Cruickshank and Ko (2003)
Hti Lin, Magwe State, Myanmar	Late Cretaceous	Coniferous	Resinite	Sun et al. (2015)
Dolomites, Italy	Late Triassic	Coniferous	Resinite	Trevisani and Ragazzi (2013)

Figure 2: The state of Chiapas, Mexico, is the source of the amber specimens in the Yi Kwan Tsang Collection. Map adapted by A. Leone.

the presence of succinic acid (which is a carboxylic acid): ambers are classified as *succinite* (i.e. containing succinic acid) or *resinite* (lacking succinic acid; Vávra, 2009). A more detailed chemical classification of fossil resins (Anderson et al., 1992; Anderson and Botto, 1993; Anderson, 1994) consists of five classes: Class I—succinites with succinic acid and communic acid (Class IA; Baltic amber and some Canadian amber produced from conifers), resinites with polymers of communic acid but without succinic acid (Class IB; amber from New Zealand) and resinites with polymers of ozic or zanzibaric acid (Class IC; East African, Mexican and Dominican ambers produced from *Hymenaea* species); Class II—fossil resins derived from Dipterocarpaceae; Class III—fossil resinites derived from Hamamelidaceae (a *Liquidambar* found in Germany); Class IV—amber-like materials of unknown botanical origin (from Moravia, Czech Republic); and Class V—fossil resins derived from angiosperms (from Ecuador and Austria).

The most important amber mines in Mexico are located in the area of Simojovel, but there are several deposits elsewhere in Chiapas State (Figure 2; Poinar, 1992). Chiapas is the southernmost state of Mexico and is relatively isolated from the rest of the country. Amber from this region was observed in jewellery of indigenous people by early European explorers, who at first believed the amber was derived from Baja California (Poinar, 1992).

The Yi Kwan Tsang Collection (named after the owner's wife) consists of 115 amber samples from Chiapas, many of which contain abundant plant and animal fossil inclusions. One sample even hosts an extremely rare frog inclusion. The ambers were acquired over a 10-year period (~2004–2013) in San Cristóbal de las Casas, which is the most important manufacturing centre for material mined in the area near Simojovel. Many of the amber pieces in the Yi Kwan Tsang Collection have been incorporated into jewellery (e.g. Figure 1), and the collection was displayed in 2015 at the Tucson Gem and Mineral Show and in 2016 at the Beijing International Jewelry Fair. This article characterizes Mexican amber from this collection using a variety of methods, including those not very common in gemmology, such as taxonomy studies and mass spectrometry using techniques optimized for organic molecules.

Geological Setting

The geology of Chiapas is rather complex (Sapper, 1896; Moran-Zenteno, 1994; SGM, 2014). The southern part is underlain by Paleozoic plutonic rocks, while the central and northern regions consist of Mesozoic and Tertiary formations. Above these strata are Quaternary deposits that form extended plains (Böse, 1905).

The Simojovel area is characterized by three stratigraphic units that contain amber (Berggren and Van Couvering, 1974; SGM, 2014). From bottom to top, these are the La Quinta Formation (28–20 Ma), the Mazantic Shale (23–14 Ma) and the Balumtum Sandstone (16–12 Ma; see Licari,

Figure 3: Chiapas amber is mined from hand-dug tunnels and pits, such as this one near Simojovel de Allende. Photo by the owner of the Yi Kwan Tsang Collection.

1960; Castañeda-Posadas and Cevallos-Ferriz, 2007). The La Quinta Formation is comprised of three units: the Camino Carretero member (shales alternating with sandstones and limestones), the Florida Limestone member (sandstone strata with coal layers in the lower part and thick limestone layers eroded at the top) and the Finca Carmitto member (conglomerates at the bottom and sandstones at the top; Frost and Langenheim, 1974). According to Grimaldi (1996), most of the amber deposits are associated with lignites, friable shales and deltaic clays in the sandstones.

Mining and Production

According to the owner of the Yi Kwan Tsang Collection, who visited the mining area during the 2002–2006 period, there are hundreds of amber mines in the tropical forest around Simojovel (e.g. Figure 3). Most of these workings consist of narrow tunnels about 1–2 m high that extend into the hills for 5–500 m, following the amber-bearing strata. The amber is mined manually using hammers and chisels. The miners sometimes work in precarious conditions, illuminating the tunnels with candlelight. The extracted material is carried out of the mines in wheelbarrows and buckets, and then dumped into large piles for sorting. The rough amber is taken to Simojovel or San Cristóbal de las Casas for cleaning, polishing and trading, and is then sold to intermediaries or directly to jewellers.

Amber extraction is not continuous through the year; during the rainy season (from late May to late October) mud often invades the tunnels, making mining almost impossible. Most of the miners are also farmers, and during the rainy season they cultivate their fields and coffee plantations.

The question of who owns the earth that the miners work is vexing. Some land is held in common and some is privately owned, and arguments over mining rights often set off fierce fighting. Some of the miners are independent, and others rent their mines from landowners.

Materials and Methods

For this study, the authors had access to 27 pieces of amber from the Yi Kwan Tsang Collection that were selected by the owner for non-destructive examination, as well as three amber fragments (derived from the manufacturing of pieces in the Collection) for destructive analyses. All of the samples were polished and of gem quality; they ranged from 0.85 to 10.0 cm in maximum dimension. Nine samples (Figure 4; Table II) were studied using standard gemmological instruments. Refractive index measurements were performed with a Kruss ER6040 refractometer, which allowed RIs in the range of 1.30–1.80; all readings were taken from flat polished surfaces. Specific gravity was determined using a Presidium PCS-100 balance (0.002 g precision). Fluorescence was observed with an 8-watt UV lamp equipped with 254 nm (short-wave) and 365 nm (long-wave) bulbs. Inclusions were examined in all 27 samples using a stereoscopic microscope (30×–40× magnification).

Destructive techniques consisted of XRD analysis, Fourier-transform infrared (FTIR) spectroscopy and mass spectrometry. FTIR spectra were taken using three Mexican amber fragments (Figure 4, samples 1–3), as well as three Baltic and three Dominican ambers for comparison. (The

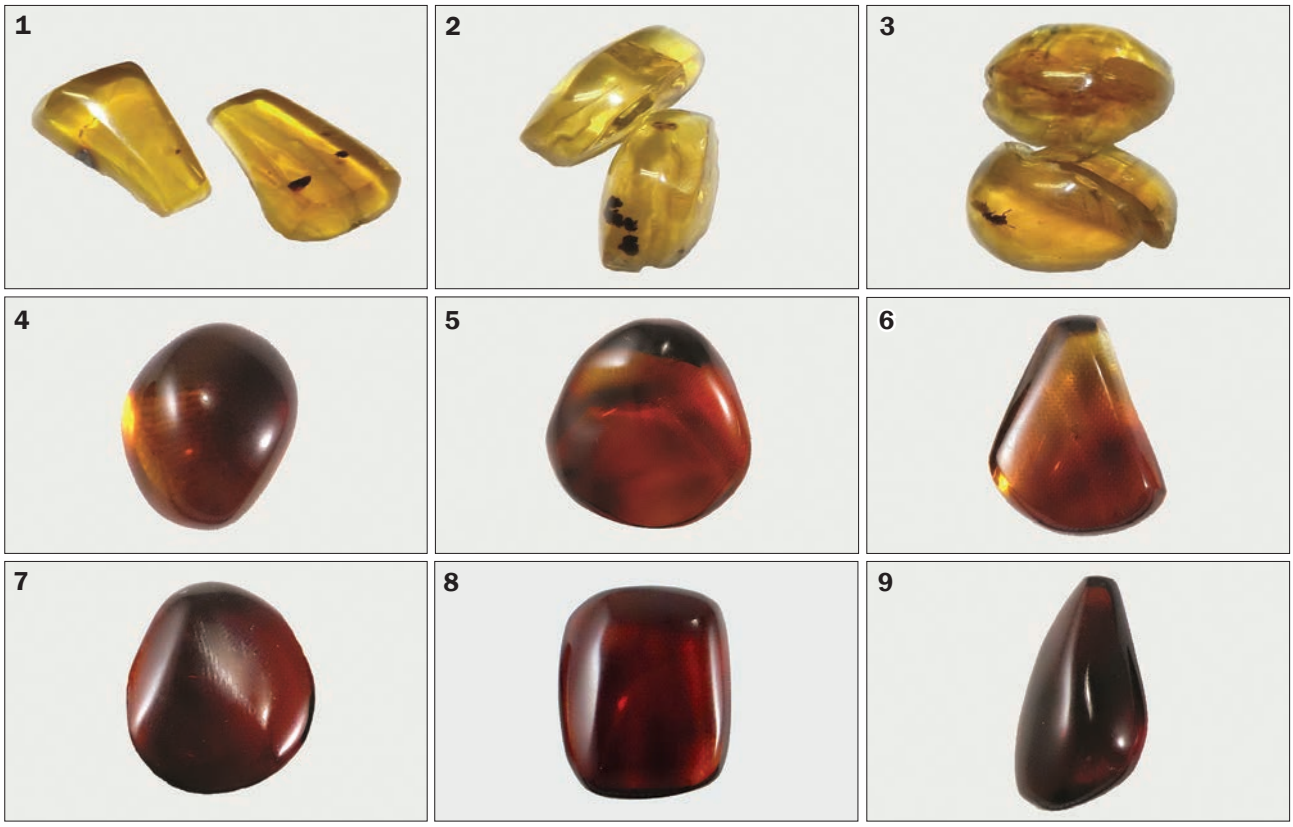

Figure 4: These nine pieces of Mexican (Chiapas) amber from the Yi Kwan Tsang Collection were used for gemmological analysis. Portions of samples 1–3 were used for destructive testing. See Table II for sample descriptions. Photos by V. L. Villani.

Baltic ambers ranged from golden yellow to red and measured 0.7–1.9 cm, while the Dominican ambers were orange to red and measured 0.4–1.7 cm.) XRD analysis and mass spectrometry were performed on one sample from each locality.

For XRD analysis and FTIR spectroscopy, the samples were powdered with a mortar and pestle. The XRD analyses were conducted with a Philips PW1800 powder diffractometer, using Cu*K*α radiation (λ = 1.5418 Å, 35 kV, 45 mA) and a scan speed of 1°/min, in the range 2–65° 2θ. Natural resin/amber is amorphous, so XRD analysis does not yield information on the amber itself but can identify mineral inclusions. The interpretation of the X-ray patterns was done with PANalytical X'Pert HighScore software.

Table II: Gemmological data for the Mexican amber samples in Figure 4.

Sample	Size (mm)	Weight (ct)	SG	RI	Colour	UV fluorescence (long-wave)*
1	17.7 × 8.5	5.32	1.03	1.540	Dark golden yellow	Strong light blue
2	18.4 × 11.5	7.46	1.03	1.540	Dark golden yellow	Strong light blue
3	14.0 × 13.7	5.84	1.03	1.540	Dark golden yellow	Strong light blue
4	15.7 × 9.7	5.60	1.04	1.540	Orange-red	Weak chalky white
5	21.2 × 9.4	9.86	1.03	1.540	Orange-red	Weak chalky white
6	27.2 × 14.0	10.69	1.03	1.540	Orange	Weak blue
7	27.2 × 13.0	6.74	1.03	1.538	Dark orange	Weak chalky white
8	27.0 × 15.0	9.47	1.03	1.540	Orange-red	Weak chalky white
9	21.3 × 19.0	7.63	1.03	1.540	Dark orange	Weak chalky white

* All samples were inert to short-wave UV radiation.

The FTIR spectra were collected in the mid-infrared range (4000–500 cm^{-1}) with a Thermo Nicolet Nexus 670 spectrometer equipped with a diffuse reflectance (DRIFT) unit coupled with a mercury-cadmium telluride (MCT) detector. About 20 mg of amber powder was mixed with 200 mg of KBr (1:10 ratio of sample:KBr) and compacted with a hydraulic press into a thin pellet for analysis. The spectral resolution was 4 cm^{-1} (200 scans).

Mass spectrometry was performed to determine the presence of free succinic acid in the amber samples. This method leaves the polymeric structure of the resin unaltered, allowing the quantification of unbound, free succinic acid (which is used to distinguish succinites from resinites). The analyses were performed with a Thermo Scientific LCQ Fleet ion trap mass spectrometer, using 26.5 mg of Mexican amber, 24 mg of Baltic amber and 20.3 mg of Dominican amber. The samples were powdered in an agate mortar, and 1 ml of water+methanol (70:30 by volume) was added. The vials were sonicated for 20 minutes in an ultrasonic bath, which optimized the contact between the amber powder and the solution. The vials were then centrifuged for 20 minutes at 7,000 rpm, and the homogenized mixtures were filtered to prevent larger particles from entering the mass spectrometer. The resulting samples were diluted 1:10 with a mixture of water+methanol (50:50 by volume), and mass spectra of the solutions were taken to see if any impurities were present. For the acquisition of the amber mass spectra, each solution was injected into the mass spectrometer ionization source using specially designed inlets with controlled flow. The solutions were evaporated into a gas phase by heating, and then the gas molecules were ionized and the ions were mass analysed with the spectrometer. For a better signal, all measurements were performed in negative ion mode. The free succinic acid content of the amber samples was determined by adding known amounts of prepared standard solutions to the original solutions. The succinic acid standards were added to the amber solutions to obtain concentrations of added succinic acid of 0.25×10^{-6}, 5.0×10^{-6} and 1.25×10^{-6} M. The free succinic acid concentrations were calculated by the method of Tonidandel et al. (2008) using the function $I = fC$ (I = ion intensity, C = concentration).

Figure 5: These three amber samples from the Yi Kwan Tsang Collection range from golden yellow to orange. Dark stripes are shown by samples A and C. Sample A is ~4.5 × 3.8 cm, B is ~2.9 × 2.1 cm and C is ~4.0 × 3.4 cm. Photo by V. L. Villani.

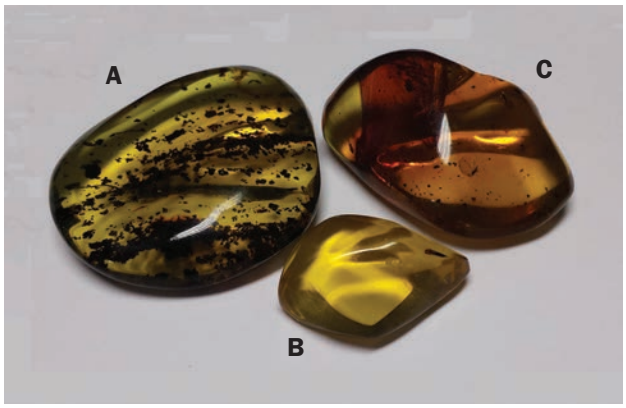

Results and Discussion

Gemmological Properties

Gemmological data for the analysed Mexican ambers are reported in Table II. The 27 samples we examined for inclusions were transparent and typically ranged from golden yellow, orange and orange-red to dark orange; a few pieces were dark brown, and some displayed a little natural green coloration. However the colour range of all samples comprising the entire Yi Kwan Tsang Collection is more extensive: yellow to golden yellow, orange, dark orange and red.

Internal features consisted of inclusions (described below), as well as less common colour variations (e.g. dark stripes, see Figure 5) and small surface fractures (Figure 6). The fractures are probably related to stress associated with the

Figure 6: Cracks are present in the surface of a Mexican amber sample. Photomicrograph by V. L. Villani; magnified 30×.

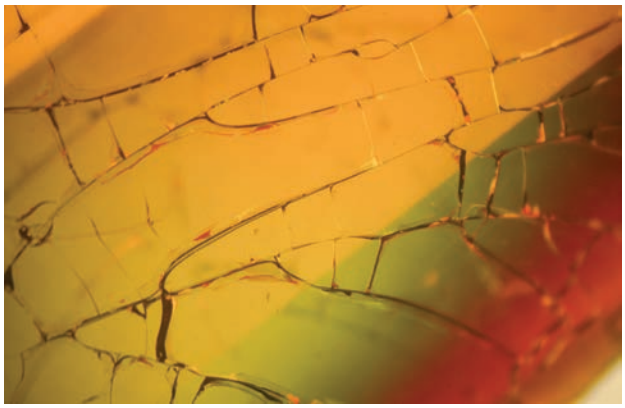

Figure 7: The Mexican amber samples showed a chalky white or light blue reaction to long-wave UV radiation. Photo by V. L. Villani.

polymerization of the resin. All of the pieces were inert to short-wave UV radiation but displayed weak to strong fluorescence to long-wave UV (chalky white or light blue; Figure 7). Such fluorescence behaviour also is seen in ambers from the Baltic Sea and the Dominican Republic (Villani, 2016). The RI values were constant (1.540 for all but one sample that showed 1.538), and they were similar to those of Baltic and Dominican amber (cf. Villani, 2016). Average SG values were found to be homogeneous and relatively low (1.03) compared to the literature in general (see, e.g., Abduriyim et al., 2009) and, specifically, as compared to Baltic (1.06) and Dominican (1.05) ambers (Villani, 2016). We hypothesize these differences are due to the different age and burial history of the ambers, which influence their chemical composition and structure.

Botanical and Animal Inclusions

To identify the animal and plant fossils in the amber, we relied on observation of their specific characteristics and comparison with the literature (McAlpine et al., 1981; Goulet and Huber, 1993; Brown et al., 2009; Calvillo-Canadell et al., 2010; Poinar and Heiss, 2011). The determination of the taxa was difficult because the species that lived in Chiapas during the Oligocene-Miocene were different from modern ones. Also, several of the insects were present as incomplete body parts and/or they were altered by the organic acids and/or glued together by the amber-forming resin. Figures 8–12 show the most significant botanical and animal inclusions in the examined samples, and Figure 13 illustrates soil fragments and bubbles.

From a paleontological point of view, the most important plant inclusions were represented by a petal (Figure 8a) and a leaflet (Figure 8b) of the genus *Hymenaea* (Poinar, 1991). The petal ranged from light brown to red and was completely glabrous (smooth), with a central vein and a path of secondary veins. According to Poinar and Brown (2002), such inclusions belong to the species *Hymenaea mexicana*, which is now extinct. It would be interesting to compare such inclusions with other species of *Hymenaea* found in amber from the Dominican Republic and East Africa, which are quite similar.

Animal inclusions were more common in the amber samples than those of botanical origin. They consisted of arthropods of the orders Diptera (Figure 9) and Hymenoptera (Figure 10), and

Figure 8: (a) A flower petal inclusion of the species Hymenaea mexicana *(Fabaceae family, Late Oligocene–Early Miocene; Poinar and Brown, 2002 and Calvillo-Canadell et al., 2010) is seen in this Mexican amber sample. The petal measures 1.1 cm long and 0.7 cm wide, and shows a narrow midrib base and basal laminar lobes with a central vein and branches of secondary veins. It appears completely glabrous (smooth). (b) The* H. mexicana *leaflet in this Mexican amber measures 3.3 cm long and 1.1 cm wide. The surface is glabrous and its veins are not visible in this view. Photomicrographs by V. L. Villani.*

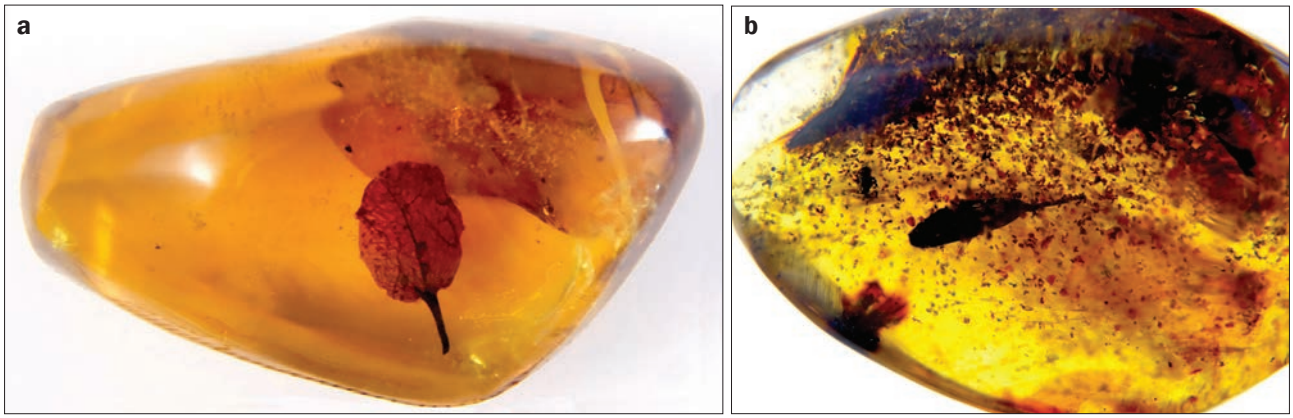

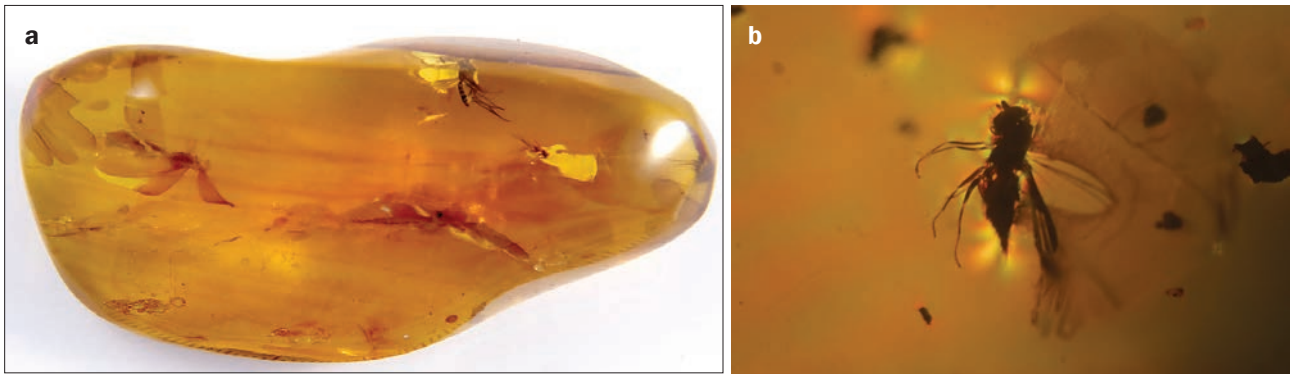

Figure 9: (a) A female mosquito of the genus Ochlerotatus *(order Diptera) is trapped near the top of this Mexican amber; it measures 0.7 × 1.0 cm. It displays two wings and a segmented abdomen, but the thorax and head are not visible. (b) This fly (order Diptera) in Mexican amber measures less than 0.3 cm long and shows a pair of functional and membranous wings. Photomicrographs by V. L. Villani, in plane-polarized light (a) and cross-polarized light (b).*

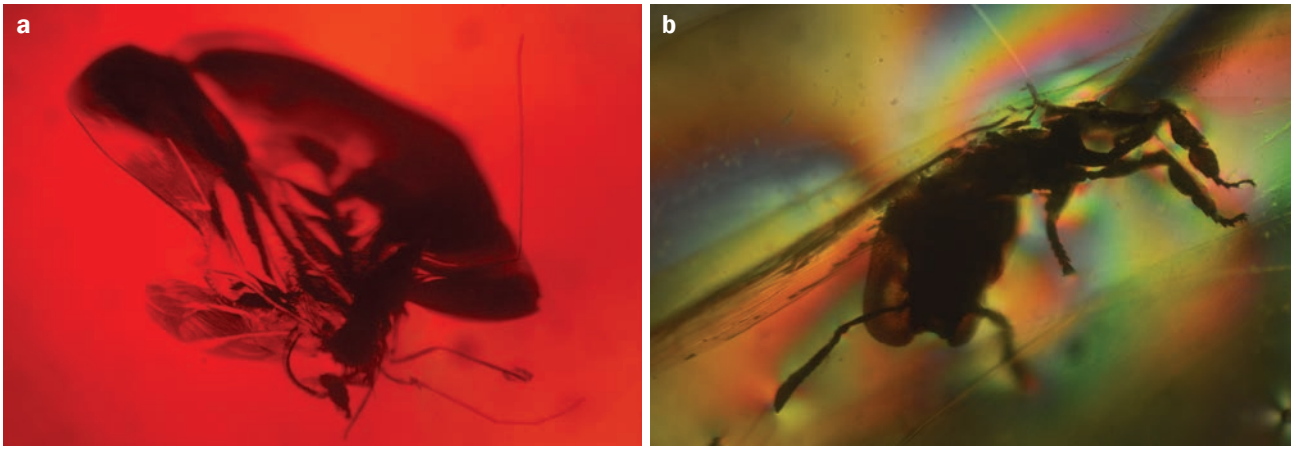

Figure 10 (a) Shown adjacent to a fracture, this Hymenoptera inclusion (1.6 × 1.0 cm) in Mexican amber displays two pairs of wings and elongated legs. The antennae are geniculate (bent at a sharp angle). (b) This Hymenoptera insect inclusion in Mexican amber measures 1.84 × 1.15 cm. The hind wings are shorter than the forewings, and their membranes are not obscured by dense hair or scales. The morphology of the legs is decisive for the Hymenoptera identification. Photomicrographs by V. L. Villani, in plane-polarized light (a) and cross-polarized light (b).

Figure 11: A planthopper of the species Nogodina chiapaneca *(order: Hemiptera, family:* Nogodinidae*; Solórzano Kraemer and Petrulevicius, 2007) is shown at the bottom of this sample. It measures 11 mm long, and displays a rounded head and a clearly visible thorax with one foreleg. The wings have several veins, but the scales are not preserved. This species is known only from Chiapas amber. Photomicrograph by V. L. Villani.*

Figure 12: These winged termites and isolated wings (rare in Mexican amber) of the order Isoptera (reclassified as part of Blattodea) were likely trapped at the beginning of the wet season, when termites start to swarm and then shed their wings. The length of the wings is ~1.1 cm. Photo by V. L. Villani.

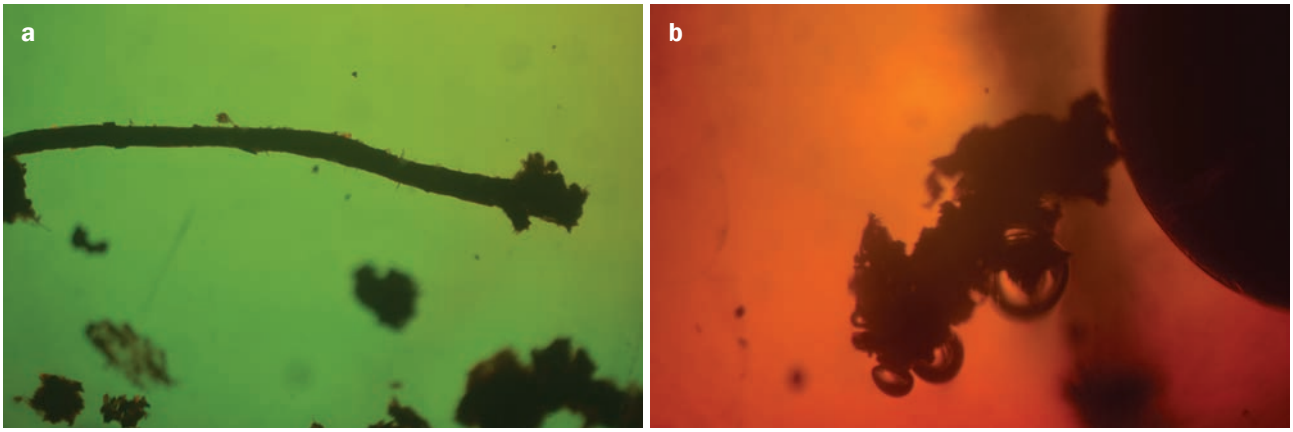

Figure 13: (a) Soil particles and a plant fragment (0.4 cm long) are observed in this Mexican amber sample. (b) Another Mexican amber sample contains a soil fragment and gas bubble inclusions (total dimensions 1.4 cm long and 2.7 cm wide). Photomicrographs by V. L. Villani, in cross-polarized light (a) and plane-polarized light (b).

less commonly of the orders Hemiptera (Figure 11), Psocoptera and Isoptera (i.e. termites, which now are classified as part of the Blattodea order). The presence of termite wings in the amber samples is extremely rare (Figure 12; see also Snyder, 1960). At the beginning of the wet season, termites start to swarm and then shed their wings to establish a new colony. The planthopper species *Nogodina chiapaneca* (Figure 11; Solórzano Kraemer, 2007, 2010; Solórzano Kraemer and Petrulevičius, 2007) has been found only in amber samples from Chiapas. It is an extinct species dated to the Middle Miocene, and it lived in a tropical or subtropical climate. The presence of an arthropod of the genus *Ochlerotatus* (Figure 9a; female mosquito) indicates an aquatic environment. Overall, the fossil inclusions observed in Chiapas amber in this study and in the literature are consistent with a sub-tropical forest (Villani, 2016).

X-ray Powder Diffraction Analysis

The XRD patterns showed the expected amorphous characteristics of amber (i.e. the broad peak at ~15° 2θ), but the software also identified very small amounts of some crystalline phases. In particular, we found the presence of refikite and hartite (both organic minerals), as well as calcite. Calcite was clearly identified only in the amber from Chiapas by a diagnostic peak at 3.03 Å (or 29.8° 2θ; see Figure 14). Refikite and hartite have a composition similar to that of resin but possess a crystalline structure. They have similar XRD patterns and were identified in the ambers from all three localities, according to very small peaks. They both have a main peak at about 5.5 Å (16.1° 2θ), while refikite has a second, more intense peak at 6.09 Å (14.5° 2θ), and hartite has additional peaks at 6.64 (13.3° 2θ) and 5.45 Å (16.25° 2θ).

Refikite ($C_{20}H_{32}O_2$) was originally found as incrustations and acicular crystals in the roots of fossilized spruce trees in a swamp in Kolbermoor (Germany) and in lignite strata near Teramo (Italy); its name derives from the Turkish journalist Refik Bey (Strunz and Contag, 1965; Mottana, 1990). This mineral also was found as thin and acicular crystals in the bark and wood of the remains of pine trees in a peat deposit in western Bohemia, Czech Republic (Pažout et al., 2015). Hartite ($C_{20}H_{34}$) is a diterpene hydrocarbon, originally described by Haidinger (1841). It is a vitre-

Figure 14: This XRD pattern from a Mexican (Chiapas) amber sample shows broad features that are typical of an amorphous material, along with a very small peak diagnostic of calcite.

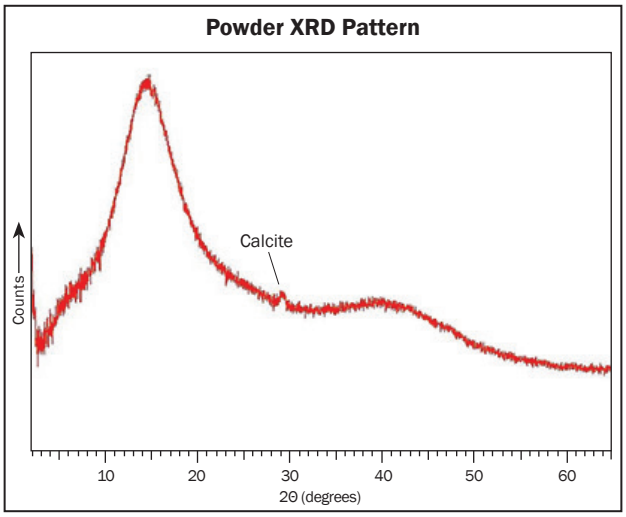

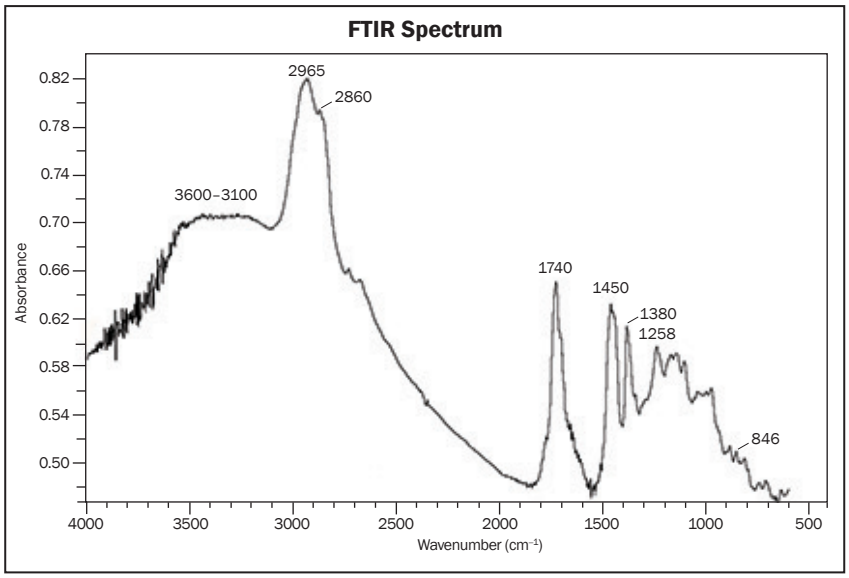

Figure 15: FTIR spectroscopy of a Mexican (Chiapas) amber shows typical peaks at: 3600–3100 cm^{-1} (broad absorption band due to the O-H stretching vibration); 2965 and 2860 cm^{-1} (C-H stretching); 1740 cm^{-1} (C=O stretching, esters and acid groups); 1450 and 1380 cm^{-1} (C-H aliphatic hydrocarbons); 1260–1030 cm^{-1} (C-O stretching aromatic esters and secondary alcohols); and 846 cm^{-1} (C-C stretching of unsaturated olefins).

ous white-grey mineral that is found in lignite seams and fractures in fossil coalfields and silicified tree trunks. Because refikite and hartite were scarce and yet ubiquitous in the ambers, these minerals could not be considered as markers of provenance. They are probably associated with the polymerization process of the resins.

FTIR Spectroscopy

FTIR analysis provided important information about the chemical composition of the samples, which is related to the botanical typology and therefore to the provenance of the ambers. The obtained spectra may vary depending on the portion of the sample that is analysed, because amber has an amorphous structure that is affected by compositional heterogeneity. Three wavenumber ranges that are important for amber characterization are 3700–2000 cm^{-1}, 1820–1350 cm^{-1} and 1250–1045 cm^{-1}; these regions are associated with hydroxyl and carbonyl groups and to C=C double bonds (Beck et al., 1964; Langenheim and Beck, 1965; Litescu et al., 2012, 2013). Samples from a particular deposit may show variations in the region related to methylene, methyl, etc. ($[CH_2]_n$, CH_3, CH, etc.) chains, namely 2962–2850 cm^{-1}, and to specific tensile bands of CH_3 at 1375 cm^{-1} (Litescu et al., 2012, 2013). All of these features also could be observed in our amber samples, with small variations for each locality. The peak assignments in the following paragraphs are from Beck et al. (1964, 1965), Langenheim and Beck (1965), Cunningham et al. (1983), Litescu et al. (2012, 2013) and Rao et al. (2013).

The FTIR spectra of the Mexican amber (e.g. Figure 15) presented a broad absorption band in the 3600–3100 cm^{-1} region due to the symmetric stretching vibration of O-H bonds associated with carboxylic acid. The peaks at 2965 and 2860 cm^{-1} are linked to the stretching vibration of methyl and methylene groups, respectively, and reveal their cyclic ring structure. The intense peak at 1740 cm^{-1} corresponds to the C=O stretching vibration of esters and acid groups. The two peaks at 1450 and 1380 cm^{-1} are correlated to C-H aliphatic hydrocarbons. The absorption features at 1260–1030 cm^{-1} are due to the C-O stretching of aromatic esters and secondary alcohols. This spectral region is quite different in Baltic amber, in which the area near 1260 cm^{-1} is flat (known as the 'Baltic shoulder'; Beck et al., 1964; Villani, 2016). The weak peak at 846 cm^{-1} is related to C-C stretching of unsaturated olefins.

The IR features of our Baltic samples were very similar to those of other Baltic amber reported in the literature. Absorption in the 3600–3100 cm^{-1} region is due to the symmetric stretching vibration of O-H bonds associated with carboxylic acid. An absorption peak at 1650 cm^{-1} was typical of Baltic amber. The 1260–1180 cm^{-1} region was characterized by the broad horizontal 'Baltic shoulder' followed by a sharp absorption peak at 1159 cm^{-1} (Beck et al., 1964, 1965; Abduriyim et al., 2009; Litescu et al., 2012, 2013) assigned to C-O stretching of –CO-O- (carboxylic single-bond groups, succinate).

The IR features of our Dominican amber samples were very similar to those described in the literature, which resemble those of Mexican amber

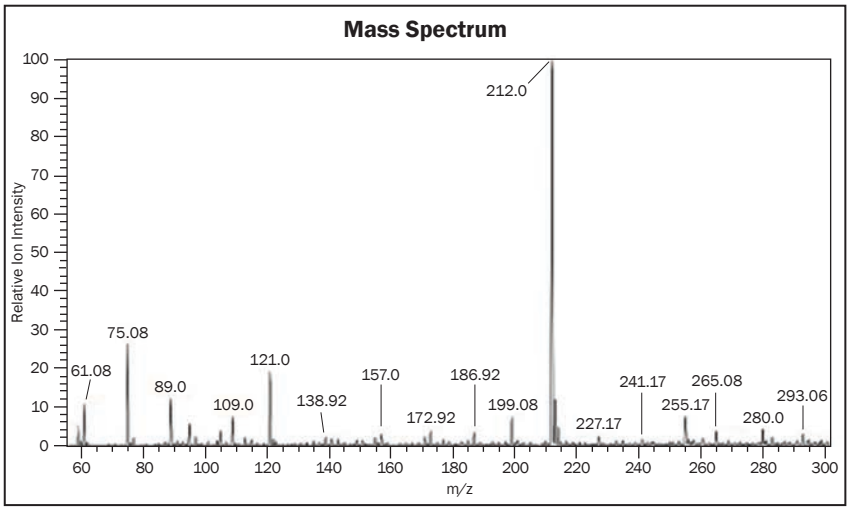

Figure 16: The mass spectrum of a Mexican (Chiapas) amber sample displays no peak of the m/z 117 ion related to the presence of succinic acid; we therefore classify the material as a resinite.

from Chiapas. However, a narrow peak at 3095 cm^{-1} (C-H stretching) was not observable in the spectrum of our Mexican amber. Peaks at 2930–2860 cm^{-1} are linked to C-H stretching of CH_3 methyl and methylene groups, and a doublet at 1730–1700 cm^{-1} is linked to C=O stretching of carboxylic esters. A sharp peak also was present at 1800 cm^{-1} in the Dominican amber, and a particular absorption morphology was recorded in the 1500–1000 cm^{-1} region—with two isolated peaks at 1030 cm^{-1} (C-O stretching) and 930 cm^{-1} (C-H stretching) that are not present in the spectra of Mexican amber.

The Late Cretaceous ambers from Hti Lin in Myanmar show significant absorptions at 1225 and 1136 cm^{-1} (Tay et al., 2015) that were not visible in the spectra of our samples from Mexico, the Baltic Sea or the Dominican Republic; in addition, the spectra of those Burmese ambers did not show the Baltic shoulder or the OH absorption band (i.e. 3700 cm^{-1}). FTIR spectra of Sicilian amber (simetite) show main absorption peaks in the 1300–1100 cm^{-1} region (maximum absorption at 1245 cm^{-1}) and a secondary absorption at 1185 cm^{-1} (Beck and Hartnett, 1993).

Mass Spectrometry

Confirmation of succinic acid is obtained from the m/z 117 ion (the negative ion mass peak) corresponding to $(M\text{-}OH)^-$ of succinic acid (Tonidandel et al., 2008, 2009). The mass spectrum of the Mexican amber did not show the m/z 117 ion (Figure 16), so the level of succinic acid in this amber was lower than the limit of quantization (1 ppm by weight), classifying it as a resinite. The Dominican sample showed a spectrum very similar to that of the Mexican amber, indicating the absence of succinic acid, while the m/z 117 ion was clearly identifiable in the spectrum of the Baltic amber sample (indicating the presence of succinic acid).

Conclusions

FTIR spectroscopy was confirmed as a useful technique to determine the provenance of the amber samples. Our data on Mexican and Dominican ambers and data from the literature on Burmese ones do not show the 'Baltic shoulder' in the wavenumber region 1260–1180 cm^{-1}. Also, only in the Mexican and Dominican spectra was there a peak at 2860 cm^{-1} that reveals the cyclic structure of these ambers. Although the Mexican and Dominican spectra were quite similar, it was possible to differentiate between them: the Mexican amber spectra lacked the particular absorption morphology between 1500 and 1000 cm^{-1} that is found in Dominican samples, as well as the absorption at 3095 cm^{-1} and the two peaks at 1030 and 930 cm^{-1}.

XRD analysis revealed traces of the organic minerals refikite and hartite, and also calcite in the Mexican amber. The calcite probably originated from the amber-bearing strata. Mass spectrometry showed that free succinic acid was absent from the Mexican and Dominican samples, while it was present in the Baltic ones. The Mexican (and Dominican) amber therefore belongs to Class IC (resinites produced from *Hymenaea*) of the chemical classification of amber.

The taxonomical investigation of the inclusions revealed important information. The most common fossil animal inclusions in Mexican amber samples from the Yi Kwan Tsang Collection

were arthropods of the orders Diptera and Hymenoptera, followed by the orders Hemiptera, Psocoptera and Isoptera (Blattodea). Most of the insects were eye-visible, while others were easier to identify at higher magnification (40×). Most of them are not indicative of a specific environment, while others (*Ochlerotatus*, female mosquito) are typical of aquatic or humid/warm environments. The identification of specific arthropods such as *Nogodina chiapaneca* confirms that the climate in Mexico during the Middle Miocene was tropical. Furthermore, the presence of isolated termite wings is indicative of a specific period at the beginning of the wet season.

In the investigated samples, botanic inclusions were rarer than animal ones, as commonly described in Mexican ambers (Calvillo-Canadell et al., 2010). The identification of a leaflet and a flower petal of the species *Hymenaea mexicana* clearly indicate a tropical environment. This paleoenvironment is consistent with the general abundance of biotic inclusions in amber from the Chiapas locality.

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Conferences

2017 Dallas Mineral Collecting Symposium

This year's Dallas Mineral Collecting Symposium, held 25–27 August 2017, saw a transformation when the gem-related presentations at this primarily mineral-based conference approached 50% of the programme's content for the first time. The Symposium attracted more than 200 attendees, and a DVD containing the presentations was distributed to more than 5,000 others worldwide.

Richard Hughes (Lotus Gemology, Bangkok, Thailand) stressed 'humanistic gemmology' as the interaction of gems and people, as part of his whirlwind tour of the world's ruby sources.

Federico Bärlocher (Como, Italy, and Yangon, Myanmar) presented a video tour of some Burmese ruby mines. The video covered the 2,000-year history of ruby production in Mogok, where half-a-million people are involved with the gem industry. The video concluded with a 20 ct Mogok ruby that brought US$30 million at auction.

Dr George Rossman (California Institute of Technology, Pasadena, California, USA) discussed the science of colour in gems, including the absorption and reflection of light due to metal ions, as well as radiation effects. In addition, he showed how the colour of rose quartz is due to a fibrous mat of micro-inclusions. According to Dr Rossman, of the 5,300 known minerals, cause of colour has been studied in only 400.

Dr Emanuele Marini (Nimeral Min-Lab, Milan, Italy) provided his perspectives on the repair and restoration of mineral specimens in order to return the natural form to an otherwise damaged piece. Both the appearance and durability of a specimen can be altered. Although the gem world has dealt with treatments for a long time, now the restoration of mineral specimens is raising age-old questions. How should these treatments of minerals be disclosed? How can secondary buyers be made aware of such treatments?

Christoph Keilmann (The Munich Show, Munich, Germany) shared the history of The Munich Show, a family-owned gem, mineral and jewellery exhibition that has grown over the past 54 years. At its beginning in 1963, it had only 20 exhibitors. It now hosts 1,300 dealers and attracts more than 40,000 visitors.

John Cornish (John Cornish Minerals, Port Angeles, Washington, USA) took attendees on an in-depth journey into Australia's Adelaide mine, noted for its production of crocoite crystals. Cornish described the mining techniques, using chisels and handsaws, required to extract the fragile mineral specimens.

Dr Peter Lyckberg (European Commission, Brussels, Belgium) described the challenges of mining at elevations of over 14,000 feet (4,267 m) in the Shigar Valley of Pakistan, where more than 100,000 miners have been involved with exploiting granitic pegmatites for aquamarine, apatite and other minerals.

Bruce Bridges (Bridges Tsavorite, Nairobi, Kenya) presented a video celebrating the 50th anniversary of his father's discovery of tsavorite, and shared his views on the colour range, quality and value of this green garnet coloured by vanadium (primarily) and chromium. The East African tsavorite deposits formed approximately 550–600 million years ago.

Dr Robert Hazen (Geophysical Laboratory, Carnegie Institution, Washington DC, USA) discussed how mineralogists now look at mineral evolution alongside human development, as well as the predictability of new mineral deposits. Mineral network analysis follows much the same patterns as social networks and can be used to see how relationships in the mineral world behave similar to human social interactions.

Eric Fritz FGA DGA
Gem-A, Tucson, Arizona

World of Gems Conference V

The 5th World of Gems Conference was held in Rosemont, Illinois, USA, on 23–24 September 2017. Approximately 150 people from a total of six countries were in attendance. The conference was opened by Richard Drucker (Gemworld International, Glenview, Illinois), who also was the moderator and one of the 11 speakers at the event (Figure 1).

Dr Emmanuel Fritsch (Institut des Matériaux Jean Rouxel, University of Nantes, France) reviewed the identification of natural vs. synthetic and HPHT-treated diamonds using short-wave UV phosphorescence, anomalous double refraction, luminescence imaging (e.g. using the DiamondView to see growth patterns) and photoluminescence spectroscopy. He predicted that synthetic diamonds will become more and more perfect in the future, but their growth patterns should still make them recognizable.

Jon Phillips (Corona Jewellery Co., Toronto, Ontario, Canada) provided an overview of the diamond industry, covering production, marketing and pricing. He mentioned that by the end of 2017 the Diamond Producers Association will have spent US$60

Figure 1: The speakers at the 5th World of Gems Conference included (from left to right): Dr Emmanuel Fritsch, Nicholas Sturman, Alan Bronstein, Jon Phillips, Dr J. C. (Hanco) Zwaan, Richard Drucker, Al Gilbertson, Dr Çiğdem Lule, Stuart Robertson, Kerry Gregory and Roland Schlussel. Photo by B. M. Laurs.

million on the generic marketing of diamonds. In addition, De Beers will spend $140 million on marketing in 2018 (the largest amount since 2008), which will be geared toward millennials and female self-purchasers.

Nicholas Sturman (Gemological Institute of America [GIA], Bangkok, Thailand) examined pearls, their molluscs and global sources (both saltwater and freshwater), and their treatments. Pearls may be both worked and polished, for mounting purposes or to enhance their shape and/or lustre. Other pearl treatments that continue to be seen are dyeing, irradiation, bleaching, filling and coating.

Roland Schlussel (Pillar & Stone International, Tiburon, California, USA) detailed the classification and quality factors of Burmese jadeite. The numerous varieties are defined by a combination of texture and transparency, colour and colour pattern, and mineral composition. Microscopic studies show that jadeite with the highest transparency contains small and uniformly shaped grains that show a preferred crystallographic orientation and have indistinct grain boundaries.

Stuart Robertson (Gemworld International) and **Dr Çiğdem Lule** (Kybele LLC, Buffalo Grove, Illinois, USA) reviewed gem treatments and then discussed the pricing of treated gems. In most cases, the price of an untreated stone serves as a benchmark, and its treated equivalent trades at a discount (e.g. diamond). Or, for gems that are nearly always treated (e.g. clarity-enhanced emeralds), the untreated stone will trade at a premium.

Kerry Gregory (Gemmology Rocks, UK) described how she quickly and efficiently separates the more valuable pieces among large quantities of gemstones recovered from scrapped jewellery. She first sorts them according to their colour category (red, green or blue) and then uses a polariscope, refractometer and sometimes a spectroscope (for red stones) to select those that are likely worth reselling.

Dr J. C. (Hanco) Zwaan (Netherlands Gemmological Laboratory, Naturalis, Leiden) started the second day of the conference with a detailed look at the geological origin of Sri Lankan sapphires. By studying known primary deposits, he inferred that sapphires in the economically important secondary deposits originally formed via a multistage process involving (ultra)high temperature metamorphism to 'prime' the host rocks by removing Si through partial melting, followed by tectonic activity along contacts between different rock types to create space for crystallization, and finally fluid/pegmatitic melt transfer to enable the formation of larger crystals though metasomatic processes.

Dr Çiğdem Lule examined the challenges of identifying black gems, including their lack of transparency, RI values that are commonly over-the-limit of a standard refractometer, and issues pertaining to nomenclature and disclosure. Properly identifying black diamonds can be particularly challenging because in addition to separating them from imitations, they should be assessed for treatments. Equipped with an understanding of the various black gem materials and their structures, microscopy can be helpful for concluding whether a black sample is diamond or not, which is often a sufficient determination for these low-value materials.

Al Gilbertson (GIA, Carlsbad, California) discussed the challenges of developing a fancy-cut grading system for diamond. Due to the abundance of measurement variables that may lead to an overwhelming number of parameters in comparison to round brilliants, it is necessary to simplify the process by limiting the fancy-cut grading system to the evaluation of carefully selected criteria.

Alan Bronstein (Aurora Gems, New York, New York, USA) shared his knowledge of the fancy-coloured diamond market. Although he estimated that 95% of fancy-coloured diamonds are cut as radiants to maximize their face-up colour, he indicated that there is no perfect all-around shape for these diamonds, and the goal of cutting should be to balance a stone's intrinsic colour and with its brilliance.

Richard Drucker covered gem pricing challenges. He noted that while useful, price lists do have their shortcomings: data are less reliable for higher-end stones and for gem varieties that are not heavily traded, since less information is available on them for comparison. Also, for jewellers and appraisers in particular, he

mentioned that there is no uniform way to determine retail pricing since mark-ups vary in different markets.

The formal presentations were followed by an open discussion session in which conference attendees brought up a variety of subjects related to those covered by the speakers, as well as other topics.

A poster session was included for the first time at the World of Gems Conference. The seven posters covered topics that included the jet group; the effects of chromium in ruby, emerald and alexandrite; fluorescence in diamond; assessing and valuing coloured gemstones; and more.

A conference proceedings volume was distributed in print to all attendees and as a free PDF file to industry members. To obtain the PDF or purchase a print version, visit https://gemguide.com/events/world-of-gems-conference.

Brendan M. Laurs FGA

Gem-A Conference

The annual Gem-A Conference took place 4–5 November 2017 at the etc.venues County Hall in London and was attended by approximately 220 people from 20 countries.

The event was introduced by Gem-A's CEO **Alan Hart**. Then **Adonis Pouroulis** (Petra Diamonds, Johannesburg, South Africa) provided an informative review of global diamond production, with a focus on Petra's five mines: Finsch, Cullinan, Koffiefontein and the Kimberley Ekapa Mining Joint Venture in South Africa, and Williamson in Tanzania. He stated that the new processing plant at the Cullinan mine is designed for the recovery of large diamonds and is the world's most technologically advanced facility of its kind.

John Benjamin (John C. Benjamin Ltd., Aylesbury, Buckinghamshire) provided an entertaining review of jewellery design during the Georgian period, a 135-year span that mostly covered the 18th century. Mourning jewellery was popular during this time and commonly contained a lock of hair of the deceased; the designs were initially rather revolting and shifted toward more attractive sentimental motifs by the 1800s. In the mid-18th century diamond jewellery became popular as a means of demonstrating one's social mobility, while designs featuring paste glass were sought by those who couldn't afford diamonds.

Klemens Link (Gübelin Gem Lab, Lucerne, Switzerland) gave a two-part presentation. First he discussed new technologies for the radiometric age dating of sapphires (using the U-Pb technique on zircon inclusions) and emeralds (using the Rb-Sr method to date the beryl itself). Then he described the 'Provenance Proof' system of marking rough or cut gems (mainly emeralds) using artificial DNA encased within tiny silicon beads (100 nm in diameter) that are introduced into microfractures within a stone. The technique allows information to be permanently implanted into a stone such as its country and/or mine of origin, when it was mined, cutter/manufacturer, etc.

Evan Caplan (Evan Caplan, Los Angeles, California, USA) reviewed the localities and quality factors for alexandrite. Brazil, Russia, Sri Lanka, India, Tanzania and Madagascar are the main sources, and stones should be evaluated according to the extent of their colour change, then their clarity and finally their cut. Caplan noted that gemmological laboratories may provide inconsistent colour descriptions, making it difficult to sell such stones.

Reena Ahluwalia (Reena Ahluwalia, Toronto, Ontario, Canada) explained how she tells stories through the jewellery she creates. Some examples included a jewel featuring diamonds from the Bunder mine in Madhya Pradesh (India), a canoe-shaped necklace showcasing Canadian diamonds, a diamond-set mace for the government of Ontario and a tiara featuring Royal Asscher-cut diamonds for Kate Middleton. Ahluwalia also described her large-format paintings of cut diamonds, which convey themes such as dreams, temptation, luminosity, perfection and eternity.

At the end of the first day of the conference, **Alan Hart** announced that **Andrew Cody** (Cody Opal, Melbourne, Victoria, Australia) had been awarded an Honorary Fellowship for his outstanding contributions to the industry.

Patrick Dreher (Dreher Carvings, Idar-Oberstein, Germany; Figure 2) started the second day of the conference by recounting his family's long history of carving gems, and then he outlined the steps involved in creating realistic renditions of animals in a variety of materials such as agate, quartz (rock crystal, citrine, smoky and 'strawberry'), tourmaline, beryl (aquamarine and heliodor) and obsidian. Dreher reported that carving a multi-coloured opaque stone such as agate is particularly challenging because it is not possible to see the contours of the colour layers inside the piece, and they must be precisely integrated into the particular form of the animal being carved.

Dr John Rakovan (Miami University, Oxford, Ohio, USA) reviewed factors that control the morphology and the flat faces exhibited by crystals, such as temperature, pressure, fluid and chemical composition, growth rate, and the presence and types of defects (e.g. dislocations). Conditions favouring morphological and internal perfection (such as exhibited by attractive mineral specimens and gem crystals) include unrestricted crystal growth, a slow growth rate and a homogenous stable environment.

Figure 2: Patrick Dreher discusses his innovative gem carving techniques at the Gem-A Conference. Photo by B. M. Laurs.

Bernhard Berger (Cartier Tradition, Geneva, Switzerland) described the Cartier Collection of historic pieces of jewellery, timepieces and *objets d'art* that are intended to educate and share Cartier's history with the public and their staff. He also recounted the history of the Cartier family saga and its employees and designers, and described several famous pieces and clients. He showed various examples that illustrated different styles (e.g. Garland, Art Deco and Tutti Frutti, as well as the Panther Collection), and also Mystery Clocks that are cleverly designed with hour and minute hands mounted onto rock crystal discs so they appear to float freely.

Dr Ulrika D'Haenens-Johansson (GIA, New York, New York) tracked the evolution of synthetic diamonds and their identification. Photoluminescence spectroscopy in combination with other techniques provides a reliable means of identifying these synthetics. Visual clues for identifying HPHT-grown synthetic diamonds include the presence of metallic rod-shaped inclusions, the lack of a discernible strain pattern visible with crossed polarizers and a cuboctahedral pattern that typically displays blue or green fluorescence with strong greenish blue phosphorescence when examined with the DiamondView. CVD-grown synthetics may contain small black inclusions/pinpoints (although are typically of high clarity), strain patterns visible with crossed polarizers, and orange, pink or red fluorescence (as-grown) or green to green-blue fluorescence with greenish blue phosphorescence (HPHT processed) along with striations, layers and/or violet-blue dislocation bundles when examined with the DiamondView.

Vladyslav and Samanta Yavorskyy (Yavorskyy, Hong Kong) showed photos (mostly from Vladyslav's various books) and videos depicting their travels in search of coloured stones in Central Asia, Sri Lanka, Myanmar, Tanzania and Madagascar. They promoted the importance of bringing back the glory and romance of natural untreated coloured stones.

At the end of the conference, Gem-A president **Maggie Campbell Pedersen** provided an insightful recap of the widely varying presentations that were delivered during the two days.

On 6 November, three workshops were held at Gem-A's headquarters: coloured stone grading and pricing (hosted by **Richard Drucker**, Gemworld International Inc., Glenview, Illinois, USA), jadeite testing and grading (hosted by **Dominic Mok**, Asian Gemmological Institute and Laboratory Ltd., Hong Kong) and separating black stones (hosted by **Sarah Steele**, Ebor Jetworks Ltd., Whitby, North Yorkshire). That evening marked Gem-A's graduation ceremony and presentation of awards at Central Hall Westminster in London.

On 7 November, two separate field trips took attendees for private viewings of the British Crown Jewels and of the Natural History Museum's gem and mineral collection.

Brendan M. Laurs FGA

World Ruby Forum

The World Ruby Forum 2017 was attended by about 200 people and took place 4 November in Bangkok, Thailand, one day prior to and in conjunction with the annual World Jewellery Confederation (CIBJO) Congress. It was organized by the Gem and Jewelry Institute of Thailand (GIT) in collaboration with the Department of International Trade Promotion, Ministry of Commerce (DITP); the Asian Institute of Gemological Sciences (AIGS); and the Association Française de Gemmologie (AFG). The purpose of this forum was to promote, support, raise awareness and improve understanding of ruby, as well as to create global recognition of the value and beauty of ruby. The stone is considered a major strength of the Thai gem industry.

Following introductions by **Duangkamol Jiambutr** (director of GIT) and **Henry Ho** (chairman emeritus of AIGS; Figure 3), the forum was officially opened by **Apiradi Tantraporn** (Minister of Commerce).

The first speaker, **Didier Giard** (AFG, Lyon, France), stressed the importance of rubies and the psychological significance and symbolism of the colour red, creating an ultimate 'alchemy' between ruby and red. The different colour variations of ruby can be connected with people's personality and behaviour, as well as symbolize attractiveness, beauty, value, activity, fire and love, but also the sins of the flesh, death and hell, indicating a duality that is always present and reflected in how red is used in different cultures and religions. Giard also promoted the establishment of an annual international day for the sustainable management of gem mines, and advocated the protection of cities such as Mogok (Myanmar) by applying for UNESCO heritage status.

Sean Gilbertson (Gemfields, London) elaborated on the mining of rubies by Gemfields in the Montepuez area of Mozambique during the past six years, beginning with bulk sampling and the construction of an initial washing plant in 2012, and then the first auction of rubies in 2014, followed by the installation of a new washing plant in 2016 and the construction of a new sort house to be completed in December 2017. The largest portion of high-value rubies comes from the Mugloto secondary deposits (currently nine pits). The prices of the rough ruby vary widely from US$0.02 to $500,000 per gram (average of US$29.55 per carat). Approximately 1,100 people are employed in processing 375,000 tonnes per month, equivalent to 514 tonnes per hour on a 24/7 basis, recovering 8.5 million carats per year. Apart from mining, Gemfields has built schools and introduced a mobile clinic that sees 4,500 patients each month. They also support efforts to prevent rhinoceros poaching.

Nay Win Tun (Ruby Dragon Group of Companies, Yangon, Myanmar) described Ruby Dragon's mines in Mogok and Mong Hsu. In Mogok, the group works four mines, including open pit (secondary) and underground (primary) deposits. One of the latter includes a 400 m shaft with a slope of 60°, and tunnels up to 3 m wide and high to allow the extraction of ore by trucks. Both primary and secondary deposits are mined in Mong Hsu, with one underground operation going 200 m deep with a shaft inclined at 35°. Only Myanmar citizens are allowed to extract rubies from the ground, but after the political change in 2011 there are fewer restrictions on stone trading. Continuous efforts are underway to create a more transparent, ethical and socially responsible business and attract more foreign investors.

Dr Cedric Simonet (Kenya Chamber of Mines, Nairobi, Kenya) gave an overview of African ruby deposits and their geological origin as they relate to the Pan-African Mozambique Belt (metamorphic rocks) and the Cenozoic rifts and associated volcanism (alkali basalts). In addition to the known deposits—such as the John Saul mine (Tanzania), the Baringo deposit (Kenya), the Longido mine (Tanzania) and the occurrences near Montepuez (Mozambique)—the Alale deposit in West Pokot, Kenya, is a new marble-hosted ruby occurrence that shows good quality and potential for the future. As in Longido and Lossogonoi, ruby is found in a 50-cm-thick zoisite-bearing amphibolite, which is hosted by a serpentinite body. However, the Alale rubies are much more transparent and of better quality than those in Longido. With regard to the Montepuez ruby deposits, an expansion of mining activities in this region may be accomplished via large-scale operations by mining companies or through well-organized artisanal mining within a formal structure. Active exploration also is needed; based on available geological data, there is great potential for the discovery of new deposits. Primary deposits are targets on their own, but these also should be considered as pathfinders for secondary deposits.

Figure 3: Henry Ho, chairman emeritus of AIGS, welcomes participants to the 2017 World Ruby Forum in Bangkok.

Vincent Pardieu (VP Consulting, Manama, Bahrain) presented an historical overview of ruby sources, including those in Mogok and Thailand (dominant during 1962–1992); Winza, Tanzania (since 2007); and Mozambique (since 2009). He also covered Longido, Tanzania; Chimwadzulu Hill, Malawi; discoveries in Madagascar, such as in Didy (2012); and Greenland. Many of the new discoveries are related to amphibole-bearing rocks, and the rubies from these might have similar (amphibole) inclusions. However, they can be separated by trace-element chemistry, using a binary V:Fe diagram, with Greenland rubies having more V than African stones.

Gaetano Cavalieri (CIBJO, Milan, Italy) explained that the needed corporate social responsibility (CSR) system for coloured stones has been delayed because production in the ruby industry is largely derived from artisanal and small-scale miners. Gemfields and Greenland Ruby A/S are the only two larger ruby mining companies in this sector. A viable CSR strategy needs to be defensive, socially active and inclusive, showing responsibility towards employees, customers, stakeholders (especially people who live close to a mine) and society at large. The need to take the initiative is urgent, and full transparency is required.

Dr Visut Pisutha-Arnond (GIT) stressed the importance of Thailand in the gem and jewellery industry. In Thailand the industry employs 700,000 workers, and the export of coloured stones generates US$1.07 billion. In total the export revenues of gems and jewellery are $6.97 billion. Thailand offers VAT exemption for importing rough material, will organize rough stone auctions, and has the ambition to make Chanthaburi the most important gemstone hub ('gem metropolis') by 2021. From a geological perspective, Thai rubies can be considered very rare, being related to pyroxenite xenoliths present in the Trat basalt, indicating a deep-mantle origin.

Richard Hughes (Lotus Gemology, Bangkok) elaborated on the psychology of colour and the history of red as 'the first colour'. Red is the symbol of love, romance, luck; red is sexy; red is power; it stands out and runs deep in most cultures (e.g. red dragons, wedding dresses and envelopes in China; red 'third eye' and hand tattoos in India). Ruby is the 'gem of the sun', so it should be set in the centre of a piece of jewellery. Hughes stated that since many rubies formed during the Pan-African event 550–700 million years ago, holding a ruby is like holding eternity in the palm of your hand.

Alessio Boschi (Alessio Boschi, Bangkok) worked 27 years with masters in the jewellery design and branding field all over the world. He showed some of his very detailed and delicate work, which represents a 'precious journey'—a story behind the inspiration of all his designs. He uses particular cuts and delicate gems such as tanzanite and opal. He employs platinum, titanium and palladium casting, as well as microsettings, which are considered to be a specialty of Asia. 'Shading' of colours is often employed in this type of work, and he showed examples of how he has used ruby and rubellite in this respect.

The Forum concluded with two panel sessions: (1) ruby trade and commerce, with panellists **Santpal Sinchawla** (Sant Enterprises, Bangkok), **Andrew Cody** (Cody Opal, Melbourne, Australia), **Paolo Valentini** (Italian Gem Association) and **Barbara Wheat** (AIGS, Bangkok), and (2) the laboratory perspective on ruby with regard to reporting and standards used, with panellists **Dr Pornsawat Wathanakul** (gemstone specialist retired from GIT), **Boontawee Sripasert** (GIT), **Dr Tajin Lu** (National Gemstone Testing Center, Beijing, China), **Hpone-Phyo Kan-Nyunt** (Gübelin Gem Lab, Hong Kong), **Kennedy Ho** (AIGS) and **this author**.

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Gem-A Notices

GIFTS TO THE ASSOCIATION

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Roger Trigg FGA, Constantia, Cape Town, South Africa, for brilliant-cut samples of andalusite, chrysoberyl, hiddenite, scapolite and vesuvianite, and a cabochon of Gilson synthetic turquoise, plus two cases of minerals and gemstones.

GEM-A CONFERENCE

The 2017 Gem-A Conference was held at etc.venues County Hall, London, on 4 and 5 November. A full report of the Conference and events was published in the Winter 2017 issue of *Gems&Jewellery*. Highlights of the presentations are given in the Conferences section of this issue of *The Journal*, pages 768–769.

Workshops were held on 6 November at the Gem-A headquarters. Richard Drucker (president, Gemworld International Inc., Glenview, Illinois, USA), presented a workshop on 'Coloured Stone Grading and Pricing', introducing new concepts in colour grading. Dominic Mok (founder and principal of AGIL, Hong Kong) presented a workshop titled 'Contemporary Jadeite Testing and Grading', providing theoretical and practical experience in jadeite testing. Sarah Steele (owner of Ebor Jetworks Ltd., Whitby, North Yorkshire) gave a workshop on 'Separating Black Stones', which covered a wide range of materials, both rough and in jewellery.

A visit was arranged on 7 November to the Mineral Gallery at the Natural History Museum for a guided tour by Mike Rumsey, senior curator in charge, followed by coffee hosted by Lyon & Turnbull at The Club at Ten Trinity Square where participants had the chance to view highlights from their November jewellery auction. A tour also was arranged to the Tower of London for a private viewing of the Crown Jewels.

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GRADUATION CEREMONY

The Graduation was held on 6 November in the Lecture Hall at the magnificent Central Hall Westminster. The ceremony was attended by 122 graduates from Canada, China, French Guiana, Hong Kong, India, Japan, Madagascar, Taiwan and the USA, as well as various European countries.

The ceremony was opened by Alan Hart, CEO of Gem-A. The address was given by Richard Drucker (president, Gemworld International Inc., Glenview, Illinois, USA), who spoke about following one's passion and how fortunate we are to be in a business that attracts so many interesting people. Networking with these people can bring new opportunities and lifelong friendships. He also provided some inspiring quotes from advertisements he'd seen in airline jetways during his travels, and related them to the graduates' present situation of embarking on their exciting careers.

The ceremony was followed by a reception in the Library.

Richard Drucker finishes his address to the graduates. Seated next to him are Maggie Campbell Pedersen (Gem-A President), Justine Carmody (Gem-A chair of the Board) and Alan Hart (Gem-A CEO).

GEM-A AWARDS

In the Gem-A examinations held in January and June 2017, 501 students qualified in the Gemmology Diploma examination, including 28 with Distinction and 63 with Merit, and 587 qualified in the Foundation Certificate in Gemmology examination. In the Diamond Diploma examination 118 qualified, including 27 with Distinction and 21 with Merit.

In the **Gemmology Diploma** examination, the **Christie's Prize for Gemmology** for the best candidate of the year was awarded to **Jiaqi Yu** of Beijing, China. The **Read Practical Prize** for excellence in the practical examination also was awarded to **Jiaqi Yu** as well as to **Mak Shuk Kwan** of Cheung Sha Wan, Hong Kong. The **Anderson Bank Prize** for the best set of theory papers was awarded to **Ungkhana Atikarnsakul** of Bangkok, Thailand.

In the **Foundation Certificate in Gemmology** examination, the **Anderson Medal** for the candidate who submitted the best set of answers which, in the opinion of the examiners, were of sufficiently high standard, was awarded to **Zoe Elizabeth Lewis** of Sheffield, South Yorkshire, and to **Gaëlle Daru** of Antananarivo, Madagascar.

In the **Diamond Diploma** examination, the **Bruton Medal** for the best set of answers which, in the opinion of the examiners, were of sufficiently high standard, was awarded to **Marianne Pughe** of Hexham, Northumberland.

The **Deeks Diamond Prize** for the best set of theory answer papers of the year was awarded to **Anne Galmiche** of London.

The **Mok Diamond Practical Prize** for excellence in the Diamond Practical examination, sponsored by Dominic Mok of AGIL, Hong Kong, was awarded to **Lucy Bedeman** of London.

The **Tully Medal** was not awarded.

The names of the successful candidates are listed below.

Examinations in Gemmology

Gemmology Diploma

Qualified with Distinction

Atikarnsakul, Ungkhana, *Tungkru, Bangkok, Thailand*
Chen Shenrui, *Beijing, China*
Chen Yu, *Beijing, China*
Dong Kaihua, *Beijing, China*
Gong Linhui, *Changsha City, Hunan, China*
Guo Chulan, *Foshan, Guangdong, China*
Guo Hongshu, *Beijing, China*
Huang Haodong, *Beijing, China*
Jing Ruolin, *Beijing, China*
Li Jia Yuan, *Shanghai, China*
Li Wei, *Beijing, China*
Liao Siqin, *Beijing, China*
Liu Wenqing, *Beijing, China*
Lu Yuhan, *Kunshan City, Jiangsu, China*
Ma Chengyao, *Beijing, China*
Rogerson, Hannah, *Sevenoaks, Kent*
Rossi, Roberta, *Genoa, Italy*
Suzuki, Hiroki, *Tokorozawa-shi, Saitama, Japan*
Tanaka, Junko, *Tokyo, Japan*
Tsang, Rebecca, *San Marcos, California, USA*
Wang Xiaofang, *Beijing, China*
Wang Yu, *Beijing, China*
Wongrawang, Patcharee, *Bangrak, Bangkok, Thailand*
Wu Niuniu, *Beijing, China*
Xu Benyan, *Beijing, China*
Xu Hanyue, *Beijing, China*
Yu Jiaqi, *Beijing, China*
Zhao Chunyi, *Beijing, China*

Qualified with Merit

Bie Zhi Tao, *Shanghai, China*
Bigot, Violaine, *Versailles, France*
Chang Chia-Jui, *Taipei, Taiwan*
Chau Chui Ping, *Tin Shui Wai, Hong Kong*
Chau Pongki, *Beijing, China*
Chen Huimin, *Beijing, China*
Chen Yang, *Shanghai, China*
Chow Tinyi, *Prince Edward, Hong Kong*
Cui Jingjing, *Guangzhou, Guangdong, China*
Daru, Gaëlle, *Antananarivo, Madagascar*
Du Chen, *Shanghai, China*
Fukuchi, Yukiko, *Tokyo, Japan*
Grant, Henrietta, *London*
Huang Xiaotong, *Beijing, China*
Hung Chun Man, *Yau Ma Tei, Hong Kong*
Ju Dan, *Beijing, China*
Kang Jin, *Beijing, China*
Kawasaki, Kimie, *Tokyo, Japan*
Li Hiu Ying, *Chai Wan, Hong Kong*
Li Qiang, *Zhuhai City, Guangzhou, China*
Li Ruonan, *Shijiazhuang City, Hebei, China*
Li Xin, *Beijing, China*
Li Xinmei, *Beijing, China*
Li Yihang, *Beijing, China*
Liu Ruoyang, *Beijing, China*
Long Zhaoyang, *Beijing, China*
Lou Xiaomeng, *Beijing, China*
Lv Yingchen, *Beijing, China*
Maimenjiang Yilalai, *Beijing, China*
Masini, Chiara, *Florence, Tuscany, Italy*
Miao Ling, *Beijing, China*
Möller, Katharina, *Toronto, Ontario, Canada*
Peng Huizhong, *Beijing, China*
Sun Ziyin, *San Diego, California, USA*
Tian Yuan, *Wuhan City, Hubei, China*
Tjong Lee Ping, *Tsing Yi, Hong Kong*
Tong Hoi Yum, Louise, *Sham Shui Po, Hong Kong*
Tung Chun-Hsiao, *Douliu City, Yunlin County, Taiwan*
Von Baeyer, Anne, *London*
Wang Chenchen, *Beijing, China*
Wang Junlan, *Beijing, China*
Wang Xueding, *Beijing, China*
Wang Yuanyuan, *Beijing, China*
Wang Zihe, *Beijing, China*
Wei Zhongshu, *Shenyang City, Liaoning, China*
West, Beth, *Reading, Berkshire*
Xia Yuncong, *Wanchai, Hong Kong*
Xin Di, *Beijing, China*
Xu Chengcheng, *Beijing, China*
Xu Mudan, *Beijing, China*
Yan Hui Zhen, *Beijing, China*
Yang He, *Urumqi City, Xinjiang, China*
Yang Ruilan, *Beijing, China*
Yang Xihan, *Changde City, Hunan, China*
Yang Ming, *Beijing, China*
Yin Jiayi, *Beijing, China*
Yu Li, *Hamburg, Germany*
Zhang Biyao, *Beijing, China*
Zhang Shu, *Beijing, China*
Zhang Xiaomin, *Beijing, China*
Zhao Buqing, *Beijing, China*
Zheng Lili, *Beijing, China*
Zheng Yuyu, *Beijing, China*

Qualified

Agrawal, Rohan, *Bardonia, New York, USA*
Angus, Emily, *Petworth, West Sussex*
Baggott, Sophie Louise, *Plymouth, Devon*
Bai Liping, *Beijing, China*
Bai Yanning, *Beijing, China*
Bakshi, Anisha, *Birmingham, West Midlands*
Baume, Emilie, *Aigrefeuille-d'Aunis, France*
Benfield, Emma, *Winchester, Hampshire*
Bi Hanwen, *Shenzhen City, Guangdong, China*
Bockenmeyer, Ingrid, *Bangkok, Thailand*
Bupparenoo, Pimtida, *Bangkok, Thailand*
Cao Ying, *Bejing, China*
Chan Han-Wen, *Tainan, Taiwan*
Chan Yuen Ling Agnes, *Sheung Wan, Hong Kong*
Chang Tien-Chin, *Taipei City, Taiwan*
Chao Yi-Hsuan, *Taipei, Taiwan*
Chauvin, Alice, *Ventabren, France*
Che Zhengsheng, *Shaoxing, Zhejiang, China*

Chen Chi-Jer, *New Taipei City, Taiwan*
Chen Chi-Kuang, *New Taipei City, Taiwan*
Chen Hongyu, *Chongqing, China*
Chen Hsiao-Han, *New Taipei City, Taiwan*
Chen Hsuan-Wen, *Pingtung, Taiwan*
Chen Jianhua, *Chongqing, China*
Chen Jie, *Shanghai, China*
Chen Lian, *Guilin, Guangxi, China*
Chen Lu, *Danyang, Jiangsu, China*
Chen Suokai, *Shanghai, China*
Chen Wei Ci, *Shanghai, China*
Chen Wenwei, *Beijing, China*
Chen Xiaoxi, *Brockley, London*
Chen Xiaoyi, *Beijing, China*
Chen Yanqiu, *Beijing, China*
Chen Yuhan, *Guilin, Guangxi, China*
Cheng Wen Hsin, *Kaohsiung City, Taiwan*
Cheung Chak Ting, Christine, *Kadoorie Hill, Hong Kong*
Cheung Shuk Ting, *Tsing Yi, Hong Kong*
Chiang Rei Yi, *New Taipei City, Taiwan*
Cho Shuk Ping, *Hunghom, Hong Kong*
Choi Yi Ling, *Shatin, Hong Kong*
Chow Sze Kam, *Tuen Mun, Hong Kong*
Chu Jie Wei, *Shanghai, China*
Chu Pik Wa, *Kwai Chung, Hong Kong*
Chuan Wang Hsin, *Taichung City, Taiwan*
Chuang Su-Ying, *Taipei, Taiwan*
Chung Wen-Hao, *Hualien, Taiwan*
Chung Yu-Chen, *Taichung City, Taiwan*
Coquebert de Neuville, Jehan, *Boulogne-Billancourt, France*
Cui Wen, *Kunming City, Yunnan, China*
Dai Yi Qing, *Shanghai, China*
Daver, Lucille, *Montreal, Québec, Canada*
De Samie, Cecile, *Limoges, France*
Ding Xinghua, *Yan'an City, Shanxi, China*
Dobrzanski, Andrew, *Edinburgh, Scotland*
Dong Ruinan, *Dalian, Liaoning, China*
Dong Yitan, *Liaoning Province, China*
Drault-Bisaillon, Mathieu, *Longueuil, Québec, Canada*
Du Jialin, *Beijing City, China*
Dubois, Nastasia, *Brunoy, France*
Duperrut, Didier, *Antananarivo, Madagascar*
Ebalard, Dominique, *Saint-Germain-en-Laye, France*
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Fang Jun, *Suzhou City, Jiangsu, China*
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Flynn, Inez, *London*
Fortunato, Francesca, *Rome, Italy*
Francey, Daniel, *Auckland, New Zealand*
Fuchino, Izumi, *Urayasu-Shi, Chiba, Japan*
Fung Hang Shun, Jessica, *Tai Po, Hong Kong*
Gan Zexuan, *Guilin, Guangxi, China*
Gao Shuo, *Guangzhou, China*
Garcia Lopez, Melissa, *Montreal, Québec, Canada*
Garvey, Francesca, *Sale, Cheshire*
Ge Chen Lei, *Shanghai, China*
Ge Yuexia, *Saint-Hubert, Québec, Canada*
Geijsen, Lara Nicole Irene, *Amsterdam, Netherlands*
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Hai Midi, *Beijing, China*
Han Dongmei, *Shenzhen City, Guangdong, China*
Han Jingyu, *Beijing, China*
Han Yi, *Beijing, China*
Hann, Janet, *Dubai, UAE*
Hao Sijia, *Beijing, China*
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Hopkins, Prudence, *Debden, Essex*
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Kirad, Rasika, *Pune, India*
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Kuo Chang-Cheng, *Kaohsiung City, Taiwan*
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Kuo Yi-Qian, *Taipei City, Taiwan*
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Shekhar, Aarti, *New Delhi, India*
Shih Mei-Yu, *Xinbei City, Taiwan*
Shiham, Mohamed Mohamed Nizar, *Beruwala, Sri Lanka*
Simon, Sophie, *Marseille, France*

Sit Shan Na, *Tseung Kwan O, Hong Kong*
Sohm Reubi, Felicitas, *Montreal, Québec, Canada*
Song Na, *Wuhan City, Hubei, China*
Song Yixiong, *Xianyang City, Shanxi, China*
Sonoda, Tetsuro, *Fukuoka, Japan*
Spencer, Sally Jane, *Didcot, Oxfordshire*
Stapleton, Rebecca, *Chelmsford, Essex*
Su Xin Yao, *Yuhuan, Zhejiang, China*
Su Zeya, *Shenzhen, Guangdong, China*
Sudprasert, Patharaphum, *Bangkok, Thailand*
Sumino, Akiko, *Kanagawa, Japan*
Sun Jialiang, *Harbin, Heilongjiang, China*
Sun Jingyao, *Beijing, China*
Sun Xin, *Tianjin, China*
Sz Wing, *Chai Wan, Hong Kong*
Tai Hsiao Ting, *Taipei, Taiwan*
Takeda, Ami, *Ibaraki, Japan*
Tam Suk Han, Sara, *Ma On Shan, Hong Kong*
Tang Lun-Yu, *New Taipei City, Taiwan*
Tang Qianru, *Shaoguan City, Guangdong, China*
Thatcher, Laura, *London*
Tian Yuan, *Qingdao City, Shandong, China*
Ting Evon, *Tsuen Wan, Hong Kong*
Ting Po-Jui, *Taichung City, Taiwan*
Tong, Runhui, *Beijing, China*
Tsai Cheng Tao, *Kaoshiung, Taiwan*
Tsai Hsin-Chen, *Kaohsiung, Taiwan*
Tsai Ya Ni, *New Taipei City, Taiwan*
Tsang Man, Judy, *Siu Sai Wan, Hong Kong*
Tsuboi, Mina, *Tokyo, Japan*
Tsui Yu-Yen, *Kaohsiung City, Taiwan*
Tu En, *Taipei City, Taiwan*
U Wai Fan, *Kowloon, Hong Kong*
Van Eerde, Christa Lynn, *North Haledon, New Jersey, USA*
Van Leeuwen, Suzanne, *Amsterdam, Netherlands*
Vertriest, Wim, *Bangrak, Bangkok, Thailand*
Vuillaume-Stap, Charlotte, *Fishbourne, West Sussex*
Wang Changsong, *Beijing, China*
Wang Haoyu, *Taiyuan City, Taiyuan, China*
Wang Jiaying, *Beijing, China*
Wang Juo-Ping, *New Taipei City, Taiwan*
Wang Kexin, *Beijing, China*
Wang Lu, *Dalian City, Liaoning, China*
Wang Na, *Beijing, China*
Wang Shuo, *Beijing, China*
Wang Tuan Lien, *Kaohsiung City, Taiwan*
Wang Wei-Ying, *Taipei City, Taiwan*
Wang Xi, *Shanghai, China*
Wang Xiao Ying, *Shanghai, China*
Wang Xiaoyu, *Shenzhen City, Guangdong, China*
Wang Xuan, *Beijing, China*
Wang Yanjia, *Baotou City, Inner Mongolia, China*
Wang Yuhua, *Beijing, China*
Wang Yuwen, *Beijing, China*
Wang Zeyuan, *Beijing, China*
Weber, Laurence, *Geneva, Switzerland*
Wei Jung-Huan, *Taoyuan City, Taiwan*
Wei Yi, *Xuchang City, Henan, China*
Wei Ying, *Qinzhou City, Guangxi, China*
Weng Mei Han, *Taipei City, Taiwan*
Wicker, Joanne, *Ashford, Kent*
Wong Ching Man, *Discovery Bay, Hong Kong*
Wong Ho Yin, *Tai Po, Hong Kong*
Wong Kwong Mei Ice, *Mong Kok, Hong Kong*
Wong Wai Ki, Vikki, *Shatin, Hong Kong*
Wong Yik Ling, *Yuen Long, Hong Kong*
Wu Bin, *Verdun, Québec, Canada*
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Xu Jiayin, *Balwyn, Victoria, Australia*
Xu Jun, *Shanghai, China*
Xu Wei, Karen, *Leeds, West Yorkshire*
Xu Xian, *Shanghai, China*
Xu Yao, *Beijing, China*
Xu Zheng, *Nanyang, Henan, China*
Xue Qi, *Beijing, China*
Yan An, *Guilin, Guangxi, China*
Yang Jia Hui, *Shanghai, China*
Yang Fan, *Shanghai, China*
Yang Han, *Guangzhou, China*
Yang Ming-Hsun, *Tainan City, Taiwan*
Yang Rujie, *Beijing, China*
Yang Shu-Yun, *Taoyuan, Taiwan*
Yang Wei, *Beijing, China*
Yang Ya-Chu, *London*
Yao Han, *Beijing, China*
Ye Danning, *Beijing, China*
Ye Ziying, *Guilin, Guangxi, China*
Yeh Chen-Wei, *New Taipei, Taiwan*
Yim Cheukying, *Tsing Yi, Hong Kong*
Yin Wenqing, *Bangkok, Thailand*
Yin Yiming, *Anshan City, Liaoning, China*
Yu Chen, *Hefei City, Anhui, China*
Yu Qunjie, *Beijing, China*
Yu Shih Yang, *Taipei City, Taiwan*
Yu Tzu Fang, *Zhudong Township, Taiwan*
Yu Xinmiao, *Beijing, China*
Yu Yi Fen, *Kaohsiung City, Taiwan*
Yuan Tsao Chang, *Taoyuan, Taiwan*
Yuan Yue, *Beijing, China*
Yuanyuan Qin, *Guilin, Guangxi, China*
Zeng Ming, *Wuhan City, Hubei, China*
Zeng Zhukun, *Loudi City, Hunan, China*
Zgraja, Amy, *London*
Zhang Dongmei, *Beijing, China*
Zhang Dongyu, *Beijing, China*
Zhang Hemin, *Xian City, Shanxi, China*
Zhang Jing, *Beijing, China*
Zhang Jing Yao, *Haimen City, Jiangsu, China*

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Videlier, Marie, *Savigny le Temple, France*
Vildiridi, Lilian Venetia, *Knightsbridge, London*
Vitharana, Padma, *Ratnapura, Sri Lanka*
Wang Fan, *Beijing, China*
Wang Hsin-Ning Stacey, *Taiwan*
Wang Hui, *Beijing, China*
Wang Jinyi, *Kowloon, Hong Kong*
Wang Juo-Ping, *New Taipei City, Taiwan*
Wang Lin, *Beijing, China*
Wang Mu Tan, *Taipei, Taiwan*
Wang Shufei, *Jilin Province, China*
Wang Shuming, *Beijing, China*
Wang Tuan Lien, *Kaohsiung City, Taiwan*
Wang Wei Feng, *Shanghai, China*
Wang Wei-Ling, *Taipei City, Taiwan*
Wang Wei-Ying, *Taipei City, Taiwan*
Wang Xiaojun, Shawn, *London*
Wang Yuqing, *Beijing, China*
Watanabe, Hiromi, *Musashino-shi, Tokyo, Japan*
Weerasinghe, Piyumal, *Colombo, Sri Lanka*
Wei Jian Feng, *Kowloon, Hong Kong*
Wei Jung-Huan, *Taoyuan City, Taiwan*
Wei Yanshi, *Guilin, China*
Wen Fang, *Shanghai, China*
Weng Yi Fan, *Shanghai, China*
West, Beth, *Reading, Berkshire,*
Widmer, Stephanie Andrea, *Singapore*
Williams, Charlotte, *London*
Winnicott, Elizabeth, *Birmingham, West Midlands*
Wolf, Fabian Nikolaus, *Braintree, Essex*
Wong Hiu Mei, *Tsing Yi, Hong Kong*
Wong Mei Tsz Macy, *Tin Shui Wai, Hong Kong*
Wong Shu Hung, *Chai Wan, Hong Kong*
Wong Sze Wan, *Yaumatei, Hong Kong*
Wong Sze Ling, *Quarry Bay, Hong Kong*
Wray, Vanessa, *Mississauga, Ontario, Canada*
Wright, Emma, *London*
Wu Bin, *Verdun, Québec, Canada*
Wu Dan Qing, *Wuxi City, Jiangsu, China*
Wu Jing, *Zhejiang, China*
Wu Lan, *Suzhou City, Jiangsu, China*
Wu Lingyi, *Guilin, China*
Wu Pei-Hsuan, *New Taipei City, Taiwan*
Wu Siying, *Beijing, China*
Wu Siyu, *Saitama, Japan*
Wu Tong, *Beijing, China*
Wu Wei-Ting, *Tapei City, Taiwan*
Wu Xi Xi, *Wen Zhou, China*
Wu Yi-Ching, *Taipei, Taiwan*
Xiao, Yuyue, *London*
Xie Wen Hua, *Shanghai, China*
Xie Xiaotong, *Shijiazhuang, Hebei, China*
Xing Xinyu, *Guilin, Guangxi, China*
Xu Bei Wen, *Shanghai, China*
Xu Chen, *Guangde, Anhui, China*
Xu Wei, Karen, *Leeds, West Yorkshire*
Xu Yu Sheng, *Liupanshui City, Guizhou, China*
Xu Zhao Jie, *Shanghai, China*
Xuan Zhe Wen, *Shanghai, China*
Yamada, Sayaka, *Kobe City, Hyogo, Japan*
Yamamoto, Natsumi, *Kashiwa-shi, Chiba, Japan*
Yan An, *Guilin, Guangxi, China*
Yan Yen, Isabella, *Winchmore Hill, London*
Yang Lin, *Beijing, China*
Yang Meng-Pei, *New Taipei City, Taiwan*
Yang Shu Ran, *Shenzhen, Guangdong, China*
Yang Shu-Yun, *Taoyuan, Taiwan*
Yang Tsun-Wen, *Kaohsiung, Taiwan*
Yang Zhuo, *Beijing, China*
Yanping, Lan, *Colombo, Sri Lanka*
Ye Ziying, *Guilin, Guangxi, China*
Yeh Chen-Wei, *New Taipei, Taiwan*
Yin Wenqing, *Bangkok, Thailand*
Yip Tak Wai, *To Kwa Wan, Hong Kong*
Yoshida, Yuzuru, *Tokyo, Japan*
Yu Hangwei, *Guilin, Guangxi, China*
Yu Li, *Hamburg, Germany*
Yuan Tsao Chang, *Taoyuan, Taiwan*

Yuan Xue, *Beijing, China*
Yuan Zhi Ying, *Zhongshan City, Guangdong, China*
Yuen Ching Chi, *Diamond Hill, Hong Kong*
Yuen Hoi Ling, *Choi Wan, Hong Kong*
Yun Menghe, *Beijing, China*
Zeng Zhiyao, *Shenyang, Liaoning, China*
Zhang Bowen, *Beijing, China*
Zhang Hong, *Guangzhou, Guangdong, China*
Zhang Lei Tong, *Nanchang, Jiangxi, China*
Zhang Lili, *Zhucheng, Shandong, China*
Zhang Ling, *Tianjin, China*
Zhang Qidong, *Beijing, China*
Zhang Shuo, *Tokyo, Japan*
Zhang Tianran, *Beijing, China*
Zhang Xin, *Beijing, China*
Zhang Yi, *Guilin, Guangxi, China*
Zhang Yue, *Beijing, China*
Zhang Yumei, *Foshan, Guangdong, China*
Zhang Yuxin, *Xuzhou City, Jiangsu, China*
Zhang Yuxue, *Beijing, China*
Zhang Yuyan, *Guangzhou, Guangdong, China*
Zhang Zhuohan, Jessica, *London*
Zhao He, *Xinxiang, Henan, China*
Zhao Jiahui, *Foshan, Guangdong, China*
Zhao Jing Ling, *Guizhou, China*
Zhao Longpei, *Guangzhou, Guangdong, China*
Zhao Xi, *Shenyang, Liaoning, China*
Zhao Xiaoqian, *Paris, France*
Zheng Manqiao, *Hung Hom, Hong Kong*
Zheng Zehui, *Kaifeng, Henan, China*
Zhong Yuliang, *Shaoxing, Zhejiang, China*
Zhou Chen Yuan, *Hangzhou, Zhejiang, China*
Zhou Jie, *Hangzhou, Zhejiang, China*
Zhou Qi, *Shanghai, China*
Zhou Shixu, *Beijing, China*
Zhu Fei Yan, *Shanghai, China*
Zhu Li, *Shanghai, China*
Zhuang Shao Bai, *Shanghai, China*
Zong Rui, *Beijing, China*
Zou Yin, *Nanchang, Jiangxi, China*

Diamond Diploma Examination

Qualified with Distinction

Botros, Michael Youssef, *Cairo, Egypt*
Bullock, Emily, *Birmingham, West Midlands*
Chen Chi-Jer, *New Taipei City, Taiwan*
Fung Chun Yan, *Shatin, Hong Kong*
Galmiche, Anne, *London*
Garcia-Carballido, Carmen, *Tarves, Aberdeenshire, Scotland*
Guy, Angharad, *London*
Harding, Kealey, *Trinity, Jersey*
Haylett-Mustafa, Gaynor, *St Neots, Cambridgeshire*
Hug, Samuel Richard John, *Rochester, Kent*
Ibison, Hannah, *Garstang, Lancashire*
Katayama (Flores), Jurin, *St Andrews, Fife, Scotland*
Koroma, Barickeh Charles Kholifa, *Romford, London*
Li Renjing, *Beijing, China*
Logan, Amy, *Birmingham, West Midlands*
Longhurst, Stephanie, *Blandford Forum, Dorset*
Patel, Hemma, *London*
Pregun, David, *Birmingham, West Midlands*
Pughe, Marianne, *Hexham, Northumberland*
Saruwatari, Kazuko, *Tokyo, Japan*
Simmonds, Amy, *London*
Vogt, Kai-Ludwig, *Leyton, London*
Wicker, Joanne, *Ashford, Kent*
Williams, Rick, *Henley on Thames, Oxfordshire*
Winnicott, Elizabeth, *Birmingham, West Midlands*
Yamamoto, Akiko, *Tokyo, Japan*
Yu Wen Li, *New Taipei City, Taiwan*
Yuan Tsao Chang, *Taoyuan, Taiwan*

Qualified with Merit

Barrow, Fay, *Whitchurch, Shropshire*
Cadzow-Collins, Jessica, *London*
Chen, Victoria, *London*
Chow Pui Yi, *Lai Chi Kok, Hong Kong*
Dieu de Bellefontaine, Mary, *Billericay, Essex*
Hall, Claire-Louise, *Newcastle upon Tyne, Tyne and Wear*
Horner, Oliver, *Bounds Green, London*
Jeffrey, Christopher (Kip), *Burras, Helston, Cornwall*
Kouya, Yuriko, *Tokyo, Japan*
Krontira, Sophia, *Lamia, Greece*
Lui Wing-Tak, *New Taipei City, Taiwan*
Pettersson, Rachel, *Norrtelje, Sweden*
Poon, Shuk Chong, Mimien, *Ilford, London*
Suttie, Laura, *Croydon, Surrey*
Wang Wei-Ying, *Taipei City, Taiwan*
Ward, Sanya Lisa, *Alton, Hampshire*
Wong Tik, *Kwai Chung, Hong Kong*
Yan Ming Wai, Iris, *Quarry Bay, Hong Kong*
Yang Mei, *Beijing, China*
Yip Tak Wai, *To Kwa Wan, Hong Kong*
Zirogiannis, Athanasios, *Athens, Greece*

Qualified

Bagga, Parvinder, *Sutton Coldfield, West Midlands*
Balmer, Isabel, *Derby, Derbyshire*
Becket, Alexandra, *Birmingham, West Midlands*
Bergamin, Irene, *Zurich, Switzerland*
Boccardo, Laura, *Genova, Italy*
Brown, Gareth, *Bristol*
Chan Hiu Lam, Patsy, *Tai Po, Hong Kong*
Cheng Kwok Hoo, Henry, *Quarry Bay, Hong Kong*
Cheng Yueqin, *Tsuen Wan, Hong Kong*
Cupples, Laura, *Birmingham, West Midlands*
Dang Jing, *Hunghom, Hong Kong*
Eguchi, Yumi, *Tokyo, Japan*
Farrell, Stefanie Patricia, *London*
Feng Shaw-Lynn, *Taipei City, Taiwan*
Ho Ka Ying, *Chai Wan, Hong Kong*
Hong Shilei, *Beijing, China*
Horrocks, Anthony, *Gillingham, Dorset*

Hsieh Meng-Chun, *Taipei, Taiwan*
Hung Erh-Nu, *New Taipei City, Taiwan*
Hunt, Lauren, *Birmingham, West Midlands*
Ibrahim Sharif, Sucaad, *Birmingham, West Midlands*
Kim, Heekyung, *New Malden, Surrey*
Ko Feng-Hua, *Taoyuan City, Taiwan*
Krawiec, Natalia, *Birmingham, West Midlands*
Lai Kwok Hung, Andy, *Tsing Yi, Hong Kong*
Lai Pin-Miao, *Taipei, Taiwan*
Lam Wing Yee, *Tin Shui Wai, Hong Kong*
Lau Yu Hang, *Kwun Tong, Hong Kong*
Law Lai Kuen, *Kowloon City, Hong Kong*
Lee Hsin Ping, *Taipei City, Taiwan*
Lee Tak Yan, *Tsing Yi, Hong Kong*
Lee Yu-Erh, *Taipei, Taiwan*
Leung Car Ni, *Quarry Bay, Hong Kong*
Leung Kin Ping, *Yau Tong, Hong Kong*
Leung Sze Wai, *Tsueng Kwan O, Hong Kong*
Leung Yuen Man, *Tseung Kwan O, Hong Kong*
Lister Kroening, Susan, *Leeds, West Yorkshire*
Liu Yi-Lin, *New Taipei City, Taiwan*
Lusher, Lila, *Whangarei, Northland, New Zealand*
Man Yat Chun, *Wong Tai Sin, Hong Kong*
Medi, Tanyol, *Eastbourne, East Sussex*
Mok Kan Pong, *Sheung Shui, Hong Kong*
Ng Chin Kiu, *Tin Shui Wai, Hong Kong*
Reid, Evie, *Tunbridge Wells, Kent*
Robinson, Sophie Helen, *West Hampstead, London*
Shih Yu Hong, *New Taipei City, Taiwan*
So Yuk Mei, *Tuen Mun, Hong Kong*
Statton, Andrew James, *Ivybridge, Devon*
Sze Yuen Tung, *Kwun Tong, Hong Kong*
Tam Wai Man, *Wanchai, Hong Kong*
Tang Chun Shan, *Tai Po, Hong Kong*
Templeton, Heather, *Stewarton, East Ayrshire, Scotland*
Thacker, Zara, *London*
Thomas, Lauren, *Birmingham, West Midlands*
Trolle, Natascha, *Copenhagen, Denmark*
Tsang Hing Cheung, *Sheung Wan, Hong Kong*
Westmoreland, Samantha, *Burntwood, Staffordshire*
Wong Shi Kam, *Tsuen Wan, Hong Kong*
Wong Cheuk Ying, *Kowloon Tong, Hong Kong*
Wright, Emma, *London*
Wu Chung-Kang, *New Taipei City, Taiwan*
Wu On Kei, *Wong Chuk Hang, Hong Kong*
Xia Liyu, *Beijing, China*
Xue, Zixuan, *Birmingham, West Midlands*
Yat, Richard, *Tung Chung, Hong Kong*
Yeh Ji-Miao, *New Taipei City, Taiwan*
Yoong Li Min, Rachel, *Birmingham, West Midlands*
Yu Wing Yan, *Tsing Yi, Hong Kong*
Yuen Angel, *Tsuen Wan, Hong Kong*

OBITUARY

Alfred Douglas Morgan
1919–2017

It is announced with great sadness that Alfred Douglas (Doug) Morgan FICME FGA (D. 1969), Birmingham, West Midlands, passed away on 20 November 2017. On 21 October 2017 he suffered a stroke which led to gradual deterioration of his health.

Born 1 March 1919, Doug lived to the age of 98. He pursued a varied career in the industries associated with cast iron and foundries, spearheading their technical development to general acclaim. Over the years and after his retirement, he became well-known in many spheres including mineralogy, microscopy, gemmology and faceting.

Doug received his early chemical and metallurgical training at Birmingham College of Technology. In 1936 he joined the British Cast Iron Research Association (BCIRA) as analytical chemist dealing with methods of microanalysis of non-metallic inclusions and, during World War II, he was involved with the development of nickel-molybdenum acicular cast irons and the physical testing of cast iron. In 1944 he became metallurgist at the Idoson Motor Cylinder Co., where he developed the production of acicular irons for the Avon aircraft jet engine and introduced the new shell moulding process for intricate automobile

Doug at 95 years of age.

cylinder castings. In 1953 he became chief metallurgist at the Radiation Group Central Research Laboratories, where he investigated problems arising in the vitreous enamelling of cast iron and steel and, as a Fellow of the Institute of British Foundrymen (now the Institute of Cast Metals Engineers), was awarded a diploma for his work on the role of manganese sulphide segregation in causing enamelling defects.

In 1956 he re-joined BCIRA as development engineer and, in 1959, was appointed head of the Moulding Materials and Methods Investigation Group. His work on the testing and control of processes using the newly introduced furfuryl-phenol formaldehyde resin binders resulted in the invention of the BCIRA hot distortion tester and the design of other high-temperature methods for testing core-making materials. Following this he was instrumental in developing the sand casting process.

His pioneering work on the study of waste foundry sand reclamation pertained to the industrial development of this highly important ecological and economical aspect of the industry, and indicated the direction that should be taken to avoid complex problems of nitrogen and hydrogen pick-up by the liquid metal. During this period he served as chairman of the Foundry Industry Joint Sand Committee, and also as a council member of the Institute of British Foundrymen and as Great Britain delegate to CIATF Commission 1.5 dealing with standardisation of test sieves for moulding sand. He continued to investigate slag and refractory problems and, in 1963, he published an article titled 'Identification of slag and dross inclusions' that became the main reference work dealing with the subject. The optical work involved with this research triggered his interest in crystallography and mineralogy, which later became his dominating interests.

Doug's lectures in moulding and core-making technology—usually ending in a specially composed verse—were well-known, and his publication of over 30 papers and technical articles resulted in him being awarded the prestigious Oliver Stubbs Gold Medal for services to the industry by the National Iron-Founding Employers Federation. Doug reported that, when presented with the medal, he was told "The best thing you can do with this, dear boy, is to pawn it!"

In 1969 Doug passed the Diploma of Gemmology and became a Fellow of the Gemmological Association of Great Britain. He lectured in this subject at Birmingham Institute of Art and Design School of Jewellery and Silversmithing (later to become the University of Central England and then Birmingham City University). In addition, he presented his 'Reflections on Gemstones' at numerous international conferences. He served as chairman of the Midlands Branch of the Gemmological Association during its 25th anniversary in 1977. Doug retired in 1984, and served on the council of the Association from 1983 to 1990. He became a skilled gem cutter and was a member of the UK Facet Cutters' Guild. His article 'Development of concave cutting of gemstones' was published in *The Journal* in 2002 (Vol. 28, No. 4, pp. 193–209).

Doug was curator of the reference collection of the British Micromount Mineral Society, and a member of the Postal Microscopical Society and the Russell Society. In 2000 he received the Eric Marson Award of the Queckett Microscopical Club for 'excellence in microscopical preparation'. In 2008 he was awarded the Founders' Cup of the British Micromount Society.

Doug continued to be an active committee member of the Midlands Branch of the Gemmological Association into his early nineties. In 2012 he exhaustively researched the formation of tiger's-eye in an article titled 'Tiger's-eye revisited', published in *Gems&Jewellery* (Vol. 21, No. 3, pp. 8–12). He had a special interest in producing superbly faceted fluorite, but less well known was that fact that he fashioned the neodymium-doped YAG filters for the Hubble telescope.

Doug was a lovely man of many facets whose life was remarkable. He was modest but aware of his valued contributions to many individuals and organizations, both official and informal, having been involved with diverse activities. His enthusiasm, great knowledge, wisdom and keen sense of humour inspired us all. He was always stimulating company, of enormous generosity giving readily of time and effort to those around him. His thought-provoking insights and quiet reflections, and the sensitive and understanding way he dealt with difficulties posed by others, made him a role model that few could emulate. His energy and drive were such that, in his nineties, he worked on and completed challenging projects that would have deterred many people half his age. His kind entertaining manner, keen mind and lively sense of humour will be sorely missed.

Doug's wife Edna, who died in 1996, was a great supporter of his activities, and her learning in languages and teaching had a strong influence on the quality of his work. We send our condolences and heartfelt good wishes to his daughters, son-in-law, grandchildren and great grandchildren. We have lost a man of great magnitude.

Gwyn Green FGA DGA

Learning Opportunities

CONFERENCES AND SEMINARS

Symposium: 'Commerce with All the World'—Being a Goldsmith in the 16th and 17th Centuries
19 January 2018
The Goldsmiths' Company, London, UK
www.thegoldsmiths.co.uk/company/today/events/2018/symposium-commerce-all-world-being-goldsmith-16th-

49th ACE© IT Annual Winter Educational Conference
28–29 January 2018
Tucson, Arizona, USA
www.najaappraisers.com/html/conferences.html

Diamonds: Geology, Gemology and Exploration
29 January–2 February 2018
Bressanone, Italy
www.internationaldiamondschool.org

AGTA Gemfair
30 January–4 February 2018
Tucson, Arizona, USA
www.agta.org/tradeshows/gft-seminars.html
Note: Includes a seminar programme

2018 AGA Tucson Conference
31 January 2018
Tucson, Arizona, USA
www.accreditedgemologists.org/currevent.php

2018 Tucson Gem and Mineral Show: Crystals and Crystal Forms
8–11 February 2018
Tucson, Arizona, USA
www.tgms.org/show
Note: Includes a seminar programme

23rd Hasselt Diamond Workshop
7–9 March 2018
Hasselt, Belgium
www.uhasselt.be/sbdd

Jewelry Industry Summit
9–10 March 2018
New York, New York, USA
www.jewelryindustrysummit.com

Amberif—25th International Fair of Amber, Jewellery & Gemstones
21–24 March 2018
Gdańsk, Poland
http://amberif.amberexpo.pl/title,Jezyk,lang,2.html
Note: Includes a seminar programme

inArt2018—3rd International Conference on Innovation in Art Research and Technology
26–29 March 2018
Parma, Italy
www.inart2018.unipr.it

European Geosciences Union General Assembly 2018
8–13 April 2018
Vienna, Austria
https://egu2018.eu
Session of interest: Gem Materials

2nd International Conference on Diamond, Graphite & Carbon Materials
16–17 April 2018
Las Vegas, Nevada, USA
http://diamond-carbon.conferenceseries.com/symposium.php

45th Rochester Mineralogical Symposium
19–22 April 2018
Rochester, New York, USA
www.rasny.org/minsymp

American Gem Society Conclave
23–26 April 2018
Nashville, Tennessee, USA
www.americangemsociety.org/page/conclave2018

Scottish Gemmological Association Conference
4–6 May 2018
Cumbernauld, Scotland
www.scottishgemmology.org/conference

4th Mediterranean Gem and Jewellery Conference
18–20 May 2018
Budva, Montenegro
www.gemconference.com
Note: Includes workshops on ruby and sapphire, emerald, diamond and diamond identification with advanced instruments

The 32nd Annual Santa Fe Symposium
20–23 May 2018
Albuquerque, New Mexico, USA
www.santafesymposium.org

Compiled by Sarah Salmon and Brendan Laurs

The 12th International New Diamond and Nano Carbons Conference
20–24 May 2018
Flagstaff, Arizona, USA
www.mrs.org/ndnc-2018

Society of North American Goldsmiths' 47th Annual Conference
23–26 May 2018
Portland, Oregon, USA
www.snagmetalsmith.org/conferences/made

JCK Las Vegas
1–4 June 2018
Las Vegas, Nevada, USA
http://lasvegas.jckonline.com/en/Events/Education
Note: Includes a seminar programme

SAIMM: Diamonds – Source to Use 2018
11–14 June 2018
Johannesburg, South Africa
http://tinyurl.com/y9k5spzu
Note: Includes a pre-conference workshop and post-conference technical visits

Scandinavian Gem Symposium
Kisa, Sweden
16–17 June 2018
https://sgs.gemology.se

22nd Meeting of the International Mineralogical Association
13–17 August 2018
Melbourne, Victoria, Australia
www.ima2018.com
Sessions of interest:
- Recent Advances in our Understanding of Gem Minerals
- Sciences Behind Gemstone Treatments
- Mantle Xenoliths, Kimberlites and Related Magmas: The Diamond Trilogy

29th International Conference on Diamond and Carbon Materials
2–6 September 2018
Dubrovnik, Croatia
http://tinyurl.com/yb5d9t4x

6th European Conference on Crystal Growth
16–20 September 2018
Varna, Bulgaria
http://eccg6.eu

Mallorca GemQuest II
22–23 September 2018
Sóller, Mallorca, Spain
www.mallorcagemquest.com

2018 GIA Symposium: New Challenges. Creating Opportunities
7–9 October 2018
Carlsbad, California, USA
http://discover.gia.edu/symposium

CGA Gemmological Conference
19–21 October 2018
Vancouver, British Columbia, Canada
Email: info@canadiangemmological.com

EXHIBITIONS

Europe

Companions. Jewellery and Objects from Saskia Detering and Peter Frank
Until 14 January 2018
GfG, Hanau, Germany
http://tinyurl.com/yayj2epx

Dazzling Desire: Diamonds and Their Emotional Meaning
Until 14 January 2018
Museum aan de Stroom, Antwerp, Belgium
www.mas.be/en/activity/dazzling-desire

The European Triennial for Contemporary Jewellery 2017
Until 4 February 2018
WCC-BF, Mons, Belgium
http://tinyurl.com/yc7l34ox

The Russia Season: Royal Fabergé
Until 11 February 2018
Sainsbury Centre for Visual Arts, Norwich, Norfolk
https://scva.ac.uk/art-and-artists/exhibitions/the-russia-season

Hague Chic – Steltman: 100 Years of Jewellery and Silverware
Until 18 February 2018
Gementeemuseum Den Haag, The Hague, The Netherlands
www.gemeentemuseum.nl/en/exhibitions/centenary-celebration-steltman-jewellers

Pretty on Pink – Éminences Grises in Jewellery
Until 25 February 2018
Schmuckmuseum, Pforzheim, Germany
www.schmuckmuseum.de/flash/SMP_en.html

Contemporary Jewellery Exhibition "Heartbeats in Winter Mittens"
Until 28 February 2018
Putti Art Gallery, Riga, Latvia

https://putti.lv/en/event/contemporary-jewellery-exhibition-heartbeats-winter-mittens

Gold! Watches and Jewellery Collected by Sophia Lopez Suasso
Until 2 April 2018
Cromhouthuis, Amsterdam, The Netherlands
www.cromhouthuis.nl/en/activities/gold-collected-sophia-lopez-suasso

Modernist Jewellery
Until 29 April 2018
National Museum of Scotland, Edinburgh
http://tinyurl.com/y9oq29p8

Fibulae
Until 3 June 2018
Rijksmuseum, Leiden, The Netherlands
www.rmo.nl/english/exhibitions/fibulae

Smycken: Jewellery—From Decorative to Practical
Ongoing
Nordiska Museet, Stockholm, Sweden
www.nordiskamuseet.se/en/utstallningar/jewellery

North America

The Glamour and Romance of Oscar de la Renta
Until 28 January 2018
The Museum of Fine Arts, Houston, Texas, USA
www.mfah.org/exhibitions/glamour-romance-oscar-de-la-renta

Golden Kingdoms: Luxury and Legacy in the Ancient Americas
Until 28 January 2018
Getty Center, Los Angeles, California, USA
www.getty.edu/visit/cal/events/ev_1726.html

Wiener Werkstätte 1903–1932: The Luxury of Beauty
Until 29 January 2018
Neue Galerie, New York, New York, USA
www.neuegalerie.org/content/wiener-werkst%C3%A4tte-1903-1932-luxury-beauty

Extravagant Objects: Jewelry and Objects d'Art from the Masterson Collection
Until 18 March 2018
The Museum of Fine Arts, Houston, Texas
www.mfah.org/exhibitions/extravagant-objects-jewelry-masterson-collection-rienzi

Bestowing Beauty: Masterpieces from Persian Lands
Until 11 February 2018
The Museum of Fine Arts, Houston, Texas, USA
www.mfah.org/exhibitions/bestowing-beauty-masterpieces-persian-lands

Glorious Splendor: Treasures of Early Christian Art
Until 18 February 2018
Toledo Museum of Art, Ohio, USA
http://tinyurl.com/y94bebz4

Peacock in the Desert: The Royal Arts of Jodhpur, India
4 March–19 August 2018
The Museum of Fine Arts, Houston, Texas, USA
www.mfah.org/exhibitions/peacock-in-desert-royal-arts-jodhpur-india

Beads: A Universe of Meaning
Until 15 April 2018
The Wheelwright Museum of the American Indian, Santa Fe, New Mexico, USA
https://wheelwright.org/exhibitions/beads

Jewelry of Ideas: Gifts from the Susan Grant Lewin Collection
Until 28 May 2018
Cooper Hewitt, Smithsonian Design Museum, New York, New York, USA
www.cooperhewitt.org/channel/jewelry-of-ideas

American Jewelry from New Mexico
2 June–14 October 2018
Albuquerque Museum, New Mexico, USA
www.albuquerquemuseum.org/exhibitions/upcoming-exhibitions?/exhibition/103

Fabergé Rediscovered
9 June 2018–13 January 2019
Hillwood Estate, Museum & Gardens, Washington DC, USA
www.hillwoodmuseum.org/exhibitions/faberg%C3%A9-rediscovered

After Fabergé
Until 24 June 2018
The Walters Art Museum, Baltimore, Maryland, USA
https://thewalters.org/events/event.aspx?e=4952

Fabergé and the Russian Crafts Tradition: An Empire's Legacy
Until 24 June 2018
The Walters Art Museum, Baltimore, Maryland, USA
https://thewalters.org/events/event.aspx?e=4769

Past is Present: Revival Jewelry
Until 19 August 2018
Museum of Fine Arts, Boston, Massachusetts, USA
www.mfa.org/news/past-is-present-revival-jewelry

Centuries of Opulence: Jewels of India
Until 10 October 2018
GIA Museum, Carlsbad, California, USA
www.gia.edu/gia-museum-exhibit-centuries-opulence-jewels-india

Crowns of the Vajra Masters: Ritual Art of Nepal
Until 16 December 2018
The Met Fifth Avenue, New York, New York, USA
www.metmuseum.org/exhibitions/listings/2017/crowns-of-vajra-masters

Gemstone Carvings: The Masterworks of Harold Van Pelt
Ongoing
Bowers Museum, Santa Ana, California, USA
www.bowers.org/index.php/exhibitions/upcoming-exhibitions/484-gemstone-carvings-masterworks-by-harold-van-pelt

Australasia

Cartier: The Exhibition
30 March–22 July 2018
National Gallery of Australia, Canberra, New South Wales
https://nga.gov.au/cartier

OTHER EDUCATIONAL OPPORTUNITIES

Gem-A Workshops and Courses
Gem-A, London
www.gem-a.com/education/courses/workshops

The Oxus Treasure in Detail
9 January 2018
The British Museum, London
http://tinyurl.com/y8bfbk33

Talking Diamonds
14 January 2018
Canadian Gemmological Association, Calgary, Alberta, Canada
www.canadiangemmological.com/index.php/education/gen-interest
Note: This five-hour course provides practical easy-to-understand essential information about diamonds.

Gem Appreciation Workshop
4 March 2017
Canadian Gemmological Association, Calgary, Alberta, Canada
www.canadiangemmological.com/index.php/education/gen-interest
Note: This five-hour course explores the nature of gemstones and their timeless allure.

Gemstone Safari to Tanzania
25 June–12 July 2018
Visit Morogoro, Umba, Arusha, Longido, Merelani and Lake Manyara in Tanzania
www.free-form.ch/tanzania/gemstonesafari.html
Note: Includes options for a lapidary class and/or a private visit to ruby mines near Morogoro and Mpwapwa (including Winza)

Lectures with Gem-A's Midlands Branch
Fellows Auctioneers, Birmingham, West Midlands
Email georgina@fellows.co.uk

- 23 February 2018
  Gwyn Green—Diamond Treatments
- 23 March 2018
  Alan Hodgkinson—Zircon
- 27 April 2018
  James Gosling—The History of Stickpins

Lectures with The Society of Jewellery Historians
Society of Antiquaries of London, Burlington House, London
www.societyofjewelleryhistorians.ac.uk/current_lectures

- 23 January 2018
  Helen Molesworth—A History of Gemstones
- 27 February 2018
  Cornelie Holzach—250 Years: The Jewellery Industry in Pforzheim, Rise and Transformation
- 27 March 2018
  St John Simpson and Aude Mongiatti—Gold of the Scythians: Art, Culture and Techniques
- 24 April 2018
  Dr Zara Power Florio—All that Glitters: Jewellers and Gems in Georgian Ireland
- 25 September 2018
  Christopher Thompson Royds—TBA
- 23 October 2018
  Anna Tabakhova—Clasps: 4,000 Years of Fasteners in Jewellery
- 27 November 2018
  Helen Ritchie—Designers and Jewellery: Jewellery and Metalwork from the Fitzwilliam Museum 1850–1950

New Media

Pearl Buying Guide: How to Identify and Evaluate Pearls, 6th edn.

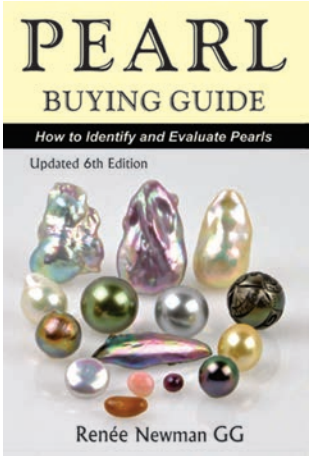

By Renée Newman, 2017. International Jewelry Publications, Los Angeles, California, USA, www.reneenewman.com/pearl.htm, 153 pages, illus., ISBN 978-0929975528. US$19.95 softcover.

This well-written book contains a great amount of beneficial information for anyone—whether a novice or someone experienced in the gem and jewellery trade—who is interested in finding a variety of information on pearls. Over 300 fabulous colour photographs and diagrams are dispersed throughout the book. This edition is a little more informative than its predecessor, with some additional photos, diagrams and updated chapters, but overall the changes are somewhat limited compared to the 5th edition.

Chapter 1, titled 'Curious Facts About Pearls', has been updated with some informative colour diagrams. Chapter 2 covers 'Pearl Price Factors in a Nutshell'. Chapter 3—'Pearl Types'—dives into the many different pearl varieties and their localities. Chapter 4 covers 'Pearl Shapes' and Chapter 5 is on 'Judging Luster & Nacre Thickness'. Chapter 6, titled 'Judging Color', discusses the complex coloration of pearls, including main body colour, overtone, iridescence and orient, as well as the lighting used for viewing pearls. Chapter 7's 'Judging Surface Quality' covers additional factors to consider when selecting a pearl. Chapter 8 is about 'Size, Weight & Length'. Chapter 9, on 'Judging Make', explains how to assess how well pearls match or blend, how centred are the drill holes and how seamless is the transition of pearl sizes in a graduated strand. Chapter 10—'South Sea Pearls (White & Golden)—has been rewritten to discuss the topic in greater detail. Chapter 11, on 'Black Pearls', discusses their colour variations and localities. Chapter 12 covers 'Freshwater Pearls'.

Chapter 13—'Pearl Treatments'—points out what might have been done to a pearl after initial cleaning. Chapter 14, titled 'Imitation or Not', describes several tests that require no equipment other than a loupe. Chapter 15—'Natural or Cultured'—also covers several simple procedures that do not require expensive equipment, plus other more extensive testing procedures such as those involving the use of X-rays or UV fluorescence.

The remaining chapters are: Chapter 16, 'Antique Pearl Jewelry'; Chapter 17, 'Choosing the Clasp'; Chapter 18, 'Versatile Ways to Wear a Strand of Pearls'; Chapter 19, 'Creating Unique Pearl Jewelry with Colored Gems'; and Chapter 20, 'Caring for your Pearls'.

The *Pearl Buying Guide* is an interesting, easy-to-understand reference on pearls. I highly recommend it to consumers and professionals interested in buying or selling pearls, as it is a very useful, up-to-date tutorial to have in your library.

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The Sisk Gemology Reference

By Jerry Sisk, 2016. America's Collectible Network Inc. dba Jewelry Television, Knoxville, Tennessee, USA, www.jtv.com/SGR, Vol. 1: Prominent Gems, 436 pages, illus., ISBN 978-0692713181; Vol. 2: Noteworthy Gems, 302 pages, illus., ISBN 978-0692794722; Vol. 3: Gallery of Gems, 302 pages, illus., ISBN 978-0692794739. US$199.99 hardcover with slipcase.

Gemmology is an ever-growing field with the discovery of new materials, treatments and synthetics occurring annually. Although excellent reference books on the subject exist, a fresh interpretation of a discipline in constant flux is often sought. Thus, an additional reference source for professional gemmologists to consult is always welcome.

The author, Jerry Sisk, was a Graduate Gemologist (GIA) and cofounder of Jewelry Television (JTV). He sadly and suddenly passed away in 2013, before this set of books was published. He was an accomplished gemmologist who was voted one of the five most influential people in the jewellery industry by

JCK Magazine in April 2012. A short biography of Sisk is provided at the start of each of the three volumes of *The Sisk Gemology Reference*, followed by a foreword by JTV president Timothy Matthews and tributes to Sisk from JTV cofounders F. Robert Hall and William Kouns. These provide a wonderful tribute to the author but do come across as somewhat repetitive.

The three volumes comprising the set are very well organized. The photography is stunning and beautifully illustrates rough, cut and mounted gems. The colour reproduction seems to be very accurate and the images are all crisp and detailed. An index is included at the back of each volume.

The first volume, Prominent Gems, is the 'meat' of the three-volume 'sandwich' so to speak. The first section—Gemstones and Their Properties—focuses on what a gemstone is, the classification and composition of gems and how to interpret each listing that follows. Crisp graphics and clear but simple explanations lead the reader through 'observational properties' such as colour, transparency, lustre and dispersion to more complex characteristics that require gemmological tools for measurement.

In the Optical Properties section, polariscope reactions and optic character depictions are clearly represented. Considering that the polariscope is so thoroughly discussed, I was surprised that the refractive index section does not mention different techniques used to obtain an RI reading, such as the spot method for curved surfaces. However, the birefringence section provides a nice illustration of the appearance of a doubly refractive material in the refractometer, explaining what the shadows on the numerical RI scale represent. Ultraviolet fluorescence and reaction to the Chelsea Colour Filter are presented correctly as additional diagnostic tools that can provide clues to identification but that should be used in conjunction with other tests. The section discussing absorption spectra and the spectroscope is brief, but the explanations are clear and easy to understand.

The section on Physical Properties covers fracture, cleavage, specific gravity, hardness, toughness, streak and the Mohs scale. Following the description of fracture is a helpful chart with thumbnail photos of different fracture surfaces. Cleavage is explained along with a colourful graphic that explains different types (e.g. basal, prismatic, etc.) as well as illustrations denoting the number of cleavage planes present in a given type. A definition of SG is provided and acknowledged as an additional diagnostic tool (i.e. a test that is indicative but not necessarily definitive). Hardness and toughness are defined, and a Mohs hardness scale is illustrated. Streak also is discussed and acknowledged as a destructive test that is rarely performed. I found it helpful to read the author's explanations of these physical and optical properties, which gave me different perspectives on these important characteristics.

The next part of Volume 1 provides descriptions of various gem types, listed alphabetically. Each one is accompanied by a box of properties for quick reference, which is very helpful if you don't want to hunt through paragraphs of text looking for basic numerical values such as RI or SG. Many of the entries have maps showing the principal deposits, and it is convenient to see all the localities in a single place. Some aspects I found to be interesting but more opinion than fact. For example, when picturing aquamarine from different sources, a greener example is labelled from Africa and a bluer one is labelled from Brazil. I am not aware that this distinction is generally accepted in the gemmological community, and of course heating can alter the colour of aquamarine. Some important treatments are not mentioned. For example, in the coral section there is no mention of dyeing or bleaching, which are commonly seen in the trade and should always be considered when identifying, pricing or purchasing coral. In other entries, the subject of treatment is more heavily emphasized. Several descriptions include an important historical stone or piece of jewellery; famous diamond replicas are included in the section on diamonds and the one on natural pearls includes a photograph and brief history of La Peregrina, a famous large pearl once owned by actress Elizabeth Taylor. There are small omissions: In the section on spinel, for example, Tajikistan is listed as a less-notable locality, although it is a historically important source of spinel that is still being mined today.

The first volume concludes with charts listing gem properties, including RI, hardness, SG, dispersion, cleavage, Chelsea filter reactions and organization by crystal system, group, species, variety and series. Following are gem spectra organized by colour. Also provided is a list of contributors followed by a fairly substantial bibliography and additional resources.

The second volume begins the same way as the first, and gemstone properties are reviewed again, sometimes placed in charts rather than (as in the first volume) discussed in paragraphs. I found the first portion of this second volume to be unnecessarily repetitive, but perhaps if only one volume is available it would be helpful. Following the first section, the book delves into brief but informational descriptions of lesser-known but noteworthy materials, from acanthite to zincite. Again, all the photographs are crisp and accurate regarding colour. Many of the specimens are depicted in their most prevalent crystal habit, helping with visual identification. Also convenient are the short but mostly accurate descriptions of each mineral. Following this encyclopaedic portion of Volume 2 is a fairly extensive section on gemmological terms, from 'abas' (an ancient Persian unit of weight) to 'zoning'. While informative for the amount of space given, these definitions sometimes lack key information or are otherwise incomplete. For example, under 'flame structure', no mention is made of conch or Melo pearls, which are both known for this

appearance. The definition of a 'GG' mentions a designation earned after completion of GIA's Colored Stones programme, but Graduate Gemologists also must study Diamonds and Gem Identification. Interestingly, under the entry for 'Gemological Institute of America (GIA)', no mention is made of the diamond-grading scales that were developed by GIA and continue to be followed internationally. Under the 'phenomena' description, the term 'stars' is included after mention of aventurescence, rather than after asterism. The emphasis on terminology concerning blue topaz (i.e. Swiss Blue, London Blue) perplexed me until I realized that the author was writing primarily for the JTV audience, which were his customers. Thumbnail photographs or drawings that accompany many of the definitions help illustrate what is under discussion. Volume 2 concludes with a section citing contributors and a bibliography.

Volume 3 focuses on portraying stunning photographs of gems and mineral specimens. A section on famous diamond replicas already depicted in Volume 1 is unnecessarily repetitive. The photos are organized according to crystal structure, starting with organic and amorphous gems and then detailing gem and mineral specimens of each of the crystal systems. Although the photographs are of primary importance, a larger typeface would have been helpful to those who don't want to reach for their reading glasses!

Overall, I found this three-volume set an enjoyable if inconsistent read. If this set of volumes is to be used for reference, it should be backed up with at least one other source. The photographs were what I really found interesting. In gemmological science, I am a firm believer that the more you see, the more you learn, and the photographs in particular are really helpful and can teach a lot.

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OTHER BOOK TITLES*

Coloured Stones

Mehr Erlesene Achate/More Exquisite Agates
By Dietrich Mayer, 2017. Bode Verlag, Salzhemmendorf, Germany, 424 pages (in German and English). €58.00 hardcover.

Ruby
By Joanna Hardy, 2017. Thames & Hudson, New York, New York, USA, 368 pages, ISBN 978-0500519417. US$125.00 hardcover.

Gem Localities

***Amber in Poland and in the World,* 2nd rev. edn.**
By Barbara Kosmowska-Ceranowicz, 2017. University of Warsaw, Poland, 316 pages, ISBN 978-8323526032 (in Polish and English). PLN69.00 softcover.

Handy Pocket Guide to Asian Gemstones
By Carol Clark, 2017. Periplus Editions (HK) Ltd., North Clarendon, Vermont, USA, 64 pages, ISBN 978-0794607982. US$6.95 softcover.

***Namibia – Minerals and Localities*, Vol. II**
By Ludi von Bezing, Rainer Bode and Steffan Jahn, 2016. Bode Verlag, Salzhemmendorf, Germany, 664 pages, ISBN 978-3942588195. €78.00 hardcover.

General Reference

***Curiosités Minérales*, 2nd edition**
By Didier Nectoux and Cyrille Benhamou, 2017. Omniscience, Mouans-Sartoux, France, 264 pages, ISBN 978-2916097855 (in French). €35.00 softcover.

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Dreher Carvings: Gemstone Animals from Idar-Oberstein
Ed. by Johanna Eberl, 2017. Arnoldsche Art Publishers, Stuttgart, Germany, 240 pages, ISBN 978-3897905078. €48.00 hardcover.

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By Livia Tenuta, 2016. Marsilio, Venice, Italy, 96 pages, ISBN 978-8831726092 (in Italian and English). €20.00 softcover.

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By Pilar Vélez, 2017. Arnoldsche Art Publishers, Stuttgart, Germany, 296 pages, ISBN 978-3897904941. €48.00 hardcover.

Liv Blåvarp. Jewellery – Structures in Wood
By Cecilie Skeide and Anne Britt Ylvisåker, 2017. Arnoldsche Art Publishers, Stuttgart, Germany, 144 pages, ISBN 978-3897904972. €34.00 hardcover.

* Compiled by Sarah Salmon and Brendan Laurs

Narrative Jewelry: Tales from the Toolbox
By Mark Fenn, 2017. Schiffer Publishing Ltd., Atglen, Pennsylvania, USA, 304 pages, ISBN 978-0764354144. US$60.00 hardcover.

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By Carole Tanenbaum and Eve Townsend, 2017. Glitterati Inc., New York, New York, USA, 228 pages, ISBN 978-0998747408. US$50.00 hardcover.

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Dirty Gold: How Activism Transformed the Jewelry Industry
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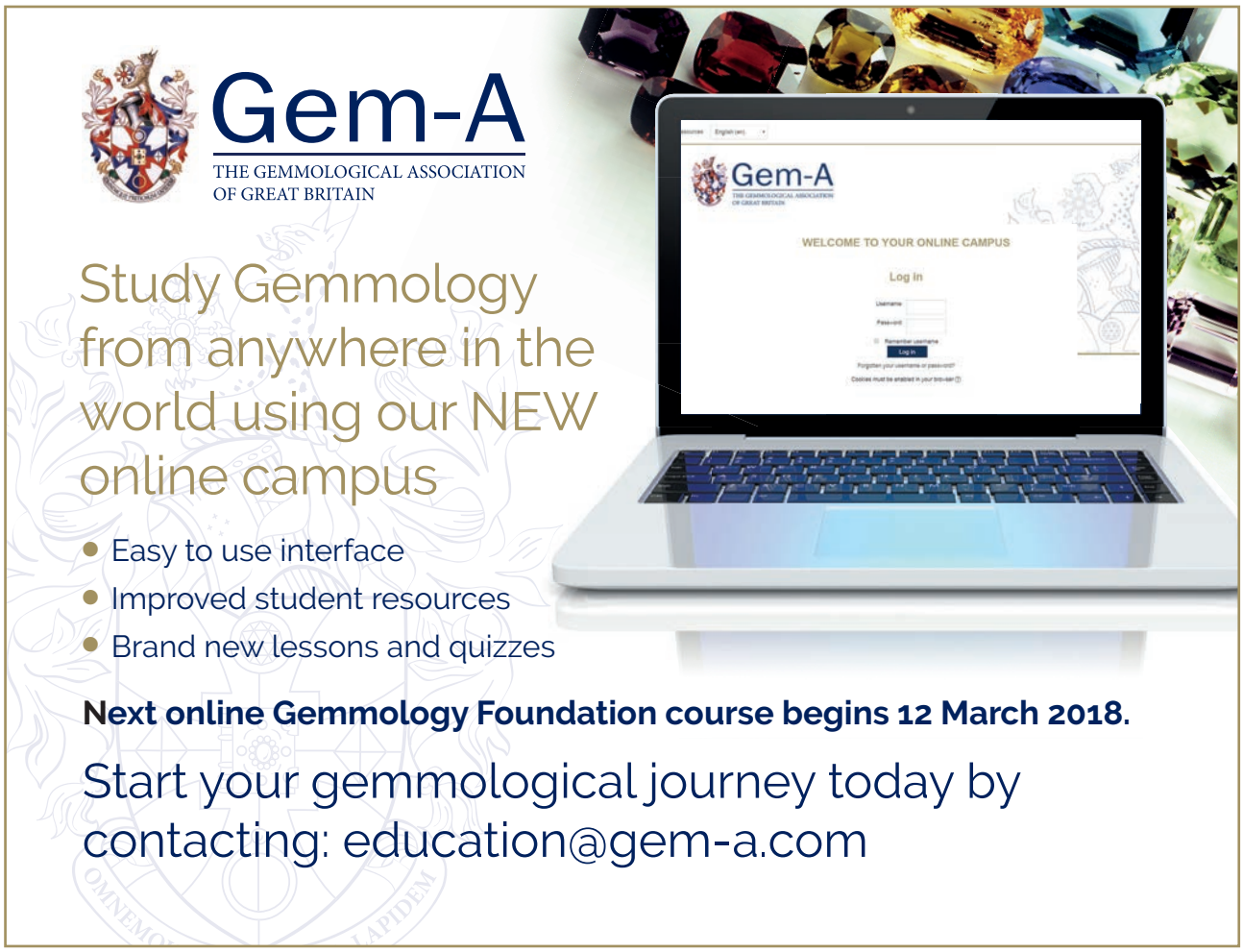

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* Article freely available online, as of press time

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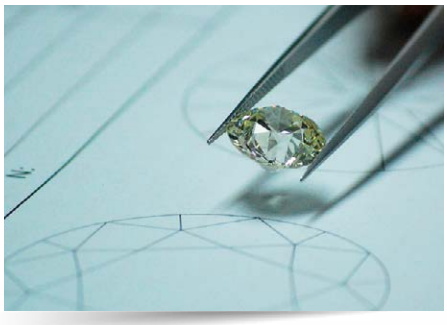

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COLUMNS

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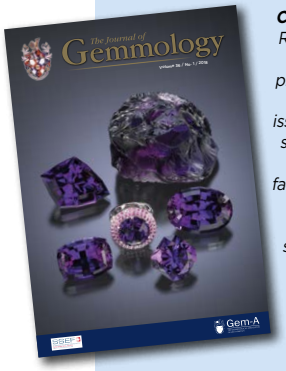

Cover photo: *Amethyst from Rwanda may display unusual optical and microscopic properties, as described in an article on pp. 26–36 of this issue. The Rwandan amethyst shown here includes a rough piece weighing 101 g, loose faceted gems of 26.62–63.41 ct and an 11.61 ct centre stone that is surrounded by pink sapphires in a 14-carat white gold ring. Courtesy of Steve Moriarty, Moriarty's Gem Art, Crown Point, Indiana, USA; photo by Jeff Scovil.*

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The Editor-in-Chief is glad to consider original articles, news items, conference/excursion reports, announcements and calendar entries on subjects of gemmological interest for publication in *The Journal of Gemmology*. A guide to the various sections and the preparation of manuscripts is given at www.gem-a.com/index.php/news-publications/publications/journal-of-gemmology/submissions, or contact the Editor-in-Chief.

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Editorial

AN UPDATED DESIGN FOR *THE JOURNAL OF GEMMOLOGY*

With this issue of *The Journal*, we begin a new volume (36) and also introduce a fresh new design. Unfortunately, however, we also see the departure of Mary Burland as production editor. Mary states, "I am sorry to be leaving *The Journal* after over 50 years working in various capacities from typing copy to production manager. In recent years I also have been responsible for the layout, which I have really enjoyed. I wish *The Journal* luck for the future—may it go from strength to strength." Thank you, Mary, for your many decades of dedication to ensuring that *The Journal* is informative, looks good and free of typos!

Gem-A has now appointed Zest (in London) for the design and production of *The Journal*. While the range of content will remain the same, you will notice a more contemporary look to the pages, particularly the Feature Articles. As shown by the images on this page, the design of *Journal* articles has evolved several times over the years. One aspect that has remained the same, though, is the care and attention given to manuscripts throughout the review, revision and editing process to maintain their educational value and scientific rigor. For this I particularly thank *The Journal*'s Associate Editors for their expertise, advice and constructive comments, and the authors for their perseverance and commitment to ensuring the high quality of their contributions.

I also would like to take this opportunity to acknowledge the valuable financial support of our sponsors and advertisers, which helps make it all possible—thank you.

Brendan Laurs
Editor-in-Chief

Updated Feature Article design alongside article pages from *The Journal* spanning 1947–2014

What's New

INSTRUMENTATION

ABCD Gem Testing Set

In June 2017, the Asian Gemmological Institute and Laboratory Ltd in Hong Kong released a compact portable kit consisting of 13 gem-testing instruments: polariscope, handheld incandescent lamp, darkfield and diffuse adaptors for the lamp, rotating plate for the polariscope, loupe, long-wave UV lamp, tweezers, four-claw stone holder, conoscope, reflective diffuse block, lanyard and gem cloth. For additional information, including a guide for use, visit www.agil.com.hk/en/gemtesting.php?gemtestingid=13. *CMS*

Jewellery Inspector

Manufactured by Gemetrix (Perth, Australia), the Jewellery Inspector debuted January 2018. This cousin of the Melee Inspector (see Vol. 35, No. 8, p. 687 of *The Journal*) features a tray that can hold jewellery to allow observation of both short- and long-wave UV luminescence and phosphorescence of mounted or unmounted samples through the unit's 45 × 45 mm viewing area. For more information, visit www.gemconference.com/store/instruments/jewellery-inspector. *CMS*

GemoAid Universal Microscope Upgrade Kit

Released in late 2017, this useful set of gemmological microscope accessories includes four dock bases (to accommodate various models of microscopes) for placing accessories over the light well, a diffuser lens, a glass immersion cell, mounting rods of two different heights, two polarizing lenses, and yellow and blue colour filters. The kit is structured in a modular way that allows mounting of several accessories at the same time (e.g. diffuser, immersion cell and colour filter). The kit is compatible with most current gemmological microscopes, and is available for US$139.00 plus $6 shipping. For additional information and online ordering, visit www.gemoaid.com/universal-microscope-upgrade-kit-special-price or email instruments@gem-a.com. *CMS*

NEWS AND PUBLICATIONS

AGTA GemFair Tucson Seminars

From 30 January to 4 February 2018, the American Gem Trade Association hosted an array of seminars during the gem shows in Tucson, Arizona, USA. Presenters from around the world discussed various aspects of the industry, including marketing, mining, appraising, identification and jewellery. The lectures also covered various gem materials, including ruby, sapphire, pearl, jade, coral and more. A flash drive containing recordings and slides of 22 of the 26 seminars can be purchased for US$50.00. Visit www.agta.org/education/seminars.html for a summary of the presentations, a list of the speakers and an order form. *CMS*

Global Diamond Industry 2017

The seventh annual report prepared by Antwerp World Diamond Centre and Bain & Co. was released in December 2017, titled *The Global Diamond Industry Report: The Enduring Story in a Changing World*. The report covers 2016 and the first half of 2017, and includes a forecast of the diamond industry through 2030. Diamond jewellery sales were fairly stagnant through 2016 and appeared to remain so for 2017, and mid-2016 revenues fell slightly. Key challenges include declining demand for diamond jewellery, the impact of laboratory-grown diamonds and financial instability of certain sectors of the trade. Download the report at www.bain.com/Images/bain_diamond_report_2017_pages.pdf. *CMS*

Gem Testing Laboratory (Jaipur, India) Newsletter

GTL Jaipur's latest *Lab Information Circular* (January 2018) features reports on a black micaceous rock embedded with hexagonal-shaped artificial glass imitating emerald crystals, faceted specimens of eudialyte, purple 'Morado' opal from Mexico, resin-filled amazonite beads, quartz with abundant graphite inclusions, and photos of various gem materials from Namibia. Download the issue at www.gtljaipur.info/ProjectUpload/labDownLoad/LIC_January2018.pdf. *CMS*

Gold Demand Trends 2017

This annual report from the World Gold Council, released in February 2018, includes a section that focuses on gold jewellery. In 2017, gold jewellery demand rose 4% globally, with notable recovery in India, despite an overall decline in demand for gold worldwide. This was the first increase in gold jewellery demand since 2013. The gold jewellery market in the USA and China climbed at gradual rates. However, demand in Europe, and especially the UK, continued to decline. Download the report at www.gold.org/research/gold-demand-trends. *CMS*

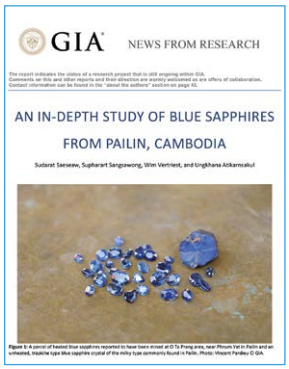

Sapphires from Pailin, Cambodia

In this Research News release from December 2017, titled 'An In-Depth Study of Blue Sapphries from Pailin, Cambodia', authors from the Gemological Institute of America's Bangkok laboratory analyse 68 heated and unheated blue sapphires from Pailin, Cambodia, presenting LA-ICP-MS chemical analysis, UV-Vis-NIR and FTIR spectroscopy, and inclusion studies using microscopy and Raman spectroscopy. Download the report at www.gia.edu/gia-news-research/blue-sapphires-pailin-cambodia. *CMS*

SSEF *Facette*

In February 2018, the Swiss Gemmological Institute SSEF released No. 24 of its annual publication *Facette Magazine*. This issue covers padparadscha-like sapphires with unstable coloration; an excursion to Paraíba tourmaline mines in Brazil; emerald and sapphire from Ethiopia; Afghan emeralds with properties similar to Colombian stones; artificial resin fillers in Burmese rubies and Paraiba tourmalines; detection of sapphire heat treatment using Fe-hydroxide transformation; GemTOF analysis of sapphires from Madagascar and Kashmir; age dating of sapphires and their inclusions; SIMS analysis of carbon isotopes in natural and synthetic diamonds; natural diamonds mixed into batches of synthetic diamonds; collector's stones including grandidierite, fluorite and musgravite; 'Sannan-Skarn' resembling maw-sit-sit; identification of jadeite and related samples; 'Mini Ming' cultured pearls from China; impact of water pollution regulations on Chinese freshwater cultured pearl production; a cultured pearl with an Fe-rich core; a hollow pearl containing metallic beads; SSEF-affiliated research projects and publications; several exceptional items with SSEF reports sold at auction in 2017; recaps of SSEF courses; SSEF news and instrumentation; conference reports; and more. Download this and previous issues of *Facette* at www.ssef.ch/ssef-facette. *BML*

SSEF Trade Alert: Artificial Resin in Rubies

SSEF issued a trade alert in February 2018 about a series of relatively high quality Burmese rubies recently encountered in their laboratory that were fracture-filled with artificial resin to improve their clarity. The resin-filled fissures were rather difficult to see, with only a few small air bubbles, and sometimes tiny worm-like dendrites in the fissures that appeared much different from the rounded dendritic patterns often displayed by oil-filled fissures. FTIR spectroscopy confirmed the presence of the resin filler. Download the report at www.ssef.ch/wp-content/uploads/2018/03/2018_artificial_resin_rubies.pdf. *BML*

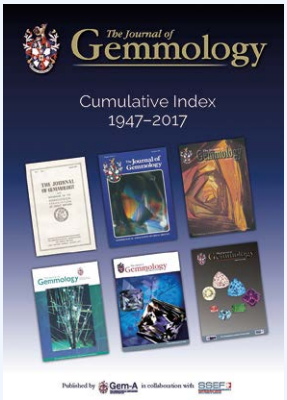

Updated Cumulative Index for *The Journal*

In March 2018, *The Journal of Gemmology's* cumulative index was updated to cover issues from 1947 to 2017 (Vols. 1–35). In addition, issue numbers have been included for the listings, making it easier to locate corresponding information in *The Journal*'s online archive. The contents are listed alphabetically by subject, and the file also can be searched electronically for specific authors as well as topics. The cumulative index is available in electronic (PDF) format only, and can be freely downloaded at https://gem-a.com/news-publications/publications/journal-of-gemmology#the-journal-index. *CMS*

What's New provides announcements of new instruments/technology, publications, online resources and more. Inclusion in What's New does not imply recommendation or endorsement by Gem-A. Entries were prepared by Carol M. Stockton (CMS) or Brendan M. Laurs (BML), unless otherwise noted.

The Fire Within

"For in them you shall see the living fire of the ruby, the glorious purple of the amethyst, the sea-green of the emerald, all glittering together in an incredible mixture of light."

– Roman Elder Pliny, 1st Century AD

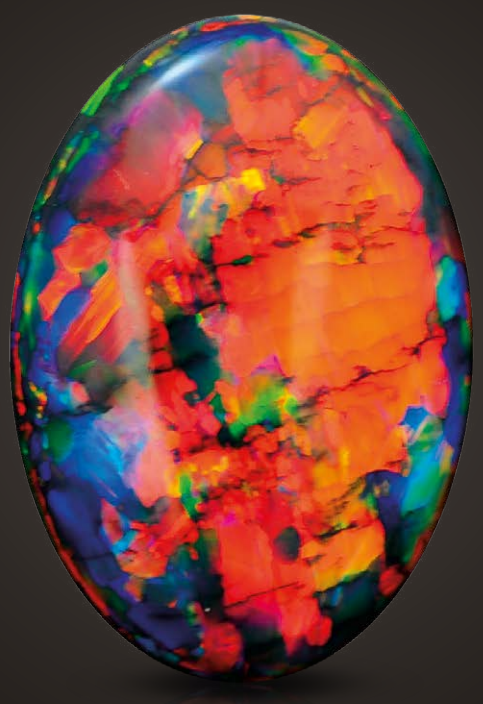

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Gem Notes

COLOURED STONES

Figure 1: Artisanal mining is ongoing at the 2017 find of amethyst in an arid region of Santo Se municipality, Bahia State, Brazil. Photo by Adilton Venegeroles.

Amethyst Discovery in Bahia, Brazil

In April 2017, a new amethyst deposit was discovered by accident near the top of Serra da Quixaba, Santo Se municipality, in the far north-west of Bahia State, Brazil (Figure 1). Word spread quickly, and by June as many as 8,000 people had converged on the locality, including miners and individuals with supporting activities.

Personnel from Brazil's National Department of Mineral Production (DNPM) in Bahia soon visited the area and decided to allow the ongoing extractive activity, while quickly helping to formalize the area into a 200 Ha artisanal mining preserve and establish miners' cooperatives. This locality's biome, *caatinga*, is extremely arid and the area is one of the poorest in Brazil. DNPM's actions of encouraging the mining of amethyst served to benefit the municipality and avoid the 'social chaos' that might have occurred if the rush was shut down.

Buyers from Brazil, China and India quickly established themselves in the town of Santo Se. Nowadays, Wi-Fi connectivity is enabled by using solar panels in even the most remote areas of Brazil, and news spreads rapidly via platforms such as WhatsApp.

The amethyst crystals range up to 130 g, and clean, cobbed pieces typically weigh 5–50 g. The material varies from pale to saturated purple and commonly exhibits colour zoning (e.g. Figure 2). Some zones may display a bluish violet appearance, which adds to the overall desirability of this material.

Brian Cook (bc@naturesgeometry.com)
Nature's Geometry, Tucson, Arizona, USA

Figure 2: Representative examples of amethyst from Santo Se, Bahia, Brazil, are shown by this 53.25 ct carved 'Aromajewel' and 5.2-cm-tall crystal specimen. Photo by Jeff Scovil.

Yellow Brucite from Balochistan, Pakistan

Brucite is a layered magnesium hydroxide, $Mg(OH)_2$, that typically forms compact aggregates with a vitreous, waxy or pearly lustre. Until recently, it has not been encountered in the gem trade except as an imitation of nephrite jade and Shoushan stone in China (Li Jianjun et al., 2010). At the February 2018 gem shows in Tucson, Arizona, USA, yellow brucite from a relatively new find in Pakistan was available as faceted stones (e.g. Figure 3) and beads. However, the vast majority of this brucite was offered as mineral specimens (e.g. Figure 4).

The brucite comes from Pakistan's Balochistan (Baluchistan) Province, with both the Killa Saifullah and Khuzdar districts being reported as the area where mining takes place. A photo and video of one such mine is available at www.irocks.com/brucite-a-chemists-treasure. Pale yellow brucite from Balochistan first appeared in the mineral specimen market in 2015, followed by pale to bright yellow material in 2016. Many of the aesthetic yellow specimens offered at this year's Tucson shows were mined in mid-2017. They typically consisted of coarse-grained translucent aggregates of yellow brucite on a matrix of hydromagnesite and/or altered serpentinite.

Brucite has been documented in the literature from magnesite deposits in the Khuzar area, where ultramafic rocks were serpentinized and then hydrothermally altered into assemblages of magnesite, hydromagnesite and brucite (Bashir et al., 2009). The colour of the brucite, however, was not specified, and it is unknown to the present author if the recent finds of yellow brucite are related to these deposits.

Figure 3: These faceted brucites weigh 3.33–3.45 ct and the specimen measures 19 × 21 × 4 mm. Photo by Mauro Pantò.

Figure 4: This brucite specimen from Pakistan measures approximately 11 cm wide and 9 cm tall. The brucite formation at the top resembles the profile of a woman wearing a tiara, leading some to refer to it as 'Queen Elizabeth'. Courtesy of Ghulam Mustafa, Fine Art Minerals, Peshawar, Pakistan; photo by Joaquim Callen.

The faceted brucite was displayed in Tucson by Mauro Pantò (The Beauty in the Rocks, Sassari, Italy), who kindly donated one cut stone to Gem-A. He had approximately 60 brucites (total weight ~150 carats) that mostly ranged from 1 to 3 ct each. With a Mohs hardness of 2½–3 and perfect cleavage on {0001}, brucite is challenging to facet. In addition, the brucite aggregates typically form rather thin layers and often contain some white areas, so Pantò estimates that 70% of the rough material cannot be used for faceting unless very small stones are cut.

Brendan M. Laurs FGA

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Li Jianjun, Yu Xiaoyan, Cai Jia, Liu Xiaowei, Fan Chengxing and Cheng Youfa, 2010. The gemmological properties and infrared spectra of brucite, an imitation of nephrite and Shoushan stone. *Journal of Gemmology*, **32**(1–4), 67–73, http://dx.doi.org/10.15506/jog.2010.32.1-4.67.

Figure 5: At the Katjanga tourmaline deposit, miners use a pneumatic drill to prepare the pegmatite for blasting, while a front-end loader removes waste rock from the pit. The inset shows the pure greenish blue hue of a tourmaline preform from this mining area. Photos by B. M. Laurs.

Update on Some Coloured Stone Mining in Namibia

After attending the 35th International Gemmological Conference on 12–15 October 2018 in Windhoek, Namibia, this author visited some coloured stone deposits to obtain updated information on the mining and production there. Guided by Markus Wild (Paul Wild OHG, Kirschweiler, Germany), we saw active mining for tourmaline at Katjanga and Neu Schwaben, and for demantoid at the Parrot mine.

The Katjanga mining area has produced blue to blue-green gem tourmaline over the past two decades. It is situated on a private farm owned by Jeano Foelscher that is located approximately 40 km south-east of Omaruru. Several granitic pegmatites are present in an area measuring approximately 4 km^2, and the largest one was being mined in an open cut during our visit (Figure 5). The pit was being worked by a crew of 4–5 miners, who drill and blast the pegmatite with explosives. Most of the pegmatite that we saw was relatively fine grained, and it locally contained elongate coarse-grained segregations that were typically up to 1 m (rarely up to 2 m) wide and 3–6 m long; they dipped ~35° south-east. The miners look for areas where these 'veins' are cross-cut by near-vertical iron-stained joints or fractures, since this is where 'pockets' or cavities seem to occur. Most of the pockets contain only quartz, feldspar and mica, and perhaps 20% of them are mineralized with gem tourmaline. Such cavities are typically small and may produce up to ~1.5 kg of tourmaline, of which ~5% is gem quality in some cases and ~30% in others. Fine gem tourmaline also has been produced from eluvial deposits overlying the pegmatites. Most of the tourmaline from Katjanga is pure blue to blue-green and lacks any greyish or brownish hues (e.g. Figure 5, inset),

Figure 6: Numerous open pits explore the Neu Schwaben pegmatite for tourmaline, but only a few of them were being actively mined in October 2017. The prismatic greenish blue crystals in the inset are typical of tourmaline from this locality. Photos by B. M. Laurs.

Figure 7: Demantoid is mined from a hard layer of calc-silicate rock at the Parrot mine using hand tools. Photo by B. M. Laurs.

and also has an 'open' c-axis that is prized by gem cutters and connoisseurs.

The Neu Schwaben mining area has been known for decades, and in 1996–1997 it produced large quantities of tourmaline in attractive blue-to-green colours from secondary deposits associated with a large pegmatite (Johnson and Koivula, 1997). Subsequent production has been mostly rather small and inconsistent due to the disorganized nature of the mining; this was noted by Laurs (2002) and this situation continues to the present time. During our visit we saw numerous pits (e.g. Figure 6) ranging up to 8–10 m deep over an area of approximately 3–4 km^2. The pits were located on both sides of a prominent north/south-trending ridge that is formed by the pegmatite, and four of them were actively being mined by separate groups of 3–5 people. We saw two air compressors used to power pneumatic drills (although it was not clear if they were both in use), but otherwise no mechanized equipment was present. The geology was quite similar to that seen at Katjanga, with a large relatively fine-grained pegmatite that locally contained coarse-grained 'veins' ~0.5 to 1.5 m thick that dipped shallowly to moderately south-east. According to the local miners, the pockets typically vary from 10 to 60 cm long, and may contain tourmaline that is blue to green (e.g., Figure 6, inset) or black. Although some of the tourmaline from Neu Schwaben shows an 'open' c-axis, such material is less commonly encountered than in tourmaline from Katjanga.

Demantoid and brownish to greenish yellow andradite is mined from Tubussis Farm 22 in the Erongo region of west-central Namibia. We visited the Parrot mine, which is owned by Manfred Lehrl (Esme Fine Gemstones, Omaruru) and is located adjacent to the Green Dragon mine (Reif, 2017). The main open pit extended to a depth of ~18 m, and in early October Lehrl had shifted to shallower workings that were ~7 m deep. A crew of four workers was following the steeply-dipping mineralized zone using pry-bars and feathers-and-wedges (Figure 7). The garnets were hosted by a narrow ~0.5 m layer of calc-silicate rock (skarn) adjacent to marble that had been locally intruded by granitic veins. Lehrl preferred not to use explosives near the mineralized zone to avoid breaking the garnets, and therefore mining proceeded slowly. Most of the production consisted of small broken crystals (e.g. Figure 8), although larger stones are occasionally found.

Brendan M. Laurs FGA

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Figure 8: Most of the Parrot mine demantoid production consists of broken crystals such as these. Photo by B. M. Laurs.

Copper-bearing Opal from West Java, Indonesia

West Java in Indonesia has long been known as a source of opal, with much of it displaying play-of-colour (e.g. Einfalt, 2007). More recently, common opal showing various body colours (mostly greenish blue to bluish green) was found as pebbles and cobbles in streams, and subsequently the primary source was discovered (e.g. Figure 9). The deposit is located in the Garut Regency of West Java, which is south of the city of Bandung. What makes this material particularly interesting is that is it commonly associated with fossilized wood (Figure 10) in the remnants of an ancient petrified forest, and also some pieces of the opal contain concentrations of native copper (Figure 11). Fossilized (silicified) tree remains are well known in West Java and elsewhere in Indonesia, and some of these deposits are hosted by Late Miocene–Pliocene volcaniclastic strata (van Gorsel, 2014). The volcanic material was ejected during major eruptions that locally smothered and preserved entire forests. According to geologist Joel Ivey (IndoAgate.com, Bangkok, Thailand), the opal-bearing silicified wood in the Garut area formed as a result of hydrothermal solutions associated with an epithermal system circulating through the volcanic sequence. The solutions contained various metallic impurities (Cu, Mn and Fe) that resulted in the colourful appearance of the opal.

Figure 9: A relatively new deposit of mostly blue-to-green opal associated with petrified wood is located in steep jungle terrain in West Java, Indonesia. The opal-bearing material is mined from several small tunnels. Photo courtesy of Dace Irwan.

Figure 10: A lensoidal shape and layered pattern are displayed by this specimen of greenish blue opal from West Java. The top photo shows a cross-section of the piece, and the bottom image views the top portion of the sample with surface textures that would be expected for fossilized wood material. The specimen weighs 10.2 kg and measures approximately 40 × 26 × 11 cm. Courtesy of Joe Jelks; photos by B. M. Laurs.

The mining area is located at an elevation of 394 m in steep terrain that is cloaked by jungle (Figure 9), making exploration and extraction difficult, particularly when large petrified logs are recovered (see photo at www.interweave.com/?p=414313&preview=1&_ppp=1496058d6c). The opal is locally concentrated in specific layers within the logs (e.g. Figure 10) and also is found in veins and structures in the associated tuffaceous deposits. According to

Figure 11: Abundant flecks of native copper decorate this sawn slab of West Java opal. Photo courtesy of Joel Ivey; image width ~10 cm.

Figure 12: This opal cabochon from West Java, Indonesia contains various bluish green and brown hues in a layered arrangement. Photo by Joe Jelks.

Dace Irwan (coralagate.com, Sukabumi, Indonesia), approximately 500 kg of mixed-quality opal is produced monthly, and Ivey estimates that more than a tonne of rough opal material has been recovered so far.

Both rough and cut opal were offered at the February 2018 Tucson gem shows, and Joe Jelks (Horizon Mineral Lapidary, Lewes, Delaware, USA) showed this author some interesting pieces that he obtained from two shipments in November 2017. The first batch weighed 63 kg and consisted mostly of small-to-medium sized rough, from which he cut approximately 300 cabochons ranging from 12 to 50 mm in maximum dimension. They typically showed a banded brown and blue-green appearance, as seen in Figure 12. The next shipment consisted of larger rough, and in Tucson he displayed pieces weighing 1.85–10.2 kg (e.g. Figure 10). The opal in most of the rough pieces ranged from greenish blue to bluish green with some light-to-dark brown and black areas, although pieces containing white, orange and yellowish green areas also have been recovered.

Furuya (2017) characterized one rough and two cabochon-cut samples (bluish green ± dark brown). Most of the material was identified as opal, although some portions of the rough sample showing better transparency were chalcedony. Energy-dispersive X-ray fluorescence spectroscopy revealed enriched copper contents (10–20 wt.% CuO). Although it is likely that the greenish blue to bluish green material is coloured by impurities of Cu-bearing minerals such as chrysocolla, the exact origin of the coloration has not yet been confirmed.

This Cu-bearing opal may resemble the chrysocolla-bearing quartz and chalcedony from Indonesia that was documented by Einfalt (2006), particularly when cut as homogenously coloured cabochons. However, most of the opal samples show patterning that is distinctly different from that material.

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Figure 13: Front and oblique side views are shown of a gold ring featuring a sapphire (15 × 12 × 1.5 mm) that displays conspicuous growth zoning. Specimen BM.89462; courtesy of NHM London, © The Trustees of the Natural History Museum, London.

A Sapphire Ring in the Natural History Museum Collections

The author recently had the pleasure to view a historical sapphire ring (Figure 13) from the gem collection of the Natural History Museum (NHM), London. The ring is listed in the handwritten mineralogy registers as BM.89462 and described as 'Corundum, pale-blue, faceted, showing hexagonal markings. India.'

The ring features a medium violetish blue sapphire, 15 × 12 × 1.5 mm, with a large flat table, facets around the edges and a very shallow pavilion. The stone is set in unmarked gold, with a thin band and a decorative bezel setting. What makes this gem so interesting are the prominent, alternating transparent blue and silky white bands, which outline two sides of the hexagonal growth pattern. As the ring is moved, the silky layers reflect light and highlight the zoning. The silk is formed of fine clouds of particles (likely rutile; Palke and Breeding, 2017) that follow the host sapphire's growth zones. Interestingly, the alternating transparent and silky layers do not match up on adjacent hexagonal prism faces (Figure 14), seemingly forming preferentially on one face and then the other as the crystal grew. Other inclusions include clusters of transparent euhedral crystals, negative crystals and partially healed fractures.

The specimen came to the museum as part of the Allan-Greg Collection. This mineral and gem collection was begun by Thomas Allan (1777–1833), a natural scientist based in Edinburgh. After Allan's death, Robert Hyde Greg (1795–1875) of Manchester purchased the collection, and his son Robert Philip Greg (1826–1906), then of Norcliffe Hall near Manchester, added to it. The collection was global in its coverage, but was famed for its British minerals and formed the basis for the *Manual of the Mineralogy of Great Britain and Ireland* (Greg and Lettsom, 1858). For nearly 150 years this was the only attempt at a complete catalogue of the mineralogical diversity of the British Isles, and it stands as one of the most important books on British Mineralogy ever published.

The Trustees of the British Museum purchased the Allan-Greg Collection in 1860 (British Museum, 1904), at which time it consisted of approximately 9,000 specimens and was thought to be the finest collection in the UK. The collection is beautifully catalogued in three volumes, with chronological entries written by Thomas Allan (up to 1833) and by R. P. Greg (during 1850–1859). The catalogue is arranged by mineral species, and the sapphire ring is listed as no. 116 under 'Rhombohedral Corundum'. (This is one of four lists of corundum groups, the first being 'Dodecahedral Corundum', which is in fact spinel; red spinels were commonly mistaken for rubies.) The entry for this sapphire ring does not give much further information, stating only, 'Ring stone set; of a pale blue colour + transparent, showing

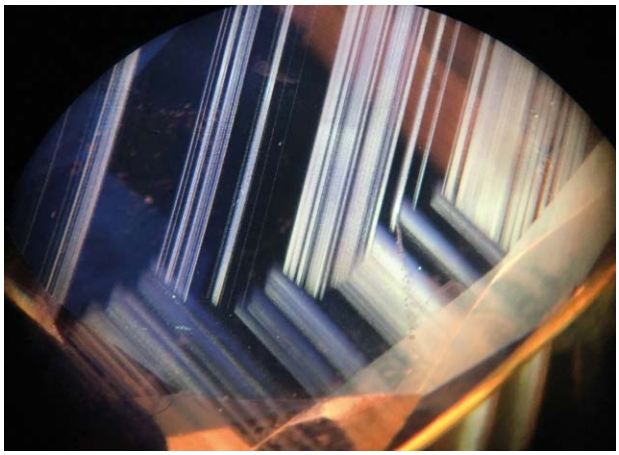

Figure 14: Alternating bands of 'silk' follow the hexagonal growth zoning in the sapphire pictured in Figure 13. Photomicrograph by R. Hansen; magnified 60×. Courtesy of NHM London, © The Trustees of the Natural History Museum, London.

the hexagonal markings – £4. India'. The previous catalogue entry, no. 115, has the year 1857 written next to it, so it is likely that the ring was purchased by R. P. Greg between 1857 and 1860, when the collection was sold.

India has long been known for its gemstones, including sapphire and ruby. It is most famed for its Kashmir blue sapphires; however, these were discovered around 1880 (Hughes, 1997), which post-dates this ring. India also was an important cutting centre and trade route for gems, so it is likely that the present sapphire was cut and the ring purchased in India, with the rough originating from another location such as Sri Lanka or Burma.

This ring is one of several early and important sapphires held in the NHM collection that are listed as being from India (and similarly were probably cut and sold in India, but mined elsewhere). Three others include a rose-cut sapphire mounted in a Mughal turban button acquired by Sir Han Sloane (whose collection founded the British Museum, dating this gem before 1753), a blue sapphire carved as a Buddha and mounted on a pin (the stone thought to originate from Burma) and an 88 ct star sapphire bead with a drill-hole at one end (purchased by NHM in 1825, thought to come from Sri Lanka). The ring is currently displayed in the newly redeveloped corundum case in NHM's Earth's Treasury gallery, and the other three sapphires mentioned here are displayed in the Vault (although one of them is currently on tour).

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Cat's-eye Indicolite Tourmaline from Afghanistan

Chatoyant tourmaline with sharp well-developed 'eyes' is uncommonly encountered in the gem trade, and when such stones are available they typically show green or pink body colours (e.g. Laurs, 2004).

It was therefore surprising to encounter a rather large amount of fine-quality cat's-eye indicolite at the February 2018 Tucson gem shows. The stones were displayed by Wali Beekzad of Five Lions Gems, San Jose, California, USA. They were cut from a 1.5 kg parcel of rough material that was mined in late 2016 in Laghman, Afghanistan. The cutting was performed in July 2017 by a Brazilian gem cutter with expertise in manufacturing cat's-eye stones. He produced 373 cabochons with a total weight of 2,435 carats, which ranged from approximately 2 to 66 ct each.

The stones displayed an attractive greenish blue colour and sharp 'eyes' that were caused by growth tubes oriented parallel to the c-axis (Figure 15). A few well-formed crystals from this find were preserved as mineral specimens, but otherwise the remainder of the production was cut. Given the rarity of cat's-eye indicolite, it seems unlikely that significant further production of this material will take place in the future.

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Figure 15: These chatoyant tourmalines from Laghman, Afghanistan, measure 4.2 cm tall (crystal specimen with quartz) and weigh 31.65 ct (cabochon). Photo by Jeff Scovil.

Cat's-eye Tremolite from Badakhshan, Afghanistan

In recent years there have been descriptions of transparent gem-quality tremolite from apparently two different locations in Tanzania (Zwaan and Hawthorne, 2015; Williams et al., 2017), and now this report covers tremolite that is from a different locality—Afghanistan—which also displays chatoyancy. Gem dealer Dudley Blauwet (Dudley Blauwet Gems, Louisville, Colorado, USA) first encountered this material in 2015, and obtained a total of four parcels during various visits to the gem and mineral bazaar in Peshawar, Pakistan. According to his Afghan supplier, the specimens originated from the Dar-e-Zu mine, Sar-e-Sang, Kokcha Valley, Badakhshan Province, Afghanistan. The material in the parcels ranged from pale greyish green or brownish green to black, and Blauwet was particularly interested in selling any unbroken well-formed crystals as mineral specimens. Since much of the rough material was opaque and lacked strong schiller, only a small proportion of the parcels were suitable for cutting cat's-eye gemstones. Furthermore, the narrow cross-section of those crystals showing the most desirable coloration restricted the size of any cut stones. Nevertheless, after initial efforts to cut a 4.1 g piece yielded a 4.70 ct cat's-eye cabochon, Blauwet then sent 16 pieces weighing 96.5 g to his cutting factory in July 2017, and they successfully produced six cabochons with a total weight of 33.58 carats. The largest was a translucent black gem weighing 11.26 ct, and the smallest was a pale greyish green stone that was ~0.90 ct.

Figure 16: A prismatic crystal (1.4 g) and an oval cat's-eye (2.09 ct) tremolite from the Dar-e-Zu Mine, Afghanistan, were gemmologically characterized for this report. Photo by Orasa Weldon.

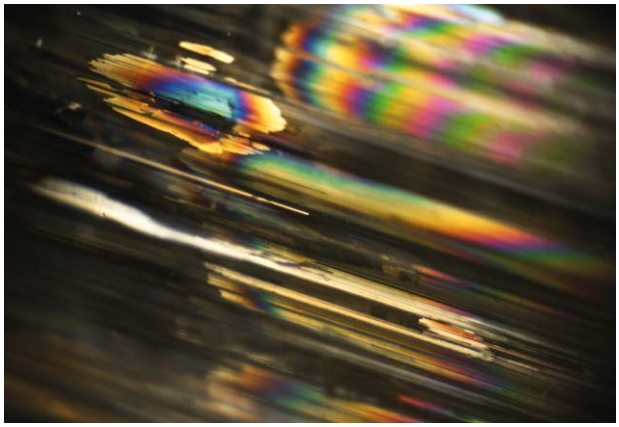

Figure 17: The Afghan cat's-eye tremolite contains growth tubes, incipient cleavage planes and fissures showing bright rainbow colours when viewed with magnification and oblique illumination. Photomicrograph by J. C. Zwaan; image width 5.0 mm.

During the February 2017 Tucson gem shows, Blauwet supplied some rough and cut samples of the chatoyant tremolite to the authors for examination.

A gemmological characterization was performed by author JCZ of the samples in Figure 16. The prismatic crystal and the oval cabochon were transparent to translucent and were light greyish green to greyish brown; in addition, a dark brown zone was present at one end of the crystal. The specimens respectively weighed 1.4 g and 2.09 ct and measured 20.53 × 9.40 × 3.83 mm and 12.71 × 6.68 × 2.88 mm.

The crystal had broken terminations, and on one side there was a small piece of matrix. Parallel to the longitudinal direction, striations were visible on the crystal faces and ran parallel to many straight fibres present inside the crystal. Incipient cleavage planes additionally ran parallel to the length of the crystal, which also contained small partially healed fissures. The oval cabochon essentially showed the same inclusions, with parallel fibres along its length being responsible for the cat's-eye. Viewed with magnification, some fissures in the cabochon showed bright iridescence with oblique illumination (Figure 17). Some slightly thicker fibres in the stone appeared to be lined with limonite or filled with diamond polishing residues where they reached the surface (confirmed by Raman analysis), which indicates that the parallel fibres consist of hollow growth tubes.

Clear RI readings were obtained from the flat base of the cabochon: 1.610–1.638, yielding a birefringence of 0.028. The hydrostatic SG was 3.01. The dichroscope revealed weak-to-distinct trichroism in greenish yellow, pale grey-green and greyish green. Both specimens were inert to long- and short-wave UV radiation.

Comparing these properties with those of amphiboles in the tremolite-actinolite-ferroactinolite series (Deer et al., 1997), the relatively low SG corresponds to tremolite, although distinct trichroism indicates the presence of some iron. Raman spectra most closely matched the spectra of tremolite recorded in the RRUFF database. Furthermore, electron microprobe analysis of another sample by authors FCH and MD confirmed that the material is indeed tremolite, with the formula: $(Na_{0.14}K_{0.01})_{0.15}(Ca_{1.95}Fe^{2+}_{0.03}Na_{0.02})_2(Mg_{4.68}Fe^{2+}_{0.20}Al_{0.10}Ti_{0.01}Mn_{0.01})_{5.00}(Si_{7.70}Al_{0.30})_8O_{22}(OH_{1.91}F_{0.09})_2$. This is well within the compositional range of tremolite, which extends from $\square Ca_2Mg_5Si_8O_{22}(OH)_2$ to $\square Ca_2Mg_{4.5}Fe^{2+}_{0.5}Si_8O_{22}(OH)_2$ (with $\square$ = A-site vacancy; Hawthorne et al., 2012).

In conclusion, the Dar-e-Zu mine in Afghanistan is one of the few known occurrences of gem-quality tremolite, apart from localities in Tanzania (see references above and also Fritz et al., 2007).

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Wavellite and Drusy Variscite from Arkansas

Wavellite and variscite are both aluminium phosphate minerals with a Mohs hardness of approximately 3½–4 (up to 4½ for variscite). Although variscite is commonly slabbed to show its attractive coloration and patterns, wavellite is typically appreciated for its botryoidal formations and radiating textures.

Since at least 1870, wavellite has been collected near the town of Avant in Garland County, Arkansas, USA (Smith, 2010). The area also is a source of drusy variscite, and both minerals are hosted by brecciated sedimentary rock of the Big Fork Chert Formation (Barwood and de Linde, 1989). The wavellite occurs in a range of colours (blue, blue-green, green, greenish yellow and yellow), which have been attributed to variations in the amounts and valence states of vanadium (Foster and Schaller, 1966).

One of the most important sources of wavellite and variscite in Arkansas is the de Linde mine (also known as the H. de Linde No. 3 or the Stuart Schmidt deposit), and many specimens from this claim have been cut for use in jewellery over the past decade. In 2009 the property was purchased by Avant Mining LLC (Paramus, New Jersey, USA), and they started extracting rough material in early 2010. According to owner James Zigras, the company recently expanded its production of jewellery material, and at the February 2018 Tucson gem shows they had multiple booths that displayed cut stones ranging from 10 to 500 ct each.

Both the wavellite and variscite are cut into various freeform shapes. While the variscite consists of pure drusy green coatings (Figure 18), the wavellite is

Figure 18: Various pieces of drusy variscite (up to 68 × 45 mm) from the de Linde mine are displayed on a background of Arkansas quartz. Photo by Jeff Fuller.

polished on the surface and sometimes includes areas of the breccia matrix material. Most of the wavellite ranges from greenish yellow to yellowish green, and it often exhibits intergrown radiating and concentric textures (Figure 19). It is commonly stabilized with Opticon.

Zigras reported that the de Linde deposit is worked in an open pit with a single trackhoe, and mining typically takes place twice annually for a two-week period, producing about one tonne of good specimen- and cutting-quality material. Several hundred stones have been cut from the variscite and about 1,000 pieces of wavellite have been polished.

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Figure 19: This pendant features a cabochon of Arkansas wavellite that measures 25 × 20 mm. Photo by Jeff Fuller.

DIAMONDS

Diamond Mining at Namdeb's Southern Coastal Mines, Namibia

In conjunction with the 35th International Gemmological Conference in Windhoek, Namibia, this author joined a pre-conference tour that took place on 8–11 October 2018 with approximately 30 participants in attendance. A highlight of this excursion was a visit to Namdeb Diamond Corporation's Southern Coastal Mines to witness active mining of a series of old raised beach deposits (Figures 20–22). This concession is situated in an area previously known as Mining Area No. 1, which extends along ~ 120 km of Namibia's coast from the Orange River at Oranjemund northward to Chameis Bay.

Our tour leader was geologist Dr Jurgen Jacob (Namdeb, Oranjemund, Namibia), who started by giving an informative presentation on the geology, exploration, mining and production of Namibia's diamond deposits (both marine and onshore). Then, after passing through an extensive security facility, the group boarded a Namdeb bus for the trip to the pit that was being worked. As we passed through the historic diamond mining area called the *Sperrgebiet*, we saw abandoned mining pits, dormant and active processing plants, and conveyor belts that were used to transport sand to enormous seawalls designed to keep the Atlantic Ocean from flooding the pits.

A linear beach deposit extends for 110 km along the Sperrgebiet, but 95% of it has been mined out in a series of pits that extend down to 25 m below sea level. Through a process called *accretion*, Namdeb has pushed back the shoreline using sand walls that typically are 50–60 m wide (and locally

Figure 20: In October 2017, diamond mining was taking place at this pit in Namdeb's Southern Coastal Mines. The pit is flanked by sand walls, and ocean water is held back by the seawall to the far left. Previously mined bedrock gullies are visible in the centre of the photo, and on the right side is a series of transvac units and bins located adjacent to the current mining area. Photo courtesy of Namdeb.

Figure 21: To recover diamond-bearing gravels from the bedrock trapsites, excavators and bulldozers first remove overlying sediments, as well as some areas of the bedrock itself, and then transvac machines (each with an accompanying bin) are used to vacuum any remaining sediments from the bedrock surface. Photo courtesy of Namdeb.

Figure 22: A portion of the exposed bedrock (right side) has been vacuumed to remove any diamond-bearing sediments, while on the left an excavator prepares the area for the transvac crews. Photo courtesy of Namdeb.

Figure 23: Members of the transvac crew work in pairs. They will stop vacuuming to pick up any diamonds that they see in the bedrock gullies, although such 'pick ups' typically occur only about twice per week. Photo courtesy of Namdeb.

up to 150 m wide). Adjacent to the active mining pit we visited, the seawall towered 8 m above the beach and was being replenished by 40 tonne dump trucks. Namdeb also constructs sand walls along the flanks of each mining pit (e.g. Figure 20), so if the seawall is breached by the ocean during intense storms then only a small portion of the entire pit system is flooded.

After sand overburden is removed to within 1–2 m of the underlying bedrock (which consists of schist of the Gariep Belt), the pits are then mined in a two-step proces. First, the *bulking* team uses bull-dozers and excavators to remove the remaining sediments and some of the bedrock protuberances, and then the *transvac* team uses powerful vacuums to suction any remaining sediments from the bedrock (Figure 23). The diamonds were deposited within gravels hosted by scour deposits along gullies and potholes in the bedrock (see Jacob et al., 2006, for details), so particular attention is paid to such trapsites. The vacuumed material is discharged into collection bins that are mounted on trailers and hauled to a treatment plant for processing. The material removed by the bulking team also is processed, while the overlying 15–18 m of sand is used for the seawall construction mentioned above.

The bedrock gullies in the linear beach deposits range from 1 to 4 m deep and have variable grade, but overall they tend to produce ~6 carats per 100 tonnes. Diamonds are actually seen by the transvac crews only about twice per week. The diamonds average ~0.7 ct per stone, and typically about 5–10 carats may be recovered by hand from gravels in some trapsites. However, the vast majority of the diamonds are recovered at the processing plant, which treats material ranging from 2 to 30 mm. A concentrate is produced using dense media separation, and this material then undergoes X-ray sorting.

At the time of our visit, the Southern Coastal Mines employed a total of 700 people who worked in three 8-hour shifts (although the transvac crews were only active in the daytime).

In total, Namdeb is currently producing 500,000 carats/year from its onshore operations and 1.3 million carats/year from its marine concessions. The diamonds are 95%–98% gem quality, since most of the lower quality stones broke down during the extensive journey along the Orange River and while being transported northward along the Atlantic coast in longshore currents. Although Namdeb's mine plan for its onshore operations is scheduled to last for five years, there is the potential to explore and extend the diamond reserves until at least 2050.

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SYNTHETICS AND SIMULANTS

Feldspar-Sapphirine Rock as a Grandidierite Imitation

Grandidierite is a rare Mg-Fe-Al-borosilicate, which was first described by Lacroix (1902) and named after the French scientist Alfred Grandidier (1836–1912). The type locality is Cap Andrahomana in southern Madagascar.

Chemically, grandidierite [$MgAl_3O_2(BO_3)(SiO_4)$] forms a solid-solution series with the iron end-member ominelite [$Fe^{2+}Al_3O_2(BO_3)(SiO_4)$]. Grandidierite ranges from bluish green to greenish blue with strong pleochroism (due to iron), and is found as an accessory phase in aluminium-bearing, boron-rich pegmatites. Standard gemmological properties are reported as n_x = 1.583–1.602, n_y = 1.620–1.636 and n_z = 1.622–1.639, with a birefringence of 0.037–0.039 and an SG ranging from 2.85 to 3.00 (Henn, 2012).

Recently the authors have examined an increasing number of grandidierite gemstones from a new find in Madagascar (cf. Bruyére et al., 2016; Laurs, 2016). Most of the material has been translucent, but some rare transparent samples also have been investigated, including a bright greenish blue specimen weighing 1.26 ct. We also examined a stone that drew attention because of its unusual appearance (Figure 24), which had been purchased by the client as grandidierite from Madagascar. The refractometer gave values of 1.548–1.555 with a maximum birefringence of 0.007. The hydrostatic SG was 3.03. The RIs and birefringence correspond to the typical values of plagioclase feldspars, although the SG is close to that of grandidierite.

Figure 24: This 2.61 ct feldspar-sapphirine rock was sold as grandidierite from Madagascar. Photo by S. Müller.

In the microscope, we observed numerous greenish blue tabular inclusions (Figure 25) that showed a higher lustre than the surrounding matrix in reflected light (Figure 26). Analyses with a Renishaw inVia Raman spectroscope confirmed plagioclase as the matrix material. Most of the inclusions were identified as sapphirine, although some mica grains were present. Figure 26 shows that the material consists of approximately 50% sapphirine.

Figure 25: With magnification, tabular greenish blue sapphirine inclusions can be seen in the feldspar matrix of the grandidierite imitation. Photomicrograph by T. Stephan, transmitted light; field of view 2.8 mm.

Figure 26: With reflected light on the table facet of the feldspar-sapphirine rock, the sapphirine inclusions show a brighter reflection than that of the plagioclase matrix. Photomicrograph by T. Stephan, reflected light; field of view 5.0 mm.

Although the stone showed typical RIs for plagioclase, it actually is a rock consisting of both plagioclase and sapphirine. This is consistent with the SG that we measured, which lies between the values for plagioclase (2.61–2.77) and sapphirine (3.42–3.51) reported in the literature (cf. Henn, 2012). It is interesting to note that grandidierite occurs together with both plagioclase and sapphirine in the Madagascar deposit (Bruyére et al., 2016).

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Glass Doublets Simulating Rutilated and Tourmalinated Quartz

During the February 2018 Tucson gem shows, some new variations of simulated rutilated and tourmalinated quartz were offered as pendants at the JOGS Gem & Jewelry Show by Amulete Gems Inc. (based in Manteca, California, USA). The company disclosed the fact that they were not natural, and indicated that the host material is manufactured in China, where it is called 'hydroquartz'. However, rather than being constructed of some type of quartz, these doublets consisted of two pieces of glass that were cemented together along with flat gold metallic or black strips (probably plastic) to imitate the appearance of rutile or tourmaline inclusions in rock crystal quartz. In addition, another variety containing iridescent strips was available. The doublets were faceted in a checkerboard style, and were cut into round, pear and teardrop shapes. The finished pendants ranged from 0.6 to 3.0 cm wide, and the pear/teardrop shapes were up to about 5 cm tall. The doublets were mounted in a yellow, white or oxidized metal bezel, with one to three bails for suspending them in jewellery. The metals reportedly consisted of sterling silver, but this was not confirmed by the author.

Gem-A purchased six of the pendants for its teaching collection (Figure 27). At first glance, the 'tourmalinated' simulants were rather convincing. Upon examination with a loupe, however, it was clear that the long strips imitating the inclusions

Figure 27: Both 'rutilated' and 'tourmalinated' glass doublets are mounted in these pendants (approximately 0.6–3.0 cm wide). Photo by Henry Mesa.

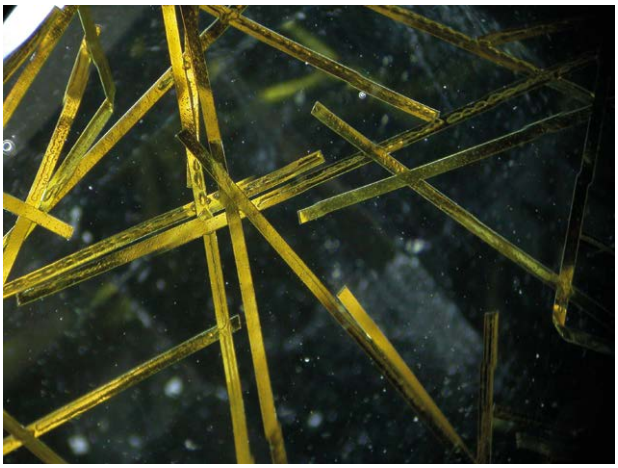

Figure 28: The 'inclusions' in the glass simulants of rutilated quartz consist of tinsel-like flat gold metallic strips with squared ends. Note the gas bubbles and films along some of the strips. Photomicrograph by L. Faber; magnified 30×.

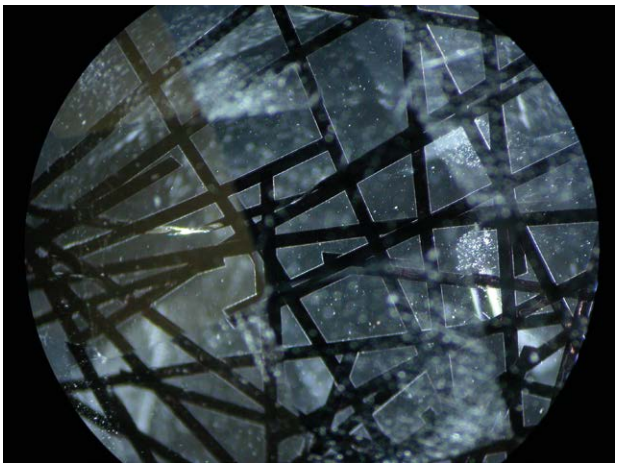

Figure 29: The pendants simulating tourmalinated quartz contain dark-coloured strips between the two layers of glass. These strips also displayed squared ends. Photomicrograph by L. Faber; magnified 30×.

were flat and had squared ends, much like pieces of cut tinsel (Figures 28 and 29). Also, the glass making up some of the samples contained gas bubbles. In addition, flattened and elongated gas bubbles were seen along just one side of the 'inclusions' in both types of doublets. One sample displayed iridescence as well as large, flattened areas that appeared to be air pockets where the two halves of glass had been partially adhered.

When examined with a polariscope, the host glass either stayed dark through a full 360° rotation of the sample or exhibited some strain, consistent with the isotropic optic character of glass. The black-appearing 'inclusions' often appeared light and dark through a 360° rotation, but the gold metallic ones did not allow any light to pass through them. Testing with a refractometer further revealed that the material was singly refractive, with RIs ranging from 1.516 to 1.520, which are well within the range for artificial glass. Polishing lines were present on each of the six examples, as well as some abrasions, indicating a relatively soft material that was not polished with close attention.

The pendants debuted in early 2016, and according to the seller they have been very popular, particularly in the past year or so. At the JOGS show there were several hundred pieces available for purchase at a fraction of the price expected for natural examples of comparable size.

Although the joint lines between the glass halves were obscured by the bezel settings, these doublets could be easily identified by a close examination of their 'inclusions'. A similar type of doublet manufactured from natural quartz with metallic foils was documented by Hänni and Henn (2015).

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Reference

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More on Black Star Rutile Imitations

In the previous issue of *The Journal*, this author reported on a 10.67 ct black star cabochon that was purchased by a Canadian gem collector as star rutile from Sri Lanka but proved to be black cubic zirconia (Deljanin, 2018). After receiving the results on this sample, the same client submitted for identification two more black star cabochons that were sold to him as 'natural star rutile from Sri Lanka'.

Both samples displayed six-rayed stars, and their RIs were over the limits of the refractometer. One of them weighed 38.82 ct (Figure 30, left) and appeared translucent dark red with strong transmitted illumination. It had a hydrostatic SG of 4.23, consistent with natural rutile (4.20–4.30). However, star rutile has been documented only as very rare four-rayed stones (Steinbach, 2017, pp. 667–670). Raman spectroscopy performed at the GRS lab in Hong Kong with a GemmoRaman-532SG instrument yielded a spectrum that matched garnet. The other sample, a 41.12 ct opaque black star cabochon

Figure 30: Both the 38.82 ct garnet (left) and the 41.12 ct hematite-magnetite (right, of probable manufactured origin) shown here were sold as natural black star rutile. Photos by Matthias Alessandri.

(Figure 30, right), revealed a higher SG of 5.01, and featured a metallic lustre composed of light and dark grey domains; it also was strongly magnetic. Clearly it was not composed of rutile, and additional testing was needed to identify it (see below).

Microscopic examination using overhead lighting revealed parallel scratches on the surface of both samples (e.g. Figure 31) that were responsible for the perceived asterism (cf. Schmetzer and Steinbach, 2002; Steinbach, 2017, pp. 274–281). Re-examination of the two black star CZ samples reported by Deljanin (2018) showed that similar grooves had been scratched on their surfaces (Figure 32). Thus, the asterism in all of these samples was artificially induced.

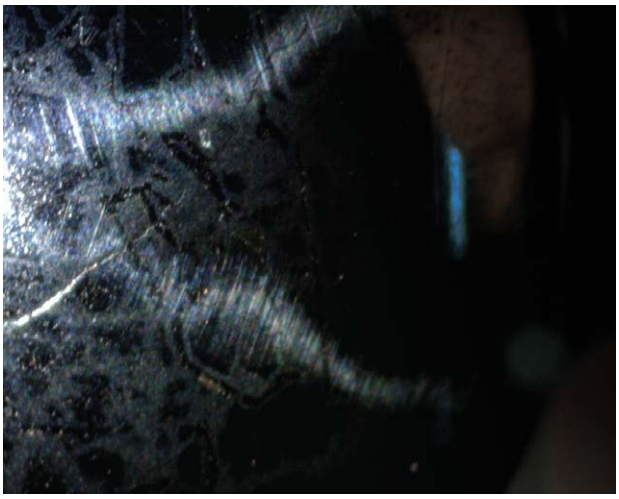

Figure 31: Parallel scratches on the surface of the 41.12 ct hematite-magnetite cabochon (shown here with two of the three orientations scratched on the sample) were responsible for its six-rayed star. Photo by B. Deljanin.

X-ray powder-diffraction (XRD) data were collected on the 38.82 and 41.12 ct samples at University of British Columbia using a Bruker D8 Advance diffractometer. With the client's permission, small amounts of powder were scraped from the 38.82 ct cabochon using a diamond file and from the 41.12 ct sample using SiC abrasive paper. The data were collected with Bragg-Brentano geometry over a range of 10°–140° 2Θ with Co*K*α radiation, an Fe monochromator foil, a 0.6 mm (0.3°) divergence slit, incident- and diffracted-beam Soller slits and a LynxEye XE detector. The 38.82 ct sample consisted mainly of almandine with minor pyrope, grossular and spessartine components. Energy-dispersive spectroscopy recorded with a scanning electron microscope confirmed it to be primarily almandine with minor Mg, Ca and Mn, and a trace of Ti. XRD analysis of the 41.12 ct cabochon revealed it to be hematite-magnetite (2:1 content; Figure 33). The absence of trace rock-forming minerals such as quartz, goethite, etc. might suggest a synthetic origin (Prof. Mati Raudsepp, pers. comm., 2017). According to Marion (2012), natural hematite is rare, expensive and generally not suitable for lapidary work, and therefore most of the 'hematite' beads and cabochons on the market are actually simulants (e.g. formed from powdered hematite).

These two additional cases of imitation black stars are reminders that standard and advanced testing are necessary for non-transparent black stones. While chemical analysis is sometimes needed to reveal a natural or synthetic origin of such material, simple observation using a microscope with proper lighting should reveal if a star is

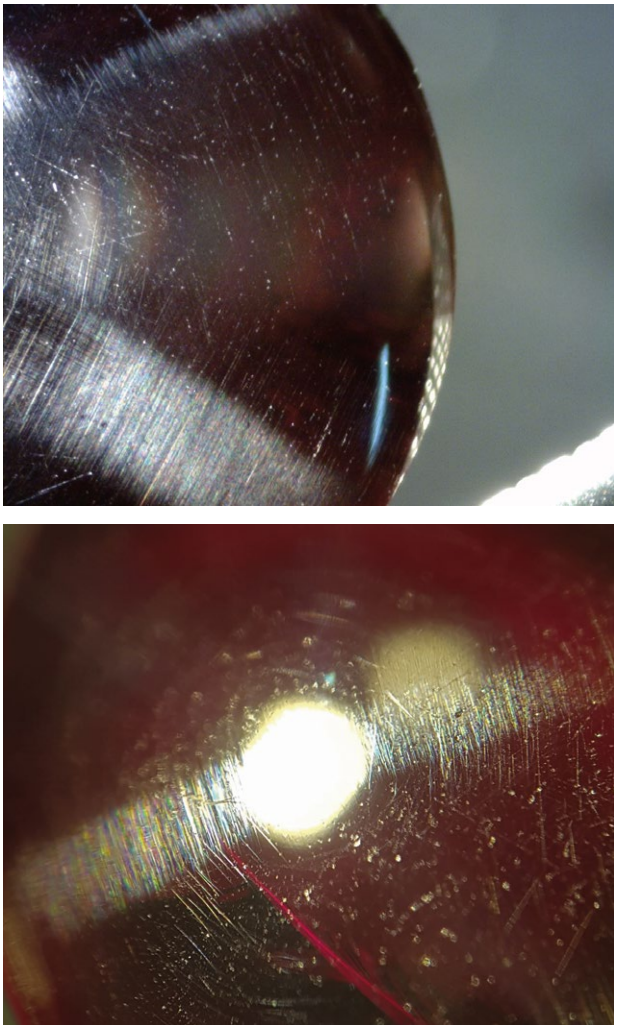

Figure 32: Upon close examination, the CZ imitations of black star rutile reported by Deljanin (2018) also showed surface scratches that created their asterism. Photos by B. Deljanin (left, 10.67 ct) and Alberto Scarani (right, 8.77 ct).

naturally or artificially induced. While garnets have been previously documented with artificial stars (see references cited above), this is the first time to the author's knowledge that hematite-magnetite has been reported with a scratch-induced star.

Acknowledgements: The author thanks Prof. Mati Raudsepp (Department of Earth, Ocean and Atmospheric Sciences, University of British Columbia, Vancouver, Canada) for XRD and SEM-EDS testing and useful feedback; Matthias Alessandri (GRS Lab Ltd., Hong Kong) for Raman spectroscopy of the 38.82 ct sample and for photos of both cabochons; Alberto Scarani (Magilabs, Rome, Italy) for the photomicrograph of the 8.77 ct star CZ that he encountered; and John Chapman (Gemetrix, Perth, Australia) for helpful comments and editing.

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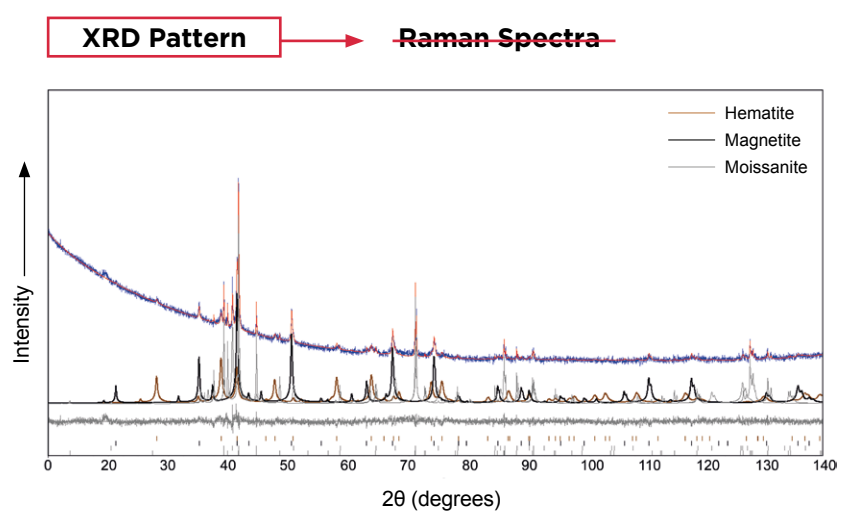

Figure 33: XRD analysis of the 41.12 ct sample proved that it consists of hematite-magnetite. This Rietveld refinement plot shows various patterns (blue line = observed intensity at each step; red line = calculated pattern; solid grey line below = difference between observed and calculated intensities; vertical bars = positions of all Bragg reflections). The differently coloured baseline-corrected peaks correspond to individual diffraction patterns of the detected phases (hematite and magnetite, as well as some contamination by synthetic moissanite from abrading the sample with SiC paper).

MISCELLANEOUS

Mid-Year 2017 Myanma Jade & Gems Emporium and Yangon Gems & Jewellery Fair

The Mid-Year 2017 Myanma Jade & Gems Emporium was held 12–21 December in Nay Pyi Taw, Myanmar. Gems that were offered included parcels of ruby (e.g. Figure 34, left), sapphire, spinel, peridot (Figure 34, right), amber, aquamarine, danburite, garnet and assorted coloured stones. Lot no. 111, consisting of 1.1 g of rough ruby, fetched €63,229. Mong Hsu rough ruby lot no. 176, weighing 2.50 kg, sold for €65,431. The highest price paid for rough sapphire—€40,099—was for lot no. 63, which had two pieces weighing a total of 18.2 g. Rough spinel lot no. 53, consisting of one 5.6 g piece, brought €100,088. Lot no. 168, a parcel of rough peridot weighing 720 g, sold for €51,550. This particular Emporium also had finished products manufactured from Myanmar 'jade', including a tree constructed of carved jadeite; jadeite necklaces, bangles, cabochons and beads; semi-cut jadeite and quartzite; and quartzite bangles, cabochons and beads.

A 14 December 2017 Burmese newspaper article reported that the Emporium was attended by foreign visitors from China, Thailand, Macao and Canada, as well as 1,339 local attendees, for a total of 3,999 participants. Table I summarizes the Emporium's offerings and sales.

From 11 to 14 January 2018, the 1st Yangon International Gems & Jewellery Fair (organized by Yangon Gems & Jewellery Entrepreneurs Association) was held at the Lotte Hotel in Yangon. There were 76 stalls with 104 exhibitors displaying their products (e.g. Figure 35). A total of 6,774 domestic buyers and 686 foreigners attended. Sales of loose stones were US$250,000 and jewellery sales totalled $294,602.50. A seminar programme included two

Figure 34: Gems offered at the Mid-Year 2017 Myanma Jade & Gems Emporium included heat-treated cabochons of Mong Hsu ruby (left, 1,142 carats total weight) and rough Burmese peridot (right, 772.8 g). Photos by T. Hlaing.

foreign presenters: Tay Thye Sun (Far East Gemological Laboratory, Singapore) discussed Burmese amber from Hti Lin and the use of Raman spectroscopy for separating amber from copal and other imitations, and Richard Hughes (Lotus Gemology, Bangkok, Thailand) described the internal features of ruby.

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Table I: Sales at the Mid-Year 2017 Myanma Jade & Gems Emporium.

Material	Total Lots	Sold Lots	Total sales (million €)
Jade*	6,660	4,050	438.58
Gems	190	32	0.767

* Consists of rough and semi-cut pieces.

Figure 35: The 1st Yangon International Gems & Jewellery Fair provided a meeting place for vendors and buyers of Burmese gems. Photo by T. Hlaing.

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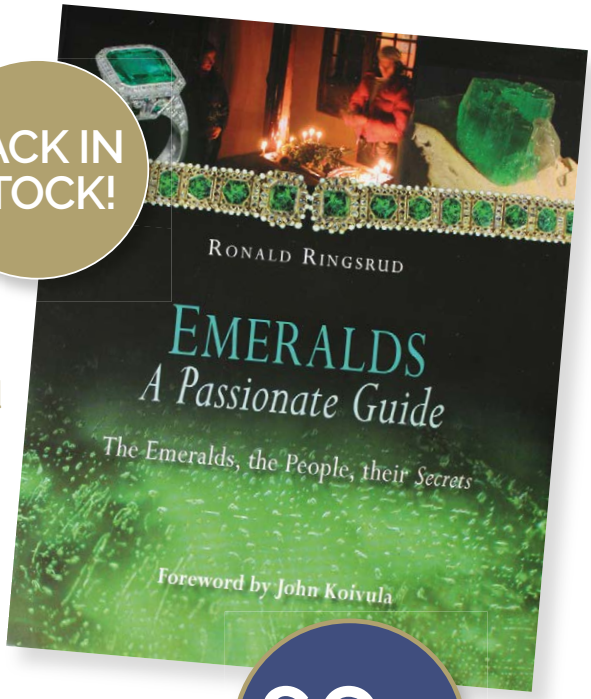

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Figure 1: These faceted amethysts from the Ngororero District of Rwanda weigh 7.30 ct (left) and 10.91 ct (right). Courtesy of Jack Lowell; photo by Jeff Scovil.

Gem-Quality Amethyst from Rwanda: Optical and Microscopic Properties

Karl Schmetzer and Bear Williams

Recent years have witnessed the emergence of reports regarding new finds of amethyst in Rwanda. A study of Rwandan material by the present authors shows that the majority of samples displayed characteristic features distinct from those considered typical of most amethyst from other localities. In particular, light violet to almost colourless rhombohedral growth sectors frequently exhibited Brazil-law twinning, while purplish violet or intense violet growth sectors were untwinned. Distinct pleochroism when viewed parallel to the c-axis also was notable, even in samples that showed no Brazil-law twinning. However, a small fraction of the material examined from Rwanda instead showed properties that were generally consistent with those commonly seen in amethyst. This suggests that amethyst has entered the market from different Rwandan sources, and recent finds in both the Ngororero and Ruhango Districts have been cited.

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INTRODUCTION

Since late 2015, various reports have emerged regarding new finds of amethyst in Rwanda, and faceted stones of high quality (e.g. Figure 1) have entered the international market. The gems are primarily violet in colour, occasionally appearing slightly purplish violet in daylight and somewhat more intensely purplish violet in incandescent light.

Two areas of Rwanda have been cited as potential sources for the new material: the Ngororero and Ruhango Districts (Figure 2). Ngororero is located in Western Province, about 40 km south-east of Goma (W. Radl, pers. comm., 2017). Internet news reports pertaining to this amethyst deposit further specified the Kavumu Sector of Ngororero District as the source of the occurrence (Rwanda News

Figure 2: The approximate locations of the two recent finds of Rwandan amethyst are shown on this map. The red symbol refers to the Kavumu Sector of the Ngororero District (see National Institute of Statistics of Rwanda, 2010; Tuyisabe, 2015) and is located about 40 km south-east of Goma. The centre of the Ruhango District is represented by the blue symbol.

Agency, 2017; see Tuyisabe, 2015, for the subdivision of provinces and districts in Rwanda), and they showed images of workings located on a sloped grassy terrain (e.g. Figure 3A) where local miners used hand tools to search for amethyst (e.g. Figure 3B). Internet resources also indicated that the deposit was discovered in 2015 (e.g. *Hope Magazine*, 2017).

The second area referenced as a potential source of gem-quality amethyst in Rwanda, likewise discovered in 2015, is the Ruhango District in Southern Province (Footprint to Africa, 2015; Kigali Today, 2015). Samples said to have originated from this find were described by Stephan and Schmitz (2016, 2017). Those authors noted distinct colour zoning with intense violet and colourless areas. They also mentioned observing polysynthetic twinning on the Brazil law, a typical feature of natural amethyst.

Following the initial reports in November 2015, samples of the new Rwandan amethyst reportedly from the Ngororero District were supplied by rough stone dealer Farooq Hashmi, and a preliminary examination by one of the authors (BW) revealed interesting optical and spectroscopic characteristics. It was then decided to conduct a more detailed study with additional samples to identify and better understand the underlying properties. This article describes the optical and microscopic aspects, and a future paper by one of the authors (BW) is planned to examine the spectroscopic properties of the Rwandan amethyst.

Figure 3: (A) The recently discovered amethyst deposit within the Ngororero District is located on sloped terrain. (B) Local miners use hand tools to search for amethyst. The photos were taken by a local miner and are courtesy of Farooq Hashmi.

MATERIALS AND METHODS

This study began with 28 amethyst crystals and crystal fragments, ranging from ~1 × 1 × 0.5 cm (0.6 g) to 7 × 5 × 4 cm (171 g), and 14 faceted gemstones weighing 1.45–16.17 ct. The samples, represented as being from the Ngororero District, were provided by Farooq Hashmi, John Garsow, Jack Lowell and Werner Radl (see Acknowledgements). With permission from the owners, eight of the rough samples were sawn approximately perpendicular to the c-axis, generally yielding three to five slices per sample.

For comparison, the study was subsequently augmented with 10 rough (5.6–28.7 g) and four faceted (5.20–25.67 ct) amethysts from the same German company that had supplied the research material described by Stephan and Schmitz (2016, 2017). The supplier reported that the samples had originated from the western part of Rwanda, but the company had no further information about the particular source locality (E.-O. Sahm, pers. comm., 2017).

All samples were examined microscopically, with and without immersion, using standard gemmological techniques. Some of the rough material was encrusted with white or black material adhered to the surface, and a small quantity of these coatings was analysed by X-ray powder diffraction using a Philips PW1800 diffractometer.

RESULTS

Samples Reportedly from the Ngororero District

Morphology of the Rough and Characterization of Encrustations: The complete crystals generally showed six rhombohedral **r** and **z** faces (Figure 4, occasionally with some prismatic m faces (Figure 5A). The relative proportions of each group of symmetry-equivalent rhombohedral **r** and **z** faces varied (Figures 5B–D), insofar as all crystals were highly distorted (Figure 4).

X-ray diffraction of the encrustations on the crystals identified them as opal-CT (whitish coatings; Figure 4) and lithiophorite (black coatings). Their presence indicated that, subsequent to amethyst crystal growth, the deposit experienced conditions allowing for the deposition of minerals formed at relatively low temperatures.

Figure 4: Amethyst crystals from Rwanda display six rhombohedral faces, occasionally in combination with short prism faces. The rhombohedral **r** and **z** faces are highly distorted, with symmetry-equivalent faces differing in size. The whitish encrustation was identified as opal-CT. The sample weighs 68 g and measures 50 × 45 mm. Photo by K. Schmetzer.

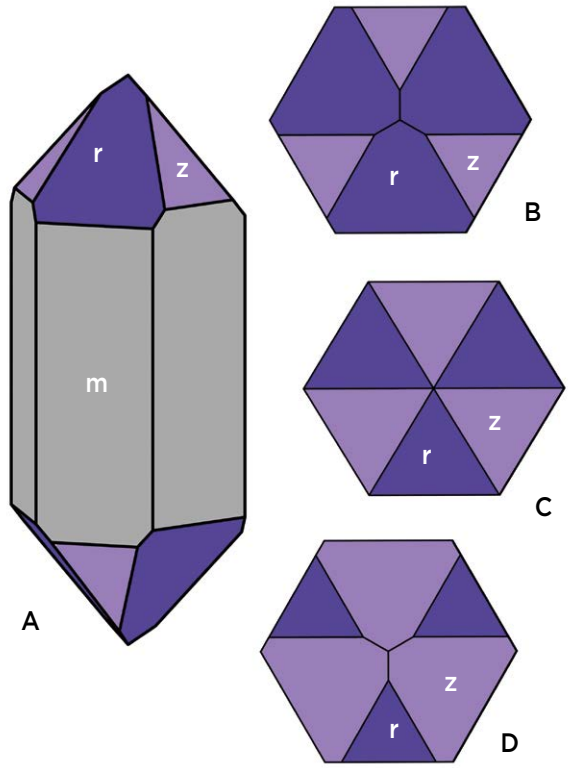

Figure 5: The morphology of amethyst crystals from Rwanda comprises primarily rhombohedral **r** and **z** faces, occasionally in combination with prismatic **m** faces. Shown here are (A) an idealized clinographic projection and (B–D) idealized (non-distorted) projections viewed parallel to the c-axis showing different sizes of **r** and **z** faces. Normally, the Rwandan amethyst crystals are distorted and broken (i.e. samples with two ends were not seen by the authors). Drawings by K. Schmetzer.

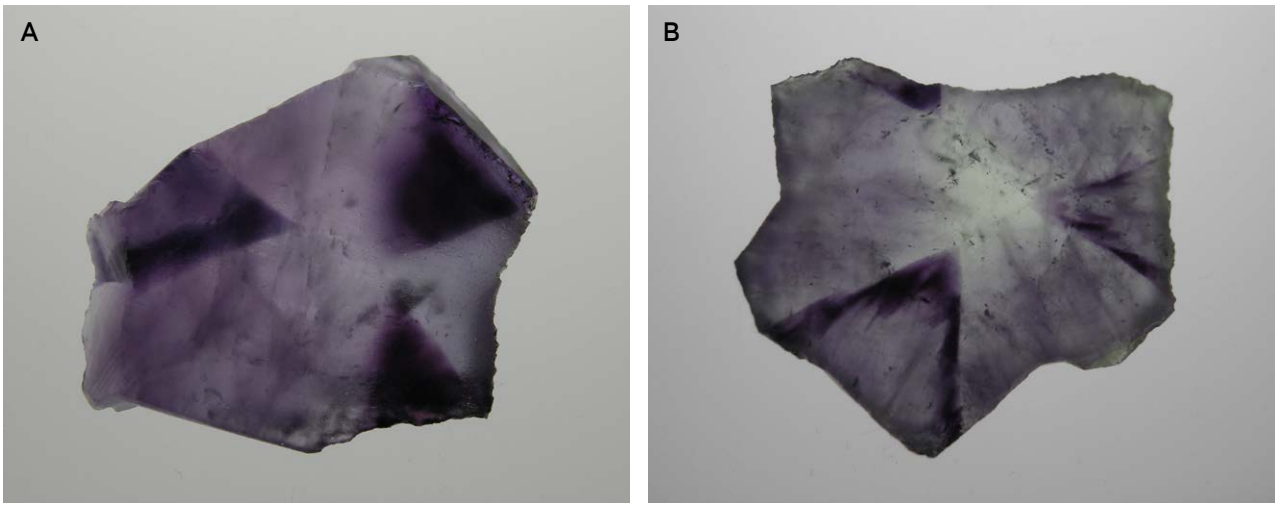

Figure 6: Slices of amethyst from Rwanda, cut perpendicular to the c-axis, show growth sectors that vary from intense violet to lighter violet to almost colourless. The slices measure (A) 36 × 23 × 6 mm and (B) 40 × 34 × 5 mm. Photos by K. Schmetzer.

Colour Zoning of Rhombohedral Growth Sectors: All rough and faceted samples displayed colour zoning that corresponded to the different rhombohedral growth sectors. Such sectorial colour zoning was best seen in slices cut perpendicular to the c-axis, using transmitted light (Figure 6). Frequently, larger light violet areas were observed in combination with smaller triangular growth sectors exhibiting a more intense purplish violet or violet colour (Figure 6A). Within these deeply coloured sectors, lighter and darker stripes also were seen (Figure 6B). In faceted samples, the sectorial colour zoning was more apparent when viewed from the pavilion (Figure 7).

Figure 7: Faceted Rwandan amethyst commonly displays sectorial colour zoning, which typically consists of intense violet to purplish violet and lighter violet to almost colourless zones. The zoning may be visible in views toward the table facet (top), but it is more apparent in views toward the pavilion of the samples (bottom). The stones weigh 7.71 ct (left) and 10.03 ct (right). Photos by K. Schmetzer.

Figure 8: This schematic representation of the pleochroism in amethyst demonstrates that, in a view parallel to the c-axis, symmetry-equivalent rhombohedral growth sectors (violet and light purple) ideally show identical pleochroism after rotation about the c-axis through an angle of 120°. The labels X1, X2, Y1 and Y2 represent the colours observed within the different growth sectors using one polarizer between the sample and the observer. Drawing by K. Schmetzer.

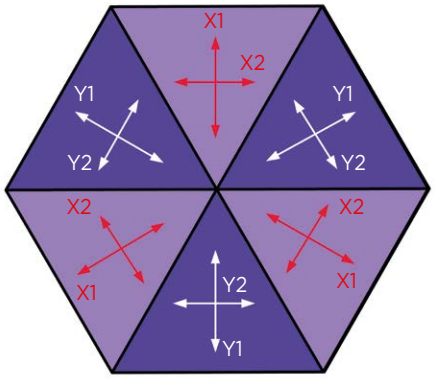

Pleochroism of Rhombohedral Growth Sectors: It has been demonstrated that some amethyst—despite being α-quartz and therefore belonging to the trigonal system—shows pleochroism when viewed parallel to the optic axis in slices cut perpendicular to the c-axis (Pancharatnam, 1954; Lietz and Münchberg, 1956). In such slices, the three symmetry-equivalent **r** or **z** growth sectors exhibit identical pleochroism and colour. Consequently, when a sample is viewed in plane-polarized light and rotated about the c-axis, each rotation through 120° will reveal an identical growth sector with identical pleochroism (Figure 8). Some of the present samples from the Ngororero District exhibited this property, which was especially evident in slices cut from the crystals.

Table I: Pleochroism typical of Rwandan amethyst, viewed parallel to the c-axis.*

Type	Sector colour	Pleochroism
I	Light violet to almost colourless	Light violet and colourless
II	Purplish violet	Intense purplish violet and yellow to light orange-yellow
III	Intense violet	Intense violet and lighter slightly purplish violet

* In views perpendicular to the c-axis of the samples available for this study, the light path always traversed multiple types of rhombohedral growth sectors. To evaluate and accurately describe the pleochroism in such orientation, and for each of the three different types of growth sectors, it would be necessary to obtain numerous slices parallel to the c-axis that each contained only a single growth sector. Slices of that nature were not available for the present research.

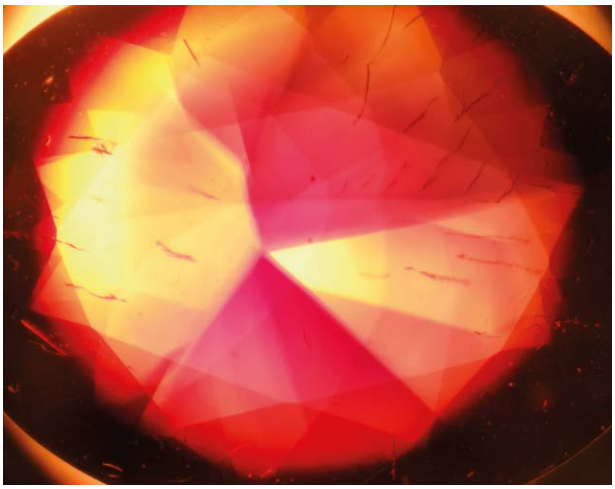

Figure 9: Viewed parallel to the c-axis, this amethyst from Rwanda shows sectorial colour zoning with two light violet to almost colourless growth sectors (type I) and two intense violet growth sectors (type III). Photomicrograph by K. Schmetzer, in immersion; field of view 12.8 × 10.0 mm.

Three different types of pleochroism were seen in the triangular growth sectors, depending on their coloration (Table I). In general, a particular specimen showed two of the three types of growth sectors/pleochroism—that is, a combination of type I and type III growth sectors (Figures 9 and 10A) or a combination of type I and type II growth sectors (Figure 10B). However, in some samples all three types of growth sectors were found (Figure 11). Nevertheless, because most samples featured a high degree of distortion, there were frequently fewer than the ideal six rhombohedral growth sectors. Examples with just four discernible rhombohedral growth zones are depicted in Figures 9 and 11.

Other types of zoning—possibly related to twinning—are discussed below.

Brazil-law (Optical) Twinning: Natural amethyst normally shows colour zoning with somewhat more intense violet **r** growth sectors and somewhat lighter violet **z** growth sectors. Viewed parallel to the c-axis with crossed polarizers, the intense violet **r** growth sectors typically exhibit interference patterns consisting of more-or-less regular black stripes (Brewster fringes). This pattern is a result of Brazil-law polysynthetic twinning in these sectors. No such pattern was found in the purplish violet or intense violet growth sectors of the Ngororero amethyst. In contrast, the samples revealed three scenarios with respect to Brazil-law twinning features:

- Pattern A: No interference patterns with Brewster fringes were seen in any of the growth sectors

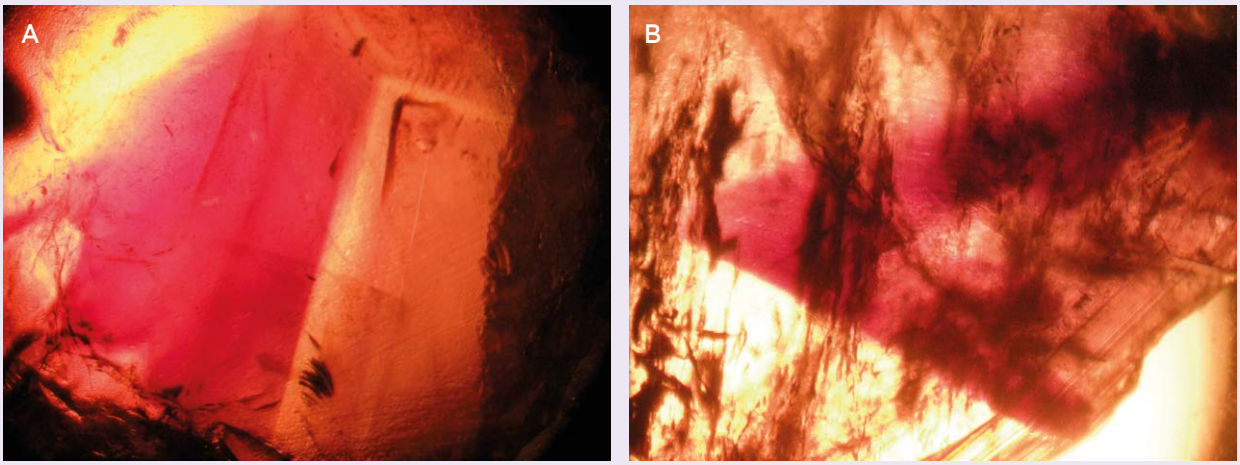

Figure 10: With plane-polarized light, in a view parallel to the c-axis, the rhombohedral growth sectors of Rwandan amethyst exhibit different combinations of colour and pleochroism: (A) a combination of light violet to almost colourless (type I) and intense violet (type III) sectors, and (B) a combination of light violet to almost colourless (type I) and purplish violet (type II) sectors. Photomicrographs by K. Schmetzer, in immersion; field of view 14.5 × 10.9 mm.

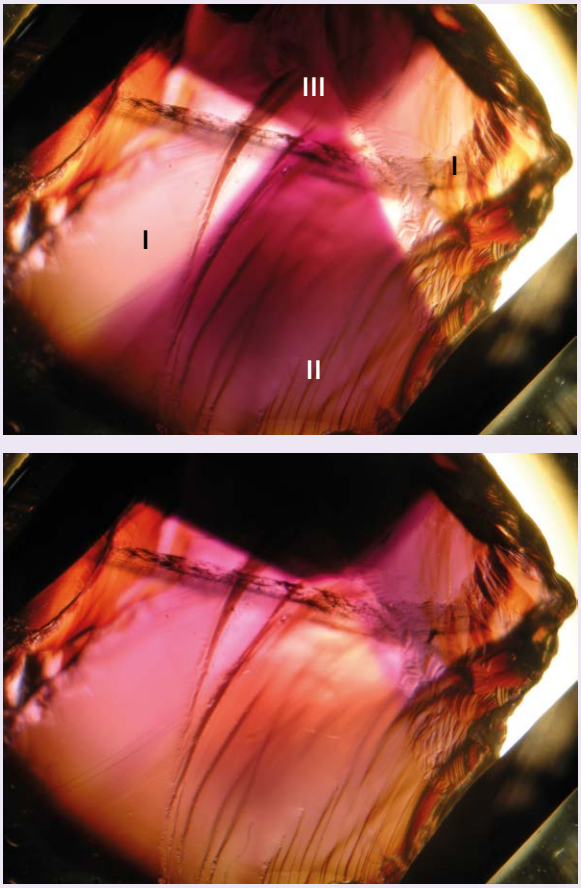

Figure 11: In a view parallel to the c-axis, this distorted Rwandan amethyst sample shows three different types of rhombohedral growth sectors with varying colour and pleochroism. The two views show the pleochroism that is seen upon rotation of the polarizer. In the two type I growth sectors, the pleochroism is light violet and colourless; in the single type II growth sector, the pleochroism is intense purplish violet and yellow; and in the single type III growth sector, the pleochroism is intense violet and a somewhat lighter, slightly purplish violet. Photomicrographs by K. Schmetzer, in immersion; field of view 14.5 × 10.9 mm.

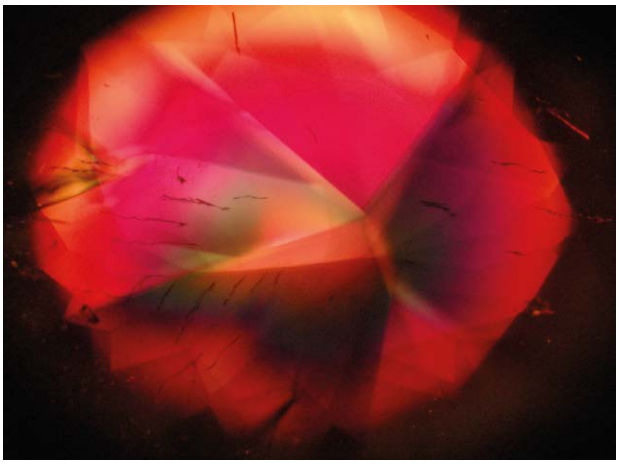

Figure 12: Viewed parallel to the c-axis with crossed polarizers, this amethyst from Rwanda shows different rhombohedral growth sectors but no Brewster fringes indicative of polysynthetic Brazil-law twinning. Photomicrograph by K. Schmetzer, in immersion; field of view 14.5 × 10.9 mm.

(Figure 12), despite the presence of different types of rhombohedral growth zones as described above.

- Pattern B: Single Brewster fringes confined to the boundaries between different growth sectors were observed (Figure 13).
- Pattern C: In addition to Brewster fringes following the boundaries between different growth sectors as described in pattern B, polysynthetic twinning on the Brazil law was observed in the light violet to almost colourless growth zones, at times resulting in highly complex patterns (Figure 14).

Dauphiné Twinning: Certain samples also contained irregularly shaped domains displaying coloration (more intense violet or more purplish violet) and pleochroism that were different from the surrounding host material (Figure 15). These domains and the surrounding material showed no interference patterns with crossed polarizers and are most likely related to Dauphiné twinning.

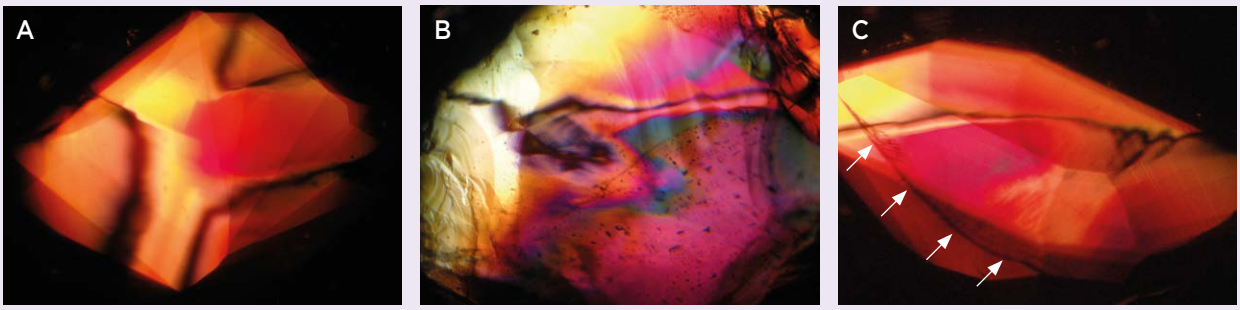

Figure 13: A single black interference line (Brewster fringe) confined to the boundaries between various rhombohedral growth sectors is commonly seen in Rwandan amethyst when viewed parallel to the c-axis with crossed polarizers. (The dark line highlighted with arrows in photo C is a partially healed fracture.) Photomicrographs by K. Schmetzer, in immersion; field of view (A) 12.4 × 9.3 mm, (B) 11.5 × 8.7 mm and (C) 9.5 × 7.2 mm.

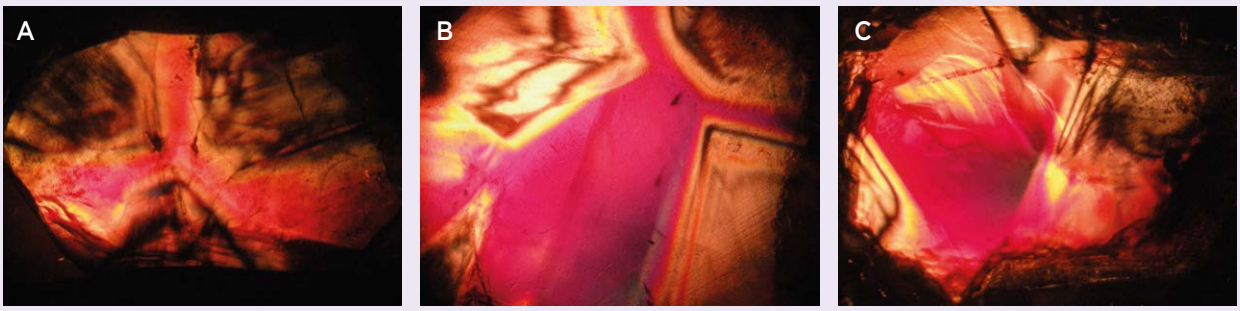

Figure 14: In several Rwandan amethyst samples, complex arrangements of optical twinning features are evident. In these views parallel to the c-axis with crossed polarizers, single black interference lines (Brewster fringes) follow the boundaries between various rhombohedral growth sectors and are accompanied by dense patterns of Brewster fringes indicating Brazil-law polysynthetic twinning in the light violet to almost colourless sectors. Photomicrographs by K. Schmetzer, in immersion; field of view (A) 13.5 × 10.1 mm, (B) 11.9 × 9.0 mm and (C) 14.0 × 10.5 mm.

Other Zoning: One sample displayed another type of colour zoning and pleochroism that was seen in a view inclined 42° to the c-axis as a thin growth zone (Figure 16). It was apparently related to the boundary between two rhombohedral growth sectors. This zoning also might be related to twinning, but the pattern is not completely understood (see also the pleochroism in different rhombohedral growth sectors described in the next paragraph).

Rhombohedral Growth Zoning and Striations: Striations parallel to the external rhombohedral faces of the amethyst crystals were frequently observed within the rhombohedral growth sectors. In a view inclined 42° to the c-axis, these striations occasionally were found in two different rhombohedral growth sectors. The two series of parallel striations formed an angle of 133.7° with each other (Figure 17). In this orientation, the two different rhombohedral growth sectors also showed different pleochroism.

For faceted gems, it should be reiterated that stones cut from significantly larger rough material may consist of only one rhombohedral growth sector (Figure 18). Such gems would present only a single series of parallel growth striations (Figure 19).

Inclusions: The rough samples showed abundant inclusions, primarily in the form of partially healed fractures, negative crystals and two-phase inclusions (liquid/gas; e.g. Figure 20). Conversely, the faceted material was very clean, only rarely incorporating inclusions. The implication therefore would be that, as is common practice for amethyst, the rough material was processed (sawn and/or cobbed by hammering) to remove impure parts and obtain clean areas for faceting.

In some samples, reddish brown solid inclusions were seen as well (Figure 21). Features with a similar appearance have been described in the gemmological literature as 'beetle-legs' and have been attributed to platelets or fibres of hematite (White, 2000; Troilo et al., 2015).

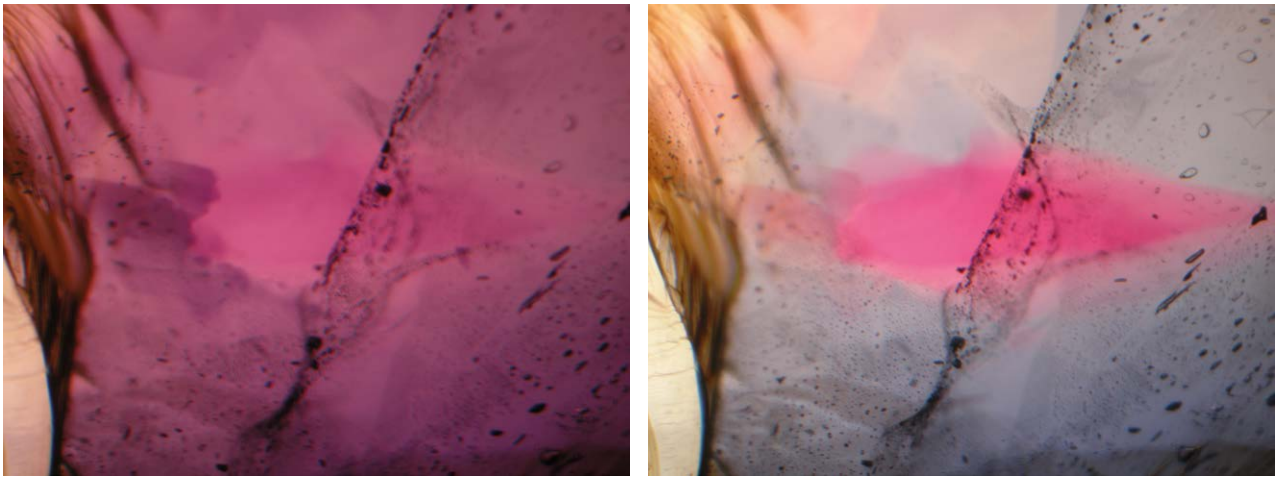

Figure 15: These two views of a Rwandan amethyst taken with different rotations of the polarizer show an irregularly shaped domain that displays a different coloration than the surrounding amethyst host. Photomicrographs by K. Schmetzer, in immersion; field of view 8.1 × 6.1 mm.

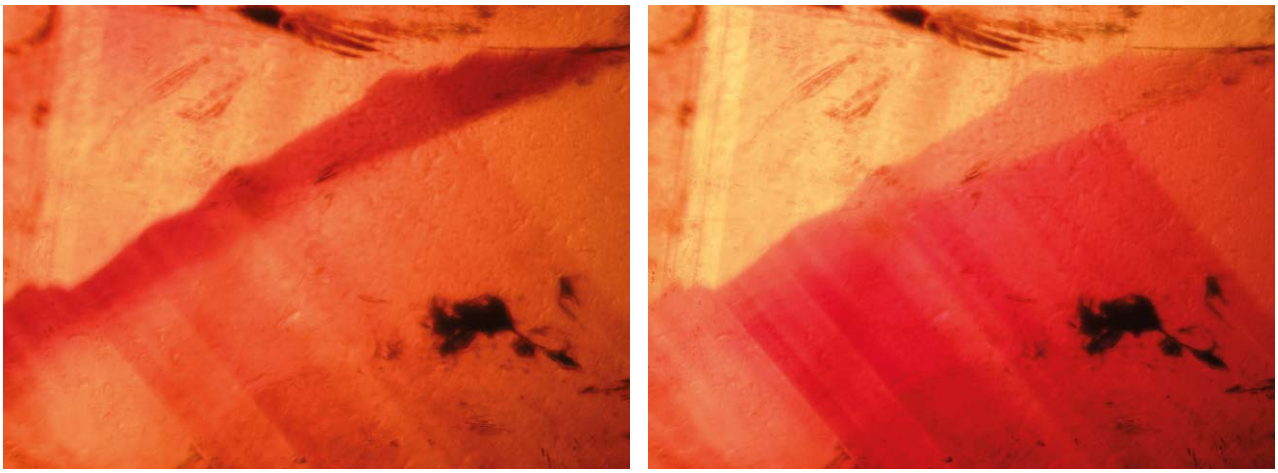

Figure 16: In this amethyst from Rwanda, a thin growth zone differing in colour and pleochroism from the two adjacent rhombohedral growth sectors is visible in a view inclined 42° to the c-axis. Its colour varies as the polarizer is rotated. Photomicrographs by K. Schmetzer, in immersion; field of view 7.6 × 5.7 mm.

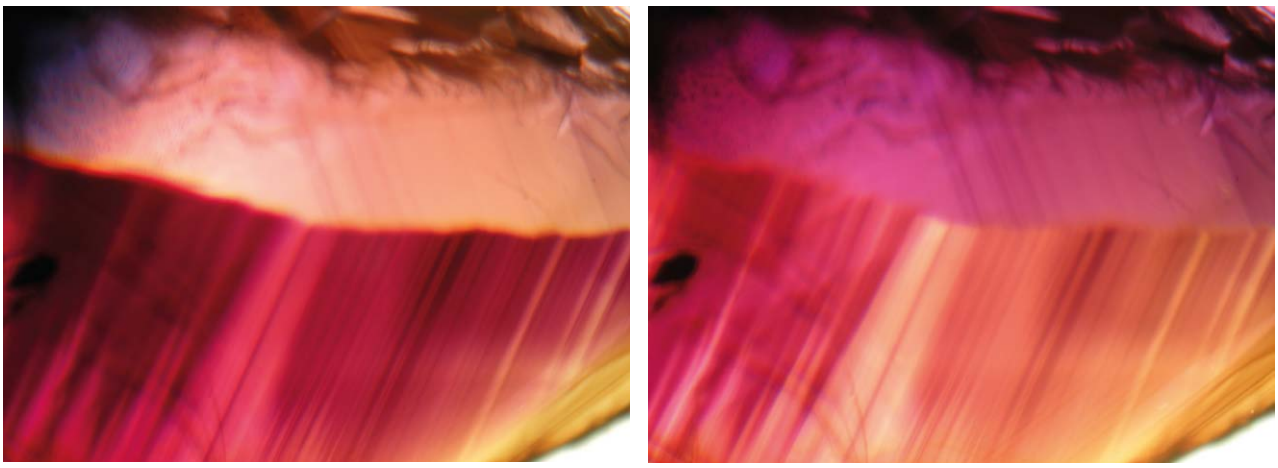

Figure 17: This Rwandan amethyst displays two rhombohedral growth sectors that, when using plane-polarized light and rotating the polarizer, exhibit both pleochroism and growth striations. In a view inclined 42° to the c-axis, the two series of striations form an angle of 133.7° with each other. Photomicrographs by K. Schmetzer, in immersion; field of view 8.1 × 6.1 mm.

Figure 18: If an amethyst is faceted from a single intense violet growth sector, no sectorial colour zoning is observed. Such samples may look homogeneous or may display a single series of rhombohedral growth striations in views toward both the table facet and the pavilion. The samples weigh 5.81 (left) and 8.26 ct (right). Photos by K. Schmetzer.

Figure 19: Faceted Rwandan amethyst consisting of a single growth sector will show only a single series of growth striations parallel to one rhombohedral face. Photomicrograph by K. Schmetzer, in immersion; field of view 8.7 × 7.1 mm.

Figure 20: A partially healed fracture with two-phase inclusions is seen in this rough sample of Rwandan amethyst. Photomicrograph by K. Schmetzer, in immersion; field of view 4.1 × 3.1 mm.

Samples Reportedly from Western Rwanda

Of the 14 samples (four faceted and 10 rough) reportedly from 'western Rwanda', 10 of them displayed the same characteristics and patterns described above for the samples from Ngororero. Four samples, however, were different (e.g. Figure 22). They consisted of one or two rhombohedral growth zones, and when two growth zones were present, they exhibited no or only very weak colour zoning between them. More specifically, both sectors were intense violet. In addition, Brewster fringes caused by Brazil-law twinning were seen in all sectors (Figure 23), as were rhombohedral growth striations. The striations formed angles of 94° with each other, thereby demonstrating symmetry-equivalent rhombohedral growth zones. Thus, to summarize, these four amethyst samples differ from the other Rwandan samples by being composed of two adjacent intense violet growth zones, both of which are twinned.

DISCUSSION AND CONCLUSIONS

Comparison of Amethyst Properties

Amethyst from multiple sources worldwide is generally characterized by sectorial growth zoning with somewhat more intense violet rhombohedral **r** growth sectors and somewhat lighter violet **z** growth sectors. In such amethyst, the more intense violet **r** growth zones show polysynthetic twinning on the Brazil law (see, e.g., Kiefert and Schmetzer, 1991; Lieber, 1994). Untwinned crystals of natural amethyst are rare, but limited examples have been mentioned (Lietz and Münchberg, 1958).

With respect to the Rwandan material examined for this study, the typical situation just described was largely reversed. The samples either were not polysynthetically twinned or, when polysynthetic twinning was present, the twinned sectors were related to the light violet or almost colourless areas. This was the case for all 28 of the rough stones reportedly from the Ngororero District. For the faceted amethysts, about one third of the samples were cut from a single intense violet rhombohedral growth sector and did not show Brewster fringes and polysynthetic twinning.

The literature reports few comparable examples, although amethyst from the Caxarai mine, Brazil, has similar optical properties (Kitawaki, 2002). That study designated the twinned sectors as **r** (light violet) and the untwinned sectors as **z** (intense violet). Such interpretation may be correct, but in the absence of more definitive data for the Rwandan material, the opposite also might apply. Therefore, for purposes of the present article, the authors have left this point open (i.e. the designation of twinned and untwinned growth sectors as **r** or **z**, respectively), simply because either interpretation might be accurate and a decision cannot be made on the basis of microscopic examination and the optical features observed.

Anomalous pleochroism in amethyst has been explained by variance in the uptake of trace elements, especially iron, at different lattice sites and/or in different rhombohedral **r** and **z** growth sectors (Cox, 1977; Adekeye and Cohen, 1986; Flörke et al., 2000). A detailed discussion of the various mechanisms that might apply is beyond the scope of this study.

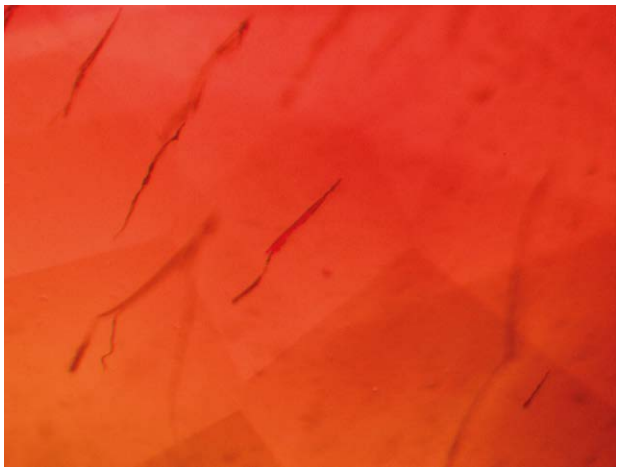

Figure 21: Some of the Rwandan amethyst samples display reddish brown solid inclusions. These are often referred to as 'beetle-legs' in the gemmological literature and have been attributed to platelets or fibres of hematite. Photomicrograph by K. Schmetzer, in immersion; field of view 4.6 × 3.5 mm.

Figure 22: These amethysts, reportedly from 'western Rwanda', proved to contain intense violet growth zones twinned on the Brazil law. The samples weigh 19.72, 11.99 and 5.20 ct. Photo by K. Schmetzer.

In contrast to the distinctive nature of the larger group of Ngororero material, only four of the investigated samples reportedly from 'western Rwanda' exhibited the properties typical for amethyst from many other sources throughout the world (see, e.g., Kiefert and Schmetzer, 1991). Their presence suggests that the amethyst in these two groups might have originated from two (or even more) different Rwandan localities.

The two potential mining areas in the Ngororero and Ruhango Districts mentioned in the Introduction are approximately 40–50 km from each other (Figure 2), so it would be easy for traders to include in parcels material from both localities. It is unknown if the two localities involve different host rocks and/or different modes of amethyst formation. Such factors could explain the contrasting properties of the two types of Rwandan samples. Geological fieldwork at both locations would be necessary to clarify this point.

Distinction from Synthetic Amethyst

If a faceted Rwandan amethyst consists of several growth sectors, the gem can be distinguished from synthetic material by optical examination. Such natural samples show sectorial growth zoning, in most cases also associated with polysynthetic twinning and, occasionally, with other forms of growth zoning or twinning (e.g. Dauphiné twinning). These patterns are absent from synthetic amethyst.

However, if a Rwandan amethyst has been faceted from only a single untwinned growth sector, the microscopic pattern would show only rhombohedral growth zoning parallel to a single rhombohedral face and no twinning (and thus no Brewster fringes). An analogous pattern is common for synthetic amethyst. Thus, samples with these features would require additional examination, such as by infrared spectroscopy, to identify the nature of the material.

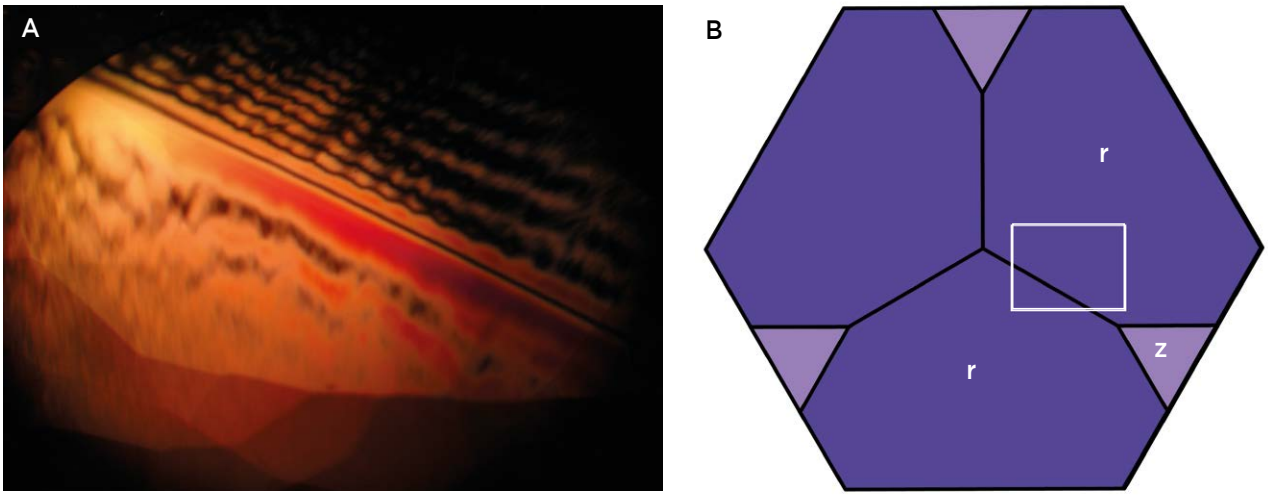

Figure 23: (A) Viewed parallel to the c-axis with crossed polarizers, this amethyst from 'western Rwanda' displays Brewster fringes due to Brazil-law twinning in two different, adjacent rhombohedral growth sectors. (B) The schematic diagram shows a crystal in the same view, highlighting the area in photo A. Photomicrograph by K. Schmetzer, in immersion; field of view 14.5 × 10.9 mm. Drawing by K. Schmetzer.

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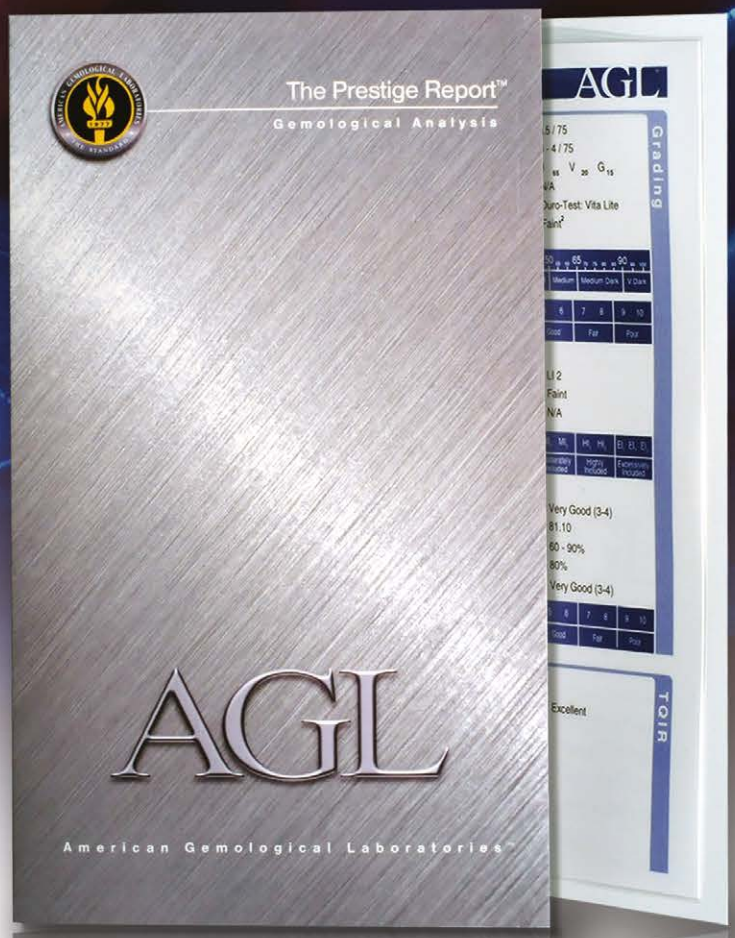

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A Preliminary SIMS Study Using Carbon Isotopes to Separate Natural from Synthetic Diamonds

Hao A. O. Wang, Laurent E. Cartier, Lukas P. Baumgartner, Anne-Sophie Bouvier, Florence Bégué, Jean-Pierre Chalain and Michael S. Krzemnicki

This preliminary study focuses on using secondary ion mass spectrometry (SIMS) to measure relative carbon isotope ratios for natural and synthetic diamonds (i.e. those grown by both chemical vapour deposition [CVD] and high-pressure, high-temperature [HPHT] techniques). The synthetic diamonds (of both CVD and HPHT origin) had significantly lower relative carbon isotope values than the natural diamonds. The lowest value was obtained for the CVD synthetic diamond sample, in agreement with results from other investigators. More research is desirable on the carbon isotope variation of synthetic diamonds.

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INTRODUCTION

Natural diamonds have been used in jewellery and for industrial purposes (e.g. abrasives) for centuries (Harlow, 1998). They constitute some of the most famous and valuable gems found worldwide. Diamonds form in the earth's mantle, and a number of different hypotheses for their specific geological formation continue to be discussed (Stachel and Harris, 2009; Stachel and Luth, 2015) and reviewed (Cartigny et al., 2014) in the literature. The chemical and physical properties of diamonds also are widely studied subjects (Clark et al., 1979; Shirey et al., 2013; Zaitsev, 2013).

However, openly available research on the identification and formation of synthetic diamonds is much scarcer. Synthetic diamonds were first produced in the 1950s in the USA and Sweden (Angus, 2002; Martineau et al., 2004). In recent years, advances in CVD and HPHT technology—the two methods used to synthesize diamonds—have made these synthetics much more widely available and of higher quality (Figure 1). The introduction of undisclosed synthetic diamonds into the market has become a critical issue for the diamond and jewellery industry at large (Even-Zohar, 2012; Kitawaki et al., 2013; Sheintal, 2015). Although various laboratory techniques involving spectroscopy (Fourier-transform infrared, ultraviolet-visible–near infrared and photoluminescence) and imaging (ultra-short-wave UV and cathodoluminescence) can be used to distinguish natural from synthetic diamonds, further research is required to understand their formation mechanisms (Shigley et al., 1997; Wang et al., 2003).

Rapid developments in both CVD and HPHT technology require that research keep pace to ensure synthetic diamonds can be conclusively identified in the future, and to maintain consumer confidence in the diamond trade. Isotopic studies, such as those using SIMS instrumentation that are presented in this article, provide additional information for such efforts. Other studies that have applied SIMS to diamond research—for purposes of documenting chemical zoning and distinguishing different geological sources—include those by Hauri et al. (2002), Deines and Harris (2004), Cartigny (2005), Palot et al. (2012, 2014) and Stern et al. (2014). In addition,

Figure 1: Seven colourless and fancy-colour diamonds (weighing up to 3.03 ct) of various natural or synthetic origins are shown here. The top-right and bottom-left round brilliants are HPHT- and CVD-grown, respectively, and the other diamonds are natural. The confident separation of natural and synthetic diamonds is critical to maintaining consumer confidence in the trade. Composite photo by Luc Phan, SSEF.

Wang et al. (2014) used SIMS to investigate carbon isotopes in both natural and CVD synthetic diamonds. The current study includes HPHT synthetics along with CVD and natural samples.

SAMPLE SELECTION AND PREPARATION

Nine faceted samples were examined for this study: five natural diamonds, three colourless HPHT-grown synthetics and one colourless CVD synthetic diamond. The geological origin of the five natural diamonds and the exact manufacturing processes of the synthetic diamonds are not known. The samples were randomly chosen from different types of diamonds found in the market. Table I provides a summary of the samples.

Table I: Diamond samples analysed for this study.

Sample no.	Weight (ct)	Origin	Colour
1 (reference)	0.136	Natural	Brownish
2	0.088	Natural	Colourless
3	0.628	Natural	Grey
4	0.062	Natural	Green
5	0.028	Natural	Colourless
6	0.230	HPHT synthetic	Colourless
7	0.019	HPHT synthetic	Colourless
8	0.031	HPHT synthetic	Colourless
9	0.092	CVD synthetic	Colourless

To prepare them for analysis, the samples were pressed into indium metal in a sample holder. They were mounted with their table surface (or other large flat surface) facing upward. Last, the prepared holder was coated with gold before being inserted into the SIMS sample chamber.

METHODS

SIMS is an ion-beam microprobe technique used in surface analysis. The high sensitivity, high mass-resolving power and micrometre- to nanometre-scale spatial resolution of SIMS have made it a widely used technique in advanced materials research (Benninghoven et al., 1987; de Laeter, 2001). A primary ion beam is used to ionize elements on a sample's surface, thereby generating secondary ions that are analysed using a mass spectrometer. The SIMS method has a wide range of applications, including the analysis of carbon and nitrogen isotopes.

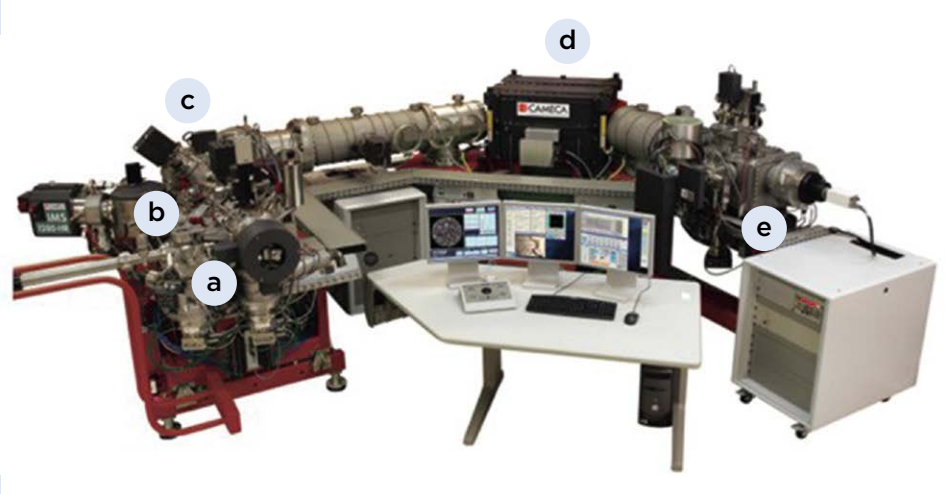

Figure 2: The SIMS instrument (Cameca IMS 1280-HR) at the SwissSIMS facility of the University of Lausanne consists of the following components: (a) sample chamber, (b) primary ion source, (c) electrostatic analyser, (d) magnet and (e) detection unit. Photo courtesy of SwissSIMS, University of Lausanne.

The carbon isotopes in our samples were measured using a Cameca IMS 1280-HR instrument (Figure 2) at the SwissSIMS facility of the Institute of Earth Sciences at the University of Lausanne, Switzerland (Seitz et al., 2017; Siron et al., 2017). We used a 10 kV Cs^+ primary beam and an ~0.6 nA current, resulting in an ~10 µm rastered beam size. An electron flood gun, with normal incidence, was used to compensate charges. We gathered $^{12}C^-$ and $^{13}C^-$ secondary ions, accelerated at 10 kV, in multi-collection mode using a Faraday cup (for $^{12}C^-$) and an electron multiplier (for $^{13}C^-$). A mass resolving power of ~6,000 was achieved, to overcome polyatomic interference of $^{13}C^-$ with $^{12}CH^-$, for example (Fitzsimons et al., 1999). The Faraday cup was calibrated at the beginning of the session. Each spot analysis took ~7 minutes, including pre-sputtering (60 seconds) and automated centring of secondary ions. The results of the analyses were expressed as the isotopic signature $\delta^{13}C$, which is a measure of the ratio of the isotopes $^{13}C/^{12}C$, reported in parts per thousand (per mil, ‰).

Since no standard reference diamond of known isotopic composition was available for this work, accurate $\delta^{13}C$ values were not obtainable. Nevertheless, the analyses were precise, and differences were meaningful. Natural diamond sample 1 was found to yield relatively homogeneous $^{13}C/^{12}C$ ratios (2σ = 0.21‰, 18 analyses). Therefore, for the purpose of qualitative analysis in this study, sample 1 was used as an external reference diamond to which the carbon isotope ratios for all other samples were normalized. For samples 2–9, four or five separate cluster locations on their surfaces were measured to address possible sample heterogeneity. At each cluster location, three SIMS analyses were carried out. The distance between these three replicates was much smaller compared to that between different cluster locations on a sample. After every six measurements of samples 2–9, two analyses were carried out on sample 1. Instrument drift over time was corrected in post-data evaluation using third-order polynomial fitting of the $^{13}C/^{12}C$ signal of sample 1. In addition, a homogeneity test was conducted on the surface of sample 2, in which two orthogonal directions across the table were scanned by lines of spots. Each SIMS analysis spot measured 10 µm in diameter and had a depth of less than a few hundred nanometres, which is not visible to the unaided eye. To remove the thin gold coating required for SIMS analysis, the samples were immersed in aqua regia that was heated to 40°C.

Ideally, $\delta^{15}N$ also would be a candidate to distinguish synthetic from natural diamonds. There are numerous studies investigating $\delta^{15}N$ in natural diamonds (Cartigny et al., 2001; Cartigny, 2005; Hogberg et al., 2016). However, the nitrogen concentrations in the synthetic samples randomly selected for this study were below the detection limit of the SIMS instrument. Natural type II diamonds also contain amounts of nitrogen that cannot be detected by SIMS. Therefore, using nitrogen isotope ratios to determine natural or synthetic origin is not applicable to general cases and was not pursued in this study.

The present research thus focused on using SIMS to determine normalized carbon isotope ratios, which could be measured on a relative basis without the use of a standard. To obtain quantitative data, it would be imperative to have bulk $\delta^{13}C$ results on a reference sample. This was not pursued in the context of this preliminary study, as the aim was to investigate only the possible separation of natural from synthetic diamonds.

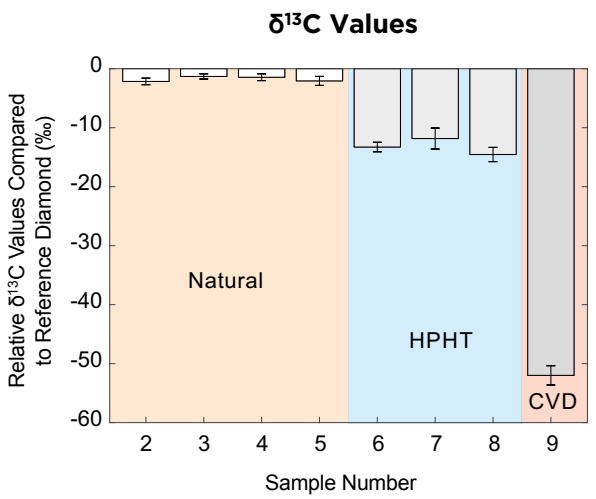

Figure 3: Relative $\delta^{13}C$ values are presented here for the four natural diamonds and the four of synthetic (HPHT and CVD) diamonds.

RESULTS

A summary of the carbon isotopic values is shown in Figure 3. Relative $\delta^{13}C$ for the four measured natural diamonds (samples 2–5) varied from –2.16 ± 0.56‰ (2σ) to –1.31 ± 0.43‰ (2σ). The three HPHT synthetic diamonds (samples 6–8) had lower relative $\delta^{13}C$ values ranging between –14.55 ± 1.21‰ (2σ) and –11.84 ± 1.78‰ (2σ). The CVD synthetic diamond (sample 9) had the lowest relative $\delta^{13}C$ value of –51.99 ± 1.63‰ (2σ), which is consistent with the work of Wang et al. (2014), who found that there was no overlap of $\delta^{13}C$ values for the natural and CVD synthetic diamonds they analysed. The low $^{13}C/^{12}C$ ratio for the CVD synthetic diamond might be explained by the ^{13}C-depleted methane used as a synthetic precursor to obtain good crystal quality and a flat surface on the CVD plates (Fiori et al., 2013). For HPHT-grown synthetic diamonds, the carbon source is different (commonly graphite), and fractionation in these crystals was investigated in detail by Reutsky et al. (2008). According to Cartigny (2005), there are three commonly hypothesized explanations for the different $\delta^{13}C$ values found in natural diamonds: (1) distinct carbon sources (i.e. different geological origins), (2) primordial isotopic variability and (3) fractionation of stable isotopes at mantle temperatures.

For the purpose of evaluating synthetic vs. natural origin, we observed no significant differences in relative carbon isotope ratios in the different areas analysed on the surfaces of the individual samples (both natural and synthetic). Nevertheless, other studies have shown that growth orientation and sectorization in natural and synthetic diamonds can have an influence on $\delta^{13}C$ and $\delta^{15}N$ ratios (Boyd et al., 1992; Bulanova et al., 2002, Reutsky et al., 2008; Fiori et al., 2013). Figure 4 shows the minor variability of relative $\delta^{13}C$ values in both of the line scans across the table facet of sample 2.

Figure 4: Sample 2, a colourless old-mine cut natural diamond of 0.088 ct (2.53 × 2.35 × 2.13 mm), exhibits only minor variability of relative $\delta^{13}C$ values in both directions across the surface of the table facet. The four white spots indicate cluster locations (three data points each) of SIMS analyses, and the arrows show the locations of the SIMS analytical traverses. Near the top-right cluster are three black spots resulting from laser ablation inductively coupled plasma mass spectrometry (performed for a separate study). Photo by SSEF.

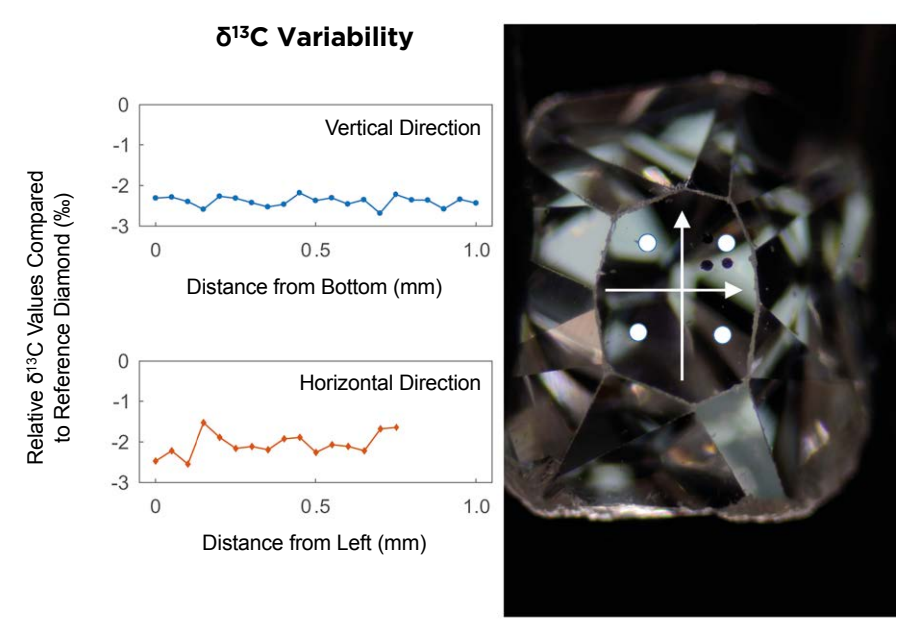

CONCLUSIONS

Among the samples analysed in this SIMS study, the synthetic diamonds had distinctly lower relative $^{13}C/^{12}C$ values than the randomly selected natural samples. The data also showed that HPHT and CVD synthetic diamonds potentially can be distinguished from one another on the basis of their relative carbon-isotope ratios. More research is required to understand $\delta^{13}C$ variability and fractionation in synthetic diamonds. In addition, this preliminary study has shown the need for a carbon-isotope standard to obtain quantitative data for comparison with other diamond carbon-isotope studies. Future research using the SIMS technique will continue to provide a deeper understanding of diamond growth, and as such is complementary to other methods being used to separate natural from synthetic diamonds.

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Figure 1: Rainbow lattice sunstone displays conspicuous colourful patterns that are produced by light reflecting at a specific angle from inclusions. The gold ring on the left contains a 6.17 ct sunstone and the polished fragment on the right weighs 15.00 ct. Courtesy of Rainbow Lattice; photo by Jeff Scovil.

Revisiting Rainbow Lattice Sunstone from the Harts Range, Australia

Jia Liu, Andy H. Shen, Zhiqing Zhang, Chengsi Wang and Tian Shao

Rainbow lattice sunstone from the Harts Range, Northern Territory, Australia, shows a rare combination of phenomena including aventurescence, adularescence and a distinctive lattice pattern caused by oriented inclusions. Electron microprobe and X-ray diffraction (XRD) analysis, combined with laser Raman spectroscopy, indicate the host mineral is orthoclase ($Or_{96}Ab_4$), as previously reported in the literature. The inclusions causing the aventurescence were identified as hematite, while lattice patterns were found to consist of orangey brown platelets of hematite and black platelets of magnetite (rather than ilmenite, as previously reported). Scanning electron microscopy-energy dispersive spectroscopy (SEM-EDS) analysis of the magnetite showed that it is composed of very thin plates containing only Fe and O, without any Ti. The presence of magnetite is consistent with the black inclusions' attraction to a magnet, as well as testing with a vibrating sample magnetometer, which provided a ferromagnetic response.

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INTRODUCTION

Feldspar-group minerals are framework aluminosilicates (among the most common rock-forming minerals) that contain variable amounts of Na, K and Ca. Isomorphic substitution in feldspars is well developed, resulting in two solid-solution series: alkali feldspar (orthoclase–albite) and plagioclase (albite–anorthite). These can form an array of gem varieties—including sunstone, moonstone, etc.—which can differ widely in appearance.

In the gem trade, *sunstone* typically refers to aventurescent feldspar, and is known from various localities, mainly Tanzania and India (i.e. oligoclase with hematite inclusions) and Oregon, USA (i.e. labradorite with copper inclusions), although other occurrences have been reported (O'Donoghue, 2006). Viewed with pinpoint lighting from certain directions, sunstone exhibits a spangled appearance with interesting optical and physical properties that can include not only aventurescence, but also various body colours and strong pleochroism (Johnston et al., 1991; Choudhary and Huang, 2008). Aventurescence in sunstone typically arises from thin, platy hematite inclusions (Akizuki, 1976).

A rare gem feldspar known as *rainbow lattice sunstone* (e.g. Figures 1 and 2) exhibits both aventurescence (as seen in sunstone) and adularescence (as displayed by moonstone), with the added presence of oriented elongate and triangular mineral platelets. The material was discovered in the mid-1980s and was briefly described as a new gem variety by Koivula and Kammerling (1989). Since it has not been characterized in detail, the present authors examined this sunstone using microscopy, electron microprobe and XRD analysis, magnetic measurements, and SEM-EDS and Raman spectroscopy. We confirmed some of the results of previous studies but also report some unexpected new findings.

LOCATION AND GEOLOGY

Rainbow lattice sunstone is found in a localized remote area of desert named the Mud Tank Zircon Field (Faulkner and Shigley, 1989) in the Harts Range north-east of Alice Springs, Northern Territory, Australia. This area is comprised of dry plains with rocky outcrops. The sunstone was first discovered in late 1985 by Darren Arthur and Sonny Mason, who happened upon it while scouting the area near an abandoned mica mine. The mineralized area measures 500 × 600 m and is covered by a single mining claim. (Another rainbow lattice sunstone occurrence is located ~7 km away, but produces lower-quality material.) The sunstone is mined by Asterism Gems Australia Pty Ltd and marketed through Rainbow Lattice (www.rainbowlattice.com). Miners gather the rough material using only hand tools. The stones are then washed and sorted to separate the occasional pieces of rainbow lattice sunstone from the non-phenomenal feldspar. Over the years only a few kilograms of good-quality rough material has been produced, and the sunstone is sold as both partially polished rough pieces and cabochons. Some is stabilized with resin to make it saleable, and it also may be waxed or oiled as per standard processes used in the gem trade.

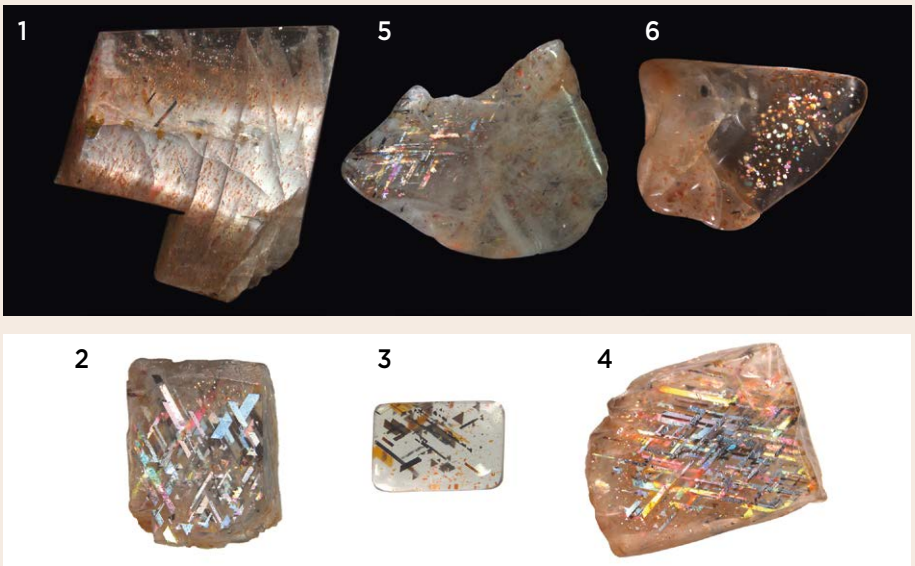

Figure 2: The six samples of rainbow lattice sunstone obtained for this study display a combination of optical effects, including adularescence (e.g. sample 1), aventurescence (see samples 1 and 6, in particular) and a rainbow lattice effect, which can be seen using different lighting conditions and directions. The samples weigh 0.29–3.57 g. Composite photos by J. Liu.

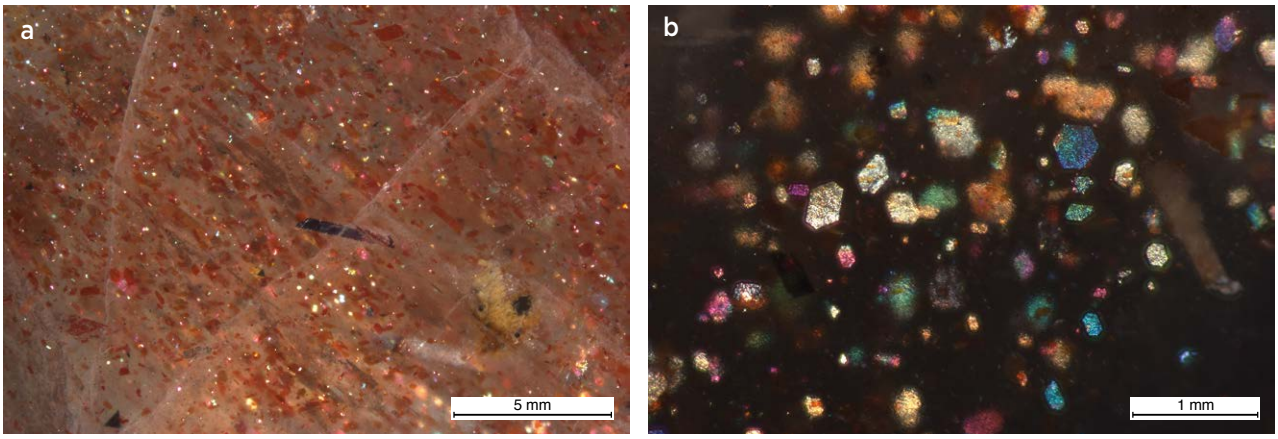

Figure 3: The aventurescence phenomenon in the sunstone is produced by pseudohexagonal reddish brown platelets of hematite (a) that exhibit a sparkling appearance with diverse colours in reflected light (b). The images are taken from sample 1 (a) and sample 6 (b). Photomicrographs by J. Liu.

The Harts Range comprises a complex assemblage of granite gneiss, marble, calc-silicate, amphibolite, psammite and pelite that have been metamorphosed to upper amphibolite to granulite facies (Huston et al., 2006). The metamorphosed sedimentary rocks are intruded mainly by granite, granodiorite and metamorphosed mafic rocks of uncertain origin. The igneous rocks are generally associated with widespread metasomatic granitization (Joklik, 1955; Daly and Dyson, 1956). The granodiorite in the Bruna gneiss unit contains pegmatites in which K-feldspar occurs, and the mining area is crosscut by quartz veins and pegmatite outcrops.

MATERIALS AND METHODS

Six study samples of rainbow lattice sunstone from the Harts Range were obtained at the 2017 gem shows in Tucson, Arizona, USA (Figure 2). From these, we chose two representative specimens (samples 1 and 2) for detailed examination.

Photomicrographs of all six samples were taken with a Leica M205A microscope at the Gemological Institute, China University of Geosciences (Wuhan). Refractive indices of all samples were measured with a refractometer, and specific gravity was determined hydrostatically.

Quantitative chemical analysis of the host feldspar was performed at the Earth Sciences Institute at China University of Geosciences (Wuhan) with a JEOL JXA-8230 electron microprobe operating with an accelerating voltage of 15 keV and a beam diameter of 3 µm. Structural analysis of the host feldspar was performed at the Gemological Institute, China University of Geosciences (Wuhan), with a Bruker AXS D8 Focus X-ray diffractometer equipped with a LynxEye X-ray detector (Cu*K*α X-ray source, Ni filter, accelerating voltage of 40 kV, current of 40 mA, scanning range of 15–90° and λ = 1.540598 Å).

SEM-EDS compositional data for a black lattice-forming inclusion in one of the sunstones were collected using an Oxford Instruments X-Max^N energy-dispersive spectroscopic system on a Zeiss Sigma 300 field emission scanning electron microscope in the State Key Laboratory of Geological Processes and Mineral Resources of China University of Geosciences (Wuhan), using a magnification of 284×, working distance of 8.5 mm, accelerating voltage of 20 kV and aperture size of 120 µm. The magnetic properties of the black inclusions were tested with a Lake Shore Cryotronics 7400 Series vibrating sample magnetometer (VSM) at the School of Materials Sciences and Engineering, Northeastern University, Shenyang, China.

Raman spectroscopy of the feldspar and the inclusions in all six samples was performed with a Bruker Senterra R200-L Raman spectrometer (laser wavelength 532 nm, resolution ~3–5 cm^{-1}, spectral range 45–3600 cm^{-1}, integration time 5 s, aperture 50 × 1000 µm, laser power 20 mW and 20 × objective lens). The inclusions were analysed with a lower laser power (5 mW) and a higher magnification (100 ×) in order to prevent phase transition from the laser's energy.

RESULTS AND DISCUSSION

Gemmological Properties

Observed with magnification, the typical aventurescence of the sunstone can be seen in Figure 3. The scattered reddish brown platelets showed pseudohexagonal and rhomb-shaped morphology. As illustrated in Figure 4, the lattice-forming inclusions in

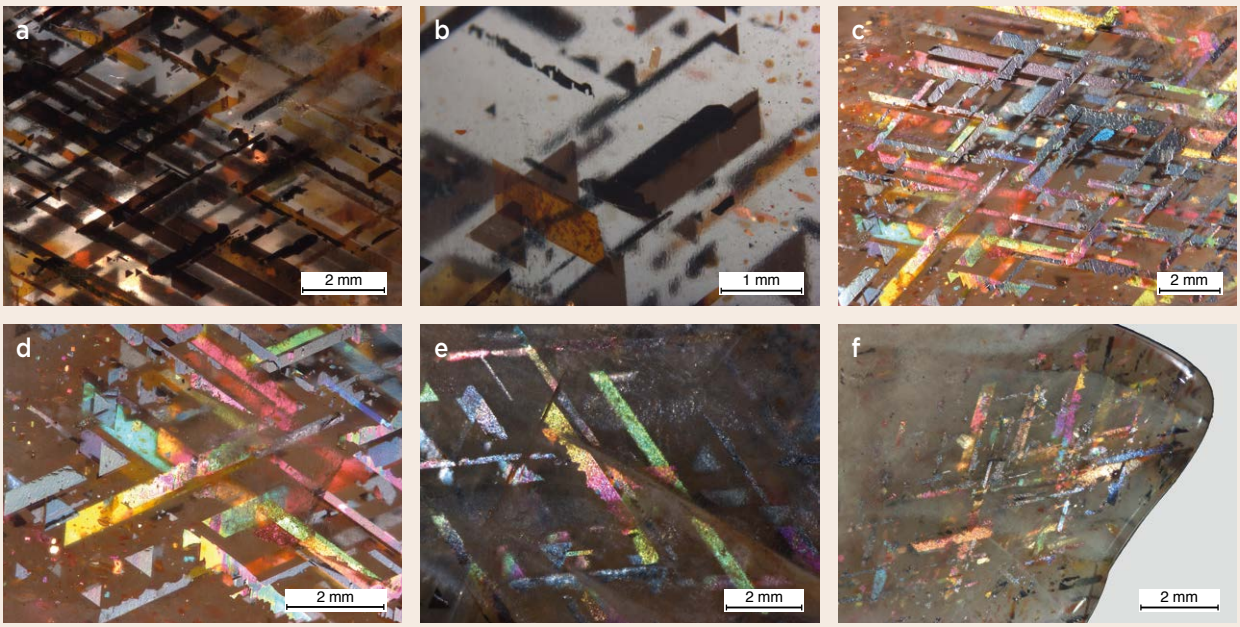

Figure 4: The black to orangey brown, platy, elongate and triangular inclusions that produce the rainbow lattice effect are shown in both transmitted (a, b) and reflected (c–f) light. The specimens include the following: sample 3 (b), sample 4 (a, c, d) and sample 5 (e, f). Photomicrographs by J. Liu.

the sunstone consisted of orangey brown to black elongate and triangular plates. The orangey brown ones displayed colourful reflections when viewed with oblique pinpoint lighting. Some of the samples displayed obvious adularescence when observed using various incident light angles (Figure 5).

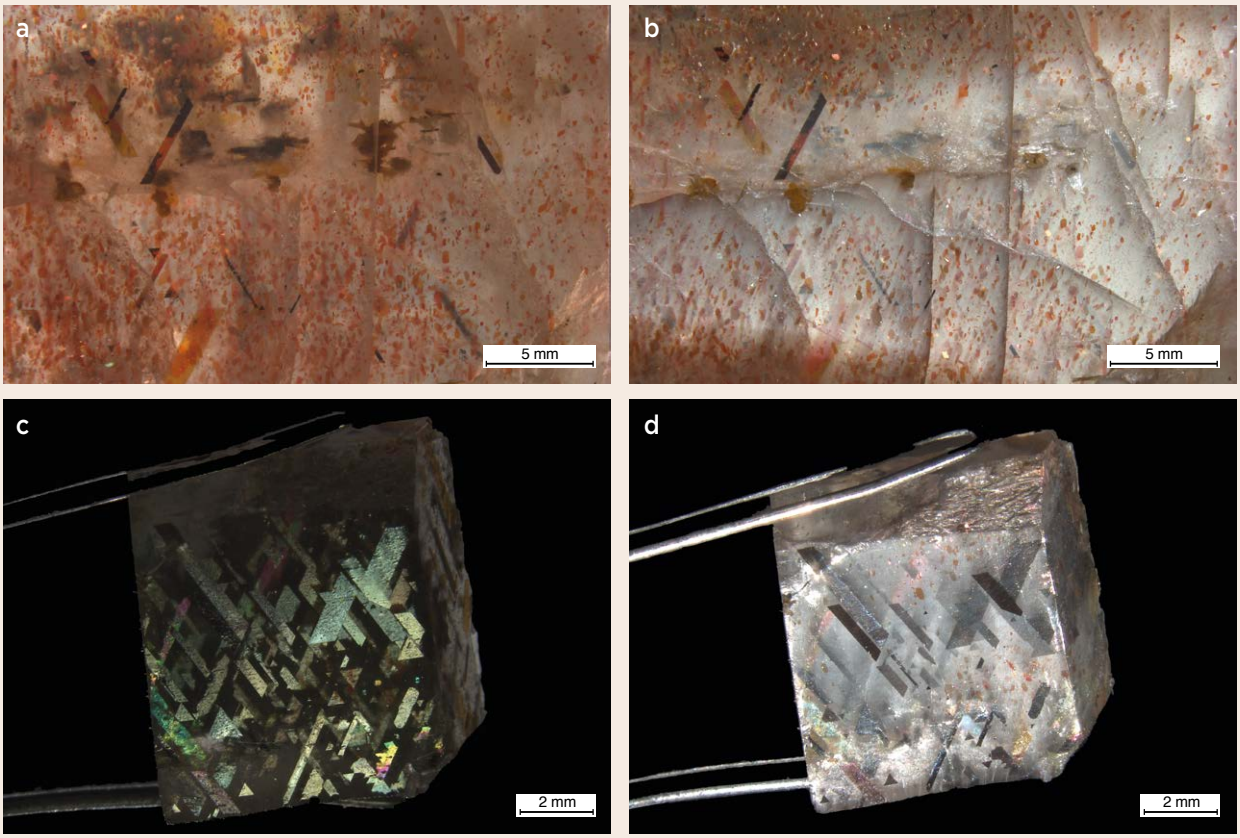

Figure 5: Rainbow lattice sunstone sample 1 displays abundant reddish brown hematite inclusions and also shows obvious adularescence when viewed with the lighting positioned at certain angles (a, b). Sample 2 reveals adularescence upon a slight tilting of the specimen with respect to the incident light (c, d). Photos by J. Liu.

Table I: Electron microprobe analyses of orthoclase constituting rainbow lattice sunstone samples 1 and 2.

Analysis no.	1	2	3	4	5
Oxides (wt.%)					
SiO_2	65.26	65.90	65.85	65.80	65.95
TiO_2	nd*	0.02	nd	nd	0.02
Al_2O_3	18.79	18.94	18.82	18.87	18.76
FeO	nd	0.02	nd	0.09	0.06
MnO	0.01	nd	nd	nd	0.02
MgO	nd	0.01	nd	nd	nd
CaO	0.10	0.05	0.09	0.03	0.04
Na_2O	0.64	0.65	0.66	0.68	0.59
K_2O	15.37	15.54	15.32	15.55	15.84
Total	100.17	101.13	100.74	101.02	101.28
Ions on the basis of 8 oxygens					
Si	2.605	2.607	2.614	2.605	2.604
Al	1.000	0.999	0.996	0.996	0.988
Ti	nd	0.001	nd	nd	0.001
Fe	nd	0.002	nd	0.007	0.005
Mn	0.001	nd	nd	nd	0.002
Mg	nd	0.001	nd	nd	nd
Ca	0.008	0.004	0.007	0.002	0.003
Na	0.102	0.103	0.105	0.108	0.093
K	2.455	2.459	2.433	2.463	2.502
Mol.% end members					
Or	95.70	95.84	95.60	95.72	96.29
Ab	3.99	4.01	4.12	4.19	3.59
An	0.31	0.15	0.28	0.09	0.12

* Abbreviation: nd = not detected.

Gemmological testing of the rainbow lattice sunstone revealed average RIs of 1.518 to 1.540, and an SG of 2.58, which are consistent with those of orthoclase (cf. RIs of 1.518–1.536 and SG values of 2.54–2.61; Lazarelli, 2010).

Chemical Composition, XRD Analysis and Magnetic Testing

Composition of the Host Feldspar. The quantitative chemical compositions and end-member components of the host feldspar are given in Table I. Our analyses showed 96% orthoclase and 4% albite.

Rochow (1962) reported the feldspar in the Harts Range as being microcline that has the same composition as the orthoclase. XRD analysis of the rainbow lattice sunstone (Figure 6) yielded a pattern that matched orthoclase in the Powder Diffraction File (PDF2 database, sample 00-019-0931).

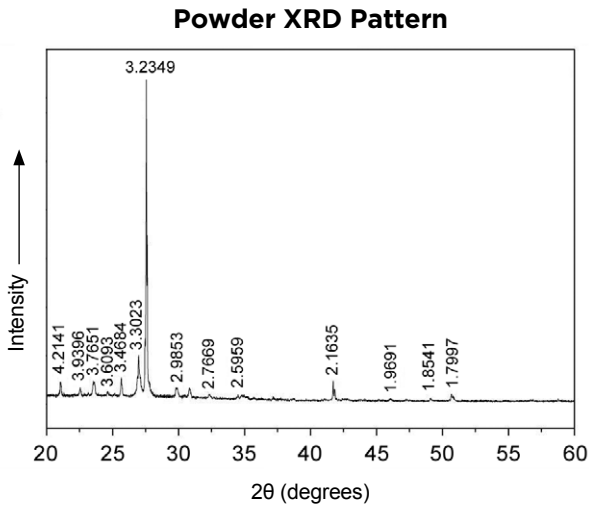

Figure 6: The XRD pattern of the host feldspar identified it as orthoclase rather than microcline. The diffraction peaks are labelled with the corresponding d-spacings (in angstroms).

Most gem feldspar that displays aventurescence is oligoclase (sodic plagioclase), although the effect is sometimes seen in orthoclase (K-feldspar). Hence two kinds of this gem material can be distinguished: 'oligoclase sunstone' and 'orthoclase sunstone' (Choudhary and Huang, 2008; Freeman et al., 2008). Rainbow lattice sunstone is of the latter variety.

Composition of the Black Lattice-Forming Inclusions. The black platy, elongate or triangular inclusions consisted of thin sheets with nanometre-scale thickness (Figure 7). Observations made with the SEM after the samples had been ground and polished showed that the inclusions were very brittle and easily removed by mechanical force. Qualitative SEM-EDS analysis revealed that these inclusions contained Fe and O. Although a previous report (Koivula and Kammerling, 1989) mentioned the black inclusions were ilmenite, no Ti was detected in the present study.

Suspecting that these inclusions were magnetite, we performed a simple magnet test on the sunstone, but this proved challenging because of the minute volume of the black platelets relative to the feldspar. Directly using a magnet to test the bulk sample did not show any magnetic behaviour. However, we found that a tiny fragment of the sunstone containing only one black inclusion was strongly attracted to a Nd-Fe-B magnet (Figure 8). This simple test proved

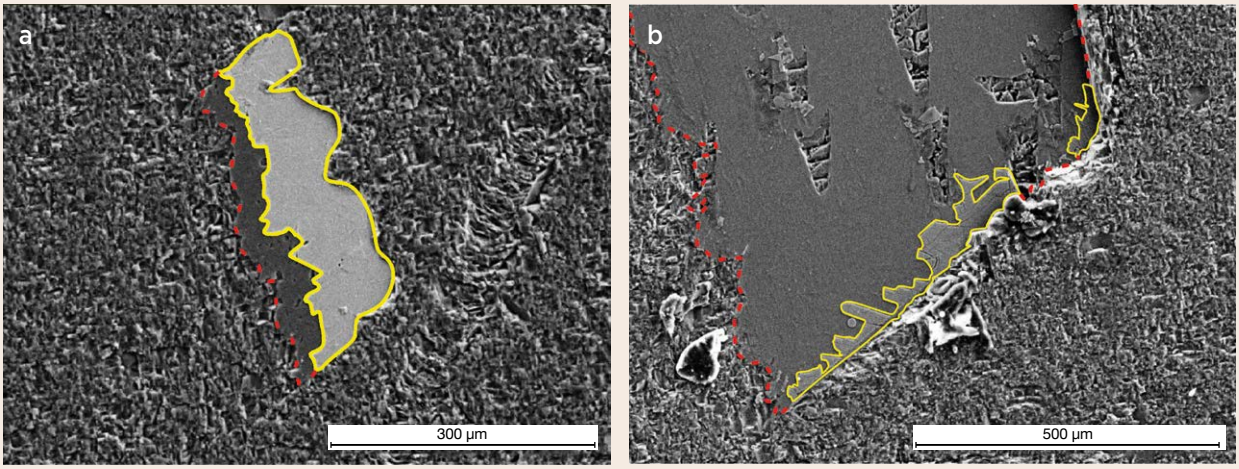

Figure 7: These SEM images of the black inclusions of magnetite in rainbow lattice feldspar reveal the brittle nature that resulted in their being partially removed by the grinding and polishing process used to prepare the samples. The yellow line designates the remaining areas of magnetite, while the dashed red lines show the inferred outline of the original platelets. Images by J. Liu.

that the black inclusion consisted of an oxide of iron that possessed strong magnetism.

Further VSM testing of the fragment mentioned above yielded a magnetic hysteresis loop (Figure 9) that showed the closed magnetization curve of a ferromagnetic substance with the hysteresis phenomenon. The hysteresis loop is an important feature of ferromagnetism; paramagnetic and diamagnetic substances do not show this phenomenon. The presence of magnetite

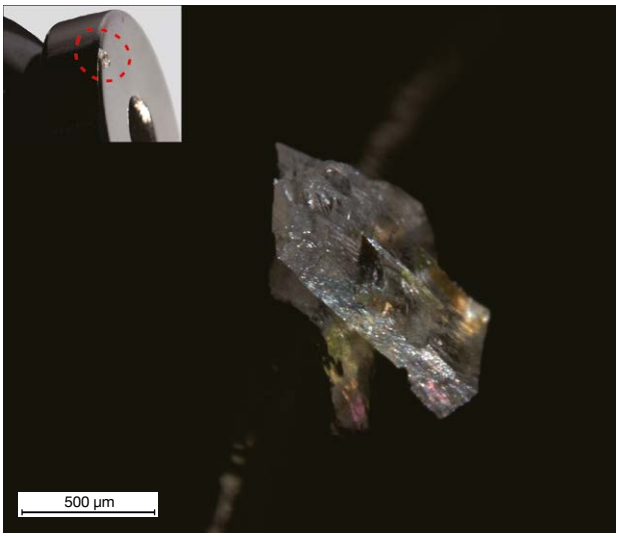

Figure 8: Magnetic testing of the black inclusions in the rainbow lattice sunstone was performed by placing this tiny piece of feldspar containing a single black platelet next to a Nd-Fe-B magnet. It was readily attracted to the magnet, as shown in the inset. Photomicrographs by J. Liu.

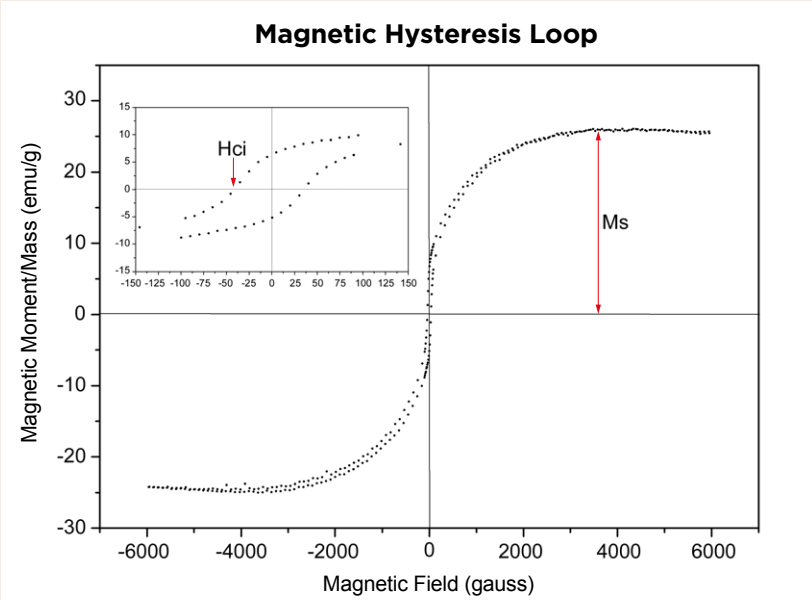

Figure 9: The magnetic hysteresis loop obtained with VSM analysis of the tiny feldspar fragment with a black inclusion in Figure 8 shows a coercivity (Hci) of 38.348 gauss and a mass magnetization (Ms) of 25.527 × 10^{-3} electromagnetic units/gram.

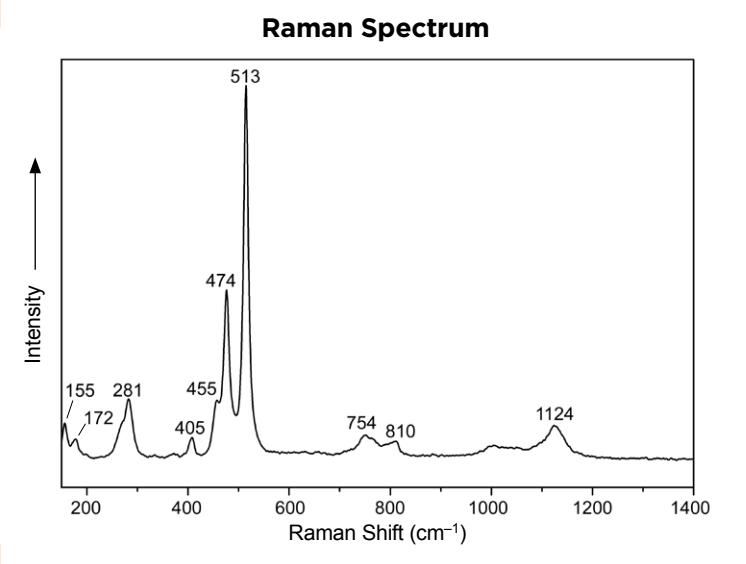

Figure 10: This representative Raman spectrum of the host feldspar shows peaks at 455, 474 and 513 cm^{-1} that prove its identity as orthoclase.

as the ferromagnetic material is consistent with the SEM-EDS analysis. The total mass of the fragment was 0.0254 g, the coercivity was 38.348 gauss and the mass magnetization (magnetic saturation state) was 25.527 × 10^{-3} electromagnetic units/gram. The low saturation of the magnetization is due to the trace amount of magnetite present in the fragment.

Raman Spectroscopy

Raman analysis of the feldspar (Figure 10) showed the strongest bands in the 450–520 cm^{-1} spectral region (455, 474 and 513 cm^{-1}) belonging to the vibrational modes of the four-membered rings of tetrahedra. The Raman peaks below 400 cm^{-1} (155, 172 and 281 cm^{-1}) corresponded to rotation-translation modes of the four-membered rings and cage-shear modes. The weaker Raman peaks in the 900–1200 cm^{-1} region (e.g. 1124 cm^{-1}) were assigned to the vibrational stretching modes of the tetrahedron. The moderate-to-weak peaks in the 700–900 cm^{-1} region (754 and 810 cm^{-1}) belonged to the deformation modes of the tetrahedron (McKeown, 2005). All of the Raman shifts provided a good fit with orthoclase.

The main Raman shifts (Figure 11) of the reddish brown platelets causing the aventurescence and the orangey brown lattice-forming inclusions were 226, 245, 297, 411, 500, 612 and 1319 cm^{-1}, which match hematite. The peaks at 226 and 500 cm^{-1} correspond to A_{1g} vibration modes, while the 245, 297 and 411 cm^{-1} features belong to E_g modes (León et al., 2004). The presence of the 655 cm^{-1} peak indicates an imperfect hematite crystal, and is called a 'disorder band' (Bersani et al., 1999). The 1319 cm^{-1} feature is assigned to a second harmonic vibration (Zoppi et al., 2005).

The main Raman shifts (Figure 12) of the black lattice-forming inclusions were 303, 538 and 664 cm^{-1}, which fit nicely with magnetite. The feature at 538 cm^{-1} is the T_{2g} symmetry mode, while the peaks at 303 and 664 cm^{-1} belong to the E_g and A_{1g} vibration modes (Shebanova and Lazor, 2003a,b). Combined with the SEM-EDS and VSM results, this confirmed that the black inclusions were magnetite.

Inclusions Producing the Aventurescence and Rainbow Lattice Effects

Sunstone inclusions may be composed of hematite, ilmenite, magnetite, native copper or goethite (Andersen, 1915; Sobolev, 1990). The appearance of the aventurescence phenomenon depends on the size of the inclusions. Small particles produce a reddish or golden sheen, while larger inclusions create an attractive, glittery appearance.

According to our study, the lattice appearance displayed by rainbow lattice sunstone is created by inclusions of hematite and magnetite. These minerals form very thin blades that occur within planes of a single orientation at different levels in the feldspar (like pages in a book). Platelets of hematite also produce aventurescence. Viewed with reflected light, the aventurescence is illuminated from one direction, while the colourful lattice effect appears when the lighting is shifted to a different angle.

The magnetite and hematite predominantly form triangular shapes or elongate blades with terminations that are parallel to the triangular directions. The magnetite inclusions in many cases have oxidized to hematite, corresponding to the iridescence or rainbow effect across the lattice patterning. In contrast, the unaltered magnetite is black with a metallic sheen.

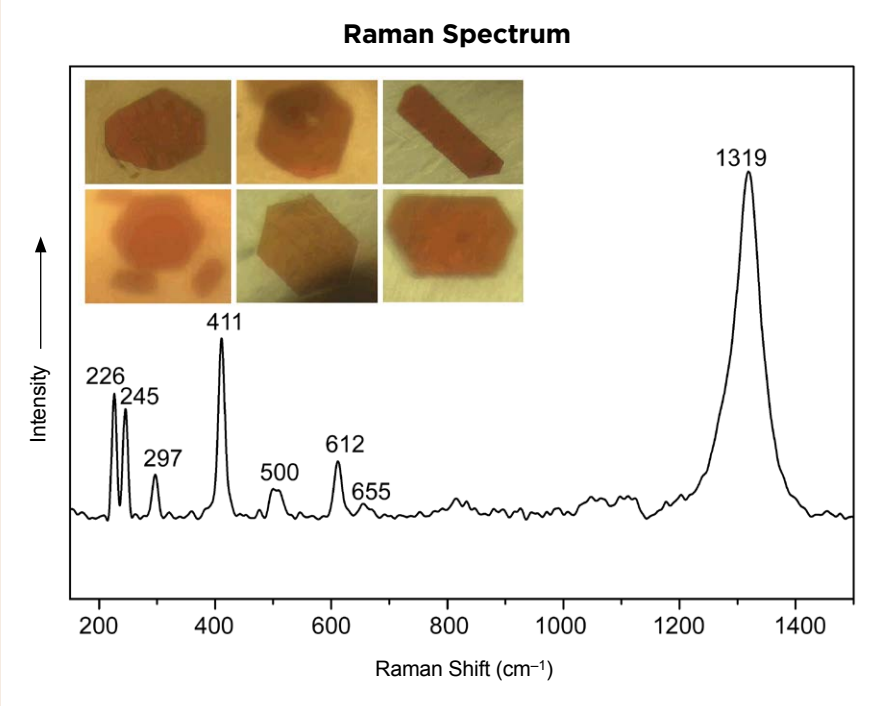

Figure 11: A representative Raman spectrum is shown for the reddish brown platelets (50–200 µm in dimension) in all six samples of rainbow lattice sunstone, confirming the inclusions are hematite. Inset photomicrographs by J. Liu.

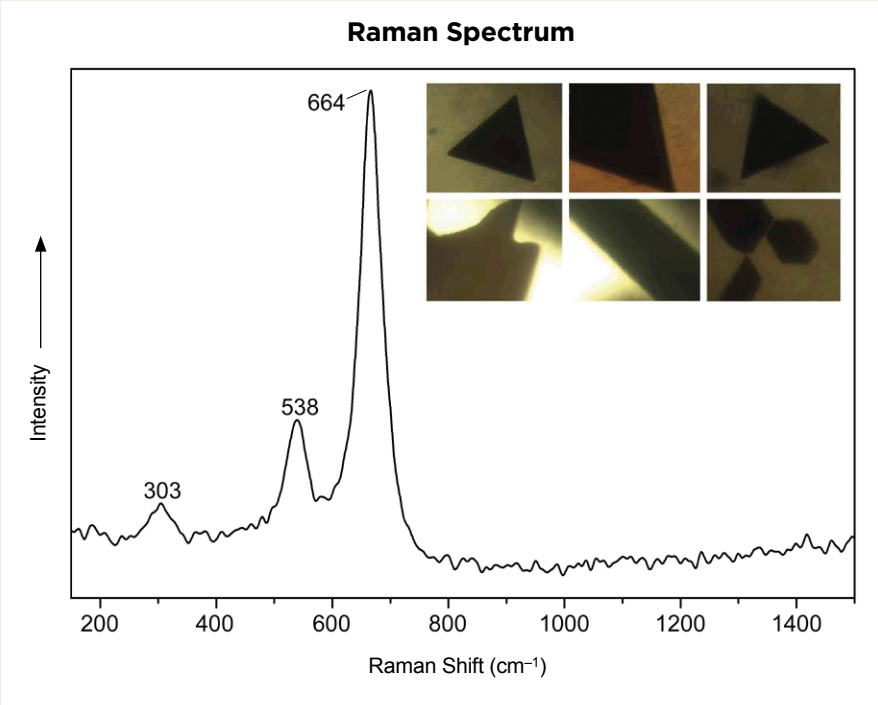

Figure 12: The black inclusions (50–200 µm in dimension) forming the lattice pattern in all six samples of rainbow lattice sunstone were identified as magnetite, as shown in this representative Raman spectrum. Inset photomicrographs by J. Liu.

CONCLUSIONS

Sunstone from the Harts Range, Australia, can show different optical effects including aventurescence, a colourful lattice pattern and adularescence. Electron microprobe data, XRD analyses and Raman spectroscopy revealed that the host feldspar is orthoclase with the composition $Or_{96}Ab_4$. The reddish brown platelets that cause the aventurescence were identified as hematite. The lattice pattern is created by black, elongate and triangular, platy inclusions that were previously believed to be ilmenite, but our investigations confirmed are magnetite. Some of these have altered into orangey brown hematite.

It is rare for aventurescence (as seen in sunstone) to occur together with adularescence (as exhibited by moonstone), and the added presence of a colourful lattice pattern that displays perfect parallel lines and equilateral triangles promotes further interest in this attractive feldspar.

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Neutron Radiography and Tomography: A New Approach to Visualize the Internal Structures of Pearls

Carina S. Hanser, Michael S. Krzemnicki, Christian Grünzweig, Ralph P. Harti, Benedikt Betz and David Mannes

Non-destructive imaging of the internal structures of pearls has so far been mainly based on X-ray imaging methods. As organic matter is almost transparent to X-rays, the identification of some structures can be difficult. This study shows that neutron imaging can be a helpful complementary method to visualize structures inside pearls beyond standard X-ray radiography and tomography, as neutrons are highly attenuated by hydrogen-bearing (organic) matter within pearls. The use of neutron radiography and tomography is shown for selected natural and cultured pearls (beaded and non-beaded). In addition, we present neutron phase contrast and darkfield images of a beaded cultured pearl, in analogy to X-ray phase contrast and darkfield imaging described in a previous study. While neutron imaging of pearls is particularly useful for understanding material inhomogeneities and void structures, this methodology is currently only available at large-scale facilities that are equipped to deal with nuclear reactions.

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INTRODUCTION

For about a century, the identification of pearls (i.e. differentiating between their natural or cultured formation; Figure 1) has been a crucial task for gemmologists, given the enormous differences in their rarity and price. Pearl identification is mostly based on the interpretation of internal structures, traditionally visualized by imaging methods such as X-ray radiography (Anderson, 1932; Scarratt et al., 2000; Strack, 2006; Sturman, 2009) and, more recently, X-ray computed microtomography (Wehrmeister et al., 2008; Karampelas et al., 2010; Krzemnicki et al., 2010; Otter et al., 2014) and X-ray phase contrast and darkfield imaging (Revol et al., 2016; Krzemnicki et al., 2017).

With this article, the authors present neutron imaging as a new and complementary method to visualize internal pearl structures. This paper is part of a larger joint research study between author CSH, the SSEF Swiss Gemmological Institute and the Paul Scherrer Institute, in which a total of 32 samples (13 natural and 19 cultured pearls) were investigated with the aim of comparing various imaging methods for pearl testing (Hanser, 2015). It is a follow-up to the article about X-ray phase contrast and darkfield imaging that was recently published in *The Journal* (Krzemnicki et al., 2017).

Similar to X-rays, neutrons can be applied for imaging purposes because of their selective attenuation via absorption and scattering by certain materials. But unlike X-rays, neutrons interact with the atomic nuclei only. Thus, even some lighter elements such as hydrogen strongly attenuate neutrons, whereas X-rays (which interact with the electrons of atoms) are very weakly attenuated by light elements and are increasingly affected by heavier elements (directly related to the element's atomic number). Generally speaking, neutron radiography images are inverse to

X-ray radiographs in many aspects, and in the case of pearls can reveal complementary information to the gemmologist. Calcium carbonate, which forms the pearl, absorbs neutrons rather weakly (and thus appears dark grey in neutron radiographs) in contrast to X-rays, which are strongly absorbed (appearing bright grey in X-ray radiographs). In contrast to this, zones rich in organic matter (and hydrogen) appear bright grey in neutron radiographs (i.e. they are strongly attenuated), whereas they are dark grey in X-ray radiographs (weakly attenuated). Empty cavities, drill holes and fissures remain dark in both methods, as both neutrons and X-rays are well transmitted and not absorbed.

The fact that neutrons are strongly attenuated by some lighter elements such as hydrogen makes them particularly interesting for imaging purposes in which organic matter is involved, such as in materials science (Lehmann and Wagner, 2010; Kardjilov et al., 2011), archaeology and cultural heritage studies (Lehmann et al., 2005; Mannes et al., 2015), including historic jewellery (Rehren et al., 2013; Saprykina et al., 2017), gemstones and pearls (Okamoto et al., 1983; Vontobel and Lehmann, 2010; Hanser, 2015; Mannes et al., 2017; Vitucci et al., 2018).

Pearls commonly contain macroscopic organic matter and void/cavity/fissure features within their calcium-carbonate matrix. As calcium, carbon and oxygen do not interact strongly with neutrons, high contrast between the hydrogen-containing organic matter and the calcium-carbonate polymorphs in pearls can be achieved with neutron imaging methods, as shown in this article.

MATERIALS AND METHODS

For this article we selected two natural and four cultured pearls (see Table I) from the 32 previously investigated samples in order to represent the full range of types (freshwater and saltwater, natural as well as beaded and non-beaded cultured) and display the most telling internal features. All of them had been identified and fully characterized using X-ray radiography and tomography, X-ray phase contrast and darkfield imaging, and energy-dispersive X-ray fluorescence spectroscopy for assessing freshwater vs. saltwater origin.

Figure 1: These pearls (0.7–9.3 ct) were submitted to SSEF for identification and differentiation into natural or cultured origin. Neutron imaging can complement the use of X-rays for difficult cases of identification that might be encountered in a group of pearls such as this. Photo by Luc Phan, © SSEF.

Table I: Natural and cultured pearls analysed for this study.

Sample no.	Type	Bead Nucleus	Origin	Species	Source	Weight (ct)	Diameter (mm)
NP-2e	Natural	–	Saltwater	*Pinctada radiata*	Bahrain	6.49	10.3
NP-2i	Natural	–	Saltwater	*Strombus gigas*	Caribbean Sea	1.86	7.3
CP-1b	Cultured	Non-beaded	Freshwater	*Hyriopsis cumingii*	China	9.92	13.0
CP-2m	Cultured	Non-beaded	Saltwater	*Pinctada margaritifera*	Polynesia	8.14	13.8
CP-2a	Cultured	Beaded	Saltwater	*Pinctada fucata*	Asia	3.89	8.3
CP-2g	Cultured	Beaded	Saltwater	*Pinctada margaritifera*	Polynesia	12.14	16.6

Neutron imaging was performed using the ICON beamline (Kaestner et al., 2011) of the Paul Scherrer Institute (PSI) in Villigen, Switzerland (Figure 2), using a cold neutron spectrum. Since neutrons (i.e. the uncharged particles of an atom's core) can be generated only by nuclear reactions, obtaining access to neutrons is limited to large-scale facilities. The two nuclear reactions that are commonly applied for this purpose are fission and spallation (see Glossary). At PSI, the neutrons were generated with a SINQ continuous spallation source (Blau et al., 2009), and were then passed into a moderator tank filled with heavy water at ambient conditions (to produce a thermal neutron spectrum) and a cold moderator filled with liquid deuterium at 25 K (for a cold neutron spectrum).

For neutron radiography, the pearls were placed on a sample holder using double-sided tape and affixed to an aluminium bar. To keep them in position, some of the pearls were wrapped in aluminium foil, as aluminium is practically transparent to neutrons. For neutron tomography, the samples were wrapped in aluminium foil and placed inside a thin-walled aluminium cylinder, which was placed close to the detector. The acquisition time was 90 s for each radiograph, recorded with a proton current of 1.42 mA by a scintillator-CCD camera system with a field of view of 27 × 27 mm (2048 × 2048 pixels) and a corresponding pixel size of 13.5 µm/pixel (Lehmann et al., 2007). The scintillator was a gadolinium oxysulfide screen with a coating thickness of 20 µm. For neutron

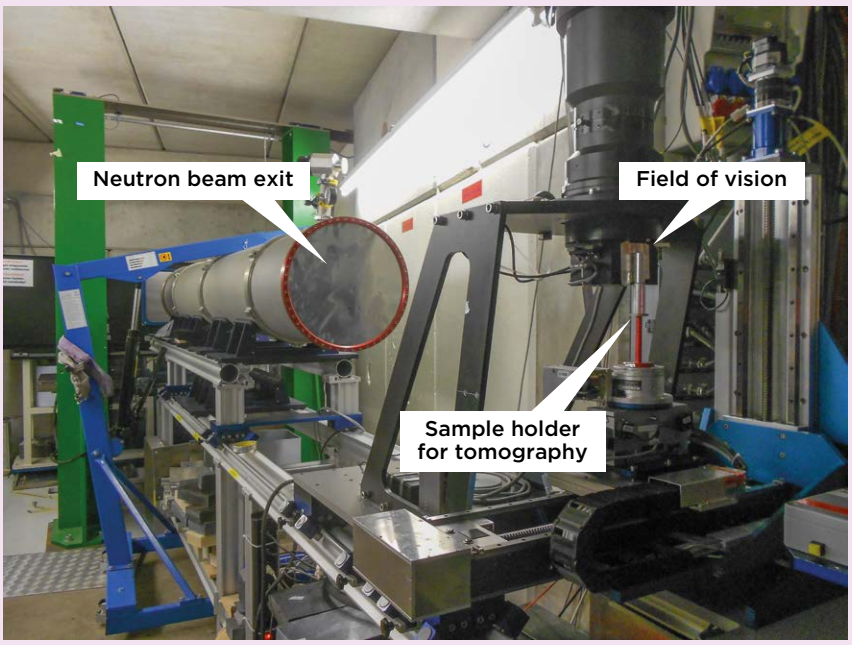

Figure 2: Shown here is a portion of the ICON beamline at the Paul Scherrer Institute that provides a cold neutron spectrum. The neutron beam passes through the exit and the field of vision and then strikes the sample. The signal produced is then recorded by a scintillator-CCD camera system (not visible in this image). Photo by C. Hanser.

Glossary

Nuclear fission: Highly energetic radioactive decay process by which an atomic core (nucleus) is split into smaller/lighter nuclei (e.g. in a chain reaction), often accompanied by the production of free neutrons and gamma radiation.

Nuclear spallation: Using a particle accelerator, a heavy nucleus (atom) emits a large number of neutrons each time it is hit by a high-energy particle. These highly energetic neutrons have to be slowed down to be usable for analysis purposes by a process known as moderation.

tomography the same setup was used, with each tomograph consisting of 626 radiographs over 360°, summing up to an overall acquisition time of approximately 22 hours.

None of the analysed pearls showed any change in colour after exposure to the neutrons. However, they did become temporarily radioactive due to the long time necessary for neutron tomography, and had to remain at the facility until reaching a threshold level below 0.1 µSv/h (as tested by a radiation protection officer using an officially calibrated dosimeter), a process which took several hours to a few days for the various pearls.

Neutron phase contrast and darkfield imaging were performed with the samples fixed on double-sided tape and using a lower acquisition time of 45 s for each image. No residual radioactivity was detected in the samples after this type of imaging. A detailed description of the setup and neutron interferometer gratings is given by Grünzweig et al. (2008) and Mannes et al. (2017).

RESULTS AND DISCUSSION

X-ray and neutron imaging were done independently on two completely different instrumental setups, and although we attempted to fix the samples in a consistent orientation, we were unable to obtain images with a perfectly matching sample position. All radiographs were edited (contrast sharpening and homogenizing of the black background around the samples) using built-in filters in Adobe Photoshop software. A comparison of X-ray radiography and neutron radiography images immediately reveals the complementary nature of these two methods.

Examples of Natural Pearls

Figure 3 shows natural pearl sample NP-2e (*Pinctada radiata*), which is characterized by an organic-rich core of radially arranged calcite prisms and multiple radial fissures overgrown by a nacre layer about 3 mm thick with weak onion-like structures. In the X-ray radiograph (Figure 3b) the nacre is distinctly brighter (higher X-ray attenuation) compared to the organic-enriched core (lower X-ray attenuation). Fissures appear dark, as they are voids with no attenuation effect on X-rays. (Note: Readers wishing to see X-ray phase contrast and darkfield images of this pearl are directed to Figure 6 in Krzemnicki et al., 2017.)

Neutron radiography of this pearl (Figure 3c) shows the inverse to X-radiography, with a brighter core owing to the enrichment of organic matter (i.e. strong neutron attenuation by hydrogen) compared to the dark grey nacre (distinctly lower neutron attenuation by calcium carbonate). Similar to the X-ray radiograph, the void fissures (mainly visible in the core) are dark, indicating no neutron attenuation; it can therefore be postulated that they contain no organic matter. However, compared to the image

Figure 3: (a) Saltwater natural pearl NP-2e (*Pinctada radiata*, 10.3 mm in diameter) is shown here with its X-ray radiograph (b) and neutron radiograph (c). The inverse attenuation of the organic-rich core (dark grey in X-rays and light grey in neutrons) and the dense surrounding nacre layer (light grey in X-rays and dark grey in neutrons) is obvious.

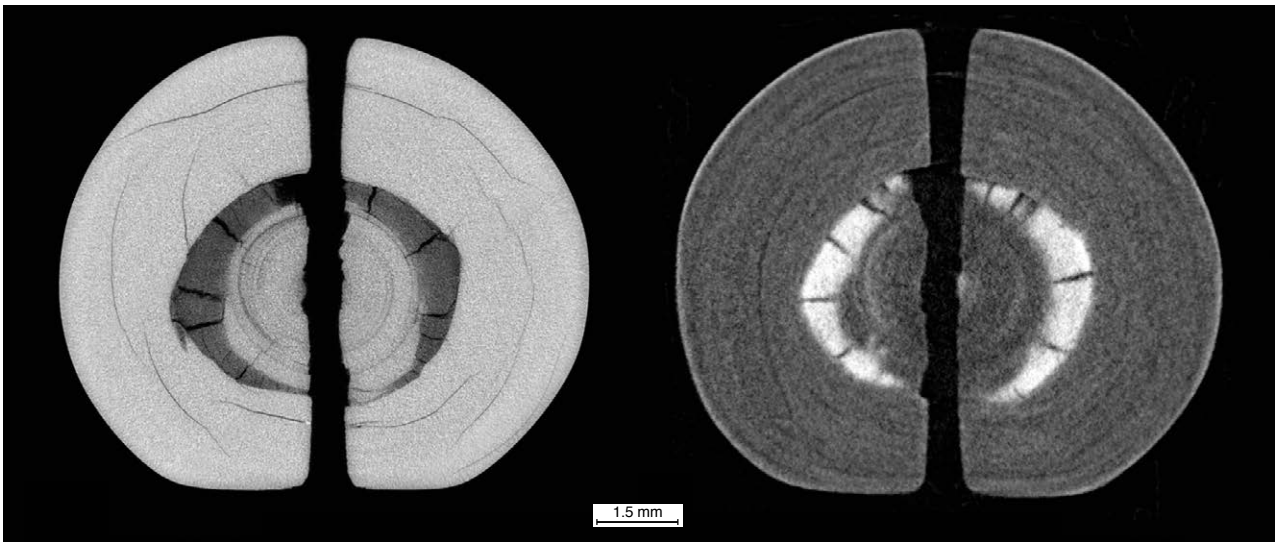

Figure 4: X-ray tomography (left) and neutron tomography (right) of the natural pearl shown in Figure 3 also illustrates the inverse attenuation of X-rays and neutrons in pearls. The organic-rich outer core layer with numerous radiating desiccation fissures appears dark grey in X-rays and bright grey in neutrons.

obtained with state-of-the-art digital X-ray radiography, the neutron radiograph appears less sharp using the current analytical setup.

Better contrast and resolution are shown by image slices of the same sample obtained by X-ray and neutron tomography (Figure 4). These images reveal that this saltwater natural pearl in fact contains an irregularly shaped core consisting of two phases: (1) an inner core portion dominated by calcium carbonate that appears bright grey in the X-ray tomograph and dark grey in the neutron tomograph (and also contains tiny radial calcite columns, of the type pictured in Figure 3b of Gutmannsbauer and Hänni [1994], together with fine onion-like structures), and (2) an outer core layer of calcium carbonate that is heavily enriched in organic matter and appears dark grey in the X-ray tomograph and bright grey in the neutron tomograph (along with pronounced desiccation fissures). The reason for such a distinct enrichment of organic matter in the outer core is not known, but might be the result of a haemorrhage event within the pearl sac during formation of this natural pearl. These tomographic slices allow a much more detailed interpretation of internal structures because they are not blurred by condensing a three-dimensional pearl on to a two-dimensional image, as with radiography.

Figure 5 shows a comparison of image slices obtained by X-ray and neutron tomography of non-nacreous natural pearl sample NP-2i, reportedly from *Strombus gigas* (Sue Hendrickson, pers. comm., 2015). This pearl is characterized by a large irregular-shaped internal cavity that is partially filled with numerous small spherules. X-ray tomography (Figure 5b) shows a rather strong attenuation of these spherules, resembling the bright appearance of the non-nacreous calcium carbonate surface layer (densely interwoven fibrous aragonite), thus indicating a rather calcareous nature of these spherules. However, the neutron tomograph (Figure 5c) clearly illustrates that these spherules also highly attenuate neutrons and are thus presumably rich in hydrogen. This indicates a distinctly different nature than the calcium carbonate (aragonite) of the pearl's surface. Similar tiny spherules have been documented previously (see Figure 4 in Krzemnicki et al., 2010), and research into their nature is ongoing.

Examples of Cultured Pearls

Figure 6 shows non-beaded freshwater cultured pearl CP-1b (*Hyriopsis cumingii*), imaged using X-ray and neutron radiography. Both images are dominated by a rather uniform attenuation as a result of the dense nacre of this cultured pearl. The irregular 'moustache' structure in the centre is clearly visible in the X-ray radiograph but also to some extent in the neutron image. (The slightly different shape of this structure in these two radiographs is due to variations in the sample's orientation.) Such tiny structures are highly characteristic of mantle-grown non-beaded cultured pearls (Scarratt et al., 2000; Strack, 2006). The fact that this structure is dark grey (i.e. has very low attenuation) in both types of radiographs indicates that it actually represents a tiny folded void and—at least in this case—is not filled with organic matter. The X-ray radiograph (Figure 6b) also shows a few very fine dark ring structures, which appear light grey in the neutron radiograph (Figure 6c), thus

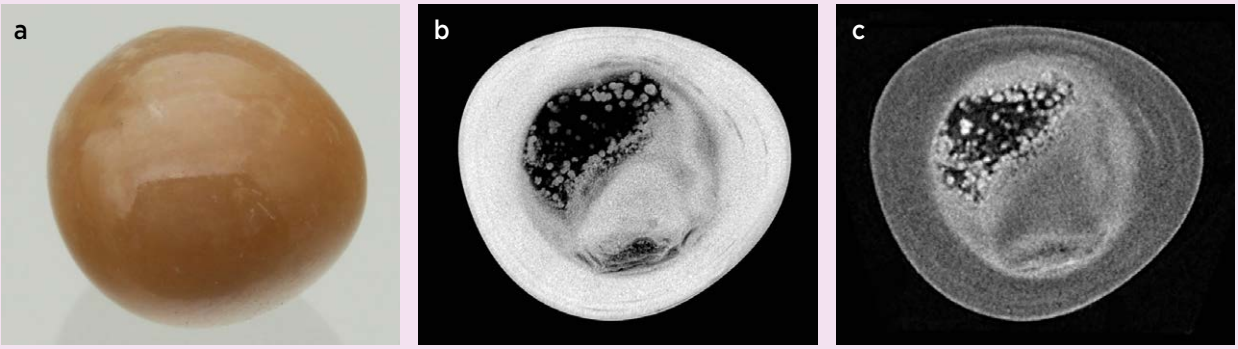

Figure 5: (a) Non-nacreous natural pearl NP-2i (*Strombus gigas*, 7.3 mm in diameter) is shown with its corresponding tomographic slices obtained using X-rays (b) and neutrons (c), which reveal a large cavity containing numerous small spherules.

implying that they represent onion-like growth features enriched in organic matter. However, the fuzzy appearance of the neutron radiograph obtained with the current analytical setup demonstrates that it is not the first choice for visualizing such fine internal features crucial for pearl identification. Much more detailed X-ray phase contrast and darkfield images of this same cultured pearl are presented in Figure 9 of Krzemnicki et al. (2017).

Figure 7 shows the complex external and internal structures of non-beaded saltwater cultured pearl CP-2m (*Pinctada margaritifera*; see also Figure 10 in Krzemnicki et al., 2017). The neutron radiograph (Figure 7b) highlights local concentrations of organic matter (containing hydrogen) as bright areas. The baroque shape, however, creates spurious overlay effects when condensed into a two-dimensional X-ray radiograph (which is therefore not shown here for comparison). As evident in the reconstructed image slices obtained by X-ray and neutron tomography (Figures 7c and 7d), the internal structures are much more discernible and displayed in great detail by both methods. The main feature is a large folded cavity structure (dark grey to black in the X-ray tomograph), accentuated by desiccation fissures. The neutron tomograph provides additional information that is different from what can be inferred from the X-ray tomography only. What seems to be an open void on the left side of the large folded cavity structure in the X-ray image proves to be filled with organic matter (bright grey in the neutron tomograph). The remaining part of the folded cavity is only coated by a thin layer of organic material resulting in a fine but pronounced light grey depiction of the cavity's outline. The smaller additional cultured pearl attached at the top, also known by the Japanese term *tokki*, is a common feature for gonad-grown cultured pearls (Krzemnicki et al., 2011; Gauthier et al., 2015). Interestingly, this tokki shows a small dark ring (with a tiny brighter spot in its centre) in both tomographic images. Based on X-ray tomography, this feature could be misinterpreted as having a local enrichment of organic matter in a small growth ring. The low neutron

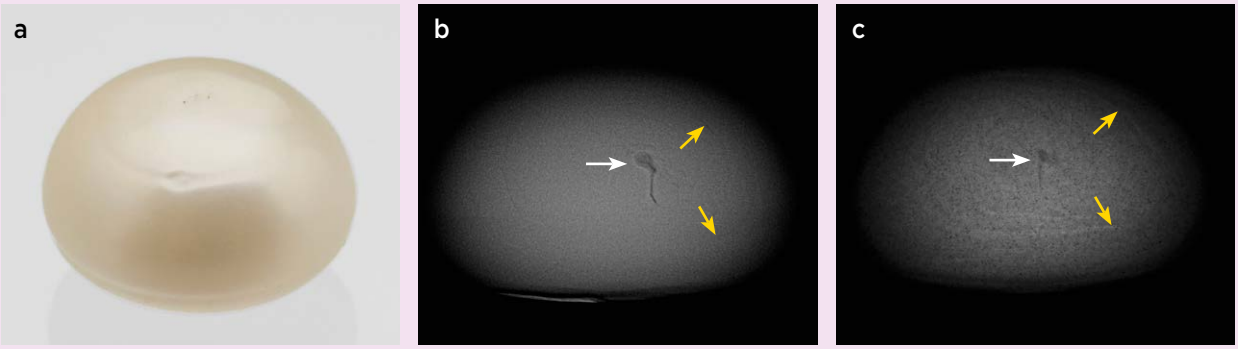

Figure 6: (a) Non-beaded freshwater cultured pearl CP-1b (*Hyriopsis cumingii*, 13.0 mm in diameter) is shown with its X-ray (b) and neutron (c) radiographs. The latter two images were not taken in exactly the same position, resulting in a slightly different appearance of the tiny 'moustache' void structure in the centre (white arrows). Fine growth rings (yellow arrows) appear light grey in the neutron radiograph, indicating that they are enriched in organic matter.

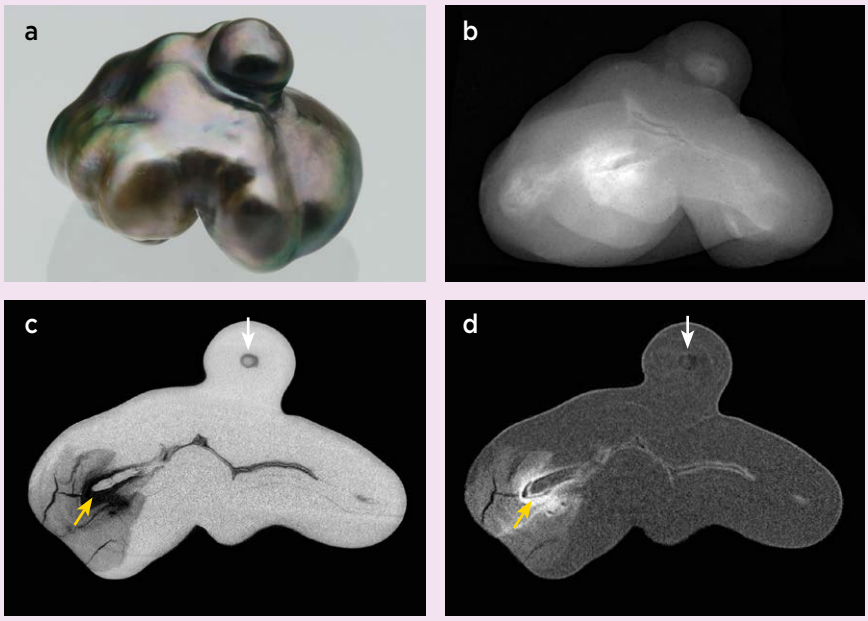

Figure 7: (a) Non-beaded saltwater cultured pearl CP-2m (*Pinctada margaritifera*, 13.8 mm in diameter) is imaged with neutron radiography (b), X-ray tomography (c) and neutron tomography (d). The tomographic sections display a large folded cavity structure (yellow arrows), with distinct enrichment of organic matter shown in the neutron tomograph. Attached to the top of the sample is a small additional cultured pearl (tokki), with a dark growth ring marked by white arrows.

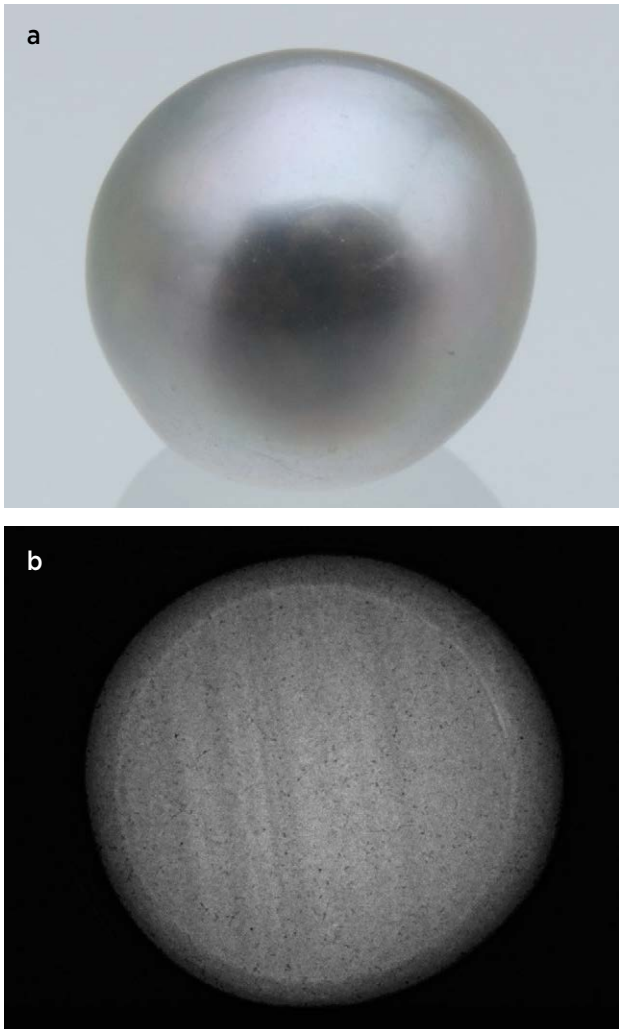

Figure 8: (a) Imaging of Akoya-type beaded saltwater cultured pearl CP-2a (*Pinctada fucata*, 8.3 mm in diameter) was performed with neutron radiography (b), which reveals a banded structure within the shell bead and a thin light grey circle resulting from a film of organic matter on the bead.

attenuation by this feature, however, indicates that the growth ring might be due to another reason, such as a distinctly lower nacre density.

Beaded cultured pearls are readily identified with both X-ray and neutron radiography. Figure 8 shows Akoya-type beaded cultured pearl CP-2a (*Pinctada fucata*) with distinct banding in the shell bead (a freshwater origin for this bead was confirmed by X-ray luminescence imaging; see Hänni et al., 2005). Inversely to X-ray radiography, the darker bands in the neutron radiograph are not inferred to represent layers showing variations in organic matter but rather zones of denser freshwater shell material, whereas the brighter bands might contain slightly higher amounts of organic matter. (An X-ray radiograph of this sample is not included here for comparison because it was taken in a slightly different position and therefore did not show the internal layering of the bead.) The bright thin layer between bead and nacre overgrowth represents a thin film of organic matter deposited on the bead in the newly formed pearl sac before the nacre overgrowth formed during pearl cultivation. The bead appears slightly brighter than the surrounding nacre because, as with all spherical objects, there is a gradual increase of attenuation with increasing transmission path through the sample. In addition, the thin layer of organic matter (seen here as the light grey circle between the bead and nacre overgrowth) also might contribute to the brighter overall appearance of the bead in this neutron radiograph.

A final example (Figure 9) is provided by beaded saltwater cultured pearl CP-2g (*Pinctada*

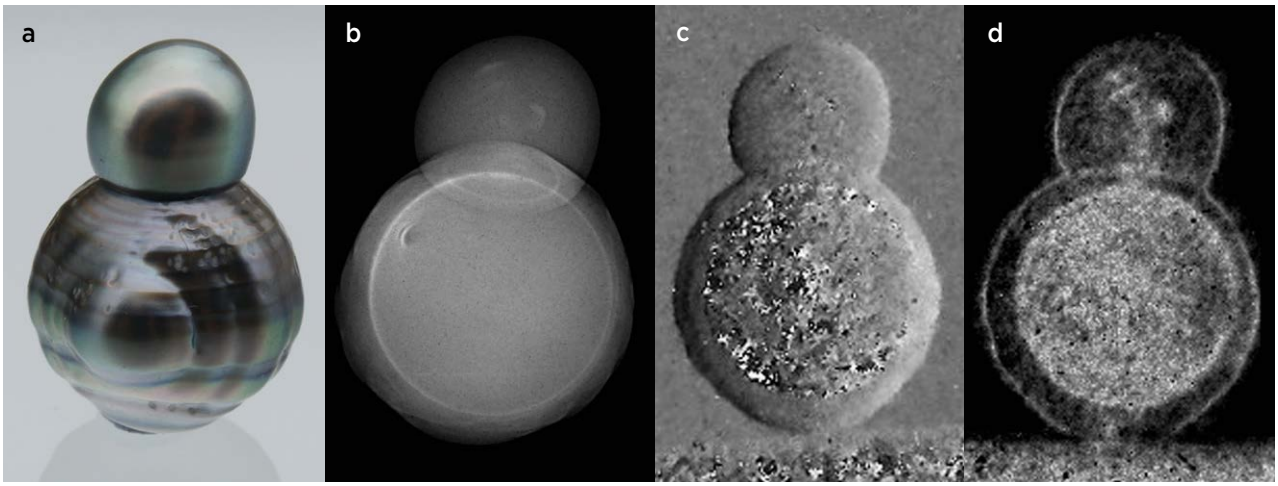

Figure 9: (a) Saltwater cultured pearl CP-2g (*Pinctada margaritifera*, 16.6 mm in diameter) is shown with its neutron radiograph (b), neutron phase contrast image (c) and neutron darkfield image (d). The bead is readily discernible by its organic coating, both with neutron radiography (bright grey circle) and neutron interferometry, which shows different appearances related to artefacts (in the neutron phase contrast image) and small-angle scattering (in the darkfield image).

margaritifera) with a relatively large additional cultured pearl (tokki) and distinct circling structures in two directions on its surface (cf. Gauthier et al., 2015). The bead is easily recognized in the neutron radiograph (Figure 9b) by a bright grey outline resulting from a distinct organic layer that surrounds it. For this sample (and all other samples studied by Hanser, 2015), we present additional neutron phase contrast and neutron darkfield images (Figures 9c and 9d, respectively). Using the current setup and analytical parameters, these images are, however, characterized by rather low resolution and noticeable artefacts, which limits their usefulness. The neutron phase contrast image reveals a noisy signal related to the bead, whereas in the neutron darkfield image the organic-rich coating on the bead and a few organic-rich spots in the tokki produce strong neutron small-angle scattering (i.e. a distinct bright reaction).

CONCLUSIONS

Most structures inside pearls can be visualized readily by X-ray imaging methods. However, neutron radiography and tomography can yield additional information that cannot be obtained by X-rays. Neutron imaging methods are especially useful to better understand material inhomogeneities and void structures, as well as filling substances (solid or liquid) in large hollow pearls (cf. Otter et al., 2014). Since access to neutron imaging techniques is, however, limited to large-scale facilities, their routine application to gemmological testing is impossible at this time. Still, in difficult cases of identifying the nature of a pearl, further analysis with neutrons can be helpful. It is important to note that activation of the samples as a result of neutron tomographic imaging will likely require that they be quarantined for up to several days after testing.

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Conferences

AGA TUCSON CONFERENCE

The 2018 Accredited Gemologists Association Conference in Tucson, Arizona, USA, took place 31 January and was attended by 142 people. The event was moderated by AGA president **Stuart Robertson** (Gemworld International Inc., Glenview, Illinois, USA) and featured six presentations.

Dr Thomas Hainschwang (GGTL-GEMLAB Laboratories, Balzers, Liechtenstein) provided an update on his ambitious project of characterizing treated-colour diamonds (Figure 1). He and his team have analysed a carefully pre-selected sample base of 105 natural untreated diamonds of various colours (colourless, yellow, brown, 'olive' green, grey and violet) using several spectroscopic techniques as well as fluorescence imaging. The stones are currently in the process of being treated by various methods (i.e. irradiating with neutrons, heating in small steps over a range of 100–1,300°C and annealing under high-pressure, high-temperature [HPHT] conditions). After each treatment step the samples are characterized again by the same techniques.

Shane McClure and **Andy Lucas** (Gemological Institute of America [GIA], Carlsbad, California, USA) described the geographic origin determination of emeralds, and started by differentiating two main types: high iron (from mica schist-type deposits such as Zambia and Brazil) and low iron (from localities such as Colombia and Afghanistan). They illustrated the inclusions, ultraviolet-visible (UV-Vis) spectral features and chemical composition of emeralds from various deposits in the context of the high- and low-iron categories.

Figure 1: During the AGA Tucson Conference, Dr Thomas Hainschwang presents a status report of his research project on characterizing treated-colour diamonds. Photo by B. M. Laurs.

Dr Çiğdem Lüle (Kybele LLC, Buffalo Grove, Illinois, USA) highlighted current challenges involving gemmological nomenclature and terminology, including the naming of newly discovered gem varieties, colour descriptions on laboratory reports, treatment disclosure and branded gems.

Nathan Renfro (GIA, Carlsbad) showed beautiful photomicrographs of internal features in ruby, emerald and sapphire, and provided useful examples of how certain features are characteristic of natural, treated or synthetic samples, and also can be indicative of specific geographic origins.

Richard and Billie Hughes (Lotus Gemology, Bangkok, Thailand) provided an overview of some gems from Madagascar, with examples of localities visited in 2005, 2010 and 2016. They also reviewed internal features seen in sapphires from various unspecified localities in Madagascar, and described experiments to investigate the effects of relatively low-temperature heat treatment (800–1,300°C) on the inclusions and UV-Vis spectra of Madagascar sapphires.

Sonny Pope (Suncrest Diamonds, Orem, Utah, USA) reviewed the colour enhancement of diamond using HPHT and irradiation treatments. The latest developments from his company include a new range of light 'baby' pink colours (derived from dark brown type IIa starting material) and 'sky' blue coloration produced by sequential HPHT and irradiation treatment of brown type IIa diamonds.

The conference also featured workshops by **Alan Hodgkinson** (Whinhurst, West Kilbride, Scotland) on visual optics, **Claire Mitchell** (JTV, Knoxville, Tennessee, USA) on testing gems with UV fluorescence and **Sarah Steele** (Ebor Jetworks Ltd, Whitby) on distinguishing black gem materials.

The AGA Gala took place that evening, where The Antonio C. Bonanno Award for Excellence in Gemology was presented to **William Hanneman** (Monterey, California, USA) in honour of his many contributions to gemmology that range from education to the development of innovative and affordable gem-testing instruments.

Brendan M. Laurs FGA

Figure 2: IGC participants and guests gather for a group photo in front of the Safari Hotel in Windhoek, Namibia. Photo courtesy of Tasnara Sripoonjan.

35TH INTERNATIONAL GEMMOLOGICAL CONFERENCE

The 35th biennial IGC took place at the Safari Hotel in Windhoek, Namibia, 11–15 October 2017. The conference was organized by **Dr Ulrich Henn** (German Gemmological Association, Idar-Oberstein), **Prof. Dr Henry Hänni** (GemExpert, Basel, Switzerland) and **Andreas Palfi** (Palfi, Holman and Associates, and Geo Tours Namibia, Windhoek). More than 80 delegates, observers and guests from 28 countries gathered for the conference (e.g. Figure 2), and some of them attended pre- and post-conference field trips. (For a report on the pre-conference excursion to a diamond mine on Namibia's coast, see pp. 16–18 of this issue of *The Journal*). A proceedings volume containing extended abstracts of the oral and poster presentations can be downloaded at www.igc-gemmology.org/igc-2017-programme.

The conference was opened by IGC Executive Committee secretary **Dr Jayshree Panjikar** (PANGEMTECH, Pune, India), followed by speeches from **Veston Malango** (Chamber of Mines, Windhoek) and The Honourable Deputy Minister **Kornelia Shilunga** (Ministry of Mines and Energy, Windhoek).

Gems of Namibia and South Africa were covered in the first conference session. **Dr Gabi Schneider** (Namibian Uranium Association, Swakopmund) reviewed the history of diamond mining in Namibia, from when they were discovered in 1908 to the present time. The coastal area from Oranjemund northward to Lüderitz has become one of the most important diamond-producing areas in the world. The initial rush spurred an industrial revolution to address the challenges of mining in the Namib Desert, a remote area that lacked nearby water and electricity. **Andreas Palfi** covered deposits for coloured stones and ornamental gems in Namibia, including tourmaline, garnet (demantoid and spessartine), aquamarine, topaz, quartz and other silica-based gems (pietersite and agates) and mineral specimens. He estimated that approximately 3,000 people are active in the industry, mostly as independent small-scale miners. **Dr Ulrich Henn** and co-authors from the German Gemmological Association reviewed the localities and gemmological properties of tourmaline from the Karibib and Usakos regions of Namibia. Henn reported that heating the tourmaline to 650°C for one hour can alter the colour from blue-green to green due to the conversion of Fe^{2+} to Fe^{3+}. **Edward Boehm** (RareSource, Chattanooga, Tennessee, USA) examined the geology, gemmology and market for spessartine from Namibia. Commonly sold as 'Mandarin garnet', Namibian spessartine commands relatively high prices (typically more than US$1,000/ct or ~£720/ct) compared to material from other localities (i.e. Nigeria, Mozambique, Brazil, Sri Lanka, Tanzania and Zambia). **Dr Harmony Musiyarira** and co-authors (Namibia University of Science and Technology, Windhoek) developed a growth strategy for the Namibian jewellery industry and coloured stone value chain. They collected information from small-scale miners by conducting interviews, distributing questionnaires and visiting mining areas, and determined that there is a need to move from a cost-based sector to a high-value-added and

competitive brand in the global market. At the end of the session, **this author** described recent mining of some alluvial diamond deposits in South Africa (for details, see Gem Note in *The Journal*, Vol. 35, No. 6, 2017, pp. 484–485).

The next session focused on gem corundum. **Terrence Coldham** (Sydney, Australia) presented convincing evidence that the Lava Plains deposit in northern Queensland is an *in situ* pyroclastic sapphire deposit. Since there are not enough sapphires found in alkali basalts to account for the grades of their associated alluvial deposits, he proposed that a large proportion of the world's BGY (blue, green, yellow)-type sapphires may have been brought to the surface during a pyroclastic phase of volcanism (rather than by eruptions of basaltic lava); in most cases the sapphires were then concentrated into economically significant deposits by weathering of the pyroclastics. **Dr Emmanuel Fritsch** (Institut des Matériaux Jean Rouxel and University of Nantes, France) and co-authors suggested that elongate crystallographically oriented inclusions in ruby and sapphire, which are commonly referred to as 'boehmite needles', are actually empty channels that form at the intersections of polysynthetic twin planes. **Shane McClure** (GIA, Carlsbad, California, USA) described recent sapphire mining at Gem Mountain (Rock Creek) and El Dorado Bar (Missouri River) in Montana, USA. Also he reported that another very active operation (Potentate Mining) recovered more than 40 kg of sapphires during the recent mining season at Wildcat Gulch in the Rock Creek area. **Wiliwan Atichat** and co-authors (The Gem and Jewelry Institute of Thailand [GIT], Bangkok) described GIT's system of colour grading padparadscha sapphires, which relies on the use of master stones consisting of three groups: orangey pink, orange-pink and pinkish orange.

In a session on diamonds, **Kentaro Emori** and co-authors (Central Gem Laboratory, Tokyo, Japan) documented two synthetic samples (1.03 ct brown CVD-grown and 0.07 ct yellow HPHT-grown synthetic diamonds) with features resembling natural stones. He reminded the audience that it is important to use comprehensive methodology for identifying challenging synthetics that are now present in the marketplace. **Roman Serov** and co-authors (Gemological Center, Lomonosov Moscow State University, Russia) reported on natural diamonds overgrown by a thick CVD synthetic layer to add weight. The latest generation of these 'hybrid diamonds' may contain jellyfish-like inclusions (Figure 3), and they generally lack a discernible natural/CVD boundary when viewed with a gemmological microscope (although this is readily seen with the DiamondView). **Dr Rainer Schultz Güttler** (University of São Paulo, Brazil) documented features of natural radiation staining on green diamonds from Brazil. In addition to the typical green spots on such diamonds, he showed how radioactive fluids may stain diamonds along cleavage fractures or may even 'dye' the surface of entire stones (though only to a depth of 25 µm). **Tay Thye Sun** (Far East Gemological Laboratory, Singapore) and co-authors examined the properties

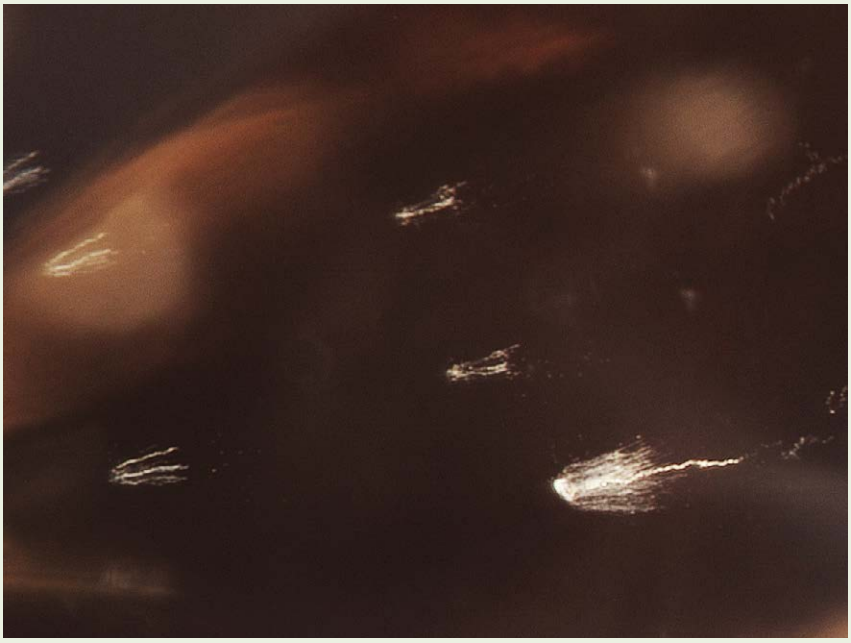

Figure 3: A 'hybrid' diamond contains jellyfish-like inclusions that nucleate at the boundary with the natural diamond and extend into the CVD synthetic diamond overgrowth. Photomicrograph by Roman Serov; image width 1.2 mm.

of diamonds from Landak River in West Kalimantan, Indonesia. They obtained samples during a visit to the mining area that ranged from colourless to yellow, brown, green and black, and most of them were type Ia (except for one that was type IIa). A photoluminescence (PL) peak of unknown origin was present in some of the diamonds at 612.4 nm.

Spinel, tourmaline and garnet were covered in the next session. **Dr Jayshree Panjikar** and **Aatish Panjikar** (PANGEMTECH, Pune, India) characterized spinel from Kermunda in Odisha State, India. The stones were mined from the soil by local villagers and tumbled into beads. They ranged from pale purplish red to dark orangey red, and UV-Vis spectroscopy revealed features related to Cr^{3+} and Fe^{2+}. Co-author **Dr Andy Shen** presented research of his PhD student **Cheng-Si Wang** (Gemmological Institute, China University of Geosciences, Wuhan, China) on reversible PL spectral features in Cr^{3+}-bearing spinel with heat treatment. Samples from Myanmar and Tanzania were heated from 200°C to 1,600°C for one hour in air, and then were quenched to room temperature, and finally were annealed to 700°C for several days (or under HPHT conditions for 45 minutes). Changes in the PL spectra that occurred during the initial heating could not be completely reversed by the annealing process, so the PL spectral criteria used to identify heated spinel were shown to be quite robust. **Dr Claudio Milisenda** and **Stefan Müller** (DSEF German Gem Lab, Idar-Oberstein) examined rare-earth element (REE) photoluminescence in Paraíba-type tourmaline from Maraca, Mozambique. Samples from this locality contain elevated Ca (and are thus liddicoatite), and PL spectroscopy showed REE features in the 850–920 nm range that were due to Nd^{3+}. By contrast, the Cu-bearing tourmaline from Mavuco (~20 km from Maraca) is elbaite and does not show REE-related PL features. **Dr Karl Schmetzer** (Petershausen, Germany) and co-authors reported on garnets from archaeological and presently known deposits in India (see article in *The Journal*, Vol. 35, No. 7, 2017, pp. 598–627).

Gem corundum was the topic of the next session. **Dr J. C. (Hanco) Zwaan** (Netherlands Gemmological Laboratory, Naturalis Biodiversity Center, Leiden) and co-authors studied the origin of sapphires from Sri Lanka (as reported in the FEEG conference report on p. 70 of this issue). **Dr Shang-i (Edward) Liu** (Gemmological Association of Hong Kong) and co-authors described the recent mining of some gem corundum deposits in Sri Lanka, including those at Kataragama, Rakwana, Hatton and Pohorabawa, and they also summarized the gemmological properties of sapphires from those localities. **Sutas Singbamroong** and co-authors (Gemstone and Precious Metal Laboratory, Dubai Central Laboratory, United Arab Emirates) documented lead-glass-filled padparadscha sapphires that appeared in December 2016 in Chanthaburi, Thailand. The stones showed typical features for this treatment, and the starting material was inferred to be fractured orangey pink corundum from East Africa. **Seung Kwon Lee** and **Kiran Kwon** (Wooshin Gemological Institute of Korea, Seoul, South Korea) performed a Raman spectroscopic study of heat-treated sapphires, and found inconclusive evidence about whether structural relaxation by impurities in the corundum is useful for identifying heat treatment.

A session on analytical techniques featured four presentations. Co-author **Walter Balmer** presented research by **Dr Michael Krzemnicki** and colleagues from the Swiss Gemmological Institute SSEF (Basel, Switzerland) on analysing trace elements and isotopes in gemstones and pearls using GemTOF (see article in *The Journal*, Vol. 35, No. 3, 2016, pp. 212–223). **Kentaro Emori** and **Dr Hiroshi Kitawaki** (Central Gem Laboratory, Tokyo, Japan) applied discriminant analysis and linear regression to trace-element data for natural and synthetic amethyst. Initial results showed that the multivariate analyses were more effective than comparing trace-element concentrations for differentiating between various geographic origins as well as natural vs. synthetic samples. **Masaki Furuya** (Japan Germany Gemmological Laboratory, Kofu, Japan) described procedures for screening synthetic diamonds from melee-sized parcels using phosphorescence imaging. In general, the parcels that Furuya encountered either contained a rather large amount of synthetics (which he inferred as intentional salting by suppliers) or had less than 1% synthetics (which were likely introduced by mistake). **Bahareh Shirdam** and **Dr Soheila Aslani** (University of Tehran, Iran) used inductively coupled plasma mass spectrometry (ICP-MS) and X-ray fluorescence spectroscopy to differentiate Persian turquoise from the historical Neyshabur area in Khorasan Province from a newer mining area at Meiduk in Kerman Province. Although certain trace elements (Cr, Fe, Zn, As and Sr) were found to be helpful in some cases for distinguishing between turquoise from the two localities, the samples' inclusions and gemmological characteristics also should be considered to make a reliable separation.

Organic gems—specifically pearls and amber—were covered in the next session. **Nick Sturman** and co-authors (GIA, Bangkok, Thailand) characterized *Pinctada maxima* non-bead cultured pearls obtained from Jewelmer's farms in Palawan, Philippines, and found six types of internal structures using real-time X-ray imaging: structure-free voids, voids containing partitions, voids surrounded by organic areas, linear voids, atypical features such as intermediate boundaries, and other features (including mixtures of these various types). **Dr Stefanos Karampelas** and co-authors (Bahrain Institute for Pearls & Gemstones [DANAT], Manama, Bahrain) examined natural pearls harvested from *Pinctada radiata* in the Kingdom of Bahrain, and found structures generally consisting of onion-skin-like layering with a darker-appearing centre; some samples also contained radial columnar structures in their core. **Elisabeth Strack** (Gemmologisches Institut Hamburg, Hamburg, Germany) described freshwater pearls from north-western Russia (see article in *The Journal*, Vol. 34, No. 7, 2015, pp. 580–592). **Dr Shang-i (Edward) Liu** studied feather and insect inclusions in Burmese amber. Biologists recently have discovered new species of ants that lived only during the Cretaceous Period, and their presence as inclusions in amber therefore provides evidence of Burmese origin.

The next session was devoted to miscellaneous gems. **Willow Wight** (Canadian Museum of Nature, Ottawa) reviewed the production and marketing of ammolite from Alberta, Canada. Korite Minerals is growing their presence in the Chinese market, and they recently expanded their mine to increase their annual production of ammolite gems from 6 million carats in 2016 to an estimated 8 million carats in 2017. **Anette Juul-Nielsen** and **Arent Heilmann** (Ministry of Mineral Resources, Nuuk, Greenland) are producing a gem occurrence map of Greenland. As part of a larger project to document mineral localities in that country, gem materials have been added since 2015 (focusing on central-western Greenland), with 300 data entries so far. **Stephen Kennedy** (Gem & Pearl Laboratory, London) and **Dr Jens Najorka** (Natural History Museum, London) studied imitations of Tianhuang and Shoushan stones. These carvings (e.g. seal stones) are highly valued in China and typically consist of compact yellow clay-mineral aggregates sourced from near Fuzhou, Fujian Province, China. X-ray powder diffraction analysis of recently encountered imitations revealed two types of chlorite, and the yellow colour of the carvings was due to dyeing. **Dr Çiğdem Lüle** (Kybele LLC, Buffalo Grove, Illinois, USA) described gemmological nomenclature and terminology challenges (as reported in the AGA conference report on p. 64 of this issue).

The final oral session was devoted to beryl, cordierite and jade. **Dr Lore Kiefert** and co-authors (Gübelin Gem Lab, Lucerne, Switzerland) described the mining and properties of emerald from Ethiopia. Local diggers began producing significant amounts of emerald in the Kenticha area of southern Ethiopia in May 2016, and numerous pits of 5–10 m depth have been dug in the sloped terrain. The emeralds are typically light coloured and have high clarity, and they exhibit gemmological and chemical properties that are consistent with stones derived from schist-hosted deposits. **Dr Karen Fox** and **Dr Chris Yakymchuk** (University of Waterloo, Canada) reviewed occurrences of gem-quality cordierite in Canada. Chemical analysis of samples from 15 localities using laser ablation ICP-MS and electron microprobe showed various amounts of overlap. **Dr Ahmadjan Abduriyim** (Tokyo Gem Science and GSTV Gemological Laboratory, Tokyo, Japan) and co-authors reviewed the history and gemmology of jadeite jade from Japan, and compared it with jadeite from other sources. Significant differences in the accessory mineral content and chemical composition (i.e. for the chromophores V, Co, Mn, Cr, Fe and Ti) were described for material from Japan (Itoigawa), Myanmar, Guatemala and Russia.

Poster presentations at the IGC covered a range of subjects related to coloured stones; those named below are the first authors (although some of them could not be in attendance and had co-authors present the research). **Dr Laurent Cartier** (Swiss Gemmological Institute SSEF) and colleagues reviewed possible strategies, opportunities and limitations of tracking gems from mine-to-market and from market-to-mine using various approaches. **Thanong Leelawatanasuk** and co-authors (GIT, Bangkok) described unusual fancy-colour sapphires from the Bo Phloi gem field in Kanchanaburi, Thailand. The samples were violet, purple, pink, green, yellow and parti-coloured, and the different colours related well to their trace-element contents. **Thanapong Lhuaamporn** and co-authors from GIT characterized high-quality untreated blue sapphires that reportedly were produced from Bo Phloi. Rather than the typical dark tone of sapphires produced from this basaltic deposit, many of the samples showed an attractive intense medium blue colour. **Dr Panjawan Thanasuthipitak** (Chiang Mai University, Thailand)

Figure 4: Namibian dealers display rough and cut gems as well as finished jewellery at the Namibian Coloured Gemstone & Jewellery Showcase, which took place in conjunction with the IGC. Photo by B. M. Laurs.

and co-authors highlighted various gem materials from northern Thailand with the potential for use in jewellery, including rock crystal, almandine, fluorite, serpentinite and silicified rhyolite. **Dr Arūnas Kleišmantas** (Vilnius University, Lithuania) and co-authors described the chemical composition (i.e. chromophores V, Cr, Fe and Co) and mineral inclusions in spinel from Sri Lanka and Vietnam. **Dr Michael Krzemnicki** and co-authors documented cobalt diffusion-treated spinel, including its coloration patterns, microscopic features, visible absorption spectra, and physical and chemical properties. **Dr Leander Franz** (University of Basel, Switzerland) and co-authors described kosmochlor-bearing jadeite rocks from Kenterlau-Itmurundy near Lake Balkhash, Kazakhstan. The samples were found to consist of jadeitites, omphacite jadeitites, phlogopite-analcime jadeitites, phlogopite-omphacite jadeitites and kosmochlor-analcime-albite-omphacite jadeitites. **Gagan Choudhary** (Gem Testing Laboratory, Jaipur, India) characterized 'Aquaprase' (blue to bluish green chalcedony) from Africa, which is coloured by Cr ± Ni impurities. **Prof. Dr Henry Hänni** described 'Sannan-Skarn', an ornamental stone from Balochistan, Pakistan, that mainly consists of calc-silicates. **Jian Mao** (Gemstone Testing Centre of ECUST, Shanghai, China) and **Elizabeth Su** (Gemsu Rona [Shanghai] Jewellery Co. Ltd, Shanghai, China) used Raman spectroscopy to identify inclusions of graphite and zircon in Myanmar jadeite. **Dr Andy Shen** and co-authors reported that the colour change exhibited by diaspore from Turkey is caused by Fe^{2+}–Ti^{4+} pairs located in adjacent edge-sharing octahedral sites in the crystal structure. **Dr John Saul** (ORYX, Paris, France) related the formation of different types of coloured stone deposits to collisional and extensional processes related to the amalgamation and breakup, respectively, of continents. **Daniel Barchewitz** (B&WTek, Lübeck, Germany) demonstrated how the GemRam portable Raman spectrometer can be used for gem identification. Both desktop and handheld models are available.

On 12–13 October, the Namibian Coloured Gemstone & Jewellery Showcase took place at the Safari Hotel in conjunction with the IGC (Figure 4). Approximately 20 dealers from throughout Namibia offered gem rough, mineral specimens, cut stones and finished jewellery. The event also featured a photo exposition, business matchmaking programme, live auction and jewellery competition.

The next IGC will take place in August 2019 in Nantes, France.

Brendan M. Laurs FGA

50TH IGE ANNIVERSARY AND 20TH FEEG SYMPOSIUM

The 50th Spanish Gemmological Institute (IGE) and 20th Federation for European Education in Gemmology (FEEG) joint conference took place on the weekend of 18–19 November 2017 in the Hall of the Gómez Pardo Foundation in Madrid, Spain. The event was attended by 125 people, and coincided with the second occurrence of ExpoGema, a Spanish gemmological fair and an exhibition of unique gems from some leading Spanish dealers and collectors. A highlight of the weekend was the FEEG Diploma Ceremony, which took place in the auditorium of the Madrid School of Mines.

Benjamin Calvo (IGE president, Madrid), **Dr Loredana Prosperi** (FEEG president, Madrid) and **Dr Egor Gavrilenko** (IGE Gem Testing Laboratory, Madrid) inaugurated the conference and workshops.

Mikko Åström and **Alberto Scarani** (Magilabs, Helsinki, Finland and Rome, Italy) reviewed the application of techniques such as Raman, photoluminescence, UV-Vis-NIR and Fourier-transform infrared spectroscopy in everyday gemmological practice.

Dr Thomas Hainschwang (GGTL-GEMLAB Laboratories, Balzers, Liechtenstein) gave an overview of the current status of diamond synthesis and treatments. He pointed out the many challenges that exist today in the distinction of natural and synthetic diamonds and in identifying the colour origin of natural diamonds.

Fabian Schmitz (German Gemmological Association, Idar-Oberstein) examined the tourmaline group, which is characterized by an extraordinary variety of colour. He discussed the different colour causes in tourmaline and explained the Usambara effect, which is a colour change (green/red) that depends on the path length of transmitted light. The longer the path length, the more red will be observed.

Dr Fernando Gervilla (Departamento de Mineralogía y Petrología e Instituto Andaluz de Ciencias de la Tierra, Universidad de Granada–Consejo Superior de Investigaciones Científicas, Granada, Spain) investigated the nature of Cr-rich inclusions in green nephrite jade, including chromian spinel with variable chemical composition, chlorite, Cr-rich zoisite and/or Cr-rich garnet. The results suggested that it might be possible to create a reference database for source-tracing studies of nephrite using specific mineralogical assemblages of 'black inclusions'.

Dr J. C. (Hanco) Zwaan (Netherlands Gemmological Laboratory, Naturalis Biodiversity Center, Leiden), explored sapphire formation in Sri Lanka. He visited a recently discovered locality for *in situ* sapphire where large corundum crystals were surrounded by plagioclase, K-feldspar and biotite. He concluded that gem-quality sapphire formation in Sri Lanka was essentially a metasomatic process, promoted by a sequence of events which included ultra-high-grade metamorphism priming the rocks, a tectonic contact that created space, and fluid/pegmatitic melt transfer from underthrusted gneisses.

Dr Ilaria Adamo (Italian Gemmological Institute, Milan) reviewed various gem localities in Italy. Val Malenco is the source of nephrite jade, gem-quality serpentine, demantoid, rhodonite and 'clinothulite' (a varietal name for the opaque pink variety of clinozoisite). Elba Island is the type locality for elbaite tourmaline. Other gems include Sardinian peridot, Sicilian simetite amber and red coral or *Corallium rubrum*, which is endemic to the Mediterranean Sea.

Geoffrey Domini (World Gem Foundation, Palma de Mallorca, Spain), explored the various instruments used in the past to identify gem materials and why they are as relevant today as they were 50 years ago.

Dr Egor Gavrilenko shared some experiences with using a coloured stone quality-grading system at the IGE Gem Testing Laboratory, and pointed out some aspects that seem problematic and need more elaboration in the future. Colour-quality grading at the laboratory is based on Gemewizard's system, clarity is evaluated by the unaided eye except for the 'Loupe clean' grade, and cut quality is mostly graded using the unaided eye as well. The most important cut parameters are light return, windowing, face-up symmetry and polish quality.

Dr Peter Lyckberg (European Commission, Brussels, Belgium) highlighted the importance of

Figure 5: Antoinette Matlins leads a workshop titled 'Gem Identification Made Easy'. Photo courtesy of IGE.

Figure 6: The diploma ceremony for new European Gemmologists was held in the auditorium of the Madrid School of Mines. Photo courtesy of IGE.

origin information for both minerals and gems. The exact origin is vital for understanding their genesis. He provided various examples, from very old deposits such as 1.7 billion-year-old Volodarsk pegmatites that yield heliodor and bicoloured topaz, to the youngest 4–23 million-year-old deposits of aquamarine and topaz in the Hindu Kush-Karakoram-Himalaya mountain ranges.

Antoinette Matlins (South Woodstock, Vermont, USA) never attends any gem or jewellery show without a Chelsea filter, a calcite dichroscope, a 10× loupe, a portable UV lamp, a flashlight and an SSEF Diamond Spotter. A trained gemmologist can identify more than 85% of gem materials with those instruments. She explained how to properly use them to avoid costly mistakes and recognize profitable opportunities.

Gail Brett Levine (National Association of Jewelry Appraisers, Rego Park, New York, USA) gave some guidelines for appraising antique-cut diamonds. Table- and point-cut diamonds are not valued individually, so one has to valuate the entire jewellery item as a whole. The same rule applies to rose cuts, although larger stones may command a premium. The past five years have seen an upsurge at auction of Old European-cut diamonds accompanied by recent GIA reports. A chipped girdle on such stones might have been repaired, which results in a modern-looking girdle, or these diamonds might have been repolished to remove abrasions. Pricing guides can be useful for tackling appraising issues.

Johann Leibbrandt (Bonhams, Madrid) presented information about his company. Bonhams was founded in London in 1793 and is today the sole international auction house that is privately owned and in British hands.

Five workshops were offered after the conference. **Mikko Åström** and **Alberto Scarani** offered hands-on experience with various spectroscopic techniques applied to gemmology. They also introduced a new tool in their line of equipment: the EXA spectrometer for identifying natural vs. synthetic diamonds. In advanced mode it is also very useful for coloured stone identification. **Dr Egor Gavrilenko** gave a workshop on basic and advanced techniques for identifying synthetic diamonds, focusing on the use of microscopic observation, anomalous birefringence, magnetism, fluorescence, phosphorescence, short-wave UV transparency and the application of various instruments (SSEF Diamond Spotter, D-Screen, DiamondSure, DiamondView and more). **Antoinette Matlins** explained the clues that portable and inexpensive gemmological tools can provide for gemstone identification (Figure 5), especially on field trips, at gem shows and in small labs. **María Milla** and **Mara Soriano** (IGE) showed the use of Macrorail equipment for the photomicrography of inclusions in gemstones. **José María Alonso Florentino**, **Benedicte Parnaudeau** and **Vicky Redondo** (IGE) offered a practical session in gem cutting and polishing.

FEEG celebrated 50 new graduates (e.g. Figure 6), bringing the total to 1,140 European Gemmologists since its start in 1996. There is a growing need to serve an expanding network of gem enthusiasts and jewellery professionals throughout the European continent, and these graduates are the future of gemmology.

The next FEEG Symposium will be held in Vicenza, Italy, in January 2019.

Dr Egor Gavrilenko and Guy Lalous
Spanish Gemmological Institute
Madrid, Spain

Gem-A Notices

Gifts to the Association

Gem-A is most grateful to the following for their generous donations which will support continued research and teaching:

Terrence Coldham, Intogems Pty Ltd, Normanhurst, New South Wales, Australia, for four imitation star stones (one blue and three red cabochons) and for a 1.13 ct faceted unheated tanzanite.

Anzor Douman, Arzawa Mineralogical lnc., Winchester, Virginia, USA, for seven demantoids from Kerman Province, Iran.

Mauro Pantò, Sassari, Italy, for a faceted yellow brucite from Pakistan and a faceted black plagioclase from Greenland.

Helen Serras-Herman FGA, Gem Art Center, Rio Rico, Arizona, USA, for a 24.38 ct pear-shaped cabochon consisting of chrysocolla, atacamite and malachite, from the Tiger mine, Arizona, USA.

Vanna Tea, Hope Gems LLC, San Jose, California, USA, for a 2.69 ct oval mixed-cut blue zircon from Cambodia.

Diploma Preparation

Gem-A has recently expanded our range of workshops and classes to includes a new Foundation-to-Diploma five-day transfer workshop. This is designed to support the transition from Foundation level to the more intense Diploma course, and includes a full review of all instruments as well as some of the science behind gemstones. This is especially valuable to those students who may have had to step away from their studies for a little while, and who consequently might feel less confident about returning to the classroom. It also may be taken by those who would just like a quick brush up of their practical and theoretical skills. Please contact education@gem-a.com for more information.

New Position at Gem-A: Head of Education

As part of our ongoing commitment to progress, Gem-A is now looking to appoint a new full time Head of Education at its headquarters in London. Located in the heart of London's historic jewellery district, this is an exciting opportunity to be an integral part of a successful and growing global organisation. As the world's longest established provider of gem and jewellery education, our prestigious and internationally recognised Gemmology and Diamond Diplomas are taught in seven different languages and 26 countries around the world. While this role will be primarily based in London, Gem-A forms an international community of gem professionals and enthusiasts, and this new position offers the opportunity for significant international and UK travel. Please visit www.gem-a.com/jobs for more information.

New Professorship in Gemmology at University of Arizona

The RealReal, a leading authenticated luxury consignment company, has recently announced a first-of-its-kind collaboration with the University of Arizona (Tucson, Arizona, USA) to create an endowed chair in gemmology. This now enables the creation of a long-awaited degree program in geosciences with a concentration in gemmology. Offering a full curriculum of undergraduate, master's and PhD programs, as well as scientific research, the University of Arizona and The RealReal also have partnered with Gem-A to offer students the opportunity to obtain Gem-A diploma certifications. The University is currently looking to appoint a professor to this prestigious position, and Gem-A will keep our members updated on how this ground-breaking venture is progressing.

Save the Date: Gem-A Conference 2018

This year's annual Gem-A Conference will take place from 3–4 November 2018, at etc.venues County Hall, Central London. The Gem-A Conference offers an amazing line-up of speakers from all corners of gemmology, exclusive workshops and trips including private viewings of museum collections, and the opportunity to network with some of the leaders in the field. Please visit www.gem-a.com/event/conference for video highlights from the 2017 Conference, and for future announcements on 2018 Conference registration.

Learning Opportunities

CONFERENCES AND SEMINARS

8th Annual International Gold Conference – Gold: Vortex, Virtues, and Values
12–13 April 2018
New York, New York, USA
https://iacgold2018.eventbrite.com

15th Annual Sinkankas Symposium – Tanzanite & Tsavorite
14 April 2018
Carlsbad, California, USA
www.sinkankassymposium.net

2nd International Conference and Expo on Diamond, Graphite & Carbon Materials
16–17 April 2018
Las Vegas, Nevada, USA
http://diamond-carbon.conferenceseries.com/symposium.php

45th Rochester Mineralogical Symposium
19–22 April 2018
Rochester, New York, USA
www.rasny.org/minsymp

American Gem Society Conclave
23–25 April 2018
Nashville, Tennessee, USA
www.americangemsociety.org/page/conclave2018

Scottish Gemmological Association Conference
4–6 May 2018
Cumbernauld, Scotland
www.scottishgemmology.org/conference

4th Mediterranean Gem and Jewellery Conference
18–20 May 2018
Budva, Montenegro
www.gemconference.com
Note: Will include workshops on ruby and sapphire, emerald, and diamond, as well as diamond identification with advanced instruments

32nd Annual Santa Fe Symposium
20–23 May 2018
Albuquerque, New Mexico, USA
www.santafesymposium.org

12th International New Diamond and Nano Carbons Conference
20–24 May 2018
Flagstaff, Arizona, USA
www.mrs.org/ndnc-2018

Society of North American Goldsmiths' 47th Annual Conference
23–26 May 2018
Portland, Oregon, USA
www.snagmetalsmith.org/conferences/made

AGA Las Vegas Conference
1 June 2018
Las Vegas, Nevada, USA
http://accreditedgemologists.org

JCK Las Vegas
1–4 June 2018
Las Vegas, Nevada, USA
http://lasvegas.jckonline.com/en/Events/Education
Note: Includes a seminar programme

17èmes Rendez Vous Gemmologiques de Paris
11 June 2018
Paris, France
www.afgems-paris.com/rdv-gemmologique
Note: Simultaneous English-French translation will be provided.

Diamonds – Source to Use 2018
11–14 June 2018
Johannesburg, South Africa
www.saimm.co.za/saimm-events/upcoming-events/saimm-diamonds-source-to-use-2018

14th Biennial Pan American Conference on Research on Fluid Inclusions (PACROFI XIV)
12–14 June 2018
Houston, Texas, USA
www.pacrofi.com

RFG2018 Resources for Future Generations: CIM-GAC-MAC Joint Meeting
16–21 June 2018
Vancouver, British Columbia, Canada
www.rfg2018.org
Session of interest: New Developments in Canadian Diamond Exploration – Finding the Next Generation of Diamond Deposits

Sainte-Marie-aux-Mines 55th Mineral & Gem Show
21–24 June 2018
Sainte-Marie-aux-Mines, France
www.sainte-marie-mineral.com/english/modules/cultural-activities
Note: Includes a seminar programme

Northwest Jewelry Conference
10–12 August 2018
Seattle, Washington, USA
www.northwestjewelryconference.com

22nd Meeting of the International Mineralogical Association
13–17 August 2018
Melbourne, Victoria, Australia
www.ima2018.com
Sessions of interest:
- Mantle Xenoliths, Kimberlites and Related Magmas: The Diamond Trilogy
- Pegmatite Mineralogy, Geochemistry, Classification and Origins
- Recent Advances in our Understanding of Gem Minerals
- Sciences Behind Gemstone Treatments

Dallas Mineral Collecting Symposium
24–26 August 2018
Dallas, Texas, USA
www.dallassymposium.org

IJL London
2–4 September 2018
London
www.jewellerylondon.com/Whats-On/Seminars
Note: Includes a seminar programme

29th International Conference on Diamond and Carbon Materials
2–6 September 2018
Dubrovnik, Croatia
www.elsevier.com/events/conferences/international-conference-on-diamond-and-carbon-materials

Hong Kong Jewellery & Gem Fair
12–18 September 2018
Hong Kong
http://exhibitions.jewellerynetasia.com/9jg/en-us/specialevents
Note: Includes a seminar programme

2018 GIA Symposium: New Challenges. Creating Opportunities
7–9 October 2018
Carlsbad, California, USA
http://discover.gia.edu/symposium

Munich Mineral Show
26–28 October 2018
Munich, Germany
https://munichshow.com/en
Note: Includes a seminar programme

Swiss Geoscience Meeting
30 November–1 December 2018
Bern, Switzerland
https://geoscience-meeting.ch
Note: Includes a gemmology session

EXHIBITIONS

Asia and Middle East

Art & Jewelry
Until 2 June 2018
Custot Gallery, Dubai, United Arab Emirates
www.custotgallerydubai.ae/copie-de-black-white

Australia and New Zealand

Cartier: The Exhibition
Until 22 July 2018
National Gallery of Australia, Canberra, Australia
https://nga.gov.au/cartier

Europe

Gold! Collected by Sophia Lopez Suasso
Until 2 April 2018
Cromhout Huis, Herengracht, Amsterdam, The Netherlands
www.cromhouthuis.nl/en/activities/gold-collected-sophia-lopez-suasso

Splendours of the Subcontinent: A Prince's Tour of India, 1875–6
Until 22 April 2018
The Queen's Gallery, Palace Holyroodhouse, Edinburgh, Scotland
www.royalcollection.org.uk/whatson/event/831418/Splendours-of-the-Subcontinent

Modernist Jewellery
Until 29 April 2018
National Museum of Scotland, Edinburgh
www.nms.ac.uk/national-museum-of-scotland/whats-on/modernist-jewellery

Fibulae
Until 3 June 2018
Rijksmuseum, Amsterdam, The Netherlands
www.rmo.nl/english/exhibitions/fibulae

Jewellery: Made By, Worn By
Until 3 June 2018
Museum Volkenkunde, Amsterdam, The Netherlands
https://volkenkunde.nl/en/exhibition-jewellery-madeby-wornby

Eva's Beauty Case & Adam's Necessaire. Schmuck und Styling im Spiegel der Zeiten
Until 12 August 2018
Braunschweigisches Landesmuseum, Braunschweig, Germany
www.3landesmuseen.de/Eva-s-Beauty-Case-Adam-s-Necessaire.1649.0.html

East Meets West – Exquisite Treasures from the Aga Khan Collection
5 May 2018–6 January 2019
Schmuckmuseum Pforzheim, Germany
www.schmuckmuseum.de/flash/SMP_en.html

The Splendour of Power
6 May–30 September 2018
Museet på Koldinghus, Kolding, Denmark
www.koldinghus.dk/uk/exhibitions-2017/the-splendour-of-power-2018.aspx

North America

Beads: A Universe of Meaning
Until 15 April 2018
The Wheelwright Museum of the American Indian, Santa Fe, New Mexico, USA
https://wheelwright.org/exhibitions/beads

Louis Comfort Tiffany: Treasures from the Driehaus Collection
Until 27 May 2018
Taft Museum, Cincinatti, Ohio, USA
www.taftmuseum.org/cur_exhib

Golden Kingdoms: Luxury and Legacy in the Ancient Americas
Until 28 May 2018
The Met Fifth Avenue, New York, New York, USA
www.metmuseum.org/exhibitions/listings/2018/golden-kingdoms

Jewelry of Ideas: Gifts from the Susan Grant Lewin Collection
Until 28 May 2018
Cooper Hewitt, Smithsonian Design Museum, New York, New York, USA
www.cooperhewitt.org/channel/jewelry-of-ideas

Fabergé and the Russian Crafts Tradition: An Empire's Legacy
Until 24 June 2018
The Walters Art Museum, Baltimore, Maryland, USA
https://thewalters.org/events/event.aspx?e=4769

'Modern Gem & Jewelry Collection' Presented by Somewhere in the Rainbow
Until July 2018
Flandrau Science Center & Planetarium, University of Arizona, Tucson, Arizona, USA
https://flandrau.org/exhibits/somewhere-rainbow

Peacock in the Desert: The Royal Arts of Jodhpur, India
Until 19 August 2018
The Museum of Fine Arts, Houston, Texas, USA
www.mfah.org/exhibitions/peacock-in-desert-royal-arts-jodhpur-india

Crowns of the Vajra Masters: Ritual Art of Nepal
Until 16 December 2018
The Met Fifth Avenue, New York, New York, USA
www.metmuseum.org/exhibitions/listings/2017/crowns-of-vajra-masters

Past is Present: Revival Jewelry
Until 19 August 2018
Museum of Fine Arts, Boston,
Massachusetts, USA
www.mfa.org/news/past-is-present-revival-jewelry

American Jewelry from New Mexico
2 June–14 October 2018
Albuquerque Museum, New Mexico, USA
www.cabq.gov/culturalservices/albuquerque-museum/exhibitions/american-jewelry

Fabergé Rediscovered
9 June 2018–13 January 2019
Hillwood Estate, Museum & Gardens,
Washington DC, USA
www.hillwoodmuseum.org/exhibitions/faberg%C3%A9-rediscovered

OTHER EDUCATIONAL OPPORTUNITIES

Gem-A Workshops and Courses
Gem-A, London
www.gem-a.com/education/courses/workshops

American Society of Appraisers Courses

- Jewelry Forensics for Appraisers
  7–8 May 2018
  Gemological Institute of America,
  Carlsbad, California, USA
  www.appraisers.org/Education/View-Course?CourseID=623

- Appraising Gems and Jewelry for Insurance Coverage
  9–11 May 2018
  Gemological Institute of America, Carlsbad,
  California, USA
  www.appraisers.org/Education/View-Course?CourseID=448

Jewelry and Decorative Arts Tour of Israel
21–30 April 2018
The Jewelry Center, New York,
New York, USA
www.92y.org/class/arts-tour-of-israel

Introduction to Gemstones
6 June, 15 August, 4 October or 13 December 2018
London Jewellery School, London
www.londonjewelleryschool.co.uk/taster-classes/introduction-to-gemstones

Lectures with Gem-A's Midlands Branch
Fellows Auctioneers, Birmingham
Email louiseludlam@hotmail.com

- 27 April 2018
  James Gosling—Cravat Pins & Tie Pins: The Chronological and Gemmological Development of these Beautiful and Almost Forgotten Items of Jewellery

Lectures with The Society of Jewellery Historians
Society of Antiquaries of London,
Burlington House, London
www.societyofjewelleryhistorians.ac.uk/current_lectures

- 24 April 2018
  Dr Zara Power Florio—All that Glitters: Jewellers and Gems in Georgian Ireland
- 26 June 2018
  Tara Kelly—Purchasing the Past: Consumers of Irish Facsimile Jewellery, 1840–1940
- 25 September 2018
  Christopher Thompson Royds—My Work as a Jeweller
- 23 October 2018
  Anna Tabakhova—Clasps: 4000 years of Fasteners in Jewellery
- 27 November 2018
  Helen Ritchie—Designers and Jewellery: Jewellery and Metalwork from the Fitzwilliam Museum, 1850–1950

Compiled by Sarah Salmon and Brendan Laurs

New Media

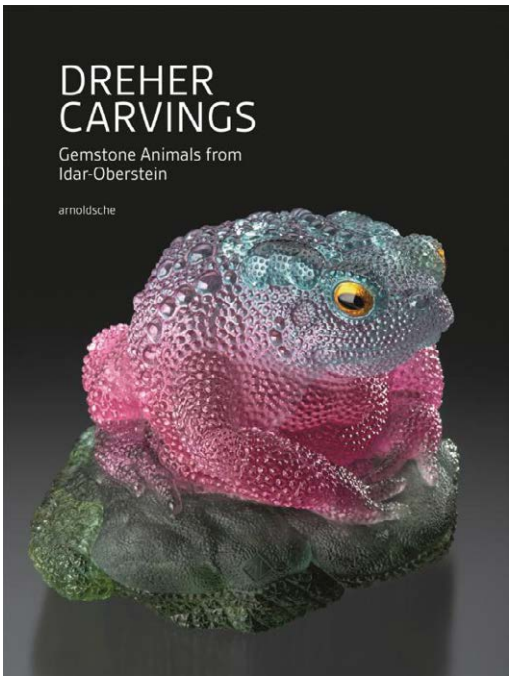

Dreher Carvings: Gemstone Animals from Idar-Oberstein

Ed. by Johanna Eberl, 2017. Arnoldsche Art Publishers, Stuttgart, Germany, www.arnoldsche.com/en/New-Books/dreher-carvings.html, 240 pages, illus., ISBN 978-3897905078. €48.00 hardcover.

This volume starts with the compilation of a number of relatively short passages by various authors, each of which gives a summary of a topic related to the gem carvings created by the Dreher family in Idar-Oberstein, Germany. Following a Foreword by Dieter Hahn and Jörg Lindemann of the German Gemstone Museum, Oleg Gerdt prepared the first contribution, 'Idar-Oberstein, a Gemstone of Europe'. He outlines the historical development of Idar-Oberstein and its gem industry, which was based on 400-million-year-old deposits of agate, jasper and amethyst. These were known to the ancient Romans, but first references to large-scale production date from the 14th century. The first water-driven lapidary mill was recorded in 1454, and the secrets of the gem cutters were closely guarded by their guild. The activities only declined with the depletion of the agate deposits and the arrival of Napoleon. Fortunately, the discovery of Brazilian agates and the development of their coloration techniques led to a revival, and Idar-Oberstein became the leading cutting and carving centre technologically and an important furnisher for luxury firms such as Fabergé.

In this line of tradition, Wilhelm Lindemann then describes 'Gerd and Patrick Dreher – The Art of Stonecutting Today'. While mainly cameos, seals, etc. have been engraved since antiquity, stone sculptures have been created since the Renaissance and Mannerist eras, mostly in France (Paris) and Idar-Oberstein. Stone carving no longer just meant copying templates but expressing oneself as an artist. Parallel to the development of Idar-Oberstein as a jewellery furnishing centre, carving artists appeared in the 19th century, but only after Fabergé's times were they recognized as such. The Dreher family is a good example of this development. Today, Gerd and Patrick are the first members of the family who sign their creations.

Will Larson and Gerd Dreher co-wrote the section titled 'Five Generations of Gemstone Carving: The Dreher Family'. They provide a portrait of the family history from simple stonecutters and carvers to outstanding artists, including their relation with Fabergé, their specialization in animal carvings and their international activities, such as various expositions.

In 'The Dreher Family Cultural Code', Mikhail Ovchinnikov focuses on the development and mutual influence of the Idar-Oberstein carvers and the Russian tradition of gem carving, especially in St Petersburg, as well as other influences visible in the Drehers' creations (e.g. Japanese netsuke).

Ekkehard Schneider then describes 'The Process of Carving a Gemstone'. This process has depended on the development of carving techniques and tools, always of great importance for the quality of the carvings. Thus, finer tools made much more precise carvings possible. Especially since the 1970s, fine diamond tools allowed great steps forward.

Robert Weldon contributed 'Photographers Delight: Capturing a "Living" Dreher Carving'. Taking photos means representing three-dimensional objects with a two-dimensional medium. This makes it difficult to capture the manifold forms, surfaces, movements, colours and expressions with the appropriate choice of background, lighting, perspective and detail.

The text part of the volume ends with a two-page spread titled 'Step by Step: A Gemstone Animal Comes to Life'. Several photos illustrate the five-step process of carving an obsidian hippopotamus, from

rough fashioning of the overall form with a diamond saw to finer and finer elaboration of details to the final polishing of the surface.

Elsewhere in the volume, various 'Homages' by Raquel Alonso-Perez, Anton Ananiev, Maxim Artsinovich, Galina Gabriel, Alan Hart, Johannes Keilmann, Bill Larson, Carl Larson, Will Larson, Robert Myers, and Rüdiger Pohl relate stories of their personal acquaintance and friendship with the Drehers. Finally, a list of selected exhibitions and television documentaries rounds off the book.

The remaining three quarters of the volume are dedicated to 'Wildlife in Gemstones', which is a fantastic gallery of some 200 colour photos showing the range of animal carvings created by Gerd and Patrick Dreher. They contain a complete zoo: snails and toads, starfish and sea horses, fish and otters, mice and mallards, cockatoos and bears, hippopotamuses and warthogs, horses, gorillas and chimpanzees. While some of them, such as the mallard, are composed of various stone species (like the Fabergé carvings), most are carved out of a single block of rough. For the latter pieces, the artist uses the potentialities of the stone in a precise manner so that the colours and structures of the rough form specific parts of the animal, as well as the base it is sitting on. What cannot be described adequately, but can be shown by the photos, is the way in which the typical movement and posture of the animals is captured in the carvings. A perfect example of this is the carving of two playing otters on p. 122.

Although quite a number of Dreher carvings are made from valuable gem materials—such as ruby in zoisite, various beryls and tourmaline—most of their works are executed in less expensive stones such as obsidian, jasper, agate, rock crystal and other quartzes. This gives the viewer a greater appreciation of how incredibly artfully the character of the animals is captured. A good example of this is a mouse on a mushroom that is carved in smoky quartz (pp. 84–85). But don't come too close! Maybe it will run away...

When I was asked about reviewing *Dreher Carvings*, I didn't know very much about them. Carved gems had never been the focus of my interest as a collector, but this has changed dramatically. Now I am an absolute fan, and as the book is so much more affordable than the actual carvings, I certainly recommend buying it.

Dr Rolf Tatje
Duisburg, Germany

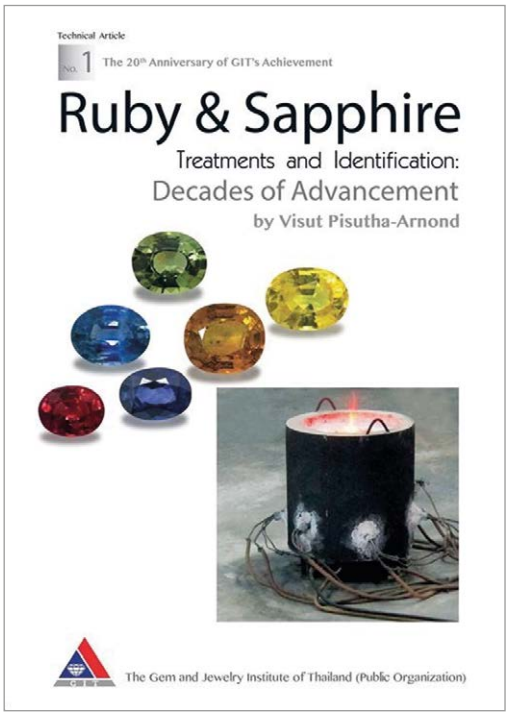

Ruby & Sapphire – Treatments and Identification: Decades of Advancement

Visut Pisutha-Arnond, 2017. Technical Article No. 1, Gem and Jewelry Institute of Thailand, Bangkok, www.git.or.th/bookstore/product_detail.aspx?lang=en&pid=80&ptype=book, 95 pp., illus., ISBN 978-6169145097. US$15.00 softcover.

Heat treatment of corundum is probably the most important and controversial treatment performed on coloured stones, and constant developments are reported. Because of this importance, a multitude of articles and books have been dedicated to this subject during the past few decades.

This booklet by Dr Pisutha-Arnond consists of 90 pages of text, plus an extensive reference list, and is the first in a series of special Technical Articles that the Gem and Jewelry Institute of Thailand plans to publish for their 20th anniversary. It describes classical heat treatment, high-temperature heating with and without flux, low-temperature heat treatment, heating with the addition of elements such as Ti, Cr, Be and Pb (with or without colorants), as well as a relatively new treatment that involves high-pressure and temperature conditions in the presence of water. It also briefly mentions other treatments used to enhance corundum.

The author gives a thorough overview of the

mechanisms taking place within corundum during the various types of heat treatment (using triangular diagrams to help explain the formation of certain colours), describes the heating processes themselves and shows images of microscopic features useful for detecting these treatments. This section also explains spectroscopic features and chemical properties associated with the various treatments, such as changes in FTIR and UV-Vis spectra, and the addition of chemical elements not intrinsic to corundum.

It is obvious from the text that the writer is not a native English speaker, which sometimes makes it difficult to read through the material. In addition, the illustrated UV-Vis spectra have varying wavelength ranges—with the narrowest range spanning 350–750 nm and the widest range covering 300–1500 nm, as well as other ranges in between—which makes it difficult to compare the spectra at first glance.

Overall, however, the booklet provides a good compilation of information on corundum treatments, including the newest developments, with relevant illustrations and graphs. I recommend it for the interested student as well as for practicing gemmologists. Hopefully some improvements could be made to the English and the graphs in a second edition.

Dr Lore Kiefert FGA
Gübelin Gem Lab, Lucerne, Switzerland

Other Book Titles

COLOURED STONES

Collector's Guide to Silicates: Di- and Ring Silicates
By Robert J. Lauf, 2017. Schiffer Publishing, Atglen, Pennsylvania, USA, 272 pages, ISBN 978-0764354366. US$45.00 hardcover.

DIAMOND

Carbon: The Black, the Gray and the Transparent
By Tapan Gupta, 2018. Springer, Cham, Switzerland, 319 pages, ISBN 978-3319664040. US$129.00 hardcover or $99.00 eBook.

GEM LOCALITIES

Lake Superior Agates
By James Magnuson, 2018. Adventure Publications, Cambridge, Minnesota, USA, 22 pages, ISBN 978-1591938088. US$9.95 spiral-bound.

GENERAL REFERENCE

Fleischer's Glossary of Mineral Species, 12th edn.
By Malcolm Back, 2018. Mineralogical Record Inc., Tucson, Arizona, USA, 424 pages. US$38.00 softcover.

Rock Explorer: Gems
By Claudia Martin, 2018. QED Publishing, London, 24 pages, ISBN 978-1784939632. £6.99 softcover.

JEWELLERY HISTORY

American Baroque: Pearls and the Nature of Empire, 1492–1700
By Molly A. Warsh, 2018. Omohundro Institute of Early American History and Culture and the University of North Carolina Press, Chapel Hill, North Carolina, USA, 304 pages, ISBN 978-1469638973. US$39.95 hardcover.

Bejewelled: Men and Jewellery in Tudor and Jacobean England
By Natasha Awais-Dean, 2017. The British Museum, London, 165 pages, ISBN 978-0861592098. £40.00 softcover.

Engraved Gems: From Antiquity to the Present
Ed. by Ben J. L. van den Bercken and Vivian C. P. Baan, 2017. *Papers on Archaeology of the Leiden Museum of Antiquities (PALMA)* 14, Sidestone Press, Leiden, The Netherlands, 184 pages, ISBN 978-9088905063. €120.00 hardcover, €39.95 softcover or €9.95 eBook.

Natter's Museum Britannicum: British Gem Collections and Collectors of the Mid-Eighteenth Century
By John Boardman, Julia Kagan and Claudia Wagner, 2018. Archaeopress Archaeology, Oxford, 316 pages, ISBN 978-1784917272. £55.00 hardcover.

Treasures of the Mughals and the Maharajas: The Al Thani Collection
By Amin Jaffir and Gian Carlo Claza, 2018. Skira Editore, Milan, Italy, 304 pages, ISBN 978-8857235943. €60.00 hardcover.

JEWELLERY AND *OBJETS D'ART*

1990s Jewellery: The Hans Schullin Collection
By Sophie Beer and Hans Schullin, 2018. Arnoldsche Art Publishers, Stuttgart, Germany, 128 pages, ISBN 978-3897904842. €28.00 hardcover.

Art as Jewellery: From Calder to Kapoor
By Louisa Guinness, 2018. ACC Art Books, Suffolk, 336 pages, ISBN 978-1851498703. £45.00 hardcover.

Bulgari: Treasures of Rome
By Vincent Meylan, 2018. ACC Art Books, Suffolk, 296 pages, ISBN 978-1851498796. £55.00 hardcover.

Chaumet: Arts, Photography, Fêtes
By Antoine de Baecque, Gabriel Bauret and Jerome Neutres, 2017. Assouline Publishing, New York, New York, USA, 80 pages, ISBN 978-1614286233. US$75.00 hardcover box set.

Ebbe Weis-Weingart: 70 Years of Jewellery
By Christianne Weber-Stöber, Sabine Runde, Peter Schmitt and Christoph Engel, 2018. Arnoldsche Art Publishers, Stuttgart, Germany, 208 pages, ISBN 978-3897905092. €44.00 hardcover.

Fabergé and the Russian Crafts Tradition: An Empire's Legacy
By Margaret Trombly, 2017. Thames & Hudson, London, 224 pages, ISBN 978-0500480229. £18.49 hardcover.

Gianfranco Ferré – Under Another Light: Jewels and Ornaments
By Francesca Alfano Miglietti, 2018. Skira Editore, Milan, Italy, 276 pages, ISBN 978-8857236698. €45.00 softcover.

Gianmaria Buccellati Foundation: A Century of Goldsmith's Art
By Gianmaria Buccellati, 2018. Skira Editore, Milan, Italy, 320 pages, ISBN 978-8857234366. €76.93 hardcover.

Gemologue: Street Jewellery Styles & Styling Tips
By Liza Urla, 2018. ACC Art Books, Suffolk, 354 pages, ISBN 978-1851498819. £25.00 softcover.

Jewellery Matters
By Marjan Unger, 2018. NAI Publishers, Rotterdam, The Netherlands, 520 pages, ISBN 978-9462083752. €39.95 hardcover.

Jewelry of Ideas: The Susan Grant Lewin Collection
By Ursula Ilse-Neuman, 2018. Arnoldsche Art Publishers, Stuttgart, Germany, 176 pages, ISBN 978-3897905122. €28.00 hardcover.

Peacock in the Desert: The Royal Arts of Jodhpur, India
By Karni Jasol, 2018. Museum of Fine Arts, Houston, Texas, USA, 288 pages, ISBN 978-0300232967. US$85.00 hardcover.

Stuart Devlin: Designer Goldsmith Silversmith
By Carole Devlin and Victoria Kate Simkin, 2018. ACC Art Books, Suffolk, 528 pages, ISBN 978-1851498727. £75.00 hardcover.

Traditional Indian Jewellery: The Golden Smile of India
By Bernadette van Gelder, 2017. ACC Art Books, Suffolk, 608 pages, ISBN 978-1851498536. £125.00 hardcover.

MISCELLANEOUS

The Denver Gem & Mineral Show: A Retrospective
By Mark Ivan Jacobson, 2017. Greater Denver Area Gem and Mineral Council Inc., Denver, Colorado, USA, 144 pages, ISBN 978-0692939918. US$14.00 softcover.

Compiled by Sarah Salmon and Brendan Laurs

Literature of Interest

COLOURED STONES

Accurate reporting of key trace elements in ruby and sapphire using matrix-matched standards. J. Stone-Sundberg, T. Thomas, Z. Sun, Y. Guan, Z. Cole, R. Equall and J.L. Emmett, *Gems & Gemology*, **53**(4), 2017, 438–451, http://dx.doi.org/10.5741/gems.53.4.438.*

The absorption- and luminescence spectra of Mn^{3+} in beryl and vesuvianite. M. Czaja, R. Lisiecki, A. Chrobak, R. Sitko and Z. Mazurak, *Physics and Chemistry of Minerals*, 2017, 14 pp., http://dx.doi.org/10.1007/s00269-017-0934-x.*

Colored gemstones. It's now time to sell cut. J. Dyer, *Rivista Italiana di Gemmologia/Italian Gemological Review*, No. 3, 2018, 49–56.

Gemmological characteristic comparison of aquamarines from four different origins. T. Wu and Z. Yin, *Journal of Gems & Gemmology*, **19**(3), 2017, 35–44 (in Chinese with English abstract).

Gemmological characteristic and identification of gem-quality benitoite. S. Xu and X. Shi, *Journal of Gems & Gemmology*, **19**(2), 2017, 49–56 (in Chinese with English abstract).

Inclusions in natural, synthetic, and treated ruby. N.D. Renfro, J.I. Koivula, J. Muyal, S.F. McClure, K. Schumacher and J.E. Shigley, *Gems & Gemology*, **53**(4), 2017, 457–458, http://dx.doi.org/10.5741/gems.53.4.457.*

LA-ICP-MS U–Pb dating of rutile inclusions within corundum (ruby and sapphire): New constraints on the formation of corundum deposits along the Mozambique Belt. E.S. Sorokina, D. Rösel, T. Häger, R. Mertz-Kraus and J.M. Saul, *Mineralium Deposita*, **52**(5), 2017, 641–649, http://dx.doi.org/10.1007/s00126-017-0732-x.

Silica colloid ordering in a dynamic sedimentary environment [Australian opal]. M. Liesegang and R. Milke, *Minerals*, **8**(1), 2018, 12 pp., http://dx.doi.org/10.3390/min8010012.*

Study on the spectral characteristics and the alexandrite effect of diaspore. D. Zhou, T. Lu, J. Ke, H. Chen, G. Shi and K. Li, *Spectroscopy and Spectral Analysis*, **37**(11), 2017, 3504–3509 (in Chinese with English abstract).

CULTURAL HERITAGE

Amber, beads and social interaction in the late prehistory of the Iberian Peninsula: An update. C.P. Odriozola, A.C. Sousa, R. Mataloto, R. Boaventura, M. Andrade, R. Villalobos García, J.Á. Garrido-Cordero, E. Rodríguez, J.M. Martínez-Blanes, M.Á. Avilés, J. Daura, M. Sanz and J.A. Riquelme, *Archaeological and Anthropological Sciences*, 2017, 29 pp., http://dx.doi.org/10.1007/s12520-017-0549-7.

Daryā-ye Nur: History and myth of a crown jewel of Iran. A. Malecka, *Iranian Studies*, **51**(1), 2017, 69–96, http://dx.doi.org/10.1080/00210862.2017.1362952.

Gemmes et sculptures anciennes du Proche-Orient (Ancient gems and sculptures from the Middle East). H.-J. Schubnel, *Revue de Gemmologie A.F.G.*, No. 201, 2018, 17–24 (in French).

Mechanical engineering in ancient Egypt, part 58: Semiprecious stones applications. G.A. Hassaan, *International Journal of Emerging Engineering Research and Technology*, **5**(9), 2017, 20–31, www.ijeert.org/papers/v5-i9/3.pdf.*

Preserving the heritage of gemstone regions and resources worldwide: Future directions. L. Cartier, *InColor*, No. 37, 2018, 74–78, www.incolormagazine.com/incolor/37/74.*

Restitution de «vingt des plus beaux diamants» de Tavernier vendus à Louis XIV. Partie 2 : Les nouvelles découvertes (Restitution of "twenty of the most beautiful diamonds" Tavernier sold to Louis XIV. Part 2: The new discoveries). F. Farges, P. Dubuc and M. Vallanetdelhom, *Revue de Gemmologie A.F.G.*, No. 201, 2018, 26–31 (in French).

DIAMONDS

Crystal morphological evolution of growth and dissolution of curve-faced cubic diamonds from placers of the Anabar diamondiferous region. A.D. Pavlushin, D.A. Zedgenizov and K.L. Pirogovskaya, *Geochemistry International*, **55**(12), 2017, 1193–1203, http://dx.doi.org/10.1134/s0016702917090051.

Diamond miners respond. S. Walker, *Engineering and Mining Journal*, **218**(9), 2017, 58–66, http://emj.epubxp.com/i/872627-sep-2017.*

Diamond with unusual Diamond View [*sic*] fluorescence pattern. M. Chauhan, *Rivista Italiana di Gemmologia/Italian Gemological Review*, No. 3, 2018, 30–31.

Discussion on diamond color grading system. Y. Cheng, H. Liu, C. Fan, C. Zhang, Y. Wang and Q. Jia, *Journal of Synthetic Crystals*, **46**(1), 2017, 174–177 (in Chinese with English abstract).

Evidence for large scale fractionation of carbon isotopes and of nitrogen impurity during crystallization of gem quality cubic diamonds from placers of north Yakutia. V.N. Reutsky, A.A. Shiryaev, S.V. Titkov, M. Wiedenbeck and N.N. Zudina, *Geochemistry International*, **55**(11), 2017, 988–999, http://dx.doi.org/10.1134/s001670291711009x.

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Mineral inclusions in diamonds may be synchronous but not syngenetic. F. Nestola, H. Jung and L.A. Taylor, *Nature Communications*, **8**, article 14168, 2017, 6 pp., http://dx.doi.org/10.1038/ncomms14168.*

Nanosculptures on round surfaces of natural diamonds. A.A. Chepurov, S.S. Kosolobov, D.V. Shcheglov, V.M. Sonin, A.I. Chepurov and A.V. Latyshev, *Geology of Ore Deposits*, **59**(3), 2017, 256–264, http://dx.doi.org/10.1134/s1075701517030023.

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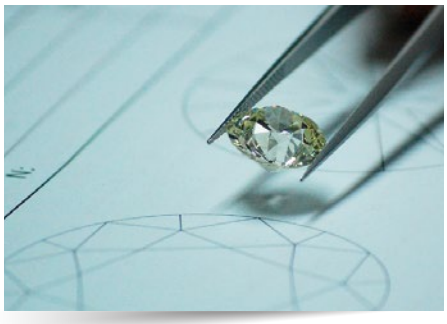

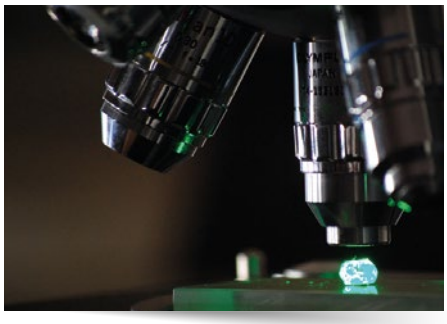

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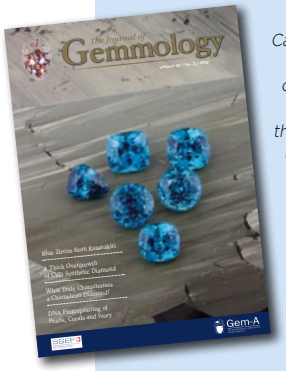

Cover photo: *Zircon from Cambodia (here, 8.92–15.17 ct) is prized for its bright blue colour after undergoing heat treatment. The properties of this zircon are described in an article by Manuela Zeug and co-authors on pp. 112–132 of this issue. Photo by Prasit Prachagool, Thai Lanka Trading Ltd Part., Bangkok, Thailand.*

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What's New

INSTRUMENTATION

GemTrue Veritas

Released in early 2018, the GemTrue Veritas is the latest diamond tester from DiKai Industrial (Shenzhen, China), a compact unit designed to distinguish natural diamond from CVD/HPHT synthetics and synthetic moissanite. The tester operates on four AAA batteries or USB, calibrates automatically upon start-up, and indicates results via an LED display. Limited information is available at www.dikaitools.com/en/Diamond_Testers_Moissanite_Testers/20170909/636.html. *CMS*

Synthetic Diamond Identification Kit

In January 2018, the Mediterranean Gemmological and Jewellery Conference store began offering its Synthetic Diamond Identification Kit, a zippered, fitted pouch with three instruments and two booklets assembled to provide everything the gemmologist-on-the-go needs to separate synthetic, treated and natural diamonds. The kit contains a Gemetrix PL-Inspector UV lamp (see *The Journal*, Vol. 35, No. 5, 2017, p. 373), a miniature folding polariscope and a portable light. Accompanying these is a handbook titled *Fluorescence as a Tool for Diamond Origin Identification—a Guide* (see *The Journal*, Vol. 35, No. 5, 2017, p. 374), along with tweezers, a loupe and a stone-cleaning cloth. Visit www.gemconference.com/store/instruments/synthetic-diamond-identification-kit. *CMS*

NEWS AND PUBLICATIONS

11th International Kimberlite Conference Abstracts and Field Trip Guidebooks

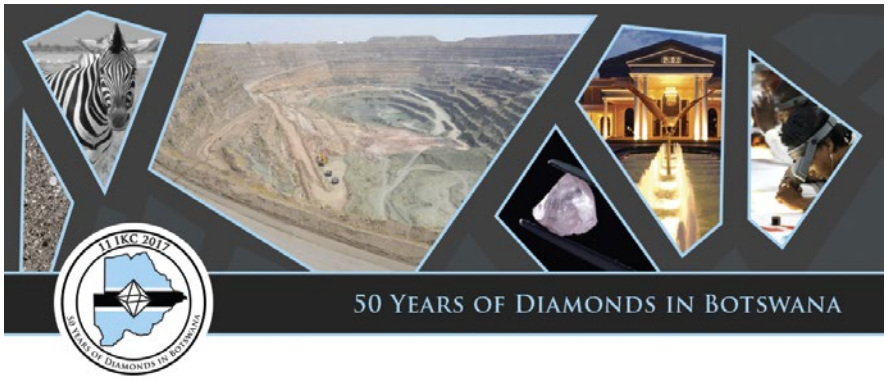

Extended abstracts of oral and poster presentations from the 11th International Kimberlite Conference (held 18–22 September 2017 in Gaborone, Botswana) are available for individual download at http://11ikc.com/long_abstract/oral.htm and http://11ikc.com/long_abstract/poster.htm. In addition, field trip guidebooks for two of the excursions (Trip 2—Kimberley region, South Africa and Trip 4—Lesotho) can be downloaded at http://11ikc.com/showcontent.aspx?MenuID=1998. *CMS*

ASEAN Gem & Jewelry Review

Issue 1, 2018, of this English-language gem and jewellery trade publication for the Association of Southeast Asian Nations (ASEAN) focuses on trade developments in Thailand, Malaysia and Myanmar, as well as export statistics and trade news for the ASEAN area. A centrefold map highlights the major gem and jewellery production sources for member countries in Southeast Asia. Download the issue at www.git.or.th/thai/info_center/trade_review/2018/ASEAN_Gem_Review_issue1.pdf. *CMS*

De Beers Diamond Insight Report 2017

This De Beers Group report profiles the diamond industry value chain (downstream, midstream and upstream segments, as well as focusing on China) and then examines three key trends pertaining to the female consumer (increased participation of women in the economy, changing family and personal relationships, and femininity redefined). Global consumer demand for diamond jewellery in 2017 was mainly driven by the USA market and climbed to a total of US$82 billion, an all-time high and a 2% increase on the previous year. The document concludes with an outlook for 2018. View or download the report at www.debeersgroup.com/en/reports/insight/insight-reports/insight-report-2017/overview.html. *BML*

GIT Lab Update: Rare Poudretteite

In April 2018, The Gem and Jewelry Institute of Thailand (GIT) in Bangkok released a report titled 'Rare Pink Poudretteite'. It describes a 1.38 ct faceted pink stone that was submitted to GIT's laboratory for identification. The sample's RI and SG distinguished it from similar-appearing gems such as tourmaline, kunzite and morganite, and its Raman spectrum matched poudretteite. The pink colour is rare for facet-quality material; poudretteite is usually colourless. Download this and previous GIT lab updates at www.git.or.th/articles_technic_en.html. *CMS*

Inhorgenta 2018 Presentations

Videos of seminar presentations and/or speaker interviews from the February 2018 Inhorgenta Munich show can now be accessed at http://inhorgenta.com/events-news/inhorgenta-forum/program/index.html, and a list of the presentations is available at http://jlm-guides.de/INHORGENTA_MUNICH/en/seminar-programme. The topics include pearls, coloured stones, diamond, watches, online sales and future trends. *BML*

INHORGENTA MUNICH seminar program

PDAC 2018 THE WORLD'S PREMIER MINERAL EXPLORATION & MINING CONVENTION

PDAC 2018 Diamond Abstracts

The Prospectors & Developers Association of Canada convention held March 2018 featured a special session titled 'The 25th Anniversary of Canadian Diamond Mining: The Next Generation'. The session featured six presentations that covered various Canadian diamond deposits, including Renard in Quebec, Chidliak in Nunavut, Star and Orion South in Saskatchewan, and three mines in the Northwest Territories: Gahcho Kué, Ekati, and Diavik. Abstracts of all but the Diavik presentation are available at http://tinyurl.com/ycx8xqto.

CMS

OTHER RESOURCES

Diamond Terminology Guideline

Nine diamond industry organisations (AWDC, CIBJO, DPA, GJEPC, IDI, IDMA, USJC, WDC and WFDB) have worked together to develop the Diamond Terminology Guideline, which was released in January 2018. The Guideline is intended to be a reference document for the diamond and jewellery trade to encourage the use of clear, fair, and effective terminology pertaining to natural and synthetic diamonds and diamond simulants. The Guideline is based on the ISO 18323 standard *Jewellery – Consumer Confidence in the Diamond Industry* and the *CIBJO Diamond Blue Book*. It is available on the Diamond Producers Association website at www.diamondproducers.com/diamond-industry/diamond_terminology. *CMS*

Gemworld Pricing Calculator

Recently, Gemworld International released a new diamond and gem pricing calculator called GemGuide Pricing, which is freely available for desktop computers and also can be downloaded as an app for iOS and Android mobile devices. To access pricing information, users must have a current subscription to *GemGuide*.

The calculator works for both diamonds and coloured stones. For diamonds, enter any set of parameters and the weight, and the calculator returns a wholesale price or a retail price using your mark-up. Parameters that will automatically adjust the price include cut grade and fluorescence. For coloured stones, the user can input a colour from any grading system including Gemworld's own World of Color. When using World of Color, and entering the clarity and cut features, the calculator will automatically price the gem, again at wholesale or retail. The calculator interactively determines gem pricing, and when using colour grading systems other World of Color, the user can override the grade and the software will then calculate a price. By selecting other attributes of clarity and cut, the grade will automatically adjust by taking appropriate deductions. When finished, an estimated price is provided, both per carat and per stone. More than 70 coloured stone varieties are priced. In addition, the calculator will convert to any of 33 international currencies.

To access GemGuide Pricing, visit https://app.gemguide.com. To download the app, search the app stores for 'GemGuide Pricing'. For more information, visit www.gemguide.com/the-gemguide/pricing-app-tutorial.

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What's New provides announcements of new instruments/technology, publications, online resources and more. Inclusion in What's New does not imply recommendation or endorsement by Gem-A. Entries were prepared by Carol M. Stockton (CMS) or Brendan M. Laurs (BML), unless otherwise noted.

Gem Notes

COLOURED STONES

Figure 1: Some of the aragonites from the Czech Republic displayed during the 2018 Tucson gem shows include these stones (12.61–15.94 ct) that were faceted by Luigi Mariani. Photo by Mauro Pantò.

Aragonite from the Czech Republic

The gem and mineral shows that take place every February in Tucson, Arizona, USA, are an excellent place to see rare and collectable gemstones. Among the many items on display at the 2018 shows was an attractive array of faceted aragonite from the Czech Republic (e.g. Figure 1). The stones were shown by Mauro Pantò (The Beauty in the Rocks, Sassari, Italy), who had 12 gems weighing up to 21.83 ct that were cut from two pieces of rough material he had purchased in Tucson in 2016. They ranged from near-colourless to pale yellow or brownish yellow, and showed colourful dispersion.

Figure 2: Weighing an impressive 74.31 ct, this pale yellowish brown aragonite is an example of the larger stones obtained from Cicov Hill in the Czech Republic. Photo by J. Hyršl.

Faceted aragonite is rather rare in the gem trade, and cut stones usually weigh up to several carats. The most significant production of gem-quality rough material has come from the Czech Republic, where it has been mined since the early 19th century (Hyrsl, 1996). The most important locality is Cicov Hill near Horenec, in the Bílina region of north-western Czech Republic (Filippi and Hyrsl, 2004). Gem-quality portions of crystals from this locality may occasionally attain dimensions of 1–2 cm, yielding faceted stones that are quite large (e.g. Figure 2). Cicov Hill is the source of some of the world's largest faceted aragonites (some exceeding 100 ct), but they are very rare.

It is not known when the rough material was found that was faceted into the stones seen recently in Tucson, but these attractive gems show that good-quality aragonite from the Czech Republic still occasionally becomes available in the marketplace.

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Large Green Beryls from Pancas, Brazil

For decades, the Pancas area of Espírito Santo State in eastern Brazil has been known as a source of gem-quality chrysoberyl and beryl (Cassedanne and Roditi, 1993; Reys, 2017). Recently a significant discovery of green beryl occurred there, and in January 2017 the crystals were brought to the Tucson gem shows, where they were purchased by Joe Jelks (Horizon Mineral Lapidary, Lewes, Delaware, USA). The parcel weighed a total of 3.83 kg, and the largest crystal was 1.24 kg and approximately 14 cm long. The colour of the beryl varied from 'mint' green to yellow-green (e.g. Figure 3). The crystals were heavily etched, and contained portions that were 'silky' as well as large clean facet-grade areas.

Jelks partnered with gem cutter Frank Schaffer (FGS Gems, Philadelphia, Pennsylvania, USA), who had experience with faceting larger stones for the collector market (Figure 4). After mapping each piece and sawing out the cleanest areas, the first stone was produced: a 104 ct Portuguese-cut round measuring 63 mm in diameter (Figure 5, left). Over the course of a one-year period, cutting of the rest of the parcel yielded a total of approximately 3,400 carats. The largest stones consisted of a 747 ct cushion, 499 ct teardrop, 487 ct cushion and 363 ct trilliant (Figure 5, right). A number of smaller stones in the 60–100 ct range were also produced. In addition, several cabochons were cut that exhibited strong chatoyancy. Rather than heating the material to obtain a bluer hue, Jelks and Shaffer retained the natural green colour of the beryl. The stones were exhibited for the first time at the 2018 Tucson gem shows.

Although mining in Brazil has slowed in recent years (Reys, 2017), this find shows that significant gems are still occasionally produced there.

Brendan M. Laurs FGA

Figure 3: Some of the large green beryl crystals produced recently from the Pancas area of Brazil are shown here. The largest crystal is ~9 cm long. Photo by Joe Jelks.

Figure 4: A 363 ct 'mint'-green beryl from Pancas is shown being cut by Frank Schaffer. The stone measures approximately 70 × 55 mm. Photo by Joe Jelks.

Figure 5: The Portuguese-cut green beryl on the left (named 'The Headlight') weighs 104 ct, while the green beryl trilliant on the right is 363 ct. Photos by Joe Jelks.

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Chrysocolla Chalcedony with Native Copper Inclusions

Chrysocolla chalcedony, or 'gem silica', is a blue-to-green gem material that is commonly polished into cabochons and beads, and is known mainly from Peru (Hyršl, 2001). Its attractive colouration is caused by dispersed inclusions of chrysocolla within the chalcedony host. Fine-quality material typically has a rather homogeneous colour appearance, but at the February 2018 Tucson gem shows a distinctive cabochon with obvious metallic inclusions was seen among many samples of 'gem silica' that were displayed by Larry Woods (Jewels from the Woods, Blanco, Texas, USA). Woods obtained the rough material several years ago, when it reportedly came from a new deposit in northern India. The ~20 kg of mixed-quality rough material ranged from light blue to deep greenish blue. Cutting has yielded dozens of stones, but the metallic inclusions were retained in only one of them that has been polished so far (39.05 ct; see Figure 6).

Woods loaned the 39.05 ct specimen for examination, and energy-dispersive X-ray fluorescence (EDXRF) chemical analysis of the inclusions by author NDR yielded a strong signal for Cu, as expected for their appearance resembling native copper where they intersected the polished surface of the cabochon (Figure 7). The copper inclusions were surrounded by a thin opaque reddish purple coating that was identified as cuprite by Raman analysis.

Figure 6: Weighing 39.05 ct, this 'gem silica' cabochon contains obvious inclusions of native copper. Photo by Robison McMurtry, © GIA.

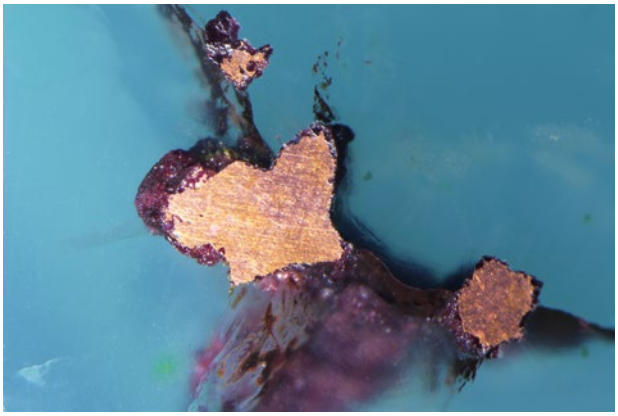

Figure 7: The native copper inclusions in the gem silica are surrounded by a thin coating of cuprite. The coppery metallic lustre is only seen where the inclusions intersect the polished surface of the cabochon. Photomicrograph by N. D. Renfro, © GIA; image width 3.86 mm.

While it is not uncommon for native copper, cuprite and chrysocolla to be associated with one another in copper deposits, it is rather unusual for copper/cuprite inclusions to occur in otherwise pure gem-quality chrysocolla chalcedony. The only similar occurrence known to the authors is blue chalcedony from Bolivia (see www.gemstonemagnetism.com/overview_p_4-_the_magnetic_metals_that_color_gems.html).

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Reference

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Colourless Cordierite—and Quartz—from Tanzania

Cordierite, often referred to as *iolite* by gemmologists, is typically encountered in the gem trade as a blue stone that may resemble sapphire and, therefore, is also called 'water sapphire'. In addition, very rare colourless cordierite has been documented from Sri Lanka (Bank, 1985; Zwaan, 1986, 1996), and is also known to occur in Tanzania and Madagascar (Hanus et al., 2016). The properties of the Sri Lankan samples examined by Bank (1985) were: RIs—1.527–1.536, birefringence—0.009 and SG—2.55. Zwaan (1996) obtained RI readings from a group of stones that ranged from 1.520 (lowest) to 1.541 (highest), and an SG of 2.57. Compared to typical blue cordierite, the very low RI and SG values—as

Figure 8: These rough and cut stones all originated from the same parcel that was represented as colourless cordierite. Despite their similar overall appearance, the two samples on the left proved to be quartz while the other three are cordierite. The faceted stones weigh 1.08–5.85 ct. Photo by Robison McMurtry, © GIA.

well as the lack of pleochroic blue colouration—are consistent with depleted Fe and high Mg contents, and Zwaan (1986, 1996) further mentioned that the Sri Lankan material had up to 95 mol.% occupancy of the Mg sites. In addition, Johnson and Koivula (1998) documented a colourless cordierite from an unspecified locality with slightly higher properties that were indistinguishable from plagioclase (RIs—1.531–1.541, birefringence—0.010, optic character—biaxial positive, and SG—2.62).

During the February 2017 Tucson gem shows, Adam Pearl (East African Gem Traders Ltd, Nairobi, Kenya and Cleveland, Ohio, USA) showed one of the authors (BML) a small parcel of colourless rough material that his supplier represented as cordierite, and this identity was subsequently confirmed for one of the pieces by Raman analysis. The stones reportedly came from central Tanzania, and about 300 g of rough material were produced. All of the pieces showed evidence of chemical etching, and were transparent with a slightly hazy appearance (e.g. Figure 8). Pearl faceted the largest stone in the parcel, but when he submitted it for a laboratory report he was surprised to learn that it was quartz. Pearl then faceted two more stones, and Raman analysis by author NDR showed that one of them was quartz and the other was cordierite (again, see Figure 8). Two pieces of rough from the parcel were also identified as cordierite by Raman analysis. The gemmological properties of the faceted cordierite were as follows: RIs—1.529–1.540, birefringence—0.011, optic character—biaxial positive, and SG—2.52.

Despite the very similar colourless hazy appearance of both the cordierite and quartz to the unaided eye, microscopic examination of the samples showed that their inclusions were very different. While the quartz contained fine needles throughout the stones, the cordierite displayed some discernible etch tubes along with finely textured, linear patterned clouds that gave the stones an overall slightly milky appearance (Figure 9). These features were consistent in both of the faceted quartzes and in the three cordierites (two rough and one cut) that were examined.

It is an interesting coincidence that cordierite and quartz with quite similar appearances were mixed in the same parcel of rough material, and this is particularly unusual given the rarity of colourless cordierite. Nevertheless, they can be readily separated by their optic character, SG values and inclusions.

Brendan M. Laurs FGA and Nathan D. Renfro

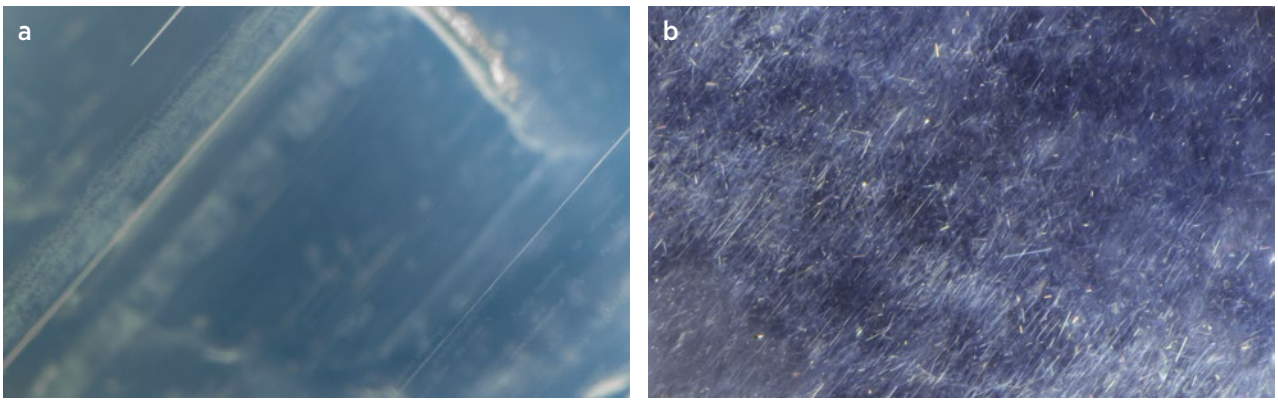

Figure 9: (a) The slightly milky appearance of the cordierite is due to fine linear clouds, seen here with a few etch tubes. **(b)** The hazy appearance of the quartz is caused by the presence of fine needles throughout the stone. Photomicrographs by N. D. Renfro, © GIA; image widths 4.10 mm.

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Faceted Blue Dumortierite from Madagascar

Since late 2016, the authors have seen blue faceted stones from Madagascar weighing up to approximately 2.3 ct that ranged from light to dark violetish blue, often with a hint of grey in the lighter colours (e.g. Figure 10). Such material has been sold in Madagascar as 'tanzanite' (reportedly with identification reports from a Malagasy lab), and in December 2016 a few of these rough and cut stones were brought to the Mineral Expo show in Paris, France.

Four rough pieces were loaned to the authors for identification by two different traders, including Patrick Lefebvre (Aix-en-Provence, France), who specialises in Madagascar minerals. Fourier-transform Raman spectra were obtained using a Bruker MultiRam spectrometer equipped with a 1064 nm Nd:YAG laser (300 mW power, 4 cm^{-1} resolution and 100 scans). The spectra clearly identified the four stones as dumortierite, with main peaks at 204, 508 and 970 cm^{-1} (Figure 11). A similar-looking light violet-blue, 2.36 ct faceted oval was submitted to the Laboratoire Français de Gemmologie (LFG) in January 2017 (again, see Figure 10), and was also identified as dumortierite with Raman spectroscopy.

Figure 10: Weighing 2.36 ct, this faceted dumortierite from Madagascar was submitted to the Laboratoire Français de Gemmologie (LFG) in January 2017. Photo courtesy of LFG.

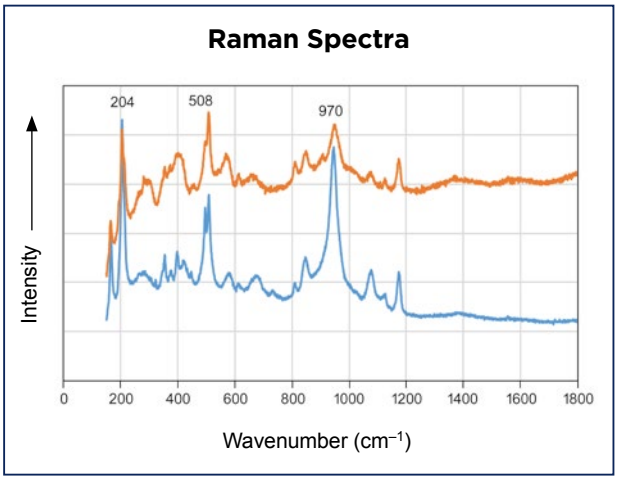

Figure 11: Raman spectra are shown here for two of the rough blue dumortierites from Madagascar. They show peaks at 204, 508 and 970 cm^{-1} that are typical of dumortierite.

RI measurements obtained by the spot method on flat areas of the rough pieces were 1.67–1.69, with a biaxial negative character. The hydrostatic SG ranged from 3.17 to 3.40. All of the samples showed very strong pleochroism from near-colourless to dark violetish blue (Figure 12), which is reportedly due to Fe^{2+}–Fe^{3+} intervalence charge transfer (Rossman, 2015). By contrast, Fe^{2+}–Ti^{4+} charge transfer is believed to give a different (pink) colour in dumortierite (Goreva et al., 2001).

The RI values are somewhat low for tanzanite, and also for dumortierite, probably due to the imperfect surface of the rough samples. The SG measurements span the range for both tanzanite and dumortierite, and the strong pleochroism is also common to both gems. This makes confusion between tanzanite and dumortierite likely.

The stones were inert to long-wave UV radiation but fluoresced a strong whitish blue to short-wave UV. This

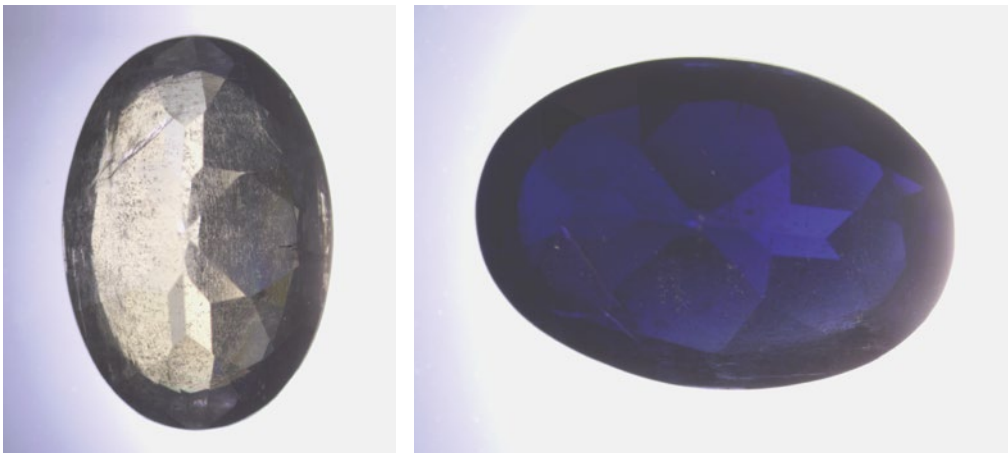

Figure 12: The 2.36 ct dumortierite displays very strong pleochroism from near-colourless to dark violetish blue, attributed to Fe^{2+}–Fe^{3+} charge transfer. Photos courtesy of LFG.

property, together with the biaxial negative character, helps differentiate tanzanite from dumortierite when using classical gemmological methods.

A strong blue short-wave fluorescence is often related to titanium (probably TiO_6 groups, i.e. in sapphire, benitoite and elbaite; Fritsch and Waychunas, 1994). Indeed, a semi-quantitative X-ray fluorescence spectrum obtained with a Rigaku Nex CG instrument revealed, besides the expected Al and Si, a fair amount of Ti (possibly ~1 wt.%), traces of Fe (also related to the colour), Ga and Ge (common substituents of Al and Si), and traces of As. The presence of Ti is consistent with our hypothesis for the origin of the short-wave-only strong whitish blue fluorescence. Further, the dumortierite supergroup contains species with As and Ti as main components (Pieczka et al., 2013), making both elements likely impurities in this species.

Two of the pieces of rough contained many blue, near-parallel, rounded and somewhat elongated inclusions (Figure 13), which were identified with Raman spectroscopy as lazulite. A similar inclusion was seen in the 2.36 ct stone, along with many fluid inclusions and other, unidentified crystal inclusions. The blue lazulite inclusions are reminiscent of those seen in 'blue' quartzite from Mt Bity, also in Madagascar (Rondeau et al., 2016), which is coloured by such inclusions.

Facet-grade blue dumortierite is not common but has been reported previously: Ostwald (1964) mentioned a 4 ct faceted stone (no further details) with Madagascar among the possible localities. Hänni (2007) reported both brownish pink (2.06 ct) and violetish grey (up to 1.18 ct) dumortierite from Tunduru, Tanzania. These gems were also Ti-bearing and fluoresced 'white' in short-wave UV only. Rossman (2015) provided spectra and a photograph of near-gem violetish blue dumortierite from Sahirina, Madagascar. So this 'new' discovery might originate from an area where sporadic finds of such gem dumortierite occurred previously in Madagascar.

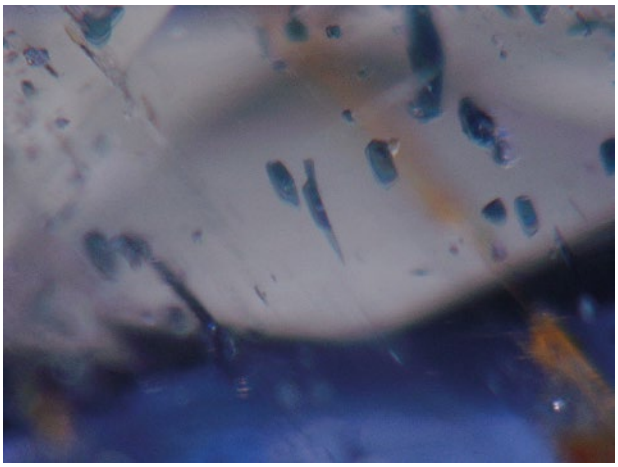

Figure 13: Inclusions of blue lazulite were clearly visible in some of the samples of dumortierite from Madagascar. Photomicrograph by A. Delaunay; magnified 160×.

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Blue Gahnite from Nigeria

Gahnite ($ZnAl_2O_4$) is the zinc-rich member of the spinel group, and forms solid-solution series with spinel *sensu stricto* ($MgAl_2O_4$) and hercynite ($Fe^{2+}Al_2O_4$). Gem-quality gahnite is rarely encountered, although pale blue to dark blue stones up to approximately 1 cm of near end-member composition have been characterised from pegmatite deposits located near Jemaa, central Nigeria (e.g. Jackson, 1982; Batchelor and Kinnaird, 1984; D'Ippolito et al., 2013; Fregola et al., 2014). The blue colour of this material was attributed by D'Ippolito et al. (2013) to a combination of Fe^{2+} spin-forbidden electronic transitions and Fe^{2+}–Fe^{3+} intervalence charge transfer, while Fregola et al. (2014) proposed traces of cobalt (≤200 ppm).

During the June 2017 JCK show in Las Vegas, Nevada, USA, gem dealer Eric Braunwart (Colombia Gem House, Vancouver, Washington, USA) showed these authors some small blue 'spinels' from Nigeria. They reportedly came from south-eastern Nigeria near the border with Cameroon, which is quite far from the Jemaa area referenced above. The crystals typically ranged from slightly worn euhedral octahedra to waterworn subhedral and rounded crystals indicating possible secondary (eluvial or alluvial) deposition. The rough material showed a consistent deep blue colour, which was retained even when cutting melee down to 1 mm in diameter. Production has consisted of sporadic small parcels weighing 10–50 g. Most of the rough is quite small, yielding 1–3 mm melee; the largest gem cut to date is a round brilliant of 0.30 ct (4 mm in diameter).

Figure 14: Three octahedral crystals (0.11–0.20 g) and two faceted samples (0.17 and 0.19 ct) of blue gahnite from Nigeria were examined for this report. Photo by E. Boehm.

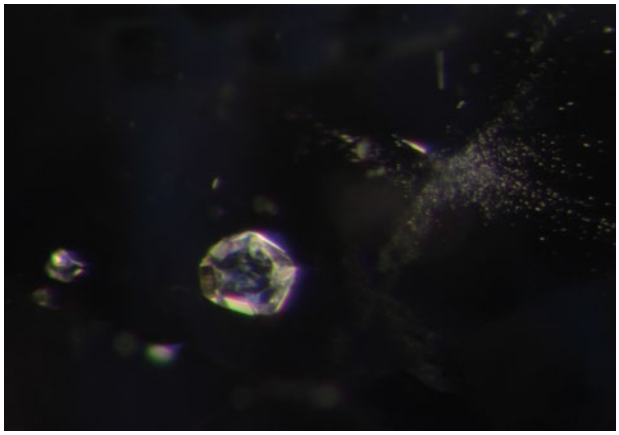

Figure 15: Internal features in the Nigerian gahnite shown here consist of a rounded transparent colourless crystal, a smaller colourless crystal on its left side and a cloud of particles. Photomicrograph by E. Boehm, magnified 45×.

Braunwart loaned some rough and cut samples (Figure 14) to one of the authors (EB) for examination. Two of the faceted gems, weighing 0.17 and 0.19 ct, showed an RI reading of 1.795 consistent with gahnite. (A third faceted stone yielded RIs of 1.762–1.770 and displayed hexagonal growth zoning; it was therefore identified as a sapphire.) A spot RI reading of 1.78 was also obtained from one of the crystals. The faceted gems were too small to provide an accurate hydrostatic SG reading, but the SG of the crystals varied from 4.40 to 4.65, which also falls within the range of gahnite. The RI and SG data from these samples were similar to those obtained by Jackson (1982): 1.793–1.794 and 4.40–4.59, respectively.

Microscopic examination of the rough and cut samples revealed rounded transparent colourless crystals

with the appearance of apatite, euhedral transparent colourless crystals with rectangular cross-sections, flat transparent hexagonal crystals, negative crystals and clouds of fine particles (e.g. Figure 15). The samples showed a moderate red reaction in the Chelsea filter, and a digital spectroscope revealed a strong absorption band in the blue region from 460 to 465 nm and a weak band in the yellow range from 570 to 590 nm. Similar features were documented in the Nigerian gahnite characterised by Jackson (1982), together with some additional absorptions.

Industry demand for the new Nigerian gahnite reportedly has been robust, even considering the small size of the stones, and the market will likely continue to absorb all of the material that is produced.

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Garnet from Eldorado Bar, Montana, USA

The alluvial sapphire deposits of the Eldorado Bar area on the Missouri River near Helena, Montana, USA (Hsu et al., 2017) have yielded small quantities of garnets as a by-product of mining for gem corundum. Although much research has focused on sapphires from this area, little is published on the garnets. During the February 2017 Tucson gem shows, some rough and cut samples of Eldorado Bar garnet were loaned for examination by Todd Wacks (Tucson Todd's Gems, Tucson, Arizona, USA). The stones consisted of two pieces of rough (0.83 and 0.87 g) and one faceted trilliant (0.94 ct; see Figure 16). He had obtained the rough material from Farooq Hashmi (Intimate Gems, Glen Cove, New York, USA), who in 2016–2017 saw 200–300 g of facetable stones of mostly sub-gram size; the largest pieces weighed 2–3 g.

Gemmological characterisation was performed by authors CW and BW. The rough stones consisted of waterworn dodecahedral crystals that were deep orangey red. The faceted stone was deep reddish orange, and its RI was 1.750 and hydrostatic SG was 3.80. It showed patchy anomalous double refraction in the polariscope. A rare-earth magnet was able to lift and hold the faceted stone. An ultraviolet-visible (UV-Vis) spectrum (Figure 17) obtained with an Ocean Optics USB4000 spectrometer recorded features corresponding to both almandine (Fe^{2+}) and spessartine (Mn^{2+}), and Raman spectroscopy with a GemmoRaman-532SG instrument showed the closest match to pyrope-almandine reference spectra. EDXRF chemical analysis indicated major Si, Al, Fe and Mg, and moderate Ca and Mn.

Figure 16: These rough (0.83 and 0.87 g) and cut (0.94 ct) garnets from Eldorado Bar, Montana, were examined for this report. Photo by B. M. Laurs.

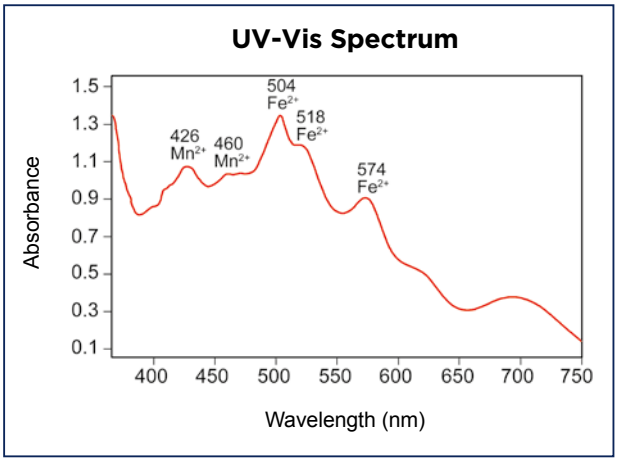

Figure 17: UV-Vis spectroscopy of the faceted Montana garnet showed absorptions at 426 and 460 nm attributed to spessartine (Mn^{2+}), and at 504, 518 and 574 nm attributed to the almandine (Fe^{2+}) component.

Chemical analysis of one of the rough stones and the faceted garnet by laser ablation inductively coupled plasma mass spectrometry (LA-ICP-MS) was performed by author ZS using a Thermo Fisher Scientific iCAP Qc ICP-MS, coupled with an ESI NWR-213 laser ablation system with a frequency-quintupled Nd:YAG laser (213 nm wavelength). The data showed the samples were pyrope-almandine (~$Pyr_{62}Alm_{30}$) with minor grossular and spessartine components (Table I). The data were quite consistent within each stone, indicating that they contained very little chemical zoning. Among the trace elements, Y was most abundant (Table II).

Garnet from Eldorado Bar is sometimes referred to as 'malaya' (or 'malaia') because of its colour, but this term should be reserved for pyrope-spessartine rather than pyrope-almandine.

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Table I: Average chemical composition of two Montana garnets by LA-ICP-MS.*

Composition	Faceted	Rough
Oxide (wt.%, converted)		
SiO_2	40.16	39.85
Al_2O_3	23.45	23.07
FeO	15.34	15.67
MnO	0.85	1.88
MgO	18.00	16.48
CaO	2.02	2.98
Total	99.83	99.93
Ions per 12 oxygens		
Si	2.93	2.93
Total tet.	2.93	2.93
Al	2.02	2.00
Total oct.	2.02	2.00
Mg	1.96	1.81
Fe^{2+}	0.94	0.96
Mn	0.05	0.12
Ca	0.16	0.23
Total dodec.	3.10	3.13
Mol.% end members		
Almandine	30.1	30.4
Grossular	5.1	5.9
Pyrope	63.1	61.3
Spessartine	1.7	2.4

* Analytical parameters: 55 µm diameter laser spot size, fluence (energy density) ~10–12 J/cm^2 and 15 Hz repetition rate. Argon was used as nebuliser gas (0.95 L/min), auxiliary gas (0.8 L/min) and cooling gas (14 L/min). Helium, used as part of the carrier gas, had a flow rate of 0.8 L/min. Argon and He gas flow, torch position, sampling depth and lens voltage were optimised to achieve maximum sensitivity (counts per concentration) and low oxide production rates ($^{232}Th^{16}O/^{232}Th$ <1%). Ablated material was vaporised, atomised and ionised with a plasma power of 1,550 W. Data acquisition was performed in time-resolved mode. Dwell time of each isotope was 0.01 s except ^{27}Al and ^{28}Si, which were measured for 0.005 s. Gas background was measured for 20 s, while dwell time of each laser spot was 40 s. Only the second half (20 s ablation) of the laser profile was used to calculate concentrations, which eliminated surface contamination. ^{29}Si was used as an internal standard and GSD-1G, GSE-1G and NIST 610 were used as external standards. Three spots on each sample were analysed. V and Cr were not detected.

Table II: Average trace-element composition of two Montana garnets by LA-ICP-MS.*

Element (ppmw)	Faceted	Rough
Li	4.38	2.90
Na	104	45.8
P	92.2	54.4
Sc	91.6	36.5
Ti	52.0	59.5
Co	27.5	23.4
Ni	0.775	0.786
Zn	35.0	38.1
Ga	4.61	5.32
Ge	3.08	2.94
Y	515	84.5
Zr	19.3	34.1
Sn	1.17	0.350
Ce	0.088	0.123
Pr	nd	0.091
Nd	1.60	2.05
Sm	5.21	5.235
Eu	1.04	1.77
Gd	28.7	13.5
Tb	8.90	2.37
Dy	86.1	16.0
Ho	18.8	3.01
Er	55.2	9.13
Tm	7.42	1.31
Yb	50.8	9.46
Lu	6.70	1.27
Hf	0.508	0.664

* Abbreviations: ppmw = parts per million by weight; nd = not detected.

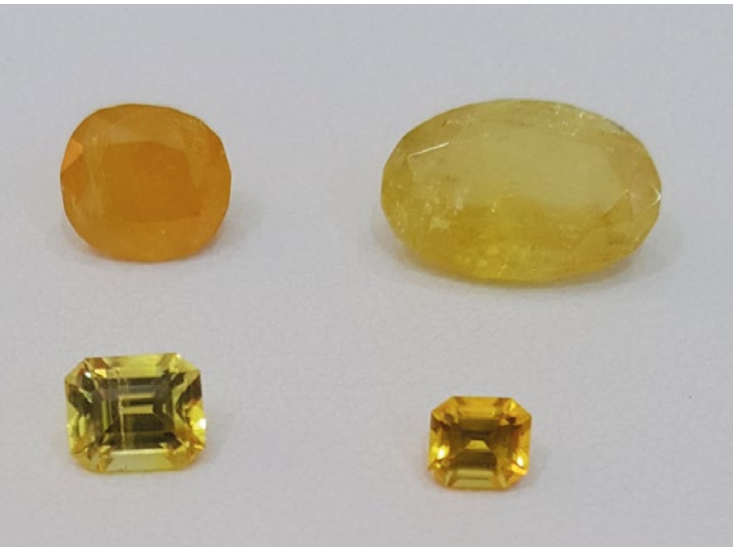

Figure 18: Some of the faceted legrandites studied for this report include a 2.15 ct translucent yellowish orange oval modified brilliant, a 5.15 ct moderately included 'canary' yellow oval modified brilliant, a 1.07 ct slightly included 'canary' yellow emerald cut and a 0.43 ct eye-clean orangey yellow emerald cut. Photo by D. Gravier.

Legrandite from Mapimí, Mexico

Legrandite is a hydrated zinc arsenate, $Zn_2(AsO_4)(OH) \cdot H_2O$, with a Mohs hardness of 4½, which is rarely encountered in faceted form (e.g. Liddicoat, 1967). It ranges from colourless to yellow to orange, and the best-known localities are in Mexico: the Ojuela mine, Mapimí, Durango State and the Flor de Peña mine in Nuevo León State.

Facetable legrandite is rare due to its natural scarcity and its brittleness. The included crystals tend to break apart parallel to their longest direction, and clean pieces are seldom seen. In late 2017, a small quantity of facetable legrandite entered the market, reportedly from Mapimí. From approximately 20 kg of matrix material, one of the authors (DG) recovered ~100 g of rough from which about 40 stones were cut. The gems weighed 0.15 ct to approximately 5 ct, although clean stones were less than 1 ct. They ranged from an intense yellow (transparent) to yellowish orange (semi-transparent; see, e.g., Figure 18).

Some of the faceted stones were characterised for this report. RI values of four samples showed they were biaxial positive with n_α = 1.699–1.701, n_β = 1.706 and n_γ = 1.738–1.739, yielding a birefringence of 0.037–0.040. These results are comparable with those reported by Anthony et al. (2001): n_α = 1.702, n_β = 1.709 and n_γ = 1.740. Hydrostatic SG values of 4.08–4.12 were obtained for a 5.15 ct stone, and these values are somewhat higher than the 3.98–4.01 range given by Anthony et al. (2001). No distinctive absorption features were seen with a handheld spectroscope. Typical inclusions consisted of feathers and incipient fissures (Figure 19a). Also present were 'fingerprints', and one stone contained a tiny cluster of orangey brown material with the appearance of iron oxide or hydroxide (Figure 19b). The larger gems showed obvious doubling (Figure 19c).

Few gems show the intense yellow colour of legrandite, but its rarity and low hardness classify it as a collector's stone.

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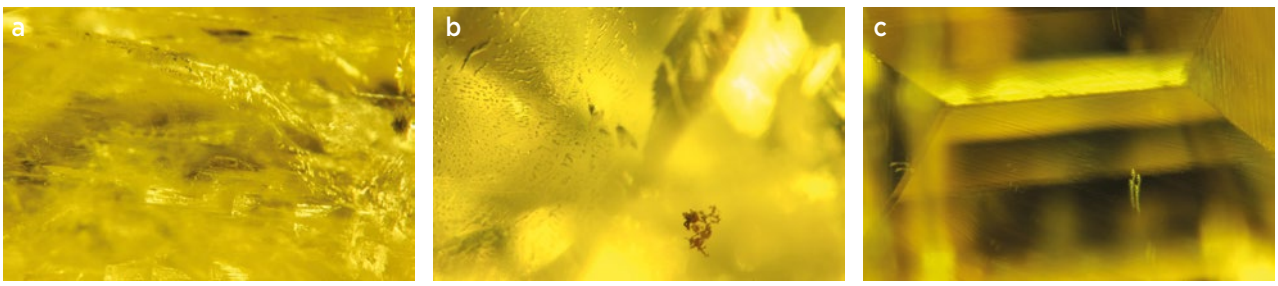

Figure 19: Internal features in the legrandite gemstones examined for this report include **(a)** feathers and incipient fissures, **(b)** 'fingerprints' and a tiny cluster of orangey brown material, and **(c)** obvious doubling displayed by the larger stones. Photomicrographs by D. Gravier; image widths 4.0 mm (a), 1.8 mm (b) and 3.2 mm (c).

Figure 20: 'Manakarra' quartz is typically purple (i.e. amethyst; left), although some of the stones show bluish green colouration (right). Photos courtesy of Joel Ivey.

Grape-like 'Manakarra' Quartz from Sulawesi, Indonesia

In 2014, a new quartz gem material was discovered near the town of Mamuju on Sulawesi Island, Indonesia. According to geologist Joel Ivey (IndoAgate.com, Bangkok, Thailand), it was initially found on a beach, and then was traced up streambeds into the nearby jungle, where local miners have dug narrow tunnels into the steep hillsides (see www.indoagate.com/manakarra.html for more information). The original production consisted of friable, pale grey to brown material with a dull lustre, but by 2016 much higher quality stones were found *in situ* that consisted of grape-like purple or bluish green clusters with a sparkling lustre (e.g. Figure 20). The material commonly has been sold as 'grape' chalcedony or 'grape' agate, and is also called *Batu Manakarra* or simply *Manakarra* (e.g. Thompson, 2016), which refers to the name of a beach near the initial discovery.

According to Ivey, who has visited the mining area, the specimens are hosted by clay-filled areas associated with submarine pillow lavas that form part of a Miocene-age volcanic sequence dominated by mafic lavas, volcanic breccias and tuffs. Ivey estimates that well over 500 tonnes of mixed-quality stones have been recovered, with the largest clusters weighing up to 80 kg. However only about 10% of the material is colourful, and the ratio of specimen- to lapidary-grade stones is approximately 60/40. The quartz typically shows purple (amethyst) or grey-green to bluish green colouration, and less commonly is pale pink, yellow or colourless. Approximately 80% is purple, 15% is green and other colours constitute 5% or less of the production. Individual spheres or 'orbs' range up to 18 mm, but are mostly 3–6 mm in diameter. Orbs measuring 6–10 mm are rare, and larger ones are very seldom encountered. Freeform drusy pieces are cut from the material (Figure 21), and many of the smaller orb-like clusters are wire-wrapped for jewellery use. The larger single or double orbs are commonly drilled and used for beads, or polished and set into pins, brooches and other items. Those showing a low lustre are tumble-polished to produce a shiny fibrous appearance.

Figure 21: Drusy pieces of the Manakarra amethyst have been cut into various shapes for jewellery use. The stones shown here range from 26 × 18 mm to 45 × 28 mm. Photo by Joe Jelks.

Figure 22: A thin slice (0.56 mm thick) of a 4.1-mm orb of Manakarra amethyst displays radial cracks and grain boundaries that are most visible toward its interior **(a, b)**. In cross-polarised light, the radiating growth habit of the quartz is obvious **(c)**. The individual quartz domains are generally about 20 µm wide. Photomicrographs by G. R. Rossman; image widths 1.97 mm (b and c).

Ivey donated some purple and grey-green samples to one of the authors (GRR), and Raman analysis confirmed that the material was quartz. Optical absorption spectroscopy of a doubly polished slice of a purple sphere matched the spectrum of amethyst. EDXRF chemical analysis showed that the purple spheres were mostly Si with about 150 ppm Fe and around 10 ppm Ga and Zn. EDXRF spectroscopy of the green spheres also showed mostly Si, but they contained a much broader array of minor components including nearly 1% Mg, 0.2% Ca, about 1,000 ppm Fe, and traces of Ga, Rb, Sr, Mn, Ge, Y and U.

Internal features in the purple spheres consisted of a radial aggregate of pervasive cracks and grain boundaries (Figure 22a,b) that may host some of the Fe detected in the material. The radiating growth structure was also seen in a thin section of an orb when viewed in cross-polarised light (Figure 22c). The green spheres contained numerous green inclusions (Figure 23).

The amethyst colouration of the quartz is apparently related to the background radiation of the host rock. According to a geological map produced by the Indonesian government, the basaltic rocks that host the amethyst overlie a large granitic body with the potential for uranium mineralisation. Remobilisation of radioactive components could have deposited them into the amethyst host rocks. Indeed, gamma-ray spectroscopy by author GRR showed that the low-level radioactivity of the host rock is mostly from the thorium decay series. As is the case with typical crystals of amethyst, heating the spheres to 400°C resulted in a loss of the amethyst colour.

Although the bulbous appearance of the orbs is reminiscent of some chalcedony or agate (both of which consist of cryptocrystalline quartz), the Manakarra material consists of much coarser-grained radiating micro-crystals. The grape-like form of the quartz is due to its radial growth pattern, with multiple nucleation points producing the clusters of spheres associated with its distinctive appearance.

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Figure 23: Numerous inclusions cause the colour of the green orbs of Manakarra quartz, as shown here in a slice of a sphere cluster measuring 5.1 mm wide and 1.75 mm thick. Photomicrograph by G. R. Rossman.

Green Aventurescent Quartzite from a New Find in Tanzania

A relatively new deposit of green aventurescent quartzite has been discovered in northern Tanzania, and the material is being marketed as 'Emerald quartz', 'Green Tanzurine' or 'Emerald Tanzurine' (e.g. White and Dickson, 2018). The latter two names are being used by USA-based supplier Jonathan Bartky (Ariel Treasures, Livingston, New Jersey), who has exported ~2 tonnes of rough material. He introduced the green aventurescent quartzite to the USA market at the September 2016 Denver Gem & Mineral Show. Since then, various items have been manufactured from this material, including spheres, eggs, cabochons, tumbled stones, pendants and beaded strands.

Two pieces of rough (~30 g each) and three polished stones (25–750 ct) were examined for this report. One of the rough pieces was then polished, and a portion of it was used to prepare thin sections. Additionally, for comparison two samples of aventurine quartz from India (15 g rough and 122.5 ct polished) were also examined, and a thin section was prepared.

The rough material from Tanzania was predominantly opaque, but appeared translucent in strong transmitted light. The translucency was better in the polished samples (e.g. Figure 24), and macroscopically it was obviously an aggregate material coloured by flecks of green inclusions. An aggregate appearance was also seen in the polariscope, which further revealed that the individual grains were doubly refractive. The RI and hydrostatic SG values were consistent with quartz: n_o = 1.543, n_e = 1.552, birefringence = 0.009 and SG = 2.65. Microscopic observation revealed numerous round, partially pseudo-hexagonal, green platy inclusions (Figure 25, left). Raman analysis with a Renishaw inVia spectrometer identified the inclusions as fuchsite, the same chromian mica that colours green aventurine quartz (i.e. quartzite that shows a schiller effect).

Nevertheless, we noted some significant differences

Figure 24: Green aventurescent quartzite from a relatively new deposit in Tanzania was polished by Jürgen Christmann into this egg (765 ct) and drop-shaped cabochon (82 ct). Collection of Robert Myers; photo by T. Stephan.

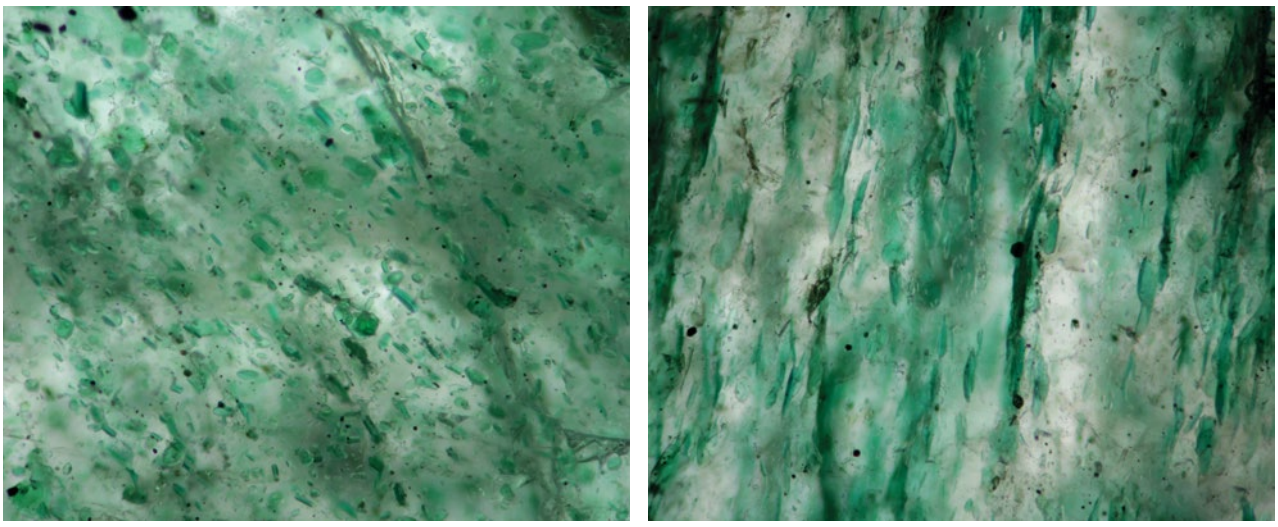

Figure 25: Viewed in transmitted light, the distribution of fuchsite inclusions is shown in the new green aventurescent quartzite from Tanzania (left, image width 3.46 mm), as compared to typical green aventurine from India (right, image width 3.37 mm). Photomicrographs by T. Stephan.

between typical aventurine quartz and this new material from Tanzania. India is the major producer of green aventurine quartz and a detailed mineralogical study of this material was reported by Monroe (1986). Fuchsite-bearing quartzite is commonly rather fine grained (i.e. up to 1–2 mm), with even smaller grains of fuchsite that are incorporated as an accessory constituent along the boundaries between the quartz grains. The fuchsite is mainly oriented in one direction along the foliation of the rock (e.g. Figure 25, right). By contrast, the Tanzanian material consists of coarser grains of quartz (1–5 mm), and the fuchsite forms inclusions within the quartz. Furthermore, the material lacks schistosity, which implies a lower-grade metamorphism. The textural differences between this new green aventurescent quartzite and typical aventurine are particularly evident in thin sections viewed with crossed polarisers (Figure 26).

Acknowledgements: Samples of the green aventurescent quartzite from Tanzania were kindly donated by Impexco (Idar-Oberstein, Germany).

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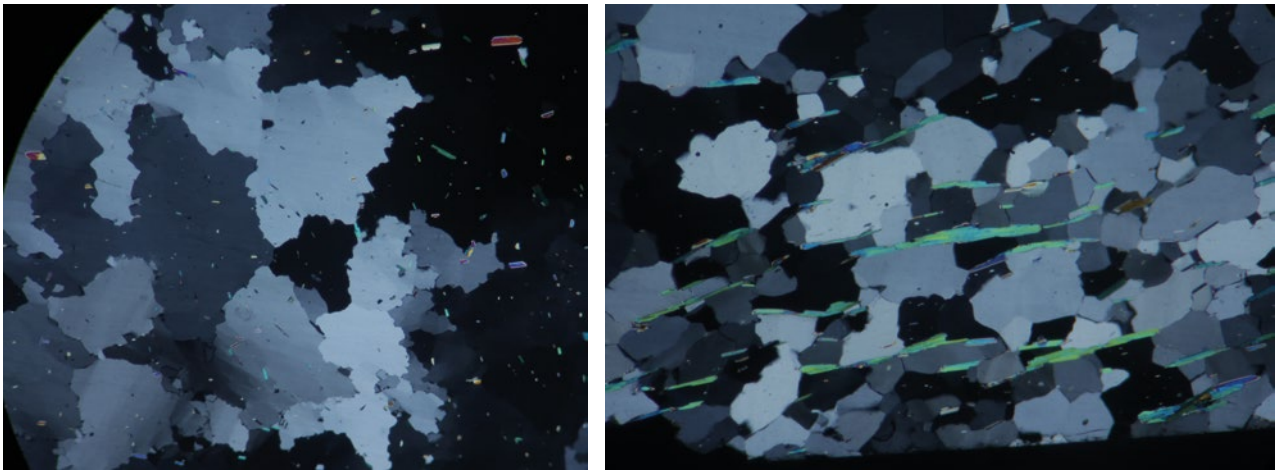

Figure 26: Obvious textural differences are seen between the Tanzanian green aventurescent quartzite and Indian aventurine when thin sections of these materials are viewed with cross-polarised light. The quartz grains display low-order grey-to-black interference colours, while the fuchsite appears highly birefringent. In the material from Tanzania, randomly oriented fuchsite grains are included within coarse interlocked quartz (left, image width 6.62 mm). By contrast, aventurine from India contains subparallel fuchsite laths that are aligned between grain boundaries in relatively fine-grained quartz aggregates (right, image width 3.73 mm). Photomicrographs by T. Stephan.

Blue-to-Violet Spinels from Mozambique

Mozambique was recently noted as a source of pink spinel (Boehm, 2016), and at approximately the same time rough stone dealer Farooq Hashmi reported seeing purple and blue spinels from Mozambique while on a buying trip to Africa. He first encountered them in mid-November 2015 in Arusha, Tanzania, where he saw several kilograms of rough material as broken pieces that were mostly below 3 g each. He was offered more of this spinel while visiting Arusha in May and June 2016. From the rough stones he obtained, Hashmi selected one piece to be faceted for testing, and it was cut into a 1.36 ct round brilliant (Figure 27). Characterisation of this stone by one of the authors (EB) revealed the following properties: colour—slightly violetish blue, RI—1.718, hydrostatic SG—3.66, Chelsea filter reaction—inert, and no absorption features were discernible with a handheld spectroscope. In addition, no inclusions were visible with the gemmological microscope.

Figure 27: This 1.36 ct violetish blue spinel is from Mozambique. The stone was faceted by Marvin M. Wambua (Safigemscutters Ltd, Nairobi, Kenya). Photo by E. Boehm.

More recently, at the 2018 Tucson gem shows, a range of greyish to greenish blue to violet to purple spinels from Mozambique were displayed by one of the authors (MS) and Kobi Sevdermish (Advanced Quality, Ramat Gan, Israel). They started cutting the material in early 2017, and produced faceted stones from 2 mm in diameter up to 8 ct. About 3,000 carats of the larger stones have been cut. Seven spinels weighing 1.20–3.83 ct (Figure 28) were characterised by one of the authors (GB). Five of them were violetish purple to reddish purple with medium-to-dark tone and moderate-to-vivid saturation, and two of them were greenish blue to blue with dark tone and high saturation. The RI was 1.718 ± 0.001 and hydrostatic SG values were 3.58–3.62. Internal features consisted of fine needles showing various patterns, including short silk-like inclusions and elongate networks with a partially dissolved appearance (Figure 29). Intersecting networks of needles created a spiderweb-like appearance in some samples.

Figure 28: Weighing 1.20–3.83 ct, these spinels from Mozambique show various purple-to-blue hues. Photo by Maria Shpak.

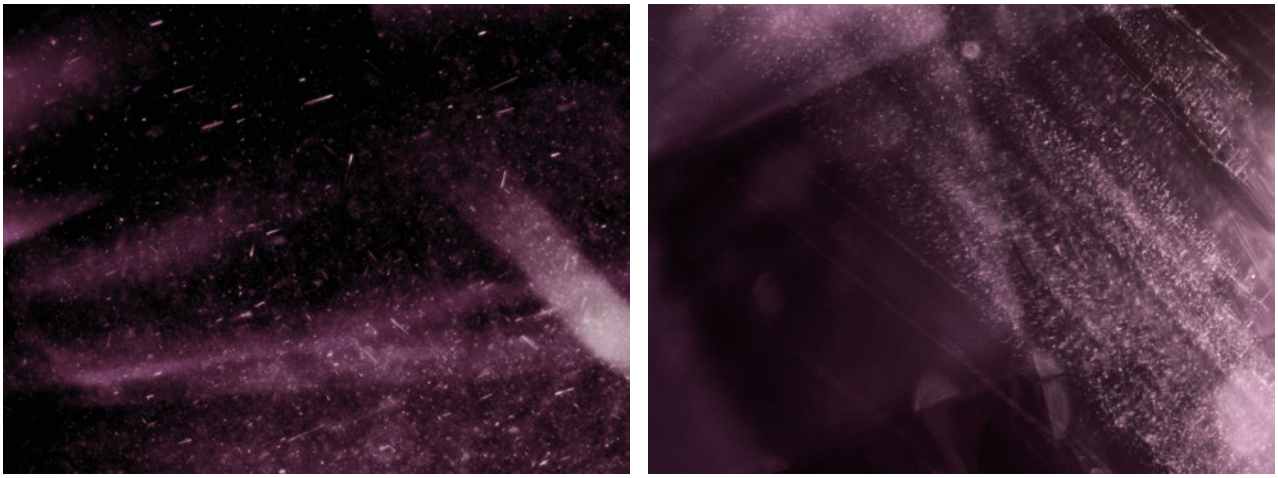

Figure 29: Some of the Mozambique spinels contained fine silk-like needles that were dispersed (left, magnified 60×) or present in elongate networks with a partially dissolved appearance (right, magnified 50×). Photomicrographs by G. Borenstein.

Figure 30: Colourless hexagonal prisms with the appearance of apatite also formed inclusions in the Mozambique spinels. Photomicrograph by Idan Shaulov; magnified 60×.

Also present were 'fingerprints' and small transparent hexagonal prisms that were doubly refractive and had the appearance of apatite (Figure 30).

The specific locality (or localities) for these spinels in Mozambique is presently unknown to the authors, but given the differences in the colour appearance and SG of the stones examined by each author, it is possible that they came from more than one deposit.

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Reference

Boehm E., 2016. Gem Notes: Pink spinel from Mozambique. *Journal of Gemmology*, **35**(2), 109–111.

Violet Tourmaline from Democratic Republic of Congo

Gem-quality tourmaline is known in virtually every colour, but violet is rather uncommon. While on a buying trip to Africa in the first part of 2017, rough stone dealer Farooq Hashmi obtained an unusual violet tourmaline from his supplier in Rwanda. The crystal was taken from a small parcel of rough tourmaline that reportedly came from a new mine in the Democratic Republic of Congo (DRC). The crystal measured ~1.2 cm long (Figure 31), and the bottom part of it was subsequently faceted into a 1.42 ct round modified brilliant for this report (Figure 32).

The faceted stone and crystal section were examined by authors CW and BW. The crystal exhibited a hexagonal cross section, and the prism faces were lightly striated parallel to the c-axis. The crystal termination was composed of three near-equal rhomboid pyramidal faces. Both the rough and cut samples were greyish violet and were inert to UV radiation. The RIs of the faceted stone were 1.620–1.640, yielding a birefringence of 0.020. The SG of the faceted stone was measured hydrostatically as 3.06. The main inclusions in both samples were fluid-filled partially healed fissures. In addition, the crystal hosted numerous growth tubes oriented parallel to the c-axis that were filled with a reddish brown epigenetic material (Figure 33), while the

Figure 31: This violet tourmaline crystal (~1.2 cm long) was reportedly produced from a new mine in the DRC. Photo by Farooq Hashmi.

faceted stone contained some fine frosted 'fingerprint' inclusions and some reddish brown solid inclusions with no discernible crystal form. Raman analysis with the GemmoRaman-532SG instrument gave the closest match to elbaite, and EDXRF spectroscopy gave strong peaks for Mn, Fe, Ca and Zn. Although Zn is somewhat unusual in gem tourmaline, a significant amount of this element was likewise detected (together with the other elements mentioned above) in a chemical analysis of the crystal by John Attard (Attard's Minerals, San Diego, California, USA) using EDXRF spectroscopy.

Energy-dispersive chemical analysis of the faceted stone with a scanning electron microscope by author AUF showed that the tourmaline was elbaite with Mn as the principal chromophoric element.

It remains to be seen whether additional production of this unusually coloured gem tourmaline from DRC will enter the market.

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Figure 32: A portion of the tourmaline crystal in Figure 31 was faceted into a 1.42 ct gemstone by Todd Wacks (Tucson Todd's Gems). The remaining part of the crystal is 6.54 mm long. Photo by B. Williams.

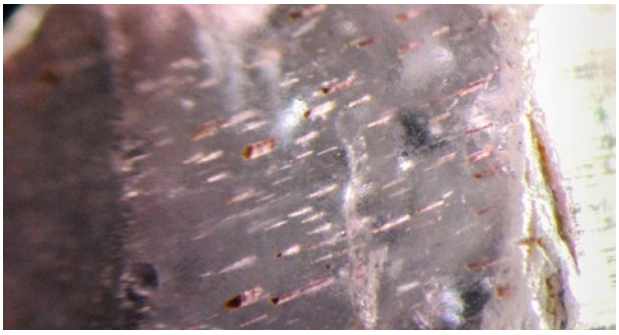

Figure 33: An array of growth tubes oriented parallel to the c-axis are located just under the pyramidal termination of the tourmaline crystal, and are filled with a reddish brown epigenetic material. Photomicrograph by B. Williams; magnified 25×.

ORGANIC MATERIALS

Burmese Amber from Khamti, Sagaing Region

Burmese amber, also called *burmite* (or *pa-yin* in Burmese), is a Cretaceous fossilised resin. Most commercial extraction of burmite has focused on several important sites in the Hukawng Valley of Kachin State in northern Myanmar (Figure 34). In recent years, political instability in Kachin State forced many amber (and gold) miners to flee the area and search for deposits in other regions of Myanmar. For example, in 2010–2011 a new locality for Burmese amber was discovered near Hti Lin, Magway Region, central Myanmar (Figure 34; Tay Thye Sun et al., 2015).

In addition, many local miners (who are mainly farmers) from Kachin State started searching for new gem deposits to the west along the Chindwin River. In 2012–2013, another amber mining area was found near Khamti (or Hkamti) Township, which is located 180 km northwest of Myitkyina, in the Sagaing Region of north-western Myanmar (Figure 34). Currently more than 1,000 miners are active there in both open-pit and underground workings (Figure 35). The amber-bearing seams form in strata with coal and calcite that are hosted within shale layers, typically ~20–30 m below the surface. The overlying soil is around 3–5 m thick. In addition to producing amber, the miners also recover *fei cui* (Burmese jadeite) and gold in this area.

Thirty-two Khamti amber samples were examined using standard gemmological instruments and Fourier-transform infrared (FTIR) spectroscopy. All were polished cabochons or free-forms of gem quality, weighing 0.72–55.67 ct. They displayed a wide range of colours, from pale 'lemon' yellow, 'honey' yellow and brownish yellow to dark brown, as well as some unusual colours such as 'cherry' red and 'tea-leaf' green to dark greenish brown (e.g. Figure 36, left). Some brownish yellow, reddish brown and cherry-red samples showed a bluish

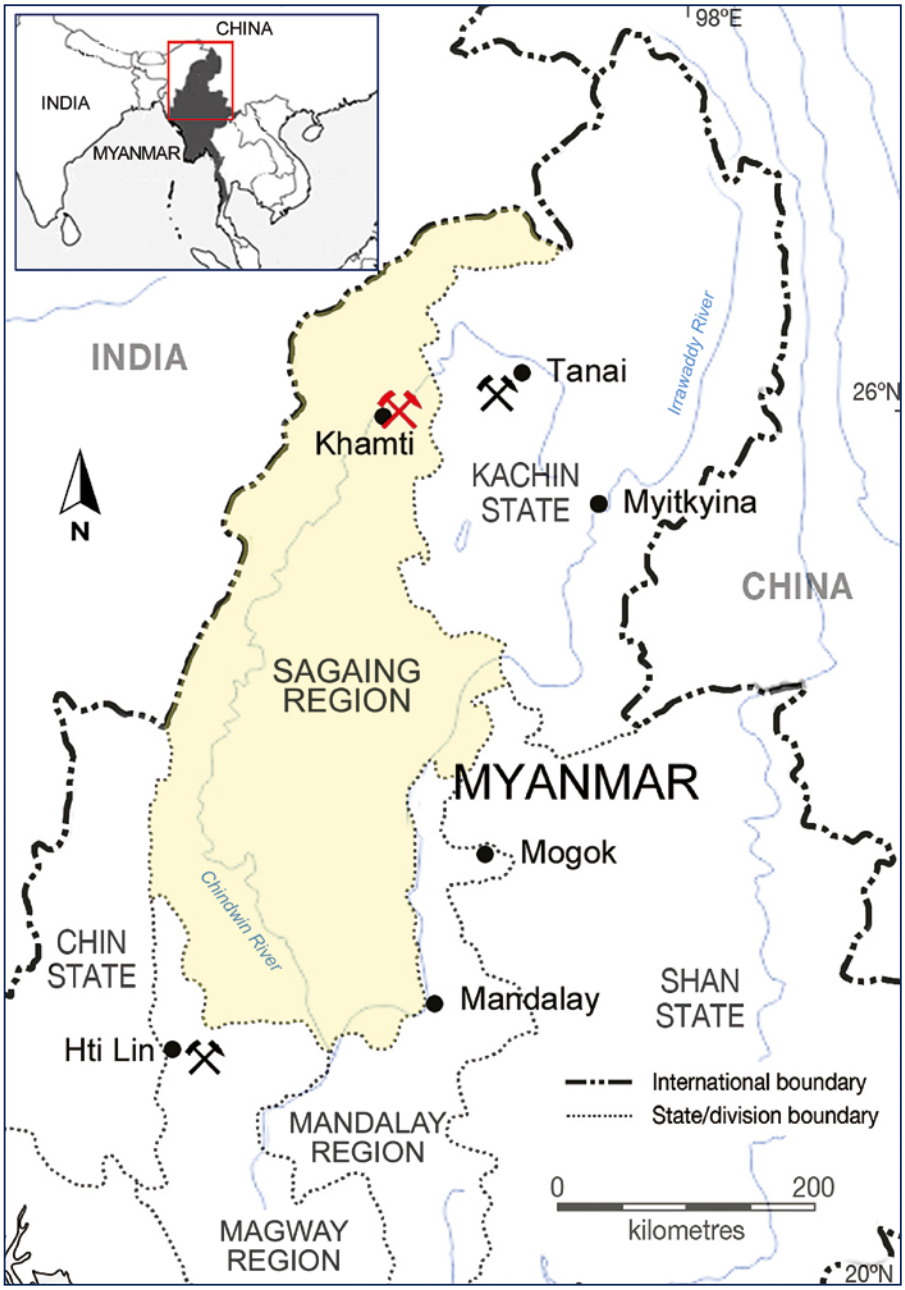

Figure 34: There are three main amber-mining areas in Myanmar. The Khamti deposits (red symbol) are located in Sagaing Region (yellow shading) of north-western Myanmar, while the famous Hukawng Valley mines are located south-west of Tanai in Kachin State. The Hti Lin area is in Magway Region, central Myanmar.

green surface colour in daylight that may be attributed to Tyndall scattering of light by clouds of very fine gas bubbles. The spot RI ranged from 1.54 to 1.55, and the hydrostatic SG was 1.03–1.06. Most samples showed chalky blue to light purple fluorescence (Figure 36, right), which was strong in long-wave and weak under short-wave UV radiation. However, some of the samples luminesced moderate-to-strong pink (sometimes with blue veins or patches corresponding to plant debris), and this fluorescence was likewise stronger under long-wave than short-wave UV radiation (again, see Figure 36, right). The pink UV luminescence helps explain why some brown to dark brown samples (i.e. lower left in Figure 36) displayed a purple surface colour in reflected daylight.

Most of the amber samples were clean and transparent, and only a few were translucent to opaque. Microscopic observation revealed many tiny, flattened, oval gas bubbles and swirled flows of brownish coloured debris. Inclusions consisting of a cockroach and a cricket were found in two different brownish yellow samples, while samples with more unusual body colours were typically free of insects. Other inclusions—such as fern leaves, scorpions, lizards and feathers—have also been discovered in Khamti amber (Maung Muang Minn, pers. comm., 2017).

Specular reflectance FTIR spectroscopy showed that most of the Khamti amber samples had spectra similar to those of burmite from the Hukawng Valley (cf. Beck et al., 1964; Wang et al., 2015). However, some cherry-red

Figure 35: In the Khamti area, amber is mined from open pits (left) and from hand-dug shafts (right). Photo by Ben Sim.

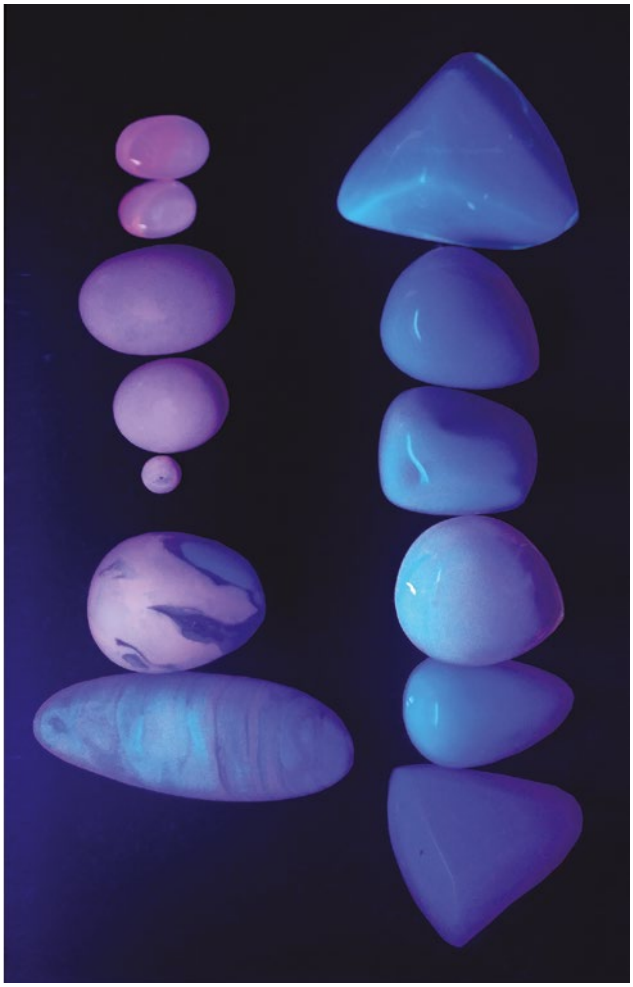

Figure 36: These 0.72–55.67 ct samples of Khamti amber (left) display variable fluorescence (right), consisting mostly of pink in the left column and blue-to-purple in the right column. The fluorescence is shown here under long-wave UV radiation. Photos by S.I Liu.

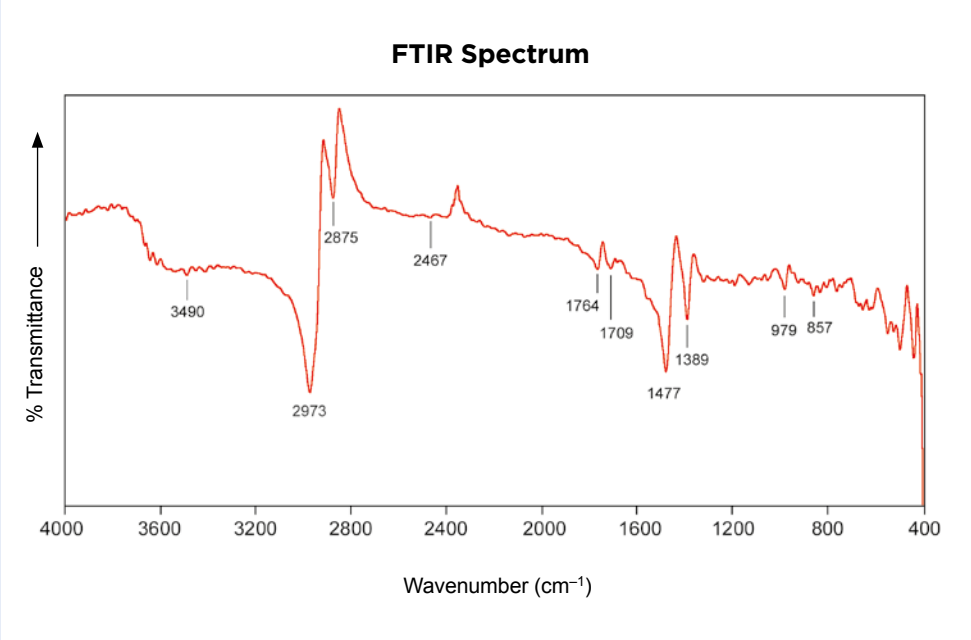

Figure 37: Some unusual features for Burmese amber are shown in this FTIR spectrum of a cherry-red sample from Khamti, including weak-to-absent absorptions at 1734 cm^{-1} and in the 1250–1050 cm^{-1} region, and an additional band at 1764 cm^{-1}.

and light yellow samples had somewhat different infrared spectra. The significant absorption band in Burmese amber at 1734 cm^{-1} corresponding to the C=O stretching vibration of carboxylic esters and acid groups was very weak (or sometimes absent), and an additional absorption at 1764 cm^{-1} was present in these Khamti ambers (Figure 37). The C–O stretching vibrations in the 1250–1050 cm^{-1} region were also relatively weak. Further investigations should be undertaken to better characterise such Khamti samples using Raman and mass spectroscopy, as well as FTIR spectroscopy of pressed KBr pellets in transmission mode.

The presence of these relatively recently discovered amber deposits in the Khamti area of the Sagaing Region suggests that there might be more as-yet undiscovered burmite deposits in Myanmar, which could provide additional new amber varieties and help ensure a sufficient supply of Burmese amber to the growing international market.

Acknowledgements: The author thanks Maung Muang Minn for providing samples and discussions of Hkamti amber, Ben Sim for photographs of the mining area, and Kin Wah (Tommy) Tsui and Chun Kit Lau (China Gems Laboratory Ltd, Hong Kong) for FTIR spectroscopy.

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Wang Y., Shi G.H., Shi W. and Wu R.H., 2015. Infrared spectral characteristics of ambers from three main sources (Baltic, Dominica and Myanmar). *Spectroscopy and Spectral Analysis*, **35**(8), 2164–2169 (in Chinese with English abstract).

MISCELLANEOUS

Opal Master Reference Sets

In light of numerous developments concerning opals during the past two decades—including new deposits, varieties and synthetics—a series of comprehensive opal master reference sets were recently released by Andrew and Damien Cody (Cody Opal, Melbourne, Australia). A total of 60 sets have been assembled after more than two years of research and development.

Designed to be used as a tool for education, identification, classification and grading, each set comprises nine acrylic boards (e.g. Figure 38) containing a total of 216 reference samples. The specimens were assembled from more than 200,000 pieces, with nearly 13,000 of them selected for the sets. Natural opals were sourced from several significant localities worldwide, and synthetics were acquired from leading manufacturers.

The nine boards in each set consist of the following:

- **Board 1**—*Natural Precious Solid Opal*: Body Tone Scale (black to light; Munsell N1–N9) and Australian Black Opal Grading Scale (red-multi, orange-green, green and blue; AAA–D)
- **Board 2**—*Natural Precious Solid Opal*: Diaphaneity Scale (transparent–opaque), Australian Light Opal Grading Scale (red-multi and green-blue; AAA–F) and Light Opal of the World
- **Board 3**—*Natural Precious Opal on Host Rock*: Australian Boulder Opal Grading Scale (AAA–C), Opal on Host Rock Examples and Host Rock Types
- **Board 4**—*Natural Precious Opal in Host Rock (Matrix)*: Queensland (Australia) Boulder Matrix Opal Examples, Andamooka (Australia) Matrix Opal Examples and Matrix Opal of the World
- **Board 5**—*Natural Precious Hydrophane Opal*: Ethiopian Light Opal Grading Scale (AAA–C), Wollo (Ethiopia) Opal Examples, and Other Hydrophane Opal
- **Board 6**—*Natural Common Opal*: Mexican Fire Opal Grading System (cherry red–orange-yellow), Brazilian Fire Opal Grading System (orange–yellow) and Other Common Opal
- **Board 7**—*Composite Opal*: Doublet Grading Scale (red-multi and green), Triplet Grading Scale (red-multi, green and blue) and Other Composites
- **Board 8**—*Artificial Opal*: Kyocera (both mineral-type and resin-impregnated synthetics), Fuji (resin-impregnated synthetic and resin hybrid), Sterling (resin-impregnated synthetic) and Imitations
- **Board 9**—*Opal Specimens*: Opalized Fossils (molluscs, worm burrows and wood) and Formation Examples (hyalite, nobby and seam)

Each set is individually numbered, and the boards are secured with tamper-proof screws and holographic security labels. A loose-leaf handbook of explanatory notes on the samples accompanies each set. As opal nomenclature is currently under review, both the handbook and the boards themselves can be updated as necessary by Cody Opal.

The opal sets were initially displayed in early 2018 at the International Jewellery Tokyo show in Japan and the GJX show in Tucson. This is the first time that comprehensive opal master sets have been assembled, and the majority of them have already been acquired by most of the world's important gemmological laboratories and institutions, including Gem-A. It is hoped that these sets will help educate the gem trade and facilitate the consistency of opal grading, classification and terminology throughout the industry.

Brendan M. Laurs FGA

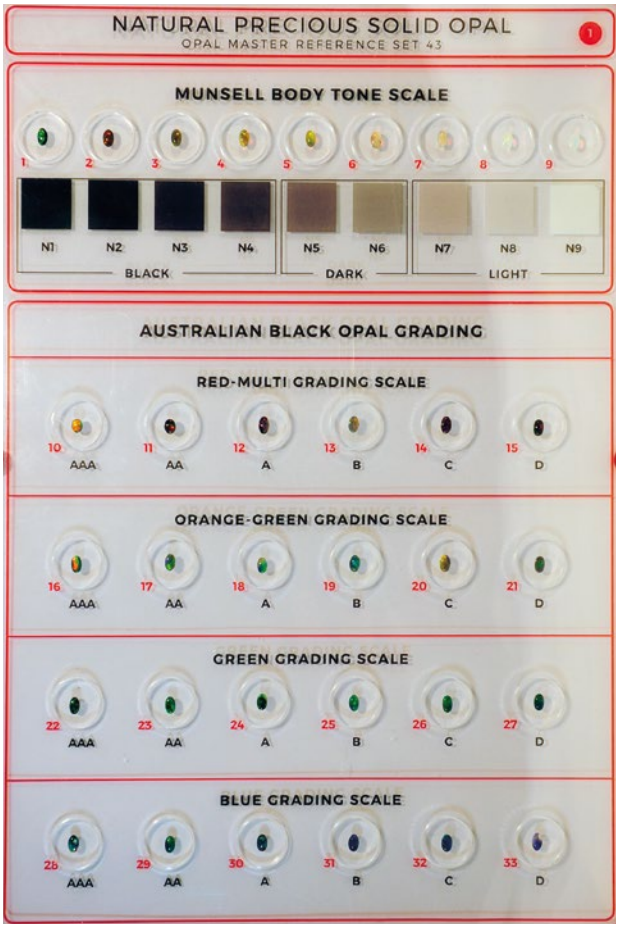

Figure 38: Comprehensive opal master reference sets have been released, with each consisting of nine boards. Shown here is board no. 1, which displays a body tone scale and an Australian black opal grading scale. The board measures 30 × 21 cm, and the samples are mounted within an assemblage of three acrylic plates. Photo courtesy of Cody Opal.

Figure 1: These zircons (10.45–20.51 ct) from Ratanakiri, Cambodia, show the attractive blue colouration of heat-treated material from this locality. Photo by Mark H. Smith, Thai Lanka Trading Ltd Part., Bangkok, Thailand.

Blue Zircon from Ratanakiri, Cambodia

Manuela Zeug, Lutz Nasdala, Bhuwadol Wanthanachaisaeng, Walter A. Balmer, Fernando Corfu and Manfred Wildner

ABSTRACT: Zircon from Ratanakiri Province, north-eastern Cambodia, is well known in the gem trade for its vivid blue colour that results from heat treatment. The untreated brown material turns blue under reducing conditions at ~900–1,000°C. Ratanakiri zircon is characterised by remarkably low contents of trace elements. In particular, the actinides have low concentrations (e.g. approximately 120 ppm U and 95 ppm Th). Together with the very young age of the zircon (<1 million years [Ma]), this results in an extremely low self-irradiation dose, which in turn is in agreement with its non-radiation-damaged, nearly perfectly crystalline state. The heat treatment, therefore, does not result in detectable changes in the zircon's structural state. The cause of the blue colour, presumably related to a valence change upon heating in the reducing environment, is still under debate. The absorption of the treated Ratanakiri zircon is decidedly different from that of blue U^{4+}-doped and blue V^{4+}-doped synthetic $ZrSiO_4$. Absorption spectra show a strongly pleochroic band at 18,200–13,000 cm^{-1} (corresponding to ~550–770 nm wavelength) that is clearly responsible for the treated blue colour; however, its assignment remains unresolved.

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Zircon has been used as a gem material for thousands of years. This is not least because of the mineral's high refractive index and optical dispersion. Transparent colourless zircon nearly approaches diamond in fire and brilliance, and therefore has been used as a diamond imitation for centuries. Colourless zircon is occasionally known in the gem market by its misnomer 'Matara (or Matura) diamond', named after the city of Matara on the southern coast of Sri Lanka (Roskin, 2003). In addition to being colourless, zircon occurs in a wide range of hues including slightly smoky or pale yellow ('jargoon' or 'jargon'), orange to reddish brown ('hyacinth' or 'jacinth'), yellowish to brownish green, dull dark brown to nearly black (often belonging to metamict varieties such as 'cyrtolith' or 'malacon') and purple and pink (Faulkner and Shigley, 1989; Nasdala et al., 2003; Kempe et al., 2016). Natural untreated blue zircon, however, is extremely rare. For example, small dipyramidal crystals of 'sky'-blue colour (occasionally with a greyish, greenish or purplish tint) are known from the San Vito quarry on the western slope of the Somma-Vesuvius volcanic complex in Italy (Russo and Punzo, 2004; see also Kempe et al., 2016).

Besides Sri Lanka, gem-quality zircon was, and still is, produced in Cambodia, Vietnam, Thailand, Myanmar, India, Pakistan, China, Russia, France, Tanzania, Madagascar, the USA, Canada, Australia and other countries (Faulkner and Shigley, 1989; Roskin, 2003; Watson, 2007; Smith and Balmer, 2009; Shigley et al., 2010; Chen et al., 2011; Sutherland et al., 2016). The reddish brown to brown zircon from Ratanakiri (or Ratanak Kiri), Cambodia, has become increasingly important in the gem trade, since it is known that this material turns into different shades of blue upon heat treatment, including a significant fraction that is vivid blue (Figure 1; Smith and Balmer, 2009). In addition to 'Starlite', the term 'Ratanakiri zircon' has developed into a common trade name for gem-quality blue zircon. The proliferation of 'Ratanakiri zircon' is somewhat comparable to the term 'Paraiba tourmaline', which has developed into a general trade name for vivid blue-to-green Cu-bearing tourmaline that is used regardless of a stone's geographical origin. Additional locations known to produce zircon that in some cases can be enhanced to (rather light) blue include Shan State in north-western Myanmar; Bang Kacha and Tok Prom near Chanthaburi, Thailand; Bo Phloi near Kanchanaburi, Thailand; and the Central Highlands of Vietnam (e.g. Roskin, 2003; Satitkune et al., 2013; Huong et al., 2016). However, none of these locations produces zircon that can be treated to such an intense, vivid blue colour as the Ratanakiri material. Here we present recent research regarding blue Ratanakiri zircon.

BACKGROUND

Zircon ($ZrSiO_4$) has a tetragonal structure (space group $I4_1/amd$) with a unit cell composed of four SiO_4^{4-} and four ZrO_8^{12-} groups (formula unit Z = 4). Non-formula cations incorporated in the zircon structure include trivalent rare-earth elements (REE^{3+}) as well as Hf^{4+}, Ti^{4+}, Th^{4+}, U^{4+}, U^{5+}, P^{5+}, Nb^{5+} and Ta^{5+} (Hoskin and Schaltegger, 2003; Kempe et al., 2016; and references therein). Although REEs are considered incompatible elements because of their large ionic radii, they commonly substitute in small amounts for Zr^{4+}, which has dodecahedral coordination in the zircon lattice (Hanchar and van Westrenen, 2007). The incorporation of trivalent REE for tetravalent Zr, however, requires charge compensation. This is mostly realised by combined incorporation of REE^{3+} along with a pentavalent ion, either P^{5+} (for Si^{4+}) or Nb^{5+}/Ta^{5+} (for Zr^{4+}; see Hoskin et al., 2000; Hoskin and Schaltegger, 2003; and references therein). Even though zircon has occasionally been reported to contain 10–30 wt.% Hf (Ma and Rossman, 2005; Pérez-Soba et al., 2007; Van Lichtervelde et al., 2009) or up to 13 wt.% U (Zamyatin et al., 2017), non-formula elements normally have low concentrations in this mineral. Other than Hf (with HfO_2 typically in the range 0.6–2.0 wt.%), all non-formula elements are well below the weight-percent level in gem-quality zircon.

Zircon is a common accessory mineral that occurs in many igneous and metamorphic rocks. Relatively large, gem-quality crystals grow predominantly in felsic pegmatites and more rarely in metasomatic rocks. Because of its hardness, remarkable physical stability and chemical resistance, zircon also is a common detrital component in sediments; hence this mineral often occurs in gravel deposits. Its susceptibility to weathering and other fluid-driven alteration, however, is appreciably increased upon the accumulation of radiation damage (e.g. Ewing et al., 2003; Hay and Dempster, 2009; Xu et al., 2012; Malusà et al., 2013). That is, alpha-decay events of U, and to a lesser extent Th (and their unstable daughter nuclei), result in structural damage, with the final, amorphous state being called *metamict* (Ewing, 1994). The accumulation of radiation damage in zircon is connected with a range of property changes, including a decrease in refractive index and birefringence (Sahama, 1981). Also, the density decreases from ~4.7 g/cm^3 to well below 3.9 g/cm^3 (Holland and Gottfried, 1955). Highly radiation-damaged zircon (that nevertheless might have some gem quality areas, usually showing a green colour) is therefore often referred to as 'low zircon' in the gemmological community.

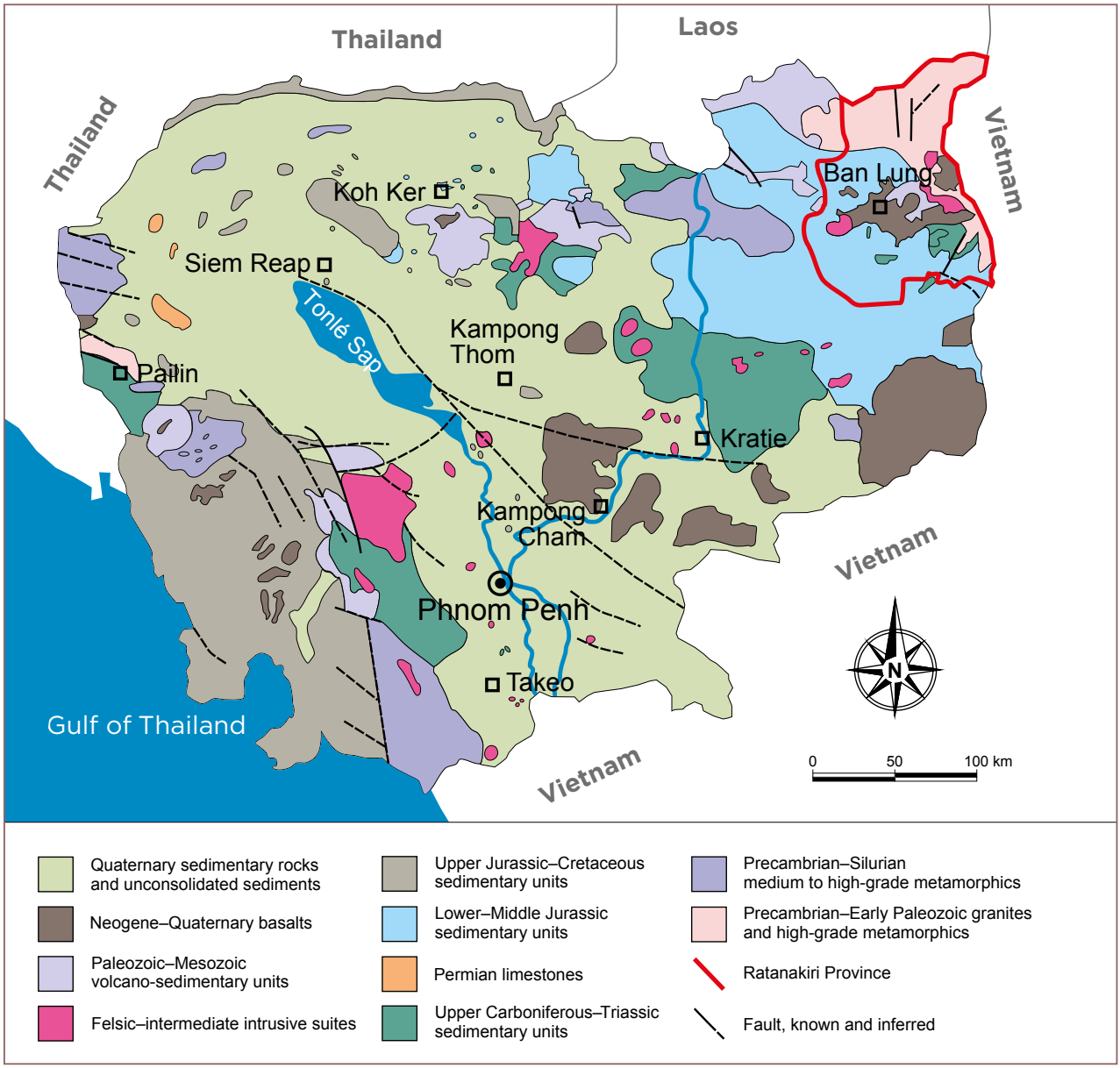

Figure 2: Ratanakiri Province, located in north-eastern Cambodia, is outlined in red on this simplified geological map of the country (modified after United Nations, 1993; Douglas et al., 2008). The zircon deposits are associated with the weathering of Neogene–Quaternary basaltic rocks (shown in dark brown).

The large variety of zircon colours depends on the content of transition metals and radiation-induced colour centres (Burns, 1993; Anderson and Payne, 1998; Nasdala et al., 2003), and might also involve crystal-field or charge-transfer transitions (Klinger et al., 2012; Kempe et al., 2016). However, the causes of most zircon colours remain unclear, or at least seem controversial to date. The only comprehensive summary of the literature, along with original spectroscopic results, was recently published by Kempe et al. (2016). The trace-element-related interpretations of colour causes proposed by these authors, however, remain unsupported as they did not present chemical data for their samples.

It should be added that doped synthetic $ZrSiO_4$ of various colouration is used as high-temperature stable and chemically inert pigments. These include, for instance, yellow Pr^{3+}-doped $ZrSiO_4$ (Stiebler et al., 1992; Del Nero et al., 2004), 'lemon'-yellow Tb^{3+}-doped $ZrSiO_4$ (Kar et al., 2004), blue V^{4+}-doped $ZrSiO_4$ (Demiray et al., 1970; Niesert et al., 2002; Pyon et al., 2011) and pink-to-red Fe-doped $ZrSiO_4$ (Cappelletti et al., 2005). It is, however, well known that the colours of natural zircon have different causes than those of the synthetic pigments, the latter of which contain dopant levels several orders of magnitude above the concentrations of the same elements in natural zircon.

ZIRCON MINING IN RATANAKIRI

Geological Setting

Ratanakiri is the north-easternmost province of Cambodia. Here, zircon crystals are found in numerous alluvial deposits that formed from the weathering of Cenozoic (Neogene–Quaternary) basaltic rocks. The Ratanakiri volcanic province belongs to the Indochina Cratonic Terrane that covers eastern Thailand, Laos, Cambodia and southern Vietnam. The development of the Ratanakiri volcanic province heralds the start of the collision of the Eurasian and Indian continents during the Himalayan orogeny (55–45 Ma ago; Gibbons et al., 2015). Extensive volcanic activity occurred much later along reactivated crustal boundaries around the Pliocene–Pleistocene boundary spanning 4.3–0.8 Ma ago (Rangin et al., 1995). The Cenozoic basalt magmatism changed from early tholeiitic flood basalts to scattered volcanic cones of alkaline composition (Hoang and Flower, 1998). Alkali basaltic rocks are considered to be the host of Ratanakiri zircon (Figure 2). During a number of eruptive events that were confined to intersections of strike-slip faults, zircon crystals were transported as xenocrysts in the alkaline magma from considerable depths to the earth's surface (Rangin et al., 1995; Balmer et al., 2009). Gem-bearing alluvial layers are presently scattered throughout the region, and they vary in thickness and depth below the surface.

Mining

Gem mining activities in Ratanakiri started in the mid-1930s (Saurin, 1957). At present, several zircon-bearing areas with numerous small workings are active (e.g. Figure 3). Their number, however, fluctuates depending on the economic situation. For instance, many mining sites closed during the past few years in favour of developing rubber plantations, which presently are more profitable than zircon mining. Productive areas for zircon are located near Ban Lung and Bae Srak (a settlement located just a few kilometres south of Ban Lung), and further east and northeast toward the Tonlé San River, especially around Bo Keo (the latter being 25 km east of Ban Lung and about 30 km from the border with Vietnam on the east). Here, gem zircon occurs in two different types of basalt-related deposits. The first consists of basaltic and pyroclastic material that is completely weathered into laterite soil, from which miners can easily extract zircon crystals by hand. The second type constitutes undecomposed basaltic gravels, requiring the use of water cannons to break up the material in search of zircon (cf. Smith

Figure 3: (a) A miner brings up a bucket filled with gravel-bearing soil at this zircon mine near Bo Keo, Ratanakiri, where shafts extend to 17 m depth. **(b)** Near Bo Loi, Ratanakiri, gravel panning is done in a small pool lined with a plastic tarp. **(c)** In addition to zircon, the washed material includes garnet, sapphire, quartz, ruby and spinel. **(d)** This reddish brown, euhedral zircon crystal is from Phnum Trom, Ratanakiri. Photos by Ralf Grunert (a, c) and L. Nasdala (b, d).

and Balmer, 2009; Balmer et al., 2009; Wanthanachaisaeng et al., 2014).

The mining methods are quite diverse because the zircon-bearing layers of various thicknesses occur at different depths. In the north (e.g. near Bo Loi, 25 km northeast of Ban Lung), gravel layers can be at fairly shallow depths; in some cases, they are even mineable in small open pits. Near Bo Keo and Phnum Trom (Bo Keo area), by contrast, miners must dig shafts up to 17 m deep into the red soil. These shafts typically are less than 1 m in diameter and have no reinforcement at all; just simple footsteps are dug into the side walls. At the bottom of the shaft, small horizontal tunnels are dug into the gravels. The miners face the constant danger of collapsing material. Buckets containing gravel and soil material are hoisted to the surface using manual winches (Figure 3a). Zircon and other heavy minerals are extracted by either dry hand-picking or pan-washing. In dry areas, washing may be done in small water-filled pits lined with plastic tarps (Figure 3b). Associated minerals found with the zircon include garnet, sapphire, quartz, ruby and spinel (Figure 3c).

Ratanakiri zircon is predominantly brown, often with a reddish or sometimes yellowish secondary hue; pale stones occur only occasionally. The shape of the zircon pieces varies considerably, ranging from completely rounded grains to perfectly euhedral crystals of predominantly short-prismatic habit (Figure 3d). Most, however, consist of moderately rounded, broken pieces that occasionally show crystal faces. Some of them have resorption features that might be due to transport in the basaltic magma (Balmer et al., 2009; Smith and Balmer, 2009).

Colour Enhancement

The brown zircon starting material is turned blue (Figure 4) by a simple heating process. The heat treatment takes place under reducing conditions at 900–1,000°C for one to a few hours (Smith and Balmer, 2009). The brown zircon (Figure 5a) is put into an alumina crucible (Figure 5b) that is sealed with a refractory clayey material (Figure 5c,d). The crucible is then enclosed in a larger crucible, which is sealed in the same manner. This assemblage is then placed in a charcoal furnace (Figure 5e) and covered with plenty of charcoal to achieve reducing conditions in an atmosphere of carbon monoxide and nitrogen. Obtaining the right temperature and atmosphere is a matter of experience; local gem treaters know the correct amount and type of charcoal to be used (for instance, charcoal made from mangrove wood works well). After two to three hours of heating, the crucible is opened and the still-hot zircon pieces initially appear colourless (Figure 5f). Only upon slow cooling do the zircon specimens develop the blue colour (Figure 5g,h).

The blue colouration of Ratanakiri zircon is long-term stable both in 'regular' daylight and in the dark; however, it shows a pronounced tenebrescence to both long- and short-wave UV radiation. Tenebrescence (i.e. reversible photochromism) is not a rare phenomenon in gems, and it has been occasionally observed for different colours and irradiations of zircon (McClure, 2011; Suthiyuth, 2014). The blue colour of Ratanakiri zircon changes to an unstable muddy greyish brown upon irradiation with long-wave UV radiation (including strong direct sunlight). The colour change appears to be fairly stable in the dark but reverses fairly soon after the sample is exposed to visible light without a UV component (Koivula and Misiorowski, 1986; Renfro, 2016).

Figure 4: These zircon samples from Ratanakiri (0.3–5.1 g) include two untreated brown crystals and three blue specimens that were heat treated at ~1,000°C under reducing conditions for a few hours. Photo by M. Zeug.

Figure 5: For the heat treatment of Ratanakiri zircon in a reducing environment, **(a)** the brown starting material is put into **(b)** an alumina crucible, and the lid is sealed with a refractory clayey material **(c, d)**. Heat treatment at ~900–1,000°C for 2–3 h is done in fairly simple ovens **(e)**, with plenty of charcoal to ensure reducing conditions. After opening the crucible lid, the still-hot zircon material appears rather colourless **(f)**, but becomes increasingly blue upon cooling **(g)**. A good fraction of the heated zircon **(h)** shows the typical vivid blue colour. Photos by L. Nasdala (a, d, e, h), Ralf Grunert (b, c, g) and Astrid Wittwer (f).

MATERIALS AND METHODS

Six gem-quality zircon specimens from Ratanakiri, Cambodia, ranging from 0.53 to 6.76 g, were sliced in half so that one part could be subjected to heating experiments while the other was retained for reference. Additional gem specimens from Ratanakiri also were heated without being sliced. The untreated samples were brown to reddish brown, some with light brown zones; the largest specimen showed fairly narrow primary growth zoning (Figure 6).

For comparison, we also analysed synthetic $ZrSiO_4$ crystals grown using Li-Mo flux techniques. These included (1) a batch of 0.5–0.8 mm 'sky'-blue V^{4+}-doped $ZrSiO_4$ (made available by Dr John M. Hanchar; for a description of the synthesis technique, see Hanchar et al., 2001); (2) one ~3 mm short-prismatic crystal of purplish blue U^{4+}-doped $ZrSiO_4$ (see Chase and

Osmer, 1966) provided by Dr George R. Rossman; and (3) various crystals of synthetic $ZrSiO_4$ individually doped with Pr, Sm, Nd, Tm or Dy, made available by Dr Dominik Talla (see Lenz et al., 2015). Optical absorption spectroscopy was performed on the first two sample sets, and photoluminescence (PL) spectroscopy was done on the third set, using the instrumentation described below.

The two largest Ratanakiri zircon specimens that were sliced—reportedly from Phnum Trom near Bo Keo—were bought from a local dealer in Ban Lung and were slabbed in his shop. Cutting was done parallel to the longest dimension of the nearly euhedral crystals to yield a pair of plates with matching faces. In both cases, the c-axis was oriented almost parallel to the cutting plane. One half of each specimen was then heat treated in Ban Lung by the same dealer (e.g. Figure 6). The other four zircon specimens that were sliced were first crystallographically oriented at the University of Vienna on a Nonius Kappa charge-coupled device (CCD) four-circle single-crystal X-ray diffraction system. Ten frames were obtained with a step width of 2° using Mo–K_α radiation. The samples were then cut in half along their c-axis using a diamond-coated tungsten wire. One half of each sample pair was subjected to heat treatment for two hours at 900°C in an electric oven, together with excess charcoal to ensure reducing conditions, whereas the other half was left in its original state. For all six samples, parallel-plane, doubly polished plates were prepared from both the heated slice and its untreated counterpart. After the completion of analyses, one blue zircon half was again heat treated, but this time under oxidising conditions at 1,000°C for three hours. Additional heating experiments were carried out on unsliced specimens under reducing conditions at 800°C, 900°C and 1,000°C, and under oxidising conditions at 300°C, 600°C, 800°C and 1,000°C. The samples were placed in a graphite crucible, which was heated at a rate of 10°C per minute to the designated temperature. After the three-hour annealing run, the furnace was switched off and the samples were allowed to cool down slowly. Those treated under reducing conditions were packed in charcoal, and those annealed under an oxidising atmosphere were simply heated in air.

Specific gravity values (here reported as mass density) were determined for the unheated halves of the two largest stones that were cut in Cambodia, as well as on the four other samples before they were sliced in half. All samples appeared more-or-less free of inclusions. The mass density values were determined by repeated weighing of the specimens in air and in distilled water (with a minute amount of detergent added to reduce surface tension).

Chemical analysis of major elements in the six samples, including both the untreated and annealed halves, was done by means of a Cameca SX 100 electron probe micro-analyser (EPMA) operated at 15 kV and 40 nA. The focal-spot diameter of the electron beam was 5 µm. The following synthetic and natural calibrant materials were used (lines analysed are shown in parentheses): $ZrSiO_4$ (Si–K_α; Zr–L_α), Hf metal (Hf–M_α), YPO_4 (Y–L_α), sanidine (Al–K_α), $ScVO_4$ (Sc–K_α), U

Figure 6: These two slices were cut from a gem-quality zircon crystal from Phnum Trom (largest dimension 17 mm). The samples were prepared as doubly polished plates (2.7 mm thick), and the half on the right was subjected to heat treatment whereas the one on the left remained in its initial state. The untreated specimen shows strong zoning, which disappeared after heat treatment. Photo by Astrid Wittwer.

metal (U–M_β), brabantite (Th–M_α), titanite (Ca–K_α), fluorapatite (P–K_α), almandine (Fe–K_α) and $YbPO_4$ (Yb–L_α). Peak/background counting times varied between 20/10 s and 80/40 s (the latter for the actinides). The modified φ(ρz) routine of Merlet (1994) was used for matrix correction and data reduction. Additional experimental details pertaining to EPMA analysis are described elsewhere (Breiter et al., 2010; Škoda et al., 2015).

Trace elements in the six samples, again including both untreated and annealed halves, were analysed with a Finnigan Element XR high-resolution laser ablation inductively coupled plasma mass spectrometer (LA-ICP-MS) system coupled to a GeoLas 193 nm excimer laser. The ablated material was transported to the ICP-MS using He carrier gas with a flow rate of 1.25 l/min, with additional Ar make-up gas added after the ablation cell. Elements in high abundance were analysed in analogue mode, whereas trace elements were analysed using a digital pulse counting mode. External independent calibration was done using NIST glasses 610 and 612 (Pearce et al., 1997) and USGS standard BCR-2G (Jochum et al., 2005). The laser spot size was varied between 40 µm (NIST glasses) and 59 µm (BCR-2G and zircon samples), resulting in an energy density of approximately 5 J/cm^2. The laser repetition rate was 8 Hz. Data reduction was done using the Iolite software package (Paton et al., 2011). For more analytical details, see Dorais and Tubrett (2012).

The U–Pb age of Ratanakiri zircon was determined for three fragments by means of solution isotope dilution thermal ionisation mass spectrometry (ID-TIMS) analysis (Krogh, 1973). The Pb and U isotope compositions were measured with a Finnigan MAT 262 mass spectrometer. After being cleaned with nitric acid, water and acetone, and weighed on a microbalance, the fragments were transferred to a Krogh-type FEP container and dissolved in hydrofluoric acid at 195°C after adding a ^{202}Pb–^{205}Pb–^{235}U spike. The spike composition was calibrated against synthetic ET100 solution (Condon et al., 2008) provided by the Earthtime initiative (www.earth-time.org). Further details of the analytical procedure are reported elsewhere (Corfu, 2004). All isotope ratios and ages were corrected for fractionation, spike and blank. The ^{204}Pb method was applied to correct for initial common Pb (based on Stacey and Kramers, 1975). The data were corrected for ^{230}Th disequilibrium according to Schärer (1984) and assuming a Th/U ratio of 4 in the magma.

Unit-cell dimensions were determined on five small chips (three brown and two blue) with a Huber 5042 four-circle single-crystal X-ray diffraction system. Analyses were done using non-monochromatised Mo radiation from a sealed-tube source at 50 kV and 30 mA. Fitting was done as implemented in the SINGLE software (Angel and Finger, 2010), and analytical settings of Hejny et al. (2012) were used.

Raman and PL spectroscopy of the six sliced samples, including untreated and annealed halves, was performed at room temperature using a dispersive Horiba LabRAM HR Evolution spectrometer equipped with an Olympus BX Series optical microscope and an Si-based, Peltier-cooled CCD detector. The analysed light was dispersed using a diffraction grating with 1,800 (Raman) or 600 (PL) grooves per millimetre. Raman spectra were excited with the 632.8 nm emission of an He-Ne laser, and PL spectra were obtained using the 473 nm emission of a diode-pumped solid-state laser. In both cases, the laser power was 10 mW at the sample. The system was calibrated using the Rayleigh line and emission lines of a Kr lamp, resulting in a wavenumber accuracy of better than 0.5 cm^{-1}. Band fitting was done after appropriate background correction, assuming Lorentzian–Gaussian band shapes. Calculated full widths at half-band maximum (FWHMs) were corrected for instrumental broadening using the empirical formula of Váczi (2014).

Optical absorption spectra in the visible to near-infrared range were obtained for all six samples in the two principal polarisations (i.e. E⊥c and E||c) in the spectral range 24,100–5,250 cm^{-1} (which roughly corresponds to 415–1,900 nm wavelength*). Analysis of the UV range was omitted because of the well-known tenebrescence

* In this article, optical absorption spectra and PL spectra are plotted and discussed on the wavenumber ($\tilde{\nu}$) scale. The wavenumber is defined as the reciprocal of the wavelength λ; it is quoted in reciprocal centimetres (conversion $\tilde{\nu}$ [cm^{-1}] = 10^7 / λ [nm]). The wavenumber scale is preferred when evaluating spectroscopic data because wavenumber values (but not the wavelengths) are proportional to the photon energy of the detected light. This makes possible reliable band fitting and direct comparison of important diagnostic features (e.g. FWHMs, band shapes and band asymmetries) across the entire spectral range. By contrast, spectra plotted on the wavelength scale are distorted in energy, with the blue and UV ranges being compressed and the red and NIR portions being stretched. This results in strongly distorted band shapes that will bias any band fitting. The authors understand that the wavelength scale is traditionally preferred among gemmologists for describing the UV, visible and NIR spectral ranges. For convenience, we therefore present all PL and optical absorption spectra with additional labels for the top abscissa axis showing the wavelength scale (in nm), and wavenumber values in the text and figures are accompanied by their respective wavelength values in parentheses.

of blue zircon (irradiation with UV light, as an analytical artefact, produces a colour change that would bias the spectra obtained). Spectra were recorded at room temperature using a Bruker IFS 66v/S Fourier-transform infrared spectrometer equipped with a mirror-optics IR-scope II microscope and a quartz beam splitter. A calcite Glan prism was used to polarise the light. Circular areas 200 µm in diameter were analysed in transmission geometry. The following combinations of light sources and detectors were used: Xe-lamp source and GaP detector for the spectral range 24,100–20,000 cm^{-1} (40 cm^{-1} spectral resolution; 1,024 scans), W-lamp source and Si detector for the range 20,000–10,000 cm^{-1} (20 cm^{-1} spectral resolution; 1,024 scans) and W-lamp source and Ge detector for the range 10,000–5,200 cm^{-1} (10 cm^{-1} spectral resolution; 512 scans). The final spectra therefore consisted of a combination of three sub-spectra that were aligned to match in absorbance if necessary.

RESULTS AND DISCUSSION

General Description and Heat Treatment

Many of the untreated brown Ratanakiri zircon specimens contained macroscopically visible dark impurities and/or large cavities. The latter were partially filled with baddeleyite (identified by Raman spectroscopy) and other secondary phases (Figure 7a,b). In addition, fluid inclusions showing various appearances were commonly observed. Some of them were transparent and colourless (Figure 7c), and others were dark brown and apparently opaque (Figure 7d) or consisted of two-phase inclusions filled with liquid and gas (Figure 7e). The fluid phase was predominantly composed of H_2O (broad, low-intensity Raman band in the 3,200–3,500 cm^{-1} range). Occasionally they contained CO_2 gas bubbles (Figure 7e; doublet of narrow Raman bands at 1,285 and 1,388 cm^{-1}). Many fluid inclusions were surrounded by a network of veinlets that appeared to be partially healed fissures (Figure 7c). Much more rarely, dark fluid inclusions sometimes were surrounded by a halo containing phases that obviously were derived from the inclusion itself (Figure 7d). The water-rich fluid phase in the halo occasionally contained hematite flakes (identified by Raman spectroscopy; see Figure 7d).

Mass density values of the six untreated samples averaged 4.674 ± 0.005 g/cm^3. This corresponds well to published density values in the range of 4.63–4.72 g/cm^3 for non- to mildly radiation-damaged zircon from Sri Lanka (Vaz and Senftle, 1971; Murakami et al., 1991).

Before heat treatment, the specimens showed brown to reddish brown colour, occasionally with an orangey hue, and some displayed distinct colour zoning (Figures 6 and 7f). Heating under reducing conditions at 800°C created a very pale blue colour. After heating at 900°C or 1,000°C under reducing conditions, the zircon samples showed a rather intense blue colouration, but with some variation in the depth of colour (see Figure 5h). The blue colour was rather uniform within single stones; primary growth zoning became invisible after the heating process (Figure 6). Our observation of a more-or-less equally intense blue colour after heating at 900°C and 1,000°C is in some contrast to the results of earlier studies. Thongcham et al. (2010) found maximum colouration after heating at 900°C, whereas at 1,000°C the colour was clearly paler. Laithummanoon and Wongkokua (2013), by contrast, produced a rather pale blue at 900°C, whereas the richest colour was reached at 1,100°C. Summarising all available data, we conclude that 900–1,000°C (Smith and Balmer, 2009) is the most promising temperature range for the creation of attractive blue colour in Ratanakiri zircon.

Heating of both the untreated brown and the heated blue zircon under oxidising conditions at 300°C resulted in significant but incomplete decolouration. This appears to be consistent with the results of Wanthanachaisaeng et al. (2014) and Siriaucharanon et al. (2017), who observed fading of the dark brown colour to nearly colourless at 400°C, although after initially heating their samples under reducing conditions. We found in our experiments that after oxidised heating at 600°C and above, the zircon samples became colourless to pale orange, without further significant changes at 800°C and 1,000°C.

We also did a series of 'alternative heating' experiments, in which the zircon specimens were subjected to multiple heat treatments at 1,000°C for three hours each: first in a reducing atmosphere, then under oxidising conditions, then again under a reducing atmosphere and so on. Heating in a reducing atmosphere resulted in blue, subsequent oxidised heating produced nearly colourless with an orange tinge, then the same shade of blue reappeared after heating under reducing conditions, etc. We were able to switch the blue colour on and off within the same specimen. In conclusion, the blue colouration can be restored, whereas there is no heat-treatment technique that recovers the initial brown to reddish brown colour. This indicates that the initial brown colour is likely caused by an irradiation-induced defect that anneals upon heat treatment.

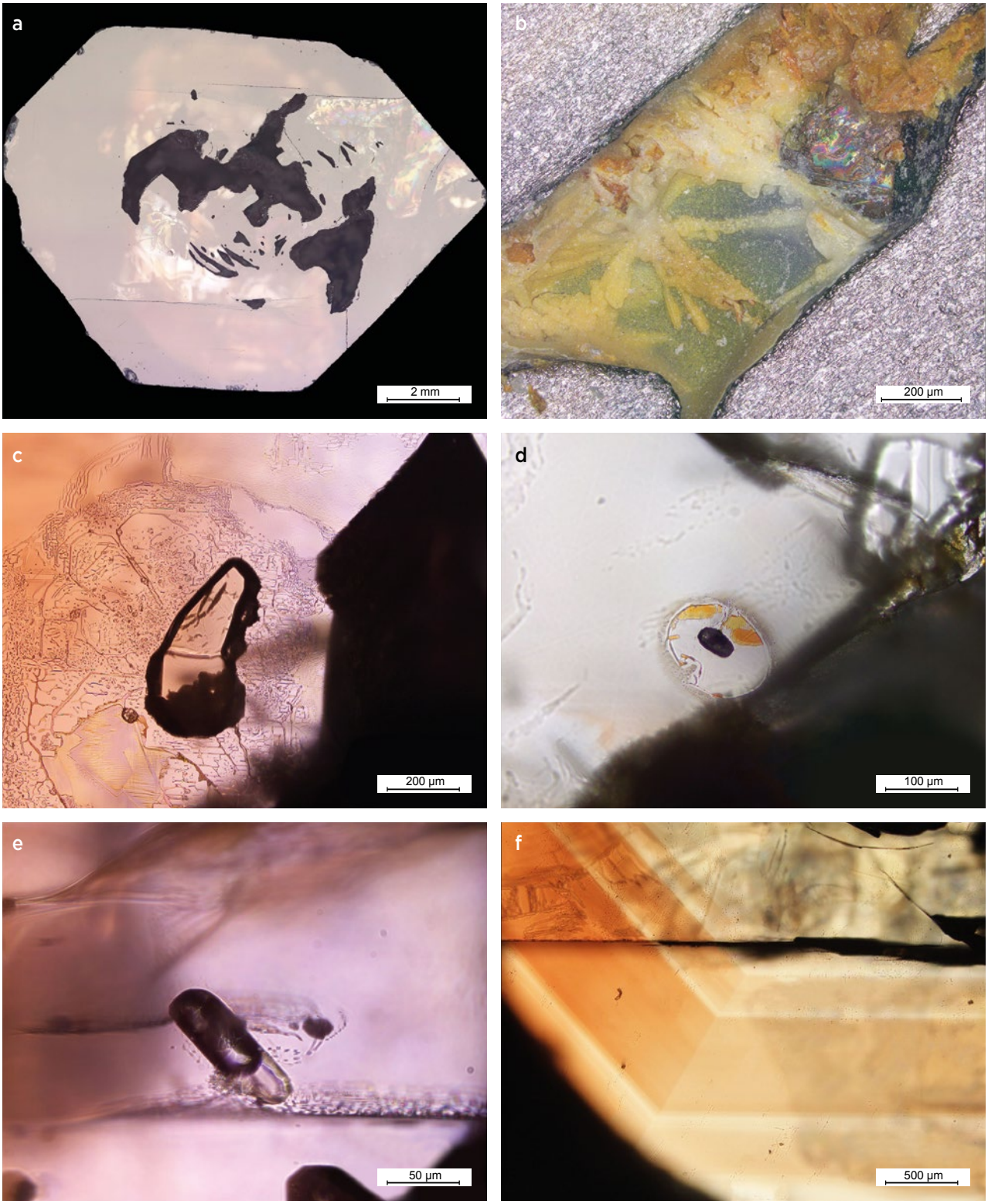

Figure 7: Various internal features are displayed by unheated Ratanakiri zircon. **(a)** Partially filled cavities are present inside a sliced zircon crystal. **(b)** The cavities are filled with yellowish baddeleyite and other unidentified alteration products. **(c)** This transparent fluid inclusion (mainly consisting of water) is surrounded by delicate patterns that trace fluid movement along fissures into the surrounding host. **(d)** An opaque inclusion of unknown composition is surrounded by a halo composed of water (clear area) and hematite (orange phase). **(e)** This fluid inclusion contains a large CO_2 bubble. **(f)** Typical primary colour zoning is shown in an unheated brown zircon specimen. Photomicrographs by M. Zeug, in reflected light (a, b) and plane-polarised transmitted light (c–f).

Chemical Composition

Chemical data for Ratanakiri zircon determined by EPMA and LA–ICP–MS analyses are summarised in Table I. The samples generally had low contents of non-formula elements, below the 0.1 wt.% level, with the only exception being Hf (~0.7 wt.% HfO_2). This value is well within the typical range for zircon and hence it does not provide any particular hint as to the formation milieu (e.g. Belousova et al., 2002). Actinide and REE concentrations were slightly higher in zones and areas of darker brown colour, compared to paler brown regions. The actinides U and Th had average concentrations of approximately 120 ppm and 95 ppm, respectively. As is common for zircon, heavy REEs were enriched relative to the middle and light REEs (Table I; cf. Hoskin and Schaltegger, 2003; Hanchar and Westrenen, 2007). This also was evident in laser-induced PL spectra, which were dominated by strong emissions of Dy^{3+}, along with lower-intensity emissions of Sm^{3+}, Pr^{3+}, Tm^{3+} and Nd^{3+} (Figure 8). The REE mass fractions of Ratanakiri zircon were slightly off the general trend for igneous zircon (Figure 9). We also observed a positive Ce anomaly (Ce/Ce* = 42) but virtually no Eu anomaly (Eu/Eu* = 1.07). By contrast, most igneous zircon samples display both a positive Ce anomaly and a negative Eu anomaly (Hoskin and Schaltegger, 2003). Our observations indicate formation of Ratanakiri zircon under oxidising conditions, where Eu is mainly trivalent and Ce is mainly tetravalent (Hanchar et al., 2001). The absence of a negative Eu anomaly is not unusual; it has been observed in zircon crystals derived from kimberlites (Hoskin and Ireland, 2000) and syenite xenoliths associated with corundum (Hinton and Upton, 1991; Sutherland et al., 2002).

Age Determination

Results of seven ID-TIMS analyses of Ratanakiri zircon are presented in Table II. The mean $^{206}Pb/^{238}U$ age was determined at 0.92 ± 0.07 Ma (error quoted at the 95% confidence level). This very young age appears consistent with the LA–ICP–MS results of Sutherland et al. (2015), who determined a mean $^{206}Pb/^{238}U$ age of 0.83 ± 0.15 Ma for three zircon inclusions in sapphires from Bo Loi, Ratanakiri. Those zircon inclusions, however, were genetically different from Ratanakiri gem zircon, as indicated by their much higher actinide concentrations of 299–1,114 ppm U and 150–1,270 ppm Th (Sutherland et al., 2015).

Table I: Average chemical composition of Ratanakiri zircon determined by EPMA and LA-ICP-MS.

EPMA results (n = 172)[a]		LA–ICP–MS results (n = 26)					
Oxide	Concentration (wt.%)[b]	Element	Isotope measured	Concentration (ppm)[c]	Element	Isotope measured	Concentration (ppm)[c]
SiO_2	32.6 ± 0.2	P	31	73.5 ± 15.6	Tb	159	4.37 ± 2.37
ZrO_2	66.8 ± 0.3	Ti	49	6.37 ± 2.46	Dy	163	48.5 ± 23.7
HfO_2	0.693 ± 0.035	V	51	nd[d]	Ho	165	16.3 ± 7.2
P_2O_5	0.042 ± 0.009	Y	89	440 ± 182	Er	166	63.6 ± 24.6
Total	100.2 ± 0.4	Nb	93	5.62 ± 3.97	Tm	169	12.1 ± 4.1
		La	139	nd	Yb	172	104 ± 31
		Ce	140	2.84 ± 1.89	Lu	175	16.6 ± 4.2
		Pr	141	0.07 ± 0.05	Hf	179	5,869 ± 266
		Nd	146	1.11 ± 0.83	Pb	208	nd
		Sm	147	2.30 ± 1.45	Th	232	94.2 ± 94.9
		Eu	153	1.84 ± 1.10	U	238	119 ± 68
		Gd	157	11.9 ± 6.7			

[a] Al_2O_3, Sc_2O_3, CaO, FeO, Yb_2O_3, UO_2 and ThO_2 were not detected or averages were below 0.005 wt.%.
[b] Quoted errors are 2σ. [c] Quoted errors are 1σ. [d] nd = not detected.

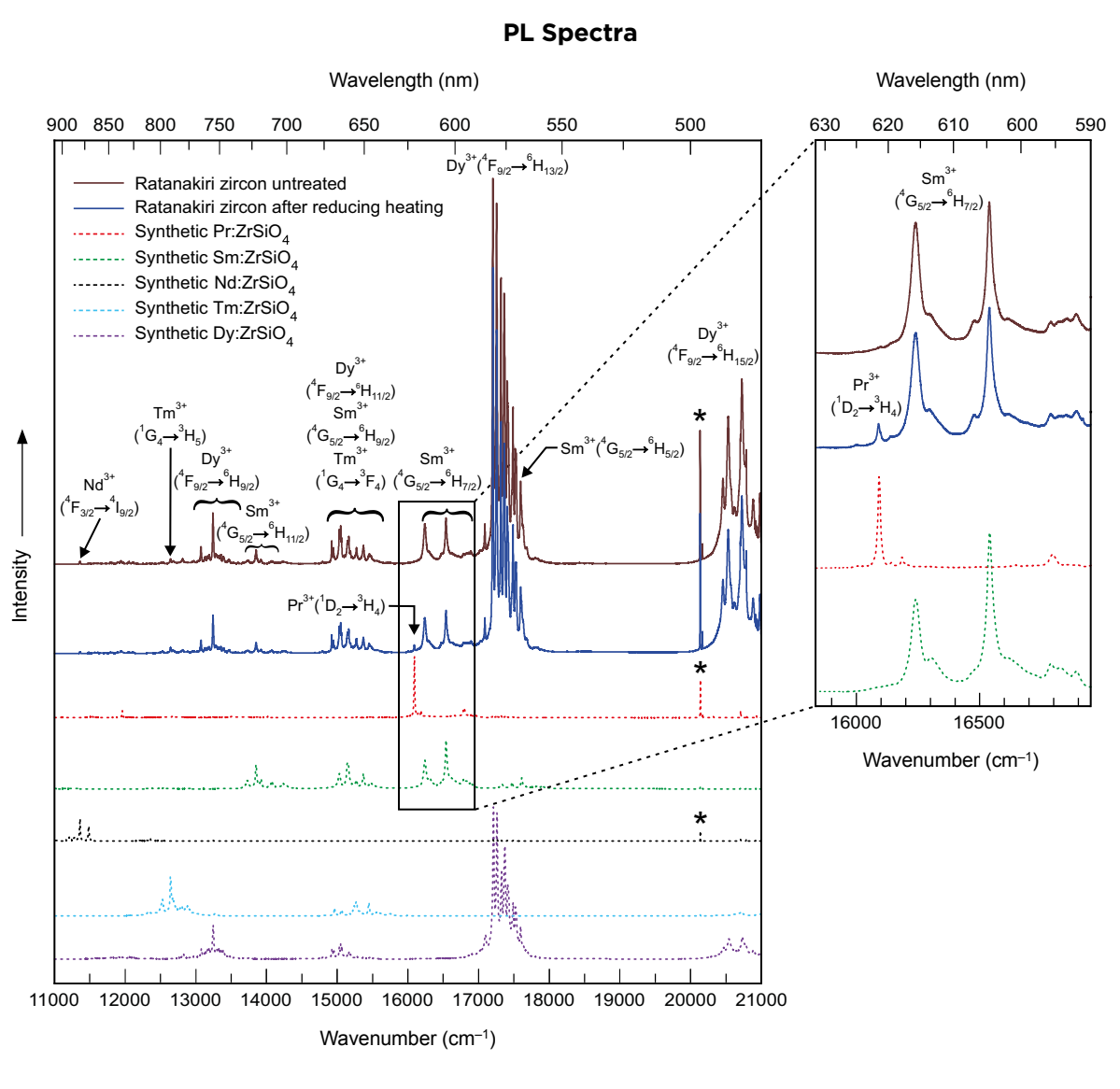

Figure 8: Representative PL spectra are shown for unheated and heat-treated Ratanakiri zircon, and compared to reference spectra of REE-doped synthetic $ZrSiO_4$. Note that the $^1D_2 \rightarrow {}^3H_4$ transition of Pr^{3+} is only observed in the PL spectrum of heat-treated blue Ratanakiri zircon. Raman bands in the PL spectra are marked by asterisks. For assignment of PL lines see Gaft et al. (2000) and Lenz et al. (2015); for assignment of Raman bands see Nasdala et al. (1995; and references therein).

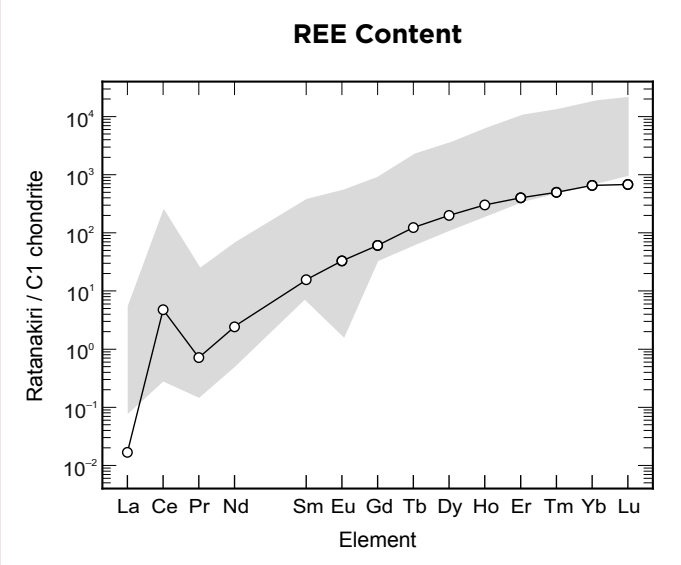

Figure 9: The average C1 chondrite-normalised REE concentrations in Ratanakiri zircon determined by LA-ICP-MS are plotted together with a shaded grey area, which shows the REE ranges of typical unaltered igneous zircon (graphically extracted from Figure 4 of Hoskin and Schaltegger, 2003).

Table II: U-Pb geochronology data (ID-TIMS results) for Ratanakiri zircon.

Analysis no.	Weight (µg)	Pb (ppm)	U (ppm)	Th (ppm)	Pb_{com}[a] (pg)	$^{206}Pb/^{204}Pb$[b]	$^{206}Pb/^{238}U$)	$^{206}Pb/^{238}U$ age (Ma)	$^{207}Pb/^{235}U$	$^{207}Pb/^{206}Pb$
389/10	529	0.020	39.4	6.9	9.8	37.8	0.000160 ± 0.000003	**1.03 ± 0.02**	0.00124 ± 0.00021	0.0563 ± 0.0100
389/10[c]	–	0.008	39.5	11.6	3.6	64.9	0.000143 ± 0.000001	**0.92 ± 0.01**	0.00093 ± 0.00010	0.0472 ± 0.0051
391/1	1166	0.004	31.9	11.6	1.8	191.1	0.000145 ± 0.000000	**0.93 ± 0.00**	0.00108 ± 0.00004	0.0539 ± 0.0020
394/1	585	0.031	39.3	54.3	16.4	29.0	0.000128 ± 0.000004	**0.83 ± 0.03**	0.00080 ± 0.00025	0.0451 ± 0.0155
391/2	840	0.014	46.4	20.5	8.5	56.6	0.000148 ± 0.000001	**0.95 ± 0.01**	0.00136 ± 0.00008	0.0668 ± 0.0044
394/2	948	0.022	58.1	24.1	14.9	47.9	0.000142 ± 0.000002	**0.91 ± 0.01**	0.00132 ± 0.00010	0.0676 ± 0.0054
394/3	833	0.038	40.0	1.1	29.1	27.1	0.000134 ± 0.000005	**0.86 ± 0.03**	0.00094 ± 0.00030	0.0510 ± 0.0187

[a] Pb_{com} = total common Pb in sample (initial plus blank).
[b] Raw data, corrected for fractionation and spike.
[c] The solution for sample 389/10 was separated after dissolution and before chemical separation, for aliquot analysis.

Structural State

The dimensions of the tetragonal unit cell were determined as a_0 = 6.604 ± 0.001 Å and c_0 = 5.979 ± 0.001 Å, resulting in a unit cell volume of 260.73 Å^3. These values coincide (within errors) with the unit cell parameters of synthetic pure $ZrSiO_4$ (Nasdala et al., 2002; Van Westrenen et al., 2004). The unit cell dimensions convert to an 'X-ray mass density' of 4.6699 g/cm^3, comparable to the average measured density of 4.674 ± 0.005 g/cm^3. The FWHM of the $\nu_3(SiO_4)$ Raman band, which is used to estimate the degree of self-irradiation damage in zircon (Nasdala et al., 1995), averaged 1.8 ± 0.2 cm^{-1} (Figure 10a), indicative of a very high degree of crystallinity. The Raman spectrum of Ratanakiri zircon is, therefore, indistinguishable from that of synthetic pure $ZrSiO_4$ (Nasdala et al., 2002).

Both X-ray and Raman results were identical within errors for unheated samples and their heat-treated analogues. This, and the conformity to synthetic pure $ZrSiO_4$, indicates first that the generally low amounts of trace elements do not cause detectable deviation from the ideal zircon structure. Second, the absence of any detectable structural change upon annealing indicates that Ratanakiri zircon has not accumulated noticeable amounts of radiation damage. The alpha dose, calculated from the U–Pb age and average U and Th concentrations, is 4 × 10^{14} α/g, which is well below the self-irradiation level of ~5 × 10^{16} α/g that is known to cause initial spectroscopically detectable changes to zircon (Figure 10b; cf. Zhang et al., 2000; Nasdala et al., 2001).

Hence, it is not possible to unravel the heat treatment of Ratanakiri zircon by means of structural analysis. By contrast, there was a minor but interesting difference in the PL spectra: We found that the emission of treated Ratanakiri zircon always contained a low-intensity, narrow line at 16,090 cm^{-1} (621.5 nm wavelength; strong E⊥c polarisation), whereas untreated specimens did not show this feature. It is assigned to the $^1D_2 \rightarrow {}^3H_4$ electronic transition of Pr^{3+} (Figure 8; cf. Gaft et al., 2000). Its presence, however, cannot be used as a general indicator for the heat treatment of zircon, as the Pr^{3+} line has also been observed in untreated zircon specimens (e.g. the Sri Lankan reference zircon GZ7; Nasdala et al., research in progress).

Optical Absorption Spectroscopy

Optical absorption spectra are shown in Figure 11. Note again that the UV spectral region was not analysed in the present study because of the material's strong photochromism—that is, the fairly fast blue-to-brown colour change upon irradiation with, and hence analysis in, UV light.

The optical absorption spectrum of untreated Ratanakiri zircon was dominated by the following features: an intense absorption edge that extended from the UV into the blue range and down towards the NIR region; an intense broad absorption band near 19,800 cm^{-1} (505 nm wavelength); a rather weak, broad absorption band near 12,500 cm^{-1} (800 nm wavelength); and two groups of narrow absorption bands near 9,025 cm^{-1} (1,108.0 nm wavelength, with a shoulder at ~9,190 cm^{-1} or 1,088.1 nm) and 6,665 cm^{-1} (1,500.4 nm wavelength) that are polarised with E⊥c (Figure 11a). The reddish brown colour of the unheated zircon is due to the combination of the first two features listed above, which cause enhanced absorption in the blue-to-green range. The

~19,800 cm^{-1} (~505 nm) band appears to be an analogue of the 510–515 nm absorption band described by Klinger et al. (2012). Those authors assigned reddish brown zircon colouration to a paramagnetic oxygen-hole centre nearest-neighbouring to an uncompensated Y^{3+} that substitutes for Zr^{4+}. This assignment is supported by the disappearance of the 505–515 nm band upon heating: It has been known for a long time that electron- or hole-related colour centres are irreversibly destroyed at fairly low temperatures of a few hundred degrees Celsius (Gastil et al., 1967; Fielding, 1970). Such hole centres may be generated slowly in zircon by radioactive self-irradiation (Rossman, 1981). If this is confirmed true, the very low self-irradiation dose experienced by Ratanakiri zircon might suggest that both the development of Y^{3+}-related brown colouration and its saturation require fairly low irradiation levels. The two narrow absorptions in the spectral range below 10,000 cm^{-1} (i.e. above 1,000 nm wavelength) are due to U^{5+} (Vance and Mackey, 1974; Zhang et al., 2003). However, they do not contribute to the colouration, as these absorptions are in the NIR range.

After heating at 1,000°C in reducing conditions, the absorption edge and the bands at ~19,800 cm^{-1} (~505 nm) and ~12,500 cm^{-1} (~800 nm) were reduced significantly in intensity (Figure 11b). The spectra showed a new, strongly pleochroic (E⊥c) absorption band centred at ~15,600 cm^{-1} (~640 nm wavelength) with an FWHM of >3,000 cm^{-1} (≥125 nm wavelength; Figure 11b). The absorption in the 18,200–13,000 cm^{-1} (~550–770 nm wavelength) range results in a 'window' of reduced absorption in the blue to greenish blue region. Only a minor fraction of the uranium was reduced to U^{4+}, whereas the majority remained in the pentavalent state. The appearance of tetravalent U is seen in particular with E⊥c polarisation by two narrow, low-intensity bands at 15,290 cm^{-1} (654.0 nm wavelength) and 14,480 cm^{-1} (690.6 nm wavelength). Due to their very small area integral compared to that of the broad ~15,600 cm^{-1} (~640 nm) band, the contribution of U^{4+} absorption is considered insignificant for blue zircon colouration.

After heating at 1,000°C in oxidising conditions, the ~15,600 cm^{-1} (~640 nm) band disappeared completely (Figure 11c). It is worth noting that oxidised heating was

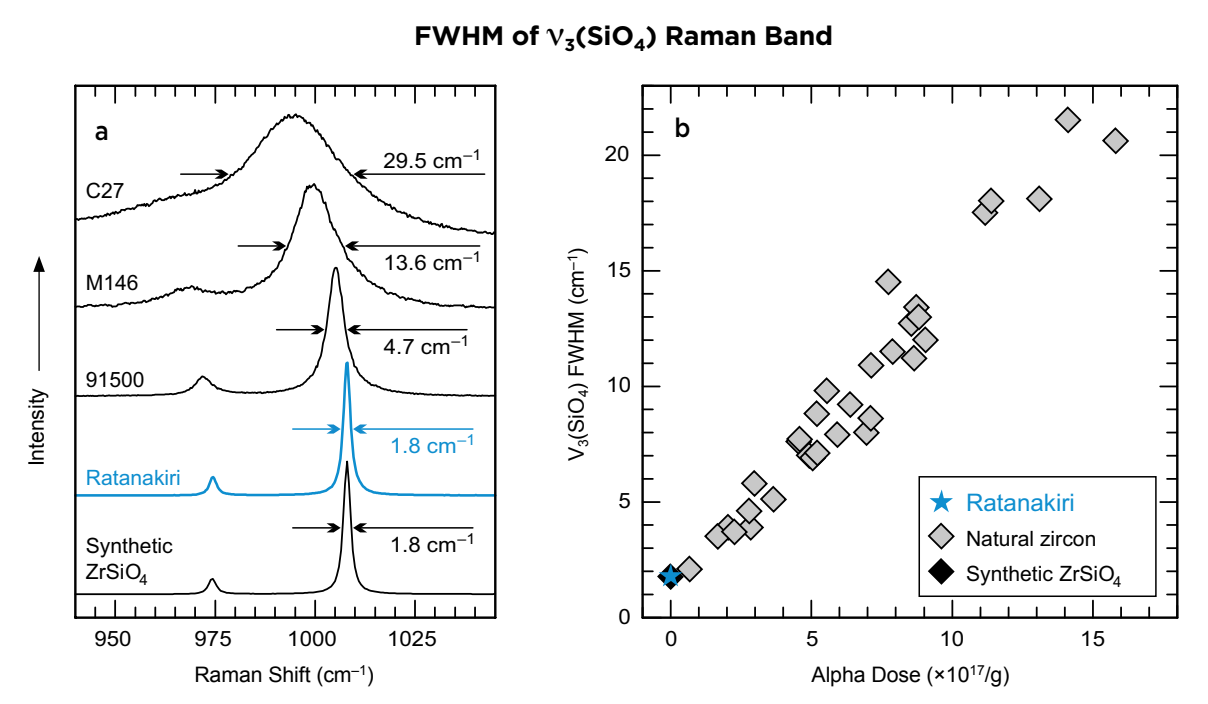

Figure 10: (a) The Raman spectrum (SiO_4 stretching region) of Ratanakiri zircon is shown in comparison with spectra of synthetic $ZrSiO_4$ and three natural zircons with different degrees of radiation damage: sample 91500 from Kuehl Lake, Ontario, Canada (mildly damaged; see Wiedenbeck et al., 2004); and samples M146 (moderately damaged) and C27 (severely damaged), both from gem gravels in Ratnapura, Sri Lanka (for both, see Nasdala et al., 2004). **(b)** A plot of the FWHM of the $\nu_3(SiO_4)$ Raman band near 1,000 cm^{-1} against the alpha dose includes data for Ratanakiri zircon, various samples of natural zircon (from Nasdala et al., 2001) and synthetic $ZrSiO_4$. Both plots reveal that Ratanakiri zircon is spectroscopically indistinguishable from (perfectly crystalline) synthetic $ZrSiO_4$, indicating that Ratanakiri zircon has accumulated extremely low amounts of radiation damage.

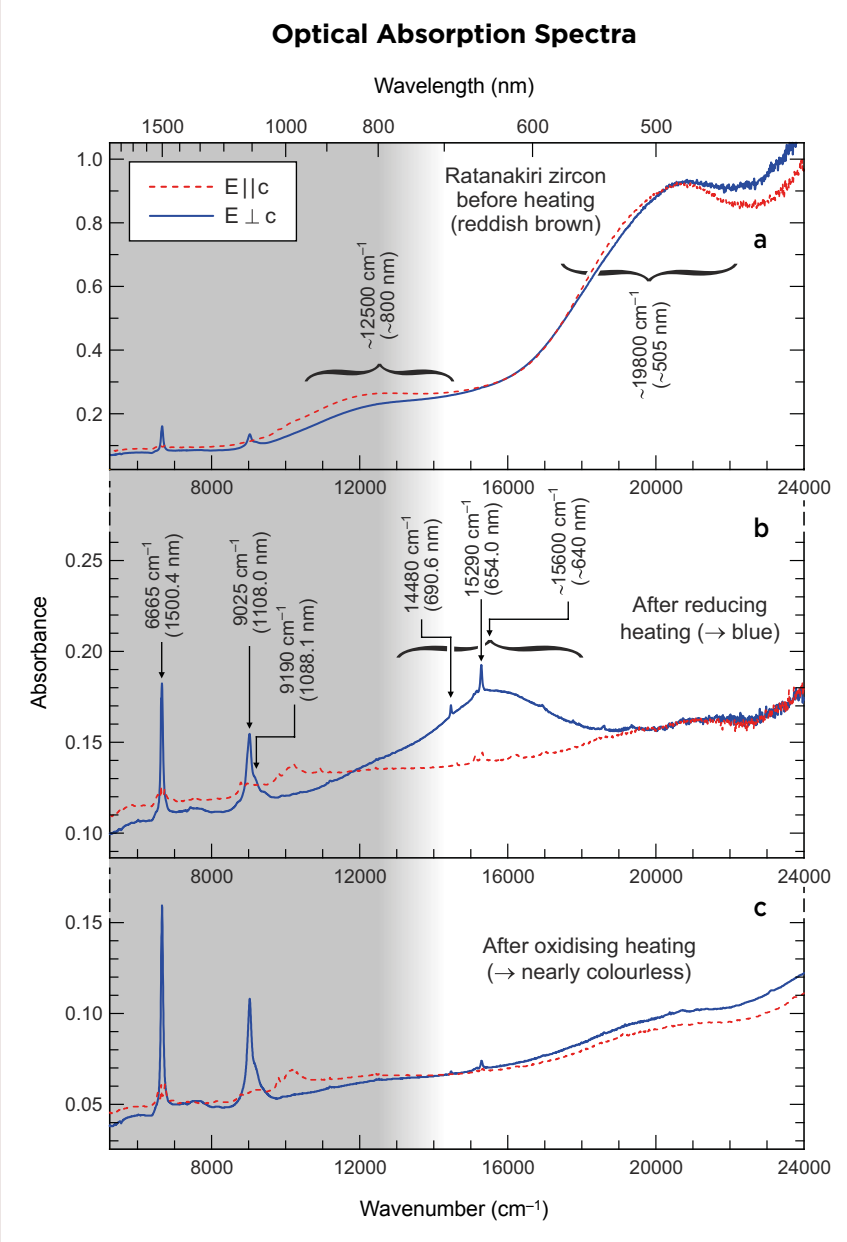

Figure 11: Polarised optical absorption spectra of Ratanakiri zircon (sample thickness 2.7 mm) were obtained from the same specimen **(a)** before heating, and then after heat treatment at 1,000°C under **(b)** reducing and **(c)** oxidising conditions. The near-infrared range, invisible to the human eye, is shaded grey. After heating under reducing conditions, a broad absorption band in the 18,200–13,000 cm^{-1} (~550–770 nm) region is observed with E⊥c. This band, of unknown attribution, results in a 'window' of reduced absorption in the blue to greenish blue range. Intense, sharp bands in the NIR region, especially at 6,665 cm^{-1} (1,500.4 nm) and 9,025 cm^{-1} (1,108.0 nm) are assigned to U^{5+}-related centres; these bands, however, do not contribute to the colouration.

found to produce the same colouration (near-colourless) and absorption spectrum, independent of whether the starting material was unheated reddish brown or heat-treated blue. Similar to the results obtained for blue samples, the absorption edge and the ~19,800 cm^{-1} (~505 nm) and ~12,500 cm^{-1} (~800 nm) bands were reduced significantly, with the absorption in the entire visible range being even slightly lower than in samples heated under reducing conditions. Compared to the spectrum of the blue zircon, the U^{4+} absorption features at 15,290 cm^{-1} (654.0 nm) and 14,480 cm^{-1} (690.6 nm) were appreciably lessened, in favour of a slight re-increase of the U^{5+} features at 9,025 cm^{-1} (1,108.0 nm) and 6,665 cm^{-1} (1,500.4 nm).

Cause of the Blue Colouration

The interpretation of the ~15,600 cm^{-1} (~640 nm) band that causes blue colouration is problematic. This band appears quite similar in spectral position, width and polarisation to the ~15,650 cm^{-1} (~639 nm) absorption band of V^{4+} in synthetic $ZrSiO_4$ (Figure 12a; cf. Niesert et al., 2002). Nevertheless, the blue colour of Ratanakiri zircon cannot be assigned to V^{4+}. First, the ~6,900 cm^{-1} (~1,450 nm wavelength) absorption of V^{4+} with E||c is missing from the optical absorption spectra of blue Ratanakiri zircon. Second, the concentration of V in Ratanakiri zircon is below the LA-ICP-MS detection limit (< 0.04 ppm), whereas blue V^{4+}-doped $ZrSiO_4$ has vanadium concentrations in the weight percent range (e.g. Niesert

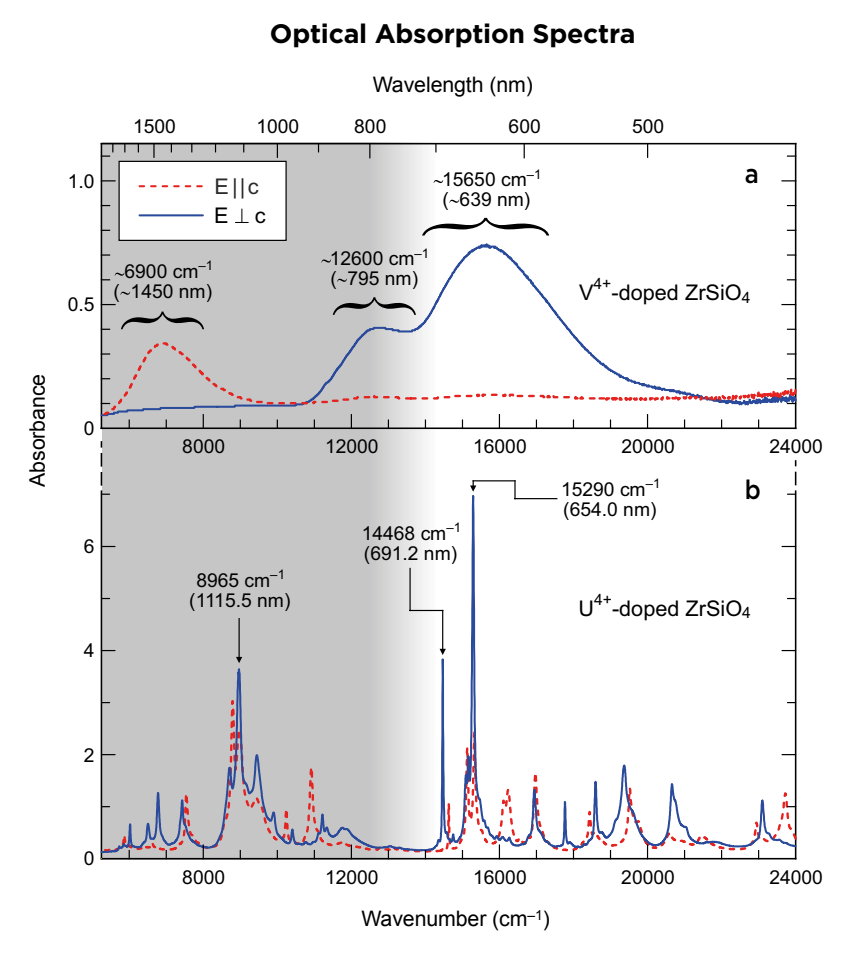

Figure 12: These polarised optical absorption spectra of two blue synthetic $ZrSiO_4$ samples doped with **(a)** V^{4+} (sample thickness ~0.3 mm) and **(b)** U^{4+} (~1.5 mm thick) are shown for comparison with the Ratanakiri zircon in Figure 11.

et al., 2002 reported 1.28 wt.% V for their blue pigment). Third, if V^{4+} caused the colour of Ratanakiri zircon, a valence change of the V needs to be assumed to explain the colour change upon oxidised heating. This is in contrast to the fact that blue V^{4+}-doped $ZrSiO_4$ is grown under oxidising conditions (Niesert et al., 2002). Also, we performed heat-treatment experiments on V^{4+}-doped $ZrSiO_4$ crystals, and neither reduced nor oxidised heating seemed to affect their blue colouration.

Another possible cause of the blue colour of zircon is the elevated presence of U^{4+}. The absorption of this ion in the $ZrSiO_4$ structure is characterised by numerous, strongly polarised lines (Richman et al., 1967), with the strongest absorptions in the red range. Together with the commonly present absorption edge that extends from the UV into the blue range, U^{4+} absorption might cause green zircon colouration (Kempe et al., 2016, and references therein), whereas U^{4+} alone causes blue. We had the opportunity to verify this by studying one of the historic synthetic U^{4+}-doped $ZrSiO_4$ crystals grown by Judith A. Osmer, now in the sample collection of Dr George R. Rossman. Whereas Chase and Osmer (1966) described green U-doped zircon, the specimen loaned to us displayed blue colour with a weak purplish hue. The optical absorption spectra are shown in Figure 12b.

Previous authors (Wanthanachaisaeng et al., 2010; Satitkune et al., 2013) have assumed that the blue colour of Ratanakiri zircon might be assigned to a change in the oxidation state of uranium. This was questioned by Thongcham et al. (2010), who found that upon heating above 900°C, the blue colour decreased whereas the narrow U^{4+} absorption still increased. Our optical absorption spectra of blue Ratanakiri zircon (Figure 11) show U^{4+} absorption lines of very low intensity. Despite the reducing conditions during heating, most of the U remained in the pentavalent state. There was minor $U^{5+} \rightarrow U^{4+}$ transformation; this, however, was negligible compared to the observed change in colour. Another consideration questioning U as the colour cause is that, of all zircons, the low-U Ratanakiri material is particularly susceptible to develop blue colour. One would expect that if U caused blue colour, zircon containing

Figure 13: This yellow gold ring contains a 4.84 ct heat-treated Ratanakiri zircon. Courtesy of Beau Soleil (Scottsdale, Arizona, USA); photo by Jeff Scovil.

more U should show an even more intense blue. That, however, is not the case.

Another attempted assignment of the blue colour was published by Laithummanoon and Wongkokua (2013). They speculated that the blue colouration is due to a change in the oxidation state of Tb (i.e. $Tb^{4+} \rightarrow Tb^{3+}$) upon heating under reducing conditions. This was based on the two observations that the colour change was accompanied (1) by the disappearance of Tb^{4+} signals in electron paramagnetic resonance spectra and (2) by the concurrent appearance of a small absorption feature near 650 nm. However, the ~650 nm feature also was present in optical absorption spectra obtained by Laithummanoon and Wongkokua (2013) after oxidised heating at 600°C and 700°C, which produced nearly colourless samples and questions the contribution of the ~650 nm feature to zircon colouration. We assign the broad ~650 nm band observed by Laithummanoon and Wongkokua (2013) to U^{4+} (cf. 15,290 cm^{-1} or 654.0 nm band in Figure 12b). Also, one should note that the electronic structure of Tb^{3+} shows a huge gap between ~20,000 and 6,000 cm^{-1} (~500–1,667 nm wavelength; Dieke and Crosswhite, 1963; Couwenberg et al., 1998), which suggests that absorption of visible light is only possible in the blue range.

CONCLUSIONS

Zircon from Ratanakiri Province in north-eastern Cambodia is mined from secondary deposits associated with the weathering of alkali basaltic rocks. We determined a mean $^{206}Pb/^{238}U$ age of 0.92 ± 0.07 Ma for the zircon. The unit cell dimensions and Raman data indicated a very high degree of crystallinity, which is consistent with the young age and the low concentration of actinides. Our samples also had consistently low contents of other non-formula elements (i.e. below the 0.1 wt.% level), with the only exception being Hf (~0.7 wt.% HfO_2, which falls within the typical range for zircon).

Ratanakiri zircon turns vivid blue (e.g. Figure 13) upon heat treatment under reducing conditions at 900–1,000°C. Based on the new data presented here, the authors exclude several of the potential colour causes that have been proposed in the literature thus far. However, we are still unable to provide convincing explanations (1) for the blue colour of Ratanakiri zircon and (2) for why zircon from other localities is much less, or even not at all, susceptible to an analogous colour change. Even though we have demonstrated that the blue colour is due to a broad, strongly polarised absorption band (E⊥c) in the red-to-yellow range (centred at ~15,600 cm^{-1}, or ~640 nm wavelength), a definitive assignment of this band remains enigmatic.

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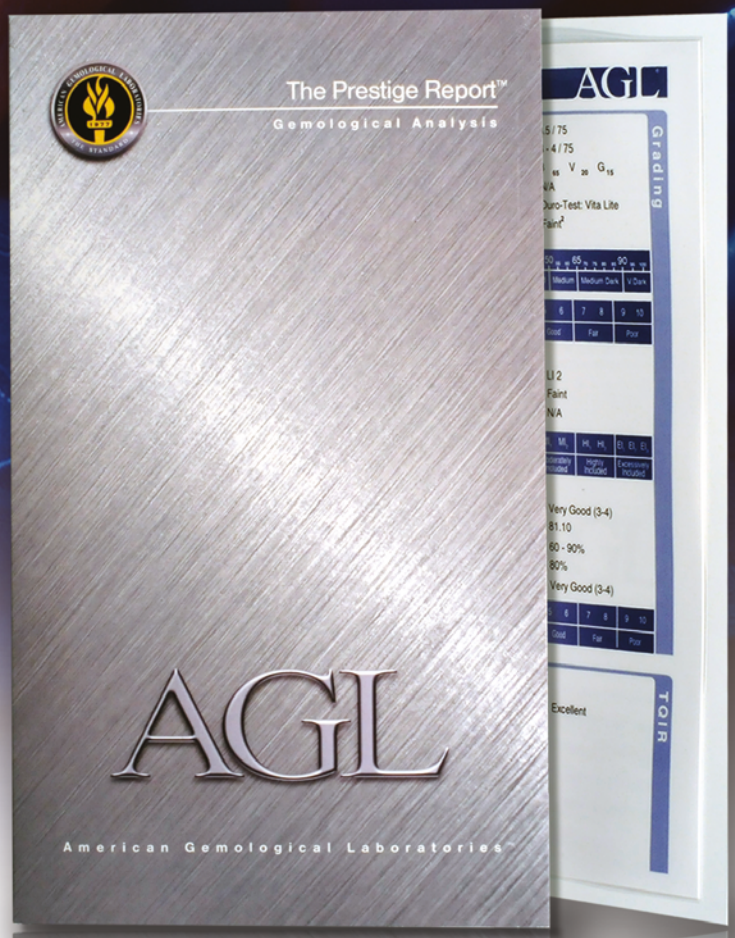

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A Thick Overgrowth of CVD Synthetic Diamond on a Natural Diamond

Shi Tang, Jun Su, Taijin Lu, Yongwang Ma, Jie Ke, Zhonghua Song, Jun Zhang and Houxiang Liu

ABSTRACT: In October 2017, a natural diamond overgrown by a thick layer of CVD synthetic diamond was identified at the Beijing laboratory of the National Gemstone Testing Center (NGTC). The round-brilliant-cut sample was near-colourless and weighed 0.11 ct. No sign of the overgrowth was observed with magnification. However, DiamondView images showed a distinct boundary in the pavilion separating layers of different luminescence: The upper layer displayed red fluorescence with greenish blue phosphorescence, while the lower portion showed deep blue fluorescence and no phosphorescence. Infrared spectroscopy revealed that the upper layer was type IIa and the lower portion was type Ia. Ultraviolet-visible-near infrared (UV-Vis-NIR) spectroscopy recorded an unusual co-existence of the N3 centre at 415 nm together with absorption due to $[Si\text{-}V]^-$ defects at 737 nm. The photoluminescence (PL) spectrum confirmed a high level of $[Si\text{-}V]^-$ defects. The approximate thickness of the CVD synthetic layer was ~740 µm, which is much thicker than previously reported for such overgrowths. The presence of the N3 centre in the natural diamond layer caused this sample to be passed as natural by various screening instruments. Luminescence imaging is key to identifying such overgrowths, and should be relied upon more heavily in the screening procedures used by gemmological laboratories in the future.

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The deposition of single-crystal synthetic diamond thin films on natural diamond by the chemical vapour deposition (CVD) method has been known for many years. One case reported in 1993 involved a greyish blue type IIb CVD synthetic diamond thin film grown on nonconductive natural diamond, resulting in a product very similar to high-quality natural type IIb blue diamond (Fritsch and Phelps, 1993). The same year, another study reported on the preferential incorporation of defects in CVD synthetic diamond films grown on different crystal faces of diamond substrates (Yacobi et al., 1993). More recently, additional types of coatings have been documented, such as Au- or Ag-doped SiO_2/Fe_2O_3 films on natural diamond to induce fancy colours (Shen et al., 2007), and nanocrystalline diamond-like films to improve the appearance and/or durability of colourless cubic zirconia (i.e. 'Diamantine'; Shigley et al., 2012). Subsequently, Eaton-Magaña (2014) reported on a boron-doped CVD synthetic diamond film deposited on the pavilion of a natural diamond to create a bluish colour; that particular sample showed significant degradation in colour appearance due to years of daily wear. In all of these studies, the thickness of the coating layer was no more than 10 µm, which is negligible compared to the thickness of the substrates, so the existence of the films did not significantly influence the size or weight of the substrates (although in some cases they were sufficient to change the overall colour appearance).

Not until 2017 was the first example of synthetic CVD overgrowth on natural diamond reported by a laboratory on a client stone (Moe et al., 2017). The 0.33 ct Fancy blue sample was composed of a layer of type IIb blue CVD synthetic diamond on a natural colourless type

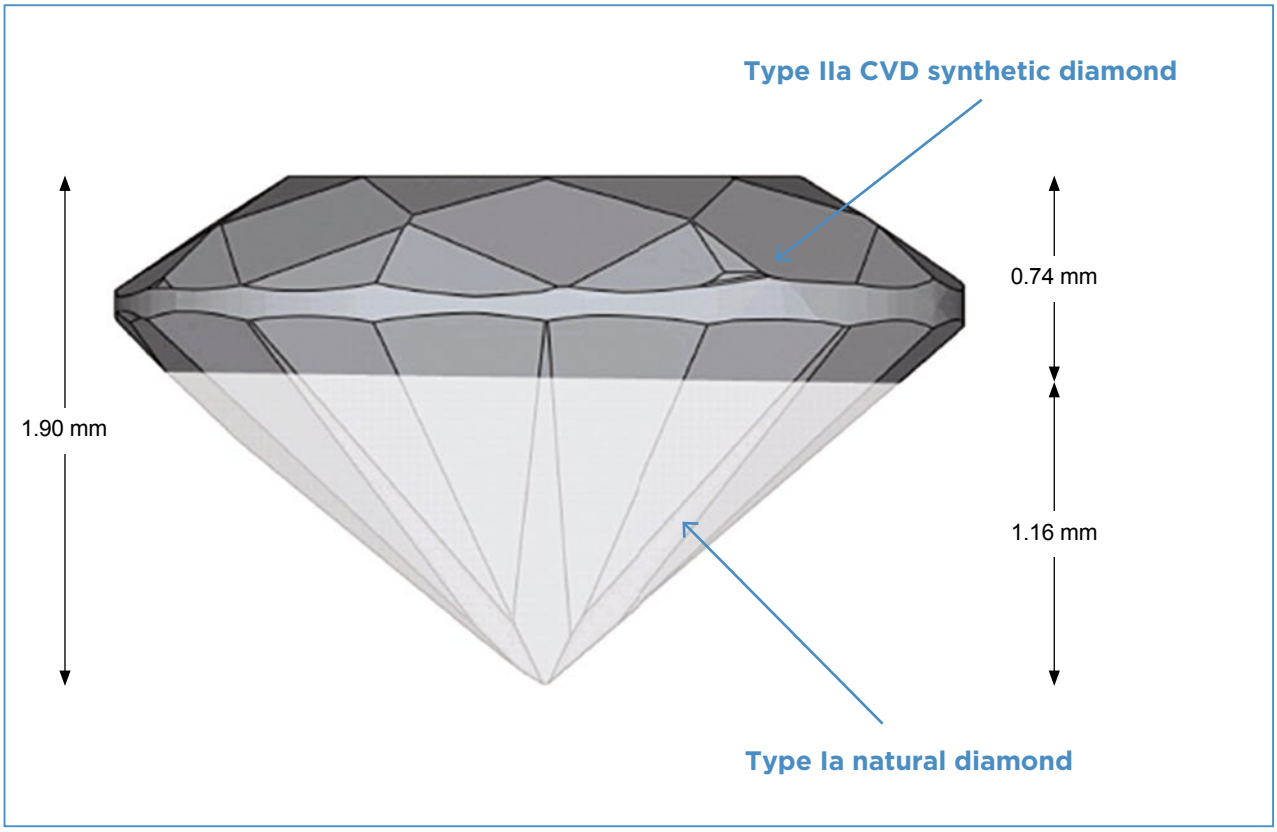

Figure 1: This drawing shows the distribution of the CVD synthetic diamond overgrowth on natural diamond that constitutes the 0.11 ct sample described in this article.

Ia diamond. The CVD layer was confined to the top of the crown and was approximately 80 µm thick, much greater than typical CVD coatings or films. The infrared spectrum revealed very unusual mixed-type Ia and IIb features. DiamondView imaging showed yellowish green fluorescence and phosphorescence when examined face-up, and deep blue fluorescence and no phosphorescence in the face-down view. PL spectra showed emissions from $[Si\text{-}V]^-$ defects at 736.6 and 736.9 nm. A distinct interface was visible under magnification, with cloud-like inclusions trapped at the boundary with the overgrowth, as well as dark needles located at or near this interface. Furthermore, Serov et al. (2017) described five 'hybrid' diamonds produced by a company in Russia. These 0.08–0.29 ct faceted samples consisted of natural diamond with a thick layer (~400 µm) of CVD synthetic diamond deposited on their crowns.

The growth of type IIa CVD synthetic diamond on the surface of natural type Ia diamond is strictly limited by many technical factors, such as crystal lattice matching, growth conditions and surface preparation. As a result, the technique's progress has been relatively slow, and few such samples are known so far. Nevertheless, on 26 October 2017, NGTC's Beijing laboratory identified such an overgrowth on a 0.11 ct near-colourless round brilliant. The lower pavilion of the sample was colourless natural diamond and the top part consisted of a thick layer (~740 µm) of colourless CVD synthetic diamond (Figure 1).

The sample was submitted by a client for an identification report. According to the client, the gem was bought at a jewellery fair in Hong Kong. The customer was told that the diamond was treated but received no further information. NGTC subsequently learned that the sample was manufactured in China by a company that keeps a low profile. According to the company, the main purpose of the overgrowth is to increase the weight of diamond gemstones. As of late 2017, the technique was still undergoing development and had not yet been applied on a large scale.

This is the first time that such an overgrowth-bearing diamond has been encountered in a gemmological laboratory in China, and it is also the thickest CVD overgrowth reported so far on a natural diamond. A brief announcement about this sample was made in December 2017 (Rapaport News, 2017), and this article describes its gemmological characteristics and the results of testing with various screening instruments.

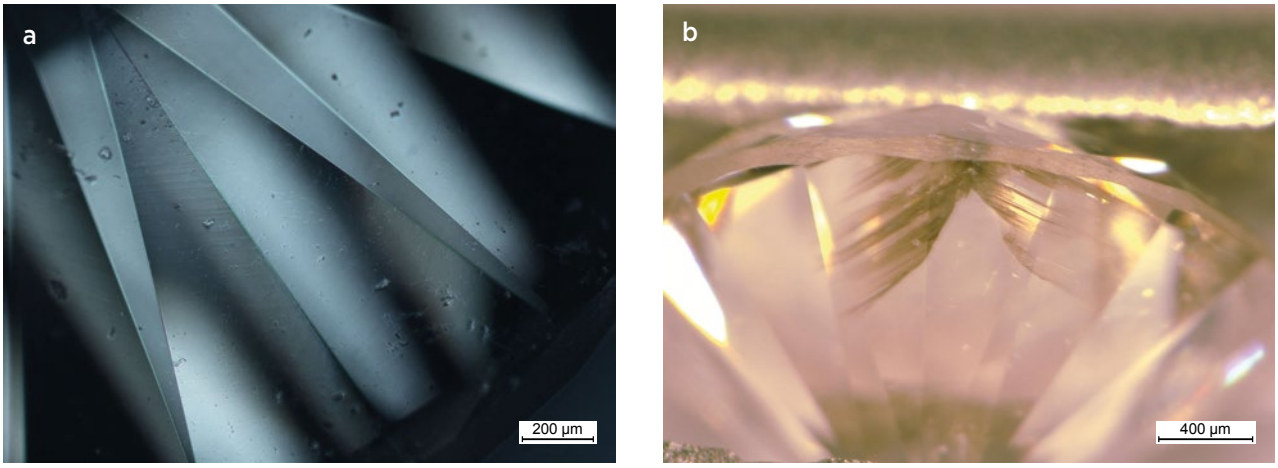

Figure 2: (a) The sample showed no visible signs of overgrowth with microscopic observation, as shown here on the pavilion with reflected light. **(b)** Near the girdle of the specimen, a large fracture ran through the crown and pavilion, including both the CVD synthetic and natural diamond layers. Photomicrographs by S. Tang.

MATERIALS AND METHODS

A thorough characterisation of the 0.11 ct sample was done at the NGTC laboratory in Beijing. Inclusions and anomalous birefringence were observed with a standard gemmological microscope and a high-powered microscope (up to 100×). A DiamondView instrument was used to observe the fluorescence and phosphorescence, as well as growth structures in multiple orientations. Fourier-transform infrared (FTIR) spectra were obtained separately through the upper and lower layers of the sample using a Thermo Nicolet 6700 spectrometer (6000–400 cm^{-1} range, 1,280 scans and 2 cm^{-1} resolution). A Gem-3000 UV-Vis-NIR spectrometer was used to obtain absorption spectra at room temperature. PL spectra were collected with four laser excitations (325, 473, 532 and 785 nm), at liquid-nitrogen temperature, using a Renishaw InVia Raman microspectrometer. The sample also was tested with two commonly used screening instruments, a DiamondSure and a DS2000 Natural Diamond Selector.

RESULTS AND DISCUSSION

Basic Properties

Weighing 0.11 ct, the round-brilliant-cut sample was near-colourless with a slight brown hue and low clarity (equivalent to L colour and I_1 clarity, respectively, in GIA's diamond grading system).

The total depth of the specimen was 1.90 mm. Based on the ratio of the two layers revealed by the DiamondView (described below), the approximate thickness of the CVD synthetic diamond layer was 0.74 mm, while the natural diamond substrate was 1.16 mm thick. A rough calculation of the volumes of the two parts showed that the natural diamond portion weighed ~0.0078 g (0.039 ct), which means the CVD synthetic diamond layer constituted two-thirds of the sample's total weight.

Microscopic Characteristics

Observations using both a standard gemmological microscope and a high-powered microscope showed no internal or external characteristics that related to, or indicated the existence of, a synthetic overgrowth (Figure 2a). There was no visible boundary marking the interface of the two layers, and the sample displayed uniformity in every aspect such as colour distribution, clarity characteristics, and cutting and polishing condition. On one side of the girdle there was a large fracture that ran through the crown and pavilion, through both the natural and synthetic layers, reinforcing the appearance of a homogeneous diamond (Figure 2b). High-power microscopic observation with crossed polarisers revealed no obvious differences in anomalous birefringence (as expected, given the small size of the sample).

Luminescence Features

When observed with a standard UV lamp, the specimen displayed no noticeable luminescence. However, in the DiamondView instrument the sample emitted distinctly different colours of luminescence and showed a sharp fluorescence boundary in particular directions. Viewed table-up, red fluorescence and bluish green phosphorescence were seen (Figure 3a,b). In the table-down view, a large area of the pavilion showed deep blue fluorescence and no phosphorescence, but the area toward the girdle displayed a ring of red fluorescence

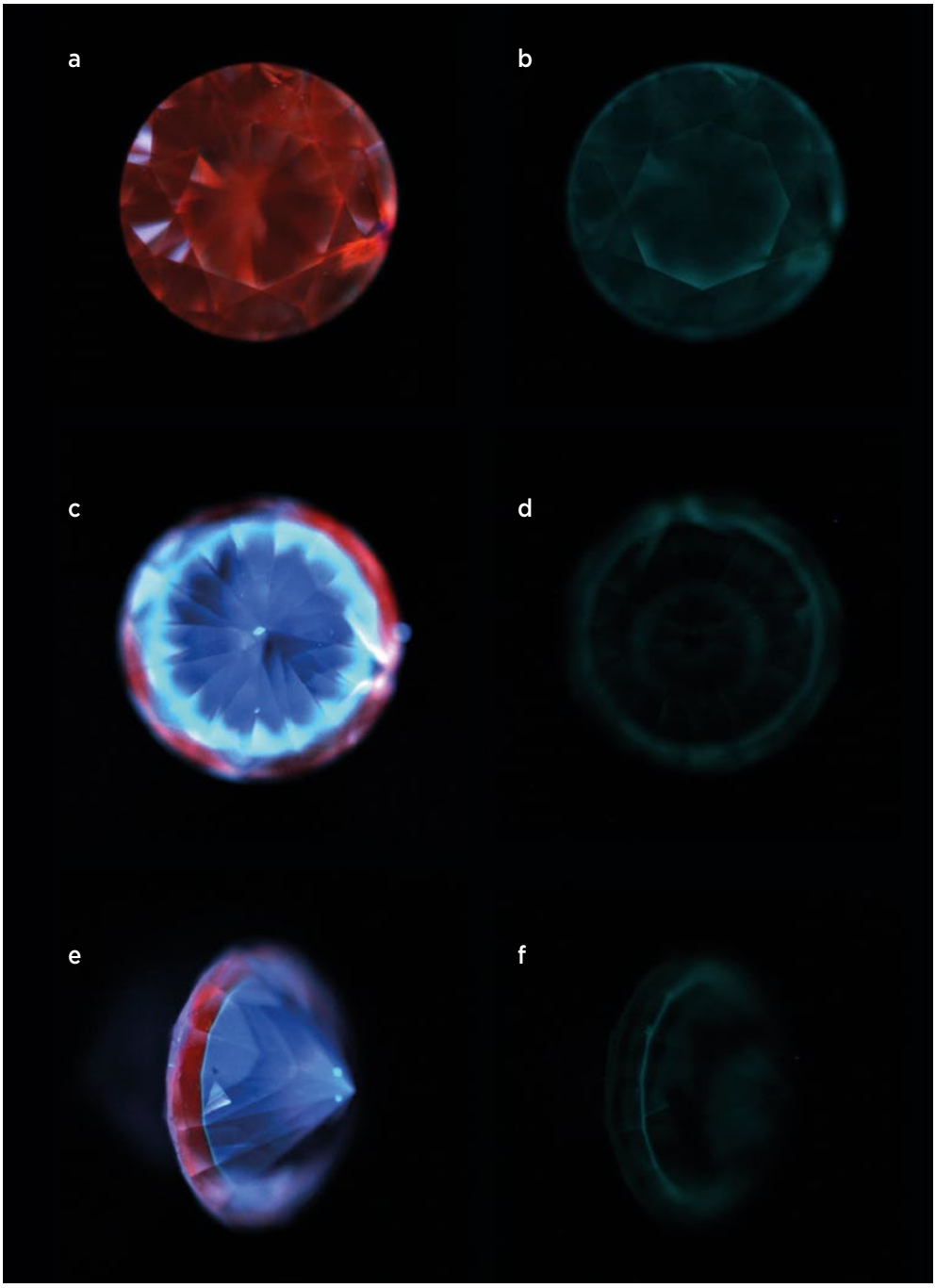

Figure 3: Fluorescence (left) and phosphorescence (right) images of the 0.11 ct sample are shown with the DiamondView instrument, as viewed table-up, table-down and obliquely through the pavilion. The CVD layer displays red fluorescence and greenish blue phosphorescence, while the natural diamond substrate emits deep blue fluorescence and no phosphorescence. Images by S. Tang.

and bluish green phosphorescence (Figure 3c,d). Viewed obliquely through the pavilion, a distinct boundary was clearly seen between the two layers of luminescence, and significantly stronger phosphorescence was visible along the interface (Figure 3e,f). The red fluorescence resulted from NV centres associated with trace single-nitrogen impurities in the CVD synthetic diamond layer, while the deep blue fluorescence dominating the natural diamond substrate was generated by large-scale lattice dislocations as well as abundant N3 centres (cf. Luo and Breeding, 2013).

UV-Vis-NIR Absorption Spectrum

The sample's UV-Vis-NIR absorption spectrum showed an unusual coexistence of the N3 centre at 415 nm and the $[Si\text{-}V]^-$ defect at 737 nm (Figure 4). The N3 centre, which is formed by three nitrogen atoms surrounding a vacancy, is the most commonly seen colour centre in type Ia natural diamond and is seldom found in synthetic diamond. The $[Si\text{-}V]^-$ defect is generated by a silicon impurity combined with a vacancy and is negatively charged; it is quite common in CVD synthetic diamonds and has become a main identification criterion for them.

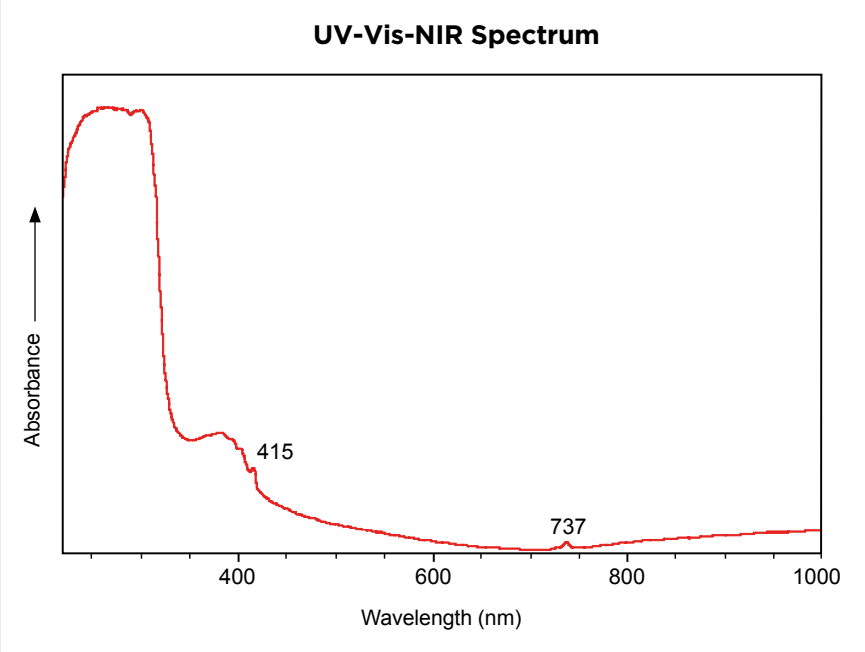

Figure 4: The UV-Vis-NIR spectrum of the hybrid diamond displays a very unusual combination of absorptions from the N3 centre at 415 nm and the [Si-V]⁻ defect at 737 nm.

Occasionally the [Si-V]⁻ defect does appear in natural diamond, but the content is so low that it cannot be detected by UV-Vis-NIR spectroscopy (Breeding and Wang, 2008). Only with PL spectroscopy can this defect be detected in natural diamond. The phenomenon of coexisting absorptions from the N3 centre and [Si-V]⁻ defect in the same spectrum is extremely unusual and should arouse suspicion about a sample's origin.

FTIR Spectra

FTIR transmission spectra were obtained separately through the pavilion (near the culet) and through the crown of the sample (Figure 5). To avoid collecting mixed signals, for each measurement the infrared beam passed through the sample in a direction parallel to the table facet. The resulting spectra showed that the lower portion of the pavilion was type Ia, with absorptions from aggregated nitrogen impurities at 1368 and 1282 cm^{-1}. However, the crown of the sample turned out to be type IIa, since no absorption related to nitrogen impurities appeared between 1400 and 1100 cm^{-1}, and no boron-related absorptions were detected at 2800 or 1290 cm^{-1}. Natural diamonds are nearly all (98%) type Ia and contain nitrogen impurities detectable with the FTIR spectrometer. Most of these impurities exist in the form of aggregated nitrogen, characteristic of type Ia diamond (Breeding and Shigley, 2009). Colourless and near-colourless CVD synthetic diamonds normally contain no detectable nitrogen (or extremely low amounts of single-nitrogen defects), defining them as type IIa by their FTIR spectra. CVD synthetic diamonds doped with boron during their growth are type IIb and show blue colouration.

The two distinct FTIR spectra obtained from the sample show that it is composed of two different types of diamond material. It should be noted that a bulk FTIR scan of the sample would result in a mixed-type spectrum consisting of features from both layers, and the specimen would thus appear to be type Ia.

Photoluminescence Spectra

The PL spectra of the sample collected at liquid-nitrogen temperature using various laser excitations revealed more detailed information about the subtle impurities and defects it contained. The 532 nm laser excited a strong [Si-V]⁻ defect emission at 737 nm, along with a weak doublet at 596/597 nm (Figure 6a). Both of these features are regarded as diagnostic for CVD synthetic diamonds (Wang et al., 2003). The 596/597 nm doublet emission is unstable in a high-temperature environment and would be eliminated during post-growth high-pressure, high-temperature (HPHT) treatment (Eaton-Magaña and D'Haenens-Johansson, 2012). The brownish hue of near-colourless CVD synthetic diamond is commonly reduced or even removed by HPHT treatment, which also transforms NV centres into H3 defects. As a result, the dominant fluorescence colour changes from red to green or bluish green, depending on the treatment temperature (Eaton-Magaña and Shigley, 2016). Thus, we deduce that the

present sample had not undergone high-temperature colour treatment, based on the existence of the 596/597 nm doublet and the red fluorescence colour of the CVD layer, as well as the slightly brownish hue of the sample.

PL spectra collected with both the 473 and 532 nm lasers exhibited strong emissions due to the NV^- centre at 637 nm and the NV^0 defect at 575 nm, consistent with the red fluorescence of the CVD layer.

PL spectra obtained with 325 nm excitation caused an emission at 415 nm from the N3 centre in the natural diamond layer, even when the beam was focused on the surface of the table facet (Figure 6b). Ni-related emissions at 883/885 nm were generated by the 785 nm laser (Figure 6c), and were far more intense when the culet was analysed with the 830 nm laser, together with multiple peaks of unknown attribution at 829–831 nm. Although Ni-related features are often attributed to an HPHT synthetic origin, they also can appear rarely in natural diamond (Tang et al., 2017).

Although PL spectra were recorded from both the crown and pavilion sides of this small sample, overall they showed few differences except for the strengths of some emissions. Even when focused on the natural diamond near the culet, excitation with the 532 nm laser still produced the 737 nm emission. In addition, when analysed on the table facet (CVD side) with the 325 nm laser, the 415 nm emission was shown as well.

Testing with Screening Devices

Over the past decades—especially during the last few years, after colourless HPHT synthetic diamonds became more common—various types of diamond screening devices have been developed and effectively applied. Most of these devices are based on the same detection principle: testing a sample for absorption at 415 nm due to the N3 centre. As mentioned above, the vast majority of natural colourless to near-colourless diamonds are type Ia, which contain nitrogen impurities, and the N3 centre is the most commonly seen defect in these stones. Conversely, colourless to near-colourless synthetic diamonds are normally type IIa, with no N3 centre. As a result, by detecting only the existence of the N3 centre, a diamond can be quickly diagnosed as natural or suspect. The small percentage of suspect samples then can be tested further with FTIR spectroscopy to determine their diamond type, and type Ia diamonds are passed as natural (leaving only type IIa specimens in need of further testing). However, natural diamonds with an overgrowth layer of CVD synthetic diamond might not be properly detected with such screening devices.

Testing of the 0.11 ct sample in multiple orientations with both the DiamondSure and the DS2000 instruments gave 'pass' results, since the N3 absorption was detectable regardless of how the specimen was oriented.

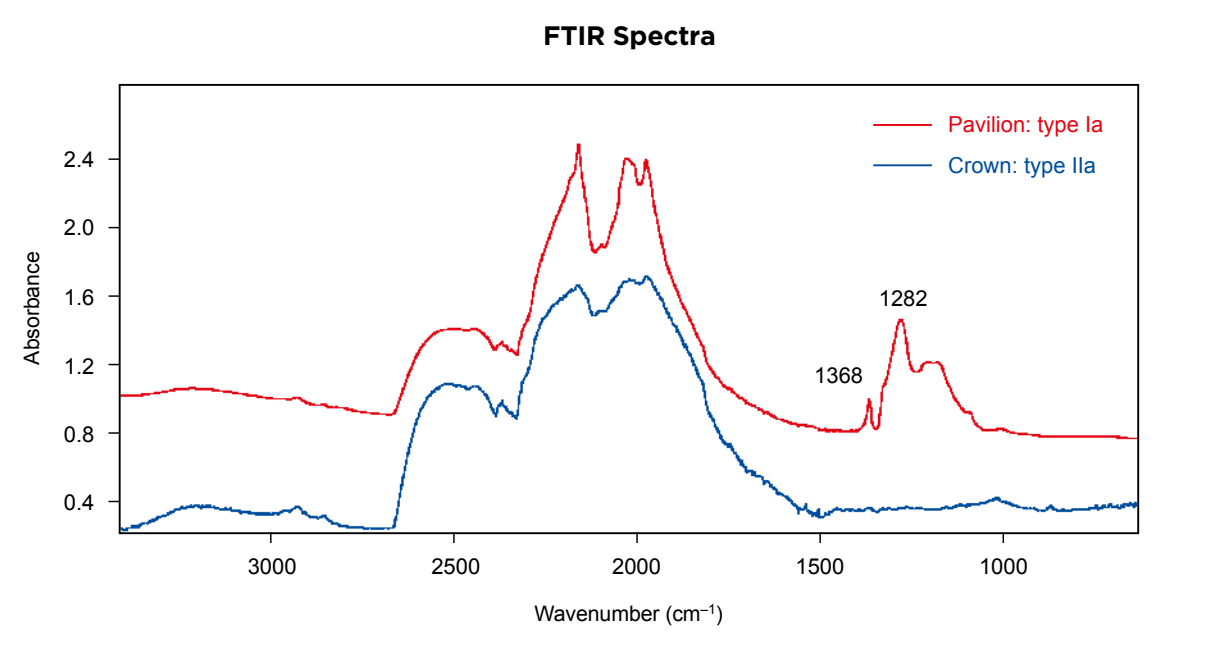

Figure 5: FTIR spectra of the two different layers of the sample show features indicative of type Ia diamond in the lower pavilion and type IIa diamond in the crown. The absorptions in the 3000–2800 cm^{-1} region are artefacts due to surface oils. The spectra are stacked vertically for clarity.

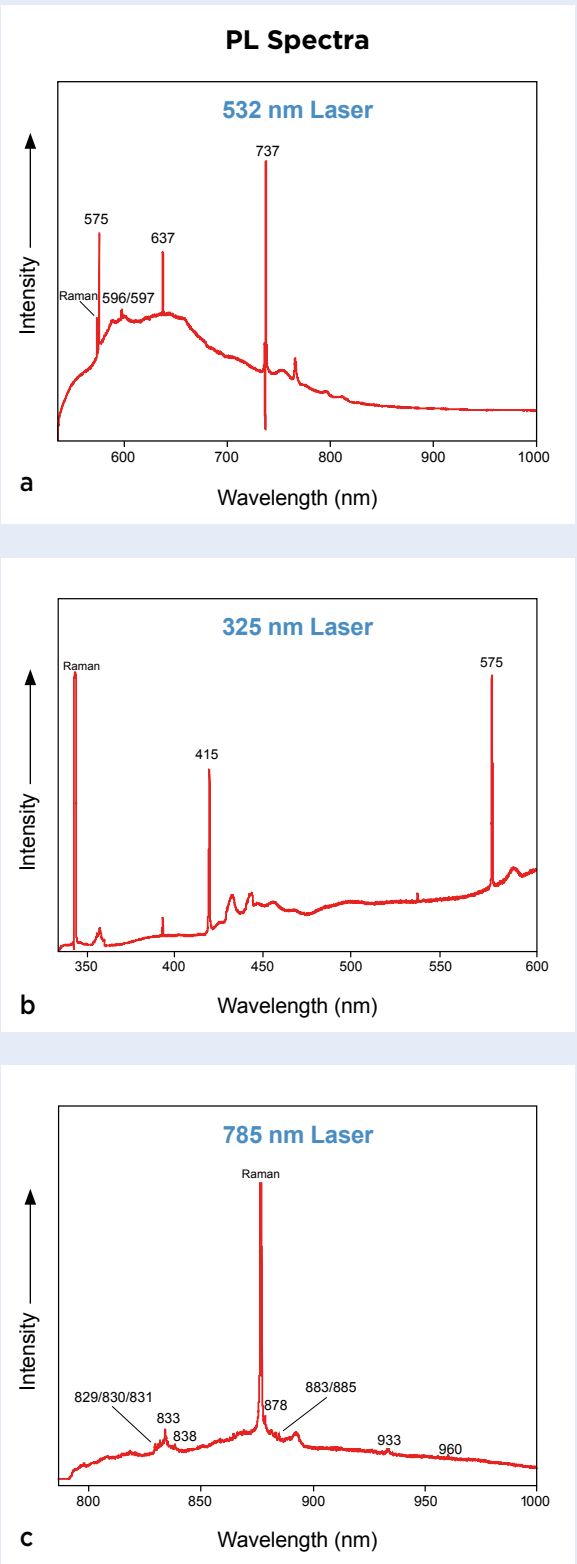

Figure 6: The PL spectra of the sample collected with **(a)** 532 nm, **(b)** 325 nm and **(c)** 785 nm laser excitation at liquid-nitrogen temperature reveal features representative of two different diamond types and raise questions as to the nature of this hybrid specimen.

It is clear that a single absorption criterion (such as the N3) or a single feature (such as diamond type classification) is not enough to correctly identify such a hybrid diamond.

DISCUSSION AND CONCLUSIONS

This is the first time that CVD synthetic diamond overgrown on natural diamond has been encountered in a Chinese gemmological laboratory. The thickness of the synthetic layer (~740 µm) was much greater than previously reported for such overgrowth-bearing diamonds, and it significantly influenced the weight and size of the sample. Although we initially suspected that the sample might have resulted from simply not removing the natural diamond substrate material after prolonged CVD growth, our further investigations into the producer showed that the synthetic overgrowth was done deliberately to increase the weight of the natural diamond.

The visual appearance of the synthetic overgrowth layer was indistinguishable from that of the natural diamond. Unlike a type IIb CVD synthetic layer, which has a blue colour different from the colourless natural diamond substrate, the type IIa CVD layer on the near-colourless type Ia natural diamond showed no visible colour difference or boundary. In addition, we observed no inclusions located at or near the interface, such as dark needles that were described previously (Moe et al., 2017). The major inclusion in the 0.11 ct sample was a large fracture extending across the crown and pavilion. The evenly distributed colour and lack of distinguishing features increased the difficulty of properly identifying the sample.

Screening instruments that rely on detecting N3 absorption in a bulk infrared spectrum would likely pass such a sample as type Ia natural diamond due to the presence of nitrogen defects in the natural layer. However, the 737 nm feature due to $[Si\text{-}V]^-$ defects in the CVD synthetic layer was easy to detect in a UV-Vis-NIR absorption spectrum taken at room temperature. In addition, DiamondView images illustrated the overgrowth very clearly as a separate layer. The PL spectrum provided further confirmation of the hybrid origin of the specimen. In the laboratory report for this sample, we used the wording 'natural diamond with synthetic diamond overgrowth'.

To conclude, the identification of a thick CVD synthetic overgrowth is not difficult for a well-equipped gemmological laboratory, as long as thorough testing and comprehensive judgements are performed. Of concern, however, is the challenge to screening methods and

equipment that are based on specific spectral characteristics or diamond type classification. Traditional screening procedures for colourless to near-colourless diamonds that rely on single features are not sufficient and need to be improved. While it is unknown how rapidly this overgrowth technique might progress, for now the impact seems more academic than practical, since currently there is no indication that such products are becoming more common in the market (e.g. no additional samples of this type have been identified by the authors, even after initiating a full-range screening process in our Beijing laboratory to test not only for the N3 centre but also for the $[Si\text{-}V]^-$ defect). However, this sample does illustrate the need for future development of procedures and instrumentation to deal with such hybrid diamonds.

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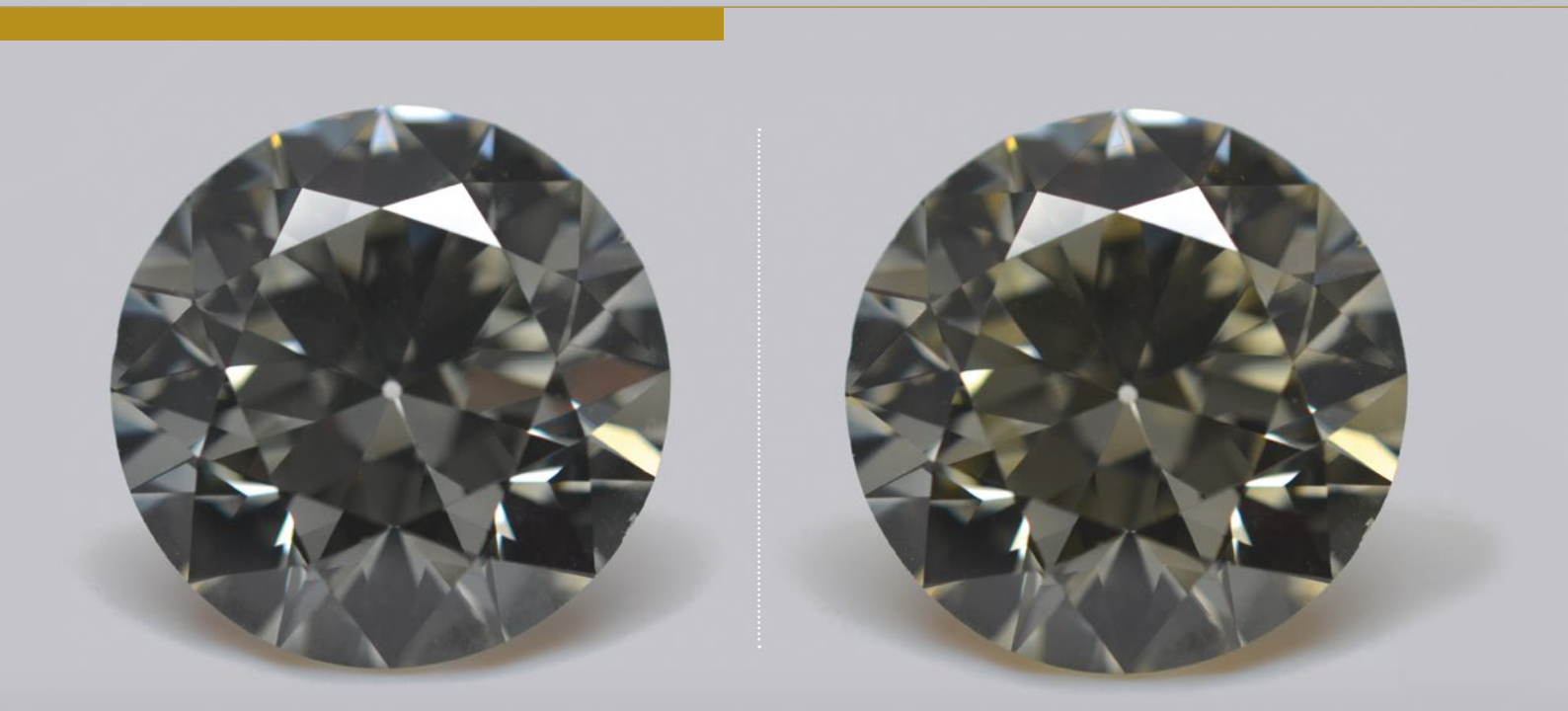

Figure 1: The 25.85 ct chameleon diamond studied by the authors is shown with its slightly greyish green 'stable' colour at room temperature (left) and its greyish yellow 'heated' colour (right). Photos by A. Delaunay.

What Truly Characterises a Chameleon Diamond? An Example of an Atypical 25.85 ct Stone

Emmanuel Fritsch and Aurélien Delaunay

ABSTRACT: We document an exceptionally large, 25.85 ct diamond that shows a slight colour change but exhibits some atypical properties for chameleon diamonds, including white luminescence to long- and short-wave UV radiation, as well as a network-like pattern seen in most orientations with the DiamondView. In considering whether to call this a chameleon diamond, we undertook a review of available data to compile the properties that are commonly exhibited by these gems. We found that, in addition to their defining photochromic and thermochromic behaviour, nine characteristics all must be present: long-lasting yellow phosphorescence, a zoned DiamondView growth pattern showing yellow-green/blue/inert areas, the presence of dominant A aggregates and also some hydrogen in the infrared spectrum, a continuum of absorption in the visible range related to a very weak type Ib character, a 480 nm absorption band that is possibly related to trace amounts of oxygen, a 425 nm absorption band, a weaker absorption band in the red to near-infrared region consistent with hydrogen-related defects, and traces of nickel detected with photoluminescence spectroscopy.

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Chameleon diamonds change colour when heated or left in the dark. Such gems are thus thermochromic and photochromic, respectively. Obviously, the term *chameleon* refers to the reptile known to change colour according to its environment. The 'heated' colour of such diamonds is at best an attractive orangey yellow, while the other ('stable') colour is much less saturated and darker, often tending toward greyish green. This unusual colour behaviour, combined with the attraction for coloured diamonds in general, makes chameleon diamonds much-valued collectibles, and gemmological laboratories occasionally issue reports on them. Here, we detail an unusual example, which poses the questions: What is the definition of a chameleon diamond? What properties must a diamond have to be properly named *chameleon*?

In addition to their collectable and gemmological aspects, chameleon diamonds are of interest to science in general. The so-called 'X-chrome' materials (X- being *thermo*, *photo*, *tribo*, *electro* or some other prefix related to an excitation that results in a change in colour) have a great interest in physics (e.g. for optical storage; Irie, 2000). Hence chemists have produced a number of X-chromes, and physicists attempt to understand the physical phenomena behind the colour change. From this perspective, chameleon diamonds represent a superlative as they combine two X-chrome behaviours with a super-material, diamond, also often used by theoreticians because of its simple chemistry and structure. Thus, several studies have attempted to understand the electronic structure and atomic defects responsible for this colour behaviour, so far unsuccessfully. If one could duplicate such behaviour in diamond, this would be an outstanding X-chrome material as diamond is already an exceptional substance—even without the chameleon effect. This would be a good example of what we call mineralo-mimetism: Nature is capable of producing minerals with interesting properties that humans try to duplicate for their own benefit. (This notion parallels bio-mimetism, but outside the biological world.) Amusingly, while humans do not entirely understand the mechanism involved in chameleon diamond, the colour behaviour of the eponymous reptile has only recently been elucidated (Teyssier et al., 2015).

The French Gemmological Laboratory (Laboratoire Français de Gemmologie, LFG) recently documented a 25.85 ct chameleon diamond submitted for a grading report (Figures 1 and 2). This is the largest such diamond seen at LFG, and it was analysed in detail. Its properties are somewhat surprising, such that it was not readily recognised as a chameleon when submitted. Its remarkable phosphorescence is what prompted the laboratory to test its change of colour, which was present but subtle.

Many chameleon diamonds have been documented in the gemmological literature. The largest one is the 31.31 ct oval-cut Chopard diamond acquired by the Swiss jeweller in 2007 (Fritsch et al., 2004; Chopard, 2014). Until now, the second largest was a 22.28 ct heart-shaped stone named 'the 22 ct Green Chameleon Diamond' (Moses, 1992; Fritsch et al., 1995). The stone documented in the present article represents a new second-largest documented chameleon diamond, which further explains our interest in scrutinising its characteristics.

METHODS

The diamond was graded using standard procedures, and its colouration was documented in a Macbeth Judge II viewing booth using a D65-like illuminator. Luminescence was observed with a Vilber Lourmat VL-6 UV lamp equipped with 6 W tubes (long-wave 365 nm and short-wave 254 nm) in a standard cabinet, with the diamond placed about 7 cm from the lamp. Luminescence images excited with ultra-short-wave UV radiation (~220–230 nm) were acquired with a DiamondView instrument. A Fourier-transform infrared (FTIR) absorption spectrum was obtained with a Bruker Tensor 27 infrared spectrometer with 2 cm^{-1} resolution, accumulating 2,000 scans to improve the signal-to-noise ratio. An ultraviolet-visible (UV-Vis) absorption spectrum was collected with a

Figure 2: Viewed here table-down, the 25.85 ct chameleon diamond displays a progressive change in colour when heated from ambient conditions (left) to 160°C (right). Photos by A. Delaunay.

Figure 3: The 25.85 ct diamond luminesces intense chalky white to long-wave UV radiation (left) and weaker white to short-wave UV (centre). The unusual yellow phosphorescence (right) is characteristic of chameleon diamonds. Photos by A. Delaunay.

Jasco V-670 spectrophotometer, with a sampling interval and spectral bandwidth of 1 nm. Photoluminescence (PL) spectra were obtained at liquid-nitrogen temperature with a Renishaw inVia Raman spectrometer using two laser excitations (325 and 514 nm), with a sampling interval of 0.043 nm in a single scan.

RESULTS

The diamond weighed 25.85 ct and measured approximately 19.22 × 19.71 × 11.31 mm. Its clarity grade was VS_1 due to small feathers on the crown and little chips on the crown and girdle. The colour changed from Fancy slightly greyish green to Fancy greyish yellow when heated to 160°C on a chemistry heating plate (again, see Figure 2). The diamond reverted to its 'stable' colour very rapidly (in less than one minute) when left at room temperature. In addition to this thermochromic behaviour, the diamond became yellower after being stored overnight in a dark safe, demonstrating its photochromism.

Under long-wave UV radiation, the diamond emitted an intense chalky white luminescence with some vaguely yellowish and bluish zones (Figure 3). White fluorescence is not common in diamond, and often is forgotten as a possible colour of luminescence. It results from concurrent blue and yellow emissions which, taken separately, are the most common colours of fluorescence in diamond. When the UV lamp was turned off, a strong yellow phosphorescence was observed that decayed slowly (approximately 5 minutes). Weaker white luminescence and shorter yellow phosphorescence were also observed with the short-wave UV lamp.

Luminescence images acquired with the DiamondView revealed the surprising presence of what appeared to be a dislocation network superimposed on the diamond's overall blue emission (Figure 4). The dislocation network was inert on the surrounding blue matrix, which is exactly the reverse of what has been observed in many natural type IIa diamonds. The network appeared somewhat layered or banded. The pavilion of the stone contained a distinct zone of yellow-green emission (with inert and blue areas) along graining in the diamond (Figure 5). This yellow-green luminescence is somewhat different from the green emission produced by the H3 centre. Yellow-green/blue/inert zoned luminescence is characteristic of 'classic' chameleon diamonds in the DiamondView.

The FTIR absorption spectrum was typical of type Ia diamond with high nitrogen content (Figure 6). The relative proportion of A to B aggregates can be seen by comparing the bands at 482 cm^{-1} (A aggregates) and 1010 cm^{-1} (B aggregates). A comparison of the size of these two bands indicates that the diamond is type IaA>>B, like other chameleons described in the past (see, e.g., Hainschwang et al., 2005). In addition, some hydrogen-related absorptions at 3107 and 1405 cm^{-1} were recorded, indicating a moderate H content. Hydrogen is always present in chameleon diamonds, but often at relatively high concentrations (approaching 'H-rich' amounts; Hainschwang et al., 2005), which is not the case here.

The UV-Vis absorption spectrum consisted of a combination of several features. An underlying continuum gradually increased from the red towards the violet region. On it was superimposed a complex, broad band located in the red to near-infrared region starting at ~580 nm. This feature is postulated to be related, at least in part, to the thermochromic behaviour (Fritsch et al., 1995). Considering its spectral range, as well as its complex multi-component nature, it is similar to absorption features related to hydrogen (Fritsch et al., 2007a). In addition, there was a weak feature at 425 nm and a broad

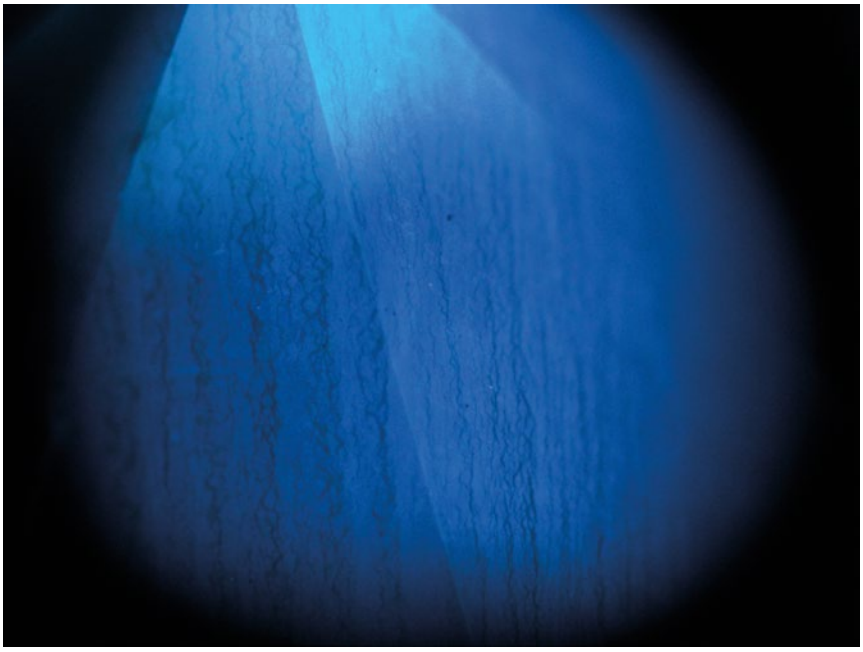

Figure 4: In the DiamondView, the 25.85 ct diamond shows an atypical dislocation network. Photomicrograph by A. Delaunay; image width 9 mm.

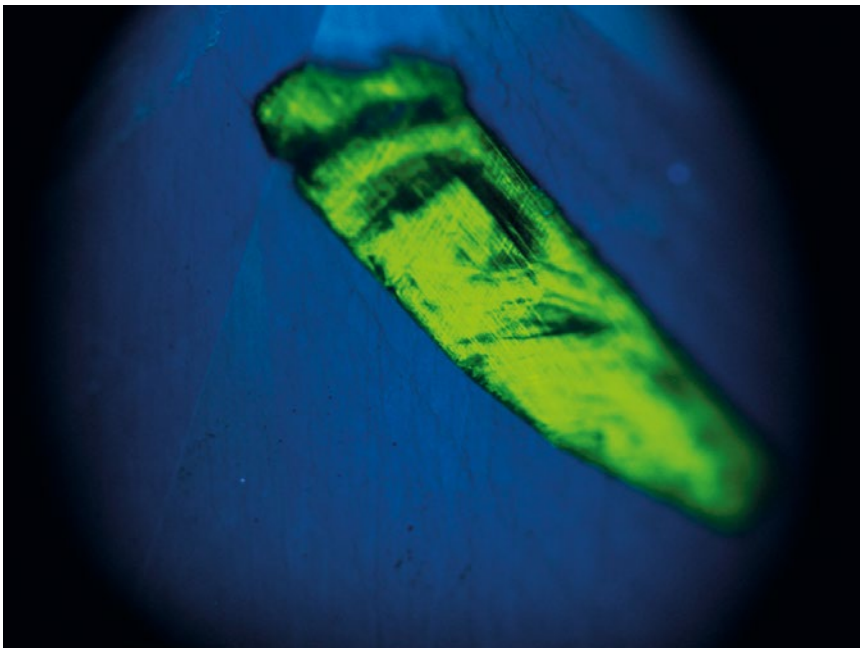

Figure 5: A yellow-green-luminescing zone with graining is seen on the pavilion of the chameleon diamond with the DiamondView, together with black (inert) and blue zones. Photomicrograph by A. Delaunay; image width 9 mm.

band at 480 nm (Figure 7; Hainschwang et al., 2005). The 480 nm band is known to occur in yellow-orange diamonds and is always present in chameleons, along with its 425 nm companion (Chabert and Reinitz, 2000). The 480 nm band is possibly due to traces of oxygen (Hainschwang et al., 2008). The N3 centre at 415 nm was also observed, and has been documented previously in chameleon diamonds (Chabert and Reinitz, 2000).

Photoluminescence spectra obtained with 514 nm excitation revealed Ni-related emissions at 700.5, 793.6 and 881.3 nm (Figure 8), which have been documented previously in typical chameleon diamonds (Hainschwang et al., 2005). In addition, there was a weak peak at 884.7 nm, which might be part of the well-known Ni-related doublet in the 883 nm region. A broad band at 630 nm was seen in the 514 nm PL spectrum, as well as other weaker underlying broad bands. The 630 nm band was previously documented in type IaA/Ib orange to

orange-yellow diamonds that exhibit the 480 nm absorption (Hainschwang et al., 2005). Other broad bands were present as well, roughly at ~700 and 800 nm. No GR1 (741 nm) feature was observed for this stone, whereas all previous chameleon diamonds studied by the authors displayed a weak GR1. In the PL spectrum obtained with 325 nm excitation, the main broad band was at ~560 nm. Emission peaks of the N3 centre at 415 nm and the H3 centre at 503 nm were otherwise the most prominent features of this spectrum (Figure 9), and there also appeared to be an underlying broad, intense feature, possibly centred in the red region.

DISCUSSION: WHAT IS COMMON TO ALL CHAMELEON DIAMONDS?

The fact that this diamond, as well as some others before it, at first eluded proper identification as chameleons (see, e.g., Fryer, 1981) proves that such diamonds cover a range of possible properties. This begs the question: What combination of properties are always present in chameleon diamonds that might be considered unique to this variety? We will exclude the 'reverse chameleon' variety defined by Hainschwang et al. (2005), which has not been documented again since. The following

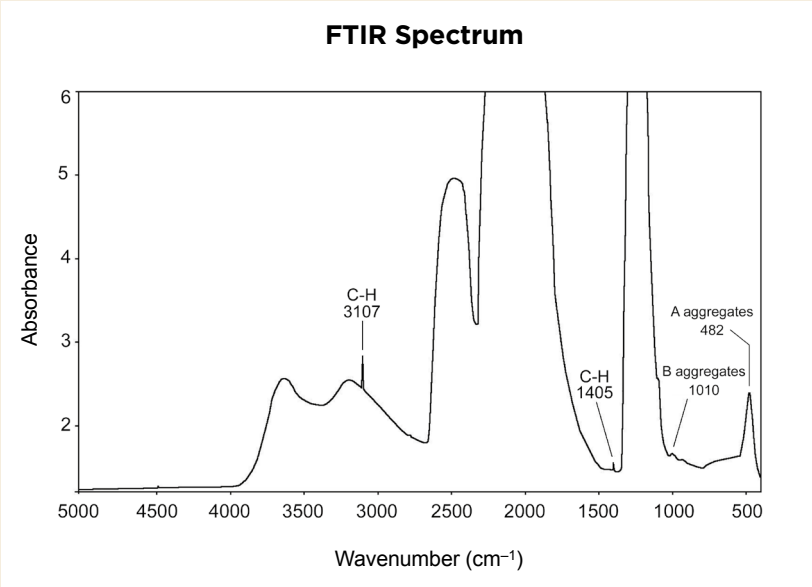

Figure 6: The FTIR spectrum of the chameleon diamond reveals a high concentration of nitrogen in A-aggregate form (482 cm^{-1}), a small amount of B aggregates (1010 cm^{-1}) and a low content of hydrogen (3107 and 1405 cm^{-1}).

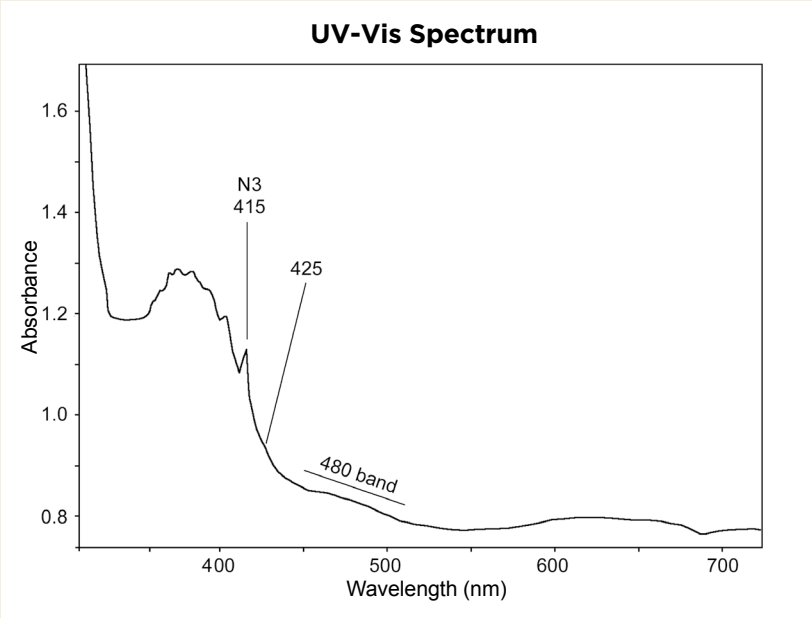

Figure 7: The UV-Vis spectrum of the chameleon diamond taken at room temperature displays the N3 centre at 415 nm, a weak band at 425 nm, a broad band at 480 nm and another broad band in the red to near-infrared region. These features are all superimposed on a slight absorption continuum that rises towards the ultraviolet. The spectrum was obtained through the girdle, for an approximate optical path length of 19.5 mm.

discussion is based on the authors' documentation of approximately 100 chameleon diamonds, often during short loans. Thus, not all properties could be documented for all of them, depending on the time and instrumentation available. However, a consistent pattern appears from this intermittent study over almost 30 years.

Again, the defining property of classic chameleon diamonds is their combined thermochromic and photochromic behaviour. They must change colour when left in the dark for several hours or after being moderately heated (160–200°C). The return to the original colour is generally within a minute after being brought from darkness to normal lighting conditions, or after being left at room temperature in normal lighting after heating. There is a range of possibilities for the two hues observed. Overall, the diamond changes from a tint containing some green to another containing yellow (see, e.g., Koivula and Kammerling, 1991; Fritsch; 1998; Hofer, 1998). Figure 10 illustrates a diamond showing a distinct colour change, in contrast to the subtle change in the ~25 ct gem reported here. Brown and grey also are common colour components of chameleon diamonds (Breeding et al., 2018). Hofer (1998) described some chameleon colours as 'olive', an imprecise term, which consists of a mixture of colours

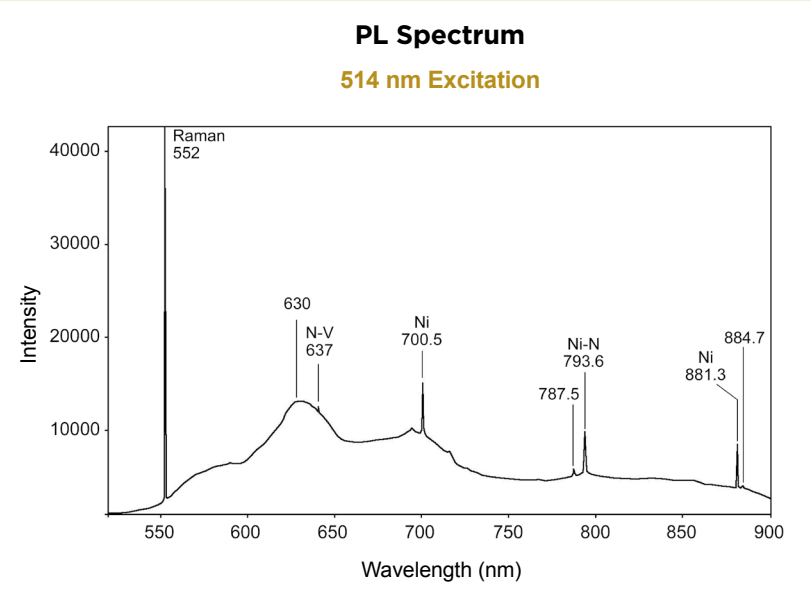

Figure 8: Photoluminescence spectroscopy of the chameleon diamond with 514 nm laser excitation at liquid-nitrogen temperature reveals numerous emissions related to Ni.

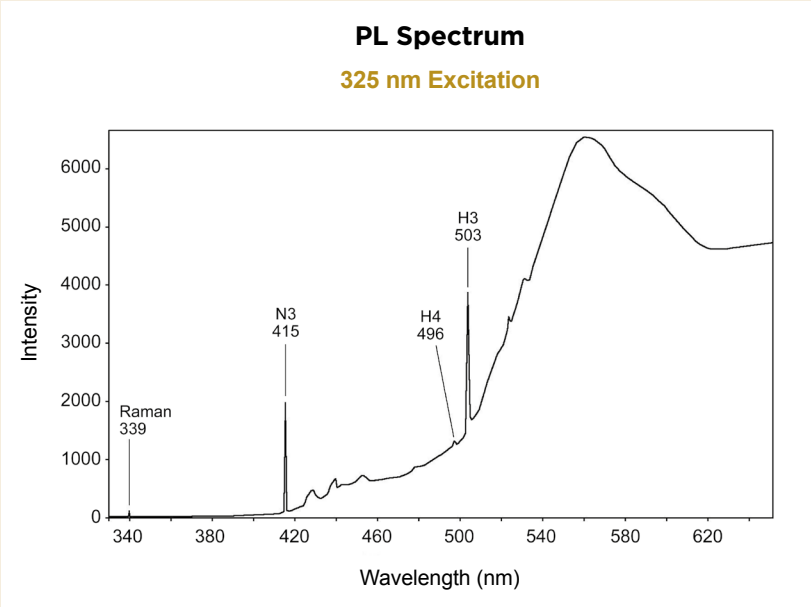

Figure 9: Distinct emissions from N3 and H3 centres are seen in the PL spectrum of the chameleon diamond obtained with 325 nm laser excitation at liquid-nitrogen temperature.

Figure 10: This 4.85 ct chameleon diamond shows a pronounced colour change (here, with heating) from greyish green to orangey yellow. Photo courtesy of SanaDiam, Antwerp, Belgium.

including green, with the addition of brown, yellow and grey (Hofer, 1998; Gaillou and Rossman, 2017).

Thermochromic behaviour has been associated with 'chameleon' diamonds since at least 1867 (Figuier, 1867). At that time, however, it was described as a reversible change from near-colourless to pink. This curious property was subsequently mentioned in one of the least-known books by Jules Verne, *The Star of the South* (*L'Etoile du Sud*), published in 1884 (Fritsch, 2016). In the book, the 'chameleon' diamond changed from black to pink. The first modern definition of a chameleon diamond that we could find is in the first edition of *The Diamond Dictionary* (Copeland et al., 1960).

The characteristic that often alerts a gemmologist that a diamond might be a chameleon is yellow phosphorescence excited by a typical short-wave UV lamp. The phosphorescence may be of varying intensity, but it is characteristically quite prolonged (i.e. over several minutes if observed in total darkness). However, this property alone does not correlate to the chameleon character (Moe et al., 2017). It is just a convenient method to highlight diamonds that might be chameleons, as this yellow phosphorescence is otherwise rare in diamond. It is generally accompanied by a strong yellow emission (which was present in the 25.85 ct stone together with blue N3 emission) when excited with long-wave UV radiation (Breeding et al., 2018). This yellow emission, as mentioned above, is indirectly related to the 480 nm band in chameleon diamonds (explained below). It has been described as a broad band of 'moderate' intensity centred at ~560 nm (i.e. using fluorescence spectroscopy; Eaton-Magaña et al., 2007). Sometimes a sharper feature at about 507 nm accompanies this broad emission band (Byrne et al., 2015).

In the small number of cases (about a dozen) when chameleon diamonds were observed by the authors in the DiamondView, they all showed a patchy yellow-green and blue emission with some inert areas (Figure 11). Characteristics of the colour distribution are consistent with the blue zones resulting from octahedral growth, whereas the yellow-green zones (often with curved boundaries) correspond to cuboid growth. Although these two growth habits are often associated in diamond, this specific pattern seems unique to chameleons. In addition, we have never seen such an appearance in the DiamondView for non-chameleon diamonds, for which we have carefully documented hundreds, and possibly thousands, of patterns. Furthermore, we were able to identify two chameleon diamonds through their DiamondView pattern that had not been recognised previously as such.

The zoning described above is a curious aspect of chameleon diamonds. Despite this rather obvious and distinct growth zoning, both the body colour distribution and the colour change appear homogeneous when observed with the unaided eye.

Regarding their infrared spectra, chameleon diamonds are consistently type Ia, with low-to-moderate concentrations of nitrogen. In all cases, A aggregates largely dominate, even in some rare diamonds that also contain B aggregates; absorption from the latter is never as strong as that of the A aggregates (e.g. Panjikar and Panjikar, 2015). In the infrared region, they always show low-to-moderate absorption of the 3107 cm^{-1} system (Fritsch et al., 2007a), some even reaching the 'H-rich' level (Fritsch, 1998).

In the UV-Vis region, chameleon diamonds all show a combination of: (1) a continuum of absorption rising

towards the UV, starting at ~550 nm; (2) an often weak but distinct 480 nm broad band and its companion band at ~425 nm; and (3) a broad band in the red to near-infrared region. Of course, the individual components are easier to identify if the spectrum is obtained at liquid-nitrogen temperature. The N3 absorption is common but sometimes absent, so its presence does not seem mandatory for chameleon diamonds. The change of colour with heat corresponds in our experience to a slight shift of the continuum towards higher wavelength, combined with a decrease of the red to near-infrared feature. This makes the green transmission window disappear, together with the green colour component. The resulting spectrum is typical of some orangey yellow diamonds, with both the shifted continuum and the 480 nm feature contributing to the yellow component. In our view, the slight decrease of the 425 and 480 nm bands plays almost no role in the change of colour. By contrast, Khan et al. (2010) as well as Gaillou and Rossman (2017) attributed the change in colour to variations in 480 and 800 nm absorptions, not taking into account the underlying continuum.

The absorption continuum, starting at ~560 nm and increasing towards the ultraviolet, might be attributed to a very weak type Ib component, which can be resolved in the infrared spectrum of many chameleon diamonds (Hainschwang et al., 2005), but not all. A type Ib visible-range absorption continuum can be found even in the absence of the 1344 cm^{-1} infrared absorption typical of type Ib diamond (Hainschwang, 2014). As those infrared features are slight, they might easily be missed or not looked for in some stones. The temperature behaviour of the continuum, which is slightly thermochromic, is consistent with that of type Ib diamonds. A band at 425 nm is found in type Ia diamonds known to contain hydrogen (Fritsch et al., 2007b), but this band in chameleon diamonds might be due to a different defect, given that it appears to be a 'companion' of the 480 nm band (Collins, 1982). The 480 nm band typically found in all chameleons (Chan et al., 2015) is believed to be related to the presence of oxygen (Hainschwang et al., 2008, and references therein). In addition, three non-chameleon yellow diamonds displaying the 480 nm absorption contained ESR-active defects linked to oxygen (unpublished data of Solveig Felton at the University of Warwick in 2009). The red to near-infrared feature seems to vary in shape from chameleon to chameleon, probably because it is a combination of several features, possibly involving other broad bands in the near-infrared (Fritsch et al., 2007a). This pattern might be related to the presence of hydrogen-related defects, possibly linked to A aggregates (Goss et al., 2011).

In laser-excited photoluminescence spectra, no single peak seems absolutely characteristic, but the ~701 nm system appears very common. As with some other emissions documented in chameleon diamonds, this one is related to traces of nickel. Thus Ni traces might be necessary to obtain the chameleon effect. Nickel was detected by energy-dispersive X-ray fluorescence spectroscopy in some chameleon diamonds (as well as 'canary' diamonds) exhibiting the 480 nm absorption (De Weerdt and Van Royen, 2001). In essence, when Ni is looked for in a chameleon diamond, it is found. Nickel is actually not so rare an impurity in natural diamond, particularly in natural type Ib diamonds

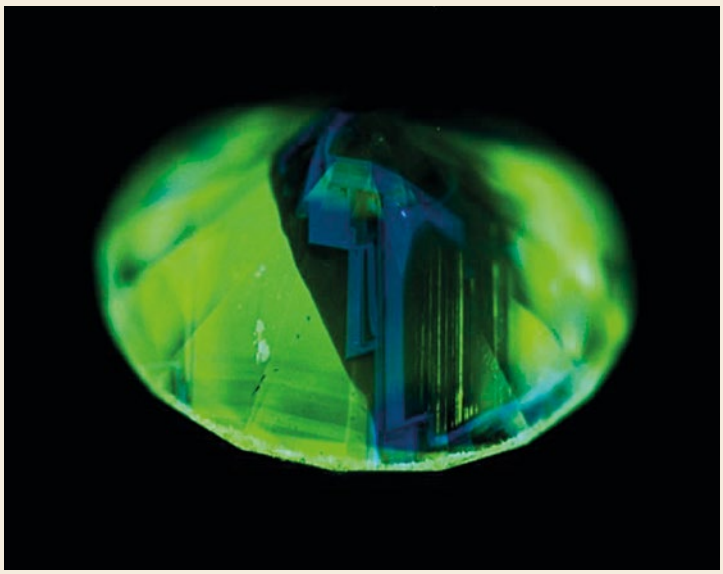

Figure 11: This 0.27 ct chameleon diamond shows a DiamondView pattern typical for chameleons, with a combination of yellow-green, blue and inert zones. The straight blue-luminescing growth zones represent octahedral growth. The curved boundary between the inert and yellow-green zones is reminiscent of a cuboid sector. Photomicrograph by A. Delaunay; image width 6.4 mm.

(Hainschwang et al., 2013), even outside the chameleon variety. However, it was not always detected in the past in chameleon diamonds (Fritsch et al., 2007b), simply because the necessary instrumentation was not available or, alternatively, it was not looked for.

The list below summarises the features documented in all the chameleon diamonds that we have examined, in addition to their defining photochromic and thermochromic behaviour: They change from a greener to a yellower colour when left in the dark for several hours, or after being moderately heated (160–200°C) for about a minute.

- Long-lasting (several minutes) yellow phosphorescence to short-wave UV radiation
- Zoned growth pattern, with a combination of blue octahedral and yellow-green cuboid growth, seen in the DiamondView
- Type IaA dominant, plus a type Ib component
- Some hydrogen, as indicated by the 3107 cm^{-1} system
- Absorption continuum in the UV-Vis range, related to the type Ib character
- 480 nm band, possibly related to an oxygen impurity
- 425 nm band, possibly related to hydrogen
- Broad feature in red to near-infrared region, likely H-related
- Traces of Ni

We thus believe that all of these features must be taken into account to explain the thermochromism and photochromism shown by chameleon diamonds. This list, which is quite long, is difficult to reconcile with a simple electronic structure relating to the defects responsible for chameleon behaviour. Various authors have suggested different explanations (Massi et al., 2006; Fritsch et al., 2007b; Butler et al., 2017; Byrne et al., 2018), but the complex nature of chameleon diamonds, combined with the nine characteristics listed above, makes their optical behaviour difficult to model. Numerous defects are present, associated with several impurities (nitrogen, in particular N-N or A aggregates, as well as hydrogen, nickel and oxygen), and it is difficult to assess if all necessarily play a role. However, the consistency of our observations on chameleon diamonds for almost 30 years leads us to believe that all these factors are significant. The list of nine characteristics should thus be taken into account in any forthcoming model for the chameleon-inducing electronic structure in diamond.

CONCLUSION

The study of an exceptionally large, 25.85 ct diamond with some unusual properties for chameleon diamonds prompted the question of what actually defines this unusual variety. By compiling the data provided by the available literature and combining it with the authors' own experience, it appears that the specifications are more numerous than expected. Indeed, the nine characteristics identified in this article appear to be necessary in combination. This likely explains why the origin of the chameleon behaviour in diamond remains a mystery.

Even though the 25.85 ct stone documented in this article had some unusual properties, it did have all of the characteristics required for a chameleon diamond.

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DNA Fingerprinting of Pearls, Corals and Ivory: A Brief Review of Applications in Gemmology

Laurent E. Cartier, Michael S. Krzemnicki, Bertalan Lendvay and Joana B. Meyer

ABSTRACT: This article reviews the extraction of DNA (deoxyribonucleic acid) from biogenic gem materials (pearls, corals and ivory) for determining species identification and geographic/genetic origin. We describe recent developments in the methodology adapted for gem samples that is minimally destructive, as well as the successful DNA fingerprinting of cultured pearls from various *Pinctada* molluscs to identify their species. The DNA analysis methods presented here can also potentially be used for fingerprinting corals and ivory.

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Biogenic gems—often called 'organic gems' (see Galopim de Carvalho, 2018, for a recent discussion of terminology)—are some of the oldest-used gem materials and have been cherished since pre-history (Hayward, 1990; Tsounis et al., 2010; Charpentier et al., 2012). Rather than having a geological origin, these gem materials—such as pearls, precious corals and ivory (e.g. Figure 1)—are products of biomineralisation processes in which living animals produce mineral substances (e.g. calcium carbonate or calcium phosphate) in terrestrial and marine environments (Mann, 2001). Due to their importance in jewellery and decorative arts, the study of biogenic gem materials constitutes an important part of gemmological research.

Natural pearls form in wild molluscs without any assistance, whereas cultured pearls are the result of human intervention on cultivated pearl-producing molluscs (Strack, 2006; Hänni, 2012). Pearls and their shells consist of secretions of different polymorphs of calcium carbonate ($CaCO_3$) such as aragonite, calcite and vaterite. Pearls are sometimes coloured by organic pigments.

Precious corals have not been cultivated commercially so far, and those used in jewellery and *objets d'art* represent the coral skeleton (secreted by living polyps), which consists of $CaCO_3$ as well as protein, glycosaminoglycans and proteoglycans (Debreuil et al., 2012). They can be coloured by carotenoids and other types of pigments.

Finally, elephant ivory from African (*Loxodonta spp.*) and Asian (*Elephas spp.*) elephant tusks is comprised of collagen and carbonate-rich hydroxyapatite (dahllite, $Ca_{10}[PO4]_6[CO_3] \cdot H_2O$; Edwards et al., 2006). Ivory can be found in a large number of animal species, of which elephant ivory is the most studied due to its value, recognition and cultural importance. In recent years, fossilised mammoth ivory has appeared more widely on the market, as elephant ivory trade restrictions have taken force (e.g. under the Convention on International Trade in Endangered Species of Wild Fauna and Flora, or CITES; www.cites.org/eng/niaps). CITES regulates the trade in biogenic gem materials that are produced by species included in its Appendices I, II or III. Among these are various species of precious coral, queen conch (pearls) and giant clam (pearls).

The ability to trace biogenic gem materials back to their species-related and geographic origins can provide greater transparency and help curb trade in illegal materials (and thus restrict poaching and smuggling). Furthermore, such research can yield important information

on the sources and trade routes of biogenic gems in historic items. The aim of this article is to provide an overview of DNA fingerprinting techniques to a gemmological audience, with particular emphasis on a previous detailed publication by some of the authors (Meyer et al., 2013) that focused on technical aspects concerning pearl genetics for species identification.

GEMMOLOGICAL RESEARCH

Traditional gemmological testing of pearls, corals and ivory in past decades was carried out mainly to separate these biogenic gem materials from imitations and, in the case of pearls, to separate natural from cultured (i.e. since the appearance of the latter on the market in the early 20th century: Anderson, 1932; Farn, 1986). This testing mostly has been visual, focusing both on the surface of examined materials and their internal structures. In addition, pigment analysis to help detect pearl treatments and gather more information for the possible determination of pearl species has also been carried out (Li and Chen, 2001; Elen, 2002; Karampelas et al., 2011). In recent years, research has focused on three-dimensional visualisation techniques of pearls and their internal structures (Krzemnicki et al., 2010; Revol et al., 2016; Mannes et al., 2017). Radiocarbon age dating of pearls has also been reported (Krzemnicki et al., 2017).

Research on corals in gemmology is much sparser than for pearls, and has focused on spectroscopic approaches (Rolandi et al., 2005; Henn, 2006; Smith et al., 2007; Karampelas et al., 2009). Elephant ivory has also been studied using techniques such as Raman and Fourier-transform infrared spectroscopy (Edwards and Farwell, 1995; Edwards et al., 2006), along with detailed visual analysis and preliminary trace-element studies (Yin et al., 2013). In addition, geochemical research on isotopes present in ivory has been conducted (van der Merwe et al., 1990; Ziegler et al., 2016).

BIOLOGICAL RESEARCH

A large amount of research has been carried out on the biological formation and characteristics of pearl-producing molluscs and also corals. This research is rarely linked to, and used in, gemmology. Much of this work focuses on detailed genetic aspects of pearl-producing molluscs, including various *Pinctada* species used for pearl farming. Among these are *P. maxima* (Kono et al., 2000; Lind et al., 2012), *P. margaritifera* (Arnaud-Haond et al., 2003a), *P. mazatlanica* (Arnaud-Haond et al., 2003b) and the *Pinctada* genealogy (Cunha et al., 2010), as well as the Akoya pearl oyster complex

Figure 1: Biogenic gem materials suitable for DNA testing include items such as these from the SSEF and H. A. Hänni collections: cultured pearls and associated shell material (*P. maxima* and *P. margaritifera*, ~15 cm tall), corals (including *Corallium rubrum* branches up to ~10 cm tall) and ivory (warthog and mammoth). Photo by Vito Lanzafame, SSEF.

(Wada and Tëmkin, 2008; Al-Saadi, 2013) and Pteriidae-family species such as *Pteria sterna* (Arnaud-Haond et al., 2005). The above-mentioned Akoya complex includes *Pinctada* species such as *P. fucata*, *P. imbricata*, *P. martensii* and *P. radiata*, which are closely related in genetic terms (Cunha et al., 2010). In addition, the genetics of freshwater mussel species used in cultured pearl production have been intensively studied (Peng et al., 2012; Shi et al., 2015). Most of this research was done with the goal of reducing mortality during pearl cultivation and improving the quality of cultured pearls.

Precious coral species such as *Corallium rubrum* (Mediterranean or Sardinian coral) have been studied extensively to understand their formation mechanisms (Grillo et al., 1993; Allemand and Bénazet-Tambutté, 1996), genetic diversity (Ledoux et al., 2010) and populations (Santangelo et al., 2003). Again, little of this biological research has crossed over to the gemmological community.

In elephant research, the link between declining populations and demand for ivory has been widely researched (Maisels et al., 2013, Wittemyer et al., 2014). Much of the scholarly work has focused on declining elephant populations and how to address poaching.

Figure 3: Vigorous vortexing of the nacre sample material in EDTA solution is necessary to detach the DNA molecules from the $CaCO_3$ framework. Photo by L. Cartier, SSEF.

DNA FINGERPRINTING FOR SPECIES (AND ORIGIN) DETERMINATION

Pearls

Pearls and pearl oyster shells contain small amounts of organic matter interspersed within a nacreous mineral matrix (Cuif and Dauphin, 1996; Comps et al., 2000; see Figure 2). In particular, they consist of approximately 92% $CaCO_3$, 4% organic matter (mainly conchiolin and porphyrins), 4% water and minute amounts of other substances (Taylor and Strack, 2008). The organic material has been studied in detail and contains different types of proteins, but previously it had not been reported to contain DNA (Levi-Kalisman et al., 2001; Nudelman et al., 2006; Dauphin et al., 2009). Nevertheless, negatively charged DNA molecules are known to have a high affinity for the Ca^{2+} ions of $CaCO_3$ (Barton et al., 2006), which might enhance the conservation of DNA in biogenic gems such as pearls.

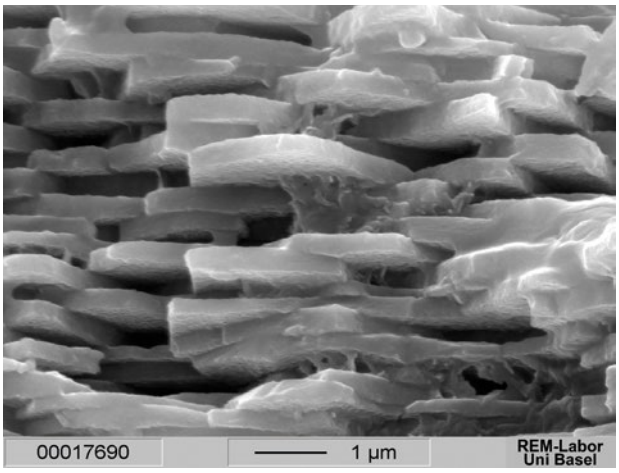

Figure 2: Scanning electron microscopy reveals the individual aragonite tablets in a cross-section through pearl nacre. DNA is thought to be found in organic matter between the individual tablets. Image by Henry A. Hänni and Marcel Düggelin, Zentrum für Mikroscopie, University of Basel, Switzerland.

Research by some of the present authors (Meyer et al., 2013) found DNA in organic matter within nacre from *P. margaritifera* (Tahitian black-lip pearl oyster), *P. maxima* (South Sea pearl oyster) and *P. radiata* (from the Arabian/Persian Gulf, part of the Akoya complex), thus allowing the separation of pearls (and mother-of-pearl) from different *Pinctada* species. A destructive technique for DNA identification was recently published by Saruwatari et al. (2018) focusing on *P. fucata* cultured pearls from Japan. For minimally destructive DNA extraction, the present authors developed a method that uses only a minute sample quantity and thus is applicable to jewellery-quality pearls (Meyer et al., 2013, and subsequent unpublished research by the authors).

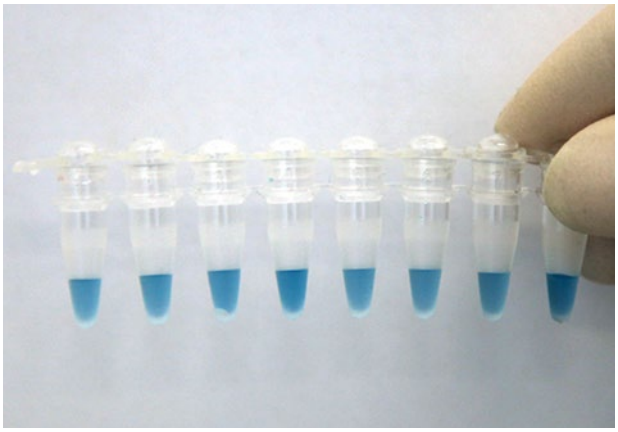

Figure 4: These tubes contain the amplified PCR product (internal transcribed spacer, ITS2) obtained for eight cultured pearls. Photo by L. Cartier, SSEF.

A Dremel workstation with a fixed 1 mm drill head was used to make a small hole in the nacre, and then a second non-fixed 0.9 mm drill bit was used to slightly enlarge the interior part of the hole without damaging the surface around it. The sample material was collected in a Petri dish. Given that most pearls are already drilled for jewellery use, the extraction of 10–20 mg (0.05–0.10 ct) of nacre material from within a pre-existing drill hole is considered quasi-non-destructive. However, this is not the case for pearls that cannot be drilled. The drill powder was then suspended in 1,000–2,000 µl of ethylenediaminetetraacetic acid solution (0.5 M EDTA solution at pH 8.0), vigorously vortexed for two minutes (Figure 3) and incubated overnight at 56°C in a water bath. EDTA dissolves the calcium carbonate structure of the mother-of-pearl. Oyster DNA was extracted from the sample material using a DNA extraction kit according to specific protocols (see Meyer et al., 2013). To genetically discriminate between *Pinctada* species, PCR-RFLP analysis (see Glossary) was performed on a PCR-amplified DNA fragment (internal transcribed spacer, ITS2; see Figure 4), and compared to equivalent RFLP profiles obtained from reference-positive controls (i.e. fresh mollusc tissue from these species; see Figure 5). Alternatively, PCR amplification only of specific ITS2 regions that discriminate between the oyster species was performed.

The research by Meyer et al. (2013) showed that in most cases it was possible to separate pearl oyster species based on their DNA profile extracted from only a minute amount of nacre material. Interestingly, amplification was also successful from samples composed of white nacre powder (i.e. no organic matter evidently visible), indicating that DNA can be obtained through demineralisation from the $CaCO_3$ structure of the nacre and/or from small samples (e.g. 10–20 mg). As technology costs come down and these methods are further refined, the authors foresee DNA fingerprinting being carried out on even smaller amounts of nacre material.

Current research by the authors shows that DNA fingerprinting can be adapted to other species of pearl-bearing molluscs and their pearls. This includes a range of freshwater mussels such as Chinese *Hyriopsis schlegelii* and *Hyriopsis cumingii schlegelii* mussel hybrids or the American washboard mussel (*Megalonaias nervosa*) that is frequently used as bead nucleus material in Akoya,

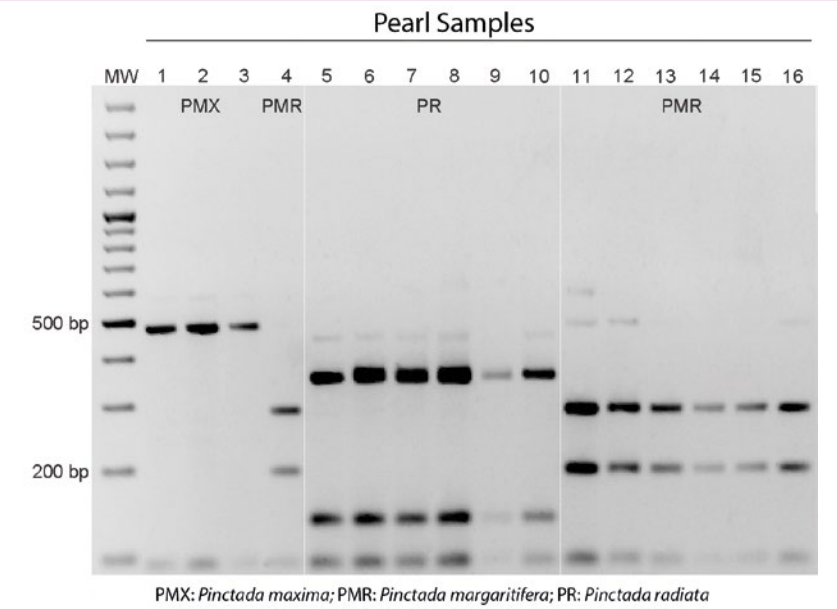

Figure 5: A PCR-RFLP assay of the ITS2 DNA fragment was used to differentiate the species associated with 16 cultured pearls. Lanes 1–3 correspond to *Pinctada maxima*, lanes 4 and 11–16 are for *P. margaritifera* and lanes 5–10 are for *P. radiata*. 'MW' corresponds to molecular weight and 'bp' to base pairs. Image by J. B. Meyer; modified from Meyer et al. (2013).

Figure 6: This five-row necklace contains 377 natural pearls ranging from 3.90 to 9.45 mm, likely from *P. radiata* of the Arabian Gulf. DNA fingerprinting could provide further documentation of the provenance for such exceptional pearls. Photo by Luc Phan, SSEF.

South Sea, Tahitian and Fijian pearl cultivation. We also are adapting this analytical approach to conch pearls (*Lobatus gigas*, formerly commonly known as *Strombus gigas*) and pearls from the giant clam (*Tridacna gigas*), in anticipation that DNA fingerprinting could contribute to more transparency in these CITES-regulated pearls.

Other Biogenic Gem Materials

The methodology used by Meyer et al. (2013) has been recently piloted by the authors on samples from various precious coral species commonly used in jewellery (including those from the Mediterranean, Asian and Midway Islands regions). This ongoing research should allow the separation of different species of precious corals and conclusively identify and distinguish non-CITES-regulated species (e.g. *Corallium rubrum*, or Mediterranean coral) from CITES-regulated species (e.g. *Corallium elatius*, known in the trade as Momo, Cerasuolo or Satsuma coral).

There have also been developments in techniques to determine geographic/genetic origin and species identification of seized elephant ivory using DNA and microsatellite methods (i.e. analysis of repeated DNA sequences in the genome that enable the distinction between different elephant population groups). However, so far this has been performed in a destructive way, requiring relatively large amounts of material (Comstock et al., 2003; Wasser et al., 2004, 2015). A less destructive method, like that used by Meyer et al. (2013), might be adapted to ivory too, thereby requiring much smaller amounts of material for testing such samples.

RESEARCH OUTLOOK AND CONCLUSIONS

DNA fingerprinting offers various advantages for the research and trade in biogenic gem materials. It provides a new option to increase transparency (through origin and species determination) and to help address fraud or illegal trading by separating protected from non-protected species.

The state-of-the-art minimally destructive extraction methodology outlined in this article can offer conclusive identification of the mollusc species to which a pearl corresponds, unlike other methods currently available in gemmology today. Furthermore, DNA analysis has the potential to reveal the geographic origin of cultured or natural pearls (Figure 6) based on more specific fingerprinting. For corals, species determination may considerably contribute toward resource conservation efforts and also provide more information on the provenance of historic items. As such, this research is relevant to the work of international customs officials within the context of biogenic gem materials protected by CITES. With ivory, origin determination based on DNA analysis has already been proven possible (Wasser et al., 2004). However, the available methodology requires large amounts of sample material and is thus not appropriate for jewellery or other items that cannot be destructively tested. Ongoing research and specifically next-generation sequencing (see Glossary) enables the screening of a large number of DNA sequences from smaller samples

at lower costs, subsequently reducing the amount of sample material required. DNA fingerprinting is, therefore, becoming less destructive and more useful for biogenic gem materials.

DNA fingerprinting as a tool in gemmology further illustrates the importance of multidisciplinary research collaborations (in this case, with marine biology and genetics scientists) to develop new gem-testing techniques for the 21st century.

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Glossary*

Deoxyribonucleic acid (DNA): Contains all the information an organism needs to develop, live and reproduce. It is formed by the four nucleobases (or 'bases') adenine (A), cytosine (C), guanine (G) and thymidine (T). The order of the bases (e.g. ATCGGTT…) codifies the specific instructions for any living organism.

DNA sequencing: The reading of nucleobases (A, C, G and T) in DNA. One can choose to sequence an entire genome (whole/full genome sequencing) of a tested sample or just sequence a few targeted nucleobases that are useful for distinguishing different species (DNA fingerprinting).

Genome: An organism's full set of DNA, including all of its genes.

Microsatellite: Repetitive DNA sequences that can be used as genetic markers to measure levels of relatedness between species or individuals. They can be used for genetic population studies and thus may offer more information on the geographic origin of individuals from a species.

Next-generation sequencing (NGS): Allows massive parallel sequencing of DNA, enabling a rapid and cost-effective way to sequence large amounts of genetic regions and whole genomes of organisms. With its ultra-high throughput, NGS has revolutionised genomic research.

DNA amplification and polymerase chain reaction (PCR): A method for amplifying DNA sequences. The technique involves using short DNA sequences called primers (see below) to select the portion of a genome for amplification. In PCR, sample temperature is repeatedly increased and decreased to help a DNA replication enzyme synthesise the target DNA sequence. As such, PCR can produce thousands to millions of copies of the target sequence in several hours, which can then be analysed. For example, it allows the identification of specific DNA sequences using visual inspection (e.g. gel electrophoresis) or they may be read through sequencing.

Primer: A primer is a short DNA sequence that serves as a starting point for DNA synthesis by PCR. Primers are selected according to the sequence region targeted for DNA amplification. These are, for example, regions in the genome of various oyster species (specific genetic markers) for which differences allow species determination.

Restriction fragment length polymorphism (RFLP): A technique based on variations in the DNA sequence (e.g. from different species) recognised by restriction enzymes. The resulting restriction fragments are separated according to their length by gel electrophoresis. The length (in base pairs) can differ between individuals and species such that the positions of gel bands can be used to separate samples from different species.

* Sources: National Human Genome Research Institute glossary (www.genome.gov/glossary), National Center for Biotechnology Information Probe glossary (www.ncbi.nlm.nih.gov/probe/docs/glossary) and Wikipedia.

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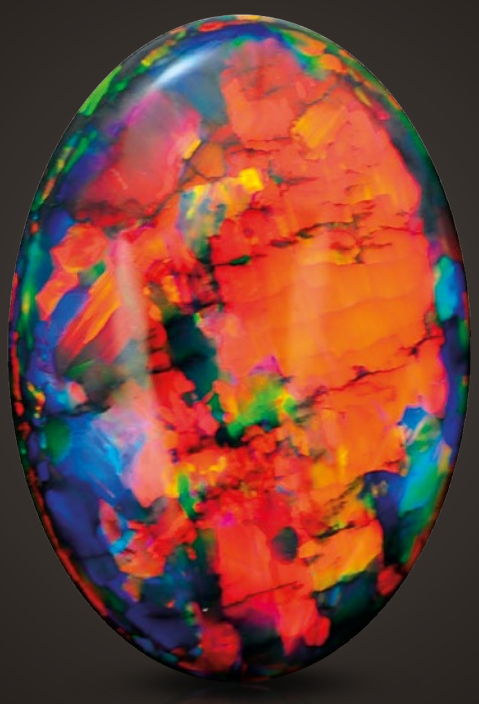

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JOG

Conferences

15TH ANNUAL SINKANKAS SYMPOSIUM—TANZANITE & TSAVORITE

On 14 April 2018 the 15th Annual Sinkankas Symposium was held at the Gemological Institute of America (GIA) in Carlsbad, California, and was co-hosted by the Gemological Society of San Diego. Approximately 160 people were treated to informative presentations by 11 speakers (Figure 1), as well as a beautiful display of tanzanite and tsavorite crystal specimens and gemstones that was assembled for the event. Abstracts of the presentations are available on the conference website at www.sinkankassymposium.net. The symposium was moderated by **Robert Weldon** (GIA, Carlsbad), who also delivered a poem that he wrote specifically for the event.

Dr Raquel Alonso-Perez (Harvard University, Cambridge, Massachusetts, USA) examined the geology of East Africa's Mozambique Belt in order to explain why tanzanite and tsavorite form in the same region. Both gems are Ca-Al silicates that are associated with graphitic gneiss and other metamorphic rocks. While tanzanite forms during retrograde metamorphism, tsavorite may crystallise during either prograde or retrograde events.

Robert Gessner (Gessner Gems, Beverly Hills, California) described his experience mining tanzanite at Merelani Block C in north-eastern Tanzania, where he was employed by TanzaniteOne. The mineralisation is hosted by fractured boudins formed by calc-silicate minerals that are concentrated along the axes of complex fold structures.

Nathan Renfro (GIA, Carlsbad) reviewed the internal features of tanzanite and tsavorite, both of which typically host relatively few inclusions. Tanzanite may contain ribbon-like growth tubes, 'fingerprints', fractures (sometimes with epigenetic residues), lamellar twinning, growth zoning, and crystals of graphite and hematite. Inclusions in tsavorite may consist of 'fingerprints', colourless crystals (possibly diopside), etch tubes and platelets, rare three-phase inclusions, and crystals of graphite and pyrite.

Stuart Robertson (Gemworld International Inc., Glenview, Illinois, USA) reviewed tanzanite price trends, and emphasised how the management of supply is critical to the sustainability of a single-source gem

Figure 1: Speakers at the 15th Annual Sinkankas Symposium gather together with a life-size bronze sculpture of Richard T. Liddicoat Jr. From left to right: Nathan Renfro, Meg Berry, Stuart Robertson, Will Larson, Shane McClure, Bill Larson, Judith and Bruce Bridges, Raquel Alonso-Perez, George Rossman and Robert Gessner. Photo by Jim Parrish.

material such as tanzanite. Viewed in the context of its rarity, the current wholesale prices of tanzanite may prove to be one of the biggest bargains in coloured stones.

Father-and-son team **Bill and Will Larson** (Pala International, Fallbrook, California) conveyed their experience with collecting tanzanite and tsavorite crystals. Bill chronicled the history of his involvement with procuring fine specimens, and Will showed a video of his 2012 visit to a tanzanite mine at Merelani Block C. The period from 2008 to 2011 was good for obtaining tanzanite crystals since the market for cut stones was relatively slow. Nevertheless, both matrix specimens and good undamaged crystals of tanzanite are very rare.

Bruce and Judith Bridges (Bridges Tsavorite, Tucson, Arizona, USA) described the history of the discovery and mining of tsavorite in Kenya. The mother-and-son team shared stories of life in their mining camp with husband/father Campbell Bridges before he was tragically murdered in 2009. Although the price of tsavorite has increased greatly since that time, new Tanzanian mining regulations are making it very difficult for foreign investment to continue.

Meg Berry (Megagem, Fallbrook) described the process of cutting a suite of fancy-colour zoisite. She used a dichroscope to orient each piece of rough in order to attractively blend the pleochroic colours while taking into account the shape/yield of the resulting gemstones. She prefers a crown angle of 25°–30° for zoisite, and her yields generally ranged from 25% to 30%.

Shane McClure (GIA, Carlsbad) covered the treatments and imitations of tanzanite and tsavorite. Both gem varieties can be clarity enhanced by filling surface-reaching fractures with oil. Tsavorite is not subjected to any other treatments, while tanzanite is commonly heat treated at 500–700°C to produce its attractive blue-to-violet colouration from brown starting material. Tanzanite has been imitated by various materials including synthetic sapphire, yttrium aluminium garnet (YAG), synthetic forsterite and high-RI glass, whereas tsavorite is only rarely imitated with high-RI laboratory-grown products such as YAG and CZ-like materials.

Dr George Rossman (California Institute of Technology, Pasadena) examined the colour causes of tanzanite and tsavorite. In tanzanite, V is the dominant trace element, and other chromophores include Cr, Mn and Fe, but the exact mechanism that causes its colour remains elusive. Tsavorite colouration is much more straightforward, being caused mainly by V^{3+}, together with some contribution from Cr^{3+} when present in sufficient amounts.

Brendan M. Laurs FGA

SWISS GEMMOLOGICAL SOCIETY

On 7–8 May 2018, the Swiss Gemmological Society (SGS) held its 76th annual conference at Hotel de la Paix in Lugano, southern Switzerland. In attendance were approximately 70 SGS members and guests (Figure 2). The meeting was chaired by **Hans Pfister** (SGS president), **Michael Hügi** (SGS director) and **Dr Michael Krzemnicki** (Swiss Gemmological Institute SSEF, Basel). The main theme of the conference was diamonds from southern Africa, although a variety of additional topics was covered.

Mike Brook (Debswana, Gaborone, Botswana) profiled Botswana's diamonds, including their prospecting history, localities, mining, production and incorporation into jewellery. Today, Botswana is the world's second largest diamond producer by value and there are currently eight operating mines. Good governance practises since 1966 have allowed the significant diamond revenues accrued by Botswana's government to directly benefit the nation (once one of the poorest in the world), transforming it into a middle-income economy with one of the largest gross domestic products on the African continent. **Dr Jurgen Jacob** (Namdeb Diamond Corporation Pty Ltd, Oranjemund, Namibia) reviewed the characteristics of Namibia's diamond megaplacer, which has so far produced more than 100 million carats. Several geological factors contributed to its formation as the world's most spectacular placer diamond deposit, including: a fertile craton that has hosted numerous diamondiferous kimberlite intrusions throughout geological time; the presence of a single exit point at the mouth of the Orange River; a low volume of diluting sediments; extensive regional uplift followed by a long period of erosion; a relatively high-energy marine depositional environment that helped separate the diamonds from the other sediments, combined with northward prevailing winds and longshore currents that helped remove sand from the diamondiferous gravels; and the relatively young age of the sediments so they are unlithified and easy to mine. A brief history of mining over the past 110 years was given, as well as current challenges and innovations which should enable mining in this area to continue well into the future, both of the onshore and offshore deposits. **This author** covered recent mining of some alluvial diamond deposits in South Africa (see *The Journal*, Vol. 35, No. 6, 2017, pp. 484–485).

In other diamond presentations, **Gilles Walthert** (Edigem Ltd, Lucerne, Switzerland) examined the current diamond market. He summarised 2017 reports from Bain & Co. (see *The Journal*, Vol. 36, No. 1, 2018, p. 3) and

from De Beers (see p. 88 of this issue of *The Journal*), and then examined factors that affect diamond pricing, including physical properties ('4 Cs'), the presence of fluorescence, the stone's cut grade and whether it exemplifies a 'critical weight', the seller's situation and the gem's charm (particularly for fancy cuts). **Michael Hügi** discussed synthetic diamonds (Figure 3), which are becoming more common in the jewellery trade—2 million carats in 2017. He reviewed the diagnostic features of natural and synthetic diamonds that are seen with standard gemmological equipment, and also examined the marketing strategies being promulgated by mining companies and synthetics producers. He indicated that it is essential to have well-educated sales staff who should emphasise the exclusiveness of natural diamond.

Coloured stone overviews were delivered in two presentations. **Antoinette Starkey** (Antoinette Starkey Pierres Précieuses, Geneva, Switzerland) provided a coloured stone market report. She indicated that increasing demand for alternative gem varieties to ruby, emerald and sapphire are boosting the prices of those less-common stones. Overall, price increases are evident for top-quality gemstones of all varieties. **Dr Michael Krzemnicki** reviewed various gem materials that recently have come through SSEF's laboratory, including emeralds and sapphires from Ethiopia; sapphires from Bemainty, Madagascar with unstable padparadscha-like colouration; rubies from Mozambique that have undergone low-temperature heat treatment; fissure-filled rubies and Paraíba tourmalines; a glued jadeite bangle; grandidierite from Madagascar; 'mini-Ming' cultured pearls; saltwater natural pearls mixed with beadless freshwater cultured pearls that had been 'aged' to hide their presence; various types of fake pearls; and an opalised dinosaur vertebra.

Coloured stone localities were covered by several speakers. **Dr Klaus Schollenbruch** (Gübelin Gem Lab, Lucerne) described his May 2017 trip to Bemainty, Madagascar, where sapphire mining had slowed since the initial rush in late 2016. He estimated that 1,000–2,000 miners were active in each of two mining areas near Bemainty, and sapphire production was low. He then compared the gemmological properties of these sapphires with those from Kashmir, and found some significant differences in their inclusions and trace-element compositions. **Dr Lore Kiefert** (Gübelin Gem Lab, Lucerne) provided an update on emeralds from Ethiopia. The main emerald-producing area near the Kenticha tantalum deposit was closed by government authorities in December 2016 and reopened in 2017 after the formation of a local mining cooperative. The hillside was cleared of vegetation and soil using heavy machinery, but only small amounts of emerald were found. Another Ethiopian emerald deposit is located 150 km further south, approaching the Kenyan border.

Figure 2: Participants assemble for a poolside photo during the 2018 Swiss Gemmological Society conference. Photo by Michael Hügi.

Figure 3: Michael Hügi lectures on synthetic diamonds at the Swiss Gemmological Society conference. Photo by B. M. Laurs.

It is being worked by Gemfields, and so far most of the production has consisted of pale-coloured emerald and green beryl. **Alexander Klumb** (Swiss Gemmological Institute SSEF, Basel) summarised an October 2017 field trip by three SSEF gemmologists to Paraíba tourmaline mines in Brazil. They witnessed mining, sorting, cutting and trading activities in both Paraíba (São José da Batalha) and Rio Grande do Norte States (Mulungu mine near Parelhas), and they also learned about the geological context of the mining areas and collected research samples. At the time of their visit, Mulungu was the only mine producing significant quantities of Paraíba tourmaline, although mostly in smaller sizes.

Judy Tu (Swiss Gemmological Institute SSEF, Taipei, Taiwan) reviewed gem materials of Taiwan, which consist of nephrite, chrysocolla chalcedony, aragonite, rhodonite and precious coral. In the 1960s, Taiwan was an important nephrite producer (>1,200 tonnes/year), but by 1983 mining had mostly stopped. For nearly a century, precious coral has been fished from waters around Taiwan (eventually extending across the Pacific Ocean to Midway Island), with most production occurring from 1976 to the 1990s. Nowadays, Taiwanese government regulations limit harvesting to 200 kg per vessel per year, for a total of up to 60 tonnes. **Dr Karl Schmetzer** (Petershausen, Germany) recounted some little-known history of the Chivor emerald mine in Colombia. German gem merchant Fritz Klein re-opened Chivor in 1912, together with Colombian miner Francisco Restrepo, who rediscovered the mine in the late 19th century after it had lain forgotten in the jungle for about 200 years. Restrepo died in 1914, and Klein stopped his mining operations because of the outbreak of World War I. In the early 1920s, Klein was hired for two periods by an American company (Colombian Emerald Syndicate Ltd) that had bought the mining titles of Chivor in 1919. **Prof. Dr Henry Hänni** (GemExpert, Basel) and co-authors studied 'Sannan Skarn', a green ornamental stone from the Muslim Bagh area of Pakistan. SEM-EDS analysis revealed that the rock mainly consists of a groundmass of anorthite and diopside that contains crystals of green Cr-bearing hydrogrossular composed of 58 mol.% grossular, 33 mol.% uvarovite, 7 mol.% andradite and 1 mol.% pyrope.

Jörg Gellner (Gellner GmbH & Co. KG, Wiernsheim, Germany) reviewed the various types of cultured pearls, as well as their localities and production in 2017. He then explored quality criteria for cultured pearls that he defined according to the '5 Cs': size, shape, shade, surface/spot level and shine. For each category, he assigned different value factors according to specific characteristics that resulted in price premiums or discounts.

Dr Walter Balmer (Chulalongkorn University, Bangkok, Thailand) described a March–April 2018 SGS trip to Sri Lanka. SGS excursions to gem mining regions are organised every 2–3 years and are open to a maximum of 12 people who are SGS members or their close relatives/spouses. Rather than being buying trips, the excursions provide an opportunity to gain first-hand knowledge of the history, mining and culture of a gem-producing region, while also building friendships. **Martin Julier** (Bucherer Gem Lab, Lucerne) described his involvement with the BusinessKind aid project in Myanmar. He first visited Myanmar in 2007 as a gem merchant, and in 2008 he became interested in social work when he personally witnessed the devastation caused by Cyclone Nargis. BusinessKind has organised the manufacture of bed nets and citronella candles to help prevent malaria, and also provides employment training. Its most recent project, Thone Pan Hla, is Myanmar's first female garment factory workers' association.

Brendan M. Laurs FGA

Gem-A Notices

Gifts to the Association

Gem-A is most grateful to the following for their generous donations which will support continued research and teaching:

Eric Braunwart, Columbia Gem House Inc., Vancouver, Washington, USA, for a variety of imitation gem materials.

Dr Rui Galopim de Carvalho, for donating two books to Gem-A's library: *Precious Stones in Sacred Art in Portugal* by Rui Galopim de Carvalho and *O Santo Lenho da Sé de Évora* by Rui Galopim de Carvalho, Artur Goulart de Melo Borges and Gonçalo Vasconcelos e Sousa.

Farooq Hashmi, Intimate Gems, Glen Cove, New York, USA, for an assortment of rough garnet from the Democratic Republic of Congo.

William Hasselrot, for a monetary donation.

Ronda Hipwell, for a monetary donation.

Syed Iftikhar Hussain, Syed Trading Co., Islamabad, Pakistan, for three afghanite crystals from Afghanistan.

Dr Jaroslav Hyršl, Prague, Czech Republic, for a 'zebra garnet' cabochon from Peru.

Charles Mark, Elizabeth, Colorado, USA, for a piece of rough Larimar from the Caribbean.

John Osborne, for a monetary donation.

Lorne Stather, for donating four books to Gem-A's library: *Birthstones of the Month* by Joan Frank, *Carving Shells and Cameos* by Carson I. A. Ritchie, *Consumer Guide to Coloured Gemstones* by David Federman and *Diamants* by Hubert Bari and Violaine Sautter.

Estelle Weiner, for diamond manufacture models.

Tak Yi Yung, for a monetary donation.

NAJ and Gem-A Field Trip to Sri Lanka

1–16 October 2018
Collaborative National Association of Jewellers and Gem-A field trip to Sri Lanka accompanied by gem experts Colin and Hillary Winters. For more information, contact lindsey.straughton@naj.co.uk.

Gem-A Open Evening

18 July 2018
Tour Gem-A's headquarters and meet our tutors.
http://gem-a.com/event/rsevents/event/25-gem-a-open-evening.

Gemstone Photographer of the Year Competition 2018

Gem-A's annual photography competition returns this summer 2018 for all members and students of Gem-A. There are three categories for entry: **'Internal'** (including photomicrography, gemscapes and unusual inclusions), **'External'** (unusually cut or faceted gemstones, carvings and *objets d'art*) and **'Humanity in Gems'** (life around gemstones, including mining, dealing, and gemmologists at work or studying).

Please submit all entries to editor@gem-a.com, specifying your membership/student number and category of entry. For files larger than 10 MB, please submit via Dropbox or WeTransfer.

A member award and a student award, and honourable mentions for each category, will be announced at the 2018 Gem-A Conference. Closing date for entries is Friday 31 August 2018.

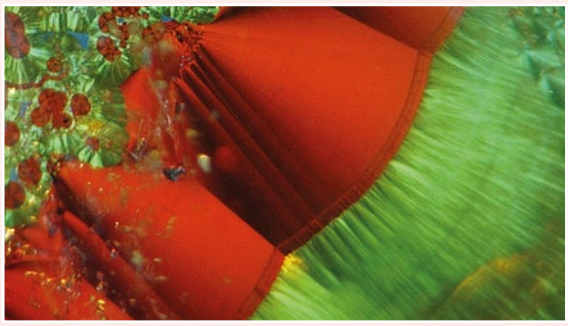

Iron oxide in quartz from Brazil. Image by Oliver Segura.

Learning Opportunities

CONFERENCES AND SEMINARS

Sainte-Marie-aux-Mines 55th Mineral & Gem Show
21–24 June 2018
Sainte-Marie-aux-Mines, France
www.sainte-marie-mineral.com/english/modules/cultural-activities
Note: Includes a seminar programme

Northwest Jewelry Conference
10–12 August 2018
Seattle, Washington, USA
www.northwestjewelryconference.com

22nd Meeting of the International Mineralogical Association
13–17 August 2018
Melbourne, Victoria, Australia
www.ima2018.com/program
Sessions of interest:

- Mantle Xenoliths, Kimberlites and Related Magmas: The Diamond Trilogy
- Pegmatite Mineralogy, Geochemistry, Classification and Origins
- Recent Advances in our Understanding of Gem Minerals
- Sciences Behind Gemstone Treatments

Dallas Mineral Collecting Symposium
24–26 August 2018
Dallas, Texas, USA
www.dallassymposium.org

Scandinavian Gem Symposium 2018
25–26 August 2018
Kisa, Sweden
www.sgs.gemology.se/#home

Japan Jewellery Fair
28–30 August 2018
Tokyo, Japan
www.ubmjapan-group.com/jjf/en/seminar
Note: Includes seminar programme

IJL London
2–4 September 2018
London
www.jewellerylondon.com/Whats-On/Seminars
Note: Includes a seminar programme

29th International Conference on Diamond and Carbon Materials
2–6 September 2018
Dubrovnik, Croatia
www.elsevier.com/events/conferences/international-conference-on-diamond-and-carbon-materials

Hong Kong Jewellery & Gem Fair
12–18 September 2018
Hong Kong
http://exhibitions.jewellerynet.com/9jg/en-us/specialevents
Note: Includes a seminar programme

Fabergé Museum International Academic Conference: Jewellery Art of the 19th & Early 20th Centuries
20–22 September 2018
St Petersburg, Russia
https://fabergemuseum.ru/en/news/article/118

Mallorca Gemquest
22–23 September 2018
Sóller, Mallorca, Spain
www.mallorcagemquest.com

2018 GIA Symposium: New Challenges. Creating Opportunities
7–9 October 2018
Carlsbad, California, USA
http://discover.gia.edu/symposium

ASMOSIA XII—Association for the Study of Marble & Other Stones in Antiquity International Conference
8–14 October 2018
Izmir, Turkey
www.asmosia2018.com

II World Emerald Symposium
12–14 October 2018
Bogotá, Colombia
www.regonline.com/builder/site/Default.aspx?EventID=2137425

2018 Friends of Mineralogy, Pacific Northwest Chapter Symposium—Minerals of California
19–21 October 2018
Kelso, Washington, USA
http://pnwfm.org/2017/12/19/2018-symposium-minerals-of-california

Canadian Gemmological Association Gem Conference 2018
19–21 October 2018
Vancouver, British Columbia, Canada
http://canadiangemmological.com/events-conferences/upcoming-conferences

The Munich Show: Mineralientage München
26–28 October 2018
Munich, Germany
https://munichshow.com/en/the-munich-show/public-days/highlights
Note: Includes a seminar programme

Singapore Jewellery & Gem Fair
26–29 October 2018
Singapore
www.singaporejewellerygemfair.com/JewelTalk
Note: Includes seminar programme

Gem-A Conference 2018
3–4 November 2018
London
https://gem-a.com/event/conference

The Geological Society of America 130th Annual Meeting
4–7 November 2018
Indianapolis, Indiana, USA
http://community.geosociety.org/gsa2018/home
Session of interest: Gemological Research in the 21st Century—Characterization, Exploration, and Geological Significance of Diamonds and Other Gem Minerals

Swiss Geoscience Meeting
30 November–1 December 2018
Bern, Switzerland
https://geoscience-meeting.ch/sgm2018
Note: Includes a gemmology session

Gem-A Midlands Branch Conference
23 February 2019
Birmingham
Email louiseludlam@hotmail.com

Inhorgenta Munich
22–25 February 2019
Munich, Germany
www.inhorgenta.com
Note: Includes a seminar programme

American Gem Society Conclave
8–10 April 2019
Seattle, Washington, USA
www.americangemsociety.org/page/conclave2019

European Gemmological Symposium 2019
24–26 May 2019
Idar-Oberstein, Germany
Email info@dgemg.com

EXHIBITIONS

Australia and New Zealand

The Language of Things: Meaning and Value in Contemporary Jewellery
Until 24 June 2018
The Dowse Art Museum,
Lower Hutt, New Zealand
http://dowse.org.nz/exhibitions/detail/the-language-of-things

Cartier: The Exhibition
Until 22 July 2018
National Gallery of Australia, Canberra, Australia
https://nga.gov.au/cartier

Lustre: Pearling & Australia
Until 22 July 2018
National Museum of Australia, Canberra, Australia
www.nma.gov.au/exhibitions/lustre-pearling-and-australia

Europe

De Calder à Koons, Bijoux d'Artistes. La Collection Idéale de Diane Venet
Until 8 July 2018
Musée des Arts Décoratifs, Paris, France
http://tinyurl.com/ydb28ru8

Grant MacDonald: International Silversmith
Until 25 July 2018
Goldsmiths' Hall, London
https://grantmacdonald.com/exhibition

Designers and Jewellery 1850–1940: Jewellery and Metalwork from the Fitzwilliam Museum
31 July–11 November 2018
The Fitzwilliam Museum, Cambridge
http://tinyurl.com/ybvy7oj6

Eva's Beauty Case & Adam's Necessaire. Schmuck und Styling im Spiegel der Zeiten
Until 12 August 2018
Braunschweigisches Landesmuseum, Braunschweig, Germany
http://3landesmuseen.de/Eva-s-Beauty-Case-Adams-Necessaire.1649.0.html

Jewellery by Giò Pomodoro – The Sign and the Ornament
Until 2 September 2018
Museo del Gioiello, Vicenza, Italy
http://tinyurl.com/y7bdzt4h

The Splendour of Power
Until 30 September 2018
Museet på Koldinghus, Kolding, Denmark
www.koldinghus.dk/uk/exhibitions-2017/the-splendour-of-power-2018.aspx

Brussels Horta & Wolfers. Reopening of the Wolfers Frères Jewellery Store, 1912
Until 30 December 2018
Cinquantenaire Museum, Brussels, Belgium
www.kmkg-mrah.be/expositions/horta-wolfers

East Meets West – Jewelled Splendours of the Art Deco Era. The Prince and Princess Sadruddin Aga Khan Collection
Until 6 January 2019
Schmuckmuseum Pforzheim, Germany
www.schmuckmuseum.de/en/current.html

BVLGARI. Tribute to Femininity. Magnificent Roman Jewels
7 September 2018–13 January 2019
The Moscow Kremlin Museums, Russia
www.kreml.ru/en-Us/exhibitions/moscow-kremlin-exhibitions/bvlgari-tribute-to-femininity

From Zeus to Earth and from Chile to Neapolis
1 October–31 December 2018
Ilias Lalounis Jewelry Museum, Athens, Greece
http://lalaounis-jewelrymuseum.gr/en/exTdetails.asp?exid=39

North America

American Jewelry from New Mexico
Until 14 October 2018
Albuquerque Museum, New Mexico, USA
www.cabq.gov/culturalservices/albuquerque-museum/exhibitions/american-jewelry

Fabergé and the Russian Crafts Tradition: An Empire's Legacy
Until 24 June 2018
The Walters Art Museum, Baltimore, Maryland, USA
https://thewalters.org/event/faberge-and-the-russian-crafts-tradition-an-empires-legacy

A Modern Gem and Jewelry Collection
Until July 2018
Flandrau Science Center & Planetarium, University of Arizona, Tucson, Arizona, USA
https://flandrau.org/exhibits/somewhere-rainbow

Past is Present: Revival Jewelry
Until 19 August 2018
Museum of Fine Arts, Boston, Massachusetts, USA
https://mfa.org/news/past-is-present-revival-jewelry

Peacock in the Desert: The Royal Arts of Jodhpur, India
Until 19 August 2018
Museum of Fine Arts, Houston, Texas, USA
https://mfah.org/exhibitions/peacock-in-desert-royal-arts-jodhpur-india

Centuries of Opulence: Jewels of India
Until 10 October 2018
GIA Museum, Carlsbad, California, USA
www.gia.edu/gia-museum-exhibit-centuries-opulence-jewels-india

Crowns of the Vajra Masters: Ritual Art of Nepal
Until 16 December 2018
The Met Fifth Avenue, New York, New York, USA
https://metmuseum.org/exhibitions/listings/2017/crowns-of-vajra-masters

Fabergé Rediscovered
Until 13 January 2019
Hillwood Estate, Museum & Gardens, Washington DC, USA
http://hillwoodmuseum.org/faberge-rediscovered

Beadwork Adorns the World
Until 3 February 2019
Museum of International Folk Art, Santa Fe, New Mexico
http://internationalfolkart.org/exhibition/3348/beadwork-adorns-the-world

East Meets West: Jewels of the Maharajas from the Al Thani Collection
3 November 2018–24 February 2019
Legion of Honor Museum, San Francisco, California, USA
http://legionofhonor.famsf.org/exhibitions/east-meets-west

OTHER EDUCATIONAL OPPORTUNITIES

Gem-A Workshops and Courses
Gem-A, London
https://gem-a.com/education/courses/workshops

American Society of Appraisers—Appraising Gems & Jewelry for Advanced Assignments: Development and Report Writing
23 August 2018
McLean, Virginia, USA
www.appraisers.org/Education/View-Course?CourseID=72

Pearls as One – Pearl Specialist Course
Online pearl course from The Cultured Pearl Association of America (CPAA), supported in part by Swiss Gemmological Institute SSEF. Gem-A members have been granted complimentary access (normally US$599) to the course by SSEF and CPAA. Sign up at www.pearlsasone.org using discount code 'Gem-A' at the payment menu.

Lectures with Gem-A's Midlands Branch
Fellows Auctioneers, Augusta House, Birmingham
Email louiseludlam@hotmail.com

- Craig O'Donnell—Styles & Stones
  28 September 2018
- Paul Phillips—Photography & Micro Photography
  26 October 2018
- Vanessa Paterson—Amber
  30 November 2018

Lectures with The Society of Jewellery Historians
Society of Antiquaries of London, Burlington House, London
www.societyofjewelleryhistorians.ac.uk/current_lectures

- Tara Kelly—Purchasing the Past: Consumers of Irish Facsimile Jewellery, 1840–1940
  26 June 2018
- Christopher Thompson Royds—My Work as a Jeweller
  25 September 2018
- Anna Tabakhova—Clasps: 4000 Years of Fasteners in Jewellery
  23 October 2018
- Helen Ritchie—Designers and Jewellery: Jewellery and Metalwork from the Fitzwilliam Museum 1850–1940
  27 November 2018
- Martin Henig—Personal Cameos of Roman Date in the Content Family Collection
  22 January 2019
- Jack Ogden—TBA
  26 February 2019
- Peter Semrád—The Story Behind 'Hungarian' Opals
  26 March 2019
- Beth Wees—TBA
  25 June 2019

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New Media

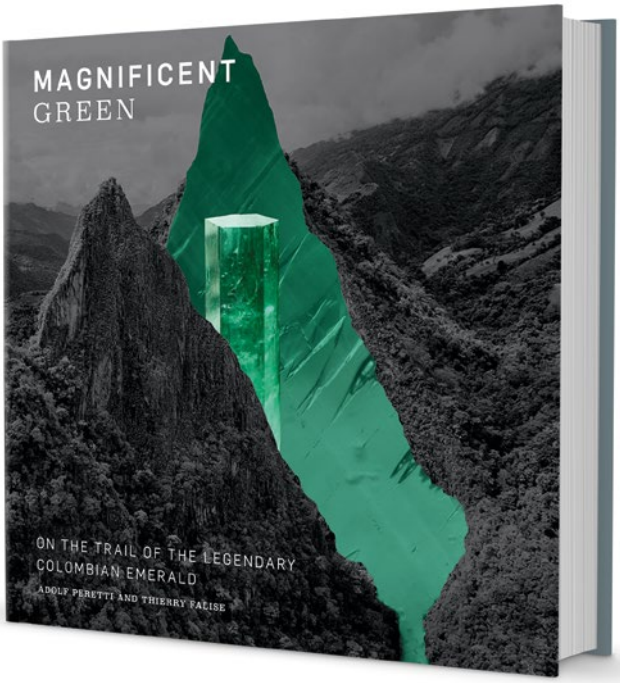

Magnificent Green – On the Trail of the Legendary Colombian Emerald

By Adolf Peretti and Thierry Falise, 2017. GRS Gemresearch Swisslab AG, Lucerne, Switzerland, http://gemresearch.ch/product/magnificent-green-on-the-trail-of-the-legendary-colombian-emerald, 337 pages, illus., ISBN 978-3906905099. US$150.00 hardcover

Books on single gem varieties are few and far between, so the addition of a book specifically on Colombian emeralds is quite a treat. Co-author Dr Adolph Peretti, who attended more than 40 gem and jewellery auctions between 1994 and 1998, has created a unique database of some of the rarest and highest-quality emeralds ever offered on the international market. Many of the Colombian emerald jewels he studied are pictured in this book, and they represent masterpieces of jewellery art.

On first impression *Magnificent Green* looks like a 'coffee-table' book, with lots of beautiful pictures but not a lot of serious content to offer. So, I was pleasantly surprised by the quality of information that coincided with wonderful photos of the mines and the emeralds—rough, cut and in jewels—which are depicted throughout the book. Detailed maps and extracts from geological reports help to further enlighten the reader on the origins and formation of Colombian emeralds. Rare photographs capture the open-cut Muzo mine workings from 1872, and other historical photos illustrate different mines in the early years of the 20th century.

The authors lead the reader through historical and modern accounts of the people for whom emeralds are their daily existence. The indigenous Colombian inhabitants were the first to appreciate the green stones. By the time the Spanish arrived in the 16th century, the locals had been trading emeralds for centuries, calling them 'Stones of Earth' and believing that they were associated with fertility. The Spanish conquistadors brought these New World emeralds back to Europe, revealing to gem merchants of the time that the term *Oriental* emerald was a false attribution, and proving that most of the fine-quality emeralds in collections originated from South America, not Asia. Mining in 16th-century Colombia was difficult, carried out by enslaved indigenous people as well as African slaves who rarely survived more than a few years before succumbing to brutal overseers, disease or starvation. Besides reviewing this important back history, the book also brings the reader up to date in regard to current activities. Muzo is presently the most productive mine in the region and has been run by an American company since 2009. Chivor, after being lost for 200 years, is now again producing vivid green emeralds as well. Cunas, Coscuez and Gachalá too are all still being exploited.

Throughout the book the authors weave together tales of famous jewels, antique and modern, and brief portraits of the renowned jewellers who created them. Some of the antique pieces include the jewelled mirror of King Louis XIV, the 'Sun King' of France; La Lechuga, an 18 carat gold liturgical monstrance set with 1,485 Muzo emeralds along with numerous natural pearls, diamonds, amethysts, rubies and one sapphire; and the 'Crown of the Andes', a 17th-century gold and emerald crown made to adorn a statue of the Virgin Mary in Popayan, Colombia and acquired by the Metropolitan Museum of Art in New York City in 2015. These are just a few of the historical jewels that are described. Also included is a helpful timeline of events in Colombia compared with developments in the rest of the world from roughly 2000 BC to the present day, which helps put Colombian emeralds into a global context.

Although there is a discussion of emerald quality and how the gemmological properties of Colombian emeralds help make them so special, the human stories interested me the most. Conflicts were common in the region during most of the 20th century, but were somewhat resolved in 1990 with a negotiated peace agreement between prominent emerald families. But with the 2013 death of

Victor Carranza, a key figure in the peace negotiations, violence once again became a concern. (In one place the book indicates that Carranza died of cancer, but elsewhere it states that Carranza was murdered. There are other inconsistencies in the book, but they do not detract from the main narrative.) In 2009 Carranza had agreed to work with the American company Minería Texas Colombia (MTC) to modernise mining and management in the emerald region, effectively cutting out the independent prospectors (*guaqueros*) who traditionally searched through the tailings produced by the various mining activities. That, combined with general political and social unrest in Colombia, made for a dangerous situation. A new peace agreement was suggested in 2015 through the gathering of 400 people, including the Catholic Church, civil society and the armed forces, but sadly it never came to fruition. Currently, MTC is working to set an example and encourage other emerald mines to run their operations to American standards. Health and safety measures have been greatly upgraded, and salaries, benefits and living conditions are being improved. The inclusion of women in the Colombian emerald industry is common in most areas of business, and with improved social and safety measures this should become even more prevalent in the future.

An Appendix at the end of the book includes a selection of laboratory reports on Colombian emeralds sold through international auction houses; all the reports were created by GRS Gemresearch Swisslab AG, run by Dr Peretti. In addition, information has been compiled including the auction house, date of sale, auction location and brief description of the item, but no selling prices are included, which would have been helpful.

This book is unusual (and is to be commended) in having been created, in part, to fund a charitable organisation known as Clay Hands, which plans to use the proceeds of the book's sale to sponsor the building of a school in Muzo that will be called 'GRS Muzo School for Young Talents'. Furthermore, in an effort to marry different communication formats, there are several QR matrix codes throughout the book, and scanning them with a smartphone links the reader to informative videos. It is nice to see modern technology combined with the age-old comfort of a handheld book. Overall, *Magnificent Green* weaves together an excellent compilation of the many different aspects that comprise Colombian emeralds and the complex and quickly changing industry that surrounds them. The charitable aspect is an added bonus.

Jo Ellen Cole GG
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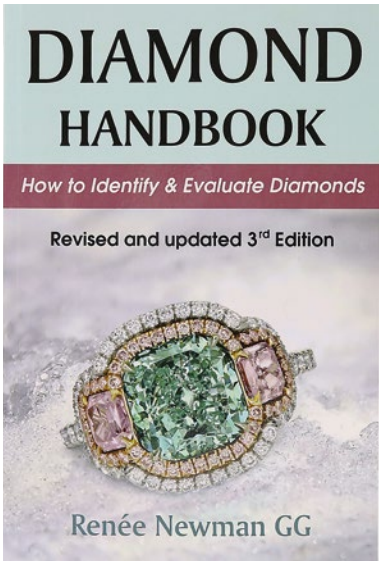

Diamond Handbook, 3rd edn.

By Renée Newman, 2018. International Jewelry Publications, Los Angeles, California, USA, www.reneenewman.com/handbook.htm, 168 pages, illus., ISBN 978-0929975535. US$19.95 softcover.

This third edition of the *Diamond Handbook* by Renée Newman provides a welcome update to her series. Information has been added in the chapters titled Fancy Color Diamonds, Diamond Fluorescence, Diamond Treatments, Recutting Diamonds and Antique Cuts & Jewelry. Overall, the content follows the first (2005) and second (2010) editions, but there are some significant deletions and additions.

Two chapters from previous editions have been deleted: Judging Light Performance—a topic with little consensus in the trade—and Diamond Grading Reports. This reviewer is disappointed to see this latter chapter being omitted, since it will be missed by the novice hoping to learn about diamonds and avoid being cheated by unscrupulous sellers using unreliable grading reports. The Synthetic Diamonds chapter has been reworked and expanded, adding more explanation of advanced testing and the newest instrumentation currently available on the market. New to this third edition is a chapter titled Diamond Imitations, which includes the separation of black diamonds from other black stones. In addition, more high-quality images have been added to the chapter called Judging Fancy Color Diamonds, making this complicated subject a little easier to understand.

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Bumble Bee Stone from Indonesia

Tracking and Traceability in the Gem Industry

Circling on Ming Cultured Pearls

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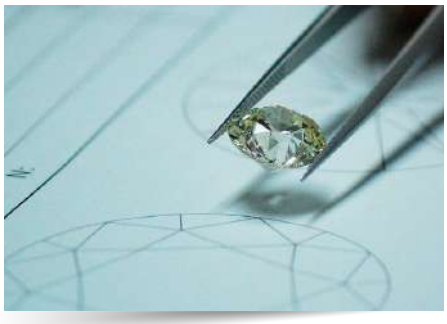

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Cover photo: *Bumble Bee Stone from Indonesia is an unusual carbonate-rich rock that is coloured by arsenic sulphide minerals and may also contain black areas of 'sooty' pyrite. A pattern resembling an erupting volcano is seen in this cabochon (45 × 65 mm), and is reminiscent of the volcanic origin of this gem. Courtesy of Rare Earth Mining Company.*

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What's New

INSTRUMENTATION

Alrosa Diamond Inspector

Released in March 2018, the Diamond Inspector from Russian diamond mining company Alrosa was developed jointly with the Technological Institute for Super Hard and Novel Carbon Materials in Moscow. The instrument is designed for separating polished loose or mounted natural, treated and synthetic diamonds, as well as simulants. Testing takes less than one minute per sample and reportedly employs three analytical methods. Near-colourless (D–K) samples that range from 0.03 to 10 ct may be tested; the analysis is performed on a round flat area of the sample with a diameter of at least 1.5 mm. The Diamond Inspector weighs 1.8 kg (plastic frame) or 3.1 kg (metal frame), and measures 25 × 15 × 10 cm. Visit http://alrosa-inspector.com. *BML*

D-Tect for Synthetic Diamonds

In May 2018, HRD Antwerp in Belgium released its new D-Tect instrument. It is designed to be the final step in the identification of synthetic diamonds, following screening by HRD's M-Screen+ or any other diamond screening device that refers samples for further testing. D-Tect is a compact table-top instrument that can be used for both loose and mounted diamonds of all sizes and shapes in the D–Z colour range. It separates natural from laboratory-grown diamonds, as well as common diamond simulants. The unit is non-automated (requiring operator training) and is based on UV luminescence imaging and Raman and photoluminescence spectroscopy. For further information, or to request a demonstration, visit https://hrdantwerp.com/equipment/d-tect?language_content_entity=en. *CMS*

DiaColor Colorimeter from OGI Systems

OGI Systems Ltd (Ramat Gan, Israel) released two models of their DiaColor colorimeter in 2017: C-300 and C-1000. Both are designed to automatically measure the colour of rough diamonds in the D–Z range with about ½-colour-grade accuracy. The C-300 can accommodate samples weighing 0.30–300 ct, while the C-1000 can take diamonds up to 1,000 ct. The instrumentation reportedly can also indicate yellow and blue fluorescence, and detect diamonds that are type IIa (identifying those that are candidates for HPHT treatment), type IIb (blue or grey) and irradiated blue. Visit www.ogisystems.com/diacolor.html. *CMS*

Torcia 365 Long-wave LED Torch

During the June 2018 JCK Las Vegas show in Nevada, USA, the author obtained a new long-wave UV torch distributed by Mike Gray of Coast-to-Coast Rare Stones (Mendocino, California, USA). The flashlight, called the Torcia 365, is manufactured by Way Too Cool LLC (Glendale, Arizona, USA). The unit features a 3-watt Nichia 365 nm LED and a rechargeable battery. It produces a strong long-wave UV beam that can be used to check the fluorescence of a wide variety of gem materials. Its portable, battery-powered nature makes it useful for testing stones in the field (e.g. for quickly separating highly fluorescent stones such as ruby and spinel from non-fluorescent materials such as red garnet). Another potential application is checking for fracture fillings in emerald, as most emerald fillers show blue or yellow fluorescence. The author measured the flashlight's output with a spectrometer and confirmed it to be centred at approximately 368 nm (long-wave UV is 365 nm) with almost no visible-light component as a result of the unit's special filter. This waterproof flashlight is estimated to operate for approximately 1 hour per charge of the 18650 Li-ion battery. For more information, visit www.fluorescents.com/products-torcia.html.

Nathan D. Renfro FGA
Gemological Institute of America
Carlsbad, California
USA

NEWS AND PUBLICATIONS

Amberif 2017 and 2018 Conference Proceedings

Proceedings of conferences that took place during the 2017 and 2018 International Fair of Amber, Jewellery & Gemstones—Amberif—are available as free PDF files. The 42-page 2017 volume contains articles on 'amber personality' Wiesław Gierłowski, the origin of fossil resins, bio-inclusions in Burmese amber and the history of amber artefacts. The 167-page 2018 volume contains a much more extensive range of topics, including abstracts and full articles. The 2017 volume can be downloaded from http://tinyurl.com/y7u8k6u6 and the 2018 volume from http://tinyurl.com/y9ucpvxw. *CMS*

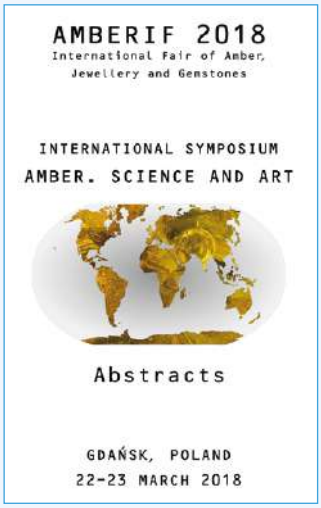

EGU General Assembly 2018 Gem Abstracts

Abstracts from the 8–13 April 2018 European Geosciences Union General Assembly in Vienna, Austria, are now available online. Of particular interest to gemmologists are poster presentations from the session 'Gem Materials: Properties and Genesis Processes', which can be viewed at https://meetingorganizer.copernicus.org/EGU2018/posters/27160. The abstracts cover a wide range of topics related to coloured stones. *CMS*

FTC's 'Jewelry Guides' Revised

In July 2018, the U.S. Federal Trade Commission (FTC) approved revision of its 'Jewelry Guides' (formerly 'Guides for the Jewelry, Precious Metals, and Pewter Industries'). The updated Guides incorporate public input invited with regard to specific topics since 2012. The revisions help align guidance with consumer expectations, and address technological and industry practice developments that affect nomenclature and terminology. Gem-specific revisions relate to 'composite gemstone products', 'varietals', 'cultured' diamonds, claims about synthetics, pearl treatment disclosures, use of the term 'gem', misleading illustrations and the definition of 'diamond'. For more information, and links to the full-text Guides, visit the FTC press release at www.ftc.gov/news-events/press-releases/2018/07/ftc-approves-final-revisions-jewelry-guides. *CMS*

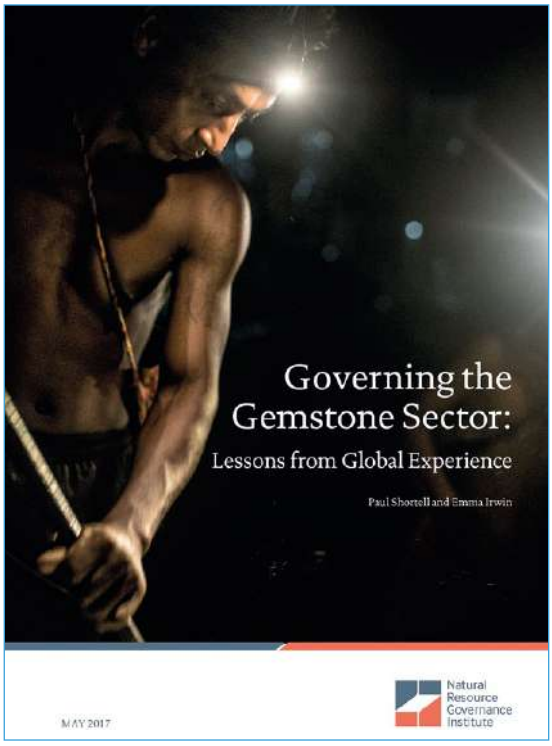

Governing the Gemstone Sector: Lessons from Global Experience

From the National Resource Governance Institute, this May 2017 report gathers and contextualises case studies on the management of gemstone resources and trade by governments of various gem-producing countries: Botswana, Brazil, Guyana, Madagascar, Myanmar, Pakistan, Sierra Leone, Sri Lanka, Tanzania, Thailand and Zambia. Topics cover citizen mining, modernisation of state-owned operations, fiscal terms, valuation processes, beneficiation, trade policies and accountability. To download the 72-page PDF, go to http://tinyurl.com/y9dt6xa8. *CMS*

Sapphires from Mogok, Myanmar

In June 2018, the Gemological Institute of America released a 56-page report titled 'Characterization of Blue Sapphires from the Mogok Stone Tract, Mandalay Region, Burma (Myanmar)'. It includes photos of mining areas and internal features in the sapphires, as well as UV-Vis-NIR and FTIR spectra and chemical data. The study concludes that a combination of features appear promising to identify the origin of Burmese sapphires. Download the report at http://tinyurl.com/y7d7h37l. *CMS*

Abstract of Papers Presented at Annual Meeting of the Gemmological Society of Japan

GSJ 2018 Annual Meeting Abstracts

Abstracts of Special Lectures presented at the 2018 Annual Meeting of the Gemmological Society of Japan (held 9–10 June in Toyama, Japan) can now be accessed online. The 20 abstracts include a wide variety of topics on diamonds, coloured stones and cultured pearls. Downloadable PDFs are available (in Japanese and English) from www.jstage.jst.go.jp/browse/gsj/list/-char/en. *CMS*

PGI Insight 2018

Each issue of this publication from Platinum Guild International provides in-depth information on a focused topic regarding market trends in the platinum jewellery industry. The 2018 issue of *PGI Insight* addresses 'Rejuvenation of Platinum Jewellery in China'. The report opens by pointing out that China is the world's largest platinum jewellery market. However, demand has declined during the past four years. The report examines possible reasons for this decline and explores options to rebuild the market in China. The primary solution proposed is a change from weight-based to piece-based pricing. To download this and other PGI publications, visit http://platinumguild.com/research-publications/pgi-insight. *CMS*

Wooshin Gem Lab Magazine Vol. 5 2018

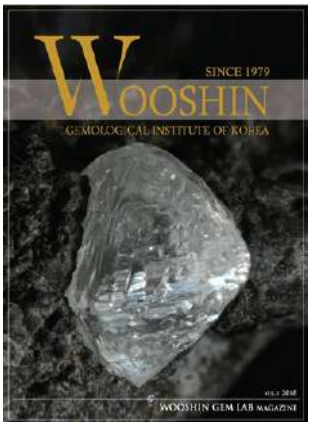

The 2018 issue of this publication from the Wooshin Gemological Institute of Korea is now available online in both Korean and English. Included are articles on the isotopic signatures of gem materials, the iridescence of mother-of-pearl, anorthite with uvarovite inclusions, identification of melee-size cubic zirconia diamond simulants in a ring, Raman spectroscopy of serpentine from Iran, and a review of colour-change gemstones, along with recent Wooshin events. To download the PDF, visit www.wooshinlab.com/LabStory/Research/Read.wgk?ArticleID=212, click the blue button, and select '2018WGK_EN.pdf'. *CMS*

OTHER RESOURCES

Yellow Diamonds Educational Video

In June 2018, the Natural Color Diamond Association (NCDIA) announced its first educational video, 'Natural Yellow Diamonds.' The 30-minute video is designed to appeal to both consumers and trade members. It covers the causes of yellow colour in diamond, range of colour, geographic origins, differences between natural and synthetic samples, comparison to other yellow gems, and more. The goal is to improve communication between consumers and trade professionals, as well as promote industry growth of affordable diamond jewellery. To order the video (US$100.00), visit https://ncdia.com/education. *CMS*

NCDIA NATURAL COLOR DIAMOND ASSOCIATION

MISCELLANEOUS

Call for Papers: Gem Issue of *The Extractive Industries and Society*

A special issue of *The Extractive Industries and Society* will focus on 'Gemstones: Perspectives and Trends in Mining, Processing and Trade of Precious Stones'. The goal is to attract papers from a broad range of contributors and disciplines associated with the production and trade of gem materials. The deadline to submit full papers is 1 December 2018. Authors will be notified of acceptance or rejection by 1 March 2019, and publication will occur in early 2019. For author guidelines, topic suggestions and a link to submit papers, visit http://tinyurl.com/yaw5e9qb. *CMS*

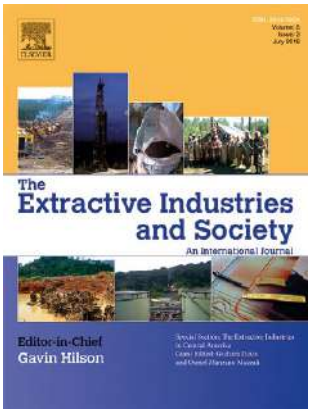

What's New provides announcements of new instruments/technology, publications, online resources and more. Inclusion in What's New does not imply recommendation or endorsement by Gem-A. Entries were prepared by Carol M. Stockton (CMS) or Brendan M. Laurs (BML), unless otherwise noted.

Diamond Museum Opens in Botswana

In March 2018, the Adrian Gale Diamond Museum opened in northern Botswana at Debswana's Orapa diamond mine. The museum is named after the late Dr Adrian Gale, who was general manager at the Orapa, Letlhakane and Damtshaa mines during 2012–2015. The museum showcases the discovery of diamonds in Botswana (in Orapa in 1967, a year after Botswana became independent from Britain), which have played an important role in the economic development of the country.

The museum is divided into two parts—a permanent and a temporary exhibition hall—with the latter to be developed in the future. The storyline follows six key thematic areas comprising: Introduction, The Formation of Earth and Geology, Diamond Prospecting and Exploration, Diamond Mining, Diamond Ore Processing, and Processing of the Final Diamonds. To visit, contact Debswana Corporate Affairs at Orapa by emailing kpilane@debswana.bw.

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COLOURED STONES

Ametrine with Trapiche-like Patterns from Brazil

Ametrine is colour-zoned amethyst-citrine that is commercially known from only two deposits (approximately 50 km apart), which are both located in Bolivia (Vasconcelos et al., 1994; Laurs, 2010). It was with considerable interest, therefore, when ametrine reportedly from a new locality—Minas Gerais, Brazil—appeared at the February 2018 gem shows in Tucson, Arizona, USA. The stones were displayed by Dr Marco Campos Venuti (Seville, Spain), who obtained the rough material during the August 2017 Feira Internacional de Pedras Preciosas (FIPP) gem show in Teófilo Otoni, Brazil. The quartz crystals displayed corroded pyramidal terminations and commonly formed flared individuals that were bounded by irregular surfaces (i.e. contact points with adjacent crystals). Viewed in reflected light, they appeared mostly grey with central areas containing some amethyst (Figure 1, left). In transmitted light, the central portion of the crystals displayed a combination of amethyst and citrine colouration, while both the base and termination areas appeared very dark (Figure 1, right). Clearly, it was necessary to cut and polish these crystals before their inner beauty could be appreciated.

From approximately 400 kg of rough, Dr Campos Venuti cut about 36,000 carats of polished tablets and cabochons in various shapes up to 43 mm in maximum dimension. To best show their zoning patterns, the stones were oriented so that they are viewed down the c-axis. Those cut from the central part of the crystals displayed various colour-zoned patterns of amethyst and citrine (Figure 2, top left). Compared to ametrine from Bolivia, the colours were less saturated and the stones contained more abundant inclusions (mostly parallel bundles of feathers and veils, as well as black particles and filaments). More striking in appearance were stones cut from the dark area toward the base of the crystals. These showed patterned black cores of various size that were surrounded by amethyst-citrine zones, or in some cases the stones were cut entirely from the black areas of the crystals (again, see Figure 2). The black colour was due to dense networks of radiating inclusions that commonly formed segments which were separated by six radiating arms of clear quartz. Such spoked patterns are typical of the trapiche structure exhibited by some

Figure 1: The rough ametrine from Brazil typically consists of flared pieces that are bounded by corroded pyramidal terminations and appear mostly grey in reflected light (left). Transmitted illumination shows a central portion that displays a combination of amethyst and citrine colouration, with adjacent dark areas at the base and termination (right). Photos courtesy of Marco Campos Venuti.

Figure 2: These cabochons of trapiche-like quartz from Brazil show various patterns created by the amethyst-citrine colour zones and/or areas containing abundant black inclusions. The stones range from 15.5 × 11.7 mm to 21.3 × 15.9 mm. Gift of Marco Campos Venuti; photo by Jeff Scovil.

gem materials. However, rather than having transparent sectors separated by inclusion-rich arms, the black areas of this quartz consisted of included sectors that were separated by spokes of transparent quartz.

Sun et al. (2018) recently examined similar stones from Brazil (which they described as amethyst, rather than ametrine), and using Raman spectroscopy they identified the black inclusions as an iron sulfide mineral, likely pyrite. They also documented tiny brownish bullet-shaped inclusions in the arms of the trapiche-like structure that could not be identified but were probably goethite. The latter inclusions were only barely present in just one of the samples examined.

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Hessonite from Mogok, Myanmar

At the February 2018 gem shows in Tucson, Arizona, USA, gem cutter Meg Berry (Megagem, Fallbrook, California, USA) obtained some faceted garnets that were reportedly from a new occurrence in Mogok, Myanmar. The parcel consisted of 12 'native-cut' rectangular cushion-shaped gems. According to her supplier (Sai Tit of Cleopatra Gems, Chiang Rai, Thailand), who specialises in Burmese minerals, the stones came from the Lae Oo mine. This may be the same as the 'Le-U' mining area that was described by Themelis (2008) as lying below the well-known Dattaw deposit. According to Themelis (2008), Le-U has produced ruby, bicoloured tourmaline, moonstone, quartz, topaz, danburite and spinel (no garnet was listed), and the mines there were closed in 2001.

Eight of the stones were loaned to authors CW and BW for characterisation, weighing 0.68–1.14 ct (total weight 7.05 carats). Their colour ranged from light-to-medium 'golden' brown (Figure 3). Their RIs spanned from 1.740 to 1.748, with no consistent variation according to their tone. Due to the rather small size of the stones, no hydrostatic SG measurements were taken.

Figure 3: These garnets (0.68–0.99 ct) from Mogok, Myanmar, were identified as hessonite. Photo by Dean Brennan, Stone Group Laboratories.

The GemmoRaman-532SG identified all of them as grossular, and their colouration was fairly consistent with the hessonite variety. Energy-dispersive X-ray fluorescence (EDXRF) chemical analysis with an Amptek X123-SDD spectrometer revealed the expected high levels of Ca and Fe, with minor Mn, Ti and Cr. All samples were inert to long- and short-wave UV radiation, and exhibited some magnetic susceptibility (being just barely dragged by a magnet).

Viewed in the microscope between crossed polarisers, all of the stones exhibited various patterns of bright interference colours (Figure 4). This optical effect may

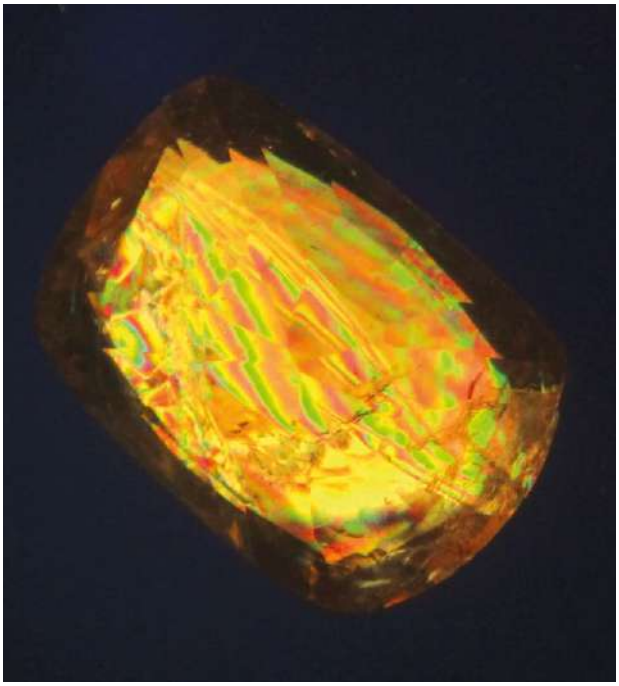

Figure 4: Viewed between crossed polarisers, this 1.14 ct hessonite displays bright interference colours. Photomicrograph by B. Williams.

Figure 5: Internal features in the hessonite consisted of (**a**) various fluid-filled inclusions hosted by partially healed fissures, (**b**) fluid-filled growth tubes and (**c**) an overall haziness in one stone. Photomicrographs by C. Williams; magnified 25× (a) and 40× (b and c).

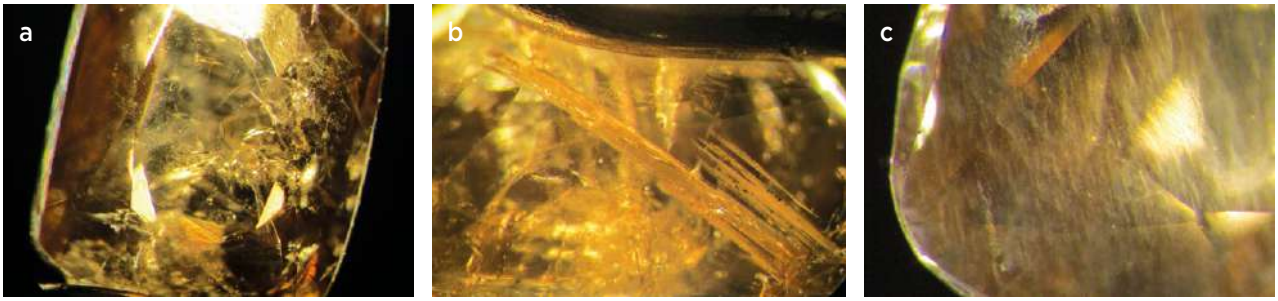

have been caused by variously oriented twin planes (and associated internal strain) that were prevalent throughout the samples. The stones were moderately included to the unaided eye. The most common internal features were intricate, fluid-filled, partially healed fissures (Figure 5a). Several samples also exhibited a slightly roiled optical effect that was weaker than that typically seen in hessonite. In addition, fluid-filled growth tubes were common (Figure 5b). Similarly oriented, but non-parallel, growth lines were also seen. A hazy area was observed in one sample (Figure 5c).

According to Themelis (2008), facetable hessonite is often found in the Mogok area, particularly around Sakangyi, as crystals that commonly weigh 1–2 ct. The apatite inclusions that he mentioned occurring in the hessonite were not seen in the samples examined here.

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Yellowish Green to Yellow Opal from Brazil

Several occurrences and varieties of opal are known from Brazil (for a brief review, see Caucia et al., 2009). During the August 2017 FIPP gem show in Teófilo Otoni, Brazil, a purportedly new discovery of yellowish green to yellow 'common' opal (e.g. Figure 6) was brought to market by some artisanal miners. They had ~5 kg of rough material, which was purchased by gem and mineral dealer Dr Marco Campos Venuti. He polished dozens of cabochons and tablets in a variety

Figure 6: These cabochons (1.89–6.35 ct) show the range of colour in a new find of common opal from Brazil. Gift of Marco Campos Venuti; photo by Diego Sanchez, © GIA.

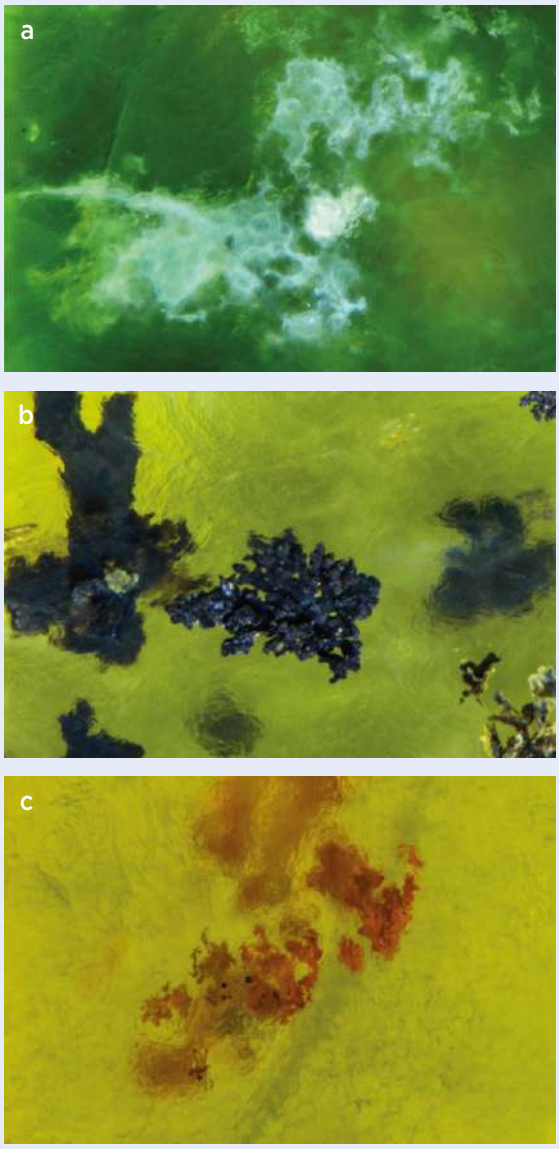

Figure 7: The yellowish green opal from Brazil contained distinct white clouds (**a**, image width 2.4 mm). Also present in the Brazilian opals were black plumes (**b**, image width 1.6 mm) and brown aggregates (**c**, image width 1.9 mm), which probably consist of manganese oxide and hematite, respectively. Photomicrographs by N. D. Renfro, © GIA.

of shapes that ranged from 5 to 20 mm in maximum dimension. He kindly donated three specimens to Gem-A's research and teaching collection that showed the range of colour for this new material (1.89–6.35 ct; again, see Figure 6).

Examination of the three stones by author NDR showed properties consistent with opal (spot RI of 1.44 and hydrostatic SG of 2.10). All three samples fluoresced a very weak red to orange to both long- and short-wave UV radiation. They were semi-transparent, and various inclusions were easily visible to the unaided eye. Viewed with the microscope, all three opals showed abundant swirl marks (Figure 7), similar to those documented in yellow opal from West Africa (Moe, 2012). The yellowish green stone contained some white clouds (Figure 7a), and Raman analysis of one such dense white area was inconclusive, giving only a weak signal consistent with quartz. Also present in the samples were irregular black and/or brown aggregates (Figures 7b and 7c). Unfortunately, no discernible signals could be obtained for these inclusions using Raman spectroscopy.

EDXRF analysis of the opals showed strong peaks for Ni, Fe and Cr. It is well known that Ni is involved with producing green colouration in silica minerals (Rossman, 1994) such as 'prase' opal, and Fe causes a yellow-to-brown body colour in common opal (Gaillou et al., 2008). Where black inclusions were present in our opal samples, EDXRF spectroscopy showed Mn in addition to Ni and Fe; this is consistent with their appearance as manganese oxide plumes. Where brown inclusions were present, EDXRF analysis showed only Fe and Ni. This suggests that the brown inclusions are likely hematite. The hematite inclusions were randomly scattered throughout the opal matrix, and therefore they may have been incorporated during its formation. Conversely, the black manganese oxide plumes were generally confined to specific linear or interconnected areas, indicating that they may have been introduced during a secondary process of cracking and re-healing of the opal.

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Ethiopian Opal with Dendritic Inclusions

Play-of-colour opal from Wollo Province, Ethiopia, has become well known in the gem trade since its discovery in early 2008. These opals were characterised in detail by Rondeau et al. (2010), who reported relatively few inclusion features in the stones they examined. Among these were cylindrical inclusions (most likely composed of chalcedony), dispersed micro-crystals of pyrite and, rarely, 'black minerals [that] were included in the body of the opal, filling fissures or forming dendrites' (Rondeau et al., 2010, p. 100).

Recently, an Ethiopian (Wollo) opal containing some conspicuous black inclusions was loaned for examination by rough stone dealer Farooq Hashmi (Intimate Gems, Glen Cove, New York, USA). The 4.34 ct partially polished sample contained a series of well-formed black dendrites (Figure 8). Raman analysis by author NDR was unable to identify the inclusions, perhaps because the opal matrix degraded the signal so that it was not resolvable. Nevertheless, EDXRF spectroscopy confirmed that the inclusions were Mn rich, which is consistent with their being composed of manganese oxide (presumably pyrolusite).

Figure 8: This 4.34 ct partially polished sample of Ethiopian opal contains eye-visible black inclusions. Photo by Robison McMurtry © GIA.

Rather than forming two-dimensional dendrites like those commonly seen in some gem materials as epigenetic fillings along fissures, the inclusions in this Ethiopian opal occurred as three-dimensional plumes that radiated in various directions (Figure 9). One set of plumes formed along an elongate structure that was reminiscent of a plant fossil, such as those documented in Wollo opal by Chauviré et al. (2017).

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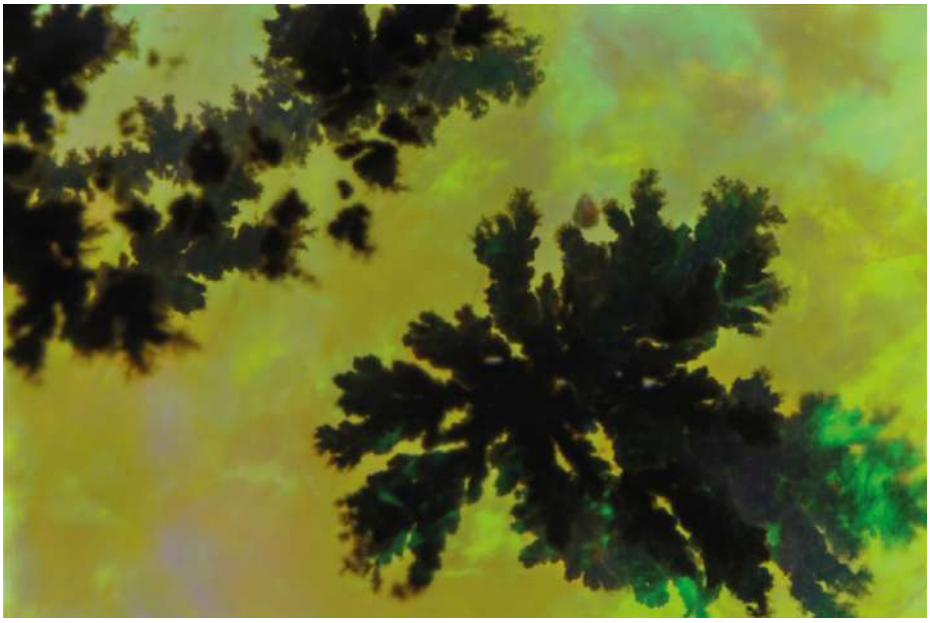

Figure 9: A closer view of the black inclusions shows a three-dimensional array of dendrites. Their Mn-rich composition is consistent with a manganese oxide mineral such as pyrolusite. Photomicrograph by N. D. Renfro, © GIA; image width 3.6 mm.

The Fire Within

"For in them you shall see the living fire of the ruby, the glorious purple of the amethyst, the sea-green of the emerald, all glittering together in an incredible mixture of light."

– Roman Elder Pliny, 1st Century AD

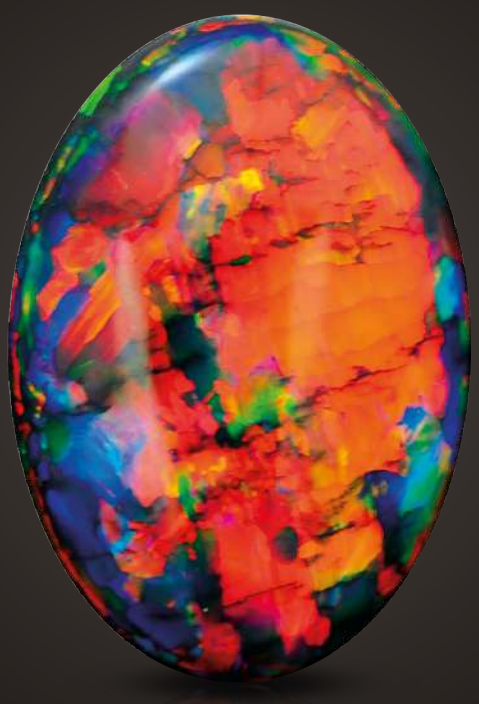

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Figure 10: A 203.41 ct phenakite from Madagascar is shown together with another large phenakite (105.74 ct) that reportedly came from the Anjanabonoina pegmatite. Both stones were obtained by Dudley Blauwet, although the smaller gem was purchased significantly earlier (June 2014) than the larger one (November 2017). Photo by Jeff Scovil.

Large Phenakite from Madagascar

Madagascar is known as a source of fine-quality crystals of colourless phenakite (e.g. Wilson, 1989). The main source is the Anjanabonoina pegmatite in central Madagascar, which occasionally produces large crystals, such as 'a rather flattened, doubly terminated, fully transparent gem crystal weighing 1.1 kg' that was mentioned by Weiss (1995). As Malagasy phenakite crystals tend to be well formed, most of them are sold to mineral collectors rather than as gem rough.

Recently, however, Dudley Blauwet (Dudley Blauwet Gems, Louisville, Colorado, USA) obtained a large faceted phenakite from Madagascar that weighed 203.41 ct (Figure 10). He obtained the stone in Sri Lanka in November 2017, and his supplier reported that the original rough weighed 500 ct and was purchased in Mananjary on Madagascar's east coast.

Although phenakite is known to occur in phlogopite schist at the Ambodivandrika emerald mine in the Mananjary area (www.mindat.org/loc-45813.html), the large size and high clarity of the stone obtained by Blauwet strongly suggest that it came from a pegmatite deposit. In addition to Anjanabonoina, there are at least three other phenakite occurrences in Madagascar that are potential sources of large, gem-quality material, according to Frédéric Gautier (Little Big Stone, Antananarivo, Madagascar). One of these localities (Fianarantsoa area) produced several hundred grams of transparent phenakite in 2017 and continues to produce rough material. Since these pieces typically do not show any crystal faces, it seems likely that they would be sold as gem rough.

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Recent Production of Poudretteite from Mogok, Myanmar

Poudretteite is an extremely rare borosilicate ($KNa_2B_3Si_{12}O_{30}$), and faceted examples are seldom encountered (cf. Smith et al., 2003; Mayerson, 2006). According to Dr Kyaw Thu (Macle Gem Trade Laboratory, Yangon, Myanmar), recently there were two new poudretteite discoveries in the Mogok area of Myanmar (e.g. Figure 11). First, an alluvial concentration of poudretteite was found by a miner looking for yellow danburite across the valley from Pein Pyit. Most of the rough material was colourless and had rough surfaces. Exactly when it was found and how much was produced is unclear. Then, in March 2018, a group of miners began working an area at Pyant Gyi (located in eastern Mogok, near Pein Pyit; Figure 12) and found both *in situ* and eroded poudretteite. This is the first time that a primary deposit of poudretteite has been found in Mogok.

Figure 11: This fine 2.6 g poudretteite crystal was mined from a newly discovered primary deposit in the Pyant Gyi area of Mogok. Photo by Thai Lanka Trading.

Figure 12: Local miners work the Pyant Gyi area of Mogok in search of poudretteite and other minerals. Photo by Kyaw Thu.

Pyant Gyi is a flat plain, and the *in situ* poudretteite was apparently found on the hill above it. The Pyant Gyi area was already a known source of alluvial poudretteite, and it also hosts primary and secondary deposits of spinel, ruby and sapphire, as well as rarer gems such as johachidolite and hackmanite (Themelis, 2008).

The recent mining has yielded a small quantity of poudretteite as broken pieces, well-formed crystals, and crude matrix specimens with smoky quartz. The best crystal known to author MHS is a 2.6 g bicoloured (colourless-pink) specimen that he purchased in May 2018 (again, see Figure 11). Most of the recently produced poudretteite is of low quality, being quite included with hollow tubes. The majority of the material is colourless with a pink 'skin' that is usually lost in faceting. The largest cut stone seen by author MHS weighed 9.59 ct but was heavily included and poorly cut. Some lightly included stones weighing more than 3 ct were obtained by this author, but after recutting to proper angles most of them weighed <2 ct. The faceted stones range from colourless to pink, or may display both colourless and pink areas (e.g. Figure 13). It is extremely rare to encounter a pure pink poudretteite that is nearly eye clean and >1 ct.

The total production of all grades of poudretteite from Pyant Gyi since March 2018 is estimated by Dr Kyaw Thu to be only about 100 g, so poudretteite remains a very rare gem material despite these recent discoveries.

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Figure 13: Recent poudretteite production from Pyant Gyi ranges from colourless (**a**: 1.06 carats total weight) to pink (**b**: 0.73 ct), and some stones may show colourless/pink zones (**c**: 2.48 ct). Photos by Thai Lanka Trading.

Gem-quality Pseudomalachite from Slovakia

Pseudomalachite [$Cu_5(PO_4)_2(OH)_4$] is a mineral species named for its similarity in appearance to malachite [$Cu_2(CO_3)(OH)_2$]. There exist a number of dark green copper-phosphate minerals, including pseudomalachite and its polymorphs reichenbachite and ludjibaite (Hyršl, 1991). Before 1950 it was thought that dihydrite, lunnite, ehlite, tagilite and prasin were separate mineral species, but they all were found to be pseudomalachite (Berry, 1950). Compared to malachite, the much rarer pseudomalachite typically lacks pronounced light and dark banding and is slightly harder and denser. To verify an identification, pseudomalachite will not react to warm hydrochloric acid, while malachite will effervesce.

Pseudomalachite occurs as a secondary mineral in the oxidised zone of copper deposits. It usually forms botryoidal crusts and hemispherical aggregates of microscopic crystals. It also occurs as reniform, botryoidal or massive aggregates with a radial-fibrous structure and concentric banding in which the fibres are elongated, foliated and microcrystalline, or dense and colloform. Pseudomalachite is known from Slovakia as well as several other localities (e.g. Portugal, Namibia, Poland, Zambia, Chile, Germany and Australia).

The small region around the central Slovakian municipality of L'ubietová in the Banská Bystrica region has a rich mining history that dates back to the 14th century. There are three small copper deposits near L'ubietová called Podlipa, Svätodušná and Kolba (Luptáková et al., 2016). Extensive dumps as well as some accessible parts of the old mines are of interest to scientists and mineral collectors. The Podlipa deposit is situated in the Vepor Mountains of central Slovakia, about 1 km east of L'ubietová village, on the southern slope of the Carpathian mountain of Vysoká (995.5 m) above Zelená dolina (Green Valley). Podlipa is the type locality for libethenite (Breithaupt, 1823) and mrázekite (Řídkošil et al., 1992), and also hosts other rare minerals such as ludjibaite and reichenbachite (Hyršl, 1991).

Thin crusts of pseudomalachite are commonly found at all three of the Slovakian localities mentioned above. However, in 2016–2017 some gem-quality material was discovered in this area by author RG that consisted of coarser layers of relatively pure pseudomalachite that could be cut into cabochons without any accompanying matrix material. After separating these layers from the host rock, approximately 200 g of rough material was produced during the most recent mining activities. We polished 15 high-quality cabochons (e.g. Figure 14), ranging from 13.33 × 10.74 mm to 20.61 × 15.56 mm, and also cut a few dozen lower-quality cabochons of various shapes. The samples appeared greenish blue in daylight (again, see Figure 14) and green in incandescent light. They had RIs of 1.624–1.689 and hydrostatic SG values of 3.93–4.17. Their identity as pseudomalachite was confirmed by Raman spectroscopy, which showed peaks at 1084, 1055, 1004, 964, 886, 795, 748, 544, 482, 443, 364, 302 and 269 cm^{-1}.

Figure 14: These pseudomalachite cabochons (21.59–34.80 ct) are from the Ľubietová area in the Banská Bystrica region of central Slovakia. Photo by J. Štubňa.

Thin crusts of pseudomalachite combined with quartz and limonite matrix have been used by local Slovakian jewellers for a long time. The future potential for obtaining thicker, pure layers of gem-quality pseudomalachite from this area is unknown, as the site is not mined on a regular basis or with mechanised methods.

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Figure 15: These quartz slices (3.7 and 4.0 cm tall) from Madagascar contain attractive patterns created by amethystine colour zoning and oriented inclusions. Photo by Diego Sanchez, © GIA.

Quartz Slices from Madagascar with Interesting Inclusions

During the February 2018 Tucson gem shows, Madagascar mineral dealer Frédéric Gautier had some new quartz specimens containing attractive inclusion patterns. He reported that the rough material was found in August 2017 in the Mandritsara District (in former Mahajanga or Majunga Province) of north-central Madagascar. The exterior faces of the crystals were rather crudely developed, and to best show their internal beauty Gautier prepared polished slices from the larger crystals. Of the approximately 10 kg of quartz that he purchased, only about 4–5 kg were large enough to cut into attractive slices. From six crystals he obtained 25 slices measuring 1.5 to 5.0 cm across, which showed attractive 'phantoms' formed by a combination of inclusions and amethystine colour zoning. The slices were oriented perpendicular to the c-axis, and their edges (parallel to the prism faces) were also cut and polished.

Gautier loaned two samples of the quartz for examination (3.7 and 4.0 cm tall; Figure 15). Their cores contained distinct amethystine zones, and one of them also had an additional area of amethyst positioned between the core and the rim, together with some planar smoky zones that were parallel to two adjacent prism faces. Both slices contained abundant fluid inclusions and linear arrays of brownish red to black inclusions that extended toward the prism faces (e.g. Figure 16). Flat 'sheets' of the brownish red inclusions were also present in the amethyst zones. Based on their colour and appearance, both the linear and sheet-like inclusions consisted of hematite (sometimes referred to in the literature as 'lepidocrocite'). Primary fluid inclusions formed along growth zones as minute parallel aggregates or large conspicuous cavities. In addition, secondary fluid inclusions formed veils of particles along partially healed fractures.

The combination of the amethystine colour zoning and oriented inclusions made these slices both attractive and unusual. According to Gautier, this is the first time that quartz with this distinctive appearance has come from Madagascar.

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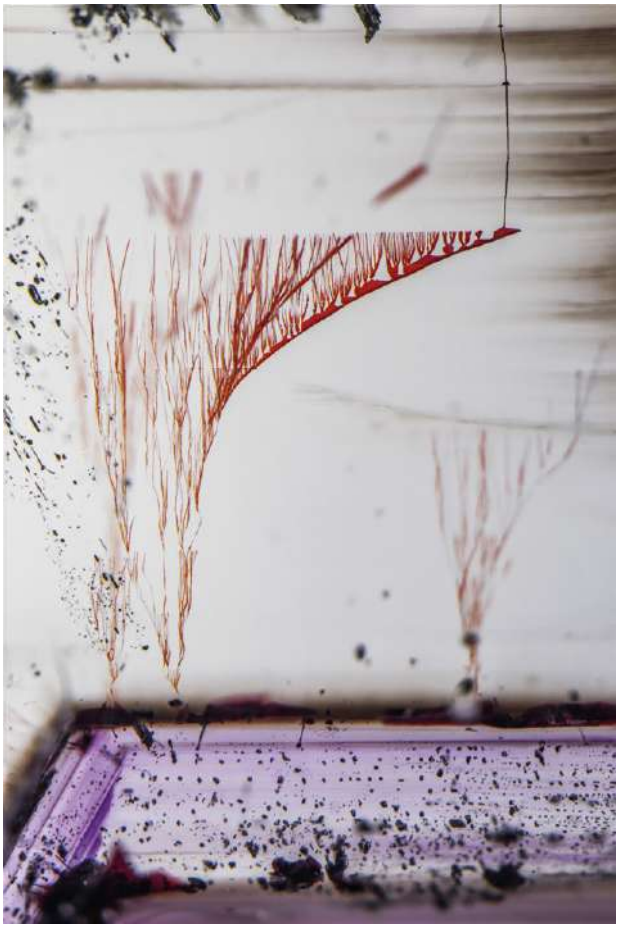

Figure 16: A closer view of one of the quartz slices shows a curved array of sub-parallel brownish red inclusions of hematite that abruptly end along a plane parallel to a prism face. In the underlying amethystine zone are planes of primary fluid inclusions that appear black in the brightfield lighting used to capture this image. Photomicrograph by N. D. Renfro, © GIA; image height 8.9 mm.

Red Aventurescent Quartzite from Tanzania

At the September 2016 Denver Gem & Mineral Show in Denver, Colorado, USA, red aventurescent quartzite from a new find in Tanzania was introduced to the USA market. According to Jonathan Bartky (Ariel Treasures, Livingston, New Jersey, USA), the material—also called 'Cherry Tanzurine' or 'Natural Cherry Quartz'—is mined in a joint venture on Maasai tribal land in northern Tanzania. Mining has been ongoing since early 2016. The material is extracted from an open pit using pneumatic hammers and hand tools but no explosives. Approximately 20 tonnes have been recovered so far, and about one tonne has been cut and polished into spheres and bookends (in Tanzania), beads (in Germany and India), pendants (in China) and eggs (in Germany). The first polished material was exhibited at the February 2017 Tucson gem shows (e.g. Figure 17).

Also debuting at the September 2016 Denver gem shows was a new green aventurescent quartzite from Tanzania (Stephan et al., 2018; White and Dickson, 2018). This material, coloured by inclusions of fuchsite (as in 'classic' green aventurine quartz), has some similarities to the red aventurescent quartzite. Recently, White and Dickson (2018) described the red material as quartzite of metamorphic origin that is coloured by pink-to-red mica inclusions. Based on SEM-EDS analyses, these authors reported that the inclusions are most likely lepidolite but possibly Mn-bearing muscovite.

For our investigations, we examined two pieces of rough red adventurescent quartzite (42.29 and 13.19 g), a polished egg (765 ct) and a beaded strand (with beads measuring ~10 mm in diameter), which were offered by the company Impexco (Idar-Oberstein, Germany). Wolfgang Weinz from Impexco received the material from a local Tanzanian miner and dealer in Dar es Salaam, Tanzania. One of the rough pieces was polished on both sides, and the other was used to prepare thin sections. For comparison we examined two tumbled pieces of red quartzite, one from India (196.86 ct) and one from South Africa (36.06 ct), from which thin sections were also prepared.

The rough and polished samples from Tanzania were translucent in smaller sizes (i.e. the beads and the smaller piece of rough), but appeared predominantly less translucent in larger sizes. Macroscopically it was obvious that the material was an aggregate of grains up to 10 mm in diameter, and it was coloured by pink-to-red inclusions. The polariscope gave a doubly refractive aggregate reaction, and RI and hydrostatic SG values were consistent with quartz: n_o = 1.543, n_e = 1.552, birefringence = 0.009 and SG = 2.65. With magnification (Figure 18a), the inclusions were seen to have the same round, partially pseudo-hexagonal, platy shape as reported for the fuchsite grains in the green aventurescent quartzite from Tanzania (cf. Stephan et al., 2018).

Figure 17: These bead necklaces (6–10 mm in diameter) and earrings (approximately 30 mm in diameter) are typical of the new red aventurescent quartzite from Tanzania. Photo by Jeff Scovil.

Analysis of the pink-to-red inclusions with a Renishaw inVia micro-Raman spectrometer identified them as mica. A further comparison with reference spectra obtained from our database, and from muscovite and lepidolite samples in the collection of the German Gemmological Association, showed that the Raman spectra provided the closest match with muscovite. Nevertheless, both muscovite and lepidolite can have pink-to-red colouration caused by Mn^{3+} substituting for Al^{3+}, and to confirm our identification we performed X-ray powder diffraction. With these results, we were able to exclude lepidolite and identify the mica inclusions as most probably muscovite. The presence of muscovite inclusions in this quartzite is also consistent with the

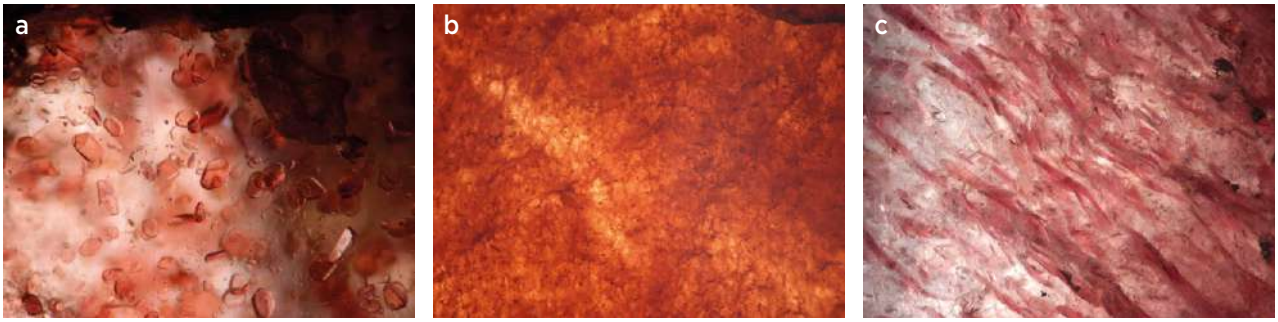

Figure 18: Polished slices of various types of red quartzite are viewed here in transmitted light. (**a**) The red aventurescent quartzite from Tanzania is coloured by muscovite inclusions. (**b**) In quartzite from India, the individual quartz grains are surrounded by thin films of hematite. (**c**) Quartzite from South Africa is also coloured by hematite, which forms platy, pink-to-red flecks oriented in one direction. Photomicrographs by T. Stephan; image widths 3.15, 7.14 and 3.32 mm, respectively.

material's geological occurrence, whereas lepidolite (a member of the polylithionite-trilithionite series of lithium micas) is not known to occur in quartzite.

By contrast, the red quartzites from India and South Africa were found to be coloured by hematite. In the sample from India, thin films of hematite surrounded the individual quartz grains (Figure 18b). It therefore showed no aventurescence because it lacked any reflective inclusions. However, the hematite in the red quartzite from South Africa formed platy inclusions (Figure 18c) that were present between the quartz grains. The inclusions were also oriented in a consistent direction, which produced aventurescence and implies schistosity. Further differences between these red quartzites and the new material from Tanzania were seen in their grain sizes: the Indian and South African quartzites were generally fine-to-medium grained (0.06–2 mm), while the Tanzanian material had much coarser overall grain sizes of 1–10 mm (Figure 19); this is even coarser grained than the new green aventurescent quartzite from Tanzania (1–5 mm; Stephan et al., 2018). As in the green material, the micas in the red aventurescent quartzite from Tanzania form inclusions within the single quartz grains and are not present as accessory phases between the grain boundaries.

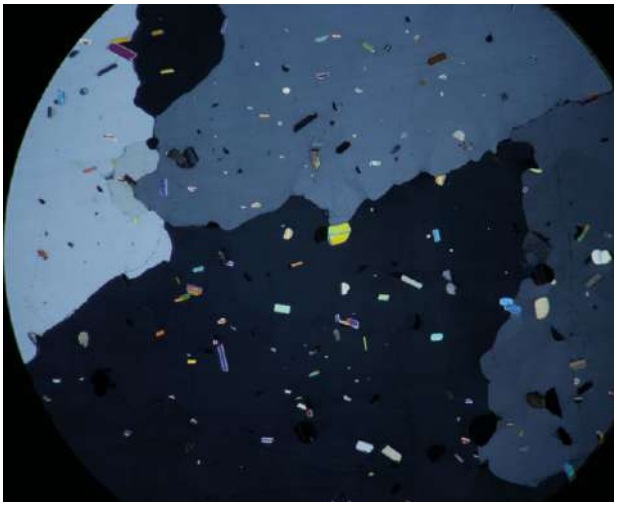

Figure 19: Viewed in cross-polarised light, a thin section of red aventurescent quartzite from Tanzania displays quartz grains with low-order grey-to-black interference colours, whereas the muscovite inclusions (up to 10 mm long) appear highly birefringent. The muscovite grains show no preferred orientation. Photomicrograph by T. Stephan; image width 8.14 mm.

Acknowledgements

The samples of the red aventurescent quartzite that were studied for this report were kindly donated by Impexco. One of the polished samples was loaned by Robert Myers. In addition, one slab and one polished lozenge were subsequently donated to Gem-A by Jonathan Bartky. We also thank Dr Tobias Häger (Institute for Gemstone Research, Johannes Gutenberg-University, Mainz, Germany) for performing the X-ray powder diffraction analysis.

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Yellow Scapolite from Tanzania Showing Peculiar Daylight Fluorescence

Yellow scapolite has been reported from two areas of Tanzania: the Umba area in the eastern part of the country (Zwaan, 1971) and in central Tanzania (Graziani and Gübelin, 1981). During the April 2016 Arusha Gem Fair in Tanzania, rough stone dealer Farooq Hashmi acquired a scapolite crystal that was reportedly found in Umba, and it was subsequently faceted by Peter Torraca (Torraca Gemcutting, Houghton, New York, USA). Due to the stone's unusual colour behaviour, it was loaned to author JCZ for further examination.

The cut-cornered rectangular modified brilliant (radiant cut) weighed 3.60 ct and measured approximately 10.93 × 7.13 × 6.83 mm. It was transparent, and when viewed in daylight-equivalent lighting it was slightly greenish yellow (Figure 20). In sunlight it appeared to turn to a purer, more vivid yellow, while peculiarly it looked slightly more orange in indirect sunlight (Figure 20, inset), particularly when tilted slightly.

RI readings gave 1.555–1.589, yielding a birefringence of 0.034, and the stone showed a uniaxial negative optic character. Hydrostatic measurements yielded an SG value of 2.73. The dichroscope revealed only weak dichroism, in slightly greenish yellow and yellow. The stone was free of inclusions except for one large, spiky, needle-like growth channel. This inclusion had a rhomb-shaped cross-section, and where it reached the surface it appeared to be filled with some secondary, fine-grained material. As shown in Figure 21, the stone luminesced a very strong yellow to long-wave (365 nm) and a moderate orangey yellow to short-wave (254 nm) UV radiation. In both cases, no phosphorescence was observed. A photoluminescence (PL) spectrum excited by a green (532 nm) laser showed a strong band centred at 620 nm in the orange-red region (Figure 22).

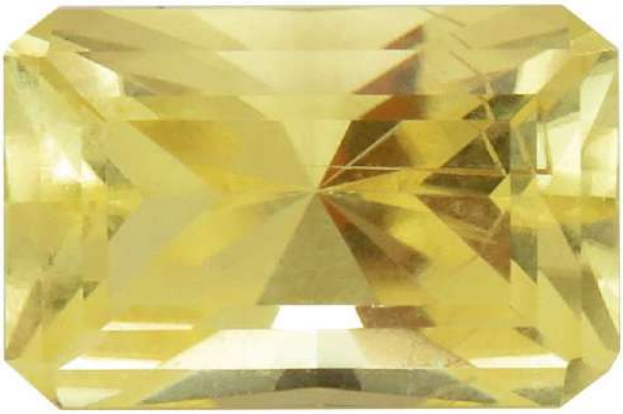

Figure 20: This 3.60 ct scapolite from Tanzania is slightly greenish yellow in daylight-equivalent lighting, but appears slightly more orange in indirect sunlight (right). Photos by Dirk van der Marel (main image) and B. M. Laurs (right).

The RI and SG values, and especially the high birefringence, of this scapolite correspond to a meionite composition, which has RIs of 1.556–1.600, birefringence values of 0.024–0.037 and an SG of ~2.78 (Deer et al., 2004). Meionite ($Ca_4Al_6Si_6O_{24}CO_3$) is isomorphous with marialite ($Na_4Al_3Si_9O_{24}Cl$) in a series that constitutes 'scapolite'. There is an approximate linear variation between mean RI and scapolite composition (expressed as %Me or mol.% meionite), as well as between birefringence and %Me (Deer et al., 2004). Using the mean RI

Figure 21: The 3.60 ct scapolite fluoresces a very strong yellow under long-wave UV (left) and a moderate orangey yellow under short-wave UV radiation (right). Photos by J. C. Zwaan.

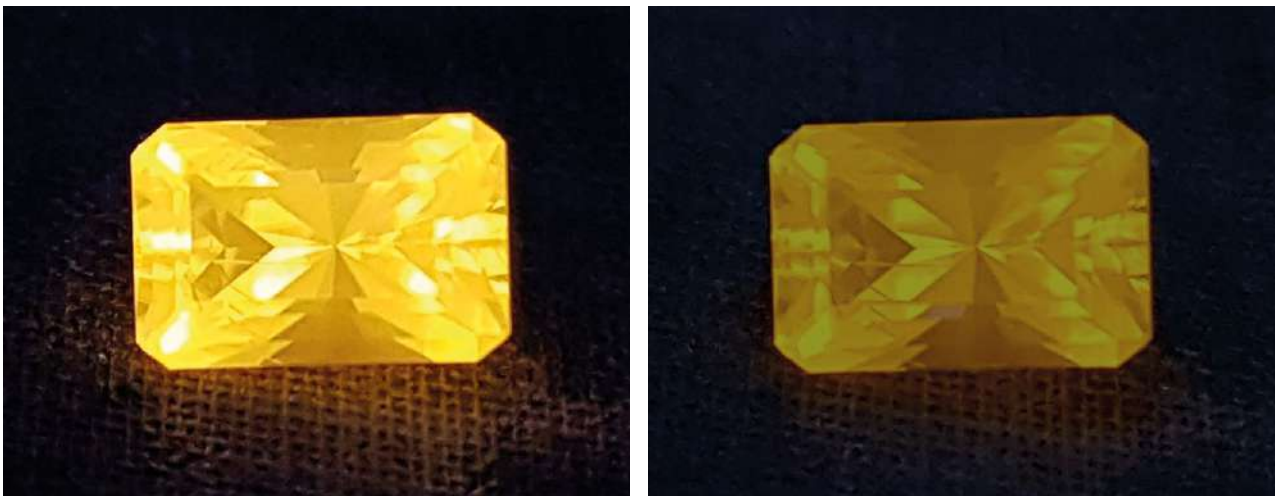

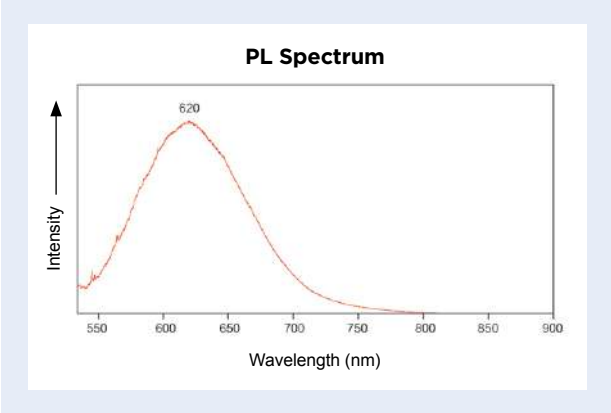

Figure 22: The yellow Tanzanian scapolite produced strong photoluminescence at 620 nm (orange-red region) when excited with a green (532 nm) laser. The small peaks on the left are Raman features.

$(\varepsilon+\omega)/2 = 1.572$ in the expression $(\varepsilon+\omega)/2 = 1.5346 + 0.000507$ %Me, the present scapolite is estimated to consist of 74 mol.% meionite. However, based on its high birefringence of 0.034, a composition of ~85 mol.% meionite would be expected. Thus, the stone's composition is inferred to be somewhere in the 74–85 mol.% meionite range.

Raman spectra most closely matched the spectra of meionite in the RRUFF database. Semi-quantitative EDXRF chemical analyses confirmed the dominance of Ca over Na, in accordance with a meionite composition, and also showed traces of sulphur (0.6 wt.% SO_3) and iron (0.03–0.04 wt.% FeO). In the mid-infrared spectrum, the presence of a sharp feature at ~2560 cm^{-1} confirmed the presence of HCO_3^- (an associated part of the scapolite crystal structure; Swayze and Clark, 1990) in the anion site.

Strong yellow fluorescence in scapolite is attributed to the presence of S_2^- in the anion site (Burgner et al., 1978), but as suggested by the PL spectrum (again, see Figure 22), the emission spectrum appears to be dependent on excitation wavelength. Burgner et al. (1978) also showed that the luminescence emission spectrum displays a series of distinct bands covering the region from 500 to 700 nm, which according to them indicates that S_2^- occupies a number of different sites. At room temperature and under long-wave UV excitation, Kirk (1955) recorded the PL spectrum of scapolite with a most intense peak at 570 nm. However, the strongest emission peak in scapolite recorded by Sidike et al. (2008) was 596 nm (slightly yellowish orange) using 390 nm (violet) excitation. The latter study also showed that the excitation efficiency is lower at 365 nm than in the violet range. For the present scapolite, the orangey yellow fluorescence that was evidently excited by the violet component of daylight was strong enough to be seen in indirect sunlight.

During the February 2018 Tucson gem shows, one of the authors (BML) was shown another yellow scapolite from Tanzania with very similar colour and fluorescence behaviour (Figure 23). This 11.52 ct scapolite in the collection of Herb and Monika Obodda (Warwick, Rhode Island, USA) had been recut by gem dealer Mark Smith from a stone that he obtained in Sri Lanka in late 2017. Herb Obodda reported that he first encountered such scapolite in the late 1970s as two stones in a parcel of rough yellow grossular from the Leletema Hills of north-eastern Tanzania. They were identified as meionite by Dr Pete Dunn at the Smithsonian Institution (Washington DC, USA). Their yellow fluorescence made them easy to separate from the garnet parcel.

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Figure 23: Weighing 11.52 ct, this scapolite from Tanzania has similar colour and long-wave UV fluorescence as the stone documented in this report. Photo by Thai Lanka Trading.

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Cr-bearing Green Spodumene from Northern Nigeria

During a buying trip to Nigeria in October 2017, rough stone dealer Farooq Hashmi obtained a few broken pieces of a green gem material that was sold to him as hiddenite. Its exact origin was not disclosed, but he was told it came from northern Nigeria.

Hashmi provided two of the pieces to author PK for faceting, and unfortunately the first stone cleaved during pre-forming of the pavilion. Cutting of the second stone yielded a 3.32 ct rectangular brilliant. Author PK has faceted numerous hiddenites from North Carolina, USA, and by comparison the material from Nigeria seemed harder, but it split much more easily along cleavages. During the cutting process, it was necessary to use nothing coarser than a worn-out 1,200 grit lap. Even so, the stone developed minor cleavage separations just from polishing the first crown main.

The faceted stone and cleaved preform were examined by authors CW and BW, together with three pieces of rough weighing 1.69–7.34 g (e.g. Figure 24) that Hashmi supplied. The faceted gem measured 9.98 × 7.21 × 5.48 mm, and the cleaved preform was incipiently polished for examination and weighed 5.62 ct. The stones were a pale, slightly bluish green and showed strong pleochroism in bluish green, light green and pale greenish yellow. RIs of the faceted stone were 1.662–1.679 (birefringence = 0.017) and of the preform were 1.663–1.680 (also birefringence = 0.017). Hydrostatic SG values were 3.19 for the faceted stone and 3.20 for the largest piece of rough. The samples appeared pink with the Chelsea Colour Filter, and they fluoresced weak-to-moderate yellow to long-wave UV and were inert to short-wave UV radiation. These properties are comparable to those of Cr/V-bearing green spodumene from Afghanistan documented by Chadwick et al. (2007), except the Afghan material showed no UV fluorescence and yielded a somewhat higher SG value (3.25).

The rough and preformed Nigerian stones exhibited prominent cleavage faces and some conchoidal fractures; no natural crystal faces were present. Internal features consisted of parallel, rain-like, colourless solid inclusions and fluid trapped within cleavage fractures. The faceted stone contained prominent cleavage cracks and incipient fissures, as well as some very fine, parallel needles that were probably growth tubes.

To test the colour stability of the material, one of the rough pieces was placed in a window where it was subjected to direct sunlight. No fading was seen after a period of three days.

Raman spectroscopy with a GemmoRaman-532SG instrument confirmed the stones were spodumene. Ultraviolet-visible–near infrared (UV-Vis-NIR) spectroscopy of the faceted stone with a MAGI GemmoSphere instrument revealed sharp peaks at 685 and 689 nm due to Cr^{3+}, as well as strong features at 370 and 379 nm and at 432 and 437.5 nm (Figure 25) that are ascribed to Fe^{3+} (cf. Walker et al., 1997; Anderson and Payne, 1998). The green colouration corresponds to a transition window that is formed by the prominent band at 620 nm

Figure 24: This Cr-bearing spodumene is reportedly from northern Nigeria. The cut stone is 3.32 ct and the larger piece of rough weighs 7.34 g. Photo by Dean Brennan, Stone Group Laboratories.

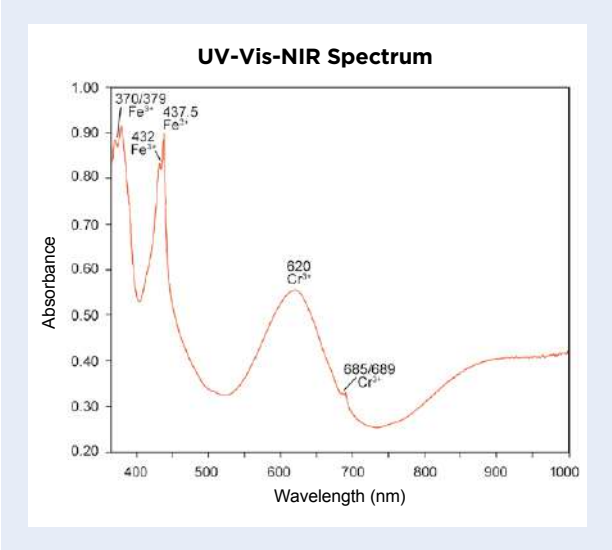

Figure 25: UV-Vis-NIR spectroscopy of the faceted green Nigerian spodumene showed features due to Cr^{3+} and Fe^{3+}.

and another underlying band near 450 nm, both due to Cr^{3+}; the latter feature is obscured by Fe^{3+} bands in the 430–440 nm region, which also contribute to the transmission window (and therefore the green colouration).

EDXRF spectroscopy with an Amptek X123-SDD spectrometer indicated prominent Fe and Mn, minor Cr, and traces of Ni, Zn and K. By comparison, the green Afghan spodumene documented by Chadwick et al. (2007) likewise contained Fe>Mn>>Cr, as well as 59–72 ppm V.

Regarding the proper use of the term *hiddenite*, Chadwick et al. (2007) indicated 'there is no consistent definition for this variety of spodumene. Although this term is typically used to refer to yellow-green to green Cr-bearing spodumene, it is unclear if the saturation of the green colour is important to the definition.' These authors also mentioned that in addition to the classic locality at Hiddenite, North Carolina, Cr-bearing spodumene is known from Brazil, India, Siberia and Afghanistan.

Although spodumene (kunzite) has previously been reported from northern Nigeria (Laurs, 2001), this is the first time that the green Cr-bearing variety has been documented from there.

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Titanite (Sphene) from Zimbabwe

In early 2017, a new deposit of gem-quality titanite (sphene) was found in north-east Zimbabwe. According to Bill Larson (Pala International, Fallbrook, California, USA), the titanite comes from the Homestead mines in the Merewa area of Mutawatawa District in Mashonaland East Province. Although titanite has previously been reported from at least four Zimbabwean localities (www.mindat.org/locentries.php?p=21891&m=3977), none of them are located in this province. The stones were recovered as loose broken crystals in the soil. Shallow pits were dug with hand tools (e.g. Figure 26), but the miners soon encountered bedrock, and titanite production ceased.

Larson obtained about 4.5 kg of rough material, of which 10% was of fine quality. Some large crystals were recovered (up to ~12 cm in maximum dimension), and many pieces of the titanite contained cuttable areas between fractures. Faceted stones have ranged up to 40 ct (Stone-Sundberg and Schumacher, 2018), with fine clean gems weighing up to 30 ct (see www.palagems.com/gem-news-2017-11/#Sphene). Several hundred carats have been faceted so far by Pala International, mostly as calibrated stones of 1–3 ct for sale through Jewelry Television. The colour

ranges from greenish yellow to yellowish green (Figure 27).

Chemical analysis of multiple spots on two fragments of light yellowish green titanite by author GRR using an INAM Expert 3L X-ray fluorescence unit revealed the presence of several trace elements: 0.20–0.40% Fe, 0.16–0.25% V, 0.01–0.13% Nb, 0.03–0.05% Mn, 26–47 ppm Zr, 15–20 ppm Y and 10–20 ppm Sr.

The Vis-NIR absorption spectra in Figure 28 were obtained from a 5.0-mm-thick slab—taken from one of the titanites which was chemically analysed—with a centred Bxa orientation (i.e. in the optical plane containing the acute bisectrix; see Thomas et al., 2014). Both polarisations showed a single absorption band centred at ~619 nm (and an absorption edge extending inward from the UV region). This absorption band is in the region where V^{3+} absorption occurs in other minerals (Schmetzer, 1982). The presence of trace amounts of V in the chemical analysis is also consistent with vanadium being the origin of the yellow-green colouration in this titanite.

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Figure 26: A new deposit in north-east Zimbabwe has yielded gem-quality titanite (sphene) from the soil in shallow pits. Production ceased when the miners encountered bedrock. Photo courtesy of Bill Larson.

Figure 27: These titanites from Zimbabwe weigh 12.45–14.46 ct and show the range of colour for material from the new deposit. Photo by Mia Dixon.

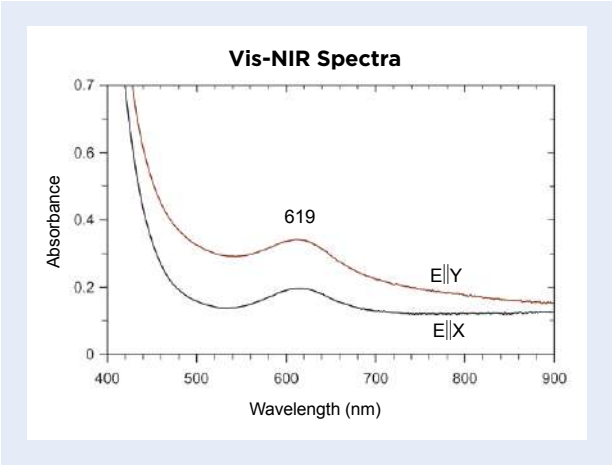

Figure 28: These polarised Vis-NIR absorption spectra of a 5.0-mm-thick slab of light yellowish green titanite from Zimbabwe were taken in the X=α and the Y=β extinction directions (E||X and E||Y, respectively).

Native Copper Inclusions in a Cu-bearing Tourmaline

Since the 1989 discovery of bright blue-to-green Cu-bearing tourmaline in Brazil's Paraíba State (Fritsch et al., 1990), these gems have completely changed how the global marketplace appreciates and values tourmaline as a gemstone. In addition to the array of 'electric' colours that have been seen in Cu-bearing tourmaline from Brazil (and subsequently from Nigeria and Mozambique), some intriguing new inclusion features have also come to light.

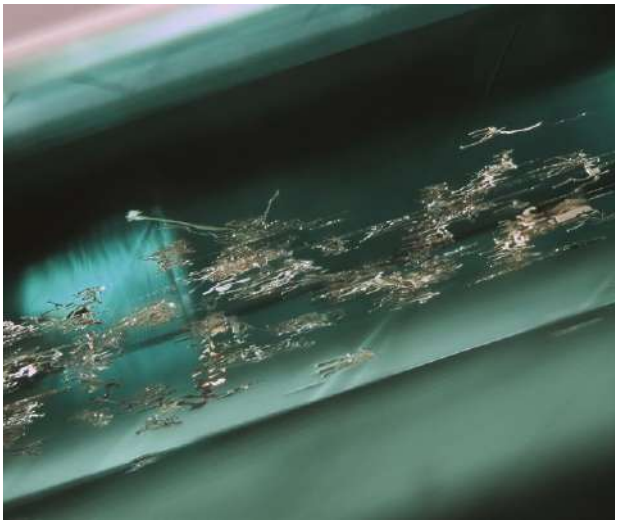

Figure 29: Dendritic platelets of native copper are oriented primarily along the c-axis of this Cu-bearing tourmaline. Photomicrograph by Bilal Mahmood; magnified 58x.

Recently, the American Gemological Laboratories received a 1.35 ct Cu-bearing tourmaline for identification and enhancement determination. The moderately saturated blue-green colour of the stone was not typical of the intensely coloured Paraíba-type tourmalines revered by the industry. Gemmologically, however, the stone was of much greater importance. Orientated primarily along the c-axis were numerous skeletal clusters of native copper inclusions (Figure 29).

Early publications on Cu-bearing tourmaline from Brazil make reference to native copper inclusions (e.g. Brandstätter and Neidermayr, 1994), however, they are only very rarely observed in cut stones found on the market. For gemmologists and mineralogists, inclusions such as these are paramount to understanding the environment in which minerals and gems form, particularly when chromophores are involved.

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Tourmaline Mining at Ijero, Nigeria

In October 2017, rough stone dealer Farooq Hashmi visited an active tourmaline mining area near Ijero (or Ijero-Ekiti), which is located ~200 km by road (about 2.5 hours) north-east of Ibadan in the south-western part of Nigeria. The mines have been worked since the early 1990s, and have produced pink, green, blue and multi-coloured tourmaline. In addition, the deposit is a source of industrial minerals such as feldspar and sheet mica, as well as tantalum-niobium and lithium mineralisation (Ale et al., 2014).

At the time of Hashmi's visit, there were five different areas being worked for tourmaline by separate groups who leased the digging rights from a local pastor who owned the mine. Most of the tourmaline production at Ijero has come from eluvial deposits explored by open pits ranging from 10 to 30 m deep (e.g. Figure 30). When the miners encounter the underlying primary (granitic pegmatite) deposits, they dig vertical shafts for several more metres (Figure 31). Much of the work is done by hand, although one excavator was active during Hashmi's visit (Figure 32).

During his visit to Nigeria in 2017, Hashmi personally saw recently produced tourmaline that amounted to hundreds of kilograms of cabochon-quality rough material and 5–10 kg of facet-grade crystals. In addition, he saw 10–20 kg parcels of this tourmaline during a recent trip to gem markets in Bangkok. Shortly before his mine visit, most of the tourmaline from Ijero that Hashmi saw on the market was bright pink with colourless zones (Figure 33a), in pieces up to 3 g (although larger stones were produced). The production then transitioned into somewhat darker material, much of it multi-coloured (Figure 33b); some clean crystals exceeding 50 g were available. More recently, in early 2018, a small

Figure 30: Miners have removed eluvial material from this pit in the Ijero area of south-western Nigeria in search of gem tourmaline. Photo by Farooq Hashmi.

Figure 31: Once the Ijero miners reach the unweathered pegmatite, they dig shafts in search of tourmaline. Photos by Farooq Hashmi.

Figure 32: An excavator is used to dig into the eluvial deposit adjacent to a tourmaline-bearing pegmatite at Ijero. Several shafts are evident in the unweathered pegmatite. Photo by Farooq Hashmi.

amount of green tourmaline entered the market from Ijero (Figure 33c). In addition, a sizable quantity of brownish pink or 'peach' coloured tourmaline was produced, sometimes as large gemmy crystals (e.g. Figure 33d).

The Ijero area has produced large amounts of gem tourmaline in the nearly three decades that it has been mined. As exploitation of the deposit proceeds to deeper levels, requiring more hard-rock mining, it is expected that tourmaline production from this area will decrease.

Brendan M. Laurs FGA

Reference

Ale P.T., Dada J.A. and Adewumi A.J., 2014. Industrial minerals potentials [*sic*] of Ijero pegmatite in Ekiti State, southwestern Nigeria. *World Applied Sciences Journal*, **29**(3), 415–420.

Figure 33: Recent tourmaline production from Ijero has consisted of (**a**) bright pink/colourless, (**b**) multi-coloured, (**c**) green and (**d**) brownish pink crystals. The tourmalines in photos (a)–(c) typically range up to 3 g, while the unusually large crystal in (d) weighs 52 g. Photos by Farooq Hashmi.

DIAMONDS

Reduced Phosphorescence of Type II HPHT-grown Synthetic Diamonds After Electron Beam Irradiation

Since about 2015, large amounts of melee-size high-pressure, high-temperature (HPHT) synthetic diamonds have entered the market, and the gem and jewellery industry is struggling to discriminate them from natural ones. Several screening devices have been developed for making this separation. Most of them are based on measuring properties such as UV transmission, UV luminescence and IR absorption, although the methods used by some devices are undisclosed. The detection of phosphorescence is widely used among them since both loose and mounted stones can be rapidly inspected. HPHT-grown type II synthetic diamonds are known to show phosphorescence (e.g. Eaton-Magaña et al., 2017)—ranging in duration from milliseconds to tens of seconds—allowing their separation from most natural diamonds, which do not show phosphorescence (the main exception being type IIb stones).

However, in April 2018 an instrument developer in Hong Kong issued an alert that cautioned against using screening devices that look for phosphorescence at room temperature to detect irradiated HPHT-grown synthetic diamonds (Diamond Services, 2018). The alert claimed that the phosphorescence of such samples may be quenched by irradiation. In response, both the International Institute of Diamond Grading & Research and GIA reported that their identification instruments have no problem separating irradiated HPHT-grown synthetics (Meirovich, 2018).

With this background, we investigated the influence of electron-beam irradiation on the phosphorescence of HPHT-grown synthetic diamond melee. We used 10 samples (0.008–0.032 ct) of apparently colourless synthetics that were grown in China. They were divided into two groups (A and B) of five samples each (Figures 34 and 35), and were irradiated at 2 MeV in a stepwise fashion using an electron beam from a Cockcroft Walton-type radiation generator. Group A was irradiated with 1.0×10^{15}, 10.0×10^{15} and then 50.0×10^{15} electrons/cm^2, and Group B with 5.0×10^{15}, 25.0×10^{15} and then 100.0×10^{15} electrons/cm^2. Fluorescence and phosphorescence images were taken before and after irradiation using a GLIS-3000 screening device by Biaoqi Scientific Corp. (Guangzhou, China). The samples were excited by UV radiation from a deuterium arc lamp that covered a wide wavelength range between

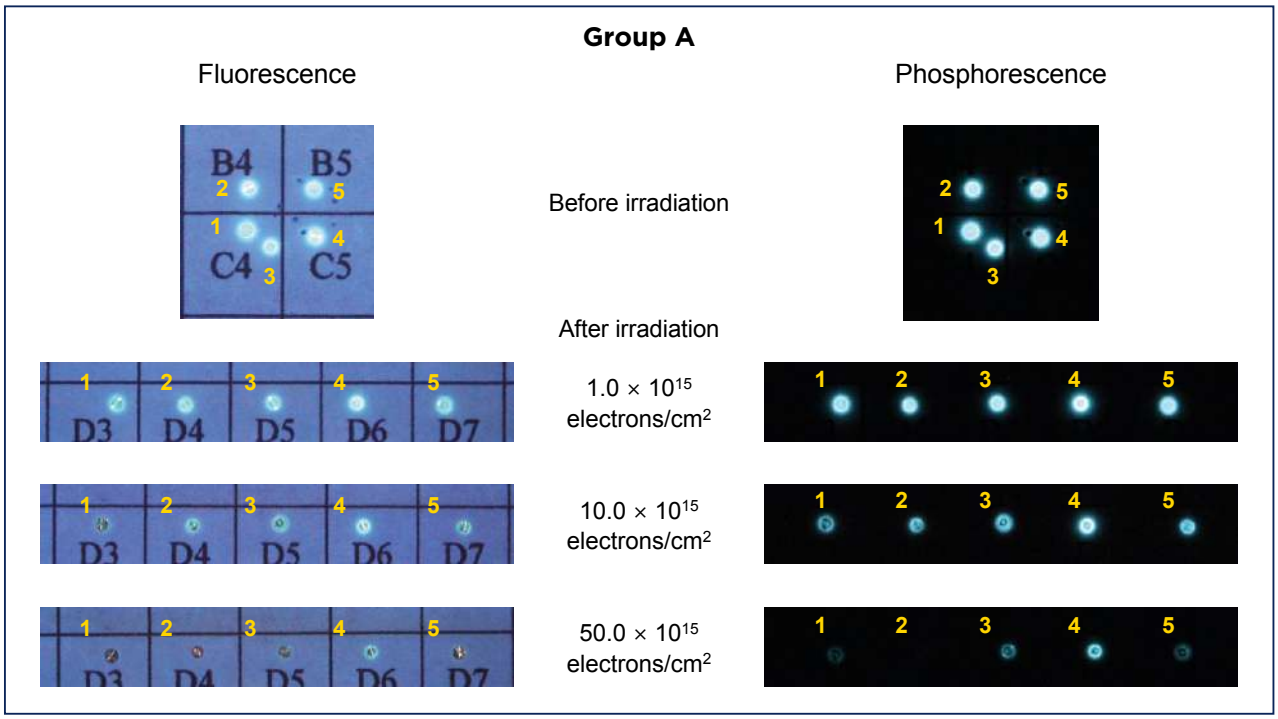

Figure 34: Fluorescence and phosphorescence images are shown for Group A synthetic diamonds (0.008–0.017 ct) before and after sequential irradiation with an electron beam. Photos by K. Koide.

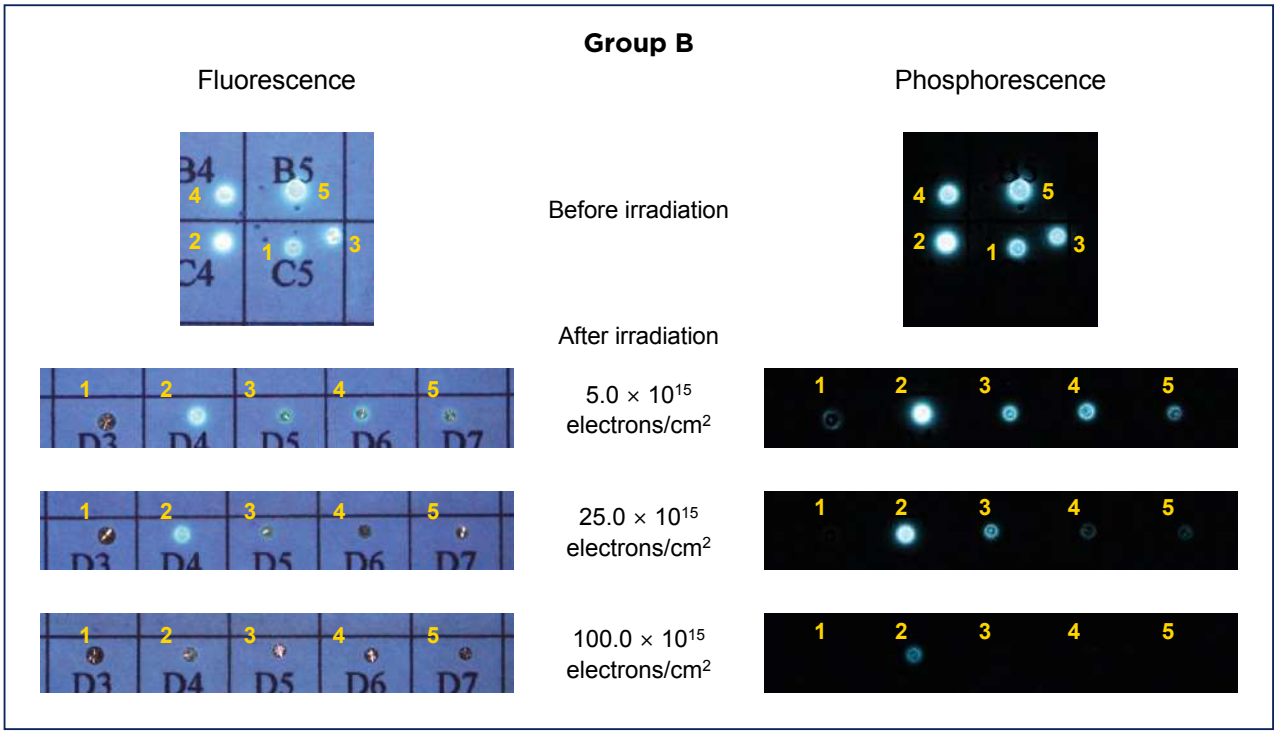

Figure 35: Fluorescence and phosphorescence images are shown for Group B synthetic diamonds (0.013–0.032 ct) before and after sequential irradiation with an electron beam. Photos by K. Koide.

180 and 250 nm. Phosphorescence photos were taken 200 milliseconds after turning off the lamp.

As shown in Figure 34, the synthetic diamonds in Group A displayed no reduction in fluorescence and phosphorescence after irradiation with 1.0×10^{15} electrons/cm^2, and a slight reduction after 10.0×10^{15} electrons/cm^2, although the intensity of the phosphorescence decrease was not uniform in the five samples. Irradiation with 50.0×10^{15} electrons/cm^2 caused the fluorescence and phosphorescence intensity to be reduced considerably, with no phosphorescence seen in one of the samples (no. 2).

Group B samples were exposed to a larger dose of electron-beam irradiation, causing their fluorescence and phosphorescence to be reduced more conspicuously (Figure 35). After irradiation with 100.0×10^{15} electrons/cm^2, all but one sample showed undetectable phosphorescence. Sample no. 2 displayed exceptionally strong phosphorescence before irradiation, and therefore it was not completely quenched by the treatment.

Figure 36 shows Group A samples after irradiation with 50.0×10^{15} electrons/cm^2, as illuminated by a daylight-equivalent lamp and while they phosphoresced. The daylight images were taken on a white, fluorescence-free tray used for diamond grading. Sample nos. 1, 3 and 5 appeared faint blue, which is due to the GR1 centre generated by the irradiation. However, their faint colour intensity would look almost colourless when set in jewellery. The strength of the samples' phosphorescence was not consistent with the presence or absence of blue colouration.

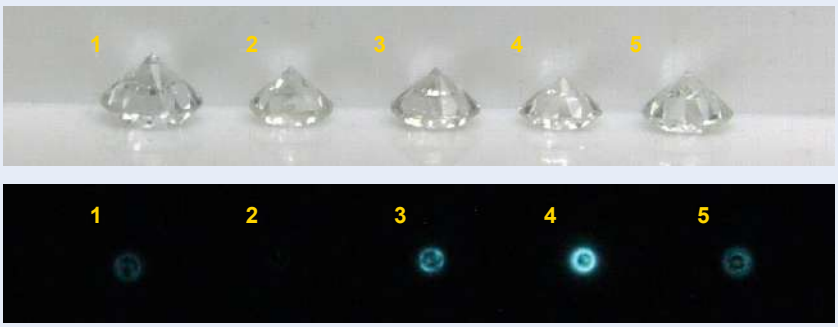

Figure 36: Group A synthetic diamonds (0.008–0.017 ct) irradiated with 50.0×10^{15} electrons/cm^2 are shown in daylight-equivalent illumination and after UV excitation. Some blue colouration is seen in nos. 1, 3 and 5, which emit variable amounts of phosphorescence. Photos by H. Kitawaki (top) and K. Koide (bottom).

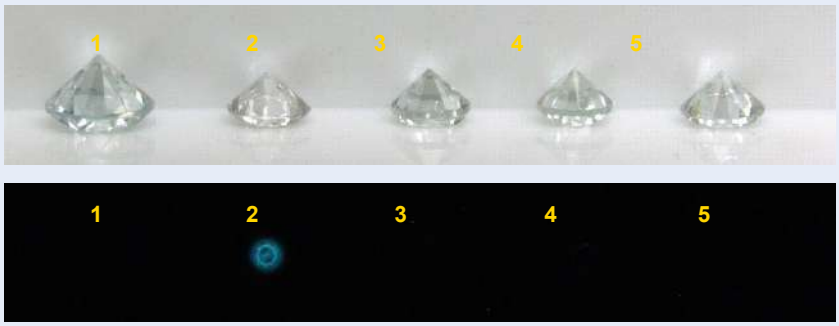

Figure 37: Group B synthetic diamonds (0.013–0.032 ct) irradiated with 100.0 x 10^{15} electrons/cm^2 are shown in daylight and after UV excitation. All samples except no. 2 exhibit some blue colouration but no phosphorescence. Photos by H. Kitawaki (top) and K. Koide (bottom).

Figure 37 shows Group B samples after irradiation with 100.0 × 10^{15} electrons/cm^2. All except no. 2 show some blue colouration, and their phosphorescence is undetectable. Sample no. 2 remained colourless and showed some phosphorescence.

According to our experiments, increasing the dose of electrons reduced both fluorescence and phosphorescence, and induced blue colouration as well. In particular, the irradiated synthetic diamonds that showed no phosphorescence also changed to light blue, although a few irradiated samples with undetectable phosphorescence remained colourless. We confirmed that the phosphorescence shown by HPHT-grown synthetic diamonds is reduced, and may finally disappear, after sequential irradiation with an electron beam. Therefore, by only measuring phosphorescence one may overlook these treated synthetics. However, detailed observation of their colour will help separate them from natural diamonds because the irradiation usually induces a blue colouration if the dose is high enough.

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Kentaro Emori and Keiji Koide
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Diamond Services, 2018. Lab Alert: HPHT-grown diamonds might escape detection as synthetics, once they are treated with irradiation, 17 April. http://tinyurl.com/yah5w8ud, accessed 7 August 2018.

Eaton-Magaña S., Shigley J.E. and Breeding C.M., 2017. Observations on HPHT-grown synthetic diamonds: A review. *Gems & Gemology*, **53**(3), 262–284, http://doi.org/10.5741/GEMS.53.3.262.

Meirovich L., 2018. Labs refute claims HPHT escaping detection. Rapaport News, 25 April, http://tinyurl.com/y9x8kmm2, accessed 7 August 2018.

ORGANIC MATERIALS

Ammonites Inlaid with Ammolite and Turquoise

For many years, ammonite fossils from Madagascar have been used for decorative and ornamental purposes, including jewellery (e.g. Laurs, 2001). They are commonly sliced in half and polished to display their attractive coiled pattern and the suture lines separating their chambers.

During the June 2018 JCK show in Las Vegas, Nevada, USA, Bill Heher (Rare Earth Mining Co., Trumbull, Connecticut, USA) displayed some Madagascar ammonites that were inlaid with Ammolite from Canada and turquoise from the Sleeping Beauty mine in Arizona (Figure 38). He debuted these ammonites at the February 2018 Tucson gem shows. The individual chambers in the ammonite slices were hollowed out

Figure 38: These ammonites from Madagascar are inlaid with Ammolite (left, 27 mm long) and turquoise (right, 30 mm long). Photo by Orasa Weldon.

and then filled with pieces of these gem materials. The filled cavities were sealed with colourless lacquer, and then the pieces were ground and polished.

Depending on the inlay material used, the mosaic-set fossils showed colourful areas of iridescence (Ammolite) or a pleasing colour contrast (turquoise). They typically ranged from 30 to 75 mm long with some larger pieces available, and approximately 500 of them are being produced each month by artisans in Bali, Indonesia. Production will continue until Heher's stock of Ammolite and Sleeping Beauty turquoise pieces are consumed.

Brendan M. Laurs FGA

Reference

Laurs B.M., 2011. Gem News International: Iridescent ammonite from Madagascar. *Gems & Gemology*, **47**(3), 235–236.

SYNTHETICS AND SIMULANTS

Figure 39: These two oval specimens, weighing approximately 750 ct each, were represented as black opal. They proved to be imitations made with a magnesite core coated with a layer of grey cement that locally contains tiny grains having the appearance of opal. The lower edge of the left specimen was chipped off for study. Also note the uneven colour patches, suggesting that different materials were used in their manufacture. Photo by G. Choudhary.

Unusual Matrix Opal Imitations

Matrix opal from Andamooka, South Australia, is a well-known gem material that may be used to imitate black opal. It is primarily a porous rock that has been infiltrated by play-of-colour opal, and it is commonly carbonised (or 'sugar treated') to produce its dark colour (e.g. Brown, 1991). Recently Amit Soni of Jaipur showed this author two large oval-shaped specimens with the appearance of matrix opal (and sold as black opal), both of which turned out to be unusual imitations.

The samples were rather large, with each weighing approximately 750 ct and measuring ~82.0 × 60.0 × 16.0 mm. They displayed uneven body colours with brown, grey and black areas (Figure 39). Specks of spectral colours, suggesting the presence of opal, were restricted mainly to the brown portions (Figure 40), while other areas had a granular texture composed of angular fragments but lacked any play-of-colour. Such restricted areas of 'opal' raised suspicion about the origin of the specimens, so further testing was performed. Observation with long- and short-wave UV radiation revealed blue-white fluorescence (Figure 41) that was confined to the brown areas (i.e. containing the 'opal' specks), while the rest of each sample was inert. The hydrostatic SG was ~3.26 (although SG is of no significance for a matrix opal), and no shadow edge could be resolved with a refractometer. Qualitative EDXRF analysis revealed the presence of S, Ca, Ba, Fe and Sr, in addition to Si. Recently, we have seen quite a few ceramic turquoise imitations with similar chemical elements, which further raised our suspicion of these samples.

With permission from the owner, the edge of one of the specimens was chipped off (again, see Figure 39), which revealed a thick grey granular layer over an underlying blue-green-white material (Figure 42); this core was

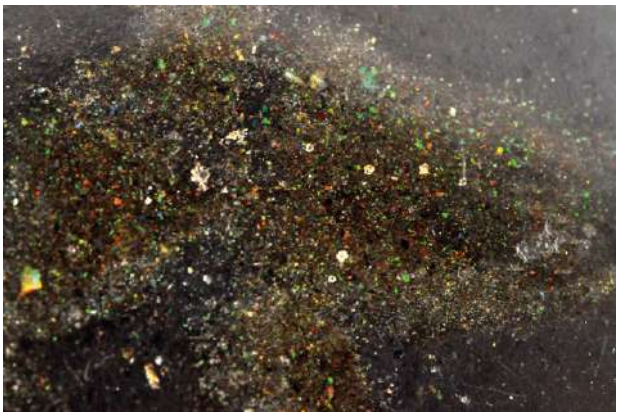

Figure 40: Grains showing play-of-colour are mainly restricted to the brown areas of this imitation matrix opal. The have been embedded into the top layer of grey cement. Photo by G. Choudhary.

Figure 41: The brown areas (containing the grains showing play-of-colour) of this imitation matrix opal fluoresce blue-white, while the other areas remain inert. The reaction to long-wave UV (shown here) was stronger than it was to short-wave. Photo by G. Choudhary.

blue-green towards the rim and white at the centre, with a chalky to powdery appearance. No play-of-colour was seen in the core or in the overlying grey layer. Raman spectroscopy of the blue-green and white areas of the core identified it as magnesite, and the colour of the blue-green rim suggested the presence of a dye.

On the basis of our observations and analysis, we deduced that these opal imitations were produced using a pre-form of dyed magnesite, which was first coated with a thick layer of grey cement (barium sulphate based). Next, cavities or pits were etched on the top surface and filled with a paste containing opal grains. Finally, the specimens were finished off with a polish.

It is difficult to understand the purpose of using magnesite as the core material and putting so much effort into manufacturing such imitations. Further, it is relatively easy to find treated black matrix opal in the marketplace (but not in such large pieces). Although it was straightforward to identify these samples as imitations and separate them from matrix opals, their true nature was only revealed with destructive testing. They proved highly unusual in both the materials used and the method of production.

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Reference

Brown G., 1991. Treated Andamooka matrix opal. *Gems & Gemology*, **27**(2), 100–106, http://doi.org/10.5741/gems.27.2.100.

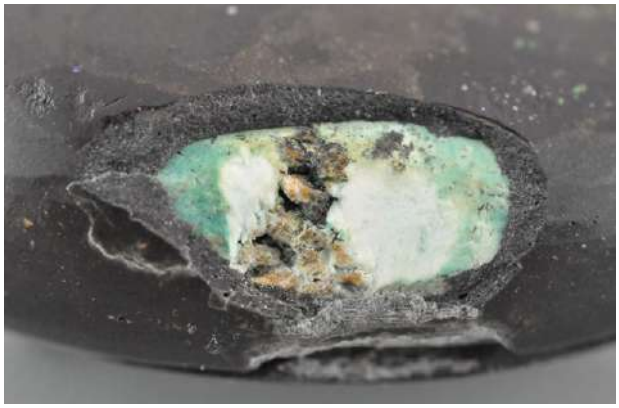

Figure 42: The chipped edge of one of the imitation matrix opals reveals the underlying magnesite used as the core, which was coated with a thick layer of granular grey cement. Also note the blue-green rim and white centre of the core, which suggests the local presence of dye in the magnesite. Photo by G. Choudhary.

MISCELLANEOUS

55th Myanmar Gems Emporium

On 20–29 June 2018, the 55th Myanmar Gems Emporium took place in Nay Pyi Taw. It was attended by about 2,800 foreign merchants and 1,200 local buyers. In addition, 500 local gem companies were in attendance, and they offered a variety of rough and polished gems.

Of the 336 'Gems' lots that were offered during this Emporium, 69 of them sold for a total of €1.379 million. In addition to ruby and sapphire, the Gems lots included spinel, peridot, topaz, petalite and amber. The highest Gems sale was a parcel of rough ruby (lot no. 175) weighing 2,997 carats that sold for €152,999.

There were 360 'Pearl' lots offered, and 341 of them sold for €2.598 million. Pearl lot no. 524 received the highest price of €32,999.

Of the 6,795 'Jade' lots offered, 5,259 sold for a total of €423.118 million. The highest Jade sale was lot no. 1796, which consisted of two pieces weighing a total of 83 kg that sold for €9,000,099.

The total sales for the event were €427.095 million, a decrease compared to €516.50 million at the 54th Emporium.

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Letters

Transparency of Emerald Tanzurine

In the Gem Note titled 'Green aventurescent quartzite from a new find in Tanzania' (Vol. 36, No. 2, 2018 , pp. 103–104) authors Tom Stephan, Dr Ulrich Henn, Fabian Schmitz and Brendan Laurs describe Emerald Tanzurine as 'predominantly opaque'. Yet the polished egg and cabochon illustrated in their Figure 24 strongly suggest otherwise. There is a very simple test for opacity in gem materials: if inclusions within the gemstone are clearly visible, as they are in the objects in Figure 24, then it cannot be opaque. By definition you cannot see into an opaque material. In fact, not only is the Emerald Tanzurine not opaque, but one can reasonably argue that it is actually transparent. If it were not transparent, one would certainly not be able to view the fuchsite inclusions which can easily be seen in Figure 24. Admittedly, some of the Emerald Tanzurine is quite dark, but being dark does not make it opaque.

We have another modest concern with the article in general. Jonathan Bartky, the discoverer of Emerald Tanzurine, claims that the location of his deposit is undisclosed. The authors of the Gem Note did not use samples in their study supplied by Bartky, but instead their samples were donated by Impexco (Idar-Oberstein, Germany). There is no information provided regarding Impexco's source of their samples, so the possibility exists that it is not the same material as Bartky's. Samples could have been obtained from Bartky for this study, thereby eliminating this possibility.

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Dr Loretta D. Dickson
Lock Haven, Pennsylvania, USA

Authors' Reply

We thank Mr White and Dr Dickson for their comments. In our Gem Note on green aventurescent quartzite, we described the samples not only as 'predominantly opaque', but more precisely as follows: 'The rough material from Tanzania was predominantly opaque, but appeared translucent in strong transmitted light. The translucency was better in the polished samples (e.g. Figure 24)…' However, we use the following definitions for a gem's transparency: transparent—one can see through it; translucent—light can pass through it; opaque—one cannot see light pass through it. Furthermore, our description gave the sample's overall appearance, and not just on a micro-level relative to its inclusions. When investigating the samples shown in Figure 24, we observed that no light could pass through them under normal lighting conditions. Only by using very strong transmitted illumination could we observe a slight translucency at the edges. According to this observation, we maintain that these samples were '…predominantly opaque, but appeared translucent in strong transmitted light.'

On the samples' origin: The material was offered on the German market by Impexco in Idar-Oberstein, Germany. Wolfgang Weinz of Impexco received the material from a local Tanzanian miner and dealer in Dar es Salaam, Tanzania. Given the timing of these samples' arrival on the market and their close resemblance to material obtained from Jonathan Bartky, it seems reasonable to assume that they constitute the same material that Bartky sells as Emerald Tanzurine.

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Brendan M. Laurs FGA

Erratum

In the Gem Note titled 'More on Black Star Rutile Imitations' (see *The Journal*, Vol. 36, No. 1, pp. 21–23), the title of Figure 33 should have been 'XRD Pattern'.

Blockchain, Chain of Custody and Trace Elements: An Overview of Tracking and Traceability Opportunities in the Gem Industry

Laurent E. Cartier, Saleem H. Ali and Michael S. Krzemnicki

ABSTRACT: Recent developments have brought due diligence, along with tracking and traceability, to the forefront of discussions and requirements in the diamond, coloured stone and pearl industries. This is a result of consumer demands for detailed information on the provenance of gems, banking requirements aiming to reduce risk, industry and company initiatives seeking to bring greater transparency, and growing government legislation on mineral supply chains. To address this trend, certification mechanisms and technologies (such as blockchain) are being developed to solve inherent traceability challenges. As applied to gems, such standards and associated technology could benefit from the support of existing gemmological approaches (e.g. geographical origin determination) to enhance traceability and transparency measures. Recent initiatives are not just limited to corporate social responsibility reporting and due diligence requirements, but they also embrace supply chain management (including quality control and process improvements)—for example, to correctly identify and disclose treated and synthetic materials throughout the jewellery industry—as well as address consumer demand for provenance information. This article provides an overview of current trends and developments in the tracking and traceability of gems, along with an explanation of the terms used in this context.

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Traceability and transparency—including tracking (from mine to market) and tracing (from market to mine)—of coloured stones, diamonds and pearls is an increasingly important topic in the industry, as shown by recent research and reports (Archuleta, 2016; Walker, 2017; CIBJO, 2018; Human Rights Watch, 2018). The complex and fragmented nature of the global gem industry means that little information is typically available about these supply chains and how specific gem materials are mined, manufactured and sold. Traceability is one way to provide more transparency, and it is argued that by increasing transparency, supply chain issues can be better mapped and understood, ultimately helping to improve the environmental and social impact of a supply chain (Mol, 2015). Consumers are increasingly interested in knowing where and how the materials they consume are extracted and manufactured (Nash et al., 2016; De Angelis et al., 2017; see also Figure 1). Media and non-governmental organisations are placing the gem industry under increased scrutiny regarding the origin and sustainability footprint of various stones (Cross et al., 2010; IndustriALL et al., 2013; Global Witness, 2015, 2016; RESP, 2016). At the same time, some companies want to be proactive so as to mitigate risks and better understand their own supply chains and potential

Figure 1: An artisanal miner in Madagascar holds a treated blue topaz set in a ring. As the gem trade and consumers become increasingly interested in tracing the history and provenance of a gemstone or piece of jewellery, technological solutions and management models need to be developed to respond to these needs. Photo by L. E. Cartier.

sustainable development impact (Bloomfield, 2017). Governments want to improve the management and revenue collected from gem resources, and global governing bodies have highlighted issues such as smuggling and money laundering in recent years (Schroeder, 2010; 'Expert meeting to discuss…', 2013; Financial Action Task Force, 2013; OECD, 2016; Shortell and Irwin, 2017). Both the USA (through the Dodd-Frank Wall Street Reform and Consumer Protection Act) and the EU (through the upcoming Conflict Minerals Regulation in 2021) are requiring that companies carry out due diligence to ensure that the trade in four minerals—tin, tantalum, tungsten and gold—does not fund conflict in certain countries and regions. Although gold is presently the only commodity of concern to the jewellery industry in this context, such regulations could be expanded to diamonds and coloured stones in the future. The jewellery industry has been less scrutinised than other sectors (particularly in terms of legislation) and has been relatively late in responding to some of these concerns in a manner that integrates all materials used in jewellery products.

To further address these issues, a multi-fold approach is required—for example, strengthening specific ethical and sustainability standards and improving resource governance pertaining to the mining, processing and selling of gem materials worldwide (Cartier, 2011; Ali et al., 2017). Documenting the provenance and sources of gems through traceability schemes is one way to increase transparency and provide a supporting mechanism to strengthen the accountability and credibility of sustainability-certification schemes. In this article, we focus on gems (e.g. Figure 2) rather than jewellery as a whole, as track-and-trace in jewellery would also cover more wide-ranging issues such as quality control and inventory management in manufacturing. We briefly address the historic role of provenance in gems and jewellery, and how scientific origin determination of gemstones emerged in recent decades, thereby providing some knowledge about a stone's origin in the absence of a clear paper trail. We then review general concepts of traceability and track-and-trace approaches and how these might apply to gems through a compilation of various industry initiatives. Then, an overview of blockchain technology is given along with examples of emerging projects in the gem industry. A Glossary is included that defines key terms pertaining to provenance, traceability and related topics that are covered in this article. Finally, we conclude with an outlook on traceability, and argue that there is no 'silver bullet', but rather that multiple approaches and technologies are likely to spur greater transparency in the industry.

SIGNIFICANCE OF THE GEOGRAPHICAL ORIGIN OF GEMS

Historical Perspectives

Gems have been coveted by humans for millennia (e.g. Ali, 2009). Traded as precious objects or used for personal adornment, they have long been linked to different symbols and represented as commercial valuables. In some cases, the origin and nature of the minerals unearthed and traded was vital because of historical and spiritual connotations (Raden, 2016).

In the early days of gem commerce, only a few sources were known. With expanding global exploration and trade, new and diverse gem deposits were discovered. Traditionally, diamonds were sourced from India (Golconda) and Borneo until the discoveries in Brazil in the 18th century and in South Africa in the 19th century, which revolutionised the diamond industry. Similarly, the emerald sector experienced a surge in the 16th century with the discovery of Colombian deposits by the Spanish (Giuliani et al., 2000). Due to the emotional connection with gem materials from specific localities, knowing the provenance of these gems continued to be of interest for both traders and consumers, and was largely built on a system of trust and experience (Bernstein, 1992; Brazeal, 2017).

Opportunities and Limitations

As the science of gemmology emerged in the early 20th century, and synthetics and treatments became critical research issues, interest grew in carrying out structured investigations on gem materials from different origins to better characterise their properties. For example, Chesley (1942) attempted to correlate spectroscopic features of diamonds to their source localities. Geographical origin determination of coloured stones as we know it today appeared in the 1980s, and at the beginning focused on characterisation of typical microscopic inclusions from a deposit (Gübelin and Koivula, 1986). This was subsequently complemented by chemical and spectroscopic work on gem materials from various localities (Hänni, 1994; Krzemnicki, 2007; Rossman, 2009; Bui et al., 2012; Ogden, 2017), such as the early work on Kashmir sapphires by Hänni (1990). For more than a decade, the use of laser ablation inductively coupled plasma mass spectrometry (LA-ICP-MS) has provided greater quantitative insight into the trace- and ultra-trace-element composition of gems for fingerprinting their origin (Guillong and Günther, 2001; Rankin et al., 2003; Abduriyim and Kitawaki, 2006a,b). Recent work using GemTOF (SSEF's time-of-flight LA-ICP-MS instrument) in combination with complex multivariate statistical analysis has shown the potential to improve

Figure 2: Emeralds (~0.4–1.0 ct) from various origins: are they natural, treated or synthetic? What is the amount of fracture-filling treatment? What is their country of origin? Can they be traced back to individual mines? What can be said of the conditions in which they were mined and cut? Traceability technologies, represented by the schematic bar code, could help us answer these questions in the future. Photo by L. E. Cartier.

Glossary*

Blockchain: A system for storing data in which groups of valid transactions, called blocks, form a chronological chain, with each block securely linked to the previous one. Originally invented for the digital currency bitcoin, a blockchain is a permanent, unalterable digital file of encrypted transactions that can be distributed in multiple copies across a network of devices linked to the blockchain. Given that every storage device has an exact and updated copy of the ledger, data can be verified and is considered immutable—an important property when transactions are occurring among users that do not know or trust each other.

Chain of custody: Under OECD's 2016 Due Diligence Guidance, chain of custody refers to the document trail recording the sequence of companies and individuals that have custody of minerals as they move through a supply chain.

Code of Practices: The Responsible Jewellery Council (RJC) Code of Practices defines responsible ethical, human rights, social, and environmental practices for businesses in the diamond, gold and platinum-group metals jewellery supply chain. It is being expanded to include coloured stones as well ('RJC to expand…', 2016).

Corporate social responsibility (CSR): 'A management concept whereby companies integrate social and environmental concerns in their business operations and interactions with their stakeholders' ('What is CSR?', 2018).

Disclosure: The release of information by companies required by regulators or requested by business partners in the supply chain.

Due diligence: The act of proactively ensuring that the products sourced and traded by companies within a supply chain conform to national and international regulations. This can include treatment disclosure, banning child labour and money laundering, and a wide range of other issues. For further information, see OECD (2016).

Geographical origin: In gemmological terms, this is commonly understood to be the country of origin of a gem provided as a scientific opinion based on microscopic, spectroscopic and chemical properties of a stone compared to a reference collection of samples and the gemmological literature. Ultimately this is linked to the geological origin of a stone. In some cases, such as rubies from Thailand and Cambodia, geologically similar or identical deposits are found on both sides of the border and thus cannot be separated by country.

Geological origin: The type of geological deposit in which a gem formed. In some countries (e.g. Madagascar), gem deposits may have different geological origins and thus can be separated accordingly (e.g. Ambondromifehy basaltic sapphires and Ilakaka metamorphic sapphires).

Origin determination: Origin determination of gems is an expert scientific opinion on the origin (country) of a stone, based on characteristic inclusions and chemical and spectroscopic features.

Provenance: A (documented) claim made on the origin (e.g. country or mine), source (e.g. recycled, mined, artisanally mined, natural, synthetic), previous ownership (e.g. a historic gemstone or a piece of jewellery formerly in a royal collection) or extraction and processing practices (e.g. conflict free, untreated, responsibly sourced).

Supply chain transparency: The extent to which information about the companies, suppliers, sourcing locations (including mines) and processing conditions (cutting and treatment processes) is available to end consumers and to other companies in the supply chain. There is growing demand for transparency in supply chains, as consumers and companies want detailed information about the origin of products.

Sustainable development: Defined in 1987 by the Brundtland Commission report as 'development that meets the needs of the present without compromising the ability of future generations to meet their own needs' (Brundtland, 1987, p. 15). This integrates economic, environmental and social pillars.

Tracing: The use of traceability records or an object's properties to identify the origin, attributes or history of a product within the supply chain. In the case of gemmology, this comes down to country-of-origin determination where documents are not available but physical and chemical properties allow for a conclusion of possible country-of-origin. If a gem has been tagged using tracking technology, it can be traced back upstream using this information.

Tracking: The use of traceability records to track an item from its origin to the end consumer through the supply chain. This is often complemented by the use of tracking technology such as radio-frequency identification (or RFID) chips, near-field communication, synthetic DNA implantation, barcodes or other forms of tagging.

Traceability: 'The ability to identify and trace the history, distribution, location, and application of products, parts, and materials' (Norton et al., 2014, p. 6, as per the International Organization for Standardization or ISO).

* Sources: Norton et al. (2014); OECD (2016); RJC (2017); Future of Fish et al. (2018); 'What is CSR?' (2018)

the precision and reliability of origin determinations (Wang et al., 2016).

Thus, today's laboratory reports offer origin opinions for certain coloured stones based on the scientific interpretation of their microscopic, spectroscopic and chemical properties compared to a reference collection of samples and the gemmological literature. Table I lists the gem varieties submitted to labs for origin reports and their common sources. As databases for tested gems grow and further research is carried out, origin determination will likely be extended further to include other gem varieties. Although it is not possible to trace a coloured stone back to a specific mine, origin determination can help validate claims made by companies regarding country of origin. For example, in the context of the now-defunct Tom Lantos Block Burmese JADE (Junta's Anti-Democratic Efforts) Act of 2008 that banned the import of Burmese rubies and jade (Dickinson DeLeon, 2008) into the USA, gemmological methods were useful for providing information to clients.

Origin reports are an important part of today's high-end gem and jewellery markets, where factors such as rarity, branding and provenance are critical to some consumers, investors and traders (Shor, 2013; Ogden, 2017). Rather than providing definitive proof of a stone's source, a country-of-origin report is used in general to support a claim made about the geographical origin of a high-end gemstone (e.g. at auction). This is very similar to expert-opinion reports on ceramics, furniture, paintings and wine (e.g. Spencer, 2004; Bull, 2016). Gemmological origin interpretations can vary in certain cases, and such variations in origin reports may show up between different labs (Gannon, 2004; Ogden, 2017). As accessibility to advanced analytical instrumentation improves, and as databases of documented rough material from different mines become more robust, the scope of geographical origin determination will also expand.

Table I: Selected gem varieties for which geographical origin determination can commonly be performed by gem laboratories.

Gem variety	Commonly identifiable (and commercially relevant) sources
Alexandrite	Africa (Madagascar, Tanzania), Brazil, Russia, Sri Lanka
Cu-bearing tourmaline	Brazil, Mozambique, Nigeria
Demantoid	Madagascar, Namibia, Russia
Emerald	Afghanistan, Brazil, Colombia, Ethiopia, Zambia
Ruby	Afghanistan, Madagascar, Mozambique, Myanmar, Tanzania (Winza), Thailand, Vietnam
Sapphire	Kashmir, Madagascar, Myanmar, Sri Lanka
Spinel	Madagascar, Myanmar, Sri Lanka, Tajikistan, Tanzania, Vietnam
Tsavorite	East Africa (Kenya, Tanzania)

Although considerable research on the origin determination of diamonds was conducted at the turn of the 21st century due to the issue of 'blood diamonds', until now no technique has been found to conclusively identify faceted stones from various origins based on scientific means (Dalpé et al., 2010). As such, it is not possible to determine the country or mine source for a cut diamond of unknown origin through commercially available geochemical, isotopic or spectroscopic methods. The diamond industry has thus had to focus on chain of custody and other mechanisms to support origin claims on sold diamonds (e.g. Table II). This includes the Kimberley Process Certification Scheme, the De Beers Best Practice Principles, the Signet Responsible Sourcing Protocol for Diamonds (D-SRSP) and the Responsible Jewellery Council's consultation for its chain of custody to become applicable to diamonds (RJC, 2017).

Research on pearls has focused on distinguishing natural from cultured and freshwater from saltwater samples, rather than geographical origin determination. However, recent work (Hänni and Cartier, 2013; Meyer et al., 2013; Cartier et al., 2018) has increasingly looked at mollusc species and the potential geographical origin determination of cultured pearls.

TRACKING AND TRACING

Tracking (from origin to market, or forward traceability) and tracing (from market to origin, or backward traceability) conceptualise the path of an item and how it can be identified within a supply chain (Schwägele, 2005). Whereas tracking and tracing describe path direction of goods, traceability is a more overarching term (see Glossary). Various sectors, such as the food and pharmaceutical industries, use both track and trace for different purposes. In such contexts, tracking can locate an item based on specific criteria (e.g. vital when recalling non-compliant items) whereas tracing is the basis for finding the cause of non-compliance (Bechini et al., 2008).

Table II: An overview of industry initiatives in responsible business practices and traceability programmes (modified from Solomon and Nicholls, 2010).

Initiative	Year founded	Target material	Chain of custody model (or model provided)	Strategy	Claim made/ aim of initiative	Supply chain segment
World Jewellery Confederation (CIBJO)	1961	Jewellery, metals, diamonds, coloured stones, pearls and coral	Product disclosure	Publish 'Blue Books' that cover industry-wide accepted nomenclature for claims made about gems and metals in the jewellery industry	Provide material disclosure guidelines for the jewellery industry	Entire jewellery industry
Kimberley Process Certification Scheme	2000	Diamonds	Bulk commodity (traceability)	Packages of rough diamonds are certified by exporting governments as conflict free	Diamonds are conflict free	Country of export, only for rough stones
CanadaMark (Dominion Diamond Mines)	2003	Diamonds	Bulk commodity (traceability)	Diamonds are certified to be of Canadian origin (from Diavik or Ekati mines)	Canadian origin (not tracked back to individual mine)	Diamond industry, from mine to end consumer
Extractive Industries Transparency Initiative (EITI)	2003	Oil, gas and mineral resources	EITI Standard	Annual EITI Progress Report to disclose information on: contracts and licences, production, revenue collection and allocation, and social and economic spending	Improve transparency in extractives sector	Mining company payments made to governments
Diamond Development Initiative	2005	Diamonds	Maendeleo Diamond Standards (MDS)	Standards and certification for responsible artisanal small-scale mining (ASM) diamond production	Responsibly mined ASM diamond according to MDS standards	ASM diamond mines (e.g. Sierra Leone)
Responsible Jewellery Council	2005	Coloured stones, diamonds, gold, platinum and silver	Code of practices and chain of custody (gold only)	RJC members commit to and are independently audited against the RJC Code of Practices, an international standard on responsible business practices for diamonds, gold and platinum-group metals	Responsible practices	Entire jewellery supply chain (coloured stones are currently under review)
Initiative for Responsible Mining Assurance	2006	Minerals and metals	Independent third-party verified responsible mining assurance system for mining companies	Certify mine-site practices	Certified to follow best practices for mining	Mining companies
Love Earth (Walmart)	2008	Gold and diamonds	Identity preservation (traceability)	Traceability of product back to mine (by consumer), with mining company, refiner and manufacturer self-reporting against a set of environmental and social criteria along with third-party audits	Jewellery material components are traceable and comply with Wal-Mart's responsible sourcing practices	Select mines, refineries, manufacturers and retailers
OECD Due Diligence Guidance for Responsible Supply Chains of Minerals from Conflict-Affected and High Risk Areas	2009	Minerals (including diamonds and coloured stones)	Due diligence guidelines for sourcing of minerals	Provide due diligence recommendations for mineral sourcing	(Not applicable)	Entire supply chain

Table II (continued): An overview of industry initiatives in responsible business practices and traceability programmes (modified from Solomon and Nicholls, 2010).

Initiative	Year founded	Target material	Chain of custody model (or model provided)	Strategy	Claim made/ aim of initiative	Supply chain segment
Diamonds with a Story (Rio Tinto)	2013	Diamonds	Identity preservation (traceability)	Australian (Argyle) origin certified as stones are tracked through supply chain	Argyle (Australia) origin	From mine to end consumer
Signet Responsible Sourcing Protocol for Diamonds (D-SRSP)	2016	Diamonds	Guidelines for responsible diamond sourcing	Protocol that provides transparency and to assure that all Signet diamonds are sourced through identified and verified sources, over time, through a process of continuous improvement	Compliant with D-SRSP	Suppliers to Signet Jewelers
Emerald Paternity Test (Gübelin Gem Lab)	2017	Coloured stones	Identity preservation and/or bulk commodity (traceability)	Rough stone batches (e.g. emeralds from Gemfields) are marked with unique ID nanoparticles that can be read downstream to provide data on the stones	Support provenance claims made by reading information contained in nanoparticles found in tagged emeralds	From mine to retail; information about a stone can be verified by a lab
M2M Program (GIA)	2017	Diamonds	Platform for consumers to visualise a diamond's story from rough to cut	GIA documents rough diamonds submitted by miner and then each stone is cut and sent back to GIA for grading; GIA confirms that each one is the same stone originally submitted	Story of the diamond from rough to cut, documented by GIA	A rough diamond submitted by a diamond mining company, tracked all the way through manufacturing and retail via M2M platform
Tracr (De Beers)	2017	Diamonds	Blockchain traceability	Develop mine-to-finger blockchain for diamonds	Demonstrate traceability of diamonds from mine to finger via blockchain	From mine to end consumer via blockchain
Diamond Time-Lapse Protocol	2018	Diamonds	Permissioned private blockchain	Show the journey of a diamond to an end consumer via blockchain and app; option for manufacturers to track stock through manufacturing process via blockchain	Journey of a diamond can be followed through manufacturing via blockchain and app	Manufacturer and retailer interface as well as a consumer interface
Provenance Proof	2018	Coloured stones	Blockchain traceability	Mine-to-finger blockchain for coloured stones developed by Everledger and the Gübelin Gem Lab	Demonstrate traceability of coloured stones from mine to finger via blockchain	From mine to end consumer, via blockchain
TrustChain	2018	Gold and diamonds	Permissioned private blockchain	Offer traceability of diamond jewellery via blockchain by working with selected certified miners, certifiers, manufacturers and retailers	Provenance claims for the source of metals and diamonds used in jewellery items	From mine to end consumer, via blockchain

Although traceability in current discussions in the gem and jewellery industry is often understood to mean an object is fully traceable (i.e. an individual gem is uniquely documented and identifiable at each step of the supply chain from mine/farm to market and end consumer), there are four different possible models of product traceability (Norton et al., 2014):

1) Identity Preservation or Track-and-Trace
2) Bulk Commodity or Segregation
3) Mass Balance
4) Book and Claim

The aim of these traceability approaches (see Table III) can be to substantiate sustainability and origin claims made by companies. A more detailed description of this, with examples for diamond and gold jewellery, can be found in Solomon and Nicholls (2010).

Clear guidelines exist for how chain of custody could be put in place in the jewellery industry (RJC, 2012, 2017) and how due diligence for responsible business practices can be carried out (OECD, 2018). Demand for both tracking and tracing within the gem industry is growing, as origin claims need to be verified. In addition, sustainability claims are increasingly being made about gems. In such cases, traceability is equally vital to uphold and validate such claims. In addition to improving chain-of-custody practices and auditing options, technology can provide solutions to verify such claims. Recent efforts have focused on individually marking and separating each stone or cultured pearl so that it can be identified and tracked back to its mine or farm of origin (Hänni and Cartier, 2013; Theodosi, 2017). The ultimate system of traceability should ideally offer a consumer transparent and proven access to the unique and complete story of a gemstone or piece of jewellery, and potentially

Table III: An overview of available traceability models used to support sustainability claims.

Traceability model	Approach	Level of traceability	Cost	General example	Gem example
Identity Preservation or Track-and-Trace	Certified materials and products are physically separated from non-certified materials and products at each stage along the supply chain.	Highest	Very costly	Consumer would know exact farm from which a banana or salad was sourced.	Exact mine-of-origin information is tracked through the supply chain.
Bulk Commodity or Segregation	Separates certified from non-certified materials but allows mixing of certified materials from different sources. All producers must comply with the certification standards.	High	Costly	An organic chocolate bar that contains cacao beans from various organically certified producers. Another example is Kimberley Process rough diamonds certified as 'conflict free'.	An aggregation of goods from one company that operates several mines; also useful for gem regions/ countries and could be complemented by gemmological analysis.
Mass Balance	Certified and non-certified materials can be mixed. However, the exact volume of certified material entering the supply chain must be controlled. Claims of 'this product contains X% of certified ingredients' can be made.	Low	Slightly costly	If 20% of the total cocoa purchased comes from fair-trade sources, 20% of a company's chocolate bars made with that mix of cocoa can include the fair-trade certified label.	Material from different mines (and certified and non-certified goods) can be mixed. Traceability information is lost.
Book and Claim	Allows all actors of a supply chain to trade in certificates for certified sustainable materials. Buying certificates allows retailers and manufacturers to claim that their business supports the production of sustainable materials. Claims of 'this product supports the sustainable sourcing and production of essential commodities' can be made.	Low	Reasonable	Companies wishing to make sustainability claims can purchase certificates (even though their goods may not be certified) that support sustainable production.	A synthetic diamond manufacturer may buy credits and contribute to sustainable mining activities.

continue to follow the piece as it is resold and recycled. Although the present consensus is that such a model is not feasible for the entire industry, research shows that many consumers want to know specific information about the origin of, for example, the cultured pearls they purchase (Nash et al., 2016). An integral part of this is marking or tagging—enabling an item to be uniquely tracked—so that it can be linked to the corresponding chain-of-custody document trail. Ultimately, combined approaches are necessary: solely marking a stone or a cultured pearl does not guarantee claims that are made about it; it must be uniquely identifiable in addition to having a chain of custody.

Laser inscription of diamonds has been offered for several years, whereby a logo or a report number is inscribed on the girdle of a stone after cutting. This is done by some natural diamond sellers (e.g. Forevermark) and synthetic diamond manufacturers to document the provenance of such products (Eaton-Magaña and Shigley, 2016). The inscription of a QR (quick response) code can link to further information about a stone that is accessible to consumers (Figure 3). The drawback associated with physically marking gems is linked to the fact that they are processed from rough to cut and thus initial surface markings would disappear. Furthermore, polished gemstones can be re-cut and such markings can be lost or fraudulently used or modified. In cultured pearls, tagging/marking techniques have ranged from inserting radio-frequency identification chips into composite nuclei (i.e. used in beaded cultured pearl production), chemically marking them via their inherent porosity (e.g. with fluorine) or trialling hologram surface markings (Hänni and Cartier, 2013; Segura, 2015). Most recently, in 2017, an 'Emerald Paternity Test' was developed that involves introducing unique synthetic DNA-based, nano-sized particles that can store specific information (e.g. mine location or mining period), which can later be retrieved and decoded in a laboratory (Branstrator, 2018). Clearly, there is no single solution or approach to providing traceability in the gem industry.

Know Your Source: Due Diligence, Chain of Custody and CSR

Several factors have spurred the jewellery industry to increasingly document its supply chains, including globalisation, greater reporting to shareholders by major groups due to 'conflict mineral' legislation, the need to reduce risk in order to secure financing, and pressure from the media and non-governmental organisations on issues such as 'blood diamonds' or 'dirty gold' (Bloomfield, 2017). It is widely argued that through increased transparency and knowledge of its supply chain, a company can better manage its risks and identify business opportunities (Carter and Rogers, 2008). In this context, chain of custody, a widely used concept in supply chain management, has become a pillar of reporting and verification in the industry (see Table II for various examples). The creation of the Responsible Jewellery Council (RJC) in 2005 further reinforced this trend with its strong focus on chain of custody to track and validate codes of practices by stakeholders (Solomon and Nicholls, 2010). To exemplify this trend further, Signet, a major American retail group, introduced its D-SRSP initiative in 2016 that vendors must adhere to if they want to be suppliers to Signet Jewelers (Bates, 2016).

The Organisation for Economic Cooperation and Development (OECD) recently developed the guidelines followed by companies seeking to respect human rights and avoid contributing to conflict through their mineral sourcing decisions and practices; these guidelines now

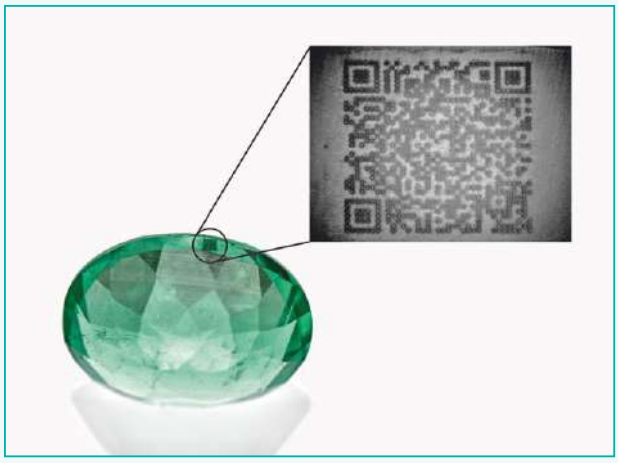

Figure 3: A tiny QR code can be inscribed on a gemstone during chemical analysis with GemTOF instrumentation (Wang and Krzemnicki, 2016). The QR code shown here measures 500 × 500 µm and has been inscribed on the girdle of an emerald weighing 2.5 ct. The material ablated during the inscription of the code is used to measure trace-element concentrations that are evaluated for determining country of origin. The code can be read (after magnification) using a QR reader on a smartphone, and gives the user access to various types of information on the stone. Composite photo by H. A. O. Wang and V. Lanzafame, SSEF.

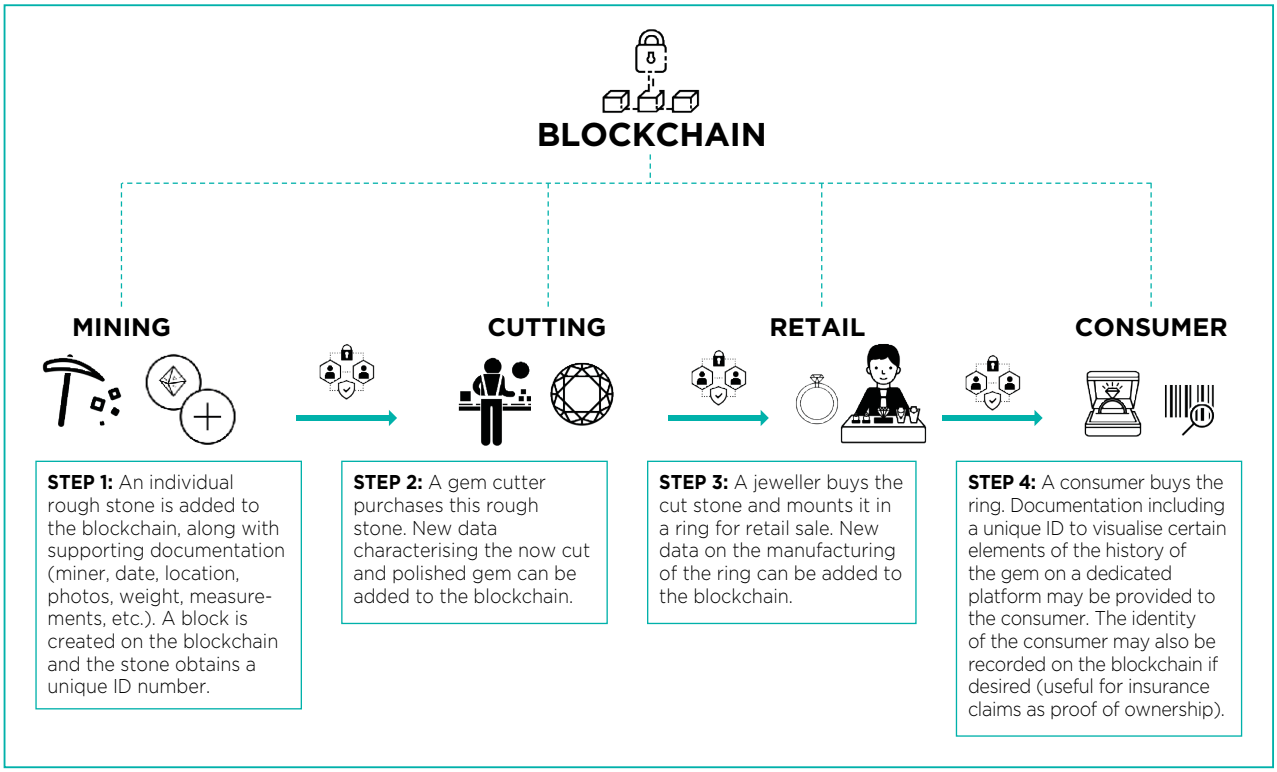

Figure 4: This generalised example of a blockchain serves to illustrate how information can be documented on a single gem's journey from mining to cutting and onward to retail and eventually the end consumer. After the stone is mined, the trade and transfer of ownership are validated at each step by both parties involved and recorded immutably to the blockchain. Illustration by L. E. Cartier.

apply to all minerals (OECD, 2016). Lombe et al. (2015, p. 15) in turn outlined due diligence and chain of custody in the following terms:

> Firstly, social and environmental risks are typically a product of an operator's behavior or environment, so knowing who has handled the material and where is an integral part of risk assessment and management. Secondly, tracking and traceability provide evidence to a company or auditor that a claim being made about a mineral (e.g. country of origin, sustainability dimensions, conflict free, etc.) is in fact true.

Traceability concerns and solutions are, thus, a natural, complementary extension to due diligence and chain of custody, depending on the context.

Blockchain Revolution: How Can It Be Applied to Gems?

Blockchain is a digitally distributed ledger technology that can support chain of custody through a system that makes documentation tamper-proof and, potentially, provides new opportunities for traceability in the highly complex and fragmented sectors of diamonds, coloured stones and pearls (e.g. Figure 4). Data added to the blockchain (e.g. by mobile phone, tablet or computer) at each recorded transaction step are verified, ownership is attributed, and the information is time stamped, encrypted, and stored permanently in a distributed and decentralised manner, providing an immutable record that is formed of a single, yet shared, source of information about a gem's journey from source to end consumer. As such, blockchain can be used to document the origin and path of a gem from mine to market, as well as verify ownership (and potentially possession, e.g. when a gem is out on memo). Blockchain technology has particularly grabbed the attention of the art world as a way to authenticate artwork back to its artist, and to record ownership and authenticity of artwork along a permanent and potentially anonymised chain of custody (O'Neill, 2018).

In blockchain, there are four types of ledgers: traditional (centralised), permissioned private, permissioned public and distributed permissionless public (Jeppsson and Olsson, 2017). A permissioned blockchain is a shared database that requires users to obtain permission before reading or writing to the chain. In permissionless blockchains, anyone can join. The rules in a blockchain are defined by the users, who can be either a private consortium (e.g. TrustChain) or public users. These rules are enforced as 'smart contracts' by computer software. Any computer that connects to the blockchain is called a node. The energy consumption of blockchain networks (documented to be very high in public ones such as

Figure 5: (a) Artisanal diamond miners sift gravels on the Sewa River in Sierra Leone. **(b)** A mixed parcel of rough diamonds from Sierra Leone was produced by such diggers. Programmes such as the GemFair initiative aim to bring certified responsibly produced artisanal diamonds to market, and complement this with blockchain to document the path of the diamonds. Photos by L. E. Cartier.

bitcoin using proof-of-work protocols; see O'Dwyer and Malone, 2014; Orcutt, 2017) must be taken into consideration when deciding what kind of ledger is selected and how it is managed and organised.

A so-called smart contract is software stored in a blockchain that automatically moves digital assets between accounts if pre-required conditions (collaboratively defined by the blockchain's users) are met, and it cannot be unilaterally changed (Iansiti and Lakhani, 2017). Smart contracts are being increasingly explored as solutions for ownership authentication and automatic validation of trades (Kim and Laskowski, 2018). They can potentially provide a huge gain in efficiency (especially with regards to demonstrating compliance and know-your-customer procedures), and they are one of the main reasons why blockchain is being widely investigated as a means of traceability and in logistics (Shrier et al., 2016). Depending on the type of blockchain, users may have transparent insight into the business rules by which the transactions are completed. Therefore blockchain can provide transparency to the regulators and other users who require it, while still providing the privacy and the specific views into the ledger that are relevant for each different type of user. This is an important factor for the gem and jewellery industry, which demands verified, but often anonymised, chain-of-custody solutions.

Blockchain is especially suitable for complex industries (Jansson and Peterson, 2017), and different variations of blockchain have been proposed for diamonds (Abeyratne and Monfared, 2016; Wall, 2016), diamond trading ('Singapore Diamond Investment Exchange…', 2017), jewellery (Irrera, 2018), art (O'Neill, 2018), coloured stones (Branstrator, 2018), minerals (RCS Global, 2017) and many other luxury products (Meraviglia, 2018). The Kimberley Process Certification Scheme has investigated blockchain as a solution for its system of warranties (Sulayem, 2016). The company Everledger recently developed the Diamond Time-Lapse Protocol ('Everledger announces…', 2018) to highlight the individual journey of a diamond that can be followed by a consumer through a smartphone application.

However, a blockchain is only as strong as the data supplied, because blockchain only verifies the data and not the event itself. Therefore, it does not replace robust standards in the supply chain (requiring external validation of data and production practices along with audits). However, it has the strong potential to reinforce claims by providing an immutable record of a product's history that can be verified (through the blockchain), and these data are secured using cryptography. A range of properties and information can be recorded in the blockchain, including: weight, quantity, photos, videos, certification/audits, reports, mine of origin, ownership at each step of the supply chain, workers who handle the material at each step, grade, and other factors. Blockchain clearly has enormous potential in the gem and jewellery industry, but more research is required to understand how the efficiency and transparency it can provide can best be put to use, and whether industry-wide consensus is possible or necessary. Further research is also required to understand how all levels of the supply chain (including artisanal miners) can benefit from traceability opportunities that blockchain technology could provide.

The recent launch of De Beers' GemFair programme with the Diamond Development Initiative (Sanderson, 2018) provides insight into how some key characteristics can be recorded in a blockchain. The programme involves a highly localised partnership with civil society groups in areas of artisanal and small-scale mining (Figure 5),

with photographic evidence and verification mechanisms at the digging pit itself. De Beers is also investing heavily in developing a blockchain platform for tracking its diamonds more broadly, and in due course plans to link that platform with GemFair (Sanderson, 2018).

OUTLOOK—WHAT'S NEXT?

The informal and highly fragmented nature of some parts of the gem industry makes full transparency a complex and challenging undertaking. Sorting and aggregation steps in supply chains—in which goods may be sorted in terms of quality rather than origin—may further complicate this endeavour (see Figures 6 and 7). Regulatory requirements and consumer demands for supply chain integrity and knowledge of provenance will push the industry to find solutions. Due diligence and chain-of-custody requirements will continue to grow and, as such, all levels of the trade will need to find solutions to address these traceability and transparency challenges. This may also provide newfound opportunities if, for example, synthetics and treated stones can be separated more clearly from natural/untreated material in the supply chain based on traceability information to verify the ownership and authenticity of gem materials at all stages.

Technological solutions such as blockchain and various tagging methods will become increasingly important as complementary responses to improve chain of custody and provide increased transparency in the supply chain. Blockchain and other tracking methods can also provide much more data and information that are increasingly important to consumers and regulators. Importantly, gemmological science can continue to provide much-needed assistance regarding claims of origin (geographical and whether a gem is natural or synthetic) and whether or not a gem has been treated. A gem's inclusions and their location within the stone can be used to help verify its identity, as well as provide gemmological data that can later be compared to existing chain-of-custody information. The current focus on full mine-to-market traceability may not be as realistic as it has been shown for other sectors, nor may the market necessarily want or require it. For example, rather than focussing all efforts on uniquely tracking a stone from its individual mine, tracing gem materials from specific regions that can be verified through gemmological means may prove to be an alternative and complimentary model (Cartier, 2017).

Country-of-origin determination is not a stand-alone traceability solution, but it offers independent verification of claims made about a gem's locality. This model has also been explored for tin, tungsten and tantalum (coltan) supply chains via the analytical fingerprint method (Schütte et al., 2018). Gemmology can complement and supplement the claims and documentation made by more standard traceability approaches that are inspired from other industries. The informal and highly fragmented nature of the coloured stone industry is likely to place stronger reliance on innovations in traceability rather than common tracking techniques that are more feasible for gold, diamonds and other commodities.

Figure 6: At a processing facility in Hunan, China, freshwater cultured pearls are aggregated from different farms and sorted according to various characteristics. Such processing on the basis of quality rather than source poses a challenge for traceability. Photo by L. E. Cartier.

Figure 7: At an amethyst-cutting workshop in Jaipur, India, rough material is generally purchased and sorted by size and quality rather than according to specific sources. The cutting and polishing of gems is an under-researched bottleneck for traceability. Photo by L. E. Cartier.

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Figure 1: These cabochons (up to 40 mm long) and rough pieces of Bumble Bee Stone (BBS) were produced in 2017. The samples are more orange than previously mined material that contained yellow areas. Photo by J. Ivey.

Bumble Bee Stone: A Bright Yellow-to-Orange and Black Patterned Gem from West Java, Indonesia

Emmanuel Fritsch and Joel Ivey

ABSTRACT: Bumble Bee Stone (BBS) is a bright yellow-to-orange and black patterned gem material. Although sometimes referred to as a jasper, it is actually a carbonate-rich rock rather than a silica-based gem. It is mined from sulphide-bearing veins near an active volcano in West Java, Indonesia. Its most remarkable characteristic is its bright yellow colour, which is caused by the presence of an unexpected sulfide, pararealgar. The orange colour in some samples consists of a mixture of pararealgar with realgar. Both minerals are polymorphs of As_4S_4, arsenic sulphide. Areas of black colouration are due to aggregates of micron-sized pyrite crystals ('sooty' pyrite). The successive growth layers, when cut through in different orientations, give rise to a variety of attractive patterns. BBS has been mined for the past 15 years, and new veins are still occasionally found.

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Figure 2: The three polished specimens of BBS on the left (12–26 cm long) show spectacular orbicular (also called 'bull's-eye') patterns with a strong colour contrast. The typical bull's-eye pattern ranges from 10 to 14 mm in diameter, but may be much larger (see Figure DD-1 in *The Journal*'s online Data Depository). Such pieces are derived by cutting across botryoidal areas such as shown by the BBS slab on the right. The colourless calcite crystals (up to ~3 cm long) induce the botryoidal structure in the overlying sulphide-bearing layers. Photos by J. Ivey.

An attractive, generally opaque stone patterned in bright yellow-to-orange and black has been mined in Indonesia since 2003. It has been difficult for vendors to agree on a name for this unique material, and examples include Bumble Bee Stone (hereafter abbreviated BBS), 'Bumble Bee Jasper', 'Mustard Jasper' and 'Eclipse Jasper' (e.g. Overlin, 2014; Figures 1 and 2). Its main attraction is its saturated yellow-to-orange colour, as well as the striking contrast formed by black bands in the material. Other colours may be present, such as grey to near-white or near-colourless. Some pieces show a desaturated greyish yellow colour that is reminiscent of some mustards, hence the 'Mustard Jasper' appellation (Figure 3).

The term *jasper* was identified as a misnomer early on, as the material is a carbonate-rich rock (Serras Hermann, 2013). Bumble Bee Stone is easy to fashion, as its Mohs hardness is 5 or below (Overlin, 2014). The bright yellow-to-orange colouration is said to come from orpiment and realgar, which are both arsenic sulphides (raising the question about possible toxicity of the dust produced during fashioning), while the black layers are reportedly manganese rich (Serras Hermann, 2013).

Very few such opaque bright yellow-to-orange gem materials are known, with the possible exception of the little known Forcherite, a bright yellow variety of opal from Austria (Bojar and Taucher, 1994). In addition, opaque crusts of bright yellow opal are known from the town of Saint Nectaire in central France (Gaillou, 2006). Also, some unusual agates displaying yellow-to-orange and grey to near-colourless layers have been found in Xuanhau, Hebei Province, China (Meng et al., 2016).

In addition to its colouration, another interesting aspect of BBS is its range of patterns. Pieces with irregular striping are possibly the easiest to find on the market, whereas homogeneous yellow cabochons are quite rare. An orbicular variety is the most sought after, obtained by slicing across botryoidal concretions (Figure 2). Other eye-catching landscape and human-like patterns can be obtained by cutting the material at different angles. Some rare pieces may look like a volcano, which is reminiscent of the volcanic origin of this gem (see cover image of this issue).

Figure 3: These cabochons show various textures and colours, with typical 'Mustard Jasper' corresponding to the yellowish grey pieces. The orange piece in the centre is sample no. 1877, measuring 20 × 19 × 4 mm. Photo by Olivier Segura.

Figure 4: Eddie, a cutter at the CV Anugrah Alam workshop in Sukabumi, admires a 12.7 cm sphere of BBS he just fashioned (left). The bangle on the right was carved from a single piece of BBS. Photos by J. Ivey.

As it is opaque, BBS is mostly fashioned as cabochons, plaques or polished blocks for decoration. The cabochons are flat, and are often oval but also free-form. They typically measure a few centimetres across. Many have been cut into matched pairs extracted from the same piece of rough. Recently, several spheres have been fashioned, and even a hololith bangle was made from BBS (Figure 4).

This article reports on the location, geology and gemmological properties of BBS, focusing on the cause of its extraordinary colouration.

LOCATION

The mining area for BBS is situated on the lower slopes of an active volcano, Mt Ciremai (or Cereme), which is located about 25 km south-west of the coastal town of Cirebon in West Java (Figure 5). The diggings are located a few kilometres south of the resort town of Kuningan and about 20 km from the volcano's summit. Its eruptions are not frequent, but they have produced dangerous explosions and lahars. The summit area is

Figure 5: The BBS deposit is located at the base of Mt Ciremai, an active volcano, in the vicinity of Kuningan, West Java, Indonesia.

Figure 6: (a) Peak extraction of BBS occurred over a six-month period in mid-2011 with a rented excavator. Here, on the opposite side of the muddy pool, the flat, smooth, grey surface represents the outside surface of the vein. **(b)** Mt Ciremai, seen here, is an active stratovolcano where the world's only known deposit of BBS is found. **(c)** The BBS vein consists of layers of bright yellow sulphides and black areas coloured by sooty pyrite. Photos by J. Ivey.

formed by a caldera about 1 km in diameter. It is the highest peak in West Java, culminating at 3,078 m. The area is covered by the small Mount Ciremai National Park (Taman Nasional Gunung Ciremai; 155 km^2). The volcano may be climbed by hikers, but care is required.

HISTORY AND PRODUCTION

Some pieces of BBS initially appeared on the Jakarta market in 2003. The first rough material seen by one of the authors (JI) around 2005 was likely obtained close to the surface. It was a flat wedge with alternating bands of dusty yellow and dark grey (see Figure DD-2 in the online data depository on *The Journal*'s website). These bands were narrow (3–5 mm) and relatively straight. Although the name 'Bumble Bee' came immediately to mind, the colour contrast was not as striking as the deeper-mined material seen on the market today. A 50 kg sample brought to the gem shows in Tucson, Arizona, USA in 2005 was enthusiastically greeted by buyers, and was sold as 'Bumble Bee Jasper'. This was considered a good commercial name, even though many wholesalers were aware the gem was not silica-based. Unfortunately the material proved to be too soft for fashioning, and demand waned for pieces mined near the surface. In Indonesia, initial enthusiasm spurred the locals to dig up a large pile of the BBS, and it was sold in nearby towns and stone markets in Jakarta, and even exported to Bali. An American dealer (Zee Haag of Tucson, Arizona) bought up the villagers' stockpile and tried re-introducing it as 'Eclipse Jasper' around 2008. Around that time, gem dealer Paul Ingram in Bali marketed BBS in his customer newsletter as 'Mustard Jasper'.

In October 2010, locals started hand digging a small vein that ran across a hilltop in the area. Of the approximately 2 tonnes of material that was produced, 500 kg was brighter and showed higher contrast and more colourful patterns than the original surface rough. At that time, it was estimated that about 10 tonnes of BBS could be recovered from the deposit.

In May 2011, the landowner subcontracted an excavator from a road crew. In several months, they opened up access to one of the larger veins of BBS by removing the wall rock from one side to a depth of ~15 m (Figure 6a).

Figure 7: BBS rough material is washed and sorted (top). The largest piece of BBS to date was extracted in 2011 and weighed 222 kg (bottom). Photos by J. Ivey.

It appeared that as mining progressed deeper, the material became harder and showed more attractive patterns. The pyroclastic wall rock (andesitic tuff) was carefully chiselled off as much as possible. Consisting of 70%–80% lapidary material, 6 tonnes of BBS were collected from 2011 to 2013 (e.g. Figure 7). Container loads of lower-grade material were purchased by Korean and Taiwanese stone brokers.

In 2013, several large blocks containing narrow BBS veins were mined. They were interesting as specimens, but most of them were too fragile to process into lapidary rough. Some were sent to Bali to polish into free-form pieces like those in Figure 2. This material spurred local dealers to visit the mining area and buy the remaining stockpile of more than 110 tonnes of rough, which was shipped to Bali, and then onward to Hong Kong, Australia and the USA.

In the past few years only hand digging has taken place, but several new veins have been discovered across the hill, and mining still continues as of this writing. Although production varies according to season (greater in the dry period than in the rainy season from November to March), currently up to ~500 kg/month is being mined, of which about 30% is BBS vein material. The estimated total amount of rough BBS produced so far exceeds 500 tonnes. This includes a considerable amount of volcanic wall rock, and we estimate that the actual amount of lapidary material is about 150 tonnes.

There are several local workshops in the Sukabumi area of West Java that cut and polish BBS as their main product. This material is still very common on the local gem market and in tourist shops around Indonesia. Much BBS is actively traded on Instagram and Facebook by young locals. Indonesians highly value domestic gem materials, and they are often willing to pay more than buyers elsewhere.

LOCAL GEOLOGY

BBS formed within a solfatara (a fumarole that vents gases rich in sulphur) occurring in close proximity to the Mt Ciremai volcano (Figure 6b). This type of vent is common near active stratovolcanoes, and results from the heating of circulating groundwaters containing various elements or compounds extracted from the volcanic system—in this case iron, sulphur, calcium carbonate and arsenic. Such a system produces abundant 'sooty' pyrite, consisting of very small crystals of the iron sulphide, crystallising rapidly near the surface, which looks like black soot. As the gases escape the solfatara, minerals are deposited as more-or-less regular bands in fractures within the volcanic rock, which is here comprised of fine-bedded volcanic ash and intercalated pyroclastic tuff (an accumulation of volcanic ejecta of varied size). The veins are near vertical, with individual colour bands rarely exceeding 5 cm (e.g. Figure 6c). The tuffaceous wall rock contains marcasite, an iron sulphide that is unstable when exposed to air and moisture. After about 1–2 weeks in this environment, the breakdown of marcasite facilitates the separation of BBS vein material from its volcanic host rock.

BBS is thus not formed from 'a mixture of Indonesian volcano lava and sediment' (Overlin, 2014), but is the indirect result of volcanic activity.

MATERIALS AND METHODS

We analysed eight cabochons ranging from 9.48 to 96.90 ct, representing typical colours of BBS. The specimens were acquired on the open market: Nos. 1877–1882 were sold with others (Figure 3) as a necklace by Marcus McCallum, London; others were purchased at the Tucson gem shows or in Bangkok, Thailand. The samples used in this study are listed in Table I and illustrated in Figure 8.

Figure 8: BBS samples used for this study are shown here. From left to right and top to bottom: nos. 1591, 1877–1882 and 2396; see Table I for weights and dimensions. Photo by Philippe Deuxgniards.

Observations were undertaken using a Leica MZ6 binocular microscope with Nossigem gemmological observation attachments. SG values were measured with a calibrated Mettler Toledo XS104 electronic scale. Fluorescence was tested with a Vilber Lourmat UV lamp with a power of 6 W per tube emitting long-wave (365 nm) or short-wave (254 nm) radiation, with the stone being placed 7 cm from the lamp.

Visible-range absorption spectra were obtained using a PerkinElmer Lambda 1050 spectrometer in the range of 400–800 nm with a spectral bandwidth of 1 nm for a sampling of 1 nm. The spectra were obtained in reflectance mode on an accessory using a 150 mm integrating sphere with an InGaAs detector. Raman spectra were obtained using a Bruker MultiRAM Fourier-transform Raman spectrometer, with a 1064 nm Nd:YAG laser at a maximum power of 2 W. The spectral resolution was set at 4 cm^{-1}.

Observations and micro-chemical analyses were conducted with a JEOL 7600F scanning electron microscope equipped with an energy-dispersive spectrometer. Two additional BBS samples (not listed in Table I) were sacrificed for this analysis, as they needed to be metallised with platinum and the coating cannot be completely removed.

Table I: BBS samples and methods used for this report.

Sample number	Main colour(s)	Weight (ct)	Dimensions (mm)	Tests/Analyses
1591	Yellow and black	96.90	40.0 × 31.0 × 10.6	SG, microscopy, and Raman and visible-range spectroscopy
1877	Orange	9.48	20.0 × 19.0 × 4.0	SG, microscopy, and Raman and visible-range spectroscopy
1878	Yellow	11.29	19.0 × 13.0 × 5.2	SG, microscopy and Raman spectroscopy
1879	Black and yellow	10.62	19.0 × 13.0 × 5.0	SG, microscopy, and Raman and visible-range spectroscopy
1880	'Mustard'	10.61	19.0 × 14.0 × 5.5	SG, microscopy, and Raman and visible-range spectroscopy
1881	Yellow and orange	10.22	18.0 × 13.0 × 5.2	SG and visible-range spectroscopy
1882	Orange and black	11.22	20.0 × 13.0 × 5.2	SG and visible-range spectroscopy
2396	Yellow	50.36	40.0 × 30.0 × 5.3	Microscopy and Raman spectroscopy

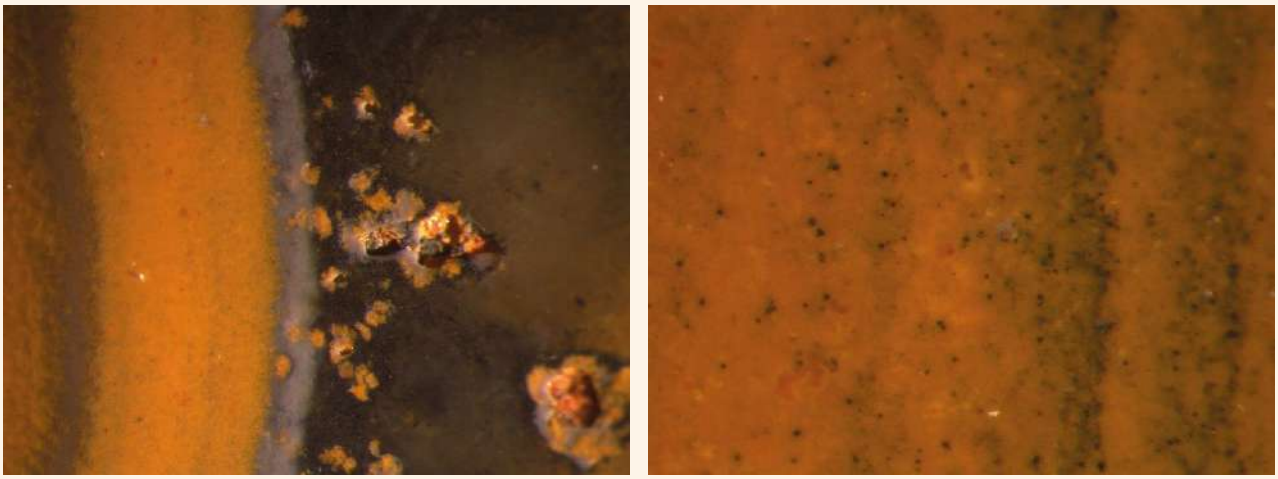

Figure 9: The pulverulent appearance of the colour banding in BBS is shown here under magnification in sample no. 1591. Left: Yellow-to-orange pigment is disseminated within the carbonate matrix, forming colour bands, within which micro-geodes are found. Right: The black pigment forms minute discs that are resolvable only at higher magnification. Photomicrographs by E. Fritsch; image width 3 mm (left) and 6 mm (right).

RESULTS

Refractive index values were difficult to measure because of the material's porosity. Some attempts were made to obtain a spot measurement, but the results were so variable that we decided not to use them. Specific gravity varied between 2.42 and 2.74; the average of seven measurements was 2.57. When exposed to the UV lamp, part of each sample (corresponding to transparent colourless areas) emitted some yellow fluorescence, while other parts remained inert; the yellow luminescence was slightly stronger in long-wave UV.

Bubbles appeared when a drop of diluted hydrochloric acid was placed on the surface, confirming that this material is carbonate rich. Therefore, it is not jasper, which is an opaque form of microcrystalline quartz.

Magnification

As the material is almost completely opaque, it does not show inclusions *per se*. However, when examined with the binocular microscope, the appearance was that of coloured powders cemented in the carbonate matrix (Figure 9). The black-appearing areas were due to the presence of many black dots; the larger ones formed discs (Figure 9, right). Small cavities were actually micro-geodes; many contained very small crystals that were orange or tended towards red. The overall colour of the samples varied according to the proportion and overall abundance of yellow, orange and black pigments in an otherwise colourless (transparent) or white (opaque) matrix.

Visible-range Absorption Spectroscopy

The visible-range reflectance spectra of all colours of BBS, except black, had an overall sigmoid shape (Figure 10). In general, the point of inversion of such a pattern marks the 'absorption edge' of a particular pigment. The steeper the slope at this point, the more saturated the colour. The higher the maximum of reflectance, the more luminous the colour appears, as more light is reflected towards the eye. In addition, the higher the step, the brighter the colour (more light participates in the perception of the colour).

In BBS, the absorption edge was at ~530 nm for the yellow areas. Thus, the colour perceived is a combination of all wavelengths above 530 nm (green), which is observed as yellow. The maximum reflectance was over 80% and the edge was roughly 50% high, although there were slight variations in the position of the absorption edge and in the slope at the inversion point within the bright yellow samples. The edge shifted towards 550 nm in the orange areas (again, see Figure 10), as is logical (less yellow equates to more red), still with a fairly high step of about 40% reflectance.

Black areas provided a nearly flat spectrum at about 35% reflectance, which is low (and subsequently, dark). 'Mustard' samples showed a maximum reflectance of about 50% and an edge height of approximately 15%. Both of these values are much lower than for the bright yellow areas, corresponding to the less saturated and luminous appearance of the 'mustard' samples.

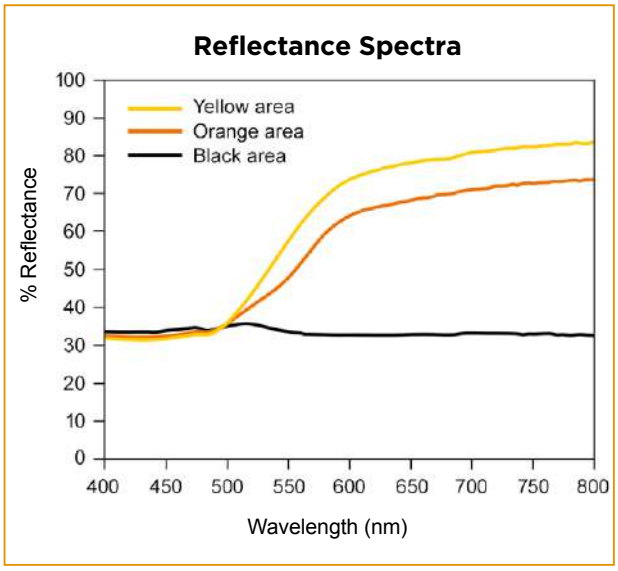

Figure 10: Visible-range reflectance spectra are shown for various coloured areas of BBS. The yellow regions have an absorption edge at ~530 nm, which is shifted towards 550 nm in the orange areas. The black portions show a nearly flat spectrum.

Raman Spectroscopy

The Raman spectra of all analysed samples of BBS consistently presented bands for calcite at about 285 and 160 cm^{-1} (Figure 11), indicating calcite as the major carbonate mineral present in this material. We obtained aragonite bands in only one part of one orange sample. Accordingly, we contend that calcite is the near-colourless transparent to white opaque matrix material seen in many pieces.

In 'mustard'-to-yellow parts of BBS, additional major bands were recorded at about 346, 284, 233 and 157 cm^{-1} (Figure 11). They correspond to pararealgar, which has the formula As_4S_4. It is a bright yellow monoclinic polymorph of realgar, a more common and better-known red arsenic sulphide, which is also monoclinic but with a different class of symmetry.

The Raman spectrum of realgar dominated the bright orange areas (Figure 11) and the reddish crystals in the micro-geodes mentioned above, with main peaks at approximately 355, 221, 194 and 184 cm^{-1}. It had a much higher Raman scattering intensity than pararealgar, thus it dominated the spectrum of a mixture of both polymorphs. As such, the orange areas appeared to be a mixture of pararealgar and realgar. The signal for orpiment, As_2S_3, previously reported as one of the BBS pigments, was looked for but not found.

In the black areas, a small Raman signal appeared at about 378 cm^{-1}. It was clearly not related to the calcite matrix. The closest signal we could find is pyrite, FeS_2, which has a strong doublet at 385 and 355 cm^{-1}. If one broadens the doublet significantly, it would give a single peak at about 378 cm^{-1}. This signal is difficult to attribute to manganese oxides, previously deemed as the possible origin of the black colour, as this class of black minerals has its most intense Raman bands at positions very different from 378 cm^{-1}.

Scanning Electron Microscopy and Microanalysis

Two pieces of BBS were mounted for this technique, and yellow, orange, and near-colourless areas were marked for observation and microanalysis, as well as the black disc-like particles. The nearly ubiquitous presence of Ca confirmed that the material is mostly calcite, although the consistent presence of a small Mg peak suggested it was a slightly magnesian calcite.

Yellow-to-orange areas were rich in S and As. The As-bearing particles, which were easy to recognise in backscattered electron images because of their very light tone, were of irregular shape and measured ~1–20 µm (see Figure DD-3 in *The Journal*'s online Data Depository). Because of their small or irregular nature and the abundance of calcite, no precise quantitative analysis could be performed, but various attempts were consistent with an overall composition of arsenic sulphide corresponding to the yellow-to-orange colouration. This supports the identification of pararealgar and realgar by Raman analysis.

Finally, the black discs were composed of circular aggregates with maximum diameters ranging from ~5 to 30 µm (Figure 12, left). They were composed

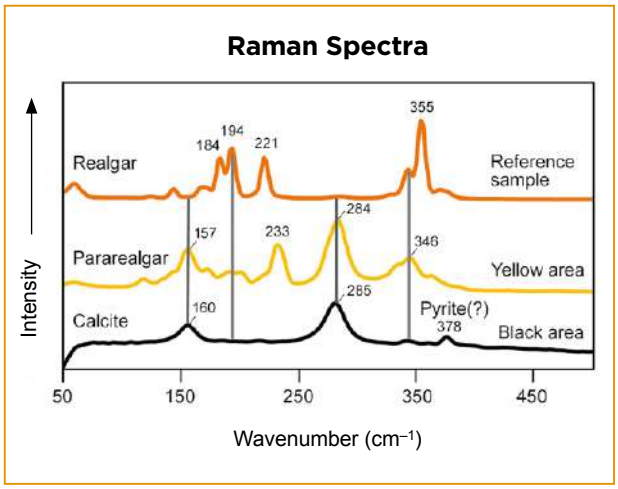

Figure 11: The Raman spectra of the BBS samples tested always showed peaks for calcite, with additional features corresponding to pararealgar and realgar in yellow and orange areas. The spectrum shown here for realgar is from a reference crystal, as no area of BBS we analysed consisted of pure realgar.

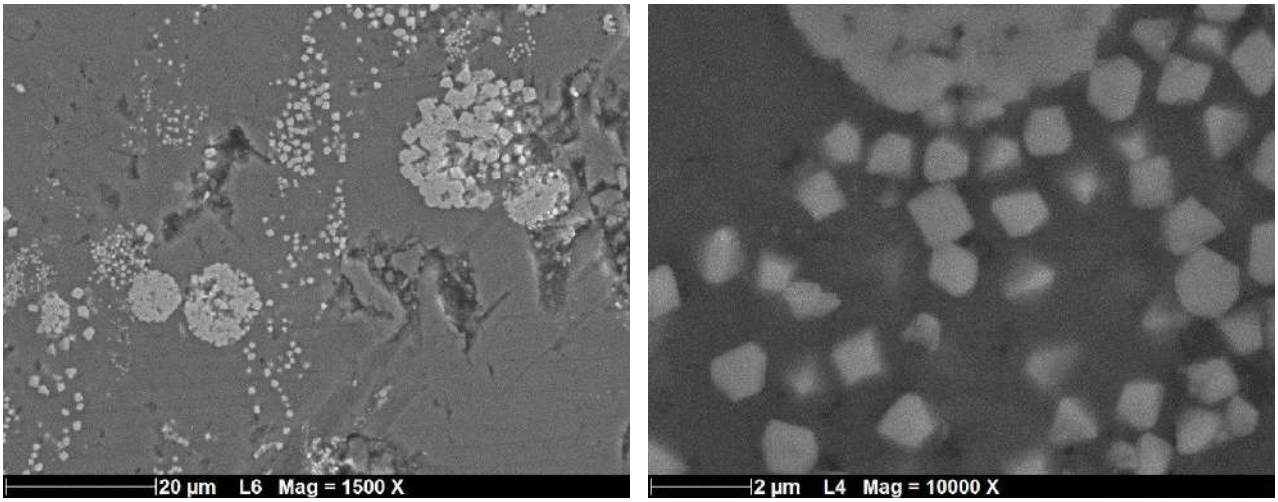

Figure 12: The black discs seen in the binocular microscope are actually aggregates of small pyrite crystals (left, light grey areas). The pyrite has a variety of micro-morphologies, ranging from cubic to octahedral (right). Micrographs by E. Fritsch.

of micrometre-sized crystals identified as pyrite. Curiously their morphology varied, from nearly cubic (square faces) to cubo-octahedral (pseudo-hexagonal faces) to octahedral (triangular faces), as illustrated in Figure 12-right. This is reminiscent of framboidal pyrite. The term *framboid* describes an aggregation of uniformly-sized particles of the same mineral, from the French *framboise* for raspberry, as this berry is composed of aggregated uniformly sized drupelets. Some additional micron-sized pyrite crystals were dispersed in the calcite matrix. The matrix was also commonly riddled with polishing marks, due to the low hardness of calcite, and many small pores were observed in all samples, confirming the micro-porosity noticed when using RI liquid.

DISCUSSION

BBS (Figure 13) is a type of carbonate-rich rock that is polycrystalline with a variety of minerals present, and therefore its measured properties can be quite variable. In addition, it is porous, with some pieces containing many vacuoles (see Figure DD-4 in *The Journal*'s online Data Depository), which further complicates RI and SG measurements. This explains why the hydrostatic SG values obtained from most of our samples were below that of calcite (2.71), despite the presence of the sulphides that are denser (realgar having an SG of 3.59). The yellow luminescence was observed only in the calcite areas of the samples. Although yellow is not a common luminescence colour for calcite, further research into this is beyond the scope of the present study.

The main attraction of BBS is its bright yellow -to-orange colour, caused by the presence of pararealgar ± realgar. The yellow colour is similar to that of orpiment, an arsenic sulphide, yet no trace of this mineral was found in Raman analyses of many yellow areas in our samples. This demonstrates the caution needed if determining the origin of colour on the basis of chemical composition alone, without confirmation by another type of spectroscopy (i.e. the Raman scattering performed here).

This is not the first time that pararealgar has been identified as the colouring agent in a gem material. Gaillou (2006) documented this pigment via Raman scattering in a little-known bright yellow opal from the area of Saint Nectaire in central France. Another bright yellow-to-orange opal, Forcherite, from Austria, is reportedly coloured by orpiment (on the basis of an X-ray diffraction analysis), but no Raman investigation was reported (Bojar and Taucher, 1994).

Yellow pararealgar is best known to be produced from red realgar in two different ways. First, through the action of light, in particular UV: in a well-known photo-induced phase transformation (Kyono, 2010), red realgar is slowly covered by a yellow dusting of pararealgar, a phenomenon feared by mineral museum curators. Second, this polymorph may be obtained by grinding (Gaillou, 2006). This is demonstrated in Figure 14, which shows how grinding a crystal of realgar in an agate mortar produced a yellow-orange powder. Its Raman signal was that of a mixture of pararealgar and realgar. As realgar is quite soft, it was difficult to crunch all the material into a fine powder, and in three experiments we consistently obtained a mixture of the two minerals as the final product. However, pararealgar in BBS formed as a primary product of the volcanic vent, and is unlikely to be the result of either transformation described above. (Note that any photo-induced phase transformation of realgar to pararealgar in the

Figure 13: A variety of BBS cabochons (30–50 mm long), including some matched pairs, display typical yellow-to-orange and black, grey and white colour contrast with crisp patterns. Photo by J. Ivey.

orange areas of BBS is expected to be minimal due to the small percentage of realgar present on the surface. In addition, no evidence of any instability due to this phase transition has been observed since BBS has been on the market.)

Regarding the presence of pyrite in black areas of BBS, it is not surprising that finely divided micrometric pyrite gives an overall black colour, rather than the golden yellow metallic colour that is commonly seen for macroscopic crystals of this iron sulphide. Commonly known as 'sooty' sulphides by miners, such material is black and composed of very small particles, reminiscent of soot. Framboidal pyrite, in particular, is associated with dark colour, often in the grey-to-black range (Wignall and Newton, 1998; Bond and Wignall, 2010; Wang et al., 2013). In addition, the micrometric size of the crystals might explain the broadening of the pyrite Raman doublet. (It is well known with Raman scattering that the more finely divided the material, the broader the band.) Furthermore, framboidal pyrite is often associated with

Figure 14: Grinding a red realgar crystal into powder produced a yellow-orange mixture of pararealgar and realgar. Photos by E. Fritsch.

amorphous iron sulfide, another factor which could explain a broader band. We could not find a published Raman spectrum of natural framboidal pyrite for comparison with our own. This unique variety of pyrite is found in many different environments that are strongly reducing (little oxygen available), and also in volcanic-associated massive sulphide deposits. This is somewhat consistent with what we know of the occurrence of BBS.

CONCLUSION

BBS is a carbonate-rich gem material with bright yellow-to-orange and black colour contrast, often in attractive patterns (e.g. Figure 13). It formed in a solfatara vent associated with an Indonesian volcano, as a rock that is dominated by slightly magnesian calcite coloured by sulphide pigments of pararealgar (yellow), realgar (giving an orange colour when mixed with pararealgar) and pyrite (producing black areas). Therefore, BBS belongs to a rare category of gems coloured by micro-inclusions of sulphide pigments, such as yellow opals from France and Austria, and myrickite, a bright orange-to-red silica-rich material coloured by cinnabar inclusions from various mercury deposits in California, USA (Wright, 1957). Considering the abundance of arsenic sulphides in BBS, lapidaries should wear protective gear to avoid toxicity of the dust produced during fashioning.

BBS is currently a single-source gem material, with no other deposit having been documented elsewhere. Production has been ongoing since 2003, yielding an estimated 150 tonnes of lapidary material. It is difficult to predict future production, due to the discontinuous nature of the veins and the traditional, labour-intensive methods of exploration and production. Although in 2013 it was thought the BBS deposit was exhausted, fortunately through hand trenching some additional discoveries of sub-parallel veins and extensions have been made, and mining is ongoing.

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Figure 1: The Ming cultured pearls in these strands display several circles (top, 11–14 mm wide) or only one or two circles (bottom, 13–15 mm wide). Photo by J.-P. Gauthier.

An Explanation of a Specific Type of Circling as Observed on Ming Cultured Pearls

Jean-Pierre Gauthier, Jacques Fereire and Thanh Nhan Bui

ABSTRACT: The name *Ming pearls* refers to gonad-grown Chinese freshwater cultured pearls. In these beaded cultured pearls, the nuclei are predrilled and a tissue graft is placed into the drill hole at the same time the bead is inserted into the mollusc. A large number of these cultured pearls exhibit circling on their surface, typically with one or two main rings and sometimes additional ones. Examination of sliced samples by optical microscopy highlights the primary origin of the circling and the predominant role of predrilling the nucleus. As the cultured pearl rotates during its formation, each orifice on the drilled bead induces a groove on its surface with a spot defect right over the opening. When this drill hole is perpendicular to the rotational axis of the cultured pearl, only one 'equatorial' ring is generated. When there is a fairly large tilt angle between the bead's drill hole and the rotational axis, two grooves appear symmetrically relative to the equatorial plane, diametrically opposite with respect to the nucleus centre. With only a slight tilt angle between the drill hole and the rotational axis, the circles nearly overlap and a narrow ridge might eventually develop between the grooves. The disturbance created by the drill hole is generally more pronounced on the side where the graft was inserted. Round-, drop- and baroque-shaped non-circled Ming cultured pearls were also investigated to clearly understand the influence of the nucleus drill hole. This research raises awareness of one of the major causes of defects that result from grafting techniques using drilled nuclei.

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Circling is a common surface feature on freshwater and saltwater cultured pearls (Ky et al., 2015a). Although this 'defect' is sometimes appreciated, it more often downgrades the value of the cultured pearls. In addition, the grooves that form the circling are often lined with brownish organic matter that further degrades their value. As a result, circling is of major concern to pearl farmers, and efforts have been made to reduce its frequency (Ito, 2009; Ky et al., 2014; Kishore and Southgate, 2015, 2016; Ky et al., 2015b,c).

The origin of such circling, however, has been little studied (Ito, 1996, 2011; Ogimura et al., 2012). Research on Polynesian black cultured pearls from *Pinctada margaritifera* has shown that, for this mollusc, the rings are related to surface defects resulting from the emergence of narrow holes that extend through the nacre layers to the bead nucleus (Gauthier et al., 2014; Cuif et al., 2018). However, the simple presence of spot defects is not sufficient to result in circling; there also must be rotation of the developing cultured pearl around a fixed axis. The rotation of bead nuclei inside the gonad was demonstrated conclusively by Gueguen et al. (2015).

This article sheds light on one of the likely prime causes of circling phenomena, using Ming cultured pearls as an example (e.g. Figures 1 and 2). Currently, this type of pearl is cultured in China and marketed under the names 'Ming' (Hänni, 2011) and 'Edison' (Laurs, 2012). The culturing process is actually of Japanese origin—having been practised in Lake Kasumigaura on hybrid varieties of the freshwater bivalves *Hyriopsis schlegeli* and *Hyriopsis cumingii* (Strack, 2011)—and consists of simultaneously introducing a bead and a tissue graft into the gonad of the pearl mussel. The implant location in freshwater molluscs is reportedly less accessible (Hänni, 2011) than in saltwater oysters (*P. margaritifera*, *P. maxima* and *P. martensii*). For this reason, the graft is partially recessed in a cylindrical cavity drilled into the bead, so the two elements, bead and graft, can be implanted in one single operation. The drill hole usually extends clear through the bead.

Following the layer-by-layer deposition of nacre, the harvested cultured pearls vary in shape—round, drop, button or baroque—but they often display coaxial rings or grooves. In such cases, the cultured pearls are then usually drilled perpendicular to the circling (i.e. parallel to the rotational axis). As for non-circled cultured pearls, the hole is drilled either partway through for mounting as a pendant or earrings, or all the way through for stringing on a necklace. This double drilling of bead and cultured pearl has been well illustrated by X-radiography of both Kasumiga (Hänni, 2000) and Ming (Hänni, 2011) cultured pearls (see also Karampelas, 2012).

MATERIALS AND METHODS

The affordability of Ming cultured pearls enabled us to acquire numerous (approximately 100) circled samples for possible destructive analyses in order to study their circling phenomena. Some of the purchased strands contained primarily multi-circled cultured pearls (e.g. Figure 1, top), while those in other strands had only one or two grooves (e.g. Figure 1, bottom). The latter constitute the main topic of this study. For comparison, we later acquired 26 non-circled Ming cultured pearls: eight drop-shaped (12–16 mm long), 15 round (11–15 mm in diameter) and three baroque (16–19 mm long). In addition, a non-beaded mantle-grown Chinese freshwater cultured pearl was also investigated to evaluate potential confusion with the beaded Ming products.

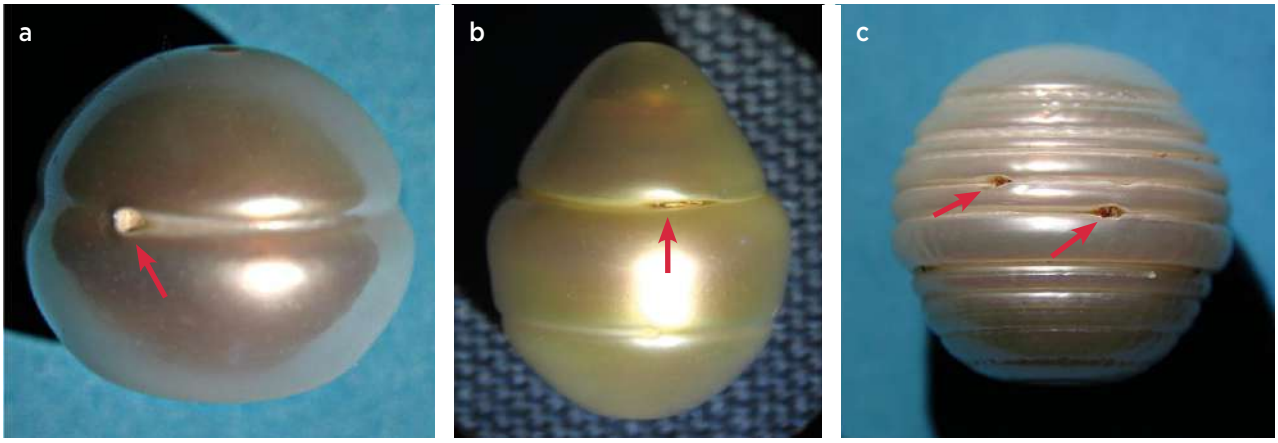

Figure 2: Shown here are three examples of circling on Ming cultured pearls with a rotational axis displaying **(a)** one ring, **(b)** two rings and **(c)** several rings. The arrows indicate spot defects in the grooves. From left to right, the cultured pearls are 10.5, 15.5 and 11.5 mm long. Photos by J.-P. Gauthier.

Preliminary observation of the circled samples with the unaided eye revealed characteristic defects in the grooves (Figure 2). To understand their origin, 34 cultured pearls were chosen for this study: 21 drop-shaped, five near-round and eight capsule-shaped. The 34 samples, ranging from 11 to 19 mm long, were sliced by author JF using a diamond saw. The cutting plane (Figure 3a) was always chosen near these defects so as to observe both (1) the defects and their extension within the cultured pearl, and (2) the profile of the surface shaped by the circling. The cultured pearls were cut in half or into thick slices, and the cut surfaces were then polished on an oiled aluminium disc charged with 3,000 mesh diamond powder.

The samples were examined and photographed with a Leica S8 APO binocular microscope equipped with a Canon PowerShot S70 digital camera. When possible, the thick slices were photographed in both transmitted illumination and between crossed polarisers to provide better contrast.

RESULTS

The 34 circled cultured pearls sliced for examination displayed evidence of a rotational axis, as indicated by the direction of circling. For the drop-shape samples (the most common shape we encountered), we refer here to the tapered side as the upper pole or 'apex', and the opposite, rounded side as the lower pole or 'base'. We classified the 34 samples into three categories, depending on the number of circles perpendicular to the rotational axis:

- One circular groove, in the equatorial plane (12 cultured pearls)
- Two circular grooves, symmetrical with respect to the equatorial plane (17 cultured pearls)
- Multiple circles (five cultured pearls)

Category 1: One Equatorial Circle

Figure 4 represents the typical case of a Ming cultured pearl with a single groove. The groove on such samples always appeared in the plane through the maximum diameter of the bead nucleus, perpendicular to the rotational axis, even if the groove appeared off-centre due to a sample's drop shape. For this condition, we use the term *equatorial groove*. We also observed that a single groove almost always contained two spot defects (Figures 4a and 4b), diametrically opposite and often large, although one of them was sometimes barely visible. These defects were often composed of cavities, but sometimes they were protrusions or bumps (red arrows in Figure 4).

In the slice shown in Figure 4c, it is apparent that the two diametrically opposed defects originated at the orifices of the hole drilled in the nucleus before the

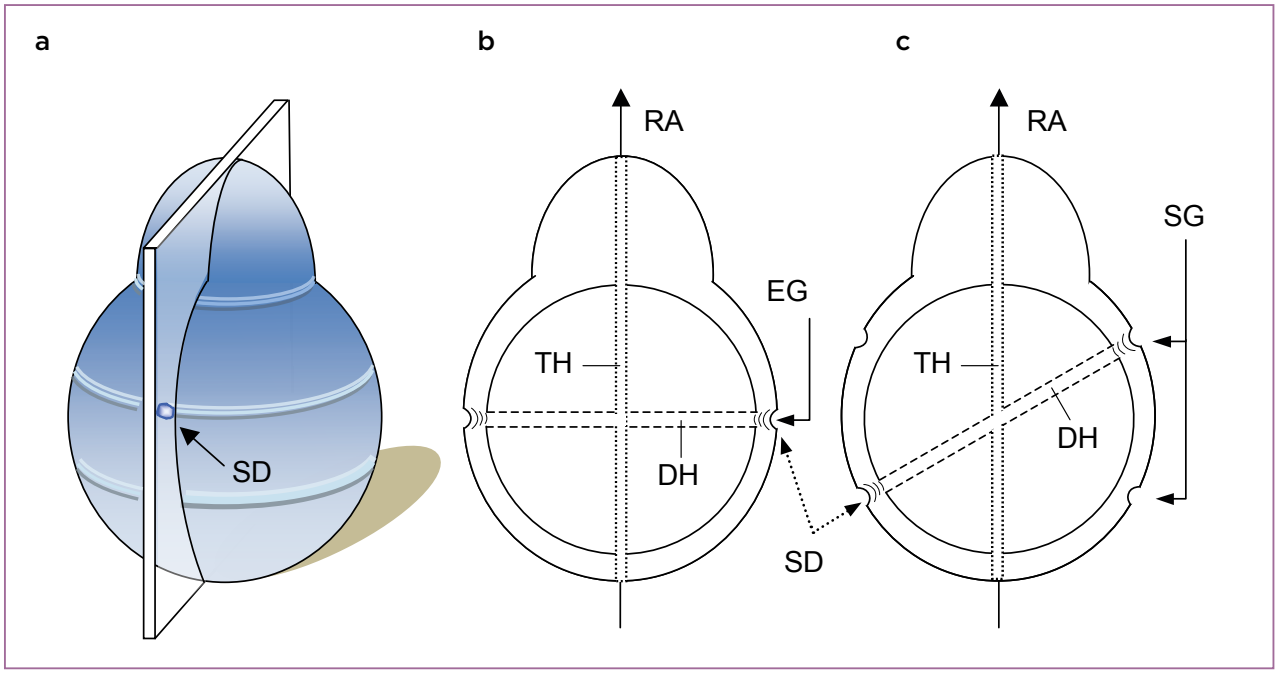

Figure 3: These sketches illustrate **(a)** a vertical slice through a circled Ming cultured pearl with spot defects (SD) visible on one circle; **(b)** a section showing a nucleus drill hole (DH) perpendicular to the rotational axis (RA), generating a single equatorial groove (EG); and **(c)** a section in which the drill hole through the nucleus is tilted with respect to the rotational axis of the cultured pearl, generating a pair of symmetrical grooves (SG). TH is the threading drill hole, which is usually, as shown here, oriented along the rotational axis. Drawing by J.-P. Gauthier.

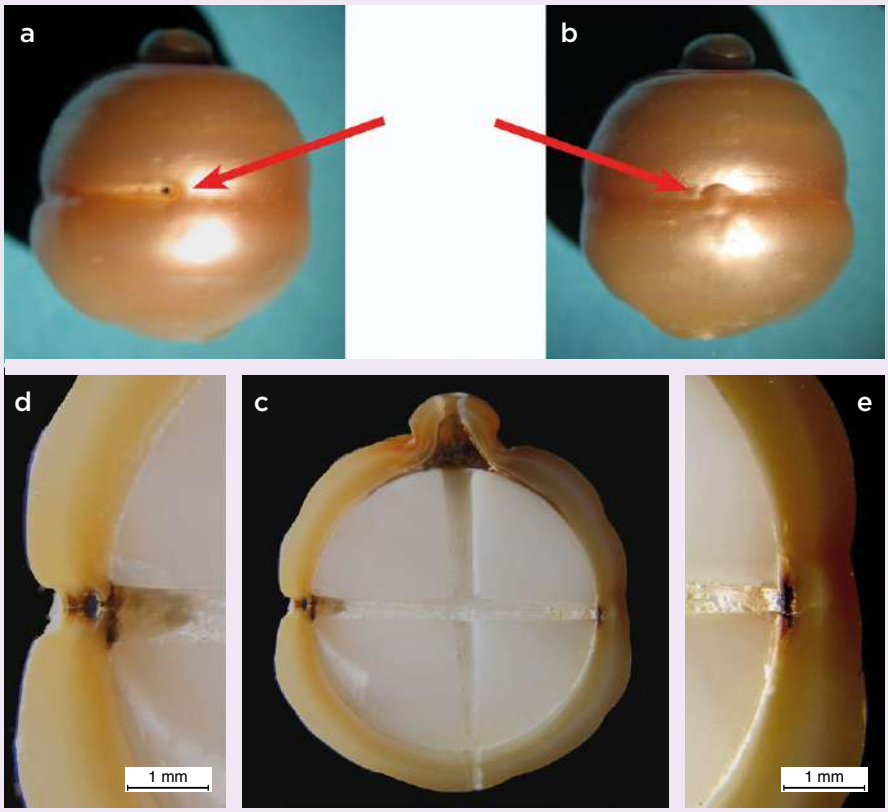

Figure 4: In this cultured pearl (12 mm long) with one 'equatorial' groove, each view of the two opposite sides **(a, b)** shows a defect in the equatorial plane perpendicular to the vertical rotational axis. In this case, the defects appear as a small depression on one side and a bump on the other side (red arrows). **(c)** A cross-section of this cultured pearl (2.5-mm-thick slice), observed between crossed polarisers and viewed parallel to the rotational axis, displays the defects originating from the openings of the horizontal hole drilled in the nucleus. **(d, e)** A closer view of the defects shows they are characterised by dark desiccated organic matter, mainly on the left side where the matter probably corresponds to the graft. Photos by J.-P. Gauthier.

pearl cultivation process. The dark mass seen only on one end of this hole (Figure 4d) might correspond to organic matter, possibly residue from the graft introduced into the drill hole. Outside both ends of the hole, in the perinuclear region, brown organic layers account for a lack of nacre deposition during the early stages of cultured pearl growth, followed by resumed nacre growth, leading to a depressed tubular region on one side (Figures 4a and 4d) and to a small bump on the other side (Figures 4b and 4e).

The vertical hole seen in Figure 4c was drilled along the rotational axis after cultivation for threading.

Category 2: Pair of Circles

Figures 5a and 5b show a sample of the second category, equally typical, of a Ming cultured pearl with a pair of grooves. In this, as in all similar samples, only one defect appears in each groove (indicated by red arrows in Figure 5).

The slice depicted in Figure 5d clearly shows the tilt angle of the nucleus drill hole relative to the equatorial plane. Considering the formation of the grooves as a result of cultured pearl rotation in the host mollusc, this tilt angle explains the systematically opposite position of the defects compared to the bead centre, the two grooves being located symmetrically in relation to the equatorial plane of the bead and the presence of only a single defect within each groove (see also Figure 3c).

The depth of the grooves is greatest at the location of the defect, and becomes progressively shallower with increasing rotational distance away from it. Thus the direction of the cultured pearl's rotation can be inferred (from the right to the left in Figures 5a and 5b, indicated by green arrows), as previously pointed out by Gauthier et al. (2014). The cut section (Figure 5d) illustrates how the furrows are less pronounced on the sides opposite the spot defects (blue arrows). Figures 5e and 5f are enlarged views of the nucleus drill hole openings. A dark mass of organic matter lies in the right-hand opening, which is probably the side in which the graft was introduced.

The apex of this cultured pearl has a protrusion surrounding a bulge (Figure 5c), which might be responsible for the anchorage of its rotational axis in the soft tissue of the gonad. Again, the threading hole was drilled along the rotational axis.

Category 3: Multiple Circles

The third category comprises multi-circled Ming cultured pearls. In addition to the presence of one or two grooves, along with all features present in categories 1 and 2, these had additional circles, each generated by a defect

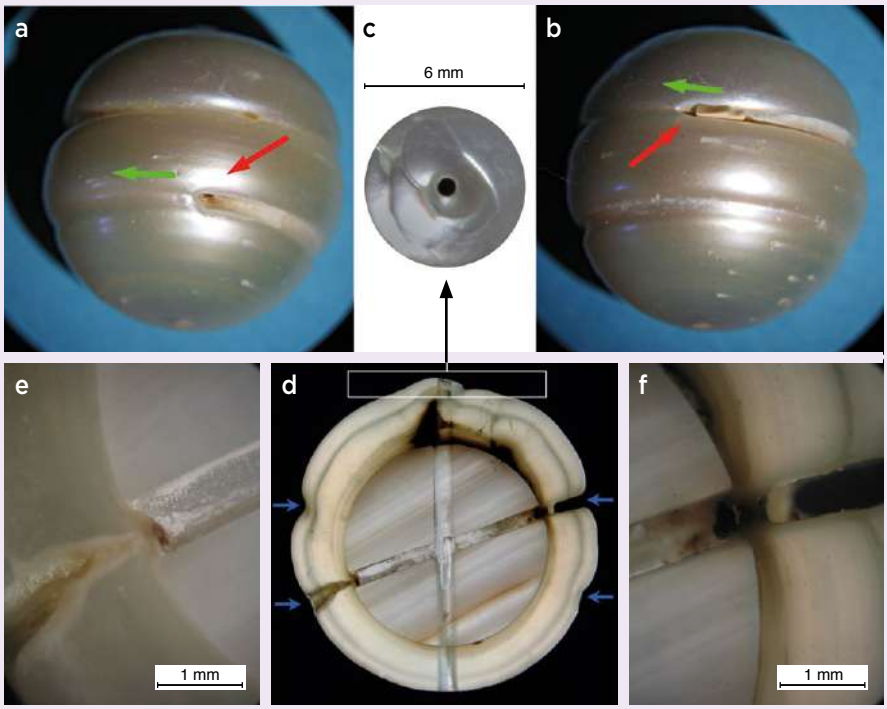

Figure 5: A cultured pearl (14 mm long) with two equatorial grooves is shown in two opposite views **(a, b)**. Red arrows point to the single defect in each groove, and green arrows indicate the rotation direction of the cultured pearl during its growth. **(c)** A top view of the cultured pearl shows a small dome at the apex responsible for fixing its rotational axis. **(d)** The profile of the grooves is highlighted (blue arrows) on this cross-section slice (2 mm thick), observed between crossed polarisers. Also shown are enlarged views **(e, f)** of each end of the bead drill hole. Photos by J.-P. Gauthier.

of various width. The positions of these defects were random. In the two former cases, the two diametrically opposed defects and the rotational axis defined the plane along which a specimen was sliced for examination. In this third case, which we will discuss briefly, it was not possible to incorporate all of the defects into a single thick slice.

Drilling of the nucleus bead can explain the existence of two grooves on most circled cultured pearls having a fixed rotational axis. For those with more than two grooves, another cause of circling needs to be found, but this is beyond the scope of the present study. Nevertheless, it should be noted that additional circles are usually generated at spot defects quite similar in appearance to those due to the nucleus drill hole, as shown in Figure 6. This beaded cultured pearl may have incorporated another, much smaller, non-beaded cultured pearl that grew independently in the gonad. Known by the Japanese name *tokki pearl* (Krzemnicki et al., 2011), this structure could be responsible for the drop shape of this sample. The overall shape dictated the orientation of the rotational axis. The apparent attachment point between the two cultured pearls is also another cause of circling (blue arrow in Figures 6a and 6c).

Three main defects are visible in Figure 6a. Two of them lie in a single plane that passes through the rotational axis, and their profile is visible on the slice from this cultured pearl (green arrows in Figure 6c). At the centre of the section is a cylindrical cavity almost perpendicular to the slice that corresponds to the nucleus drill hole. This slightly tilted drill hole generated the two near-equatorial grooves, quite close together. The combination gives rise to an equatorial ridge (red arrow). The two defects highlighted in Figure 6b lie precisely within these grooves. Before slicing the sample, one might assume that one of the defects was positioned directly above an orifice of the nucleus drill hole, but this was not the case.

ADDITIONAL RESULTS

We examined several additional Ming cultured pearls to better understand the nature of the circling and its presence or absence. These included a multi-circled sample with a pair of opposite spot defects near the poles, as well as several non-circled cultured pearls that were not yet drilled for threading (eight drop-shaped, 15 round and three baroque). In addition, to evaluate potential confusion with the beaded Ming products, we examined a non-beaded mantle-grown Chinese freshwater cultured pearl.

Ming Cultured Pearl with a Pair of Defects near the Poles

Figure 7 illustrates a multi-circled Ming cultured pearl belonging to category 3 above, which provides an interesting example regarding the tilt angle of the drill hole with respect to the rotational axis. It displays at least

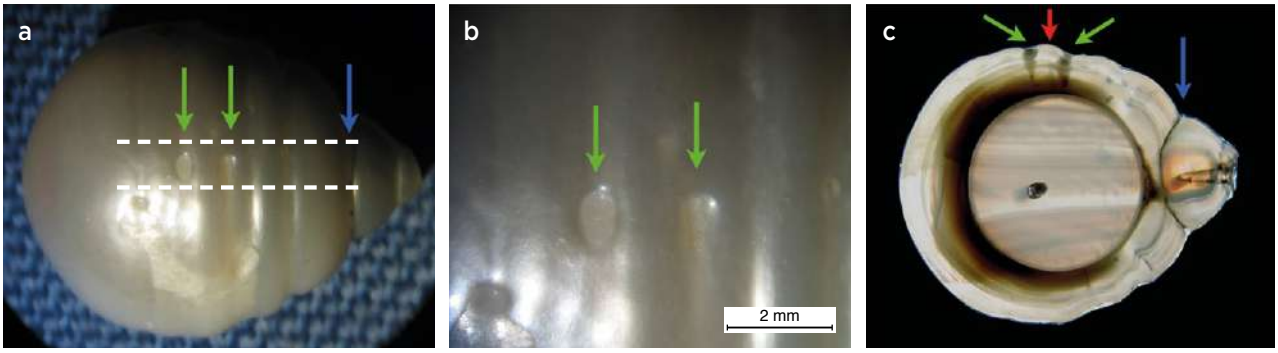

Figure 6: This multi-circled cultured pearl (14 mm long) displays **(a)** an external appearance with circles (e.g. green arrows) and another type of defect (blue arrow). The dashed lines represent the planes of the cuts that yielded the 1-mm-thick slice in (c). **(b)** Enlargement reveals details of the spot defects (e.g. green arrows). **(c)** A slice of this sample observed between crossed polarisers shows the profile of two spot defects (green arrows) lying in the grooves created by the drill hole being slightly tilted relative to the equatorial plane of growth rotation. The dark oval near the centre of the nucleus is an oblique cut through the nucleus drill hole. Also note the presence of a bump between the two defects (red arrow). A possible 'tokki pearl' is visible at the apex. Photos by J.-P. Gauthier.

seven grooves with three random defects appearing only on one side, with two of them in the same vertical plane (red arrows in Figure 7b). In addition, two diametrically opposite defects appear near the upper and lower poles (green arrows in Figures 7c and 7d). Based on our previous findings, these should correspond to the orifices of the nucleus drill hole. This was confirmed by the slice shown in Figure 7e. The nucleus drill hole (dashed red line in Figure 7e) is positioned at a slight angle from the threading hole (i.e. near the rotational axis).

The proximity of one orifice to the upper pole suggests that the end where the graft was introduced could be involved in the development of the apical dome. In this case, the large size of the cavity was enough to create a protrusion that induced a fixed axis of rotation. However, the protrusion was slightly deflected relative to the axis of the nucleus drill hole, leading to the formation of circumpolar grooves. The origin of the dome being due to the graft environment is not a general case, as already discussed for categories 1 and 2 above, in which the cavity near the orifice does not extend enough to create a bump on the surface.

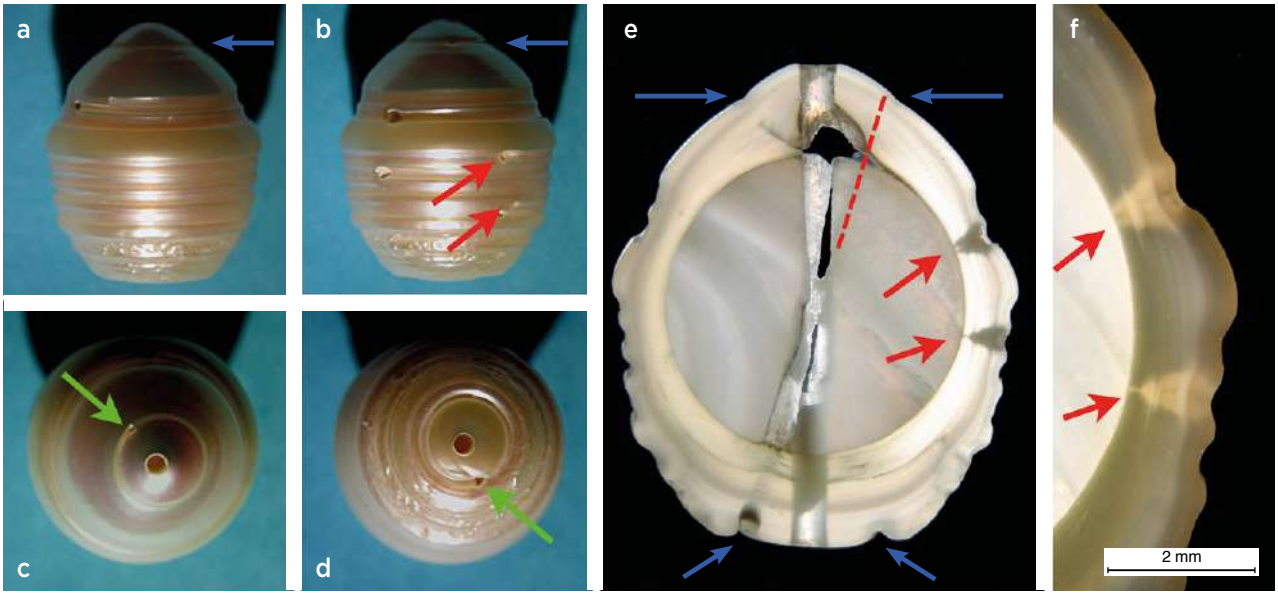

Figure 7: Another multi-circled cultured pearl (13 mm long) has a nucleus drill hole slightly tilted relative to the rotational axis. Two opposite lateral views **(a, b)** display several rings. Views of the apex **(c)** and base **(d)** show defects symmetrical with respect to the nucleus centre, marking the presence of the orifices of the nucleus drill hole (green arrows) and generating specific grooves (blue arrows in a, b and e). **(e)** A slice (2 mm thick) along a plane through the rotational axis and two defects (indicated by red arrows) is shown here between crossed polarisers. The threading drill hole is vertical, while the dashed red line indicates the nucleus drill hole direction. The organic mass of the graft, removed during the slicing process, was lying in the apical cavity. **(f)** An enlarged view of the defects is shown here in reflected light. Photos by J.-P. Gauthier.

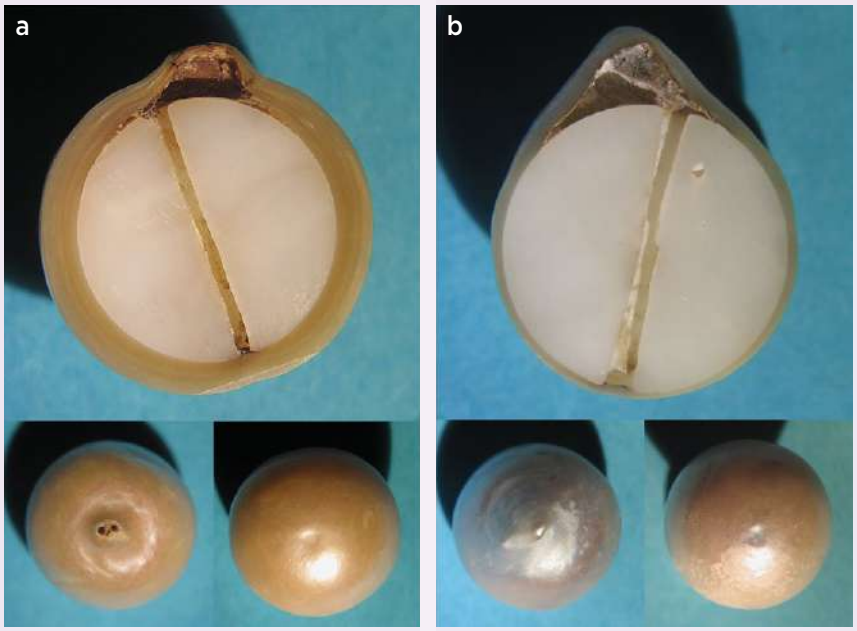

Figure 8: Two drop-shaped Ming cultured pearls (**a:** 11 mm long, **b:** 13.5 mm long) of low quality, without circles and not drilled for threading show nucleus drill holes slightly tilted with respect to the rotational axis. The apical bumps are related to the graft placed in one end of the drill hole of the bead nucleus. Photos of the apex and base of each cultured pearl before it was sliced are shown at the bottom (left and right, respectively). Photos by J.-P. Gauthier.

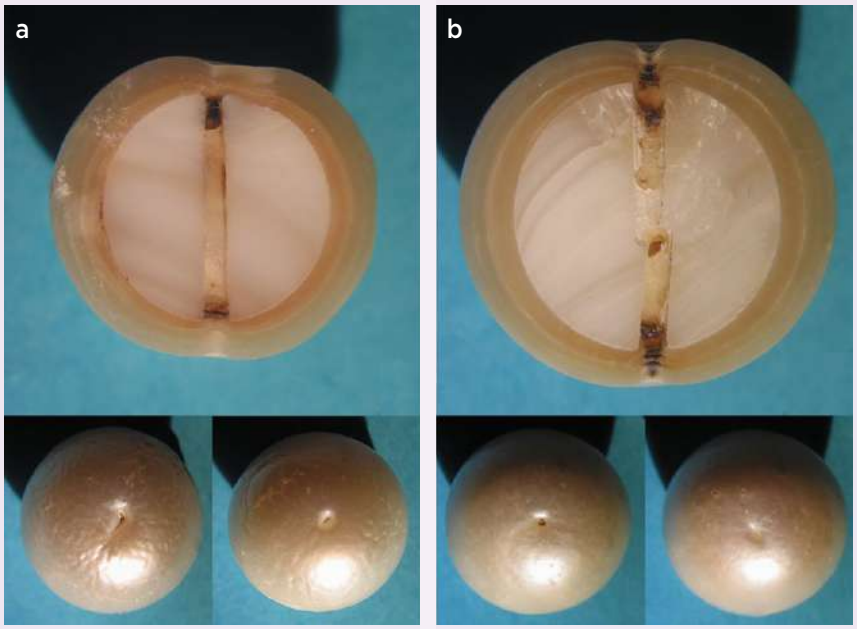

Figure 9: Two round Ming cultured pearls (**a:** 12 mm, **b:** 13.5 mm) of low quality, without circles and not drilled for threading show upper and lower spot defects that correspond to the extremities of the nucleus drill hole (see left and right photos, respectively, of the apex and base of each cultured pearl before it was sliced). Their round shape allowed them to rotate around axes of various directions, so no circling was generated. Photos by J.-P. Gauthier.

Non-Circled Drop-Shaped Ming Cultured Pearls

One might wonder whether all Ming cultured pearls with a symmetric shape along their rotational axis should display circling. The eight non-circled drop-shaped Ming cultured pearls that we examined were of unmarketable low quality and had not been drilled for threading. All of them were near-round, with a protrusion at the apex. In addition, all samples showed a hole or depression at the centre of the apex protrusion and a slight circular depression at or near the centre of the lower pole. These features are illustrated by two samples in Figures 8a and 8b.

The cultured pearls were sliced along their rotational axis, which revealed that all of them had a nucleus drill hole that was slightly tilted with respect to the rotational axis (as illustrated in the previous example), and yet none displayed any circling. The bump at the apex probably corresponds to the end of the nucleus drill hole where the graft was introduced. However, the cavities associated with the grafts were perhaps large enough to prevent the upper drill holes from imprinting on the nacreous envelope, thus explaining the lack of circles. The basal depressions were slight enough to also avoid basal circles.

Non-Circled Round Ming Cultured Pearls

Non-circled round Ming cultured pearls, often of high quality, also exist in the market. The 15 undrilled low-quality round samples that we examined all showed two opposite spot defects, similar to the examples described above. However, without the bumps that created the drop shapes documented above, these cultured pearls turn, but not around a fixed axis. Hence they move in multiple orientations, thus avoiding the formation of circles. Two examples are shown in Figure 9, and the interiors of the other 13 round cultured pearls were quite similar.

Round Ming cultured pearls of good quality sometimes also exhibit such marks due to the drilled bead nucleus (Figure 10). The two opposite spots consist of slight depressions, indicating the position of each end of the nucleus drill hole. In such a case, a threading hole drilled along this axis would entirely eliminate the surface defects.

Such defects are entirely absent from round Ming cultured pearls of high quality. These depressed areas most likely were present during the early stage of growth, but progressively disappeared as nacre deposition accumulated, and as the round cultured pearl rotated around a randomly shifting axis.

Non-Circled Baroque Ming Cultured Pearls

Three baroque Ming cultured pearls were examined, since in principle they did not rotate (as shown by their shape). As expected, we noticed the presence of two opposite spot defects on all three samples, marking the existence of a nucleus drill hole. As an example, one of the samples is shown in Figure 11.

Mantle-grown Non-beaded Cultured Pearl

It is worth mentioning that non-beaded mantle-grown cultured pearls sometimes have defects quite similar to those reported in this study of beaded Ming cultured pearls. An example that could cause confusion is shown

Figure 10: This round Ming cultured pearl (11 mm) of good quality shows two diametrically opposed slight defects due to the hole drilled through the nucleus bead. Photos by T. N. Bui.

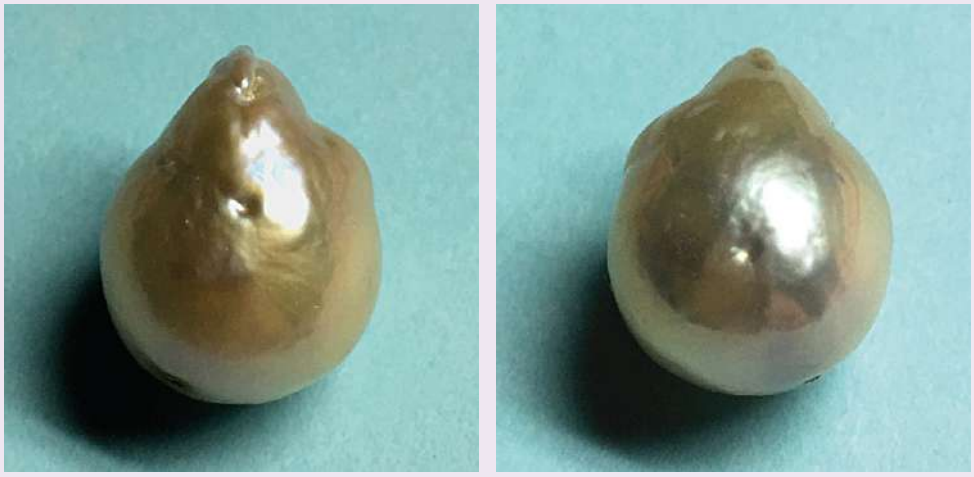

Figure 11: A baroque Ming cultured pearl (11 × 13.5 mm) shows two opposite spot defects marking the presence of a nucleus drill hole, but the lack of circling indicates that it did not rotate during its formation. Photos by T. N. Bui.

in Figure 12a. The appearance of this Chinese mantle-grown cultured pearl with two major grooves is very similar to a beaded Ming cultured pearl containing a nucleus drill hole that is tilted with respect to the rotational axis. However, a closer examination reveals that the two circles are not symmetrical with respect to the equatorial plane of a possible bead nucleus, even if the position of such a bead cannot be defined precisely. Moreover, the lower circle has a spot defect, but none is visible opposite on the upper circle, as would be expected for the presence of a bead with a drill hole. Microradiography might clarify this situation, if necessary.

A slice through this cultured pearl parallel to the rotational axis and passing through the spot defect (Figure 12b) confirmed the absence of a bead nucleus. The defect originated from the interior of the cultured pearl, but at the surface it closely resembles a spot that could have been generated by a drilled nucleus.

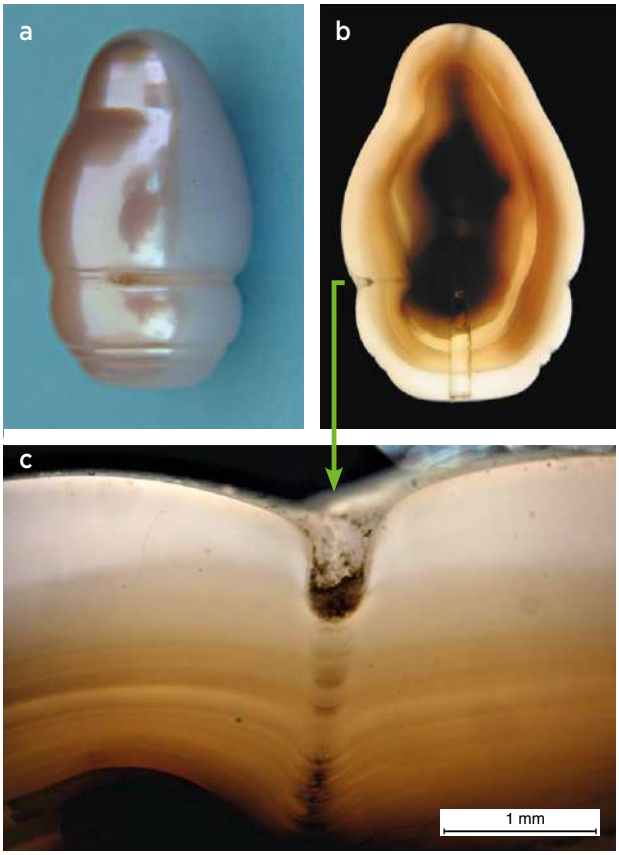

Figure 12: This non-beaded mantle-grown Chinese freshwater cultured pearl (**a:** 18.5 mm long) contains defects that induced circling due to rotation around a fixed axis. A cross-section slice (**b:** 2 mm thick) observed between crossed polarisers shows the profile of a defect (green arrow) lying in one of the grooves. **(c)** Enlargement of the defect illustrates features similar to those observed in beaded Ming cultured pearls. Photos by J.-P. Gauthier.

DISCUSSION

Circling is a feature frequently encountered on saltwater and freshwater cultured pearls, and is suggestive of a fixed rotational axis perpendicular to the circles. This rotational movement, for a long time only theoretical, was finally demonstrated in a recent experiment (Gueguen et al., 2015), and one possible mechanism for inducing such rotation was suggested by Cartwright et al. (2013). An internal defect, emerging at the cultured pearl's surface and generating circles, was suggested by Gauthier et al. (2014) and later confirmed by Cuif et al. (2018) on pearls cultured in black-lip oysters. In rare cases, the orientation of the initial fixed rotational axis can change suddenly and take another fixed position (Gauthier et al., 2015).

The Role of the Drill Hole in Creating Spot Defects and Circling

Our study has shown that a specific type of circling on Ming cultured pearls is generated by the presence of the hole drilled in the bead nucleus before pearl cultivation in order to introduce a graft into the gonad simultaneously (Hänni, 2011). However, the influence of this nucleus drill hole may be seen even on non-circled cultured pearls.

During the early stages of pearl cultivation, organic layers facing the drill-hole orifices settle poorly or do not biomineralise, leading to depressed areas more-or-less visible on the surface during the latter growth stages, when more uniform nacre deposition occurs. The cultured pearl's rotation and the possible presence of pits unrelated to the nucleus drill hole modify this simple mechanism, and thus may create the following situations for the circling and spot defects:

1. Drop-shaped cultured pearls (formed around a fixed rotational axis), with a bead nucleus drill hole that is:
   - perpendicular to the rotational axis (category 1): *one groove, with two opposite spots on this groove.*
   - tilted at a significant angle relative to the rotational axis (category 2): *two grooves with one spot each, opposite with respect to the bead centre.*
   - tilted relative to the rotational axis, plus the presence of defects (pits) unrelated to the bead drill hole (category 3): *additional circles.*
   - slightly tilted with respect to the rotational axis: *no grooves if the nucleus drill hole does not touch the nacreous envelope; two opposite spot defects near the poles.*

2. Round-shaped cultured pearls (random, multiple rotational axes):
   - *no grooves, two opposite spots*, eventually removed by thread drilling, or
   - *no grooves, no spots*, if the later stage of biomineralisation makes them disappear (top quality).
3. Baroque cultured pearls (no rotation): *no grooves, two spots*.

The Role of the Graft

Cochennec-Laureau et al. (2010) noted that, during surgical insertion of the graft into the pearl pouch of Polynesian black-lip oysters, tissue debris (gametes and haemocytes) can be introduced at the same time. In addition, depending on the surgical preparation of the graft (cutting of the donor oyster's mantle), it can become necrotic causing organic debris. Both tissue alterations may lead to deformation and/or a change in the functional integrity of pearl sac development. The absence of pearl sac epithelial cell homogeneity induces modifications of the nacre layer deposits.

A bump near one end of the bead drill hole corroborates the graft's influence. Moreover, if the graft slides out of the bead hole, a bump more distant from the hole also could be explained in the same way. Such excrescences induce the anchorage of the cultured pearl in the pearl sac, leading it to rotate around a fixed axis. In such an instance, the presence of the bead drill hole may induce the circling.

The Role of Epithelial Cells of the Pearl Sac

The pearl biomineralisation process is very similar to the repair of the shell of a living pearl oyster, as described by Caseiro and Gauthier (1997) after piercing a *Pinctada margaritifera* valve with a drill bit. The pallial epithelium (i.e. consisting of cells of the type that form a pearl sac) covered the hole very quickly (within a day) with an organic layer for emergency repair, followed later by the deposition of fibrous aragonite and tablets of mother-of-pearl. With regard to the current study, which involves pearls cultured with a hybrid freshwater *Hyriopsis* mussel, the epithelium of the pearl sac also appears to have initially deposited organic layers (as shown in Figures 4d and 4e) and then started the conventional process of biomineralisation.

This observation suggests that the deposition of matter by the epithelial cells depends strongly on the cellular quality of the pearl sac or its environment (e.g. its contact with the bead). Facing a nucleus drill hole, a mollusc produces organic layers more-or-less deficient in biomineral, and the return to normal nacre deposition seems delayed. As the cultured pearl rotates, cells that previously faced a hole come into contact with a solid part of the bead, but they do not immediately produce mineral layers, as evidenced by the persisting groove, and this occurs for all cells located along the circular path travelled by the hole. We can thus understand the formation of the spot defects, which develop thereafter into grooves during cultured pearl rotation about a fixed axis.

CONCLUSION

The observations described here on circled Ming cultured pearls and extended to non-circled ones provide, by means of classical microscopy, a dataset that helps explain the mechanism of occurrence of certain types of circling, including the development of one, two or more, or no such circles. Only those rotating around a fixed axis during growth present the specific grooves described here. Conversely, circles are absent from round cultured pearls for which the rotational axis changes direction continuously during growth, and from baroque cultured pearls that do not rotate. Such samples may present only two opposite defects—holes or crater-like depressions—that disappear during the growth of top-quality round cultured pearls. The graft introduced into the bead nucleus drill hole can have a major influence on a cultured pearl's shape, inducing a bump, which is responsible for fixing the rotational axis. The early formation of spot defects—which then develop into grooves during rotation relative to the orifices of the nucleus drill hole or other cavities existing near the bead—can be attributed to the behaviour of the adjacent epithelial cells.

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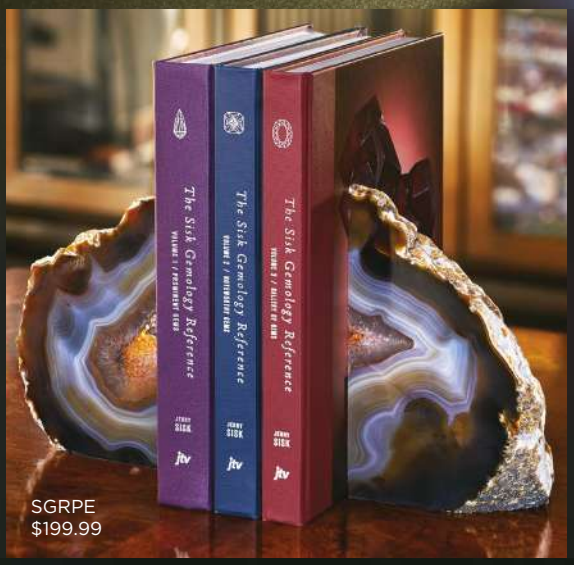

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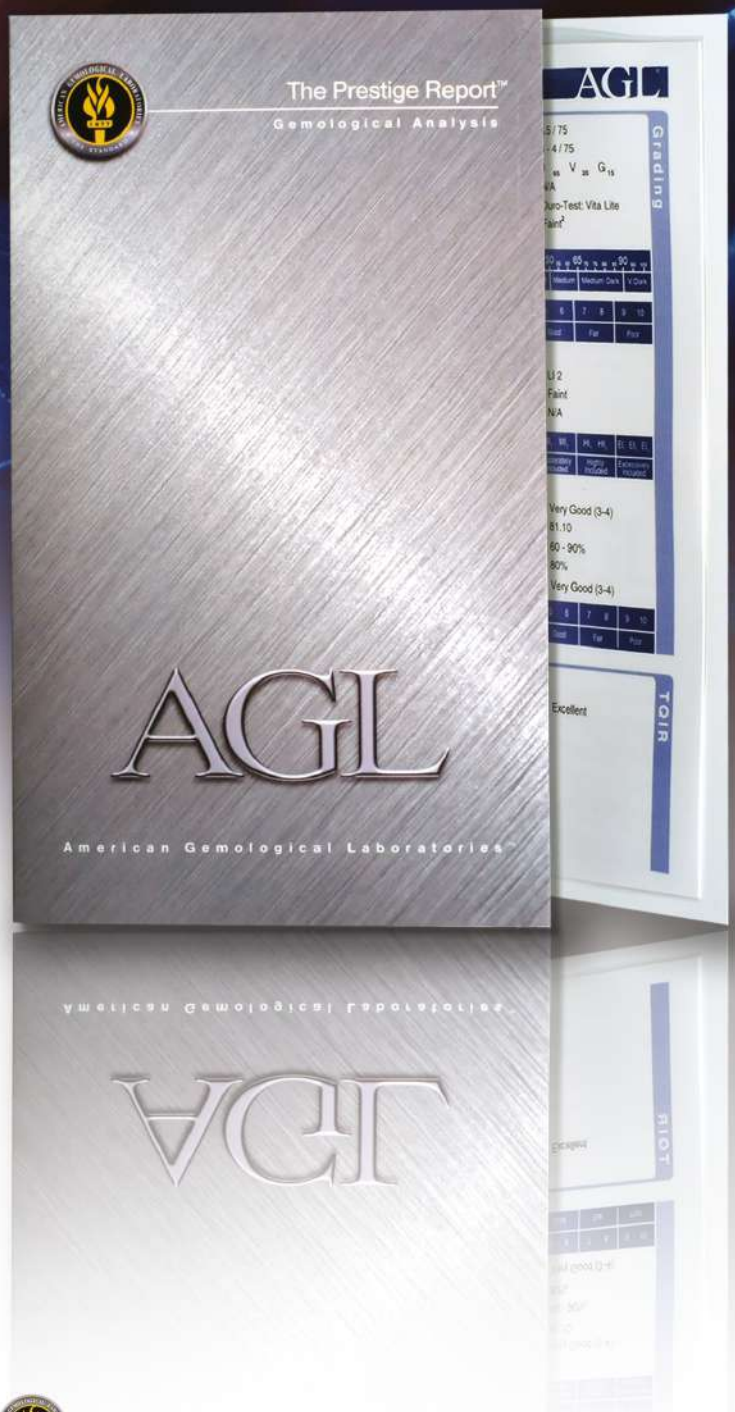

AMERICAN GEMOLOGICAL LABORATORIES AGL

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Conferences

AGA LAS VEGAS

The Accredited Gemologists Association's 2018 Las Vegas conference took place on 1 June during the JCK Show in Nevada, USA. Attended by 67 people, the event was chaired by AGA president **Stuart Robertson** and featured five speakers.

Dr Wuyi Wang (Gemological Institute of America, New York, New York) covered advances in the growth and identification of synthetic diamonds. In the past 10–15 years, both HPHT and CVD technologies for gem diamond synthesis have made significant progress, in both quality and quantity of specimens produced. Millions of synthetic gem diamonds—in melee sizes (e.g. Figure 1) and as larger crystals—are now produced annually. It is highly likely that growth technology will continue to improve, and that more D-to-Z and fancy-colour synthetic diamonds will enter the jewellery market. Disclosure of whether a diamond is natural or synthetic, or has been treated to enhance its appearance, is crucial. This disclosure requires that instrumentation technology and identification processes keep pace with new developments to help ensure that every synthetic diamond is definitively identified.

Alberto Scarani (Magilabs, Rome, Italy) described fluorescence spectroscopy for near-colourless diamond screening and coloured stone analysis using his EXA instrument. In the screening mode, the instrument indicates 'pass' for natural diamonds and 'refer' for synthetic diamonds and simulants (although in rare cases, some very pure, low-nitrogen type IaA natural diamonds are referred for further testing). The instrument's 'advanced' mode is used to display the fluorescence emission spectrum of a sample, which is useful for further differentiating near-colourless natural from synthetic diamonds and imitations, as well as testing some coloured diamonds and identifying emerald filling substances, separating natural/synthetic/heated spinel and evaluating coloured stones for the presence of Cr^{3+}.

Dr Thomas Hainschwang (GGTL Laboratories, Balzers, Liechtenstein) began his presentation by reviewing different instrumentation he has developed specifically for gem testing, most of which uses luminescence imaging for separating natural from synthetic diamonds—including the new D-Tect machine marketed by HRD Antwerp for testing near-colourless diamonds rejected by most screening devices (see p. 181 of this issue of *The Journal* for more information). Then he reviewed his ambitious ongoing diamond treatment project, in which he and his team are collecting data on carefully pre-selected natural and synthetic diamonds before and after irradiation, heat treatment and HPHT processing.

Jon Phillips (Corona Jewellery Co., Toronto, Ontario, Canada) discussed the advantages and disadvantages of five different commercial diamond screening units, and emphasised that no machine 'does it all' for the average jeweller. Prospective buyers of a screening unit should understand how the machine works, its ease of use, details of its warranty and any service contracts, availability of in-house training, its up-front cost and delivery time.

Martin Rapaport (Rapaport Diamond Corp., New York, New York) shared his ideas on synthetic diamonds in the marketplace, both presently and in the future. He sees De Beers' recently announced initiative of selling 'Lightbox' synthetic diamonds as a way to push down other sellers of synthetics, and he feels that the company is prioritising making money over promoting natural diamonds. He emphasised that there is already a lot of jewellery containing melee-sized synthetic diamonds (mainly produced in China) on the market, and predicted that the price of natural diamond melee could eventually fall to that of synthetic melee.

Brendan M. Laurs FGA

Figure 1: These near-colourless melee-sized rough synthetic diamonds (2–3 mm each) were grown in China. Photo by Jianxin (Jae) Liao, © GIA.

22ND MEETING OF THE INTERNATIONAL MINERALOGICAL ASSOCIATION

On 13–17 August 2018, the quadrennial meeting of the International Mineralogical Association (IMA) was hosted by the Geological Society of Australia and took place at the Melbourne Convention and Exhibition Centre in Melbourne, Victoria, Australia. The conference was attended by approximately 550 people, and featured a series of plenary lectures and several parallel sessions of oral presentations on a variety of mineralogical topics. A 536-page abstracts volume can be downloaded from the conference website at www.ima2018.com/ima2018-abstracts. Notably, the conference featured two sessions on gems: 'Sciences Behind Gemstone Treatments' (Figure 2) and 'Recent Advances in Our Understanding of Gem Minerals'. In addition, various presentations of interest to gemmologists were given in other sessions that focused on mineral museums, granitic pegmatites and diamond geology. Oral presentations attended by this author are profiled below.

Several presentations featured topics related to coloured stones. **Grant Hamid** (Hamid Bros. Gem Merchants, Melbourne, Victoria, Australia) reviewed developments during the past 50 years with gem corundum localities, synthetics and treatments (see also the Gem-A Conference report in *The Journal*, Vol. 34, No. 8, 2015, p. 717). **Dr Frederick (Lin) Sutherland** (Australian Museum, Sydney) and co-authors presented new geochemical and radiometric age data for rubies from Myanmar. U-Pb isotopic age determinations of zircon inclusions in Mong Hsu rubies yielded 23.9 ± 1.0 million years (Ma) and of titanite inclusions in a ruby from Mogok (Thurein Taung) gave 32.4 ± 1.0 Ma. Trace-element plots showed a clear separation between the Mong Hsu and Mogok rubies, as well as differences from rubies derived from eastern Australian gemfields. **Dr Isabella Pignatelli** (University of Lorraine, Nancy, France) and colleagues used X-ray tomography and trace-element analysis to characterise some new trapiche rubies from the Khoan Thong placer in Luc Yen, northern Vietnam. They deduced that the corundum in the dendritic arms formed at the same time as the interstitial corundum of the trapiche crystals.

Philippe Belley and **Dr Lee Groat** (University of British Columbia, Vancouver, Canada) performed trace-element fingerprinting of cobalt-blue spinel from Baffin Island in Canada in comparison with other localities. They found two types of Co-bearing spinel: low V and/or Cr (showing the best blue colour) and high V and/or Cr combined with low Mn and possibly some Fe (corresponding to purple samples). All showed Ni enrichment. **Dr Gaston Giuliani** (IRD and CRPG, University of Lorraine, Nancy, France) and co-authors reviewed the geology of demantoid deposits. They defined Type I deposits as being hosted by serpentinised ultramafic rocks within ophiolitic sequences (e.g. Italy, Russia, Iran and Pakistan) and Type II deposits as Ca-Mg skarns (e.g. Madagascar and Namibia). Oxygen isotope values can be used to separate those from Madagascar and Namibia as well as from Italy and Iran. **Dr Allan Pring** and colleagues (Flinders University, Adelaide, Australia) analysed 200 opal samples from various localities using X-ray diffraction (for pre-screening), Raman and far-infrared spectroscopy and nuclear magnetic resonance. The samples were categorised according to opal-A (i.e. amorphous: from Australia, Slovakia and the USA), opal-CT (i.e. cristobalite and tridymite: some samples from Australia) or opal-C (i.e. cristobalite: very rarely encountered). **Bahareh Shirdam** and colleague (University of Tehran, Iran) examined the photoluminescence spectra of turquoise with 290 nm excitation. The main luminescence peaks were positioned at 361, 392 and 455 nm, and the 410–570 nm region showed variations related to rare-earth elements and other trace impurities.

There was one diamond presentation, given by **Dr Sally Magaña** (Gemological Institute of America [GIA], Carlsbad, California), who examined spatial variations and the effects of heating on radiation stains in green diamonds. Because the green colour of these stains turns brown within minutes when heated to 550–600°C, the natural irradiation must take place relatively near the earth's surface (i.e. at less than 30 km depth). Confocal Raman depth profiling and photoluminescence mapping at liquid-nitrogen temperature showed differences in the depth penetration and spatial patterns between natural- and laboratory-irradiated stains, and therefore may help distinguish the origin of a green diamond's colouration.

Gem treatments featured prominently at the conference, particularly on corundum. **Dr Visut Pisutha-Arnond** and co-authors (Gem and Jewelry Institute of Thailand [GIT], Bangkok) reported on blue-diffused sapphires produced from colourless natural and synthetic starting materials. Chemical analysis across slices of both natural and synthetic samples showed an enrichment in Ti along with various other elements (e.g. Be and Li, as well as Fe and Ga in the synthetics) in the diffused blue colour layer. The blue layer was thinner in the synthetics than in the natural corundum, but larger samples of the synthetic starting

material could be successfully diffused because of its lack of inclusions and consistent chemical composition. Co-author **Thanapong Lhuaamporn** gave a presentation for **Thanong Leelawatanasuk** (GIT, Bangkok) on the characteristics of blue sapphire enhanced by a relatively new process using heat and pressure. Sri Lankan sapphires that did not react favourably to traditional heat treatment were placed in a specially designed crucible containing graphite and a small amount of water, and were heated multiple times of short duration under conditions of <1,800°C and <1 kbar. FTIR spectroscopy of the sapphires after treatment showed four main patterns created by strong OH-related absorptions that have not been seen in traditionally heated Sri Lankan sapphires. **Dr Pornsawat Wathanakul** (Kasetsart University, Bangkok, Thailand) and colleagues performed traditional heating experiments on Sri Lankan sapphires and observed changes in their infrared spectra. The intensity of the 3309 cm^{-1} band was orientation dependent, so the samples had to be carefully oriented to obtain meaningful data. Also, the use of the 3309 cm^{-1} band to detect heat treatment only worked for sapphires with a relatively low Ti content (i.e. < 0.05 wt.% TiO_2), and therefore generally could be applied to metamorphic but not magmatic sapphires. **Aumaparn Phlayrahan** (Kasetsart University, Bangkok, Thailand) and co-authors studied the influence of Ti content on the 3309 cm^{-1} infrared absorption band in heat-treated ruby. The band only appeared in samples containing moderate-to-high Ti (i.e. 100–200+ ppm), and only when the samples were heated to ≥1,200°C, due to the high affinity of Ti^{4+} for the OH^- liberated from diaspore and/or boehmite during the heating process.

Chengsi Wang and colleagues (Gemmological Institute, China University of Geosciences, Wuhan) reported preliminary results of a synchrotron-radiation X-ray absorption spectroscopy study of natural and treated Oregon sunstone. Yellow Oregon labradorite underwent Cu diffusion treatment to produce red and

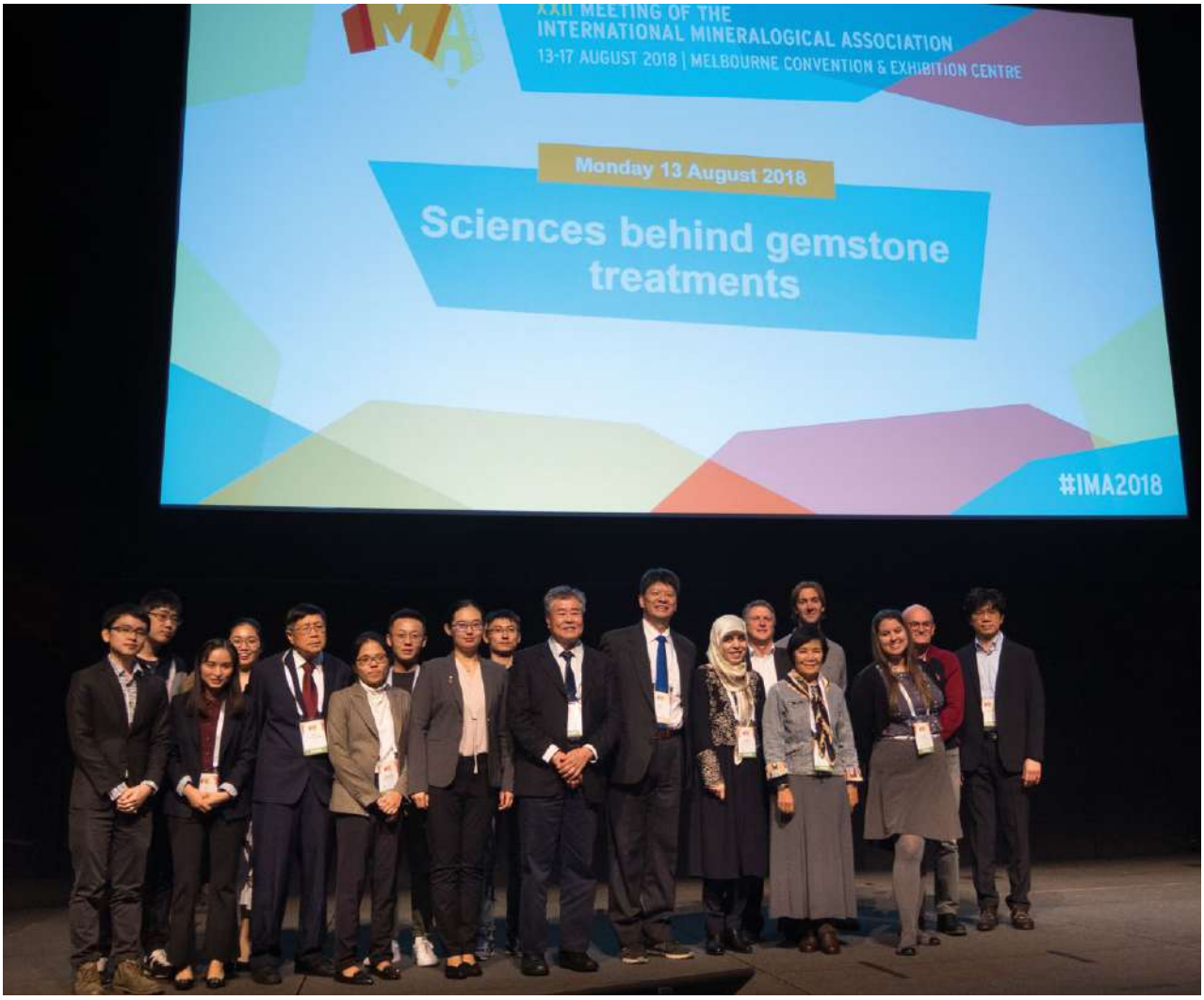

Figure 2: Oral and poster presenters of the IMA session titled 'Sciences Behind Gemstone Treatments' gather together. Photo by B. M. Laurs.

green zones that are typical of natural Oregon sunstone. In the red and green zones of the diffused samples (and in the red zone of an untreated Oregon sunstone), the copper was likely present as nanoparticles of Cu^{+} and/or Cu^{2+} (rather than Cu^{0}, as reported previously), with the different colours possibly related to the copper valance state and the local environment. **Tay Thye Sun** (Far East Gemological Laboratory, Singapore) reviewed the development and identification of various jadeite treatments since the 1980s, and differentiated between A-jade (untreated), B-jade (bleached and polymer impregnated), C-jade (dyed) and, most recently, D-jade (jadeite doublet with a white base and green cap).

Gem localities were covered in 10 presentations. **Wim Vertriest** (GIA, Carlsbad, California) reviewed the challenges of performing field studies of ruby and sapphire deposits. The discovery of new deposits is unpredictable, and these localities may show rapid and unexpected developments (including being abandoned) that are driven by various factors influenced by the gem trade (e.g. response to heat treatment or resemblance to stones from famous localities). **Dr Ian Graham** (University of New South Wales, Sydney, Australia) and co-authors examined alluvial sapphires from Orosmayo, Argentina, using microscopy (for morphological studies) and the analysis of trace elements and oxygen isotopes. They inferred that the sapphires formed due to metasomatic exchange between mantle-derived carbonatised lamprophyres and crustal felsic magmas, and they were later brought to the surface by ascending intermediate magmas. **Kandy Wang** (University of New South Wales) and colleagues reported new oxygen isotope ratios ($\delta^{18}O/\delta^{16}O$) for cabochon-quality rubies from Paranesti, northeastern Greece. The oxygen isotope compositions ranged from –0.3‰ to +1.3‰; such a narrow range straddling 0‰ has not previously been documented for metamorphic corundum. **Peter Lyckberg** (Museum of Natural History, Luxembourg) reviewed gems and minerals from granitic pegmatites of Afghanistan and Pakistan. While those in Afghanistan are a major source of gem-quality tourmaline, spodumene and morganite, the pegmatites in Pakistan are known mainly for producing aquamarine, topaz and a variety of rare minerals. In another presentation, **Lyckberg** recounted his experiences in 2013–2018 with mining topaz, heliodor and smoky quartz from 'chamber'-type pegmatites in Volodarsk, Ukraine. One particularly notable pocket in 2017 formed a large vertically oriented cavity that yielded more than 6 tonnes of topaz, including large crystals weighing 96 and 230 kg each; a 9,000 ct topaz was subsequently faceted. **Dr Lee Groat** (University of British Columbia, Vancouver, Canada) reviewed recent advances in coloured stone exploration in Canada. Using geochemistry, hyperspectral imagery and drone footage, he and his team have identified several targets for emerald in the Canadian Cordillera, and also for sapphire and spinel on Baffin Island. In a pair of presentations, **Dr William Simmons** and **Dr Karen Webber** (Maine Mineral & Gem Museum, Bethel, Maine, USA) and colleagues obtained new U-Pb age dates for zircon and apatite from gem-bearing pegmatites in Oxford County, Maine. The ages range from ~250 to 270 Ma, which are about 30 Ma younger than the Sebago pluton, so the pegmatites cannot be related to fractional crystallisation of this pluton as previously proposed. Instead, the pegmatites may have formed from the crystallisation of anatectic melts generated during post-orogenic extension prior to the rifting of Pangea. The pegmatite magmas could have been generated by decompression melting of leucosomes in the metamorphic basement rocks, and they eventually ascended to ~8 km where they crystallised at 2.5 kbar conducive for pocket formation. **Jeffrey Morrison** (New England Mineral Association, Yarmouth, Maine, USA) and co-authors described mining for tourmaline and other minerals at the Havey pegmatite in Poland, Maine. The mine is known for producing fine gem tourmaline with a consistent bluish green colour (see *The Journal*, Vol. 34, No. 5, 2015, pp. 394–395). **Kemala Wijayanti** (Padjadjaran University, Bandung, Indonesia) and colleagues performed SEM, XRF and petrographic analyses on green jasper from the southern part of Java, Indonesia. Samples from three localities (Bungbulang, Klawing and Samigaluh) contained inclusions of chlorite ± limonite and had trace amounts of Fe, Mg, Al and Mn.

Australian gem deposits were the subject of several presentations. **Dr Ahmadjan Abduriyim** (Tokyo Gem Science, Saitama, Japan) and colleagues performed U-Pb age dating of zircon megacrysts from three localities in the New England sapphire fields (Kings Plains, Swan Brook and Mary Anne Gully) in New South Wales. The ages defined two main formational events during 216–174 Ma and 45–37.7 Ma. In addition, U-Pb age dating of syngenetic zircon inclusions in blue sapphires from Inverell (also in New South Wales) gave ages of 34.9 ± 1.4 Ma, similar to the Eocene range mentioned above for some of the zircons. **Nick Raffan** (University of New South Wales) examined an alluvial sapphire deposit at Tomahawk Creek in the Anakie gemfields of central Queensland. This area is known for producing large colour-zoned green/yellow sapphires, including the 82.4 ct Tomahawk Tiger. **Dr Simon Pecover** (Pan Gem Resources Pty Ltd, Palm Grove, Queensland) presented evidence for the

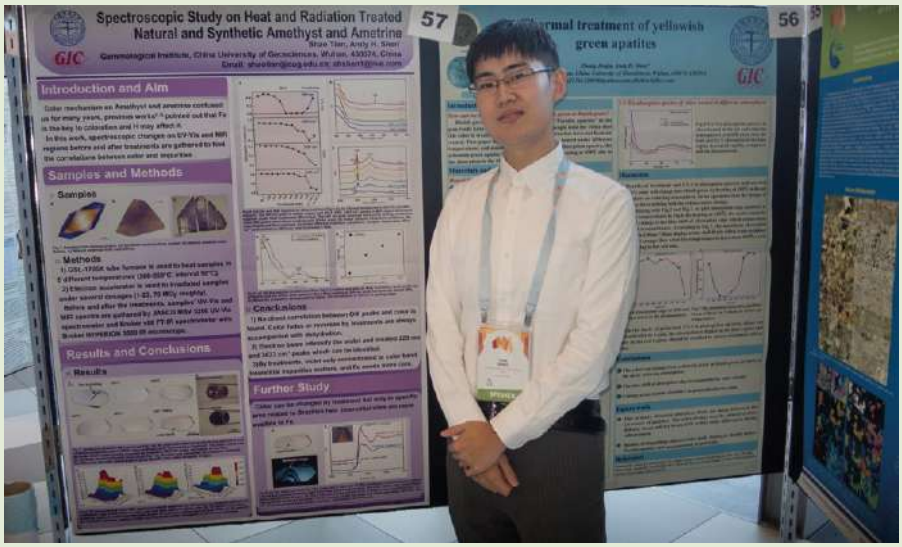

Figure 3: The IMA poster sessions featured nine presentations related to gems, including Tian Shao's spectroscopic study of heat-treated and irradiated natural and synthetic amethyst and ametrine. Photo by B. M. Laurs.

vigorous flow of opal-forming fluids in some Australian opal deposits. In such a scenario, he invoked shear-induced ordering of silica spheres to form play-of-colour opal, which alternated with layers of potch opal (i.e. lacking play-of-colour) due to disordered deposition of silica spheres. **Dr Peter Downes** (Western Australian Museum, Northbridge) and co-authors examined variscite and associated phosphate minerals from the Mt Deverell deposits in the Gascoyne region of Western Australia. The variscite has been mined since the 1970s, and forms veins <12 cm wide that cross-cut silicified mudstone and siltstone of Proterozoic age. It ranges from pale green to green to blue and contains traces of Cr and V.

In other presentations, **Dr Hao Wang** and co-authors (Swiss Gemmological Institute SSEF, Basel, Switzerland) reviewed advances in the origin determination of coloured stones using laser ablation inductively coupled plasma time-of-flight spectroscopy (i.e. with GemTOF instrumentation; see *The Journal*, Vol. 35, No. 3, 2016, pp. 212–223). Using two data analysis techniques—principal components analysis (PCA) and t-distributed stochastic neighbour embedding (t-SNE)—he and his team have made significant progress in using trace elements to separate blue sapphires from Kashmir and Madagascar, and also to distinguish emeralds from various localities. **Dr Ruslan Kostov** (University of Mining and Geology 'St. Ivan Rilski', Sofia, Bulgaria) described gem minerals and gold from archaeological finds in the Balkans (south-eastern Europe). The materials in the artefacts included nephrite, jadeite, serpentinite, talc, malachite, rock crystal, chalcedony, jasper, turquoise and jet. **Zhiqing Zhang** and **Dr Andy Shen** (Gemmological Institute, China University of Geosciences, Wuhan) used FTIR spectroscopy to analyse KBr pellets made from 52 amber samples from various localities, including the Baltic Sea, Myanmar, China (Fushun), Mexico (Chiapas) and the Dominican Republic. The spectral features could be used to separate all but those from Fushun and Myanmar.

The two gem sessions also included nine posters (e.g. Figure 3), which covered the low-pressure, high-temperature treatment of brown type Ia diamond; spinel from Tanzania; lead glass-filled ruby; heat treatment of blue sapphire, tanzanite and greenish yellow apatite; heated and irradiated gem materials (i.e. dark green tourmaline and natural/synthetic amethyst and ametrine); and chrysocolla chalcedony from Taiwan. The posters were displayed in an exhibition area where delegates could also interact with instrument manufacturers, publishers, professional organisations and mineral dealers.

Three additional oral presentations were given at an evening reception hosted by the Gemmological Association of Australia on 14 August. **Dr Gaston Giuliani** described the geological occurrence of Colombian emeralds, and also traced their early mining history. **Dr Lee Groat** recounted gem-exploration activities on Baffin Island, where the major challenges are the sparse infrastructure (with accompanying large expenses necessary to mobilise work parties in this area), extensive permitting and the presence of polar bears that are known to stalk humans for their next meal. **This author** closed the evening with an update on tourmaline, demantoid and diamond mining in Namibia (see *The Journal*, Vol. 36, no. 1, pp. 8–9 and 16–18).

Brendan M. Laurs FGA

Learning Opportunities

CONFERENCES AND SEMINARS

Fabergé Museum International Academic Conference: Jewellery Art of the 19th and Early 20th Centuries
20–22 September 2018
St Petersburg, Russia
https://fabergemuseum.ru/en/news/article/118

Goldsmiths' Fair 2018
25 September–7 October 2018
London
www.goldsmithsfair.co.uk/talks
Note: Includes a seminar programme

2018 GIA Symposium: New Challenges. Creating Opportunities
7–9 October 2018
Carlsbad, California, USA
https://symposium.gia.edu

ASMOSIA XII: Association for the Study of Marble & Other Stones in Antiquity International Conference
8–14 October 2018
Izmir, Turkey
www.asmosia2018.com

2nd World Emerald Symposium
12–14 October 2018
Bogotá, Colombia
www.emeraldsymposium.com

CIBJO Congress 2018
15–17 October 2018
Bogotá, Colombia
www.cibjo.org/congress2018

Canadian Gemmological Association Gem Conference 2018
19–21 October 2018
Vancouver, British Columbia, Canada
http://canadiangemmological.com/events-conferences/upcoming-conferences

Friends of Mineralogy, Pacific Northwest Chapter, 2018 Symposium—Minerals of California
19–21 October 2018
Kelso, Washington, USA
http://pnwfm.org/2017/12/19/2018-symposium-minerals-of-california

The Munich Show: Mineralientage München
26–28 October 2018
Munich, Germany
https://munichshow.com/en/the-munich-show/public-days/highlights
Note: Includes a seminar programme

Singapore Jewellery & Gem Fair 2018
26–29 October 2018
Singapore
www.singaporejewellerygemfair.com/JewelTalk
Note: Includes seminar programme

Gem-A Conference 2018
3–4 November 2018
London
https://gem-a.com/event/conference

7º Simpósio Brasileiro de Geologia do Diamante (7th Brazilian Symposium on Diamond Geology)
4–9 November 2018
Salvador, Bahia, Brazil
www.simposiododiamantebahia.com.br/en/
Note: Optional field trip to the Braúna diamond mine

Geological Society of America 130th Annual Meeting
4–7 November 2018
Indianapolis, Indiana, USA
https://community.geosociety.org/gsa2018/home
Session of interest: 'Gemological Research in the Twenty-First Century—Characterization, Exploration, and Geological Significance of Diamonds and Other Gem Minerals'

16th Swiss Geoscience Meeting
30 November–1 December 2018
Bern, Switzerland
https://geoscience-meeting.ch/sgm2018
Note: Includes a gemmology session

21st FEEG Symposium
19–20 January 2019
Vicenza, Italy
www.feeg-education.com/symposium
Note: Takes place during the Vicenzaoro international gold and jewellery show

AGTA Gemfair
5–10 February 2019
Tucson, Arizona, USA
www.agta.org/tradeshows/gft-seminars.html
Note: Includes a seminar programme

2019 Tucson Gem and Mineral Show
14–17 February 2019
Tucson, Arizona, USA
www.tgms.org/show
Note: Includes a seminar programme

Inhorgenta Munich
22–25 February 2019
Munich, Germany
www.inhorgenta.com/events-news/inhorgenta-forum
Note: Includes a seminar programme

Gem-A Midlands Branch Conference
23 February 2019
Birmingham
Email louiseludlam@hotmail.com

Hasselt Diamond Workshop 2019: SBDD XXIV
13–15 March 2019
Hasselt, Belgium
www.uhasselt.be/UH/SBDD/SBDD-XXIV

Initiatives in Art and Culture (IAC) 9th Annual International Gold Conference
4–5 April 2019
New York, New York, USA
http://artinitiatives.com

American Gem Society Conclave 2019
8–10 April 2019
Seattle, Washington, USA
www.americangemsociety.org/page/conclave2019

55th Gemboree 2019
19–22 April 2019
Rockhampton, Queensland, Australia
http://aflaca.org.au/gemboree
Note: Includes a seminar programme

European Gemmological Symposium 2019
24–26 May 2019
Idar-Oberstein, Germany
www.dgemg.com/en/organisation/16-newsletter/termine/385-european-gemmological-symposium-2019.html

Geological Society of Namibia 50th Anniversary Conference
1–4 September 2019
Windhoek, Namibia
www.gssa.org.za/?p=4214
Note: Possible field trip to diamond mining areas in Namibia

EXHIBITIONS

Europe

Empire of the Sikhs
Until 23 September 2018
The Brunei Gallery,
School of Oriental and African Studies,
University of London
http://www.soas.ac.uk/gallery/empire-of-the-sikhs

Pearls: Treasures of the Seas and Rivers
Until 1 October 2018
State Historical Museum, Moscow, Russia
www.shm.ru/shows/11652

The Art of Power: Habsburg Women in the Renaissance
Until 7 October 2018
Schloss Ambras, Innsbruck, Austria
www.schlossambras-innsbruck.at/en/visit/exhibitions/the-art-of-power

Splendours of the Subcontinent: A Prince's Tour of India 1875–6
Until 14 October 2018
The Queen's Gallery, Buckingham Palace, London
http://tinyurl.com/y84c2dr9

The Splendour of Power
Until 21 October 2018
Museet på Koldinghus, Kolding, Denmark
www.koldinghus.dk/uk/exhibitions-2017/the-splendour-of-power-2018.aspx

Le Trésor de Preslav
Until 5 November 2018
Louvre Museum, Paris, France
http://mini-site.louvre.fr/trimestriel/2018/Agenda_juin_aout_2018/10

Russia: Royalty & the Romanovs
9 November 2018–28 April 2019
The Queen's Gallery, Buckingham Palace, London
http://tinyurl.com/ybecrdbj

Designers & Jewellery 1850–1940: Jewellery & Metalwork from The Fitzwilliam Museum
Until 11 November 2018
The Fitzwilliam Museum, Cambridge
http://tinyurl.com/ybvy7oj6

Bijoux-Bijoux! Costume Jewellery from Chanel to Dior
13 November 2018–27 January 2019
Kunstgewerbemuseum, Berlin, Germany
www.smb.museum/en/exhibitions/detail/bijoux-bijoux-modeschmuck-von-chanel-bis-dior.html

Horta & Wolfers: Reopening of the Wolfers Frères Jewellery Store, 1912
Until 30 December 2018
Art & History Museum, Brussels, Belgium
www.kmkg-mrah.be/expositions/horta-wolfers

The Portland Miniatures: Joel Arthur Rosenthal
Until 31 December 2018
The Harley Gallery, Worksop, Nottinghamshire
www.harleygallery.co.uk/exhibition/the-portland-miniatures-joel-arthur-rosenthal

From Zeus to Earth and from Chile to Neapolis
Until 31 December 2018
Ilias Lalounis Jewelry Museum, Athens, Greece
http://lalaounis-jewelrymuseum.gr/en/exTdetails.asp?exid=39

East Meets West – Jewelled Splendours of the Art Deco Era
Until 6 January 2019
Pforzheim Jewellery Museum, Germany
www.schmuckmuseum.de/en/current.html

Hidden Gems: Scotland's Agates
Until 6 January 2019
National Museum of Scotland, Edinburgh
www.nms.ac.uk/national-museum-of-scotland/whats-on/hidden-gems-scotland-s-agates

BVLGARI. Tribute to Femininity. Magnificent Roman Jewels
Until 13 January 2019
The Moscow Kremlin Museums, Russia
http://tinyurl.com/yahq83nk

The Crown of Kerch: Treasures from the Dawn of European History
Until 29 September 2019
Neues Museum, Berlin, Germany
www.smb.museum/en/exhibitions/detail/die-krone-von-kertsch.html

North America

Centuries of Opulence: Jewels of India
Until 10 October 2018
GIA Museum, Carlsbad, California, USA
www.gia.edu/gia-museum-exhibit-centuries-opulence-jewels-india

American Jewelry from New Mexico
Until 14 October 2018
Albuquerque Museum, New Mexico, USA
www.cabq.gov/culturalservices/albuquerque-museum/exhibitions/american-jewelry

East Meets West: Jewels of the Maharajas from The Al Thani Collection
3 November 2018–24 February 2019
Legion of Honor Museum, San Francisco, California, USA
http://legionofhonor.famsf.org/exhibitions/east-meets-west

Jewelry: The Body Transformed
12 November 2018–24 February 2019
The Met, New York, New York, USA
www.metmuseum.org/exhibitions/listings/2018/jewelry

Crowns of the Vajra Masters: Ritual Art of Nepal
Until 16 December 2018
The Met Fifth Avenue, New York, New York, USA
https://metmuseum.org/exhibitions/listings/2017/crowns-of-vajra-masters

Fabergé Rediscovered
Until 13 January 2019
Hillwood Estate, Museum & Gardens, Washington DC, USA
http://hillwoodmuseum.org/faberge-rediscovered

Beadwork Adorns the World
Until 3 February 2019
Museum of International Folk Art, Santa Fe, New Mexico, USA
http://internationalfolkart.org/exhibition/3348/beadwork-adorns-the-world

Treasures of a Desert Kingdom: The Royal Arts of Jodhpur, India
9 March–2 September 2019
Royal Ontario Museum, Toronto, Ontario, Canada
www.rom.on.ca/en/exhibitions-galleries/exhibitions/rajasthan

OTHER EDUCATIONAL OPPORTUNITIES

Gem-A Workshops and Courses
Gem-A, London
https://gem-a.com/index.php/education/courses

- Understanding Gemstones
  5 October 2018, 10 and 28 January 2019
- Understanding Gemstone Testing
  12 October 2018, 11 and 29 January 2019
- Understanding Diamond Grading
  16 November 2018, 10 and 31 January 2019
- Understanding Diamond Simulants
  23 November 2018, 11 January 2019, 1 February 2019
- Investigating Gemstone Treatments (Intermediate)
  7 December 2018, 3 May 2019
- Ruby, Sapphire and Emerald (Intermediate)
  26 October 2018
- Investigating Jade and Its Imitations (Intermediate)
  19 October 2018, 8 March 2019
- Diamond Grading and Identification Course
  24–28 September 2018, 22–26 October 2018, 25 February–1 March 2019
- Investigating Gemstone Treatments
  7 December 2018
- Diploma Preparation (new for 2018, UK only)
  28 January–1 February 2019
  3 days practical, 2 days theory

Lectures with Gem-A's Midlands Branch
Fellows Auctioneers, Augusta Street, Birmingham
Email louiseludlam@hotmail.com

- Craig O'Donnell—Styles & Stones
  28 September 2018
- Paul Phillips—Photography & Micro Photography
  19 October 2018
- Vanessa Paterson—Amber
  30 November 2018

Lectures with the Society of Jewellery Historians
Society of Antiquaries of London, Burlington House, London
www.societyofjewelleryhistorians.ac.uk/current_lectures

- Christopher Thompson Royds—My Work as a Jeweller
  25 September 2018
- Anna Tabakhova—Clasps: 4000 Years of Fasteners in Jewellery
  23 October 2018
- Helen Ritchie—Designers and Jewellery: Jewellery and Metalwork from the Fitzwilliam Museum 1850–1940
  27 November 2018
- Martin Henig—Personal Cameos of Roman Date in the Content Family Collection
  22 January 2019
- Jack Ogden—TBA
  26 February 2019
- Peter Semrád—The Story Behind 'Hungarian' Opals
  26 March 2019
- Beth Wees—TBA
  25 June 2019
- Rachel Church—Brooches, Badges and Pins at the Victoria and Albert Museum
  26 November 2019

New Media

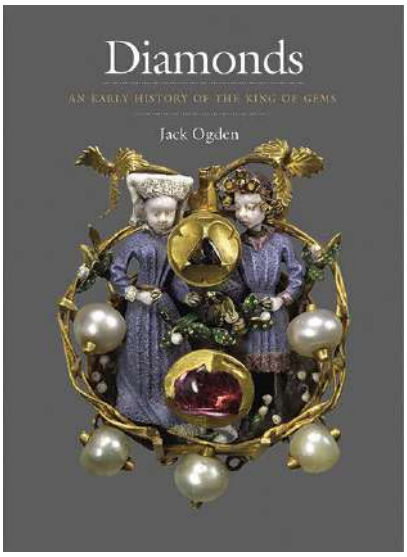

Diamonds—An Early History of the King of Gems

By Jack Ogden, 2018. Yale University Press, New Haven and London, http://tinyurl.com/Yale-Ogden-Diamonds, 408 pages, illus., ISBN 978-0300215663. £30.00 hardcover.

'The aim of this book is to consider the history of the trade in diamonds from India to Europe and the Near East, from its roots some two and a half thousand years ago until the early 1700s, when the diamond deposits in Brazil displaced India as the world's primary supplier' (Preface, p. x). This is what author Jack Ogden declares to be his intention, but in reality, this volume offers a lot more. Among other things, Ogden also delivers a history of the development of diamond cutting and its influence on jewellery styles, and he explains how the myths and legends from ancient times have gradually given way to real facts and figures. In 15 chapters, Ogden guides the reader through these topics.

In Chapter 1, 'The Diamond', Ogden presents what we know from the scarce old sources about what people in the ancient world believed to be the characteristics of diamonds—covering the well-known myths, from their indestructibility to their solubility in buck's blood, as well as the famous 'Valley of Gems'—and their social function in ancient cultures. Diamonds had always been rare and represented not only great wealth, but also high status and power. Interestingly, their oldest use seems to have been for grinding and as polishing powder for the cutting of other gems. In jewellery, only well-formed, uncut octahedra were used. Of the few surviving jewels, the oldest is a Hellenistic ring from Afghanistan of ca. 300 BC, after the Alexandrian Conquest.

Chapter 2 describes the role of diamonds in 'The Ancient World', where—not surprisingly—the most important source of information is Pliny's *Natural History*. Chapter 3 gives an outline of what old Eastern sources reveal about diamonds in 'Early Persia and the East'. All diamonds at the time came from India, but only smaller stones reached the Mediterranean World and these were initially used for cutting, drilling and grinding. Only after the increased contact with India following the expansion of the Macedonian kingdom by Alexander the Great were diamonds also used more and more in jewellery. In Chapter 4, Ogden describes the situation in 'Medieval Europe'. After the arrival of the Sasanian Persians and the westward expansion of Islam in the Near East, the old trade routes were almost cut off, and only small amounts of diamonds trickled into Europe. Diamonds were nearly forgotten during the so-called Dark Ages. This also explains why it is only after ca. 1200 AD that one finds the first clear documentary evidence for diamonds in medieval European jewellery. The first surviving jewels date from the later 1300s.

The following six chapters are dedicated to diamond polishing and cutting, 'the most fundamental development in the history of diamond' (p. 79). Chapter 5 considers 'The Dawn of Diamond Cutting in Europe'. According to the sparse evidence, the cutting process had probably been understood by 1300 AD. It all started with the discovery that the faces of diamond crystals could be polished with diamonds. Inevitably, this discovery led to diamond polishing in India, but it was in Europe where 'The Fifteenth-Century Technical Revolution' (Chapter 6) took place: the invention of a horizontal rotating iron wheel (scaife) and other tools, which are still in use to this day. The following chapters describe the different stages of diamond cuts from 'Renaissance Table and Point Cuts' (Chapter 7) to 'Renaissance Multifaceted Cuts' (Chapter 8) to 'The Early Brilliant Cut' (Chapter 9). Generally speaking, the simple cuts of tables and roses were eventually replaced by sparkling brilliants, made possible by the advancements of 'cutting-edge' cutting technology, and the innovative spirit of the cutters. Chapter 10 discusses 'Diamond Cutting in London', following England's rise as a colonial power. With the establishment of the East India Company in 1600, large quantities of diamonds began to reach England. Within a relatively short time, London became a major cutting and trading hub, and it was the main diamond cutting

centre until Amsterdam and Antwerp took over about a century later.

Chapter 11 covers 'The Value and Assessment of Diamonds', where the author states that 'in the past, as today, diamonds were a sign of wealth, if not wealth itself, and their value was of concern to dealers and owners alike' (p. 203). Ogden follows diamond prices through the ages and the criteria for the assessment of the diamond qualities, as well as the motivations behind both. He stresses the great importance of honesty and experience, quoting Thakkura Pheru (India, 14th century): 'Those who fix a high price for an inferior gem or a low price for a superior gem, due to arrogance or avarice, will become lepers' (p. 231).

The last four chapters are dedicated mainly to India. They describe 'The Indian Diamond Mines' (Chapter 12), 'The Diamond Trade in India' (Chapter 13), 'Diamond Cutting in India and the East' (Chapter 14) and, finally, 'The Eclipse of Indian Diamonds' (Chapter 15). In all four chapters it becomes evident that the 'knowledge' described in ancient sources was mostly a compilation of myths and legends (e.g. the Valley of Gems). With growing contacts, first by people such as Marco Polo, and later by traders such as Jean-Baptiste Tavernier and the activities of the major trade organisations such as the East India Company, more and more first-hand information reached the Western World and created a detailed and realistic picture of the situation in the Orient.

After a short epilogue, the volume is rounded off with an appendix reproducing Nathanial Cholmley's *A Description of the Diamond-Mines* of 1677, followed by an impressive bibliography of 462 titles and an index, which contains primarily names and places, with less than a tenth of the entries devoted to general keywords.

With this book, Ogden does not claim to reinvent the wheel:

> This is not the first study of the history of diamonds and their cutting—there is Godehard Lenzen's 1970 study—but new research means that we can supplement or suggest some reconsideration of the findings of his and older works (Preface, p. x).

Nor does he claim to have exhaustively covered the topic:

> There will always be further archives, inventories and collections that could shed light on this subject, there is much of relevance out there in myriad languages (…) that will have to await consideration by those with the relevant skills (Preface, p. xi).

On the other hand, he states that 'this book has been interesting and enjoyable to research and write' (Preface, p. xi). I would like to add that reading it was equally enjoyable and interesting. It is written in an easily readable, yet eloquent, style and Ogden manages to present the history of diamonds as an exciting adventure, while at the same time he has written a well-researched scholarly work. Ogden's meticulous and painstaking approach leads to an almost flawless result (in fact, I stumbled over just one error: the author talks about 'the Florentine Diamond, now in Vienna' [p. 215], which is surprising, as this stone was stolen in 1918 and has never turned up again). To complement the text, this book is richly illustrated with pictures of old diamond jewels and images from old sources, some of which are rare and difficult to find.

All in all, Ogden's early history of diamonds is not only an impressive scholarly masterpiece, but is also a great pleasure to read which I would recommend to everyone.

Dr Rolf Tatje
Duisburg, Germany

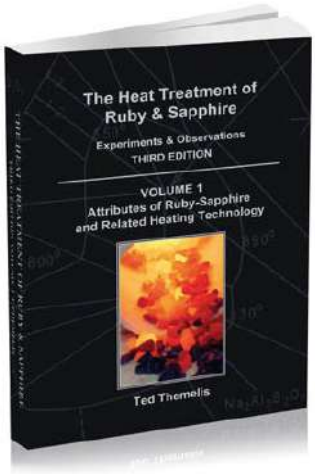

The Heat Treatment of Ruby & Sapphire: Experiments & Observations, 3rd edn., Vol. 1: Attributes of Ruby-Sapphire and Related Heating Technology

By Ted Themelis, 2018. Self-published, http://themelis.com/Books-Heat-TRS3.html, 294 pages, illus., ISBN 094-0965577. US$150.00 hardcover.

When I was invited to review this book I was very excited, since I have long been curious about the processes that happen when a gemstone is heated, but never had the chance to get actively involved. When I then held the book in my hand, I almost rejected the task because it was full of so much information that it seemed impossible to get through. However, the more

I read, the more I was captivated by it.

In his preface, Themelis points out that this book is not intended to be scientific, and the results presented are often based on trial and error without any explanations behind them. He also gives a short rundown on the instruments, furnaces and samples that he has used for his experiments.

The book then starts with a very informative chapter about the history of heating corundum, giving some early accounts, and then delving into more precise descriptions when heat treatment became more common in the 1970s. Themelis then goes into the history of heating corundum from certain origins.

Following the historical part, there is a wild mix of introductory subjects, including corundum definitions, disclosure issues, stability of heat treatments, values of the treated gems compared to their untreated counterparts, as well as information about the gem trade and various markets, economic impact, the value of gemstone reports, gemmologists in the trade, technologies for heat treatment, and the physical and chemical properties of corundum. For a laboratory gemmologist like myself, some of these subjects (e.g. various markets and worldwide heat-treatment facilities) were extremely interesting because I am not often exposed to them. However, I missed seeing a paragraph about trade shows, and also sample reports from the various laboratories (at least the better-known ones).

The next two chapters are dedicated to the properties of corundum and the effect of heat treatment on them. A detailed account of all possible colour impurities and irregularities is given, often with further explanations on their reaction to heat treatment, accompanied by numerous images of corundum from various localities, as well as charts for a better understanding. Themelis also describes different types of colour zoning and other defects such as twinning, parting, fissures, etc., and their effects on the outcome of heat treatment. A large part of the book is concerned with the description of internal features in corundum, again noting how they are affected by heat treatment. This includes not only mineral inclusions, but also fluid inclusions, 'silk' and staining in fissures. Material on the surface of a stone is also covered. A special section mentions inclusions separately in alphebetical order with their origins and melting points. The descriptions in these chapters are complemented by numerous images.

Starting with Chapter 5, the volume covers the practical side of heat treatment. It lists various heating parameters for different cases with detailed explanations of why it is important to choose certain steps, and explains the types of heating environments and the gases that are used. This is followed by a chapter that alphabetically lists additives in the heating process, with their chemical formulas, melting points and where and how they are used. Themelis then goes on to review other additives such as fertilisers, natural substances, etc., followed by helpful notes.

In Chapter 8, Themelis describes the entire methodology involved in heating corundum, starting with identifying rough material in the field and sorting it from other gem materials. He also gives an overview of classical gemmology, as well as advanced gemmological instruments for identification found in major gemmological laboratories, before continuing with a sub-chapter on the chemical cleaning of corundum. He lists all the acids that are used in various cleaning processes, generally with a description of the substance it is supposed to remove, the necessary equipment and a detailed description of how to clean the corundum. He then describes pre-burning processes and why they are performed, why shaping the rough stones may be necessary, how to assess certain features and attributes of the corundum, and how to classify it into different groups. Afterwards, he explains step by step how to determine the appropriate heating process, with many tips on what to watch out for when loading the crucible, choosing the right atmosphere, running the heating process, retrieving the stones and assessing the results.

In Chapter 9, Themelis gives a rundown of heating equipment from blow pipes to primitive furnaces to the most complicated electric furnaces. This chapter again gives many examples of which corundum is heated with which oven, together with some historical data from the 1980s. It is followed in Chapter 10 by an account of problems and damage that can occur during the heating process, be it failure of the instrument, overheating or contamination, as well as the effects fluxes may have on equipment.

The final chapter (Chapter 11) gives a classification of the heating processes for ruby and sapphire, accompanied by flow charts and before-and-after images of treated corundum. Here, I was a bit puzzled about the group classifications in the flow charts because I did not see an explanation why Themelis provided these group names without using them elsewhere to describe the processes (perhaps this will be done in Vol. 2).

In conclusion, this is a very thorough book, mainly addressed toward someone wanting to learn about heat treatment, but I also highly recommend it to the interested gemmologist as there is information that is not found elsewhere (e.g. types of fluxes and cleaning

substances, the effect of heating on certain inclusions and the temperatures used for certain treatments). However, the book contains such a wealth of information based on experience that it is sometimes hard to combine the information found in the various chapters. The individual pages appear slightly overloaded with images and text, but this helps to keep the book at a reasonable size that is easy to use as a reference guide. Overall, I think it is a valuable book wherever heat treatment is concerned, and I am curious how Themelis will follow it in the second volume.

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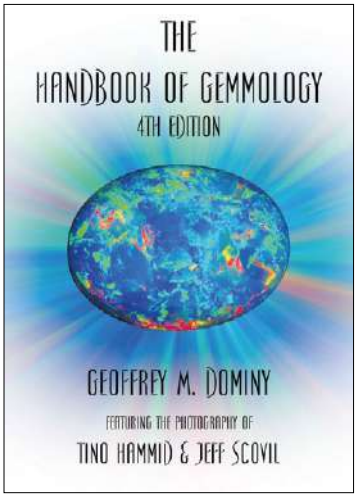

The Handbook of Gemmology, 4th edn.

By Geoffrey M. Dominy, 2017. Amazonas Gem Publications, Mallorca, Spain, http://handbookofgemmology.com, 1,342 pages, illus., ISBN 978-0991888238. US$49.95 eBook.

Now in its 4th edition, Geoffrey Dominy's digital *Handbook of Gemmology* continues its expansion into the gemmological field, creating an indispensable electronic reference that should be in every gemmologist's library. Running an impressive 1,342 pages, this edition aims to be a one-stop reference source, more easily carried and accessed than any traditional paper book of this size.

If downloaded as the 'flip-book' option, the *Handbook* comes complete with a handy overlay function that details the interactive features of the book and helps the user get the maximum potential from this format. Thumbnail previews allow the equivalent of quickly flicking through a traditional paper book, enabling sections to be easily located. The book also can be downloaded as a PDF file which, for technophobes, still allows a high level of interactivity and searchability. Colour-coded bookmarks, highlights and positionable 'post-it' notes are available, thus making each person's copy a truly unique and individual book. These features provide an interesting crossover from paper to digital format, and are bound to prove useful to those not wishing to mark up a traditional paper book. Another way to access the eBook is to log in and view it online, so there is no need to take up space on one's hard drive.

Using a columnar format, and high-quality images throughout, Dominy illustrates each chapter, often with full-page views of gemstones or features, bringing his customary style to all areas of the book.

Certain areas enjoy greater detail and more in-depth discussion than previous editions. For example, when considering atoms and bonding, Dominy includes s, p, d and f orbitals in a way that the lay person can follow. This is beyond the information provided by most other gemmological courses, but with advances in treatments and synthesis, it is increasingly important to have a greater understanding of such properties in gem materials.

Each crystal system also gets its own explanation, often covering several pages, and is related back to familiar household items, such as the tetragonal system that is explained by way of a milk carton. Crystallographic concepts are often difficult for students to grasp, which makes this a useful teaching tool. Within the same chapter the author also lists an extensive range of magnetic/paramagnetic reactions from various gem materials, an area that I have always found interesting but lacking in most mainstream texts. Dominy provides a reasonably extensive list of these magnetic reactions, covering the main gem materials that are found in today's jewellery market.

Spectroscopy and light absorption are covered in another chapter, and a variety of spectra are provided, with colour illustrations accompanied by lists of important absorption lines. With an ever-expanding use of laboratory equipment, these spectral lines play an increasing role in gemmological testing. This is demonstrated at the end of the chapter, where the visible spectrum is overlaid onto spectral traces obtained from a spectrophotometer, which allows direct comparisons to be made and eases the transition from traditional to modern laboratory gemmology.

The section on refraction covers detailed use of the refractometer and underlying theory, and gives an excellent visual representation of the distant-vision or spot method for obtaining a reading from a non-planar surface.

This is an area that many students struggle with, and this may prove useful in teaching centres globally. Beyond this, Dominy considers alternative ways of determining the RI value(s) of a stone, including Alan Hodgkinson's 'Visual Optics' and the use of immersion cells for estimating RI (and assisting with observing internal features).

In the chapter that discusses polarised light, Dominy covers the enantiomorphism of quartz, and shows how left- and right-handedness can be determined in a way often overlooked in all but the highest levels of gemmological education. Filters are also dealt with in great detail, not only in terms of results, but also regarding their construction and usage, whether something as simple as crossed polarisers or a full filter set.

The chapter on specific gravity has been updated to show a more visual representation of the various methods and principles, making it easier for the non-specialist to understand and increasing its potential use for students.

An interesting addition to this edition is a section on building a smartphone microscope camera, which is useful given the high quality of images now obtainable from most phones. In place of simply holding a smartphone over a microscope eyepiece, Dominy details how a simple apparatus can be constructed that supports the phone at a suitable distance and position for images to be captured. The pages immediately after this provide an extensive range of inclusion images, showcasing what can be done with the right equipment.

Subsequent chapters cover composite gems and synthetics. Each is covered in detail, with images and diagrams to highlight key features and what to look for when faced with specimens that are potentially laboratory grown. Synthetic diamond, as might be expected, is covered in its own in-depth section, which goes beyond prior editions of this book. Modern production techniques (both HPHT and CVD) are covered in detail, and accompanied by numerous images showing rough and cut examples. Where this edition significantly exceeds all previous ones is a description of the advanced technology currently in use to detect synthetic diamonds, even down to melee sizes. Although most readers will not have a chance to see or use these tools, Dominy gives a good explanation of their capabilities, as well as when—and in which sequence—they should be used.

The important area of treatments is given greater consideration, spanning more than 60 pages of high-quality information and illustrations, bringing the reader up to date with the latest developments. This provides an essential reference source for all levels of reader.

Both diamond and coloured stone grading are dealt with in detail. The former is to be expected in any gemmological text nowadays, but the extensive detail provided on the latter—including systems, nomenclature and processes—exceeds most other texts.

Next are a series of chapters dedicated to gem identification and ordered by colour, which are very useful for any student. Following these is an extensive 'Gemfacts' section that provides in-depth coverage of 17 gem materials. Last are a series of appendices that make useful references.

In conclusion, this updated version of *The Handbook of Gemmology* builds upon previous successes, expanding and enhancing the prior editions with new and in-depth information. Given the digital portability of this work, and the range of formats in which it is available, this continues to be a ground-breaking publication, and an essential tool for any level of gemmologist.

Editor's note: A two-volume 5th anniversary printed edition of *The Handbook of Gemmology* was released in May 2018 for €309.00 in Europe and €329.00 elsewhere.

Andrew S. Fellows FGA DGA
Birmingham City University, Birmingham

Other Book Titles

COLOURED STONES

Turquoise: The World Story of a Fascinating Gemstone, updated edn.
By Joe Dan Lowry, 2018. Gibbs Smith, Layton, Utah, USA, 256 pages, ISBN 978-1423650898. US$75.00 hardcover.

DIAMOND

Evolution of Magmatic and Diamond-forming Systems of the Earth's Lower Mantle
By Anna V. Spivak and Yuriy A. Litvin, 2018. Springer, Cham, Switzerland, 108 pages, ISBN 978-3319785172. €109.99 hardcover or €91.62 eBook.

GENERAL REFERENCE

The Jeweller's Directory of Gemstones
By Judith Crowe, 2018. Herbert Press, Bloomsbury, London, 176 pages, ISBN 978-1912217182. £20.00 softcover.

INSTRUMENTATION

Confocal Raman Microscopy
Ed. by Jan Toporski, Thomas Dieing and Olaf Hollricher, 2018. Springer, Cham, Switzerland, 596 pages, ISBN 978-3319753782. €140.17 softcover or €118.99 eBook.

Scanning Electron Microscopy and X-Ray Microanalysis, 4th edn.
By Joseph I. Goldstein, Dale E. Newbury, Joseph R. Michael, Nicholas W. M. Ritchie, John Henry J. Scott and David C. Joy, 2018. Springer-Verlag, New York, New York, USA, 550 pages, ISBN 978-1493966745. US$129.00 hardcover or $99.00 eBook.

JEWELLERY AND *OBJETS D'ART*

Boucheron: Free-Spirited Jeweler
By Anita Coppet, 2018. Abrams, New York, New York, USA, 216 pages, ISBN 978-1419734908. US$80.00 hardcover.

Fabergé: His Masters and Artisans
By Ulla Tillander-Godenhielm, 2018. Unicorn Publishing Group, London, 272 pages, ISBN 978-1911604204. £30.00 hardcover.

Seals and Status: Power of Objects
Ed. by John Cherry, Jessica Berenbeim and Lloyd de Beer, 2018. British Museum Press, London, 225 pages, ISBN 978-0861592135. £40.00 softcover.

Sustainable Jewellery: Principles and Processes for Creating an Ethical Brand
By Jose Luis Fettolini, 2018. Promopress, Barcelona, Spain, 176 pages, ISBN 978-8416851201. €27.00 softcover.

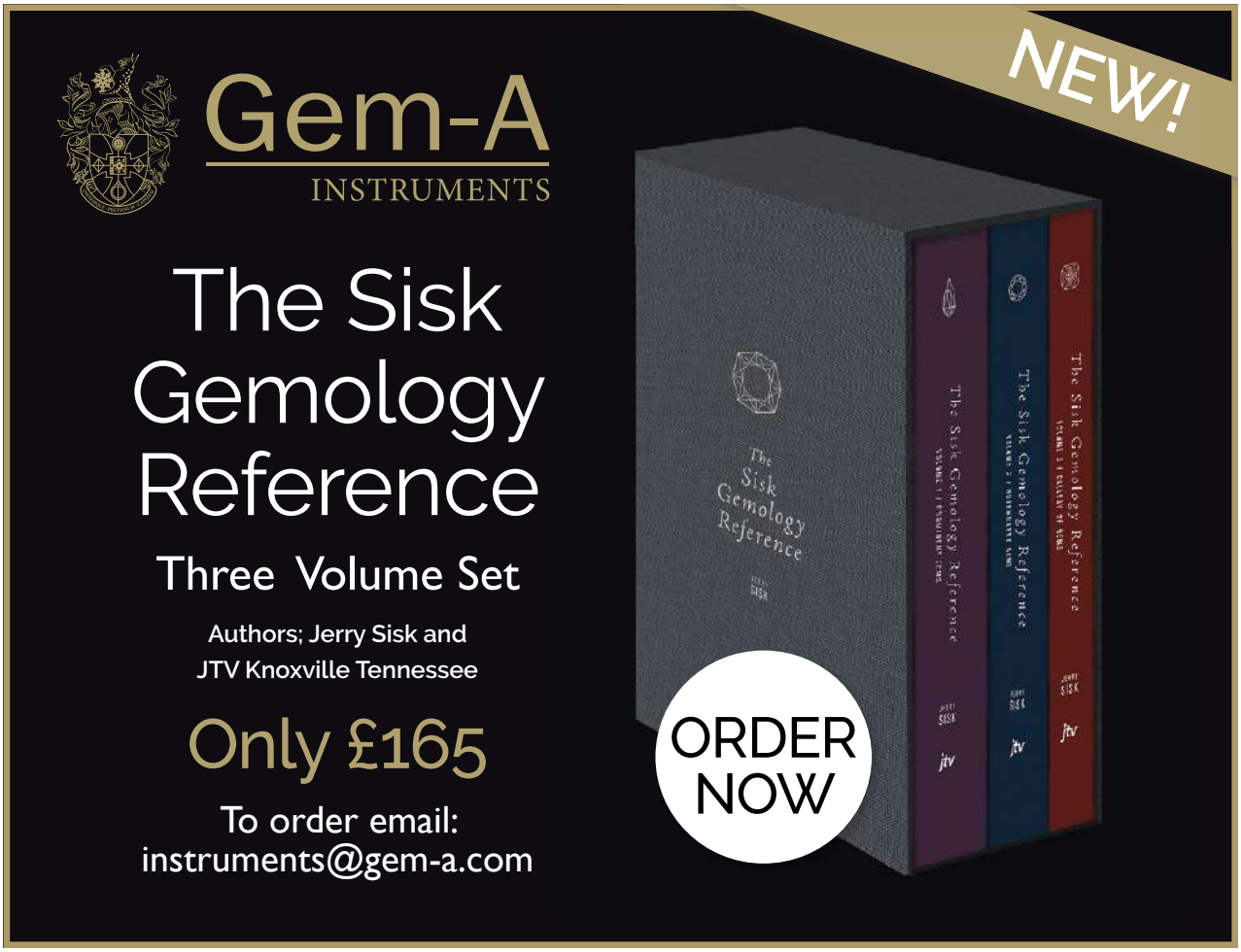

Gem-A Notices

Gifts to the Association

Gem-A is most grateful to the following for their generous donations, which will support continued research and teaching:

Jonathan Bartky, Ariel Treasures, Livingston, New Jersey, USA, for two samples of red aventurescent quartzite from Tanzania, marketed as Cherry Tanzurine.

Dr Marco Campos Venuti, Seville, Spain, for three cabochons of green-to-yellow opal from Brazil and four cabochons of trapiche-like ametrine from Brazil.

Denis Ho, Hong Kong, for a selection of African sapphires and a folding lightbox.

Adam Pearl, Cleveland, Ohio, USA, for four rough pieces of colourless cordierite from Tanzania.

Dr Lola Rafieva, London, for various beads and jewellery including coral, glass, bone and plastic.

Estelle Weiner, Cheadle, for diamond-cutting tools that once belonged to her mother, Rebecca Staal.

New Head of Education

Gem-A is delighted to announce the appointment of Nysa Pradhan as our new Head of Education. Nysa started on 28 August 2018, and is leading and developing Gem-A's worldwide educational activities. While being based at Gem-A's headquarters in London, Nysa will be visiting our teaching centres and shows around the world, so you may be seeing her sometime soon.

Gem-A Annual General Meeting

Gem-A members are invited to attend our AGM on Tuesday 2 October 2018 from 18:30 to 21:00 at the Goldsmiths Centre, Britton Street, London. Gem-A members can log onto our website to access AGM documents, and may also join us for drinks at 18:00 before the meeting.

Gem-A Conference 2018: Bringing together the greatest minds in gemmology

Gemmologists from around the world will gather in London for the annual Gem-A Conference 3–4 November. The Conference boasts an incredible line-up of speakers, including expert gemmologists from every area of the field, exclusive workshops and trips including private viewings of museum collections. Registration closes on Sunday 21 October 2018. Make sure you don't miss out on the gemmological event of the year. Register now at https://gem-a-conference-2018.eventbrite.co.uk.

Literature of Interest

COLOURED STONES

Anorthite with uvarovite garnet inclusions. E-A. Jeong, *Wooshin Gem Lab Magazine*, **5**, 2018, 16–20, www.wooshinlab.com/LabStory/Research/Read.wgk?ArticleID=212.*

Beauty created by light: Color change gemstones. M.-R. Heo, *Wooshin Gem Lab Magazine*, **5**, 2018, 28–31, www.wooshinlab.com/LabStory/Research/Read.wgk?ArticleID=212.*

Cause of tri-colour change effect of a rare garnet. Y. Shen and P. Ye, *Journal of Gems & Gemmology*, **20**(2), 2018, 17–23 (in Chinese with English abstract).

Colour grading system of emerald. Y. Zuo, C. Carmona, L. Liu, F. Wu, D. Fortaleche and Q. Lin, *Journal of Gems & Gemmology*, **20**(2), 2018, 9–16 (in Chinese with English abstract).

A common origin for Thai/Cambodian rubies and blue and violet sapphires from Yogo Gulch, Montana, U.S.A.? A.C. Palke, J. Wong, C. Verdel and J.N. Ávila, *American Mineralogist*, **103**(3), 2018, 469–479, http://doi.org/10.2138/am-2018-6164.

Gemmological and mineralogical characteristic of "Lanshui" jadeite [green jadeite from Guatemala]. L. He, J. Liu, C. Long and B. Liao, *Journal of Gems & Gemmology*, **20**(2), 2018, 31–37 (in Chinese with English abstract).

The gemological characteristics of American "mica jade" [clinostrengite]. H. Zhu, B. Sun, F. Yan, P. Wang and X. Zhao, *Superhard Material Engineering*, **29**(4), 2017, 64–66 (in Chinese with English abstract).

Gemological characterization of sapphires from Yogo Gulch, Montana. N.D. Renfro, A.C. Palke and R.B. Berg, *Gems & Gemology*, **54**(2), 184–201, http://doi.org/10.5741/GEMS.54.2.184.*

Infrared and Raman spectra of high-quality turquoise from Hubei and Anhui, China: Characteristics and significance. C. Wen-jun, G. Shi, Y. Wang, J. Ren, Y. Yuan and H. Dai, *Spectroscopy and Spectral Analysis*, **38**(4), 2018, 1059–1065 (in Chinese with English abstract).

Inhabituel quartz de Madagascar imitant naturellement une grandidierite [Unusual Madagascar quartz naturally imitating grandidierite]. J.-M. Arlabosse, *Revue de Gemmologie A.F.G.*, No. 202, 2018, 6–9 (in French).

Isotopes [*sic*] signatures of gem minerals. G. Giuliani and A.E. Fallick, *Wooshin Gem Lab Magazine*, **5**, 2018, 2–9, www.wooshinlab.com/LabStory/Research/Read.wgk?ArticleID=212.*

Out of the blue…dealing with kyanite. A. Vaia, *Rivista Italiana di Gemmologia/Italian Gemological Review*, No. 4, 2018, 41–43.

Paraíba tourmaline revisited. C. Milisenda, *InColor*, No. 39, 2018, 34–41, www.gemstone.org/incolor/39.*

The provenance of nephrite in China based on multi-spectral imaging technology and gray-level co-occurrence matrix. D. Chen, M. Pan, W. Huang, W. Luo and C. Wang, *Analytical Methods*, **10**, 2018, 4053–4062, http://doi.org/10.1039/c8ay01274a.

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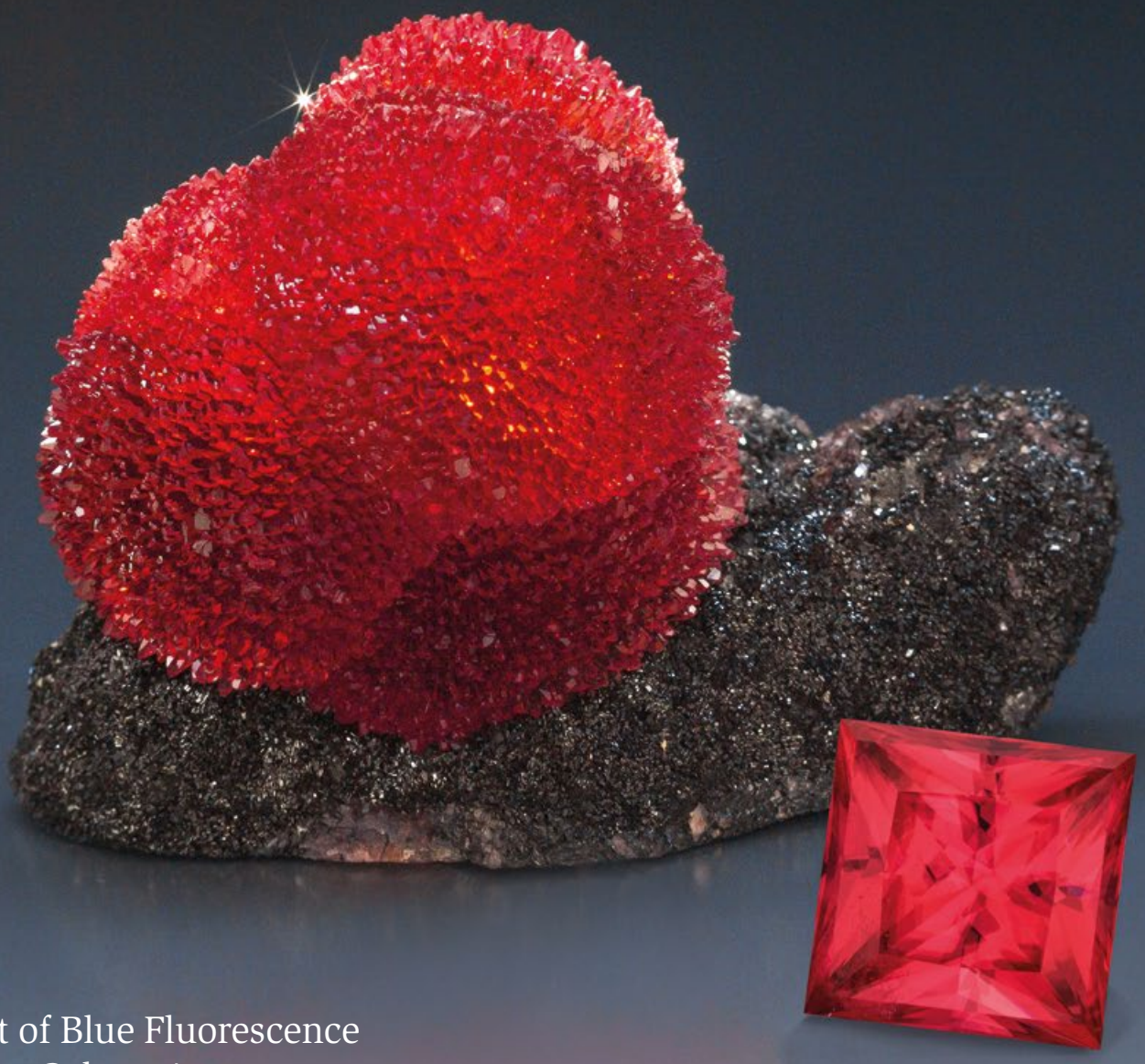

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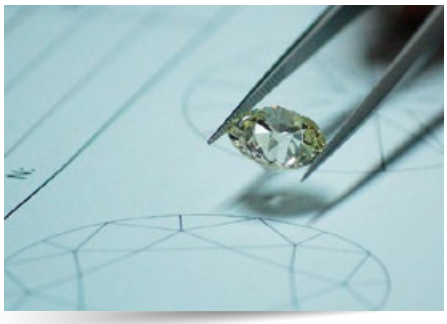

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Cover photo: *Rhodochrosite is prized as both mineral specimens and faceted stones, which are represented here by 'The Snail' (5.5 × 8.6 cm, from N'Chwaning, South Africa) and a 40.14 ct square-cut gemstone from the Sweet Home mine, Colorado, USA. For more on rhodochrosite, see the article on pp. 332–345 of this issue. Specimens courtesy of Bill Larson (Pala International/The Collector, Fallbrook, California, USA); photo by Ben DeCamp.*

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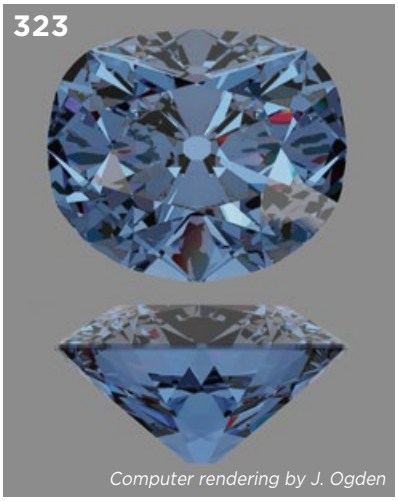

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What's New

INSTRUMENTATION

J-Smart

The newest, 6th generation J-Smart scanner from DRC Techno (Dharmanandan Research Center, Surat, India) was released in mid-2018, and identifies both CVD and HPHT laboratory-grown diamonds. It supersedes DRC Techno's J-Secure technology (see What's New section, Vol. 35, No. 4, 2016, pp. 271–272), and this version of J-Smart has a smaller footprint and provides faster results (90 seconds) than the previous model. The instrument can be used to screen loose or mounted diamonds 0.003 ct and larger of any shape in D through J colours. The 9 × 5½ inch (23 × 14 cm) scanning tray allows for large-scale examination of store inventories or manufacturing production. Visit www.drctechno.com/Products.aspx.

SciAps Handheld LIBS Unit

In February 2018, USA-based SciAps Inc. released its latest version of the handheld laser-induced breakdown spectroscopy instrument called the Z-300. The unit has three spectrometers for a range of 190–950 nm, making it capable of measuring every element in the periodic table from H to U. It comes with Android OS software that allows the user to customise calibrations for a variety of materials. As for all LIBS devices, a certain amount of material is vaporised, in this case with a 100 µm spot size. The unit has a replaceable cartridge to provide an argon purge to boost the signal, which is especially valuable for measuring light elements. The instrument weighs 1.8 kg with the battery and measures ~21 × 29 × 12 cm. Visit www.sciaps.com/libs-handheld-laser-analyzers/z-300.

SYNTHdetect XL

The International Institute of Diamond Grading & Research, part of the De Beers group of Companies, announced the latest generation of its synthetic diamond screening device in September 2018. Like its predecessor (see What's New section, Vol. 35, No. 8, 2017, p. 688), the 'XL' model uses time-resolved photoluminescence to screen colourless to near-colourless loose and mounted diamonds. The new model, however, can process multiple items at a faster rate and accommodates larger jewellery pieces. Visit www.debeersgroup.com/media/company-news/2018/iidgr-introduces-synthdetect-xl.

NEWS AND PUBLICATIONS

Bursztynisko, The Amber Magazine

The September 2018 issue (No. 42) of *Bursztynisko* is now available at https://issuu.com/internationalamberassociation/docs/bursztynisko_42_internet. Articles include a history of the Bursztyny cooperative, where amber artefacts were produced for over a century; the oldest surviving description of animal inclusions in Baltic amber; assorted short notes on amber specimens, jewellery and events; reports on notable recent exhibitions and promotions worldwide; and mid-infrared spectroscopy testing of resins.

De Beers *Diamond Insight Report 2018*

THE DIAMOND INSIGHT REPORT 2018

This annual report from De Beers covers major trends in the diamond value chain based on 2017 data. Demand for diamond jewellery continued to rise in 2017, primarily driven by the USA and China. Midstream trading stabilised following monetary changes that affected the Indian cutting/polishing industry, while diamond production worldwide in 2017 increased 14% over 2016. Analysis of the market indicates a need for the industry to align with the desires and values of Millennials and Generation Z. Download the report at www.debeersgroup.com/reports/insights/the-diamond-insight-report-2018.

The World Jewellery Confederation

CIBJO 2018 Special Reports

In August–October 2018, CIBJO released eight Special Reports in advance of the 2018 CIBJO Congress. The Coloured Stone Commission report covers responsible practices. The Coral Commission report surveys various topics related to sustainability and education. The Diamond Commission report looks at terminology used to distinguish natural from synthetic diamonds. The Ethics Commission report focuses on the impact on the jewellery industry of the revised Guides released by the U.S. Federal Trade Commission. The Gemmological Commission report gives results of a survey of worldwide gem labs about how they report on synthetic and treated diamonds. The Marketing & Education Commission report focuses on the impact on the jewellery market of Generation Z. The Pearl Commission report looks at the industry's commitment to marine sustainability. The Precious Metals Commission report examines the influence of political, regulatory and ISO decisions on the jewellery industry. Download them all at www.cibjo.org/news.

SAIMM THE SOUTHERN AFRICAN INSTITUTE OF MINING AND METALLURGY

Diamonds — Source to Use 2018 Proceedings

Slide presentations and full papers are available online as individual PDF files from this 11–14 June 2018 conference organised by The Southern African Institute of Mining and Metallurgy, held in Johannesburg, South Africa. They cover extensive information about the geology and mining of African diamonds, including exploration, recovery and development of specific mines, as well as keynote addresses by Ernie Blom (World Federation of Diamond Bourses) on the state of the diamond market and James A. H. Campbell (Botswana Diamonds) on financing diamond projects. Of particular interest to gemmologists is an article on De Beers' diamond verification instruments and associated research. Download the files at www.saimm.co.za/Conferences/Diamonds2018.

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SYNTHETIC MOISSANITE AS 'FAKE' DIAMOND ROUGH

Since the later part of 2017, synthetic moissanite presented as rough diamond crystals, fashioned in the form of octahedrons (mostly distorted), has been a regular feature at the Gem Testing Laboratory, and that too, in impressive sizes of up to 16.51 carats. Recently, we received a light yellow sample (figure 1) of synthetic moissanite weighing 4.88 ct, fashioned as octahedron with flattened and rounded corners, displaying a frosty surface, typically associated with diamond rough.

Closer examination of the sample indicated that the angles and patterns of the crystal were not consistent with that of a diamond. The surface features (responsible for the frosty appearance) ranged from hexagonal to pyramidal to rectangular on different faces (figure 2), whereas, a similar pattern of growth features is expected in a diamond crystal, because of its cubic nature. It was interesting to note that two opposite faces displayed hexagonal patterns (etch pits as well as growth hillocks), while the faces oriented perpendicular to these, displayed rectangular patterns; the intermediate areas displayed pyramidal patterns. This sample further displayed conical tube-like inclusions oriented in one direction, along the length of the rectangular growth patterns or perpendicular to the hexagonal patterns. Such growth features are often seen in crystals belonging to hexagonal or trigonal crystal systems.

The crystal pattern and growth features were sufficient enough to rule out the possibility of diamond rough, while identity of this specimen was established on the basis of its doubly refractive nature under crossed-polars, hydrostatic specific gravity of 3.20, infra-red and Raman spectroscopy.

1. This 4.88 ct light yellow synthetic moissanite, fashioned as octahedron with frosted surface was presented as diamond rough.

2. The moissanite crystal displayed hexagonal etch pits and growth hillocks on faces perpendicular to 'c' axis (top, right), rectangular hillocks on faces parallel to 'c' axis (bottom, right), and pyramidal patterns at intermediate faces (top). Also note the conical tubes oriented along the 'c' axis (top).

Gem Testing Laboratory (Jaipur, India) Newsletter

The July 2018 (Vol. 76) issue of GTL Jaipur's Lab Information Circular is available at http://gtljaipur.info/ProjectUpload/labDownLoad/LIC76_July%202018.pdf. It describes recent notable items submitted to the laboratory, including a fake diamond octahedron made of synthetic moissanite, a garnet-and-glass doublet, a jade-like carving of saussurite, an orange cabochon of triphylite-natrophilite, banded sphalerite marketed as 'schalenblende' and polymer-filled rubies.

IMA List of Gem Materials Updated

The Commission on Gem Materials of the International Mineralogical Association updated its list of gem materials in July 2018. A work in progress, the list includes names of gem materials (with their IMA status, if any), formulae for those with IMA status, comments (such as mineral or mineral group, colour information, etc.), and selected references. In the gem material name column, entries are shown in normal font for minerals, boldface for non-minerals (varieties and trade names), all caps for rocks, and italics for organics and glasses. To download the list, go to www.ima-mineralogy.org/docs/IMA_CGM_List_(2018-07).pdf.

Journal of Jewellery Research

A new annual peer-reviewed, open-access journal on jewellery was initiated in February 2018. Edited by Roberta Bernabei, the focus is on the 'design, theory, and praxis of jewellery studies'. Articles encompass the discussion and analysis of jewellery, both contemporary and historical, with an emphasis on visual presentation. Volume 1 includes articles on body imagery, design of digital devices, jewellery materials, jewellery from ancient burials, and the personal meanings of jewellery. Volume 2 is scheduled to go online in February 2019. Visit www.journalofjewelleryresearch.org.

OTHER RESOURCES

'The Curse of the Hope Diamond' Podcast

In August 2018, the Smithsonian Institution in Washington DC, USA, released a podcast on the Hope diamond. The 28-minute audio feature covers some of the less-than-fortunate episodes in the history of this famous blue diamond (on permanent display at the Smithsonian's National Museum of Natural History). Do these stories really mean that the Hope Diamond is cursed? To hear the tales, including interviews with

Smithsonian experts, and decide for yourself, visit www.si.edu/sidedoor/ep-1-curse-hope-diamond.

MISCELLANEOUS

New Diamond Museum in Antwerp

The city of Antwerp in Belgium has been a centre of the diamond industry for more than five centuries. May 2018 marked the opening of a new museum called 'DIVA, Antwerp Home of Diamonds' (www.divaantwerp.be), which features diamonds, jewellery (see photo above) and silversmithing. It is located in the historical heart of Antwerp (address: Suikerrui 17–19), and has a permanent hall exhibiting Antwerp's diamond story, as well as space for temporary exhibitions presented by guest curators.

Photo © DIVA, Antwerp Home of Diamonds

The first special exhibition, named 'Room of Wonder I: Axel Vervoordt', opened in October 2018 and will be on display until 28 April 2019. Axel Vervoordt is an antiquarian and interior designer who drew upon DIVA's collection and also added various loans. Among them, Pascal Entremont was invited to exhibit approximately 30 pieces of his rare gems collection. Entremont authored the 1998 book *Chasseur de Pierres* (*Gem Hunter*) and has amassed a private collection of hundreds of gems (currently available for sale) over the past 30+ years. Some of these stones were recently described in *The Journal* or are in preparation for future issues: 'Ceylon Stars', the largest known 12-rayed star sapphire from Sri Lanka, weighing 112.64 ct (Vol. 35, No. 5, 2017, pp. 430–435); 'Time Quartz', a 50.55 ct faceted rock crystal exhibiting an outstanding 'pinwheel' inclusion of black tourmaline (Vol. 35, No. 7, 2017, pp. 586–587); 'Two Pound Star', one of the world's largest star garnets at 5,737 ct; and 'Radjāh', a 149.90 ct intense pink spinel from Badakhshan (see photo below). For more information on 'Room of Wonder I: Axel Vervoordt', visit www.divaantwerp.be/en/visit/events-exhibitions/room-of-wonder-i-axel-vervoordt.

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Photo by T. N. Bui

What's New provides announcements of new instruments/technology, publications, online resources and more. Inclusion in What's New does not imply recommendation or endorsement by Gem-A. Entries were prepared by Carol M. Stockton unless otherwise noted.

The Fire Within

"For in them you shall see the living fire of the ruby, the glorious purple of the amethyst, the sea-green of the emerald, all glittering together in an incredible mixture of light."

– Roman Elder Pliny, 1st Century AD

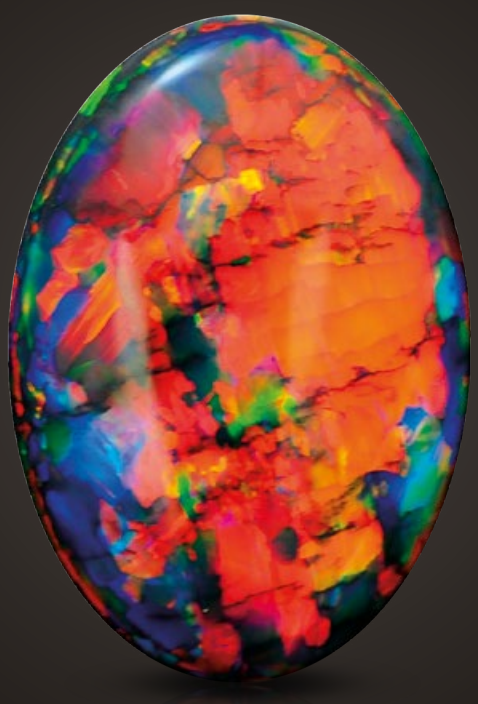

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Gem Notes

COLOURED STONES

Figure 1: This selection of brooches from the W. G. Rutherfurd collection demonstrates the beauty of picture agates and jaspers that were probably collected in New Zealand around 1912. Clockwise from the upper left: specimen BM.1985,MI15557 is mounted in a brooch with the likeness of a goat's head, while the other specimens portray landscapes (BM.1985,MI15555 'Sepia Seascape'; BM.1985,MI15550; BM.1985,MI15558 'Derwent Water'; BM.1985,MI15552 set with opals; and BM.1985,MI15549). The brooches range from 30 to 53 mm in maximum dimension. Courtesy of the NHM London, © The Trustees of the Natural History Museum, London.

W. G. Rutherfurd Collection of Agates

The gemstone and worked-object collections held in the Natural History Museum (NHM), London, have grown to ~4,500 specimens, incorporating smaller collections and individual specimens over several hundred years. The largest expansion occurred with the 1985 merger of the collections of the Geological Museum (GM; formerly the Museum of Practical Geology), which significantly increased the gemstone holdings and added many worked objects. One of the many incorporated collections consists of agates of Mr W. G. Rutherfurd Esq.

The Rutherfurd collection contained over 2,000 agates as nodules, slices and a small selection of jewellery, a large portion of which was presented to the GM. It is accompanied by a handwritten register from Rutherfurd, dated 5 May 1912, in the back of which are several pages describing its formation and his collecting trips. The agates range mostly through whites, greens, reds and browns of various sizes and appearances (e.g. Figure 1). Rutherfurd had an excellent eye for colours and patterns, and he carefully selected the best picture agates to create pieces of jewellery, wanting to make 'something better than the ordinary agate brooch'. The resulting pieces are indeed works of art. The muted tones of some of the polished slices depict misty seascapes and landscapes, framed in jewellery settings created by J. W. Ritchie of Edinburgh. Other agates in the collection were marked up for cutting to identify the best area for depicting landscapes or other patterns to be displayed in jewellery.

From a curatorial perspective, what gives this collection such value is the accompanying information, providing history and context. The register data and the correspondence between Rutherfurd and the GM staff make for a fascinating read, especially as most are dated during the First World War.

Rutherfurd began collecting agates as a schoolboy in Scotland in 1858, and his passion culminated in a collecting expedition with his wife that took them from England to New Zealand in 1910–1912. From Bristol they travelled by boat to visit Jamaica and Cuba; then to Florida and up to Quebec, Canada; and then to Vancouver, British Columbia, Canada; and finally to Brisbane in Australia and onward to New Zealand. It was in New Zealand that Rutherfurd collected a large portion of his agates—in the Clent Hills in Canterbury. He took three-day round trips when the weather permitted, by train and then horseback. He described tonnes of agates weathering out from the lava rocks, dramatically changing every 50 m with a variety of colours, including some of the best picture agates he had found. Others had stalactitic forms within clear chalcedony, plus moss agates, jaspers and common opal. Some agates, although not beautiful, were over 1 m in size. The best specimens were found on the hilltop spurs, and he commented about them being found *in situ* and not waterworn.

Correspondence with the curator at the time (John A. Howe) indicates the arrival at the GM of several crates of agates in early 1917, both for the museum to select specimens and for safekeeping during the war. In mid-1917 Rutherfurd visited the museum to unpack crates and bring the collection of brooches to be presented if 'deemed good enough', and in November he asked if 'during the raiding season what would you think of putting the brooches down below out of danger as I shall never replace them if they get a bomb'. Later correspondence discussed the best way to set agates as brooches, including backing them with 'looking glass' for maximum effect. It is assumed the agates in these brooches all originated from New Zealand. The jewellery was registered by the GM in 1923 under one number and re-registered in 1924 to give individual numbers. In the 1924 catalogue, 'New Zealand' was pencilled next to the jewellery entries, perhaps given by word of mouth, but further research would be required to confirm their provenance.

According to Smith and Cole (1996) and Oliver (1977), the Clent Hills area consists of Triassic–Jurassic sedimentary rocks (Torlesse Supergroup) overlain by a Late Cretaceous calc-alkaline volcanic suite (Mount Somers Volcanics). The volcanic rocks show multiple stages of eruptions, and one unit, the Barrosa Andesite, covers much of the Clent Hills. This unit is known for silica-rich amygdules (rounded cavities from gas bubbles in the lava filled by later mineralisation) that include agates, moss agates, chalcedony and opals matching the descriptions given by Rutherfurd of his collecting. The lava flows were deposited at a low inclination, resulting in the flat-top hills. The agates are thought to have formed not long after the Barrosa Andesite from hot silica-rich fluids associated with this higher-temperature volcanism. The agates are typically horizontally banded, assumed to indicate their orientation during formation, and the *in situ* agates have been used to indicate tilting of the andesite by later geological processes.

The beauty in these agates, combined with an understanding of their journey and the passion of the man who made it happen, makes them a fascinating part of the NHM collection.

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Earth Science Department
Natural History Museum, London

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Axinite-(Mg) from Parachinar, Pakistan

Axinite is known from various locations in Pakistan, including the Shigar Valley area of Gilgit-Baltistan (Agheem et al., 2013) and the Taftan Mountains in Baluchistan (Fritz et al., 2007). While on a buying trip to Peshawar, Pakistan in October 2015, gem dealer Dudley Blauwet (Dudley Blauwet Gems, Louisville, Colorado, USA) was offered a 240 g parcel of rough transparent axinite from another locality: the Parachinar area, in the Federally Administered Tribal Areas within Khyber-Pakhtunkhwa Province of northwestern Pakistan. Blauwet selected 27 of the cleaner pieces weighing 100.2 g and had them faceted in July 2016. The cutting yield was rather small, due to the irregular shape and platy habit of the rough. He obtained 100 clean faceted stones that totalled 23.90 carats, with the largest gem weighing 1.36 ct. Compared

Figure 2: These purplish (to more orangey) brown axinites from Parachinar, Pakistan, weigh 0.81–1.36 ct and are strongly pleochroic, even to the unaided eye. Photo by J. C. Zwaan.

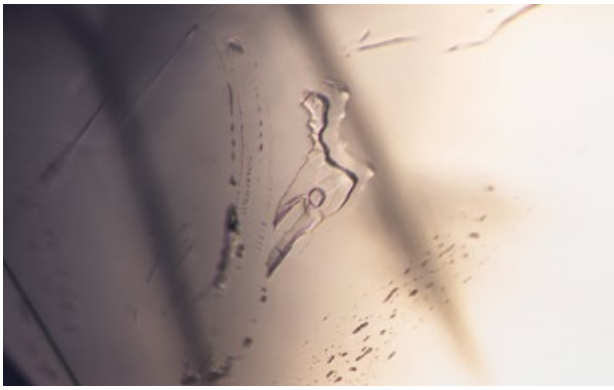

Figure 3: Partially healed fissures containing minute cavities and occasional two-phase inclusions are typical in the axinites from Parachinar. Photomicrograph by J. C. Zwaan; transmitted lighting, image width 1.4 mm.

to the brown colour of typical axinite, most of these stones showed an overall purplish brown appearance.

Blauwet loaned four faceted axinites for examination: one cushion, two ovals and one trilliant that weighed 0.81–1.36 ct (Figure 2). The stones were purplish brown or orangey brown and displayed strong pleochroism that was visible to the unaided eye. When viewed face-up and slightly tilted, the cushion and the 0.81 ct oval cut showed purplish, orangey and yellowish modifying colours, whereas the trilliant showed purplish and orangey hues and the 1.36 ct oval cut showed orangey and pale yellowish modifying colours. Using a calcite dichroscope, distinct trichroism in orangey brown, purple and light (slightly greenish) yellow was observed in each stone.

RIs ranged from 1.667 to 1.679, yielding birefringence values of 0.011–0.012. Applying the RI measurements as explained by Sturman (2007)—n_α = 1.667–1.668, n_β = 1.672–1.673 and n_γ = 1.678–1.679, with n_β being closer to n_α than to n_γ—the optic character proved to be biaxial positive. Average hydrostatic SG values were 3.23–3.25. The prism spectroscope revealed only a vague band at approximately 490 nm. The gems were inert to both long- and short-wave UV radiation.

These properties are consistent with axinite, with RIs and SGs between those of the end members axinite-(Mg)—which has RIs of 1.656–1.668, a birefringence of 0.009–0.012 and an SG in the range of 3.17–3.18—and axinite-(Fe)—which has RIs of 1.672–1.685, a birefringence of 0.010 and an SG in the range of 3.28–3.32 (cf. Deer et al., 1986; Dedeyne and Quintens, 2007). Although textbooks generally indicate the optic character of axinite is biaxial negative, the value of the optic axial angle (2V) increases with greater Mg content (cf. Deer et al., 1986), and Jobbins et al. (1975) reported an axinite-(Mg) from Tanzania to be biaxial positive, like these specimens from Pakistan.

The samples were eye clean to slightly included and contained partially healed fissures (sometimes with two-phase inclusions; Figure 3) and faint purple straight growth zoning. In addition, hexagonal and slightly rounded doubly refractive inclusions were seen in the trilliant (Figure 4). From their morphology and very low relief, these inclusions were probably apatite; Raman analysis with a Thermo DXR Raman microspectrometer was inconclusive. The principal Raman peak of apatite lies at ~967 cm^{-1}, but axinite also has a Raman feature at the same position (see below). Although the Raman spectrum of the analysed inclusion showed relatively more fluorescence (like many apatites), it was not possible to obtain a spectrum that was distinctive from the axinite host to confirm its identity.

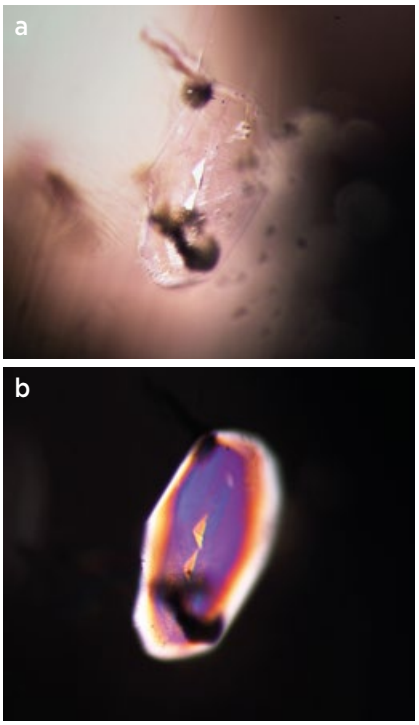

Figure 4: Doubly refractive, slightly rounded inclusions occurring in the trilliant-cut axinite are probably apatite crystals. Photomicrographs by J. C. Zwaan in (**a**) plane-polarised light and (**b**) between crossed polarisers; image widths 2.8 mm.

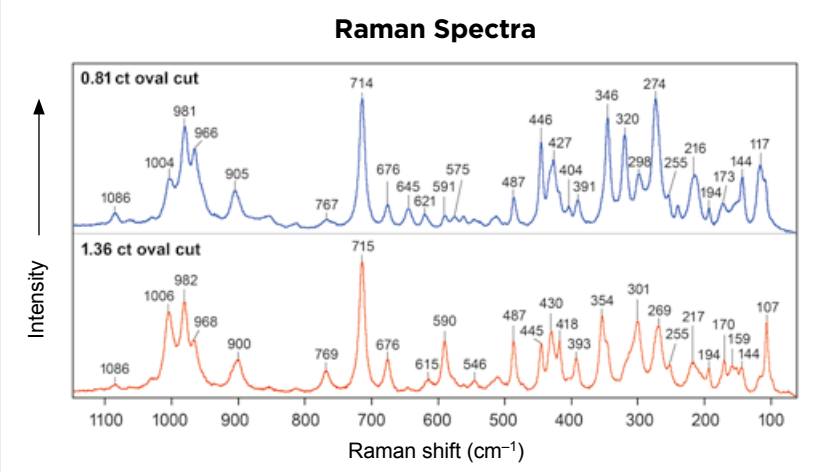

Figure 5: Two representative Raman spectra of the axinites from Parachinar show their variation and complexity; see text for explanation.

Raman spectra of three of the samples showed similar features, while the 0.81 ct oval cut produced a slightly different spectrum (Figure 5). The spectra of all four samples matched those of axinite-(Fe) in the RRUFF database; the three stones with similar spectra also matched axinite-(Mg). Raman spectra of axinites (triclinic borosilicates) are complex; the strong feature at 714 cm^{-1} is attributed to OBO-bending vibrations, while features in the ranges 1020–950 cm^{-1} and 690–380 cm^{-1} are attributed to $(SiO_4)^{2-}$ stretching and bending modes, respectively. Other features are more difficult to interpret; the band at ~902 cm^{-1} is possibly due to FeOH and MgOH deformation vibrations, while the band at ~768 cm^{-1} is ascribed to MgOH and other $M^{2+}OH$ deformations. Various bands are sometimes present at lower wavenumbers; the features at 320 and ~300 cm^{-1} are related to FeO stretching vibrations (cf. Frost et al., 2007).

Chemical analyses were obtained by energy-dispersive X-ray fluorescence (EDXRF) spectroscopy with an EDAX Orbis Micro-XRF Analyzer on the tables of the four stones, using a spot size of 300 µm. Apart from the main elements Si, Al and Ca, the analyses showed 6.1–6.8 wt.% MgO, 3.6–4.0 wt.% FeO and 0.5–0.6 wt.% MnO. This compares well with a summary of electron microprobe data for these stones provided by authors AUF and WBS, with 6.35–6.42 wt.% MgO and 3.68–3.73 wt.% FeO, giving predominantly axinite-(Mg) with a lesser proportion of axinite-(Fe). By contrast, specimens from the other localities in Pakistan mentioned in the first paragraph of this report were identified as axinite-(Fe).

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Trapiche-type Chrysoberyl

Numerous gem varieties showing a fixed star pattern within a transparent matrix have been designated 'trapiche'. In general, the non-transparent arms of the star pattern radiate from a central point or a central area toward the rim of the crystal, and they separate transparent (or at least translucent) areas of the specimen. If the transparent areas correlate with growth sectors and the arms of the star pattern represent the less transparent boundaries between such growth sectors, it is referred to as a trapiche pattern, as seen in some emeralds, rubies and tourmalines (e.g. Schmetzer et al., 1996, 2011). If the arms of the star pattern are formed by inclusions trapped within the centre of symmetry-equivalent growth sectors, it is referred to as a trapiche-type pattern, as seen in some beryls and sapphires (Schmetzer et al., 2011). Samples belonging to this second group of materials have also been designated 'trapiche-like minerals' (Pignatelli et al., 2015). In trapiche-type samples, the arms of the star pattern can become relatively wide and the transparent boundaries between growth sectors can be small.

The rough chrysoberyl described here was loaned by Farooq Hashmi (Intimate Gems, Glen Cove, New York, USA). The stone was purchased in the USA gem market and was said to have originated from Brazil. It measured 25 × 17 mm and weighed 10.18 g. Its identity as chrysoberyl was confirmed by Bear Williams (Stone Group Labs, Jefferson City, Missouri, USA) using Raman spectroscopy (GemmoRaman-532SG instrument). The sample showed one large planar face exhibiting a trapiche pattern consisting of relatively broad, milky arms separated by somewhat smaller transparent areas (Figure 6). Within the uneven part of the sample's surface, the trapiche pattern was not visible. Perpendicular to the large planar face were several crystal faces and one area with a larger re-entrant angle. In immersion and transmitted light (not shown) it could be seen that the entire sample, including the large planar face and the uneven parts of the surface, consisted of a cyclic twin (trilling). The crystal showed the common morphology of a chrysoberyl trilling with a large **a** {100} pinacoid and several smaller **i** {011} prism faces (see, e.g., Schmetzer, 2011).

By superimposing the photos taken in transparent light in immersion with those taken in reflected light in air (not shown), it was established that the twin boundaries ran through the transparent areas of the trapiche pattern, with the less transparent milky arms of the star located between the twin boundaries (Figure 7). Compared to the milky areas, the transparent zones were narrow, and different-sized areas sometimes appeared on the two sides of the twin planes. It was also apparent that the boundaries between transparent and milky zones were uneven and did not consist of planar faces or straight separation lines.

Examination of the area shown in Figure 7 at higher magnification in transmitted light (without immersion) was prevented by the combined effect of the low transparency of the chrysoberyl trilling and the approximately 9.7 mm thickness of the sample. In reflected light, the large planar **a** pinacoid of the trilling showed a dense pattern of growth striations oriented parallel to the

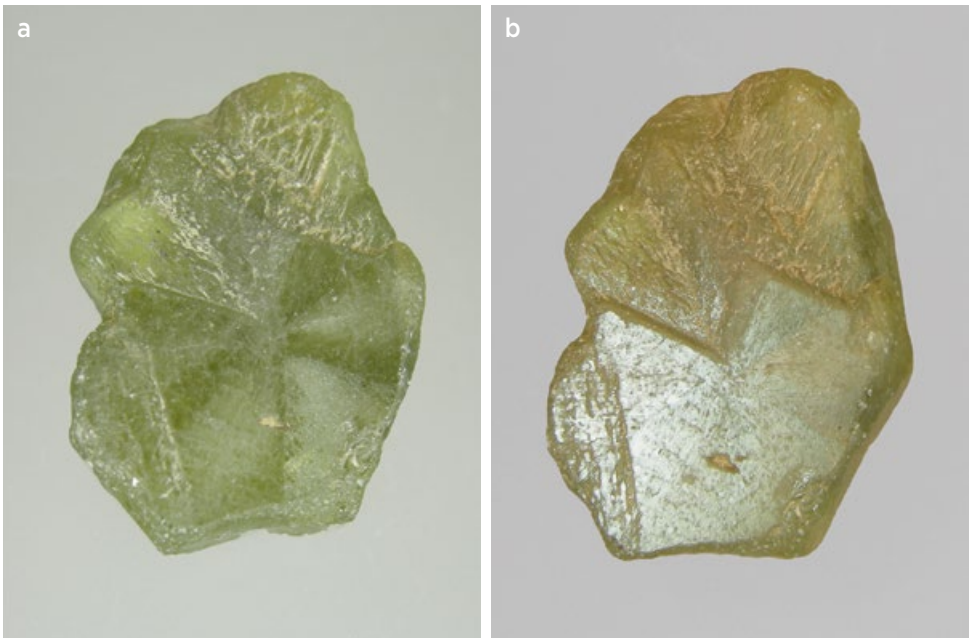

Figure 6: (**a**) This chrysoberyl trilling with a large planar face shows a trapiche-like pattern forming a fixed star consisting of larger triangular, somewhat milky areas separated by smaller transparent zones. (**b**) When the sample is tilted slightly, the larger planar face shows a homogeneous reflection. In the uneven part of the trilling (upper part of the sample), the trapiche-like pattern is not visible. The sample measures 25 × 17 mm; photos by K. Schmetzer.

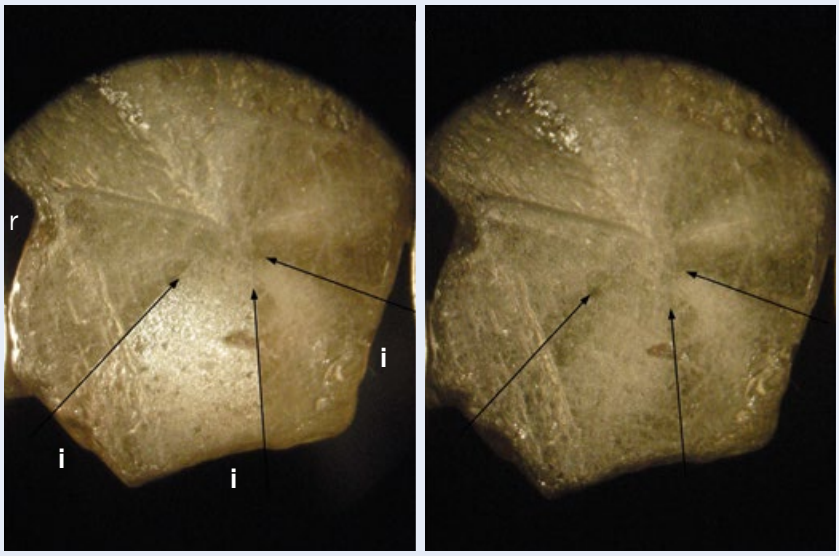

Figure 7: Viewed with reflected light at slightly different angles, the planar **a** pinacoid of the chrysoberyl trilling is seen here, as well as some **i** prism faces (perpendicular to the **a** pinacoid) and one re-entrant angle (r). Twin boundaries (black arrows) are perpendicular to the **i** prism faces and the **a** pinacoid, running through the more transparent areas that separate the milky zones forming the arms of the fixed star. Photomicrographs by K. Schmetzer; image width 16 mm.

c-axes < 001 > of the different parts of the chrysoberyl trilling (Figure 8). Due to the presence of these dense patterns of growth lines, which were observed in all the more-or-less transparent parts of the trapiche pattern, it was impossible to observe different concentrations of inclusions within the sample at high magnification (without polishing the surface of the specimen) in order to identify such inclusions.

Using the established definitions (see above), this chrysoberyl trilling should be described as trapiche-type chrysoberyl. In this special case, the different zones of the star pattern are separated by twin boundaries and not—as is commonly observed in trapiche specimens—by the boundaries between different growth sectors.

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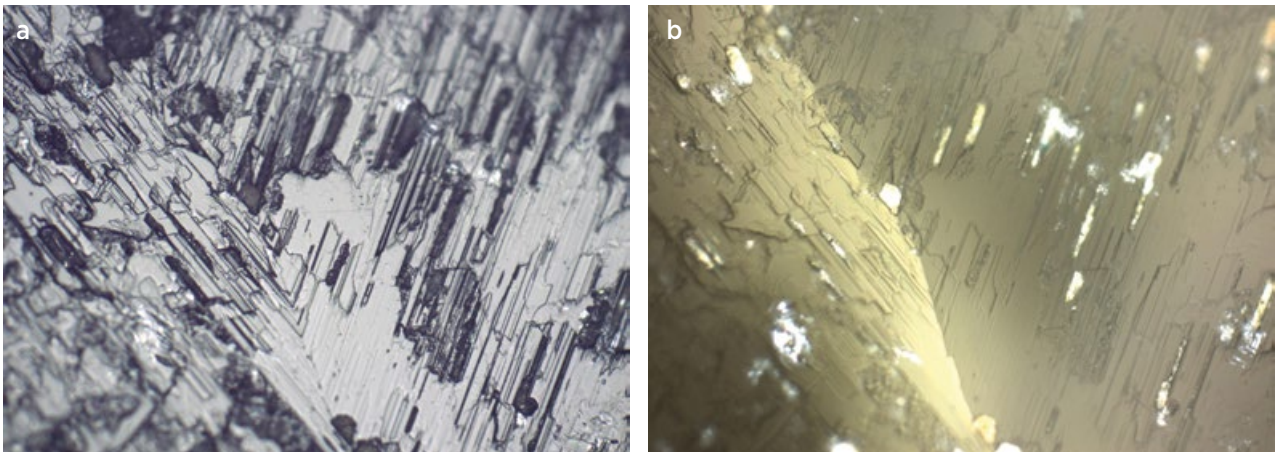

Figure 8: (**a**) At higher magnification, the chrysoberyl trilling shows a dense pattern of surface features and growth striations in reflected light; the growth features run parallel to the c-axes of the different parts of the trilling. (**b**) Viewed with crossed polarisers, the different parts of the trilling are clearly separated. Photomicrographs by H.-J. Bernhardt; fields of view 560 × 420 µm.

Montebrasite from Afghanistan

Faceted gemstones of the amblygonite-montebrasite isomorphous series $LiAlPO_4(F,OH)$ are rarely encountered in the gem trade, and mostly consist of pale 'straw' yellow material from Brazil. The mineral series has a Mohs hardness of 5½–6 and perfect cleavage on {100}, as well as some additional cleavage directions that are not as well developed. The faceted stones are commonly sold as 'amblygonite', which is ambiguous because the term can refer to any mineral of the amblygonite series or more specifically to the amblygonite mineral species, $LiAlPO_4F$. Rondeau et al. (2006) analysed several faceted specimens from Brazil, and determined that all of them were rather pure montebrasite, which they mentioned is consistent with an origin in granitic pegmatites within late-stage cavities (where fluorine was depleted relative to hydroxyl content, favouring the relatively late crystallisation of montebrasite).

In early 2017, rough stone dealer Farooq Hashmi encountered gem-quality montebrasite from Afghanistan. During a buying trip to Peshawar, Pakistan, he was shown a parcel weighing ~2 kg consisting of broken pieces that were colourless to very pale purple. He obtained one piece for research purposes, and it was faceted by Todd Wacks (Tucson Todd's Gems, Tucson, Arizona, USA) into an oval cut weighing 3.79 ct (Figure 9).

Examination of the stone by author BML showed that it was moderately included and displayed polishing marks on the table. During the faceting of the stone, Wacks reported that he was unable to obtain a good polish on the table, despite recutting it three times and changing the angle and direction of polish. Similarly, Schunk and Deane (1955) reported that when cutting 'amblygonite', it showed a 'tendency to leave polish marks or very slight scratches rather than to leave an absolutely flawless mirror polish'. The 3.79 ct stone studied for this report yielded indistinct RI readings (apparently due to the poor polish) of approximately 1.60–1.62, for a birefringence of ~0.02. Microscopic examination revealed abundant fluid inclusions as both 'fingerprints' and jagged cavities that contained liquid and a gas bubble (Figure 10). Also present were irregular stringers and reflective liquid films, which were sometimes arranged in parallel orientation along incipient cleavages.

Figure 9: Afghanistan is the source of these montebrasite samples, consisting of a 3.79 ct gemstone and the 6.72 g piece of rough that remained after the stone was cut. Photo by B. M. Laurs.

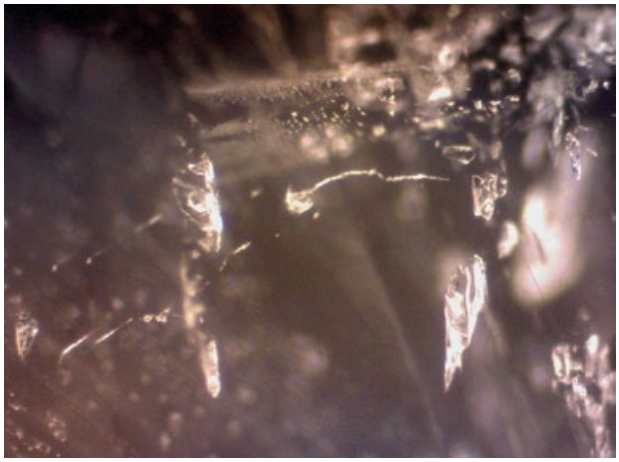

Figure 10: The Afghan montebrasite displays jagged two-phase fluid inclusions, 'fingerprints' and irregular stringers. Photomicrograph by B. M. Laurs; magnified 27×.

The chemical composition was obtained by authors AUF and WBS, who performed standard-based scanning electron microscopy-energy dispersive spectroscopy (SEM-EDS) analysis using a JEOL JSM-6400 instrument with the Iridium Ultra software package by IXRF Systems Inc. The data showed 4.4–4.8 wt.% F along with traces of Na, Mn, Fe and Ca. The amount of fluorine measured by SEM-EDS correlates well with the upper RI value (cf. Černá et al., 1973) and confirms a montebrasite composition (~60% montebrasite and ~40% amblygonite).

Although the amblygonite-montebrasite series is known to occur in various pegmatite areas of Afghanistan (Orris and Bliss, 2002), this is the first time that gem-quality material has been documented from there. The pale purple colour is unusual for montebrasite, although one of the Brazilian stones documented by Rondeau et al. (2006) was 'purple grey', and purple-and-white masses have been found by one of the present authors (AUF) at the Emmons pegmatite in Greenwood, Maine, USA.

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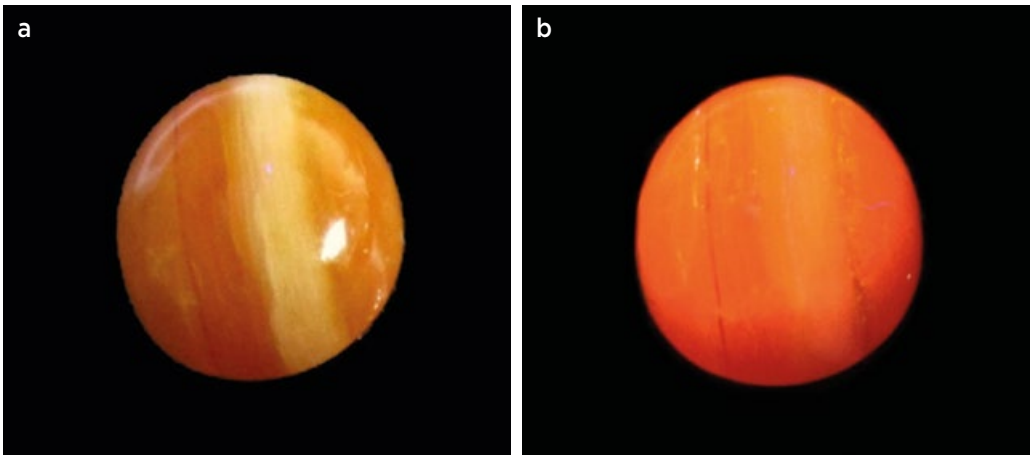

Figure 11: (**a**) This 2.20 ct opal, reportedly from Hokkaido, Japan, displays prominent banding. (**b**) Viewed with long-wave UV radiation, the sample demonstrates a vibrant orange reaction in the orange bands, but the thin transparent colourless areas are inert. Photos by B. Williams.

Orange-Fluorescing Common Opal from Japan

During the June 2018 JCK Las Vegas show in Nevada, USA, gem dealer Dudley Blauwet had some interesting banded orange common opal that was notable for exhibiting strong orange fluorescence to long-wave UV excitation. The opal came from the Shikaribetsu Lake area in Kato District, Tokachi Province, Hokkaido, Japan (Okazaki et al., 2014). This region is covered by Daisetsuzan National Park, and contains numerous volcanos and hot springs. The geochemistry of the opal was characterised by Okazaki et al. (2015) and by Kanai et al. (2016). Both studies were unable to find an unambiguous relationship between chemical composition and fluorescence colour, leading the authors to propose that organic compounds may be involved.

Blauwet had four opal cabochons weighing up to 2.20 ct, and he loaned the largest sample for examination (Figure 11a). The stone was cut as a double cabochon and showed prominent, parallel, colour banding ranging from a translucent strong orange to very pale orange with some thin transparent colourless layers (Figure 12). The latter areas were inert to the UV lamp, but the orange areas fluoresced a vibrant orange (Figure 11b), which was stronger to long-wave than to short-wave UV radiation.

The RI of the stone, approximated by the spot method, was ~1.42. Specific gravity was measured hydrostatically as 2.12. Viewed between crossed polarisers, most of the stone remained light upon rotation (consistent with an amorphous structure), and no strain was visible, but the colourless areas blinked dark with every 90° of rotation. (However, we were unable to find any evidence of the

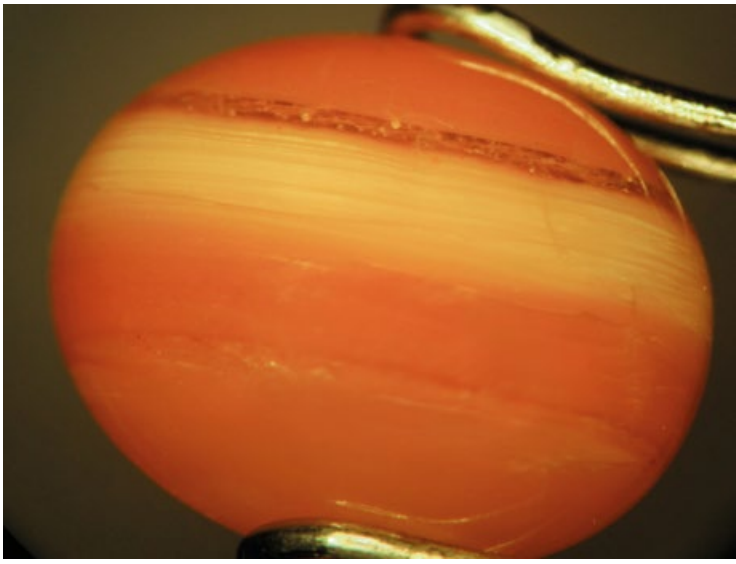

Figure 12: A closer view of the 2.20 ct opal shows the pronounced layered texture. Photo by Dean Brennan, Stone Group Laboratories.

presence of quartz to provide a reason for the blink.) There was no detectable magnetic susceptibility. No discernible results were obtained by Raman spectroscopy on either the coloured or colourless areas, but the 'fingerprint' region of the Fourier-transform infrared (FTIR) spectrum matched that of opal.

Energy-dispersive X-ray fluorescence spectroscopy with an Amptek X123-SDD spectrometer revealed the presence of minor Ca and traces of Fe, the latter being common in many orange opals. Moderate amounts of Mn were present, as were traces of Th. Using a Geiger counter, we detected low radiation emissions, at only about 1.5× background levels.

Strong orange fluorescence in common (pink) opal has been attributed to organic compounds called quinones (Fritsch et al., 2004), and may indicate the presence of organic material during the opal's formation.

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Two Large Rubies from the Pamir Mountains, Tajikistan

In 2016, a sizeable amount (about 600 g) of facet-grade ruby rough was offered on the New York market that had been collected over multiple mining seasons from the Pamir Mountains of Tajikistan. The material was examined by the author, and subsequent to manufacturing, several stones were submitted to the American Gemological Laboratories (AGL) for gemmological reports.

Rubies and pink sapphires from Tajikistan were first reported in the late 1990s (Smith, 1998). Since that time, little additional information has come forward, with the exception of an excursion to the region in 2006 (see, e.g., www.ruby-sapphire.com/tajikistan_ruby_and_spinel.htm). Since rubies of Tajik origin are not particularly well known or recognised in the gem and jewellery industry, this report provides a refresher of their key identifying features—as seen in the two largest, unheated rubies examined here, which weighed 12.08 and 17.14 ct (Figure 13).

The stones showed a highly saturated red colour. Consistent with rubies originating from marble-type deposits, they exhibited a strong red and moderate red reaction when exposed to long- and short-wave UV radiation, respectively. Microscopically, they contained

Figure 13: Weighing an impressive 12.08 ct (ring) and 17.14 ct (loose), these two unheated rubies were the best gems cut from a recent production of about 600 g of rough material from the Pamir Mountains of Tajikistan. Photo by Bilal Mahmood, AGL.

faint, very fine-grained planar clouds that had a whitish or slightly bluish appearance when illuminated with fibre-optic lighting (Figure 14). Concentrations of fine stringers were present, as well as colourless carbonate inclusions (calcite; identified by Raman spectroscopy) that commonly exhibited tiny black inclusions of their own (probably graphite). Partially healed fissures

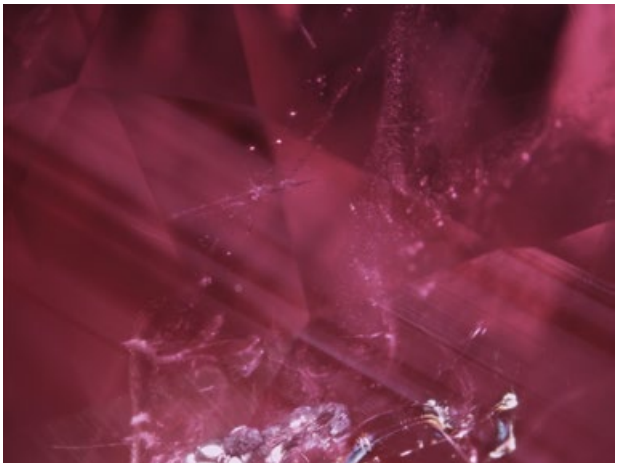

Figure 14: Common inclusion features in the rubies from Tajikistan consist of very fine-grained planar clouds that can have a whitish or faint bluish appearance when viewed with fibre-optic lighting. Photomicrograph by C. P. Smith; magnified 30×.

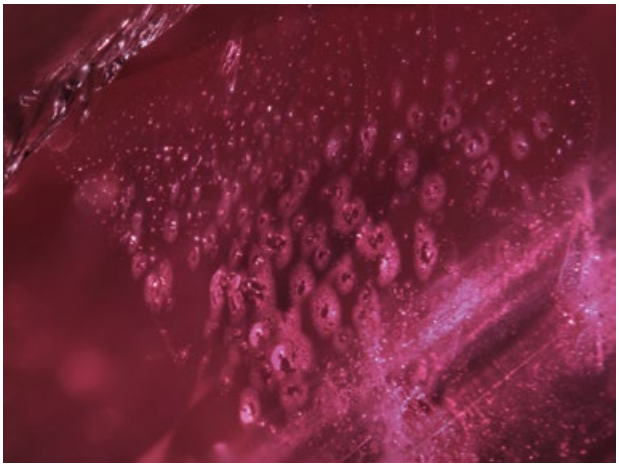

Figure 15: The most recognisable and diagnostic inclusion feature for rubies of Tajik origin consists of small negative crystals, each individually associated with basal-oriented thin films. These occur in groups along planar concentrations, as shown here, or as isolated features. Also present are fine, reflective stringers. Photomicrograph by C. P. Smith; magnified 38×.

showing various patterns were evident, as well as open fissures encrusted by epigenetic coatings of AlOOH, phyllosilicates and other minerals. However, the most distinctive inclusion feature in rubies from this source consists of negative crystals associated with tiny, basal-oriented thin films. These characteristic inclusions occurred in high numbers associated in planar concentrations (Figure 15) or as isolated features.

EDXRF spectroscopy of the two rubies revealed (in wt.%): 0.05 Ti, 0.01 V, 0.28 Cr, 0.04 Fe and 0.01 Ga for the 12.08 ct stone; and 0.03 Ti, 0.01 V, 0.14 Cr, 0.04 Fe and 0.01 Ga for the 17.14 ct ruby.

All of the features documented in this note are consistent with those reported previously for rubies and pink sapphires of Tajik origin. Beautiful, unheated stones such as these demonstrate the potential for Tajikistan to produce superior-quality rubies that can rival—and even be mistaken for—those of other, more well-known marble-type deposits of the region, including the historic Mogok Valley and, more recently, the Mong Hsu region of Myanmar (Burma), as well as the Jegdalek area of Afghanistan and Luc Yen region of northern Vietnam.

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Reference

Smith C.P., 1998. Rubies and pink sapphires from the Pamir mountain range in Tajikistan, former USSR. *Journal of Gemmology,* **26**(2), 103–109, http://doi.org/10.15506/JoG.1998.26.2.103.

Peculiar Trapiche-like Pattern in a Gold Sheen Sapphire

Gold Sheen sapphires were first described by Bui et al. (2015), in which the appearance of the golden sheen was ascribed to the presence of oriented platelets or needles that were identified as hematite and ilmenite in the form of exsolution intergrowths. A more brownish sheen of this type is also encountered in sapphires from several localities. Most Gold Sheen sapphires cut *en cabochon* exhibit a golden six-rayed star, but not 12-rayed stars as seen in black sapphires from Sri Lanka or Thailand (Bui et al., 2017). Moreover, neither a trapiche nor trapiche-like pattern, as defined by Schmetzer et al. (2011), has been reported so far in this corundum variety.

This author recently examined a Gold Sheen sapphire displaying a trapiche-like pattern (Figure 16). The sample, a marquise-shaped tablet, weighed 1.40 ct (12.03 × 6.94 × 1.32 mm) and reportedly originated from the same mine in Kenya that has produced Gold Sheen sapphire in the past. The slice was cut perpendicular to the c-axis to emphasise the golden sheen effect. The trapiche-like pattern consisted of a darker central core with six semi-transparent arms extending from the core toward the edges of the sample. In reflected light, the remainder of the stone displayed a golden sheen where the growth bands were visible.

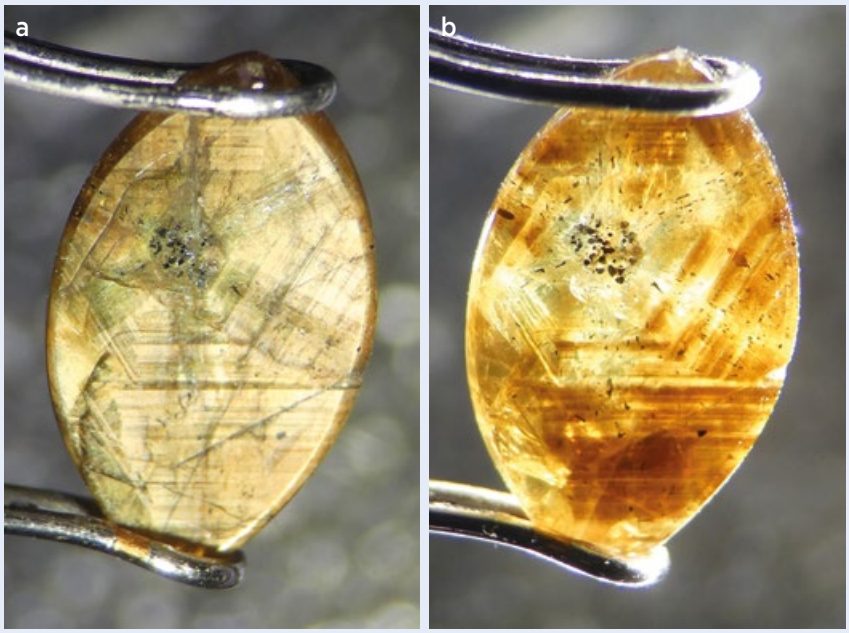

Figure 16: This 1.40 ct Gold Sheen sapphire tablet (12.03 × 6.94 × 1.32 mm) from Kenya displays a trapiche-like pattern. Photomicrographs by T. N. Bui using (**a**) brightfield and (**b**) darkfield illumination; magnified 10×.

Close examination with an optical microscope revealed that the hexagonal shape of the central core was parallel to the colour banding. The six arms were approximately perpendicular to these bands, as illustrated in Figure 17. These observations are consistent with sapphire displaying a trapiche-like pattern (see p. 245 in Gübelin and Koivula, 2008, and figure 20 in Bergman, 2016), irrespective of the nature of the inclusions forming the fixed star. The darker appearance of the central core was due to the presence of platy black inclusions that were present along the c-axis. These were identified as magnetite by a comparison to previously confirmed magnetite inclusions in Gold Sheen sapphire (see figure 13 in Bui et al., 2015), as well as the slight attraction of the sample's core to a neodymium magnet. The magnetite inclusions were also present in the six arms of the trapiche-like structure, but in lower density and mostly showing an elongated shape in the direction of the arms (Figure 17a); they were even more apparent with transmitted illumination (Figure 17b). In contrast to trapiche-like patterns reported previously in the literature for sapphire, the six branches in the present case were almost devoid of hematite/ilmenite inclusions, and they also lacked the growth bands of the interstitial areas (Figure 17b).

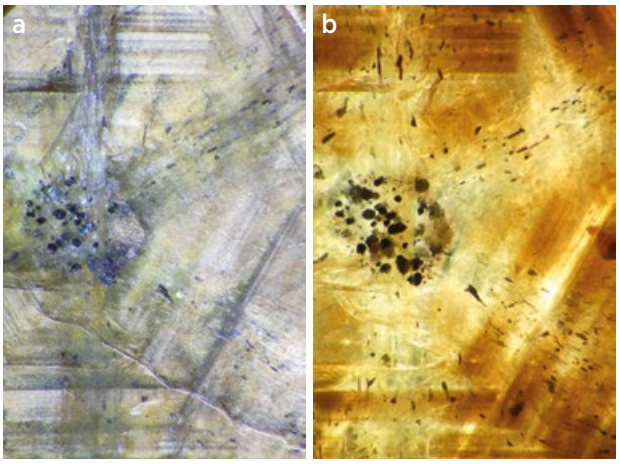

Figure 17: The core and six arms of the trapiche-like sapphire contain magnetite inclusions. In both of these areas, the hematite/ilmenite platelets and needles that form the sheen are nearly absent (**a**, brightfield illumination). Transmitted, darkfield illumination (**b**) confirms these observations. Photomicrographs by T. N. Bui; fields of view 5.67 × 3.78 mm.

Similar to the star in asteriated corundum, the colour of the arms forming the trapiche-like pattern depends on the nature of their constituting inclusions. Hematite/ilmenite inclusions lead to a brownish colour of the arms (Khotchanin et al., 2010), while rutile needles produce a white colour (Kiefert, 2012). In common trapiche-like corundums, the contrast is created by the colour of their arms versus the body colour of the stone. Here, the pattern is inverted: the arms display the body colour of sapphire while the rest of the stone displays a golden sheen.

In addition to the classical trapiche pattern (particularly in emerald), a trapiche-like pattern has been reported for several minerals but has not been as thoroughly investigated. To the best of our knowledge, the origin of the trapiche-like pattern is still not well understood. A reverse trapiche-like pattern—as seen in the present sapphire—should exist in sapphires from other localities, but no such examples are known to this author. Rough samples presenting a common or reverse

trapiche-like pattern should be investigated further to determine the origin of this phenomenon.

Acknowledgements: The author is grateful to Tanzim Khan Malik (Genuine Gems & Jewellery Co. Ltd, Bangkok, Thailand) for supplying the sample.

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Sri Lankan Sapphire with Spinel Inclusions

Recently, a 5.06 ct yellow sapphire was submitted to the American Gemological Laboratories (AGL) for testing (Figure 18). Standard gemmological analyses distinguished that this was an unheated yellow sapphire originating from Sri Lanka.

What caught the eye of this gemmologist were two well-formed octahedral crystals situated under the table of the gem (Figure 19). Raman analyses identified them as spinel. Corundum and spinel often form in similar geological environments and geographical locations. Given this, it is not surprising that spinel (as well as gahnospinel) has been identified previously in gem-quality corundum from a variety of sources, such as Sri Lanka and Myanmar/Burma (see, e.g., Gübelin and Koivula, 2008). However, it is not as common to see such euhedral colourless crystals of spinel as are present in this yellow sapphire.

Christopher P. Smith FGA

Reference

Gübelin E.J. and Koivula J.I., 2008. *Photoatlas of Inclusions in Gemstones*, Vol. 3. Opinio Publishers, Basel, Switzerland, 672 pp.

Figure 18: This 5.06 ct sapphire from Sri Lanka contains interesting inclusions under the table facet. Photo by Alex Mercado, AGL.

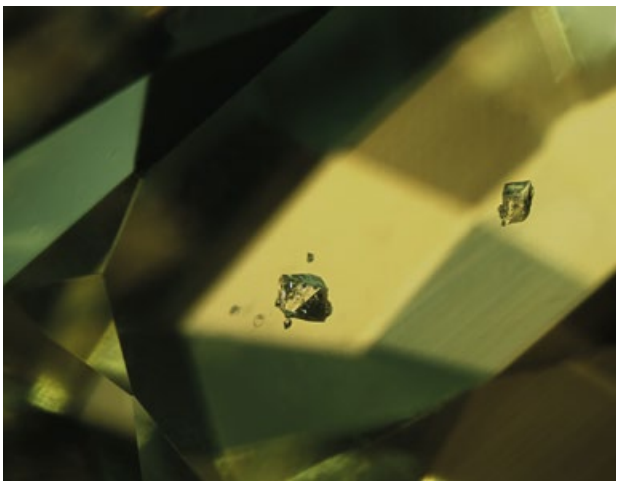

Figure 19: The inclusion scene in this sapphire is dominated by two octahedral colourless crystals that were identified by Raman spectroscopy as spinel. Photomicrograph by C. P. Smith; magnified 32x.

Colour-change Tephroite from South Africa

The olivine group is formed by three minerals: forsterite (Mg_2SiO_4), fayalite (Fe_2SiO_4) and tephroite (Mn_2SiO_4). The most important gem variety of the group is peridot, with a rather limited composition for gem-quality material of about 85–88% forsterite and 12–15% fayalite (cf. Webster, 1994). Much rarer is gemmy, colourless, near-end-member forsterite, known from Tajikistan, Sri Lanka, Myanmar and Vietnam (Hanus and Štubňa, 2017). Tephroite is the rarest mineral of the group, and to this author's knowledge only a few light violet cabochons have been cut from material originating in Sweden, Italy and the USA (New Jersey). Recently, new finds from the Wessels and N'Chwaning mines in the Kalahari manganese field in the Northern Cape Province of South Africa yielded some gem-quality tephroite.

Tephroite from South Africa forms columnar crystals up to almost 2 cm long. They are usually opaque (Figure 20), but some translucent crystals have been faceted into a few cut stones weighing up to 6 ct (Figure 21). The gems examined by this author were greenish grey in daylight and red-brown in incandescent light. Their RIs were 1.778 and over-the-limits of a standard refractometer, comparable to published data of n_α = 1.770–1.788, n_β = 1.807–1.810 and n_γ = 1.817–1.825 (Bernard and Hyršl, 2015). SG was determined hydrostatically as 4.05. The stones were strongly pleochroic (very dark brown and light brown) and were inert to UV radiation. The visible-near infrared (Vis-NIR) spectrum obtained with a GL Gem Spectrometer showed absorptions at 420, 456, 499 and 587 nm (Figure 22); the reason for the colour change was not clear.

Faceted tephroite from South Africa is interesting especially for its colour change, but it will remain a collector's rarity.

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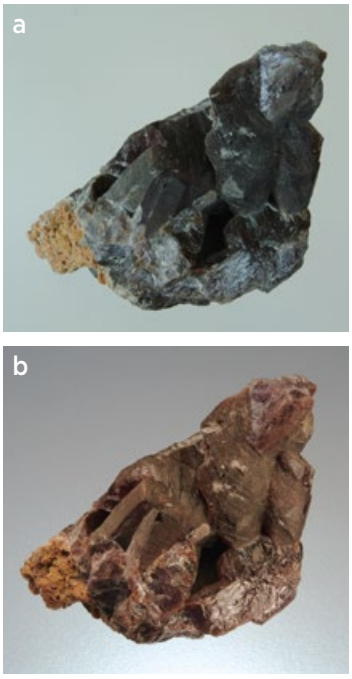

Figure 20: This tephroite crystal specimen (3.9 cm wide) from the Wessels mine in South Africa reveals a colour change from daylight (**a**) to incandescent light (**b**). Photos by J. Hyršl.

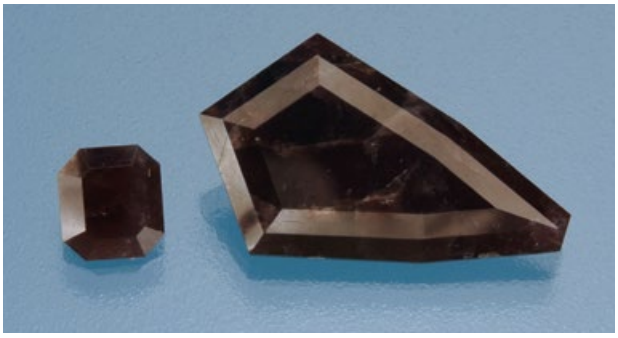

Figure 21: These faceted tephroites from South Africa weigh 0.56 and 6.25 ct. Photo by J. Hyršl.

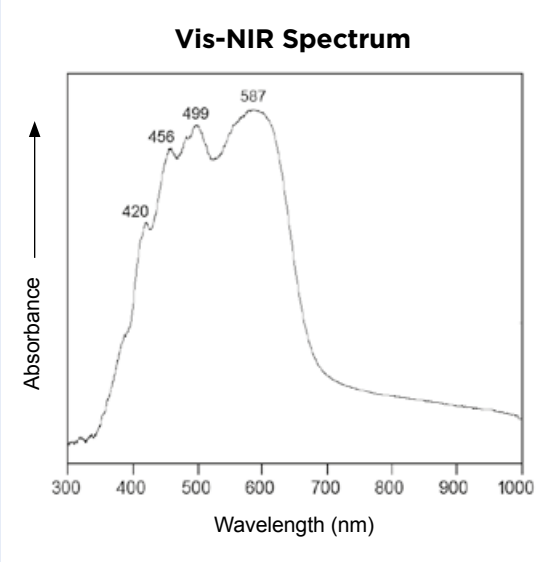

Figure 22: The Vis-NIR spectrum of tephroite from South Africa displays absorptions at 420, 456, 499 and 587 nm.

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SYNTHETICS AND SIMULANTS

Glass Imitation of Ametrine

Ametrine is a popular bicoloured quartz that comes mainly from the Anahí mine in eastern Bolivia (Vasconcelos et al., 1994). Synthetic ametrine from Russia has been known for a long time (Balitsky et al., 1999), and is usually darker than the natural material. Imitations made from pieces of citrine and amethyst that are glued together are also known.

The author bought a faceted bicoloured sample (Figure 23, top) from an Indian dealer at the Prague gem show in September 2018. It was presented as synthetic ametrine, and the price in comparison with its quality was very reasonable. The sample weighed 28.98 ct and measured 23.3 × 16.9 × 10.9 mm. The dark yellow half had a homogenous colour, while the dark violet half showed distinct colour zones at a low angle to the colour boundary (Figure 24), typical for natural amethyst exhibiting Brazil-law twinning. However, this was strange because Brazil-law twinning is very rare in both synthetic amethyst and synthetic ametrine. Also surprising was the presence of several rounded bubbles along the colour boundary (again, see Figure 24). They suggested a glued imitation, but examination of the surface with reflected light did not show any disconformity.

Figure 23: The glass imitation of ametrine (top, 28.98 ct) studied here displays darker colour and a sharper colour transition than two typical synthetic ametrines (9.62 and 2.62 ct). Photo by J. Hyršl.

Figure 24: Viewed table-down, the 28.98 ct glass imitation of ametrine in Figure 23 shows colour zoning in the dark violet half and gas bubbles along the colour boundary. Photo by J. Hyršl.

Gemmological testing easily identified the sample as a glass imitation. The RI of both halves was 1.510, the sample was isotropic and its SG was 2.45. When exposed to short-wave UV radiation, the yellow half fluoresced chalky yellow and the violet part was inert, while in long-wave UV the yellow half was inert and the violet half glowed light yellow. The presence of bubbles along the colour boundary is consistent with the identification as glass.

This shows that even glass—one of the oldest and simplest imitations—can be challenging to identify without proper testing.

Dr Jaroslav Hyršl

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A Treated Mixed-Type Synthetic Yellow Diamond

The Gem and Jewelry Institute of Thailand's Gem Testing Laboratory in Bangkok recently examined a 0.70 ct round brilliant (Figure 25) that was submitted to determine whether it was a natural or synthetic diamond

Figure 25: This 0.70 ct Fancy Vivid yellow round brilliant proved to be an HPHT-grown synthetic diamond that was apparently treated by low-pressure, high-temperature annealing. Photo by T. Sripoonjan.

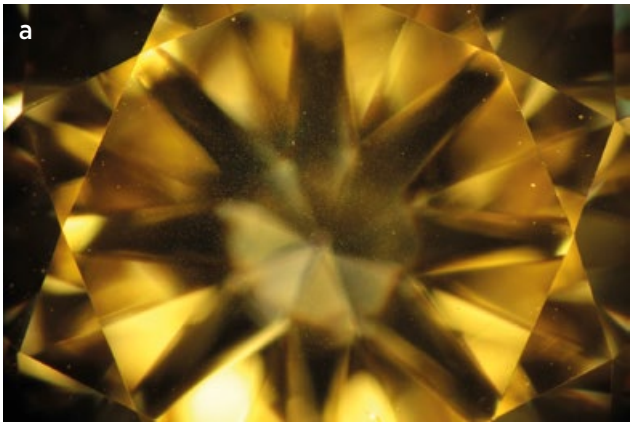

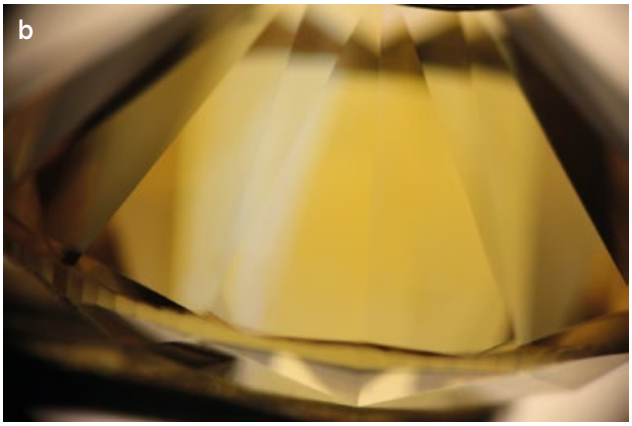

Figure 26: The 0.70 ct sample displays (**a**) clouds of pinpoint inclusions under the table facet and (**b**) yellow colour zoning through the pavilion with diffused illumination. Photomicrographs by M. Maneekrajangsaeng; magnified 50×.

and to establish the origin of its yellow colour. The sample was graded Fancy Vivid yellow with a clarity of VS_2. It fluoresced weak green to long-wave UV radiation and moderate green to short-wave UV. With magnification, clouds of pinpoint inclusions were seen under the table facet (Figure 26a) and a small fracture was present near a star facet. No strain was observed with cross-polarised filters. Examination with diffused illumination showed yellow colour zoning (Figure 26b). The DiamondView revealed the distinctive luminescence pattern of cubo-octahedral growth structures associated with high-pressure, high-temperature (HPHT) synthesis (Figure 27). The diamond was therefore identified as synthetic.

The visible-range spectrum (Figure 28a) revealed features typically attributed to type Ib diamond, with strong absorption at wavelengths below 500 nm; such a pattern, which is due to isolated single nitrogen, has also been observed in as-grown synthetic diamond (Kazuchits et al., 2016). The photoluminescence spectrum (PL) acquired with 532 nm laser excitation at liquid-nitrogen temperature showed a dominant doublet at 692/694 nm, which has been reported in high-nitrogen synthetic diamonds grown in a Ni-containing environment and after annealing at temperatures above 1,700°C (Zaitsev, 2001, p. 189), thus confirming that this was an HPHT-grown synthetic yellow diamond.

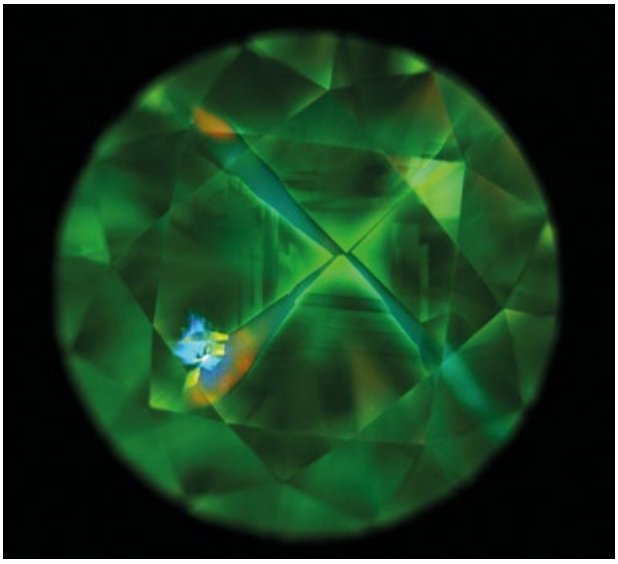

Figure 27: Seen with the DiamondView, a cubo-octahedral growth pattern is evident in the 0.70 ct synthetic diamond. Photo by M. Maneekrajangsaeng.

By contrast, the mid-IR spectrum of this synthetic diamond showed an unusual mixed type of dominant IaA (indicated by the band at 1282 cm^{-1}, due to two adjacent substitutional nitrogen atoms, N-N) and minor Ib (indicated by the bands at 1344 and 1130 cm^{-1}, due to single nitrogen), as seen in Figure 28b. Although such a mixed type is quite common among natural yellow diamonds, HPHT-grown yellow synthetic diamonds typically belong only to type Ib (Shigley et al., 1993).

Recent studies (e.g. Kazuchits et al., 2016; Kitawaki et al., 2017) suggested that the type IaA aggregation of nitrogen could occur during post-growth treatment of HPHT-grown synthetic diamond under a low-pressure, high-temperature (LPHT) annealing process. We infer that the present sample was initially synthesised as a type Ib yellow diamond by the HPHT process, and afterwards some isolated nitrogen was converted to N-N centres during LPHT treatment, as shown by the presence of the 1282 cm^{-1} band in the FTIR spectrum. This conclusion is also supported by the presence of the 692/694 nm doublet in the PL spectrum, which is known to be produced during annealing at temperatures above 1,700°C (Zaitsev, 2001).

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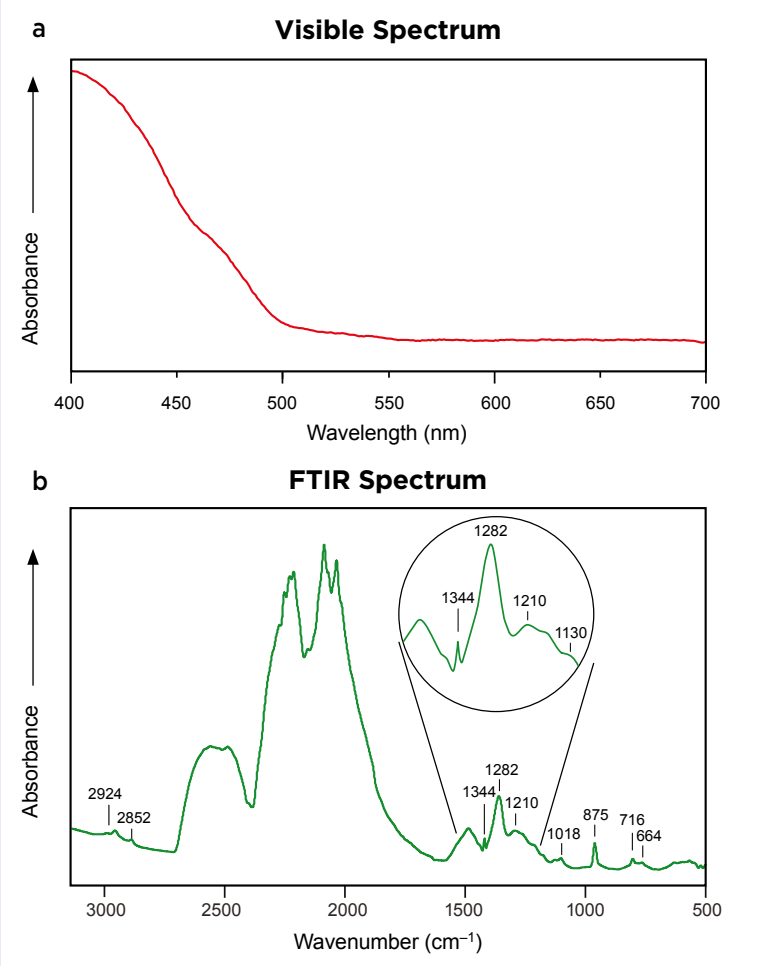

Figure 28: (**a**) The optical spectrum of the synthetic diamond reveals strong absorption at wavelengths below 500 nm. (**b**) The sample's FTIR spectrum shows features associated with mixed diamond types of IaA (1282 cm^{-1}) and Ib (1344 and 1130 cm^{-1}), which is quite unusual for synthetic diamond.

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ERRATUM

Petroleum Inclusion in Pink Spinel

In the Gem Notes section of Vol. 35, No. 1, 2016 (pp. 20–21), we described the presence of petroleum in a negative crystal inclusion in a pink spinel. At that time, we were told that this spinel was reportedly of Sri Lankan origin. Upon further inquiry with the original supplier, it has been established that this spinel was of Burmese origin. We thank Richard Hughes for bringing this to our attention.

Christopher P. Smith and Monruedee Chaipaksa

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The Effect of Blue Fluorescence on the Colour Appearance of Round-Brilliant-Cut Diamonds

Marleen Bouman, Ans Anthonis, John Chapman, Stefan Smans and Katrien De Corte

ABSTRACT: To better understand the influence of blue fluorescence on the colour appearance of (near)-colourless (D–J) diamonds, carefully selected sets of round-brilliant-cut samples of varying fluorescence intensity were observed at HRD Antwerp under lighting conditions that simulated four different environments in which diamonds are commonly viewed: Outdoor, Indoor, Grading and Office lighting. Each of these environments contained a different level of long-wave UV radiation (emitted from LEDs) combined with daylight-equivalent fluorescent lighting (filtered to remove its UV component). Diamonds were presented to observers in both table-up and table-down orientations, and the effect of blue fluorescence on their colour appearance was determined by observing them with and without the UV component of the lighting and also by visual comparison with non-fluorescent master stones in each of the four lighting environments. The observers consisted of experienced graders, industry participants and consumers. For colours of J and higher, the simulated Outdoor lighting (which contained the greatest UV component) elevated the grade of diamonds with strong and very strong fluorescence to D–E colour when viewed table-down. The table-up effect was less pronounced. The UV content of the Office lighting was insufficient to produce any observable effect, even for diamonds with very strong fluorescence. HRD Antwerp's laboratory performs colour grading in an environment that lacks significant UV radiation.

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When illuminated by UV radiation, some diamonds emit visible light, or fluorescence. Diamonds can fluoresce in a range of colours, but the most common colour is blue (e.g. Figure 1). The effect of this blue fluorescence on the appearance of (near-)colourless diamonds has been a subject of debate for many years. In the early 20th century, fluorescence was looked at as a positive attribute because it was believed to make diamonds appear 'brighter' or whiter when viewed in daylight (Moses et al., 1997). The blue fluorescence emitted by such diamonds can counteract the appearance of a yellow tinge in their body colour, making them appear whiter. Since the late 1970s and early 80s, however, fluorescence has been perceived as an undesirable characteristic (Cowing, 2010). This has resulted in price discounts as high as 30% for strongly fluorescent diamonds. The price differentiation is linked to a number of reasons, including concerns about over-grading of colour, as well as reduced transparency (perceived as an oily appearance). The term *over-grading* refers to an improvement in colour grade that is assigned to a blue-fluorescent diamond when it is graded in a light source that contains a UV component. This effect can be seen only when the light source contains enough UV radiation to excite fluorescence and the diamond

Figure 1: These earrings and pendant are shown under normal lighting conditions (left) and under a long-wave UV lamp (right). The sapphire centre stones are surrounded by near-colourless diamonds exhibiting various fluorescence intensities and colours (i.e. mostly blue for those stones that are not inert). The earrings measure approximately 20 × 19 mm and the pendant is 30 × 28 mm. Photos courtesy of HRD Antwerp on behalf of Veilinghuis de Ruiter.

possesses sufficiently intense blue UV luminescence. Contradictory information about such diamonds has led to a great deal of confusion regarding the relation between fluorescence and the way such stones are perceived.

A few studies have investigated the effect of blue fluorescence on the appearance of polished diamonds (see Moses et al., 1997; AGA, 2009; Cowing, 2010). The research conducted for the present article uses a larger suite of diamonds across a wide spectrum of D–J colours and fluorescence intensities, observed under four different lighting conditions. The goal of this work is to investigate the influence of lighting conditions and diamond fluorescence intensity on the perception of body colour in blue-fluorescing diamonds and the magnitude of any colour difference. Initial results of this research were presented at the 4th Mediterranean Gemmological and Jewellery Conference in May 2018, the Hong Kong Jewellery & Gem Fair in September 2018 and the GIA (Gemological Institute of America) International Gemological Symposium in October 2018 (e.g. Anthonis et al., 2018a,b; De Corte, 2018; Robinson, 2018).

MATERIALS AND METHODS

We carefully selected several dozen round-brilliant-cut diamonds showing various amounts of fluorescence. Four different experiments included experienced graders, as well as industry participants and consumers in two of the experiments, who viewed the samples under four different lighting environments that were modelled to contain different levels of UV radiation. Visual comparison with non-fluorescent master stones enabled the observers to determine any difference in the colour appearance of the sample diamonds.

The standard way to colour-grade diamonds in a laboratory is to observe them through their pavilion (i.e. table-down), so that the body colour of a diamond can be assessed without being obscured by the light flashes that are typically observed through the table (Shipley and Liddicoat, 1941). However, most consumers typically see diamonds table-up when they are set in jewellery. Therefore, we used both orientations in this study: table-down in the first two experiments and table-up in the latter two experiments. Each pair of experiments was designed (1) to assess whether there was any colour difference in the various lighting environments and (2) to determine the magnitude of that difference.

Details of the fluorescence grading of diamonds at HRD Antwerp, sample selection for this study, simulation of the various lighting environments and conditions of the viewing experiments (participants and setup) are described below.

Fluorescence Grading

To select the samples used for this study, we first graded the fluorescence intensity of a large number of diamonds. Normally the HRD Antwerp lab uses a four-tiered system to grade fluorescence—*nil*, *slight*, *medium* and *strong*—as prescribed by the International Diamond Council (IDC, 2013). Three fluorescence master diamonds represent the lower boundaries for each grade (i.e. slight, medium and strong). A nil grade coincides with a diamond having a

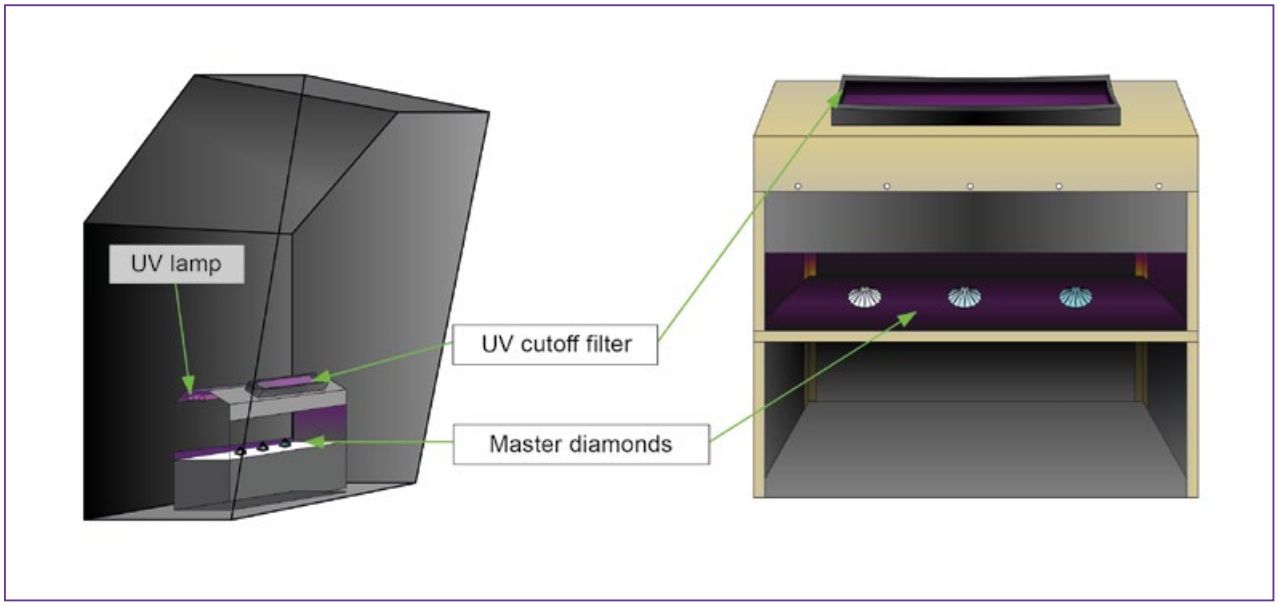

Figure 2: This diagram shows how diamond fluorescence is graded in the HRD Antwerp lab. Left: Examinations are conducted within a cabinet in a darkened room. Right: The grading box is designed so that diamonds can be placed next to fluorescence master stones. Graders look through the UV cutoff filter at the top, perpendicular to the pavilion facets. The UV lamp is located under the ceiling of the grading box, adjacent to the cutoff filter.

lower fluorescence intensity than the master diamond representing the nil/slight boundary. Internationally, the term *very strong* is also used for diamonds with intense fluorescence. Therefore, this category was also included in our research. The border between strong and very strong was determined by experienced graders using a strong-fluorescent master stone.

Fluorescence grading at HRD Antwerp is conducted in a dark room, using a small box containing a long-wave UV lamp (Figure 2). (The bulb consists of a Philips TL/4W/08 F4T5/BLB Blacklight Blue, and its emission spectrum is available in a leaflet at http://tinyurl.com/ycj4e4t9.) A UV cutoff filter at 400 nm is used to protect the viewer's eyes from harmful UV radiation. The diamond and master stones are placed table-down, and the grader looks perpendicular to the pavilion facets to compare the fluorescence of the sample with that of the master diamonds. The distance between the UV lamp and diamonds is fixed at 7 cm.

Because the diamonds in this study were observed table-up as well as table-down, we developed a method to assign the level of their fluorescence when viewed table-up. Photographs were taken of all diamonds using a fixed camera setting in a controlled environment under the UV lamp mentioned above in a darkened chamber. The fluorescence intensity of each diamond was determined from the average greyscale value of the fluorescence image. This greyscale value was used to represent the fluorescence intensity of the diamond, as schematically depicted in Figure 3.

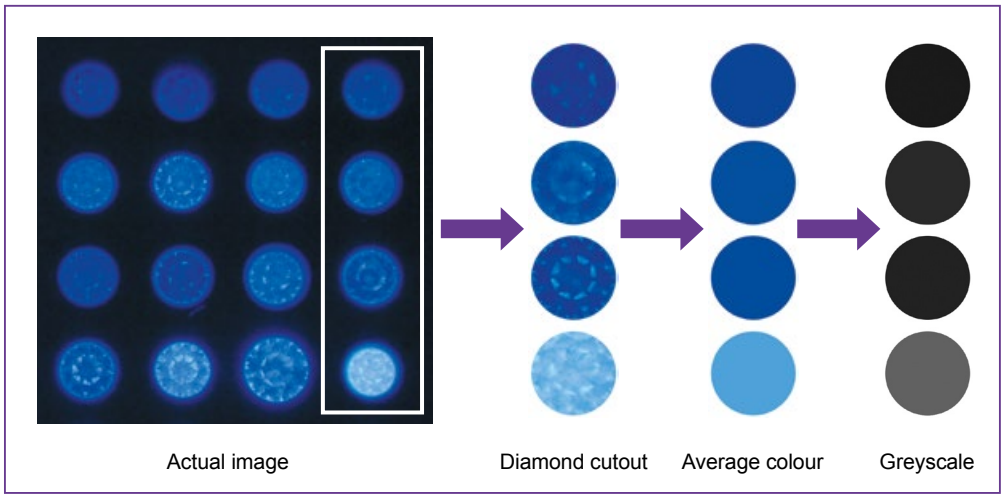

Figure 3: Diamond images are extracted from an actual photograph in order to convert the table-up fluorescence to a greyscale representation of luminescence intensity. Diamond photo courtesy of HRD Antwerp.

Sample Selection

The diamonds selected for this study met several criteria, notably (according to HRD Antwerp standards):

- Shape: round brilliant
- Weight: 0.30–1.10 ct
- Colour: D–J
- Clarity: Loupe Clean to SI_1
- Cut: excellent to very good

Fluorescence levels of the samples ranged from nil through slight, medium and strong to very strong. We further divided the slight, medium and strong fluorescence levels into sub-grades, indicated by the symbols '++', '+' and '=', which represent increasing grades, respectively. The subgrade '++slight' was not used, because the fluorescence level of those samples was so weak that the effect was not noticeably different from the nil grade.

For the table-down experiments, the samples consisted of seven colour sets (ranging from D to J) of diamonds, as shown in Table I. We initially intended to use these same diamond sets for the table-up experiments, but this was not possible because some of the diamonds were found to appear more or less fluorescent when viewed table-up. (This is probably due to inhomogeneous distribution of fluorescence being modified by internal reflections when viewed table-up.) All of the diamonds that showed a distinctly different fluorescence intensity viewed table-up compared to table-down were excluded from the table-up sample set. Seven colour sets were then assembled that included as many stones as possible (16) from the table-down set (see Table II). While the table-down set consisted of 69 diamonds, the table-up set contained 56 stones.

Table I: The 69 diamonds selected for table-down experiments (Experiments 1 and 2).*

	D COLOUR			E COLOUR			F COLOUR			G COLOUR			H COLOUR			I COLOUR			J COLOUR		
Fluo	#	ct	Clar	#	ct	Clar	#	ct	Clar	#	ct	Clar	#	ct	Clar	#	ct	Clar	#	ct	Clar
Nil	9	0.57	LC	–	–	–	60	0.55	VVS_1	32	0.71	VVS_1	15	0.56	VVS_1	39	0.70	VVS_2	–	–	–
++SL	–	–	–	–	–	–	–	–	–	62	0.50	VVS_1	46	0.46	VVS_2	–	–	–	**117**	0.60	VVS_1
+SL	42	0.55	LC	61	0.50	VVS_1	**54**	0.52	VVS_1	–	–	–	–	–	–	102	0.40	VVS_2	361	0.43	LC
=SL	**103**	0.50	VVS_1	49	0.57	VVS_1	214	0.55	VVS_2	235	0.59	LC	312	0.56	VVS_1	114	0.50	VS_1	369	0.52	VVS_2
++M	89	0.42	VVS_1	**115**	0.55	VS_2	109	0.56	VVS_2	**113**	0.55	VVS_2	99	0.40	LC	348	0.72	VVS_1	350	0.31	LC
+M	116	0.59	VVS_1	**194**	0.30	VVS_1	98	0.43	VVS_1	279	0.58	VVS_2	266	0.51	VVS_1	119	0.62	VVS_1	**381**	0.51	VVS_1
=M	108	0.51	VVS_1	193	0.36	VVS_2	**132**	0.45	VVS_1	**238**	0.53	LC	**274**	0.54	VVS_1	**253**	0.32	VVS_1	371	0.53	LC
++ST	154	0.71	VVS_1	131	0.41	VVS_1	–	–	–	158	0.76	VS_2	275	0.54	LC	**139**	0.50	LC	157	0.74	VVS_1
+ST	152	0.60	VVS_1	–	–	–	149	0.50	VVS_1	–	–	–	146	0.52	VVS_1	–	–	–	**147**	0.52	VVS_1
=ST	–	–	–	**159**	0.70	VVS_1	**110**	0.50	VVS_1	173	0.70	VVS_2	140	0.50	LC	321	0.41	VVS_1	–	–	–
++VST	176	0.71	VS_1	167	0.50	LC	169	0.53	VVS_1	179	1.01	LC	–	–	–	185	1.01	SI_1	390	0.52	VVS_2
+VST	164	0.52	LC	210	0.35	VVS_1	175	0.74	VVS_1	**171**	0.64	VVS_2	165	0.51	VVS_1	352	0.38	VVS_2	366	0.51	LC

* Abbreviations: # = sample number, ct = carat weight, Clar = clarity grade, Fluo = fluorescence intensity, SL = slight, M = medium, ST = strong and VST = very strong. Sample numbers in bold indicate those diamonds that were also used in table-up experiments. A set of 10 samples was used for every colour except E, which included nine diamonds.

Table II: The 56 diamonds selected for table-up experiments (Experiments 3 and 4).*

	D COLOUR			E COLOUR			F COLOUR			G COLOUR			H COLOUR			I COLOUR			J COLOUR		
Fluo	#	ct	Clar	#	ct	Clar	#	ct	Clar	#	ct	Clar	#	ct	Clar	#	ct	Clar	#	ct	Clar
+SL	93	0.43	VVS_1	–	–	–	–	–	–	–	–	–	–	–	–	80	0.76	VS_2	–	–	–
=SL	**103**	0.50	VVS_1	59	0.52	VVS_1	**54**	0.52	VVS_1	245	0.58	VVS_2	101	0.41	LC	315	0.33	LC	**117**	0.60	VVS_1
++M	107	0.51	VVS_2	**115**	0.55	VS_2	95	0.43	LC	267	0.53	LC	309	0.52	VVS_1	305	0.50	VVS_1	85	0.30	LC
+M	199	0.40	VVS_1	**194**	0.30	VVS_1	97	0.42	VVS_1	**113**	0.55	VVS_2	280	0.55	VVS_1	**253**	0.32	VVS_1	340	0.50	VVS_1
=M	188	0.33	LC	218	0.55	VVS_2	**132**	0.45	VVS_1	**238**	0.53	LC	**274**	0.54	VVS_1	–	–	–	**381**	0.51	VVS_1
++ST	124	0.30	VVS_1	130	0.41	LC	142	0.50	VVS_1	265	0.50	VVS_1	295	0.42	VVS_1	**139**	0.50	LC	370	0.53	VVS_1
+ST	128	0.40	VVS_2	187	0.31	VVS_1	150	0.50	LC	135	0.41	VVS_1	251	0.30	VVS_1	338	0.51	VVS_2	156	0.73	VVS_1
=ST	122	0.31	LC	**159**	0.70	VVS_1	**110**	0.50	VVS_1	144	0.51	VVS_1	284	0.33	VVS_1	328	0.41	LC	**147**	0.52	VVS_1
++VST	–	–	–	–	–	–	–	–	–	–	–	–	148	0.58	LC	300	0.53	LC	374	0.56	VVS_1
+VST	–	–	–	229	0.33	LC	232	0.36	LC	**171**	0.64	VVS_2	–	–	–	–	–	–	–	–	–

* Abbreviations: # = sample number, ct = carat weight, Clar = clarity grade, Fluo = fluorescence intensity, SL = slight, M = medium, ST = strong and VST = very strong. Sample numbers in bold indicate those diamonds that were also used in table-down experiments. A set of eight samples was used for every colour.

Simulation of Lighting Environments

To simulate different lighting environments, a system was constructed comprising an array of 20 UV light-emitting diodes (LEDs) spanning a length of 30 cm. These LEDs emitted long-wave UV radiation centred at 365–370 nm (with a full width at half maximum of about 20 nm). The LEDs were ground down to remove the epoxy lens so as to produce a more diffuse and even illumination. A Wood's glass filter was used to remove the small component of visible light that the LEDs emitted. The LEDs were connected to a circuit that provided variable current through a potentiometer, with a switch to turn them on and off manually. The emission spectrum of the LEDs did not vary with current, other than in its intensity.

For table-down observations, the above-mentioned UV array was placed alongside an HRD colour-grading lamp for which the UV component was removed with a 3-mm-thick sheet of clear polycarbonate, which acted as an effective filter for wavelengths below 400 nm. Although diamond fluorescence can be activated by wavelengths up to 415 nm, there are no readily available filters that can remove such wavelengths while allowing even (non-colouring) transmission of the visible wavelengths. Our measurements showed that for a UV-filtered grading lamp the integrated intensity of the 400–415 nm band was about one-quarter that of the 300–400 nm band of the unfiltered lamp, suggesting that the polycarbonate sheet removes most of the fluorescence-activating radiation.

For table-up observations, the UV array was installed in a Gretag Macbeth Judge II cabinet of the type that is commonly used by major laboratories. It comprises an open-sided grey-coated 'box' with fluorescent tube lighting in the ceiling of the cabinet. The UV array was positioned alongside the daylight-equivalent fluorescent tubes, as seen in Figure 4 (left). Polycarbonate sheeting was placed in front of the fluorescent tubes. To prevent the diamonds from being exposed to ambient lighting during the observation experiments, a grey panel was installed across the opening of the cabinet. It had a small 'letter box' opening for viewing the samples, and two cut-outs in the bottom corners allowed the observer's arms to enter the cabinet (see Figure 4, right).

For both table-down and table-up configurations, the combination of the UV-filtered daylight fluorescent tubes and the adjacent strip of UV LEDs provided white-light illumination with a controllable UV component. However, because the combined spectrum of the white light and the UV LEDs does not correspond to that of the sun or common white-light sources, a significant challenge was how to mix the UV and white light to correspond to the four lighting environments that were modelled for this study (Table III).

To measure the UV component of a light source or environment, a customised sensor was developed (Figure 5) based on the fluorescence intensity of diamond. A 1 × 1 cm mosaic of strong-intensity blue-fluorescent rough diamonds was attached to a white (non-fluorescent) plate using double-sided (non-fluorescent) tape. A small housing with a stand held the plate centrally at a 45° inclination to the illumination source and a

Figure 4: Left: A Gretag Macbeth Judge II cabinet is fitted with a UV LED array covered with a Wood's filter (black area next to the fluorescent tubes), and the diamonds are viewed in the tray that is raised above the base of the cabinet. A polycarbonate filter for the fluorescent tubes is not shown in this image. Right: The cabinet was modified for the observation experiments by fitting it with a front cover to exclude ambient light. Photos courtesy of HRD Antwerp.

viewing port. To measure the white-light component of a light source or environment, the diamond mosaic was replaced with a matt-white plate. An opening above the plate through which the source light entered could be covered by either a Wood's filter (for UV radiation) or a transparent acrylic window (for white light). As the white plate was non-fluorescent, the UV properties of the window were not important for the white light measurements, and acrylic has fabrication advantages over polycarbonate. A lens, having a focal length similar to the distance to the centre of the inclined plate, was positioned in the viewing port facing the diamond mosaic or white plate. External to the lens could be placed either a camera or spectrometer, as shown in the schematic diagram in Figure 5.

An Ocean Optics Red Tide spectrometer with an aperture of 200 µm was used to measure the fluorescence strength of the diamond mosaic based on the intensity of the main emission peak at 456 nm (again, see Figure 5). Then, with the Wood's filter replaced by the acrylic window, a digital camera (Canon PowerShot SX540 HS) held against the lens was used to photograph the white plate. The brightness of the white light component was expressed by the exposure time (at ISO 100 and f/8)

Table III: The four simulated lighting environments.*

Modelled environment	Calibration conditions	Fluorescence intensity readings
Outdoor	Out of direct sunlight but with a large expanse of blue sky	117
Indoor	Next to an office window facing north-east; protected from direct sunlight by high-rise buildings	83
Grading	Under a daylight-equivalent (6,500 K) fluorescent tube, in a room with weak indirect sunlight	10
Office	In a room illuminated with Osram Dulux L (5,400 K) 55 W bulbs; a north-facing window was present but did not supply any direct light	7

* The calibrations for the Outdoor and Indoor environments were based on the weather in Antwerp in November 2017 and were performed between 10:00 and 14:00 on a nearly cloudless day.

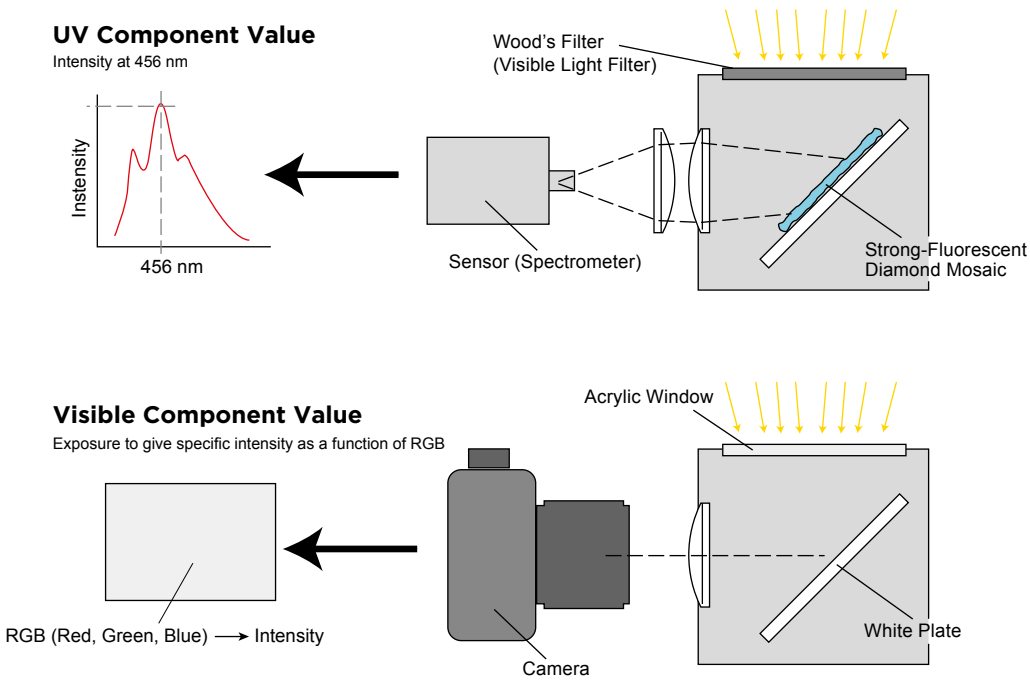

Figure 5: These schematic diagrams illustrate the calibration conditions used to model the various illumination environments. Top: A spectrometer measures the fluorescence intensity of the main peak at 456 nm for a strong-fluorescent diamond mosaic. Bottom: A digital camera photographs a white plate with a range of exposure times in order to obtain a greyscale value of 175.

required to achieve a greyscale value of 175 in the resultant image of the white plate. As it was not possible to obtain live readings of the greyscale value, initially a range of exposures was applied to generate a mathematical relationship between exposure and greyscale value. From this relationship it was then possible to determine the camera exposure that would be necessary to obtain a specified greyscale value.

For a particular viewing environment, the lighting could be characterised by the relative values of the diamond mosaic fluorescence intensity reading at 456 nm (for 2 sec) and the camera exposure necessary to obtain a greyscale value of 175 for the matt-white surface. These two figures—say 710 and 1/30 sec—provide a measure of the relative UV component in a light source. Following the example mentioned above, 1420 and 1/60 sec would therefore correspond to a light source with the same relative UV component.

The sensor array described above was then brought to the four different lighting environments to be modelled. A photograph of the white inclined plate defined the white-light intensity, after which the target diamond fluorescence level was calculated for each of the lighting conditions. After coupling the spectrometer with the housing, we adjusted the current to the LEDs until the desired fluorescence intensity (at 456 nm) was reached. The amount of current necessary to provide the level of UV radiation needed to simulate each intended lighting condition was noted. The fluorescence intensity readings of the four simulated lighting environments are given in Table III. Since there was a near-linear relationship between LED output (UV intensity) and the current applied, the readings can be considered relative to each other.

For the table-up lighting cabinet, determining the UV setting for the LEDs was more difficult because the light seen by the viewer in a diamond comes not only from the direct illumination of the lamp, but also from light scattered off the cabinet wall facing the stone (whereas the fluorescence is mostly from direct UV illumination). The calibration was thus based on photographing the surface of the cabinet wall facing the diamond.

The final lighting spectra that were used to simulate Outdoor, Indoor, Grading and Office environments are shown in Figure 6. As expected, the spectra show distinct intensity variations in the region corresponding to long-wave UV radiation from the LEDs at 365–370 nm, but are otherwise identical.

The methodology described above was checked by colour grading a strongly fluorescent diamond alongside a non-fluorescent master stone in an indoor situation (i.e. in proximity to a north-east-facing window) and finding the result consistent with that observed under the simulated Indoor environment. This was done in both table-down and table-up orientations.

Participants and Experimental Setup

Our study involved four experiments (see Table IV). In Experiments 1 and 2, a conventional laboratory viewing configuration was used to examine the diamonds through their pavilion (table-down). Only certified graders from the HRD Antwerp lab participated in this part of the study. In Experiments 3 and 4, the samples were viewed through the table (table-up). In addition to the certified graders, observers included 'industry participants' and 'consumers'. The industry participants consisted of employees from the HRD Antwerp lab who work in administration and reception (i.e. who see diamonds every day but do not have any experience with colour grading). The consumers

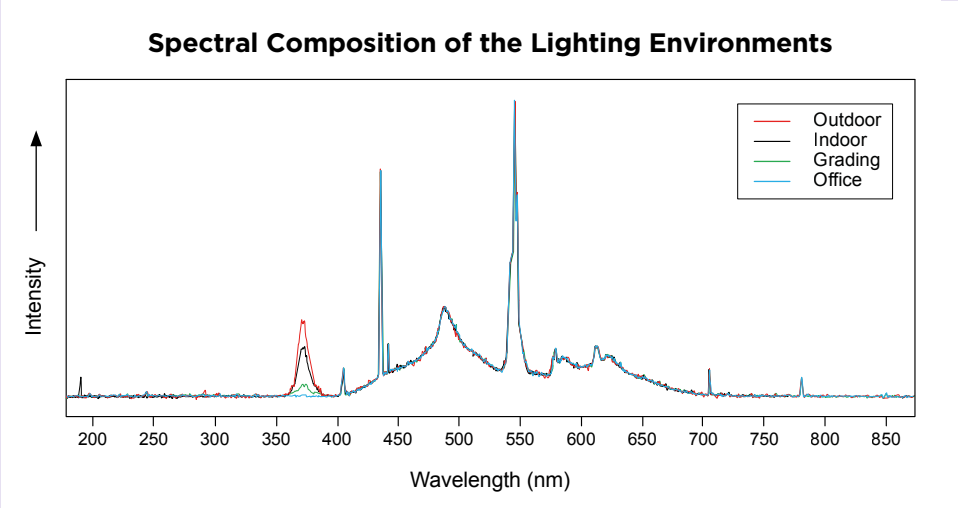

Figure 6: Emission spectra are shown for the four different simulated lighting environments. The spectra demonstrate that the UV component (<400 nm) of the Outdoor lighting is highest of the four environments, while in the Office lighting it is nearly absent.

Table IV: Overview of the four experiments that were carried out in this study.

Experiment no.	View	Objective	Samples	Views per sample	Observers[a]			Lighting environments
					Graders	Industry	Consumers	
1	Table-down	Colour difference? (yes/no)	56[b]	10	14	–	–	Outdoor Indoor Grading Office
2	Table-down	Colour grading	69	10	17	–	–	Outdoor Indoor Grading Office
3	Table-up	Colour difference? (yes/no)	56[c]	12	12	5	6	Outdoor Indoor Grading Office
4[d]	Table-up	Colour grading	49	12	13	8	14	Outdoor Indoor Grading

[a] Due to the availability of graders, industry participants and consumer observers, a larger group of people (more than 10) was used for each experiment, but each sample was viewed 10 or 12 times. (Thus, not every observer looked at every diamond.) The average of these observations was then calculated.

[b] Experiment 1 excluded diamonds with nil, ++slight and +slight fluorescence intensities. Thus, for every colour a set of eight samples was used.

[c] Experiment 3 excluded diamonds with nil fluorescence. Thus, for every colour a set of eight samples was used.

[d] Experiment 4 excluded samples with nil through =slight fluorescence intensities (except a +SL diamond was included for D and I colours since they lacked a ++VST and a +M sample, respectively). Thus, for every colour a set of seven samples was used. Office lighting was not included in Experiment 4 because no colour changes were observed in that environment in Experiment 3.

were HRD Antwerp employees who work outside the laboratory. Both sets of non-graders were included in this part of the study to investigate whether untrained people could also notice fluorescence-related colour differences that were obvious to graders. The number of observers used in each experiment is shown in Table IV.

Experiment 1 (Table-Down, Colour Difference). The objective of Experiment 1 was to determine whether a difference in colour could be noticed in the diamonds positioned table-down when switching between UV-containing and UV-free light sources. The diamonds were generally placed 25 cm below the lighting array in a dark room. For the Outdoor environment, a distance of 35 cm was used. (Because the desired UV level exceeded the output of the UV unit, the visible light was 'dimmed' by raising the daylight tube 10 cm.) The samples were arranged in rows according to their colour (Figure 7). Within each row, the diamonds were ordered by increasing fluorescence intensity from left to right. The graders were informed about the setup of the diamonds (increasing colour and fluorescence level; nil to +slight intensities were not included). For each diamond, the grader recorded if he/she observed any colour difference when switching on and off the UV source (i.e. the LEDs). This was done by 10 different graders, and we then

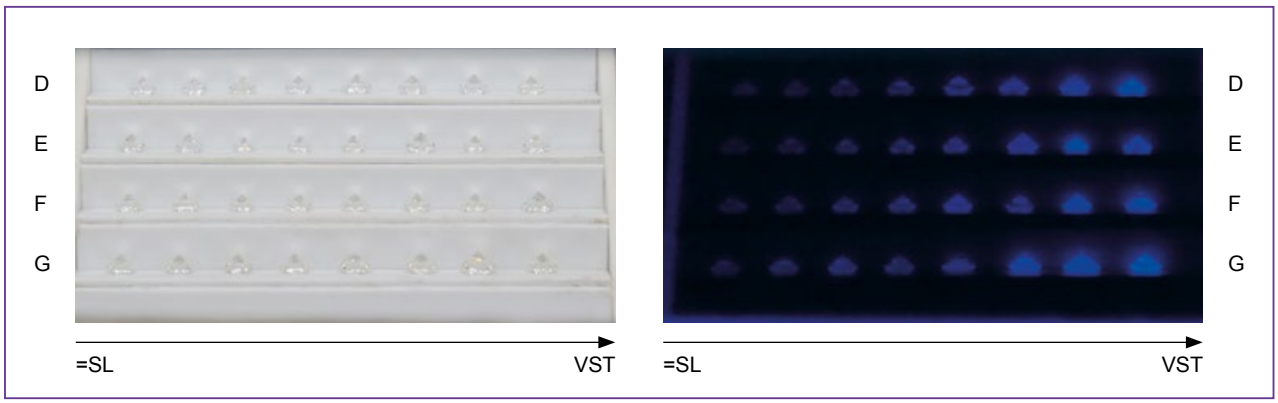

Figure 7: For the setup of Experiment 1, each row contains brilliant-cut diamonds having a certain colour grade. Here only D to G colours are shown. The diamonds have fluorescence intensities ranging from =slight to very strong, and are shown here in normal lighting (left) and under the UV lamp (right). Photos courtesy of HRD Antwerp.

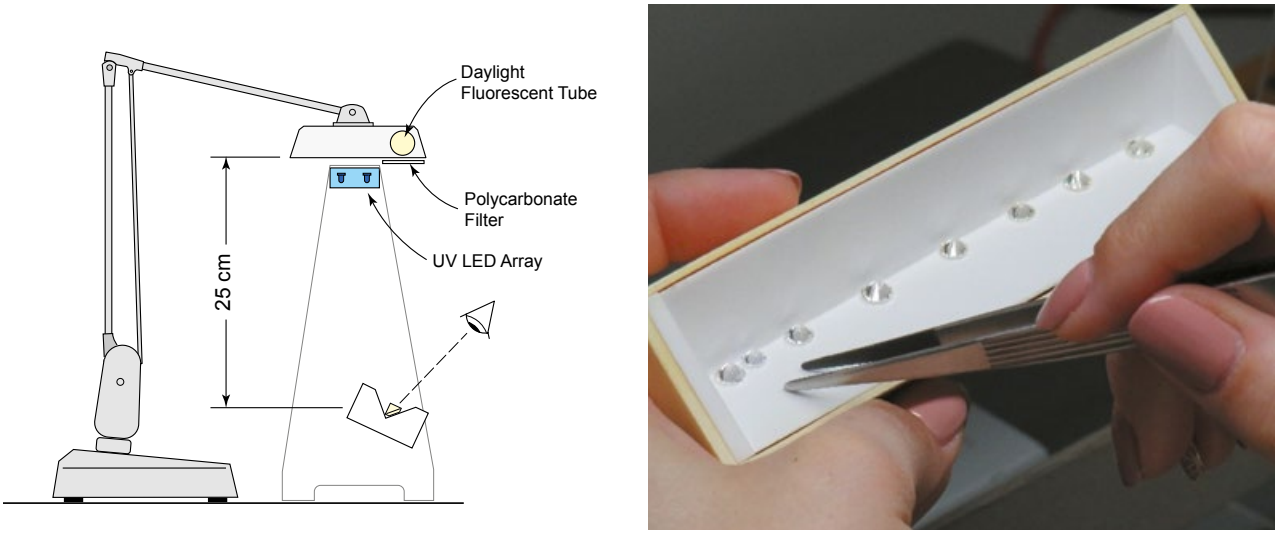

Figure 8: Left: This diagram illustrates how colour grading was conducted in Experiment 2. Right: A participant compares the colour of a sample diamond (left corner) to a set of master stones. Photo courtesy of HRD Antwerp.

calculated a single result for each sample by averaging the 10 observations. This experiment was repeated for each of the lighting environments—Outdoor, Indoor, Grading and Office.

Experiment 2 (Table-Down, Magnitude of Colour Difference). The objective of Experiment 2 was to determine the magnitude of any difference in each diamond's perceived colour in different UV-containing lighting environments. The same samples were used as in Experiment 1, except that diamonds with nil to +slight fluorescence intensities were also included.

One at a time, the samples were placed in a tray alongside a colour-grading master set of nil-fluorescing diamonds for comparison. The master diamonds met the requirements of IDC to grade colour (IDC, 2013). The tray was made of Spectralon, which is known to reflect more than 95% of all light, including UV (Georgiev and Butler, 2007). The tray was positioned approximately 25 cm under the light source (Figure 8). The graders were asked to tilt the tray to look just behind the perpendicular view of the pavilion facets. For each sample, the participants recorded the colour grade on a survey sheet (e.g. Figure 9), and this process was repeated for each

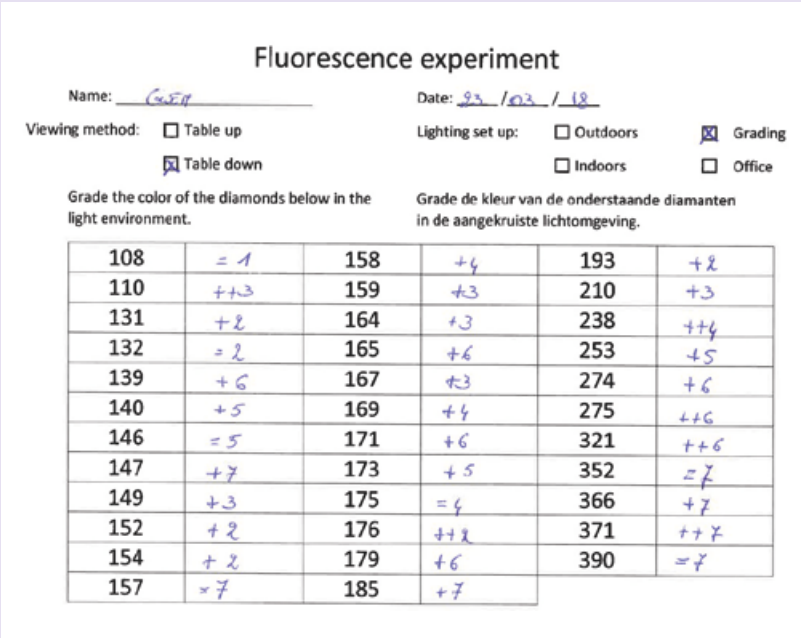

Fluorescence experiment

Name: [illegible] Date: 23 / 03 / 18

Viewing method: ☐ Table up ☒ Table down

Lighting set up: ☐ Outdoors ☐ Indoors ☒ Grading ☐ Office

Grade the color of the diamonds below in the light environment.

Grade de kleur van de onderstaande diamanten in de aangekruiste lichtomgeving.

108	=1	158	+4	193	+2
110	++3	159	+3	210	+3
131	+2	164	+3	238	++4
132	=2	165	+6	253	+5
139	+6	167	+3	274	+6
140	+5	169	+4	275	++6
146	=5	171	+6	321	++6
147	+7	173	+5	352	=7
149	+3	175	=4	366	+7
152	+2	176	++2	371	++7
154	+2	179	+6	390	=7
157	=7	185	+7		

Figure 9: An example of a completed survey sheet shows how colour grades were reported for Experiment 2.

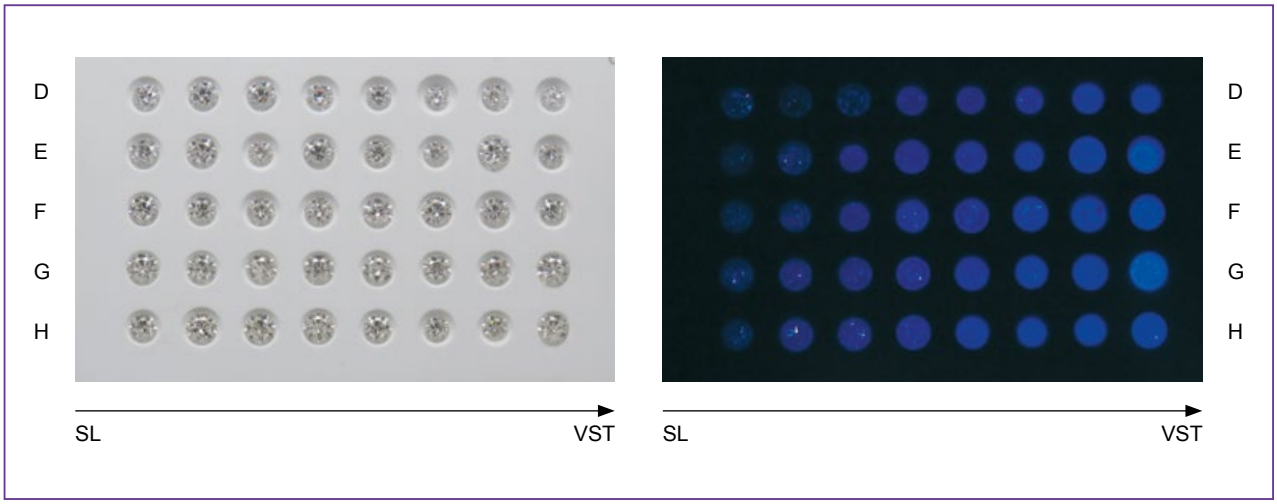

Figure 10: For Experiment 3, several rows of diamonds (here, colours D–H) are positioned table-up. The diamonds have fluorescence intensities ranging from =slight to very strong, and are shown here in normal lighting (left) and under the UV lamp (right). Photos courtesy of HRD Antwerp.

lighting environment. Observations by 10 different graders were averaged into a single result for each diamond.

An example of a completed survey sheet is shown in Figure 9. The colour grades are represented by numerical values, where D-colours are represented by a 1, E-colours by a 2 and so on. This was done so that the results could be averaged mathematically. The numerical values were subdivided using the symbols '++', '+' and '='. For instance, '++2' corresponded to a value of 2.167, '+2' corresponded to 2.5 and '=2' corresponded to 2.833.

Experiment 3 (Table-Up, Colour Difference). Experiment 3 tested whether the participants noticed any colour difference in the diamonds with and without the UV component in each of the four different lighting conditions, but with the samples oriented table-up (Figure 10). Every sample was viewed 12 times, consisting of observations from six graders (50%), three industry participants (25%) and three consumers (25%). The observation procedure was the same as in Experiment 1. Experiment 3 started in the environment with the greatest UV intensity (Outdoor) using the samples with the most fluorescence (+VST, ++VST and =ST). The tests continued with lower fluorescence strengths until participants did not observe any colour difference when switching on and off the UV source, so nil, ++slight and most +slight samples were not included in Experiments 3 and 4.

Experiment 4 (Table-Up, Magnitude of Colour Difference). In Experiment 4, samples were graded table-up in order to quantify any perceived colour difference due to fluorescence. The 12 observations per sample were again divided as above. This experiment included only those diamonds that appeared, on average, to change colour while the UV lamp was switched on and off in Experiment 3. Accordingly, samples with nil to =slight fluorescence intensities were excluded. Also, Office lighting was not included, because in Experiment 3 no colour changes were observed in that environment.

The diamonds were placed on a small strip that could be moved next to a row of non-fluorescing master diamonds spanning colour grades from D to K (Figure 11). In this way, participants were able to compare the diamond samples with the master set to determine their colour. The colour was not determined in the same level of detail as in Experiment 2 because the non-graders participating in this experiment were not trained in colour grading. Thus, the prefixes '++', '+' and '=' were not used.

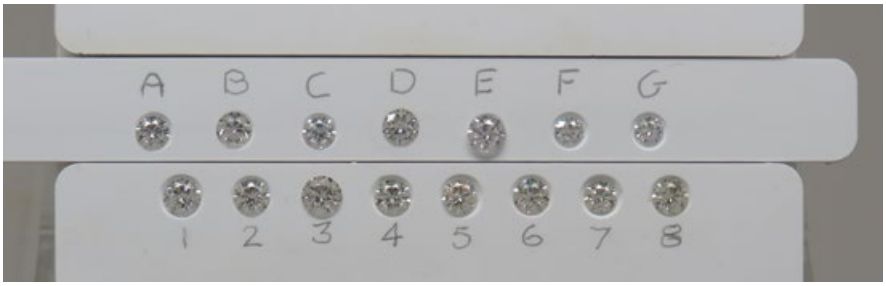

Figure 11: In Experiment 4, diamonds were observed table-up in order to evaluate the magnitude of any perceived colour difference in different lighting environments. The master set is numbered from 1 to 8, where 1 represents D colour and 8 is K colour. The series to grade is labelled A to G on a sliding strip. Photo courtesy of HRD Antwerp.

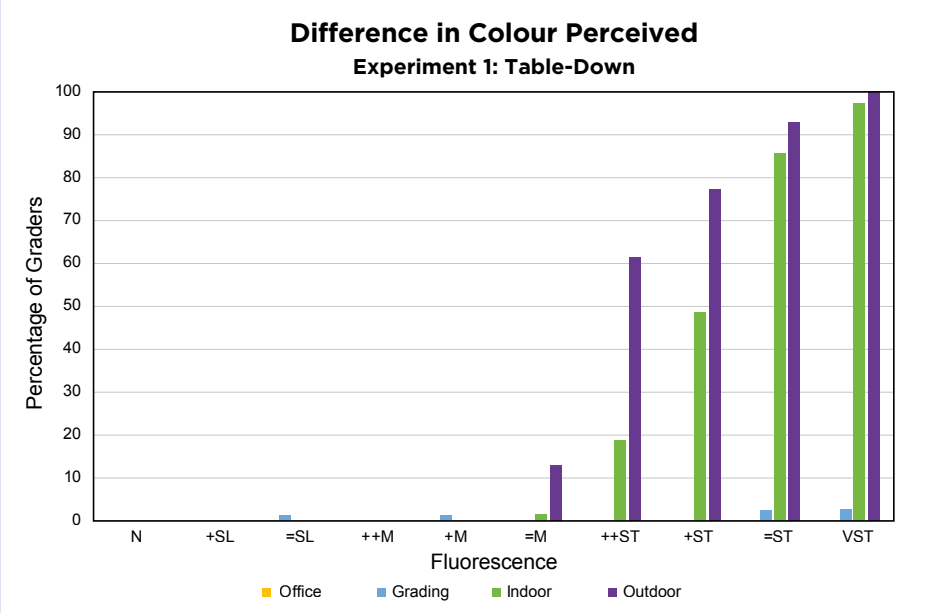

Figure 12: Results plotted for Experiment 1 show the percentage of graders who noticed a difference in colour with and without UV radiation in the diamonds viewed table-down. Participants mainly noticed a colour difference for samples with strong and very strong fluorescence levels. In addition, the effect was primarily observed in environments with higher UV content (Outdoor and Indoor).

RESULTS

Experiment 1: Table-Down, Colour Difference

Regardless of diamond colour, for simulated lighting environments containing higher UV contents (Outdoor and Indoor), graders observed a colour difference in those diamonds with medium, strong and very strong fluorescence. In the lighting environments with a low UV factor (Grading and Office), as expected, almost no colour difference was noted in any of the diamonds. The plot in Figure 12 shows the percentage of graders who noticed an effect from fluorescence in the various lighting environments. For the Grading environment, a small percentage (within the margin of error; less than 5%) could observe a difference in colour between lighting with and without UV.

Experiment 2: Table-Down, Magnitude of Colour Difference

Figures 13–16 show the results of Experiment 2. Differences seen between the HRD Antwerp lab-graded colour and each of three simulated lighting environments (Outdoor, Indoor and Office) are plotted according to diamond fluorescence intensity. (Note that results from the Grading environment are not shown in Figures 13–16 because they were equivalent to the HRD Antwerp lab-graded colour, within the errors mentioned below, as expected.) Each data point represents an average of the 10 observations of each sample. Variations in colour grading between individual participants were expressed as a numerical value of 0.67 (⅔ grade) and were determined by analysing results obtained at HRD Antwerp over the years. The error bars shown in the plots account for these differences between individual graders. The diagonal shading across the centre of each plot represents the area where no colour difference was noted.

When comparing results of the different lighting environments for diamonds with very strong fluorescence, it is clear that the UV component influenced colour appearance in the simulated Outdoor and Indoor lighting (Figure 13). For instance in the Outdoor environment, all diamonds with very strong fluorescence appear to have been 'enhanced' towards D and E colour, regardless of the colour they were graded in the lab. This means that even I- to J-colour samples with very strong fluorescence appeared as D–E colour in the Outdoor environment. As the UV component in the modelled illumination diminishes, the effect decreases as well. This is clearly visible in the results for the Indoor and Office lighting environments in Figure 13.

For samples with strong fluorescence (Figure 14), the same trends are noticeable. In the Outdoor environment, the influence of fluorescence elevates the colour grade to D or E regardless of a sample's lab grade. In the Indoor environment, it is improved by about one grade in the lower-colour stones. There is essentially no difference between the Office environment and lab-graded colour, as shown by the position and 45° slope of the regression line through the Office data.

Overall, the threshold fluorescence grade for a UV effect on colour grade in the Outdoor environment appears to be around medium (Figure 15). For slight- and nil-fluorescent

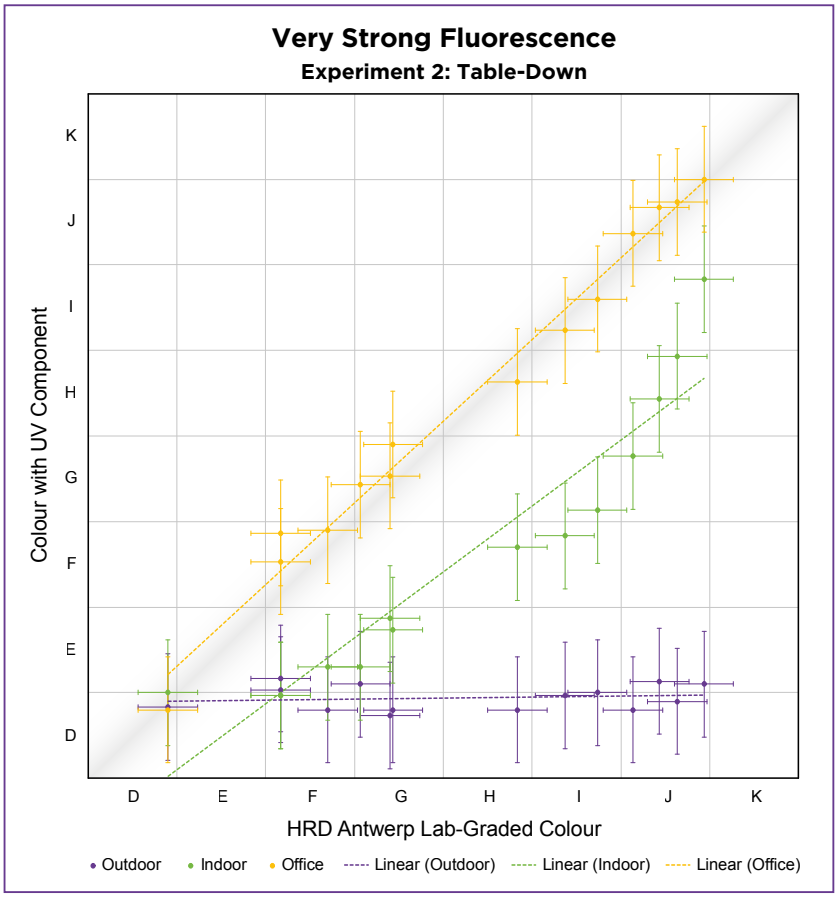

Figure 13: This graph shows the results of Experiment 2 for diamonds with very strong fluorescence graded table-down by comparing the colour observed with a UV component (y-axis) against the HRD Antwerp lab-graded colour (x-axis). The shading in the centre of the plot represents the area where no colour difference was noted. For the Outdoor environment, all samples show an apparent improvement towards D–E colour. This effect is less pronounced with Indoor and Office lighting (environments with lower UV content). Linear regression lines through the data points are added for enhanced visibility.

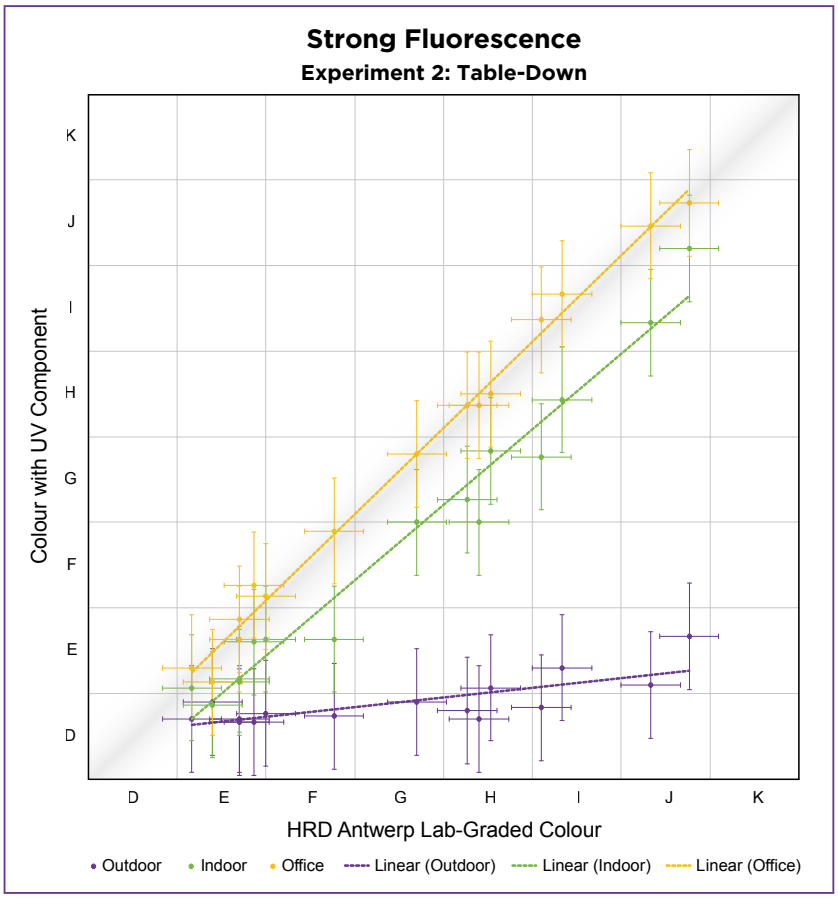

Figure 14: The results of Experiment 2 for diamonds with strong fluorescence graded table-down are displayed here. For the Outdoor environment, the samples appear to have a much better colour compared with their HRD Antwerp lab-graded colour. The influence of fluorescence on colour grade decreases for environments with a lower UV component (Indoor and Office).

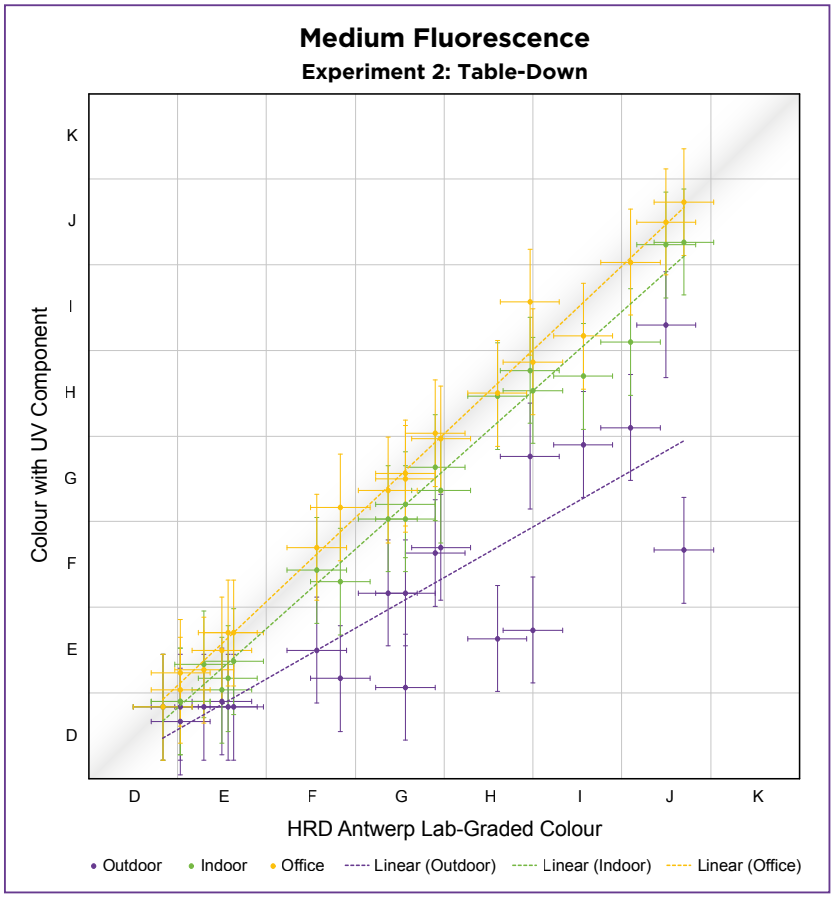

Figure 15: The results of Experiment 2 for diamonds with medium fluorescence graded table-down reveal less effect of the UV component on observed colour in comparison to the previous graphs. In addition, the data points are more scattered, in particular for the Outdoor environment.

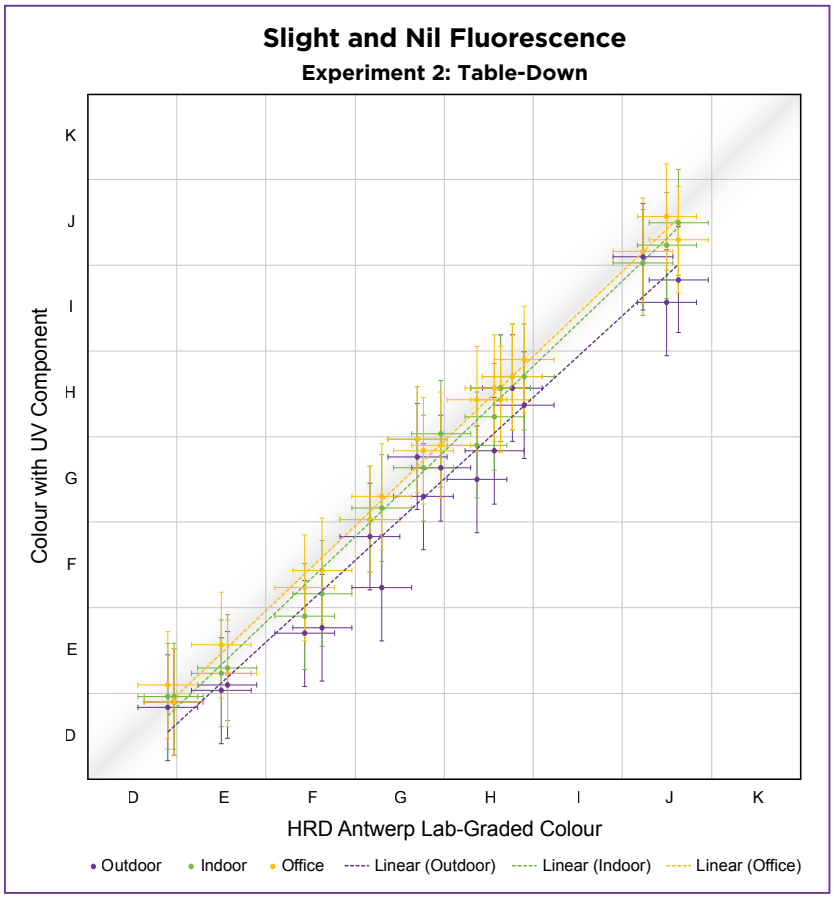

Figure 16: The results of Experiment 2 for diamonds with nil to slight fluorescence graded table-down resulted in data points that show good correlation between HRD Antwerp laboratory grading (UV-free) and UV-containing lighting conditions.

diamonds, the colour was unaffected by fluorescence, with even the Outdoor environment producing no significant colour improvement, as shown in Figure 16.

Experiment 3: Table-Up, Colour Difference

When switching on and off the UV source, participants saw a colour difference table-up in the Outdoor lighting environment for all diamonds with very strong fluorescence and for some of the strong-fluorescent diamonds as well. The colour difference seen in the Indoor environment was significantly less, with the effect mainly limited to the very strong fluorescence category. The participants reported no colour differences for diamonds in the Grading and Office lighting. The overall results are presented in Figure 17.

Examining the results for the Outdoor environment (Figure 18), it is clear that the HRD Antwerp graders, although not trained in the table-up colour grading

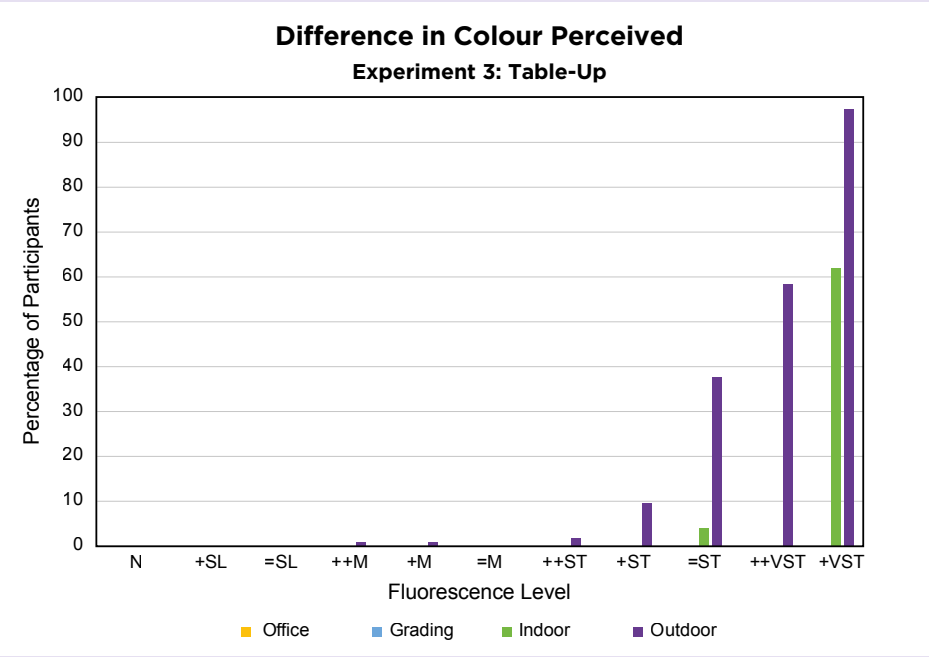

Figure 17: This plot shows the results of Experiment 3, expressed as the percentage of participants who noticed a colour difference in lighting with and without UV radiation for diamonds viewed table-up. Mainly those samples with strong and very strong fluorescence showed an effect, which was most prominent in the Outdoor environment.

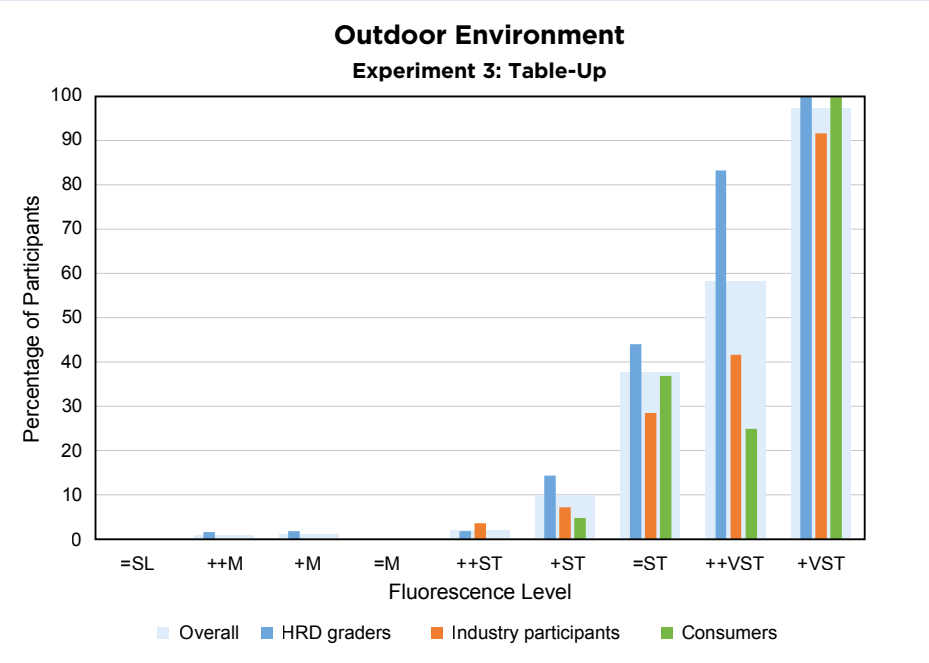

Figure 18: The perception of colour differences in diamonds viewed table-up by graders and non-graders in the Outdoor environment was found to be similar for samples with the strongest blue fluorescence. The effects of medium or less fluorescence were perceived only by HRD graders.

procedure, were more sensitive to subtle differences in colour than non-graders. For the stones with the most extreme very strong fluorescence, also known as 'over-blue' diamonds, almost every participant saw a colour difference when switching on and off the UV light source. This means that even for top colours (D–G) a change was noticed.

For the diamonds with very strong fluorescence close to the strong border (++VST), more than 80% of the HRD Antwerp graders—but only 25% of the consumers—perceived a difference in colour between the Outdoor environment and UV-free lighting. Some of the consumers also noticed a difference in colour for the strong fluorescence category, but neither consumers nor industry participants noticed any effect for lower levels of fluorescence in the Outdoor environment.

For the Indoor environment (Figure 19), the results changed drastically. Only for the diamonds with the strongest fluorescence was a colour difference noticed significantly. For the strong and lower fluorescent grades, the effect was negligible. Again, the consumers were less observant to differences in colour than more experienced participants. For the two remaining environments (Grading and Office), no colour difference was noticed by any of the participants.

Experiment 4: Table-Up, Magnitude of Colour Difference

In Figures 20–22, each data point represents an average of the 12 observations of each sample. For very strong fluorescence, some diamonds viewed table-up received a better colour grade in Outdoor conditions (Figure 20). Unfortunately, the number of data points is too limited to draw any meaningful conclusions since only six diamonds with very strong fluorescence were included. For the strong (Figure 21) and medium fluorescent diamonds (Figure 22), little or no significant differences were observed.

DISCUSSION

The debate about the effect of blue fluorescence on the appearance of a faceted diamond and the price discount for strong fluorescence is not new. However, the topic has recently experienced a renewed interest in the trade (e.g. Sivovolenko and Serov, 2018).

In 1997, GIA published an article (Moses et al., 1997) investigating the effect of blue fluorescence on the appearance of faceted diamonds. In that study, a limited sample set of 24 diamonds encompassing four colour grades (E, G, I and K) was used.

In the present study, we focused on a more extended sample set, including all colour grades ranging from D to J. We also simulated four common lighting environments (i.e. Outdoor, Indoor, Grading and Office). Our results show that there is a significant difference between table-up and table-down changes in perceived colour due to fluorescence. Apparent improvements in colour were greater in the table-down position. This is possibly related to the fact that a diamond's body colour is easier to distinguish through the pavilion. An

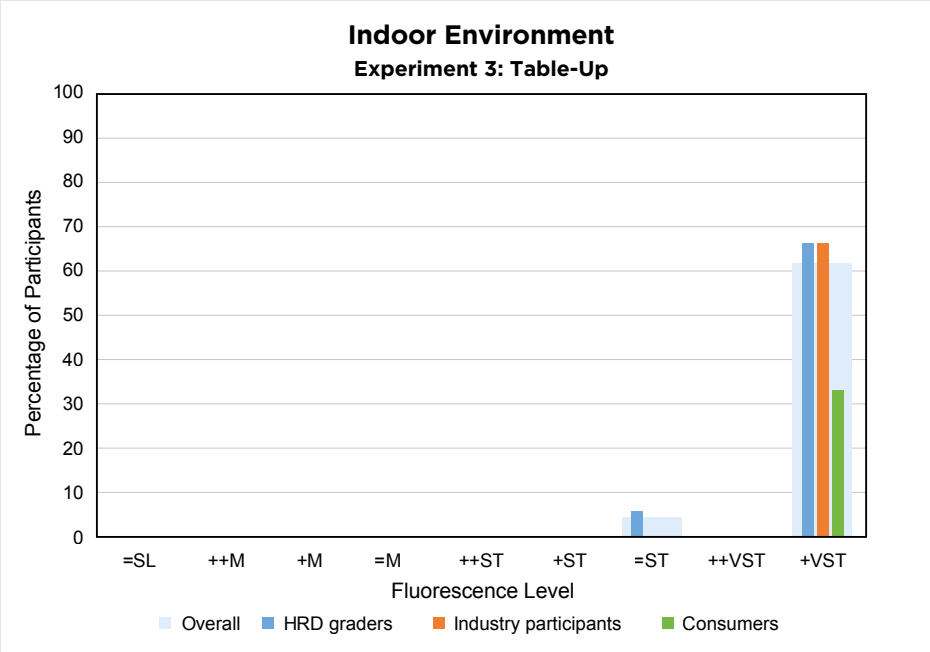

Figure 19: Graders and industry participants and, to a lesser extent, consumers perceived a difference in colour in diamonds with the strongest blue fluorescence when switching between Indoor and UV-free lighting environments.

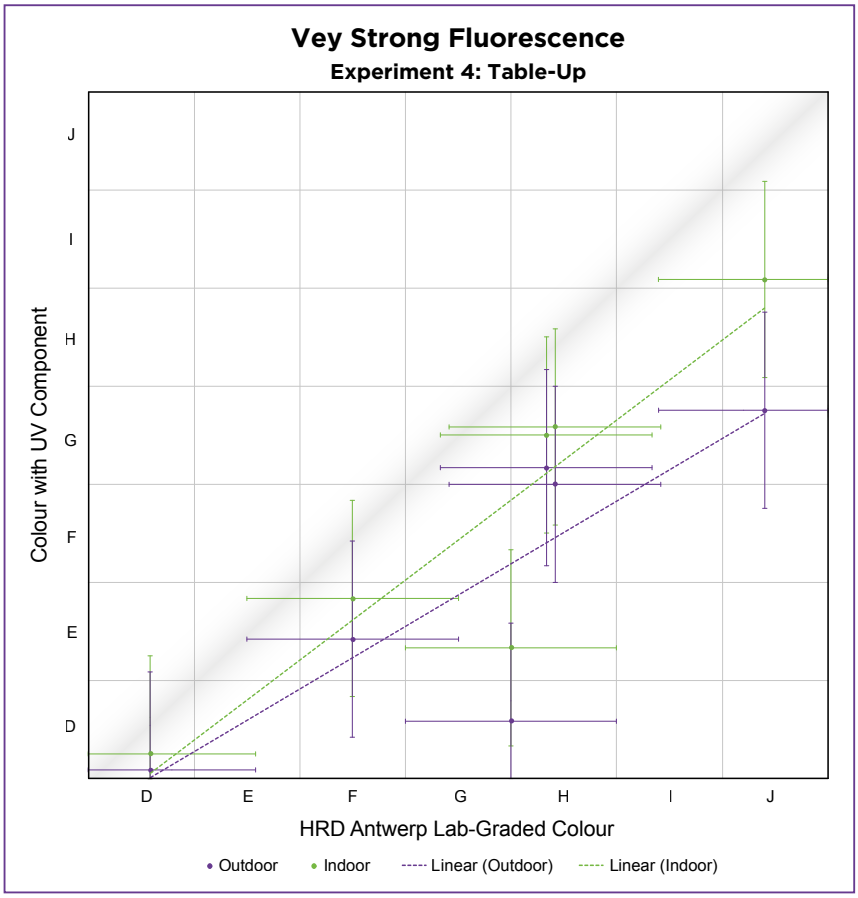

Figure 20: The results of Experiment 4 for diamonds with very strong fluorescence showed that the colour-grade improvement for the samples graded table-up is much smaller compared to table-down results.

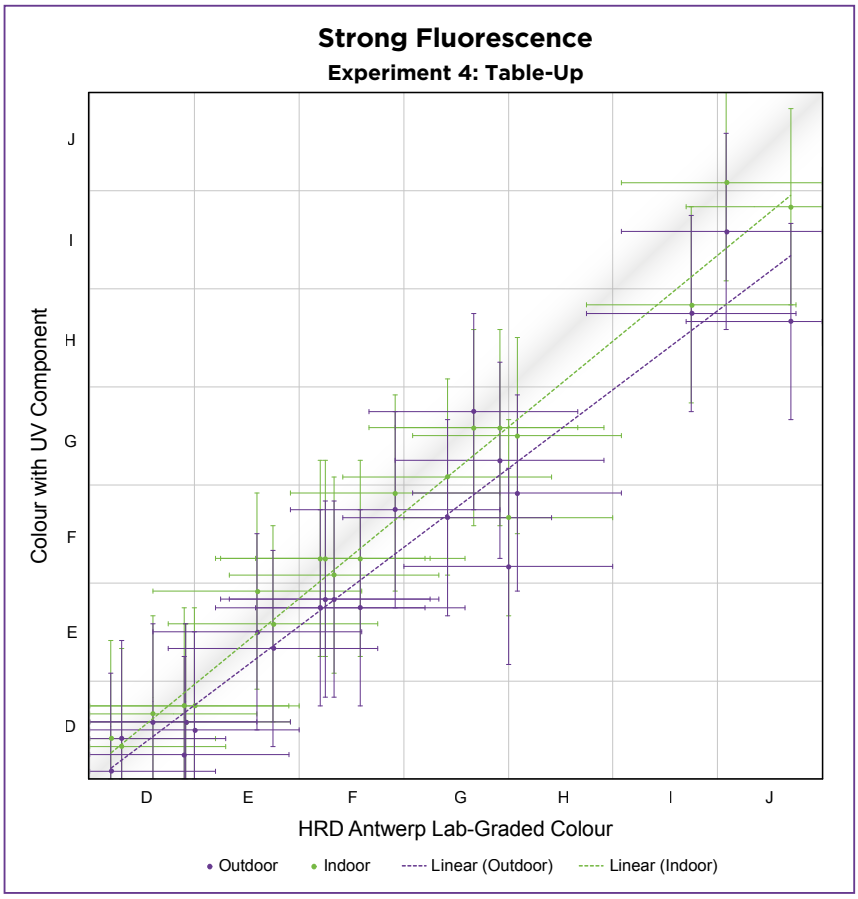

Figure 21: The results of Experiment 4 for diamonds with strong fluorescence graded table-up revealed that little or no significant difference in colour was observed.

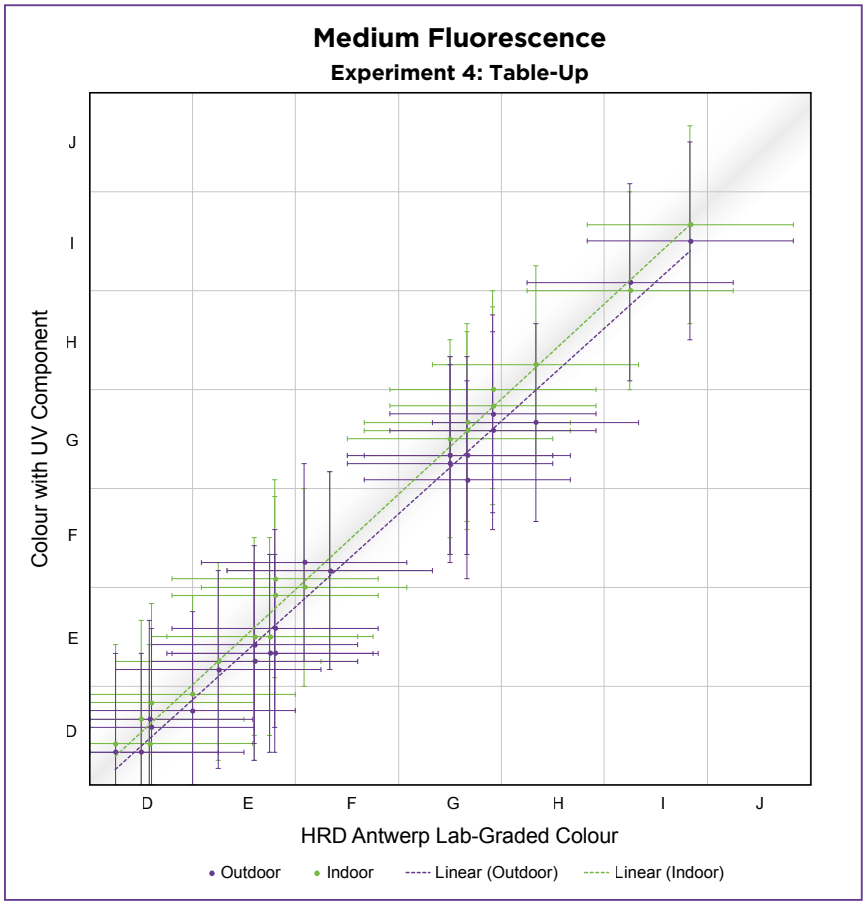

Figure 22: The results of Experiment 4 for diamonds with medium fluorescence graded table-up yielded essentially no colour difference perceived in any of the lighting environments.

interesting observation was the difference in fluorescence intensity seen between table-down and table-up directions for some samples, which is likely due to the interplay between fluorescence zoning and internal reflections in the brilliant-cut diamonds. This led to the decision to use a (partly) different sample set for the table-up experiments.

In some cases, perceived improvements in colour under lighting with a significant UV component were related to the experience of the observer. For diamonds with very strong fluorescence close to the strong border, only 25% of the consumers could detect a difference in table-up colour between the Outdoor environment and UV-free lighting (Figure 18). This means that under everyday outdoor conditions (without direct sunlight), probably only a small percentage of people would notice a fluorescence-related difference in the colour of diamonds mounted in jewellery. The effect would be most obvious in a piece of jewellery containing several diamonds of the same colour but with different fluorescence intensities.

We also found a difference between Indoor and Grading conditions, which contrasts with the results of Moses et al. (1997). In the latter, the results were more-or-less the same between these conditions, but we documented a colour improvement in Indoor conditions for very strongly fluorescent diamonds due to UV content. In addition, our study found no significant difference in perceived colour between our Grading and Office environments. As demonstrated by our lighting simulations, the UV level in the grading lamps used by HRD Antwerp does not affect the colour grade.

CONCLUSIONS

The experiments conducted for this study revealed several significant points:

1) Conventional grading through the pavilion in Outdoor conditions had the effect of improving the colour grade for diamonds with a (blue) fluorescence grade of medium and stronger, elevating the apparent colour of diamonds with E–J grades to D or E for those with strong and very strong fluorescence.

2) In table-up orientation, the intensity of blue fluorescence did not directly correlate with the fluorescence grade in the conventional table-down position, such that

a diamond with a grade of medium could show table-up fluorescence equivalent to that of a diamond having either a slight or strong grade.

3) The effect of blue fluorescence on the perceived colour appearance of a diamond viewed table-up is much less than in the table-down position.

4) For medium blue fluorescence we found no significant improvement in table-up colour appearance in Outdoor lighting.

5) Graders were more able than industry participants or consumers to discern colour differences resulting from blue fluorescence.

To conclude, we did not observe any negative impact of blue fluorescence on diamond colour. In our grading environment, the percentage of lab graders who could observe a colour difference with and without UV was insignificant. Our study shows that blue fluorescence can greatly enhance the table-down colour appearance of a strongly fluorescent diamond when viewed in outdoor conditions. For diamonds with medium or less blue fluorescence, to a casual observer there would be no apparent effect seen table-up, even when viewed outdoors. Given these observations, it can be argued that there are no grounds to justify the price penalties currently applied to blue-fluorescent diamonds—and arguably a premium could be warranted, except in the case of extreme blue fluorescence.

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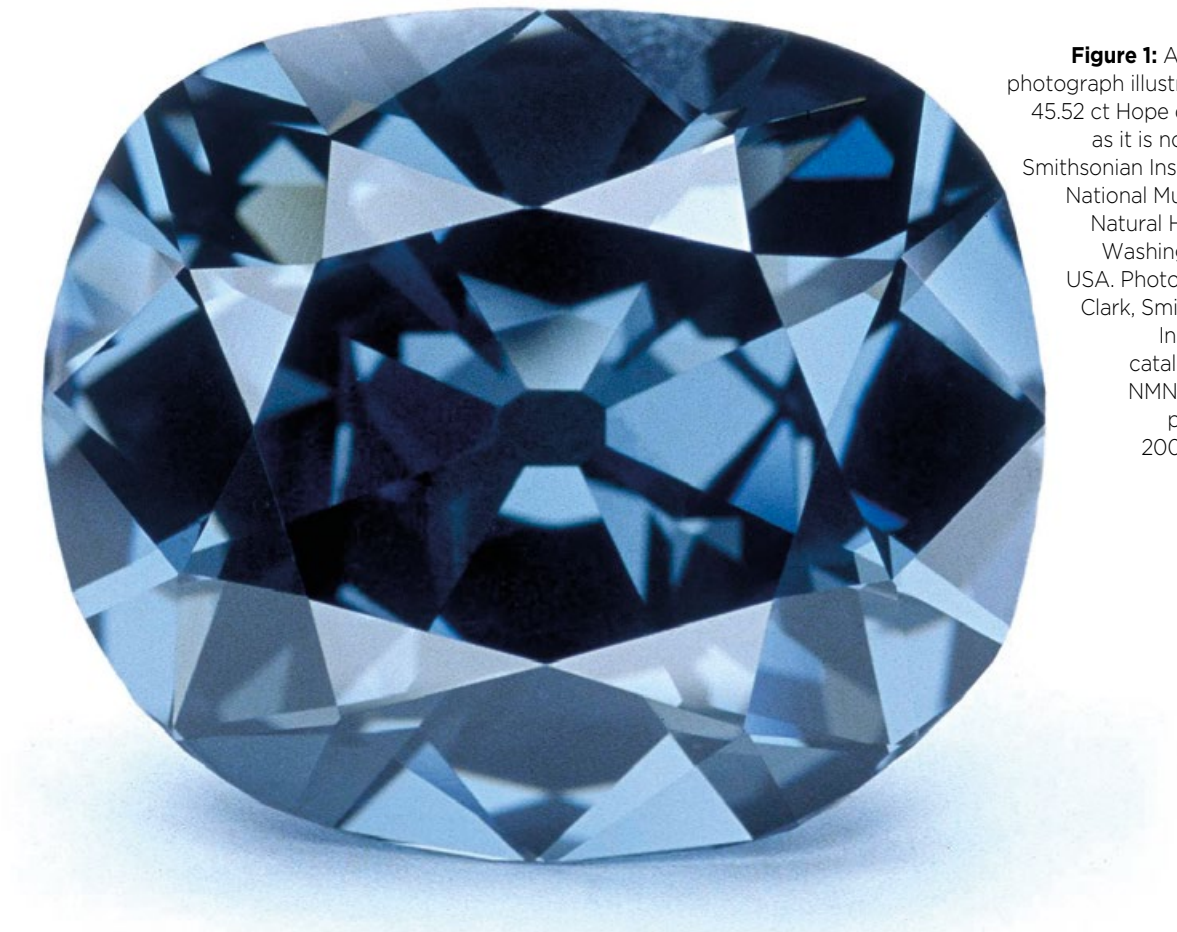

Figure 1: A modern photograph illustrates the 45.52 ct Hope diamond as it is now in the Smithsonian Institution's National Museum of Natural History in Washington DC, USA. Photo by Chip Clark, Smithsonian Institution; catalogue no. NMNH G3551, photo no. 2003-37145.

Out of the Blue: The Hope Diamond in London

Jack M. Ogden

ABSTRACT: Our knowledge of the history of the French Blue/Hope diamond between the time of its theft from the French Crown Jewels in 1792 and its publication as part of the collection of Henry Philip Hope in 1839 has many tantalising gaps. Based on new research, this article covers what we now know of this diamond after its reappearance in London in 1812. A painting of the diamond by the mineralogist James Sowerby has been located, along with Sowerby's notes. These formed the basis for an advertising pamphlet for the gem produced by London jeweller Daniel Eliason, published in English and French versions, which can now be dated to 1813. We also learn that Eliason and Sowerby exhibited, or at least planned to exhibit, a blue glass model of the diamond at the Linnean Society in London. Several sources point to 1821 as being the year Henry Philip Hope purchased the diamond in London. The testimonies in the 1840s court cases surrounding the ownership of Hope's gem collection following his death in 1839 provide useful background information and, remarkably, suggest that in 1838 there was an attempt to sell the diamond back to the French Crown.

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The history of the famous Hope blue diamond (Figure 1)—its journey from the East to the French King Louis XIV in the 17th century, its theft during the French Revolution, its pride of place in the Hope collection in London, and then its eventual arrival in the gem and mineral collection at the National Museum of Natural History in USA—is one of the best-known stories in the history of diamonds (Figure 2). The research presented here aims to fill some gaps in our knowledge of this extraordinary gem and of those who were involved when it reappeared, seemingly out of the blue, in London in 1812. Previously unpublished archival material provides a new witness to its appearance in London—the mineralogist James Sowerby, who painted it, as well as the court testimony of diamond dealer Abraham Hertz, author of the catalogue of the Hope Collection of Gems—which throws further light on various aspects of the Hope, including an attempt to sell it back to the French Crown.

OUT OF THE EAST TO FRANCE

In 1663, the French Huguenot gem dealer, Jean Baptiste Tavernier, set off on what was to be his sixth and final trip to Persia and India (Tavernier, 1676). He took with him jewellery and precious objects worth 400,000 livres (~US$10 million in modern terms), which belonged to several notable French jewellers, to offer for sale (Ogden, 2017). His aim was to sell these pieces to the Persian Shah in Isfahan (in what is now Iran), and to the Mughal Emperor in India, and then invest the proceeds in diamonds from India. One diamond generally assumed to be brought back to France from that successful trip was a large blue one weighing 112 3/16 old carats (or 115.28 metric carats; see Ogden, 2017). Tavernier gave no information as to where he purchased it, and there is one hint that he may have bought it in Iran during his somewhat trying overland journey home (Ogden, 2017). Once back in Paris in 1669, Tavernier sold this large blue stone, along with other diamonds, to the French King Louis XIV. In 1673, it was cut by Jean Pitan into a kite-shaped brilliant of 67 1/8 old carats (Bapst, 1889; equivalent to 68.9 metric carats). Decades later it was set in the Order of the Golden Fleece in the French Crown Jewels for Louis XV (Figure 3). The gem, described then as 'the blue diamond of the crown' (Bapst, 1889, p. 267), is now usually referred to as the 'French Blue'. Little more than a century after the royal purchase of the gem, it was confiscated during the French Revolution, only to be stolen from the poorly guarded Royal Repository in Paris in mid-September 1792 (Bapst, 1889, pp. 447–452. Uncertainty surrounds what happened next.

TIMELINE FOR THE FRENCH BLUE/HOPE DIAMOND

1669
Sold by Jean Baptiste Tavernier in Paris to French King Louis XIV

1673
Cut by Jean Pitan into a kite-shaped brilliant

1749
Mounted into the Golden Fleece ornament of French King Louis XV

1792
Stolen from the French Crown Jewels during the French Revolution

↕

Whereabouts unknown for 20 years

↕

1812
Recorded in London in possession of jeweller Daniel Eliason

1821
Possibly sold to Henry Philip Hope in London

1832
Certainly in the Hope collection by this time

1839
Published in Abraham Hertz's catalogue of the Hope collection

Death of Henry Philip Hope

1848
In the division of Hope's collection after his death, his nephew Henry Thomas Hope receives the Hope diamond

1862
Henry's wife Adele inherits it on Henry's death

1884
On Adele's death it is inherited by Henry Thomas Hope's grandson Lord Francis Hope

1901
Sold to London dealer Adolph Weil, who sells it to New York dealer Simon Frankel

1908
Sold to Salomon Habib, possibly for Sultan Abdul Hamid

1909
Bought at Habib auction in Paris by Paris dealer Simon Rosenau

1910
Sold to Pierre Cartier

1911
Purchased for Evalyn Walsh McLean by her husband

1949
Sold to Harry Winston following Evalyn's death

1958
Donated by Harry Winston to the Smithsonian Institution's National Museum of Natural History

Figure 2: This timeline shows the whereabouts of the French Blue/Hope diamond from 1669 until 1958, when the stone was donated to the National Museum of Natural History, where it presently resides. The blue font indicates the portion chronicled by the present article.

REAPPEARANCE IN LONDON

According to the French historian Germain Bapst, son of the last Crown Jeweller of France, in his exhaustive study of the French Crown Jewels written at the end of the 19th century, following its theft the large blue diamond was taken to London by a man he named as Cadet Guillot, where it was cleaved into two pieces to disguise it (Bapst, 1889, pp. 270–271). This seems to be the earliest mention of Guillot and his involvement, but the basis for Bapst's assertion is unclear. An alternative story is that the theft of the French Crown Jewels was an inside job by revolutionaries, and the blue diamond was used to bribe the Duke of Brunswick, who was threatening to attack France to restore the monarchy (Bapst, 1889, p. 448). This ties in with a rumour reported in the British press shortly after the theft that the revolutionaries had taken the Crown Jewels themselves and that 'their endeavours to discover the robbers are only a mere deception to deceive the public' (e.g. *Kentish Gazette*, 5 October 1792, p. 3). A further version of the tale links the French Blue with the large blue gem worn by Queen María Luisa, wife of Charles IV of Spain, in a 1799 painting by Francisco Goya (now in the Taft Museum of Art, Cincinnati, Ohio, USA), although the gem in the painting is a very different shape (Tillander, 1975). Yet another story—with a series of manifestations of its supposed curse—has the blue gem reaching Wilhelm Fals, a diamond cutter in Amsterdam. The diamond was then supposedly stolen from him by his sons and given to Francis Beaulieu of Marseille, France, who brought it to London and eventually sold it to the London diamond dealer Daniel Eliason (see the section on Eliason below).[1]

As we will see, the French Blue was in London by September 1812, with Eliason, by then cut as an oval brilliant weighing 177 grains or 44¼ pre-metric carats. The 19th-century British carat is usually stated to be around 0.2053–0.2054 grams. That would put the weight of the blue diamond as it was in London in 1812 at between approximately 45.42 and 45.44 metric carats. However, the present weight of the Hope diamond is 45.52 metric carats, and it must have lost at least a little of its weight when slight repolishing, including of the girdle, was done while it was owned by

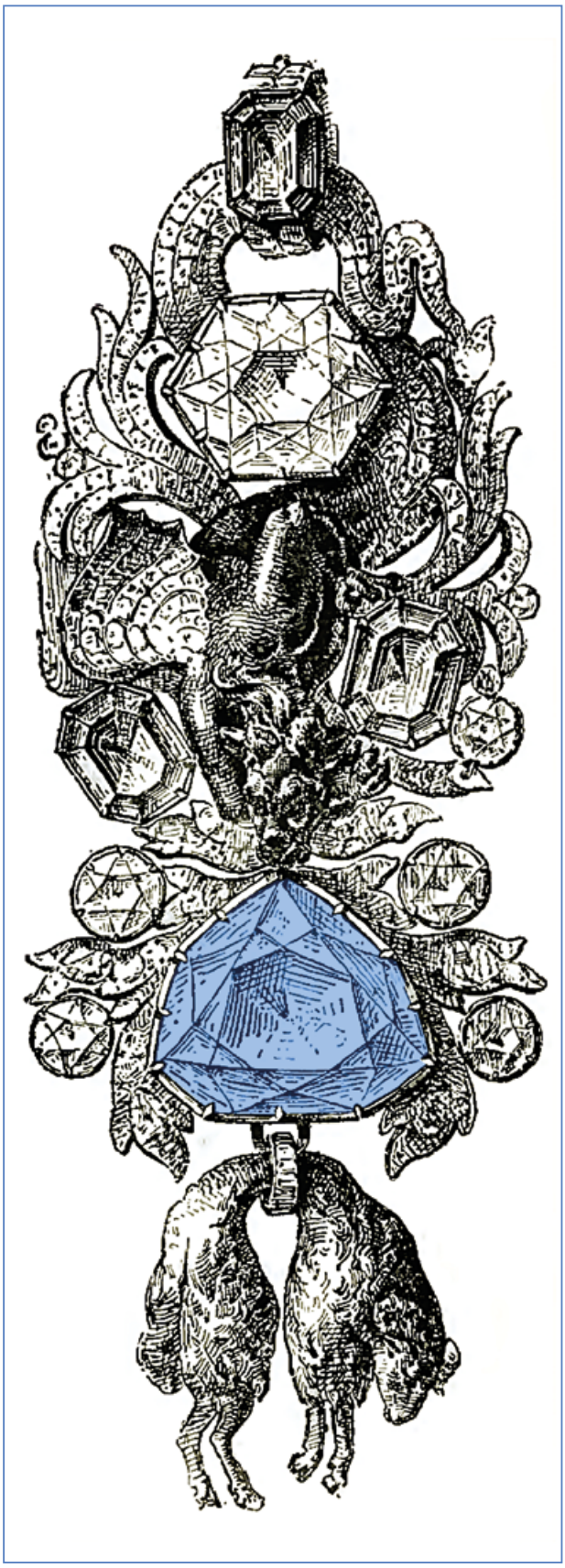

Figure 3: The ~69 ct French Blue diamond was set in the Golden Fleece ornament of Louis XV, which was designed by court jeweller Andre Jacquemin in 1749. From Bapst, 1889, p. 268.

[1] So far the present author has found no mention of a Francis (or François) Beaulieu in connection with the French Blue before this version of the theft was widely reported in the world press in 1909 (e.g. *The Times*, 25 June 1909, p. 5). The origin of this story seems unknown.

Figure 4: The business card of Cripps & Francillon names them as jewellers to his Royal Highness the Prince of Wales (the future King George IV), and also to the Duke and Duchess of Württemberg. © Bodleian Library, Oxford, John Johnson Collection.

Harry Winston in the 1950s. This means that the carat weight used by Eliason (and later by Hertz) must have been nearer to 0.206 grams or more. This seemingly would fit with an 1811 explanation (Kelly, 1811, p. 258) that there were 150 carats to 1 troy ounce, giving a carat then of just over 0.207 g.

The blue diamond later found its way to the collection of gems belonging to Henry Philip Hope and then, through various owners, to Washington DC in the USA as the Hope diamond. Research based on a surviving lead model of the gem as cut by Pitan along with computer modelling has established that the Smithsonian's Hope diamond is indeed the recut French Blue (Farges et al., 2009).

EARLY SIGHTINGS IN LONDON

London jeweller John Francillon (1743–1816), a doctor by training, was of Huguenot descent and had joined London goldsmith and watchmaker John Cripps to form the firm of Cripps & Francillon (Figure 4) no later than 1769. In September 1812, he recorded in his so-called Francillon Memo (Figure 5) a blue diamond in London weighing 177 grains (44¼ pre-metric carats) and provided a coloured drawing, having traced round it 'by leave of Mr Daniel Eliason'. He stated that 'it is beautyfull and all perfection, without specks or flaws, and the Color even and perfect all over the Diamond'. The Francillon Memo,

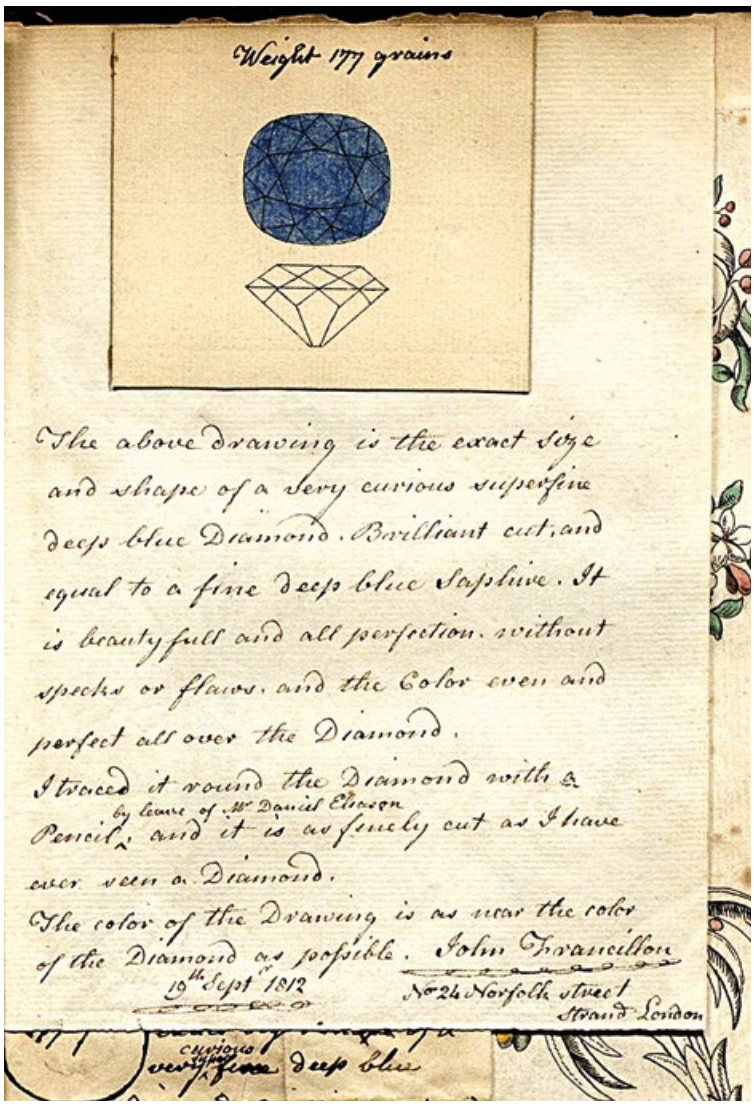
Weight 177 grains

The above drawing is the exact size and shape of a very curious superfine deep blue Diamond. Brilliant cut, and equal to a fine deep blue Saphire. It is beautyfull and all perfection, without specks or flaws, and the Color even and perfect all over the Diamond.

I traced it round the Diamond with a Pencil, by leave of Mr Daniel Eliason and it is as finely cut as I have ever seen a Diamond.

The color of the Drawing is as near the color of the Diamond as possible. John Francillon

19th Sept 1812 No 24 Norfolk street Strand London

curious very fine deep blue

Figure 5: The so-called Francillon Memo describing the blue diamond, written in London in 1812, was found tucked within a copy of Pouget's 1762 *Traité des Pierres Précieuses*, which was once owned by George F. Kunz and perhaps by Francillon himself. Francillon's drawing of the blue diamond was attached to the Memo. Courtesy of the United States Geological Survey Library.

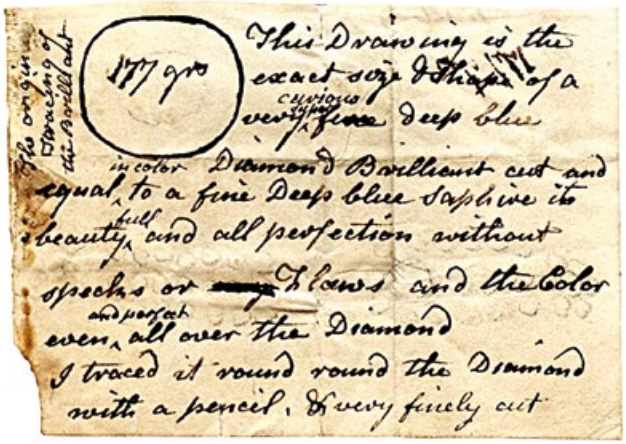

Figure 6: This rough draft of the Francillon Memo in Figure 5 was found in the same volume of Pouget's *Traité*. Courtesy of the United States Geological Survey Library.

and an earlier draft of it (Figure 6), were found tucked into a copy of the 1762 *Traité des Pierres Précieuses* by Jean Henri Prosper Pouget that was later purchased by the gem and jewellery expert George F. Kunz.[2]

Francillon's 1812 drawing and handwritten note were not published, and the diamond was not announced to the wider world until the following year, of which we have evidence of two mentions. The first is a footnote in John Mawe's 1813 *Treatise on Diamonds and Precious Stones* in which he notes the presence of 'a superlatively fine blue diamond' in London, weighing over 44 carats, but without indicating its ownership (Mawe, 1813, pp. 16–17†). Relegating the mention of this extraordinary diamond to a footnote rather than incorporating it into the text (something remedied in his second edition: Mawe, 1823) might suggest that he only saw or heard of the gem after the book was essentially complete, around spring 1813.[3] It is possible that Mawe had not seen the stone himself in 1813, but learned of it from a two-page printed pamphlet that described the diamond, with a hand-coloured illustration of it, which we can now also date to that year. The present author knows of three surviving versions of this pamphlet. Two are in French: one was bound into the same copy of Pouget's *Traité* as the Francillon Memo, and the other is in the manuscript collection of the Natural History Museum, London (Sowerby Coll. MSS B127/1). The third version, now in the British Museum (inv. no. D,2.1787), has the same text in English (Figure 7):

[2] This and other inserts in Kunz's copy of Pouget's 1762 *Traité* seem to be in the same handwriting as text annotations, which suggest that Francillon may have been the original owner of this book, as noted by Kunz (1897).

[3] Mawe's *Treatise* was described as 'nearly ready for publication' in the *Morning Post* of 23 April 1813 (p. 3) and was published the following August (*Morning Post*, 2 August 1813, p. 2).

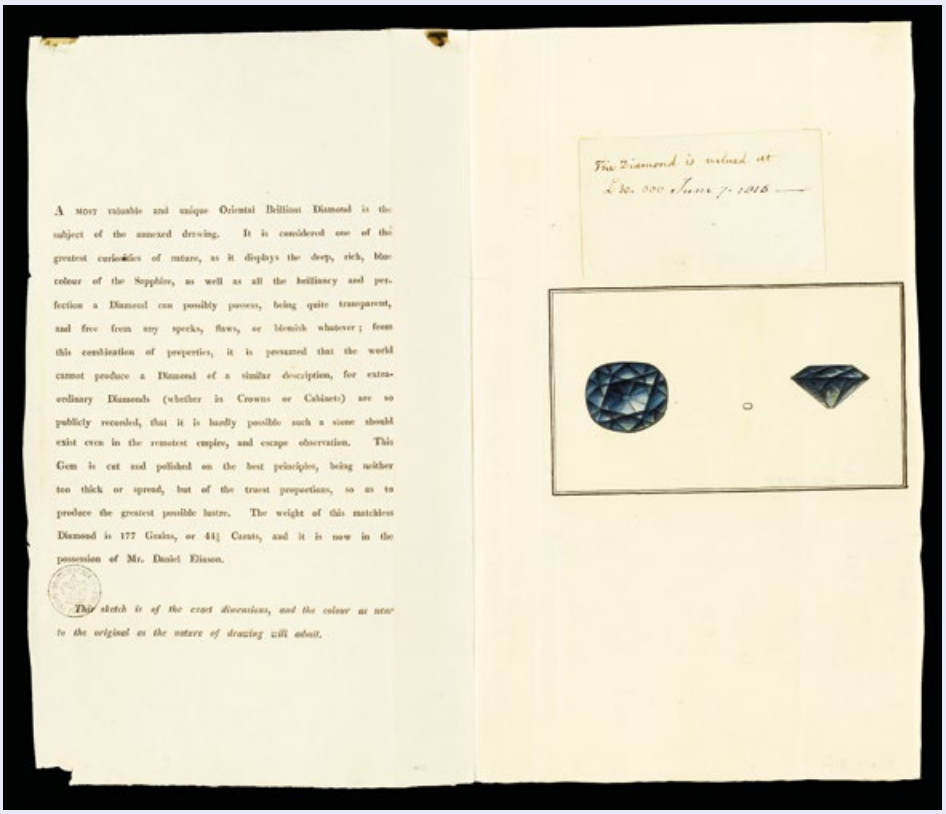
A MOST valuable and unique Oriental Brilliant Diamond is the subject of the annexed drawing. It is considered one of the greatest curiosities of nature, as it displays the deep, rich, blue colour of the Sapphire, as well as all the brilliancy and perfection a Diamond can possibly possess, being quite transparent, and free from any specks, flaws, or blemish whatever; from this combination of properties, it is presumed that the world cannot produce a Diamond of a similar description, for extraordinary Diamonds (whether in Crowns or Cabinets) are so publicly recorded, that it is hardly possible such a stone should exist even in the remotest empire, and escape observation. This Gem is cut and polished on the best principles, being neither too thick or spread, but of the truest proportions, so as to produce the greatest possible lustre. The weight of this matchless Diamond is 177 Grains, or 44¼ Carats, and it is now in the possession of Mr. Daniel Eliason.

This sketch is of the exact dimensions, and the colour as near to the original as the nature of drawing will admit.

The Diamond is valued at £20,000 June 7th 1818

Figure 7: An English edition of a pamphlet, believed to have been written by James Sowerby, describes the blue diamond that was in the possession of Daniel Eliason, along with a hand-coloured etching showing two views of the stone and an attached note on its value. © Trustees of the British Museum, inv. no. D,2.1787.

> A most valuable and unique Oriental Brilliant Diamond is the subject of the annexed drawing. It is considered one of the greatest curiosities of nature, as it displays the deep, rich, blue colour of the Sapphire, as well as all the brilliancy and perfection a Diamond can possibly possess, being quite transparent, and free from any specks, flaws, or blemish whatever; from this combination of properties, it is presumed that the world cannot produce a Diamond of a similar description, for extraordinary Diamonds (whether in Crowns or Cabinets) are so publicly recorded, that it is hardly possible such a stone should exist even in the remotest empire, and escape observation. This Gem is cut and polished on the best principles, being neither too thick or spread, but of the truest proportions, so as to produce the greatest possible lustre. The weight of this matchless Diamond is 177 Grains, or 44¼ Carats, and it is now in the possession of Mr. Daniel Eliason.

The British Museum pamphlet in Figure 7 has glued to it a piece of paper with the handwritten note 'The Diamond is valued at £30,000 June 7, 1816'. This suggests that the stone was still in Eliason's hands and for sale in 1816. Neither the French nor the English version of this pamphlet bears the artist's name or the date when it was printed, but these can be learnt from the 1840 catalogue of London bookseller John Bohn (p. 647), in which one item is:

> 7048 Sowerby's Drawing of a most valuable and unique Oriental Brilliant Diamond, weighing 177 grains, or 44¼ Carats, and of the colour of the Sapphire, in the possession of Mr. Daniel Eliason; with description; 2 leaves, 4to. PRIVATELY PRINTED, *5s*. 1813.

This catalogue entry helps us to attribute the pamphlet text and drawing to the well-known English naturalist and illustrator James Sowerby (1757–1822), aptly the son of a lapidary.[4] The second French version of the pamphlet is in the Sowerby Archives in the library of the Natural History Museum, London, along with a hand-coloured proof printing of the illustration (as shown in the pamphlet) and Sowerby's original watercolour illustration of the gem (as reproduced in the pamphlet; Figure 8), plus his hand-written note (Figure 9; Sowerby Coll. MSS B127/2):

> The drawing which accompanies this is an humble representation of the most extraordinary Diamond in the world, and as it may not, possibly, remain in England I was desirous that the Linnean Society should have information. The Gentleman who possesses it is so kind as to further my desires by bringing a model of it to show its size, but as it could not be equalled in colour, the model as well as the drawing is much too dull, but may assist the mind with the help of description as the Gem itself is too valuable to be carried about.
>
> Its weight is 177 Grains or 44¼ Carats. It is perfectly clear and transparent and of a fine steel blue colour and lustre. It is ~~cut into~~ a perfect brilliant and has been most scientifically managed in the cutting and polishing and is now the property of D Ellison [*sic*] Esq. Merchant, London.
>
> James Sowerby

This note does not bear a date, but it and the drawing must predate the printed pamphlet of 1813. The Linnean Society, focusing on natural history, was founded in 1788, and both Sowerby and Francillon were members.

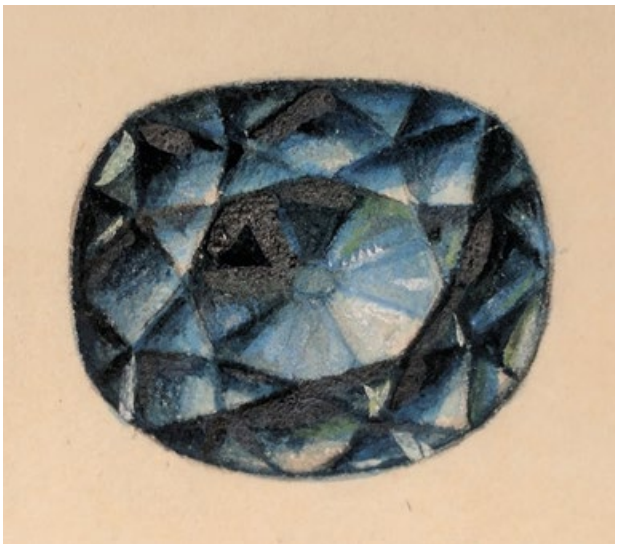

Figure 8: James Sowerby's original painting of the blue diamond dates to no later than 1813. © The Trustees of the Natural History Museum, London.

[4] It has been suggested by Paul Henderson (pers. comm., 26 June 2017)—Sowerby specialist and the author of Henderson (2015)—that there is a possibility that some of the Sowerby drawings, including those for Mawe's book, and thus perhaps the blue diamond, were actually by Sowerby's son, James de Carle Sowerby (1787–1871), who continued his father's work. However, the Sowerby who described the blue diamond in 1813 was a member of the Linnaean Society (see text) for which James junior, then about 25 years old, was probably too young. Besides, Eliason was more likely to have known James senior, who was close to his own age.

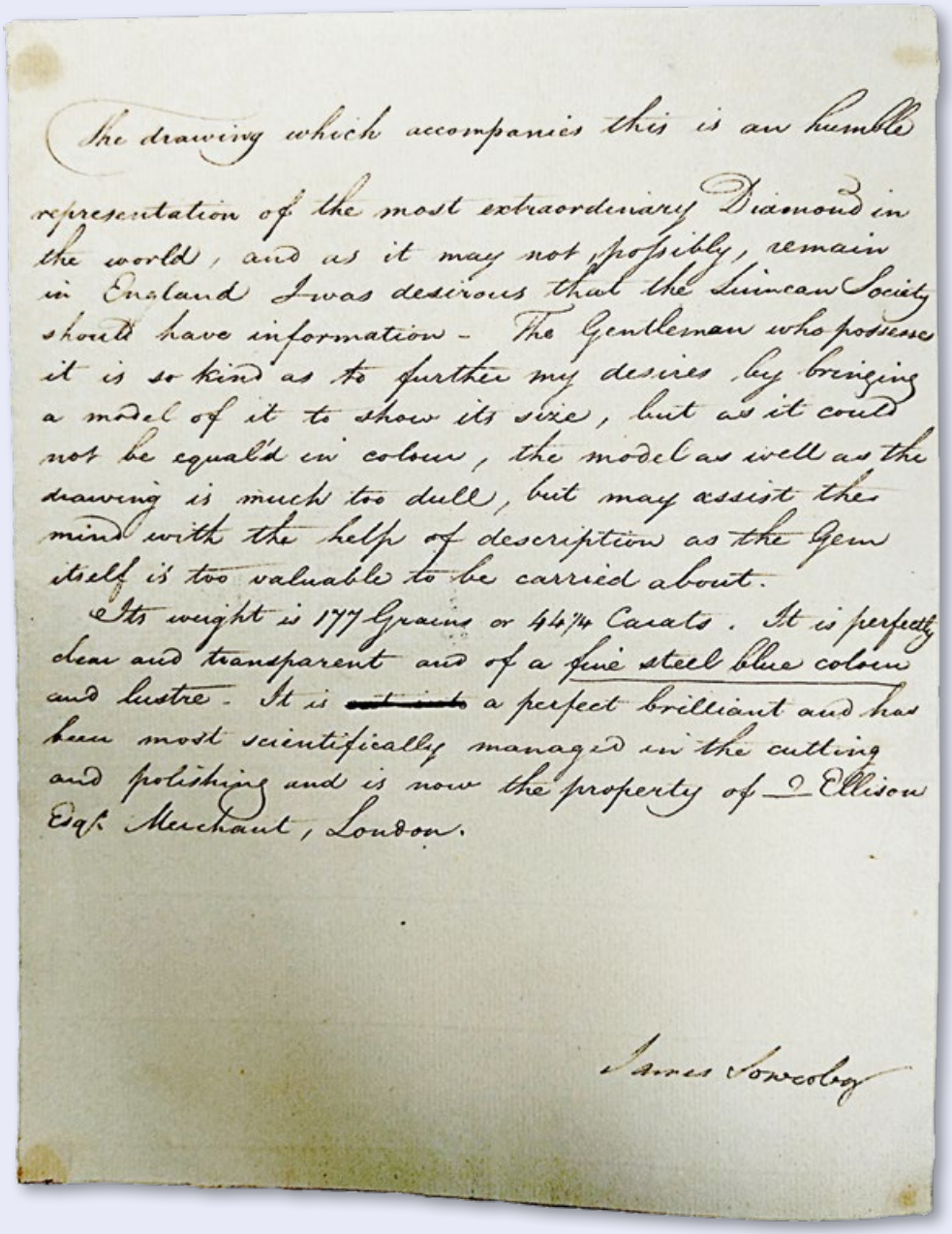

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Its weight is 177 Grains or 44¼ Carats. It is perfectly clear and transparent and of a fine steel blue colour and lustre. It is ~~[illegible]~~ a perfect brilliant and has been most scientifically managed in the cutting and polishing and is now the property of D. Ellison Esq.r Merchant, London.

James Sowerby

Figure 9: This description of the blue diamond by Sowerby was written no later than 1813. Natural History Museum Library, Sowerby Coll. MSS B127/2. © The Trustees of the Natural History Museum, London.

The model would most likely have been of glass.[5] When Sowerby referred later to this diamond in his 1817 *Exotic Mineralogy*, he noted that 'Daniel Eliason, Esq. has in London a nearly perfect blue Brilliant, of 44½ carats, that is superior to any other coloured diamond known', and he added a footnote that this diamond was 'Remarkable for so little of the purple, that paste [i.e. glass] which is liable to that tinge, cannot be found to imitate it' (Sowerby, 1817, p. 40, text accompanying plates 118 and 119).

In 1812, John Francillon noted that his drawing was made by tracing round the stone. Indeed, the diamond's outline on the draft (Figure 6), like Sowerby's beautifully rendered representation (Figure 8), depicts the familiar slightly lop-sided oval shape, but Francillon's coloured 'fine copy' in Figure 5 shows a more regular oval cushion shape. The facet pattern of Sowerby's painting is essentially identical to that in the 1839 catalogue of the Henry Philip Hope collection (Hertz, 1839, pl. 5, no. 1). Figure 10 shows a computer-generated image of the blue diamond as it was around 1812–1813.

[5] Unfortunately, despite the kind efforts of Dr Isabelle Charmantier and her colleagues at the Linnean Society, London, nothing has been located in their archives to shed any further light on if and when the drawing and model were displayed at a meeting there.

DANIEL ELIASON

The possessor of the blue diamond around 1812–1813 was diamond merchant Daniel Eliason, otherwise known as Tanhum ben Elijah Neumegen, who was born in Amsterdam and moved to London. He was in business as a jeweller by at least 1782. We have various insights into Eliason's diamond business and know of at least two other major stones he handled. Another insert in Pouget's *Traité*, also possibly in Francillon's hand, reveals that in 1802 Eliason purchased a 'most superb Brilliant of fine Water, correct proportions, & noble shape' weighing 37.5 Dutch carats (about 38.6 metric carats) for £4,500 at auction from W. Sharp, Son and Kirkup, diamond and pearl brokers and auctioneers. The advertisement for the auction called this gem 'one of the finest diamonds now on sale in Europe' (*Morning Chronicle*, 15 February 1802, p. 4). Eliason also supposedly sold a 34 ct diamond to Napoleon for £8,000 that he wore at his wedding to Josephine in 1796, but 'It was not a fine and faultless gem' (*The Wesleyan Methodist Magazine*, Vol. 70, No. 1, 1847, p. 571).

Eliason was also implicated in a notorious diamond scandal and trial that, according to some observers at the time, was one of the sparks that ignited the French Revolution. Jeanne de Valois-Saint-Rémy, also known as Countess de La Motte, was guilty of (or framed for) stealing an extravagantly magnificent diamond necklace believed to have been purchased by Marie Antoinette. The various official records and depositions relating to the Countess' trial reveal the different sides to the story (see La Motte, 1789; Funck-Brentano, 1911). The Countess, an intimate of the Queen, claimed that the Queen had given her part of the necklace as a gift, and that her husband had taken these diamonds to London to sell. He took them first to Nathaniel Jefferys in Piccadilly, who made an offer but could only pay in instalments, not cash. The Count then took them to Bond Street jeweller William Gray in Piccadilly, who brought in diamond dealer Eliason. Eliason had already been shown the gems by Jefferys—diamond dealing was a small world then, as now—but a deal was struck, and Gray and Eliason bought the diamonds. Back in Paris the Countess was found guilty, and a few years later the British press reported a duel between Count de La Motte and jeweller William Gray in Brussels in August 1791 (*Oxford Journal*, 27 August 1791, p. 1). Count de La Motte won, although reports that Gray had died were later said to be erroneous. This duel took place just a day or two after the Countess died and according to some press reports was 'supposed to have related to the sale of some jewels, a few years since, taken from the Queen of France, and tendered by the Count as his own' (*Cumberland Pacquet, and Ware's Whitehaven Advertiser*, 30 August 1791, p. 2).

Anyone in possession of the stolen French Blue diamond in the years following its theft and reading Countess de La Motte's detailed and highly popular 1789 account—published in both French and English—would have Eliason's name high on the list of potential 'no-questions-asked' purchasers of major diamonds.

WHY LONDON IN 1812?

The earliest record of the blue diamond in London is of it being in Eliason's hands in 1812. An ingenious explanation for its appearance that year was provided by Winters and White (1991, 1992): This was exactly 20 years after its theft during the French Revolution and thus the time when the 20-year statute of limitations for theft at a time of war in France would have expired. However, this might not be correct: the Napoleonic law code of 1804 superseded earlier French law and clearly defined the statute of limitations for theft in civil law as just three years (§ 227). If this applied to the French Blue, it would have been available for sale after 1804; however, it is

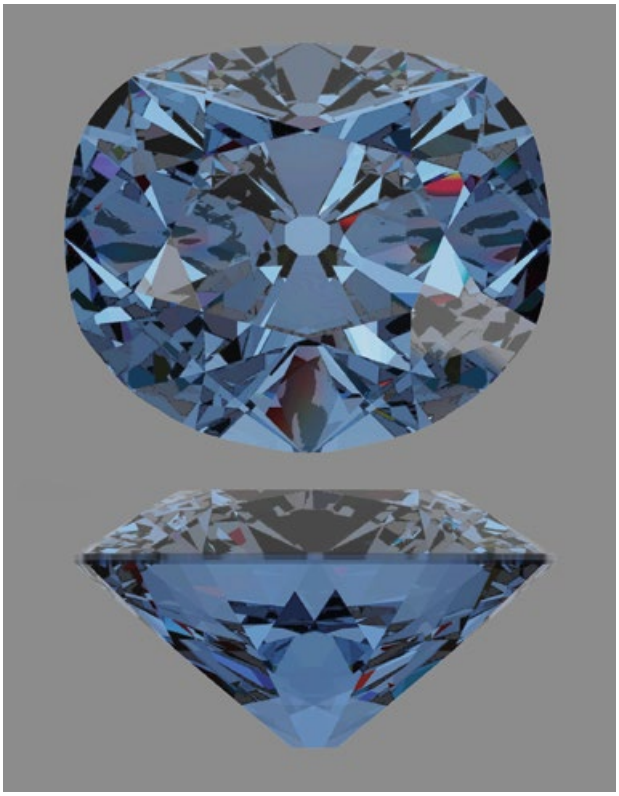

Figure 10: This computer-generated rendering of the ~44 ct blue diamond as it was in 1812–1813 is based on Sowerby's painting in Figure 8 and a later drawing in the Hope collection catalogue (Hertz, 1839, pl. 5, no. 1). Computer rendering by J. Ogden.

possible that neither civil nor martial law is applicable here. Furthermore, the French Blue diamond—as the property of the French Crown—automatically became State property when confiscated during the Revolution. For the theft of French State property, no statutes of limitation apply. Of course, the possessor of the diamond in the years leading up to 1812 may well have believed there to be such a statute. Certainly, the seeming reappearance of the diamond in London exactly 20 years after its theft in Paris seems more than a coincidence.

Another possible argument against the explanation provided by Winters and White is that it seems overly cautious to decrease the value of the French Blue by recutting it to a fraction of its former size—so that it could not be recognised—but still wait until it was deemed safe to sell because of a statute of limitations. Winters and White suggested that Mawe may have known that the stolen French Blue and Eliason's diamond were one and the same and, in Lord Balfour's words, he was 'endeavouring to lay a smokescreen so as to facilitate the eventual sale of the 44-carat gem' (Balfour, 2009, p. 133). If so, Mawe kept to his pretence with remarkable determination. The 1823 second edition of his Treatise includes a drawing of the blue diamond that Eliason had owned, and describes both this stone, which he says was sold by Eliason, and the French Blue, which he still stated to be part of the French Crown Jewels (Mawe, 1823, pp. 44 and 46). It leads to the question: was Sowerby, someone particularly well acquainted with Eliason's gem, also in on the deceit? In his 1817 *Exotic Mineralogy*, Sowerby notes Eliason's blue gem and adds that 'the most curious [diamond] is a sky-blue one, among the crown jewels of France, weighing 67 carats and two-sixteenths' (Sowerby, 1817, p. 40). On balance, it seems highly unlikely that Mawe and Sowerby suspected that the two diamonds were the same.

If Winters and White's statute-of-limitation explanation is not relevant, the diamond's 'appearance' could relate in some way to 1812 being a traumatic year for Eliason and his business partners, with perhaps an urgent need to raise money. In 1810, Abraham Goldsmid, Eliason's son-in-law and a business partner, killed himself after having got into huge debt through the sale of Exchequer Bills for the government. In June 1812 an Act of Parliament was passed 'to provide for the more complete and effectual Liquidation of this debt from the late Abraham Goldsmid, Merchant and his surviving Partners' (*Crown Debt of Abraham Goldsmid*, 52 George III. c.75). There were also other changes. Eliason had quit his partnership with George Goldsmid and George's son in effect from 1 January 1812 (Hackney Archives Department M1481).

GEORGE IV DIAMOND

It is almost certain that Eliason had sold the blue diamond before his death at the age of 91 on 17 November 1824, as there is no mention of the diamond in his will (PROB 11/1693/189) or in the catalogue of March 1825 when Christies auctioned 'A small but highly valuable and particularly select assemblage of set and loose brilliants, including several of considerable magnitude and unparalleled beauty, being the remaining stock of the late Partnership of Messrs. Daniel Eliason and Nephews' (*Morning Chronicle*, 17 February 1825, p. 4). The largest diamonds on offer weighed 18 and 15.3 ct.

In 1822, mineralogist Delvalle Lowry (later Delvalle Varley) mentioned the blue diamond in her book on mineralogy, presented as a series of conversations between her and two other women, 'Frances' and 'Mary' (Varley, 1822, p. 288). When asked if she owned a blue diamond, she replied that she had one with a faint tinge, and then mentioned 'the large one in the possession of Mr Eliason, which you have probably heard of'. Mary replied that she had heard it was worth £30,000. By early 1822 it was being widely reported in the British press that 'a violet-coloured diamond has lately been purchased by his Majesty for 20,000L [£20,000], and that Mr. ELIASON, of Hatton-garden, is setting it'. This referred to King George IV, who was crowned in July 1821, and the assumption has been that this was the diamond we now know as the Hope. An early statement of Royal ownership is in the *Leicester Chronicle* on 16 February 1822 (p. 3), seemingly quoting a report in the *Morning Chronicle* from a few days earlier, but not located by the present author. The following year, Mawe noted that Eliason's large blue diamond was said to be owned by the King (Mawe, 1823, p. 44). In 1831, in his *A Memoir on the Diamond*, John Murray mentioned 'the so-called George IV diamond', said to weigh 29½ ct, and 'of a rich and splendid blue colour' sold to the King by Eliason for £22,000 and worn in his coronation crown. It quotes Mawe on the 44 ct blue diamond that belonged to Eliason and was reported as having been sold by Eliason to the King of Holland (Murray, 1831, p. 41). He illustrates the George IV diamond along with other important diamonds in plate 1 of his book, based on 'correct and beautiful models' in his possession. It is not the lop-sided oval of the Hope but bears similarities to Francillon's representation of Eliason's stone. The weight discrepancy between the King's supposed 29½ ct blue diamond, as quoted by Murray, and the 44¼ ct Hope was presumably an error—unless there were two large blue diamonds. An error seems more likely. In his 1839

second edition, Murray gives the weight of George IV's blue diamond as 44¼ ct, with the same drawing forming his plate (Murray, 1839, pp. 49–50).

By the mid-1840s, it appears that the George IV diamond was assumed to be the same as the large blue diamond published in the 1839 catalogue of the Hope Collection, even though the author of the latter, Bram Hertz, does not mention any royal connection. For example, *The Wesleyan Methodist Magazine* in 1847 (Vol. 70, No. 1, p. 568) noted that the George IV diamond had been sold by Eliason to Hope for £13,000. This assumption has continued to the present time.

It is not impossible, of course, that George IV had owned the diamond, possibly while he was still Prince of Wales. He may have sold it to Eliason sometime prior to 1812, but then wanted to borrow it back for his coronation in 1821. There is no real evidence for this, and it seems doubtful. It was noted above that one theory regarding the French Blue's theft at the time of the Revolution in 1792 was that revolutionaries used it to bribe Charles William Ferdinand, Duke of Brunswick, to give up on his attempt to restore the French monarchy by force.[6] Three years later, the Duke of Brunswick's daughter Caroline married George, Prince of Wales. Although this is an intriguing coincidence, there is no evidence for the 'bribery' theory or that the Duke had possessed the diamond. The Duke's grandson, Charles II, Duke of Brunswick, was a famous diamond collector and owned a small blue diamond that several have suggested was fashioned from the smaller section cut off the French Blue, but the recent computer modelling of the French Blue strongly suggests that it cannot have been. This intriguing but almost certainly erroneous Brunswick link across the three generations was seemingly first suggested in Charles Dickens' magazine *All Year Round* in 1894 (Vol. 12, No. 293, Third Series, 11 August, pp. 126–132).

It has been speculated that George IV had owned the Hope based on a portrait in the Owensboro Museum of Fine Art in Kentucky, USA: 'it was obvious from across the room that the blue ovoid stone in it, near the bottom of the Golden Fleece worn by King George IV of England, was the same stone we know as the Hope Diamond' (Winters and White, 1992, p. 49).[7] The difficulty with this theory, apart from the chronology, is that the Golden Fleece ornament shown on the Owensboro portrait is remarkably close to one still in the Royal Collection (Figure 11), which is set with a fine cushion-shaped blue sapphire (Royal Collection RCIN 441169). The King appears to have owned at least three ornaments of this type, and one may have once been set with the large blue diamond. Equally the sapphire could be a later

Figure 11: The 'Order of the Golden Fleece; Badge of Prince Albert' is set with a large sapphire. It may have belonged to George IV ca 1820. Royal Collection RCIN 441169, 9 × 6 cm. Royal Collection Trust/© Her Majesty Queen Elizabeth II, 2018.

[6] The Duke's 'Brunswick Proclamation' of 25 July 1792 had threatened war with France unless the French King Louis was restored to the throne.

[7] This painting by Sir Thomas Lawrence (1769–1830) is one of numerous portraits of the King by this painter or his studio. The earliest seemingly is from 1818 and is now in the Hugh Lane Gallery, Dublin (Garlick, 1964, pp. 86–88).

replacement for a blue diamond, but without further documentary evidence the portraits cannot support that the Hope diamond was once owned by King George.[8] The origin for the various mentions of the King purchasing the diamond from early 1822 onwards, including Mawe's clear statement, is puzzling but may just be erroneous. Nevertheless, as we will see, the sale of the diamond may well have taken place in 1821, but to Henry Philip Hope.

HENRY PHILIP HOPE

By 1832, the blue diamond had entered the collection of Henry Philip Hope in London (Figure 12; 1774–1839), the youngest son of Jan (or John) Hope, a Dutch banker. At his death in 1839, there was no mention of his gem collection in his will, and his executors thus assumed the stones should be distributed between the three

Figure 12: This portrait of Henry Philip Hope (1774–1839) was painted in enamel by Henry Bone in 1802. Courtesy of Cognacq-Jay Museum, Paris, France; inv. no. J786.

Figure 13: This business card of Abraham Hertz dates to ca 1840, after he had moved to Great Marlborough Street. © Bodleian Library, Oxford, John Johnson Collection.

nephews—Henry Thomas Hope, Adrian John Hope and Alexander Beresford Hope—as part of the residual estate. It was not to be so simple. Alexander claimed that the gem collection had been gifted to him in deeds dated 1832 and 1838, while Henry Thomas Hope claimed that the gems belonged to him under the terms of another deed from 1821. This was all played out in court in a series of cases debating the veracity of the deeds through the 1840s. Ultimately, in 1848, Henry Thomas Hope received a selection of the gems, including the large blue diamond. The court cases are of particular interest because of the specific light they throw on the diamond.[9]

One witness in the 1840s court proceedings, Abraham Hertz, a gem dealer and diamond expert, had learned his trade working for the London diamond dealer Levi Barent Cohen. Cohen was the cousin of the wife of George Goldsmid, one of Eliason's business partners, and became a successful diamond dealer in his own right (Kaplan, 2006, pp. 7–8; Ogden, forthcoming). His business card is shown in Figure 13. Hertz said he was shown Hope's gems in 1832, when he argued that the gems could not properly be called a collection until they had been scientifically classified. In late 1832 or early 1833, Hertz began working with Hope part time to organise the collection, modestly enlarge it to fill gaps, and advise on the recutting and setting of some of the stones. His masterful catalogue of the collection was published in August 1839 (Hertz, 1839) and included a simple drawing of the large blue diamond (Figure 14).

In Hertz's court testimony, he said that when he first saw the Hope collection in 1832, 'a blue diamond of great value' was already part of it and that 'Mr. Hope paid for the blue diamond £13,000' (*The Standard*, 3 December 1844, p. 4). This price is far lower than the earlier asking price of £30,000 in 1816, as noted on the slip of paper glued onto the pamphlet in Figure 7. According to press reports at the time of the 1851 Great Exhibition, Hope had managed to purchase the blue diamond for this low price because 'the diamond-merchant in whose possession it was being in want of money, and finding some difficulty in meeting with a customer for so valuable a gem' (*The Standard*, 17 June 1851, p. 3). The Scottish scientist David Brewster also noted that although it sold for £13,000, the diamond had earlier been pledged for sums of £15,000 and £16,000 (Brewster, 1852, p. 221). Brewster based his information about the price paid on a currently untraceable account from mineralogist James Tennant. Tennant had been an assistant to Mawe, who became acquainted with the blue diamond when it was still in Eliason's hands.

The date of Henry Philip Hope's purchase of the large blue diamond is unclear, but it was certainly prior to 1832 when Hertz saw the stone in Hope's collection, and there is evidence that it may have been considerably earlier. Henry Thomas Hope took possession of the large blue diamond in the agreement reached by the three nephews following the 1840s court cases. This suggests that it had been purchased by his uncle no later than 1821, when the deed in his favour had been drawn up. Perhaps the

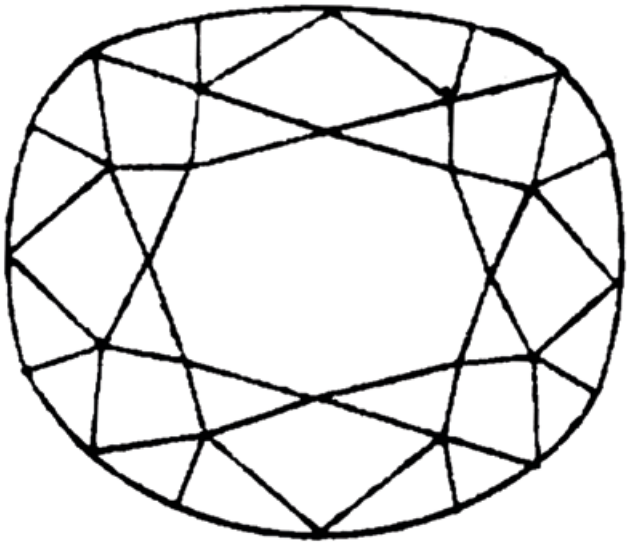

Figure 14: This drawing from the Hope collection catalogue shows the Hope diamond as it was in 1839. From Hertz (1839, pl. 5).

[8] Interestingly, there is one large blue diamond that was in a Golden Fleece ornament at around this time—the Wittelsbach, which had been mounted in the Bavarian Elector's Golden Fleece in 1745, then remounted in a crown in 1806.

[9] The details here and following are from the abundant press reports of the 1840s court cases.

addition of the rare and valuable blue diamond to the collection prompted Henry Philip Hope to consider the collection's long-term future, hence the deed.

We find corroboration for an 1821 purchase date, albeit of uncertain veracity, in the 1845 *Memoirs* of the manufacturer and inventor Sir Edward Thomason. He recalled that in 1816 he gave a lecture on diamonds to the Birmingham Philosophical Society, his fifth presentation to them on the topic of minerals. He described this lecture and expanded on it in his *Memoirs*, which include a description of the 25 most important diamonds in the world. One was what he calls 'The Blue Hope'. He recounted the following (Thomason, 1845, pp. 134–136):

> Mr. Elliason [*sic*], the great diamond merchant, residing in London, in 1821 (the year of the coronation of George IV.), was possessed of a very fine oval diamond of a sky blue, and of intense brilliancy. It was cut and polished as a brilliant, and its play of colour was matchless. In spread it was two-thirds the size of the Piggot diamond, being a little thinner, which the colour made up for; and it was of the same oval form. Report said that Mr. Elliason had visited the different courts in Europe, first asking £30,000, although it weighed only 27½ [*sic*] carats, and of course, if it had been white, the usual colour of the diamond would only be valued at £6,050. Before he left the continent he came down to £20,000, but could not find a purchaser. George the IVth was desirous to have this diamond to ornament the belt of his plume of feathers at his coronation, on the 19th of July, 1821; a treaty was commenced to have the loan of this stone for three days. Mr. Elliason was very adverse to lend any of his diamonds; the King's private exchequer or privy purse was too low to make the purchase, and an offer was made to Mr. Elliason of 1,000 guineas for the use of it for the day. Mr. Elliason required to have some days to consider it, when, in the meantime, Mr. Hope called upon Mr. Elliason about it, as he had frequently done in admiration of this beautiful gem; but Mr. Elliason always demanded too much. Hearing, however, that it was likely to be hired out for the occasion of the coronation, which circumstance of making it thus public would, in his feelings, much reduce its value, he observed to Mr. Elliason that he called upon him once more respecting the sky blue diamond; and after having stated that he found the King would not purchase it even for the approaching coronation, another opportunity might not occur for years, and he would make him a last offer, conducted, as report says, as follows:—Mr. Hope called for pen and ink, and filled up a cheque for 13,000 guineas, placed his watch upon the table, and said he would give Mr. Elliason, five minutes only, to determine to make up his mind, whether to take up the cheque or the diamond. When the time arrived within a few seconds of the five minutes, Mr. Elliason pocketed the cheque, with much grumbling, declaring it more than "dog cheap." Mr. Hope placed the diamond in his splendid collection of minerals among the order of combustibles.

If essentially accurate, Thomason's account would place Hope's purchase of the blue diamond to sometime just prior to mid-July 1821 and supports the other accounts of the price paid. The guinea was £1.1s (£1.05) making the price mentioned by Thomason £13,650. The detail he gives does have the ring of truth about it, such as the attempts to sell it in Europe (recalling the French version of Sowerby's pamphlet and Eliason's wish to bring the stone to the attention of the Linnean Society because it might leave England) and the Prince of Wales' wish to rent it for three days for his coronation. The noted original asking price of £30,000 also matches that given elsewhere. Furthermore, according to this account, Hope was already acquainted with the blue diamond, having seen it several times with Eliason. It is unfortunate that the nature of the 'report' on which Thomason's account was based is unknown.

A more melodramatic story of the purchase appeared a few years after Thomason's memoirs, at the time of the Great Exhibition in 1851, in the *Illustrated London News* (Vol. 18, 7 June 1851, p. 516). Here Eliason has three rather than five minutes to make up his mind and looks aghast at Hope's 'cool, and calm, and determined' face as the watch ticks, culminating in the less respectful final statement: 'You've got it cheap—dog—dirt cheap'. Whether the *Illustrated London News* drew its account from Thomason or they both derived from the same untraced 'report' is so far unknown.

In his catalogue of the collection, Hertz noted that the large blue diamond 'on account of its mounting, could not be placed in the drawer with the diamonds, but is kept in Drawer 16, together with the other extraordinary specimens of this collection' (Hertz, 1839, p. 25). He describes the mount as having 'a border *en arabesque* of small rose diamonds, surrounded by 20 brilliants of equal size, shape, and cutting, and of the finest water, and averaging four grains [1 ct] each'. This was almost certainly the setting in which Henry Thomas Hope displayed the diamond at the 1851 Great Exhibition in London (Figure 15, based on Ellis, 1851, p. 682). James

Tennant's description of the diamond on show in 1851 (Tennant, 1853, p. 86) is almost identical to Hertz's 1839 catalogue entry. Hertz oversaw some simple setting and resetting of some of Hope's gems, so as to best show off the stones, but it seems unlikely that he would be a proponent of mounting the rare blue diamond in such an elaborate form (*Evening Mail*, 4 December 1844, p. 3). The suspicion must be that the mount dates back at least as far as Henry Philip Hope's purchase of the diamond. The style of the mount would certainly allow for a date around 1820.[10]

From the Hope family the large blue diamond made its way through various hands until it reached the National Museum of Natural History, part of the Smithsonian Institution, in Washington DC in 1958 (Figure 1), nearly three centuries after Jean-Baptiste Tavernier had purchased the gem.

THE EQUATION OF THE HOPE AND THE FRENCH BLUE

There is another interesting revelation in Hertz's court testimony. He said that in 1838 he was negotiating the sale of Hope's large blue diamond, 'the only one of value in the world', to the 'King of France'. The gem was worth £30,000 and Hope 'did not wish to have such a valuable one in his collection'. This raises the question as to whether Hope and Hertz were unaware of the origin of the diamond, or were they knowingly negotiating to repatriate it?

In his 1839 catalogue of the Hope gems, Hertz says of the blue diamond (Hertz, 1839, p. 25):

> …we may presume that there exists no cabinet, nor any collection of crown jewels in the world, which can boast of the possession of so curious and fine a gem as the one we are now describing; and we expect to be borne out in our opinion by our readers, since there are extant historical records and treatises on the precious gems, which give us descriptions of all the extraordinary diamonds in the possession of all the crowned heads of Europe, as well as of the princes of Eastern countries. But in vain do we search for any record of a gem which can, in point of curiosity, beauty, and perfection, be compared with this blue brilliant.

We might assume that a diamond expert such as Hertz, acquainted with 'extant historical records and treatises on the precious gems', would have read of Tavernier's large blue gem and known of the famous French Blue, if only from Mawe's mention of it. This is not the first time that Hertz's apparent ignorance of the French Blue has been pointed out. In 1890, Adela Orpen commented that 'Mr. Hertz was no doubt a good jeweller and a clever expert, but he was not very learned in the history of precious stones or he could never have made this astonishing claim' (Orpen, 1890, p. 128). With the benefit of hindsight, it is tempting to see in Hertz's statements that he knew or suspected something of the Hope diamond's history. If Hertz knew Hope's blue diamond to be the stolen French Blue, one would indeed have searched in vain among the crown jewels of Europe for another such stone.

Suspicions that Hope's diamond was the French

Figure 15: The drawing on the left illustrates the Hope diamond as it was displayed at the Great Exhibition in 1851, and as described in Hertz (1839), and thus probably as it was when first purchased by Hope. On the right is a computer-generated rendering based on the drawing and description, allowing for the asymmetrical shape of the diamond. Computer rendering by J. Ogden.

[10] Edwin Streeter in the 4th edition of his *Precious Stones and Gems* (1884, facing p. 21) shows the Hope diamond in a pendant mount, superficially similar to that in Figure 15, but certainly not the same.

Blue only appear publicly nearly two decades after the publication of Hertz's Hope catalogue. Charles Barbot, a jeweller, voiced in 1856 'We suspect it, because of its rare perfection, to be the reduction of the blue diamond of France' (Barbot, 1858, p. 269). Barbot may have seen the Hope the previous year when it had been in Paris at the 1855 Exhibition, by then set in a girdle ornament made by the jewellers Hancock of Bruton Street, London (Figure 16). The centre section had the 'celebrated blue Hope diamond, and on each side two very rich rubies'.

Nevertheless, the equation of the Hope with the French Blue had been made prior to 1855 by someone. A lead model of the gem prior to recutting had been donated to the Museum of Natural History in Paris by Mr Achard, a Parisian lapidary who died in 1832 (Farges et al., 2009, p. 11; and F. Farges, pers. comm., 27 October 2018). The museum catalogue entry for 1850 described the blue diamond as remarkable for its clarity and belonging to Mr 'Hoppe' of London (Farges et al., 2009, p. 8). This model played a leading role in the recent recreation of the size and exact cut of the French Blue, and its equation with the Hope, but it has raised as many questions as it has answered. The lead model is a cast made before re-cutting the diamond as the oval brilliant. In theory, it could have been made any time from the late 1600s onwards, but such casts were most typically made when recutting was being planned. One explanation is that Achard recut the French Blue, or it had passed through his hands when its re-cutting was being considered.[11] The mention of 'Hoppe'—presumably Hope—is particularly intriguing, because it shows that Achard knew that the French Blue was now the Hope, but possibly Achard only became aware of its ownership when he recognised it in Hope's collection.

CONCLUSIONS

The present article fills in some of the missing history of the Hope diamond and offers some new discoveries. Sowerby's painting and comments on it when it was first in London have now been identified, and press accounts and court proceedings have shed further light on Henry Philip Hope's purchase of the gem and mention an 1830s attempt to sell it back to French royalty. Future researchers will no doubt gradually complete more of the history and, hopefully, find out where it was between its theft in 1792 and its reappearance in London in 1812. Until then, as the saying almost goes, it can be as satisfying to travel with the Hope as to arrive.

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Figure 16: This drawing of the girdle ornament exhibited by Hancock's of London at the 1855 Paris Exhibition shows the Hope diamond (centre) flanked by two large rubies. From the *Illustrated London News* (Vol. 27, No. 752, 14 July 1855, pp. 51–52).

[11] The use of lead casts of diamonds to plan cutting or recutting is well attested as far back as the Renaissance (Ogden, 2018, pp. 211–212).

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Rhodochrosite Gems: Properties and Provenance

J. C. (Hanco) Zwaan, Regina Mertz-Kraus, Nathan D. Renfro, Shane F. McClure and Brendan M. Laurs

ABSTRACT: Gem-quality rhodochrosite is rarely encountered, and is here described and characterised from the few known localities in the USA (Colorado), China, South Africa, Peru, Argentina and Brazil. The gemstones examined for this study were all relatively clean, with the main internal features consisting of partially healed fissures and two- and three-phase inclusions. Generally, rhodochrosite from China showed the most visible internal features, whereas the samples from South Africa showed peculiar growth-zoning patterns, which can be related to the distinctive crystal habits of material from this locality. A reconnaissance study of the chemical composition of a few samples from each locality showed that the South African stones were the purest rhodochrosite, with low Mg and very low Ca and Fe. The Brazilian material showed the highest Fe content, along with very low Mg, while rhodochrosite from China showed greater Mg but low Ca. Elevated traces of Pb, Y and heavy REEs were found in rhodochrosite from Colorado.

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Rhodochrosite is a trigonal manganese carbonate ($MnCO_3$) that is not commonly encountered in the gem trade. Although its intense pink-to-red colour is prized by gem connoisseurs, its low hardness (3½–4 on the Mohs scale) and perfect cleavage on $\{10\bar{1}1\}$ make it a collector's stone. Lustrous, well-formed crystal specimens of rhodochrosite are highly valued by mineral collectors. It usually occurs as translucent-to-opaque, fine-grained aggregates—often showing a banded pattern of white and pink due to the presence of impurities—but transparent gem-quality single-crystal rhodochrosite is known from a few localities. In particular, the Sweet Home mine in Colorado, USA, yielded considerable amounts of facetable rough from the 1990s until 2004 when it was closed, and significant quantities of gem-quality material have also come from the Kalahari Desert region in South Africa and from Guangxi, China (e.g. Webster, 1994; Knox and Lees, 1997; Weldon, 2007; Lees, 2009; Cairncross et al., 2017).

Because gem rhodochrosite is so rare, relatively little work has been done to study gem-quality stones of various provenance. Recently the authors had the opportunity to characterise an important suite of high-quality faceted rhodochrosite (Figure 1), together with offcuts and rough material from some of these samples, as well as pieces obtained from additional localities. This article provides a summary examination of these samples, with gemmological properties as well as spectroscopic and chemical characteristics of material from the USA (Colorado), China, South Africa, Peru, Argentina and Brazil.

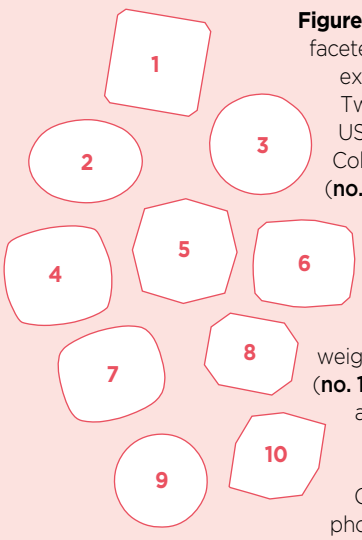

Figure 1: This collection of 10 faceted rhodochrosites was examined for this report. Two stones are from the USA (Sweet Home mine, Colorado), weighing 5.04 (**no. 8**) and 11.04 ct (**no. 1**); three are from China, weighing 6.53 (**no. 4**), 7.65 (**no. 7**) and 7.96 ct (**no. 3**); three are from South Africa, weighing 4.84 (**no. 9**), 5.03 (**no. 10**) and 9.43 ct (**no. 5**); and two are from Peru, weighing 6.22 (**no. 2**) and 6.51 ct (**no. 6**). Courtesy of Bill Larson; photo by Robert Weldon.

GEOLOGICAL SETTING OF VARIOUS RHODOCHROSITE DEPOSITS

The most famous source of gem-quality rhodochrosite is the Sweet Home mine in the Alma District of Colorado, where fine crystal specimens were recovered from cavities at the intersections of faults and quartz-pyrite-sphalerite-fluorite veins that are hosted by monzonite porphyry and granodiorite; the veins are interpreted to represent a porphyry-molybdenum type hydrothermal deposit (Misantoni et al., 1998; Bartos et al., 2006). High-quality specimen- and gem-grade rhodochrosite also has been extracted from the Wutong mine in China's Guangxi Zhuang Autonomous Region (Lees, 2009), where hübnerite-rhodochrosite veins are hosted by an Ag-Pb-Zn deposit that is interpreted to represent a relatively shallow magmatic-hydrothermal system (Lecumberri-Sanchez et al., 2013). In the Kalahari manganese field in the Northern Cape Province of South Africa, fine gem-quality rhodochrosite was recovered in 1977–1978 at the N'Chwaning I mine (Cairncross et al., 2017; see, e.g., Figure 2). The geological history of this region is complex, having undergone several periods of deformation and alteration over its 2.2 billion years. Most of the gem- and specimen-quality minerals in the Kalahari manganese field are related to the so-called Wessels hydrothermal event (1.0–1.25 billion years ago; Gutzmer and Beukes, 1996), but the rhodochrosite formation is believed to have happened much later (i.e. 45–90 million years ago), during the Smartt alteration event (Cairncross and Beukes, 2013).

There are many localities for rhodochrosite in Peru, but only three places have yielded banded material used for cabochons: the Manuelita mine in Morococha District (very similar to stones from Argentina), Yauricocha near Huancavelica, and the Huinac mine near Huaraz (Hyršl, 2017). In addition, well-formed translucent-to-transparent crystals are known particularly from Pasto Bueno and the Uchucchacua mine; the majority of faceted Peruvian rhodochrosite (e.g. Figure 3) comes from there, where Ag-Mn-Pb-Zn mineralisation occurs as veins and skarns in fractured limestone adjacent to dacite intrusions (Crowley et al., 1997; Hyršl et al., 2011). Large quantities of rhodochrosite have been mined from the Catamarca region of Argentina for nearly six decades. Although most of the material is opaque to semi-transparent, it has been used extensively as a gem (mainly cabochons; e.g. Figure 4) and ornamental material due to its rhythmic banding. Much of this material has been cut from rhodochrosite stalactites mined at the Capillitas mine, where rhodochrosite occurs as a gangue mineral (with quartz and barite) associated with polymetallic sulphide veins containing complex Cu-Pb-Zn-Fe-Mn-As-Sb epithermal mineralisation (Putz et al., 2009). In Brazil, small amounts of gem-quality rhodochrosite (e.g. Figure 5) have occasionally come from granitic pegmatites in the Virgem da Lapa area of Minas Gerais State (Zwaan, 2015).

Figure 2: These rhodochrosites (2.85 and 3.65 ct) show distinct differences in colour and are both from the N'Chwaning I mine in South Africa. Specimens and photo courtesy of Bruce Cairncross.

Figure 3: Peru's Uchucchacua mine is the source of this 13.90 ct rhodochrosite. Specimen and photo courtesy of Jaroslav Hyršl.

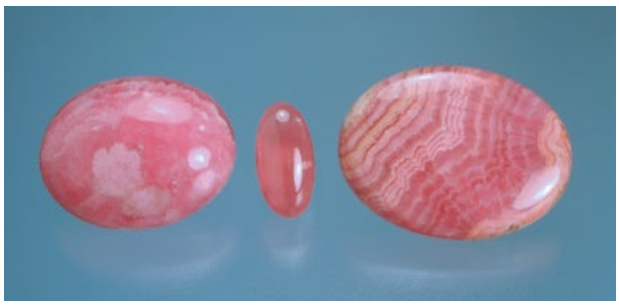

Figure 4: Rhodochrosite from Argentina is cut into cabochons that commonly display banded patterns. The largest stone is 38.7 mm wide and weighs 98.51 ct, while the smallest is 19.5 mm tall and weighs 9.76 ct. Specimens and photo courtesy of Jaroslav Hyršl.

Figure 5: Weighing 7.78 ct, this faceted rhodochrosite is from Brazil. Photo by Dirk van der Marel.

MATERIALS AND METHODS

Samples

A total of 31 transparent to translucent rhodochrosites were studied for this report (Table I). Ten of these consisted of fine-quality faceted gemstones ranging from 4.84 to 11.04 ct (Figure 1) that were loaned by Bill Larson (Pala International, Fallbrook, California, USA) and came from various localities: China, Peru, South Africa and the USA (Colorado). The other 21 samples were kindly donated for this project by Brett and Allyce Kosnar (Kosnar Gem Co., Golden, Colorado, USA). A portion of this material included crystals, cleavage fragments and offcuts obtained when Brett Kosnar faceted some of the stones for Bill Larson. In addition, this donation included three oval faceted stones from the Wutong mine in China and a crystal cluster from the Uchucchacua mine in Peru.

The Larson samples were examined at the Gemological Institute of America (GIA) in Carlsbad, California, and the Kosnar donations were characterised at the Netherlands Gemmological Laboratory (NGL) in Leiden.

Microscopic Analysis and Spectroscopy

Physical properties were measured and observed on the Kosnar samples using standard gemmological instruments. A System Eickhorst GemLED refractometer was used to obtain RIs on three faceted rhodochrosites from China, and SG was measured using the hydrostatic method on the three faceted stones from China and on most of the rough samples. (Not measured were two of the rough samples because of their small size and one matrix specimen from Peru.) Pleochroism was observed with a calcite dichroscope, and absorption spectra were viewed with a prism-type spectroscope. Long-wave (366 nm) and short-wave (254 nm) UV lamps were used to check for fluorescence. Internal features were observed with a standard gemmological microscope and a Nikon Eclipse E600POL polarising microscope, together with a Nikon DS-Ri2 camera for recording images. At GIA, a Nikon Eclipse LV100 compound microscope, also outfitted with a Nikon DS-Ri2 camera, was used to image internal features in the Larson samples.

At GIA, ultraviolet-visible-near-infrared (UV-Vis-NIR) and infrared absorption spectra of the Larson samples were collected using a PerkinElmer Lambda 950 spectrometer and a Thermo Nicolet 6700 Fourier-transform infrared spectrometer, respectively. Unoriented Raman spectra of the rhodochrosites were taken using a Renishaw inVia Raman system with a 514 nm laser. Inclusions in four Kosnar samples were analysed at NGL with a Thermo DXR micro-Raman spectrometer using 532 nm laser excitation.

LA-ICP-MS Chemical Analysis

Laser ablation inductively coupled plasma mass spectrometry (LA-ICP-MS) was used to determine the trace-element composition of 18 of the Kosnar rhodochrosite samples (15 rough and the three Chinese faceted stones). Analyses were performed at the Institut für Geowissenschaften, Johannes Gutenberg-Universität Mainz, Germany, using an ESI NWR193 excimer laser equipped with a TwoVol2 ablation cell coupled to an Agilent 7500ce quadrupole ICP-MS.

On each sample, 3–11 spot analyses were performed. Most were randomly distributed across the sample surface, but a line of 11 spot analyses was made on one larger sample from Argentina. We used a spot size of 80 µm and a pulse repetition rate of 10 Hz. The energy density was about 3.5 J/cm^2. Ablation was carried out in a He atmosphere, and the sample gas was mixed with Ar before entering the plasma. For each analysis, background signals were acquired for 15 s, followed by 30 s of ablation and a 20 s wash out. We used the multi-element synthetic glass NIST SRM 610 for calibration of the element concentrations, applying the preferred values of the reference material reported in the GeoReM database (http://georem.mpch-mainz.gwdg.de; version 21, January 2017; Jochum et al., 2005, 2011) as the 'true' concentrations to calculate the element concentrations of the samples. In addition, we analysed the reference materials FeMnOx-1 (Jochum et al., 2016), USGS BCR-2G and USGS MACS-3 during each sequence as quality control materials (QCMs) to monitor precision and accuracy of

Table I: Optical and physical properties of gem-quality rhodochrosite from various occurrences.*

Country	USA		China	South Africa	Peru	Brazil	Argentina
Locality	Sweet Home mine, Mount Bross, Alma District, Park County, Colorado	Sunnyside mine group, Bonita Peak, Gladstone, Eureka District, San Juan County, Colorado	Wutong mine, Liubao, Cangwu County, Wuzhou prefecture, Guangxi Zhuang Autonomous Region	N'Chwaning mines, Kuruman, Northern Cape Province	Uchucchacua mine, Oyon Province, Lima Department	Minas Gerais	Capillitas mine, Andalgalá Department, Catamarca
Samples	Two faceted (5.04 and 11.04 ct); two rough (0.66 and 2.12 g)	Two rough (1.43 and 2.55 g)	Six faceted (0.29, 0.29, 0.76, 6.53, 7.65 and 7.96 ct)	Three faceted (4.84, 5.03 and 9.43 ct); three rough (0.03, 0.10 and 1.38 g)	Two faceted (6.22 and 6.51 ct); one rough (1.07 g); one crystal cluster (18.5 g)	Seven rough (0.04, 0.05, 0.13, 0.14, 0.15, 0.21 and 1.10 g)	Two cabochons (8.06 and 30.56 ct)
Diaphaneity	Transparent	Transparent	Transparent	Transparent	Transparent	Transparent	Transparent to translucent
Colour	Pink, orangey pink	Pink	(Strong) pink	Light pink-orange; orangey red	Pink-orange, orangey pink-red and pink-red	Light pink, pink and light, slightly orangey pink	Pink and white banding
Pleochroism	Moderate pink and light orange	Moderate pink and light orange	Weak light pink and light orange to distinct pink and very light orange	Weak orangey pink and light orange	Distinct pink-red and (light) orange	Weak light pink and light orange, or moderate pink and light orange	Weak orangey pink and light pinkish orange, or moderate pink and light orange
RI (lower reading)	—	—	1.600	—	—	—	—
SG	3.57–3.63	3.54–3.59	3.71–3.73	3.65–3.66	3.65	3.63–3.72	3.59–3.63
Internal features	Relatively clean; veil-like partially healed fissures and fluid inclusions (two-phase, some rhombohedral)	Relatively clean; two-phase inclusions; faint straight colour zoning	(Large) partially healed fissures and rhombohedral two-phase fluid inclusions; fine parallel needle-like inclusions	Minute rounded to subhedral (rhombohedral) grey inclusions; light orange and pink alternating straight and spiky, chevron-like zoning	Partially healed fissures with geometric patterns; growth lines; straight and narrow alternating zones of orange and pink	Relatively clean; partially healed fissures; fluid inclusions (two- and three-phase); randomly oriented needle-like inclusions; colourless mica	Many partially healed fissures; minute inclusions

* All samples were inert to long- and short-wave UV radiation, and the spectroscope showed a dark band at ~410 nm and weaker bands at ~450 and 550 nm.

the measurements. The program GLITTER 4.4.1 (www.glitter-gemoc.com; Griffin et al., 2008) was used for data reduction. Measured isotope intensities were normalised to ^{55}Mn, applying the stoichiometric MnO content of $MnCO_3$ of 61.71 wt.% for the rhodochrosite samples and the values reported in the GeoReM database for the QCMs. The measured concentrations of most elements in the QCMs agreed within 15% of the preferred values reported in the GeoReM database for FeMnOx-1 and USGS BCR-2G, and for the preliminary reference values for USGS MACS-3 in Jochum et al. (2012). For the QCMs, relative standard deviations (1RSD) for the averaged element concentrations determined during the experiment were typically $<10\%$.

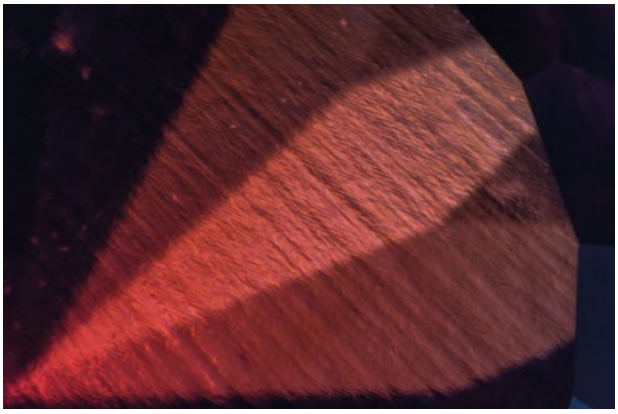

Figure 6: Prominent growth zoning is commonly displayed in South African rhodochrosite, which is here observed as linear zones of roiled graining in a 4.84 ct stone (no. 9 in Figure 1). Photomicrograph by N. D. Renfro; image width 4.6 mm.

RESULTS

Gemmological Properties

The gemmological properties of the studied rhodochrosites are listed in Table I. All were transparent, except for the samples from Argentina, which contained white translucent bands. Colours varied from light pink to (strong) pink and pink-red, with or without orange as a modifier; the more orangey stones were from South Africa and Peru, and samples with the darkest tones were from South Africa.

The RI readings of the faceted rhodochrosites from China showed one shadow line at a minimum value of 1.600 and a higher value that was above the limit of the refractometer (>1.790). The birefringence of rhodochrosite is 0.220 (e.g. Webster, 1994), which means that the higher RI was probably around 1.820. Hydrostatic SG values varied between 3.54 and 3.73, with rhodochrosite from China and Brazil showing the highest average values (3.72 and 3.68, respectively). These SGs are the highest known for this mineral; by comparison, Webster (1994) reported an SG range of 3.45–3.70.

Depending on their overall colour appearance, the samples displayed varying dichroism: weak in orangey pink and light (pinkish) orange or in light pink and light orange; and moderate-to-distinct in pink and (very) light orange or pink-red and (light) orange. The samples were inert to both long- and short-wave UV radiation. The spectroscope showed a dark band at ~410 nm and weaker bands at ~450 and 550 nm.

Microscopic Characteristics

The rhodochrosites from most of the localities were relatively clean. The main exception was the Argentina samples, which were microcrystalline (causing somewhat diminished transparency) and also locally contained white impurities. Of the single-crystal samples, the Chinese rhodochrosite generally showed the most visible internal features.

The South African rhodochrosites displayed prominent growth zoning (e.g. Figure 6). This was seen as undulating to straight, alternating light orange and pink colour zoning and a columnar type of zoning, but also swirly growth lines and spiky, chevron-like growth zoning. One stone also showed minute rounded, subhedral (rhombohedral) grey inclusions, most of which appeared flat. They could not be identified by Raman micro-spectroscopy.

The rhodochrosites from Colorado, China and Brazil all showed similar inclusions: partially healed fissures (e.g. Figure 7a) and fluid inclusions containing a gas bubble (e.g. Figure 7b). The samples from Colorado showed fine, veil-like, partially healed fissures and quite a few two-phase inclusions with rhombohedral

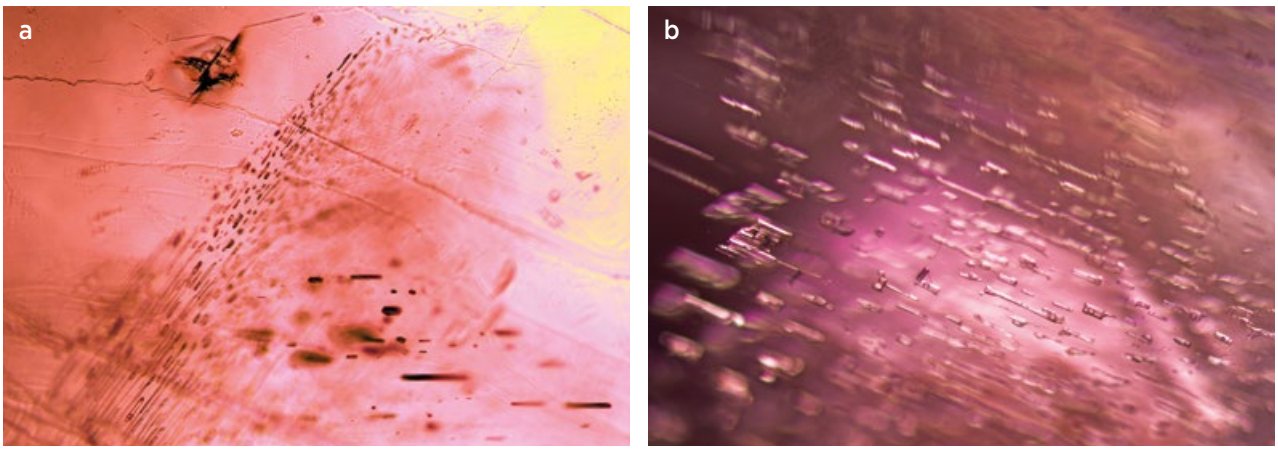

Figure 7: Partially healed fissures were typically encountered in rhodochrosite from Colorado, China and Brazil. They commonly contain two-phase fluid inclusions, as shown here in samples from Colorado (**a**, transmitted light) and China (**b**, darkfield illumination). Photomicrographs by J. C. Zwaan; image widths 1.2 mm.

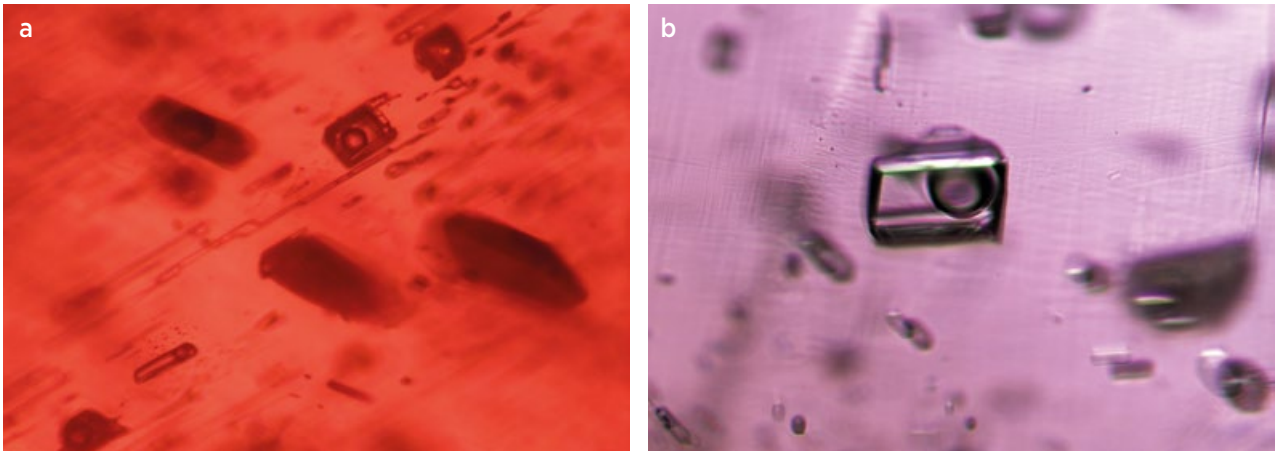

Figure 8: Rhombohedral negative inclusions, containing liquid and a gas bubble, were seen in rhodochrosite from both China and Colorado. (**a**) A tiny negative crystal occurs in the middle of a partially healed fissure in a rhodochrosite from the Sweet Home mine, Colorado. (**b**) A slightly larger negative crystal is present in a rhodochrosite from China. Photomicrographs by J. C. Zwaan; transmitted light, image widths 0.40 mm (a) and 0.33 mm (b).

Figure 9: This two-phase (liquid and gas) fluid inclusion is present in a rhodochrosite from China (no. 4 in Figure 1). Photomicrograph by N. D. Renfro, image width 1.2 mm.

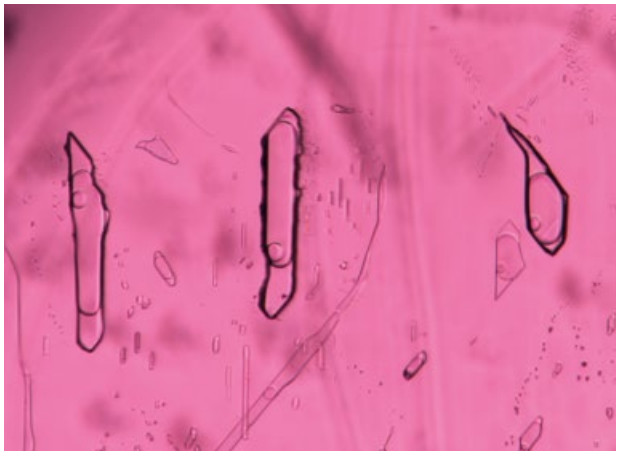

Figure 10: Three-phase inclusions, containing two immiscible liquids and a gas bubble, occur in this rhodochrosite from Brazil. Photomicrograph by J. C. Zwaan; image width 0.4 mm.

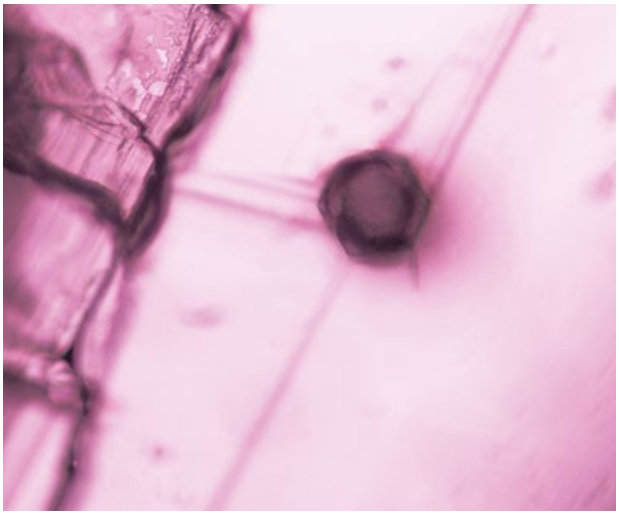

Figure 11: A six-sided tabular crystal of mica (either muscovite or trilithionite) is present in a rhodochrosite from Brazil. Photomicrograph by J. C. Zwaan; image width 0.6 mm.

negative crystals (Figure 8a). The Chinese samples also showed rhombohedral negative crystals (Figure 8b) and fairly large, partially healed fissures containing larger two-phase inclusions (Figure 9); one stone contained fine, parallel-oriented, needle-like inclusions. The Brazilian stones showed not only two-phase but also three-phase (liquid-liquid-gas) inclusions (Figure 10). One Brazilian rhodochrosite contained randomly oriented needle-like inclusions. Two Brazilian stones hosted small, colourless crystals (e.g. Figure 11) that were identified as mica: Raman analysis revealed either muscovite or trilithionite (a lithium-rich mica). In the samples from Peru, we encountered partially healed fissures with geometric patterns, straight and slightly undulating growth lines, and also straight and narrow alternating zones of orange and pink. Finally, the Argentinian stones contained small partially healed fissures and abundant minute inclusions.

Spectroscopy

All 10 samples in Figure 1 showed a typical UV-Vis-NIR spectrum for rhodochrosite (Figure 12), with pronounced peaks at ~342–343, ~362–363 and 407 nm, and slightly broader bands at 312, ~443–446 and ~542–551 nm, which are all attributed to Mn^{2+} (cf. Jørgensen et al., 1954). Although only two to four rhodochrosites from each country were analysed, the spectra showed slight but systematic differences. The samples from South Africa displayed a gradual increase in absorption towards shorter wavelengths, while the Chinese material showed a slight gradual increase in absorption from 800 towards 1000 nm. Rhodochrosite from Peru had a very intense absorption at 407 nm relative to the other bands. Earlier analysis of rhodochrosite from Brazil showed a similar absorption trend towards longer wavelengths as seen in the Chinese material (cf. Zwaan, 2015).

Mid-infrared spectra (Figure 13) typically recorded broad and strong absorption bands in the 3050–2750, 2650–2400 and 2250–2100 cm^{-1} regions, pronounced features at approximately 4229–4227, 3913–3905, 3564, 3203, 3132, 2276–2274 and 1948 cm^{-1} (with the first three having shoulders at higher wavenumbers), and weak broad bands at 5282, 4970 and 4601 cm^{-1}. The spectra of the South African rhodochrosites showed a broader strong absorption region, between roughly 3600 and 2750 cm^{-1} (Figure 13b), and in one stone even between 3600 and 2400 cm^{-1}.

Raman analysis of each stone yielded a carbonate spectrum, with the main peak typically at 1087 cm^{-1}, and additional features at 1726, 1415, 719, 289 and 184 cm^{-1} (Figure 14), in agreement with Komura et al. (1983). Vibrations related to the symmetric stretching of the CO_3^{2-} anion at about 1087 cm^{-1} are quite similar for rhodochrosite and calcite. Only at the lower wavenumbers can the two carbonates be differentiated, with rhodochrosite showing bands at 719, 289 and 184 cm^{-1} (the latter two bands being due to translatory oscillations between the cation and anion groups, Mn^{2+} and CO_3^{2-}), as opposed to calcite, which has bands at 712–711, 281 and 155 cm^{-1} (e.g. Wehrmeister et al., 2009).

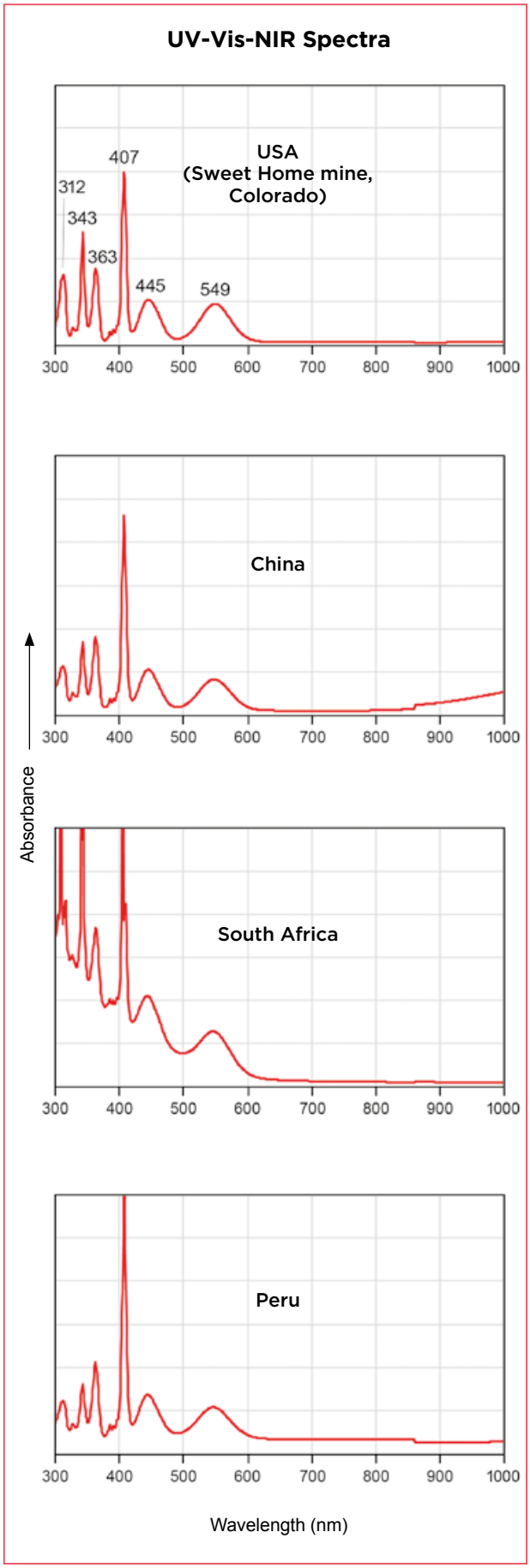

Figure 12: Representative UV-Vis-NIR spectra are shown for rhodochrosite from the USA (Sweet Home mine, Colorado), China, South Africa and Peru. The spectra were taken from a 5.04 ct rectangle, a 6.53 ct cushion, a 5.03 ct fancy cut and a 6.51 ct cushion (nos. 8, 4, 10 and 6, respectively, in Figure 1).

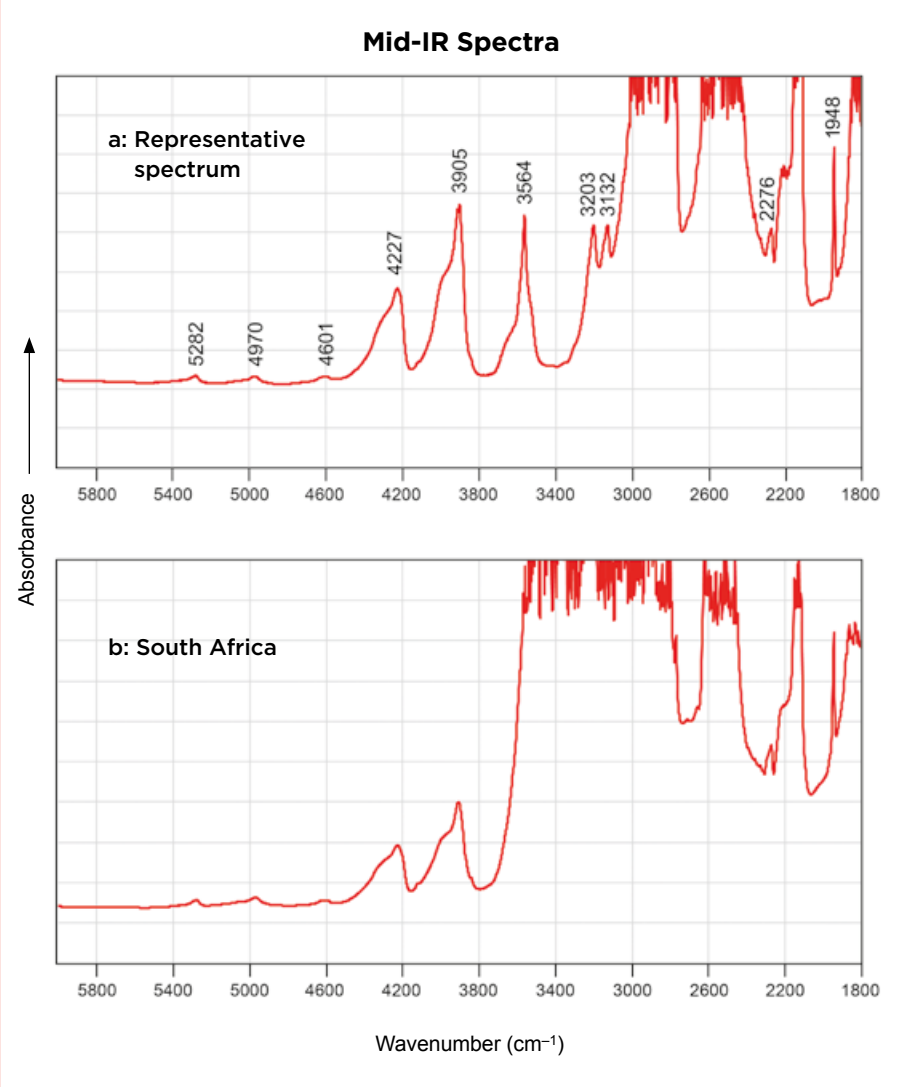

Figure 13: A representative mid-IR spectrum of rhodochrosite specimens from various localities studied for this report (**a**) is compared to a spectrum from a South African rhodochrosite (**b**) that shows strong and broad absorption between 3600 and 2750 cm^{-1}. The spectra were collected from a 6.22 ct oval and a 9.43 ct octagon (nos. 2 and 5, respectively, in Figure 1).

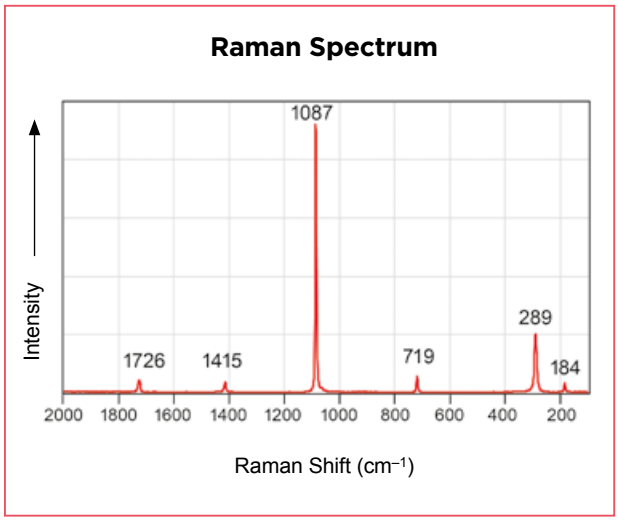

Figure 14: This Raman spectrum of an 11.04 ct rhodochrosite from Colorado (no. 1) is representative of the spectra collected from all 10 stones depicted in Figure 1.

Chemical Composition

The chemical composition of the analysed samples is summarised in Table II. The main trace elements were Fe (average 21–41,110 ppmw), Ca (average 51–12,740 ppmw) and Mg (average 62–3,570 ppmw). Also present in most samples at varying concentrations were Na (average <215 ppmw) and Al (average <61 ppmw). Zn was detected in all samples (average 3.1–220 ppmw) except in those from Peru. Minute traces of Mo were found in every sample (average 1.5–1.9 ppmw). For the rare-earth elements (REEs), the heavier REEs such as Dy, Er and Yb were commonly detected.

The white-banded, microcrystalline rhodochrosite from Argentina showed much higher values of Ca, Mg and Na (on average) than the singe-crystal transparent material from the other localities. The Argentina samples also showed considerable W, which was barely detected in only some of the transparent rhodochrosites.

Table II: Range of trace-element concentrations by LA-ICP-MS in rhodochrosite from various occurrences.[a]

Locality	USA (Sweet Home mine, Colorado)		USA (Sunnyside mine group, Colorado)		China		South Africa		Peru		Brazil		Argentina	
No. samples	2		2		3		3		2		4		2	
No. analyses	8		8		11		11		6		14		14	
Minor and trace elements (ppmw)	Range	Avg.	Range	Avg.	Range	Avg.	Range	Avg.	Range	Avg.	Range	Avg.	Range	Avg.
Li	bdl	–	bdl[b]–0.65	–	bdl	–	bdl–0.20	–	bdl–0.32	–	bdl–0.22	–	bdl–13	3.8
Na	bdl	–	bdl–194	46	bdl	–	bdl	–	bdl–13.6	6.4	bdl	–	bdl–2534	215
Mg	174–409	264	155–1650	672	555–1490	809	57–206	108	52–131	91	28–87	62	767–10050	3570
Al	bdl	–	bdl–352	68	bdl–0.53	–	9–31	21	bdl	–	bdl–2.9	–	bdl–154	61
Ca	292–2710	1280	1390–11460	4920	182–549	296	bdl–101	51	bdl–5650	2730	2380–3230	2920	361–47190	12740
Fe	1190–13170	7020	8440–26760	13390	4480–9390	6170	11–34	21	2220–4480	3310	26990–50740	41110	7120–54130	18520
Cu	bdl	–	bdl–2.7	–	bdl	–	bdl–5.8	–	bdl	–	bdl	–	bdl–2.2	–
Zn	14–62	34	19–1660	407	9.7–31	16	1.9–5.6	3.1	bdl	–	43–54	48	bdl–383	46
As	bdl	–	bdl	–	bdl	–	bdl	–	bdl–5.3	–	bdl	–	bdl	–
Rb	bdl	–	bdl–2.0	–	bdl	–	bdl	–	bdl	–	bdl	–	bdl	–
Sr	bdl–0.43	–	bdl–1.0	–	0.05–0.21	0.09	bdl–0.12	–	bdl–2.48	1.2	bdl	–	bdl–22	4.0
Y	bdl–16	7	bdl–4.4	3.1	bdl–1.9	–	bdl–0.20	–	bdl	–	bdl–1.3	0.38	bdl–2.8	–
Mo	1.2–1.9	1.6	1.6–4.8	2.2	1.2–1.7	1.5	1.3–2.1	1.8	1.6–2.0	1.7	1.4–2.0	1.6	1.2–1.8	1.6
Ag	bdl	–	bdl–0.50	–	bdl	–	bdl	–	bdl	–	bdl	–	bdl–4.9	0.45
Sn	bdl	–	bdl–1.5	–	bdl	–	bdl	–	bdl	–	bdl	–	bdl–3.1	0.73
Cs	bdl	–	bdl–0.14	–	bdl	–	bdl	–	bdl	–	bdl	–	bdl	–
Ba	bdl	–	bdl–1.5	–	bdl	–	bdl	–	bdl–0.38	–	bdl	–	bdl–3.3	0.54
La	bdl–0.45	–	bdl–0.11	–	bdl	–	bdl	–	bdl	–	bdl	–	bdl–0.06	–
Ce	bdl–0.95	0.29	bdl–0.86	0.22	bdl	–	bdl	–	bdl	–	bdl	–	bdl–0.48	–
Pr	bdl–0.10	–	bdl–0.49	–	bdl	–	bdl	–	bdl	–	bdl	–	bdl	–
Nd	bdl–0.62	–	bdl–0.25	–	bdl	–	bdl	–	bdl	–	bdl	–	bdl	–
Sm	bdl–0.51	–	bdl–0.18	–	bdl–0.21	–	bdl	–	bdl	–	bdl	–	bdl	–
Eu	bdl–0.09	–	bdl–0.03	–	bdl–0.05	–	bdl	–	bdl	–	bdl	–	bdl–0.11	–
Gd	bdl–1.1	–	bdl–0.31	–	bdl–0.63	–	bdl	–	bdl	–	bdl	–	bdl	–
Tb	bdl–0.29	–	bdl–0.07	–	bdl–0.21	–	bdl	–	bdl	–	bdl	–	bdl	–
Dy	bdl–2.7	1.3	bdl–0.62	–	bdl–1.9	–	bdl–0.03	–	bdl	–	bdl–0.08	–	bdl–0.63	–
Ho	bdl–0.60	0.30	0.05–0.19	–	bdl–0.48	0.09	bdl	–	bdl	–	bdl	–	bdl–0.12	–
Er	bdl–2.4	1.2	0.22–0.81	–	bdl–1.9	0.38	bdl–0.02	–	bdl	–	bdl–0.13	–	bdl–0.48	–
Tm	bdl–0.45	0.24	bdl–0.19	–	bdl–0.33	–	bdl	–	bdl	–	bdl–0.04	–	bdl–0.08	–
Yb	bdl–4.0	2.1	0.48–1.8	1.1	bdl–2.8	0.53	bdl	–	bdl	–	bdl–0.81	–	bdl–0.83	–
Lu	bdl–0.60	0.33	bdl–0.29	0.20	bdl–0.38	0.07	bdl	–	bdl	–	bdl–0.17	–	bdl–0.17	–
W	bdl	–	bdl–2.5	0.6	bdl	–	bdl	–	0.02–3.0	1.5	bdl	–	6.2–239	77
Pb	bdl	–	bdl–73	17	bdl	–	bdl	–	bdl–0.92	–	bdl	–	bdl–0.82	–
U	bdl–0.06	–	bdl–3.5	0.73	bdl	–	bdl–0.06	–	bdl	–	bdl	–	bdl–0.07	–

[a] Data are reported in parts per million by weight (ppmw). Data for B, Si and P were not included because of interference effects. Interference with both boron isotopes (^{10}B and ^{11}B) is assumed to come from an overlap with the large carbon peak (also called the ^{12}C spread) that is caused by the abundance of carbon present in a $MnCO_3$ sample (cf. May and Wiedmeyer, 1998). Interferences could not be corrected by the reference material because no carbon was present in the NIST glasses. The same applies to the Si isotopes: interferences occur such as $^{12}C^{16}O^{1}H^{+}$, $^{12}C^{16}O^{1}H^{2+}$, $^{12}C^{17}O^{+}$, $^{13}C^{16}O^{+}$, $^{13}C^{16}O^{1}H^{+}$ and $^{13}C^{17}O^{+}$; P also has interferences involving carbon: $^{13}C^{18}O^{+}$ and $^{12}C^{18}O^{1}H^{+}$ (May and Wiedmeyer, 1998; Jochum et al., 2012).

[b] bdl = below detection limit; Sb and Au were below detection limits in all analyses. Averages are not provided where most values were below detection limit and/or averages were under the limit of quantification.

DISCUSSION AND CONCLUSIONS

Overall, the gem-quality rhodochrosites studied for this report showed many similar characteristics, as well as some differences. The darkest and most orangey samples came from South Africa, but as seen in Figure 2 even a single mine can yield material ranging from orange to pink. The most common internal features were partially healed fissures and two-phase fluid-and-gas inclusions; mineral inclusions were rarely encountered. The peculiar growth zoning observed in the faceted rhodochrosites from South Africa may be related to the distinctive crystal forms and habits of the rough. Transparent, intergrown spherical aggregates and distinct 'wheat-sheaf' aggregates of subparallel crystals are known for rhodochrosite from the N'Chwaning mine, and trigonal wheat-sheaf habits are typical of rhodochrosite from the Hotazel mine (Wilson and Dunn, 1978; Cairncross et al., 2017). The undulating, swirly and spiky growth zoning could be understood to reflect those typical habits, and in particular the chevron-like zoning can be related to the trigonal wheat-sheaf habit (cf. Wilson and Dunn, 1978, especially figure 5g).

UV-Vis-NIR spectra showed some systematic differences in absorption towards shorter or longer wavelengths (in samples from South Africa and China, respectively), although the spectra are not baseline corrected so some caution must be taken in their interpretation. The intense pink-to-orange-to-red colour of rhodochrosite is due to a series of Mn^{2+}-related absorptions that result in the transmission of mainly orange-red and some blue wavelengths. (The addition of blue and red create magenta, consistent with the pink colour of some rhodochrosite.) Wenrich (1998) noted that the most highly saturated colour of Sweet Home rhodochrosite corresponds to purer $MnCO_3$ content (i.e. lower impurities of Ca, Mg and particularly Fe). The more orangey colour of the South African samples studied for this report may correspond to their greater absorption in the blue/violet end of the spectrum, the cause of which is unknown to the authors. The South African rhodochrosites also yielded distinctive mid-infrared spectra, which showed broader absorptions (compared to the other samples) between roughly 3600 and 2400 cm^{-1}.

Although only a limited number of stones from each locality were analysed by LA-ICP-MS for their chemical composition, some trends became apparent that may be indicative of a particular provenance. Setting aside the rhodochrosite from Argentina, which contained high levels of impurities, plotting of Ca vs. Mg (Figure 15) and Fe vs. Mg (Figure 16) shows relatively low Mg, Ca and Fe in rhodochrosite from South Africa (which had the most pure rhodochrosite composition); relatively low Ca and some high to very high Mg values in rhodochrosite from China; and low-to-moderate Mg, Ca and Fe in rhodochrosite from Colorado (except for one stone from the Sunnyside mine group, which showed high Ca and Mg contents). Brazilian rhodochrosite displays intermediate

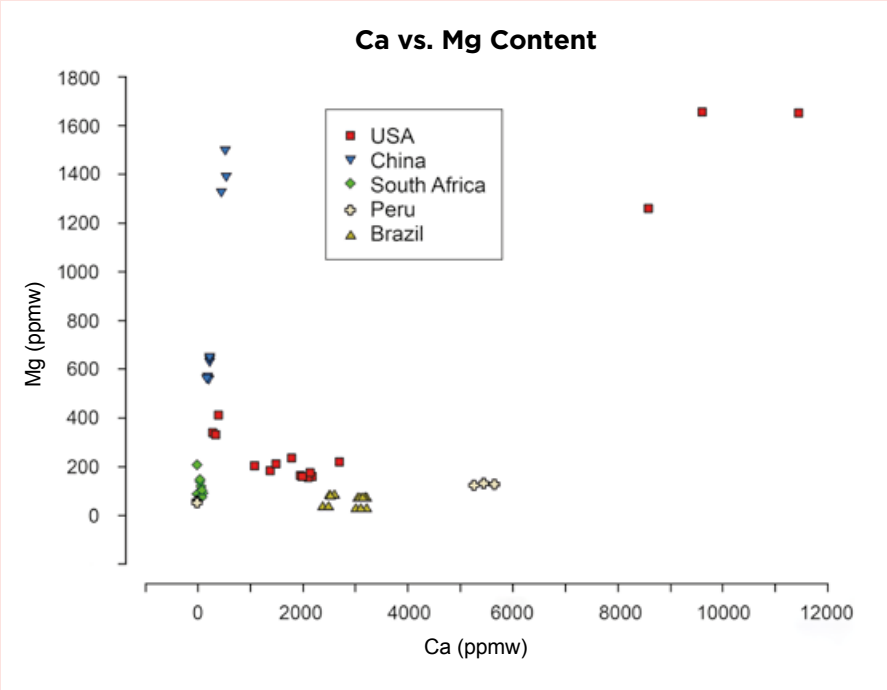

Figure 15: A plot of Ca vs. Mg in the analysed rhodochrosites shows different trends for each provenance, with some overlap in the stones from South Africa and Peru.

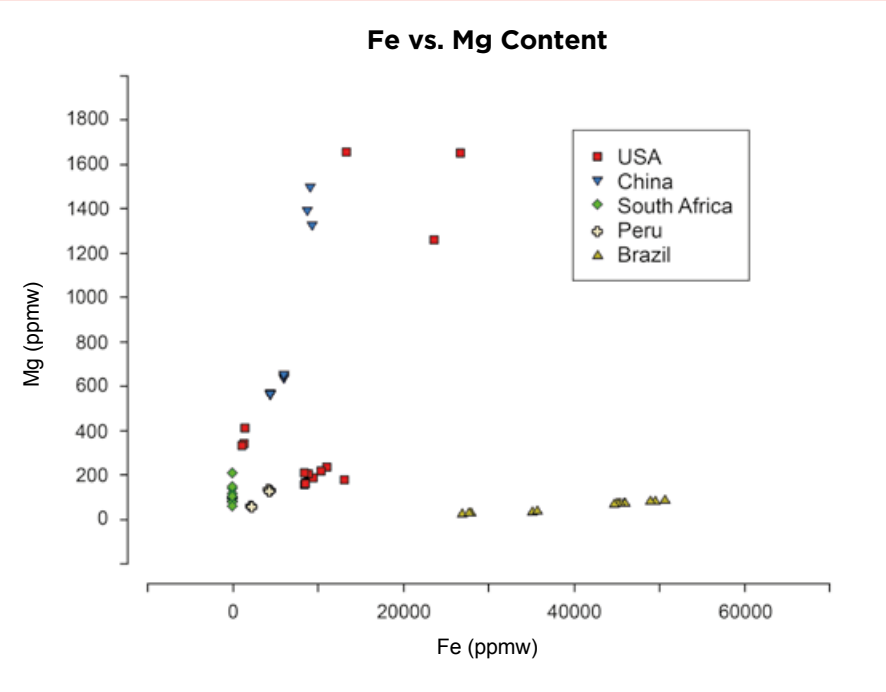

Figure 16: A plot of Fe vs. Mg in the analysed rhodochrosites shows a clear separation between the South African, Brazilian and Chinese stones.

Ca and very low Mg, but very high Fe. The enriched Fe content of Brazilian rhodochrosite is consistent with an earlier study on a crystal and faceted stone (Zwaan, 2015). Finally, rhodochrosite from Peru shows a trend of low to fairly high Ca, with Fe and Mg staying low.

Other elements were present only in trace amounts. On average, Colorado rhodochrosites showed substantially higher Y concentrations compared with samples from the other localities. In addition, the higher average Zn and Pb contents in the rhodochrosites from Colorado are influenced largely by the previously mentioned sample from the Sunnyside mine group which gave 1,420 and 1,660 ppmw Zn and 58 and 73 ppmw Pb. The other Zn measurements in Colorado rhodochrosite were all between 14 and 62 ppmw, hence at similar levels to those in the samples from China and Brazil. The other Pb measurements in Colorado rhodochrosite all ranged from below detection levels up to 1 ppmw, as in the samples from all other localities.

REEs were largely absent from the analysed samples, but trace amounts of heavy REEs—in particular Dy, Er and Yb—were detected in rhodochrosite from Colorado (especially from the Sweet Home mine), showing linear trends when plotting Er vs. Dy and Er vs. Yb. One of the Chinese stones showed similar trends (Figure 17). Mineralised magmatic, metasomatic or hydrothermal fluids are sometimes enriched in Y and heavy REEs, and can be present during late-stage granite and pegmatite development (e.g. Fryer and Edgar, 1977). The elevated

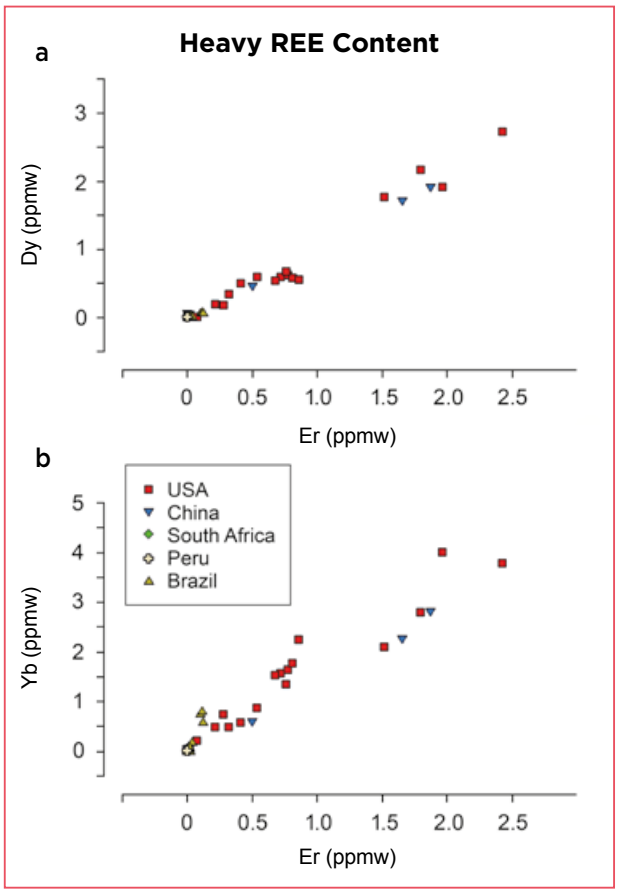

Figure 17: Traces of heavy REEs were measured in some of the analysed rhodochrosites, particularly in the stones from Colorado and China. These plots of (**a**) Er vs. Dy and (**b**) Er vs. Yb display a linear trend, showing that contents of these elements increase or decrease simultaneously.

Y and heavy REE concentrations in the Colorado rhodochrosite are therefore consistent with the hydrothermal mineralisation inferred for the Sweet Home mine, having both magmatic and externally derived (meteoric) fluid sources, occurring coeval with a final stage of magmatic activity, at depths of about 3,000 m, as proposed by Lüders et al. (2008).

Overall, the systematic variations in the chemical data obtained in this study suggest that more samples should be analysed to obtain a better idea of the compositional range of gem rhodochrosite from various localities.

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Figure 1: This 9.1 ct sapphire from the Ambatondrazaka area of Madagascar shows vivid pink colouration (far left). After exposure to a long-wave UV lamp for a few minutes, the stone changed to a vivid pinkish orange typical of that shown by padparadscha sapphires (centre). With fade testing, the colour shifted back to the chromium-related pink colour (below). Composite photo by Vito Lanzafame, SSEF.

Unstable Colouration of Padparadscha-like Sapphires

Michael S. Krzemnicki, Alexander Klumb and Judith Braun

ABSTRACT: After the October 2016 discovery of a new gem deposit at Bemainty near Ambatondrazaka, Madagascar, a number of sapphires with padparadscha-like colour entered the trade. However, most of these stones were found to have unstable colour, which changes from pinkish orange to more-or-less pure pink after a few weeks in daylight. In this study, the authors investigate the colour stability of padparadscha-type sapphires of metamorphic origin—mainly those originating from Madagascar (Ambatondrazaka and Ilakaka) and Sri Lanka. The 48 samples could be separated into three groups after colour-stability testing: sapphires that did not show a noticeably different appearance (case A); sapphires with a slight-to-moderate colour difference within the padparadscha range (case B); and fancy-colour sapphires showing a distinct change in appearance that fell outside of the padparadscha range (case C). The last situation was especially common for the stones from Ambatondrazaka, thus revealing that careful colour-stability testing is mandatory for proper gemmological identification of any sapphire showing a yellow to orange colour component.

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In late 2016, a 9.1 ct stone was submitted to the Swiss Gemmological Institute SSEF by a client as a padparadscha sapphire, a sought-after variety of corundum showing pinkish orange to orangey pink colour (cf. Crowningshield, 1983). After the routine analytical work was completed, it became evident that the stone was vivid pink instead of showing a padparadscha appearance. This colour difference led us to perform further research on the causes and stability of padparadscha colouration.

Our examination revealed that the colour of the stone changed considerably to a vivid pinkish orange by simply exposing it to a long-wave UV lamp for a few minutes (Figure 1). The orange colour component, however, was not stable and slowly faded in the course of several days to weeks (or hours with colour-stability testing), as was later confirmed by the client who had submitted the stone as a padparadscha sapphire.

Having encountered a number of similar cases in the past few months (Krzemnicki, 2018), this article presents our findings on padparadscha-like sapphires with unstable colour, with special emphasis on such stones from a recently discovered deposit at Bemainty, near Ambatondrazaka, Madagascar.

PADPARADSCHA: DEFINITION, COLOUR CAUSES AND STABILITY

Padparadscha sapphires are generally described as exhibiting a pinkish orange to orangey pink colour of moderate to low saturation (Crowningshield, 1983; Notari, 1996; LMHC, 2018). Originally known from alluvial deposits in Sri Lanka, today this attractive variety of corundum is also mined in Tanzania (e.g. Tunduru; Johnson and Koivula, 1997) and Madagascar (e.g. Ilakaka; Milisenda et al., 2001), with additional production coming from a recently discovered deposit near Ambatondrazaka, which is also a source of exceptional blue sapphires of large sizes (Perkins and Pardieu, 2016; Krzemnicki, 2017; Pardieu et al., 2017).

From a gemmological viewpoint, padparadscha colour can be described as a subtle and variable mixture of pink and orange, commonly resulting from the absorption of visible light by Cr^{3+} (main bands at 410 and 560 nm, responsible for the pink component) and one or more yellow to orange colour centres (Schmetzer et al., 1983, Nassau and Valente, 1987; Schmetzer and Schwarz, 2005; Hughes et al., 2017 and references therein) that are partly superposed by absorptions from Fe^{3+} at 385, 390 and 450 nm. As such, padparadscha sapphires can show variable absorption spectra. In terms of colour stability, it can further be assumed that the pink colour is stable, as it is only related to the concentration of Cr^{3+}. However, the stability of the yellow-to-orange colour component is more complex. It has been known for many years that yellow to orangey yellow hues induced by colour centres (formed naturally or by artificial irradiation) in corundum are not always stable (i.e. type 2 of Nassau and Valente, 1987), thus resulting in a yellow colour that fades slowly upon exposure to daylight (Schiffmann, 1981; Nassau and Valente, 1987; Hughes et al., 2017). Additional cases of colour centres that are unstable in daylight are not uncommon in mineralogy, as seen, for example, in some amethyst (Hatipoğlu et al., 2011), and also quite dramatically in Maxixe-type beryl (Nassau et al., 1976) and in hackmanite—a rare sulphur-bearing variety of sodalite that becomes stunningly purple after brief exposure to UV radiation before fading (rather quickly) to greyish white in daylight (Medved, 1954; Kondo and Beaton, 2009).

The effect of fading in daylight and reactivation by UV radiation is known in the scientific literature as *reversible photochromism* or *tenebrescence* (Medved, 1954; Kirk, 1955). Interestingly, this effect has been reported previously for synthetic corundum (Hughes et al., 2017) and for a light blue heat-treated sapphire (Gaievskyi et al., 2014), and has also been observed in SSEF's in-house colour-stability studies on a small number of unheated yellow sapphires from Sri Lanka (cf. Hughes, 1997). In all of these cases, the stones consistently gained slight brownish yellow to marked yellow hues after UV exposure, which under normal lighting conditions faded out over a period of several days (or hours with fade testing; see below for parameters). So far, none of the tenebrescent unheated yellow sapphires we have seen changed completely to colourless after fade testing, but instead they showed a noticeable reduction in their yellow colour saturation, which suggests they were coloured by a combination of stable (in terms of exposure to daylight) and unstable yellow colour centres.

MATERIALS AND METHODS

Over a period of several months, the authors analysed 48 sapphires of metamorphic origin that showed padparadscha-like colour (see Table I). All of them were unheated except for one sample from Ambatondrazaka. Apart from microscopic observation and routine gemmological testing—as well as chemical analysis, Fourier-transform infrared (FTIR) spectroscopy and Raman spectroscopy—all studied samples were investigated using SSEF's standardised colour-stability testing protocol. Their

Table I: Sapphires of padparadscha-like colour investigated for this study.

Origin*	No. samples	Weight range (ct)	No. samples with a distinct change of colour
Sri Lanka	12	1.14–20.2	1 (8.3%)
Madagascar (Ilakaka)	17	0.88–3.07	3 (17.6%)
Madagascar (Ambatondrazaka)	11	4.18–30.4	9 (81.8%)
Unknown origin	8	1.17–12.4	1 (12.5%)

* The indicated origin is based on a combination of analytical data and microscopic observation.

colour was observed in three stages: initially just after submission to the laboratory (stage 1), after fade testing (stage 2) and finally after exposure to a long-wave UV lamp (stage 3). When a pink stone was submitted, stages 2 and 3 were swapped, thus performing the long-wave UV exposure and then (if it changed to a padparadscha-like colour) subsequently pursuing the fade testing.

For fade testing, we followed a protocol used at SSEF for many years to examine the colour stability of gems (K. Schmetzer, pers. comm., 2009), mostly for yellow sapphires. The stone is placed in a reflecting bowl made of aluminium foil and exposed for three hours to a daylight-equivalent light source (100 W halogen Fiberoptic Heim LQ 1100). (During this process, the stone is slightly heated by the light exposure, but never above approximately 70°C.) For UV activation testing, the stone is placed in a black box for 10 minutes directly on the glass plate of a long-wave UV lamp (6 W Vilber Lourmat VL-6.LC).

After each stage, visual colour grading was performed by at least two gemmologists using the padparadscha sapphire chart developed by Notari (1996) and Munsell colour charts under daylight-equivalent illumination. The stones were also photo-documented in a white light box (cube of approximately 1 m^2 with a colour temperature of 5,500 K) using a Nikon F7 camera under standardised settings and lighting conditions. In addition, polarised absorption spectra in the 300–800 nm range were collected (ordinary ray) after each stage using either a Cary 500 ultraviolet-visible–near infrared (UV-Vis-NIR) spectrophotometer or SSEF's portable UV-Vis spectrometer manufactured by SattGems SA, a subsidiary of SSEF.

RESULTS AND DISCUSSION

Properties of the Ambatondrazaka Samples

Interestingly, most of the sapphires with unstable padparadscha-like colour originated from the Ambatondrazaka area of Madagascar (see below). Based on our observations, these sapphires commonly contain very few inclusions, and they are often characterised by distinct purple colour zoning (Figure 2). Also typical are fine 'milky' lamellae with a spacing of approximately 100 µm (Figure 3). Similar zoning features have been seen occasionally in blue sapphires from this deposit (e.g. Krzemnicki, 2017). In addition, we observed small zones of dispersed (presumably exsolved) particles (Figure 4) resembling those seen in yellow and padparadscha sapphires from Sri Lanka (cf. Hughes et al., 2017, p. 603). These particle zones were, however, less pronounced and less common than in stones from Sri Lanka.

A few of the studied samples from Ambatondrazaka contained very tiny inclusions of slightly rounded prismatic shape that were identified by Raman spectroscopy as zircon. They showed broad Raman peaks resulting

Figure 2: This exceptional 30 ct fancy-colour sapphire from Ambatondrazaka displays a distinct purplish colour zone, and therefore would not be termed 'padparadscha'. Composite photo by Luc Phan, SSEF.

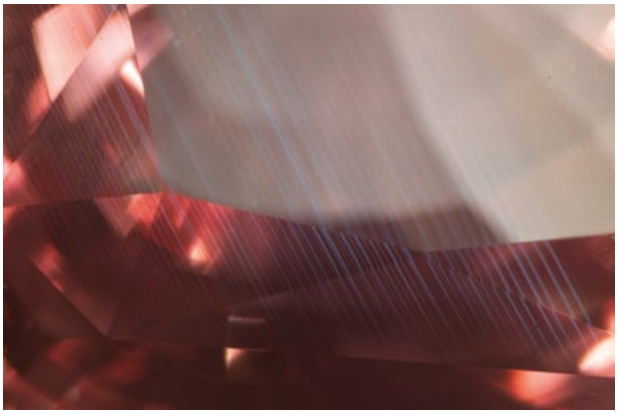

Figure 3: Fine 'milky' lamellae are seen in this fancy-colour sapphire from Ambatondrazaka. Photomicrograph by M. S. Krzemnicki; magnified 30×.

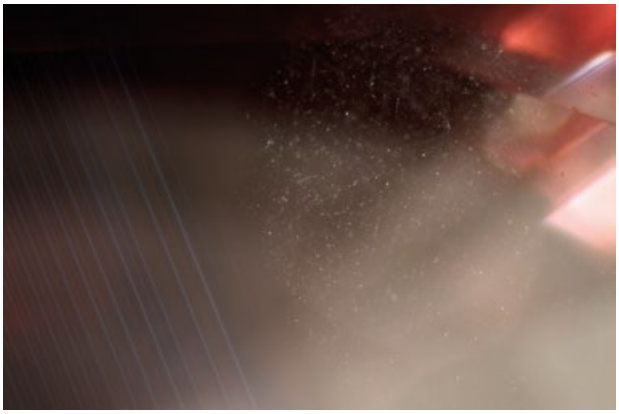

Figure 4: A group of tiny particles are present in a fancy-colour sapphire from Ambatondrazaka. See also the 'milky' lamellar zoning on the left side of the image. Photomicrograph by M. S. Krzemnicki; magnified 50×.

from metamictisation (Figure 5), a feature also characteristic for Kashmir-like blue sapphires from the same deposit (Krzemnicki, 2017).

Colour-Stability Testing

The samples could be separated into three groups after fade testing: sapphires with no notable difference in appearance (case A); sapphires that showed a slight-to-moderate shift of colour within the padparadscha colour range (case B); and fancy-colour sapphires with unstable colour that distinctly changed from padparadscha-like pinkish orange to pink (case C). These groups mostly apply to unheated sapphires of padparadscha-like colours, although they may also be encountered in some heated stones of similar colours. Interestingly, most of the 'case C' stones were found to originate from the Bemainty deposit near Ambatondrazaka in Madagascar, while fewer of this type were noted from the more 'classic' sources of Ilakaka and Sri Lanka.

Case A. Colour-Stable Samples: Nine of the 48 study samples showed no noticeable change in appearance after fade testing (four from Sri Lanka, two from Ilakaka and three of unknown origin). Their colour ranged from 'classic' padparadscha (see Figure 6, inset photos) to orangey pink (including vivid orangey to reddish pink

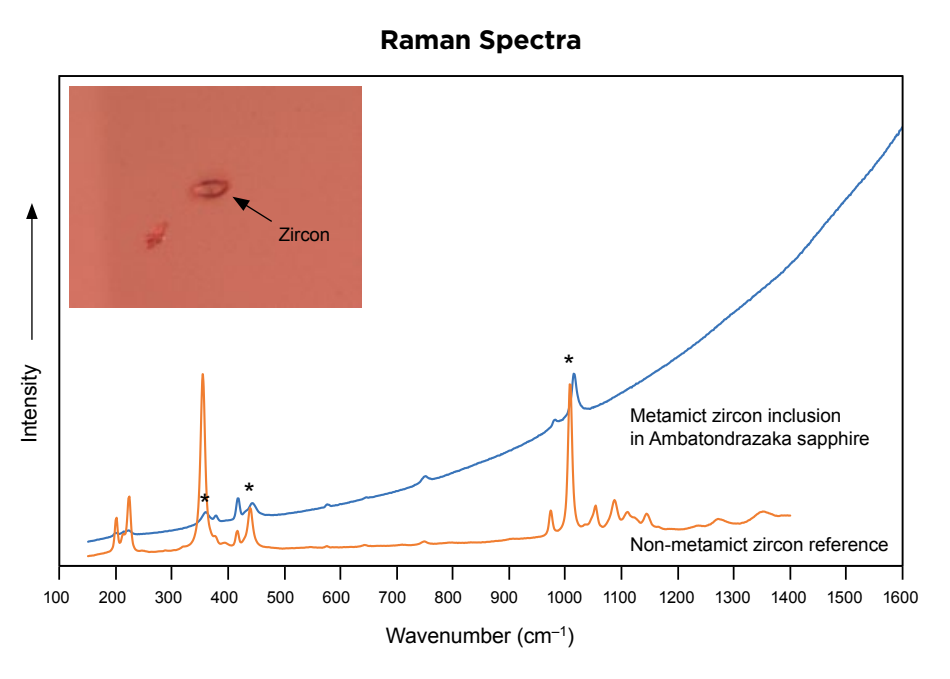

Figure 5: The Raman spectrum of a zircon inclusion in a padparadscha-like sapphire from Ambatondrazaka reveals its metamict nature, compared to a reference spectrum of a non-metamict zircon inclusion (together with some additional tiny Raman peaks). Asterisks mark the main Raman peaks of zircon shown by the inclusion. Inset photomicrograph by M. S. Krzemnicki; magnified 50×.

that was strongly zoned, and thus out of the padparadscha colour range as defined by SSEF and LMHC; e.g. Figure 7). Case A stones also showed only very minor differences in their absorption spectra before and after fade testing (again, see Figures 6 and 7). Their spectra revealed a general and more-or-less steady increase in absorption towards the ultraviolet region due to stable yellow colour centres, overprinted by broad Cr^{3+} bands and more-or-less prominent Fe^{3+} absorption peaks.

Case B. Samples with Somewhat Unstable Colour: A slight to moderate shift of colour was shown by 25 of the studied samples after fade testing (and/or long-wave UV exposure). Their shift in appearance mostly affected the intensity of the orange hue (Figure 8), but not enough to disqualify them from the padparadscha colour range (Notari, 1996; LMHC, 2018). Sapphires of this group mostly originated from Sri Lanka (seven samples) and Ilakaka (12 samples); six were of unknown origin.

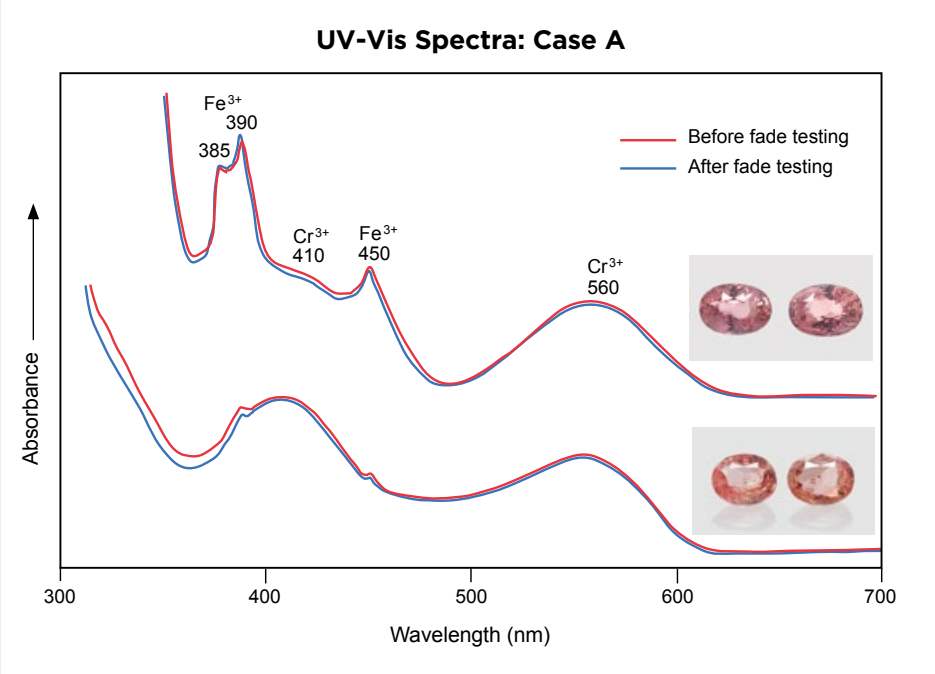

Figure 6: UV-Vis absorption spectra (ordinary ray) are shown for two padparadscha sapphires that do not display any noticeable difference in colour before and after fade testing (case A). The stones differ mainly in the intensity of their Fe^{3+}-related absorptions. The sapphires weigh 5.42 ct (top) and 5.05 ct (bottom), and the images show the stones before (left) and after (right) fade testing. Inset photos by M. S. Krzemnicki.

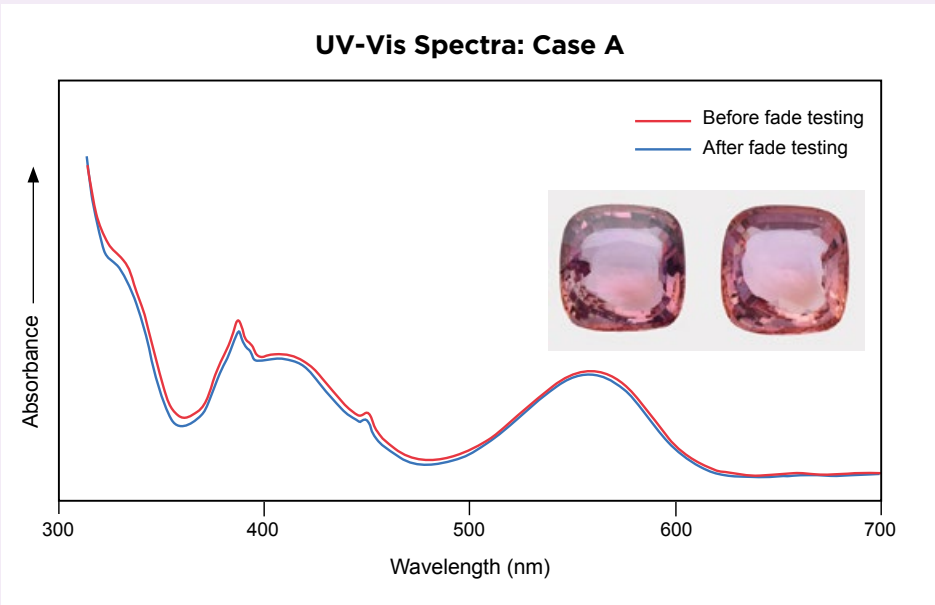

Figure 7: The nearly identical absorption spectra of a 12.02 ct sapphire with a distinct purplish pink colour zone (thus disqualifying it as padparadscha; see LMHC, 2018) are consistent with the lack of a noticeable colour difference before and after fade testing (i.e. case A). Inset photos by M. S. Krzemnicki.

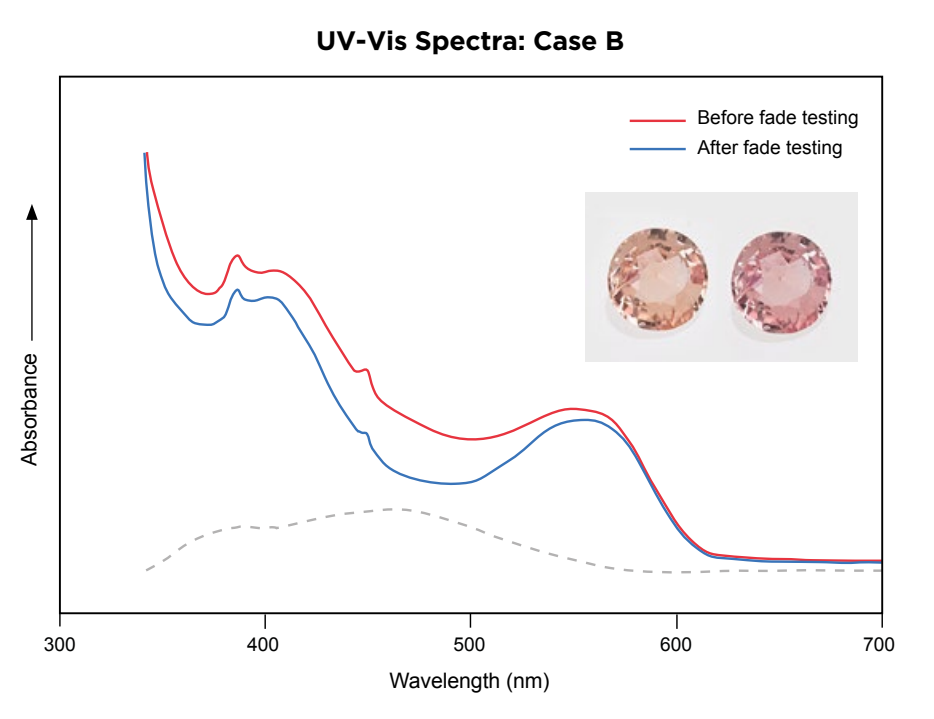

Figure 8: A 1.05 ct sapphire with a moderate change of colour before (left) and after (right) fade testing—but within the range of padparadscha; i.e. case B—yielded these absorption spectra. The dashed grey line shows the result of subtracting one trace from the other, representing the spectral contribution from the unstable orange or yellow colour centre. Inset photos by M. S. Krzemnicki.

Their absorption spectra before and after fade testing were characterised by a notable change due to variations in the strength of an unstable orange or yellow colour centre superposed on an existing stable yellow colour centre (possibly a trapped hole involving Mg^{2+} associated with an Fe^{3+} chromophore; see Emmett et al., 2017). The presence of this unstable orange or yellow colour centre is visualised by the grey dashed line in Figure 8, which represents a subtraction of the absorption spectra before and after fade testing.

Case C. Samples with Distinctly Unstable Colour: Most interestingly, 14 of the stones showed a distinct change in appearance, with a padparadscha-like orange-pink colour seen only after being activated by long-wave UV radiation (unstable colour) and a more-or-less pure pink hue after fade testing. As shown in Table I, most of the case C sapphires were from Ambatondrazaka (nine samples), compared to those from Ilakaka (three), from Sri Lanka (one) and of unknown origin (one).

Similar to the stones in case B, the absorption spectra of the case C samples were characterised by the presence of an unstable colour centre (represented by the grey dashed line in Figures 9 and 10) that pushed their colour towards pinkish orange when activated by UV radiation. However, in contrast to the abovementioned case B, these fancy-colour sapphires completely lacked or had only a very weak stable yellow colour centre, as can be seen by their lack of absorption, and thus a distinct transmission window, at ~480 nm after fade testing (Figure 11). The contrasting colour behaviour of case B can be explained by the presence of a stable yellow colour centre that is discernible by the greater absorption in the transmission window region at ~480 nm and therefore is less affected by fade testing (again, see Figure 11). This absence of a stable yellow colour centre in case C samples results in a more-or-less pure pink colour after fade testing. This 'stable' colour is thus distinctly out of the padparadscha colour range (Figure 12).

CONCLUSIONS

This study shows that metamorphic sapphires of padparadscha-like colour do not always have stable colouration, very similar to that of some yellow sapphires. Instead, they may show a tenebrescent behaviour in which the yellow/orange colour component is developed by long-wave UV exposure and is faded by exposure to daylight over time. While most of the studied samples from 'classic' sources in Sri Lanka and Ilakaka in Madagascar showed no change in appearance or a slight-to-moderate colour difference after colour-stability testing, sapphires from the recently discovered deposit near Ambatondrazaka in Madagascar often showed a distinct colour instability, shifting from pinkish orange (when 'activated' by a long-wave UV lamp) to pure pink

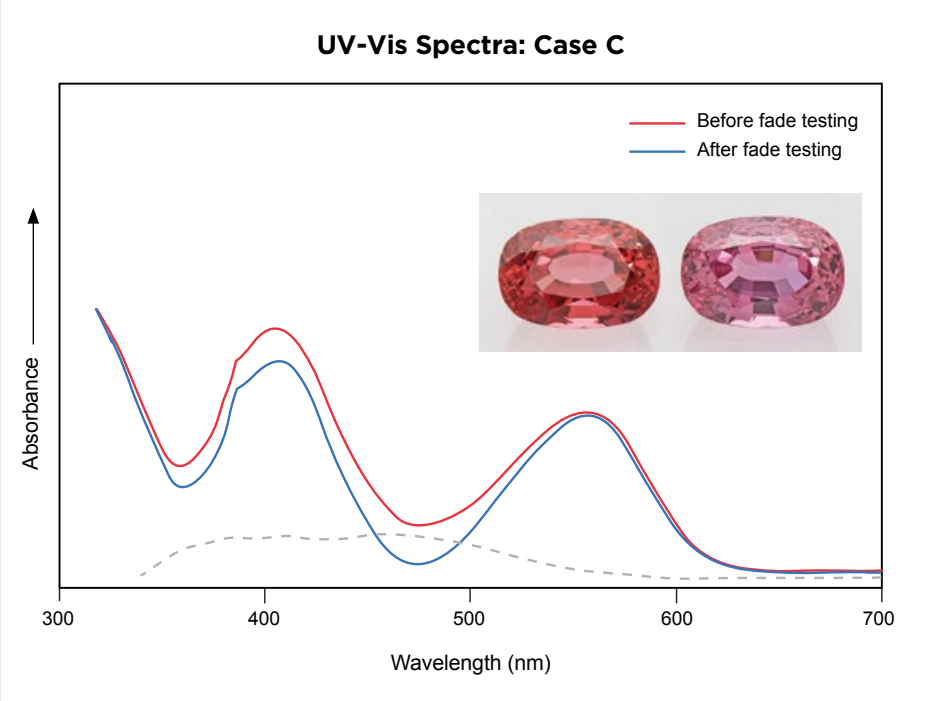

Figure 9: The 9.1 ct fancy-colour sapphire in Figure 1 displays a distinct difference in appearance before (left) and after (right) fade testing (i.e. case C), and yielded these absorption spectra. The dashed grey line representing subtraction of the two spectra shows the spectral contribution from the unstable orange or yellow colour centre. Conversely, there is no evidence of a stable yellow colour centre, which explains why the difference in appearance is so distinct. Inset photos by M. S. Krzemnicki.

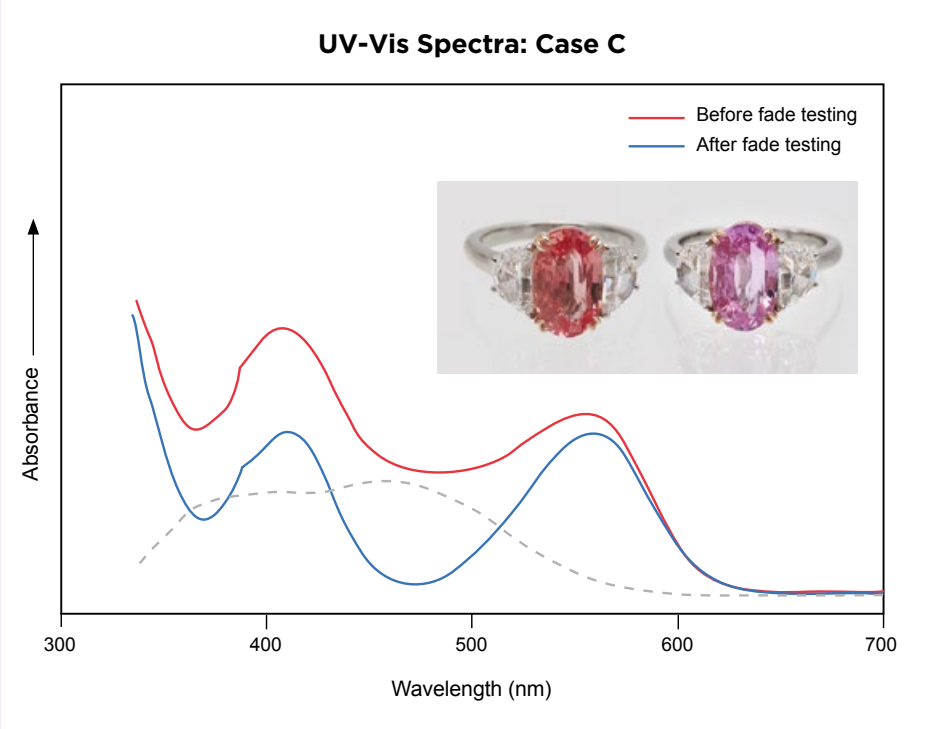

Figure 10: The absorption spectra of a ring-mounted fancy-colour sapphire (declared weight of 4.00 ct) show a distinct difference in appearance after fade testing (i.e. case C). The spectra demonstrate the contribution of an unstable orange or yellow colour centre (represented by the dashed grey line) that is even stronger than that in Figure 9. Inset photos by M. S. Krzemnicki.

after several weeks (or hours under fade-testing conditions) in daylight. Such stones that shift to a colour that is out of the padparadscha range should not be assigned the coveted varietal name 'padparadscha', which historically refers to pinkish orange to orangey pink stones that are colour-stable within this range (see LMHC, 2018).

The results of this study highlight the need to carefully test the colour stability of any corundum showing a yellow to orange colour component before an identification report is finalised.

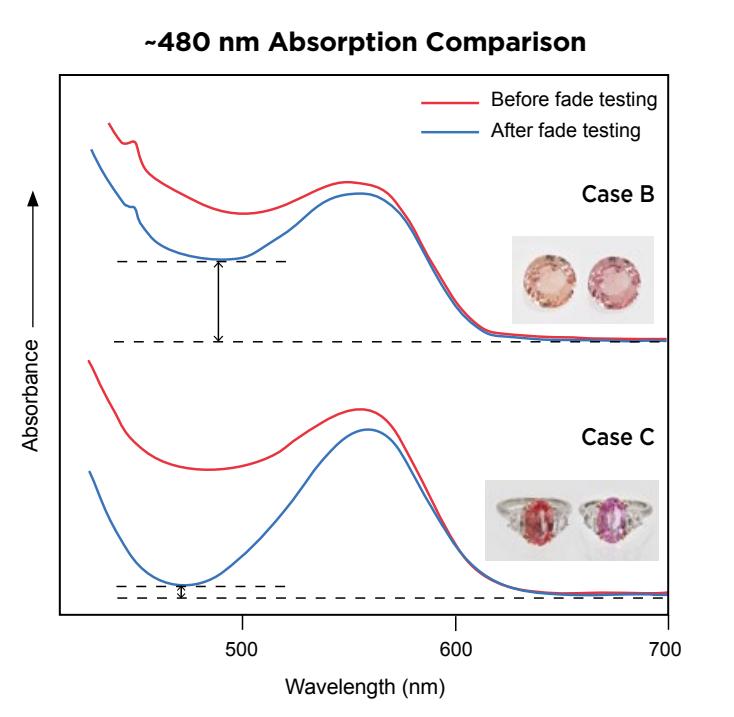

Figure 11: The main criteria that separate padparadscha sapphires with a slight to moderate shift in colour (case B) from fancy-colour sapphires with a distinct change in appearance (case C) after fade testing is not only the presence and strength of an unstable orange or yellow colour centre (see dashed grey lines in Figures 8–10), but mostly the prevalence of a stable yellow colour centre, which is visualised here by the large (top) or small (bottom) absorption step at ~480 nm before and after fade testing. The examples shown here are excerpted from Figures 8 and 10.

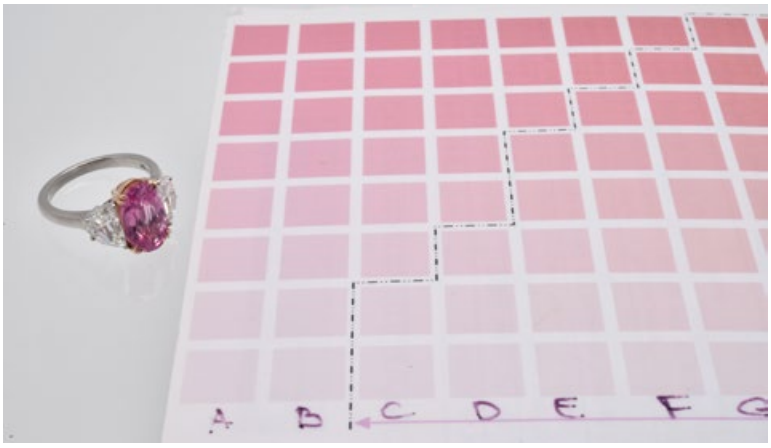

Figure 12: A fancy-colour sapphire ring (also seen in Figures 10 and 11) is shown next to a small portion of a chart proposed by Notari (1996) to represent padparadscha colour space (starting to the right of the dashed line). The pink colour of the sapphire shown here after fade testing falls outside of the padparadscha range. Photo by Luc Phan, SSEF.

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Conferences

4TH MEDITERRANEAN GEMMOLOGICAL AND JEWELLERY CONFERENCE

Following the previous Mediterranean Gemmological and Jewellery Conferences in Greece (2015), Spain (2016) and Italy (2017), the 4th MGJC took place in Budva, Montenegro, 18–20 May 2018. It was organised by the CGL-GRS Swiss Canadian Gemlab (Canada) and the Independent Gemological Laboratory (Greece), and supported by OctoNus (Finland), Magilabs (Italy/Finland), MSU Gemmological Centre (Russia), International Institute of Diamond Grading & Research (IIDGR; UK), Gemewizard (Israel), Gemetrix (Australia), HRD Antwerp (Belgium), the National Council of Jewellery Valuers (Australia) and the National Association of Jewelry Appraisers (USA). The conference attracted 75 participants from more than 25 countries (e.g. Figure 1).

The major theme of the conference was 'Synthetic Diamonds and Gems in 21st Century' and 10 speakers covered this topic. Invited lecturer **Dr Thomas Hainschwang** (GGTL, Balzers, Lichtenstein) presented 'Colour origin of untreated and treated natural and synthetic diamonds'. His presentation gave an overview of the colours that can be found in natural and synthetic diamonds, the colours that can be created by treatments and the challenge of identifying their origin. **Roman Serov** (OctoNus, Tampere, Finland, and Moscow State University Gemmological Center, Moscow, Russia) explained the 'Impact of fluorescence on diamond appearance'. He and his colleagues have developed a device for creating a lighting environment with different levels of UV content corresponding to D65 lighting, laboratory lighting and UV-free lighting, and objectively measuring the impact of fluorescence on diamond appearance. **Dr Philip Martineau** (De Beers Technologies Research Centre, Maidenhead, Berkshire) updated participants on 'CVD synthetic diamonds and their detection'. His talk described the development of different generations of screening and detection equipment now sold by IIDGR, including the new instruments launched in 2018: AMS2 and SYNTH-detect. **Branko Deljanin** (CGL-GRS Swiss Canadian Gemlab, Vancouver, British Columbia, Canada) and **George Spyromilios** (Independent Gemological Laboratory, Athens, Greece) covered 'Identification of melee to large synthetic HPHT-grown diamonds with standard instruments'. They described the use of fluorescence, phosphorescence and cross-polarising filters to help identify high-pressure, high-temperature (HPHT)-grown and most chemical vapour deposition (CVD)-grown synthetics using standard instruments (e.g. those included in MGJC's portable Synthetic Diamond Identification Kit).

Figure 1: MGJC 2018 participants gather at Budva beach before the conference's gala dinner. Photo courtesy of Branko Deljanin.

Ans Anthonis (HRD, Antwerp, Belgium) delivered a presentation titled 'Red carpet for blue fluorescent diamonds?' detailing results of research investigating the relationship between fluorescence and colour grade, in which it was found that the levels of UV in standard office and grading lighting were insignificant to produce any observable effect, even for diamonds having very strong fluorescence. **Ya'akov Almor** (MDBC Ltd, Tel Aviv, Israel) talked on 'Present and future of synthetic diamond jewellery – the ethical challenges'. Synthetic diamonds have proven to be a blessing in disguise, as the industry at large has been forced to invest in the generic promotion of natural diamonds and, consequently, to rethink how diamonds need to be marketed to the consumer. **Menahem Sevdermish** and **Guy Borenstein** (Gemewizard, Ramat Gan, Israel) introduced 'Big data analysis and insights in the online gem and jewellery trade'. Big data analytics is the process of collecting, organising and analysing large data volumes to reveal hidden patterns and unfamiliar correlations, identify market trends, and extract other useful information which otherwise might go unnoticed. **Bear Williams** (Stone Group Labs, Jefferson City, Missouri, USA) gave a talk on 'Insights into gemmological observations and techniques'. He noted that microscopy and fluorescent reactions can reveal the hidden practise of adding chemical chromophores into flux mixtures that can be diffused into corundum to create a natural-appearing colour. In his talk on 'Gem lab notes from Canada', **Branko Deljanin** covered some unusual new imitations, such as star CZ and star hematite-ilmenite sold as natural star rutile from Sri Lanka. **Martin Steinbach** (Steinbach – Gems with a Star, Idar-Oberstein, Germany) gave a presentation on asterism in gems, and he covered the history of asterism, the treatments and imitations of star stones, synthetic stars, double stars, networks of stars and various star gems (e.g. ruby, sapphire, quartz and spinel) showing 12–24 rays. In a talk on 'Tracking gemstones at auction', **Gail Brett Levine** (National Association of Jewelry Appraisers, Rego Park, New York, USA) observed that the prices achieved at auction for certificated rubies, emeralds and sapphires are not sufficient for valuations of other such gems without understanding the descriptive value factors, limitations of lab reports and country of origin.

A 'round table' discussion on 'Marketing of synthetic diamonds and synthetic gems in 21st century' included seven international experts and was guided by moderator **Ya'akov Almor**. Panellists were **Dr Thomas Hainschwang**, **Branko Deljanin**, **Yuri Shelementiev** (Moscow State University Gemmological Center), **Cara Williams** (Stone Group Labs), **Alberto Scarani** (Magilabs, Rome, Italy), **Dr Joe C. C. Yuan** (Taidiam Technology, Taipei, Taiwan) and **Sergey Sivovolenko** (OctoNus). With the increasing presence of synthetic diamonds on the market, the direction of the industry is changing. The panel and audience explored the impact of synthetic gems and diamonds and how they are establishing themselves in the gem and jewellery market.

Figure 2: Mikko Åström of Magilabs demonstrates the EXA spectrometer during a workshop at the MGJC. Photo courtesy of Branko Deljanin.

Participants were offered hands-on experience at various pre- and post-conference workshops (Figure 2). Basic workshops were 'Unusual uses of portable, affordable tools in identifying most gems in the marketplace' by **Antoinette Matlins** (South Woodstock, Vermont, USA) and 'Ruby, sapphire, emerald and coloured diamond grading' by **Menahem Sevdermish** and **Guy Borenstein**. Intermediate-level workshops were offered on 'ID of rubies and sapphires treatments with standard and advanced instruments' by **Branko Deljanin** and 'ID of natural and synthetic emeralds with standard and advanced instruments' by **Yuri Shelementiev**. Two intermediate-to-advanced workshops on diamonds were given on 'ID of loose and mounted synthetic diamonds with portable instruments' by **Branko Deljanin** and **George Spyromilios** and 'ID of treated synthetic and natural diamonds with standard and advanced instruments' by **Mikko** Åström (Magilabs, Järvenpää, Finland; Figure 2) and **Alberto Scarani**.

Posters and equipment displays gave participants further opportunities to increase their knowledge. A proceedings volume (for 2018, as well as past years) is available for purchase at www.brankogems.com/shop/proceedings/proceedings-2018-mediterranean-gem-and-jewellery-conference-budva-montenegro.

The 5th MGJC will take place 17–19 May 2019 in Limassol, Cyprus. The main topic will be 'Manufacturing of Gems and Diamonds'. For more details on the programme, venue, tours and workshops visit www.gemconference.com.

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GIA SYMPOSIUM

Hosted by the Gemological Institute of America (GIA), the 2018 GIA Symposium took place 7–9 October at the Westin Carlsbad Resort and Spa in Carlsbad, California, USA. Approximately 770 full registrants and students attended the conference (both research and business tracks) from 36 countries. About 190 of them primarily attended the research track, and the research session was commonly near the full capacity of 320 people since the attendees could move as they chose between the research and business sessions. This report highlights those oral presentations of greatest interest to gemmologists. A conference proceedings volume containing abstracts of all the oral and poster presentations in the research track was published in the Fall 2018 issue of *Gems & Gemology*.

Diamonds were covered in several talks. **Dr Christopher Breeding** (GIA, Carlsbad) reviewed the effect of lattice defects on the colour of diamond. He also stressed the rarity of coloured diamonds, which make up only 0.4% of the diamonds submitted to GIA for reports. Of those, 70% are yellow, 17% are 'red' (including red, pink, purple and brown), 10% are green and 3% are 'blue' (including blue to violet). **Dr Wuyi Wang** (GIA, New York, New York) examined the properties of 'true' canary yellow diamonds, which consist of very rare type Ib stones with a highly saturated yellow colour. The main sources of such diamonds are the Zimmi deposit in Sierra Leone and mines in Siberia, Russia. They typically display a patchy colour distribution, very weak or no strain, and green fluorescence in the DiamondView. **Dr Ulrika F. S. D'Haenens-Johansson** (GIA, New York) studied some large rough diamonds that were recovered in late 2015 from the Karowe mine in Botswana by Lucara Diamond Corp. These stones were found at approximately the same time as the 1,109 ct Lesedi la Rona; two offcuts from this rough diamond were also studied. The Fourier-transform infrared (FTIR) and photoluminescence (PL) spectral characteristics, as well as zoning patterns of blue fluorescence seen in the DiamondView, suggest that all of these samples originally formed a single piece of rough that weighed more than 2,774 ct. **Ans Anthonis** (HRD Antwerp, Belgium) examined the impact of blue fluorescence on the colour appearance of round brilliant-cut diamonds. Various groups of observers examined numerous stones, which were grouped according to fluorescence strength, both table-up and table-down, under four different simulated lighting conditions: outdoor, indoor (near a window), office and grading; the latter two environments contained virtually no UV component. Viewed table-down, significant differences in colour (i.e. a whiter appearance) were seen only in the outdoor and indoor (near a window) environments for diamonds that had very strong or strong fluorescence. The effect was less pronounced when viewed table-up, with a significant colour difference seen only in the outdoor lighting environment for diamonds with very strong fluorescence. **Janak Mistry** (Lexus Group, Gujarat, India) used computer-generated imagery to render the appearance of brilliance and fire in faceted diamonds. The appearance of an actual diamond is influenced by a combination of objective optical effects and subjective perceptions. The amount of brilliance is strongly affected by pattern contrasts as well as movement, while fire is particularly dependent on the size of the colour flashes (i.e. affected by cutting style). **Sergey Sivovolenko** (OctoNus, Tampere, Finland) delivered a presentation for **Roman Serov** on performing quantitative absorption spectrum reconstructions to model the effect of different cutting styles on the colour appearance of fancy-colour diamonds. Using OctoNus software, he showed how a 1.20 ct Fancy yellow radiant could be recut into a 1.00 ct Fancy Intense yellow diamond.

Synthetic diamonds were also described in a series of presentations. **Dr David Fisher** (De Beers Technologies, Maidenhead, Berkshire) reviewed the challenges of detecting and screening for synthetic diamonds (Figure 3). He discussed the capabilities and limitations of the DiamondView, AMS2 and SYNTHdetect instruments, and then presented a brief synopsis of the CVD synthetics that are being sold in De Beers' new Lightbox jewellery line. They are easily identified by their orange-to-pink luminescence in the DiamondView, as well as their yellow fluorescence in the SYNTHdetect instrument. They also show a 596/597 nm doublet in their photoluminescence spectra, which is indicative of a CVD origin. **Dr Sally Eaton-Magaña** (GIA, Carlsbad) provided a summary of the CVD synthetic diamonds seen in GIA's

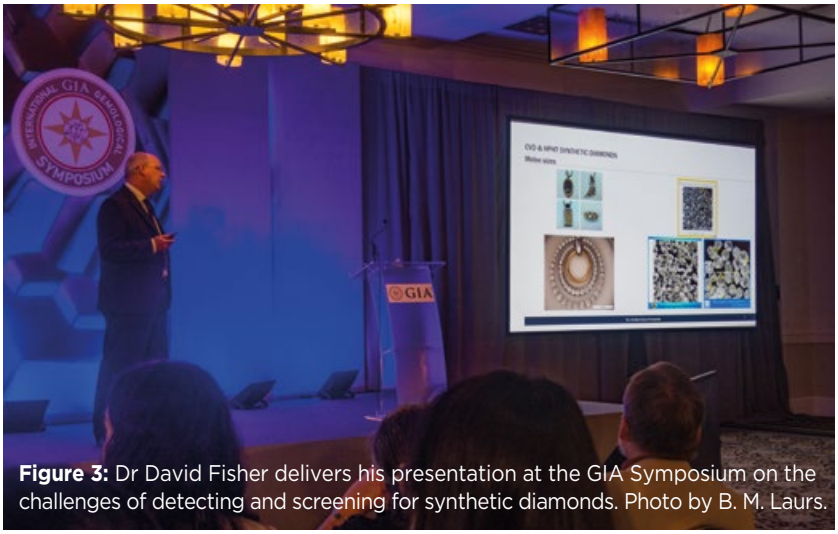

Figure 3: Dr David Fisher delivers his presentation at the GIA Symposium on the challenges of detecting and screening for synthetic diamonds. Photo by B. M. Laurs.

laboratories. The (near-)colourless products typically are G-to-N colour and of high clarity, with any inclusions formed by non-diamond carbon, pinpoints and clouds. While those submitted in 2003–2013 showed some UV fluorescence (typically green, yellow or orange), in 2014–2018 almost all of them were inert. Approximately 74% had undergone post-growth HPHT treatment to remove brown colouration, while ~26% were untreated. **Dr Taijin Lu** (National Gemstone Testing Center, Beijing, China) chronicled recent developments in synthetic diamonds in China. HPHT synthetics are being produced by at least 10 companies, mostly using cubic presses that employ the temperature gradient technique. Type Ib crystals may attain weights of 10+ ct with those ranging up to 3–4 ct being mass produced, while type IIa crystals may reach 8 ct with those under 1 ct being mass produced in the D-to-H colour range. CVD synthetics are produced mostly by DC arc plasma torch technology, yielding type IIa and IIb crystals that are mass produced in sizes ranging up to 12 × 12 × 3 mm. **Dr Hiroshi Kitawaki** (Central Gem Laboratory, Tokyo, Japan) described a 0.192 ct low-pressure, high-temperature (LPHT) treated pink CVD synthetic diamond. While pink CVD synthetics are typically produced using HPHT treatment followed by irradiation with electrons and then low-temperature annealing, the spectral characteristics of this sample indicated that it had undergone LPHT treatment in the range of 1,500–1,700°C.

Diamond geology was covered in detail. **Dr D. Graham Pearson** (University of Alberta, Edmonton, Alberta, Canada) discussed modern advances in the understanding of diamond formation. He emphasised that diamond-bearing terranes need not be exclusively Archean age (>2.5 billion years old), but may also be Proterozoic, as shown by the presence of diamond-bearing pipes in Canada's Sask craton and in Siberia, both of which have lithosphere ages of ~2 billion years old. **Dr Steven Shirey** (Carnegie Institution for Science, Washington DC, USA) reviewed how to obtain and interpret diamond ages. Syngenetic mineral inclusions may provide useful age data, with silicates occurring in lithospheric and super-deep diamonds (datable by Rb-Sr, Sm-Nd and K-Ar methods), and sulphides occurring in lithospheric diamonds (datable by the Re-Os method). The ages provide insights into the relationship between continental geology and origin of diamond-bearing fluids. **Dr Thomas Stachel** (University of Alberta) covered diamond-forming reactions in the earth's mantle. He indicated that the most important reaction involves diamond precipitation from the cooling of high-density C-, H- and O-bearing fluids according to the reaction $CO_2 + CH_4 = C$ (diamond) $+ H_2O$. In this fluid-driven reaction, the mantle wallrocks do not actively participate in diamond formation. **Dr Evan Smith** (GIA, New York) explained the formation of type IIa and IIb diamonds. Type IIa stones are typically large and contain relatively few inclusions, but recent investigations of syngenetic inclusion clusters have revealed the presence of majoritic garnet and $CaSiO_3$-perovskite, which indicate formation at extreme depths of 360–750 km. Rare inclusions in type IIb diamonds also indicate superdeep formation, and the traces of boron that colour these diamonds are derived from subducted seafloor at depths greater than 660 km.

Presentations on coloured stones covered a wide range of gem materials. **Dr Emmanuel Fritsch** (Institut des Matériaux Jean Rouxel and University of Nantes, France) provided compelling evidence that 'boehmite needles' in corundum are actually crystallographically oriented tube-like inclusions known as rose channels. The empty channels form at the intersections of polysynthetic twin planes, and may be explained by deformation twinning that creates vacancies that could migrate to form hollow tubes. **Dr Aaron Palke** (GIA, Carlsbad) examined the colouration of Co-bearing spinel. GIA's laboratory defines this gem variety as having a bright, saturated blue colour that is mainly due to Co. Although Fe may also be present, the visible absorption spectrum must be dominated by Co^{2+} absorptions at ~550, 580 and 630 nm. In general, at least 50 ppm Co is necessary to produce the colouration

associated with 'cobalt spinel', although smaller quantities may produce suitable colour in larger stones (e.g. ~20 ppm for an 8 ct gem). **Dr Barbara Dutrow** (Louisiana State University, Baton Rouge, Louisiana, USA) looked at the importance of tourmaline as a guide to geological evolution. By selectively encoding chemical information about its formational environment that is retained through long periods of geological time, tourmaline can reveal insights about processes in the earth's crust. Information can be gleaned on the tourmaline's original host rock environment/composition/provenance, the thermal history of metamorphic reactions that are related to tectonic events, and the fluid composition, pressure conditions and time of formation of tourmaline-bearing rocks. **Dr Zemin Luo** (China University of Geosciences, Wuhan) performed trace-element analysis on green nephrite from five major origins in Canada (British Columbia), Russia (Siberia), Taiwan and China (Hetian and Manasi in Xinjiang). Linear discriminant analysis of the data showed a clear separation between nephrite from Siberia and Manasi, but overlaps between nephrite from British Columbia, Taiwan and Hetian. The most important trace-element trends were relatively low Ba, Sr and Ti in nephrite from Manasi and high contents of these elements in British Columbian samples. **Martin Steinbach** (Steinbach – Gems with a Star, Idar-Oberstein, Germany) provided an overview of asteriated gems. He indicated that approximately 60 gem varieties are known to show asterism, and there are also about 15 trapiche gem types that show fixed stars. The most important sources of star stones are Sri Lanka, Brazil, India, Madagascar, Tanzania and Vietnam.

Presentations on new technologies included laboratory as well as digital (Internet) topics. **Dr Raquel Alonso-Perez** (Harvard University, Cambridge, Massachusetts, USA) analysed emeralds from ~20 localities worldwide, with a combined approach of inductively coupled plasma mass spectrometry (ICP-MS) and Raman spectroscopy, for the purpose of origin determination and to establish petrogenetic indicators for the various deposits. Approximately 5–10 mg of the samples were digested for ICP-MS analysis to obtain trace-element signatures, while Raman spectroscopy employed a hyperspectral darkfield technique to obtain information on the channel constituents of the emeralds. Colombian samples were identifiable by both techniques, while emeralds from Zambia, Madagascar and Brazil showed enrichments in heavy rare-earth elements. **Dr Claudio Milisenda** (DSEF German Gem Lab, Idar-Oberstein, Germany) examined the value of photoluminescence spectroscopy for coloured stone identification. This technique can be used to separate natural vs. synthetic vs. heated spinel; to identify dyed corundum, coral and pearls; to detect fracture filling; and in some cases to provide an indication of a gem's geographic origin (e.g. for corundum and Cu-bearing tourmaline). In addition, PL spectroscopy can be used to identify mineral species (if reference spectra are available) and as a screening device when examining coloured stone parcels. **Menahem Sevdermish** (Gemewizard, Ramat Gan, Israel) used 'big data analysis' to provide insights into the online gem and jewellery trade (see MGJC report on p. 357). By tabulating the prices, reported attributes (including whether natural, treated or synthetic) and colour (determined digitally using the Gemewizard system) of gems that are offered through a popular online selling platform, the software is able to flag items that have anomalous properties and therefore may be fraudulently represented by the seller. **Klemens Link** (Gübelin Gem Lab, Lucerne, Switzerland) discussed the Provenance Proof blockchain, which will launch in February 2019 to coincide with the gem shows in Tucson, Arizona, USA. This system for following stones through the entire supply chain is independent from the Gübelin Gem Lab and will be free for anyone to use. To connect the digital information in the blockchain with an actual gem, users may consider using the Paternity Test (to implant DNA-encoded nanoparticles into the stone), which is currently available only for emeralds. **Dr Gregory Hodgins** (University of Arizona, Tucson) explained the radiocarbon (^{14}C) age dating of pearls. He explained the data corrections that are necessary due to the inhomogeneous distribution of ^{14}C in the world's oceans, and how above-ground nuclear testing that caused a spike in ^{14}C from 1955 onward must be taken into account. **Chunhui Zhou** (GIA, New York) discussed the limitations and future potential of 'unconventional' techniques in pearl testing, including radiocarbon age dating, DNA barcoding, chemical/isotopic analysis and three-dimensional reconstruction of internal structures.

Gem localities were the subject of four presentations. **Wim Vertriest** (GIA, Bangkok, Thailand) described GIA's field gemmology programme as a modern approach to origin determination. The main focus is on obtaining reliable samples, which is accomplished by going to the mining locations and keeping detailed records of how the samples are acquired. So far, 20,626 samples have been obtained (mostly ruby, emerald and sapphire) during 90 field expeditions over the past decade. **Peter Lyckberg** (Museum of Natural History, Luxembourg) documented gem pegmatites in Ukraine, Russia, Afghanistan and

Pakistan (see also p. 256 of the IMA conference report in *The Journal*, Vol. 36, No. 3, 2018). He focused mainly on the Ukraine deposits, for which ~1,900 pegmatites are known and ~1,500 of them have been mined. They are important sources of gem-quality heliodor and topaz (light brown/blue, sometimes bicoloured). **Dr Lee Groat** (University of British Columbia, Vancouver, Canada) recounted his scientific studies of various coloured stone deposits in Canada. Although challenges to fieldwork include the remoteness of the localities, harsh climate in Arctic regions and the often small size of the gem showings, such studies may provide clues to explore for similar deposits elsewhere. Groat also reviewed origin determination of emeralds and rubies using chemical and isotopic analysis. **William Larson** (Pala International, Fallbrook, California) profiled gems and their localities from pegmatites in San Diego County, California. Most of the gem and mineral production occurred in 1900–1912 and was driven by Chinese Empress Dowager Cixi's desire for pink-to-red tourmaline (e.g. Figure 4). Larson recounted his personal experience with many exciting discoveries at the Tourmaline Queen and Himalaya mines, and also described recent developments at the Oceanview mine (for kunzite and bicoloured pink-green tourmaline) and the Mountain Lily mine (which is currently being explored for tourmaline and topaz).

Figure 4: This antique Chinese snuff bottle (5 × 4 × 2.5 cm) is carved of tourmaline from the Himalaya mine in San Diego County, California. Courtesy of Pala International; photo by Mia Dixon.

In other presentations, **Edward Boehm** (RareSource, Chattanooga, Tennessee, USA) explained the challenges of working as a gem trader in the 21st century. Successful dealers must differentiate themselves from others who are buying gems in cutting centres, and also must be more knowledgeable about all aspects of the trade, from evaluating rough material and identifying treatments and synthetics to becoming vertically integrated in the business. Due to gem traceability requirements from large publically traded retailers, Boehm predicted that origin determination and stone tracing will become even more important in the future. **Dr Saleem Ali** (University of Delaware, Newark, USA) examined sustainability in the gem industry. Although there are many challenges to sustainability, particularly in the highly fragmented coloured stone arena, some possible solutions include (1) life-cycle analysis to measure the impacts of mining in both ecological and social terms, (2) consumer education about gem origin and the impact of mine development coupled with origin assurance, and (3) conservation initiatives such as levying mineral-origin 'royalties' each time a gem is sold to promote wildlife conservation in the mining area. **Cristina Villegas** (Pact, Washington DC, USA) described a collaboration between GIA and her company to help close the knowledge gap across the supply chain in Tanzania. The team provided two days of theoretical and practical training to local miners, accompanied by simple educational reference books and sorting trays. This provided the miners with greater knowledge about quality/value factors, more confidence in dealing with gem rough, increased financial independence, and better preparation of the gem rough for selling and cutting.

Brendan M. Laurs FGA

CANADIAN GEMMOLOGICAL ASSOCIATION CONFERENCE

Celebrating the 60th anniversary of the Canadian Gemmological Association (CGA), Gem Conference 2018 took place 19–21 October in Vancouver, British Columbia, Canada. Approximately 70 people attended, representing six countries (Australia, Canada, Costa Rica, Hong Kong, UK and USA).

CGA president **Donna Hawrelko** opened the conference, and she then asked various CGA staff and students to take turns introducing the speakers. **Duncan Parker** (Dupuis Fine Jewellery Auctioneers, Toronto, Ontario, Canada) surveyed gems in ancient texts. The oldest mentions were by Aristotle, Theoprastus and Pliny the

Elder, and these were followed by an approximately 1,600 year gap until publications on gemmological topics were resumed by Robert Boyle and subsequently by authors such as David Jefferies, William Hyde Wollaston, Lewis Feuchtwanger, Edward Streeter, Julius Wodiska, Herbert Smith and A. H. Church.

Joseph DuMouchelle (Joseph DuMouchelle Jewelry Buyers, Birmingham, Michigan, USA) chronicled trends in jewellery and collectibles at auction. In general, auction prices are reflective of shifting world markets, changes in consumer buying habits and style, and the status of the economy. For 2018 and beyond, he indicated that buyers are returning (with a focus on quality), and also that signed pieces and understated styles should remain popular. The Internet has revolutionised auctions by providing access to a worldwide market, with buyers for nearly everything.

Mike Botha (Embee Diamonds, Prince Albert, Saskatchewan, Canada) described his development of the Sirius Star diamond cut to provide more light return than a standard round brilliant. The cut employs 32 crown facets and 48 pavilion facets (in four tiers), resulting in a diamond that reportedly looks larger and brighter due to more even light distribution from the crown mains, star facets and table. He has subsequently developed variations of the Sirius Star in octagon, square and cushion shapes, in patterns that incorporate 80, 84, 88 or 100 facets.

Kelly Ross (Ross Inc., Edmonton, Alberta, Canada, and formerly diamond programme coordinator for the Royal Canadian Mounted Police) explained how stolen jewellery is used by criminals to pay debts (i.e. to drug dealers) or to obtain illicit drugs. Cases involving jewellery theft are often difficult to bring to trial because of the difficulty of proving that seized items are the proceeds of a crime, as well as the time-consuming process of doing so.

Jon Phillips (Corona Jewellery Co., Toronto, Ontario, Canada) reviewed recent developments pertaining to Canadian diamonds. Canada is now the second largest diamond producer by volume and fourth largest by value. Currently active mines include Ekati, Diavik, Gahcho Kué, Renard and Victor, and future diamond production is expected from Chidliak and the Star-Orion South project. The sorting, evaluation and sales of Canadian diamond rough mainly take place in India and Botswana (with a small amount being done in Antwerp, Belgium). Nearly all of the diamonds undergo manufacturing in India.

Simon O'Brien (De Beers Group of Companies, Calgary, Alberta, Canada) explained De Beers' new 'Building Forever' initiative, which focuses on building trust through natural, conflict-free diamonds, community benefit and environmental quality at the mines. He emphasised that such positive aspects provide important talking points for educating the gem-buying public. He also described De Beers' newly developed Lightbox synthetic diamond jewellery, which is being positioned in the market to commemorate 'incremental' occasions and self-purchase.

Dr Çiğdem Lüle (Kybele LLC, Buffalo Grove, Illinois, USA) reviewed the occurrences and varieties of garnets, as well as their history and lore. Garnets are common today, but they were rare in the Western world until Alexander the Great opened up trade routes with the East (e.g. the Silk Road), and subsequently they were obtained by Roman seafarers.

Andrew Cody (Cody Opal, Melbourne, Victoria, Australia) covered opal classification according to type and variety. He indicated that uniform opal nomenclature is needed to avoid inconsistencies in terminology used by gemmological laboratories and educational institutions. He displayed a complete opal master reference set (see *The Journal*, Vol. 36, No. 2, 2018, pp. 110–111) that was obtained by CGA, and mentioned the development of an exciting new resource that will published in the near future called *The Opal Handbook for Professionals*.

Lily Vongwattanakit (Van Cleef & Arpels, New York, New York, USA) described in detail the process of creating exquisite jewellery art at Van Cleef & Arpels. Such jewels represent beauty, femininity, refinement, artistic essence, innovation, uniqueness and exceptional craftsmanship. Most of the pieces take two years to complete, and a number of steps are required including inspiration, obtaining the stones, designing and rendering. The last process is particularly time consuming because before being manufactured each piece is made into a three-dimensional model (using pewter for the metal and glass for the gems).

Gary Roskin (International Colored Gemstone Association, New York, New York, USA) examined various aspects of the value vs. price vs. cost of gem materials (i.e. someone's belief of worth vs. what someone is willing to pay vs. what is actually paid). He indicated that uncertainty in the global economy is driving the ultra-wealthy to diversify their holdings to include high-value gemstones such as coloured diamonds. He then reviewed some market trends derived from the September 2017 Hong Kong Jewellery & Gem Fair.

Sarah Steele (Ebor Jetworks Ltd, Whitby) surveyed the history, properties and characterisation of jet. Used for ornamentation and decorations for 19,000 years, jet became the biggest gem trend in 1830–1910 when

the British government issued a decree for its use in mourning jewellery. However, its popularity collapsed when large quantities of inferior-quality jet were imported from Spain, causing a loss in consumer confidence. It is desirable to know the source of jet due to general differences in the stability of the material from various localities, and efforts are currently underway to find a non-destructive spectral technique for doing so.

Alex Grizenko (Lucent Diamonds Inc., Los Angeles, California, USA) reviewed the growth techniques and identification of synthetic diamonds produced by both HPHT and CVD methods. He also summarised methods of separating natural from synthetic diamonds (HPHT and CVD) using classical gemmological techniques and various screening devices.

Dr Lee Groat (University of British Columbia, Vancouver, Canada) explored coloured stone localities in Canada (see GIA Symposium report on p. 361). He also briefly looked at processes affecting the clarity of gem materials, such as fracturing due to stress and the subsequent healing of fissures that is accompanied by the formation of secondary fluid inclusions, which are the main cause of diminished transparency in gem crystals.

Art Samuels (Vivid Diamonds & Jewelry and EstateBuyers.com, Florida, USA) provided diverse insights from his extensive experience dealing with gems and jewellery. He covered the risks and rewards of recutting diamonds for improved clarity grades, decolourising brown type IIa diamonds via HPHT processing, and challenging GIA laboratory reports for diamonds with borderline SI_2/I_1 clarity grades and Fancy Deep/Fancy Vivid colour grades.

Stuart Robertson (Gemworld International Inc., Glenview, Illinois, USA) examined various trends in the gem industry. Millennials represent the greatest potential market for future jewellery consumption, but they demand non-traditional styles and materials that tie into their need for individualism. They are best approached through e-commerce, social media and influencer marketing (i.e. in which a person with lots of followers 'likes' a product on social media). For the coloured stone market, Robertson predicted that garnet is poised for increasing popularity, and that there will be a growth in demand for non-classic gems.

Dr Dominic Mok (Asian Gemmological Institute and Laboratory Ltd, Hong Kong) reviewed jade quality factors and grading. He emphasised the '3Cs' of **c**lass (overall variety), **c**olour (hue description) and **c**raftsmanship (execution of shape and polish); other important considerations include size, transparency, internal shine and purity. He also explained testing protocols for jade using microscopy and spectroscopy (FTIR, ultraviolet-visible and Raman).

Figure 5: CGA president Donna Hawrelko presents the inaugural CGA Diamond Award to Alan Hodgkinson in recognition of his outstanding contributions to Canadian gemmology. Photo by Kenneth Waters.

Alan Hodgkinson (Whinhurst, West Kilbride, Scotland) described simple gemmological techniques for differentiating various gem materials with overlapping RI values or for cases where RI values cannot be obtained (such as some mounted stones), which included natural vs. synthetic Co-bearing spinel, red spinel vs. garnet, red beryl vs. ruby and blue kyanite vs. sapphire. He also reminded the audience about the use of top-lighting with the refractometer to obtain RI values of gems for which clear readings are difficult to obtain.

Several awards were given during the CGA Banquet on 21 October. The **CGA Lifetime Achievement Award** was presented to **Donna Hawrelko**, the inaugural **CGA Diamond Award** for outstanding contributions to Canadian gemmology was awarded to **Alan Hodgkinson** (Figure 5) and winners were announced for CGA's first jewellery design contest: 1st place went to **Yiwei Zhang** (George Brown College, Toronto, Ontario) for her Sprout Spring neckpiece, 2nd place went to **Jackie Zheng** (Vancouver Community College, Vancouver, British Columbia) for his Autumn Melody bracelet, 3rd place went to **Alexandro Gage** (Vancouver Community College) for his After Picasso pendant and an honourable mention went to **Charlize Nhung** (OCAD University, Toronto) for her Element of Canada necklace.

Four workshops took place before and after the conference: visual optics by **Alan Hodgkinson**, jade by **Dr Dominic Mok**, opals by **Andrew Cody** and common gem treatments by **Dr Çiğdem Lüle**.

Brendan M. Laurs FGA

GEM-A CONFERENCE

On 3–4 November 2018, gemmologists from around the world gathered for the annual Gem-A Conference at etc.venues County Hall in London. With close to 300 attendees over the two days, the delegates were treated to a variety of talks ranging from gemmology to geology, sustainable mining, and artistic cutting and jewellery.

Gem-A CEO **Alan Hart** opened the conference by noting that 2018 marks 110 years of organised gemmology in the UK, since Samuel Barnett originally proposed gemmological education to the National Association of Goldsmiths in 1908. Celebrating Gem-A's proud history, and the legacy of Basil Anderson starting the world's first gem-testing laboratory, this year's conference presentations demonstrated the multi-disciplinary and international nature of Gem-A, as well as an increasing focus on social and gender equality in our industry.

Internationally renowned Hong Kong jewellery artist and innovator **Wallace Chan** explored his philosophy and journey as a gem cutter and carver, and how his past mistakes formed an essential part of his progress. Chan shared the insights behind some of his spectacular creations, including the illusionary carving technique called the Wallace Cut, the butterfly-themed jewels that showcase his mastery of titanium metalwork, and his Secret Abyss project that took over a decade and many broken pieces of rock crystal to complete. Asserting 'failure is part of the process', Chan demonstrated how unexpected turns often form part of the creative journey.

Dr Eloïse Gaillou (Mines ParisTech, Paris, France) discussed the various defects that cause colour in diamonds. Given the increasing popularity of coloured diamonds, which have been attaining record prices at auction houses across the globe, Gaillou asserted the importance of understanding the causes of their colour to help differentiate between natural, treated and synthetic diamonds. She explored the various types of defects that cause blue, pink-to-red, green, yellow and brown colouration, as well as the types of inclusions that create a black or white appearance in diamond.

Geologist and mineral expert **Peter Lyckberg** (Museum of Natural History, Luxembourg) discussed gem-bearing pegmatites of Afghanistan and Pakistan. Emphasising the importance of studying gems *in situ* at their deposits to ensure the correct information is obtained for museum collections, Lyckberg displayed stunning images of his visits to several important gem and mineral localities. Some of the specimen highlights were a spiral-included aquamarine and a top-quality matrix specimen of aquamarine from Pakistan's Shigar Valley.

Master faceter **Victor Tuzlukov** (Bangkok, Thailand) discussed precision-cut gemstones according to their high level of perfection and lack of faceting defects (Figure 6). He also shared the philosophy behind his Heritage cuts, and his experience with teaching precision gem-cutting, which demands attentiveness, accuracy and harmony, and taps into creative consciousness as well as knowledge of the natural sciences.

Closing Saturday's presentations, **Justin Hunter** (J. Hunter Pearls, Savusavu, Fiji) outlined his initiatives to preserve, protect and sustain the oceans through pearl farming. In 2016 his farm was severely damaged by cyclone Winston, nearly causing him to close operations, but he saw first-hand how the local inhabitants (many of whom were his employees) needed the pearl farm to remain open. Since pearl farms require healthy oceans to function, this experience proved the value of tropical marine biodiversity. In 2017 he created the Fiji Pearl Development Plan, which envisions a 'blue industry' that focuses on sustainable living conditions for island communities who have given up their fishing grounds for the creation of marine protected areas.

Writer, jewellery expert and entrepreneur **Monica Stephenson** (Anza Gems and iDazzle.com, Seattle, Washington, USA) began Sunday's presentations by taking the audience on a virtual trip to an East African tsavorite mine that is worked by local artisanal diggers. Stephenson wants to refocus the narrative of African mining away from 'blood diamonds' towards the positive impact that gems can have on mining communities. To this end, she shared how she uses her past jewellery experience and her new contacts in East Africa to ensure the industry reinvests back into the community—particularly by supporting women miners and artisans.

Gem and mineral collector/dealer **Federico Bärlocher** (Yangon, Myanmar, and Como, Italy) investigated the ruby deposits of Mogok, Myanmar. With 1,200 mines,

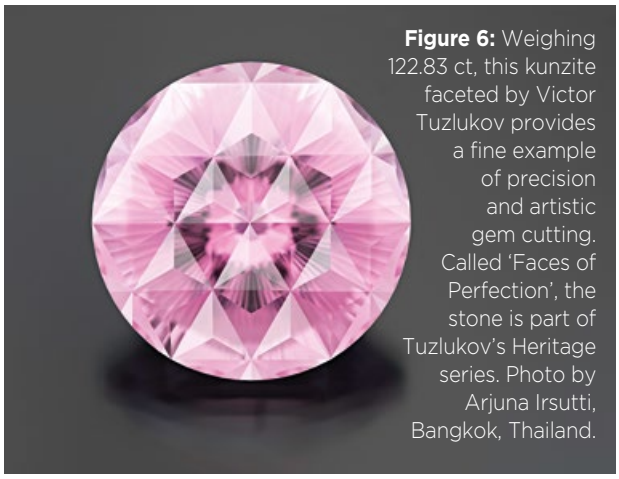

Figure 6: Weighing 122.83 ct, this kunzite faceted by Victor Tuzlukov provides a fine example of precision and artistic gem cutting. Called 'Faces of Perfection', the stone is part of Tuzlukov's Heritage series. Photo by Arjuna Irsutti, Bangkok, Thailand.

this unique locality hosts important occurrences of ruby, sapphire, spinel, peridot and many other gems. Bärlocher explained how local people recently began using UV torches to search for rubies at night in mine tailings, and then he showed a documentary film exploring the underground workings and processing plants at the Dattaw and Kadoke-Tat ruby mines.

Figure 7: Dr Jeff Post delivers his presentation to a packed room at the Gem-A Conference. Photo by Henry Mesa.

Dr Jeffrey Post (National Gem and Mineral Collection, Smithsonian Institution, Washington DC, USA; Figure 7) discussed the impact of the Hope diamond on the museum's collection. With its fascinating history of intrigue, famous owners and reported curses, it generates widespread curiosity that few other objects can attain. And, being a 45.52 ct blue diamond, it is truly a unique treasure of the earth. Post noted that attendance to the Smithsonian almost doubled after the Hope arrived, and he shared research proving it was recut from the French Blue diamond (which had a facet pattern suggesting a bespoke design for 'Sun King' Louis XIV of France). Post concluded that gems and minerals provide a wonderful way to get people into science exhibits, as they capture the imagination and inspire scientists of the future.

Rui Galopim de Carvalho (PortugalGemas Academy, Lisbon, Portugal) explored various aspects of precious coral. He emphasised the important distinction between reef-forming coral and precious coral. Of the 7,000 species of coral that are known, only eight of these constitute precious coral. Education of the trade and consumers is key to ensuring sustainability and responsible sourcing in the coral industry. Sharing insights from his work on CIBJO's Coral Commission, Galopim de Carvalho discussed CITES regulations for protecting certain precious corals and the exciting initiatives currently under investigation to help reintroduce precious corals into depleted seabeds.

London-based fine-jewellery specialist **Joanna Hardy** closed Sunday's talks by exploring the history of emeralds —from the desert landscape of Cleopatra's emerald mine in ancient Egypt to the Byzantine empress Theodora bedecked with emeralds. Hardy then shared her recent experience with visiting the Coscuez mine in Colombia and also mentioned the 2017 discovery of a 144.65 ct alluvial emerald called the Apple of Muzo. She completed her presentation by showing some exquisite emerald items from London's Cheapside Hoard, as well as more modern creations that included jewellery manufactured by Van Cleef & Arpels and a radiant Princess Eugenie wearing the Greville Tiara made by Boucheron in 1919.

The conference was closed by Gem-A president **Maggie Campbell Pedersen**, who commented on the international nature of our industry. The speakers explored a wide variety of places, taking the audience up mountains, to the depths of the earth and sea, and to exquisite collections in world-renowned museums. A continual theme was the importance of sustainability in procuring gem materials, and the need to benefit local communities and protect our planet. Presentations covered the deeper meaning of gem cuts and their poetic philosophies, and investigated the stories behind gems from the deepest mines to the workshops of the most revered designers.

On 5 November, three workshops were held at Gem-A's headquarters: coloured stone grading and pricing (hosted by **Richard Drucker**, Gemworld International Inc., Glenview, Illinois, USA), fluorescence spectroscopy (hosted by **Alberto Scarani** and **Mikko Åström** of Magilabs, Rome, Italy, and Järvenpää, Finland) and social media etiquette (hosted by **Monica Stephenson** and freelance jewellery and watch editor **Barbara Palumbo**). That evening marked Gem-A's graduation ceremony and presentation of awards at the Royal Institution of Great Britain in London.

On 6 November, field trips took attendees to private viewings of the British Crown Jewels at the Tower of London, the gem and mineral collection at the Natural History Museum, and the Jewellery Gallery at the Victoria and Albert Museum.

Sarah Bremner
Gem-A, London

Brendan M. Laurs FGA

Gem-A Notices

GEM-A CONFERENCE 2018

The 2018 Gem-A Conference was held at etc.venues County Hall, London, on 3 and 4 November. Highlights of the speaker presentations are reported in the Conferences section of this issue of *The Journal*, pages 364–365, and round up in the Winter 2018 issue of *Gems&Jewellery*. Workshops took place on 5 November at Gem-A HQ, and on 6 November some delegates visited the Mineral Gallery at the Natural History Museum for a guided tour by Gem-A CEO Alan Hart, while others went on a private tour of the British Crown Jewels at the Tower of London or attended a jewellery handling session at the V&A Museum.

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We would also like to thank DG3 Diversified Global Graphics Group (www.dg3.com) for producing the Gem-A Conference materials.

GRADUATION CEREMONY

The 2018 Graduation Ceremony was held at the Royal Institution of Great Britain, Albemarle Street, London, on 5 November. This year, 600 students passed the Gemmology and Diamond Diploma examinations, and 46 of these students passed with Distinction. November's Graduation was a truly international gathering with successful candidates joining us from Canada, China, France, Hong Kong, India, Italy, Japan, Lithuania, Madagascar, Malaysia, Myanmar, The Netherlands, Norway, Russia, Spain, Sweden, Switzerland, Taiwan, USA and Venezuela, as well as the UK. Alan Hart, CEO of Gem-A, opened the ceremony by welcoming graduates, families and guests to the Royal Institution (RI), and celebrated the shared history between Gem-A and the RI: Nobel Prize winners Sir William Henry Bragg and his son Sir Lawrence Bragg were both resident professors at the RI and Gem-A presidents.

Guest speaker John Benjamin FGA DGA gave an inspiring speech on the value of the post-nominals across the world, before presenting the Diplomas, and Maggie Campbell Pedersen FGA ABIPP, Gem-A President, awarded the Gem-A Medals and Prizes.

GEMMOLOGY DIPLOMA PASSES

Runa A, P.R. China
Karoline Aas-Engelstad, Norway
Lobar Abraeva, United Kingdom
Mohamed Faleel Hussain Akiff, Sri Lanka
Jeanine Albronda, The Netherlands
Loujaine AlMoallim, Canada
Adreana Alves dos Santos, France
Michael Arnoulet, France
Fay Barrow, United Kingdom
Alexandra Becket, United Kingdom
Leïla Ben Haj Larbi, France
Charles Bexfield, United Kingdom
Cyrielle Blassiaux, France
Emma Boshoff, Wales, United Kingdom
Jean Dominique Bouriaud, France
Alexandra Bowkett, United Kingdom
Sophie Brassington, United Kingdom
Henri Marcel Cadenet, Madagascar
Liang Cai, P.R. China
Xiangyi Cao, P.R. China
Ziheng Cao, P.R. China
Qing Cha, P.R. China

Siu Chung Chan, Hong Kong
Lok Cheong Chan, Hong Kong
Chung Chih Chang, Taiwan (R.O.C.)
Han Chang, P.R. China
Un Man Chao, Taiwan (R.O.C.)
Yujing Chen, P.R. China
Junyi Chen, P.R. China
Qijing Chen, P.R. China
Yu Chen, P.R. China
Li-Chen Chen, Taiwan (R.O.C.)
Silin Chen, P.R. China
Jianxia Chen, P.R. China
Qingqiang Chen, P.R. China
Huijing Chen, P.R. China
Jielin Chen, P.R. China
Ji-Kang Chen, Taiwan (R.O.C.)
Kaka Cheng, P.R. China
Yuk Yin Cheung, Hong Kong
Wai Man Cheung, Hong Kong
Tzu-Yu Chin, Taiwan (R.O.C.)
Lucy Clarke, United Kingdom
Elodie Clement, France
Raphaelle Cousteix, United Kingdom
Yichuan Cui, P.R. China
Nicholas Tristan Barritt Davenport, United Kingdom
Leigh Davis, United Kingdom
Morgane De La Gandara, Switzerland
Muhammadh Ashfaq Deen, Sri Lanka
Lara De-Leuw, United Kingdom
Jie Deng, P.R. China
Ya Hui Deng, P.R. China
Weijia Deng, P.R. China
Brian Denney, United States of America
Mary Dieu De Bellefontaine, United Kingdom
Lei Ding, P.R. China
Yi-Siang Ding, Taiwan (R.O.C.)
Kexin Dong, P.R. China
Chuoxin Du, P.R. China
Yi Duan, P.R. China
Aurelia Ducor, France
Marie Caroline Ducrot, France
Rachel Evershed, United Kingdom
Ting Fang, P.R. China
Qiang Fei, P.R. China
Yilin Feng, P.R. China
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Luc Gagnon, Canada
Wasantha Gamlath, Sri Lanka
Le Gao, P.R. China
Hettige Don Darshana Gayan Umayanga, Sri Lanka
Meng Geng, P.R. China
Penelope Gilliver, United Kingdom
Martin Grigorov, Bulgaria
Xiaoqing Guan, P.R. China
Delphine Guérin, France
Audrey Hagedorn, United States of America
Qi Han, P.R. China
Junjie He, P.R China
Harriet Hedges, United Kingdom
Ho Lam Ingrid Ho, Hong Kong
Kit Yi Ho, Hong Kong
Pui Lam Ho, Hong Kong
Pui Wing Sandy Ho, Hong Kong
Shan Jung Ho, Taiwan (R.O.C.)
Yuk Lin Hong, Hong Kong
Yi Xin Hong, P.R. China
Oliver Horner, United Kingdom
David Horstmann, Switzerland
Femke Hovinga-Tiller, The Netherlands
Iona Howard, United Kingdom
Man-Shiuan Hsu, Taiwan (R.O.C.)
Yu Ying Hu, P.R. China
Jia Qian Hu, P.R. China
Yuxi Huang, P.R. China
Wenmin Huang, P.R. China
Ziyun Huang, P.R. China
Augustine Huang, Taiwan (R.O.C.)
Danyan Huang, P.R. China

Huang Huang, P.R. China
Isabelle Hugon, France
Carmen Kai Man Hui, Hong Kong
Geoffrey Hummel, France
Antoine Jacob, France
Andry Jhonson, Madagascar
Xiao Jing Jia, P.R. China
Yangyang Jia, P.R. China
Yuan Jiang, P.R. China
Zhuyu Jin, P.R. China
Anqi Jin, P.R. China
Shijie Jin, P.R. China
Aunyavee Jirapattaroj, Thailand
Monika Jockute, United Kingdom
Shicong Ju, P.R. China
Aleksandr Kanevskij, Japan
Yanis Kariche, France
Fredrik Karlsson, Sweden
Nadine Kerba, Canada
Kaylan Khourie, South Africa
Yuka Kinjo, Japan
Feng-Hua Ko, Taiwan (R.O.C.)
Ka Yin Ko, Hong Kong
Ye Kong, P.R. China
Iakovina Kotsakou, Greece
Corlijne Kouw, The Netherlands
Melanie Krummel, United States of America
Yalun Ku, P.R. China
Aung Mon Kyaw, Myanmar
Audrey Laguerre, France
Tin Wai Lam, Hong Kong
Wing Yee Lam, Hong Kong
Pui Sze Lam, Hong Kong
Solange Lasserre, France
Chi Ho Lau, Hong Kong
Yi-Chen Lee, Taiwan (R.O.C.)
Cheng-Chieh Lee, Taiwan (R.O.C.)
Wai Ching Lee, Hong Kong
Zhang Lei, Thailand
Thomas Lelièvre, France
Kam Wah Leung, Hong Kong
Wing Ting Leung, United Kingdom
Zhuchenzi Li, P.R. China
Xiaodui Li, P.R. China
Geyu Li, P.R. China
Yingqing Li, P.R. China
Meng Yi Li, P.R. China
Baoming Li, France
Yi-Jen Li, Taiwan (R.O.C.)
Jing Li, P.R. China
Xian Li, P.R. China
Siwen Li, P.R. China
Xianyun Li, P.R. China
Xingyu Li, P.R. China
Peixuan Li, P.R. China
Fei Li, P.R. China
Xingqi Li, P.R. China
Meng-Hsun Li, Taiwan (R.O.C.)
Yaqi Li, P.R. China
Françoise Li - de Vries, France
Sai Kit Lim, Hong Kong
Zhi Yi Lin, Hong Kong
Chun-Ni Lin, Taiwan (R.O.C.)
Yingxin Lin, P.R. China
Sarah Little, United Kingdom
Baitong Liu, P.R. China
Dan Liu, P.R. China
Changda Liu, P.R. China
Qi Liu, P.R. China
Mengying Liu, P.R. China
Wenhui Liu, P.R. China
Chunrui Liu, P.R. China
Yang Liu, P.R. China
Linghan Liu, P.R. China
Yuwei Liu, P.R. China
Nga Man Lo, Hong Kong
Tsung-Chi Lo, Taiwan (R.O.C.)
Jialing Long, P.R. China
Hongwei Lou, P.R. China
Zhenping Lu, P.R. China

Mei Chun Lu, Taiwan (R.O.C.)
Chiu-Chun Lu, Taiwan (R.O.C.)
Yilin Luan, P.R. China
Yaxin Luo, P.R. China
Aye Aye Khine Ma, Hong Kong
Yutian Ma, P.R. China
Wei Ma, P.R. China
Man Ho Mak, Hong Kong
Anu Malhi, United Kingdom
Abigail Marsh, United Kingdom
Lorna McNaught, United Kingdom
Xiaoliu Mei, P.R. China
Xiaochen Mei, P.R. China
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Soumeya Merabti, France
Guanhao Mo, P.R. China
Anaïs Morales, France
Ashley Moy, United States of America
Malgorzata Mozolewska, United Kingdom
Yuen-Li Naa, Malaysia
Ayako Nakase, Japan
Wing Sze Ng, Hong Kong
Wanying Nie, P.R. China
Vaz Nishka, India
Yun Niu, P.R. China
Mari Obonai, Japan
Mohammed Odowa, United Kingdom
Anne Offringa, The Netherlands
Ashlyn Oprescu, United States of America
Yen-Shuo Ou, Taiwan (R.O.C.)
Haixia Pan, P.R. China
Hong Pan, P.R. China
Yu Pan, P.R. China
Sumarni Paramita, Indonesia
Xiaolu Peng, P.R. China
Géraldine Piguet-Reisser, Switzerland
Charlotte Pittel, United Kingdom
Amanda Pollarolo, United Kingdom
Zhaojuan Qi, P.R. China
Guoming Qian, P.R. China
Li Qiang, P.R. China
Dandan Qie, P.R. China
Zhongni Qin, P.R. China
Xian Qing Qin, P.R. China
Xiaoci Qiu, P.R. China
Mei Ya Qiu, P.R. China
Lola Rafieva, United Kingdom
Sandrina Chan Ramanantsoa, Madagascar
Yong Ren, P.R. China
Wenya Ruan, P.R. China
Joanne Rusch, United Kingdom
Marya Samman, Canada
Kazumi Sato, Japan
Virginia Schneider, United States of America
Chia Chen Shen, Taiwan (R.O.C.)
Yun-Tung Shen, Taiwan (R.O.C.)
George Shihadeh, United States of America
Emily Smeaton, United Kingdom
Craig Smith, United Kingdom
Kin Yee So, Hong Kong
Jian Song, P.R. China
Myongha Song, Japan
Ying Song, United Kingdom
Xiu Yu Sun, P.R. China
Ran Sun, P.R. China
Wanjie Sun, P.R. China
Ningyue Sun, P.R. China
Miwako Tada, Japan
Tamara Kumari, Sri Lanka
Li Mei Tang, P.R. China
Jun Tang, P.R. China
Yuchen Tang, P.R. China
Ebba Tegnesjo, Sweden
Ivan Louis Alphonse Serge Temey, Reunion Island
Wei Chen Teng, Taiwan (R.O.C.)
Syh-Tang Teng, Taiwan (R.O.C.)
Tiancheng Tian, P.R. China
Keqing Tian, P.R. China
Yu Tian, P.R. China
Xi Tong, P.R. China

Yung Tsang, Hong Kong
Huang Ying Tseng, Taiwan (R.O.C.)
Patricia Van Bragt-Verhage, The Netherlands
Tim Van Heijningen, The Netherlands
Naomi Vane-Wright, United Kingdom
Gemma Venus, United Kingdom
Simin Wan, P.R. China
Hui Wang, P.R. China
Yuqing Wang, P.R. China
Lin Wang, P.R. China
Ke Wang, P.R. China
Jie Wang, P.R. China
Lei Wang, France
Yi-Chen Wang, Taiwan (R.O.C.)
Xu Wang, P.R. China
Yuhan Wang, P.R. China
Zilin Wang Wang, P.R. China
Changxi Wang, P.R. China
Yulin Wang, P.R. China
Hiromi Watanabe, Japan
Oliver Webb, United Kingdom
Chathura Sachith Weerakoon, Sri Lanka
Shuiyan Wen, P.R. China
Charlotte Williams, United Kingdom
Rose Wilson, United Kingdom
Elizabeth Winnicott, United Kingdom
Mei Tsz Macy Wong, Hong Kong
Tsung-Jen Wu, Taiwan (R.O.C.)
Hong Zheng Wu, P.R. China
Jing Wu, P.R. China
Lingyi Wu, P.R. China
Siying Wu, P.R. China
Tong Wu, P.R. China
Wen Jing Xia, P.R. China
Wen Hua Xie, P.R. China
Kewei Xie, P.R. China
Zengzheng Xie, P.R. China
Yuan Xie, P.R. China
Mingxin Xie, P.R. China
Yu Sheng Xu, P.R. China
Hui Xu, P.R. China
Rui Xu, P.R. China
Jie Xu, P.R. China
Lifen Xu, P.R. China
Zhe Wen Xuan, P.R. China
Sayaka Yamada, Japan
Akiko Yamamoto, Japan
Yufei Yan, P.R. China
Qicheng Yan, P.R. China
Xiangfei Yan, P.R. China
Meng-Pei Yang, Taiwan (R.O.C.)
Zhuo Yang, P.R. China
Yi Yang, P.R. China
Yuwei Yang, P.R. China
Li Yang, P.R. China
Ji-Miao Yeh, Taiwan (R.O.C.)
Yuan Jung Yeh, Taiwan (R.O.C.)
Hiu Ying Rosa Yeung, Hong Kong
Yanling Ying, P.R. China
Tak Wai Yip, Hong Kong
Po Yan Yiu, Hong Kong
Yang Yu, P.R. China
Hangwei Yu, P.R. China
Yu Yu, P.R. China
Jingmin Yu, P.R. China
Zhi Ying Yuan, P.R. China
Peng Yuan, P.R. China
Hoi Ling Yuen, Hong Kong
Yat Kwok Yung, Hong Kong
Diana Zavala, United States of America
Zhiyao Zeng, P.R. China
Qingying Zeng, P.R. China
Yidan Zhang, P.R. China
Shuo Zhang, Japan
Yue Zhang, P.R. China
Qidong Zhang, P.R. China
Tianran Zhang, P.R. China
Yuxue Zhang, P.R. China
Lili Zhang, P.R. China
Ling Zhang, P.R. China

Yumei Zhang, P.R. China
Yuyan Zhang, P.R. China
Yi Zhang, P.R. China
Chudi Zhang, P.R. China
Mengdi Zhang, P.R. China
Peng Zhang, P.R. China
Yunrui Zhang, P.R. China
Xiqian Zhang, P.R. China
He Zhao, P.R. China
Longpei Zhao, P.R. China
Jiahui Zhao, P.R. China
Ting Zhao, P.R. China
Ziye Zhao, P.R. China
Man Qiao Zheng, Hong Kong
Ruixin Zheng, P.R. China
Yuliang Zhong, P.R. China
Qi Zhou, P.R. China
Xue Zhou, P.R. China
Li Zhu, P.R. China
Ze Kun Zhu, P.R. China
Fangying Zhu, P.R. China
Shaobai Zhuang, P.R. China
Rui Zong, P.R. China
Yiran Zou, P.R. China

GEMMOLOGY DIPLOMA PASSES WITH MERIT

Gabriel Chauvet, France
Cheng-Hung Chen, Taiwan (R.O.C.)
Xi Chen, P.R. China
Po-Hao Cheng, Taiwan (R.O.C.)
Helen Dong, P.R. China
Cheng Chen Feng, P.R. China
Li Yun Fu, P.R. China
Yu Fu, P.R. China
Peih Yinn Gam, Malaysia
Jia Gu, Australia
Kai Peng Guo, P.R. China
Yilin Han, P.R. China
Juliette Hibou, United Kingdom
Alethea Inns, United States of America
Yuhong Jiang, P.R. China
Yuntao Jing, P.R. China
Emily Jones, United Kingdom
Simar Khokhar, India
Sarah Kinsey, United Kingdom
Te-Han Lan, Taiwan (R.O.C.)
Yannick Le Guennec, Canada
Stephanie Lezy, France
Huining Li, P.R. China
Xinyu Li, P.R. China
Yujin Li, P.R. China
Zixi Li, P.R. China
Yuanya Lian, P.R. China
Mingyan Liu, P.R. China
Jun Lu, P.R. China
Gaurav Malhotra, India
Na Meng, P.R. China
Mengyu Min, P.R. China
Ming Chu Ng, Hong Kong
Congcong Niu, P.R. China
Yi Dong Peng, P.R. China
Shuk Chong Poon, Hong Kong
David Pregun, United Kingdom
Yan Qiu, P.R. China
Sophie Rodari, France
Taffy Schneider, United Kingdom
Deping Shi, P.R. China
Derui Shi, P.R. China
Hao Sun, P.R. China
Zhulin Sun, P.R. China
Maki Takashima, Japan
Stacie Tayler, United Kingdom
Yidan Wang, P.R. China
Ziting Wang, P.R. China
Xiaojing Wang, P.R. China
Qiuyue Wang, P.R. China
Fanbo Wei, P.R. China
Hiu Mei Wong, Hong Kong

Shaokun Wu, P.R. China
Chenjie Xiao, P.R. China
Xiaotong Xie, P.R. China
Bingqing Xie, P.R. China
Biqian Xing, P.R. China
Lin Yang, P.R. China
Yao Yao, P.R. China
Yuzuru Yoshida, Japan
Tiantian Yu, P.R. China
Xiangyi Zeng, P.R. China
Zhaohui Zhang, P.R. China
Sufei Zhang, P.R. China
Tingya Zhang, P.R. China
Wenchu Zhang, P.R. China
Yu Zhang, P.R. China
Yufei Zhang, P.R. China
Chenjia Zhang, P.R. China
Lian Zhang, P.R. China
Hanbin Zhang, P.R. China
Yue Zhang, P.R. China
Xiaojing Zhao, P.R. China
Fen Zheng, P.R. China
Li Zhou, P.R. China
Yuying Zhou, P.R. China
Rui Zhou, P.R. China

GEMMOLOGY DIPLOMA PASSES WITH DISTINCTION

Noémie Carlier-Mensan, France
Hung-Ju Chen, Taiwan (R.O.C.)
Xiaohua Chen, P.R. China
Jiayi Gao, P.R. China
Xinyu Gong, P.R. China
Wing Yan Leung, Hong Kong
Zoe Lewis, United Kingdom
Enqi Li, P.R. China
Yunting Li, P.R. China
Shan Li, P.R. China
Xiaomin Liu, P.R. China
Xinwei Liu, P.R. China
Jing Luo, P.R. China
Sarah Osprey, United Kingdom
Zheng Qin, P.R. China
Nathalie Reitzer-Minet, France
Jiaqi Shen, P.R. China
Ziqing Shen, P.R. China
Haoxiang Sun, P.R. China
Jiaxin Wan, P.R. China
Natsumi Yamamoto, Japan
Hongyan Yuan, P.R. China
Ziyun Zhang, P.R. China
Peng Zhang, P.R. China
Cuiling Zhen, P.R. China

DIAMOND DIPLOMA PASSES

Karoline Aas-Engelstad, Norway
Philliam Aliga, United Kingdom
Haseena Aswat, United Kingdom
Adeline Auvinet, France
Elizabeth Bailey, United Kingdom
Laura Baldock, United Kingdom
Saul Castro Gomez, Sweden
Nicole Wing Sum Chan, Hong Kong
Wing Lan Chan, Hong Kong
Chin Fung Nelson Cheng, Hong Kong
Man Yuk Cheung, Hong Kong
Sum Yee Cho, Hong Kong
Chung Tak Redi Choi, Hong Kong
Cheung Choi, Hong Kong
Nim Yan Chu, Hong Kong
Hoi Kin Chu, P.R. China
Yin Fong Chu, Hong Kong
Nga Nga Chuang, P.R. China

Ella Clarke, United Kingdom
João Da Silva Baptista, Portugal
Andrew Dobrzanski, Scotland, United Kingdom
Liz Fortune, Scotland, United Kingdom
Izumi Fuchino, Japan
Nathan Gray, United Kingdom
Sheng-Wen Huang, Taiwan (R.O.C.)
Joseph Hukins, United Kingdom
Saarah Hyder, United Kingdom
Tom Jarvis, United Kingdom
Qi Jin, P.R. China
Krystina Johnson, United Kingdom
Wing Shan Kam, Hong Kong
Aly Khalil, Egypt
Nicholas King, United Kingdom
Balraj Kler, United Kingdom
Laura Knowles-Cutler, United Kingdom
Valeriia Kuznetsova, Russia
Pak Sing Jacky Kwok, Hong Kong
Chin-Ting Kwong, Hong Kong
Fung Chi Charlie Lai, Hong Kong
Po Ha Lam, Hong Kong
Chi Wa Lau, Hong Kong
Yuk Fung Lau, Hong Kong
Chin Pang Lee, Hong Kong
Yi-Chen Lee, Taiwan (R.O.C.)
Ming Ki Lee, Hong Kong
Aliana Leong, P.R. China
Kin Shing Leung, P.R. China
Da Li, P.R. China
Qi Li, P.R. China
Peishan Li, Hong Kong
Yazhu Liu, P.R. China
Li Juan Luo, Hong Kong
Kayleigh McDermott, United Kingdom
Ian McLeod, United Kingdom
Hoi Ting Mok, Hong Kong
Joanne Moore, United Kingdom
Ayako Nakase, Japan
Gary Nelson, United Kingdom
Nathan Oke, United Kingdom
Emi Okubo, Japan
Lara Oyedele, United Kingdom
Jennifer Pardoe, United Kingdom
Stephane Phan, Hong Kong
Denitsa Popova, Scotland, United Kingdom
Brianna Quinn, United Kingdom
Elva Robins, Republic of Ireland
Miyuki Sato, Japan
Vanessa Elisabeth Maria Schuch-Des Forges, UK
Yan Pok Sher, Hong Kong
Chung Yin Sin, Hong Kong
Lisa Spence, United Kingdom
Ka Yan Tang, Hong Kong
Laura Thatcher, United Kingdom
Sarah Thorneloe, United Kingdom
Sarah-Jane Tidy, United Kingdom
Wai Hong Wong, Macau
Nga Wai Wong, Hong Kong
Freya Worrall, United Kingdom
Lucy Yao, P.R. China
Hiu Ying Rosa Yeung, Hong Kong
Man Hoi Yip, Hong Kong
Po Yan Yiu, Hong Kong
Wing Ho Yuen, Hong Kong
Mei Yuk Yung, P.R. China

DIAMOND DIPLOMA PASSES WITH MERIT

Siu Foon Elisa Chung, P.R. China
Leigh Davis, United Kingdom
Brian Denney, United States of America
Leona Eyre, United Kingdom
Lily Faber, United Kingdom
Ziyou Fan, United Kingdom
Andrea Giner-Serra, United Kingdom
Matthew Handley, United Kingdom
Prudence Hopkins, United Kingdom
Monika Jockute, United Kingdom

Mika Konishi, Japan
Yannick Le Guennec, Canada
Sarah Little, United Kingdom
Anu Malhi, United Kingdom
Abigail Marsh, United Kingdom
Ross Pietkiewicz, United Kingdom
Charlotte Pittel, United Kingdom
Hannah Ratcliffe, United Kingdom
Craig Smith, United Kingdom
Felicitas Sohm Reubi, Japan
Sullivan Taylor, United Kingdom
Hei Ching Elly To, Hong Kong
Nicole Unsworth, United Kingdom
Kai-Lee Wang, Taiwan (R.O.C.)
Jia Hui Yang, P.R. China
Meng-Pei Yang, Taiwan (R.O.C.)
Yi-Chen Yeh, Taiwan (R.O.C.)
Isabelle Chen Zhou, United Kingdom

DIAMOND DIPLOMA PASSES WITH DISTINCTION

Pixie Allen, United Kingdom
Toby Cairn, United Kingdom
Ruth Davis, Scotland, United Kingdom
Catherine Fox, United Kingdom
Penelope Gilliver, United Kingdom
Yu Hanaki, Japan
Paul Haywood, United Kingdom
Gill Hughes, United Kingdom
Emily Jones, United Kingdom
Wei Hao Li, Taiwan (R.O.C.)
Eleanor Marshall, United Kingdom
Lola Rafieva, United Kingdom
Anna Robertson, United Kingdom
Mina Sasaki, Japan
George Shihadeh, United States of America
Asako Takagi, Japan
Isobel Turner, United Kingdom
Naomi Vane-Wright, United Kingdom
Beth West, United Kingdom
Wei Karen Xu, United Kingdom
Yuxin Zhang, P.R. China

PRIZE AND MEDAL WINNERS

Awards and prizes presented to the best candidates of the year, selected from our students worldwide.

GEMMOLOGY FOUNDATION CERTIFICATE

Anderson Medal

Awarded for the best set of papers for the year in the Foundation examination.

This medal was established in 1981 in honour of Basil W. Anderson FGA, former Director of the Gem Testing Laboratory, London.

2018 Winner: Charlotte Glyde, Online Student, UK

GEMMOLOGY DIPLOMA

Christie's Prize for Gemmology

Awarded to the candidate submitting the best papers of the year for the Gemmology Diploma examination.

This prize was established in 1954 as the Rayner Prize, renamed the Diploma Trade Prize in 1991, replaced and sponsored from 2001 by Christie's London.

2018 Winner: Zoe Lewis, Online Student, UK

Anderson Bank Prize

Awarded for the best set of Theory papers for the year in the Gemmology Diploma examination.

Established in 1981 and named after Basil W. Anderson FGA and Dr H. Bank FGA, former director of the German Gemmological Association in Idar-Oberstein, Germany.

2018 Winner: Dr Juliette Hibou, Daytime Student, Gem-A London

Tully Medal

Recognises an individual who submits the best set of answers in the Gemmology Diploma examination in any one year and who is also, in the opinion of the Examiners, of sufficiently high standard to merit the award.

This silver medal was established in 1930 in memory of B J Tully, the inventor of the table model refractometer for jewellers.

2018 Winner: Zoe Lewis, Online Student, UK

The Read Practical Prize

Awarded to the candidate who submitted the best practical papers of the year for the Gemmology Diploma examination.

First awarded in 2009 and named in memory of Peter Read FGA, author and former tutor for Gem-A. In 2018 the prize is sponsored by Richard Drucker FGA (Hons) of Gemworld International.

2018 Winner: Sarah Osprey, Evening Student, Gem-A London

Gem-A would like to congratulate all of our students who achieved such fantastic results!

DIAMOND DIPLOMA

The Deeks Diamond Prize

Awarded to the best theory candidate of the year in the Diamond Diploma examination.

First awarded in 2001, the prize is sponsored by Noel W. Deeks FGA DGA, a Vice-President of the Association.

2018 Winner: Da Li, a Student from BGGI Beijing

The Mok Diamond Practical Prize

Awarded to the best practical candidate in the Diamond Practical examination.

First awarded in 2009 and sponsored by Dr Dominic Mok FGA DGA, AGIL, Hong Kong.

2018 Winner: Anna Williamson, Daytime Student, Gem-A London

The Bruton Medal

Awarded to the overall best candidate of the year in the Diamond Diploma examination.

This silver medal was established in 1996 in honour of Eric Bruton FGA to recognise his work in the field of diamonds.

2018 Winner: Beth West, Daytime Student, Gem-A London

GIFTS TO THE ASSOCIATION

Gem-A is most grateful to the following for their generous donations that will support continued research and teaching:

G. F. Williams, London, for one turquoise simulant, 13 small faceted rubies and five oval amethysts.

Freya Worrall, London, for a yellow synthetic sapphire.

GEM-A ANNUAL GENERAL MEETING 2018

The 2018 AGM was held at The Goldsmiths' Centre, London, on Tuesday 2 October and was opened at 18:35 by Justine Carmody FGA, Chair of the Association's board. In accordance with the articles of the Association, trustees Justine Carmody, Christopher Smith FGA and Jack Ogden FGA FSA retired by rotation. Being eligible, all offered themselves for re-election. Nigel Israel FSA FGA DGA chaired this motion, and all three were reinstated. Nigel Israel and Kerry Gregory FGA DGA retired as trustees at the conclusion of the AGM.

In additional orders of business, suggestions of holding the AGM during the conference/graduation period were raised and discussed. Justine Carmody stated that all suggestions will be taken into consideration and reviewed by the board to increase members' attendance at the AGM and to make the meeting more accessible. The date of the next meeting will be advised and the AGM was formally brought to a close at 19:11.

The Goldsmiths' Centre, London.

An innovator in gemstone reporting

• Identification of colored gemstones • Country of origin determination • Full quality and color grading analysis

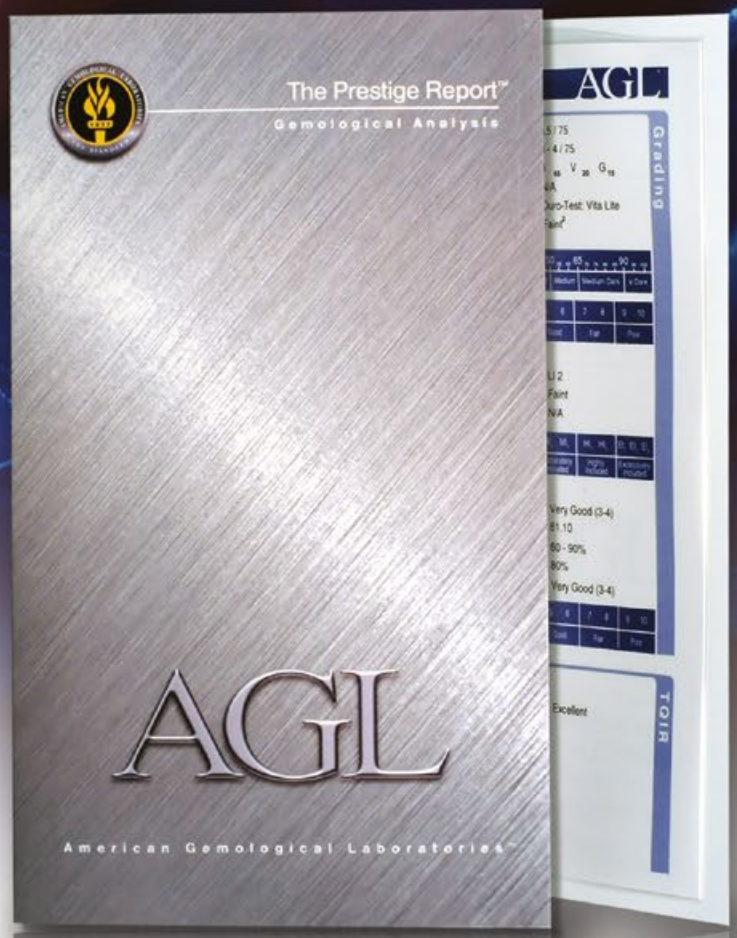

AMERICAN GEMOLOGICAL LABORATORIES AGL

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Learning Opportunities

CONFERENCES AND SEMINARS

21st FEEG Symposium
19 January 2019
Vicenza, Italy
http://feeg-education.com/symposium
Note: Takes place during the Vicenzaoro January International Gold and Jewellery Show, which occurs 18–23 January 2019

3rd Jewelry Industry Summit
2–3 February 2019
Tucson, Arizona, USA
www.jewelryindustrysummit.com

51st NAJA ACE© IT Annual Winter Educational Conference
3–4 February 2019
Tucson, Arizona, USA
www.najaappraisers.com/html/conferences.html

AGTA Gemfair Tucson
5–10 February 2019
Tucson, Arizona, USA
https://agta.org/seminars
Note: Includes a seminar programme

AGA Tucson Gemological Conference
6 February 2019
Tucson, Arizona, USA
https://accreditedgemologists.org/currevent.php

Tucson Gem and Mineral Show
14–17 February 2019
Tucson, Arizona, USA
www.tgms.org/show
Note: Includes a seminar programme

Inhorgenta Munich
22–25 February 2019
Munich, Germany
www.inhorgenta.com/events-news/inhorgenta-forum/index-2.html
Note: Includes a seminar programme

Gem-A Midlands Branch Conference
23 February 2019
Birmingham
Email louiseludlam@hotmail.com

Prospectors & Developers Association of Canada
3–6 March 2019
Toronto, Ontario, Canada
www.pdac.ca/convention
Session of interest: Diamond Exploration and Mining: Optimizing Outcomes through Increased Understanding of Technology

Hasselt Diamond Workshop 2019: SBDD XXIV
13–15 March 2019
Hasselt, Belgium
www.uhasselt.be/SBDD

Copenhagen Gemmological Symposium
23–24 March 2019
Copenhagen, Denmark
www.gemmologi.dk

American Gem Society Conclave
8–10 April 2019
Seattle, Washington, USA
www.americangemsociety.org/page/conclave2019

45th Rochester Mineralogical Symposium
11–14 April 2019
Rochester, New York, USA
www.rasny.org/minsymp

Scottish Gemmological Association Conference
3–6 May 2019
Cumbernauld, Scotland
www.scottishgemmology.org/conference

GAC-MAC-IAH (Geological Association of Canada–Mineralogical Association of Canada–International Association of Hydrogeologists)
12–15 May 2019
Québec City, Québec, Canada
www.gacmac-quebec2019.ca/en
Session of interest: Recent Advances in the Study of Gems and Gem Deposits

NDNC 2019: 13th New Diamond and Nano Carbons Conference
12–17 May 2019
Hualien, Taiwan
www.ndnc2019.org

5th Mediterranean Gemmological & Jewellery Conference
17–19 May 2019
Limassol, Cyprus
https://gemconference.com

The 33rd Annual Santa Fe Symposium
19–22 May 2019
Albuquerque, New Mexico, USA
www.santafesymposium.org

48th Annual Society of North American Goldsmiths (SNAG) Conference
22–25 May 2019
Chicago, Illinois, USA
www.snagmetalsmith.org/conferences/the-loop

European Gemmological Symposium 2019
24–26 May 2019
Idar-Oberstein, Germany
www.dgemg.com/en/organisation/16-newsletter/termine/385-european-gemmological-symposium-2019.html

JCK Las Vegas
31 May–3 June 2019
Las Vegas, Nevada, USA
http://lasvegas.jckonline.com
Note: Includes a seminar programme

International Exposition of Agate
6–9 June 2019
Austin, Texas, USA
https://ntrocks.com/international-exposition-of-agate
Note: Includes a seminar programme

PEG 2019: 9th International Symposium on Granitic Pegmatites
11–18 June 2019
Pala, California, USA
http://peg2019.com/index.html
Note: Includes field trips to gem-bearing pegmatites

Northwest Jewelry Conference
9–11 August 2019
Seattle, Washington, USA
http://northwestjewelryconference.com

Dallas Mineral Collecting Symposium
23–25 August 2019
Dallas, Texas, USA
www.dallassymposium.org

15th Biennial Meeting of the Society for Geology Applied to Mineral Deposits
27–30 August 2019
Glasgow, Scotland
www.sga2019glasgow.com
Session of interest: Supergenes, Gems and Non-Metallic Ores

36th International Gemmological Conference
27–30 August 2019
Nantes, France
www.igc-gemmology.org

42nd Joint Mineralogical Societies of Australasia Seminar
31 August–1 September 2019
Perth, Western Australia
www.mineral.org.au/seminar/seminar19.html

9th European Conference on Mineralogy and Spectroscopy (ECMS 2019)
11–14 September 2019
Prague, Czech Republic
http://ecms2019.eu
Workshop of interest: Gemstone deposits

14th International Congress for Applied Mineralogy (ICAM 2019)
23–27 September 2019
Belgorod, Russia
www.geo.komisc.ru/icam2019/en
Themes of interest: Precious Stones; Cultural Heritage

ICA Congress
12–15 October 2019
Bangkok, Thailand
www.gemstone.org/events/2019-congress

EXHIBITS

Europe

Horta & Wolfers: Reopening of the Wolfers Frères Jewellery Store, 1912
Until 30 December 2018
Art & History Museum, Brussels, Belgium
www.kmkg-mrah.be/expositions/horta-wolfers

The Portland Miniatures: Joel Arthur Rosenthal
Until 31 December 2018
The Harley Gallery, Welbeck, Worksop, Nottinghamshire
www.harleygallery.co.uk/exhibition/the-portland-miniatures-joel-arthur-rosenthal

From Zeus to Earth and from Chile to Neapolis
Until 31 December 2018
Ilias Lalounis Jewelry Museum, Athens, Greece
http://lalaounis-jewelrymuseum.gr/en/exTdetails.asp?exid=39

East Meets West – Jewelled Splendours of the Art Deco Era
Until 6 January 2019
Schmuckmuseum Pforzheim, Germany
www.schmuckmuseum.de/en/current.html

Hidden Gems: Scotland's Agates
Until 6 January 2019
National Museum of Scotland, Edinburgh
www.nms.ac.uk/national-museum-of-scotland/whats-on/hidden-gems-scotland-s-agates

Victoria Revealed
Until 6 January 2019
Kensington Palace, London
www.hrp.org.uk/kensington-palace/explore/victoria-revealed/#gs.Z=4WqrY

BVLGARI. Tribute to Femininity. Magnificent Roman Jewels
Until 13 January 2019
The Moscow Kremlin Museums, Russia
www.kreml.ru/en-Us/exhibitions/moscow-kremlin-exhibitions/bvlgari-tribute-to-femininity

Bijoux-Bijoux! Costume Jewellery from Chanel to Dior
Until 27 January 2019
Kunstgewerbemuseum, Berlin, Germany
www.smb.museum/en/exhibitions/detail/bijoux-bijoux-modeschmuck-von-chanel-bis-dior.html

Die Bilderwelt der Kelten (The Imagery of the Celts)
Until 27 January 2019
Kelten Römer Museum Manching, Germany
www.museum-manching.de/index.php?id=743,47

Russia: Royalty & the Romanovs
Until 28 April 2019
The Queen's Gallery, Buckingham Palace, London
http://tinyurl.com/ybecrdbj

Bejewelled: Badges, Brotherhood and Identity
Until 24 August 2019
The Library and Museum of Freemasonry, Freemasons' Hall, London
http://freemasonry.london.museum/event/bejewelled-badges-brotherhood-identity

The Crown of Kerch: Treasures from the Dawn of European History
Until 29 September 2019
Neues Museum, Berlin, Germany
www.smb.museum/en/exhibitions/detail/die-krone-von-kertsch.html

North America

Fabergé Rediscovered
Until 13 January 2019
Hillwood Estate Museum & Gardens, Washington DC, USA
http://hillwoodmuseum.org/faberge-rediscovered

Emperors & Jewels: Treasures of the Indian Courts from the al-Sabah Collection, Kuwait
Until 27 January 2019
Aga Khan Museum, Toronto, Ontario, Canada
www.agakhanmuseum.org/exhibitions/emperors-and-jewels

Outrageous Ornament: Extreme Jewelry in the 21st Century
Until 27 January 2019
Katonah Museum of Art, Katonah, New York, USA
www.katonahmuseum.org/exhibitions

Maker & Muse: Women and Early Twentieth Century Art Jewelry
29 January–26 May 2019
Flagler Museum, Palm Beach, Florida, USA
http://tinyurl.com/y896wt9u

Beadwork Adorns the World
Until 3 February 2019
Museum of International Folk Art, Santa Fe, New Mexico, USA
http://internationalfolkart.org/exhibition/3348/beadwork-adorns-the-world

Empresses of China's Forbidden City
Until 10 February 2019
Peabody Essex Museum, Salem, Massachusetts, USA
https://pem.org/exhibitions/empresses-of-chinas-forbidden-city

East Meets West: Jewels of the Maharajas from the Al Thani Collection
Until 24 February 2019
Legion of Honor Museum, San Francisco, California, USA
http://legionofhonor.famsf.org/exhibitions/east-meets-west

Jewelry: The Body Transformed
Until 24 February 2019
The Met Fifth Avenue, New York, New York, USA
www.metmuseum.org/exhibitions/listings/2018/jewelry

Treasures of a Desert Kingdom: The Royal Arts of Jodhpur, India
9 March–2 September 2019
Royal Ontario Museum, Toronto, Canada
www.rom.on.ca/en/exhibitions-galleries/exhibitions/rajasthan

Boston Made Arts and Crafts Jewelry and Metalwork
Until 29 March 2020
Museum of Fine Arts, Boston, Massachusetts, USA
www.mfa.org/exhibitions/boston-made

Uneasy Beauty: Discomfort in Contemporary Adornment
Until 21 April 2019
Fuller Craft Museum, Brockton, Massachusetts, USA
https://fullercraft.org/event/uneasy-beauty-discomfort-contemporary-adornment

Ornamental Traditions: Jewelry from Bukhara
Until 30 June 2019
Art Institute of Chicago, Illinois, USA
www.artic.edu/exhibition/ornamental-traditions-jewelry-bukhara

OTHER EDUCATIONAL OPPORTUNITIES

Gem-A Workshops and Short Courses
Gem-A, London
https://gem-a.com/education

- Understanding Diamond Grading Workshop
  10 and 31 January 2019
- Understanding Gemstones Workshop
  10 and 28 January 2019
- Understanding Diamond Simulants Workshop
  11 January 2019
- Understanding Gemstone Testing Workshop
  11 and 29 January 2019
- Investigating Jade and its Imitations Workshop
  8 March 2019
- Diamond Grading and Identification Short Course
  25 February–1 March 2019; 1–5 April 2019; 8–12 July 2019
- Diploma Preparation Short Course (new for 2019, UK only)
  28 January–1 February 2019

Lectures with the Society of Jewellery Historians
Burlington House, London
www.societyofjewelleryhistorians.ac.uk/current_lectures

- Martin Henig—Personal Cameos of Roman Date in the Content Family Collection
  22 January 2019
- Jack Ogden—A Whiter Shade of Pale: Platinum in 19th Century Jewellery
  26 February 2019
- Peter Semrád—The Story Behind 'Hungarian' Opals
  26 March 2019
- Beth Wees—TBA
  25 June 2019
- Rachel Church—Brooches, Badges and Pins at the Victoria and Albert Museum
  26 November 2019

Lecture: An Archaeologist's Wife and Her Jewellery: A Window into 19th Century 'Assyriamania'
17 January 2019
The British Museum, London
http://tinyurl.com/ya7yxbhd

New Media

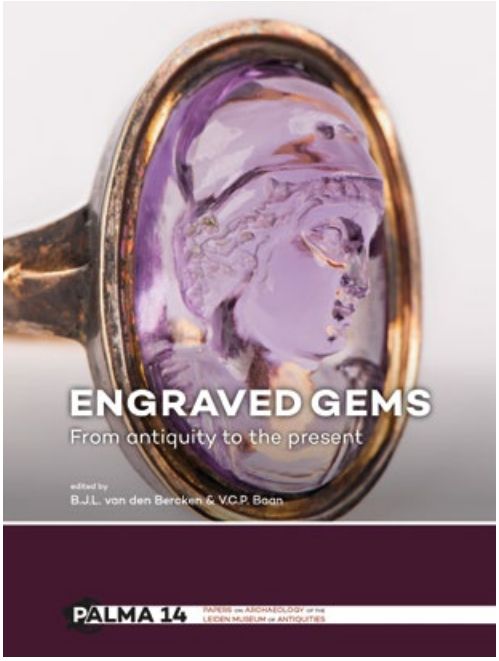

Engraved Gems: From Antiquity to the Present

Ed. by Ben J. L. van den Bercken and Vivian C. P. Baan, 2017. Papers on Archaeology of the Leiden Museum of Antiquities (PALMA) 14, Sidestone Press, Leiden, The Netherlands, www.sidestone.com/books/engraved-gems, 184 pages, illus., ISBN 978-9088905063 (hardcover) or 978-9088905056 (softcover). €120.00 hardcover, €39.95 softcover, €9.95 eBook or read online for free.

A collection of about 4,300 ancient engraved gems and about 20,000 gem impressions returned to Leiden in 2013 and found a new home at the National Museum of Antiquities (Rijksmuseum van Oudheden, or RMO). Originally, the collection was drawn together by a decree of William I, the first king of The Netherlands, from the Royal Collection and the National Numismatic Collection to form the Royal Collection of Coins, Medals and Engraved Gems of The Hague ('Royal Coin Cabinet' or 'Penningkabinet'). Since 1816 and during most of the time since then, when the collection was housed in Leiden, and later in Utrecht at the 'Money Museum' (GeldMuseum), public display was limited, as was the opportunity for scholarly study of the objects. When the GeldMuseum closed its doors in 2013, the gems and related objects in the Penningkabinet moved back to Leiden, but this time to a more salutary setting at the RMO. The existing collection of glyptic (engraved gems) and related materials at the RMO was then extended four-fold, and the cultural epochs now range from mid-third millennium Mesopotamia to modern Europe.

Committed to displaying more of the engraved gems, and by doing so making them available to researchers, the RMO mounted an exhibition in 2016 called 'Splendour & Precision' and also hosted a conference that was titled 'From Cylinder Seals to Lippert's Dactyliotheca'. These events coincided with the bicentennial of the founding of the Penningkabinet and commemorated the RMO's now significantly expanded antiquities collection. Eleven papers based on the conference programme, plus three additional articles, were published the following year in the RMO's PALMA series, titled *Engraved Gems: From Antiquity to the Present*, which is reviewed here. Prior to this, the only other major publication on the ancient gems in the Penningkabinet was the 1978 *catalogue raisonné* by Marianne Maaskant-Kleibrink. It was a landmark contribution to ancient gem studies, as she identified typologically distinct characteristics based on toolwork/engraving technique and grouped the gems accordingly within the conventional cultural chronology and subject/style arrangement. She had a keen eye for associating artists with their preferred materials and their choice of gems to complement the carved subject. Later, the methodology that Prof. Kleibrink developed and refined enabled her to recognise groups of gems as products of specific workshops, and even the handiwork of different artists.

While the collections now assembled under one roof in Leiden have a broad historical sweep—more than four and a half millennia—the RMO curators acknowledge that they cannot boast of prodigious volume, depth or number of masterworks on a par with the monumental collections of Europe such as those found in Berlin, Florence, St Petersburg or Vienna. However, as the work of Prof. Kleibrink demonstrates, there is much to commend what has been brought together in Leiden. Clearly, the organisers of the 2016 conference appreciated where the strengths of the collection lay, not only in its exceptional specimens, but also in the history of its assembled parts—how the collections were formed, dispersed and created anew, and how gems were interpreted, valued and put to use at different times since antiquity.

Reverend Prof. Martin Henig, specialist in ancient gems from archaeological contexts in Roman Britain, was the keynote speaker for the 2016 conference. In his essay, he examines old collections of Roman gemstones whose connection with their archaeological findspot

is lost, as is the case for most of the ancient gems in the collections of major European museums, including Leiden. Acknowledging the value of a 'stratigraphical context', he reminds the reader that because of their value, many gems were never buried but survive from antiquity passed from one owner to the next, each one in succession attaching the imprint of his or her own values and uses to the 'object biography', whether as an individual gem or a collection. For gems that survive as heirlooms, Prof. Henig thoughtfully considers their role as 'witnesses to historical events'. This essay sets the stage very well for the papers that follow, more or less in cultural chronological order.

Some authors of the articles in this book focus in detail on a single gem or genre. Attilio Mastrocinque elucidates his process for deducing alternative interpretations of inscriptions on two gemstones. Marianne Kleibrink examines the features of comparable gem types (comparanda) depicting Cassandra, the prophetess of mythology who warned of the fall of Troy at the hands of the Greeks. Prof. Kleibrink draws attention to how the compositions very much reflect the intentions of different gem carvers, each emphasising different aspects of Cassandra's tragic demise. Diederik Meijer introduces the RMO's collection of Mesopotamian cylinder seals, with the promise of a complete catalogue forthcoming. Ben van der Bercken contributes a paper on 14 previously unpublished ancient Egyptian and Archaic Greek scarabs. Rika Gyselen explains how the owners of intaglios are identified in a Sasanian gem's engraved features, and the tell-tale indications of reuse and recutting, which are distinctly different from earlier and contemporary cultures. In a continuation of a discussion on *grylloi* by Kenneth Lapatin in a 2011 British Museum seminar, Carina Weiss differentiates the physiognomic features of fantastical hybrid creatures and mask-head depictions prevalent in ancient glyptic. In addition to the features differentiating *grylloi* from non-*grylloi*, she suggests that the intended use of the engraved gem is an important criterion for differentiating *grylloi* from *baskania*, which are apotropaic amulets (produced to ward off evil).

Historical perspective on the production and use of cameo carving bridges the art form in antiquity to its enthusiastic revival in the Renaissance, which then persisted in the production of adaptive forms into the 19th century (Platz-Horster and Wagner). That brings the reader fully into the modern era. Marcia Pointon focuses on a single ancient gem whose engraved subject and quality of carving inspired a painting by no less an artist than Peter Paul Rubens in the 17th century. Jørge Hein examines a 17th century gilt porcelain lidded bowl inlaid with 79 cameos and 19 intaglios (most of which were produced during the Renaissance). The bowl belongs to a group of luxury vessels produced for northern European royal patrons in the 16th to 18th centuries. The ornate decoration, gilded flourishes and lapidary-encrusted surfaces may seem like a baroque artistic confection to a 21st century sensibility, but they serve to illuminate the object biography of an ancient art form co-opted and repurposed in an altogether novel way.

The history of ancient gems is the subject of an essay by Valentin Kockel. The gem cabinets or *dactyliotheca* popularised in the 18th and 19th centuries are yet another iteration in the history of the use and study of ancient gems. Dealers targeting antiquarian collectors hit upon an ingenious way to market antiquities to a wider audience, making impressions of gems in wax, clay or paste (sometimes called collectively 'sulphurs'), which is how they were appreciated anyway (not in the original carved gem itself). The pastes were curated as both customised and pre-packaged groupings arranged in cabinets with many narrow drawers. Often the case was made to resemble an oversized book. In this way, endless copies of an original engraved gem could be sold (while the dealer/collector could retain the original). Their aim was not only pecuniary, but depth of audience reach. The cabinets were popular as educational props for art historians and archaeologists teaching their discipline, or antiquarians demonstrating their connoisseurship.

Hanco Zwaan and Christine Swaving present a report on gemmological analyses performed on selected gems in the collection, primarily with the aim of confirming sight identifications. Of the gems they examined, 35% had been misidentified. Even today, analytical studies are often omitted from volumes whose main interest is historical or archaeological. If correct identification is its own virtue, once ascertained, other questions of more pressing interest to archaeologists might be answered. That the RMO has such capable experts with facilities nearby should encourage the curators to initiate further analytical investigations into its collection of ancient gems.

This inaugural publication on engraved gems under the auspices of the Rijksmuseum van Oudheden is an excellent step toward bringing the collection out from the shadows and into the light. This volume of papers written by specialists for other specialists should not dissuade the curious reader. It is accessible and provides a unique view into the histories and cultures of bygone eras.

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Suomen Korukivet/ Gemstones of Finland

Ed. by Kari A. Kinnunen, 2017. Geological Survey of Finland, Espoo, http://tinyurl.com/ycfzbqw9, 342 pages, illus., ISBN 978-9522172532 (hardcover) or 978-9522172549 (eBook). €40.00 hardcover or free eBook (http://tupa.gtk.fi/julkaisu/erikoisjulkaisu/ej_098.pdf; in Finnish and English).

This recent publication from the Geological Survey of Finland is a welcome contribution to national monographs on gem materials. Finland could be viewed as the no. 1 producer of gem materials in Europe during the past few decades, if one considers its spectrum of gems and the large crystals found at the granitic pegmatite exploited by the Karelia Beryl mine near Luumäki in Karelia, south-east Finland, which are of a quality and size not found anywhere else in Europe.

The book commences by introducing the eight contributing authors, all of whom are well-known geologists of the Geological Survey of Finland and the University of Helsinki. Many of the authors have a life-long personal interest in geology/mineralogy—pursuing this field not merely as a job—and have extensive field and laboratory experience.

This is followed by a 55-page chapter that provides a detailed introduction to the field of Finnish *korukivet* and *jalokivet*. Nordic countries use these two variations for the word *stone* in jewellery, meaning *gemstone* and *precious stone*, respectively. *Korukivet* could be, for instance, coloured opaque beryl, jasper or aventurine, but not a stone for faceting such as transparent green beryl or heliodor (which would be referred to as *jalokivet*). The interpretations of the meaning of *gemstone* and *precious stone* vary with cultures, traditions and time. Since the 1960s, as the authors point out, the outdated *semi-precious stone* is generally disused in Europe.

The chapter is subdivided into concise sections such as 'Finnish Speciality, Rock Types as Gemstones', with a map showing the main locations of about 100 deposits. It is refreshing to see that the Geological Survey is aware of, and clearly writes about, the importance of some old abandoned mines for mineral tourism, where many local and foreign collectors come and search for minerals during weekends and holidays. The authors also take us through a variety of other topics including: 'The Properties of Gemstones', 'The Gifts of Light', 'Inclusions in Gemstones' and 'Beauty is Born from Shape'. In 'Associations, the Founts of Gemstone Knowledge', well-selected photographs show mine tailings, mineral shows, local 'rock clubs' and how to get children interested by organising treasure hunts. 'Identification in Laboratories' provides a nice introduction to mineral identification, and a small section also introduces trade names such as Spectrolite. The choice of themes and images, and the way they are presented in short but informative sections, is excellent. This chapter is not intended for an advanced mineralogist or gemmologist, but rather for the beginner, but nevertheless should certainly be read by everyone for its beauty of selection and presentation. If you want to understand Nordic and especially Finnish culture this chapter provides a very good introduction, and an appreciation of what Finland has to offer. This is all the more relevant given the education reforms in Finland that provide more free time to explore and discover these wonders, optimising education both in and out of the classroom.

The following chapters cover various regions, starting with southern Finland. The authors note how this region was mined for garnet at Kitilä by Sweden's King Johan III in the 16th century. For 800 years, Sweden had four main regions, with the most south-eastern area being Finland. Since the beginning of the 1580s, garnets (believed to be rubies) were mined by the barrel-load on the king's order in this south-east corner of Karelia, and were sent to the court. (Subsequently, in 1809, Russia forced Sweden to give up Finland and part of Lapland, as well as Österbotten, and these areas became a semi-independent Grand Duchy of Russia.) The authors present Adolf Erik Nordenskiöld as the father of mineralogy in Finland during the 1800s, with the first gem deposits discovered in the south and along the coast, where there were more people and more mining/quarrying activities. Covering this period, the authors note how in 1930 Prof. Pentti Eskola found a large gem-quality topaz crystal at Väkkärä quarry at Eurajoki during the construction of anti-tank obstacles at the Salpa Line. This chapter also covers the

most well-known, and quantitatively significant, finds of Spectrolite and gem beryl in the anorthosite and rapakivi granitic pegmatites of the Viborg massif in Karelia. The history of both deposits is covered with concise descriptions of key elements regarding geology and mineralogy, and is accompanied by excellent images of Spectrolite twinning, beryl etching and finished jewellery. At this stage it will be clear to the reader that Finland has more to offer than most people are aware of, and this is just the start. A full-page photograph depicts a well-formed crystal of bicoloured topaz from Kotka set in jewellery, followed by a faceted one. Next follows a description of the Viitaniemi lithium pegmatite, which is also rich in topaz as well as rare phosphates. Gems from here include rose quartz and blue topaz that was found as fist-sized crystals. Graphic granite is presented as a popular ornamental gem that is heavily used in Finland.

The next chapter, on eastern and central Finland, presents various gems including diamond crystals in and out of matrix, Nuummite, cordierite and more.

In the chapter on western Finland we are taken to the famous Kaatiala pegmatite, known from at least 1855 when its first description was published. Here, green and red tourmaline, rose quartz, amethyst, goshenite, heliodor and even columbite were faceted. This is followed by the Haapaluoma pegmatite, which is well described and known for its rubellite, kunzite, deep purple lepidolite and morganite.

The chapter on northern Finland introduces the reader to a giant amethyst deposit found in 1985 at Lampivaara, which is now a tourist attraction with 15,000–20,000 visitors per year. A rich *in situ* vein is pictured, as are faceted stones as well as deeply coloured amethyst crystal groups weighing up to 650 kg. At the end of the chapter, gem-quality rubies and sapphires found in the gold washings are also presented.

Each chapter is followed by a very handy reference list, which is easier to navigate than an extensive single reference list at the end of the book. The large format, good colour reproductions and, most importantly, the detailed information provided in an easily accessible way that spans geology, history, mineralogy, gemmology and the connection to people, is a rare and excellent way to present the subject to everyone. The authors are heartily congratulated on a most welcome book for which years of work have clearly gone into its preparation. I highly recommend it to any serious library, researcher and collector.

Peter Lyckberg
Scientific Collaborator to the Department of Mineralogy, Luxembourg Museum of Natural History

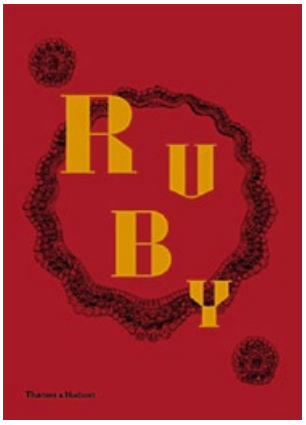

Ruby: The King of Gems

By Joanna Hardy, 2017. Thames & Hudson, London, http://tinyurl.com/ya823apy, 328 pages, illus., ISBN 978-0500519417. £75.00 hardcover.

Ruby: The King of Gems is a beautifully illustrated and expertly researched tribute to the alluring and regal sovereign of all gemstones. The artistic layout, from the modern font to full-page photos of inclusions, complements the treasure trove of historically significant jewellery and gemstone images that are generously featured throughout the book.

Following the introduction, the first chapter 'Ruby Spinel' is a surprising but very well-deserved tribute to spinel, which, as many gem traders know, has contributed greatly to the fame and reverence ruby has received. Most of the famous large red gems in royal and ecclesiastical regalia that were thought to be ruby are actually spinel. This chapter features images and the fascinating histories associated with many of these regal red spinels. These unusually large spinels were likely discovered in Badakhshan along the Silk Road that linked China with Europe. Their size made them ideal for Mughal rulers who inscribed their names on the gems to claim ownership and posterity over the prior owner. These gems were considered important symbols of power and wealth, and they were also used for adornment. Trade and conquest resulted in many of the largest of these spinels adorning prominent positions in the crown jewels of England, Russia, Iran and India. Such spinels have become so famous as 'rubies' that they still retain names such as the 'Black Prince's ruby' and the 'Timur ruby'. An approximately 400 ct spinel is the centrepiece of the Great Imperial Crown first worn by Catherine the Great, who was Russia's longest reigning female ruler, serving as empress from 1762 to 1796.

The second chapter, 'Ruby the King of Gems', provides an early history and clearly accounts for why

ruby is still regarded as one of the most valuable gems. Rubies were of course also traded along the Silk Road and were highly coveted even though gem-quality material was typically much smaller than their spinel counterparts. Burma was historically the main source for fine rubies, and it is still the most sought-after locality for connoisseurs despite many new sources discovered in the late 20th and early 21st centuries. Hardy provides a fascinating summary of early Burmese ruby mining and history, including a detailed story of the infamous Nga Mauk ruby. The images and descriptions of early Burmese, Chinese, English, Persian, Russian and Indian jewels are exceptional in quality and detail.

The third chapter, titled 'Pioneers', is one of my favourite sections. Hardy starts out by attempting to 'lift the veil of mystery' not only about famous gem-producing localities but also about the explorers and traders who paved the way for future generations. She accurately writes, 'Gems have always attracted the adventurous and the passionate, individuals in pursuit of dreams, egos, wealth and power who expect to find their fortunes through dealing with gemstones, only to become victims of their quest, discovering that instant monetary gratification may not be so easy to obtain'. Most dealers would agree that buying and selling gems is one of the most incredibly exciting, rewarding and often humbling professions one can pursue. Hardy elaborates that 'knowledge and patience are key to understanding the complexities and challenges that the gemstone market entails. It takes time, appreciation and a passion for the subject to make a success of the gem business, along with a sprinkling of good fortune'.

Hardy goes on to feature Old European sovereign and coronation jewellery, describing how their historical influence weaves in and out of the social and political fabric of the period. One of the highlights is a fascinating story of the discovery of long-lost Hennell jewellery renderings. These beautifully illustrated drawings showcase the attention to detail and design aesthetic that represented this 'age of elegance and splendor'.

The famous Mallerio dits Meller firm was one of the most prolific creators of neo-classical royal regalia for the likes of Marie Antoinette, Josephine Bonaparte, Queen Victoria and even Princess Grace of Monaco. A full-page colour photograph of Princess Grace wearing a fabulous neo-classical Cartier ruby and diamond diadem along with a diamond necklace showcases the enduring influence and cultural importance associated with the high-end jewellery of that period.

The 'Gilded Age' is featured next with incredible examples of the talents of the house of Boucheron. One of the most interesting parts of this chapter is the inclusion of hand-drawn illustrations showing rubies once owned by Boucheron accompanied by detailed descriptions of their colour, weight, shape and internal features. Boucheron and Chaumet were also famous for the Art Nouveau garland style of jewellery creation. (My favourite piece in the entire book is a ruby and diamond hummingbird aigrette, because it so beautifully captures the grace and energy of that magical creature and because it has always been my mother's favourite bird.) This chapter concludes with another fabulous photo of the Mackay ruby and diamond necklace by Boucheron.

In the late 19th to early 20th centuries, India had a powerful influence on Western jewellery design. Parisian houses such as Cartier, Chaumet, Van Cleef & Arpels, Lacloche Freres and others created Indian-inspired jewels for the wealthy Maharajahs and Maharanis, ushering in a period of opulent ruby, pearl and diamond bib necklaces, turban ornaments, and playful 'Tutti Frutti' bracelets and earrings. In the early 20th century and into the 1920s, floral and architectural influences from Paris and America were derived from topics ranging from nature and skyscrapers to opulent manicured gardens and homes of the aristocracy. With these themes, combined with the discovery of Egyptian King Tutankhamen's tomb, jewellery evolved into the more geometric linear 'Art Deco' style that was so representative of the optimism coming from the New World.

Unfortunately, the Great Depression followed by World War II put a sudden end to the frivolity of the Roaring Twenties. The military's need for precious metals brought on a more toned-down conservative style, which then evolved into the 'Retro' period of the 1940s and '50s. This was followed by a more decadent style led by Cartier, Chaumet, Van Cleef & Arpels, Boivin & Belperron, David Webb, Vedura and even Dali. The 1970s–80s featured bold cabochon and large faceted ruby pieces by the Parisian houses mentioned above, as well as Bulgari, Grima, Boghossian, Hemmerle, Millerio, Graff, Henry Dunay and others. The early 21st century has enjoyed a renaissance of contemporary style that has challenged even the lasting influence of the Art Deco period. Artists such as JAR, Michelle Ong, Wallace Chan, Lauren Adriana, Bina Goenka, Fei Lui and Leo De Vroomen are all featured with fabulous photos of their dream-like creations. Hardy concludes this incredible tribute to ruby with a chapter on 'Technique', focused on jewellery design and fabrication followed by examples of rubies from the relatively new mines in Mozambique compared with the traditional sources of Thailand, Cambodia and Myanmar (Burma).

I can honestly say that in the 40-plus years I've been reading about gems, I have never experienced greater joy than from this fabulous tribute to ruby. The fact that Hardy gives such credit to spinel in the first chapter certainly influenced my initial reaction, but as I continued to read on, I became almost hypnotised by the immense amount of fascinating information, figures and photos she provides with such artistic style and grace. I even carried the book on several of my travels over the past year, getting odd looks from fellow passengers as I pulled out this large ruby-red tome. Most quickly became engrossed while stealing glances of the incredible jewellery photos and illustrations. I highly recommend this magnificent work of art to anyone who wants to learn almost everything there is to know about ruby and the jewellery containing it, or simply wants to be mesmerised by Hardy's storytelling expertise to escape from the burdens of the 'real world' for a while. Enjoy!

Edward Boehm FGA
RareSource, Chattanooga, Tennessee, USA

Other Book Titles

COLOURED STONES

Early Chinese Jades in the Harvard Art Museums
By Jenny F. So, 2018. Yale University Press, London, 272 pages, ISBN 978-0300237023. £40.00 hardcover.

Turmaliny [Tourmaline]
By Tomasz Sobczak, 2018. Polish Gemmological Society, Warsaw, 102 pages, ISBN 978-8393439997. PLN84.00 hardcover (in Polish).

GEM LOCALITIES

Burma Gems. Sri Lanka Gems.
By Vladyslav Y. Yavorskyy, 2018. Yavorskyy Co. Ltd, New York, New York, USA, 236 pages, ISBN 978-0692919682 (Burma) and ISBN 978-0692121412 (Sri Lanka). US$188.00 hardcover with slipcase.

The Gemstone Detective: Buying Gemstones and Jewellery in Sri Lanka
By Kim Rix, 2018. Filament Publishing, Croydon, 100 pages, ISBN 978-1912635238. £12.99 softcover.

Mogok: La Vallée des Pierres Précieuses/ Mogok: The Valley of Precious Stones
By Kennedy Ho, Emmanuel Fritsch, Jean-Baptiste Rabouan, Franck Notari, Candice Caplan and Thomas Hainschwang, 2018. Glénat, Grenoble, France, 192 pages, ISBN 978-2344029763. €39.50 hardcover (French edition) or US$100.00 (English edition).

Rocks, Landscapes & Resources of the Great Artesian Basin: A Handbook for Travellers
[includes Australian opal]
By Warwick Willmott, Alex Cook and Barry Neville, 2017. Geological Society of Australia, Queensland Division, 112 pages, ISBN 978-0987427861. A$15.00 softcover.

GENERAL REFERENCE

Modern Rockhounding and Prospecting Handbook, 2nd edn.
By Garret Romaine, 2018. FalconGuides, Guilford, Connecticut, USA, 272 pages, ISBN 978-1493032358. US$24.95 softcover.

The Pebbles on the Beach: A Spotter's Guide
By Clarence Ellis, 2018. Faber & Faber, London, 218 pages, ISBN 978-0571347933. £9.99 softcover.

INSTRUMENTATION

Handbook of Materials Characterization
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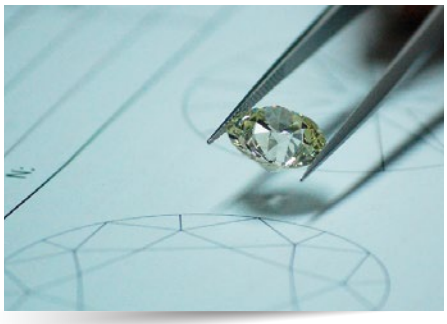

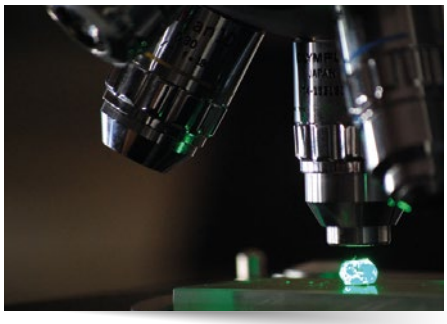

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Cover photo: *Burmese spinel is available as attractive crystals and colourful gemstones, and a detailed study of the inclusions in this material appears on pp. 418–435 of this issue. The Burmese spinels shown here include the 6.30 ct centre stone in a gold and carbon-fiber ring that was designed and manufactured by Marc Höllmüller for Carley Jewels (Chattanooga, Tennessee, USA), as well as three larger and nine smaller crystals (courtesy of Federico Barlocher, Como, Italy, and Kathryn Bonanno, New York, New York, USA, respectively) and numerous cut gemstones that weigh up to 10.48 ct (courtesy of RareSource, Chattanooga Tennessee, USA). Photo by Jeff Scovil.*

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What's New

INSTRUMENTATION

GemPen

Sweden-based Gemometrics AB released its GemPen in 2018. The rechargeable handheld tool utilises different combinations of UV wavelengths and filters to induce various fluorescence reactions that provide indications for screening natural from synthetic diamond (both HPHT and CVD grown), as well as some treatments such as HPHT + irradiation, glass fillings, and oiling or fracture filling. The instrument's case can be used to provide a darkened space for testing. Owners of the instrument can join the GemPen Academy to learn more about how to use the device. Visit https://gemometrics.com/product/gempen.

J-Certain Synthetic Diamond Detector

The J-Certain from Massive Tech Labs (Gujarat, India) is a diamond screening instrument with a large (20 × 11 cm) scanning platform that can handle samples 0.002–10 ct of all shapes, whether loose or mounted in jewellery. It offers rapid testing capable of scanning up to 300,000 melee-sized (1 mm) samples per hour to distinguish natural from synthetic diamonds (CVD and HPHT). Issued in July 2018, the J-Certain evolved from the company's 2017-release G-Certain, which is essentially a smaller version suitable primarily for loose diamonds. Visit www.massivetechlab.com/j-certain-a-synthetic-diamond-detector-for-studded-jewellery.

Sherlock Holmes 2.0 Synthetic Diamond Detector

In January 2019, Yehuda Diamond Co. released version 2.0 of its Sherlock Holmes diamond tester. The instrument is designed for use with colourless to near-colourless (D–K) diamonds ranging from melee to any size that will fit in the instrument's drawer, whether loose or mounted, single stone or assorted parcel. It can distinguish CVD and HPHT synthetic diamonds from natural ones, even if the latter have been colour-enhanced through an HPHT process. The user manual, available for download, provides details of how the mobile-phone-based instrument operates, along with exceptions to its capabilities. The portable instrument includes a mobile phone interface, international charger, two trays, ring holders and a lab-grown diamond. To learn more, visit www.yehuda.com/shop/hphtmachine.

NEWS AND PUBLICATIONS

ABN-AMRO Diamond Reports

Economists at the Amsterdam-based bank recently delved into diamond industry concerns with two reports: 'Diamond Sector Watch – De Beers Launch Lightbox: Disruption' (June 2018) and 'Diamond Sector Outlook – Entering a Growth and Disruption Phase' (January 2019). The first report focuses on the launch of De Beers' synthetic diamond jewellery line. The second describes an industry move from a 'relatively stable environment to a highly uncertain environment', which seems to have been associated with the Lightbox launch, threatening to reduce demand for natural diamonds and forcing diamond miners to 'rethink their strategies' as diamond prices decline. To read or download the two reports, visit https://insights.abnamro.nl/en/2018/06/diamond-sector-watch-de-beers-launch-lightbox-disruption and https://insights.abnamro.nl/en/2019/01/diamond-sector-outlook-entering-a-growth-and-disruption-phase.

AGTA GemFair Tucson Seminars

From 5 through 10 February 2019, the American Gem Trade Association hosted an array of educational lectures and presentations during the gem shows in Tucson, Arizona, USA. Presenters from around the world discussed gem treatments, cultured pearls, marketing strategies and more. Audio recordings and slides of 25 presentations are available on flash drive for USD50.00. To order, visit https://agta.org/resources.

Gem Abstracts from the 16th Swiss Geoscience Meeting

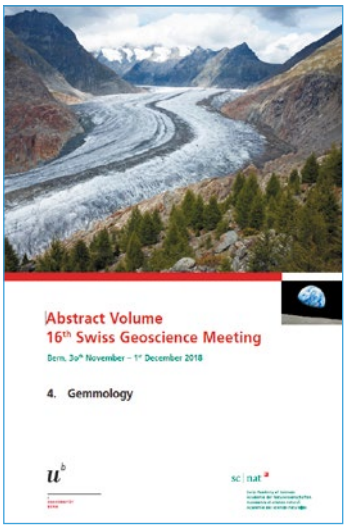

The 16th Swiss Geoscience Meeting was held 30 November to 1 December 2018 in Bern, Switzerland. A half-day session on gemmology included four talks that covered ruby deposits in the Morogoro region of Tanzania, colour instability of padparadscha-like sapphires, inclusions in spinels from Mogok (Myanmar) and age determination of zircon inclusions in Kashmir sapphires. Download the proceedings volume at https://geoscience-meeting.ch/sgm2018/wp-content/uploads/SGM_2018_Symposium_04.pdf.

Gem Abstracts from the 2018 GSA Annual Meeting

The 130th annual meeting of the Geological Society of America took place 4–7 November 2018 in Indianapolis, Indiana, USA. Fourteen abstracts from the session titled 'Gemological Research in the Twenty-First Century—Characterization, Exploration, and Geological Significance of Diamonds and Other Gem Minerals' can be viewed at https://gsa.confex.com/gsa/2018AM/webprogram/Session45040.html. Topics include natural diamond colouration, photoluminescence of pink diamond, naturally irradiated black diamonds, chemical imaging of diamonds, inclusions in diamond and sapphire, ruby and sapphire origin determination, rutilated quartz formation, origin of tourmaline-sapphire-phlogopite rocks in Afghanistan and oxygen-isotope ratios in freshwater cultured pearls from Tennessee, USA.

Gem Identification Pamphlet and Poster

Branko Gems/Gemmological Research Industries Inc. (Vancouver, British Columbia, Canada) recently released two products focused on practical gemmology. A pamphlet titled 'ID of Transparent Red, Pink and Purple Gems with Portable Instruments' describes how to separate natural from synthetic gem materials within this colour range using four instruments: 10× loupe, polariscope, spectroscope and the PL-Inspector/Jewellery Inspector. A poster (82.5 × 40.0 cm) titled 'Steps in Screening and ID of Lab-Grown Diamonds' provides a convenient reference for the process of identifying synthetic diamonds using both basic and advanced instrumentation. To order these and other publications, visit www.brankogems.com/shop/product-category/books.

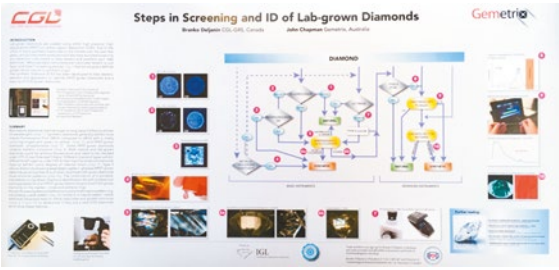

GIT Reports on Colour-Change Grossular and Musgravite

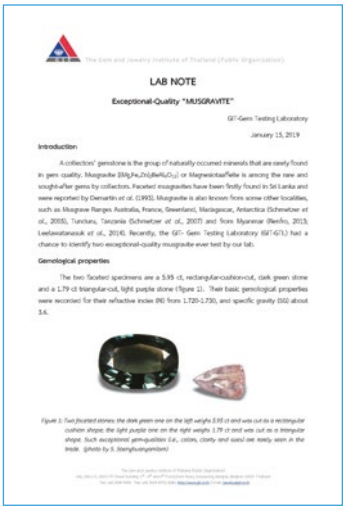

In December 2018, the Gem and Jewelry Institute of Thailand (GIT) reported on two unusual colour-change garnets that proved to be grossular-rich rather than the pyrope-spessartine, Cr-bearing pyrope or Cr-bearing grossular-andradite varieties typically associated with this colour phenomenon in garnet. They exhibited a distinct change from green in daylight to brownish red in incandescent illumination. Raman spectroscopy and EDXRF chemical analysis confirmed their grossular-rich composition, and visible absorption spectroscopy showed that Cr^{3+} ± Fe^{3+} are responsible for the colour change. Download the report at www.git.or.th/eng/testing_center_en/lab_notes_en/glab_en/2018/11/Article-2711201801.pdf.

In January 2019, GIT described two faceted specimens of exceptional-quality musgravite recently examined in their laboratory: a 5.95 ct dark green stone and a 1.79 ct light purple gem. The report includes details of microscopic features, semi-quantitative chemical analyses, and Raman, infrared and UV-Vis spectra. Visit www.git.or.th/eng/testing_center_en/lab_notes_en/glab_en/2019/01/Article-1501201901.pdf

Global Diamond Industry 2018

The eighth annual report on the global diamond industry from the Antwerp World Diamond Centre and Bain & Co. was released in December 2018, titled 'The Global Diamond Industry 2018: A Resilient Industry Shines Through'. The report covers 2017 and the first half of 2018, and includes a forecast of the diamond industry through 2030. The industry experienced approximately 2% growth overall despite 'volatility' in 2017, and diamond production increased almost 20% by volume. In the same period, diamond jewellery sales increased slightly. Factors predicted to affect the industry's future are the influence of digital technologies, lab-grown diamonds and a gradual long-term growth of the diamond market. Visit www.bain.com/insights/global-diamond-industry-report-2018 to read or download the full report.

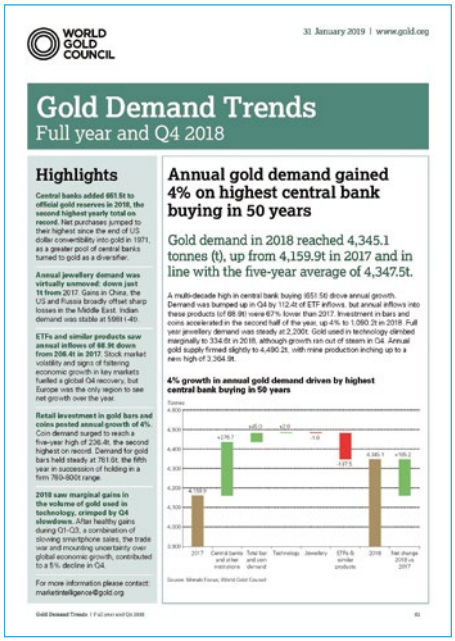
WORLD GOLD COUNCIL

31 January 2019 | www.gold.org

Gold Demand Trends
Full year and Q4 2018

Highlights

Annual gold demand gained 4% on highest central bank buying in 50 years

Gold demand in 2018 reached 4,345.1 tonnes (t), up from 4,159.9t in 2017 and in line with the five-year average of 4,347.5t.

4% growth in annual gold demand driven by highest central bank buying in 50 years

Gold Demand Trends 2018

The World Gold Council released a combined report in January 2019 that covers the full year and the fourth quarter of 2018. Overall demand for gold during 2018 was higher than in 2017 but consistent with a five-year average of 4,347.5 tonnes. Gold jewellery demand remained steady. Gold supply for the year reached 4,490.2 tonnes, aided by a new high in mine production of 3,364.9 tonnes. To obtain the full report, infographics, data and statistics, go to http://tinyurl.com/y7oguc7y.

Jewelry Development Impact Index Studies

The online Gemstones and Sustainable Development Knowledge Hub offers reports and presentations from various case studies undertaken as part of the Jewelry Development Impact Index. Research results from 2018 cover gems and precious metals in South Africa (platinum), Madagascar (sapphires), Afghanistan (lapis lazuli) and Myanmar (rubies). The studies examine the impact of mining on governance, economy, environment, and health and human rights, and offer suggestions for improvement. Download presentations or full reports at www.sustainablegemstones.org/jewelry-development-index-jdi.

The Journal's Cumulative Index Updated, Plus Subject Bibliographies

The Journal of Gemmology's cumulative index has been updated to cover all issues from 1947 through 2018. Because the index is provided in electronic (PDF) format, it can be searched for specific authors as well as topics. In addition, bibliographies of articles and notes published in *The Journal* are now available that cover several different gem materials, including biogenic gems, chrysoberyl and alexandrite, diamond, emerald and other beryls, ruby and sapphire, garnet, opal, pearl, quartz and tourmaline. Bibliographies on additional gem materials will be added in the future. The index and bibliographies are freely available to download at https://gem-a.com/news-publications/journal-of-gemmology#the-journal-index-and-bibliography-lists.

LMHC Information Sheet Updates

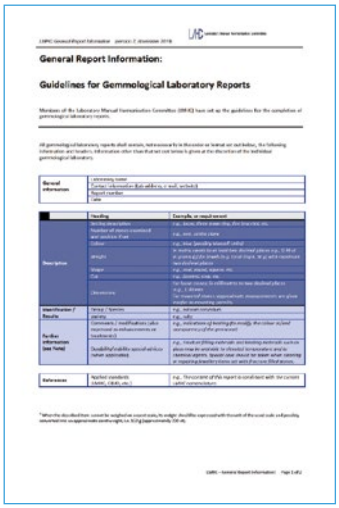
General Report Information:

Guidelines for Gemmological Laboratory Reports

In November 2018, the Laboratory Manual Harmonisation Committee updated four of its Information Sheets: 'Gemmological Laboratory Reports', 'Padparadscha Sapphire', 'Corundum – No Indications of Heating and Indications of Heating', and 'Alexandrite and Other Colour-Change Gemstones'. In addition, new Information Sheets were issued on 'Organic Fillers (Oil, Resin, Wax) in Gemstones' and 'Hydrophane Opal'. Download the sheets at www.lmhc-gemmology.org/gemstones.

MVI Marketing Research on Millennials and Synthetic Diamonds

MVI Marketing, a USA-based company focused on market research on luxury goods (primarily jewellery), released a report titled 'Millennial Consumer Research: Lab Grown Diamonds' in May 2018. It summarises the results of an online research study involving 1,010 respondents in the USA, aged 21–40 years, from a range of incomes. More than 75% of men and nearly 65% of women reported they would consider a lab-grown diamond for the centre stone in an engagement ring, on average a 13% increase from the previous year. Reasons included obtaining a larger stone for their money, the ability to save money on an engagement ring, and both environmental and social concerns about diamond mining. Key findings break down the information to help trade members explore ways of marketing lab-grown diamonds to millennials. To receive a presentation of this research (PDF format) via email, submit the form at www.mvimarketing.com/download-report.php?report=34.

Assure Program for Testing Diamond Verification Instruments

The Diamond Producers Association hosts the Assure Program, a collaborative venture designed to evaluate the performance of 'diamond verification instruments' (DVI). The project has developed the DVI Standard that includes test protocols and methods used to determine the performance of DVIs. In collaboration with DVI manufacturers, the Assure Program oversees the testing through UL, an independent testing organisation that guides the development of and sets internationally recognised standards in a variety of technical fields. Manufacturers submitted their instruments under one of three categories: those that separate natural from synthetic diamonds; those that distinguish natural diamonds from synthetic diamonds and diamond simulants; and those that separate natural diamonds, synthetic diamonds and diamonds simulants. The first phase of testing started in 2018 and on 5 March 2019 results were posted for 11 instruments at https://diamondproducers.com/assure, which also contains advice for how to read the test results, select an appropriate instrument and maintain diamond pipeline integrity.

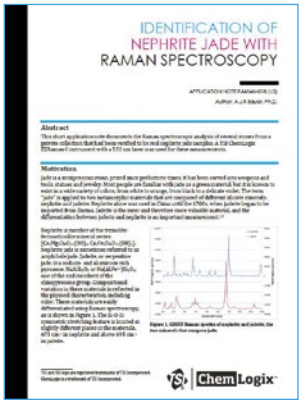

Raman Spectroscopy of Jade and Its Imitations

TSI Incorporated, an instrument manufacturer based in Minnesota, USA, published two application notes in September 2018 titled 'Identification of Nephrite Jade with Raman Spectroscopy' and 'Detection of Imitation Jade with Raman Spectroscopy'. The first report compares the Raman spectra of greenish blue and white nephrite samples, as well as various amphiboles from the RRUFF database. The second report provides the results of Raman analysis of four 'jade' samples purchased from three different online vendors. Two of the stones were identified as chrysotile and aventurine quartz, and the other two samples (obtained from a single vendor) consisted of chrysotile that was coated with a material that fluoresced when exposed to the instrument's 532 nm laser. Download the reports from www.tsi.com/system/search-results/?searchtext=jade.

Responsible Sourcing CIBJO Blue Book

Released in January 2019, *The Responsible Sourcing Book* is a 14-page guide to CIBJO's responsible sourcing policy. The report covers aspects such as supply chain due diligence, risk assessment, product integrity and certification, and concludes with a series of appendices that include lists of various supply chain guidance and standards organisations, a list of audit companies and a checklist for responsible sourcing. Download the document at www.cibjo.org/downloads/19-01-06%20Responsible%20Sourcing%20Book%20.pdf.

Santa Fe Symposium Proceedings

Papers from 23 presentations delivered at the 32nd Santa Fe Symposium (held 20–23 May 2018 in Albuquerque, New Mexico, USA) are available for download, on topics such as precious metals, history of metallurgy, jewellery manufacturing methods, long-term predictions for the jewellery industry and more. Visit www.santafesymposium.org/papers to download PDF files of these papers, as well as those from earlier symposia dating back to 2000.

Sapphires Heated with Pressure

Blue sapphires that have undergone high-temperature heat treatment under pressure (sometimes called 'HPHT-treated' sapphires) have recently been the subject of various investigations. GRS Lab researchers in Switzerland, Thailand, Sri Lanka and Hong Kong contributed to a November 2018 report on how GRS identifies these sapphires and describes them on identification reports. The research covers 159 treated samples seen in GRS labs during 2015–2018 and 128 samples examined at various stages of treatment. Analytical methods included FTIR, UV-Vis-NIR, LIBS, EDXRF and Raman spectroscopy, and DiamondView fluorescence imaging. A unique set of inclusion features can help distinguish these treated sapphires from untreated and conventionally heat-treated samples, and the researchers also noted durability issues (e.g. increased brittleness) attributed to the treatment. GRS distinguishes these sapphires on its identification reports with the code 'PHT' to separate them from conventionally heat-treated sapphires. Download the report at http://gemresearch.ch/wp/wp-content/uploads/2018/11/GRS_HPHT_Update_2018_11_12_Sm.pdf. Also available on the GRS website (http://gemresearch.ch/retake-gilc-2019) is a video presentation by Dr Adolf Peretti on these treated sapphires from research that was originally presented at the February 2019 Gemstone Industry & Laboratory Conference (GILC) conference in Tucson.

Version 12 November 2018

Identification and characteristics of PHT ('HPHT') - treated sapphires - An update of the GRS research progress

Adolf Peretti[1,2,3,4*], Maya Mosa[1], Willy Bieri[1], Edward Cleveland[2], Ishtiyaaq Ahamed[3], Matthias Alessandri[4], Lawrence Hahn[4]

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Fig. 1. A series of faceted HPHT-treated sapphires in a color range from pastel, vivid (royal blue) to deep blue in different shape and sizes (4-14ct).

Introduction

A series of peculiar events that commenced in 2015 brought a degree of uncertainty to the Sri Lankan gemstone industry. Sri Lanka is known as the world's foremost producer of 'heated' corundum. So far only corundum of higher clarity has been used to produce clean sapphires. It was noticed that a few buyers began purchasing previously 'untreatable' rough at uncommonly high prices. A rumor spread that a new treatment was developed and from emerged that a new type of diffusion treatment could be responsible. Shortly afterwards some sapphire vendors were selling 'heated' sapphires below the already decreasing market prices of heated sapphires, and rumors were confirmed that a new type of sapphire treatment had been discovered. While speculations that HPHT-treated sapphires being responsible for the price decrease of heated sapphires are unsubstantiated, it can not be ignored (see Fig. 29.) due to the coincidental occurrence of events. The appearance of this new treatment came at a critical time of political and economical changes in Asia. If it did not negatively affect the market, it surely did not help.

In 2009, a Korean company called HB Laboratory Co. Ltd first successfully treated corundum with a new HPHT technique. The new heat treatment executed at elevated pressures is similar to how diamonds are being HPHT-treated, although the applied pressure is significantly lower. The applied pressure during the HPHT-treatment for diamonds is larger than 50 Kbar (Dobrinets, Vins and Zaitsev, 2013) whereas the

categories of sapphires: untreated rough and already conventionally heat treated sapphires (multi-step treatment). The treated product has been commercially available since 2013. An influx at GRS lab was seen in 2015.

The advantages of this new technique are significant when compared to traditional heat-treating methods. The traditional heat-treatment methods require high temperature soaking times between 1500-1800°C for many hours or even several days. The new elevated pressure method reduces the soaking time to less than 30 minutes similar temperatures. Another key competitive advantage is the healing effect on fractures and surface reaching feathers. The process of crack-healing and improvement of clarity has also been reported by Choi et al., 2018.
The Korean Hanmi Gemological Institute Laboratory (GIG) first reported in November 2011 on blue sapphires having unusual infrared spectroscopic characteristics. The HPHT-processed gemstones show a strong absorption band centered around the 3047cm^{-1} in the infrared

During the GILC conference, a presentation on these treated sapphires was also given by the LMHC group of gemmological laboratories, and a PDF file containing the slides can be downloaded at www.lmhc-gemmology.org/s/Heat-with-pressure-LMHC-final-for-web-Feb2019.pdf. Based on this research, on 27 February 2019, Lotus Gemology posted an article titled 'Squeezing Sapphire: Corundums treated with high temperatures and low pressure (HT + P)'. It provides a compendium of information from numerous labs worldwide, including a history of the heat treatment of corundum (which puts the relatively new method into context), a description of the treatment methodology (from visits to a heating facility in South Korea) and characteristics of inclusions, UV fluorescence, trace-element composition and various spectral features in sapphires treated by this method. The article concludes with the results of various durability tests, which revealed no particular problems associated with this treatment. Read the article at www.lotusgemology.com/index.php/library/articles/346-sapphires-treated-with-high-temperature-and-low-pressure or download it from http://gtljaipur.info/publications.aspx.

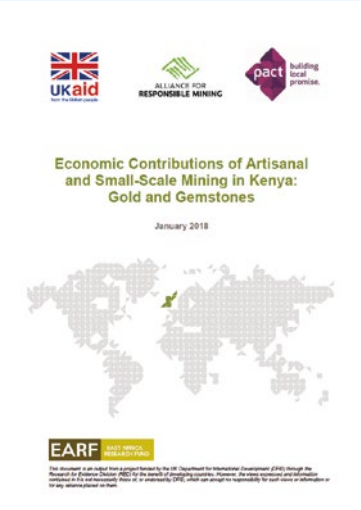

Small-Scale Mining in Kenya

Released in January 2018, 'Economic Contributions of Artisanal and Small-Scale Mining in Kenya: Gold and Gemstones' is a collaborative report from Pact Global and the Alliance for Responsible Mining that describes recent revisions to mining regulations and policies in Kenya, and includes recommendations intended to further develop gold and gem mining in that country. Case studies that form the foundation of the report include gold mining in Migori and gem mining in Taita Taveta. Recommendations include improvement of the mine permitting and granting process, training in extraction methods, encouragement of gender inclusion, and the development of gem cutting and marketing centres. Download the report at www.pactworld.org/sites/default/files/Pact%20-%20DFID%20EARF-%20Kenya%20case%20study%20-Jan%202018VF.pdf.

SSEF *Facette*

Facette Magazine No. 25 was released by the Swiss Gemmological Institute SSEF in February 2019. The issue covers: gem traceability and blockchain; low-temperature heated rubies from Mozambique; damage to emeralds; repair-related laser damage to sapphires; recently encountered examples of synthetic ruby, sapphire and spinel; DNA fingerprinting of pearls, coral and ivory; colour-change phenomena in various gem materials; lead-glass-filled pink sapphire; gem deposits of Luc Yen, northern Vietnam; age dating of ruby in a Harry Winston necklace; a historic sapphire that belonged to Catherine the Great of Russia; spinel from Mogok; pink cobalto-calcite from Switzerland; V-rich ruby from Mogok; a cultured pearl with a bead containing organic matter; artificial aging of cultured pearls; cultured pearls with natural pearl beads; chemical analysis of Paraíba tourmaline; a review of diamond HPHT treatment research at SSEF; auction highlights of gems and jewellery accompanied by SSEF reports, including Marie Antoinette's pearl pendant; several conference and travel reports; and information on various SSEF news and services. Download this and previous issues of *Facette Magazine* at www.ssef.ch/ssef-facette.

Synthetic Periclase Identified by GRS

The GemResearch Swisslab released a Special Alert on synthetic periclase in December 2018. The report describes research on numerous rough and cut samples showing various colours (brownish orange, yellow, green and colourless) that were offered as garnet from Turkey. The gemmological properties were consistent with periclase, and by destructively targeting selected areas of rough samples for inclusion investigation the researchers conclusively identified the material as synthetic periclase by the presence of an artificial dicalcium silicate compound. The material was further characterised by DiamondView fluorescence, SEM-EDS and LA-ICP-MS analyses, and by Raman, photoluminescence, FTIR and UV-Vis-NIR spectroscopy. An abstract and a link to the full article are available at http://gemresearch.ch/synthetic-periclase. See also the Gem Note on synthetic periclase in the Gem Notes section of this issue (pp. 414–416).

OTHER RESOURCES

ColorCodex Update

An updated version of the ColorCodex colour referencing system was launched at the February 2019 AGTA show in Tucson. Originally released in a slightly different format in early 2017 (see What's New section, Vol. 35, No. 5, 2017, p. 376), the system has been expanded into a more practical and innovative tool for industry professionals to compare and reference the colour of gemstones.

The ColorCodex system consists of coloured windows that have a shiny, reflective and textured surface which mimics the appearance of colour in transparent faceted gemstones. There are 65 columns representing different hues (labelled with even numbers 10 through 138) that are distributed on 13 ColorCodex sheets. Each column has eight rows of coloured windows (labelled with odd numbers 03 through 17) that depict varying saturations of that colour. (Tonal values are brought in through the addition of grey overlays.) Combining the two numeric values (e.g. 22-07) defines not only a specific colour (column 22), but also its saturation (level 07). The numbering convention used by the system

allows for the situation of a colour falling between two windows. The system references a particular colour using a precise numeric code without the introduction of colour descriptions. Numeric codes are not influenced by how individuals learn to describe colour, nor by cultural or geographical considerations. By eliminating the ambiguity inherent in colour terminology, the system's colour designations are useful toward a wide range of applications from gemmological education and appraisals to laboratory terminology. Because it is intuitive, one is able to master the use of the system with little instruction. For more information, visit www.color-codex.com.

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GemePrice Update

The GemePrice online wholesale pricing system for diamonds, coloured stones and jewellery from GemeWizard Inc. (Ramat Gan, Israel) was updated in late 2018 with new pricing, gem colour borders, gem type information, tutorials and support. The changes are also reflected in the GemePrice app, available for both iOS and Android mobile devices. Access is by annual subscription. For detailed information, video demonstrations and a trial version (limited to amethyst), visit www.gemewizard.com/products-services/gemtrade/buyers/gemeprice/index.html.

MISCELLANEOUS

Museum of Whitby Jet Opens

W. Hamond jewellers, the oldest manufacturer and retailer of Whitby jet (founded in 1860), recently opened the Museum of Whitby Jet to house its collection of antique jet specimens along with displays of the history and manufacturing of this Yorkshire gem material. The museum is located in restored Wesley Hall in the heart of old Whitby, and offers periodic educational courses focusing on jet and jewellery. For more on the museum's background, displays and access, visit www.museumofwhitbyjet.com.

What's New provides announcements of new instruments/technology, publications, online resources and more. Inclusion in What's New does not imply recommendation or endorsement by Gem-A. Entries were prepared by Carol M. Stockton unless otherwise noted.

The Fire Within

"For in them you shall see the living fire of the ruby, the glorious purple of the amethyst, the sea-green of the emerald, all glittering together in an incredible mixture of light."

– Roman Elder Pliny, 1st Century AD

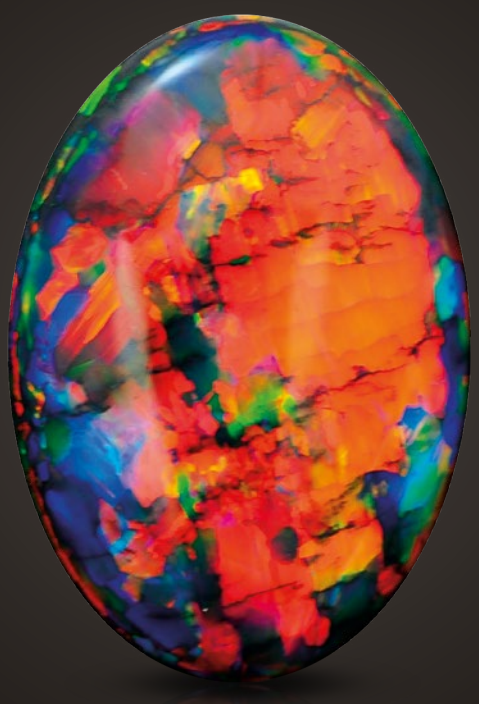

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Gem Notes

COLOURED STONES

Figure 1: Anorthoclase from Antarctica (here, 2.29 and 1.61 ct) has a dark appearance due to the presence of abundant melt inclusions. Photo by Mauro Pantò.

'Black Anorthoclase' from Antarctica

Mount Erebus is an active volcano on Ross Island in Antarctica, and is known as a source of large 'anorthoclase' feldspar crystals (i.e. phenocrysts) that occur in lava flows and volcanic bombs on the mountain's flanks (Dunbar *et al.* 1994). (*Editor's note*: Although mining on Antarctica is prohibited, samples may be collected for scientific research. The mineral name *anorthoclase* has been discredited by the International Mineralogical Association, but the term remains widely used—especially by geologists studying Mount Erebus—and therefore this term will continue to be used here, without quotes for simplicity. It refers to an intermediate member of the solid-solution series constituted by high albite–sanidine alkali feldspar.) The crystals are hosted by phonolite, which is an uncommon volcanic rock of intermediate chemical composition (i.e. between felsic and mafic). The phonolite contains abundant (up to 30% by volume) anorthoclase megacrysts up to 10 cm long, and physical weathering of the lavas and bombs has resulted in lag deposits containing abundant anorthoclase crystals that are locally present on the summit cone of the volcano (Dunbar *et al.* 1994; Kelly *et al.* 2008). The anorthoclase is chemically zoned with a compositional range of $An_{10.3–22.9}Ab_{62.8–68.1}Or_{11.4–27.2}$ (expressed as mol.% anorthite, albite and orthoclase, respectively; Kelly *et al.* 2008). Besides their large size, the anorthoclase crystals are notable for containing abundant melt inclusions that may give them a dark greyish brown to nearly black appearance.

At the 2018 gem shows in Tucson, Arizona, USA, Mauro Pantò (The Beauty in the Rocks, Sassari, Italy) had a few anorthoclase gemstones from Mount Erebus. They were cut from a single piece of rough that was presented to him as a gift from a geologist who had also received it as a gift. The rough piece measured about 30 mm long and 8 mm wide, and yielded six stones ranging from approximately 1 to 3 ct (e.g. Figure 1). Pantò kindly donated one of the stones to Gem-A, and it was characterised by authors CE and PD.

The stone had RIs of 1.531–1.538 (birefringence 0.007) and a hydrostatic SG of 2.66. These values are both somewhat high for anorthoclase, which may be due to the abundant melt inclusions (Figure 2). Chemical analysis with a Thermo Scientific ARL Quant'X energy-dispersive X-ray fluorescence (EDXRF) spectrometer showed major amounts of Si, Al, Na, Ca and K, consistent with

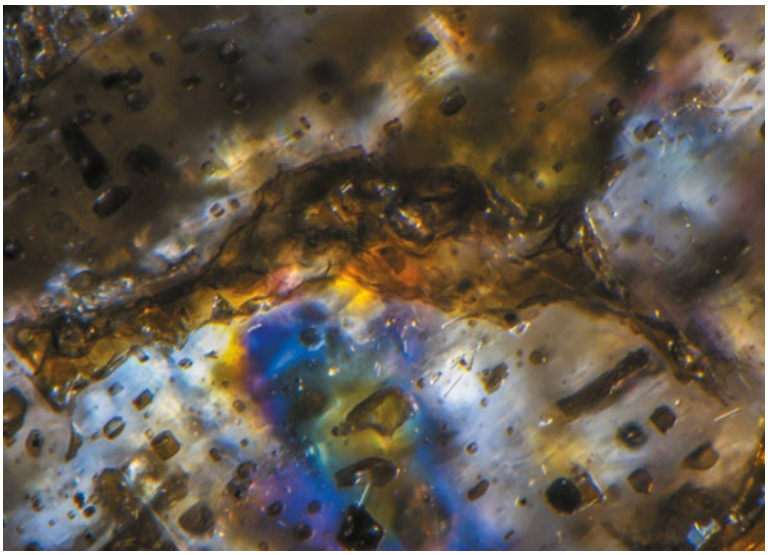

Figure 2: Melt inclusions in the anorthoclase form relatively large irregular masses or smaller rectangular bodies, both of which contain contraction bubbles. Photomicrograph by N. D. Renfro, © GIA; image width 0.96 mm.

anorthoclase. In addition, the analyses showed traces of Fe and Ti (probably due to the melt inclusions), as well as Sr and Ba (which are common impurities in the feldspar).

Microscopic examination of the stone by author NDR showed that two types of melt inclusions were present: those that were large and irregular, and those that were small and rectangular (again, see Figure 2), as previously reported by Dunbar and Kyle (1990). Raman analysis of the inclusions yielded spectra that would be expected for a glass, which is consistent with the presence of contraction bubbles that formed in the melt as it cooled into glass. Also common were iridescent cleavage fractures (Figure 3).

Moussallam *et al.* (2015) determined that the anorthoclase megacrysts at Mount Erebus formed in a vigorously convecting magmatic system involving perhaps 1–3 complete journeys between the magma chamber (at a depth of several kilometres) and the lava lake at the earth's surface, and that a typical crystal of 1 cm across may have formed over a period of at least 14 years.

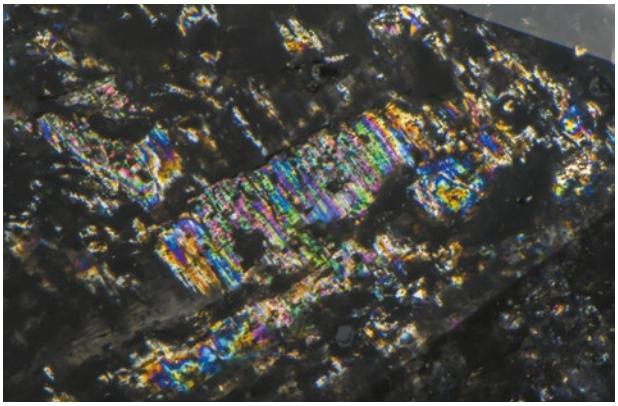

Figure 3: Iridescent cleavages are commonly seen in the anorthoclase. Photomicrograph by N. D. Renfro, © GIA; image width 4.10 mm.

Considering the recent age of some of the lava flows (several years to decades in some cases), these may be the youngest feldspars that have been cut into gemstones.

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Blödite—A Rare Collector's Stone

Blödite is a rare, hydrated Na-Mg sulphate with the chemical formula $Na_2Mg(SO_4)_2 \cdot 4H_2O$. It is monoclinic and typically forms short prismatic crystals with glass-like lustre, or it may occur in granular to massive aggregates; it is usually colourless, pale red or dark grey (Bernard & Hyršl 2004). Blödite was discovered in 1821 in a salt deposit at Ischler Salzberg in Bad Ischl, Gmunden, Austria, and was first described by Johann Friedrich John, who named it in honour of German chemist Karl August Blöde (John 1821). Decades later, Austrian mineralogist Gustav Tschermak named a new mineral *simonyite* (after the geographer Friedrich Simony; Tschermak 1869), but it turned out to be the same mineral as blödite (Groth & Hintze 1871). Today the name *simonyite* is discredited, but sometimes it is used synonymously with blödite.

Blödite is found mainly in marine evaporite deposits (Bernard & Hyršl 2004). The mineral is easily soluble in various liquids, even in cold water (www.mindat.org/min-695.html). It will dehydrate in air, resulting in a white crust forming on its surfaces. Due to these qualities, as well as its low hardness (Mohs 2½–3), blödite is rarely faceted and certainly qualifies as a collector's stone.

Figure 4: This faceted blödite (1.26 ct), reportedly from California, USA, was examined for this report. Photo by Samantha Laddin, DSEF German Gem Lab.

The author recently had the opportunity to investigate a faceted blödite of 1.26 ct, which reportedly came from California, USA (Figure 4). The mineral has RIs of n_x = 1.483, n_y = 1.486 and n_z = 1.487, and its SG is 2.25 (Schaller 1932; Madsen 1966; Bernard & Hyršl 2004), so it can be identified by standard gemmological testing (though not by hydrostatic weighing to determine SG due to its solubility). Nevertheless, because of its fragility, the identity of the stone shown in Figure 4 was confirmed using Raman spectroscopy, with the spectra compared to the RRUFF database as well as to the reference collection of the German Gemmological Association. Observation with the gemmological microscope revealed growth structures, partially healed fractures and minute two-phase inclusions (Figure 5).

Specimens of blödite should be stored in an airtight container to prevent them from dehydrating.

Acknowledgements: The author thanks Michael Wild of Werner Wild e.K., Idar-Oberstein, Germany, for loaning this faceted blödite.

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Figure 5: Examination with a gemmological microscope revealed this two-phase inclusion in the faceted blödite in Figure 4, which is seen here among prominent polishing lines. Because of the low hardness and the solubility of blödite, it is difficult to achieve a good polish. Photomicrograph by T. Stephan in transmitted light; image width 1.5 mm.

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Purple Fluorite in Opal from Utah, USA

The Tucson gem shows are an ideal place to find new and exotic gem materials (some of which might not be accurately labelled), as well as those that are familiar with only a new name or new origin. During the 2018 Kino 'Electric Park' show, one dealer had dozens of opaque mottled purple cabochons and beads—some of which had a brecciated appearance with white to light brown areas—which he represented as 'opalized fluorite' from Utah, USA. However, the material did not have the typical look of an opalised product, and it had a greater

Figure 6: These cabochons (up to 31.5 × 16.5 mm) are representative of the more uniformly purple material from Utah, USA that is sold as 'opalized fluorite'. Characterisation of two similar samples showed they consisted of opal-A with abundant purple fluorite inclusions. Photo by Brendan M. Laurs.

heft than opal. Similar material (e.g. Figure 6) was seen at the 2018 and 2019 AGTA shows in Tucson with gem dealer Bill Gangi (Gangi Gems, Franklin Square, New York, USA). Two mottled purple cabochons obtained from Gangi were characterised for this report. Standard gemmological properties were determined separately by authors EF and CW, and advanced testing by authors EF and BW included EDXRF and Raman spectroscopy, scanning electron microscopy and visible-range reflectance spectroscopy.

The colour of the material was somewhat patchy and ranged from light to dark purple, with irregular colour patterns. There were also some veins that were semi-transparent and slightly milky with chevron-like shapes. The samples exhibited the moderate-to-low vitreous lustre typical of common opal. The RI value, measured by EF using the spot method on different areas of the samples, ranged from 1.45 to 1.50 (a slightly lower value of 1.44 was obtained by CW). The SG was measured hydrostatically by author EF to be between 2.24 and 2.66, and author CW obtained a value of 2.31. The range of RI and SG measurements relates to the inhomogeneous and also possibly porous nature of this material.

Ultraviolet luminescence was observed with a Vilber Lourmat VL-215.LC UV lamp using both long-wave (365 nm) and short-wave (254 nm) radiation, with a power of 6 W for each lamp, at a distance of 7 cm from the sample, in total darkness. The stones luminesced a whitish blue to long-wave UV, with the whiter areas emitting a moderate green. In short-wave UV, the whitish blue was somewhat weaker but the green component was much stronger. This is reminiscent of the short-wave UV luminescence of many common opals due to traces of uranium (Gaillou *et al.* 2012).

Microscopic observation revealed the inhomogeneous nature of the material, with purple spots in an otherwise grey to white matrix. The purple inclusions showed at least two size ranges (Figure 7). This is reminiscent of purple fluorite mixed with opal from various localities, including so-called Tiffany Stone from Utah and Morado opal from central Mexico (https://geology.com/gemstones/opal/morado-opal.shtml).

With an Amptek X123-SDD EDXRF spectrometer we detected significant Ca, minor amounts of Zn, Fe and Pb, and traces of U. A Geiger counter revealed radioactivity emitted at 180–210 counts per minute, which is approximately three times background levels. This amount of emission is not considered dangerous or of health consequence.

Raman spectroscopy using a Fourier-transform spectrometer provided no useful spectra, even though this is usually the preferred instrument to identify opal (Ostrooumov *et al.* 1999; Fritsch *et al.* 2012). Using a typical dispersive Horiba Scientific T64000 Raman spectrometer with 514 nm excitation (argon-ion laser), we obtained a weak signal with a main broad band centred at ~400 cm^{-1}. This is consistent with opal-A

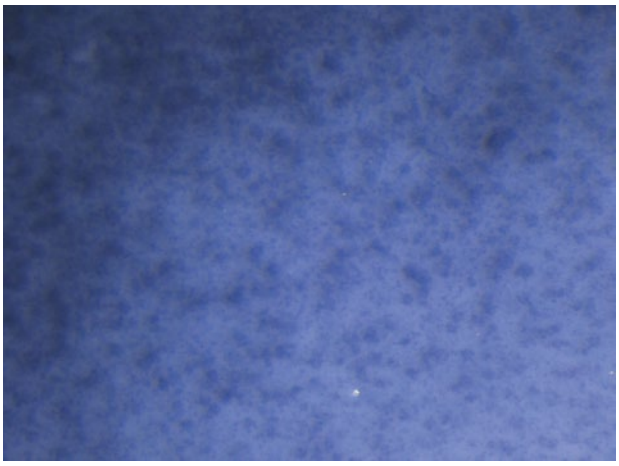

Figure 7: Magnification of the purple gem material from Utah reveals an inhomogeneous mixture of purple spots of various sizes in a light-coloured matrix. Photomicrograph by E. Fritsch; image width 2.0 mm.

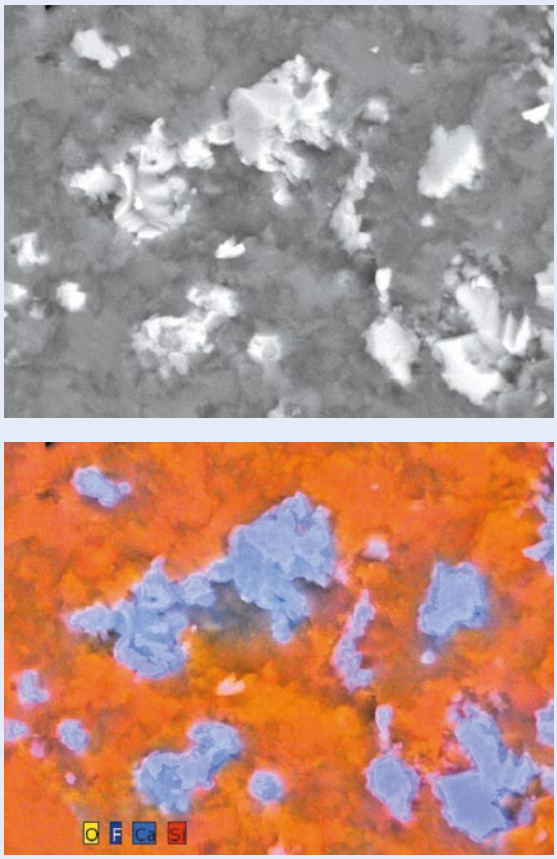

Figure 8: SEM-BSE imagery of the purple material shows the presence of two main domains. At the top, a standard BSE image displays medium grey and light grey areas consistent with different average atomic weights. Below, false-colour chemical imaging of the same area demonstrates a mixture of silica (SiO_2, in orange, formed by a mixture of O in yellow and Si in red) with fluorite (CaF_2, in blue, formed by a mixture of Ca in blue and F in violet). Image widths 40 µm.

(amorphous), which also commonly displays weaker opal-related Raman bands at 780, 970 and 1068 cm^{-1}. Using an Enwave 785 nm laser Raman spectrometer, we detected fluorite in the purple areas. The Gemmo-Raman-532SG identified some grains as quartz.

Examination of a freshly broken sample with a JEOL 5800 scanning electron microscope (SEM) at 2,000× magnification in backscattered electron (BSE) mode revealed a mixture of two components with different fracture types and contrasting chemical compositions (Figure 8). The matrix material appeared medium grey in the BSE images (thus, composed of relatively lighter elements) and showed a rather smooth, curved, probably conchoidal fracture. The much lighter grey-appearing inclusions (thus composed of relatively heavier elements) had a blocky appearance, with flat surfaces (possibly cleavages) measuring a few micrometres across and sharp edges that sometimes showed 90° angles. Veins and occasional inclusions measuring several hundred micrometres were observed in some areas. Energy-dispersive spectroscopy with the SEM revealed that the matrix was composed essentially of Si and O, whereas the inclusions contained Ca and F. This confirms the presence of fluorite (CaF_2) inclusions in a matrix of opal ($SiO_2 \bullet nH_2O$).

The colour of this gem is due to the purple fluorite inclusions, as initially suggested by microscopic observations. A visible-range reflectance spectrum obtained with a PerkinElmer Lambda 1050 spectrophotometer with an integrating sphere showed that the colour is induced by a broad band centred at around 580 nm (Figure 9a). This is a classic absorption feature of purple fluorite, due to nano-precipitates of colloidal Ca (Braithwaite *et al.* 1973).

Finally, the green short-wave UV emission is typical

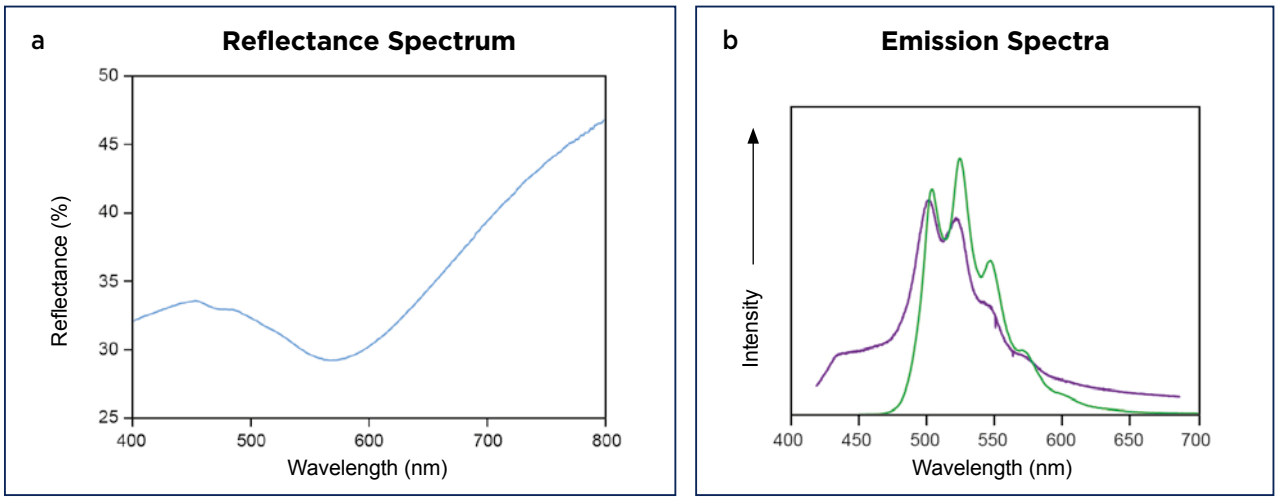

Figure 9: (**a**) The visible-range reflectance spectrum of this gem material is typical of purple fluorite, with a broad band centred at ~580 nm. (**b**) Comparison of the short-wave UV emission of the purple gem material with hyalite opal from Mexico (green spectrum) shows closely matching positions of the emission maxima and troughs, as well as similar band widths and shapes. This emission is typical of opal containing traces of U.

of various opals. Figure 9b compares the emission spectrum of this purple material with that of hyalite opal from Mexico (see also Fritsch *et al*. 2015). The emissions are very close in position, width and perceived colour, confirming that the luminescing matrix is indeed opal containing traces of U.

This gem material from Utah is constituted by common opal (i.e. opal-A) containing myriad of minute purple fluorite inclusions that cause its colour. It is similar to Morado opal from Mexico, which also consists of common opal coloured by purple fluorite (e.g. Renfro 2012). Most purple opals coloured by fluorite inclusions tend to be mixed with quartz and a whitish host rock and have a mottled, uneven colouration. Although Tiffany Stone from Utah reportedly contains bertrandite [$Be_4(Si_2O_7)(OH)_2$] as a common constituent (e.g. Serras-Herman 2012), this mineral was not detected by Raman spectroscopy in the relatively homogeneous purple samples that were tested for this report.

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Garnets from Eastern Democratic Republic of the Congo

While on a June 2016 buying trip in Rwanda, rough stone dealer Farooq Hashmi (Intimate Gems, Glen Cove, New York, USA) encountered some new garnets that reportedly came from Caminola, which is located in eastern Democratic Republic of the Congo (DRC) at the northern end of Lake Tanganyika near the border with Burundi. He purchased approximately 1 kg of rough material, which consisted mostly of small waterworn pebbles that weighed up to approximately 0.5 g each. The garnets ranged from yellowish orange to dark red to pinkish purple (Figure 10).

Four round brilliants were faceted for this report: three were cut by Todd Wacks (Tucson Todd's Gems,

Figure 10: The garnets from eastern DRC show a variety of colours. The largest samples shown here weigh approximately 0.5 g. Photo by Farooq Hashmi.

Tucson, Arizona, USA) that weighed 0.85, 1.10 and 2.14 ct, and one was faceted by Mary van der Aa (Mary van der Aa, Port Huron, Michigan, USA) that was 3.48 ct (Figure 11). The physical and chemical properties of the samples are summarised in Table I. In general, the most prominent internal features were rounded colourless crystals (Figure 12), which were surrounded by tension fractures in one of the samples. In addition, cross-hatched anomalous double refraction (ADR) was commonly seen, and one of the samples also displayed angular graining patterns (Figure 13).

The chemical composition of the garnets was obtained by authors AUF and WBS, who performed standard-based scanning electron microscopy–energy-dispersive spectroscopy (SEM-EDS) using a JEOL JSM-6400 instrument with the Iridium Ultra software package by IXRF Systems Inc. The data showed widely variable spessartine, almandine, pyrope and grossular components (again, see Table I), as well as traces of V and Cr. The 2.14 ct garnet had a much higher pyrope content than the other samples and also showed different internal features (i.e. parallel needles rather than rounded colourless crystals and no ADR), making it distinctive from the rest of the garnets.

Table I: Physical and chemical (by SEM-EDS) properties of four garnets from eastern DRC.

Property	3.48 ct	2.14 ct	1.10 ct	0.85 ct
Colour	Red	Dark red	Orangey red	Yellowish orange
RI	1.790	1.780	1.801	>1.81
SG	4.12	4.03	4.14	4.21
Internal features	Colourless crystals, cross-hatched ADR	Parallel-orientated short needles in one direction (not birefringent), fine particles	Colourless crystals surrounded by tension fractures, few birefringent short needles, cross-hatched ADR	Clouds of white particles, irregular-shaped dark planar film, prominent cross-hatched ADR with angular graining
Oxides (wt.%)				
SiO_2	37.39	38.93	37.11	37.12
TiO_2	0.10	0.09	0.36	0.07
Al_2O_3	20.99	21.71	21.11	20.94
FeO	13.82	21.08	4.11	17.93
MnO	21.61	6.61	32.96	20.35
MgO	2.10	7.53	1.63	1.83
CaO	3.97	4.02	2.70	1.73
Total	99.99	99.98	99.99	99.97
Ions per 12 oxygens				
Si	3.006	3.012	2.994	3.006
Al	1.988	1.979	2.007	1.998
Ti	0.006	0.005	0.022	0.004
Mg	0.252	0.868	0.196	0.221
Fe	0.929	1.364	0.277	1.215
Mn	1.471	0.433	2.252	1.395
Ca	0.341	0.333	0.233	0.150
Mol.% end-members				
Spessartine	49.1	14.4	75.2	46.6
Pyrope	8.4	29.0	6.5	7.4
Almandine	31.0	45.5	9.3	40.5
Grossular	11.0	10.1	7.8	5.0
Others	0.5	1.0	1.2	0.5

Figure 11: The DRC garnets studied for this report range from red to yellowish orange and weigh 1.10, 2.14, 3.48 and 0.85 ct (from left to right). Photo by Robison McMurtry, © GIA.

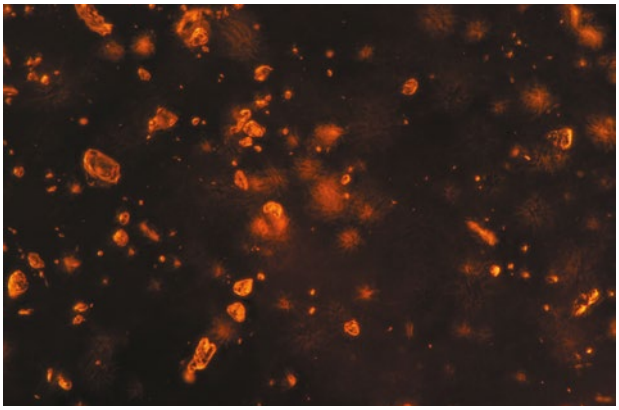

Figure 12: Numerous rounded, colourless crystals form inclusions in the 3.48 ct garnet. Photomicrograph by N. D. Renfro, © GIA; image width 3.20 mm.

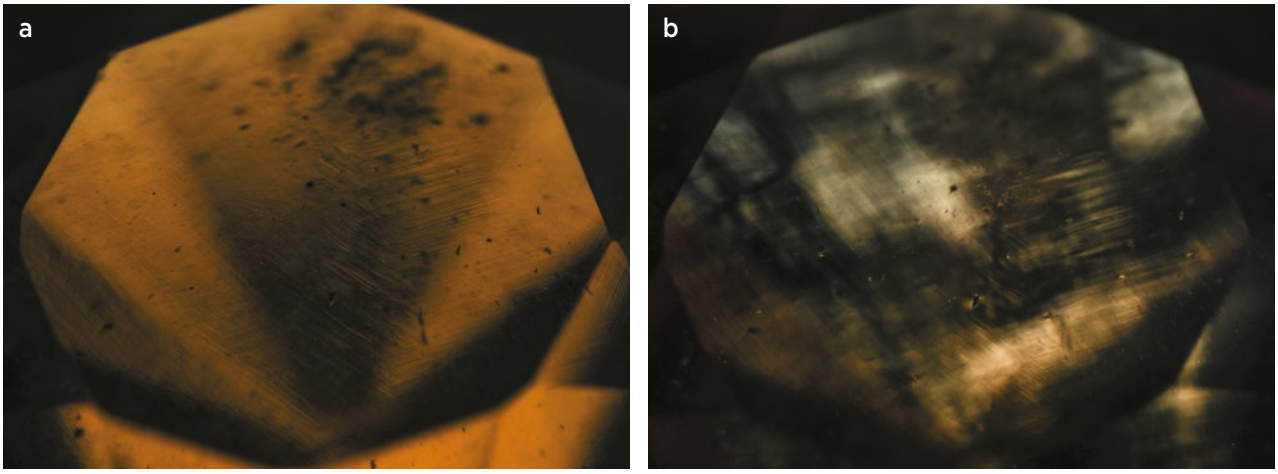

Figure 13: Microscopic examination of the 0.85 ct garnet reveals (**a**) angular graining patterns in shadowed transmitted light and (**b**) anomalous double refraction in cross-polarised light. Photomicrographs by N. D. Renfro, © GIA; image widths 3.57 mm.

The rough parcel obtained by Hashmi also contained three dark-coloured stones that appeared different from the rest of the garnets. These were identified by SEM-EDS as two pieces of dark brownish green dravite–uvite tourmaline and a black to dark purple spinel. It is not clear if this mineral assemblage together with the garnets of varying composition resulted from mixing different parcels or if the stones were derived from the weathering of a variety of geological environments that formed this alluvial deposit in eastern DRC.

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Obsidian from Slovakia

Obsidian is a natural glass of volcanic origin. It was often used by prehistoric man to make tools because it is easily knapped. Several obsidian occurrences are known in Europe, and most are in the eastern Mediterranean. In the Tokaj Mountains of Slovakia and Hungary, obsidian is associated with Late Tertiary volcanic activity. The stones appear quite dark, in mostly blackish to greyish tints, although in some cases deep greenish or brownish hues are found. The obsidian is most abundant between the villages of Viničky and Veľká Bara in the Košice region of eastern Slovakia (Illášová & Turnovec 2003). Tribes initially settled in this area as early as the Paleolithic, and archaeological aspects of obsidian in the Tokaj Mountains have been covered in various articles (e.g. Soják & Wawrzczak 2017).

In present-day Slovakia, prospecting for gem deposits

Figure 14: These faceted obsidians (0.40–3.20 ct) are from the Tokaj Mountains in the Košice region of eastern Slovakia. Photo by J. Štubňa.

Figure 15: The transparency of this relatively large Slovakian obsidian (24.06 ct or 20.42 × 20.45 × 13.81 mm) is shown here in transmitted light. Photo by J. Štubňa.

has resulted in the discovery of various siliceous materials, including obsidian, which were not previously identified for gem use (Illášová & Spišiak 2010). In recent years, a traditional obsidian craft industry has produced small ornamental hangings and various objects such as arrowheads, hair and clothing accessories, and jewellery such as necklaces, pendants and earrings. The gems are fashioned into cabochons as well as faceted stones.

For this study, we examined 100 rough and 10 faceted samples of obsidian from the Tokaj Mountains. The rough pieces varied from 1 to 20 cm in maximum dimension and the cut stones weighed 0.40–24.06 ct (e.g. Figures 14 and 15). They ranged from black to dark grey; thin areas along their edges appeared grey to pale grey or brownish. Their hydrostatic SG ranged from 2.33 to 2.36 and their RIs were around 1.489–1.491. Microscopic examination of the cut stones revealed micro-phenocrysts of plagioclase, biotite, ilmenite and, rarely, orthopyroxene (Figure 16). The inclusions were identified by optical microscopy and by comparing them to photomicrographs in Bačo *et al.* (2017) and in Gübelin and Koivula (2008). The samples commonly showed a banded texture with alternating dark and light streaks caused by flow-oriented minute crystals. This internal fabric is the probable cause of sculpturing into fluted shapes that occurs when the glass is exposed to weathering (Bačo *et al.* 2017).

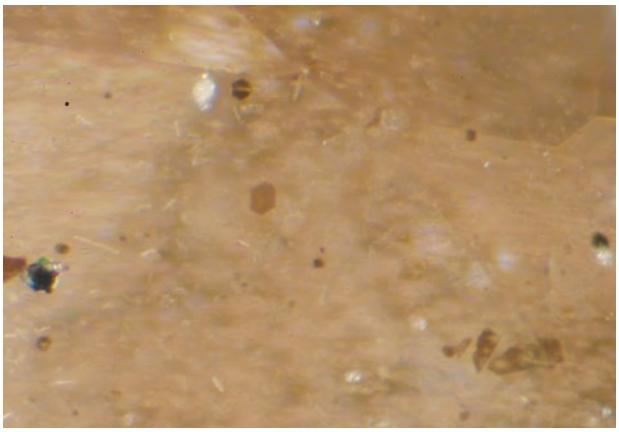

Figure 16: A closer look at the 0.40 ct Slovakian obsidian in Figure 14 shows minute crystallites of plagioclase (white), biotite (brown), ilmenite (black) and pyroxene (colourless) that are locally flow-aligned. Photomicrograph by J. Štubňa; magnified 30×.

Obsidian from Slovakia has been used for millennia and could experience a renaissance in present times as a non-traditional gemstone.

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Spessartine Crystals from Oyo State, Nigeria

Nigeria is a well-known source of gem-quality spessartine (e.g. Lind & Henn 2000), which has mostly been produced from secondary deposits. In 2017, a small amount of well-formed spessartine crystals was found at a granitic pegmatite in the Oyo State of western Nigeria. According to rough stone dealer Farooq Hashmi, most of the production consisted of loose single crystals and clusters, although a few matrix specimens were available. Prized by mineral collectors for their deep orange colour, high lustre and euhedral crystal form, the material soon became scarce in the market.

During the February 2019 Tucson gem shows, this author was surprised to see a full layout of these spessartine crystals that was assembled together for mounting in jewellery. Displayed at the booth of Valerio Zancanella (Cavalese, Italy), it consisted of 38 pieces for mounting in a necklace, a matched pair of crystals for earrings and a larger crystal cluster for a pendant or brooch (Figure 17). A parure featuring these attractive garnets would clearly be unique.

[*Editor's note*: Reports on additional items seen at the 2019 Tucson shows will appear in the Gem Notes section of upcoming issues of *The Journal*.]

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Figure 17: This spessartine layout, displayed at the 2019 Tucson gem shows, features well-formed crystals from Oyo, Nigeria. The entire set weighs ~31 g and the largest crystal cluster is ~2 cm tall. Photo by B. M. Laurs.

Reference

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A Faceted Sulphur

Sulphur is a commonly occurring native element, but it is rarely transparent enough to facet. It is nearly always bright yellow, sometimes tending towards green or orange. Sulphur ranges from only 1½ to 2½ on the Mohs scale, roughly equivalent to the hardness of a fingernail. It is also quite frail, so even a slight physical shock can break it. The softness, combined with its fragility and extreme heat sensitivity (if placed in the hand it could shatter due to the thermal shock), all conspire to make it very difficult to cut. Recently this author concave-faceted a large (29.25 ct; Figure 18) sulphur gemstone from Vodinskoye, Samara Oblast, Russia, and this report describes some of the challenges with cutting this delicate material.

The first step involved attaching the rough stone to a dop stick for insertion into the faceting machine. Selecting the appropriate glue was not easy because it must hold fast during cutting and then be released from the stone after faceting is complete. In addition, the substance used to dissolve the glue must not also attack the sulphur. In this case, five-minute epoxy was used. The epoxy can be released by soaking in vinegar for two weeks, but since vinegar is corrosive to the metal normally used for dops it was necessary to custom-make a glass dop stick.

Preforming was done on a special lap created by gluing a piece of sandpaper to a worn-out lap. Then, grinding was done on a wax lap that was fabricated from a dimensionally stable wood material with molten casting wax poured over it and machined flat. The wax was coated with 1,200 grit diamond paste for fine grinding, and 3,000 grit diamond paste was used on a separate wax lap for pre-polishing. Polishing was done with aluminium oxide on yet another wax lap.

In concave cutting, most (if not all) of the stone is initially cut with flat facets, and then selected facets are ground into concave shapes. Cutting this stone was no different. However, the curved facets posed a considerable challenge because the intersection of two curved surfaces produces a sharp ridge. For a delicate material like sulphur, such edges would be very fragile and could lead to cracking and chipping. Special tooling and techniques had to be developed through trial and error, and the facet pattern itself had to be designed so that these intersections were minimised. This was done by placing flat facets between each of the eight curved pavilion facets.

The sequence of cutting the facets was also out of the ordinary. Most stones are cut pavilion first and then crown second. However, this requires attaching the dop to the pointed culet in order to cut the crown. This is problematic for sulphur, since it is likely that the fragile culet would be damaged when releasing the stone from the glue. Therefore, cutting the crown first meant that the dop could then be attached to the flat table facet, a far less risky approach. Since there was still no guarantee that the table facet would be unharmed when releasing the epoxy, the crown was step cut so that any damage could be removed by hand-holding the stone during grinding and polishing without affecting facet meets and symmetry.

Several additional considerations for faceting this sulphur were taken into account. To protect it from exposure to heat, a small piece of chamois leather was used to handle the stone and oil was used as a lubricant to help dissipate heat while grinding and polishing. The oil was also used to remove swarf (the powdered sulphur created from the grinding process). To minimise exposing the stone to shear forces (which can create sub-surface damage or cracking) as it was rubbed across the lap, only slow rotation speeds were used (i.e. during grinding) or the lap was held stationary (i.e. during polishing). Additional considerations were involved with the complex interactions between the sulphur, grit, lubricant and lap, as well as the crystallographic orientation of the stone.

Faceted sulphur is quite rare, but the result of proper cutting is a beautiful and unusual stone that is prized by collectors.

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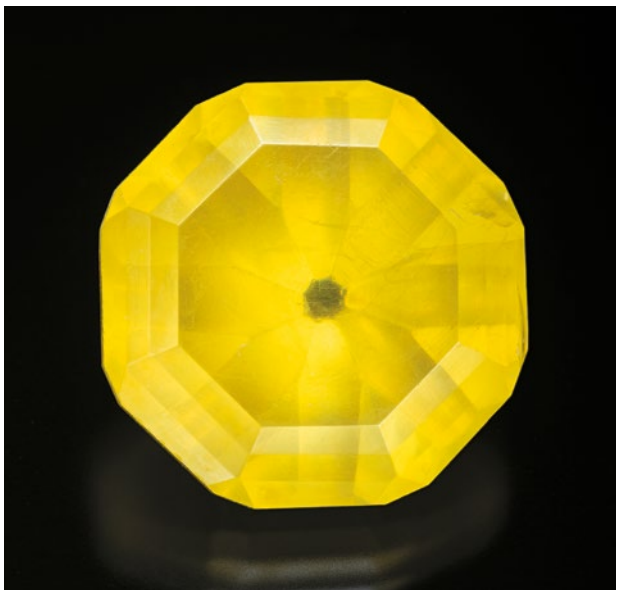

Figure 18: Special techniques were developed by the author to facet this 29.25 ct concave-cut sulphur. Photo by Jeff Scovil.

DIAMONDS

Chidliak: A Sustainable Future Diamond Mine in Canada?

In July 2018, news broke that De Beers Canada purchased the Chidliak diamond resource from Peregrine Diamonds Ltd (Jamasmie 2018). The purchase closed in September 2018 for a cost of CAD107 million. Both BHP Billiton and De Beers had walked away from previous joint ventures in 2012 and 2013, respectively. This time, De Beers jumped back into the resource and bought it outright. This may be because there are no new tier-one diamond mine assets coming online in the next 10 years, and as we look to the future of slowly declining inventories with slightly increasing demand for diamonds (Linde *et al*. 2018), any new viable mine would make sense. History shows us, however, that for Chidliak it has always been the cost-to-benefit analysis that had suitors backing off. Even though the diamonds are of high quality, the costs associated with mining the diamonds were deemed too high.

Chidliak is located on Baffin Island, about 120 km from Iqaluit, the capital of Nunavut, Canada (Figure 19). The asset hosts at least 74 kimberlites, eight of which are potentially economic, and has an inferred resource of 22 million carats (Jamasmie 2018). Since the area is very remote, access to transportation and logistics support for any mining operation is expensive. The average

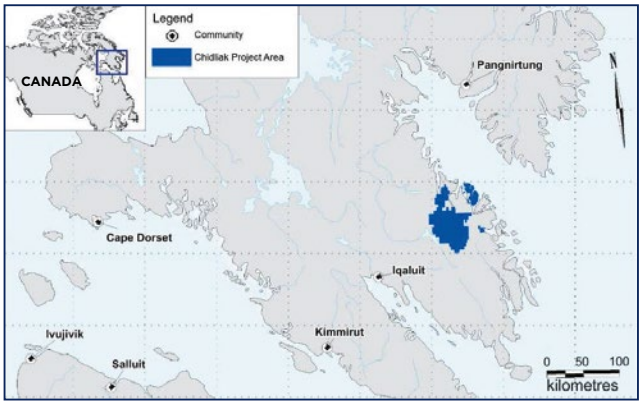

Figure 19: The Chidliak diamond property (shown in blue) is located in a remote part of Baffin Island. Courtesy of Peregrine Diamonds Ltd.

temperature in February is –27°C and there is just 4½ hours of daylight in December (https://en.climate-data.org/north-america/canada/nunavut/iqaluit-1251). Chidliak does not have a winter ice road for bringing in supplies and diesel fuel like the diamond mines at Ekati, Gahcho Kué and Diavik in Canada's Northwest Territories. Therefore, everything must be taken in or out either by plane or, in the summer months, by boat to Iqalaut.

In December 2018, during the 6th annual meeting of the Energy and Mines World Congress in Toronto, the CEO of De Beers Canada, Kim Truter, announced their goal to make the mine 100% 'renewable'. To accomplish this, they will look at 'radical solutions' like dramatically reducing the footprint of the mine, including eliminating the need for haul trucks and not building a road from Iqaluit (which would be a major contributor to overall carbon emissions of the project), and making the site fly-in only by helicopter (Rolfe 2018). There is actually a precedent for sustainability at a Canadian diamond mine: Rio Tinto built a windfarm at Diavik in 2012, which resulted in a diesel offset of 3.8 million litres in its first year. The windfarm has since achieved peak power generation of 52% of the mine's energy needs. Before the windfarm, Diavik relied on diesel for all its energy usage. The windfarm reduces greenhouse gas emissions by approximately 12,000 tonnes (or 6% of emissions), and by diversifying the energy mix, Diavik offsets some of the risks associated with reliance on diesel (National Resources Canada 2018). Elsewhere in Canada, De Beers' Victor mine in Ontario (which is closing this year) draws a mix of nuclear and hydroelectric power from Nunavut's grid, while its joint-venture Gahcho Kué property in the Northwest Territories relies on diesel.

If a diamond mine at Chidliak proves economic, it will be a perfect opportunity for De Beers to put into action their new FutureSmart Mining approach being developed by Anglo American, De Beers' parent company. This initiative aims to adopt new processes and technology to enable precision mining with minimal energy, water and capital intensity with an aim of carbon neutrality (see http://tinyurl.com/y7k7o65s).

De Beers' approach to Chidliak is admirable, and would make a fantastic case study, but we will have to wait and see the outcome. The motivation for change is more than just doing the 'right thing' and the potential profits from high-quality diamonds (e.g. Figure 20). New Canadian government regulations to fight carbon emissions, and increasing investor and consumer demands for more sustainably mined goods, especially in the diamond market, have motivated many major companies to look more closely at their mining processes.

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Figure 20: This selection of colourless and yellow diamonds is from Chidliak's CH-6 kimberlite. The largest stone weighs 3.54 ct. Photo courtesy of De Beers Canada.

SYNTHETICS AND SIMULANTS

Figure 21: Although represented as being natural stones from a new discovery in Turkey, these samples were identified as synthetic periclase. Photo by Alex Mercado, AGL.

Identifying Synthetic Periclase

In November 2018, American Gemmological Laboratories was asked to identify three rough gems that were bicoloured orange-brown (sample 1), yellowish green (sample 2) and bicoloured colourless-white (sample 3), as seen in Figure 21. They were represented by the supplier as natural stones from a new discovery in Turkey. We collected standard gemmological properties and also performed Fourier-transform infrared (FTIR), EDXRF and Raman spectroscopy.

The samples showed no birefringence (regardless of their colour) or anomalous double refraction, and were inert to long- and short-wave UV radiation. An RI of 1.735 and hydrostatic SG of 3.58 were measured for all three samples. EDXRF data showed a high Mg concentration, with small amounts of Cr, Ca, Fe and Si. The optical properties and chemical composition pointed us toward the mineral periclase (MgO), and are similar to the characteristics provided for synthetic periclase by Kitawaki (2004).

Periclase crystals occur naturally in small sizes, and no facetable periclase has been reported so far. However, starting in 1969, synthetic periclase was sold for jewellery purposes as Lavernite, and various techniques have been employed to produce transparent MgO. Abraham *et al.* (1971) refer to a carbon arc-fusion technique for growing high-purity, large single-crystal MgO free of microbubbles. Brown (1993) reported that large facetable crystals of synthetic periclase were produced as a by-product of the fabrication of magnesia (MgO) from magnesite ($MgCO_3$). The procedure uses nodules of magnesite that are calcined to magnesia which is then electro-fused to form ingots of cryptocrystalline synthetic periclase. Bowles *et al.* (2011) reported that synthetic periclase can be produced from various minerals, including brucite,

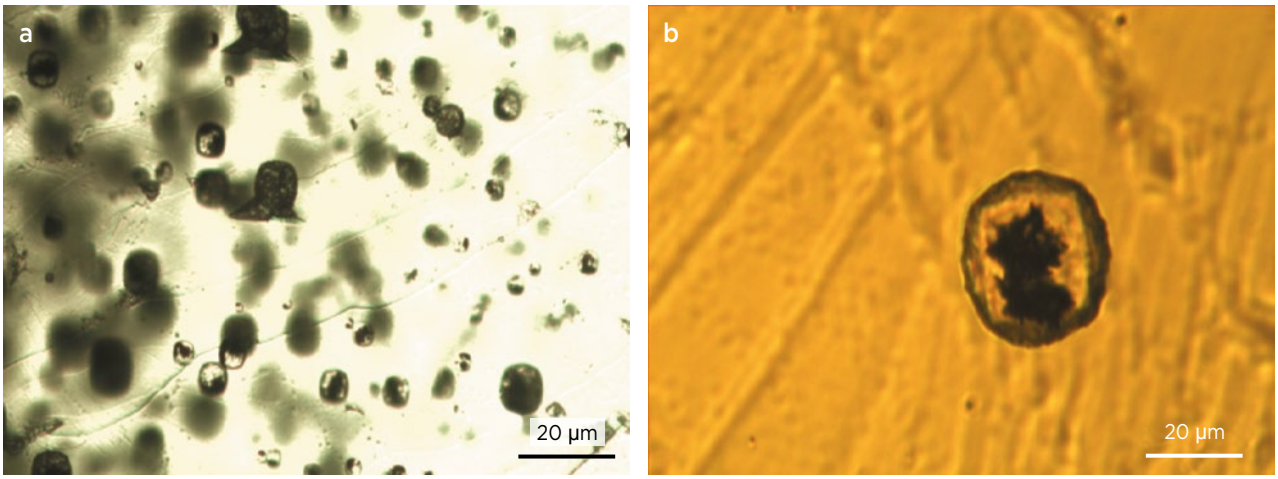

Figure 22: Rounded inclusions in the synthetic periclase consisted of (**a**) concentrations of many individuals, as seen here in sample 3, and (**b**) isolated features, as shown here in sample 1. Photomicrographs by R. Zellagui in transmitted light.

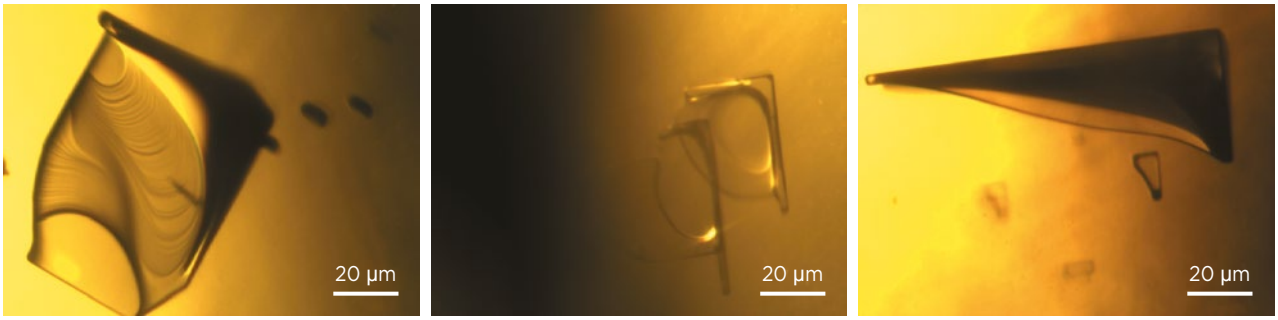

Figure 23: Plate-like negative crystals displaying squarish shapes showed various forms in the synthetic periclase, as seen here in sample 1. Photomicrographs by R. Zellagui in transmitted light.

ankerite, leuchtenbergite, talc, antigorite, vermiculite, forsterite and spinel; white, yellow and brown colours can be produced by the addition of Fe, while green is due to the addition of Cr and Fe to the system.

Microscopic observations showed rounded inclusions (Figure 22), as well as some plate-like negative crystals with square shapes (Figure 23), as previously described in synthetic periclase (Brown 1993; DeMaggio & McClure 1997; Peretti *et al.* 2018).

FTIR spectroscopy of samples 1 and 3 showed two narrow bands at 3312 and 3296 cm^{-1} (Figure 24) associated with V_{OH}^{-} centres in the MgO structure of a hydrogen-doped synthetic periclase (Joachim *et al.* 2012). Sample 2, however, did not display these bands, indicating it was anhydrous. All samples displayed bands at 3697 and 3648 cm^{-1} corresponding, respectively, to brucite and portlandite OH vibrational modes; these are known as alteration products of periclase, and are indicative of water diffusion that takes place when the material is heated (Joachim *et al.* 2012). A strong band was observed at 3730 cm^{-1} in samples 2 and 3, but its cause has not yet been identified. Other minor unidentified bands were observed at 3672, 3625, 3603, 3595, 3562 and 3548 cm^{-1}.

Raman analysis of the synthetic periclase did not show any relevant bands, which concurs with the fact that MgO has no first-order Raman scattering (Farmer 1974). Raman microspectroscopy of the rounded inclusions revealed the presence of merwinite ($Ca_3Mg[SiO_4]_2$) in sample 3 and monticellite ($CaMgSiO_4$) in sample 2. By comparison, Raman analysis of synthetic periclase inclusions

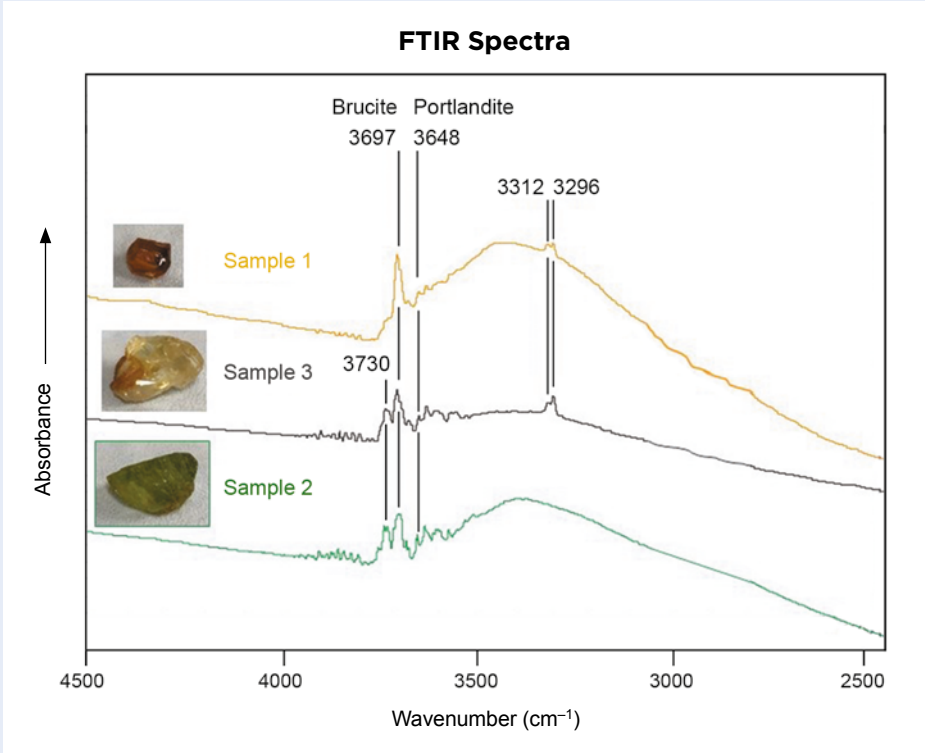

Figure 24: FTIR spectra of the synthetic periclase samples reveal bands associated with brucite and portlandite, along with other unidentified features. Samples 1 and 3 display narrow bands at 3312 and 3296 cm^{-1} that are characteristic of OH centres in hydrogen-doped synthetic periclase. The absence of these features from sample 2 suggests it is anhydrous.

by Peretti *et al*. (2018) identified a dicalcium silicate cement hardener as well as forsterite and monticellite. Indeed, depending on the starting material, manufacturing technique and temperature used for calcination and fusing of magnesite, a variety of impurities can be produced, including forsterite, monticellite, merwinite, and dicalcium and tricalcium silicates (Perepelitsyn & Perepelitsyna 1971; Ebrahimi-Nasrabadi *et al*. 2011).

The combination of gemmological properties and advanced testing confirms the identity of this material as synthetic periclase. It has been reported that faceted synthetic periclase tends to alter in contact with the atmosphere and produce a thin layer of brucite on the surface, which diminishes its usefulness as a gem (Brown 1993).

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MISCELLANEOUS

Myanma Gems Enterprise 2018 Rough Stone Sale and Opening of Mandalay Yatanar Mall

On 12–17 November 2018, the Myanma Gems Emporium held its sixth sale (in kyats) for local merchants of gem and jade rough material in Nay Pyi Taw, Myanmar. There were 1,493 merchants who attended this emporium (1,440 for jade and 53 for gems). A total of 96 gem lots and 3,339 jade lots were offered for sale. The gem lots included 29 for ruby, 18 for sapphire and l5 for peridot, as well as others for topaz, quartz, goshenite and assorted gems. A total of 50 gem lots sold for approximately 795 million kyats and 3,185 jade lots sold for about 48,300 million kyats. The highest price paid for jade was lot no. 305, with 555 pieces weighing a total of 3,470 kg fetching 320,007,777 kyats. Overall, sales were down compared to most previous rough stone emporiums (Table II).

Figure 25: The Mandalay Yatanar Mall hosts numerous gem and jewellery dealers with storefronts, as well as those who are involved with online trading. Photo courtesy of T. Hlaing.

In Mandalay, the Yatanar Mall opened in January 2017. 'Yatanar' means 'gems and jewellery', and the sales area is located on the second floor of a five-storey building (e.g. Figure 25). Of the 385 available rooms, about 200 were reserved for Mogok merchants, but only 120 were occupied as of December 2018. A wide variety of rough and polished stones from Myanmar are offered at the mall.

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Table II: Rough gem and jade sales at various Myanma Gems Emporiums.

No.	Date	Type	Lots Shown	Lots Sold	Amount (million kyats)
1	December 2012	Jade	1,520	1,342	22,217.74
2	January 2014	Gems and Jade	2,996	2,362	77,839.63
3	October 2014	Gems and Jade	7,142	6,110	128,763.74
4	December 2015	Gems and Jade	6,978	5,606	80,841.85
5	March 2017	Gems and Jade	4,649	4,267	61,915.21
6	November 2018	Gems and Jade	3,435	3,235	49,093.39

Educational Aspects of Myanmar Gem Fairs Held in January 2018

The 2nd Yangon International Gems & Jewelry Fair took place at the Lotte Hotel in Yangon 9–13 January 2019, and was organised by the Gems and Jewellery Entrepreneurs Association in Yangon. In addition to a show catalogue, attendees received a book titled *Alphabetical Summary of Myanma Gem Species* (Figure 26), which contains a list of gem varieties available from Myanmar (with their basic gemmological properties), as well as photos of the fair's organising committee and foreign delegation, information on Nawarat rings and birthstones, and the story of Albert Ramsay (an Englishman who pioneered the cutting of Burmese star rubies). A Myanmar Gems Forum included talks from Dr Kyaw Thu titled 'Gem Mining and Sustainability in Myanmar' and Daw Mai Mu Mu Win on the 'Role of Ethics in Gem Trading World', as well as two panel discussions moderated by Dr Yin Yin Nwe: (1) 'Sustainable Sourcing Gems with Full Awareness of Environmental and Social Impacts' featuring Dr Ye Myint Swe, Min Thu, Ye Minn Htun and Maung Maung, and (2) 'Ethical Value Chain from Mine to Market' with Hla Aung, Hpone-Phyo Kan-Nyunt, Aye Myo Naing and Aung Kyaw Zin.

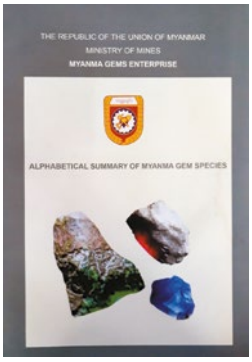

Figure 26: Attendees of the 2nd Yangon International Gems & Jewelry Fair received an informative book published by Myanma Gems Enterprise. Photo courtesy of T. Hlaing.

The 1st Mandalay Yatanar Mall International Gems & Jewellery Fair took place 15–19 January 2019 at the Mandalay Yatanar Mall. The show was held under the guidance of the Myanmar Gems Enterprise with the support of the Myanmar Gems & Jewellery Entrepreneurs Association in collaboration with the Gems & Jewellery Entrepreneurs of Mandalay Yatanar Mall. Attendees received a fair booklet containing a message from the Minister, a list of committee members and vendors, insights on Buddhist culture and information on various aspects of jade, gold, amber, and gems and jewellery from Myanmar. The show included a lecture programme that featured Dr Thet Tin Nyunt, Aung San Win, Maung Maung, Hpone-Phyo Kan-Nyunt, Tay Thye Sun, Richard Li, Kyaw Win and Tin Kyaw Than.

The total sales of gems and jewellery at the two January 2019 Myanmar gem fairs are shown in Table III.

Table III: Gem and jewellery sales at January 2019 Myanmar gem fairs.*

Show location	Amount sold (in currencies received)		Total (GBP)
	Kyats	USD	
Yangon	15,627,690	4,863	11,847
Mandalay	665,480,150	20	342,477
Total	681,107,840	4,883	354,324

* Source: Myanma Gems Enterprise.

Dr U Tin Hlaing

Spinel from Mogok, Myanmar—A Detailed Inclusion Study by Raman Microspectroscopy and Scanning Electron Microscopy

Myint Myat Phyo, Eva Bieler, Leander Franz, Walter Balmer and Michael S. Krzemnicki

ABSTRACT: Mineral inclusions within 100 gem-quality spinels from both primary marble and secondary alluvial mining sites within Myanmar's Mogok Valley were analysed using Raman microspectroscopy and scanning electron microscopy (including backscattered-electron imaging and energy-dispersive spectroscopy). The samples ranged from pink to red, orangey pink to orangey red, and grey to purplish grey. We identified a number of inclusions that are reported here for the first time in Mogok spinel: amphibole (presumably pargasite), anatase, baddeleyite, boehmite, brucite, chlorite, clinohumite, clinopyroxene, diaspore, geikielite, goethite, halite, marcasite, molybdenite, periclase and pyrrhotite. We also found several minerals that were previously known as inclusions in Mogok spinel, including anhydrite, apatite, carbonates (calcite, dolomite and magnesite), chondrodite, elemental sulphur, graphite, iron oxides or iron hydroxides, phlogopite and zircon. We further differentiated the occurrence of inclusions in spinel from different mining sites in Mogok to assess whether these mineral assemblages can enhance our understanding of the geological origin of these gems and whether the inclusions can help separate Mogok spinels from those of other marble-related deposits worldwide.

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Since ancient times, gem-quality spinel (ideally $MgAl_2O_4$) has been appreciated for its range of colour and often exceptional clarity, and today spinel is the second most important and popular red gemstone after ruby (Cesbron *et al.* 2002; Pardieu *et al.* 2008). Spinel's significance is well illustrated by the famed 'Balas rubies'—which are actually spinels from historic mines in Badakhshan (i.e. Kuh-i-Lal, in what is today Tajikistan)—that were described and praised by the Persian scholar Al-Biruni (973–1048 AD). Exceptional pinkish red spinels were part of the Moghul imperial jewels, two of which were later integrated into British royal jewels (the Black Prince's 'Ruby' and the Timur 'Ruby'; see also Pardieu & Hughes 2008; Yavorskyy & Hughes 2010; Truong 2017).

Spinel may form by high-grade metamorphism in calc-silicate rocks and marbles (Balmer *et al.* 2017) or in skarns (contact zones between Ca-rocks and magmatic intrusions; Gorghinian *et al.* 2013), and is also found in secondary deposits (Thein 2008). It shows a wide variety of colours, mainly pink to red and purple, orange, violet to blue, green and even black. Although sometimes

showing greyish or brownish hues, it may also display strong colour saturation, especially in the pink to red range. Moreover, the demand for and value of spinel have increased sharply in recent years. Although known from deposits throughout the world (Myanmar, Sri Lanka, Tanzania, Madagascar and Vietnam, to name a few), some of the finest spinels are found in the Mogok area of Myanmar (e.g. Figure 1). Mogok is one of the world's most eminent gem sources, renowned for producing exceptional rubies, sapphires and other popular stones, as well as rarities such as hibonite, jeremejevite, johachidolite, poudretteite and painite (Iyer 1953; Hughes 1997, 2017b; Themelis 2008).

Although the literature contains some information on inclusions in Burmese spinel (see, e.g., Gübelin & Koivula 1986; Hughes 1997; Themelis 2008; Malsy & Klemm 2010; Zhu & Yu 2018), most publications to date describe Burmese spinel in general (Themelis 2008; Peretti *et al.* 2015), or focus on specific gemmological features (Pardieu 2014; Vertriest & Raynaud 2017) or the oxygen isotope composition of these spinels (Giuliani *et al.* 2017). Several publications deal with inclusions in spinel from worldwide localities (Gübelin & Koivula 1986, 2005; Cooper & Ziyin 2014; Hughes 2017a).

In this study, we describe in detail the solid inclusions found in pink to red, orangey pink to orangey red and grey to purplish grey gem-quality spinels collected from various sites (and local gem markets) in the Mogok area. We found systematic variations in the inclusions related to the different mining sites, suggesting that such inclusion research may be applied to the origin determination of spinels and to separating them from their synthetic flux-grown counterparts (Krzemnicki 2008).

GEOLOGICAL SETTING AND MINING METHODS

Since the 15th century, the Mogok area of Myanmar has been known as a major source of rubies and other gems (Iyer 1953). Often referred to as the 'Mogok Stone Tract' (La Touche 1913; Fermor 1931; Chhibber 1934; Iyer 1953), this gem-rich area is located within the central part of the Mogok Metamorphic Belt. This assemblage is composed of Palaeozoic and Mesozoic high-grade metasediments and intrusive rocks (Searle & Haq 1964; Barley *et al.* 2003; Searle *et al.* 2007; Thu *et al.* 2016; Phyo *et al.* 2017) and forms part of the Mogok-Mandalay-Mergui belt (Figure 2), which extends for more than 2,000 km, north to south, along the western margin of the Shan-Thai (or Sibumasu) terrane, from the Himalayan syntaxis to the Andaman Sea (Bender 1983; Zaw 1990, 2017; Zaw *et al.* 2015). The Mogok Stone Tract is mainly composed of gneiss, marble, calc-silicate rocks and quartzite, which were intruded by various felsic to mafic igneous rocks (Iyer 1953).

Ruby, sapphire, spinel and other gems are mined from primary deposits (calc-silicate rocks and marbles, with spinel only forming in the latter) and from secondary

Figure 1: The spinels in this photo are all from Mogok, Myanmar. The faceted stones range from approximately 7 to 35 ct (not shown to scale). Composite photo by V. Lanzafame, © SSEF.

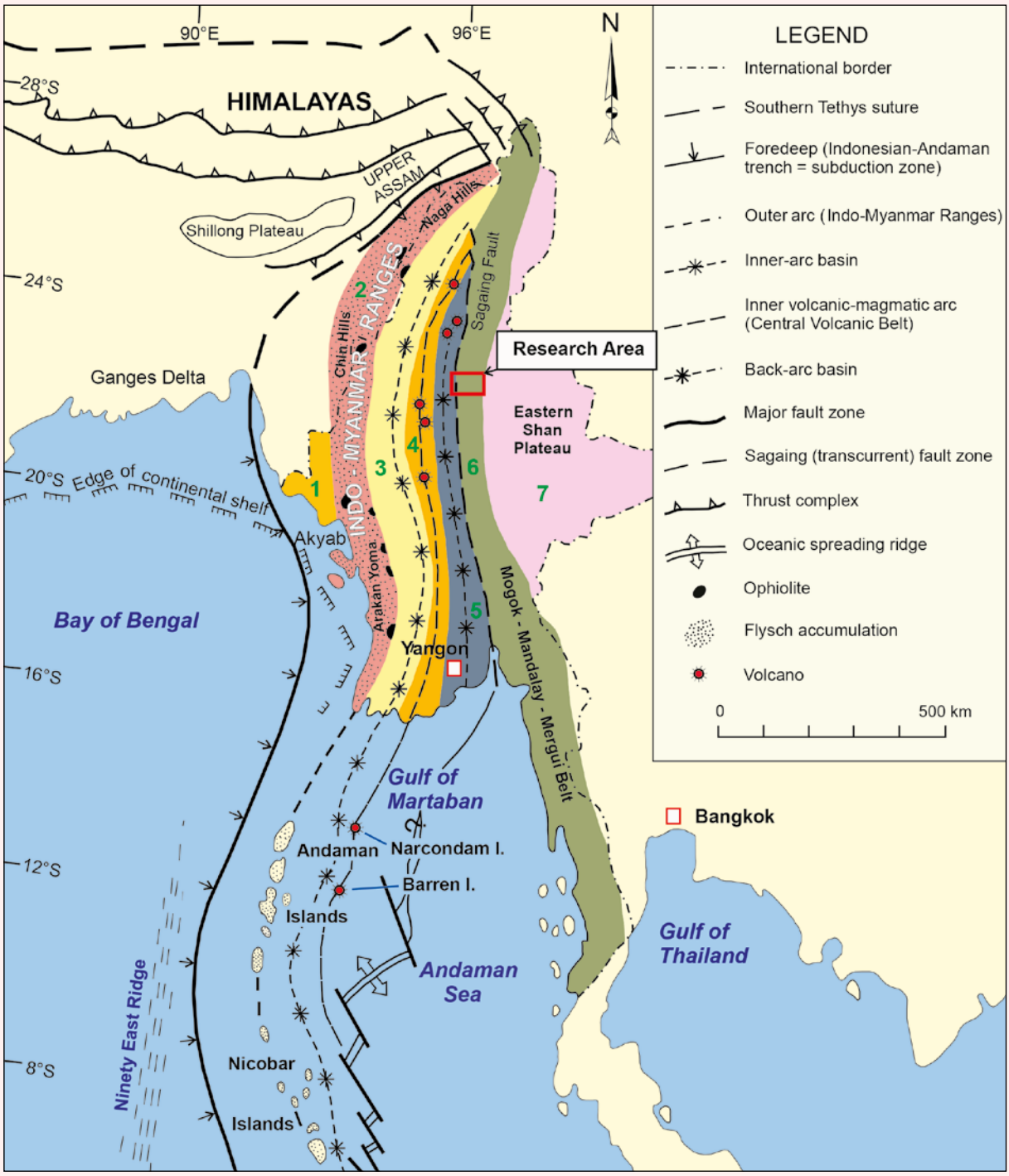

Figure 2: The Mogok research area is indicated on this regional map of Myanmar, which shows the main tectonic domains (numbered 1–7 from west to east) and fault structures (after Bender 1983; Zaw *et al.* 1989, 2015; Zaw 1990). The domains are: (1) Arakan (Rakhine) Coastal Strip, (2) Indo-Myanmar Ranges, (3) Western Inner-Burman Tertiary Basin, (4) Central Volcanic Belt (or Central Volcanic Line), (5) Eastern Inner-Burman Tertiary Basin, (6) Mogok-Mandalay-Mergui Belt and (7) Eastern Shan Highlands.

Figure 3: The main tunnel at the Kyauksaung mine in central Mogok provides an example of spinel extraction from primary (marble) host rocks. Photo © S. Hänsel, 2016.

deposits such as alluvial and eluvial placers, as well as karstic sinkholes and caverns (Thein 2008). To extract the gems from the primary rocks and associated karstic deposits, an extensive network of tunnels (e.g. Figure 3) has been excavated by drilling and blasting. For the secondary deposits, traditional mining methods are used such as *twinlon* (digging shafts in the soil/gravel with a maximum depth of ~30 m), *myawdwin* (hydraulic mining along hillsides; Figure 4) and *ludwin* (mainly used in sinkhole and cavern excavations). In the alluvial plains of the Mogok area, the gem-bearing gravel is usually reached at approximately 6–7 m below the surface (Iyer 1953). Detailed descriptions of the traditional mining methods used in the Mogok area are given in numerous reports (e.g. Gordon 1888; Halford-Watkins 1932a, b, c; Ehrmann 1957; Gübelin 1965; Keller 1983).

MATERIALS AND METHODS

For this study, we collected and analysed 87 pink to red, orangey pink to orangey red and grey to purplish grey gem-quality spinel samples from six mining sites in the Mogok area (Yadanar Kaday Kadar, Bawlongyi, Kyauksin, Kyauksaung, Pyaungpyin and Mansin; see Figure 5) and 13 samples bought in local gem markets. A list of the samples is shown in Table I.

We polished the surface of each spinel to provide a clear view of the interior and then used a standard gemmological microscope (Cambridge Instruments) at 10×–70× magnification to observe mineral inclusions in the samples. Photomicrographs of the inclusions were taken with a Nikon D7000 digital camera attached to a System Eickhorst GemMaster microscope using 16×–80× magnification.

Raman microspectroscopy was performed on the inclusions in each sample using one of two different setups: a Renishaw inVia Raman system coupled with a Leica DM2500 M microscope, using an argon-ion laser at 514.5 nm wavelength; and a Bruker Senterra Raman spectrometer coupled with an Olympus microscope, using a solid-state Nd-YAG laser at 532 nm or a direct diode laser at 785 nm. Raman spectra were mostly collected in the range of 1400–100 cm^{-1}, except for graphite (1600–100 cm^{-1}) and apatite (4000–100 cm^{-1}, to detect water peaks). Maximum exposure time per scan was 10 seconds and 10–50 scan accumulations were collected. Remarkably, there was only minor interference with the fluorescence of spinel. However, we were not able to identify very tiny inclusions with Raman

Figure 4: Hydraulic mining of gem-bearing gravels at Mansin in north-eastern Mogok demonstrates how spinels are obtained from secondary deposits. Photo © M. M. Phyo, 2016.

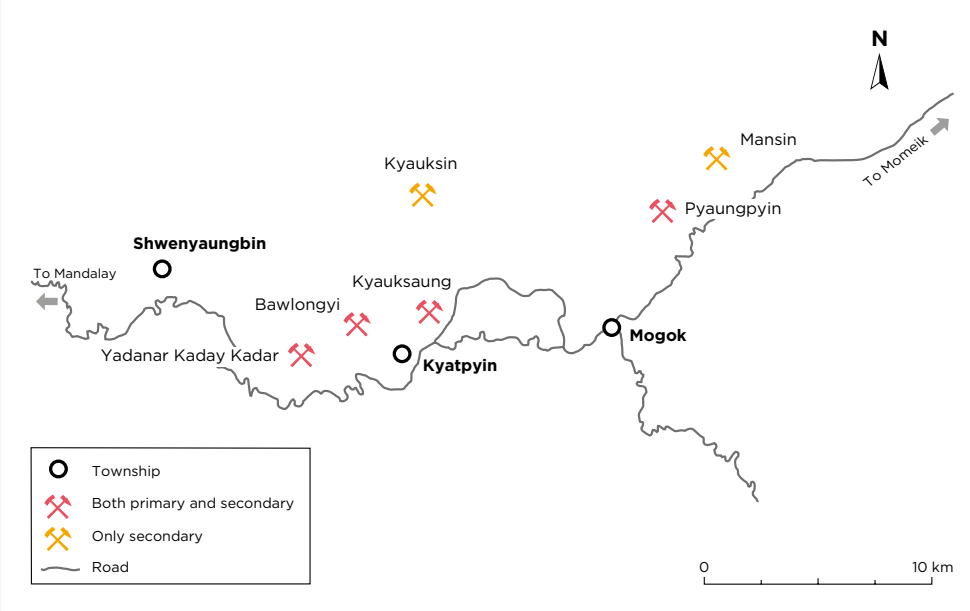

Figure 5: The mining locations from which spinel samples were obtained for this study (the 'research area' shown in Figure 2) are plotted on this map of the Mogok area.

Table I: Mogok spinel samples investigated for this study.

Location*	Coordinates	No. samples	Weight range	Colour	Photo
Yadanar Kaday Kadar	22°54′18.54″N 96°22′38.18″E	5	0.18–0.35 ct	Orangey pink, light pink to red	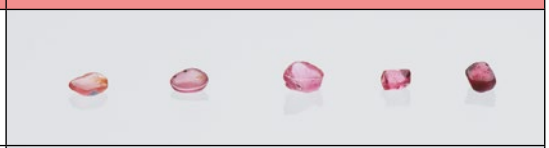
Bawlongyi	22°54′53.59″N 96°23′53.09″E	19	0.16–2.21 ct	Light pink to red, dark red, orange to orangey red, grey, purplish grey	
Kyauksin	22°57′26.51″N 96°25′31.63″E	17	0.45–1.24 ct	Light orange to orange, purplish grey	
Kyauksaung	22°55′20.08″N 96°25′55.44″E	10	0.10–0.62 ct	Light orange to orange, grey to purplish grey	
Pyaungpyin	22°57′13.53″N 96°31′10.63″E	6	0.45–0.67 ct	Intense red	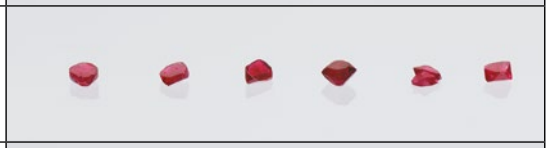
Mansin	22°58′28.64″N 96°32′23.57″E	30	0.05–2.59 ct	Light pink to strong pink, red to dark red	
Market	_	13	0.54–8.65 ct	Light pink to dark red, grey	

* Sample locations (top to bottom) are arranged from west to east. Photos by M. M. Phyo.

microspectroscopy due to their small size. In addition, some inclusions produced Raman spectra of superposed combinations of two or more minerals, while others did not reveal a conclusive spectrum (probably because their weak Raman signal was dominated by the signal from the host spinel).

Scanning electron microscopy (SEM) was used to gain more information about selected mineral inclusions by visualising their shape and paragenetic intergrowths. In addition, SEM with energy-dispersive X-ray spectroscopy (EDS) was used to analyse their chemical composition. To accomplish this, the samples were carefully polished to expose the inclusions at the surface, and were then analysed at the Nano Imaging Lab of the University of Basel using a REM-FEI Nova NanoSEM 230 unit equipped with an energy-dispersive spectrometer and both secondary-electron (SE) and backscattered-electron (BSE) imaging modes. This system employed an in-lens detector for producing secondary-electron images and an Octane Elite detector for EDS analysis. With this setup, we were able (in principle) to detect elements ranging from carbon to uranium as long as they were above the instrumental detection limit. We used an accelerating voltage of 15 kV, with magnifications of 50×–2,500× and a working distance of 4.0–12.5 mm.

RESULTS

The solid inclusions that we identified in the Mogok spinels are listed in Table II, along with those identified

Table II: Alphabetical list and abundance of solid inclusions in Mogok spinels documented in the present study and compared with previously published work and other localities.

Mineral	Mogok area		Other localities				
	Present study[1]	Previous studies[2]	Vietnam	Tajikistan	Tanzania	Madagascar	Sri Lanka
Amphibole (presumably pargasite)	xxx	—	—	—	—	—	—
Anatase	x	—	—	—	—	—	—
Anhydrite	x	3	—	—	—	—	—
Apatite	xxx	1, 2, 3, 6, 7	1, 3	—	1	1	1, 7
Baddeleyite	x	—	—	—	—	—	—
Boehmite	x	—	—	—	—	—	1
Brucite	x	—	—	—	—	—	—
Calcite	xxxxx	3, 6, 7	3	—	—	—	1
Chlorite	x	—	—	—	—	—	—
Chondrodite	xxxxx	3	—	—	—	—	—
Clinohumite	x	—	—	—	—	—	—
Clinopyroxene	xxx	—	—	—	—	1	—
Diaspore	x	—	—	—	—	—	1
Dolomite	xxxxx	1, 3, 6	3	—	—	—	1
Geikielite	xxx	—	—	—	—	—	—
Goethite	x	—	1	—	—	—	—
Graphite	x	1, 3	3	—	—	—	1
Halite	x	—	—	—	—	—	—
Ilmenite	—	1	—	—	1	—	—
Magnesite	xxx	3	3	—	—	—	—
Marcasite	x	—	—	—	—	—	—
Molybdenite	x	—	—	—	—	—	—
Olivine (forsterite)	x	1	—	—	1	—	1
Periclase	x	—	—	—	—	—	—
Phlogopite	xxx	1	—	—	1	—	1
Potassium feldspar	—	3	3	—	—	—	1
Pyrite	—	1	—	—	—	—	1
Pyrrhotite	x	—	—	—	—	—	1
Quartz	—	1	—	—	—	—	1
Rutile	—	1	—	—	1	1	1
Sulfur	xxxxx	4, 5, 7	—	—	—	—	—
Titanite	—	1	3	—	—	—	1
Uraninite	—	1	—	—	1	—	1
Zircon	x	2	3	3	—	—	1

[1] Abbreviations: xxxxx = frequently seen; xxx = sometimes encountered; x = rarely found; — = not found.
[2] References: 1 = Gübelin & Koivula (1986, 2005); 2 = Themelis (2008); 3 = Malsy & Klemm (2010); 4 = Pardieu *et al.* (2016); 5 = Peretti *et al.* (2017); 6 = Zhu & Yu (2018); 7 = www.lotusgemology.com (accessed June 2018).

by other researchers in the published literature for spinels from Mogok and various deposits worldwide. The Raman spectra of representative inclusions that we identified are available in the Appendix at the end of this article, and photomicrographs and BSE images of the inclusions are shown below. Mineral abbreviations in these images are from Whitney & Evans (2010).

In general, most of the inclusions formed anhedral grains, although some of them (such as amphibole and phlogopite) showed subhedral to euhedral shapes. Inclusion sizes commonly ranged from 1 µm to several millimetres. Their wide range of composition is reflected in the presence of several mineral groups (silicate, oxide, hydroxide, carbonate, phosphate, sulphate, sulphide and native element).

Optical Microscopy and Raman Analysis

Since Mogok spinels formed in marbles, it was not surprising to find abundant carbonates (i.e. calcite, dolomite and magnesite; e.g. Figure 6) in most of the samples. They were typically present as colourless, irregularly shaped (partially resorbed) inclusions. Raman microspectrometry further revealed that carbonates sometimes also occurred as filling substances in octahedral negative crystals (similar to calcite and dolomite found by Zhu & Yu 2018).

A range of Ca- and Mg-bearing silicates was found in the investigated spinels. The humite-group minerals chondrodite [$(Mg,Fe^{2+})_5(SiO_4)_2(F,OH)_2$] and clinohumite [$Mg_9(SiO_4)_4F_2$] were the most abundant Mg-silicates in our samples (Figure 7). A colourless, short-prismatic Ca-Mg amphibole (presumably pargasite; Figure 8a) and clinopyroxenes (diopside and augite) were found in spinels from both Kyauksin and Mansin. Figure 8b reveals a colourless clinopyroxene inclusion with distinct cleavage that is associated with minute yellow elemental sulphur

Figure 6: An example of carbonate inclusions observed in the Mogok spinel samples is shown here by magnesite (Mgs). Photomicrograph by M. M. Phyo.

and black marcasite grains in a spinel from Mansin. In accordance with Gübelin & Koivula (2005), we also found forsterite, the Mg end member of the olivine group, as colourless rounded crystals (Figure 8c) in a few Mogok spinels. However, we did not find titanite and feldspar in our samples, both of which were mentioned by Gübelin & Koivula (2005) in spinel from Mogok. Zircon, although a common inclusion in sapphires and rubies from Mogok, was found only as tiny accessory inclusions in a few spinels from Kyauksin and Kyauksaung.

Oxides were commonly present as accessory phases in the studied spinels. We found yellow, rounded anatase (TiO_2) and yellow, prismatic baddeleyite (ZrO_2) inclusions, both surrounded by tension cracks (Figure 9a, b). Interestingly, using SEM-EDS we identified geikielite ($MgTiO_3$) as tiny needles/lamellae in spinel from Yadanar Kaday Kadar (western Mogok; Figure 9c). They were oriented along {111} lattice planes and

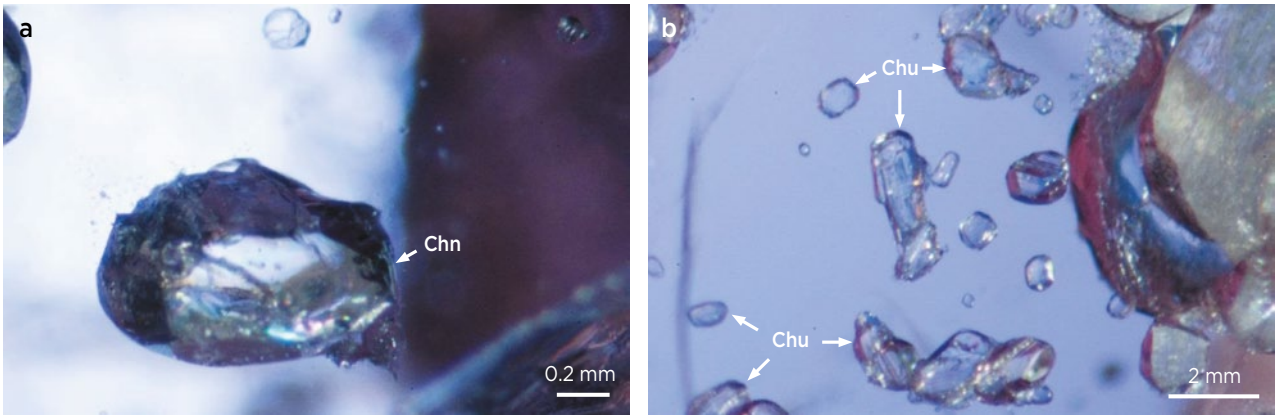

Figure 7: Among the silicate inclusions that were identified, humite-group minerals were common in some of the spinels: (**a**) anhedral chondrodite (Chn) and (**b**) a cluster of subhedral clinohumite (Chu) crystals. Photomicrographs by M. M. Phyo.

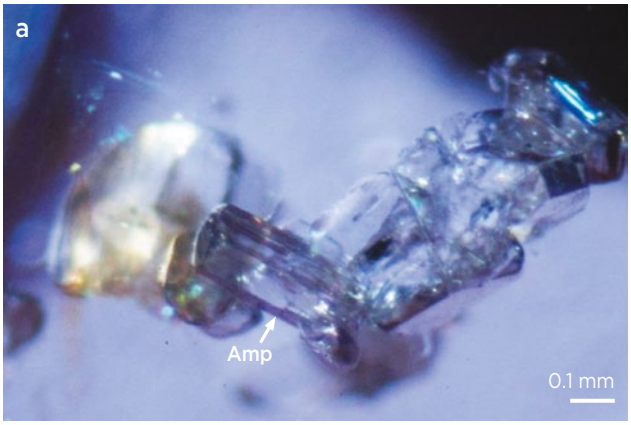

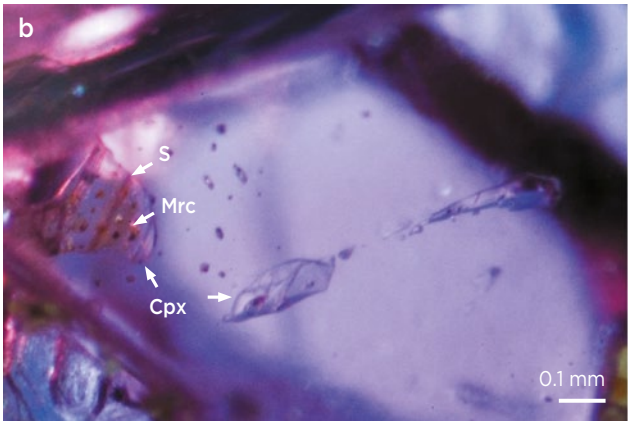

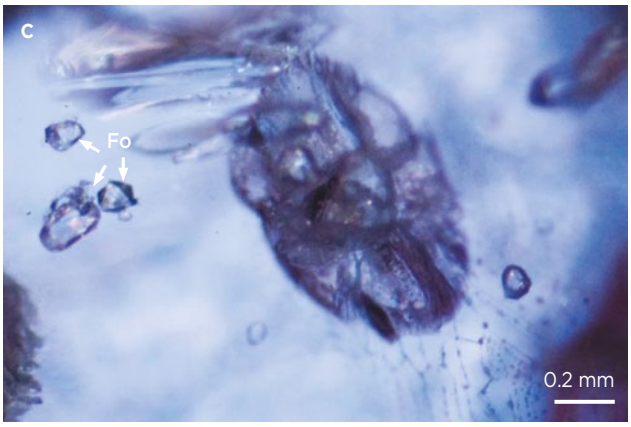

Figure 8: Other Ca- and Mg-bearing silicate inclusions were also present in the spinels. (**a**) Euhedral colourless amphibole (Amp; presumably pargasite) crystals form clusters in Kyauksin spinel. (**b**) Anhedral clinopyroxene (Cpx) showing a distinct set of cleavage planes is associated with tiny yellow sulphur (S) and black marcasite (Mrc) spots in a spinel from Mansin. (**c**) Anhedral olivine (forsterite; Fo) crystals are seen here next to a larger clinohumite inclusion. Photomicrographs by M. M. Phyo.

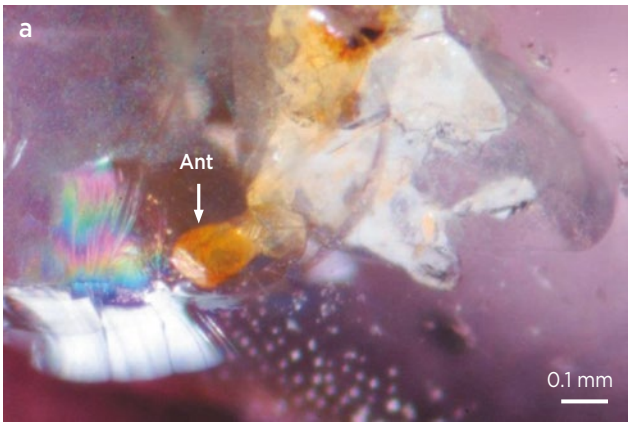

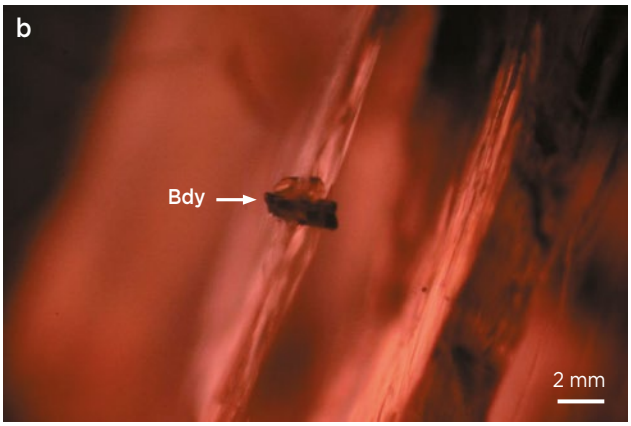

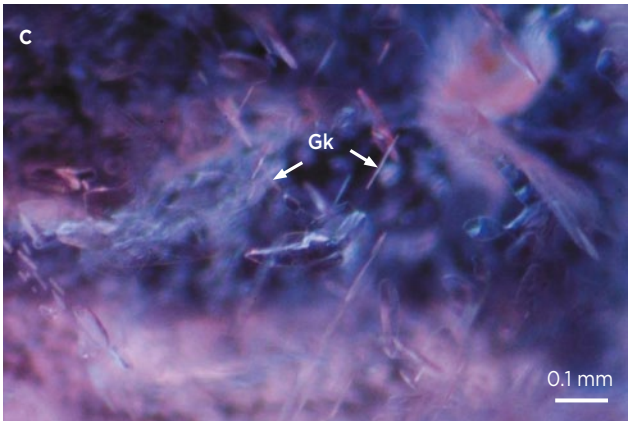

Figure 9: Oxide minerals identified in the spinels include (**a**) yellow anatase (Ant) that is surrounded here by negative crystals and tension cracks, (**b**) baddeleyite (Bdy) crystals that are also often associated with tension cracks and (**c**) tiny flake-like colourless geikielite (Gk) lamellae along {111} lattice planes in a spinel from Yadanar Kaday Kadar. Photomicrographs by M. M. Phyo.

presumably formed by epigenetic exsolution, similar to geikielite-rich ilmenite exsolution lamellae seen in chromite-chrome spinel from metacarbonates in Austria (Mogessie *et al.* 1988). To our knowledge, this is the first time such geikielite exsolution lamellae have been reported in gem-quality spinel.

We also found several hydroxides in our spinels, including diaspore [α-AlO(OH)], boehmite [γ-AlO(OH)], brucite [$Mg(OH)_2$] and goethite [α-$Fe^{3+}O(OH)$]. They probably formed as retrograde phases, and were present in secondary inclusion trails (boehmite) or associated with phlogopite (brucite) or pyrrhotite (goethite).

Additional accessory inclusions in our spinels included anhydrite ($CaSO_4$, also known from Mogok rubies; Smith & Dunaigre 2001), apatite [$Ca_5(PO_4)_3(F,Cl,OH)$], sulphides (marcasite, molybdenite and pyrrhotite), graphite (C) and elemental sulphur (S_8). Apatite was seen as transparent to semi-transparent, anhedral to subhedral crystals (Figure 10). As for the elemental sulphur, its presence within fluid inclusions and as solid inclusions (Figure 11) seems to be highly characteristic for spinels from Mansin (Pardieu *et al.* 2016; Peretti *et al.* 2017). Less commonly, we also found elemental sulphur in the spinels from Kyauksaung and Pyaungpyin.

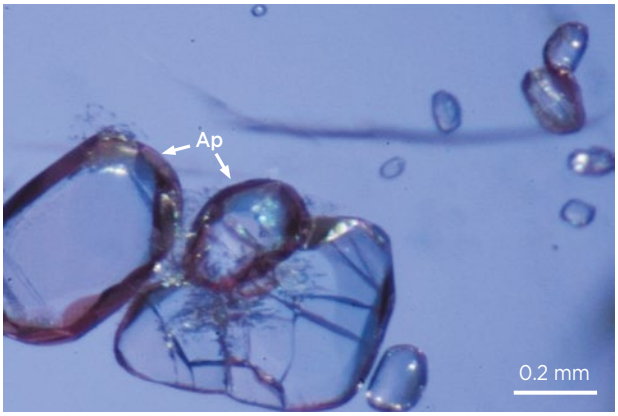

Figure 10: Rounded anhedral apatite (Ap) inclusions are present in this Mogok spinel. Photomicrograph by M. M. Phyo.

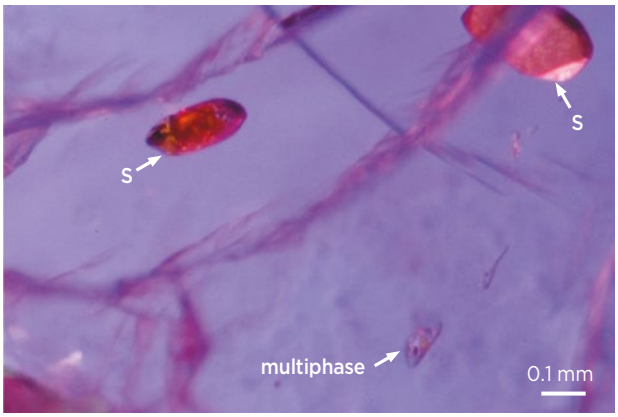

Figure 11: Solid inclusions of elemental sulphur (S) are seen here with multiphase fluid inclusions (probably containing liquid and sulphur) in a spinel from Mansin. Photomicrograph by M. M. Phyo.

SEM Imaging and EDS Analysis

Using SEM-EDS, it was possible to visualise and identify for the first time the complex intergrowth of multiphase inclusions (some containing small fluid cavities) within spinel from Mogok. These assemblages consisted of various minerals such as calcite ($CaCO_3$), dolomite [$CaMg(CO_3)_2$], halite (NaCl), phlogopite [$KMg_3(AlSi_3O_{10})(F,OH)_2$], apatite and/or anhydrite of sugary texture (Figure 12). They were similar to the inclusions containing residues of molten salts described by Giuliani *et al.* (2015) in rubies from Mogok.

SEM-EDS also revealed other inclusion features in the spinels. A euhedral amphibole inclusion contained

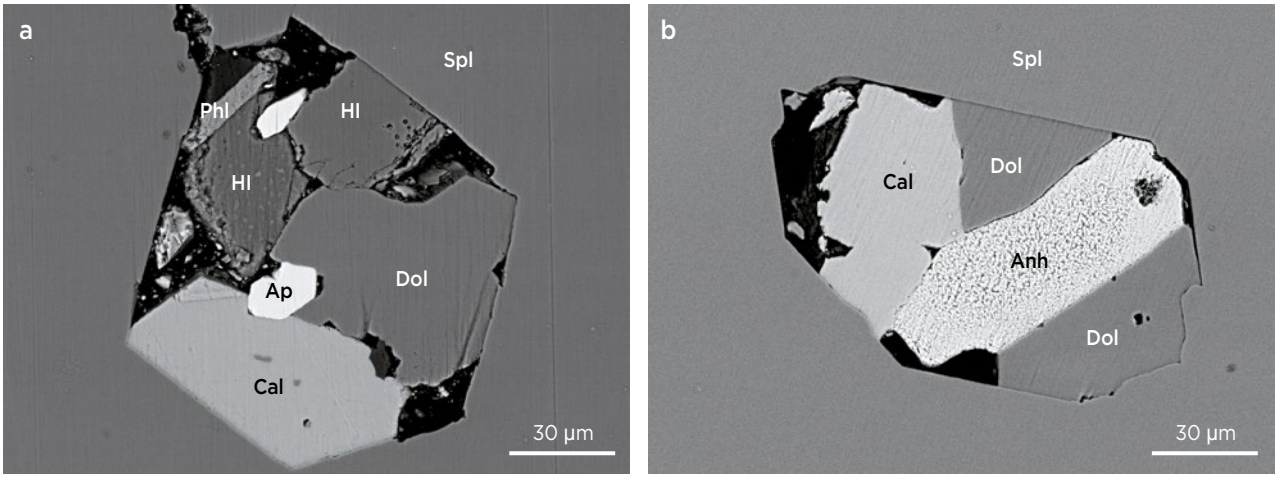

Figure 12: BSE images reveal the contents of multiphase inclusions in Mogok spinel (Spl): (**a**) calcite (Cal), dolomite (Dol), halite (Hl), phlogopite (Phl) and apatite (Ap); and (**b**) calcite, dolomite and anhydrite (Anh).

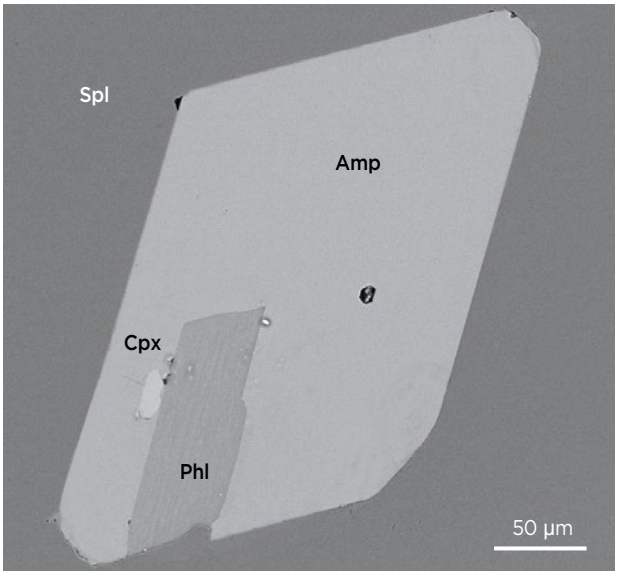

Figure 13: BSE imaging shows that a euhedral amphibole (Amp) inclusion in a spinel from Kyauksin contains inclusions of phlogopite (Phl) and clinopyroxene (Cpx).

clinopyroxene and phlogopite domains in a spinel from Kyauksin (Figure 13). We also imaged some phases that presumably exsolved from their hosts: dolomite blebs in certain calcite inclusions (Figure 14a) and the geikielite lamellae in spinel (Figure 14b) that were mentioned above. Furthermore, rare accessory inclusions of baddeleyite (also mentioned above) were easily visible with the SEM (Figure 15).

Various secondary mineral inclusions were identified with SEM-EDS, such as chlorite and brucite together with a phlogopite inclusion (Figure 16a), and a bright red powder-like substance that proved to be an iron compound (e.g. an Fe oxide or hydroxide, probably goethite) that formed an epigenetic encrustation along the cleavages and boundaries of a phlogopite inclusion (Figure 16b).

DISCUSSION

In the present study, we not only confirmed the presence of most inclusions previously described in the literature for Burmese spinel, but also identified for the first time 16 new solid inclusions in our samples from Mogok: amphibole (presumably pargasite), anatase, baddeleyite, boehmite, brucite, chlorite, clinohumite, clinopyroxene, diaspore, geikielite, goethite, halite, marcasite, molybdenite, periclase and pyrrhotite (see Table II).

Interestingly, we did not observe in our study any 'belly button' apatite inclusions that are considered typical for spinel from Mogok (Gübelin & Koivula 1986, 2005). These inclusions are characterised by a tiny black graphite or ilmenite platelet attached to rounded apatite. As previously described by Malsy & Klemm (2010), we only observed in our samples subhedral to anhedral colourless apatite crystals as individuals or clusters.

We also documented for the first time in gem-quality spinel multiphase inclusions (Figure 12) with small fluid cavities, which may be interpreted as residues of molten salts (Giuliani *et al.* 2003, 2015, 2018; Peretti *et al.* 2017, 2018). Their assemblages are reflective of paragenetic relationships within the host rock (e.g. calcite-dolomite-phlogopite-apatite). Some of the spinel inclusions also demonstrate mineral exsolution (e.g. oriented geikielite lamellae in Figures 9c and 14b) and retrograde transformations after spinel formation (e.g. the breakdown of phlogopite to chlorite, brucite and Fe oxides/hydroxides; see Figure 16; Yau *et al.* 1984).

We observed carbonate inclusions in our spinels from all mining locations sampled in the Mogok area. Some of these carbonate inclusions did not occur as a single mineral phase but were present within multiphase inclusions (Figure 12) and possibly as exsolved assemblages

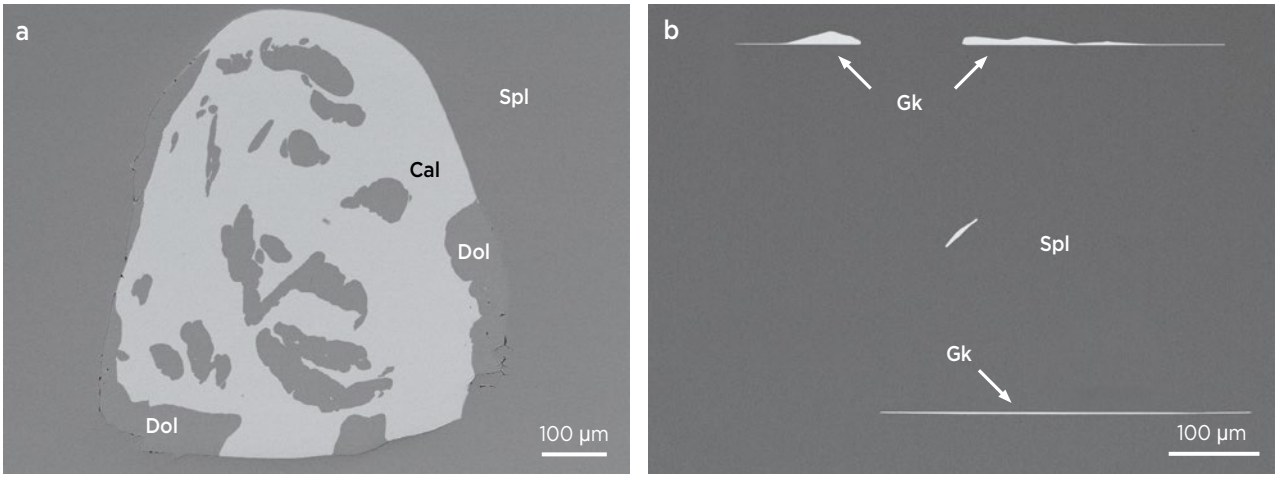

Figure 14: Evidence of exsolved mineral phases in Mogok spinels is seen in these BSE images of (**a**) dolomite (Dol) blebs in a calcite (Cal) inclusion and (**b**) oriented geikielite (Gk) lamellae.

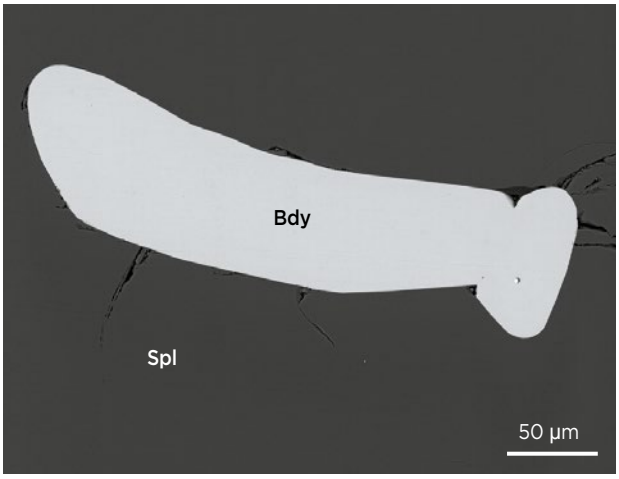

Figure 15: A baddeleyite (Bdy) inclusion with tension cracks shows high contrast against the host spinel in this BSE image.

(Figure 14a). In a few cases, such carbonates were also found in negative-crystal cavities. Moreover, the presence in spinel of various silicates such as amphibole (presumably pargasite), chondrodite, clinohumite and zircon—similar to the carbonate inclusions—reflects the compositional range of the host-rock marbles with interlayered calc-silicates in which these spinels from the Mogok area were formed.

The complex metamorphic evolution of the Mogok Stone Tract during the Himalayan orogeny is connected to and influenced by several magmatic events (Barley *et al.* 2003; Searle *et al.* 2007). Geographically and geologically, all of the spinel localities that were sampled for this study (primary marbles and secondary deposits) were found in close proximity to granite intrusions (Thu 2007). Mineral inclusions such as anatase, olivine, clinopyroxene, periclase and chondrodite could have formed either during granulite-facies regional metamorphism (Thu 2007; Phyo *et al.* 2017; Thu & Zaw 2017) or by contact metamorphism from the nearby intrusions. Remarkable is the prevalence of elemental sulphur and graphite in spinel from Mansin (Gübelin & Koivula 2005; Pardieu 2014; Vertriest & Raynaud 2017), which points to highly reducing conditions. Moreover, the multiphase inclusions with small fluid cavities that we observed in our Mogok spinels showed similarities to hypersaline fluid inclusions in Mansin spinel (Peretti *et al.* 2017, 2018) and to the residues of molten salts found in Mogok ruby (Giuliani *et al.* 2015).

We also sought to investigate whether it is possible to separate spinels from different locations within the Mogok Stone Tract based on their inclusions (see Figure 17; see also the sample locations in Figures 5 and 18). Although the number of samples (87, not including those obtained from local markets) and inclusions (about 400) that were analysed might not be sufficient, we can still report meaningful results. Similar to Themelis (2008) and Malsy & Klemm (2010), and as expected for marble-related spinels, we observed an abundance of carbonate inclusions in spinels from all of the studied localities. Closely related are impurities in the marble host rock—graphite, apatite and phlogopite—which were present in spinels from nearly all of the localities, although in distinctly smaller quantities. Additional inclusion phases were observed in spinel from a few localities, such as elemental sulphur (most prominently from Mansin but also from Pyaungpyin and Kyauksaung), anatase (Yadanar Kaday Kadar, Kyauksin and Kyauksaung) and chondrodite (Bawlongyi, Kyauksaung and Mansin). In contrast, a number of inclusions were found only in samples from one locality, such

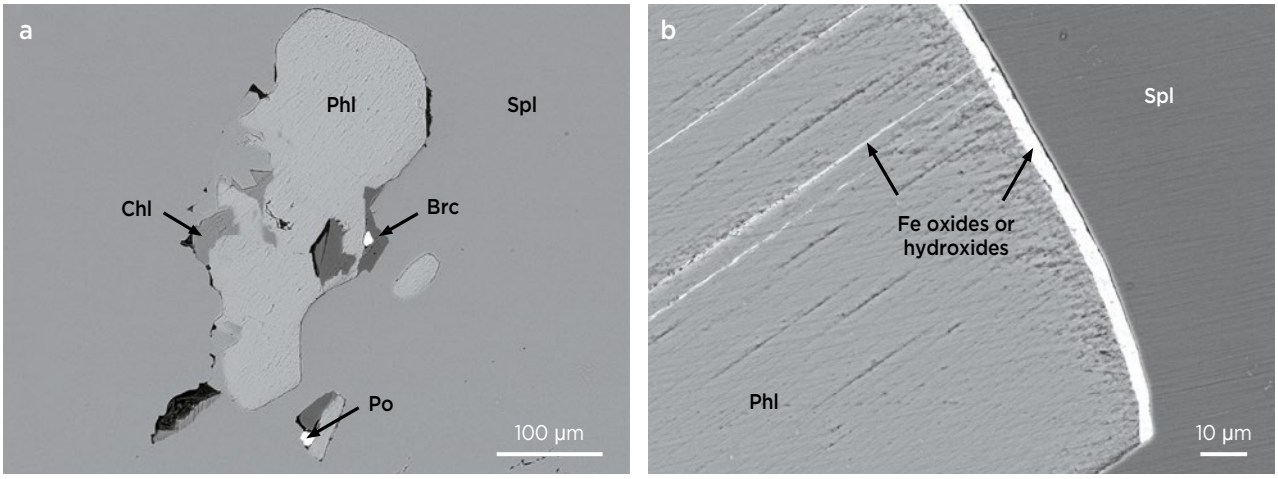

Figure 16: BSE imaging showed various secondary mineral assemblages associated with phlogopite (Phl) in Mogok spinel. (**a**) Phlogopite inclusions with tiny pyrrhotite (Po) grains are intergrown with the secondary minerals brucite (Brc) and chlorite (Chl). (**b**) Secondary Fe oxides or hydroxides are seen as bright areas along the rim and within cleavages in this phlogopite inclusion.

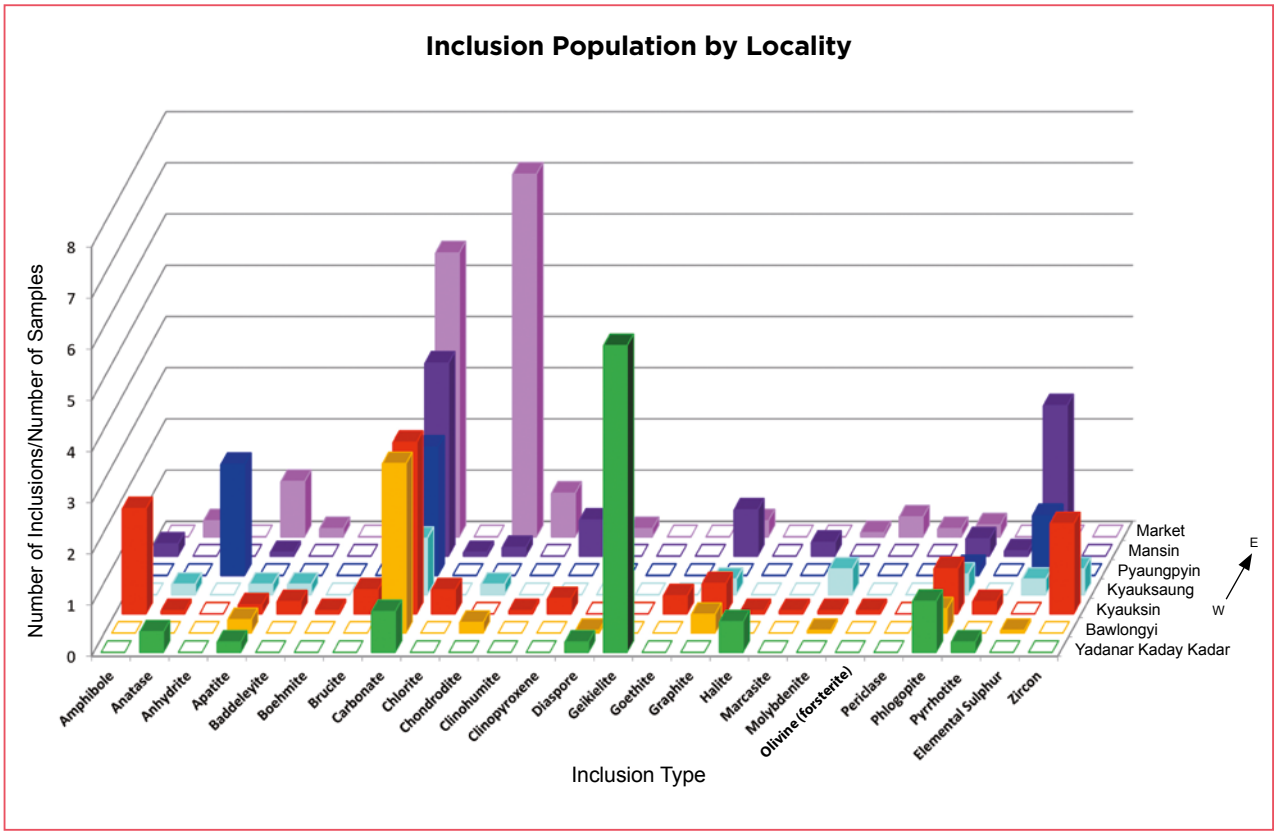

Figure 17: To express the relative amount of inclusions found in spinel from various mining sites (and local markets) in the Mogok region of Myanmar, the total number of observed inclusions was divided by the number of samples from that location. The distribution of the different inclusion types suggests that, with further research, they could be helpful for distinguishing spinels from certain localities.

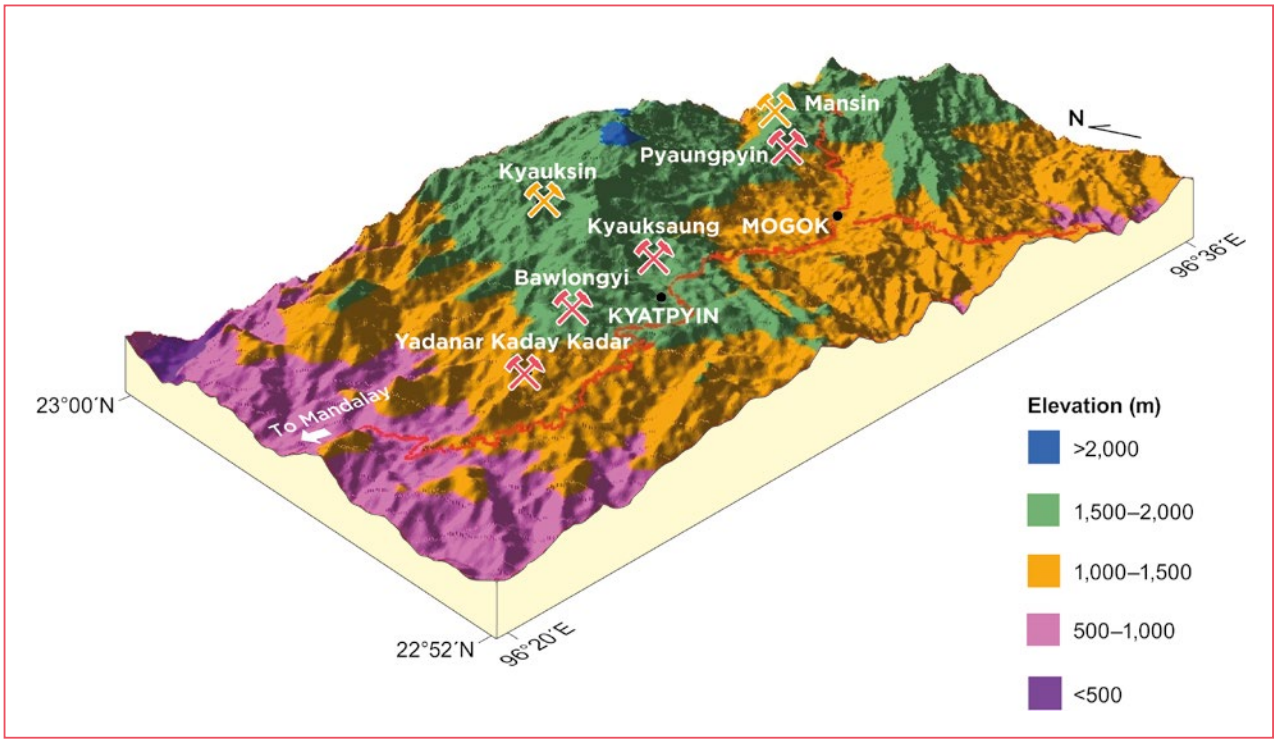

Figure 18: The mine sites sampled for this study are shown on this three-dimensional map of the Mogok area. Most of them are situated at elevations ranging from 1,500 to 2,000 m. The colouration of the mine symbols is explained in Figure 5. Spatial data are based on topographic maps of Northern Shan State and the Katha District (93 B-5 and 93 B-9, scale 1" = 1 mile, 1945).

as goethite (Kyauksin), anhydrite (Pyaungpyin) and geikielite lamellae (Yadanar Kaday Kadar). Whether these findings are truly specific to these locations or just the result of the limited sampling is presently unknown. Nevertheless, the assemblages documented in spinel from Mogok and elsewhere are clearly different from the inclusions seen in synthetic flux-grown spinel (Krzemnicki 2008), and therefore are useful for separating natural spinels from their synthetic counterparts.

CONCLUSION

This study presents the first detailed description of inclusions in spinel from Mogok, Myanmar. It documents several solid inclusions for the first time in these spinels, as well as multiphase assemblages (some containing small fluid cavities) that add to their complexity. All of the mineral inclusions are related to the local geology and geochemistry of the host rocks in the Mogok area. Spinel and its associated minerals such as ruby, diopside, olivine, chondrodite and clinohumite testify to granulite-facies metamorphic conditions in the Mogok Metamorphic Belt (Thu *et al.* 2016; Phyo *et al.* 2017). Elemental sulphur and graphite inclusions furthermore indicate highly reducing conditions during the formation of these spinels. The generation of gem-quality spinel by skarn-forming processes can be excluded due to the absence of typical skarn mineral inclusions (e.g. vesuvianite, pectolite or nephrite) in our samples.

Based on the data presented in this article, the authors feel that such inclusion studies can help distinguish Mogok spinels from those of other sources worldwide (e.g. Figure 19), and therefore contribute to the origin determination of spinels in gemmological laboratories. We expect that further studies of spinel inclusions in the future will add to this knowledge.

Figure 19: Detailed inclusion studies may be helpful toward geographic origin determinations of spinel from various world localities, such as those shown here. All of the crystals are from Mogok, and the cut stones are from Tanzania (7.31 ct pink oval), Tajikistan (5.90 ct pink cushion), Vietnam (all pear shapes, up to 3.22 ct) and Mogok (4.01 and 2.63 ct red cushions). Photo by Prasit Prachagool, Thai Lanka Trading Ltd Part., Bangkok, Thailand.

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APPENDIX

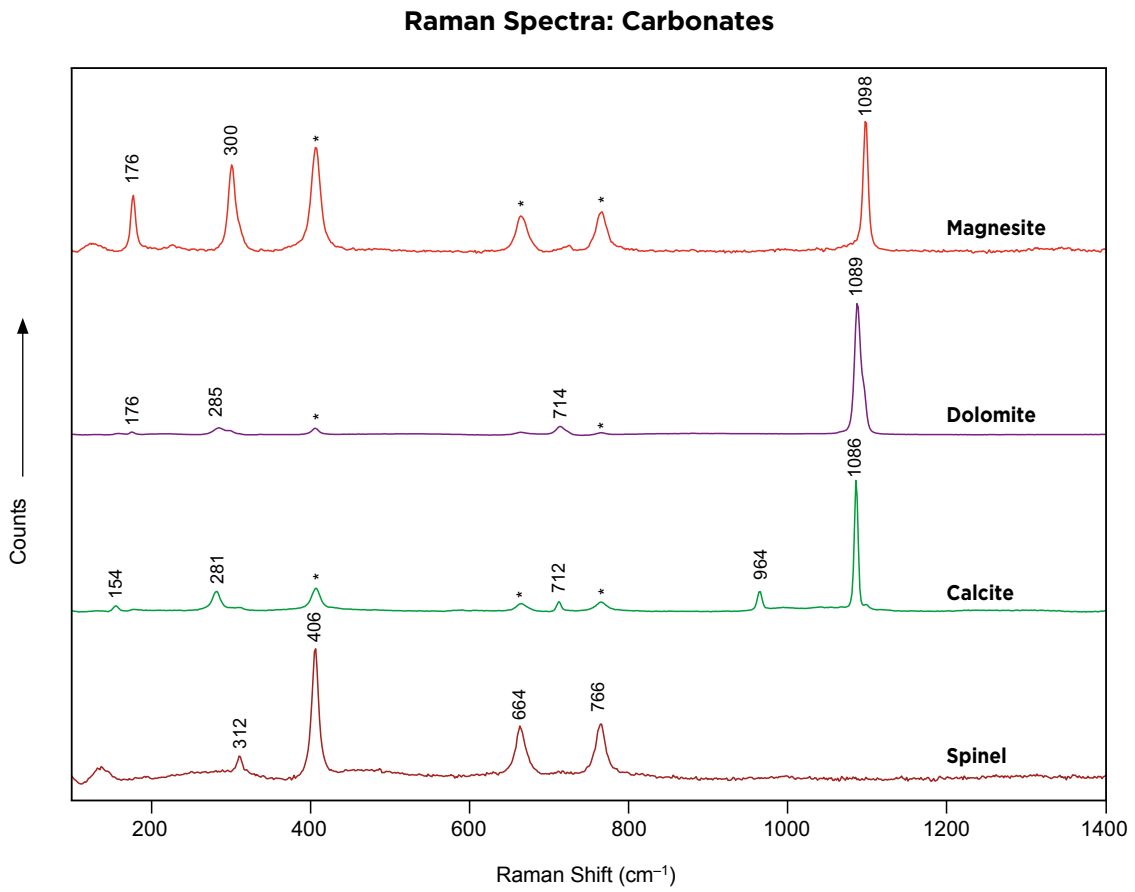

Representative Raman spectra are shown for carbonate mineral inclusions analysed in our samples from Mogok, together with a spectrum of the host spinel. Peaks in the inclusion spectra that are marked with an asterisk are from the host spinel.

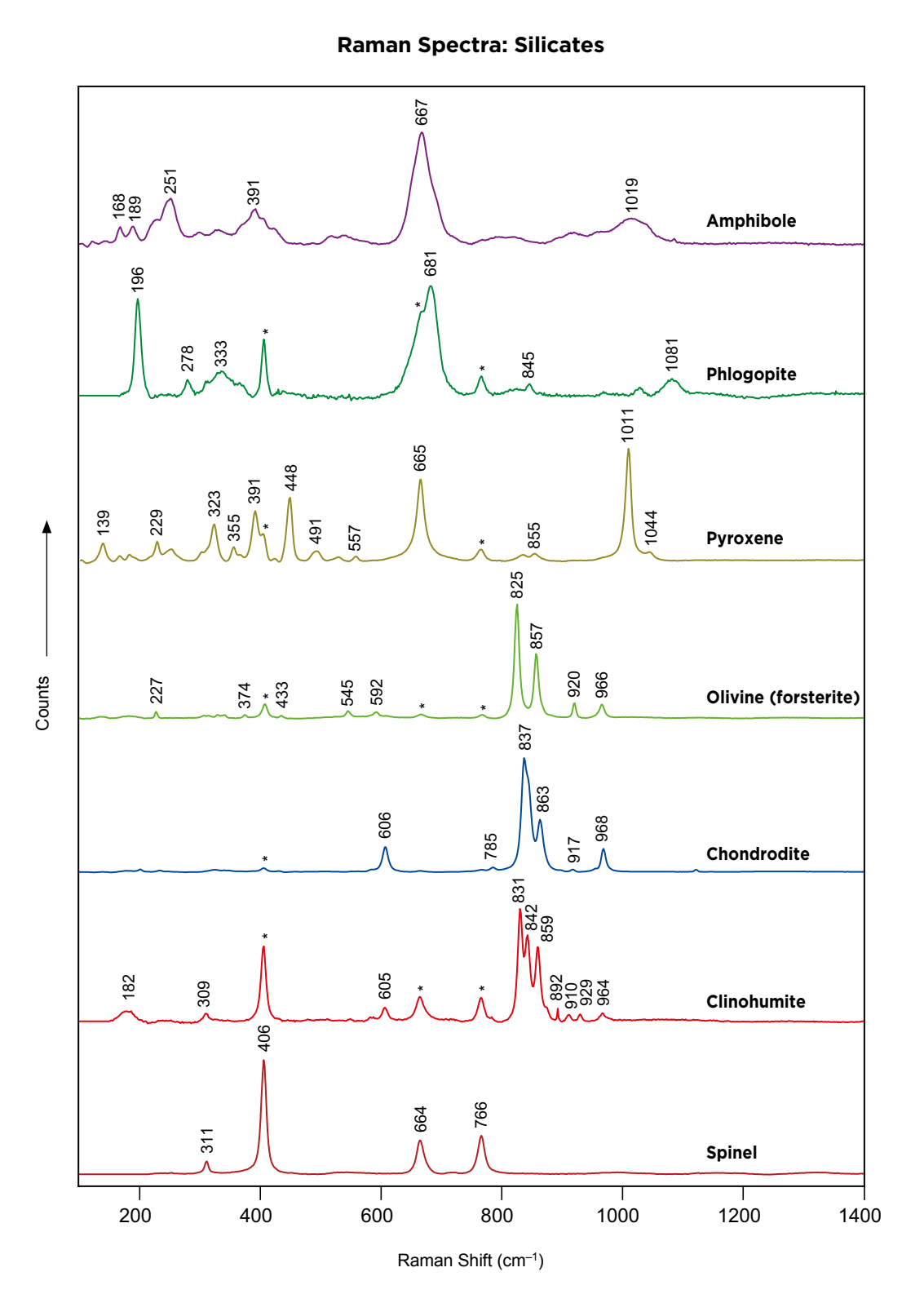

Representative Raman spectra are shown for various silicate mineral inclusions analysed in our samples from Mogok, together with a spectrum of the host spinel. Peaks in the inclusion spectra that are marked with an asterisk are from the host spinel.

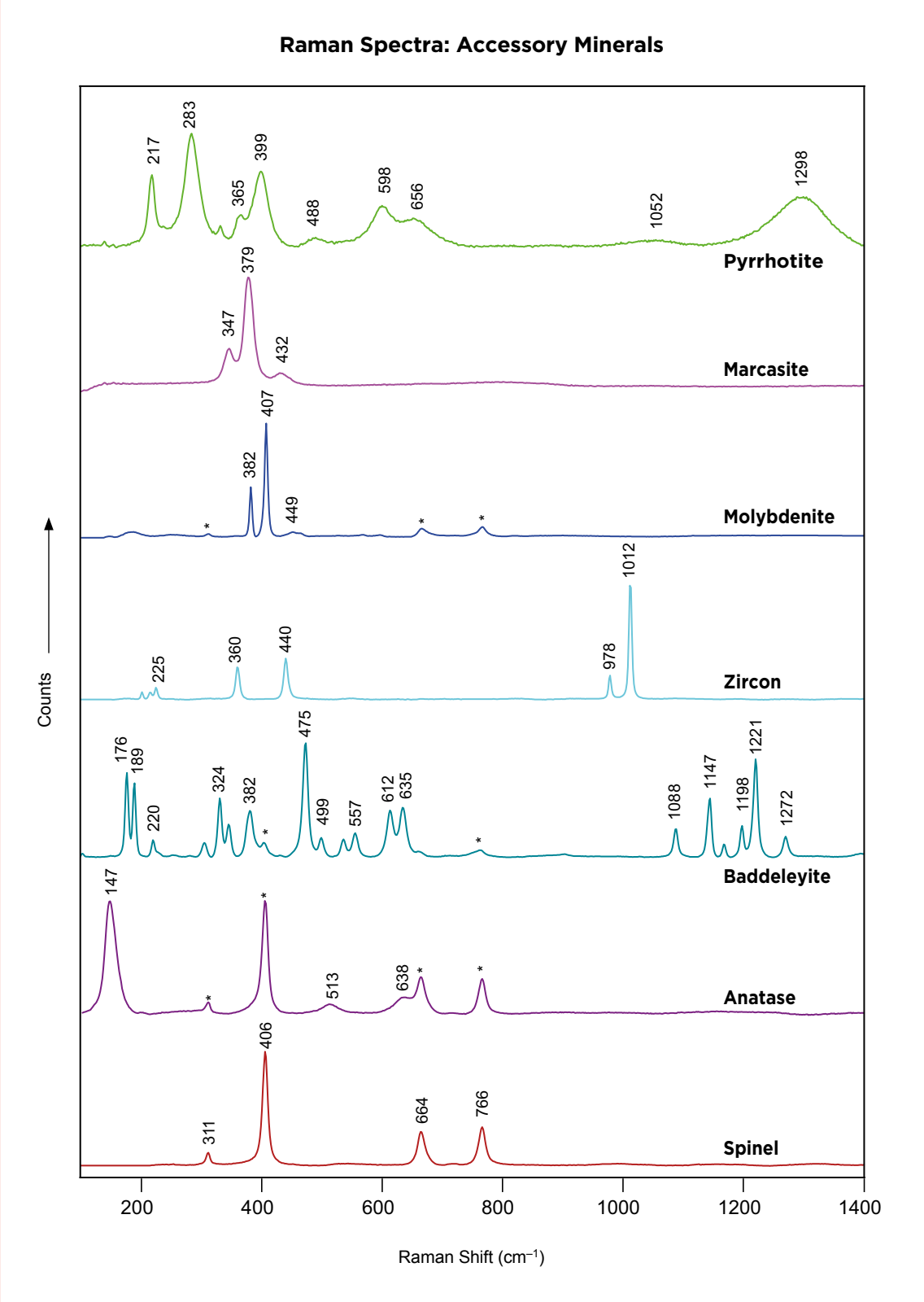

Representative Raman spectra are shown for various accessory mineral inclusions analysed in our samples from Mogok, together with a spectrum of the host spinel. Peaks in the inclusion spectra that are marked with an asterisk are from the host spinel..

Figure 1: Peridots from Yiqisong, Jilin Province, China (left), and from North Korea (right) were investigated for this article. The Yiqisong sample weighs 2.15 ct and displays a yellowish green colour, while the North Korean peridot is 2.75 ct and is more brownish green. Photo by Z. Zhang.

Characterisation of Peridot from China's Jilin Province and from North Korea

Zhiqing Zhang, Min Ye and Andy H. Shen

ABSTRACT: Peridot from Neogene olivine-bearing basalt in the Yiqisong District of Jilin Province, China, and from North Korea are available in the global gem market. We characterised 100 stones from each of these two localities, and found similar RI, birefringence and SG values, but slightly different colour ranges, UV-Vis-NIR spectral characteristics and internal features. The most common inclusions in both the Yiqisong and North Korean samples were 'lily pad' discoid fractures; also present were diopside, chromite, enstatite and lizardite (the latter two were observed only in Yiqisong peridot). Chemical analyses indicated that most samples had forsterite contents ranging from 89.4 to 92.2 mol.%, with a trend toward slightly higher Fe in the North Korean samples. Statistical processing of the trace-element data with Fisher linear discriminant analysis (Fisher-LDA) showed that Al, Zn, Ti, Na and Ge are useful for separating peridot from these two localities.

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Gem-quality peridot has been reported in the gemmological literature from several sources, including Zabargad Island, Egypt (Gübelin 1981); San Carlos, Arizona, USA (Koivula 1981); Kilbourne Hole, New Mexico, USA (Fuhrbach 1992); Tanzania (Stockton & Manson 1983); Kohistan, Pakistan (Jan & Khan 1996); Sardinia, Italy (Adamo *et al.* 2009); and the Central Highlands of Vietnam (Huong *et al.* 2012; Nguyen *et al.* 2016). In addition, pallasitic peridot has been investigated to separate it from its terrestrial counterpart (Shen *et al.* 2011). Furuya & Davies (2015) used statistical analysis of trace-element data to establish the geographic origin of peridot from some locations.

Chinese peridot has been known since the 1980s, initially from the Zhangjiakou-Xuanhua area of Hebei

Province (Koivula & Fryer 1986) and later from the Jiaohe and Baishan areas in Jilin Province (Wang 1996; Liu 2001; Chen & Xing 2011; Gu *et al.* 2015). In 2016, a new deposit of gem-quality peridot (see, e.g., the left-hand stone in Figure 1) was discovered in the Yiqisong District (43°47′ N, 127°56′ E), located approximately 5 km north-east of the previously known Dashihe peridot mine near Jiaohe (Figure 2). The deposit covers an area of ~5.1 km^2 and is hosted by Neogene basalts in the Dunhua-Mishan fault zone (Wang 1996, 2017). Known as the Yiqisong South Mountain mine, this deposit has been worked since 2016 by Yanbian Fuli Peridot Mining Industry Co. Ltd (Dunhua, Jilin, China) using the room-and-pillar method of underground mining. According to an unpublished company report supplied by Yanbian Fuli Peridot Mining Industry Co. Ltd, the reserves are estimated at approximately 450 tonnes of gem-quality peridot. The rough material is fractured but contains transparent areas and can attain large sizes of 3–10 cm and exceptionally up to 25 cm (Wang 2017). The company report indicates that the amount of faceted peridot could reach 20 million carats per year. The stones are sold under the Fuli Jewelry brand.

Because of the high quality of Yiqisong peridot (i.e. attractive yellowish green colour and high clarity) and its significant mineral reserves, it is expected to play an increasingly important role in the global gem market. However, some traders and consumers are confusing Yiqisong peridot with that from North Korea (again, see Figure 1). Although details of the North Korean peridot deposit are not well known, its regional setting places it within the Rangrim massif (cf. Yang *et al.* 2010), and mining takes place in the Changyon District of South Hwanghae Province (see Figure 2).

To provide a scientifically based separation of peridot from the two localities, we performed a detailed gemmological characterisation on numerous samples from Yiqisong and North Korea, focusing on their inclusions, as well as on spectroscopic and chemical data, and the latter were processed using statistical analysis.

MATERIALS AND METHODS

We studied 200 samples of peridot from Yiqisong and North Korea, consisting of 50 rough and 50 faceted stones from each locality (Figure 3). The rough was prepared by polishing windows to facilitate observation of the inclusions. Standard gemmological testing and spectroscopy were performed at the Gemmological Institute of China University of Geosciences (Wuhan).

Colour analysis was performed by taking digital photographs of all rough samples using a Nikon D810

Figure 2: The Yiqisong peridot deposit is located in Jilin Province, north-eastern China, approximately 5 km from the Dashihe peridot mine and ~200 km from another Chinese peridot locality near Baishan. An additional peridot deposit in North Korea is located near the Yellow Sea in South Hwanghae Province. The different colours of the inset map refer to administrative divisions of Jilin Province (yellowish green = Jilin City and pink = Yanbian Autonomous Prefecture).

Figure 3: A total of 200 peridot samples from Yiqisong (**a**: rough and **b**: faceted) and North Korea (**c**: rough and **d**: faceted) were included in this study. Photos by M. Ye.

camera in a light box (6,500 K colour temperature), and camera settings were calibrated using a ColorChecker Gray Balance card. We then used Adobe Photoshop to determine colour parameters (L*a*b*; see, e.g., Berns 2000) with the 5-by-5 Average colour picker.

Refractive indices were measured on 20 faceted samples (10 from each locality) with a GR-6 refractometer produced by Wuhan Xueyuan Jewelry Technology Co. Ltd, and SG values were determined hydrostatically using a Sartorius BT 224 S balance. Microscopic observations and photomicrography of internal features were done with a Leica M205 A microscope equipped with transmitted and fibre-optic illumination.

Raman spectra of inclusions were collected in the range of 1550–100 cm^{-1} using a Bruker Senterra R200-L Raman microspectrometer equipped with a 532 nm laser. The laser output power was 20 mW and the spot size was 50 µm. The inclusions were identified using Opus and CrystalSleuth software, and compared to the RRUFF database of mineral Raman spectra (http://rruff.info).

Polarised ultraviolet-visible–near infrared (UV-Vis-NIR) spectra were obtained on two rough samples (one each from Yiqisong and North Korea) in the 360–1650 nm range with a resolution of 0.5 nm using a JASCO MSV-5200 spectrometer. Spectra were collected along all three crystallographic directions.

Major-element chemical analysis was performed on 10 rough samples (five from each locality, selected as representative by their trace-element data) using a JEOL JXA-8230 electron probe microanalyser (EPMA) in the Center for Global Tectonics, School of Earth Sciences at China University of Geosciences (Wuhan). The following operating conditions were employed: 15 kV accelerating voltage, 20 nA current and a 3 µm beam diameter.

Trace-element analysis was done on all the samples by laser ablation inductively coupled plasma mass spectrometry (LA-ICP-MS) at Wuhan Sample Solution Analytical Technology Co. Ltd, using an Agilent 7700 Series ICP-MS coupled with a GeoLasPro 193 nm excimer laser. The laser employed a 5 Hz pulse rate and a 44 µm diameter spot size. Reference materials included USGS (BCR-2G, BHVO-2G and BIR-1G) and NIST (SRM 610) glasses, and ^{29}Si was used as the normalised element to calculate the concentrations of 55 trace elements with ICPMSDataCal software (Liu *et al.* 2008).

Statistical processing of the trace-element data

was done with the Fisher linear discriminant analysis (Fisher-LDA) model (Fisher 1936; Hastie *et al.* 2009; Blodgett & Shen 2011). We randomly selected 40 samples (20 from each origin) as 'unknowns' and left these samples out while building the LDA model from 160 'known location' samples, using the SPSS statistical analysis software platform (Denis 2018). The results of discriminant analysis were expressed as two linear equations called discriminant functions (or classification functions) and plotted in diagrams.

RESULTS

As shown in Table I, the Yiqisong and North Korean samples had similar RI, birefringence and SG values, but there were some differences in their colour, pleochroism and internal features.

Colour

In general, the Yiqisong samples were yellowish green (Figure 3a, b), while many of the North Korean ones were brownish green (Figure 3c, d) and therefore they also showed brownish pleochroic colours. The colours were plotted in L*a*b* colour space (defined by the International Commission on Illumination [CIE] in 1976), which expresses colour as three numerical values: L* for lightness, and a* and b* for saturation of green–red and blue–yellow colour components, respectively (Berns 2000). As shown in Figure 4a, most stones from Yiqisong had a somewhat higher L* value than those from North Korea, which means Yiqisong peridot tends to be brighter than material from North Korea. In Figure 4b, the samples from Yiqisong tended to have lower a* values, which demonstrates that they are inclined to show less brownish green.

Table I: Gemmological properties of peridots from Yiqisong (China) and North Korea.

Property	Yiqisong, China	North Korea
Colour	Light yellowish green to darker yellowish green	Brownish green to darker brownish green
Pleochroism	Weak: light yellowish green to yellowish green	Weak: light brownish green to brownish green
Diaphaneity	Transparent	Transparent to translucent
RI	1.654–1.695	1.654–1.694
Birefringence	0.035–0.038	0.036–0.038
SG	3.33–3.36	3.33–3.38
Internal features	'Lily pad' inclusions; partially healed fractures; chromite, diopside, enstatite and lizardite (in one sample) inclusions; brown staining	'Lily pad' inclusions; partially healed fractures and smoke-like veils; chromite and diopside inclusions; brown staining

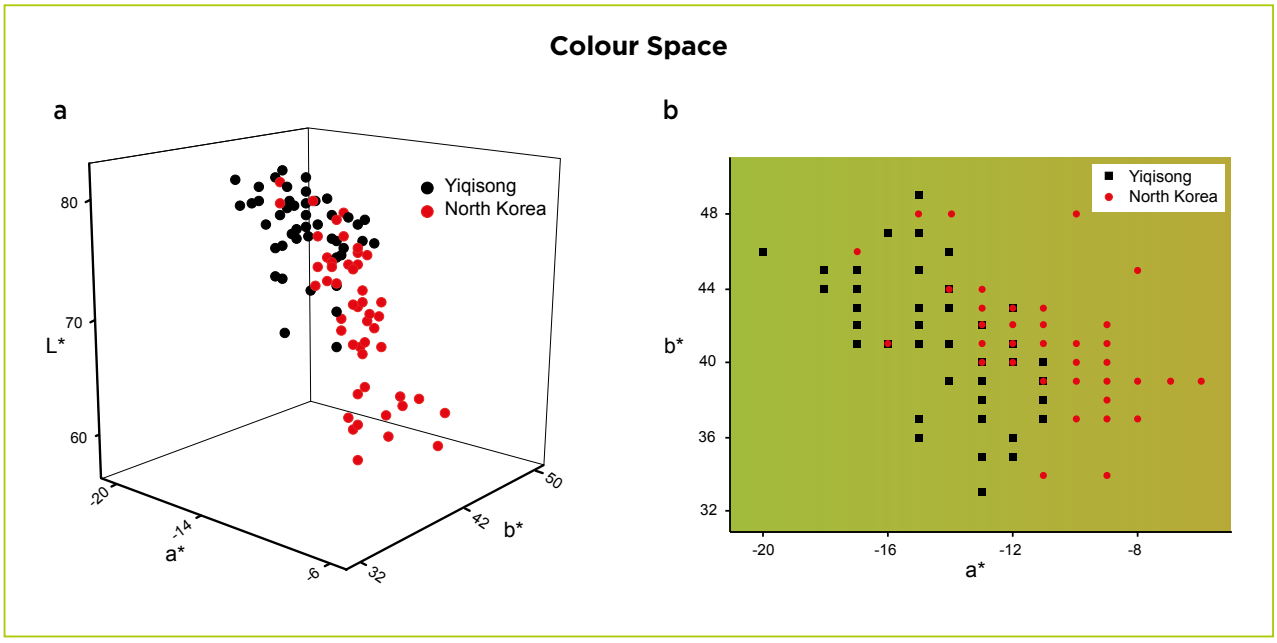

Figure 4: (**a**) A three-dimensional scatter diagram shows how representative peridot samples from Yiqisong and North Korea plot in L*,a*,b* colour space. (**b**) A plot of a* vs. b* for L* = 75% shows that peridot samples from Yiqisong generally have lower a* values, indicative of less brown colouration than the North Korean samples.

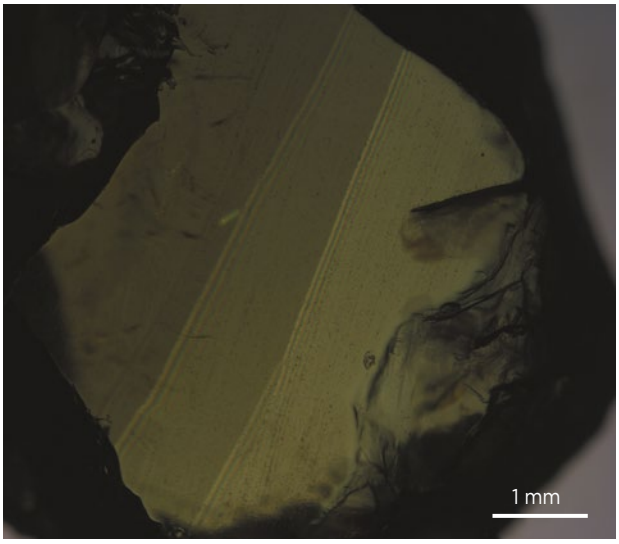

Figure 5: A rough peridot sample from Yiqisong shows wavy extinction between crossed polarisers. Photomicrograph by Z. Zhang.

Internal Features

Some stones from both localities showed wavy extinction between crossed polarisers (Figure 5), which is probably due to plastic deformation that occurred during formation and/or uplift.

In peridot from Yiqisong, inclusions most commonly consisted of 'lily pads' (Figure 6a). This feature is formed by a decrepitation halo, usually surrounding a rounded transparent negative crystal (Gübelin & Koivula 1986) or a dark chromite inclusion (Figure 6b). The surrounding decrepitation halo consisted of two- or three-dimensional planes with radial or geometric shapes. Partially healed fractures were also common in Yiqisong peridot, showing forms such as feathers, veils, etc. (Figure 6c). We did not observe any smoke-like veils in Yiqisong peridot. Occasionally, isolated dark inclusions of chromite (identified by Raman analysis) occurred as needles and flakes, and some samples also contained green and brownish green crystals (Figure 6d, e) that were identified by Raman microspectroscopy as diopside and enstatite, respectively. One Yiqisong sample contained a dark inclusion that proved to be lizardite (Figure 7).

The North Korean peridot also contained 'lily pads' which, in most cases, consisted of a dark crystal (probably chromite) in the centre of one or more decrepitation halos (Figure 8a, b). Partially healed fractures showing feather- and veil-like patterns were common (Figure 8c), and smoke-like veils were often seen in faceted samples of North Korean peridot (Figure 8d). Isolated dark chromite inclusions were relatively more common than in Yiqisong peridot, and they formed octahedral, needle-like or columnar crystals. In addition, isolated transparent green diopside inclusions were also present (Figure 8e). Rough samples of North Korean peridot often showed brownish yellow staining.

Absorption Spectra

The UV-Vis-NIR absorption spectra (Figure 9) of peridots from Yiqisong and North Korea showed differences that were consistent with their colour appearance. In the visible-light region, Yiqisong stones had a transmission

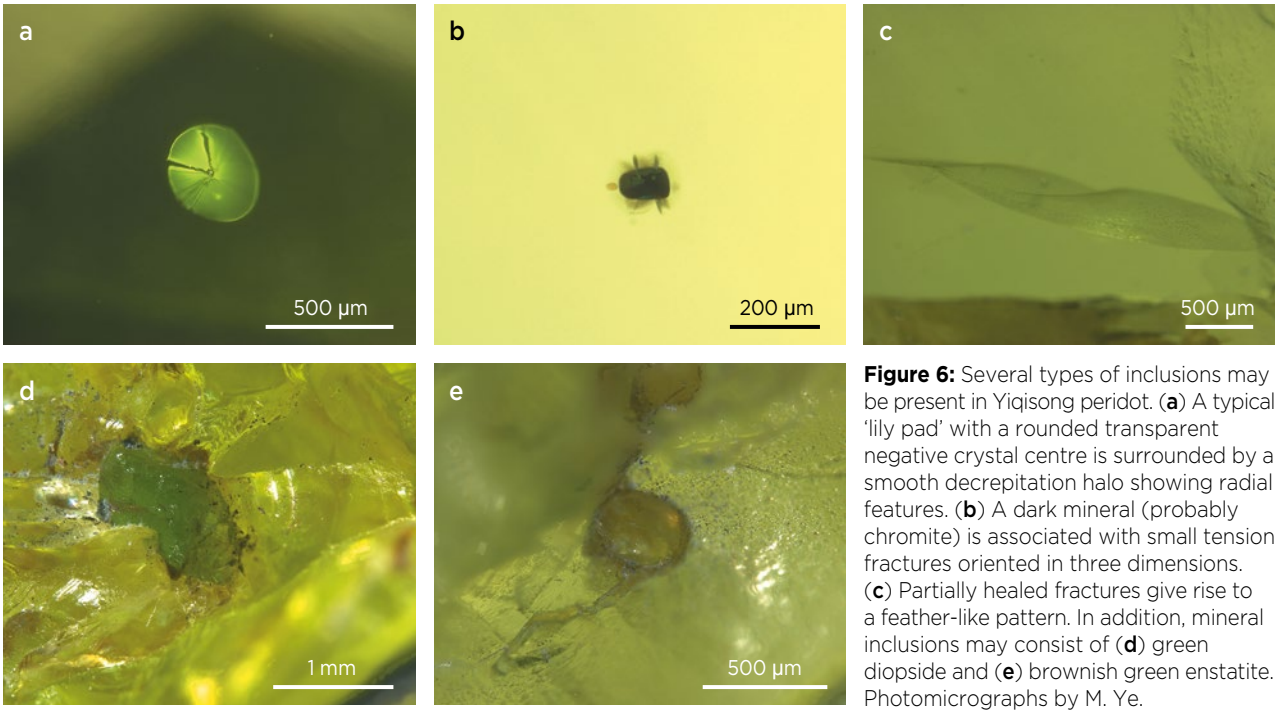

Figure 6: Several types of inclusions may be present in Yiqisong peridot. (**a**) A typical 'lily pad' with a rounded transparent negative crystal centre is surrounded by a smooth decrepitation halo showing radial features. (**b**) A dark mineral (probably chromite) is associated with small tension fractures oriented in three dimensions. (**c**) Partially healed fractures give rise to a feather-like pattern. In addition, mineral inclusions may consist of (**d**) green diopside and (**e**) brownish green enstatite. Photomicrographs by M. Ye.

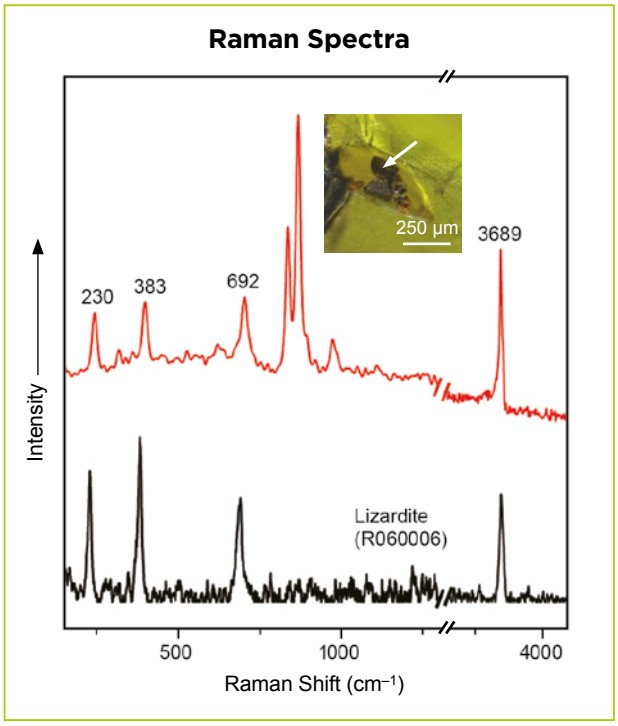

Figure 7: Raman peaks at 230, 383, 692 and 3689 cm^{-1} show clearly that a dark inclusion in a peridot from Yiqisong is lizardite (see spectrum of RRUFF sample R060006 for comparison). This common serpentine species forms as a secondary mineral during metamorphism at relatively low temperatures. Inset photomicrograph by M. Ye.

window centred at 557 nm resulting in a yellowish green colour, while in North Korean ones this window was centred at 565 nm corresponding to a brownish green colour. A broad band at 635 nm was present in all of the spectra and an additional broad absorption at 528 nm was recorded mainly in the β direction. Peaks at 426, ~450, 470 and 490 nm were also noted, particularly in the North Korean samples, and they showed differences in relative absorbance along the α, β and γ directions. In the NIR region, samples from both localities presented similar absorption bands located near 862 nm (α direction) and at 1047 and 1226 nm (α and γ directions). In the β direction, the main band was centred at 1066 nm in Yiqisong peridot, while in North Korean samples it tended to occur at longer wavelengths near 1079 nm.

Chemical Composition

Major Elements. The composition of major elements is listed in Table II. Samples from Yiqisong showed a narrower range of Fe content compared to those from North Korea, with a forsterite component of 90.7–92.2 mol.% for Yiqisong versus 89.4–91.9 mol.% for North Korean peridot.

Trace Elements. The trace-element content of peridots from the two origins was quite similar overall (Table III), but in general the Yiqisong stones contained less Al and Zn than the North Korean samples. Nickel was the most abundant trace element, ranging from 2692 to 3240 ppm (2984 ppm on average) in Yiqisong samples and from 2291 to 3127 ppm (2887 ppm on average) in North Korean samples, followed by, in order of decreasing abundance, Mn, Ca, Co, Cr and Al.

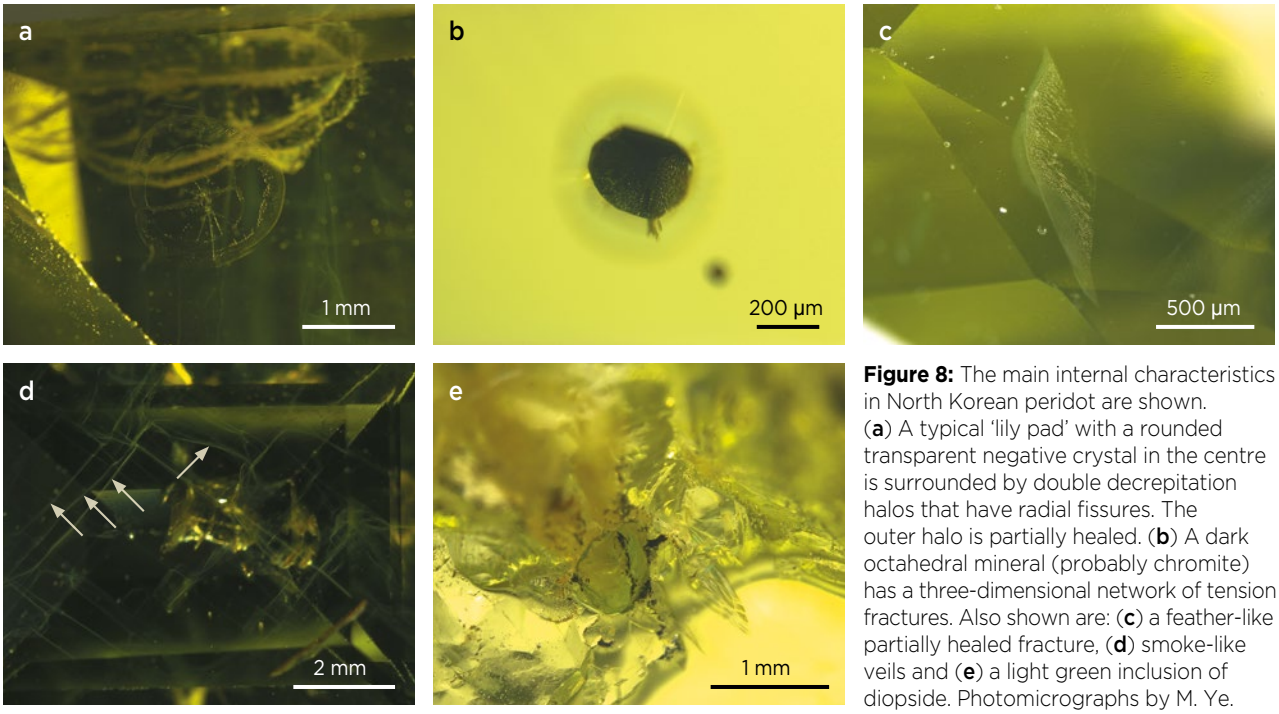

Figure 8: The main internal characteristics in North Korean peridot are shown. (**a**) A typical 'lily pad' with a rounded transparent negative crystal in the centre is surrounded by double decrepitation halos that have radial fissures. The outer halo is partially healed. (**b**) A dark octahedral mineral (probably chromite) has a three-dimensional network of tension fractures. Also shown are: (**c**) a feather-like partially healed fracture, (**d**) smoke-like veils and (**e**) a light green inclusion of diopside. Photomicrographs by M. Ye.

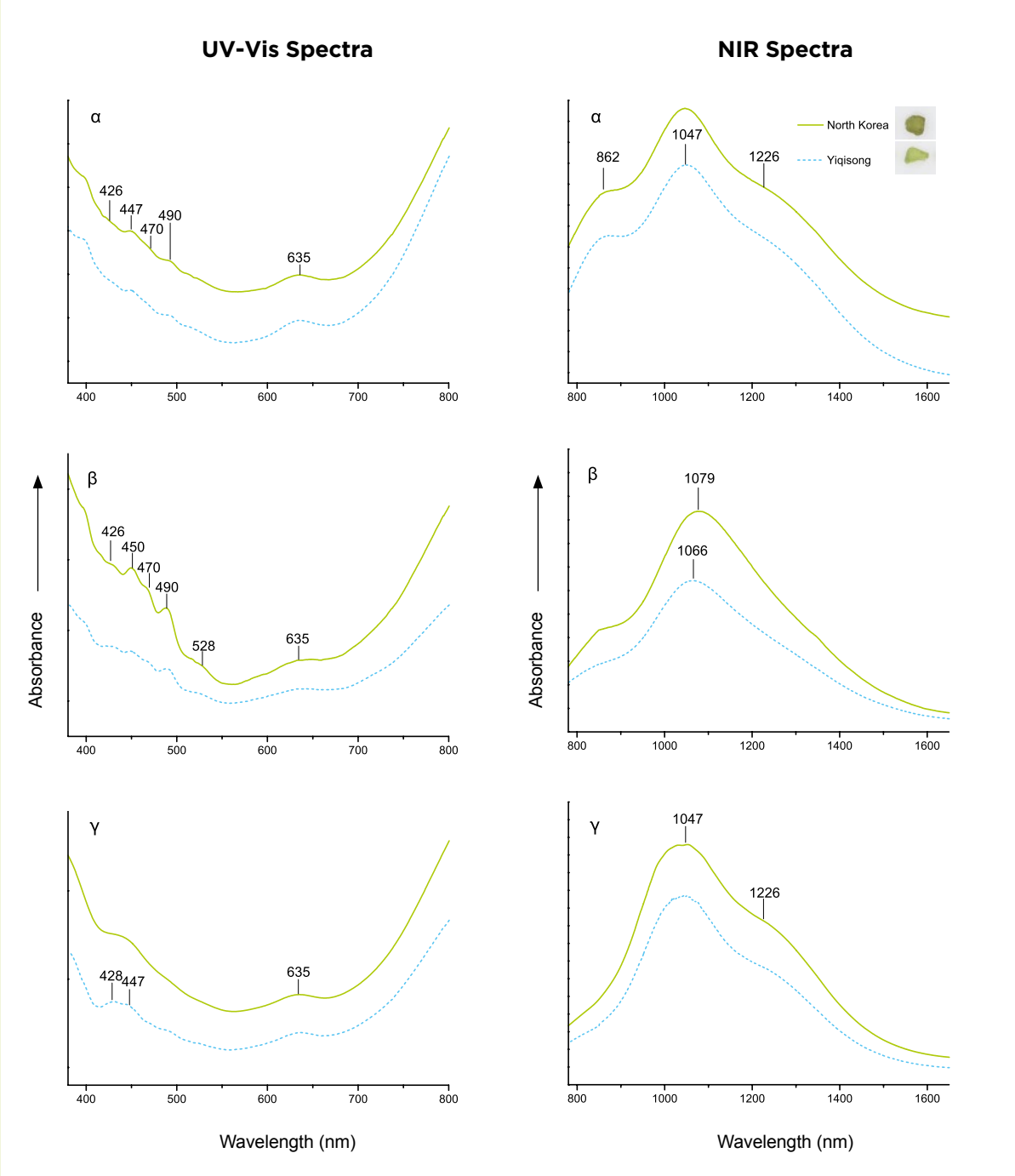

Figure 9: UV-Vis spectra (left) and NIR spectra (right) of peridot samples from Yiqisong and North Korea are shown in α, β and γ directions. All spectra have been shifted vertically for clarity. The approximate path lengths are 1.45 mm for the Yiqisong sample and 1.60 mm for the North Korean peridot.

Fisher-LDA Analysis of Trace-Element Data. For Fisher-LDA statistical analysis, five selected variables were used: Al, Zn, Ti, Na and Ge. Together they provide well-defined fields for peridots from the two origins, with an accuracy of up to 93.8% (cross-validation results). The results gave rise to two linear equations (discriminant functions):

$$x = -15.146 + (0.060 \times C_{Al}) + (0.511 \times C_{Zn}) + (0.105 \times C_{Ti}) - (0.033 \times C_{Na}) + (3.850 \times C_{Ge})$$

$$y = -30.279 + (0.142 \times C_{Al}) + (0.584 \times C_{Zn}) + (0.228 \times C_{Ti}) + (0.049 \times C_{Na}) + (1.958 \times C_{Ge})$$

Table II: Chemical composition of peridots from Yiqisong (China) and North Korea by EPMA.*

Oxide (wt.%)	Yiqisong, China	North Korea
SiO_2	41.10–41.99 (41.48)	41.26–42.10 (41.69)
FeO	7.42–8.76 (7.97)	7.81–10.19 (8.77)
MgO	48.03–49.87 (49.09)	48.14–49.51 (48.66)
Total	98.00–99.64 (98.53)	98.00–100.17 (99.12)
Average composition	$Fo_{91.7}$:$Fa_{8.3}$	$Fo_{90.8}$:$Fa_{9.2}$

* Average amounts are shown in parentheses. Abbreviations: Fo = forsterite, Fa = fayalite.

Table III: Trace-element concentration range of peridots from Yiqisong (China) and North Korea by LA-ICP-MS.*

Element (ppmw)	Yiqisong, China	North Korea
Li	0.92–2.21 (1.37)	0.90–3.94 (1.54)
Na	7.46–77.7 (29.8)	13.8–123 (71.1)
Al	35.4–129 (54.5)	55.2–231 (118)
Ca	96.4–822 (343)	216–1208 (495)
Sc	2.32–6.04 (4.00)	2.90–6.53 (4.34)
Ti	0.84–28.0 (7.17)	1.93–41.9 (15.9)
V	1.55–4.01 (2.49)	1.22–5.57 (3.10)
Cr	37.3–199 (93.0)	29.1–205 (126)
Mn	934–1093 (1002)	958–1489 (1104)
Co	128–144 (136)	127–148 (137)
Ni	2692–3240 (2984)	2291–3127 (2887)
Cu	<7.73 (1.33)	0.15–21.8 (1.91)
Zn	38.0–56.0 (44.9)	44.0–116 (56.3)
Ge	<1.69 (0.075)	0.062–1.48 (0.72)
Sn	<5.81 (1.88)	0.13–7.47 (2.06)

* Average amounts are shown in parentheses.

Figure 10 plots the resulting Fisher-LDA classification function values (x,y) for Yiqisong and North Korean peridots based on the LA-ICP-MS data. We also plotted the 40 'unknown' samples (20 from each locality that we set aside for this purpose) on the two diagrams to check for accuracy. Every Yiqisong and North Korean 'unknown' sample fell into its respective oval field. Only four Yiqisong 'unknown' and seven North Korean 'unknown' samples fell into the overlapping area covered by fields from both localities. Although this is undesirable, the fact that these 11 spots still fell within their respective oval regions (and none of them fell outside of their corresponding field) indicates that our statistical model is valid. A table showing the results from both the initial and cross-validation stages of the Fisher-LDA analysis is available in the online data depository on *The Journal's* website.

DISCUSSION

The RI, birefringence and SG values for peridot samples from Yiqisong and North Korea (again, see Table I) are similar to those previously reported for peridot from some sources (i.e. Egypt, USA [Arizona], China, Vietnam and Italy; see references given in the Introduction). However, the SG range of our samples from both localities is lower than that of peridot from New Mexico and Pakistan (again, see references given in the Introduction). Chinese peridot (i.e. from the Zhangjiakou, Baishan and Jiaohe areas) is typically yellowish green, while North Korean peridot appears more like some of the material from Arizona, with a somewhat brownish green colour.

Internal features such as 'lily pads' (associated with negative crystals or chromite grains), crystals of chromite or green diopside, and veil-like partially healed fractures have also been observed in peridots from various origins. The lizardite that we documented in one peridot from Yiqisong may provide evidence of serpentinisation (Li 1993).

Since peridot is an idiochromatic gem material, the typical features of its UV-Vis spectra (Figure 9) are mainly due to the presence of Fe^{2+}. Specifically, bands near 470, 490 and 526 nm are caused by Fe^{2+}, while those at 426 and 635 nm are likely due to Ni^{2+}, and the feature at ~450 nm might be associated with Fe^{2+} and Mn^{2+} (Burns 1970; Rossman *et al.* 1981). Since Fe^{2+} is mainly responsible for the colouration in peridot (Tang *et al.* 2012, 2016), we are inclined to infer that the 447 nm feature is related to Fe^{2+} rather than Mn^{2+}. In the NIR region, along the β direction, the main band associated with Fe^{2+} content at

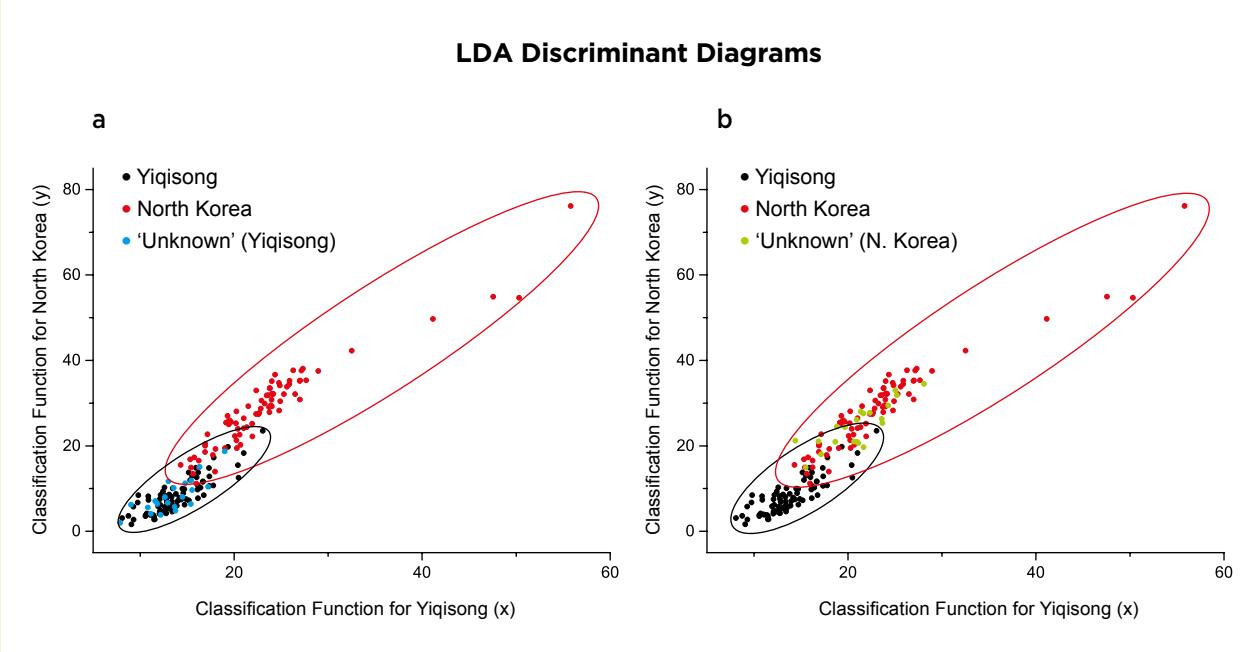

Figure 10: Scatter diagrams of Fisher-LDA classification function values (x, y) are shown for Yiqisong and North Korean peridots based on LA-ICP-MS data. Although the fields show some overlap between the two localities, data for randomly selected 'unknown' samples from Yiqisong (**a**) and North Korea (**b**) plot with their respective groups.

1066 nm in Yiqisong peridot shifts to longer wavelengths near 1079 nm in North Korean material, consistent with the greater Fe content measured in those stones by EPMA (see Table II; Burns 1970).

The chemical constituents of olivine fall along the forsterite (Mg_2SiO_4; abbreviated Fo) to fayalite (Fe_2SiO_4; expressed as Fa) solid-solution series, in which Mg^{2+} and Fe^{2+} can substitute for each other completely. Gem-quality peridot typically contains about 8–10% FeO (Gübelin 1981), otherwise reported as falling within the ranges of $Fo_{88–93}$ (Jan & Khan 1996), $Fo_{88.3–92.0}$ (Embey-Isztin & Dobosi 2007) or $Fo_{88.6–96.0}$ (Shen *et al.* 2011). Our samples from both localities correspond to $Fo_{89.4–92.2}$, consistent with the ranges shown by gem-quality peridot from elsewhere.

Trace-element data and statistical analysis provided reliable means to help separate peridot from Yiqisong and North Korea. The cross-validation results indicated a 93.8% accuracy, while our 40 randomly selected 'unknown' samples all fell in their correct fields (as plotted in Figure 10). However, 11 of them plotted in the overlapping area for the two localities, supporting the fact that any final conclusion of a sample's origin should be drawn from a combination of characteristics, including colouration, distinctive inclusions and chemical evidence. The statistical analysis of trace-element chemistry is just one piece of evidence to reach a sensible conclusion.

CONCLUSIONS

Peridots from Yiqisong (e.g. Figure 11) and North Korea have gemmological characteristics and inclusion features similar to those of peridot from other deposits worldwide. In addition, stones from both localities have forsterite contents that are typical for gem-quality peridot. While both Yiqisong and North Korean peridots have the well-known 'lily pad' inclusions, smoke-like veils were seen only in North Korean samples, whereas enstatite and lizardite were documented only in peridot from Yiqisong. Comprehensive statistical analysis (i.e. Fisher-LDA) of LA-ICP-MS data has shown that most peridots from these two localities can be separated by their trace-element contents.

In conclusion, the key factors for separating Yiqisong from North Korean peridot are: (1) colour, (2) the distinctive inclusions and (3) trace-element composition combined with Fisher-LDA statistical analysis. To successfully determine the origin of a sample, it is important to consider a combination of information covering all of these aspects so that a consistent set of data supports the conclusion.

Figure 11: The centre stone in this pendant is a peridot from Yiqisong that weighs 4.35 ct. Photo courtesy of Yanbian Fuli Olivine Mining Co. Ltd.

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The Modern History of Gemstone Faceting in Sri Lanka

Justin K Prim

ABSTRACT: Drawing on information provided by cutters, factory owners and machine manufacturers, this article traces the evolution of gem-cutting technology in Sri Lanka, from the use of traditional machines such as the *hanaporuwa* and the *bannku opa pattalaya*, to the birth of the modern cutting industry that started in the 1970s with the introduction of the Imahashi faceting machine from Japan. Modifications to its design by visionary Sri Lankan companies such as Bandu Wickrama Engineering Works and Sterling Gems & Lapidary provided further innovations that facilitated the introduction of affordable and precision-quality machines into commercial cutting facilities, leading to great improvements in the quality of gemstone faceting in Sri Lanka.

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The art of fashioning stones in Sri Lanka (formerly Ceylon) goes back more than 2,000 years, and gems have been mined on the island for even longer (ICA Congress 2017). Gemstones are deeply tied to Sri Lanka's history, and the island is referenced in many historical texts, from Pliny in 77 AD (Corso *et al.* 1988) to Marco Polo in ~1300 (Moule & Pelliot 1938). Polo tells us, 'You must know that rubies are found in this Island and in no other country in the world but this. They find there also sapphires and topazes and amethysts, and many other stones of price' (Moule & Pelliot 1938). In 1344, the Islamic traveller and scholar Ibn Battuta wrote (Gray 1996, p. 45):

> Gems are met with in all localities of the island of Ceylon. In this country the whole of the soil is private property. An individual buys a portion of it and digs to find gems. He comes across stones white blanched: in the interior of these the gem is hidden. The owner sends it to the lapidaries who scrape it until it is separated from the stones which conceal it. There are the red (rubies), the yellow (topazes), and the blue (sapphires) which they call neilem (nilem)[1].

The modern history of Sri Lankan gem cutting began in the early 1980s, and its evolution since then has resulted in dramatic improvements in the faceting of stones there (e.g. Figure 1). Prior to the modern era, a more ancient narrative was in progress that is much harder to pin down. The Sri Lankan cutting industry initially developed around the south-western coastal towns of Galle, Gintota and Beruwala, at a time when the Sri Lankan gem trade was mainly in the hands of Middle Eastern traders who settled in the country between 400 and 800 AD (Ahmed Shareek, pers. comm. April 2017). They had caravans that travelled inland to buy rough from miners in gem-bearing localities such as Ratnapura and Eheliyagoda, and then brought the stones back to the seaports of Colombo and Galle for export on Arab ships (Mahroof 1989).

Efforts to modernise the gem industry in Sri Lanka (e.g. Kularatnam 1975) were mostly unsuccessful until the 1980s. Among the many subsequent developments were important advances in the Sri Lankan gem-cutting industry, which are described here and based on information provided by cutters, factory owners and machine manufacturers. As the industry has developed, it has also grown, and it is now estimated that there are around 15,000 coloured stone cutters in Sri Lanka (National Gem and Jewellery Authority 2014) that facet free-size, calibrated and melee gems for the jewellery and watch industries.

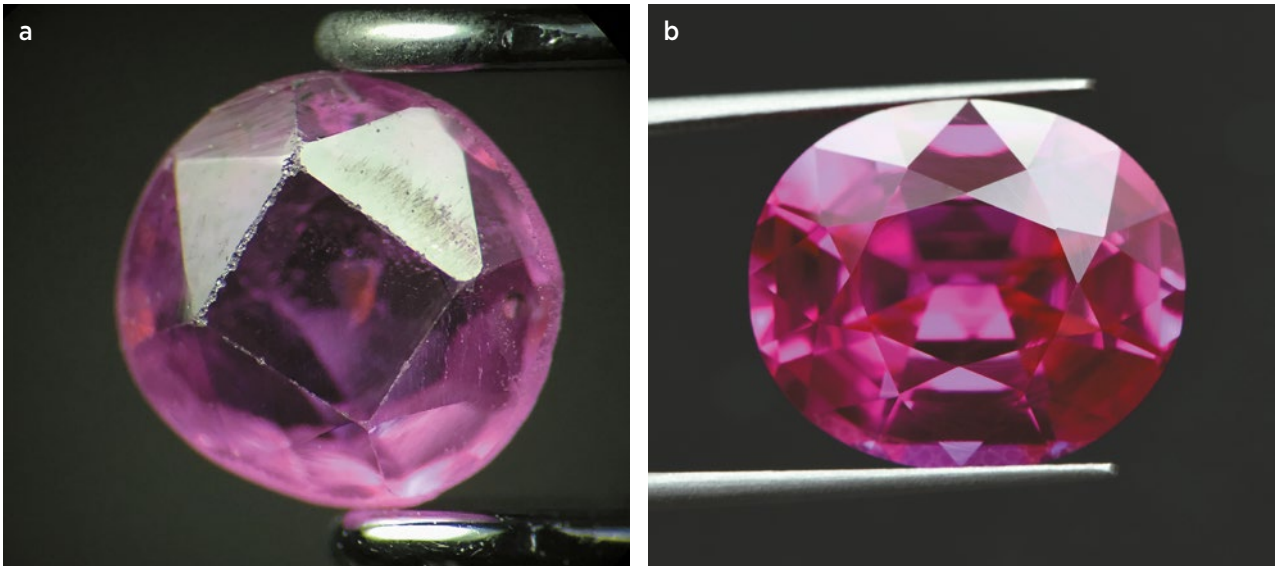

Figure 1: These pink sapphires demonstrate the dramatic improvement in Sri Lankan gem-cutting. (**a**) This 1.5 ct stone was cut on a *hanaporuwa* cutting machine in the 1970s and shows a so-called native cut appearance. (**b**) By comparison, this 19 ct gem was faceted on a modern Sri Lankan machine in a well-executed 'Ceylon' mixed-cut style. Photos by J. Prim.

TRADITIONAL CUTTING TECHNIQUES

The traditional machine used for cutting gems in Sri Lanka is called the *hanaporuwa*, and this bow-driven device was typically used to both preform and facet stones (Zwaan 1982). The cutter sits in front of the machine and draws the bow back and forth with his right hand (Figure 2) in order to spin a vertical lap disc that is made of lead embedded with carborundum powder. The stone is pressed against the lap with the left hand. The cutter rotates the stone with his fingers to cut a cabochon, and this is still the preferred method of cutting star sapphires in Sri Lanka. Flat facets are created by holding the stone steady against the lap (ICA Congress 2017; Naji Sammoon, pers. comm. September 2018). Cutting in this freehand style often results in so-called native-cut proportions (e.g. Figure 1a). The stone is then taken to another machine, the *bannku opa pattalaya*, for polishing.

Bannku opa pattalaya literally means 'bench machine'. It consists of a large (20 in., or 51 cm) copper wheel built into a table and connected to a crank with a rope (Figure 3a). One person would crank the machine (e.g. Figure 4), which would cause the copper wheel to spin, and the lapidary would use a handpiece called a *thanaasuwa* (or *sanaasuwa*) to press the stone against the wheel. In Beruwala, until the late 1980s such machines were typically cranked by men from nearby rice fields who made INR10 (GBP1.15) per day (Naji Sammoon, pers. comm. April 2017). The legs of this heavy machine had to be very strong, and consisted of large wooden timbers (6 × 6 in. or ~15 × 15 cm) that suspended the 5 cm-thick wooden table.

The *thanaasuwa* handpiece represents an interesting example of early faceting technology because we see a similar design—called a *cadran* (or quadrant)—in Prague in 1609 (de Boodt 1609) and in France in the 1670s (e.g. Figure 3b; Félibien 1676). The origin of the handpiece has passed out of living memory in Sri Lanka, but it seems to have been in use for about a

Figure 2: A Sri Lankan lapidary operates a traditional *hanaporuwa* in Ratnapura. The stone is held against a vertical lap, which is spun by drawing the bow back and forth. Photo by J. Prim.

[1] The modern Singhalese word for sapphire is *nila*.

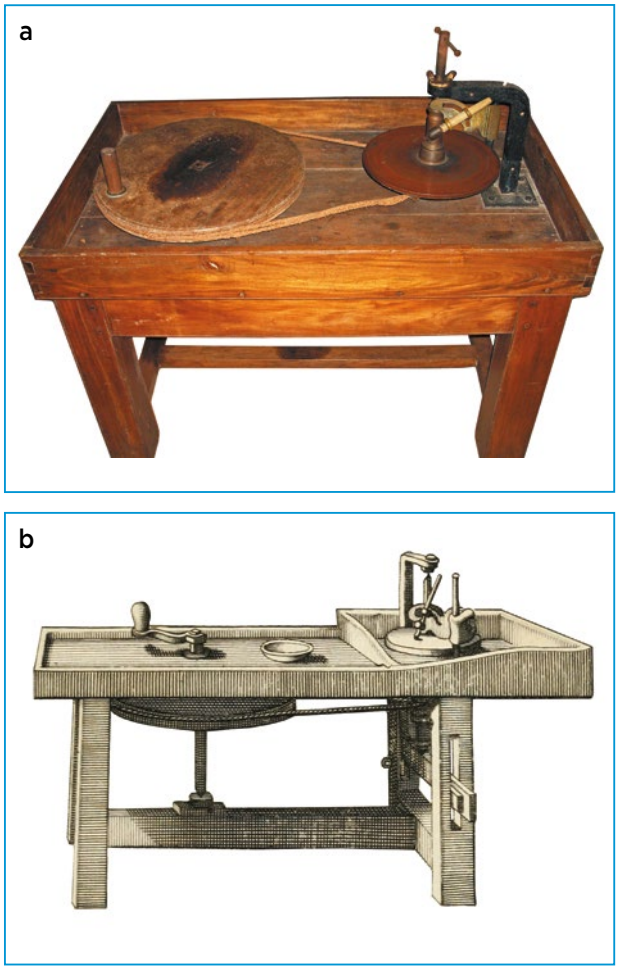

Figure 3: A 20th-century *bannku opa pattalaya* machine (**a**) shows similarities to a French cutting machine from 1676 (**b**). Photo courtesy of Dmitry Petrochenkov; engraving from Félibien (1676).

century, indicating that it would have made its way to Sri Lanka in the 1860s, possibly from Burma, which by then had already had 100 years of political interactions with France.

A homemade polishing compound was used on the *bannku opa pattalaya* machines until diamond powder was first adopted in the 1970s. According to Keerthi Jayasinghe (pers. comm. October 2017), the traditional polishing compound (*wadi*) was made from the ashes of midribs from *kitul* palm fronds, plus the ashes of burned rice husks. The ashes were cooked together in equal parts along with a trace of lime ($CaCO_3$) to make fist-sized balls. The balls were burned for a few hours using rice shells, and the ashy remains were then partially dissolved in water. Several rounds were required to get the mixture down to the finest particles, which would then be used for polishing. Jayasinghe maintained that this ash-based compound produced a better polish than the finest diamond grit.

Figure 4: A lapidary polishes a stone with a *bannku opa pattalaya* machine, while an assistant turns the large wooden crank wheel. Photo courtesy of Ika Dayananda.

INTRODUCTION OF THE IMAHASHI MACHINE

The traditional Sri Lankan cutting machines started going out of fashion in the mid-1960s as new technology from Thailand, and then Japan, entered the country. Although a government-sponsored gem-cutting programme was proposed in 1939 (Anonymous 1939), it seems that official cutting classes were not offered until the early 1970s, when Badra Marapana started one at the Gem Bureau in Ratnapura. The class combined traditional Sri Lankan cutting methods that had developed over centuries (Mahroof 1989) with Japanese and European techniques (Zwaan 1982; Naji Sammoon, pers. comm. April 2017) in order to teach modern cutting methodology to a new generation of lapidaries.

The Japanese-made Imahashi machine was first introduced to the island by M. S. M. Hamza of Universal Gems, a leading gem dealer from Galle. He visited the Imahashi factory in Japan and saw the potential of using these machines in Sri Lanka. In 1976, with the help of the State Gem Corporation, the machines were placed in the Technical College of Ratnapura (Keerthi Jayasinghe, pers. comm. October 2017). Initially they were used only for training purposes, but subsequently a few individuals imported the machines for personal use. This style of machine had not been seen before in Sri Lanka. Its handpiece 'faceter' design descended from an older German company called EDUS (Figures 5a and 5b; Sandun Aponsu, pers. comm. September 2017). According to Keerthi Jayasinghe (pers. comm. October 2017), when it was introduced the Imahashi machine cost INR15,000 (GBP160), while the Graves machine from the USA cost around INR75,000 (GBP800).

Figure 5: Shown here are faceting handpieces from EDUS (**a**), Imahashi (**b**) and Sterling Gems & Lapidary (**c**). Photos by J. Prim.

By the time two groups of students had graduated from the Technical College, the demand for Imahashi machines began to grow. A government-funded institute called the National Youth Services Council established faceting schools in many districts around Sri Lanka. In the late 1970s and early 1980s, a few cutters were already using imported machines such as those made by Graves, Ultratec and 3M, but for the most part it was a huge challenge for these new types of motor-driven machines to become accepted in Sri Lanka (Keerthi Jayasinghe, pers. comm. October 2017). The dealers strongly believed that the motorised machines unnecessarily wasted weight during cutting, and that the polish was not as good as that produced with the *bannku opa pattalaya*. The adherence to traditional beliefs was noted 40 years earlier when the Sub-Committee of the Executive Committee of Labour, Industry and Commerce reported that 'there is an inherent prejudice towards new innovations however efficient they may be' (Anonymous 1939, p. 26). During this transitional period, a lot of education was needed within the gem community to convince people about the precision and efficiency of the modern machines (Naji Sammoon, pers. comm. April 2017). As the demand for (what became known as) 'machine cut' stones increased, and older members of the gem trade retired, a new generation of gem cutters adopted the motorised machines. These younger cutters knew little about the old ways of cutting and polishing, including the aversion to motor-driven machines.

In the late 1970s, Thai-style machines (Figure 6a) were brought to Sri Lanka by Thai gem dealers who were buying cheap Sri Lankan pale 'geuda' rough for heating into valuable blue sapphires (Naji Sammoon, pers. comm. April 2017). Some cutters, such as those around Beruwala, Ratnapura and Eheliyagoda, liked the Thai machines because they seemed good for retaining weight, meaning they could produce heavier and therefore more valuable gems. In general, though, the Thai machines did not gain widespread traction in Sri Lanka. In some cases, the Thai machines were modified to use Imahashi-style handpieces, or they were replaced completely by Imahashi-style machines (Figure 6b).

Figure 6: Thai jamb-peg-type cutting machine (**a**) is shown in comparison with a Sri Lankan Imahashi-style handpiece machine (**b**). Photos by J. Prim.

MODERN CUTTING ERA

Innovations by Bandu Wickrama Engineering Works

The early 1980s marked the beginning of a mass technological change in Sri Lanka's gem-cutting industry. An example of this was provided by Naji Sammoon, who ran a cutting factory in Hong Kong until it became too expensive for him to stay profitable there. He returned to Sri Lanka and started a new factory in Colombo. Sammoon first bought an Imahashi 'Faceter C' machine in 1982 from M. S. M. Hamza, who by then had become the director of Unique Gemstones, an Imahashi agent. Sammoon wanted to equip his factory with these machines, but they were too expensive to buy in large quantities. Furthermore, he felt the Imahashi handpiece was too complicated for the Sri Lankan cutting industry, so Sammoon gave one to Bandu Wickrama Engineering Works in Galle and asked the two brothers who ran the company, Aloysius and Bandu, to modify it for use in his factory (Naji Sammoon, pers. comm. April 2017). Bandu did the drawings and manufacturing for several variations of the handpiece, and the final design (Figure 7a) was modified to eliminate the oval cam movement and reduce its weight (Bandu Wickramasingha, pers. comm. September 2018). In addition, the machine employed a rubber V-belt to connect the motor to the lap wheel, rather than the flat leather belt of the Thai-style devices. Both the motor and wheel were fixed on a small steel table (Figure 7b), and the machine was designed to use three laps: a diamond lap for cutting and two cast-iron laps for polishing, instead of the single large cast-iron lap used in the Thai machines (Bandu Wickramasingha, pers. comm. September 2018).

Bandu Wickrama Engineering Works made about six of the cutting machines for Sammoon over six months, all the while tweaking the design. Since their first one was completed in 1980, Bandu Wickrama Engineering Works has continued to make various types of faceting machines for the gem industry in Sri Lanka (www.gemlapidary.com/about-us). By 1992, Aloysius left the faceting machine business and his brother Bandu took over as the sole leader of Bandu Wickrama Engineering Works, which now sells their machine under the company name Gem Lapidary (Bandu Wickramasingha, pers. comm. September 2018).

Innovations by Sterling Gems & Lapidary

In the suburb of Moratuwa, located 20 km south of Colombo, the family-run Sterling Gems & Lapidary company was started by Palitha Aponsu in 1982. The author visited the Aponsu family home and workshop in September 2017, and Palitha and his son Sandun related their role in introducing modern gem-cutting methods to Sri Lanka. Palitha's father was the chief draftsman of the mechanical department in the local university. Palitha was an engineer by training who had studied gem cutting at the Gem Bureau in Ratnapura under Badra Marapana. He saw a photo of the Imahashi handpiece in the early 1980s and constructed a modified version of it (Sandun Aponsu, pers. comm. September 2017). In 1984, Palitha began manufacturing several types of gem-cutting machines (e.g. Figure 8), which are now used throughout the world.

During the initial development of their machines, Sterling made various modifications and enhancements and then started mass production. The Sterling handpiece (Figure 5c) is lightweight and user-friendly, which makes it easier to retain a stone's weight while cutting accurately. When the machine first appeared on the market, it cost about half the price of the one imported from Imahashi, which made it an affordable option for

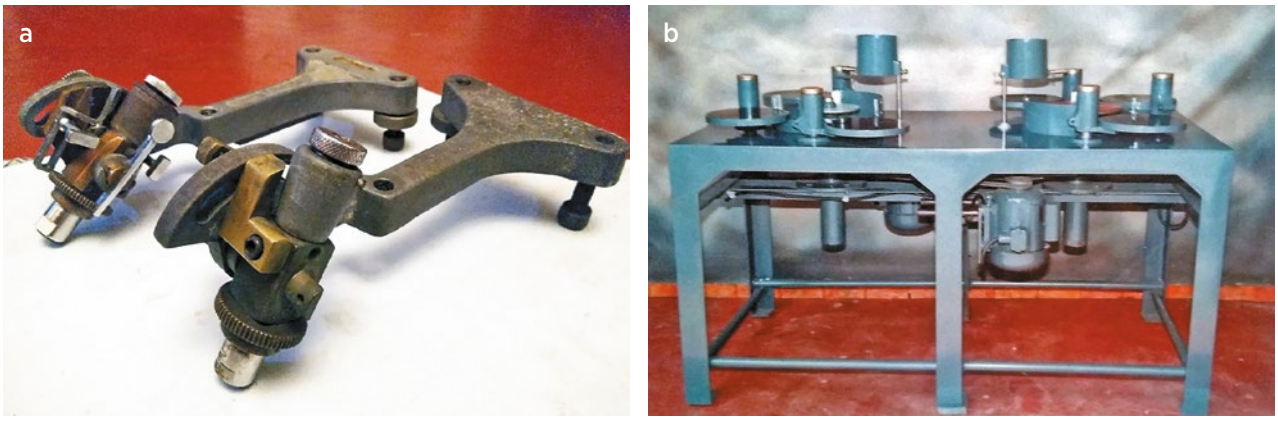

Figure 7: (**a**) A handpiece modified by Bandu Wickrama Engineering Works (front) is shown next to an original Imahashi handpiece (back). (**b**) These early dual faceting machines from Bandu Wickrama Engineering Works were designed with three laps: a diamond lap for cutting and two cast-iron laps for polishing. Photos courtesy of Bandu Wickrama Engineering Works.

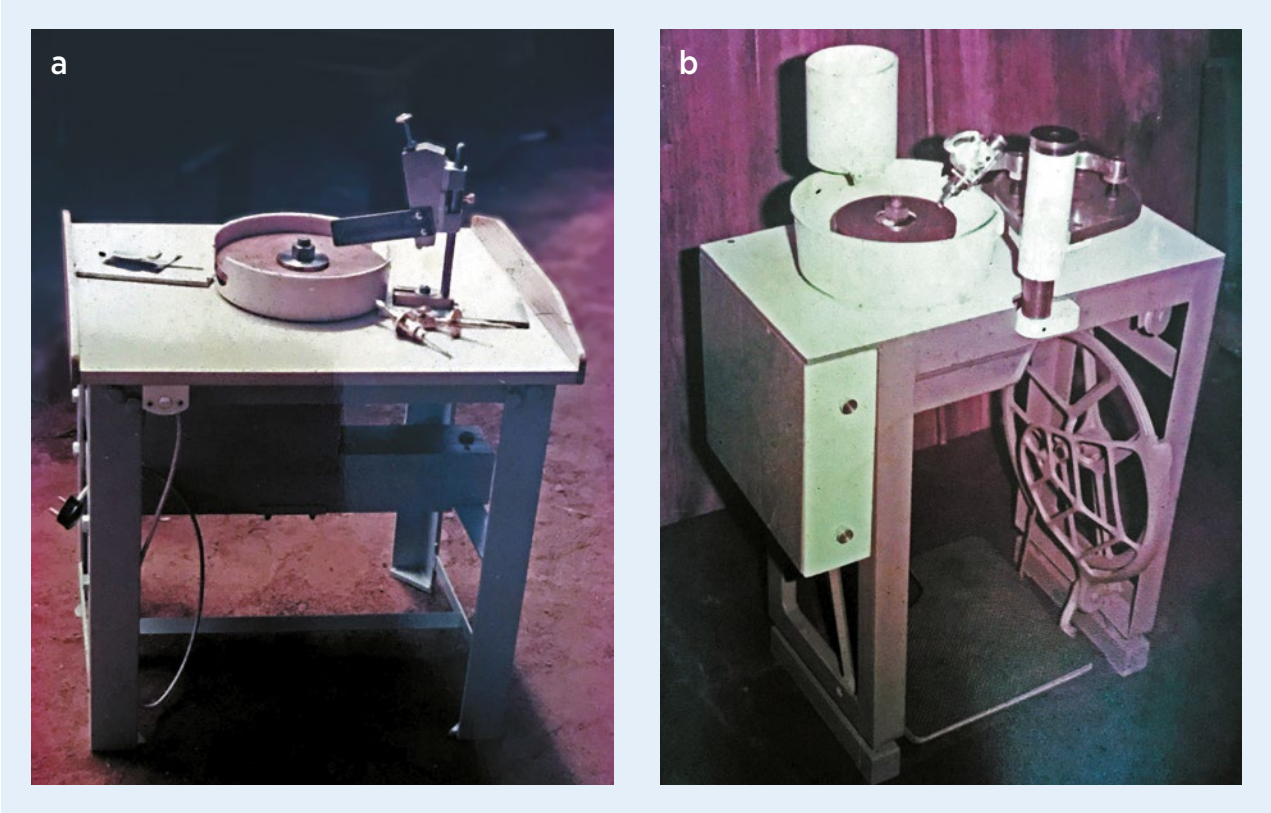

Figure 8: Early Sterling-made faceting machines include: (**a**) Thai-style and (**b**) a foot-powered Sri Lankan variation. Photos courtesy of Sterling Gems & Lapidary.

local cutting factories (Sandun Aponsu, pers. comm. September 2017). Some of these first-generation Sterling machines were delivered to Sammoon in Colombo for his cutting factory (Naji Sammoon, pers. comm. April 2017).

The company continues to hand-make their machines with a crew of six part-time workers. They recycle as much aluminium as possible from local machine shops, car parts and any other source they can find. When they need more than the recycling market can provide, they buy new aluminium from a local source. In their casting factory, the aluminium is melted and poured into moulds to make their handpieces, faceter heads and machine bodies. The cast pieces are then moved to another building for cleaning, polishing, powder coating and final assembly. Sterling can make a complete faceting machine in a single day within their small workshop.

RAISING THE BAR ON CUTTING STANDARDS

Since 1980, redesigned cutting machines have become the main faceting implements in Sri Lanka. The author has visited a dozen different cutting workshops in Ratnapura and Beruwala, and every cutter was using these handpiece-based machines alongside a few *hanaporuwas*. In one shop, the *hanaporuwa* and handpiece cutters were sitting side-by-side, working together (Figure 9). The person on the handpiece machine would cut a stone and then hand it to the lapidary who would polish it on the *hanaporuwa*. This integration of old and new technology was a delightful surprise. Despite the fact that Sri Lankans can do every step of the cutting process on a single machine, they still choose to combine the best qualities of each type of machine to produce a high-quality product, while keeping relevant the older cutters with their different specialities (Lucas *et al.* 2014).

Because of this kind of innovation and ingenuity, Sri Lanka has risen to the top of the world's commercial stone-cutting industry. The Sri Lankan cutters are able to quickly cut a well-proportioned stone (e.g. Figure 10), while maintaining a reasonable wage. The author's research indicates that cutters in Thailand make about GBP1 for every carat they cut, whereas in Sri Lanka cutters make about GBP2 per carat (Naji Sammoon, pers. comm. April 2017). This means that a Sri Lankan cutter can theoretically spend a little more time per stone to ensure the cut quality is high.

In Sri Lanka, as well as in other commercial cutting countries, an important distinction is made between

Figure 9: In this Ratnapura cutting shop, a traditional lapidary using a *hanaporuwa* works side-by-side with a modern cutter using a handpiece machine. Photo by J. Prim.

cutters and polishers. Insight on this was provided during a visit by the author to the family home of Hiflan Sala, reputedly one of the best cutting families in Beruwala. According to Hiflan, the job of the cutter is considered the more advanced skill. The cutter must be able to evaluate the shape of the rough and any mineral inclusions that it contains, and navigate around the inclusions to create a pleasing final form for the gemstone (Hiflan Sala, pers. comm. April 2017).

Hiflan demonstrated his technique to the author by preforming a stone freehand on a Sri Lankan-made machine. He took an irregular rough ruby and turned it into a pleasing oval shape with a table, crown, pavilion, girdle and keel. As Hiflan worked, he spoke with pride about the skill of the preformers and cutters. His family preforms the rough and then cuts the facets into the stones. The stones are then sent to a polisher who makes the facets shine. In the author's experience, the polishing process has its own challenges, but it takes a master to properly preform a stone, as Hiflan pointed out. Preforming is the hardest part of cutting a gemstone from rough starting material and has the greatest influence on a stone's finished value.

Figure 10: Modern Sri Lankan cutting reveals the beauty of this 25 ct tanzanite. Photo by J. Prim.

CONCLUSION

It is incredible to consider how recently the gem-cutting industry in Sri Lanka has changed. Nearly all of the technology in use today has been around for only the past 35 years or so. This shift in technology and the mentality accompanying it has enabled Sri Lanka to develop some of the best cutters in the world. Sri Lanka's history with sapphires and rubies, and the steady rise in cutting quality, has caused a lot of the faceting work to move from India and Thailand to Sri Lanka. Since the 1990s, many Sri Lankan cutting factories have transitioned into producing stones that meet the highest international cutting standards (e.g. Figures 1b and 10; Lucas *et al.* 2014), as opposed to the 'native cuts' they were known for in previous decades (Anonymous 1939). They have even secured some precision-cutting work from Switzerland for its gem-encrusted watch industry (Ahmed Shareek, pers. comm. November 2017; Yavorskyy 2018). This is not surprising, considering how adaptable the people of Sri Lanka have proved to be and how active they are in the gem industry. Sri Lanka has one of the oldest relationships with gemstones, as well as a unique story within the world of gem cutting. As an industry, we can look forward to the next 2,000 years.

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Figure 1: These examples of Connemara marble jewellery were produced by Harry Grant & Co., Torquay, in the early 1900s: a harp-shaped brooch and a shamrock-and-harp necklace, as well as four amulets (e.g. heart- and boot-shaped charms) worn by Irish soldiers in World War I (Dougherty 2015). The harp in the centre is 4.5 cm long and the amulets are up to 2 cm long. Photo by Pat O'Connor.

Mineral Liberation Analysis and Scanning Electron Microscopy of Connemara Marble: New Mineral Distribution Maps of an Iconic Irish Gem Material

Martin Feely, Derek H. Wilton, Alessandra Costanzo, Albert D. Kollar, Dylan J. Goudie and Ambrose Joyce

ABSTRACT: This article reports results from mineral liberation analysis–scanning electron microscopy (MLA-SEM) of six samples of the iconic Irish gem material, Connemara marble. New false-colour mineral distribution maps along with quantitative mineral abundance data for each sample facilitate correlations between marble mineralogy and millimetre- to centimetre-scale colour variations in banding observed in each sample. The modal mineral data were used to classify each of the samples, and indicate that they define a petrological continuum from calc-silicate to metacarbonate rocks. The results demonstrate the efficacy of MLA-SEM methodology for generating mineral distribution maps along with quantitative modal analysis that inform and enhance the study of inhomogeneous gem materials such as the Connemara marble. Finally, this study demonstrates the potential for MLA-SEM analyses to aid in the fingerprinting and authentication of other polymineralic gems akin to Connemara marble.

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Connemara marble is the standout Irish geological and gem material, and is therefore recognised as the iconic stone of Ireland (Horgan 2002; Walsh 2014). Its use in jewellery (e.g. Figure 1) can be regarded as one of Ireland's indigenous industries, and the quarrying of Connemara marble is a centuries-old endeavour (Feely 2002). The stone exhibits intricate millimetre- to metre-scale corrugated layers that range from white through sepias to various shades of green. The polished stone's appeal was described by American art critic Charles Caffin (1897, p. 955) as 'the exquisite mystery of graded greens and greys and black, their tempestuous streakings and tender veining, and the perfect texture of their polished surface'.

The colour variations displayed by Connemara marble derive from the relative abundance of the coloured silicate minerals present (e.g. deep green hues appear when serpentine predominates). By contrast, white-to-grey marble such as that quarried at Carrera, Italy, consists of relatively pure metamorphosed calcite- and/or dolomite-bearing limestone. Max (1985) noted that only a small portion of the Connemara marble horizons contain sufficient proportions of carbonate minerals to be properly termed 'marble', and furthermore it is the other minerals (i.e. mainly calc-silicates and serpentine) that impart the colour varieties so typical of the stone traded as Connemara marble.

Despite a number of reports on the mineralogy of Connemara marble (Cronshaw 1923; Leake *et al.* 1975; Max 1985), descriptions of the relationship between the mineralogy and colour variations are absent from the literature. We present new mineral distribution maps and mineral abundance statistical data (expressed as area percent) from six polished thin sections of Connemara marble, using a novel analytical technique called mineral liberation analysis–scanning electron microscopy (MLA-SEM). The mineral distribution maps highlight the correlations between mineralogical composition and the layered, polychromatic characteristics of the marble. In addition, a triangular discriminant plot of the quantitative mineral abundance data indicates that the marble samples display a petrological continuum from calc-silicate to metacarbonate rock. The mixture of these components in the rock results in mineralogical and textural variations that impart the interesting ornamental characteristics to this gem material.

GEOLOGICAL SETTING

The Connemara region of western Ireland (Figure 2) is composed of a number of major rock units (Leake & Tanner 1994; Pracht *et al.* 2004). The central zone comprises the Connemara Metamorphic Complex (CMC) containing Dalradian metasediments (ca. 650 million

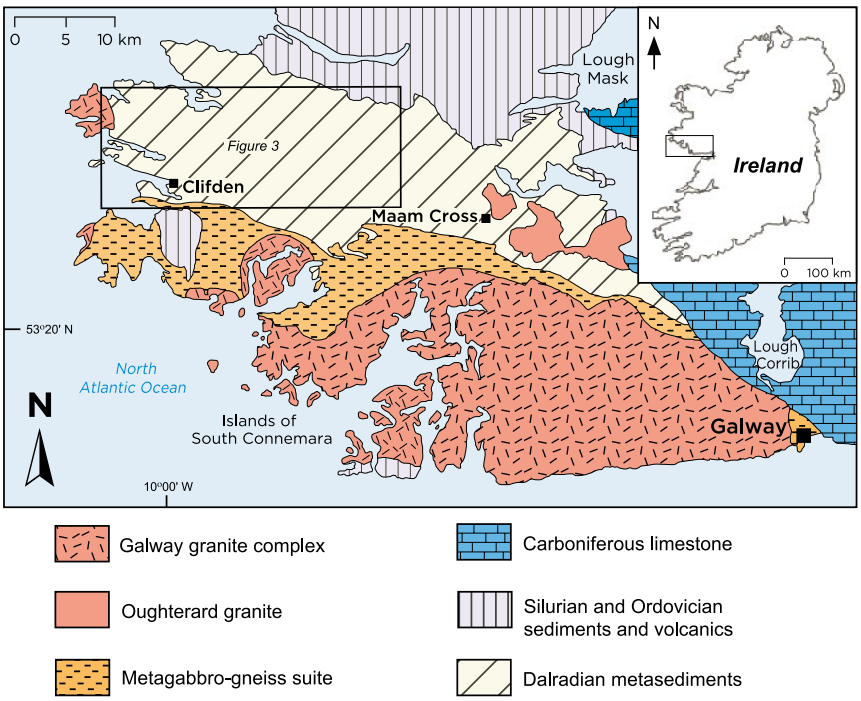

Figure 2: This map of the Connemara area shows the distribution of the main geological units. The Connemara Metamorphic Complex comprises the ca. 470 Ma metagabbro-gneiss suite and the Dalradian metasedimentary rocks that contain the Connemara Marble Formation. Adapted from Leake & Tanner (1994), Pracht *et al.* (2004), Feely *et al.* (2006) and Lees & Feely (2016, 2017).

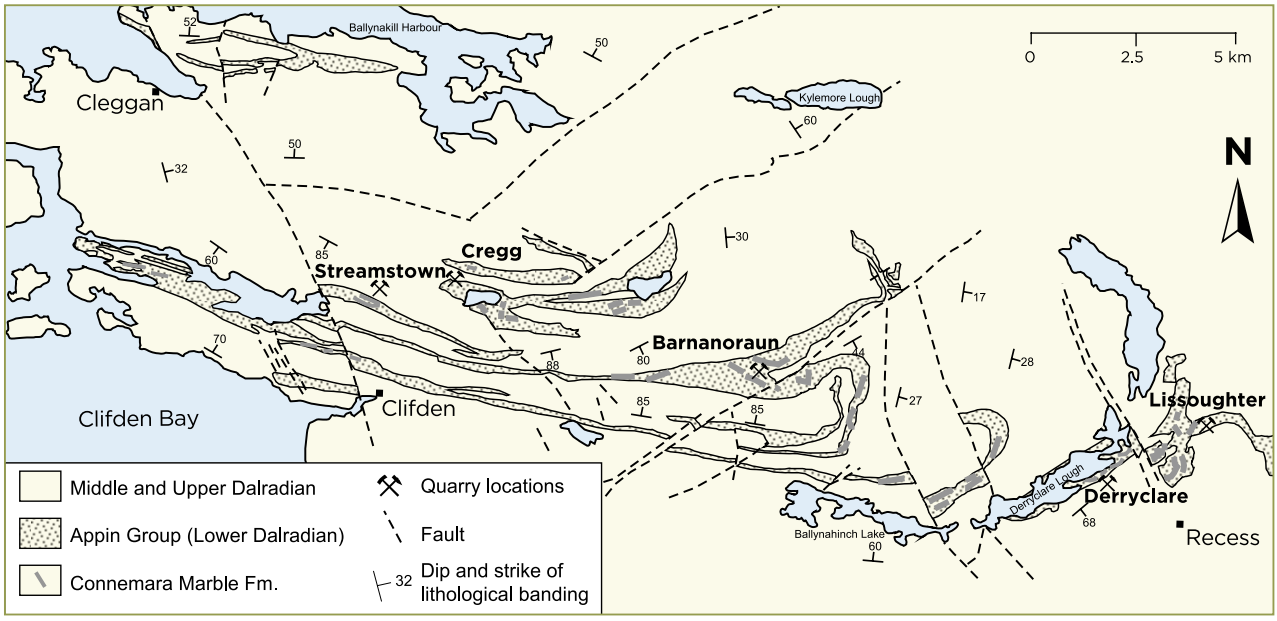

Figure 3: This simplified geological map shows the distribution of the Connemara Marble Formation, which forms part of the Lower Dalradian Appin Group. The five main Connemara marble quarry locations are: Streamstown, Cregg, Barnanoraun, Derryclare and Lissoughter. The folded nature of the Appin Group and the east-west distribution of the marble reflect the regional structural trend of the Connemara Metamorphic Complex. Adapted from Max (1985).

years old [Ma]) and a 475–463 Ma metagabbro-gneiss suite (Leake 1989; Dewey & Ryan 2016; Friedrich & Hodges 2016). The intrusion of the Oughterard granite, east of Maam Cross (Friedrich & Hodges 2016), occurred during the end stage of the Grampian orogeny (ca. 475–462 Ma). The CMC is bounded to the north by Silurian and Ordovician sedimentary and volcanic rocks (Leake & Tanner 1994), and to the east it is in faulted contact with Carboniferous limestones (Lees & Feely, 2016; 2017). To the south lie the younger Caledonian Galway granites (~425–380 Ma; see Feely *et al.* 2010; 2018). Some exposures of Ordovician sedimentary and volcanic rocks occur just south of Clifden and further south on the islands of South Connemara (Figure 2).

Horizons of Connemara marble typically range up to 80 m thick (Leake and Tanner 1994) and are hosted by the Connemara Marble Formation, which belongs to Lower Dalradian (=Appin Group) metasediments (Figure 3). The marble is a metamorphosed impure siliceous dolomitic limestone (Leake *et al.* 1975; Tanner & Shackleton 1979; Treloar 1982; Max 1985). Amphibolite-greenschist facies metamorphism during the Grampian orogeny induced the formation of silicate minerals that include olivine, diopside, tremolite, talc and chlorite. In addition, calcite and dolomite occur throughout, locally representing significant portions of the mineralogical assemblages. Indeed, the relative proportions of all of these minerals vary widely due to the different compositional layers present in the marble protoliths. Later hydrothermal metamorphism led to wholesale serpentinisation of the earlier-formed high-grade olivine, diopside and tremolite (Cronshaw 1923; Leake *et al.* 1975; Max 1985). The serpentinisation, in part, may be linked to the generation of hydrothermal fluids syn- or post-emplacement of the Galway granites (Jenkin *et al.* 1997; O'Reilly *et al.* 1997).

CULTURAL HERITAGE

Connemara marble has played a key role in the development of the renowned cachet that characterises the Irish jewellery design and manufacturing sector. The marble's popularity in jewellery and souvenir gift items during the Victorian era (Horgan 2002) initiated the prestige that it still enjoys to this day. The deep green variety known as *Irish Jade* was in particularly high demand. When Queen Victoria visited Ireland in 1900 she was presented with an ornamental harp (~30 cm tall) fashioned from Connemara marble.

Birmingham, England, was one of the major centres for the manufacture of Connemara marble jewellery, and many of the antique brooches (e.g. harps and shamrocks), pendants and bracelets have the anchor hallmark of the Birmingham Assay Office. Harry Grant & Co., located in Torquay (1847 to early 1980s), produced a large range of silver and gold jewellery inlaid with Connemara marble. During World War I, Irish soldiers carried heart-, boot-, bean- and shamrock-shaped amulets of Connemara marble manufactured by Harry Grant & Co. (see Figure 1;

Dougherty 2015). Stamping dyes and samples from Harry Grant & Co. are on display in the Connemara Marble Visitor Centre, Moycullen, County Galway, Ireland. Records of marble quarrying go back to at least the 18th century (Feely 2002; Feely & Costanzo 2014). Indeed, lyrical descriptions of the marble are to be found in the stone trade's literature. For example, Hoyt (1903, p. 122) described its colour as ranging from 'the light greens, almost verging on yellow, to the deep, dark lustrous greens that suggest in turn the emerald, the depths of the sea and the moss of the forest covert'.

Connemara marble is currently in the process of being proposed as a candidate for Global Heritage Stone status in recognition of its widespread utilisation in architectural and ornamental masterpieces, particularly in the UK and USA. During the Gilded Age (late 19th to early 20th century) of architecture in the USA, many of the great public buildings in Boston, New York, Chicago, Washington DC, Harrisburg and Pittsburgh incorporated classical ornamental stones from Europe, including Connemara marble (Wyse Jackson *et al.* in press).

Five main quarries for Connemara marble occur along a west-to-east-trending corridor from Clifden to Recess in County Galway: Streamstown, Cregg, Barnanoraun, Derryclare and Lissoughter (Figure 3). Their spatial distribution reflects the exposures of folded Appin Group rocks and the dominant east-west structural trend of the CMC. The history of marble quarrying at these localities is outlined in Naughton *et al.* (1992) and Feely (2002). An image of the Streamstown quarry was used by Stanley (1999, figure 2.26, p. 53) to highlight the ornamental use of metamorphic rocks such as Connemara marble.

MATERIALS AND METHODS

The six Connemara marble samples used for this study came from the Streamstown quarry, located approximately 3 km north of the town of Clifden. The quarry contains typical examples of folded and banded green marble (Figures 4a and b). Four of the samples (nos. 3–6) were supplied by author ADK and are representative of Connemara marble used as ornamental inlays (Figure 4c)

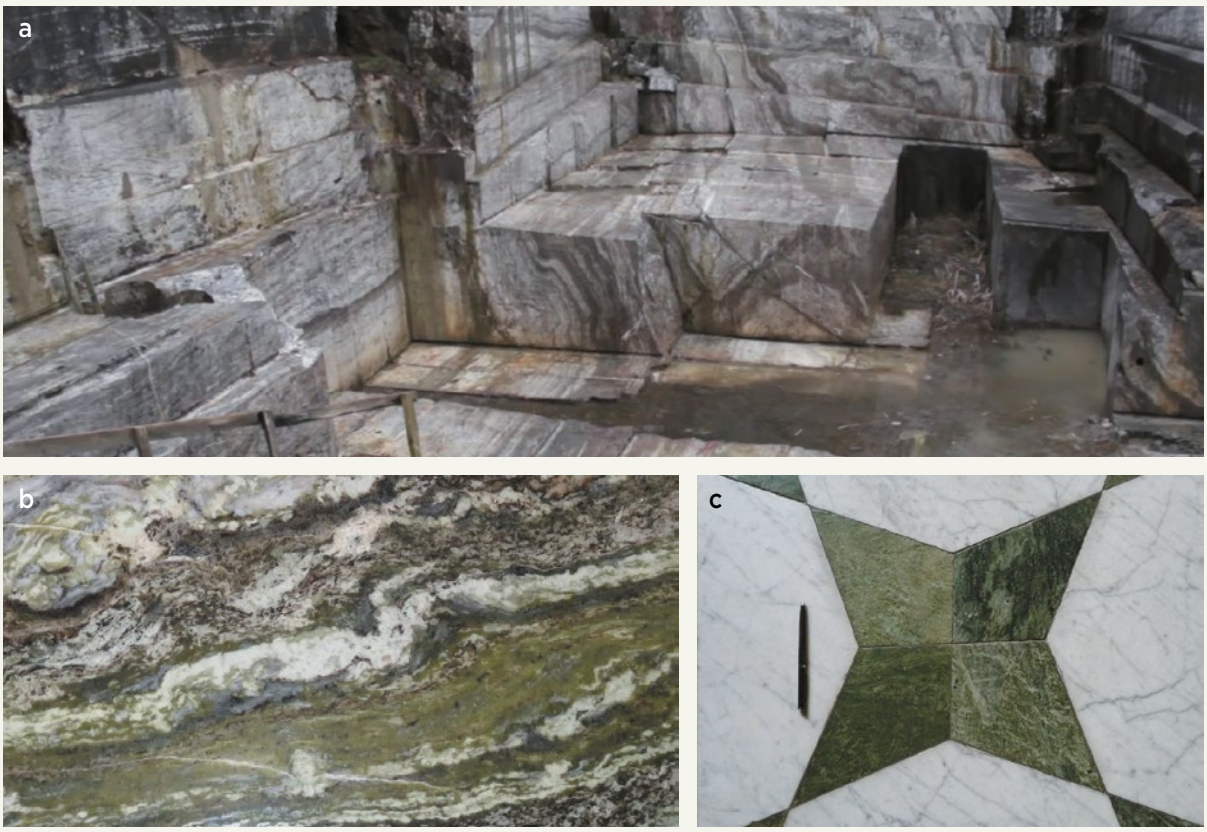

Figure 4: (**a**) In this photo of the Streamstown quarry, near Clifden, the folded and banded Connemara marble is clearly visible. This image is a frame taken from a LiDAR (light detection and ranging) survey of the quarry by McCaffrey *et al.* (2008). (**b**) A polished slab of Connemara marble (image width 30 cm) from the Streamstown quarry displays typical centimetre-scale banding and colour variations. (**c**) Streamstown Connemara marble inlays decorate the Carnegie Museum in Pittsburgh, Pennsylvania, USA (see pen for scale). Photos by M. Feely.

during the early 20th century construction of the Carnegie Museum in Pittsburgh, Pennsylvania, USA (Kollar *et al.* 2017). Samples 1 and 2 are from a recently obtained quarry floor drill core supplied by author AJ.

A polished thin section (0.03 mm thick) was prepared for each sample. The thin sections were imaged using a digital scanner at Memorial University, St Johns, Newfoundland, Canada, and the corresponding marble samples from which they were cut were photographed (Figure 5). The thin sections then underwent MLA-SEM analysis (Box A).

RESULTS AND DISCUSSION

The MLA-SEM analyses (a) identified the major, minor and accessory mineral phases in each marble sample; (b) provided quantitative data on the contents of all the mineral phases present as a percentage of the total sample area (see Table I and Figure 5); and (c) created false-colour mineral distribution maps for each of the thin sections that are easily compared with the actual thin sections and the rock slabs from which they were

BOX A: MLA-SEM INSTRUMENTATION AND METHODOLOGY

Mineral liberation analysis–scanning electron microscopy (MLA-SEM) can identify the mineral phases present and quantitatively define their modal abundances in polished rock thin sections. The basis for MLA studies is the derivation of an energy-dispersive X-ray (EDX) spectrum for each mineral in a sample. The MLA software compares the analysed EDX spectra with a library of mineral spectra to identify the particular phases that are present in a sample.

The MLA-SEM facility in the CREAIT laboratories at Memorial University (Figure A-1; Sylvester 2012; Grant *et al.* 2016; Wilton *et al.* 2017) consists of a 2011-model FEI Quanta FEG 650 scanning electron microscope (SEM) equipped with mineral liberation analysis (MLA) software written by the University of Queensland's Julius Kruttschnitt Mineral Research Centre in Australia. The Memorial University group has developed a sophisticated, proprietary library of species identification protocols (SIPs) that can be used to indicate almost all minerals present within a sample, down to <0.3% detected unknowns (e.g. Wilton & Winter 2012; Wilton *et al.* 2015, 2017), using a matching threshold of 70% in the MLA software. The confidence level for the spectral match is set during the initial analysis. The software scales the probability between 0% and 100%, where 100% is a perfect match (probability of 1) and 50% is an 'average match' (Mateo 2010). New mineral spectra are added to the SIP library as they are identified.

The SEM at Memorial University is equipped with a dual Bruker EDS detector, and utilises a field emission gun at an operating voltage of 25 kV and a beam current of 10 nA. The working distance between the sample and detector is 13.5 mm, and for the present study the spot size was ~2.5 µm. The imaging scan speed was 16 microseconds, with a resolution of 500 pixels per frame (each frame 1.5 × 1.5 mm) and X-ray collection at 12 milliseconds.

The MLA software provides a false-colour digital map of the mineral phases present within a rock thin section and it also yields mineral abundance data (as a function of the area percent of the analysed thin section). In this study, the samples each took 4–6 hours to analyse and obtain thin-section maps.

Figure A-1: The MLA-SEM facility in the CREAIT laboratories at Memorial University in Newfoundland is shown here. Photo by Derek Wilton.

Table I: Mineral abundance data (area %) generated by the MLA-SEM analyses of six Connemara marble samples.

Mineral	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Sample 6
Dolomite	58.67	21.64	24.70	44.85	13.52	14.99
Calcite	16.18	15.40	32.17	32.55	37.62	41.49
Serpentine	15.40	25.50	27.17	17.93	27.26	34.37
Clinochlore	1.46	15.34	0.46	0.92	0.18	0.40
Diopside	3.27	11.67	4.17	0.26	12.17	0.82
Tremolite	3.51	7.74	3.26	1.17	3.22	1.72
Phlogopite	1.02	0.41	6.97	1.63	5.57	5.84
Omphacite	0.40	1.87	0.68	0.29	0.36	0.33
Talc	0.04	0.19	0.28	0.04	0.09	0.03
Accessory phases	0.05	0.24	0.14	0.36	0.01	0.01
Total	100.00	100.00	100.00	100.00	100.00	100.00
Carbonates	74.9	37.0	56.9	77.4	51.1	56.5
Other minerals	25.1	63.0	43.1	22.6	48.9	43.5

cut (Figures 6 and 7). In addition, Figure 7 shows the relative abundance of each mineral phase present.

The mineral-phase abundance data indicate that dolomite (14–59%), calcite (15–41%) and serpentine (15–34%) were the dominant minerals in all six samples. Less abundant mineral phases were clinochlore (0.20–15%), diopside (0.30–12%), tremolite (1–8%), phlogopite (0.40–7%) and omphacite (0.30–2%). Accessory phases, including zircon, were $<0.50\%$.

The modal mineral abundances were plotted on a triangular discriminant diagram (Figure 5) adapted from Robertson (1999). The samples define a linear trend extending from the calc-silicate to the metacarbonate rock fields. However, as noted earlier, the stone has been referred to as Connemara 'marble' for centuries even though Figure 5 indicates that it is composed of significant amounts of silicate minerals along with calcite and dolomite. Small-scale patches of true marble were evident in all six of our samples. Suffice it to say that the variable mineralogical nature of Connemara marble from millimetre to metre scale makes it a challenging rock to classify, and it should be viewed as occurring

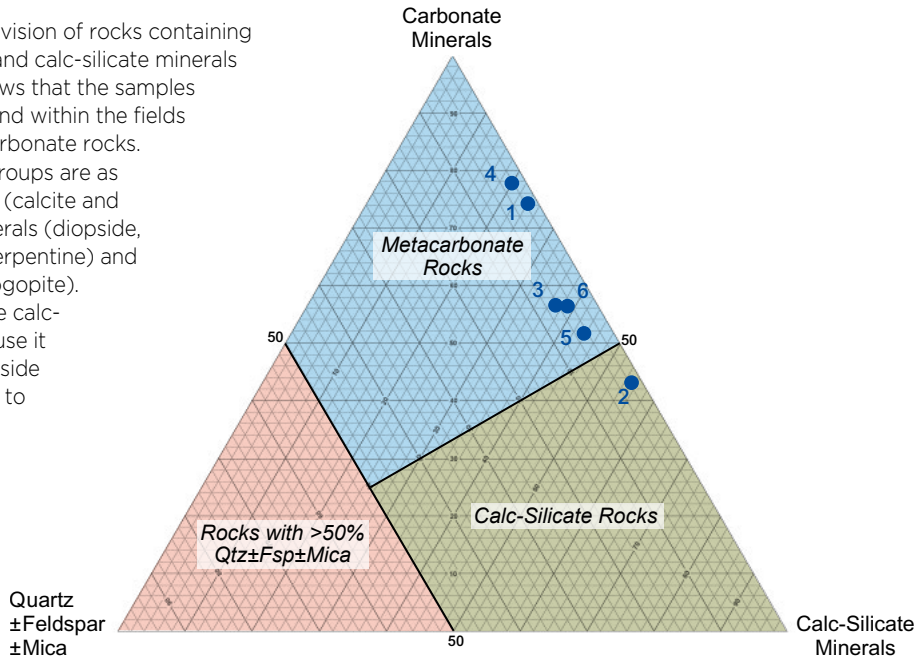

Figure 5: A triangular subdivision of rocks containing more than 50% carbonate and calc-silicate minerals (after Robertson, 1999) shows that the samples (nos. 1–6) define a linear trend within the fields for calc-silicate and metacarbonate rocks. The end-member mineral groups are as follows: carbonate minerals (calcite and dolomite), calc-silicate minerals (diopside, tremolite, omphacite and serpentine) and quartz±feldspar±mica (phlogopite). Serpentine is included in the calc-silicate mineral group because it replaces forsterite and diopside and is therefore considered to be a proxy for these two silicate minerals.

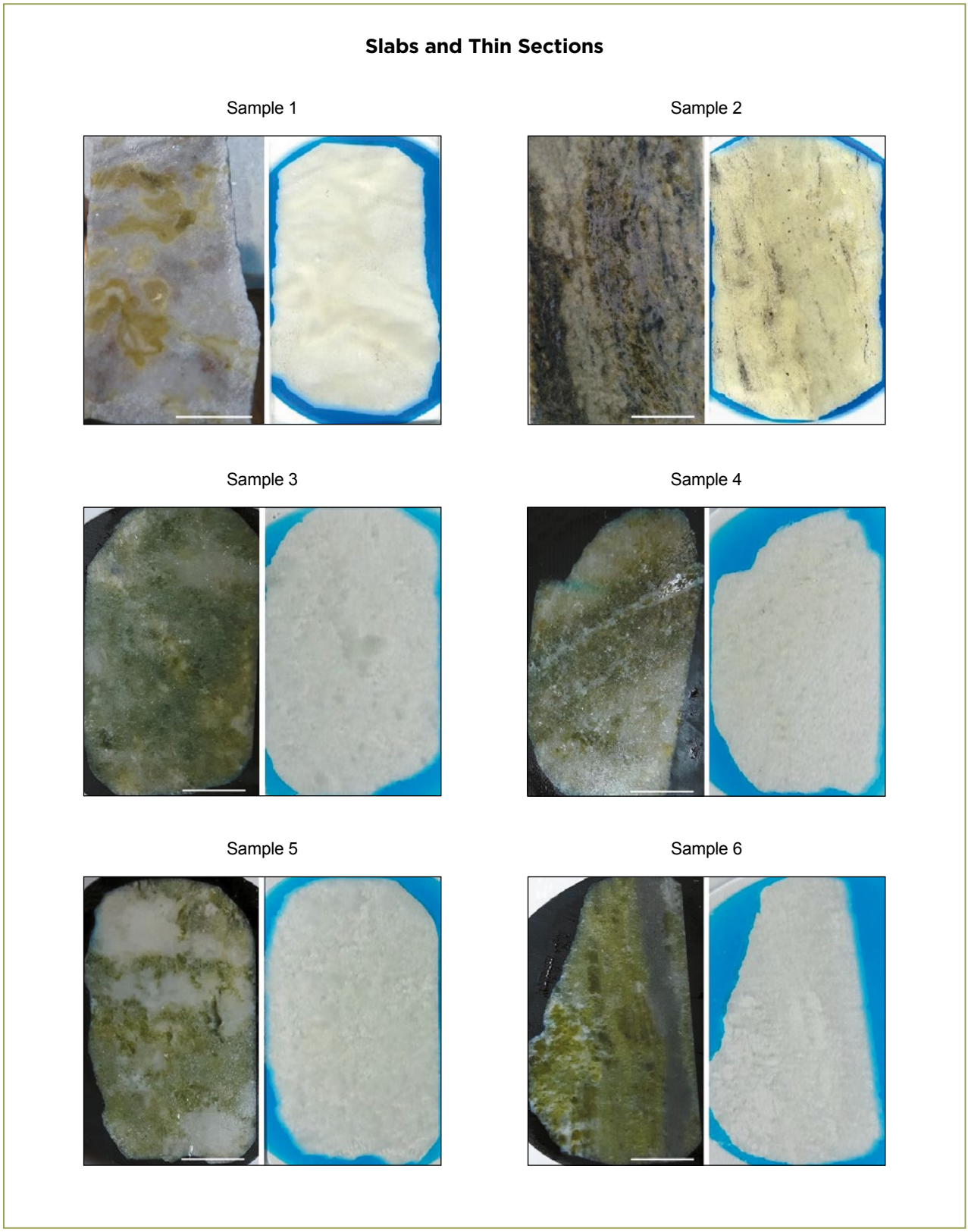

Figure 6: Six samples of Connemara marble from the Streamstown quarry were analysed using MLA-SEM. Samples 1 and 2 were recently collected, while nos. 3–6 represent marble quarried during the late 19th to early 20th centuries and used as decorative stone tiling in the Carnegie Museum (see Figure 4c). For each sample, a photo of a sawn slab (left) is shown together with its matching polished thin section (right, surrounded by blue epoxy). Samples 2, 4 and 6 display characteristic millimetre- to centimetre-scale banding that reflects the mineral composition of each layer. Samples 1, 3 and 5 have a more inhomogeneous appearance with white areas intimately admixed with coloured patches. Photos by M. Feely and A. Costanzo; the scale bar in the slab photos is ~1 cm long.

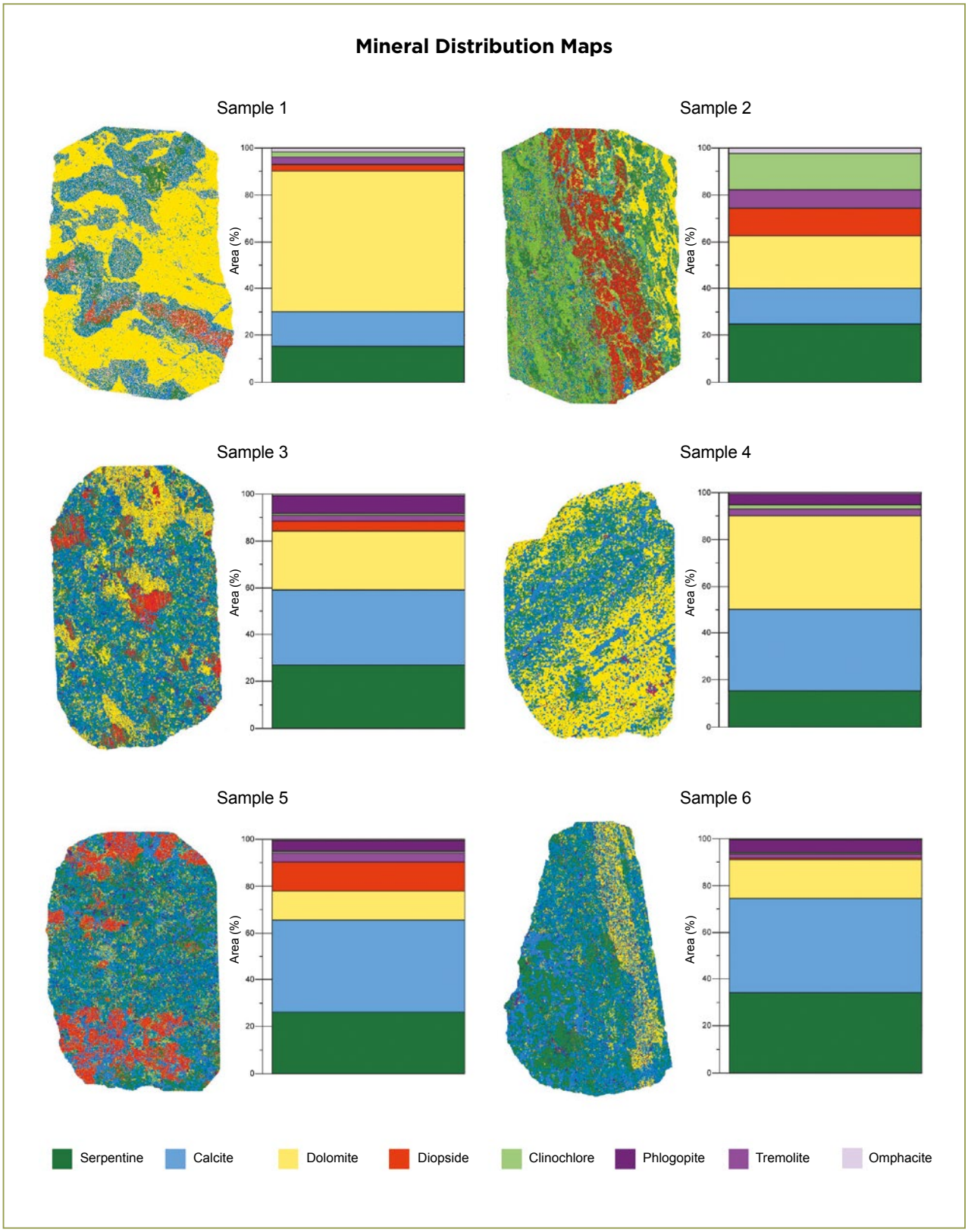

Figure 7: False-colour mineral distribution maps are shown for each marble sample along with graphic representations of the mineral phase area-percent data that were generated by MLA analysis. The maps display the correlation between mineral phases, their spatial distribution and the ensuing colours observed in the marble (as seen in Figure 6). Calcite and dolomite, for example, correlate with the white to grey areas and bands seen in the marble. Diopside commonly occurs in association with these carbonates, and correlates with pale green areas of the marble. A more intense green colour in the marble is primarily produced by serpentine, which is pervasive and present in each sample. Furthermore, clinochlore in association with serpentine defines the layering on the left side of sample 2.

Figure 8: Connemara marble products displaying the characteristic range of colours and textures typical of this gem material are shown here. The Claddagh ring (upper left) and bracelet (top, 18 cm long) were produced by Harry Grant & Co. in the early 1900s. The shamrock-themed silver brooch in the centre is a relatively recent creation (late 20th century) by Ambrose Joyce and is on display in the Connemara Marble Visitor Centre. Also in this photo are various cabochons, and the oval ones are up to 2.5 cm long. Photo by Pat O'Connor.

across the lithological spectrum from true marble to calc-silicate in nature.

The false-colour mineral-distribution maps (Figure 7) reflect the composite and banded nature of the marble and the mineralogical causes of the colour variations (from deep green to white) evident in the samples. Dolomite and calcite dominated the grey to white layers and patches, whereas the green layers and patches reflected the presence of serpentine and diopside. The mineral maps also showed that the layers were not monomineralic but consisted of aggregates of calcite and dolomite with variable calc-silicate mineral contents (mainly diopside) and serpentine. The anhedral character of the diopside (see in particular samples 1, 2 and 5 in Figure 7) and its spatial relationship to the serpentine reflects serpentinisation of the diopside, along with the formation of forsterite and tremolite, during late-stage hydrothermal metamorphism (Wyse Jackson *et al.* in press).

CONCLUDING REMARKS

Connemara marble (Figure 8) is an iconic Irish gem material, and until now the relationship between its mineralogy and colour variations had not been reported. MLA-SEM analysis was used to generate a series of mineral distribution maps and mineral abundance data that:

- allow for the study and correlation of the mineralogically driven colour variations and banding in the marble samples;
- facilitate the classification of the marble using quantitative modal abundance data;
- illustrate mineralogical textures that result from the pervasive serpentinisation of early-formed minerals, particularly diopside (indeed, the serpentine is a proxy mineral for other minerals such as forsterite and tremolite); and
- demonstrate the potential for MLA-SEM analyses to aid the fingerprinting and authentication of polymineralic gem materials akin to Connemara marble.

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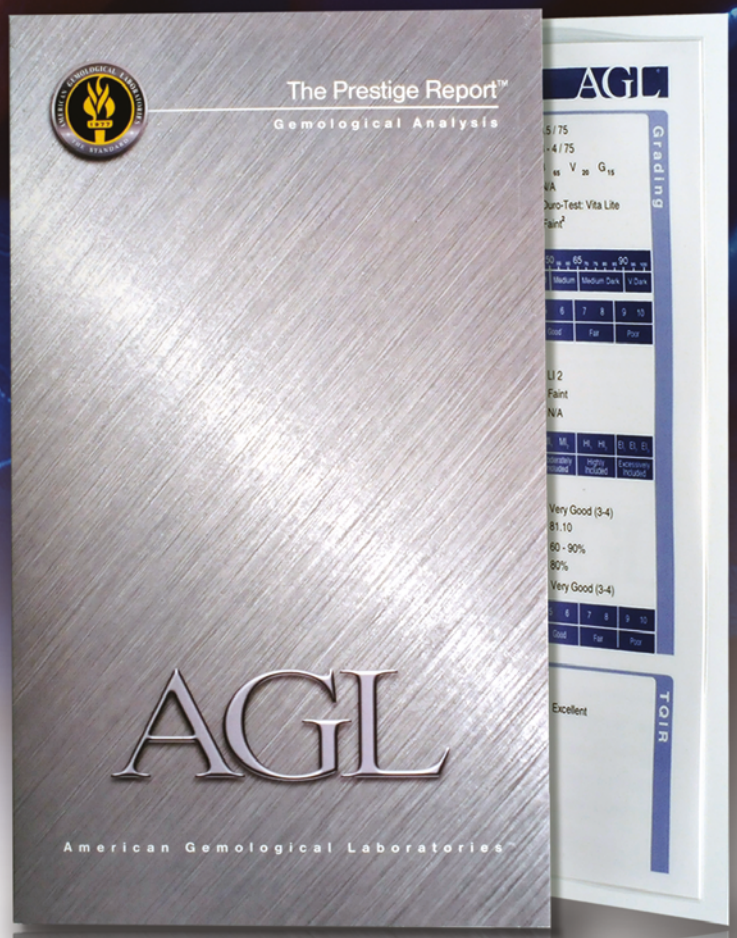

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A Brief Study of Three Reported 'Coconut Pearls' from Southeast Asia

Henry A. Hänni and Chiara Parenzan

ABSTRACT: We investigated three so-called coconut pearls loaned to us by a private collector. The white, roundish 'pearls' possessed peculiar longitudinal surface grooves, and on one side they had either one or three small bulges. The samples were found to consist of polycrystalline aragonite, as shown by Raman spectroscopy, supported by SG measurements and their reaction to hydrochloric acid. They revealed a parallel-layered structure that is consistent with shell material. The surface grooves showed evidence of filing, and it was obvious that the samples had been manually shaped. Based on the thickness of the shell that must have been used to make these imitations, and the similar structures seen in *Tridacna* shell material, we infer that they were manufactured from giant clam shell. There are no indications to suggest the samples actually derived from a coconut-related origin.

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So-called coconut pearls have been reported as curiosities since the 13th century (Kunz & Stevenson 1908, p. 78), and they have been postulated as originating from the giant clam, *Tridacna gigas*, in Singapore (Kunz & Stevenson 1908, p. 351) or in the Celebes Sea between Indonesia and the Philippines (Anonymous 1947). These 'pearls' have also been described as '*Mestica calappa*' (or '*Mystica klapa*'), being related to a coconut palm from Ambon (Indonesia) in which they reportedly were occasionally found (Cleyern *et al.* 1704).

On the Internet, 'coconut pearls' are described as extreme rarities and often very high prices are asked. But so far, the present authors have found no documented examples of these exotic formations that prove such material formed in coconuts, and there is no clear source of the reported 'coconut pearls' given in the literature (see further discussion at www2.palomar.edu/users/warmstrong/ww0601b.htm). Furthermore, 'coconut pearls' from various countries in Southeast Asia have been described regularly as objects of questionable authenticity, and for decades they have been widely believed to be hoaxes (e.g. Anonymous 1947). Some references regarding 'coconut pearls' include Reyne (1951), Child (1974), Armstrong (2000), Veldkamp (2002) and Campbell Pedersen (2010).

In November 2018 a private collector, Peter Bauer, supplied three 'coconut pearl' samples (Figure 1) for our examination that measured 11.85–19.45 mm in maximum dimension. The specimens reportedly were collected in Indonesia by his father, Swiss aviation pioneer Joseph Bauer, while crop spraying in Southeast Asia in 1969. This article describes our identification of the material constituting these objects and our interpretation of its probable origin.

RESULTS AND DISCUSSION

Material Identification

Using a hydrostatic balance, we found the three samples had SG values of 2.80, 2.84 and 2.85, which is in agreement with that of aragonite (i.e. shell; cf. Bolman, 1941). In addition, testing of an inconspicuous area with a droplet of 10% hydrochloric acid showed the effervescent reaction expected for carbonate-based substances. The Raman spectrum produced with a GemRam desk-model spectrometer (Hänni & Hunziker 2011) also indicated aragonite.

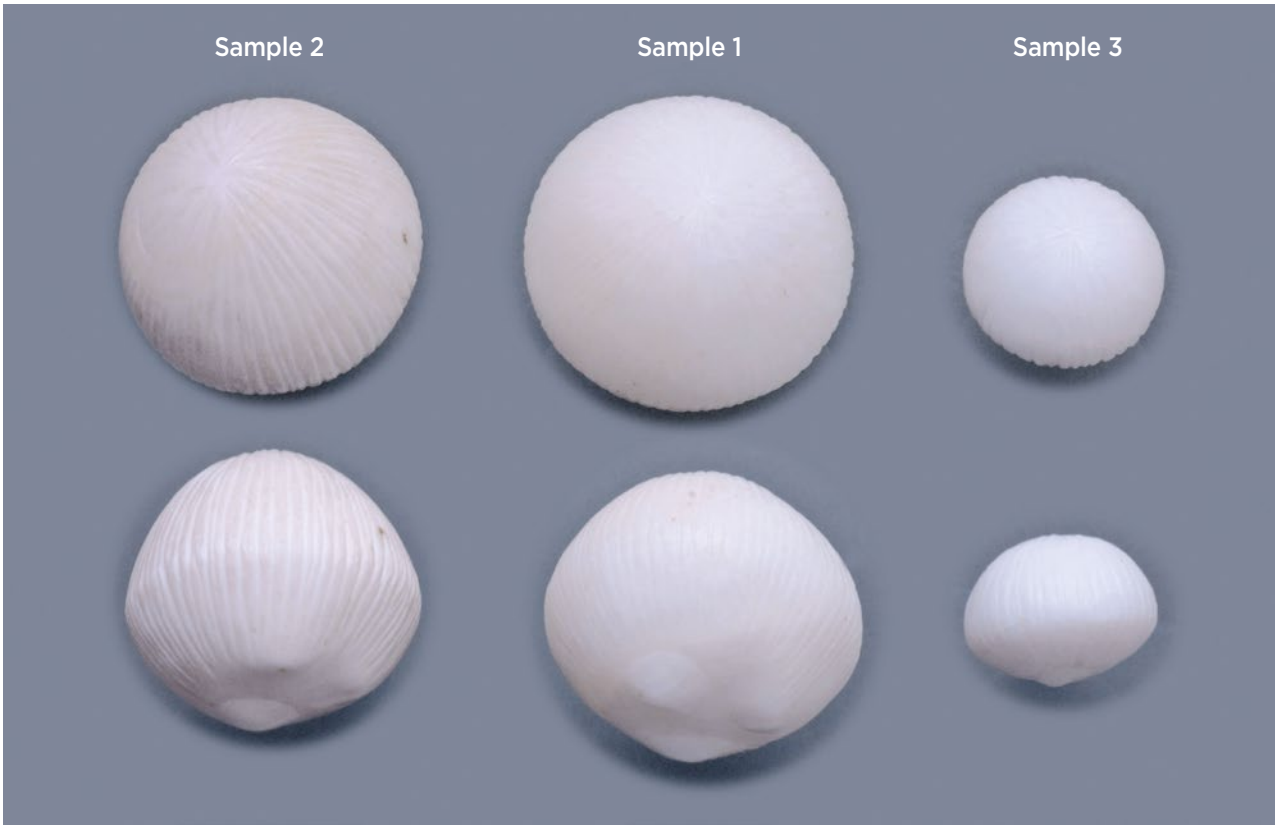

Figure 1: The three 'coconut pearl' samples investigated for this study are shown here from their top and side views. Sample 1 weighs 42.30 ct and measures 19.45 × 16.55 mm, sample 2 weighs 36.54 ct and measures 18.10 × 17.45 mm, and sample 3 weighs 9.11 ct and measures 11.85 × 9.40 mm. Composite photo © H. A. Hänni.

Microscopic Features

The surface of the spherules was roughly polished, with longitudinal grooves that locally intersected one another and appeared to have been made by a file (Figure 2). In addition, the basal portion of one sample showed a small bulge and the other two had three such bulges (see Figure 1, bottom row). Strong fibre-optic illumination of the objects revealed a parallel-layered structure (Figure 3). In addition, all of them were crossed by multiple fractures in various directions independent of the layered structure.

This internal structure is similar to the texture reported in some shell material used to manufacture bead nuclei for cultured pearls (e.g. Figure 4; Strack 2006). This material, also consisting of aragonite, is polished into beads that are larger than those that are commonly cut from common freshwater shells such as mussels from Mississippi and Tennessee, USA. Such thick-walled shell may be produced by *Tridacna* spp. giant clams, which have been protected since 1985 and are listed in CITES Appendix II (http://checklist.cites.org). Recent unpublished research on some large cultured pearl bead nuclei by one of the authors (HAH) showed that besides recent *Tridacna* shell, older giant clam shell material is also possibly used. Carbon-14 dating at the ETH Zurich Laboratory of Ion Beam Physics was performed on two large beads from Tahitian and South Sea cultured pearls that had cracked during the drilling process. The dating gave ages more than 300 years old, which may explain the presence of fractures in the bead nuclei. This

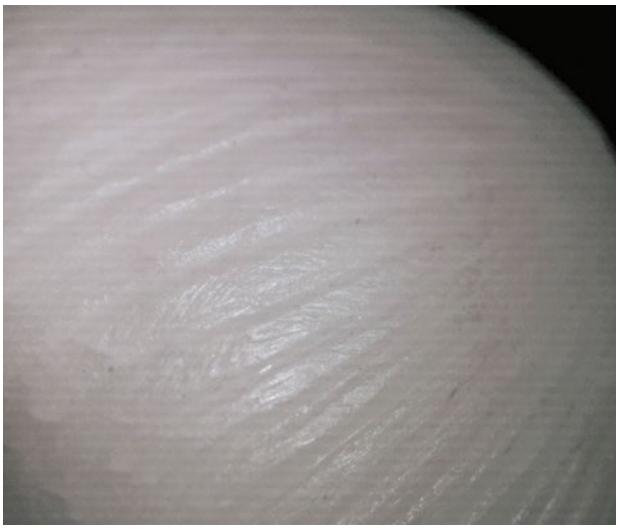

Figure 2: Indications of filing on the surface of 'coconut pearl' sample 2 are clearly visible as longitudinal grooves. Photomicrograph © H. A. Hänni; magnified 20×.

Figure 3: Layered growth structures and fine fissures (seen here as vertical dark lines) were visible in all three 'coconut pearl' samples, shown here for sample 3 in transmitted light. Photomicrograph © H. A. Hänni; magnified 20×.

indicates that material used for beads is available from giant clam shell derived from other than recently living individuals. The source of the aged white aragonite shell material is not currently known, but it may be from Papua New Guinea (cf. Kinch 2008).

A thin section of the dated bead material (Figure 5a) displays structures similar to those seen in Figure 3. By contrast, recent *Tridacna* shell material shows layered structures with a different appearance and without any noticeable cracks (Figure 5b).

In addition to being polished for use as bead nuclei, giant clam shell has also been worked and shaped into pearl imitations (Krzemnicki & Cartier 2017), and an object that was very similar to those described here was documented by Hainschwang (2011).

Origin

Accounts of 'coconut pearls' are always rather vague when it comes to the exact origin of the objects. The reports underline spiritual forces with enthusiastic descriptions, but documented evidence of a link to coconuts remains missing. When we take into account the SG of plant-derived materials, which may only approach 1.5, this is quite unlike the SG range of 2.80–2.85 measured for the (aragonite) samples in this study. Furthermore, botanists have not reported any plants producing pure $CaCO_3$, either regularly or by exception. Therefore, there is no plant tissue known that can precipitate aragonite. The densest material found in plants is probably vegetable ivory produced from the large nuts of several species of palm tree, which has an SG of 1.40–1.43 (i.e. tagua palm nut: O'Donoghue, 2006). This is roughly half the SG of aragonitic calcium carbonate. It is thus another point that sends 'coconut pearls' into the realm of fantasy.

No flame structure such as is found in *Tridacna* shell material or conch shell (cf. Hänni 2010) was visible on the present samples because their surfaces were not polished, and preparation of thin sections for more detailed examination was not possible. As described above, their layered growth structure is similar to that seen in older shell bead material that is sometimes used for large bead nuclei in cultured pearls. Note that if such spherical samples were formed naturally, any layered appearance would be expected to form concentric rather than flat-parallel patterns.

CONCLUSION

Our examination of three 'coconut pearls' indicates that they consist of aragonite shell material that was shaped into rough spheres with a grooved surface appearance. Such objects can be identified by their worked appearance and by their SG value of ~2.8, layered internal growth structure and Raman spectral identification as aragonite, all of which are consistent with shell material such as that derived from *Tridacna* spp. giant clams (either recent or older animals). Although the intersecting surface grooves and overall worked appearance are helpful for distinguishing the artisanal-made character of such objects, even highly polished samples would be straightforward to identify by their non-concentric internal layering, as well as the other identifying characteristics of aragonite—a mineral with no known botanical origin.

Figure 4: This 10-mm-diameter Tahitian cultured pearl contains a bead nucleus of atypical aragonite material that is characterised by a layered growth structure (typical of giant clam shell), superimposed by crossing fissures. Photo © H. A. Hänni.

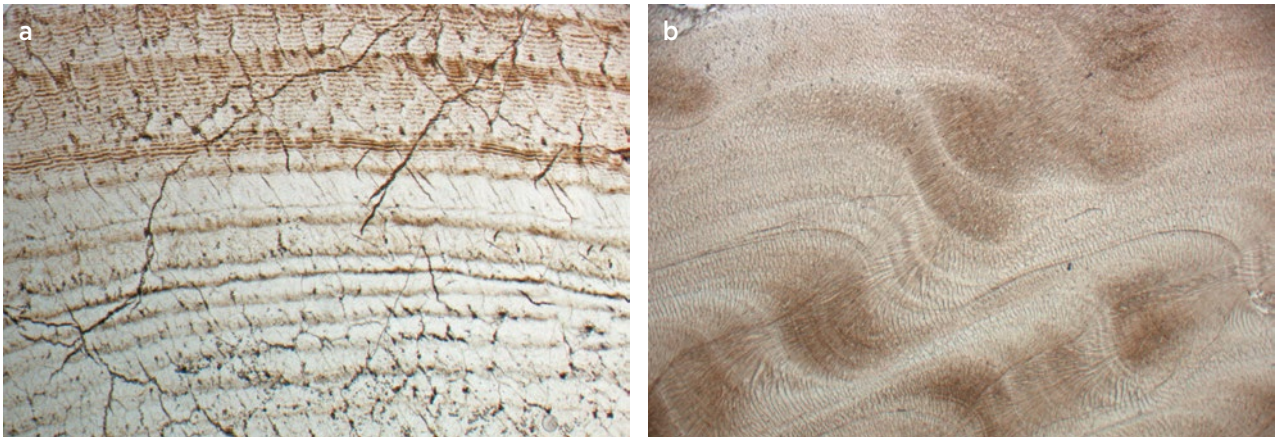

Figure 5: Thin sections of inferred *Tridacna* bead material are shown for (**a**) a specimen more than 300 years old (as determined by radiocarbon dating) with layered structures that strongly resemble those seen in the three 'coconut pearls' examined in this study, and (**b**) a recent specimen that shows wavy structures. Note also the presence of cracks in the old shell material and the uncracked nature of the recent shell. Photomicrographs © H. A. Hänni; magnified 16×.

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Conferences

AGA TUCSON CONFERENCE

The 2019 Accredited Gemologists Association Conference in Tucson, Arizona, USA, took place 6 February and was attended by 138 people from nine countries. The event was moderated by AGA president **Stuart Robertson** (Gemworld International Inc., Glenview, Illinois, USA) and featured five presentations. The day closed with the AGA Gala and award presentations (Figure 1; see the end of this report for a full list of awardees).

Jeffery Bergman (Primagem, Bangkok, Thailand) described the history, gemmological properties, clarity enhancement (with cedarwood oil) and marketing of emeralds from the Halo mine in the Shakiso area of Ethiopia. Their main internal features are colour zoning, biotite inclusions, growth tubes and blocky two- and three-phase fluid inclusions, and their similarity to Zambian emeralds means that trace-element analysis is necessary for distinguishing them from one another.

Gina Latendresse (American Pearl Company, Nashville, Tennessee, USA) covered the history, production and varieties of freshwater natural pearls from USA. Approximately one in 10,000 freshwater mussels contains a pearl, and of those only 5% have a symmetrical shape and 1% are round; the remainder have various baroque shapes that are termed 'feathers', 'rose buds', 'turtlebacks', etc. Latendresse then touched on natural pearls of marine origin such as those from quahog, abalone and conch molluscs, and also described various pearl imitations made from polished shell material.

Dr Claudio Milisenda (DSEF German Gem Lab, Idar-Oberstein, Germany) reviewed the composition and structure of the tourmaline group, and then described the properties and sources of various colour varieties of gem tourmaline, which most commonly consist of the elbaite, liddicoatite and dravite-uvite species. He indicated that clarity enhancement of tourmaline with oils and polymers is becoming more common, particularly for rubellite.

Dr Daniel Nyfeler (Gübelin Gem Lab, Lucerne, Switzerland) discussed the traceability of gemstones. Barriers to attaining full transparency along the supply chain from source to end consumer include the remoteness of the deposits, the numerous transactions during which stones change hands frequently and the informal/artisanal nature of mining of many coloured stones. Nyfeler described the Emerald Paternity Test for implanting an invisible barcode (using DNA tagging technology) into newly mined emeralds, and explained how the new Provenance Proof initiative uses blockchain technology to provide a digital tracer of a stone's journey through the supply chain. Anyone can sign up to use the blockchain for free at www.provenanceproof.io.

Jon Phillips (Corona Jewellery Co., Toronto, Ontario,

Figure 1: Dr Karl Schmetzer holds his 2019 Antonio C. Bonanno Award for Excellence in Gemology, while a long list of his publications is displayed by Antoinette Matlins (left), Stuart Robertson (centre-left) and Dr Lore Kiefert (right), as Kathryn Bonanno (blue dress) and Karen Bonanno DeHaas (pink dress) look on. Photo courtesy of AGA.

Canada) reviewed diamond mining activities in Canada including Ekati (where underground operations are under development at the Misery pit), Diavik (where the third open pit [A21 pipe] was started in August 2018), Victor (which will close in 2019) and Gahcho Kué (where a 60.59 ct yellow octahedral diamond was found in October 2018). Phillips also covered the cutting and marketing of Canadian diamonds.

The conference featured workshops by **Dr Çiğdem Lüle** (Kybele LLC, Buffalo Grove, Illinois, USA) on gem treatments and their influence on the market, **Gary Smith** (Smith's Jewelers, Montoursville, Pennsylvania, USA) on precious metal testing and **Samantha Lloyd** (Gem-A, London) on hand-held gemmological testing instruments.

The AGA Gala took place that evening, where awardees were honoured with the 2019 Antonio C. Bonanno Award for Excellence in Gemology in three categories: (1) for gemmological education, **Donna Hawrelko** (Vancouver Community College, British Columbia, Canada) was recognised for her contributions to the field and her commitment to numerous gemmology students; (2) for gemmological instruments, **Alberto Scaran**i and **Mikko Åström** (Magilabs, Rome, Italy, and Helsinki, Finland) were honoured for making advanced spectroscopy technology more accessible and affordable to gemmologists; and (3) for gemmological research, **Dr Karl Schmetzer** (Petershausen, Germany) was lauded for over 50 years of publications and presentations on mineralogical and gemmological topics (again, see Figure 1).

Brendan M. Laurs FGA

21ST FEEG SYMPOSIUM AND CIBJO SEMINAR ON RESPONSIBLE SOURCING

The 21st symposium of the Federation for European Education in Gemmology (FEEG) was organised by the Istituto Gemmologico Italiano (IGI) as a joint event with a seminar presented by CIBJO, the World Jewellery Confederation, on responsible sourcing and sustainability. The event took place on 19 January 2019 during the Vicenzaoro jewellery trade show in Vicenza, Italy.

Dr Gaetano Cavalieri (CIBJO president, Milan, Italy) introduced and moderated the CIBJO seminar. He explained that consumer confidence, on which the entire premise of the gem business is built, requires more than just maintaining the integrity of the product. The ways in which the members of the jewellery industry behave and impact society and the environment are fundamental components of consumer confidence.

This author (FEEG president, Brussels, Belgium) welcomed the delegates and introduced FEEG. He pointed out that we are confronted with an explosion of knowledge and an increasing need to serve a growing network of gem enthusiasts and jewellery professionals throughout Europe. Excellence in gemmological training is vital. It is the aim of FEEG to be the world's finest and fastest-growing gemmological education organisation to passionately teach industry members and consumers about gems.

Philip Olden (CIBJO, Bern, Switzerland) provided an overview of CIBJO's new 'blue book' on responsible sourcing, which is meant to provide guidance and a framework within which all members of the industry can perform responsible-sourcing due diligence, irrespective of their size and type of business.

Francesca Marino (CIBJO, Bern) looked at how the implementation of social responsibility practices could change through the application of blockchain technology. Blockchain makes the process of ethically evaluating the behaviour of a company more objective, eliminating the arbitrariness that sometimes accompanies other methods.

Rui Galopim de Carvalho (CIBJO and Portugal-Gemas Academy, Lisbon, Portugal) presented a gemmological and historical overview of gem-quality coral, and explained that it is critical to differentiate the eight precious coral species from the thousands of other common (i.e. reef-building) corals. In light of the current emphasis on sustainability and corporate social responsibility, it is important to educate members of the trade and consumers to the fact that coral used in jewellery does not pose a threat to coral reefs, although it does need to be sustainably harvested.

Vincenzo Liverino (CIBJO, Bern) described research being conducted at scientific institutes around the world with the support of the CIBJO Coral Commission. These efforts are yielding promising results that could help with the regrowth and repopulation of common corals affected by global warming. The CIBJO Coral Commission will soon launch an online course about coral and will assist gemmological education organisations with providing information on coral in their programmes.

Prof. Roberto Vona (Business Management Department, University of Naples Federico II, Italy) considered how blockchain technology could be applied to manage the precious coral supply chain, and so provide opportunities to improve the quality and sustainability of the product. Blockchain could deliver objective and unalterable records

Figure 2: Speakers at the 21st FEEG symposium included (left to right) Clement Sabbagh, Valentina Gagliardi, Giacomo Diego Gatta, Andrea Zullino and Fabrizio Nestola. Photo courtesy of Italian Exhibition Group.

of what is known about a product as it moves along the chain of distribution, providing evidence that sustainable practices have been complied with throughout the harvesting, processing and sales activities.

For the afternoon session, the FEEG Symposium was opened by **Paolo Valentini** (IGI vice president, Milan, Italy), who welcomed the delegates and introduced the five speakers (Figure 2).

Clement Sabbagh (International Coloured Stone Association [ICA], Governador Valadares, Brazil) discussed the role ICA plays in the gem industry, as well as the networking power and services that ICA provides to its members.

Valentina Gagliardi (IGI, Milan, Italy) delved into the unambiguous identification protocols of jade, which consists of two different gem materials: jadeite and nephrite. Both are silicates and form aggregates. Jadeite is an Al-rich pyroxene and nephrite is an Mg-rich amphibole, and they can be separated by standard gemmological tests. The deposits as well as classifications (i.e. A, B and C jade) were discussed. Jadeite and omphacite are both pyroxenes that form a solid-solution series, and Raman spectroscopy can be used to differentiate them.

Prof. Giacomo Diego Gatta (University of Milan, Italy) discussed the potential of single-crystal X-ray diffraction as a non-destructive technique in gemmology. After a brief introduction to the basic aspects of X-ray diffraction theory, he described an actual case study: a 4 mm crystal was identified as chambersite [ideally $(Mn^{2+},Fe^{2+})_3(B_7O_{13})Cl$] using a four-circle X-ray diffractometer combined with openly available databases containing basic crystallographic parameters of minerals.

Andrea Zullino (IGI, Milan, Italy) spoke about the role of defects in diamond classification. Optical defects occur in very low concentrations in diamond, and they may cause absorption features in the visible-range spectrum to produce colour. Their presence can be detected using spectroscopic techniques. A novel indicator of the exposure of type Ia diamonds to artificial ionising radiation and subsequent annealing consists of narrow photoluminescence lines in the red region, between 681 and 725 nm, which result from vacancies trapped by interstitial carbon aggregates and platelets. The interstitial structures become sites of vacancy trapping—by thermal migration of radiation-induced vacancies—when a diamond undergoes treatment.

Prof. Fabrizio Nestola (University of Padua, Italy) described his research on determining the depth and growth mechanisms of diamond formation by characterising mineral and fluid inclusions. The presence of syngenetic inclusions of ringwoodite proves the super-deep formation of diamond. Ringwoodite constitutes 60% or more of the lower part of the earth's transition zone, between 525 and 660 km depth, and this hydrous mineral indicates the presence of a significant amount of water in this region. 'CLIPPIR' (Cullinan-like, large, inclusion-poor, pure [type II], irregular-shaped, resorbed) diamonds are of such 'super-deep' origin. Their inclusion composition indicates that the deep mantle environment contains small pockets of oxygen-deficient metallic liquid from which the diamonds crystallised.

The day ended with the FEEG diploma ceremony (Figure 3), which celebrated 56 new graduates. They represent the future of gemmology. FEEG gemmologists master knowledge of the properties of gems and achieve academic excellence in gemmology. The next FEEG symposium will be held in Schoonhoven, The Netherlands, in January 2020.

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Figure 3: Presenters at the FEEG diploma ceremony in 2019 were (left to right) IGI president Raffaele Maino, FEEG president Guy Lalous, CIBJO president Dr Gaetano Cavalieri and Charles Evans of Gem-A. Photo courtesy of Italian Exhibition Group.

Gem-A Notices

Gifts to the Association

Gem-A is most grateful to the following for their generous donations that will support continued research and teaching:

Andrew Hinds, F. Hinds, UK, for a signed and framed photograph of Eric Bruton sitting at Ayers Rock that was taken on NAG's 'Jewellers' Study Tour to Australia' in 1980.

Dennis Ho, Hong Kong, for three carvings, one bangle and a fragment of jadeite; six absorption spectra boxes; two interference figure boxes; and five bags of rough material: sapphire (Tanzania), kyanite (Myanmar), topaz (Brazil), chrome tourmaline (Myanmar) and spinel (Myanmar).

Mauro Panto, The Beauty in the Rocks, Italy, for a 'rhodusite' (magnesio-riebeckite) doublet from Jezkagan (Zhezkazgan), Kazakhstan.

Dr Marco Campos Venuti, Spain, for a selection of polished stones from Brazil: albite, scapolite, quartz with biotite(?) inclusions, quartz with triphyllite inclusions, apatite in jasper and opal with dendrites.

New COO for Gem-A

A new year and a new start for Daniel Heath, Gem-A's new Chief Operating Officer. Joining us from his previous role at The Sports Grounds Safety Authority, where he was Head of Corporate Services, Daniel is a Chartered Management Accountant and has been heading up finance and operations at Gem-A since January 2019.

Gem-A
THE GEMMOLOGICAL ASSOCIATION OF GREAT BRITAIN

Gem-A presents...

FREE GEMMOLOGY WEBINARS

Are you based outside of the UK? Do you find it difficult to get to Gem-A HQ in London for our workshops? For the first time, Gem-A is pleased to offer a series of one-hour webinars, designed to boost your gemmological knowledge no matter where you are in the world. Our convenient webinars are targeted at beginners who want to get a grasp of the basics, fast. Each of our webinars is entirely free – just book your place by searching 'Gem-A' on Eventbrite and join us from the comfort of your own home or office.

Understanding Gemstones

18 Jul 2019

Start your gemmology journey with this accessible beginner's guide to gemstones. This tutor-guided webinar will explain the physical characteristics of popular gems such as sapphire, emerald and ruby, while explaining their origins, history and vital care techniques. At the end of this webinar, you will have a better grasp of basic gemmology and the terminology that makes it an exciting and varied field of study.

Understanding Diamonds

10 Oct 2019

Are you passionate about diamonds but want to know more? This tutor-guided webinar will explain how diamonds are formed, what makes them special and how to assess their value and qualities using the 4Cs: cut, colour, clarity and carat weight. You will learn the basics of diamond certification and begin to discover the broader issues of diamond synthetics and simulants. At the end of the webinar, participants will be one step closer to understanding the uniqueness of diamond.

Obituary

Edward Allan Jobbins
1923–2019

Alan, as he was known to his friends and colleagues (he rarely, if ever, used either 'Edward' or the second 'l'), was born on 14 December 1923 in Rotherhithe, London. He was educated at the John Roan School, Greenwich, where he first developed an interest in geology during field trips to the Lake District organised by his geography teacher. From 1939 to 1942, during World War II, Alan was evacuated to Ammonford, Wales, where he boarded with a solicitor and his family who helped Alan through his formative years.

Alan gained entry to King's College, London, but then joined the Queen's Regiment. He was declared 'Grade 3' due to his poor eyesight and was therefore sent to teach mathematics and English at the Army College in Scotland. He later returned to King's College to complete his degree in geology, where he not only gained First Class Honours, but also won the Myers prize in mineralogy and the Tennant prize in geology. In addition to his geology degree, Alan also became a qualified Civil Engineer, which possibly accounted for his interest in building stone.

In 1950 Alan joined The Geological Survey/The Geological Museum in London as a geologist, progressing to become curator of minerals and gemstones where he was responsible for the care and display of the gem and mineral collections, including acquisitions and organising exhibitions. He was responsible for the creation of a superb permanent display of gems at the museum, which not only showed the specimens at their best but also provided comprehensible and interesting information for visitors. Sadly, this display was subsequently dismantled when the collections were incorporated into The Natural History Museum. Alan also undertook research into many important gemmological and mineralogical subjects such as East African garnets, the structure and identification of synthetic opals, and the identification and characterisation of a new mineral, magnesio-axinite. He was also called to investigate the meteorite which fell on the town of Barwell, near Leicester, on 24 December 1965.

During his time at the museum, Alan was seconded to UN/UNESCO and the British Overseas Development Administration, where his assignments took him to numerous gem-producing areas in Brazil (the diamond mines and Piauí opal deposits), Myanmar (previously Burma), Cambodia (the Pailin ruby and sapphire deposits), Guyana, India and Sri Lanka (surveying the gem mining and cutting industries). His work included carrying out geological and gemmological surveys of the deposits to determine how the resources could be developed and utilised. Much of this work became the subject of papers in a number of learned publications, including *The Journal of Gemmology*. Alan was particularly proud of his time in Burma (1967–1968), where he set up a research laboratory and taught gemmology to a class of Burmese students. Ten of them passed their Gemmology Diploma under his tutorship, with two progressing to doctorates at Cambridge and Durham Universities. It was during his time in Burma that Alan developed a love of and expertise in jade, and with jadeite in particular.

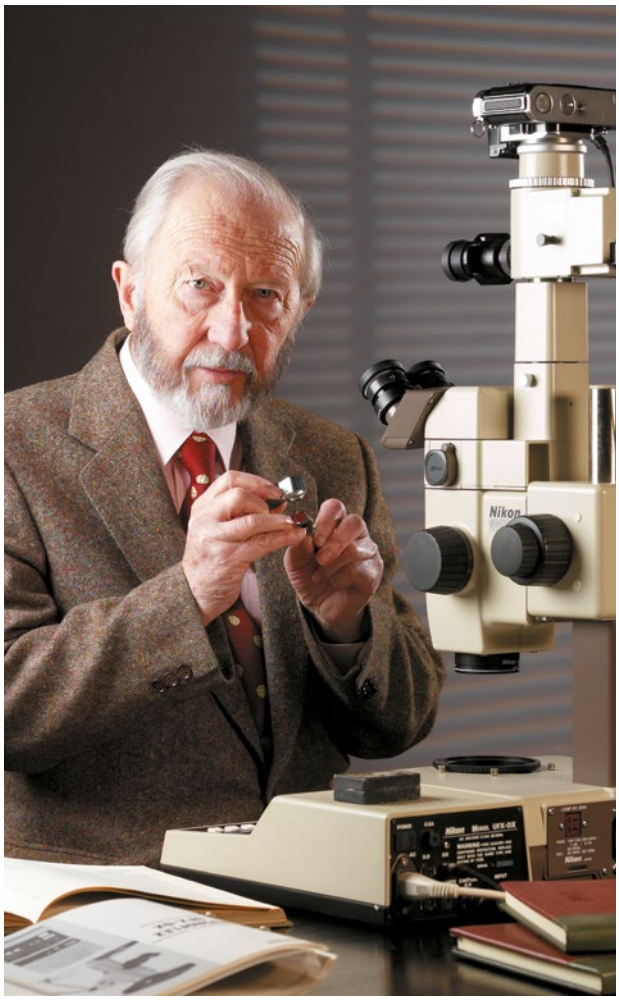

Although Alan retired from The Natural History Museum in 1983, he remained a consultant for a further

two years and continued his work with gems and gemmology. Both during his time at the museum and after his retirement, Alan was closely connected to the wider gemmological world and, in particular, with The Gemmological Association of Great Britain (now Gem-A). He assisted *Journal* editor J. R. H. Chisholm from 1973 until 1985 when, beginning with the April issue, he briefly acted as joint editor before becoming editor himself in 1986, a post he held until the end of 1993. Alan also helped to review papers, not just for *The Journal* but also for other publications. He was always happy to offer advice and guidance to authors, and he was often asked to review new books. Alan revised the 6th and 7th editions of Robert Webster's *Gemmologists' Compendium* and the 10th edition of Basil Anderson's *Gem Testing*.

Perhaps one of Alan's 'crowning' achievements was that, under commission of The Royal Collection, he assembled a team of expert gemmologists to carry out a comprehensive examination and description of the British Crown Jewels and royal regalia. The work was carried out between 1986 and 1989, and the results were detailed in *The Crown Jewels: The History of the Coronation Regalia in the Jewel House of the Tower of London*, a two-volume, leather-bound, numbered, limited-edition book published in 1995 by Her Majesty's Stationery Office. In fact, Alan's connection with The Royal Collection went further, as he was occasionally asked to examine other objects for confirmation of identity or updating of details prior to lending to external exhibitions.

Alan took his Gemmology Diploma examinations in 1972 and passed with a mark of 98% after the chief examiner, Basil Anderson, deducted two points for poor handwriting! His performance won him the Tully Medal. Alan was an examiner for the Gemmological Association's examinations from 1975 to 1995 and served on the Executive Committee/Council of Management from 1987 to 1993. He was elected president of the Association, a position he held from 2004 to 2008, after which he remained as vice president until his death on 9 February 2019.

Alan was a long-standing member of IGC (the International Gemmological Conference) and served on their Executive Committee. He was also a founding member of ICA (the International Colored Gemstone Association) and contributed to CIBJO's industry rules. In addition, he advised the laboratory at the London Chamber of Commerce, which later became the Gem Testing Laboratory of Great Britain. Closer to home, Alan taught a post-diploma class at Sir John Cass College for well over 20 years and was a key member of the learned group JPH (Jewellery, Plate and Horology). He also served as president of the Society of Jewellery Historians.

Continuing his work for the Gemmological Association, Alan travelled to Wuhan and Beijing, China, on a number of occasions with Dr Jamie Nelson to introduce the Association's courses to China. This resulted in a significant increase in the number of students from China who gained their Gemmology Diploma, just at a time when the potential of the country's huge resources was being realised, coupled with a growth in the demand for gems in their domestic market.

In recognition of a lifetime dedicated to gemmology, Alan was presented with the 2005 Antonio C. Bonanno Award for Excellence in Gemology by the Accredited Gemologists Association.

Despite all his accomplishments and his high standing within the gem world, Alan always remained a modest man who was delighted to share his knowledge and experience without any material gain. Passing on his knowledge to others with the possibility to inspire was reward enough. He was renowned for the many and varied lectures that he gave without the 'safety net' of notes. 'My slides are my notes' was often his response when asked. It was not uncommon for members of the audience to comment afterwards that they had just heard the best talk they had ever attended. He would treat each audience with warmth and respect regardless of whether he was speaking to experts at a prestigious event, a small mineral society or a local interest group.

Aside from gems and geology, Alan also had a passion for birdwatching, and it was in 1970, on an organised birding holiday to the Algarve in Portugal, when Alan met his future wife and soulmate, Mary. It was apparently 'love at first sight'. Together, they enjoyed many happy holidays birdwatching, and they shared a love of fine food and wine, with Mary's culinary prowess complementing Alan's excellent knowledge of fine wine. They didn't keep such pleasures to themselves but, with their customary generosity and hospitality, would often entertain friends, colleagues and groups, both large and small.

Such was Alan's kindness and generosity of spirit that so many of his former colleagues and students regarded him as a true friend and will miss him deeply. I am honoured to consider myself one of those very fortunate people.

Alan is survived by Mary and by his son, Simon.

Peter Wates **FGA DGA**
Purley, Surrey

Learning Opportunities

CONFERENCES AND SEMINARS

46th Rochester Mineralogical Symposium
11–14 April 2019
Rochester, New York, USA
www.rasny.org/minsymp

16th Annual Sinkankas Symposium—Pearl
27 April 2019
Carlsbad, California, USA
www.sinkankassymposium.net

Swiss Gemmological Society Conference
28–30 April 2019
Meisterschwanden, Switzerland
https://gemmologie.ch/en/current

Scottish Gemmological Association Conference
3–6 May 2019
Cumbernauld, Scotland
www.scottishgemmology.org/conference

GAC-MAC-IAH (Geological Association of Canada–Mineralogical Association of Canada–International Association of Hydrogeologists) Conference
12–15 May 2019
Québec City, Québec, Canada
https://gacmac-quebec2019.ca
Session of interest: Recent Advances in the Study of Gems and Gem Deposits

NDNC 2019: 13th New Diamond and Nano Carbons Conference
12–17 May 2019
Hualien, Taiwan
www.ndnc2019.org

5th Mediterranean Gemmological & Jewellery Conference
17–19 May 2019
Limassol, Cyprus
https://gemconference.com

33rd Annual Santa Fe Symposium
19–22 May 2019
Albuquerque, New Mexico, USA
www.santafesymposium.org

48th Annual Society of North American Goldsmiths (SNAG) Conference
22–25 May 2019
Chicago, Illinois, USA
www.snagmetalsmith.org/conferences/the-loop

European Gemmological Symposium 2019
24–26 May 2019
Idar-Oberstein, Germany
www.dgemg.com/egs-2019-en.php

Sustainable Development in the Mining Industry (SDIMI 2019)
27–29 May 2019
Sydney, Australia
http://sdimi.ausimm.com

JCK Las Vegas
31 May–3 June 2019
Las Vegas, Nevada, USA
http://lasvegas.jckonline.com
Note: Includes a seminar programme

International Exposition of Agate
6–9 June 2019
Austin, Texas, USA
https://ntrocks.com/international-exposition-of-agate
Note: Includes a seminar programme

Jewelry of the 20th Century, 1900–1960s
9 June 2019
Boston, Massachusetts, USA
www.jewelryconference.com

PEG 2019: 9th International Symposium on Granitic Pegmatites
11–18 June 2019
Pala, California, USA
http://peg2019.com
Note: Includes field trips to gem-bearing pegmatites

18èmes Rendez-Vous Gemmologiques de Paris
~~17 June 2019~~ 9 September 2019
Paris, France
www.afgems-paris.com/rdv-gemmologique

Mineralogical Society of America Centennial Symposium
20–21 June 2019
Washington DC, USA
www.minsocam.org/MSA/Centennial/MSA_Centennial_Symposium.html
Sessions of interest: Scientific Characterization of High-Value Gemstones; Mineral Inclusions in Diamonds from the Deep Earth; Museum Mineral Collections in the Next 100 Years

ECROFI 2019: European Current Research on Fluid and Melt Inclusions
23–27 June 2019
Budapest, Hungary
https://ecrofi2019.elte.hu

Sainte-Marie-Aux-Mines 56th Mineral & Gem International Show
27–30 June 2019
Sainte-Marie-aux-Mines, France
www.sainte-marie-mineral.com/english
Note: Includes a seminar programme

19th International Meeting on Crystal Chemistry, X-ray Diffraction and Spectroscopy of Minerals
2–5 July 2019
Apatity, Russia
www.ksc.ru/en/xrd2019

Goldsmiths' Company Jewellery Materials Congress 2019
8–9 July 2019
London
www.assayofficelondon.co.uk/events/the-goldsmiths-company-jewellery-materials-congress

2019 Antique Jewelry & Art Conference
27–28 July 2019
Newark, New Jersey, USA
www.jewelrycamp.org

Northwest Jewelry Conference
9–11 August 2019
Seattle, Washington, USA
http://northwestjewelryconference.com

Goldschmidt Conference
18–23 August 2029
Barcelona, Spain
https://goldschmidt.info/2019
Session of interest: Origin and Evolution of Continental Mantle Lithosphere and its Resource Endowment

Dallas Mineral Collecting Symposium
23–25 August 2019
Dallas, Texas, USA
www.dallassymposium.org

15th Biennial Meeting of the Society for Geology Applied to Mineral Deposits
27–30 August 2019
Glasgow, Scotland
www.sga2019glasgow.com
Session of interest: Supergenes, Gems and Non-Metallic Ores

36th International Gemmological Conference
27–30 August 2019
Nantes, France
www.igc-gemmology.org

Japan Jewellery Fair 2019
28–30 August 2019
Tokyo, Japan
www.japanjewelleryfair.com/en
Note: Includes a seminar programme

42nd Joint Mineralogical Societies of Australasia Seminar
31 August–1 September 2019
Perth, Western Australia
www.minsocwa.org.au/gallery.html

International Jewellery London (IJL)
1–3 September 2019
London
www.jewellerylondon.com
Note: Includes a seminar programme

Geological Society of Namibia 50th Anniversary Conference
1–4 September 2019
Windhoek, Namibia
www.gssa.org.za/wp-content/uploads/GeolSocNam.pdf
Note: A field trip to diamond areas is planned.

10th International Congress on the Application of Raman Spectroscopy in Art and Archaeology (RAA2019)
3–7 September 2019
Potsdam, Germany
www.raa2019.de

30th International Conference on Diamond and Carbon Materials (DCM 2019)
8–12 September 2019
Seville, Spain
www.diamond-conference.elsevier.com

9th European Conference on Mineralogy and Spectroscopy (ECMS 2019)
11–13 September 2019
Prague, Czech Republic
http://ecms2019.eu
Workshop of interest: Gemstone Deposits

Denver Gem & Mineral Show
13–15 September 2019
Denver, Colorado, USA
www.denvermineralshow.com
Note: Includes a seminar programme

2019 National Association of Jewellers' Loughborough Conference
14–16 September 2019
Loughborough
www.naj.co.uk/whats-on/2019-conference/8201?OccId=11716

Hong Kong Jewellery & Gem Fair
16–22 September 2019
Hong Kong
http://tinyurl.com/yyogn944
Note: Includes a seminar programme

14th International Congress for Applied Mineralogy (ICAM 2019)
23–27 September 2019
Belgorod, Russia
www.geo.komisc.ru/icam2019/en
Themes of interest: Precious Stones; Cultural Heritage

International Colored Gemstone Association (ICA) Congress
12–15 October 2019
Bangkok, Thailand
www.gemstone.org/events/2019-congress

Chicago Responsible Jewelry Conference
25–26 October 2019
Chicago, Illinois, USA
www.chiresponsiblejewelryconference.com

Munich Show/Mineralientage München
25–27 October 2019
Munich, Germany
https://munichshow.de/?lang=en
Note: Includes a seminar programme

Gem-A Conference 2019
2–3 November 2019
London
https://gem-a.com/event/conference-2019

MAESA 2019: Earth Sciences and Sustainable Development
30 November–1 December 2019
Yangon, Myanmar
www.maesa.org
Sessions of interest: Mineralogy and Origin of Gem Deposits; Geographic Typing of Gemstones and Advances in Instrumentation

OTHER EDUCATIONAL OPPORTUNITIES

Gem-A Workshops and Courses
Gem-A, London
https://gem-a.com/education

Lectures with Gem-A's Midlands Branch
Fellows Auctioneers, Augusta House, Birmingham
Email louiseludlam@hotmail.com

- Charles Bexfield—Silverware, Assay Offices & Hallmarks
  26 April 2019
- Shirley Mitchell—Valuations
  25 October 2019

Lectures with the Society of Jewellery Historians
Society of Antiquaries of London, Burlington House, London
www.societyofjewelleryhistorians.ac.uk/current_lectures

- Beth Wees—TBA
  25 June 2019
- Maria Maclennan—Forensic Jewellery
  24 September 2019
- Rachel Church—Brooches, Badges and Pins at the Victoria and Albert Museum
  26 November 2019

New Media

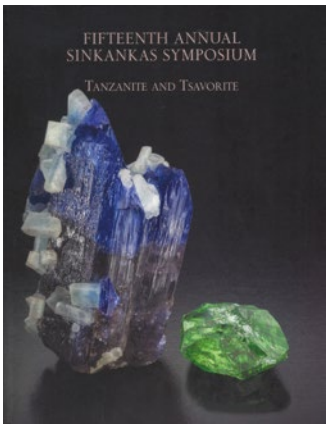

Fifteenth Annual Sinkankas Symposium—Tanzanite and Tsavorite

Ed. by Stuart Overlin, 2018. Pala International, Fallbrook, California, USA, 88 pages, illus., ISBN 978-0991532032. Print on demand; price available upon request (promotional@dpidirect.com).

The Fifteenth Annual Sinkankas Symposium, featuring tanzanite and tsavorite, was held in April 2018 at the Gemological Institute of America in Carlsbad, California, and was co-hosted by the Gemological Society of San Diego (for a report on that event, see the Conferences section of *The Journal*, Vol. 36, No. 2, pp. 162–163). Attendees received an attractive proceedings volume that provides an excellent record of some of the topics covered by the speakers.

The volume begins with a listing of the symposium programme, speaker biographies and abstracts. These are followed by speaker contributions covering a range of topics: geology and gemmology of tanzanite (Robert Gessner); inclusions in tanzanite and tsavorite (Nathan Renfro); the process of cutting a suite of fancy-colour zoisites (Meg Berry); collecting tanzanite and tsavorite crystals (Will Larson); the history of the discovery and mining of tsavorite in Kenya, and the introduction of tanzanite into the world market by Campbell Bridges (Bruce and Judith Bridges); tanzanite price trends (Stuart Robertson); and treatments and imitations of tanzanite and tsavorite (Shane McClure). The volume also includes reprints of three short publications by Campbell Bridges on tsavorite and other East African gems. It closes with extensive bibliographies covering tanzanite and tsavorite.

The book is printed on heavy paper stock and features many beautiful photos (mostly by photographer extraordinaire Robert Weldon) of tanzanite and tsavorite that convey their beauty as both faceted stones and mineral specimens. Gemmologists, geologists, gem and mineral collectors, and enthusiasts of tanzanite and tsavorite will appreciate this attractive and informative book.

Brendan M. Laurs FGA

Mogok: La Vallée des Pierres Précieuses/ Mogok: The Valley of Precious Stones

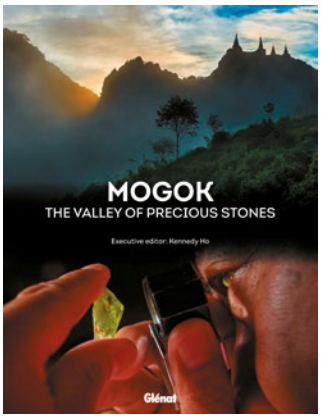

Ed. by Kennedy Ho and Emmanuel Fritsch, 2018. Glénat, Grenoble, France, 192 pages, illus., ISBN 978-2344029763. EUR39.50 hardcover (separate French and English versions).

Full disclosure before reviewing this magnificent book: I love Mogok! I have travelled to Burma/Myanmar on more than 35 occasions since my first trip in 1993 arranged by Dr Eduard Gübelin, including a dozen times to Mogok Valley itself. I also met Waing Kong Ho in 1974 and have known some of his children for many years, including both Kennedy and his brother Henry. I have also known Dr Emmanuel Fritsch since his years at GIA, so this book is like family to me. That said, let us examine what they have published. There have been various books prepared on Mogok in the past couple of decades. Most all are well done. However, this one is very well done.

In the preface, Kennedy Ho captures the spirit that is felt throughout this work:

> We have designed the book to appeal to the widest possible audience. A special effort has been made to present the scientific information it contains in an accessible manner that harmonises effectively with the book's content as a whole. We also wanted to convey the indescribable beauty of Mogok and its gems, which makes the heart beat faster and sets the spirit soaring. The photographs taken in the field as well as the laboratory images created using electronic microscopes reveal an array of unique mineral wonders, including rubies, spinels, peridots, sapphires....

The following nine chapters—assembled by a team of five professionals during two years of work—stir one's gemmological interest. 'Blood from the Earth' by Jean-Baptiste Rabouan introduces the reader to this team and their journeys into Mogok Valley to visit various mines and gem markets. 'The Mythical Valley of Mogok' by Candice Caplan delves into the mythology and the actual history of Mogok. Numerous references are quoted chronologically, so an accurate history is presented to the reader. The point is made that Mogok rubies have a history dating back to the 6th century according to Chinese documents from the Shan dynasty. This is much earlier than the usually quoted 'fact' that Mogok has been mined for almost a thousand years. Also included in the history are some famous personalities as well as notable 'jewels for the crowns of the world'. A final section covers 'miners and Buddhism'. The next chapter, 'A Sino-Burmese Saga' by Jean-Baptiste Rabouan, provides a fascinating account of the Ho family's history from China to Burma, into exile, and finally welcomed by Thailand. As summed up by Kennedy Ho, 'It all started with 30 dollars in cash, and a lot of sacrifices…'

The following chapter, 'The Dragon with Ruby Eyes' by Dr Emmanuel Fritsch, uncovers some of the region's very complex geology. Highlighted are the blue and white marbles which contain spinel and ruby. There's also a brief mention of gem-bearing pegmatites and sections on sapphires that occur mostly in syenites and on the overall diversity of gem species in the Mogok area. The chapter closes with a discussion of 'mining operations both large and small'. 'Rubies: The "Glowing Coal" among Burmese Gems' by Franck Notari describes the exceptional colour of rubies from Mogok, as well as some of the other properties that set them apart. A section is devoted to the colour term 'pigeon's blood' and another describes the inclusion features seen with the microscope. The chapter ends with several pages on ruby mining activities, focusing on alluvial deposits. Next, 'The Sapphires of Mogok' by Dr Thomas Hainschwang discusses the comparative rarity of sapphires in Mogok and describes some of their distinctive properties (e.g. inclusions). Besides blue sapphires, the chapter briefly covers other colours (including colour-change stones) as well as trapiche sapphires. The next chapter, 'Spinels, Peridots and Other Treasures from the Valley of Wonders' by Dr Emmanuel Fritsch and Candice Caplan, is rather short but provides an accurate discussion of spinel and peridot gems and mines, followed by other rare Mogok gems including painite, poudretteite and the recently discovered kyawthuite.

'Hunting for Treasure' by Jean-Baptiste Rabouan offers an in-depth look at the life of the independent miner—'a hard life with flashes of hope'. Also described are mining companies that operate in Mogok and their efforts to balance economic interests with protecting the environment. The final chapter, 'The Gemstone Road, from Mogok to the World' by Jean-Baptiste Rabouan, provides a fine summary of buying gems at the source. The reader is taken from the local 'umbrella market' in Mogok to private negotiations for a 10 ct 'pigeon's blood' ruby, ending with the book's last words: 'And that's all we get to see: the rest of the negotiations take place behind closed doors. At this level, absolute discretion is always the rule.'

All recent books on Mogok are filled with wonderful photographs, as the locality is truly remarkable. This book also stuns the reader with amazing photography of this mystical locality, and presents many images of cultural and gemmological interest including mines, local dealers (past and present), and great gemstones and jewellery pieces (both historic and modern). The excellent photos and insightful text come together to make this book an integral part of your personal library.

Bill Larson FGA
Pala International
Fallbrook, California, USA

Other Book Titles

COLOURED STONES

Mineralogy of Quartz and Silica Minerals
Ed. by Jens Götze, 2018. MDPI, Basel, Switzerland, 274 pages, ISBN 978-3038973485 (softcover) or 978-3038973492 (PDF). CHF59.50 softcover or free PDF.

The Tears of Fura: An Emerald Miner's Adventures Thru Revolution and Evolution
By Manuel J. Marcial, 2018. Self-published at Outskirts Press, Denver, Colorado, USA, 314 pages, ISBN 978-1478799030 (hardcover) or 978-1478799023 (softcover). USD49.95 (hardcover), USD29.94 (soft cover) or USD9.99 Kindle edn.

DIAMOND

Diamond Fields of Southern India
By S. Ravi, K.S. Bhaskara Rao and R. Ananda Reddy, 2018. Geological Survey of India Bulletin Series A, No. 68, 996 pages. INR3109.00.

Evolution of Magmatic and Diamond-Forming Systems of the Earth's Lower Mantle
By Anna V. Spivak and Yuriy A. Litvin, 2019. Springer International Publishing, Cham, Switzerland, 95 pages, ISBN 978-3319785172 (hardcover) or 978-3319785189 (eBook). CHF121.00 hardcover or CHF96.50 eBook.

Geology, Resources and Exploration Potential of the Ellendale Diamond Project, West Kimberley, Western Australia
By G. Boxer and G. Rockett, 2018. Geological Survey of Western Australia, Perth, Australia, 49 pages, ISBN 978-1741688153. Free PDF.

Geoscience and Exploration of the Argyle, Bunder, Diavik, and Murowa Diamond Deposits
Ed. by Andy T. Davy, Chris B. Smith, Herwart Helmstaedt, A. Lynton Jaques and John J. Gurney, 2018. Society of Economic Geologists Special Publication 20, 451 pages, ISBN 978-1629493060 (print), 978-1629493541 (flash drive) or 978-1629496399 (PDF). USD120.00 hardcover plus flash drive or USD99.00 PDF.

A Glossary of Kimberlite and Related Terms: Part 1—Glossary; Part 2—Practical Guide; Part 3—Abundance and Size Descriptors
By Barbara H. Scott Smith, Tom E. Nowicki, J. Kelly Russell, Kimberley J. Webb, Roger H. Mitchell, Casey M. Hetman and Jock V. Robey, 2018. Scott-Smith Petrology Inc., Vancouver, British Columbia, Canada, 144 pages (Part 1), 59 pages (Part 2), 56 pages (Part 3), ISBN 978-1775280606. CAD250.00 spiral-bound softcover.

GEM LOCALITIES

The Ankarana Plateau in Madagascar: Tsingy, Caves, Volcanoes and Sapphires
By Eric Gilli, 2019. Springer Nature, Switzerland, 148 pages, ISBN 978-3319998787 (hardcover) or 978-3319998794 (eBook). EUR139.99 hardcover or EUR118.99 eBook.

GENERAL REFERENCE

Catalogue of the Collections of the Geominero Museum Mineral Collection of the Autonomous Regions and Cities: Madrid Region
By Ramón Jiménez Martínez, Ruth González Laguna, María José Torres Matilla, Rafael Pablo Lozano Fernández, Eleuterio Baeza Chico, Carmen de Prada Galende, Héctor Sánchez Molinero, Alba María Carvajal de Lago and Silvia Cervel de Arcos, 2018. Instituto Geológico y Minero de España, Madrid, Spain, 77 pages. Free eBook.

Gemstone Detective: Buying Gemstones and Jewellery in Australia
By Kim Rix, 2019. Filament Publishing, Croydon, Surrey, 160 pages, ISBN 978-1912635252. GBP14.99 softcover.

Gemstone Detective: Buying Gemstones and Jewellery in Thailand
By Kim Rix, 2019. Filament Publishing, Croydon, Surrey, 128 pages, ISBN 978-1912635214. GBP12.99 softcover.

Gemstone Detective: Buying Gemstones and Jewellery Worldwide
By Kim Rix, 2019. Filament Publishing, Croydon, Surrey, 160 pages, ISBN 978-1912635467. GBP14.99 softcover.

JEWELLERY HISTORY

Ancient Rings: An Illustrated Collector's Guide
By T.N. Pollio, 2018. McFarland, Jefferson, North Carolina, USA, 180 pages, ISBN 978-1476673851. USD55.00 softcover.

The History of Jewelry: Joseph Saidian & Sons
By Caroline Childers, 2019. Rizzoli, New York, New York, USA, 194 pages, ISBN 978-0847865383. USD35.00 hardcover.

JEWELLERY AND *OBJETS D'ART*

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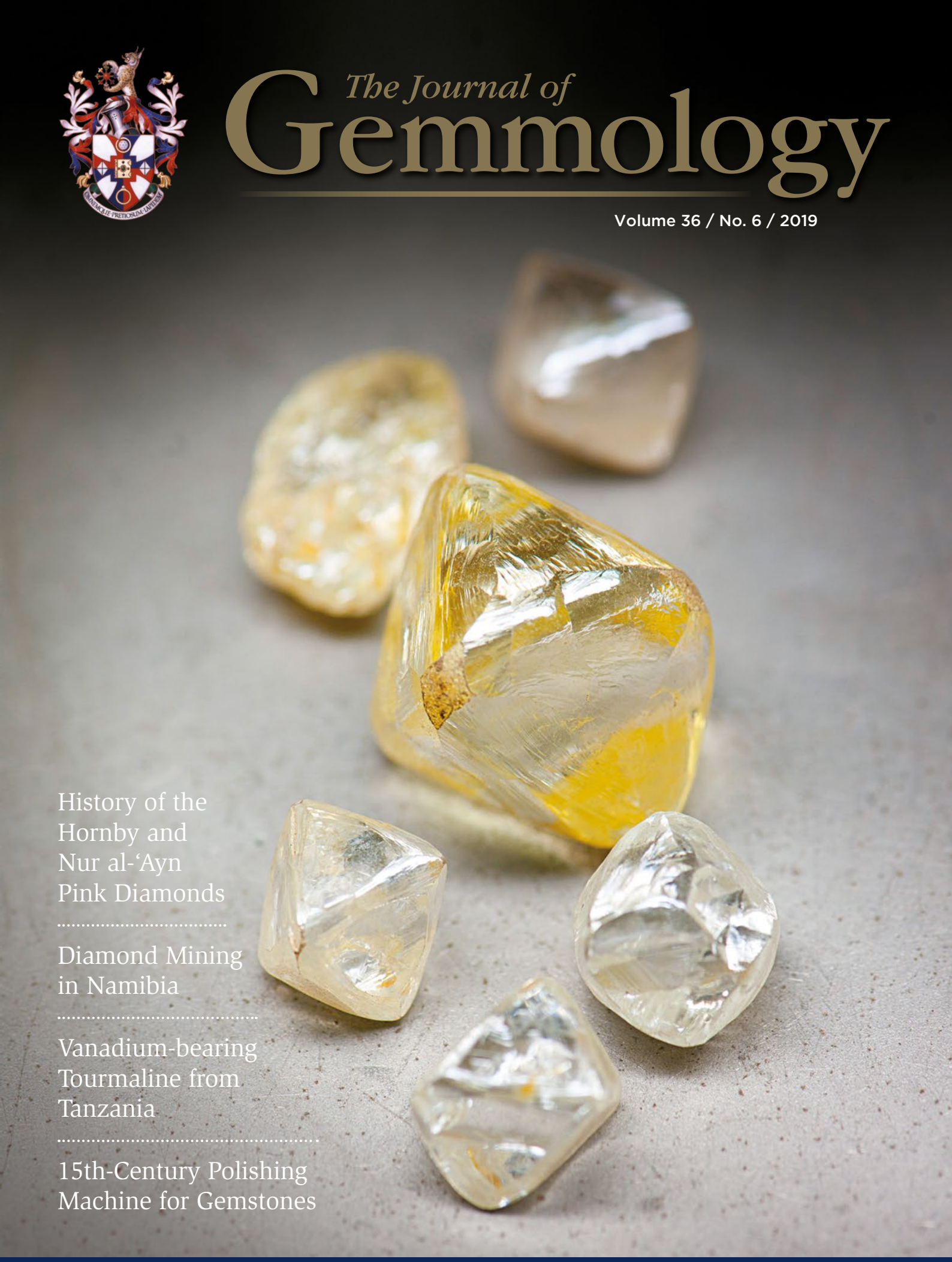

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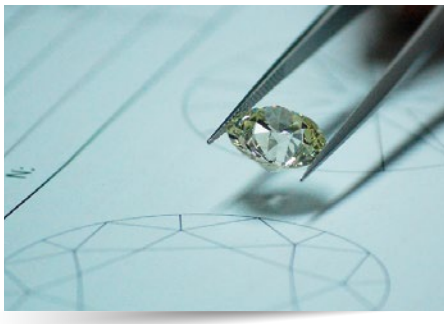

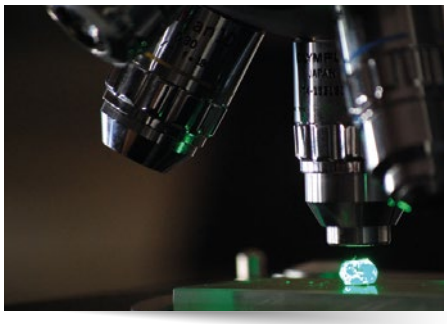

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Cover photo: *Namibian diamonds are renowned for being of high gem quality, and an article on pp. 524–532 of this issue uncovers the geology, mining and exploration of onshore and nearshore deposits lying on the south-western Namibian coast. The largest stone shown here is a yellow octahedron weighing 58.42 ct that was mined in 2011. Photo courtesy of De Beers.*

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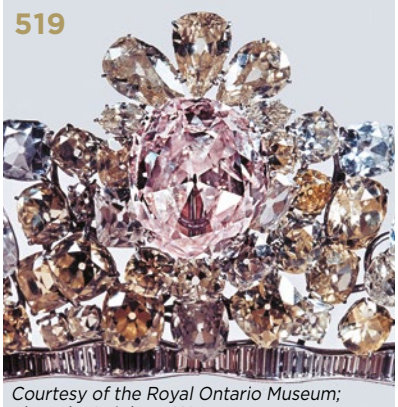

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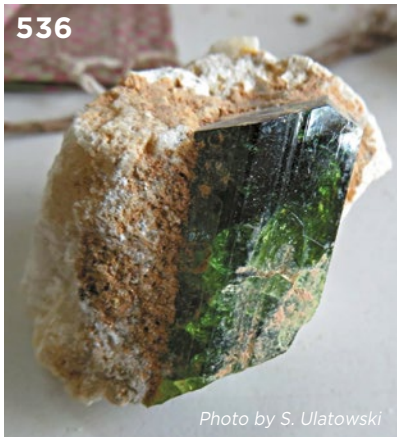

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The Editor-in-Chief is glad to consider original articles, news items, conference/excursion reports, announcements and calendar entries on subjects of gemmological interest for publication in *The Journal of Gemmology*. A guide to the various sections and the preparation of manuscripts is given at https://gem-a.com/index.php/news-publications/journal-of-gemmology/submissions, or contact the Editor-in-Chief.

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What's New

INSTRUMENTATION

B2B MiNi 5.0 360° Photography System

Version 5.0 of the Vision360 B2B MiNi diamond photography system was released at the June 2019 JCK show in Las Vegas, Nevada, USA. This update improves on the 360° video imaging by adding brilliance, fire and scintillation characteristics. It also provides darkfield and fluorescence imaging following guidelines from 'global diamond certification authorities'. Visit https://v360.in/b2bmini_5.aspx for more information, sample images and a promotional video.

DRC Techno's New Diamond-Detection Instruments

In May 2019, DRC Techno announced the release of two new instruments—J-Detect 9000 and J-Mini—as well as an update of its J-Smart instrument (see What's New section, Vol. 36, No. 4, 2018, p. 275), called J-Smart Pro. All are designed to separate natural from CVD- and HPHT-grown synthetic diamonds. The J-Detect 9000 features a 5 × 5 inch (~13 × 13 cm) tray, scans in 15–25 seconds, and accommodates both loose and mounted diamonds (0.003 ct and larger, in primarily D–K colour). The J-Mini, weighing a mere 3 kg, is designed for smaller operations. It has a 2.5 × 3 inch (~6 × 8 cm) tray that accommodates the same size and colour ranges of both loose and mounted diamonds, with a scan speed of 10–15 seconds. It is compatible with Android mobile phones. For more information, visit http://drctechno.com/home/products.

M-Screen 4.0

Released in March 2019, M-Screen 4.0 is the newest-generation melee-screening device from HRD Antwerp. The table-top instrument uses short-wave UV illumination with a patented method to screen large amounts of diamond melee, automatically sorting round brilliant diamonds (0.005–0.20 ct, D–J colour) from synthetics and simulants at a rate of three stones per second, or up to 15,000 per hour. Visit www.hrdantwerp.com/en/equipment/detail/m-screen.

NEWS AND PUBLICATIONS

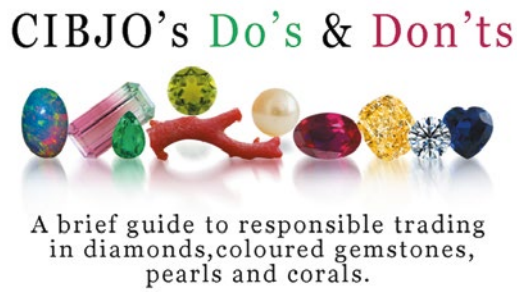

CIBJO's Ethical Trading Do's & Don'ts

Following the release of its *Responsible Sourcing Book* in January 2019 (see What's New section, Vol. 36, No. 5, 2019, p. 397), in March 2019 CIBJO issued 'Ethically Responsible Trading in Diamonds, Coloured Gemstones, Pearls & Corals: The Do's & Don'ts'. The 11-page booklet includes a checklist of items to help members of the gem trade ensure compliance with guidelines in the CIBJO Blue Books to promote ethically responsible behaviour. It includes lists of treatments that should be disclosed, as well as appropriate terminology for 'artificial products'. Available in 11 languages, the guide can be downloaded for free in PDF format at www.cibjo.org/dos-donts-guide.

Diamond Mining Report by Trucost

Trucost is an affiliate of S&P Global Market Intelligence and assesses risks related to climate change, natural resource constraints, and broader environmental, social and governance factors. The Diamond Producers Association (DPA), which is the representative consortium for the world's seven largest diamond producers, commissioned Trucost to prepare a report titled 'The Socioeconomic and Environmental Impact of Large-Scale Diamond Mining', which was released in May 2019. The study examines the impacts of large-scale diamond mining and uses this information to identify how to minimise those impacts and optimise potential benefits, with an emphasis on greenhouse gas emissions. To download the 37-page summary report, visit https://diamondproducers.com/app/uploads/2019/05/Trucost_Socioeconomic_and_Environmental_Impact_of_Large-Scale_Diamond_Mining.pdf.

International Kimberlite Conference: Extended Abstracts

Extended abstracts from past meetings of the International Kimberlite Conference (IKC) are now freely available via the *Journal of International Kimberlite Conference Abstracts*. As stated on its website, which is hosted by the University of Alberta Libraries (Canada), 'The purpose of this journal is to create a permanent, readily accessible and citable archive of these valuable contributions, as a record of the progress in kimberlite-related research since the instigation of the first IKC in Cape Town, 1973.' So far, 11 IKCs have taken place at generally 4–5 year intervals. Topics covered by the extended abstracts include detailed geologic descriptions of various kimberlites and their geological settings worldwide, as well as information about exploration, mining and diamond characteristics. Visit http://ikcabstracts.com/index.php/ikc.

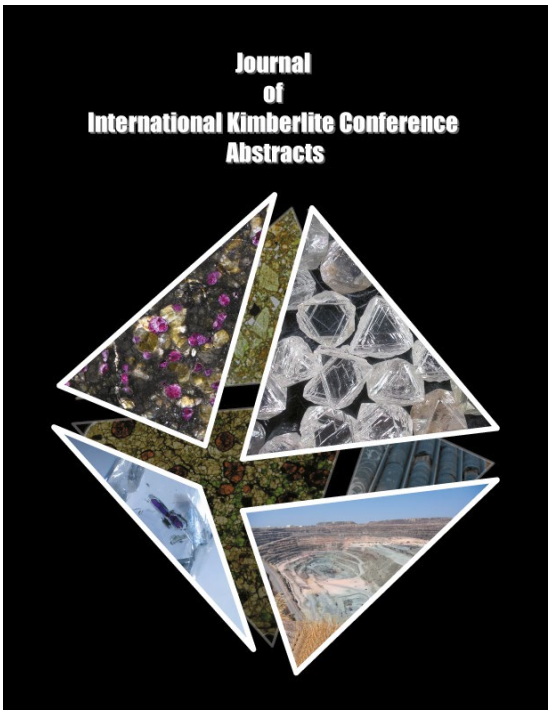

Jewelry Industry Summit 2019 Presentations

Just prior to the February 2019 gem shows in Tucson, Arizona, USA, numerous participants met for two days at the Third Jewelry Industry Summit to share concerns and raise awareness regarding ethical and sustainability issues facing the gem and jewellery industry. Several of the presentations are now available online for download (as PDF and MOV files). Topics include blockchain platforms, the Jewellery Development Impact Index, sustainable mining, due diligence and responsible sourcing. Visit www.jewelryindustrysummit.com/summit-archive.

JEWELRY INDUSTRY SUMMIT

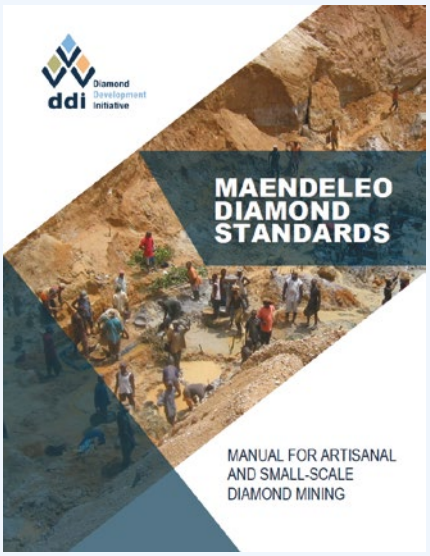

Maendeleo Diamond Standards from DDI

The Diamond Development Initiative (DDI) is a non-profit organisation that addresses social and economic issues faced by artisanal diamond miners in Africa and South America. In April 2019, DDI launched its Maendeleo Diamond Standards (MDS) to provide guidelines for their certification system to ensure that these miners are included in responsible supply chains. MDS certification allows for the responsible sourcing of diamonds from small-scale miners in Kimberley Process-approved zones. Download the MDS at http://ddiglobal.org/wp-content/uploads/2019/04/MDS_Manual_April_2019_reduxed_for_web.pdf.

RJC Code of Practices Updated

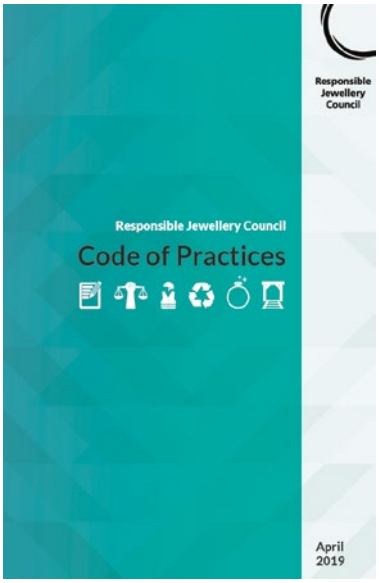

The Responsible Jewellery Council issued its latest Code of Practices in April 2019. This standard 'defines the responsible ethical, human rights, social and environmental practices that all certified RJC members must adhere to'. The Code consists of 42 provisions that cover general legal and regulatory requirements; responsible supply chains, human rights and due diligence; labour rights and working conditions; health, safety and the environment; gold, silver, platinum-group metals, diamond and coloured stone products; and responsible mining. Visit www.responsiblejewellery.com/files/RJC-COP-April-2019.pdf.

Presentations from the 7th Brazilian Symposium on Diamond Geology

Presentations from the 7º Simpósio Brasileiro de Geologia do Diamante, held 4–7 November 2018, are available for download online. Topics primarily cover diamond deposits and mining in Brazil (with a single presentation on Canadian mines), as well as internal features and spectroscopy of Brazilian diamonds. In addition, the conference included general presentations on geology, exploration, mining, processing and terminology. Most presentations are in English, but some are only provided in Portuguese. To download the files (PDFs delivered in ZIP format), visit www.simposiododiamantebahia.com.br/en/presentations.

7º SIMPÓSIO BRASILEIRO DE GEOLOGIA DO DIAMANTE
25 anos | Salvador - Bahia - 2018

Silver Institute Publications

The Silver Institute has published its World Silver Survey annually since 1990 (see www.silverinstitute.org/all-world-silver-surveys). The 104-page 2019 report was released in April 2019, and includes international data through 2018 on silver prices, investment, mine supply, 'recycled' supply, silver bullion trade, industrial fabrication, and jewellery and silverware. Both total supply and overall demand in 2018 were higher than in 2009 but lower than in 2010, with ups and downs in the intervening years.

Also, in March 2019 the Silver Institute released its 2018 Silver Jewelry Sales Results, which presents data from an online survey of jewellery retailers that compares 2018 silver jewellery sales to those of 2017. Information is provided on overall sales, holiday sales, merchandise categories, inventories and buyer demographics. More than half of the respondents reported an increase in sales over 2017. Download the report at www.silverinstitute.org/publications, where you will also find other Silver Institute publications.

OTHER RESOURCES

Pearl Academy by Raw Pearls

Family-owned and UK-based pearl wholesaler Raw Pearls recently created the Pearl Academy to educate retail jewellery staff and better prepare them to market natural and cultured pearls to consumers. This free online educational resource consists of a series of videos, and those available up to May 2019 included: 'Introducing Pearl Academy', 'Part 1: Natural, Cultured & Fake Pearls', 'Part 2: From the Hatchery to Raw Pearls' and 'Part 3: Types of Cultured Pearl'. Parts 1–3 are accompanied by notes in PDF format. Visit www.rawpearls.com/services/pearl-training.

Podcasts from L'École School of Jewelry Arts

L'École des Arts Joailliers (Paris, France) is supported by Van Cleef & Arpels, and offers an e-library with numerous video podcasts in which experts discuss various works of jewellery art, aspects of jewellery history and specific gem materials. Topics include individual works from various genres and time periods, including Art Nouveau, Art Deco, 19th century and more. Gems discussed include opal, sapphire, ruby, emerald and biogenic gems, along with treatments and origins. Ranging from ~1–8 minutes long, some of the podcasts are in English and others are in French. Visit www.lecolevancleefarpels.com/en/go-further.

What's New provides announcements of new instruments/technology, publications, online resources and more. Inclusion in What's New does not imply recommendation or endorsement by Gem-A. Entries were prepared by Carol M. Stockton unless otherwise noted.

Gem-A INSTRUMENTS

Current Gem-A Members and Students receive a 10% discount on instruments!

NEW IN STOCK!

PROFESSIONAL CARAT SCALE KIT

Available now from Gem-A Instruments, these precision scales are professional, compact and portable for the busy gemmologist who wants reliable accuracy on-the-go.

Gem-A Instruments is pleased to to introduce the On Balance CTP-250 Pro Carat Scale, which is now available to purchase. This professional and portable carat scale is designed for the hands-on gemmologist and comes as part of a kit which includes slide-lock tweezers, 20g and 50g calibration weights, a gem tray, universal USB power plug and a zip travel case.

The Pro Carat Scale is a precision instrument designed for the weighing of coloured gemstones and diamonds and benefits from exceptional accuracy (to 0.005 carat and 0.001 grams) and a 250 carat (50g) capacity. Its sleek appearance is suitable for those conducting client-facing work, while its compact (dimensions 141 × 75 × 36mm), portable and user-friendly design makes it easy to transport and store.

Retail Price £80.40

Current Gem-A Members and Students receive a 10% discount on instruments

To view a selection of our instruments visit shop.gem-a.com

Gem Notes

COLOURED STONES

Anorthite from Japan

Plagioclase is a common rock-forming mineral that consists of the albite-anorthite series (i.e. ranging from $NaAlSi_3O_8$ to $CaAl_2Si_2O_8$). While gem-quality plagioclase is known to occur throughout this compositional range, end-member anorthite is only rarely encountered as a gemstone (e.g. from Fugoppe, Yoichi area, Hokaido, Japan; Bank *et al.* 1998).

During the February 2019 Tucson shows in Arizona, USA, gem dealer Dudley Blauwet (Dudley Blauwet Gems, Louisville, Colorado, USA) had rough and cut samples of anorthite from Miyake Island (Miyake-jima), a part of the Izu archipelago located ~180 km south-east of Honshu, Japan. Although anorthite from this locality is well known to mineralogists and geologists (see, e.g., Kikuchi 1888; Murakami *et al.* 1991), this is the first time that we are aware of it being available as faceted gemstones. Blauwet obtained five clean stones, ranging up to 1.5 ct, from approximately 30 pieces that were collected and cut by his supplier, Takeshi Kamitaki. The largest faceted stone in Kamitaki's inventory weighed 8 ct but was heavily included.

Blauwet loaned one rough and one cut stone for examination (Figure 1). The rough sample weighed 0.25 g and was pale yellow. Several cleavages were evident on its surface and a small area of host rock was embedded on one side. It was mostly transparent with some areas that were semi-transparent. The faceted stone was a round Portuguese cut weighing 0.43 ct, and it was extremely pale yellow and eye-clean. Microscopic observation revealed a few isolated pinpoint inclusions, two stringers composed of multiple pinpoints, and several fine, colourless needles. At the base of the stone was a small 'fingerprint' inclusion, giving the culet a slightly frosted appearance. The polariscope showed a biaxial 'bow tie' optic figure. The RIs were 1.575–1.589, yielding a birefringence of 0.014. It was not possible to record an accurate SG value due to the small size of the samples and the presence of host rock attached to the rough piece. Nevertheless, the RIs are indicative of end-member anorthite (cf. 1.575–1.588; Deer *et al.* 1992).

Raman spectroscopy of the faceted stone with a GemmoRaman-532SG instrument provided close matches for both anorthite and bytownite in the RRUFF database. Chemical analysis by energy-dispersive X-ray spectroscopy of another sample of gem-quality Miyake plagioclase from the same supplier yielded a composition of 95% anorthite and 5% albite (i.e. An_{95}). Analysis of the present faceted stone by EDXRF spectroscopy on an Amptek X123-SDD instrument showed a similar composition, as expected for the anorthite end-member indicated by the RI values.

Miyake anorthite formed as megacrysts that were ejected from an active volcano and are associated with basaltic lava (Kikuchi 1888). Similar occurrences of anorthite are known from elsewhere in the Izu archipelago, and Kimata (1995) stated that these megacrysts may be colourless, 'red-clouded' or yellow. Murakami *et al.* (1991) documented tiny platelets of native copper in 'wine red' Miyake anorthite, but such inclusions were not present in the pale yellow samples examined for this report.

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Figure 1: These cut (0.43 ct) and rough (0.25 g) samples of anorthite from Miyake Island, Japan, were examined for this report. Photo by B. Williams.

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Aquamarine from Southern Ethiopia: An Update

Figure 2: These beryls, seen during the February 2019 Tucson gem shows, are reportedly from southern Ethiopia. The largest crystal weighs 613.4 g. Photo by T. Sripoonjan.

During the February 2019 Tucson gem shows, author TS encountered some beryl crystals that were reportedly from the Shakiso region of southern Ethiopia (Figure 2). Some of them consisted of aquamarine, showing apparently hexagonal prism faces, which were relatively larger in size (up to 600+ g) than previously reported by Laurs (2012) and Laurs *et al.* (2014). The vendors, Arjit and Apurva Birani (Plum Colors, Bangkok, Thailand), informed the author that the beryl came from a recent discovery that occurred near the Shakiso emerald deposit. In addition to the rough material, they also had faceted stones, although these had all sold before the author visited their booth.

Recently, at the Plum Colors office in Bangkok, these authors saw some more of the Ethiopian aquamarine. One of the faceted stones was an attractive, consistent blue with high clarity (Figure 3). Author TS borrowed

Figure 3: This 8.16 ct Ethiopian aquamarine was recently cut in Bangkok and shows an attractive blue colour. Photo by T. Sripoonjan.

Figure 4: (**a**) Etch pits of various shapes decorate the prism face of an Ethiopian aquamarine crystal (reflected light, image width 10.0 mm). (**b**) Thin films displaying iridescent colours are arranged in planes perpendicular to the c-axis of the aquamarine (reflected light, image width 2.0 mm). (**c**) The only internal features that were visible in the faceted Ethiopian aquamarine in Figure 3 are these growth lines (darkfield illumination, image width 5.2 mm). Photomicrographs by T. Sripoonjan.

this gem and six rough samples for examination. The faceted stone weighed 8.16 ct (16.32 × 8.97 × 7.47 mm) and the rough ranged from 2.3 to 16.3 g. The samples were greenish blue to pure medium blue and showed strong pleochroism in near-colourless and blue. The RIs were 1.570–1.582 (birefringence 0.012) and the hydrostatic SG averaged 2.66. The samples were inert to both long- and short-wave UV radiation.

The aquamarine crystals exhibited obvious etch pits of various shapes on their prism faces (Figure 4a). Internal features in the rough material consisted of a complex network of parallel partially healed fissure planes, two-phase fluid inclusions, colourless mineral inclusions (0.1–0.5 mm) and especially multiple planes of thin films showing iridescence (Figure 4b). However, the faceted stone solely contained growth lines (Figure 4c).

Raman spectroscopy with a Renishaw inVia unit confirmed that the stones were beryl (aquamarine). Polarised ultraviolet-visible-near infrared (UV-Vis-NIR) spectroscopy of the faceted stone revealed two sharp peaks at 370 and 427 nm related to Fe^{3+} and a strong, broad absorption band centred at ~820 nm due to Fe^{2+} (Figure 5a). Two sidebands at ~620 and 955 nm have been attributed to Fe^{2+} intervalence charge transfer (Burns 1993). The Fe-related absorptions formed a transition window at around 480–530 nm that accounts for blue colouration in aquamarine. A peak at 1147 nm has yet to be assigned, and there were essentially no distinct absorption features in the visible region of the spectra.

Mid-infrared spectroscopy of all samples using a Thermo Scientific Nicolet 6700 FTIR spectrometer yielded consistent features in the 7400–4500 cm^{-1} region (e.g. Figure 5b). A band at around 7140 cm^{-1} was more intense than the adjacent features at 7098 and 7075 cm^{-1}. This correlates to a prevalence of type I H_2O associated with very low alkali contents in this aquamarine (cf. Saeseaw *et al.* 2014).

Energy-dispersive X-ray fluorescence (EDXRF) spectroscopy of all samples with a Thermo Scientific ARL Quant'X instrument showed distinct amounts of iron (0.40–1.40 wt.% Fe_2O_3), although substantially less than in some aquamarine reported in the literature (e.g. Canada, Adamo *et al.* 2008; Vietnam, Huong *et al.* 2011). In addition, these

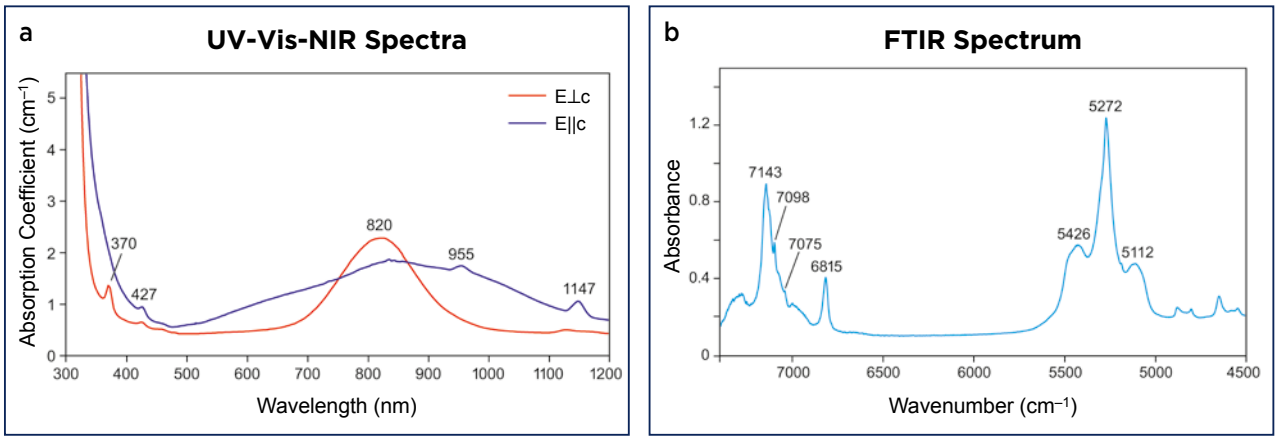

Figure 5: (**a**) Polarised UV-Vis-NIR spectra of the faceted Ethiopian aquamarine in Figure 3 show features mainly associated with iron. The path length of the beam through the sample was 7.47 mm. (**b**) A representative FTIR spectrum of the Ethiopian aquamarine reveals several bands related to type I and type II H_2O, with the former being more prevalent.

Ethiopian aquamarines were characterised by relatively high concentrations of potassium (up to 0.24 wt.% K_2O). Caesium contents were very low (averaging 0.03 wt.% Cs_2O) compared to those of aquamarine from other sources (Bocchio *et al.* 2009; Huong *et al.* 2011).

Previous articles (Laurs 2012; Laurs *et al.* 2014) supplied brief information on Ethiopian aquamarine, and this report provides additional data that may be helpful to gemmologists in case this material becomes more common in the marketplace in the future.

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Chrysocolla from the Ray Mine, Arizona, USA

For decades, the Ray mine near Kearny, Pinal County, Arizona, USA, has been a well-known source of copper minerals that are prized by collectors (e.g. Jones & Wilson 1983). The copper ore at this porphyry copper deposit was naturally concentrated by secondary enrichment processes, resulting in the formation of abundant chrysocolla and other secondary copper minerals. Chrysocolla has been mined as bright blue-to-green masses, vug fillings, stalactites and pseudomorphs. The mine is still being exploited for copper, and occasionally small amounts of high-quality chrysocolla specimens, gem rough and polished stones appear on the market, such as those seen by this author at the February 2019 Pueblo Gem & Mineral Show in Tucson (e.g. Figure 6). In addition to mineral specimens, there were approximately 50 cabochons that had been cut from ~3 kg of rough material produced in 2018. The largest cabochon measured 30.5 × 18.5 mm, and the chrysocolla was translucent to semi-transparent with an attractive blue to bluish green colour that was evenly distributed in most of the polished pieces.

Figure 6: This rough specimen (68.0 mm long) and cabochon of chrysocolla were recently produced from the Ray mine in Arizona. Shown for comparison is a carving (27.4 mm long) made from high-quality chrysocolla that is from elsewhere in Arizona. The rough specimen is covered by drusy quartz, and the greener portion may correspond to the presence of malachite. Photo by B. M. Laurs.

Although chrysocolla from the Ray mine is seldom seen on the market today, occasionally high-quality material is encountered, as shown by the examples documented here.

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Figure 7: These samples of rough and cut grossular are reportedly from the Tanga region of north-eastern Tanzania. The rough stones show various amounts of iron staining on their surfaces. The cut stone was faceted by the author and weighs 8.89 ct. Photo by V. Lanzafame, SSEF.

Grossular from Tanzania with Uncommon Inclusions

At the October 2018 mineral and gem show in Munich, Germany, rough stone dealer Fabian Kneipp (Roughstore24 GmbH, Herrsching, Germany) presented the author with some interesting grossular specimens from the Tanga region of north-eastern Tanzania (Figure 7). Kneipp reported that several kilograms of the material had recently come to the market. The author purchased several rough specimens, and Kneipp kindly donated some additional pieces containing small green colour concentrations for further study at the Swiss Gemmological Institute SSEF (Figure 8).

After a search of the literature and of the SSEF rough stone collection, it became clear that this material was not actually new to the market. Similar grossular from Tanzania was described in the 1980s (Manson & Stockton 1982; Hänni 1987) and was catalogued in 2004 in SSEF's reference collection, and material resembling this garnet was also available on the Internet dating back several years. Nevertheless, since this grossular has not yet been characterised in detail, the author analysed six samples consisting of five rough pieces (1.10–4.64 g) and one faceted stone (8.89 ct).

The rough specimens appeared water-worn and some of them showed a granular-appearing surface texture. The rough ranged from near-colourless to light yellow and orangey yellow, while the faceted stone was near-colourless (again, see Figure 7). The RI varied slightly from 1.739 to 1.741, with an average RI of 1.740. Hydrostatic SG values were 3.57–3.62 (average 3.60) and were consistent with those reported in the literature. All samples were inert to long- and short-wave UV radiation.

Chemical analysis by energy-dispersive X-ray fluorescence (EDXRF) spectroscopy with a Thermo Scientific ARL Quant'X instrument revealed a composition consistent with that of nearly pure grossular, with major amounts of Si, Al and Ca, as well as minor Fe and traces of Ti and Mn. In addition, traces of Cr were measured in the samples containing green areas.

In addition to a roiled appearance seen in the faceted stone, some of the samples contained mineral inclusions that were visible with the unaided eye or a 10× loupe. Two of them were selected for Raman microspectroscopy with a Renishaw inVia microscope equipped with a 514 nm argon-ion laser. Transparent, well-shaped crystals in one rough sample (Figure 9) were identified as titanite

Figure 8: Two of the rough grossular samples (2.40 g and 0.59 g) obtained for this study contain small green zones. Photo by V. Lanzafame, SSEF.

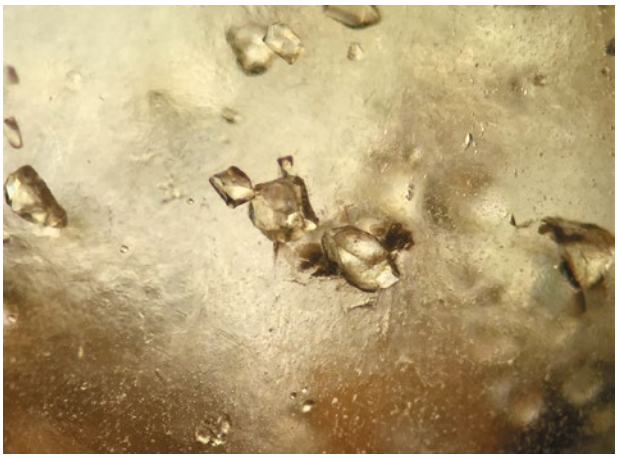

Figure 9: Raman analysis identified this group of well-formed crystals as titanite. Photomicrograph by S. Hänsel; image width 2.8 mm.

(sphene), and an eye-visible inclusion in the faceted stone (Figure 10) turned out to be anhydrite. Although so far not documented as inclusions in gem-quality grossular, both titanite and anhydrite are well known from grossular-bearing metamorphic rocks. Titanite is a common accessory mineral found together with grossular in Ca-silicate rocks (e.g. skarn-related or by metasomatism during regional metamorphism), and anhydrite has been attributed to the presence of evaporites in the genesis of gems (e.g. Feneyrol *et al.* 2012).

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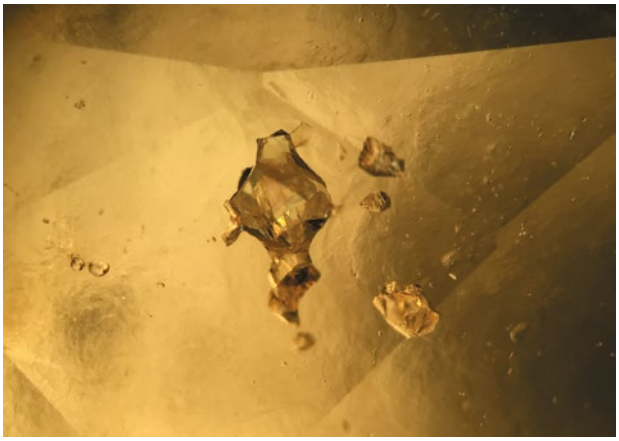

Figure 10: The largest transparent crystal with high relief shown here was identified as anhydrite by Raman analysis. Photomicrograph by S. Hänsel; image width 4.0 mm.

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Purple Hydroxylherderite from Brazil

Hydroxylherderite [$CaBePO_4(OH,F)$] is a phosphate mineral that forms a solid-solution series with herderite in which hydroxyl (OH) is dominant over fluorine (F). The term *herderite* is commonly used to refer to both minerals of the herderite-hydroxylherderite series, although most specimens on the market are actually hydroxylherderite (www.mindat.org/min-1876.html). Mainly found in granitic pegmatites, herderite can crystallise as attractive, well-formed crystals, and is sometimes transparent enough for faceting. Most gem-quality herderite comes from Minas Gerais in Brazil (Johnson 1996; Wentzell 2004) and from northern Pakistan (Laurs & Quinn 2006). It is found in a limited range of colours, including colourless, grey, brown, pale yellow, pale green and greenish yellow, and much more rarely light blue and purple.

The 1.57 ct round brilliant-cut gemstone described in this report shows an unusually strong purple colour (Figure 11) and was therefore characterised in detail. It reportedly came from Virgem da Lapa in the Araçuaí region of Minas Gerais, Brazil. One deposit in this area, the Xanda (Xandra) mine, is a known source of hydroxylherderite—especially showing purple colour—along with other minerals such as feldspar, tourmaline, muscovite and quartz (Dunn *et al.* 1979; www.mindat.org/loc-6818.html).

Figure 11: The faceted purple hydroxylherderite from Virgem da Lapa described here weighs 1.57 ct. Photo by T. Cathelineau.

The stone showed the following properties: colour—slightly greyish purple overall, appearing greyish blue in daylight (and under 'cool white' bulbs) or slightly greyish purple to purple in incandescent light; pleochroism—strong, in purple and almost colourless (a third colour was not observed, although herderite is biaxial); diaphaneity—transparent; RIs—1.590–1.620; birefringence—0.030; hydrostatic SG—3.02; magnetism—none; Chelsea Colour Filter reaction—none; fluorescence—inert to both long- and short-wave UV radiation; and no absorption features observed with a desk-model spectroscope. These properties are consistent with those reported for herderite by O'Donoghue (2006). Microscopic examination revealed moderate doubling, as well as a few fissures and partially healed fractures.

The refractive indices of herderite vary with the F/OH ratio (Leavens *et al.* 1978), and the RIs of 1.590–1.620 measured for this sample correspond to a herderite (F) content of 43% ± 1% and thus a hydroxylherderite (OH) content of 57% ± 1%. Since this composition falls on the hydroxyl-rich side of the series, it is hydroxylherderite.

The infrared reflectance spectrum (Figure 12) was collected from the stone's table facet without regard for polarisation or orientation. The spectrum covered the 2000–400 cm^{-1} range, although Figure 12 is truncated above 1400 cm^{-1} because no features were recorded in that range. Due to the setup of the FTIR spectrometer, the water and hydroxyl region around 3600 cm^{-1} was not measured. The major bands in the ranges 1200–1000 cm^{-1} and 600–500 cm^{-1} are characteristic of the PO_4^{3-} ion, and confirm the presence of a phosphate mineral. Comparison of the spectrum to the herderite-hydroxylherderite series in the RRUFF database—although the RRUFF spectra were not collected in reflectance mode, but rather using the ATR method—and to the IR transmission spectra published by Chukanov (2014), unambiguously identified the sample as herderite-hydroxylherderite. However, without information on the bands in the 3600 cm^{-1} region it is impossible to conclude whether a sample is herderite or hydroxylherderite (Frost *et al.* 2014).

The herderite-hydroxylherderite series is optically biaxial so, as mentioned above, one might expect three colours associated with the three polarisation directions. Collecting the Vis-NIR spectrum for each of the three directions is typically not feasible for a faceted gemstone, so spectra were recorded for only two of them using a polarising filter with the beam oriented parallel to the direction of maximum pleochroism. The resulting two spectra (Figure 13) correspond to the observed pleochroic colours of purple and almost colourless. The spectrum associated with the purple colour showed a strong absorption edge in the violet region and a strong and broad absorption band at ~577 nm (yellow region), creating two transmission windows at ~470 nm (blue

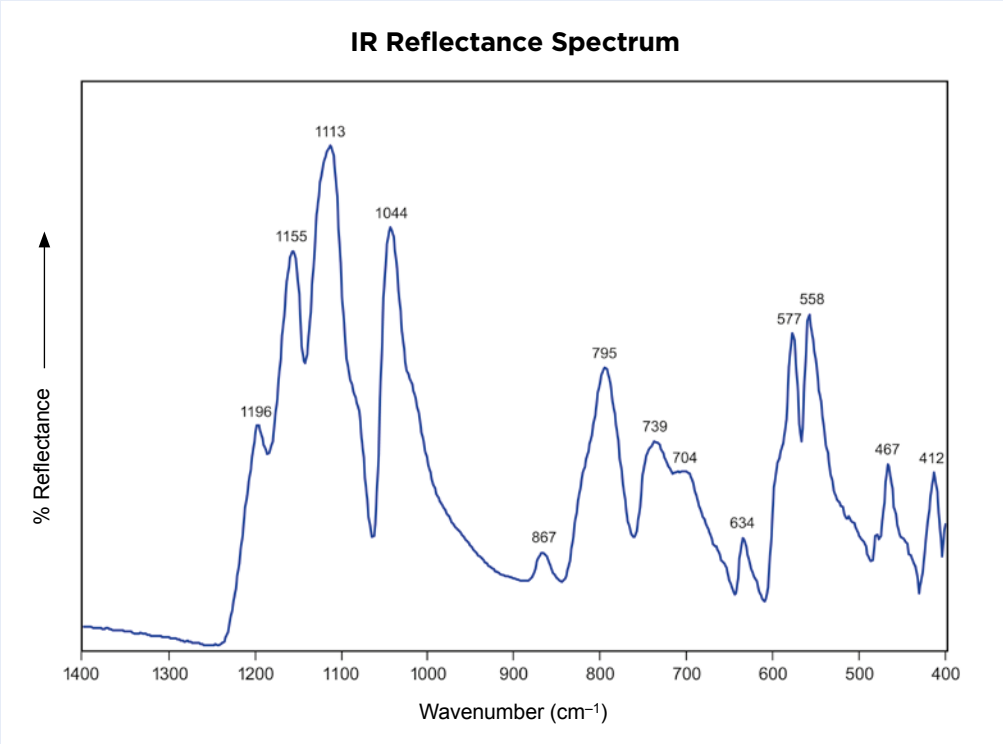

Figure 12: The IR reflectance spectrum characterises the stone in Figure 11 as a member of the herderite-hydroxylherderite series.

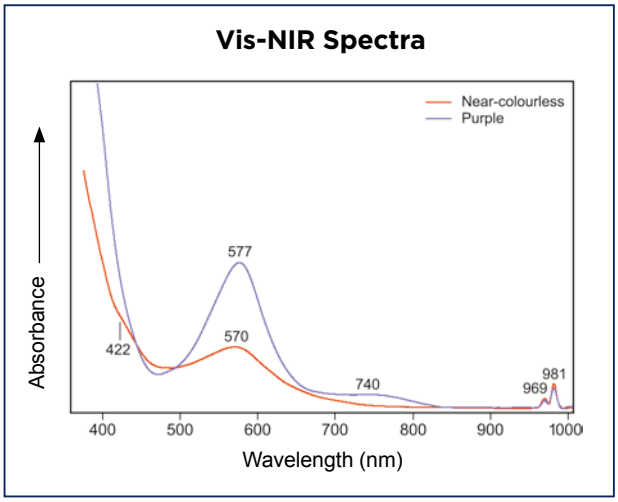

Figure 13: Vis-NIR spectra were collected for the purple and almost colourless pleochroic directions of the hydroxylherderite. Transmission windows in the blue (~470 nm) and red (~660–720 nm) regions are responsible for the purple colour of the stone, as well as its colour change. The path length of the beam through the sample was approximately 5 mm.

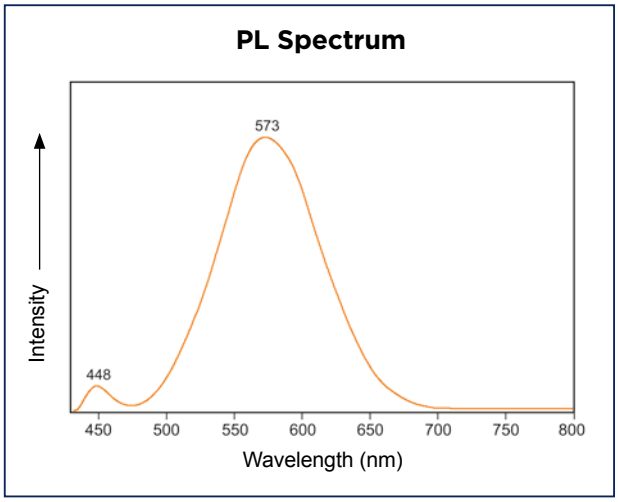

Figure 14: The PL spectrum of the purple hydroxylherderite obtained with 405 nm excitation shows a strong emission at 573 nm that is indicative of Mn^{2+}.

region) and above ~660 nm (red and NIR region). Also present were a weak but broad band centred at ~740 nm and a doublet at 969/981 nm in the NIR region (the latter being linked to the second overtone [$3\nu_{OH}$] of the OH fundamental absorptions in the 3600 cm^{-1} region; Frost *et al.* 2014). The spectrum associated with the almost colourless direction had similar—but much weaker—features, as well as a shoulder at 422 nm. The stone's purple colour is related to the transmission windows in the blue and red regions of the spectrum. Such coupled transmission windows are often responsible for colour-change behaviour, as was also seen in this hydroxylherderite.

The stone's photoluminescence (PL) spectrum was studied using four excitation sources: 254, 280, 377 and 405 nm, but only the last one gave any results. The 405 nm laser produced a main large emission peak centred at 573 nm and a weaker emission at 448 nm (Figure 14). These features are ascribed to Mn^{2+} and Eu^{2+}, respectively (Gorobets & Rogojine 2001). While it is tempting to ascribe the cause of the purple colouration to manganese, further investigations are required. The spectral pattern across the visible range shows similarities to those of pink and purple apatite (colour caused by F centres), deep violet apatite (Mn^{5+}), blue and violet fluorite (F centres), and even amethyst (radiation-induced colour centres).

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Dendritic Opal from Brazil

Dendritic inclusions are fairly commonly found in agate, chalcedony and other varieties of gem silica, but are less frequently encountered in opal (e.g. Milisenda *et al.* 1994). At the February 2019 Tucson gem shows, Dr Marco Campos Venuti (Sevilla, Spain) had some new dendritic opal specimens from Brazil. He obtained the rough material in August 2018 while visiting Brazil and was told that it was mined from near Teófilo Otoni in Minas Gerais State. The production consisted of about 300 kg of large blocks with a nodular appearance that contained colourless transparent-to-translucent areas and white semi-translucent material resembling opal and chalcedony, respectively. Dark brown dendritic inclusions were present in some of the transparent-to-translucent areas. So far, Dr Campos Venuti has cut and polished ~10,000 carats of the dendritic material, producing gems up to 40 mm in maximum dimension.

Dr Campos Venuti kindly donated one polished specimen to Gem-A (Figure 15), and it was studied by the author for this report. The sample weighed 11.85 ct and measured 18.69 × 15.61 × 5.50 mm. It ranged from transparent (colourless) to translucent (milky white) and had a dull waxy lustre. The RI, measured by the spot method, was ~1.44, and the hydrostatic SG value was 2.26. Dark brown dendrites were concentrated mainly in the colourless area of the stone (Figure 16). Their three-dimensional habit supports a primary origin of growth in the silica gel that formed the opal, rather than a secondary origin of two-dimensional growth along fractures after the opal solidified (Campos Venuti 2012). The stone fluoresced strong yellowish green under short-wave UV radiation and faint light blue under long-wave UV. The dendrites showed a faint greenish luminescence to long-wave UV.

Figure 15: This 11.85 ct opal contains dark brown dendrites that are probably composed of pyrolusite. Photo by A. Costanzo.

Figure 16: A closer view of the dendrites in the opal shows their intricate patterns. Photomicrograph by A. Costanzo; image width 3.0 mm.

The RI and SG values are consistent with those of opal, and this identification was confirmed by Raman analysis using a Horiba LabRam II confocal Raman microspectrometer equipped with a 532 nm laser and a high-resolution diffraction grating. Raman spectra obtained from several spots on the stone all displayed a broad band at ~330 cm^{-1} together with two weaker characteristic peaks at ~1078 and ~785 cm^{-1}; this pattern is characteristic of opal-CT (cf. Pop *et al.* 2004; Ilieva *et al.* 2007).

In general, dendritic inclusions may be composed of oxides of iron, manganese or other metals. Raman microspectroscopy of the inclusions in the present opal showed two peaks at 676 and 543 cm^{-1} that were indicative of pyrolusite (MnO_2). Although the appearance of this dendritic opal is quite similar to that from Zambia documented by Milisenda *et al.* (1994), the inclusions in that material were identified as psilomelane (another Mn-oxide mineral).

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Phenakite from Carnaíba, Brazil

For decades, the Carnaíba-Socotó deposits in Brazil's Bahia State have been mined for emerald, which is associated with phlogopite schist adjacent to pegmatitic veins (Giuliani *et al.* 2019). According to Cook (2009, p. 341), 'Phenakite is also well known from the emerald deposit at Socotó, Bahia, where it is referred to as "white emerald" by the miners. Interestingly, phenakite is almost unknown in the similar emerald deposit at Carnaiba less than 50 kilometers to the southwest.'

Despite the previous rarity of phenakite at Carnaíba, starting in 2017 significant amounts of it were produced as a by-product of emerald mining there. Crystal specimens and cut stones were seen by this author during the February 2019 Tucson gem shows at the booth of Frederico de Vasconcelos (MultiGemas, Governador Valadares, Brazil). Some large phenakite crystals were produced, and a few of them contained gemmy areas that yielded faceted stones exceeding 50 ct (e.g. Figure 17). According to Vasconcelos, approximately 1,000 carats/year of phenakite were cut in 2017–2018, mostly in sizes ranging from 1–3 ct. All of the phenakite from this recent production is colourless.

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Figure 17: Recent production of phenakite from Carnaíba, Brazil, includes this mineral specimen (9.5 cm high) and these faceted stones (46.55, 17.00 and 56.40 ct, from left to right). Courtesy of Vasconcelos Brazil; photo by Jeff Scovil.

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Quartz with Triphylite Inclusions from Brazil

Triphylite ($LiFe^{2+}PO_4$) is an anhydrous phosphate mineral that previously has been documented as elongate inclusions in quartz (Hyršl 2003). However, during the February 2019 Tucson gem shows, Dr Marco Campos Venuti had rock crystal quartz with triphylite inclusions showing a rather different appearance. He obtained the rough material in August 2018 while visiting Brazil, and it was reportedly mined from the Galiléia area in Minas Gerais State. From several kilograms of quartz blocks he cut 50–70 stones as cabochons and buff-tops containing the eye-visible inclusions; the largest gem measured 24 × 11 mm. The stones were first sold at the September 2018 Denver Gem & Mineral Show in Colorado, USA.

Dr Campos Venuti kindly donated one buff-top specimen to Gem-A (Figure 18a), and it was examined

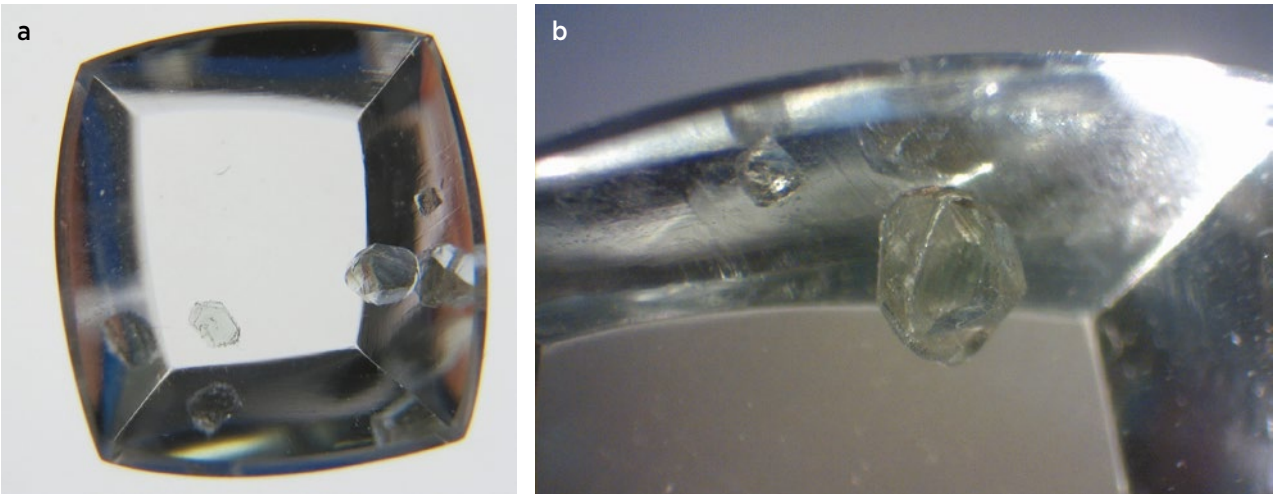

Figure 18: (**a**) The 2.70 ct buff-top quartz described here contains eye-visible inclusions of triphylite. (**b**) The inclusions are mostly equant and rather euhedral, showing pseudo-octahedral shapes (image width 5.1 mm). Photos by A. Costanzo.

by this author. It weighed 2.70 ct and measured 8.82 × 8.29 × 3.92 mm. The stone contained three inclusions that were easily visible through the table facet. Two of the crystals were roughly equidimensional (Figure 18b) and measured ~1.2 and 0.5 mm, whereas the other one was more tabular (~1 mm). Raman microspectroscopy of the inclusions using a Horiba LabRam II confocal Raman unit equipped with a 532 nm laser and a high-resolution diffraction grating confirmed they were triphylite. The main peaks were recorded at 1065.9, 999.5, 950.9 and 463.9 cm^{-1}, together with several secondary peaks (e.g. at 627.0 and 204.9 cm^{-1}).

Some additional quartz specimens from this find that contained rather large triphylite inclusions were brought to our attention by gem dealer Luciana Barbosa (Gemological Center, Weaverville, North Carolina, USA). The triphylite crystals displayed strong pleochroism in brownish green and brown (Figure 19), as well as a distinct colour change from slightly bluish green in daylight to brown in incandescent light (Figure 20). By comparison, the colour change shown by faceted triphylite from Brazil is typically much weaker (cf. Cevallos 2009). Viewed in reflected light, one of the large triphylite inclusions showed attractive iridescence (Figure 21), apparently due to thin-film interference along the boundary between the inclusion and the surrounding quartz.

Compared to the triphylite inclusions that were previously documented by Hyršl (2003), those in the present specimens are generally larger and more euhedral, and they do not commonly show cleavage breaks. In the 1990s, triphylite inclusions were also found in morganite from the Urucum mine in Minas Gerais; they occurred together with black tourmaline, near the edges of the crystals (Dr Jaroslav Hyršl, pers. comm. 2019).

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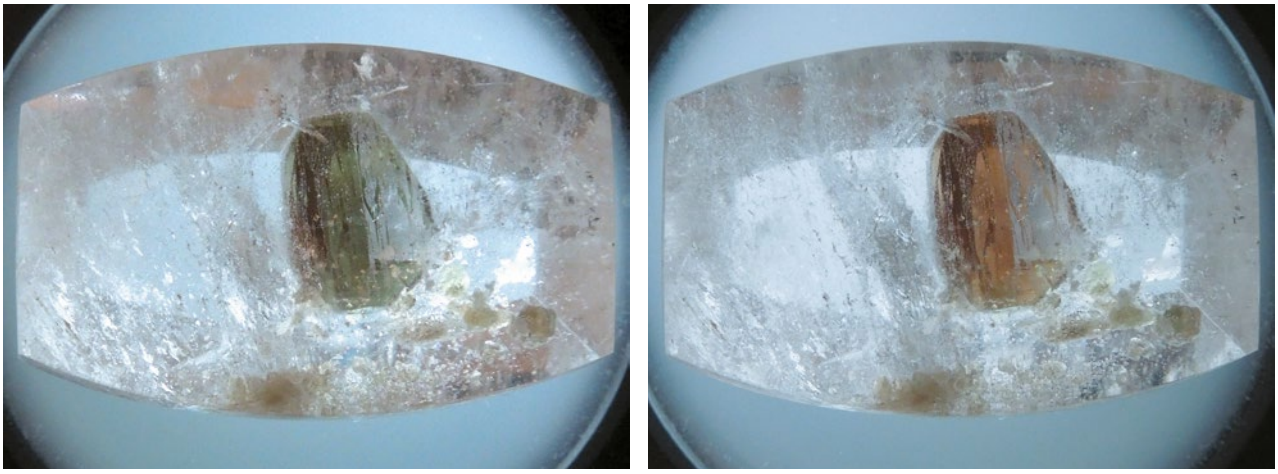

Figure 19: The large triphylite inclusion in this 73.80 ct quartz specimen displays strong pleochroism as the polariser is rotated. Photos by Luciana Barbosa.

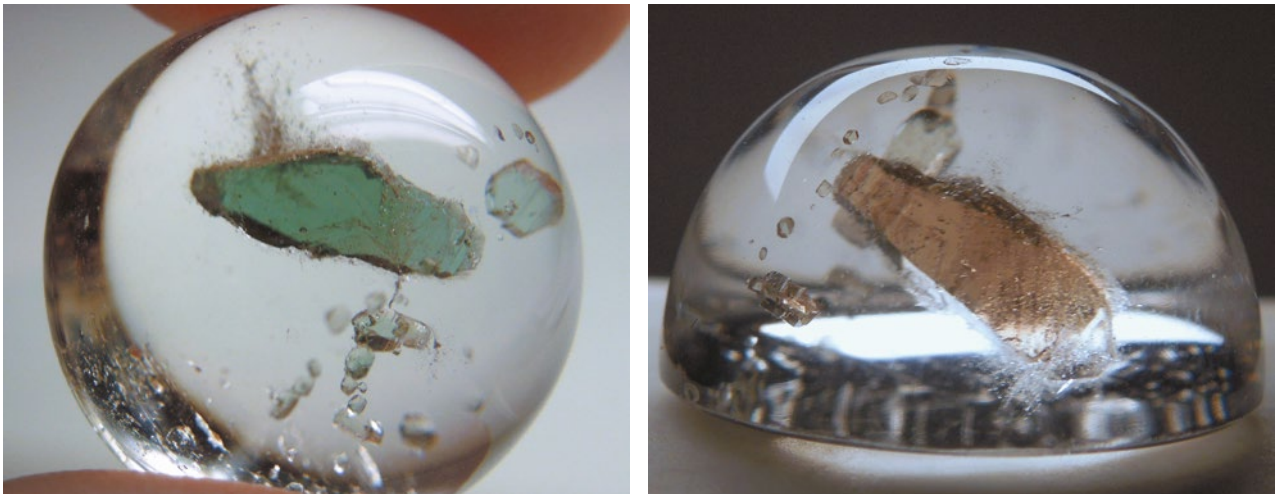

Figure 20: A distinct colour change from slightly bluish green in daylight to brown in incandescent light is shown by the large triphylite inclusion in this 31.80 ct quartz cabochon. Photos by Luciana Barbosa.

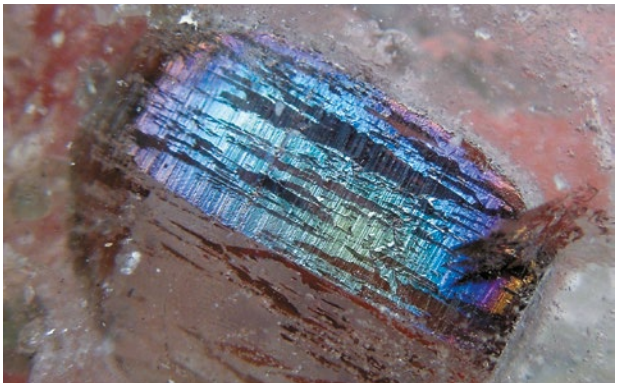

Figure 21: Viewed in reflected light, the triphylite inclusion (11.0 mm long) in the specimen shown in Figure 19 displays colourful iridescence. Photo by Luciana Barbosa.

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DIAMONDS

Searching for the Sancy Diamond

In 1888 there were reports in the British press that the maharaja of the princely Indian state of Patiala had an immense wealth of jewels including 'a fabulously costly diamond necklace, in which figures the famous Sancy diamond purchased from the Empress EUGENIE' (*Sheffield Evening Telegraph*, 20 December 1888, p. 2). The supposed ownership of the Sancy diamond by the maharajas of Patiala was subsequently often noted, but was this really the historic Sancy diamond?

At the beginning of 1947, Robert M. Shipley, president of the Gemological Institute of America and the first American FGA, was preparing the fifth edition of his book, *Famous Diamonds of the World*. He wanted to know more about the Sancy diamond, so he wrote to British gemmologist Robert Webster to see if he could confirm whether it was still owned by the maharaja of Patiala (then, Yadavindra Singh, who reigned from 1938 to 1974; Figure 22) or if it had passed into other hands. To seek an answer to Shipley's question, Webster wrote to the India Office, the London-based British government department which oversaw the administration of what was at the time British India. His letter, written on 30 January 1947, is preserved together with subsequent correspondence within old files of the India Office that are now held in the British Library in London (India Office Records and Private Papers, IOR/L/PJ/7/10870).

Webster's letter was not directed at any named individual at the India Office, but on its arrival there it was forwarded to William Rayner, an administrative officer, with the handwritten note 'Can you help, please? If so, perhaps you wd reply direct'. Rayner forwarded the request to Esmond Lumby, one of the principal administrators, to see if he had any idea, noting 'I haven't any knowledge of the Sancy diamond and certainly

don't possess it!' And if Lumby didn't know, maybe 'Sir Patrick' would. It is unclear to this author who Sir Patrick was, but the letter was forwarded to him, seemingly by Miles Clauson (acting assistant secretary), with the note 'I suppose you don't happen to know the answer to this one!' 'No', was the brief written retort. So, Clauson sent it next to 'Colonel Fraser' with the note 'Can you help'. This must surely have been lieutenant colonel D. de M. S. Fraser, no less than the political *aide-de-camp* to the British Secretary of State for India. Back it came, however, with the brief note 'Sorry cannot help at all'. The next suggestion was for Clauson to try asking 'Rushbrook Williams', with the honest but revealing comment that he might have an idea of 'what is meant by SANCY'. Professor Lawrence Rushbrook Williams was a British historian with a particular interest in India who was also a consultant to the British newspaper *The Times*. So, a letter was duly sent to him at that newspaper's address repeating the enquiry, which was described as 'quite a respectable one', but inaccurately referring to it as coming from 'a firm of jewellers who simply want to have the information for inclusion in a publication on famous gems'.

Prof. Rushbrook Williams did offer some information: 'When last I saw the Sancy Diamond it was the central pendant of a great rivière in the Patiala state regalia. In all probability, it is still in the Patiala toshakhana [treasure house]. An enquiry to Malik, the Prime Minister, might settle the point.' He added a postscript: 'Indian Princes hardly ever sell jewels: they occasionally use them as security for a loan however!' This reply was forwarded to Clauson, and on 28 February he replied to Webster's original letter in true diplomatic fashion: 'Such enquiries as it has been possible to make have not indicated the likelihood of any recent change in the ownership of the Sancy Diamond.' He added that if more certainty were required, an enquiry might be made to the Patiala prime minister. Webster acknowledged this letter saying he had 'had pleasure in forwarding' their reply to GIA.

The original Shipley correspondence does not exist in the GIA archives, but a brief note titled 'Ownership of the Sancy Diamond in Question' appeared in GIA's *Gems & Gemology* in late 1947 (Anonymous 1947). This shows that Shipley had indeed written to Patiala; it said: 'a letter has lately been received by the Gemological Institute of America from the secretary of the Maharajadhiraj of Patiala, in India, saying that His Highness is the owner of the diamond'. A letter was sent back asking about the weight of this stone. A reply was received, presumably, because Shipley's fifth edition of *Famous Diamonds of the World*, published in 1948, lists two

Figure 22: Yadavindra Singh was the maharaja of Patiala at the time of the Sancy correspondence in 1947, and he was the ninth and last maharaja there. Image courtesy of Wikimedia Commons.

Sancy diamonds. One was the historic Sancy diamond now in the Louvre (Paris, France) that weighs 55.23 ct, and the other was given as the 'Patiala Sancy' weighing 60.4 ct. The history and present whereabouts of this latter stone are unclear.

The India Office correspondence recorded above sheds little light on the Sancy diamond, but is remarkable for showing that several people within the India Office, some at high level, attempted to find an answer to Shipley's question on a historic diamond, roping in a famous British historian on India and even suggesting a direct approach to the Patiala prime minister. It is especially remarkable when you consider the timing. On 20 February 1947, as the above correspondence and handwritten comments were circulating around the India Office, the British prime minister announced that Britain would grant full self-government to British India. This was the time of Indian independence. The India Office closed that summer.

Acknowledgement: The author thanks Cathy Jonathon at the GIA Library in Carlsbad, California, USA, for her assistance.

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London

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SYNTHETICS AND SIMULANTS

Magnesio-riebeckite ('Rhodusite') Doublets from Kazakhstan

During the February 2019 Tucson gem shows, Mauro Pantò (The Beauty in the Rocks, Sassari, Italy) displayed 'rhodusite' (magnesio-riebeckite) doublets from Jezkazgan (Zhezkazgan), Kazakhstan. The material showed attractive bluish grey to greyish blue sheen in various patterns that were formed by the felty aggregates of magnesio-riebeckite (Figure 23). He obtained 26 pieces from his Russian supplier that ranged up to 26 × 33 mm. One of them showed chatoyancy (Figure 24a). Because the material is somewhat friable, the cabochons were backed by a hard polished black material (Figure 24b)—stated by Pantò's supplier as being 'black jade'—to improve their overall durability and protect their edges from chipping.

Magnesio-riebeckite, $\square Na_2(Mg_3Fe_2^{3+})Si_8O_{22}(OH)_2$, is a sodic amphibole with Na and vacancies (□) at the A site, $Mg>Fe^{2+}$ at the Y site and OH at the W site (Hawthorne *et al.* 2012). It is usually found as fibrous 'asbestiform' masses, but only rarely are these aggregates solid enough for gem use. Magnesio-riebeckite is closely related to the sodic amphibole glaucophane (from *glaukos* 'blue sky' and *phainestrai* 'to appear'), and a bluish grey colour is typical of these amphiboles (Anthony *et al.* 1990). According to Dmitriy Belakovskiy (pers. comm. 2019), curator of the Fersman Mineralogical Museum, Moscow, the gem-quality magnesio-riebeckite from Kazakhstan comes from the Kyzyl-Barbas deposit, which has been known for several decades (since at least 1938). Gem artisans historically have used it to make ornamental boxes.

Pantò kindly donated a 12.45 ct oval specimen to Gem-A, and it was examined by this author. The cabochon measured 23.42 × 10.18 × 7.34 mm and was opaque with a silky sheen. Observed with the microscope (Figure 25), the specimen was seen to consist of intricate asbestiform aggregates composed of long, thin fibrous crystals that showed the characteristic bluish grey colouration in certain orientations. Where the light did not reflect

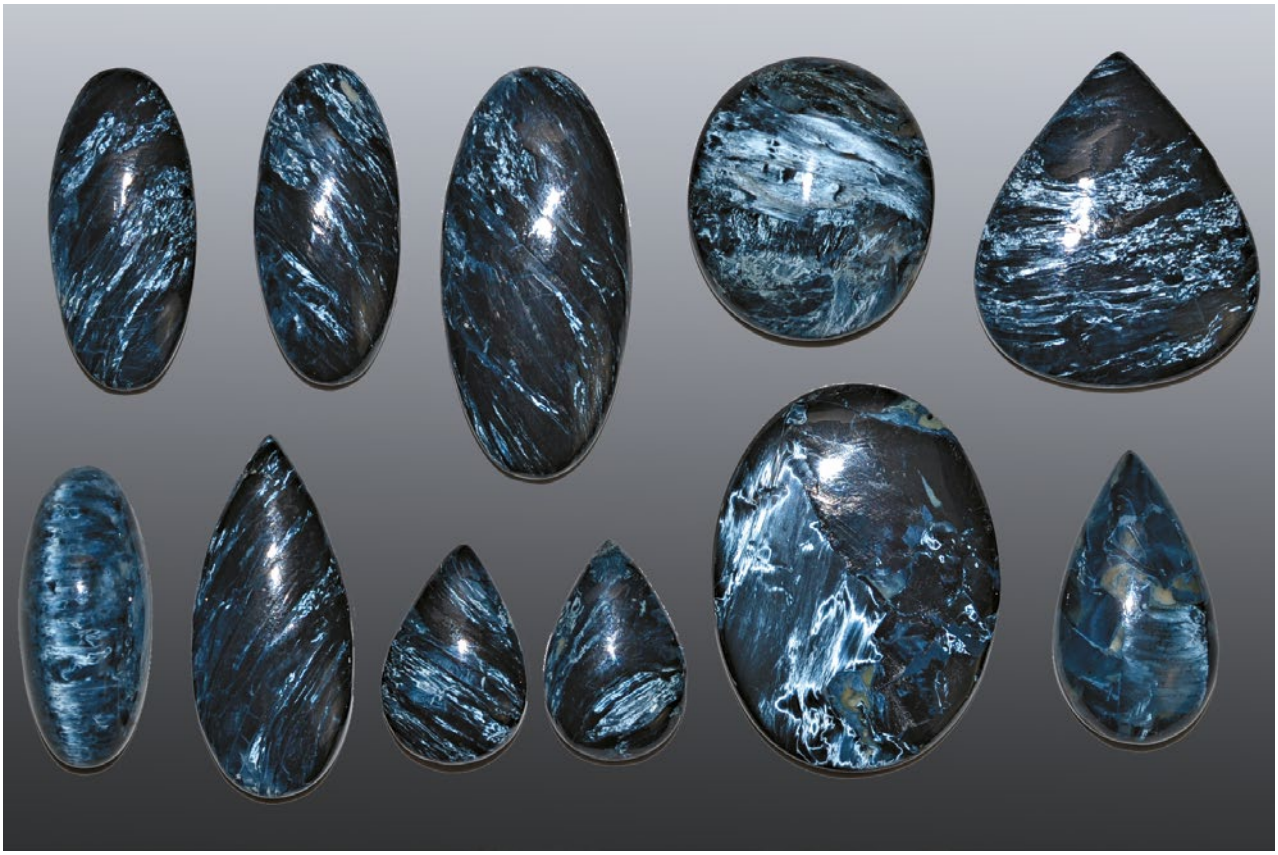

Figure 23: Rhodusite doublets were available in various shapes at the February 2019 Tucson gem shows. The specimens shown here range from 19 to 28 mm long. Photo by Mauro Pantò.

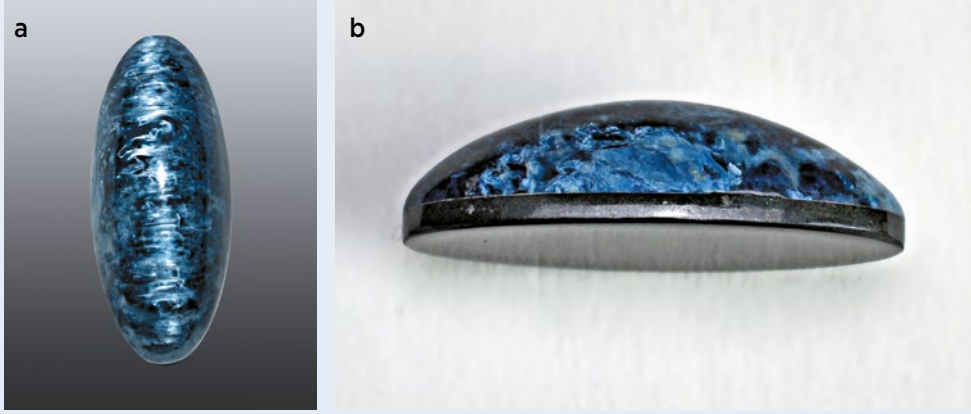

Figure 24: This 16.20 ct (26.2 × 11.4 mm) rhodusite doublet displays a diffuse cat's-eye effect. It is shown from the top (**a**) and side (**b**) views. The black backing is clearly visible in the side view. Photos by Mauro Pantò.

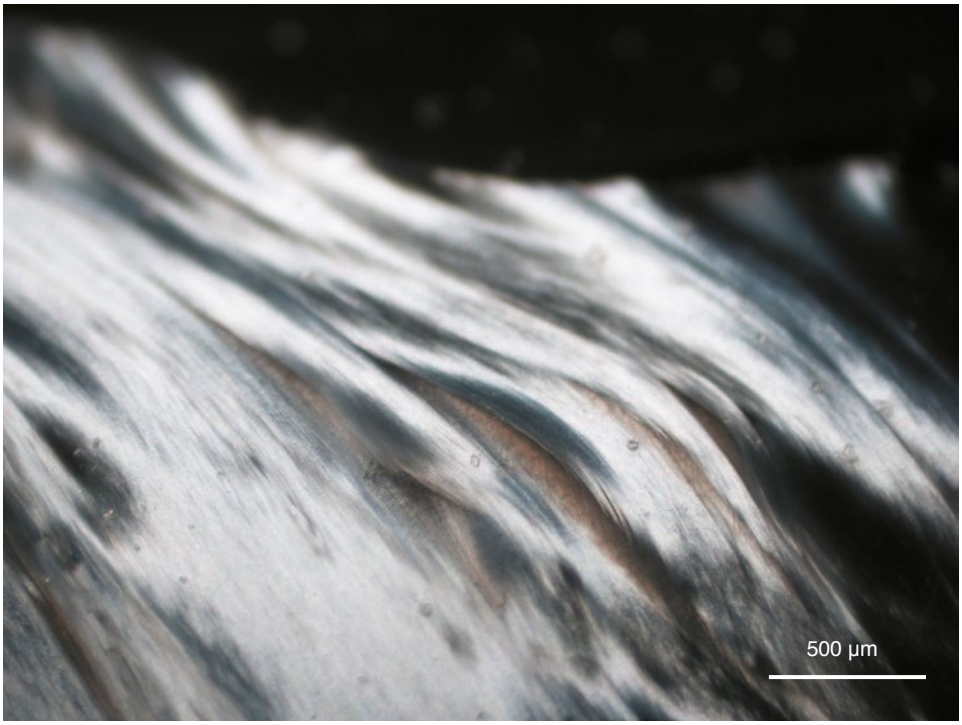

Figure 25: The wavy asbestiform habit of the aggregates of long, thin, fibrous crystals of magnesio-riebeckite is seen here with reflected light. Photomicrograph by A. Costanzo.

from suitably oriented fibres, the material appeared dark grey or black. Raman microspectroscopy using a Horiba LabRam II confocal Raman unit equipped with a 532 nm laser and a high-resolution diffraction grating confirmed the material was magnesio-riebeckite, with several points on the sample all yielding peaks at ~527, ~350, ~270 and ~160 cm^{-1}, which are characteristic of this amphibole species (Rinaudo *et al.* 2004). However, Raman analysis of the backing material did not yield any useful spectra.

The bluish grey to greyish blue sheen displayed by these doublets is not commonly encountered in other gem materials, and therefore they make an interesting addition to the marketplace.

Dr Alessandra Costanzo FGA DGA

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MISCELLANEOUS

Figure 26: Several local gem companies displayed their products at the 56th Myanma Jade & Gems Emporium. Photo by T. Hlaing.

56th Myanma Jade & Gems Emporium

On 11–20 March 2019, the 56th Myanma Jade & Gems Emporium took place in Nay Pyi Taw. Burmese vice president Henry Van Thio opened the Emporium and visited the display room. The event was attended by 2,912 foreign merchants and 1,649 local buyers. Numerous local companies had booths there (e.g. Figure 26).

There were 6,973 'Jade' lots offered, and 5,263 of them sold for a total of EUR474,141,803. The pieces included cut slabs, beads and bangles. The highest sale consisted of two sawn pieces of jadeite weighing a total of 1,380 kg that sold for EUR10,588,888. A jadeite-encrusted bed weighing 460 kg with a reserve price of EUR10,000 was not sold. Non-jade lots (26 total) included albite, quartzite, idocrase, bowenite (a variety of antigorite) and amphibole.

Of the 500 'Gems' lots that were offered during this Emporium, 69 of them sold for a total of EUR1,024,243. The highest price (EUR76,531) was paid for a parcel of Mong Hsu ruby consisting of 249 pieces weighing 6.84 kg. Fifteen lots of peridot were also sold (e.g. Figure 27), with the highest one fetching EUR75,148.

There were 274 'Pearl' lots offered, and 269 of them sold for EUR1,518,847. The total sales for the event were EUR476,684,893, an increase compared to ~EUR427,095,000 sold at the 55th Emporium.

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Figure 27: Buyers examine a parcel of Burmese peridot at the 56th Myanma Jade & Gems Emporium. Photo by T. Hlaing.

Mr Hornby's Diamond: Its Travels, Diplomatic Role and Possible Equation with the Nur al-'Ayn

Jack M. Ogden

ABSTRACT: The Hornby diamond has received scant attention in the literature on gems, with writers noting merely that it was supposedly sold to a shah in Persia in the early 1800s. Detailed information about this diamond is available, however, in a book written by the British diplomat Sir Harford Jones Brydges in the 1830s. From this and other documentation it is possible to pick up the trail of this ~60 ct pink diamond, proceeding from the Iranian Shah Karim Khan to India and then to Britain, where it was put up for auction, and finally back to the Iranian court where, as a diplomatic gift, it helped thwart Napoleon's plans to invade British India. If this diamond still resides within the Iranian Crown jewels, it seems possible that it is the pink Nur al-'Ayn ('Light of the Eye'), which is estimated to weigh approximately 60 ct.

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The Hornby diamond is little talked about. Lord Balfour, in his monumental *Famous Diamonds* (2009 and earlier editions), makes no mention of it at all. Edwin Streeter in his 1882 *Great Diamonds of the World* (p. 304) calls it 'Another Gem unknown to History' and simply quotes from the 1839 edition of John Murray's *A Memoir on the Diamond*, adding that 'Nothing further is known of this stone'. Murray, who did not mention the Hornby in his first edition (1831), was brief: 'The 'Hornby' diamond, brought from the East Indies by the Hon. William Hornby, governor of Bombay, in 1775, weighs 36 [*sic*] carats, and is now, I believe, the property of the Schah of Persia' (Murray 1839, p. 70). As shown below, he was slightly incorrect about the date, very wrong about its weight, but correct about its ownership.

In reality, by the time Murray penned his brief 1839 note on the Hornby diamond, its history had been recorded in some detail, but not in the usual gem-related volumes. To uncover its history it is necessary to start with Sir Harford Jones' (later Sir Harford Jones Brydges[1]) account of his 1807–1811 royal mission to the Persian court (Jones Brydges 1834) and the introduction to his 1833 translation of Ma'āṯer-e solṭānīya (*The Dynasty of the Kajars*). The story that unfolds from these books, contemporary press reports, and parliamentary and other sources reveals a much-travelled gem and one that played an important role in international diplomacy.

FROM TEHRAN TO LONDON

The stone that became known as the Hornby diamond was almost certainly of Indian origin and was possibly among the wealth of gems brought to Iran following Nadir Shah's sack of Delhi in 1739. When Haji Yusuf, the

[1] In the 1820s Sir Harford Jones added his grandmother's name, thus becoming Sir Harford Jones Brydges, under which name he authored his 1830s books. He is called Sir Harford Jones here in the text, but Jones Brydges in the references. For more on Harford Jones, see Perry (1989).

Figure 1: Shah Karim Khan, shown here with the Ottoman ambassador Vehbi Effendi, reputedly wore a large pink diamond in a ring. The painting is attributed to Abu'l Hasan Mustawfi, Iran, 1775. Courtesy of the David Collection (Copenhagen, Denmark), inventory no. 21/1999; photo by Pernille Klemp.

chief jeweller to Shah Lotf Ali Khan (reigned 1789–1794) was shown the gem in 1809, he said he knew it well and that Shah Karim Khan (Figure 1; reigned 1751–1779) had worn it in a ring (Jones Brydges 1834). He explained that following Karim Khan's murder in 1779, some of the women of the palace took it. Later that same year it arrived in Bombay, India, with Armenian merchants (Jones Brydges 1834). There it was purchased by an Armenian diamond merchant, a woman reportedly called 'Cross' or 'Madame Pompone', although nothing more has been found about her. She then offered the diamond to William Hornby, who was governor of the East India Company in Bombay and a successful merchant. He bought the stone jointly for 'something like £21,000' (Jones Brydges 1834, p. 14) with David Scott, a Scottish merchant in Bombay and later a director of the East India Company. Soon afterwards Hornby bought out Scott's share [2].

In 1782, Hornby's son-in-law was entrusted with carrying the diamond back from India to London, apparently without knowing the contents of the package. This was Thomas Holmes (~1751–1827), who had married

[2] One must wonder whether Hornby was suspicious about the source of the diamond. In his position as governor of the East India Company in Bombay, he had been quickly notified of the death of Karim Khan in a letter sent by the East India Company's resident in Bushehr, Iran (British Library, MSS IOR/R/15/1/3, pp. 16–18).

Hornby's daughter Hannah and also worked with the East India Company. Once in Britain the diamond was delivered to John Hunter, a director of the Company who had made his fortune in India before returning to Britain in the late 1770s. There was a close relationship here: Hunter had married William Hornby's widowed mother-in-law.

Hornby resigned his post, sailing from Bombay on the East India ship Raymond on 17 December 1783 and arriving home in England on 13 June 1784[3]. Upon his return he built Hook Park, an imposing country home based on the Government House in Bombay. Hornby's intention was to sell his diamond, but as with some other large diamonds brought back from India, such as the Pigot (Ogden 2009a, b), it was not easy to find a purchaser in London. So, Hunter set off to St Petersburg in Russia to offer the stone to Catherine the Great (Jones Brydges 1834). There seems to be nothing known of this trip other than that it was unsuccessful, and Hunter returned to London with the diamond. This trip must have been made prior to 1796, when Catherine the Great died. Why Hunter undertook this trip rather than Hornby is unclear; perhaps he was travelling to Russia on other business.

IN LONDON

Hornby had not managed to sell the diamond by the time he died in 1803. His lengthy and detailed will makes no specific mention of the large gem, but it was almost certainly in the 'very small Box covered with paper and sealed', which had been lodged with Messrs Herries, Farquhar & Co (a major London bank at the time), the contents of which were 'to be taken and to be considered as part of my personal estate'.[4] Unfortunately, 'the personal estate of the said *William Hornby*, exclusive of the said diamond, … [was] insufficient for the discharge of his debts and legacies'. Thus, attempts continued to be made to sell the diamond 'by private contract, and every diligence used to dispose of it, even much under its estimated value, but without success' (House of Commons 1806–1807, p. 160).

The next move was to put the diamond up for public auction, which took place at Phillips auctioneers at 68 New Bond Street, London, on 15 January 1807. Prior to the auction the stone was advertised as 'An unique, magnificent, and superb PINK BRILLIANT, weighing

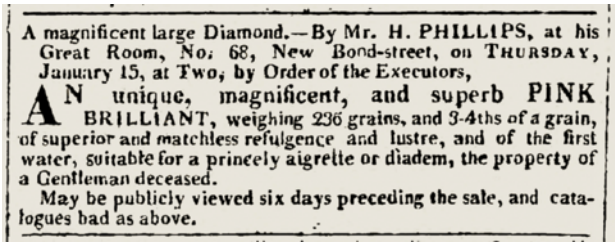
A magnificent large Diamond.—By Mr. H. PHILLIPS, at his Great Room, No. 68, New Bond-street, on THURSDAY, January 15, at Two, by Order of the Executors,

AN unique, magnificent, and superb PINK BRILLIANT, weighing 236 grains, and 3-4ths of a grain, of superior and matchless refulgence and lustre, and of the first water, suitable for a princely aigrette or diadem, the property of a Gentleman deceased.

May be publicly viewed six days preceding the sale, and catalogues bad as above.

Figure 2: This advertisement for the sale of Hornby's 'superb PINK BRILLIANT' appeared in the *Morning Post* (7 January 1807, p. 4).

236 grains, and 3-4ths of a grain [59.2 old carats, or ~61 metric carats], of superior and matchless refulgence [brightness] and lustre, and of the first water, suitable for a princely aigrette or diadem, the property of a Gentleman deceased' (Figure 2; *Morning Post*, 7 January 1807, p. 4). Another report, published after the auction, described it as 'the only Pink Brilliant ever brought to this Country of considerable size' (*Morning Post*, 22 January 1807, p. 2). A further article commented that the diamond 'is unique in brilliancy, magnitude, and weight, and has been in England 22 years, under the care of a banker in London; but during that time it has never been exposed to the air, nor has it been injured in the least. It has lately been estimated at £25,000' (*Oxford University and City Herald*, 24 January 1807, p. 3). The article also noted that the diamond sold at the auction for 5,000 guineas (£5,250) to 'a Mr. Morthbrooks'. Other reports gave the buyer's name as Mr Friedeberg (e.g. *Morning Post*, 24 January 1807, p. 3). This uncertainty over the identity of the buyer is easily explained: The diamond did not sell. When important auction lots are 'bought-in', that is unsold, it can be embarrassing for the auction house and in the past it was not unusual for them to give a fictitious buyer's name. As Hornby's son John bemoaned, it had been 'put up for sale by public auction, but no actual bidding being made, which bore any proportion to its value, it was not disposed of' (House of Commons 1806–1807, p. 160).

A month after the auction, on 23 February 1807, a petition from John Hornby was presented to Parliament which pointed out that, because of the high estimated value of the gem – £25,000 – 'there is no prospect of selling or disposing of the same, except by way of Lottery or Chance : And therefore praying, That leave may be given to bring in a Bill for that purpose' (House of Commons 1806–1807, p. 160). Hornby was seeking

[3] His resignation letter is in the British Library (MSS IOR/E/1/72, ff. 218–219v).

[4] British National Archives, PROB 11/1401/316.

to dispose of the gem by public lottery, something that needed parliamentary permission. There was a good precedent here, as just a few years earlier in March 1801 the 47.7 ct Pigot diamond had been disposed of by lottery when, similarly, its price was too high for a private buyer (Ogden 2009a, b). A House of Commons committee was set up to consider the matter of a Hornby diamond lottery, but nothing more is known of this. Perhaps it was refused, or it stalled with the upheaval of the change of British government a few weeks later, but another factor may have been the fortuitous intervention of Sir Harford Jones (1764–1847; Figure 3).

Sir Harford had been the East India Company assistant and factor at Basra in the Persian Gulf (1783–1794) and Company resident at Baghdad (1798–1806). In January 1807, recently home from the East and, in his words, 'being in London, and having nothing to do' he wandered into the Phillips auction house at 68 New Bond Street 'when a large brilliant diamond was offered for sale, for which the biddings were so low, that it was bought in' (Jones Brydges 1834, p. 13). After the sale he asked auctioneer Harry Phillips about the gem, and was told that it had belonged to the late William Hornby. Sir Harford realised that it was a diamond with which he 'had long been acquainted' and recounted the story of how and when it arrived in Bombay, and of its purchase by Hornby, information he must surely have gained in India (Jones Brydges 1834, p. 13). Sir Harford provided a succinct description of the gem: 'The form is what the oriental jewellers call an irregular circle, but capable of being much improved if the stone were submitted to new cutting and some loss of substance' (Jones Brydges 1834, p. 15). Its pink colour, he noted, 'is never considered by jewellers to deteriorate the value of a diamond' (Jones Brydges 1834, p. 15).

BACK TO IRAN

Sir Harford knew the East well and spoke Persian fluently, and so, as the Napoleonic wars raged on in the early 1800s, he was a good choice to lead a British mission to Iran to try to persuade the shah to favour the British

Figure 3: Sir Harford Jones carried the Hornby diamond from Britain back to Iran as a diplomatic gift in 1807–1808. Portrait by Thomas Lawrence; photo © John Lucas-Scudamore Collection/ Bridgeman Images.

rather than the French, and thus to stall Napoleon's feared overland attack on British India. So, in February 1807 Sir Harford was appointed 'Envoy Extraordinary and Minister Plenipotentiary to the Court of Tæheran' and was to head East on his mission as soon as possible (Jones Brydges 1834, title page and *passim*). At this point he must have realised the huge potential diplomatic bargaining value of the diamond he had seen a few weeks earlier. He negotiated with Henry Fawcett of Bruce, Fawcett & Co, a well-established trading house now handling the stone, and it was agreed that the gem would be transported by them to Bombay and taken into the care of that company's offices there. Once Sir Harford was himself in Bombay and about to set off for Tehran, he would take the diamond with him, at the risk of the owner and with sole discretion as to how it was disposed of in Iran. From what was later stated, it would seem that the inheritors of the Hornby diamond would now accept the sum of £10,000 for it (Jones Brydges 1834, Note II following p. 472).

A change in the British government meant that there was a few months' delay before Sir Harford's appointment was confirmed by the new government, in the summer of 1807. In August he was made baronet, a status befitting the important role he was to play (*Morning Chronicle*, 24 August 1807, p. 2) and then, on 27 October 1807, he sailed from Portsmouth on the Sapphire. Sir Harford arrived in Bombay on 26 April 1808 and headed to Iran, with the Hornby diamond, arriving at the Persian Gulf trading port of Bushehr on 14 October 1808 (Jones Brydges 1834). Then with his colleagues, including James Morier as private secretary and Thomas Henry Sheridan as political assistant, he set off on the 2,000-km overland journey north to Tehran.

In Shiraz, where they arrived on 30 December 1808, Sir Harford was reacquainted with the jeweller Haji Yusuf,[5] whom he knew from his earlier days in the region and who had been chief jeweller to Lotf Ali Khan, the last shah (reigned 1789–1794) of the Zand dynasty (Jones Brydges 1834). Sir Harford showed him the diamond and '"Oho!" cried he, "this is an old acquaintance of mine"' (Jones Brydges 1834, p. 143). The jeweller conveyed its history, of it being worn by Shah Karim Khan (1751–1779) in a ring 'which, through the hands of some of the women, it was conveyed out of the palace, on his death'. He also explained that since that loss, subsequent shahs Ali Murad Khan (1781–1785), Jafar Khan (1785–1789) and Lotf Ali Khan (1789–1794) had all requested him to look for it. Haji Yusuf gave the diamond's value as 20,000 tomans, 'that is about £20,000 sterling' (Jones Brydges 1834, pp. 143–144).

In early February 1809 there was a potential delay occasioned by Abdullah Khan, the governor in Isfahan, which Sir Harford neatly circumvented by explaining that 'if you stop me here, you will prevent my delivering to the King of Persia the magnificent diamond with which I am charged from my sovereign' (Jones Brydges 1834, p. 171). He showed him the Hornby diamond; he specifically called it that. The astonished governor, who supposedly 'lost his balance and fell back from his seat quite out of breath' (Eastwick 1864, p. 119), asked if he might make a note of its size. Sir Harford agreed, guessing that this information would be sent rapidly ahead to the shah. Abdullah Khan did this by placing the diamond on a piece of paper and cutting around it with 'a clumsy pair of scissors' (Jones Brydges 1834, p. 172). Not surprisingly, the result was an oversized reproduction. As Sir Harford sagely noted, 'it was his representation, not mine; so that had he made it as large as the largest of the jewels which the Genus of the lamp presented Aladeen, he alone was answerable for the mistake' (Jones Brydges 1834, p. 172). General Sir James Sutherland, who was present at this meeting, is reported as saying that the diamond was in a ring which Sir Harford produced from his waistcoat pocket (Eastwick 1864), although there is no corroborating evidence that it was then mounted in that way.

Finally, on 17 February 1809, the Mission was received by Fath Ali Shah in Tehran. The occasion was recorded in an oil painting by the English artist Robert Smirke (Figure 4). The diamond, which Sir Harford suggested was worth more like £25,000, was presented along with other gifts which, Thomas Sheridan noted, included 'a gold-enamelled snuff-box, on the lid of which was the king's picture set round with large brilliants; and a small ebony box, on the lid of which a representation of the Battle of Trafalgar was beautifully cut in ivory; and some other smaller things which I forget' (Jones Brydges 1834, p. 186). These 'other things' included another wooden box, this one with an ivory carving of Windsor Castle, and 'a small blood-stone Mosaic box for opium' (Morier 1812, pp. 186–187). The boxes with the carvings of the Battle of Trafalgar and Windsor Castle were an unsubtle reminder to the shah of Britain's supremacy over the French and

[5] Sir Harford refers to him as 'Hajee Eusoof' in his 1834 account of the Mission, and as both 'Hajy Eusoph' and 'Hajy Eusoof' in his 1833 translation of *The Dynasty of the Kajars*, where he describes him as principal jeweller to Lotf Ali Khan (Jones Brydges 1833, 1834).

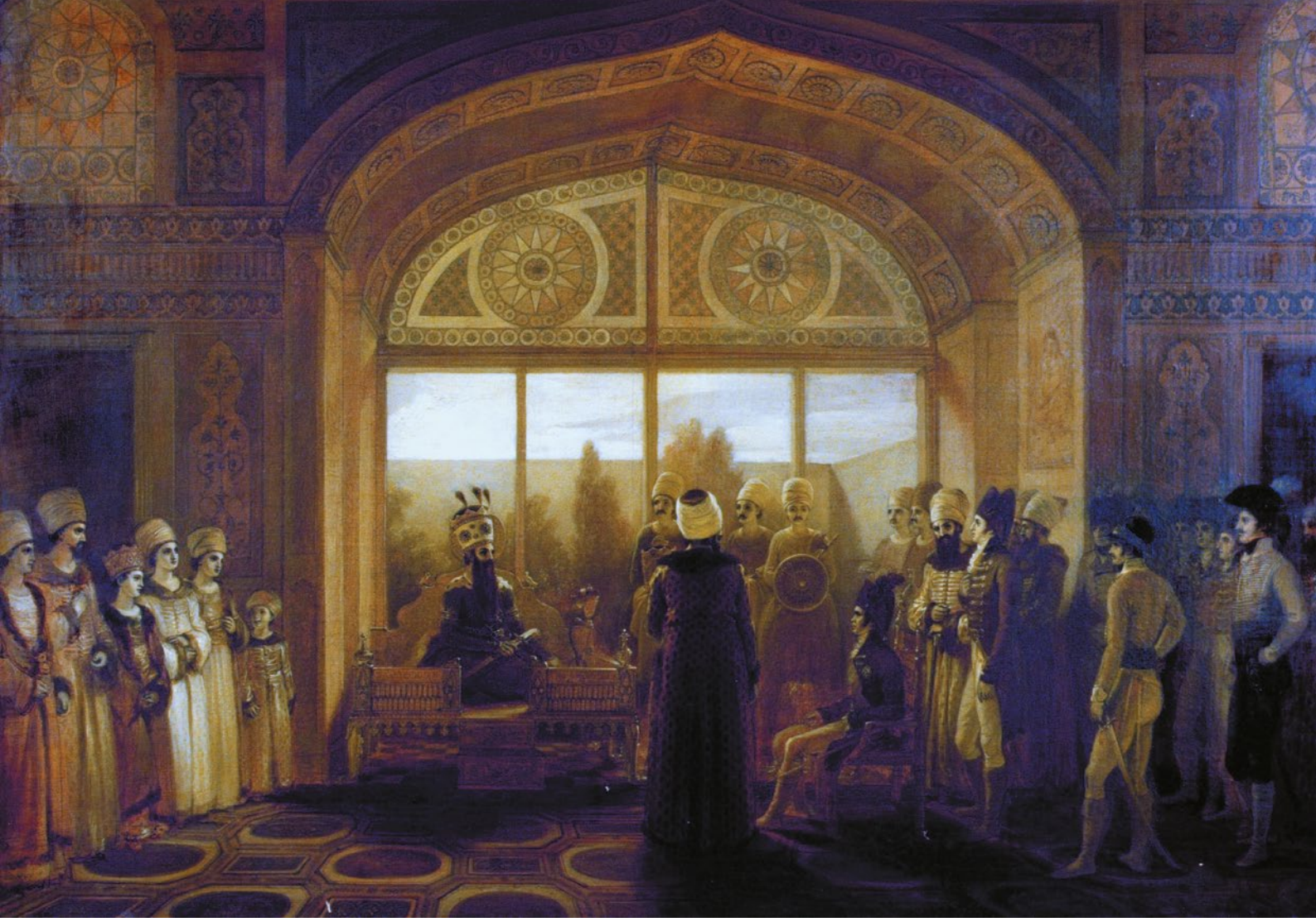

Figure 4: This painting depicts Fath Ali Shah (the shah of Persia in 1797–1835) meeting with Sir Harford Jones (seated). Painting by Robert Smirke (1752–1845); courtesy of a private collection/Bridgeman Images.

the power of the British monarchy. A long letter to the shah from British King George III ended with 'may the friendship and interests of England and Persia henceforward become inseparable' (Morier 1812, p. 190).[6]

It worked. In his journal, Thomas Sheridan recorded that the Mission was told the shah was pleased 'with all the gentlemen, and delighted with the presents, and that His Majesty swears he will never again have any thing to do with the French' (Jones Brydges 1834, pp. 189–190). The French Mission was expelled from the country. An anonymous 'officer', who was with Sir Harford's Mission, sent a letter from Tehran dated 22 May 1810 saying that 'the diamond estimated at twenty five thousand pounds, was of finer water than any the Persian Monarch possessed. He had it immediately set, and wore it as a ring the next day' (*Evening Mail*, 22 August 1810, p. 3). Apparently, the shah also more privately noted his surprise and admiration 'that Sir Harford, when there was nobody to detect him, had not substituted another [diamond] in its place' (Jones Brydges 1834, p. 209).

The formal treaty that Sir Harford concluded with the shah on 12 March 1809 laid down that no European force other than Britain could pass through Iran and that, should any European force invade Iranian territories, Britain would come to Iran's aid (Hobhouse 1839). Napoleon, who it was believed had ambitions to create a base in Iran from which he could launch an attack on

[6] There is a large collection of Sir Harford Jones' correspondence and related manuscripts in the British Library that is not indexed. An examination of those papers most obviously dealing with the 1807–1811 Mission revealed no further information about the diamond. A collection of more than 3,000 of his personal and official papers were sold at Sotheby's London in 2009 (auction of 'English Literature, History, Children's Books & Illustrations', 14 July 2009, lot 6; see www.sothebys.com/en/auctions/ecatalogue/2009/english-literature-history-children39s-books-illustrations-l09773/lot.6.html). According to Sotheby's summary of the contents, the correspondence reveals that Jones was involved in the 'sale' of the Hornby diamond to the shah, which suggests that the summary does not provide much detail about this incident. There is also a collection of correspondence from Sir Harford Jones in The Huntington Library, San Marino, California, USA (Mss HJ 1-88), but it was not possible for the author to access it for this study.

British India, abandoned any such plan (Dodwell 1929).

Sir Harford later noted that 'I could not foresee such a "God-send" as this diamond, by which the Company, at the expense of £10,000, gave the Shah that which he estimated at £20,000*l*. or £25,000*l*' (Jones Brydges 1834, Note II following p. 472). More than 50 years later, the orientalist, diplomat and conservative member of Parliament Edward Backhouse Eastwick (1814–1883) commented (House of Commons 1872, col. 1088):

> The truth was, then, that the Royal Envoy [Sir Harford] would have been sent back by the Persians from Shiraz…had it not been for a subtle device of Sir Harford, who had been long enough at Bagdad to take the exact measure of the Persian Court. With a view to the difficulty he would have to encounter, Sir Harford had provided himself with a magnificent diamond which had been in the signet ring of Karim Khan.

The shah seemed oblivious to the fact that he was receiving back a diamond stolen from one of his predecessors. And sensibly, Sir Harford did his best to ensure secrecy. He asked Haji Yusuf, the jeweller who had recognised the gem and knew its history, for a favour: '… never to mention that you have seen this stone, or that it belonged to Kerim Khan. Of this latter circumstance, they must be ignorant at Tæheran' (Jones Brydges 1834, p. 144). The only other person who might have had some earlier knowledge of the stone was the man he called 'Meerza Bozurg', that is Mīrzā 'Abbās Nūrī, known as Mīrzā Bozorg, a prominent Iranian government official then in Tehran. Sir Harford called him an 'old and powerful friend' and a 'great pillar of confidence', and was certain he could 'easily procure his silence' with regard to the history of the gem (Jones Brydges 1834, pp. 31, 38 and 144).

The realisation in Tehran that, with the presentation of the Hornby diamond, Britain had simply given them their own gem back probably came no later than 1834 when Sir Harford published his account. This does not seem to have caused a diplomatic scandal, and it is even possible that the Hornby diamond briefly returned to Britain. In 1873 Shah Naser al-Din (1848–1896) visited England, travelling overland through Russia, Germany and Belgium. Press reports talk of the 'blaze' of diamonds he wore, although the only diamond that was specifically named was the square pink Daryā-ye Nur, which 'glittered' in his belt on one occasion and 'hung from his button-hole' on another (*Essex Herald*, 11 February 1873, p. 7; *The Graphic*, 2 July 1873, p. 10).[7] This ties in closely with a statement made by Malecka (2018, p. 73), based on Iranian sources, that Naser al-Din wore the Daryā-ye Nur as a belt buckle and on his watch chain.[8]

SUBSEQUENT WHEREABOUTS

Sir Harford returned to Britain in 1811, but what of the Hornby diamond he had left in the appreciative hands of the shah?

A report that the Hornby diamond travelled to France appeared widely in the press in 1851 (e.g. *The Observer*, 18 May 1851, p. 4). This rumour was seemingly in the context of the Great Exhibition held in London from May to October that year. At the Exhibition there was a small showcase in the 'British Department' in which were exhibited crystal models of 'all the largest diamonds in the world' (*London Evening Standard*, 17 June 1851, p. 3).[9] One was 'an English gem, called the Hornby diamond, sold to Persia for £8,000, and afterwards obtained by France' (*ibid.*). There seems to be no further substantiation that the Hornby went back to France, and there may have been confusion with the Pitt or Regent diamond which was indeed in France.[10] When Edward Eastwick, secretary to the British legation in Iran from 1860 to 1863, saw the shah's amazing jewels, he specifically mentioned just three large diamonds: the ~180 ct Daryā-ye Nur, one he called the 'Táj i Humá' (presumably the Taj-i-Mah of ~114 ct) and, in a ring, 'the

[7] *The Graphic*, 2 July 1873, was a special issue devoted to 'The Progress of His Majesty NUSSER-OOD-DEEN Sovereign of Persia (Shah-in-Shah, King of Kings) from Teheran to Great Britain'.

[8] The large 'Darria-i-Noor' diamond exhibited in the 'Indian Department' at the 1851 Great Exhibition in London was a very different gem (Anonymous 1851, p. 115; Singh & Singh 1985, p. 103).

[9] The author could find no further information about the simulated diamonds, although it is possible that they were lead-crystal models made by the celebrated glass company Apsley Pellatt, which manufactured models of the Koh-i-Noor and 'its two attendant gems' that were shown at the Great Exhibition (for the Koh-i-Noor model, see Tarshis 2000). The author cannot recollect ever having seen a model of the Hornby diamond among the many glass models that have been made for famous diamonds.

[10] The implausibility that the Pitt diamond had travelled to Iran and back was raised by a correspondent to *Notes and Queries* (No. 122, 30 April 1864, pp. 357–358), with the editor suggesting that the diamond was surely not the Pitt itself but one of the 'fragments taken off in the cutting of [the] diamond'. This unconvincing explanation was nevertheless widely repeated over the succeeding years.

Figure 5: (**a**) The ~60 ct Nur al-'Ayn diamond was set in the centre of a tiara designed by Harry Winston for Farah Diba to wear at her marriage to Shah Mohammed Reza Pahlavi in 1958. The tiara resides in The Treasury of National Jewels in the Central Bank of Iran in Tehran. Courtesy of the Royal Ontario Museum; photo by Leighton Warren. (**b**) This image of the diamond was digitally isolated from the crown by the author to show it in more detail.

famous Pitt diamond sent by George IV [*sic*] to Fath Ali Shah' (Eastwick 1864, pp. 115, 119).[11] This appears to show both a confusion with the Pitt diamond and that the Hornby diamond was still in Iran at least as late as the 1860s. Eastwick said he was told about the arrival of this diamond in Iran by Sir James Sutherland, who had been present with Sir Harford in Isfahan. So perhaps this confusion of Hornby's diamond with the Pitt stems from Sutherland's faulty recollections or from Sir Harford's deliberate obfuscations among his colleagues at the time of his Mission, when he did not want the true origin of the gem known too widely.

The Hornby diamond may have been sold or given away by one of the subsequent shahs. Such things did happen. Lotf Ali Khan Shah briefly considered selling two of his largest diamonds, the pink Daryā-ye Nur and the Taj-i-Mah (Jones Brydges 1833, p. cxxv). In 1935 it was announced that an exceptionally fine pink diamond of 14 ct was on the market that had been 'presented to Catherine the Great of Russia by the Shah of Persia about 1780' (*Warwick and Warwickshire Advertiser*, 19 January 1924, p. 6). Reputedly, it had been brought to Britain after the Russian Revolution by the Grand Duchess Michael, hidden in her clothing. Another pink diamond that had supposedly once belonged to the shah was a 10 ct stone that was noted in a Bond Street, London, shop in 1901 (*Manchester Courier*, 11 November 1901, p. 4). It was supposedly named 'Nur-ed-din'. If two relatively small pink diamonds that had reached Europe from Iran were noted in the press, it seems unlikely that the arrival of an ~60 ct pink diamond would not have been noted and therefore would not have remained unknown for more than a century. The shahs also continued to buy diamonds. One report from Paris in 1859 explains how Napoleon III, on a tip-off from the French consul in Tehran, had sent a 'trusted person' there to buy a magnificent diamond that a Portuguese jeweller had taken to that country to sell to the shah (reported in *Warschauer Zeitung*, 12 October 1859, pp. 642–643).[12] It had presumably just come from India, since its previous owner was said to be a Jewish person from Goa.

POSSIBLE EQUATION WITH THE NUR AL-'AYN

In the absence of clear evidence that the Hornby pink diamond left Tehran, could it still be there? There is indeed a large oval brilliant-cut pink diamond in The Treasury of National Jewels in the Central Bank of Iran in Tehran that weighs an estimated 60 ct. This is the Nur al-'Ayn (the 'Light of the Eye'), and it is set in the centre of a tiara (Figure 5) that was designed by Harry Winston which Farah Diba wore at her marriage to Shah Mohammed Reza Pahlavi in 1958. Victor Meen and Arlotte Tushingham, who examined this gem in the 1960s, described it as 'the world's [then] largest recorded rose-pink diamond', a 'Slightly drop shaped,

[11] A widely repeated statement in the British press in the summer of 1810 that 'A superb diamond ring, the centre brilliant of which is valued at 3000 guineas, is made as a present for his Majesty the Emperor of Persia' (e.g. *Morning Post*, 28 June 1810, p. 3) probably refers to a different ring.

[12] The author is grateful to Anna Malecka for bringing this to his attention.

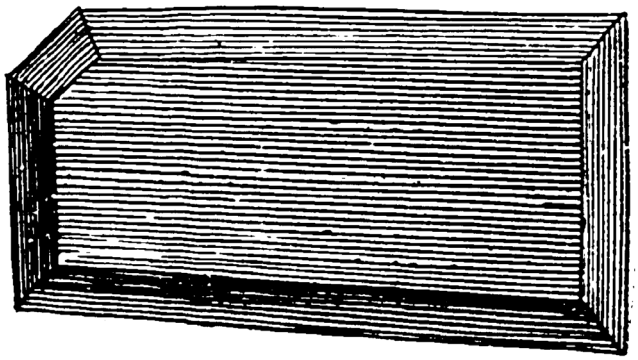

Figure 6: The Great Table diamond, here as illustrated by Jean Baptiste Tavernier in the first edition of his *Voyages* (Tavernier 1676), is a possible source of the material from which the Nur al-'Ayn diamond was cut.

oval brilliant, 30 × 26 × 11 mm (est. 60 carats), pink, very limpid' (Meen *et al.* 1967; Meen & Tushingham 1968, p. 139). They also describe it as having 'asymmetric shoulders': one rounded, one square (Meen *et al.* 1967, p. 1,007; Meen & Tushingham 1968, p. 28). This does sound like the brilliant-cut pink diamond, an 'irregular circle' weighing ~60 ct and of high clarity, which had been brought to England by William Hornby.

A counter argument against the Hornby diamond and the Nur al-'Ayn diamond being one and the same is the quoted history of the latter stone. This history has been examined in some depth recently (Malecka 2014). In brief, from the 18th century come accounts that Nader Shah brought a diamond called the Nur al-'Ayn from India following his sack of Delhi in 1739 (Malecka 2014, 2018). Then, according to the 19th-century Ottoman scholar Ahmed Cevdet Pasa, it was stolen following Nader Shah's murder in 1747 and subsequently sold in Constantinople to the Ottoman Sultan Selim III (reigned 1789–1807; Malecka 2014). If true, then this diamond cannot be the Hornby, which was worn by Karim Khan up to 1779 and then owned by William Hornby through the 1780s and 1790s. However, Cevdet Pasa also said that the Nur al-'Ayn was a pyramid-shaped rough weighing ~60 ct when it was taken to the Ottoman court in the 1700s; if he was correct, then it cannot be the ~60 ct pink brilliant-cut diamond in Tehran that now bears the name Nur al-'Ayn (Malecka 2014). Malecka (2014) pointed out that there is seemingly no mention of the Nur al-'Ayn in 19th-century Iran before 1834. This, coincidentally, is the year in which Sir Harford's account of his Mission was published and the history of the Hornby diamond was made public. The stories of the original ~60 ct Nur al-'Ayn being stolen from the murdered Nader Shah in 1747 and the ~60 ct pink diamond being stolen from the murdered Karim Khan in 1779 are remarkably similar. Is it possible that, when it became known in Tehran that the diamond presented by Sir Harford in 1809 had been stolen from an earlier shah, this diamond was wrongly assumed to be Nader Shah's Nur al-'Ayn and has borne that name ever since?

There is another argument for the Hornby and Nur al-'Ayn not being the same gem. Meen *et al.* (1967) showed that two large pink diamonds in Tehran—the Nur al-'Ayn and the rectangular Daryā-ye Nur—could have both come from the large diamond illustrated by Jean Baptiste Tavernier and which, since the 1860s at least, has been called the 'Great Table' (Figure 6; Tavernier 1676, pp. 334–335 and figure 3 facing p. 334; King 1865, p. 414; Streeter 1877; Meen *et al.* 1967). The end could have cleaved off, or been cleaved off, the Great Table. The investigation by Meen *et al.* (1967) of the crystallographic orientation of the Daryā-ye Nur and the presence of a cleavage flaw in the Nur al-'Ayn showed this to be feasible. Indeed, they demonstrated how cutting the Nur al-'Ayn from the cleaved-off portion of the Great Table 'accounts for the slight drop-shape of the stone, the one nicely rounded shoulder and the other rather square shoulder' (Meen *et al.* 1967, p. 1,007). Their proposition is shown in Figure 7, based on measurements and models published by Meen e*t al.* (1967). This raises a problem in identifying the Hornby with the Nur al-'Ayn because Sir Harford says he was shown the Great Table intact in Tehran in 1791, while the Hornby was in Britain.

Sir Harford was invited by Shah Lotf Ali Khan (reigned 1789–1794) to give advice on the potential sale of two of his largest diamonds, and he recognised that one of them, the Daryā-ye Nur, 'perfectly agreed' with Tavernier's drawing of the Great Table, a copy of which he conveniently had with him.[13] There was a weight discrepancy, however, since Tavernier gave the weight of the Great Table as '176 1/8 mangelins [an old Indian weight unit for gems] which are of our carats 242 5/16', whereas Sir Harford was told by 'Mirza Jaunee… a very tolerable lapidary', that the diamond he saw was just over 176 'Persian carats' (Tavernier 1676, pp. 334–335; Jones Brydges 1833, p. cxxxvi). He mulled

[13] The images of the Great Table shown in different editions of Tavernier vary in their orientation. Some have the cut corner upper right, some upper left. The drawing shown in Figure 6 is from the first edition (Tavernier 1676, facing p. 334).

over this discrepancy and even 'began to doubt whether it could be the same stone' but concluded that they were indeed identical (Jones Brydges 1833, p. cxxxvi). However, a strong indication that he was mistaken—that the Daryā-ye Nur he was shown was the larger section of the Great Table, not the whole of it—comes from his own report. That same skilled lapidary assured Sir Harford that 'the Dereya-noor had substance enough to allow of facets being cut from a girdle; which when effected, would give the stone pretty much the form and lustre of a properly-proportioned brilliant' (Jones Brydges 1833, p. cxxxvi). Sir Harford, experienced with diamonds, would not take seriously the proposal that a diamond with the attenuated tablet shape of the original Great Table—nearly twice as long as it was wide—would be easy to facet into a properly proportioned brilliant. The coincidence of Sir Harford being told the Daryā-ye Nur weighed '176 carats and a small fraction' and Tavernier's weight for the Great Table of 176 1/8 mangelins was not lost on Meen and his colleagues, but coincidence it may be (Meen *et al.* 1967, p. 1,004).

Recent research by Malecka (2018) into the Daryā-ye Nur based on textual and pictorial sources has also concluded that the Great Table was divided well prior to Sir Harford's viewing in 1791. If so, then there is no clear argument against the Nur al-'Ayn now in Tehran and the Hornby diamond being the same gem other than Cevdet Pasa's statements about a gem named the Nur al-'Ayn being in Ottoman Turkey. The weight details he gives, however, do not match with either the Nur al-'Ayn now in Tehran or the Hornby, and it is not improbable that he was referring to a different gem—perhaps a diamond where the name meaning 'light of the eye' was more appropriate than it would seem to be for a pink one. So although we may never know for certain whether Hornby's diamond is the Nur al-'Ayn now in Tehran, it does seem improbable that there would two slightly asymmetric, ~60 ct brilliant-cut pink diamonds in Iran in the 19th century. If there had been such extraordinarily rare twins there, surely those privileged to view the treasury would have mentioned them. Indeed, a description of the Iranian royal treasury from 1893 (though possibly based on an earlier report) notes that the two finest diamonds among the 51,355 gems in the treasury were the Daryā-ye Nur and the one 'sent by George IV [*sic*], as a present to Fath Ali Shah' (*Hampshire Telegraph*, 25 February 1893, p. 11). It is also highly unlikely that one of a unique pair would be disposed of intentionally, because a pair would be more highly valued than two singletons.

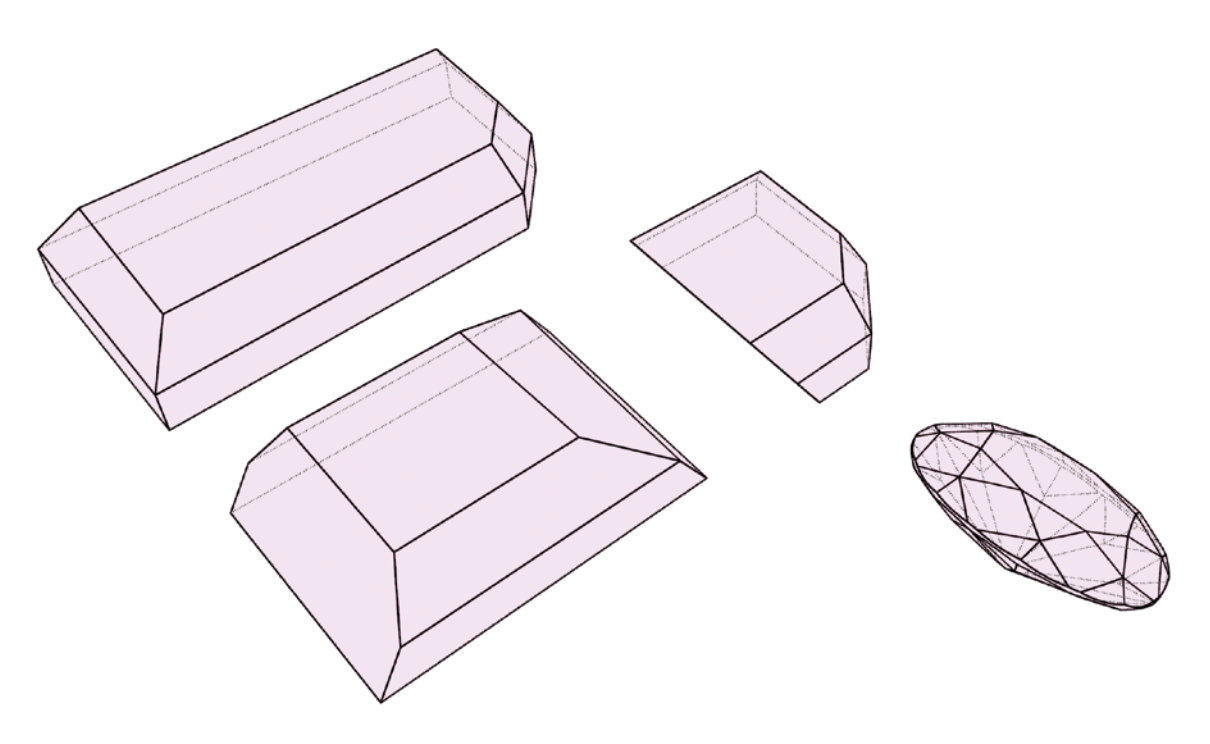

Figure 7: This drawing shows how the Great Table diamond could have cleaved to produce the starting material for cutting the Daryā-ye Nur (left) and the Nur al-'Ayn (right) diamonds, based on drawings and measurements in Meen *et al.* (1967). Drawing © J. Ogden.

CONCLUSIONS

This article sheds some light on the ~60 ct Hornby pink diamond, which Edwin Streeter had described as a 'Gem unknown to History' (Streeter 1882, p. 304). Various documentation traces it from its theft from Iran in 1779 to Britain, into a London auction in 1807, and then back to Iran in 1809 as a diplomatic gift from the British Crown to Fath Ali Shah which arguably changed the course of the Napoleonic Wars. The close similarities of weight, shape and colour strongly suggest that the Hornby diamond may be one and the same as the celebrated Nur al-'Ayn diamond.

If the Nur al-'Ayn and Hornby diamonds are the same, then Phillips, the auctioneers of the latter stone in London in 1807, were remarkably prophetic. They called the Hornby diamond 'suitable for a princely aigrette or diadem' (*Morning Post*, 31 December 1896, p. 4). The Nur al-'Ayn was set in the centre of a tiara (again, see Figure 5), and today it resides in The Treasury of National Jewels in the Central Bank of Iran in Tehran.

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The Fire Within

"For in them you shall see the living fire of the ruby, the glorious purple of the amethyst, the sea-green of the emerald, all glittering together in an incredible mixture of light."

– Roman Elder Pliny, 1st Century AD

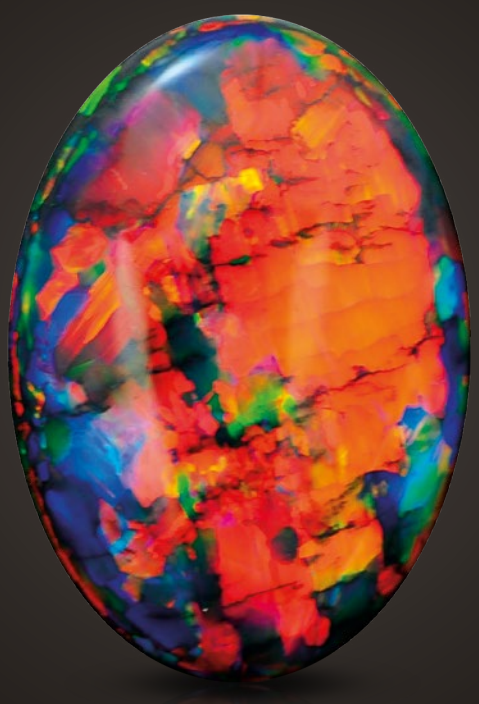

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Figure 1: Placer deposits along the south-western coast of Namibia are an important source of diamonds, most of which (95%) are gem quality. The stones shown here range from ~0.5 to 10 ct. Photo courtesy of De Beers.

Onshore and Nearshore Diamond Mining on the South-Western Coast of Namibia: Recent Activities and Future Exploration Techniques

Jana Jacob and Gottfried Grobbelaar

ABSTRACT: Diamond mining along the onshore and nearshore zones of south-western Namibia has been active for the past 90 years. A high proportion (95%) of the diamonds are gem-quality. This mega-placer is the result of a weathering and conveyor system that liberated diamonds from kimberlite pipes in the interior of southern Africa and transported them along the Orange River drainage system to the Atlantic Ocean. The onshore marine component of the placer is virtually mined out. However, new techniques of processing and interpreting geophysical datasets that were recently acquired from both onshore and offshore sectors of the deposit have revealed controls on the diamondiferous gravels that provide much-needed guidance for future mining operations, and should help extend the exploitation of the nearshore deposits for decades to come.

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The south-western coast of Namibia is renowned for its deposits of high-quality gem diamonds (Figure 1). Since the discovery of the first diamond near Lüderitz in 1908, mining activities have taken place in the region for more than a century (nearly continuously for the past 90 years). The placer deposit, which in this context constitutes a secondary concentration of diamonds through sedimentary transport processes, is situated in the *Sperrgebiet* ('restricted area'), a coastal region roughly 80 km wide that extends mainly from the mouth of the Orange River to Lüderitz (Figure 2). In 2008, the Tsau //Khaeb National Park was established in the *Sperrgebiet* area and provides restricted access for tourism. However, much of the historic diamond mining areas—and all of the active operations—remain closed to visitors, and access is strictly controlled by Namdeb (a 50/50 joint venture between the Namibian government and De Beers Group).

The coastal strip between the mouth of the Orange River and Chameis Bay (again, see Figure 2) has been the mainstay of diamond production, having yielded more than 63 million carats since 1928. The largest diamond recovered from this area to date weighed 246 ct. Annual diamond production peaked in the 1970s at 2 million carats, and currently about 300,000 carats are mined per year. Bedrock gullies created effective trap sites for diamondiferous gravels during marine concentration and upgrading processes (Jacob *et al.* 2006). However, the vast majority of onshore beaches along this roughly 100-km-long coastal strip have been mined out. Submerged beaches extending just offshore (in waters too shallow for ship-based mining) are currently being sampled and mined through the use of

Figure 2: The marine component of the Namibian diamond mega-placer extends from the mouth of the Orange River at Oranjemund northward to Lüderitz, in both onshore and offshore deposits. This map shows the location of the Southern Coastal Mines (previously known as Mining Area 1) within the *Sperrgebiet*.

innovative technology. This article gives an overview of the diamond emplacement model, and briefly describes progress in geophysical data processing and exploration techniques, as well as recent and future mining activities in Namibia's onshore and nearshore diamond deposits. Reclamation and environmental activities in the mined-out areas are also described.

DIAMOND MEGA-PLACER

A diamond mega-placer is defined as a deposit containing at least 50 million carats of 95% or higher gem-quality stones (Bluck *et al.* 2005). The diamond population mined along the south-western coast of Namibia yields 95% gem-quality diamonds and has one of the highest dollar-per-carat values in the world. The reason for the high gem quality stems from the extensive transport of the diamonds from kimberlite pipes some 1,000+ km in the interior of southern Africa to the coastal placer (Gurney *et al.* 1991; Bluck *et al.* 2005). During this long journey the relatively weaker non-gem and inclusion-bearing diamond fraction was mostly broken down.

The diamond mega-placer in Namibia comprises a fluvial component along the lower Orange River, a marine component along the Atlantic coastline and a deflation/aeolian component (i.e. formed by wind action) in the northern half of the *Sperrgebiet*. These areas are covered by Namdeb's Orange River Mines, Southern Coastal Mines (previously known as Mining Area 1) and Northern Coastal Mines, respectively. The formation of this mega-placer relied on four key elements.

The first is the Orange River system, which drains the interior of southern Africa and has been active for the past 100 million years (Ma; see Bremner *et al.* 1990; Brown *et al.* 1995; Aizawa *et al.* 2000). The drainage basin of the Orange River system includes the Vaal River, a major tributary of the Orange, which drained areas containing many of the diamondiferous kimberlite pipes in the Kaapvaal craton (de Wit 1999). The river evolved from a free-meandering system to confined channel flow during the early Tertiary period (~60 Ma; see Ward *et al.* 2002; Bluck *et al.* 2005, 2007). Phillips & Harris (2009) showed that 80% of the diamonds were less than 300 million years old. This is consistent with palaeo-drainage reconstructions, suggesting that Cretaceous Group I and Group II kimberlites in southern Africa were the most likely sources of the Namibian alluvial diamonds.

The second key element in the formation of the Namibian mega-placer was early Tertiary uplift of the interior of southern Africa (Aizawa *et al.* 2000), which led to increased erosional capacity of the Orange River system. As a result, material eroded from the kimberlite pipes was effectively transported to the Atlantic Ocean. Third, after the diamondiferous sediment load of the Orange River system reached the Atlantic Ocean, longshore currents transported the diamondiferous gravel northward along the coast (Spaggiari *et al.* 2006). And fourth, a predominantly southerly wind regime created the diamondiferous deflation and aeolian deposits in coastal environments near Bogenfels and Lüderitz (Figure 2).

Figure 3 illustrates approximate changes in diamond input through time in the sedimentary system.

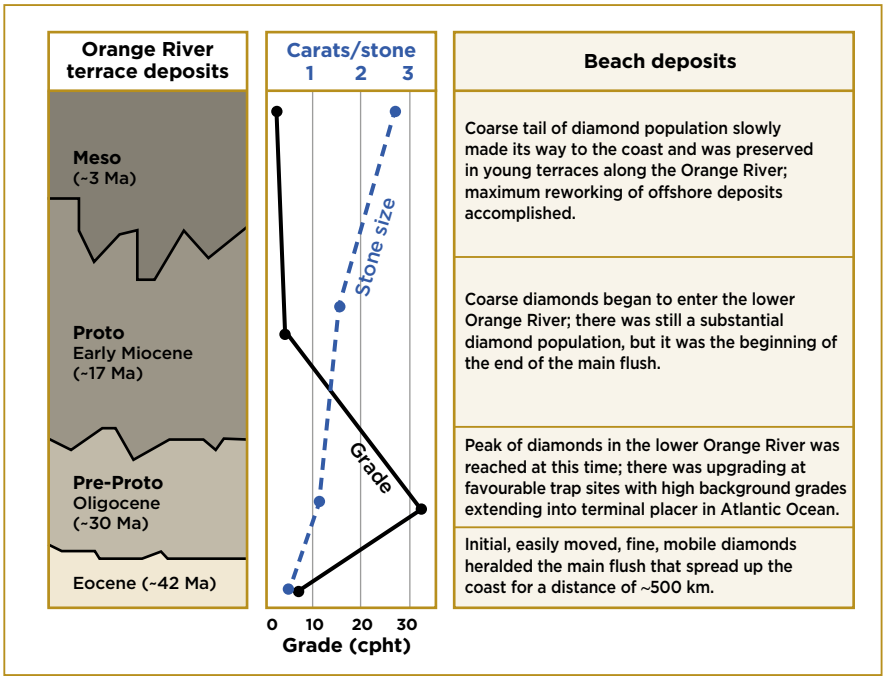

Figure 3: This diagram schematically illustrates a section through the lower Orange River terraces, together with variations in diamond grade (in carats per 100 tonnes) and stone size. Characteristics are also given for diamond placers hosted by beach deposits of equivalent ages to the terraces. After Jacob *et al.* (2006).

Figure 4: In this satellite image from Google Earth (imagery date 18 October 2017, viewed from approximately 7,660 m elevation), the high-water line for the year 2000 is shown in blue, illustrating areas where the land has been extended up to 500 m seaward since that time. A series of flooded mining pits are present along the coastline. The Orange River is visible on the far right, and the town of Oranjemund is seen as the dark area in the upper part of the image.

Overall, there is an increase in diamond size from initially smaller stones in the Eocene (~42 Ma) to coarser diamond populations in the younger meso-terraces (~3 Ma) of the Orange River (Jacob *et al.* 1999; Bluck *et al.* 2005). Diamond grades also show significant variations, and the highest grades are associated with Pre-Proto Oligocene (~30 Ma) terraces. Subsequently there was a decrease in diamond grade. Since Eocene time, multiple transgression and regression cycles resulted in various sea level stands. Generally, regressions resulted in the formation of currently drowned (i.e. below present sea level) diamondiferous beaches, while transgressions caused the raised beaches that are now present up to 200 m above sea level. Well-developed Plio-Pleistocene (prior to ~2 Ma) raised beaches have been the mainstay of diamond production in the *Sperrgebiet* since 1928 (Figure 4).

RECENT EXPLORATION METHODS IN THE SOUTHERN COASTAL MINES

Enhanced understanding of regional controls affecting the offshore extent and morphology of the submerged marine placer has recently been achieved through a thorough integration of airborne (electromagnetic and magnetic) and marine (seismic) geophysical datasets with historical mining data generated over the 90 years of onshore mining history (Kirkpatrick & Green 2018; Kirkpatrick *et al.* 2019a, b). These studies revealed that in the onshore area, diamond grade is controlled by the gradient of the bedrock and the width of wave-cut platforms, and such relationships can be extended to the offshore environment and used to develop a targeted exploration strategy for the inner shelf.

The newly developed composite geophysical model has been successfully tested using various drilling and sampling techniques, including a probe drill platform (PDP), a 2.5-m-diameter sampling tool (called BG36) and a small-diameter sonic drilling tool (Figure 5). The PDP is a custom-built jack-up platform fitted with a probe drill that is used to gather geological information regarding gravel occurrence, bedrock conditions and overburden thickness. It is designed to withstand winds up to 144 km/hour and ocean swells up to 5 m high, and can operate in the surf zone in up to 7 m water depth during relatively calm seas. The large-diameter BG36 sampling tool is used to assess the diamond content of the gravel horizons. The highly mobile, small-diameter sonic drill is used to gather the same geological information as the PDP but operates between the high- and low-water lines. These techniques and the new information they provide will be used to extend the estimated mine life for decades to come.

Figure 5: Three exploration tools currently being employed at the Southern Coastal Mines are visible here (left to right): a probe drill platform, a large-diameter sampling tool known as BG36 and a small-diameter sonic drilling tool. Photo by Edmund Nel.

MINING TECHNIQUES IN THE SOUTHERN COASTAL MINES

Laurs (2018) briefly described some of the mining techniques in use in the Southern Coastal Mines (SCM). Here, the mining methods are described in more detail, and further information and new developments pertaining to mining techniques at the SCM were provided by Kirkpatrick & Mukendwa (2019).

Figure 6 shows a typical exploitation site in the SCM, following the removal of overburden sand to expose gravel and bedrock. The bedrock underlying the diamondiferous gravel in the SCM typically contains well-developed gullies varying from less than 1 m to 7 m in depth. However, some areas are underlain by a soft clay footwall with a relatively flat surface that has a much lower potential for diamond entrapment.

Since nearly all of the onshore diamondiferous gravel has been mined out, current activities take place below sea level through a deliberate beach accretion process (Figure 7), in which overburden sand is deposited on the high-water line using dump trucks and conveyor belts

Figure 6: Diamondiferous marine gravel trapped in bedrock gullies has been exposed by the mining process. The rounded cobbles show where the gravel is located within a gully in the schist bedrock. The blue machines seen at the upper right are transvac units. Photo by Jennifer Nehoya.

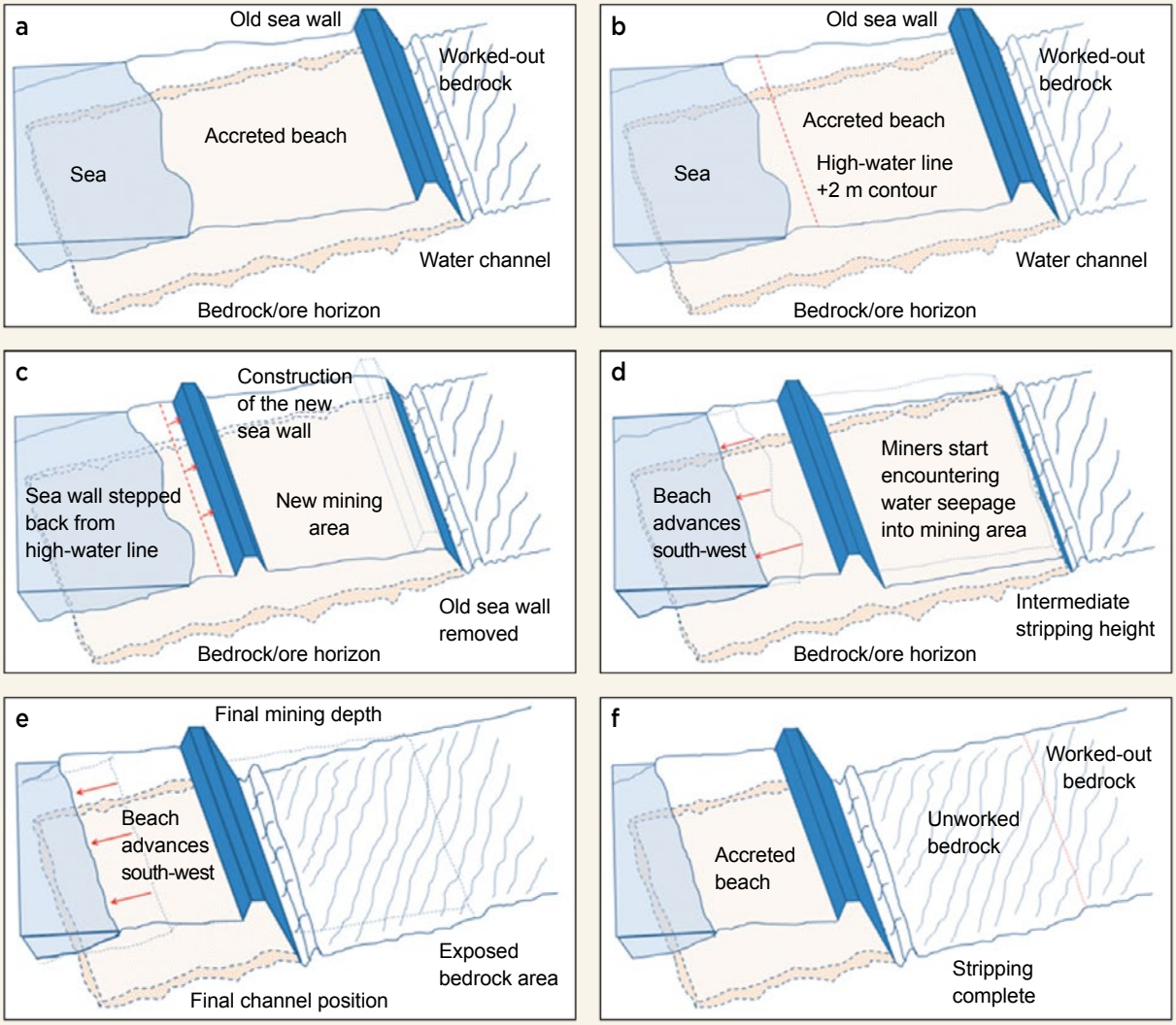

Figure 7: These drawings depict the beach accretion and mining process. Sand is dumped on the seaward side of the sea wall (**a**) until it reaches 2 m above the high-water line (**b**). A new sea wall is set back at least 25 m from the +2 m contour (**c**), and sand overburden is removed from behind the sea wall and is used for further beach accretion (**d**). Seawater seepage is routed to a channel along the eastern toe of the sea wall as the bedrock is exposed (**e**), and diamondiferous gravels are removed from gullies and other trapsites in the bedrock (**f**).
After Kirkpatrick & Mukendwa (2019).

(Figure 8). This allows submerged beaches to become accessible for extraction using conventional land-based mining techniques. The extent of beach accretion since 2000 can be seen in Figure 4. In some places the land has been extended up to 500 m seaward, making substantial areas available to onshore mining.

Beach accretion advances the mining area seaward (south-west) in a series of steps, as shown in Figure 7. Sea walls constructed along the seaward side (Figures 7a and b) protect the pits from storm events. Prior to opening a new pit, a new sea wall is constructed to a typical height of 7–10 m above sea level (Figure 7c), with a width of at least 20 m. To further mitigate the risk of storm damage, sea walls are set back at least 25 m north-east of the +2 m contour above the high-water line (Figures 7b and c) and are often widened to more than 30 m. On completion of the sea wall and enclosing side walls, the stripping fleet—consisting of 80-tonne excavators and 40-tonne articulated dump trucks—focuses on removing overburden sand from the newly protected mining area and dumping it on the beach to the south-west of the sea wall (Figure 7d). In the past, the sand was also removed by cutter suction dredges, in which a rotating cutter head mobilises the sand which is then sucked up by the dredge pump and discharged through a floating pipeline.

Figure 8: In order to increase the land surface, beach accretion takes place by moving sand from the interior onto the beach. Wave action aids in transporting the sand along the beach. Photo by J. Jacob.

Overburden material laying close to the original surface is generally dry, but at deeper levels water seepage from the sea eventually ingresses into the pit, resulting in much wetter overburden material and, consequently, the need for water management. A channel is constructed along the north-eastern toe of the sea wall (Figure 7e) to move water to a sump where it is pumped out of the pit. Channels and sumps are deepened as mining progresses downward. Once excavators 'hit bedrock' (i.e. the excavator bucket starts to scrape against the highest bedrock points), the stripping operation is complete (Figure 7f), and bedrock teams then move in to start removing the diamondiferous gravel (again, see Figure 6).

The gravel is bulldozed into piles and then loaded onto trucks. Final clean-up of the remaining gravel from the irregular, creviced bedrock is done using large mobile vacuum cleaners ('transvacs') and hand lashing (i.e. using brushes to remove trapped gravel from bedrock trapsites where needed). The gravel is then taken to processing plants where it is sized, sorted and put through a dense-medium separation (DMS) process. DMS processing generates a high-density diamondiferous concentrate that is routed to X-ray luminescence sorters, and finally the diamonds are removed by hand.

ENVIRONMENTAL IMPACT AND RECLAMATION ACTIVITIES

The SCM area is located in the Tsau //Khaeb (Sperrgebiet) National Park (Figure 2), which is earmarked for mining-based tourism. Rehabilitation of mined-out areas is primarily focused on the removal of material introduced during mining processes (e.g. redundant infrastructure such as equipment, fences, roads, etc., for which no alternative uses are identified after the termination of mining activities). This includes removal of steel via a joint venture with a scrap merchant. Since 2008 more than 100,000 tonnes of steel have been removed from Namdeb's mining licences, mostly from the SCM area.

Landscape rehabilitation of mine dumps is done by using the tailings for the beach accretion process. Ponds containing seawater often remain after the mining process has been completed (Figure 4), and they are currently being assessed for their ecological value, inclusive of salt marshes, birds, fish, plankton and benthic (seabed-associated) organisms. Natural processes mostly drive revegetation of the area. Seeds are placed at selected sites, and the prevailing southerly winds together with the availability of coastal fog allow for the natural re-establishment of plants in the area.

Namdeb continues to engage with government and non-government organisations on activities in the SCM area via the Annual Environmental Stakeholders Forum. The rehabilitation plans are frequently reviewed in consultation with external and internal stakeholders. Key stakeholder engagements include the Ministry of Environment and Tourism (end land user of the park) and the Ministry of Fisheries and Marine Resources. Monitoring programmes are aligned with mining activities and discussed at Namdeb Marine Scientific Advisory Committee meetings. This committee consists of reputable scientists (independent of Namdeb) in southern Africa who provide guidance on the design- and impact-monitoring programmes. Namdeb is ISO14001:2015 certified, which provides additional guidelines for the type of mining that takes place along the SCM coastline. In addition, other assurances regarding the environmental impact are provided by Anglo American and De Beers Groups.

SUMMARY OF DIAMOND PRODUCTION CHARACTERISTICS

From the mouth of the Orange River, which is the point source for diamondiferous gravel delivered to the marine system, there is a progressive decrease in the size of diamonds deposited northward (as they are moved by longshore currents) along the coast. In general, larger diamonds (1–2 ct per stone) are deposited closest to the Orange River mouth, with a decrease in stone size to about 0.40 ct per stone at Chameis Bay located 100 km up the coast (Figure 9). There is an additional decrease in stone size further north in the deflation and aeolian placers, and finally the average stone size drops to 0.10 ct per stone north of Lüderitz (see Figure 2).

The diamond mega-placer of the *Sperrgebiet* is renowned for its high proportion of gem-quality stones, which are popular with manufacturers because of their very high yield (i.e. their lack of inclusions results in less waste during cutting). A high proportion of the stones are dodecahedral in shape, but twinned diamonds (macles) and octahedra are also present (Figures 10 and 11). Blocky, sawable shapes also occur. The diamonds typically range from colourless through strong fancy yellows.

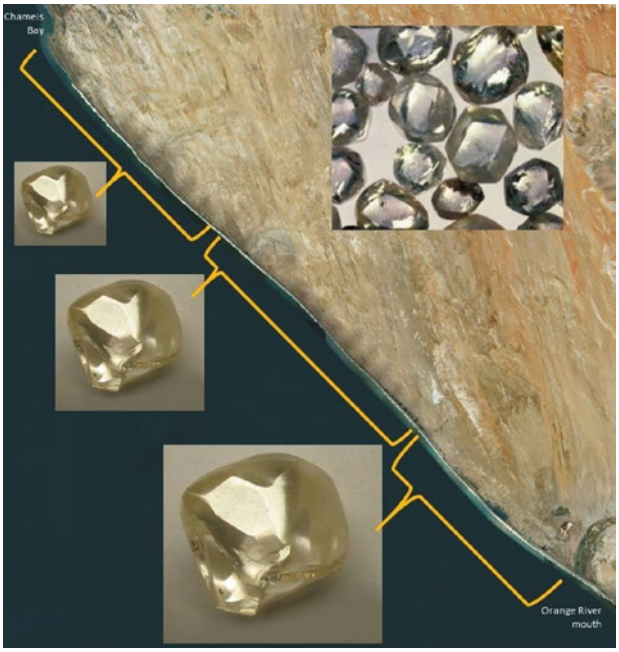

Figure 9: This schematic illustration shows how diamond size decreases northward along the shore away from the mouth of the Orange River. The average stone size is generally 1–2 ct near the Orange River mouth and 0.40 ct at Chameis Bay. The inset shows the typical appearance of diamonds from the SCM. Diamond photos by Elana Groenewald and satellite image from Google Earth.

CONCLUSIONS

The key to 90 years of sustained onshore mining of the south-western Namibian mega-placer has been ongoing innovation and perseverance. The remote desert location adds to the techno-economic challenges of mining this 95% gem-quality diamond resource. The onshore marine component of the placer has been virtually mined out, so targeted beach accretion, at an appropriate scale, is being employed to access the submerged beaches, which are naturally covered by overburden sand. This process makes previously inaccessible areas available for land-based mining. Developments in iterative and integrated geophysical processing and interpretation now provide much-needed guidance for the strategic extension of mining operations into nearshore areas that are too shallow for sea-based mining. Continued exploration work remains key to expanding the mining activities in these deposits, which are expected to produce diamonds for decades to come.

Figure 10: A selection of diamonds from the southern part of the SCM illustrates a range of shapes and sizes (scale in millimetres) that are recovered from this area. Photo by Elana Groenewald.

Figure 11: These diamonds (2–10 ct) from Namibia show the high gem quality that is typical of stones from this alluvial deposit. Photo courtesy of De Beers.

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Vanadium-bearing Tourmaline from the Commander Mine, Nadonjukin, Tanzania

Clemens Schwarzinger, Manfred Wildner, Steve Ulatowski and Marsha Sawyer

ABSTRACT: In 2016, fine intense green and bicoloured brown-green V-bearing tourmaline was found at what became known as the Commander mine in Nadonjukin, Tanzania. Although dubbed *chrome dravite* by the gem trade, this material proved to be a mixture of dravite and uvite, with Cr present only in small amounts. Multicoloured crystal sections analysed with various techniques identified the chromophores V and minor Cr in the green parts, and Fe and Ti in the brown portions. Heat treatment produced no changes in colouration, which is consistent with the presence of iron in the brown tourmaline as Fe^{2+}, as indicated by optical spectroscopy.

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In 2016, intense 'chrome' green (Figure 1) and bicoloured green-brown tourmalines were found near Nadonjukin, Tanzania, roughly 70 km south of Arusha. The material was discovered in previously abandoned diggings by a miner named 'Kamanda', which led author SU to refer to the locality as the Commander mine. This author was among the first to see this incredible find, and he acquired some of the production. A total of approximately 25 kg of the tourmaline was found as fragments and crystals ranging up to 10 cm long. About 11 kg of the material was set aside as crystals or specimens, from which author SU procured 8 kg. Less than 600 g of the total production was of faceting quality, and the remainder was suitable for cabbing or beading.

Figure 1: (**a**) The Commander mine in Tanzania is the source of this 14-mm-long tourmaline of pure green colour. (**b**) Faceting of this crystal by author CS yielded a 2.13 ct gemstone with the table oriented parallel to the c-axis. Photos by C. Schwarzinger.

A first note on this material by Williams *et al.* (2017) reported RIs of 1.620–1.638 (birefringence 0.018) and an SG value of 3.06. Energy-dispersive X-ray fluorescence analysis suggested the tourmaline was mainly dravite with a lesser uvite component, and contained the chromophores Ti, V, Cr, Fe and Mn. Rossman (2017) described V rather than Cr as being primarily responsible for the green colour, with V/(V + Cr) = 86% in the darker rim and 83% in the lighter core.

To investigate further how different elements contribute to the colouration of this tourmaline, we analysed slices cut perpendicular and parallel to the c-axis displaying brown, intense green and pale green zones with laser ablation inductively coupled plasma mass spectrometry (LA-ICP-MS). We compared the LA-ICP-MS results to chemical data obtained by X-ray photoelectron spectroscopy. In addition, we performed Fourier-transform infrared (FTIR) microscopy and polarised ultraviolet-visible-near infrared (UV-Vis-NIR) spectroscopy, and also conducted experiments to see if the brown colour could be modified by heat treatment.

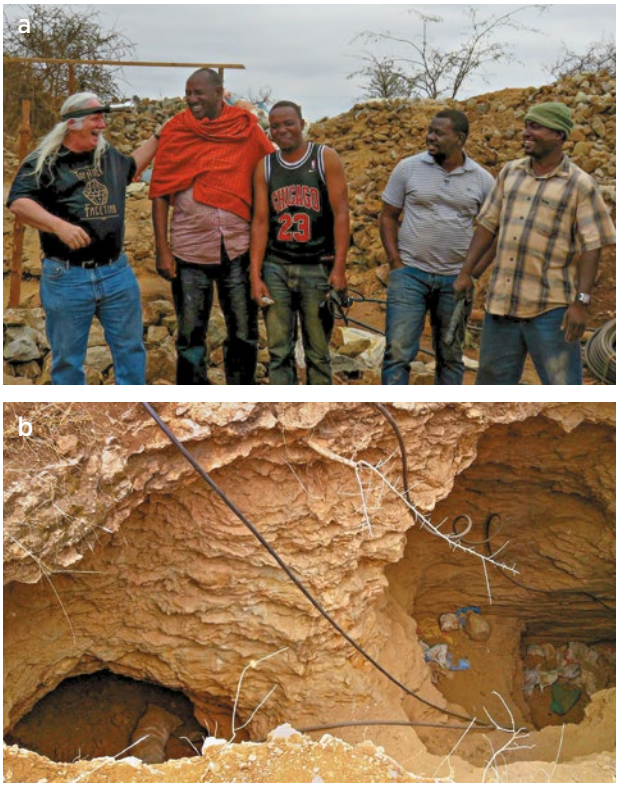

Figure 2: (**a**) One of the authors (SU) shares a light moment with local miners at the Commander mine in 2016. (**b**) This view shows some of the underground mine workings. Photos by Khai Thanoonil (a) and S. Ulatowski (b).

BACKGROUND

According to local miners (e.g. Figure 2a), the deposit that is now known as the Commander mine was first worked in 1997. It is located about 14 km from a small village called Nadonjukin in the Simanjiro area of northeast Tanzania, and is accessible by a two-hour drive on back roads from Arusha. Initial work yielded so little production that the mine was soon abandoned. On a whim, in late August 2016, the miner called 'Kamanda' decided to explore the deposit once again (Figure 2b). Good luck came to him, as he hit a pocket containing about 5 kg of mine-run material (e.g. Figure 3a). Some fine crystal specimens were recovered, but unfortunately for mineral collectors many of the best pieces were broken up to obtain highly valued facet-grade rough.

A second, larger, pocket was discovered in September 2016, and the miners were advised by a partner of author SU not to break up any well-formed crystals because they were just as valuable as the gem rough. Careful extraction of this pocket yielded 3 kg of the best crystals from the new find, as well as several kilograms of lower-grade material. Author SU was able to secure most of the production from this second pocket (e.g. Figure 3b).

While the first and second pockets were found in soft clayey material, the miners subsequently encountered hard rock, making it much less likely that the tourmalines could be extracted without damaging them. Production then slowed down so much that the miners moved on to other locations. It therefore seems likely that there will not be any additional availability of crystals or facet rough from the Commander mine in the foreseeable future.

MATERIALS AND METHODS

We examined one gem-quality crystal (Figure 4) and analysed polished slices from four crystals for this research. Three bicoloured tourmaline crystals were sliced into 1–3 mm thick sections perpendicular to the c-axis, and one bicoloured crystal was sliced parallel to the c-axis. The slices from two of the crystals are shown in Figure 5, but the other samples were so heavily fractured that no complete slices remained intact. The sawn areas were polished with diamond powder and, for X-ray photoelectron spectroscopy (XPS; see below), surface cleaning was done by argon bombardment.

Polarised UV-Vis-NIR spectra (Figure 6) were obtained from two bicoloured samples: first, slab 1c in Figure 5 containing the crystallographic c-axis (allowing the measurement of polarised spectra with E⊥c and E||c, the latter of which were used for Figure 6); and second, a thin slice cut perpendicular to the c-axis (not pictured;

Figure 3: (**a**) Only rarely were tourmaline matrix specimens recovered, such as this 40 × 30 × 20 mm sample. (**b**) Most of the tourmaline production consisted of bicoloured crystals such as this 37 × 11 mm example. Photos by S. Ulatowski (a) and C. Schwarzinger (b).

Figure 4: A gem crystal (14 × 8 mm) from the Commander mine is shown here perpendicular to the c-axis with the polarising filter in 0° (left) and 90° (right) positions. Photos by C. Schwarzinger.

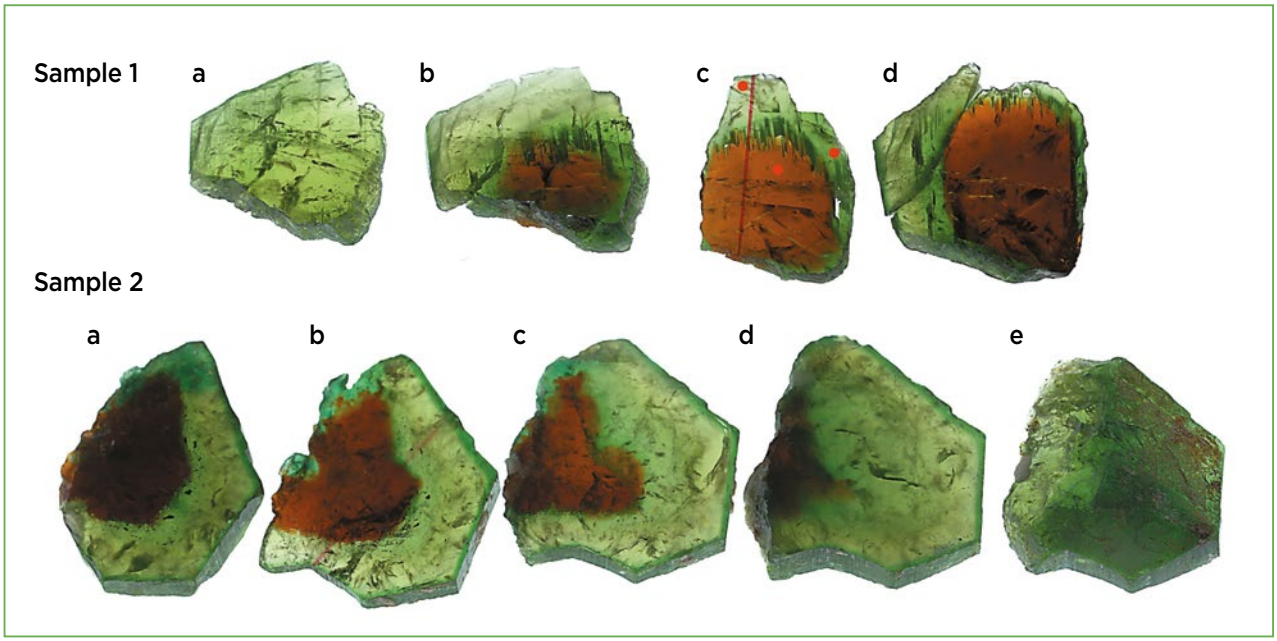

Figure 5: These slices were sawn from two different bicoloured tourmaline crystals. Sample 1 was sliced parallel to the c-axis (which in all slabs runs north-south) from the rim (left) to the core (right) of the crystal. Sample 2 was cut perpendicular to the c-axis from the bottom (left) to the top (right) of the crystal. On sample 1c, the red line shows the location of the LA-ICP-MS point traverse and the red dots indicate the positions where UV-Vis-NIR spectra were collected. The maximum dimension of the slices is 25 mm. Photo by C. Schwarzinger.

allowing the measurement of spectra with E⊥c with unpolarised light, which were also used for Figure 6). With a spot size of 250 µm in diameter, the spectra were acquired from the pale green, intense green and brown parts of each sample. Spectra were collected at room temperature in the range 33000–6500 cm^{-1} (~300–1550 nm) with a Bruker IFS 66v/S FTIR spectrometer coupled with a mirror-optics IR-ScopeII microscope. A quartz beam splitter and appropriate combinations of light sources (xenon or tungsten lamp) and detectors (GaP, Si or Ge diode) were used to cover the desired spectral range. Hence, each full spectrum was a combination of three partial spectra: 33000–20000 cm^{-1} (300–500 nm), spectral resolution 40 cm^{-1}, averaged from 1,024 scans; 20000–10000 cm^{-1} (500–1000 nm), spectral resolution 20 cm^{-1}, averaged from 512 scans; and 10000–6500 cm^{-1} (1000–1550 nm), spectral resolution 20 cm^{-1}, averaged from 256 scans. For the polarised measurements, a calcite Glan prism was used as a polariser. The final absorption spectra were displayed as wavelength (nm) vs. linear absorption coefficient (cm^{-1}).

LA-ICP-MS chemical analysis was performed on three of the slices (two bicoloured and one pure green: samples 1c, 2b and 2e in Figure 5) using a Teledyne Cetac LSX-213 G2+ laser ablation system coupled to a Thermo Scientific XSeries 2 ICP-MS. Tuning and calibration were carried out using NIST 610, 612 and 614 glass standards; reference values were taken from Jochum *et al.* (2011). The laser was operated with two different settings. The first used a 100 µm spot size, a laser energy of 10% and a repetition rate of 10 Hz; 130 shots were made on each spot, and the ablated products were transferred to the ICP-MS in He gas with a flow rate of 500 mL/min. The second setting used 20% laser energy, 230 shots on each spot and an He flow rate of 600 mL/min. The spot size and repetition rate were the same as the first setting, as it could be shown that the signal-to-noise ratio could be improved without losing linearity. Each slice was measured in a line of points (35–45 each) across the sample, for a total of 278 individual analyses. To ensure reproducibility of the data, duplicate analyses were performed on nearby spots for all samples.

X-ray photoelectron spectroscopy (XPS) is a technique that is used to determine the chemical composition of a solid's surface, and is similar to energy-dispersive X-ray (EDX) spectroscopy. X-rays are used to excite the inner electrons, causing them to leave the atom, and from their kinetic energy the binding energy (which is specific to each element) can be determined. The benefit of XPS is that the sample does not have to be electrically conductive (as is necessary for EDX), which means that insulating materials (e.g. non-metallic substances such as tourmaline) do not have to be coated with gold or carbon. Additionally, XPS is capable of detecting all elements, including the light elements H, Li, Be, etc. XPS measurements

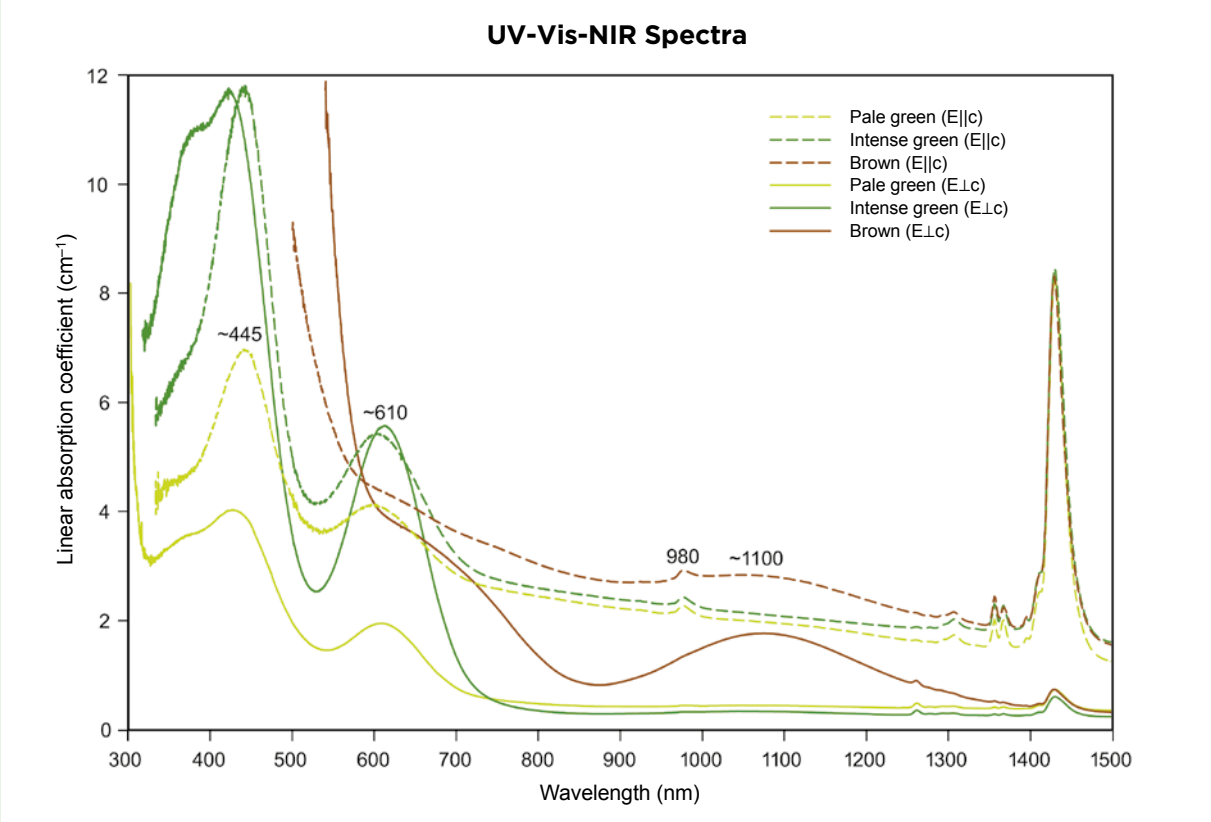

Figure 6: Polarised UV-Vis-NIR spectra are shown for pale green, intense green and brown areas of the tourmaline with E||c (dashed lines; obtained from sample 1c that was sliced parallel to the c-axis; measurement positions are indicated by the red dots in Figure 5) and with E⊥c (solid lines; measured from a second crystal cut perpendicular to the c-axis).

were performed with a Thermo Scientific Theta Probe device, which used a monochromatic Al(*K*α) X-ray source with a photon energy of 1486.6 eV and a dual flood gun for surface charge neutralisation. The surface X-ray spot was 400 µm in diameter. The survey spectra were recorded using a pass energy of 200 eV and an energy step width of 1 eV.

Infrared spectral mapping was done on sample 2b in Figure 5 in order to investigate whether this technique can be used to trace any compositional features that influence colour. The experiments were carried out with a Thermo Scientific Nicolet iN10 MX FTIR microscope in reflection mode. Spectra were collected in the range 4000–680 cm^{-1} with a resolution of 8 cm^{-1}; 16 scans were averaged for each spectrum. A total of 4,384 points were measured on the slice with a step size of 100 µm in the x and y directions.

Inclusions in the tourmaline samples were analysed with confocal Raman spectroscopy, using a Thermo Fisher Scientific DXR Raman microscope equipped with a 780 nm laser, a standard grating and a 10 × objective.

Heat treatment experiments were performed on the bicoloured slices in an attempt to change the brown colour. The samples were heated in a muffle furnace to 500°C and in a second run to 600°C. The samples were placed into charcoal to create a reducing atmosphere.

RESULTS AND DISCUSSION

Colouration

The tourmalines from the Commander mine mostly show distinct colour zoning that typically consists of an intense green cap (antilogous pole) and a brown base (analogous pole). When viewed with polarised light perpendicular to the c-axis, the basal (brown) portion of the crystals showed strong pleochroism from a deep brown to a pale orange (Figure 4) as the polariser was rotated.

In general, the sequence of slices that were cut from the bicoloured crystals showed the same colouration trends: a brown basal (or core) zone that was overgrown by a sequence of intense green and pale green layers of varying thicknesses (Figure 5). The boundary between the brown and green portions contained hollow growth tubes oriented parallel to the c-axis; these were particularly evident in sample 1.

UV-Vis-NIR Spectroscopy

UV-Vis-NIR spectra of the pale green and intense green areas of the two slabs were similar (Figure 6), with two intense bands at ~445 and 610 nm. The main difference in the spectra was an OH-related peak at around 980 nm that was only seen in the E||c spectra (cf. Rossman *et al.* 2016). The two major bands at ~445 and 610 nm are well in agreement with V^{3+} bands as described by Schmetzer *et al.* (2007), and indicate that V is the major chromophore, as Cr bands would be expected at lower wavelengths (417 and 588 nm; Schmetzer *et al.* 2007).

The spectrum of the brown area of each sample was dominated by a spectral cutoff at 500–600 nm with a shoulder at around 650 nm (due to the underlying V^{3+} band) and a broad band at roughly 1100 nm. An intense band centred at 445 nm has been assigned to Ti^{4+}–Fe^{2+} intervalence charge transfer, as found in dravite, and the broad band between 550 and 900 nm has been ascribed to Fe^{2+}–Fe^{3+} intervalence charge transfer; these Fe^{2+}/Fe^{3+} systems are known to be strongly polarised in anisotropic minerals, thus causing distinct pleochroism (Smith 1977; Taran *et al.* 2015). Finally, the broad band at ~1100 nm was attributed by Smith (1978) to a single-ion d-d transition of Fe^{2+} when polarised with E||c, and to an intensified Fe^{2+}-transition of nearest neighbour Fe^{2+}–Fe^{3+} pairs when polarised with E⊥c.

Chemical Composition

Williams *et al.* (2017) reported that Commander mine tourmaline is a mixture of mainly dravite with some uvite, as analysed by energy-dispersive X-ray spectroscopy. The contents of dravite [$NaMg_3Al_6(Si_6O_{18})(BO_3)_3(OH)_3OH$] and uvite [$CaMg_3(MgAl_5)(Si_6O_{18})(BO_3)_3(OH)_3OH$] are best evaluated with the molar ratio of Na and Ca, in accordance with the chemical formulae of these tourmaline species. In the present samples, Ca/Na molar ratios of about 1:1 were determined by XPS and confirmed by LA-ICP-MS. Higher concentrations of Ca (and therefore greater uvite contents) were found in the brown core, while more Na (dravite) was measured in the green outer rim, with Ca/Na ratios ranging from 0.7 to 1.7 in the three bicoloured slices and 0.54–0.91 in the pure green sample. XPS also revealed the presence of about 1 at.% fluorine. Chromium was not detected by XPS. However, subsequent analyses with LA-ICP-MS revealed 150–1200 ppmw (parts per million by weight) Cr, with one value attaining 1700 ppmw. Nevertheless, the abundance of V over Cr (see Table I) indicates that the name *chrome dravite* is a misnomer.

Chemical data obtained by LA-ICP-MS are summarised in Table I, and selected minor and trace elements are plotted in Figures 7–9. Figure 7 shows the analyses of a bicoloured slice from the basal portion of a crystal cut

Table I: Minimum and maximum values of some minor and trace elements by LA-ICP-MS for the dravite-uvite slices in Figures 7–9.[a]

Sample no.	2b		2e		1c	
Sample orientation	⊥ c-axis		⊥ c-axis		|| c-axis	
Analyses[b]	Scan 1	Scan 2	Scan 1	Scan 2	Scan 1	Scan 2
Minor elements (wt.%)						
Na	1.6–2.0	1.5–1.9	0.9–1.4	1.6–1.9	1.4–2.0	1.1–1.9
Ca	2.3–3.1	2.1–3.0	1.1–1.9	1.8–2.5	2.1–3.9	2.2–3.5
Ti	1.3–1.6	0.9–1.2	0.3–0.7	0.5–1.0	1.2–1.7	0.9–1.3
Trace elements (ppmw)						
V	2300–12800	1500–10500	850–3200	1300–4200	1900–14000	2000–12500
Cr	390–1200	300–960	150–640	240–800	200–1700	160–810
Mn	125–380	91–260	36–70	66–120	160–350	100–270
Fe	170–4900	120–3600	46–93	83–160	145–5500	170–4000
Zn	40–230	24–230	13–27	23–41	45–240	38–200
Ga	130–200	92–160	39–66	69–106	120–240	98–160
Sr	3400–4700	2300–3400	900–2000	1350–2700	3300–5400	2600–3800

[a] Sc was below 55 ppm, and Li, Ni, Zr and Ba were below 25 ppm; Be, Co, Cu and Ge were not detected in the samples analysed.
[b] Scan 1 and Scan 2 represent near-duplicate traverses across the samples, with analyses done in slightly different positions.

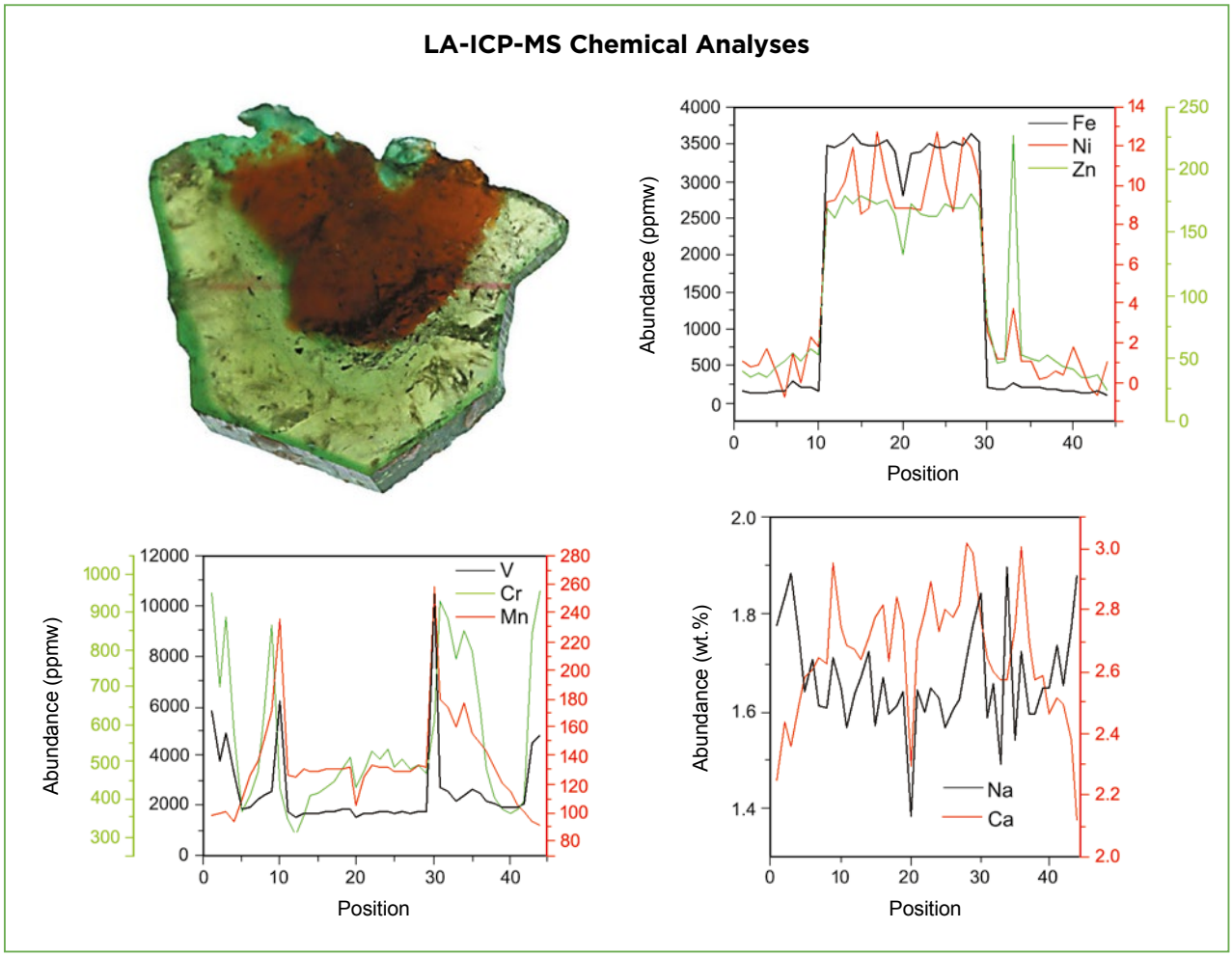

Figure 7: LA-ICP-MS chemical analyses of sample 2b were done from left to right along the red line that is marked on the slice. The plots show the concentrations across the sample of Fe, Ni and Zn; V, Cr and Mn; and Na and Ca. Photo by C. Schwarzinger.

perpendicular to the c-axis (sample 2b in Figure 5). The brown core had relatively high Fe, which dramatically decreased in the green areas. Ni and Zn followed the same profile, but their concentrations were much lower. The intense green zones adjacent to the brown zone and along the outer rim were characterised by relatively high contents of V and Cr, with V being the dominant chromophore. The V/(V + Cr) content of 83–86% determined by Rossman (2017) was confirmed on average, with individual values ranging from 73% to 95%. Between the intense green zones was a yellowish green area containing higher traces of Mn and Ga (although still lower than Cr). Along the outer rim of the crystal we measured greater Sc and Ba with maximum concentrations of only about 50 and 10 ppm, respectively. Ti and Sr were both relatively enriched at ~1 wt.% and 3000 ppm, respectively; however, no trends were evident for these elements along the traverse analysed. Plotting Ca and Na concentrations confirmed the XPS data, but care must be taken as these elements (and also Al and Si) could not be calibrated well for LA-ICP-MS analysis because their concentrations were too similar in all three NIST glass standards. Also, elements present in the weight percent range (i.e. B, Mg, Al and Si) are typically outside the linear range of the detector and are therefore subject to large errors. In addition, K was hard to measure due to strong interference from adducts of O + Na, and from Ar (used as plasma gas).

The next slice analysed (sample 2e in Figure 5), which did not show any brown colouration, was the top section of the same crystal (Figure 8). As expected, Fe was low (about 150 ppm) and did not vary across the analysed area. Vanadium and Cr were enriched in the rim (which was intense green, although not visible in Figure 8), but not in an adjacent pale green area. A similar trend was found for Sc and Ba, while Ti and Sr had maximum concentrations near the border between the pale and intense green zones. Mn was concentrated in the centre portion of the crystal and decreased towards the rim.

The third slice (sample 1c in Figure 5) was cut parallel

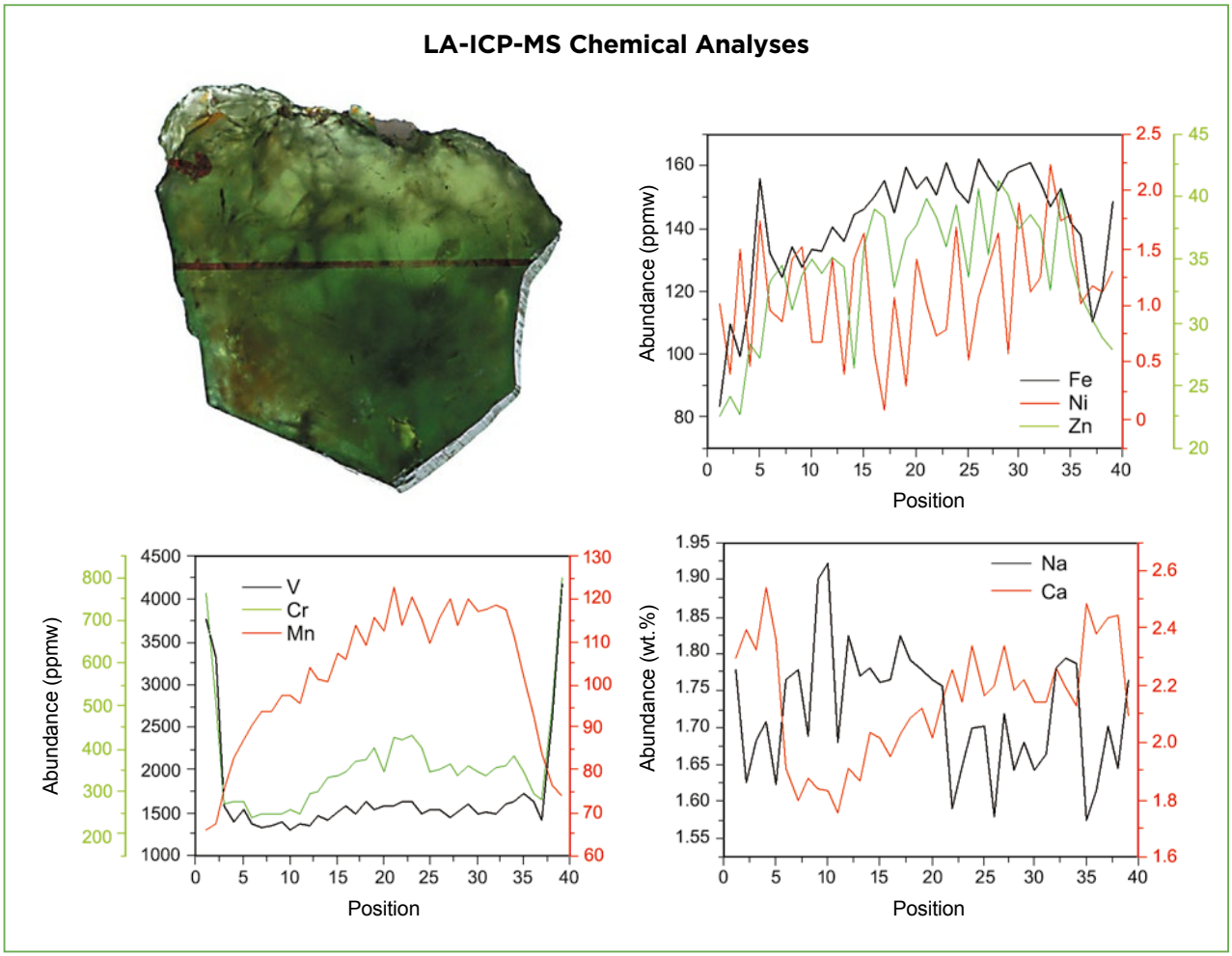

Figure 8: LA-ICP-MS chemical analyses of sample 2e were done from left to right along the red line marked on the slice. The plots show the concentrations across the sample of Fe, Ni and Zn; V, Cr and Mn; and Na and Ca. Photo by C. Schwarzinger.

to the c-axis through the core of the crystal, from the brown base to the green tip (Figure 9). The elemental trends according to colour were the same as described above for the other slices, with the brown zone having relatively high Fe concentrations that decreased in the green portion. Vanadium was greatest in the intense green zone adjacent to the brown core and then decreased in the pale green area. Chromium and Mn were also greatest in the intense green part but decreased gradually towards the tip of the crystal. Sodium increased from an average of ~1.5 wt.% in the brown area to ~1.7 wt.% in the green part, while Ca decreased from ~1.8 wt.% in the brown zone to ~1.4 wt.% in the green section (i.e. the brown areas were richer in the uvite component).

The chemical data support the results from UV-Vis-NIR spectroscopy that Ti^{4+}–Fe^{2+} and also Fe^{2+}–Fe^{3+} intervalence charge transfer were responsible for the brown colour, and V (along with some Cr) caused the intense green colour. By comparison, the pale green tourmaline had relatively low Fe, Cr and V but more enriched Mn.

Infrared Microscopy

In general, the infrared spectra of the analysed slice (sample 2b) resembled those of both dravite and uvite, which are very similar (Figure 10; cf. Lafuente *et al.* 2015).

The infrared spectral map in Figure 10 shows the relative intensity of the 1370 cm^{-1} band (darker orange indicates a higher concentration, while green indicates the background), which was assigned to a BO_3 stretching vibration by Frost *et al.* (2007). This band was slightly more pronounced in the brown core than in the surrounding green zones, but otherwise no differences could be found in the FTIR spectra according to colour. The green-appearing spots within the infrared map are hollow tubes that surround the brown core.

Heating Experiments and Cutting

We observed no changes in the colouration of the samples after heating, which provides a further indication that iron in the brown zones is already in the bivalent charge state and therefore cannot be reduced further.

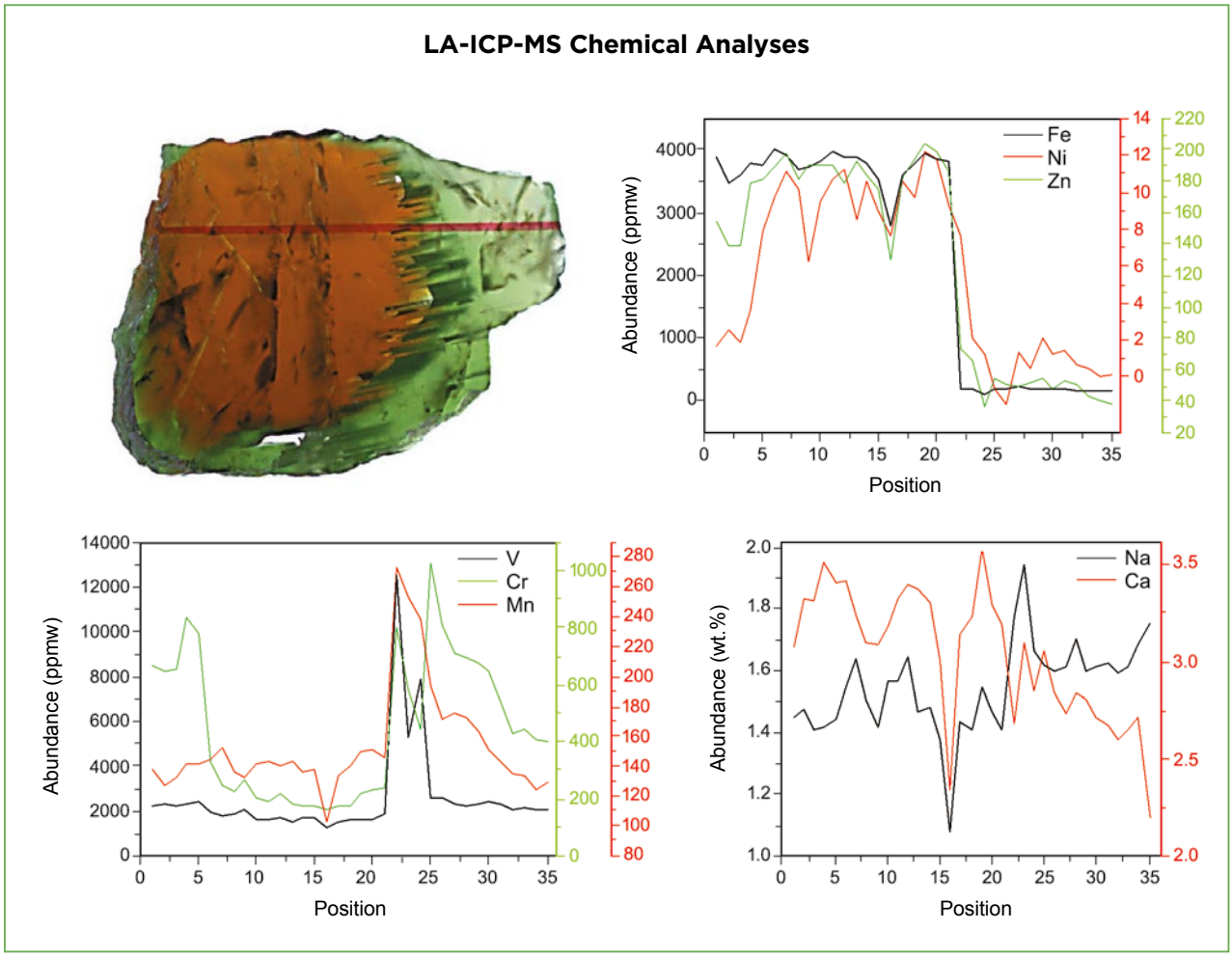

Figure 9: LA-ICP-MS chemical analyses of sample 1c were done from left to right (bottom to top of the crystal) along the red line marked on the slice. The plots show the concentrations across the sample of Fe, Ni and Zn; V, Cr and Mn; and Na and Ca. Photo by C. Schwarzinger.

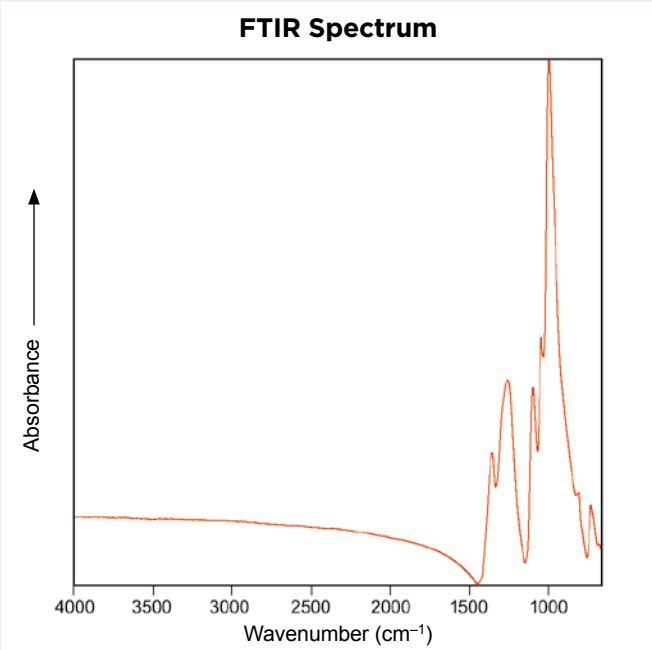

Figure 10: A representative infrared spectrum (collected from the green part of sample 2b) is shown with the infrared spectral map of this tourmaline slice displaying the relative intensity of the 1370 cm^{-1} band. This band is slightly less intense in the brown core region of the sample.

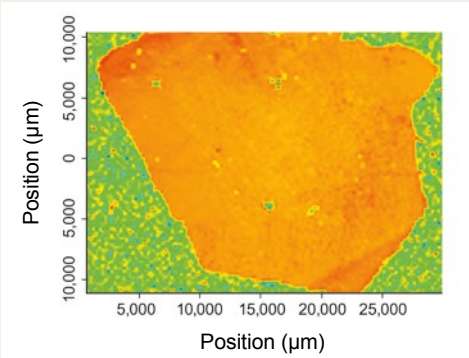

A special note to lapidaries: As with tsavorite from this region, the Commander mine tourmaline produces an unpleasant smell when cut, which is easily recognisable as a sulphur compound. A first hypothesis, based on the findings of Feneyrol *et al.* (2013) for tsavorite and Rankin *et al.* (2014) for tanzanite, is that liquids containing H_2S-S_8 might be trapped as inclusions in the crystals, but this could not be confirmed by confocal Raman spectroscopy. However, LA-ICP-MS revealed a sulphur content of several hundred to thousand parts per million throughout the crystal sections. So, either the hydrogen sulphide is homogenously distributed throughout the crystal, or during cutting the sulphur content undergoes a reaction with water that is catalysed or, more specifically, accelerated by the heat generated from friction on the lap.

CONCLUSIONS

In 2016, a remarkable find of tourmaline was made near Nadonjukin, Tanzania. Many of these tourmalines were bicoloured, with Ti^{4+}–Fe^{2+} and Fe^{2+}–Fe^{3+} intervalence charge transfers producing the brown colour, and V as well as minor Cr being responsible for the green colour. *Chrome dravite* is a misnomer for this tourmaline, as chemical analyses showed unambiguously that the crystals are uvite-dravite mixtures with a tendency towards dravite in the green parts, and thus the correct nomenclature is *vanadium-bearing dravite* or *vanadium-bearing dravite-uvite*. Although most of the tourmaline production was sold as crystals, some faceted gems are available that display a rich green colour.

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A 15th-Century Polishing Machine for Gemstones Attributed to Henri Arnaut

Karl Schmetzer

ABSTRACT: The Late Middle Ages, spanning from the 12th to the 15th centuries, witnessed a transition in the techniques used to fashion gemstones from handheld tools to mechanised equipment. A concomitant shift arose from simple shaping, smoothing and polishing to faceting in regular patterns. Notable in this progression were three instruments employing manually driven rotating wheels depicted in 15th-century Latin codices. Descriptions of two of these have appeared in multiple publications. The third, the design of which has been attributed to Henri Arnaut and most likely dated between 1432 and 1454, has received minimal attention and is the subject of this study. Also outlined briefly are further developments that were bridged by these 15th-century instruments and occurred towards the early 17th century.

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Gemstone fashioning initially relied on simple handheld tools. Early descriptions are found in texts such as one referred to as *Upon Various Arts* by the monk Theophilus (dated about 1120; see English translations by, e.g., Hendrie 1847 and Dodwell 1961) and another designated *Manuscripts of Eraclius* (dated to the 12th or 13th century; see English translation by Merrifield 1849, and for additional parts see also Richards 1940). These documents reference shaping and polishing of the irregularly shaped natural surfaces of rough gem materials, 'thereby bringing out its potential colour and clarity' (Bol 2019, p. 225).

In general, the stones were rubbed on flat, smooth, fixed plates, frequently in contact with fine-grained abrasives. Theophilus further noted that the gems could be attached with 'tenax' to handheld wooden sticks for the manual polishing operations. An alternative technique for polishing engraved gems that involved rotating a stylus, with or without abrasives, was also described in a 13th-century manuscript known as the *Doctrina Poliendi Pretiosos Lapides* (see French translation and discussion by Grassin 1999). A detailed summary and discussion of these texts with respect to gemstone shaping and polishing techniques was given recently by Bol (2019).

Evidence of further developments can be found in 13th- and 14th-century European jewellery. A limited number of faceted coloured stones with planar faces have been documented in pieces from the era (Falk 1975; Lightbown 1992; Content 2016), and the beginning of gem faceting in Europe is thought to date from this period. As time progressed, examples with a symmetrical cut design and a regular facet arrangement began to appear, and they were featured in 14th- and 15th-century royal regalia such as the crown of the Holy Roman Emperor Charles IV—made originally in 1347 and reworked several times prior to Charles IV's death in 1378 (Hyršl & Neumanova 1999)—and the crown of Blanche of Lancaster (Gray 1989, first mentioned in two English inventories dated 1398/1399; see Figure 1).

From solely handheld tools, the techniques then turned to the use of manually driven rotating wheels or discs for shaping, smoothing or polishing gemstones, as first described in the 15th century. Three notable instruments of the type are depicted in two mid-15th-century manuscripts: the *Codex Latinus Monacensis 197* by an anonymous author, archived at the Bayerische

Figure 1: This faceted blue sapphire (14 × 10 mm) is set in the late 14th-century crown of Princess Blanche of Lancaster, kept in the Munich Residence Museum, Germany. Photo by K. Schmetzer.

Staatsbibliothek (Bavarian State Library) in Munich, Germany (one device; see Hall 1971, 1979), and the Latin 7295 codex attributed to Henri Arnaut and others, archived at the Bibliothèque Nationale de France (National Library of France) in Paris (two devices; see also Le Cerf & Labande 1932).[1]

Two of the three tools have been covered in several publications (e.g. Feldhaus 1914; Schroeder 1930; Gille 1966; Fischer 1968; Hall 1971, 1979; White 1978; Samuel 1980; von Stromer 1993; Ogden 2018), as well as in recent work on faceting history available online (Prim 2018a, b). These were relatively simple instruments. The polishing device illustrated in the *Codex Latinus Monacensis 197* (Figure 2), for instance, shows no mechanism for holding and adjusting the stone. By comparison, the third such instrument was more complex and has, to the author's knowledge, only been addressed briefly by Ogden (2018). The present study thus seeks to examine this apparatus in more detail.

Such manually driven devices would eventually give way to those relying on external power sources. It has been speculated that the use of water-driven sandstone wheels for shaping and polishing quartz in the vicinity of Idar-Oberstein, Germany, dates back as far as the documented start of gem cutting in the region in the first half of the 15th century, around 1434 (Jerusalem, 2003). However, the extant written record offers unambiguous confirmation of the use of watermills for gem fashioning in the area only as of the 16th century, specifically in 1531 (Fischer 1957; Jerusalem 2003) or before 1544 (Lange 1868). Somewhat earlier usage of a watermill in this regard (in the second half of the 15th century) can be verified for other areas of Germany, such as the cities of Freiburg, Zweibrücken and Saarbrücken (Fischer 1956, 1957, 1968; Wild 1959; Jerusalem 2003).

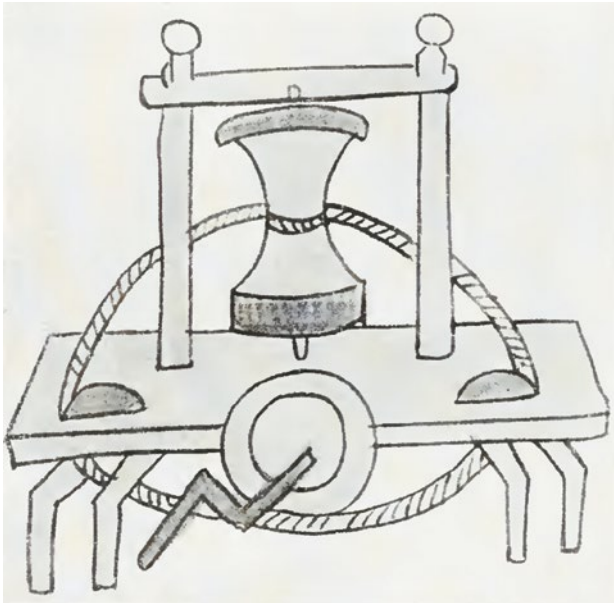

Figure 2: An instrument for polishing gemstones was depicted in the 15th-century *Codex Latinus Monacensis 197* by an anonymous author. From Feldhaus (1914).

HENRI ARNAUT DE ZWOLLE AND THE LATIN 7295 CODEX

The two gemstone-fashioning devices premised on manually driven rotating wheels or discs depicted in the Latin 7295 codex have been attributed to Henri Arnaut: one simpler type that is briefly summarised below, and another more complicated tool, which is the focus here. The life of Henri Arnaut de Zwolle (alternately Henricus Arnault/Arnold/Arnoldus) was the subject of a work by Le Cerf and Labande (1932), who also edited part of the Latin 7295 codex.

[1] The information available on the website of the Bibliothèque Nationale de France about the Latin 7295 codex originates from *Catalogus Codicum Manuscriptorum Bibliothecae Regia* (1744) but is not so cited. Such information, at least in part, is inconsistent with more recent literature (e.g. Le Cerf & Labande 1932).

Arnaut was born in Zwolle (located east of Kampen, The Netherlands) around 1400 and died of the plague in Paris in 1466. He studied in Paris and became a doctor of medicine, but he additionally trained under the instrument maker Jean de Fusoris. Arnaut served as physician, astronomer, astrologer and organist to Philip the Good, Duke of Burgundy (1396–1467) in Dijon and, later, to the French kings Charles VII (1403–1461) and Louis XI (1423–1483) in Paris.

The Latin 7295 codex contains treatises on musical instruments, astronomical devices and various technical objects, and the texts were written by Arnaut and three other known authors (Jean de Muris, Jean de Linières and Jean de Fusoris) whose work Arnaut apparently either used or copied, as well as by several anonymous contributors. Although specific dates for the penning of different portions of the manuscript are uncertain, it has been assumed that part of the text was written in Dijon, where Arnaut most likely lived between 1432 and 1454.

Folio 137 recto and verso (front side and back side) depict two different cutting and polishing mills for gemstones. According to Le Cerf and Labande (1932), the accompanying text written on the front side of folio 137 is from an anonymous hand, but the text written on the back side is attributed to Arnaut.

The Instrument for Polishing Gemstones on Folio 137 Recto

The device illustrated on the front side of folio 137 of the Latin 7295 codex (Figure 3), which has already been described in several publications, shows a large wheel (1) attached via a pivot to a horizontal spindle used as a drive shaft and turned by a crank handle (not visible).

A transmission belt (2) drives a smaller faceting and polishing wheel (3) that rotates on a vertical shaft (5). Gemstones (4) are affixed to a stylus and pressed to the wheel (3). This apparatus offered little flexibility in orienting the stone, and applying the necessary pressure would have been laborious.

The Instrument for Polishing Gemstones on Folio 137 Verso

The instrument depicted on the back side of folio 137 of the Latin 7295 codex is shown in Figure 4. The Latin text explains that the instrument is used for smoothing and polishing the pre-formed facets of a gemstone. It is said that by means of the separate 'quadrat' with the (vertical) axis *AB* it is possible to position the pre-formed stone ideally for the polishing process. The Latin text reads:

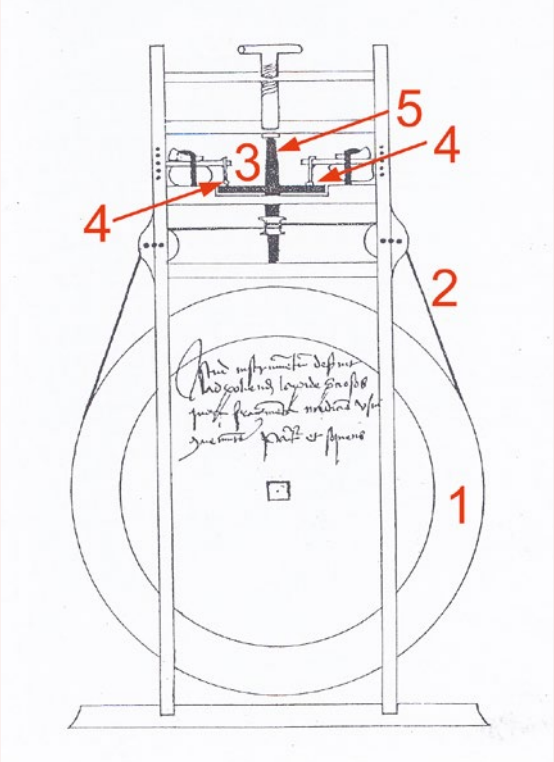

Figure 3: An instrument for polishing gemstones was depicted in the Latin 7295 codex, archived at the Bibliothèque Nationale de France (National Library of France) in Paris, on the front side of folio 137. The numbered parts are described in the text of this article. After von Stromer (1993).

> *Notandum circa istum quadratum quod bonum est quod axis AB. Fiat etiam flexibilis ita quod B possit aliquando dextri ad sinistrum et hoc ea de causa ut post sculpturam lapidis ad poliendum etiam possit perfectum adaptari. Ad facies suas iam sculptas quod alias non bene fieri poterit.*

And is translated to:

> It has to be taken into account that the quadrat is good because of the axis AB. In that way B becomes flexible at any time from right to left, and this is because after shaping the gemstone can be perfectly adapted to polish the already shaped faces, because this is not rightly done in another way.

Using this information, it is feasible to discuss the operation of the tool's various components (Figure 5). A large wheel (1) is attached via a pivot to a horizontal spindle used as a drive shaft and turned by a crank handle (2). A transmission belt (3) drives a smaller polishing wheel (4), which likewise rotates on a horizontal shaft. Such construction transmits power to the smaller polishing

wheel while at the same time increasing the rotational speed, compared to the driving wheel, thus achieving a rate sufficient for gemstone smoothing and polishing.

The component referenced in the Latin text as a quadrat (5) shows two loop bearings (6) that are placed along a vertical axis *AB*. The two loops (6), which function as guide sleeves, attach the quadrat (5) to a vertical shaft (7) and enable the quadrat to pivot on the shaft. The shaft (7) is supported by a horizontal arm (8). A pre-formed gemstone (9) can be affixed to a metallic or wooden stylus (10), which is guided at its opposite end by a groove (11) in the quadrat. This feature allows the stone to be held at a precise inclination. Consistent with such functionality, Ogden (2018) recently referred to the quadrat as an 'angle gauge'. Moreover, in further augmenting the adaptability of the device, it is likely that the arm (8) carrying the quadrat (5) and the shaft (7) can also be shifted horizontally (see arrow in Figure 5).

Nonetheless, although the general principles of the instrument's construction seem deducible, some details of the exact use and alignment of the machine remain unclear. Yet the basic technology of the apparatus, using a round wheel with a horizontal shaft for smoothing and polishing (as depicted and described in the short Latin text), was applied later in Idar-Oberstein for faceting gemstones using somewhat larger sandstone wheels.

CONCLUSIONS AND CONTINUING DEVELOPMENTS

The design of the instrument depicted on the back side of folio 137 of the Latin 7295 codex incorporates multiple adjustments facilitating orientation of a pre-formed gemstone with respect to a polishing wheel (again, see arrows in Figure 5). As such, Arnaut's instrument joins other known belt-driven devices that represent a shift from simple handheld tools to modern faceting and polishing equipment for coloured stones and diamonds

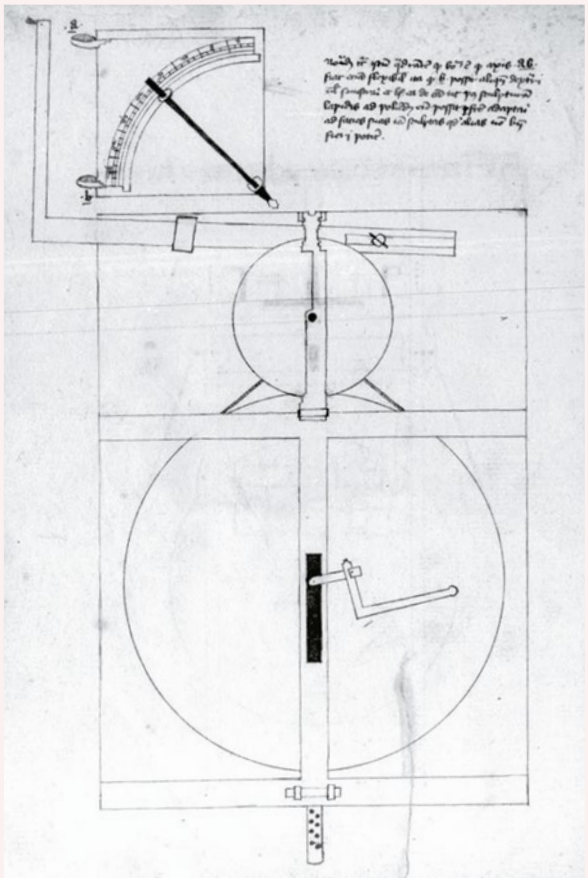

Figure 4: Another instrument for polishing pre-formed gemstones was depicted in the Latin 7295 codex on the back side of folio 137. Also slightly visible through the page are the darkest parts of the other instrument shown on the front side of folio 137. Courtesy of Bibliothèque Nationale de France, Paris; reproduced by permission.

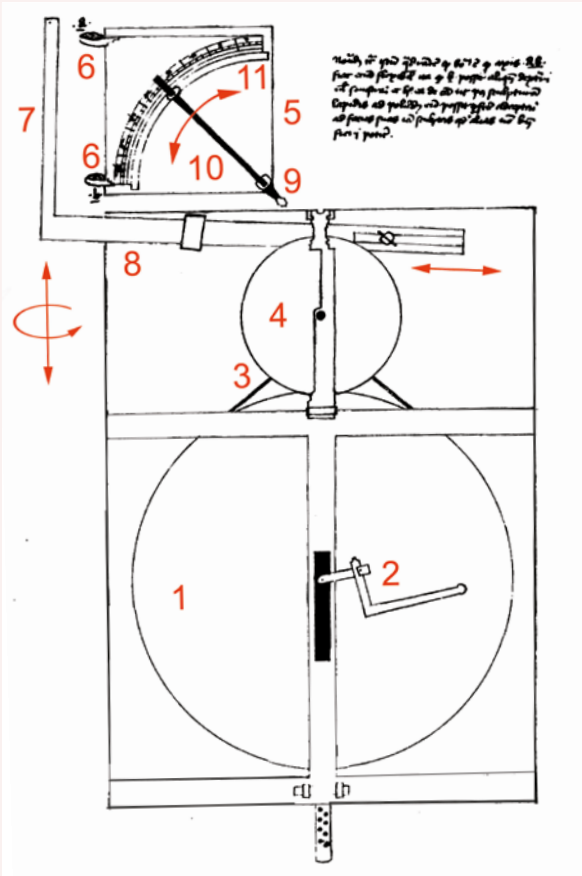

Figure 5: The instrument in Figure 4 is shown here with reference numerals added by the present author to facilitate explanation of the device's various components (see text for details).

with regular cuts, bridging the technological transition from the Late Middle Ages to the Renaissance.

At present it is unknown if the devices attributed to Arnaut in the Latin 7295 codex were widely distributed and applied in practice. The historical record suggests that progress thereafter might have been sporadic and nonlinear. For example, the tool for cutting gemstones depicted in Volmar's *Steinbuch* (1498) still shows only a rotating disc, with no device to hold and adjust the gemstone (Figure 6). Some further developments in faceting and polishing technologies were described in a treatise by Peder Månnson, written (in Swedish) around 1520. This work was translated by Johannsen (1941), who also reconstructed the instruments in operable form, and the various tools were more recently reprised by Bol (2019).

Yet another example in the ongoing experimentation appeared in a book by Rößlin (1550) describing plants, animals, minerals and gemstones. A scene in this book depicts a large, hand-cranked wheel used as a power source for polishing gems (Figure 7). In that arrangement, a horizontal driving wheel (1) is attached to a vertical spindle used as a drive shaft. A transmission belt (2) drives a smaller polishing wheel (3), which likewise rotates on a vertical shaft. The shaft of the driving wheel (1) is connected by gears (4) to a large horizontal shaft (5). That shaft (5) is connected by another transmission belt (6) to a wheel (7) rotated by manpower using a crank handle (8).

A stronger link with modern faceting technologies can be traced to the beginning of the 17th century in the treatise on mineralogy and gemmology by Anselmus Boëtius de Boodt, published first in Latin in 1609. The faceting devices described there are discussed in detail by Theobald (1984) and also illustrated by Prim (2018a). The primary novelty in their construction was the application of two parts (Figure 8), namely, a horizontal wheel with a vertical shaft for faceting and polishing, and a mechanism with another vertical shaft for setting a precise inclination of the gemstone to the flat side of the wheel.

In de Boodt's apparatus, a large wheel (A) is attached to a vertical spindle used as a drive shaft and turned by a crank handle (B). A transmission belt drives a smaller faceting and polishing wheel (C), which likewise rotates

Figure 6: A disc for shaping and polishing gemstones was depicted in Volmar's *Steinbuch* (1498).

Figure 7: An apparatus for polishing gems was depicted in a book about plants, animals, gemstones and minerals written by Eucharius Rößlin in 1550. The large wheel used as the power source (7) is seen in the background, and the horizontal driving wheel (1) for the smaller polishing wheel is at the right. See text for an explanation of the numbers and parts. After Rößlin (1550).

on a vertical shaft. A mechanism (E) to hold and adjust the gemstone (K) is shown at the upper right, enlarged but still placed in the correct orientation to the faceting wheel (C). That mechanism (E) is attached by a block (B) to another vertical shaft (D) and supports a stylus (I) holding the gemstone (K) at a precise inclination. The stylus (I) is affixed by two wooden blocks (G and H) and guided in a groove. A more detailed description is given by Theobald (1984).

As such, the apparatus depicted by de Boodt incorporated both a vertical shaft for the faceting and polishing wheel (which enabled contact with the gemstone to occur on the flat side of the wheel), and an adjustable mechanism for orienting the stone. De Boodt's work can thus be described in theory as a combination of the two beneficial features already shown separately by Arnaut. This combination, in turn, was pivotal in the progression towards modern fashioning technology.

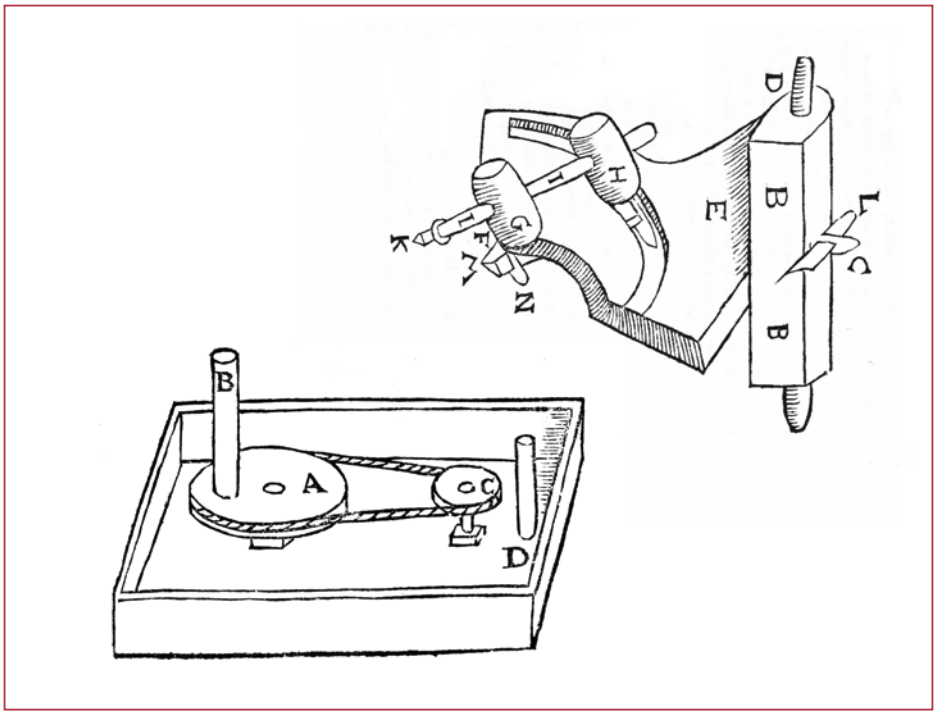

Figure 8: An instrument for faceting and polishing gemstones was depicted in the treatise on mineralogy and gemmology by Anselmus Boëtius de Boodt (1609). The mechanism (E; upper right) for orienting the gemstone, generally affixed to the vertical shaft (D), is enlarged compared to the principal tool (lower left) with driving and faceting wheels (A and C). See text for further explanation of the numbers and parts. After de Boodt (1609).

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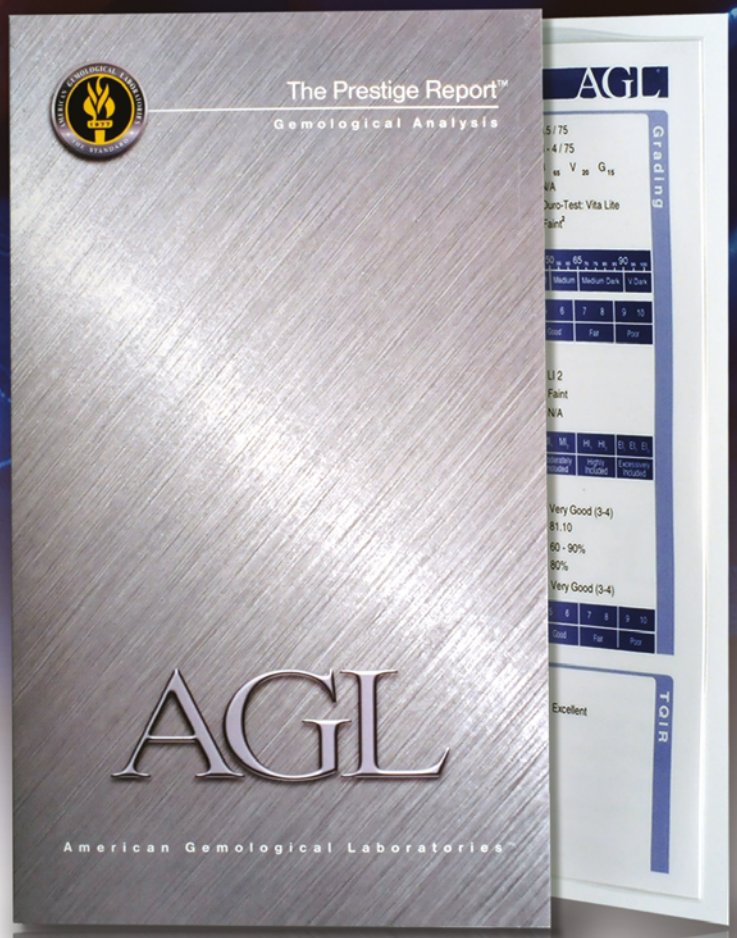

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Conferences

SECOND WORLD EMERALD SYMPOSIUM

The Second World Emerald Symposium took place 12–14 October 2018 in Bogotá, Colombia, three days prior to and in conjunction with the annual World Jewellery Confederation (CIBJO) Congress. The first time this emerald conference took place was in 2015, also in Bogotá. It was organised by Fedesmeraldas, the Colombian National Emerald Trade Association, to coincide with their 20th anniversary.

The symposium provided a comprehensive analysis of all elements of the emerald industry, across the entire supply chain from mine to market, and was well attended by about 300 people. One focus was on how blockchain technology could help the emerald industry, with an emphasis on traceability, and how corporate responsibility could help improve social conditions while strengthening confidence in emerald in Colombia. This also included branding and retailing in the new millennium, and using social media alongside the 'red carpet' to boost the Colombian emerald brand. It was stressed that artisanal miners need more support and should have a greater voice and more participation in the industry, as well as a legitimate chain of distribution. At the same time, the promotion of responsible practices should not disadvantage small enterprises. In general, it became clear that the Colombian government is seriously committed to supporting and legalising the emerald sector.

Several gemmological topics were covered on the first day of the conference, and below are highlights of some of the many worthwhile contributions, which were presented simultaneously in Spanish and English.

Dr Gaston Giuliani (Centre de Recherches Pétrographiques et Géochimiques [CRPG], Nancy, France) gave a comprehensive overview of emerald formation, with about 30% of the world's production coming from black shales in Colombia, and 70% from granite-related deposits that occur in many countries around the globe. Geologically, the Colombian emerald deposits are unique, with the erosion of ultramafic rocks providing sources of V and Cr in the shales, and halokinesis (movement of salt and salt bodies) playing a key role in mobilising the elements necessary to form emerald.

Charles Burgess (Minería Texas Colombia, Boyacá, Colombia) elaborated on the modernisation of the emerald industry in Colombia. After privatisation of the emerald mines in the 1970s, violent conflicts and intense competition increased, preventing investment. Change has been dramatic since 2009, when his company obtained mining rights to the Muzo mine. They are complying with new rules (including environmental standards and safety procedures), progress is being made in the local cutting industry, professional laboratories are operating, social responsibility is an integral part of their mining operation, and marketing and sales have improved.

Dr Lee Groat (University of British Columbia, Vancouver, Canada) discussed the challenges of exploration for emeralds in Canada, which has a number of occurrences in the Yukon and Northwest Territories. In these vast, remote areas with low population density, there are only three months of the year (June through August) that are amenable to exploration activities. Drones are increasingly being used as exploration tools, which can save 80% of the time spent in the field. Interestingly, near Mountain River, Northwest Territories, a discovery of green beryl in sediments shows some resemblance to Colombian-type mineralisation. Investigating black shale units in north-western Canada hopefully will result in additional emerald discoveries.

Gabriel Angarita (CDTEC Gemlab, Bogotá, Colombia) introduced a new resin, called Naturalys, to enhance the clarity of emeralds (Figure 1). After discussing the advantages and disadvantages of oils and resins, he explained the properties of Naturalys, which is a colourless natural product with an RI very close to that of emerald. It is reportedly easy to remove and possesses excellent stability, with minimal or even invisible changes over time (guaranteed for more than 12 years). Since the resin is not hardened, it does not glue the stone together.

Dr Taijin Lu (National Gemstone Testing Center [NGTC], Beijing, China) introduced the Chinese national standard of emerald grading, which is applied by NGTC's nine laboratories in China. It includes grading of colour, clarity, clarity enhancement, cut and brilliance ('4 Cs and a B'). The international standards of the Laboratory Manual Harmonisation Committee are followed with regard to clarity enhancement. He reported they also issue opinions on the geographic origin of emerald, using

Figure 1: Gabriel Angarita introduces a new type of natural resin called Naturalys for the clarity of enhancement of emeralds. Photo by J. C. Zwaan.

isotope analysis as well as spectroscopy, trace-element fingerprinting, optical properties, internal features and luminescence.

Vincent Pardieu (Bahrain Institute for Pearls and Gemstones—DANAT, Manama, Bahrain) elaborated on emeralds from Madagascar and on geographic origin determination. Trace-element chemistry using LA-ICP-MS has become very useful for assessing emerald localities, but it is still not easy and not cheap, and the interpretation of the data depends on the availability of a reliable reference collection. As origin determination is a major concern—auction houses are asking for origin reports, because origin strongly influences price—it is therefore important to collect reference materials at the sources where emeralds are found.

Olivier Segura (L'École des Arts Joailliers [The School of Jewelry Arts], Paris, France) described his introductory school for the general public that was launched in 2012 and supported by Van Cleef & Arpels. The school includes a design studio where one can learn gouache techniques (technical jewellery drawing), a jewellery workshop, a gemmology lab, a lacquer and enamelling facility, two classrooms dedicated to the history of jewellery and art, a lecture hall and a library. The 20 courses currently offered are intended mainly for adults, and each lasts 2–4 hours. Segura advocated education as the most powerful tool to make consumers appreciate jewellery.

Andy Lucas (Guild Institute of Gemmology, Hong Kong and Shenzhen, China) described how education is the gateway to the huge Chinese market. According to him, there is very little availability of online (or offline) education about gems and jewellery in China, which results in a lack of trust for buyers. He is working on a mine-to-market education programme to help build consumer confidence. This will include first-hand information from gem traders and visits to mines, explaining what it takes to find gemstones, the value-added skills that are required in the pipeline for cutting and designing, and the role of middlemen and brokers. The consumer will then appreciate better what goes into choosing the right stones and why (sometimes huge) differences in value exist.

Doug Hucker (American Gem Trade Association, Dallas, Texas, USA) emphasised that when looking for strategies to sell more emeralds, the international community should take an active part in improving mining conditions and giving a fair share of their profits for the welfare of local communities that depend on the recovery and trade of emeralds. He provided some examples of concrete actions that show this is real, not just posturing. Only then can customers continue to fall in love with emeralds, knowing that they are 'doing good' when purchasing such stones.

At the end of this long day, two panel sessions were held. One of the sessions was on emerald treatments with **Ronald Ringsrud** (Ronald Ringsrud Co., Saratoga, California, USA), **Dr Laurent Cartier** (Swiss Gemmological Institute SSEF, Basel, Switzerland), **Gagan Choudhary** (Gem Testing Laboratory, Jaipur, India) and **Rodrigo Giraldo** (Laboratorio de Gemología RG, Bogotá). One particular issue they discussed at length was the quantification of clarity enhancement. Because (for good reasons) the terms 'minor', 'moderate' and 'significant' clarity enhancement are not very precise, well-defined terms, Ringsrud suggested putting the word 'approximate' in front of them. Giraldo advocated for an adjustment of the current system with a few more categories, encompassing none (NE), insignificant (E1), minor (E2 or E3), moderate (E4 or E5) and significant (E6). The other panel session covered challenging laboratory issues pertaining to emeralds.

More information on the Second World Emerald Symposium was published in a special issue of *InColor* magazine (No. 40, 2018), which is freely downloadable from www.gemstone.org/incolor/40.

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GEM-A MIDLANDS CONFERENCE

On 23 February 2019, Gem-A's Midlands branch held its conference in Birmingham. With more than 60 guests attending, it had the feel of a professional conference, but with a casual atmosphere and an intimacy that allowed old friends and acquaintances to catch up, as well as meet and interact with new people. The event featured six speakers and was organised by the Gem-A Midlands branch committee (Figure 2).

Gem-A Midlands president **Gwyn Green** and chairperson **Louise Ludlam-Snook** opened the conference. The speakers programme began with **Amanda Good** (G.F. Williams & Co., London), a stone dealer with more than 35 years' experience and a Gem-A practical examiner for 20 years. Her talk—'Emeralds – Their history, properties and treatments'—started with a review of the world's major emerald deposits and their significance in the market, including Zambia as producing the largest quantity and Colombia as having the highest value. She also discussed the processes of cutting, faceting and treating emeralds, detailing a new enhancement called Permanente that has been introduced in Colombia and takes 5–7 days to perform. Resin, with a hardener, is impregnated into the stones under vacuum. It can fill larger cracks and stabilise material previously unsuitable for faceting. Additional aspects of her talk included synthetics, trading practices and historical emeralds.

Maggie Campbell Pedersen (Gem-A president, London) presented 'Ivory and tortoiseshell – Past uses and present emotions'. She discussed the use of these biogenic materials for ornamentation and adornment, and continued with other animal products that have been used for various purposes, including kingfisher feathers to decorate Chinese screens, hornbill casques for carved ornaments and rhino horns thought to have medicinal properties such as reducing fever in children. The talk also covered historical and modern information on different types of biogenic materials, with advice on how to identify them. These included elephant and walrus ivory, hippo and sperm whale teeth, vegetable 'ivory', bone and narwhal tusk, the last of which was once thought to be derived from unicorns and to be a cure for poisons. Campbell Pedersen also discussed the coming new laws in the UK for the sale of elephant ivory, and the various exemptions that will allow some trade in a few specific items. As of 2013, it was illegal to sell any ivory that had not been significantly altered from its raw state.

Craig O'Donnell (SafeGuard Valuations at Birmingham Assay Office), a jewellery valuer and antiques dealer with more than 25 years' experience, was the final speaker of the morning with his talk on 'The Joy of Text, Original Catalogues and Design Books'. His slides featured jewellery trade catalogues and design books and their illustrations. Giving overviews of jewellery designs from 1900 to 1950, he showed how fashion trends in subject matter, materials, gemstones and styles have changed over the decades, and he gave examples of what instigated these changes. For example, at the turn of the 20th century, jewellery items commonly featured tennis rackets, bicycles, cars, and art and leisure activities, which were all popular themes at the time. Some items were fashionable for only short periods, such as 19th-century 'Dearest' jewellery that was named for the multiple gem varieties it contained (i.e. **d**iamond, **e**merald, **a**methyst, **r**uby, **e**merald, **s**apphire and **t**opaz).

Figure 2: Gem-A Midlands branch committee members and conference speakers gather for a group photo. From left to right: standing—Gwyn Green, Georgina Southam, Amanda Zhang, Ann Phillips, Louise Ludlam-Snook, Andrew Fellows, Paul Phillips, Amanda MacKinnon and Stephen Alabaster; sitting—Amanda Good, Rosamond Clayton, Maggie Campbell Pedersen, David Callaghan and Craig O'Donnell. Photo courtesy of Paul Phillips.

Rosamond Clayton (independent jewellery valuer with the London Diamond Bourse) kicked off the afternoon with her presentation titled 'Jade – The Stone of Heaven'. She gave a brief overview of the use of jade in Chinese history, in which the Qianlong period (18th century) was the high point of jade carving. She covered the quality factors that should be considered when evaluating jade, including colour, texture, translucency, distribution and intensity of colour, and overall appearance. Clayton also showed slides of jade jewellery from different periods and discussed the meaning of some of the carvings. She talked of the complexities when dealing in jade. Buying jade rough is a huge gamble because only a few small areas of a boulder's surface are typically polished for the buyer to assess the quality of the interior.

Andrew Fellows (School of Jewellery, Birmingham City University) kindly delivered a presentation titled 'Synthetic Diamonds' as a replacement for **Miranda Wells** (also from the School of Jewellery), who was scheduled to discuss 'The Changing Face of Tourmaline' but could not attend due to illness. Fellows made an impressionable entrance wearing a Sherlock Holmes outfit complete with a pipe. He then gave a brief history of synthetic diamonds, and covered the size ranges, colours and cuts of gem-quality material. He also discussed the standard tests used to identify synthetic diamonds, such as examination of inclusions, reaction to UV radiation and strain patterns seen with crossed polarising filters. Finally, he explained how advanced instrumentation can help identify synthetic diamonds, including the Raman spectrometer and various instruments developed by De Beers such as the DiamondView, PhosView and SYNTHdetect. In addition, he covered Yehuda's 'Sherlock Holmes' device (which prompted his attire), which uses mobile phone technology and short-wave UV illumination to identify natural vs. synthetic diamonds.

The final speaker of the day was **David Callaghan** (former senior director of Hancocks, London). He spoke on 'Design – A Look at the Works of René Lalique and Andrew Grima', giving a colourful and visual tribute to the enormous range of designs and objects produced by these two artists during their lifetimes. He compared the two men and their work—both of whom were great observers of nature, skilled at pencil drawing, produced hundreds of designs and stuck to their own ideas, such that their designs influenced trends. Lalique often used less conventional materials such as horn, amber and ivory imitations in combination with gold, gems and diamonds. As for Grima, in 1969 Omega offered him a budget of £1 million to design watches set in rings. These Cerini timepieces often had citrine watch glasses and featured eccentric shapes.

Figure 3: Emily Jones and Paul Haywood were the recipients of the Doug Morgan Award and the Gwyn Green Award, respectively. Photo by Paul Phillips.

The day finished with a celebration dinner, which included award presentations to Midlands-area Gem-A students who attained the highest marks in the 2018 diploma exams. The Doug Morgan Award (Gemmology Diploma) was presented to **Emily Jones** and the Gwyn Green Award (Diamond Diploma) was awarded to **Paul Haywood** (Figure 3). A further presentation was made to **Gwyn Green** for her outstanding contributions to gemmology for more than 30 years.

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DANISH GEMMOLOGICAL SOCIETY SYMPOSIUM

Over the weekend of 23–24 March 2019, the Danish Gemmological Society held its first symposium. The venue was the historic Odd Fellows Mansion in the centre of Copenhagen, and the symposium was attended by about 70 delegates, mostly from Scandinavia. All presentations were in English. The event was organised by the Society under the leadership of its president, **Niels Ruddy Hansen**, who is a diamond expert, Danish representative of CIBJO and former chair of CIBJO's Sector A. He opened the symposium with a brief history of the Danish Gemmological Society, which was founded in 1955 as a forum for gemmologists and anyone interested in gemstones.

Figure 4: The panel discussion gave participants of the Danish Gemmological Society Symposium an opportunity to present questions to the speakers and discuss issues affecting the jewellery and gem industry. Photo courtesy of Niels Ruddy Hansen.

Dr Gaetano Cavalieri, president of CIBJO (Milan, Italy), was the keynote speaker. He spoke about CIBJO's global role in the gem and jewellery industry, how CIBJO evolves and changes with the times, the importance of transparency in the jewellery supply chain, and how essential it is that the industry be seen today as ethical.

Dr Claudio Milisenda (DSEF German Gem Lab, Idar-Oberstein, Germany) reviewed the identification of coloured stone enhancements and the various methods used, both in the past and today, as well as what is acceptable in the trade. In a separate presentation he described rubies from Mozambique, including their identifying features (e.g. their UV fluorescence is much weaker than that seen in rubies from Mogok, Myanmar).

Dr Ulrich Henn (DSEF German Gem Lab) also gave two talks. The first was on the treatment of corundum, and the second was about synthetic diamonds and their manufacture, and the treatment of natural ones. He pointed out that the jewellery trade represents only a small part of the whole diamond industry, and that the larger market (i.e. for technological and industrial uses) wants and needs synthetics.

This author discussed ivory and tortoiseshell, noting the popularity of these materials and their numerous and diverse uses through the ages, the plight of the animals involved, and the laws and emotions surrounding their use today. She also mentioned the conservation status of the corals used in the jewellery trade, most of which are today covered by quotas rather than outright bans.

Hayley Henning (Greenland Ruby, New York, New York, USA; part of LNS Group, a Norwegian company) described rubies from Greenland. She stated that with an inferred age of 3 billion years this is the world's oldest ruby deposit, yet Greenland Ruby is one of the most recent mining ventures.

Carolina Santiago (Centro de Tecnologia Mineral, Rio de Janeiro, Brazil, and University of Bremen, Germany) gave a fascinating talk about the geological formation of gems and their classifications. She also described the past, present and future of Brazilian gems.

Anette Juul-Nielsen (Ministry of Mineral Resources and Labour, Nuuk, Greenland) reviewed the gems of Greenland, and covered the geology of the country and its various rock formations, which are some of the oldest in the world. Among the many gems that can be found there are corundum, diamond, tugtupite, chalcedony and garnet.

Erik Jens (FinTech, Amsterdam, The Netherlands, and DiamHolding, New York, New York, USA) spoke on a completely different subject area, one which is of importance to anyone in the trade: sustainability,

innovation and bankability. He emphasised the need for 'CSR' (corporate social responsibility) to be part of any successful company's business strategy today.

The symposium finished with a panel discussion (Figure 4) moderated by **Niels Ruddy Hansen** in which delegates had the opportunity to ask questions of the speakers. The main topics were how to ensure a successful business in the jewellery industry, and how to convince consumers—now and in the future—that jewellery and gems are relevant in today's world.

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16TH ANNUAL SINKANKAS SYMPOSIUM—PEARL

On 27 April 2019, the 16th Annual Sinkankas Symposium was held at the Gemological Institute of America (GIA) in Carlsbad, California, and was co-hosted by the Gemological Society of San Diego. The theme of this year's event was 'Pearl', and approximately 150 attendees heard presentations by eight speakers (Figure 5). There was also an impressive display of pearl and shell specimens and jewellery that was assembled for the event. As at past Sinkankas symposia, each participant received a colourful proceedings volume (reviewed on p. 570 of this issue of *The Journal*).

The symposium was introduced and moderated by **Robert Weldon** (GIA, Carlsbad), who also delivered a poem that he wrote specifically for the event. Then, **Douglas McLaurin-Moreno** (Perlas del Mar de Cortez, Guaymas, Sonora, Mexico) described the history and production of natural and cultured pearls from Baja California, Mexico. This region has been a source of pearls since the 16th century, but commercial production ended by 1940 when the fishery was exhausted due to overfishing and a major die-off event; gathering natural pearls has been banned since then. McLaurin-Moreno has been culturing pearls at his Guaymas farm since the 1990s, and currently he has approximately 300,000 rainbow-lipped *Pteria sterna* molluscs and 25 employees. The farm produces about 4,000 cultured pearls annually using sustainable methods.

Blaire Beavers (Designs by Blaire, San Diego, California) reviewed the history of pearls. Two important ancient pearling areas were the Persian Gulf (with Basra being the trading centre) and the Gulf of Mannar between

Figure 5: Speakers and organisers of the 16th Annual Sinkankas Symposium assemble with a life-size bronze sculpture of Richard T. Liddicoat Jr. From left to right: Bill Larson, Robert Weldon, Stuart Robertson, Betty Sue King, Douglas McLaurin-Moreno, Dona Dirlam, Hisano Shepherd, Jeremy Shepherd, Blaire Beavers, Donna Beers, Elisabeth Strack and Chunhui Zhou. Photo by B. M. Laurs.

India and Ceylon. Beavers also chronicled the use of pearls and shells in jewellery through the ages until the present time.

Betty Sue King (King's Ransom, Sausalito, California) described the evolution of her career as a pearl dealer, and stressed the importance of hard work and networking for success in the industry. She uses her background as a teacher to educate her buyers, as well as reach out to the public through various activities.

Elisabeth Strack (Gemmologisches Institut Hamburg, Germany) surveyed the varieties and sources of freshwater and saltwater pearls, both natural and cultured. She described the evolution of freshwater pearl culturing methods in China, including mantle growth (producing the 'fireball' variety) and in-body growth (yielding the 'Edison' type). She also noted a growing popularity of 'exotic' natural pearls during the past 15 years, such as those from gastropods (abalone and other marine snails) and from marine bivalves other than *Pinctada* and *Pteria* genera (e.g. lion's paw scallops, pen shells, etc.).

Bill Larson (Pala International, Fallbrook, California) described his experience with collecting rare and unusual natural pearls, particularly those from Baja California. He pointed out that natural pearls from *Pinctada mazatlanica* in the La Paz area are most commonly white, but may also be 'golden', 'copper' and grey-black, which are desired by collectors. He also highlighted several books that are excellent resources for gaining knowledge about pearls and their history.

Chunhui Zhou (GIA, New York, New York, USA) reviewed the history of pearl publications in *Gems & Gemology*. Various articles since the journal's inception in 1934 have documented an evolution in identification techniques from simple observations such as 'candling' to the use of endoscopy, X-ray radiography/fluorescence, X-ray computed microtomography, radiocarbon dating, DNA testing and trace-element analysis.

Stuart Robertson (Gemworld International Inc., Glenview, Illinois, USA) reviewed market and pricing trends. He indicated that 95% of the pearls on the market are cultured, so those have been the main focus of his research. They represent a vibrant sector of the gem industry, and range from affordable to very expensive, yet they constitute only about 2% of retail jewellery sales. Robertson ascribed this underperformance to the fact that the marketing of cultured pearls 'is not keeping up with the product'. He stated that the current market is less focused on strands and prefers single cultured pearls that make a statement for the designer and consumer.

Hisano Shepherd (little h jewelry, Los Angeles, California) described how she is reinventing pearl jewellery design through her various custom collections. Many of her pieces feature cultured pearls that she has sawn or carved and then set with various gems and seed pearls (see, e.g., the Gem Notes section of *The Journal*, Vol. 34, No. 8, 2015, p. 677).

The symposium ended with a special viewing of a new documentary film by Ahbra Perry and Taylor Higgins called 'Power of Pearl'. The screening was introduced by **Jeremy Shepherd** (Pearl Paradise, Los Angeles), who was one of the film's producers. Taking the viewer to pearl farms in Australia, the Philippines and Indonesia, the film documents various challenges to pearl fisheries created by environmental impacts attributed to climate change and other human-induced factors.

Brendan M. Laurs FGA

SWISS GEMMOLOGICAL SOCIETY CONFERENCE

On 28–30 April 2019 the Swiss Gemmological Society (SGS) held its 77th annual conference in Meisterschwanden on beautiful Lake Hallwil in Switzerland (Figure 6). As in the past, the conference was well attended with about 90 Society members and guests. This year the main topic was jade: its mineralogy, deposits, historical and cultural significance, quality assessment and trade. The conference was chaired by **Hans Pfister** (SGS president), **Dr Michael Krzemnicki** (Swiss Gemmological Institute SSEF director) and **Michael Hügi** (SGS director).

Richard Hughes (Lotus Gemology, Bangkok, Thailand) gave the keynote presentation on the cultural significance and use of jade in China. He described the historically important 'mutton-fat jade' (nephrite) deposits of Khotan in western China. Then he showed some impressive modern Chinese jade carvings displaying incredibly fine workmanship and artistic craftsmanship, along with the masters who designed and carved them. In a separate presentation, Hughes focused on the colour red. His lecture revealed the power of this colour and how it has connected emotions, beliefs and behaviour since early human history. The colour red continues to be important today, and ruby is the most appreciated red gem variety worldwide.

Prof. Dr Henry Hänni (GemExpert GmbH, Basel) presented an overview of the mineralogical characteristics and classification of jade (i.e. jadeite and nephrite), pointing out its highly complex mineralogical

Figure 6: Some of the speakers for the 2019 SGS conference gather at Lake Hallwil. From left to right: Michael Hügi, Richard Hughes, Prof. Dr Henry Hänni, Dr Michael Krzemnicki, Hans Pfister, Helen Molesworth, Roland Schluessel and Dr Lore Kiefert. Photo by Daniela Bellandi.

composition, as well as the different meanings of the historical term 'jade' in Asia and the Western world. In a second lecture, Prof. Hänni described a specimen of nearly colourless tourmaline from Madagascar that showed red haloes around dark grey inclusions. These inclusions were identified as columbite-tantalite with a relatively high content of uranium. The radioactivity caused the red spots in the host tourmaline via localised natural irradiation.

Helen Molesworth (Gübelin Academy, Lucerne, Switzerland) gave an extensive overview of the history of jade. She covered the ancient, millennia-old use of jade in China, through the famous burial masks of the Maya culture, to the medals of the 2008 Summer Olympic Games in China that incorporated nephrite.

To round off the jade topic, **Roland Schluessel** (Pillar & Stone International Inc., San Francisco, California, USA) presented trade aspects of Burmese jadeite, focusing on the assessment of quality and value using a complex grading system of colour, texture, transparency, etc. This system requires a lot of experience but is very helpful for carrying out appraisals of jadeite jewellery and artwork.

Two lectures were given on spinel. **Myint Myat Phyo** (University of Basel) gave an extensive overview of inclusions in spinel from Mogok, Myanmar. A large variety of mineral inclusions have been observed in Burmese spinel, many of them for the first time (see article in *The Journal*, Vol. 36, No. 5, 2018, pp. 418–435). **Dr Thomas Hainschwang** (GGTL Laboratories, Balzers, Liechtenstein) presented the results of his research on the heat treatment of blue, pink and purple spinels. He concluded that the treatment may have a positive effect on clarity but generally not on colour, thus confirming previous studies on this topic.

Dr Bertalan Lendvay (University of Zurich, Switzerland, in collaboration with SSEF) described a cutting-edge approach for identifying precious coral species. By using quasi-non-destructive sampling methods, it is now possible to carry out genetic (DNA) analysis with forensic validation on pearls and corals processed and used in jewellery. This new methodology will eventually contribute towards enforcing CITES regulations.

Dr Michael Krzemnicki reviewed current research at SSEF and highlighted some exceptional specimens tested in recent months. This included radiocarbon age

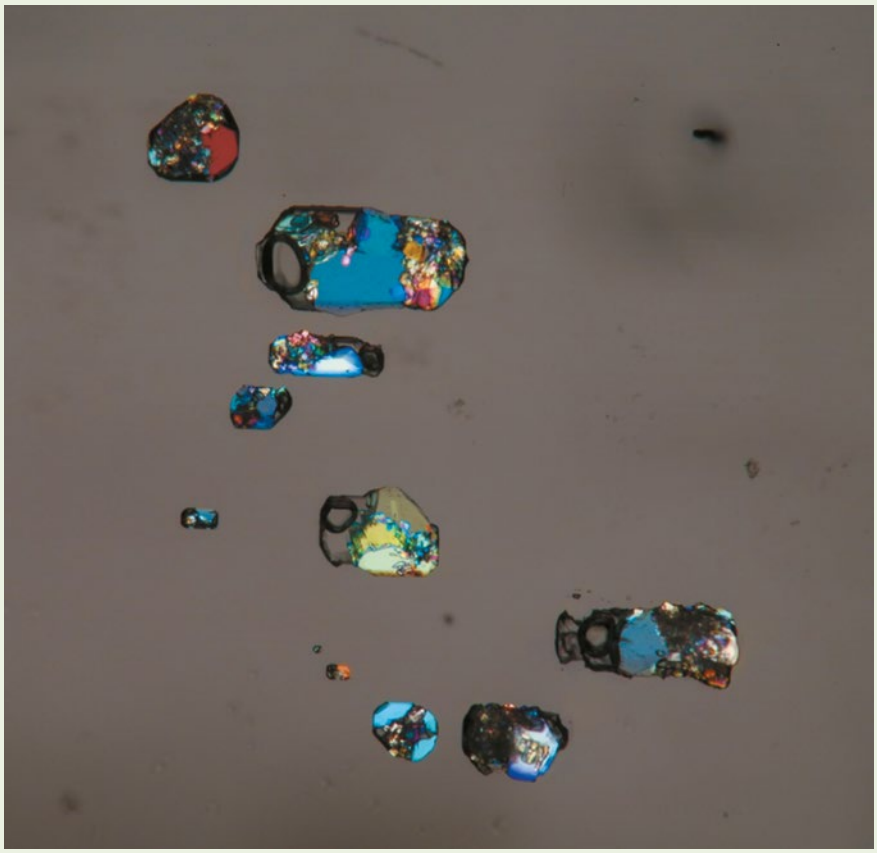

Figure 7: A group of three-phase fluid inclusions in an aquamarine from Pakistan contain mineral grains of muscovite and quartz, which show bright interference colours in cross-polarised illumination. Photomicrograph by M. Hügi; magnified 100×.

dating of the historic 'Ana Maria Pearl' and SSEF's new GemTrack service for documenting a gemstone's journey from rough to cut to jewellery.

Dr Lore Kiefert (Gübelin Gem Lab, Lucerne, Switzerland) gave an insight on sapphires heated with pressure to enhance their colour. This method is similar to traditional heating processes but involves a much shorter treatment time. As there is no diffusion from external sources, the colour improvement strongly depends on trace-element concentrations in the starting material. The presentation was the result of a joint study by 10 international laboratories, and further information can be found online at www.lmhc-gemmology.org/news.

Michael Hügi (Swiss Gemmological Society, Bern) presented a series of photomicrographs of inclusions in quartz, pegmatite gems (e.g. Figure 7) and natural glasses. He explained how to derive important information on the authenticity, formation and origin of a gem by 'squeezing out' all possible deductions when observing inclusions.

As in past years, the conference also featured presentations on the condition of the gem market. **Antoinette Starkey** (Antoinette Starkey Pierres Précieuses, Geneva, Switzerland) reported on the recent evolution of the coloured stone trade, highlighting the pros and cons of the considerable price increases for high-quality ruby, sapphire, spinel and emerald in recent years. Concerning the market situation for cut diamond, **Corina Muff** (Muff Fine Diamonds, Muri AG, Switzerland) described a shift in the demand for certain qualities: while stones of top colour and clarity (D/IF) are currently weaker in demand (and price), her company's customers increasingly ask for more commercial qualities such as F–G colour and VS–SI clarity in order to obtain a better size-to-price ratio.

In addition to hearing the presentations, the participants had plenty of time for discussions and networking. As with past SGS conferences, the main social event was a special highlight, and this year featured a boat trip on Lake Hallwil for a night of dinner and dancing.

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Gem-A Notices

Gifts to the Association

Gem-A is most grateful to the following for their generous donations that will support continued research and teaching:

John Bradshaw, for examples of faceted apatite, nephrite, aventurine quartz, jadeite, sodalite and Montana sapphire, along with a selection of rough stones including willemite, tourmaline, scapolite, halite, natrolite, fluorite and danburite.

P.J. Watson, UK, for a collection of 24 books.

Dennis Ho, Hong Kong, for a collection of 20 crystals including diopside from South African, apatite and sphene from Madagascar, and topaz and sphene from Myanmar.

Harry Thomson, for a collection of assorted loose gemstones from a student collection.

Barbara Kolator, UK, for examples of faceted labradorite, azurite 'suns', three 'thunder eggs', boulder opal slabs, 'fairy' opal and a selection of sapphire 'wash' from Queensland, Australia.

Gem-A Open Evening

16 July 2019

Tour Gem-A's headquarters and meet our tutors. https://gem-a.com/event/rsevents/event/50-gem-a-open-evening

Gem-A USA

In February 2019 Gem-A announced the establishment of Gem-A USA, an independent, non-profit entity, which will provide Gem-A's signature Gemmology and Diamond Diploma courses to the next generation of gemmologists in the United States.

Gem-A USA are delighted that Jewelry Television (JTV) will be the first to offer its Gemmology Foundation, Gemmology Diploma and Diamond Diploma courses in Knoxville, Tennessee, as an Accredited Teaching Centre (ATC).

Gem-A CEO, Alan Hart FGA DGA, commented: 'With fantastic partnerships across Asia and Europe, we believe now is the perfect time for Gem-A to expand its reach with Gem-A USA. As our affiliate in the U.S. market, both institutions share the same commitment to gemmological education, quality courses and teaching excellence that has shaped Gem-A since its inception in London in 1908. We are also thrilled to welcome JTV as the first ATC for Gem-A USA. In the coming months, we look forward to welcoming more institutions, schools and colleges who share our passion for gemmology and nurturing the next generation of gemstone and jewellery professionals.'

Gem-A USA classes will commence with JTV in September 2019.

Gem-A presents...

FREE GEMMOLOGY WEBINARS

Are you based outside of the UK? Do you find it difficult to get to Gem-A HQ in London for our workshops? For the first time, Gem-A is pleased to offer a series of one-hour webinars, designed to boost your gemmological knowledge no matter where you are in the world. Our convenient webinars are targeted at beginners who want to get a grasp of the basics, fast. Each of our webinars is entirely free – just book your place by searching 'Gem-A' on Eventbrite and join us from the comfort of your own home or office.

Understanding Gemstones

18 Jul 2019

Start your gemmology journey with this accessible beginner's guide to gemstones. This tutor-guided webinar will explain the physical characteristics of popular gems such as sapphire, emerald and ruby, while explaining their origins, history and vital care techniques. At the end of this webinar, you will have a better grasp of basic gemmology and the terminology that makes it an exciting and varied field of study.

Understanding Diamonds

10 Oct 2019

Are you passionate about diamonds but want to know more? This tutor-guided webinar will explain how diamonds are formed, what makes them special and how to assess their value and qualities using the 4Cs: cut, colour, clarity and carat weight. You will learn the basics of diamond certification and begin to discover the broader issues of diamond synthetics and simulants. At the end of the webinar, participants will be one step closer to understanding the uniqueness of diamond.

Learning Opportunities

CONFERENCES AND SEMINARS

Mineralogical Society of America Centennial Symposium
20–21 June 2019
Washington DC, USA
www.minsocam.org/MSA/Centennial/MSA_Centennial_Symposium.html
Sessions of interest: Scientific Characterization of High-Value Gemstones; Mineral Inclusions in Diamonds from the Deep Earth; Museum Mineral Collections in the Next 100 Years

Sainte-Marie-Aux-Mines 56th Mineral & Gem International Show
27–30 June 2019
Sainte-Marie-aux-Mines, France
www.sainte-marie-mineral.com
Note: Includes a seminar programme

19th International Meeting on Crystal Chemistry, X-ray Diffraction and Spectroscopy of Minerals
2–5 July 2019
Apatity, Russia
www.ksc.ru/en/xrd2019
Note: Will include several presentations on diamond

Goldsmiths' Company Jewellery Materials Congress 2019
8–9 July 2019
London
www.assayofficelondon.co.uk/events/the-goldsmiths-company-jewellery-materials-congress

2019 Antique Jewelry & Art Conference
26–27 July 2019
Newark, New Jersey, USA
www.jewelrycamp.org
Note: Includes a seminar programme

Asia Oceania Geosciences Society 16th Annual Meeting
28 July–2 August 2019
Singapore
www.asiaoceania.org/aogs2019/public.asp?page=home.htm
Session of interest: Tectonics, Minerals, Metals and Gems Resources of Asia Oceania Region

52nd NAJA Mid-Year ACE© It Conference
3–6 August 2019
Dallas, Texas, USA
www.najaappraisers.com/html/conferences.html

Northwest Jewelry Conference
9–11 August 2019
Seattle, Washington, USA
http://northwestjewelryconference.com

Dallas Mineral Collecting Symposium
22–25 August 2019
Dallas, Texas, USA
www.dallassymposium.org

15th Biennial Meeting of the Society for Geology Applied to Mineral Deposits
27–30 August 2019
Glasgow, Scotland
www.sga2019glasgow.com
Session of interest: Supergenes, Gems and Non-Metallic Ores

36th International Gemmological Conference
27–30 August 2019
Nantes, France
www.igc-gemmology.org

Japan Jewellery Fair 2019
28–30 August 2019
Tokyo, Japan
www.japanjewelleryfair.com/en
Note: Includes a seminar programme

42nd Joint Mineralogical Societies of Australasia Seminar
31 August–1 September 2019
Perth, Western Australia
www.minsocwa.org.au/gallery.html

International Jewellery London (IJL)
1–3 September 2019
London
www.jewellerylondon.com
Note: Includes a seminar programme

10th International Congress on the Application of Raman Spectroscopy in Art and Archaeology (RAA2019)
3–7 September 2019
Potsdam, Germany
www.raa2019.de

30th International Conference on Diamond and Carbon Materials
8–12 September 2019
Seville, Spain
www.elsevier.com/events/conferences/international-conference-on-diamond-and-carbon-materials

XVIIIème Rendez-Vous Gemmologiques de Paris
9 September 2019
Paris, France
www.afgems-paris.com/rdv-gemmologique

9th European Conference on Mineralogy and Spectroscopy (ECMS 2019)
11–14 September 2019
Prague, Czech Republic
http://ecms2019.eu
Workshop of interest: Gemstone Deposits

Denver Gem & Mineral Show
13–15 September 2019
Denver, Colorado, USA
www.denvermineralshow.com
Note: Includes a seminar programme

Geological Society of America (GSA) Annual Meeting
22–25 September 2019
Phoenix, Arizona, USA
www.geosociety.org/GSA/events/GSA2019
Session of interest: Gemological Research in the Twenty-First Century—Characterization, Exploration, and Geological Significance of Diamonds and Other Gem Minerals

14th International Congress for Applied Mineralogy (ICAM 2019)
23–27 September 2019
Belgorod, Russia
www.geo.komisc.ru/icam2019/en
Themes of interest: Precious Stones; Cultural Heritage

International Colored Gemstone Association (ICA) Congress
12–15 October 2019
Bangkok, Thailand
www.gemstone.org/events/2019-congress

Chicago Responsible Jewelry Conference
25–26 October 2019
Chicago, Illinois, USA
www.chiresponsiblejewelryconference.com

Munich Show/Mineralientage München
25–27 October 2019
Munich, Germany
https://munichshow.de/?lang=en
Note: Includes a seminar programme

Gem-A Conference 2019
2–3 November 2019
London
https://gem-a.com/event/conference-2019

2019 CIBJO Congress
18–20 November 2019
Manama, Bahrain
www.cibjo.org/congress2019

MAESA 2019: Earth Sciences and Sustainable Development
29 November–1 December 2019
Yangon, Myanmar
www.maesa.org
Sessions of interest: Mineralogy and Origin of Gem Deposits; Geographic Typing of Gemstones and Advances in Instrumentation

Jewelry History Series
4–8 January 2020
Miami, Florida, USA
www.originalmiamibeachantiqueshow.com/show/special-events

52nd NAJA ACE© It Annual Winter Conference
2–3 February 2020
Tucson, Arizona, USA
www.najaappraisers.com/html/conferences.html

AGTA Gemfair Tucson
4–9 February 2020
Tucson, Arizona, USA
https://agta.org/seminars
Note: Includes a seminar programme

Tucson Gem and Mineral Show
13–16 February 2020
Tucson, Arizona, USA
www.tgms.org/show
Note: Includes a seminar programme

Inhorgenta Munich
14–17 February 2020
Munich, Germany
www.inhorgenta.com/index.html
Note: Includes a seminar programme

47th Rochester Mineralogical Symposium
23–26 April 2020
Rochester, New York, USA
www.rasny.org/minsymp

American Gem Society Conclave
27–29 April 2020
Denver, Colorado, USA
www.americangemsociety.org/mpage/conclave2020-home

Diamonds – Source to Use 2020
9–11 June 2020
Johannesburg, South Africa
www.saimm.co.za/saimm-events/upcoming-events/diamonds-source-to-use-2020

OTHER EDUCATIONAL OPPORTUNITIES

Gem-A Workshops and Courses
Gem-A, London
https://gem-a.com/education

Lectures with Gem-A's Midlands Branch
Fellows Auctioneers, Augusta House, Birmingham
Email louiseludlam@hotmail.com

- Miranda Wells—The Changing Face of Tourmaline
  27 September
- Shirley Mitchell—Valuations
  25 October
- Richard Maymon—Pearls
  29 November

Lectures with The Society of Jewellery Historians
Society of Antiquaries of London,
Burlington House, London
www.societyofjewelleryhistorians.ac.uk/current_lectures

- Beth Wees—Jewelry for America
  25 June
- Maria MacLennan—Forensic Jewellery
  24 September
- Calling all Potential Lecturers! [three speakers TBA]
  22 October
- Rachel Church—Brooches, Badges and Pins at the Victoria and Albert Museum
  26 November
- Thomas Holman—A Box Full of Buttons: The Life and Work of Frederick James Partridge (1877–1945)
  28 January 2020
- Stephen Whittaker—TBA
  25 February 2020
- Carol Michaelson—Chinese Jade Jewellery and Ornaments from the Neolithic to the Present
  24 March 2020
- Ute Decker—TBA
  26 May 2020
- Kirsten Kennedy—TBA
  23 June 2020

New Media

Burma Gems/Sri Lanka Gems

By Vladyslav Y. Yavorskyy, 2018. Yavorskyy Co. Ltd, New York, New York, USA, www.gemstonesbook.com, 232 pages (Burma) and 236 pages (Sri Lanka), illus., ISBN 978-0692919682 (Burma) and ISBN 978-0692121412 (Sri Lanka). USD188.00 hardcover with slipcase for the two-volume set.

Yavorskyy's two companion volumes—*Burma Gems* and *Sri Lanka Gems*—are photographic adventures that engage anyone who wants a visual treat. They can make you feel as if you are on location with the author.

Burma Gems

Early in this book (p. 5) the author states, 'the selection of topics and ratio of gemstones covered in this book is strictly subjective and defined by the author's personal taste'. Every following page is filled with colourful photographs taken by the author between 1996 and 2018; in only one instance (p. 11) is the page not in full colour. He further states:

> There is no coloured gemstone more highly valued than ruby nor is there any land in any civilization that produces more beautiful rubies than Burma. Rubies throughout history were mined in Mogok. These deposits together with jade, blue sapphire, spinel, chrysoberyl, zircon, amber, moonstone and other coloured stones make Burma the most prominent source of gems ever to have existed. But to me the more precious gems of Burma are its people, nature, culture, history, and its mysterious spirit which inspired me to create this book.

And from here to the end of the book, Yavorskyy has produced page after colourful page filled with either gemstones or a combination of stones with other 'precious gems' alluded to above—most often the Burmese people. Various stones are highlighted using dramatic images accompanied by labels such as 'Red Spinel', 'Red Ruby', 'Blue Sapphire', or 'Not All Sapphires are Blue'. Often the same gems are shown in multiple photos from different angles. Sidebars provide simple explanations where Yavorskyy thought necessary, but they are kept brief so as not to distract from the photographic beauty. For many two-page spreads, no words are necessary at all.

The reader soon realises that this book, like *Sri Lanka Gems* covered below, is a labour of love. It documents Yavorskyy's extraordinary travels into what he calls 'the land of adventure'. Towards the end of the book, in a few brief paragraphs on pp. 229–230, Yavorskyy gives more background about his interests in 'My Story': '… this country has always had a special place in my heart, and will always remain my sacred haven, my precious home away from home.'

Having been to Burma myself numerous times, this reviewer can confirm that Yavorskyy has captured what many of us know who have been there: Burma is a unique place for anyone who loves life, history, beauty and romance, and has a passion for gems.

Sri Lanka Gems

Yavorskyy's *Sri Lanka Gems* is an extraordinary photographic journey of this island paradise which includes history, gem-mining areas, wildlife, and various topics pertaining to other aspects of Sri Lankan life, cities and people. While there are no written chapters as such, near the front of the book are brief contributions titled 'About the Book' by Rachel J. Beard and 'Sri Lanka: Island of Gems' by Jack Ogden (covering Sri Lanka's history). Several two-page spreads consist of illustrations taken from Robert Knox's *An Historical Relation of the Island Ceylon in the East Indies* (1681), which is probably the first book written in English on Ceylon.

Sri Lanka Gems focuses on people and beautiful places, both in the wild and in mining areas and towns. Interspersed throughout are many full-page or double-page photos of dazzling gemstones from historic jewellery pieces, private collections and dealer friends. Actually, every page seems to have a few small inserts of fine gems—mostly sapphires of all colours, but also spinels, chrysoberyls, garnets and various other local gems. Most of the stones in the book have been in

Yavorskyy's hands over his years in the gem trade.

I find this quotation from p. 60 emblematic of this fine book:

> Despite the relatively small scale of the island itself, Sri Lanka boasts a fabulously diverse landscape and wildlife population. From coast to coast, the undulating topography creates an array of microclimates and, consequently, a host of biodiversity and animal species not found anywhere else. Rich in rivers, waterfalls, mountain ranges, plains, and pristine coastlines, the vistas of the Sri Lankan landscape are truly unique.

Both *Burma Gems* and *Sri Lanka Gems* are books that can be appreciated by novices, advanced gem collectors and the general public. They are written to accompany Yavorskyy's other three books: *Terra Spinel*, *Terra Garnet* and *Gemstones: Terra Connoisseur*. Anyone who has been to Burma or Sri Lanka, desires to go there or just wants to learn more about them should consider these books for their library.

Bill Larson FGA
Pala International
Fallbrook, California, USA

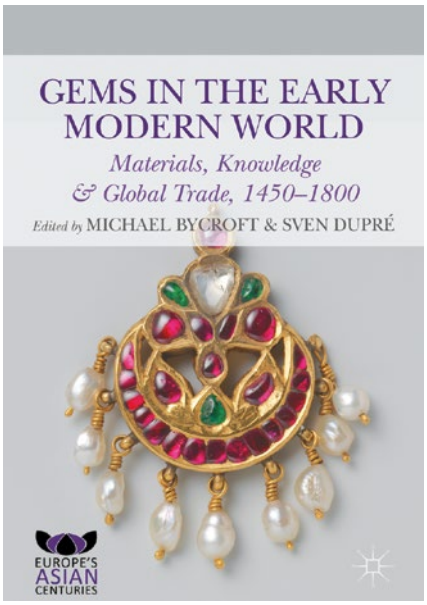

Gems in the Early Modern World: Materials, Knowledge and Global Trade, 1450–1800

Ed. by Michael Bycroft and Sven Dupré, 2019. Palgrave Macmillan, London, www.palgrave.com/us/book/9783319963785, 359 pages, illus., ISBN 978-3319963785 (hardcover) or 978-3319963792 (eBook). USD119.99 hardcover or USD89.00 eBook.

Recent years have shown an upsurge in research into the origins, trade and use of gemstones in the past, with the results published in a wide range of journals, from gemmological to historical and archaeological. The present volume reflects this interest by presenting 11 essays, plus an introductory chapter by the editors, which are grouped under three headings: 'Motion', 'Value' and 'Skills'. The authors are all specialists in their fields, and the net result is a volume which sheds a broad light on gem history and summarises the state of present knowledge.

The introductory chapter by the editors sets the scene by discussing, briefly, how studies of the interrelationship among materials, technology, economics and art can shed light on such subjects as the early exploitation of Brazilian diamonds and Colombian emeralds. This introductory chapter is an erudite contribution in its own right.

The first chapter, by Hugo Miguel Crespo on 'The Plundering of the Ceylonese Royal Treasury, 1551–1553: Its Character, Cost, and Dispersal', leaps straight in to show how the global movement of gems was by no means always a consensual process. One only has to wander around the museums in Colombo, Kandy and elsewhere in Sri Lanka to see how very little old jewellery survives in what was for more than two millennia the 'Island of Gems'. An inventory of the Ceylonese royal treasury drawn up by the Portuguese in the 1550s listed vast amounts of jewels as well as gold and silver coinage and objects, most of which were put up for sale. Crespo shows how a few equivalent pieces that survive in European museums provide insight into the types of gems and jewellery mentioned in the inventory.

Next, Christina Anderson focuses on one Antwerp family—the Hellemans—which made several gem-trading expeditions via the overland route to India in the years between around 1550 and 1610. The information was gleaned from archives in Antwerp and Venice. Anderson's chapter is primarily concerned with just one generation of the family, and how they spread out to important trading centres such as Venice, Seville (from which they could also trade with the New World) and Constantinople. As the documents show, the gems they dealt with included not only diamonds and pearls but also emeralds from South America (which were

already being traded in India by that time) and opals. The author does not mention if the documents note the origin of the opals, but Mexico is a possibility.

Robert Boyle's 1672 *Essay About the Origins and Virtues of Gems* is well known to gemmologists who have an interest in history. The third chapter of *Gems in the Early Modern World* takes a fascinating new look at this work in 'The Impact of European Trade with Southeast Asia on the Mineralogical Studies of Robert Boyle', by Claire Sabel. Boyle lived at a time when science was supplanting superstition in the consideration of gems, and when the global gem trade (and the London diamond trade in particular) was in full spate. Boyle's enquiring mind sought factual information about gems from Southeast Asia. As the author notes, Boyle wanted to show how a gem's composition and formation might explain its physical characteristics.

The next chapter crosses the world to draw on textual and pictorial sources to consider coral in China during the Ming dynasty. In 'Branches and Bones: The Transformative Matter of Coral in Ming Dynasty China', Anna Grasskamp explains how this gem material was an important export from the Mediterranean region to China, a route that went in the opposite direction to most of the trade in gem materials. This long predated direct European sea trade with the East and had established coral as a rare material with Buddhist connotations—and also reinforced the monopoly of the Ming emperor in theory if not in practice. The author suggests that coral was seen as a 'transformative material' between sea and land. Add in the tree-like (and perhaps bone-like) appearance of branched coral and its blood-like colour, and symbolic importance is inevitable. In Renaissance Europe coral could relate to the resurrection of Christ; in Buddhist China coral could similarly represent transformation. This essay, to the present reviewer anyway, covers the least familiar subject in the book, and could well be expanded into a whole book by itself. The popularity of coral in Tibetan Buddhist ornaments (about as far away from the sea as you can get) has always intrigued, but this reviewer's knowledge of coral in China has been limited to Berthold Laufer's succinct discussion in his 1919 *Sino-Iranica; Chinese Contributions to the History of Civilization in Ancient Iran, with Special Reference to the History of Cultivated Plants and Products* (incidentally not mentioned in Grasskamp's detailed bibliography, which probably means that this century-old work is outdated).

The next chapter takes us back to Europe, in which Michael Bycroft looks at 'Boethius de Boodt and the Emergence of the Oriental/Occidental Distinction in European Mineralogy'. The belief that gems from the East were better than those from nearer lands can be traced back to classical writers and continued through medieval times (e.g. the heat of the sun in the Orient was more favourable to gem growth). As geographical knowledge grew, so did knowledge of gem sources, but still Oriental gems were deemed the best. It would have been useful had the author pointed out more clearly that in many cases the Oriental/Occidental distinction might have derived from gems being long identified by colour rather than species. 'Oriental amethyst' was purple sapphire and far harder, of course, than the purple variety of quartz we know as amethyst; similarly, 'Oriental topaz' was yellow sapphire and not the softer yellow topaz (or citrine); and so on. These terms were used in the trade into the 20th century.

Marcia Pointon follows this with the best-known 'Oriental' gem in the 17th century: diamond. In 'Good and Bad Diamonds in Seventeenth-Century Europe' Pointon mainly focuses on what were termed *laskes*—Indian-cut diamonds, typically thin cleavage slices—which were considered too unattractive for use in Europe. Although an object of trade, they were almost invariably seen as material for recutting. A detailed discussion of this often-forgotten style of diamond is useful, but there seems a lack of understanding of diamonds here. For example, Pointon describes a cleaved diamond as 'cut across the natural grain of the stone', and also she is seemingly unaware that the 'violet' diamond illustrated by Tavernier was what later became the French Blue and then the Hope. It was never a 'rose cut' as she describes. This reviewer also questions whether gems such as the Koh-i-Noor should be, or ever have been, described as *laskes*. At the time the Koh-i-Noor arrived in Britain it was described as a 'rose'.

The medicinal use of gems in ancient times and through to the Renaissance is well known, but it is interesting to see the extent to which such traditions survived after that. In 'The Repudiation and Persistence of Lapidary Medicine in Eighteenth-Century Dutch Medicine and Pharmacy', Marieke Hendriksen argues that the use of gem materials in medicine might have lingered because of conservative guilds and possibly even wealthy patrons. Belief in the medicinal properties of some gems survives to some extent to this day, but was largely rejected due to a wider understanding of chemistry from the early 18th century onwards. Perhaps the author could have pointed out that behind some of the apparent mumbo-jumbo there might be some truth. For example, the Roman author Pliny said the copper mineral and gem material malachite had medicinal properties, and it was used in

medieval times to fight infection. It works. Soldiers, for example in the jungles of Vietnam, have been advised to put copper compounds in their socks to prevent fungal infections. There are many more examples.

A contribution to our understanding of the history of gem cutting comes in Marjolijn Bol's *Polito et Claro*: The Art and Knowledge of Polishing, 1100–1500'. Bol discusses in detail the various texts describing gem cutting, in particular the *Doctrina Poliendi* of ca. 1300. However, it is not clear what the author adds to Geoffroy Grassin's original publication of this text, and, if anything, might confuse the issue. For example, Bol seems to imply that the engraving of diamond is mentioned, and that what this reviewer takes to be a description of the polishing of the engraved designs (i.e. the hollows) on gems is instead a reference to rotary polishing the gems' flat surfaces. What the author calls 'a landmark treatise' on gem cutting—an anonymous work of which an early 16th-century copy by Peder Månsson survives—illustrates a crank-operated rotary gem-polishing machine. As Bol points out, the date of the original manuscript is unknown, and thus the date of the equipment shown is uncertain. Her suggestion of late 15th to early 16th century seems correct. Certainly, having the flywheel mounted with a vertical axis seems to be an advance on the gem-polishing machines in the 15th-century drawings by (probably) Henri Arnaut de Zwolle and in the *Codex Latinus Monacensis 197*. (*Editor's note*: See the article by K. Schmetzer on pp. 544–550 of this issue for more on this subject.)

Gems in the Mughal world are considered by Taylor Viens in 'Mughal Lapidaries and the Inherited Modes of Production'. Viens starts by discussing an (unfortunately undated) gem-set and enamelled falcon from the collections of the Qatar Islamic Museum. The essay then looks at the historical background to the Mughal artistic tradition, the nature of the workshops in which such objects were made and patronage. The author notes that the authenticity of the falcon has been doubted, although not formally in a publication. Perhaps the author's seemingly strange choice of this undated object as the point of departure for his essay was because it allowed him to air his brief but astute questioning of certain aspects of the falcon in a long endnote. This interesting essay is let down slightly by a seeming lack of familiarity with gems and lapidary work. For example, the statement that rubies and sapphires can only be cut with other rubies or sapphires (and diamond) ignores emery, the mainstay of Indian lapidary work. Also, he says 'as the Mohs scale of mineral hardness was not developed until 1812, it is not possible that the Mughals were operating under an identical perception of mineral hardness'. Since the Mohs scale is purely relative, the Indian lapidary would have had an identical understanding of hardness, as did the Medieval Islamic gem cutters.

We come back to Europe with Karin Hofmeester's 'Knowledge, Technique, and Taste in Transit: Diamond Polishing in Europe, 1500–1800'. Hofmeester describes the migration of diamond cutting centres—from Venice to Flanders—first in Bruges and later Antwerp. By the mid-1580s Antwerp had 31 diamond cutters and 21 diamond polishers; some 60 years later there were 160 polishers. Then cutting moved to Amsterdam. Against this background the essay traces the development of diamond cuts: point cuts, tables, roses and eventually brilliants. The author then considers the ways in which skills and ideas of new cuts were transferred—via books as well as apprenticeships—and also how diamond merchants obtained their knowledge about where best to buy, how to judge quality and, of course, where best to sell. The popularity of books on gems, including information on diamonds and diamond cutting, starting with Cellini's 1569 *Trattato*, might well have been as much for the personal standing of the author (and his business) as for the education of the public.

Wherever there are gems, there are imitations of them. This has been true throughout history. In 'Gems and Counterfeited Gems in Early Modern Antwerp: From Workshops to Collections', Marlise Rijks starts with a 16th-century manuscript in the Museum Plantin Moretus in Antwerp. It includes recipes for making counterfeit pearls and instructions for how to detect fake gems. Rijks then uses a variety of sources, including archives and paintings, to look at gems in society, from the trade and guilds to patrons. Considering gems in society brings the author back to the final section of her essay: counterfeit gems and recipes for them. Rijks notes the problem of inventories that seldom explicitly mention fake gems but discusses the few cases where they do. There is also discussion of who was the target audience for such recipes, along with the suggestion that they might have been for the educated public, as well as those in the trade and those who actually wanted to learn the 'profitable arts'. Wider public accessibility of such information, of course, came in the wake of printing.

Bearing in mind the number of essays and the obvious size constraints of a single volume, it is perhaps unfair to point out where additional essays might have provided a more rounded picture of the subject. Nevertheless, one important aspect that is absent is the gemmological side: the research carried out on gems set in surviving medieval and Renaissance objects over the last few decades. Overall the volume provides a useful contribution to the subject

and, following on from 2017's *Gemstones in the First Millennium AD: Mines, Trade, Workshops and Symbolism* (Römisch-Germanisches Zentralmuseum; reviewed in *The Journal*, Vol. 35, No. 7, 2017, pp. 680–681), shows a growing interest in gem and lapidary history. Input from a gemmologist in the editing stage would have made this a more authoritative book, and it seems fair to suggest that more gem and jewellery historians could benefit from a working knowledge of gemmology.

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London

The Practical Guide to Jewelry Appraising, 4th edn.

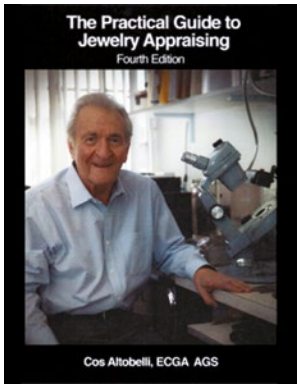

By Cos Altobelli, 2018. Self-published, http://altobelli.com/order, 285 pages, illus., ISBN 978-1513636603. USD99.99 (AGS members) or US$129.99 (non-members) softcover.

True to its title, the fourth edition of *The Practical Guide to Jewelry Appraising* is a useful resource to those beginning their career as fine jewellery appraisers. This book also offers, for gemmologists considering the profession, a glimpse into the ups and downs of appraisal practice. As in past editions, this version covers a wide variety of jewellery appraisal issues, providing tips and guidance based largely on Altobelli's decades of experience in the field. The author delivers insight and information through case histories and real-life experiences, helping to drive the concepts home. Sample templates and forms included in the final chapter are invaluable tools for the new appraiser.

New to the fourth edition are sub-chapters on color-vision testing and chipped diamonds, as well as suggested text to assist the appraiser in dealing with the difficulty of detecting synthetic and HPHT-treated diamonds. The profession of personal property appraisal has developed and changed dramatically over the past 35 years, due in no small part to pioneers and visionaries such as Altobelli. However, some of the information provided in this book is outdated and not in keeping with current personal property appraisal standards. The author states that personal property appraisers have been given guidelines in the form of USPAP (Uniform Standards of Professional Appraisal Practice) but are not governed by or held to these standards. Most professional jewellery appraisal organisations consider USPAP the 'standard of care' in the profession and require adherence by their members.

Throughout the text the author reiterates the necessity for appraisers to complete formal appraisal education and to be cognisant of their level of competency when accepting and completing an appraisal assignment. Altobelli also stresses the importance of continuing education for practising appraisers. *The Practical Guide to Jewelry Appraising* is written from the perspective of an American Gem Society Emeritus Certified Gemologist Appraiser (AGS ECGA) and an AGS retail jewellery store owner, and is therefore most appropriate for those working in the USA.

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Rock Creek Sapphires: A Kaleidoscope of Color

By Jeffrey R. Hapeman, 2019. Self-published, www.earthstreasury.com/product/rock-creek-sapphires-a-kaleidoscope-of-color, 84 pages, illus., ISBN 978-0464752288. USD79.00 hardcover.

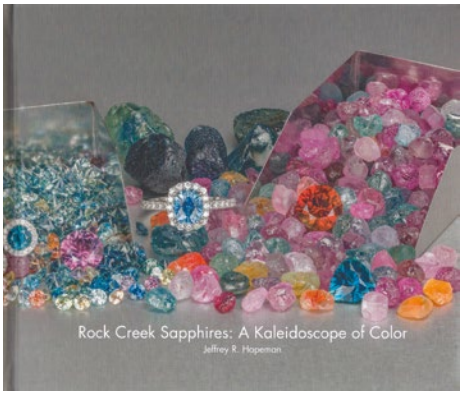

Rock Creek Sapphires is a relatively small book, at just 84 pages. As the name suggests, it focuses on sapphires originating from just one location: Rock Creek, Montana, USA. This deposit was discovered

in the early 1890s, and between 1930 and 1936 the sapphires were sold mostly to the Swiss watch trade for use as jewel bearings. Before heat treatment, more than 90% of the rough material typically yields light- to medium-toned greyish blue to greyish green cut gems that are less than 4 mm in diameter.

As the name also suggests, *Rock Creek Sapphire: A Kaleidoscope of Color* is primarily a picture book. What makes it interesting and of value to gemmologists is that it showcases some of the finest heat-treated and untreated gems that have been produced from this deposit. Although comprising only 10% of the current production, fancy-colour sapphires occur across the entire spectrum of sapphire colours. The author, a skilled lapidary as well as an excellent photographer, treats the reader to a beautiful panorama of these paradigm gems.

Of particular use to gemmologists is a small but useful section of photomicrographs illustrating inclusions that are typical of untreated sapphires from this deposit. Photomicrographs showing inclusions in treated stones also would have been useful. There is an image of one characteristic inclusion (p. 33) that resembles a bird's-eye view of a hexagonal spider's web. Similar inclusions occur in the majority of heat-treated gems from this locale.

Other sections illustrate modern mining and sorting methods practised at the Rock Creek deposit, along with images of typical mine-run production from the current operations.

Well written and intelligently organised, this book provides an excellent addition to both the jeweller's and gemmologist's library. It is also an excellent reference for gem collectors.

Richard W. Wise
Author of *Secrets of the Gem Trade, The Connoisseur's Guide to Precious Gemstones* and *The French Blue*
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Sixteenth Annual Sinkankas Symposium—Pearl

Ed. by Stuart Overlin, 2019. (No publisher listed)
108 pages, illus., ISBN 978-0991532049.
Print on demand; price available upon request
(promotional@dpidirect.com).

The 16th Annual Sinkankas Symposium, focusing on natural and cultured pearls, was held in April 2019 at the Gemological Institute of America in Carlsbad, California, and was co-hosted by the Gemological Society of San Diego (for a report on this event, see the Conferences section of this issue of *The Journal*, pp. 557–558). Attendees received an attractive proceedings volume that contains contributions from each of the speakers and also some supplementary information on natural and cultured pearls.

The volume begins with a listing of the symposium programme, speaker biographies and abstracts of the presentations. These are followed by speaker contributions covering a wide range of topics: a historical overview of pearls from Mexico's Sea of Cortez and information on cultured pearls from the author's farm in Guaymas (Douglas McLaurin-Moreno), a brief history of pearls and the use of natural and cultured pearls in jewellery (Blaire Beavers), an autobiographical journey of a pearl dealer (Betty Sue King), a review of the varieties and sources of freshwater and saltwater natural/cultured pearls (Elisabeth Strack), information on collecting natural pearls from Mexico's Baja California and elsewhere (Bill Larson), a review of pearl publications in *Gems & Gemology* (Chunhui Zhou), an overview of cultured pearls in the gem/jewellery market and pricing trends (Stuart Robertson), and reinventing pearl jewellery design (Hisano Shepherd). The volume closes with sections on pearl history and a bibliography that are reprinted from the 2013 book titled *Splendour & Science of Pearls* by Dona Dirlam and Robert Weldon.

The book features many beautiful photos of natural and cultured pearls, jewellery and interesting historical subject matter. It is produced on heavy paper stock and

the quality of the printing is excellent. A limited number of advertisements are placed on the inside covers and opening/closing pages so they do not interrupt the flow of the articles. This reviewer would have appreciated having the sizes of the natural/cultured pearls indicated in several of the photo captions, but this is a minor quibble. Gemmologists, enthusiasts, collectors and anyone interested in natural and cultured pearls will benefit from having this attractive and informative book in their library.

Brendan M. Laurs FGA

Other Book Titles

COLOURED STONES

Banded Agates, a Genetic Approach
By Marco Campos Venuti, 2018. Edizioni AccorpaMente, Italy, 200 pages, ISBN 978-8894038040. USD35.00 softcover.

GEM LOCALITIES

Derbyshire Blue John, 3rd edn.
By Trevor Ford, 2019. East Midlands Geological Society, Nottingham, 80 pages, ISBN 978-0951971796. GBP6.50 softcover.

JEWELLERY HISTORY

The Steppe and the Sea: Pearls in the Mongol Empire
By Thomas T. Allsen, 2019. University of Pennsylvania Press, Philadelphia, Pennsylvania, USA, 240 pages, ISBN 978-0812251173. USD45.00 hardcover.

JEWELLERY AND *OBJETS D'ART*

Anna Hu: Symphony of Jewels, Opus II
By Janet Zapata with Sarah Davis, 2019. Vendome Press, New York, New York, USA, 192 pages, ISBN 978-0865653412. USD75.00 hardcover.

The Art of the Jeweler: Excellence and Craftmanship
By Guillaume Glorieux, 2019. Gallimard Publishing House, Paris, France, 76 pages, ISBN 978-2072822605. EUR14.50 softcover.

Carnet by Michelle Ong
By Vivienne Becker and Joel Rosenthal, 2019. Thames & Hudson, New York, New York, USA, 272 pages, ISBN 978-0500021637. USD95.00 hardcover.

Farah Khan: A Bejewelled Life
Ed. by Paola De Luca, 2019. Rizzoli, New York, New York, USA, 304 pages, ISBN 978-8891818904. USD125.00 hardcover.

Gioielli del Potere: Corene e Tiare (Jewellery of Power: Crowns and Tiaras)
Ed. by Alba Cappellieri, 2018. Silvana Editoriale, Milan, Italy, 96 pages, ISBN 978-8836641529 (in English and Italian). EUR18.00 softcover.

Jean Schlumberger: The Rachel Lambert Mellon Collection from the Virginia Museum of Fine Arts
By Kristie Couser, 2018. Virginia Museum of Fine Arts, Richmond, Virginia, USA, 120 pages, ISBN 978-0300238747. USD30.00 hardcover.

Jewellery Illustration and Design, Vol. 1
By Manuella Brambatti and Vinci Cosimo, 2018. Promopress, Barcelona, Spain, 160 pages, ISBN 978-8416851577. EUR35.00 softcover.

Jewels & Jewelry
By Clare Phillips, 2019. Thames & Hudson, New York, New York, USA, 224 pages, ISBN 978-0500480342. USD40.00 softcover.

Looking at Jewelry: A Guide to Terms, Styles, and Techniques
By Susanne Gänsicke and Yvonne J. Markowitz, 2019. Getty Publications, Los Angeles, California, USA, 132 pages, ISBN 978-1606065990. USD19.95 softcover.

Medieval Art in Motion: The Inventory and Gift Giving of Queen Clémence de Hongrie
By Mariah Proctor-Tiffany, 2019. Penn State University Press, University Park, Pennsylvania, USA, 232 pages, ISBN 978-0271081120. USD89.95 hardcover or USD39.99 Kindle edn.

Literature of Interest

COLOURED STONES

The 9th Annual National Opal Symposium. R. Benjamin-Thomas, *InColor*, No. 41, 2019, 18–23, www.gemstone.org/incolor/41.*

The art & science of reading rough jadeite jade: 2 parts science, 1 part art, and a lot of luck. R.S.K. Lee, *Journal of the Gemmological Association of Hong Kong*, **39**, 2018, 48–59, www.gahk.org/journal/2018/a12.pdf.*

Behind the silk screen: A surprise in a star ruby. E.B. Hughes, *Journal of the Gemmological Association of Hong Kong*, **39**, 2018, 37–38, www.gahk.org/journal/2018/a10.pdf.*

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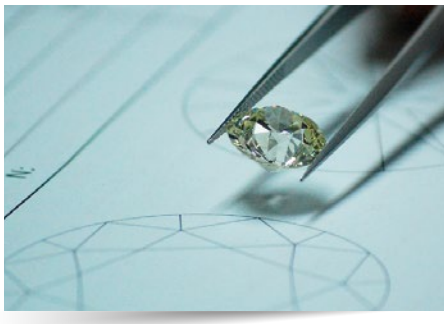

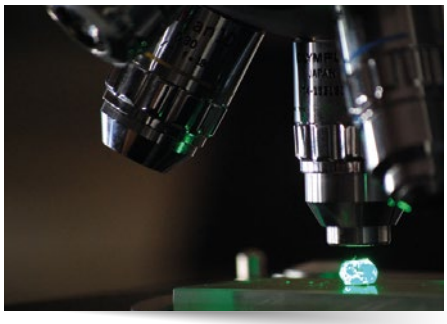

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Cover photo: *Thai rubies are rarely mined today, although the stones continue to circulate in the market. An article on pp. 634–645 of this issue provides a detailed view of the inclusions in these rubies. The heat-treated stones shown here include loose rubies weighing 3–24 ct (courtesy of a private collector) and diamond rings set with 3.58, 4.43 and 3.26 ct centre stones (left ring courtesy of Thai Lapidary International Co. Ltd, Bangkok, Thailand, and the center and right rings are from Prima Gems, Bangkok). Photo by Chanchai Kamemakanon.*

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The Editor-in-Chief is glad to consider original articles, news items, conference/excursion reports, announcements and calendar entries on subjects of gemmological interest for publication in *The Journal of Gemmology*. A guide to the various sections and the preparation of manuscripts is given at https://gem-a.com/index.php/news-publications/journal-of-gemmology/submissions, or contact the Editor-in-Chief.

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Editorial

THE JOURNAL JOINS THE PRESTIGIOUS SCIE DATABASE

I am very pleased to announce that *The Journal of Gemmology* has been accepted for coverage in the Science Citation Index Expanded (SCIE) database, in the Web of Science Core Collection. This indicator of academic excellence for scientific journals is a landmark accomplishment for *The Journal*, which passed a rigorous selection process involving numerous evaluative criteria to ensure that it meets high standards of academic quality.

The SCIE is a comprehensive database covering more than 9,200 scientific journals across 178 disciplines. Along with *The Journal*'s coverage in the SCIE, it is also included in Clarivate Analytics' *Journal Citation Reports* and its *Current Contents—Physical, Chemical and Earth Sciences*.

Importantly, coverage in the SCIE will allow *The Journal* to obtain an impact factor (a measure of citation activity). Although *The Journal* was previously included in the Web of Science through its coverage in the Emerging Sources Citation Index, that database does not include an impact factor. Since authors from some academic institutions can only receive 'credit' for articles published in journals with an impact factor, *The Journal*'s coverage in the SCIE will allow it to attract even more high-quality research from around the world.

A journal's impact factor is calculated by counting the number of citations to the articles it published in the previous two years, and dividing this number by the total citable articles that it published during those two years. *The Journal*'s initial impact factor will thus be determined by adding up the number of citations received during 2019 for articles published in 2017 and 2018, and dividing this by the total number of articles published in 2017 and 2018. Clarivate Analytics will perform the calculations in early 2020, and the impact factor will be published in the *Journal Citation Reports* (and posted on *The Journal*'s website) in approximately June 2020.

Specialised publications such as *The Journal* typically have relatively low impact factors compared to those covering mainstream disciplines such as chemistry and physics. This is certainly understandable, considering that citations are only counted from journals already in the SCIE. There is currently only one other gemmological journal in that database (*Gems & Gemology*), although some citation activity would also be expected from earth and materials science journals in the SCIE.

As for any title covered by the SCIE, *The Journal* must continue to maintain its quality and impact criteria, as judged by Clarivate Analytics, in order to remain in this database. The evaluation process and selection criteria are described at https://clarivate.com/webofsciencegroup/journal-evaluation-process-and-selection-criteria.

The Journal's coverage in the SCIE reflects Gem-A's core values of providing high-quality gemmological education and sharing cutting-edge research with the gemmological and earth science communities. Inclusion of *The Journal* in the SCIE will help elevate gemmology even further with scientists and academics. I thank *The Journal*'s Associate Editors for sharing their expertise and maintaining high scientific standards while reviewing articles submitted for publication. I am also grateful to our authors for sharing their research and for their perseverance during the review process. Finally, I thank our readers for their ongoing support. Please join me in celebrating this important milestone for *The Journal of Gemmology*.

Brendan M. Laurs FGA
Editor-in-Chief

What's New

INSTRUMENTATION

3DPro 360° Video Imaging System

In April 2019, ImaGem Inc. (Ardmore, Pennsylvania, USA) released 3DPro, a digital photo box designed to capture videos of mounted and unmounted gemstones during a 360° rotation. The 23 × 23 × 23 cm box comes with a built-in rotary stage, lighting, camera, software and 12-volt adapter usable worldwide. Operation requires a laptop computer. Lighting, background colour, and camera position can all be modified. Output is 5 MP in a variety of graphic formats. For additional information and sample videos, visit https://imageminc.com/3d.

DiaTrue CS, CL and CM

In the first half of 2019, OGI Systems Ltd. (Israel) launched its latest models in the line of DiaTrue diamond detectors, accompanied by updates to the entire DiaTrue line, which enable all of the models to simultaneously scan and identify CVD- and HPHT-grown synthetic diamonds, as well as CZ and synthetic moissanite. DiaTrue CS is a compact desktop unit with a 5 × 5 cm tray that can accommodate small melee parcels or ring-mounted samples in the D–K colour range. A scan takes approximately 7–10 seconds. The unit measures 26.5 × 21 × 22.5 cm and weighs 6.5 kg. DiaTrue CL is the largest of the three; the tray is 20 × 20 cm and the unit measures 28 × 25 × 50 cm (8.5 kg). DiaTrue CM is intermediate in size and capacity between the CS and CL. All models can save test data and create printable DiaTrue reports. Visit www.ogisystems.com/diatruecs.html (for the CS), www.ogisystems.com/diatruexl.html (for the CL) and www.ogisystems.com/diatrue.html (for the CM).

GLIS Mini

A portable version of the GLIS-3000 (see What's New section, Vol. 35, No. 4, 2016, p. 271) was released in early 2019. The GLIS Mini weighs ~3 kg and can test small batches of loose or mounted diamonds within an area measuring 5 × 6 cm. As with the GLIS-3000, the GLIS Mini uses UV fluorescence and phosphorescence to determine natural vs. synthetic (CVD and HPHT) origin, yielding results in approximately 10 seconds. Visit www.glismachines.com/collections/frontpage/products/mini-glis.

Q-Chk++

Released in 2019, the third generation of this synthetic diamond detector from GII Arotek (Gemmological Institute of India and Arotek Scientific Instruments) features expanded capabilities. It can distinguish HPHT- and CVD-grown synthetic diamonds of any shape, size and colour grade, both loose and mounted (including pavé), within an area of 11 × 6 cm. It can reportedly test up to 1,000 samples in as little as 7 seconds based on UV fluorescence and photoluminescence together with 'optically stimulated luminescence'. The unit has a footprint of about 60 × 60 cm. Visit https://giionline.com/q-chk-adc or www.arotekscientific.com/lan-grown-diamond-detector.html.

Smart-Raman Portable Spectrometer

From Napco Precision Instruments (China) comes this 2019 Raman unit packed in a portable case (40 × 31 × 17 cm), including laser, detector, cooling unit and laptop computer with dedicated software and a Raman database. It features a 100–500 mW continuously adjustable laser, 3950–150 cm^{-1} range and 8 cm^{-1} resolution. It is powered by AC voltage or rechargeable lithium batteries with an operating life of about 3 hours. The unit can display printable Raman spectra with customisable features, and can enable a trained gemmologist to identify a variety of gem materials and screen diamonds. Visit www.napcobalances.com/product_view_152_162.html.

Varna-D Diamond Colour-Grading Instrument

ImaGem Inc. released the Varna-D diamond colour-grading instrument in April 2019. The self-contained unit grades faceted diamonds in the colour range D–L from 0.25–5 ct with a repeatable accuracy of ±½ colour grade. It is able to take into account fluorescence, zoning and secondary hues. The unit measures 15.2 × 10.8 × 8.9 cm, weighs 1 kg, and operates on a USB-chargeable Li-ion battery, making it relatively portable. An external battery pack and stone calibration sets are available separately. Visit https://imageminc.com/products/varna-d.

Vista

In May 2019, Gemlogis (Hong Kong) released the Vista for separating HPHT- and CVD-grown synthetic from natural diamonds. This portable instrument can test both loose and mounted samples (open- or closed-back settings) in the colour range D–J as small as 0.02 ct. The unit weighs 0.73 kg and measures 16.5 × 16.5 × 12.7 cm. The small size of the unit limits its capability to one stone or jewellery piece at a time. It is powered by a rechargeable lithium battery and also comes with an AC adapter. For additional information and to view the video on the device, visit www.gemlogisusa.com/gemlogis-vista.html.

NEWS AND PUBLICATIONS

2017 and 2018 Dallas Mineral Collecting Symposium Presentations

The Dallas Mineral Collecting Symposium is held annually in August in Dallas, Texas, USA, and attracts mineral enthusiasts from around the world. Presentations from the 2017 and 2018 Symposia are now available online at www.dallassymposium.org/videos, and include topics such as gem minerals of Myanmar, colour in minerals, treasures from Pakistan, notable gems and minerals in French museums, and the history of the discovery and mining of tsavorite.

Diamond Disclosure Reports from De Beers

On 29 March 2019, the De Beers Group released two reports on disclosure: *Standard Guidance: Undisclosed Synthetic Diamonds* and *Best Practice Principles: Disclosure Practice Note 2019*. The first of these addresses the increased occurrence of undisclosed synthetic diamonds within the diamond supply chain and the potential damage they may cause to the diamond industry, and proposes modifications to the De Beers Group's Best Practice Principles (BPP). Download the full report at www.debeersgroup.com/~/media/Files/D/De-Beers-Group/documents/reports/library/2019/Standard-Guidance_Undisclosed-Synthetic-Diamonds-2019.pdf. The second report is a companion to the BPP that provides guidance to Sightholders and Accredited Buyers on how to reduce the risk of trading in undisclosed synthetic diamonds. It includes various approaches to screening and testing, with references to De Beers' AMS2 and SYNTHdetect instruments. This report is available at www.debeersgroup.com/~/media/Files/D/De-Beers-Group/documents/reports/library/2019/Disclosure-Practice-Note-2019.pdf.

Abstract of Papers Presented at Annual Meeting of the Gemmological Society of Japan

Gemmological Society of Japan 2019 Annual Meeting Abstracts

Abstracts of Special Lectures presented at the 2019 Annual Meeting of the Gemmological Society of Japan are now available online. The 22 abstracts cover a wide variety of topics, including synthetic diamond research and identification, diamond fluorescence, origin determination of gem corundum from Luc Yen (Vietnam), jadeite from the Polar Urals (Russia), red corals (origins and trace-element composition) and more. To download the abstracts from this and previous conferences, visit www.jstage.jst.go.jp/browse/gsj/list/-char/en.

Jewelry Development Impact Index Report on Emerald Mining in Colombia and Zambia

In May 2019, researchers from the American University School of International Service produced *Jewelry Development Impact Index: A Comparative Case Study of Emerald Mining in Colombia and Zambia*. The 88-page report examines the historical and cultural background of emerald mining in these two countries, and then provides numerical scores on a variety of areas (governance, economics, environment, health and human rights) for both localities. Download this and other recent JDI publications at www.sustainablegemstones.org/jewelry-development-index-jdi.

MSA Centennial Symposium Presentations

The Mineralogical Society of America celebrated its 100th anniversary with a Centennial Symposium, held 20–21 June 2019 in Washington DC, USA. Sessions of interest to gemmologists included 'Scientific Characterization of High-Value Gemstones', 'Mineral Inclusions in Diamonds from the Deep Earth' and 'Advances in Mineral Analysis'. Videos of all the presentations and a report of the symposium are available at www.minsocam.org/MSA/Centennial/MSA_Centennial_Symposium.

MJSA Expo Seminar Presentations

Videos of presentations and panel discussions from the March 2019 Manufacturing Jewelers & Suppliers of America (MJSA) Expo are available at https://mjsa.org/eventsprograms/mjsa_expo/expo_seminars. Presentations featuring experts in jewellery marketing and design include 'Where does custom design go from here?', 'What's new in responsible sourcing?', 'You've lost that handcrafted feeling', 'Celebrating the American jewelry design movement' and 'Tracking your digital advertising'.

Platinum Jewellery Business Review 2019

Platinum Guild International released their 2019 Platinum Jewellery Business Review on 15 May with a review of the 2018 market and outlook for 2019. It identifies the jewellery industry as the second largest market for platinum and emphasises the value of marketing to drive demand. In the four largest markets, Japan continued to show a slight (1%) growth of retail sales through 2018, the USA had notable (11%) growth, China experienced a decline (7%) and India demonstrated significant growth (17%). The predictions for 2019 are that these trends will continue. Download the report at https://platinumguild.com/research-publications/platinum-jewellery-business-review.

What's New provides announcements of new instruments/technology, publications, online resources and more. Inclusion in What's New does not imply recommendation or endorsement by Gem-A. Entries were prepared by Carol M. Stockton unless otherwise noted.

Gem Notes

COLOURED STONES

Albite from Minas Gerais, Brazil

During the February 2019 Tucson gem shows in Arizona, USA, Dr Marco Campos Venuti (Seville, Spain) had some new faceted albite from Brazil. He obtained 50 kg of rough material in August 2018 while visiting Brazil, and was told that it was mined near Teófilo Otoni in Minas Gerais State. He processed the rough into 5 kg of cuttable material and then faceted several hundred carats of the albite. The largest clean gems weighed ~6.5 ct and the more-included stones ranged up to 10 ct.

Dr Campos Venuti kindly donated a 2.50 ct faceted albite to Gem-A (Figure 1), and it was characterised by author AC for this report. The stone was colourless and transparent with a vitreous lustre. The hydrostatic SG was 2.65, the RIs were 1.535–1.542 (birefringence 0.007) and the stone had a uniaxial positive optic character. These properties are consistent with albite, and this identity was confirmed by Raman analysis using a Horiba LabRam II confocal Raman microspectrometer equipped with a 532 nm laser and a high-resolution diffraction grating. The stone fluoresced moderate reddish under short-wave UV radiation and was inert to long-wave UV.

Figure 1: This 2.50 ct albite from Brazil contains conspicuous linear features. Gift of Dr Marco Campos Venuti; photo by A. Costanzo.

Figure 2: In addition to containing two sets of lamellar twinning with slightly different orientations, the albite hosts elongate hollow inclusions that appear to be etched dislocations. Photomicrograph by A. Costanzo; image width 2.6 mm.

The most common internal feature was parallel-planar lamellar twinning. A subordinate set of the twin planes was angled at a slightly different orientation (Figure 2), perhaps because the sample also contained another twin law. Even more conspicuous than the twinning were roughly textured linear features that were parallel to the main set of twin planes (again, see Figure 2). Raman microspectroscopy only yielded patterns for the host albite, suggesting that these inclusions consisted of etched dislocation channels running along twin/cleavage planes. Their hollow nature was supported by the presence of dark foreign material (probably polishing residue) where they intersected the surface of the stone.

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Figure 3: Shown from the side and top views, this deeply etched dark blue beryl crystal (236.7 g and 61 × 50 × 49 mm) is from Khyber Pakhtunkhwa in northern Pakistan. Courtesy of 3090 Gems; photos by Sara Rey.

Dark Blue Beryl from Pakistan

Pakistan is a well-known source of aquamarine, which commonly occurs as lustrous, well-formed crystals that are prized by mineral collectors. Most of the aquamarine comes from the Shengus–Dassu (or Shingus–Dusso) and Chumar Bakhoor areas of Gilgit-Baltistan (Kazmi *et al.* 1985; Appiani 2007). During the February 2019 Tucson gem shows, Meg Berry (Megagem, Fallbrook, California, USA) showed one of the authors (BML) some interesting dark blue beryl from a new find in Pakistan. According to her supplier, Bryan Lichtenstein (3090 Gems, San Francisco, California, USA), it comes from Khyber Pakhtunkhwa in northern Pakistan. The initial discovery was made in September 2018 by Raza Shah (Gems Parlor, Fremont, California), who has partnered with Lichtenstein in providing the material to the gem trade. Only a limited amount has been produced so far, mostly as 1–2 g pieces, but some are in the 30–50 g range. The largest crystal known so far weighs 236.7 g (Figure 3). The rough material is heavily etched, and some pieces are colour zoned in dark blue to dark blue-green.

Berry cut a cabochon (Figure 4) from one of the larger pieces of this beryl, and two offcuts from that sample were provided to one of the authors (GRR) for analysis. Semi-quantitative energy-dispersive X-ray fluorescence (EDXRF) chemical analysis using an INAM Expert 3L unit yielded an iron-rich composition with ~2.5 and 3.6 wt.% Fe in the two samples, as well as relatively high levels of Cs (1.5 and 2.3 wt.% Cs). Also present were minor amounts of Mg and traces of Mn, Rb, S, Zn, Cu, Ga, Ni and V.

Visible-near infrared (Vis-NIR) spectroscopy of one of the beryl specimens was accomplished with a combination of silicon-diode and InGaAs array microspectrometers. The spectrum shows that the beryl's dark blue colour is due to an absorption minimum in the 450–500 nm region that is bounded by absorption bands in the visible region that arise from the presence of abundant Fe (Figure 5). Absorption features centred near 830 and 1080 nm are from Fe^{2+} while the band near 600 nm is due to Fe^{2+}–Fe^{3+} intervalence charge transfer. These absorptions are strongly polarised, and are much more prominent in the spectrum taken with light polarised parallel to the c-axis. A weak, sharper feature near 440 nm is due to Fe^{3+}. A series of sharp absorptions near 1400 nm arise from overtones of the vibrations of water molecules in the channels of the beryl structure. Additional weaker water-related features appear near 970 and 1160 nm (Wood & Nassau 1967). None of the absorptions commonly seen in Maxixe beryl were recorded in the spectra of this material from Pakistan.

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Figure 4: This cabochon of dark blue-green beryl from Pakistan weighs 7.49 ct. Pinpoint reflections are created by iridescent feathers in the stone. Photo by Orasa Weldon.

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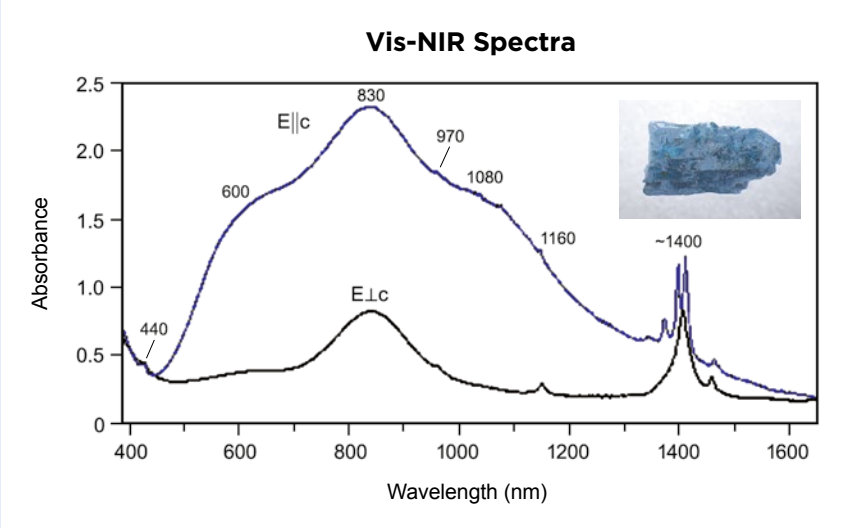

Figure 5: Vis-NIR spectroscopy shows that the dark blue colour of the beryl is due to Fe-related features. The sample is 18 mm wide and the path length of the beam was 3.3 mm. Inset photo by G. R. Rossman.

Emerald from the Anuri Prospect, Nunavut, Canada

In the summer of 2012, a geologist working for North Country Gold Corp. identified significant amounts of emerald in drill core obtained in 2005 and 2006 from the Anuri gold-and-silver prospect in Nunavut, Canada. The prospect is located at 66° 27.4' N, 92° 31.0' W, approximately 410 km north of Rankin Inlet, and is accessible only by air. The area is underlain by the Committee Bay Greenstone Belt, which forms part of the Rae domain of the western Churchill Province, within the Neoarchean volcano-sedimentary Prince Albert Group.

The emeralds occur in potassic-altered komatiites (ultramafic, high-Mg volcanic rocks) and are associated with highly elevated Be values. Similar rocks have been documented up to 7 km east of the Anuri prospect (Turner 2007), which has implications for the potential extent of emerald mineralisation in the area.

The emerald was found in seven ~1 m intervals from three drill holes, from 76 to 180 m depth. Ten polished thin sections of the seven intervals were studied with a petrographic microscope, scanning electron microscope and electron microprobe. The results show that the beryl occurs within a texturally and mineralogically variable matrix of phlogopite, muscovite, actinolite, plagioclase and pyrite, with occasional quartz, calcite and accessory minerals such as fluorapatite, titanite, rutile, chalcopyrite, molybdenite and rare tellurides.

The beryl can occur as large, slightly altered grains in coarse-textured, hydrothermally altered, silicified zones, as well as at altered protolith contacts, as inclusions in other minerals (such as amphibole), and as a fine-grained, pervasive overprint that may represent a sodic alteration event. In most cases the emerald is present as rims on near-colourless beryl, and there appears to be an association of emerald with molybdenite veinlets; some even have molybdenite inclusions.

Refractive indices of $n_\varepsilon = 1.583 \pm 0.001$ and $n_\omega = 1.591 \pm 0.001$, yielding a birefringence of 0.008, were measured from an emerald crystal. Electron microprobe analyses (245 points) of the beryl showed a wide range of compositions, but the dominant chromophore in the emerald was Cr (with essentially no V), with a maximum of 2.62 wt.% Cr_2O_3, equivalent to 0.20 Cr per formula unit (pfu). The emerald also contained unusually high concentrations of Mg (up to 3.41 wt.% MgO or 0.48 Mg pfu) and Fe (up to 1.99 wt.% FeO or 0.16 Fe pfu). The highest Mg contents were observed in beryl inclusions in the cores of euhedral amphibole crystals. Only emeralds from the Ianapera deposit in Madagascar (Vapnik *et al.* 2010) show more substitution at the Al site. The Anuri emerald also showed unusually high concentrations of Na (up to 2.66 wt.% Na_2O or 0.49 Na pfu).

Electron microprobe analyses identified the micas as F-rich phlogopite, fluorophlogopite and muscovite. Amphiboles ranged between tremolite and ferri-magnesiohornblende, and were enriched in F and Na (0.2–1.2 F pfu; ≤0.42 Na pfu). The plagioclase was albite to oligoclase (≤0.2 Ca pfu). Titanite had elevated contents of F and Al (≤0.17 F pfu, ≤0.14 Al pfu).

Figure 6: Emeralds were recovered from drill cores at the Anuri gold-and-silver prospect in Nunavut, Canada. Shown here are (**a**) a 13.16 ct cabochon of emerald-bearing rock and (**b**) a 0.27 ct opaque faceted emerald containing dark amphibole and brassy pyrite inclusions. Both pieces were cut by Bradley S. Wilson (Alpine Gems, Kingston, Ontario, Canada). Photos by Tom Fa/Panotora.

The emerald likely formed via the interaction of the komatiite with Be-, F- and Na-bearing fluids from an unexposed pegmatite dyke or hydrothermal vein, with later overprinting by a metamorphic event. The dyke or vein is probably associated with a nearby tonalite dated 2,718 ± 2 million years (Skulski *et al.* 2003) that intrudes the komatiite and was intersected by a drill hole approximately 100 m south of the main area investigated (Turner 2007).

The emerald-bearing rock has been polished into a small number of cabochons, and one opaque emerald containing amphibole and pyrite inclusions has been faceted (Figure 6). It is unlikely that more material will become available unless fieldwork shows that the emerald-bearing horizons extend up to the surface.

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Aesthetic Mesolite Cabochons from India

Well known amongst mineral collectors, zeolite minerals are sometimes encountered as collector gemstones (e.g. pollucite, leucite, natrolite, analcime, etc.). Specimen- and gem-grade zeolites commonly form as secondary minerals within cavities in basalts, and perhaps the most famous deposits are hosted by the Deccan volcanic province in India (Ottens *et al.* 2019). During the past few years, white cabochons composed of radiating crystal clusters described as scolecite (a zeolite of the natrolite subgroup) have been available from India. Early in 2019, similar stones with mixed white and orangey pink ('salmon') colouration exhibiting aesthetic patterns entered the market from India's Maharashtra State. Two such samples (28.10 and 36.73 ct) were characterised for this report (Figure 7).

Natrolite-subgroup zeolites are composed of three

Figure 7: The cabochons from Maharashtra State in India examined for this study (28.10 ct, bottom, and 36.73 ct, top) show aesthetic patterns due to differently coloured mesolite aggregates. Photo by T. Cathelineau.

main species: scolecite ($CaAl_2Si_3O_{10} \cdot 3H_2O$), natrolite ($Na_2Al_2Si_3O_{10} \cdot 2H_2O$) and mesolite ($Na_2Ca_2Si_9Al_6O_{30} \cdot 8H_2O$). They commonly form attractive sprays of slender radiating crystals up to 30 cm in size, in colourless, white, grey, brown, bluish, yellowish, or more rarely pink or orange. The orthorhombic natrolite and the monoclinic mesolite and scolecite all form pseudo-tetragonal prisms with an almost square section. If a cabochon of such aggregates is cut perpendicular to the prisms, a chequered pattern may result, as shown by the 28.10 ct stone in Figure 7. When cut parallel to the slender crystals, they produce a radiating acicular pattern, as shown by the 36.73 ct cabochon in Figure 7.

The 36.73 ct sample showed the following properties: colour—'salmon' and white; diaphaneity—translucent in the 'salmon' areas and opaque in the white ones; RI—1.505; birefringence—could not be determined from the RI readings (see below); hydrostatic SG—2.23; magnetism—diamagnetic; Chelsea Colour Filter reaction—none; fluorescence—faint white in white areas and inert in 'salmon' portions when exposed to short-wave UV radiation, and inert to long-wave UV; and spectroscope spectrum—strong absorption in the violet and blue regions with moderate absorption in the green. The 28.10 ct stone showed the same properties except that it was opaque and had an SG value of 2.18; no RI or spectrum could be obtained. Both stones increased in weight when left immersed in water for several minutes. The RI and SG values are consistent with those reported for mesolite by O'Donoghue (2006). (Although mesolite is biaxial positive, all three RI values are ~1.505, so birefringence is almost unobservable with a gemmological refractometer.)

Infrared reflectance spectra were collected from several spots on the cabochons (both 'salmon' and white areas), and all yielded the same pattern (e.g. Figure 8). The spectra are characteristic of a silicate mineral, and comparison with the author's Spec4Gem database (www.spec4gem.info/databases/irs/40) revealed an exact match with mesolite samples analysed a few years ago. The identification of the earlier samples as mesolite was achieved by comparing their IR spectra to those of the natrolite subgroup in the RRUFF database and to the

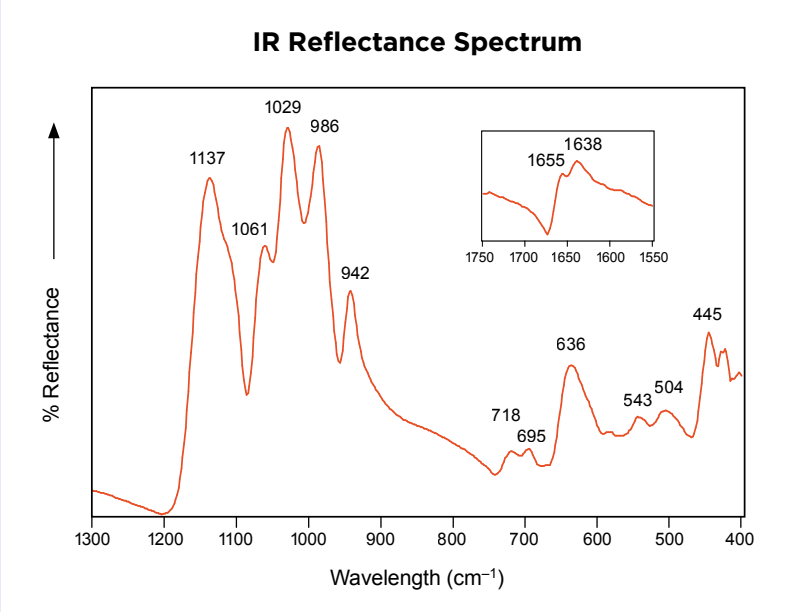

Figure 8: The IR reflectance spectrum characterises the stones in Figure 7 as mesolite, the main Ca-Na member of the natrolite subgroup. The 1655 and 1638 cm^{-1} bands (inset) indicate H_2O bending vibrations.

IR transmission spectra published by Chukanov (2014, pp. 846, 848, 869). The 1655 and 1638 cm^{-1} bands are associated with H_2O bending vibrations (Geiger 2012).

A Vis-NIR spectrum (Figure 9) was collected from a translucent 'salmon' area of the 36.73 ct cabochon with the beam oriented nearly perpendicular to the mesolite prisms. It showed strong absorption in the violet, blue and green regions with an edge in the yellow-green region caused by a prominent band at ~535 nm. Also present was a moderate band at ~665 nm (red region), a weak band at ~855 nm and a moderate band at ~980 nm (NIR). The overall spectral pattern displayed an absorption continuum towards the UV, which is responsible for the 'salmon' colouration. Iron is easily incorporated into zeolites, as demonstrated by Suhartana *et al.* (2018); Fe-bearing zeolite is generally orange-brown, which is similar to the 'salmon' colouration seen in the present samples, although the author is not aware of any corresponding Vis-NIR spectra. The 980 nm band is very likely due to OH second overtones, as deduced by the author from the OH stretching vibrations of H_2O between 3600 and 3100 cm^{-1} (Geiger 2012).

Photoluminescence of the white areas of the cabochons was studied using 254 nm excitation, in accordance with the fluorescence observations mentioned above. (Other wavelengths at 377, 405 and 447 nm did not produce any photoluminescence.) The 254 nm source induced a broad but very weak emission peaking at 480 nm (Figure 10). This spectrum is similar to those of zeolites published without explanation by Gorobets & Rogojine (2002, p 150). It is possible that the luminescence could be related to organic molecules and/or an oxygen centre.

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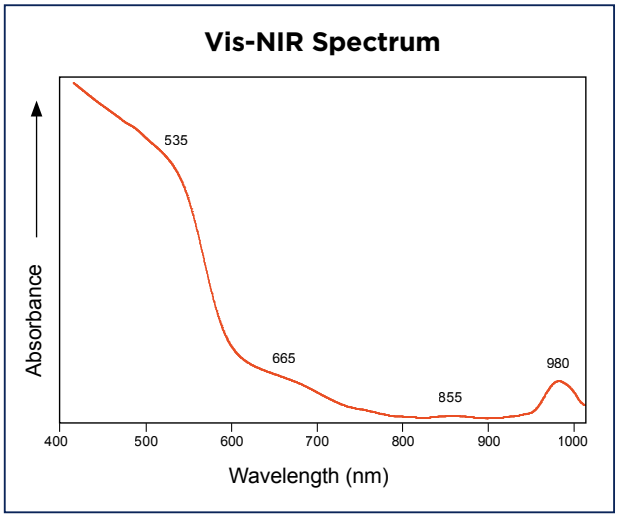

Figure 9: This Vis-NIR spectrum was collected from a 'salmon'-coloured area of the 36.73 ct mesolite cabochon. A continuum of absorption in the violet, blue and, to a lesser extent, green regions gives the stone its 'salmon' colouration.

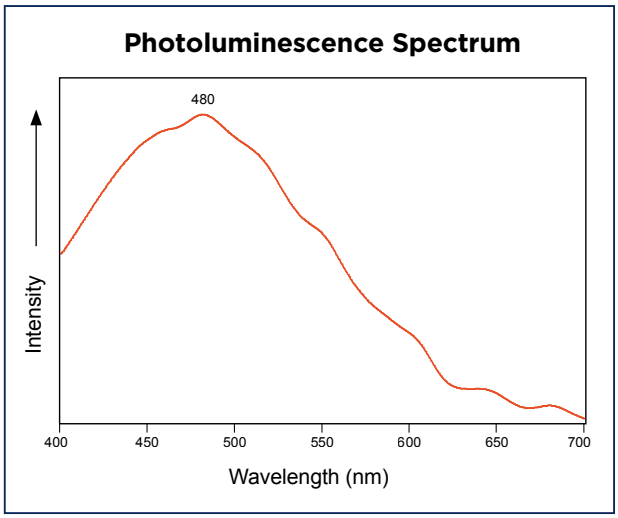

Figure 10: The photoluminescence spectrum of a white area of the 36.73 ct mesolite obtained with 254 nm excitation shows a broad but weak emission centred at 480 nm.

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Quartz from Brazil with Biotite Inclusions

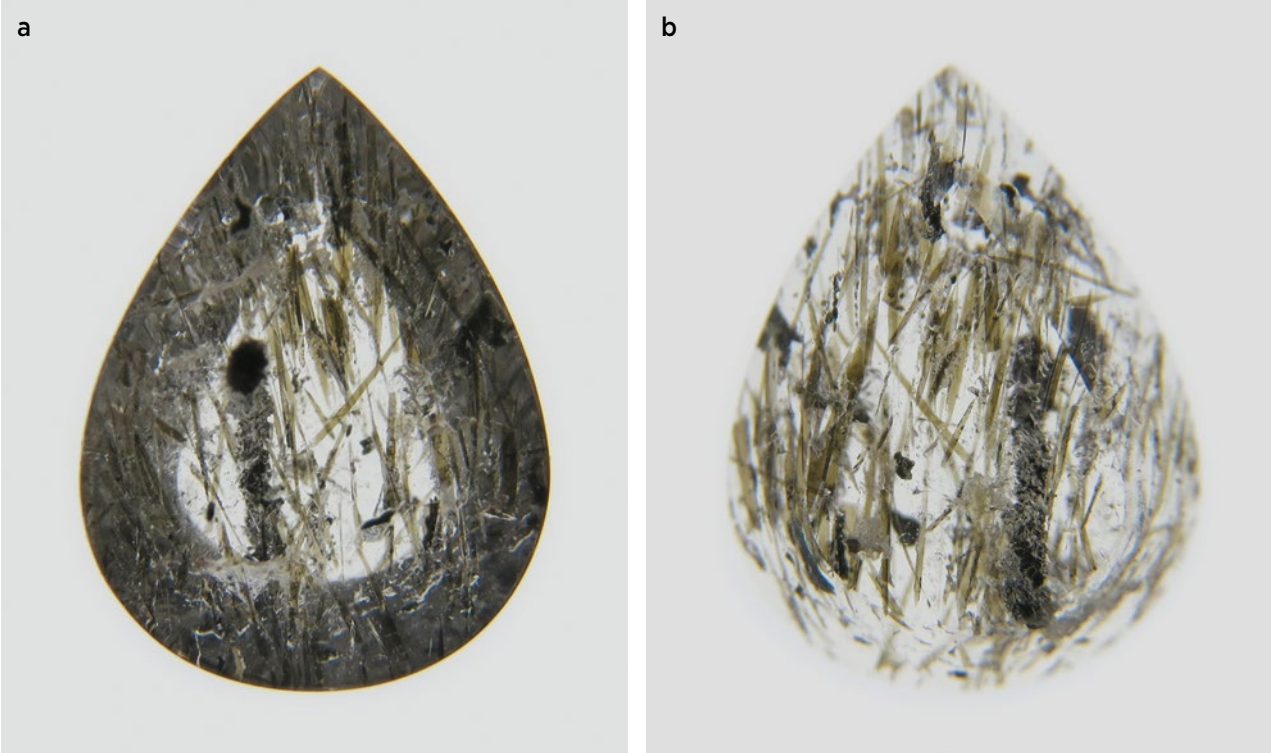

Figure 11: This 2.70 ct buff-top quartz, shown in (**a**) table-up and (**b**) table-down positions, contains abundant greenish brown inclusions that proved to be biotite. Also visible is a large etch channel filled with a dark-coloured foreign substance. Gift of Dr Marco Campos Venuti; photos by A. Costanzo.

During the August 2018 Feira Internacional de Pedras Preciosas (FIPP) gem show in Teófilo Otoni, Brazil, stone dealer Dr Marco Campos Venuti obtained some new rough quartz from Minas Gerais containing abundant inclusions. Only a few of these quartz crystals were available, and from them he cut 30–40 stones (both faceted and buff tops), yielding a total of about 100 carats. Dr Campos Venuti displayed the gems at the February 2019 Tucson gem shows, and he kindly donated a 2.70 ct specimen to Gem-A for examination (Figure 11).

The pear-shaped buff-top quartz was colourless and heavily included with elongate greenish brown flakes (Figure 12). They were mostly sub-parallel, but some were present in different orientations. Observation with a petrological microscope indicated the inclusions were composed of a dark mica (e.g. biotite) showing high-order interference colours in cross-polarised light and straight optical extinction. The identification as biotite was confirmed with Raman microspectroscopy using a Horiba LabRam II confocal Raman microspectrometer equipped with a 532 nm laser and a high-resolution diffraction grating. Also present in the quartz were numerous liquid-rich two-phase (liquid and vapour) inclusions, as well as solid-rich three-phase (liquid, vapour and solid) inclusions. In addition, a large etch channel filled with a dark-coloured foreign substance (probably polishing compound) formed a prominent columnar inclusion in the quartz (again, see Figure 11).

Although quartz and biotite are both common

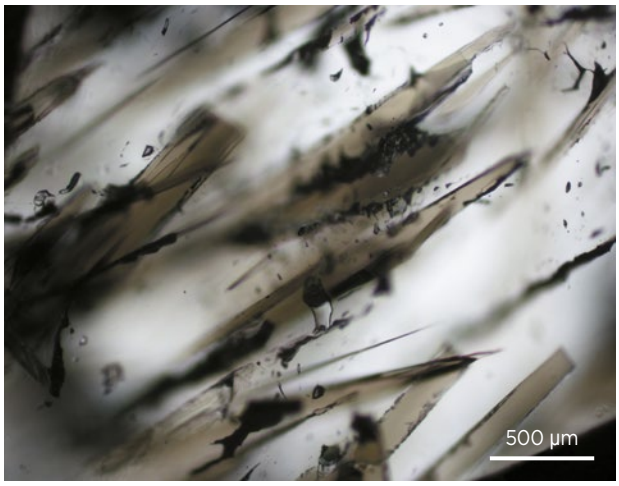

Figure 12: The biotite inclusions in the Brazilian quartz form elongate flakes accompanied by smaller fluid inclusions. Photomicrograph by A. Costanzo.

rock-forming minerals, it is somewhat unusual to encounter quartz in the gem trade containing monomineralic biotite inclusions. Hyrsl & Niedermayr (2003, p. 205) documented quartz from Alpine-type veins in the Ganesh Himal region of Nepal that contained large biotite plates up to several centimetres long and 1 cm wide.

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Quartz from Brazil with Dendritic Inclusions

Brazil is one of the most prolific sources of quartz containing interesting inclusions. During the February 2019 Tucson gem shows, Frederico de Vasconcelos (MultiGemas/Vasconcelos Brazil, Governador Valadares, Brazil) displayed two new finds of quartz with dendritic inclusions from Minas Gerais. He reported that quartz with black dendritic inclusions (Figure 13) was discovered in December 2018 by miners looking for aquamarine near Leopoldina in south-eastern Minas Gerais near the border with Rio de Janeiro State. The largest quartz crystal recovered weighed 500 kg, and was cut into seven larger polished stones and approximately 3,000 carats of smaller gems. The dendrites range from dark grey to black and commonly show a plant-like appearance.

Figure 13: These quartz specimens (64 × 81 and 44 × 50 mm) from Leopoldina, Brazil, contain dendritic inclusions with a somewhat plant-like appearance. Photo by Jeff Scovil.

Just prior to this discovery, in November 2018, quartz with red-orange dendritic inclusions (Figure 14) was found at an unspecified locality in Minas Gerais. So far, approximately 20,000 carats have been cut into stones ranging from 10 to 60 ct each. The dendrites in this quartz form delicate patterns, and they are commonly accented by a granular-appearing white coating within some of the fractures (Figure 15).

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Figure 14: Brazil is also the source of this 41 × 25 mm quartz with red-orange dendrites. Photo by Robison McMurtry, © GIA.

Figure 15: The red-orange dendrites in the quartz are accompanied by a granular-appearing white material in the fractures. Photo by N. D. Renfro, © GIA; image width 12.9 mm.

Sapphire with Unusual Inclusion Scenery

Recently, the authors examined an unheated blue sapphire of ~2 ct, presumably from Myanmar (Burma), which displayed unusual inclusion scenery. Raman microspectroscopy of the inclusions was carried out at the DSEF German Gem Lab using a Renishaw inVia Raman microscope, at room temperature with 514 and 785 nm laser excitations in confocal mode.

One side of the sapphire contained hundreds of colourless, transparent, doubly refractive crystal inclusions with a euhedral, short-prismatic habit. These were identified as scapolite. Scapolite is rarely seen as inclusions in gem corundum, although it was documented in ruby by Gübelin & Koivula (2008). One of the larger scapolite inclusions attracted our attention because it contained some negative crystals filled with CO_2 together with some (unidentified) daughter crystals (Figure 16).

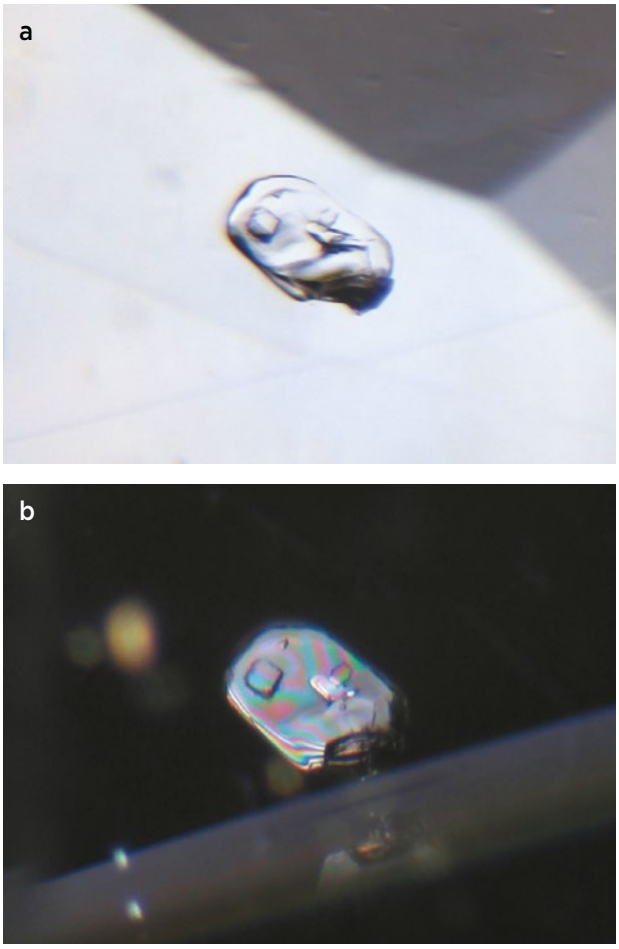

Figure 16: (**a**) This inclusion in a blue sapphire was identified as scapolite, which contains negative crystals filled with CO_2 and unidentified daughter crystals. (**b**) Viewed with crossed polarisers, the doubly refractive nature of the scapolite (and some of its inclusions) is evident. Photomicrographs by T. Stephan; image widths 3.2 mm.

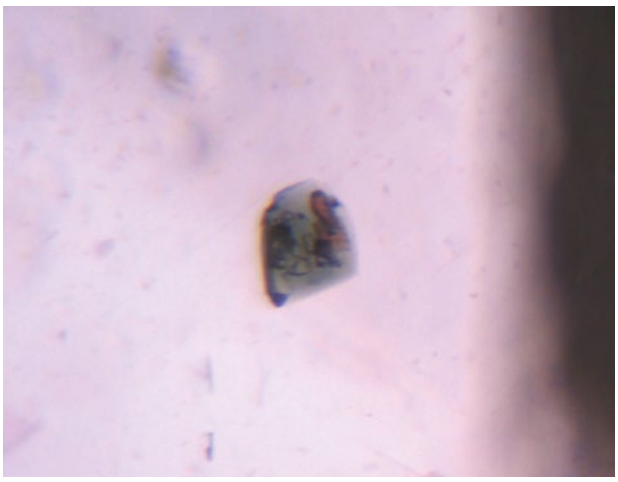

Figure 17: This greenish mineral in the blue sapphire was identified as spinel, which itself contains inclusions of dolomite, feldspar, mica and primary rutile. Photomicrograph by T. Stephan; image width 2.1 mm.

Near the scapolite inclusions, the sapphire also hosted a greenish mineral, the colour of which reminded us of amphibole inclusions commonly seen in gem corundum from East Africa. We identified it as spinel, which is known to occur in sapphires from Myanmar (Gübelin & Koivula 2008; Smith 2018). However, this particular spinel inclusion was of further interest because it hosted several crystals showing various shapes and colours (Figure 17), which consisted of rhombohedral colourless dolomite, rounded colourless feldspar, brownish mica flakes and primary rutile grains. Raman analysis also showed the presence of CO_2 in the spinel inclusion.

These two multi-phase inclusions reflect the complex geological formation environment of this sapphire. It is fortunate that the stone did not undergo high-temperature heat treatment, which would have destroyed these interesting internal features.

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Scapolite from Brazil with Interesting Inclusions

Various localities in Brazil have produced gem-quality light yellow scapolite. Espírito Santo State is a source of facetable scapolite crystals, which are sometimes fairly large (up to ~6 g), although they usually contain numerous long thin tubes (Sauer 1982). Gem scapolite is also known from Minas Gerais State, and was chemically analysed by Dunn *et al.* (1978). Furthermore, Zwaan & Arps (1980) reported gemmological and powder X-ray diffraction data for a scapolite from an unspecified locality in Brazil.

During the February 2019 Tucson gem shows, Dr Marco Campos Venuti debuted a new production of light yellow scapolite from an unspecified locality in Brazil. He obtained ~3–4 kg of rough while visiting Brazil in August 2018, from which approximately 1,000 carats of faceted stones were produced. The gems consisted of mostly clean stones up to 20 ct (typically 2–10 ct). Dr Campos Venuti kindly donated to Gem-A an elongate cushion weighing 5.50 ct (Figure 18), which was characterised by author AC for this report.

The stone was transparent with a vitreous lustre, and exhibited weak dichroism in slightly greenish yellow and yellow. It luminesced strong red under short-wave UV radiation and displayed faint yellowish fluorescence to long-wave UV. The RIs were 1.545–1.560, yielding a birefringence of 0.015, and the stone showed a uniaxial negative optic character. Hydrostatic measurements yielded an SG value of 2.64.

The scapolite group includes an isomorphous series between the end members marialite ($Na_4Al_3Si_9O_{24}Cl$) and meionite ($Ca_4Al_6Si_6O_{24}CO_3$), and both the optical properties and SG of scapolite vary with the relative amounts of Na and Ca (Zwaan & Arps 1980; Deer *et al.* 2004). The properties obtained for the present scapolite specimen correspond to a marialite composition, and are comparable (though with slightly higher RI and SG values) to the data for Brazilian marialite given by Zwaan & Arps (1980). By contrast, Dunn *et al.* (1978) indicated a meionite composition for scapolites from Minas Gerais and Espírito Santo.

The 5.50 ct stone contained conspicuous inclusions, consisting of elongate parallel arrays of brown to black particles (Figure 19). Some of the black inclusions had a skeletal growth appearance. Unfortunately, these particles could not be identified by laser Raman microspectroscopy due to their small size.

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Figure 18: This 5.50 ct Brazilian scapolite has a marialite composition and contains parallel trails of dark inclusions. Gift of Dr Marco Campos Venuti; photo by A. Costanzo.

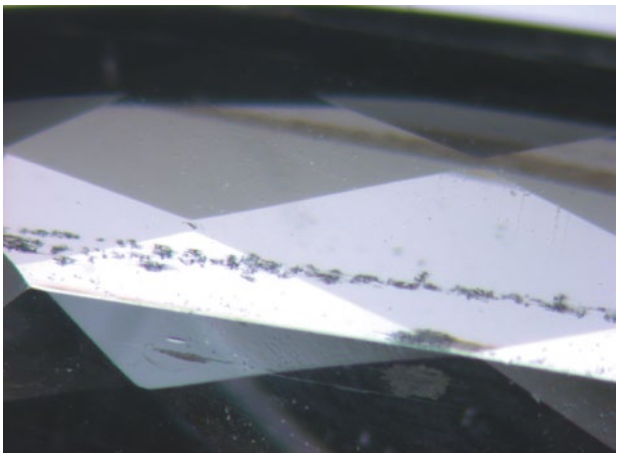

Figure 19: Black skeletal inclusions form an elongate array in the scapolite. Photomicrograph by A. Costanzo; image width 5 mm.

Spessartine Reportedly from Ethiopia

Ethiopia has become an important source of coloured stones such as opal, sapphire and emerald. Recently, the authors examined various rough samples, reportedly from Ethiopia, which were provided by Sascha Weiß (Ethio Star, Germany). These included several (mostly red) garnets, two greenish brown clinozoisites, one brown epidote and a green sapphire. We were especially interested in a bright orange 6.46 g stone (Figure 20), which was identified by Raman spectroscopy as spessartine. The SG was measured hydrostatically as 4.24 and the RI was ~1.80 (measured from a small polished surface with a Presidium digital reflectometer). Microscopic examination revealed mainly fluid inclusions (some multi-phase) and growth structures.

The semi-quantitative chemical composition of the sample was obtained by EDXRF spectroscopy with a Thermo Scientific ARL Quant'X instrument, and compared (along with RI and SG data) to that for spessartine from other localities (Table I; see also Laurs & Knox 2001; Milisenda *et al.* 2010). The data reveal a particularly Mn-rich composition ($Sps_{91.5}Alm_{6.2}Pyr_{1.3}Grs_{0.9}$) that is typical of some spessartine from granitic pegmatites (e.g. in Nigeria). The absorption spectrum of this sample is

Figure 20: This 6.46 g spessartine, reportedly from Ethiopia, was examined for this report. Photo by T. Stephan.

Table I: RI, SG and chemical data for spessartine from various localities.[a]

Property	Namibia	Pakistan	Nigeria	Tanzania	Ethiopia
	Lind *et al.* (1994); Lind (2002)	Qasim Jan *et al.* (1995); Henn (1996); Lind (2002)	Lind & Henn (2000); Lind (2002)	Milisenda *et al.* (2010)	This work
RI[b]	1.790–1.797	1.798–1.802	1.801–1.803	1.777–1.785	~1.80
SG	4.09–4.16	4.05–4.23	4.15–4.22	4.02–4.08	4.24
Oxide (wt.%)					
SiO_2	33.93–38.48	35.01–36.80	36.01–37.04	37.33–37.48	36.92
TiO_2	nd–0.22	nd–0.08	0.01–0.09	0.06–0.08	0.01
Al_2O_3	18.87–21.23	19.92–20.68	20.63–21.48	21.06–21.23	17.76
Cr_2O_3	nd–0.06	nd–0.008	nd–0.07	nd–0.03	nd
FeO_{tot}	nd–1.13	4.45–6.88	0.62–5.93	nd	2.86
MnO	35.56–42.45	33.28–36.98	37.67–43.08	34.75–34.88	41.64
MgO	2.47–4.32	nd–0.01	0.03–0.99	4.32–5.14	0.35
CaO	0.35–0.98	1.55–1.60	0.09–0.41	1.34–1.79	0.33
End member (mol.%)[b]					
Sps	81.5–87.0	80.3–85.3	86.3–96.7	75.8–76.5	91.5
Alm	0–2.5	10.1–14.8	1.4–13.2	—	6.2
Pyr	9.5–17.4	—	0.1–4.1	18.8–19.8	1.3
Grs	1.0–2.5	4.6–4.8	0.3–1.2	3.7–5.0	0.9

[a] Abbreviations: Alm = almandine, Grs = grossular, nd = not detected, Pyr = pyrope and Sps = spessartine.
[b] The RI and end-member compositions also include data from Milisenda *et al.* (2010).

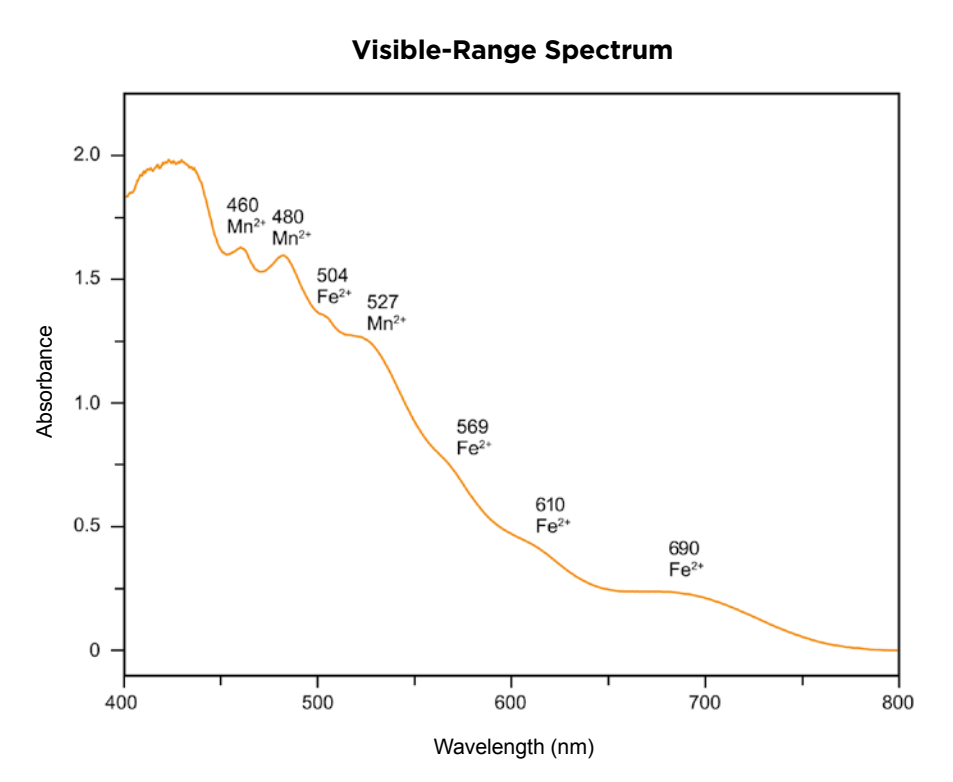

Figure 21: The visible-range spectrum of the spessartine in Figure 20 shows mainly Mn^{2+}-related absorption bands and minor Fe^{2+}-related features. The path length of the beam was ~9 mm.

shown in Figure 21. In addition to absorptions attributed to Mn^{2+}, bands associated with Fe^{2+} are present, as expected for spessartine (cf. Lind 2015).

The spessartine sample described here reportedly came from the Shakiso region of southern Ethiopia, which is also a source of emerald, pyrope, aquamarine, ruby, sapphire and tourmaline (S. Weiß, pers. comm., 2019). Spessartine has been previously reported from highly evolved granite–pegmatite rocks in the Kenticha area near Shakiso (Mohammedyasin 2017), but this is the first time that the authors have seen gem-quality spessartine from Ethiopia.

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DIAMONDS

Diamond Mining at Theindaw, Myanmar

For decades, diamonds have occasionally been recovered from alluvial sediments in various parts of Myanmar, including the Momeik Valley (near Mogok), the Tanintharyi region in the south and the Hukawng Valley in the north (e.g. Mitchell 2018). Some of the mining sites include Bokpyin, Dawei (old name: Tavoy), Theindaw, Kyauk-O Chaung (south-east of Taungoo) and Nambyu (in the Tanai area). The diamonds are typically recovered as by-products of mining the alluvial deposits for other commodities such as tin, tungsten and coloured stones.

In June 2019, one of the authors (TTS) visited a small privately owned mining operation in the Theindaw area of the Tanintharyi region. (There is also a government-owned mine at Theindaw, which provides employment for the local community.) From the town of Myeik it took more than four hours to reach the mining area. The trip (during the rainy season) included two hours by car on paved and muddy roads, a river crossing by ferry, and then another two hours riding a motorbike on a slippery, muddy road.

In the Theindaw area the miners mainly seek tin and tungsten, and occasionally they find diamond and gold. The area is mainly underlain by Carboniferous sedimentary rocks and rare Permian limestones, and is locally intruded by lamprophyre dykes; the primary source of the alluvial diamonds in these 'headless placers' is unknown. During the author's visit, a crew of three workers hydraulically mined a small open pit (Figure 22), and the slurry was pumped to a sluice where the heavier minerals were removed by hand.

The mine manager displayed an approximately 0.50 ct diamond that was found some years ago at that location (Figure 22, inset). The pale brown rounded tetrahexahedron was consistent in appearance with typical diamonds from Myanmar, which are commonly brown to reddish brown or yellow, and sometimes colourless (Griffin *et al.* 2001). Also, most Theindaw diamonds are rounded and contain percussion marks, lamination lines, pits and stepped growth faces (trigons). In order of abundance, the diamond forms are the octahedron, dodecahedron and trisoctahedron, and less commonly

Figure 22: In the Theindaw area of southern Myanmar, miners searching for tin and tungsten occasionally recover diamonds (see, e.g., the 0.50 ct stone in the inset) from small alluvial mining operations. Photos by Tay Thye Sun.

the hexoctahedron, tetrahexahedron, hexatetrahedron, various combinations of forms, aggregates and fragments (Nyunt 2002). According to the knowledge of authors NH and TTN, from 1985 to 1990 the average diamond content of the alluvium was 0.44 carats per 100 cubic yards and the average stone weight was 0.77 ct. Available records from the Myanmar Gems Enterprise for diamond production from Theindaw during the period July 1985 to March 1992 indicate a total of 1,886 stones recovered with a total weight of 1,458 carats; the smallest diamond was 0.02 ct and the largest was 72.55 ct. No production records have been kept for diamonds from Myanmar since 2002.

Acknowledgements: Author TTS sincerely thanks U Kyaw Kyaw (group leader), U Han Min Ko, U Thant Zin Oo and driver U Kyaw Htoo for providing a safe journey to the mining area.

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Drawing Fire: An Early Illustration of Sparkle in Diamonds

Photographers of diamonds and other gems are well aware of the challenge posed by reflections. Excellent return of light might be a positive feature for a diamond, but not where photography is concerned; too many reflections obscure the form and appearance of the gem. In the days before photography, illustrators had exactly the opposite problem. How might they render the fire and sparkle of a diamond in a drawing?

In 1766, French wood engraver and illustrator Jean Michel Papillon wrote a comprehensive treatise on the craft of engraving wood blocks used in printing. In the second volume, he described one way to indicate sparkle in diamonds (Papillon 1766, pp. 279–285). He shows what he describes as the four most beautiful diamonds in the world, with their sparkle rendered as radiating lines of irregular length (Figure 23). These gems, as numbered in his plate, are (1) the Grand Mogul's diamond, (2) the Duke of Tuscany's diamond, (3) the Sancy and (4) the Regent.

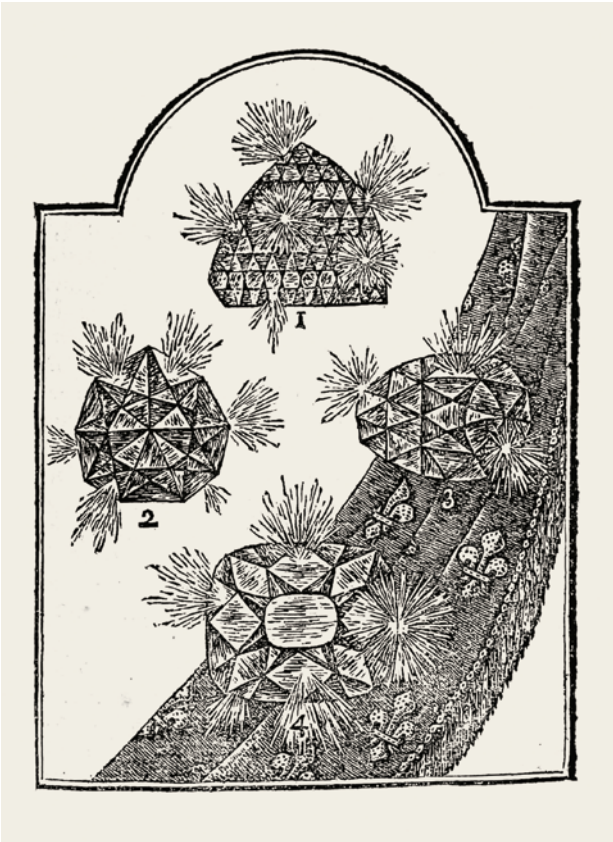

Figure 23: This illustration by Papillon (1766, p. 281) renders the sparkle associated with what he considered the four most beautiful diamonds in the world.

For comparison, he referred the reader to his earlier drawing that was published by Antoine-Joseph Dézallier d'Argenville in 1755, showing these same four diamonds unembellished with 'sparkle' (Figure 24).

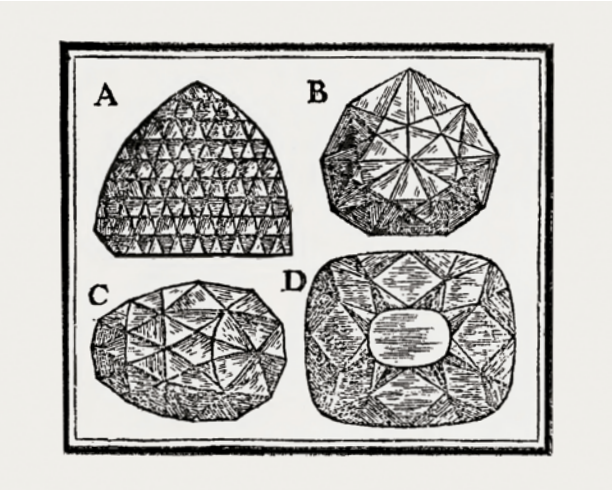

Figure 24: An earlier drawing by Papillon of the same four diamonds (published by Dézallier d'Argenville 1755, p. 157), shown without 'sparkle', was mentioned by Papillon (1766) for comparison.

The use of radiating lines in drawings to represent light was nothing new. You could argue that the same approach was used in representations of the sun several millennia earlier, in Egypt, for example. Similar radiating lines were also used in medieval art for fire and explosions, but applying such lines to gems was a novel idea. Whether Papillon's method is effective is a matter for the viewer to decide, but it is worth noting that it does not appear to have been adopted by other illustrators.

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The Nur al-'Ayn Diamond, Rephotographed

During the preparation of the recent article in *The Journal* on the history of the Hornby diamond (Vol. 36, No. 6, 2019, 512–522), the author attempted to obtain a new photo of the ~60 ct brilliant-cut Nur al-'Ayn diamond, which is set in a tiara made by Harry Winston in the 1950s (Figure 25). The only image available at the time was taken in the 1960s by Canadian gemmologists Victor Meen and Arlotte Tushingham when they studied the Iranian Crown Jewels in what is now the National Jewelry Treasury (or Treasury of National Jewels) in the Central Bank of the Islamic Republic of Iran, Tehran.

By good fortune, David Brough (editor and co-founder of *Jewellery Outlook*) put the author in touch with Iranian gemmologist Dr Vahid Ahadnejad of the Gemmology Center, Shahid Beheshti University, in Tehran. Dr Ahadnejad graciously agreed to explore the possibility of obtaining a new photograph. Unfortunately, it was not a simple process, and when it seemed that a new photo was unlikely to be available in the short term, the author decided to use the Meen and Tushingham photo, which Nicola Woods at the Royal Ontario Museum (Toronto, Ontario, Canada) kindly provided.

Figure 25: This recent photo shows the ~60 ct Nur al-'Ayn pink brilliant diamond in the centre of a tiara designed by Harry Winston for Farah Diba to wear at her marriage to Shah Mohammed Reza in 1958. Photo courtesy of the National Jewelry Treasury, Central Bank of the Islamic Republic of Iran.

Dr Ahadnejad subsequently forwarded an excellent new photo of the tiara that he arranged through the management of the National Jewelry Treasury in Tehran (again, see Figure 25). It is important to show it here not simply because it illustrates what is quite possibly the largest brilliant-cut pink diamond in the world, but because it also reveals that the older photo, as supplied by the Royal Ontario Museum, was reversed. The new photo shows the correct orientation and provides a far clearer view of this slightly misshapen but highly important diamond.

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PEARLS

Cultured Abalone Pearls from Chile

Chile is an important aquaculture producer of abalone meat for the Asian market, with exports reaching 1,000 tonnes per year. In 2012, a research project for producing cultured abalone pearls was started by the University of Antofagasta in northern Chile under the leadership of authors RAV and JMZ. The goal was to develop a new source of income for Chilean abalone farmers. First attempts led to the successful production of prototype blister and whole cultured pearls (e.g. Figure 26), and international patent applications followed (e.g. Araya Valencia *et al.* 2017).

In 2016, one of the larger abalone companies in Patagonia made available about 800 of the animals for grafting with spherical beads (6 mm in diameter). In August 2018, after a growth period of 16 months, about 14% of the molluscs produced whole cultured pearls with nacreous outer layers of 0.5–0.6 mm thickness. About 50% of them were of acceptable gem quality and showed a variety of colours, often combining hues of gold, blue, silver and green.

Importantly, nearly all of the abalone survived the grafting process; the mortality rate was only ~1%, thus demonstrating to abalone farmers that culturing pearls would, in the long run, not disturb their main business of producing meat. It is hoped that this initiative will eventually evolve into a Chilean cultured abalone pearl industry that will successfully market its own 'Abalone Patagonia Pearls', although more research is needed to achieve this aim. For example, one of the next steps will focus on increasing the ratio of nacre to organic substance secreted by the mantle cells when coating the bead, thus improving the quality of the cultured pearls.

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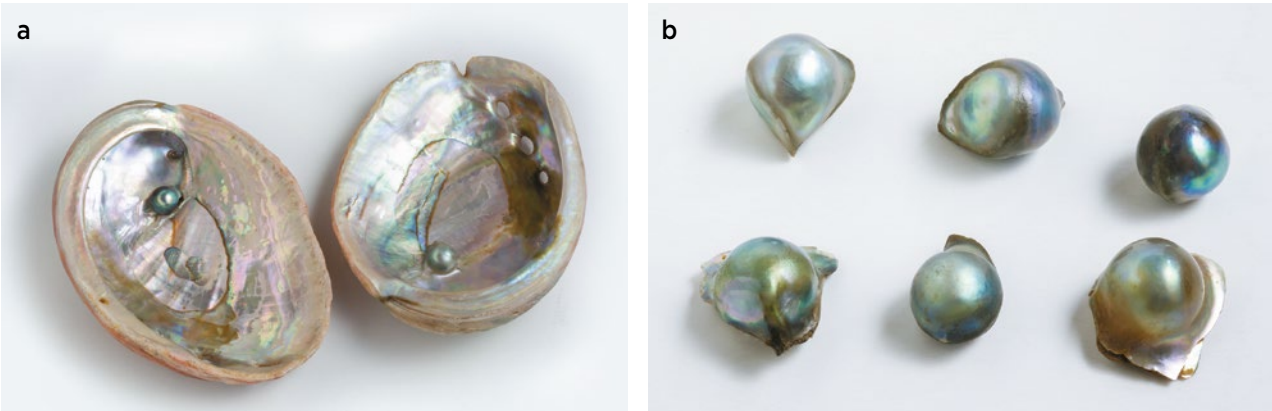

Figure 26: Experimental culturing of abalone pearls in Patagonia, Chile, yielded (**a**) these blisters attached to the shells (which are 10 and 12 cm long) and (**b**) this assortment of whole cultured pearls. Both the blisters and the whole cultured pearls were produced using 6-mm-diameter beads and are overgrown by a layer of nacre that is 0.5–0.6 mm thick. Photos courtesy of R. Araya Valencia and J. Maturana Zuñiga.

Pearls from *Tutufa bubo*

During the February 2019 Tucson gem shows, Pacific Coast Pearls (Petaluma, California) displayed for the first time natural pearls from the marine gastropod *Tutufa bubo*, commonly known as the giant frog snail (Figure 27). Named by Carl Linnaeus in 1758, the species is notable for its large size, as the shell can attain a length of more than 30 cm. It lives in relatively shallow waters (up to 180 m deep) of the Red Sea and Indo-Pacific region, where it feeds primarily on sea stars (see www.marinespecies.org/aphia.php?p=taxdetails&id=476597).

Figure 28: These rare pearls from *Tutufa bubo* weigh 31 ct (left) and 38 ct (right). Photo courtesy of the Rankin family/Pacific Coast Pearls.

Figure 27: The giant frog snail *Tutufa bubo* (here, approximately 20 cm long) is the source of the pearls described in this report. Photo courtesy of the Rankin family/Pacific Coast Pearls.

The two pearls shown in Tucson, weighing 31 and 38 ct, represent true novelties (Figure 28). Both had symmetrical pear shapes, the larger (about 30 mm long) being more pointed than the other. The larger pearl showed an evenly distributed orange colour that became yellow at the broader end, while the smaller pearl had an overall yellowish colour. Both had porcelaneous lustre, with a barely perceptible flame structure (comparable to that of conch and *Tridacna* pearls) that was visible in places. The pearls reportedly originated from the Indo-Pacific Ocean, but no information was available as to their specific location or date of discovery.

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SYNTHETICS AND SIMULANTS

Eulytine Inclusions in a Manufactured Glass—A Rare Encounter

In November 2018, the American Gemological Laboratories (AGL) received two faceted samples for identification. They were slightly brownish orange and lacked lustre and shine (Figure 29). Both were acquired by Marcus McCallum FGA, a gem dealer in Hatton Garden, London, who purchased them already cut from a merchant based in southern Africa. The merchant, in turn, had reportedly bought them from an 'itinerant' source in Zimbabwe. Unfortunately, we were unable to obtain further information regarding their origin. McCallum provided the samples to Charles Evans (Gem-A, London) and Kerry Gregory (Gemmology Rocks, Rochester), who then sent them to AGL for further testing.

Both pieces displayed numerous eye-visible inclusions, which were dipyramidal and colourless (Figure 30). The samples were singly refractive (1.645 and 1.650), and we measured hydrostatic SG values of 3.16 and 3.11. The higher SG corresponded to the greater abundance of inclusions in the pear-shaped specimen. The RI and SG data proved inconclusive for identifying the samples, so we undertook ultraviolet-visible and Fourier-transform infrared spectroscopy, but these were also inconclusive. EDXRF chemical analysis of both samples showed major amounts of Al, Si, Mn, Ca and Na with traces of Fe, Mg, Ti, Ba and Sr. Such a composition (except for Na) could be expected for

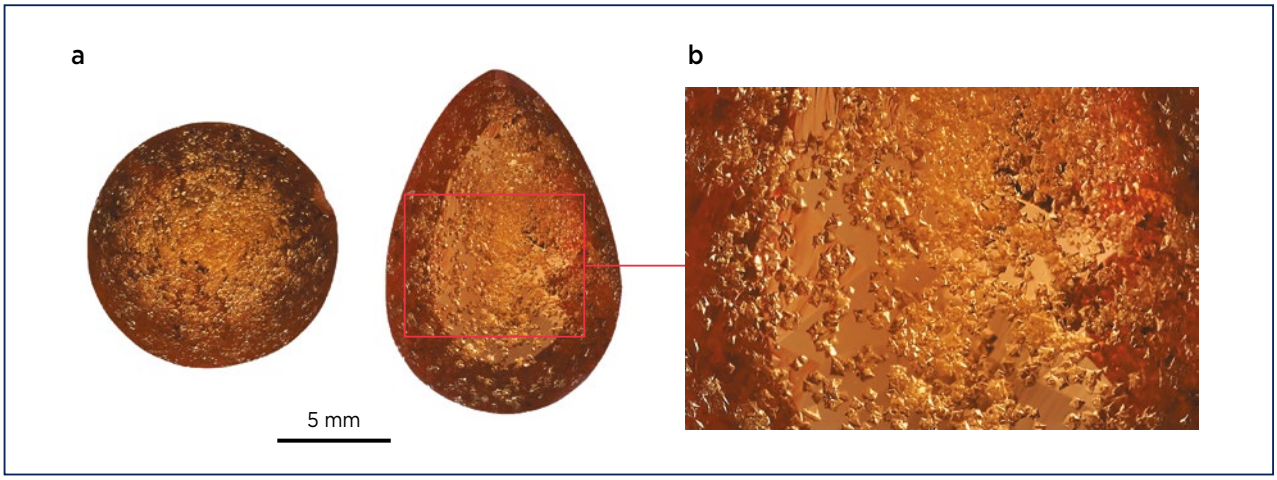

Figure 29: (**a**) These brownish orange round (1.38 ct) and pear-shaped (1.76 ct) samples were submitted to AGL for analysis. They proved to consist of manufactured glass, and (**b**) contained abundant inclusions that were identified as eulytine. Photos by Alex Mercado, AGL.

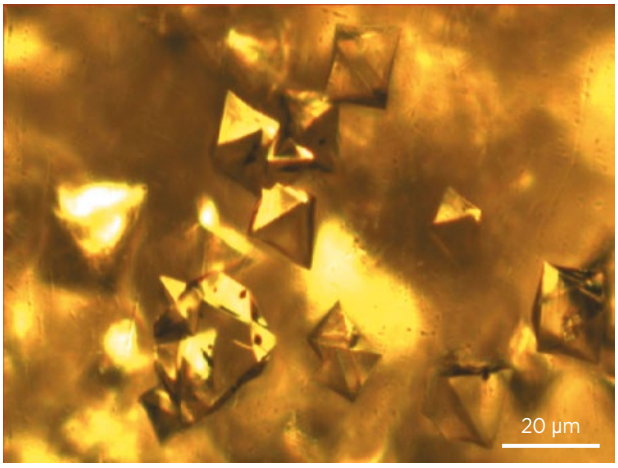

Figure 30: Magnification of the eulytine inclusions reveals their bipyramidal shape. Photomicrograph by R. Zellagui, transmitted light.

grossular-spessartine. However, since the other properties differed from the garnet family, further investigation was necessary to identify these samples.

Raman microspectroscopy of the matrix material of both samples presented intense broad bands at around 800–1100 cm^{-1} and another band in the 400–600 cm^{-1} region (Figure 31), which are characteristic of manufactured glass (White & Minser 1984). Furthermore, Raman analysis of the (surface-reaching) inclusions revealed they were eulytine ($Bi_4Si_3O_{12}$; Figure 32).

The only reference we could find for a host matrix containing eulytine inclusions was for bismuth-germanium oxide crystals ($Bi_4Ge_3O_{12}$, also called BGO; see Piekarczyk *et al.* 1978). Single crystals of BGO are grown for their exceptional electro-optical, electro-mechanical

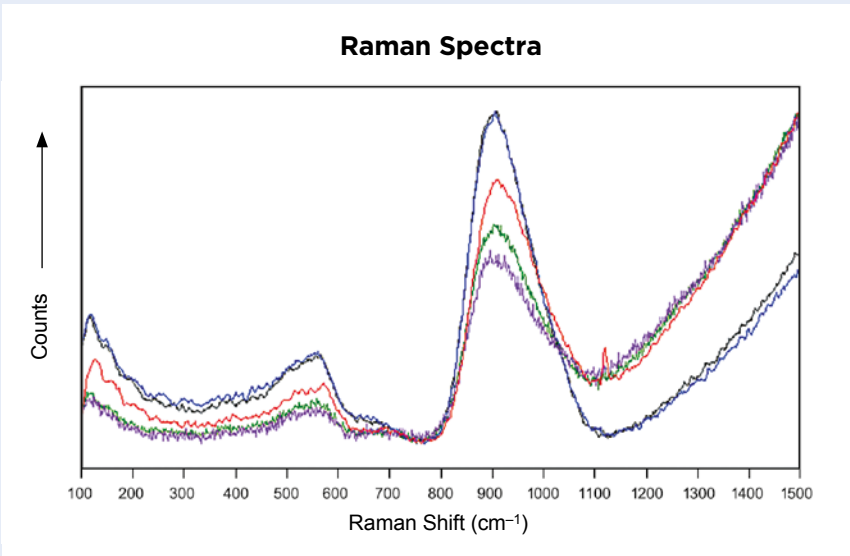

Figure 31: Raman spectra of the matrix of both samples reveal broad features associated with a glass. The different analyses were performed on various areas of both samples.

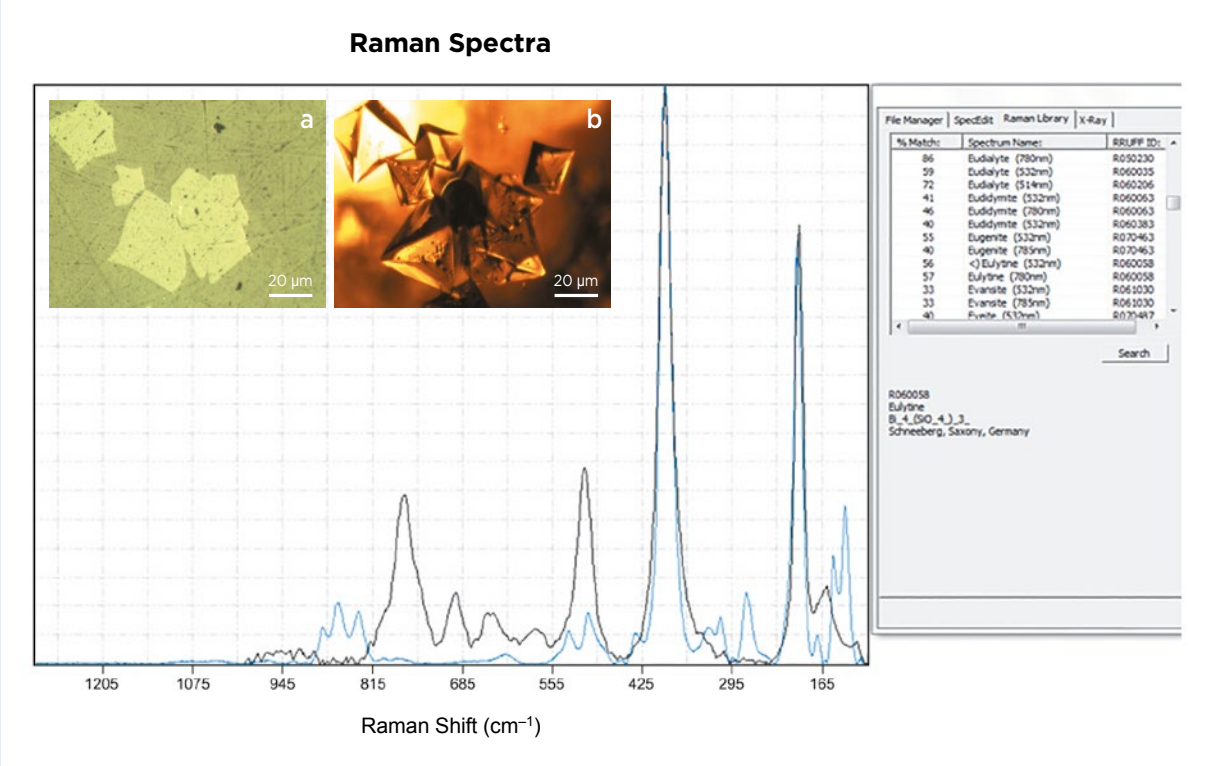

Figure 32: Raman spectroscopy of the inclusions (black line) shows a fairly close match to eulytine in the RRUFF database (blue line). Inset photomicrographs by R. Zellagui, in (**a**) reflected light and (**b**) transmitted light.

and luminescence properties (Takagi *et al.* 1981), as scintillometers, for example (Gévay 1987). Various mechanisms of BGO crystal growth are known, but most important is the Czochralski method. With this technique, single crystals of BGO can be produced that sometimes have cloudy inclusions identified as eulytine (Piekarczyk *et al.* 1978). These impurities considerably modify the optical and physical properties of the crystal.

Our hypothesis is that the present glass samples are sub-products or by-products of the production of BGO or a similar material for industrial applications, in which eulytine inclusions precipitated out of a melt. It is presumed that the low transparency of the pieces led them to be discarded, only to be 'recycled' into the gem industry as faceted material. Nevertheless, EDXRF analyses performed on various locations of both samples did not reveal Bi or Ge (as would be expected for a BGO material; also Bi from the eulytine inclusions), and the reason for this is unknown. The presence of the eulytine inclusions in a glass is witness of its manufactured nature.

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Opal Doublets from Slovakia

The most famous gem material from Slovakia is play-of-colour opal (also known as precious opal). The deposits occur in the eastern part of the Western Carpathians, in the Libanka and Šimonka mountains of eastern Slovakia, near Dubník, Prešov District, between Zlatá Baňa and Červenica. The stones are commonly called 'Hungarian' opals because this region was part of Hungary until the end of World War I (Rondeau *et al.* 2004; Caucia *et al.* 2013). Historically, these deposits were the only source of gem opal in Europe, and represented the largest and most significant play-of-colour opal deposits from Roman times to the 19th century. They dominated the world opal market until the discovery of play-of-colour opal in Australia (Caucia *et al.* 2013), resulting in the closure of the Dubník mines in 1922–1923.

The modern history of Dubník opals began in the 1990s after a new geological survey of the area indicated the deposit appeared to be economically profitable (Semrád 2015). However, administrative problems delayed the start of opal mining. Then, starting in 2008, large quantities of play-of-colour opal from Wollo (or Welo/Wello), Ethiopia, entered the market, so the project to renew opal mining near Dubník was abandoned (Semrád 2015). At present it is possible to find only small quantities of mostly low-quality rough opal from Dubník at regional mineral shows in Slovakia or the Czech Republic. This recent production comes from local collectors who dig the opal from old tailings piles.

The Dubník material has been found as pure masses of opal, as well as boulder and matrix varieties. It has a white to very pale milky grey body colour, and the play-of-colour is mostly limited to blue and violet (although not as bright as Mexican or Australian opal), with bright red spots being rare.

Figure 33: These doublets (0.38–2.08 ct) are formed by a top portion of play-of-colour opal from Dubník (Slovakia) cemented to a base of Slovakian obsidian. Photo by J. Štubňa.

Doublets and triplets made from Dubník opal were not known historically because such composites were first developed only towards the end of the 19th century (Semrád 2015). Recently, however, we encountered opal doublets with a Slovakian gem dealer at a local mineral show in Bratislava (Figure 33). According to the dealer and the authors' own investigations, the doublets consist of Dubník opal that has been cemented to a base formed by another local material: obsidian from the Tokaj Mountains of Slovakia (Štubňa *et al.* 2019). So far, only six pieces have been produced experimentally, in round, oval and pear shapes that ranged from 5.52 × 3.56 mm (0.38 ct) to 8.60 × 8.60 mm (2.08 ct). Viewed from the side, their assembled nature is clearly seen (Figure 34). The obsidian portion is semi-transparent and exhibits inclusions and a banded texture

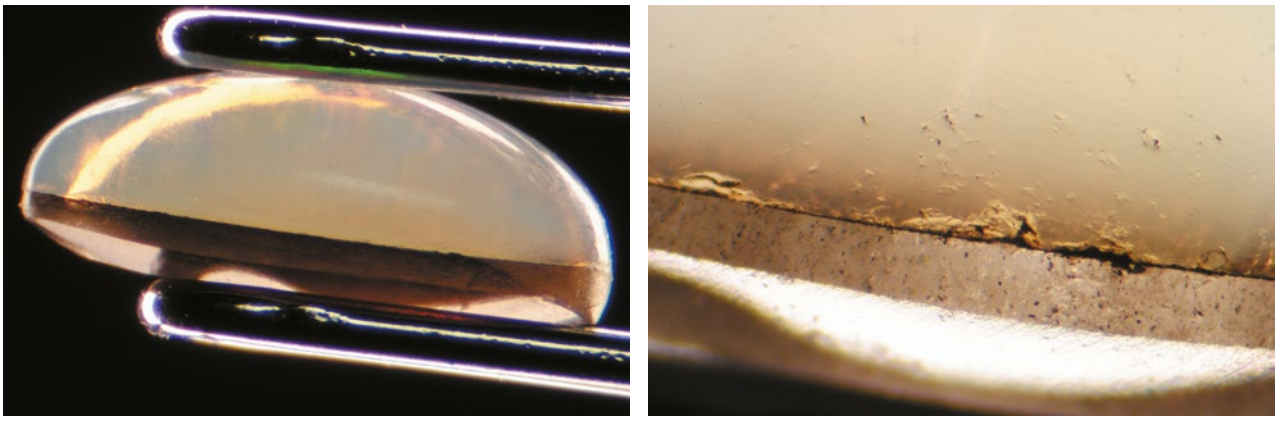

Figure 34: (**a**) Viewed from the side, the composite nature of this opal-obsidian doublet is obvious. (**b**) Higher magnification reveals dark-coloured cement at the interface between the opal and obsidian. Photomicrographs by J. Štubňa; magnified 7.5× (a) and 20× (b).

that are typical of this material (cf. Štubňa *et al*. 2019; Figure 35). The overall dark appearance of some of these doublets is due to the dark colour of the obsidian and the cement used to assemble these composites, causing them to resemble black opal. Therefore their face-up appearance may be confused with doublets of play-of-colour opal from Australia.

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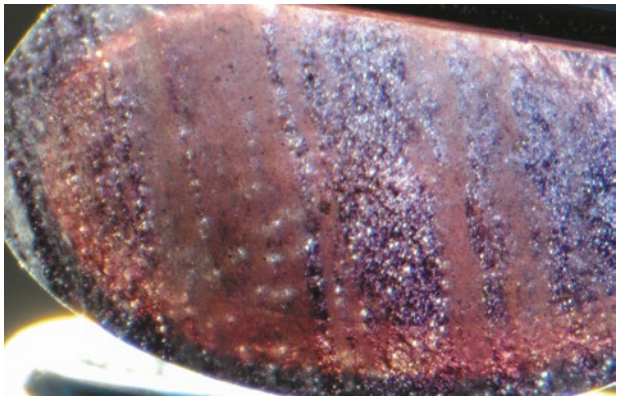

Figure 35: The base of this doublet shows a banded texture within the semi-transparent obsidian. Photomicrograph by J. Štubňa; magnified 10×.

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TREATMENTS

Heated Sapphires with Unstable Colour Centres

Recently there has been a renewed focus on certain sapphire varieties that may exhibit a colour shift (or tenebrescence) as a result of unstable colour centres (Krzemnicki *et al*. 2018; American Gemological Laboratories [AGL] 2019; Krzemnicki & Cartier 2019). Over the past year, AGL has been collecting data on gem corundum that may display unstable colouration, specifically pink, padparadscha, orange and yellow sapphires.

The potentially unstable colour centre causing the colour shift is a trapped-hole centre related to Mg^{2+}. This is a naturally occurring phenomenon and is generally stable. However, in certain circumstances, trapped-hole centres are unstable for reasons that are not yet fully understood. When stable, the Mg^{2+}-related trapped-hole centre is active and responsible for the yellow colour in the vast majority of yellow sapphires (see, e.g., Emmett & Douthit 1993). Moreover, it is also an essential contributing chromophore in orange sapphires and in the orangey colour component of padparadscha sapphires. However, when the trapped-hole centres are not stable, there are two states: (1) the colour centre is inactive and therefore does not contribute to a stone's colour appearance, and (2) the colour centre is activated by exposure to UV radiation and then contributes to the observed colour. The trapped-hole colour centre can be returned to its relaxed (inactive) state by exposing the stone to the heat of a lamp (or otherwise warming it) for a brief period.

At the time of the April 2019 AGL press release, our data had shown that such changes in colour can occur in both unheated sapphires and in those that had been heated at relatively low temperatures. That release further indicated that the colour shifts had thus far not been observed in stones heated at relatively higher temperatures.

Recently, however, AGL examined five sapphires that displayed unexpected results when subjected to colour stability testing. They ranged from colourless to very pale blue and light yellow when they were first examined (Figure 36a). After exposure to short-wave UV radiation for 10 minutes, all five stones exhibited a distinctly stronger yellow colouration (Figure 36b). What was unexpected was that all five sapphires revealed clear evidence of having been heated at relatively high temperatures. This

Figure 36: (**a**) These heat-treated sapphires (2.63–4.19 ct) ranged from colourless to near-colourless (pale blue) and pale to light yellow when they were initially examined at AGL. (**b**) Exposing them to short-wave UV radiation for a period of 10 minutes activated unstable colour centres and caused a distinctly stronger yellow colouration. For each case, the stones are shown table-up (left) and from the side (right). Photos by Alex Mercado and Bilal Mahmood, AGL.

was apparent from the presence of heavily altered mineral inclusions, as well as thermally induced and altered stress fractures and partially healed fissures (Figure 37).

Previously it was thought that the heating process stabilised these colour centres, meaning that a colour shift would no longer be observed. The present discovery proves this is not always the case, which has direct implications for gemmological laboratories and the trade at large. Until now, colour-stability tests have been largely relegated to unheated sapphires. The more recent observations that unstable colour centres may be present in sapphires heated at relatively low temperatures—and now at relatively high temperatures—indicate that virtually all sapphires in the colour range of pink through padparadscha and orange to yellow, as well as colourless to near-colourless, should be tested for their colour stability regardless of their unheated or heated condition.

It remains unclear as to why a colour shift was not observed previously in sapphires heated at relatively high temperatures. However, one factor might be the kinds of sapphires that are typically submitted for laboratory testing, which consist of strongly coloured stones. Therefore, the potential influence of trapped-hole centre absorption may be minimised or reduced. Furthermore, the total trace-element composition (relative to Mg content) of more strongly coloured sapphires may provide a better environment to stabilise the trapped-hole centres than lighter stones with a reduced total trace element composition (again relative to Mg: see, e.g., Emmett *et al.* 2003).

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Figure 37: Each of the five sapphires with an unstable colour revealed clear evidence of relatively high-temperature heat treatment, including heavily altered mineral inclusions surrounded by tension fractures, thermally altered and induced stress fractures, and partially healed fissures. Photomicrographs by C. P. Smith; magnified 60× (a), 52× (b) and 48× (c).

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MISCELLANEOUS

2019 Rough Stone Sales in Myanmar

Kachin State in northern Myanmar has an area of more than 89,000 km^2, and is bounded on the north and east by China, and partially on the north-west by India. It hosts a portion of Myanmar's important jadeite deposits (i.e. near Hpakan). The Kachin people, with great effort and enthusiasm, formed the Kachin State Gems and Jewellery Entrepreneurs Association in Myitkyina Township, and organised the second rough jade emporium there on 14–18 May 2019 (Figure 38). The chairman of the association opened the emporium, in the presence of a large crowd, at the association's facility in the industrial zone of Sitapur Quarter. Attendees consisted of parliamentary members, gem merchants and departmental officers. Total jade sales at the emporium amounted to 6,573.98 million kyats, representing 384 lots sold out of 492 lots offered. Panhoke Duwa Co. paid the highest price for a single lot: 4,637.77 million kyats for lot 93, weighing 53,354 kg.

Figure 38: In May 2019, a rough jade emporium was held in Myitkyina, northern Myanmar. Photo courtesy of T. Hlaing.

On 8–13 June 2019, Myanmar Gems Enterprise held its seventh sale (in kyats) for local merchants of gem and jade rough material in Nay Pyi Taw. Attendees included 1,140 jade merchants and 53 gem dealers. Total sales were 60,891.97 million kyats, obtained from 3,011 jade lots (60,529.88 million kyats) and 45 gem lots (362.09 million kyats). The highest price was paid for jade lot no. 2983 containing four pieces weighing 8,330 kg, which sold for 520.09 million kyats. The gem emporium included 127 ruby and 63 sapphire lots, but only 10 ruby lots (eight of which were from Mong Hsu) and 26 sapphire lots were sold. Other sales included peridot and topaz, but none of the lots were sold of amber, amethyst, aquamarine, garnet, goshenite, moonstone, quartz, rubellite and zircon. Overall, proceeds from this year's emporium were higher than at the previous rough stone sale that took place in November 2018 (Table II).

Table II: Total sales at the 2018 and 2019 rough stone emporiums in Nay Pyi Taw.

Date	Lots shown	Lots sold	Total sales (million kyats*)
November 2018	3,435	3,235	49,093.39
June 2019	3,368	3,060	60,891.97

* 1 kyat = 0.00055 British pound or 0.00067 U.S. dollar.

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The Fire Within

"For in them you shall see the living fire of the ruby, the glorious purple of the amethyst, the sea-green of the emerald, all glittering together in an incredible mixture of light."

– Roman Elder Pliny, 1st Century AD

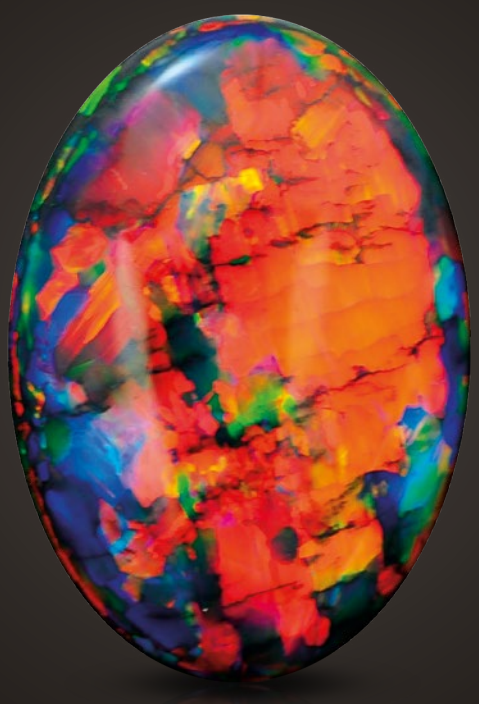

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JOG

Selecting a Diamond Verification Instrument Based on the Results of the Assure Program: An Initial Analysis

Harold Dupuy and Jon C. Phillips

ABSTRACT: Recently, the rapid growth in synthetic diamond production—particularly in melee sizes—and the salting of melee parcels with synthetics have generated a commensurate increase in the need for diamond verification instruments (DVIs). Ongoing independent third-party testing of these instruments is being done through the Assure Program. DVI performance is tested in a UL laboratory using carefully developed testing standards and sample sets (i.e. natural diamonds and as-grown and treated synthetics, as well as simulants as appropriate). The initial phase of testing was performed during latter 2018 and the first part of 2019, and as of July 2019 results for 16 widely available devices from 12 DVI manufacturers were published online in the Assure Directory (https://diamondproducers.com/assure/assure-directory). From these test results, the authors have evaluated several important parameters that will help users select the best instrument for their needs. Performance results from several additional DVIs are expected to be released in the near future, and further testing and publication of the data will occur as new instruments are introduced and existing ones are updated.

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Conversations within the gem and jewellery trade on how to separate natural from synthetic diamonds have been ongoing for decades. General Electric succeeded in growing synthetic diamonds in the mid-1950s (Bruton 1978), but several decades passed before such products became commercially available in sizes and qualities suitable for gems (i.e. in the mid-1980s from Sumitomo Electric Industries in Japan; Shigley *et al.* 1986). Today, synthetic diamonds are readily available for gem and jewellery use, both legitimately—when they are sold and identified as such—and nefariously, when they are intentionally represented as natural or the customer is allowed to infer that they are natural without proper disclosure from the seller (Rapaport 2013). Large quantities of small-sized synthetics (especially <0.05 ct) produced using high-pressure, high-temperature (HPHT) growth methods are readily available in variable clarities and in the D–N colour range, particularly from Chinese manufacturers (Eaton-Magaña *et al.* 2017). Chinese factories produce approximately 200,000 carats of HPHT-grown melee per month (Shigley 2017), and production capacity continues to increase. In addition, synthetic diamonds grown by chemical vapour deposition (CVD) are improving in quality and are undergoing limited commercial production for the gem industry (Eaton-Magaña & Shigley 2016). At the same time, reports have been circulating of melee diamond parcels (e.g. Figure 1) and jewellery being salted with synthetics (e.g. Poon *et al.* 2016; Bhoir *et al.* 2017; Ambalathveettil *et al.* 2018), causing concern in the trade. Stories on the Internet and in other consumer

Figure 1: There is growing concern in the gem and jewellery industry over the presence of synthetics and simulants in diamond parcels, particularly for melee-sized goods such as those shown here. Photo courtesy of De Beers Group Industry Services.

media have also highlighted problems surrounding undisclosed synthetics and simulants, and the average jeweller must contend with the fact that they could unknowingly be dealing in these products.

An experienced gemmologist who remains current on the growth technology and properties of the synthetics (both HPHT and CVD grown) can, in some cases, distinguish between natural and laboratory-grown diamonds through the use of classical gemmological tools. However, this is impractical for situations in which numerous stones (often melee-sized) must be quickly and cost-effectively tested on a regular basis. While several gem-testing laboratories offer melee screening services (e.g. Figure 2), it can be expensive and impractical to send quantities of diamonds to labs, and the cost and lost time make it desirable in some cases to have access to in-house instrumentation.

Numerous diamond verification instruments (DVIs) are currently on the market for diamond testing, and as of this writing the authors have identified 49 devices from 24 manufacturers (Table I). Some DVIs have been available for more than two decades (e.g. Welbourn *et al.* 1996), but many have only recently been released. Manufacturers claim their instruments can separate colourless to near-colourless natural from synthetic diamonds and from some simulants or, at a minimum, refer those in question for further testing. These instruments range from relatively inexpensive to very costly, and present a diverse array of marketing claims and features (Drucker & Phillips 2018). Hundreds of businesses in the supply chain have acquired these instruments and base their hard-earned reputations on the results they produce. However, until recently, there was no independent means to verify the accuracy and reliability of such testing and screening devices.

In 2017, the Diamond Producers Association (DPA) proactively sought to address this problem by creating an initiative named Project Assure (Freedman 2017), which was subsequently renamed the Assure Program. This initiative is managed by DPA with support from Signet Jewelers (Akron, Ohio, USA). As of July 2019, the results

Figure 2: Melee screening services are offered by several gem-testing laboratories. The diamonds in this parcel were identified as natural by the International Institute of Diamond Grading & Research. Photo courtesy of De Beers Group Industry Services.

Table I: Assure-tested and untested diamond verification instruments.[a]

Instrument	Manufacturer	Website
Assure tested		
AMS2	De Beers Group Industry Services (UK)	www.debeersgroupservices.com/instruments/automated-melee-testing
ASDI	SATT Gems (Switzerland)	www.sattgems.ch/asdi
DiamondDect 3	Taidiam Technology (Zhengzhou) Co. Ltd (China)	http://en.taidiam.com/product/11.html
DiamondDect 5	Taidiam Technology (Zhengzhou) Co. Ltd (China)	http://en.taidiam.com/product/11.html
DiamondSure	De Beers Group Industry Services (UK)	www.debeersgroupservices.com/instruments/diamondsure
DiamondView	De Beers Group Industry Services (UK)	www.debeersgroupservices.com/instruments/diamondview
G-Certain	Massive Tech Lab (India)	www.massivetechlab.com/g-certain
GemPen	Gemometrics (Sweden)	https://gemometrics.com/product/gempen
GIA iD100	Gemological Institute of America (USA)	www.gia.edu/id100
GV5000	National Gemstone Testing Center (China)	www.ngtc.com.cn/index.php?m=Article&a=show&id=485
J-Certain	Massive Tech Lab (India)	www.massivetechlab.com/j-certain-a-synthetic-diamond-detector-for-studded-jewellery
Leo[b]	Gemlogis (Hong Kong)	www.gemlogis.com/product-details/leo
M-Screen+[c]	HRD Antwerp (Belgium)	http://hrdantwerp.com/en/equipment/detail/m-screen
Sherlock Holmes[d]	Yehuda Diamond Co. (USA)	www.yehuda.com/shop/hphtmachine
SYNTHdetect	De Beers Group Industry Services (UK)	www.debeersgroupservices.com/instruments/synthdetect
Synthetic Diamond Screener II	Presidium (Singapore)	https://presidium.com.sg/psdproduct/synthetic-diamond-screener-ii-sds-ii

from 16 tested instruments (see Table I and Figure 3) have been published in the Assure Directory (https://diamondproducers.com/assure/assure-directory), both as summary web pages and as more detailed downloadable PDF files. The results are complicated and somewhat confusing to interpret due to the wide variety of parameters, as well as the range of DVI features and capabilities. For example, it is necessary to simultaneously consider whether an instrument is designed for screening or testing, can take loose and/or mounted stones, can test for simulants, and will provide results that are automated or require the user's interpretation, as well as several other variables (speed, cost and reliability). These choices and considerations can be overwhelming, and until now the results of the testing done so far and their implications have only been briefly discussed (e.g. Freedman 2019).

This article describes the Assure Program's initiative of rigorously evaluating the performance of several commercially available DVIs (as of July 2019). The authors summarise the testing procedures, sample sets and results of instrument performance, and consider implications for selecting an appropriate DVI from those tested so far.

BACKGROUND

Both authors work in the diamond and jewellery wholesale business and have considerable experience with testing diamond parcels using various DVIs. Neither author is associated with the Assure Program or its affiliates, nor were they involved in the testing of the DVIs. During the preparation of this article, the authors obtained information from Lisa Levinson, DPA's strategic project manager, and Thomas Gelb, a technical consultant to the Assure Program who assisted with the development of testing standards but did not take part in the actual DVI evaluation process.

For the initial phase of testing, DPA reached out to DVI manufacturers representing the most widely available devices in the market. Many responded, but not all. Those DVI manufacturers that chose to participate paid a fee directly to the testing organisation (UL, described below) to cover the cost of the testing process. In 2018, final arrangements were made with 11 manufacturers to test 18 DVIs, and as of July 2019 the results obtained for 16 of them (see Table II) were published in the Assure Directory. After undergoing the

Table I: (continued)

Instrument	Manufacturer	Website
Not Assure tested		
Alpha Diamond Analyzer	HRD Antwerp (Belgium)	https://hrdantwerp.com/en/equipment/detail/alpha-diamond-analyzer
Alrosa Diamond Inspector	Alrosa Technology (Russia)	https://alrosa-inspector.com
D-Guard	Sparrow Technologies (India)	http://sparrowdg.com
D-Screen[e]	HRD Antwerp (Belgium)	https://hrdantwerp.com
D•Secure+	DRC Techno (India)	https://drctechno.com/products/gemological/d-secure-plus
D-Tect	HRD Antwerp (Belgium)	https://hrdantwerp.com/en/equipment/detail/d-tect
DFI Mid-UV Laser+	GGTL Laboratories (Liechtenstein and Switzerland)	www.ggtl-lab.org/products.html
DiamondPlus	De Beers Group Industry Services (UK)	www.debeersgroupservices.com/instruments/diamondplus
Diasure	Maruti Enterprises (India)	www.diatech.co.in
DiaTrue CL	OGI Systems Ltd (Israel)	www.ogisystems.com/diatruexl.html
DiaTrue CM	OGI Systems Ltd (Israel)	www.ogisystems.com/diatrue.html
DiaTrue CS	OGI Systems Ltd (Israel)	www.ogisystems.com/diatruecs.html
DiaTrue Mobile	OGI Systems Ltd (Israel)	www.ogisystems.com/diatruemobile.html
DS2000	Nanjing Baoguang Testing Technology (China)	www.bgyq.cn/spe/spe.html
DS5000	National Gemstone Testing Center/Nanjing Baoguang Testing Technology Co. Ltd (China)	www.ngtc.com.cn/index.php?m=Article&a=show&id=486
GEM-3000 Jewelry Detector	Guangzhou Biaoqi Optoelectronics Technology Development Co. Ltd (China)	www.gzbiaoqi.com/ProductShowen.asp?ArticleID=9
GEM-Smart Portable Jewelry Detector	Guangzhou Biaoqi Optoelectronics Technology Development Co. Ltd (China)	www.gzbiaoqi.com/ProductShow.asp?ArticleID=387
GIA DiamondCheck	Gemological Institute of America (USA)	https://store.gia.edu/DiamondCheck-p/215000.htm
GLIS-3000	Guangzhou Biaoqi Optoelectronics Technology Development Co. Ltd (China)	www.gzbiaoqi.com/ProductShowen.asp?ArticleID=66
J•Detect 9000	DRC Techno (India)	https://drctechno.com/products/gemological/j-detect-9000
J•Mini	DRC Techno (India)	https://drctechno.com/products/gemological/j-mini
J-Screen (formerly EXA by Magilabs)	HRD Antwerp (Belgium)	https://hrdantwerp.com/en/equipment/detail/j-screen
J•Smart Pro	DRC Techno (India)	https://drctechno.com/products/gemological/j-smart-pro
Jewellery Inspector	Gemetrix Pty Ltd (Australia)	www.gemetrix.com.au/JewelleryInspector.html
Melee Inspector	Gemetrix Pty Ltd (Australia)	www.gemetrix.com.au/melee.html
NDC-415 Natural Diamonds Chooser	Guangzhou Biaoqi Optoelectronics Technology Development Co. Ltd (China)	www.gzbiaoqi.com/ProductShow.asp?ArticleID=388
PL-3000	Guangzhou Biaoqi Optoelectronics Technology Development Co. Ltd (China)	www.gzbiaoqi.com/ProductShowen.asp?ArticleID=67
PL5000	National Gemstone Testing Center (China)	www.ngtc.com.cn/index.php?m=Article&a=show&id=487
PL-Inspector	Gemetrix Pty Ltd (Australia)	www.gemetrix.com.au/PLinspector.html
Q-Chk++	Gemological Institute of India and Arotek Scientific Instruments (India)	https://giionline.com/q-chk-adc
Screen-I	SmartPro (Thailand)	www.smartproinstrument.com/event-2/screen-1
SSEF Diamond Spotter	Swiss Gemmological Institute SSEF (Switzerland)	www.ssef.ch/instruments-books
Vista	Gemlogis	www.gemlogisusa.com/gemlogis-vista.html

[a] To the authors' knowledge, this list was current as of 1 July 2019, and is subject to change as instruments are updated, newly released and/or discontinued.
[b] Leo has been discontinued. The tested device was acquired on the open market, so Gemlogis is not an Assure Partner.
[c] Succeeded by M-Screen 4.0.
[d] Succeeded by Sherlock Holmes 2.0.
[e] According to HRD Antwerp, the D-Screen was still available at press time, although it is no longer being produced and is not shown on their website.

Figure 3: As of July 2019, the Assure Program had tested 16 diamond verification instruments. From left to right, these are: (top row) AMS2, ASDI, DiamondDect 3 and DiamondDect 5; (second row) DiamondSure, DiamondView, G-Certain and GemPen; (third row) GIA iD100, GV5000, J-Certain and Leo; (bottom row) M-Screen+, Sherlock Holmes, SYNTHdetect and Synthetic Diamond Screener II. These photos were supplied to the Assure Program by the instrument manufacturers.

testing, the instruments were returned to the submitting manufacturers.

The Assure Tested Certification Mark (Figure 4) is made available only to Assure Partners, that is, manufacturers that have agreed to submit their instruments for testing by the Assure Program. The certification mark simply indicates that a particular DVI has been tested by the Assure Program, and does not indicate any performance criteria or results. Therefore it is important to look beyond the certification mark and evaluate the actual test results.

Figure 4: The Assure Tested certification mark may be used only by DVI manufacturers that submit their instruments for testing in the Assure Program.

Table II: Specifications of the Assure-tested instruments.[a]

Instrument	Portability	Dimensions (W × D × H, in cm)	Weight (kg)	Operation category[b]	Detects or refers synthetics	Sample size range (ct)	'Smalls Sample' tested
AMS2	Desktop	31.5 × 40 × 55	25	3	Detects	0.0033–0.20	Yes
ASDI	Floor	170 × 90 × 160	350	2	Refers	0.002–0.20	Yes
DiamondDect 3	Portable	22 × 20 × 12	3	1	Detects	0.005–10	Yes
DiamondDect 5	Desktop	20 × 23 × 29	7	1	Refers	0.005–10	Yes
DiamondSure	Portable	17 × 26 × 10	3.5	1	Refers	0.005–10	No
DiamondView	Desktop	20 × 40 × 25	13	1	Detects	0.01–10	No
G-Certain	Desktop	30 × 30 × 37	12	1	Detects	0.001–10	Yes
GemPen	Portable	24 × 3.6 × 3.2	1	1	Detects	Any	Yes
GIA iD100	Portable	16.5 × 20 × 8	1	2	Refers	0.005+	Yes
GV5000	Desktop	50 × 25 × 61	17	3	Detects	0.002–20	Yes
J-Certain	Desktop	43 × 34 × 52	22	1	Detects	0.002–10	Yes
Leo[f]	Portable	20.3 × 14 × 11.4	0.73	3	Refers	0.01–12	No
M-Screen+	Desktop	45 × 30 × 55	45	2	Refers	0.005–0.20	Yes
Sherlock Holmes	Portable	15 × 24 × 15	2.2	1	Detects	Any	Yes
SYNTHdetect	Desktop	31 × 34 × 45.8	30	2	Refers	0.001–100	Yes
Synthetic Diamond Screener II	Portable	13 × 10 × 6.5	0.2	1	Refers	0.02–10	No

Instrument	Colour range	Shapes allowed	Single or multiple samples[c]	Mounted jewellery	Auto-feed and dispense	Operator skill level[d]	Cost (USD, Feb. 2019)
AMS2	D–J	All	Multiple	No	Automatic	Novice	45,000
ASDI	D–J	Round	Multiple	No	Automatic	Novice	Not listed
DiamondDect 3	D–J	All	Single	Yes	Manual	Novice	5,730
DiamondDect 5	D–J	All	Multiple	Yes	Manual	Novice	5,730
DiamondSure	D–J	All	Single	Yes	Manual	Novice	18,200
DiamondView	All	All	Single	Yes	Manual	Expert	35,000
G-Certain	D–Z	All	Multiple	Yes	Manual	Novice	9,999
GemPen	D–Z[e]	All	Multiple	Yes	Manual	Expert	2,300
GIA iD100	D–J	All	Single	Yes	Manual	Novice	4,995
GV5000	D–N	All	Multiple	Yes	Manual	Expert	43,200
J-Certain	D–Z	All	Multiple	Yes	Manual	Novice	13,999
Leo[f]	D–M	All	Single	Yes[g]	Manual	Novice	499
M-Screen+	D–J	Round	Multiple	No	Automatic	Novice	63,000
Sherlock Holmes	D–K	All	Multiple	Yes	Manual	Expert	6,495
SYNTHdetect	D–J	All	Multiple	Yes	Manual	Expert	17,000
Synthetic Diamond Screener II	D–J	All	Single	Yes[g]	Manual	Novice	599

[a] Sample size range, colour range and shapes allowed are as reported by the manufacturer.
[b] Operation category is illustrated in Figure 5.
[c] Single = tests one sample at a time; multiple = tests more than one sample at a time.
[d] Interpretation of results: novice = instrument automatically displays results (or auto-sorts the samples, as for AMS2, ASDI and M-Screen+); expert = user interprets luminescence (and growth structure when using DiamondView) to obtain results.
[e] Not designed for Fancy yellows.
[f] Device dimensions and weight obtained from Gemlogis website.
[g] Only handles open-back settings.

INSTRUMENT CATEGORIES

Thirteen of the 16 instruments are *screeners*, for which the results indicate either a natural diamond or that a sample should be 'referred' for further testing. The latter samples could consist of natural diamonds (typically type IIa), synthetic diamonds (HPHT- or CVD-grown) or simulants (e.g. cubic zirconia, synthetic moissanite, etc.). High referral rates generate extra work and expense, either in house or by sending samples to a laboratory to obtain conclusive results.

Three of the 16 instruments are *testers*, which give a conclusion as to the identity of a stone. Testers are designed to identify samples as either natural diamonds, synthetic diamonds (CVD or HPHT) or simulants. However, such instruments sometimes may 'refer' more challenging samples.

DVIs are grouped by the Assure Program into three categories based on their claimed capabilities to identify simulants and differentiate synthetics from simulants (Figure 5).

Category 1

Manufacturers of Category 1 devices state that they can correctly separate natural from synthetic diamonds in most cases. However, they cannot identify diamond simulants. They also cannot identify the specific type of synthetic diamond (HPHT or CVD). Therefore, users of Category 1 DVIs must pre-screen all samples to ensure that no simulants are present. If knowledge of the type of synthetic diamond is required, such samples will need further testing. Category 1 includes the majority (nine of 16) of the DVIs tested so far.

Category 2

Manufacturers of Category 2 instruments state that they can correctly separate natural from synthetic diamonds and simulants. Unlike Category 1, the Category 2 DVIs can recognise that synthetic diamonds and simulants are 'non-natural diamonds' and group them together under that description. They cannot tell the difference between a synthetic diamond and a simulant, just that it is not a natural diamond. Thus, samples identified by Category 2 DVIs as 'non-natural diamond' need further testing to determine whether they are synthetic diamonds or simulants. Category 2 includes four of the 16 DVIs tested so far.

Category 3

Manufacturers of Category 3 devices state that they can correctly identify and separate natural and synthetic diamonds and simulants. However, samples identified

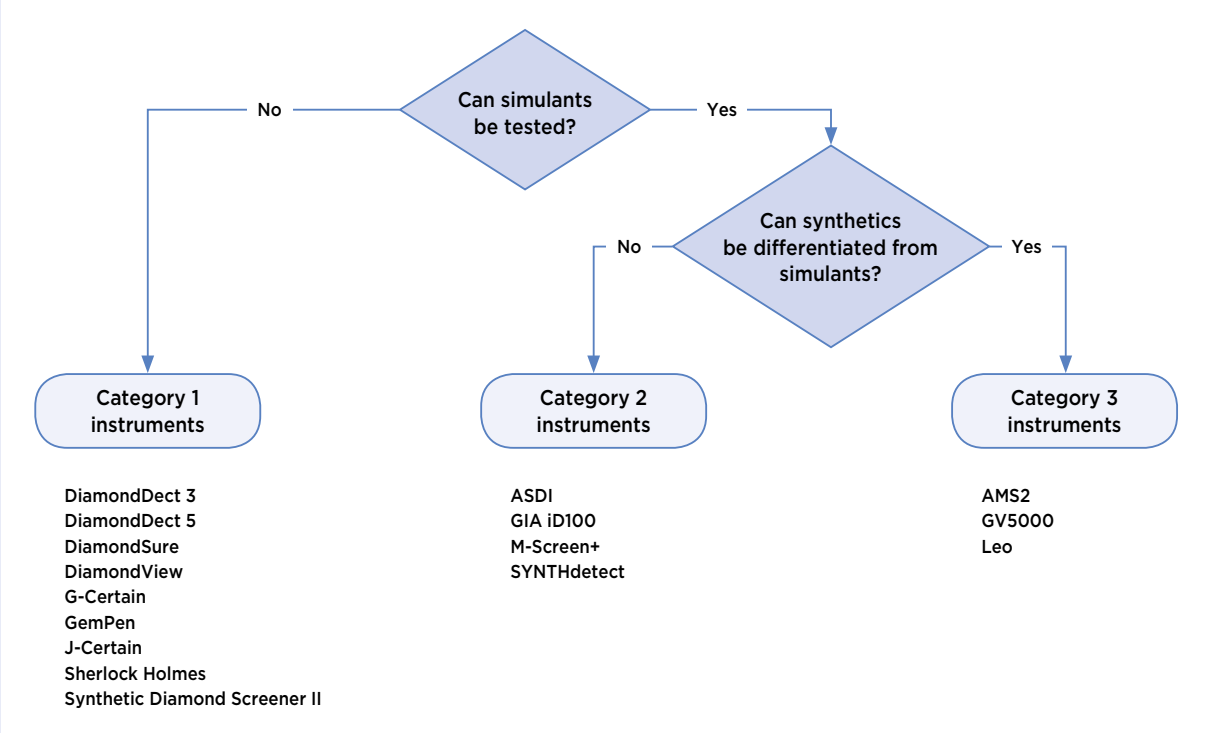

Figure 5: This flowchart shows the process for determining a DVI's operational category. The instruments listed were Assure tested as of July 2019. Courtesy of DPA.

as other than natural diamond probably will need further testing to determine the specific type of synthetic diamond or simulant. Category 3 is the most robust testing category and includes only three of the 16 DVIs tested so far.

TESTING STANDARD

The methodology by which instruments are tested by the Assure Program is called the DVI Standard, which is used to evaluate device performance in testing/screening for synthetic diamonds and/or diamond simulants. The DVI Standard was developed and applied in collaboration with UL, a well-known global standards testing company headquartered in the USA. According to the company website (www.ul.com/media-center/company-information), since 1894 UL has helped to set more than 1,600 standards defining safety, security, quality and sustainability, and the company operates in more than 143 countries and across more than 20 industries. The DVI testing was done at a UL laboratory in Canton, Massachusetts, USA, in a controlled environment with the goal of giving accurate and quantifiable testing information on the instruments.

Development of the DVI Standard was supported by the manufacturers, who collaboratively shared basic information about how their instruments operate. Efforts by the authors to obtain information from DVI manufacturers pertaining to their instruments' technology were met with limited success (see Table III), which is expected considering the desire to avoid disclosing proprietary information and perhaps also the status of pending patent applications. In any case, such technical details are beyond the scope of the present article.

The first draft of the DVI Standard was developed in early 2018 and subjected to an initial testing phase using three different instruments to ensure practical applicability. Throughout the development of the DVI Standard, expertise was provided by a technical committee of leading scientists, academics and gemmological laboratory personnel from around the world. Contributors included De Beers Group Industry Services (UK), the Federal State Budgetary Institution of the Technological Institute for Superhard and Novel Carbon Materials (Russia), Gemmological Institute of India, Gemological Institute of America, National Gemstone Testing Center (China), Scientific and Technical Research Center for Diamond (Wetenschappelijk en Technisch OnderzoeksCentrum voor Diamant or WTOCD; Belgium) and Swiss Gemmological Institute SSEF (Switzerland). All DVIs were tested using the same sample set(s) and conditions (see below) to ensure the performance results are comparable.

Table III: Instrument technology for Assure-tested DVIs, as provided by the manufacturers.

Instrument	Technology
AMS2	Time-resolved photoluminescence using short-wave UV radiation to view fluorescence and short- and long-lived phosphorescence; also takes an additional photoluminescence measurement
ASDI	Raman spectroscopy and short-wave UV transparency
DiamondDect 3	(Manufacturer did not respond)
DiamondDect 5	(Manufacturer did not respond)
DiamondSure	Visible-range absorption spectroscopy
DiamondView	Luminescence imaging of fluorescence or long-lived phosphorescence using ultra-short-wave UV radiation
G-Certain	(Manufacturer did not respond)
GemPen	'Ultra Spectrum Optical Filtering' technology that uses unique combinations of UV wavelengths and filtering to provoke variable fluorescence and phosphorescence
GIA iD100	Fluorescence spectroscopy
GV5000	(Manufacturer did not respond)
J-Certain	(Manufacturer did not respond)
Leo	(Manufacturer did not respond)
M-Screen+	(Manufacturer did not respond)
Sherlock Holmes	(Manufacturer would not disclose)
SYNTHdetect	Time-resolved photoluminescence using short-wave UV radiation to view fluorescence and short- and long-lived phosphorescence
Synthetic Diamond Screener II	Short-wave UV transparency vs. short-wave UV opacity

DPA has made the DVI Standard available exclusively to Assure Partners to create an incentive for them to submit their instruments for testing. It gives manufacturers an opportunity to do in-house testing for internal research-and-development purposes in accordance with the Standard, even in the absence of using the Assure Program's sample sets.

Testing Environment

The DVI Standard specifies particular conditions for lighting, room temperature and humidity, and no manufacturer asked to have their instrument tested outside of those parameters. Other conditions, such as the ideal power supply (i.e. operating voltage and amperage requirements), were set in accordance with the device operating manuals. These factors are important to consider because an instrument's test environment was not necessarily designed to replicate the ordinary commercial setting in which DVIs might be used. Therefore, the Assure Program specifies that the 'test results are not necessarily an indicator of how effectively the instrument would perform in normal commercial operating conditions' (Diamond Producers Association 2019). For commercial settings, DVI users should read the operating manual to learn important information about achieving optimal performance and understanding the limitations of the screening/testing instrumentation.

Sample Sets

Two main sample sets were developed by the Assure Program. The Core Sample was used for testing every instrument, while the Smalls Sample was utilised only for those instruments that could handle melee-sized stones (i.e. ≤2.0 mm diameter; see Table II). The Core Sample (e.g. Figure 6) included 1,000 natural diamonds, 200 synthetic diamonds and, when applicable, 200 diamond simulants. The Smalls Sample had a similar composition and number of specimens as the Core Sample. The very high proportion of synthetic diamonds (20%), as compared to what might be encountered in the marketplace (~2%), enabled the instruments to be tested on a broad range of synthetic diamond material. The Core Sample also included challenging custom-made synthetic diamonds that are not currently commercially available, as they are too difficult to produce and/or prohibitively costly for commercial purposes. The Assure Program used these outliers for two reasons: (1) to 'future-proof' the sample set (in anticipation of the next generations of synthetics) and (2) to help UL differentiate effectively and fairly among the instruments. Consequently, an instrument's performance in a commercial setting is likely to be better than under the test conditions (but only if the manufacturer's optimum operating conditions are adhered to).

Some further details of the sample sets are as follows:

- Core Sample: round brilliant cuts with >2.0 mm girdle diameter (~0.03–0.20 ct), D–J colour (with hints of either yellow or brown), and SI_2 or better clarity.
- Smalls Sample: round brilliant cuts with 1.0–2.0 mm girdle diameter (~0.005–0.03 ct), D–J colour (with hints of either yellow or brown), and SI_2 or better clarity. (Note that five DVIs are claimed to be able to test diamonds below 1.0 mm in diameter—AMS2, ASDI, GV5000, J-Certain and Sherlock Holmes—but the Smalls Sample did not test this range.)

Figure 6: These photos show some of the natural diamonds (left) and simulants (colourless sapphires; right) in the Assure Core Sample. Photos courtesy of DPA.

- The natural diamonds in both sets have a consistent distribution of type Ia/IIa stones.
- The synthetic diamonds include both HPHT- and CVD-grown samples, and some of them were treated (e.g. irradiated or HPHT processed after CVD growth to improve their colour).
- The simulants include cubic zirconia, synthetic moissanite, foil-backed glass and colourless synthetic corundum.

Additional sample sets were developed specifically to include lower colour grades (K–Z) and mounted jewellery (see Table IV). These sets were only used for testing those instruments described by manufacturers as having the capability to handle such samples. The results of this additional testing are included for applicable DVIs in the Assure Directory, but they are not evaluated in this article.

TEST RESULTS

Table V summarises the performance testing results for the Core and Smalls sample sets according to three parameters (listed in order of importance, as determined by the authors): false positive rate, accuracy and referral rate. The results for each of these performance metrics are expressed as percentages, and are reported separately for natural diamonds, synthetic diamonds and simulants (if applicable). The percentages may be calculated differently depending on the DVI category (1, 2 or 3), and examples illustrating the calculations for each of these cases can be downloaded from the Assure Project website at https://diamondproducers.com/app/uploads/2019/05/5.1.-ASSURE-Performance-Metrics-Infographic-20190523.pdf.

Diamond false positive rate is the most important—and most complicated—of the three performance metrics, and refers to the percentage of synthetic diamonds (and diamond simulants, if applicable) erroneously classified as natural diamond out of the total number of synthetic diamonds (and simulants) in the sample set. The optimal diamond false positive rate is 0%, meaning the instrument classified no synthetic diamonds or simulants as natural diamonds. By analogy, the *synthetic diamond false positive rate* refers to the percentage of natural diamonds (and simulants, if applicable) erroneously classified as 'synthetic diamond' out of the total number of natural diamonds (and diamond simulants, if applicable) in the sample set. The *simulant false positive rate* refers to the percentage of natural and synthetic diamonds erroneously classified as simulants out of the total number of natural and synthetic diamonds in the sample set.

Diamond accuracy is the percentage of natural diamonds that are correctly categorised as natural out of the total number of natural diamonds. The optimal diamond accuracy is 100%, in which all natural diamonds are correctly classified as natural. *Synthetic diamond accuracy* and *simulant accuracy* are defined as the fraction of test samples correctly classified by the DVI as synthetic diamonds and simulants, respectively.

Diamond referral rate is the percentage of natural diamonds that are referred for further testing out of the total number of natural diamonds in the sample set. Referred samples are unable to be classified by the DVI as natural or synthetic (and, where capable, synthetic or simulant), and require further testing to determine their identity. The lower the referral rate, the better. *Synthetic diamond referral rate* and *simulant referral rate* are the fractions of synthetic diamonds and simulants, respectively, which are referred by the DVI for further testing.

Novice or Expert Operator

The results in Table V are based on the 'Operator skill level' given in Table II, which indicates whether a novice or expert performed the testing of a particular DVI. A novice operator received an introductory level of training, which may have included reading the device's operating manual, watching video tutorials and receiving

Table IV: Additional sample sets developed by the Assure Program.

Sample set	Description
Sample B	>2.0 mm girdle diameter, K–Z colour, round brilliant cuts, mixed clarity
Sample D	1.0–2.0 mm girdle diameter, K–Z colour, round brilliant cuts, mixed clarity
Simple Jewellery	Open-back jewellery set with D–J colour, round brilliant cuts, mixed clarity
Intricate Jewellery	Closed-back jewellery set with D–J colour, round brilliant cuts, mixed clarity
Melee Jewellery	Open-back jewellery set with D–J colour, round brilliant cuts, mixed clarity

Table V: Summary of Assure Program test results for 16 diamond verification instruments.[a]

Instrument	Operation category	Core Sample test results (>2.0 mm)								
		Diamond			Synthetic diamond			Simulant		
		False positive rate	Accuracy	Referral rate	False positive rate	Accuracy	Referral rate[b]	False positive rate	Accuracy	Referral rate[b]
AMS2	3	0%	99.1%	0.7%	0.1%	70.9%	29.1%	0.1%	99.0%	1.0%
ASDI	2	0%	93.6%	6.4%	0%		100%	0%		100%
DiamondDect 3	1	0%	96.4%	0.6%	3.0%	99.5%	0.5%			
DiamondDect 5[c]	1	22.6%	91.6%	8.4%	0%		77.4%			
DiamondSure	1	0%	95.3%	4.7%	0%		100%			
DiamondView	1	0%	100%	0%	0%	100%	0%			
G-Certain	1	17.6%	99.7%	0.2%	0.1%	69.3%	13.1%			
GemPen	1	15.1%	98.7%		1.3%	84.9%				
GIA iD100	2	0%	96.7%	3.3%	0%		100%	0%		100%
GV5000	3	1.0%	98.5%		1.1%	97.5%		0.6%	98.0%	
J-Certain	1	19.6%	99.7%	0.2%	0.1%	67.3%	13.1%			
Leo	3	4.6%	51.6%	3.7%	0%		52.3%	45.2%	91.3%	0%
M-Screen+	2	0%	95.9%	4.1%	0%		100%	0%		100%
Sherlock Holmes	1	0%	97.5%		2.5%	100%				
SYNTHdetect	2	0%	99.3%	0.7%	0%		100%	0%		100%
Synthetic Diamond Screener II	1	0%	84.5%	15.5%	0%		100%			

[a] Includes results released as of 1 July 2019. Shaded areas indicate 'not applicable' (i.e. beyond the device's testing capability or the way it classifies samples; see the detailed test summary report PDFs in the Assure Directory).

in-person basic training as indicated by the manufacturer. The results obtained by a novice operator are to be expected for someone who has recently purchased and just begun using the device. Conversely, an expert operator is a representative from the DVI manufacturer or a UL technician trained by the manufacturer so that they are deemed an expert at operating the instrument. The results obtained by an expert operator are expected to be consistent with someone who is very familiar with using a specific instrument.

Instruments tested by an expert operator are also tested by a novice user for comparison, and the results for both types of operators can be found in the detailed reports available in the Assure Directory. As expected, better results overall were obtained for these DVIs when operated by an expert rather than a novice (e.g. Table VI).

SELECTING A DVI

To select the most appropriate DVI, users should first assess their needs to help match their business requirements to the capabilities of the instruments (e.g. Table VII). For example, is speed important? Are simulants to be pre-screened? Will the testing be limited to loose diamonds? If so, as principal centre stones or as batches of melee? In what colour range? Will finished jewellery be tested? If an expert operator is required, is one currently on staff? Is automation needed for volume processing, or is manual operation sufficient? Does the instrument need to be portable? And, of course, instrument cost is another important criterion.

Screening (eliminating any non-natural diamonds) is distinctly different from detection (positive identification of a synthetic diamond or a simulant). Therefore, it may be helpful to start with identifying an appropriate DVI category (again, see Figure 5). If it is necessary to simply separate synthetics from natural diamonds, then a DVI of at least Category 1 is sufficient, and the user can consider

Table VI: Example of test results for novice and expert operators of the same instrument (here, SYNTHdetect).

Parameter	Novice	Expert
Diamond false positive rate	0%	0%
Diamond accuracy	98.6%	99.3%
Diamond referral rate	1.4%	0.7%
Speed (stones/hour)	225	583

Table V: (continued)

Smalls Sample test results (1.0–2.0 mm)									Average speed (samples tested/ hour)	Instrument
Diamond			Synthetic diamond			Simulant				
False positive rate	Accuracy	Referral rate	False positive rate	Accuracy	Referral rate[b]	False positive rate	Accuracy	Referral rate[b]		
0%	98.9%	0.7%	0.1%	87.4%	12.6%	0.3%	99.5%	0.5%	2,677	AMS2
0%	93.2%	6.8%	0%		100%	0%		100%	6,511	ASDI
1.0%	90.6%	4.0%	5.5%	99.0%	0%				289	DiamondDect 3
9.4%	97.8%	2.2%	0%		90.6%				557	DiamondDect 5[c]
									193	DiamondSure
									112	DiamondView
4.7%	99.3%	0.6%	0.1%	95.3%	0%				908	G-Certain
4.7%	99.5%		0.5%	95.3%					813	GemPen
0%	95.8%	4.2%	0%		100%	0%		100%	440	GIA iD100
0.3%	97.5%		1.4%	95.3%		1.4%	100%		296	GV5000
5.8%	99.3%	0.3%	0.4%	93.7%	0.5%				792	J-Certain
									219	Leo
0%	90.9%	9.1%	0%		100%	0%		100%	12,317	M-Screen+
0%	97.8%		2.2%	100%					530	Sherlock Holmes
0%	98.1%	1.9%	0%		100%				583	SYNTHdetect
									240	Synthetic Diamond Screener II

[b] Referral rates for synthetic diamonds and simulants vary widely depending on the way each DVI categorises these sample types.
[c] Although the DiamondDect 5 can only handle HPHT-grown synthetics, the Assure sample sets contain both HPHT- and CVD-grown samples.

Table VII: Assure-tested DVIs listed according to various requirements.[a]

Requirement	Capable instruments
Identifies diamond simulants	AMS2, ASDI, GIA iD100, GV5000, Leo, M-Screen+, SYNTHdetect
Tests multiple stones at once	AMS2, ASDI, DiamondDect 5, G-Certain, GemPen, GV5000, J-Certain, M-Screen+, Sherlock Holmes, SYNTHdetect
Auto-feed and dispense	AMS2, ASDI, M-Screen+
Size <0.01 ct	AMS2, ASDI, DiamondDect 3, DiamondDect 5, DiamondSure, G-Certain, GemPen, GIA iD100, GV5000, J-Certain, M-Screen+, Sherlock Holmes, SYNTHdetect
Fancy shapes	AMS2, DiamondDect 3, DiamondDect 5, DiamondSure, DiamondView, G-Certain GemPen, GIA iD100, GV5000, J-Certain, Leo, Sherlock Holmes, SYNTHdetect, Synthetic Diamond Screener II
Mounted jewellery	DiamondDect 3, DiamondDect 5, DiamondSure, DiamondView, G-Certain, GemPen, GIA iD100, GV5000, J-Certain, Leo[b], Sherlock Holmes, SYNTHdetect, Synthetic Diamond Screener II[b]
Automatic interpretation of results	AMS2, ASDI, DiamondDect 3, DiamondDect 5, DiamondSure, G-Certain, GIA iD100, J-Certain, Leo, M-Screen+, Synthetic Diamond Screener II
Portable	DiamondDect 3, DiamondSure, GemPen, GIA iD100, Leo, Sherlock Holmes, Synthetic Diamond Screener II
Cost <USD10,000	DiamondDect 3, DiamondDect 5, G-Certain, GemPen, GIA iD100, Leo, Sherlock Holmes, Synthetic Diamond Screener II

[a] Instruments are listed in alphabetical order (see Table V for the performance results for each device). Leo has been discontinued, M-Screen+ has been succeeded by M-Screen 4.0 and Sherlock Holmes has been succeeded by Sherlock Holmes 2.0.
[b] Only handles open-back settings.

the full array of 16 DVIs (as of writing this article) in the Assure Program's test set. If simulant detection is required, then DVIs of at least Category 2 are appropriate, for which seven choices have been Assure tested. If Category 3 capabilities are needed—separating natural from synthetic diamonds, natural diamonds from simulants and synthetic diamonds from simulants—then currently there are three Assure-tested instruments with this capability.

Next, the authors suggest focusing on the most important performance metric in the test results: the diamond false positive rate (i.e. identifying a synthetic or simulant as a natural diamond). Ten of the 16 DVIs tested produced zero diamond false positive results for the Core Sample set (>2.0 mm diameter): AMS2, ASDI, DiamondDect 3, DiamondSure, DiamondView, GIA iD100, M-Screen+, Sherlock Holmes, SYNTHdetect and Synthetic Diamond Screener II. Furthermore, six of the 12 DVIs tested with the Smalls Sample set (1.0–2.0 mm) produced zero diamond false positive results: AMS2, ASDI, GIA iD100, M-Screen+, Sherlock Holmes and SYNTHdetect. In addition to diamond false positives, diamond accuracy and, finally, diamond referral rate should be considered. Across all three metrics, only one DVI scored perfectly in the Assure testing: the DiamondView at a cost of USD35,000 and requiring an expert operator.

Synthetic diamond dealers may also benefit from using a DVI, as they seek to protect their inventory from mixing with natural diamonds. For larger-sized samples (>2.0 mm) nine DVIs provided zero false positive results for synthetic diamonds (ASDI, DiamondDect 5, DiamondSure, DiamondView, GIA iD100, Leo, M-Screen+, SYNTHdetect and Synthetic Diamond Screener II). For smaller samples (1.0–2.0 mm), five DVIs had zero false positive results for synthetic diamonds (ASDI, DiamondDect 5, GIA iD100, M-Screen+ and SYNTHdetect).

When shopping for a DVI, the buyer should ask the seller 'What is the best use of this instrument?' Even more importantly, 'What are the limitations of this instrument?' In other words, what can't it do? An informed buying decision would also include questions relating to the skillset required to properly operate the instrument and any training that is offered, as well as warranty details and any service requirements/arrangements.

In the end, it is possible that more than one DVI may be required to meet one's business needs, since, for example, testing parcels of diamond melee and larger individual samples (or loose stones and jewellery) might not be practical with a single instrument.

CONCLUSIONS

Diamonds (e.g. Figure 7) are a critical component of the global gem and jewellery industry, and it is imperative to correctly separate natural stones from synthetics and simulants. Beyond statutory requirements, consumer confidence is the bedrock of the jewellery business worldwide. A single incidence of an undisclosed synthetic diamond sold as natural can cause reputational harm and even legal consequences for the seller. Furthermore, such instances may quickly reverberate across social media and potentially have far-reaching ramifications for the industry. While a false-positive result (identifying a synthetic diamond as a natural diamond) is perhaps the most egregious error, a false negative (calling a natural diamond a synthetic diamond) can also damage one's reputation.

To address such concerns, particularly for melee-sized goods, DVIs are now being sought by many segments of the jewellery supply chain (manufacturers, brokers, wholesalers and retailers). Until recently, however, there was no way to verify a DVI manufacturer's claims regarding the effectiveness of their device for screening or identifying natural and synthetic diamonds and simulants. The authors applaud the Assure Project for addressing this need, and we look forward to the release of future testing results for additional/updated DVIs as they are published in the Assure Directory.

The testing results released for the DVIs tested so far show an overall wide range of performance, and prove that not all devices are equally effective at identifying or

Figure 7: To maintain consumer confidence in diamonds, it is important to reliably separate natural, as-mined diamonds (such as the ~0.70 ct stones from Canada shown here) from synthetic diamonds or simulants. The use of one or more DVIs that have received high marks from the Assure Program can help with this endeavour. Photo courtesy of Dominion Diamonds.

screening synthetics and/or simulants. DVIs are evolving quickly, and some initially-released models have already been discontinued or replaced by second-generation units that have undergone technical and ergonomic improvements. The authors expect this 'upgrading' trend to continue as detection technology improves and stays current with advances in synthetic diamond growth technology. We therefore urge future device purchasers to check the Assure Directory for updates.

The diversity of DVI features and capabilities, combined with the testing results from the Assure Program, requires that several factors be considered when choosing an instrument. During the decision-making process, users should first determine their needs and requirements, and then consider the instrument categories and review the published Assure Program test results. In some cases, more than one DVI may be necessary to fulfil a company's business needs. Whatever instrument is used, it is critical for the operator to understand at least some of the fundamental operating science employed by it, as well as its limitations, to prevent lapsing into a 'black box' mentality of pressing a button and always expecting a correct answer. The topic is not that simple and never will be.

The synthetic diamond industry is developing rapidly and DVI manufacturers are following, not leading, the technology. As growth techniques evolve, DVIs will have to keep pace. Products such as CVD-coated simulants and 'composite diamonds' (natural diamonds with CVD synthetic overgrowths) will further challenge some of the existing instruments.

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Figure 1: The Sapphire Jubilee Snowflake Brooch was designed by Saskatchewan-based jeweller Hillberg & Berk and presented to Queen Elizabeth II in July 2017. It is composed of 48 pale to deep blue sapphires from Baffin Island (10.19 carats total weight), together with more than 400 Canadian diamonds (4.39 carats total weight), which are set in 18 ct Canadian white gold. The brooch measures 6.1 × 6.6 cm. Photo courtesy of Hillberg & Berk.

Adding Logic to Luck: Recent Advances in Coloured Stone Exploration in Canada

Lee A. Groat

ABSTRACT: Canada exhibits many of the challenges involved with exploring for coloured stones in countries with very low population densities, temperate-to-arctic climates and a lack of infrastructure hindering access to most prospective areas. Despite this, a number of discoveries have occurred, mainly during the past two decades. These include emeralds from Northwest Territories (1997) and Yukon (1998); sapphire (2002) and spinel (from 1982)—including cobalt-blue stones—from Baffin Island in Nunavut; and ruby and pink sapphire (2002) from British Columbia. Such discoveries can be assisted by undertaking scientific research into gem formation, as well as by applying exploration criteria developed elsewhere to uncharted territory. Future exploration in Canada and other countries facing similar challenges will likely benefit from additional geological studies to identify prospective areas and features; innovative means of transportation, such as boats instead of aircraft; drones for exploring rugged terrain; hyperspectral imaging for mineral sensing; surveying with UV lamps to identify minerals associated with gem mineralisation; and careful prospecting (including field mapping and collecting heavy mineral concentrates) by experienced individuals.

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Most coloured stone deposits are discovered by accident, and new finds are more likely to occur in countries with moderate-to-high population density, tropical-to-temperate climates and reasonable access to the land mass. Some gem discoveries are made while exploring for other resources, but most explorationists are unfamiliar with the geology of coloured stone deposits—and furthermore their surface exposures may be quite small—which makes them difficult to find even when they occur in areas being explored for other materials. New gem deposit discoveries are particularly challenging in Canada, with its very low population density (approximately four people per square kilometre, one of the lowest densities in the world), a challenging climate which restricts exploration and poor access to most of the land mass such that many areas can only be explored by air (usually by helicopter).

Canada is a major producer of diamonds, but apart from ammolite in Alberta and jade in British Columbia and Yukon, the country is not a significant producer of coloured stones. Nevertheless, sapphires from Baffin Island in Nunavut made headlines in July 2017 when they were included in the Sapphire Jubilee Snowflake Brooch which celebrated the 65th anniversary of Queen Elizabeth II's reign (Figure 1). Additional coloured stone discoveries—some in remote Arctic terranes—have provided encouragement for further exploration and suggest that additional deposits are awaiting discovery. Although beyond the scope of the present article on Canadian gems, the recent opening of the Arctic's first economic ruby deposit in Greenland at Aappaluttoq is also an important milestone in gem exploration and mining in this part of the world (e.g. Turner *et al.* 2019).

The goal of this article is to review the geology and discovery of various coloured stone deposits in Canada (Figure 2), and to examine how scientific study can

Figure 2: This map shows the main coloured stone deposits in Canada that are reviewed in this article.

inform exploration strategies and techniques that could be used for locating additional gem-producing areas. It is hoped that these insights will provide inspiration for future exploration activities in Canada and in other countries that share similar challenges to finding new coloured stone deposits.

EMERALD IN NORTH-WESTERN CANADA

Tsa da Glisza, Yukon

In 1998, William Wengzynowski of Archer Cathro & Associates (1981) Ltd. (Vancouver, British Columbia, Canada) was exploring for volcanogenic massive sulphide deposits in talus on the north side of a ridge in south-central Yukon, when he found green crystals that, on closer inspection, revealed a hexagonal outline. He was confident that they were emerald, and his identification was later confirmed by powder X-ray diffraction at the University of British Columbia.

At this locality, subsequently named Tsa da Glisza ('green stone' in the Kaska language), the emerald occurrence is underlain by a granite pluton containing 9.8 to 13.2 ppm Be. The mineralisation is associated with quartz–tourmaline veins and aplite dykes that intruded chlorite–plagioclase schist containing on average 960 ppm Cr (Groat *et al.* 2002). Emeralds occur most commonly at the margins of the quartz veins, but are also found within the veins themselves and in alteration zones surrounding them. The granite is inferred as the source of Be for several reasons, including its close proximity to the deposit, the consistent correlation of Be with Sn, W and Bi in whole-rock and soil geochemical data, and the boron isotopic composition of the tourmaline that is consistent with a granitic source of B (Galbraith *et al.* 2009). The Cr chromophore in the emerald is most likely derived from the schist (Groat *et al.* 2002).

Emerald mineralisation occurred synchronous with regional deformation and metamorphism related to intrusion of the 112 million-year-old (Ma) granite pluton (Neufeld *et al.* 2004). In particular, mineralisation was syn- to late-tectonic, coinciding with the waning stages of granite emplacement, and took place at temperatures of 365–498°C (Marshall *et al.* 2003). There appears to be a genetic link between (1) the granite intrusion, aplite and pegmatite bodies, and (2) the beryl-bearing quartz veins, which is supported by the presence of beryl in at least two of the aplite dikes (Neufeld *et al.* 2003, 2004; Neufeld 2004). Chromium entered the fluid system and interacted with the Be-bearing fluids by either (1) mixing with hydrothermal fluids that had interacted with the host schist and extracted Cr, or (2) via element exchange during metasomatic alteration (in which the composition of the rock changes as the result of the introduction or removal of chemical constituents adjacent to the vein by the mineralising fluids). The geology suggests that, in the recent classification scheme of Giuliani *et al.* (2019), Tsa da Glisza is a type I (tectonic-magmatic related), subtype A (hosted in mafic-ultramafic rocks) deposit.

True North Gems Inc. (Vancouver, British Columbia, Canada) built an all-season mining camp near the deposit (Figure 3) and spent the better part of a decade and several million dollars evaluating the deposit using geochemical prospecting, geological mapping, trenching, core drilling and underground work via an adit (see Rohtert & Montgomery 2002; Davison 2005,

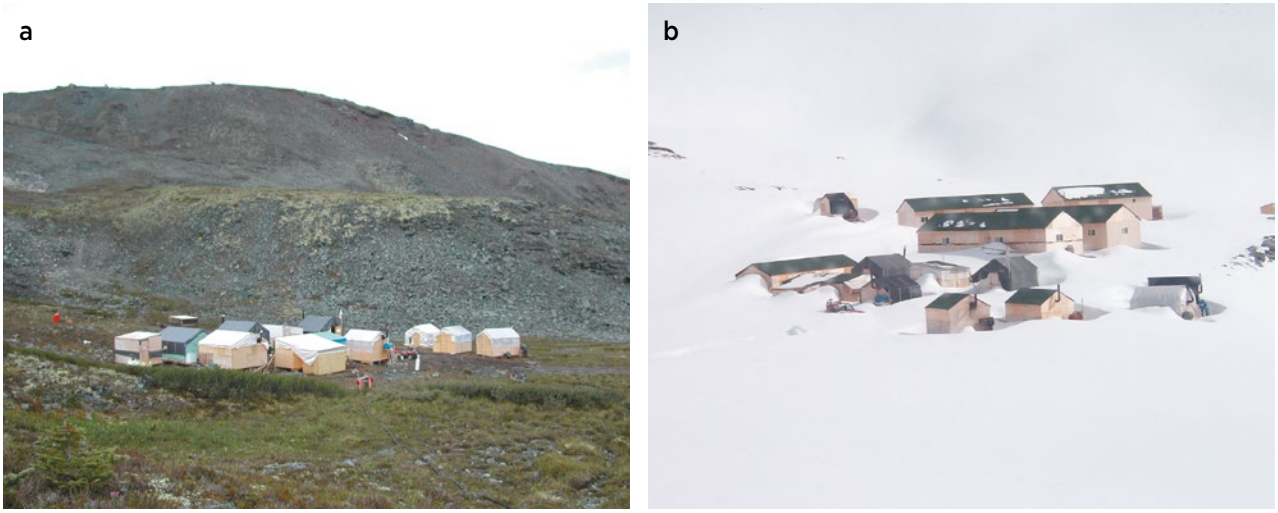

Figure 3: The mining camp at the Tsa da Glisza emerald deposit is shown here in (**a**) summer 2002 and (**b**) winter 2004. Photos by (a) L. A. Groat and (b) courtesy of True North Gems Inc.

2006; Figure 4). The results showed that although there is much emerald material showing good colour, the majority of the crystals have been affected by post-crystallisation deformation and therefore could only yield rather small cut stones (Figure 5a). Although some gems up to approximately 2.5 ct were cut, they were quite rare. After limited sales of loose stones and experiments with setting the emeralds in melee jewellery (Figure 5b), the company concluded that mining would not be economic, and the deposit was abandoned after environmental rehabilitation in 2013.

Lened, Northwest Territories

In 1997, prospector Ron Berdahl discovered emeralds at Lened in western Northwest Territories (Figure 6), approximately 160 km north-east of the Tsa da Glisza deposit. The emeralds are hosted by quartz veins that cut skarn and older strata proximal to the ~100 Ma Lened pluton. Approximately half of the 26 outcropping quartz veins contain opaque-to-translucent beryl crystals, which range from colourless to yellowish green to bluish green. Almost all of the crystals are euhedral, but less than 5% of the beryl is transparent and bluish green (and therefore can be considered pale emerald; Figure 7). The crystals are typically <0.5 cm wide and may attain a length of up to 5 cm; only a few stones have been cut from this material.

Lake *et al.* (2017) used field relationships, geochronology, whole-rock geochemistry, stable isotopes and

Figure 4: William Wengzynowski washes material sampled from Tsa da Glisza in 1999, a year after his discovery of emeralds there. Photo by L. A. Groat.

Figure 5: Faceted emeralds from Tsa da Glisza show attractive colour but are typically small. (**a**) These three stones were assessed at USD1,500 per carat but weigh only ~0.1 ct each (up to ~3 mm in longest dimension). Stones courtesy of Bradley S. Wilson; photo composite by Tom Fa/Panotora. (**b**) Melee-size emeralds are featured in these pendants set in gold (left) and silver (right). Photo courtesy of True North Gems Inc.

Figure 6: At the Lened occurrence in Northwest Territories, emeralds occur in quartz veins cutting a skarn (white area in top-centre, in front of black mudstones). An old cabin is seen in the foreground and a tent used during prospecting in 2002 is shown in the background. Photo by L. A. Groat.

Figure 7: The Lened deposit is the source of these pale emerald specimens, which include a euhedral crystal on quartz and a 0.17 ct faceted stone (inset). Photos by Donald J. Lake and Tom Fa/Panotora (inset; specimen courtesy of Bradley S. Wilson).

mineral chemistry to assess the sources of the emerald-forming fluids and chromophores. The results showed that the emerald occurrence is related to the proximal pluton and can be classified as a type I (tectonic-magmatic related), subtype B (hosted in metasedimentary rocks) deposit (Giuliani *et al.* 2019). Beryllium and other incompatible elements (i.e. W, Sn, Li, B and F) in the emerald, vein minerals and surrounding skarn were introduced during the terminal stages of crystallisation of the Lened pluton. Decarbonation during pyroxene-garnet skarn formation in the host carbonate rocks probably caused local overpressuring and fracturing that allowed ingress of magmatic-derived fluids and formation of quartz-calcite-beryl-scheelite-tourmaline-pyrite veins. The chromophoric elements (V>Cr) were mobilised by metasomatism of metasedimentary rocks that underlie the emerald occurrence (Lake *et al.* 2017).

Emerald Exploration 2003–2004

The Tsa da Glisza and Lened discoveries, as well as reports of numerous beryl occurrences in north-western Canada, suggested that emerald-focused exploration could result in more discoveries. In mid-2002 the author approached True North Gems Inc. with a proposal for an emerald exploration programme. Archer Cathro & Associates (1981) Ltd. was hired to develop targets using publicly available data—primarily regional geochemical surveys (mostly of silt samples) and assessment reports filed by companies—and their own extensive database of traverse reports, geochemical data and geological maps. The target development involved four steps, the first of which was to search the databases for occurrences of beryl, other Be-bearing minerals such as chrysoberyl and potential accessory minerals such as tourmaline. The second step was to consider geochemical reservoirs as suggested by Murphy *et al.* (2002), who plotted potential Be sources (plutonic rocks) and Cr and V reservoirs (ultramafic rocks, volcanic rocks and the Earn Group black shale) in Yukon, and suggested looking for emeralds where these elements come together. The third step was to consider the reservoirs in more detail as suggested by Lewis *et al.* (2003), who noted that all known beryl occurrences in Yukon are intrusion-related, but for an intrusion to become enriched enough to reach beryllium saturation to form beryl it must be 'ultra-fractionated'. Numerous lithological and geochemical features (e.g. accessory mineralogy, Rb/Sr ratio from whole-rock analyses, K/Rb ratio in K-feldspar and others) can help pinpoint fractionated pegmatites with elevated gem potential. The fourth step was to search the regional geochemical survey data for enrichment in the chromophores Cr and V. This task was constrained by the fact that in 2002–2003 these data were only available for portions of Yukon, Northwest Territories and British Columbia.

The result of this four-step programme was a list of approximately 100 targets for type I (tectonic-magmatic related) emerald deposits in Yukon, Northwest Territories and the northern part of British Columbia. During the summer of 2003 a team primarily composed of the author, William Wengzynowski, and students

Heather Neufeld and Dawn Kellet spent approximately four months evaluating 20 of the targets. No emerald was found, but the team did make other discoveries: the True Blue aquamarine prospect (Turner 2006; Turner *et al.* 2007), which produced unusually dark blue crystals that subsequently were used to confirm the cause of the blue colour in aquamarine (Groat *et al.* 2010, Lin *et al.* 2013); the Batea Pb-Zn occurrence (Davison & Skinner 2008); and the Amigo Ni-As-Cu-Pb prospect (Davison 2007). This shows that coloured stone exploration by experienced prospectors can result in the discovery of other commodities. More work was conducted in 2004, but by then interest in emerald exploration was waning because the price of gold, in particular, began to rise.

Mountain River, Northwest Territories

In 2007, a team of geologists from the Northwest Territories Geological Survey discovered green beryl (Figure 8) near Mountain River in western Northwest Territories (Mercier 2008). Although the green colour is due to the chromophores Cr and V (Mercier 2008), the stones are not transparent enough for gem use, and are therefore referred to here as green beryl rather than emerald. The beryl is hosted by extensional quartz–carbonate veins cutting Neoproterozoic sandstone and siltstone within the hanging wall of a thrust fault that emplaced these strata above Paleozoic rocks (Hewton *et al.* 2013). The occurrence was studied in detail by Hewton *et al.* (2013), who showed that the isotopic composition of water extracted from the beryl is typical of evolved sedimentary sulphate brines. The inferred temperature of vein formation is 380–415°C. Calculations based on mineral pair isotope equilibration and the typical geothermal gradient indicate vein formation at depths of 6–11 km. A Re-Os age of 345 ± 20 Ma from pyrite indicates that mineralisation was contemporaneous with estimated ages of some northern Cordilleran Zn-Pb occurrences.

Figure 8: These samples of green beryl are from the Mountain River occurrence. The largest piece is approximately 2 × 1 cm. Specimens courtesy of Donald J. Lake; photo by Tom Fa/Panotora.

Inorganic thermochemical sulphate reduction via the circulation of warm basinal brines through siliciclastic, carbonate and evaporitic rocks is thought to have liberated the elements necessary to form beryl (Hewton *et al.* 2013). The Mountain River green beryl occurrence thus represents a variant of the type II (tectonic-metamorphic related), subtype B (hosted in sedimentary rocks: black shales) emerald deposit in the classification scheme of Giuliani *et al.* (2019).

Such emerald deposits are unusual because there is no evidence for associated magmatic activity. The best (and until the Mountain River discovery, the only) examples of this type are in Colombia, where more than 200 emerald mines and occurrences produce the world's highest-quality emeralds. Colombian emeralds are hosted by extensional carbonate-silicate-pyrite veins, pockets and breccias in a black shale-limestone succession, and they are thought to have formed as a result of hydrothermal growth associated with tectonic activity (Ottaway *et al.* 1994; Giuliani *et al.* 1995; Cheilletz & Giuliani 1996; Branquet *et al.* 1999a, b). The parent fluids are inferred to have formed at depth from meteoric and formational water interacting with evaporitic sequences (Escobar & Mariano 1981; Giuliani *et al.* 2000). The occurrence of a variant of this type of deposit at Mountain River suggests the potential for Colombian-type emerald mineralisation in north-western Canada.

Colombian Emerald Exploration Criteria Applied to North-Western Canada

Both the Lened and Mountain River occurrences are hosted in rocks of the Selwyn Basin which were deposited on the passive margin of Laurentia (ancestral North America). However, unlike in the Cordillera Oriental of Colombia, where there are no significant occurrences of igneous rocks, the Paleozoic black shales and mudstones of the Selwyn Basin are commonly intruded by Cretaceous felsic stocks of the Selwyn and Tombstone plutonic suites. (Nevertheless, the closest intrusion to the Mountain River occurrence is at least 150 km away.)

Lake (2017) applied criteria for emerald exploration in Colombia to Canada's Yukon and Northwest Territories. These criteria include: (1) the Na content of stream sediments (Beus 1979); (2) the Li, Na and Pb content of soil samples from altered tectonic blocks

(Ringsrud 1986); (3) the presence of gypsum and anhydrite deposits, which provide evidence for evaporite sequences (Cheilletz & Giuliani 1996); (4) favourable structures such as thrust faults (Branquet *et al.* 1999a, b); and (5) the presence of cogenetic minerals such as fluorite, fluorapatite, parisite-(Ce) and florencite-(Ce) in heavy mineral concentrates (HMCs; Lake *et al.* 2017).

Lake (2017) applied the first criterion to stream-sediment geochemical data made publicly available by the Yukon and Northwest Territories geological surveys (the latter without Be). The criterion had to be adjusted for a number of factors, including the absence of Be data in Northwest Territories and elevated Na due to plutonic alkali feldspar weathering into black shale drainages. Lake (2017) also noted that Colombian-type emerald deposits have relatively small footprints, and regional-scale geochemical surveys with data points located 5–10 km apart might not be sufficient to show an emerald occurrence. In fact, the Mountain River deposit was not predicted by this analysis. Therefore, Lake (2017) was unsure of the usefulness of this technique with the existing data density.

Despite these constraints, Lake (2017) used multiple criteria to identify several regions of interest (Figure 9). Similar to emerald localities in Colombia, the anomalous areas within black shale units are also in the vicinity of important thrust zones (the Dawson, Tombstone and Robert Service thrusts, and the Mackenzie fold-and-thrust belt). Lake (2017) also noted that florencite-(Ce) occurs in the Rusty Shale Formation in the Mackenzie Mountains (Pouliot & Hofmann 1981) and has been recovered in HMCs from the Selwyn Range west of Lened (Falck *et al.* 2015). Lake (2017) mentioned several targets in need of follow up, but evaluating them has been constrained by available time and funds, and it is obvious that there is ample scope for additional fieldwork.

SAPPHIRE AND SPINEL ON BAFFIN ISLAND, NUNAVUT

Sapphire

In the summer of 2002, brothers Seemeega and Nowdluk Aqpik were hunting south of Kimmirut on Baffin Island when they saw a barrel-shaped blue crystal protruding from an outcrop. The brothers took the crystal back to Kimmirut, where district geologist Paul 'Jethro' Gertzbein identified it as a sapphire. True North Gems Inc. acquired the property soon after and discovered more occurrences of sapphire (colourless and yellow, as well as blue; see Figures 1 and 10) and Co-bearing spinel (see below). The company's activities were described by Rohtert & Pemberton (2005) and Rohtert (2006).

The sapphires occur in scapolite-rich calc-silicate rock hosted in marble of the Lake Harbour Group

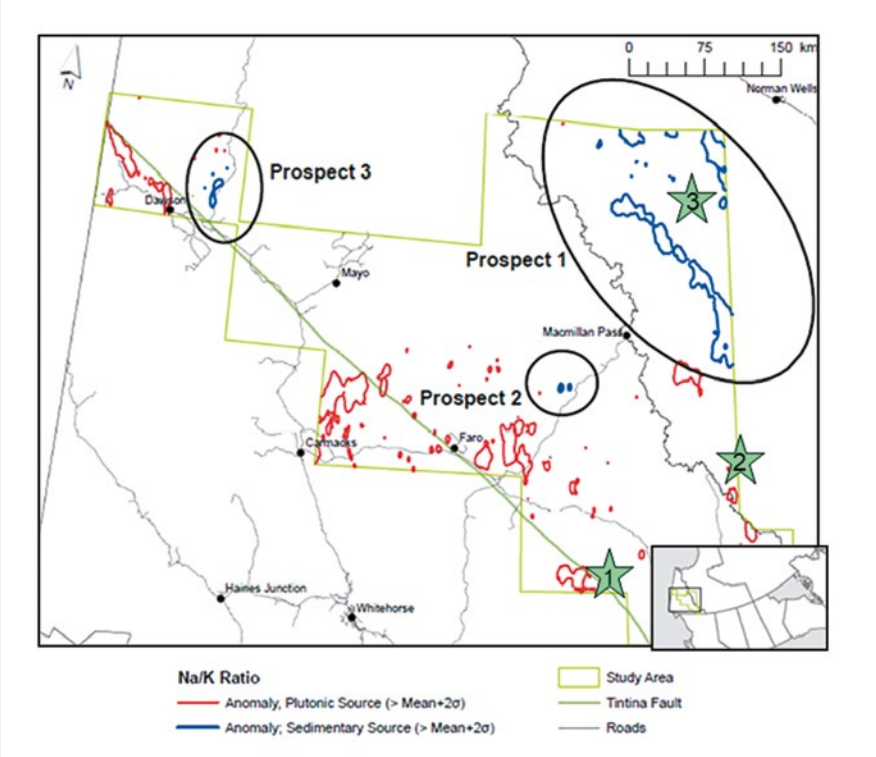

Figure 9: Areas defined by Lake (2017) as being prospective for type I (tectonic-magmatic related, shown in red) and type II (tectonic-metamorphic related, shown in blue) emerald deposits were determined using regional geochemical survey data and, in the case of the type II deposits, by applying exploration criteria developed in Colombia. Green stars indicate known occurrences (1 = Tsa da Glisza, 2 = Lened and 3 = Mountain River), and black ovals outline areas for additional exploration for type II emerald deposits, which will be a focus of future work by the author's team.

Figure 10: These sapphires are from the Kimmirut occurrences on Baffin Island. Clockwise from upper left: 1.47 ct yellow from Beluga South, 2.50 ct colourless from Aqpik, 0.58 ct blue from Beluga and 1.17 ct deep blue from Beluga. All of the gems are unheated. Stones courtesy of Bradley S. Wilson; photos by Tom Fa/Panotora.

(Figures 11 and 12). Belley *et al.* (2017) compared the Beluga occurrence of blue-to-colourless sapphires to a similar calc-silicate pod generally lacking corundum but containing nepheline (Bowhead occurrence) located 170 m south-southwest. They concluded that corundum formation depended on three equally important sequential metamorphic reactions: (1) formation of nepheline, diopside and K-feldspar (inferred) at granulite facies peak-metamorphic conditions; (2) partial retrograde replacement of the peak assemblage by phlogopite, oligoclase, calcite and scapolite (Me_{50}–Me_{67}) as a result of CO_2-H_2O-Cl-F-bearing fluid influx at 1,782.5 ± 3.7 Ma (720°C, 6.2 kbar); and (3) retrograde breakdown of scapolite + nepheline (with CO_2- and H_2O-bearing fluid) to form albite, muscovite, corundum and calcite. Based on thermodynamic models, the corundum-forming reaction occurred only in a <100°C temperature window, with the upper limit determined by scapolite-nepheline stability and the lower limit determined by the formation of Al-silicate rather than corundum. The protolith was inferred to be dolomitic argillaceous marl (calcareous sediments) with no evidence to suggest the initial presence of evaporites (Belley *et al.* 2017). Belley *et al.* (2017) concluded that in the Baffin Island area, the most prospective areas are contiguous to the thrust fault separating the Lake Harbour Group and Narsajuaq

Figure 11: The Beluga sapphire occurrence is shown here after extraction of a bulk sample. Note the characteristic mottled appearance of the calc-silicate rock within the marble, and also the diamond-bladed chainsaw (at the end of the hose) used for removing pieces of the sapphire-bearing rock. Photo by Bradley S. Wilson.

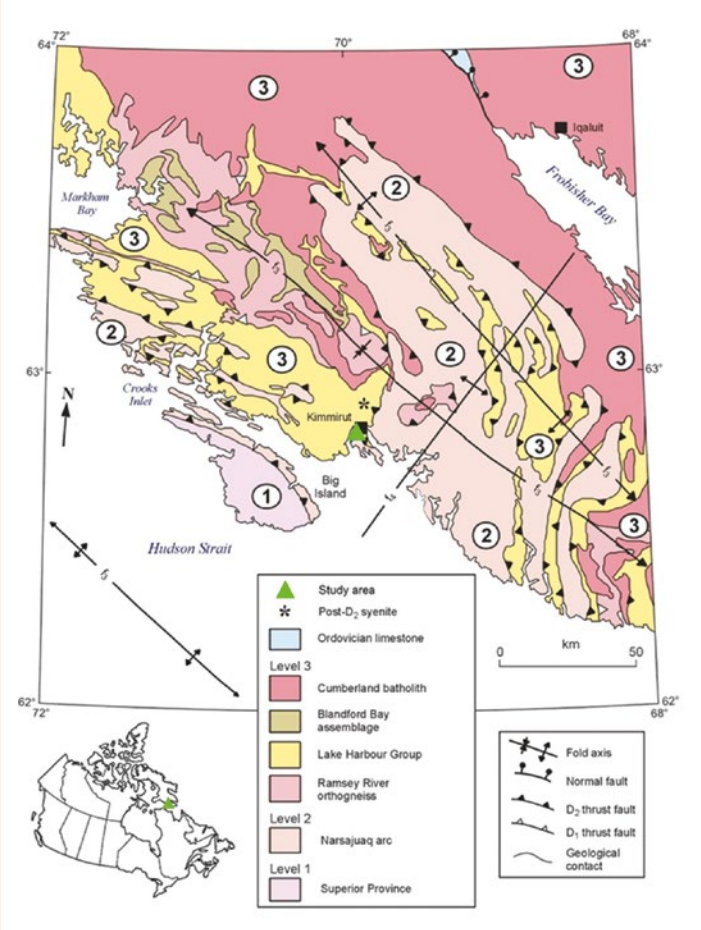

Figure 12: This map shows the location of known sapphire occurrences (green triangle) and the regional geology of south-western Baffin Island. Level 1 refers to rocks composing the margin of the Superior Province basement (~2.80 billion years old), Level 2 to rocks of the Ungava terrane (crustal material from one tectonic plate accreted to crust lying on another plate) and Level 3 to rocks of the Meta Incognita terrane. The most prospective areas for sapphire are contiguous to the thrust fault separating the Lake Harbour Group and Narsajuaq terranes (Belley *et al.* 2017). Modified after St-Onge *et al.* (2001).

terranes (Figure 12), where the metamorphic conditions are most favourable for the formation of corundum.

From 2007 to 2010, employees of True North Gems Inc. used headlamps equipped with multiple UV wavelengths to explore for associated scapolite (which is strongly fluorescent) and discovered approximately 15 new sapphire occurrences. Scapolite could be seen fluorescing up to 5 m away, but exploration was constrained by the limited hours of darkness in the Arctic summer (Lepage & Rohtert 2006). Turner *et al.* (2017) studied rock samples from the Baffin Island sapphire occurrence in the laboratory using imaging spectroscopy in the short-wave infrared region (~975–2500 nm). The unique spectral responses they encountered suggest that high spatial-resolution hyperspectral imaging could be used to map and explore for gem corundum targets during regional surveys.

Spinel

Gem spinel is widespread in the Lake Harbour Group on Baffin Island. Wilson (2014) described the following occurrences: (1) violet crystals up to 3 cm in marble near the Soper River lapis lazuli occurrence; (2) blue and violet crystals up to 3 cm at Waddell Bay; (3) violet crystals up to 4.5 cm in a mica exploration trench at Soper Lake; (4) violet crystals in 'chondrodite' at Soper Falls; (5) violet crystals up to 5 cm at Glencoe Island (see also Grice *et al.* 1982); (6) cobalt-blue, mostly opaque pieces up to 1 cm discovered by employees of True North Gems Inc. at the Qila occurrence near Kimmirut (Figure 13); and (7) cobalt-blue, occasionally transparent and heavily fractured crystals up to 2.7 cm, also discovered by employees of True North Gems Inc., at the Trailside occurrence near Kimmirut. Small faceted gemstones (almost all under 0.5 ct) and a 2.14 ct cabochon have been produced from these localities (Wilson 2014).

Belley & Groat (2019) studied spinel from 14 localities in the Lake Harbour Group. Most was blue to violet and not of gem quality, with the exception of the vivid blue, Co-bearing (0.03–0.07 wt.% CoO) stones from the Qila and Trailside localities. The spinel mostly occurs in metasedimentary (*sensu stricto*) deposits, with the exception of two metasomatic occurrences at Markham Bay. All of the spinels occur in marble and calc-silicate/silicate-rich metacarbonate rocks. Minerals occurring

in a stable assemblage with spinel include calcite, dolomite, phlogopite, pargasite, diopside, humite, forsterite, scapolite, anorthite, graphite and pyrrhotite. The spinel formed under peak granulite-facies metamorphic conditions, and at two localities it is partly replaced by retrograde corundum.

Belley & Groat (2019) interpreted the spinel-bearing metacarbonates to have the following protoliths: (1) impure dolomite-bearing and dolomitic limestone, (2) dolomitic marl and (3) evaporitic magnesitic marl. They determined that spinel genesis in the metacarbonates is favoured by: (1) the low abundance of Si relative to Al, which is the primary control on whether spinel forms in most calc-silicate rocks; (2) low K activity limiting the formation of phlogopite and thus leaving Al available for spinel formation (this factor is predominant in marbles, but also occurs in calc-silicates); and (3) insufficient quantities of Mg or dolomite reactant in diopsidite, limiting Al incorporation into phlogopite to form spinel.

Belley & Groat (2019) noted that the spatial distribution of Co enrichment at the cobalt-blue spinel occurrences is indicative of highly localised enrichment, with possibly only small-scale (≤1 m) diffusion occurring during metamorphism. Cobalt and Ni are expected to have been enriched in the original sediment or during diagenesis (the conversion of sediment to sedimentary rock) or low-grade metamorphism. Concentrations of Co (especially) and Ni are anomalously high (up to 29 ppm, conservatively twice the expected Co concentration in a comparable metasediment), while concentrations of Fe, Mn, V, Cr and Cu are much lower than expected; this is a chemical signature that possibly, with the exception of low Fe and Mn, could be caused by diagenetic processes prior to metamorphism.

Ferrous iron was found to be the most common chromophore in Lake Harbour Group spinel (with the exception of Co-bearing spinel; Belley & Groat 2019). Too much Fe in spinel leads to overly dark colours. Pyrrhotite strongly partitions Fe relative to spinel, and therefore abundant sulphide is expected to improve the gem quality of spinel by decreasing the amount of Fe available during its crystallisation (Belley & Groat 2019).

Belley & Groat (2019) suggested that marbles containing abundant layers of metamorphosed dolomitic marl (magnesian calc-silicate) offer the best potential for gem spinel discoveries on southern Baffin Island. Small, sometimes localised variations in whole-rock Al/Si and K/Al ratios can correspond to the occurrence of spinel.

RUBY AND PINK SAPPHIRE IN BRITISH COLUMBIA

Bradley S. Wilson discovered a calcite marble-hosted gem corundum locality north-west of Revelstoke in British Columbia in 2002 (Figure 14). Several sapphires and rubies from this locality have been faceted, although the largest is under 0.5 ct.

The geology of the property is described by Dzikowski *et al.* (2014). The corundum occurs in thin, folded and stretched layers with green muscovite + Ba-bearing K-feldspar + anorthite ± phlogopite ± scapolite. Predominantly pink (locally red or purple) opaque-to-transparent corundum crystals contain elevated Cr_2O_3 (up to 0.21 wt.%), variable amounts of TiO_2 and low Fe_2O_3 (generally <0.07 wt.%). The associated micas have elevated Cr, V, Ti and Ba contents. Petrography of the silicate layers showed that corundum formed from muscovite at the peak of metamorphism (~650–700°C and 8.5–9 kbar). The corundum was preserved because, occurring in an almost pure calcite marble, it did not react with dolomite to

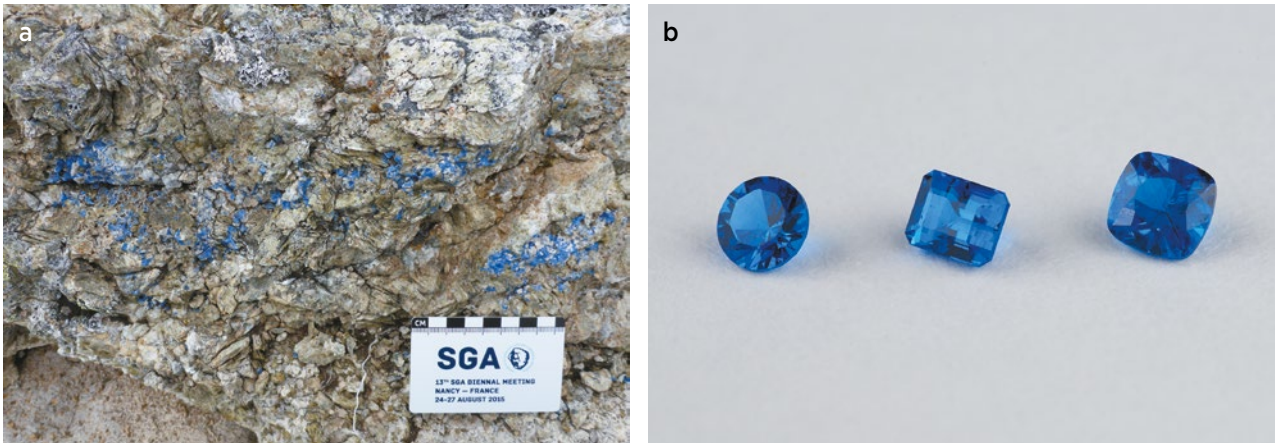

Figure 13: (**a**) This outcrop at the Qila locality on Baffin Island contains Co-bearing spinel with white carbonate in calc-silicate rock. Photo by L. A. Groat. (**b**) These Co-bearing spinel gemstones were faceted from Qila material; the largest weighs 0.16 ct. Stones courtesy of Bradley S. Wilson; photo by Tom Fa/Panotora.

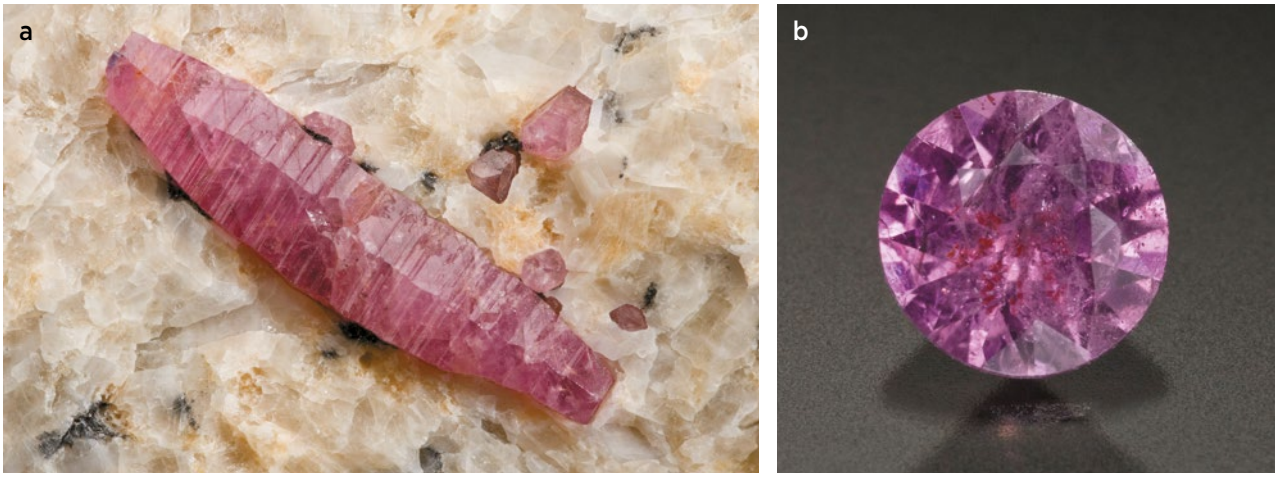

Figure 14: (**a**) The Revelstoke occurrence in British Columbia is the source of this pink sapphire (2.1 cm long) in marble. (**b**) The 0.20 ct pink sapphire shown here was faceted from Revelstoke material. Specimens courtesy of Bradley S. Wilson; photos by Michael J. Bainbridge.

form spinel + calcite during decompression. Gem-quality corundum crystals formed especially on the borders of the mica-feldspar layers in an assemblage with calcite.

Whole-rock geochemical data show that the corundum-bearing silicate (mica-feldspar) layers formed by mechanical mixing of carbonate with the host gneiss protolith. High element mobility is supported by the homogenisation of oxygen- and carbon-isotope values in carbonates and silicates within the marble and silicate layers. The silicate layers and the gneiss contain elevated contents of Cr and V due to a volcanoclastic component of their protolith (Dzikowski *et al.* 2014).

There is potential for placer gem corundum in this area, but it has not yet been evaluated. This discovery and reports of sapphire in HMCs from British Columbia, Yukon and Northwest Territories (Falck *et al.* 2015) suggest the potential for additional gem corundum occurrences as both primary and secondary (placer) deposits.

CONCLUSION AND FUTURE EXPLORATION

In addition to the emerald, sapphire and spinel occurrences mentioned in this article, several other gem localities are known in Canada, including amethyst, aquamarine, garnet, iolite, peridot, scapolite, topaz, tourmaline and zircon (see, e.g., Wilson 2014 and Figure 15), and large areas remain to be explored. How do we increase the odds of discovering new gem deposits in large, thinly populated countries such as Canada? A first step is to use geological and geochemical data to define prospective areas. These areas can then be evaluated by experienced prospectors, such as those individuals celebrated as 'Prospector of the Year' by the Prospectors & Developers Association of Canada and the Yukon Prospectors Association. Prospecting is a skill that requires concentration, and for that reason experienced practitioners often work alone and do short traverses (e.g. prospectors working in Yukon will often cover only 7 km per day). They also know that it is important to look where others haven't, for example, in talus rather than on ridge tops (see Bill Wegzynowski's discovery of Tsa da Glisza above), and to look for unusual features such as rusty areas around quartz veins (cf. Tsa da Glisza).

A significant number of exploration companies in Canada have been using drones to map claims, among other applications. The author's students Philip Belley and Donald Lake have employed a drone to explore for peridot in British Columbia. The peridot crystals occur in mantle xenoliths entrained in basaltic lava flows, and the drone was used to rule out unproductive sites by air, accomplishing an estimated two weeks of work in just three days. The drone weighs less than 1 kg and does not require any special licencing.

In the future, the author and his team intend to follow up on the ~80 emerald targets from the 2003–2004 exploration programme, and also to explore the areas highlighted for emerald by Lake (2017), as time, funding and logistics (in particular, the availability of helicopters proximal to the areas of interest) become available. The team also intends to look for sapphires by mapping and exploring the entire Lake Harbour Group on Baffin Island, especially the area contiguous to the thrust fault separating the Lake Harbour Group and Narsajuaq terranes. Given the lack of roads and high cost of helicopters, access to this area might be best accomplished from the sea; the team envisages using a converted fishing boat with drones (perhaps carrying imaging sensors) and all-terrain vehicles (perhaps towing

Figure 15: Detailed prospecting has uncovered a variety of gem occurrences in Canada, some of which are illustrated by the following stones (clockwise from upper left): a 0.94 ct peridot from Whitehorse, Yukon; a 0.68 ct elbaite from the Stargazer claim, O'Grady Lake, Northwest Territories; a 5.51 ct scapolite from Kimmirut, Nunavut; and an ~2.25 ct topaz from Mount Foster, British Columbia. Stones courtesy of Bradley S. Wilson; photos by Michael J. Bainbridge.

trailers with imaging sensors and geophysical equipment). It has been suggested that customised filtered glasses would allow us to see scapolite UV fluorescence in daylight (S. Gumpesberger, pers. comm. 2018). Although the team's focus will be on gem materials, it is likely that such an exploration programme would discover occurrences of other commodities, as happened with the emerald exploration programme in 2003–2004.

Other areas that face similar exploration challenges as Canada include Russia and Alaska (USA). Developing successful coloured-stone exploration programmes in these areas will likely require additional scientific study to identify prospective terranes and features, and also the training of prospectors. Innovative means of transport such as boats or even airships might lower the cost of exploration in distant areas that lack infrastructure. Remote observations using drones will undoubtedly play an increasing role in coloured stone prospecting, as will various types of imaging. The gem discoveries that have been made in Canada (and Greenland) in the past few decades suggest that further prospecting will identify additional coloured-stone occurrences in such areas.

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An Update on Mineral Inclusions and Their Composition in Ruby from the Bo Rai Gem Field in Trat Province, Eastern Thailand

Supparat Promwongnan and Chakkaphan Sutthirat

ABSTRACT: The Bo Rai alluvial gem field in Trat Province, eastern Thailand, was a major mining site for Thai ruby during the early 1980s, and this material continues to circulate in the gem market worldwide. For this study, approximately 1,000 Bo Rai ruby samples were examined and pre-screened for mineral inclusions. The rough stones usually formed platy, waterworn, tabular crystals with etched or resorbed surfaces. UV-Vis-NIR spectroscopy indicated a relatively high Fe content, which was confirmed by trace-element analysis. Solid inclusions typically consisted of Al-rich pyroxene, plagioclase and pyrope with subordinate sillimanite and spinel (both of which are reported here for the first time), as well as sulphides and silicate melt inclusions. The inclusion assemblage of pyroxene, plagioclase, pyrope and spinel closely resembles the mineralogy of mafic granulite xenoliths in alkali basalt associated with the Bo Rai gem field, which supports ruby formation in mafic granulite prior to being transported to the earth's surface via basaltic eruptions.

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For decades, Thai ruby has been well known for its attractive purplish red colour, which can be heat treated to deep red (Figure 1). The stones typically occur in alluvial deposits associated with Cenozoic intraplate basalts (Vichit 1992; Sutthirat *et al.* 1994). During the early 1980s (Keller 1982), the Bo Rai gem field—located in Trat Province, eastern Thailand, close to Cambodia—was the main source of Thai ruby, and associated minerals in the alluvium include garnet, magnetite, pyroxene and ilmenite (Vichit *et al.* 1978; Vichit 1992). Some other significant mining areas for Thai rubies include Na Wong and Nong Bon in Trat Province and Pong Nam Ron and Bo Welu in Chanthaburi Province. In addition, minor Thai ruby occurrences are known in Ubon Ratchathani and Si Sa Ket Provinces in the north-eastern part of the country (Vichit 1992; Pattamalai 2015). Although there is currently very little production of Thai ruby, the material continues to circulate in the global gem market.

Several authors have previously described the properties of Thai ruby (e.g. Gübelin 1971; Intasopa *et al.* 1999; Saminpanya *et al.* 2003; Saminpanya & Sutherland 2011; Sangsawong *et al.* 2017). Moreover, various types of mineral inclusions in Thai corundum (both ruby and sapphire) have been investigated (Gübelin 1940). Optical microscopy, Raman spectroscopy and powder X-ray diffraction have been used to identify the mineral inclusions in Thai corundum (e.g. Gübelin & Koivula 1986; Koivula & Fryer 1987; Intasopa *et al.* 1999; Hughes 2017; Saeseaw *et al.* 2017; Sangsawong *et al.* 2017), whereas the chemical composition of these minerals has been investigated using electron probe

Figure 1: This collection shows the deep red appearance of high-quality Thai rubies (here, 0.87–2.86 ct). They have been heat treated to improve their colour. Stones courtesy of Thai Lapidary International Co. Ltd; photo by S. Promwongnan.

micro-analysis (EPMA; e.g. Gübelin 1971; Guo *et al.* 1994; Sutherland *et al.* 1998a; Sutthirat *et al.* 2001; Khamloet *et al.* 2014), proton microprobe analysis (Guo *et al.* 1994) and scanning electron microscopy with energy-dispersive X-ray spectroscopy (Saminpanya & Sutherland 2011).

Sutherland *et al.* (1998b) separated the mineral inclusions in basaltic-type gem corundum into two groups: metamorphic origin (e.g. Mg-rich spinel, sapphirine, 'fassaite' [pyroxene with a low Fe content] and garnet) and magmatic origin (e.g. plagioclase, zircon, Fe-Ti oxides, Nb-Ta oxides, U-Th oxides and rare-earth phosphates). Typical inclusions in Thai rubies have been reported by various researchers as pyrrhotite, apatite, garnet, diopside, sapphirine and plagioclase (Gübelin 1971; Intasopa *et al.* 1999; Sutthirat *et al.* 2001; Saminpanya & Sutherland 2011), and some of these authors also suggested that Thai ruby possibly crystallised from high-grade metamorphosed mafic rocks. Recently, Sutthirat *et al.* (2018) documented ruby-bearing mafic granulite xenoliths from the Bo Rai deposit, which provide the most significant direct evidence for the primary metamorphic formation of Thai ruby.

In this study, approximately 1,000 unheated Bo Rai rubies were pre-screened to select samples for examination of mineral inclusions. (These included some purple sapphires, although the sample collection is here classified as 'ruby' since during heat treatment the purple stones are usually transformed into the colour range of ruby.) Our examination of the inclusions particularly focused on mineral chemistry, which is the primary aim of this project. In addition, the samples' gemmological properties, optical and spectroscopic characteristics and trace-element compositions were investigated.

MATERIALS AND METHODS

Using a gemmological microscope, we selected 88 samples (containing 141 mineral inclusions) for examination from the approximately 1,000 unheated rough Bo Rai rubies. The samples were carefully cut and polished with a Facetron faceting machine to expose their mineral inclusions at the surface for analysis. After polishing, they ranged from 0.006 to 0.17 g.

Standard gemmological properties (i.e. colour, diaphaneity, RIs and fluorescence reactions to long- and short-wave UV radiation) were recorded for all 88 samples. (Specific gravity was not measured due to their small size.) Internal and external features were observed with a gemmological microscope, and an attached Canon EOS 7D camera was used for photomicrography.

Mid-infrared spectra (4000–400 cm^{-1}) were obtained in transmittance mode for all 88 samples (resolution of 4.0 cm^{-1} and 128 scans) using a Thermo-Nicolet 6700 Fourier-transform infrared (FTIR) spectrometer. Ultraviolet-visible-near infrared (UV-Vis-NIR) absorption spectra were obtained for all samples using a PerkinElmer Lambda 950 spectrophotometer in the range 250–800 nm with a 3.0 nm sampling interval and 441 nm/minute scan speed. Good-quality trace-element analyses were obtained for 78 of the samples by energy-dispersive X-ray fluorescence (EDXRF) spectroscopy with an Eagle III system; semi-quantitative results for Al, Cr, Fe, Ti, V and Ga were subsequently normalised and reported as oxides. Preliminary identification of the mineral inclusions in all samples was performed with a Renishaw inVia Raman microspectroscopy system utilising 532 nm excitation from an Nd:YAG laser. The magnification of the objective lens was 50×. All of the analyses mentioned above were done at the Gem Testing Laboratory of the Gem and Jewelry Institute of Thailand (Public Organization) in Bangkok.

Mineral inclusions in 41 of the rubies were selected for major- and minor-element analysis by EPMA. The samples were mounted in epoxy resin and polished prior to carbon coating and analysis with a JEOL JXA-8100 instrument based at the Geology Department, Faculty of Science, Chulalongkorn University, Bangkok. Operating conditions included an accelerating voltage of 15.0 kV and a sample current of ~25.0 nA, with a focused beam of <1 µm in diameter. Measurement times for each element were set at 30 seconds for peak counts and 10 seconds for background counts. The analytical results were then subjected to automated ZAF correction and reported as weight percent oxides. The ferrous and ferric iron contents of some minerals (e.g. pyroxene, garnet and spinel) were calculated using the methodology of Droop (1987).

RESULTS

Gemmological Properties

The samples typically formed platy waterworn crystals that were semi-transparent to transparent. Their colouration (see, e.g., Figure 2) can be summarised as follows: moderate to slightly purplish red (pR, ~2% of the collection), purple-red to red-purple (PR-RP, ~79%), reddish purple (rP, ~17%) and purple (P, ~2%). They had RIs of 1.760–1.771 and birefringence values of 0.008–0.010. They showed inert-to-moderate red fluorescence to long-wave UV radiation and were inert to short-wave UV.

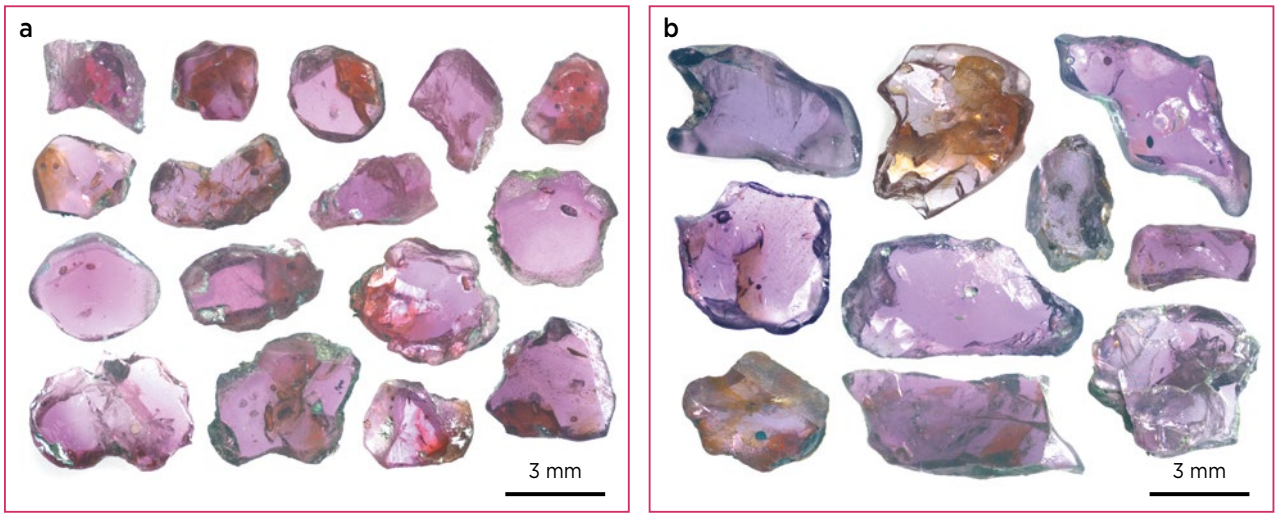

Figure 2: Representative rough pieces of Bo Rai gem corundum show a range of colour: (**a**) moderate to slightly purplish red to red-purple, and (**b**) reddish purple to purple. Most of the samples have been polished on both sides to expose mineral inclusions on their surfaces. Photos by S. Promwongnan.

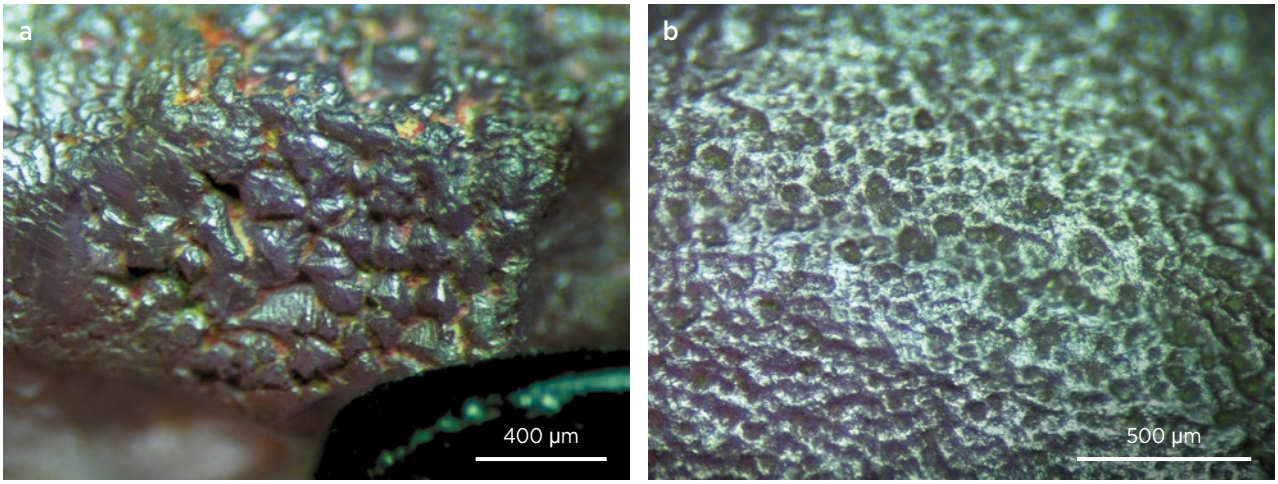

Figure 3: These photomicrographs show etched and dissolved features on the surfaces of two rough rubies from Bo Rai. Photomicrographs by S. Promwongnan in reflected light.

Before being polished into plates for inclusion examination, some of the samples presented etched or dissolved surfaces (Figure 3).

Spectroscopic Features

The FTIR spectra of the rubies showed similar patterns for all the samples, including bands at approximately 2363 and 2342 cm^{-1} due to CO_2, and at 2924 and 2852 cm^{-1} due to C-H stretching (Figure 4; cf. Beran & Rossman 2006). Some samples (e.g. Figure 4, red spectrum) also presented a shoulder at about 3170 cm^{-1} and a series of sharp bands at 3697, 3669, 3652 and 3620 cm^{-1} that relate to the hydrous component of a kaolinite-group mineral (cf. Beran & Rossman 2006; Schwarz *et al.* 2008).

UV-Vis-NIR spectra showed an absorption at ~330 nm related to high Fe content (Figure 5, blue spectrum), and in some samples this absorption was so strong that the spectra presented a cut-off in this region (Figure 5, red spectrum). Most of the pR and PR-RP samples showed distinct Cr-related absorption features at around 410, 560 and 694 nm (Figure 5, blue spectrum), consistent with their dominantly red colour. However, those samples falling in the rP to P colour range clearly showed intense Fe-related absorptions at 387 and 450 nm (Figure 5, red spectrum).

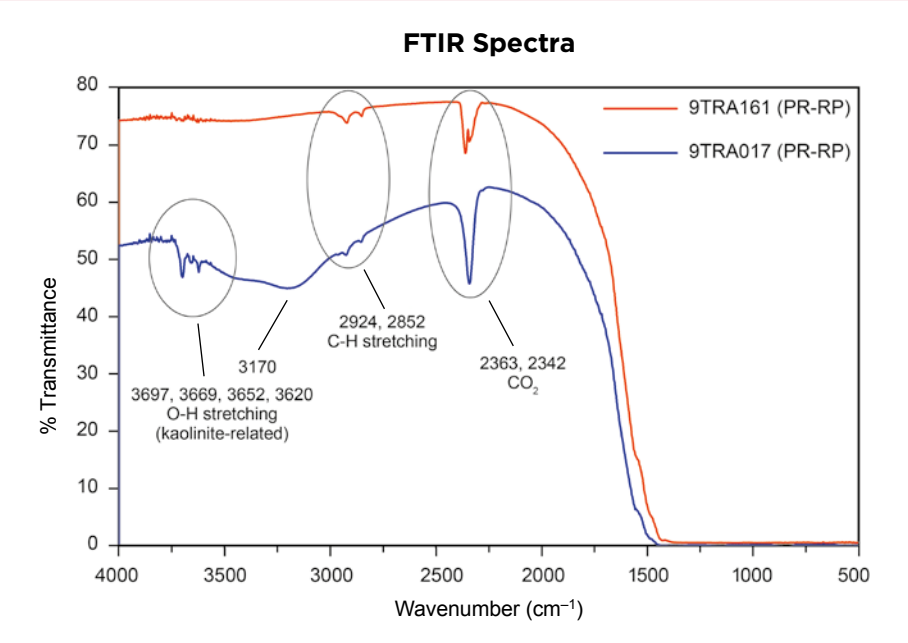

Figure 4: Representative mid-IR spectra of two purple-red to red-purple ruby samples from Bo Rai reveal bands at approximately 2363 and 2342 cm^{-1} due to CO_2, and at 2924 and 2852 cm^{-1} due to C-H stretching. Sharp features at 3697, 3669, 3652 and 3620 cm^{-1} in the lower spectrum are due to O-H stretching related to a kaolinite phase.

EDXRF Analyses

Semi-quantitative chemical analyses of the Bo Rai samples varied within fairly narrow ranges (e.g. Table I). Overall, Fe and Ti concentrations ranged from ~0.35 to 1.26 wt.% Fe_2O_3 and 0.01 to 0.67 wt.% TiO_2, respectively. Chromium contents fell within the range of 0.06–0.92 wt.% Cr_2O_3. Overall, the rP to P samples contained less Cr than those falling into the pR to PR-RP colour range. About 20% of the samples yielded V contents below the detection limit, and the highest value was only ~0.04 wt.% V_2O_5. Gallium was below the detection limit in some samples, while the greatest amount measured was ~0.03 wt.% Ga_2O_3.

Internal Features

Apart from the mineral inclusions described below, a variety of internal features could be seen in our samples with the microscope. The most typical characteristics were minute crystals (too small to be reliably identified by Raman or microprobe analysis) surrounded by equatorial thin films (Figure 6a). Also present were parallel twin planes, needle-like inclusions (Figure 6b) and partially healed fractures ('fingerprints'). In addition, some samples hosted inclusions containing multiple fluid/gas phases (Figure 7a) or two-phase assemblages consisting of a solidified silicate melt and a gas phase (possibly CO_2; Figure 7b). The latter

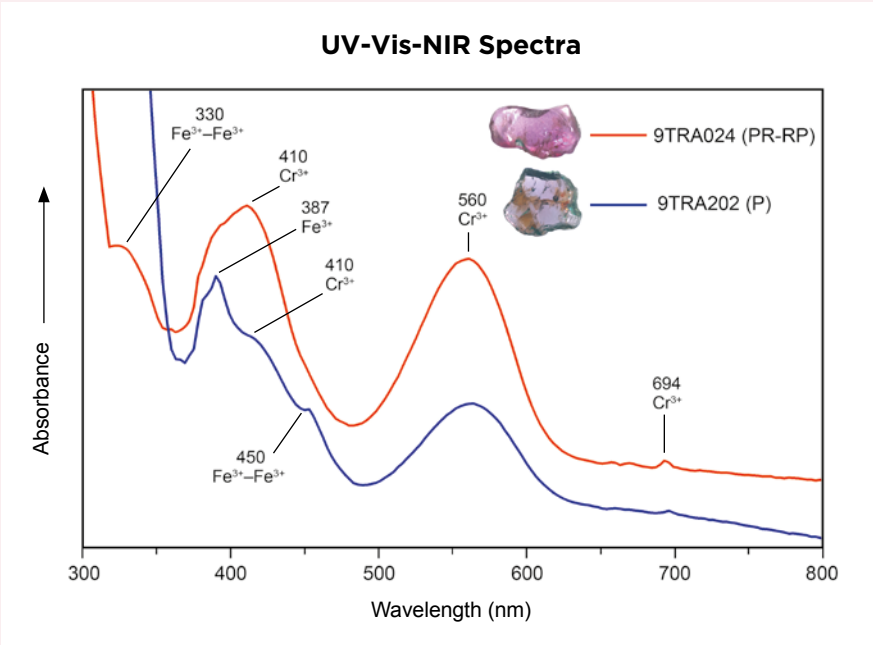

Figure 5: These representative UV-Vis-NIR absorption spectra of Bo Rai gem corundum (taken of the ordinary ray) display features due to Cr and Fe. A red-purple ruby sample reveals an Fe^{3+}-related absorption feature at ~330 nm and Cr^{3+}-dominated peaks at 410, 560 and 694 nm causing the red colour. A purple sample reveals obvious Fe^{3+}-related peaks with a cut-off at ~330 nm and a peak at 387 nm. The path lengths of the beam through the samples were 0.74 mm (9TRA024) and 1.20 mm (9TRA202).

Table I: Representative semi-quantitative EDXRF analyses of the Bo Rai ruby sample set.

Colour range	Purple-red to red-purple						Reddish purple to purple						
Sample no.	9TRA 075	9TRA 045	9TRA 208	9TRA 212	9TRA 124	9TRA 078	9TRA 219	9TRA 217	9TRA 137	9TRA 156	9TRA 228	9TRA 029	9TRA 155
Oxide (wt.%)													
V_2O_5	0.01	nd*	0.01	0.01	0.01	nd	0.01	nd	0.04	0.01	0.01	nd	0.01
TiO_2	0.44	0.17	0.04	0.06	0.08	0.67	0.04	0.05	0.07	0.08	0.02	0.02	0.08
Al_2O_3	98.16	98.49	99.13	99.09	98.75	97.83	99.07	98.91	98.54	98.95	99.29	99.44	98.83
Cr_2O_3	0.50	0.48	0.27	0.26	0.35	0.45	0.24	0.26	0.31	0.18	0.08	0.06	0.12
Ga_2O_3	nd	0.02	0.01	0.01	0.02	nd	nd	0.01	0.02	nd	0.01	0.01	0.01
Fe_2O_3	0.89	0.84	0.55	0.57	0.79	1.05	0.64	0.77	1.03	0.78	0.60	0.46	0.95
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

*Abbreviation: nd = not detected.

commonly formed rounded shapes, and EPMA analyses of the melt inclusions showed major Si, Al and Ca, with minor Fe, Mg, Na and K.

Pyroxene was the most common mineral inclusion identified in this study, with 122 of these crystals observed in 71 of the 88 samples of Bo Rai ruby. It usually formed rounded crystals with ellipsoidal or columnar shapes (Figure 8). Most were colourless, but some appeared light brown (Figure 8c). Their chemical composition characterised them as Al-rich pyroxene, close to diopside composition (see Table II and Figure 9; cf. Clark & Papike 1968).

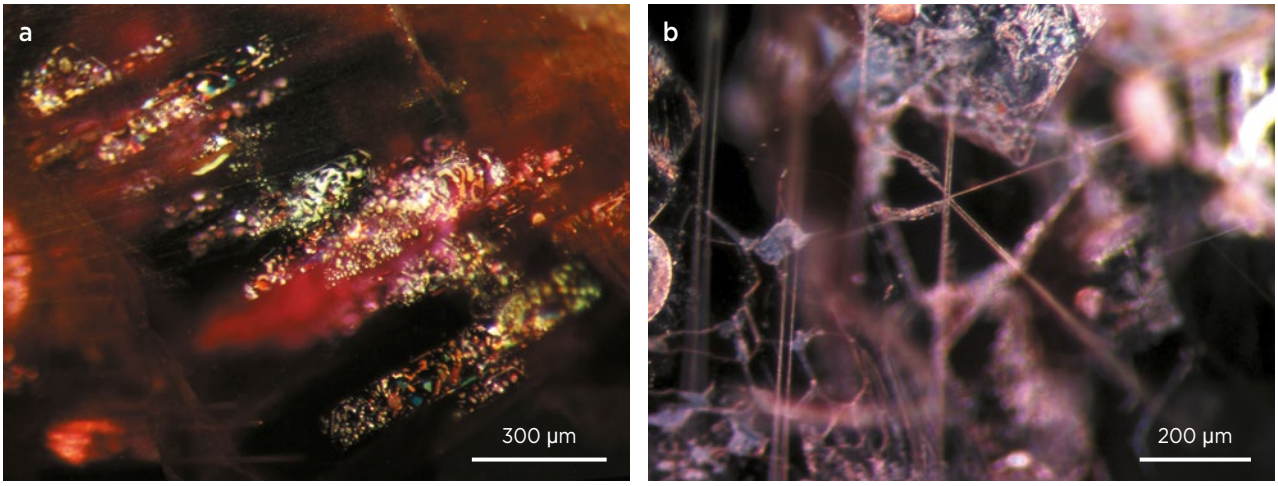

Figure 6: Internal features observed in the Bo Rai ruby samples include: (**a**) equatorial thin films surrounding minute crystals and (**b**) needle-like inclusions. Photomicrographs by S. Promwongnan; darkfield illumination with fibre-optic light.

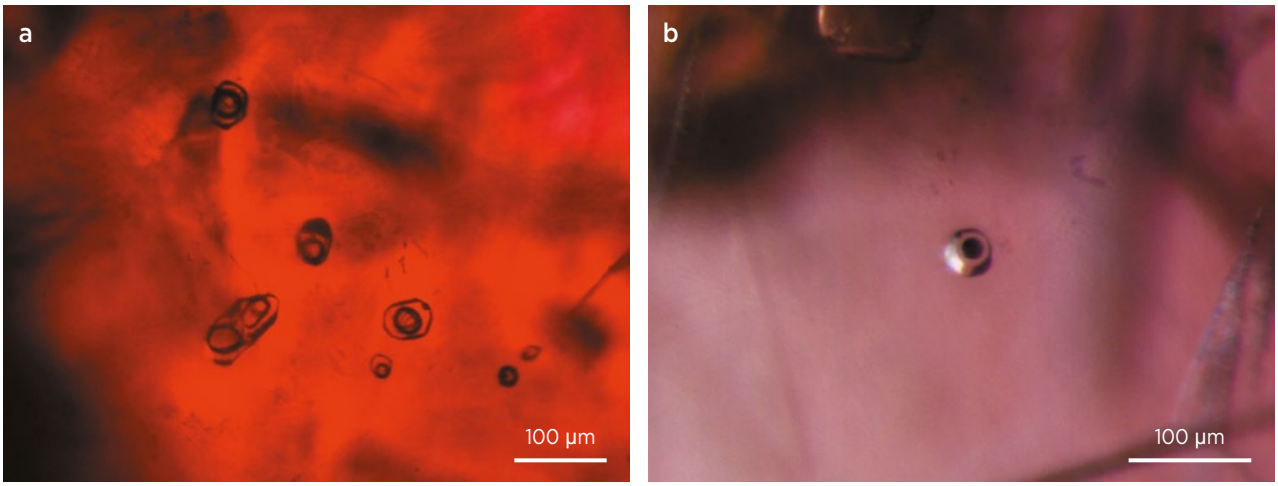

Figure 7: (**a**) These inclusions in a Bo Rai ruby appear to contain multiple fluid/gas phases. (**b**) Silicate melt inclusions in the rubies were associated with a gas phase (likely CO_2). Photomicrographs by S. Promwongnan; (a) darkfield illumination and (b) brightfield illumination with fibre-optic light.

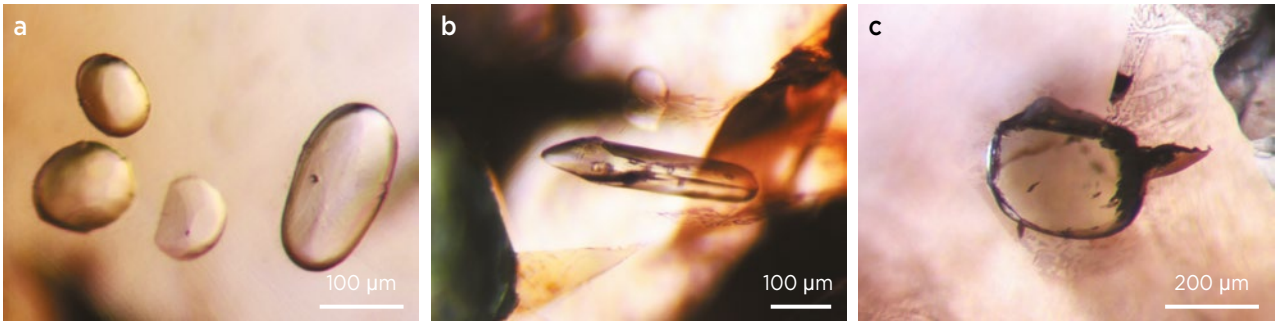

Figure 8: Pyroxene is a common mineral inclusion in Bo Rai ruby and typically forms (**a**) ellipsoidal or (**b**) columnar shapes. Most are colourless, but some are light brown (**c**). Photomicrographs by S. Promwongnan; brightfield illumination with fibre-optic light.

Table II: Representative EPMA analyses of pyroxene inclusions in the Bo Rai ruby sample set.

Sample no.	9TRA 016-1	9TRA 023-1	9TRA 118-2	9TRA 124-1	9TRA 036-1	9TRA 156-1
Oxide (wt.%)						
SiO_2	46.51	47.10	46.85	46.16	46.55	47.56
TiO_2	0.14	0.04	0.03	0.08	0.11	0.60
Al_2O_3	14.68	14.69	14.50	15.81	13.88	14.15
Cr_2O_3	0.14	0.08	0.04	0.13	0.04	0.07
FeO_{tot}	2.25	2.25	3.39	2.79	2.67	3.51
MnO	nd*	0.04	0.08	0.02	0.01	0.05
MgO	11.93	11.65	11.97	11.10	13.32	11.01
CaO	22.09	21.76	20.98	22.24	21.34	21.47
Na_2O	1.02	1.20	1.44	0.87	0.97	1.41
K_2O	0.01	0.01	0.01	0.02	0.01	nd
Total	98.76	98.81	99.29	99.21	98.89	99.81
Formula per 6(O)						
Si	1.705	1.722	1.713	1.687	1.706	1.731
Ti	0.004	0.001	0.001	0.002	0.003	0.016
Al	0.634	0.633	0.625	0.681	0.599	0.607
Cr	0.004	0.002	0.001	0.004	0.001	0.002
Fe^{3+}	0.025	0.005	0.071	0.000	0.077	0.000
Fe^{2+}	0.044	0.063	0.032	0.085	0.005	0.107
Mn	nd	0.001	0.002	0.001	0.000	0.002
Mg	0.652	0.635	0.653	0.605	0.727	0.597
Ca	0.868	0.853	0.822	0.871	0.838	0.837
Na	0.073	0.085	0.102	0.062	0.069	0.099
K	0.000	0.001	0.000	0.001	0.001	nd
Total	4.008	4.002	4.024	3.999	4.026	3.998
% Ca	55.50	55.00	54.55	55.80	53.38	54.32
% Mg	41.69	40.94	43.33	38.76	46.31	38.74
% Fe	2.81	4.06	2.12	5.45	0.32	6.94
Total	100.00	100.00	100.00	100.00	100.00	100.00

*Abbreviation: nd = not detected.

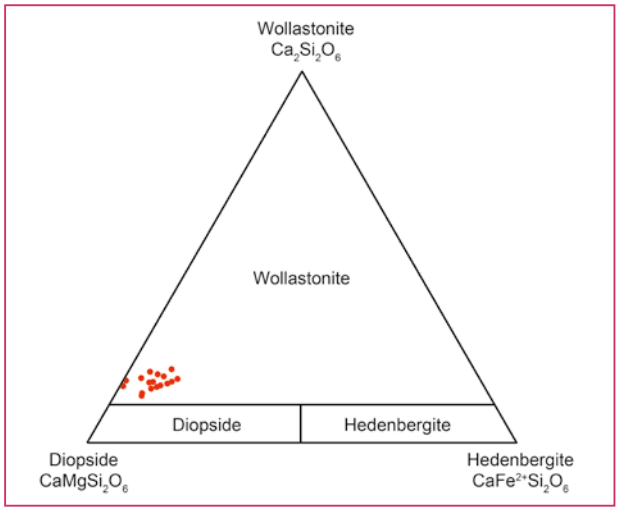

Figure 9: A compositional plot of Al-rich pyroxene inclusions analysed in the Bo Rai rubies shows them to be close to diopside composition. The apparent shift from diopside is caused by substitution from the Ca-Tschermak's component ($CaAl_2SiO_6$), which is not taken into account by this diagram. (diagram after Morimoto *et al.* 1988).

Garnet commonly formed subhedral crystals that appeared either colourless or pale purplish red (Figure 10a). The garnet inclusion in one sample (9TRA053) was oriented along the trigonal structure of the host ruby (Figure 10b). The dominant composition of the garnet inclusions was pyrope, and most had very low Cr contents (see Table III). This is similar to the composition of garnet inclusions reported previously in Thai ruby (Sutthirat *et al.* 2001; Saminpanya & Sutherland 2011). One elongated garnet inclusion associated with black crystals (probably a sulphide; Figure 10c) in sample 9TRA029 contained higher Fe and slightly lower Mg than most of the garnets analysed in our samples.

Feldspar inclusions were observed in four of the samples. They usually formed rounded to ellipsoidal grains (Figure 11) with chemical compositions that indicate plagioclase (i.e. bytownite: $Ab_{11-15}An_{85-89}Or_{0.1-0.2}$). One

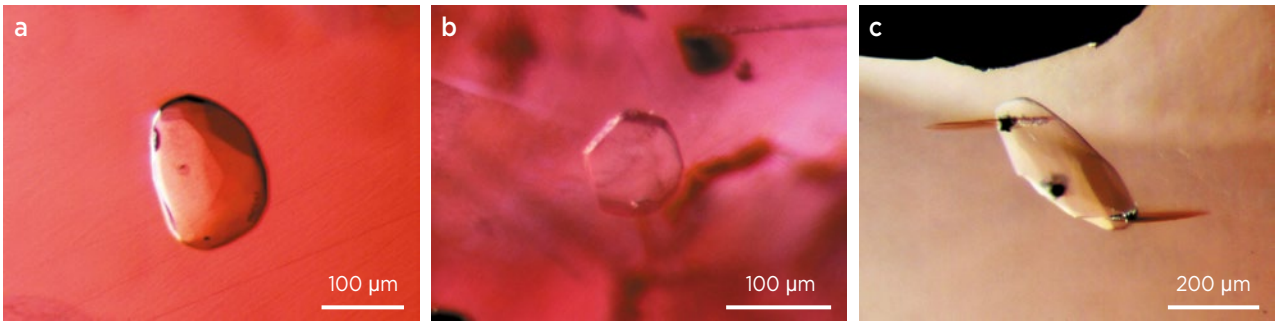

Figure 10: Garnet inclusions in Bo Rai ruby consist of low-Cr pyrope that usually form (**a**) colourless to pale purplish red crystals. (**b**) In one sample, a garnet inclusion clearly reflects the trigonal structure of the host ruby. (**c**) Another ruby sample hosts a garnet inclusion that was shown to contain relatively higher Fe and lower Mg, together with minute black crystals (likely a sulphide). Photomicrographs by S. Promwongnan; brightfield illumination with fibre-optic light.

Table III: Representative EPMA analyses of garnet, sillimanite and spinel inclusions in the Bo Rai ruby sample set.

Mineral	Garnet (pyrope)							Sillimanite		Spinel
Sample no.	9TRA 049-1	9TRA 053-1	9TRA 053-2	9TRA 206-3	9TRA 215-1	9TRA 218-1	9TRA 029-1	9TRA 169-1	9TRA 024-1	9TRA 024-2
Oxide (wt.%)										
SiO_2	41.77	42.56	41.94	41.88	42.07	41.43	41.45	36.60	36.49	0.09
TiO_2	0.02	0.01	0.03	0.01	0.05	0.02	0.05	nd*	nd	nd
Al_2O_3	23.01	23.30	23.32	22.65	23.39	24.12	23.09	62.42	62.24	67.59
Cr_2O_3	0.18	0.06	0.10	0.05	0.09	0.10	0.02	0.02	0.21	1.41
FeO_{tot}	6.55	7.09	7.05	7.21	9.27	6.29	11.29	0.39	0.73	8.12
MnO	0.20	0.22	0.16	0.20	0.19	0.12	0.23	nd	0.01	0.03
MgO	18.33	17.97	18.27	17.21	15.69	18.71	15.65	0.07	0.12	22.59
CaO	8.78	8.48	8.35	9.43	9.33	9.90	8.58	0.27	0.16	nd
K_2O	nd	nd	nd	nd	nd	nd	0.01	0.18	0.08	0.01
Na_2O	0.02	0.02	0.02	nd	nd	nd	nd	0.03	0.03	0.01
Total	98.85	99.70	99.73	100.69	100.07	99.73	100.36	99.98	100.07	99.85
Formula	per 12(O)							per 20(O)		per 4(O)
Si	3.004	3.033	3.005	3.030	3.023	2.933	2.997	3.969	3.960	0.002
Ti	0.001	0.001	0.002	0.001	0.003	0.001	0.003	nd	nd	nd
Al	1.950	1.957	1.969	1.932	1.981	2.012	1.967	7.977	7.960	1.969
Cr	0.010	0.004	0.006	0.003	0.005	0.006	0.001	0.002	0.018	0.028
Fe^{3+}	0.048	0.000	0.023	0.005	0.000	0.169	0.051	0.035	0.066	0.000
Fe^{2+}	0.346	0.422	0.399	0.432	0.557	0.203	0.631	—	—	0.168
Mn	0.012	0.013	0.010	0.012	0.012	0.007	0.014	nd	0.001	0.001
Mg	1.965	1.908	1.951	1.856	1.681	1.974	1.687	0.011	0.019	0.832
Ca	0.677	0.647	0.641	0.731	0.718	0.751	0.665	0.031	0.019	nd
K	nd	nd	nd	nd	nd	nd	0.001	0.025	0.011	0.000
Na	0.003	0.002	0.003	nd	nd	nd	nd	0.006	0.006	0.000
Total	8.016	7.987	8.008	8.002	7.981	8.057	8.017	12.05	12.060	3.000

*Abbreviation: nd = not detected.

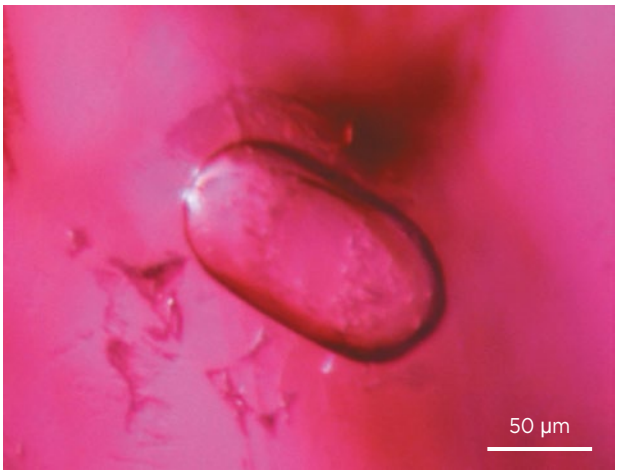

Figure 11: Plagioclase forms rounded to ellipsoidal grains in Bo Rai ruby. Photomicrograph by S. Promwongnan; brightfield illumination with fibre-optic light.

inclusion of andesine ($Ab_{56}An_{38}Or_6$) was also found in sample 9TRA031 (see Table IV and Figure 12).

Sillimanite was hosted by a fluid inclusion in sample 9TRA169 (Figure 13a). Moreover, a composite sillimanite-spinel inclusion was observed in sample 9TRA024 (Figure 13b), and it could be clearly differentiated using backscattered-electron imaging (Figure 13c). This is the first report of both sillimanite and spinel inclusions in Thai ruby. The sillimanite contained traces of Fe and Mg, and the spinel also contained some Fe: $(Mg_{0.83}Fe_{0.17})Al_2O_4$ (again, see Table III).

Sulphide inclusions formed metallic opaque black crystals with rounded or sub-hexagonal shapes (Figure 14). They were mostly present as tiny rounded grains that were each surrounded by a tension disc. EPMA analyses of the sulphides usually showed low total compositions,

Table IV: Representative EPMA analyses of plagioclase inclusions in the Bo Rai ruby sample set.

Sample no.	9TRA017-1	9TRA031-1	9TRA171-8	9TRA219-2
Mineral	Bytownite	Andesine	Bytownite	Bytownite
Oxide (wt.%)				
SiO_2	47.20	58.17	45.34	46.31
TiO_2	nd*	0.08	0.01	nd
Al_2O_3	33.36	24.72	33.87	34.47
CaO	17.52	7.52	18.13	17.02
FeO	0.13	0.46	0.42	0.22
MnO	nd	0.02	0.03	nd
MgO	0.01	0.64	nd	0.07
K_2O	0.02	1.05	0.02	0.03
Na_2O	1.68	6.02	1.48	1.14
Total	99.92	98.68	99.30	99.26
Formula per 8(O)				
Si	2.171	2.643	2.111	2.139
Ti	nd	0.003	0.000	nd
Al	1.808	1.324	1.858	1.876
Ca	0.863	0.366	0.905	0.842
Fe	0.005	0.017	0.016	0.008
Mn	nd	0.001	0.001	nd
Mg	0.001	0.043	nd	0.005
K	0.001	0.061	0.001	0.002
Na	0.149	0.530	0.134	0.102
Total	4.998	4.988	5.026	4.974
Element (at.%)				
Ca	85.15	38.27	87.02	89.02
Na	14.73	55.40	12.87	10.79
K	0.12	6.34	0.11	0.19

*Abbreviation: nd = not detected.

and apart from Fe and S, Ni and Cu were present as major and minor components in some samples (Table V). The sulphide inclusion in ruby sample 9TRA231 yielded the composition of pyrrhotite (Fe_7S_8). Others were closer to compositions of pentlandite ($[Fe,Ni]_9S_8$; sample 9TRA055) or digenite (Cu_9S_5; sample 9TRA160).

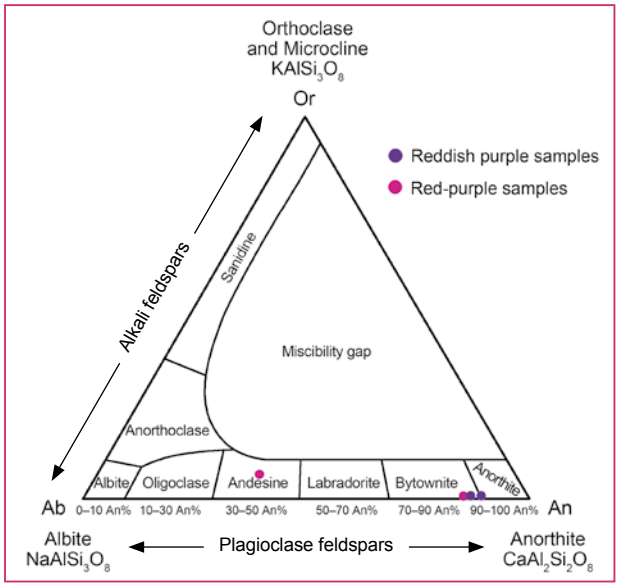

Figure 12: This ternary diagram shows that the feldspar inclusions in our Bo Rai samples fall within the plagioclase range (bytownite and andesine).

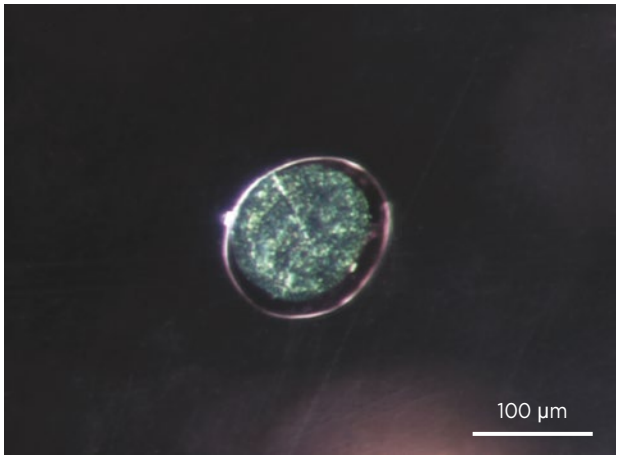

Figure 14: The sulphide inclusions in Bo Rai rubies typically form rounded to sub-hexagonal opaque grains that appear black, although they may show metallic reflections (causing the greenish grey appearance seen here). Photomicrograph by S. Promwongnan; darkfield illumination with fibre-optic light.

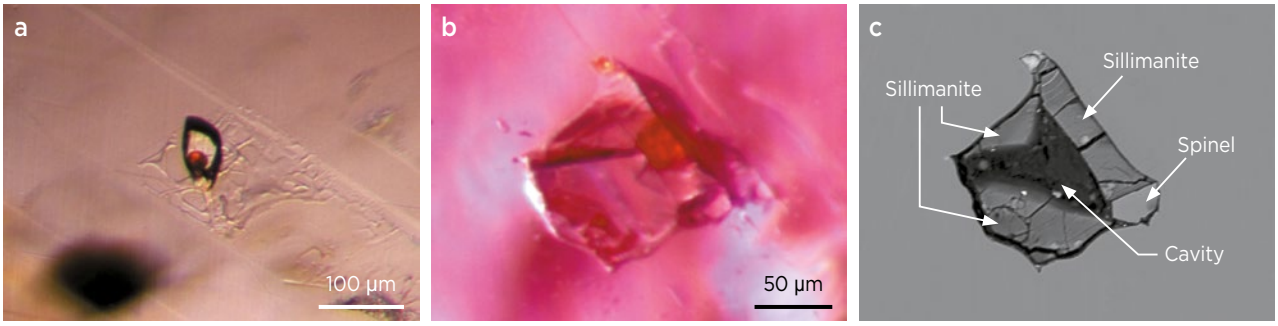

Figure 13: (**a**) The colourless crystal seen here in a Bo Rai ruby, identified as sillimanite, is hosted by a fluid inclusion and itself contains a rounded area of red material. (**b**) Sillimanite also forms part of a subhedral composite inclusion along with spinel. (**c**) The sillimanite and spinel components of the composite inclusion are clearly visible with the use of backscattered-electron imaging. Photomicrographs by S. Promwongnan; brightfield illumination with fibre-optic light (a, b).

Table V: Representative EPMA analyses of sulphide inclusions in the Bo Rai ruby sample set.

Sample no.	9TRA214-1	9TRA160-1	9TRA176-1	9TRA208-1	9TRA055-1	9TRA231-1	9TRA202-1
Element (wt.%)							
Al	0.09	0.04	0.06	0.05	0.04	0.11	0.03
S	18.71	19.35	14.93	22.12	27.72	25.34	26.49
Ti	0.29	nd*	0.04	0.21	0.37	0.18	0.3
Fe	9.39	9.19	9.21	21.61	34.68	42.42	31.21
Ni	0.06	0.06	4.59	0.14	22.63	4.58	11.67
Co	nd	na*	nd	nd	na	na	nd
Cu	62.17	64.39	51.69	42.88	0.03	1.05	18.32
Zn	nd	na	nd	nd	na	na	nd
As	nd	na	nd	nd	na	na	nd
Mo	0.23	0.39	0.43	0.44	0.42	0.44	0.45
In	0.01	nd	nd	0.05	nd	nd	nd
Sn	nd	na	nd	nd	na	na	nd
Ba	0.28	0.35	0.27	0.22	nd	nd	0.11
Pt	nd	nd	nd	nd	0.02	0.14	0.04
Pb	nd	nd	nd	nd	nd	nd	nd
Total	91.24	93.78	81.22	87.71	85.90	74.25	88.63

*Abbreviations: na = not analysed, nd = not detected.

DISCUSSION

The etched patterns on the surfaces of some samples of Bo Rai ruby were apparently caused by chemical resorption in the magma. Such features are also typically observed on corundum from basaltic terranes elsewhere (Coenraads 1992).

Spectroscopic features within the mid-IR range showed the presence of a kaolinite-group mineral in these untreated rubies, which has been documented previously in basaltic-related corundum (e.g. in sapphires from southern Vietnam: Smith *et al.* 1995). This hydrous phase appears to form in corundum as a secondary product (Smith *et al.* 1995; Beran & Rossman 2006; Schwarz *et al.* 2008) and may be used as an indicator of an unheated stone.

UV-Vis-NIR spectra of the rP to P samples commonly showed iron- and chromium-related absorption features, consistent with their chemical compositions, in particular an Fe_2O_3:Cr_2O_3 ratio that was usually >3.

The most common mineral inclusion observed in our samples from Bo Rai was Al-rich pyroxene, which had compositions similar to those of pyroxenes associated with alluvial rubies from Bo Rai and Pailin (Sutherland *et al.* 1998b; Sutthirat *et al.* 2001), as well as those found in ruby-bearing mafic granulite xenoliths in alkali basalt from Bo Rai (Sutthirat *et al.* 2018). The pyroxene inclusions analysed in this study were also similar to ruby-bearing mafic xenocrysts embedded in alkali basalt from the Nong Bon gem field (Sutthirat *et al.* 2001), located about 20 km west of Bo Rai.

The Cr-poor pyrope inclusions in Bo Rai ruby have compositions that are similar to those of garnet xenocrysts embedded in Nong Bon basalt and to garnet in mafic xenoliths from Bo Welu (located ~30 km northwest of Bo Rai), which were documented by Sutthirat *et al.* (2001) and Saminpanya & Sutherland (2011), respectively. Plagioclase was reported previously as an inclusion in Thai ruby by Gübelin (1971), although the compositions of such inclusions were not documented until now. The spinel inclusions analysed in this study contained greater Mg than that of a pleonastic spinel inclusion found in ruby from western Pailin in Cambodia (Sutherland *et al.* 1998b). The varying composition of the sulphide inclusions in Bo Rai rubies may reflect locally heterogeneous formational environments. Gübelin (1971) documented chalcopyrite ($CuFeS_2$) in Thai rubies, and additional sulphide minerals have been reported by other researchers.

Overall, the inclusion assemblage in Bo Rai ruby—particularly clinopyroxene, garnet, plagioclase and spinel—closely resembles the minerals composing ruby-bearing mafic granulite xenoliths (plagioclase + clinopyroxene + spinel ± garnet ± corundum) in basalts surrounding the Bo Rai gem field (Promprated *et al.* 2003; Sutthirat *et al.* 2018). The mineral chemistries of these assemblages are also comparable, indicating that the alluvial rubies originally crystallised in mafic granulites prior to being transported to the surface via basaltic eruptions. Weathering of the basalts resulted in the accumulation of gem corundum within the alluvial

deposits. Based on the isotope study of Yui *et al.* (2006), mafic metamorphic rock was suggested to be related to the original formation of Thai ruby. This agrees with corundum formation in mafic granulites, which are high-grade metamorphic rocks.

Palke *et al.* (2018) documented melt inclusions in reddish violet sapphire from Yogo Gulch, Montana, USA, and in rubies from Thailand and Cambodia, with similar compositions of 53.4–60.5% SiO_2, 20.6–24.0% Al_2O_3, 4.9–6.2% CaO and 4.3–5.2% Na_2O with negligible Ti, Mg, Fe and K. These melt compositions were interpreted together with trace elements and oxygen isotopic analyses of their corundum hosts. In their genetic model, Palke *et al.* (2018) suggested that Thai ruby was associated with the transformation of anorthosite to garnet pyroxenite along with a partial melting process. The melt inclusions found in our Bo Rai ruby samples contained approximately 48.5–56.5% SiO_2, 26.4–31.9% Al_2O_3, 9.7–11.1% CaO, 1.6–2.0% FeO_{tot}, 3.0–3.2% MgO and 0.8–1.4% Na_2O, and therefore have lower Si and Na contents and higher Al, Ca, Fe and Mg contents compared to those reported by Palke *et al.* (2018). These variations in composition could relate to different degrees of partial melting and crystallisation. The presence of sillimanite and silicate melt inclusions in the Bo Rai samples clearly suggests exposure to high temperatures (>500ºC), consistent with partial melting, prior to the crystallisation of Thai ruby.

CONCLUSIONS

Bo Rai rubies commonly contain minute mineral inclusions surrounded by equatorial thin films. In addition, various mineral inclusions were identified in this study, particularly pyroxene, pyrope and plagioclase and minor spinel, which is consistent with the inferred original source rock of mafic granulite. Moreover, sillimanite and silicate melt inclusions indicate a high-temperature environment during crystallisation. The presence of sillimanite and spinel inclusions is described here for the first time in Thai ruby.

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Doubling and Differential Magnification of Images Seen Through Calcite and Other Uniaxial Materials

Harold Killingback

Although the beauty of diamonds is universally admired and much pleasure is derived from the ostentatious display of them and other precious stones in necklaces and rings, those whose curiosity and desire for understanding is greater than their love of luxury will, I believe, be no less impressed by a transparent crystalline material which has recently come to us from Iceland. Its properties are so wonderful and unusual that it is surely one of nature's most fascinating creations.—Erasmus Bartholinus (Bartholini 1669), referring to the colourless transparent form of calcite called Iceland spar; opening sentence translated from the original Latin by H. Killingback

ABSTRACT: Image doubling can be seen when looking at an object or inscription through a piece of transparent calcite bounded by plane surfaces. As shown in this article, in uniaxial crystals such as calcite, the maximum separation angle between the axes of these images is determined not by the magnitude of either refractive index (RI), nor by the difference between them (the birefringence), but by the ratio of the highest RI to the lowest RI value, regardless of whether the crystal is optically positive or negative. Doubling is not seen when the crystal is viewed either along or at right angles to the optic axis. When the surface of the material is curved rather than planar (thus forming a lens), two images can be seen even when the crystal is viewed at right angles to the optic axis. This effect is not due to ray separation but is ascribed to the different magnifying powers resulting from the two RIs. The author therefore recommends that the term *doubling* be reserved for the effect of ray separation, while the phenomenon associated with surface curvature should be called *differential magnification*. When the curved surface is viewed in directions oblique to the optic axis, the effects of both ray separation and differential magnification can be seen.

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Calcite is the crystalline form of calcium carbonate and, when pure, is commonly colourless and transparent. (The soft, porous form of calcium carbonate is chalk.) Calcite crystals readily cleave on three planes, forming rhombic parallelepipeds (i.e. rhombohedrons or rhombs; Figure 1). These have six faces, all of parallelogram shape, with opposite faces being parallel.

Calcite is uniaxial and doubly refractive (i.e. it has two RI values). The value of the RI for the ordinary ray is constant at 1.658, but the RI for the extraordinary ray decreases from 1.658 along the optic axis to 1.486 at right angles to the optic axis, so calcite is described as optically negative.

This article examines the images that can be seen when looking through a piece of transparent calcite at an object or an inscription below it. The refraction of the ordinary ray obeys Snell's Law, with the RI value being equal to the sine of the angle of incidence of a light ray into the crystal, divided by the sine of the angle of

refraction within it. Different rules apply to the extraordinary ray. It and the ordinary ray take separate paths except when the crystal is viewed along or at right angles to the optic axis, when there is no separation of the rays.

MATERIALS AND METHODS

This study employed observations of five samples of transparent calcite: (1) a rhomb in the author's collection measuring 26 × 50 × 76 mm; (2) a polished block measuring 35 × 29 × 32 mm, loaned by Marcus McCallum (Hatton Garden, London), that was cut with opposite polished plane faces oriented parallel to the optic axis; (3) a sphere of 40 mm in diameter in the collection of Cornell University, Ithaca, New York, USA; (4) a sphere of 90 mm in diameter displayed at the Natural History Museum (NHM) in London; and (5) a sphere of 31.4 mm in diameter that McCallum had cut for the author for this study.

Photographs of all but the NHM and Cornell samples (which were not directly handled by the author) were taken using a Canon G15 pocket digital camera. The camera was mounted on a tripod and the timer was used for releasing the shutter so that any movement or blur could be eliminated. Focus and exposure were automatic, while the aperture was set to minimum to obtain the maximum depth of field. Photographing the rhomb was challenging because any one face showed portions of adjacent parallel planes. In addition, the view through a small sphere is highly sensitive to position because its surface curvature produces high magnification. The smallest sphere was kept stationary for photography by placing it on a slight depression made by punching a hole through a piece of cardboard that lay under the paper background. A circle was drawn on the paper to be viewed through the calcite sphere. The paper was carefully positioned so that the hole and the circle were concentric. No photographic enhancements were done except for routine cropping, brightness and clarity adjustments.

A London dichroscope was used to visualise the orthogonal polarisation of the refracted rays through the calcite samples.

IMAGES SEEN THROUGH CALCITE

Specimens with Plane Surfaces

The most commonly encountered form of crystalline calcite is the cleavage rhomb. The separation of rays upon entering a transparent calcite crystal can be made visible by the fluorescence caused by the beam of a 405 nm laser pointer (Killingback 2014). Figure 1 shows the rhomb sample standing on its smallest face (26 × 50 mm) with a laser aimed vertically downward through the top face. The camera view is normal to its 50 × 76 mm face. The ordinary ray continues vertically downward, in accordance with Snell's Law. The extraordinary ray is separated from the ordinary one, illustrating that it does not conform to Snell's Law in this orientation of the crystal relative to the incident beam.

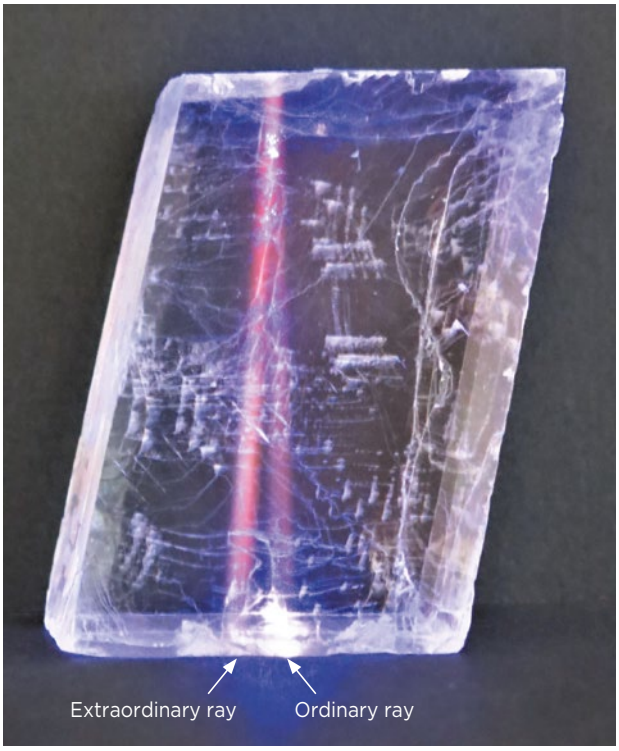

Figure 1: Laser-induced fluorescence makes visible the path of a 405 nm laser beam through a calcite rhomb (26 × 50 × 76 mm). The beam is normal to the top face. The ordinary ray continues vertically downward, in accordance with Snell's Law. The extraordinary ray proceeds separately and does not obey Snell's Law. Photo by H. Killingback.

Figure 2a shows the view looking perpendicular to the 50 × 76 mm face (i.e. through the least thickness of the rhomb) as it lies on an X mark. Figure 2b shows the view perpendicular to the 26 × 50 mm face (i.e. through the greatest thickness of the rhomb). A comparison of these photographs shows that, as the ray paths lengthen, the size of the two X's (and the distance between them) increases, but within each view both images of the X are of the same size. Scaling from the photographs, the separation angle (α) between the two rays is about 5.7°.

Figure 3a shows the view normal to the 26 × 76 mm face (i.e. through the intermediate thickness of the rhomb). Figure 3b shows the same view, with a London dichroscope aligned over the images so that the border between the two abutting Polaroid sheets (which have their axes of polarisation at right angles to one another) lies over the centre of each image. Only half of each X

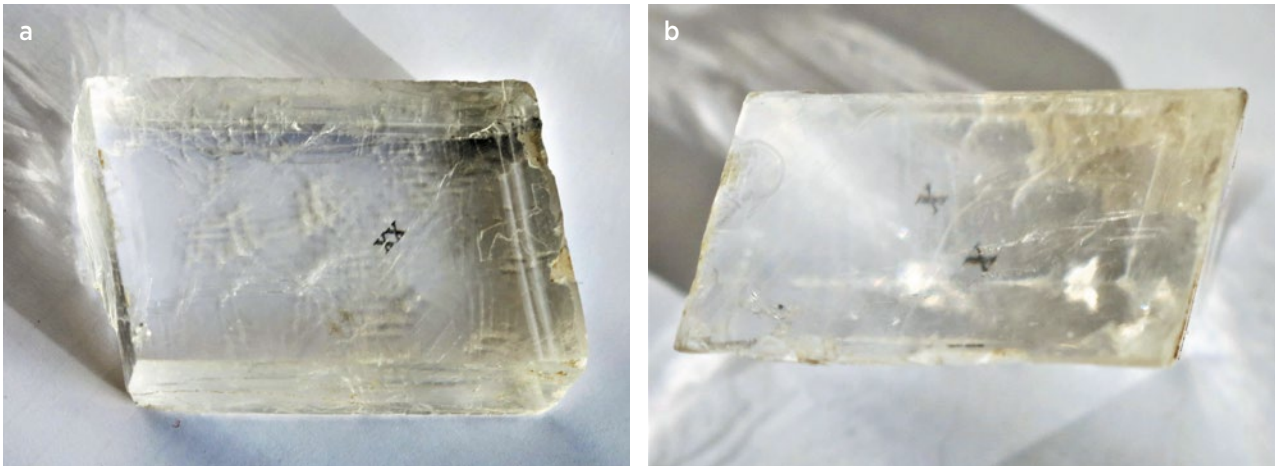

Figure 2: The same calcite rhomb lies on an X mark and is viewed (**a**) through the 50 × 76 mm face, which is the smallest distance through the specimen, and (**b**) through the 26 × 50 mm face, showing the greatest distance through the specimen. Photos by H. Killingback.

image can be seen, showing that the rays forming each of the images are orthogonally polarised.

The maximum value of the separation angle, α_{max}, between the largest and smallest RI values (n_{max} and n_{min}) can be calculated using the following formula (Sturman & Back 2002):

$$\tan \alpha_{max} = (n_{max}^2 - n_{min}^2) / 2 \times n_{max} \times n_{min}$$

Using Q for the ratio n_{max}/n_{min} and rearranging, we get:

$$2 \times \tan \alpha_{max} = Q - 1/Q$$

Thus, the maximum separation angle depends only on the *ratio* of the refractive indices (Q), not on their individual values nor on their difference (the birefringence). This explains why the maximum separation angle in calcite (α_{max} = 6.30°) is greater than that in rutile (α_{max} = 5.97°). Although rutile's RIs are large (2.616 and 2.903), and their difference is high (birefringence = 0.287), their ratio Q = 1.110 is a little smaller than that for calcite, for which the RIs are 1.486 and 1.658 (birefringence = 0.172) and Q = 1.116.

It can be calculated that the greatest separation of the rays in calcite is seen when the angle between the optic axis and the normal to the cleavage face being viewed is about 42° (Sturman & Back 2002). The angle between the optic axis and the cleavage plane of calcite is just over 44°. Therefore, looking perpendicularly through the face of a calcite cleavage rhomb gives almost the best view of the doubling (Skalwold & Bassett 2015).

Figure 4 shows a plot of α_{max} vs. Q for various materials. Sodium nitrate, with Q = 1.186, is not of interest as a gem because it is soluble in water, but it has been included to

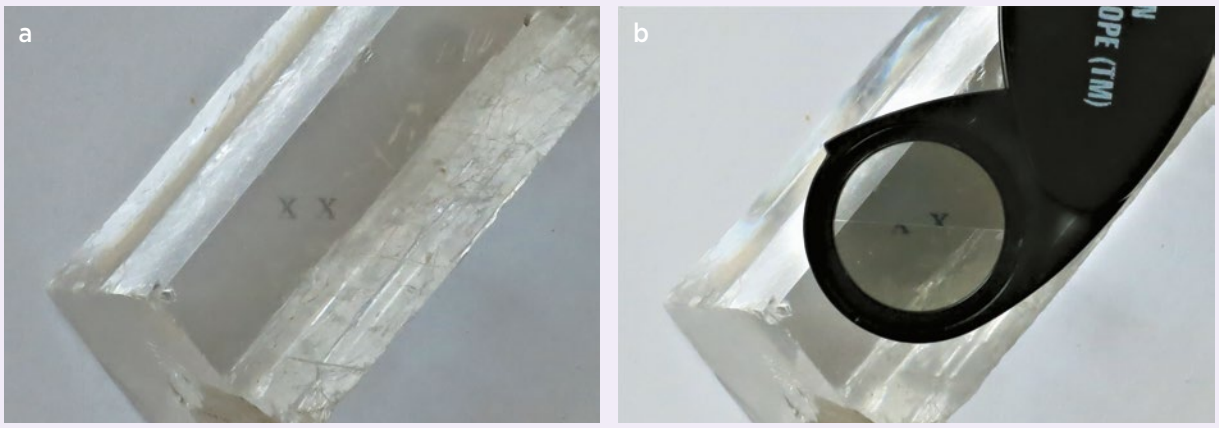

Figure 3: (**a**) The same calcite rhomb is seen here with the X mark viewed through the 26 × 76 mm face, showing an intermediate distance through the specimen. (**b**) A London dichroscope is orientated so that the junction between its polarising plates coincides with the centres of the two X images. The images seen through the dichroscope show that the rays are polarised at a right angle to one another. Photos by H. Killingback.

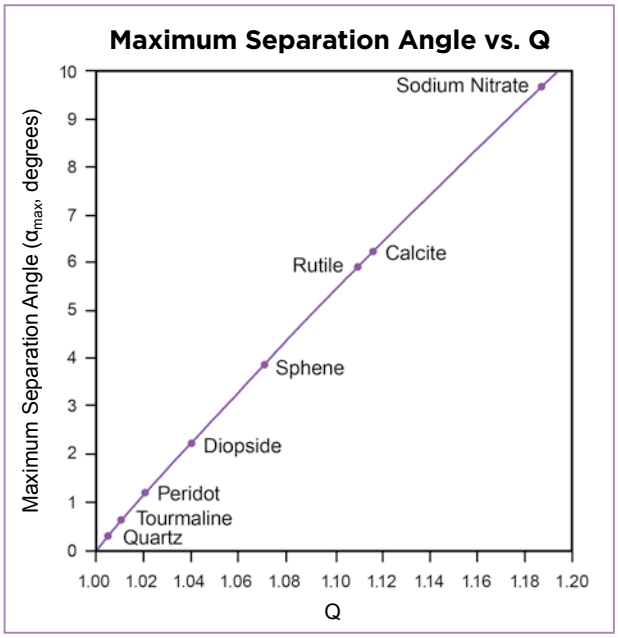

Figure 4: The maximum ray separation angle for various crystals is plotted against Q, the ratio of the highest RI to the lowest RI value.

show that calcite is far from having the highest value of Q. The graph is virtually a straight line. A close approximation to this line is provided by the simple equation:

$$\alpha_{max} = 56 \times (Q - 1)$$

This equation can be used to provide a quick estimate of the maximum separation angle for any transparent uniaxial substance for which the RIs are known.

Figure 5a shows a block of calcite which has opposite polished plane faces parallel to the optic axis. The block is resting on a circle mark, and the view vertically downward is at a right angle to the optic axis. There is only one image of the circle. This is in accordance with Snell's Law and confirms that only one image can be seen in this direction. Looking obliquely, as in Figure 5b, there are two overlapping images.

Specimens with Curved Surfaces

Because calcite cleaves easily, it is difficult to find a large piece of rough without cracks, let alone to cut a sphere from one. The author was, therefore, very impressed by a 90 mm diameter optically clean calcite sphere displayed at the Natural History Museum in London. In fact, it was this specimen that stimulated his interest in the behaviour of images seen through calcite. He therefore asked if the curator could supply a photograph looking vertically down on the sphere, lying on a 4 mm diameter circle and orientated so that its optic axis was horizontal. The result is shown in Figure 6. A second 4 mm circle is seen to the upper left of the sphere, for comparison. Through the sphere is seen not one image as in Figure 5a, but three: two near the centre and another weaker one near the periphery of the specimen.

At that time, the author was unable to obtain a calcite sphere for himself to confirm what was seen through the NHM sphere, so he made the same photo request to the curator at Cornell University, as he knew there was a 40 mm diameter calcite sphere in their collection. The

Figure 5: (**a**) This block of calcite has opposite polished faces (35 × 29 mm) that are cut parallel to the optic axis direction. It is viewed here perpendicular to the optic axis (through a thickness of 32 mm), and this orientation shows a single image of the circle on which the block stands. (**b**) Viewed obliquely, the same calcite block now shows two images of the circle. Photos by H. Killingback.

Figure 6: A calcite sphere (90 mm diameter) resting on a 4 mm diameter circle viewed perpendicular to the optic axis displays three concentric images of the circle: two near the centre and a third located near the periphery of the sphere. Another 4 mm circle is shown to the upper left of the sphere for comparison. Image of specimen BM.55140 courtesy of NHM London, © The Trustees of the Natural History Museum, London.

Figure 7: A view through a 40 mm diameter calcite sphere resting on a 4 mm diameter circle looking normal to the optic axis displays the same effect as seen in the larger sphere in Figure 6. Photo by Elise A. Skalwold.

photo she supplied is shown in Figure 7. Again, three images of the circle are seen through the calcite.

There is of course an important difference between the spheres and the specimens with plane surfaces (i.e. the rhomb and the polished block): the interface between calcite and air at the top of a sphere is curved, not planar. This interface is also curved where the sphere stands on the underlying circle, but as the gap between them is so small, the magnification is principally due to the convex lens formed by the top surface of the sphere. Because this calcite lens has two RIs, it also has two powers of magnification, hence two images of different sizes are seen near the centre of the sphere. In this view, the larger of these two circles is produced by the ordinary ray. The smaller circle is due to the extraordinary ray which, at right angles to the optic axis, is at its minimum RI (calcite is optically negative). The axes of the sets of rays forming each image do indeed coincide and the images are concentric, but the magnifications are not the same. Using a circle as the subject being imaged through the sphere allows the viewer to see the larger image separately from the smaller one whereas, had an X been used, the smaller image would merely have reinforced the larger one (see Figure 8).

The ray diagram in Figure 9 was constructed using the highest and the lowest RIs of calcite. (A detailed description of the preparation of this diagram is given in the Appendix.) The lines represent diametrically opposite rays from the sets forming each circle. The ordinary rays are shown in green and the extraordinary rays in red. The diameter of the small circle on which the sphere rests is indicated by a–a. The rays leaving the sphere represent those seen by a distant observer, so they are shown as parallel lines. (In reality, the camera was relatively close, and the rays toward it were thus convergent, so the description here is only approximate.) The image formed by the extraordinary ray is represented by b–b and that due to the ordinary ray is c–c. There is also a third, weaker, image of the circle, represented by d–d, near the periphery of the sphere. It is caused by another refraction path for the ordinary ray, as shown. Theoretically, there could be a fourth image further out due to the extraordinary ray, but this is not visible to the camera because its viewpoint is too close to the sphere, and therefore the image is 'over its horizon'.

During the preparation of this article, the author obtained the 31.4 mm diameter calcite sphere that is

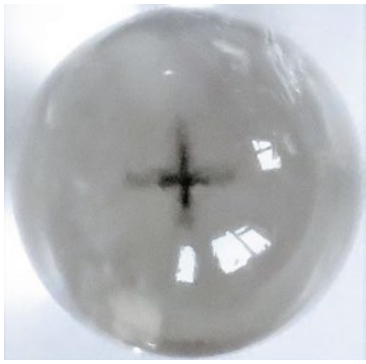

Figure 8: A calcite sphere (31.4 mm diameter) has been positioned over an X mark and is viewed here at right angles to the optic axis. Two images of different size overlap, with the smaller image reinforcing the larger one. Photo by H. Killingback.

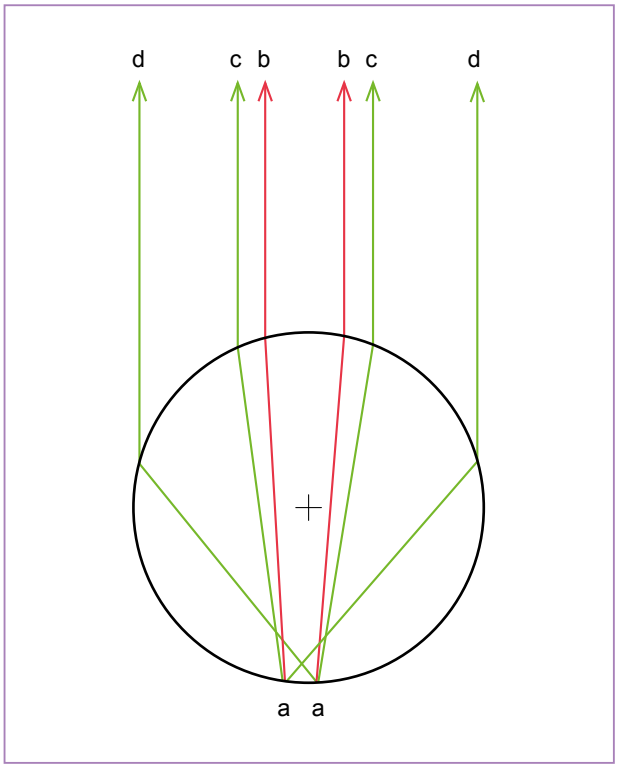

Figure 9: This simplified ray diagram shows a calcite sphere, with its optic axis horizontal, resting on a small circle (a–a). The green lines (d and c) represent the ordinary rays (RI = 1.658), and the red lines (b) are the extraordinary rays (RI = 1.486). The diagram demonstrates why we see three concentric images of the circle when viewed from above through the sphere.

depicted in Figure 10 (viewed at right angles to the optic axis). The sphere is shown resting on a circle of about 2 mm diameter. Another 2 mm circle is drawn to the upper left for comparison with the images seen through the sphere. Three images are visible, as with the other spheres, but the greater magnification resulting from the sharper curvature of this smaller sphere draws attention to the fact that the image due to the extraordinary ray is elliptical, rather than circular.

Figure 10a is taken at right angles to the optic axis, so the RI for the extraordinary ray is at its minimum, hence the smaller size of the central image. The shorter axis of the ellipse image lies in the direction of the optic axis (lowest RI, least magnification). Rotating the sphere on this axis does not alter the image seen, apart from the effects of cracks that come into view. However, if the calcite sphere is rotated a little, other than on the optic axis, the effects of differential magnification and of ray separation can both be seen, as shown in Figure 10b.

What if the Sphere Is Raised Above the Subject Circle?

When the sphere is raised above the surface on which the circle is drawn, the curvature of the lower surface of the sphere has a significant effect because then we are looking through a double convex lens. Figures 11 and 12 show views when the sphere is supported about 10 mm above a 2 mm diameter circle. Figure 11a shows the view when looking at right angles to the optic axis where the extraordinary ray has its lowest RI (1.486). Figure 11b is the same, with the addition of a London dichroscope, showing the two circle images are orthogonally polarised.

Figure 12 is a view along the optic axis, where the RIs of the ordinary and extraordinary rays are both the same (1.658), so there is only one image of the circle.

The ray paths were calculated by means like those described in the Appendix, extending the analysis to include refraction at the lower surface of the sphere. The result is portrayed in Figure 13, which shows that the larger of the central images is due to the extraordinary ray—not, as in Figure 9, to the ordinary ray. The calculated diameter of the image due to the extraordinary ray is 14.3 mm (i.e. a magnification of just over 7×) and that due to the ordinary ray is 6.3 mm (about 3×). The ratio of these diameters is 2.3. In the photo in Figure 11a, the

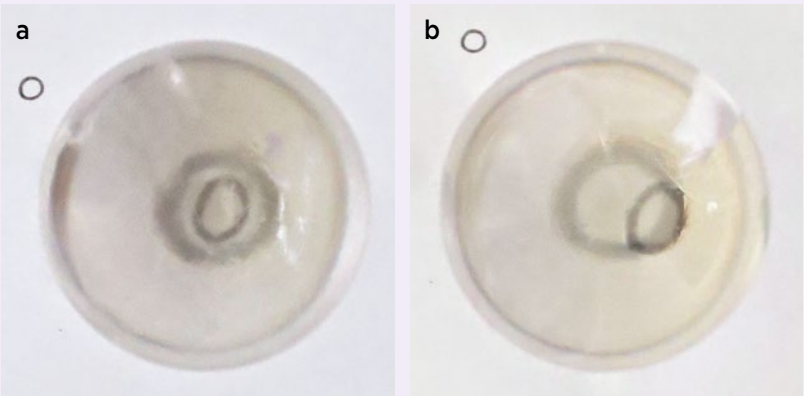

Figure 10: This 31.4 mm diameter calcite sphere is shown resting on a 2 mm circle. It is viewed (**a**) at right angles to the optic axis, and (**b**) after rotating the sphere slightly from being perpendicular to the optic axis, causing the extraordinary ray image to be offset. Photos by H. Killingback.

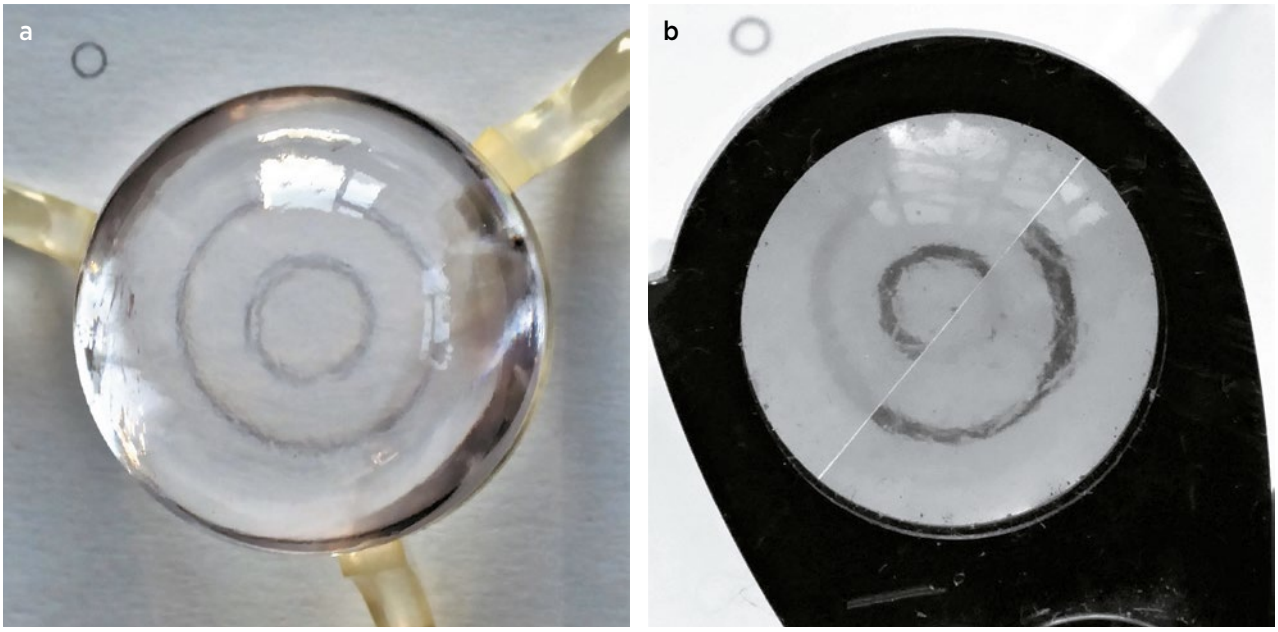

Figure 11: When the sphere is raised above the circle mark, the magnification of the circle images increases because the sphere acts like a double convex lens. (**a**) This is shown here for the 31.4 mm diameter calcite sphere, with the optic axis horizontal, which has been raised about 10 mm above a 2 mm circle. (**b**) Viewing the images through a London dichroscope confirms that the refracted rays are orthogonally polarised. Photos by H. Killingback.

ratio of these diameters is 2.6. In view of the acknowledged approximation of the basis for the calculations, these numbers are in sufficient agreement to provide confidence that Figure 13 gives an approximately true representation of the ray paths and allows us to visualise what is happening. Figure 13 does not include the possibility of images seen close to the periphery of the sphere.

Figure 12: Only one circle image is seen in the same sphere and setup as in Figure 11 but viewed in the direction of the optic axis, along which there is only one RI (1.658). Photo by H. Killingback.

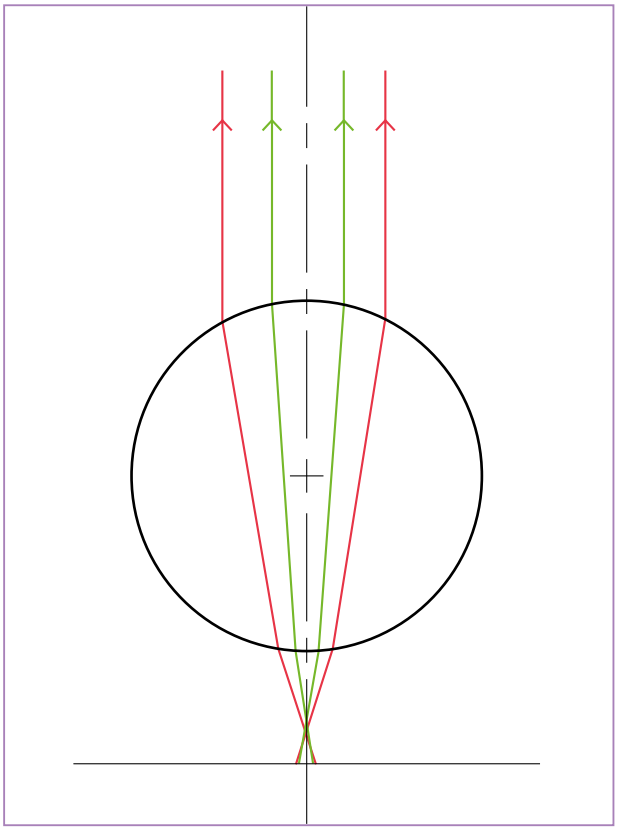

Figure 13: This diagram approximates the paths of the rays when the calcite sphere is raised above the circle mark. It demonstrates how the double-lens effect increases the magnification of the two concentric images of the circle. The larger image (red) is due to the extraordinary ray, rather than the ordinary ray (green); this is opposite to the positions of these rays seen in Figure 9.

CONCLUSIONS

When a light ray enters a birefringent uniaxial crystal at an angle other than along, or normal to, the optic axis, it is divided into two divergent rays. The maximum value of the separation angle between these rays is not determined by the value of either RI, nor by their difference (the birefringence), but by the ratio, Q, of the highest to the lowest RI, whether the crystal is optically positive or negative.

The rule that a double image cannot be seen when the crystal is viewed along or normal to the optic axis is not in question when the surface of the specimen is planar. It should be remembered, however, that if surfaces through which the rays pass are curved, the crystal acts as a lens, having two powers of magnification by virtue of its two RIs. For example, if a sphere with its optic axis horizontal stands on a circle mark, two concentric images of the circle are seen when looking vertically downward. (A third, weaker image of the circle is seen near the periphery of the sphere, due to another refraction path for the ordinary ray.) It is recommended that when two or three concentric images are seen through a curved surface, the effect should not be referred to as *doubling* but rather as *differential magnification*.

From a practical viewpoint, this article may encourage authors of gemmological textbooks to provide a table of values of Q, not of birefringence. This article also provides a simple equation whereby an approximate value of the maximum angle of ray separation can be obtained for any transparent uniaxial crystal for which the maximum and minimum RIs are known. Finally, this article introduces the concept of differential magnification and warns against mistaking it for doubling when looking through a curved surface of any uniaxial stone.

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All this collaboration and support was most valuable for my research. As stated by John of Salisbury in 1159, 'We are like dwarfs on the shoulders of giants, so that we can see more than they, and things at a greater distance, not by virtue of any sharpness of sight on our part, or any physical distinction, but because we are carried high and raised up by their giant size' (as quoted in R. K. Merton's *On the Shoulders of Giants*, 1965).

APPENDIX: CONSTRUCTION OF RAY DIAGRAMS FOR DIFFERENTIAL MAGNIFICATION

For simplicity, ray paths were calculated as seen by a distant observer. This means that the rays going to the observer were parallel to the line of sight. (In reality, the observer might be, say, 800 mm from the sphere, in which case the radius of the 31.4 mm diameter sphere would subtend an angle of 1.1°, which is not significantly different from 0°.)

Figure A-1 shows a ray A–B–C which could represent either rays a–b or a–c in Figure 9. Although what we see is light coming up through the calcite sphere, we can equally well envisage rays of light going down from the viewer's eye. Ray A–B, coming vertically down from a distant observer, meets the sphere at incident angle, i, or A–B–D. The angle of refraction, r (or C–B–O), can be calculated using Snell's Law, n = sin i / sin r, where n is the RI. Snell's Law was used for the extraordinary ray as well as for the ordinary ray because the views are perpendicular to the optic axis in this case.

Angle B–O–E = i, angle B–O–C = 180 – 2r and angle E–O–G = 180°, so angle COG is 2r – i. Therefore C–G = O–C sin (2r – i). C–G is the radius of the circle on which the sphere rests. O–C is the radius of the sphere. The author made a guess of the incident angle, i, and calculated the angle of refraction, r, for each RI of calcite, and then worked out the associated values of C–G. This was repeated until a value of i was found that resulted in the correct radius for C–G. The light path is then A–B–C. (Because the sphere in this case is resting on the viewed circle, it is sufficiently accurate to ignore refraction at the lower interface. It is as if a circle of radius C–G were inscribed on the surface of the sphere.)

Figure 9 shows, in simplified form, the light paths A–B–C for both rays in the case of the 31.4 mm diameter sphere. It is resting on a 2 mm diameter circle, and we find i is approximately 19.0° for the ordinary ray and 10.7° for the extraordinary ray. The magnification produced at the top surface of the sphere is B–E / C–G. According to these calculations, this is about 5.1× for the ordinary ray and 2.9× for the extraordinary ray. Their ratio is about 1.75. The photos of this 31.4 mm diameter sphere in Figure 10 show rather fuzzy images and, as noted in the text, the circle image that is due to the extraordinary ray is elliptical. The observed ratios between the two images range from 1.7 to 2.0.

A similar geometric procedure was followed to investigate the circle d–d (ordinary ray) image in Figure 9. The calculated radius of this image is 15.15 mm—very close to the size of the radius of the sphere (15.70 mm). The radius of an image due to the extraordinary ray was calculated to be approximately 15.69 mm, so it is no wonder that it cannot be seen by the camera taking the photo in Figure 10, as it would be over the horizon.

By the same methods, the ray diagram in Figure 13 was constructed. It predicts the ordinary ray image diameter to be approximately 6.3 mm and that for the extraordinary ray image to be 14.3 mm, a ratio of 2.3. From Figure 11a, the ratio of the actual image sizes seen by the camera is 2.6.

Close agreement cannot be expected when comparing the results from photographs taken about 800 mm from the sphere with those calculated from simplified assumptions, including having the observer at an infinite distance from the sphere (rays between observer and sphere being parallel). The author suggests, however, that the ray diagrams are sufficiently accurate to allow us to visualise how the images are formed.

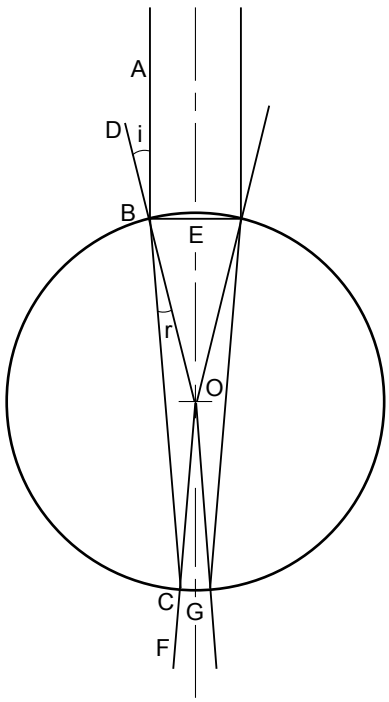

Figure A-1: This ray diagram shows in greater detail how Figure 9 was created.

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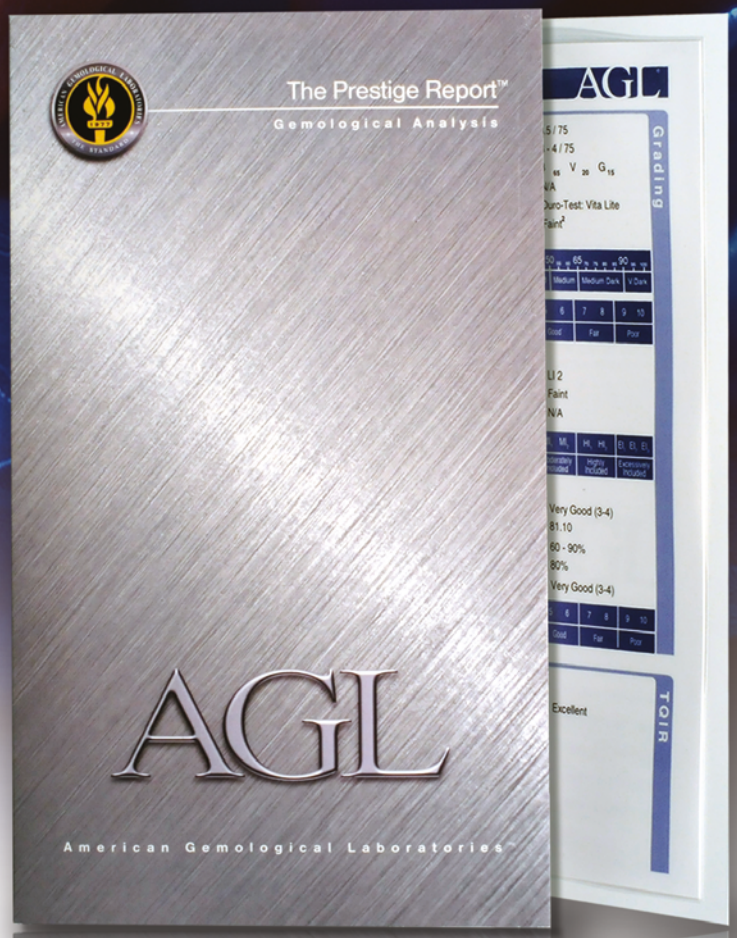

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Conferences

SCOTTISH GEMMOLOGICAL ASSOCIATION 2019 CONFERENCE

The annual conference of the Scottish Gemmological Association (SGA) took place in Cumbernauld, Scotland, 3–6 May 2019. The conference was organised by the SGA board, and featured eight speakers and several workshop presenters (e.g. Figure 1). Attendance at the SGA conference has grown significantly in recent years, and this year achieved a new high of more than 120 delegates, not only from the UK but also many other countries.

A Friday night welcome cocktail reception was followed by an informative and entertaining talk by **John Benjamin** (John C. Benjamin Ltd, Aylesbury, Buckinghamshire), covering a broad range of jewellery history from Elizabeth I of England through Elizabeth Taylor. A familiar contributor to the popular British television programme *Antiques Roadshow*, Benjamin provided a number of humorous anecdotes as he guided the audience through centuries of jewellery history.

On Saturday morning, **Christopher Smith** (American Gemological Laboratories [AGL], New York, New York, USA)—the keynote speaker of this year's SGA conference—discussed the clarity enhancement of emeralds. There have been many debates and much misinformation circulating about emerald treatments through the years, so this talk highlighting actual examples from AGL's case studies was helpful for sorting out points of confusion about these enhancements. Smith effectively educated gemmologists regarding filler types, as well as how they are added to stones by the treaters, their visual impact and their stability. His talk also covered how to identify the filler type and determine its effect on an emerald's apparent clarity.

The second presentation was given by **John Andrew**, curator of the Pearson Silver Collection, which is devoted to post-World War II British silver. He presented work from Maureen Edgar's enamelling career, which started in the 1950s. In the following decades, she became one of the best enamel artists in Scotland and produced an impressive collection of work until 2000. Some of her pieces were displayed during the conference for attendees to examine and enjoy.

Alex Grizenko (Lucent Diamonds Inc., Los Angeles, California, USA) presented an elaborate timeline of synthetic diamond production, starting with Lavoisier's diamond structure discovery in the 18th century. He continued through the failed attempts prior to World War II and, following the announcement of General Electric's success in the mid-1950s, the subsequent development of better synthesis methods, including a chronology of both

Figure 1: Members of the SGA board and some of the speakers/workshop presenters gather at the SGA conference's Saturday evening event (Ceilidh Night). From left to right, in the front row are Sylvia Gumpesberger, Dr Çiğdem Lüle, Alan Hodgkinson and Jan Calligan, and behind them are David Callaghan, Christopher Smith, Alex Grizenko, Stuart Robertson, Dr Jack Ogden, Ewen Taylor, Alistair Tait and Clare Blatherwick. Photo by Kim Rix.

HPHT and CVD growth technologies. He then reviewed synthetic diamond-producing companies and how their products were subject to colour treatments until colourless synthetic diamond was finally commercially produced in 2012. Grizenko also discussed identification challenges and techniques for synthetic diamonds.

Stuart Robertson (Gemworld International Inc., Glenview, Illinois, USA) gave an update on gem market trends, observations from the 2019 Tucson gem shows and the effects of the global economy on the gem industry. His presentation covered not only the gem side of the business but also some of the people, especially small-scale miners, who are involved in the global market. The growing awareness of 'fair trade' goods and ethical mining is important to the market, but it is also giving rise to unintended consequences. While some attempts and practices hit the target, others seem to exist as added-value labels devoid of any meaningful action. And still others are leading to a consolidation of the supply chain that could freeze out participation by the small-scale miners altogether. Therefore, Robertson indicated, it may be wise to ask, 'Fair trade? Fair for whom?'

Sylvia Gumpesberger (Toronto, Ontario, Canada) gave an engaging presentation on the use of light sources with various filters throughout gemmological history and how today's LED technology affects our daily work. She discussed the pros and cons of LED illumination, and demonstrated several applications in which LED lighting is suitable for gemmology. The audience then joined in to experiment with diffraction-grating glasses and various light sources. Encouraged by the practicality and low cost of LED lighting options, gemmologists should be aware of the benefits as well as the limits of LEDs when using them with basic tools.

The day concluded with an engrossing presentation by **Dr Jack Ogden** (Society of Jewellery Historians, London). He started with a history of diamond mining and emphasised how important diamonds were for reasons other than adornment. He provided a detailed history of many famous diamonds, such as the Pigot, Hornby and Nassak, including their questionable journeys to London from India, and how they ended up in early lottery schemes to generate money, were presented as diplomatic gifts, and even used in bribery.

The second day of the conference (Sunday) began with a presentation on developments in colour communication for gemmology given by **Christopher Smith**. He discussed his new colour-reference system called ColorCodex, which after more than three years in development provides an innovative system for describing the colour of transparent faceted coloured gemstones. He explained the challenges of colour communication in gemmology and the limitations of previous attempts at producing comprehensive colour systems for the trade. ColorCodex offers a unique approach by addressing the depth and internal reflections of a faceted stone. It provides an intuitive comparison environment with well-defined numeric codes rather than ambiguous colour names.

Clare Blatherwick (independent jewellery consultant, Edinburgh, Scotland) gave a vibrant and enchanting presentation on how jewellery making has been inspired by nature (especially flowers) through millennia. Techniques and cultural meanings might have changed over time, but humans have continuously been inspired by their surroundings and natural habitat.

Sunday morning's programme closed with an award ceremony for gemmology students and GemSet 2019 winners. This jewellery design competition encourages many young people to join the gem industry.

As in the past, this year's SGA conference concluded with Sunday afternoon workshops. Ranging from specialised talks to hands-on sessions, they were well attended. The workshop presenters included **David Callaghan**, **Kerry Gregory**, **Pat Daly**, **Tammy Cohen**, **Tatiana Conte** and **this author**, as well as many of the speakers from the previous day. An optional excursion on Monday visited the recently opened V&A museum branch in Dundee, Scotland, which features Scotland's design heritage.

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5TH MEDITERRANEAN GEM AND JEWELLERY CONFERENCE

The 5th Mediterranean Gem and Jewellery Conference (MGJC) was held under the Mediterranean sun of Limassol, Cyprus, 17–19 May 2019. As in previous years (i.e. in Greece, Spain, Italy and Montenegro), the conference was organised by **George Spyromilios** (Independent Gemological Laboratory, Athens, Greece) and **Branko Deljanin** (CGL-GRS Swiss Canadian Gemlab, Vancouver, British Columbia, Canada). The event attracted 75 gemmologists, appraisers, traders and others interested in the gem industry. Those who arrived early were introduced to some of the island's history with a visit to Roman ruins at Kurion, where a 'bonus' was provided by an army battalion being photographed in the amphitheatre.

Half-day workshops were held before and after the conference. This year an opal workshop (Figure 2) was instructed by **Gail Brett Levine** and **Travis Lejman** (National Association of Jewelry Appraisers, Rego Park, New York, USA), with many samples available that allowed participants to examine different types of opal—including material from different sources, as well as treated and synthetic specimens. An afternoon workshop on ruby, sapphire and emerald, presented by **Branko Deljanin**, focused on treatments and synthetics. As the sun set, a welcome cocktail party by the conference hotel pool saw delegates from 24 countries meeting friends old and new.

The next morning, the conference opened with an overview of previous MGJCs by **Branko Deljanin**. **Yianni Melas** (Limassol, Cyprus) chaired this year's conference, introducing speakers and adding anecdotes of his experiences with them. He is known in the trade for sourcing gem material from remote localities and championing fair trade for artisanal miners.

Olga Okhrimenko (OctoNus, Moscow, Russia) outlined what she believes is the reason for a stagnating diamond industry: most customers only purchase a diamond once in their lifetime. Okhrimenko postulated that with the vast majority of diamonds being round brilliants, consumers are not educated about the variety of shapes and cuts that can generate different levels of brilliance, fire and scintillation. Such awareness, she believes, would excite consumers to return for repeat purchases. **Roman Serov** (OctoNus) followed with proposed solutions in the form of in-store displays to educate consumers about cut options, although he conceded that the stock carried by most jewellery stores consists exclusively of round brilliants, with no option to 'test drive' alternative cuts.

This author described the various processes that a rough diamond undergoes during its transformation to a faceted gem. He highlighted how technology and lasers have transformed the industry for cut planning as well as sawing/cleaving and bruting operations, and how polishing on scaifes remains the most time-consuming step of the process. He also showed how the processing time varies as a function of rough diamond size and type.

Dr Michael Schlamadinger (Swarovski, Wattens, Austria) reviewed the synthetic diamond industry, starting with a snapshot of how China now produces 10 billion carats annually from more than 10,000 presses. While they are typically of industrial quality, the addition of a 'nitrogen getter' into the growth medium can enable the growth of colourless synthetic diamonds. CVD production has become a force in the industry, with WD Lab Grown Diamonds (Washington DC, USA) boasting more than 200 reactors. Dr Schlamadinger cited a study that found the energy needed to mine diamonds is about twice that for growing synthetics. An overview of the technical applications for synthetic diamonds showed various alternatives to gem use.

Figure 2: Held just prior to the MGJC, a workshop on opals was conducted by Gail Brett Levine (standing centre) and Travis Lejman (standing right). Photo by Branko Deljanin.

Garry Holloway (Holloway Diamonds, Melbourne, Australia) described his new parameter for judging diamond cut: 'looks like' as a measure of the apparent diameter of a faceted diamond, which can be affected by the amount of light reflection near the periphery of a stone. Poorly cut diamonds look smaller than they actually are, as can be measured using computer simulations. To demonstrate the message, he handed participants two CZs of the same weight. One was a Tolkowsky-cut brilliant while the other had a deeper pavilion, resulting in a physically smaller diameter but also lower light return near the periphery. Relying on a 'Triple X' cut grade is no assurance of a good cut, as was illustrated by a diamond with a 65% height that showed poor periphery reflection.

Dr Katrien De Corte (HRD Antwerp, Belgium) delivered a short 'sponsor' talk on detecting near-colourless CVD-grown synthetic diamonds. A notable characteristic is an absorption and PL peak at 737 nm attributed to silicon, but it is not always present or conspicuous. However, in an HRD study of 150 samples at liquid-nitrogen temperature, a PL peak at 467 nm was always present in these CVD synthetics. DiamondView images showed blue, orange and red fluorescence, with the blue not always exhibiting phosphorescence.

Sergey Buks (Alrosa, Moscow, Russia) also gave a short 'sponsor' presentation on the Alrosa Diamond Inspector, a recent addition to his company's line of instruments for detecting synthetic diamonds. Their system is based on three spectroscopic measurements applicable to individual 0.03–10 ct colourless diamonds and simulants, both loose and mounted.

After lunch, **Dr Stefanos Karampelas** (Bahrain Institute for Pearls & Gemstones [DANAT], Manama) reported on how his lab collects and labels samples for their research database. The lab's activities are not limited to pearls, and Dr Karampelas also reported research on the heat treatment of amber at 180–220°C.

Edward Boehm (Rare Source Gems, Chattanooga, Tennessee, USA), explored the sustainability of the gem industry. He noted that 80% of coloured-stone production comes from artisanal diggers, while only 20% is derived from large-scale mining. Origin is an important consideration for consumers and there are several methods to assess it, including gemmological evidence (e.g. inclusions) and blockchain technology. However, blockchains do not support artisanal miners, and trade anonymity along the supply chain is compromised.

Abeer Al-Alawi (DANAT), with **Dr Stefanos Karampelas**, focused on the Bahrain pearl industry, which dates back centuries, to the oldest documented pearl being from 5500 BCE. The industry there is protected by prohibiting the trade of cultured pearls, which make up 99.8% of global production. In 2018, 2 million pearls were harvested in Bahrain, with only one in 100 molluscs bearing a pearl. The formation of natural pearls is stimulated not by an irritating grain of sand (as is commonly believed), but by a malfunctioning organ. Karampelas gave an overview of pearl colour, lustre, shape and surface texture—the last potentially enhanced by 'pearl doctors' who can transform a damaged surface by sanding and polishing.

Stefan Müller (DSEF German Gem Lab, Idar-Oberstein, Germany) described various items seen in his laboratory. He noted that emeralds from Ethiopia can be separated from those of other deposits such as Zambia and Brazil by their trace elements measured with EDXRF, and that the majority of rubies currently in the trade are from Mozambique. The main treatments applied to gem corundum are heating and fracture filling with borax, glass, oil or resins. In some instances, the heat of a lamp can cause bubbles to form within oiled fissures, as was clearly shown in a video clip. He also shared cautionary experiences with a garnet-glass doublet, rough diamond imitations and a foil-backed beryl.

Dr Clemens Schwarzinger (Johannes Kepler University, Linz, Austria) is a master cutter and gave some insights into precision gem cutting, an art rarely recognised in a trade that pays by the carat. He showed examples of poor cuts, and blamed inferior equipment for asymmetric outlines and bad facet 'meet points'. He receives inspiration for his award-winning designs from plants and architecture, while the smoothest finishes are achieved by polishing with 250 nm grit, which produces 'scratches' with widths less than the wavelength of visible light. Soft gems are harder to polish, while other challenges are presented by complex stones such as colour-zoned tourmaline, which can show a brown appearance if faceted incorrectly. He lamented that precision cutting is unlikely to be recognised as long as there is no grading system for gemstone cuts that rewards cutters financially. Dr Schwarzinger brought several of his gemstones to show the audience during conference breaks (Figure 3).

Dr Gamini Zoysa (Ceylon Gemmological Services, Colombo, Sri Lanka) shared his expertise on ruby and sapphire and their value. He showed examples of rubies from different deposits, of which the Thai/Cambodian ones are almost exhausted. Rubies from his Sri Lankan homeland show distinctive photoluminescence compared to those from Mozambique, which dominate the market. He stated that generally all basaltic sapphires are heat treated. Yellow sapphires can be much larger than blue, being up to 40–50 ct, but their prices are about one-third those for blue sapphires. Photos of violet, purple and colour-change sapphires were shown along with price tables and auction examples.

Figure 3: Master cutter Dr Clemens Schwarzinger exhibited a collection of his precision-cut gemstones at the MGJC. Photo by J. Chapman.

Two short talks followed, with **Yuri Shelementiev** (MSU Gemological Center, Moscow, Russia) announcing a gem excursion to the Ural Mountains that will be held in 2020, and **Elena Deljanin** (Gemmological Research Industries Inc., Vancouver, Canada) describing 'philosophical stones' polished by master cutter Victor Tuzlukov. **Mark Cullinan** (Cullinan Diamonds, Monaco) took the podium briefly to describe the background of the Cullinan diamond. He passed around a model of the 3,106 ct rough diamond for participants to examine.

The last speaking event was a round-table discussion on 'Manufacturing Gems and Diamonds in the 21st Century', which included panellists **Garry Holloway**, **Sergey Sivovolenko** (OctoNus, Finland), **Yuri Shelementiev**, **Clemens Schwarzinger** and Israeli diamond polisher **Moish Lempel**. **This author** acted as moderator, and initiated discussions surrounding gem cuts, including whether price guides rather than beauty dictate polishers' choices, and how consumers could be better educated to appreciate cut. Discussions considered lab reports, consumer engagement, online sales, experiences selling fancy cuts and retailer knowledge. **Antoinette Matlins** (South Woodstock, Vermont, USA) from the audience was vocal on her views about how customers perceive diamonds, so she was invited to join the panel.

Sunday featured more workshops. **Sergey Sivovolenko** and **Roman Serov** demonstrated the factors that affect a faceted diamond's beauty, with the aid of custom lighting and viewing equipment. **Branko Deljanin** ran concurrent workshops on identifying synthetic and treated diamonds with the use of standard and advanced instruments.

Some delegates joined a post-conference tour to the capital of Cyprus, Nicosia. In addition, a group of 20 people continued on a special three-day tour to Israel, guided by **Branko Deljanin** and **Moish Lempel**. Participants had a chance to see large diamonds being cut at the DDS factory in Ramat Gan, followed by a tour of Sarine Technology by the manager, **David Block**. They also visited the trading floor at the Israeli Diamond Bourse, where Deljanin delivered a talk on the provenance of pink diamonds and synthetic diamonds to about 100 bourse members. A tour of Jerusalem and a local CVD growth facility completed the week-long conference events.

The next MGJC will be held in Greece, on 15–17 May 2020. Details will be posted on the conference website (www.gemconference.com) as they become available.

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AGA LAS VEGAS

The Accredited Gemologists Association's (AGA) 2019 Las Vegas conference took place on 31 May during the JCK Show in Nevada, USA. This year's event was attended by 58 people and featured three speakers. The conference was opened by AGA past-president **Donna Hawrelko**, whilst AGA president **Stuart Robertson** introduced the speakers.

Shane McClure (Gemological Institute of America [GIA], Carlsbad, California, USA) described the visual characteristics of heat treatment in gem corundum according to three different temperature categories: low (up to 1,200°C, when rutile needles start to be affected), high (1,200–1,700°C) and extreme (1,700–1,850°C). Corundum heated under extreme temperature is easy to identify because the inclusions are pervasively damaged. Furthermore, high-temperature heat treatment is not difficult to distinguish if certain features are present, such as dissolved rutile (leaving lines of points and/or blotchy colour zoning), 'snowballs' (indicating former uraninite crystals) and glassy discoid fractures. Low-temperature heating may not be possible to detect visually unless damage is evident in carbonate or diaspore inclusions. McClure also described some recent low-temperature heating experiments on Mozambique ruby, as well as low- to high-temperature experiments on blue sapphires (including heating with pressure).

Dr Thomas Hainschwang (GGTL Laboratories, Balzers, Liechtenstein) reviewed diamond colour treatments and then provided an update on his ambitious project to record detailed measurements on a wide variety of diamond types before and after irradiation, annealing and/or HPHT processing. Importantly, the creation of the N3 centre (and resulting blue fluorescence) provides a clue for HPHT treatment in both natural and synthetic type Ib diamonds.

Dror Yehuda (Yehuda Diamond Co., New York, New York, USA; Figure 4) described various diamond testers/detectors and gave some results for several instruments that have been evaluated so far by the Assure Program. (*Editor's note*: See the article on pp. 606–619 of this issue for more on this topic.) He then focused on diamond testing with his company's Sherlock Holmes 2.0 device. The instrument uses fluorescence and phosphorescence to distinguish between natural and synthetic diamonds, as well as some simulants (cubic zirconia and synthetic moissanite). The results require some interpretation from the user, although red markings shown on the device's screen make it relatively straightforward to detect the presence of synthetics and simulants in loose parcels and mounted jewellery.

Figure 4: Dror Yehuda delivers his presentation at the AGA Las Vegas conference. Photo by B. M. Laurs.

The conference concluded with hands-on opportunities for attendees to examine natural and synthetic diamonds using various instruments, including the GemmoRaman-532SG by Magilabs, the Diamond Inspector by Alrosa, the D•Secure by DRC Techno and the Sherlock Holmes 2.0.

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EUROPEAN GEMMOLOGICAL SYMPOSIUM 2019

The 7th European Gemmological Symposium took place on 24–26 May 2019 in Idar-Oberstein, Germany, and was attended by 200 participants from more than 20 countries. The conference was hosted by the German Gemmological Association (Deutsche Gemmologische Gesellschaft E.V., or DGemG) and the German Foundation for Gemstone Research (Deutsche Stiftung Edelsteinforschung/DSEF German Gem Lab), and celebrated the 50th anniversary of the DSEF German Gem Lab. The programme featured 17 invited speakers (Figure 5) who delivered presentations over a two-day period.

The opening ceremony included three lectures. **Dr Thomas Lind** (president of DGemG and chairman of the board of the DSEF German Gem Lab) recounted the history of DGemG and the DSEF German Gem Lab, and also chronicled the European Gemmological Symposium—which initially took place in Idar-Oberstein in 2007 to mark the 75th anniversary of DGemG. Next, **Frank Frühauf** (Lord Mayor of Idar-Oberstein and patron of the conference) welcomed the attendees to the beautiful town of Idar-Oberstein. Then **Dr Gaetano Cavalieri** (president of CIBJO—The World Jewellery Confederation) described the history of CIBJO and its role as the 'United Nations of the jewellery industry', in which it represents 20 countries and nearly 100 million people who are working in the gem and jewellery business.

Hans-Jürgen Henn (Henn GmbH, Idar-Oberstein) gave the keynote speech, titled 'A Gem of a Life', in which he described how gems are brought to market by recounting his personal experiences with sourcing coloured stones from around the world. Timeliness, luck and financial liquidity through partnerships with others have all benefited his dealings. One of his proudest accomplishments was sourcing a 26 kg aquamarine from Teófilo Otoni, Brazil, which was subsequently carved into the 'Dom Pedro' by Bernd Munsteiner and donated to the Smithsonian Institution in Washington DC, USA, where it is seen by millions of people annually.

Dr James Shigley (GIA, Carlsbad, California, USA) discussed synthetic diamonds, including their types, characteristics and identification. He indicated that the main concerns surrounding these products are their accurate identification, disclosure in the supply chain and appropriate pricing. The three main categories of synthetic diamonds include those larger than 5 ct (which are quite rare in the market), those ranging from 0.2 to 2.5 ct (i.e. commercial sizes that are commonly submitted to gemmological laboratories) and melee (<0.20 ct, which pose the greatest identification challenge to the industry).

Figure 5: Speakers, organisers and special guests of the 7th European Gemmological Symposium include (from left to right): Hans-Jürgen Henn, Dr Robert Chodelka, Prof. Dr Andy Shen, Frank Frühauf, Claudio Milisenda, Branko Deljanin, Dr Thomas Lind, Prof. Dr Henry Hänni, Dr Gaetano Cavalieri, Kenneth Scarratt, Dr James Shigley, Dr Ahmadjan Abduriyim, Dr Michael Krzemnicki, Tom Stephan, Prof. Dr Emmanuel Fritsch, Dr Federico Pezzotta, Jörg Michael Schlossmacher, Dr Ulrich Henn and Dr Tobias Häger. Photo by B. M. Laurs.

In 2018, more than two million 'small' samples were submitted to GIA's automated testing service.

Branko Deljanin (CGL-GRS Swiss Canadian Gemlab, Vancouver, British Columbia, Canada) compared pink diamonds from the Argyle mine in Australia to those from other sources, as well as treated stones and synthetics. Argyle produces 14 kg of diamonds per day, and although only 0.1% are pink, they represent 10% of the value from the mine. Characteristics of Argyle pink diamonds include pink octahedral graining, blue fluorescence (strong to long-wave and moderate to short-wave UV radiation) and patchy anomalous double refraction seen with crossed polarisers. Long-wave UV fluorescence provides a useful means of separating natural, treated and synthetic pink diamonds.

Dr Robert Chodelka (Ziemer Swiss Diamond Art AG, Port, Switzerland) discussed his company's production of synthetic diamonds. HPHT growth takes place at 55,000 bars pressure and >1,400°C for 88 hours, whereas CVD production is done under vacuum for up to three weeks' duration, and has a much higher energy cost (due in part to post-growth processing).

Prof. Dr Emmanuel Fritsch and co-author **Martine Philippe** (Institut des Matériaux Jean Rouxel and University of Nantes, France) described dissolved dislocations, which have been documented in nearly 20 gem species (e.g. danburite, spinel, garnet, topaz and diamond). Post-growth dissolution processes preferentially follow dislocations in the crystal lattice. Since various combinations of one-dimensional defects and screw-type dislocations may be present, the dissolution features can exhibit a variety of shapes, including straight and bent, as well as loops, forks and networks. They form hollow channels that always reach the surface and commonly have a tapered form with a polygonal cross-section.

Prof. Dr Andy Shen and co-authors (Gemmological Institute, China University of Geosciences, Wuhan) used synchrotron-based X-ray absorption spectroscopy to investigate the role of iron and hydrogen in the colouration of ametrine. In the violet sectors, Fe^{3+} occupies two different sites, and may be compensated by H^{+} in tetrahedral sites. In the yellow sectors, Fe^{3+} occupies more symmetrical sites together with molecular water. Therefore, both colours are caused by iron in different lattice sites, rather than being due to variations in iron valence or concentration.

Dr Federico Pezzotta (Civic Museum of Natural History of Milan, Italy) reviewed the sources and recent production of rubellite and polychrome tourmaline from Madagascar. He categorised two types of crystals: a first

generation of large tourmalines followed by a second generation of smaller crystals that are less abundant but of higher quality. Most of the rubellite-bearing granitic pegmatites are rather small, although one famous locality—the Anjanabonoina pegmatite—is quite large, and in 2018 it produced well-formed rubellite crystals weighing up to 26 kg.

Dr Tobias Häger and co-authors (Institute of Geosciences, Johannes Gutenberg University Mainz, Germany) reviewed the localities and gemmological properties of Colombian emeralds. He showed photomicrographs of characteristic three-phase inclusions and explained how UV-Vis-NIR spectra indicate that type I H_2O is much more abundant than type II H_2O in these emeralds. While it is not currently possible to differentiate emeralds according to individual mines, in the future stones from different belts in Colombia may be distinguishable.

Dr Daniel Nyfeler (Gübelin Gem Lab, Lucerne, Switzerland) described technologies for tracing and tracking gems along the supply chain, including the Emerald Paternity Test and Provenance Proof blockchain (see Conferences section of *The Journal*, Vol. 36, No. 5, 2019, p. 472).

Dr Claudio Milisenda (DSEF German Gem Lab) provided a review of spectroscopic research at DGemG and the DSEF German Gem Lab. The early history included contributions by Georg O. Wild, Prof. Dr Karl Schlossmacher and Prof. Dr Hermann Bank, and also involved collaborations with Heidelberg University and the German state of Rhineland-Palatinate. More recently, work has focused on the photoluminescence spectroscopy of alexandrite and Cu-bearing tourmaline, as well as the UV-Vis-NIR spectroscopy of Santa Maria-type aquamarine, spessartine from Namibia and rhodolite from various localities.

Dr Michael Krzemnicki (Swiss Gemmological Institute SSEF, Basel) explained how his lab differentiates between different colour varieties of gems. SSEF distinguishes some gems based only on colour (ruby vs. pink sapphire and padparadscha vs. pink, orange or fancy-colour sapphire), and others based on colour and spectroscopy (Co-spinel vs. blue spinel, emerald vs. green beryl and alexandrite vs. chrysoberyl). Such differentiations depend on employing standard procedures regarding the light source and observer, and the use of internal standards (e.g. master stones or colour charts) that correspond to the gem variety being observed.

Tom Stephan (DGemG) discussed his Ph.D. research on the role of V^{3+} in gems that are mainly coloured by Cr^{3+}. He used spectral fitting to subdivide overlapping absorption bands and to describe/calculate colour in ruby and emerald. He found that V^{3+} intensifies the colour of both gem varieties, while also producing a more violetish hue in ruby and a purer green hue in emerald.

Kenneth Scarratt (Bahrain Institute for Pearls & Gemstones [DANAT], Manama) described an October 2018 trip by two of his co-authors to acquire and characterise natural pearls from Australia. They joined a commercial shell- and meat-gathering expedition for *Pinctada maxima* near Darwin, where the processing of 6,837 molluscs yielded 793 natural pearls. The pearls formed in various parts of the molluscs, including the hinge, adductor muscle, mantle lip and gut areas.

Dr Ahmadjan Abduriyim (Tokyo Gem Science, Tokyo, Japan) summarised the history and gemmological characteristics of freshwater cultured pearls from Lake Kasumigaura, Japan. Currently 37 kg/year are produced from three farms, and the cultured pearls range from 11 to 15 mm with a nacre thickness of ~3 mm. Similar cultured pearls from China can be differentiated by plotting their Ga vs. Ba content.

The conference also featured a diploma ceremony for current DGemG graduates that was conducted by **Dr Thomas Lind**. At the end of the graduation ceremony, DGemG's coveted Golden Needle of Honour was presented to **Prof. Dr Henry Hänni** by **Dr Thomas Lind** and **Dr Ulrich Henn** (Figure 6).

Brendan M. Laurs FGA

Figure 6: Dr Ulrich Henn (left) and Dr Thomas Lind (right) present the Golden Needle of Honour award to Prof. Dr Henry Hänni. Photo by B. M. Laurs.

Gem-A Notices

Gifts to the Association

Gem-A is most grateful to the following for their generous donations that will support continued research and teaching:

Rui Galopim de Carvalho, Portugal, for a selection of jewellery, rocks and minerals.

Roland Naftule, USA, for eight synthetic sapphire/strontium titanate doublets.

Olivier Segura, France, for four books: *For the Love of Jewelry* by Jean-Noël Mouret; *The Art of the Jeweller* by Guillaume Glorieux; *Flora, The Art of Jewelry* by Patrick Mauriès and Évelyne Possémé; and *Fauna, The Art of Jewelry* by Patrick Mauriès and Évelyne Possémé.

Ian Thomson, UK, for a selection of 20 carved pillboxes, two carved resin figures imitating ivory and an original boxed Rayner UV lamp set.

Kathryn Wyatt, Australia, for three publications: *A Field Guide to Australian Rocks, Minerals & Gemstones* by Wolf Mayer; *Collecting Australian Gemstones* by Bill James; and an issue of *Australian Gemmologist*.

We are also particularly thankful to the family of the late **Mr Irwood** of West Finchley, London, who donated an extensive collection of fluorescent minerals, amounting to 111 in total, along with four publications: *Journal of the Fluorescent Mineral Society 1977, Ultraviolet Guide to Minerals* by Sterling Gleason, *Collecting Fluorescent Minerals* by Stuart Schneider and *The Story of Fluorescence* by Harry Wain.

Gem-A Confirms Oldest-Known Carved Tourmaline at the Ashmolean Museum, Oxford

In July 2019, Gem-A Tutor Pat Daly FGA and Operations Manager Charles Evans FGA DGA visited Oxford's Ashmolean Museum to study a unique and highly significant carved tourmaline. Gem-A's expertise had been requested by Gloria Staebler (co-founder of the mineralogy publishing house, Lithographie), who had been researching the piece for an upcoming publication titled *Rubellite—Tourmaline Rouge*.

The 2.4 cm-wide intaglio depicting Alexander the Great in profile was suspected to be a carved tourmaline, although the stone had never been subjected to gemmological testing. Based on the quality and accuracy of the portrait, along with the presence of an ancient Indian script in the carving, the intaglio is thought to date to the period of the famed king's reign (circa 334–323 BCE).

The study at the Ashmolean Museum brought about a landmark gemmological finding as observations by Daly and Evans, aided by a GemmoRaman spectrometer, confirmed that the stone was indeed a red-yellow tourmaline, making it the earliest known use of tourmaline as an ornament. For further information on the Ashmolean Museum's historic intaglio and Gem-A's involvement in the research visit https://gem-a.com/news-publications/news-blogs/news/industry/gem-a-confirms-oldest-known-carved-tourmaline-intaglio.

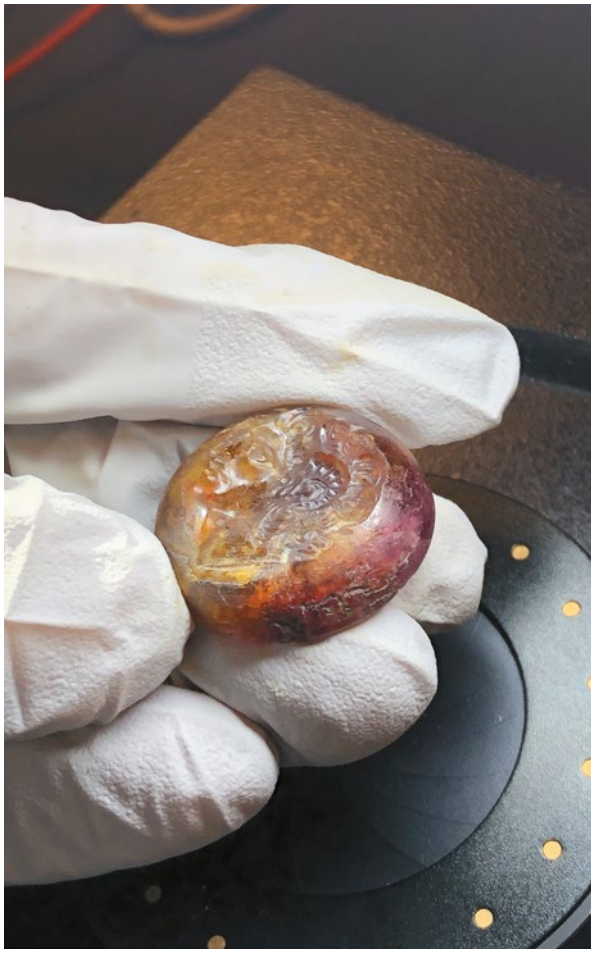

A red-yellow tourmaline intaglio depicts the profile of Alexander the Great. Photo by Charles Evans.

Gem-A Annual General Meeting

The Gem-A AGM will be held Wednesday 30 October 2019 at etc.venues The Hatton, 51–53 Hatton Garden, London, EC1N 8HN. We look forward to welcoming Gem-A Members to the Emerald Suite on the second floor for drinks from 18:00. The AGM will commence at 18:30.

No further action is required at this stage but please add this date to your diary. AGM documentation and nomination for election information will be released soon.

Gem-A's Webinar Debut

On 18 July 2019 Gem-A hosted its first of a series of brand new webinar sessions live from our London headquarters. Gem-A Tutor Pat Daly FGA presented 'Introduction to Gemstones', a beginner's gemmology lesson, which explained the physical characteristics, origins and vital care techniques of popular gems including sapphire, emerald and ruby. The 45-minute session was followed by a 15-minute Q&A and provided a free taster of our renowned gemmology courses to attendees across the world, reaching as far afield as Brazil, Indonesia and Australia.

Our next webinar, 'Introduction to Diamonds', will be held 10 October 2019 and will explain how diamonds are formed, what makes them special, and how to assess their value and qualities using the 4Cs: cut, colour, clarity and carat weight. This beginner's session will be ideal for a diamond enthusiast who has no prior gemmological knowledge. Keep an eye on our website for details on how to register.

Obituary

Professor Dr Hermann Bank

19 January 1928 – 14 August 2019

The esteemed member of the global gemmological community, published author and proactive member of the German Gemmological Association passed away in August 2019.

The Journal of Gemmology is saddened to announce the passing of Professor Dr Hermann Bank. Born in Idar-Oberstein in January 1928, Prof. Dr Bank was inspired by the gemmological heritage of his hometown and chose to study both geology and mineralogy at Johannes Gutenberg University in Mainz, Germany, and at ETH Zurich (Swiss Federal Institute of Technology) in Switzerland. In 1953, Prof. Dr Bank secured a Ph.D. in geology and was named the very first German Fellow of the Gemmological Association of Great Britain, before later being awarded honorary membership.

Following the completion of his Ph.D., Prof. Dr Bank became a leading light within the European gemmological community. The 1960s were a particularly exciting decade: he became partner and managing director of gemstone-cutting company Gebrüder Bank; joined the International Gemmological Conference (IGC) committee; and was named president of the German Gemmological Association and chairman of the German Foundation for Gemstone Research.

Prof. Dr Bank continued to lend his efforts to leading and inspiring those around him, while encouraging a sense of cooperation among European and global gemmological organisations. In 1996, he was named chairman of the Federation for European Education in Gemmology (FEEG), and by 2003 was honorary president of both the German Gemmological Association and FEEG. His honorary memberships were vast, including gemmological associations and gem trade organisations in Japan, the United States, Brazil, France and Poland. His passionate dedication to gemmological education and continued learning was an inspiration to his colleagues, peers and contemporaries, including Gem-A staff and Members.

For a man with such impressive accolades and achievements, including two Crosses of the Order of Merit of the Federal Republic of Germany, more than 1,000 published articles and seven books, Prof. Dr Bank never lost sight of his broader goals: to connect the gem and jewellery sectors with the science of gemmology. He envisioned the popularisation of gemmology in a way that furthered understanding for all, and eagerly pursued his own research projects while teaching the next generation. Friends and colleagues fondly remember his 'gemmological brooch'—a simple mounting he used to transport topical stones to conferences across the world and share his insights with others.

Gem-A would like to express our sincere condolences to Prof. Dr Bank's family and friends. His enthusiasm, passion and significant contribution to the field of gemmology has created a multi-faceted legacy that will continue to benefit further generations of gemmologists.

Learning Opportunities

CONFERENCES AND SEMINARS

12th Annual Portland Jewelry Symposium
29–30 September 2019
Portland, Oregon, USA
https://portlandjewelrysymposium.com

International Colored Gemstone Association (ICA) Congress
12–15 October 2019
Bangkok, Thailand
http://icacongress2019.com

Chicago Responsible Jewelry Conference
25–26 October 2019
Chicago, Illinois, USA
www.chiresponsiblejewelryconference.com

Munich Show: Mineralientage München
25–27 October 2019
Munich, Germany
https://munichshow.de/2019/06/26/2019-forum-minerale/?lang=en
Note: Includes a seminar programme

Gem-A Conference 2019
2–3 November 2019
London
https://gem-a.com/event/conference-2019

2019 China International Gems & Jewelry Academic Conference
13–14 November 2019
Beijing, China
Email ngtcyjb@163.com

MAESA 2019: 2nd International Conference on Applied Earth Sciences
29 November–1 December 2019
Yangon, Myanmar
www.maesa.org/info_2019.html
Notes: A conference theme is 'Mineralogy, Gemology and Genesis of Gem Deposits'. A post-conference excursion on 2–7 December will include a visit to Mogok.

Jewelry History Series
3–4 January 2020
Miami, Florida, USA
https://originalmiamibeachantiqueshow.com/show/jewelry-history-series
Note: This conference is part of The Original Miami Beach Antique Show.

22nd FEEG Symposium
24–27 January 2020
Schoonhoven, The Netherlands
www.feeg-education.com/symposium

NAJA 53rd ACE© IT Annual Winter Conference
2–3 February 2020
Tucson, Arizona, USA
www.najaappraisers.com/html/conferences.html

AGTA Gemfair Tucson
4–9 February 2020
Tucson, Arizona, USA
https://agta.org/seminars
Note: Includes a seminar programme

AGA Tucson Conference
5 February 2020
Tucson, Arizona, USA
https://accreditedgemologists.org/currevent.php

Tucson Gem and Mineral Show
13–16 February 2020
Tucson, Arizona, USA
www.tgms.org/show
Note: Includes a seminar programme

Inhorgenta Munich
14–17 February 2020
Munich, Germany
www.inhorgenta.com/index.html
Note: Includes a seminar programme

Prospectors & Developers Association of Canada PDAC 2020
1–4 March 2020
Toronto, Ontario, Canada
www.pdac.ca/convention/programming/technical-program
Theme of interest: The Business of Diamonds: From Rock to Ring

36th International Geological Congress
2–8 March 2020
New Delhi, India
www.36igc.org
Sessions of interest: Geology and Gemstones; Advances in Synthetic Gemstones; Diamonds Today; Gem Species and their Varieties

MJSA Expo
15–17 March 2020
New York, New York, USA
https://mjsa.org/eventsprograms/mjsa_expo
Note: Includes a seminar programme

Amberif
18–21 March 2020
Gdańsk, Poland
http://amberif.amberexpo.pl/title,Jezyk,lang,2.html
Note: Includes a seminar programme

10th National Opal Symposium
8–9 April 2020
Coober Pedy, Australia
www.opalsymposium.org

inArt 2020: 4th International Conference on Innovation in Art Research and Technology
14–17 April 2020
Paris, France
https://inart2020.sciencesconf.org

47th Rochester Mineralogical Symposium
23–26 April 2020
Rochester, New York, USA
www.rasny.org/minsymp

American Gem Society Conclave
27–29 April 2020
Denver, Colorado, USA
www.americangemsociety.org/mpage/conclave2020-home
Note: Includes a seminar programme

Diamonds – Source to Use 2020
9–11 June 2020
Johannesburg, South Africa
www.saimm.co.za/saimm-events/upcoming-events/diamonds-source-to-use-2020

9th International Conference Mineralogy and Museums
5–7 July 2020
Sofia, Bulgaria
www.bgminsoc.bg
Note: Gem minerals will be covered in a session titled 'Mineralogical Research and Museums'.

25th Congress and General Assembly of the International Union of Crystallography
22–30 August 2020
Prague, Czech Republic
www.xray.cz/iucr
Sessions of interest: Science Meets Art: Crystallography and Cultural Heritage; X-ray Spectrometry and X-ray Diffraction in Art and Archaeology; Superhard Materials: Status & Prospects

OTHER EDUCATIONAL OPPORTUNITIES

Gem-A Workshops and Courses
Gem-A, London
https://gem-a.com/education

AIGS Mogok Mines, Market & Culture Tour
Mogok, Myanmar
17–21 October 2019
www.aigsthailand.com/Mogok-Trip-Register/1/EN
Note: After the ICA Congress, visit gem mines and markets in the Mogok area with the Asian Institute of Gemological Sciences.

Lectures with Gem-A's Midlands Branch
Fellows Auctioneers, Augusta House, Birmingham
Email louiseludlam@hotmail.com

- Miranda Wells—The Changing Face of Tourmaline
  27 September 2019
- Shirley Mitchell—Becoming A Valuer & the Part Gemmology Plays
  25 October 2019
- Richard Maymon—Pearls
  29 November 2019
- Dr Maria MacLennan—Forensic Jewellery
  28 February 2020
- Peter Buckie—The Treasures Seen by an Expert Valuer
  27 March 2020
- Roy Starkey—Minerals of the English Midlands
  24 April 2020

Lectures with The Society of Jewellery Historians
Society of Antiquaries of London,
Burlington House, London
www.societyofjewelleryhistorians.ac.uk/current_lectures

- Sarah Steele, Léonard Pouy and Sigrid van Roode—New Research on Jewellery
  22 October 2019
- Rachel Church—Brooches, Badges and Pins at the Victoria and Albert Museum
  26 November 2019
- Thomas Holman—A Box Full of Buttons: The Life and Work of Frederick James Partridge (1877–1945)
  28 January 2020
- Stephen Whittaker—TBA
  25 February 2020
- Carol Michaelson—Chinese Jade Jewellery and Ornaments from the Neolithic to the Present
  24 March 2020

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New Media

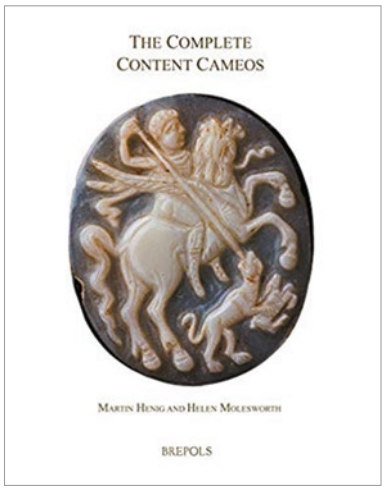

The Complete Content Cameos

By Martin Henig and Helen Molesworth, 2018. Brepols Publishers, Turnhout, Belgium, www.brepols.net/Pages/ShowProduct.aspx?prod_id=IS-9782503578965-1, iv+407 pages, illus., ISBN 978-2503578965. EUR150.00 hardcover.

Note: the correct year is 1990.

Derek Content's collection of hardstone cameos is, as far as is known, the largest in private hands. Between ~~1900~~ and 2000 the Ashmolean Museum displayed the collection, as it was then, in a specially built case, with an accompanying catalogue. The collection is now very much larger and is extraordinarily comprehensive. In view of the additions and the greatly increased scholarly knowledge of cameos (due in part to several recent catalogues of other collections), this new catalogue was called for. Over a number of years Martin Henig, one of the world's great engraved gem scholars, together with Helen Molesworth, an archaeologist and gemmologist, compiled this magnificent volume with contributions from other specialists, including Christopher Cavey, Jeffrey Spier and Content himself. It is beautifully produced on heavy art paper with stunning photographs. Although Content says in the preface that 'it is time to consider the collection a closed entity', he is still, unsurprisingly, collecting; perhaps there will be a supplemental volume in the future.

Cameos were for many years considered poor relations of intaglios, although the skills involved in deep three-dimensional carving of very difficult materials, using the different colour layers, were quite extraordinary.

Note: The correct number is 441.

The ~~425~~ cameos dealt with in this book range from the 9th century BCE to the 18th century CE. The ancient specimens are presented mostly in chapters by theme, rather than strictly chronologically, including Portraits, Deities and Myths, Dionysiac, Eros, Gorgoneia, Animals, Daily Life, Theatre and Music, and Legends. Separate chapters cover important periods (Hellenistic, Byzantine and Medieval, and Renaissance and Later), followed by a chapter on less-common countries of origin and one titled 'Carvings in the Round'. The book ends with an essay on ancient mountings; indexes by subject, material, mountings and provenance; and an extremely comprehensive bibliography.

The number of published cameos now available for comparative study allowed the authors to examine the popularity of particular subjects during various periods, together with the development of styles and techniques, and the use of gem materials. The authors attempted to date every item, although they admit this is an inexact science. Indeed, it is inevitable that more international research will result in the need to revise some attributions. It is hoped that this publication will spur such research and encourage some of the great institutions to produce comparable catalogues of their collections. (The British Museum catalogue is still the rather cursory 1926 listing by H. B. Walters!)

It is a great pity that a DVD of the images was not included with the book (as has been done with some recent catalogues). This would have greatly enhanced the ability to study these superb cameos. Also, as great as the photographs are, two-dimensional images cannot really give the feel of deeply carved objects. Modern technology—such as high-definition three-dimensional scanning—would enable the cameos to be turned and viewed in all orientations on a screen.

This really splendid publication will remain, however, a major standard reference work for the foreseeable future, and it is currently the only major modern publication in English on ancient cameos. Indeed, it is extremely difficult to imagine that any future serious research into hardstone cameos could be conducted without reference to it.

Nigel Israel FGA DGA
London

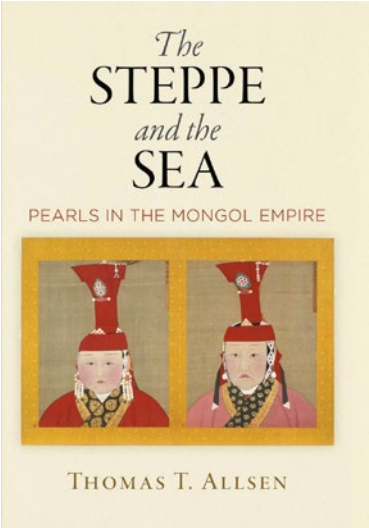

The Steppe and the Sea: Pearls in the Mongol Empire

By Thomas T. Allsen, 2019. University of Pennsylvania Press, Philadelphia, Pennsylvania, USA, www.upenn.edu/pennpress/book/15970.html, 240 pages, illus., ISBN 978-0812251173. USD45.00 hardcover or USD36.00 eBook.

This volume is part of the 'Encounters with Asia' series from the University of Pennsylvania Press, and its author was professor emeritus of The College of New Jersey. The 'was' is sadly significant, because Prof. Allsen passed away in February 2019, shortly before this book was published. Allsen was a highly respected expert and author on medieval Eurasia and the Mongol Empire. It is gratifying that he directed his erudite attention to a gem material—the pearl—and looked at it in the context of its trade and importance in and across the Mongol Empire from 1206 to 1370. Even those not familiar with the Mongol Empire will know of its founder, Genghis Khan. At its height in the late 1200s, before it began to split under Genghis's grandsons, the Mongol Empire was the largest contiguous land empire the world has yet seen, stretching from what is now Eastern Europe across to China. It also extended as far south as the Persian Gulf, with trade routes directly linking the Chinese court with the Arabian pearl beds.

At the outset, it must be stated that this book is a highly academic work, the fruit of very extensive research and clear evidence of Prof. Allsen's proficiency in the Chinese, Persian, Arabic and Russian languages. It is a valuable addition to information we have about pearls and their value, symbolism and trade in the past, supplementing Robin Donkin's monumental and essential *Beyond Price: Pearls and Pearl Fishing* (1998). It is neither a light read nor particularly visually appealing; it is a reference work. It is amusing to note that the publishers, presumably hoping to widen its appeal, begin the inside dust-jacket blurb with mention of a female prisoner in 1221 who confessed to having swallowed her pearls, only to be killed and eviscerated on the spot.

The book itself proves less sensationalist generally, of course, but despite the tight focus on history and the myriad textual sources, Allsen wears his scholarship lightly and consummately puts pearls within a very human context. At one point, for example, he refers to the 'price fixing, kickbacks, gross mismanagement and outright theft' within the pearl-loving Mongol court. In another case he notes, with regard to the diminishment of a treasury as a result of lax guarding and bribery, 'What happened in those instances would now be called a breakdown of inventory control, though it is fairly obvious that little if any control was ever exercised.' Referring to the sad susceptibility of pearls to decay with time, he notes succinctly, 'While diamonds are forever, pearls are not.'

The wealth of textual information Allsen has gathered from across the Mongol world is distilled into chapters that cover everything from pearl fishing and processing to prices and counterfeits. With regard to the latter, he notes that the culturing of pearls in China dates back to as early as the ninth century—much sooner than I thought.

The lack of illustrations in the book is a huge shame. There are just four, all in greyscale (apart from the dust jacket). There are no images of actual pearl-set jewellery. The closest are two images of early gold jewellery that have nothing to do with Mongol culture and are included because they illustrate spherical gold components that are resourcefully described as 'pearl shaped'. Even in a scholarly book that concentrates on the historical aspects of pearls, a few choice illustrations would have been good. Photos of some impressive Mongol gold jewellery have been published in recent years, including pearl-set pieces, as seen in Mikhail Piotrovskii's beautifully illustrated *The Treasures of the Golden Horde* (2000).

According to the dust jacket, Jos Gommans, professor of Colonial and Global History at Leiden University, The Netherlands, described this book as offering 'new insights into the wider socioeconomic and cultural history of the Mongol Empire'. Since this review is in a gemmological publication, I will simply plagiarise this statement with a slight modification and say that this book offers new insights into the wider socioeconomic and cultural history *of the pearl*. It is a welcome addition to the gem or jewellery historian's bookshelf.

Dr Jack M. Ogden FGA
London

Other Book Titles

CULTURAL HERITAGE

All That Glittered: Britain's Most Precious Metal from Adam Smith to the Gold Rush
By Timothy Alborn, 2019. Oxford University Press, New York, New York, 276 pages, ISBN 978-0190603519. USD35.00 hardcover or USD23.99 Kindle edn.

Masterpieces in Miniature: Engraved Gems from Prehistory to the Present
By Claudia Wagner and John Boardman, 2018. Philip Wilson Publishers, London, 304 pages, ISBN 978-1781300626. GBP40.00 hardcover.

GENERAL REFERENCE

The Science of Gemstones
By Ahmadjan Abduriyim, 2019. Ark Publishing Inc., 271 pages, ISBN 978-4860592066 (in Japanese). JPY2,500.00 softcover.

INSTRUMENTATION

Handbook of Advanced Non-Destructive Evaluation
Ed. by Nathan Ida and Norbert Meyendorf, 2019. Springer, Cham, Switzerland, 1,626 pages, ISBN 978-3319265520 (print), 978-3319265537 (eBook) or 978-3319301228 (print plus eBook). EUR727.99 hardcover, EUR832.99 eBook or EUR1,143.99 hardcover plus eBook (in two volumes, not available separately).

JEWELLERY HISTORY

Chaumet en Majesté: Joyaux de Souveraines Depuis 1780
By Stéphane Bern and Christophe Vachaudez, 2019. Flammarion, Paris, France, 288 pages, ISBN 978-82081489349 (in French). EUR30.00 softcover.

Designers and Jewellery 1850–1940
By Helen Ritchie, 2018. Philip Wilson Publishers, London, 176 pages, ISBN 978-1781300671. GBP16.95 softcover.

JEWELLERY AND *OBJETS D'ART*

The Art of the Jeweler: Excellence and Craftsmanship
By Guillaume Glorieux, 2019. Éditions Gallimard, Paris, France, 76 pages, ISBN 978-2072822605. EUR14.50 softcover.

Bejeweled: The World of Ethical Jewelry
By Kyle Roderick, 2019. Rizzoli, New York, New York, USA, 224 pages, ISBN 978-0847865888. USD65.00 hardcover.

Brooches and Badges
By Rachel Church, 2019. Thames & Hudson, New York, New York, USA, 160 pages, ISBN 978-0500480359. USD24.95 hardcover.

Bulgari: The Perfume of Gems
By Brian Eno, Annick Le Guerer, Chiara Gamberale and Renato Bruni, 2018. Rizzoli, New York, New York, USA, 272 pages, ISBN 978-0847865383. USD150.00 hardcover.

Bulgari: Stories of Gems and Jewels
Ed. by Lucia Boscaini and Chiara Ottaviano, 2019. Rizzoli, New York, New York, USA, 352 pages, ISBN 978-8891824325. USD65.00 hardcover.

Diamond Jewelry: 700 Years of Glory and Glamour
By Diana Scarisbrick, 2019. Thames & Hudson, New York, New York, USA, 256 pages, ISBN 978-0500021507. USD75.00 hardcover.

Marie-Helene de Taillac: Gold and Gems
By Marie-Helene de Taillac and Eric Deroo, 2019. Rizzoli, New York, New York, USA, 224 pages, ISBN 978-0847865376. USD85.00 hardcover.

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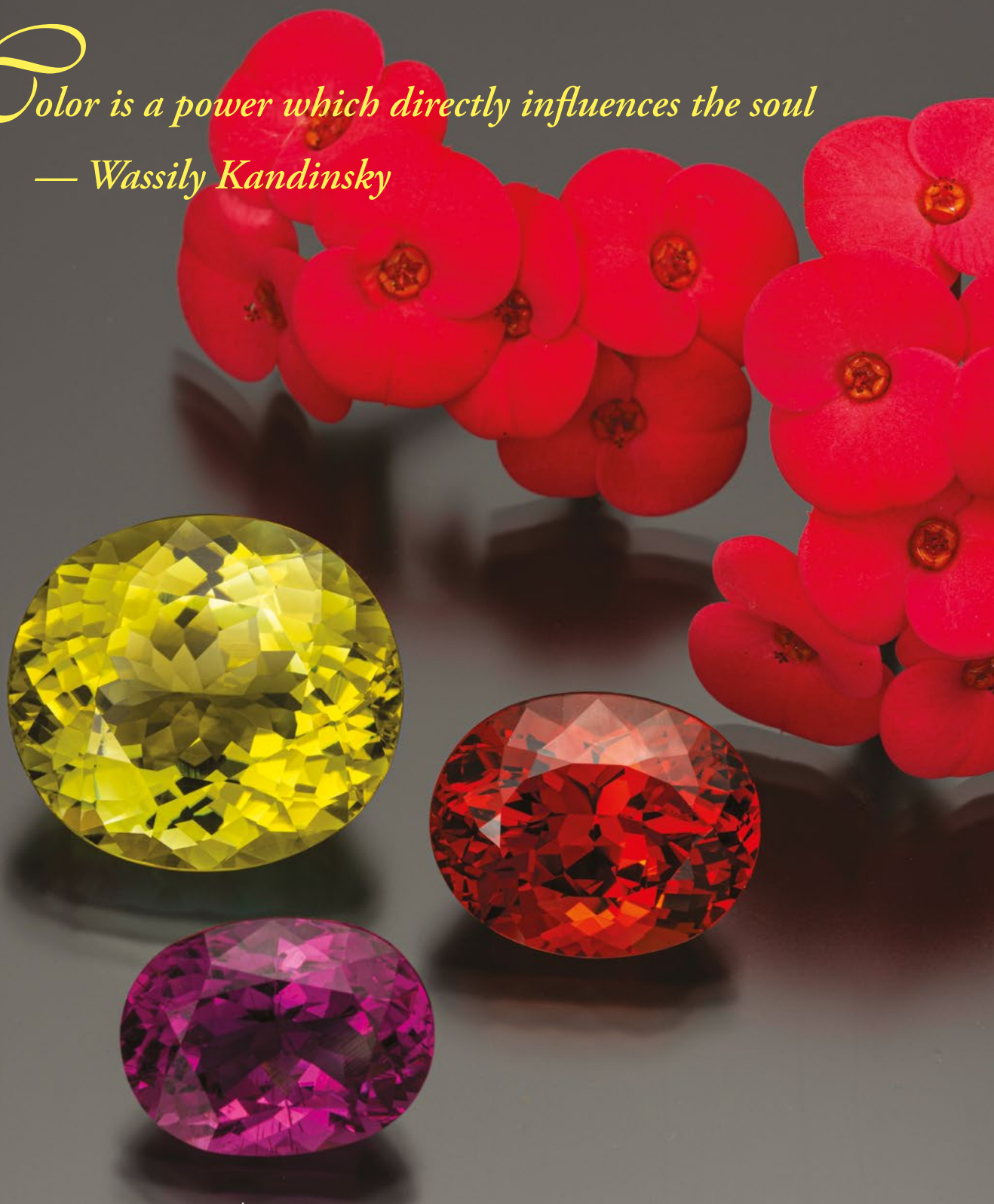

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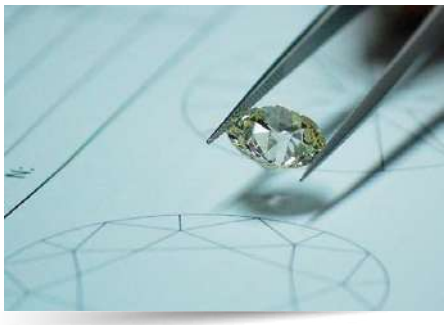

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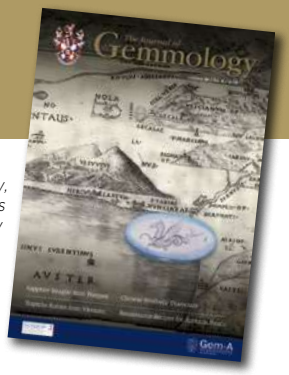

Cover photo: *An 11.62 ct intaglio excavated in 1986 from Pompeii, Italy, proved to be a basaltic-type sapphire (see article on pp. 710–725 of this issue) and therefore does not have a Sri Lankan origin as commonly described for Roman sapphires. The background map, from Italian Renaissance painter Girolamo Mocetto, shows the region near Mount Vesuvius, which erupted in 79 CE and buried Pompeii and the surrounding area under a thick layer of ash.*

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What's New

INSTRUMENTATION

ABCD Pro-1 Gem Testing Set

In November 2019, the Asian Gemmological Institute and Laboratory Ltd (AGIL) released an updated version of its ABCD Gem Testing Set. The 16-piece gemmological instrument kit includes a 10× loupe, incandescent Maglite torch with darkfield attachment, polariscope, prism spectroscope, long-wave UV source, conoscope, diffuser, stone holder, tweezers, and various adaptors and diffusers. New additions include a spectroscope stand and rotatable stage that can be used in conjunction with the spectroscope and the torch/UV source. Holders for the various instruments and filters permit convenient handling of the gem being examined for pleochroism, single/double refraction, inclusions and absorption/fluorescence spectra. Packaged in a convenient carrying case, the set weighs 0.78 kg and is designed for use by the travelling gemmologist. Visit http://eshop.agil.com.hk/index_eproduct_view.php?products_id=3.

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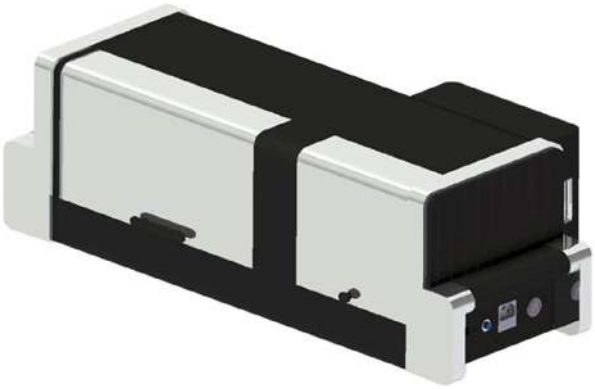

D-Imaging

DRC Techno (Gujarat, India) released the D-Imaging system in September 2019. The all-in-one unit is designed to produce a 360° image of a diamond that can display characteristics such as clarity, cut, colour, fluorescence and the 'hearts-and-arrows' optical effect. The system allows for enhanced representation of a diamond when it is not possible for a buyer to view the stone in person. The unit is 676 × 280 × 224 mm and weighs 10 kg. Visit www.drctechno.com/products/retail/d-imaging.

Raman Spectroscopy Application Notes

United ID RAMAN LAB

United ID Raman Laboratory (Taipei, Taiwan) has issued a series of application notes on Raman spectroscopy pertaining to gemmology. Topics include diamond, jadeite, nephrite, ruby, sapphire, amber, emerald, coral, pearl, chalcedony, opal and more. Some are freely available, while others are accessible only to United ID customers. Visit www.uid-ramanlab.com/gemstones.

NEWS AND PUBLICATIONS

CIBJO Special Reports

Reports prepared in advance of the 18–20 November 2019 CIBJO Congress are available for download at www.cibjo.org/congress2019/special-reports. They review issues for discussion by the various CIBJO commissions, with topics including Generation Z as a future consumer group (Marketing & Education Commission), corporate social responsibility principles for the jewellery industry (Responsible Sourcing Commission), market trends and supply chain integrity (Precious Metals Commission), natural vs. laboratory-grown diamonds (Diamond Commission), technology and nomenclature (Coloured Stone Commission), compliance and disclosure requirements (Ethics Commission), gemmological laboratory reports (Gemmological Commission), and environmental issues (Pearl and Coral Commissions).

Gem Abstracts from the 2019 GSA Annual Meeting

Abstracts of oral and poster presentations from the 131st annual meeting of the Geological Society of America, held in Phoenix, Arizona, USA, on 22–25 September 2019 are now available online. Oral presentation abstracts can be viewed at https://gsa.confex.com/gsa/2019AM/webprogram/Session47368.html and include topics such as diamond deposits and localities, causes of colour in diamond, inclusions in and chemical composition of sapphire, Oregon sunstone, jet, and the new beryl-group member johnkoivulaite (see What's New entry, above right). Poster session abstracts are available at https://gsa.confex.com/gsa/2019AM/webprogram/Session48617.html and cover the geochemistry of Cr in sapphire, Ni in diamond, inclusions in type II pink diamond, the sapphire auction market in China, and auction pricing of pink and blue diamonds.

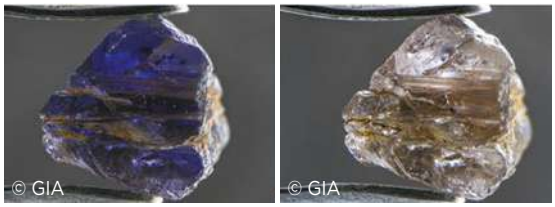

Johnkoivulaite, a New Mineral

A new mineral of the beryl group—johnkoivulaite, $Cs(Be_2B)Mg_2Si_6O_{18}$—has been named after renowned gemmologist John I. Koivula, who is best known for his contributions to photomicrography and research on gem inclusions. The 1.16 ct crystal from Mogok, Myanmar, is strongly pleochroic (deep violet to near-colourless; see photo) and has the following properties: RI—1.608 (birefringence too small to measure accurately), hydrostatic SG—3.01, Mohs hardness—7½, and inert to long- and short-wave UV radiation. News of the discovery was first announced at the September 2019 GSA Conference (see What's New entry, below left) and further information was published in the Gem News International section of *Gems & Gemology* (Vol. 55, No. 3, 2019, pp. 454-455).

Market Research on Responsibly Sourced Diamonds

In September 2019, MVI Marketing released a report titled 'The Need for 3rd Party Verification of Mined and Lab-Grown Diamond Claims of Positive Social and Environmental Impact'. It describes the results of consumer research conducted in July 2019, which found that roughly 40% of consumers make diamond-purchasing decisions based on information about social and environmental responsibility, including country-of-origin claims, especially when supported by third-party verification of such claims. Many will even pay a premium for responsibly sourced diamonds with a known geographic origin. Download the report after filling out an online form at www.mvimarketing.com/download-report.php?report=49.

Santa Fe Symposium Proceedings 2019

Proceedings of the 2019 Santa Fe Symposium (19–22 May) are now available online. While the primary focus of this long-running conference (held annually in New Mexico, USA) is on jewellery manufacturing, some of the presentations are also of interest to gemmologists. These include 'Getting started with blockchain', 'Conflict diamonds and corporate social responsibility in the U.S. jewelry industry' and 'The use of computed tomography in the evaluation and cutting of opaque gemstone material'. Full papers covering the presentations can be downloaded at www.santafesymposium.org/2019-santa-fe-symposium?category=2019. Proceedings from previous symposia are also available back to 2000.

OTHER RESOURCES

2019 SSEF Presentations

Presentations given in 2019 by staff of the Swiss Gemmological Institute SSEF are available online in PDF format, including those titled 'Age dating applied as a testing procedure to gemstones and biogenic materials', 'Multi-element analysis of gemstones for country of origin determination, 'Study of a recut HPHT synthetic diamond', 'A gemmological approach to distinguishing natural from synthetic rubies' and 'Where is the boundary between colour varieties of gems?'. Older presentations (2009–2018) are also available. Visit www.ssef.ch/presentations.

Jewelry Journey Podcasts

The Jewelry Journey Podcast website at https://thejewelryjourney.com/podcasts hosts podcasts dating from October 2018 that feature experts in gems, jewellery and art, from antique to modern. Recent podcasts of potential interest to gemmologists cover the art, jewellery and history of ancient Nubia; a preview of New York City's Jewelry Week 2019; the appraisal of gems, antique and estate jewellery; and much more. Currently, 49 podcasts are available via the website and the Jewelry Journey Podcast app for mobile devices. Podcast host Sharon Berman is a marketing and public relations expert who is also a gemmologist involved in various jewellery organisations, as well as a jewellery collector.

MISCELLANEOUS

Gemewizard Launches Gem Color Academy

In August 2019, Gemewizard Group (Ramat Gan, Israel) introduced its online Gem Color Academy. Two courses are currently offered: grading of fancy-colour diamonds and grading of coloured stones. The courses provide in-depth training with an assigned class and instructor, and are designed to appeal to a broad range of students, from gem and diamond traders to gemmologists and trade professionals to hobbyists. Visit www.gemcoloracademy.com.

What's New provides announcements of new instruments/technology, publications, online resources and more. Inclusion in What's New does not imply recommendation or endorsement by Gem-A. Entries were prepared by Carol M. Stockton unless otherwise noted.

Gem Notes

COLOURED STONES

Amethyst from Zimbabwe

Zimbabwe is known as a source of various gems, including diamond, emerald, aquamarine, chrysoberyl, alexandrite, iolite, garnet, euclase, tourmaline and quartz-family varieties such as amethyst (Ncube 1988). During the February 2019 gem shows in Tucson, Arizona, USA, author BML learned about a new find of amethyst in Zimbabwe from rough stone dealer Sir-Faraz Ahmad (Farooq) Hashmi (Intimate Gems, Glen Cove, New York, USA). He reported that in late 2018, one pocket produced 10–15 kg of good-quality material in pieces weighing up to about 150 g. A significant portion of the rough contained oriented hematite inclusions that were visible in certain directions. Hashmi provided one clean rough sample for faceting to Todd F. Wacks Jr. (Tucson Todd's Gems, Tucson, Arizona). The piece was strongly colour zoned, particularly near the crystal termination, and cutting of its basal portion yielded a 76 ct Portuguese round (Figure 1).

Examination of the faceted stone by author NDR showed that it contained only a few inclusions. A partially healed fracture consisting of two-phase (liquid and gas) fluid inclusions showed thin-film interference colours (Figure 2), and also present were a few elongate brownish needles.

Figure 2: A partially healed fracture in the faceted amethyst consists of fluid inclusions that display thin-film interference colours when viewed with darkfield and oblique fibre-optic illumination. Photomicrograph by N. D. Renfro, © GIA; image width 4.7 mm.

The visual appearance of these slightly curved whiskers indicated they were almost certainly hematite.

The location within Zimbabwe of this amethyst find is not known, and it is not clear if it represents a new mining area or came from an existing deposit such as those in the Karoi District or the Zambezi Valley (cf. www.mindat.org/locentries.php?p=21891&m=198).

Figure 1: The Zimbabwean amethyst on the right (76 ct) was cut from the crystal fragment remaining on the left. Photo by Diego Sanchez, © GIA.

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Reference

Ncube, A.N. 1988. Occurrences of gemstones and ornamental stones in Zimbabwe. *Zeitschrift der Deutschen Gemmologischen Gesellschaft*, **37**(3/4), 139–142.

Apatite from Durango, Mexico

Extensive information is known about the geology of the classic locality for gem-quality fluorapatite at Cerro de Mercado, near Durango, in Durango State, Mexico (e.g. Megaw & Barton 1999, 2013). The use of this apatite as a geochronological and mineralogical standard has also been discussed extensively (e.g. Corona-Esquivel *et al.* 2018). However, less information can be found in the literature on the gemmological properties of this material, so this author was pleased to examine two faceted samples loaned by gem dealer Dudley Blauwet (Dudley Blauwet Gems, Louisville, Colorado, USA). He reported that although faceted Mexican apatite was somewhat available in the trade from approximately 1990 to 2005, the stones were commonly overlooked due to an abundance of new items from previously unobtainable sources that followed the fall of the Soviet Union and Eastern Bloc, along with new finds in Africa and China, which the market considered more exotic than Mexico.

The emerald- and cushion-cut stones measured 14.97 × 9.47 × 7.97 mm (10.00 ct) and 13.88 × 10.51 × 8.69 mm (9.42 ct), respectively. Both were transparent, with a homogeneous greenish yellow colour (Figure 3). The RIs of both samples were 1.631–1.636, yielding a birefringence of 0.005. Their optic character was uniaxial negative. The average hydrostatic SG value for both was 3.21. A calcite dichroscope revealed weak dichroism of light yellow and light greenish yellow. A prism spectroscope revealed a strong doublet at 580 nm, a narrow band at about 525 nm, and other lines visible at about 480, 510 and 600 nm. The gems were inert to long-wave UV radiation, but fluoresced weak yellow to short-wave UV. This differs from the 'lilac pink' fluorescence for yellow apatite indicated by Webster (1994).

Both stones were relatively clean. Microscopic examination of the cushion revealed straight growth zoning. The emerald cut contained a small liquid feather (Figure 4a) composed of multiphase and necked-down single-phase inclusions (Figure 4b).

Figure 3: These faceted apatites from Durango, Mexico, weigh 9.42 ct (cushion cut) and 10.00 ct (emerald cut). Photo by J. C. Zwaan.

A visible-near infrared (Vis-NIR) absorption spectrum collected with a Thermo Scientific Evolution 600 spectrometer gave a more detailed picture of the features observed with the spectroscope, consisting of pronounced peaks at about 514, 526, 578/585 (doublet), 749 (with a shoulder at 740) and 803 nm, accompanied by weaker bands at about 483 and 598 nm (Figure 5). The most pronounced transmission window was at around 545–565 nm, which was responsible for the greenish yellow colour, in conjunction with a gradual absorption in the blue towards an absorption edge in the violet region.

A Raman spectrum obtained with a Thermo Scientific DXR Raman microscope using 532 nm laser excitation showed an excellent match with spectra for fluorapatite in the RRUFF database. Photoluminescence spectra collected with the same green laser showed strong emission peaks in the red region, at about 600 and 645 nm (Figure 6).

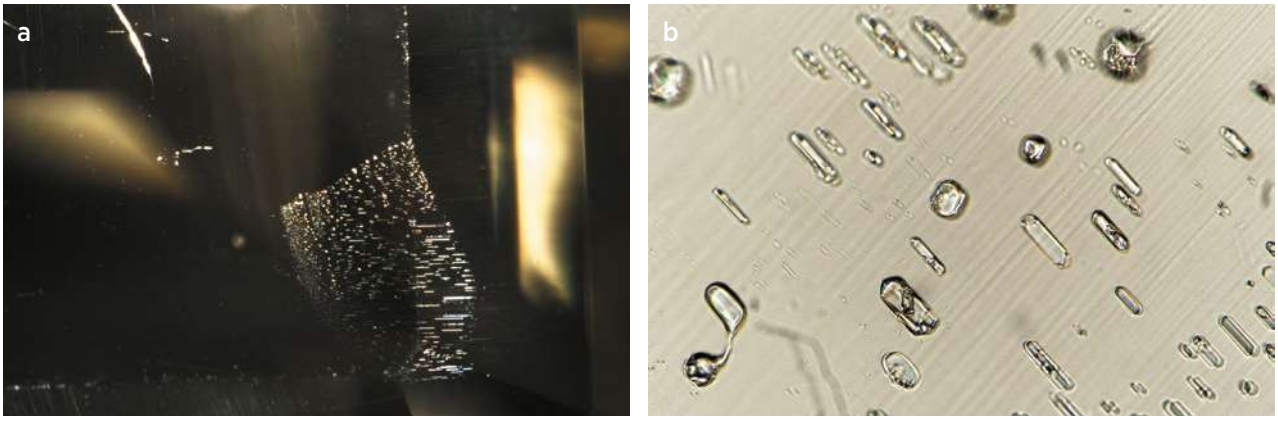

Figure 4: (**a**) A small partially healed fracture is seen in the emerald-cut apatite. (**b**) Closer examination of this feather reveals multi-phase inclusions, with necking-down of some of them (at left) resulting in mono-phase fluid inclusions. Photomicrographs by J. C. Zwaan; (a) darkfield illumination and image width 4.6 mm, and (b) brightfield illumination and image width 0.3 mm.

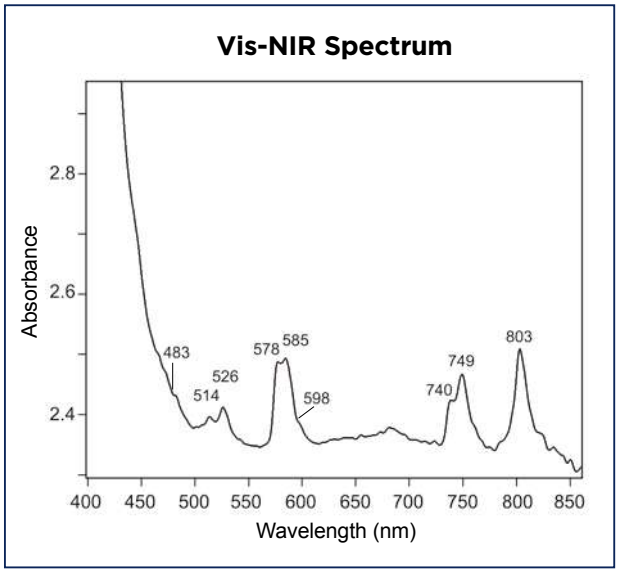

Figure 5: A non-polarised, room-temperature Vis-NIR spectrum of the apatite shows features typically produced by rare-earth elements, in particular Nd^{3+}. The path length of the beam was about 7.5–8.0 mm.

Gemmological textbooks (e.g. Anderson 1980) mention that the characteristic 'didymium' absorption spectrum of apatite is due to the presence of rare-earth elements (REE), in particular neodymium (Nd) and praseodymium (Pr). Although these elements were not detected by energy-dispersive X-ray fluorescence (EDXRF) spectroscopy with an EDAX Orbis Micro-XRF Analyzer, REE can be present at very low concentrations (below 100 ppmw) yet still be detectable with absorption spectroscopy and luminescence techniques. The multiple peaks seen in the Vis-NIR spectrum are typically due to the presence of trivalent rare-earth ions. In particular, the absorption bands centred at around 740 and 800 nm (Figure 5) can be attributed to Nd^{3+}, the intense photoluminescence in the red region (Figure 6) is due to the presence of Pr^{3+}, and the weak fluorescence to short-wave UV might indicate the presence of Ce^{3+} (Cantelar *et al*. 2001).

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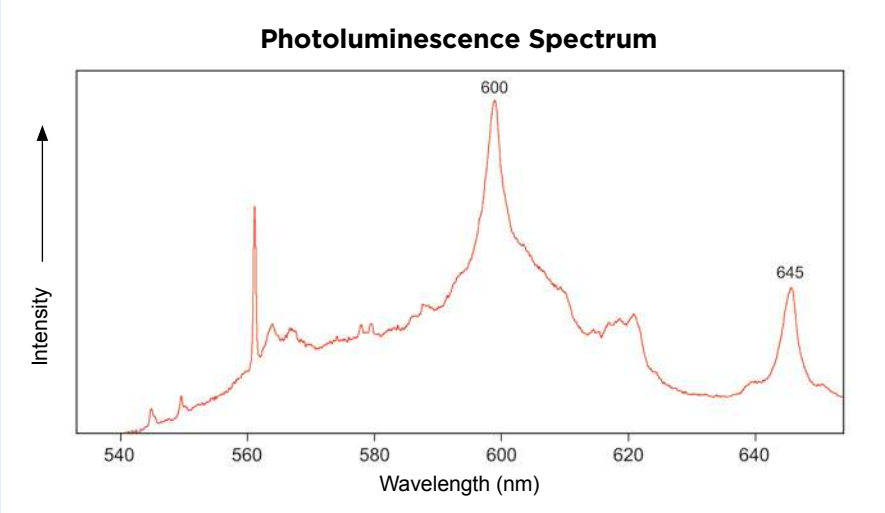

Figure 6: Strong photoluminescence in the red region, excited by a green laser, can be attributed to the presence of Pr^{3+}. Sharp Raman bands of fluorapatite are present in the 540–580 region.

Cobaltocalcite or Cobaltoan Calcite: A Swiss Answer

Switzerland is not known for its gem production, but rather as an important platform for trading, auctioning and certifying gems. However, at the May 2019 GemGenève fair (Geneva International Gem and Jewellery Show), a new Swiss gem material debuted in the designer area. Geneva-based art jeweller Grégoire Maret (Pierre d'Alexis S.A.) presented pink to purplish pink cobaltoan calcite from Switzerland—marketed as 'Rose of Mine'—in his handmade jewellery creations (e.g. Figure 7).

Cobaltoan calcite, $(Ca,Co)CO_3$, is rarely seen in high-end jewellery, and is rather unusual in its nature and geological origin. It is coloured by traces of Co^{2+} in octahedral coordination within the calcite structure (Fritsch & Rossman 1987), and may show variations in saturation and hue. The Swiss rough material, previously described by Meisser (1999), is sporadically extracted from abandoned coal mines situated near the village of Isérables in the canton of Valais in south-west Switzerland. The gemmy material is polished *en cabochon*, and so far approximately 30 stones have been cut, ranging from 5 to 35 ct.

This attractively coloured calcite variety formed under unique conditions. Following the cessation of coal mining in 1943, surface waters interacted with the surrounding rocks, and the cobaltoan calcite crystallised at ambient temperature and pressure through the percolation of fluids enriched with Co, Ni and Zn (Meisser 1999), forming speleothems on black shale host rock (Figure 8) in the moist darkness of the abandoned coal mines.

Figure 7: A free-form cabochon of translucent cobaltoan calcite from Switzerland is set in this pendant (5 cm long) by Grégoire Maret (Pierre d'Alexis S.A.), which is called 'L'Inattendue'. In the background is a piece of the rough speleothem on the host rock. Photo by David Fraga.

Figure 8: A speleothem (3 cm tall) of Swiss cobaltoan calcite is shown on its black shale host rock. (The white material in bottom-centre is a later generation of calcite.) Photo by Alain Pitteloud.

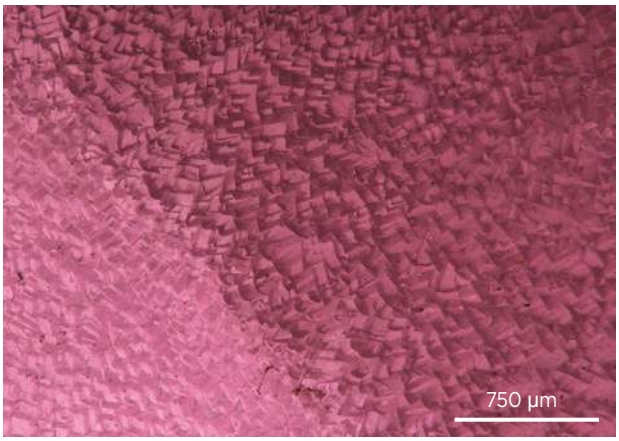

Figure 9: Aggregates of trigonal crystals are seen on the surface of the rough cobaltoan calcite. Photomicrograph by F. Notari.

Standard gemmological testing of this strongly birefringent polycrystalline material revealed RIs of 1.49–1.66 and a hydrostatic SG value of approximately 2.70. Only a very weak purplish luminescence was observed with long-wave UV radiation and the material was inert to short-wave UV. Under magnification, it showed a granular to fibrous appearance and columnar growth with inhomogeneous colour distribution resulting from the presence of remnants of the black shale host rock. The surface of the piece of uncut rough material we examined exhibited trigonal prismatic crystals without preferential orientation (Figure 9), resulting in a generally botryoidal form and making it tougher than monocrystalline calcite.

We identified the material as calcite (rather than aragonite) using infrared specular reflectance. The UV-Vis-NIR

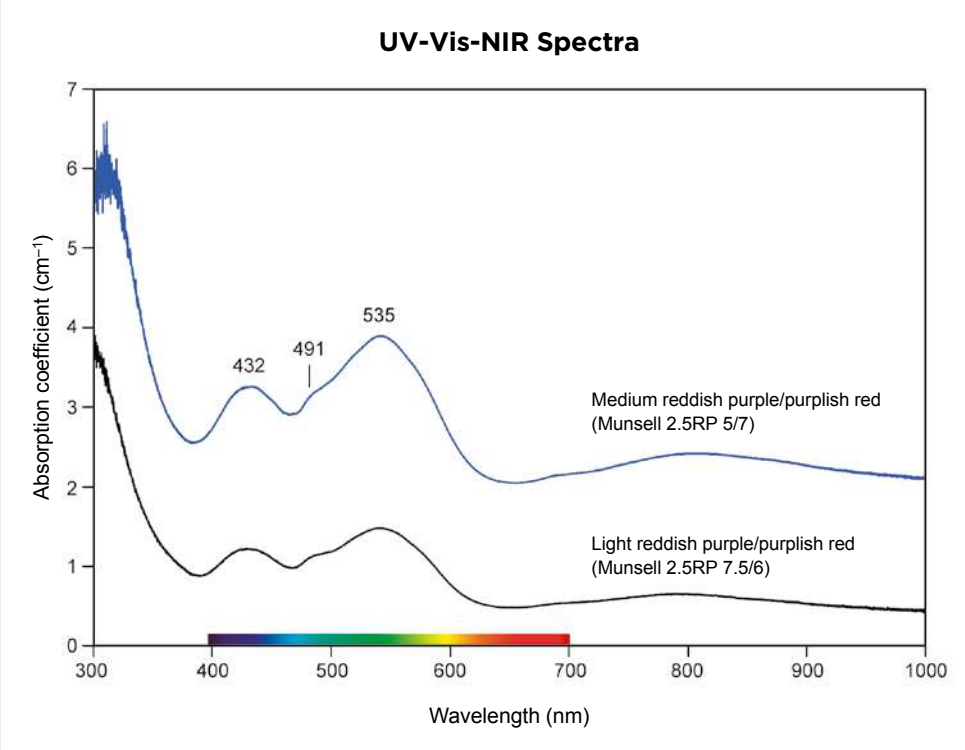

Figure 10: UV-Vis-NIR spectra taken at room temperature of two samples of cobaltoan calcite with different colouration reveal typical absorptions of Co^{2+}, consisting of two broad bands at about 535 and 432 nm and a smaller one at about 491 nm (present as a shoulder; position calculated at 77 K) of unknown attribution.

spectra (Figure 10) exhibited absorptions at about 535 and 432 nm associated with the presence of Co^{2+}. Semi-quantitative analysis of trace elements was measured on zones with different colour saturations using EDXRF spectroscopy (Thermo Fisher Scientific ARL Quant'X), and indicated the presence of about 850–1,400 ppmw Co—with higher amounts corresponding to deeper colouration—and up to about 220 ppmw Ni, as well as detectable levels of Zn. Pink colour in calcite is also known to be due to Mn, but this element was not detected in the Swiss samples by EDXRF analysis, in contrast to the cobaltoan calcite from an unspecified locality that was studied by Siritheerakul and Sangsawong (2015).

There is confusion between the names *cobaltocalcite* and *cobaltoan calcite*. *Cobaltocalcite* was introduced by Palache *et al.* (1951) for $CoCO_3$ (a carbonate of cobalt), but was refused by the International Mineralogical Association and replaced by *spherocobaltite*. The material described here is a variety of calcite in which some Ca is replaced by Co—$(Ca,Co)CO_3$—and therefore should be called cobaltoan calcite since it does not contain cobalt as a main component.

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Pyrite and Chromite Inclusion Assemblage in Emerald

Recently, American Gemological Laboratories received a parcel of emeralds for testing. One gemstone (Figure 11), weighing 0.87 ct, stood out from the rest because of its combination of inclusions. Microscopic observation revealed numerous mineral inclusions, some of which appeared to be pyrite (Figure 12a), while others formed black disseminated grains or aggregates (Figure 12b) similar to those commonly encountered in Colombian emeralds.

Raman microspectroscopy confirmed the brassy-coloured crystals were pyrite, whereas the black aggregates proved to be chromite—rather than the bits of black shale that form dark inclusions in Colombian emeralds. Such an association of pyrite and chromite has been published previously on only a few occasions: first in the 1980s (Sauer & Cassedanne 1984; Gübelin & Koivula 1986) and again almost 30 years later (Gübelin & Koivula 2008). Indeed, chromite and pyrite are two of the most distinctive inclusions of emeralds from Santa Terezinha de Goiás in Brazil. Other mineral inclusions common to this locality include amphiboles, carbonates (calcite and dolomite), enstatite, epidote, feldspars, garnet, hematite, ilmenite, phlogopite, talc, quartz and pyrrhotite (Sauer & Cassedanne 1984; Gübelin & Koivula 2008).

Further evidence confirmed the Brazilian origin of this emerald: additional microscopic features such as primary fluid inclusions; UV-Vis-NIR absorption spectra showing the presence of Fe^{2+} (837 nm), Fe^{3+} (372 nm) and Cr^{3+} (435, 607 and 681 nm); and EDXRF chemical analysis indicating considerable Fe content (Sauer & Cassedanne 1984; Schwarz 2002, 2011; Cedeño Ochoa *et al.* 2015; Giuliani *et al.* 2015).

Figure 11: This 0.87 ct emerald attracted our attention due to the presence of abundant black inclusions. Photo by Alex Mercado, AGL.

This emerald is a reminder that pyrite and black aggregates are not exclusive to stones of Colombian origin (e.g. Figure 13). The presence of pyrite, when occurring with other minerals such as chromite, as well as the appearance of the primary fluid inclusions, can help indicate a Brazilian origin.

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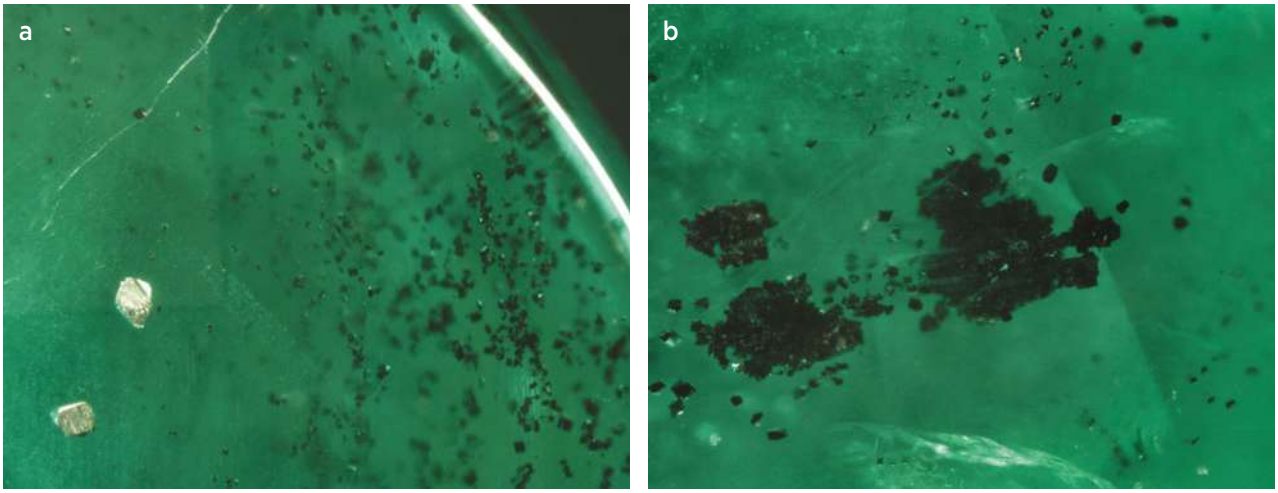

Figure 12: (**a**) Pyrite crystals and abundant chromite grains are prominent in this emerald, consistent with those from Santa Terezinha de Goiás in Brazil. (**b**) The chromite inclusions occur as both isolated grains and clusters in the emerald. Photomicrographs by R. Zellagui in darkfield illumination; magnified 9× (a) and 7× (b).

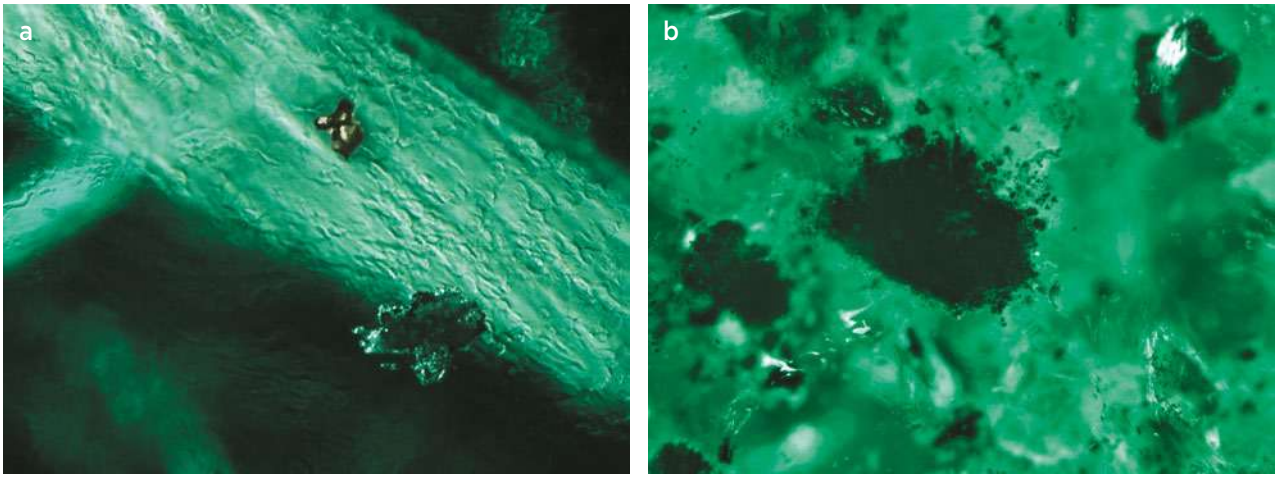

Figure 13: (**a**) Dark inclusions (from the black shale host rock) and pyrite crystals are sometimes encountered together in Colombian emeralds, as shown here. This stone also shows a strong *gota de aceite* effect (graining) that is typical of some emeralds from Colombia. (**b**) At first glance, the bits of black shale in this Colombian emerald strongly resemble the chromite inclusions seen in the Brazilian emerald in Figure 12b. Photomicrographs by R. Zellagui in darkfield illumination; magnified 10× (a) and 6× (b).

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Six-Rayed Star Enstatite from Madagascar

Enstatite may display asterism with four, six or eight rays, although it has been documented from only a few localities: southern India (Eppler 1967, 1971), Ratnapura in Sri Lanka (Henn & Bank 1991) and more recently Norway (Schmitz *et al*. 2016). Enstatite is the Mg end member of the enstatite-ferrosilite series, the orthopyroxenes of the enstatite group. Historically, the series has been divided into intermediate members such as 'bronzite', hypersthene, etc. (Dunn 1975; Deer *et al*. 1997), according to Fe content. 'Bronzite' is not recognised by the International Mineralogical Association but occasionally may be encountered in the literature.

Recently, star enstatite was found at a new locality: Madagascar (Figure 14). During the June 2019 Sainte-Marie-aux-Mines Mineral & Gem Show, Renan Deschard,

Figure 14: This 1.24 ct enstatite cabochon from Madagascar shows six-rayed asterism. The strongest rays are parallel to the length of the stone. Some cleavage and parting are also visible. The cabochon measures about 9 × 5 × 3 mm. Photo by T. Cathelineau.

a prospector in Madagascar, donated the 1.24 ct cabochon to the author for characterisation.

The enstatite showed the following properties: colour—light brown; pleochroism—strong, in orangey brown, greyish green and grey; diaphaneity—translucent; RI—1.660–1.670; birefringence—0.010; optic character and sign—biaxial positive; hydrostatic SG—3.25; magnetism—slightly attracted to an N52 (neodymium) magnet; Chelsea Colour Filter reaction—none; fluorescence—inert to long- and short-wave UV radiation; and handheld spectroscope spectrum—continuous absorption in the violet and blue regions with two sharp bands in the green at about 505 and 545 nm. These data are consistent with those reported for enstatite by O'Donoghue (2006).

Light scattering from a dense network of inclusions formed the six-rayed star, with the strongest rays seen parallel to the length of the cabochon. Microscopic examination (Figure 15) revealed parallel acicular (needle-like) inclusions (up to 2 µm wide and 150 µm long) aligned in three directions and intersecting at approximately 57° and 62°. The intersection angles are consistent with the orthorhombic pseudo-hexagonal symmetry of enstatite and published data: 57° and 64° (Eppler 1967, 1971); 57° and 61° (Henn & Bank 1991); and 64° (Schmitz *et al.* 2016). Eppler (1967) suggested rutile as a possible inclusion; Henn & Bank (1991) ascribed the asterism to hollow channels; Gübelin & Koivula (2008) indicated rutile or sillimanite in Sri Lankan enstatite; and Schmitz *et al.* (2016) identified ilmenite in Norwegian enstatite.

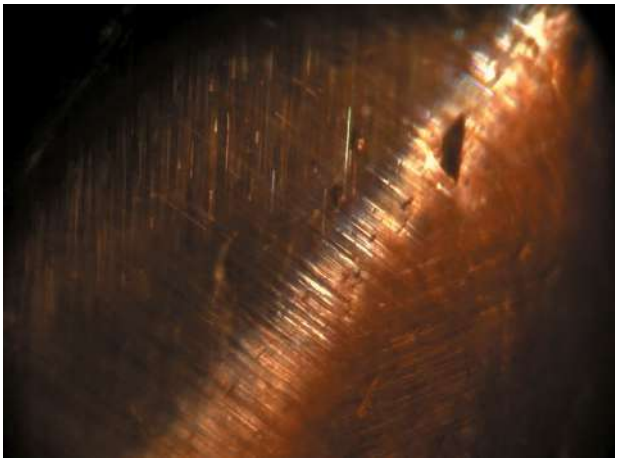

Figure 15: Viewed with oblique illumination, the enstatite shows acicular inclusions that scatter light and intersect at approximately 57° and 62°. Photomicrograph by T. Cathelineau; image width 1.0 mm.

Further investigation such as using Raman microspectroscopy would be necessary to identify the inclusions in the Madagascar enstatite.

Infrared reflectance spectra were collected from several spots on the cabochon, and all yielded the same pattern without any distinct differences (Figure 16). The spectrum is characteristic of enstatite (see spec4gem.info/databases/irs/296; Chihara *et al.* 2002).

Vis-NIR spectra (Figure 17) were collected with the beam entering from the top and oriented nearly perpendicular to the base of the cabochon. Due to the beam's orientation, only two spectra were acquired: one for the orangey brown colour and one for the greyish green

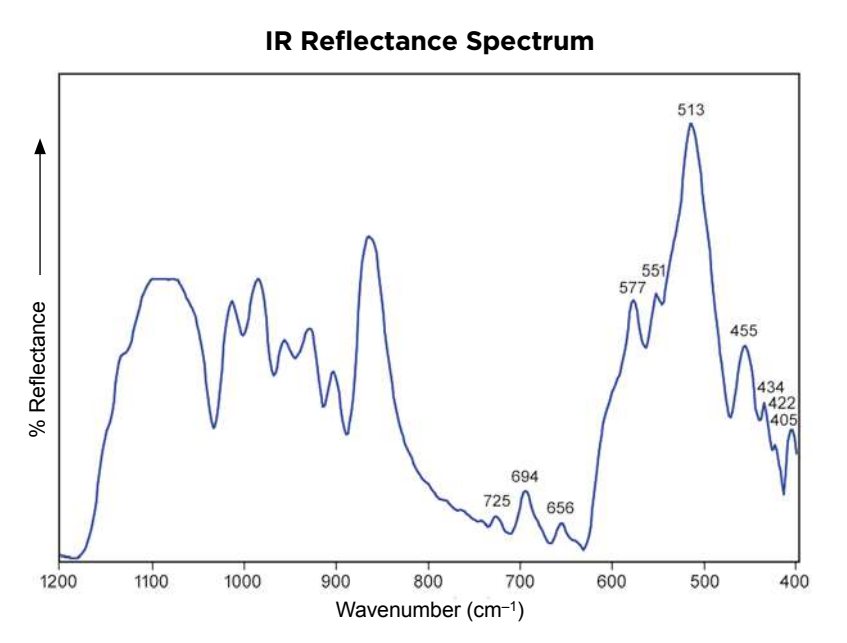

Figure 16: The IR reflectance spectrum for the cabochon in Figure 14 characterises it as enstatite, according to the series of labelled bands.

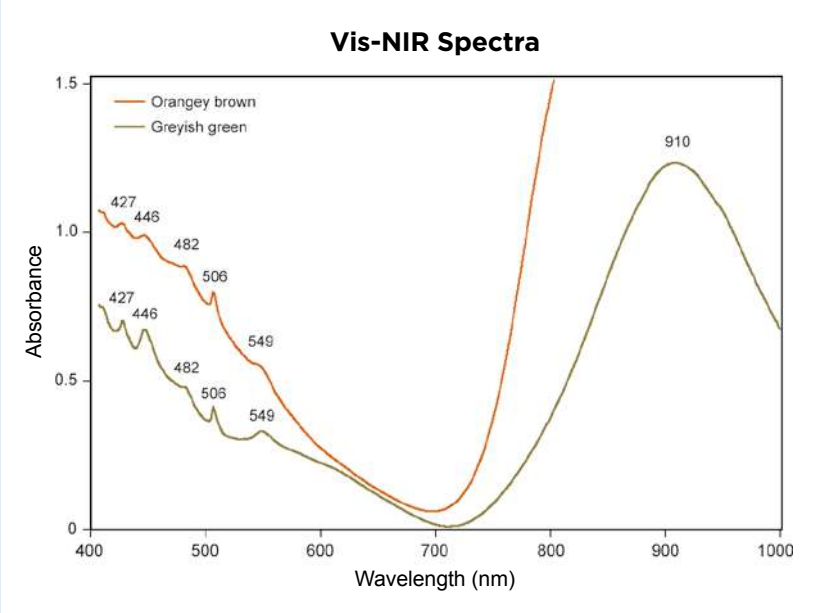

Figure 17: Vis-NIR spectra obtained for two of the enstatite's trichroic colours (orangey brown and greyish green) show iron-related features, including an Fe^{2+} band in the NIR region and characteristic Fe^{2+} spin-forbidden transition features in the 400–600 nm range. The path length of the beam was about 3.1 mm.

colour. The spectra were consistent with reference spectra for enstatite (see, e.g., spec4gem.info/databases/uvvis/297 and minerals.gps.caltech.edu/FILES/Visible/pyroxene). Across the visible range, both spectra showed a continuous absorption increasing towards the UV region (weaker for the greyish green direction), with a superimposed series of narrow bands at 427, 446, 482, 506 and 549 nm; the 506 nm band is characteristic of enstatite. In the near-IR range, both spectra showed a broad, strong absorption band centred at 910 nm (stronger in the orangey brown direction). The continuous absorption in the visible range coupled with the near-IR band creates a transmission window in the orange-to-red region, which is narrower in the orangey brown spectrum than in the greyish green one. The narrower transmission window produced the orangey brown colouration, while the broader one resulted in greyish green colouration since more green was transmitted. The continuum towards the UV and the strong band in the NIR are related to Fe^{2+} substituting for Mg^{2+} in the M1/M2 sites, and the narrow bands between 400 and 600 nm are Fe^{2+} spin-forbidden absorption bands (Hazen *et al.* 1978; Zhao *et al.* 1986). Thus, the stone is coloured by Fe^{2+}.

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Yellowish Green Enstatite (and Star Enstatite) from Tanzania

Gem-quality enstatite is typically brown to dark green, and star enstatite was first documented by Eppler (1967) as a dark brown cabochon from southern India showing six-rayed asterism. However, during the February 2019 Tucson gem shows, some attractive yellowish green enstatite entered the market from a new find in Tanzania (e.g. Figure 18). One of the authors (JW) was initially offered the rough material as 'sphene' (titanite). Although the 'chartreuse' colour and overall appearance of the pieces resembled titanite, closer inspection with a loupe did not show the expected high birefringence and dispersion. Suspecting it was peridot, this author purchased a few pieces and took them to Alberto Scarani and Mikko Åström of Magilabs (Rome, Italy and Järvenpää, Finland) for an initial identification with Raman spectroscopy, which indicated enstatite. Upon returning home from Tucson, this author ground away any surface contamination from one of the pieces and confirmed it was enstatite via Raman analysis. In addition, the RIs of 1.66–1.67 and birefringence of 0.01 were consistent with enstatite. According to the supplier, Peter Musomba, the material was mined from the Morogoro area of Tanzania. Musomba was unaware of how much rough was produced, but from a 1 kg parcel he selected approximately 150 g of the cleanest material in pieces ranging from 1 to 3 g.

Although author JW obtained rough specifically for faceting transparent stones, there was also some silky material available in Tucson that could cut cat's-eye and star stones. Gem cutter Thomas A. Trozzo (Trozzo, Culpeper, Virginia, USA) purchased a small parcel from Farooq Hashmi, who obtained it in Tanzania as 'peridot'.

Figure 18: A 2.00 ct enstatite is shown with some rough material from a new find in Tanzania. Photo by J. White.

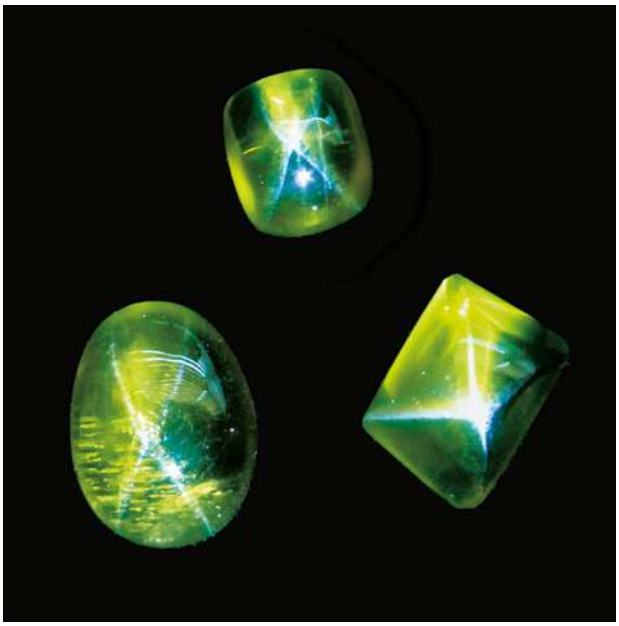

Figure 19: Weighing 3.56–7.32 ct, these star enstatites were cut from the new Tanzanian material. The samples exhibit cross-shaped four-rayed stars, although the orientation and cut of the right-hand stone make it difficult to see the appearance of the asterism. Photo by B. Williams.

Trozzo cut three star enstatites (Figure 19) and reported that although there was a sufficient amount of needle-like inclusions to create asterism, the rough stones were difficult to orient. In addition, author JW notes that enstatite is challenging to facet because of its two distinct cleavage directions, and it is also prone to fraying at the ends of the crystal. These aspects may present difficulties during the preforming and cutting stages. For example, while the stone in Figure 18 was being faceted, a significant crack spontaneously appeared during the early stages of cutting that had to be removed by sawing. To help avoid problems with cracking and fraying, it was necessary to use a fine-grit lap and minimise the pressure applied to the stone. Surprisingly, despite the difficulties encountered during the cutting stage, the enstatite polished very quickly and easily with 50,000 or 100,000 grit diamond paste.

The three star enstatites in Figure 19 along with three pieces of rough were provided by Trozzo to authors CW and BW for characterisation. The RIs were 1.660–1.669 (birefringence 0.009) and SG was measured hydrostatically as 3.25. Both of

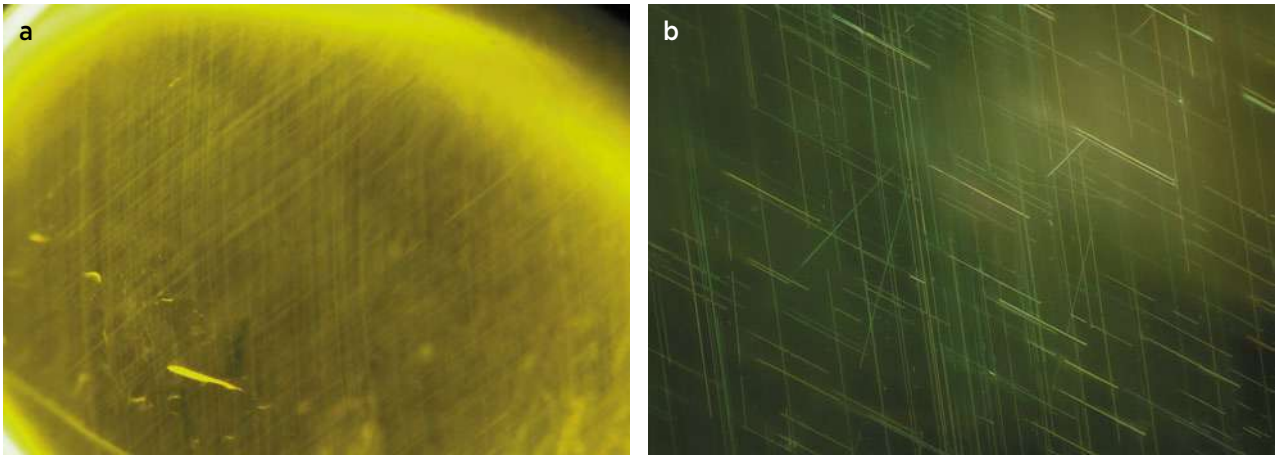

Figure 20: (**a**) Abundant needles are present in two orientations in this star enstatite. Photomicrograph by B. Williams; magnified 10×. (**b**) The faceted enstatite in Figure 18 contains fewer needles, as shown in this image created by stacking 18 photos using Helicon Focus software. The needles running from top to bottom of the photo are nearly parallel to the viewer, while those in the other predominant orientation are steeply inclined into the stone. A few needles are also present in two other orientations. Photomicrograph by J. White; image width 2.5 mm.

these values fall well within the range of enstatite, which was confirmed by Raman analysis and Fourier-transform infrared (FTIR) spectroscopy using GemmoRaman-532SG and PerkinElmer Spectrum100 instruments, respectively. EDXRF spectroscopy with an Amptek X123-SDD spectrometer showed various minor and trace elements, including Ti, V, Cr, Mn and Fe. The stones all contained elongate needles oriented in two directions (Figure 20a), and one of them also had some colour-growth zones bisecting the acicular inclusions, similar to those documented in a brown Tanzanian enstatite by Koivula *et al.* (1988). By comparison, the transparent faceted stone in Figure 18 contained fewer needles (Figure 20b).

A small fragment provided by author JW to GRR was also confirmed as enstatite by infrared reflectance, and EDXRF spectroscopy using an INAM Expert 3L unit showed 1.4% Fe, 0.4% Mn, 0.08% V, 0.07% Ti and 0.01% Cr. Initial attempts to obtain Vis-NIR absorption spectra revealed that the sample was not oriented correctly for polarised spectroscopy along the principal axes, so another piece (supplied by Trozzo) was optically oriented and fabricated into an approximate cube for spectroscopy. Analyses with a combination of a silicon-diode array microspectrometer and an InGaAs FTIR system showed that the spectra were dominated by absorption features of Fe^{2+} in the near-infrared region (Figure 21a). The colour in the visible region, however, was primarily controlled by the weaker V^{3+} absorption bands in the ranges of 420–490 nm and 600–700 nm that defined a window of maximum transmission in the yellow-green region (500–580 nm) of the spectrum (Figure 21b).

Although enstatite with such an attractive bright colour is only rarely encountered, similar material has been documented previously from both Kenya and Tanzania. Schmetzer & Krupp (1982) described transparent yellowish green enstatite from Mairimba Hill, which is located south of the Taita Hills in southern Kenya (RIs = 1.652–1.662, birefringence = 0.010, SG = 3.23), and attributed its attractive colour to small amounts of Fe and Cr replacing Mg. Stockton & Manson (1983) compared transparent yellowish green enstatite and peridot that both reportedly came from the Usambara Mountains in Tanzania (near the border with Kenya), and reported the following properties for the enstatite: n_α = 1.669, n_β = 1.672, n_γ = 1.679 and birefringence = 0.010. Enstatite and peridot can have overlapping colour, RI and SG values, but Stockton & Manson (1983) emphasised that they can be separated by their spectroscope spectra and peridot's higher birefringence (0.036). Coincidentally, both gem varieties can also form four-rayed stars. While star peridot is considered quite rare and highly collectible compared to star enstatite, the Tanzanian enstatite documented here is unusual in showing an attractive bright colouration as well as the possibility of yielding cat's-eye and star stones.

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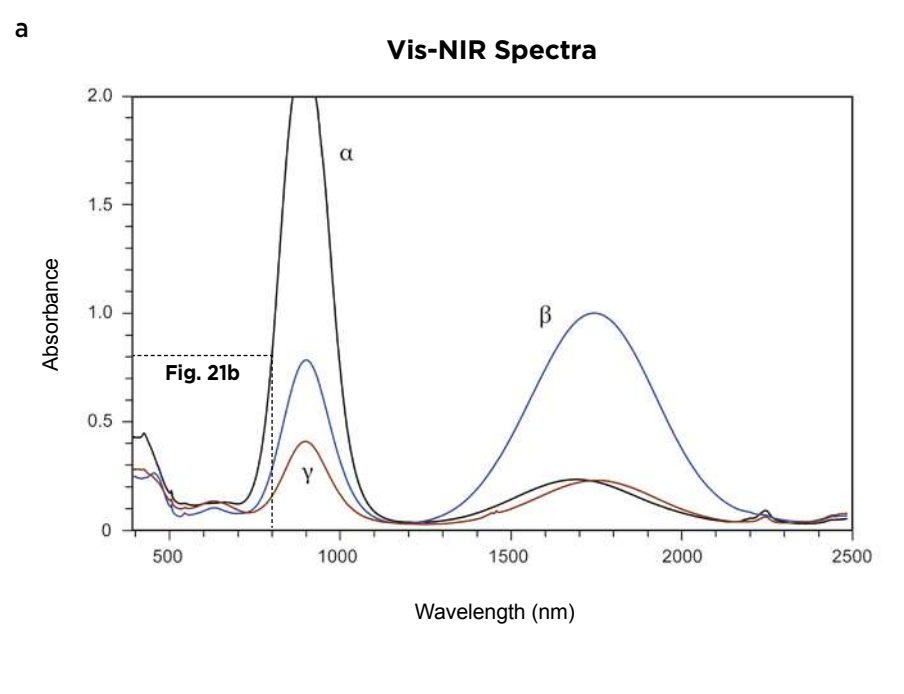

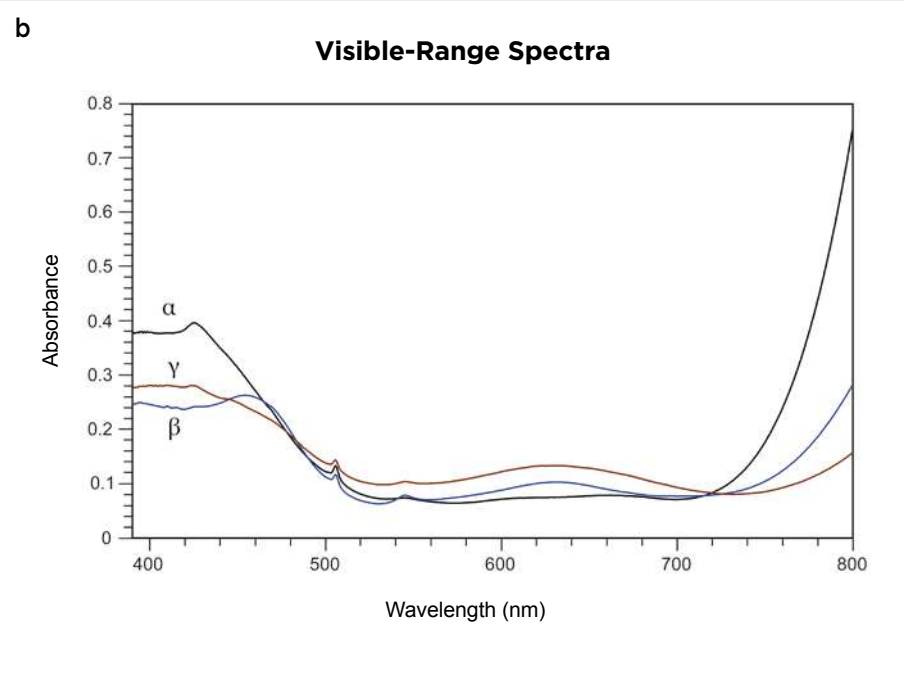

Figure 21: (**a**) Vis-NIR spectra of the Tanzanian enstatite are dominated by strong Fe^{2+} features near 900 and 1750 nm. (**b**) The visible-range spectra show broad V^{3+} features that define an area of maximum transmission in the yellow-green region. The weak, sharp Fe^{2+} peak at 506 nm is a common feature of iron in orthopyroxenes. The spectra are plotted for 2.0 mm thickness.

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Sunstone Labradorite-Bytownite from Ethiopia

Figure 22: Sunstone has been recovered from surface deposits in the Afar region of Ethiopia. Photo by T. Sintayehu.

In the past several years, Ethiopia has gained attention for a variety of new gem finds. After large deposits of play-of-colour opal were found in 2008, black opal was detected in 2013 (Kiefert *et al.* 2014). In 2016, high-quality emeralds were recovered from southern Ethiopia (Renfro *et al.* 2017; Schollenbruch *et al.* 2017), some of which rivalled those from Colombia. In December of the same year, significant deposits of basaltic blue sapphires were found in the country's north (Bruce-Lockhart 2017).

In 2015, one of the authors (TS) was shown various gem samples—including sunstone—that reportedly came from the Afar region in north-eastern Ethiopia. After further investigation, this author learned the approximate location of the sunstone deposits and later was shown several places where it was found (e.g. Figure 22). These occurrences occupy an area close to 100 km in length and width, and are located south-east of Mek'ele.

The sunstone occurs mostly as loose angular pieces (Figure 23a) but has also been found in coarse-grained rock fragments (Figure 23b) in a basaltic environment. Most of the gem rough recovered so far showed a near-colourless rim with red colour concentrated towards the centre. Occasionally, green zones were also present (again, see Figure 23a). Very few of the stones showed a schiller

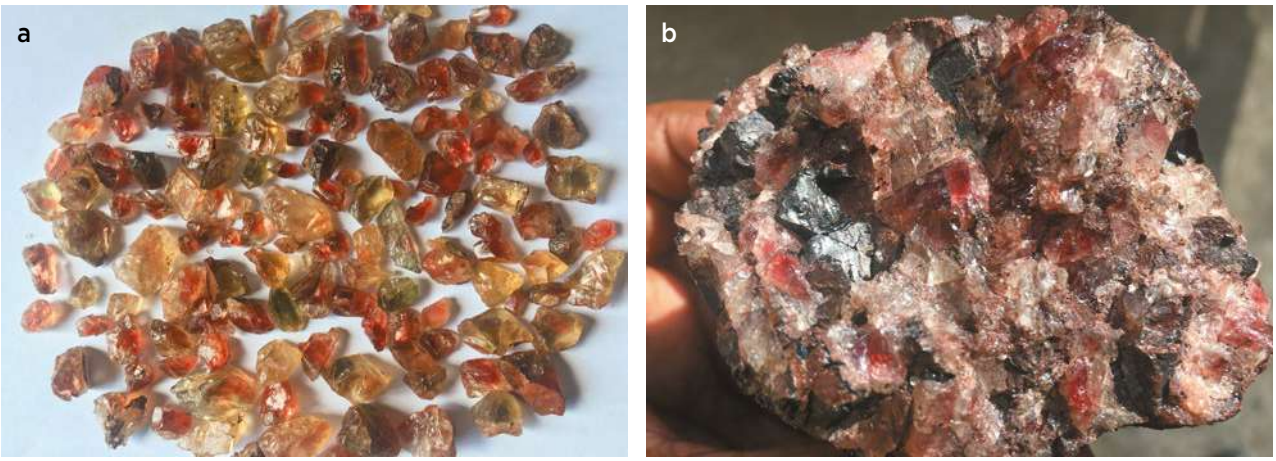

Figure 23: Ethiopian sunstone exhibits various colours (near-colourless, red and green), similar to labradorite from Oregon, USA. The Ethiopian samples shown here include (**a**) broken pieces that are about 5–20 mm long and (**b**) a rock fragment of about 120 mm in maximum dimension that is probably a glomerocryst (crystal cluster of plagioclase and pyroxene). Photos by T. Sintayehu.

Figure 24: These faceted Ethiopian sunstones (0.48–1.91 ct) display various colours. Photo by T. Sintayehu.

effect due to copper-coloured particles large enough to be visible with a gemmological microscope. So far only a few of the Ethiopian sunstones have been faceted, weighing 0.48–1.91 ct (Figure 24).

EDXRF chemical analyses of six rough samples with a Thermo Fisher Quant'X instrument yielded a chemical composition ranging from labradorite to bytownite, with contents of anorthite (An), albite (Ab) and orthoclase (Or) in the range of $An_{66.8–79.7}Ab_{18.6–31.1}Or_{0.1–2.2}$. This composition is more calcic than that of Oregon sunstone documented by Hofmeister & Rossman (1985: $An_{64.7–67.0}$).

UV-Vis microspectroscopy of a colour-zoned sample was performed with a Jasco MSV-5200 spectrophotometer. The near-colourless area showed an overall continuous increase in absorption toward the UV region, while the red portion exhibited a broad absorption band with a maximum at 568 nm (Figure 25). A similar absorption band has been recorded in red Oregon sunstone, but at a lower wavelength (i.e. 561 nm from research done by author CW, and at 560 nm according to Hofmeister & Rossman 1985). Since labradorite is triclinic, differences in sample orientation may cause the variations in the position of the band.

Overall, the colouration and UV-Vis spectral features of this new Ethiopian feldspar are similar to those of Oregon sunstone. Further data will be reported in a future article.

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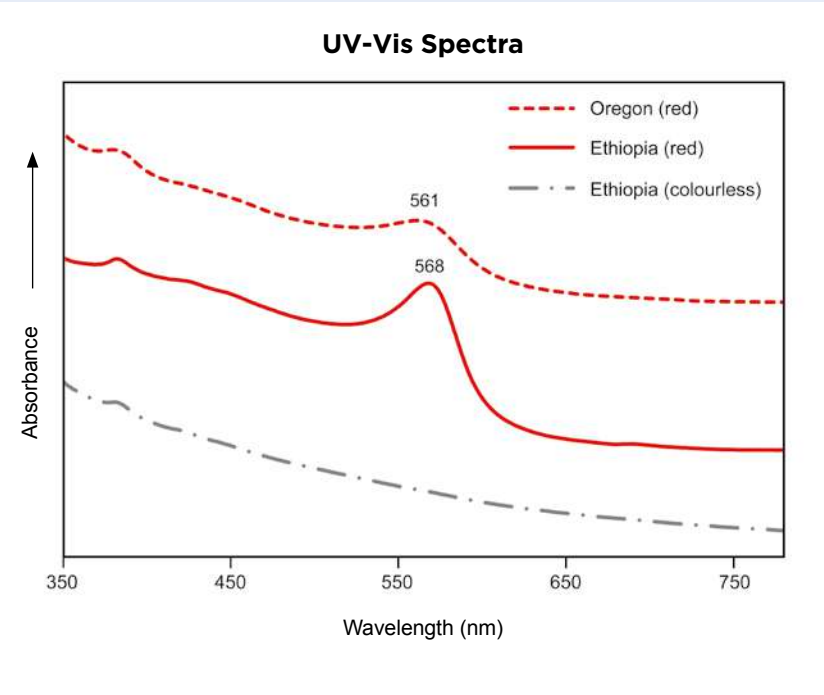

Figure 25: An 11-mm-long sample of bicoloured sunstone from Ethiopia was polished for UV-Vis microspectroscopy. The positions analysed in the near-colourless and red zones are marked with circles. Photo by C. Wang. The spectrum of the near-colourless portion shows a continuous increase in absorption towards the UV region, while the red area exhibits an absorption band centred at about 568 nm. By comparison, the absorption band for a sample of red Oregon sunstone is located at 561 nm. The spectra have been shifted vertically for clarity.

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Quartz from Brazil with Gormanite Inclusions

Since approximately 2017–2018, quartz from Brazil containing green epigenetic inclusions has appeared on the market (e.g. Figure 26). It is sometimes referred to as 'hematoid' quartz because of the similar appearance (although different colouration) as the hematite inclusions in quartz that were produced from Minas Gerais at approximately the same time (Laurs 2017). According to Luciana Barbosa (Gemological Center, Weaverville, North Carolina, USA) and Dr Marco Campos-Venuti (Seville, Spain), the quartz containing the green inclusions comes from the same pegmatite in the Galiléia area of Minas Gerais State that recently produced attractive triphylite inclusions in quartz (cf. Costanzo & Laurs 2019). Barbosa reported that some of the quartz contains both the triphylite and green inclusions within the same stone.

Barbosa loaned an 11.45 ct sample of polished quartz containing the 'hematoid' inclusions for examination (Figure 27), and Raman microspectroscopy by author NDR provided a weak signal that showed a close match with gormanite, an iron-aluminium phosphate mineral with the formula $(Fe^{2+},Mg)_3(Al,Fe^{3+})_4(PO_4)_4(OH)_6 \bullet 2H_2O$. Gormanite has been previously documented as a rare secondary mineral in granitic pegmatites (e.g. Antunes *et al.* 2013), consistent with its presence as epigenetic fracture fillings in quartz from Galiléia. The strong pleochroism shown by gormanite was evident when the sample was examined in plane-polarised light (Figure 28).

The inclusions in this quartz range from blue-green to yellow-green to yellow and orange (again, see Figure 26), suggesting that the gormanite is accompanied in places by hematite, which adds to the colour possibilities exhibited by this material.

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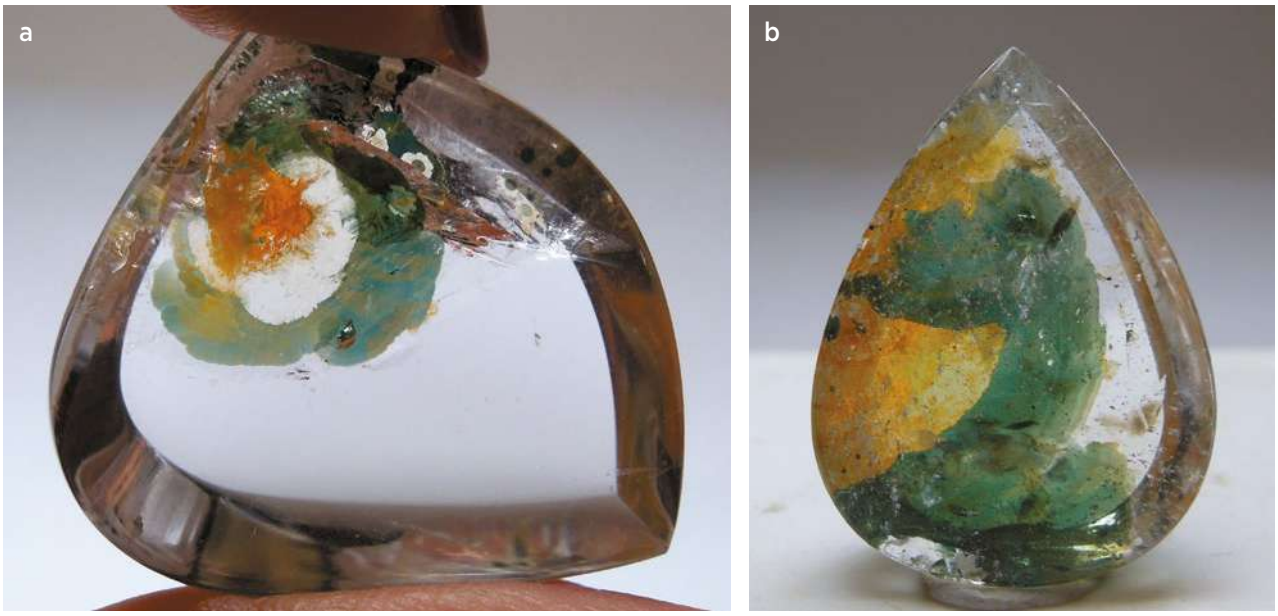

Figure 26: These polished tablets of quartz from the Galiléia area of Brazil contain epigenetic inclusions showing various colours. The samples weigh (**a**) 19.10 ct and (**b**) 20.70 ct. Photos by Luciana Barbosa.

Figure 27: The dark green inclusions in this polished quartz (11.45 ct) were analysed for this report, and proved to be gormanite. Photo by Robison McMurtry, © GIA.

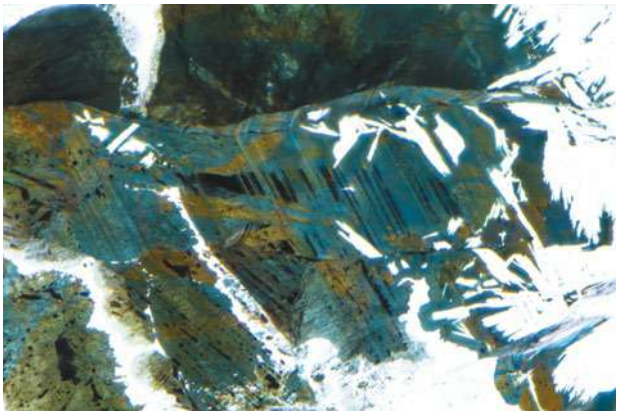

Figure 28: Viewed with plane-polarised light, the gormanite inclusions display strong pleochroism in greenish blue and brownish yellow. The surrounding quartz appears bright white due to the intense lighting needed to bring out the pleochroic colours (a diffuser plate was also placed behind the stone). Sheaf-like white areas within the gormanite appear to be caused by another mineral phase that was formerly present within the same fracture but subsequently leached away. Photomicrograph by N. D. Renfro, © GIA; image width 4.0 mm.

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Quartz from Chile with Powellite and Molybdenite Inclusions

At one time, molybdenite (MoS_2) was only rarely known as an inclusion in quartz, but this changed dramatically with a large find from the Confianza mine near Tilama, Valparaiso, Chile, in 2004 (Koivula and Tannous 2004; Koivula 2017). In 2011, the author acquired a large quartz crystal from this locality which contained a phantom, measuring 11 cm wide, composed of three planes that were decorated with inclusions. Two of the planes contained molybdenite crystals, while the third one had light brown to white plates with the same morphology as molybdenite. Their strong yellow fluorescence to short-wave UV radiation indicated they were powellite, which formed as pseudomorphs after molybdenite. Powellite is tetragonal $CaMoO_4$ and belongs to the scheelite group.

In April 2019, a new find from the same mine yielded additional quartz with molybdenite inclusions (up to 15 mm diameter; Figure 29), as well as well-formed

Figure 29: Molybdenite crystals up to 15 mm in diameter form prominent inclusions in this quartz, which was recently recovered from the Confianza mine in Chile. The stone weighs 131.35 ct and is 36 mm long. Photo by J. Hyršl.

powellite crystals (Figure 30). The powellite inclusions form transparent light yellow bipyramids up to 4.5 mm long, with a high lustre and typical yellow fluorescence. Some of the powellite crystals are bicoloured, with near-colourless and brownish yellow parts (again, see Figure 30). In addition, the powellite in some specimens forms colourless, sharp hexagonal tablets up to 2 mm across, which appear to be pseudomorphs after molybdenite. Both the powellite and molybdenite crystals are scattered through the quartz, rather than being concentrated along phantoms as in the quartz described above.

Powellite is a relatively common alteration product of molybdenite, but the occurrences mentioned here are the first times the author is aware of it forming inclusions in quartz.

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Figure 30: Inclusions of near-colourless to brownish yellow powellite occur together with dark grey molybdenite in this quartz from the Confianza mine. The stone weighs 62.33 ct and is 27 mm long. Photo by J. Hyršl.

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Quartz from Madagascar with Fuchsite Phantom Inclusions

Madagascar has long been known as a source of quartz with interesting inclusions. In early 2015, Michael Puerta (Intimate Gems, Forest Hills, New York, USA) obtained 1–2 kg of quartz crystals from Madagascar that contained conspicuous 'phantoms' decorated by minute green crystalline inclusions. Such quartz is known from Ihovitra (or Anovitra, Iovitra, Ivohitra) in the Ambatofinandrahna area of central Madagascar (www.mindat.org/loc-108282.html). The green inclusions in this quartz have been referred to in the trade as celadonite, fuchsite and chlorite. Renfro (2009) identified the inclusions as fuchsite, together with some brown radial clusters of pumpellyite.

We performed further characterisation of the fuchsite inclusions in this quartz, using rough and cut samples that were loaned by Puerta (Figure 31a). The inclusions in the 2.7-cm-long crystal formed evenly distributed micro-clusters that occurred along a sharp, thin phantom that marked the location of former quartz growth faces (Figure 31b). The 0.35 ct faceted stone incorporated an inclusion-rich area of the quartz to create an overall light green appearance (Figure 31a).

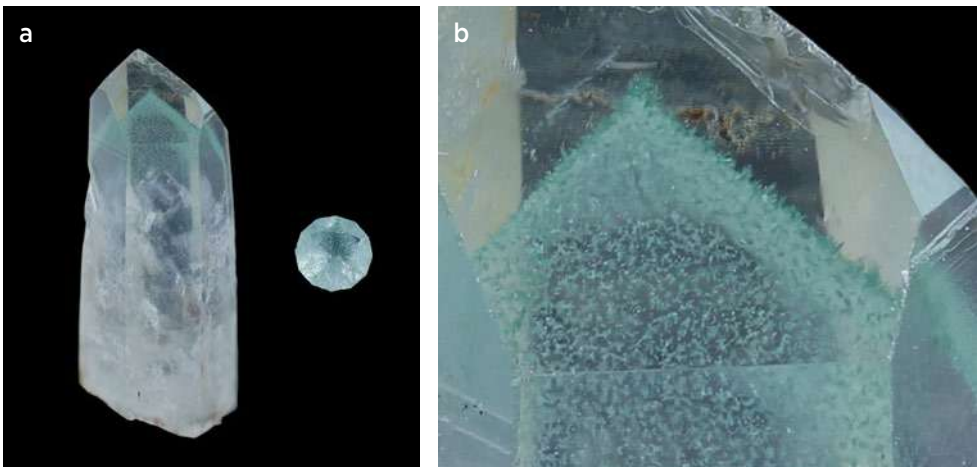

Figure 31: (**a**) These rough and cut samples of quartz from Madagascar containing green phantom inclusions were studied for this report. The crystal measures 2.7 × 1.0 cm and the cut stone weighs 0.35 ct. (**b**) A magnified view of the crystal (image width about 8.3 mm) reveals the even distribution of inclusions along phantom planes in the quartz. Photos by Greg Polley.

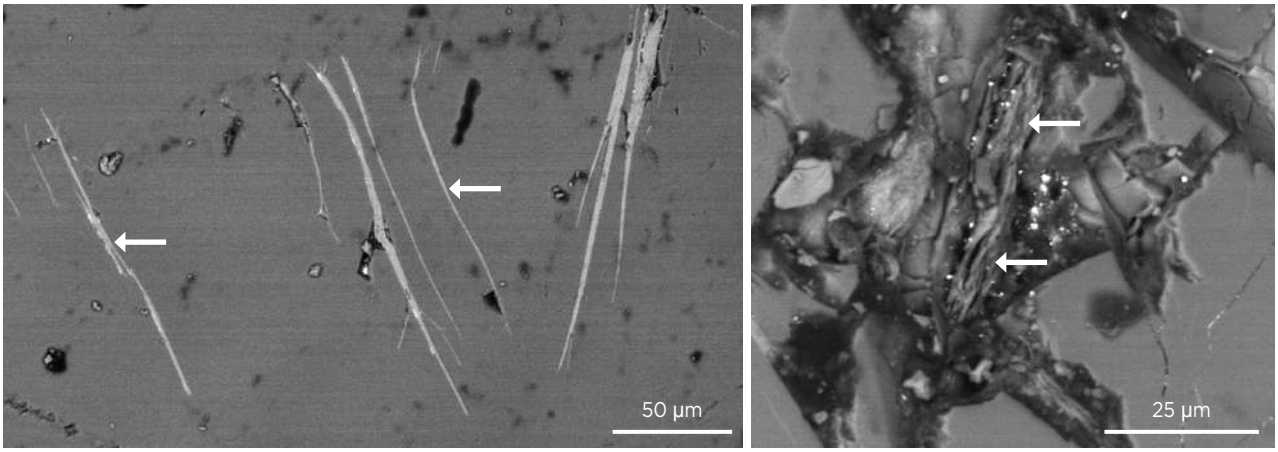

Figure 32: Backscattered electron images show the sheet-like structure of the fuchsite inclusions (see arrows) in the faceted quartz in Figure 31. This morphology is typical for a mica.

The mineralogy of the inclusions was confirmed by X-ray diffraction using a Rigaku D/Max Rapid II micro-X-ray diffractometer, which revealed a clear muscovite-like pattern as a minor phase within the dominant quartz pattern. Similar results were obtained using Raman microspectroscopy (with a Horiba LabRAM Evolution unit) by focusing a 532 nm laser onto a cluster of the inclusions that intersected one of the gem's facets. Finally, scanning electron microscopy using backscattered electron (BSE) mode and energy-dispersive spectroscopy (EDS) was performed on the same inclusion cluster in the faceted sample using an FEI Nova NanoSEM 600 instrument. The BSE images revealed that the inclusions have a sheet-like morphology expected for a micaceous phase (Figure 32). EDS analyses yielded a chemical formula consistent with Cr-rich muscovite (fuchsite) containing traces of Fe and other elements: $(K_{0.87}Na_{0.13})(Si_{3.44}Al_{0.56})(Cr_{1.06}Mg_{0.47}Al_{0.38}Fe_{0.08})O_{10}(OH)_2$.

Our analyses corroborate the previous identification of fuchsite in quartz phantoms from Madagascar. However, we did not observe any pumpellyite inclusions, as reported for the sample examined by Renfro (2009).

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Reference

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Tourmaline from Sri Lanka with Transient Tenebrescence?

While on a buying trip to Sri Lanka in November 2017, stone dealer Dudley Blauwet obtained six faceted tourmalines from his supplier in Ratnapura. The stones were reportedly mined in Nivithigala, which is located 18 km by road south-east of Ratnapura. They ranged from 'olive' green to 'golden' brown-orange, and appeared similar to some dravite-uvite from Tanzania and Kenya. Interestingly, Blauwet noticed that two of them (weighing 1.74 and 2.69 ct) appeared to show a reverse colour change—from golden brown in daylight to yellowish green in incandescent light—which is the opposite of most East African tourmaline (cf. Bank & Henn 1988). A third stone (2.72 ct) showed a much weaker colour change, while the others did not show any shift in colour. When checked with a Chelsea Colour Filter (CCF), Blauwet discovered that the two stones showing the noticeable colour change displayed a saturated greenish blue reaction, while the others were inert. The greenish blue CCF reaction was much different than the red appearance typically seen in East African tourmaline showing the typical colour change from 'chrome' green in daylight to greenish yellow in incandescent light.

After returning home, Blauwet decided to check one of the anomalous stones (1.74 ct) for tenebrescence, and he placed it on a south-facing windowsill from 8:30 am to 10:00 am on an overcast day. Surprisingly, this caused it to change from golden brown to slightly greyish olive. He then put the stone in the dark for 1.25 hours, causing it to regain some of its original colour; longer storage in darkness did not return any more of the stone's original

colour. Based on his repeated observations of the stones, Blauwet suspected that the anomalous colour behaviour displayed by the two tourmalines was a short-term transient phenomenon.

Blauwet loaned the tourmalines to authors AUF and WBS to investigate their composition. In July 2018 they performed standard-based scanning electron microscopy energy-dispersive spectroscopy (SEM-EDS) chemical analysis using a JEOL JSM-6400 instrument with the Iridium Ultra software package by IXRF Systems Inc., and found that the tourmalines were mainly uvite with one dravite and one elbaite-liddicoatite series stone. The two stones for which Blauwet noted the anomalous colour behaviour consisted of uvite (1.74 ct) and elbaite (2.69 ct), although authors AUF and WBS did not check them for any usual colour phenomena at that time.

All six tourmalines were then sent to authors AP and ZS for further chemical analysis by laser ablation inductively coupled plasma mass spectrometry (LA-ICP-MS) and thorough documentation of their colour behaviour. The chemical data confirmed the tourmaline compositions obtained by SEM-EDS, and further showed the presence of several trace elements, including variable amounts of V, Cr, Sr, Sn, La, Ce and Pb (Tables I and II).

Table I: Average chemical composition of the Sri Lankan tourmaline samples by LA-ICP-MS.*

Chemical composition	Elbaite	Dravite	Uvite	Uvite	Uvite	Uvite
	2.69 ct	1.63 ct	2.72 ct	1.74 ct	2.23 ct	2.47 ct
Oxides (wt.%)						
SiO_2	36.49	36.52	36.32	36.03	36.40	36.21
Al_2O_3	40.61	34.72	27.64	27.85	27.26	27.12
Na_2O	1.94	2.00	0.08	0.20	0.08	0.08
K_2O	0.01	0.09	nd	nd	nd	nd
MgO	nd	10.23	15.63	15.69	16.04	16.04
CaO	1.37	0.79	5.40	5.23	5.45	5.52
FeO	1.95	0.05	0.18	0.39	0.18	0.32
MnO	0.36	0.04	nd	nd	nd	nd
PbO	0.23	nd	nd	nd	nd	nd
V_2O_3	nd	0.05	0.03	0.01	0.02	0.02
TiO_2	0.01	0.49	0.16	0.20	0.08	0.23
Cr_2O_3	nd	nd	0.03	nd	0.03	0.02
Li_2O (calc.)	2.05	0.28	0.02	nd	nd	nd
B_2O_3 (calc.)	10.96	10.93	10.73	10.72	10.72	10.71
H_2O (calc.)	3.78	3.77	3.70	3.63	3.66	3.65
Atoms per formula unit (27O + 4OH)						
Si	5.788	5.809	5.884	5.844	5.901	5.879
Al	0.212	0.191	0.116	0.156	0.099	0.121
Tet. sum	6.000	6.000	6.000	6.000	6.000	6.000
B	3.000	3.000	3.000	3.000	3.000	3.000
Al (Z)	6.000	6.000	5.161	5.169	5.109	5.068
Mg (Z)	nd	nd	0.831	0.830	0.884	0.927
Z sum	6.000	6.000	5.992	5.999	5.993	5.995
Al (Y)	1.379	0.319	nd	nd	nd	nd
Ti	0.002	0.059	0.020	0.025	0.010	0.028
Fe^{2+}	0.259	0.006	0.024	0.053	0.025	0.044
Mn	0.049	0.005	nd	nd	nd	nd
Mg (Y)	nd	2.426	2.944	2.965	2.992	2.956
Li	1.305	0.178	0.012	nd	nd	nd
Y sum	2.994	2.993	3.000	3.043	3.027	3.028
Ca	0.233	0.134	0.938	0.909	0.947	0.959
Na	0.597	0.616	0.025	0.064	0.025	0.027
K	0.003	0.018	nd	nd	nd	nd
Vacancy	0.158	0.232	0.037	0.027	0.028	0.014
X sum	0.990	1.000	1.000	1.000	1.000	1.000
OH	4.000	4.000	4.000	4.000	4.000	4.000

* Average of three analyses per sample. Data were normalised to a total of 100 wt.% oxides based on the method reported by Sun *et al.* (2019). Some trace elements are not shown here but are reported in Table II. Fluorine was not measured, so the contents of the V and W sites were calculated as OH = 4, and therefore the fluor-species of tourmaline could not be determined. Abbreviation: nd = not detected.

Table II: Average minor- and trace-element composition of the Sri Lankan tourmaline samples by LA-ICP-MS.*

Chemical composition (ppmw)	Elbaite	Dravite	Uvite	Uvite	Uvite	Uvite
	2.69 ct	1.63 ct	2.72 ct	1.74 ct	2.23 ct	2.47 ct
Ti	89.2	2930	962	1220	475	1360
Sc	2.72	242	10.4	3.62	7.17	5.34
P	29.1	35.9	33.8	30.8	30.0	33.4
V	0.3	357	179	66.6	170	166
K	108	717	7.98	17.8	13.6	7.97
Cr	nd*	2.01	220	2.18	210	112
Cu	1.03	0.40	nd	0.043	nd	nd
Ni	nd	nd	5.54	0.86	3.64	0.64
Mn	2810	298	4.50	1.90	2.60	5.40
Be	32.1	1.48	2.28	0.81	0.59	0.21
Sr	467	19.7	322	59.5	366	547
Nb	8.77	0.004	0.10	0.86	0.054	0.12
Sn	165	0.13	6.55	96.4	40.7	17.1
La	56.1	3.22	48.2	1.20	47.2	1.22
Ce	183	7.08	97.6	1.53	65.8	1.46
Pr	22.0	0.65	8.81	0.099	4.20	0.092
Nd	60.7	1.98	24.2	0.20	8.95	0.18
Gd	2.05	0.15	1.04	0.009	0.25	nd
Tb	0.13	0.014	0.068	nd	0.014	0.001
Dy	0.35	0.058	0.18	0.002	0.023	0.004
Tm	0.008	0.012	0.002	nd	nd	0.001
Yb	0.054	0.040	0.016	nd	nd	nd
Lu	0.009	0.008	0.004	nd	nd	nd
Pb	2120	0.66	6.83	1.76	21.2	9.62
Bi	1.57	nd	nd	nd	nd	nd
Th	43.5	nd	0.002	0.022	0.009	0.008
U	0.64	nd	nd	nd	0.003	0.006

* Average of three analyses per sample. Abbreviation: nd = not detected. Detection limits (ppmw): Cr = 0.19, Cu = 0.036, Ni = 0.059, Tb = 0.001, Tm = 0.001, Yb = 0.004, Lu = 0.001, Bi = 0.026, Th = 0.001 and U = 0.002.

None of the trace elements showed any systematic correlation to those tourmalines that displayed the anomalous colour behaviour except Sn, which was present in somewhat greater amounts in those two samples, although this element is not known to influence the colouration of tourmaline. Notably, however, authors AP and ZS were unable to observe any colour change or tenebrescence in any of the samples, even with repeated exposure to various UV excitations and daylight after storage in the dark for up to several weeks. It appears, therefore, that Blauwet's suspicion was indeed correct that the colour phenomena were short-lived. In fact, the two stones appeared to have lost all of their golden brown colouration, appearing greyish to brownish yellowish green (Figure 33) regardless of the light source used to view them.

Figure 33: These six tourmalines were reportedly mined from alluvial deposits in the Nivithigala area near Ratnapura, Sri Lanka. Anomalous colour behaviour was seen in the 1.74 and 2.69 ct samples shortly after their purchase, but subsequently their colouration apparently stabilised. Photo by Robison McMurtry, © GIA.

A literature search did not reveal any previous reports of tenebrescence or transient colour phenomena in tourmaline, although some unusual colour behaviour has been documented, particularly in stones from East Africa. For example, Koivula & Kammerling (1991) documented a pair of dravites from Tanzania or Kenya that appeared slightly brownish yellow in incandescent or fluorescent lighting, but were greenish yellow when illuminated simultaneously with incandescent and fluorescent lighting. In addition, Johnson *et al.* (2000) examined a uvite that had been purchased in Sri Lanka which appeared strongly pleochroic in reddish brown and green in incandescent light, but was uniformly brownish yellowish green in fluorescent light. The chemical composition and gemmological properties of that stone were consistent with the tourmalines from Usambara, Tanzania, which may show dichromatism called the 'Usambara effect': a change of colour from dark green to red when a critical thickness is exceeded (e.g. Taran & Naumenko 2016 and references therein). Nevertheless, these various colour anomalies described in the literature are significantly different from the apparently transient colour behaviour that was exhibited by the two tourmalines described here.

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PEARLS

Diving for Natural Pearls off Bahrain: A Different Type of Gemmological Sample Collection

Bahrain was (and still is) considered an important centre for the natural pearl trade, and it is one of the few countries where fishing for natural pearls is legal today. Most gem-quality pearls have traditionally been found in waters located 50 km north-north-east of Bahrain (more precisely, at Hayr Shutayah, Hayr Bulthama and Hayr Bu Amamah; *Hayr* means 'oyster bed', see Figure 34). The shoals in these areas contain an average of about 4–30 'oysters' per square metre. To protect these resources, the government has implemented strict laws and regulations on mollusc fishing, and has recognised the three areas mentioned above as part of the Pearling Path project (https://pearlingpath.bh/en) and a UNESCO World Heritage Site. Bahrain is the only country where diving for natural pearls still occurs, and tourists and residents can purchase a pearl-diving pass (http://pearldiving.bh), dive with a licensed diving company, and collect and open up to 60 shells per pass.

The vast majority of pearls fished off Bahrain are found in *Pinctada radiata* (*P. radiata*) and, less commonly, in *P. margaritifera* and Pinnidae (or pen shell) bivalves. The Bahrain Institute for Pearls & Gemstones (DANAT) recently started a project to conduct a full scientific study on these molluscs and their pearls from various locations around Bahrain. For this purpose, several members of DANAT's team have obtained their scuba diving certification and received training in proper collection techniques.

The project's first step is to collect the molluscs from all over Bahrain, starting in the major and well-known

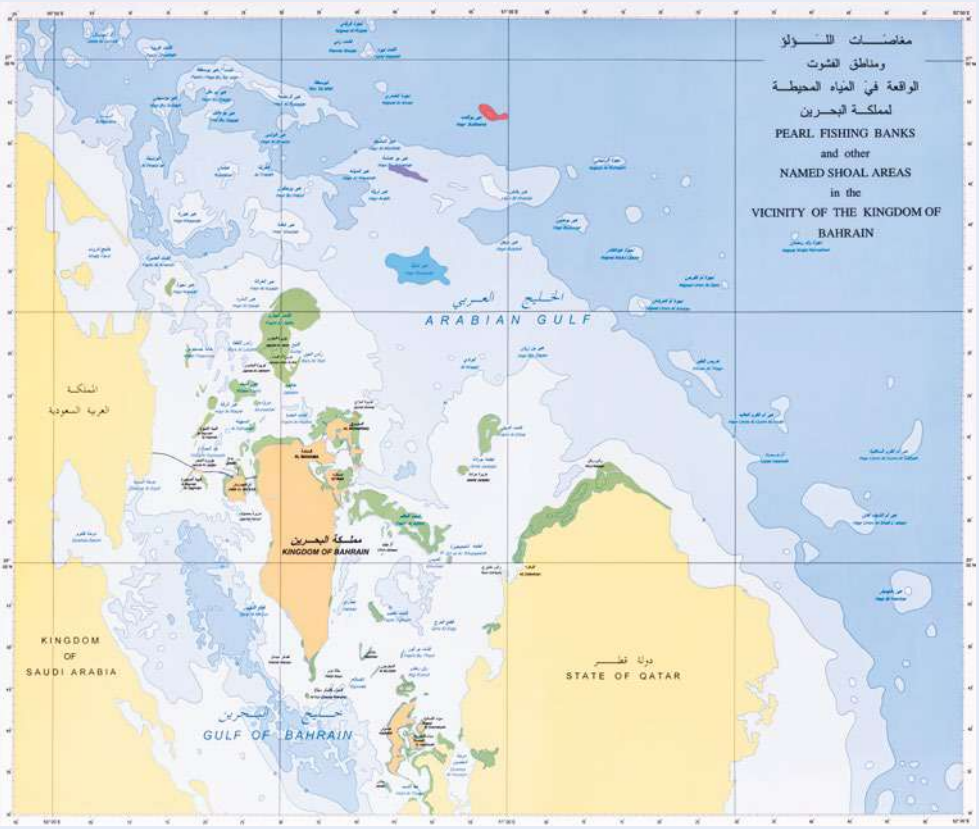

Figure 34: The most important fishing areas for natural pearls in Bahrain—Hayr Shutayah (dark blue), Hayr Bulthama (red) and Hayr Bu Amamah (purple)—are protected by law. These shoals lie about 50 km north-north-east of the main island of the Kingdom of Bahrain. Modified from the map 'Pearl Fishing Banks and Other Named Shoal Areas in the Vicinity of the Kingdom of Bahrain' (scale 1:350,000), first published in 1989 and modified in 2003; © Survey Directorate, Survey & Land Registration Bureau, Kingdom of Bahrain.

diving areas (including the three protected areas mentioned above after obtaining all necessary permissions), most of which are concentrated to the north. The team also plans to dive at 22 additional locations to the east, west and south of Bahrain. The goal is to collect around 1,000 molluscs from each location (principally *P. radiata* and all with a shell size of >6 cm wide), while recording GPS coordinates, ocean depth, water temperature, salinity, pH, etc. At the end of each day's diving, the fished molluscs are carefully opened at DANAT's premises in order to gather accurate data on the location of any pearls inside the animals (Figures 35 and 36). Sometimes multiple pearls are found within the same mollusc (Figure 37).

Figure 35: A photograph of a freshly opened *P. radiata* mollusc (7 cm wide) is overlaid with a diagram showing the various positions where natural pearls may be found. Photo by H. Abdulla, © DANAT.

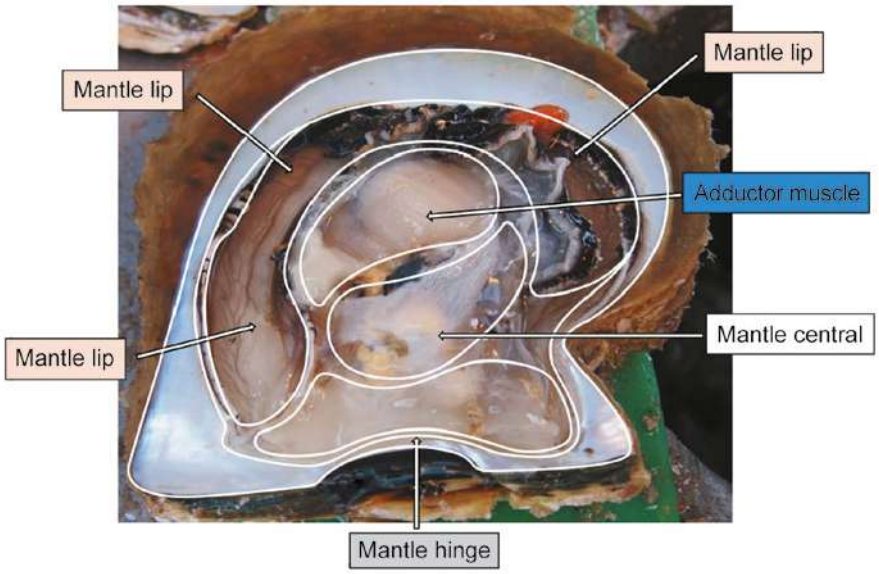

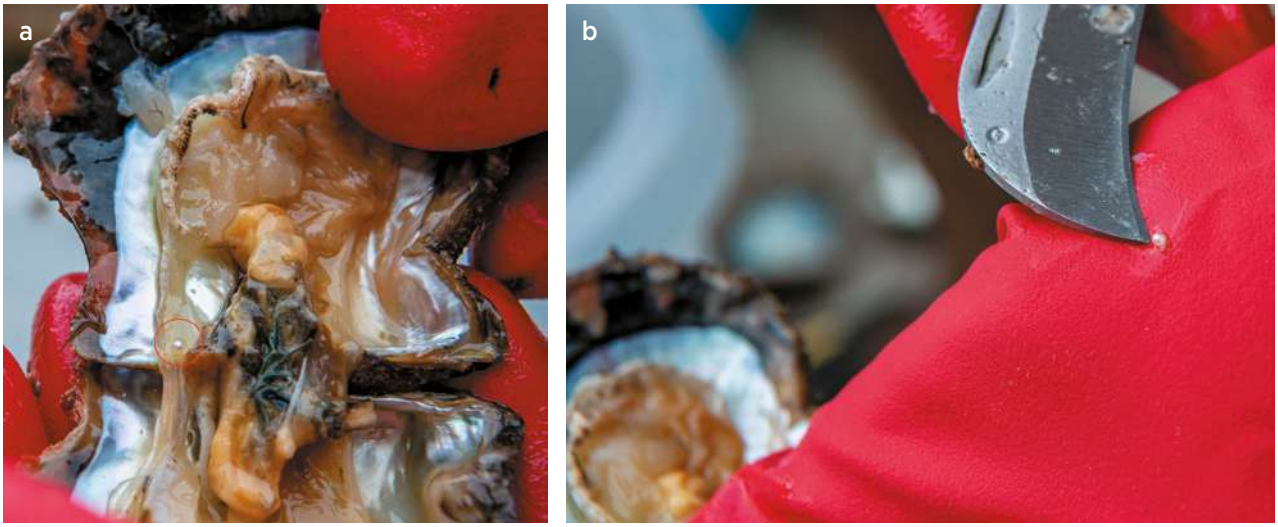

Figure 36: (**a**) Opening this *P. radiata* mollusc revealed a pearl in the mantle lip (lower left). (**b**) The extracted light cream-coloured pearl is oval-shaped and measures 1.60 × 1.49 mm. Photos by H. Abdulla, © DANAT.

Figure 37: Three light cream-coloured pearls of various shapes were found within the same *P. radiata* mollusc. The largest of the three pearls (near the tip of the knife) is 2.60 mm in diameter. Photo by H. Abdulla, © DANAT.

All of the pearls recovered by the team are examined by standard gemmological techniques to document their colour, shape, size, weight, surface features, etc. In addition, all samples are studied with X-ray microradiography and X-ray computed microtomography to look for potential links between their position in the animal and their internal structures. UV-Vis-NIR, Raman, photoluminescence and FTIR spectra are gathered on all samples, and chemical analysis is performed using EDXRF and LA-ICP-MS techniques. All these data are valuable to build a solid database for the accurate determination of a pearl's host mollusc and any treatments. In addition, incorporating the water sampling data will help us better understand the possible link between ocean conditions and chemical characteristics of natural pearls.

After collecting samples from the areas off Bahrain, our goal is to expand the project into the surrounding Arabian Gulf and elsewhere in other important natural pearl-fishing areas worldwide where it is still legal to collect the molluscs.

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A Remarkably Large Natural Pearl from *Pinctada radiata*

DANAT recently received a light cream-coloured, undrilled pearl weighing 18.07 ct (13.82 × 13.71 mm) of near-round shape. Viewed with the microscope, it showed nacreous structures. Under long-wave UV radiation (365 nm, 6 watt) the pearl fluoresced light yellow, while in short-wave UV (254 nm, 3 watt) it luminesced light yellowish green-blue. The pearl was inert to X-rays. EDXRF analysis revealed 747 ppmw Sr, with Mn below the detection limit—characteristic of nacreous saltwater pearls (Karampelas & Kiefert 2012).

Digital X-microradiographs of the pearl in three orientations, taken perpendicular to one another, showed only two growth lines (Figure 38). Some additional features were visible in various directions, such as small

Figure 38: This remarkably large (18.07 ct; 13.82 × 13.71 mm), near-round natural pearl from *P. radiata* was recently examined at DANAT. Photo by Ghadeer Abdali, © DANAT.

(i.e. <3 mm) roundish features that looked like seed pearls near the edge of the sample (Figure 39, centre and right). These, as well as the few growth lines, raised suspicions of an atypical beaded cultured pearl, with a natural pearl used as a bead.

DANAT recently upgraded its X-ray computed microtomography (micro-CT) detector and software, which significantly increases the resolution. The resulting micro-CT images of the present sample clearly revealed structures characteristic of natural saltwater pearls (Figure 40). The outer and inner growth lines are clearly visible and followed by natural concentric growth lines toward the centre. Also, natural structures could be observed inside a seed pearl in one of the images (see Figure 40, right). Thus, it became clear that the sample was a natural saltwater pearl.

Chemical analysis using LA-ICP-MS was performed on three spots, yielding an average of 4,695 ppmw ^{23}Na, 326 ppmw ^{24}Mg, 0.70 ppmw ^{55}Mn, 890 ppmw ^{88}Sr and 0.42 ppmw ^{137}Ba. These results are consistent with those previously published for natural pearls from *Pinctada radiata* fished off Bahrain (Karampelas *et al.* 2019b). Raman spectroscopy of the pearl using 514 nm laser excitation showed—apart from the bands characteristic of aragonite vibrations (at about 1086 and 703 cm^{-1})—two additional faint bands (at about 1532 and 1133 cm^{-1}) linked to vibrations of polyenic pigment; natural and cultured products from *P. radiata* and *P. fucata* are the only nacreous saltwater pearls that present such bands

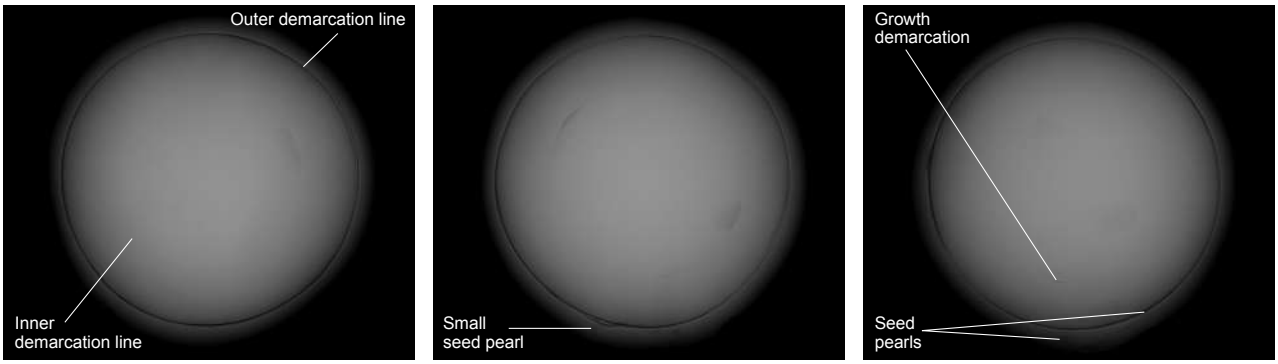

Figure 39: Digital X-microradiographs show the pearl in Figure 38 from three different directions. The contrast was adjusted to reveal features that the authors consider most informative. Depending on the contrast used, the images show some subtle features, although not enough to conclude whether this pearl is natural or cultured.

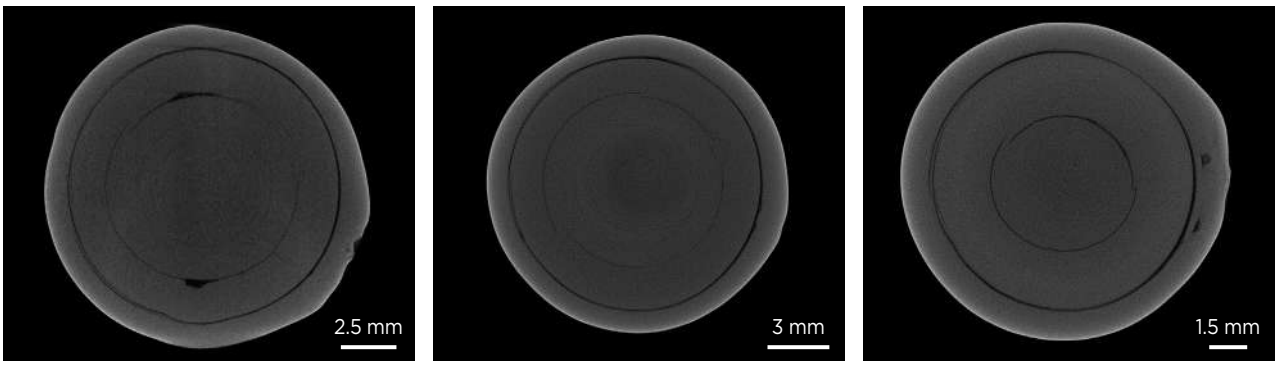

Figure 40: Two-dimensional slices of the micro-CT model of the studied pearl are shown here in three directions. These high-resolution images show natural concentric growth lines near the pearl's centre, as well as natural structures within a seed pearl near the edge of the sample (see right-hand image).

(Karampelas *et al.* 2019a). Thus, all the results are consistent with a natural pearl from *P. radiata*. However, this specimen is remarkably large, as natural pearls from *P. radiata* rarely exceed 8 mm diameter and, very rarely, 10 mm. Therefore, this near-round natural pearl with a diameter of >13.5 mm is an extreme rarity.

The client was a diver who indicated finding this sample himself in waters north of Bahrain. Bahrain is considered one of the most important sources of natural pearls, both in ancient and present times, and strict laws prohibit the trade (import and sale) of cultured pearls there. The government is currently encouraging a revival of the natural pearl fishing heritage by enacting regulations and encouraging people to pursue this profession. As a result, many young people have started pearl fishing during the last couple years.

Acknowledgement: The authors extend their appreciation to Sanad Bin Abdullah Bin Jafan, the diver who found and possesses this remarkable natural pearl, for allowing us to share our findings.

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Double Grafting in Peanut-Shaped Ming Cultured Pearls

Improved grafting techniques used for Chinese freshwater cultured pearls (FWCPs) during the past few decades (e.g. Scarratt *et al.* 2000; Akamatsu *et al.* 2001; Fiske & Shepherd 2007) have resulted in the production of numerous varieties, including high-quality and large-size round cultured pearls (Hänni 2011) similar to akoya and South Sea products. Observing the roundness and surface texture with the unaided eye can commonly discriminate whitish-coloured Chinese FWCPs from their saltwater counterparts.

The first beaded gonad-grown Chinese FWCPs, marketed under the names 'Ming' and 'Edison' (Laurs 2012), were reported by Hänni (2011) and are characterised by the presence of a drilled nucleus. The grafting technique consists of simultaneously introducing the bead and tissue graft into the gonad of the mussel. In the case of circled Ming cultured pearls, the drill hole is responsible for creating spot defects and circling, as recently reported by Gauthier *et al.* (2018).

Here, we report on a strand consisting of 18 peanut-shaped cultured pearls (Figure 41). Their colours and overtones are typically associated with Chinese FWCPs,

Figure 41: This necklace consists of beaded, gonad-grown baroque Chinese FWCPs. Each peanut-shaped cultured pearl (18.4–25.2 mm long) proved to contain two nuclei. Photo by S. Leblan.

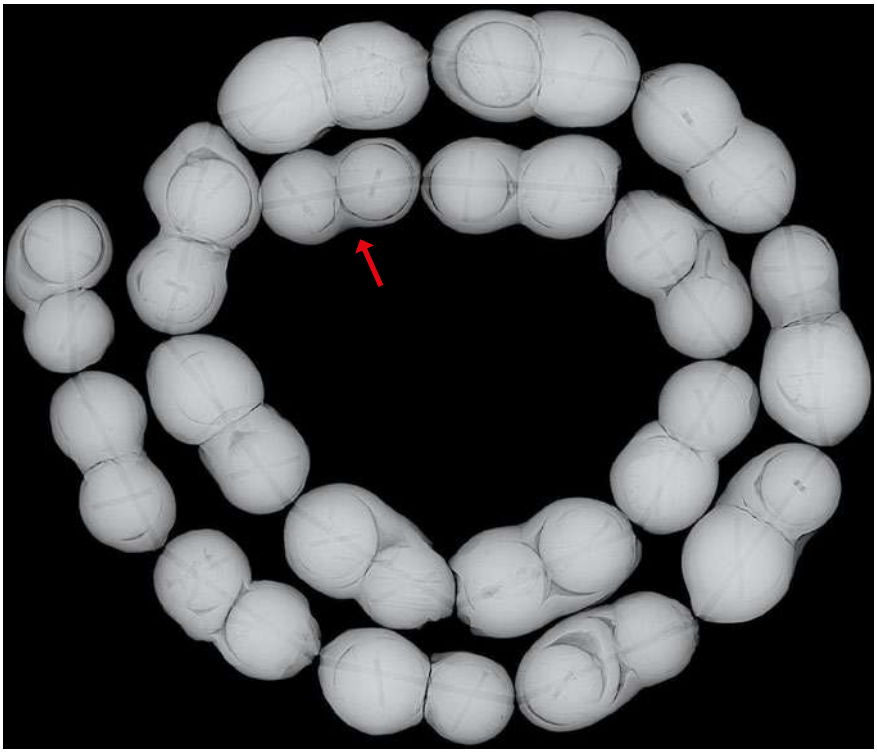

Figure 42: Microradiography of the necklace reveals the presence of two beads in each peanut-shaped cultured pearl, as suggested by external observations of their size, shape and surface texture. One of the FWCPs in the strand contains nuclei of the same size that are in contact without an intervening nacre layer (see arrow), in contrast to the other cultured pearls, which commonly contain nuclei of different sizes (with the smaller bead overgrown by a layer of nacre that appears to contact the adjacent larger bead).

especially gonad-grown products. The appearance, size (10.2–14.1 mm for each 'half') and surface features of the peanut-shaped cultured pearls suggest the presence of two nuclei. They differ from beadless and beaded mantle-grown peanut-shaped Chinese FWCPs, which frequently have a flat side due to their growth against the inner surface of the shell (e.g. Chow 2019: figure 12, left). In the case of beadless peanut-shaped FWCPs, their formation is due to the close proximity of two grafts that are responsible for the growth of the two initially separate cultured pearls, which eventually merge into one. Different colours and qualities are commonly observed in each half of the resulting peanut-shaped FWCPs.

In the strand examined for this report, the presence of nuclei was confirmed by microradiography (Figure 42). Moreover, all of the nuclei contained a randomly oriented drill hole in addition to the one created for each peanut-shaped FWCP to be threaded onto a necklace. This feature is typical of Ming FWCPs (Hänni 2011). In addition, as recently demonstrated by Chow (2019: figure 12), such cultured pearls exhibit a strong green fluorescence to X-rays, typical of FWCPs, and some of them may present a reddish orange reaction in whitish non-nacreous areas. The nuclei may also contain internal linear features that display random patterns (Figure 43), similar to ones illustrated by Chow (2019: figure 13).

In the beaded peanut-shaped FWCPs reported by Chow (2019), the size of the two nuclei were identical, and the absence of a nacre layer between them suggests to the present authors that they were simultaneously inserted into the mantle pocket in a way similar to that explained by Akamatsu *et al.* (2001). However, in the strand described here, the two nuclei in most of the peanut-shaped cultured pearls have different sizes, as seen in Figure 43. The larger nucleus seems to be in contact with a layer of nacre that has been deposited on the smaller nucleus. The difference in diameter between the two nuclei roughly and generally corresponds to the thickness of the nacre layer that was deposited on the smaller nucleus. This suggests that the insertion of each nucleus was probably done at two different times, according to the pearl farmer's understanding

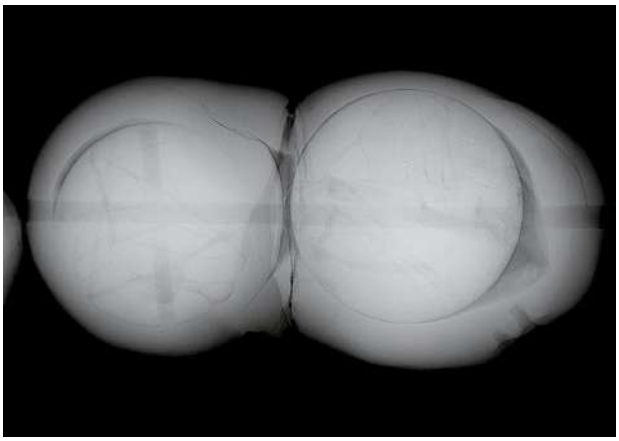

Figure 43: Microradiography of this peanut-shaped cultured pearl shows details that reveal characteristics of the two nuclei and the growth of the nacre layers.

of the growth rate of the nacre layer. By contrast, the nuclei within a FWCP on one end of the necklace (see arrow in Figure 42) seem to have the same size and are in contact without a nacre layer. Those nuclei were probably inserted into the gonad at the same time, as was done for the beaded mantle-grown peanut-shaped Chinese FWCPs described by Chow (2019).

As with gonad-grown cultured pearls in saltwater molluscs, only one Ming FWCP is, in principle, cultivated in the gonad of each mussel. Peanut-shaped cultured pearls are probably an unwanted result of double grafting, and they constitute proof that pearl farmers are tempted to insert more than one nucleus into a gonad, compared to the tens of beads commonly inserted into the mantle of such mussels. The insertion of more than one bead has also been encountered by author TNB in some saltwater cultured pearls (e.g. akoya from Vietnam).

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TREATMENTS

Dyed Banded Agate from Madagascar

Banded agates from Madagascar are popular on various Internet websites and are commonly represented as 'natural polished' material. They are typically sold for relatively inexpensive prices by dealers based in China. The pieces show banding in various colours such as black, brown, orange, white, etc.

One of the authors (MP) recently purchased one such specimen so he could investigate the cause of its colouration (Figure 44). Slicing of this sample revealed a banded white interior (Figure 45), therefore proving that it had been dyed. The dye penetrated only a short distance into the stone, although some of the more translucent layers of the agate had deeper dye penetration. The banding in this sample only conformed to a portion of its overall external morphology, suggesting that it had previously been broken, had been formed into an attractive shape and then was polished before being dyed.

Some of the stones offered online contain concentric 'eyes' that somewhat resemble those seen in natural orbicular jasper found on Madagascar's north-west coast (cf. Johnson *et al.* 2000). However, that material typically shows an orbicular pattern rather than banded texture, and it also typically has different colouration (e.g. green, blue,

Figure 44: This 'natural' agate was recently purchased from an online auction website to investigate the cause of its colour. It measures 70 × 43 × 33 mm and weighs 128 g. Photo by M. Pantò.

Figure 45: Slicing the specimen in Figure 44 revealed that it consists of dyed white-banded agate. The dye is mostly restricted to a thin layer near the surface. Photo by M. Pantò.

pink and white), as well as areas of fine-grained quartz crystals in the interstices between the jasper orbicules.

White-banded agate from Madagascar that could be used as the starting material for the dyed agates was recently documented by Goldbaum *et al.* (2019), who proposed that the complex forms of the banding were caused by secondary deformation by external forces acting upon the silica gel before it crystallised into agate.

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Figure 1: The 11.62 ct Roman sapphire intaglio examined for this study is engraved on the back side with a hippocamp. Photo by E. Butini, IGN.

Gemmological Analysis of a Roman Sapphire Intaglio and Its Possible Origin

Michael S. Krzemnicki, Flavio Butini, Enrico Butini and Ernesto De Carolis

ABSTRACT: The gemmological analysis of a Roman intaglio engraved with a hippocamp (winged 'sea-horse') reveals that it was carved from a sapphire of basaltic origin. Its bluish grey appearance is due to Rayleigh scattering by sub-microscopic inclusions and is not related to an intervalence charge transfer process. In light of historically documented extensive trade relations between ancient Rome and Ethiopia (the kingdom of Aksum), we hypothesise that the recently documented basalt-related sapphire deposits in northern Ethiopia are a possible source of raw material for this Roman intaglio (as well as other basaltic sapphires used in Roman times), in addition to previously held views that ancient sapphires originate from deposits in Sri Lanka, France and perhaps South East Asia. This rare opportunity to characterise in detail one of the very few engraved sapphires from the Roman period permits a better understanding of gem materials used in classical antiquity.

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Antique jewels and gems have long fascinated scholars and the public alike, as they offer an intimate insight into human cultural history, unveiling aspects such as adornment, beliefs, social and political status, artistic style, fashion and craftsmanship in ancient cultures (Pinckernelle 2007; Spier 2007; Entwistle & Adams 2011; Papagiannaki 2013). This fascination is further based on their relevance to modern life in design and significance (Unger & Van Leeuwen 2017). Antique jewels are also valuable to archaeological science because they can unveil ancient trade routes (e.g. the Maritime and Central Asian Silk Routes). Gems and jewels were traded extensively in ancient times together with other goods of value over long distances from their (remote) sources to historical marketplaces and political centres (Begley & Puma 1991; Borell *et al.* 2014; Borell 2017; Galli 2017; Sidebotham 2019).

Jewellery and gems of Roman age have been abundantly studied, but only in a few cases has it been possible to carry out a thorough gemmological analysis of such historical items (Giuliani *et al.* 2000; Calligaro 2005; Lüle-Whipp 2006; Entwistle & Adams 2011; Gast *et al.* 2011; Thoresen & Schmetzer 2013; Schmetzer *et al.* 2017; Thoresen 2017b; Gilg *et al.* 2018). This is mainly due to the fact that they are considered cultural heritage and often are not accessible for testing with laboratory analytical methods.

In this article we describe a glyptic masterpiece: a Roman sapphire intaglio (Figure 1) that was found in 1986 in Pompeii. In late 2017, the Museo Archeologico Nazionale di Napoli loaned the engraved sapphire to the authors for detailed examinations at the Istituto Gemmologico Nazionale (IGN; Rome, Italy) and the Swiss Gemmological Institute SSEF (Basel, Switzerland). This article provides a description of the glyptic artwork and gemmological characteristics of the specimen, while also considering possible origins for the sapphire raw material and presenting a new hypothesis that could explain its provenance, as well as that of other historical sapphires of Roman age (e.g. Butini *et al.* 2018).

HISTORICAL BACKGROUND OF POMPEII

Pompeii was an urban settlement with ancient origins (Figure 2), located on the southern slopes of Mount Vesuvius adjacent to the present city of Pompei in southern Italy. Due to its climate and location, Pompeii developed into an important commercial centre, first attracting the Greeks and Etruscans (7th–5th centuries BCE), and later the Samnites (4th century BCE). In the 3rd century BCE, although never conquered by military force, Pompeii became part of the economic

Figure 2: This drone photo of the excavated Roman city of Pompeii includes Mount Vesuvius (on the skyline), which caused the sudden burial of the area during a major volcanic eruption in 79 CE. Photo courtesy of Wikimedia Commons.

and administrative circuit of the Roman Republic, and in 80 BCE it was transformed into a colony under Roman law (Cooley & Cooley 2013 and references therein).

In 62 CE, Pompeii suffered a devastating earthquake, which left it badly damaged and severely weakened economically. The Emperors Nero and Vespasian promoted the reconstruction of the city, which was quickly restored with luxurious governmental and religious buildings and private residences. However, the city had not yet been completely rebuilt when, between August and November 79 CE, an explosive eruption of Mount Vesuvius buried Pompeii under about 6 m of pumice and ash. Approximately 1,500 inhabitants died (the city's population was estimated between 6,000 and 20,000 people), among them the famous naturalist Pliny the Elder—author of the encyclopaedic *Historia Naturalis*, still today a fundamental reference for the ancient use and provenance of gems. Pompeii was not rebuilt again and by 120 CE vegetation began to cover the area that it once occupied until it disappeared completely (De Carolis & Patricelli 2003; Cooley & Cooley 2013).

In 1748, more than 1,600 years later, the first archaeological excavations of Pompeii began at the behest of the Bourbon Dynasty (of Naples, Italy) following the discovery of Herculaneum (another inhabited centre destroyed by the same volcanic eruption). From the beginning of the 19th century the excavations went through various phases until the unification of Italy in 1861. Pompeii was almost entirely unearthed, although some areas later suffered considerable damage due to bombing during World War II. In 1997 the archaeological area was declared a UNESCO World Heritage Site, and in 2012 the Great Pompeii Project was established with the goal to restore and secure the site.

During the excavation of Pompeii a large number of jewels were discovered, consisting of approximately 800 pieces of jewellery and 94 gemstones. Eleven of these were found in 1986 in two wooden boxes at the House of Gemmarius in the south-eastern part of Pompeii (Figure 3), close to the Porta Nocera (Sodo 1988, 1992; Pannuti 1994; D'Ambrosio & De Carolis 1997). The gems in these wooden boxes included the sapphire intaglio described here (Museo Archeologico Nazionale di Napoli, Inventario P 39597; see D'Ambrosio & De Carolis 1997), along with an object identified as a 'stone holder' work tool. In this sector of the ancient city the houses were modest in size, as they were intended for middle-class members of Pompeiian society. The architecture of these buildings reconciled housing with commercial activities, so several workshops were located in this area.

The House of Gemmarius is thought to have been the private home and workshop of a gem cutter and jeweller (D'Ambrosio & De Carolis 1997). This hypothesis is supported by the Latin inscription *Prisco coelator campano gemmario feliciter* ('Prisco from Campania, successful gemstone engraver'; see Toynbee 1951) found on a wall near the house, which supposedly represents an antique billboard. Still, as there is no further written evidence, we cannot fully exclude the possibility that the two boxes just stored the gems of an unknown private owner who lived in the ancient city of Pompeii.

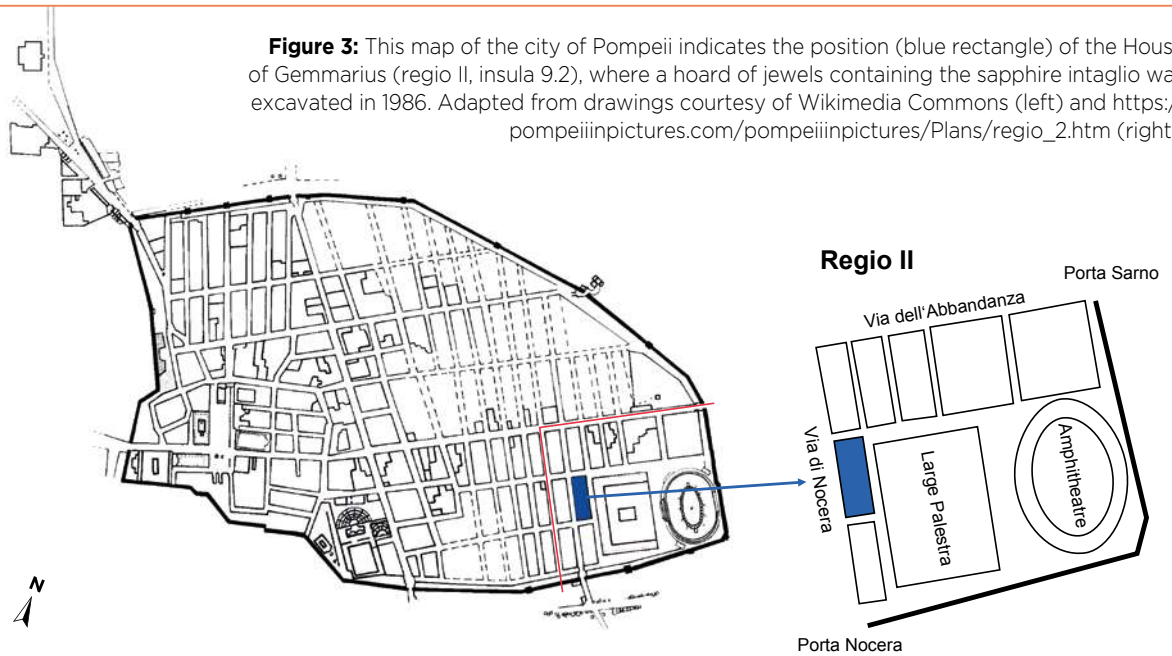

Figure 3: This map of the city of Pompeii indicates the position (blue rectangle) of the House of Gemmarius (regio II, insula 9.2), where a hoard of jewels containing the sapphire intaglio was excavated in 1986. Adapted from drawings courtesy of Wikimedia Commons (left) and https://pompeiiinpictures.com/pompeiiinpictures/Plans/regio_2.htm (right).

MATERIALS AND METHODS

The Roman sapphire intaglio is a flat, oval cabochon measuring 21.78 × 12.27 × 4.31 mm and weighing 11.62 ct.

The intaglio was examined with standard gemmological instruments such as a refractometer (spot method) and a hydrostatic balance (Mettler Toledo), and was also observed under long- and short-wave UV radiation. Detailed microscopic investigation was performed with an Eickhorst Gemmaster trinocular microscope equipped with a Nikon F7000 digital camera.

The intaglio was chemically analysed by energy-dispersive X-ray fluorescence (EDXRF) spectroscopy using a Thermo Scientific ARL Quant'X instrument. Also analysed for comparison were four other Roman sapphire cabochons (one light blue and three dark blue) from the collection of author EB. Raman microspectroscopy of inclusions in the intaglio was performed with a Renishaw inVia unit equipped with an argon-ion laser (514.5 nm). Fourier-transform infrared (FTIR) spectroscopy was accomplished with a Nicolet iS50 instrument. Polarised ultraviolet-visible-near infrared (UV-Vis-NIR) absorption spectra were collected for the o-ray (parallel to the optic axis) in the range of 280–800 nm using a Varian Cary 500 spectrophotometer in transmission mode.

RESULTS AND DISCUSSION

Glyptic and Carving of the Intaglio

The Roman intaglio is a unique piece of cultural heritage, not only because it consists of sapphire—a gem known to the Romans but only rarely used in their jewellery (Spier 2012; Thoresen 2017a, b)—but also because it combines beauty and craftsmanship with a fully documented archaeological provenance. This is very much in contrast to other ancient sapphire intaglios and carvings described in the literature, most of which are from historical gem collections and thus have a more debatable and obscure geographical/historical provenance. Examples of such specimens include the sapphire seal of Alaric II, king of the Visigoths, in the Kunsthistorisches Museum Wien (see Kornbluth 2008; Thoresen 2017b); the Cambridge sapphire cameo depicting Aphrodite (Guy Ladrière Collection; see Ogden 1982; Thoresen 2017b); and other engraved sapphires of Roman age described previously (Spier 2007; Content 2016; Thoresen 2017b).

The sapphire intaglio examined here was masterfully carved (Figure 4) on the back surface. As the sapphire is nearly free of inclusions, the carving is very discernible through the stone, perfectly revealing the fine details of the engraving and craftsmanship of the artist (again, see

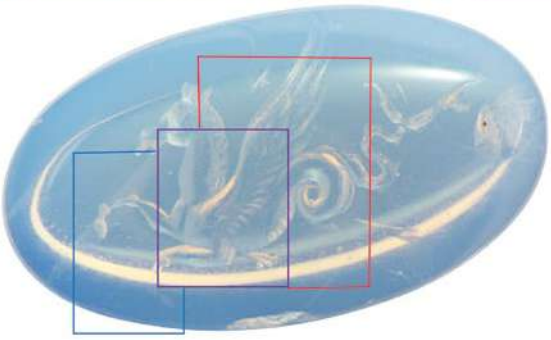

Figure 4: Details of the Roman sapphire intaglio reveal the craftsmanship involved in the creation of this gem. Photomicrographs by E. Butini, IGN; magnified 10×–20×.

Figure 5: This iron tool with a diamond tip for engraving gems was assembled by the authors based on descriptions in the literature. Photo by E. Butini, IGN.

Figure 1). The carving depicts a mythological creature known as a hippocamp—*hippokampoi* or ἱππόκαμπος in Greek, derived from ἵππος (horse) and κάμπος (sea monster)—a winged 'sea-horse' that has the upper body of a horse and the lower body consisting of the tail of a fish. Since ancient times, this motif has been one of the most common emblems of the marine world. Specifically, it appears as one of the symbols of Poseidon/Neptune, and is seen pulling his chariot or being ridden by him (Smith 1849; Charbonneau-Lassey 1994). In addition, the hippocamp is frequently depicted together with Tritons (sons of Poseidon) or Nereids (sea nymphs in Greek mythology), and because of their association with the ocean they are often engraved in 'sea-coloured' gem materials, notably aquamarine (L. Thoresen, pers. comm. 2019; see also Zwierlein-Diehl 2007 and specimen 732 in the Marlborough Gem Collection described in Boardman *et al.* 2009). Hippocamps may be depicted on Hellenistic, Roman and more recent engraved gems (see Richter 1920; Greifenhagen 1970; Zwierlein-Diehl 1991; Spier 1992; Pannuti 1994), as well as on coins (Calciati 1986), sarcophagi (Magni 2009), frescoes (Iacopi 1943) and mosaics in Roman bathing facilities (Di Nunno 2015).

Our study reveals that the hippocamp engraving on this sapphire was carried out with great detail and accuracy (again, see Figure 4). Presumably, this was done using a lathe with pivots and rotating hand-drills of various sizes that were impregnated with oils, grease and abrasives. The engraving may have also been accomplished with the aid of iron tools containing diamond tips (e.g. Figure 5). These tools were well known in Roman times (Maaskant-Kleibrink 1978, 1989; Ogden 1982, 2018; Devoto 1985; Rosenfeld *et al.* 2003), and were used for engravings in stone and gems of high hardness (corundum is 9 on the Mohs scale).

The authors were especially intrigued by small carving traces close to the hippocamp's caudal fin (see arrows in Figure 6) that were visible with the microscope. Although possibly accidental notches caused by a rotating disk, the authors favour another interpretation: at least some of them were made intentionally by the artist to express dynamic movement of the hippocamp, similar to what we recognise today as kinetic markers to express movement and speed in cartoons and comics. The authors incline to this latter hypothesis after having examined numerous other ancient engraved gems that appear to show similar kinetic markers. For example, Figure 7a is a glass 'paste' carving of Roman age reportedly originating from the Middle East (residing in a private collection) that depicts a mythological creature which exhibits five small notches near the end of its tail. These notches are very similar to those of the present sapphire intaglio and, when interpreted as kinetic markers, create a sensation of motion. An even more supportive example is shown by an early Roman green Cr-bearing chalcedony (from author EB's collection) that portrays a man operating a pedal lathe used to produce vases (Figure 7b). Several kinetic markers clearly represent his foot moving up and down on the pedal.

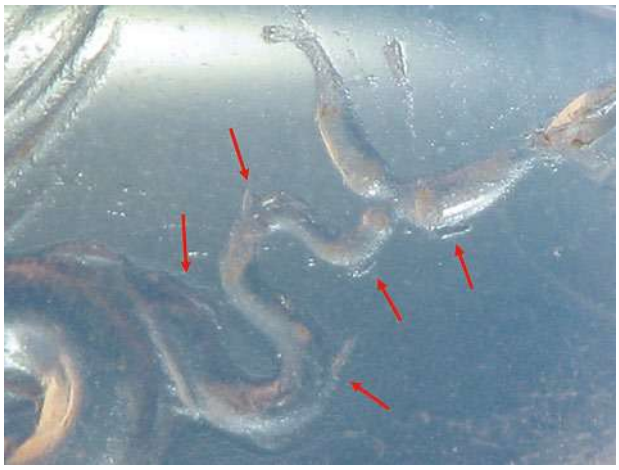

Figure 6: Small notches along the tail of the hippocamp might be kinetic markers added to suggest movement. Photomicrograph by F. Butini, IGN; magnified 15×.

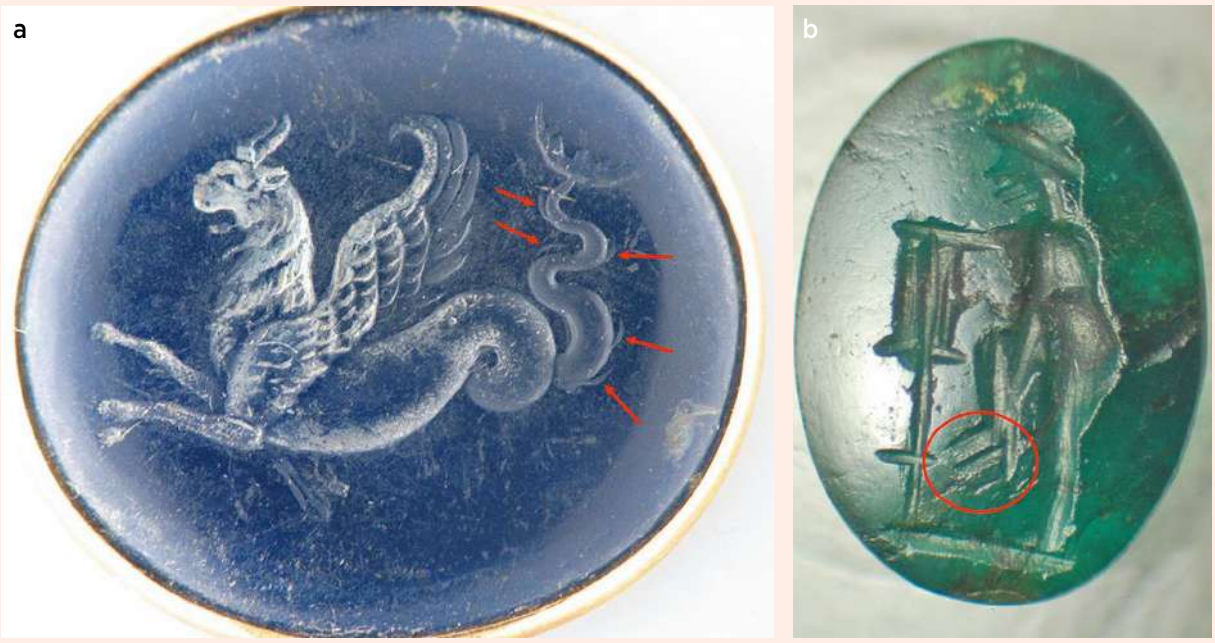

Figure 7: (**a**) This Middle Eastern glass paste intaglio (dating from around the time of the Roman Empire) measures approximately 35.0 × 25.0 mm and depicts a mythological creature. The arrows point to kinetic markers similar to those inferred in Figure 6. (**b**) An early-Roman intaglio of chromium-bearing chalcedony (8.42 × 6.14 mm) depicts a man operating a pedal lathe. Kinetic markers (see red circle) represent the up-and-down movement of his foot. Photos by F. Butini, IGN.

Gemmological Properties

The sapphire intaglio is translucent and appears light bluish grey in most lighting situations, but it is greyish brown when viewed in transmitted light (Figure 8). The bluish grey appearance is the result of light scattering by dispersed sub-microscopic inclusions within the gem, as discussed in more detail below.

The sapphire had an average RI of about 1.77 (spot method) and an SG value of 4.0, both characteristic for corundum. It was inert to long- and short-wave UV radiation. Viewed with the microscope, the sapphire showed a slightly zoned 'velvety' turbidity due to fine sub-microscopic particles (Figure 9). In addition, the specimen contained a few partially healed fissures, characterised by dispersed and randomly structured fluid inclusions. Some of the larger fluid inclusions had expansion discs consisting of a mirror-like internal plane surrounded by a rather thick and structured whitish rim of fluid droplets (Figure 10). Interestingly, these expansion discs locally contained tiny prisms in radial arrangements (see arrow in Figure 10). Based on their visual appearance, they are assumed to be an Al-hydroxide (e.g. diaspore), typical of late-stage precipitates in fissures, partially healed fractures and fluid inclusions

Figure 8: A comparison of the Roman intaglio in (**a**) reflected light and (**b**) transmitted light reveals the different colour appearances of the sapphire (bluish grey and greyish brown, respectively). Photos by M. S. Krzemnicki, SSEF.

Figure 9: Zoned turbidity is present throughout the Roman sapphire intaglio. Photomicrograph by M. S. Krzemnicki, SSEF; image width 10 mm.

Figure 10: Magnification reveals twin planes and a healing fissure with dotted fluid inclusions in the Roman sapphire intaglio. The larger fluid inclusions show structured expansion discs. The main expansion disc contains tiny, radially arranged needles (see arrow) interpreted as Al-hydroxide precipitates. Photomicrograph by M. S. Krzemnicki, SSEF; image width 3 mm.

Figure 11: Small idiomorphic plagioclase (albite) inclusions, identified by Raman microspectroscopy, are also present in the sapphire intaglio. Photomicrograph by M. S. Krzemnicki, SSEF; image width 2 mm.

in unheated sapphires from various locations (e.g. Smith 1995; Hughes 1997). In addition, we found a few small twin planes (again, see Figure 10), as well as colourless idiomorphic inclusions (Figure 11) that were identified by Raman microspectroscopy as Na-rich plagioclase (albite).

The observed microscopic features are consistent with those described in sapphires associated with alkali basalt (Guo *et al.* 1992; Smith *et al.* 1995; Krzemnicki *et al.* 1996; Gübelin & Koivula 2008; Pardieu *et al.* 2014). The specific nature of the mirror-like expansion discs with structured white rims indicates that a natural heating of the sapphire occurred (i.e. associated with its entrainment in alkali basalt). No indications of heat treatment were found in this sapphire, although heating of gemstones was known and practised in antiquity, as documented in ancient literature such as the *Papyrus Graecus Holmiensis* codex (also known as 'The Stockholm Papyrus'; Anonymous ca. 300 CE) that was compiled in the 3rd century CE (see also Caley 1927; Francis 1986; Hackens & Moucharte 1989; Sax 1996), and in Roman times by Pliny the Elder (23–79 CE) who mentioned gem treatments in a more general context in his *Historia Naturalis* (see, e.g., Hughes 1997, p. 103).

Chemical Composition and Spectroscopy

The trace-element analysis by EDXRF revealed that this sapphire of bluish grey appearance contained a relatively high amount of Fe (0.41 wt.% Fe_2O_3), traces of Ti (0.03 wt.% TiO_2) and Ga (0.02 wt.% Ga_2O_3), and almost no Cr (at the detection limit). This composition fits well with basaltic sapphires when plotted according to their trace-element ratios (Figure 12; as proposed by Abduriyim & Kitawaki 2006 and Giuliani *et al.* 2014). Because this Roman sapphire intaglio is an archaeological artefact and considered part of the historical heritage of Italy, it was not possible to analyse its trace-element composition further by laser ablation inductively coupled plasma mass spectrometry (e.g. GemTOF; Wang *et al.* 2016), as this method would have been slightly destructive (leaving a laser ablation spot). We also used EDXRF to analyse four other Roman sapphires, and three of them were found to be of basaltic origin while only one was of metamorphic origin (most probably Sri Lanka; see Figure 12). The above-mentioned analytical limitation may explain why the data obtained by EDXRF on our samples mostly plots outside the indicated distribution fields for basaltic sapphires (which were defined using LA-ICP-MS data).

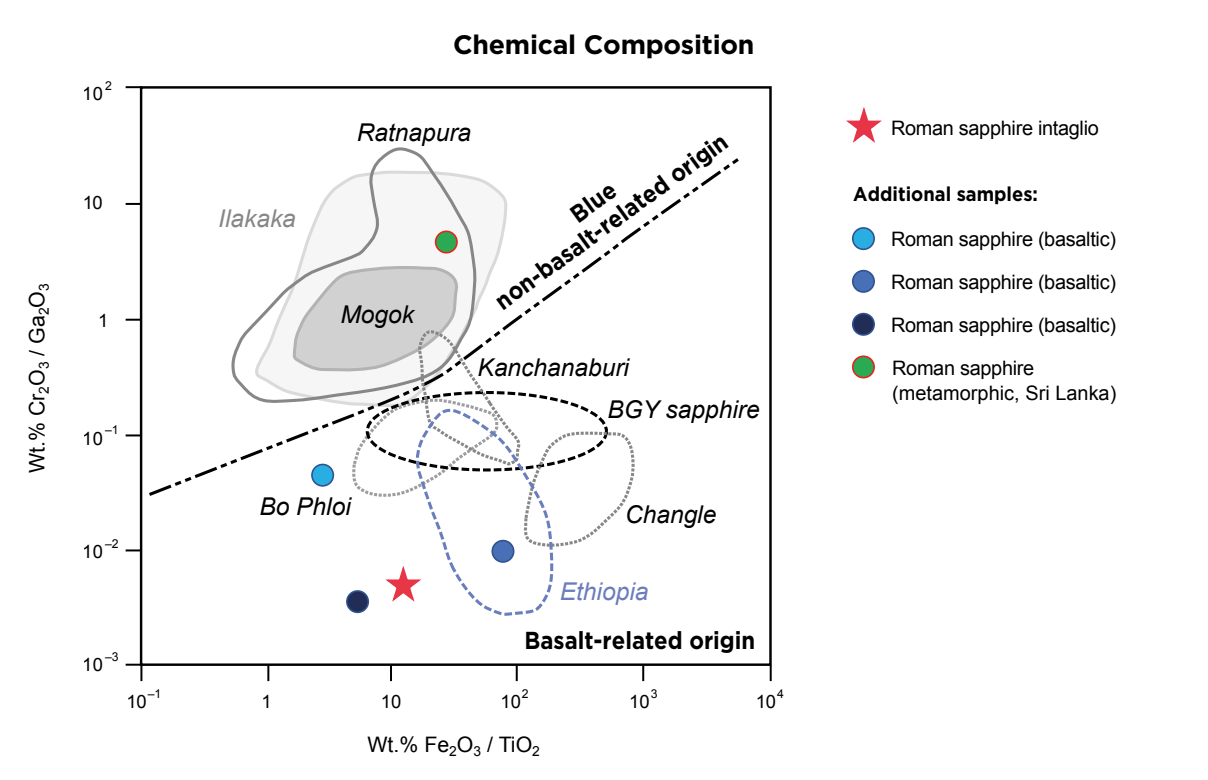

Figure 12: A trace-element ratio diagram reveals that the Roman sapphire intaglio is of basalt-related origin, similar to three other Roman sapphires. An additional Roman sample was found to be of metamorphic origin. The distribution field for Ethiopian sapphires is based on samples in the SSEF research collection. Diagram adapted from Abduriyim & Kitawaki (2006) and Giuliani *et al.* (2014).

FTIR spectroscopy of the sapphire intaglio revealed distinct hydroxide (OH^-) features, with a band at 3309 cm^{-1} dominating a series of lines at 3393, 3377, 3366, 3231 and 3183 cm^{-1} (Figure 13). Such a pattern has been attributed to intrinsic hydrous defects within the sapphire structure (Smith *et al.* 1995; Beran & Rossman 2006), and is commonly found in sapphires from basaltic deposits (unheated and heat treated) and also in metamorphic sapphires that have been heat treated. The features in the range of 2950–2800 cm^{-1} in Figure 13 are due to organic contamination (e.g. skin oils) and are not intrinsic to the sapphire.

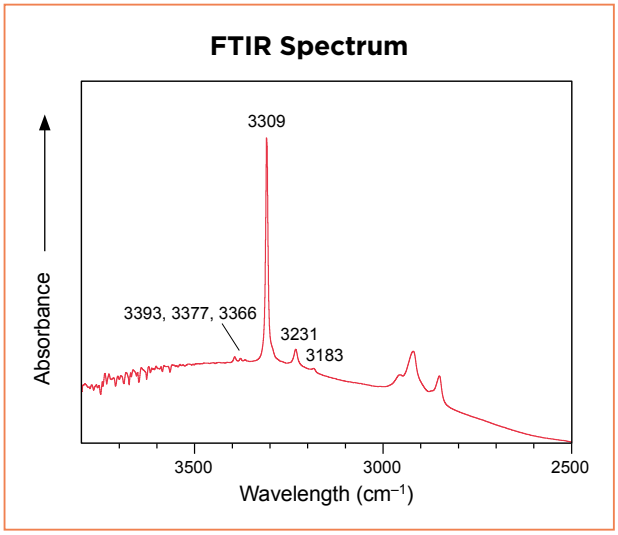

Figure 13: The FTIR spectrum of the Roman sapphire intaglio shows a characteristic pattern—a band at 3309 cm^{-1} accompanied by a series of small features—for the presence of hydroxide (OH^-) in sapphire.

UV-Vis-NIR spectroscopy of the intaglio obtained in transmission mode yielded an absorption curve related to the sapphire's greyish brown body colour (Figure 14). In detail, the spectrum was dominated by a steady increase in absorption from the near infrared towards the ultraviolet region, superposed only by small peaks related to Fe^{3+} at 376, 387 and 450 nm (Figure 14). The general absorption trend in combination with an absorption edge at about 340 nm is mainly due to the presence of numerous sub-microscopic particles that cause the slightly milky appearance of the stone.

The sapphire showed no absorption band centred at 560 nm related to Fe^{2+}–Ti^{4+} intervalence charge transfer (IVCT; Schmetzer & Bank 1981) nor at about 870 nm related to Fe^{2+}–Fe^{3+} IVCT (Ferguson & Fielding 1971;

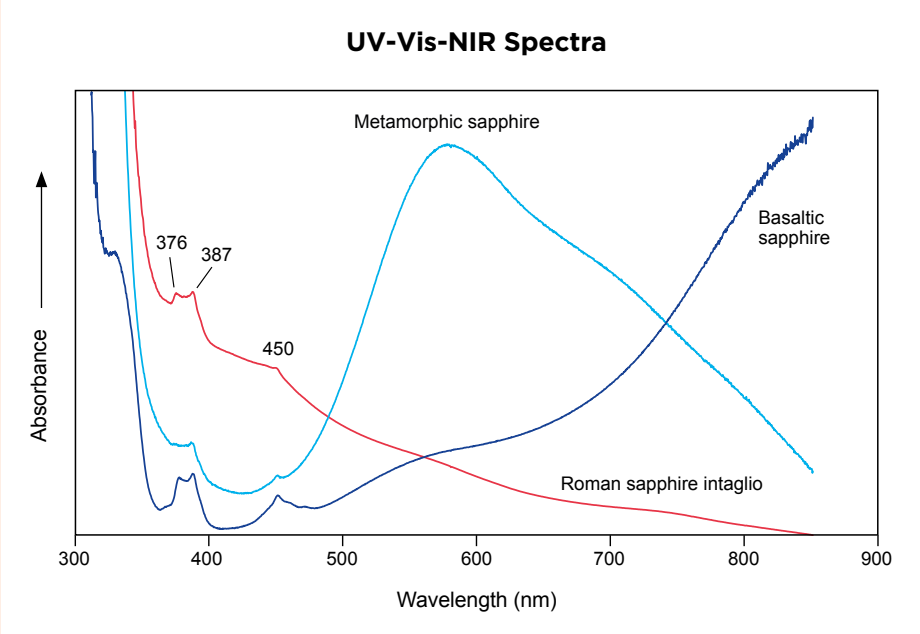

Figure 14: The polarised UV-Vis-NIR absorption spectrum of the Roman sapphire intaglio is very different from those of typical metamorphic and magmatic (basaltic) sapphires, which owe their blue colour to Fe^{2+}–Ti^{4+} and/or Fe^{2+}–Fe^{3+} intervalence charge transfer. The bluish grey appearance of the Roman sapphire is thus not related to absorption, but is the result of Rayleigh scattering by sub-microscopic inclusions. The turbidity caused by these inclusions induces a broad absorption band towards the UV region.

Schmetzer & Bank 1981). These two broad bands (either alone or in combination) are normally the main cause of blue colour in metamorphic and magmatic sapphires (see blue traces in Figure 14; Schmetzer & Bank 1981; Fritsch & Mercer 1993). Therefore, we conclude that the apparent bluish grey colour of this sapphire is not related to absorption but is only the result of Rayleigh scattering by the sub-microscopic particles within the sapphire. Similar scattering effects are well known in sapphires from both metamorphic and basaltic origins (Hänni 1990; Krzemnicki *et al.* 1996; Hughes 1997; Gübelin & Koivula 2008). In such sapphires, the scattering effect supports the blue colour that is mainly caused by IVCT absorption. By contrast, bluish colour caused mainly or only by Rayleigh scattering—as for the sapphire intaglio described here—is rather uncommon and has been described previously for basaltic sapphires from Nigeria (Pardieu *et al.* 2014). Nowadays, such stones are commonly heat treated to enhance their blue colour by creating Fe^{2+}–Fe^{3+} and Fe^{2+}–Ti^{4+} IVCT absorption bands.

POSSIBLE SAPPHIRE ORIGIN

The few sapphires found in jewellery from the Roman period can be divided into two groups: small, dark sapphires of basaltic origin (mostly lenticular beads) and paler sapphires presumably of Sri Lankan origin (Thoresen 2017a, b; J. Ogden, pers. comm. 2019). In the literature, most Roman sapphires have been attributed to Sri Lanka—called Taprobanê in Greek and Roman times—which has been known since antiquity for its gem wealth (see also the ancient text *Periplus Maris Erthraei*; Casson 1989). Stones from this origin are commonly described as being imported into the Roman Empire from the East along the Maritime Silk Route (Ogden 1982; Sevillano-López & Gonzalez 2011; Hughes 2017; Seland 2017). However, since Sri Lanka's secondary gem deposits contain only metamorphic sapphires (and no basaltic ones), it appears that there were other sapphire sources available to the Romans that provided basaltic sapphires for their jewels.

In considering a possible origin of the present intaglio—as well as other basalt-related Roman sapphires—a conclusive determination is presently not possible due to similarities in the characteristics of basaltic sapphires from various deposits. The inclusion features, trace-element concentrations, UV-Vis-NIR absorption and oxygen isotopic signatures of sapphires from alkali basalts are rather uniform, and this is very much in contrast to those from metamorphic deposits such as Ratnapura or Elahera in Sri Lanka, Mogok in Burma and Kashmir in India (Hänni 1994; Abduriyim & Kitawaki 2006; Giuliani *et al.* 2014; Wang *et al.* 2016), for which origin determination is more feasible.

Although sapphire deposits related to alkali basalts are known today from many localities (e.g. Cambodia, Laos, Vietnam, Ethiopia, Rwanda and Nigeria to name a few; see Giuliani *et al.* 2014 and references therein), it is not presently known which of these deposits were productive in the 1st millennium CE. One of the few historical basaltic sapphire deposits is located in the

Massif Central (Puy-en-Velay) in France. Although its initial discovery (first mentioned at the end of the 13th century) is generally assigned to medieval times (Forestier 1993; Gaillou 2003; Médard *et al.* 2012), it is possible that these sapphires had been found much earlier in alluvial sediments of this area. Furthermore, Ogden (2015) suggested the Massif Central as a possible source of dark blue sapphires (typical for iron-rich sapphires from alkali basalts and related volcanic rocks) in the ancient Roman period. However, to our knowledge there are no historical accounts of Roman sapphires from the Massif Central, so this option is possible but remains hypothetical.

Sapphires related to alkali basalts have been known since the 19th century from Scotland (e.g. from Arran, Mull, Ardnamurchan and Aberdeenshire; see Smith *et al.* 2008), but there is no evidence that these localities were known by the mid-1st century CE, when the Roman Empire just started its conquest of northern Britain. In addition, these Scottish sapphires are commonly described as being small and mostly not of gem quality.

Another source of basaltic sapphires in Roman times might be alkali basalt-related deposits in South East Asia, such as those in Thailand (Gunawardene & Sing Chawala 1984; Saeseaw *et al.* 2017), Cambodia (Jobbins & Berrangé 1981), southern Vietnam (Smith *et al.* 1995), Laos (Sutherland *et al.* 2002), or even China (Guo *et al.* 1992; Keller & Keller 1986; Wang 1988). We know that in Roman times the Mediterranean was connected to the Far East along the Maritime Silk Route (Borell *et al.* 2014; Dimucci 2015). This has led authors in the past to attribute antique sapphires of basaltic origin to such South East Asian deposits, although in our opinion the analytical data presented to support such claims (Butini *et al.* 2018) often do not stand up to critical scrutiny.

Most current sources of basaltic sapphire such as Australia (New South Wales and Queensland), Nigeria, Rwanda, northern Madagascar and Colombia, to name a few, can be excluded, as they were beyond reach in Roman times and no historical account has documented their discovery that early.

Although the authors have no scientific proof, we propose a new hypothesis for the origin of (some) basaltic sapphires used by the Romans: that they came from surface deposits in northern Ethiopia which were already known and productive in ancient times, but which were possibly abandoned later, forgotten and only recently rediscovered. This hypothesis is supported by comments made by Pliny the Elder (23–79 CE) and Solinus (early 3rd century CE), both of whom referred to gems from Ethiopia (J. Ogden, pers. comm. 2019) and specifically mentioned *hyacinthos*, which is generally accepted in archaeology to be the ancient name for sapphire (Thoresen 2017a). Specifically, Pliny the Elder stated 'Ethiopia, which produces hyacinthos, produces chrysolithos also, a transparent stone with a refulgence like that of gold' (Eichholz 1962), and Solinus indicated 'Amongst those things of which we have spoken [in Ethiopia] is found the hyacinthos of a shining sky blue colour' (Apps 2011).

Basalt-related sapphire deposits in northern Ethiopia are located near the town of Chila (Tigray region), about 25 km north-west and north of the city of Aksum (Bruce-Lockhart 2017; Vertriest *et al.* 2017). Structurally, this area is located at the northern end of Africa's Great Rift Valley, which is dominated by geologically young extensional tectonics (Tertiary to Quaternary; Corti 2009) similar to sapphire deposits further south of this large-scale structure, such as near Lake Turkana in Kenya (Themelis 1989) and Cyangugu in south-western Rwanda (Krzemnicki *et al.* 1996). This region is characterised by extensive igneous (magmatic and volcanic) rock suites, including alkali basalt and associated secondary gravels containing sapphires in large quantities, often showing some turbidity or milkiness (Lucas *et al.* 2018) similar to the Roman intaglio of this study.

Near the northern border of modern Ethiopia, the city of Aksum and its surroundings were an important trading centre during the Aksumite Empire (early 1st century to 900 CE), which controlled northern Ethiopia and part of present-day Eritrea, including the ancient port of Adulis. This port was an important trading hub between the Roman Empire and the Middle East and India (Figure 15), as described by an anonymous merchant or sailor around the middle of the 1st century in *The Periplus Maris Erythraei* ('Voyage Around the Red Sea'; Casson 1989). Recent archaeological excavations of several ancient graves in Aksum revealed numerous artefacts, including jewellery and glass beads, thus offering evidence of intense trade between the kingdom of Aksum and the Roman Empire (Sidebotham 1986, 1996, 2019; Wendrich *et al.* 2003) since the early 1st century CE (Morrison 1989; Alberge 2015).

Although sapphires have not been found so far in any archaeological excavation at Aksum or its surroundings, the present-day deposits in Ethiopia might have been known in antiquity, as they are located within the realm of the ancient kingdom of Aksum. In addition, the deposits are readily accessible (in mining terms) on the surface and in shallow gravel layers, such that sapphires could be easily gathered from the ground (Vertriest *et al.* 2017; Lucas *et al.* 2018).

Figure 15: This map illustrates ancient trade routes from Aksum towards the Roman Empire and elsewhere. Modified from Addis Herald, www.addisherald.com/aksumite-empire/#gmedia10093.

CONCLUSIONS

This study provides a rare case where a gemstone of archaeological significance and documented provenance (1986 excavation of Pompeii, Italy) could be analysed in a laboratory setting with advanced analytical methods. Based on our analytical data and microscopic observations, we conclude that the studied Roman intaglio was fashioned from an unheated basaltic sapphire. A possible origin from gem gravels of Sri Lanka—known since antiquity as a source of (metamorphic) sapphires and many other gems—can be definitively excluded, although the gem's hazy light bluish grey colour appearance might be considered reminiscent of some Sri Lankan sapphires. Due to its close similarity in trace-element composition to basaltic sapphires from various deposits, a clear geographic origin for this Roman sapphire intaglio cannot be determined based on the currently available data.

In addition to the existing literature, which commonly refers to the origin of ancient sapphires as South East Asia and the Far East, we propose an Ethiopian origin for the studied Roman intaglio as similarly plausible, although we have no direct evidence (by gemmological data, archaeological excavations or historical accounts) to support our hypothesis. Another option for such basalt-related sapphires might be the Massif Central in France. Although first mentioned only in the 13th century (Forestier 1993), sapphires from this area might have been known as early as the 1st century CE.

This study clearly shows that more detailed research on basalt-related ancient (Roman) sapphires is necessary. Especially with the recent progress in gem testing using chemical fingerprinting (e.g. GemTOF; Wang *et al.* 2016), statistical methodology (e.g. non-linear algorithms; see Wang *et al.* 2019) and stable isotopes (e.g. oxygen; see Giuliani *et al.* 2000, 2008, 2014), it might be possible to verify in the future whether the recently documented sapphire deposits near Aksum in northern Ethiopia were known in ancient times as a source of gem-quality basaltic sapphires showing milky bluish or dark blue colouration.

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The Fire Within

"For in them you shall see the living fire of the ruby, the glorious purple of the amethyst, the sea-green of the emerald, all glittering together in an incredible mixture of light."

– Roman Elder Pliny, 1st Century AD

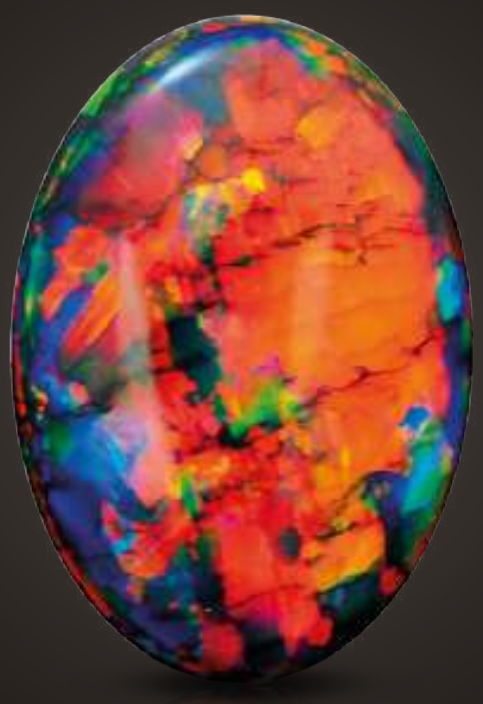

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The Texture and Chemical Composition of Trapiche Ruby from Khoan Thong, Luc Yen Mining District, Northern Vietnam

Isabella Pignatelli, Gaston Giuliani, Christophe Morlot and Pham Van Long

ABSTRACT: The trapiche texture and chemical composition of two rubies from the Khoan Thong placer in northern Vietnam were examined by X-ray computed tomography, scanning electron microscopy and electron microprobe analysis. Their texture is similar to that of some Burmese trapiche rubies, with inclusion-rich sector boundaries intersecting at a small central point and a significant concentration of elongated tube-like voids in growth sectors. The most common inclusions are anorthite and margarite; the latter formed by destabilisation of both ruby and anorthite during retrograde metamorphism. The chemical composition of the samples plots in the field of Vietnamese alluvial and primary marble-hosted deposits, although differences in Fe_2O_3, TiO_2 and Cr_2O_3 contents may distinguish trapiche rubies from various mining areas in Vietnam. Their composition differs from that of Burmese trapiche rubies by a higher Fe_2O_3/TiO_2 ratio and a lower Cr_2O_3 content. Vietnamese trapiche rubies formed in the same geological environment as non-trapiche ones, under metamorphic conditions prevailing for the Himalayan orogenesis. In this geological context, localised fluid pressure variations and hydraulic fracturing caused changes in the driving force of crystallisation, favouring the development of the trapiche texture.

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The term *trapiche* was introduced by McKague (1964) to refer to an unusual texture in some Colombian emeralds, which resembles the spokes of a milling wheel that is used to process sugar cane. In the 1990s, trapiche rubies with a similar texture appeared on the gem market from Mong Hsu in Myanmar (Schmetzer *et al.* 1996, 1999; Sunagawa *et al.* 1999). Then, in the 2000s, trapiche tourmalines were reported from Zambia (Hainschwang *et al.* 2007; Schmetzer *et al.* 2011). Recently, a fluid inclusion study of samples from Mong Hsu confirmed that both non-trapiche and trapiche rubies formed from the same parental CO_2-H_2S-rich fluid (Giuliani *et al.* 2018).

In the present article, we describe in detail (and for the first time) trapiche rubies from northern Vietnam (e.g. Figure 1). We examine two samples from the Khoan Thong placer in the Luc Yen mining district of northern Vietnam, and discuss their formation conditions, texture acquisition and growth, as well as their chemical composition, through mineralogical and petrographic studies, X-ray computed tomography and electron probe micro-analysis. The results give a complete overview of the relationships among the three components of the trapiche texture (core, growth sectors and sector boundaries) in Vietnamese rubies, which we compare to those from other localities.

Figure 1: The trapiche texture of this ruby (15 × 15 × 27 mm) is representative of the material from the Luc Yen District of Vietnam described in this article. Photo by Shang-i (Edward) Liu.

TRAPICHE TEXTURE IN RUBY

Trapiche texture is formed of growth sectors separated by more or less sharp boundaries containing abundant mineral and fluid inclusions (Win 2005; Schmetzer *et al.* 2011). These boundaries surround a central portion, generally called the 'core', and extend from its edges to the rim of the crystal. Some trapiche samples lack a distinct core, and the boundaries intersect at a central point. The trapiche texture is best seen in slices cut perpendicular to the *c*-axis, and the presence and size of the core portion depend on the slice's position within the host crystal (Pignatelli *et al.* 2015; see Figure 2).

In the literature, the terminology used to indicate the main components of the trapiche pattern varies with the mineral and the authors (Figure 3). There is consensus only for the 'core'. The growth sectors have been called 'arms' in trapiche emeralds (Nassau & Jackson 1970), and 'ruby sectors' or 'growth sectors' in trapiche rubies (Schmetzer *et al.* 1996, 1999; Sunagawa *et al.* 1999). 'Growth sectors' is also used for trapiche tourmaline (Schmetzer *et al.* 2011). More complex is the nomenclature for the boundaries between the gemmy portions: 'two-phase regions' or 'dendrites' have been used for emeralds (Nassau & Jackson 1970; Pignatelli *et al.* 2015), 'arms' for rubies (Schmetzer *et al.* 1996, 1999; Sunagawa *et al.* 1999) and 'sector boundaries' for tourmalines (Schmetzer *et al.* 2011). To avoid further confusion, in this article we use the terms *core, growth sectors* and *sector boundaries*, consistent with Schmetzer *et al.* (2011).

Trapiche texture in ruby was described for the first time by K. Schmetzer and his co-authors (Schmetzer *et al.* 1996, 1999; Sunagawa *et al.* 1999). According to their data, this texture is characterised by six yellowish or white sector boundaries separating six growth sectors. In some ruby samples the sector boundaries intersect at a central point (a core being absent), giving rise to triangular growth sectors (Figure 2c). In others, a hexagonal core is present, and the growth sectors have a trapezoidal shape (Figure 2b).

The core can appear red, black and, when similar to the sector boundaries, yellowish to white. Zoning in Cr and variable contents of other chromophores such as Ti and V have been reported in different trapiche ruby samples,

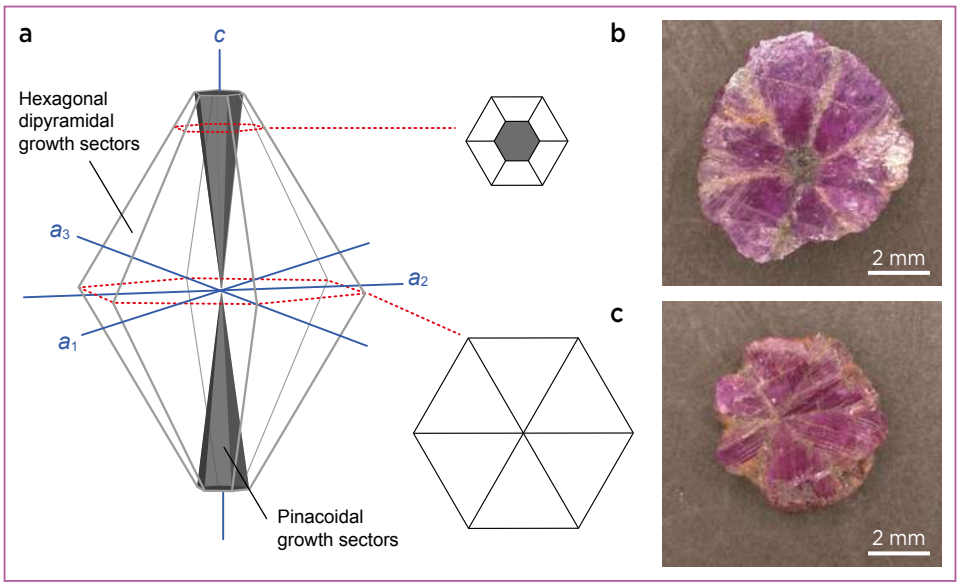

Figure 2: (**a**) Variations in the size of the trapiche core, which corresponds to the pinacoidal growth sectors, can be seen in the areas shown in grey. These sectors have a tapered shape, so the core size varies depending on where a section is cut perpendicular to the *c*-axis. The core is largest near the ends of the crystal (**b**) and decreases towards the centre, where the sector boundaries intersect (**c**). Both slices shown here are from Mong Hsu in Myanmar. Photos by I. Pignatelli and G. Giuliani.

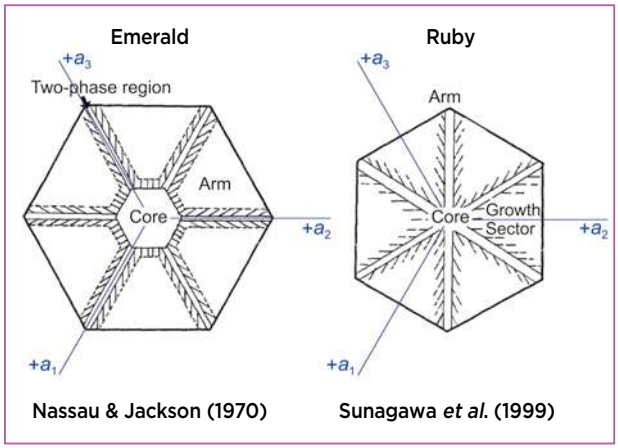

Figure 3: The trapiche texture as seen in sections perpendicular to the *c*-axis is illustrated here for emerald (left) and ruby (right). The *a*-axes are labelled in both drawings, as well as the differing descriptive terminology used in the literature. In the present article, the *arms* referred to by Sunagawa *et al.* (1999) are called *sector boundaries*. Modified from Sunagawa *et al.* (1999).

but also within the same sample (Schmetzer *et al.* 1999; Garnier *et al.* 2002a, b). This explains why the core can be red (Cr>Ti) or bluish to black (Ti>Cr; Peretti *et al.* 1996). The yellowish-to-white colour of both the core and sector boundaries has been attributed to the presence of calcite, dolomite, corundum and K-Al-Fe-Ti silicate inclusions, as well as Fe-rich secondary minerals formed during the weathering process (Schmetzer *et al.* 1999).

Other solid inclusions have also been found within the sector boundaries, including siderite, chlorite, adularia, sillimanite, rutile, titanite, graphite, baryte, mica, amphibole, zircon, diaspore and pyrite (Garnier *et al.* 2002a, b). Tube-like voids filled by solids (i.e. calcite or dolomite), liquid and gas have also been described (Schmetzer *et al.* 1996; Giuliani *et al.* 2018). They originate from the core or sector boundaries and extend into the growth sectors, running perpendicular to the sectors with an inclination of 5° relative to the {0001} faces of the ruby. In some samples, the tube-like voids in the core can also be oriented parallel to the *c*-axis.

Between the tube-like voids and/or their extensions into the sector boundaries, single-phase (liquid), two-phase (liquid + gas) or three-phase (liquid + gas + solid) inclusions have been found (Garnier *et al.* 2002a, b). These inclusions correspond to the trapping of two immiscible fluids during ruby formation: a carbonic fluid in the CO_2-H_2S-COS-S_8-AlO(OH) system and molten salts (Giuliani *et al.* 2015a, 2018).

Trapiche rubies have not been studied *in situ* in their primary deposits; instead, they are typically acquired in Thai and Burmese gem markets. Based on information given by the suppliers, they originated from the Mong Hsu mines in Myanmar, but some of them might have come from Vietnam (Schmetzer *et al.* 1996). Although the geology of Mong Hsu is not well known because of security issues, Hlaing (1991) reported that the trapiche rubies are apparently hosted by marbles similar to those in the Mogok Stone Tract. This was supported by Garnier *et al.* (2002a, b), who underlined that trapiche and non-trapiche rubies from Mong Hsu have similar mineralogical and chemical features because they formed in the same geological environment.

GEOLOGICAL SETTING OF VIETNAMESE TRAPICHE RUBIES

In northern Vietnam, the main ruby and red spinel deposits are located in marble associated with large-scale shear zones that were active during the Tertiary (Leloup *et al.* 1995; Garnier 2003; Garnier *et al.* 2008; see Figure 4). The Red River shear zone is formed by the Day Nui Con Voi metamorphic belt and the Lo Gam tectonic zone (Garnier 2003; Pham *et al.* 2004, 2013, 2018). The Lo Gam zone contains the ruby and spinel deposits, and consists of metasedimentary sequences (i.e. marble units and intercalated gneisses and schists) of Cambrian depositional age, which are situated between two main left-lateral faults in an area about 10–15 km wide within the Red River shear zone, together with granitoid intrusions of Triassic age (Garnier 2003).

Geothermobarometry of the Day Nui Con Voi metamorphic belt revealed that peak metamorphism took place under amphibolite-facies pressure-temperature (P-T) conditions of about 4.5 ± 1.5 kbar and 710 ± 70°C (Leloup and Kienast 1993; Leloup *et al.* 2001), while Nam *et al.* (1998) estimated 6.5 ± 1.5 kbar and about 690 ± 30°C. Gem ruby formed under conditions of about 620–650°C and 2.6–2.9 kbar during a retrograde P-T metamorphic path, mainly by the destabilisation of muscovite or spinel (Garnier *et al.* 2008). The metamorphic fluid system was rich in CO_2 released from the devolatilisation of carbonates, and also contained fluorine, chlorine and boron, as well as salts and sulphates (NaCl, KCl and $CaSO_4$). Evaporites are the key to explaining the formation of these ruby deposits. Molten salts mobilised *in situ* aluminium and metal transition elements contained within phengites hosted by the marbles, leading to the crystallisation of ruby (Giuliani *et al.* 2003, 2018).

Primary ruby occurs as disseminated crystals within marble—associated with phlogopite, dravite, margarite, pyrite, rutile, spinel, pargasite-edenite and graphite

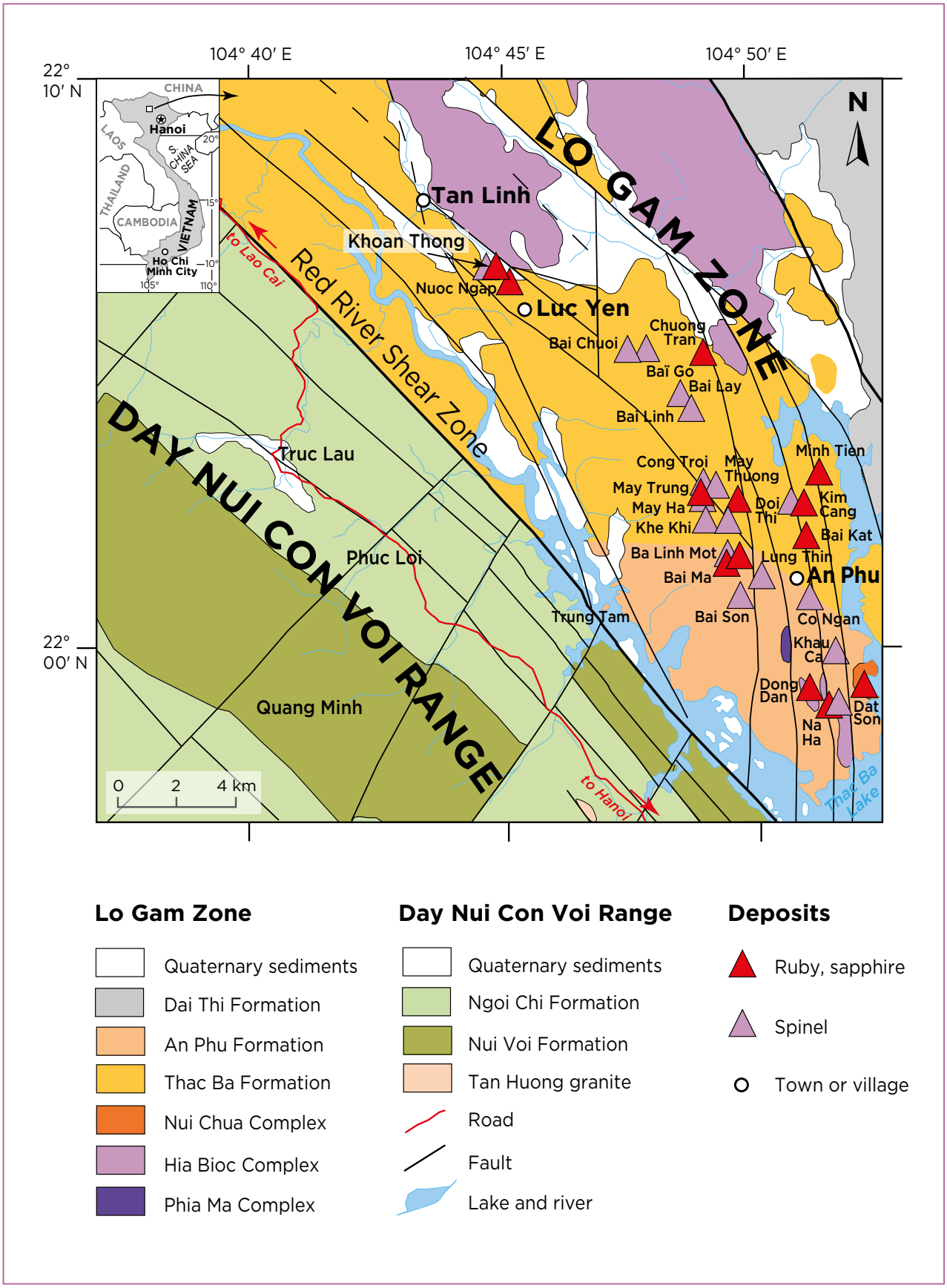

Figure 4: This geological map of the Luc Yen area in northern Vietnam (modified from Garnier 2003) shows the main ruby and red spinel deposits located in marbles associated with large-scale shear zones. The samples studied for this report originated from the Khoan Thong placer north-west of Luc Yen.

(Garnier *et al.* 2008)—in the Luc Yen mining district, which includes the Khoan Thong placer. Ruby also occurs within veinlets and fissures—which crosscut the marbles and are filled by calcite, dravite, pyrite, margarite and phlogopite—at the An Phu, Bai Da Lan and Minh Tien mines.

Placer deposits formed by the concentration of gem-bearing gravels and sands in karst and alluvial fans throughout the Luc Yen mining district. The gem-producing valleys are typically small (i.e. 2–3 km^2). Blue and fancy-colour sapphires, spinel, tourmaline, pargasite, humite and garnet are recovered together with ruby (including rare trapiche ruby). These placers furnish a variety of gem-quality materials to the Luc Yen market, which has been open daily since 1987.

MATERIALS AND METHODS

Seven trapiche rubies were collected by one of the authors (Pham Van Long) in the Luc Yen mining district, from placers related to ruby-bearing marble (i.e. the Cong Troi, May Trung and Khoan Thong mining areas; Figure 4). The crystals were alluvially transported and most of them were transformed into rounded grains. Two of the best-preserved but fractured crystals (samples T1 and T2) found in the Khoan Thong placer were analysed for the present study.

The two samples were analysed by X-ray computed tomography (CT), a non-destructive technique that has previously been used to obtain high-resolution three-dimensional (3D) details of various gem materials, including trapiche emeralds (Karampelas *et al.* 2010; Giuliani *et al.* 2015b; Morlot *et al.* 2016; Pignatelli *et al.* 2017; Richard *et al.* 2019). This technique provides information on the size, distribution and shape of solid inclusions, as well as the geometry and volume of fluid inclusions, and can quantify the volume of porosity. CT scans of the two trapiche rubies were collected with a Phoenix Nanotom S instrument, using resolutions of 6 and 3 µm/voxel and nanofocus X-ray tube tensions of 90 and 110 kV, respectively, for samples T1 and T2. The tomography produces files with voxel (3D pixel) resolutions between 30 and 0.6 µm as a function of sample size. Virtual cross-sections were digitally extracted from the volume of the samples to observe textural details (e.g. porosity) and to visualise the distribution of inclusions with different densities. The volume of porosity and inclusions was calculated using VGStudio and Avizo 9.5 software.

Both samples were sliced perpendicular to the crystallographic *c*-axis, embedded in resin and polished for

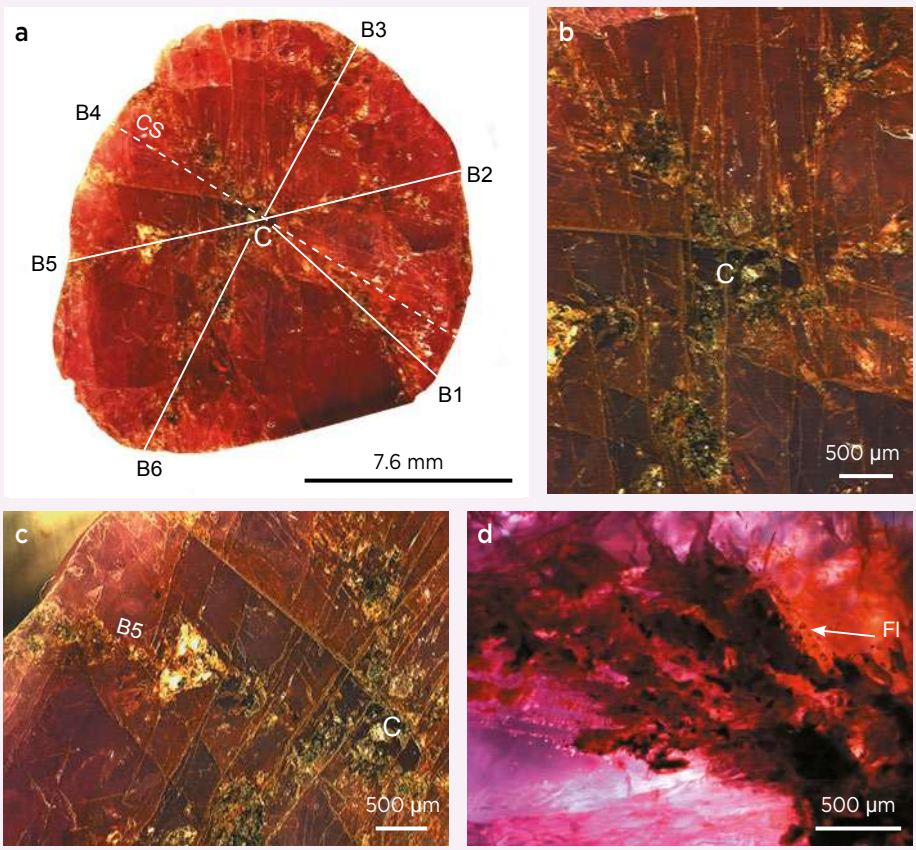

Figure 5: (**a**) Trapiche ruby sample T1 contains six sector boundaries (B1–B6) intersecting at a central point (labelled C). The dashed line (labelled CS) designates one of the EPMA traverses. Closer views of the slice show: (**b**) a dark inclusion of Cr-poor corundum at the central point, (**c**) a typical herringbone pattern of the sector boundary B5 and (**d**) planar fluid inclusions (FI) parallel to the sector boundaries. Photomicrographs by G. Giuliani.

further analysis (Figures 5a and 6a). At the CRPG-CNRS laboratory, they were studied with a JEOL JSM-6510 scanning electron microscope (SEM) equipped with a Genesis energy-dispersive X-ray (EDX) detector, using a 3 nA primary beam accelerated at 15 kV. Backscattered electron (BSE) images and EDX spectra were recorded to analyse the trapiche texture and identify the solid inclusions.

Eighty-seven point analyses of the inclusions and host rubies were performed by electron probe micro-analysis (EPMA) at the Service Commun de Microscopie Electronique et Microanalyse (GeoResources laboratory) with a fully automated Cameca SX100 instrument. The samples were analysed using: an accelerating voltage of 15 kV, a beam current of 12 nA and a raster length of 0.03 µm (focused beam on a surface of 1 µm^2) for Al; and an accelerating voltage of 25 kV, a beam current of 100 nA and a raster length of 0.03 µm for Mg, Ti, V, Cr, Fe and Ga. The collection times were 10 s for Al and 120 s for the other elements. The microprobe was calibrated using mineral and synthetic standards: olivine for Mg, corundum for Al, titanite for Ti, V-SX9 metal for V, chromite for Cr, hematite for Fe and AsGa for Ga. Special care was taken with regard to possible interferences between the chromophores Cr and V: Cr($K\beta_1$) and V($K\alpha_1$) lines were measured using a pentaerythritol (PET) analysing crystal with positive and negative background offsets of 600, large enough to have no interference, respectively, with the V($K\alpha_1$) and Ti($K\beta_1$) lines. The limits of detection were (in ppmw) 48 for Mg, 65 for Ti, 125 for Fe, 154 for Ga, 87 for V and 54 for Cr.

RESULTS

Texture Description

The abraded surfaces of the two trapiche rubies indicate that the crystals had been alluvially transported. They were rounded and fractured, such that little of their original euhedral habit was still recognisable.

Below we describe the features of the trapiche texture in the two Vietnamese samples from the core to the sector boundaries and, finally, the growth sectors.

Core: The trapiche texture in both samples was characterised by sector boundaries that intersected at a central point and the absence of a well-developed hexagonal core. In sample T1, this intersection was underlined by a small inclusion of Cr-poor corundum (Figure 7), which corresponds to the darker area labelled 'C' in Figures 5b and 5c.

Sector Boundaries: The sector boundaries in trapiche rubies develop from the core towards the rim of the crystals and follow <1$\bar{1}$0> directions, whereas they are parallel to

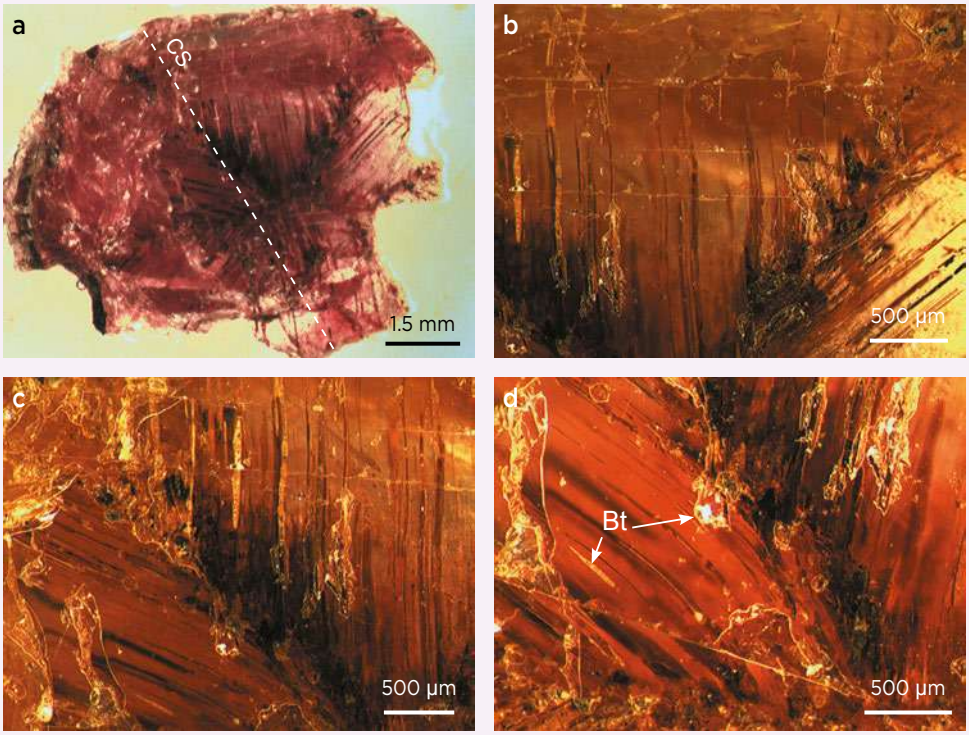

Figure 6: (**a**) Trapiche ruby sample T2 exhibits sector boundaries extending from a central point towards the rim of the crystal. The dashed line (labelled CS) designates one of the EPMA traverses. Closer views of the slice show: (**b**, **c**) tube-like inclusions extending from the sector boundaries into the growth sectors and (**d**) biotite (Bt) inclusions near the sector boundaries. Photomicrographs by G. Giuliani.

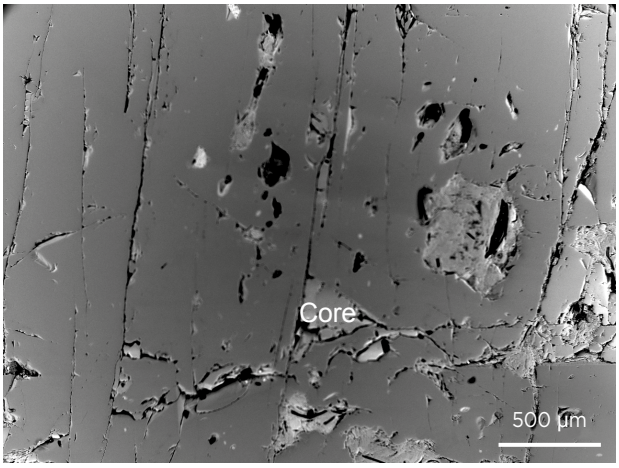

Figure 7: This BSE image of the core of trapiche ruby sample T1 shows an inclusion of Cr-poor corundum (appearing lighter grey) corresponding to the darker-coloured area seen in Figures 5b and 5c.

<100> directions (i.e. *a*-axes) in trapiche emeralds (Figure 3). Their brown colour is due to inclusions of iron oxides/hydroxides (Figures 8d, 8e, 9b and 9d) formed during a late weathering process that affected the trapiche rubies. SEM observations indicate that weathering was favoured by the high porosity of the sector boundaries, which is visible in the CT images (e.g. Figure 10). As calculated from the CT images, the porosity corresponds to a sample volume of 0.6% for T1 (total sample volume 1,720 mm^3) and 0.4% for T2 (total volume 267 mm^3).

Syngenetic solids were concentrated along the sector boundaries (see Table I); only a few of them were found in the adjacent growth sectors (Figures 11 and 12). There was no correlation between the position and size of inclusions in the rubies, as shown by Figure 12; large and small inclusions were mixed together. The volume occupied by all inclusions, as calculated from CT images, was 0.160 mm^3 for sample T1 and 0.246 mm^3 for T2 (i.e. about 0.1% and 0.9%).

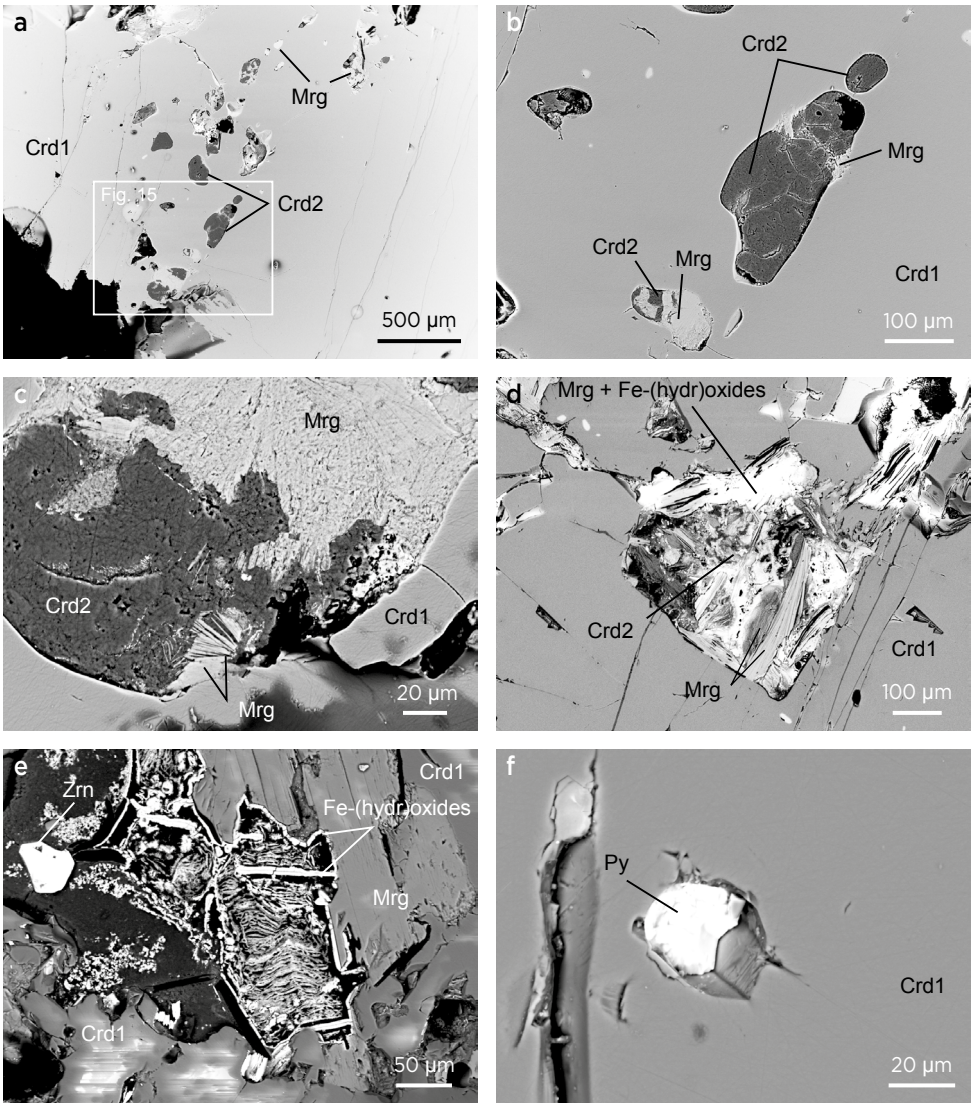

Figure 8: BSE images illustrate the nature of the various solids trapped in trapiche ruby sample T1. (**a**) Inclusions of corundum (Crd2) and margarite (Mrg) are present in the sector boundaries within the ruby (Crd1). The white rectangle corresponds to the location of Figure 15. (**b**) A closer view shows margarite partially replacing a corundum inclusion. (**c**) Margarite is present in the sector boundaries either as porous masses or as flakes developed on corundum inclusions. (**d**) Flakes of margarite are also associated with late Fe-(hydr)oxides in the sector boundaries. Remnants of corundum inclusions are also present. (**e**) Fe-(hydr)oxides are common in the sector boundaries, here associated with margarite and a zircon (Zrn) inclusion. (**f**) A pyrite (Py) inclusion is trapped within a growth sector in the trapiche ruby.

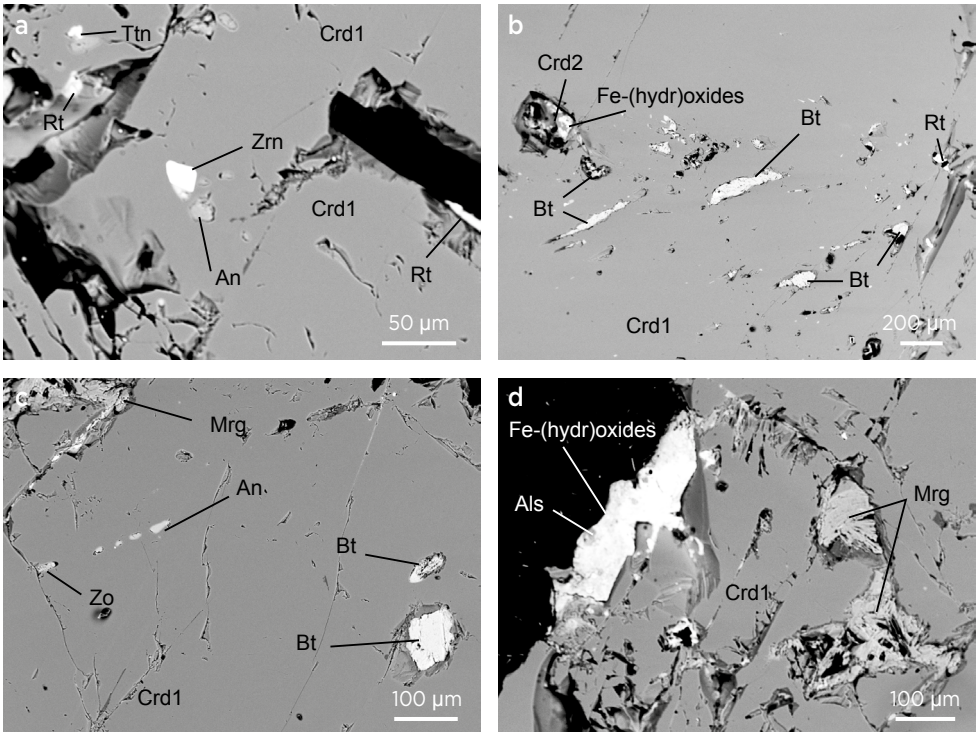

Figure 9: BSE images of sample T2 show a variety of solid inclusions in the sector boundaries of the trapiche ruby, including: (**a**) titanite (Ttn), zircon, anorthite (An) and rutile (Rt); (**b**) biotite (Bt) and corundum (Crd2); (**c**) anorthite, biotite, margarite and zoisite; and (**d**) flakes of margarite associated with Fe-(hydr)oxides and Al-silicates (Als).

The chemical compositions by EPMA of the various solids in samples T1 and T2 are reported in Table II. In sample T1, the most important syngenetic inclusions were anorthite (CaO = 20 wt.%), corundum, margarite, Al-silicates (Al_2SiO_5) and titanite; other minor phases are pyrite, calcite, zircon and rutile. Margarite was present in the sector boundaries either as porous masses (Figure 8c) or as flakes (Figure 8d) developed on corundum inclusions (Crd2—Figure 8b). In sample T2, the main inclusions were biotite and margarite, which were present along with anorthite, corundum, muscovite, rutile, titanite, zircon and zoisite. The biotite had an Fe/Mg ratio of about 1 with a composition between phlogopite and annite. The chemical composition of corundum inclusions (Crd2) is described below.

We found no supported-matrix material from the

Figure 10: This CT image shows the high porosity (here coloured blue) of trapiche ruby sample T1. The porosity corresponds to 0.6% of the sample's volume and is concentrated along the sector boundaries.

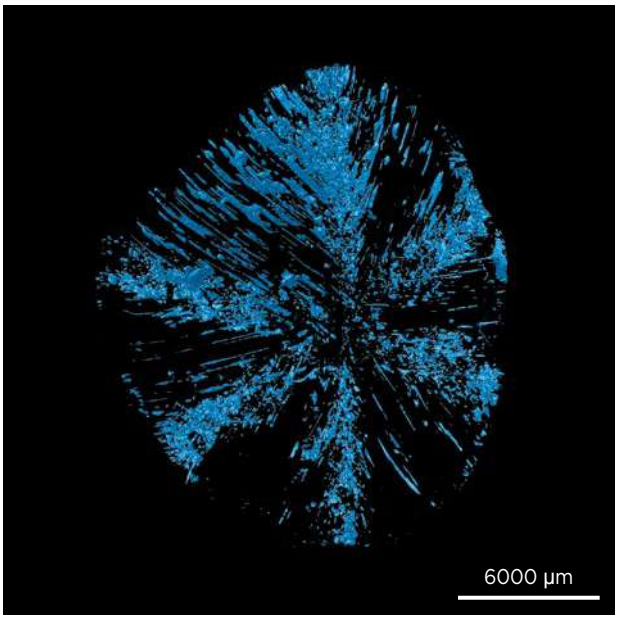

Table I: Solid inclusions observed in trapiche ruby samples T1 and T2.*

Mineral	Sample T1			Sample T2
	Sector boundary B1	Sector boundary B3	Sector boundary B5	
Anorthite	XX	XX	XX	XX
Biotite				XX
Calcite	X		X	
Corundum	XX	X	X	X
Margarite	XXX	XXX	XXX	XX
Muscovite				X
Oxides/ hydroxides of Fe (±Ti±Mn)	XXX	XXX	XXX	XXX
Pyrite	X			
Rutile	X	X		X
Al-silicates	X	X	X	X
Titanite	X	X	X	X
Zircon	X	X		X
Zoisite				X

* Symbols: XXX = main, XX = important and X = occasional phase. All are syngenetic except for the oxides/hydroxides, which are epigenetic (i.e. due to weathering).

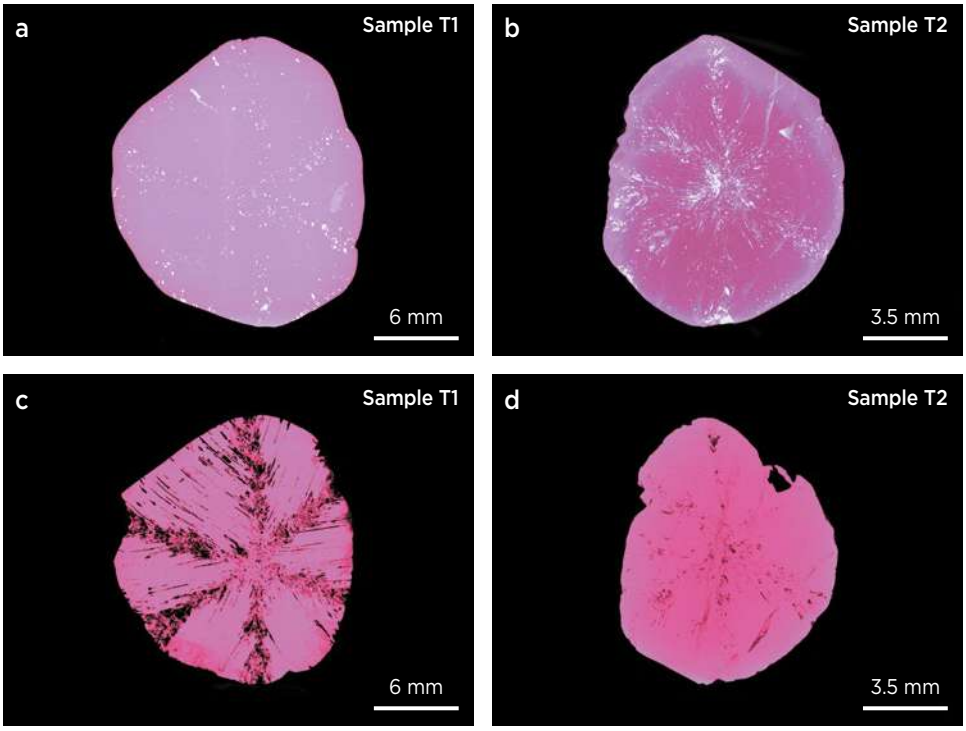

Figure 11: CT images show solid inclusions (white) and fluid inclusions (black) in trapiche ruby samples T1 and T2. (**a**) Solid inclusions in T1 are concentrated along the sector boundaries. (**b**) Tube-like inclusions in T2 are filled by solid phases. (**c**) Tube-like inclusions without solid phases developed in T1 perpendicular to the crystal's faces. (**d**) Fluid inclusions in sample T2 follow the sector boundaries.

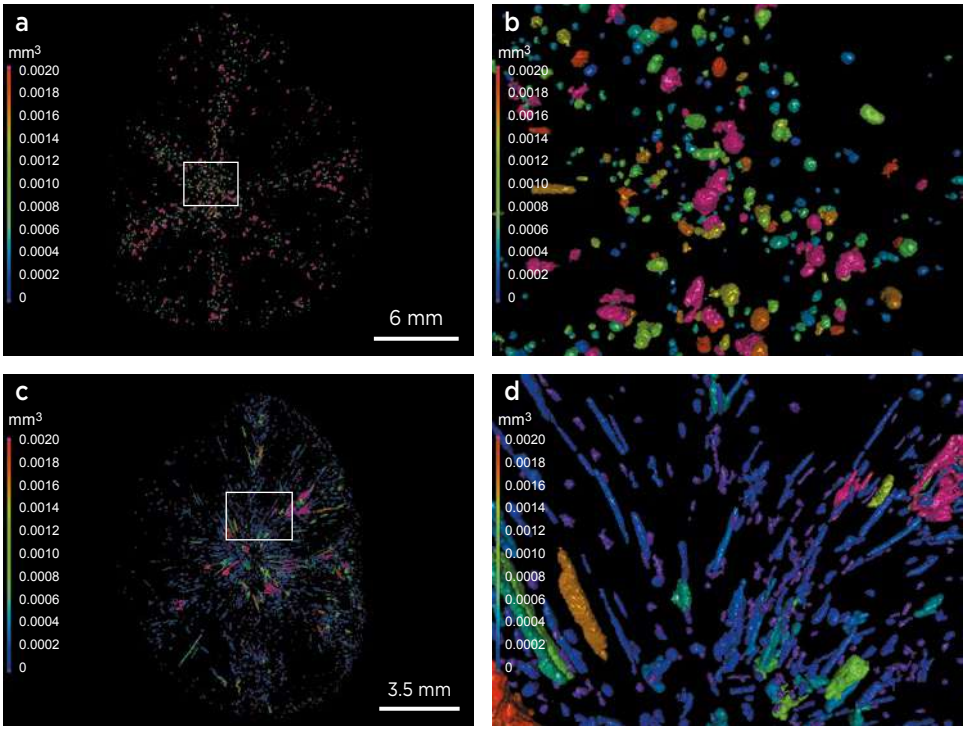

Figure 12: CT images show the spatial distribution of solid inclusions in trapiche ruby samples T1 (**a**, **b**) and T2 (**c**, **d**). The colour of each inclusion corresponds to its volume. Blue-coloured inclusions have the smallest volume and those in pink have the largest volume. The other colours represent intermediate volumes, as indicated by the coloured bar on the left side of each image.

marble host rocks incorporated along the sector boundaries of either sample. The absence of host-rock matrix from these Vietnamese rubies, as also noted previously for trapiche rubies from Mong Hsu (Schmetzer *et al.* 1996), is an important difference from the texture described for Colombian trapiche emeralds (Pignatelli *et al.* 2015).

Growth Sectors: The six growth sectors separated by the sector boundaries were sometimes fractured (e.g. sample T2; see Figure 6). The sectors could not be indexed due to the lack of a well-preserved crystal habit on the water-worn crystals, although they were most likely bounded originally by hexagonal dipyramidal faces.

Table II: Chemical composition by EPMA of solid inclusions in trapiche ruby samples T1 and T2.[a]

Oxides (wt.%)	Anorthite	Titanite	Margarite	Biotite	Muscovite	Zoisite	Corundum (Crd1)[b]	Corundum (Crd2)[b]
	T1-B1-37	T2-28	T1-B1-45	T2-13	T2-3	T2-42	T1-CS	T1-B1
Na_2O	0.90	nd	0.86	0.39	0.18	nd	na	na
MgO	nd	nd	0.38	12.15	0.45	nd	0.005	nd
Al_2O_3	36.61	4.08	52.52	23.71	36.98	33.89	99.64	99.95
SiO_2	42.23	31.81	30.30	33.51	48.25	36.92	na	na
K_2O	nd	nd	nd	10.48	10.18	nd	na	na
CaO	20.25	30.40	12.66	nd	nd	27.94	na	na
TiO_2	nd	33.96	0.03	1.61	0.01	nd	0.040	0.040
V_2O_3	nd	na	na	na	na	na	0.015	nd
Cr_2O_3	na	na	na	na	na	na	0.183	0.110
Ga_2O_3	na	na	na	nd	na	na	0.016	nd
MnO	nd	nd	nd	0.08	nd	nd	na	na
FeO	nd	nd	0.25	14.24	1.45	nd	0.160	0.160
Total	99.99	100.25	97.00	96.17	97.50	98.75	100.06	100.26

[a] Abbreviations: na = not analysed; nd = not detected.
[b] Crd1: Average values for growth sector corundum within the traverse T1-CS (22 points; see Figure 5a). Crd2: Average values for corundum inclusions within a sector boundary of T1 (five points; see Figure 15).

Elongated tube-like voids extended from the sector boundaries into the growth sectors (Figures 6b, 6c and 11d), perpendicular to the crystal faces. The tube-like voids were similar to those observed in trapiche emeralds from Colombia (Touray & Poirot 1968; Pignatelli *et al.* 2015), in trapiche rubies from Myanmar (Schmetzer *et al.* 1996; Sunagawa *et al.* 1999) and in trapiche tourmalines from Zambia (Schmetzer *et al.* 2011). CT images clearly showed that the tube-like voids in sample T2 were often filled by solid phases (Figures 11b, 12c and 12d), while those in T1 were more often fluid-filled (Figure 11c). However, closer analysis of the tomographic contrast (Figure 13) proved that the tube-like voids in sample T2 contained at least two phases: a solid and a less-dense phase (i.e. a liquid and/or a vapour). Viewed with the microscope, isolated primary fluid inclusions occurred along tube-like voids in the sector boundaries and also rarely formed cavities in the growth sectors. They were 15–50 µm wide, and sometimes showed a 'necking-down' phenomenon. At room temperature, the liquid phase occupied 30–90% of the cavity's volume and the remainder was composed of vapour. However, some of these inclusions consisted of a single phase (liquid), while others were multi-phase (liquid + vapour + solid).

Chemical Analysis of Trapiche Rubies

Three cross-sectional traverses of sample T1 and one of sample T2 were analysed by EPMA to evaluate chemical variations in the core, sector boundaries and growth sectors. Two traverses of sample T1 ran along sector

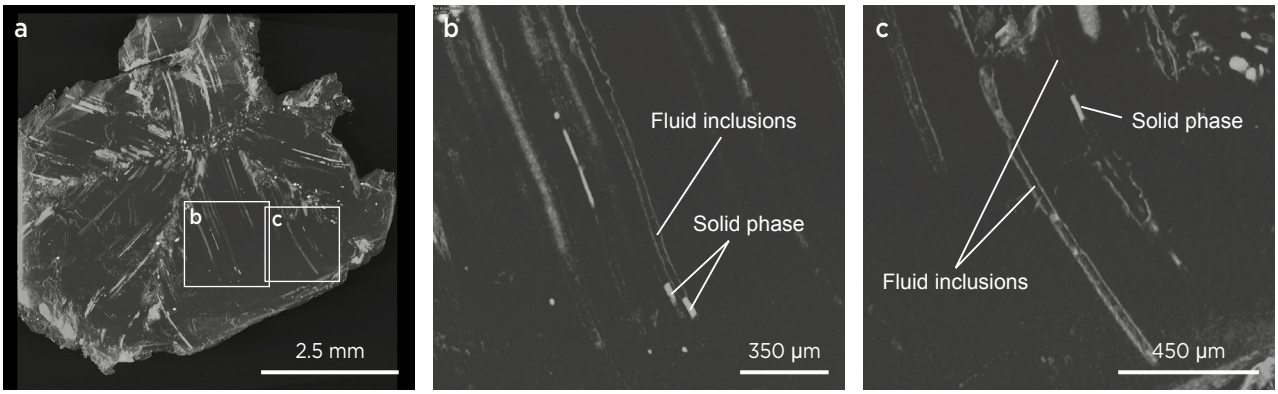

Figure 13: CT contrast images of trapiche ruby sample T2 show tube-like voids that locally contain solid phases (white) or a less-dense phase corresponding to fluid inclusions (dark grey).

boundaries from the rim to the centre (T1-B1 and T1-B3), and the third crossed the sample from rim to rim, passing through its centre (T1-CS; see Figure 5a and Tables III–V). For sample T2, one traverse was analysed between two opposite rims (CS; see Figure 6a and Table VI).

Overall, rubies T1 and T2 had some differences in chemical composition (see Tables V and VI). The Ti concentrations were lower in T2, with TiO_2 contents of 80–1,030 ppmw (vs. 40–1,470 ppmw in T1). The contents of Mg and Ga were more or less the same, with values of 20–70 ppmw for MgO and 70–240 ppmw for Ga_2O_3. Sample T1 had higher concentrations of Fe_2O_3 (1,243–1,698 ppmw) and Cr_2O_3 (1,100–3,340 ppmw). By comparison, sample T2 contained 88–1,500 ppmw Fe_2O_3 and 650–2,190 ppmw Cr_2O_3. Vanadium was much less abundant, and therefore was not the main chromophore; V_2O_3 comprised 80–210 ppmw in T1 and 60–150 ppmw in T2.

The distribution of the various chemical elements in the corundum (Crd1) along sector boundary T1-B1 is recorded in Table III and illustrated in Figure 14. The contents of Fe and V were constant, but those of Cr and Ti behaved differently. Cr_2O_3 decreased from the trapiche ruby rim (point 1—0.39 wt.%) towards the core (point 26—0.11 wt.%). This difference in Cr was not evident in

Table III: Chemical composition (wt.%) by EPMA of corundum in trapiche ruby sample T1, along sector boundary B1 shown in Figures 5a and 14, and as inclusions shown in Figure 15.*

Analysis Point	MgO	Al_2O_3	TiO_2	V_2O_3	Cr_2O_3	Fe_2O_3	Ga_2O_3	Total
Corundum (Crd1) in the Growth Sector and Near the Core								
T1-B1-1	0.007	100.00	0.009	0.011	0.388	0.137	0.018	100.57
T1-B1-2	0.005	98.02	0.009	0.012	0.366	0.139	0.014	99.57
T1-B1-3	0.008	99.41	0.029	0.012	0.326	0.130	0.017	99.93
T1-B1-4	0.002	98.67	0.011	0.016	0.325	0.146	0.019	99.19
T1-B1-5	0.005	99.02	0.015	0.012	0.333	0.139	0.014	99.54
T1-B1-6	0.003	99.78	0.009	0.011	0.312	0.164	0.018	100.30
T1-B1-7	0.006	99.86	0.040	0.017	0.268	0.153	0.017	100.36
T1-B1-8	0.007	98.93	0.048	0.018	0.270	0.100	0.016	99.39
T1-B1-9	0.005	99.65	0.050	0.015	0.268	0.153	0.017	100.16
T1-B1-10	0.002	98.07	0.034	0.014	0.258	0.147	0.021	98.55
T1-B1-11	0.002	98.07	0.034	0.014	0.258	0.147	0.021	98.55
T1-B1-12	0.004	99.20	0.015	0.011	0.222	0.149	0.020	99.62
T1-B1-13	0.010	99.22	0.057	0.019	0.232	0.147	0.020	99.70
T1-B1-14	0.005	99.42	0.054	0.017	0.214	0.148	0.015	99.87
T1-B1-15	0.006	99.00	0.027	0.016	0.210	0.147	0.019	99.42
T1-B1-16	0.006	99.67	0.034	0.014	0.214	0.152	0.028	100.12
T1-B1-17	0.007	99.84	0.050	0.017	0.184	0.157	0.016	100.27
T1-B1-18	0.005	99.08	0.063	0.017	0.199	0.155	0.016	99.54
T1-B1-19	0.004	99.76	0.020	0.016	0.168	0.155	0.020	100.14
T1-B1-20	0.009	99.53	0.024	0.015	0.163	0.160	0.017	99.92
T1-B1-21	0.002	99.60	0.023	0.014	0.141	0.150	0.017	99.95
T1-B1-22	0.004	99.49	0.062	0.017	0.155	0.164	0.015	99.91
T1-B1-23	0.006	99.85	0.050	0.018	0.120	0.155	0.017	100.21
T1-B1-24	0.004	99.95	0.055	0.016	0.124	0.161	0.017	100.33
T1-B1-25	0.005	99.57	0.069	0.018	0.122	0.160	0.016	99.96
T1-B1-26	0.008	99.85	0.020	0.018	0.109	0.184	0.011	100.20
Corundum Inclusions (Crd2) in the Sector Boundary								
1	0.002	99.50	0.020	nd*	0.100	0.200	nd	99.82
2	0.001	99.20	0.060	nd	0.090	0.100	nd	99.45
3	0.001	98.75	0.030	nd	0.150	0.150	nd	99.08
4	0.002	99.80	0.040	nd	0.110	0.160	nd	100.11
5	0.001	98.90	0.040	nd	0.010	0.170	nd	99.12

* Abbreviation: nd = not detected.

Table IV: Chemical composition (wt.%) by EPMA of corundum in sample T1 along sector boundary B3 shown in Figure 5a.

Analysis Point	MgO	Al_2O_3	TiO_2	V_2O_3	Cr_2O_3	Fe_2O_3	Ga_2O_3	Total
T1-B3-1	0.003	99.25	0.010	0.015	0.230	0.152	0.021	99.68
T1-B3-2	0.004	99.25	0.031	0.013	0.240	0.167	0.016	99.72
T1-B3-3	0.001	99.75	0.018	0.016	0.239	0.168	0.020	100.21
T1-B3-4	0.003	99.76	0.009	0.014	0.252	0.160	0.014	100.21
T1-B3-5	0.003	99.52	0.020	0.014	0.226	0.142	0.017	99.94
T1-B3-6	0.003	99.78	0.027	0.016	0.211	0.157	0.014	100.21
T1-B3-7	0.006	99.27	0.058	0.019	0.217	0.157	0.017	99.75
T1-B3-8	0.004	99.01	0.060	0.018	0.199	0.178	0.015	99.49
T1-B3-9	0.004	99.67	0.036	0.016	0.160	0.161	0.016	100.06
T1-B3-10	0.006	99.75	0.050	0.015	0.180	0.157	0.014	100.17
T1-B3-11	0.009	99.85	0.035	0.020	0.166	0.191	0.014	100.28
T1-B3-12	0.007	99.46	0.066	0.025	0.303	0.192	0.014	100.07
T1-B3-13	0.007	99.85	0.060	0.018	0.178	0.168	0.017	100.30
T1-B3-14	0.005	99.26	0.061	0.018	0.154	0.159	0.014	99.67
T1-B3-15	0.004	99.80	0.054	0.018	0.164	0.153	0.017	100.21
T1-B3-16	0.004	99.76	0.066	0.018	0.167	0.171	0.018	100.20

Table V: Chemical composition (wt.%) by EPMA of corundum in sample T1 along cross-section CS shown in Figure 5a.

Analysis Point	MgO	Al_2O_3	TiO_2	V_2O_3	Cr_2O_3	Fe_2O_3	Ga_2O_3	Total
T1-CS-1	0.007	99.82	0.009	0.009	0.334	0.128	0.017	100.33
T1-CS-2	0.003	99.40	0.013	0.016	0.262	0.145	0.019	99.86
T1-CS-3	0.004	99.40	0.037	0.016	0.244	0.158	0.018	99.88
T1-CS-4	0.004	99.68	0.086	0.016	0.207	0.147	0.018	100.16
T1-CS-5	0.004	99.69	0.042	0.015	0.193	0.157	0.016	100.11
T1-CS-6	0.003	99.61	0.021	0.014	0.114	0.141	0.014	99.92
T1-CS-7	0.003	99.51	0.037	0.014	0.149	0.149	0.008	99.87
T1-CS-8	0.007	99.62	0.058	0.018	0.143	0.158	0.021	100.02
T1-CS-9	0.005	99.31	0.147	0.021	0.159	0.169	0.024	99.84
T1-CS-10	0.003	99.53	0.051	0.019	0.150	0.170	0.012	99.93
T1-CS-11	0.004	99.83	0.004	0.012	0.110	0.152	0.012	100.12
T1-CS-12	0.007	99.55	0.072	0.016	0.139	0.162	0.015	99.96
T1-CS-13	0.005	99.49	0.065	0.019	0.136	0.159	0.015	99.89
T1-CS-14	0.005	99.76	0.035	0.017	0.143	0.154	0.016	100.13
T1-CS-15	0.007	99.84	0.038	0.017	0.163	0.161	0.011	100.24
T1-CS-16	0.007	99.87	0.016	0.013	0.111	0.143	0.018	100.18
T1-CS-17	0.007	99.05	0.021	0.013	0.176	0.145	0.016	99.43
T1-CS-18	0.006	99.85	0.020	0.014	0.209	0.151	0.021	100.27
T1-CS-19	0.003	99.97	0.013	0.016	0.205	0.134	0.018	100.36
T1-CS-20	0.006	99.66	0.015	0.014	0.210	0.153	0.018	100.08
T1-CS-21	0.001	99.97	0.009	0.017	0.206	0.131	0.013	100.35
T1-CS-22	0.004	99.74	0.009	0.008	0.253	0.124	0.012	100.15

Table VI: Chemical composition (wt.%) by EPMA of sample T2 along a traverse between opposite rims shown in Figure 6a.

Analysis Point	MgO	Al_2O_3	TiO_2	V_2O_3	Cr_2O_3	Fe_2O_3	Ga_2O_3	Total
T2-1	0.003	99.36	0.091	0.014	0.196	0.107	0.012	99.78
T2-2	0.007	99.63	0.054	0.015	0.190	0.109	0.014	100.01
T2-3	0.002	99.74	0.064	0.012	0.187	0.100	0.013	100.12
T2-4	0.004	99.74	0.076	0.012	0.184	0.143	0.009	100.17
T2-5	0.003	99.89	0.053	0.011	0.065	0.092	0.016	100.13
T2-6	0.007	99.92	0.036	0.010	0.070	0.090	0.009	100.14
T2-7	0.002	99.19	0.086	0.013	0.207	0.150	0.016	99.66
T2-8	0.002	99.23	0.052	0.012	0.155	0.099	0.013	99.56
T2-9	0.003	99.41	0.065	0.012	0.130	0.095	0.012	99.73
T2-10	0.003	99.65	0.058	0.011	0.111	0.092	0.020	99.95
T2-11	0.002	99.75	0.008	0.006	0.067	0.090	0.013	99.94
T2-12	0.005	99.33	0.060	0.012	0.144	0.104	0.017	99.67
T2-13	0.005	99.60	0.011	0.011	0.128	0.088	0.017	99.86
T2-14	0.005	99.47	0.038	0.009	0.147	0.098	0.015	99.78
T2-15	0.002	99.71	0.046	0.011	0.125	0.099	0.016	100.01
T2-16	0.005	99.98	0.059	0.010	0.160	0.097	0.014	100.32
T2-17	0.003	99.77	0.039	0.011	0.128	0.097	0.018	100.06
T2-18	0.005	99.05	0.103	0.014	0.120	0.104	0.015	99.41
T2-19	0.005	99.86	0.064	0.011	0.219	0.098	0.007	100.26

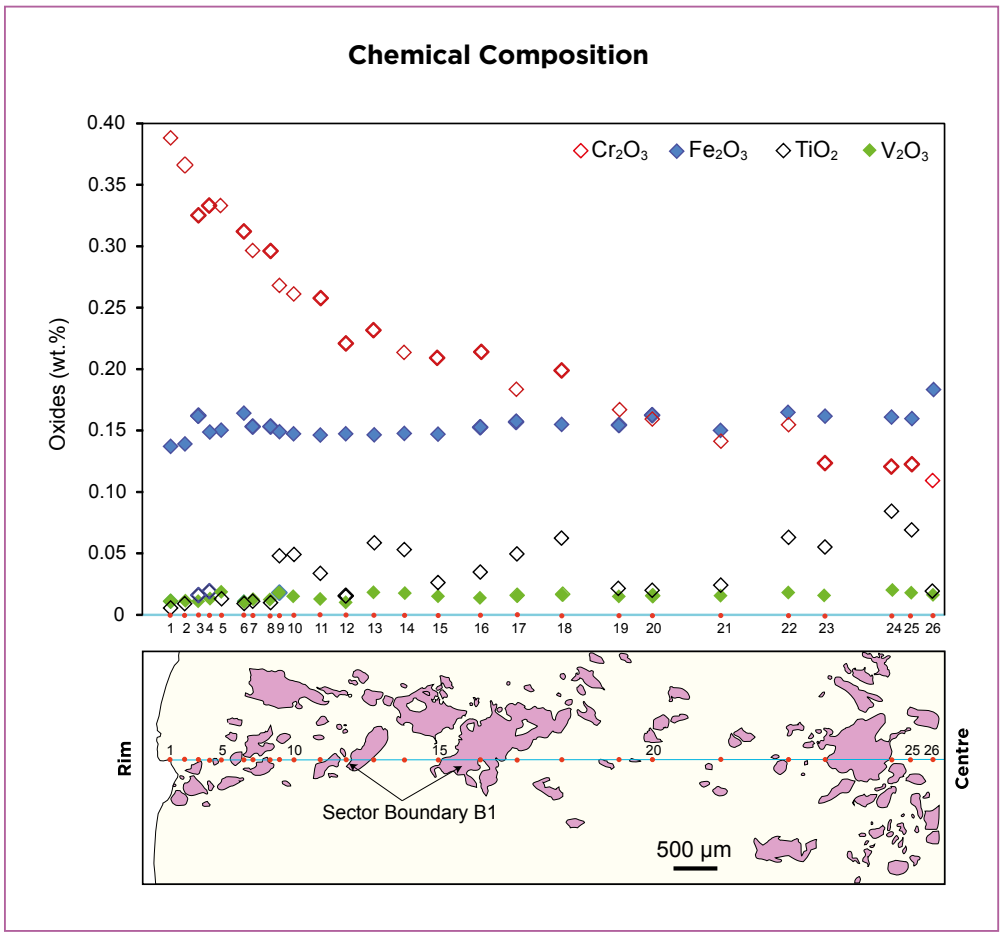

Figure 14: This graph shows variations in Cr_2O_3, Fe_2O_3, TiO_2 and V_2O_3 contents along sector boundary B1 in trapiche ruby sample T1 (see Figure 5a and Table III). The solid inclusions in this sector boundary are shown as pink in the corresponding map below the graph. The red dots in the map correspond to the EPMA point analyses of the corundum (Crd1). The Cr_2O_3 content decreases progressively from the rim towards the centre of the trapiche ruby, from 0.39 to 0.11 wt.%.

the colouration of the sample, but the regular decrease in Cr_2O_3 from the rim (point 1—0.39 wt.%) to point 11 (0.26 wt.%) indicates no sharp chemical discontinuity between the rim and the interior of the crystal. The greater Cr_2O_3 of the rim (points 1–5) corresponded to the outer 1.9 mm of the entire cross-section of the crystal (9.75 mm). The TiO_2 content increased irregularly from the rim to a maximum of 0.07 wt.% near the centre of the crystal. At the centre, the data showed the lowest Cr (and rather low Ti) but the highest Fe of the entire traverse.

The corundum inclusions (Crd2) analysed within the sector boundary (see Figure 15 and Table III) had a very different composition (average Cr_2O_3 = 0.11 wt.%; no detectable Ga_2O_3) compared to corundum Crd1 (average Cr_2O_3 = 0.18 wt.% and maximum = 0.39 wt.%; average Ga_2O_3 = 0.16 wt.%). The average Cr_2O_3 content of the corundum inclusions was similar to the lowest Cr content measured near the centre of sample T1 (see Table III, analysis point T1-B1-26).

The chemical concentrations were plotted in the correlation diagram of Cr_2O_3/Ga_2O_3 versus Fe_2O_3/TiO_2 proposed by Sutherland *et al.* (2003) and applied by Pham *et al.* (2004) to Vietnamese rubies from the Luc Yen and An Phu areas (Figure 16). Overall, the present data plot within the fields of (1) primary non-trapiche ruby-bearing marble deposits and (2) alluvial trapiche rubies from marble-hosted deposits at Luc Yen and An Phu of Pham *et al.* (2004). The chemical compositions of the alluvial trapiche rubies from various localities in Vietnam are presented in Appendix Table A-I.

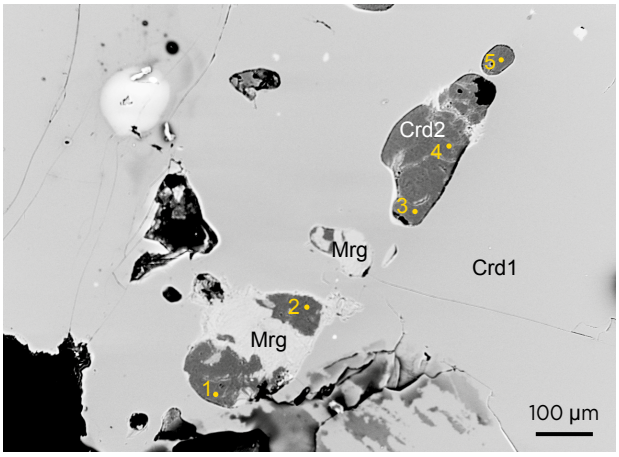

Figure 15: This BSE image (corresponding to the white rectangle in Figure 8a) shows the location of five EPMA analyses of the corundum inclusions (Crd2) in sector boundary B1 of the trapiche ruby (Crd1) sample T1.

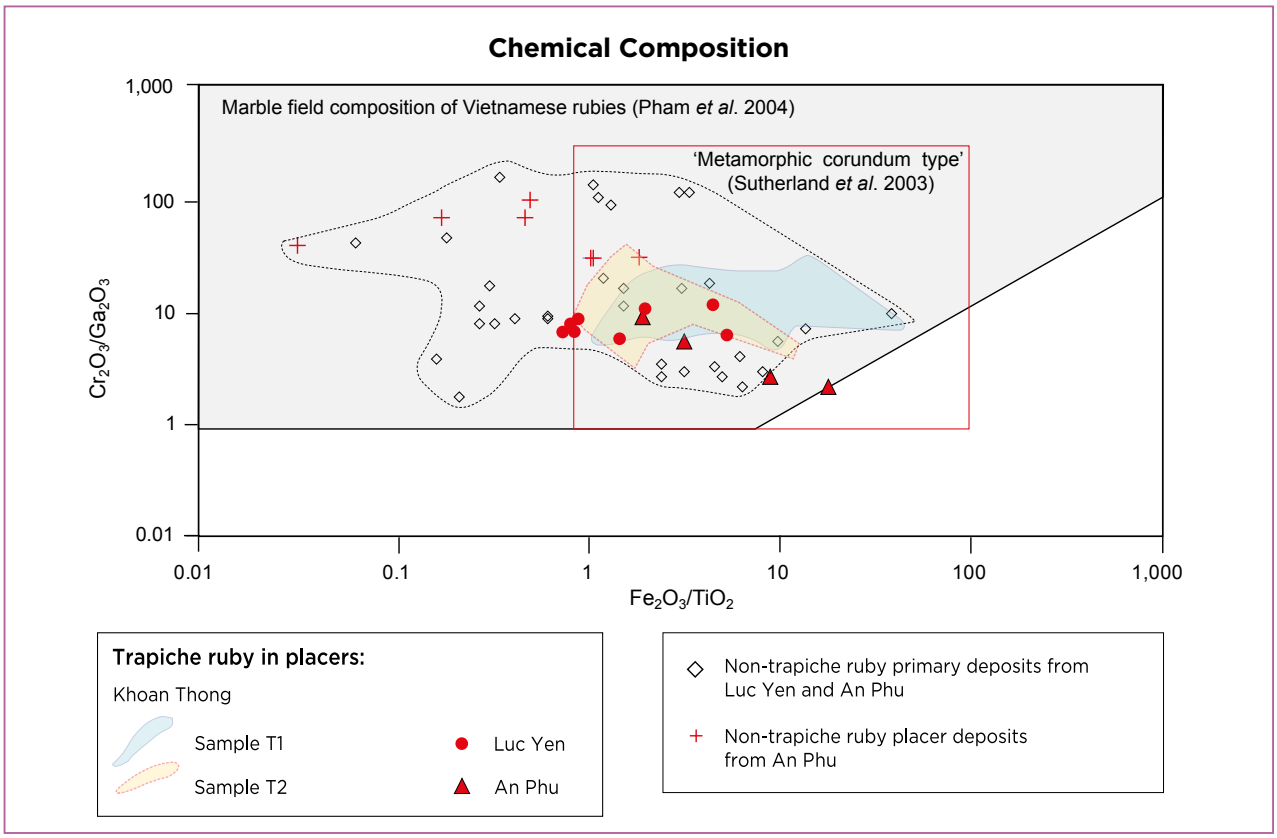

Figure 16: Chemical data for the two trapiche ruby samples (87 point analyses) from Khoan Thong plot within the marble composition field of Vietnamese rubies, as shown in this diagram of Cr_2O_3/Ga_2O_3 versus Fe_2O_3/TiO_2. Shown for comparison are data for trapiche and non-trapiche rubies from different primary and secondary deposits in Vietnam (Pham *et al.* 2004).

DISCUSSION

The solid inclusions observed in the two trapiche rubies from the Khoan Thong placer are dominated by the association anorthite-corundum-margarite. Calcite was found in small amounts and dolomite was absent. The association between coexisting anorthite and margarite with corundum has been documented for Asian ruby-bearing marble deposits (Garnier 2003; Garnier *et al.* 2008). These petrographic relations have shown that ruby and anorthite could form by destabilisation of margarite during prograde metamorphism such as described for the Jegdalek (Afghanistan) and An Phu (Vietnam) deposits (Garnier 2003). Inversely, margarite formed in the presence of water during retrograde metamorphism (Garnier 2003), following reaction 1 (Figure 17):

margarite ↔ anorthite + corundum + water (1)

$$CaAl_2(Si_2Al_2)O_{10}(OH)_2 \leftrightarrow CaAl_2Si_2O_8 + Al_2O_3 + H_2O$$

Margarite formation at the expense of corundum and anorthite was observed in both samples T1 and T2 (e.g. Figure 8). This retrograde transformation occurred at temperatures between 450 and 500°C (Garnier *et al.* 2008; see Figure 17).

The other chemical reactions involved in the formation of ruby in marbles (Garnier *et al.* 2008) are due to:

- the destabilisation of muscovite, as described at Jegdalek (Afghanistan) and at the Bai Da Lan deposits in the Luc Yen mining area (Garnier 2003):

muscovite ↔ K-feldspar + corundum + water (2)

$$KAl_2(Si_3Al)O_{10}(OH)_2 \leftrightarrow KAlSi_3O_8 + Al_2O_3 + H_2O$$

- the destabilisation of sapphirine, as evidenced at the deposit in Hunza (Pakistan):

sapphirine + 4 water ↔ 2 spinel + 6 corundum + Mg-chlorite (3)

$$Mg_7Al_{18}S_{i3}O_{40} + 4H_2O \leftrightarrow 2MgAl_2O_4 + 6Al_2O_3 + Mg_5Al(Si_3Al)O_{10}(OH)_8$$

- the destabilisation of paragonite, as evidenced at the Hunza and Nangimali (Pakistan) deposits:

paragonite ↔ albite + corundum + water (4)

$$NaAl_2(Si_3Al)O_{10}(OH)_2 \leftrightarrow NaAlSi_3O_8 + Al_2O_3 + H_2O$$

- the destabilisation of spinel in contact with calcite during retrograde metamorphism (Figure 17), which is the most common reaction, as evidenced at Jegdalek, Hunza and Luc Yen (Garnier *et al.* 2008):

spinel + calcite + CO_2 ↔ corundum + dolomite (5)

$$MgAl_2O_4 + CaCO_3 + CO_2 \leftrightarrow Al_2O_3 + CaMg(CO_3)_2$$

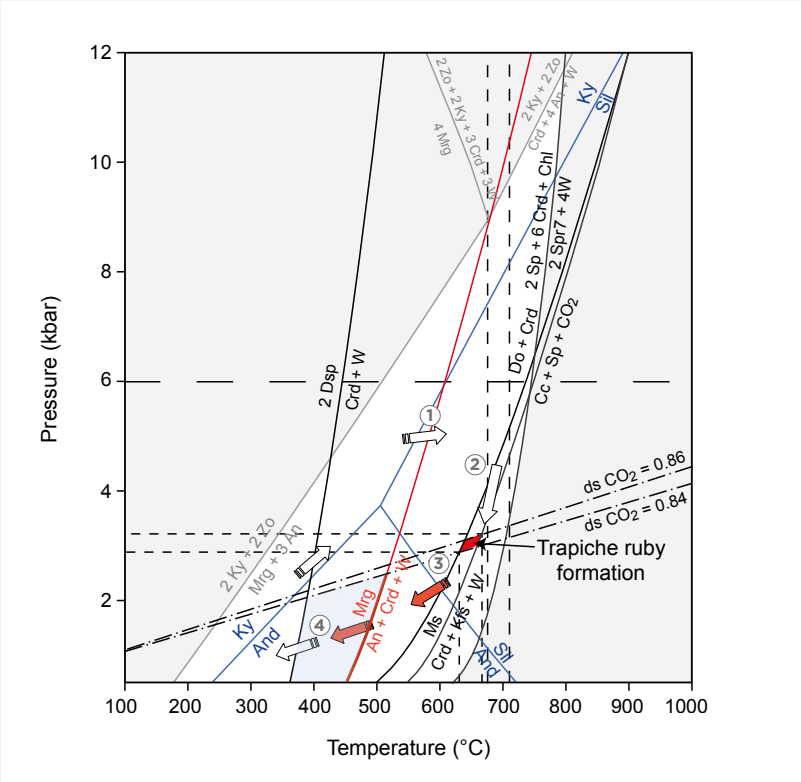

Figure 17: This pressure-temperature diagram shows the conditions of stability for mineral associations in ruby-bearing marbles from Luc Yen (modified from Garnier *et al.* 2008). White arrows 1 and 2 represent different possibilities for forming corundum during prograde metamorphism. The red arrows represent the formation of corundum during retrograde metamorphism (3) and then the transformation of corundum to margarite (4). Abbreviations: An = anorthite, And = andalusite, Cc = calcite, Clin = clinochlore, Crd = corundum, Do = dolomite, Dsp = diaspore, Ksp = K-feldspar, Ky = kyanite, Mrg = margarite, Mu = muscovite, Sil = sillimanite, Spr = sapphirine, Sp = spinel, W = water and Zo = zoisite.

The rubies that form from reaction 5 commonly have calcite and dolomite inclusions trapped either in growth sectors (Peretti *et al.* 1995; Giuliani *et al.* 2018) or in tube-like voids in trapiche rubies (Schmetzer *et al.* 1996, 1999; Giuliani *et al.* 2018). The very low amount of carbonates in trapiche rubies from Khoan Thong cannot exclude their formation in marble. Although the anorthite-corundum-margarite metamorphic assemblage is uncommon for the marble-type deposits, it was already described for the An Phu ruby-bearing marble deposit located south of Khoan Thong (Garnier 2003).

The mineral inclusion assemblage in the Khoan Thong trapiche rubies (Table VII) is completed by micas (biotite and muscovite, in addition to margarite mentioned above), Al-silicates (Al_2SiO_5), anorthite, calcite, pyrite, rutile, titanite, zoisite and zircon, as well as secondary oxide/hydroxides of Fe (±Ti±Mn).

The chemical composition of the trapiche rubies from Khoan Thong plots within the field of Vietnamese marble-hosted rubies (Figure 16). When the data are plotted in a diagram of Fe_2O_3/TiO_2 versus Cr_2O_3 (Figure 18), the Khoan Thong rubies show a similar Fe_2O_3/TiO_2 ratio but somewhat higher Cr_2O_3 contents compared to analyses of trapiche rubies from the An Phu, Luc Yen and Yen Bai mining areas (Pham *et al.* 2004). The diagram also shows that trapiche rubies from northern Vietnam can be distinguished from those of Quy Chau in central Vietnam (Pham *et al.* 2004) and Mong Hsu in Myanmar (Garnier *et al.* 2002a, b). This is due to the higher TiO_2 (up to 0.38 wt.%) and lower Fe_2O_3 (less than 0.01 wt.%) contents of Quy Chau and Mong Hsu rubies.

Table VII: Solid inclusions identified in Khoan Thong samples T1 and T2, compared to those recorded in trapiche rubies from Mong Hsu.

Solid inclusions	Mong Hsu (Myanmar)			Khoan Thong (Vietnam)
	Schmetzer *et al.* (1996, 1999)	Sunagawa *et al.* (1999)	Garnier *et al.* (2002a, b)	This work
Calcite	X	X	X	X
Dolomite	X	X	X	
Silicates (K-Al-Fe±Ti)	X	X	X	X
Corundum		X	X	X
Muscovite				X
Biotite				X
Chlorite			X	
Andularia			X	
Rutile			X	X
Titanite			X	X
Graphite			X	
Baryte			X	
Pyrite			X	X
Mica			X	
Amphibole			X	
Zircon			X	X
Al-hydroxide			X	
Oxides/ hydroxides of Fe (±Ti±Mn)			X	X
Siderite			X	
Bastnaesite			X	
Anorthite				X
Margarite				X
Zoisite				X

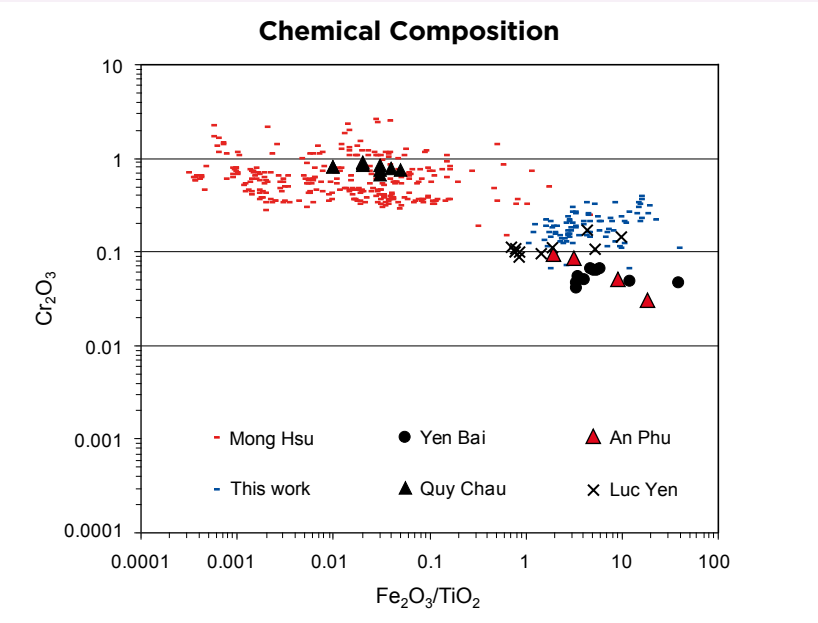

Figure 18: A plot of Cr_2O_3 versus Fe_2O_3/TiO_2 for the trapiche rubies from Khoan Thong analysed in this study is compared to data for trapiche rubies from Mong Hsu (Myanmar; Garnier *et al.* 2002b) and various Vietnamese deposits (Pham *et al.* 2004). Stones from Quy Chau (central Vietnam) and Mong Hsu have overlapping compositions, while those from northern Vietnam contain less Cr_2O_3 and have a greater ratio of Fe_2O_3/TiO_2.

According to the genetic model proposed for marble-hosted ruby deposits in Central and South East Asia by Garnier *et al.* (2008), the Vietnamese rubies formed during Tertiary regional metamorphism and are spatially related to major tectonic structures formed during the Himalayan orogenesis. The sediments of the Paleo-Tethys basin were metamorphosed in the amphibolite facies, transforming carbonates into marbles. The Al, Cr and V necessary for the formation of ruby were mobilised from micas, clay minerals and/or organic matter present in the sedimentary photoliths. Rubies formed during the beginning of the retrograde metamorphic path at 620–670°C and 2.6–3.3 kbar (Garnier 2003). The trapiche rubies formed from the same parental fluids as non-trapiche rubies in the same metamorphic zones within the Luc Yen and An Phu mining areas (Giuliani *et al.* 2015a, 2018). Moreover, the transformation of ruby and anorthite to margarite occurred at lower temperature and pressure conditions (450–500°C and <2 kbar) during retrograde metamorphism.

It is worth noting that the corundum inclusions in the sector boundaries have a similar composition as the small inclusion at the centre of sample T1 (Table III), suggesting that they formed at the same time and under the same conditions. This also means that the trapiche texture formed very quickly, such that the core did not have enough time to develop. According to the formation model proposed by Sunagawa *et al.* (1999), the core seems to be 'frozen' just after the nucleation stage (step 1 in Figure 19). Its development is hindered by the rapid formation of the sector boundaries which enveloped it (step 2). The growth sectors developed at a later stage (step 3), filling the interstices left between the sector boundaries. The rapid formation of the trapiche texture is proven by the elevated number of trapped inclusions and the formation of tube-like voids. When an inclusion is trapped, a channel can develop in the growth direction behind the inclusion, or in front of it if the inclusion moves along the growth direction. This formation mechanism was proposed for similar voids in trapiche tourmalines (Schmetzer *et al.* 2011). However, the fact that the tube-like voids are perpendicular to the faces of the ruby crystals suggests another possible mechanism of formation. They also could form by dissolution along bundles of dislocations after changes in driving-force conditions that occurred during the crystal growth (Scandale & Zarka 1982; Authier & Zarka 1994).

The three growth steps are governed by changes in driving-force conditions (Sunagawa *et al.* 1999). First, a small core can form under low driving-force conditions through layer-by-layer growth (step 1). After driving-force conditions increase, adhesive-type growth takes place, forming the sector boundaries, which constitute the 'skeleton' of the trapiche ruby (step 2). Finally, a decrease in the driving force lets the growth sectors and corresponding crystal faces develop through ordinary layer-by-layer growth (step 3). The morphological stability of the interface is dependent on the driving-force conditions (Sunagawa 2005). At the beginning, a

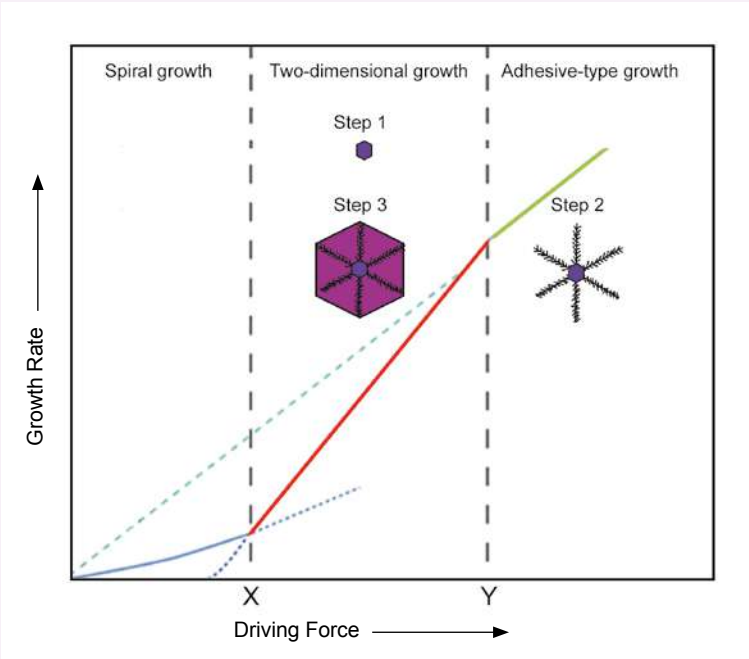

Figure 19: A diagram of growth rate versus driving force of crystallisation (modified from Sunagawa *et al.* 1999) shows the three development steps for trapiche texture in rubies from Khoan Thong. The positions marked by X and Y indicate changes in the predominant growth mechanism according to the driving force of crystallisation. The coloured lines represent growth rate versus driving force relations for spiral, two-dimensional and adhesive-type growth mechanisms. The dashed lines indicate where a particular growth mechanism is not stable.

core with smooth, flat interfaces forms, but when the driving force increases, the interface morphology loses its stability, resulting in one that is rough and dendritic. A further change in driving-force conditions will yield a euhedral ruby bounded by flat faces, with the dendritic 'skeleton' visible inside (Sunagawa 2005).

The changes in the driving-force conditions reflect variations in the growth medium (i.e. fluid composition, temperature and/or pressure). The fluid composition does not change during the rapid development of the trapiche texture, as witnessed by the fact that the corundum in the centre of the trapiche ruby has almost the same chemistry as the corundum inclusions (Crd2) in the sector boundaries. A variation of temperature was hypothesised by Garnier *et al.* (2002a) to explain the formation of Mong Hsu trapiche rubies. They suggested that the layer-by-layer growth became unstable when supercooling occurred and adhesive-type growth took over to form the sector boundaries. The chemical elements not included in the crystal structure of corundum (e.g. Ca and Mg) were pushed towards the sector boundaries and contributed to the formation of solid inclusions there. However, a rapid cooling is in disagreement with the rather stable thermal conditions of the regional metamorphism in Central and South East Asia (Giuliani *et al.* 2018).

A more plausible hypothesis involves variations in fluid pressure. The devolatilisation reactions of carbonate rocks during metamorphism produced a fluid overpressure until hydraulic fracturing occurred and, therefore, provoked an increase in the driving force. At this stage, the core and sector boundaries would have formed quickly and almost at the same time. The opening of fractures and cavities in the marbles led to a decrease of fluid pressure and, therefore, of the driving force (Giuliani *et al.* 2018). This allowed for the formation of the growth sectors that completed the trapiche texture.

CONCLUSIONS

The main conclusions of this study of two trapiche rubies from Khoan Thong can be summarised as follows:

(1) The expected hexagonal core is not well developed, and elongated tube-like voids extend from the sector boundaries into the growth sectors. The voids are filled by solid and fluid inclusions. The sector boundaries contain different syngenetic solid inclusions, in particular margarite that formed at the expense of ruby and anorthite during the retrograde metamorphic path.

Figure 20: This ruby from Tai Dinh near Minh Tien in northern Vietnam exhibits well-developed trapiche texture. Photo by Shang-i (Edward) Liu.

(2) Their chemical composition plots within the field of Vietnamese rubies hosted in marbles. Their Fe_2O_3/TiO_2 ratios (>1) are higher than those of trapiche rubies from Quy Chau (central Vietnam) and Mong Hsu (Myanmar), while their Cr_2O_3 contents are lower (<0.39 wt.%).

(3) The main mineral assemblage of inclusions in equilibrium—anorthite and ruby—has been described for several non-trapiche rubies hosted in marbles from Central and South East Asia, such as at An Phu, Vietnam. The very low amount of calcite and the absence of dolomite in the Khoan Thong trapiche rubies does not mean that these rubies could not have formed from the metamorphism of marble. It signifies that ruby did not form by the main metamorphic reaction involving the formation of corundum and dolomite through the destabilisation of spinel and calcite.

(4) A change of fluid pressure during formation was likely caused by local decompression and fracturing in the marbles. Such pressure variations enhance changes in driving-force conditions, leading to the formation of trapiche texture (e.g. Figure 20). The core forms first, followed by the sector boundaries and then the growth sectors, under high and low driving-force conditions, respectively.

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APPENDIX

Table A-1: Chemical composition (wt.%) by EPMA of alluvial trapiche rubies from the An Phu, Luc Yen, Yen Bai and Quy Chau mining areas in Vietnam (Pham *et al.* 2004; G. Giuliani unpublished data).

Analysis	MgO	Al_2O_3	TiO_2	V_2O_3	Cr_2O_3	Fe_2O_3	Ga_2O_3	Total
An Phu (Northern Vietnam)								
AP1	nd	98.73	0.080	0.005	0.080	0.255	0.014	99.16
AP2	nd	98.60	0.127	0.006	0.092	0.246	0.009	99.08
AP3	nd	98.75	0.015	0.006	0.029	0.279	0.013	99.09
AP4	nd	99.19	0.023	0.006	0.048	0.297	0.018	99.58
Luc Yen (Northern Vietnam)								
LY1	0.001	99.36	0.196	0.004	0.087	0.173	0.010	99.83
LY2	0.001	99.70	0.216	0.007	0.103	0.174	0.015	100.22
LY3	0.001	99.67	0.228	0.005	0.098	0.178	0.014	100.19
LY4	0.001	99.85	0.275	0.006	0.107	0.200	0.016	100.45
LY5	nd	99.81	0.123	0.004	0.095	0.179	0.015	100.23
LY6	nd	100.06	0.089	0.008	0.107	0.172	0.010	100.45
LY7	0.001	99.73	0.208	0.003	0.096	0.178	0.016	100.23
LY8	nd	99.77	0.031	0.006	0.103	0.166	0.015	100.09
LY9	nd	99.72	0.016	0.006	0.142	0.162	0.013	100.06
LY10	0.001	99.46	0.038	0.015	0.166	0.164	0.015	99.86
Yen Bai (Northern Vietnam)								
YB1	nd	100.88	0.086	0.005	0.044	0.288	0.007	101.31
YB2	0.002	100.04	0.073	0.005	0.047	0.288	0.008	100.46
YB3	nd	100.21	0.093	0.005	0.047	0.319	0.007	100.68
YB4	nd	100.58	0.066	0.003	0.051	0.267	0.004	100.97
YB5	nd	100.38	0.020	0.002	0.049	0.239	0.008	100.70
YB6	0.002	99.89	0.067	0.004	0.054	0.233	0.007	100.26
YB7	nd	98.55	0.051	0.002	0.066	0.308	0.010	98.99
YB8	nd	98.81	0.060	0.003	0.066	0.283	0.010	99.23
YB9	nd	99.94	0.048	0.004	0.063	0.263	0.009	100.33
YB10	nd	98.86	0.050	0.001	0.064	0.259	0.008	99.24
Quy Chau (Central Vietnam)								
QC1	0.001	98.65	0.380	0.029	0.897	0.008	0.011	99.99
QC2	0.011	98.23	0.340	0.028	0.838	0.006	0.012	99.47
QC3	0.012	98.99	0.340	0.032	0.915	0.004	0.011	100.30
QC4	0.007	98.51	0.290	0.029	0.749	0.010	0.005	99.61
QC5	0.003	99.03	0.180	0.031	0.768	0.007	0.013	100.03
QC6	0.004	99.37	0.120	0.037	0.764	0.005	0.012	100.31
QC7	0.009	98.30	0.300	0.047	0.869	0.007	0.010	99.54
QC8	0.009	99.16	0.250	0.040	0.832	0.007	0.009	100.31
QC9	0.011	98.76	0.320	0.045	0.818	0.005	0.010	99.98
QC10	0.006	99.12	0.260	0.048	0.670	0.009	0.009	100.12

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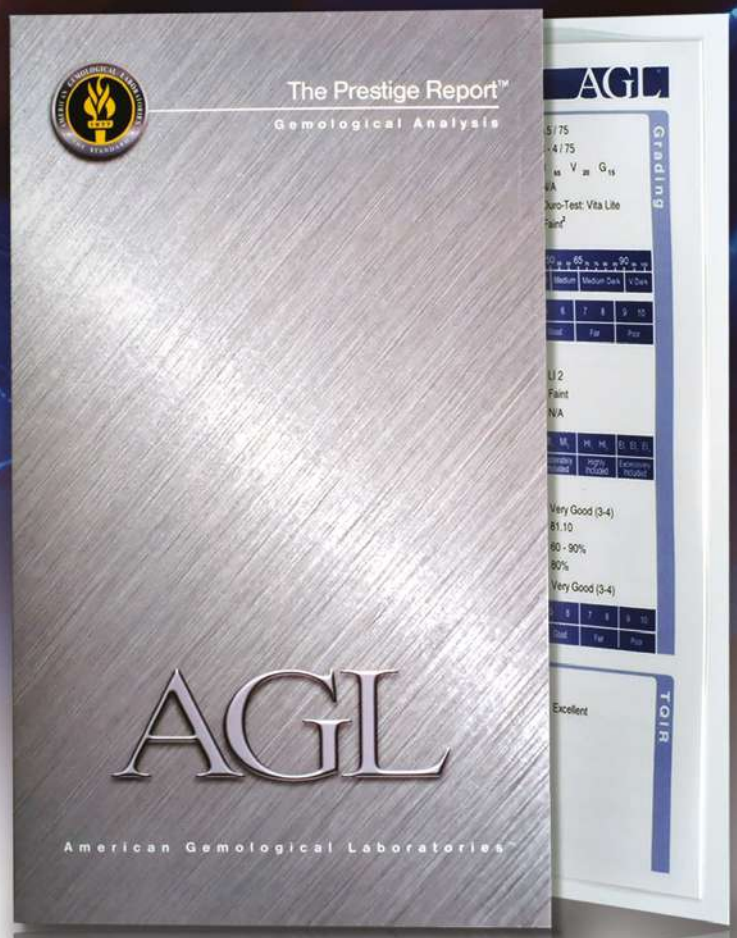

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Figure 1: These synthetic diamonds are typical of near-colourless gem-quality material grown in China. The three on the left are HPHT grown and weigh 0.57–1.0 ct, while the CVD synthetic diamond on the right is 2.0 ct. Photo by Chao Liu.

Current Status of Chinese Synthetic Diamonds

Taijin Lu, Jie Ke, Yan Lan, Zhonghua Song, Jian Zhang, Shi Tang, Jun Su, Huiru Dai and Xuxu Wu

ABSTRACT: China is the world's largest producer of industrial and gem-quality synthetic diamonds, particularly HPHT-grown products. In 2018, production of HPHT synthetic diamonds rose to 18 billion carats of industrial rough and more than 5 million carats of gem-quality rough material. This article summarises the production technology, product quality and output from various companies producing gem-quality HPHT- and CVD-grown synthetic diamonds in China. In recent years, 'hybrid diamonds' (comprised of natural diamond with a CVD overgrowth) have raised identification concerns, and we review differences in the fluorescence, structure and infrared spectrum of the CVD and natural layers. In addition, we briefly discuss diamond-detection devices developed and used in NGTC's laboratories, such as the GV5000. Finally, we compare the gemmological properties of colourless to near-colourless natural and synthetic diamonds.

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The first synthetic diamond in China was grown in the 1960s (Qi 1985). Since then, through the support of the Chinese government and joint efforts with the industry, the production of synthetic diamonds in China has seen unprecedented development, and the growth technology has also greatly improved. In the 1990s, cubic presses independently developed in China were successfully promoted and used on a large scale, and subsequently Chinese industrial high-pressure, high-temperature (HPHT) synthetic diamonds entered the world market (Guo *et al.* 2008). In 2014, Zhengzhou Sino-Crystal Diamond Co. Ltd successfully grew colourless to near-colourless melee-size HPHT synthetic diamonds of gem quality (Lan *et al.* 2015). In 2016, Jinan ZhongWu New Materials Co. Ltd grew high-quality, large, colourless HPHT synthetic diamonds, which raised concerns in the trade and were researched by both the National Gemstone Testing Center (NGTC; Song *et al.* 2016c) and the Gemological Institute of America (Wang & Moses 2016).

Compared to HPHT synthetic diamond, the development of chemical vapour deposition (CVD) synthetic diamond growth technology in China has been relatively slow and small scale, without large factories until 2012. In recent years, several companies focused on CVD synthetic diamond have appeared, and their products and growth technology have developed rapidly. These include Ningbo CrysDiam Industrial Technology Co. Ltd and Shanghai Zhenshi Technology Co. Ltd, both of which can produce various colours of gem-quality CVD synthetic diamonds on a large scale.

In the past several years, Chinese synthetic diamonds have become a hot topic for research both in China and abroad (He *et al*. 2019; Kitawaki *et al*. 2019a, b). This article summarises the growth technology, product quality and output from various companies producing gem-quality HPHT- and CVD-grown synthetic diamonds in China. We also report recent research into 'hybrid diamonds' consisting of a natural diamond substrate with a CVD overgrowth, and then review the properties and identification characteristics of colourless to near-colourless natural and synthetic diamonds.

HPHT-GROWN SYNTHETIC DIAMONDS

China is the world's largest producer of industrial synthetic diamonds grown by HPHT techniques. The volume in 2015 was more than 12 billion carats, accounting for 98% of the global supply of industrial diamonds. Chinese production of industrial HPHT synthetic diamond rose to 3,600 tonnes (18 billion carats) in 2018, according to the authors' research.

Since the 1990s, China has independently developed technology for the growth of gem-quality HPHT synthetic diamond, particularly cubic presses for the mass production of colourless type IIa material. Since the beginning of 2015, NGTC's laboratories in Shenzhen and Beijing have identified melee-size colourless HPHT synthetic diamonds submitted by various clients. Therefore, we know that by then such products had already entered the Chinese jewellery market and were being sold as natural diamonds (Lan *et al*. 2015). Currently, Chinese production of melee-size colourless to near-colourless HPHT synthetic diamonds represents about 90% of the global output. According to the authors' research, output of gem-quality HPHT synthetic diamonds in 2018 consisted of more than 5 million carats (Mct) of rough material. Most were faceted in India and distributed to the gem market worldwide (e.g. Figure 1).

Currently, nearly all Chinese producers exclusively use hinge-type cubic-anvil presses (e.g. Figure 2a). This equipment can generate high pressure in six directions. The growth block for producing colourless synthetic diamond consists of pyrophyllite with metallic solvents and catalyst nitrogen-getter materials (Figure 2b).

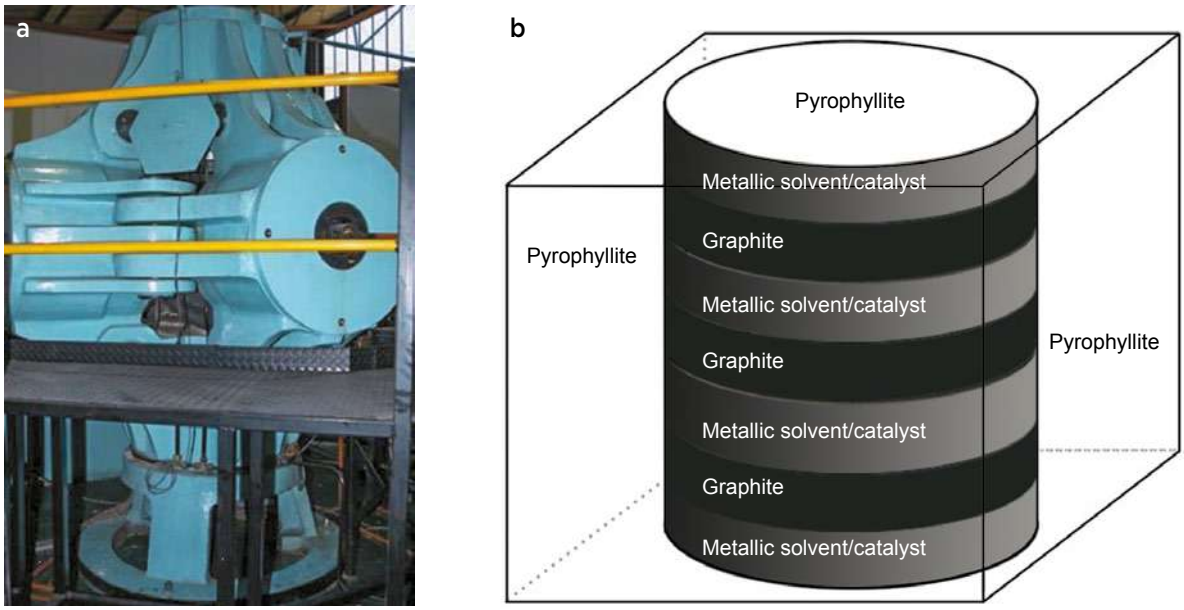

Figure 2: (**a**) A hinge-type cubic-anvil press such as this one is used by most Chinese producers of HPHT synthetic diamond. Photo by T. Lu. (**b**) The structure of the growth block for producing small HPHT synthetic diamonds consists of pyrophyllite with multiple layers of metallic solvent/catalyst and graphite.

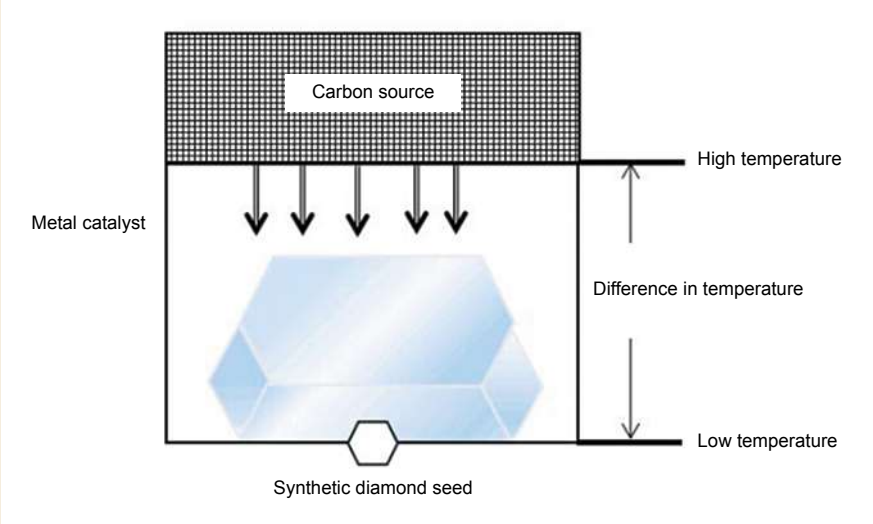

Figure 3: The temperature-gradient technique for growing larger HPHT synthetics involves a high-purity carbon source in the zone of higher temperature. Synthetic diamond crystallises on a seed substrate at the low-temperature end of the gradient.

Depending on the material to be manufactured, the interior structure and combination of these components differ. For example, a mixed powder of graphite and metallic solvent is employed for the growth of abrasive-grade synthetic diamonds. However, the growth of melee-size gem-quality synthetics involves the use of 5–9 layers of graphite and metallic solvent.

Production of larger gem-quality HPHT synthetic diamonds requires the use of a temperature-gradient technique (Figure 3), which can yield type IIa, Ib and IIb products (Eaton-Magaña *et al.* 2017). For example, to grow crystals with a morphology combining {100} and {111} faces, the temperature ranges from about 1,300 to 1,600°C, with a gradient usually around 30°C and a pressure of about 5.4 GPa (Li *et al.* 2007). Carbon from a high-purity (>99.9%) graphite source located at the end of the high-temperature zone diffuses onto seed crystals of synthetic diamond, resulting in the crystallisation of synthetic diamond on the seeds. Depending on the size to be grown, the number of seeds varies from several to several tens.

The gem-quality HPHT synthetic diamonds being produced in China vary from colourless to yellow, blue, pink, orange and brown (e.g. Figure 4). Pink is created through irradiation and annealing of nitrogen-containing material, but other colours can be produced as-grown. According to the authors' research, some companies, such as Zhongnan Diamond, have successfully developed the technology to grow rough material weighing more than 20 ct in the colourless to near-colourless (about D–H colour) range. More than five companies can mass produce colourless to near-colourless crystals weighing <1 ct, and the large-scale production of yellow crystals of up to 3–4 ct is possible.

Over the past 20 years, China has hosted nearly 100 production enterprises for HPHT and CVD synthetic diamonds. The major HPHT synthetic diamond manufacturers are located in Henan and Shandong provinces (Table I). The largest is Zhongnan Diamond, followed by Henan Huanghe Whirlwind, Zhengzhou Sino-Crystal Diamond (Figure 5), and others. Each company has around 1,000–4,000 cubic presses (e.g. Figure 6).

Figure 4: These crystals (0.40–0.80 ct) produced by Jinan ZhongWu New Materials are typical of Chinese HPHT synthetic diamonds that are (**a**) colourless, (**b**) yellow and (**c**) blue. Photo by T. Lu.

Table I: Major companies producing HPHT-grown synthetic diamond in China.

Company	Location	Scale	Products and quality	Growth technology
Zhongnan Diamond	Nanyang, Henan Province	The largest, producing 1,250 tonnes of industrial synthetic diamonds in 2018	Semi-automated production line; yellow and colourless gem-quality crystals up to 20 ct	Cubic press with high-purity graphite that is produced in-house
Henan Huanghe Whirlwind	Zhengzhou, Henan Province	Listed public company in 1998; the second largest, producing 600 tonnes of industrial synthetic diamonds in 2018	Type Ib crystals up to 10 ct possible, and type IIa colourless gem-quality crystals of 0.4–6 ct	Cubic press with temperature control of ±1.5°C
Zhengzhou Sino-Crystal Diamond	Zhengzhou, Henan Province	Listed public company in 2000; the third largest, with 2 Mct gem-quality synthetic diamonds produced in 2018 and 7 Mct projected for 2020	Gem-quality crystals of 0.1–6 ct; marketed under M&C brand name	Cubic press with large chamber (830 mm)
Jinan ZhongWu New Materials	Jinan, Shandong Province	Mainly gem-quality synthetic diamonds	Colourless, blue and yellow; gem-quality crystals of 6.5+ ct and faceted up to 3 ct possible	Cubic press; China-Ukraine joint technology; larger crystals
Henan Hold Diamond Technology	Shangqiu, Henan Province	Mainly industrial synthetic diamonds (300 tonnes per year)	Colourless gem-quality crystals of 1–4 mm (0.4–0.6 ct)	Cubic press; cooperates with State Key Laboratory of Superhard Materials at Jilin University
HeNan LiLiang Diamond	Zhengzhou, Henan Province	Produced gem-quality synthetic diamonds since 2016	Colourless and yellow gem-quality crystals of 1–8 mm	Cubic press
Penglai Bohai Diamond	Penglai, Shandong Province	Earliest manufacturer of synthetic diamonds in Shandong Province, producing mainly melee-size material	Colourless gem-quality crystals of 1–3 mm	Cubic press
Taidiam Technology (Zhengzhou)	Zhengzhou, Henan Province	Produces both HPHT and CVD synthetic diamond, small scale	Colourless, near-colourless, blue and yellow; 1–4 mm colourless gem-quality crystals	Cubic press

Figure 5: The factory of Zhengzhou Sino-Crystal Diamond in China's Henan Province is a major producer of HPHT synthetic diamonds. This facility is scheduled to produce 7 Mct of gem-quality HPHT synthetic diamonds in 2020. Photo by T. Lu.

Figure 6: A typical HPHT synthetic diamond production facility contains numerous cubic presses, some of which are shown here at the factory of Jinan ZhongWu New Materials in China's Shandong Province. Photo by T. Lu.

All of the companies in Table I produce gem-quality material, and according to the authors' research, the top three produced a total of more than 1 Mct in 2018. The company owners indicate that production capacity can be adjusted according to market needs. Zhengzhou Sino-Crystal Diamond reported that they plan to produce 7 Mct of gem-quality HPHT synthetic diamonds in 2020.

CVD-GROWN SYNTHETIC DIAMONDS

Compared to HPHT products, synthetic diamonds grown by CVD techniques have the advantages of high-quality controllability and wide industrial application. Chinese CVD enterprises are characterised by their small scale, rapid development and advanced growth techniques. All of the major CVD synthetic diamond companies in China (Table II) have the capability to produce gem-quality material, and their products first entered the gem market in 2016. However, their production scale is relatively small, and each facility typically has on the order of 10–50 growth reactors.

At present, the most common CVD methods used in China are microwave plasma chemical vapour deposition (MPCVD) for single-crystal synthetic diamonds and direct-current arc plasma jet for polycrystalline synthetics. For MPCVD, high-purity carbon is activated by high-voltage ionisation in a vacuum. The growth substrate consists of a synthetic diamond seed plate with dimensions ranging from 5 × 5 mm to 13 × 13 mm. Carbon atoms crystallise into diamond on the top surface of the seed at low pressure (usually 100–300 torr) and high temperature (typically 800–1,000°C).

The requirements for the growth of single-crystal CVD synthetic diamond by the MPCVD method are as follows (Wu 2019):

1. A carbon source such as methane, other hydrocarbons, CO or CO_2. At present, methane is the main source used.
2. High-purity hydrogen is the gas usually used to inhibit the nucleation, growth and etching of graphite.
3. Suitable C/H content for the gas source, generally less than 10%.
4. Suitable seed substrate temperature, generally limited to about 700–1,200°C, in addition to relatively low-temperature depositional conditions.
5. Low-pressure environment, generally much less than 1 atm.
6. Gas-activation technology (from one to several techniques) to stimulate the carbon sources and hydrogen, and to generate a deposition atmosphere for diamond with active carbon groups and atomic hydrogen.
7. Synthetic diamond seed for the growth of gem-quality material. To obtain high-quality synthetic diamond, it is often necessary to orient the seed crystal—commonly close to a {100} plane—and pre-treat its surface.

In addition, to improve the growth rate and reduce the formation of defects, a certain amount of N_2, O_2 and other gases are introduced into the growth chamber.

Gem-quality CVD synthetic diamonds produced in China are predominantly type IIa and type IIb, and as grown they typically consist of a transparent core surrounded by a rim of carbonaceous material (Figure 7).

Table II: Major companies producing CVD-grown synthetic diamond in China.

Company	Location	Products and quality	Growth technology*
Ningbo CrysDiam Industrial Technology	Ningbo, Zhejiang Province	Mass production of type IIa and IIb; colourless to near-colourless, pink, blue, red and orange; 10 × 10 × 4 mm plates and >1 ct faceted	MPCVD
Hebei Plasma Diamond Technology	Shijiazhuang, Hebei Province	Scientific research and industrial production; colourless to near-colourless; 13 × 13 × 1–3 mm plates	DC arc plasma jet CVD, MPCVD
Shanghai Zhengshi Technology	Shanghai municipality	Mass production of gem-quality type IIa and IIb; D–F colour; 12 × 12 × 3 mm (mainly 1–6 ct) plates	MPCVD
Carbon Star Semiconductor Technology	Xi'an, Shaanxi Province	Scientific and basic research for abrasives and gem-quality material; D–F colour up to 11 × 11 × 3 mm plates	MPCVD
Beijing Worldia Diamond Tools	Langfang, Hebei Province	Predominantly industrial use for tool abrasives, including gem-quality black material	DC arc plasma jet CVD

* Abbreviations: DC = direct current; MP = microwave plasma.

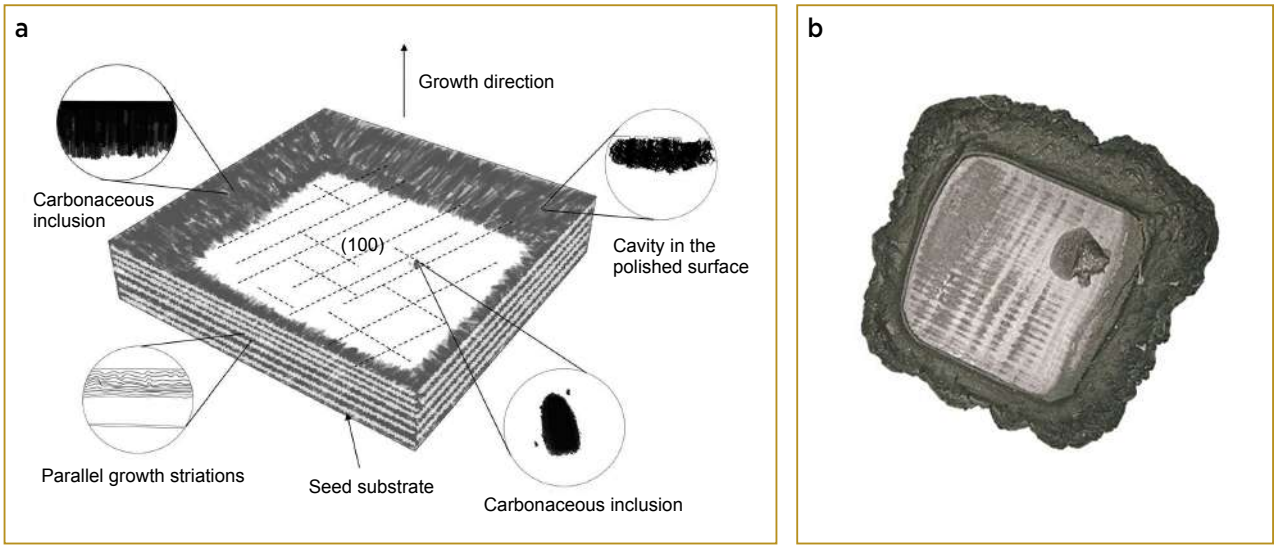

Figure 7: A sketch (**a**) and photo (**b**) of an as-grown plate of CVD synthetic diamond illustrate the typical features of this material. The CVD sample weighs 0.14 g and measures 5.79 × 5.67 × 2.07 mm. Photo by X. Wu.

They range from colourless to near-colourless, brown, blue, green, red, orange, pink and other colours (Figure 8). In some cases, post-growth treatment is needed to produce the desired colour. For example, because CVD synthetic diamonds usually contain non-diamond carbon (i.e. with sp^2 structure), the as-grown crystals are mostly brown, and HPHT treatment is needed to make them colourless to near-colourless (Eaton-Magaña & Shigley 2016). Green colouration presumably requires irradiation, while red, orange and pink are usually created with irradiation and heating (to about 800°C) of nitrogen-containing starting material. Crystals can be grown larger than 10 ct, and faceted CVD synthetic diamonds of about 1–2 ct can be mass produced. It takes about 15 days to grow a crystal weighing 4 ct.

HYBRID CVD SYNTHETIC DIAMOND ON NATURAL DIAMOND

In 2017, the Beijing NGTC laboratory identified a round brilliant-cut sample weighing 0.11 ct that consisted of type Ia natural diamond overgrown by a thick layer of CVD synthetic diamond (Tang *et al*. 2018, 2019). No boundary was visible between the two layers, even with a microscope. It was also very difficult to identify its hybrid nature using standard spectroscopic techniques. However, DiamondView imaging revealed red fluorescence and greenish blue phosphorescence in the CVD layer, separated by a sharp boundary with a layer of natural diamond showing blue fluorescence and no phosphorescence.

Figure 8: Faceted CVD synthetic diamonds from China are available in a range of colours. Shown here are (**a**) near-colourless (2.0 ct, G colour, VS_1 clarity) and (**b**) reddish pink (1.0 ct, VS_1 clarity) samples that were produced by Ningbo CrysDiam Industrial Technology Co. Ltd, and (**c**) a blue specimen (2.52 ct, Fancy Vivid, VVS_1 clarity) produced by Huzhou SinoC Semiconductor Science and Technology Co. Ltd. Photos courtesy of the companies that produced the samples.

Figure 9: Three hybrid samples of CVD synthetic diamond overgrown on natural diamond were created for this study. The samples range from 3.4 to 3.6 mm wide and have CVD overgrowths of 0.92–1.09 mm thickness. Photo by X. Wu.

To further study such material, we prepared three additional samples consisting of CVD synthetic diamond overgrown on natural diamond (Figure 9). A typical octahedral diamond crystal was sawn into three {100} substrates for CVD synthetic diamond growth. The resulting samples were H–K colour and had eye-clean CVD overgrowths of 0.92–1.02 mm in thickness. Viewed with the DiamondView (Figure 10), the substrate of each sample exhibited the typical blue fluorescence of natural type Ia diamond, while the CVD layer displayed orangey red fluorescence. The phosphorescence images also showed the presence of the two layers, with the natural diamond being inert and the CVD layer phosphorescing blue-green. The boundary between the natural diamond and the CVD layer was obvious when each sample was viewed from the side. Fourier-transform infrared (FTIR) spectroscopy with a micro-FTIR unit clearly revealed that the natural diamond substrate was type Ia and the CVD synthetic diamond layer was type IIa (Figure 11).

DIAMOND IDENTIFICATION METHODS AT NGTC

During the past few years, new diamond-identification instruments were developed at NGTC. For example, the GV5000 (Figure 12) combines imaging and spectroscopy (Lan *et al.* 2016). It enables fluorescence and phosphorescence imaging combined with spectral collection, decay-time measurement and growth-pattern observation. Its biggest advantage over similar instruments is its larger field of view and ability to test multiple samples simultaneously. In addition, when diamonds are screened, the phosphorescence spectrum and decay curves can be measured using the same instrument, enabling synthetics to be more conclusively identified based on differences in growth structure, spectroscopic features, etc. (Lu *et al.*

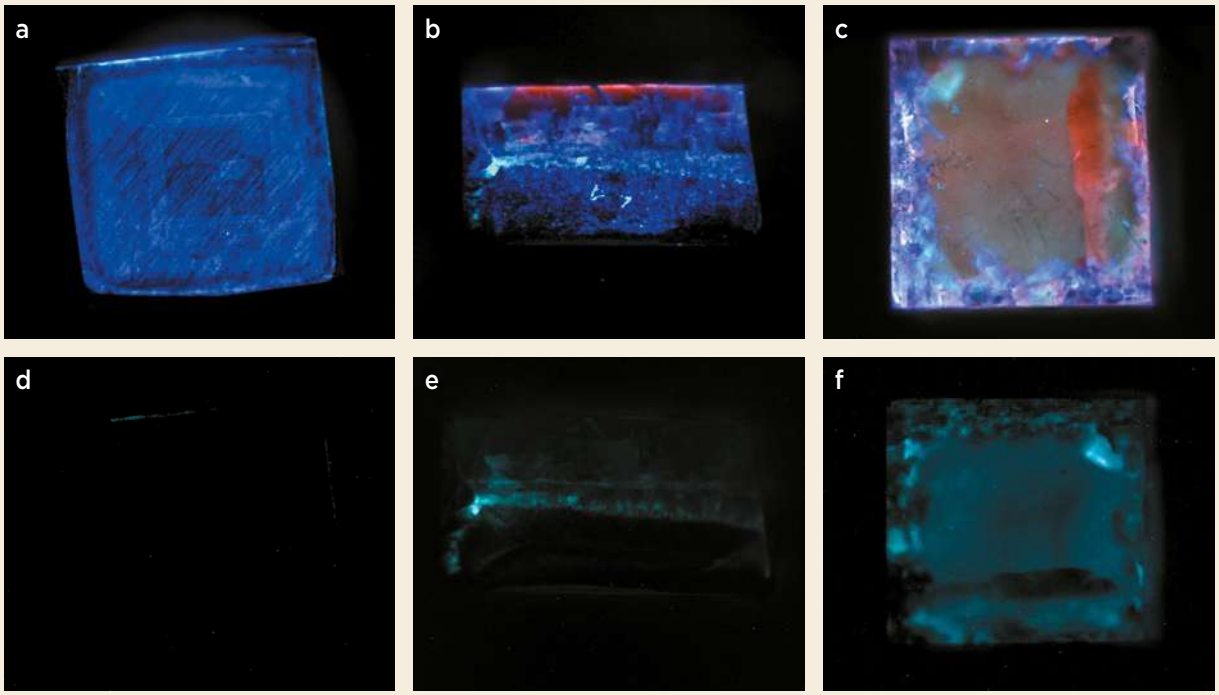

Figure 10: DiamondView images of the hybrid samples (shown here for the centre specimen in Figure 9) display blue fluorescence (**a**–**c**) for the natural diamond substrate and orangey red in the CVD overgrowth. (Views b and c show a mixture of CVD and natural features.) Phosphorescence images (**d**–**f**) show greenish blue for the CVD area while the natural diamond portion is inert. The side views (b and e) clearly show the layering of this hybrid sample. Images by X. Wu.

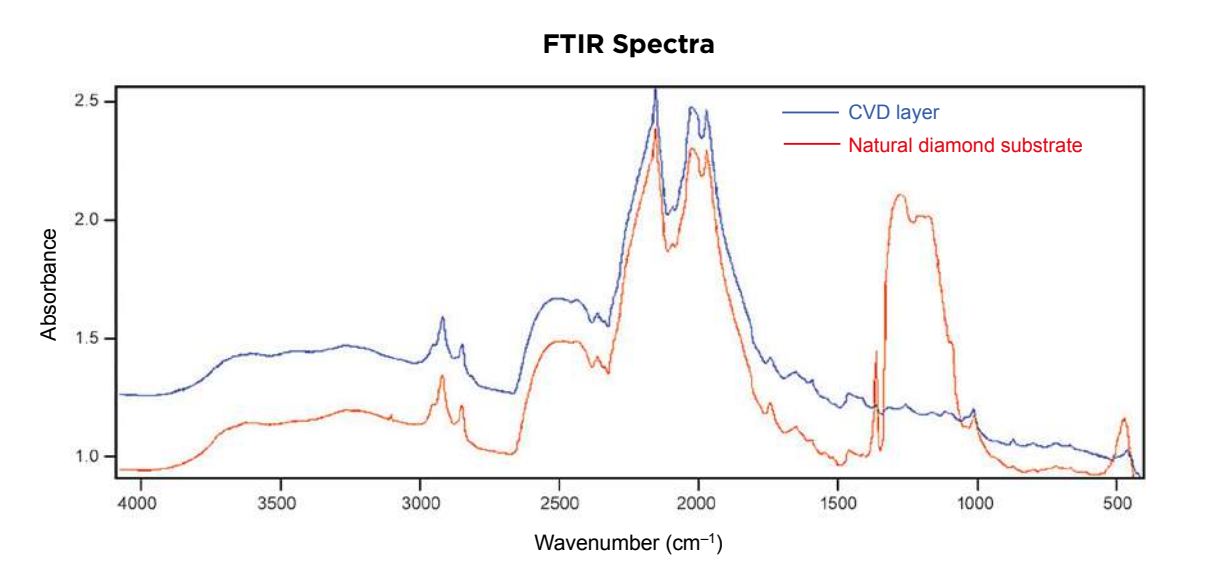

Figure 11: Micro-FTIR spectra of the different layers of the centre hybrid sample in Figure 9 demonstrate that the natural diamond substrate is type Ia and the CVD synthetic layer is type IIa.

Figure 12: The GV5000 diamond-identification instrument was developed at NGTC. It uses fluorescence and phosphorescence imaging and spectral collection, decay-time measurements, and growth-pattern observations to distinguish HPHT and CVD synthetic diamonds from natural ones. Photo by H. Dai.

2015; Lan *et al.* 2016). In China, a large amount of mounted-diamond jewellery is sent to laboratories for testing (e.g. Figure 13), and the GV5000 instrument enables the distinction of HPHT and CVD synthetics from natural diamonds on the basis of fluorescence and phosphorescence images of even numerous tiny mounted stones. The GV5000 has been extensively tested and certified by many diamond-related companies and institutions, including the Diamond Producers Association's (DPA) Assure Program (Dupuy & Phillips 2019).

We have also pioneered new techniques for identification and research using the electrical conductivity and magnetism of HPHT synthetic diamonds. Testing of about 1,000 HPHT synthetic diamonds with an electrical conductivity meter revealed that, regardless of clarity and colour, about 98% of them conducted a small electrical current, ranging from 0.01 to 5,000 µA. From this, we recently developed a highly sensitive device that can detect this conductivity, and it will be put on the market in the near future.

Research on diamond identification is ongoing at Chinese gemmological laboratories and institutions (Song *et al.* 2012, 2016a, b, c; Tang *et al.* 2017). At present, we can accurately detect and identify all natural and synthetic (HPHT- and CVD-grown) diamonds. Table III provides a summary comparison of the gemmological properties to distinguish colourless to near-colourless type II natural and synthetic diamonds manufactured in China.

Figure 13: These rings are mounted with Chinese CVD synthetic diamonds (0.25–0.30 ct). Photo by T. Lu.

Table III: Gemmological properties of colourless to near-colourless type II natural diamonds compared to HPHT synthetic and CVD synthetic diamonds manufactured in China.

Property	Natural	HPHT synthetic	CVD synthetic
Common inclusions	Crystals, clouds, feathers, etc.	Metallic thin rods and irregular shapes	Non-diamond carbon
Birefringence	Higher-order interference colours	Extremely low levels of strain	Higher-order interference colours
DiamondView imaging	Most fluoresce blue, with dislocation networks	Most fluoresce greenish blue, and a few are greenish blue with bluish green; fluorescence pattern follows cuboctahedral growth morphology	Fluorescence appears greenish blue, green, blue, yellowish green, pink with purple mottling, reddish orange, orange, etc.; thin striations or parallel bands
UV-Vis spectra	No absorption band at 270 nm	270 nm band originating from isolated nitrogen	270 nm band originating from isolated nitrogen
Near-IR spectra	Lacks spectral features	Lacks spectral features	Some show absorptions at 8750, 7840, 7354, 6855, 6425 and 5565 cm^{-1}; all these bands become weaker or even disappear with post-growth HPHT treatment
Mid-IR spectra	Type IIa features	Type IIa + IIb features; boron-related feature at 2800 cm^{-1} sometimes can be detected	Type IIa features; some show weak absorptions at 3123, 1344 and 1332 cm^{-1}; with post-growth HPHT treatment, the 3123 cm^{-1} band becomes weaker or even disappears, and a 3107 cm^{-1} band appears
Photoluminescence	GR1 emission at 741 nm present in most type IIa colourless diamonds	883/884 nm doublet related to nickel sometimes present	Si-V^- doublet at 737.6/737.9 nm is a strong indicator of CVD growth; a 596/597 nm doublet indicates a CVD sample did not undergo HPHT treatment

CONCLUSIONS

China is the world's largest producer of HPHT synthetic diamonds, with an output of more than 5 million carats of gem-quality material in 2018. Currently, the production of melee-size colourless to near-colourless HPHT synthetic diamonds in China represents about 90% of the global output. In addition, Chinese companies can grow large (up to 20+ ct) yellow and colourless HPHT synthetic diamonds.

CVD growth technology in China has been developing rapidly in recent years. Although production volume is still relatively small, the quality of Chinese CVD synthetic diamonds has improved significantly. Compared to early products, current CVD synthetic diamonds grown in China are larger and more pure, and are available in a wider range of colours.

In July 2019, the producers of both HPHT and CVD synthetic diamonds formed a sub-association under the Gems and Jewelry Trade Association of China. NGTC continues to systematically investigate the latest synthetic diamond products and is working to develop new identification techniques to keep up with improvements in growth technology.

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Figure 1: Pearls decorate this Byzantine jewelled bracelet (3.8 × 8.2 cm), which was probably made in Constantinople around 500–700 CE. Courtesy of The Met, New York, New York, USA; gift of J. Pierpont Morgan in 1917 (accession no. 17.190.1671).

Renaissance Recipes for Making Artificial Pearls by Leonardo da Vinci and Others

Annibale Mottana

ABSTRACT: A process suggested by a young Leonardo da Vinci in 1480 for reconstituting small pearls into a single large one is here translated into English for the first time. This formula is compared to two other nearly contemporaneous recipes, which are representative of a series of Renaissance processes for making artificial pearls. Leonardo da Vinci also suggested a mechanical method for polishing the reconstituted pearls, and he was aware that mother-of-pearl and pearl behave the same way when attacked with weak acids.

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Pearls were among the most popular and precious gems in the Late Medieval period and during the Renaissance (Kunz & Stevenson 1908; Bycroft & Dupré 2019). Their popularity had continued without interruption from antiquity (e.g. Figure 1), and was mainly due to their attractive round shape and natural lustre, thus not requiring any human intervention or improvement such as shaping or polishing. Their colour did not matter, although white was by far the most appreciated. When Christianity became dominant, a religious lore was attached to pearls. Indeed, the most beautiful nacreous pearls occur as single, pure white spheres within their host molluscs, just as Christ was unique in the human consortium (Friess 1980, 144–148).

Unfortunately, pure white pearls were seldom seen during the time of Leonardo da Vinci (1452–1519; usually known as 'Leonardo', and he will be referred to as such in this article). Before the lucky discovery in 1498 of a fishery in the Gulf of Paria in eastern Venezuela (fronting the island of Trinidad) during Christopher Columbus's third journey of exploration along the coast of South America (Oviedo 1526, Chap. LXXXIV), white pearls were rare in Europe and arrived by long-distance trade predominantly from marine fisheries in the Persian Gulf or, to a lesser extent, in the Gulf of Mannar (between India and Sri Lanka: Avial-Chicharro 2019). Although there were numerous scattered findings of freshwater pearls in Europe, they were typically of inferior quality (Landino 1476, Vol. IX, 115–116). Indeed, until recently, pearls were harvested in rivers of northern Europe, provided their waters were cool and oxygenated (Strack 2015), and the most common pearls that could be found in Europe during the Middle Ages were those from Britain. Pliny the Elder stated that Julius Caesar invaded Britain only for its pearl riches, and this conqueror studded his cuirass with them before he dedicated it to Venus Genetrix. Nevertheless, Pliny considered them of little worth in comparison to the marine-origin pearls from the Middle East—such as two of those exhibited by Cleopatra (Landino 1476, Vol. IX, 119)—because the freshwater ones were small, of imperfect form and showed little lustre.

Late Medieval and Renaissance portraits of royalty (e.g. Figure 2) and nobility show that pearls were common constituents of their apparel. However, the origin of these pearls is unknown; they could have come from Venezuela or have been imported from the Orient through Venice. Given the rarity of high-quality pearls at the time, it is no wonder that quite a few alchemists tried simulating them, as they did with other gems (Beretta & Conforti 2014). Many succeeded in making spherical objects with milky colour and some lustre, but no one made them so well that they would be mistaken for true pearls unless viewed from a great distance. Yet, recipes to imitate, counterfeit or simply enhance the quality of pearls are large in number. The first written evidence is believed to be from the 3rd century CE text *Papyrus Graecus Holmiensis* (Halleux 1981, pp. 113–114; Nassau & Hanson 1985), but other recipes can be found in increasing number in various technical manuscripts from the Late Medieval period and the Renaissance (e.g. Berthelot 1887–1888; von Lippmann 1919; Darmstaedter 1925, 1926, 1927a, b, 1928; Venturelli 2001; Silva 2016).

LEONARDO'S RECIPE

Leonardo da Vinci was possibly the most complex combination of artist, thinker and scientist who ever lived in Europe. He died on 2 May 1519, so it was appropriate that in 2019—which marked 500 years since his passing—his work was celebrated through various exhibitions (e.g. www.leonardodavincicelebration.org), most of which highlighted his accomplishments as a painter and scientist. In addition, we might also recall some of Leonardo's accomplishments that are less recognised in the shadow of his masterpieces. Among these lesser works are his experiments in alchemy, a practice that he tested and abandoned, as he did not like it. And within these alchemical works are small investigations pertaining to gems and jewellery materials, such as determining the gold content of metal alloys (Mottana 2018) and trying to make gems from simple materials. His method of assaying gold alloys is quite valid, and it

Figure 2: Pearls adorn Mary Stuart, Queen of Scots, painted by François Clouet in 1558 when she was the fiancée of François II, King of France. Her dress is studded with small pearls, while large white pearls make up her necklace, hair ornament and sash belt. Image courtesy of Wikimedia Commons; supplied by Royal Collection Trust / © H. M. Queen Elizabeth II 2012.

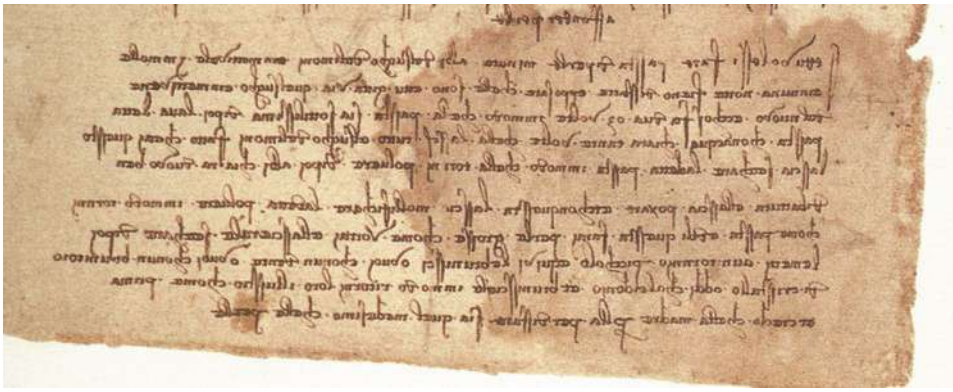

Figure 3: Leonardo da Vinci's recipe for creating artificial pearls was written in 1480 in *Codex Atlanticus* folio 304v (previously f. 109v). The 10 lines under the title 'Affonder perla' describe the method that he proposed to make a big pearl from several small ones. Although the image of the page might appear to be reversed, Leonardo was left-handed and wrote in 'mirror text' from right to left.

is still carried out today. By contrast, the rather crude methods he proposed to make artificial gems have been forgotten. However, such activities deserve to be recalled as demonstrating the variety of Leonardo's technical interests, through which he could—even if involuntarily—have become a forger.

Perhaps to challenge his own experience in alchemy, or else prove to himself that he could do better than others if needed, Leonardo wrote down a recipe to create a large pearl from a handful of small ones while he was still living in Florence. His method was intended to transform minute pearls, useful only to garnish clothing, by reconstituting them into a single large one, which in theory would be very similar in consistency and appearance to a natural pearl. The recipe is recorded in *Codex Atlanticus*, now in the Ambrosian Library of Milan, Italy, which was entirely transcribed twice: by Giovanni Piumati in 1894–1904 (under the responsibility of the Royal Lincei Academy, at that time led by Francesco Brioschi, in which the recipe appeared on f. 109v) and by Augusto Marinoni in 1975–1980 (recipe on f. 304v). It is one of the oldest manuscripts written by Leonardo and has been paleographically and linguistically dated to 1480 (P. C. Marani in Marinoni 2004, p. 75).

The text at the top of the page concerns the making of nut oil for painting, followed by the folio number 148 written alone in the middle, probably in Leonardo's hand (Marinoni 2004, p. 10). The text then continues with five lines in a smaller size (as if they were added at a different time) that describe how rotten nuts should be pressed and distilled. So far, none of this has anything to do with pearls. However, this subject appears towards the bottom of the page with the title 'Affonder perla' (meaning to blend a pearl, or to cast a pearl), in the centre of line 23 (Figure 3). The recipe encompasses 10 lines and displays large, merchant-style, carefully written characters running from right to left typical of the young Leonardo (Calvi 1925, p. 45; Manni 2008, p. 14).

To the present author's knowledge, no one has translated Leonardo's recipe into English before, not even Ladislao Reti (1952), the finest connoisseur of Leonardo's alchemical interests, and the one who first drew people's attention to this recipe by commenting on it briefly (Reti 1952, pp. 734–735). Based on Marinoni's critical transcription (1976, Vol. IV, p. 122)[1], the present author translated the text[2] as follows:

> If you wish to make a paste of very small pearls, take some lemon juice and soak them and within a night they will be dissolved. When they have settled, throw away that juice and add some new, and repeat this [soaking] two or three times until you have a very thin paste. Wash then the said paste with clear water many times, so to let all the lemon juice out. When this is done, let the said paste dry up, so that it turns into powder. Then take egg white, beat it very well and let it stand. Use this to soften the powder, so that it turns again to paste; and from this paste you can make pearls as large as you wish, and then let them dry. Afterwards you put them into a small lathe and smooth them down either with a tooth or with a polisher made of crystal or chalcedony. And polish them so that they re-acquire the same lustre as before. I believe that to dissolve the mother-of-pearl you must follow the same [process] as for pearls.

Pearls consist of calcium carbonate—mostly aragonite (orthorhombic $CaCO_3$), although some contain small amounts of calcite (the rhombohedral polymorph)—as platelets that are locally interlayered with organic matter. Interpreted in modern crystal-chemical terms, the process proposed by Leonardo begins by dissolving the organic matter (a protein similar to keratin) using a weak acid (impure citric acid, $C_6H_8O_7$). The resulting powder is then dried and mixed together with another protein (egg white albumin or ovalbumin), a readily available organic

binder but of different type than the original organic matter. The paste can then be easily manipulated into the spherical shape of a pearl.

Although Leonardo was not aware of the chemical reaction taking place during the process, he certainly knew that the final object would in itself not appear to simulate a genuine pearl unless it was polished. Indeed, pearls have an attractive bright lustre that is appropriately called *pearly*. To obtain this lustre, Leonardo described a mechanical process in which the surface of the object was smoothed down on a 'lathe' (*tornio*), using either the stiff canine tooth of a wild animal (e.g. wolf, bear or wild boar) or polished by an appropriate hard mineral such as quartz or chalcedony. At that time, the tool was likely to be just a rotating wheel driven either by hand, such as the one he later asked his pupil Boltraffio to make (manuscript CII, f. 22v of Institut de France: cf. Marinoni 1987), or by some revolving mechanical apparatus made up of a wheel and coils, similar to that described by Henri Arnaut (see figure 8 of Schmetzer 2019). There were other descriptions of tools designed to cut and polish gem materials at the time (Bol 2019) that could, perhaps, have inspired Leonardo's prototype jeweller's bench shown in Figure 4 (*Codex Atlanticus*, f. 1036v [previously f. 371v]), which he conceived and carefully designed in 1513.

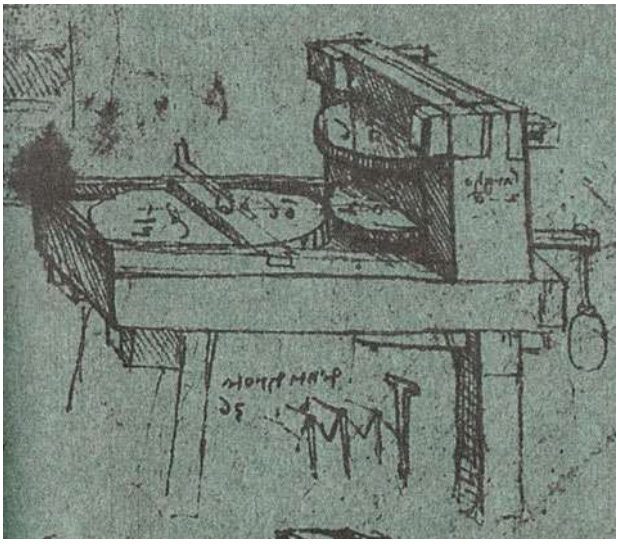

Figure 4: Leonardo da Vinci designed a jeweller's bench with a 'lathe' consisting of a horizontal wheel (left side) driven by hand with a crankshaft to modulate the rotation speed. The rotation also drove a vertical mangle to make flat metal sheets of variable thickness (right side). The surface of the rotating wheel can be smeared with emery paste to polish the gem. Detail from *Codex Atlanticus*, folio 1036v (previously f. 371v).

OTHER LATE MEDIEVAL AND RENAISSANCE RECIPES

There is no evidence whatsoever that Leonardo made use of his process for reconstituting pearls, either in Florence or in Milan—where he moved two years later and where a guild of gem counterfeiters had been established since 1472. By contrast, after moving to Milan, Leonardo conceived and carried out various experiments and wrote down several recipes to simulate coloured gemstones (A. Mottana, in preparation). Most likely, as he always worked alone and wrote for himself, his pearl formula remained largely unknown. Nevertheless, such a concept was not so unusual as not to have predecessors and successors. However, we know little about them because most scientific information at that time was communicated orally.

Ladislao Reti (1952, p. 735) suggested a possible precedent, which was written by an anonymous scientist who authored recipes 13 and 14 in chapter II of codex 164 (153) in the University of Bologna library, Italy, titled *Liber claritatis totius alkimicae artis (Book Clarifying the Entire Alchemical Art)*. This text, dating from the mid-14th century and known long since, was entirely transcribed and published as five separate articles by Ernst Darmstaedter in the 1920s (Darmstaedter 1925, 1926, 1927a, b, 1928). He believed this alchemical book was a translation from Arabic, although he also was certain its author was not the reported 'Geber', because it contained much more advanced alchemy than

[1] There are minimal orthographic differences between Reti's and Marinoni's critical transcriptions. Evidently this discrepancy derives from the fact that Reti used the 1894–1904 edition, in which Giovanni Piumati did the transcription. The present author prefers to use Marinoni's transcription because it is more recent and was performed after the *Codex Atlanticus* had undergone full restoration. The commas sometimes vary but the contents are exactly the same.

[2] *Affonder perle. / Se tu volessi fare pasta di perle minute, abbi del sugo de' limoni e mettivele in molle e in una notte fieno disfatte. E posate ch'elle sono, e tu gitta via quel sugo e mettivene del nuovo, e così fa dua o 3 volte in modo che la pasta sia sottilissima. Di poi lava detta pasta con acqua chiara tante volte, ch'ella lasci tutto el sugo de' limoni. Fatto che hai questo, lascia seccare la detta pasta, in modo ch'ella torni polvere. Di poi abbi chiara d'uovo ben / dibattuta e lascia posare. E con questa lascia mollificare la detta polvere, in modo torni come pasta; e di questa farai perle grosse come vorrai e lascerale seccare. Di poi le metti a un tornio piccolo e quivi le brunisci, o vuoi con un dente, o vuoi con un brunitoio di cristallo o di calcidonio. E bruniscile in modo ritorni loro il lustro come prima. E credo che la madreperla per disfare sia quel medesimo che le perle.*

could have been conceived by that celebrated Arabian alchemist, who had lived some eight centuries before. Darmstaedter's fifth article (1928) contains two recipes on pearls, but Reti considered only the first one, despite being in Latin, to be worth comparing with Leonardo's process. (At that time Leonardo did not know Latin, because he had received only the practical technical training appropriate for his intended career as an artisan.) The recipe, which the present author translated from Reti's reproduction in the note on p.735[3], says:

> Take small pearls and set them in a small vase. And add so much caper juice as to have the pearls covered and let it go for the entire night. Then, drain the juice slowly so as not to touch the pearls. Then wash them with citrus juice and avoid touching them and drain that juice out again. Then filter them through a piece of thick cloth so that no substance of the pearls escapes. Then take a clean slug such as naked snails or red snails and grind as much of them together with the pearls over porphyry until they became a single mass. Then shape them as pearls and pierce them immediately. After that, grease your fingers with fat from fish and set the fish together with the pearls into a warm oven and let all stay until the fish is well cooked. Afterwards, do as you did before.

Reti's suggestion of this being a precedent for Leonardo's recipe was likely too hasty, and thus faulty, owing to the little attention he dedicated to the subject (cf. Reti 1952, p. 735: only two dozen lines of an article comprising 30 dense pages). Leonardo's procedure is much cleaner than the one described above: he suggested egg white rather than the flesh of snails to bind the pearl residues, and he did not measure the time that the reconstituted pearl would take to dry and harden in the same terms that a cook would use. Moreover, there were quite a few other Late Medieval recipes to enhance the size and appearance of pearls that the young Leonardo could have heard about and used as inspiration. Paola Venturelli (2002) listed 25 such processes that span from the 13th to the 16th century, and her list is likely incomplete, as her research was performed only in the public libraries of northern Italy.

Indeed, the most likely predecessor to Leonardo's recipe occurs in another codex at the University of Bologna library (manuscript 2861), bilingual and dated to the late 15th century, possibly 1480—exactly when Leonardo wrote down his recipe in *Codex Atlanticus*. This other codex was highlighted during research aimed at finding various methods used to create the colours available to early Renaissance painters (Guerrini & Ricci 1887), but its section on pearls was neglected and long forgotten. It was never translated into English, possibly because the main subject matter of paint pigments was too well known from other sources, or perhaps because the text has inherent language difficulties. It is a mixture of an imperfectly Latinised northern Italian idiom, full of strange words familiar only to those from that region. The relevant recipe title is in poor Latin: *Ad fatiendum perlas grossas de minutis* (To make big pearls from small ones). Then it continues as follows[4] (translated by the present author):

> Grind finely the small pearls in a mortar of bronze. Afterwards take the juice of lemons and pour it through a filter and add urine and water in the amount of one-third of the lemon juice and mix the powder above with this liquid so that it becomes like a paste and leave it in sunlight for three days. Then lump it carefully and put it over a glass and make up pearls as you wish using tunny [tuna fish] oil. Then pierce them through using a pig bristle, and through that hole put a horse hair and leave them in the sun until they become dry. Afterwards put them in the belly of a very big fish[5] after extracting its entrails, and sew or stitch the belly, and make from it a pie that you shall cook; take it out [of the oven] and you shall find in it hard stones: you must rub them with barley bran in a woollen cloth, very hard. Afterwards, you shall feed them to a pigeon, or to a cock, for one day or more, as you like, and again rub them with bran as before, and they will be perfectly polished.

This recipe describes the process in such a way that some operations are more detailed and have additional steps compared to Leonardo's recipe (e.g. the formed object is made fully dry in an oven after having dried

[3] *Accipe pernas minutas et pone in vasello. Et pone tantum de suco cappari, ut coperiat pernas, et dimitte simul per totam noctem. Postea extrahe sucum desuper suaviter ut non tangas pernas. Postea ablue ipsas cum suco citri, et non tangas eas, et iterum prohice sucum istum. Postea cola ipsas in petia spissa ut non exeat de substantia pernarum. Postea accipe cocavum nudum id est limacas nudas id est marucas, et tere supra porfidum simul com pernis tantum donec efficiantur unum corpus. Postea fac inde pernas et perfora ipsas tunc. Deinde inunge digitos tuos cum pinguedine piscium et pone pisces cum pernis in furno calido et dimitte stare donec pisces sint bene cocti. Postea facias sicut prius fecisti.*

in the sun first to avoid cracking, and a hole is made beforehand to prepare the resulting 'pearls' for stringing), while other steps are simpler and do not require special instruments (e.g. the 'pearls' are placed within the greasy belly of a cooked fish, apparently to absorb additional fat as binder and perhaps acquire some lustre, and are then polished by passing them through the gizzard of a courtyard bird).

Clearly, Leonardo reckons more as an engineer, while the anonymous author of manuscript 2861 attempts to use simple procedures with tools that were readily available. Without a means to measure time, this author used the cooking period of a fish to estimate it. And as the ancient Greeks already knew (Nassau & Hanson 1985, p. 226), the author was familiar with the effectiveness of polishing by rubbing stones together within a bird's gizzard. The results of this recipe are unlikely to be the same as Leonardo's, since polishing such an artificial pearl on a wheel would certainly yield better results than passing it through the gizzard of a chicken. However, the anonymous author was evidently writing for himself, whereas Leonardo may have been preparing to use his recipe for financial gain by applying it towards someone else's pearl harvest or possibly even selling his process to a guild of counterfeiters, who would certainly have had a polishing wheel available.

CONVERTING SHELL INTO ARTIFICIAL PEARLS

The last sentence of Leonardo's artificial pearl recipe rather cryptically introduces an innovative concept: indeed, pearl and mother-of-pearl are such closely similar materials as to behave the same way when attacked by weak acids. Thus they can be manipulated in much the same way to make artificial pearls.

This is an innovation that no alchemist had ever put in writing before, but it was so obvious that soon somebody started using it. Indeed, in the middle of the following century in The Netherlands, it was written[6] (as translated by the present author): 'To counterfeit pearls… to make pearls into something else…take a large clean mussel shell, heat it and put it in wine vinegar, afterwards take the shell and make it into a powder and take crystal glass, also powdered.' Although the name 'P. Koldenbergij' is clearly indicated on the manuscript, and this was interpreted as the name of the author for a long time, it was subsequently identified to be the work of Pieter Van Coudenberghe (1517–1599), an Antwerp apothecary and botanist (Vandamme 1974, pp. 124–125). As usual for apothecaries, he collected an array of recipes, often in Latin, which he could make use of if needed. Two of them describe how to counterfeit pearls, along with a list of alchemical symbols and other miscellaneous subjects, such as a drawing of an oven to bake painted glass, and instructions on how to make or improve upon pigments, discern fake from real stones, gild metal, and make ink, mirrors, enamel and resins. Therefore, taken altogether, this bulky manuscript could be seen as the recipe book of a skilled apothecary. Furthermore, the presence of a pearl recipe fits the locality: in Antwerp, which is well known for its edible oysters, pearls were also (and still are) occasionally encountered. However, they are typically small, of unattractive colour, baroque shaped and non-nacreous—certainly not of the type that could be sold for jewels, although they were used to enhance garments, particularly those of ladies. The owner of such pearls would have understandably felt the need to enhance their appearance, and there would have been an abundance of shell material available for potentially reconstituting the shells into artificial pearls.

CONCLUSION

Bright white, perfectly spherical natural nacreous pearls were popular jewels in Europe during Greek and Roman times and continuing after the Renaissance, although they were exceedingly costly because of their rarity,

[4] *Tere parvas margaritas in mortario bronzi subtiliter. Demum accipe citositatem citrorum et distilla per filtrum et de urina et de aqua tasi quantum est tertia pars aqua citri et impasta dictum pulverem cum hac aqua ita quod deveniat sicut pasta et dimicte per tres dies ad solem. Postea conglutina diligenter et depone super vitrum et forma margaritas ad libitum cum oleo muscellino. Postea perfora cum porcina seta, per quod foramen pone setam equinam et dimite ad solem donec sicentur. Demum pone in ventre piscis bucefalli, eiectis interioribus, et sue, sive cuscias ventrem, et fac inde pastillum et coque et exerge et invenies lapides duros: et frica eas cum furfare ordei in panno, fortiter. Demum da columbo, vel gallo, comedere per diem 1 vel amplius, sicut videtur, et iterum frica cum furfure ut prius et erunt lucidissime.*

[5] The text says *piscis bucefalli,* which this author interprets to mean 'a fish the size of Bucephalus', Alexander the Great's horse, which was the largest animal of this kind in the Greek-Macedonian army.

[6] *Om perlen te conterfeyten…om perlen te maken anders…nempt groote schoon mossel sculpen ende maecktse heet ende doetse in wyn asyn, daer na nempt de sculpen ende poeyertste ende cristalynen gelas ook gepoedert* (manuscript no. 64, Museum Plantin-Moretus, Antwerp, Belgium; reported by Rijks 2014, p. 309).

Figure 5: This close-up of a portrait of Bianca Maria Sforza, painted by Giovanni Ambrogio de Predis (a co-worker of Leonardo da Vinci) in 1493 before her marriage to the future emperor Maximilian of Habsburg, shows magnificent pearls decorating her hair, head and necklace. Image courtesy of the National Gallery of Art, Washington DC, USA (Widener Collection, Accession No. 1942.9.53).

and since most of them came from far away. While the Portuguese imported them from the Gulf of Mannar and the Spaniards obtained them from the newly discovered fisheries in the Caribbean Sea (e.g. Venezuela and Panama), the traditional caravan routes continued supplying these expensive commodities to Europe via Venetian merchants all along the Middle Eastern coast and through Venice. It is no wonder that counterfeiters contemplated how to make use of the typically small, dull, poorly shaped pearls frequently found in the local freshwater fisheries, seeking to develop alchemical methods to improve them. The young Leonardo also considered reconstituting small pearls into a large one, and to make it perfectly round, bright and polished using mechanical methods he adapted from his engineering experience.

No evidence for such artificial pearls is known, although paintings representing high-ranking members of the Milan duke court where Leonardo was employed do show examples of relatively large, round, white pearls. The most magnificent illustration is the portrait of Bianca Maria Sforza, the niece of the acting duke Ludovico Maria 'il Moro'. He was determined to marry her to the emperor-to-be Maximilian of Habsburg in order to have his duke title confirmed. He had her portrayed by Giovanni Ambrogio de Predis, a co-worker of Leonardo (Figure 5), in which her head and hair are covered with perfectly round pearls, and she also wears a pearl necklace with a drop that is mounted with large gemstones and an impressive oval pearl. In addition, a pearl-studded *scopetta* (whisk), the heraldic symbol of the Sforza family, hangs above her left ear, a symbol of her being imbued with Sforza power and cleverness.

Were these beautiful white pearls all natural, or did Leonardo da Vinci, at that time employed as court jewellery designer, besides painter and architect, somehow improve them? We will never know. Certainly, if he did do something more than design the apparel of the empress-to-be, he would not have tried to substitute natural pearls with artificial ones. Ludovico Maria 'il Moro' would not have pardoned such an insult, even from his favourite court painter.

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Conferences

36TH INTERNATIONAL GEMMOLOGICAL CONFERENCE

The 36th biennial IGC took place 27–31 August 2019 at La Cité Nantes Congress Centre in Nantes, France. The conference was organised by **Dr Emmanuel Fritsch**, **Dr Nathalie Barreau** and **Féodor Blumentritt** of the University of Nantes, in collaboration with **Dr Jayshree Panjikar** (Pangemtech and Pangem Testing Laboratory, Pune, India) and the IGC Executive Committee. Approximately 96 delegates, observers and guests from 29 countries gathered for the conference (e.g. Figure 1), and some attended pre- and post-conference field trips. A proceedings volume containing extended abstracts can be downloaded at www.igc-gemmology.org (which now also hosts proceedings volumes from previous IGCs back to 2011).

The first day of the conference was devoted to an 'open colloquium' that was attended by French gemmologists who could not otherwise attend the IGC (a members-only event). **Dr Fritsch** opened the colloquium and introduced the 10 invited presenters (e.g. Figure 2). **John Koivula** (Gemological Institute of America [GIA], Carlsbad, California) reviewed internal features in gems, and showed a variety of solid and fluid inclusions. Some of them inspired the imagination, such as iron oxides in agate that looked like rifle bullets and dendrites in an iron-stained quartz fracture that resembled a cave painting. When inclusions are large and visible enough (e.g. tourmaline 'pinwheels' in quartz, bugs in amber, etc.), they become examples of wearable natural art. **Dr Hanco Zwaan** (National Museum of Natural History 'Naturalis', Leiden, The Netherlands) examined the geochemistry of sapphires for the purpose of studying their geological and geographical origins. Trace elements and their ratios are useful for assessing a magmatic (basalt-related), metamorphic or metasomatic/plumasitic origin, which is particularly helpful for investigating the primary origin of sapphires from secondary deposits such as those in Sri Lanka (which are essentially metasomatic). **Shane McClure** (GIA, Carlsbad) reviewed collaborative research done with several co-authors worldwide on sapphires that are heat-treated under pressure. The gems are treated in Korea and sold by one dealer in Sri Lanka; only a limited amount are produced (about 300–400 stones/month). Although the treatment is accomplished much faster than conventional heating processes, it is restricted to only one or two stones at a time and has a relatively high failure rate (approximately 30%). Their research showed no differences in the durability or brittleness of the treated sapphires compared to those that have undergone conventional heating. **Tom Stephan** (German Gemmological Association, Idar-Oberstein, Germany) gave a presentation for **Dr Claudio Milisenda** and co-authors (DSEF German Gem Lab, Idar-Oberstein) on Mozambique ruby. He described the history of mining at Montepuez and differentiated rubies from two main productive areas that are being mined by Gemfields:

Figure 1: Delegates, observers and guests assemble for the 36th International Gemmological Conference. Photo by Gordon Duan.

Figure 2: The first day of the IGC consisted of an 'open colloquium' that featured presentations from several speakers, including from (left to right): Tom Stephan, Dr Thomas Hainschwang, Peter Lyckberg, Brendan Laurs, John Koivula, Tay Thye Sun, Dr James Shigley, Shane McClure and Dr Hanco Zwaan. (Not shown is Kenneth Scarratt.) Photo by Ahmadjan Abduriyim.

Maninge Nice (a primary occurrence that yields large quantities of flat, light-coloured crystals) and Mugloto (a secondary deposit that produces much smaller amounts of better-quality ruby). At the time of Dr Milisenda's visit to Montepuez, Gemfields was capable of processing 3.5 million tonnes of material per year, and their washing plant was handling 150 tonnes per hour. From August 2012 to December 2015 the mining area yielded a total of 17.2 million carats of mixed-quality ruby and pink sapphire. **Peter Lyckberg** (Museum of Natural History, Luxembourg) reviewed gems and minerals from granitic pegmatites in Afghanistan and Pakistan. He described the production of tourmaline, kunzite, morganite and various rare minerals in Afghanistan since the initial discovery of pegmatites there in 1959 near Kala village in the Pech Valley. In recent times, up to 100,000 miners have been active in Pakistan's Shigar Valley. **This author** described coloured stone and diamond deposits in Namibia (see Gem Notes in Vol. 36, No. 1, 2018, pp. 8–9 and 16–18).

The open colloquium also featured two diamond presentations. **Dr Thomas Hainschwang** (GGTL Laboratories, Balzers, Liechtenstein) reviewed diamond luminescence and its usefulness for distinguishing between natural vs. synthetic material (as well as imitations), natural vs. artificial colour and natural vs. HPHT-treated colourless diamonds. The use of high power and a variety of excitation wavelengths from 210 to 400 nm is helpful for observing diamond fluorescence, even for samples that would not normally show any luminescence under standard UV lamps. **Dr James Shigley** (GIA, Carlsbad) provided an update on synthetic diamonds. While natural diamonds formed over extended periods of time and very long ago, synthetic diamonds crystallise during short periods of time and originated very recently. The key difference between them is the time spent under high-temperature conditions, which influences the type and distribution of their defects as detectable by various spectroscopic techniques, thereby enabling them to be reliably separated by a well-equipped gemmological laboratory.

Biogenic gems were covered in two presentations at the open colloquium. **Kenneth Scarratt** (Bahrain Institute for Pearls & Gemstones [DANAT]) and co-authors described natural pearls from Bahrain. Currently approximately 7 kg of pearls are produced annually from *Pinctada radiata* molluscs, which typically yield one pearl per 100 shells harvested. The pearls are classified at DANAT according to their shape, lustre, surface characteristics, colour and fluorescence, and they can be separated from *P. maxima* pearls by their trace-element composition. **Tay Thye Sun** (Far East Gemmological Laboratory, Singapore) discussed research done with his co-authors on amber from Hti Lin, Myanmar (see article in *The Journal*, Vol. 34, No. 7, 2015, pp. 606–615).

On 28 August, the IGC was opened by Executive Committee secretary **Dr Jayshree Panjikar**, who described the history of IGC activities and also announced the recent passing away of IGC delegates Alan Jobbins, Gerhard Becker and Hermann Bank. Then **Dr Fritsch** (Figure 3) welcomed the attendees to Nantes and mentioned the conference sponsors and logistics.

Diamonds were the subject of the first conference session. **Dr Eloïse Gaillou** (MINES ParisTech, Paris, France) and co-authors examined the genesis of blue diamonds by studying solid and fluid inclusions in four rough samples from the Cullinan mine in South Africa. They found graphite-H_2O assemblages in both primary and secondary inclusions, as well as the presence of a lithospheric mineral assemblage, which shows that type IIb blue diamonds may form at various depths below the deep roots of a craton and do not necessarily have a 'superdeep' origin. **Marie Schoor** (Cartier Joaillerie

Figure 3: Dr Emmanuel Fritsch was one of the organisers of the 36th IGC. Photo by B. M. Laurs.

International, Paris, and University of Nantes) and co-authors characterised growth sectors in asteriated diamonds. They examined 13 samples, most of which showed distinct patterns created by a combination of octahedral sectors that were near-colourless with cuboid sectors that were grey or brown and had 3, 4 or 6 lobes. The colour of the cuboid sectors was due to abundant graphitised discoid micro-inclusions (2–7 µm). Two of the samples contained needle-like inclusions that were interpreted as rose channels (i.e. mechanical twinning created by intense plastic deformation). **Roman Serov** (Octonus Software, Moscow, Russia) and **Sergey Sivovolenko** (Octonus Finland Oy, Tampere) studied the influence of UV fluorescence on the colour appearance of diamonds. The viewing tray is particularly important for colour grading because it is much closer to the diamond than the lamp. While diamonds are graded by laboratories using plastic trays, they are commonly viewed by members of the trade with paper trays. This, and differences in the light sources used, create inconsistencies in assessing the impact of fluorescence on diamond appearance. **Aurélien Delaunay** (Laboratoire Français de Gemmologie, Paris) and co-authors proposed a classification for type IIa diamonds on the basis of their emission colours and patterns seen in the DiamondView. The fluorescence colours reflect the presence of various defects and trace impurities, while the textures can be related to growth (i.e. sectors, banding and layering) or deformation (polygonal dislocations, graining and curved patterns). Nevertheless, growth patterns are rarely seen in type IIa diamonds and are much more easily observed in type Ia stones.

Synthetic and treated diamonds were covered in four presentations. **Dr Hiroshi Kitawaki** and co-authors (Central Gem Laboratory, Tokyo, Japan) reported on the current production of synthetic diamonds in China and India. (*Editor's note*: See the article on pp. 748–757 of this issue for more on Chinese synthetics.) China is the world's largest producer of HPHT-grown synthetic diamonds, and analyses of metallic inclusions in samples from different manufacturers revealed distinct differences in the proportions of Fe, Co and Ni. India is an important source of CVD synthetics (estimated at 125,000 carats/month) and now produces faceted goods up to 5 ct. **Dr Andy Shen** presented research on behalf of his co-authors from the China University of Geosciences (Wuhan, Hubei Province) on the phosphorescence of HPHT-grown type IIb colourless synthetic diamonds from China. Their phosphorescence was long-lived (5 minutes or longer) and was greenish blue and/or yellowish orange. Analysis with a fluorescence spectrometer showed that the phosphorescence was centred at 470 nm and was excited by wavelengths ranging from 215 to 240 nm. **Jean-Pierre Chalain** (Swiss Gemmological Institute SSEF, Basel, Switzerland) and co-authors evaluated the performance of the ASDI diamond verification instrument using different-sized type Ib HPHT synthetic diamonds with identical very low nitrogen concentrations (approximately 1 ppm). A single piece of synthetic rough material was cut into three round brilliants with diameters of 1.5, 2.0 and 3.0 mm so that the correlation between sample size, colour and short-wave UV transmission could be established (the last factor being important for the instrument's 'referral' threshold of specimens for further testing). **Dr Thomas Hainschwang** and **Gianna Pamies** (GGTL Laboratories) examined the effects of HPHT treatment on previously irradiated and annealed diamonds of various types and colours. They were surprised to find that HPHT treatment at 2,500°C of yellow 'cape' diamonds produced brown colouration that probably results from the destruction of the N3 centre, causing an unusual continuum of absorption.

The next session featured presentations on gem and jewellery history and age dating. **Dr H. Albert Gilg** (Technical University of Munich, Germany) and co-authors used the chemical composition of apatite and/or monazite inclusions to evaluate the origin of ancient red garnets of almandine to pyrope composition. Garnets encompassing Hellenistic, Roman and Early Medieval times have been grouped into at least six clusters according to their trace elements and inclusion features, but the original provenance of many of these

archaeological samples has not been well established. The morphology, chemical composition and age data obtained from apatite and/or monazite inclusions yields additional information that can help constrain the source of the garnets. **Dr Karl Schmetzer** (Petershausen, Germany) and **Dr H. Albert Gilg** studied the English crown of Blanche of Lancaster, dated to the 1380s (Late Middle Ages) in the treasury of the Residence Museum in Munich, Germany. The gems adorning the crown consist of diamonds, diamond imitations, blue sapphires, a blue sapphire doublet, pink sapphires, pink spinels, garnets, emeralds and lead glass (green and pink). **Dr Michael Krzemnicki** (Swiss Gemmological Institute SSEF) and co-authors reviewed the age dating of coloured stones and biogenic materials. In support of testing and origin determination, SSEF has successfully performed radiometric age dating (U-Pb and Th-Pb) on corundum and spinel using a variety of inclusions, such as zircon, zirconolite, xenotime, monazite, baddeleyite, rutile, apatite and titanite. For gem corundum, the age dates allow stones to be placed into one of three main global geological frameworks: Pan-African tectono-metamorphic events about 750–450 million years ago (Ma), the Himalayan orogeny about 40–10 Ma and alkali basalts related to extensional tectonics of about 4 Ma and younger. **Elisabeth Strack** (Gemmologisches Institut Hamburg, Germany) and **Bernd Augustin** (Hamburg) performed a gemmological examination of four Mogul jewellery objects dating from the first half of the 17th century. They were found to be set with diamonds (mirror, rose and table cuts, as well as macles), rubies (showing characteristics consistent with a Burmese origin), red spinels, emeralds and pearls.

The next session was devoted to coloured stones. **Carolina Santiago** (University of Bremen, Germany) and **Dr Jurgen Schnellrath** (Mineral Technology Centre, Rio de Janeiro, Brazil) studied cat's-eye opal from Socotó, Bahia, Brazil. Raman microspectroscopy showed that the fibrous mineral responsible for the chatoyancy is chrysotile, while X-ray diffraction analysis confirmed that the host material is opal-CT. The green-to-brown colouration of these opals is due to a combination of mineral inclusions and Rayleigh scattering. **Dr Alessandra Costanzo** (Figure 4) and **Dr Martin Feely** (National University of Ireland Galway, Ireland) reviewed gem and ornamental materials from Connemara, western Ireland. Connemara marble has been widely used in jewellery and souvenir gift items since the 19th century (*Editor's note*: See the article in *The Journal*, Vol. 36, No. 5, 2019, pp. 456–466), and small sapphires are known from two localities (Lough Whelaun and Toombeola). Recently (in 2015), transparent well-formed crystals of fluorite showing various colours were mined from Larkin's Shannapheasteen Granite Quarry.

Figure 4: Dr Alessandra Costanzo discusses colour-zoned crystals of fluorite from Connemara, western Ireland. Photo by B. M. Laurs.

Dr Thet Tin Nyunt (Ministry of Natural Resources and Environmental Conservation, Nay Pyi Taw, Myanmar) and co-authors studied jadeite from the Natmaw deposit in the Khamti (or Hkamti) area of northern Myanmar. Dykes of jadeitite are hosted by serpentinised peridotite associated with 'blackwall' alteration zones. Jadeite has been mined from both primary and secondary deposits, and is categorised into Imperial, commercial and utility grades, as well as into three main texture types (primary, deformed and recrystallised).

Dr Shang-i (Edward) Liu (Gemmological Association of Hong Kong) gave a presentation for **Gamini Zoysa** (Ceylon Gemmological Services, Colombo, Sri Lanka) and co-authors on spinel from Sri Lanka. The most important mining areas for spinel are Ratnapura (which produces all colours, including 'cobalt blue' and star stones), Okkampitiya (green, bluish green, pink and purple), Elahera (pink and purple) and Horana (all colours). The internal features and chemical composition were described for spinel from each of these localities. **Chengsi Wang** (China University of Geosciences, Wuhan) and co-authors characterised copper nanoparticles within Oregon sunstone. They found that red sunstone contains spherical Cu nanoparticles of about 13 nm in diameter, while dichroic green sunstone hosts oriented elongate spheroid Cu-containing nanoparticles with dimensions of about 26 nm in the orientation corresponding to green pleochroism and about 10 nm in the red direction. **Féodor Blumentritt** and co-authors (Institut des Matériaux Jean Rouxel and University of Nantes) investigated mechanisms involved with photochromism (i.e. reversible colour change resulting from exposure to UV radiation, thought to be due to sulphur) in hackmanite—and, by inference, in scapolite and tugtupite. Using synthetic hackmanite powders, they were successful at influencing the degree of the photochromism by changing the amount of sulphate in the starting material.

Peter Lyckberg and co-authors documented giant cavities containing heliodor, topaz and smoky quartz in the Volodarsk-Volinsky granitic pegmatites in Ukraine. Specifically, the Volyn Piezo Quartz deposit was mined for piezoelectric quartz but also contained topaz in 10% of the miarolitic pegmatites and beryl in 2% of them. Rough material is sold as faceting rough and is also processed using automatic cutting machines into finished gemstones (topaz and beryl) and other polished objects (quartz). **Gagan Choudhary** (Gem Testing Laboratory, Jaipur, India) discussed challenges with identifying filled emeralds. He described differences in the process of filling fissures with traditional vs. modern fillers, which typically result in an uneven/reflective vs. smooth appearance of the fractures, respectively. More than one filling substance can be present in a single stone (or fracture), and may result from the application of epoxy during the cutting and polishing process, incomplete cleaning of pre-existing resin-filled fissures, and finally refilling with oil. **Dr Shang-i (Edward) Liu** and co-authors described pezzottaite from Pyi-Gyi-Taung, Myanmar. Pezzottaite was recently produced from a rubellite-bearing pegmatite located 6 km east of Letpanhla village, and occurs mixed with beryl in well-formed pale pink crystals. Only about 1 kg of these 'mixed crystals' has been produced in the past five years. The Burmese pezzottaite contains an average of 14.4 wt.% Cs_2O, which is similar to material from Madagascar. **Tasnara Sripoonjan** and co-authors (Gem and Jewelry Institute of Thailand [GIT], Bangkok, Thailand) examined the gemmological and chemical characteristics of peridot from Yiqisong, Jilin, China. They have similar properties compared to peridot from other localities, and their internal features consist of lily pads, wispy veils, iridescent partially healed fractures and tiny unidentified crystals, as well as protogenetic tabular chromite crystals (brown to brownish red) that appear unique to peridot from this locality. **Dr Isabella Pignatelli** (University of Lorraine, Vandoeuvre-lès-Nancy, France) and co-authors examined trapiche texture in emerald and ruby. This distinctive texture has not been observed in minerals with low symmetry, and appears to be controlled by factors associated with the geological environment of crystallisation, such as the presence of organic material/graphite and evaporites, thermal reduction of sulphates, and variations in the pressure and composition of the parental fluids. (*Editor's note*: For more on this research as it applies to trapiche rubies from Vietnam, see the article on pp. 726–746 of this issue.)

Dr Jaroslav Hyršl (Prague, Czech Republic) reviewed his genetic classification of mineral inclusions in quartz. Of the 10 or more geological environments that produce quartz with inclusions, the vast majority of specimens come from Alpine fissures (hydrothermal veins). About 200 different minerals have been documented in quartz from such veins. Brazil is the largest producer of quartz with inclusions, mostly from veins hosted by quartzites. **Willow Wight** and co-authors (Canadian Museum of Nature, Ottawa, Ontario) described tourmaline from the Leduc mine in Québec, Canada. This small deposit was initially mined for muscovite in 1884, and in 1908 it was explored for gem tourmaline. The largest collection of faceted Leduc tourmaline is owned by Brad Wilson

(Alpine Gems, Kingston, Ontario, Canada) and consists of about two dozen stones that are mostly greenish blue to yellowish green. Selected samples were gemmologically and chemically analysed by the authors and found to consist of fluor-elbaite. **Dr Lutz Nasdala** (University of Vienna, Austria) and co-authors examined ekanite ($Ca_2ThSi_8O_{20}$), a metamict gem material from Sri Lanka. Inclusions consist of an apatite-group mineral, thorium silicate, silica, Ca carbonate, Ca silicate and fluids. Chemical analysis showed impurities of 2.8 wt.% UO_2 and traces of Pb and Fe.

Numerous presentations covered gem corundum. **Dr Rainer Schultz-Güttler** and **Bruno Zampaulo** (University of São Paulo, Brazil) studied unusual ruby-fuchsite rocks from eastern Brazil and western India. The rocks are polished into attractive spheres and other decorative objects, and material from each country contains different mineral assemblages. **Dr Jayshree Panjikar** and **Aatish Panjikar** (Pangemtech and Pangem Testing Laboratory) investigated rubies from Paramathi in the Karur District of Tamil Nadu, India. The material ranges from pinkish red to deep red and is semi-transparent to transparent. It is related to garnet-biotite schist and contains inclusions of zircon, spinel, garnet, ilmenite and rutile. **Supparat Promwongnan** and co-authors (GIT) discussed rubies and sapphires from the Chanthaburi-Trat and Kanchanaburi gem fields in Thailand. The Chanthaburi-Trat area is a source of both ruby and sapphire, which are inferred to have formed under different conditions: ruby from a mafic granulite source at 30–50 km depth and at about 700–1,000°C, and sapphire from a syenite source at a shallower depth and lower temperature. (*Editor's note*: For more on these rubies, see the article in *The Journal*, Vol. 36, No. 7, 2019, pp. 634–645.) Kanchanaburi only produces sapphire, which likewise has a syenite origin. Gem corundum at both localities was brought to surface by alkali basalts that are generally less than 4 Ma. **Stephen Kennedy** (Gem & Pearl Laboratory Ltd, London) discussed the identification of natural vs. synthetic Fe/Ti-diffusion-treated sapphire. Such material may not contain any distinctive inclusions, and therefore it is helpful to check for Plato lines that are characteristic of flame-fusion synthetics, collect UV-Vis spectra (strong peaks at 450 and 375/388 nm indicate a natural origin) and obtain chemical data (very low levels of Ga indicate a synthetic origin). **Kentaro Emori** (Central Gem Laboratory) and co-authors characterised Be-containing nanoinclusions in untreated blue sapphire from northern Madagascar. Analyses by LA-ICP-MS and TEM showed a good correlation of Ti:Be:Nb:Ta = 16:3:1:4 in the nanoinclusions, which may consist of an as-yet unknown mineral. **Dr Pornsawat Wathanakul** (Kasetsart University, Bangkok) delivered a presentation for her co-authors on the Fe and Ti oxidation states in ruby and blue sapphire. Various sample types (natural, synthetic, Be-treated and surface-diffusion-treated sapphires and unheated/heated rubies) were analysed at a synchrotron facility in Thailand by X-ray absorption near-edge spectroscopy. In all of the sapphires, iron was always present as Fe^{3+} and titanium as Ti^{4+}. The authors proposed that blue colour in sapphire is due to Fe^{3+}/Ti^{4+} pairs rather than Fe^{2+}/Ti^{4+} intervalence charge transfer. **Tom Stephan** and co-authors performed low-temperature and flux-assisted heat treatment of rubies and pink sapphires from Mozambique and Greenland. Bluish colour zones were removed from Mozambique rubies by heating to approximately 800°C, and the treatment could be identified by the reddening (oxidation) of secondary iron hydroxides, as well as by spectroscopic evidence for the breakdown of Al-hydroxides and the transformation of Fe-hydroxides to Fe-oxides. The diaphaneity of samples from both localities showing low clarity could only be improved by heating at high temperature with a (borax) flux. Without the use of a flux, Al-hydroxides along twin lamellae dehydrated, leaving white layers of polycrystalline corundum. **Sutas Singbamroong** (Chiang Mai University, Chiang Mai, Thailand and Dubai Central Laboratory, Dubai, United Arab Emirates) and co-authors studied Be-diffused geuda sapphires from Sri Lanka that were treated in Chanthaburi, Thailand, to intensify and even-out their blue colour while also improving their clarity. A three-part process was employed: (1) heating in a traditional furnace to about 1,500°C for two hours in an oxidising atmosphere, (2) Be diffusion in an electric furnace at about 1,700°C for 48 hours in an oxidising atmosphere and (3) reheating in a fuel-type furnace to about 1,700°C for 72 hours in a reducing atmosphere. **Thanapong Lhuaamporn** (GIT) gave a presentation for **Thanong Leelawatanasuk** and his co-authors on the characteristics of blue sapphire enhanced using heat and pressure. During a visit to the treatment facility in Korea, they learned that previously treated material is preferred since the rapid heating causes too much damage to unheated stones. Low-temperature annealing of such treated sapphires may be done to lighten their blue colour, and the authors' experiments showed that the colour faded somewhat at around 1,000°C. However, this also caused partial or complete elimination of distinctive features seen in their inclusions and IR spectra. **Shane McClure** also covered sapphires that are heat-treated under pressure, as reported above

for the open colloquium. **Martial Bonnet** (Centre de Recherches Gemmologiques, Nantes) and **Dr Emmanuel Fritsch** proposed a set of seven absorption bands that are common in the infrared spectra of corundum: a broad band consisting of a group at 3220, 3065, 3025 and 2980 cm^{-1}, and other features at 2625, 2460 and 2415 cm^{-1}.

Presentations on biogenic materials covered pearls, coral and ivory. **Bahareh Shirdam** (China University of Geosciences, Wuhan and University of Tehran, Iran) and co-authors studied rumoured Persian amber samples that were reportedly mined in eastern Azerbaijan, Alborz (north-central Iran) and the Tabas Block (east-central Iran). FTIR spectroscopy was used to classify the Persian amber samples as a type III fossilised resin (perhaps derived from *Liquidambar* or Persian ironwood trees), and their thermal behaviour indicated a high degree of maturation. **Dr Laurent Cartier** (Swiss Gemmological Institute SSEF) and co-authors reviewed the DNA fingerprinting of pearls, precious coral and ivory. DNA has been successfully extracted from cultured pearls obtained from three species (*Pinctada maxima*, *P. margaritifera* and *P. radiata*). Recent research shows that DNA can also be obtained from small samples (2 mg) of precious coral and larger samples of ivory. **Dr Stefanos Karampelas** and co-authors (DANAT) provided new insights on the X-ray luminescence of natural and cultured pearls from freshwater and saltwater bivalves. Although yellow-green luminescence is typical of freshwater cultured pearls due to their appreciable manganese contents, some samples with high Mn exhibit much lower luminescence than expected due to Mn^{2+} self-quenching. In addition, saltwater cultured pearls may also display luminescence due to the presence of a freshwater bead combined with thin nacre. **Abeer Al-Alawi** and co-authors (DANAT) described *P. radiata* cultured pearls from Abu Dhabi in the United Arab Emirates. Pearls from this species are rarely cultured. The samples had a nacre thickness of 0.8–2.0 mm, and most of them displayed green to yellowish green fluorescence to long- and short-wave UV radiation. Compared to natural pearls from *P. radiata*, the cultured products showed higher Mg and lower Ba contents. **Anette Juul-Nielsen** (Ministry of Mineral Resources and Labour, Government of Greenland, Nuuk) and **Hans Lange** (Greenland National Museum & Archives, Nuuk) described the past and present use of ivory from Greenland. The raw material is derived from narwhal and walrus, which are traditionally hunted for their meat and skin. While narwhal ivory typically has cracks along interstitial areas of its spirals, walrus ivory displays an oatmeal-like texture and a central layer of secondary dentine that shows stronger UV fluorescence than the surrounding primary dentine.

Several presentations were given in a session on general gemmology. **Dr Ahmadjan Abduriyim** (Tokyo Gem Science and GSTV Gemological Laboratory, Tokyo, Japan) recounted some gem mining activities that took place after 2000, including sapphires from Sri Lanka (2012 at Kataragama and 2015 at Bogawantalawa), sapphires and rubies from Madagascar (2017 at Bemainty), ruby from Montepuez, Mozambique and emerald from Belmont, Brazil. His presentation also described the simultaneous analyses of multiple spots on a gem sample with LA-ICP-MS using galvanometric optics. **This author** provided insights on writing scholarly gem locality articles, offering advice for the successful preparation and execution of a field expedition, as well as subsequently sharing the research in a peer-reviewed journal. **Dr Hao Wang** and co-authors (Swiss Gemmological Institute SSEF) reviewed developments in the multi-element analysis of gem materials and its application to geographical origin determination. Statistical algorithms for processing multi-element data include t-distributed stochastic neighbour embedding (t-SNE), principal component analysis (PCA) and linear discriminant analysis (LDA). The t-SNE technique was most successful for clustering data obtained for Cu+Mn-bearing tourmalines. **Menahem Sevdermish** (Gemewizard Gemological Laboratory, Ramat Gan, Israel) used colour analysis technology applied to 'big data' obtained from stones offered for sale on the Internet (with and without laboratory reports) to explore commercial gem names. He showed differences in the colour borders for 'pigeon blood' ruby and 'cornflower blue' sapphire (according to consumers from various world regions and gem laboratories), 'vivid green' emerald (according to the trade vs. laboratories) and 'Santa Maria' vs. 'classic' aquamarine. He also gave trade insights on gem varieties that are currently popular in various regions of the world and mentioned that millennials seem to prefer lighter-coloured gems since more saturated stones 'look unreal' to them.

In other presentations on general gemmology, **Lore Kiefert** and **Klaus Schollenbruch** (Gübelin Gem Lab, Lucerne, Switzerland) studied damage in gems that occurs when a jewellery repair laser misses the metal and hits the stone. Using an Nd-YAG laser (1054 nm, 1.45 J, 3+ W), they tested a variety of gems and found that the most damage occurred on the back side of each specimen where the laser beam exited the stones. Laser damage can be avoided by lowering the laser power and hand-holding the gem (or at least putting a finger on it) during the repair procedure. **Tom Stephan** (German

Gemmological Association and Johannes Gutenberg University Mainz, Germany) and co-authors performed UV-Vis-NIR spectral fitting for the quantitative determination of Cr^{3+} and V^{3+} in ruby and emerald. Spectral fitting can be used to assess the colour contribution from each element by mathematically deconvoluting the bands into constituent absorptions, thus permitting an understanding of the influence of each chromophore. In corundum, V^{3+} contributes somewhat to red colouration but is mainly involved with colour-change phenomena, while in emerald V^{3+} and Cr^{3+} both contribute to green colouration. **Dr Emmanuel Fritsch** presented research done with his co-author **Martine Philippe** (Paris) on dissolved dislocations in gems (see Conferences section of *The Journal*, Vol. 36, No. 7, 2019, p. 662).

Poster presentations at the IGC were prepared by **Quanli Chen** and co-authors (turquoise from Zhushan, Hubei Province, China), **Gagan Choudhary** and **Sandeep Vijay** (turquoise imitations), **Claude Drouin** and **Dr Emmanuel Fritsch** (history of cubic zirconia), **Dr Karen Fox** and **K. R. Fox** (gemmological applications of the Arduino open-source electronics platform), **Seung Kwon Lee** and **Randy Luo** (optical properties of hackmanite and sodalite), **Zemin Luo** and co-authors (emerald from Prince Liangzhuang's tomb, Ming dynasty, Hubei, China), **Nalin Narudeesombat** and co-authors (Tairus hydrothermal synthetic ruby and blue sapphire), **Dr Thet Tin Nyunt** and co-authors (amber from Khamti, Myanmar), **Elizabeth Su** (rarity and pricing of different colours of jadeite), **Manuela Zeug** and co-authors (characterisation of parisite), and **Zhiqing Zhang** and **Dr Andy Shen** (amber with violet UV fluorescence from Myanmar).

During the closing ceremony, those who transitioned from IGC observers to delegates were announced (Laurent Cartier, Gagan Choudhary, Stephen Kennedy, Dr Andy Shen, Elizabeth Su and this author). The year 2021 will mark the 70th anniversary of the IGC, which will take place in Tokyo, Japan (Figure 5).

Brendan M. Laurs FGA

Figure 5: The IGC banner is passed to Dr Hiroshi Kitawaki (second from the right), who is a co-host of the 2021 IGC in Tokyo, Japan. Also shown (from left to right) are IGC Executive Committee members Willow Wight, Tay Thye Sun, Dr Emmanuel Fritsch and Dr Jayshree Panjikar. Photo by B. M. Laurs.

GEM-A CONFERENCE

On 2–3 November 2019, approximately 265 attendees from 27 countries gathered for the annual Gem-A Conference at etc.venues County Hall in London. Gem-A CEO **Alan Hart** opened the conference and introduced the speakers during the two-day event.

Charlton August (Namdeb, Oranjemund, Namibia) reviewed the history, geology, mining and production from the Namibian diamond mega-placer. Since diamonds were discovered there in 1908, Namibia has produced nearly 107 million carats (Mct) from a variety of secondary deposits: 63 Mct from littoral (onshore and nearshore) sources, 22 Mct from offshore areas, 16 Mct from aeolian (from wind action) sands, 5 Mct from fluvial deposits along the Orange River and 0.5 Mct from pocket beaches. Namdeb's future activities will focus on further mining of onshore/nearshore areas (through westward beach accretion for up to several hundred metres) and exploration of ancient fluvial sediments that lie under and to the north of the town of Oranjemund.

Dr Barbara Dutrow (Louisiana State University, Baton Rouge, Louisiana, USA) described the history and uses of tourmaline as a gemstone, reviewed its crystal structure and chemical composition, and then explained how it serves as an important recorder of geological information (see also the Conferences section of *The Journal*, Vol. 36, No. 4, 2018, p. 360). As such, it is perhaps the best 'geological storyteller' of any gem material.

Rachel Dery (Gem Legacy, Royal Oak, Michigan, USA) profiled the Gem Legacy initiative, which aims to use coloured gemstones to create tangible, quantifiable change in mining communities in East Africa.

Figure 6: Gem-A CEO Alan Hart takes questions from the audience for conference speaker Prof. Fabrizio Nestola. Photo by Henry Mesa.

Gem Legacy supports education, vocational training and local economies, as demonstrated by activities such as building a school and hiring a teacher in Malawi, improving a gem faceting school in Tanzania, and funding the purchase of beds for a children's home in Kenya. Other important activities include addressing the needs expressed by miners and dealers through training and equipment acquisition.

Prof. Fabrizio Nestola (University of Padua, Italy; Figure 6) provided a connection between diamonds and the origin of the earth's oceans. He differentiated the formation of diamonds in the lithosphere (i.e. at 130–200 km depth) from those of 'superdeep' origin that are thought to have crystallised in the Earth's mantle at depths of up to 800–1,000 km. Recent research has shown that lithospheric diamonds can contain mineral inclusions that are surrounded by thin hydrous films, whereas superdeep diamonds can host inclusions that themselves may contain water (e.g. hydrous ringwoodite), indicating that large amounts of water reside in the mantle. This suggests that the oceans could have an 'internal' origin (e.g. from water initially present in the earth that slowly ascended to the surface), as well as an external origin (e.g. from other sources such as comets).

Nathan Renfro (Gemological Institute of America, Carlsbad, California) took the audience on a microscopic journey through gemstones. He explained how to use diffusers and fibre-optic illumination for optimising the lighting to show internal or external features of gems, and also discussed specialised microscopic techniques such as focus stacking and differential interference contrast. He then displayed numerous engaging photomicrographs, including a looped sequence of images of a diamond containing a mobile diamond inclusion.

Anette Juul-Nielsen (Ministry of Mineral Resources and Labour, Nuuk, Greenland) reviewed the geology and gem materials of Greenland. In addition to deposits of ruby and pink sapphire, Greenland hosts tugtupite, nuummite (aggregates of iridescent amphibole), greenlandite (microcrystalline aventurine quartz), labradorite, chalcedony, garnet, kyanite, amazonite, eudialyte, diamond and biogenic gems (bone, ivory, baleen, horn, etc.). In 2012, legislation was introduced to encourage small-scale gem mining by permanent residents, and ongoing geological mapping is also taking place in support of the gem industry.

Richard Drucker (Gemworld International Inc., Glenview, Illinois, USA) focused on gem market trends, issues and challenges. He discussed the pricing of sapphire, ruby, emerald, tanzanite, fancy-colour zoisite and red spinel, and then covered issues surrounding gem nomenclature such as the distinction between 'Paraíba' and 'cuprian' tourmaline in his pricing guides, the definition of alexandrite by gem laboratories and the use of commercial trade names for describing gem colour. He also reviewed some items that create pricing challenges such as synthetic diamonds (especially when treated), crazed opal and very large faceted stones.

Rui Galopim de Carvalho (Gem Education Consultant, Lisbon, Portugal) recounted the history of Brazilian diamonds. They were first recognised in the 1720s, and eventually the Brazilian deposits produced about 10 times more than those in India. The increased availability of diamonds from Brazil coincided with a change

in jewellery styles from intricate metalwork in the 17th through early 18th centuries to designs in which stones were dominant. Historically Brazilian production came only from alluvial deposits, although recently (in 2016) the first kimberlite pipe mine opened at Braúna in Bahia State, and ongoing exploration projects are targeting other primary deposits.

John Bradshaw (Coast to Coast Rare Stones, Nashua, New Hampshire, USA) described rare gemstones. Of the approximately 200 species that have been faceted, 25 are routinely seen in the trade and the other 175 are considered rare or collector stones. He described the properties, availability and pricing of some of these gems, including taaffeite, sphalerite, fluorite, benitoite, crocoite and haüyne. He also mentioned that recent production of fine-quality rhodonite from Brazil is expected to enter the market in the near future.

Dr Laurent Cartier (Swiss Gemmological Institute SSEF, Basel, Switzerland) covered diamonds from Sierra Leone. Large areas of the country are prospective for alluvial and primary deposits, but relatively little exploration or formal mining has taken place. Artisanal miners account for 80% of the production, mostly from gravel deposits adjacent to rivers. In addition, small teams work in the rivers themselves, diving as deep as 10 m to load diamond-bearing gravel into buckets. Cartier showed a new documentary film on the diamond divers that he produced with a videographer from a recent visit to Sierra Leone in April 2019.

The conference was closed by Gem-A President **Maggie Campbell Pedersen**, who reviewed the diversity of topics presented.

On 4 November, four workshops were held at Gem-A's headquarters: precious coral identification with **Rui Galopim de Carvalho**, new types of cultured pearls with **Dr Laurent Cartier**, visual optics with **Pat Daly** (Gem-A, London), and coloured stone grading and pricing with **Richard Drucker**. That evening marked Gem-A's graduation ceremony and presentation of awards at the Royal Institution of Great Britain in London.

On 5 November, field trips took attendees to private viewings of the British Crown Jewels at the Tower of London, a behind-the-scenes tour of the gem and mineral collection at the Natural History Museum, and a handling session with Indian jewellery objects at the Victoria and Albert Museum.

Brendan M. Laurs FGA

Gem-A Notices

GEM-A CONFERENCE 2019

This year's Gem-A Conference was held at etc.venues County Hall, London, on 2–3 November. Details of the speaker presentations are reported in the Conferences section of this issue of *The Journal*, pages 766–775, and a round-up of all the highlights from the 2019 Conference will be published in *Gems&Jewellery* (Vol. 29, No. 1, 2020). Practical gemmology workshops on precious coral identification, visual optics, new types of cultured pearls, and coloured stone grading and pricing were held at Gem-A HQ on Monday 4 November. On Tuesday 5 November, some delegates attended exclusive private excursions to three of London's best-known museums. At the Victoria and Albert Museum, attendees participated in an Indian jewellery handling session, while visitors to the Tower of London got a tour of the British Crown Jewels, and another group went behind the scenes at the Natural History Museum's gem and mineral gallery.

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We would also like to thank DG3 Diversified Global Graphics Group (www.dg3.com) for producing the Gem-A Conference materials.

GRADUATION CEREMONY

The 2019 Gem-A Graduation Ceremony was held at the Royal Institution of Great Britain, Albemarle Street, London, on 4 November. Gem-A CEO Alan Hart FGA DGA presented Gemmology and Diamond Diplomas to Gem-A graduates from around the world.

Following the presentation of the Diplomas, Joanna Hardy FGA DGA provided this year's speaker's address, in which she congratulated graduates on achieving such difficult and prestigious qualifications, and spoke of how Gem-A's education helped her develop a successful career in the jewellery industry. Joanna was then joined by Gem-A President Maggie Campbell Pedersen FGA ABIPP to present the Gem-A Medals and Prizes (see pp. 784–785).

Joanna Hardy FGA DGA and Alan Hart FGA DGA with Gem-A's 2019 graduates. Photo by Tempest Photography.

GEMMOLOGY DIPLOMA PASSES

Marianne Pughe, United Kingdom
Lilian Venetia Vildiridi, United Kingdom
Yi-Hong Wu, Taiwan (R.O.C.)
Ahmad Shajaie, Canada
Kay Yee Wong, Hong Kong (S.A.R.)
Emma Barton, United Kingdom
Shan Shan Lai, Hong Kong (S.A.R.)
Chui Ting Lau, Hong Kong (S.A.R.)
Rong Sun, P.R. China
Anuruddha Dharmasiri, Sri Lanka
Edyta Banasiak, United States of America
Elizabeth Bailey, United Kingdom
Meng-Yao Lin, Taiwan (R.O.C.)
Sammantha Maclachlan, United Kingdom
Kenneth Fogelberg, United States of America
Yuk Ting Ng, Hong Kong (S.A.R.)
Alisha Duffy, United Kingdom
Nadia Usman, United Kingdom
Chin Ching Ho, Hong Kong (S.A.R.)
Haibin Huang, P.R. China
Nancy Herdman, United Kingdom
Beverley Warden-Owen, Wales, United Kingdom
Chun Ki Stanley Yu, Hong Kong (S.A.R.)
Tatiana Poliakova, France

Anouck Armand, France
Pok Tso, Hong Kong (S.A.R.)
Mohammedi Siyam, India
Mialy Rakotoarison Amboara, Madagascar
Jemma Beeley, United Kingdom
Jingling Zhao, P.R. China
Yi Ni Li, P.R. China
Bing Yin Lee, Hong Kong (S.A.R.)
Kim Hung Kwee, Hong Kong (S.A.R.)
Shu Hung Wong, Hong Kong (S.A.R.)
Marie Bellard, United States of America
Chun Shan Tang, Hong Kong (S.A.R.)
Charlotte Elmér, Sweden
Lily Reynolds, United Kingdom
Rachel Healy, Republic of Ireland
Augusto Castillo, United States of America
Eleonore De Liedekerke, Germany
Sui-Ying Hsu, Taiwan (R.O.C)
Chor-Man Tang, Hong Kong (S.A.R.)
Suet Ying Ng, Hong Kong (S.A.R.)
Po Yin Leung, Hong Kong (S.A.R.)
Jorge Esteban Alvarado, France
Yanshi Wei, P.R. China
Karine Pollien, France
Shufei Wang, P.R. China
Jiabao Li, P.R. China
Xi Ge, P.R. China
Shuwen Yang, P.R. China
James Evans, United Kingdom
Elizabeth Gass, United States of America
Ank Trumpie-van Eijndhoven, The Netherlands
Sergé Kreher, The Netherlands
Fang Wen, P.R. China
Meng Meng Cui, P.R. China
Lan Wu, P.R. China
Fiona Haines, United Kingdom
Kelly (Jing) Dang, Hong Kong (S.A.R.)
Lezlie Bailey, United Kingdom
Michael Kay, South Korea
Wei-Ting Chang, Taiwan (R.O.C.)
Melissa Allen, United States of America
Yukari Hirashima, Japan
Marian Holt, United States of America
Tsz Fun Lee, Hong Kong (S.A.R.)
Hsuan-Ju Lee, Taiwan (R.O.C.)
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Yuchen Cheng, P.R. China
Zhelin Zhu, P.R. China
Mingyue Cui, P.R. China
Yan Yang, P.R. China
Miho Murata, Japan
Ayako Takahashi, Japan
Jean-Marie Gaultier, France
Kanjing Liu, P.R. China
Arabella Toler, United Kingdom
Zainab Rajab, Bahrain
Zainab Mohammed, Bahrain
Fatima Albedal, Bahrain
Fatema Almahmood, Bahrain
Bader Alshaybani, Bahrain
Fatema Makhlooq, Bahrain
Tyler Smith, United States of America
Henri Boussin, France
Solofo Emilien Rabenantoanina, Madagascar
Paulette Blot, France
Andrew Culpan, United Kingdom
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Wanqiang Ma, Japan
Sayo Imura, Japan
Rumi Tasaka, Japan
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Yim Yu Cheng, P.R. China
Yuen Wai Hung, P.R. China
Wing Yan Tang, P.R. China
Nicole Flavell-Avery, United Kingdom
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Xuefei Quan, P.R. China
Miao-Chan Chang, Taiwan (R.O.C.)

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Khin Kathy Kyaw, Myanmar
Su Myat Htet, Myanmar
Junjun Shen, P.R. China
Guiyang Ke, P.R. China
Zhiwei Mo, P.R. China
Yao Wang, P.R. China
Yuxi Jing, P.R. China
Siyan Liu, P.R. China
Ruocao Wang, P.R. China
Yijing Yan, P.R. China
Meng Yi, P.R. China
Weiting Zhang, P.R. China
Charlotte Glyde, United Kingdom
Noriko Tsuchiya, Japan
Junpei Yamada, Japan
Tomoe Kawamura, Japan
Qian Shi, P.R. China
Qianyi Zhang, P.R. China
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Huaiyu Gong, P.R. China
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Bokun Hao, P.R. China
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Liansai Wang, P.R. China
Dalin Wu, P.R. China
Lu Bai, P.R. China
Shuo Kong, P.R. China
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Yuying Chen, P.R. China
Minxuan Song, P.R. China
Dehua Xu, P.R. China
Meng Wang, P.R. China
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Monique De Klonia, The Netherlands
Anita Matharu, United Kingdom
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Note: Yi Shen should have been listed under 'Gemmology Diploma Passes with Distinction'.

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Xueli Wu, P.R. China
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Jie Chen, P.R. China
Wenhong Chen, P.R. China
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Zhikang Hu, P.R. China
Huixuan Huo, P.R. China
Haochan Lei, P.R. China
Jinyuan Li, P.R. China
RunQi Li, P.R. China
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Xu Miao, P.R. China
Yu Wang, P.R. China
Susu Xia, P.R. China
Na Yan, P.R. China

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Xiaomeng Ma, P.R. China
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Yu Yi Kao, Taiwan (R.O.C)
Rojoniaina François Maurice Sandranirina, Madagascar
Chih-Yu Wu, Taiwan (R.O.C)
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Yuyan Lu, P.R. China
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Lu Song, P.R China
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Anne Galmiche, United Kingdom
Katrina Hughes, United Kingdom
Catherine Fox, United Kingdom
Kazusa Tachibana, Japan
Connie Bacon, United Kingdom
Liang Zhang, P.R. China
Simone Dunlop, United Kingdom
Kristin Chase, United States of America
Hiromu Kanamori, Japan
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Ruyin Jia, P.R. China
Xiaoyao Li, P.R. China
Fangge Liu, P.R. China

Junqi Ma, P.R. China
Ying Yan, P.R. China
Ziyue Yang, P.R. China
Xue Gao, P.R. China
Ying Jiang, P.R. China
Francisca Xiaodan Liu, P.R. China
Siwen Zhou, P.R. China

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Patricia Campion, United Kingdom
Yixuan Zhang, P.R. China
Laury Fondi, France
Lucas Berruyer, France
Wen-Hsin Cheng, Taiwan (R.O.C)
Ziling Liu, P.R. China
Weihua Huang, P.R. China
Siqi Ma, P.R. China
Bo Niu, P.R. China
Lei Zhang, P.R. China
Yining Zhuang, P.R. China
Lizhen Jiang, P.R. China
Yi Shen, P.R. China

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Kwai Fong Maggie Pong, Hong Kong (S.A.R.)
Chi Ho Lau, Hong Kong (S.A.R.)
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Ka Mei Ho, Hong Kong (S.A.R.), China
Chak Hang Jeffrey Kong, Hong Kong (S.A.R.)
Pui Sze Lam, Hong Kong (S.A.R.)
Kwok Ching Wong, Hong Kong (S.A.R.)
Wai Kei Yim, Hong Kong (S.A.R.)
Wing Sing Cho, Hong Kong (S.A.R.)
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Wai Sum Sze, Hong Kong (S.A.R.)
Sunny Pal, United Kingdom
Wen Li Jheng, Taiwan (R.O.C)
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Rasika Kirad, India
Wing Yee Fung, Hong Kong (S.A.R.)
Francesca De Watts, Hong Kong (S.A.R.)
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Chiu Kwan Mang, Hong Kong (S.A.R.)
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Sin Yiu Shirley Lam, Hong Kong (S.A.R.)
Yuet Sheung Peggy Leung, Hong Kong (S.A.R.)
Yuk Ling Abey Lai, Hong Kong (S.A.R.)
Man Wai Debbie Leung, Hong Kong (S.A.R.)
Mong Suet Ng, Hong Kong (S.A.R.)
Nicola Whiting, United Kingdom
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Pei-Hsien Kevin Chou, Taiwan (R.O.C)
Teng-Yun Chang, Taiwan (R.O.C)

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Beverley Warden-Owen, United Kingdom
Charlotte Williams, United Kingdom
Kit Yi Ho, Hong Kong (S.A.R.)
Samantha Hobson, United Kingdom
Hui-Ming Lai, Taiwan (R.O.C)
Victoria Sparkes, Switzerland
Wai Yiu Wong, Hong Kong (S.A.R.)
Min-Yi Lin, Taiwan (R.O.C)
Sarah Kinsey, United Kingdom
Kim Hung Kwee, Hong Kong (S.A.R.)
Shuai Wu, Hong Kong (S.A.R.)

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Lorna McNaught, United Kingdom
Samuel Capstick, United Kingdom
Amber Rose Roberts, United Kingdom
Samantha Homes, United Kingdom
Leonie Armin, United Kingdom
Daisy Welford-Ranson, United Kingdom
Amy Zgraja, United Kingdom
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Michel Phanekham, Thailand
Taffy Schneider, United Kingdom
Wai Kiu Vicky Zee, Hong Kong (S.A.R.)

PRIZE AND MEDAL WINNERS

Awards and prizes are presented to the best candidates of the year, selected from our students worldwide.

GEMMOLOGY FOUNDATION CERTIFICATE

Anderson Medal

Awarded to the candidate submitting best papers of the year in the Gemmology Foundation examination.

This medal was established in 1981 in honour of Basil W. Anderson FGA, former Director of the Gem Testing Laboratory, London.

2019 Winner: Maxime Fondi, a student from École de Gemmologie de Montréal, Canada

GEMMOLOGY DIPLOMA

Christie's Prize for Gemmology

Awarded to the candidate submitting the best papers of the year for the Gemmology Diploma examination.

This prize was established in 1954 as the Rayner Prize, renamed the Diploma Trade Prize in 1991, replaced and sponsored from 2001 by Christie's London.

2019 Winner: Yuying Chen, a student from China University of Geosciences, Wuhan (Beijing Branch)

Anderson Bank Prize

Awarded to the candidates submitting the best theory papers of the year for the Gemmology Diploma examination.

Established in 1981 and named after Basil W. Anderson FGA and Prof. Dr Hermann Bank FGA, former director of the German Gemmological Association in Idar-Oberstein, Germany.

2019 Winners: Sarah Bromfield, an online student from UK and Yuying Chen, a student from China University of Geosciences, Wuhan (Beijing Branch)

The Read Practical Prize

Awarded to the candidate submitting the best practical papers of the year for the Gemmology Diploma examination.

First awarded in 2009 and named in memory of Peter Read FGA, author and former tutor for Gem-A. In 2019 the prize is sponsored by Richard Drucker FGA (Hons) of Gemworld International.

2019 Winner: Ziyu Zhou, a student from China University of Geosciences, Wuhan (Beijing Branch)

Gem-A would like to congratulate all of our students who achieved such fantastic results!

DIAMOND DIPLOMA

The Deeks Diamond Prize

Awarded to the candidates submitting the best theory papers of the year for the Diamond Diploma examination.

First awarded in 2001, the prize is sponsored by Noel W. Deeks FGA DGA, a Vice-President of the Association who taught the diamond course for many years.

2019 Winners: Zoe Lewis, an online student from UK and Stephane Wainer, an online student from Singapore

The Mok Diamond Practical Prize

Awarded to the best practical candidate in the Diamond Practical examination.

First awarded in 2009 and sponsored by Dr Dominic Mok FGA DGA, AGIL, Hong Kong.

2019 Winner: Daisy Welford-Ranson, a student of Gem-A London

The Bruton Medal

Awarded to the overall best candidate of the year in the Diamond Diploma examination.

This silver medal was established in 1996 in honour of Eric Bruton FGA to recognise his work in the field of diamonds.

2019 Winner: Stephane Wainer, an online student from Singapore

GIFTS TO THE ASSOCIATION

Gem-A is most grateful to the following for their generous donations that will support continued research and teaching:

Dr Dominic Mok, Hong Kong, for an ABCD Pro-1 Gem Testing Set.

Brigitte Rust, Bonn, Germany, for six issues of the *GemGuide* dating from Nov.–Dec. 2018 to Sep.–Oct. 2019 for use by Gem-A students.

Alison Summerville, Queensland, Australia, for 14 pieces of boulder opal and matrix opal.

Tay Thye Sun, Far East Gemological Laboratory, Singapore, for a sample of Burmese amber.

Ward Gemstones, Hatton Garden, London, for a lapis lazuli simulant.

GEM-A ANNUAL GENERAL MEETING 2019

The 2019 Gem-A AGM took place at etc.venues Hatton Garden, London, on 31 October and was opened by Chair of the Association's Board of Trustees Justine Carmody FGA. In accordance with the articles of the Association, trustees Kathryn Bonanno FGA and Christopher Smith FGA retired by rotation. Being eligible, each offered themselves for re-election and were reinstated. Following her appointment by trustees in January 2018, Nevin Bayoumi-Stefanovic was also elected to the Council.

In other business, the role of Gem-A trustees and their relationship with Gem-A staff was discussed, as was Gem-A's history and activity in Sri Lanka. The contributions of Evelyne Stern to Gem-A over many years were recognised, following her recent retirement as a Diamond Diploma examiner. In addition, there was a positive discussion about the diversity of the speakers scheduled for the 2019 Gem-A Conference.

Learning Opportunities

CONFERENCES AND SEMINARS

22nd FEEG Symposium
25–27 January 2020
Schoonhoven, The Netherlands
www.feeg-education.com/symposium

NAJA 53rd ACE© IT Annual Winter Conference
2–3 February 2020
Tucson, Arizona, USA
www.najaappraisers.com/html/conferences.html

ASA Fundamentals of Jewelry Appraisal Course
3 February 2020
Tucson, Arizona, USA
www.appraisers.org/Education/View-Class?ClassID=4282

AGTA Gemfair Tucson
4–9 February 2020
Tucson, Arizona, USA
https://agta.org/seminars
Note: Includes a seminar programme

AGA Tucson Conference
5 February 2020
Tucson, Arizona, USA
https://accreditedgemologists.org/currevent.php

Tucson Gem and Mineral Show
13–16 February 2020
Tucson, Arizona, USA
www.tgms.org/show
Note: Includes a seminar programme

Inhorgenta Munich
14–17 February 2020
Munich, Germany
www.inhorgenta.com/en/trendfactory/trendfactory-munich
Note: Includes a seminar programme

Prospectors & Developers Association of Canada
1–4 March 2020
Toronto, Ontario, Canada
www.pdac.ca/convention/programming/technical-program
Theme of interest: The Business of Diamonds: From Rock to Ring

ASA Fundamentals of Jewelry Appraisal Course
2 March 2020
Carlsbad, California, USA
www.appraisers.org/Education/View-Class?ClassID=4304

36th International Geological Congress
2–8 March 2020
Delhi, India
www.36igc.org
Note: Sessions of interest include Geology and Gemstones; Advances in Synthetic Gemstones; Diamonds Today; Gem Species and their Varieties; field trips will visit the diamond fields of southern India and the Indian Institute of Gems & Jewellery's training and educational institute in Jaipur

Hong Kong International Jewellery Show
4–8 March 2020
Hong Kong
https://event.hktdc.com/fair/hkjewellery-en/HKTDC-Hong-Kong-International-Jewellery-Show
Note: Includes a seminar programme

DES-AGIL International Gemmological Conference
8 March 2020
Hong Kong
www.agil.com.hk/en/news.php?newsid=140

MJSA Expo
15–17 March 2020
New York, New York, USA
https://mjsa.org/eventsprograms/mjsa_expo
Note: Includes a seminar programme

Amberif
18–21 March 2020
Gdańsk, Poland
http://amberif.amberexpo.pl/title,Jezyk,lang,2.html
Note: Includes a seminar programme

10th National Opal Symposium
8–9 April 2020
Coober Pedy, Australia
www.opalsymposium.org

47th Rochester Mineralogical Symposium
23–26 April 2020
Rochester, New York, USA
www.rasny.org/minsymp

American Gem Society Conclave
27–29 April 2020
Denver, Colorado, USA
www.americangemsociety.org/mpage/conclave2020-home

Scottish Gemmological Association Conference
1–4 May 2020
Cumbernauld, Scotland
www.scottishgemmology.org/conference

European Geosciences Union (EGU) General Assembly 2020
3–8 May 2020
Vienna, Austria
www.egu2020.eu
Session of interest: Heritage Stones: Global Relevance vis-à-vis Architectonic Heritage

6th Mediterranean Gemmological & Jewellery Conference
15–17 May 2020
Thessaloniki, Greece
https://gemconference.com

34th Annual Santa Fe Symposium
17–20 May 2020
Albuquerque, New Mexico, USA
www.santafesymposium.org

49th Annual Society of North American Goldsmiths Conference
20–23 May 2020
Philadelphia, Pennsylvania, USA
www.snagmetalsmith.org/conferences/grit-to-gold-future-fifty-2020-snag-conference

14th International Conference on New Diamond and Nano Carbons
31 May–4 June 2020
Kanazawa, Japan
www.ndnc2020.org

JCK Las Vegas
2–5 June 2020
Las Vegas, Nevada, USA
https://lasvegas.jckonline.com
Note: Includes a seminar programme

Swiss Gemmological Society Conference
7–9 June 2020
St Gallen, Switzerland
http://gemmologie.ch/en/current

Diamonds – Source to Use 2020
9–11 June 2020
Johannesburg, South Africa
www.saimm.co.za/saimm-events/upcoming-events/diamonds-source-to-use-2020

Goldschmidt Conference
21–26 June 2020
Honolulu, Hawaii, USA
https://goldschmidt.info
Session of interest: Geochemistry of Gem Minerals

Sainte-Marie-aux-Mines Mineral & Gem Show
25–28 June 2020
Sainte-Marie-aux-Mines, France
www.sainte-marie-mineral.com
Note: Includes a seminar programme

9th International Conference Mineralogy and Museums
5–7 July 2020
Sofia, Bulgaria
www.bgminsoc.bg
Note: Gem minerals will be covered in a session titled 'Mineralogical Research and Museums'.

2020 Antique Jewelry & Art Conference
25–26 July 2020
Phillips, New York, USA
www.jewelrycamp.org

Dallas Mineral Collecting Symposium
20–23 August 2020
Dallas, Texas, USA
www.dallassymposium.org

3rd European Mineralogical Conference (emc2020)
6–10 September 2020
Krakow, Poland
https://emc2020.ptmin.eu
Session of interest: Gem Materials

International Jewellery London
13–15 September 2020
London
www.jewellerylondon.com
Note: Includes a seminar programme

31st International Conference on Diamond and Carbon Materials
13–17 September 2020
Palma, Mallorca, Spain
www.elsevier.com/events/conferences/international-conference-on-diamond-and-carbon-materials

2020 American Society of Appraisers International Conference
11–13 October 2020
Chicago, Illinois, USA
www.appraisers.org/Education/conferences/asa-international-conference

Japan Jewellery Fair 2020
14–16 October 2020
Tokyo, Japan
www.japanjewelleryfair.com/en
Note: Includes a seminar programme

Munich Show: Mineralientage München
30 October–1 November 2020
Munich, Germany
https://munichshow.de/?lang=en
Note: Includes a seminar programme

OTHER EDUCATIONAL OPPORTUNITIES

Gem-A Workshops and Courses
Gem-A, London
https://gem-a.com/education

Lectures with Gem-A's Midlands Branch
Fellows Auctioneers, Augusta House, Birmingham
Email Louise Ludlam-Snook at gemamidlands@gmail.com

- Dr Maria MacLennan—Forensic Jewellery
  28 February 2020
- Peter Buckie—The Treasures Seen by an Expert Valuer
  27 March 2020
- Roy Starkey—Minerals of the English Midlands
  24 April 2020

Lectures with The Society of Jewellery Historians
Society of Antiquaries of London, Burlington House, London
www.societyofjewelleryhistorians.ac.uk/current_lectures

- Thomas Holman—A Box Full of Buttons: The Life and Work of Frederick James Partridge (1877–1945)
  28 January 2020
- Stephen Whittaker—TBA
  25 February 2020
- Carol Michaelson—Chinese Jade Jewellery and Ornaments from the Neolithic to the Present
  24 March 2020
- Ute Decker—TBA
  26 May 2020
- Kirstin Kennedy—TBA
  23 June 2020

Gemstone Safari to Tanzania
8–25 July 2020
www.free-form.ch/tanzania/gemstonesafari.html

Mineralogical Expedition to the Ural Mountains, Russia
13–18 July 2020
www.brankogems.com/shop/tours/july-13-18-2020-ural-mineralogical-expedition

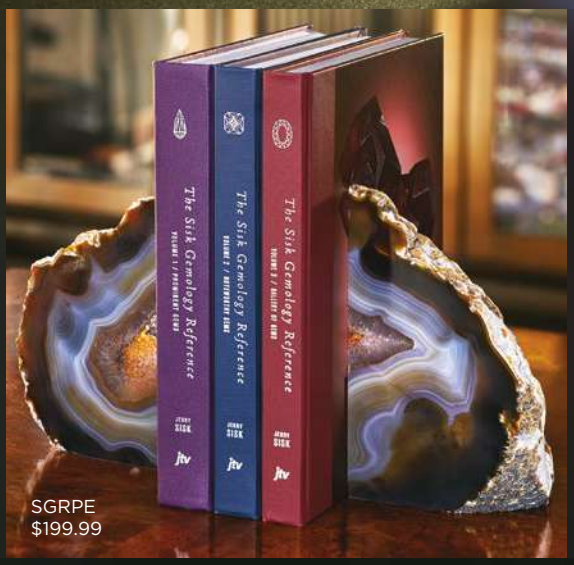

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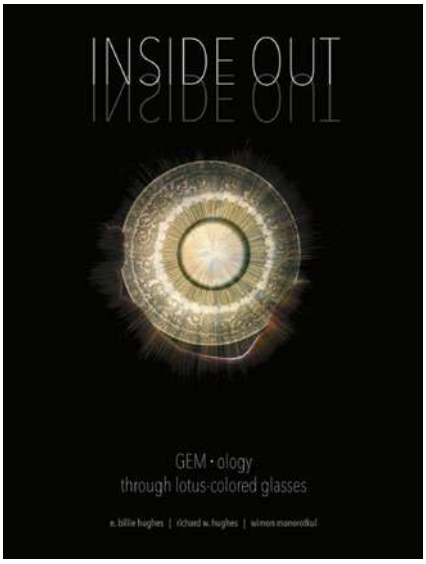

Inside Out: GEM•ology Through Lotus-Colored Glasses

By E. Billie Hughes, Richard W. Hughes and Wimon Manorotkul, 2020. Lotus Publishing, Bangkok, Thailand, and RWH Publishing, Boulder, Colorado, USA, www.lotusgemology.com/index.php/library/books/454-inside-out-gemology-through-lotus-colored-glasses-2020, 152 pages, illus., ISBN 978-0964509733 (in English and Simplified Chinese). USD100.00 (+ shipping) hardcover.

Inside Out: GEM•ology Through Lotus-Colored Glasses is not a book on gemmology or gem deposits in the literal sense. With its large format and masterful photographs, the reader experiences the emotions associated with gemstones. The book reflects in a great way the term *humanistic gemology*, as coined by co-author Richard Hughes. It is primarily about the pictorial representation of the interplay between the inner beauty of gemstones and the people who mine, process and act on them. Thus, the authors have captured the local people and environments in unique moments during their many journeys to important gem-producing regions. These images are juxtaposed with the microscopic world of inclusions in gemstones from these regions, so the aesthetics and emotions associated with the stones emerge equally.

The photographs are of the highest quality, in terms of both selection and technical implementation. The choice of the 'right' moment, which is of decisive importance to capture a mood or emotion, is particularly noticeable in the photos of people. Furthermore, Billie Hughes' micrographs reveal a diverse and incredibly rich world of the inner aesthetics of gemstones. Anyone who has ever photographed gem inclusions knows how difficult it is from a technical point of view. The photomicrographs in this book are excellent from both a technical and artistic point of view. An outstanding example of this is the depiction of a pyrite crystal in quartz on page 20.

This book fills a gap in the literature on gems by pictorially exploring the relationship between humans and gems on an artistic and emotional level. It is a work of art that lives from the quality of the photographs and gets by with minimal textual commentary on the images. The book is aimed at both experts and people who see gems as an important part of culture, as well as decorative objects in jewellery and other merchandise.

Michael Hügi FGA
Swiss Gemmological Society
Bern, Switzerland

Looking at Jewelry: A Guide to Terms, Styles, and Techniques

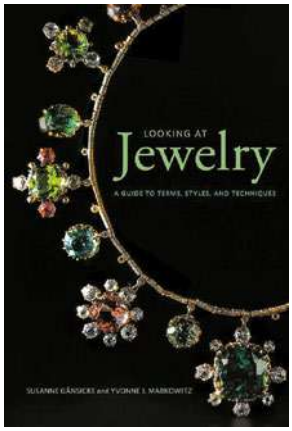

By Susanne Gänsicke and Yvonne J. Markowitz, 2019. Getty Publications, Los Angeles, California, USA, https://shop.getty.edu/products/looking-at-jewelry-br-a-guide-to-terms-styles-and-techniques-978-1606065990, 132 pages, illus., ISBN 978-1606065990. USD19.95 softcover.

This is a nicely produced book with excellent colour illustrations. It has a long introduction that gives an overview of jewellery through the ages. The 'meat' (and indeed the main purpose) of the book is the hundred-page alphabetical glossary. This is essentially a dictionary of jewellery. Surprisingly, it claims to be the first of its kind, although it mentions

the well-regarded *An Illustrated Dictionary of Jewelry* (1987) by Harold Newman in its suggested reading list. No mention is made of the earlier and really excellent *Illustrated Dictionary of Jewellery* (1973) by Anita Mason and Diane Packer.

Many of the entries provide very good comprehensive information, often aided by appropriate illustrations. Some entries are, however, extremely unsatisfactory. For example, imitation and synthetic gems are dealt with under 'Artificial Stone', which only describes Verneuil's method of producing synthetic corundum, in spite of many very long-standing better techniques. Also, 'Assay' is described only as using acid on a touchstone. The more accurate cupellation (fire assay) method has been employed for many centuries, and now XRF instrumentation can analyse metals non-destructively with extraordinary accuracy. It would seem that a wider range of specialist editors would have greatly improved the glossary. A minor irritation for some European readers in using the alphabetical glossary is the American spelling convention (e.g. the purity of gold is listed under 'Karat' rather than 'Carat').

In spite of these drawbacks, this is a useful, wide-ranging dictionary at a relatively modest price.

Nigel Israel FGA DGA
London

Other Book Titles

COLOURED STONES

Rubellite—Tourmaline Rouge
Ed. by William B. Simmons, Gloria A. Staebler, David W. Bunk, Alexander U. Falster, Sarah L. Hanson and Karen W. Webber, 2019. Lithographie, Arvada, Colorado, USA, 148 pages, ISBN 978-0983632399. USD40.00 softcover.

DIAMOND

Diamond Crystals
Ed. by Yuri N. Palyanov, 2019. MDPI, Basel, Switzerland, 174 pages, ISBN 978-3038976301 (print) or ISBN 978-3038976318 (PDF), https://doi.org/10.3390/books978-3-03897-631-8. CHF55.25 softcover or free PDF. *Note:* This book is a printed edition of a special issue on diamond crystals published in the journal *Crystals*.

Hardness 10, 3rd edn.
By Eddy Vleeschdrager, 2018. I. David, Antwerp, Belgium, 1,362 pages, ISBN 978-9090298474. EUR110.00 hardcover.

Novel Aspects of Diamond: From Growth to Applications, 2nd edn.
Ed. by Nianjun Yang, 2019. Topics in Applied Physics Vol. 121, Springer, Cham, Switzerland, 507 pages, ISBN 978-3030124687 (print) or 978-3030124694 (eBook), https://doi.org/10.1007/978-3-030-12469-4. EUR155.99 hardcover or EUR118.99 eBook.

The Origins of Natural Diamonds
By N. O. Sorokhtin, 2019. Scrivener Publishing, Beverly, Massachusetts, USA, 528 pages, ISBN 978-1119593447 (print) or 978-1119593461 (eBook), https://doi.org/10.1002/9781119593461. USD249.00 hardcover or eBook.

GEM LOCALITIES

Minerals of the English Midlands
By Roy E. Starkey, 2018. British Mineralogy Publications, Bromsgrove, Worcestershire, 426 pages, ISBN 978-0993018237. GBP35.00 softcover.

GENERAL REFERENCE

Gemstones: Identifying and Using the World's Most Fabulous Gems
By Judith Crowe, 2019. Bloomsbury Publishing, London, 192 pages, ISBN 978-1912217854. GBP25.00 hardcover.

JEWELLERY HISTORY

The Wyvern Collection: Medieval and Later Ivory Carvings and Small Sculpture
By Paul Williamson, 2019. Thames & Hudson, New York, New York, USA, 448 pages, ISBN 978-0500022832. USD95.00 hardcover.

JEWELLERY AND *OBJETS D'ART*

Be Jeweled
By Patrizia di Carrobio, 2018. Edizioni Polistampa, Florence, Italy, 144 pages, ISBN 978-8859617532. EUR14.00 softcover.

Bulgari: The Story, the Dream
Ed. by Chiara Ottaviano and Lucia Boscaini, 2019. Rizzoli, New York, New York, USA, 328 pages, ISBN 978-8891824325. USD65.00 hardcover.

Contemporary Jewellery in Portugal
By Cristina Filipe, 2019. Arnoldsche Art Publishers, Stuttgart, Germany, 408 pages, ISBN 978-3897905658. EUR54.00 hardcover.

Crystals in Art: Ancient to Today
By Lauren Haynes and Joachim Pissarro, 2019. University of Arkansas Press, Fayetteville, Arkansas, USA, 304 pages, ISBN 978-1682261118, https://doi.org/10.2307/j.ctvqsf33c. USD44.95 softcover.

Diamonds: The Collection of Benjamin Zucker
By Diana Scarisbrick, 2019. Les Enluminures, New York, New York, USA, 340 pages, ISBN 978-0578420189. USD50.00 softcover.

Lacloche Joailliers/Lacloche Jewellers
By Laurence Mouillefarine and Véronique Ristelhueber, 2019. Éditions Norma, Paris, France, 320 pages, ISBN 978-2376660248 (in English and French). EUR60.00 hardcover.

The Power of Love: Jewels, Romance and Eternity
By Beatriz Chadour-Sampson, 2019. Unicorn Publishing Group, London, 144 pages, ISBN 978-191164464. GBP25.00 hardcover.

Rings of the 20th and 21st Centuries: The Alice and Louis Koch Collection
By Beatriz Chadour-Sampson, 2019. Arnoldsche Art Publishers, Stuttgart, Germany, 304 pages, ISBN 978-3897905160 (in English and German). USD115.00 hardcover.

PEARLS

Marchands de Perles: Redécouverte d'une Saga Commerciale entre le Golfe et la France à l'aube du XXe Siècle/Pearl Merchants: A Rediscovered Saga Between the Gulf & France at the Dawn of the 20th Century
By Guillaume Glorieux and Olivier Segura, 2019. L'École des Arts Joailliers/School of Jewelry Arts, Paris, France, and French Institute of the United Arab Emirates, Dubai, 224 pages (in French, English and Arabic). EUR20.00 softcover.

Octopus Crowd: Maritime History and the Business of Australian Pearling in Its Schooner Age
By Steve Mullins, 2019. The University of Alabama Press, Tuscaloosa, Alabama, USA, 336 pages, ISBN 978-0817320249 (print) or 978-0817392383 (eBook). USD54.95 hardcover or eBook.

SOCIAL STUDIES

Opportunities and Pitfalls of Corporate Social Responsibility: The Marange Diamond Mines Case Study
Ed. by Shame Mugova and Paul R. Sachs, 2019. Springer Nature Switzerland AG, Cham, Switzerland, 253 pages, ISBN 978-3030171018 (print) or 978-3030171025 (eBook), https://doi.org/10.1007/978-3-030-17102-5. CHF141.50 hardcover or CHF80.00 eBook.

ERRATUM

In the New Media section of *The Journal* Vol. 36, No. 7, p. 670, the book review of *The Complete Content Cameos* should have indicated that the Ashmolean Museum displayed the collection between 1990 (not 1900, due to an editing error) and 2000. Also, there are 441 (not 425) cameos in the collection because 16 of them are catalogued with 'A' numbers in addition to the 425 items without 'A' numbers. We thank Derek Content for bringing these errors to our attention.

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Characteristics of faceted-quality ruby from Longido, Tanzania. T. Leelawatanasuk, N. Susawee and P. Bupparenoo, *Bulletin of Earth Sciences of Thailand*, **9**, 2018, 1–7, http://tinyurl.com/y8pzxf3m.*

The characterization of natural gemstones using non-invasive FT-IR spectroscopy: New data on tourmalines. M. Mercurio, M. Rossi, F. Izzo, P. Cappelletti, C. Germinario, C. Grifa, M. Petrelli, A. Vergara *et al.*, *Talanta*, **178**, 2018, 147–159, http://doi.org/10.1016/j.talanta.2017.09.030.

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Experimental investigation of the reaction between corundum xenocrysts and alkaline basaltic host magma: Constraints on magma residence times of basalt-hosted sapphires. L.C. Baldwin and C. Ballhaus, *Lithos*, **302–303**, 2018, 447–454, http://doi.org/10.1016/j.lithos.2018.01.020.

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Genetic significance of the 867 cm^{-1} out-of-plane Raman mode in graphite associated with V-bearing green grossular. R. Thomas, A. Rericha, W.L. Pohl and P. Davidson, *Mineralogy and Petrology*, **112**(5), 2018, 633–645, http://doi.org/10.1007/s00710-018-0563-1.

Geochemical characteristics and Ar-Ar dating of different nephrite deposits in Qinghai Province. H. Yu, Q. Ruan, B. Liao and D. Li, *Acta Mineralogica Sinica*, **38**(4), 2018, 655–668 (in Chinese with English abstract).

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Beaches and bedrock: How geological framework controls coastal morphology and the relative grade of a southern Namibian diamond placer deposit. L.H. Kirkpatrick, J. Jacob and A.N. Green, *Ore Geology Reviews*, **107**, 2019, 853–862, http://doi.org/10.1016/j.oregeorev.2019.03.029.

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Diamond exploration and mining in southern Africa: Some thoughts on past, current and possible future trends. W.F. McKechnie, *Journal of the Southern African Institute of Mining and Metallurgy*, **119**(2), 2019, 123–131, http://doi.org/10.17159/2411-9717/2019/v119n2a4.*

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Late 14th-Century Royal Crown of Blanche of Lancaster

Black Spinel from Thailand

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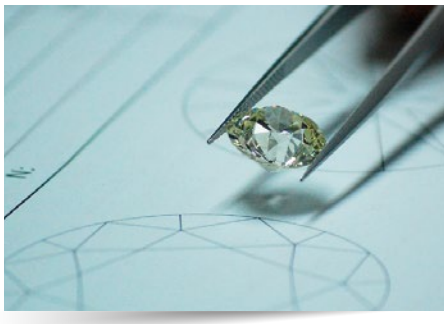

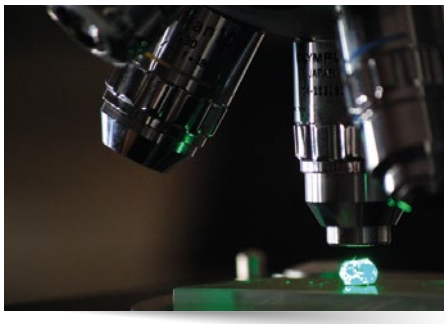

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Cover photo: *The royal crown of Blanche of Lancaster is preserved in the Treasury of the Munich Residence (Munich, Germany), and is one few extant examples of Late Middle Ages royal regalia. An article on pp. 26–64 of this issue describes its history and the gems it contains, which consist of blue and pink sapphires, pink spinels, garnets, emeralds, diamond octahedra and pearls, as well as some imitations. The various polishing/cutting styles demonstrate the transition in gemstone fashioning as the Late Middle Ages gave way to the Renaissance.*

COLUMNS

What's New 1

GemLightbox Photography System | SmartPro Aura | Universal Smartphone Microscope Adapter | AGTA GemFair Tucson 2020 Seminars | *Blockchain in the Mining Industry: Implications for Sustainable Development in Africa* | *Colourless CVD Diamonds Under the Loupe* from HRD Antwerp | Dallas Mineral Collecting Symposium Presentations | De Beers Diamond Insight Report 2019 | Global Diamond Industry Report 2019 | Gold Demand Trends 2019 | *ID of Green Gems with Portable Instruments* | *The Journal*'s Cumulative Index and Bibliography Lists Updated | New Journal: *Gemmae—An International Journal on Glyptic Studies* | Maine (USA) Mineral & Gem Museum

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The Editor-in-Chief is glad to consider original articles, news items, conference reports, announcements and calendar entries on subjects of gemmological interest for publication in *The Journal of Gemmology*. A guide to the various sections and the preparation of manuscripts is given at https://gem-a.com/index.php/news-publications/journal-of-gemmology/submissions, or contact the Editor-in-Chief.

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What's New

INSTRUMENTATION

GemLightbox Photography System

Released in July 2019 by Picup Media, GemLightbox is a lighting-and-environment system for the jewellery industry that enables the user to take 'studio quality' images using a smartphone or other camera. The basic GemLightbox comes with a lightbox, white backdrop, necklace-and-earring stand and smartphone holder. A free app is available for the Android operating system on Google Play, but the lightbox can also be used with an iPhone. Available accessories include turntable and aerial attachments that also enable video capture. Visit https://picupmedia.com/shop-page.

SmartPro Aura

In late 2019, Thailand-based SmartPro Instruments released the Aura Synthetic Diamond Scanner. The unit is designed to test both mounted jewellery and loose gems to separate natural diamond, synthetic diamond (CVD or HPHT grown) and cubic zirconia. It accommodates samples weighing 0.002+ ct, in the colour range D–K. It has a built-in smartphone with Android operating system and can automatically generate reports with test results. For details, including a user manual, visit www.smartproinstrument.com/products/aura.

Universal Smartphone Microscope Adapter

Gem-A Instruments is offering a microscope attachment that enables the user to take high-quality photomicrographs with a smartphone. It fits binocular, monocular and trinocular microscopes with 21–44 mm eyepieces, as well as most smartphones (56–85 mm wide). Cushioned surfaces protect both the microscope and smartphone, while the latter remains steady to prevent image blur. The adapter also works with telescopes and binoculars. Visit https://shop.gem-a.com/gemmological-instruments/microscopes/universal-smart-phone-microscope-adapter.

NEWS AND PUBLICATIONS

AGTA GemFair Tucson 2020 Seminars

The American Gem Trade Association's 38th GemFair was held 4–9 February 2020 in Tucson, Arizona, USA. The event offered nearly three dozen educational lectures and presentations that covered gem identification, appraisals, marketing strategies, industry trends and much more (visit https://agta.org/agta-gem-fair-tucson/seminars/all-seminars for a full list). Audio recordings and slides from most of these seminars are available on a flash drive for USD50.00 (non-AGTA-member price). To order flash drives from 2020 and previous years, visit https://agta.org/resources.

Blockchain in the Mining Industry: Implications for Sustainable Development in Africa

The South African Institute of International Affairs (SAIIA) released this report in August 2019 as part of its SAIIA Policy Insights series. The 13-page report features research by Filipe Calvão (Graduate Institute, Geneva, Switzerland) and Victoria Gronwald (Levin Sources, Cambridge). They describe 'distributed ledger technologies' whereby blockchains can securely record and publish transactions. The report uses the diamond industry as an example of how such blockchain technology can benefit local communities in Africa. Download the PDF at https://saiia.org.za/research/blockchain-in-the-mining-industry-implications-for-sustainable-development-in-africa.

Colourless CVD Diamonds Under the Loupe from HRD Antwerp

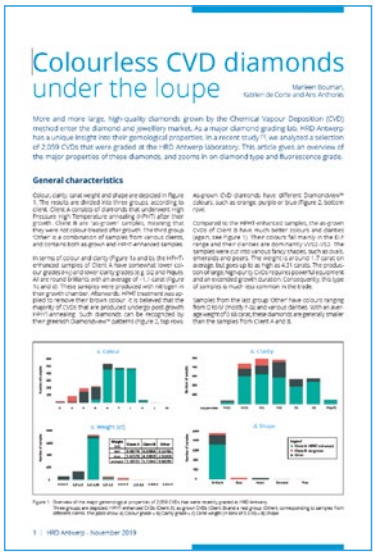

More chemical vapour deposition (CVD) synthetic diamonds of larger size and higher quality are entering the market and, thus, passing through grading laboratories. HRD Antwerp released this two-page report in November 2019 with data from 2,059 CVD samples (mostly from two clients) that were recently seen in their laboratory. The majority of the samples were type IIa, 1.0–1.5 ct, H–J colour, VVS_2–SI_2 clarity and almost entirely brilliant cut. The data also suggest that all were HPHT annealed to remove the as-grown brown colour. Download the report at www.hrdantwerp.com/en/news/colourless-cvd-diamonds-under-the-loupe.

Dallas Mineral Collecting Symposium Presentations

The Dallas Mineral Collecting Symposium is held annually in August in Dallas, Texas, USA, and attracts mineral and gem enthusiasts from around the world. Presentations from the 2019 Symposium are now available online and include topics such as gem pocket formation in pegmatites, jewels created by Paula Crevoshay, and gems from Brazil, Colombia and elsewhere. Visit www.dallassymposium.org/videos.

DALLAS MINERAL COLLECTING SYMPOSIUM

De Beers Diamond Insight Report 2019

Released in October 2019, this annual De Beers report reviews 2018 global market data for diamonds. Consumer demand increased 2% worldwide for both polished diamonds and jewellery, with the strongest growth in the USA and China, followed by Japan. India and the Gulf region saw slight declines, while the rest of the world rose less than 1%. Much of the report focuses on the value of marketing diamonds as a symbol of love, including engagement and commitment rings, and 'milestone' gifts of diamond jewellery after marriage. Same-sex couples represent a rising market in both the USA and China. Download the report at www.debeersgroup.com/~/media/Files/D/De-Beers-Group/documents/reports/insights/the-diamond-insight-report-2019.pdf.

Global Diamond Industry Report 2019

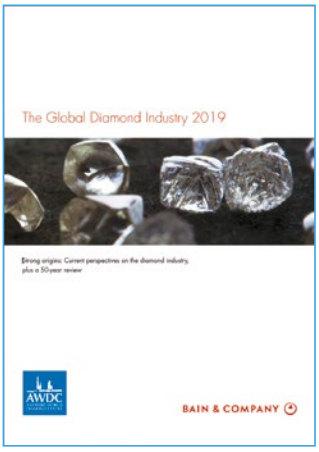

The ninth annual report from the Antwerp World Diamond Centre and Bain & Co. was released in December 2019. The report covers 2018 and the first half of 2019, reviews the diamond industry's performance over the past 50 years and examines key trends affecting the industry. The long-term forecast (through 2030) has been updated to reflect recent information on mining operations, production plans, lab-grown diamonds and economic developments, both global and regional. In general, data for 2019 showed declines in diamond jewellery retail sales, polished diamond demand and rough sales, despite stable production. Visit www.bain.com/insights/global-diamond-industry-report-2019 to read a summary online or download the full report.

Gold Demand Trends 2019

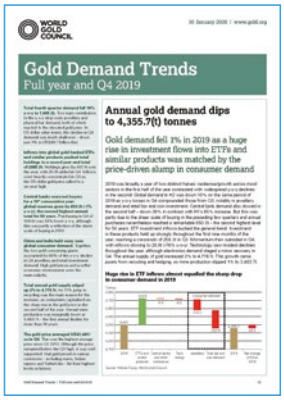

The World Gold Council released a combined report in January 2020 that covers all of 2019 and its fourth quarter. Overall demand for gold during the first half of 2019 was higher but dropped in the second half compared to 2018. In the fourth quarter, the demand for gold jewellery by volume sank to its lowest level since 2011, especially in India and China. However, demand for gold jewellery by value rose to its highest level in five years, in part due to the elevated price of gold in some currencies. Gold supply for the year rose slightly to 4,776.1 t. To read the full report online or download it (the latter requires log-in), go to www.gold.org/goldhub/research/gold-demand-trends/gold-demand-trends-full-year-2019.

ID of Green Gems with Portable Instruments

Released in February 2020, this booklet offers information on identifying various green gem materials that is oriented towards travelling gemmologists or those equipped with minimal instrumentation. It provides a catalogue of typical visible features, fluorescence, CPF (crossed-polarised features) and visible spectra for 64 natural, treated and synthetic green gem materials, arranged alphabetically. The authors explain how to identify green gem materials using basic gemmological knowledge in conjunction with a 10× loupe, long- and short-wave UV lamp, portable polariscope and hand spectroscope. Order the booklet at www.brankogems.com/shop/product-category/books.

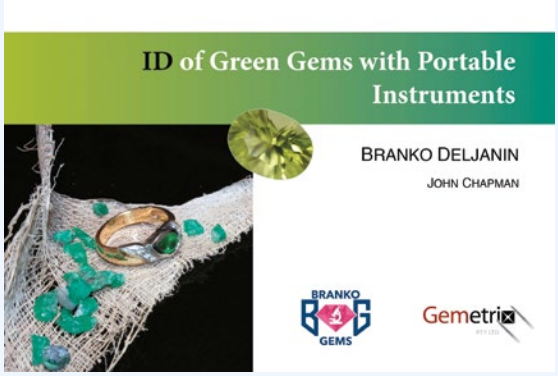

The Journal's Cumulative Index and Bibliography Lists Updated

The Journal of Gemmology's cumulative index has been updated to cover all issues through 2019. The index is provided in electronic (PDF) format, so it can be searched for specific first-authors as well as topics. In addition, the subject bibliographies covering articles and notes published in *The Journal* have been updated through 2019, and include various topics and gem materials: asterism and chatoyancy, biogenic gems, chrysoberyl and alexandrite, colour-change gems, diamond, emerald and other beryls, feldspar, ruby and sapphire, garnet, jade, opal, pearl, quartz, spinel and tourmaline. Download the index and bibliographies at https://gem-a.com/news-publications/journal-of-gemmology.

New Journal: *Gemmae—An International Journal on Glyptic Studies*

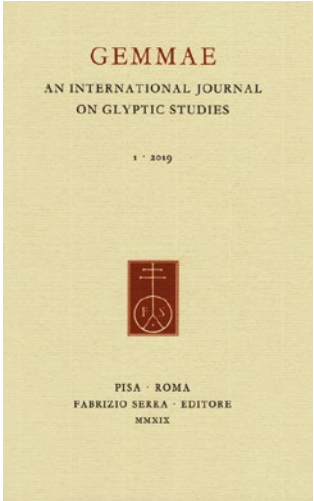

Volume 1 of this new annual journal was released in late 2019. From Italian publisher Fabrizio Serra, the focus is on the 'fascinating field of glyptics' (the art of engraving or carving gem materials). Peer-reviewed articles cover methodology, art history, iconography and technical issues, as well as the identification of copies and forgeries, the study of gems in museums and the description of items from well-documented excavations. English abstracts are provided for all articles, and some articles are written entirely in English. For more information or to subscribe, visit www.libraweb.net/riviste.php?chiave=142&h=430&w=300. To view abstracts or purchase PDFs of individual articles from Volume 1, go to www.libraweb.net/articoli.php?chiave=201914201&rivista=142.

MISCELLANEOUS

Maine Mineral & Gem Museum Opens

A museum dedicated to minerals, meteorites and gem materials officially opened in December 2019 in Bethel, Maine, USA. The 15,000-square-foot Maine Mineral & Gem Museum is situated on a land trust that includes the historic Bumpus mine, where several giant beryls were unearthed in the 1920s. The museum's collection includes numerous specimens of quartz, tourmaline and beryl, along with other minerals from Maine and elsewhere, as well as The Stifler Collection of Meteorites. Visit https://mainemineralmuseum.org.

What's New provides announcements of new instruments/technology, publications, online resources and more. Inclusion in What's New does not imply recommendation or endorsement by Gem-A. Entries were prepared by Carol M. Stockton unless otherwise noted.

The Fire Within

"For in them you shall see the living fire of the ruby, the glorious purple of the amethyst, the sea-green of the emerald, all glittering together in an incredible mixture of light."

– Roman Elder Pliny, 1st Century AD

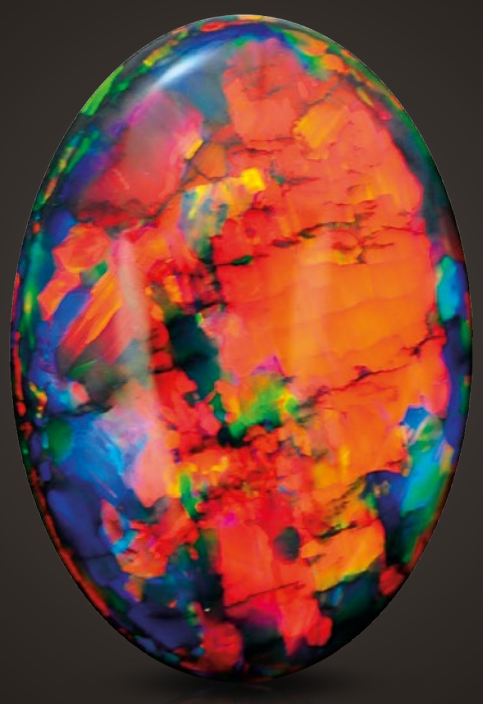

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Gem Notes

COLOURED STONES

Hessonite from Kunar Province, Afghanistan

The hessonite variety of grossular has been known from eastern Afghanistan for many years and reportedly has been produced from two localities there: Munjagal in Kunar Province and Kantiwa (or Kantiwow) in Nuristan Province (Laurs & Quinn 2004). In November 2018, gem dealer Dudley Blauwet (Dudley Blauwet Gems, Louisville, Colorado, USA) obtained some additional hessonite—reportedly from Kunar Province—that turned out to have some properties which were significantly different from those reported by Laurs & Quinn (2004). He obtained seven pieces of rough totalling 36.7 g from a trusted dealer while on a buying trip to Peshawar, Pakistan, and cutting of this material yielded a total of 75.29 carats consisting of three faceted stones and four cabochons.

The faceted samples were loaned to these authors for examination, and consisted of two medium 'golden' orange stones weighing 3.85 and 6.41 ct, and a deep reddish orange gem that was 10.49 ct (Figure 1). Their RIs were 1.744 (6.41 ct) and 1.752 (10.49 ct); the 3.85 ct stone did not yield a clear RI reading. These values are higher than those recorded by Laurs & Quinn (2004; i.e. 1.739 and 1.740). Hydrostatic SG values were 3.60 for the 3.85 ct hessonite, 3.85 for the 6.41 ct stone and 3.64 for the 10.49 ct sample; the two lighter measurements are comparable to the 3.63 and 3.64 SG values reported by Laurs & Quinn (2004).

Between crossed polarisers, the 10.49 ct stone exhibited a fine, light-appearing cross-hatched pattern and a weaker anomalous double refraction that appeared similar to a birefringence blink and occurred four times upon a 360° rotation of the stone. The 3.85 and 6.41 ct samples remained light when rotated between crossed polarisers. All of the samples exhibited the classic 'whisky and water' or treacle optic effect (e.g. Figure 2a), which has been ascribed to a polycrystalline structure in hessonite (Hänni 2019). This is in contrast to the Afghan samples characterised by Laurs & Quinn (2004), which did not show a roiled appearance.

The 3.85 ct hessonite contained several colourless, prismatic crystalline inclusions, as well as a few reflective whitish features with a granular appearance (Figure 2b) that may be related to structural interruptions (i.e. fissures) formed along a series of polycrystalline grain boundaries. The 6.41 ct sample contained thinly dispersed colourless crystalline inclusions (again, see Figure 2a), together with some planar whitish areas similar to those described above; turbidity prevented careful observation of deeper inclusions. The 10.49 ct stone exhibited strong turbidity, and microscopic examination revealed fissures and what appeared to be irregular hollow growth tubes. Unidentified whitish clusters were also observed.

The GemmoRaman-532SG spectrometer confirmed that all three stones were grossular. Energy-dispersive X-ray fluorescence (EDXRF) chemical analysis using an Amptek X123-SDD instrument revealed the expected

Figure 1: The Afghan hessonites examined for this report consist of (**a**) two medium orange gems weighing 6.41 and 3.85 ct, and (**b**) a deep reddish orange 10.49 ct oval. Photos by (a) B. Williams and (b) Dean Brennan, Stone Group Laboratories.

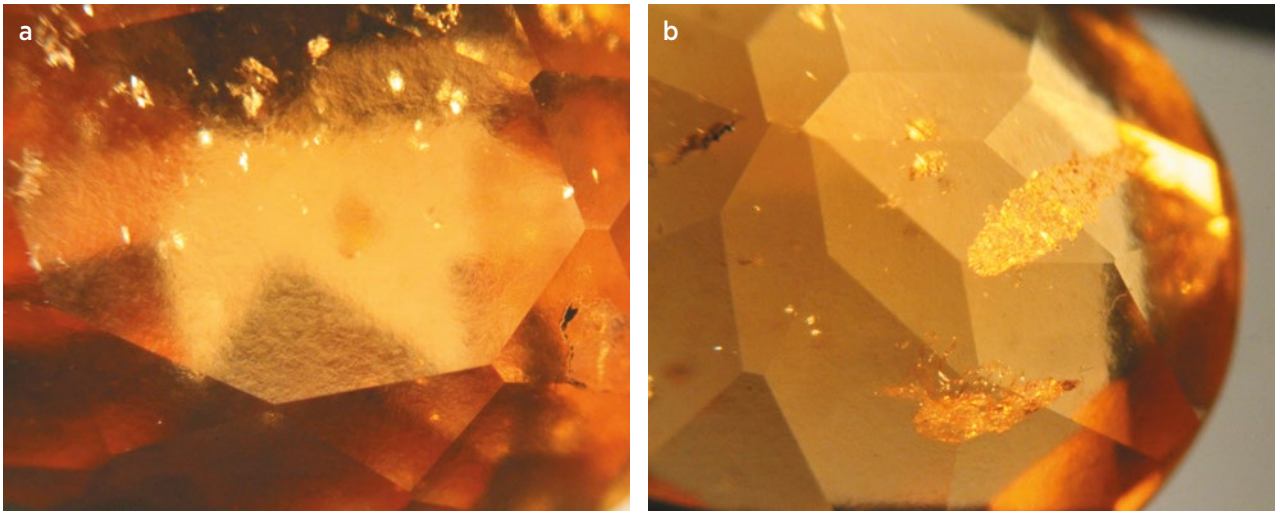

Figure 2: Internal features in the hessonites included (**a**) a treacle optic effect with colourless crystalline inclusions and (**b**) reflective whitish features. Photomicrographs by B. Williams; magnified about 20× (a) and 15× (b).

high level of Ca, but interestingly also recorded enriched Fe, together with minor Mn and Ti. While some of the Fe may be present in a minor andradite component (consistent with the RI and SG values), there was little to no evidence for the presence of andradite (or other garnet species) in the Raman spectra. We suspect that Fe, Mn and Ti impurities may be present along the polycrystalline grain boundaries of the garnet structure, although more research would be needed to confirm this.

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Olshanskyite from Japan, Offered as Parasibirskite

During the December 2019 Minéral Expo Paris show, at the booth of Emmanuel Thoreux (White River Gems, Alsace region, France), the author noticed a few cabochons of opaque white material offered as parasibirskite, a rare mineral from Japan. This material was also available at the 2019 Denver gem and mineral shows in Colorado, USA.

Parasibirskite ($Ca_2B_2O_5 \bullet H_2O$) is a borate known only from the Fuka mine, a marble quarry in Bicchu-cho near Takahashi, Okayama Prefecture, Japan (Kusachi *et al.* 1998). It is a polymorph of sibirskite, and both minerals occur at the Fuka mine in veins along the boundary between spurrite-bearing skarn and limestone. Additional borates present within the veins include olshanskyite ($Ca_2[B_3O_3(OH)_6](OH) \bullet 3H_2O$; Kusachi & Henmi 1994), frolovite ($Ca[B(OH)_4]_2$; Kusachi *et al.* 1995), takedaite, nifontovite, pentahydroborite and henmilite (Kusachi *et al.* 1999).

Thoreux loaned a 2.74 ct cabochon (Figure 3) to the

Figure 3: This 2.74 ct cabochon (13 × 8 × 4.5 mm) from the Fuka mine in Japan was offered as parasibirskite but actually consists of another borate mineral, olshanskyite. Photo by T. Cathelineau.

author for examination, and it showed the following properties: colour—white; lustre—dull; diaphaneity—opaque with slightly translucent veins; RI—about 1.56–1.58 (difficult to read even after repolishing the cabochon's underside); birefringence—about 0.02; optic character and sign—undetermined because of the approximate RI reading; hydrostatic SG—2.14; and fluorescence—inert to long- and short-wave UV radiation.

The RI, birefringence and SG values are all lower than those reported for parasibirskite (Kusachi *et al.* 1998), and are more consistent with those of olshanskyite (Kusachi & Henmi 1994) and frolovite (Kusachi *et al.* 1995) than with other borates from the same location, even if the sample's SG was slightly lower. A search of the Mindat and Webmineral online databases showed that only a few borates have such a low SG, but those also have higher RIs than recorded from the present sample. Olshanskyite and frolovite are therefore the best possibilities according to the sample's gemmological properties, but conclusive identification required additional testing.

Infrared (IR) reflectance spectra were collected from several spots on the cabochon, at various orientations to look for anisotropy, and all yielded the same pattern without any significant difference (Figure 4). The overall pattern was consistent with that of a borate mineral. Borates comprise various radical anions (e.g. BO_3, B_2O_5, $B_2(OH)_5$, etc.) that produce a large variety of IR features. The spectrum collected from the study specimen did not show any analogous features with those of parasibirskite in transmittance mode (cf. Kusachi *et al.* 1998), especially in the 1500–1200 cm^{-1} range, which is related to vibrations of the B_2O_5 radical. This confirmed the results indicated by the sample's gemmological properties.

There is a lack of available IR spectra for borates in reflectance mode; almost all of the published spectra (for samples from both Japan and Russia) are in transmittance mode. A visual comparison of the reflectance spectrum from the present cabochon to the absorption spectrum of olshanskyite from Russia (Bogomolov *et al.* 1969) and to the transformed log(1/T) spectrum of olshanskyite from the Fuka mine in Japan (Kusachi & Henmi 1994) showed correlative features, and identified the cabochon as olshanskyite.

Raman spectroscopy with 514 nm laser excitation showed an almost perfect match with reference spectra for olshanskyite, which have distinctive bands at 636 and 717 cm^{-1} (Figure 5). An additional band of unknown origin was also present at 465 cm^{-1}.

A visible-near infrared spectrum was collected from a thin, translucent area of the cabochon. The resulting spectrum showed an absorption edge below 410 nm accompanied by an asymptotic 'tail' that extended into the NIR, together with three superimposed absorption bands at approximately 675 nm (weak and very broad),

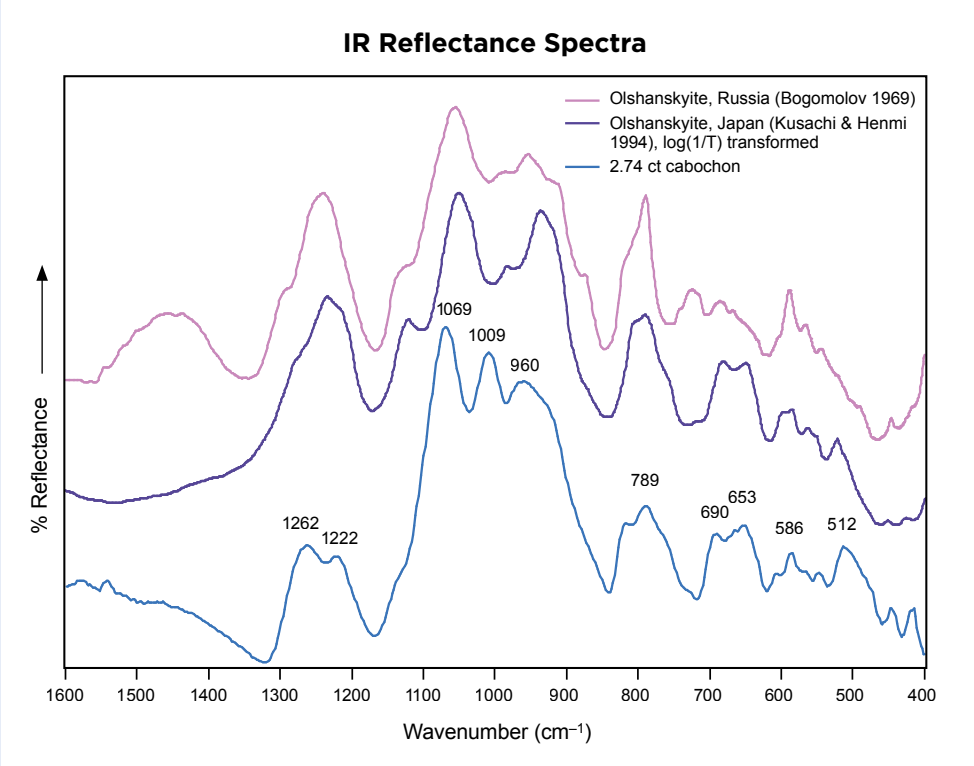

Figure 4: The IR reflectance spectrum of the cabochon in Figure 3 shows features that are consistent with those of olshanskyite, from both Russia and Japan.

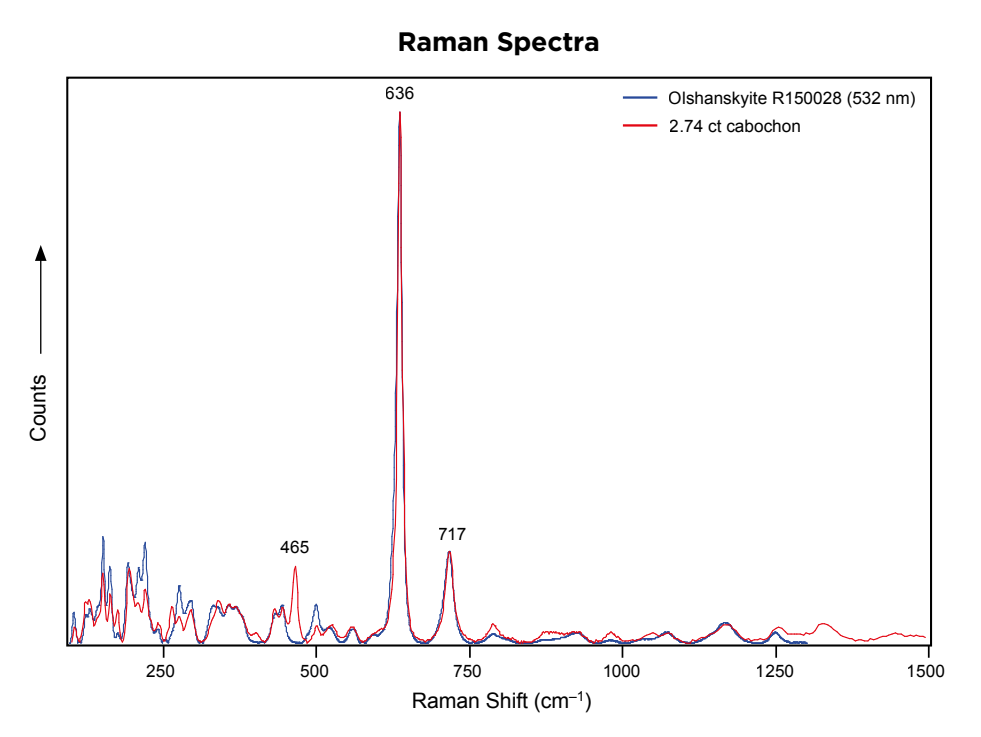

Figure 5: The Raman spectrum of the stone in Figure 3 shows a good match with a reference spectrum for olshanskyite (here, from the Shijiangshan mine, China: RRUFF R150028, collected with 532 nm laser excitation).

770 nm (weak) and 990 nm (moderate). All of these are unexplained except for the 990 nm band, which the author interprets as being related to OH overtones and combinations, in accordance with the hydrous character of the material.

The stone's photoluminescence (PL) spectrum was studied using several excitation sources: 254, 280, 375, 405 and 532 nm, but only those of 375 and 405 nm gave results, yielding bluish white luminescence (visible to the unaided eye only with the 405 nm laser). The PL spectra obtained from the two excitations differed only in their intensity, and consisted of a broad asymmetric emission from 400 to 700 nm. Such luminescence is known for olshanskyite and has been attributed to organic fluorophors (Gorobets & Rogojine 2002, pp. 269 and 272).

Standard gemmological testing showed that the cabochon was not parasibirskite, and suggested olshanskyite or frolovite as possibilities. Both IR and Raman spectroscopy conclusively identified the cabochon as olshanskyite despite the relative rareness of reference spectra for such uncommon borate minerals.

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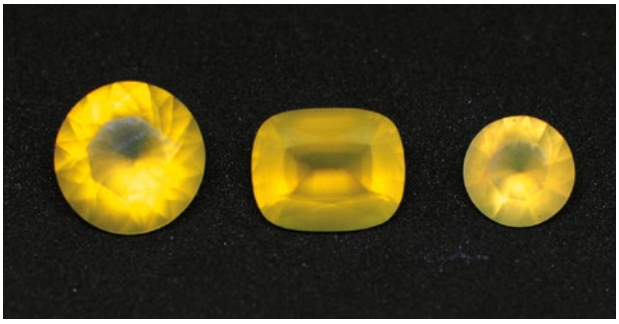

Figure 6: These faceted yellow opals, weighing (from left to right) 5.69, 5.08 and 2.24 ct, are reportedly from the Kasula District in western Tanzania. Photo by J. Štubňa.

Figure 7: Tanzanian yellow opal has also been polished into translucent cabochons (here, 8.32 and 6.83 ct). Photo by J. Štubňa.

Yellow Opal from Tanzania

Opal ($SiO_2 \bullet nH_2O$) is amorphous (opal-A) or poorly crystalline (opal-CT) hydrated silica with a water content that usually varies from 4% to 10% (Gaillou 2015). It is appreciated for its wide range of body colours and, in some cases, for its play-of-colour. Gem-quality yellow 'common' opal (without play-of-colour) has been described from Mexico (Gaillou *et al.* 2008), West Africa (Moe 2012) and Brazil (Laurs & Renfro 2018).

At the June 2014 Sainte-Marie-aux-Mines Mineral & Gem show in France, the present authors obtained some rough yellow opal samples reportedly from the Kasula District in the Kigoma region of western Tanzania, which is bordered on the north-west by Burundi. The seller had several tens of kilograms of rough material for sale. For this study, we selected 500 g of rough that was not cracked and ranged from transparent to semi-transparent. We stored the material in our laboratory for a few years to see if it was resistant to crazing but it has shown no signs of instability.

Some of the more-transparent rough material was faceted into round- and cushion-shaped mixed cuts that ranged from 10 to 13 mm in maximum dimension (2.24–5.69 ct; Figure 6). In addition, two cabochons with dimensions of 17 × 12 mm (6.83 and 8.32 ct; Figure 7) were polished from translucent material. The stones had RIs of 1.436–1.450 and hydrostatic SG values of 1.98–2.07. They were inert to long- and short-wave UV radiation. The samples were placed in water for 60 minutes to check for hydrophane character, but no improvement in their transparency was seen. Microscopic observations revealed a transparent flow structure with an oily appearance in each sample, as well as whitish clouds (Figure 8a). Small whitish globules were also observed in all stones (Figure 8b).

Powder X-ray diffraction analysis indicated that the stones were structurally opal-CT with the presence of cristobalite, tridymite and quartz. Chemical analysis by electron microprobe yielded 91.72 wt.% SiO_2, 0.40 wt.%

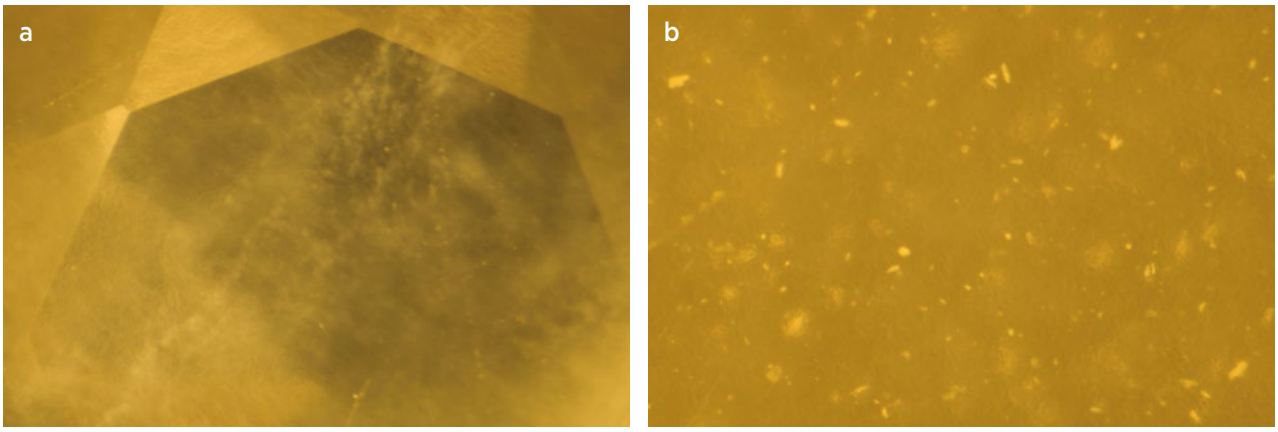

Figure 8: Whitish clouds (**a**) and small whitish globules (**b**) are present in the Tanzanian yellow opals. Photomicrographs by J. Štubňa; magnified 20× (a) and 30× (b).

FeO, 0.13 wt.% MgO and 0.12 wt.% CaO. The traces of Fe are consistent with the yellow colouration of this opal (cf. Gaillou *et al*. 2008). The characteristics of our Tanzanian samples overlap with those of the yellow opals documented from Mexico, West Africa and Brazil, which all consist of opal-CT.

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Titanite (Sphene) Inclusions in Ruby Identified by Infrared Spectroscopy

Figure 9: This 7.79 ct unheated ruby proved to contain an unusual mid-infrared absorption band, which correlated to its unusual inclusions. Photo by Alex Mercado, AGL.

More than 20 years ago, one of these authors demonstrated how mid-infrared spectroscopy could be used to identify mineral inclusions in gem corundum (Smith 1995). Since that time, author CPS has catalogued a number of mineral inclusions found in ruby and sapphire using this method. These include aluminium hydroxides (both diaspore and boehmite), calcite and weathering minerals (e.g. kaolinite and goethite), as well as various micas and other minerals.

Recently, a 7.79 ct ruby was submitted to the American Gemological Laboratories (AGL) for analysis (Figure 9). In addition to concentrations of rutile silk and a few partially healed fissures, this unheated natural ruby also possessed a large number of small, transparent, light yellow crystals (Figure 10). Raman analysis of several of these crystals identified them as titanite (sphene).

Interestingly, the mid-infrared spectrum of this ruby revealed an unusual absorption band centred at approximately 3482 cm^{-1}. Experience indicated to the authors that this band was not intrinsically related to corundum, so we compared it to the spectrum of titanite, which also shows a dominant absorption band in this region. To confirm that the 3482 cm^{-1} band recorded in the ruby was related to the dominant absorption present in titanite, the two spectra were overlaid (Figure 11).

Most minerals reveal characteristic identifying absorption features in the 7000–1000 cm^{-1} region (e.g. Hainschwang & Notari 2008). Because corundum (Al_2O_3)

Figure 10: The ruby in Figure 9 contains an unusually high concentration of titanite (sphene) inclusions. Photomicrograph by C. P. Smith; magnified 42×.

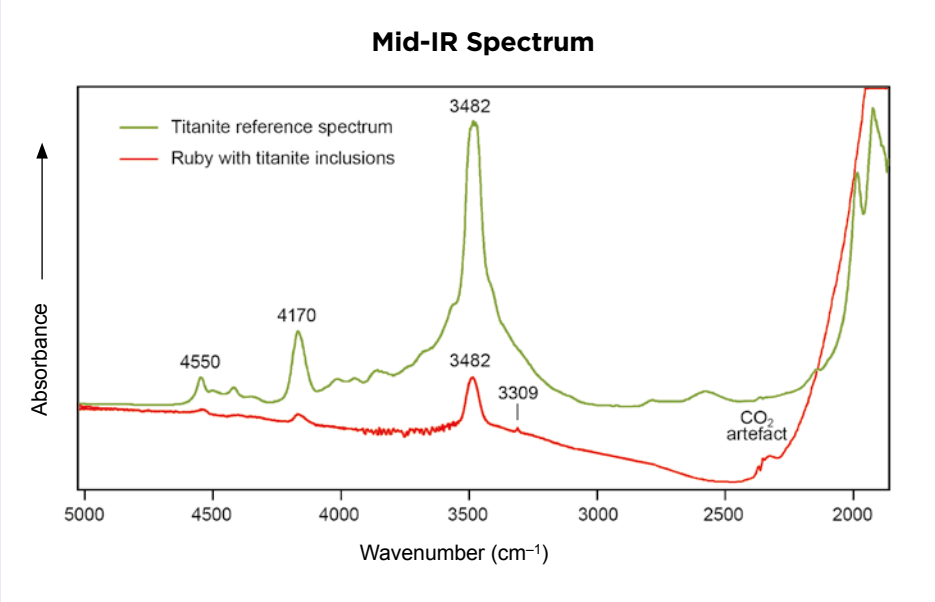

Figure 11: The mid-IR spectrum of the ruby reveals an unusual absorption band at approximately 3482 cm^{-1}. The mid-IR region of titanite possesses a dominant absorption band in the same position. The presence and shape of this band in the corundum spectrum further demonstrates the usefulness of IR spectroscopy to identify the presence of titanite inclusions.

is an anhydrous mineral, the mid-infrared region of the spectrum between 5000 and 1800 cm^{-1} can be useful for the identification of mineral inclusions, as well as the heated or unheated condition of a ruby or sapphire.

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Sphalerite from Slovakia

Sphalerite is a zinc ore mineral (ZnS) that is usually opaque black due to the presence of Fe impurities. Gem-quality material has relatively lower Fe and forms transparent crystals that are yellow to orange, brown or green. One of the most notable characteristics of sphalerite is its high dispersion (0.156), which is nearly four times greater than that of diamond.

The Banská Štiavnica precious- and base-metal ore district is one of the largest in the Carpathian arc of central Europe (Lexa *et al.* 1999). It is situated in the central zone of a large andesite stratovolcano, including the caldera, resurgent dome and an extensive subvolcanic intrusive complex (Lexa *et al.* 1999). The deposit is one of the most studied in Europe and has been well known since the 8th century, particularly for its gold and silver deposits, as well as its lead, zinc and copper ores (Lexa *et al.* 1999; Prokofiev *et al.* 1999). Base-metal production increased gradually during the 19th century from deeper veins, and attained a maximum during the 20th century, before ceasing in 1992 (Lexa *et al.* 1999).

Transparent sphalerite crystals up to 1 cm in dimension showing yellow-orange, brown and sometimes green colouration are quite common in the Banská Štiavnica ore district. However, the sphalerite has received relatively little attention as a gem material since the miners were mainly focused on the recovery of precious and base metals.

For this study, we examined 100 g of rough (1–7 mm in maximum dimension) and two relatively large (for Slovakia) representative samples of faceted sphalerite from Banská Štiavnica. The cut stones weighed around 1 ct each (Figure 12); they consisted of a brown, round, mixed cut with dimensions of 6.17 × 6.19 × 3.51 mm (1.16 ct) and a yellow-orange octagon that measured 5.62 × 5.60 × 3.41 mm (1.00 ct). The RIs of each cut stone were 2.179–2.255 (measured with a Presidium Refractive Index Meter II)

Figure 12: These faceted sphalerites from Banská Štiavnica, Slovakia, weigh 1.16 (left) and 1.00 ct (right). Photo by J. Štubňa.

and hydrostatic SG ranged from 4.09 to 4.14. Their identity as sphalerite was confirmed by Raman spectroscopy, which showed bands at 220, 278, 300, 350, 377, 393, 400, 408, 420, 609, 614, 635, 669 and 696 cm^{-1}. EDXRF spectroscopy detected Zn as a major element, along with some minor Fe, Cd, Pb and Ga. Ultraviolet-visible-near infrared (UV-Vis-NIR) spectroscopy revealed absorption bands at 460 nm (in the yellow-orange stone), 492 nm (in the brown stone), and at 668, 700 and 725 nm (in both samples; Figure 13). Overall, both the yellow-orange and brown gems showed strong absorption in the blue and violet regions and lesser absorption in the red part of the spectrum (cf. Anderson & Payne 1956).

Local collectors still obtain sphalerite from the old mine dumps in the Banská Štiavnica ore district, and rough material of various qualities and sizes is commonly available at local gem and mineral shows (where it is typically sold as mineralogical samples). A neighbouring mine in Hodruša-Hámre, Slovakia, has the potential to produce additional sphalerite. It is currently the only active underground gold mine in central Europe, and transparent sphalerite occurs there as an accompanying mineral.

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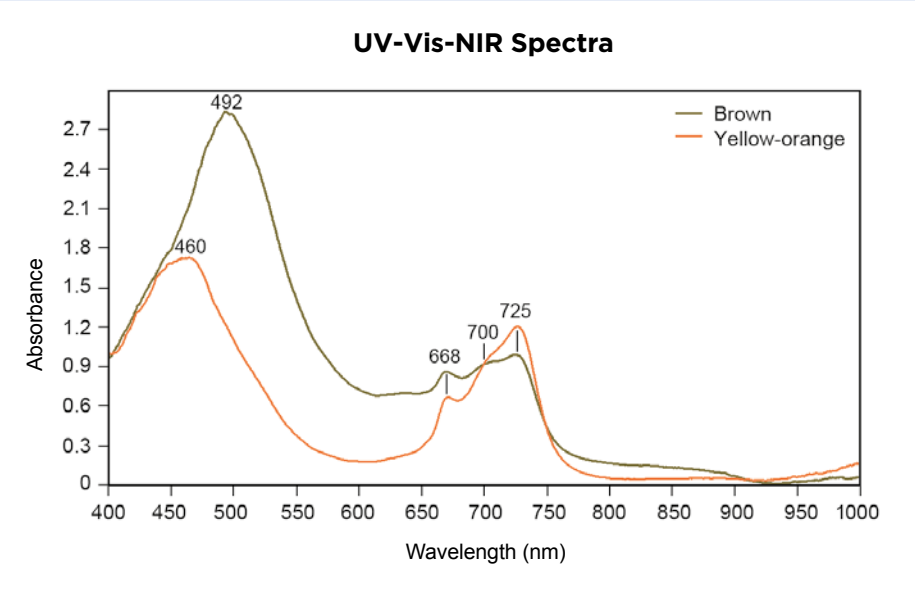

Figure 13: The UV-Vis-NIR spectra of the two faceted sphalerite samples show absorption bands at 460 (yellow-orange sample), 492 (brown sample), and at 668, 700 and 725 nm (both gems).

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DIAMONDS

Kimberley Diamond Acquired by the Smithsonian Institution, and Its Fluorescence and Phosphorescence Characteristics Revealed

The remarkable 55.08 ct Kimberley diamond was recently donated to the Smithsonian Institution's National Gem Collection by Bruce Stuart. It was unveiled to the public in the Museum of Natural History's National Gem Collection Gallery in October 2019. The Fancy yellow Kimberley diamond is noted for its distinctive emerald cut and classically elegant Baumgold Brothers necklace setting (Figure 14a). The diamond is named for its place of origin—the famous Kimberley mining region of South Africa.

Investigations into the history of the Kimberley diamond, via the Internet and classic books on famous diamonds, typically reveal some variations on a story that begins with a rough diamond of about 490 ct, sometimes described as elongated and flat, that was found in the 1870s or 1880s (or, in one case, between 1869 and 1871) at the Kimberley mine. Some sources then suggest, without references or other evidence, that the diamond became part of the Russian Crown Jewels.

It supposedly reached Europe during the upheavals of the 1917 Bolshevik revolution, and in 1921 was purchased by an anonymous buyer who had the large flat stone cut (or recut) into a 70 ct modern-shaped flawless gem. But later, as the story goes, in 1958 the stone was again recut by its new owners, Baumgold Brothers Inc. (New York, New York, USA), to improve its proportions and increase its brilliance. They then sold it to an undisclosed collector in 1971. Various newspaper accounts during the 1960s described the diamond as weighing 55 or 70 ct.

Our research has revealed that some of the early history of the Kimberley diamond is inaccurate. It was, in fact, cut around 1940 by the Baumgold Brothers to the 55.08 ct elongated emerald-cut gem we know today from a 490 ct diamond found in the Kimberley mining region of South Africa. In *Notable Diamonds of the World* (Diamond Information Center 1971), the rough diamond is referred to as the Baumgold II. This Fancy yellow diamond was then set into the current platinum necklace and accented with 80 baguette-cut diamonds that weighed an additional 20 ct. The first-known reference to the faceted diamond mounted in the current necklace is a jewellery store advertisement in the 10 March 1940 issue of *Miami News* (p. 9).

It travelled to many jewellery stores and other venues throughout the United States in the 1940s to the 1960s, often being featured in local newspapers and other media. The necklace appeared on the television shows *It Takes a Thief* and *Ironside* in 1968. (The Smithsonian's Victoria-Transvaal Diamond, which was also cut and set into a necklace by the Baumgold Brothers, appeared with the Kimberley diamond necklace on several occasions, including the episode of *Ironside*.)

The Kimberley diamond necklace was sold to an undisclosed collector in 1971. In April 1977, chemist Dr Herchel Smith acquired the necklace at a Sotheby Parke-Bernet auction in New York. Dr Smith's estate consigned the necklace to Christie's auction house in October 2002,

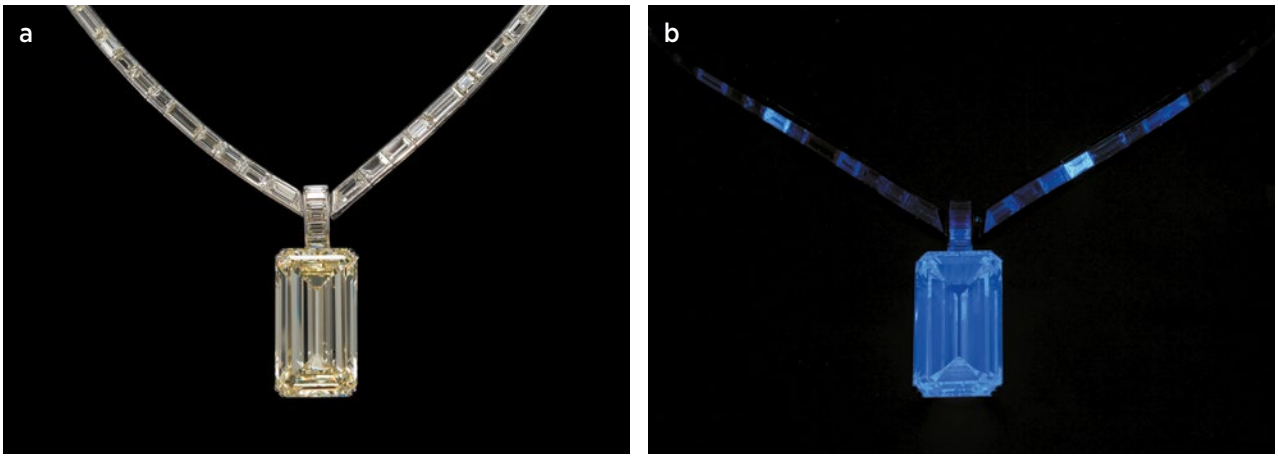

Figure 14: (**a**) The 55.08 ct Kimberley diamond was cut and mounted in a necklace by Baumgold Brothers around 1940. (**b**) The diamond fluoresces moderately strong blue under a 370 nm (long-wave) Convoy UV lamp. Photos courtesy of Smithsonian Images.

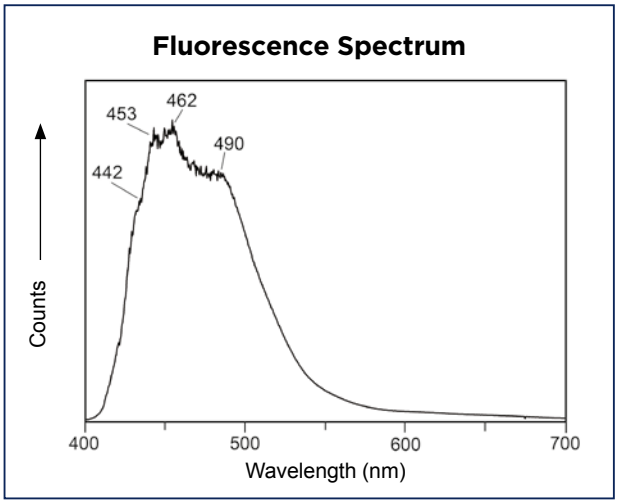

Figure 15: The fluorescence spectrum of the Kimberley diamond shows that the main emission is between 440 and 500 nm.

where it was acquired by Bruce Stuart. The diamond was on exhibit at the American Museum of Natural History in New York from July 2013 to June 2014. In July 2019, Bruce Stuart generously donated the Kimberley diamond necklace to the Smithsonian Institution.

The Gemological Institute of America issued a grading report for the Kimberley diamond in June 2002, which described it as natural Fancy yellow with VS_1 clarity (with the plot showing a chip, pinpoint, 'natural' and extra facet) having dimensions of 31.69 × 17.46 × 9.64 mm and a weight of 55.08 ct. The report also noted a faint fluorescence. We observed moderately strong blue fluorescence under long-wave UV radiation (Figure 14b), followed by a short-lived but noticeable orange phosphorescence. Several of the baguette diamonds in the necklace also exhibited weak to strong fluorescence, in various colours, under long-wave UV radiation.

We further examined the spectral characteristics of the UV-excited fluorescence and phosphorescence emissions with the spectrometer previously used to study the Hope and other coloured diamonds (Eaton-Magaña *et al.* 2007, 2008). In the present experiments, the UV source employed was a Convoy LED lamp (370 nm). Figure 15 displays the fluorescence spectral emission between 400 and 700 nm (approximately 10 nm resolution), and Figure 16 shows the phosphorescence emission as a function of time after turning off the UV source. The phosphorescence peak is centred at about 590 nm, consistent with the observed orange colour.

The fluorescence spectrum is similar to the one we measured from a small fragment of the Foxfire diamond, also donated to the Smithsonian's collection. The phosphorescence spectra are likewise similar (Butler *et al.* 2017), although the emission from the Kimberley diamond is considerably weaker than that measured for the Foxfire.

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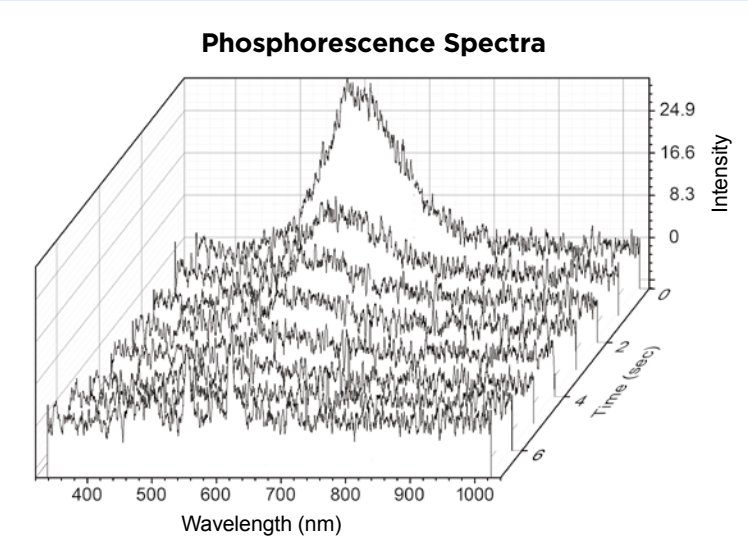

Figure 16: This series of phosphorescence spectra reveals the time of decay of emission after exposure to a 370 nm Convoy UV lamp. The spectra were collected at intervals of 1.5 seconds, with integration times of 1.5 seconds per spectrum.

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SYNTHETICS AND SIMULANTS

CVD Synthetic Diamonds Identified in a Parcel of Light Brown Melee

Figure 17: These six 2.5-mm-diameter CVD synthetic diamonds were found in a parcel of more than 1,000 light brown diamonds. Photo by T. Hainschwang.

The Liechtenstein branch of GGTL Laboratories received a parcel of more than 1,000 melee-sized (1.2–3 mm diameter) light brown diamonds for authenticity and treatment identification (part of the lab's fancy-colour diamond screening services). Their depth of colour was below that required to be called 'Fancy'.

As per the lab's common procedure, the parcel was tested with the prototype of GGTL's Mega-DFI fluorescence microscopy and spectroscopy system. The vast majority of the samples showed the expected luminescence reactions, with the exception of seven diamonds (2.5 mm diameter) that showed distinct orange fluorescence. The PL spectra of these samples, which the DFI system records simultaneously during visual observation, revealed that six of the seven were synthetic diamonds grown by chemical vapour deposition (CVD; Figure 17). Between crossed polarisers the synthetics showed obvious brush-like extinction (e.g. Figure 18), which is characteristic for CVD products but sometimes resembles the extinction patterns seen in natural type IIa brown diamonds.

The room-temperature UV-excited PL spectra recorded with the DFI system for all seven samples revealed the presence of the NV^0 centre, which is characterised by a zero-phonon line at 575 nm and vibronic sidebands extending into the red part of the spectrum, which causes orange to reddish orange fluorescence (Figure 19a). Such UV-excited PL dominated by the NV^0 centre is very rare in natural brown diamonds since it is only found in type Ib samples. Brown does occur in type Ib diamonds, although it is the rarest colour for this type (Hainschwang *et al.* 2013).

Using the seven different fluorescence excitations of the DFI system for visual and spectral analysis, we confirmed that the six samples were as-grown CVD synthetic diamonds and the one additional diamond was a natural type Ib stone. The fluorescence pattern of the synthetics revealed the characteristic CVD layer-by-layer growth and associated dislocations, while the natural diamond exhibited deformation-related green PL from the H3 centre together with the orange NV^0 luminescence.

When excited by the 405 nm laser, the luminescence of all seven samples was a distinct green (e.g. Figure 19b), a phenomenon known in both natural type Ib and CVD synthetic diamonds. In natural diamonds the 405 nm laser excites the H3 centre more strongly than the NV^0 centre, while in as-grown CVD synthetics the laser excites the 467.6 nm centre more strongly than the NV^0 centre; both the H3 and the 467.6 nm centres result in green fluorescence. The room-temperature PL spectra recorded for the seven diamonds confirmed these respective centres were responsible for the green luminescence.

Infrared spectroscopy identified the six CVD synthetic diamonds as type IIa and the natural diamond as pure type Ib. The latter displayed a very distinct 'amber centre' absorption at 4110 cm^{-1}. The IR spectra of the other samples exhibited several features characteristic for CVD synthetic diamonds, such as lines at 7362, 6856, 6424, 5566 and 3123 cm^{-1}.

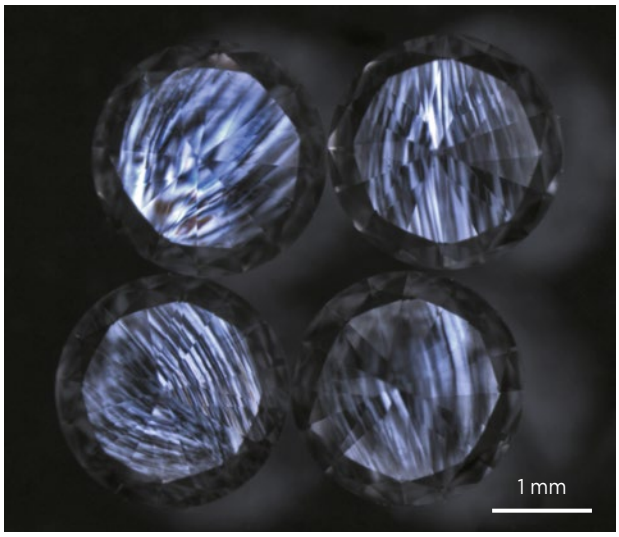

Figure 18: Some of the CVD synthetics are shown here between crossed polarising filters (and immersed in alcohol) to reveal their distinct brush-like extinction patterns. Photo by T. Hainschwang.

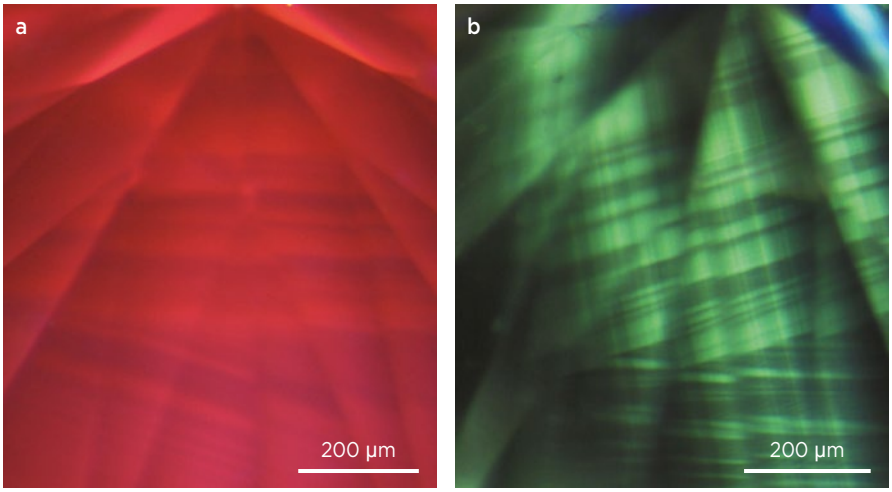

Figure 19: (**a**) Under all of the UV excitations of GGTL's DFI system, the CVD synthetic diamonds generally fluoresce a distinct orange due to the presence of the NV^0 centre, while also revealing their growth layers under some specific excitations of shorter wavelength. (**b**) Under 405 nm (in the visible range) laser excitation, the CVD synthetic diamonds fluoresce green from the 467.6 nm centre and show even more distinct growth layers. Both images were taken from the same sample. Photomicrographs by T. Hainschwang.

High-resolution, low-temperature PL spectroscopy using 360, 402, 473 and 532 nm laser excitations on a GGTL Photoluminator research PL system confirmed the findings made by DFI testing. The CVD samples all exhibited very similar spectra, with a series of defects characteristic for CVD synthetic diamonds, such as the 388.8 nm, 467.6 nm, NV^0 and Si-V^- centres. In addition to these, numerous sharp PL peaks were measured, particularly in the spectra recorded using the 360 nm laser (Figure 20). The vast majority of those are, in the author's experience, unique to CVD synthetic diamond, even though their causes are generally unknown.

The evaluation of melee-sized fancy-colour diamonds for their authenticity and colour origin is a specialised task that requires a combination of extensive diamond-testing experience and instrumentation created specifically for this type of screening. Until now, the mixing of synthetics (and colour-treated diamonds) into melee-sized parcels has almost exclusively been restricted to yellow to orange diamonds. However, the present case confirms rumours that untreated brownish CVD synthetics are now being mixed into parcels of natural brown diamonds, thereby eliminating the need for HPHT treatment of as-grown CVD material to render it near-colourless to colourless.

After preparing the first draft of this article, we received several parcels of brown and pinkish brown diamonds from various sources totalling more than 20,000 pieces,

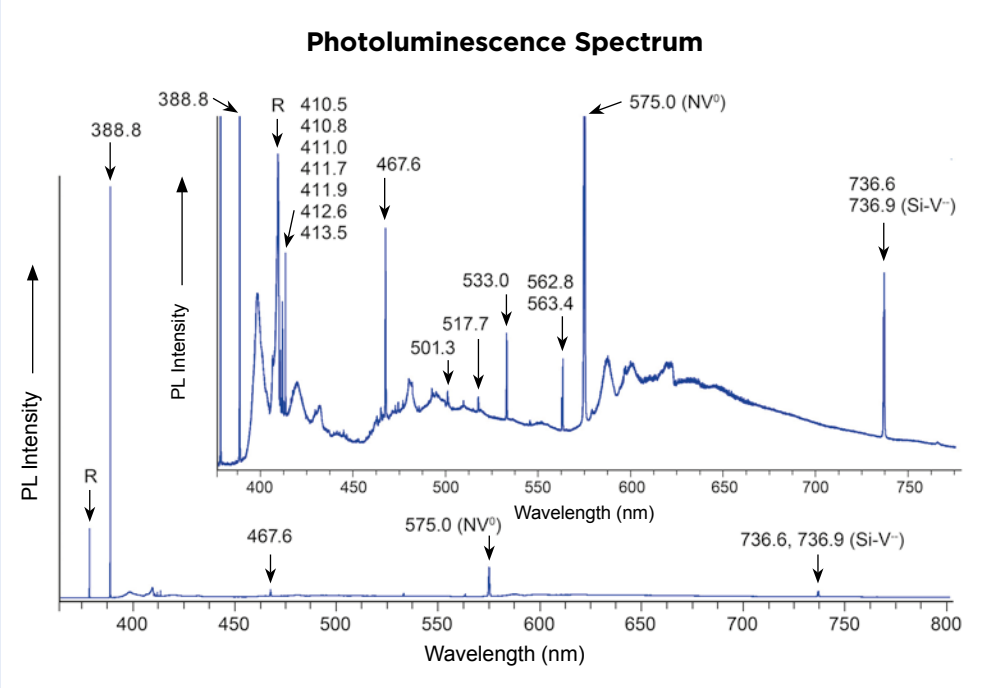

Figure 20: This PL spectrum, recorded for one of the CVD samples using 360 nm laser excitation, shows characteristic features for as-grown (that is, untreated) CVD synthetic diamond. The spectrum displays numerous very sharp peaks, and the most intense ones include the 388.8 nm, 467.6 nm, NV^0 and Si-V^- centres. The inset includes all spectral details, while the general spectral view shows the dominance of the very narrow 388.8 nm peak compared to the other PL emissions. R = Raman line.

and in these we detected more than 200 CVD synthetic diamonds, all with properties very similar to the ones described here. This provides further evidence that the contamination of brown melee parcels with CVD synthetics seems to have become a significant problem.

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Reference

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Multicoloured Synthetic Corundum and Multicoloured Glass Doublets in the Thai Gem Market

Gem-quality synthetic corundum can be grown in virtually all colours by means of the flame-fusion (Verneuil) technique (Nassau 1980). Even color-zoned samples have occasionally been observed (Kiefert 2004; Choudhary 2009). Recently, some high-quality synthetic corundum showing multiple colours has appeared in the Thai gem market. The gems are cut from colour-zoned Verneuil boules (Figure 21) that are grown by changing the composition of trace elements during synthesis (including Cr for red; Ti and Fe for blue; Cr, Ti and Fe for purple; Ni for yellow; etc.). The multicoloured rough material is produced by Thai Tech Sapphire Co. Ltd (Sathon, Bangkok, Thailand), which operates its own corundum-growth factory in Rayong Province, Thailand. Although the company only mentions monochrome synthetic sapphire on its website, it does offer production of custom-coloured boules.

We performed a basic gemmological and Raman spectroscopic investigation on six half-boules of the new multicoloured synthetic corundum (five of them are shown in Figure 21), and the experimental procedures corresponded to those described in Zeug *et al.* (2018). The material showed properties typical of synthetic corundum, including RIs of 1.753–1.760 and SG values (here reported as mass density) of 3.98–4.01 g/cm^3. The nature of this material as a synthetic flame-fusion product could be recognised by occasional curved striae visible under white-light illumination and/or UV radiation (Figure 22a; cf. Anderson 1967), as well as the presence of small, round-to-elongated gas bubbles (Figure 22b). When exposed to UV radiation, the luminescence colour and intensity depended mainly on Cr concentration and body colour. Most of the colour zones showed various intensities of red (and occasionally orange) luminescence, which was particularly strong under long-wave UV radiation. Only under short-wave UV radiation did amethyst-coloured zones (see left boule in Figure 21) show pale whitish luminescence.

Figure 21: A 24.45 ct faceted synthetic corundum and five Verneuil half-boules (21.7–33.1 g) are representative of material now being produced by Thai Tech Sapphire Co. Ltd. Photo by L. Nasdala.

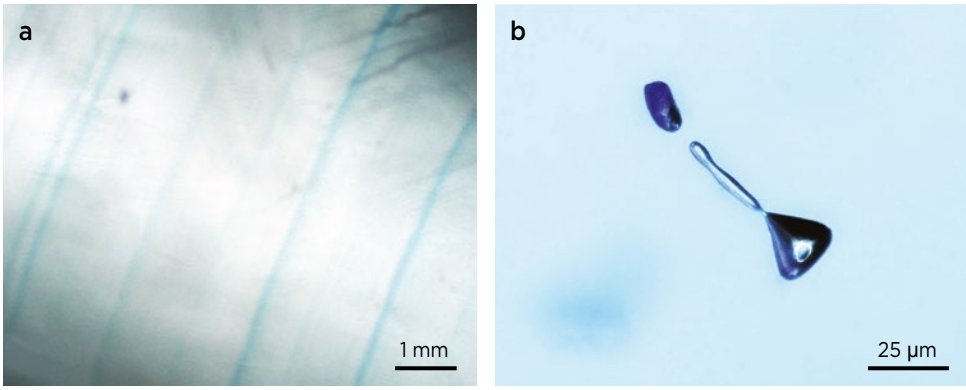

Figure 22: (**a**) Coloured curved striae visible in some samples of the multicoloured synthetic corundum are typical of Verneuil products. (**b**) This elongated gas inclusion (53 µm in length) is also characteristic of this material. Photomicrographs by L. Nasdala (a) and Michael Korntner (b).

Interestingly, the recent appearance of the multicoloured synthetic corundum in the Thai gem market seems to be accompanied by a vast increase in the supply of cheap multicoloured doublets (Figure 23a). Six of these samples (four of them are shown in Figure 23) were investigated. In contrast to the high-quality doublets described by Hänni and Henn (2015) with crown and pavilion pieces made of quartz, topaz, beryl or tourmaline, these new products simply consist of colourless soda-lime glass (identified by Raman spectroscopy; see Figure 24 and Deschamps *et al.* 2011 for a reference spectrum). A coloured resin layer (25–50 µm in thickness) is used to impart colouration and cement the two glass layers together. In some samples a single resin layer is present, whereas others contain two resin layers (i.e. coloured and colourless; Figure 24). The resins consist of acrylic polymers that are soluble in acetone, and Raman spectroscopy of the coloured ones showed a polystyrenic component (cf. Serafim *et al.* 2014) in polymethylmethacrylate (cf. Thomas *et al.* 2008). The colourless resin mainly consists of polybutylmethacrylate (cf. Kang *et al.* 2006).

These doublets are easily recognised. Viewed from the side, the colourless nature of the material could be seen through the girdle facets (Figure 23b); colour was evident when observed at angles to the central resin membrane. Insufficient contact between resin and glass may cause the appearance of colourless spots that were also visible at angles to the resin layer (Figure 23b), a quality problem that we saw in about one-third of the doublets we observed on the market. Under long-wave UV radiation, the samples (especially yellow and pink zones) showed intense 'lemon'-yellow to whitish luminescence that originated from the resin

Figure 23: (**a**) Four faceted glass doublets (6.4–14.9 ct) represent another multicoloured material that has recently appeared on the Thai gem market. (**b**) Even without immersion it can be seen that the pavilion and crown of this 6.7 ct doublet are colourless; the apparent colouration is caused by the central resin layer. The small colourless spot in the upper right of this sample (only visible from the side) is caused by insufficient contact between the pavilion and the resin layer. Photos by L. Nasdala.

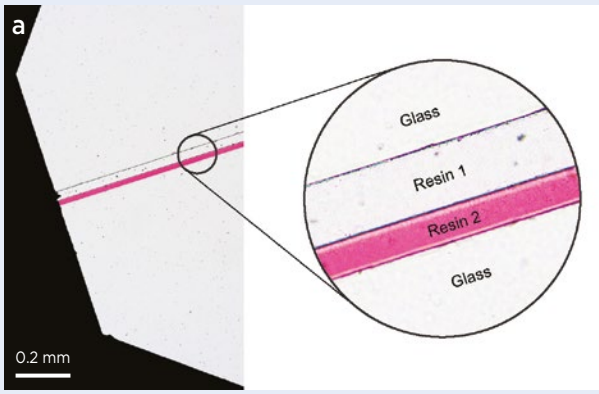

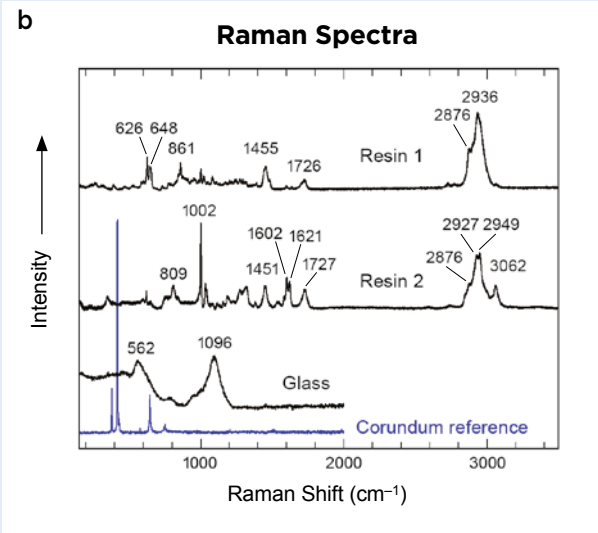

Figure 24: (**a**) A plane-polarised transmitted light image of a doubly polished, 25 µm thin section of a glass doublet reveals that the crown and pavilion are joined by two resin layers (i.e. colourless Resin 1 and coloured Resin 2). Photomicrographs by L. Nasdala. (**b**) Raman spectra are shown for both resin layers and for the glass composing the doublet. Comparison with a reference spectrum for corundum (obtained from the faceted sample shown in Figure 22) clearly shows that no corundum is present in these doublets.

membrane; only mild luminescence was seen in the green and dark blue zones. The doublets had low SG values (corresponding to a mass density of 2.48–2.50 g/cm^3) and a relatively low, glassy lustre (RI ranged from 1.510 to 1.515).

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Imitations of Trapiche Ruby and Emerald

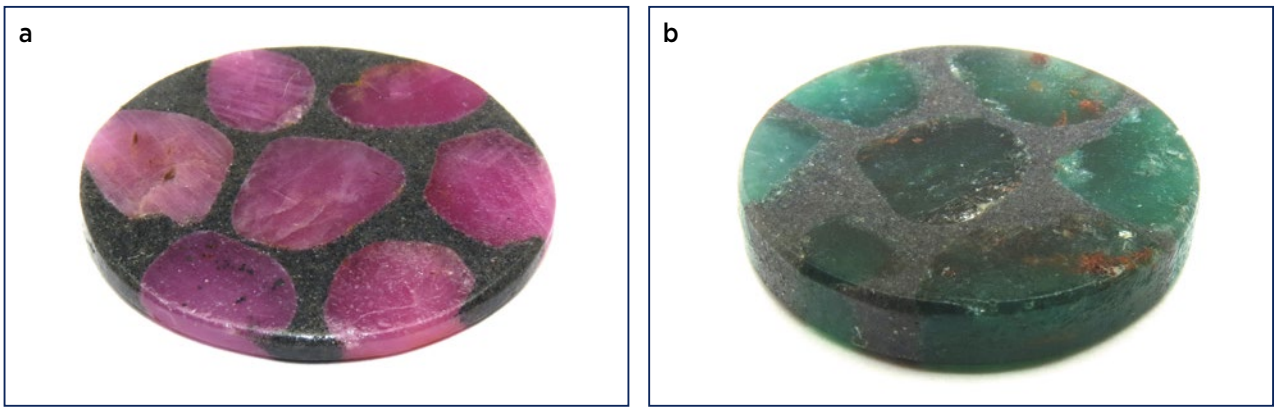

Figure 25: The two samples reported here were originally identified as (**a**) 'natural trapiche ruby' (about 27 mm wide) and (**b**) 'natural trapiche emerald' (about 24 mm wide). Photos by Dirk van der Marel.

In October 2019, a concerned customer came to the Netherlands Gemmological Laboratory with several stones, each accompanied by a report from the Authentic Gem Security Laboratory. This name did not sound familiar, but according to the lab reports this organisation is based in Delhi, India. The customer asked us to check whether the issued reports were accurate. Testing of some initial samples reported as 'natural star sapphire, heated, from Madagascar', 'natural sapphire, heated, from Sri Lanka' (in pink, purple and blue) and 'natural ruby, heated, from Mogok' showed that they were synthetic corundum.

We also selected a 'natural trapiche ruby from Mogok (Burma)' and a 'natural trapiche emerald from Colombia' for further study. Both of them had translucent areas (pink to purplish red and bluish green, respectively) together with opaque dark grey 'matrix' material. The 'ruby' specimen consisted of an oval slab measuring 26.97 × 22.93 × 2.56 mm and weighing 3.56 g (Figure 25a), and the 'emerald' specimen was a round slab measuring 24.05–24.51 × 4.29 mm and weighing 5.02 g (Figure 25b).

The pink to purplish red areas of the first specimen yielded a Cr spectrum and strong red fluorescence to long-wave UV radiation, both typical of ruby. They had rounded or hexagonal shapes and were heavily included. Lamellar twinning showed comparatively random orientations between the various areas, indicating they were actually different pieces rather than part of a single crystal. Raman analysis of these fragments with a Thermo Scientific DXR Raman microscope using 532 nm laser excitation focused slightly underneath the surface revealed Raman and PL spectra typical of ruby. Small, orangey brown inclusions were identified as rutile, confirming these ruby fragments to be of natural origin.

The dark 'matrix' areas fluoresced strong whitish blue to long-wave UV radiation (Figure 26). Magnification revealed that they were not entirely opaque, but contained abundant granular, dark angular fragments and gas bubbles within a translucent to transparent material (Figure 27).

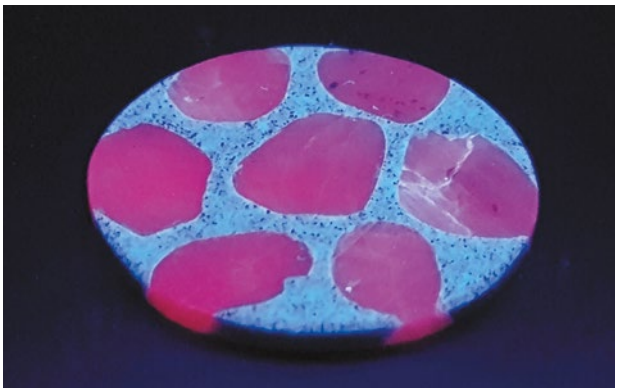

Figure 26: Exposure of the supposed 'trapiche ruby' to long-wave UV radiation produces strong red fluorescence in areas corresponding to ruby and whitish blue luminescence from the interstitial material. Photo by J. C. Zwaan.

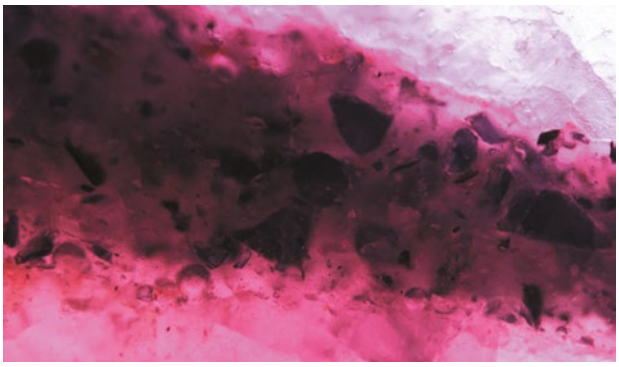

Figure 27: Microscopic examination of the 'matrix' material of the ruby-bearing sample shows abundant small, dark angular fragments and gas bubbles within a translucent to transparent material. Photomicrograph by J. C. Zwaan, brightfield illumination; image width 1.4 mm.

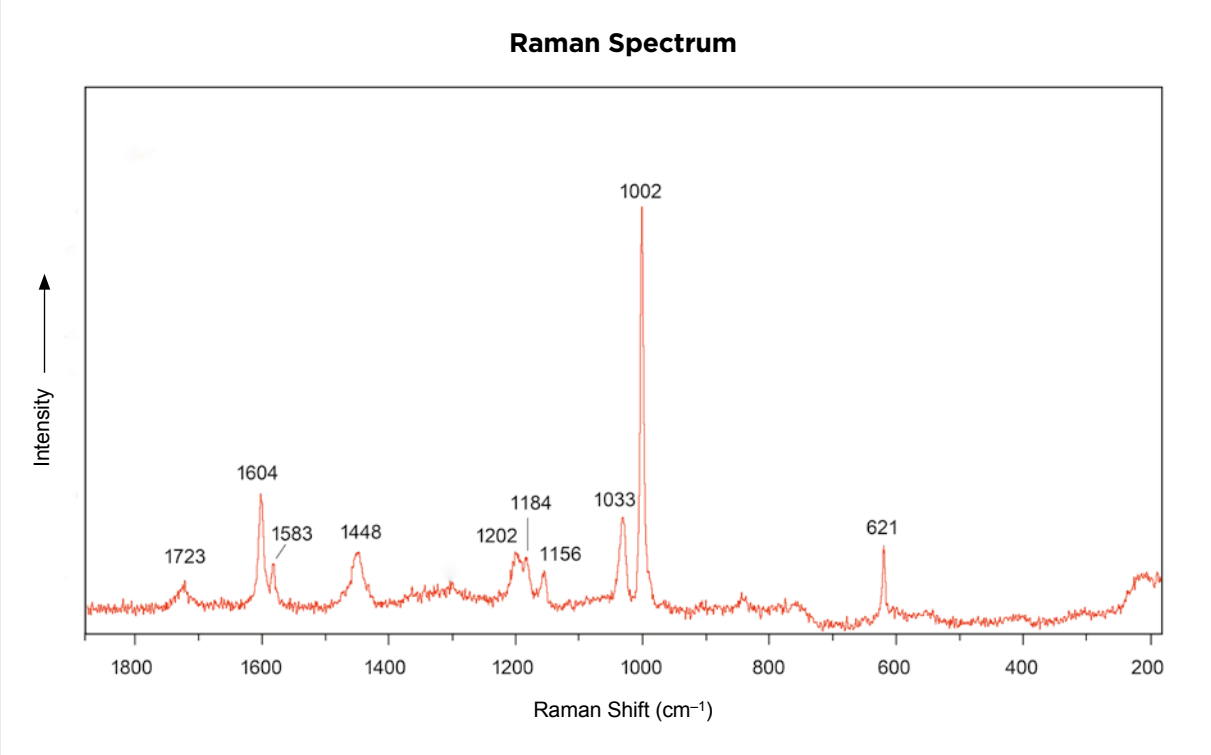

Figure 28: Raman spectroscopy of the 'matrix' material (here, from the ruby-bearing specimen) showed bands typical for ~~a res~~ polystyrene ~~mixture~~, confirming their manufactured nature.

EDXRF spectroscopy with an EDAX Orbis Micro-XRF Analyzer, using a spot size of 300 µm, revealed that the dark areas contained mainly Zr, Y and Si. At the surface of the ruby areas, a high concentration of Si was measured. Raman analysis of the small angular fragments confirmed the presence of cubic zirconia in a matrix that produced Raman bands characteristic of ~~a mix~~ polystyrene ~~and silica~~ (Figure 28), as seen in some imitation or 'synthetic' opals. These same Raman bands were observed at the surface of the ruby fragments. We concluded that this imitation of trapiche ruby was an assemblage consisting of seven ruby fragments embedded in a ~~r~~ polystyrene ~~a~~ 'matrix' containing cubic zirconia grains.

The round slab with the green material was essentially the same type of product—an assembled imitation of a trapiche gem—although no emerald was detected. Raman analysis of the green areas identified them as muscovite, and EDXRF spectroscopy showed the expected presence of major Al, Si and K, along with minor Cr and Fe. An absorption spectrum viewed with a prism spectroscope revealed a band at about 565–610 nm and a sharp line at about 630 nm, which are consistent with the optical spectrum associated with Cr^{3+} in fuchsite, a Cr-bearing muscovite (cf. Reddy *et al.* 2003 and http://minerals.gps.caltech.edu//FILES/Visible/Mica/Index.html).

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Reference

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TREATMENTS

Blue Sapphire with Partial Red Surface Diffusion

A 1.94 ct cushion-cut stone was recently submitted for confirmation of treatment. The stone was identified as corundum using a GemmoRaman-532SG spectrometer. It exhibited what at first appeared to be unusual dichroism in pale violetish blue and pink (Figure 29). Closer examination showed that the stone's body colour was pale violetish blue, while a deep reddish pink surface-related colouration was limited to the table and a small area along the pavilion (seen more easily with immersion; Figure 30a). Microscopic observation revealed several 'fingerprint' inclusions that confirmed a natural (not synthetic) origin of the sapphire. RI readings could not be obtained from the table facet.

Due to the proliferation of new coating treatments, it was initially presumed this the stone had undergone a coating process on selected surfaces. However, careful microscopic observation showed that the pink-coloured areas diffused slightly below the surface of the stone (Figure 30b), and EDXRF spectroscopy with an Amptek X123-SDD instrument indicated significant Cr. Also, the pink areas showed red fluorescence to long-wave UV excitation, whereas red-coated stones previously seen by the authors were inert. These characteristics are consistent with Cr-diffused corundum (e.g. McClure *et al.* 1993; Smith 2015). Moreover, infrared spectral features recorded with a GemmoFtir spectrometer confirmed the stone had been heat treated, so a red surface diffusion is presumed, most of which was polished off at some point.

Figure 29: This 1.94 ct sapphire exhibits an unusual colour appearance. Photo by Jeff Scovil.

It remains puzzling why the diffusion treatment was retained on some surface areas when the resulting overall appearance is so unnatural. Perhaps the intention was to create something different and unusual. With pale colours currently being in greater demand, it would not be surprising to see older treated stones

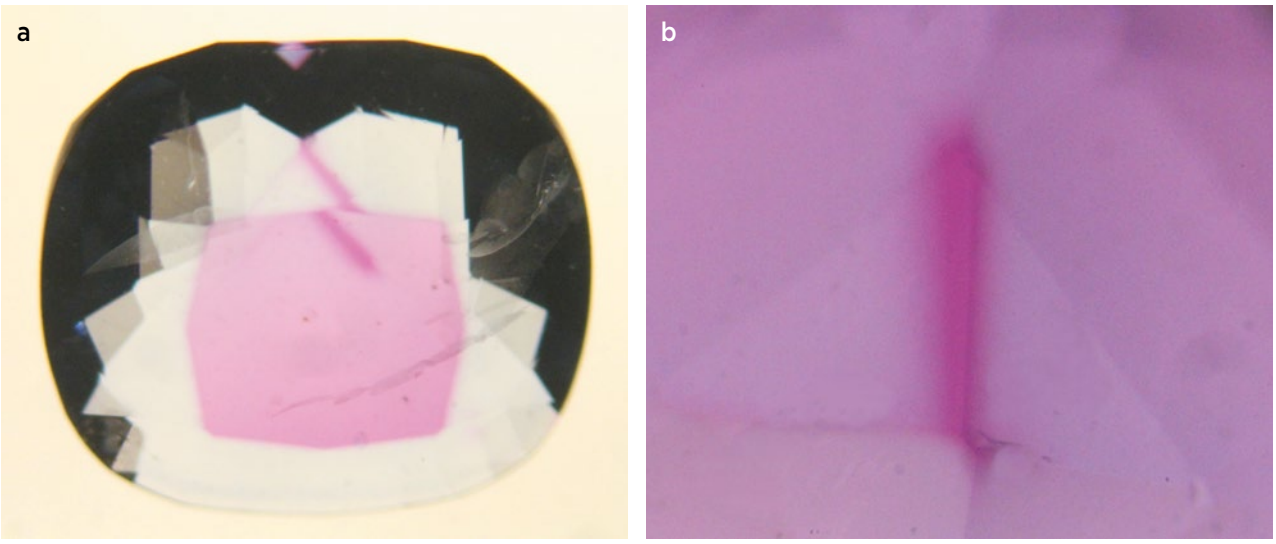

Figure 30: (**a**) Closer examination of the sapphire (immersed in water) shows pink colouration restricted to the table and along one portion of the pavilion. (**b**) At higher magnification (here, 22×), the deep pink area on the pavilion can be seen to penetrate slightly below the surface of the stone, as expected for Cr diffusion treatment. Photomicrographs by B. Williams.

being 'rejuvenated' by polishing off near-surface treatments, and such material may be more commonly encountered in the future.

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Glass-filled White Sapphire

In January 2020, a client submitted for treatment verification a 62.59 ct translucent white cabochon, stated to be white sapphire (Figure 31). The stone's vitreous lustre matched what is expected for corundum, and its internal features consisted of lamellar twinning, parting planes and fractures (e.g. Figure 32), typical of cabochon-grade material. There were no dark inclusions present in the stone. The RI was measured by the spot method at approximately 1.77 and the hydrostatic SG was 3.99, identifying it as corundum. Overall the stone was inert to long-wave UV excitation, although some flat areas within fissures exhibited a whitish fluorescence that might be expected for polishing residues. There were also several areas that fluoresced a weak red that appeared to correspond with internal fissures and voids; this reaction could be consistent with the presence of some type of clarity enhancement.

Raman analysis of the stone with an Enwave spectrometer equipped with 785 nm laser excitation confirmed it as corundum, and an additional PL peak centred around 1321 cm^{-1} was present in the range expected for a glass. EDXRF spectroscopy with an Amptek X123-SDD instrument showed the presence of significant amounts of Pb, indicating that the cabochon was filled with a lead glass (Figure 33). While we have encountered many colours of corundum with lead-glass filling, this was the first white sapphire submitted to our laboratory treated in this manner.

It is interesting to note that none of the usual visual indicators of lead-glass filling were visible with magnification (such as gas bubbles or blue and orange flash effects; see, e.g., McClure *et al.* 2006 and Milisenda *et al.* 2006). Also, the sapphire's surface did not have the variable lustre that is sometimes seen on such treated

Figure 31: This 62.59 ct white sapphire proved to be filled with lead glass. Photo by B. Williams.

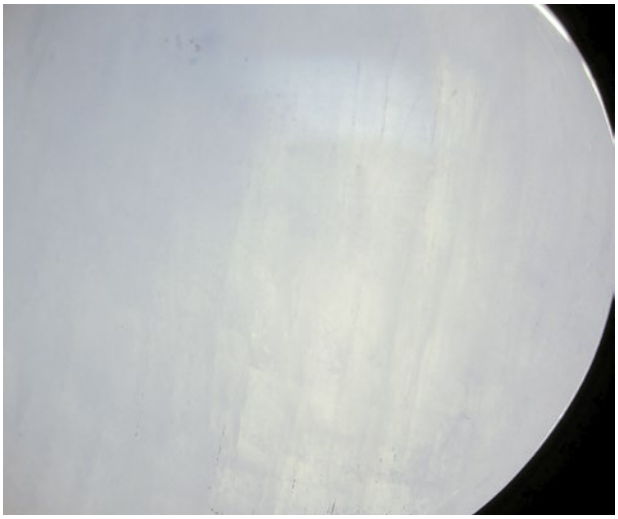

Figure 32: The low transparency of the white sapphire is due to numerous parting planes and fractures, which are typical of low-quality gem corundum. Photomicrograph by Dean Brennan, Stone Group Laboratories; magnified 20×.

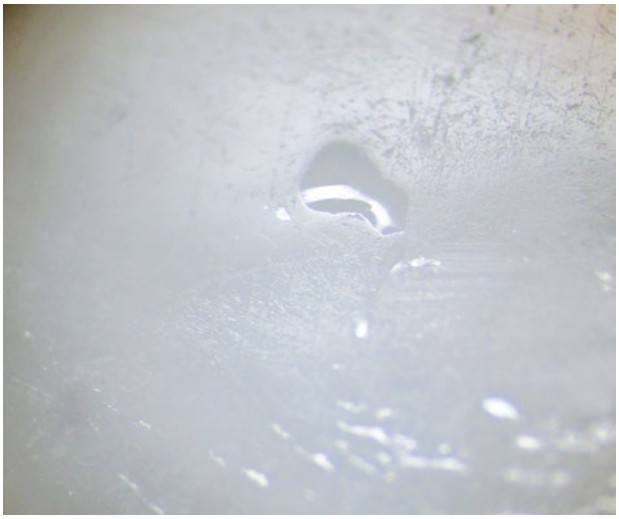

Figure 34: Depressions on the surface of the filled sapphire exhibit a glassy appearance. Photomicrograph by Dean Brennan, Stone Group Laboratories; magnified 30×.

stones, although there were at least two depressions that exhibited a glassy appearance (e.g. Figure 34). Although EDXRF spectroscopy showed the presence of significant Pb, the SG was not elevated and was in fact slightly below the 4.00 value that is typical of corundum. The lack of any dark inclusions may be due to the acid treatment that is an initial stage of this treatment process.

While identifying a treatment such as this does not pose a challenge to a well-equipped gemmological laboratory, the lack of common visual features associated with lead-glass filling could be problematic for the unsuspecting gemmologist.

Cara Williams FGA and Bear Williams FGA

Figure 33: EDXRF spectroscopy of the white sapphire shows significant amounts of Pb associated with the lead-glass filling.

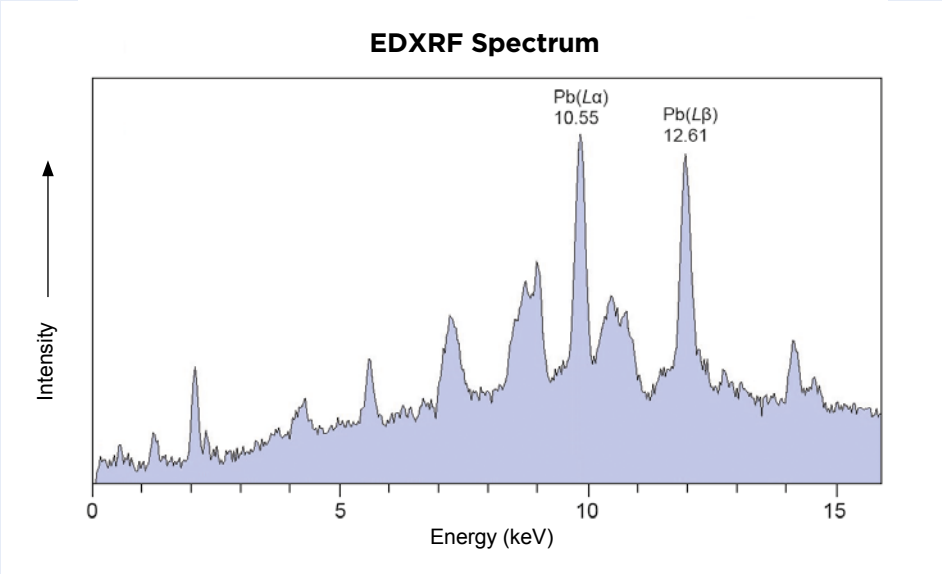

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The Late 14th-Century Royal Crown of Blanche of Lancaster—History and Gem Materials

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ABSTRACT: The richly bejewelled crown preserved in the Treasury of the Munich Residence offers a window into both European dynastic history and contemporaneous decorative practices and gem use. The crown's history can be traced from the late 14th-century court of Richard II and his wife Anne of Bohemia in London; through its role as part of the dowry in 1402 of Blanche of Lancaster, bride of future Elector Palatine Louis III in Germany; to its later decades in Heidelberg, Mannheim and finally Munich by the late 18th century. In this study, all gem materials currently decorating the piece—one of few extant examples of Late Middle Ages royal regalia—were identified by a combination of microscopy, EDXRF analysis and Raman spectroscopy, using mobile instruments on site at the museum. The gems included blue and pink sapphires, pink spinels, garnets, emeralds, diamond octahedra and pearls. Various imitations were also present, including black-coated gold pyramids (substituting for diamonds) and green and pink lead glass. The forms of the gems reflect a progression from use of merely irregularly shaped polished pebbles, to rudimentary shaping or preforming without sharp edges, to sharply faceted regular shapes, thereby demonstrating the transition in gemstone fashioning as the Late Middle Ages gave way to the Renaissance.

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Regalia owned and worn by royalty for both political and symbolic purposes have long been a source of fascination for scholars and the general population alike. The construction and materials used, modifications over time, and transitions between owners as a result of marriages, alliances and wars have all drawn interest.

A number of opulent crowns from the High Middle Ages (circa 1000–1250) are well documented (Schramm 1956) and preserved in museum collections. By contrast, the more-refined and less-massive crowns from the Late Middle Ages (circa 1250–1500) have received less attention and tend to be known largely from short descriptions in royal inventories or from depictions in artwork of the era (e.g. Figures 1 and 2). Such inventories reflect that, in general, English and French monarchs typically owned multiple crowns during the 14th century, with artistic design varying widely (Holmes 1937). An English inventory from 1324, for example, listed as many as 10 crowns, with the number of fleurons ranging from eight to 22 (Twining 1960). (*Fleurons* in this context refers to the elongated ornaments that attach to the circlet and decorate the top of a crown.) A French inventory from 1380 also enumerated 10 crowns, which contained from four to 16 fleurons (Labarte 1879).

Likewise apparent from systematic study of 14th- and 15th-century inventories is that the royal and ducal crowns were characteristically adorned with jewels, but only a limited selection of mineral gem varieties (along with pearls) was used: diamonds, blue sapphires, emeralds and three different types of pink to red gems. The latter included rubies, *balases* (or *balays*, *baleis*,

Figure 1: The *Liber Regalis*, a manuscript dated to the 1390s, depicts the coronation ceremony of an English king and queen. The monarchs shown are thought to be Richard II and Anne of Bohemia, for whom the crown in this study was most likely created. Reproduced by permission of Westminster Abbey, London.

pallas and related variants)[1] and rarely garnets (Holmes 1934). Occasionally, descriptors such as *rubis d'Alexandrie* or *saphirs d'orient* were employed, indicating that the gems found their way from the East to Europe within the stream of merchandise passing through major Mediterranean trade centres such as Alexandria, Aleppo or Constantinople. At the same time, royal regalia also contained various imitations of rubies, sapphires and emeralds (e.g. designated as *esmeraudes contrefeites*) such as glass simulants and doublets.

The scarcity of regalia that survive from the Late Middle Ages, however, has meant that modern mineralogical examinations of such items are rare. A notable exception is a detailed study undertaken to identify the gems decorating the Crown of Saint Wenceslaus (Hyršl & Neumanova 1999). That work, in turn, brought to

[1] Before it was recognised through modern mineralogy that the historical term *balas* encompassed two mineral species–corundum and spinel–European inventories in the Middle Ages frequently employed *balases*, *balays*, *baleis*, *pallas* or similar terms to indicate light red or purplish red to pink or purplish pink gems. Such stones were often described in 19th- or 20th-century mineralogical and gemmological literature as rubies or *balas rubies*, although it had been recognised that some particularly large and more famous gems such as the Black Prince's Ruby were pink to red spinels. Insofar as gemmological textbooks ('lapidaries') from the Middle Ages or the Renaissance era used *balas* to reference a light-coloured variety of the group of red gems, it is logical to assume that if texts or inventories from the Middle Ages spoke of rubies, these were darker, more intense red or purplish red gems. The methods applied in Europe in the late 14th or early 15th century did not permit separation between pink sapphires and spinels because classification was based primarily on colour.

Figure 2: A historical drawing shows Louis III, Elector Palatine from the House of Wittelsbach (centre), together with his first wife Blanche of Lancaster (right of centre), wearing a crown, and his second wife Mechthild of Savoy (far right). Likewise shown are Louis's father Rupert III, Elector Palatine and King of the Romans (King of Germany; far left) and his wife Elisabeth of Hohenzollern-Nuremberg (left of centre). This 1772 illustration is one of a series by Anna Maria Johanna Wisger, after a line of portraits from the Amberg residence depicting members of the Palatine branch of the House of Wittelsbach (see von Wiltmaister 1783). The 18th-century series was copied from an older series at Heidelberg Castle, painted circa 1500, which has been lost. Reproduced by permission of the Bayerisches Nationalmuseum, Munich.

light that descriptions offered in the crown's inventories, despite being repeated over the course of centuries, were not necessarily accurate. In particular, several of the larger red gems frequently characterised in the written record as rubies were identified as spinels and one red tourmaline, with the only rubies being small gems incorporated in the crown's arches. Other components included sapphires, emeralds and an aquamarine, while the presence of foil-backed gems offered another cautionary caveat to the inventories' claims.

An additional Late Middle Ages piece is preserved in the collection of the Treasury at the Munich Residence (Residenz München, Schatzkammer, Bayerische Verwaltung der staatlichen Schlösser, Gärten und Seen in Munich, Germany) and is referred to as the 'crown of an English queen' or the 'crown of Princess Blanche' (Figure 3 and cover of this issue). It is one of two surviving English crowns from the Late Middle Ages and is dated circa 1380. Although further appellations such as the 'Bohemian crown' or the 'Palatine crown' have been used, they have been called into question based on European chronology, amongst other factors, insofar as might concern any implications regarding origin.

The other remaining English crown from the Late Middle

Figure 3: The crown of Blanche of Lancaster, daughter of King Henry IV of England, was part of her dowry in 1402 when she married Louis, son of the King of the Romans (King of Germany) and Elector Palatine Rupert III. The piece consists of 12 segments, with six larger fleurons (18 cm tall) and six smaller fleurons (14.5 cm tall). It is richly decorated with blue and pink sapphires, pink spinels, garnets, emeralds, diamonds and pearls. Photo by K. Schmetzer, with permission from Bayerische Schlösserverwaltung, Munich.

Figure 4: The crown of Margaret of York, Duchess of Burgundy and wife of Charles the Bold, dated circa 1461, is the only other remaining English crown from the Late Middle Ages, now in the collection of the Aachen Cathedral Treasury, Aachen, Germany. Photo by P. Siebigs, reproduced by permission.

Ages (Figure 4), dated to 1461, served as the wedding coronet of Margaret of York, sister of Kings Edward IV and Richard III of England, upon her marriage to Charles the Bold, Duke of Burgundy, in 1468 (Hammond 1984). A similar crown, attributed to Margaret of Bavaria, consort of John the Fearless, Duke of Burgundy, is dated circa 1385 (Twining 1967). Both of these pieces, however, differ substantially in style and decoration from the one in the Munich Residence. Conversely, two crowns referenced in the 1380 inventory of King Charles V of France have descriptions suggesting that they could have been more analogous in style. Yet these crowns are not extant for study, nor do any drawings exist for comparison (Labarte 1879; Eikelmann 1984). Only the Crown of Saint Wenceslaus mentioned above, originally made for the coronation of Charles IV as King of Bohemia in 1347, would seem to offer any meaningful comparatives in an extant jewel, albeit a less elaborate example. The scarcity of available parallels thus heightens the academic value of the crown in the Munich Residence.

Overall Form and Characteristics

The studied crown is composed of a circlet of 12 numbered segments (designated I–XII) that serve as bases supporting 12 fleurons (again, see Figure 3). The diameter of the circlet—about 18 cm—is consistent with the size represented in the literature as usual for a woman's crown. Additional textile components, such as a fillet and barbette arrangement, would have been required to secure the piece to the head, serving as another indication that the crown was intended for a female.

No rigid metallic ring is used in the framework of the crown, resulting in a relatively flexible circular construction. The flexibility is further enhanced by elongated hinges connecting the 12 base segments (Figure 5). Each base segment consists of gold latticework displaying a stylised hexagon in the centre of a circle, from which rises a detachable fleuron composed of a gold stem topped by a lily or *fleur-de-lis* motif. The stems are fixed by prongs to vertical bars attached to the backs of the hexagons. The fleurons alternate in size, with six larger ones measuring approximately 18 cm tall (from the tip to the lowest point of the base segment) and six smaller ones measuring approximately 14.5 cm tall. The 12 base segments are each flanked by small panels containing enamelled patterns (e.g. white flowers; see Figure 5a). Both the segments and fleurons are heavily jewelled and decorated with coloured stones, diamonds and pearls. The hinge pivot between segments X and XI is easily removable, thereby allowing the segmented crown to be opened and laid flat.

While historical aspects of this crown have been studied in detail from the perspectives of both politics and art (Deibel 1927, 1928; Eikelmann 1980), a thorough examination of the numerous gem materials decorating

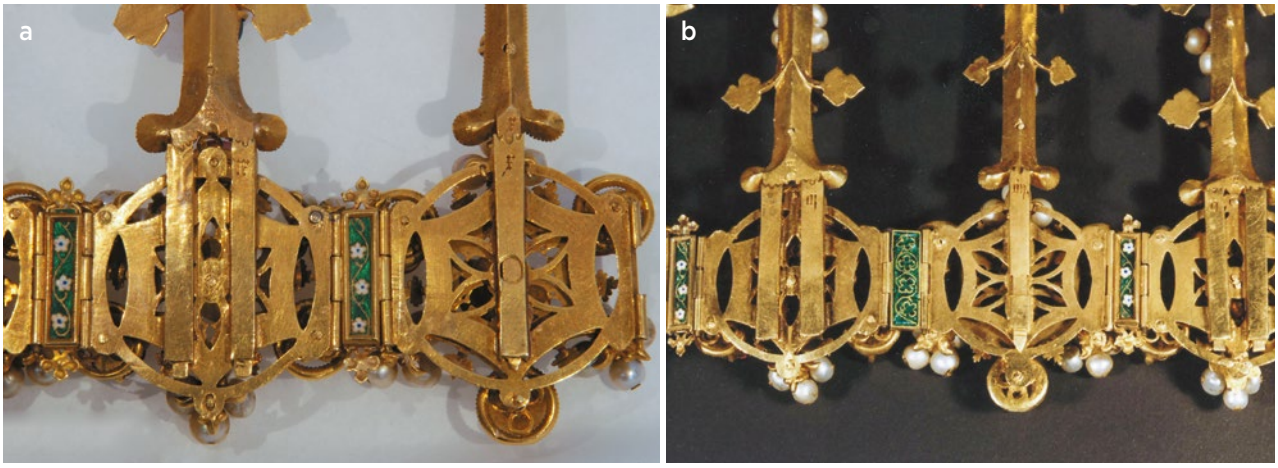

Figure 5: (**a**) The underlying gold structural framework of the crown of Blanche of Lancaster is revealed by this interior view. The base segments are flexibly connected by elongated hinges, and each segment consists of a latticework displaying a stylised hexagon in the centre of a circle. Each hexagon is backed by a vertical bar attached by prongs to its corresponding fleuron. (**b**) Another interior view of the crown shows how a base segment that was added in 1402 (centre, numbered 'iiii', but referenced as IV for purposes of this study) contrasts with the other segments in terms of its enamel decoration (left side) and goldsmith's work (see the right side of Figure 5a for comparison). Photos courtesy of Bayerische Schlösserverwaltung, Munich.

the piece has not yet been documented. Most descriptions, even in gemmological journals or textbooks (Gray 1989; Gübelin 1990), have relied only upon visual inspection and have been limited to characterising the gems primarily on the basis of their colour as sapphires, rubies, spinels (or *balas rubies* or *balases*), emeralds and diamonds. Thus, the principal aim of the present study is to offer a more thorough description of the crown's constituent gems, while taking into account its historical background.

HISTORICAL CONTEXT

Late 14th- and Early 15th-Century History and Descriptions

Documentation in early sources can offer insights into the crown's past, albeit with caveats. A general summary of the various members of the English, French, German and Bohemian royal families involved in its history in the late 14th and early 15th centuries is presented in Figure 6. In reviewing the history of this period, it is useful to recall that during the Late Middle Ages, the Holy Roman Empire (primarily equated with present-day Germany) also included Bohemia and part of Italy.

Scholars of history and art generally concur that two royal inventories, both dated 1398–1399, include catalogue entries for the Munich crown. As such, they represent the only known late 14th-century written evidence and the earliest references. The first, an inventory of the jewels and plate of Richard II (1367–1400) of England penned after January 1398 and before March 1399, was rediscovered in the 1990s (Stratford 2012). The inventory contained 1,206 entries covering nearly 2,300 treasury items accumulated by Richard II. Dispersed within was the personal jewellery of his queens, Anne of Bohemia (1366–1394, married 1382) and Isabella of Valois (1389–1409, married 1396). The list opened with 11 crowns, of which only the subject of this article (no. 7) is extant today.

The description of the crown, written in late 14th-century Norman French, was recounted by Stratford (2012)[2], and a modern translation (www.history.ac.uk/richardII/crowns.html) provides:

> Item, a crown of eleven plaques, set with eleven sapphires, thirty-three balas rubies[3], a hundred and thirty-two pearls, thirty-three diamonds, eight of them imitation gems. Item, six fleurons each with a balas ruby, five sapphires, and nine pearls, seven pearls in all being missing. Item, six smaller fleurons, each with a sapphire, four small balas rubies, an emerald

[2] *Item, j coronne de xj overages, garniz de xj saphirs, xxxiij balays et Cxxxij perles, xxxiij diamantz, dont viij contrefaitz. Item, vj florons chescun d'un balays, v saphirs chescun de ix perles, dont defaut en tout vij perles. Item, vj meyndres florons, chescun d'un saphirs, iiij petitz balays, j emeraud', dont defaut j emeraud' et ij petitz perles en chescun, pois' v marcz vij unc', et vaut outre CC li., dont la somme, CCxlvj li. xiijs. iiijd.*

[3] Notably, this modern translation, as quoted, uses the expression *balas rubies*, whereas the original text referred only to *balays*; see also footnote 1.

(one emerald being missing) and two little pearls in each, weighing 5 marks 7 oz., additional value £200, total, £246 13s. 4d.

The values given placed this crown amongst the lower-priced objects in the inventory. Noteworthy is the fact that the crown at that time was incomplete and unwearable because only 11 of the 12 base segments existed.

The second 14th-century documentation was an inventory of jewels and plate transferred from the royal treasury to Richard II's successor, Henry IV, and dates to November 1399. The inventory, comprising 340 entries, was first published in the 19th century with an introductory preamble (Palgrave 1836). The preamble indicates that the various items belonged to Edward III, Richard II, Queen Anne, the Duchess of York, the Duke of Gloucester and Sir John Golafre. The description of an item presented as entry no. 175 is nearly identical to that of crown no. 7 of the earlier inventory (including having 11 base segments).

Several theories as to how the crown came to be so included in these lists have been offered in the literature (see, e.g., Alexander 1987; Cherry 1988):

1. The crown was made and used before Anne of Bohemia came to England in December 1381 and married Richard II in January 1382.
2. The crown was part of Anne's dowry and was brought to London at the end of 1381.
3. The crown was made for and used by Anne after 1382 and before she died in 1394.
4. The crown was part of the rich dowry of Isabella of Valois, the second wife of Richard II, whom he married in 1396.

As to the first possibility, the lack of earlier references or other indications of a similar piece available in the relevant time frame renders the idea highly speculative at best. Evaluation of the remaining three theories requires considering how the crown might have fit into what was happening in Europe during the late 14th century (again, see Figure 6).

The end of the 1370s brought a number of changes in the prominent European dynasties. In 1377, Edward III, King of England, died and was succeeded to the English throne by his grandson as Richard II. In 1378, Charles IV (Holy Roman Emperor and King of Bohemia) died and

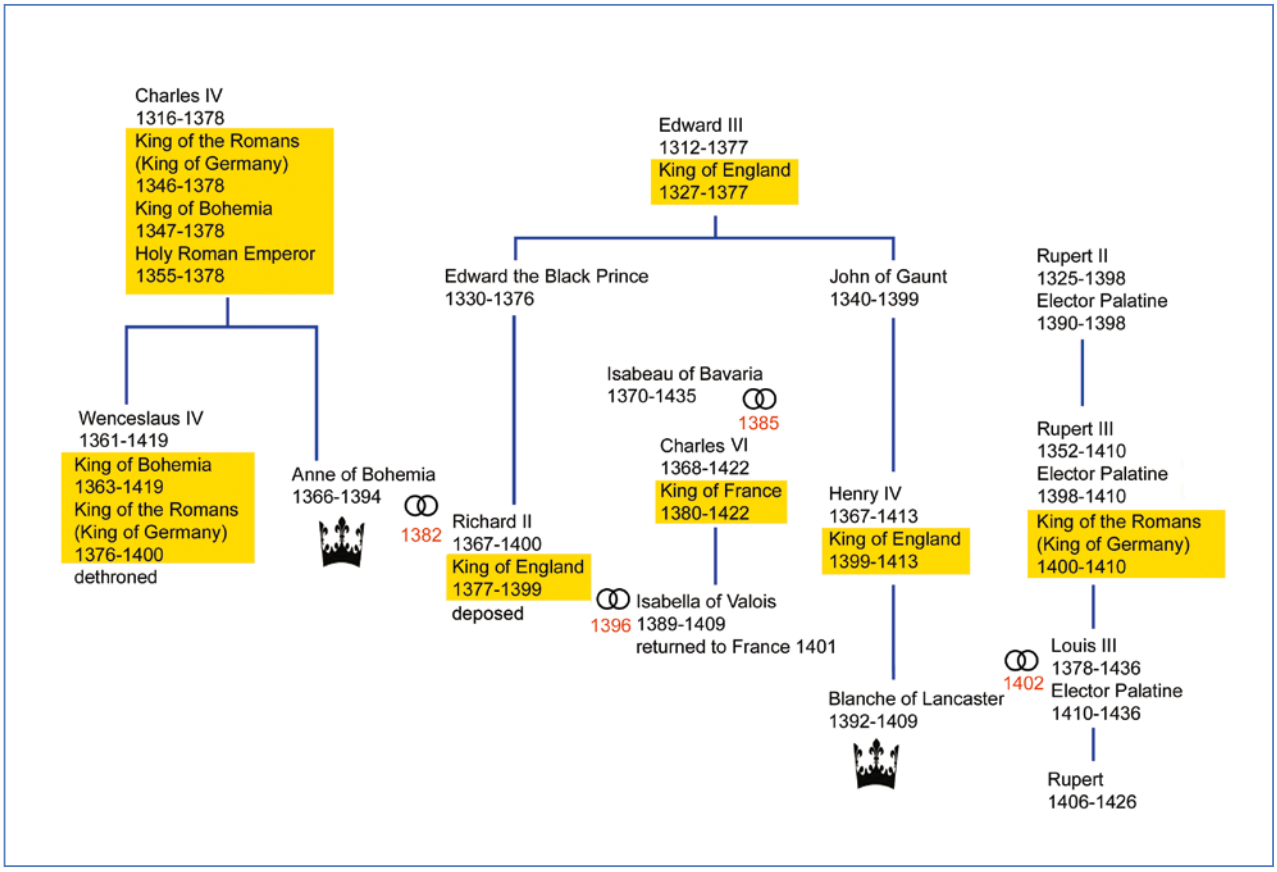

Figure 6: Relationships between royal dynasties in England, France, Germany and Bohemia in the second half of the 14th century and the first decades of the 15th century played a key role in the crown's history. The interlocking circles indicate marriages (with the year shown in red) and the crown symbols show the two inferred owners of the crown, as discussed in this article.

his son Wenceslaus IV began to rule by succession as King of Bohemia (after having been so crowned in 1363 at the age of two). Wenceslaus IV had also been elected King of the Romans (King of Germany) in 1376 through his father's influence. When Charles V, King of France, died in 1380, he was succeeded by his son Charles VI. As the new rulers sought to consolidate their power, an exigency further exacerbated by rivalries in the ongoing Hundred Years' War (1337–1453), both England and France were led to seek alliances with German dynasties (Emerson 1910).

Although Charles IV (Figure 7) had initially broached the idea of a marriage between his daughter Anne of Bohemia and Richard II in 1377, serious negotiations by envoys travelling between London and Prague began only in 1380 at the initiative of Pope Urban VI. In 1381, an agreement was signed setting forth details for a marriage between Richard II and Anne, the half-sister of Wenceslaus IV (Figure 7). However, despite promises from Wenceslaus to give his half-sister a dowry consistent with her high noble status, specifics were never fixed by contract. Instead, records indicate that Wenceslaus was not in a position to compile a lavish endowment

Figure 7: Charles IV (left), King of Bohemia from 1347 to 1378 and Holy Roman Emperor from 1355 to 1378, was succeeded by his son Wenceslaus IV (right), King of Bohemia from 1363 to 1419 and King of the Romans (King of Germany) from 1376 to 1400. This engraving is part of the reliquary cross of Pope Urban V, St Vitus Cathedral, Prague, dated to the 1370s. From Podlaha & Sittler (1903).

and even began to conflate the marriage negotiations with requests for substantial 'loans' or 'grants' from England to fund his government (20,000 and 80,000 guilders, at least a portion of which was paid). Anne ultimately left Prague in the autumn of 1381 without a dowry. She arrived in London in December 1381 and married Richard II in January 1382, followed by a coronation ceremony in London a few days later (Pelzel 1788; Strickland 1849; Heeren 1910; Saul 1997; Reitemeier 1999; Tuck 1999; Stratford 2012).

The foregoing circumstances, in particular the dire financial straits coupled with the absence of any formal written contract to supply a dowry, would thus seem to eliminate the second-listed concept—that the crown was part of Anne's dowry—and to make unlikely any similar variation in which such an ornate crown could have been manufactured in Prague and brought to London by Anne or someone else with other gifts from Bohemia (Campbell 1997).

Conversely, much about the style and decoration of the crown lends support to the third theory of procurement by Richard II for Anne between 1382 and 1394. First, regarding the crown's general style, evidence reflects that an arrangement of larger and smaller fleurons was one favoured by Richard. For example, in preparation for his marriage, Richard sent a communication directing the return of a crown with five large and five small fleurons from the City of London, where it was being held with other jewels as a pledge (Riley 1868; Stratford 2012). Such communication was described by Riley (1868): 'there is a Letter (in French) of King Richard, dated 1st of January…(A.D. 1382), requesting that the Mayor and Commonalty will lend him back the above jewels, as he requires them for his intended marriage'. It is unknown whether Richard II planned to wear this crown himself or whether he retrieved it for his future queen.

In a similar vein, a portrait of Richard II and Anne in the Shrewsbury Charter of 1389 shows both wearing crowns with larger and smaller fleurons (Whittingham 1971; Figure 8). It has also been speculated (Binski 1997) that the image of a coronation ceremony of a king and queen wearing analogous crowns in the *Liber Regalis*, a manuscript most likely dated to the 1390s, depicts Richard II and Anne (Figure 1), and at least the physiognomy of Richard is close to that in the Shrewsbury Charter. The portrait of Richard II from the 1390s in Westminster Abbey, however, reflects a different-style crown with fleurons of the same length (Scharf 1867; Holmes 1937; Campbell 1997).

Richard II was additionally known to be prolific in

Figure 8: King Richard II of England and Anne of Bohemia are depicted in the Shrewsbury Charter of 1389, a document in which Richard confirmed rights given to the people of Shrewsbury. Reproduced by permission from the Shropshire Archives, Shrewsbury.

procuring new pieces, and the crown's decoration is consistent with his purchasing habits. While orders from London goldsmiths were predominant, Richard II also turned to international suppliers. He bought costly objects, including new gold crowns from Italian and French goldsmiths or merchants (Campbell 1997), but to date no document related directly to the purchase or order of the subject crown has come to light. The artwork employed on the piece, especially the enamel embellishment, points towards one of the great courts and economic centres in France, Flanders or Burgundy. Numerous enamelled pieces of jewellery of exceptional quality with such provenance, using a technique characterised as *émail en ronde bosse* (enamelling on rounded or irregular surfaces), are known from the late 14th or early 15th century (Eikelmann 1984). Conversely, although enamel was applied to adorn the work of goldsmiths in England as well, the number of pieces comparable to the lavish examples from what is today France, Belgium and the Netherlands is small or non-existent (R. Eikelmann, pers. comm. 2018).

Moreover, further details of the decoration support a link to Anne herself. As recounted briefly above, the base segments are festooned with enamelled flowers. These flowers may be representative of daisies, an image considered symbolic of Anne of Bohemia, to the extent that she was referred to as the 'daisy queen', and the flower was used to represent her in poetry at the time (see Lawrance 1840; Morley 1873; Percival 1998; Bowers 2001; Thomas 2007; Hilton 2008; Van Dussen 2009). While a more comprehensive evaluation of such associations in late 14th-century poetry is beyond the scope of this study, one notable example should be highlighted: the English poet Geoffrey Chaucer (circa 1343–1400) was closely intertwined with the Ricardian court, and since the 19th century it has been assumed that the 'daisy queen' in Chaucer's poem *The Legend of Good Women* represented and honoured Anne of Bohemia. In addition, certain other jewellery belonging to Queen Anne was enamelled with small white flowers such as marguerites or daisies.

The fourth and last theory listed above for the origin of the crown finds little foundation in the historical record. After Anne died childless in 1394, Richard II married Isabella of Valois, daughter of King Charles VI of France and Isabeau of Bavaria, in 1396. The concomitant written agreement provided for an extended 28-year armistice in an effort to bring the Hundred Years' War to a close (Reitemeier 1999). Isabella brought a rich dowry to England, and two crowns with eight fleurons each were incorporated therein. After Richard II's death, however, Isabella returned to France in 1401, together with a substantial portion of the jewellery from her dowry, including the two crowns (Stratford 2012).

Thus, considering and evaluating the facts available at present, the most probable explanation for the crown's origin is found in the third theory: that it was made in the 1380s for Anne of Bohemia, after her marriage to Richard II.

The turn of the century saw a period of renewed turmoil amongst the ruling families in England and the Holy Roman Empire (including Germany and Bohemia). In London, Richard II's dictatorial policies had aroused the ire of powerful aristocrats, and he was deposed in a military campaign and forced to abdicate in 1399. His cousin succeeded him to the throne as Henry IV. Richard II is thought to have died in captivity the following year, although questions remain about the exact circumstances.

In Germany, Wenceslaus IV was dethroned as King of the Romans in 1400 by a vote of the four electors from the Rhineland region: Rupert III of the Palatinate (Elector Palatine) and the Archbishops of Mainz, Cologne and Trier. The deposition of Wenceslaus IV was premised on an apparent complete ineptitude in management over matters of both church and state, not to mention a widespread reputation for ruthlessness, drunkenness and a general lack of dignity. Rupert III (Figure 9a) was elected King of Germany by the same four votes, including his own, within days. He was

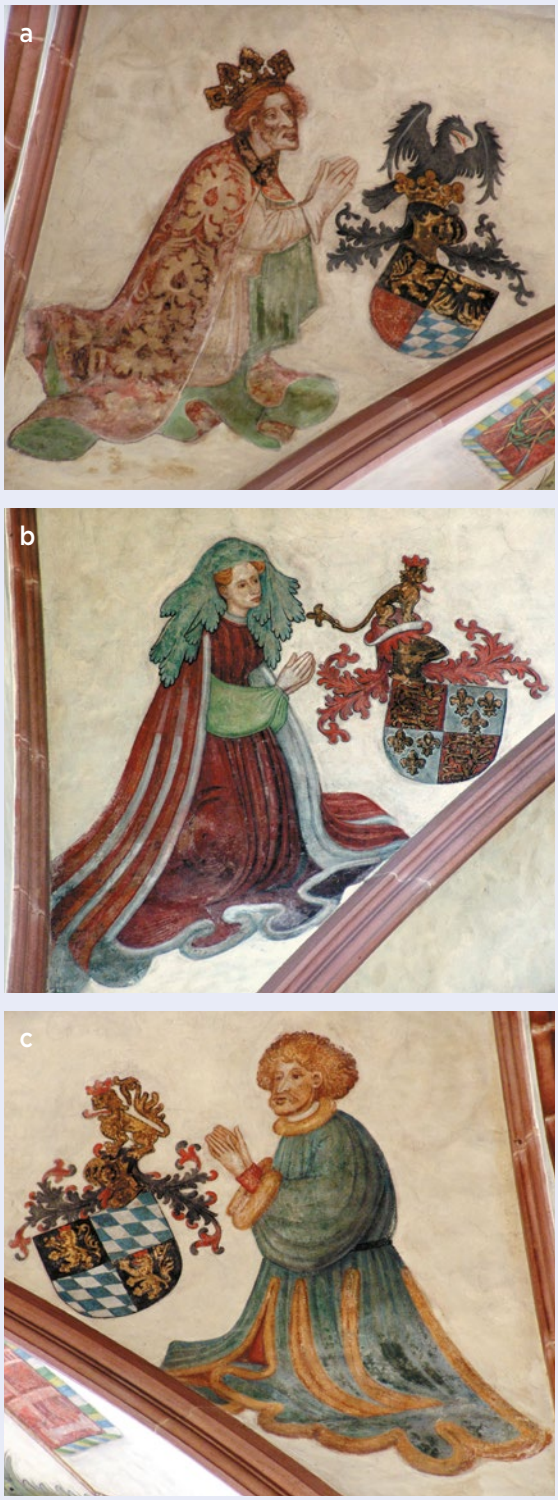

Figure 9: Portraits of (**a**) Rupert III, King of the Romans (King of Germany), (**b**) Blanche of Lancaster and (**c**) her husband Louis III, Elector Palatine, decorate the Stiftskirche church in Neustadt an der Weinstraße, Germany, where Blanche is buried. The paintings were created between 1410 and 1417 on Louis III's initiative (see Keddigkeit *et al.* 2015) and comprise Blanche's most contemporary depiction. Photos by R. Schädler, reproduced by permission.

crowned by Archbishop Frederick III in Cologne in January 1401, and a second short coronation ceremony was performed in Aachen several years later, in November 1407 (Höfler 1861; Weizsäcker 1882, 1885; Oberndorff 1912; Dürschner 2003; Auge 2005). Wenceslaus IV continued to rule as King of Bohemia and never acquiesced in his deposition as King of Germany at any time prior to Rupert's death in May 1410 (Lindner 1896; Reitemeier 1999; Dürschner 2003). In such fraught circumstances, both Henry IV and Rupert III looked again to the device of a prestigious marriage between the families as a way to elevate their status and create beneficial foreign alliances.

Serious negotiations began in 1401 concerning a marriage between Henry IV's daughter Blanche of Lancaster (1392–1409)[4]—also known as Blanche, Blanca or Blanka of England—and Rupert III's son Louis (1378–1436). Written agreements providing for an extremely rich dowry, including a monetary component of 40,000 nobles, were signed in 1401 and 1402. Taking into account the gold content and weight of the coin in the relevant time frame, the value of 1 noble is estimated to be equivalent to approximately 2.2 guilders. Communications between Rupert III and Louis, however, equated the 40,000 nobles with an estimated 100,000 guilders (see Oberndorff 1912).

Between March and April 1402, the crown was repaired by London goldsmith Thomas Lamport, who constructed a replacement base segment (labelled 'iiii' [see Figure 5b], but hereinafter numbered IV) and also added one missing emerald and nine missing pearls to existing components of the crown (Stratford 2012). Blanche (Figure 9b) and her entourage left England in June 1402 and arrived in Cologne in July, where she married the future Louis III (Figure 9c) before being guided to Heidelberg, carrying much of her dowry with her (Stratford 2012). Heidelberg served at that time as the capital of the Palatinate branch of the House of Wittelsbach and was the site of the principal castle. Records from July 1402 confirm that the crown, now complete and wearable, was formally received as part of the dowry, as was a fillet of the type that might have been used to affix a crown to a woman's head (Rall 1965). The financial component was paid by instalments, commencing in 1402 and continuing in the ensuing years (Devon 1837; Green 1857; Weizsäcker 1885; Oberndorff 1912; Holtzmann 1930; Reitemeier

[4] Not to be confused with Henry IV's mother Blanche (1342–1368), likewise called Blanche of Lancaster.

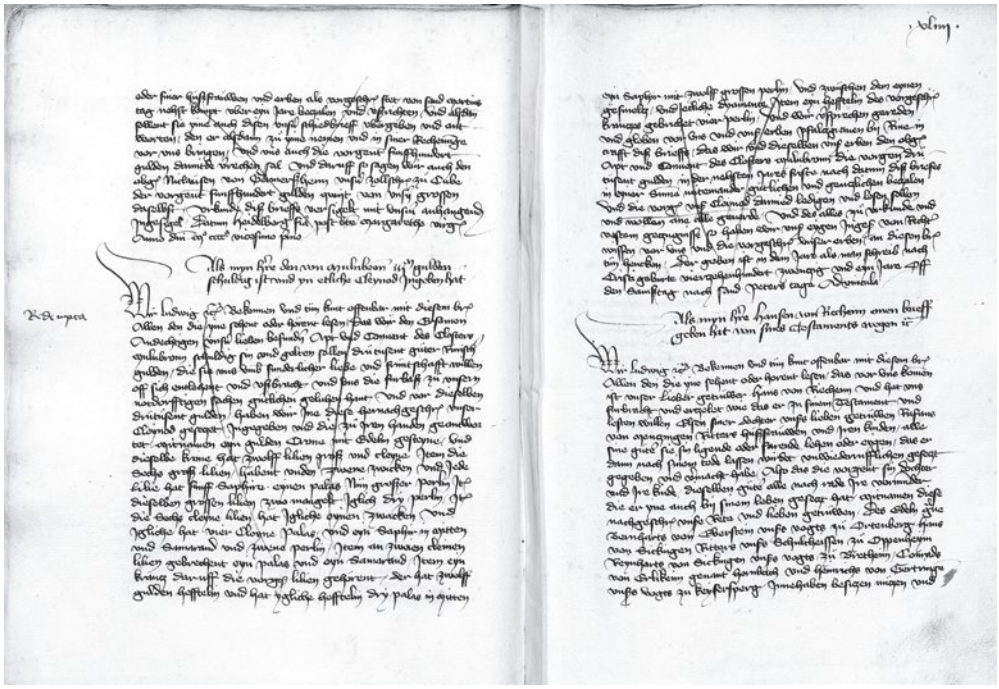

Figure 10: The crown of Blanche of Lancaster was pawned in 1421 to the monastery of Maulbronn, Germany, for 3,000 guilders. The transaction is memorialised in a volume of Elector Louis III's administrative records that set forth a detailed description of the crown's embellishment and the gems missing at that date (Generallandesarchiv Karlsruhe, Kopialbuch 67/810, Blatt 43v–44r, reproduced by permission).

1999). A portion of the sum remained outstanding as of 1444 and was sought by Louis IV, the son of Louis III and his second wife, Mechthild of Savoy (Brandenstein 1983).

In 1406, Blanche gave birth to a son, Rupert, named after his grandfather, but she died from a serious illness only three years later in 1409. Both Louis and Rupert III wrote personal letters to Blanche's father in London, expressing deep grief and mourning, and thereby suggesting a close, affectionate relationship between the spouses (Schreibmüller 1959). Blanche's widower became Elector Palatine as Louis III in 1410 upon the death of his father. Louis III was remarried in 1417 to Mechthild (or Mathilde or Matilda) of Savoy. Blanche's son Rupert, nicknamed 'the English', died in 1426, before his father.

The crown meanwhile was pawned by Louis III in 1421 to the monastery of Maulbronn, located south-east of Heidelberg, in return for 3,000 guilders. A description prepared in connection with the transaction (Figure 10), written in 15th-century German, reflects that by that point several gems were missing, including three *perlin* (pearls) from two of the larger fleurons, one *palas* (*balas*) and one *samarand* (emerald) from two of the smaller fleurons, and four *perlin* from one of the base segments. Annotations on the original administrative document indicate that the loan was subsequently repaid, and the piece was returned to Louis III from Maulbronn at an unknown date (Deibel 1927, 1928; Brandenstein 1983).

Later History and Descriptions

Later eras, from the 16th to the 20th centuries, saw the crown being kept at three primary locations in Germany—Heidelberg, Mannheim and Munich—with intermittent removals for safekeeping during times of war. Throughout the 16th and 17th centuries, the crown remained within the treasury of the Elector Palatine at the capital in Heidelberg, the ownership passing with succession. The treasury of the Elector Palatine also continued to be tracked through various inventories.

Two 16th-century inventories detailed the crown's constituent gems. One from 1544 characterised the 12 base segments as each having three *baleis*, one sapphire and 12 pearls; the six larger fleurons as each having five sapphires, one *baleis*, one small emerald and nine pearls; four of the smaller fleurons as each having one emerald, one sapphire, four *baleis* and two pearls; and two of the smaller fleurons as each having one emerald, five *baleis* and two pearls (Eikelmann 1980). The other inventory, from 1568, delineated the segments and fleurons together. The larger fleurons and attached segments were described as being decorated with six sapphires, four *rubin pallas*, 21 pearls, three diamonds and one small emerald. The smaller fleurons and attached segments contained two sapphires, seven *rubin pallas*, 14 pearls, three diamonds and one emerald (Sillib 1903).

In general, and somewhat inexplicably, the inventories from the 16th century typically denoted the crown as that of Rupert III of the Palatinate, Louis III's father

and Blanche's father-in-law. Written evidence from the 17th century is limited to various brief references, which tended to repeat the attribution to Rupert III (see, e.g., Sandrart 1679; and Huffschmid 1910, publishing a French travelogue from 1664). Such assignment, however, is contravened not only by the documented journey of Blanche's crown as recounted above but also by what has been revealed about Rupert's own crown and the fate of his valuables. Specifically, Rupert's crown was described as having 14 fleurons decorated with gems and pearls, and it was pawned at least twice, in 1401 and 1403, with the latter transaction involving just 150 guilders. Thus, neither the number of fleurons nor the apparent low value seem consistent with Blanche's crown. Moreover, Rupert's will, written two days before his death in May 1410, directed that his crown and other valuables should be sold to liquidate outstanding debt. While further details are unknown, Rupert's crown is not believed to have survived (Weizsäcker 1882, 1885; Rödel 2000; Moraw 2001; Schneidmüller 2011).

The year 1720 witnessed relocation of the capital of the Palatinate, as well as the residence and treasury of the Elector Palatine, from Heidelberg to Mannheim. Following the transfer, the crown continued to be cited in various inventories from 1729 and thereafter. Such 18th-century sources, as well as others penned in the 19th century, often attributed the crown erroneously to Frederik V, who reigned as Elector Palatine from 1610 to 1623 and as King of Bohemia from 1619 to 1620 (Deibel 1927, 1928; Brunner 1968, 1971; Eikelmann 1980). Instances in which the piece was referred to as the 'Bohemian crown' also appeared (see, e.g., Deibel 1927, 1928). The questionable nature of such attributions and appellations regarding the crown's origin was already being raised by the late 19th century (von Schauss 1879), and they were entirely discredited by the early 1900s (Sillib 1903; Weiß 1911). With respect to the condition of the crown, sporadic information included mention in a 1745 inventory that two pearls were missing and that one sapphire had been replaced by an amethyst (Brunner 1971).

Throughout the centuries following the treaty of Pavia in 1329, separate branches of the House of Wittelsbach had ruled over the Electorate of the Palatinate and the Electorate of Bavaria, which were independent hereditary estates within the Holy Roman Empire. In 1777, the last in the Bavarian line of succession died, and Charles Theodore of the Palatine branch of the House of Wittelsbach and Elector Palatine, residing in Mannheim, became Elector of Bavaria by succession. The electorates were united and combined, and Charles Theodore relocated in 1778 from Mannheim to Munich. The treasury was transferred to Munich over the course of multiple journeys and was thereafter characterised as that of the Elector of Bavaria, with the crown in particular being listed in a 1783 inventory (Eickelmann 1980).

During 1805 and 1806, in conjunction with the abolishment of the Holy Roman Empire by Napoleon, what had formerly been known as the Electorate of Bavaria became the Kingdom of Bavaria, and the ruling Elector of Bavaria became the King of Bavaria. Per the constitution enacted in 1818, the treasury was deemed to belong to the state, rather than being the private property of the royal family. The kingdom ended in 1918, giving way to a secular state. The crown is now owned by the Wittelsbacher Landesstiftung (WL) and is on display in the collection of the Treasury at the Munich Residence (inventory no. 16 WL), a museum which opened to the public in the early 1930s.

Sources dating from the late 18th century through the early 20th century incorporate details about the crown's condition as follows (Eikelmann 1980):

- 1783: Amongst the sapphires was one imitation.
- 1818/1820: Two gems (rubies?) and two pearls were missing. Amongst the sapphires was one glass piece.
- 1833: Amongst the sapphires was one glass piece.
- 1868 and 1872: Four sapphires, one ruby, two emeralds and six pearls were missing, but three of the sapphires were still available as loose gems.
- 1880: One sapphire, two rubies, one emerald and five pearls were missing.
- Undated (between 1880 and 1905): Five sapphires, one ruby, two emeralds and one pearl were missing, but three of the sapphires were still available as loose gems.

In 1925 all missing gems and pearls were replaced by Munich goldsmith Max Heiden (Deibel 1927, 1928). When the crown was examined in 1980, the numbers of only seven of the base segments corresponded with the numbers of the attached fleurons (Eikelmann 1980).

As the early 20th century progressed, it was increasingly apparent that what had been referred to as the 'Palatine crown', the 'Bohemian crown' and the crown of Blanche of Lancaster were one and the same (Sillib 1903; Weiß 1911). Finally, scholars in 1927 reached the now-accepted conclusion that the crown in Munich had come from Blanche's dowry and is identical to the crown which Louis III had pawned in 1421 (Deibel 1927, 1928).

MATERIALS AND METHODS

The crown was examined by the authors at the Munich Residence in October 2018 and January 2019. During each visit to the museum, initial evaluation took place with the crown in its fully assembled circular state (Figure 11). During the latter visit, the removable hinge pin mechanism was used to open the crown and allow the 12 pivoted segments to be laid flat for further inspection (Figure 12).

Microscopy, energy-dispersive X-ray fluorescence (EDXRF) analysis and Raman spectroscopy were employed on site. Microscopic examination utilised an Olympus X binocular stereo microscope with 6.3×–40× objectives and fibre-optic illumination (Figure 13).

Identification of the individual gems and imitations decorating the crown was achieved through EDXRF analysis (light and heavy elements) alone or in combination with Raman spectroscopy. In general, all samples were measured twice by one or both methods. The initial focus was on Raman analysis to identify the gems, but it was later established that EDXRF was sufficient to separate the rubies and pink sapphires from spinels because the Mg peak of the spinels was clearly detectable. Furthermore, Raman spectroscopy was not performed on the garnets, for which the chemical data were sufficient to determine the species or variety present. (Gemmological examination of the pearls, being an organic gem material, was not within the scope of this study. Thus, the pearls are mentioned henceforth only where relevant to explain the overall pattern of the decoration.)

The EDXRF measurements were performed using a handheld Bruker Tracer III-SD EDXRF analyser (Figure 11) equipped with a rhodium anode, a silicon drift detector with a resolution of 147 eV at 10,000 cps, and a portable vacuum pump. The size of the beam directed at the gem was about 2 × 3 mm, which in some instances, especially for smaller samples, yielded chemical signals from both

Figure 13: The flattened geometry of the opened crown facilitated microscopic examination of the 12 base segments and fleurons and allowed the individual gem materials to be more easily targeted by the EDXRF spectrometer (not shown here). Photo by K. Schmetzer, with permission to photograph and reproduce from Bayerische Schlösserverwaltung, Munich.

Figure 11: A portable EDXRF spectrometer was used to analyse constituents of the crown on site at the museum, initially with the piece in its circular state. Photo by K. Schmetzer, with permission to photograph and reproduce from Bayerische Schlösserverwaltung, Munich.

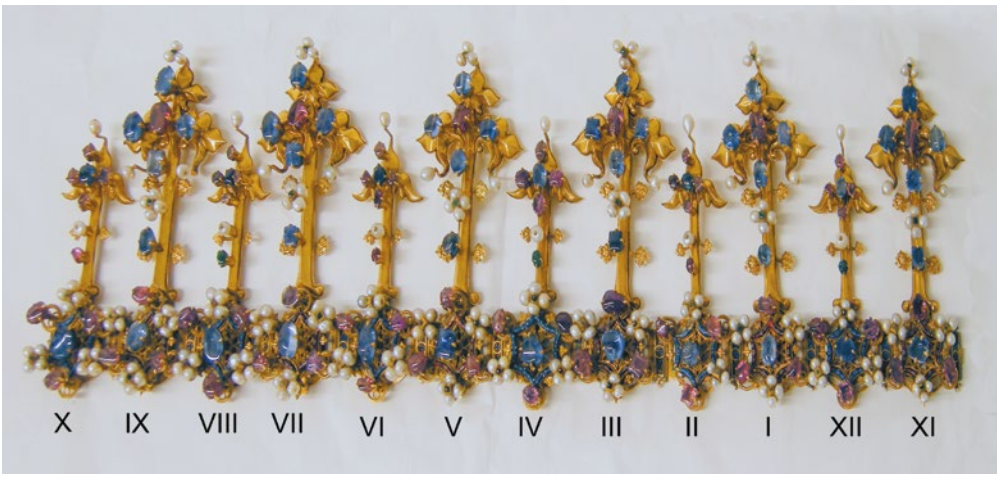

Figure 12: Once the crown was opened by means of a removable pin in one of the connecting hinges, the 12 base segments supporting the 12 fleurons could be laid flat in a band measuring approximately 60 cm in length. Photo by K. Schmetzer, with permission to photograph and reproduce from Bayerische Schlösserverwaltung, Munich.

the gem and the mounting. Light elements (Mg to K) were analysed with an accelerating voltage of 15 kV and beam current of 25 µA in a vacuum; heavier elements (K to U) were measured with 40 kV and 30 µA, employing a yellow filter (0.001 mil Ti, 0.012 mil Al). The Artax 7.4.8.2 software package (provided by Bruker Nano Analytics) and various mineral standards were used for quantification. For example, quantitative chemical analyses for garnets were measured by means of using standard samples with known compositions (as determined by electron microprobe) for comparison.

The Raman measurements utilised a portable Enwave EZRaman-N-785-B spectrometer. The instrument was equipped with a 785 nm IR laser with a maximum power of 300 mW, a glass fibre-optic probe with a 7 mm working distance, and an f/1.6 CCD spectrograph with a spectral range from 3300 to 100 cm^{-1} (resolution of 6 cm^{-1}). Spectra were plotted using CrystalSleuth software.

RESULTS

The Framework of the Crown

Previous work had indicated that the crown was constructed of 18-carat gold (Deibel 1927, 1928). EDXRF measurements revealed strong signals for gold as well as silver and copper, which is not unusual for gold from the 14th century. Quantitative analyses of several components of the framework (including the replaced segment IV), using seven calibrated gold-silver-copper standards for comparison, resulted in a composition of 81.0–82.3 wt.% Au, 7.8–8.4 wt.% Ag and 9.8–10.6 wt.% Cu (which calculates to 19.4–19.8-carat gold).

The non-original nature of segment IV was evident from differences visible on the back in both the goldsmith's work and the enamel embellishment (Figure 5b).

The Decoration – Overview

A schematic diagram depicting the arrangement of gem materials decorating the crown is provided in Figure 14. The gems are drawn to scale to show approximate size relationships between them. Table I summarises the main features of the gems, including their varieties, shapes and fashioning.

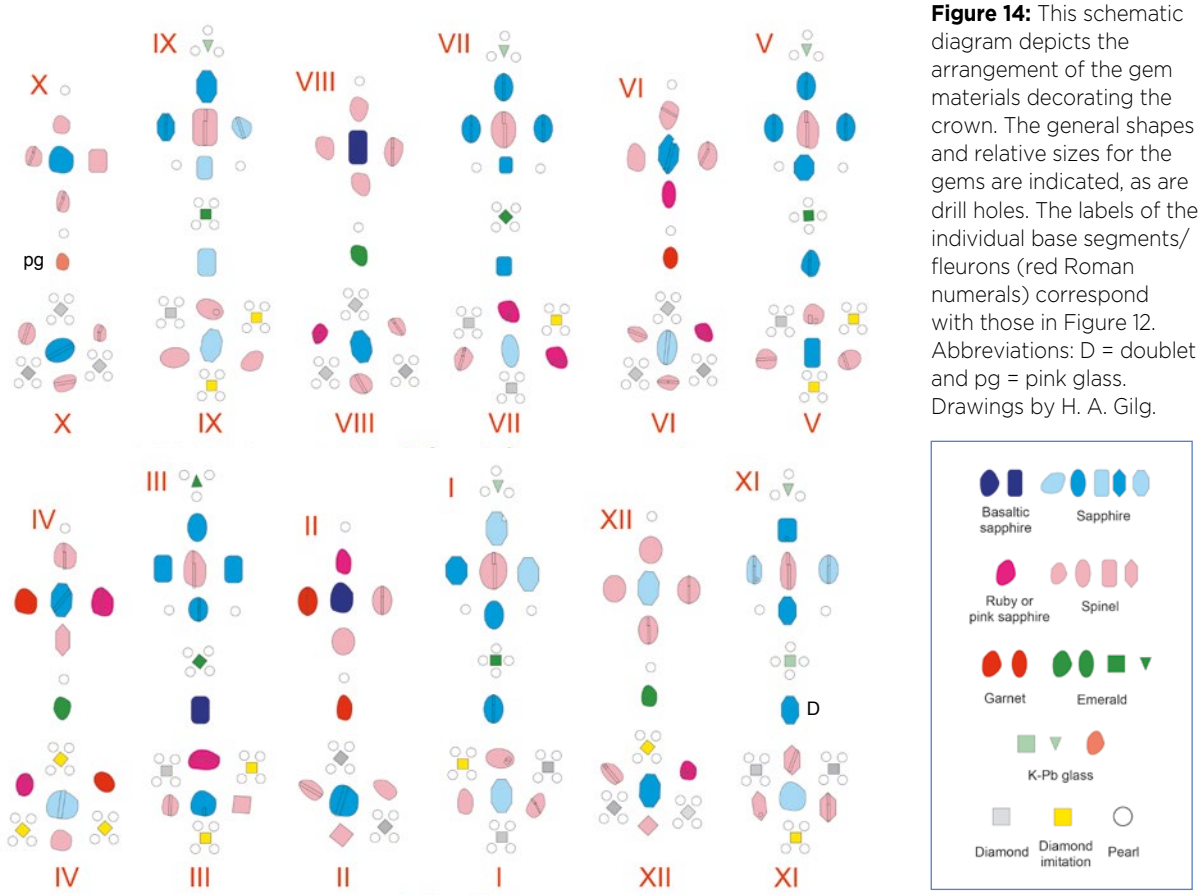

Figure 14: This schematic diagram depicts the arrangement of the gem materials decorating the crown. The general shapes and relative sizes for the gems are indicated, as are drill holes. The labels of the individual base segments/fleurons (red Roman numerals) correspond with those in Figure 12. Abbreviations: D = doublet and pg = pink glass. Drawings by H. A. Gilg.

Table I: General survey of gem materials in the late 14th-century crown of Blanche of Lancaster.

Outline/ shape as mounted	Form and cut [a]	Sapphire (dark blue, translucent)	Sapphire (light to intense blue, transparent)	Sapphire doublet (intense blue)	Pink sapphire to ruby	Pink spinel	Garnet	Emerald	Green K-Pb glass	Pink K-Pb glass	Diamond	Diamond imitation
Irregular/ pebble-like	Irregularly shaped with generally curved upper surface	1	11	–	8	41	2 + 2[b]	2	–	1	–	–
	Irregularly shaped with curved upper surface topped by shaped or preformed table	–	1	–	2	4	–	–	–	–	–	–
Oval or near oval	Curved dome	–	9[c]	–	–	1	–	1	–	–	–	–
	Dome topped with planar table	–	2	–	–		1					
Rectangle	Shaped or preformed table and one row of inclined surfaces, with rounded edges	2	4	–	–	1	–	–	–	–	–	–
	Planar table and one row of inclined crown facets, with sharp edges	–	2	–	–	2	–	–	–	–	–	–
Hexagon	Shaped or preformed table and one row of inclined surfaces, with rounded edges	–	–	–	–	1	–	–	–	–	–	–
	Planar table and one row of inclined crown facets, with sharp edges	–	1	–	–	3	–	–	–	–	–	–
Octagon	Shaped or preformed table and one row of inclined preformed surfaces, with rounded edges	–	5[d]	–	–	–	–	–	–	–	–	–
	Planar table and one row of inclined crown facets, with sharp edges	–	5[e]	–	–	–	–	–	–	–	–	–
	Planar table and one row of inclined crown facets, scissor cut, with sharp edges	–	1	–	–	–	–	–	–	–	–	–
	Planar table and one row of inclined crown facets, as well as one row which is nearly perpendicular to the table, with sharp edges	–	3	–	–	–	–	–	–	–	–	–
	Planar table and two rows of weakly inclined crown facets, with sharp edges	–	–	1	–	–	–	–	–	–	–	–
Square	Curved upper surface	–	–	–	–	–	–	5	1	–	–	–
Triangle	Curved upper surface	–	–	–	–	–	–	1	5	–	–	–
Square	Four-sided pyramid, natural octahedron	–	–	–	–	–	–	–	–	–	22	13
Sum[f]		3	44 (21)	1	10 (8)	53 (36)	5 (1)	9	6	1	22	13

[a] Green text indicates gems that appear to have only been polished without prior fashioning or were used in their natural state; red indicates shaping or preforming and polishing; blue indicates preforming, faceting and polishing.
[b] Numbers in red represent gems that were most likely replaced after 1700.
[c] Includes three asteriated sapphires.
[d] One stone with pavilion facets.
[e] One stone with crown and pavilion facets.
[f] Number of samples (from the total amount given) with drill holes is shown in parentheses.

Gems—Colour, Identity, Shape and Size. The inorganic gem materials and imitations thereof can be divided into four broad groups based on colour: blue, pink to red, green, and colourless (including black imitations, which were fashioned to simulate diamond crystals). The different varieties identified across these groups were blue sapphires; rubies, pink sapphires, pink spinels, garnets and pink glass; emeralds and green glass; and diamonds and diamond imitations. Insofar as the majority of the pink-to-red corundum would be classified as pink sapphire in the trade today, and because no precise boundary between ruby and pink sapphire exists, for simplicity only the term *pink sapphire* will be used hereinafter for this range.

The basic shapes of the gems (seen as mounted) spanned from irregular waterworn (pebble-like) or fragmented forms to more regular oval, rectangular, hexagonal, octagonal, square and triangular outlines. The larger gems—which tended to be rectangular, hexagonal and octagonal sapphires and pink spinels—measured approximately 14 × 10 mm in size. The smallest gems, which were primarily diamonds, diamond imitations and emeralds, were all approximately 4.3 mm (including the bezel setting). The remaining samples fell between these two groups (e.g. the piece of pink glass in fleuron X was 7.1 × 6.8 mm; see again Figures 12 and 14). These sizes also provide an approximation of the scale in photographs of the gems that are shown below.

Arrangement. The base segments supporting the larger fleurons incorporated a stylised hexagonal motif bordered in red enamel with small dots that appear to represent flowers (Figure 15a). Each of these segments also includes a central blue stone (sapphire) surrounded by three pink sapphires or spinels and three diamonds or diamond imitations, the latter of which, in turn, are each surrounded by four pearls. Each of the attached larger fleurons is embellished, from top to bottom, with a tiny emerald or piece of green glass surrounded by three pearls; a pink spinel surrounded by four blue sapphires,

Figure 15: Each base segment is decorated by a central blue sapphire surrounded by three pink to red stones (pink sapphires or spinels) and three diamonds or diamond imitations, with each diamond or imitation in turn being surrounded by four pearls. As further embellishment, (**a**) the base segments underlying the larger fleurons incorporate stylised hexagonal lattices that are bordered in red enamel and decorated with small white flowers, while (**b**) the segments supporting smaller fleurons have blue enamel backgrounds for the white flowers. The lowest stones on the fleurons, also visible in these images, were identified as (a) a sapphire and (b) an emerald. Photos by K. Schmetzer, with permission to photograph and reproduce from Bayerische Schlösserverwaltung, Munich.

with a pearl to the right and left of the lowest of the four sapphires; another emerald or piece of green glass surrounded by four pearls; and another blue sapphire just above the base (Figure 16a).

The base segments supporting the smaller fleurons resemble those of the larger fleurons, with the primary differences being a blue enamel border underlying the dotted pattern (Figure 15b) and a slightly broader selection of choices for the surrounding pink to red stones (sapphire, spinel or garnet). In segment II, a portion of the gold framework that would have held one diamond and the surrounding four pearls is missing. The smaller fleurons are each decorated with a pearl; a blue sapphire surrounded by four pink sapphires, spinels, or garnets; another pearl; and just above the base an emerald (in three fleurons, see Figure 16b) or a garnet or piece of pink glass (in three fleurons; not shown).

Gem Fashioning and Enhancements. The degree and style of fashioning exhibited extreme variation across the gems, from minimal processing to extensive work. The diamonds all appeared to have been left as natural crystals. For the coloured stones, a generally ascending scale of complexity could be characterised according to three basic levels, with one, two or three main steps, respectively:

1. Irregular, pebble-like shapes, with only surface polishing, achieved either naturally through erosion and alluvial transport or through deliberate polishing.
2. Materials shaped or preformed without sharp edges and then polished, ranging from cabochon or other curved forms, to curved forms with a planar table, to more polygonal forms with potentially several inclined planar surfaces.
3. Materials preformed, faceted with sharp edges and polished.

Drill holes were often visible within the gems, most commonly in those with irregular, pebble-like shapes

Figure 16: (**a**) The larger fleurons are ornamented, from top to bottom, with a tiny emerald or piece of green glass surrounded by three pearls; a pink spinel surrounded by four blue sapphires, with one pearl each to the right and left of the lowest of the four sapphires; an emerald or piece of green glass surrounded by four pearls; and another blue sapphire just above the base. (**b**) The smaller fleurons are decorated with a pearl; a blue sapphire surrounded by four pink sapphires, spinels or garnets; another pearl; and an emerald in three of the fleurons (shown here) or a garnet or piece of pink glass (not shown) just above the base. Photos by K. Schmetzer, with permission to photograph and reproduce from Bayerische Schlösserverwaltung, Munich.

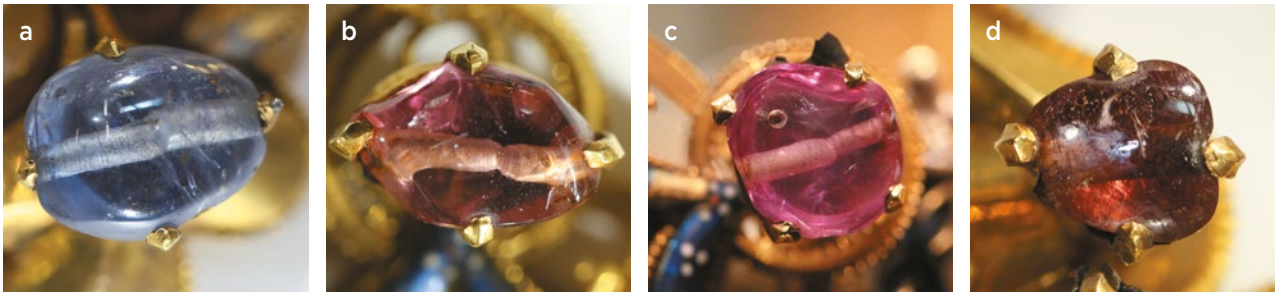

Figure 17: Drill holes are present in (**a**) a blue sapphire, (**b**) a pink spinel, (**c**) a pink sapphire and (**d**) a garnet. The holes were drilled from the opposite sides of each gem, meeting approximately in the middle. The gems may also exhibit a second drill hole at a right angle to the first, as shown in the upper left of (c). Photos by H. A. Gilg.

(Figures 17–19), but also occasionally in more polygonal gems with or without sharp facet edges (e.g. Figure 19a). The holes had been made from opposite sides of the samples, meeting approximately in the centres. Several of the gems displayed two separate drill holes oriented at right angles to each other (Figure 17c, 18b and 19d). Rarely, one complete and one incomplete drill hole could be found in the same specimen, with the incomplete hole terminating abruptly within the sample, suggesting that a problem had been encountered in the drilling operation. Some of the drill holes appeared visually empty (Figures 18a, 18b, 19a and 19b), while others exhibited darker and/or lighter material, potentially indicative of a foreign filler (Figures 18c–f and 19c–f). In general, the presence of drill holes implied previous use of the gems in other jewellery pieces or ornaments.

Evidence of a dark layer or foil behind the samples was regularly seen (Figures 17c, 18c, 18d, 19d and 19e). Also present were concave indentations or grooves on otherwise planar or convex surfaces of some gems (Figure 20). Such techniques to remove flaws by eliminating inclusions, fissures and other impurities were described in medieval Arabic and Persian texts (e.g. by Al-Beruni dated to the 10th century), and are said to have been used in India and Sri Lanka (Ceylon) even several centuries before (Said 1989; Ogden 2013, 2014; J. Ogden, pers. comm. 2019).

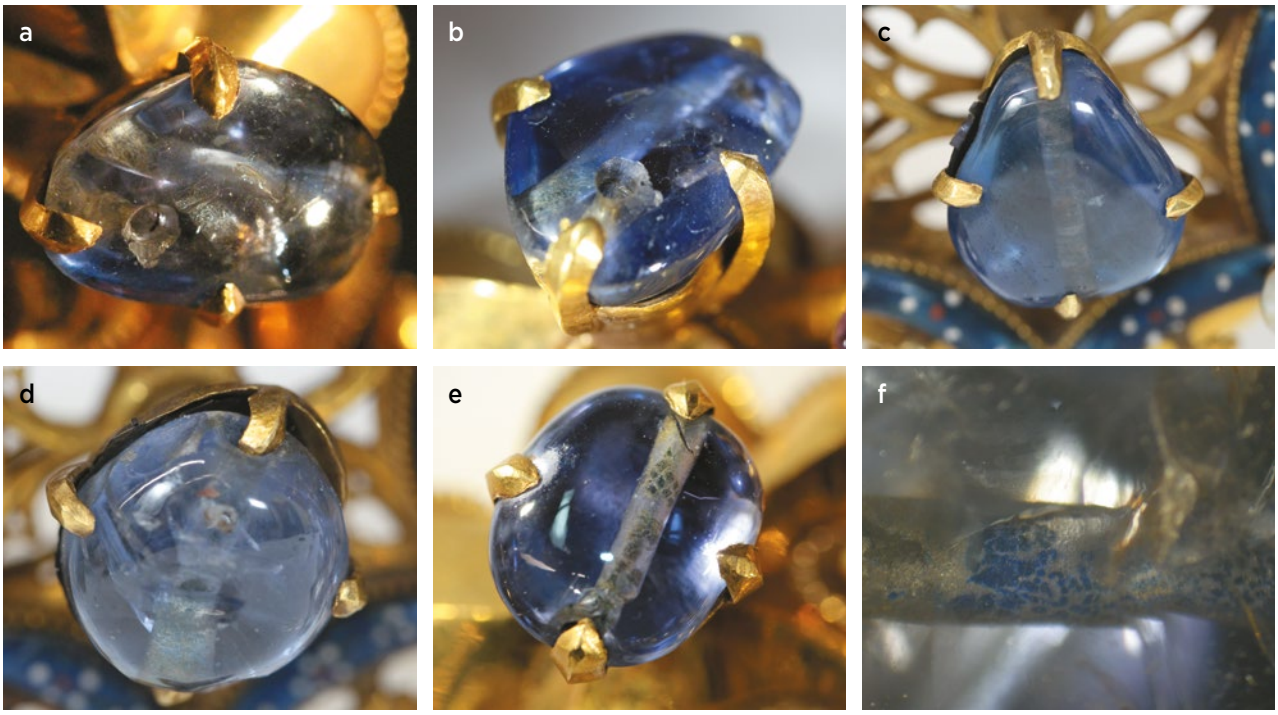

Figure 18: (**a**, **b**) In some of the blue sapphires, drill holes are exposed at the surface and appear empty, thus showing no colour improvement. (**c**–**f**) Other drill holes are filled, at least partially, with a blue material that exhibits a mosaic-like pattern at higher magnification. Particularly in instances where the setting is larger than the gem, some sapphires reveal a dark layer or foil between the gem and the gold mounting, sometimes even protruding from the setting, as visible in (c) and (d). Photos by H. A. Gilg; field of view in photomicrograph (f) is 5.80 × 4.35 mm.

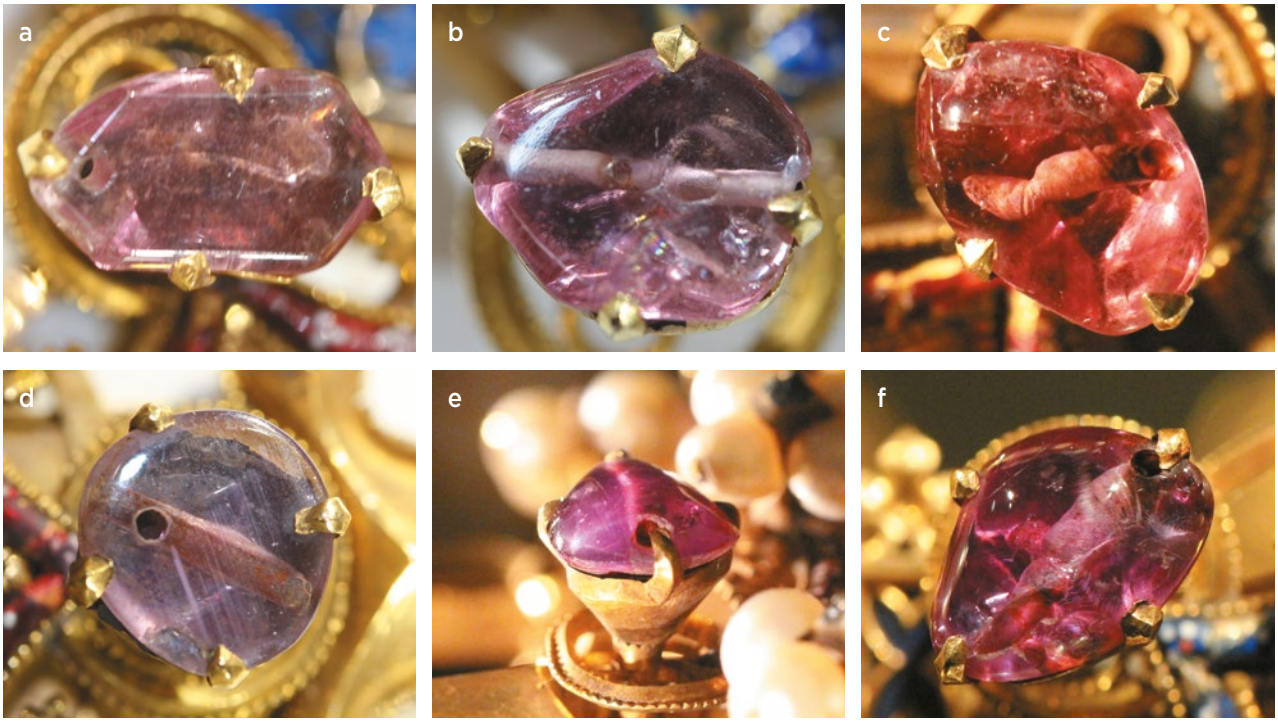

Figure 19: Several of the pink spinels (**a**–**c**) and pink sapphires (**d**–**f**) have drill holes. In some (**a**, **b**), the holes are exposed at the surface and appear empty, affording no colour improvement. Other drill holes (c–f) are filled, at least partially, with a reddish brown material that in some cases seems to be attached only to the walls of the drill holes. Some pink gems, particularly those for which the setting is larger than the gem or the gem is broken, have a dark reddish brown layer or foil between the sample and the gold mounting, sometimes even protruding from the setting, as in (e). A similar layer may also be visible through drill holes and/or if the foil does not back the entire stone, as in (d), where the unenhanced sapphire is almost colourless. Photos by H. A. Gilg.

Blue Gem Materials in Detail

The blue gems in the crown were all identified as sapphires. Two distinct subcategories were present, consisting of translucent dark blue sapphires and transparent pale-to-intense blue sapphires.

Dark Blue Sapphires. Three dark blue sapphires were used, all only translucent at best and without drill holes (Figure 21). Two had been shaped or preformed and then polished to show a rectangular outline, a large table and a single row of inclined, rounded surfaces framing the table, without sharp demarcations (Figure 21a). The third dark blue sapphire was an irregularly broken fragment surrounded, and apparently affixed within the setting, by a blue wax-like mass (Figure 21b). The Fe content measured in the three dark blue sapphires by EDXRF analysis was higher than that found in the larger group of lighter blue sapphires.

Pale-to-Intense Blue Sapphires. The 44 transparent pale-to-intense blue sapphires (plus one doublet) displayed the greatest variability in shape and amount of processing. Outlines ranged from irregular or pebble-like to oval, rectangular, hexagonal and octagonal. Processing spanned through all three categories listed above, with polishing, shaping or preforming, and faceting all present

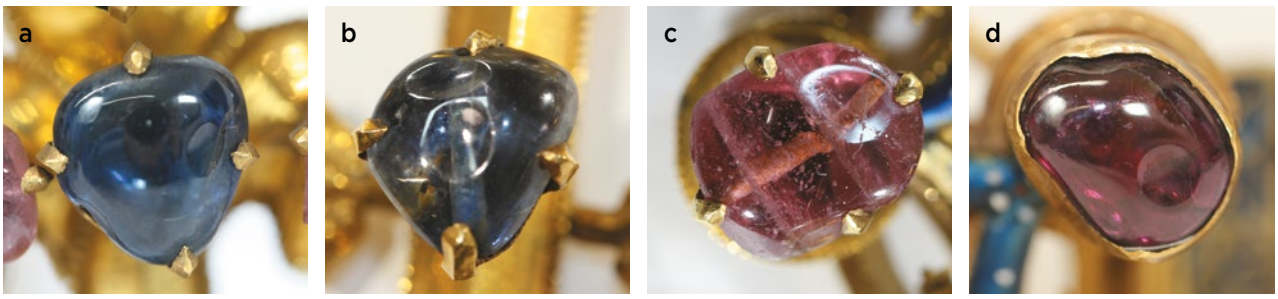

Figure 20: Surface indentations in the form of shallow cavities, presumably from attempts to remove impure areas or inclusions through polishing, are seen on sapphire (**a**, **b**), spinel (**c**) and garnet (**d**). Photos by H. A. Gilg.

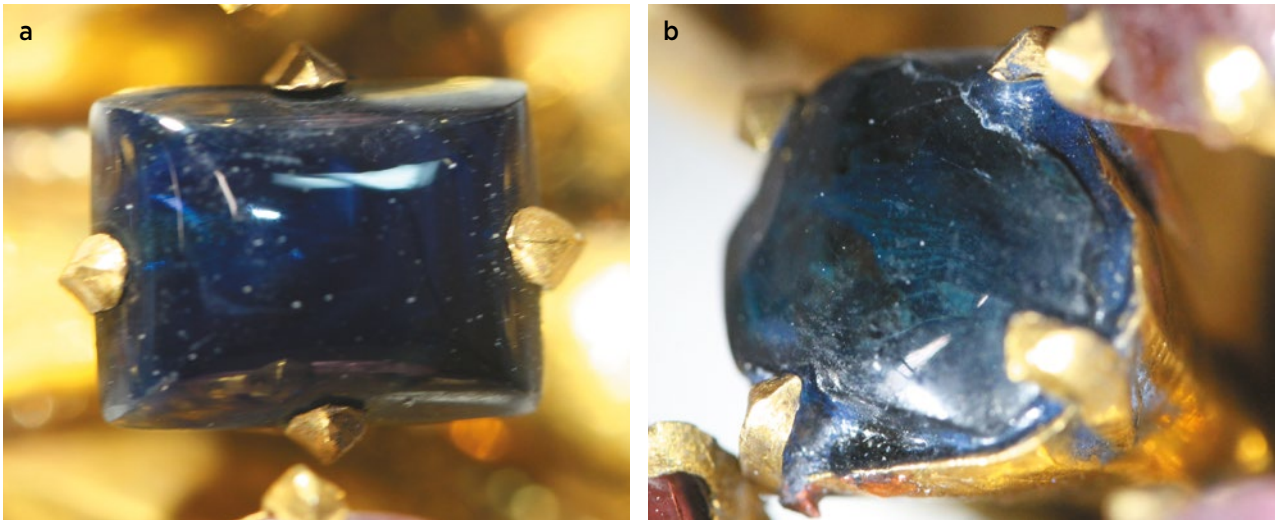

Figure 21: Three translucent dark blue sapphires are mounted in the crown. Two are rectangular without sharp edges, as shown here in one example (**a**), while the third consists of an irregular fragment surrounded by a dark blue wax-like substance (**b**). Photos by H. A. Gilg.

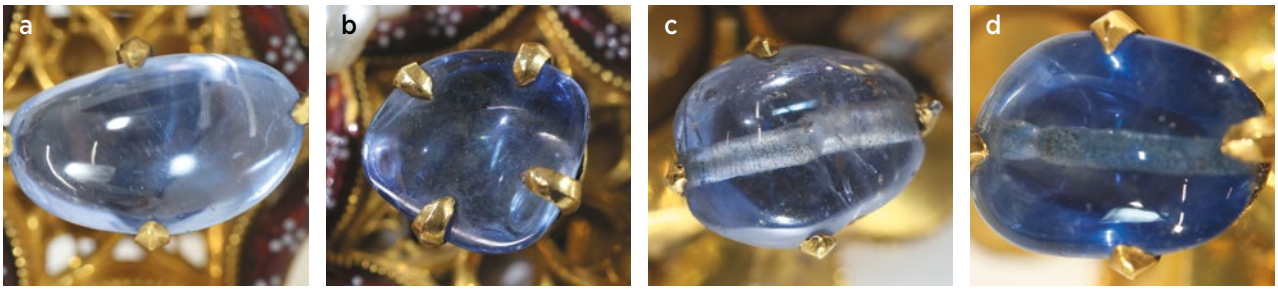

Figure 22: Many of the pale-to-intense blue sapphires are irregularly shaped (**a**), and some are topped with a planar or near-planar table face (**b**). Others are more regular ovals with curved domes (i.e. cabochons; **c**), but occasionally some of these also have a planar top surface truncating the dome (**d**). Photos by H. A. Gilg.

Figure 23: A few of the blue sapphire cabochons show six-rayed asterism. Photo by K. Schmetzer, fibre-optic illumination.

in different combinations and arrangements. For some of the more irregular shapes, it was difficult to ascertain if the form and surface polish were achieved naturally or via deliberate polishing. At the opposite end of the spectrum were the stones that had been preformed, faceted and polished, with sharp edges. Several different facet arrangements were present.

Among those with irregular, near-oval and oval outlines, some were topped with a curved upper surface or dome (Figure 22a, c), while others showed the addition of a planar or near-planar table (Figure 22b, d). Three of the oval cabochons displayed asterism (e.g. Figure 23).

The more polygonal shapes included six rectangles, one hexagon and 14 octagons. The six rectangles each showed a central table surrounded by one row of four inclined surfaces; this pattern was seen in four samples with indistinct curves and two with sharp-edged crown

facets (Figures 24f and 25f). The sole hexagon was sharply faceted with a planar table and six crown facets (Figures 24e and 25d).

The octagons demonstrated particular diversity in fashioning, with all having a near-planar or planar table, as well as:

- In five stones, one row of eight inclined curved surfaces surrounding the table (Figure 25a), with one gem having been oriented in the setting such that the eight inclined surfaces appeared akin to pavilion facets
- In six stones, one row of sharp crown facets (Figure 24a), with one of those gems also including pavilion facets (Figure 25b) and another having the eight crown facets further subdivided with a scissor-cut pattern (Figure 24d)
- In three stones, two rows of circumscribing sharp facets, the first being weakly inclined to the table and the second nearly perpendicular to the table, suggestive of girdle facets (Figures 24b and 25c)

A final octagon, which did not fit exactly in the setting, proved to be a doublet, with a table and two rows of weakly inclined crown facets (Figures 24c and 26a). The upper part of the sample was determined to be sapphire, and the separation plane was partly decomposed, revealing bubble-like structures (Figure 26b).

Drill holes were frequently seen in the blue sapphires (Figures 17a, 18, 22c, 22d and 25d), and also relatively common were surface indentations (Figure 20a). Several drill holes exposed at the surface appeared open and empty (Figure 18a, b), while a number of others seemed to display a mosaic-like appearance, consisting of irregular dark blue areas separated by granular whitish material (Figure 18e, f). This visual impression strongly indicated the presence of a foreign material, but coverage of the drill holes by the settings prevented confirmation (Figure 18c, e). Dark layers behind some of the sapphires and evidence of foil-backing (Figure 18c, d) were observed as well.

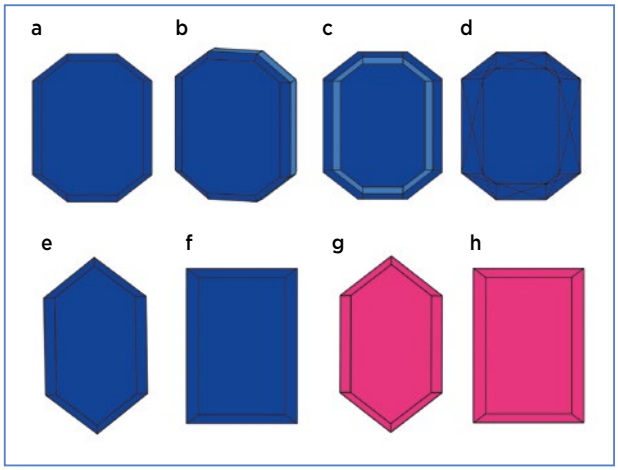

Figure 24: The sharply faceted blue sapphires and pink spinels display a multiplicity of cut layouts, including octagonal, hexagonal and rectangular outlines with flat tables, and either crown facets (**a** and **c**–**h**) or a combination of crown and girdle facets (**b**). Drawings by K. Schmetzer.

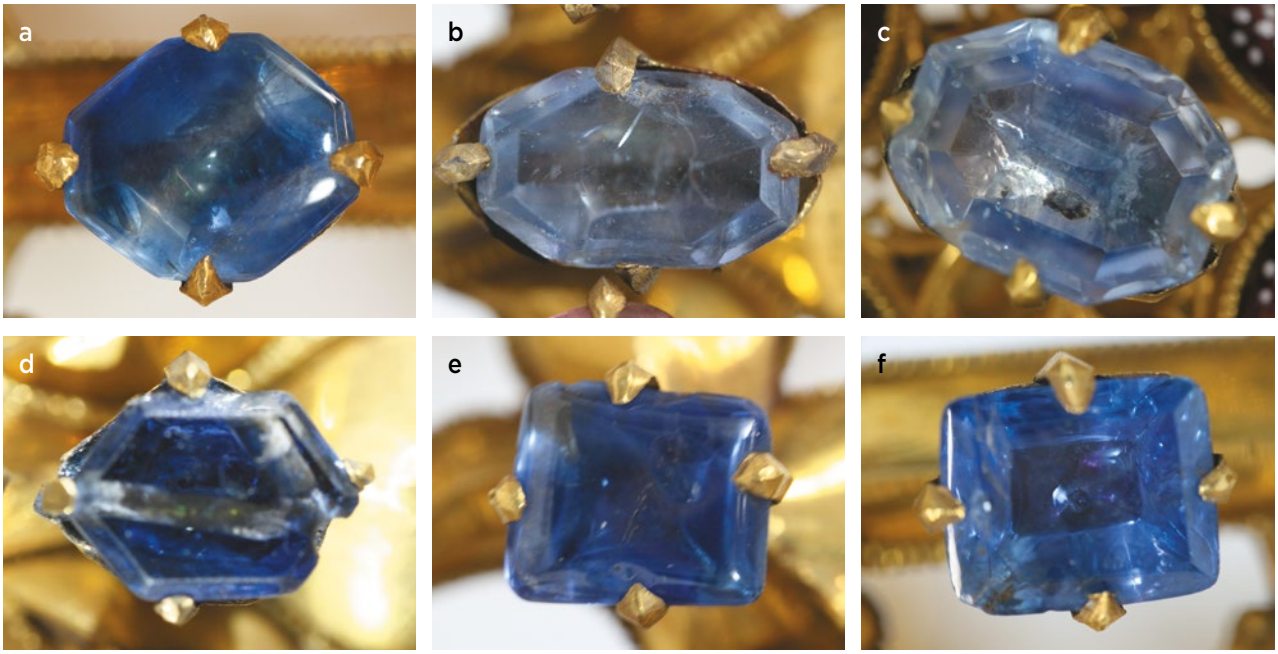

Figure 25: Blue sapphires in the crown exhibit octagonal (**a**–**c**), hexagonal (**d**) and rectangular (**e** and **f**) forms, either without sharp edges (a, e) or with sharp planar facets. Among the sharply faceted sapphires are those with one row of crown facets (d and f), crown and pavilion facets (b), crown and girdle facets (c), and even a more complex scissor cut. Photos by H. A. Gilg.

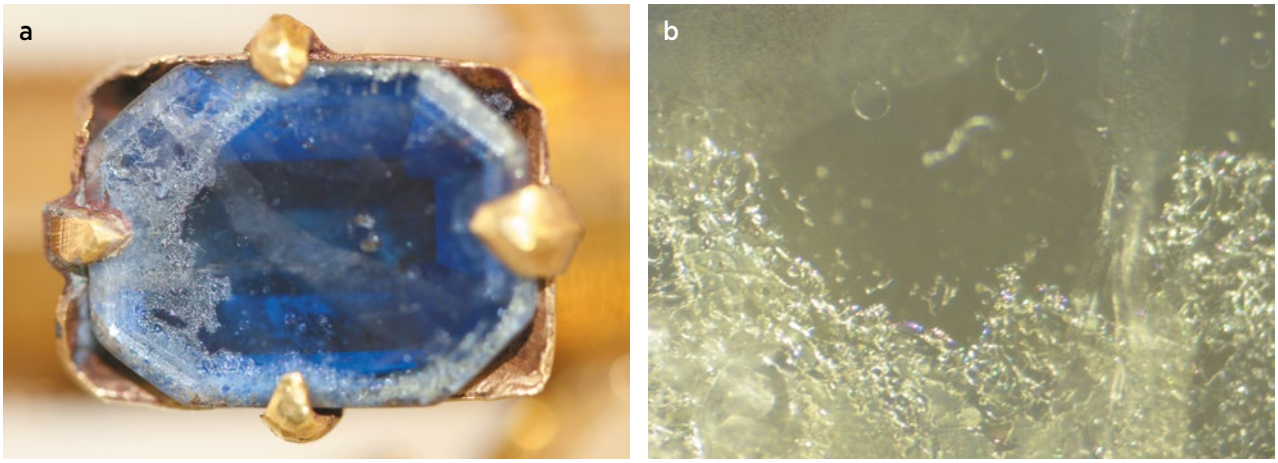

Figure 26: One sapphire doublet was found in the crown. It is mounted in a setting that is too large for it (**a**) and shows a partially decomposed separation plane with bubble-like structures (**b**). Photos by H. A. Gilg, field of view in (b) is 3.7 × 2.8 mm.

Pink to Red Gem Materials in Detail

The pink to red group comprised the greatest number of gem varieties but exhibited substantially less variation in fashioning than the blue group.

Pink Sapphires. The 10 pink sapphires were all irregular or pebble-like, with a few approaching oval in outline (Figure 27). Each exhibited a surface polish. The upper surface of most was curved (Figure 27a, c), but for two stones the curve or dome had been topped by a planar table (Figure 27b, d). As with the blue sapphires, the contribution to the shape and polish by nature or human intervention was not always discernible.

Drill holes were common (Figures 17c, 19d–f and 27), and potential enhancement by reddish brown fillers (Figures 19e, 19f and 27b) and underlying layers (analogous to those detailed below for the pink spinels) was likewise detected. If both backing and fillers were present, their respective contributions to the colouration could be challenging to separate (Figure 19f).

Pink Spinels. These were used in the crown's decoration more than any other inorganic gem variety, with 53 identified. A substantial majority (45) were irregularly shaped and primarily curved (Figure 28a), with four also incorporating a planar table (e.g. Figure 28b). More-regular shapes included one oval, three rectangles and four hexagons. The oval was a domed cabochon, while the rectangles and hexagons included both those having a table surrounded by a row of inclined curved surfaces (Figure 28c, e) and those having sharp-edged crown facets circumscribing the table (Figures 24g, 24h, 28d and 28f).

Drill holes were quite pervasive among the spinels (Figures 17b, 19a–c, 28a–d). Some, as with the blue sapphires, appeared empty (Figure 19a, b). In other instances, the holes were filled with an unknown reddish brown substance, either adhering to the walls or partially blocking the holes (Figures 19c, 28a, 28b and 28d). The likely intent was to hide the drill holes and/or intensify the gem's colour. Additional enhancement was suggested by the presence of a reddish brown layer or foil, particularly visible when a sample was broken or a drill hole was perpendicular to the table (Figure 19a). In one spinel, the incomplete nature of the backing showed its effect on colour (Figure 19c). Surface indentations were also common on the spinels (Figure 20c).

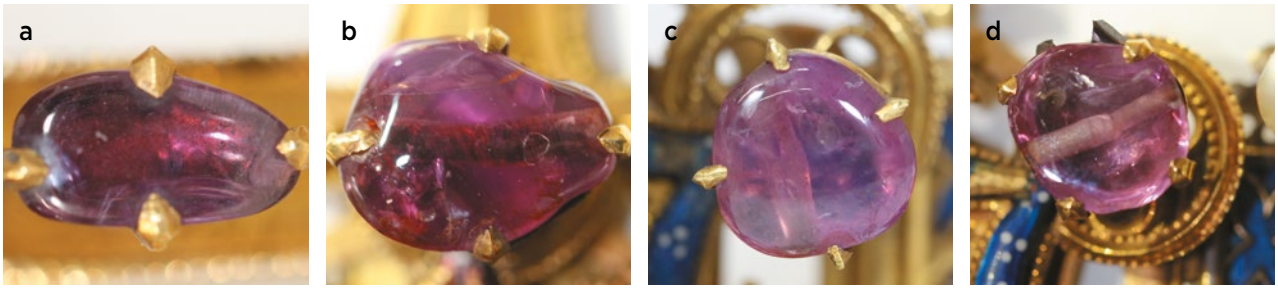

Figure 27: Most of the pink sapphires are irregularly shaped (**a**) and sometimes topped with a planar or near-planar face (**b**). A few are almost oval, with curved domes (**c**) or occasionally with a planar top surface truncating the dome (**d**). Photos by H. A. Gilg.

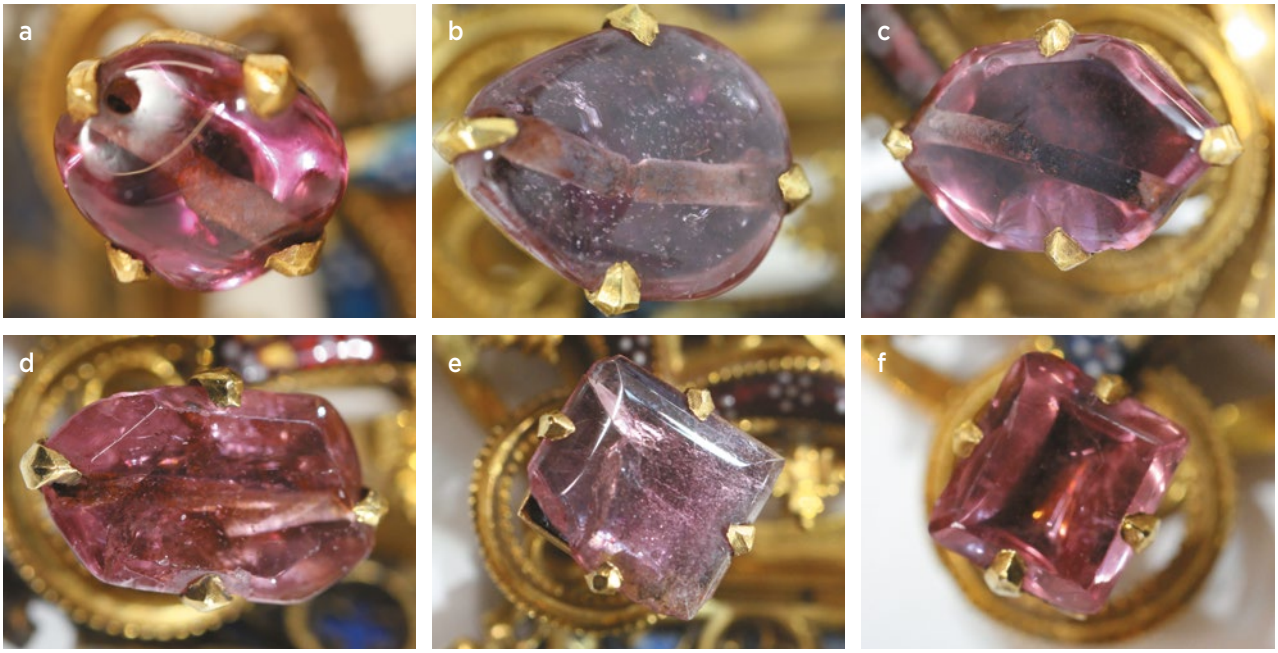

Figure 28: The majority of the pink spinels are irregular and pebble-like (**a**), frequently with surface indentations and drill holes containing foreign fillers. In only a few instances is a flat or near-planar table added to truncate the curved upper surfaces (**b**). More-regular polygons include hexagonal (**c**, **d**) and rectangular samples (**e**, **f**), either without distinct edges (c, e) or with sharp planar facets (d, f). Photos by H. A. Gilg.

Figure 29: The garnets comprise irregularly shaped pebbles (**a**, **b**) and a single oval cabochon truncated by a planar table (**c**). Chemically, the samples were identified as almandines (a, c) and pyropes (b). Photos by H. A. Gilg.

Garnets. Five garnets were used in the crown. Four were irregularly shaped, polished pebbles (e.g. Figure 29a, b), including one with a drill hole (Figure 17d) and one with surface indentations (Figure 20d). The fifth was oval with a planar table (Figure 29c). EDXRF analysis established that they consisted of two pyropes (Figures 17d and 29b) and three almandines (Figures 20d, 29a and 29c). The ranges of chemical composition are as follows:

- Pyropes: 19.1–20.1 wt.% MgO, 16.0–18.8 wt.% FeO, 1.3–1.9 wt.% CaO, 0.4–0.9 wt.% MnO
- Almandines: 2.4–4.9 wt.% MgO, 30.7–32.2 wt.% FeO, 1.7–4.1 wt.% CaO, 1.5–2.0 wt.% MnO

Pink Potassium-Lead Glass. One of the pink specimens proved to be an irregularly shaped piece of potassium-lead glass (Figure 30). The measured Pb content was higher than that for the green lead glass described below.

Figure 30: One irregularly shaped piece of pink lead glass is incorporated in the crown's embellishment. Photo by H. A. Gilg.

Green Gem Materials in Detail

Emeralds. The nine emeralds fell within two size categories: three larger, including two irregular pebbles (e.g. Figure 31a) and one oval cabochon; and six smaller, including five squares (Figure 31b) and one triangle (Figure 31c), each with a curved upper surface or dome. All the emeralds were of intense green colour, but most were only translucent due to numerous inclusions and partially healed or unhealed fractures. EDXRF analysis showed that the emeralds contained some Mg and no V.

Green Potassium-Lead Glass. Mirroring the use of the smaller emeralds and obviously imitating them were one square (Figure 32a) and five triangular (e.g. Figure 32b) samples of green potassium-lead glass. All of them had curved tops and were only translucent, appearing somewhat grainy and non-homogeneous.

Diamonds and Diamond Imitations in Detail

The 14th-century inventories of the crown characterised 33 gems as 'diamonds' (i.e. three in each of 11 base segments present at the time), eight of them being imitations. During the present investigation, these same 11 segments contained 32 purported 'diamonds' (one having been broken away from segment II) that were found to include 10 imitations. The three 'diamonds' in segment IV were all imitations (see Figure 14).

Diamonds. All the diamonds consisted of natural crystals with octahedral habit. More specifically, the main crystal form was the octahedron {111}, often modified by stepped development of the octahedral faces. Most crystals also displayed dissolution structures, as seen by the development of pseudo rhombic-dodecahedral, somewhat rounded or curved facial surfaces (Figure 33).

Diamond Imitations. The materials imitating diamonds exhibited a basic structure of four planar or near-planar gold faces forming a four-sided pyramid, covered completely or partially by a black substance (Figure 34). The initial impression was broadly akin to that of a diamond octahedron (Figure 35).

EDXRF analysis of several such imitations yielded

Figure 31: The emeralds comprise irregularly shaped (**a**), oval, square (**b**) or triangular (**c**) stones, each displaying a curved upper surface or dome. Photos by H. A. Gilg.

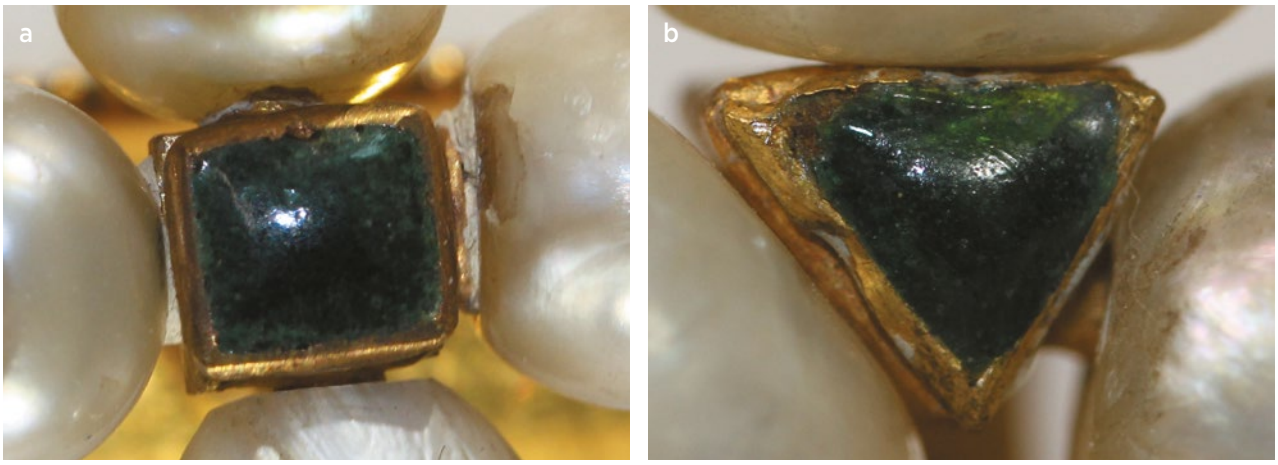

Figure 32: The samples of green lead glass imitating emeralds are square (**a**) or triangular (**b**), with curved upper surfaces. Photos by H. A. Gilg.

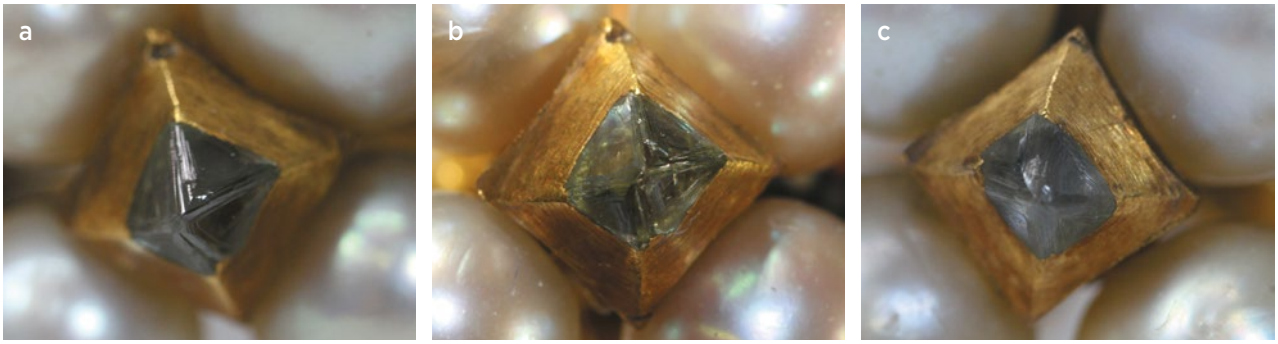

Figure 33: All the diamonds consist of natural octahedra, rarely with planar surfaces (**a**), but frequently showing stepped development of the octahedral faces (**b**) and/or somewhat rounded pseudo rhombic-dodecahedral forms (**c**). Photos by H. A. Gilg.

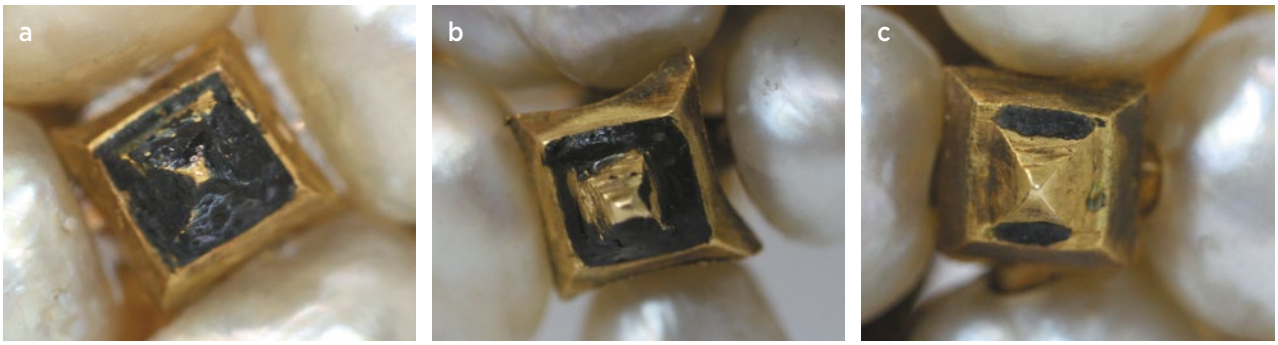

Figure 34: Diamond imitations were manufactured as a four-sided gold pyramid covered (at least partially, in some cases likely having worn away) by a layer of black K-Pb glass or enamel. Photos by H. A. Gilg.

signals for the major components of the alloyed gold (Au, Ag and Cu) and of the surrounding pearls (Ca and Sr). Additional signals were detected for K, Pb, Fe, Mn and minor amounts of Co. This combination indicates that an Fe-Mn-Co-bearing K-Pb glass or K-Pb enamel served as the black coating over the gold pyramids. Under the experimental conditions employed, Na could not be measured (especially in low concentrations) and, therefore, its presence cannot be excluded from the black layer (which would suggest a Na-K-Pb glass).

Settings in Detail

In general, the gems were set in closed-back, cup- or cone-like mountings adapted to their particular sizes and shapes (Figure 36). With one exception, all the larger gems with irregular, oval, rectangular, hexagonal or octagonal shapes were then affixed in the mountings with four prongs, occasionally taking the form of more extended curved claws (Figures 17–22, 25–30 and 31a). In some cases, the prongs corresponded with individual grooves or surface indentations on the stones. Smaller

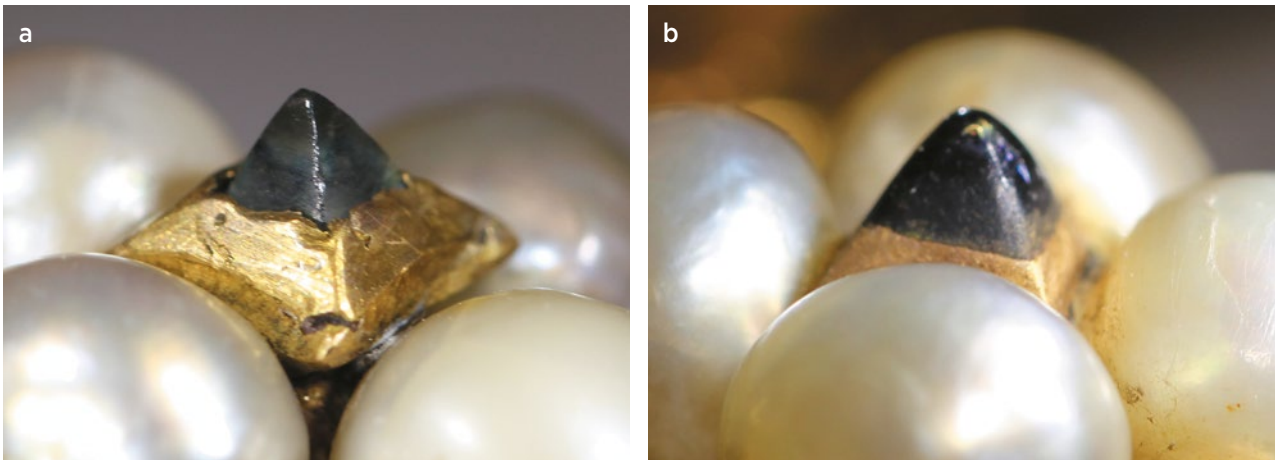

Figure 35: The visual appearance of the diamond octahedra (**a**) and diamond imitations (**b**) can be quite similar, rendering substitution of the latter for the former relatively convincing. Photos by H. A. Gilg.

Figure 36: The gem settings were adapted to the individual sizes and shapes of the available stones. Most of the larger gems are set with four prongs in a closed-back, cup- or cone-shape mounting. Photos by H. A. Gilg.

gems, such as the diamond octahedra, square and triangular emeralds, and green glass pieces, were typically secured in the mountings with a simple bezel setting (Figures 31b, 31c, 32 and 33). Only one larger garnet in the replaced segment IV showed a similar bezel setting without prongs (Figure 20d). The mountings are typical of the closed settings used for gems during the High and Late Middle Ages (Bethe 1956; Falk 1975).

DISCUSSION

The crown offers a unique window into how craftspeople of the late 14th century utilised the materials and techniques at their disposal. Each of its components, and their potential modification, can be instructive when considered within the context of the era.

Metalwork Composition

Chemical analysis yielded a composition for the metal framework comparable to 18-carat gold, a result in agreement with previous studies of the crown undertaken in the early 20th century (Deibel 1927, 1928). Notably, the compositional range of the Au-Ag-Cu alloy falls within that shown by numerous gold objects dated from the High to Late Middle Ages, thereby offering a strong indication for the crown's age (see Mecking 2010 and references cited therein).

Gem Sourcing

The crown is resplendent with multiple varieties of natural inorganic gem materials: blue and pink sapphires, pink spinels, garnets, emeralds and diamonds. Although it is beyond the scope of the present study to discuss the possible geographic provenance of the gems in detail (e.g. by comparing trace elements and inclusions with those of gems from known sources), certain general observations are relevant.

The origin of the individual gems can be considered from two distinct yet interrelated perspectives: the primary vs. secondary type of deposit and its geographic location. Regarding the deposit type, the condition of the gems in terms of their fashioning provides some insight (Figure 37a). As explained above, the degree of apparent fashioning work spans an entire spectrum from irregular, rounded and pebble-like polished shapes to sharply faceted geometric forms. A significant percentage of the sapphires, spinels and garnets showed irregular or pebble-like forms that are highly indicative of secondary deposits. It may also be reasonable to assume that the stones of these varieties that were preformed and/or faceted also originated from the same secondary deposits, given their similar visual appearance. Nonetheless, the possibility of a primary deposit, such as one of the marble-hosted deposits in Asia, cannot be excluded, particularly for some of the faceted samples. The majority of the emeralds are fashioned with a geometric shape (square or triangular), leaving both primary and secondary deposits equally possible as sources (Figure 37b). The appearance of the diamonds, being all octahedral crystals that reflect no further processing, is likewise theoretically consistent with either a primary or secondary source (Figure 37a).

With respect to potential geographic locations for the deposits, Sri Lanka is a strong candidate for the transparent pale-to-intense blue sapphires. As early as the 3rd century BCE, the great chronicle of Ceylon, the Mahavamsa, referenced sapphires amongst the known gem materials (Geiger & Bode 1912). In the Mediterranean region, the presence of blue sapphires from Ceylon has been documented from the era of the Roman Empire (Foster 1988), and the gems were an important part of the Eastern sea trade during the Roman and Byzantine periods (Bopearachchi 1997). Concerning the specific timing and quantities, present knowledge suggests that blue sapphires were extremely rare before the late 1st century BCE/early 1st century CE but became more widely known from the 2nd century CE onwards (Thoresen 2017).

Inventories from the 14th and 15th centuries frequently

differentiated between higher-quality, lighter-coloured sapphires and dark blue sapphires of inferior quality. The former were often labelled *saphirs d'orient*, a term describing mainly Sri Lankan material (Holmes 1934), characteristically traded via Arabic middlemen (Mahroof 1989). The latter were characterised as *saphirs de Puy*, indicating basaltic sapphires from Le Puy en Velay in France (Schulz 1897). The Le Puy en Velay locality was recognised at least by the mid-14th century, as it was explicitly mentioned in a text by Conrad von Megenberg written circa 1350 (Schulz 1897). These early descriptions and understandings have also been borne out in modern gemmological examinations, which have identified sapphires in numerous objects of medieval jewellery as having come from either Le Puy en Velay or Sri Lanka (e.g. Hyršl 2001). Such factors could point towards the same two sources for the dark and light sapphires, respectively, in the present crown.

The options for the pink to red gems, however, are multiple. The gem gravels of Sri Lanka, given their role in furnishing blue sapphires, would be one logical suggestion for at least some of the pink sapphires, pink spinels and garnets decorating the crown. Sri Lanka has historically been recognised as a source of such materials. Venetian merchant Marco Polo mentioned rubies from Ceylon at the end of the 13th century (Moule & Pelliot 1938). The island was similarly referenced in a text written by the Franciscan friar Odoric of Pordenone around 1330, as well as by the Moroccan traveller Ibn Battuta, who visited Ceylon circa 1340 (Yule 1866; Gray 1883). Yet little exists to rule out various other primary and secondary deposits in India and elsewhere in Asia or in Europe. For example, the Badakhshan deposits of pink spinels at Kuh-i-Lal in present-day Tajikistan have been known since the 10th century. They were first reported in Arabic texts (e.g. by Al-Beruni) and later mentioned by Western travellers such as Marco Polo (Yule 1871; Said 1989; Hughes 1994; Bowersox & Chamberlin 1995).

More questionable are the Burmese deposits of rubies, pink sapphires and spinels. Insofar as the earliest report of gems (not gem mines) in the area dates from the Venetian traveller Nicolò de' Conti, who reached Burma in the late 1420s or early 1430s (Frampton 1579), there is no clear indication that Burmese materials would have entered Western trade before the end of the 14th century. Only later would they have a meaningful presence, as evidenced by early 16th-century reports of Italian and Portuguese travellers, including Ludivico di Vartherma, Tomé Pires and Duarte Barbosa. For instance, a 1516 letter from Tomé Pires to the King of Portugal referenced rubies from Burma as well as dark red rubies and *baleis* rubies from Ceylon (Cortesão 1944). Similarly, by 1518 Duarte Barbosa was differentiating between rubies from Burma and Ceylon while also noting spinels from

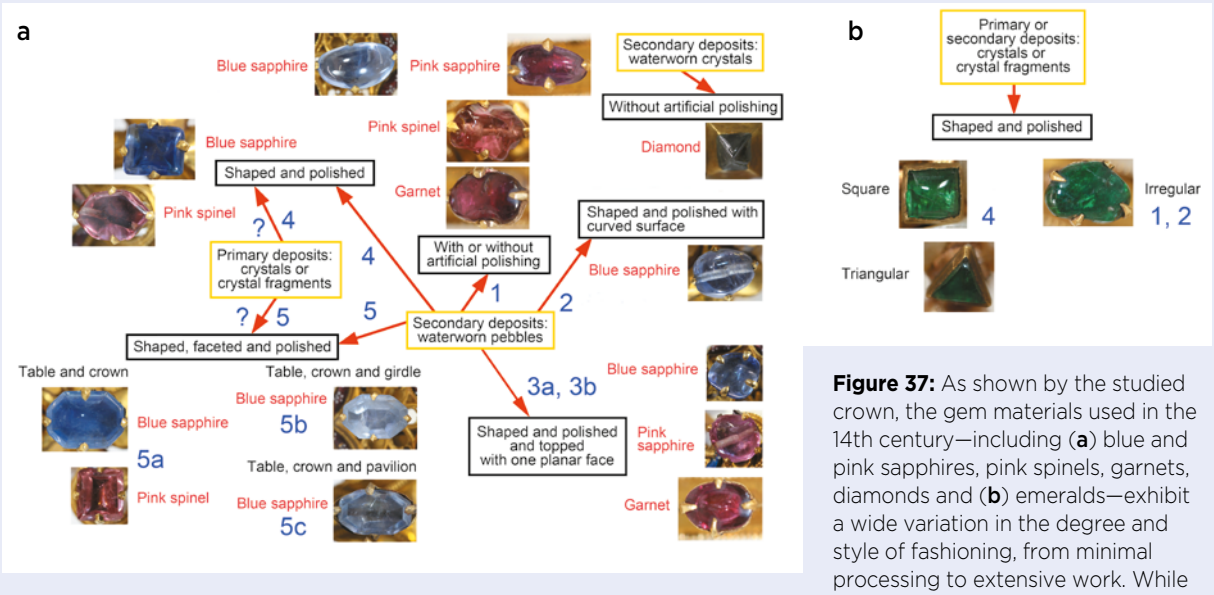

Figure 37: As shown by the studied crown, the gem materials used in the 14th century—including (**a**) blue and pink sapphires, pink spinels, garnets, diamonds and (**b**) emeralds—exhibit a wide variation in the degree and style of fashioning, from minimal processing to extensive work. While the diamonds were left as natural crystals, the coloured stones consist of: (**1**) irregular, pebble-like forms, most with polished surfaces, likely from secondary deposits; (**2**) rounded cabochon forms, shaped or preformed and polished, with a domed top; (**3**) irregular pebble (classified as **3a**) or cabochon (classified as **3b**) forms with an added planar table surface; (**4**) regular polygonal forms, shaped or preformed and polished, without sharp edges; and (**5**) regular polygonal forms, preformed, faceted and polished, with sharp edges, showing table and crown facets (see **5a**), table, crown and girdle facets (see **5b**), table, crown and pavilion facets (see **5c**), or more complex scissor-cut crown facets (not shown).

these localities and *balaches* (as a variety of ruby) from Badakhshan (Dames 1921; Mugler 1928).

Identifying possible sources for the emeralds suffers from similar complexity in the context of the Middle Ages. The deposits in Egypt, incorporating several ancient mines, have been known from antiquity (Jennings *et al.* 1993), although the principal old workings themselves were rediscovered only in the early 1800s (Cailliaud 1822). The main locality—Wadi Sikait (Mons Smaragdus area)—was operated primarily in Roman and early Byzantine times, up to the 5th or 6th century CE (Harrell 2004, 2006; Foster *et al.* 2007; Sidebotham *et al.* 2018). Excavations at neighbouring mines, including Wadi Nuqrus and Gebel Zabara, have suggested that activities there extended later into the Islamic period (e.g. from the 6th to the 9th century or from the 12th to the 16th century; Shaw *et al.* 1999). Emerald mining in the region from the late-9th to the mid-17th century is supported by the Arabic literature, although the texts do not differentiate between specific localities (Schneider & Arzruni 1892; Power 2012).

However, problems arise in that these Egyptian sources lack a demonstrated connection, based upon chemical and gemmological properties, to materials used in the Late Middle Ages. Most emeralds in pieces of the High and Late Middle Ages were, according to modern standards, of low quality, often not even translucent (Kržič *et al.* 2013), notwithstanding a few examples of better quality, such as in the treasure of Preslav, Bulgaria, dated to the 10th century (see Strack & Kostov 2010 and references therein). Compounding these difficulties are the ever-present challenges posed by nomenclature and failure to distinguish between gems of the same colour. For instance, concerning the Arabic literature, the 13th-century work of Al Tifaschi was the first to give separate descriptions for emerald and peridot, and discrepancies are replete in the mineralogical identification of the various green gems mentioned in older Arabic treatises (Abul Huda 1998).

Other sources proposed for the emeralds found in Middle Ages ornaments include Austria, Afghanistan and Pakistan (Giuliani *et al.* 2000). Nonetheless, as with the Egyptian material, a demonstrated scientific connection is lacking. Studies aiming to establish an empirical link between emeralds in historical jewellery and recently mined gems from these localities (through trace elements, inclusions, etc.) have been performed on only a few samples (see, e.g., Calligaro *et al.* 2000; Kržič *et al.* 2013). Moreover, a key concern is that early mining or use of such materials has not been documented, a shortcoming well illustrated with regard to the Austrian deposits. Danish scientist Niels Stensen (Nicolaus Steno) is reported to have travelled to the Habachtal (Heubachtal) emerald locality in 1669 (Scherz 1955). A worldwide mining list published by Brückmann (1727) broadly referenced Tyrol as the sole emerald source in Austria, and the first real published description of emeralds from Habachtal did not appear until 1797 (Schroll 1797).

The prolific Colombian deposits can be readily excluded as a source for the emeralds in Blanche's crown. Both the later 'discovery' by Europeans in the mid-16th century and their distinct chemical properties exclude them. In particular, the lack of V and the presence of Mg in the crown's emeralds is telling.

Finally, tracing the diamonds offers perhaps the highest degree of probability. The only sources for diamonds known in Europe at the end of the 14th century were the various secondary deposits in India (Bagchi & Ghose 1980; Harlow 1998; Levinson 1998; Coulson 2012; Ogden 2013). While deposits in Borneo were reportedly active from the 6th century, with gems having been traded to China (Spencer *et al.* 1988; Tay *et al.* 2005), those diamonds were not acknowledged in European texts until the mid-16th century, via descriptions by Portuguese travellers such as Gonçalo Pereira in 1530 (Lopes de Castanheda 1561; Dames 1921).

Gem Enhancements

The historical record strongly supports the use of foil-backing as a common and accepted practice during, and after, the era of the crown's creation. The Early Middle Ages witnessed extensive application of foil-backing in cloisonné-type jewellery, where doubly polished garnet plates were set in a metal framework on top of thin gold or silver foils (Gilg *et al.* 2010). In the following centuries, the widespread use of closed-back settings prolonged the popularity of the technique. By the Renaissance, sophistication had reached a level to yield publication of different compositional formulas for the foils used to enhance gems of specific colours. For example, in 1568 Italian goldsmith Benvenuto Cellini specified Au-Ag-Cu alloys to enhance yellow, red, blue and green gems (Table II; see German translations by Brinckmann 1867 and Brepohl 2005).

Table II: Alloys used for foils to enhance gems of various colours, specified by Benvenuto Cellini in 1568.

Element (wt.%)	Yellow	Red	Blue	Green
Au	9.1	37.0	18.2	5.9
Ag	18.2	29.6	9.1	35.3
Cu	72.7	33.3	72.7	58.8

Other authors, such as Agricola (in 1546; German translation by Lehmann 1810), Della Porta (in 1589; English translation attributed to Porta 1658 and German translation by Peganium 1680) and Smith (1750), described the use of foils consisting of pure copper, pure gold, gold-silver alloys and gold-silver-copper alloys. The foils, in turn, could themselves be modified to further enhance the visual effect, depending on the gem variety involved and the colour sought, by methods such as oxidation in air. The potential effectiveness of such methods is corroborated in historical pieces by the results of long-term exposure to air of portions of such foils, especially those with a high Cu content. Foil colour has frequently been influenced by partial decomposition and heavy oxidation forming cuprous oxide Cu_2O (cuprite, red) or cupric oxide CuO (tenorite, black; Cretu & van der Lingen 1999; Lee *et al.* 2016).

Foil-backing started to decline in the 18th century before largely disappearing in the 19th century, as new cuts and open settings increasingly came into vogue (Blum 1828; Bauer 1896; Kornbluth 2003; Brepohl 2005; Whalley 2012). Notably, throughout its many decades of broad application, foil-backing was not considered a fraudulent practice but an accepted and even necessary method to bring out and best display a gem's optical properties and beauty.

The foregoing indicates that observation of a dark layer or foil between many of the crown's sapphires and spinels and their closed-back mountings fits well within the context of a 14th-century creation, following established traditions of the time, and would not be out of place for the few later substitutions (see, e.g., Otavsky 1992).

The use of filler materials or dyes in drill holes to enhance gem colour and hide the holes also finds historical analogue in other examples from the Middle Ages. As noted above, Blanche's crown exhibited drill holes in blue sapphires with a dark and light mosaic-like pattern and in pink sapphires and spinels with a reddish brown hue. A similar appearance for blue sapphires in medieval jewellery objects was mentioned briefly by Hyršl (2001), and nothing suggests that the dark-appearing drill holes in the pink gems would be unusual for the time.

Gem Imitations

Imitations incorporated in the crown's decoration included green and pink samples made from lead glass and black-coated gold pyramids. The green pieces imitated emeralds while the pyramids imitated diamond crystals. These were likely used because insufficient natural emeralds and diamonds were available, both at the time of the crown's creation and when it was later repaired, to complete the intended design with the requisite symmetry. The single pink glass sample was visually similar to the other pink stones (sapphires and spinels).

Green and Pink Lead Glass. The history and use of glass to imitate gems spans almost 3,500 years. Chemical composition is key for understanding and classifying the different types of glass, their manufacture and their age. Lead glass with widely varying compositions has been employed in different cultures since antiquity and was widespread in medieval times (Wedepohl *et al.* 1995; Wedepohl 2003).

Use of lead glass for jewellery purposes in central Europe can be dated back at least to the 8th or 9th century, based on the age of lead glass beads excavated from a site in northern Germany (Pöche 2001). An early written account of the practice can be found in the text *Upon Various Arts* by the monk Theophilus, dated circa 1120 (see English translation by, e.g., Hendrie 1847 or Dodwell 1961). The treatise describes the preparation of finger rings from lead glass, including mention of Cu as an additive. Chapters of the manuscript that might have addressed the specific colour(s) of the glass have been lost (Brepohl 1999), although several extant treatises from later in the Middle Ages dealt with the topic. One, referred to as the *Manuscripts of Eraclius* and dated to the 12th or 13th century, expounds methods for preparing green lead glass with Cu added for colouration (see English translation by Merrifield 1849). Another penned by Jean d'Outremeuse at the end of the 14th century contains a similar formula for manufacturing imitation gems from green glass (Canella 2006). More than two centuries later, in 1612, a number of recipes for making lead-glass imitation gems in a variety of colours were presented in *L'Arte Vetraria* by Antonio Neri (with an English translation provided by Merrett 1662).

Potassium-bearing lead glass was among several types that were produced in different parts of Europe during the 10th–14th centuries. It was used, for example, by a 13th-century workshop in Erfurt, Germany, to produce lead-glass rings and beads (Mecking 2013).

As discussed in the Gemstone Replacement section below, the pink glass sample, with its relatively high Pb content, is assumed to have been included to replace an emerald in one of the smaller fleurons after 1568, long after the crown was originally manufactured. By contrast, the green glass pieces with lower Pb contents are thought to be part of the original decoration on the basis of both their positions and their mountings in the crown. Specifically, their locations in the design

are consistent with those of the natural emeralds, and they are properly encased by well-fit bezel settings. These contrasting conclusions regarding the pink and green samples align with the technological progress documented throughout the Middle Ages.

In summary, information about the manufacture and use of green lead glass for jewellery purposes was state of the art in the 12th–14th centuries. Conversely, the preparation and use of lead glass in a greater variety of colours for gem imitations was described only centuries later, with general reference first available at the beginning of the 17th century.

Diamond Imitations. The diamond imitations were composed of four-sided gold pyramids coated with a black layer made of K-Pb glass or enamel with Fe, Mn and traces of Co as colour-causing components. Although quantitative chemical data for similar materials are lacking, there appears to be some precedent for applying dark coatings, including black glass or enamel, to decorative objects in the Middle Ages. Notably, the three 'diamonds' in base segment IV, added during the 1402 repair in London, are all imitations, thereby demonstrating that the practice of constructing such black-coated gold pyramids as simulants was widely understood by that time.

One well-known technique for achieving a dark coating, that of niello, can be promptly excluded as a possibility. The practice had been in use since Roman times and was described in Theophilus's *Upon Various Arts* as a process of heating mixtures of silver, copper, lead and sulphur (English translation by, e.g., Hendrie 1847 or Dodwell 1961; see also Wolters 1997, for a detailed explanation of the process). While analytical data of lustrous black layers covering silver or gold art objects from the Middle Ages have confirmed its use during the period (Newman *et al.* 1982), the chemical data from the diamond imitations in the crown cannot support interpretation of the black material as niello.

With respect to black glasses and enamels, chemical analyses of artefacts from the High and Late Middle Ages show wide variations in composition, including low, moderate and extremely high Pb contents (Biron *et al.* 1996). Although research has not revealed any direct parallel in Middle Ages literature to the composition determined for the diamond imitations in the Munich crown, information on the general practice of applying such a dark lead glass or enamel layer suggests that the crown fits within the temporal context. For instance, the *Manuscripts of Eraclius* (English translation by Merrifield 1849) discussed manufacture of a special (black?) lead glass to be used for painting on other glass pieces, wherein an Fe-bearing component was added to the 'normal' green lead glass. Similarly, *Upon Various Arts* (English translation by, e.g., Hendrie 1847 or Dodwell 1961; see also Brepohl 1999, for a detailed discussion) reported preparation of a (lead?) glass with a low melting temperature that was applied to form a black layer on another glass surface, again via painting. These two sources thus indicate that techniques to create layers of iron-bearing lead glass or enamel were known in the 12th–13th centuries.

The technique continued to be employed in the following centuries and increasingly came to be referred to as *schwarzlot* (black lead), *schwarzlot painting* or *schwarzlot decoration* (see Strobl 1990; Müller 1997). These expressions derived from the 16th-century German word *loit* (meaning solder), first used in a text on glass technology written by C. Greitzer and appearing in a codex from 1565 (see also reprint published by Heyen 1963). As time progressed, references to *schwarzlot* continued to appear (Kunckel 1689), but the material was additionally designated simply as *black enamel*, especially in English texts. Numerous glass objects decorated with the technique are known from the Late Middle Ages in Germany, Flanders and Burgundy (Hahn *et al.* 2009a, b). According to analyses published for this material, it normally contained Fe or Fe and Cu, but a Mn-bearing example has been reported as well (Hahn *et al.* 2009a, b; Mantouvalou 2009; Bretz *et al.* 2016).

The only specific information published to date on the layer covering the four-sided gold pyramids in Blanche's crown was offered by Ogden (2018), who described the black layer by visual estimation as enamel. Given the foregoing, such a characterisation appears reasonable.

Gemstone Replacement

Multiple factors, alone or in combination, indicate that certain gems now embellishing the crown are replacements of the original pieces. The most explicit evidence comes from comparing the descriptions in the inventories from the Late Middle Ages onward. Other circumstantial evidence derives from features such as ill-fitting settings, lack of parallelism in design, or temporally incorrect fashioning. Taken together, these support a conclusion that a small number of blue (sapphires), pink (sapphires and spinels) and green (emeralds) stones were lost and replaced, particularly in the time frame after the crown arrived in Heidelberg as part of the dowry of Blanche of Lancaster in 1402. Moreover, corroboration for a general pattern of occasional loss and practice of replacement comes from the references in several of the crown's inventories to absent blue sapphires still being

available as loose stones, yet apparently later restored to their mountings.

With respect to specific gems, clues from the inventories suggest that three emeralds in the smaller fleurons were replaced after 1568 by three pink to red samples, now identified as two garnets and one piece of pink lead glass. By contrast, two other garnets have features, namely a drill hole and surface indentations, from which it can be inferred that they were in place on the crown by at least 1402.

Also instructive are mentions in inventories from 1783, 1818/1820 and 1833 that amongst the sapphires was one imitation or one glass piece. A logical interpretation would therefore be that the sapphire doublet (Figure 26) was characterised in the late 18th and early 19th centuries either as an imitation or as glass.

Nonetheless, the accuracy of the inventories is sometimes problematic. The 1544 text described two of the smaller fleurons as having one emerald and five *baleis* (instead of one sapphire surrounded by four pink to red gems), while the 1745 documentations noted that one sapphire had been replaced by an amethyst. In these instances, it could be that the dark basaltic sapphires in the crown were mistaken for other gem varieties, but other scenarios are possible.

Considering cases where circumstantial clues such as cut and setting weigh most heavily, the sapphire with a scissor-cut crown presents a strong candidate for replacement after 1402 or even 1700, simply because such complex cuts belong to the Renaissance or later (i.e. Baroque style), and not to the Late Middle Ages (see, for diamonds, Falk 1975; Tillander 1995; Ogden 2018). Similarly, the only sapphire exhibiting table, crown and pavilion facets (Figure 25b) is too small for its setting, again pointing to a later replacement for a lost gemstone.

The mounting of two other sapphires also implies at least reattachment, if not outright substitution. The dark sapphire surrounded by the blue wax-like mass at minimum experienced breakage and was reaffixed (Figure 21b). Likewise, one sapphire is presently attached so as to display a rounded top and 'pavilion' facets. Given the absence of logic in such an approach in the context of the closed-back settings and foiling, a more reasonable explanation might be that the stone is in a position rotated 180° from the original mounting.

Gem Cuts and Development of Faceting

Use of gems for adornment began primarily with naturally polished pebbles, which were included in jewellery objects for hundreds of years. Evidence of early developments in shaping and faceting gems can be found in 13th- and 14th-century European jewellery (Hahnloser & Brugger-Koch 1985; Jülich 1986–1987). A limited number of coloured stones exhibiting planar or near-planar surfaces have been documented in pieces from the era (Falk 1975; Lightbown 1992; Content 2016), and the beginning of gem faceting in Europe is thought to date from this period. The transition, however, was in no sense abrupt, as items dated to the Late Middle Ages tended to incorporate gems with a range of processing, from irregular pebbles, to cabochons, to those with varying degrees of further shaping or preforming and faceting.

Initially, such shaping or preforming and faceting operations were done solely with handheld tools (Figure 38), with the first more complex instruments in which the gems were fixed and/or oriented for faceting appearing in 15th-century codices (Schmetzer 2019). Hence, it must be assumed that most processing in the 13th and 14th centuries was accomplished with simple handheld techniques, thereby explaining the common presence of merely near-planar surfaces and rounded edges.

As time progressed, more examples with a symmetrical cut layout and a regular facet arrangement began to appear, featuring in 14th- and 15th-century royal regalia.

Figure 38: One of the first printed representations of gem cutting by means of a rotating wheel is found in the *Buch der Natur* (*Book of Nature*) by Conrad von Megenberg (1482).

Notably, these developments were largely exclusive to the European realm. Even through the Mughal period in India, which began in the early 16th century, faceting of coloured stones was not common in Asia and especially not in the Islamic world. Use of naturally polished pebbles continued to predominate, although some gems imported into trade centres such as Venice, Genoa or Lisbon were occasionally re-exported to the East after faceting (Byrne 1935; Keene 1981; Spink & Ogden 2013; Ogden 2013, 2014), and archaeological excavations provide only limited evidence of faceted stone use.

With respect to the European Late Middle Ages period in focus here, and as highlighted above, pieces tended to incorporate gems reflective of a range of processing levels. Nonetheless, a substantial percentage of pieces dated from the time, such as finger rings and brooches seen in the treasuries of Colmar, Erfurt and Wiener Neustadt, typically had only a single stone or a few gems (Pasch 2010; Stürzebecher 2010; Singer 2014). Items with a relatively rich embellishment—such as the crowns of Margaret of York (see Figure 4), Charles V of France, Charles IV of Bohemia, and Blanche—were far rarer, and many have been lost. For instance, one of Charles V's crowns was described in a 1380 inventory as '*très grant, très belle et la meilleure couronne du Roy*' and contained cabochons together with octagonal and square sapphires and *balaiz* (Labarte 1879), but further details are no longer available.

Comparison with the Crown of Saint Wenceslaus. Of the extant examples, Charles IV's and Blanche's crowns share sufficient parallels to provide an elucidating recapitulation of centuries of gem processing history. A comparative summary of how their components were fashioned is given in Table III.

Charles IV's crown was originally made for his coronation in 1347 as King of Bohemia and was dedicated to Saint Wenceslaus (about 907–935), becoming known as the Crown of Saint Wenceslaus (Figure 39). Charles IV would later be crowned Holy Roman Emperor by the pope in Rome as well (having previously been elected King of the Romans in 1346, a title then used for the King of Germany). The crown was reworked several times prior to his death in 1378 (Hyršl & Neumanova 1999; Šumbera 2008). As can be deduced from detailed inventories dated 1355 and 1387, a final comprehensive remodelling occurred between 1374 and 1378 (Podlaha & Sittler 1903; Otavsky 1992), bringing the piece into its present state.

Several gems in Charles IV's crown display rounded irregular, pebble-like or oval forms, occasionally with drill holes, and might have been reused from older pieces during the crown's original construction in 1347. These include both sapphires and spinels. Also quite possibly reused was one blue sapphire shaped as a four-sided flat pyramid (Figure 40a). Similar stones are found in 13th- and early 14th-century jewellery

Table III: General survey of gem fashioning in the crowns of Saint Wenceslaus and Blanche of Lancaster.

Outline shape as mounted	Irregular/ pebble-like		Oval, square, triangle		Pyramid	Rectangle, hexagon, octagon					
Characteristics	–	With planar table	Curved upper surface or dome	With planar table	Without sharp edges	Without sharp edges	Table and crown facets	Table, crown and girdle facets	Pavilion facets	Table, crown and pavilion facets	More complex scissor-cut crown facets
Crown of Saint Wenceslaus[a]	X	X	X	X	X	X	?	–	–	–	–
Crown of Blanche of Lancaster[b]	X	X	X	X	–	X	X	X	X[c]	X[d]	X[d]
Cutting and polishing processes[e]	Only surface polish (1)	Shaped or preformed and polished (3a)	Shaped or preformed and polished (2)	Shaped or preformed and polished (3b)	Shaped or preformed and polished (4)		Preformed, faceted and polished (5a)	Preformed, faceted and polished (5b)	Preformed, faceted and polished	Preformed, faceted and polished (5c)	Preformed, faceted and polished

[a] From descriptions and photos given by Otavsky (1992), Hyršl & Neumanova (1999) and Šumbera (2008).
[b] From this study.
[c] This sapphire apparently is not oriented as originally mounted in the setting, having been rotated 180°.
[d] Added later.
[e] The numbers in parentheses refer to the categories shown in Figure 37.

Figure 39: The Crown of Saint Wenceslaus was originally created for Charles IV in 1347 apparently by using, at least in part, gems from older jewellery or crowns. The crown was substantially reworked between 1374 and 1378, with various substitutions made throughout that period. The crown is richly jewelled with blue sapphires, pink to red spinels, one red tourmaline, one aquamarine, rubies, emeralds and pearls. The diameter of the headband is 19 cm and the crown's height is approximately 19 cm. The piece is in the collection of St Vitus Cathedral, Prague. Photo and stone identification by Jaroslav Hyršl.

but seldom thereafter. Other regular polygons included rectangles (two blue sapphires and two pink to red spinels) and octagons (one blue sapphire and one red spinel; Figure 40b, c). Precisely deciphering the degree of processing, insofar as concerns the sharpness of facets, is somewhat difficult from the available literature and photos (the crown is not displayed publicly), but a description by Otavsky explicitly mentioned rounded corners for the rectangular spinels, and photos from Šumbera and Hyršl show an absence of sharp edges for the rectangular and octagonal spinels and sapphires (Otavsky 1992; Šumbera 2008; J. Hyršl, pers. comm. 2018 and 2019).

Thus, taken together, the crowns of Charles IV and Blanche of Lancaster, which were manufactured within a span of one or two decades, show decorative practices for the Late Middle Ages while also demonstrating a full panoply of developments in gem processing. Although the advancements were doubtlessly nonlinear, with similar or parallel developments taking place at different places throughout the globe, a certain progression from polished pebbles to complex faceted cuts is discernible within the confines of just these two crowns (again as illustrated in Figure 37).

Figure 40: Gemstones from the Crown of Saint Wenceslaus exhibit a variety of shapes and represent early developments in gem cutting. They include: (**a**) a blue sapphire in the form of a four-sided flat pyramid, 39 × 36 mm; (**b**) one octagon, 31 × 22.5 mm, and two rectangular blue sapphires; and (**c**) an octagonal spinel, 32.5 × 23 mm. Stone identification by Hyršl & Neumanova (1999); photos by Jaroslav Hyršl.

In both crowns, gems with entirely rounded forms, either irregular pebble-like specimens or domed cabochons, were prevalent. The next stages of advancement began with the addition of near-planar to planar tables, but without altering the remainder of the rounded shapes. Another early type of modification is represented by the four-sided flat blue sapphire pyramid in Charles IV's crown (again, see Figure 40a). With no similar examples appearing in Blanche's crown, the popularity of this style may have waned by the second half of the 14th century. Such pyramidal forms might have served as a prelude to later polygonal stones with planar tables or to the various six-fold rose cuts developed in the Renaissance period and thereafter (Tillander 1995; Ogden 2018).

Both crowns likewise incorporate gems showing regular geometric forms (e.g. rectangular, hexagonal or octagonal) with near-planar tables and rows of slightly rounded crown surfaces inclined thereto, without sharp edges. Only Blanche's jewel, however, clearly reflects further developments toward planar facets and sharp edges. Then, presumably represented by replacements after 1402 or even 1700, advancements in the Renaissance and beyond can be witnessed in the more complex patterns with scissor-cut crown facets or with table, crown and pavilion facets.

Hence, by taking into account the decoration of both crowns and what is seen in many historical pieces that followed them, it becomes clear that irregularly shaped pebbles and cabochons with one near-planar face, as well as polygons with multiple inclined surfaces but without sharp edges, would disappear. What would survive from early forms would be cabochons with curved domes in a variety of shapes, and further developments would continue to yield more complex rose cuts and stones with sharply faceted crowns and pavilions.

CONCLUSIONS

The crown of Princess Blanche facilitates a rare view into the gem materials and imitations used in the last decades of the 14th century and the progression towards modern gemstone fashioning. The historical record supports that the crown was initially created for and used by Anne of Bohemia at the court of Richard II in London, before it arrived in Heidelberg as part of the dowry of Blanche of Lancaster at the time of her marriage to the future Louis III, Elector Palatine. It has since been preserved in Heidelberg, in Mannheim and, from the late 18th century, in Munich. Comparisons between inventories from the Middle Ages and new scientific data identifying the gems and materials used in the crown show remarkable consistency, confirming that only a limited number of replacements have altered the jewel's appearance. Diamonds are present as rough octahedra, and coloured stones include blue and pink sapphires, pink spinels, garnets and emeralds; imitations comprise black-coated gold pyramids and lead glass samples. Consideration of the forms of the gems further reveals an ongoing transition from the use of merely polished pebbles derived from secondary gem gravels to manufacturing complex, sharply faceted cuts. As such, centuries of history are encapsulated within a single artefact.

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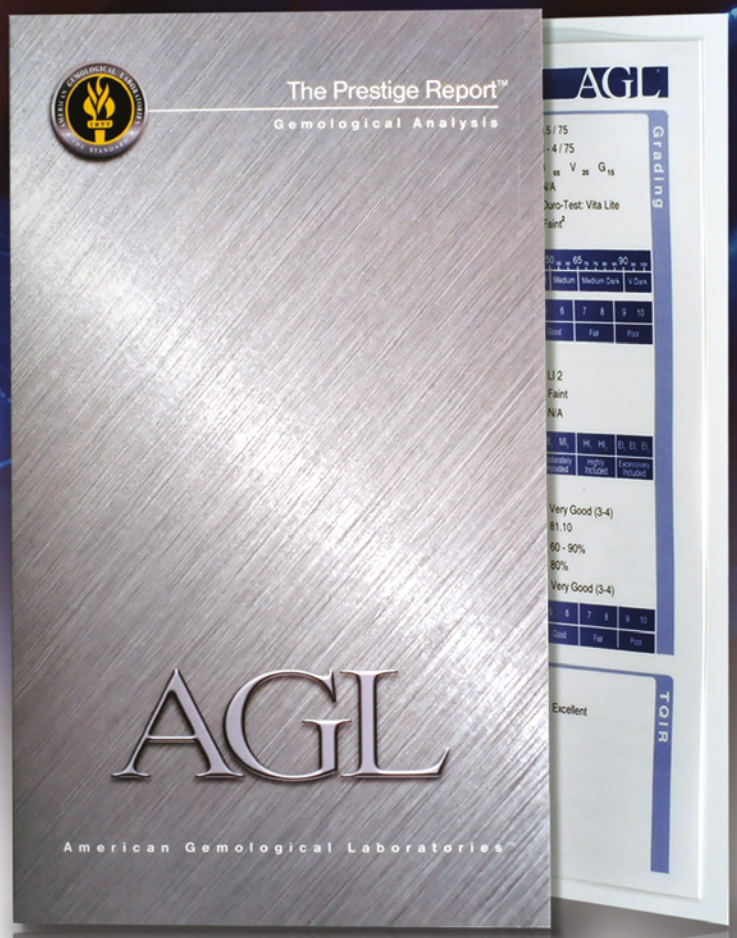

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Figure 1: These two specimens (167.4 ct pear shape and 30.3 ct carved turtle) show the deep black colour and high lustre of spinel from Bo Phloi, Thailand. Photo by M. Wildner.

Black Spinel—A Gem Material from Bo Phloi, Thailand

Ágnes Blanka Kruzslicz, Lutz Nasdala, Manfred Wildner, Radek Škoda, Günther J. Redhammer, Christoph Hauzenberger and Bhuwadol Wanthanachaisaeng

ABSTRACT: The Bo Phloi gem field in Kanchanaburi Province, western Thailand, is renowned mostly for its blue sapphire. Corundum production has now virtually ceased, so local gem cutters are focusing on high-quality black spinel, which is abundant from past stockpiles, to produce various jewellery items and carvings. A detailed mineralogical characterisation of this material showed that it is spinel *sensu stricto* ($MgAl_2O_4$) with elevated Fe contents (20.7 ± 0.9 wt.% FeO, or Mg:Fe atomic ratio about 2:1). The enriched Fe causes the dark colouration of the material. Based on Mössbauer spectroscopic results, Fe occurs in both divalent and trivalent states, the latter occupying both (four- and six-coordinated) cation sites in the crystal structure. The Fe^{3+} contributes to a 'partially inverse' occupation of the cation sites. As a result, the Raman spectrum of Bo Phloi material does not resemble that of 'normal' spinel, but rather is similar to the spectra of other spinel-group minerals that tend to show some inversion in their cation-site occupation, such as hercynite, magnetite and magnesioferrite.

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Gem-quality spinel of various colours is mined from many deposits around the world. Famous localities include Myanmar, Sri Lanka, Tajikistan, Tanzania and Vietnam (e.g. Gübelin 1982; Dirlam *et al*. 1992; Ananyev & Konovalenko 2012; Huong *et al*. 2012; Malsy *et al*. 2012; Phyo *et al*. 2019). The black variety of this mineral is rarely used for jewellery purposes, and then only if it is homogeneously coloured, free of fractures and shows high lustre. Such high-quality black spinel is known to occur near the village of Acaponeta, Nayarit State, Mexico (Rohtert 2002), and in the Bo Phloi District of Kanchanaburi Province, Thailand (Limsuwan 1999; Srithai 2007; Saminpanya & Sutherland 2008; Sutthirat *et al*. 2010). Other Thai occurrences of black spinel are known in the Chanthaburi, Phetchabun, Phrae, Sukhothai and Trat provinces (Coenraads *et al*. 1995), but these are typically not of good gem quality.

After decades of mining, blue sapphire production from the Kanchanaburi area has dwindled, so local gem cutters are turning to black spinel (Figures 1 and 2). Faceted and carved black spinel gems have therefore become more widespread in local gem markets. Several terms have been used to describe the non-transparent black spinel, with *pleonaste* and *ceylonite* (Deer *et al*. 1996) being the best known. Thai names include *nin* (meaning 'black gem'), *nin-ta-go* and *nin-tan* (the last two meaning 'solid-looking'). Some local dealers call the material *spiderman* or use the misleading terms *black sapphire* or *onyx* to describe the black spinel.

In this article we present the results of a recent study aiming to comprehensively characterise black spinel from Bo Phloi, including its physical properties, its chemical composition (major, minor and trace elements, as well as Fe^{2+} and Fe^{3+} contents), and its optical absorption and Raman spectral features.

BACKGROUND

The mineral spinel (more precisely magnesium aluminate spinel: $MgAl_2O_4$) has cubic space group $Fd\bar{3}m$ (Sickafus *et al*. 1999; cf. also Grimes *et al*. 1983). It occurs commonly as idiomorphic (i.e. well-formed crystals) to hypidiomorphic (i.e. partially developed crystal habit) grains in basic igneous rocks, in regional and contact metamorphic rocks, and as waterworn pebbles in alluvial sediments.

The spinel structure is characterised by O^{2-} ions that

Figure 2: These seven crystals (4.8–6.7 g) and one faceted stone (32.7 ct) of black spinel are typical of material from Bo Phloi. The shapes of the crystals are dominated by octahedral faces, rarely in combination with rhombic dodecahedral faces (such as the top specimen). Some pieces (see, e.g., the one at the upper right) show surface striations. Photo by M. Wildner.

form a cubic close-packed arrangement, hosting two non-equivalent cation sites (four- and six-coordinated with oxygen). Within this framework two different site occupations exist. In 'normal' spinels—such as ideal $MgAl_2O_4$—divalent cations occupy the tetrahedral cation site (four-coordination) and trivalent cations occupy the octahedral site (six-coordination), resulting in the general formula $A^{2+[4]}B^{3+[6]}{}_2O_4$. By contrast, in 'inverse' spinels half the trivalent cations occupy the four-coordinated site, whereas the remaining trivalent cations and divalent cations are incorporated at the six-coordinated site, resulting in the general formula $B^{3+[4]}(A^{2+}B^{3+})^{[6]}O_4$. An example of the latter is magnetite: $Fe^{3+[4]}(Fe^{2+}Fe^{3+})^{[6]}O_4$. However, many natural spinels represent intermediate states characterised by a 'partially inverse' site occupation. In such cases, the general formula can be summarised as $(A_{1-i}B_i)^{[4]}(A_iB_{2-i})^{[6]}O_4$, where 'i' is the inversion parameter. The degree of inversion depends on several factors (see O'Neill & Navrotsky 1983), but it is mainly controlled by the fraction of trivalent cations at the four-coordinated cation sites.

GEOLOGY AND MINING AT BO PHLOI

Geological Setting

Starting about 10 million years ago (Ma) during the Late Cenozoic, regional uplift and decompression melting resulted in extensive basaltic eruptions in Thailand (Figure 3). In the Bo Phloi area, basaltic volcanism took place either in the Inthanon Zone developed within the East Malaya block (Stauffer 1983) or within the Shan-Thai craton (Barr & Macdonald 1978). The Bo Phloi basaltic body is located in a major fracture zone transecting Silurian-Devonian quartzite of the Bo Phloi Formation. The present surface expression of the basalt is a remnant small plug approximately 1 km² in size (Bunopas & Bunjitradulya 1975). According to the currently accepted classification, the Bo Phloi basalt has a nepheline-hawaiite composition (Barr & Macdonald 1978, 1981; Yaemniyom 1982). The magma originated in the upper mantle at pressures of approximately 18–25 kbar and temperatures of 1,340–1,475°C, and ascended

Figure 3: The black patches on this simplified map show the distribution of Late Cenozoic basalt bodies in Thailand, including the Bo Phloi occurrence. Modified after Limtrakun (2003).

rapidly without any significant crustal interaction from estimated depths of 36–79 km (Barr & Macdonald 1981; Yaemniyom 1982). The basalt has been dated to the Pliocene (3.14 ± 0.17 Ma according to Barr & Macdonald 1981, or 4.17 ± 0.11 Ma according to Sutthirat *et al.* 1994; see also Choowong 2002).

The Bo Phloi basalt is a dark, dense, extremely fine-grained rock with a porphyritic texture. It contains abundant mantle xenoliths and xenocrysts such as pyroxene, spinel (Figure 4a), sanidine, olivine, plagioclase and magnetite. Less common syngenetic constituents include zircon, rutile, sapphire and ruby.

Mining

The Bo Phloi gem field comprises an area of about 60 km^2 in western Thailand, and is located about 30 km north of the town of Kanchanaburi (again, see Figure 3). Most of the mining sites are situated in gravels along the western terrace of the Lam Ta Phoen River (Limsuwan 1999; Choowong 2002). The area is renowned for the gem-quality blue sapphire that was once produced there (Bunopas & Bunjitadulya 1975; Vichit *et al.* 1978). The deposits are related to the weathering of basalt flows, and the gems have been mined from residual basalt-derived soil or gravel deposits up to 3 m thick and located up to 16 m below the surface (Hansawek & Pattamalai 1997; Choowong 2002; Khamloet *et al.* 2014). The gem-bearing fluvial deposition dates to the Pleistocene (approximately 0.7 Ma; Udomchoke 1988).

Mining in Bo Phloi with simple hand tools started in 1918, and shortly thereafter the deposit was believed to be depleted. In 1987, the site was rediscovered and subsequently exploited using modern mining tools and machinery (Limsuwan 1999; Figure 4b). However, most of these large-scale activities lasted less than two decades. The peak was during 1998–2005, when an average of 140–250 kg of sapphire were produced yearly (with a maximum of 320 kg in 2002). In 2006, sapphire production declined to only 20 kg. Since the early 2000s, miners also began to collect the initially discarded black spinel (Figure 4c). During 2003 and 2005, spinel production averaged 135 t per year, but in 2006 it decreased to about 15 t (Anonymous 2008). These numbers indicate that, although it was only a by-product of sapphire mining, black spinel was produced in huge amounts during the 2000s. There was so much available that local people built a huge Buddha statue with 49 t of crushed black spinel (Figure 4d).

Currently, mining activities have nearly ceased. At present, only negligible quantities of sapphire and black spinel are still produced as by-products of river-sand exploitation in a gravel quarry. Most mining sites are being transformed for other purposes. For example, one of the formerly most productive gem areas is now located under a golf course (Figure 4e). With the decline in blue sapphire production, the focus of local gem cutters and carvers has shifted towards black spinel, which is abundantly available for lapidaries from stockpiles that resulted from previous mining activities.

MATERIALS AND METHODS

The Bo Phloi spinel samples investigated for this study were purchased from local dealers in September 2018. They include 23 rough, more-or-less idiomorphic specimens of predominantly octahedral shape (seven of them are shown in Figure 2) and six cut and polished specimens (faceted or carved; three of them are seen in Figures 1 and 2).

Two rough pieces were cut in half (at random orientation), and one half of each was embedded in epoxy and then ground and polished; these samples were carbon coated for electron-beam imaging and major-element analysis. Doubly polished thin slabs were also prepared for optical absorption spectroscopy. For Mössbauer and powder X-ray diffraction analysis, sample material was powdered with an agate mortar and pestle.

The Mohs hardness (i.e. the resistance to being scratched) was tested by scratching one cut and four rough spinel specimens with reference minerals. SG values (here reported as mass density) were measured hydrostatically on the same five specimens, and RI was determined from polished surfaces on four spinels with a Krüss ER601-LED refractometer equipped with a diode lamp emitting 589 nm light.

Powder X-ray diffraction analysis was performed on two samples to confirm their identity and obtain their unit-cell dimensions, using a Bruker D8 Advance Eco powder diffractometer coupled with a LynxEye XE-T energy-dispersive detector with Cu($K\alpha$) radiation. The system was operated at 40 kV and 25 mA with a fixed divergence slit and sample spinning setup. The scanning range was 5–140° 2θ with a 0.01° θ step width. TOPAS version 4.2 (Bruker AXS GmbH 2009) software was used for powder X-ray diffraction data refinement.

Major-element analyses were carried out on two samples with a Cameca SX100 electron probe microanalyser (EPMA). The instrument was operated in wavelength-dispersive mode with the following conditions: accelerating voltage 15 kV, current 20 nA, and electron beam diameter of 2 µm at the sample surface. The following calibrant materials were used (with respective

Figure 4: (**a**) Two spinel xenocrysts (16 mm and 5 mm long) are embedded in their basaltic host rock. (**b**) The sapphire and spinel mining site at Ban Bung Hua Waen, southwest of Bo Phloi, as seen in 2012. (**c**) Mine employees pick sapphires from a conveyor belt in March 2012. Most of the black material in this heavy mineral fraction consists of spinel, which was stockpiled. (**d**) This Buddha statue (Luang Por Nil) is located on a hill inside the town of Bo Phloi. It measures 9 m tall and is made from crushed black spinel mixed with cement. (**e**) This area along the Lam Ta Phoen River northwest of Bo Phloi hosted the former Ban Chong Dan mining area, which has been transformed into a golf course. Photos by B. Wanthanachaisaeng.

X-ray lines analysed shown in parentheses): $MgAl_2O_4$ (Al[*K*α], Mg[*K*α]), sanidine (Si[*K*α]), titanite (Ti[*K*α]), chromite (Cr[*K*α]), wollastonite (Ca[*K*α]), hematite (Fe[*K*α]), spessartine (Mn[*K*α]), vanadinite (V[*K*α]), gahnite (Zn[*K*α]) and Ni_2SiO_4 (Ni[*K*α]). Peak counting times were 10 s for major and 30 s for minor elements; the background counting times were half the respective peak counting times. An X-PHI matrix correction routine (Merlet 1994) was applied to the raw data. The Fe^{2+}:Fe^{3+} ratio was calculated from stoichiometry, assuming four oxygen atoms per formula unit. Prior to EPMA analysis, backscattered electron images (BSE) were acquired to check for possible zoning and other heterogeneity within the crystals.

Laser ablation inductively coupled plasma mass spectroscopy (LA-ICP-MS) measurements of minor and trace elements were carried out on two samples with an Agilent 7500cx quadrupole ICP-MS unit coupled with an ESI NWR193 laser-ablation system. The instrument was operated with a 193 nm laser, working at 8 Hz repetition

rate pulse frequency with an energy of approximately 8 mJ/cm^2 at the surface and a 75 µm spot size. A gas flow of 0.75 l/min He transported the ablated material to the spectrometer unit. After every seventh measurement, NIST standard glasses SRM610 and SRM612 (Jochum *et al.* 2011) were probed for drift correction. The USGS reference glass BCR-2G (Rocholl 1998) was measured for quality control and was reproduced within 10% relative error. Aluminium was used as an internal standard. The detection limits of this method are in the range of 0.01–0.1 ppm for most trace elements. For data reduction GLITTER 4.0 software (Griffin *et al.* 2008) was utilised. Data for all elements were reduced using the SRM612 standard, except for ^{49}Ti, for which the SRM610 standard was used.

Mössbauer spectroscopy was performed on two samples to investigate the valence state of iron (Fe^{3+} and/or Fe^{2+}) and its occupancy in the spinel structure. Measurements were done with an apparatus manufactured by Halder Electronics GmbH (Starnberg, Germany) using methodology described by Redhammer *et al.* (2012). Folded spectra were deconvoluted with the Voigt-based quadrupole-splitting distribution approach (Rancourt & Ping 1991; Lagarec & Rancourt 1997). Using this procedure, distributions of quadrupole splitting due to slightly different local distortion environments around the Fe-probe site can be adequately modelled.

An optical absorption spectrum was obtained from each of the two doubly polished thin slabs mentioned above in the near-ultraviolet, visible and near-infrared spectral ranges using a Bruker IFS 66v/S Fourier-transform spectrometer. Analytical details were analogous to those of Zeug *et al.* (2018).

Raman spectroscopic measurements were performed on all 23 rough and six polished samples to confirm mineral identification and evaluate the extent of 'structural inversion' in comparison with other spinels. Analyses were done by means of a Horiba LabRAM HR Evolution spectrometer, with the same measurement setups as in Zeug *et al.* (2018). Spectra were excited with a 532 nm Nd:YAG laser (10 mW at the sample surface), using a 50× objective (numerical aperture of 0.50). The resulting energy density was well below the threshold of any laser-beam-induced sample changes, as could possibly be caused by local heating due to intense light absorption (note that, e.g., the Fe-spinel magnetite is easily oxidised by a focused laser beam to form hematite; cf. figure 8 in Nasdala *et al.* 2004). Raman analyses were carried out prior to EPMA and LA-ICP-MS analysis to avoid any possible influence on the samples from the beams used by those instruments.

RESULTS AND DISCUSSION

General Properties

All samples were non-transparent and macroscopically black. The rough pieces appeared dull and greyish black, whereas polished specimens (faceted stones and carvings) were deep black with high lustre (Figures 1 and 2). The samples' Mohs hardness was about 8. This, along with the chemical stability and the lack of clear cleavage, explains their resistance to the chemical and mechanical weathering processes that acted upon the host basalt.

The X-ray diffraction pattern of the Bo Phloi material corresponded to that of Mg-Al spinel, which confirms the material's identity as spinel *sensu stricto*. This was not certain from the outset, as a good fraction of the 'black spinels' in the Thai gem markets actually are pyroxene or another black material. The unit-cell constant was determined as a_0 = 8.1363(1) Å, which corresponds well to literature data for spinel *sensu stricto* (a_0 = 8.103 Å; Putnis 1992). The resulting cell volume is 538.62(2) Å^3.

Samples were found to be optically isotropic, without any pleochroism. The RI was determined as about 1.770, which is somewhat higher than that of transparent gem-quality Mg-Al spinel (1.720; Tropf & Thomas 1991). Mass density averaged 3.85 ± 0.01 g/cm^3, which corresponds well to the 3.86 g/cm^3 determined by Saminpanya and Sutherland (2008) for black spinel from Bo Phloi. These values are notably higher compared to the mass density of near-end-member Mg-Al spinel (3.58–3.61 g/cm^3; Deer *et al.* 1996). This, along with the dark colour, points to the presence of elevated non-formula elements (e.g. Fe). The specimens were not attracted to an Alnico magnet.

Chemical Composition

The chemical composition of black spinel from Bo Phloi, as determined by EPMA and LA-ICP-MS analysis, is presented in Table I. Samples generally contained about 59 wt.% Al_2O_3, 19 wt.% MgO, and 21 wt.% FeO (with the total Fe expressed as FeO). The measured values agree with the results of a previous study on black spinel from Bo Phloi (Saminpanya & Sutherland 2008). With the exception of Fe and Ti, the Bo Phloi spinel contains low amounts of non-formula elements (below 0.2 wt.%). The BSE images of the samples (not shown) were virtually without any internal contrast. This, and generally low variations of EPMA results within and among samples, indicate that the Bo Phloi spinel has a fairly homogeneous chemical composition.

Table I: Average chemical composition of black spinel from Bo Phloi determined by EPMA and LA-ICP-MS, and calculated mineral formula units.

EPMA results (n = 34)				LA-ICP-MS results (n = 14)					
Oxide	Concentration (wt.%)[a]	Element	Content (apfu)[b]	Element	Isotope measured	Concentration (ppm)[a]	Element	Isotope measured	Concentration (ppm)[a]
SiO_2	0.16 ± 0.02	Si	0.004	Li	7	0.74 ± 0.14	Ga	71	209 ± 3
TiO_2	0.66 ± 0.05	Ti	0.013	Be	9	0.14 ± 0.04	Sr	88	0.02 ± 0.01
Al_2O_3	59.0 ± 0.6	Al	1.801	P	31	20.6 ± 3.4	Y	89	0.01 ± 0.01
MgO	18.7 ± 0.3	Mg	0.720	Ti	49	3440 ± 34	Zr	90	0.80 ± 0.18
Cr_2O_3	0.05 ± 0.05	Cr	0.001	V	51	705 ± 7	Nb	93	0.03 ± 0.01
MnO	0.13 ± 0.02	Mn	0.003	Cr	53	253 ± 5	Sn	118	0.29 ± 0.05
V_2O_3	0.12 ± 0.02	V	0.002	Mn	55	1025 ± 9			
ZnO	0.11 ± 0.02	Zn	0.002	Co	59	283 ± 3			
NiO	0.15 ± 0.03	Ni	0.003	Ni	60	1290 ± 19			
FeO[c]	20.7 ± 0.9	Fe^{2+}	0.289	Cu	63	2.94 ± 0.38			
Total	99.8 ± 0.3	Fe^{3+}	0.161	Zn	66	1290 ± 23			

[a] All errors are quoted at the 1σ level.
[b] General chemical formula units calculated assuming three cations and four oxygen atoms per formula unit. Fe^{2+}/Fe^{3+} was recalculated to maintain charge neutrality.
[c] Total Fe is quoted here as FeO.

Mössbauer Spectroscopy

Mössbauer spectra exhibited a broad resonance absorption that could be resolved into three principal sites (Figure 5), based on their isomer shift and quadrupole splitting values. Two of these sites belonged to Fe^{3+} and the third to Fe^{2+}. As is typically found in Al-rich spinel samples, the Fe^{2+} contribution was broad and consisted of three sub-components. This is in accordance with literature data (Larsson *et al.* 1994; Carbonin *et al.* 1996, 1999; Jastrzebska *et al.* 2017).

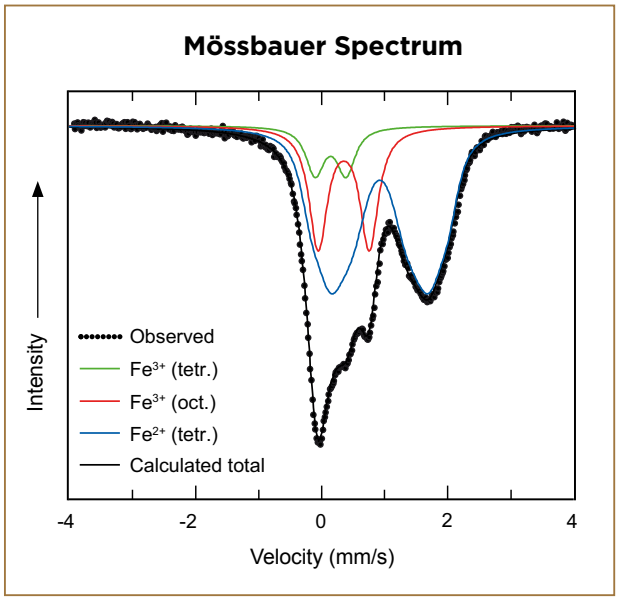

Figure 5: The Mössbauer spectrum of Bo Phloi spinel indicates the presence of three different iron site occupancies: Fe^{2+} in four-coordination, and Fe^{3+} in four- and six-coordination.

Refinement of the Mössbauer spectra showed that the broad component (being the sum of three sub-components) at the isomer shift of around 0.92 mm/s (Figure 5) is characteristic for Fe^{2+} in four-coordination. The component with an isomer shift of about 0.35 mm/s is ascribed to Fe^{3+} in six-coordination. The remaining component has isomer shifts and quadrupole splitting values typical of Fe^{3+} in four-coordination. Fits were also done without assuming the presence of this last component ($Fe^{3+[4]}$). As the results were distinctly worse for these fits, it can be assumed that a small amount of $Fe^{3+[4]}$ is present. The fit results are presented in Table II. Note that Mössbauer spectra do not yield an independent indication for the presence of Fe^{2+} in the octahedral position.

Table II: Mössbauer parameters for black spinel from Bo Phloi.

Iron species	Isomer shift (mm/s)	Quadrupole splitting (mm/s)	Fraction* (%)
Fe^{3+}; four-coordinated	0.13 ± 0.2	0.5 ± 0.3	9 ± 1
Fe^{3+}; six-coordinated	0.35 ± 0.2	0.8 ± 0.1	24 ± 2
Fe^{2+}; four-coordinated	0.92 ± 0.2	0.9 ± 0.1 1.6 ± 0.1 2.2 ± 0.1	67 ± 1

*Fractions of Fe species were determined from the ratios of integrated areas of the respective doublets and normalised to 100%.

Considering the Mössbauer results, the EPMA data (Table I) were converted to end-member fractions, which resulted in a nominal composition of the following components: 72 mol.% spinel (Mg-Al), 18 mol.% hercynite (Fe^{2+}-Al^{3+}), 8.1 mol.% magnetite (Fe^{2+}-Fe^{3+}) and 1.3 mol.% ulvöspinel (Ti^{4+}-Fe^{2+}). Despite the significant $Fe_{(total)}$ content, the material is assigned to spinel *sensu stricto* (that is, Mg-Al spinel; Figure 6). Correspondingly, the data plot near the spinel end member of the (Mg-Al) spinel-hercynite-magnetite triangle (Figure 6). The chemical formula is estimated, based on four O atoms per formula unit, as $(Mg_{0.66}Fe^{2+}_{0.30}Fe^{3+}_{0.04})^{[4]}{}_{\Sigma=0.99}(Al_{1.80}Fe^{3+}_{0.11}Mg_{0.06}Ti_{0.01})^{[6]}{}_{\Sigma=1.98}O_4$. Here, a small fraction of the Mg is assumed to be incorporated at the six-coordinated site, as otherwise there would be a significant imbalance in the occupations of A and B sites. The small but significant amounts of $Fe^{3+[4]}$ and $Mg^{2+[6]}$ characterise the cation occupation as 'partially inverse'.

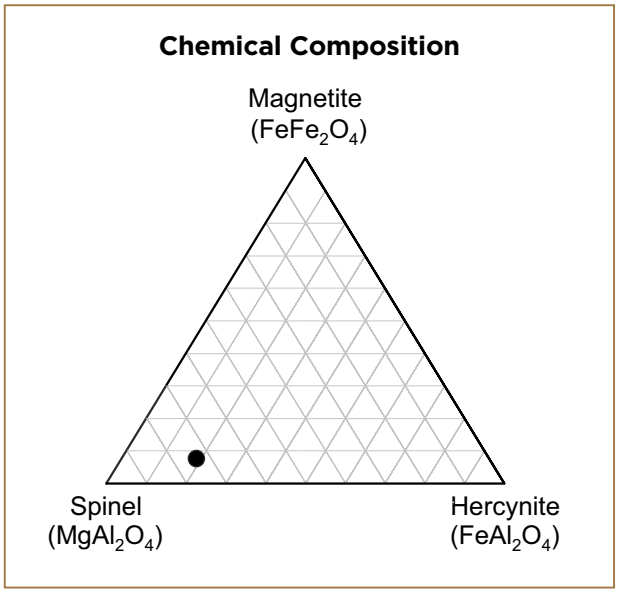

Figure 6: Results of chemical analyses of the Bo Phloi spinel (converted to nominal end-member fractions in mol.%) are plotted in the spinel end-member triangle. Note that an 0.8 mol.% ulvöspinel ($TiFe_2O_4$) component is also present in the material but is not shown in this plot.

Optical Absorption Spectroscopy

The optical absorption spectrum is shown in Figure 7 as linear absorption coefficient plotted against wavenumber (lower x-axis) and wavelength (top x-axis). Note, however, that even a 27-µm-thick slab (see transmitted-light image in Figure 7, inset) turned out to be too thick to obtain an optical absorption spectrum with adequate signal-to-noise ratio. The spectrum presented in Figure 7 was, therefore, obtained from a thinned edge of the slab (10 µm thickness). As the material's chemical composition is very homogeneous, the small sample volume that was effectively analysed in the absorption spectrometer is not believed to cause any bias.

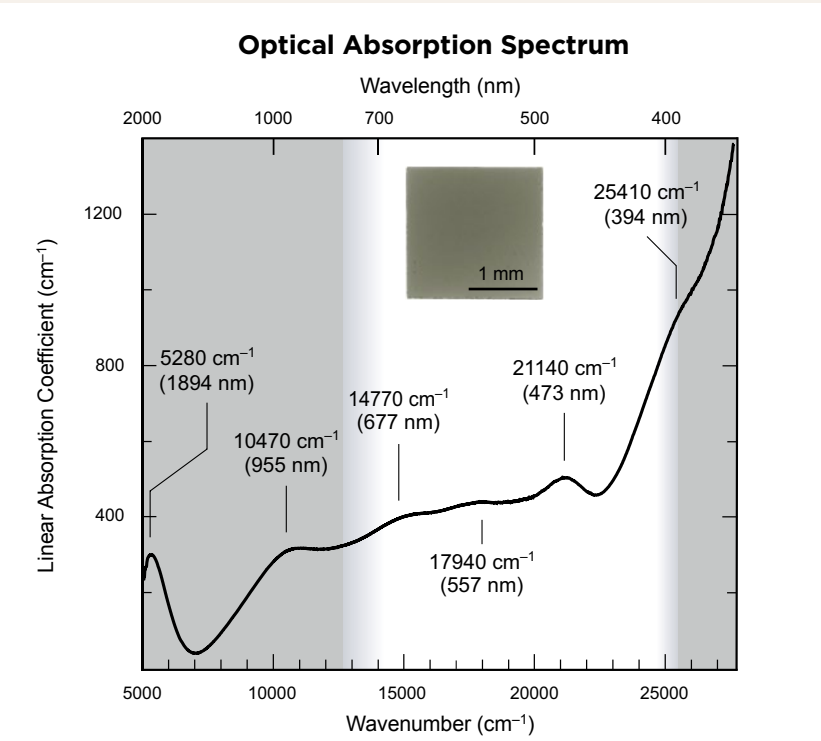

Figure 7: This optical absorption spectrum of spinel from Bo Phloi was measured in transmission mode from a 10-µm-thick slab. Spectral ranges invisible to the human eye are shaded in grey. All of the absorption features are due to iron. The inset shows a 27-µm-thick slab (transmitted-light photomicrograph), which reveals the brownish grey colour. Photomicrograph by B. Kruzslicz.

To quantify specific band positions, a twofold procedure was applied. First, several versions of 'rubber-band corrections' based on polynomials with manually selected anchor points were performed, to account for the assumed shape of the absorption edge and for linear background absorption. Second, band deconvolution implying six Gaussian band profiles was performed for each version of the resulting background-subtracted spectrum. It was found that different background corrections did not result in significant variations of fitted band positions, whereas the fitted bandwidths were quite different in some cases. The final band positions were obtained by averaging these band-fitting results, and are presented in Table III. Overall, the intense dark colouration of the black spinel from Bo Phloi is caused by a strong absorption edge that increases toward the UV range, with a number of Fe-related absorption bands in the visible range. For more details on the band assignments pertaining to the optical absorption spectra, see Box A.

Box A: Band Assignments for Optical Absorption Features in Black Spinel from Bo Phloi

A summary of the band assignments for the optical absorption spectral features in Bo Phloi black spinel is included in Table III and described below.

The comparatively sharp lowest-energy band at 5280 cm^{-1} (1894 nm; full width at half maximum about 1700 cm^{-1}) is the result of the spin-allowed d–d crystal-field transition of $Fe^{2+[4]}$, that is $^5E(D) \rightarrow {}^5T_2(D)$. Since this transition is affected by dynamic Jahn–Teller splitting, the observed band represents the high-energy component of the $^5T_2$ set only. Skogby and Hålenius (2003) identified three weaker split components at lower energies in infrared absorption spectra of spinel-hercynite mixed crystals, with the major one located at 3430 cm^{-1}.

The assignment of the broad band at 10470 cm^{-1} (955 nm) is less clear than that of the lowest-energy band. Here, no major crystal-field transition is to be expected due to the rather evidently low content of $Fe^{2+[6]}$, which was not detected in the Mössbauer spectra. However, even limited contents of $Fe^{2+[6]}$ might cause the transition of exchange-coupled six-coordinated Fe^{2+}–Fe^{3+} pairs, in accordance with the assignment of a comparable band by Hålenius *et al.* (2002). The quite flat and broad band at 14770 cm^{-1} (677 nm) is assigned, again in agreement with Hålenius *et al.* (2002), to electronic intervalence charge transfer (IVCT) between neighbouring $Fe^{2+[6]}$–$Fe^{3+[6]}$ ions. The latter interpretation too is in apparent contrast with the Mössbauer results, as it also assumes some Fe^{2+} ions in the octahedral site. It should be noted, however, that even minute amounts of Fe^{2+} in the octahedral site, well below the Mössbauer detection limit, can be enough to activate the IVCT process.

Bands at higher energies are most likely related to spin-forbidden d–d transitions of $Fe^{2+[4]}$ and/or $Fe^{3+[6]}$. The apparently weak band at 17940 cm^{-1} (557 nm) might be attributed to the (more-or-less field-independent) spin-forbidden $^3T_2(H)$ level of $Fe^{2+[4]}$, probably $^3E(G) \rightarrow {}^3T_2(H)$ with additional contributions from $^3T_1(H)$ and/or $^3T_1(G)$. A comparable assignment was proposed by Gaffney (1973) for $Fe^{2+[4]}$ in $MgAl_2O_4$. The pronounced band at 21140 cm^{-1} (473 nm) typically results from spin-forbidden d–d transitions in $Fe^{3+[6]}$, that is $^6A_{1g}(S) \rightarrow {}^4A_{1g}/{}^4E_g(G)$ (cf. Andreozzi *et al.* 2001, 2018; Taran *et al.* 2005), probably with a contribution of spin-forbidden d–d transitions of $Fe^{2+[4]}$, such as $^5E(D) \rightarrow {}^3T_2(G)$. The shoulder centred at about 25410 cm^{-1} (394 nm) within the ligand-metal charge-transfer absorption edge is also assumed to be related to a combination of spin-forbidden d–d transition of $Fe^{2+[4]}$ and $Fe^{3+[6]}$ positions, tentatively $^5E(D) \rightarrow {}^3T_2(D)/{}^3T_2(P2)$ of $Fe^{2+[4]}$ (e.g. Andreozzi *et al.* 2018) and $^6A_{1g}(S) \rightarrow {}^4T_{2g}(D)$ of $Fe^{3+[6]}$.

In summary, the interpretation of the bands at 5280 cm^{-1} (1894 nm), 10470 cm^{-1} (955 nm) and 14770 cm^{-1} (677 nm) goes along with the findings of Hålenius *et al.* (2002), who analysed samples with roughly comparable composition to this study's material. However, due to distinct differences in the composition and Fe distribution of the two studied materials (especially concerning significantly higher octahedral Fe^{3+} in our samples), assignments by analogy of the bands at 10470 cm^{-1} (955 nm) and 14770 cm^{-1} (677 nm) are not straightforward. According to Taran *et al.* (2005), an absorption band around 10500 cm^{-1} (952 nm) could also be assigned to electronic spin-forbidden transitions $^6A_{1g} \rightarrow {}^4T_{1g}$ of $Fe^{3+[6]}$. Higher-energy bands at 17940 cm^{-1} (557 nm), 21140 cm^{-1} (473 nm) and 25410 cm^{-1} (394 nm) can be attributed to spin-forbidden transitions of Fe in general (e.g. Andreozzi *et al.* 2001), but due to the complex distribution of Fe in the black spinel from Bo Phloi, singular assignments naturally bear some uncertainty.

Table III: Band positions and assignment of optical absorption bands* for black spinel from Bo Phloi.

Band position (cm^{-1})	Band position (nm)	Assignment
5280	1894	Spin-allowed d–d transition of $Fe^{2+[4]}$: $^5E(D) \rightarrow {}^5T_2(D)$
10470	955	Transition of exchange-coupled $Fe^{2+[6]}$–$Fe^{3+[6]}$ pairs
14770	677	Intervalence charge transfer (IVCT) between neighbouring $Fe^{2+[6]}$–$Fe^{3+[6]}$ ions
17940	557	Spin-forbidden d–d transition of $Fe^{2+[4]}$: $^5E(D) \rightarrow {}^3T_2(H)$ etc. (assignment uncertain)
21140	473	Spin-forbidden d–d transition of $Fe^{3+[6]}$: $^6A_{1g}(S) \rightarrow {}^4A_{1g}/{}^4E_g(G)$, probably with contribution of $Fe^{2+[4]}$: $^5E(D) \rightarrow {}^3T_2(G)$
25410	394	Spin-forbidden d–d transitions of $Fe^{2+[4]}$: $^5E(D) \rightarrow {}^3T_2(D)/{}^3T_2(P2)$ and $Fe^{3+[6]}$: $^6A_{1g}(S) \rightarrow {}^4T_{2g}(D)$ (assignment uncertain)

*Superimposed on the O–$Fe^{2+,3+}$ ligand-metal charge-transfer UV absorption edge.

Raman Spectroscopy

The Raman spectrum of Bo Phloi black spinel is shown in Figure 8, along with reference spectra of spinel *sensu stricto* (Nasdala *et al.* 2001), magnesioferrite, hercynite (D'Ippolito *et al.* 2015) and magnetite (Stähle *et al.* 2017). The spectrum is dominated by intense bands at 542 and 750 cm^{-1}, which concurs well with a Raman spectrum obtained for Bo Phloi spinel by Saminpanya and Sutherland (2008).

A most remarkable finding is that the Raman spectrum of the Bo Phloi spinel does not resemble the spectrum of natural, 'normal' Mg-Al spinel, which is dominated by an intense, narrow E_g-type band at 408 cm^{-1} (Cynn *et al.* 1992; Nasdala *et al.* 2001; Slotznick & Shim 2008; cf. also Schubnel *et al.* 1992). Instead, the most intense bands in the Raman pattern of the Bo Phloi spinel are at different spectral positions and with different relative intensities. However, the Raman spectrum of the Bo Phloi spinel does show similarities to those of other spinel-group minerals, such as hercynite and magnesioferrite, which often tend to be 'partially inverse'. Andreozzi *et al.* (2001), D'Ippolito (2013), Lenaz & Lughi (2017) and Granone *et al.* (2018) have discussed that the Raman spectra of natural spinel-group minerals and synthetic spinels are controlled predominantly by the degree of 'inversion' in the occupation of the two non-equivalent cation sites, rather than by chemical composition alone. Lenaz & Lughi (2017) found that at low inversion degrees ($i \leq 0.14$), spinel spectra are dominated by the strong 400–410 cm^{-1} Raman band of 'normal' spinel (again, see Figure 8). The low intensity or even absence of this band in the Raman spectrum of the Bo Phloi spinel suggests that its degree of 'partial inversion' must be significant, even higher than in the estimated chemical formula ($i \approx 0.04$–0.06).

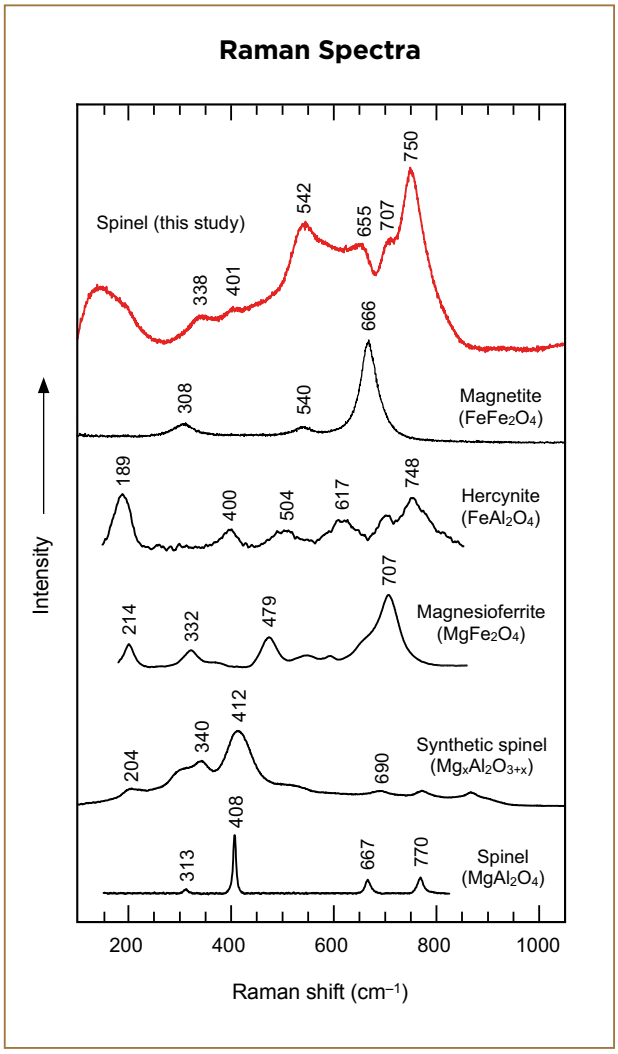

Figure 8: The Raman spectrum of Bo Phloi spinel in comparison with reference spectra for spinel-group minerals shows dissimilarity to natural and synthetic Mg-Al spinel references but similarity to the principal 'fingerprint' patterns of magnetite, hercynite and magnesioferrite. These can be explained by the degree of inverse cation occupation. Differences between natural and synthetic Mg-Al spinel are explained by the non-stoichiometry and disorder in the latter (Erukhimovitch *et al.* 2015). The reference spectrum for magnetite was obtained from a natural sample from Rumpersdorf, Austria (courtesy E. Libowitzky), and the synthetic Mg-Al spinel was provided by G. Giester. The other reference spectra were extracted from D'Ippolito *et al.* (2015; synthetic $FeAl_2O_4$ and $MgFe_2O_4$) and Nasdala *et al.* (2001; natural Mg-Al spinel from Mogok, Myanmar).

CONCLUSIONS

Black spinel from Bo Phloi, Thailand, is characterised by a remarkably homogenous chemical composition, corresponding to $MgAl_2O_4$ with particularly high Fe content. Mössbauer spectroscopic results indicate the iron consists of $Fe^{2+[4]}$ 67%, $Fe^{3+[6]}$ 24% and $Fe^{3+[4]}$ 9%. The additional presence of $Fe^{2+[6]}$ is indicated by the optical absorption spectrum, but the amount is below the detection limit of Mössbauer spectroscopy. The chemical formula (based on four O per formula unit), estimated from EPMA and Mössbauer spectroscopic data, is $(Mg_{0.66}Fe^{2+}_{0.30}Fe^{3+}_{0.04})^{[4]}{}_{\Sigma=0.99}(Al_{1.80}Fe^{3+}_{0.11}Mg_{0.06}Ti_{0.01})^{[6]}{}_{\Sigma=1.98}O_4$. This correlates to a 'partially inverse' occupation of the two principal cation sites. The Raman spectrum also indicates that the Bo Phloi spinel does not represent a 'normal' but rather a 'partially inverse' cation occupation, which suggests that it might contain some additional amounts of $Mg^{2+[6]}$ and $Al^{3+[4]}$.

The brownish grey colour of the Bo Phloi spinel can be observed only in samples with thicknesses well below 0.1 mm. Gemmologists would hence call the material 'opaque', whereas geoscientists would describe it as 'non-transparent'. For the latter, materials are considered opaque only if they are still fully non-transparent at the thickness of a petrological thin section (i.e. 25 µm). Optical absorption spectroscopy indicated that the intense dark colouration that makes the material appear black and non-transparent (Figure 9) is caused by a strong absorption edge that increases toward the UV range, with a number of Fe-related absorption bands in the visible range.

Distinguishing black spinel, especially when already faceted, from similar black, non-transparent materials such as pyroxenes and amphiboles is challenging (Johnson *et al.* 1996). Measuring RI and SG might not suffice for definitive identification. Here, Raman spectroscopy allows for quick, non-destructive mineral identification, even though the spectrum of black spinel and that of 'common' gem spinel (i.e. transparent, coloured material) differ appreciably.

Figure 9: Black spinel from Bo Phloi is being set into attractive jewellery, as shown by this sterling silver ring featuring a 35 ct centre stone surrounded by cubic zirconia accent stones. Photo by Tidarat Pruttipako.

Mining of black spinel in the Bo Phloi area has almost ended in recent years. Nevertheless, we should expect to continue seeing Bo Phloi black spinel in gem markets as existing stockpiles are processed into faceted stones and carvings.

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Gem Exploration Using a Camera Drone and Geospatial Analysis: A Case Study of Peridot Exploration in British Columbia, Canada

Philippe Maxime Belley, Pattie Shang and Donald John Lake

ABSTRACT: This case study examines the use of a consumer-grade unmanned aerial vehicle (UAV, or drone) and geospatial analysis for peridot exploration. Gem-quality olivine occurs in peridotite xenoliths hosted by Chilcotin Group basalts in south-central British Columbia, Canada. Geographic information system (GIS) geospatial analysis and satellite image verification identified 73 exploration targets consisting of basalt outcrops and talus slopes in the southern Monashee Mountains near the cities of Kelowna and Vernon. A DJI Mavic Pro drone was used in conjunction with high-definition (HD) first-person-view goggles to assess 15 localities for peridot potential. Six of them contained peridotite xenoliths, but at concentrations (1–2 vol.%) far below that of economically viable peridot deposits (30–50 vol.%). The use of the drone saved considerable time in the field, and the combined GIS-UAV approach could be applied in the future to facilitate peridot exploration throughout a large area of central British Columbia. Camera-drone remote exploration could also be applied to other types of gem deposits, such as lapis lazuli and those hosted by granitic pegmatites.

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Recent technological advances have significantly improved the range, flight time and camera quality of consumer-grade UAVs, and mass production has made them considerably more affordable. These improvements have made camera drones feasible, cost effective and potentially useful for the exploration and field reconnaissance of gem and mineral deposits. More-sophisticated drones capable of conducting hyperspectral imaging, aerial magnetic and photogrammetric surveys are already being employed in mining and exploration for various commodities (e.g. Kirsch *et al*. 2018; Jackisch *et al*. 2019). We present a case study demonstrating the use of GIS geospatial analysis combined with observations made with a camera drone and on-site in conjunction with basic exploration criteria to efficiently explore for basalt-hosted gem-quality peridot (e.g. Figures 1 and 2) in British Columbia (BC), Canada.

Production of peridot gems from BC has been sporadic and occasional, being primarily extracted by hobbyist collectors. The first record of peridot in BC was published by Galloway (1918), who noted that a prospector sent a number of stones from Timothy Mountain (also called Takomkane Mountain; Wilson 2014) to Tiffany & Co. for examination, but that they were too flawed to have significant value as a gem material. What is perhaps the most well-known peridot locality in BC, Lightning Peak, was first reported in a guidebook for mineral collectors by Sabina (1964). Several peridot occurrences have since been discovered (Wilson 2014; present article), and they

Figure 1: This basalt-hosted peridotite xenolith was found during field exploration in British Columbia, Canada. Several fragments of gem-quality peridot are visible on the surface of the broken xenolith, which is approximately 15 cm long. Photo by P. M. Belley.

have produced small amounts of rough material that yielded several dozen faceted stones weighing >1 ct. The largest peridot gems reported from the region weigh over 4 ct (or 3.52 ct for Lightning Peak specifically; Wilson 2014). Overall, gem-quality peridot is rare relative to the total amount of olivine present, since most xenoliths are generally too fine grained to yield facetable material (Wilson 2014).

BACKGROUND

Geology

Gem-quality peridot (Fe-bearing forsterite olivine) is primarily produced from two types of host rocks. In the first type, peridot typically forms euhedral crystals in open cavities or in talc/serpentine within peridotites or coarse-grained olivine dykes cutting peridotite (e.g.

Figure 2: The peridot in the xenolith shown in Figure 1 was faceted into numerous gemstones. The gems in this selection weigh up to 1.65 ct. Photo by P. M. Belley.

Egypt, Kurat *et al*. 1993; Myanmar, Kammerling *et al*. 1994; and Pakistan, Qasim Jan & Asif Khan 1996). In the second type, peridot occurs as crystalline aggregates in peridotite xenoliths that are hosted by alkali basalt (e.g. western Canada, Wilson 2014; China and North Korea, Koivula & Fryer 1986 and Zhang *et al*. 2019; Italy, Adamo *et al*. 2009; USA, Koivula 1981 and Fuhrbach 1992; and Vietnam, Thuyet *et al*. 2016).

In Canada, gem-quality peridot occurs within peridotite xenoliths in the Chilcotin Group basalts (CGB) of south-central British Columbia (Figure 3). The CGB are spread relatively thinly (averaging 70 m thick; Dostal *et al*. 1996) over an area of 25,000 km^2 in the intermontane super-terrane of central and southern BC (again, see Figure 3; Dostal *et al*. 1996; Dohaney 2009). The basalts erupted from 24 to 0.74 million years ago (Dostal *et al*. 1996 and references therein). They overlay various rock types, including Proterozoic orthogneiss, Devonian–Triassic basalt of the Nicola Group, Carboniferous–Permian greenschist, Jurassic granite, the Cretaceous Okanagan batholith, and Eocene volcanic rocks of the Kamloops and Penticton Groups (see Massey *et al*. 2005). Bevier (1983) concluded that the CGB were generated in a back-arc tectonic setting, possibly due to upwelling of the asthenosphere, in addition to possible influence from a mantle hot spot. The peridotite xenoliths (classified petrographically as primarily spinel lherzolite) were transported from the upper mantle to the earth's

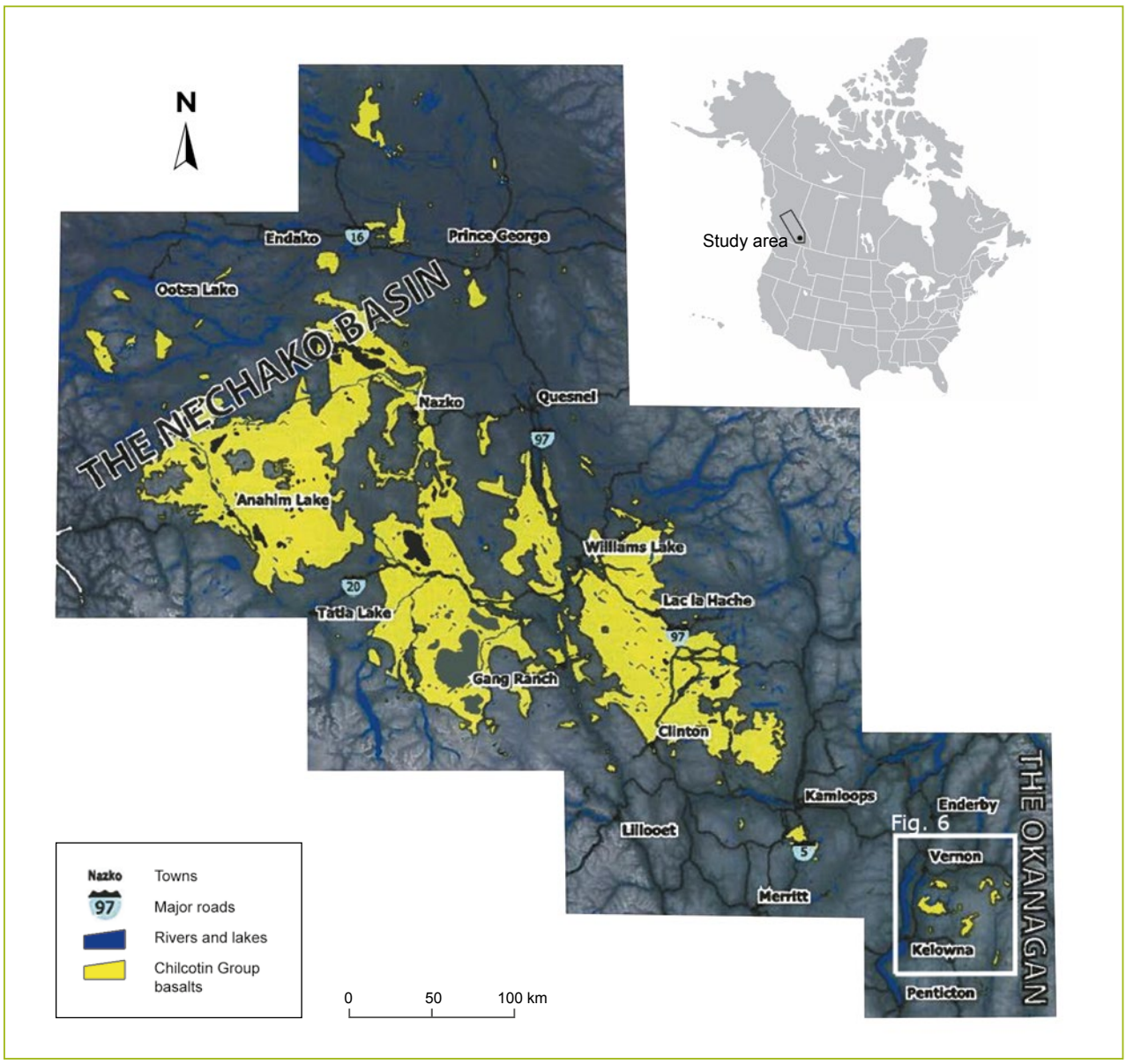

Figure 3: The study area is situated in south-central British Columbia, Canada, near the cities of Kelowna and Vernon. The distribution of Chilcotin Group basalts is shown in yellow-green. After Dohaney (2009); used with permission.

Figure 4: This view looking west from the basalt talus at Lightning Peak shows the typical terrain of the southern Monashee Mountains, where active logging takes place. See person for scale. Photo by P. M. Belley.

surface by the basaltic magma, which itself originated due to partial melting of upper mantle rocks. Only some flows contain peridotite xenoliths (e.g. Fujii & Scarfe 1982). The composition of olivine in the xenoliths from one locality in the study area was reported in the range of 87–92 mol.% forsterite (Fujii & Scarfe 1982).

The distribution and elevation of basalt exposures was influenced by the paleotopography (pre-existing hills and valleys) at the time of volcanism, with some flows having a 400 m difference in elevation (Mathews 1988). The landscape and rock outcrops were physically transformed by glacial erosion in the Pleistocene (Nasmith 1962) and subsequent erosion from freeze-thaw and gravitational forces, resulting in the formation of rock talus (e.g. Figure 4) below steep basalt outcrops.

Description of the Study Area

The study area is situated in the southern portion of the Monashee Mountains, just east of the cities of Kelowna and Vernon. It was selected because it is known to contain peridot and is in closest proximity to the authors' location in Vancouver. The elevation ranges between 1,200 and 2,140 m above sea level, and the region largely consists of hills and valleys covered primarily by coniferous forests (Figure 4). Active logging is ongoing and, as a result, gravel roads are locally present in the region. Talus can be present in steeper areas, especially along the sides of valleys. The challenging terrain, expansive forests and sparse roads make fieldwork in this area time consuming. The forests are home to numerous animals, including deer, moose, elk, cougars, wolverines, black bears and grizzly bears. Moose, deer and both species of bear were seen on several occasions during the authors' fieldwork.

MATERIALS AND METHODS

Exploration Criteria

Commercially significant basalt-hosted peridot deposits contain a high content of peridotite xenoliths: 30–50 vol.% at San Carlos, Arizona, USA (Vuich & Moore 1977) and Jilin, China (Wang 2017). Since only a small portion of peridotite xenoliths contain gem-quality material, and due to the gem's relatively low per-carat value, a high concentration of peridotite xenoliths is a key factor in the economic feasibility of a deposit.

Basalt containing about 5% or more of peridotite by volume will appear noticeably different when observed from a short distance in the field, which the authors confirmed in a camera-drone feasibility test (described below). Peridotite xenoliths can be identified in photographs and videos by their yellowish green colour and their blocky/subangular shapes within the dark basaltic matrix. For more effective exploration, the basalt needs to be well-exposed. Furthermore, the locality must be relatively accessible, since mining costs can become prohibitive in remote areas.

Therefore, the exploration criteria for basalt-hosted peridot can be summarised as: (1) occurrence of a basalt unit known to contain peridotite xenoliths, (2) good physical exposure of the rock unit, (3) relative ease of access and (4) high concentrations of peridotite within the basalt.

Geospatial Analysis

The first three exploration criteria mentioned above were employed to locate potential targets within the study area. Government of British Columbia data were used together with ESRI ArcGIS software to identify

exploration targets in the region. Several well-exposed examples of basalt-bearing talus in the study area have slopes equal to or greater than 30°, so slopes of such steepness were used to target talus for exploration. Slope was determined using the BC digital elevation model (0.75 arcsec x-y resolution, or 20–30 m). Locations of interest were determined by having the following conditions: (1) slope ≥30°, (2) bedrock geology consisting of CGB and (3) less than 10 km proximity to major roads or less than 2 km from local or logging roads. Exploration targets were then selected using Google Earth satellite imagery to filter out false positives, such as where a steep slope occurred in unconsolidated glacial sediment which, in areas, covers the older bedrock.

Camera Drone Exploration

Concentrations of peridotite within the basalt were evaluated using a DJI Mavic Pro drone (Figure 5), which weighs 734 g, has a maximum speed of 65 km/h, an overall flight time of 21 minutes (27 minutes maximum), a maximum transmission distance of 7 km (under ideal conditions), a GPS receiver and a 12.35 megapixel (effective pixels) 4K video camera. The device communicates with a radio controller and supplies a live HD video feed to the user via a smartphone or DJI Goggles. The latter are first-person-view flight goggles that receive data from and communicate with the drone in real time, which allowed us to see in far greater detail than through a smartphone app or external screen. This proved useful for rapidly assessing exploration targets as well as piloting the aircraft in close proximity to rocky outcrops and trees. However, a spotter was required when using the goggles both for legal purposes and to watch for bears.

The camera includes a 1/2.3-inch CMOS (complementary metal-oxide semiconductor) sensor and a lens with 5 mm focal length, field of view of 78.8°, f/2.2, distortion <1.5% and focus from 0.5 m to infinity. The maximum image size is 4,000 × 3,000 pixels. At 15 m flight elevation, the ground-sampling distance—the actual length of ground captured per pixel—is 0.46 cm/pixel. Although error is introduced by uneven surface topography, lens distortion, movement during capture, inaccuracy of height measurements above ground level and other factors, the ground-sampling distance is well below the expected xenolith size (e.g. commonly 5–15 cm at the San Carlos, Arizona deposit: Vuich & Moore 1977; typically 1–20 cm in Chilcotin Group basalts: Fujii & Scarfe 1982 and Wilson 2014) at distances from exposures achievable by the DJI Mavic Pro in talus (4–15 m), so the xenoliths should be clearly visible under ideal conditions. Xenoliths were identified remotely by visually inspecting photographs and live video feeds. The presence of yellow lichen, which is common at Lightning Peak, can obscure xenoliths. The xenoliths are differentiated upon closer examination of photographs by their green colour and subangular shape. While a quantitative, automated method of xenolith detection could be developed, the qualitative inspection of images required no complex development, minimal training and was extremely cost effective.

Figure 5: The DJI Mavic Pro foldable quadcopter camera drone was used for this study. It measures 33.5 cm diagonally (propellers excluded) and weighs 734 g. Photo courtesy of DJI.

RESULTS

Geospatial analysis with ArcGIS yielded 73 exploration targets in the study area (Figure 6). False positives were rare, and typically occurred in creek or river valleys that steeply cut through a top layer of unconsolidated sediment. At least four false negatives (where CGB outcrops were not successfully identified with geospatial analysis) were either found during fieldwork or seen in satellite images near identified targets. They tended to be in flatter areas that contain smaller talus slopes.

The camera drone was first tested at a location known to contain peridotite xenoliths in basalt: Lightning Peak (2,139 m elevation). At the time (4 June 2017) the locality was not readily accessible due to snow, so the drone was flown from a point more than 2 km away (Figure 7). Basalt blocks at Lightning Peak contain 3–5 vol.% peridotite (visually estimated from a previously done on-foot traverse across the talus). Yellowish green peridotite xenoliths were successfully resolved by the drone camera hovering approximately 17 m above the talus with the camera pointing straight down (Figure 8).

The drone was then used to evaluate exploration targets in other areas that ranged from 0.2 to 2.1 km away

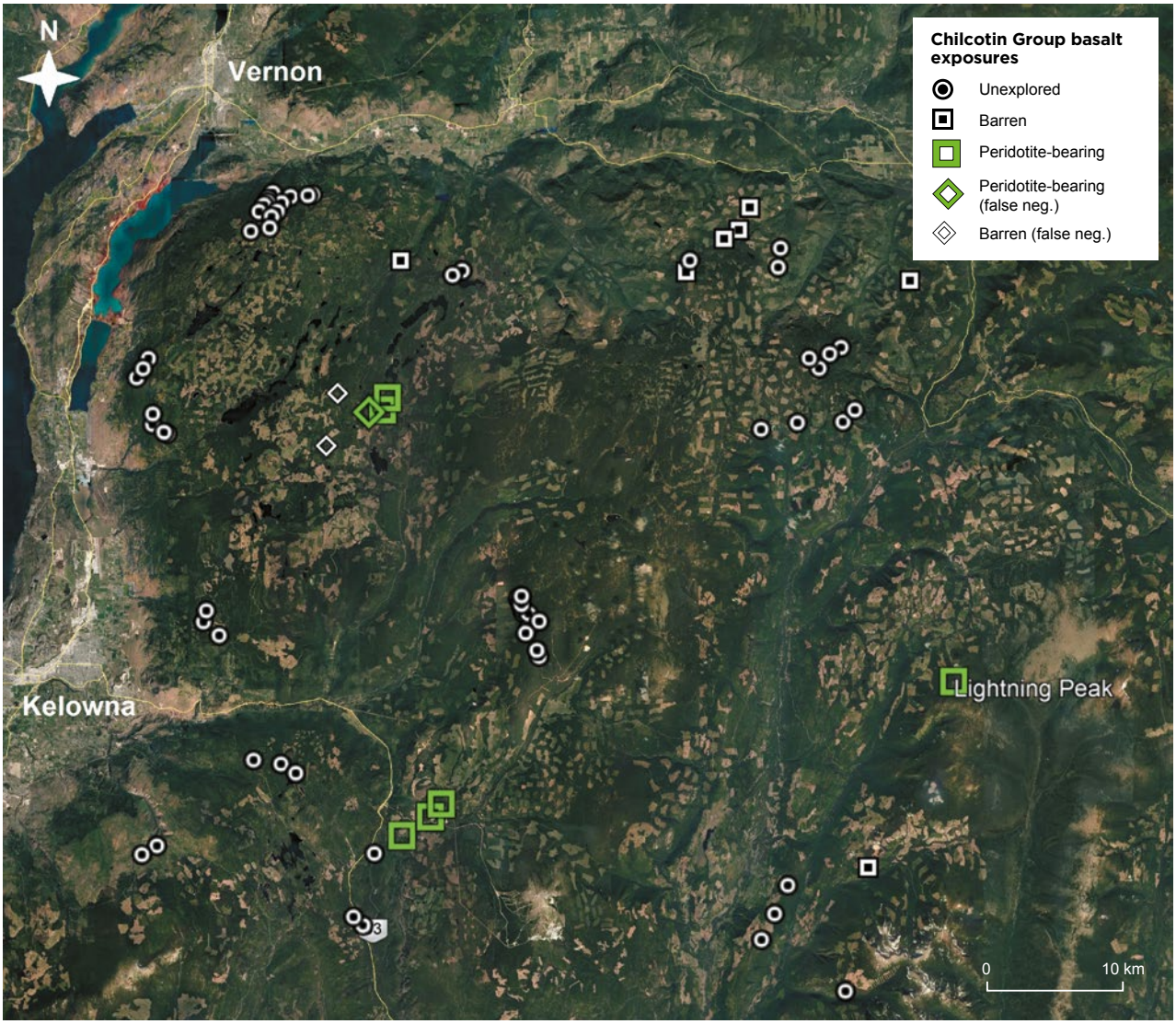

Figure 6: Exploration target results from geospatial analysis of Chilcotin Group basalt exposures in the study area are shown together with proximity to roads (yellow lines). Camera-drone exploration of some of these localities indicated those that were barren of peridotite xenoliths, as well as those containing peridotite xenoliths. Also shown are a few false negatives (i.e. those not identified via the ArcGIS analysis), as well as unexplored exposures. Satellite imagery from Landsat/Google Earth.

by air from the nearest road access point (e.g. Figure 9), with single-flight paths reaching 4.35 km in total distance. Fieldwork consisted of a total of six days in late spring and summer of 2017–2019, during which 16 targets were examined (three of which were false negatives). Excluding the previously mentioned Lightning Peak locality, six of the targets contained peridotite xenoliths and gem-quality peridot, while the other nine did not contain peridotite (again, see Figure 6). We found that peridotite xenoliths are more difficult to resolve with the drone at lower-elevation localities (e.g. at about 1,350 m) because the rocks have significantly more lichen cover than at higher elevations (e.g. at Lightning Peak), and because the peridotite at lower elevations is usually significantly more weathered. In basalt blocks that have been extensively exposed to the elements, xenoliths can be completely weathered out (Figure 10a). Xenoliths in basalt from more recent talus may show brownish surficial weathering (Figure 10b), while rare, very recent rock slides may expose fresh peridotite (Figure 1). Xenoliths in all stages of weathering were identified in drone images.

A low abundance of peridotite xenoliths typified all six targets (about 1–2 vol.% as confirmed by in-person visual estimation, compared to about 3–5 vol.% at Lightning Peak). Approximately 1–2% of the xenoliths contained facetable material (expected finished weight >0.5 ct). The cluster of localities in the southern part of the study area (again, see Figure 6) contained sparse, coarse-grained olivine crystals (2–5 cm) within peridotite xenoliths, but these crystals were generally non-transparent (the largest transparent stone faceted from this material weighed 1 ct). In the northernmost cluster of

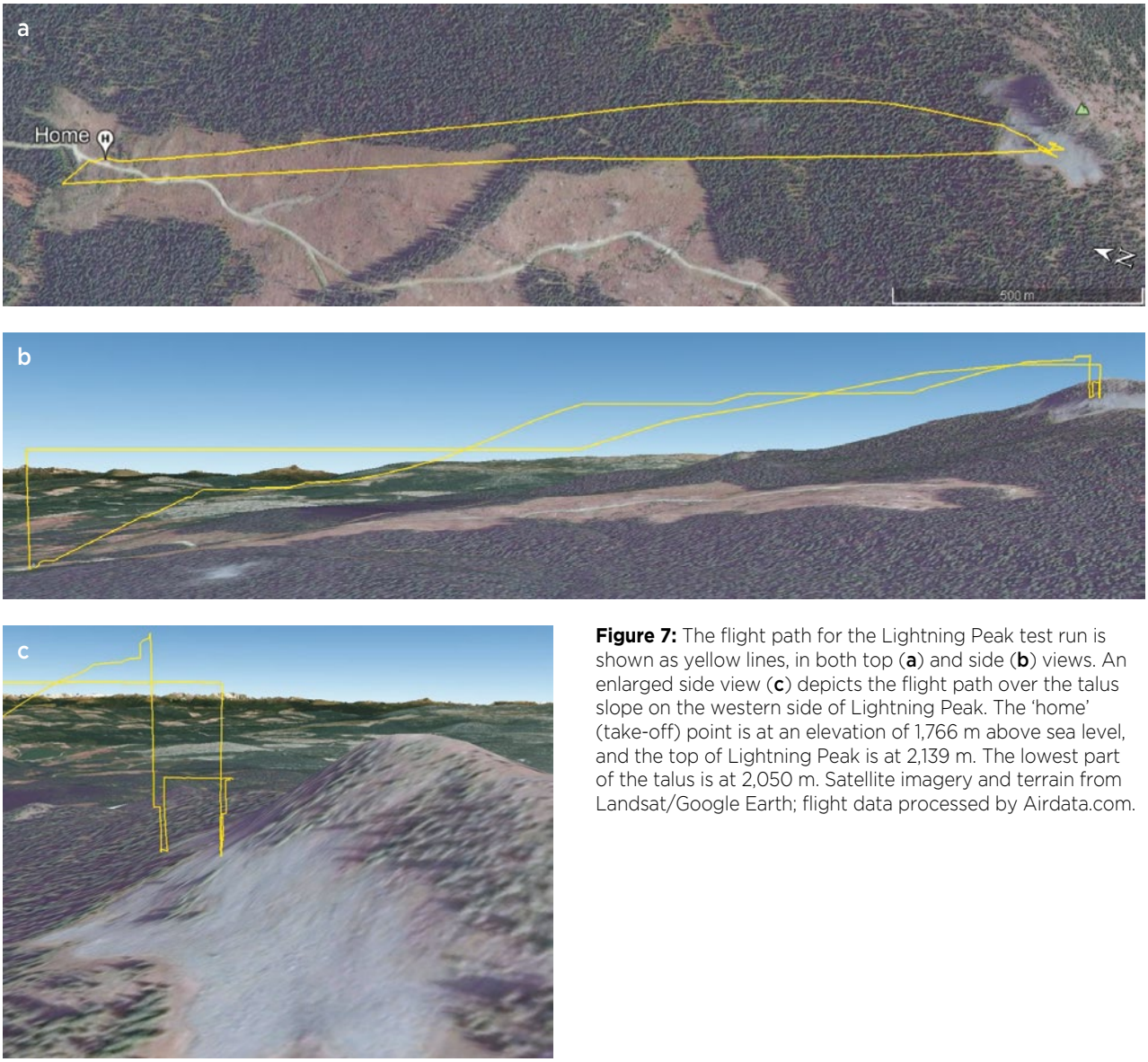

Figure 7: The flight path for the Lightning Peak test run is shown as yellow lines, in both top (**a**) and side (**b**) views. An enlarged side view (**c**) depicts the flight path over the talus slope on the western side of Lightning Peak. The 'home' (take-off) point is at an elevation of 1,766 m above sea level, and the top of Lightning Peak is at 2,139 m. The lowest part of the talus is at 2,050 m. Satellite imagery and terrain from Landsat/Google Earth; flight data processed by Airdata.com.

peridot-bearing localities, we found a few xenoliths containing gem-quality material. At one of these localities, a recent slide exposed a very large xenolith (originally about 30 × 20 × 20 cm) that broke into five pieces (e.g. Figure 1), which we found loose and within basalt blocks on the surface of the talus during an in-person traverse. Faceting of rough material from this xenolith produced 22 carats of commercial-grade cut stones weighing 0.80–1.65 ct (Figure 2), but this occurrence produced no significant gem material outside of this find.

A small portion of the xenoliths consisted of pyroxenite with very minor or no olivine. At one locality, gemmy dark green pyroxene xenocrysts up to 2 cm across occurred in low concentrations within basalt that was devoid of peridotite xenoliths. The pyroxene xenocrysts were observed in person and were too small to be identified in drone images.

DISCUSSION

Suitability of Geospatial Analysis

While geological maps could be cross-referenced to satellite images manually to locate exposures of Chilcotin Group basalt, the process is very time consuming. Geospatial analysis using ArcGIS proved extremely effective at identifying these exposures in a large-scale, automated fashion in minimal time. This process may immensely facilitate the identification of CGB outcrops over a 500 × 250 km region of central BC to the northwest of the study area. Satellite images also proved very useful both to confirm the occurrence of CGB talus and to plan navigation on logging roads. False negatives (where CGB outcrops were not successfully identified) occurred in more flat-lying areas, so geospatial analysis is most accurate in steep terrain.

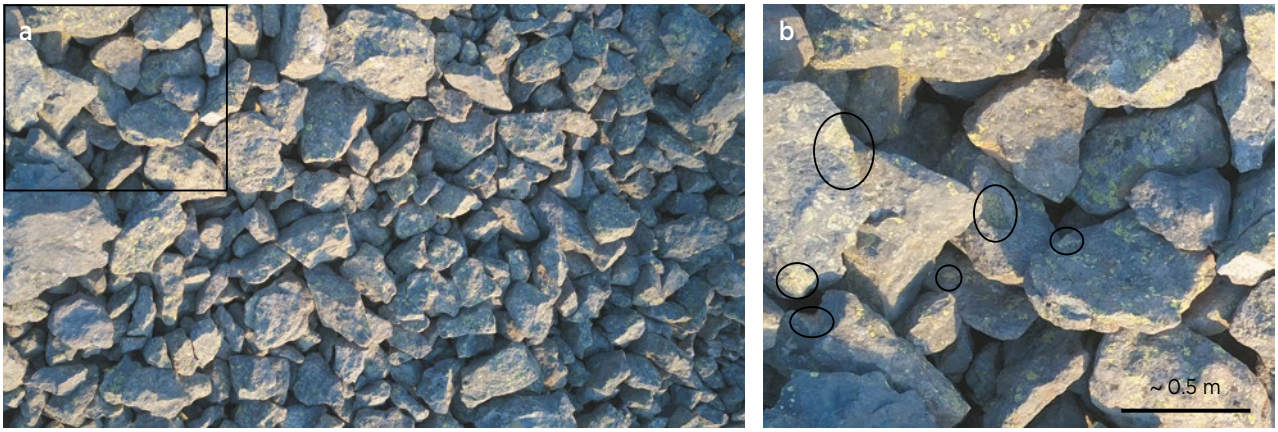

Figure 8: (**a**) This drone photograph of basalt talus at Lightning Peak (elevation 2,083 m) was taken from approximately 17 m above ground level. (**b**) A close-up of the upper left portion of (a) shows peridotite xenoliths (circled) in blocks of basalt. The locality could not be accessed by foot due to an abundance of snow, but snow-free parts of the talus could nonetheless be inspected with the drone. Photo taken 5 June 2017 with the camera oriented straight down (–90°) towards the ground.

Figure 9: An example flight path for a peridot target (here, barren basalt) is shown as yellow lines, in both top (**a**) and side (**b**) views. The 'home' (take-off) point is at an elevation of 1,407 m and the top of the basalt cliff is at approximately 1,550 m. Satellite imagery and terrain from Landsat/Google Earth; flight data processed by Airdata.com.

Figure 10: These two close-ups of the talus at a locality in the northernmost cluster of peridot occurrences (elevation approximately 1,350 m) show (**a**) holes resulting from the weathering of peridotite xenoliths and (**b**) weakly weathered brownish peridotite xenoliths in a boulder from a more recent rock fall. The weathering-out of the peridotite shown in photo (a) is not common at higher elevations (e.g. Lightning Peak). The camera was oriented straight down (-90°) towards the ground.

Camera Drone Exploration: Benefits and Limitations

Using the drone camera in the field saved considerable time and effort, since verifying targets remotely is significantly faster and easier than inspecting them in person. In addition, the telemetric and sensor capabilities of modern consumer-grade camera drones such as the DJI Mavic Pro make it possible to determine an approximate ground-sampling distance using altitude data; however, there is room for improvement. For one trip, we estimate that our three days of work would have taken two weeks with traditional prospecting (much time is lost setting up and taking down camp, and fewer sites can be verified in a day via hiking). The HD first-person-view goggles were useful for immediately assessing peridotite abundance, the alternative being the post-flight examination of photographs and video footage. More importantly, the goggles give a much clearer live view than a smartphone, which helped avoid obstacles (e.g. trees and branches) during the final approach. One limitation of the drone is that forest can sometimes obstruct communication with the drone, making a close approach to the talus (<15 m above surface) problematic due to difficulties in maintaining the live video feed. Since a close approach to talus is necessary for proper assessment, the exposure must be within (or close to being in) the line of sight. Vertical basalt exposures above talus were sufficiently above the tree line to enable target assessment in forested areas.

The presence of peridotite xenoliths in basalt—even at low concentrations (3–5 vol.%)—was easy to detect visually from images taken at approximately 15 m above ground level. However, some conditions make peridotite detection difficult: (1) weathering at lower elevations (about 1,350 m; causing round-shaped holes in the basalt that correspond to the locations of former peridotite xenoliths or a brownish appearance of less-weathered xenoliths; see Figure 10), (2) excessive lichen cover (more common at lower elevations and probably also on south-facing slopes) and (3) low peridotite concentrations. Nevertheless, it is probable that a viable peridot deposit (containing 30–50 vol.% peridotite in basalt) would be evident in drone-camera footage even under these conditions. Despite the effects of weathering, the presence of peridotite xenoliths was successfully detected from drone images. However, our field observations expanded the exploration criteria from locating only green subangular inclusions in basalt to include light brown weathered peridotite and holes left by the complete weathering of peridotite. It should be noted that open cavities or large vesicles in basalt could be mistaken for weathered xenoliths, although no such instances were observed during our fieldwork.

Assessment of Peridot Potential in the Kelowna Area

While the CGB in the Kelowna area of British Columbia has produced good-quality, albeit relatively small, peridot gemstones (e.g. Figure 11), the source material (peridotite xenoliths) was absent from more than half of the localities we examined. Even when present, the concentration of peridotite xenoliths (generally 1–2 vol.% and up to 5%) in the CGB is far below that at commercially mined deposits (30–50 vol.% at San Carlos, Arizona, and Jilin, China; Vuich & Moore 1977 and Wang 2017, respectively). Despite this, much of the CGB remains unexplored

Figure 11: South-central British Columbia, Canada, has produced small amounts of gem-quality peridot with good colour but typically in small sizes. Shown here is a rough piece (2.5 cm wide) from Lightning Peak and three faceted stones (1.1–1.25 ct) from the northernmost peridot-producing locality in Figure 6. Further gem exploration of basaltic terranes in this region using the remote-sensing techniques described in this article could result in additional production of gem-quality peridot. Photo by Michael Bainbridge.

for gem-quality peridot. Many more exploration targets identified during this study remain to be examined, and the potential for commercially viable peridot deposits may exist elsewhere in the CGB, which covers an area of 25,000 km^2 in south-central BC (Dostal *et al.* 1996). Potential also exists in other basalt units of the region, such as the Endako Group (Brearley *et al.* 1984).

Application to Other Gem Deposit Types

Qualitative camera-drone exploration is suitable for any deposit that features colours or textures easily recognisable from a distance, and the technique significantly increases productivity—particularly in steep terrain. Examples of gem deposits that might be prospected using camera drones include: (a) lapis lazuli, which is bright blue and requires large quantities to be economically viable for mining; and (b) granitic pegmatite dykes, which may be visible cross-cutting country rocks in mountainous terrain or exposed due to a relative lack of weathering. Qualitative visual examination of drone video/images is likely insufficient to detect gem deposits with a less characteristic appearance when observed from a distance. UAV exploration is most effective in areas with good surficial rock exposure, such as in polar regions (e.g. as suggested by Belley & Groat 2020) and in arid and alpine climates.

CONCLUSIONS

Geospatial analysis combined with the use of a camera drone dramatically improved the time and cost efficiency of exploring for peridot deposits in the CGB of south-central British Columbia. Peridotite xenoliths were resolved by the drone at an altitude of approximately 17 m, even at low concentrations (3–5 vol.%), but they were more difficult to observe at localities where weathering and lichen growth were more intense. However, these challenges are not expected to interfere with the remote detection of an important peridot gem deposit (i.e. basalt containing about 30–50 vol.% peridotite). Known peridot occurrences in the study area contained low peridotite concentrations (1–5 vol.%) relative to important deposits worldwide, but much of the CGB remain unexplored. The method outlined in this study could greatly facilitate exploration of the vast CGB flows located in a 500 × 250 km area of south-central BC. Drone-based visible-light imaging may also be useful for the exploration of lapis lazuli and pegmatite-hosted gem deposits.

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Conferences

THE PEARL SYMPOSIUM

DANAT, the Bahrain Institute for Pearls & Gemstones, hosted The Pearl Symposium on 14–15 November 2019 in Bahrain, a few days before the CIBJO Congress in Manama. This scientific event was promoted under the Pearl Revival Initiative, a programme that articulates historical, cultural, economic, biological and environmental knowledge to bring back the allure of the historically relevant natural pearl industry in Bahrain. The event was attended by more than 130 delegates from at least 28 countries. It started with a morning walk through the Pearling Trail in Muharraq (the former capital of Bahrain), a UNESCO world heritage site with a long-time tradition of pearl fishing, drilling and manufacturing.

Talks began that afternoon in the Sheik Ebrahim Center for Culture and Research with opening remarks by DANAT's CEO **Noora Jamsheer** and CIBJO president **Gaetano Cavalieri**. Keynote speaker **Dr Mohammed Bin Daina**, chief executive of the Supreme Council for Environment of the Kingdom of Bahrain, followed with an overview of Bahrain and its aquatic environment, focusing on historical and current pearling activities, in addition to the country's cultural, artistic, economic and tourism potential.

The technical presentations started with **Justin Hunter** (J. Hunter Pearls Fiji, Savusavu) on 'Pearling and the Environment – The Blue Pledge'. He pointed out the benefits of sustainable pearl farming for both local communities and the environment in regions with limited economic opportunities, which also host the greatest concentrations of marine biodiversity and are prone to the effects of climate change. The Blue Pledge for Sustainable Pearls is an initiative by three pearl-farming companies—J. Hunter Pearls Fiji, Jewelmer (Philippines) and Paspaley Pearls (Australia)—that merges conservation and economic opportunities, and seeks to raise awareness of sustainable luxury through cultured pearls, especially among eco-conscious millennials.

A well-documented overview on the 'The History and Archaeology of Pearl Fishing in Bahrain and the Gulf, 5500 BC to 1950 AD' was offered by **Dr Robert Carter** (London's Global University). He stressed that Bahrain has been the global centre of pearl production throughout most of recorded history, with archaeological evidence that pearling in the Gulf has been known for more than 7,500 years (i.e. since the Stone Age). Under the Greeks and Romans, Bahrain (then known as Tylos or Stoidis) was an important pearling area that also supplied the ancient Sasanian and Byzantine markets. There is evidence that great wealth was made in Bahrain during that period due to the pearl trade. For centuries, pearl fishing and trade were the main sources of income in Bahrain, especially in the Muharraq area after the early 1800s, with production peaking in the early 1900s. After the Great Depression started in the late 1920s and cultured pearls appeared on the international market, the value of the local natural pearls fell by nearly 90%.

Noura Al Sayeh (Architectural Affairs, Bahrain Authority for Culture and Antiquities, Manama) elaborated on the 'The History of the Pearling Trail', a project initiated in 2005 to document the cultural legacy of Bahrain's pearling activities—especially during the period when Muharraq was the capital (1810–1923)—including crafts and other activities related to pearl fishing, fashioning and trade. The initiative also seeks to preserve pearl-related buildings and their typical architecture. The economic impact of the pearl industry in Bahrain was quite significant to the urban development of Muharraq, until the 1930s when earnings related to pearling declined steeply. The project's goal is to translate the full cultural and urban legacy of pearling into a 3 km walking trail (which conference delegates visited that morning). The Pearling Trail encompasses 17 houses and public squares along the pedestrian path, including the homes of pearl divers and those of wealthy pearl merchants.

Dr Mohamed Al Rumaidh (marine biology and ocean science researcher) summarised investigations of pearl 'oyster' resources in Bahrain, especially regarding the local mollusc, *Pinctada radiata*. This research is based on studies from 1985 onward (i.e. 30 years after the last official pearl-fishing season in the mid-1950s), when a massive amount of data was collected on the pearl oyster resources. The research surveyed important oyster beds and provided statistical data on the yield and size of pearls from different locations, as well as the influence of fluctuations in pH, salinity and water temperature on

the breeding of the molluscs. The average number of shells was found to be 4–5.5 per square metre, totalling in excess of 200,000–400,000 per fishing area. The occurrence of pearls in the molluscs ranged from 1.9 to 7.9%, around 95% of which were below 3 mm, 4% were about 3 mm and only 1% measured 4+ mm.

Gina Latendresse (American Pearl Company Inc., Nashville, Tennessee, USA) reviewed the history of natural pearls from the Americas. Her father was John Latendresse, a key player in the production of shell beads for the cultured pearl industry. As his daughter, she witnessed not only the few natural pearls that were brought in by local fisherman but also her father's 20-year career producing beaded freshwater cultured pearls in America, an accomplishment that was first announced in 1983. Pearling in the Americas goes back to prehistoric times, according to 2,000-year-old archaeological evidence in Ohio. Latendresse described a pearl rush that occurred throughout the USA in the late 1800s to early 1900s, when significant quantities of natural freshwater pearls were obtained, including some of large size that were reportedly used by European Art Nouveau artists such as René Lalique.

The second day of The Pearl Symposium began with a panel discussion led by natural-pearl traders **Mohammed Al Mahmood** (Bahrain) and **Adi Al Fardan** (United Arab Emirates) and moderated by **Kenneth Scarratt** (ICA GemLab, Bangkok, Thailand). The discussion focused on specifics of pearl trading in the Gulf, a relatively unknown subject amongst the gemmological community. The current difficulty in sourcing fine-quality natural pearls (Figure 1), especially above certain sizes, contrasts with the relatively less-challenging times of the past. A fine, graduated necklace can take one or more years to assemble, considering that local pearl fishermen currently offer their findings on average only once a week. Amongst traders, pearls are measured by the *chaw* (an old Indian method to convert the weight of natural pearls into volume units for evaluation) rather than by the carat, although some still use ounces or pearl grains. The pricing of natural pearls is usually established through discussions within the very small pearl-traders' community spread throughout the Gulf, as well as in India and elsewhere in Asia.

Figure 1: These natural pearls from *Pinctada radiata* were presumably fished off Bahrain. The largest pearl is about 9 mm in maximum dimension. Photo © DANAT.

Kenneth Scarratt then delivered the second-day's keynote address, on the origins and modern trade usage of the term *keshi* ('poppy seed' in Japanese) in connection with natural and cultured pearls. The trade and consumers currently associate *keshi* with a non-beaded saltwater cultured pearl that resulted as an accidental by-product or intentional product of a culturing process. However, in Japan this term was originally used for the very small, rare natural pearls historically produced by *Pinctada fucata* (commonly known as the akoya pearl oyster) before the advent of pearl culturing research in the late 1890s to the early 20th century. The term was adopted by the trade and its meaning eventually corrupted to its current use worldwide. Thus, *keshi* has become a trade term for non-beaded saltwater cultured pearl by-products of various size and no longer refers to small natural seed pearls.

Abeer Al Alawi (DANAT) gave a well-illustrated presentation on the challenges presented by seed pearls in the laboratory. By law, Bahrain has prohibited the import of cultured pearls into the country since 1990. The vast majority of pearls entering Bahrain before then were seed pearls (typically 2 mm and below), which variously consisted of natural pearls or non-beaded saltwater or freshwater cultured pearls. Until 1997, testing at the former Gem & Pearl Testing Laboratory of Bahrain was performed by random sampling. If parcels or hanks had less than 10% cultured pearls, a 'pass' grade would enable them to enter the country. If they contained more than 10%, they would be returned to their origin. After 1997, the rules changed to require that each and every pearl be inspected, and the 'pass' grade for lots was reduced to 5%. Since its establishment in 2017, DANAT has played an important role in screening imported pearl products using modern testing equipment to detect undisclosed cultured or imitation pearls before being cleared through customs. As a consequence of this effective testing, a lower percentage of cultured pearls has entered Bahrain in recent years.

Nicholas Sturman (Gemological Institute of America [GIA], Bangkok, Thailand) recounted some of his interesting laboratory experiences with pearls, not only at GIA but also in his early career. He first reviewed the evolution of pearl identification techniques, from the endoscope (used by Basil Anderson at the Diamond, Pearl and Precious Stone Laboratory Branch of the London Chamber of Commerce, established in 1925) and old Lauegrams used to detect beaded cultured pearls, to custom-developed X-ray films, which were inspected under magnification to detect identifying features (a technique introduced in 1929). Today, pearl testing tackles new challenges (such as non-beaded cultured pearls) with sophisticated equipment like real-time X-radiography, X-ray computed microtomography, X-ray luminescence and energy-dispersive X-ray fluorescence, often supported by UV-Vis-NIR, Raman and photoluminescence spectroscopy, as well as chemical analysis by LA-ICP-MS. Occasionally, there are still divergent interpretations of the data collected, which demonstrates that pearl identification is not always a straightforward process. Laboratory experience is crucial when it comes to testing pearls, even when using the most sophisticated techniques.

Dr Hashim Al Sayed (University of Bahrain) offered a biological perspective on the existing pearl oyster banks in Bahrain, including their life cycle. He reminded the audience that pearl oysters are a renewable resource and more intensive scientific research is needed. He then presented a few facts related to the local molluscs. Different species of the *Pinctada* genus occur in the Gulf, but the most common is *P. radiata*, with densities that can reach up to 5–10 shells per square metre. Environmental conditions support their abundance around Bahrain, including the water temperature, abundant light (due to shallow water) and relatively high Ca content of the water. Dr Al Sayed elaborated on the ecological context of *P. radiata* (a filter-feeding organism), and described its nutritional properties, since local communities use this mollusc as meat. Its growth rate, according to regular measurements of shell length, was found to be about 58 mm in the first year (higher than in Japan).

This author presented a review of 'Antique and Museum Pearls' (Figure 2), starting with fossil pearls. While archaeological findings in the Gulf prove the antiquity of pearling activities there, even older finds have been reported from Baja California, Mexico, where worked pearls were radiocarbon dated to 8,500 years old. The significant use of pearls during ancient Roman times and the subsequent Byzantine period is illustrated by artefacts in various museums. The use of European freshwater pearls was significant in the Middle Ages

Figure 2: A presentation on famous and historic pearls was given at The Pearl Symposium by Rui Galopim de Carvalho. Photo © DANAT.

and after, notably in 19th-century jewellery from Russia. Important pearls of known historical provenance include La Peregrina, which was last seen at Elizabeth Taylor's estate auction at Christie's New York in 2011. La Peregrina has been erroneously represented as Mary Tudor's pearl, and recent research has shown that these two pear-shaped pearls are not one and the same. Other famous pearls include the Hope and Sleeping Lion pearls, the Mancini pearls, Marie Antoinette's pearl pendant and necklace, and Mae Plant's famous 1917 Cartier double-strand necklace.

Jean-Pierre Chalain (Swiss Gemmological Institute SSEF, Basel, Switzerland) delivered a talk prepared by **Dr Michael Krzemnicki** titled 'New Frontiers in Pearl Analysis: Age Dating, DNA Fingerprinting, and Novel Radiographic Methods'. He shared recent research conducted by SSEF on pearl testing, primarily on the separation of natural from cultured pearls that, for the most part, is straightforward. However, in some cases the results are a matter of opinion based on an educated interpretation of data collected from visual observations and advanced testing (e.g. X-radiography and EDXRF and Raman spectroscopy). In addition, radiocarbon dating has been successfully used on pearls. This quasi-non-destructive technique, which requires approximately 4 mg (0.02 ct) of powder (typically collected from a drill hole when possible), enables the dating of historically important samples and the separation of natural from cultured pearls based on their age. DNA fingerprinting has also proven useful, particularly for determining the species of pearl molluscs. Again, a very small amount of powdered sample is needed (as little as 2 mg). SSEF collaborates with ETH (Eidgenössische Technische Hochschule) and the Institute of Forensic Medicine at the University of Zurich to provide these services to the trade. Chalain also described two relatively new testing methods being developed to better visualise the internal structures of pearls: (1) simultaneous X-ray phase-contrast and darkfield imaging, and (2) neutron radiography and tomography.

Dr Stefanos Karampelas (DANAT) gave a well-illustrated talk on 'Pearl Species Determination: Possibilities and Limitations'. He pointed out that the availability of Central American pearls in the 1500s and 1600s (often called 'occidental pearls') made it possible to create necklaces by mixing them with Gulf pearls (often called 'Oriental pearls'), and he also noted that pearl-origin determination has traditionally been based on essentially historical information. In the 1980s, demand developed for the origin determination of cultured pearls. Today there is strong demand for the determination of mollusc origin (i.e. the host mollusc species and its location) for both nacreous and non-nacreous pearls, but only a few laboratories issue such reports. The methodology involves visual observation, radiographic (internal structure imaging) and DNA-sequencing techniques, supported by chemical and spectroscopic data (e.g. UV-Vis-NIR reflectance and Raman spectroscopy for organic pigment identification). DNA testing of pearls is not yet cost effective, but it may become so in the near future. A solid database is paramount to support the interpretation of the data collected during such testing, and must be built up by the collection and full documentation of samples from known localities. Limitations are related to the massive amount of data that has yet to be collected, and to specific issues pertaining to white pearls (no pigment information), treated pearls (e.g. bleached) and mounted or very small samples. In addition, pearls from different molluscs sometimes have overlapping data.

The 'Trade in Bahraini Pearls' was the subject of a presentation by notable natural-pearl dealer **Ali Safar** (formerly of the Gem & Pearl Testing Laboratory of Bahrain). He emphasised that Bahrain (particularly Muharraq) is still the capital of pearl trading in the Gulf, a position that has remained unchanged for centuries despite the ups and downs of the industry. The quality of the lustre, shape, size and orient of the Bahraini pearls became world famous. Due to their scarcity in larger and better qualities, their pricing is set according to the fact that each pearl is unique. With the support of DANAT, visitors to Bahrain can be assured that the pearls they buy are natural, since it is illegal to trade cultured pearls in the country. Recent efforts being undertaken to revive the pearl trade and industry are quite welcome, and have great symbolic and historical relevance to Bahrainis.

Kenneth Scarratt closed the symposium with the results of a 'Recent Expedition to Acquire and Characterise Natural Pearls from Australian *Pinctada maxima*', co-authored with **Ali Al-Atawi** (DANAT), which was also presented at the 7th European Gemmological Symposium (see *The Journal*, Vol. 36, No. 7, 2019, pp. 661–663).

The Pearl Symposium proceedings booklet, as well as videos of all the presentations and slides from some of them, are available at www.danat.bh/pearlsymposium-talks.

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22ND FEEG SYMPOSIUM

The 22nd symposium of the Federation for European Education in Gemmology (FEEG) was organised by Zadkine Vakschool Schoonhoven in the Netherlands in celebration of their 125th anniversary. The event took place 25–27 January 2020 and was attended by 110 people.

Karin Voskamp (Zadkine Vakschool Schoonhoven) kicked off the symposium and introduced Zadkine, the only vocational school in the Netherlands providing education for goldsmiths, silversmiths, jewellers and watchmakers. **This author** then welcomed the delegates and pointed out that FEEG has two main objectives: to promote excellence in gemmological training and to connect gemmological education with the gem and jewellery sectors.

Rui Galopim de Carvalho (CIBJO and Portugal Gemas Academy, Lisbon, Portugal) presented a gemmological overview of precious coral and explained that it is critical to differentiate these eight species from the thousands of other common (i.e. reef-building) coral species. Considering the current emphasis on sustainability and corporate social responsibility, it is important to educate members of the trade and consumers that coral used in jewellery does not pose a threat to the coral reefs, although it does need to be sustainably harvested.

Dr J. C. (Hanco) Zwaan (Netherlands Gemmological Laboratory, National Museum of Natural History 'Naturalis', Leiden) elaborated on the use of geochemistry to study the geological formation of sapphires and determine their country of origin. Sapphires from primary deposits in Sri Lanka were compared to those from the main alluvial gem fields in that country, showing that not all data are consistent with the classic division between metamorphic and magmatic corundum. Because they show considerable overlap with other provenances, he demonstrated that evaluating polished sapphires of unknown origin may provide results with varying degrees of certainty. A statement on geographical origin is therefore, at best, a well-founded professional opinion based on scientific evidence.

John Benjamin (John C. Benjamin Ltd, Aylesbury, Buckinghamshire) delved passionately into jewellery history from Elizabeth I of England through Elizabeth Taylor, based on his 48 years of experience in the antique jewellery business. He illustrated his talk with numerous humorous anecdotes.

Menahem Sevdermish and **Guy Borenstein** (Gemewizard, Ramat Gan, Israel) discussed how, during the past decade, Gemewizard has devised a digitised, fully automated big-data analysis system geared towards large-scale gem and jewellery online platforms, based on image colour analysis and a contextual search engine. Both lecturers had the opportunity to examine the validity of the system from vast amounts of data that were obtained from a worldwide leading online retail marketplace and from major websites. The information gathered from these surveys, together with volumes of documented data collected from traders, have provided important insights on the perceptions of traders and laboratory personnel regarding commercial gem names such as 'pigeon blood', 'royal blue' and 'cornflower blue'. They concluded that the perception of the colours represented by each of these commercial names may differ according to geographical location and also between various leading gemmological laboratories.

Ya'akov Almor (Negev Heights, Israel) has been active in the diamond and coloured stone industry since the late 1980s. He offered his vision of how the diamond industry is facing some important challenges.

George Hamel (Schoonhoven) delved into the history of a sapphire diadem. During the coronation of King Willem-Alexander of the Netherlands in 2013, his wife Máxima wore the beautiful sapphire diadem from the crown jewels of the Oranges, a Christmas present from King Willem III to his second wife, Emma, in 1881. The diadem was previously attributed to Oscar Massin, working for Mellerio in Paris, with sapphires originating from the legacy of Willem III's mother, Anna Paulowna. Further research, however, has provided evidence that the jewel was made in Amsterdam, the Netherlands, by Maison Van der Stichel with diamonds and sapphires supplied by broker Vita Israëls.

Dr Lore Kiefert (Gübelin Gem Lab, Lucerne, Switzerland) gave an extensive update on the treatment of rubies and sapphires, from the traditional heating process to the more recent high-pressure method used to enhance sapphires and the low-temperature treatment of rubies. She focused on the development and detectability of these treatments, including what to look out for and how to interpret inclusion features and spectra.

Tom Stephan (German Gemmological Association, Idar-Oberstein, Germany) gave an overview of recent heat-treatment experiments on gem corundum at the German Gemmological Association. He heated rubies and sapphires at various temperatures and documented the changes in colour, inclusion features, spectroscopic characteristics and fluorescence with increasing temperature. The experiments were successful at intensifying yellow and removing blue colouration between 600 and 1,200°C, while at higher temperatures it was possible to intensify blue colour again. With photomicrographs

Figure 3: New FEEG diploma holders gather with (in the left foreground) CIBJO Coral Commission president Enzo Liverino (tan jacket), FEEG president Guy Lalous (wearing glasses) and Dr Ilaria Adamo (next to handrail). Photo courtesy of Rob Glastra.

before and after treatment, he demonstrated how mineral and fluid inclusions were affected at various temperatures and illustrated changes in Raman, FTIR and UV-Vis-NIR absorption spectra of the samples.

On 26–27 January several workshops were held: coloured stone grading and pricing (by **Richard Drucker** of Gemworld International Inc., Glenview, Illinois, USA); coloured stone grading and coloured diamond grading (by **Menahem Sevdermish** and **Guy Borenstein**); appraising gemstone jewellery (by **Wouter Abbestee**, jewellery and silverware valuer, The Haag, The Netherlands); diamond grading (by **George Hamel**); pearl stringing (by **Monique Konst-Kurstjens** of Zadkine Vakschool Schoonhoven); visual optics (by **Alan Hodgkinson**, Whinhurst, West Kilbride, Scotland); silver jewellery making (by **Femke Toele** of Zadkine Vakschool Schoonhoven); designing and shaping your own gemstone ring (by **Ornella Schavemaker-Piva** of Lapidarists Club, The Haag); hands-on identification of red, white and blue gemstones and diamonds (by **Leone Langeslag**, Sole Leone, Amsterdam); and precious coral (by **Rui Galopim de Carvalho**).

The evening of 26 January marked the FEEG diploma ceremony (Figure 3), which celebrated 78 new graduates. The ceremony was opened by **this author** and **Dr Ilaria Adamo** (Italian Gemmological Institute, Milan, Italy). The graduation address was given by **Richard Drucker**, who spoke about following one's passion and participating in a business full of interesting people. Meeting acquaintances at gemmological conferences and other events often results in lifelong friendships.

The next FEEG symposium will be held in Paris, France, in January 2021 and will celebrate the 25th Anniversary of FEEG.

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AGA TUCSON CONFERENCE

The 2020 Accredited Gemologists Association (AGA) Conference in Tucson, Arizona, USA, took place 5 February and was attended by 144 people from more than 10 countries. The event was moderated by outgoing AGA president **Stuart Robertson** (Gemworld International Inc., Glenview, Illinois, USA) and featured six presentations covering the theme 'Awareness of Our Gem Environment and People—Challenges in Technology and Culture'. The day closed with the AGA Gala and presentation of the 2020 Antonio C. Bonanno Award for Excellence in Gemology to **Robert Weldon** (Figure 4).

The conference was opened by **Stuart Robertson**,

who welcomed the new AGA board and incoming AGA president **Teri Brossmer** (Gem Appraisals Unlimited LLC, Glendora, California, USA). Then AGA Diamond Sponsor **Art Samuels** (EstateBuyers.com, Miami, Florida, USA) gave some further remarks.

The first conference speaker was **Richard Hughes** (Lotus Gemology, Bangkok, Thailand), who described his research on jade through trips to Myanmar, New Zealand, Guatemala, Russia and China, where most recently (in 2019) he visited the Xinyuan nephrite deposits near the Korean border and mining areas for 'Dushan jade' in Henan Province. He then focused on the mining, trading and treatments of nephrite in China, before highlighting contemporary jade carving by Chinese artists. There are now more than 100 'master' carvers in China who are using their talents and modern tools to pursue a variety of carving styles, including those that use negative space, reproduce the appearance of bronze statues or create delicate 'eggshell' carvings of just 1 mm in thickness.

Dr Jeffrey Post (Smithsonian Institution, Washington DC, USA) described his studies on environmental mineralogy, which deals with interactions between the solid earth and the environment in which we live (e.g. pertaining to soils and coatings on rocks), and showed that geology and biology are not necessarily entirely separate disciplines but may be interdependent. He then described some recent acquisitions for the Smithsonian Institution's National Gem Collection, including the 55.08 ct Kimberley diamond (see Gem Note on pp. 14–15 of this issue); the 48.86 ct 'Whitney Flame' red Imperial topaz; a 1,401 ct aquamarine from Brazil; a 568 ct black opal called 'The Eternal Flame', from the Tintenbar volcanic opal field in Australia; a 68 kg lapis lazuli carving called the 'Blue Flame'; two spodumene gemstones from Afghanistan weighing 396 and 127 ct; and many more.

Eric Fritz (University of Arizona Gem and Mineral Museum, Tucson) reviewed biogenic gem materials, including their identification and trade restrictions. He focused on coral and ivory, and had many examples from his collection available for hands-on viewing after his presentation. He covered the identifying features of the different types of precious coral and also highlighted the characteristics of dyed material. Regarding ivory, he showed how it is relatively straightforward to separate elephant from mammoth tusks when they are whole, but distinguishing between smaller pieces of these materials (as encountered in jewellery or as carvings) can be quite challenging when considering the orientation of Schreger lines: Their angles may vary (and potentially overlap) from the outer to inner portions of the tusks.

Dr Laurent E. Cartier (Swiss Gemmological Institute SSEF, Basel, Switzerland) examined the traceability of gemstones and pearls. He covered both the challenges (e.g. 'conflict' minerals) and opportunities

Figure 4: Antoinette Matlins, Karen Bonanno DeHaas and Kathryn Bonanno (from left to right) present the 2020 Antonio C. Bonanno Award for Excellence in Gemology to Robert Weldon. Photo by B. M. Laurs.

Figure 5: Previous Bonanno Award winners who were present at this year's AGA Gala include (from left to right) Stuart Robertson, Thom Underwood, Donna Hawrelko, Dr Thomas Hainschwang, Shane McClure, Richard Drucker, Al Gilbertson, Robert Weldon (2020 awardee), Dr Jim Shigley, Dr Çiğdem Lüle, Dr W. William Hanneman, Mikko Åström, John Koivula, Alberto Scarani, Richard Hughes and Dr John Emmett (with Antoinette Matlins). Photo by B. M. Laurs.

(e.g. sustainability initiatives) regarding traceability, and reviewed new technological advances such as DNA fingerprinting as applied to coral, ivory and pearls. He then treated the audience to a screening of a new documentary film (which he initially showed at the November 2019 Gem-A Conference) that he produced on artisanal miners who dive for diamonds in the Sewa River of Sierra Leone.

Dr Aaron Palke (GIA, Carlsbad, California) covered treatments of spinel and garnet, which are typically assumed to be untreated. He described experiments aimed at addressing recent claims in the trade that pink-to-red spinel from Mahenge, Tanzania, can be heated to shift the colour from orangey red to more red and also potentially improve transparency. So far, Palke has been unable to reproduce these effects in his experiments. Moreover, photoluminescence (PL) spectroscopy indicates that very few of the stones in the trade are heated (i.e. show broader PL lines). Palke was able to slightly improve the colour of demantoid from Russia's Karkodin (or Karkodino) mine by removing some brown component to make the colour appear slightly brighter and greener, by heating under reducing conditions to around 700°C for 16 hours. However, heat treatment cannot remove the brown colouration from Namibian or Malagasy demantoid.

Robert Weldon (GIA, Carlsbad) described an ongoing project to help educate artisanal miners in East Africa (particularly Tanzania) about sorting and evaluating the rough stones they recover according to important value factors (e.g. size, shape, transparency and colour). Through the use of a well-illustrated booklet that is written in Swahili and English, and a translucent tray for viewing the stones, the programme empowers miners with knowledge and abilities that allow them to bargain more effectively with their buyers and realise greater financial gain for their families and communities. The project has also brought Western buyers directly to the miners while also including local brokers in the supply chain.

The AGA Conference also featured two hands-on workshops, by **Samantha Lloyd** (Gem-A, London) on using filters and **Claire Scragg** (JTV, Knoxville, Tennessee, USA) on using the spectroscope.

The AGA Gala took place that evening and was attended by 167 people. **Stuart Robertson** opened the ceremony for the 2020 Antonio C. Bonanno Award for Excellence in Gemology, and **this author** introduced honouree **Robert Weldon**, who was then presented with the award by Bonanno's daughters **Antoinette Matlins**, **Karen Bonanno DeHaas** and **Kathryn Bonanno** (again, see Figure 4). This was followed by a presentation by Weldon on his early development as a gem aficionado and journalist, as well as a gathering of all the previous Bonanno Award winners who were present at this year's gala (Figure 5).

Brendan M. Laurs FGA

Gem-A Notices

Gifts to the Association

Gem-A is most grateful to the following for their generous donations that will support continued research and teaching:

Avant Chordia, Chordia Inc., India, for 42.87 g of Aquaprase (chalcedony) specimens.

Ian Kalway, Thailand, for specimens of cobalt-blue spinel from Vietnam, including 0.53 g of crystals and a 0.05 ct faceted stone.

Mineração Costa Marques, Brazil, for several pieces of heated and unheated amethyst from the Costa Marques mine, Amazonas State, Brazil.

Leonardo Silva Souto, Gems in Gems, Brazil, for two polished pieces of amazonite in quartz from Bahia, Brazil, and for three polished samples of Aquafire (aquamarine with inclusions) from Minas Gerais, Brazil.

Martin Steinbach, Steinbach – Gems with a Star, Germany, for a sample of hauyne in matrix from Germany and for several pieces of rough ruby from Bo Rai, Thailand.

Indra Man Sunuwar, Nepali Bazaar Co. Ltd, Japan, for three demantoid crystal slices from Iran.

Steve Ulatowski, New Era Gems, USA, for four pieces of heat-treated beryl from Brazil.

Abdiaziz Mohamed Yousuf, Ethiopia, for a parcel of rough and cut hessonite from Somaliland.

Donation from European Art & Antiques

Gem-A is delighted to report that Gem-A USA has received a donation of almost 7,000 gemstones from Robert Sadian of New York-based European Art & Antiques. The extensive collection of gems, which includes more than 30 species and 50 gem varieties ranging from less than 1 ct to more than 100 ct, will be used to educate Gem-A USA students taking the Gemmology Foundation and Gemmology Diploma courses. The collection will also be made available to assist gemmological research being carried out by current FGAs.

Commenting on the recent donation, Gem-A CEO Alan Hart FGA stated: 'All at Gem-A would like to express the greatest thanks to European Art & Antiques and to owner Robert Sadian for this extremely kind gift, which marks the beginning of a very bright future for the work of Gem-A USA.' Read the full press release here: https://gem-a.com/news-publications/gem-a-press-releases.

A selection of garnet specimens from Gem-A USA's new gem collection donated by Robert Sadian of European Art & Antiques.

Scottish Gemmological Association (SGA) Conference 2020

Gem-A will be returning to the Scottish Gemmological Association's annual conference on 1–4 May 2020. This year, two Gem-A Tutors will be hosting workshops during the Sunday session. From 13:30 to 15:00, Sam Lloyd FGA DGA EG will host 'Fun with Filters', a hands-on workshop that will guide participants through some of Gem-A's favourite filters and how to use them. Directly after, from 15:30 to 17:00, Lily Faber FGA DGA EG will present 'Seeing Colour: Succeed with the Spectroscope', an entry-level workshop that will teach the basic principles of colour and selective absorption, and enable participants to get to grips with different types of portable spectroscopes.

Gem-A Instruments will also be selling gemmological tools; Gem-A Members and Students will receive 10% off instruments and 5% off books as per their usual benefits. For more information and to book tickets, visit: https://scottishgemmology.org/registration-and-student-sponsorship.

Obituary

Anthony de Goutière

23 November 1927–25 December 2019

Gem-A regrets the passing of Anthony de Goutière on 25 December 2019. He was an esteemed gemmologist, photographer and long-standing Gem-A Member who contributed to many issues of *The Journal of Gemmology* and *Gems&Jewellery* over a period of 25 years. A full obituary appears in the Spring 2020 issue of *Gems&Jewellery*, available on the Gem-A website to Members and Students: https://gem-a.com/news-publications/gems-jewellery.

Learning Opportunities

CONFERENCES AND SEMINARS

Jewelry Industry Summit
27 March 2020
Los Angeles, California, USA
www.jewelryindustrysummit.com/la-summit

Association for the Study of Jewelry and Related Arts' 15th Annual Conference
4 April 2020
New York, New York, USA
www.jewelryconference.com

10th National Opal Symposium
8–9 April 2020
Coober Pedy, Australia
www.opalsymposium.org

47th Rochester Mineralogical Symposium
23–26 April 2020
Rochester, New York, USA
www.rasny.org/minsymp

American Gem Society Conclave
27–29 April 2020
Denver, Colorado, USA
www.americangemsociety.org/mpage/conclave2020-home

Scottish Gemmological Association Conference
1–4 May 2020
Cumbernauld, Scotland
www.scottishgemmology.org/programme
Note: An excursion on 4 May will include a visit to the National Museums of Scotland Collection Centre.

6th Mediterranean Gemmological & Jewellery Conference
15–17 May 2020
Thessaloniki, Greece
https://gemconference.com

17th Annual Sinkankas Symposium—Agate & Chalcedony
16 May 2020
Carlsbad, California, USA
https://sinkankassymposium.net

34th Annual Santa Fe Symposium
17–20 May 2020
Albuquerque, New Mexico, USA
www.santafesymposium.org

49th Annual Society of North American Goldsmiths Conference
20–23 May 2020
Philadelphia, Pennsylvania, USA
www.snagmetalsmith.org/conferences/grit-to-gold-future-fifty-2020-snag-conference

Gemmological Association of Australia 74th Federal Conference
21–24 May 2020
Perth, Western Australia
www.gem.org.au/news_events

JCK Las Vegas
2–5 June 2020
Las Vegas, Nevada, USA
https://lasvegas.jckonline.com
Note: Includes a seminar programme

Swiss Gemmological Society Conference
7–9 June 2020
St Gallen, Switzerland
http://gemmologie.ch/en/current

19th Rendez-Vous Gemmologiques de Paris
8 June 2020
Paris, France
www.afgems-paris.com/rdv-gemmologique

Diamonds – Source to Use 2020
9–11 June 2020
Johannesburg, South Africa
www.saimm.co.za/saimm-events/upcoming-events/diamonds-source-to-use-2020

NAJ Summit
20–22 June 2020
Northamptonshire, East Midlands
www.naj.co.uk/summit
Note: Includes the IRV Valuers' Conference (20–22 June) and the JBN Retail Jewellers' Congress (22 June)

Sainte-Marie-aux-Mines Mineral & Gem Show
25–28 June 2020
Sainte-Marie-aux-Mines, France
www.sainte-marie-mineral.com
Note: Includes a seminar programme

9th International Conference Mineralogy and Museums
5–7 July 2020
Sofia, Bulgaria
www.bgminsoc.bg
Note: Gem minerals and archaeogemmology are among the topics that will be covered.

Dallas Mineral Collecting Symposium
20–23 August 2020
Dallas, Texas, USA
www.dallassymposium.org

Amberif 2020: 27th International Fair of Amber & Jewellery
26–29 August 2020
Gdańsk, Poland
http://amberif.amberexpo.pl
Note: Includes a seminar programme

3rd European Mineralogical Conference (emc2020)
6–10 September 2020
Krakow, Poland
https://emc2020.ptmin.eu
Session of interest: The Geology of Gem Deposits: A Session in Honour of Gaston Giuliani

International Jewellery London
13–15 September 2020
London
www.jewellerylondon.com
Note: Includes a seminar programme

31st International Conference on Diamond and Carbon Materials
13–17 September 2020
Palma, Mallorca, Spain
www.elsevier.com/events/conferences/international-conference-on-diamond-and-carbon-materials

Jewellery & Gem World Hong Kong
13–19 September 2020
https://exhibitions.jewellerynet.com/9jg/en-us/specialevents/specialevent
Note: Includes seminar programmes

Denver Gem & Mineral Show
18–20 September 2020
Denver, Colorado, USA
www.denvermineralshow.com
Note: Includes a seminar programme

13th Annual Portland Jewelry Symposium
27–28 September 2020
Portland, Oregon, USA
https://portlandjewelrysymposium.com

2020 American Society of Appraisers (ASA) International Conference
11–13 October 2020
Chicago, Illinois, USA
www.appraisers.org/Education/conferences/asa-international-conference

Japan Jewellery Fair 2020
14–16 October 2020
Tokyo, Japan
www.japanjewelleryfair.com/en
Note: Includes a seminar programme

Canadian Gemmological Association (CGA) Conference
16–18 October 2020
Vancouver, British Columbia, Canada
https://canadiangemmological.com/vancouver

Chicago Responsible Jewelry Conference
22–24 October 2020
Chicago, Illinois, USA
www.chiresponsiblejewelryconference.com

Munich Show: Mineralientage München
30 October–1 November 2020
Munich, Germany
https://munichshow.de/?lang=en
Note: Includes a seminar programme

OTHER EDUCATIONAL OPPORTUNITIES

Gem-A Workshops and Courses
Gem-A, London
https://gem-a.com/education

Lectures with Gem-A's Midlands Branch
Fellows Auctioneers, Augusta House, Birmingham
Email Louise Ludlam-Snook at
gemamidlands@gmail.com

- Peter Buckie—The Treasures Seen by an Expert Valuer
  27 March 20209
- Roy Starkey—Minerals of the English Midlands
  24 April 2020

Lectures with The Society of Jewellery Historians
Society of Antiquaries of London,
Burlington House, London
www.societyofjewelleryhistorians.ac.uk/current_lectures

- Carol Michaelson—Chinese Jade Jewellery and Ornaments from the Neolithic to the Present
  24 March 2020
- Ute Decker—TBA
  26 May 2020
- Kirstin Kennedy—TBA
  23 June 2020
- Prof. Gordon M. Walkden—The Rocks of Britain: Our Victorian Jewellery
  22 September 2020
- TBA—New Research
  27 October 2020
- Charlotte Gere—Colour in Victorian Jewellery
  24 November 2020

Gem-A East Africa Field Trip 2020
19–25 July 2020
https://gem-a.com/east-africa-field-trip-2020

mindat.org Euro Bus Tour 2020
28 June–6 July 2020
www.mindat.org/a/bustour

New Media

The Calligraphy Collection: Nicolai Medvedev, Intarsia Master Artist

By Elise Misiorowski, 2019. Kudos Publications, Newport Beach, California, USA, 34 pages, illus., ISBN 978-0464207122. USD280.00 hardcover.

The Calligraphy Collection is a short, 34-page volume that shows the genius of Nicolai Medvedev as a master intarsia artist. The 'Calligraphy Collection' is made up of eight gem boxes that took Medvedev nine years to complete. This collection represents a body of work that combines beauty and technical excellence.

This book is beautifully written by Elise Misiorowski in consultation with Mona Lee Nesseth. The text is clear and concise, and takes away nothing from the excellent photography of these eight glorious *objets d'art*. The book is illustrated by legendary photographers Erica and Harold Van Pelt, as well as James R. Thomas. The images beautifully document what it takes to be a master intarsia artist and fabricate by hand these wonderful works of art.

Misiorowski documents Medvedev's history from his birth in Ashgabat, Turkmenistan, through his studies at an art institute in Moscow, to his emigration in 1980 to the United States. Since then he has honed his talent, assembling gem materials into intricate and elegant designs on the surfaces of objects (commonly boxes).

Medvedev's gem intarsia has been exhibited in museums and galleries throughout the USA and collected by gem connoisseurs worldwide. Museums that own or have displayed his work include the Smithsonian Institution (Washington DC, USA), the Natural History Museum of Los Angeles County (California, USA), the Colorado School of Mines (Golden, Colorado, USA) and the Gemological Institute of America (Carlsbad, California), among many others.

The works of art in the 'Calligraphy Collection' feature the use of 14 different gem materials—including lapis lazuli, gold in quartz, turquoise, malachite, azurite, sugilite, maw-sit-sit and Australian opal—plus exotic woods. Each box has a name that describes the artist's intention: 'Scene and Unseen' (1996), 'Celebration Suite' (1997; two pieces), 'The Beginning' (1998), 'The Companion' (1998), 'Light of the World' (2000), 'Hope' (2003) and 'Unity' (2004). The top of each box features gem-intarsia Arabic letters in stylised calligraphy, the design of which complements the motif of each box and gives the collection its name.

Anyone who loves beauty and appreciates artists who work with gems should consider adding this limited-edition book to their library.

Bill Larson FGA
Pala International
Fallbrook, California, USA

Marchands de Perles: Redécouverte d'une Saga Commerciale entre le Golfe et la France à l'Aube du XXe Siècle/ Pearl Merchants: A Rediscovered Saga Between the Gulf & France at the Dawn of the 20th Century

By Guillaume Glorieux and Olivier Segura, 2019. L'École des Arts Joailliers/School of Jewelry Arts, Paris, France, and French Institute of the United Arab Emirates, Dubai, 224 pages, illus., no ISBN (in French, English and Arabic). EUR20.00 softcover.

This book is an excellent study of the commerce between the Persian (or Arabian) Gulf and French merchants. It was produced to accompany an exhibition that took place 28 March–13 April 2019 and was held during the second year of the 2018–2019 French-Emirati Cultural Dialogue in the Dubai Design District. The exhibition was organised

by the School of Jewelry Arts in partnership with the French Institute of the United Arab Emirates.

The book covers an era when Paris became the major player for pearl dealers, and is presented in three sections encompassing different languages. The first, in French, is the most detailed, with 93 pages of text and photographs. The second is a 42-page summary in English of the first section, without photographs. The third is similar to the first, in Arabic and with illustrations. The exhibition presented a chronological, thematic journey from the end of the 19th century to the present. The six chapters follow this design and, as translated in the English section, are:

1. Pearls of the Orient and the Luster of Pearls
2. After 1900, the Age of the Pioneers
3. The 1910s: The Explosion
4. PARIS, the Pearl Capital
5. The Dark Decade (1929–1939)
6. Between Resistance and Rebirth, the Pearl Trade of Yesterday and Today

At the end of the French section is a two-page colour map showing the Gulf region, followed by a chronological bibliography of sources and monographs.

Throughout the six chapters are many wonderful historical photographs, maps and jewellery renderings, in black and white and in colour. Often there is more than one photo or illustration/map on each page. The

photographs tell the story nicely without needing English captions. The jewellery renderings show superb classics and are in colour.

I would recommend this book to anyone with even a passing interest in natural pearls. The authors' enthusiasm for these gems is well conveyed in the 'New Actors' paragraph of the final chapter of the book: 'Certain connoisseurs are always ready to spend considerable amounts to buy themselves a part of the great history of pearls, and of humanity; a fragment of dreams and passion; a small piece of emotion…these tears from heaven wept for the pleasure of mortals.'

Bill Larson FGA

Other Book Titles

COLOURED STONES

Rhodochrosit
By various authors, 2019. extraLapis No. 56, Christian Weise Verlag GmbH, Munich, Germany, 126 pages (in German). EUR19.80 softcover.

CULTURAL HERITAGE

The Contribution of Mineralogy to Cultural Heritage
Ed. by G. Artioli and R. Oberti, 2019. EMU Notes on Mineralogy Vol. 20, European Mineralogical Union and the Mineralogical Society of Great Britain & Ireland, xii + 448 pages, ISBN 978-0903056618, https://doi.org/10.1180/emu-notes.20. GBP40.00 (individuals) or GBP55.00 (institutions) softcover, or free chapter PDFs at www.minersoc.org/emu-notes-20.html.

Enigma dei Vasi Murrini/Enigma of Murrhine Ware
By Enrico Butini, 2019. Bibliotheca Archaeologica Vol. 59, «L'Erma» di Bretschneider, Rome, Italy, 144 pages, ISBN 978-8891318206 (in Italian and English). EUR90.00 softcover.

La Parure en Callaïs du Néolithique Européen [The European Neolithic Callaïs Ornaments]
Ed. by Guirec Querré, Serge Cassen and Emmanuelle Vigier, 2019. Archaeopress Publishing Ltd, Summertown, Oxford, 642 pages, ISBN 978-1789692808 (print) or ISBN 978-1789692815 (PDF) [papers in English and French]. GBP130.00 hardcover or free PDF at www.archaeopress.com/ArchaeopressShop/Public/download.asp?id={9306B133-D594-43FC-9D57-2076B7DAEC97}.

DIAMOND

Diamonds, 4th edn.
By Fred Ward and Charlotte Ward, 2019. Gem Book Publishers, Malibu, California, USA, 64 pages, ISBN 978-1887651189. USD19.95 softcover.

GEM AND MINERAL LOCALITIES

Cornwall
By various authors, 2019. extraLapis No. 57, Christian Weise Verlag GmbH, Munich, Germany, 132 pages (in German). EUR19.80 softcover.

Fluorite: Trésors de France – French Treasures
By Christophe Lucas, 2019. Les Éditions du Piat, Saint-Julien-du-Pinet, France, 232 pages, ISBN 978-2917198438 (in French and English). EUR40.00 hardcover.

Karakorum: Inferno di Rocce, Paradiso di Gemme e Cristalli [Karakorum (Pakistan): Hell of Rocks, Paradise of Gems and Crystals]
By Giuseppe Agozzino, 2020. LoGisma, Florence, Italy, 208 pages (in Italian). EUR40.00 hardcover.

Minerals and Gemstones of East Africa
By Bruce Cairncross, 2019. Penguin Random House South Africa/Struik Nature, Cape Town, South Africa, 160 pages, ISBN 978-1775845560 (print) or ISBN 978-1775846987 (ePub). ZAR250.00 softcover or USD7.99 Kindle edn.

Mont Saint-Hilaire: History, Geology, Mineralogy
By László Horváth, Robert A. Gault, Elsa Pfenninger-Horváth and Glenn Poirier, 2019. Canadian Mineralogist Special Publication 14, Mineralogical Association of Canada, Ottawa, Ontario, 372 pages, ISBN 978-0921294610. USD125.00 hardcover.

Spinel from Pamir—Kuh-i-Lal, Pamir, Badakhshan, Tajikistan
By Vladyslav Y. Yavorskyy, 2019. Yavorskyy Co. Ltd, Hong Kong, 236 pages, ISBN 978-1733486002. USD180.00 hardcover.

JEWELLERY HISTORY

A Arte de Coleccionar—Lisboa, a Europa e o Mundo na Época Moderna (1500-1800)/The Art of Collecting—Lisbon, Europe and the Early Modern World (1500-1800)
Ed. by Hugo Miguel Crespo, 2019. Pedro Aguiar-Branco, Lisbon, Portugal, 363 pages, ISBN 978-9899618053 (in Portuguese and English). Free PDF at www.pab.pt/_usr/downloads/Catalogo_Arpab_2019.pdf.

A History of the Tudors in 100 Objects
By John Matusiak, 2019. The History Press, Cheltenham, Gloucestershire, 352 pages, ISBN 978-0750991254. GBP14.99 softcover.

JEWELLERY AND *OBJETS D'ART*

The American Gem Art Collection of EF Watermelon Catalog
Ed. by Günther Neumeier, 2018. EF Watermelon, Old Lyme, Connecticut, USA, 76 pages, ISBN 978-0692058459. USD52.00 softcover.

The Collection of EF Watermelon—Masterworks of the American Gem Art Movement
Ed. by Günther Neumeier, 2018. EF Watermelon, Old Lyme, Connecticut, USA, 104 pages, ISBN 978-0692058442. USD52.00 hardcover.

Diamond Ring Buying Guide, 8th edn.
By Renee Newman, 2020. International Jewelry Publications, Los Angeles, California, USA, 168 pages, ISBN 978-0929975542. USD19.95 softcover.

A Vanity Affair: The Art of Necessaires
Ed. by Lyne Kaddoura, 2019. Rizzoli, New York, New York, USA, 320 pages, ISBN 978-8891817945. USD150.00 hardcover.

SOCIAL STUDIES

Botswana – A Modern Economic History: An African Diamond in the Rough
By Ellen Hillbom and Jutta Bolt, 2018. Palgrave Studies in Economic History, Palgrave Macmillan/Springer Nature, Cham, Switzerland, 235 pages, ISBN 978-3319731438 (hardcover), ISBN 978-3030103231 (softcover) or ISBN 978-3319731445 (eBook), https://doi.org/10.1007/978-3-319-73144-5. EUR119.59 hardcover, EUR119.59 softcover or EUR96.29 eBook.

SYNTHETICS AND SIMULANTS

The History of Synthetic Ruby
By James Evans, 2020. Lustre Gemmology Ltd, Sheffield, South Yorkshire, 60 pages, ISBN 978-1916165205. GBP18.00 softcover.

Literature of Interest

COLOURED STONES

American gems: New sources of inspiration for the European market. E. Thoreux, *InColor*, No. 45, 2020, 72–76, www.gemstone.org/incolor/45.*

Australian faceted fluorite specimen from the Natural History Museum, London. R.F. Hansen and L.J. Rennie, *Australian Gemmologist*, **27**(1), 2019, 12–17.

Bixbite [red beryl]: The rarest common gem in the world. M. Macrì, *Rivista Italiana di Gemmologia/ Italian Gemological Review*, No. 7, 2019, 47–55.

Blue gahnospinel crystals from Nigeria. J.-M. Arlabosse, *Gemmology Today*, December 2019, 5–8, www.worldgemfoundation.com/GTDEC2019DV.*

Characterization of amethysts from Sukamara, central Kalimantan, using laser-induced breakdown spectroscopy (LIBS). K.G. Suastika, H. Suyanto, Gunarjo, Sadiana and Darmaji, *Journal of the Physical Society of Indonesia*, **1**(1), 2019, 9–12, http://journal.fisika.or.id/jpsi/article/view/8/45.*

Color and local heritage in gemstone branding: A comparative study of blue zoisite (tanzanite) and color-change diaspore (Zultanite/Csarite). M. Altingoz, N.M. Smith, H.S. Duzgun, P.F. Syvrud and S.H. Ali, *Extractive Industries and Society*, **6**(4), 2019, 1030–1039, http://doi.org/10.1016/j.exis.2019.05.013.

Color varieties of gems – Where to set the boundary? M.S. Krzemnicki, L.E. Cartier, P. Lefèvre and W. Zhou, *InColor*, No. 45, 2020, 100–103, www.gemstone.org/incolor/45.*

Determination of demantoid garnet origin by chemical fingerprinting. C. Schwarzinger, *Monatshefte für Chemie - Chemical Monthly*, **150**(5), 2019, 907–912, https://doi.org/10.1007/s00706-019-02409-3.*

Fanciful fabulous fire agate. P. Rothengatter, *InColor*, No. 45, 2020, 70–71, www.gemstone.org/incolor/45.*

Fingerprinting Paranesti [Greece] rubies through oxygen isotopes. K. Wang, I. Graham, L. Martin, P. Voudouris, G. Giuliani, A. Lay, S. Harris and A. Fallick, *Minerals*, **9**(2), 2019, article 91 (14 pp.), http://doi.org/10.3390/min9020091.*

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Gemmological characteristic and chemical composition of ruby from Guinea, Africa. J. Feng and M. Chen, *Journal of Gems & Gemmology*, **21**(3), 2019, 26–36 (in Chinese with English abstract).

Gemmological characteristic of grandidierite from Madagascar. N. Sun, G. Li, X. Li and B. Zhang, *Journal of Gems & Gemmology*, **21**(3), 2019, 37–41 (in Chinese with English abstract).

Gemological and spectral characteristic of sapphire from Australia. Y. Xu, J. Di and F. Fang, *Journal of Gems & Gemmology*, **21**(2), 2019, 24–33 (in Chinese with English abstract).

Gemstones of the garnet group – About mixed crystals and solid solution. H.A. Hänni, *Journal of the Gemmological Association of Hong Kong*, **40**, 2019, 36–42, www.gahk.org/journal/GAHK_Journal_2019_v6.pdf.*

Geographic origin determination of alexandrite. Z. Sun, A.C. Palke, J. Muyal, D. DeGhionno and S.F. McClure, *Gems & Gemology*, **55**(4), 2019, 660–681, http://doi.org/10.5741/GEMS.55.4.660.*

Geographic origin determination of blue sapphire. A.C. Palke, S. Saeseaw, N.D. Renfro, Z. Sun and S.F. McClure, *Gems & Gemology*, **55**(4), 2019, 536–579, http://doi.org/10.5741/GEMS.55.4.536.*

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The geographic origin dilemma. S.F. McClure, T.M. Moses and J.E. Shigley, *Gems & Gemology*, **55**(4), 2019, 457–462, www.gia.edu/gems-gemology/winter-2019-geographic-origin-dilemma.*

Geology of corundum and emerald gem deposits: A review. G. Giuliani and L.A. Groat, *Gems & Gemology*, **55**(4), 2019, 464–489, http://doi.org/10.5741/GEMS.55.4.464.*

Masters of green: Chromium and vanadium. K. Feral, *Gemmology Today*, March 2019, 28–32, www.worldgemfoundation.com/GTMARCH2019DV.*

Masters of green: Chromium and vanadium (part 2). K. Feral, *Gemmology Today*, June 2019, 38–45, www.worldgemfoundation.com/GTJUNE2019DV.*

Mineral inclusions in ruby and sapphire from the Bo Welu gem deposit in Chanthaburi, Thailand. S. Promwongnan and C. Sutthirat, *Gems & Gemology*, **55**(3), 2019, 354–369, http://doi.org/10.5741/GEMS.55.3.354.*

Myanmar's fei cui raw materials market. R. Wang, *Journal of the Gemmological Association of Hong Kong*, **40**, 2019, 98–103, www.gahk.org/journal/GAHK_Journal_2019_v6.pdf.*

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Pastel pyrope: A new gem variety? K. Feral, *Gemmology Today*, December 2019, 38–42, www.worldgemfoundation.com/GTDEC2019DV.*

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The power of cobalt [spinel]. G. Dominy, *Gemmology Today*, June 2019, 34–37, www.worldgemfoundation.com/GTJUNE2019DV.*

Red beryl – A very rare and highly prized gem beryl. J. Holfert and J. Fuller, *InColor*, No. 45, 2020, 62–64, www.gemstone.org/incolor/45.*

Spinel inclusions: An exercise in aesthetics. E.B Hughes, J.I. Koivula, N. Renfro, W. Manorotkul and R.W. Hughes, *InColor*, No. 43, 2019, 66–73, www.gemstone.org/incolor/43.*

The story of Blue John. E.Z. Karlin, *Adornment*, **12**(1), 2019, 28–44.

Study on the infrared spectral characteristics of H_2O I-type emerald and the controlling factors. X. Qiao, Z. Zhou, P. Nong, M. Lai, Y. Li, K. Guo, Q. Zhong *et al.*, *Rock and Mineral Analysis*, **38**(2), 2019, 169–178 (in Chinese with English abstract).

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CULTURAL HERITAGE

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ERRATA

1. In the Gem-A Notices section of *The Journal* Vol 36, No. 8 (pp. 776–785), Li Shen should have been listed under 'Gemmology Diploma Passes with Distinction' rather than 'Gemmology Diploma Passes'. Gem-A's Education Department regrets this error.

2. In the Thank You, Guest Reviewers section of *The Journal* Vol 36, No. 8 (p. 800), the affiliation for Dr Le Thi Thu Huong should have been given as Staatliche Zeichenakademie Hanau, Germany, and the affiliation for Olivier Segura should have been listed as L'École des Arts Joailliers/School of Jewelry Arts, Paris, France.

3. In the report on diving for natural pearls off Bahrain in the Gem Notes section of *The Journal* Vol. 36, No. 8 (pp. 702–704), the incorrect illustration was used for Figure 35 (which showed a photo that was actually taken by Areeya Manustrong, © GIA, of a *P. maxima* mollusc). The correct illustration is shown here. The authors apologise for the error.

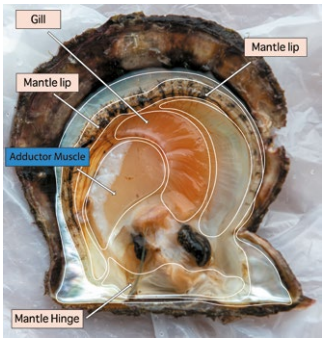

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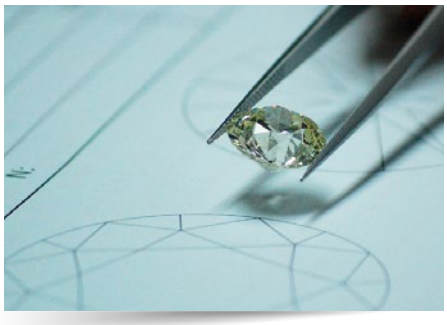

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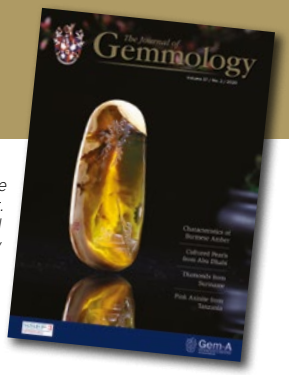

Cover photo: *An article on pp. 144–162 of this issue describes the characteristics of different varieties of amber from Myanmar. This Burmese amber carving, measuring 99 × 42 × 28 mm and weighing 66.6 g, was inspired by the poem 'A Night Mooring by Maple Bridge' written by Zhang Ji during the Tang Dynasty. The piece incorporates the natural amber textures to show an autumn scene outside Hanshan Temple, where a bridge is surrounded by maple trees. Photo courtesy of Tengchong Huo Ren Carving Studio.*

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The Editor-in-Chief is glad to consider original articles, news items, conference reports, announcements and calendar entries on subjects of gemmological interest for publication in *The Journal of Gemmology*. A guide to the various sections and the preparation of manuscripts is given at https://gem-a.com/membership/journal-of-gemmology/submissions, or contact the Editor-in-Chief.

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What's New

NEWS AND PUBLICATIONS

CIBJO Blue Books Freely Available

The Blue Books from CIBJO, The World Jewellery Confederation, are the most widely accepted set of global standards for the gem and jewellery industry. In response to the economic challenges created by the COVID-19 pandemic, in April 2020 CIBJO made all seven volumes freely available for download, even to non-members. They cover standards for diamonds, coloured stones, gemmological laboratories, pearls, precious metals, coral and responsible sourcing. Download the PDFs at www.cibjo.org/introduction-to-the-blue-books-2.

DIAMOND TERMINOLOGY GUIDELINE

Diamond Terminology Guidelines

In September 2019, the Diamond Producers Association, in conjunction with seven other leading diamond industry organisations, issued a brief reference guide on standard terminology to use when referring to natural and synthetic diamonds. The document also includes definitions and recommendations based on the internationally accepted standard ISO 18323 ('Jewellery – Consumer Confidence in the Diamond Industry') and CIBJO's Diamond Blue Book. Download the one-page PDF at https://diamondproducers.com/app/uploads/2019/09/Diamond-Terminology-Guideline-20190925.pdf.

GemGuide Articles Freely Available

Selected articles from Gemworld International's bimonthly *GemGuide* publication are now freely available at www.gemguide.com/category/web-feature-articles. They cover topics such as Ethiopian emerald, Greenland ruby, Old European-cut diamonds, and a series on coloured stone value factors, design and cut quality. Also freely available are *GemGuide*'s 'Gem Focus & Market Pulse' articles, which focus on specific gem materials, at www.gemguide.com/category/gem-market-pulse.

GIT Lab Reports on Blue Richterite and a Zultanite Imitation

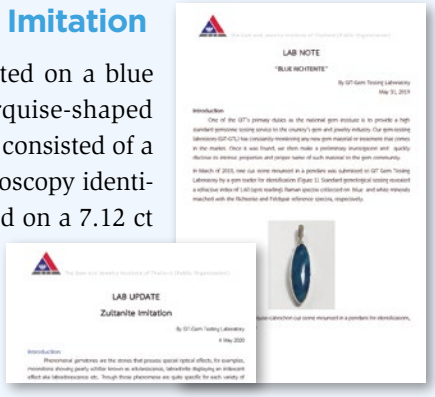
LAB NOTE
"BLUE RICHTERITE"
LAB UPDATE
Zultanite Imitation

In May 2019, the Gem and Jewelry Institute of Thailand (GIT) reported on a blue richterite submitted to their laboratory for identification. The marquise-shaped cabochon, which was bezel-set in a pendant, had a spot RI of 1.60 and consisted of a granular aggregate of blue and white mineral grains that Raman spectroscopy identified as richterite (blue) and feldspar (white). In May 2020, GIT reported on a 7.12 ct oval modified brilliant showing a colour change that was represented as Zultanite (diaspore). Gemmological, spectral and chemical characteristics clearly identified it as a manufactured glass. Download these and previous GIT lab reports at www.git.or.th/articles_technic_en.html.

Jewelry Development Impact Index Reports

Two more Jewelry Development Impact Index (JDI) studies have been published by researchers from the American University School of International Service, which are titled *A Comparative Case Study of Amethyst Mining in Brazil and Tanzanite Mining in Tanzania* (December 2019) and *A Comparative Case Study of Diamond Mining in Guinea, Sierra Leone, and Zimbabwe* (April 2020). The reports examine the historical and cultural background of mining these deposits, and then provide numerical scores on a variety of areas (governance, economy, environment, health and human rights) for the subject countries. Download these and other JDI publications at www.sustainablegemstones.org/jewelry-development-index-jdi.

Brendan M. Laurs

Platinum Jewellery Business Review 2020

Platinum Guild International's (PGI) annual *Platinum Jewellery Business Review* was released in May 2020. The report analyses retail sales of platinum jewellery, trade performance and consumer sentiment in order to provide an in-depth analysis of platinum jewellery's performance in 2019, as well as COVID-19's impact in PGI's four key international markets (China, India, Japan and the United States). The report focuses on three trends: digital consolidation, mid-market extinction and branded storytelling. To view a 45-minute video presentation or download the report, visit https://platinumguild.com/2020-platinum-jewellery-business-review.

Brendan M. Laurs

SSEF *Facette Magazine*

Issue 26 of the Swiss Gemmological Institute SSEF's annual *Facette Magazine* was released in February 2020. The 76-page issue is packed with short articles that cover boundaries for colour varieties of gems, age dating of coloured stones, SSEF's Gemtrack rough-to-cut documentation service, laser inscription of gems, DNA fingerprinting of pearls and corals, and identification of ivory species, as well as numerous others on topics such as spodumene, emerald, ruby, sapphire, garnet, vesuvianite, diamond, pearls, historical gems and *objets d'art*. The issue ends with news and announcements relating to SSEF, including the discovery of a fraudulent SSEF report. To download this and previous issues of *Facette*, visit www.ssef.ch/ssef-facette.

OTHER RESOURCES

Centurion Jewelry Show's Lectures in Tucson

The Centurion Jewelry Show in Tucson, Arizona, USA, hosted lectures at its Gem Education Day on 1 February 2020. Videos of six lectures are now available online. These cover markets for Colombian emerald and red beryl; rare and exotic gem materials; millennials and younger demographics; emeralds; ruby and sapphire; and East African gems. Visit www.youtube.com/channel/UC6lT-m_06z_0mObphTTX2uQ.

Minerals, Materials and Society Programme

The Minerals, Materials and Society programme at the University of Delaware (Newark, Delaware, USA) launched in January 2020 and focuses on sustainability and corporate social responsibility in mineral sourcing (https://sites.udel.edu/ceoe-mms). Videos on gem and jewellery topics, ranging from understanding coloured gemstones to women's participation in the jewellery supply chain in Madagascar, are hosted on the programme's YouTube channel at www.youtube.com/channel/UCJmN3DG0BVQErNI3HzRGqYA/videos.

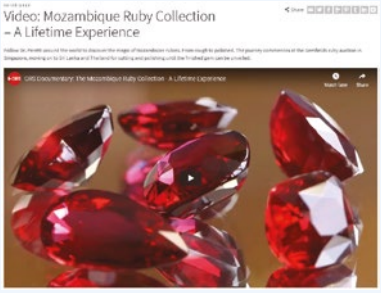

Mozambique Ruby Video

In May 2020, GemResearch Swisslab AG (Lucerne, Switzerland) released a documentary video on an exceptional suite of Mozambique rubies initially acquired as rough at a Gemfields ruby auction in Singapore. The video begins with an examination of the rough material by Dr Adolf Peretti, and then follows the rubies through the cutting process in Sri Lanka and Thailand. Each step, from the purchase of rough to the finished gems, is explained in detail. Visit http://gemresearch.ch/mozambique-ruby-collection.

Webinars and Other Videos for Online Gemmological Education

A number of educational institutions and gem industry organisations have provided webinars and other archived video content on their websites or YouTube channels, with many added since March 2020 due to the quarantines mandated by the COVID-19 pandemic.

- The **American Gem Trade Association** (Dallas, Texas, USA) has made its AGTA GemFair Tucson Seminar Series freely available for the years 2018, 2019 and 2020. The presentations cover gem identification, appraisals, marketing strategies, industry trends and much more. Visit https://agta.org/resources.
- The **Asian Institute of Gemological Sciences** (Bangkok, Thailand) has produced a series of 'AIGS Gem Tips' webinars presented by a diverse group of experts. Topics include the history of emeralds, rubies from Greenland, sapphires from Montana (USA), brown diamonds and gem luminescence. Visit www.aigsthailand.com/AIGS-News/4/master/en.

- The **Bahrain Institute for Pearls and Gemstones** (DANAT; Manama, Bahrain) has webinars on natural pearls of Bahrain, testing for natural vs. cultured pearls, diamonds (natural, synthetic and imitation) and how to buy a gemstone. Visit www.youtube.com/playlist?list=PLa8o6T7AzU1E1oTTBIMzhkpw0jn5Ev5n6.

- **Branko Gems** and **Gemmological Research Industries Inc.** (Vancouver, British Columbia, Canada) offers webinars by gemmologist Branko Deljanin focusing on gemmological instruments and the screening and identification of coloured stones and diamonds. The videos are available for a fee at www.brankogems.com/shop/product-category/webinars.

- **CIBJO, The World Jewellery Confederation** (Milan, Italy) hosts gem and jewellery industry webinars at www.cibjo.org/webinars, which are grouped into different series such as 'Home Gemmology', 'Jewellery Industry Voices' and 'Mine to Design'.

GEM & JEWELLERY INDUSTRY WEBINARS

- **Gemewizard** (Ramat Gan, Israel) offers webinars covering coloured stone and coloured diamond grading; colour trends in gemstones during pre- and post-COVID-19 times; and grading, pricing and market trends of yellow diamonds. Visit www.youtube.com/channel/UCQKKaw5_kBupL6BMUsAEO2w.

- **GemfliX** (New York, New York, USA) has a series of 'online jewelry chats' that feature jewellery design, gem cutting, auctions, history and more at www.gemx.club/gemflix. Chat-series videos are free, but other GemfliX videos require a Gem X membership.

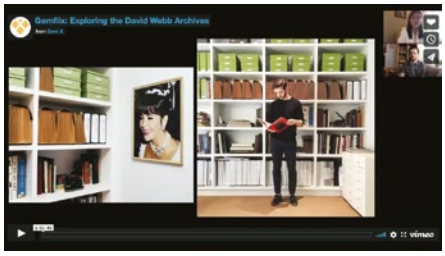

- **Gemmology Rocks** (Maidstone, Kent, United Kingdom) offers an extensive series of archived videos and live online seminars by gemmologist Kerry Gregory through its Facebook page at www.facebook.com/pg/gemmologyrocks/videos. The videos cover a wide range of topics such as origin of colour in gem materials, how to use a polariscope, gemstone inclusions, and gems and minerals of the UK.

GEMMOLOGY ROCKS

- **Gem-A** (London) has produced a series of 'Gem-A Live' webinars on glass-filled rubies and sapphires, flux-healed rubies, composite gemstones, an introduction to diamonds, fluorescence, fracture-filled gemstones, and Be- and Ti-diffused sapphires. Also available are 'How-to Guides' covering how to use a 10× loupe and stone tongs. Visit www.youtube.com/c/GemAOfficialChannel.

- The **Gemological Institute of America** (GIA; Carlsbad, California, USA) has produced a series of webinars for its 'GIA Knowledge Sessions' that cover topics such as diamond formation, synthetic diamonds, jewellery design, origin determination and rubies from Mozambique. Visit www.youtube.com/playlist?list=PLWlzLnp9A9J0dF3TjLYqpqQ3hAZ0pNC9s.

- The **House of Gübelin** (Lucerne, Switzerland) has posted a variety of educational videos on their YouTube channel at www.youtube.com/channel/UCyeDwZMMnXUNfnP_DWdP7rA, which can be found under the Gemmology and Gübelin Gem Sessions categories.

- **Justin K Prim** (Bangkok, Thailand) explores many facets of the lapidary arts and historical gemmology at www.youtube.com/user/ilostmaterialism.

- **Manufacturing Jewelers & Suppliers of America** (Attleboro, Massachusetts, USA) lists future and past webinars at https://mjsa.org/eventsprograms/mjsa_webinars. These focus on jewellery manufacturing and marketing, particularly in context of the challenges presented by the COVID-19 crisis. MJSA's Article & Video Library is also freely available at https://mjsa.org/publicationsmedia/article_and_video_library.

- The **Responsible Jewellery Council** (RJC, London) offers educational videos from its Code of Practices on topics such as product disclosure, provenance claims and human rights requirements at www.youtube.com/channel/UC6g86jYsgHHhQ1g5rUT8b9Q. As part of a webinar series hosted by the United Nations Global Compact, RJC also participated in a March 2020 event on achieving gender equality in the jewellery industry; the video is posted at www.youtube.com/watch?v=ScGFywXHovo and slides of this webinar are available at https://storage.pardot.com/591891/188386/UNGC_and_RJC_Presentation_Slides.pdf.

Carol M. Stockton and Brendan M. Laurs

What's New provides announcements of new instruments/technology, publications, online resources and more. Inclusion in What's New does not imply recommendation or endorsement by Gem-A. Entries were prepared by Carol M. Stockton unless otherwise noted.

Gem Notes

COLOURED STONES

Trapiche-like Pattern in Amethyst

Among the numerous optical phenomena displayed by quartz are asterism and chatoyancy. However, amethyst is one of the few popular gems that does not show asterism in either reflected light (epiasterim) or transmitted light (diasterism). Amethyst and ametrine displaying trapiche-like patterns were recently documented from Brazil (Laurs 2018; Sun *et al.* 2018), and trapiche-like textures have also been encountered in other quartz varieties (e.g. Krzemnicki & Laurs 2014; Wang & Song 2019). Here, we report on a trapiche-like pattern showing a prominent fixed star in an amethyst sphere that reportedly came from Brazil (Figure 1). The sphere was purchased by author MPS at the Sainte-Marie-aux-Mines Mineral & Gem Show in approximately 2005, and was briefly documented many years later (Steinbach 2016, pp. 815–816).

The amethyst sphere measures 40 mm in diameter and weighs 420.50 ct. It appears translucent due to the presence of fractures and fluid inclusions. The whitish trapiche-like pattern is conspicuous within the purple body colour of the amethyst, and consists of a roughly hexagonal core and six radiating arms. The hexagonal symmetry of the core suggests that the trapiche-like pattern developed along the basal pinacoid of the quartz crystal. Each arm started its growth from one side of the hexagonal core in that basal plane. The six arms are therefore parallel to the growth direction of the first-order hexagonal prism.

The arms consist of mostly fibrous or planar white inclusions aligned parallel to their length, as shown in Figure 2. Raman spectroscopy of the white inclusions in both the arms and the core yielded only spectra consistent with quartz.

The appearance of the trapiche-like pattern in this amethyst is reminiscent of those seen in some trapiche-like sapphires and rubies (see, e.g., Steinbach 2016, pp. 800–803). They both show a hexagonal-shaped core that contains the same fibrous inclusions which form the six arms. In corundum, white and light brown trapiche-like patterns are caused, respectively, by the presence of rutile and Fe/Ti-rich oxide inclusions (Gübelin & Koivula 2008, pp. 212 and 308). The arms broadened during growth, as typically shown by trapiche-like patterns.

The trapiche-like pattern in the present amethyst is different from typical trapiche texture that is formed by skeletal crystal growth (e.g. in ruby: see Gübelin & Koivula 2008, pp. 88–90). The pattern in this amethyst is also different from that shown by the recently documented trapiche-like ametrine/amethyst from Brazil (Laurs 2018; Sun *et al.* 2018), because in those samples the arms were composed of relatively pure quartz between heavily included areas, whereas the arms in the present amethyst correspond to oriented fibrous inclusions. In addition, the whitish core in the present amethyst is distinctly different from the black hexagonal core that is commonly present in the Brazilian trapiche-like ametrine/amethyst. The relatively large size of the amethyst specimen reported here is not surprising for quartz, but it is exceptional compared to other quartz

Figure 1: The 420.50 ct amethyst sphere described here displays a conspicuous whitish trapiche-like pattern. Photo by J.-P. Gauthier.

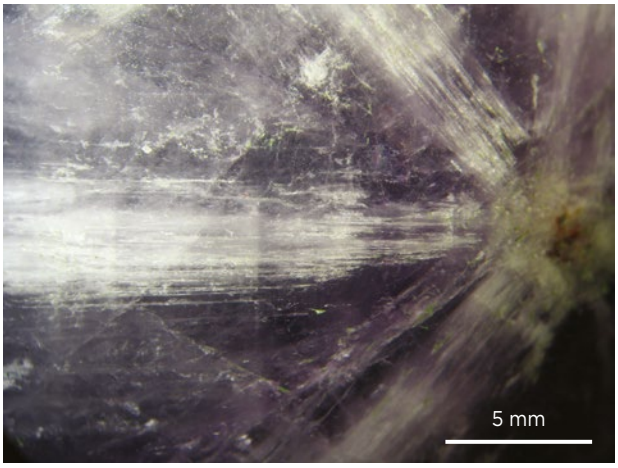

Figure 2: Each of the six arms constituting the trapiche-like pattern consists of fibrous or planar white inclusions aligned along the length of the arms. The colour of the core appears slightly different from the arms due to the presence of green-coloured polishing paste filling surface cavities in that area. Photomicrograph by J.-P. Gauthier, in brightfield illumination.

specimens showing trapiche-like patterns, which have been fashioned as slices or flattened cabochons (see Krzemnicki & Laurs 2014; Wang & Song 2019).

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Sun, Z., Muyal, J. & Hand, D. 2018. Gem News International: Trapiche-like amethyst from Brazil. *Gems & Gemology*, **54**(2), 237–238.

Wang, X. & Song, Y. 2019. Gem News International: A special type of trapiche quartz. *Gems & Gemology*, **55**(2), 285–286.

Aquamarine with Spodumene Inclusions from the Oceanview Mine, California, USA

Since 2000, mining operations at the Oceanview mine in Pala, San Diego County, California, USA, have yielded about 1 t of spodumene, 20 kg of tourmaline and small amounts of beryl (i.e. aquamarine and morganite; Jeff Swanger, pers. comm. 2020). This study documents some unusual inclusions in aquamarine from this granitic pegmatite. We studied a transparent, pale blue sample that was attached to some albite matrix (Figure 3). One side of the sample was cut and polished, while the other side was kept in its natural state.

Refractive indices of this aquamarine were in the range of iron-bearing beryls: $n_o = 1.588$ and $n_e = 1.579$, yielding a birefringence of 0.009. The hydrostatic SG value obtained from a chipped-off fragment was 2.72. Microscopic examination revealed some interesting, well-crystallised, monoclinic mineral inclusions (Figure 4). These were

Figure 3: This specimen (6 cm in maximum dimension), comprised of pale blue aquamarine and white albite from the Oceanview mine, California, USA, was examined for this study. Photo by T. Stephan.

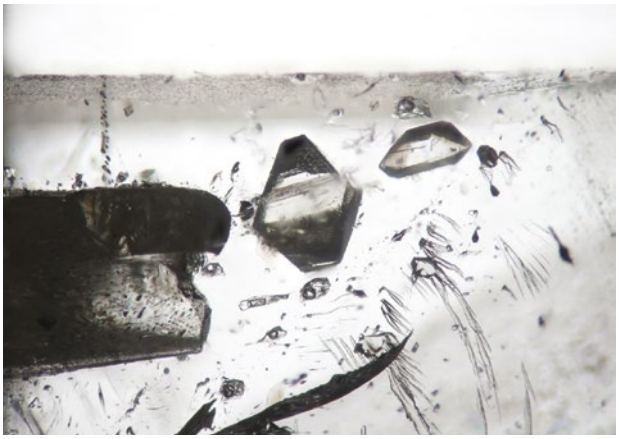

Figure 4: The angular, high-relief crystals in the aquamarine were identified as spodumene. They show well-developed {010} and {110} faces. Also present are two-phase (liquid-gas) fluid inclusions. Photomicrograph by T. Stephan, in paraffin oil with transmitted light; image width 4.1 mm.

analysed with confocal Raman spectroscopy (using a Renishaw inVia Raman microscope with 514.5 nm laser excitation), and after subtracting the contributions from the host beryl, the resulting spectrum matched that of spodumene ($LiAlSi_2O_6$) in the RRUFF database (Figure 5). Because it is rather unusual for spodumene to be associated with iron-bearing beryl (aquamarine) in gem-bearing pegmatites, we performed further analytical work to confirm the identity of these inclusions.

A small piece of the sample was broken off and polished until one of the spodumene inclusions was exposed on the surface. Prior to chemical analysis using laser ablation inductively coupled plasma mass spectrometry (LA-ICP-MS), the Si contents of both the spodumene inclusion and the beryl host were measured with electron probe micro-analysis (EPMA) in order to serve as internal standards for ICP-MS analysis. The SiO_2 content of the spodumene was 63.36 wt.% and that of the host beryl was 64.75 wt.%. LA-ICP-MS analyses of the spodumene and beryl were then conducted with an Agilent 7500c quadrupole spectrometer, using external standards NIST-SRM 610 and 612. Chemical data obtained for the inclusion confirmed its identity as spodumene, with 27.8 wt.% Al_2O_3 and 8.59 wt.% Li_2O. Deviations from ideal formula values of 27.4 wt.% Al_2O_3 and 64.58 wt.% SiO_2 were due to a slightly elevated Li_2O content and the presence of trace elements such as Na, Ca and others (Table I). Analyses of the aquamarine host revealed highly enriched amounts of Li (3713–4051 ppm) for iron-bearing beryl (cf. Viana *et al.* 2002), consistent with the presence of the syngenetic spodumene inclusions. A highly evolved composition of the pegmatitic fluids that formed the aquamarine is also indicated by the elevated alkali contents of this beryl (i.e. 7037–7816 ppm Na and 1886–4114 ppm Cs).

To the authors' knowledge, this is the first report

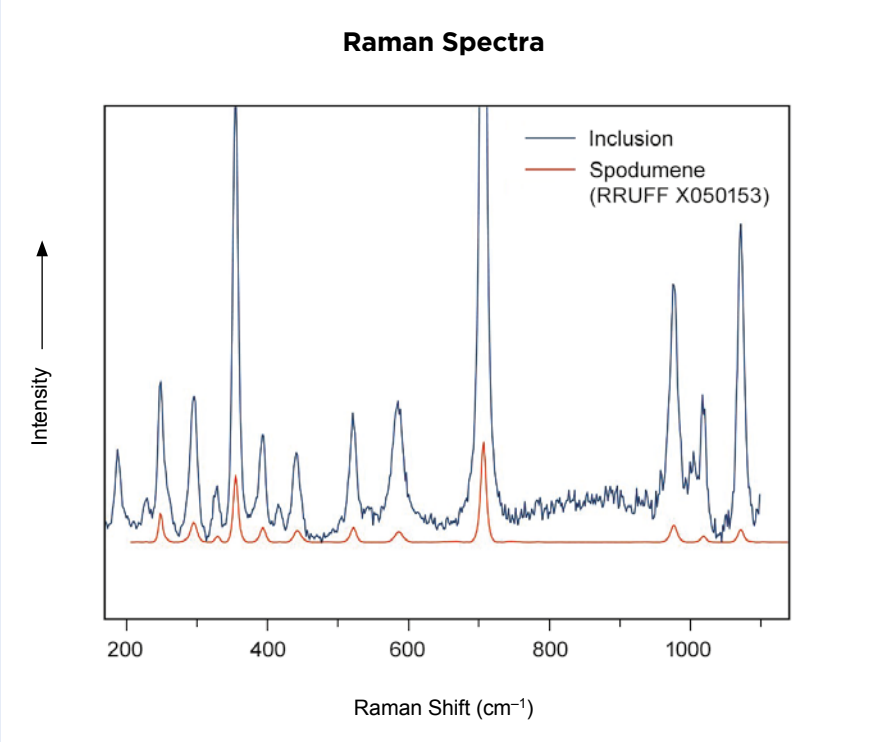

Figure 5: A Raman spectrum of one of the crystalline inclusions (shown here after subtracting the peaks from the host beryl) provides a good match with a reference spectrum for spodumene from Pala, California, in the RRUFF database.

Table I: Minor- and trace-element analysis by LA-ICP-MS of a spodumene inclusion and its aquamarine host from the Oceanview mine.[a]

Element (ppmw)	Spodumene inclusion	Aquamarine host[b]
Li	42112	3713–4051 (3910)
Na	929.5	7037–7816 (7480)
Mg	bdl	8.40–21.61 (9.63)
K	bdl	364.9–390.1 (375.9)
Ca	306.5	198.2–383.0 (270.1)
Ti	44.17	12.10–16.80 (14.72)
Fe	nd	1010–1555 (1455)
Zn	40.06	568.3–622.8 (597.1)
Ga	63.35	16.43–25.82 (20.04)
Rb	bdl	260.8–302.6 (283.9)
Cs	bdl	1886–4114 (2816)

[a] Fe was measured with EPMA and Sc was below the detection limit in all analyses. Abbreviations: bdl = below detection limit, nd = not determined, ppmw = parts per million by weight.

[b] Range of 10 spots analysed in a line across the sample, with average values given in parentheses.

of spodumene inclusions in aquamarine (although spodumene is known to form inclusions in the morganite variety of beryl).

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Demantoid/Andradite Slices from Iran

Colour-zoned demantoid/andradite from Kerman Province in southern Iran showing green/brown zones was first documented by Karampelas *et al.* (2007), who found that the green areas correlated to >0.7 wt.% Cr_2O_3. The two faceted stones examined for that report were specifically cut to display their brown-orange and green colour zoning.

During the February 2020 Tucson gem shows in Arizona, USA, demantoid/andradite from Iran was newly available as polished slices, which showed the colour zoning more effectively than faceted stones. Three such slices (Figure 6) were kindly donated to Gem-A by Indra Man Sunuwar (Nepali Bazaar Co. Ltd, Tokyo, Japan); his supplier reportedly had cut about 450 carats of this material. Stone dealer Bradley J. Payne (The Gem Trader, Cave Creek, Arizona) also obtained some of the slices in Tucson, as well as faceted stones showing colour zoning (e.g. Figure 7). Some of the slices were trimmed into polygonal shapes, while others retained their natural

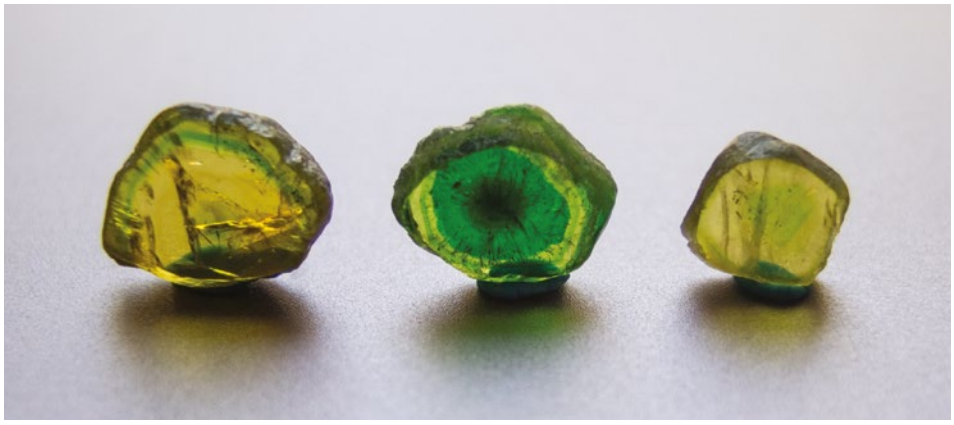

Figure 6: These colour-zoned slices of demantoid/andradite from Iran measure 5.7–8.5 mm wide. Gift of Indra Man Sunuwar; photo by B. M. Laurs.

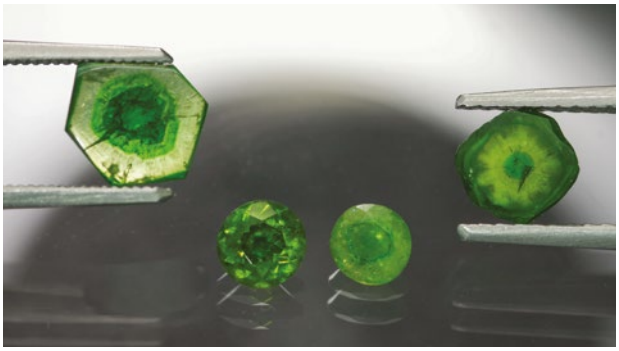

Figure 7: Attractive patterns are shown by these colour-zoned Iranian demantoid/andradite slices, which weigh 1.68 ct (left) and 1.08 ct (right). The faceted stones at the bottom centre were cut so that darker green colour zones are centred under their tables; they weigh 0.67 ct (left) and 0.52 ct (right). Photo by Bradley J. Payne.

outer surfaces along their edges. The slices that Payne obtained ranged from 1 to 2 ct and the faceted stones weighed 0.15–1.25 ct.

Although demantoid/andradite from Iran has been known since 2001, this is the first time that this author is aware of this material being cut into polished slices to showcase its attractive colour zoning—as is commonly done with multicoloured tourmaline.

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Reference

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Blue Diopside from Russia

Violane (or *violan*) is a term used for violet to blue diopside with a massive polycrystalline texture that mainly has been mined from the Praborna manganese deposit in St Marcel, Italy, and is coloured by Mn (Mottana *et al.* 1979). Although known for decades, this ornamental material is rarely mentioned in the gemmological literature (cf. Webster 1949). The term *violane* has also been applied to massive polycrystalline blue diopside from Russia, particularly by sellers on the Internet. In addition, similar material is known from Baffin Island, Canada, which is coloured by Fe^{2+}–Ti^{4+} intervalence charge transfer (Herd *et al.* 2000).

During the February 2020 Tucson gem shows, Rare Earth Mining Co. (Trumbull, Connecticut, USA) displayed some blue and blue/white cabochons represented as violane. According to Rare Earth's Bill Heher, the rough material came to market in around August 2018 and was mined from the Lake Baikal region of Russia. So far he has cut a few hundred cabochons that ranged up to about 50 mm in maximum dimension.

Ornamental blue diopside is known from three localities in Russia: the Khakassia area of eastern Siberia (Shil'tsina & Vereshchagin 2000) and two areas near Lake Baikal (Zadov *et al.* 2004; Simakin *et al.* 2019). According to D. Belakovsky (pers. comm. 2020), the Lake Baikal deposits are hosted by (1) the Yoko-Dovyrenskiy (or Yoko-Dovyren) massif near the north end of the lake and (2) the Tazheranskiy (or Tazheran) massif near the lake's south end.

Heher loaned three samples for examination (Figure 8), and they were characterised by authors CW and BW. They consisted of a blue oval cabochon weighing 17.88 ct (27.50 × 21.27 mm), and a matched pair of bicoloured blue and white/tan rectangular cabochons with a total weight of 35.71 ct (each measuring approximately 26 × 15 mm). All displayed an obvious polycrystalline structure that was fine- to coarse-grained and showed variable depth of blue colour between grains in the blue portions (Figure 9). A few sparkles seen as the samples were moved apparently corresponded to cleavage fractures in some of the diopside grains. Viewed with the microscope, the blue areas of the samples also exhibited variations in surface lustre between grains (again, see Figure 9). Although individual grains were somewhat transparent, the presence of abundant polycrystalline

Figure 8: These three cabochons containing blue diopside (17.57–17.88 ct) are from Russia's Lake Baikal region and were studied for this report. Photo by B. Williams.

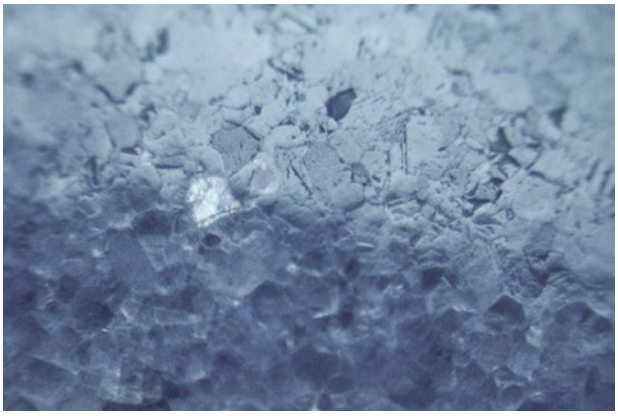

Figure 9: Microscopic examination of the blue diopside shows a polycrystalline texture with variations in surface lustre between grains and a reflection from a cleavage fracture (left centre). Photomicrograph by B. Williams and C. Williams, in reflected light; image width 9 mm.

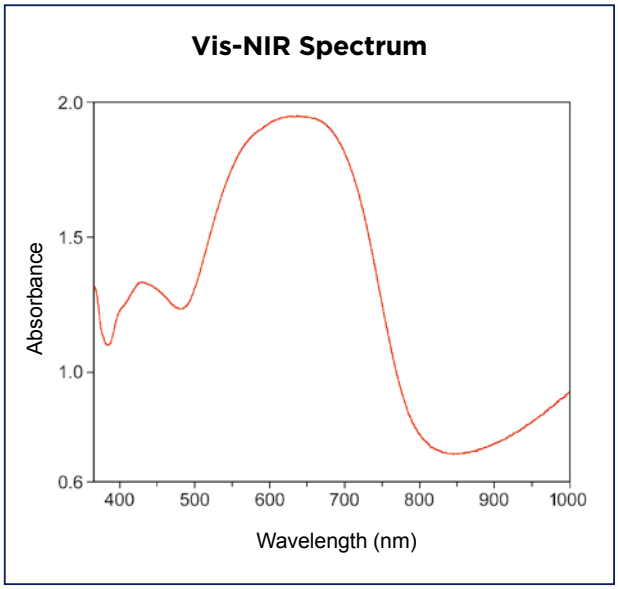

Figure 10: Vis-NIR spectroscopy of the blue diopside shows a large broad peak centred at about 630 nm and a smaller absorption at about 430 nm, consistent with colouration due to VO^{2+}.

grain boundaries created an overall semi-translucent appearance in the blue areas.

All three samples were confirmed as diopside in the blue areas by Raman analysis using a Magilabs Gemmo-Raman-532SG spectrometer. A Raman peak shift was observed in the white/tan area of the bicoloured stones, which might be due to the presence of additional mineral phases occurring with the diopside. Indeed, Simakin *et al.* (2019) reported that 'bleached' metasomatised zones associated with blue diopside from Lake Baikal consist of recrystallised white diopside and monticellite, while Zadov *et al.* (2004) indicated that the light-coloured zones consisted of foshagite and other minerals.

Spot RI readings of the cabochons could not be obtained due to the polycrystalline nature of the material. The hydrostatic SG value of the blue sample was 3.23, which is slightly lower than the typical range for diopside (3.24–3.33) but consistent with its polycrystalline structure. The stones were inert to long- and short-wave UV radiation. Energy-dispersive X-ray fluorescence (EDXRF) chemical analysis of the blue sample performed with an Amptek X123-SDD spectrometer showed traces of the chromophoric elements V, Fe and Cr (as well as very small amounts of Pt, consistent with blue diopside from the Yoko-Dovyren massif documented by Simakin *et al.* 2019).

Simakin *et al.* (2019) reported an average of 345 ppm V in blue diopside from the Lake Baikal area, and attributed its colouration to VO^{2+}. Visible-near infrared (Vis-NIR) absorption spectroscopy of the present blue cabochon with a Magilabs GemmoSphere spectrometer showed a large broad peak centred at about 630 nm and a smaller absorption at about 430 nm (Figure 10). This pattern is indeed consistent with colouration due to tetravalent vanadium in the form of the vanadyl ion (VO^{2+}), as seen for example in cavansite (Rossman 2014). Vanadium-doped synthetic diopside also shows distinct blue colouration and a similar absorption spectrum (see, e.g., sample GRR 510 at https://minerals.gps.caltech.edu/FILES/Visible/pyroxene/Index.html). Taken together, all of these aspects provide confirmation that the blue colouration of the Russian diopside studied for this report is due to VO^{2+}.

Acknowledgement: We thank Dmitriy Belakovsky (curator of the Fersman Mineralogical Museum, Moscow) for providing information and references on blue diopside from Russia.

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A Collection of Cat's-Eye Emeralds from Colombia

Fine cat's-eye emeralds are quite rare, and have been documented mostly from Brazil (e.g. Laurs 2012 and references therein). However, flattened cabochons showing chatoyancy have been reported from Colombia—specifically the Coscuez mine in the Muzo region (Johnson & Koivula 1996). More recently, Weldon and McClure (2013) described the cutting of a fine matched pair of Colombian cat's-eye emeralds that weighed 75 ct by husband-and-wife gem cutters Misael Angel Rodríguez and Claudia Patricia Beltrán Rubiano.

During the February 2020 Tucson gem shows, the same emerald cutters showed this author an impressive collection of 24 cat's-eye emeralds from Colombia (Figure 11). The stones ranged from 0.49 to 3.81 ct and had a total weight of 37.90 carats. The collection was assembled during 2019 from polished stones that they obtained on the market in Colombia; all of them had undergone clarity enhancement with cedarwood oil. According to them, the stones showed characteristics consistent with being cut from trapiche rough material mined in the Muzo area.

The cat's-eye effect was best seen when the stones were displayed over a light-coloured reflective background. Moreover, the chatoyancy appeared to be caused by very fine-scale, parallel, transparent structures, which likely correspond to the dislocations that were documented by Pignatelli *et al.* (2015) in the 'arms' of Colombian trapiche emeralds. These bundles of straight dislocations are oriented perpendicular to $\{10\bar{1}0\}$ faces, commonly with parallel elongated voids and trains of fluid inclusions. As documented by Weldon and McClure (2013), rough material obtained from the arms of trapiche crystals can be polished into attractive cat's-eye cabochons if it contains the appropriate structural properties and is suitably oriented. As awareness grows of the potential for cutting cat's-eyes from trapiche rough material, these rare chatoyant emeralds from Colombia may become more available in the future.

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Figure 11: Cat's-eye emeralds from Colombia are quite rare. The 24 stones in this impressive collection weigh 0.49–3.81 ct. Photo by Jeff Scovil.

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Gem-quality Euchroite from Slovakia

Euchroite, ideally $Cu_2(AsO_4)(OH) \bullet 3H_2O$, is a supergene copper arsenate that was originally described by Breithaupt (1823) from the Svätodušná (Svätoduška) copper deposit near the village of Ľubietová, Banská Bystrica Region, Slovakia. The mineral's name is derived from the Greek word *eyxroia* (eu = good and chros = colour), in reference to its beautiful deep green colour. It is orthorhombic and forms crystals typically up to 1 cm (exceptionally 3 cm) that are equant to short prismatic and transparent to translucent with vitreous lustre. Its hardness is rather low at 3.5–4 on the Mohs scale. The crystals range from bright 'emerald' green to darker yellow-green, and typically form supergene encrustations on fracture surfaces. The most commonly associated minerals are pseudomalachite [$Cu_5(PO_4)_2(OH)_4$], malachite [$Cu_2(OH)_2(CO_3)$], brochantite [$Cu_4(SO_4)(OH)_6$] and several other secondary copper minerals (see Figuschová 1977; Řídkošil & Medek 1981; and unpublished data of Martin Števko and Jiří Sejkora).

Euchroite specimens were commonly found by hobbyists in the tailings piles of the Svätodušná mine from 1950 until recently, when all mineral collecting activities at the site were forbidden. Gem-quality euchroite is quite rare and such pieces are seldom faceted because they are prized as crystal specimens. Recently, four euchroite gemstones (see, e.g., Figure 12) were faceted by Czech gem cutter Svatopluk Prchlík from damaged crystals that were collected in 1998 by a group organised by one of the authors (RH). The stones weighed 1.35 ct (round), 1.36 ct (octagon), 0.06 ct (octagon) and 0.04 ct (octagon); all four of them were examined for this report. Refractive indices were 1.695–1.733, with a birefringence of 0.038. The SG of each sample (measured with a pycnometer, as well as hydrostatically) was 3.45.

The authors' investigations of the euchroite rough material using powder X-ray diffraction and electron probe microanalysis (with an energy-dispersive spectrometer) revealed the presence of various mineral impurities, including olivenite, libethenite and pseudomalachite, as well as limonite and other secondary minerals (Fe ± Mn ± Ba oxy-hydroxides). Microscopic examination of the faceted stones showed a texture composed of radiating aggregates of flat needles of euchroite with interstitial fillings of olivenite and libethenite. Pseudomalachite was present alongside individual crystals of the euchroite. Limonite and other secondary minerals were present as fillings in small cavities and as coatings along some mineral grains (especially libethenite).

Euchroite is a rare mineral and encountering gem-

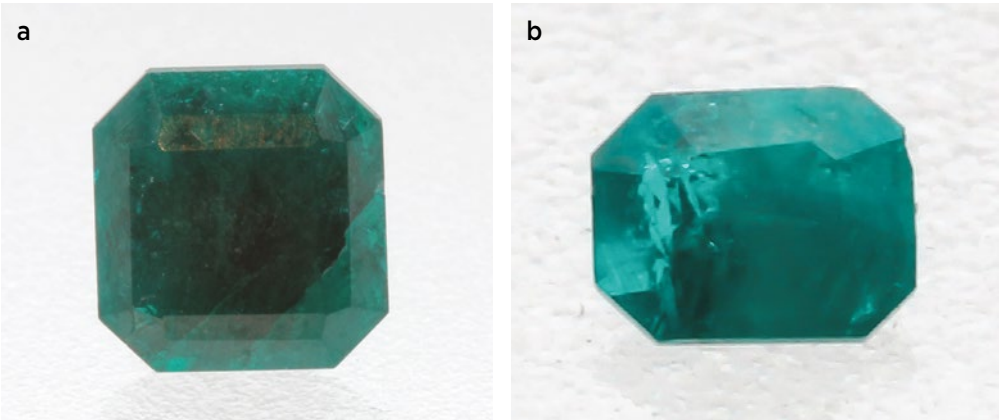

Figure 12: These euchroite gemstones were cut from rough material obtained at the Svätodušná copper deposit in Slovakia. The stones weigh (**a**) 1.36 ct and (**b**) 0.06 ct. Photos by R. Hanus.

quality material is even rarer. Euchroite is quite difficult to cut and polish due to the mineral's softness and its texture consisting of fibrous aggregates. Due to its extreme rarity in cut form, euchroite is unlikely to be encountered on the market, even as a collector's stone. Although its colour may closely resemble that of dioptase, gems cut from dioptase typically have better transparency. In addition, euchroite is commonly accompanied by inclusions of libethenite, which are emerald green show a high lustre.

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Properties of Green Fluorite from England Showing Daylight Fluorescence

A famous locality for fine-quality fluorite crystals is the historic Weardale mining district in County Durham, northern England. Weardale is the centre of the North Pennines Orefield, which has been a source of lead, iron, zinc, fluorite and other mineral commodities for the past millennium (Fisher 2013). In recent times, the most prolific source of fluorite specimens for collectors has been the Rogerley mine, which was first developed in the early 1970s by a team of local collectors. In 1999, the mine was taken over by a group of Americans and operated as UK Mining Ventures LLC (Fisher 2013). In the summer of 2017, the project changed ownership to Ian and Diana Bruce under the name UK Mining Ventures Ltd (www.ukminingventures.com/dianamaria.html). They opened the Diana Maria mine about 400 m west of the Rogerley main portal; both mines are currently being worked throughout the year. The mineralised cavities are hosted by vertical veins and by metasomatic zones or 'flats' that extend laterally from the veins, subparallel to the limestone host-rock bedding. The fluorite is most commonly green, yellow or purple, and the crystals typically form penetration twins on {111} (Fisher 2004).

In 2017, one of the authors (JŠ) obtained some green fluorite samples from UK Mining Ventures Ltd that came from the Rogerley and Diana Maria mines. Author ZP recently faceted three Diana Maria fluorites, consisting of two matched square step cuts with dimensions of 4.50 × 4.50 × 3.29 (0.60 ct) each, and one rectangular step cut measuring 5.30 × 9.45 × 4.28 (2.07 ct; Figure 13). Their gemmological properties were comparable to those of fluorite, with a singly refractive RI varying from 1.425 to 1.445 (although this range is somewhat wider than

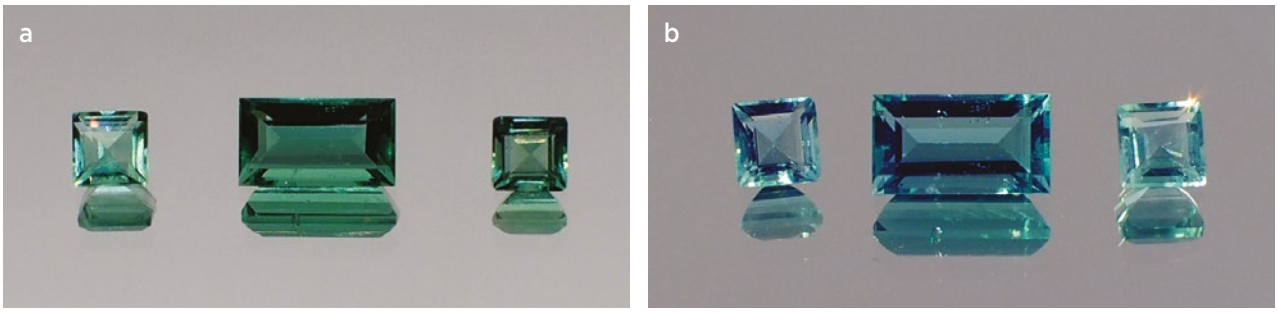

Figure 13: These faceted fluorites (from left to right: 0.60, 2.07 and 0.60 ct) are from the Diana Maria mine in the Weardale mining district of County Durham, northern England. (**a**) They are green when viewed with standard 'warm' or 'cool' white LED illumination, but (**b**) appear more blue in daylight-equivalent illumination due to their strong UV fluorescence. Photos by J. Štubňa.

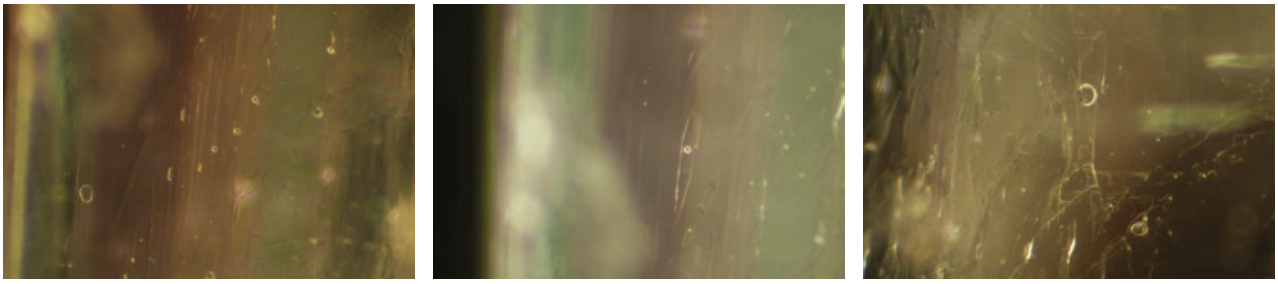

Figure 14: Two-phase (liquid-gas) inclusions displaying various shapes occur in the Diana Maria fluorites. Photomicrographs by J. Štubňa; magnified 40×.

typically reported for fluorite) and a hydrostatic SG value of 3.17–3.19. They appeared pink to red under a Chelsea Colour Filter. Magnification revealed two-phase (liquid-gas) inclusions (Figure 14), which are characteristic of fluorite from various locations.

The most striking aspect of these green fluorites was their exceptionally strong violetish blue fluorescence to long-wave UV radiation (Figure 15), which was weaker under short-wave UV. This fluorescence behaviour is similar to that shown by fluorite from many other Weardale localities, and most of the green and purple fluorite from these deposits shows blue-to-violet overtones resulting from daylight fluorescence (Fisher *et al.* 2004). This colour effect was clearly seen in the faceted stones examined for this study (again, see Figure 13).

Ultraviolet-visible (UV-Vis) spectroscopy of our green fluorites revealed absorption bands at 376, 426, 444, 617 and 688 nm (Figure 16a). O'Donoghue (2006) reported similar absorption features in green fluorite, with bands at 427, 445, 582, 610 and 634 nm. Raman spectroscopy showed numerous peaks, including a Raman band at 322 cm^{-1} (Figure 16b). Čermáková *et al.* (2014) indicated that Raman bands at wavenumbers higher than 500 cm^{-1} in fluorite are probably related to the presence of rare-earth elements (REE).

The cause of the vivid green colour shown by Weardale fluorite is still not clearly understood. However, modern analytical techniques and observations of the colour behaviour under different light sources suggest the fluorite's colouration is produced by colour centres resulting from lattice defects caused by the presence of REE (Fisher & Greenbank 2000). Weardale fluorite is enriched in light REE such as Y, Ce, La, Sm and Nd, and displays a strong negative Eu anomaly (Falster *et al.* 2001; Ixer 2003). Although the role of these elements in causing the green colour needs further study, they are apparently responsible for the fluorite's intense UV fluorescence (Falster *et al.* 2001; Fisher 2004).

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Figure 15: Intense violetish blue fluorescence is seen with long-wave UV radiation in this Diana Maria fluorite. Note also the subtle zones displaying magenta fluorescence. Photomicrograph by J. Štubňa; magnified 7.5×.

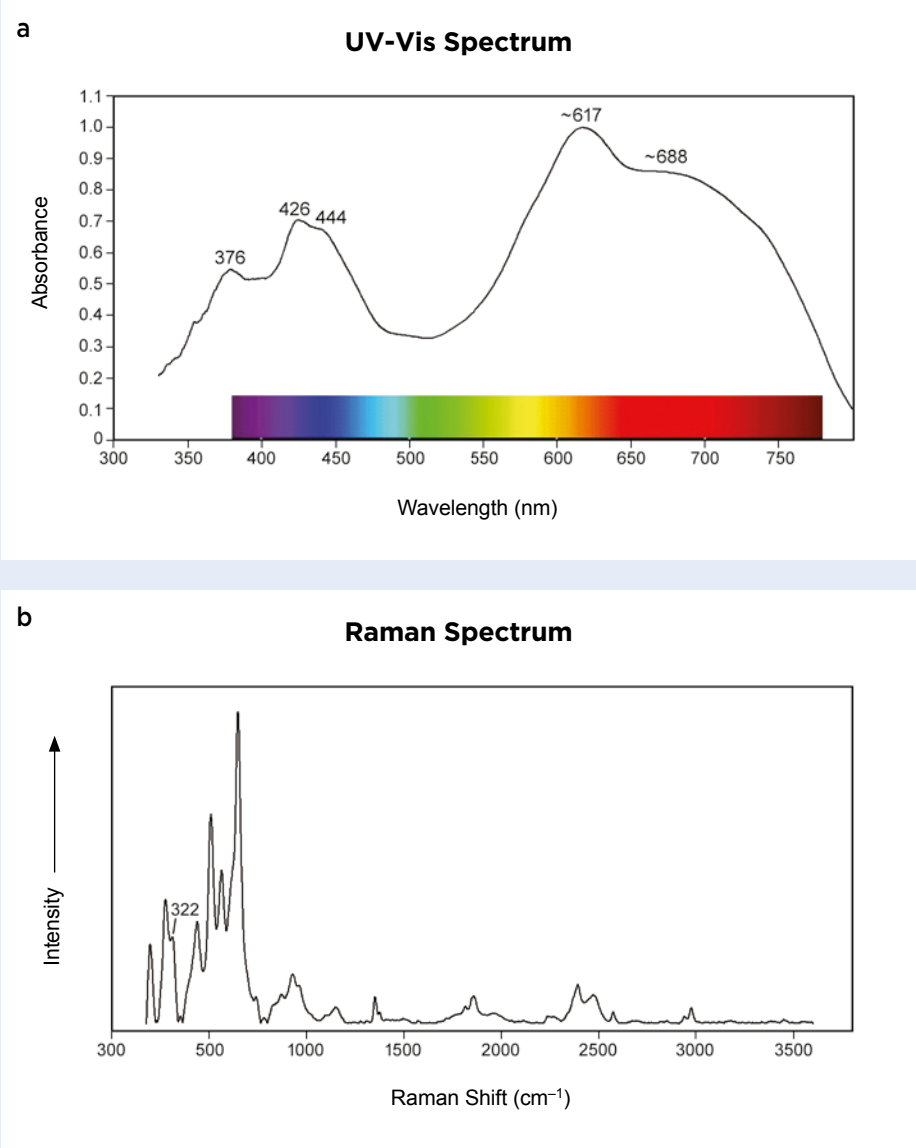

Figure 16: (**a**) This representative UV-Vis spectrum of the green fluorite from the Diana Maria mine shows absorption bands at about 376, 426, 444, 617 and 688 nm. (**b**) Raman spectroscopy shows a typical 322 cm^{-1} peak for fluorite along with several other peaks that are probably associated with REE.

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Jewellery Set with Green Fluorite from England

Fluorite from the Rogerley and Diana Maria mines in the Weardale mining district, County Durham, northern England, is prized by mineral collectors who appreciate the well-formed crystal specimens. Particularly well known from these mines is green fluorite showing daylight fluorescence (see the previous Gem Note in this issue).

During the February 2020 Tucson gem shows, Diana Bruce (Crystal Classics, East Coker, Somerset) showed this author a new line of jewellery created with faceted fluorite that mainly comes from the Diana Maria mine (e.g. Figures 17 and 18). Cutting of this material started in late 2018 and the first batch yielded about 1,000 gemstones, of which 650 have been set into pendants and earrings (called the Viridis Gems collection), and the rest are being sold as loose stones. The vast majority of the fluorites are green, although some purple and yellow gems have been cut. The shapes include round, oval and trilliant, in concave or fantasy cuts that mostly range from 6 × 6 mm to 14 × 12 mm; there are three sizes available for earrings and four sizes for necklaces. The largest stone faceted so far weighs approximately 28 ct. The cutting styles employ relatively small tables so they are less susceptible to scratching. (Viridis Gems fluorite is accompanied by information on the care and cleaning of this delicate stone.) The fluorite is set in rhodium-plated sterling silver, or in 14 or 18 ct gold. A few loose twinned crystals of the fluorite have also been set as pendants.

Figure 18: These concave-cut fluorites from the Diana Maria mine weigh 4 ct (left, set in 18 ct gold) and 6 ct (right). Photo by Olga Kaspera, Crystal Classics.

The attractive green colour, custom cutting styles and daylight fluorescence combine to make these fluorites interesting as loose stones and jewellery items.

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Figure 17: Set in rhodium-plated sterling silver, these concave-cut fluorites from the Diana Maria mine range from 8 to 12 mm (approximately 2.0–6.8 ct for the rounds and 1.8–4.9 ct for the trilliants). Photo by Olga Kaspera, Crystal Classics.

Frankamenite as an Ornamental Gem Material

Frankamenite—$K_3Na_3Ca_5(Si_{12}O_{30})(F,OH)_4 \bullet H_2O$—is a relatively new mineral (described in 1996) that occurs together with charoite from the Sakha Republic (formerly Yakutia), Russia. Frankamenite is a member of the canasite group and is the hydrated, fluorine-dominant analogue of canasite. It is triclinic and has a Mohs hardness of 5½. It forms aggregates of prismatic crystals, with individuals usually measuring about 1 cm (rarely up to 10 cm) long. Its colour is typically grey but may also be yellow, violet or (rarely) light blue or green (Rozhdestvenskaya *et al*. 1996).

For this study, we examined a cabochon consisting of frankamenite together with other minerals (Figure 19), which came from the Sirenevyi Kamen charoite deposit, located near the confluence of the Chara and Tokko rivers in the Murunskii massif, Aldan Shield, Sakha Republic. The deposit covers an area of 12 km^2 and the estimated charoite resource is around 20,000 t (Ivanov *et al*. 2018). Although *charoite* is the name of a mineral, it also refers to a rock with a distinctive purple colour that is mostly comprised of charoite *sensu stricto* with various other minerals. Charoite's colour and textural characteristics make it highly prized as an ornamental material.

The sample described here was purchased at the source locality many years ago. It was chosen for examination because its colouration is significantly different from that of charoite. The cabochon measures 43.3 × 34.5 mm and weighs 121.32 ct. It shows a coarse-grained interlocking texture, with individual crystals of about 15 mm long and 4 mm wide. With Raman microspectroscopy, the pale grey-green domains were identified as frankamenite. The following peaks were recorded and are typical of frankamenite: 461, 441, 386, 332, 266 and 187 cm^{-1} with important maxima at 1121, 645 and 625 cm^{-1} (charoite and quartz peaks were subtracted). The frankamenite crystals showed perfect cleavage, and they fluoresced intense pink to long-wave UV radiation and a weak, deep red to short-wave UV. Associated minerals (labelled in Figure 19) included charoite (purple), quartz (colourless), aegirine (black), tinaksite (orangey brown) and fedorite (as lamellar inclusions in tinaksite); these were identified by Raman spectroscopy of the cabochon or by powder X-ray diffraction analysis of samples taken from

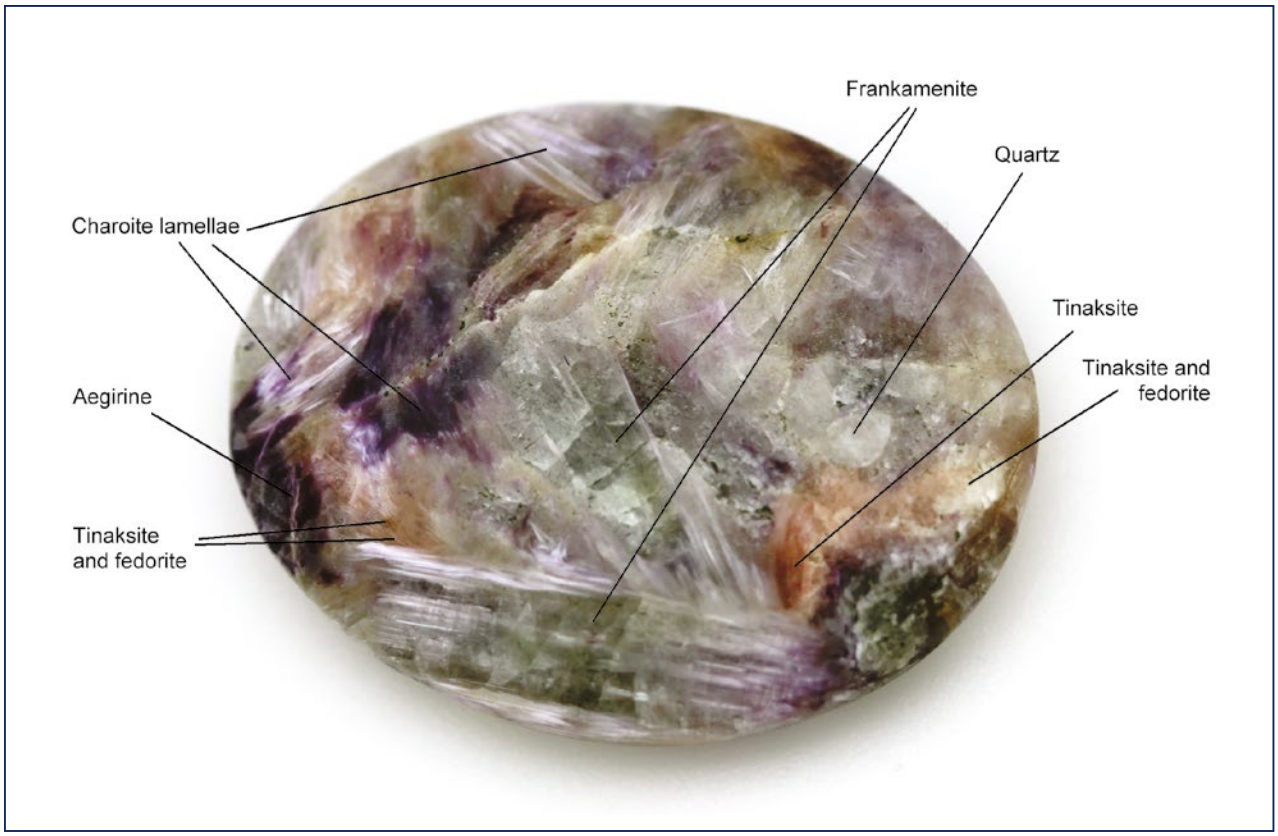

Figure 19: This 121.32 ct cabochon from the Sirenevyi Kamen charoite deposit in Russia consists of frankamenite (pale grey-green), charoite (purple), tinaksite (orangey brown) and aegirine (black), together with small amounts of quartz and fedorite. Photo by R. Hanus.

an offcut of the stone. While not identified in the present sample, celsian (barium feldspar) is also commonly found in association with charoite.

Although charoite is a better known and visually more appealing gem material, frankamenite is an unusual collector's stone and its presence together with the various associated minerals creates an interesting appearance.

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Colour-Change Garnet from Tanga, Tanzania

Colour-change garnets are well known from East Africa, and in Tanzania this material typically comes from the Umba River Valley and consists of pyrope-spessartine that can appear greenish blue in daylight and magenta in incandescent light (e.g. Jobbins *et al.* 1975). Recently, additional production of colour-change garnet reportedly occurred near Tanga, which is in the same region as Umba in north-eastern Tanzania. Gem dealer Dudley Blauwet (Dudley Blauwet Gems, Louisville, Colorado, USA) obtained the rough material at the February 2017 Tucson gem shows. He sent eight pieces of rough totalling 5.0 g to his cutting factory and they yielded eight faceted stones ranging from 0.66 to 2.03 ct (7.31 carats total weight).

Blauwet loaned three of the gems for examination (Figure 20), and they measured 8.47 × 6.97 × 4.37 mm (2.02 ct oval), 6.41–6.47 × 3.86 mm (1.09 ct round) and 6.87 × 6.76 × 3.48 mm (1.07 ct triangle). In daylight, the oval appeared dark reddish purple with flashes of deep purplish pink, and the round and triangular stones showed a strong, deep purple colour. All three changed to purplish red in incandescent light. The RIs of the oval, round and triangular samples were 1.759, 1.747 and 1.743, and their average hydrostatic SG values were 3.86, 3.77 and 3.76, respectively.

A prism spectroscope revealed absorption in the violet and blue regions to about 460 nm. The oval specimen displayed an absorption band at about 540–610 nm. In the other two stones this absorption band was slightly narrower (around 550–590 nm). All three gems were inert to long- and short-wave UV radiation.

The oval and triangular stones were eye clean, but microscopic examination revealed some needle-like inclusions oriented in four different directions. The round sample was slightly included, containing a partially healed fissure and needles that were crystallographically oriented and in seemingly random orientations.

UV-Vis-NIR absorption spectra collected with an Ocean Optics HR2000+ spectrometer gave a more detailed picture of the features observed with the spectroscope. The round and triangular stones showed identical spectra consisting of pronounced bands at about 410 and 573 nm (with a shoulder at 505 nm; Figure 21). The most pronounced transmission windows were in the blue (at about 477 nm) and red regions. The spectrum of the oval stone was slightly different (again, see Figure 21): it showed a somewhat asymmetrical band at 572 nm, a feature at 484 nm, and weak shoulders at about 460 and 525 nm. Because of its relatively greater absorption in the blue region, in daylight this sample displayed slightly less of the blue component than in the other stones, and therefore its colour change was less distinct.

The absorption spectra resembled those of colour-change pyrope-spessartine described by Lind (2015) and Schmetzer *et al.* (2009). Those samples revealed a band at about 410 nm and a weaker feature at 484 nm due to Mn^{2+}; (weak) features at 505 and 525 nm, plus a band at about 570 nm, due to Fe^{2+}; and an intense band at 573 nm due to Cr^{3+} and V^{3+}.

The RI values of the round and triangular stones were (1) considerably lower than those reported by Lind (2015)

Figure 20: The three faceted colour-change garnets from Tanga, Tanzania (2.02 ct oval, 1.09 ct round and 1.07 triangle) examined for this report are shown here in daylight-equivalent illumination. In incandescent light, all three stones appear purplish red. Photo by J. C. Zwaan.

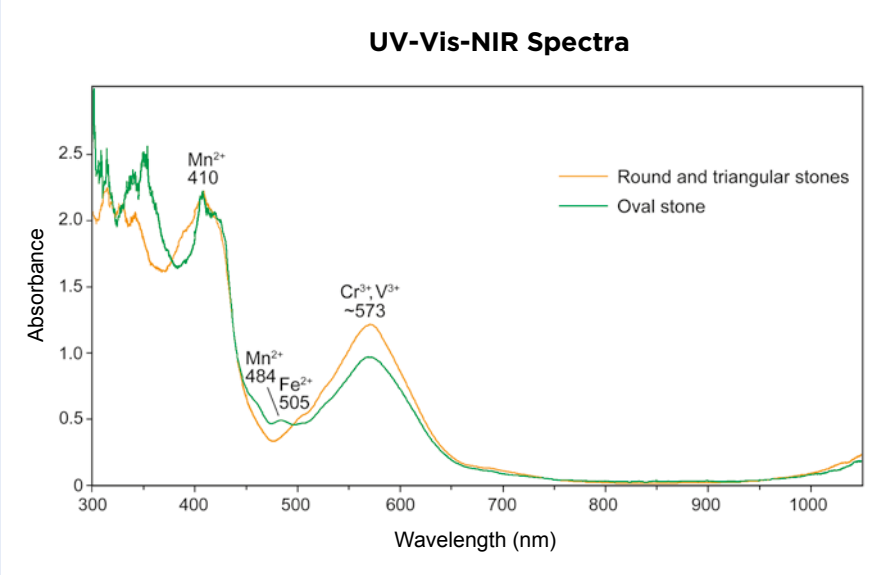

Figure 21: UV-Vis-NIR absorption spectra of the three colour-change garnets show strong bands at about 410 and 573 nm, creating transmission windows in the blue and red regions. The spectrum of the 2.02 ct oval stone also shows a feature at 484 nm, which results in relatively less transmission in the blue region.

for colour-change garnets (1.751–1.771); (2) considerably lower than those of V ± Cr-bearing pyrope-spessartine garnets from Umba (1.757; Jobbins *et al.* 1975) and from Tranoroa, Madagascar (1.768–1.773; Schmetzer *et al.* 2002); and (3) similar but still lower than those of colour-change garnets from Bekily, Madagascar (1.750–1.755; Schmetzer *et al.* 2002), indicating a higher pyrope content than is commonly present in colour-change garnets (pyrope-spessartine solid solution: pyrope dominant RI < 1.760 and spessartine dominant RI > 1.765; Lind 2015).

EDXRF spectroscopy obtained with an EDAX Orbis Micro-XRF Analyzer revealed major amounts of Mg, Mn, Al and Si (with Mg>Mn in all three stones), plus minor Ca and Fe, with traces of Cr, V and Zn (Table II). The 2.02 ct oval had a higher Mn content (about 13–14 wt.% MnO) than the other two stones (about 7–8 wt.% MnO). Comparison of the Cr_2O_3 + V_2O_3 concentrations to the spectra in Figure 21 indicates that only a slight increase in Cr^{3+} + V^{3+} can have a considerable impact on the intensity of the 573 nm band (Lind 2015).

Table II: Minor and trace elements by EDXRF in colour-change pyrope-spessartine from Tanga, Tanzania.

Oxides (wt.%)	Oval (2.02 ct)	Round (1.09 ct)	Triangle (1.07 ct)
CaO	3.6–3.9	2.5–2.6	1.8–1.9
FeO	1.9	3.4–3.5	2.5–2.6
Cr_2O_3 + V_2O_3	0.40–0.42	0.60–0.64	0.64–0.67
ZnO	0.03	0.05–0.06	0.05

The extent of the colour change in the pyrope-spessartine samples described here could be described as moderate for the round and triangular stones, and faint for the oval stone, when compared to the overall range of colour change observed in garnets, some of which display a very strong change from green to bluish green in daylight to red-purple in incandescent light (Schmetzer *et al.* 2009).

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Hessonite from Somaliland

Somaliland is an autonomous region of Somalia in East Africa, and has produced gem-quality garnet, opal, emerald, aquamarine and several other gem materials (Kinnaird & Jackson 2000). At the February 2020 Tucson gem shows, one of the authors (AMY) had some recent production of rough and cut orange garnets from Somaliland. According to his contacts in the mining area—including dealer Ahmed Shekh, a miner named Abdikarim and archaeologist Mohamed Abdi Allamagan—the garnet-bearing area is situated in an area measuring approximately 10 × 10 km that is located just south-west of the town of Daarbuduq (or Da'ar buduq), which is in between the capital city of Hargeisa and the coastal city of Berbera. Garnets have been mined from secondary deposits in this area since the 1990s, although some stones were collected from the surface before that time.

Both artisanal and mechanised methods have been used to recover the garnets. Artisanal miners work in groups of 3–5 persons and employ simple hand tools to dig shafts that are 1 m wide and average 4–6 m deep; sometimes three or four tunnels are interconnected. On average, each miner collects about 1 kg of garnet rough per day, although production may be greater during the rainy season. Mechanised mining takes place mainly along riverbanks, where about 50–100 persons work in screening operations. Depending on the capacity of the machinery used, the average daily production from each one ranges from about 15 to 40 kg.

The rough garnets consist of medium to dark orange broken fragments (rarely showing crystal faces) that typically range up to 5 g each, with the largest stones weighing 50 g. About 40% is of good quality and 60% is comprised of lower-grade material.

Author AMY donated some rough and cut garnets to Gem-A (Figure 22), and the five faceted stones were characterised by authors BW and CW. They weighed 5.66–8.16 ct and ranged from medium yellowish orange (6.13 ct) to deep orangey red (6.04 ct). The RI ranged from 1.740 (6.13 ct) to 1.749 (6.04 ct), and SG was measured hydrostatically at 3.61 (6.13 ct) to 3.64 (6.04 ct). These values are all within the expected range for grossular (hessonite), with those exhibiting a deeper, more reddish colouration—along with higher RI and SG values—inferred to contain greater amounts of iron. The identification of all the samples as grossular was confirmed by Raman spectroscopy using a Magilabs GemmoRaman-532SG spectrometer. Between crossed polarisers, some stones showed uneven, patchy, anomalous extinction while others exhibited a more striated and semi-parallel extinction pattern. Inclusions consisted of partially healed fluid-filled fissures, etch tubes (Figure 23) and colourless crystalline inclusions with a prismatic or rhomboid shape that appeared to be calcite and/or apatite. Absent was the roiled optical effect that is commonly seen in hessonite.

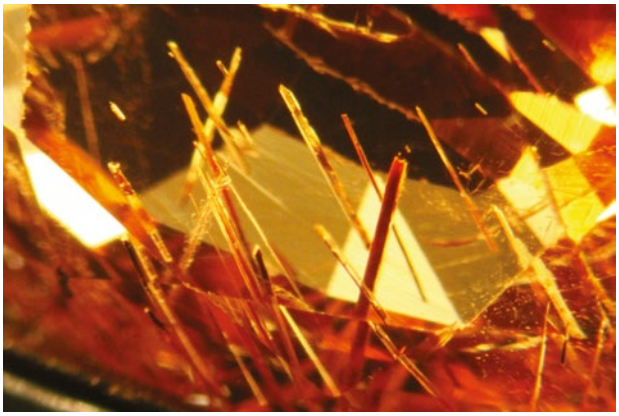

Figure 23: Etch tubes are prominent in this hessonite from Somaliland. Photomicrograph by B. Williams; image width 6 mm.

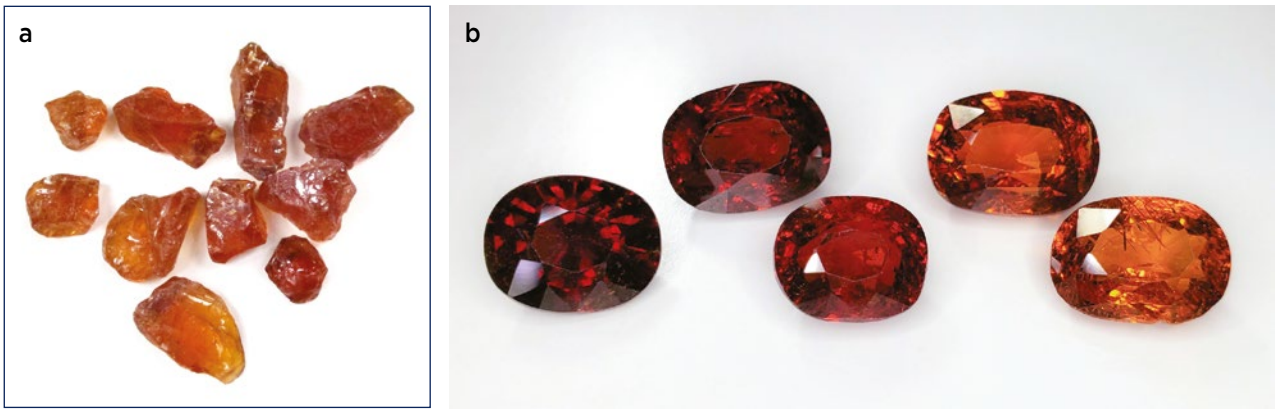

Figure 22: (**a**) These rough pieces of hessonite from Somaliland range from yellowish orange to reddish orange and weigh 0.70–2.47 g. (**b**) The five faceted hessonites examined for this report weigh 5.66–8.16 ct. Photos by (a) B. Williams and (b) C. Williams.

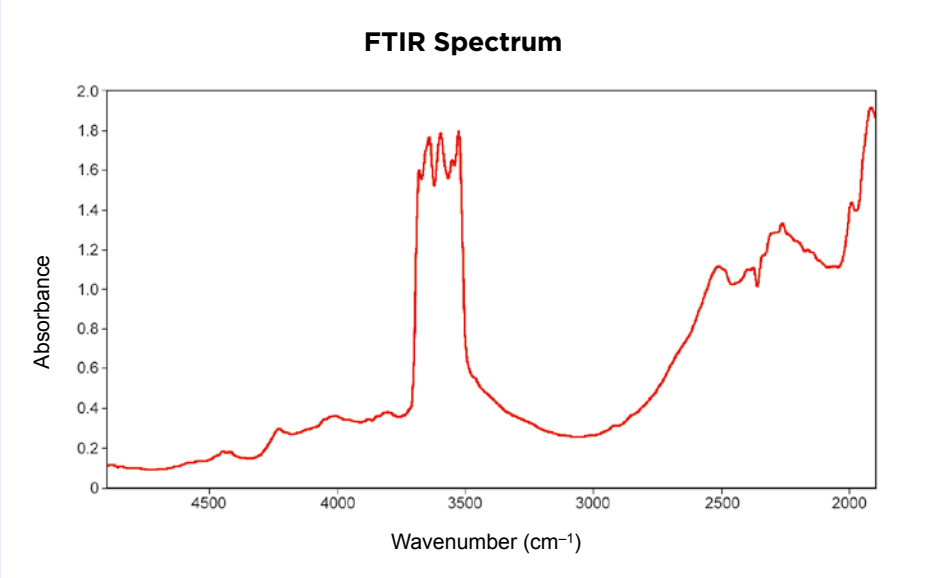

Figure 24: A strong absorption band in the mid-infrared region centred at around 3600 cm^{-1} is indicative of a high water content and is typical of hessonite.

Fourier-transform infrared (FTIR) spectroscopy using a Magilabs GemmoFtir showed a distinctive water absorption band centred at around 3600 cm^{-1} (Figure 24), which in these authors' experience is a consistent feature of hessonite.

Kinnaird and Jackson (2000) documented three different types of orange to red garnets from Somaliland: grossular, pyrope and almandine. The grossular was orange-red (i.e. hessonite) with a composition of $Grs_{86.9}And_{9.86}Alm_{2.57}$ (with traces of pyrope and spessartine components), and it contained a cluster of parallel, tubular, partially liquid-filled inclusions. Clark (2014) also documented a hessonite from Somalia, which was orange and had an RI of 1.741; it was described as containing small flake-like inclusions and transparent needle-like and tabular crystals, descriptions consistent with the inclusions noted in the present hessonites. In addition, as in the present samples, the stone examined by Clark (2014) lacked a roiled appearance.

The presence of hessonite in the Daarbuduq area is consistent with the geology of the region. According to the geological map presented by Kinnaird and Jackson (2000), the area is underlain by Proterozoic marbles and other metamorphic rocks of the Mora complex that are intruded by granitic rocks of mainly Cambrian age (500–550 million years old). The interaction between marble and granitic rock is favourable for the formation of skarn, which is a common host rock for grossular.

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Laurentthomasite, a New Gem Mineral

In March 2020, the GIT Gem Testing Laboratory (GIT-GTL) received two greenish blue faceted stones that weighed 0.98 and 1.67 ct for identification (Figure 25a). The stones' owner indicated that they reportedly consisted of a newly described mineral, laurentthomasite, named after the French mineral dealer Laurent Thomas of Polychrom France (www.mindat.org/min-53556.html). The mineral was discovered in Madagascar's Toliara Province, and in April 2019 it was approved by the International Mineralogical Association as a new member of the milarite (osumilite) group—specifically the Mg analogue of milarite ($KCa_2AlBe_2Si_{12}O_{30} \cdot 0.5H_2O$)—with an ideal chemical formula of $KMg_2AlBe_2Si_{12}O_{30}$ and hexagonal symmetry (Ferraris *et al.* 2019).

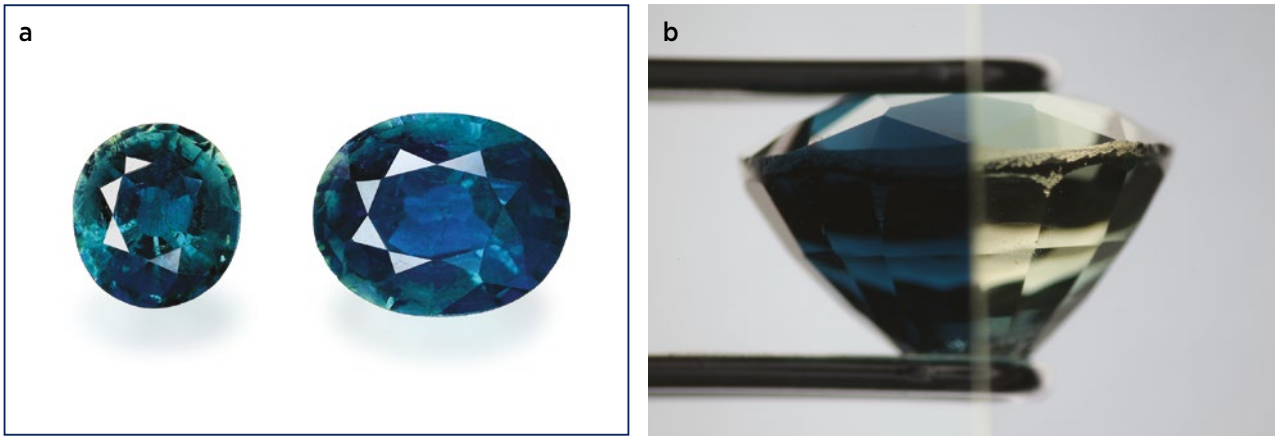

Figure 25: (**a**) The two laurentthomasite gemstones described here weigh 0.98 and 1.67 ct. (**b**) They exhibit strong dichroism in greenish blue and light greenish yellow, as shown here for the 0.98 ct stone. Photos by (a) C. Kamemaganon and (b) P. Ounorn.

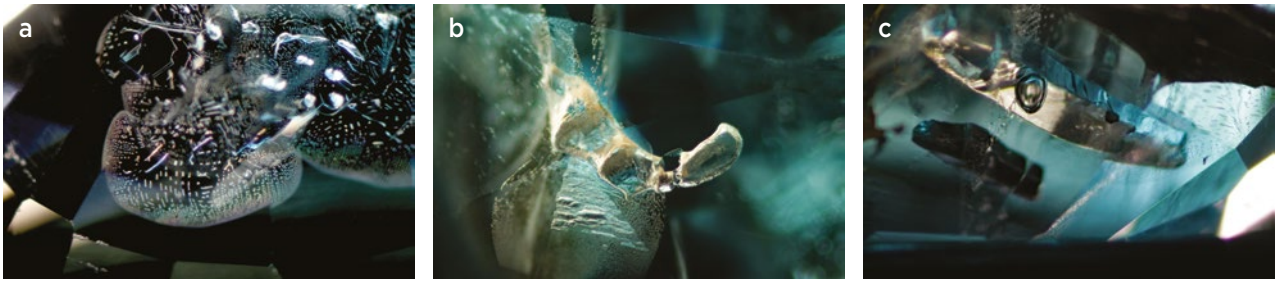

Figure 26: Magnification of the laurentthomasite gems shows (**a**) 'fingerprints', (**b**) negative crystals and (**c**) primary two-phase (liquid-gas) inclusions. Photomicrographs by P. Ounorn and C. Suphan, using darkfield illumination; image widths 3.2 mm (a) and 2.8 mm (b and c).

Both gems consisted of oval mixed cuts. Standard gemmological testing showed the following properties: RIs—1.555–1.560, birefringence—0.005, optic character—doubly refractive and uniaxial positive, hydrostatic SG—2.59–2.63, and fluorescence—inert to long- and short-wave UV radiation. Their most distinct optical characteristic was strong dichroism in greenish blue and light greenish yellow (Figure 25b). Magnification showed various features, such as 'fingerprints', negative crystals and primary two-phase (liquid and gas) fluid inclusions (Figure 26).

Polarised UV-Vis-NIR absorption spectra of the two samples in the range of 300–1500 nm, collected by a PerkinElmer Lambda 1050 spectrophotometer, showed features at 374, 407, 423, 441, 455 and 486 nm, along with a broad band at around 600–1400 nm (Figure 27).

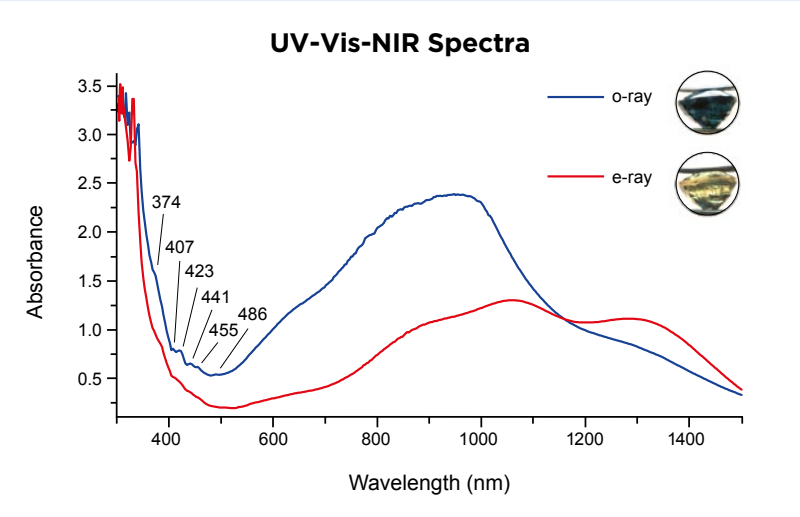

Figure 27: Representative polarised UV-Vis-NIR spectra (recorded here from the 0.98 ct stone) show broad bands centred at around 900 nm for the o-ray and 1040 nm for the e-ray, which are responsible for the strong dichroism of laurentthomasite. The path length of the beam was about 5–6 mm.

The strong dichroism corresponded to differences in the intensity and position of this broad band, which for the o-ray was centred at around 900 nm and for the e-ray was centred at around 1040 nm (and relatively weaker). As such, a distinct spectral window transmits in the blue region for the o-ray, while relatively weaker blue-green-yellow transmission is present in the e-ray direction (again, see Figure 27). (*Editor's note:* Raw data for the UV-Vis-NIR spectra are available in *The Journal*'s online data depository.)

The mid-infrared spectra of both samples, recorded with a Thermo Nicolet 6700 FTIR spectrometer, showed broad transmission in the 7000–2000 cm^{-1} range along with weak absorption features at approximately 5000, 3550, 3447 and 3253 cm^{-1} (Figure 28a). Raman spectra, collected with a Renishaw inVia spectrometer using 532 nm laser excitation, showed dominant peaks (Raman shifts) at 287, 380, 490 and 566 cm^{-1} (Figure 28b). The overall pattern was similar to the reference spectrum of milarite but showed somewhat different positions for some peaks.

Semi-quantitative EDXRF chemical analyses of both stones obtained with an Eagle III spectrometer revealed enriched Si contents, minor amounts of Al, Mg, K, Fe, Sc and Mn, and traces of Rb and Y (Table III). In addition, a significant amount of Be was detected by laser-induced breakdown spectroscopy (LIBS). The data obtained by EDXRF were normalised to 100 wt.% but do not include Be, so the actual content of Si (by far the most abundant element) is expected to be somewhat lower than the amount shown in Table III. Overall, the compositions we obtained are consistent with the chemical formula of an Al-Mg-K-Be silicate mineral (i.e. laurentthomasite) containing minor amounts of Fe, Sc and Mn.

Table III: Semi-quantitative normalised EDXRF chemical data for laurentthomasite.*

Oxides (wt.%)	0.98 ct	1.67 ct
SiO_2	83.08	80.72
Al_2O_3	3.70	4.38
Sc_2O_3	2.40	2.21
Y_2O_3	0.54	0.56
Fe_2O_3	2.37	2.87
MnO	1.26	1.66
MgO	3.39	3.97
K_2O	2.87	3.21
Rb_2O	0.39	0.42
Sum	100.00	100.00

* Be cannot be detected by EDXRF, so the Si data shown here are believed to be too high.

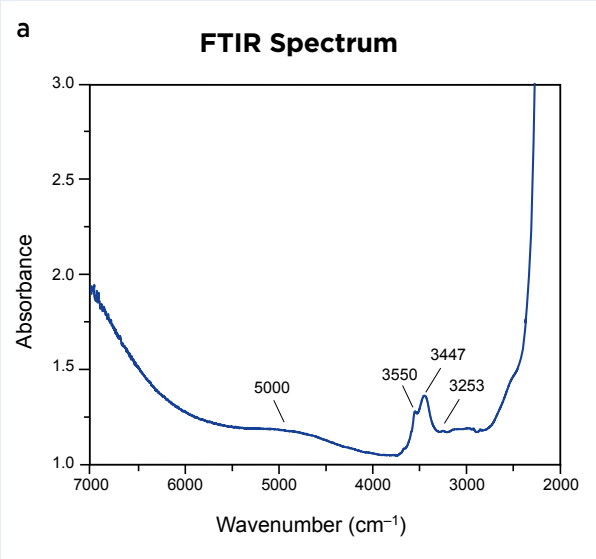

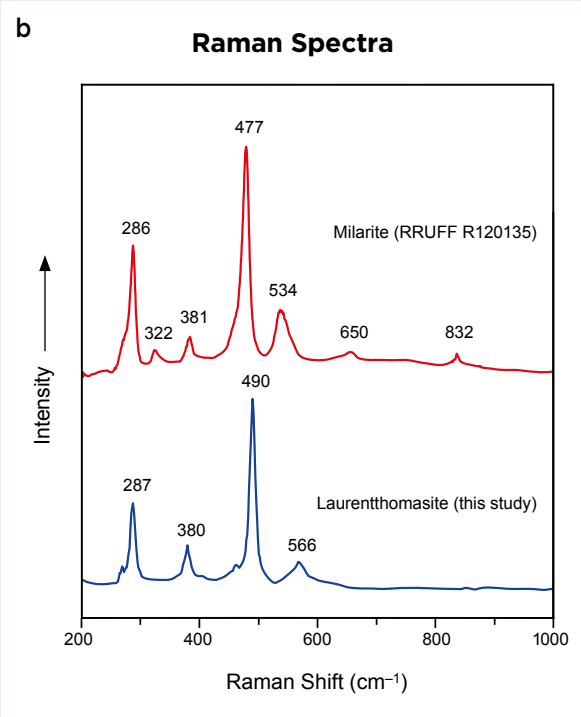

Figure 28: (**a**) The mid-IR spectrum of laurentthomasite shows weak absorptions at approximately 5000, 3550, 3447 and 3253 cm^{-1}. (**b**) The Raman spectrum of laurentthomasite resembles that of a milarite reference spectrum, with a shift in some peak positions.

Table IV: Properties of laurentthomasite.

Property	This study	C. Ferraris (pers. comm. 2020)
Colour	Greenish blue	Greenish blue
Pleochroism	Very strong, in greenish blue and light greenish yellow	Very strong, in 'cobalt' blue and greenish yellow
Optic character	Doubly refractive (uniaxial +)	Doubly refractive (uniaxial +)
RI	1.555–1.560 (birefringence 0.005)	1.540–1.545 (birefringence 0.005)
SG	2.59–2.63	2.66
Hardness (Mohs)	Not determined	Approximately 6
Cleavage	Not observed	Poor
Fluorescence	Inert to both long- and short-wave UV	Inert to both long- and short-wave UV
Inclusions	Negative crystals, 'fingerprints', primary two-phase (liquid-gas) inclusions	Dark elongated crystals (Fe-rich oxides)
UV-Vis-NIR spectrum	Absorption peaks at 374, 407, 423, 441, 455 and 486 nm with a broad absorption band at around 600–1400 nm	Not reported
FTIR spectrum	Broad transmission in the 7000–2000 cm^{-1} range with weak absorption features at about 5000, 3550, 3447 and 3253 cm^{-1}	Not reported
Raman spectrum	Peaks at 287, 380, 490 and 566 cm^{-1}	Not reported
Chemical composition	Al-Mg-K-Be-Fe-Sc-Mn silicate	$(K,Na,Y,Ca)(Mg,Sc,Fe^{2+},Mn)_2[(Be,Al,Mg,Fe^{3+})_2(Si,Al)_{12}O_{30}]$

A summary of the properties obtained for the laurentthomasite samples we examined is presented in Table IV and compared to data supplied by C. Ferraris (pers. comm. 2020; further information to be published in a future mineralogical article). The gemmological characteristics are similar except for somewhat higher RI and lower SG values shown by the two stones examined in the present study. Furthermore, the chemical data we obtained by EDXRF and LIBS analyses are consistent with the formula of laurentthomasite. Moreover, the Raman spectrum indicates a close association with milarite. Although the gemmological properties of laurentthomasite are similar to those of milarite (cf. www.gemdat.org/gem-2710.html), laurentthomasite has distinctly different colour/pleochroism than milarite, which is colourless to pale yellow or green.

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Green Orthoclase with Chatoyancy from Vietnam

Gem-quality green feldspar from Vietnam is commonly traded as amazonite, but rather than being a variety of microcline it is actually orthoclase (Ponahlo *et al.* 2001; Laurs *et al.* 2005; Huong *et al.* 2012). Most of this material has limited transparency and is therefore suitable for cabochons or carvings, although rare transparent material has been faceted into attractive gemstones. In 2008, one of the present authors (RH) obtained some samples of green orthoclase from the Minh Tien pegmatites during fieldwork in the Luc Yen District of Yen Bai Province in northern Vietnam. These pegmatites are also known as a source of colourful tourmaline, as well as smoky quartz and citrine (Nguyen *et al.* 2010).

Some of the samples obtained by author RH displayed a sheen effect that suggested they could show chatoyancy when polished as cabochons, and cutting of this material yielded two cat's-eye orthoclase gems weighing 13.18 ct (22.50 × 12.80 mm) and 47.61 ct (26.10 × 19.50 mm; see Figure 29). Their RIs were 1.519–1.524 (birefringence of 0.005) and SG values were 2.45 and 2.51. The stones were inert to long-wave UV radiation, but showed strong blue-white fluorescence to short-wave UV. The chatoyancy displayed by both cabochons was caused by aligned voids and channels (e.g. Figure 30).

The previously known occurrences of green orthoclase in the Minh Tien area have been exhausted and nowadays this material is only rarely encountered in the trade. However, light green orthoclase imitations are sometimes offered at the local gem market in Luc Yen, including transparent fluorite and included pieces of glass.

Drs Radek Hanus and Ján Štubňa

Figure 30: The cat's-eye effect in the Vietnamese orthoclase is caused by linear arrays of voids and channels. Photomicrograph by R. Hanus; image width 2.8 mm.

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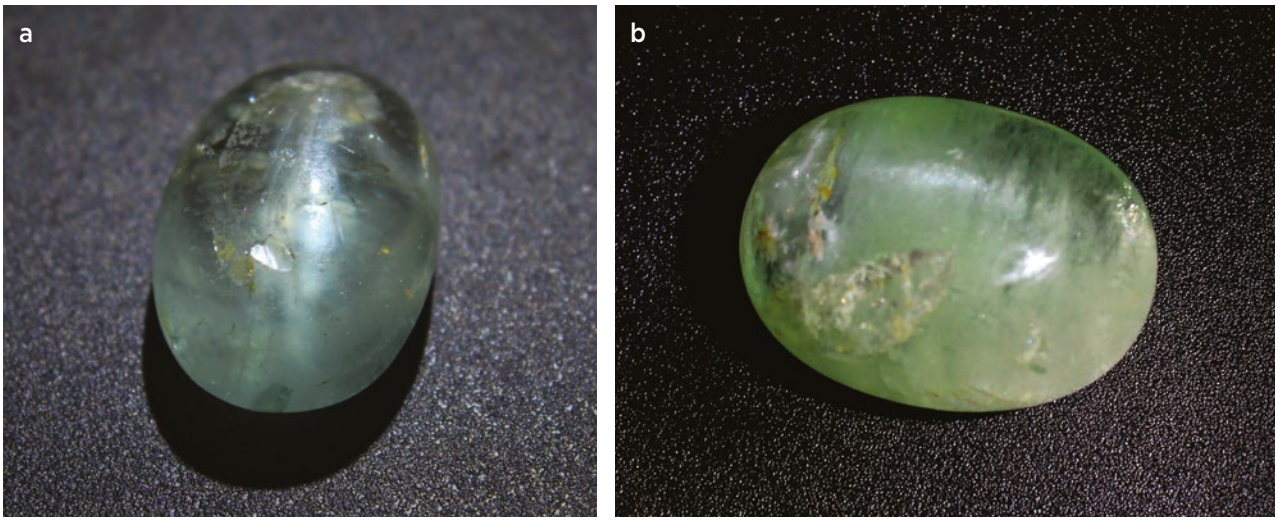

Figure 29: These two cabochons of orthoclase from Vietnam display chatoyancy. The stones weigh (**a**) 13.18 ct and (**b**) 47.61 ct. Photos by J. Štubňa.

Faceted Proustite from Chañarcillo, Chile

Proustite (Ag_3AsS_3), and its antimony analogue pyrargyrite (Ag_3SbS_3), are commonly known as *ruby silver*. They both are deep red and display an adamantine to submetallic lustre, although proustite tends to be more transparent and a lighter red than pyrargyrite. Proustite forms particularly attractive crystal clusters that are highly prized by mineral collectors, but they are very difficult to obtain:

> Good proustites are almost impossible to field collect and are typically available only from old collections or once-a-century type finds in operating silver mines. Consequently, this much-revered mineral…exemplifies one of the truly difficult-to-acquire collectible species. (Cook 1996, p. 345)

According to Cook (1996), collectible proustite crystals are found in Canada, USA, Mexico, Peru, Chile, Czech Republic, Germany, France, Italy (Sardinia) and Russia (Siberia). More recently, Morocco has also produced high-quality specimens. The finest proustites are widely regarded as coming from the Dolores silver mine in the Chañarcillo District of northern Chile. The district was discovered in 1832, reached maximum production during approximately 1860–1880, and continued to be mined in underground workings until the early 20th century (Sillitoe 2007). Proustite specimens from Chañarcillo have found their way into private and museum collections worldwide, and although faceted gemstones are very rare, Hyršl (2003) indicated that gems from this locality are known to weigh up to 55.48 ct.

Given the scarcity of fine-quality proustite today—as either specimen- or facet-grade material—this author was surprised to see a recently faceted 43.21 ct Chañarcillo proustite at the booth of Pala International (Fallbrook, California, USA) during the February 2020 Tucson gem shows. According to Bill and Carl Larson, the original rough piece was traded out of an old museum collection and then passed through another dealer before they acquired it. Since it consisted of a broken piece that was not very desirable as a mineral specimen (Figure 31a), the Larsons assessed its potential gem value and determined that it contained a large area that was transparent enough for faceting. The piece was entrusted to Tim Condron (InOro Gems and Jewels, Sedona, Arizona, USA). Preforming the rough (Figure 31b, c) was challenging due to the brittle nature of proustite (which is also quite soft, having a Mohs hardness of about 2½) and the difficulty of seeing inside the piece. Other factors that make proustite difficult to facet are its distinct cleavage on $\{10\bar{1}1\}$ and the common occurrence of twinning. In addition, proustite is photochromic, so prolonged exposure to bright light will cause it to darken and acquire a dull tarnish on the surface.

Despite the challenges of working with this material, Condron obtained the 43.21 ct stone shown in Figure 32, along with a 2.49 ct round brilliant. A very light touch was needed when cutting the gems, and Condron used a homemade wax lap for the final polish. The stones contained some feathers, partially healed fractures and growth tubes, and the larger gem also hosted a surface-reaching channel with an angular cross-section.

The red colouration of proustite is best appreciated by passing some transmitted light through the gem (again, see Figure 32). According to Loeffler and Burns (1976), proustite is red because it is a semiconductor material with a band gap of ~16,000 cm^{-1} (or 625 nm). Light wavelengths with energies greater than the band gap are absorbed, while lower-energy wavelengths are transmitted. The band gap of proustite at 625 nm is in the orange region of the spectrum, so only the lower-energy red wavelengths are transmitted.

This instance shows the value of examining rough samples of proustite (or other rare collector's stones) for

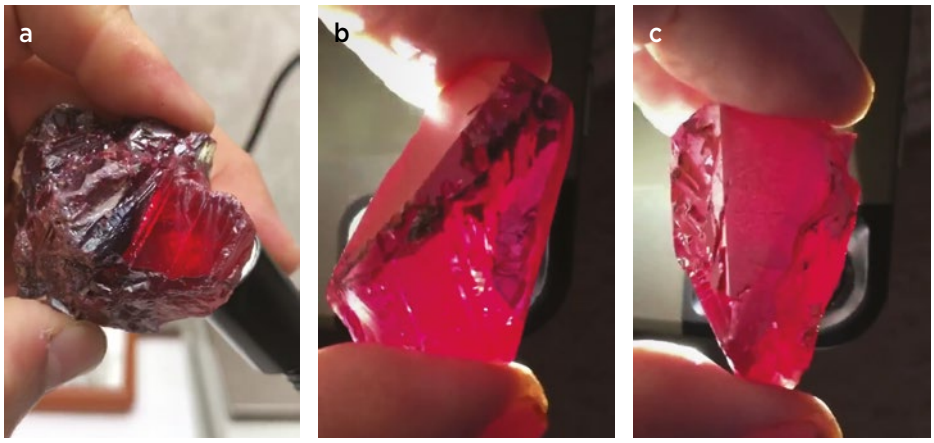

Figure 31: These images (taken from video clips) show (**a**) the original specimen before cutting, and (**b**, **c**) two views of the facetable portion of the proustite during the preforming process. Photos courtesy of Tim Condron.

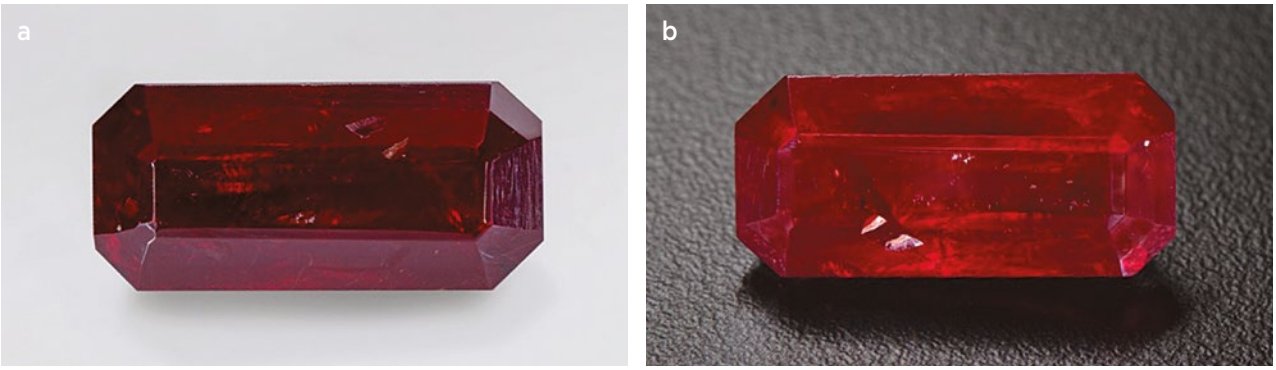

Figure 32: The finished 43.21 ct proustite is shown here (**a**) under diffuse illumination and (**b**) with partially transmitted light. Photos by Orasa Weldon.

their gem potential, particularly when they consist of broken pieces that are undesirable as crystal specimens.

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Visit to a New Blue Spinel Mining Area in Vietnam

In July 2019, this author heard rumours about a major find of blue spinel—supposedly including some fine-quality cobalt-coloured material—that occurred at a new deposit in the Luc Yen District of northern Vietnam. The mine is known as Bai Boui, which means 'Pomelo mine' in Vietnamese. It is located north-west of Thac Ba Lake, about 43 km north of the town of Yen Bai. The initial discovery took place in June 2019 and was soon followed by a mining rush, with up to 500 people digging in the area. This lasted for several weeks until government officials sent police to clear the area. (In recent years, Vietnam has become more restrictive in allowing people to mine, even on their own property.) Local dealers estimated that during July–August 2019, rough and cut blue spinel from this find sold for around USD500,000 at the local gem market in Luc Yen. Some of the production was obtained by Vietnamese dealers and most of the remainder was purchased by gem merchants from Bangkok.

In November 2019, this author and his wife, Darunee (Muy) Pisutadamongkol, went on a buying trip to Vietnam. From the capital city of Hanoi it took 4½–5 hours to drive to Luc Yen. There we visited the gem market, and saw some rough blue to violet spinel represented as being from Bai Boui that was mostly dark coloured, had grey tones and showed a colour shift to purple-grey in incandescent light. When viewed with a Chelsea Colour Filter, most of the spinel showed no reaction, or appeared 'murky' pink in the filter. Also, the spinel displayed almost no fluorescence when viewed with a 380 nm UV laser pointer. By contrast, fine 'cobalt spinel' appears bright red with the Chelsea filter and it fluoresces intense red to long-wave UV radiation. Therefore, it seemed likely that the blue colour of most of the samples examined was due mainly to iron rather than cobalt.

With the help of our local contacts, we arranged a trip to the Bai Boui spinel mine. From Luc Yen we travelled by motorbike for about 40 minutes to where steep karst formations blocked further wheeled travel. We then hiked to the site of the initial mining rush, which was marked by pits of 1–2+ m deep in the alluvial soil between the karst outcrops. Further examination showed that the soil had been removed from almost every spot of the karst that was wide enough for a person to enter. We continued climbing through challenging karst terrain, sometimes crossing bamboo bridges that traversed deep gaps between fins of weathered marble. We passed several scattered areas where digging was evident amongst the jungle growth. After proceeding about 300 m we entered an area that was about 75–100 m wide, spanning an elevation of 30–40 m, which had been cleared of most vegetation and was

Figure 33: (**a**) The Bai Boui spinel mining area is situated in karst terrain. (**b**) Gravels containing blue spinel are mined from narrow ravines in the weathered marble. Photos by (a) D. Pisutadamongkol and (b) D. Blauwet.

being actively worked (e.g. Figure 33). A mining camp consisted of a large tarpaulin with open sides where the miners slept and prepared food. Near the top of the area was a large tarpaulin tank for capturing and storing water, both for drinking and for washing the alluvial gravels. The highest worked area was at an elevation of 475 m and was located at coordinates 22°05.296′N, 104°47.271′E.

Figure 34: The spinel-bearing gravels are hand washed in a small pond using shallow baskets. Photo by D. Blauwet.

Approximately 20 people were working in the area, and most of the digging took place in narrow ravines that were 0.5–2 m wide where alluvial gravels had been deposited. The gravels were washed in a makeshift pond using wide, flat, woven bamboo baskets (Figure 34). We also saw a small hand-turned trommel at the site. Nevertheless, only small amounts of spinel had been recovered recently. Although most of the material we saw was not transparent enough for cutting, it could be sold to artisans in Luc Yen for use in making gem 'paintings'. The asking prices at the mine were too high to even consider starting the bargaining process.

The following day, we returned to the gem market and bought a parcel of small Bai Boui rough spinel for a reasonable price. We also obtained a larger fragment of Bai Boui spinel from our regular supplier that had a redder appearance under the Chelsea filter and also fluoresced, as well as showed a significant colour change. Cutting of this piece in Sri Lanka yielded a 1.15 ct stone, and some smaller gems were also cut from the other rough material (e.g. Figure 35).

Additional blue spinel from Bai Boui will probably enter the market in the future as more of the rough is cut. It is also likely that other small deposits of blue spinel will continue to be found in Vietnam in the future.

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Figure 35: Cutting of some of the rough Bai Boui spinel obtained at the Luc Yen gem market yielded these blue to violet gems (0.42–0.66 ct). Photo by D. Blauwet.

Gemmological and Spectroscopic Characteristics of Different Varieties of Amber from the Hukawng Valley, Myanmar

Xinran Jiang, Zhiqing Zhang, Yamei Wang and Fanli Kong

ABSTRACT: With its broad range of varieties, Burmese amber may show various optical effects, including 'oil gloss' (a red or green surface fluorescence effect) and phosphorescence phenomena. Samples representing golden, brown, red ('blood'), 'beeswax' and 'root' ambers were characterised, as well as those showing red or green 'oil gloss'; many of these also displayed phosphorescence. Common internal features seen with optical microscopy include reddish brown dot-like inclusions in brown amber and flow-banded concentrations of bubbles in 'beeswax' and 'root' ambers (the latter displaying patterns comprised of opaque light- and dark-coloured layers). SEM imagery revealed various scaly or layered structures on freshly broken surfaces, micro-bubbles in some samples and distinctive hollow micro-channels in 'root' amber. Fluorescence spectra recorded luminescence centres at 432 and 470 nm in all samples, and additionally at 650 nm (± 625 nm) in red 'oil gloss' amber. The 'oil gloss' appearance is caused by a mixture of surface fluorescence and the amber's body colour. Phosphorescence spectroscopy showed that the effect was strongest at 525 nm, and the phosphorescence lifetime measured at this emission wavelength ranged from 0.134 to 1.396 seconds.

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Myanmar is a major source of Asian amber (e.g. Figure 1), and Burmese amber (or Burmite) has the longest geological history (about 98 million years old: Shi *et al.* 2012) and most complicated formational patterns compared to material from other localities around the world (Edwards *et al.* 2007; Dutta *et al.* 2011; Zong *et al.* 2014). For millennia, Burmese amber has been highly valued for producing art objects and jewellery (Zherikhin & Ross 2000), and according to the authors' research it currently represents 10%–20% of China's amber market. Burmese amber is also well known for its diversity of inclusions, including invertebrates and plant materials (Laurs 2012; Lu *et al.* 2014), which have multidisciplinary importance to fields such as geology, biology and palaeontology (e.g. Xing *et al.* 2016). Most Burmese amber comes from the Hukawng Valley in northern Myanmar (e.g. Cruickshank & Ko 2003), although other deposits are known near Khamti in the Sagaing Region of northern Myanmar (Liu 2018) and near Hti Lin in the central part of the country (Tay *et al.* 2015).

Several distinctive types of amber are recognised from Myanmar, and some of them have not been found elsewhere. However, their gemmological properties and fluorescence characteristics have not been studied systematically until fairly recently (see Jiang *et al.* 2017, 2018, 2019; Xie *et al.* 2017; Xiao & Kang 2018—all in Chinese). In this study, we characterise different types of Burmese amber by observing their micro-structures as well as fluorescence and phosphorescence spectra to explain their appearance and optical effects.

Figure 1: This large faceted Burmese amber weighs 42.33 ct and shows the attractive appearance of golden amber from Myanmar. Photo by Mark Smith, Thai Lanka Trading Ltd. Part., Bangkok, Thailand.

Types of Burmese Amber

Burmese amber can be broadly divided into two main groups, according to whether it is mostly transparent or opaque. The mostly transparent ambers are classified according to their colour into golden, brown and red (or 'blood') varieties (Figures 2a–c), with brown being the most common. The red colour of 'blood' amber is caused by oxidation and is concentrated near the surface; when such material is sliced, the golden colour of the interior becomes visible (Figure 2d). If the coloured layer is particularly dark, it is called 'black' amber (Xiao *et al.* 2014; Zhang *et al.* 2017).

There are two main opaque types of amber found in Myanmar: 'beeswax' amber, which is a mixture of opaque and transparent ambers displaying flow patterns (Figure 3a); and 'root' amber, which shows a mixture of colours (e.g. white, yellow, brownish yellow, orange and/or brown) in patterns that resemble wood or tree roots (Figure 3b).

Some transparent ambers display an 'oil gloss' surface fluorescence effect when observed in sunlight and under some artificial light sources. These samples may show various body colours when viewed over a white background (yellow, greenish yellow, brown and brownish

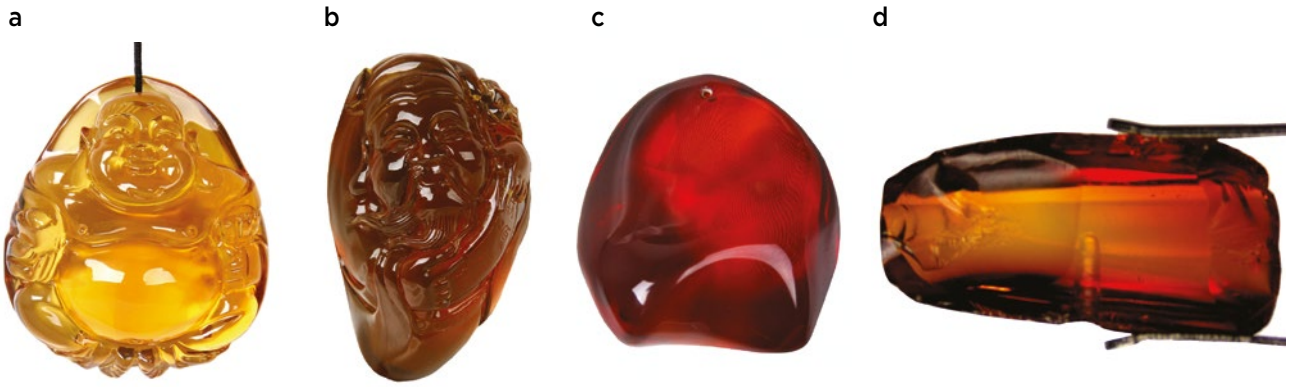

Figure 2: Transparent Burmese amber may be divided into various colour categories, such as (**a**) golden, (**b**) brown, which is the most common colour variety, and (**c**) 'blood' or red amber. (**d**) When 'blood' amber is sliced, the golden colour of the interior becomes visible, since the red colouration is only present near the surface. The samples weigh (a) 156.15 ct, (b) 146.60 ct, (c) 105.60 ct and (d) 2.83 ct. Photos a–c reprinted with permission from Wang (2018); image d by X. Jiang.

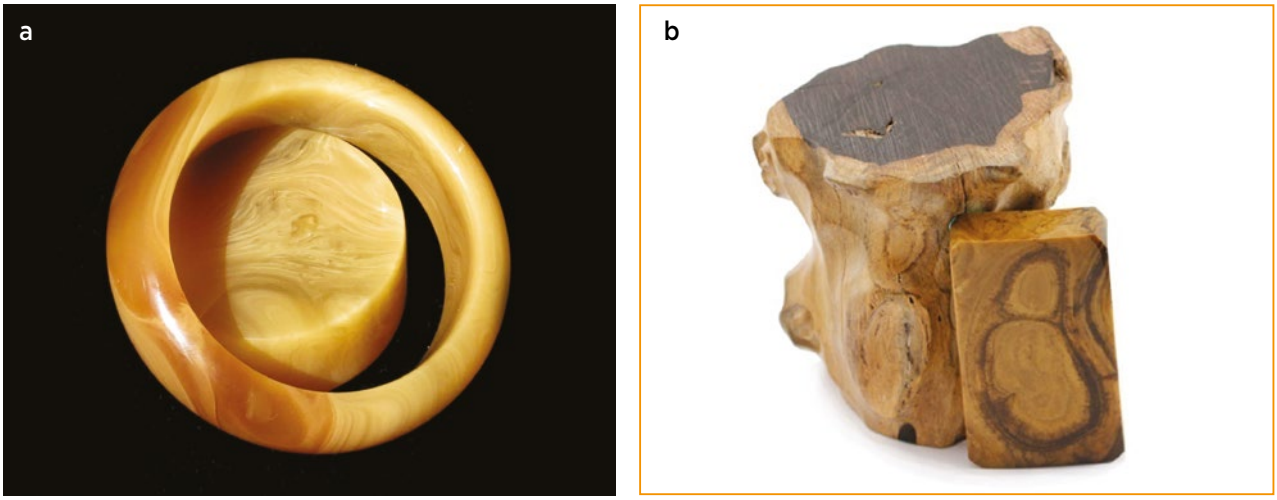

Figure 3: The two types of opaque Burmese amber consist of (**a**) 'beeswax' and (**b**) 'root' varieties. The total weight of the samples is (a) 78.77 g and (b) 25.20 g. Photos reprinted with permission from Wang (2018).

red), but appear to exhibit different surface hues over a black background. For example, amber with a greenish yellow body colour may show a reddish surface appearance when viewed against a black background (Figure 4a, b). Also, reddish brown amber can show a greenish surface appearance against a black background (Figure 4c), and is therefore sometimes known colloquially as 'chameleon' amber. Such amber is often referred to in China as having 'machine-oil gloss' because its appearance may resemble that of machine oil.

Burmese amber may also show phosphorescence. After being illuminated by bright light for a certain time period (typically at least several seconds), the exposed area will display greenish yellow phosphorescence for a short time (typically 0.5–1 s; see Figure 4d). This phenomenon may occur in various types of transparent

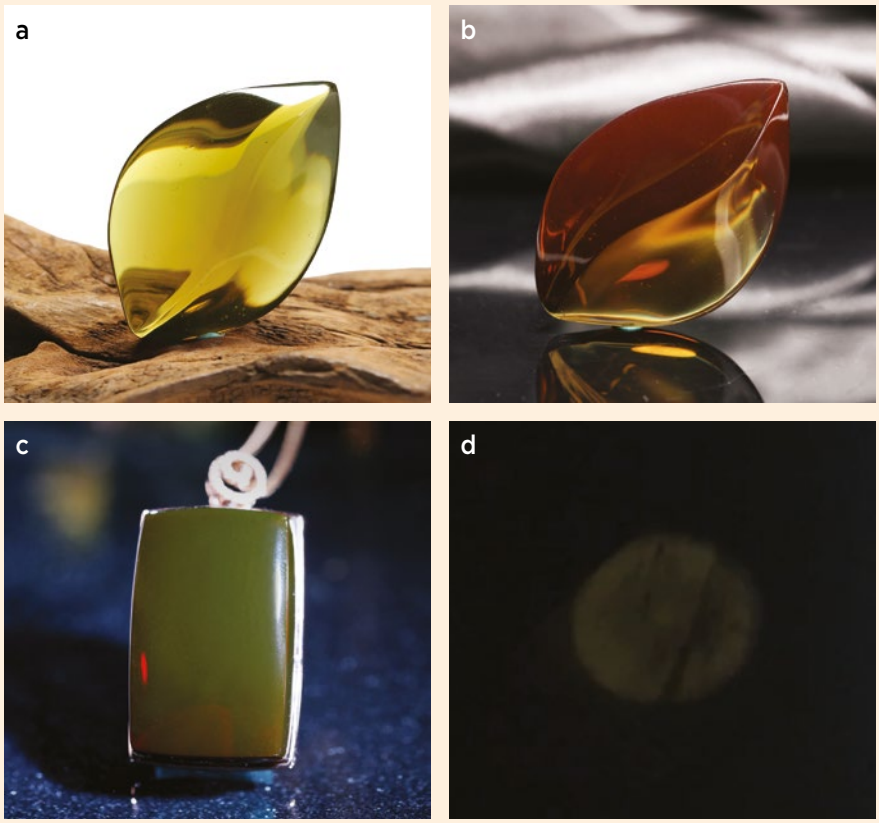

Figure 4: Some Burmese amber displays an 'oil gloss' effect, in which the stone's true body colour is seen against a light background, but a different colour appearance due to a surface fluorescence effect is observed when the amber is viewed against a dark background. (**a**) This 81.75 ct sample has a greenish yellow body colour visible against a white background, but (**b**) it appears reddish against a dark background. (**c**) The 13.75 ct amber in this pendant has a reddish brown body colour, but it appears green when viewed over a dark background. (**d**) Transparent Burmese amber (here, 96.35 ct) also commonly displays greenish yellow phosphorescence. Photos a–c reprinted with permission from Wang (2018); image d by X. Jiang.

Figure 5: This light yellow Burmese amber (**a**) appears greenish in daylight-equivalent lighting (**b**) due to its blue long-wave UV fluorescence (**c**). The sample weighs 20.21 ct; photos by X. Jiang.

Burmese amber and is commonly known as a 'glow-in-the-dark' effect.

Pale-coloured Burmese amber with blue fluorescence may appear green (from the combination of blue luminescence and yellow body colour; see Figure 5) or even blue when viewed in daylight, and is therefore sometimes called 'blue' amber; such material is known from various world localities and has been well documented (e.g. Chekryzhov *et al.* 2014; Jiang *et al.* 2017), so it is not included in the present article.

MATERIALS AND METHODS

Samples

Nine representative amber samples from the Hukawng Valley in Myanmar were studied for this report (see Table I and Figure 6). These included three pieces of transparent amber (golden, brown and 'blood'), both types of opaque amber (one 'beeswax' piece and two 'root' samples) and three 'oil gloss' ambers (two showing red 'oil gloss' and one with green 'oil gloss'). Phosphorescence was exhibited by most samples, but not by the three opaque pieces or the 'blood' amber.

Table I: General gemmological characteristics of the nine Burmese amber samples.

Type	Sample ID	Body colour	Optical effects	Transparency	SG	Internal features
Golden amber	JP	Golden	Phosphorescence	Transparent	1.04	Reddish brown impurities and calcite-filled fissures
Brown amber	ZP	Reddish brown	Phosphorescence	Mostly transparent	1.04	Reddish brown dot-like inclusions directionally arranged along flow patterns
'Blood' amber	XP	Red (surface)	–	Transparent	1.05	No features seen
'Beeswax' amber	ML	Yellowish white	–	Opaque	1.04	Yellowish white flow patterns, black inclusions
'Root' amber	GP-1	Yellowish white and yellowish brown	–	Mostly opaque	1.02	Conspicuous yellowish white flow patterns with opaque and transparent zones
	GP-2	Yellowish white	–	Opaque	1.04	Mottled structure
'Oil gloss' amber	GX-1	Reddish brown	Red 'oil gloss', phosphorescence	Transparent	1.03	Fissures resembling a bird feather or displaying iridescence
	GX-2	Greenish yellow	Red 'oil gloss', phosphorescence	Transparent	1.03	Nearly free of inclusions
	GX-3	Reddish brown	Green 'oil gloss' (or 'chameleon'), phosphorescence	Transparent with opaque impurities	1.05	Dark opaque impurities (foreign objects)

Figure 6: Burmese amber samples studied for this report include (**a**) golden, (**b**) brown, (**c**) 'blood', (**d**) 'beeswax', (**e** and **f**) 'root', (**g** and **h**) red 'oil gloss' and (**i**) green 'oil gloss' varieties. The colour appearance of the 'oil gloss' varieties is shown against both white and black backgrounds. Photos by X. Jiang.

Experimental Methods and Test Conditions

Internal features in all samples were examined with a gemmological microscope. In addition, the structural characteristics in five of the samples—consisting of the golden, brown and 'beeswax', as well as the two 'root' ambers—were studied with scanning electron microscopy (SEM), which was performed at the State Key Laboratory of Geological Processes and Mineral Resources, China University of Geosciences, Wuhan. The samples were fractured and gold coated to provide surfaces suitable for SEM examination (cf. Zhang & Li 2010). We used an FEI Quanta 200 environmental SEM operating under low vacuum with the following conditions: 20 kV acceleration voltage, 3.5 nm electron beam spot diameter, 1024 × 884 pixels resolution and 12.5–18.3 mm working distance.

Infrared spectroscopy of all samples was performed at the Guangzhou laboratory of the Gemmological Institute, China University of Geosciences. The specular reflection method was used (Kramers-Kronig transformation) with a Bruker Tensor 27 Fourier-transform infrared (FTIR) spectrometer under the following conditions: 220 V scanning voltage, 6 mm raster, 10 kHz scanning rate, 32 scans, 4000–400 cm^{-1} range and 4 cm^{-1} resolution.

The fluorescence of all samples was checked with a standard 4 W long-wave UV lamp. Three-dimensional fluorescence spectroscopy was performed on the five samples showing fluorescence (JP, ZP, GX-1, GX-2 and GX-3) with a Jasco FP-8500 spectrofluorometer at the Gem Testing Center, China University of Geosciences, Wuhan. The parameters included a bandwidth excitation of 5 nm and emission of 5 nm, response time of 10 ms, excitation range of 220–500 nm (5 nm interval), emission range of 240–750 nm (1 nm interval) and scanning velocity of 2,000 nm/min. The data were plotted according to excitation wavelength, emission wavelength and fluorescence intensity, and in addition we generated two-dimensional fluorescence spectra (emission wavelength vs. intensity) for the optimum excitation wavelength of 365 nm and for other excitations (400 and 460 nm). For comparison, we also obtained two-dimensional fluorescence spectra for samples GX-1 and GX-2 with another instrument, a Qspec photoluminescence microspectrometer (405 nm excitation), at the Guangzhou laboratory of the Gemmological Institute, China University of Geosciences.

Transient phosphorescence time-resolved spectroscopy was performed on the same five samples at the Hubei Key Laboratory of Low Dimensional Optoelectronic Materials and Devices, Xiangyang, using an Edinburgh Instruments FLS980 steady-state and transient fluorescence spectrometer with a 60 W xenon lamp (365 nm) as the excitation source. We measured the time-resolved phosphorescence spectra and the phosphorescence lifetime of each sample. The parameters included an emission range of 420–650 nm, test frequency of 100 Hz, monochromatic bandwidth excitation of 20 nm, luminous flux of 1,000, test time-frame of 8 s, trigger delay time of 0.1 ms, step size of 5 nm and a test time at each fixed wavelength of 1 min. The optimum monitoring wavelength for each sample was determined from the results of the transient phosphorescence time-resolved spectra, and the phosphorescence lifetime was then measured at that wavelength (525 nm). Each phosphorescence lifetime test had a frequency of 100 Hz, monochromatic bandwidth excitation of 20 nm, luminous flux of 1,000, test time frame of 4 s and trigger delay time of 0.1 ms. Each test utilised a total of 5,000 photons.

RESULTS

Optical Microscopy: Internal Features

The golden amber showed reddish brown impurities (Figure 7a) and surface-reaching fissures that were filled with a white mineral showing good cleavage (probably calcite; Figure 7b). The brown amber contained concentrations of reddish brown dots that were directionally arranged, resulting in dark flow patterns (Figure 7c). The 'blood' amber sample did not contain any inclusions, and there was no evidence that its red colour was created artificially by heating in the laboratory.

The 'beeswax' amber showed obvious flow patterns, with lighter-coloured bands containing large amounts of bubbles (Figure 7d; cf. Wang *et al.* 2016), as well as black inclusions (Figure 7e). The 'root' amber showed two different types of features: (1) distinctive yellowish white flow patterns that were locally concentric, with well-defined borders between transparent and opaque zones (sample GP-1; see Figure 7f), and (2) a mottled structure (sample GP-2; see Figure 7g).

Of the three samples showing the 'oil gloss' effect, GX-1 contained fissures that in one case resembled a bird feather (Figure 7h) or locally displayed iridescence. Sample GX-2 was nearly free of inclusions, while GX-3 contained some dark impurities (Figure 7i) but lacked the reddish brown dot-like inclusions.

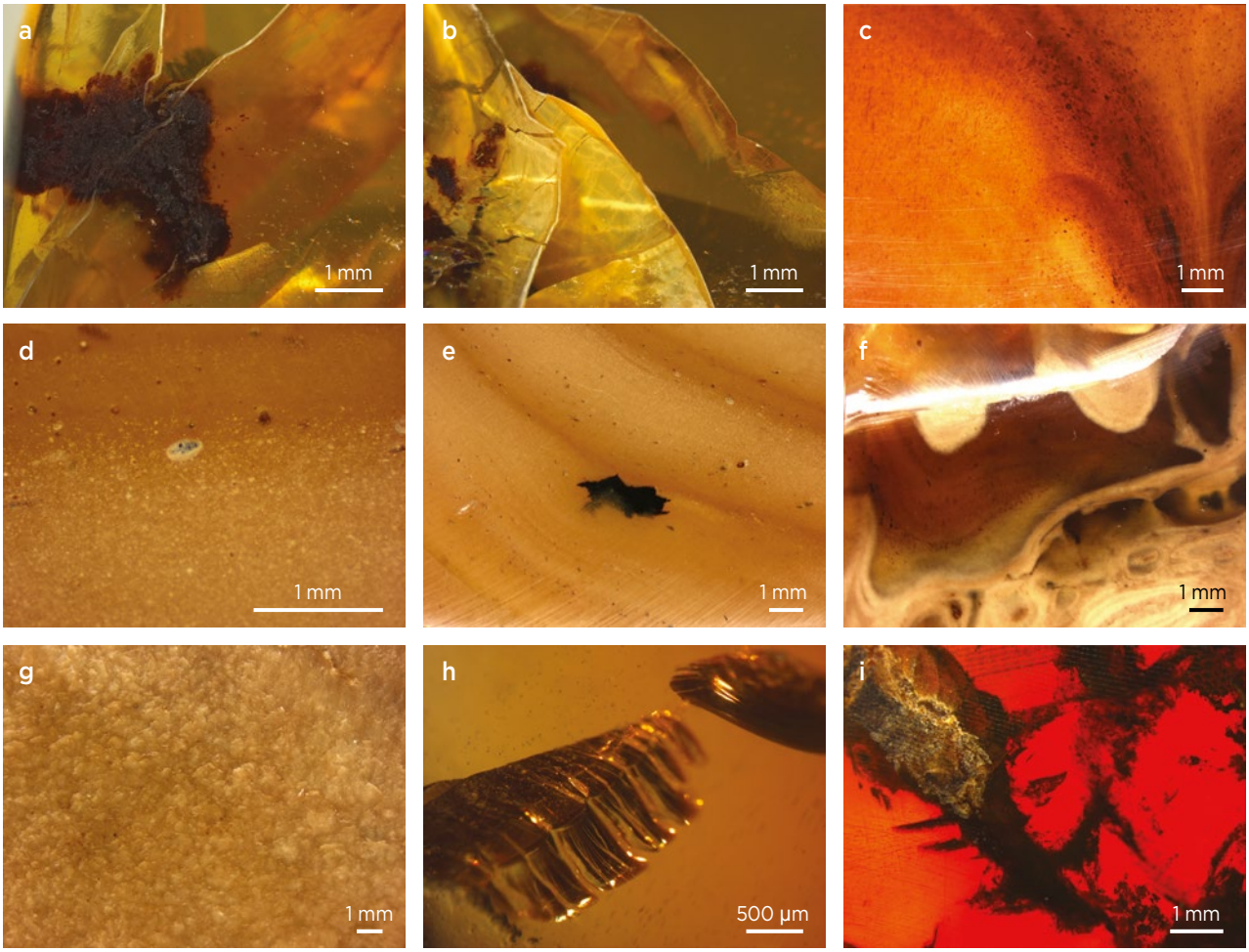

Figure 7: Various types of internal features are seen in the Burmese amber samples examined for this report. The golden amber contains (**a**) reddish brown impurities and (**b**) fractures that are probably filled with calcite. (**c**) The brown amber shows abundant reddish brown dot-like inclusions in a flow-banded arrangement. Internal features in 'beeswax' amber consist of (**d**) abundant bubbles or (**e**) flow patterns and dark inclusions. 'Root' amber may display (**f**) conspicuous flow patterns or (**g**) a mottled structure. (**h**) 'Oil gloss' sample GX-1 contains a fissure resembling a bird feather, while (**i**) GX-3 contains dark impurities. Photomicrographs by X. Jiang.

Electron Microscopy: Structural Characteristics

SEM examination of the golden amber showed a scaly, layered appearance with no bubbles (Figure 8). The surface of the brown amber was smoother, and the dot-like inclusions (which appeared reddish brown with optical microscopy; see Figure 7c) were directionally oriented along flow patterns. The individual dot-like inclusions had oval shapes (Figure 9a) and were of various sizes. Higher magnification of these inclusions revealed that they commonly contained an inhomogeneous texture (Figure 9b), consisting of smooth oval areas within a slightly more scaly-appearing matrix (Figure 9c, d).

The 'beeswax' amber contained locally abundant bubbles along flow layers that corresponded to the lighter-coloured, more opaque bands (Figure 10a, b). The flow layers were probably caused by external

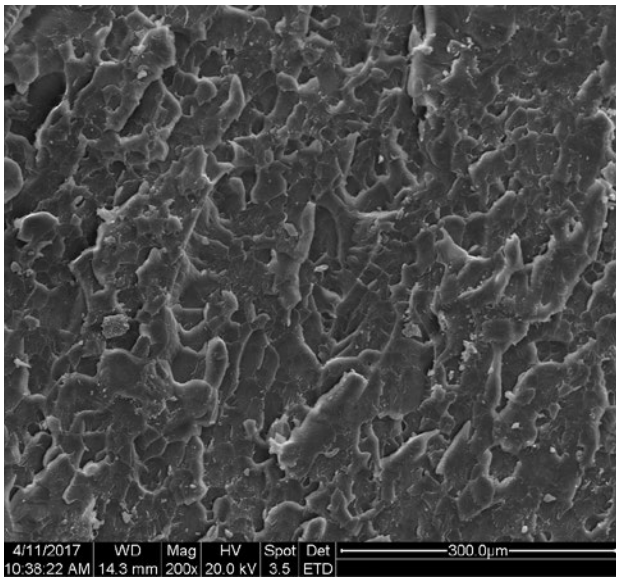

Figure 8: SEM imagery of the golden amber sample reveals a scaly, layered structure. Image by X. Jiang.

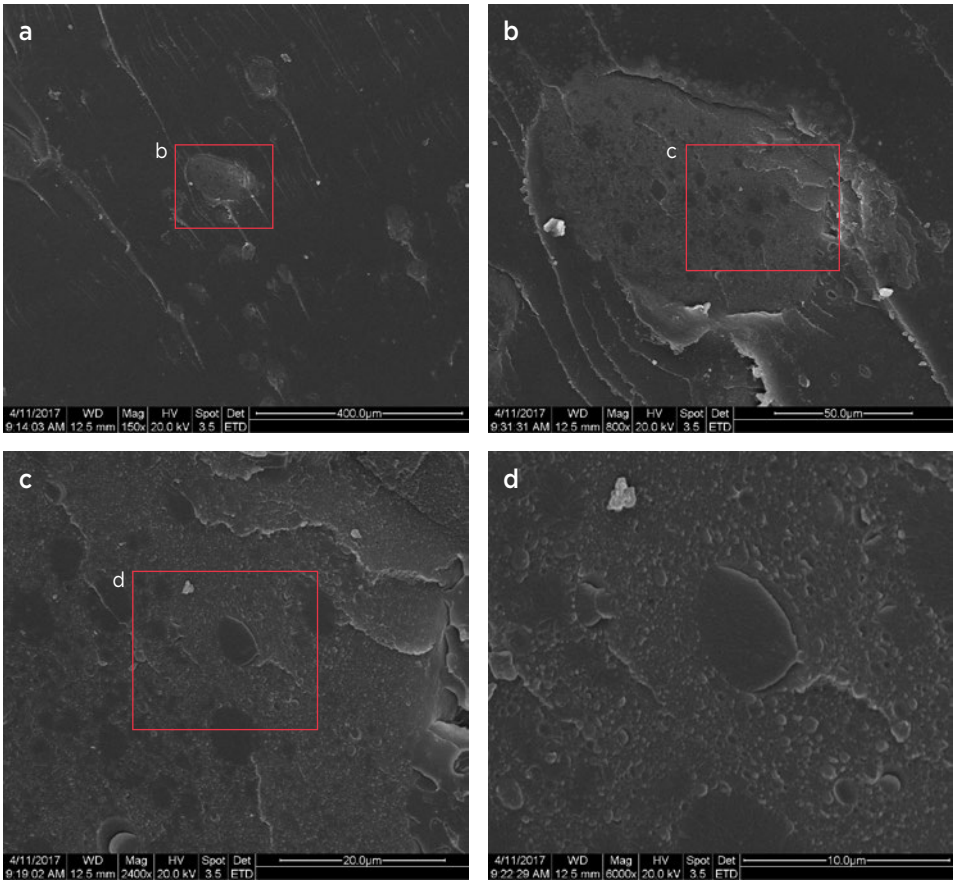

Figure 9: The structure of the reddish brown dot-like inclusions in the brown amber is shown in these successively higher-magnification SEM images, taken at (**a**) 150×, (**b**) 800×, (**c**) 2,400× and (**d**) 6,000×. Images by X. Jiang.

temperature and pressure during burial of the amber, which led to mutual extrusions between adjacent bubbles. The darker, more transparent layers in the 'beeswax' amber lacked bubbles but still showed some evidence of flow layering (Figure 10c).

The two samples of 'root' amber revealed different characteristics. A lighter-coloured, opaque area of sample GP-1 (Figure 11a) contained micro-bubbles showing various shapes and sizes, along with thin, curved, hollow micro-tubes (Figure 11b, right side of image). In some cases, the bubbles occurred alongside the tubes. A layered structure was also observed in the areas containing the bubbles and tubes. An adjacent, more transparent area of this sample appeared mostly featureless in the SEM (Figure 11b, left side). 'Root' amber sample GP-2 was examined in a mottled area that was free of consistent flow patterns (Figure 12). The SEM images showed a fine-grained scaly appearance along with elliptical bubbles of various size, although they were significantly less abundant than in GP-1.

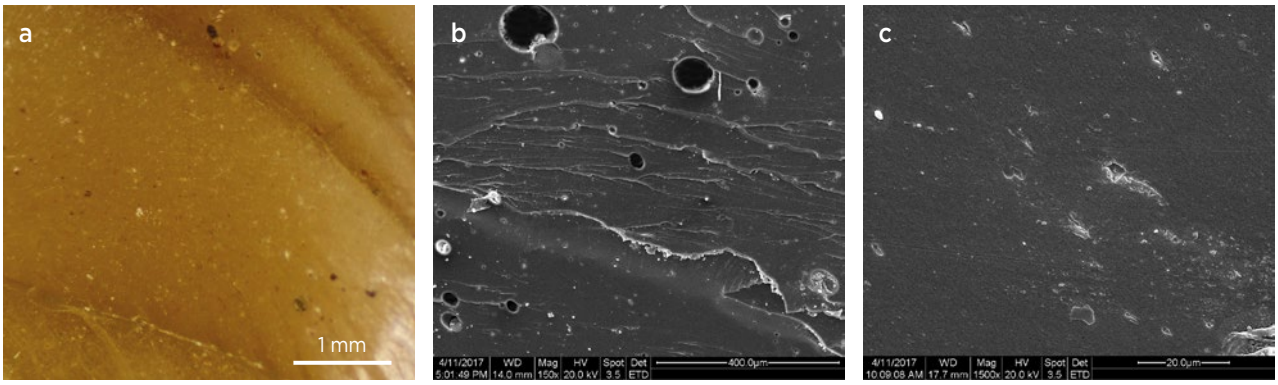

Figure 10: A closer look at the 'beeswax' amber (**a**) with the SEM reveals the microstructure of an opaque zone (**b**), which contains bubbles of various size, and a transparent zone (**c**), which has a more featureless structure. Both areas show flow patterns. Photomicrograph and SEM images by X. Jiang.

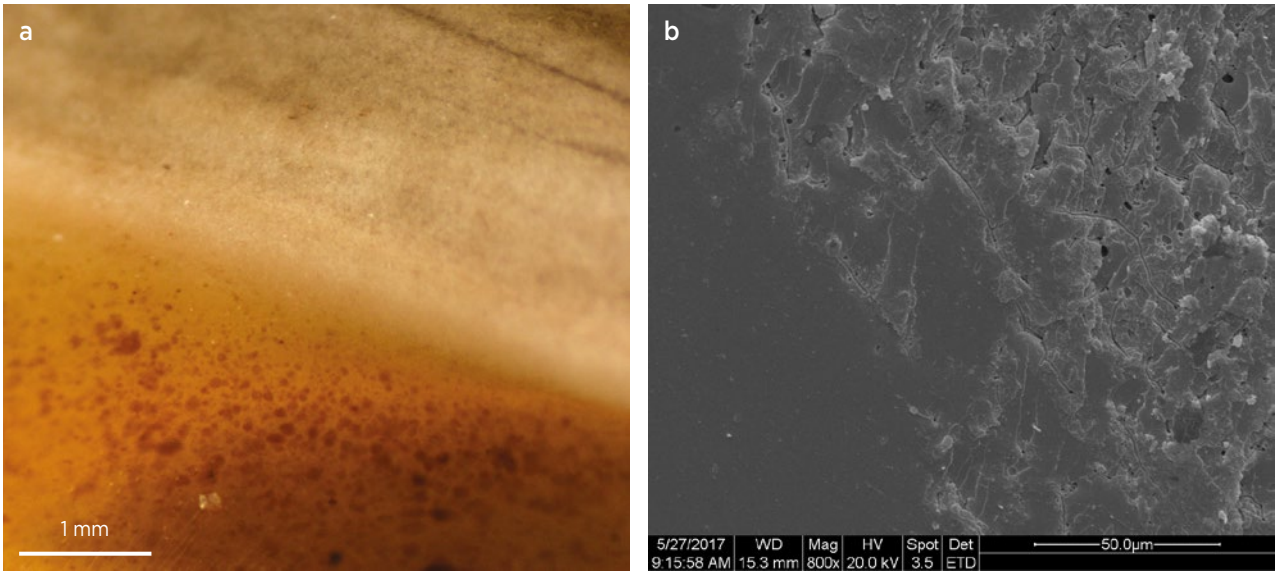

Figure 11: The transitional zone between transparent (lower left) and opaque (upper right) areas of 'root' amber sample GP-1 (**a**) is shown in this SEM image (**b**). The transparent portion appears smooth and featureless, while the opaque zone displays a layered structure with curved hollow micro-tubes between the layers that are locally associated with bubbles. Photomicrograph and SEM image by X. Jiang.

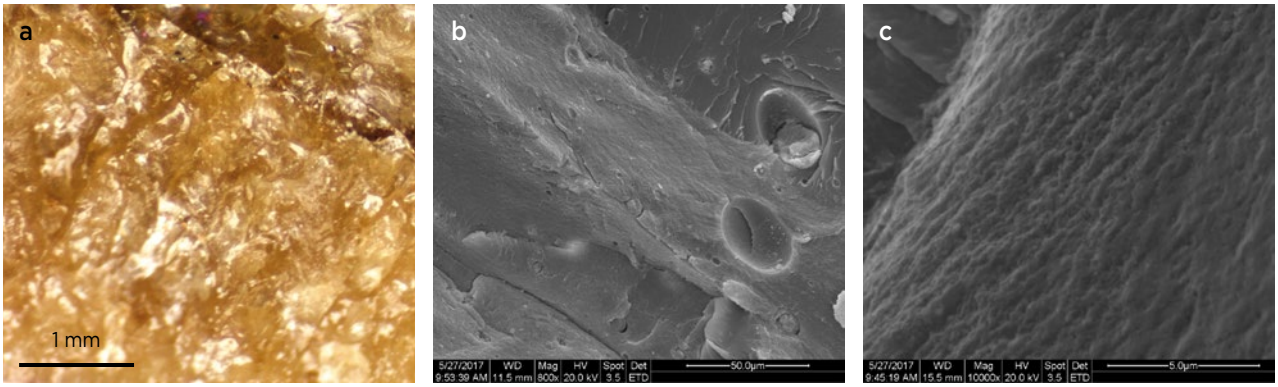

Figure 12: Examination of the mottled area of 'root' amber sample GP-2 (**a**) with the SEM reveals (**b**) heterogeneous surface features with elliptical bubbles of various size and (**c**) a fine-scaly microstructure. Photomicrograph and SEM images by X. Jiang.

Infrared Spectroscopy

The FTIR spectra were highly consistent among the different types of Burmese amber samples that were analysed (Figure 13). Strong bands at around 2928–2930 cm^{-1} and at 2862 cm^{-1} were caused by asymmetric C–H stretching vibrations. Stretching vibrations of the carbonyl (C=O) functional group caused a band at around 1719–1722 cm^{-1}. The bands at 1458 and 1375 cm^{-1} were caused by CH_2–CH_3 and symmetric deformation vibrations, respectively. Thus, the amber was confirmed to be an aliphatic compound, and the bands at 1027–1034 and 972 cm^{-1} were caused by lipid C–O–C and C–O stretching vibrations, respectively (Marrison 1951; Lambert & Frye 1982; Abduriyim *et al.* 2009; Wang *et al.* 2015, 2017; Lan *et al.* 2017).

Fluorescence and Phosphorescence

The golden and brown ambers displayed violetish blue long-wave UV fluorescence (Figure 14a, b), which is the most common luminescence colour in Burmese amber. The two samples displaying a red 'oil gloss' effect showed a peculiar magenta or violetish purple fluorescence (Figure 14c, d), while the amber displaying green 'oil gloss' showed whitish blue luminescence (Figure 14e).

The 'blood' amber and the opaque samples were inert to long-wave UV radiation, and they were also inert to the 220–500 nm excitation range utilised for fluorescence spectroscopy. Greenish yellow phosphorescence was noted in all of the transparent samples except for the 'blood' amber.

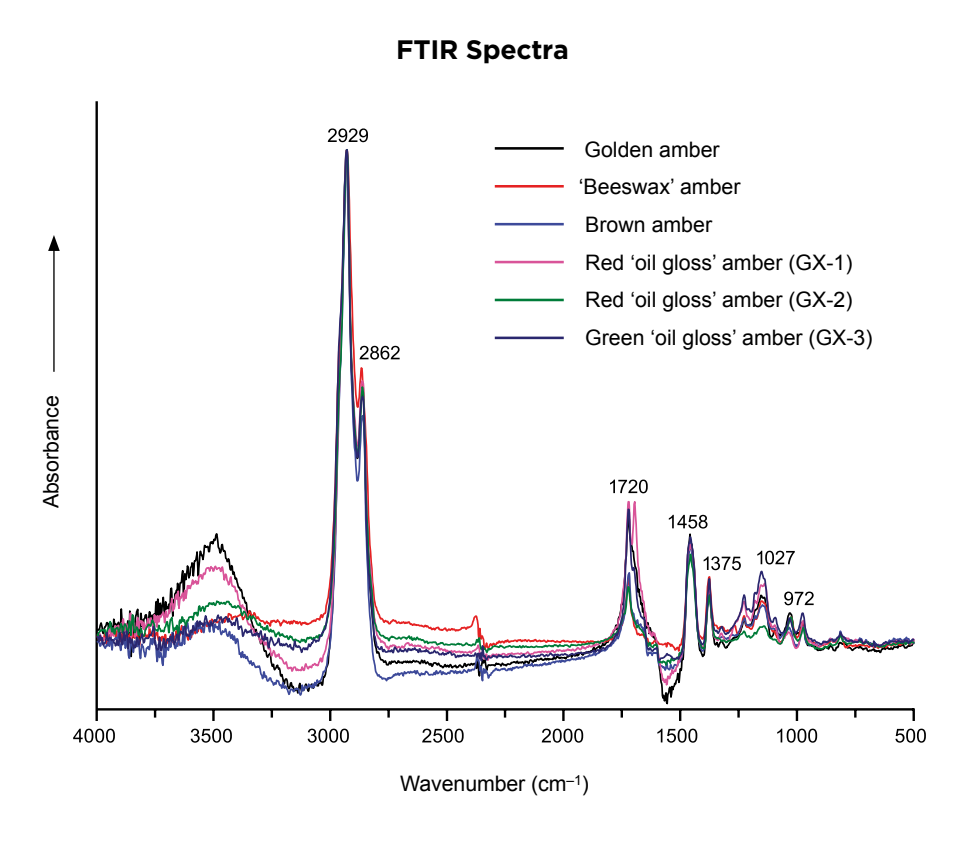

Figure 13: FTIR spectra of the six analysed specimens of Burmese amber show similar features.

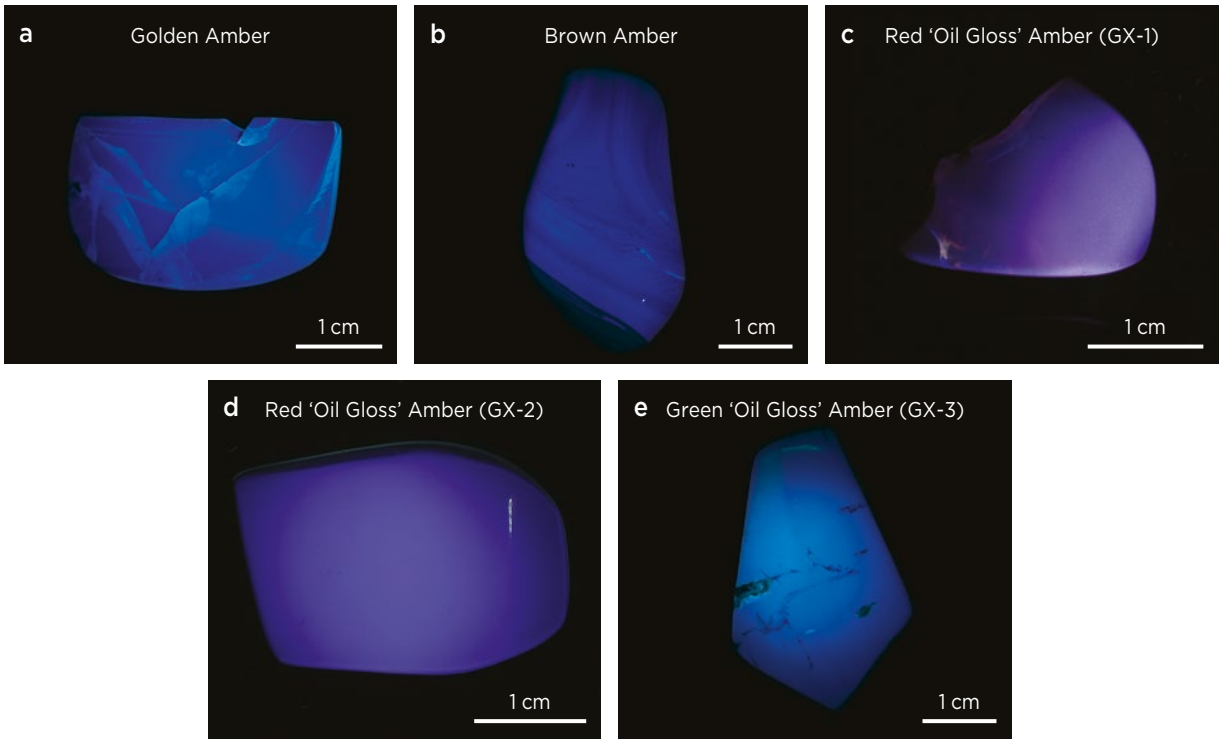

Figure 14: Viewed with long-wave UV fluorescence, Burmese amber typically fluoresces violetish blue (**a** and **b**). Less commonly, it displays magenta (**c**), violetish purple (**d**) or whitish blue (**e**) luminescence. Photos by X. Jiang.

Fluorescence Spectroscopy. Fluorescence spectra obtained for the golden and brown samples, as well as the three ambers showing the 'oil gloss' effect, recorded various luminescence centres (Figures 15–18 and Table II). Two luminescence centres in the 320–350 nm range fell outside the range of visible light. Other luminescence centres at 390 (±3) nm, 410 (±2) nm, 432 (±3) nm and 470 (±4) nm in the violet-to-blue region of the spectrum were recorded in all samples except for the amber displaying green 'oil gloss'. By contrast, the green 'oil gloss' sample showed emissions in the green region with increasing excitation wavelength (Figure 15e).

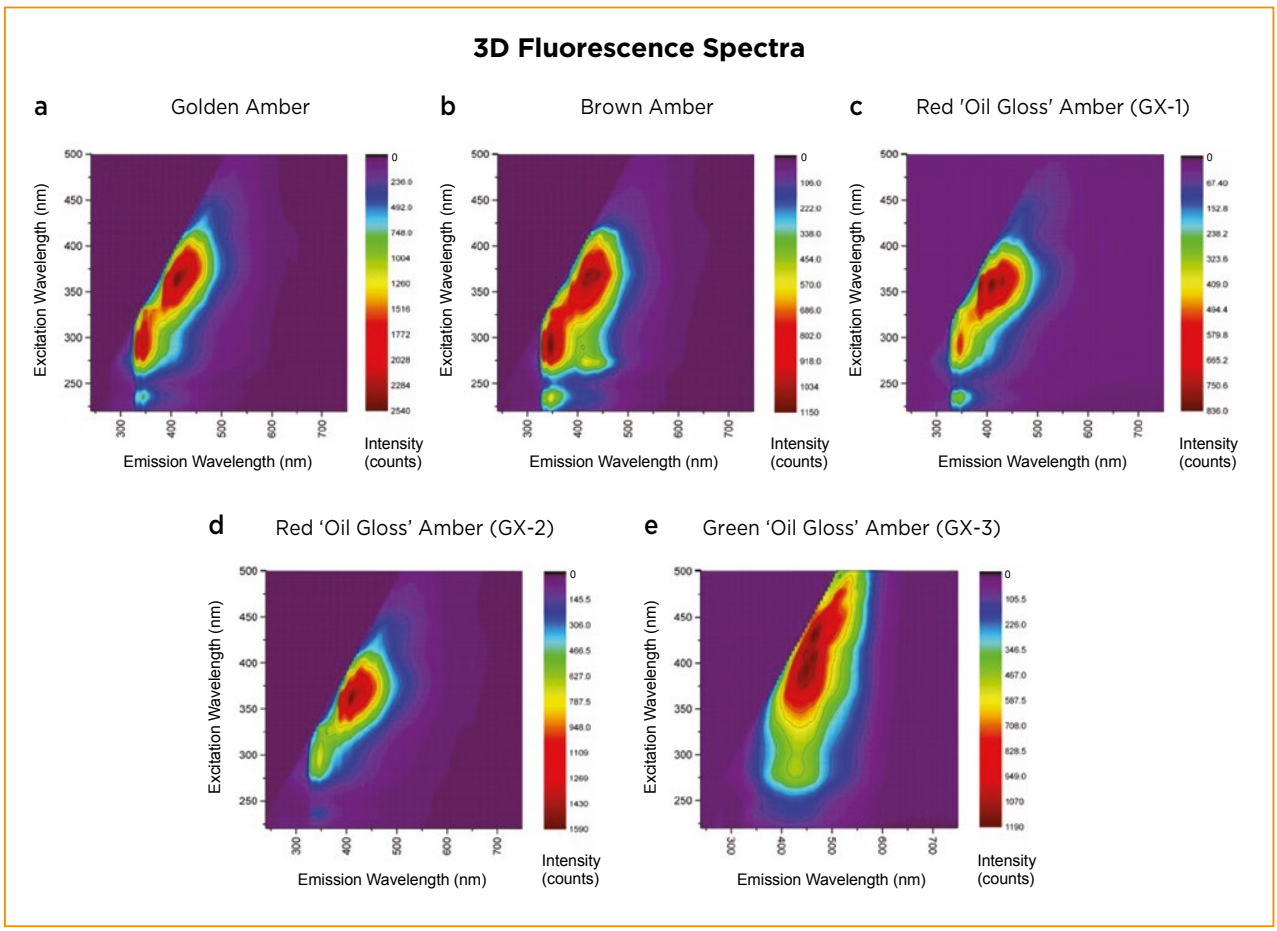

Figure 15: Three-dimensional fluorescence spectra are shown for the five Burmese amber samples in Figure 14: (**a**) golden, (**b**) brown, (**c**) red 'oil gloss' GX-1, (**d**) red 'oil gloss' GX-2 and (**e**) green 'oil gloss' GX-3. The spectra reveal luminescence centres at various wavelengths (see Table II for specific centres in each sample).

Table II: Long-wave UV fluorescence, luminescence centres (in the visible range) and phosphorescence lifetimes of Burmese amber.

Sample ID	Type	Long-wave UV fluorescence	Luminescence centres (nm)	Phosphorescent lifetimes (s)
JP	Golden amber	Violetish blue	410, 432, 470	t_1 = 0.375, t_2 = 1.396
ZP	Brown amber	Violetish blue	410, 432, 470	t_1 = 0.265, t_2 = 1.059
GX-1	Red 'oil gloss'	Magenta	410, 432, 470, 625, 650	t_1 = 0.134, t_2 = 0.447
GX-2	Red 'oil gloss'	Violetish purple	410, 432, 470, 650	t_1 = 0.154, t_2 = 0.607
GX-3	Green 'oil gloss' (or 'chameleon')	Whitish blue	432, 470, 503, 532	t_1 = 0.134, t_2 = 0.706

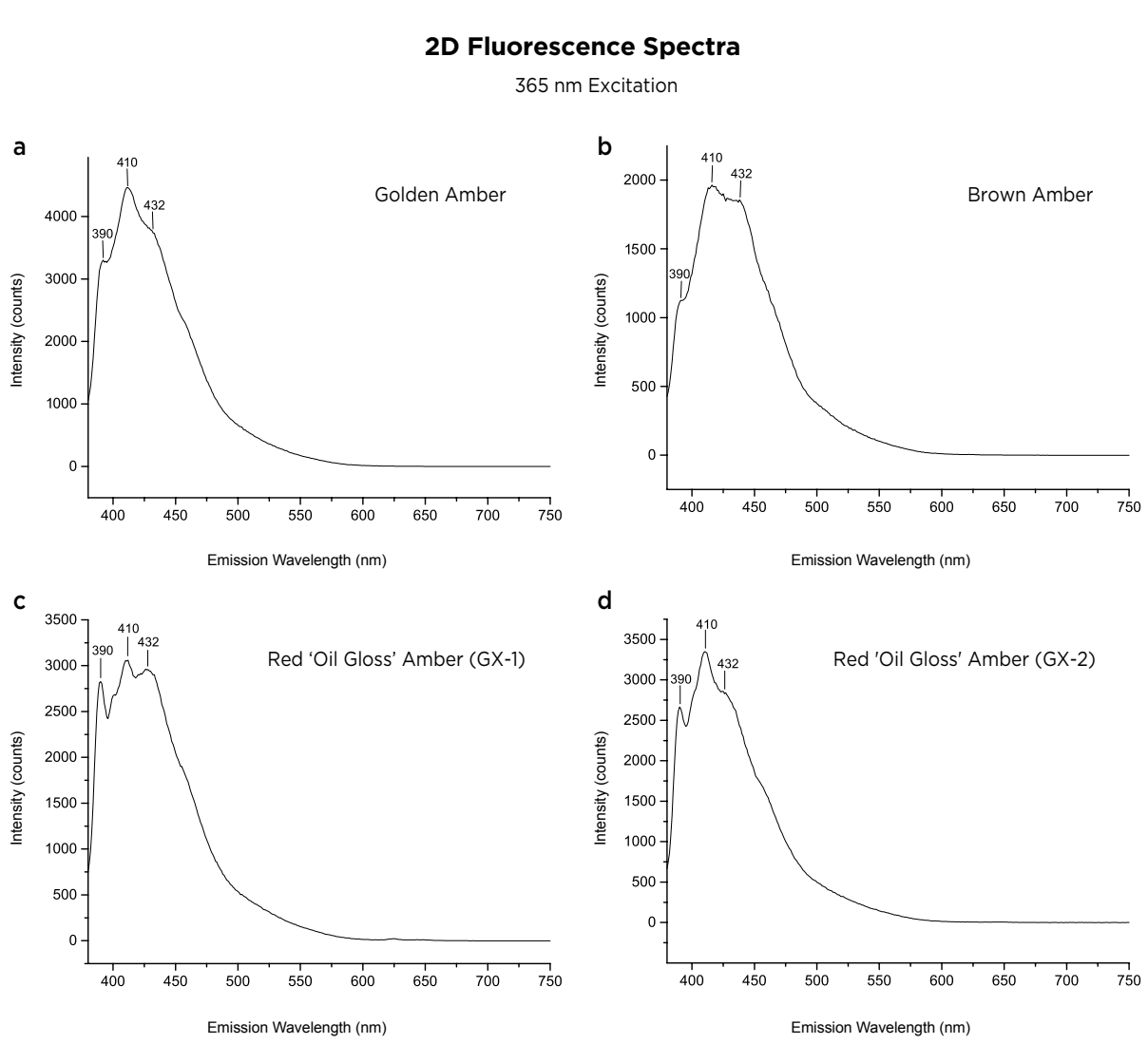

Figure 16: Two-dimensional fluorescence spectra reveal the luminescence centres at the optimum excitation wavelength of 365 nm for four of the Burmese amber samples: (**a**) golden, (**b**) brown, (**c**) red 'oil gloss' GX-1 and (**d**) red 'oil gloss' GX-2. The emissions occur at 390, 410 and 432 nm.

Two-dimensional fluorescence spectra were generated for the optimum excitation wavelength, which was 365 nm for all samples except for the amber showing green 'oil gloss' (which had an optimum excitation of 400 nm). With 365 nm excitation, the spectra showed luminescence centres at about 390, 410 and 432 nm (Figure 16). When the excitation wavelength was increased to 400 nm (i.e. in the visible range), a luminescence centre in the blue region at 470 nm appeared (Figure 17). Moreover, with 400 nm excitation the two red 'oil gloss' ambers also showed luminescence in the red region at 650 nm (±2 nm) and also at 625 nm for sample GX-1. For the green 'oil gloss' amber, the optimum excitation wavelength of 400 nm generated emissions at about 432 and 470 nm (Figure 18a). At a higher excitation wavelength of 460 nm (i.e. further into the visible region), the luminescence centres shifted to the 500–550 nm range in the green portion of the spectrum (Figure 18b).

Phosphorescence Spectroscopy. Transient time-resolved phosphorescence spectroscopy showed that the strongest phosphorescence occurred at 525 nm (Figure 19) for all samples. Thus, the phosphorescence lifetime was measured for an emission wavelength of 525 nm and calculated using the decay function of Wang (2015). The results revealed two phosphorescence lifetimes for all the samples, with t_1 ranging from 0.134 to 0.375 s and t_2 ranging from 0.447 to 1.396 s (Figure 20; see Table II for details).

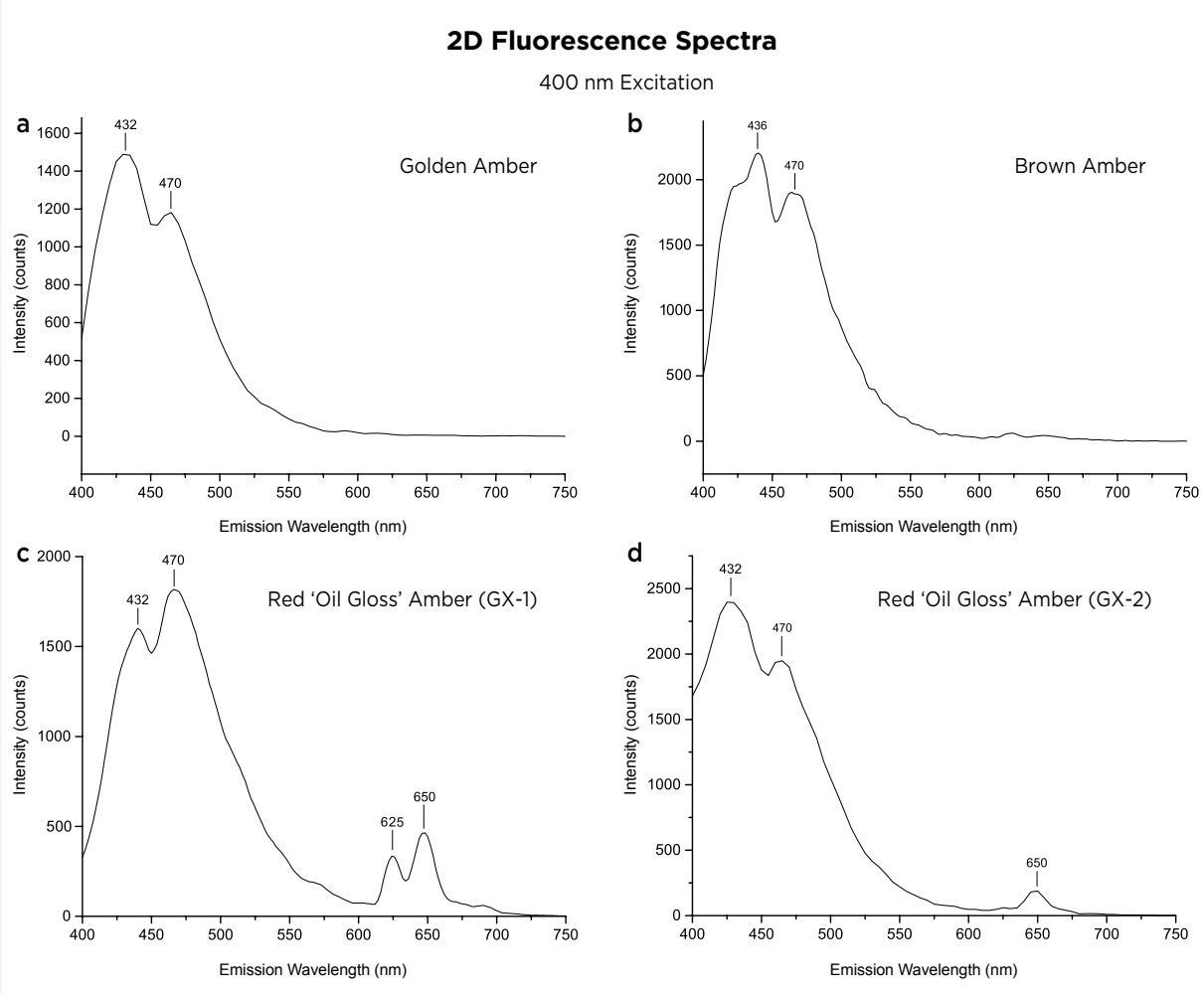

Figure 17: Two-dimensional fluorescence spectra of the same samples as in Figure 16 with 400 nm excitation show luminescence centres at 432 and 470 nm. In addition, red 'oil gloss' samples GX-1 and GX-2 have emission(s) in the red region at 650 nm ± 625 nm.

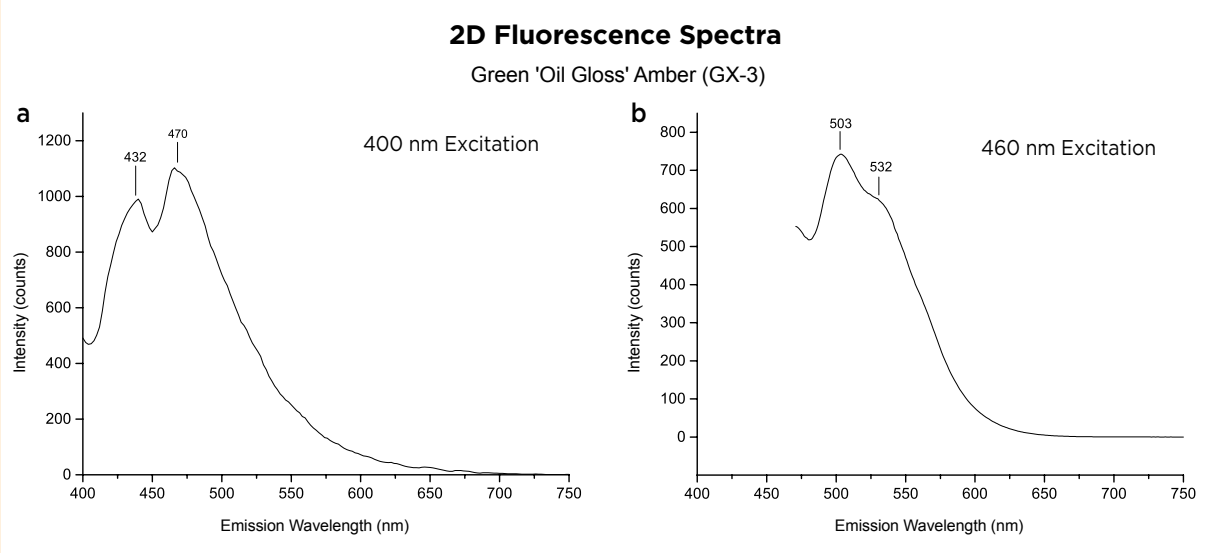

Figure 18: Two-dimensional fluorescence spectra are shown for green 'oil gloss' amber GX-3. (**a**) At the optimum excitation wavelength of 400 nm, the luminescence centres occur only at 432 and 470 nm in the violet-to-blue region. (**b**) With 460 nm excitation, luminescence centres are revealed in the green region at 503 and 532 nm.

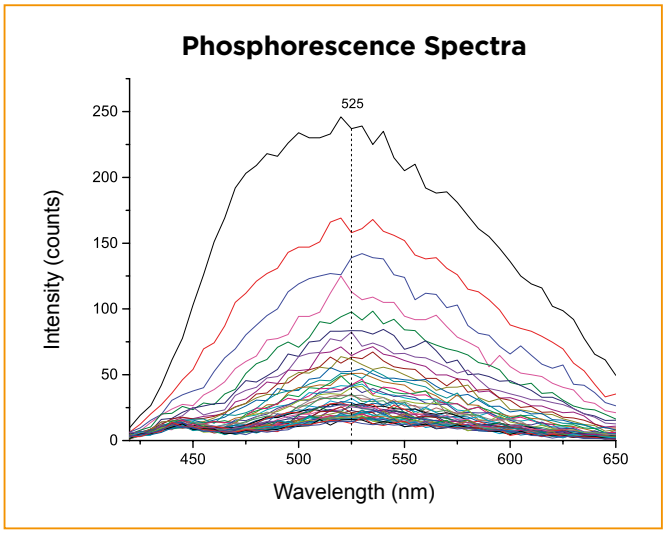

Figure 19: Time-resolved phosphorescence spectra demonstrate that the strongest phosphorescence occurred at 525 nm in all the Burmese amber samples. Each line refers to a different excitation wavelength.

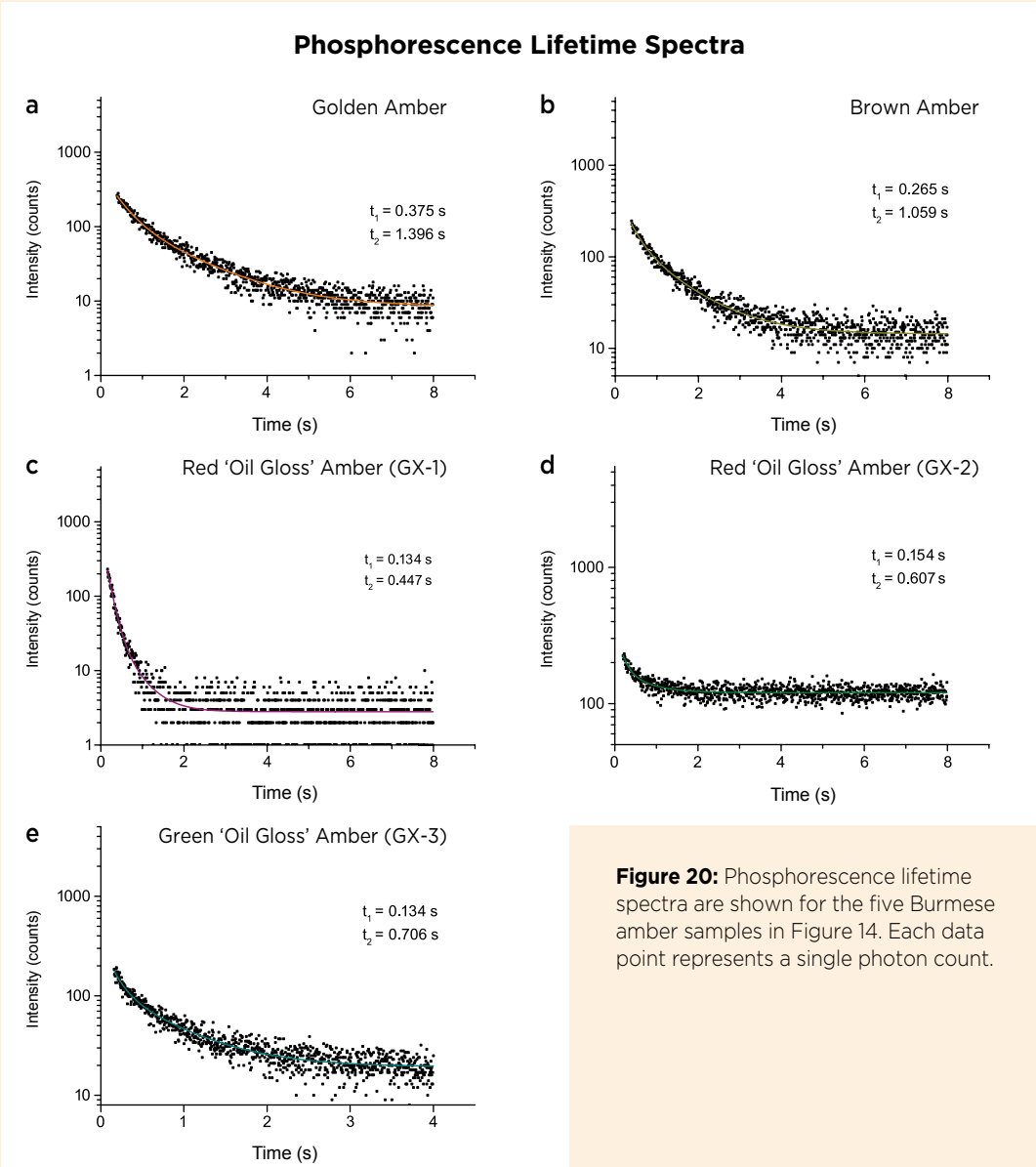

Figure 20: Phosphorescence lifetime spectra are shown for the five Burmese amber samples in Figure 14. Each data point represents a single photon count.

DISCUSSION

Formation of the Reddish Brown Dot-like Inclusions

The reddish brown dot-like inclusions in the brown amber (Figure 7c) showed a scaly structure in SEM images (Figure 9) that was clearly different from that of the surrounding amber. We speculate that these inclusions are related to some type of organic matter contained in the amber (especially volatile substances), rather than inorganic foreign material. Specifically, the inclusions may correspond to devolatilised sporopollen (chemically inert biological polymers) that were subjected to oxidation, thereby leading to a reddish brown appearance.

Structure of 'Root' Amber

According to our observations with the SEM, the diameter of the bubbles in the Burmese 'root' amber samples was micron-sized, typically ranging from 1 to 5.5 µm. In sample GP-1, an opaque region measuring 0.03 mm^2 contained 435 bubbles which took up 4.9% of the area. In the same region, hollow tubes occupied 257.1 μm^2. In the transitional zone leading into a transparent area, another 0.03 mm^2 region contained 149 bubbles of 0.9–5.5 µm diameter, which accounted for 3.1% of the area, and the hollow micro-tubes occupied 56.7 μm^2. Bubbles and hollow tubes were not present in the transparent zone. For sample GP-2, a 0.03 mm^2 region contained 47 bubbles which took up 1.8% of the area, but no hollow tubes. Thus, 'root' amber samples GP-1 and GP-2 differed considerably in their microscopic structural characteristics, and we attribute the distinctive textures seen in 'root' amber to variations in these structures.

The hollow micro-tubes accompanying the bubbles in 'root' amber GP-1 might represent escape channels for volatile components. The empty bubbles visible at the ends of the hollow tubes could have been left over when volatile components escaped along the tubes. The lack of bubbles visible at the ends of some tubes does not necessarily indicate an absence of bubbles, but may simply be due to the single plane being observed. The hollow tubes could also be related to cracks that appeared as the resin was exuded. The resin that formed Burmese amber was highly viscous, and as it was secreted in stages, small cracks could have resulted from more rapid hardening at the surface. However, the cracks could not continue to spread owing to rapid coverage by newly exuded resin. The 'internal' cracks were subsequently subjected to geological processes during burial of the host sediments. During this process, the healed fissures could have become channelways for escaping volatile components. Bubbles that remained after the volatiles escaped were mostly found along the curving, hollow tubes.

Origin of the 'Oil Gloss' Effect

The 'oil gloss' appearance of the Burmese amber is caused by a mixture of surface fluorescence and body colour, as seen in samples GX-1, GX-2 and GX-3. The effect is best seen against a black background because it reduces the influence of a sample's body colour on colour perception. The different appearances of this effect (red vs. green) depend on the luminescence centres present in the amber.

Amber with Red 'Oil Gloss'. Red surface fluorescence was noted on reddish brown and greenish yellow samples GX-1 and GX-2, respectively, when they were viewed against a black background. As expected, both showed emission in the red region at 650 nm (and also at 625 nm in GX-1) with 400 nm excitation (Figure 17c, d). Although this red emission was not recorded at the optimum excitation wavelength of 365 nm, it was present at a higher excitation wavelength in the range of visible light (i.e. 400 nm), and therefore we suggest that the red surface fluorescence of Burmese amber is related to these luminescence centres.

Nevertheless, the two samples showing the red 'oil gloss' effect also had strong luminescence centres in the violet-to-blue region at 432 and 470 nm, raising the question of how the 625 and 650 nm luminescence centres contribute to the red fluorescence. However, two-dimensional fluorescence spectroscopy of these samples using the Qspec micro-PL spectrometer (405 nm excitation) revealed that the red luminescence centres at 625 and 650 nm in GX-1 were stronger than the blue luminescence centres, and an additional red luminescence centre was also present at 690 nm (Figure 21a). In GX-2, the luminescence centres in the red region were nearly the same strength as those in the violet-to-blue region (Figure 21b). Therefore, it appears that different instruments have different sensitivities according to various emission wavelengths.

Amber with Magenta or Violetish Purple Fluorescence. Burmese amber commonly fluoresces violetish blue to long-wave UV radiation (e.g. Figure 14a). However, samples showing red 'oil gloss' showed magenta or violetish purple fluorescence under long-wave UV radiation (Figure 14c, d). Therefore, the luminescent centre(s) in the red region are not only responsible for the red 'oil gloss' effect, but they also contribute to the

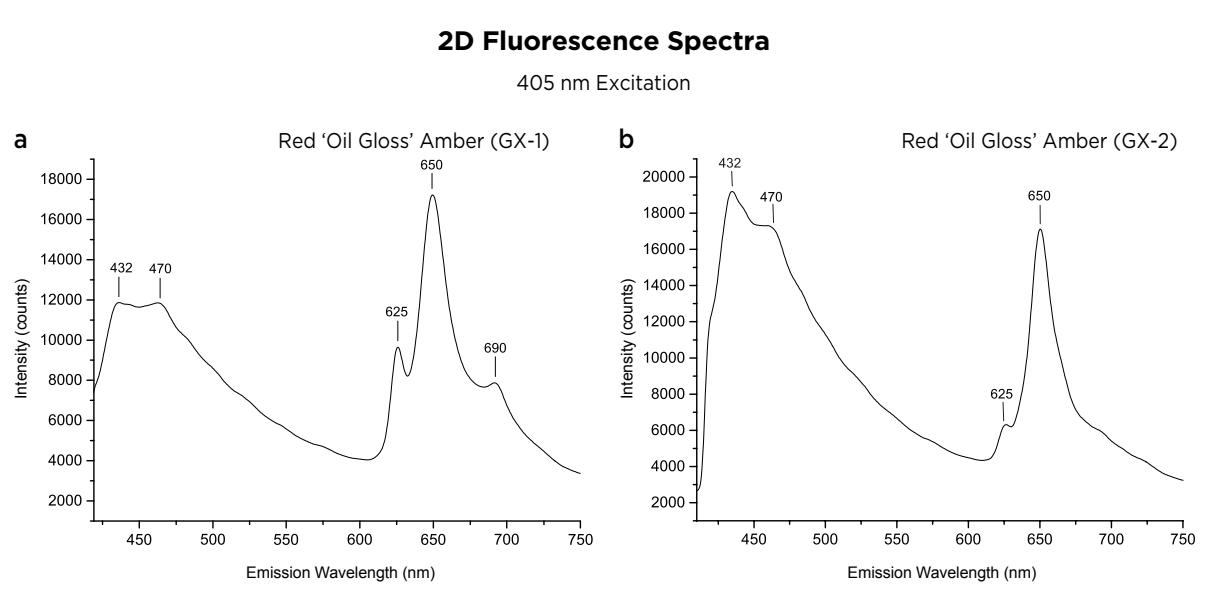

Figure 21: Two-dimensional fluorescence spectroscopy using the Qspec micro-PL instrument (405 nm excitation) shows luminescence centres in (**a**) red 'oil gloss' sample GX-1, which are much stronger in the red region at 625–690 nm than in the violet-to-blue region at 432 and 470 nm. (**b**) Red 'oil gloss' sample GX-2 shows strong emissions in both the violet-to-blue and red regions, but lacks a well-defined luminescence centre at 690 nm.

magenta or violetish purple fluorescence seen under long-wave UV radiation. The combination of luminescence centres in the red and violet-to-blue regions appears to be responsible for the distinctive magenta or violetish purple fluorescence of those samples seen under long-wave UV radiation.

Amber with Green 'Oil Gloss'. Reddish brown amber sample GX-3 displayed green surface fluorescence when viewed on a black background. In addition to the luminescence centres at 432 and 470 nm, fluorescence spectroscopy also revealed emissions in the green region (again, see Figure 18b). The spectral data were converted into Commission Internationale de L'Eclairage (CIE) chromaticity coordinate points, but the corresponding fluorescence did not plot in the green area—rather it plotted in the blue region (Figure 22). This suggests that the green 'oil gloss' of sample GX-3 is not only derived from green luminescence centres, but is also enhanced by the mixture of blue fluorescence and the amber's reddish brown body colour.

Phosphorescent Amber

'Glow in the dark' Burmese amber shows phosphorescence. With an excitation wavelength of 365 nm (typical long-wave UV radiation), the phosphorescent luminescence centre with the highest intensity was at 525 nm (yellowish green area of the spectrum), which is similar to the visually observed greenish yellow phosphorescent colour of Burmese amber. Thus, we measured the phosphorescence lifetime at 525 nm.

Phosphorescence lifetime is defined as the time it takes for the phosphorescence to decrease to 36.8% of the maximum strength (i.e. one lifetime), rather than the

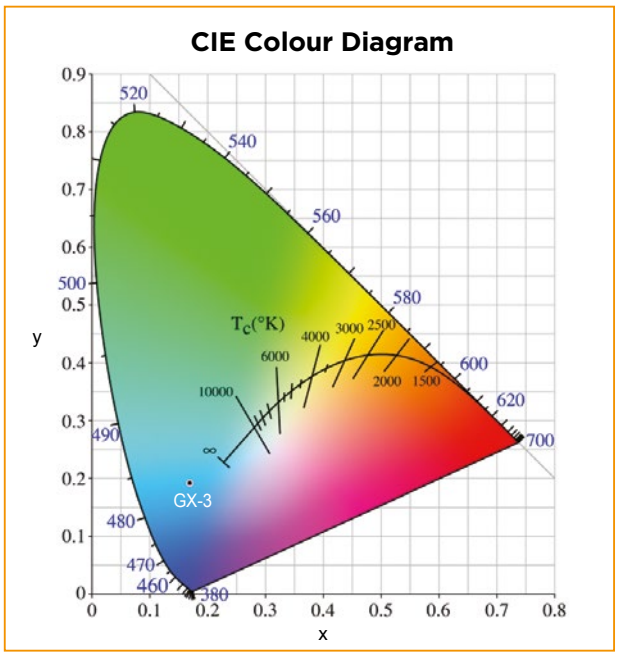

Figure 22: The CIE coordinate point calculated from the spectral data for green 'oil gloss' amber sample GX-3 confirmed the fluorescence colour as blue.

time to disappearance (when it becomes invisible to the naked eye; for more information, see Díaz García & Badía 2006). After phosphorescent amber is exposed to bright light, a large number of photons are emitted, leading to luminescence. The higher the intensity of the excitation source and the longer the exposure time, the more photons are excited in this process, resulting in longer times of luminescent energy emission. Hence, longer duration and higher intensity of irradiation contribute to longer 'luminescence times' (Xia 1992). However, after sufficient exposure time, regardless of how much longer the excitation lasts, the phosphorescence lifetime will remain nearly the same. This indicates a threshold inherent in the amber phosphorescence phenomenon. Once the quantity of excited photons reaches the threshold, the total number of active photons does not increase. At that point, the absorption and release of luminescent energy strike a dynamic balance.

Among the large number of organic compounds that are known to occur in amber, only a few can emit strong fluorescence, which is closely associated with their structures. Amber is a mixture of organic compounds, and may display fluorescence and sometimes phosphorescence when it contains the appropriate natural fluorescent impurities (e.g. Chekryzhov *et al.* 2014). Although Burmese amber is commonly thought to be the only fossil resin that displays the 'glow-in-the-dark' phenomenon, in fact amber from many origins may emit phosphorescence (e.g. Dominican amber; see Liu *et al.* 2014). The results of the authors' investigations of phosphorescence in ambers from various localities will be published in the future.

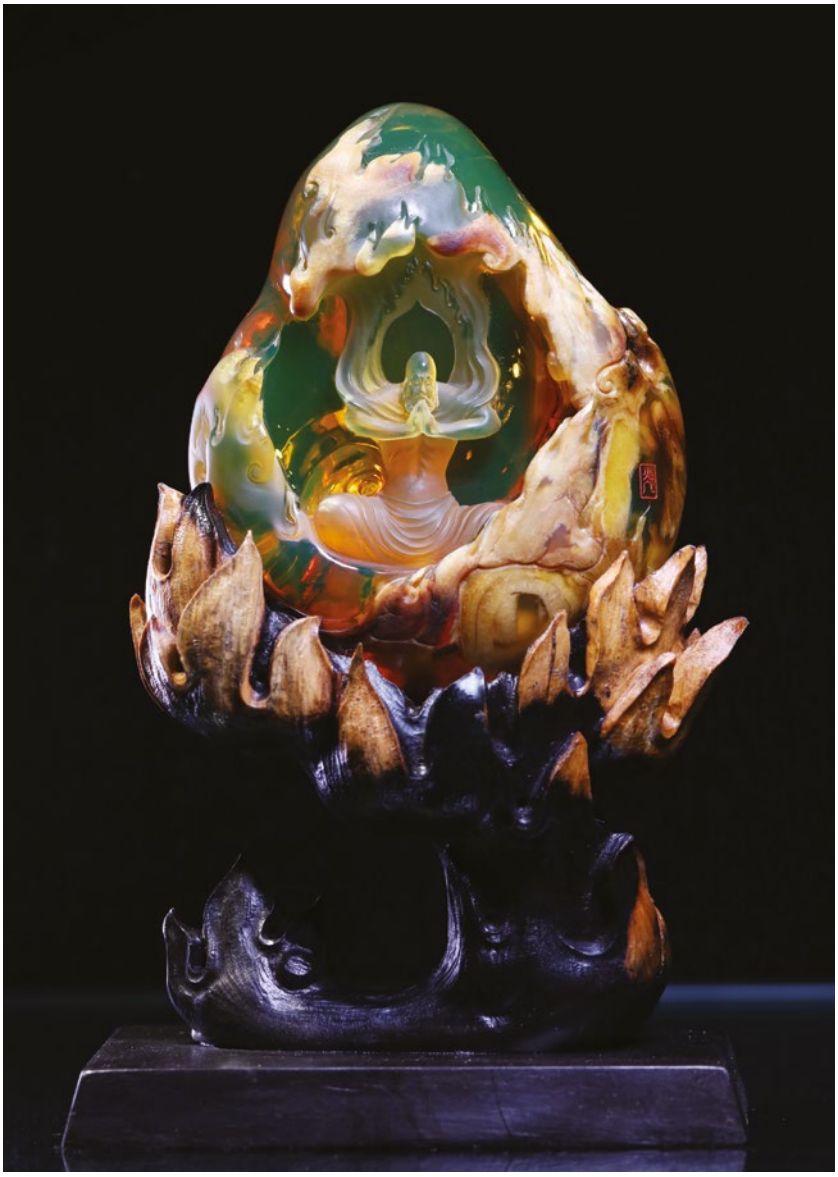

Figure 23: This Burmese amber carving depicts a *lohan* from traditional Chinese mythology. The amber displays a green 'oil gloss' effect in the transparent part, whereas the opaque areas consist of 'root' amber. The amber is 20.5 cm wide and rests on a carved wooden stand. Photo courtesy of Tengchong Huo Ren Carving Studio.

CONCLUSIONS

We characterised various types of Burmese amber, including golden, brown, 'blood', 'beeswax' and 'root' varieties, as well as those showing 'oil gloss' surface fluorescence effects and phosphorescence. Differences in the original resin secretions are responsible for the different amber types, as evidenced by the layered structure of some specimens and the characteristics of bubbles of various sizes and concentrations. It is also possible for multiple types/phenomena to occur within a single piece of Burmese amber (e.g. Figure 23).

The reddish brown dot-like inclusions in brown Burmese amber are possibly related to reactions involving volatile substances. The association of these inclusions with flow patterns suggests they may be related to the escape of volatile components. The opaque appearance

of Burmese 'root' amber is primarily attributed to its layered microscopic structure, as well as the abundance of bubbles and microscopic hollow tubes in certain areas of this material. The micro-tubes may have formed as escape channels for volatile components or they may be related to small cracks that formed during more rapid hardening of the outer surface of the resin and were then covered by successive resin exudations.

Red or green 'oil gloss' effects in Burmese amber are produced by a mixture of surface fluorescence and body colour, while the 'glow-in-the-dark' phenomenon is produced by phosphorescence. Generally, Burmese amber has two luminescence centres in the violet-to-blue region (at 432 and 470 nm), and those samples displaying red 'oil gloss' show additional emission(s) in the red region at 625–690 nm.

An important challenge facing amber researchers is the identification of specific components and structural formulas in these materials, and this investigation of the fluorescence and phosphorescence of Burmese amber not only explains various distinctive appearances shown by this material, but also provides further information for future research on the organic components in amber.

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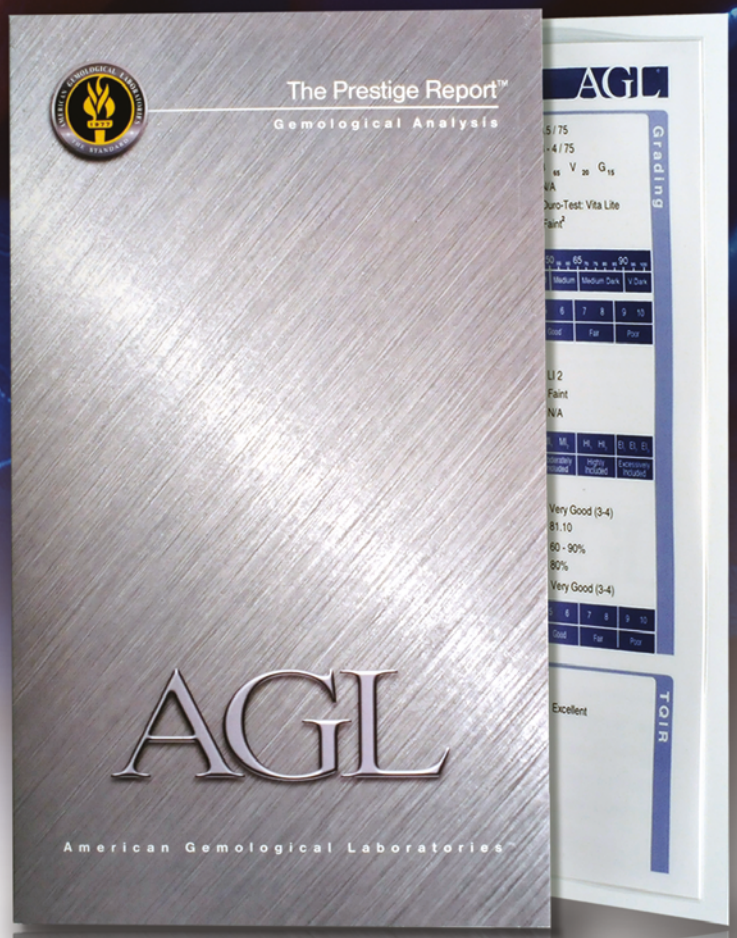

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Saltwater Cultured Pearls from *Pinctada radiata* in Abu Dhabi (United Arab Emirates)

Abeer Al-Alawi, Zainab Ali, Zainab Rajab, Fatema Albedal and Stefanos Karampelas

ABSTRACT: Since late 2007, *Pinctada radiata* molluscs have been used to produce bead-cultured saltwater pearls in the Al Dhafra region of Abu Dhabi, United Arab Emirates (UAE). This bivalve is seldom used for cultivation. The cultured pearls are harvested after two years, and some non-bead-cultured by-products are also produced. The bead-cultured pearls average 5–8 mm in diameter and show a range of body colours (principally white to yellow, and rarely grey or brown). An examination of 113 bead-cultured and 33 non-bead-cultured samples by X-ray imaging revealed classic structures associated with both types of cultured pearls, sometimes with significant overgrowth and radial-like structures rich in organic matter. Raman, photoluminescence and UV-Vis-NIR spectroscopy indicated that a series of partially substituted (i.e. partially methylated) polyenes, sometimes together with a type of porphyrin, contribute to the various body colours.

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Figure 1: This selection of finer-quality bead-cultured pearls (4.85–8.50 mm) are from *P. radiata* molluscs farmed off Abu Dhabi. They include some of the samples that were studied for this report. Photo by Hasan Abdulla, DANAT.

Pinctada radiata (P. radiata) is the native mollusc of the Arabian Gulf region, and most of the natural pearls fished there are obtained from this relatively small mollusc. Although this bivalve has rarely been used for pearl cultivation, recently gem-quality bead-cultured pearls (Figure 1) were produced from *P. radiata* in the Al Dhafra region of Abu Dhabi, UAE. Pearl cultivation is allowed in the UAE, in contrast to the Kingdom of Bahrain, where strict laws prohibit the trade (import and sale) of cultured pearls.

In late 2007, the Abu Dhabi Pearls project was initiated as a pilot study to assess the feasibility of producing gem-quality cultured pearls in the warm waters of the Arabian Gulf. Since its inception, the project has been managed by the Environment Agency – Abu Dhabi. Pearl cultivation has taken place at two sites in the Al Dhafra region: Al Mirfa (24°06′21′′N, 53°28′01′′E) and Al Mughirah (24°03′46′′N, 53°34′07′′E; see Figure 2). Other, smaller-scale farms using the same mollusc are operating in the Arabian Gulf, but no specific information on them is publicly available.

The feasibility of culturing pearls using *P. radiata* was confirmed with the Abu Dhabi Pearls project's first harvest in January 2010. To date, approximately 150,000 cultured pearls have been produced, with around 25% being of very good to excellent quality. They typically range from 5 to 8 mm in diameter, and come in a wide range of shapes and colours. No post-harvest treatment is applied. For this study, representative medium- to excellent-quality cultured pearls (both bead-cultured and non-bead-cultured) were studied using various imaging, spectroscopic and chemical methods. This is the first published scientific documentation of cultured pearls from *P. radiata*.

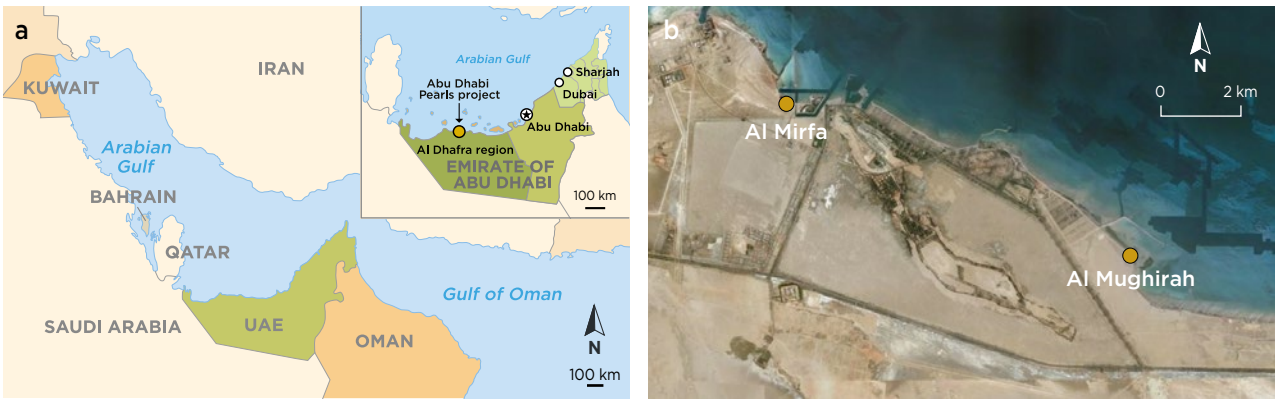

Figure 2: (**a**) The Abu Dhabi Pearls project is located in the Arabian Gulf, off the coast of UAE. The inset shows the location of the Abu Dhabi Pearls project within the Al Dhafra region in the Emirate of Abu Dhabi. (**b**) The project's two pearl-cultivation sites of Al Mirfa and Al Mughirah can be seen in this aerial photo (scale 1:130,000; courtesy of the Abu Dhabi Pearls project).

PEARL CULTURING PROCESS

The cultivation process (Figure 3) employs methodology that is similar to that used for akoya cultured pearls (*Pinctada fucata*; see Otter *et al.* 2017). The mantle tissue graft is obtained from a donor mollusc that is carefully selected based on the colour and quality of the nacre on the shell's interior. The outer epithelium layer of the mantle tissue is removed from the darker part of the mantle and then cut into the square pieces

Figure 3: The culturing process employed by the Abu Dhabi Pearls project using *P. radiata* molluscs consists of several steps. (**a**) A *P. radiata* donor mollusc displaying colourful shell nacre provides mantle tissue that will be used for the graft accompanying the bead nucleus. (**b**) The outermost part of mantle epithelium layer cut from the donor mollusc is laid out in strips (top), which are then cut into squares of about 2 × 2 mm each to create tissue grafts (bottom). The orange-red colour of the grafts shows that they have been treated with antibiotics. (**c**) Unionidae shell beads are used as cultured pearl nuclei; their yellow colour shows that they have been coated with antibiotics. (**d**) A technician prepares a host mollusc for insertion of the bead and tissue graft. (**e**) The technician makes an incision in the gonad area of the mollusc where the bead and tissue will be inserted. (**f**) The bead with the tissue graft (red) are seen in the host mollusc after insertion. Photos by A. Al-Alawi.

Figure 4: (**a**) The implanted molluscs are placed in cages to be immersed in the water. (**b**) The molluscs are removed from the ocean on a regular basis for cleaning. Photos by A. Al-Alawi.

used for graft material (or *saibo*, sometimes also spelled *seibo* in Japanese), each measuring approximately 2 × 2 mm. The valves of the acceptor molluscs are partially opened using a special tool, and a small incision is made in the gonad to allow the bead to be inserted together with the graft (with the nacre-producing side facing the bead). Cellular proliferation then rapidly forms a so-called *pearl sac*, depositing nacre on the bead. Both donor and acceptor molluscs are obtained from spat that are grown to an age of less than three years before they are used for pearl culture.

The bead nuclei range from 4 to 7 mm in diameter and are derived from freshwater mollusc shells (Unionidae) from the USA. Two types are used: normal white beads, and yellow beads that have been coated with antibiotics to decrease the possibility of the acceptor 'oysters' being infected by pathogens. The molluscs are conditioned before the operation, and this process is adjusted according to the developmental status of the mollusc's gonad. Bead insertion (simultaneously with tissue graft transplantation) takes place from November to April, using host molluscs that measure approximately 5.5 cm, which are then returned to the water (Figure 4a). The water temperature in Abu Dhabi varies throughout the year, ranging from 16°C to 37°C, and the salinity changes from 44‰ to 49‰ depending on seasonal rainfall.

For successful pearl cultivation, the farm technicians must keep track of the age of the molluscs, monitor their health and ensure that the waters are not overcrowded. In addition, to facilitate nacre growth, the molluscs are cleaned by hand (Figure 4b) or with a high-pressure sprayer to remove algae and other growths from their shells. This is done weekly, except during August and September when the water temperature is relatively high; cleaning is then performed less often (i.e. biweekly) to minimise stress on the 'oysters' since they become weaker in the warmer water. The percentage of rejected beads is still relatively high (about 30%).

Various experiments have been conducted to assess the optimal bead size range and cultivation time. For typical bead sizes of 4–7 mm in diameter, harvesting of the cultured pearls takes place after two years (Figure 5). Longer cultivation times (four years) were attempted for larger-sized beads of 7–8 mm in an effort to maintain high quality and sufficient nacre thickness, but the results were unsatisfactory. Experiments were also done to test the effect of cultivation time on final cultured pearl size. Regardless of the size of the bead used, the implanted 'oysters' were kept for either two years or four years. However, in both cases the nacre thickness was almost identical, and the ones that were cultivated for four years actually had lower lustre and quality.

After harvesting, the cultured pearls are sorted, cleaned and graded. The number of molluscs harvested is currently slightly more than 100,000 per year, which is a relatively low amount when compared to commercial akoya cultured pearl farms such as Mikimoto (1,000,000 molluscs), Kamimura (6,000,000 molluscs)

Figure 5: After a period of two years, the molluscs are opened to remove the cultured pearls. Photo by A. Al-Alawi.

and Kitamura (10,000,000 molluscs). Around 10,000 *P. radiata* cultured pearls of very good to excellent quality are produced annually. A trademark for the term *Abu Dhabi Pearls* was recently registered, and these cultured pearls will become commercially available in the near future. Currently, some of them have been given to the School of Design in Abu Dhabi to use in their future jewellery designs.

MATERIALS AND METHODS

For this study, we examined 113 *P. radiata* bead-cultured pearls from the Abu Dhabi Pearls project weighing 0.83–5.88 ct and ranging from 4.87 × 4.81 to 15.07 × 11.51 mm. We also examined 33 non-bead-cultured pearls found in the gonad after bead rejection (these by-products are sometimes referred to as 'keshi' cultured pearls); these weighed 0.34–1.31 ct and measured from 4.44 × 3.14 to 7.06 × 5.19 mm.

All samples were examined macroscopically, and with a binocular gemmological microscope using magnifications of 10×–70× and fibre-optic illumination, as well as 3 W long-wave (365 nm) and short-wave (254 nm) UV lamps. X-ray luminescence was tested for all samples with a PXI GenX-100 unit set to 100 kV and 5 mA (500 W), and recorded with a Nikon D810 camera using an exposure time of 8 seconds with F6.3 aperture and ISO Hi 0.7; samples were placed about 20 cm from the X-ray tube. X-ray microradiographs were acquired for all samples in three directions perpendicular to each other using a PXI GenX-90P instrument set to 90 kV and 80 µA, 100–120 milliseconds exposure time per frame and 128 frames. X-ray computed microtomography (micro-CT) scans were acquired on 46 samples (13 of the bead-cultured and all non-bead-cultured pearls) using a ProCon X-ray CT-Mini instrument with 800 projection views in 360° (i.e. 0.45° increments), seven frames, 100 kV, 120 mA and 250 milliseconds/frame exposure time.

Raman spectra were obtained for all samples using a Renishaw inVia spectrometer coupled with a microscope. We used a laser excitation wavelength of 514 nm (diode-pumped solid-state laser). Spectra were collected from 200 to 2000 cm^{-1} with a resolution of around 2 cm^{-1}, using a grating of 1,800 grooves/mm, 40 µm slit, laser power of 5 mW on the sample (to avoid any destruction of the fragile organic material), 50× long-distance objective, acquisition time of 30 seconds and seven accumulations. The instrument was calibrated using the diamond Raman line at 1331.8 cm^{-1}. Photoluminescence (PL) spectra were acquired for all samples using a mobile Raman spectrometer (GemmoRaman-532) with 532 nm excitation and a laser power of about 1 mW on the sample. Spectra were collected from 540 to 700 nm with a resolution of about 1 nm, acquisition time of 50–700 milliseconds and 30 accumulations; calibration was likewise performed using the 1331.8 cm^{-1} diamond Raman line.

Diffuse reflectance ultraviolet-visible-near infrared (UV-Vis-NIR) spectra were acquired for all samples using a Cary 60 spectrophotometer with an external Harrick diffuse reflectance accessory. Spectra were acquired from 250 to 1000 nm, and the data sampling interval and spectral bandwidth were set at 1 nm using a 100 nm/minute scan rate. Black sample holders with a 2-mm-diameter hole were used, and background spectra were acquired using a white MgO reference (for 100% reflectance) and with nothing (for 0% reflectance).

Chemical analysis of all samples was performed using energy-dispersive X-ray fluorescence (EDXRF) spectroscopy with a Thermo Scientific ARL Quant'X instrument using various energies and filters. In addition, the trace-element content of all samples was measured using laser ablation inductively coupled plasma mass spectrometry (LA-ICP-MS) using instrumentation and analytical conditions that were identical to those presented by Karampelas *et al.* (2019b). Several isotopes were measured, but in this article only data for ^{23}Na, ^{24}Mg, ^{55}Mn, ^{88}Sr and ^{137}Ba are presented. Three spots were analysed on each sample, on areas consisting of aragonite with nacreous microstructure (checked with Raman spectroscopy and optical microscopy).

The exact taxonomy of *P. radiata* is still under discussion, and in this article we use the terminology listed by WoRMS (World Register of Marine Species; http://marinespecies.org).

RESULTS AND DISCUSSION

Physical Characteristics

The 113 bead-cultured pearl samples had a range of colours (14 white, 29 light cream, 22 cream, six light yellow, two yellow, 36 grey and four brown) and various shapes (50 round, 13 near-round, eight near-button, 10 near-drop, three near-oval and 29 near-baroque). Half the bead-cultured pearl samples were of high quality—possessing high lustre, homogeneous colouration and a surface free from blemishes that exhibited pink overtones and iridescence—while others were of medium quality and had minor surface blemishes.

The 33 non-bead-cultured pearl samples also showed a range of colours (four white, 12 light cream, eight cream, three light grey and six grey) and various shapes (one near-round, one button, 11 near-button, one oval, five near-oval and 14 near-baroque). They were of relatively medium quality—possessing low to moderate lustre, sometimes non-homogeneous colouration and minor to moderate blemishes on the surface.

Viewed with the microscope, all samples presented typical nacreous overlapping layers of aragonite (Figure 6a, b) and some showed surface blemishes (Figure 6c).

UV and X-ray Luminescence

Most of the bead-cultured pearls (110) and all of the non-bead-cultured pearls luminesced green to greenish yellow to yellow under short-wave UV radiation, and yellow to green under long-wave UV (all of moderate intensity). Only two samples presented a different reaction: moderate light brown under short-wave UV radiation and moderate red under long-wave UV. In addition, one cultured pearl luminesced moderate yellowish orange under short-wave UV radiation and moderate orangey yellow under long-wave UV. There were no systematic variations in UV fluorescence according to body colour. Greenish yellow phosphorescence of low intensity was observed for 1–2 seconds in 35 of the bead-cultured and 30 of the non-bead-cultured pearls.

When exposed to X-rays, most of the bead-cultured pearls displayed yellow-green luminescence, which varied from strong (58 samples) to moderate (22 samples) to weak (13 samples). This luminescence most likely originated from the underlying freshwater shell bead (cf. Hänni *et al.* 2005; Karampelas *et al.* 2019b). The other 20 samples were inert, probably due to their greater nacre thickness (>1.5 mm). All of the non-bead-cultured pearls were inert to X-rays.

X-ray Imaging: Bead-Cultured Samples

X-ray microradiographs and micro-CT slices of selected bead-cultured pearls are presented in Table I. All of the images are in greyscale; lighter tones indicate materials with higher density, such as calcium carbonate (usually aragonite in most natural and cultured pearls), while darker tones represent lower-density materials (usually organic matter, cracks, cavities or voids).

Most of the bead-cultured pearls showed a slightly lighter central region (corresponding to the bead) that was surrounded by a typical demarcation line (which appears dark due to organic-rich material; see, e.g., the micro-CT scans of samples XR-5132 and XR-5136). Some of the cultured pearls showed pronounced demarcation lines around the bead, with multiple growth lines or layers (e.g. XR-5190)—sometimes displaying radial-like structures—along with thick organic-rich layers of deposition. These radial structures appeared close to those observed in cultured pearls from other bivalves, supporting the idea that cultured pearls are formed by a process similar to shell regeneration and not to a reverse-shell mechanism as previously believed (see Cuif *et al.* 2011; Sato & Komaru 2019).

Some samples showed small (<2 mm) round features that looked like 'seed pearls' within organic-rich matter in layers following the demarcation lines around the bead (e.g. XR-5189); these need further study to

Figure 6: The typical appearance of overlapping layers of nacre is shown on the surface of (**a**) bead-cultured and (**b**) non-bead-cultured pearls. (**c**) Small bumps form blemishes on a bead-cultured pearl. Photomicrographs by Z. Ali; image widths 2.1 mm.

Table I: Characteristics, X-ray microradiographs and micro-CT slices of selected samples of bead-cultured pearls from Abu Dhabi.*

Sample	Description	Photograph	X-ray microradiograph	Micro-CT slice
XR-5093	Weight: 1.90 ct Shape: Near baroque Colour: White and light cream Dimensions: 6.56 × 6.38 mm Nacre thickness: up to 0.60 mm		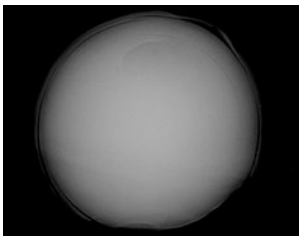	N/A
XR-5096	Weight: 2.07 ct Shape: Near baroque Colour: Light cream and cream Dimensions: 6.60 × 6.37 mm Nacre thickness: up to 0.65 mm		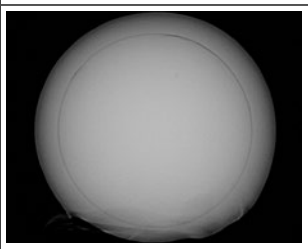	N/A
XR-5104	Weight: 2.30 ct Shape: Near baroque Colour: Light cream Dimensions: 8.71 × 6.62 mm Nacre thickness: up to 1.55 mm		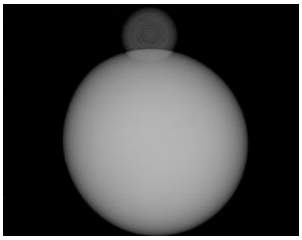	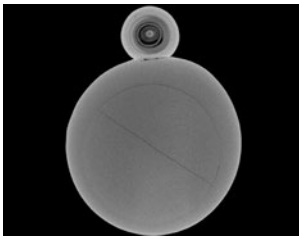
XR-5106	Weight: 2.02 ct Shape: Near baroque Colour: Light cream and orangey cream Dimensions: 7.47 × 6.36 mm Nacre thickness: up to 1.05 mm		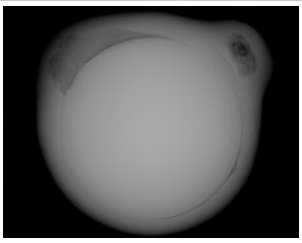	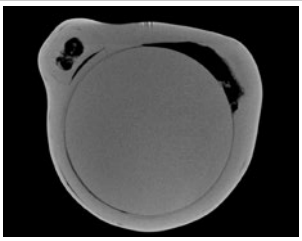
XR-5114	Weight: 1.89 ct Shape: Near baroque Colour: Brown and grey Dimensions: 7.26 × 6.19 mm Distance from the bead's edge to the cultured pearl's surface: up to 1.05 mm		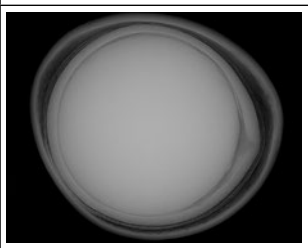	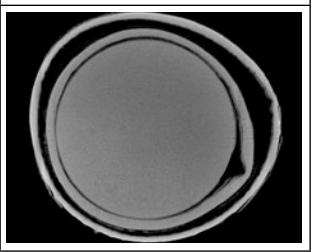
XR-5119	Weight: 1.97 ct Shape: Near round Colour: Grey Dimensions: 6.61 × 6.46 mm Nacre thickness: 0.60 mm		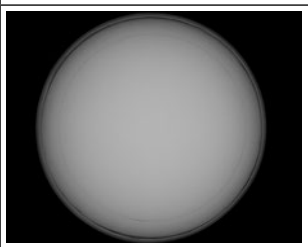	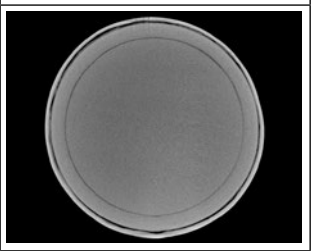
XR-5132	Weight: 0.90 ct Shape: Near round Colour: Brownish cream Dimensions: 5.02 × 4.95 mm Nacre thickness: 0.25 mm		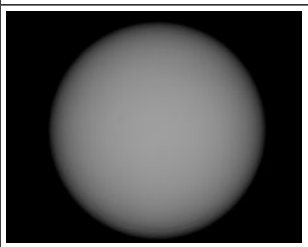	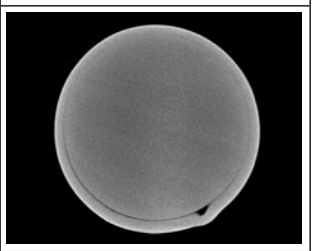

Table I: (continued)

Sample	Description	Photograph	X-ray microradiograph	Micro-CT slice
XR-5136	Weight: 0.83 ct Shape: Round Colour: Yellow Dimensions: 4.87 × 4.81 mm Nacre thickness: 0.15 mm			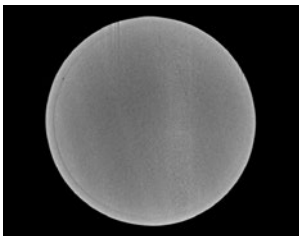
XR-5163	Weight: 3.37 ct Shape: Round Colour: Light cream Dimensions: 7.78 x 7.70 mm Nacre thickness: 1.30 mm		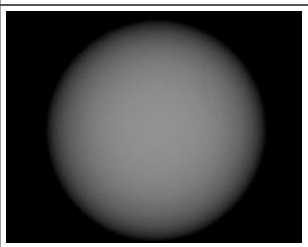	N/A
XR-5189	Weight: 3.79 ct Shape: Near baroque Colour: White Dimensions: 8.60 × 8.04 mm Nacre thickness: up to 1.10 mm		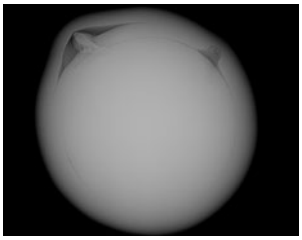	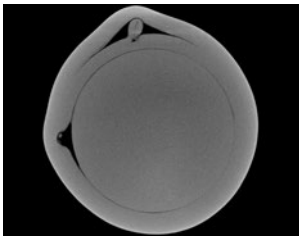
XR-5190	Weight: 3.67 ct Shape: Round Colour: Cream Dimensions: 8.05 × 8.01 mm Nacre thickness: 0.95 mm		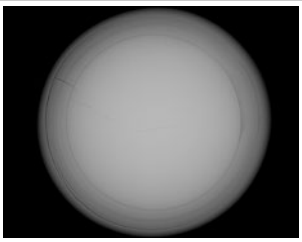	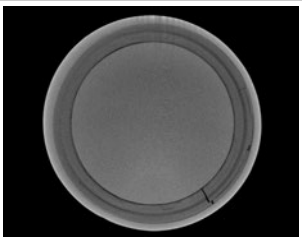
XR-5191	Weight: 5.65 ct Shape: Near drop Colour: Grey Dimensions: 11.39 × 9.78 mm Distance from the bead's edge to the cultured pearl's surface: up to 1.75 mm		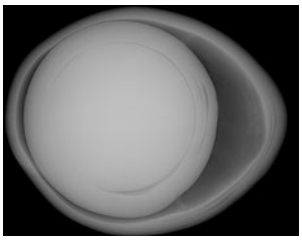	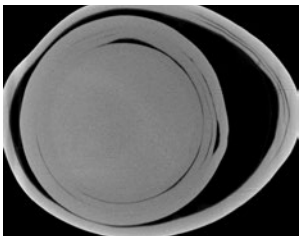
XR-5195	Weight: 5.88 ct Shape: Baroque Colour: Cream and grey Dimensions: 15.07 × 11.51 mm Distance from the bead's edge to the cultured pearl's surface: up to 3.60 mm		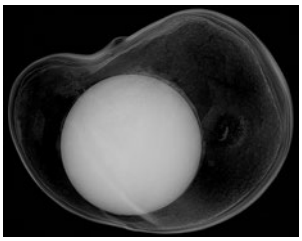	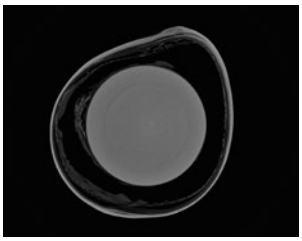

*Note: The X-ray microradiographs and micro-CT slices do not necessarily show the same sample positions.
Abbreviation: N/A = not acquired. Photos by Ghadeer Abdali, DANAT.

determine the nature of the round features. Some of the samples (e.g. XR-5104) had 'satellite pearls' containing pronounced concentric growth structures (particularly visible with micro-CT imaging), which were similar to those observed for some bead-cultured pearls with attached non-bead-cultured pearls (by-products) from *Pinctada maxima* (Krzemnicki *et al.* 2010).

The higher-quality cultured pearls ranged in size from 7.00 to 8.50 mm, with beads of 5–7 mm and nacre thicknesses of 0.50–1.50 mm; more than half had a nacre thickness exceeding 0.90 mm. The largest samples (>9 mm) were baroque shaped and presented large areas of organic-matter deposition. For example, sample XR-5195, with an 8 mm bead, contained large amounts of organic material; the maximum distance from the bead's edge to the cultured pearl's surface was 3.60 mm. The cultured pearl with the thinnest nacre was XR-5136, with a thickness of 0.15 mm. Some medium-quality cultured pearl samples (e.g. XR-5114, XR-5191 and XR-5195) had thick organic-matter deposition with multiple growth structures; they also showed mostly grey to brown body colours. Micro-CT slices of sample XR-5195 presented dark areas that are most probably associated with voids; the sound of the bead moving inside a hollow area could be heard when shaken.

Fourteen of the samples consisted of bead-cultured blister pearls (e.g. XR-5093 and XR-5096) that had a point of attachment to the inner shell of the mollusc. The nacre thickness of these samples varied from 0.15 to 2.00 mm, and in a few larger samples the distance from the bead's edge to the cultured pearl's surface was up to 3.60 mm.

X-ray Imaging: Non-Bead-Cultured Samples

The 33 non-bead-cultured pearl by-products examined by the authors were also X-rayed and studied using micro-CT imaging (see some selected examples in Table II). These samples revealed diverse types of voids, which were in some cases linear in structure and of variable dimension. They were similar to those observed in non-bead-cultured pearls from other molluscs, and different from those documented in natural pearls (see Sturman 2009; Karampelas *et al.* 2010, 2017; Krzemnicki *et al.* 2010).

Table II: Characteristics, X-ray microradiographs and micro-CT slices of selected samples of non-bead-cultured pearls from Abu Dhabi.*

Sample	Description	Photograph	X-ray microradiograph	Micro-CT slice
1-2-2	Weight: 0.68 ct Shape: Near baroque Colour: Light cream and cream Dimensions: 5.16 × 4.71 mm		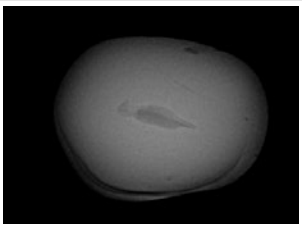	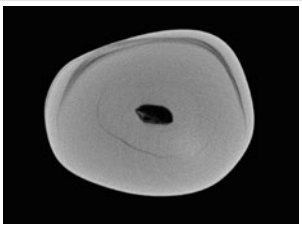
1-2-4	Weight: 0.54 ct Shape: Near baroque Colour: Light cream Dimensions: 5.43 × 4.33 mm		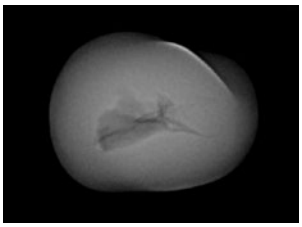	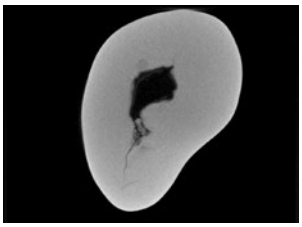
1-2-7	Weight: 0.73 ct Shape: Near button Colour: Cream Dimensions: 5.84 × 4.40 × 4.10 mm		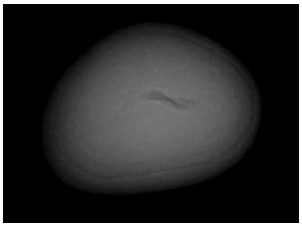	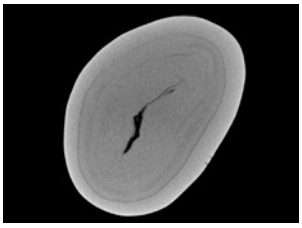
1-2-9	Weight: 0.53 ct Shape: Near baroque Colour: Cream Dimensions: 4.86 × 4.18 mm		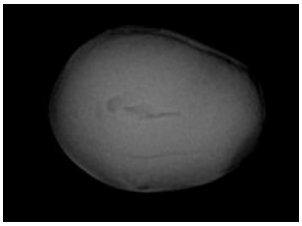	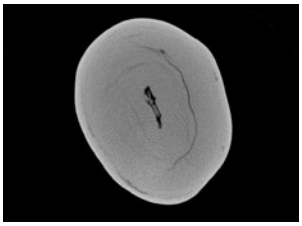

Table II: (continued)

Sample	Description	Photograph	X-ray microradiograph	Micro-CT slice
1-2-13	Weight: 0.52 ct Shape: Near oval Colour: Light cream Dimensions: 4.74 × 4.06 × 3.58 mm		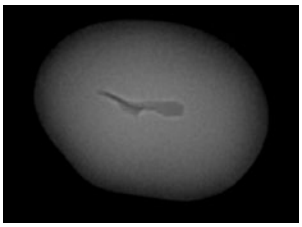	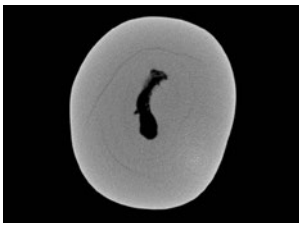
3-0-2	Weight: 0.64 ct Shape: Near button Colour: Light cream Dimensions: 5.43 × 4.52 × 3.57 mm		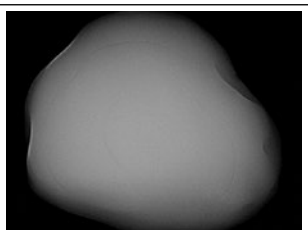	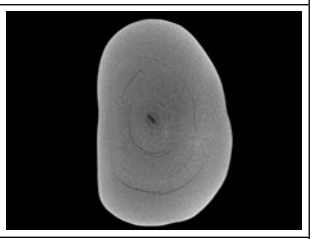
3-1-1	Weight: 0.52 ct Shape: Near baroque Colour: Light cream and grey Dimensions: 4.79 × 4.44 mm		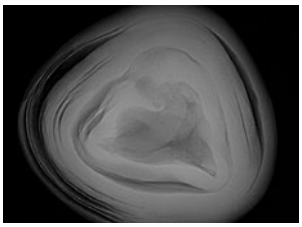	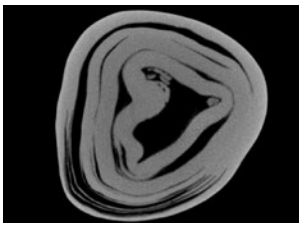
3-1-3	Weight: 0.34 ct Shape: Near oval Colour: Light cream Dimensions: 4.44 × 3.29 × 3.14 mm		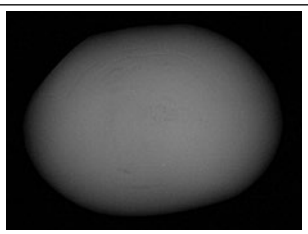	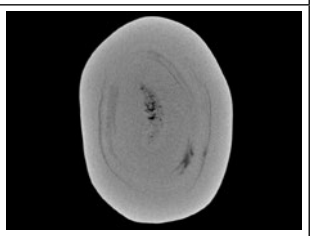
3-1-4	Weight: 0.38 ct Shape: Oval Colour: Light cream Dimensions: 4.41 × 3.44 × 3.43 mm		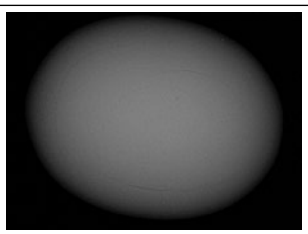	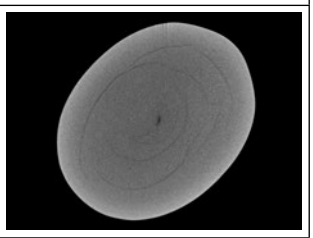
3-2-3	Weight: 0.49 ct Shape: Near round Colour: Light cream Dimensions: 4.23 × 4.03 mm		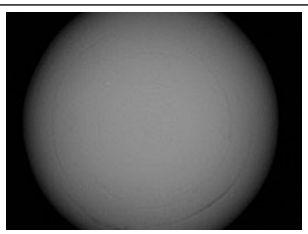	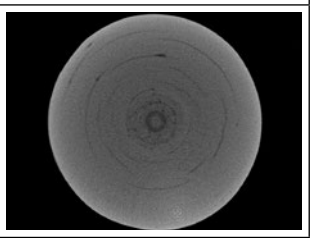
3-4-1	Weight: 0.46 ct Shape: Near baroque Colour: Cream Dimensions: 4.63 × 3.87 mm		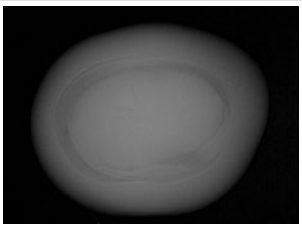	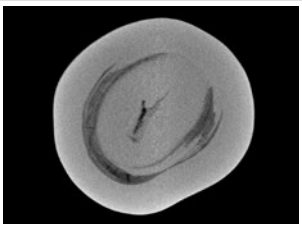

*Note: The X-ray microradiographs and micro-CT slices do not necessarily show the same sample positions. In some of the micro-CT images, an off-centre lighter-coloured patch (e.g. near the bottom of sample 3-2-3) is an artefact related to the rotation axis of the sample during measurement. Photos by Ghadeer Abdali, DANAT.

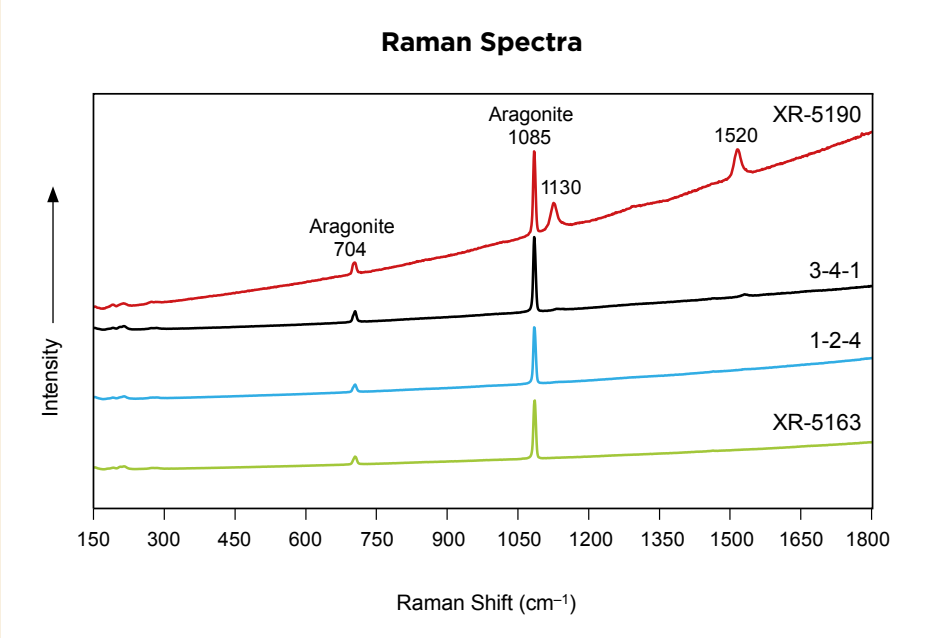

Figure 7: Raman spectra are shown for various *P. radiata* samples, including bead-cultured XR-5163 (light cream) and XR-5190 (cream), and non-bead-cultured 1-2-4 (light cream) and 3-4-1 (cream). All spectra have been normalised to the major Raman band of aragonite at 1085 cm^{-1} and shifted vertically for clarity.

The linear structures observed in our non-bead-cultured samples were related to some extent to their exterior shape, and often had a thick and dense appearance in the X-ray images (again, see Table II). These structures were revealed in considerably greater detail in the micro-CT images. In sample 3-1-1, a large irregular central cavity is visible with white spots on the sides. The organic material has a somewhat darker appearance than in the X-ray microradiographs and is surrounded by dark growth layers. An important factor to note is that the voids observed in all saltwater non-bead-cultured pearls do not change contrast significantly in different directions, and they frequently show an abrupt transition from darker to lighter colour (i.e. without intermediate shades of grey). In sample 3-2-3, a lighter core (most likely calcium-carbonate rich) is visible in the centre—particularly with micro-CT imaging—and is surrounded by fine concentric growth lines; this appearance could easily be confused with the growth pattern seen in saltwater natural pearls. However, natural pearls typically have a darker core (richer in organic matter; cf. Krzemnicki *et al.* 2010). Also noted in a few samples was a very small, fine, irregular central hairline feature surrounded by growth lines, such as in sample 3-0-2 (see also Sturman 2009). After being drilled, such cultured pearls might be challenging to identify. Morever, in a few samples, the central cavity was not clearly visible by typical X-ray microradiography but was only seen in the micro-CT images (again, see Table II).

Raman Spectroscopy

Raman spectra of all samples presented bands at around 1085 and 704 cm^{-1} (Figure 7) due to the symmetric and in-plane bending modes, respectively, of carbonate molecules in aragonite. Also present was a series of weak bands below 400 cm^{-1} due to the lattice modes of carbonate in aragonite (Urmos *et al.* 1991). The vast majority of the studied samples (light cream, cream, light yellow and light grey) had peaks at about 1130 and 1520 cm^{-1} due to C–C and C=C stretching vibrations of partially substituted (i.e. partially methylated) polyenic pigments (Karampelas *et al.* 2019a). Similar Raman bands are known in pearls from various molluscs, including akoya cultured pearls (Fritsch *et al.* 2012; Otter *et al.* 2017; Karampelas *et al.* 2019a). Only 10 white-to-light cream coloured samples showed solely bands linked to aragonite without the presence of those related to pigments (e.g. the spectra for samples XR-5163 and 1-2-4 in Figure 7).

PL Spectroscopy

The PL spectra of the samples showed various apparent maxima. Bands centred at 565 nm and at around 590 nm are both possibly due to organic compounds present in the nacre. A band at 620 nm accompanied by two other bands at 650 and 680 nm are probably due to a type of porphyrin (Miyoshi *et al.* 1987; Hainschwang *et al.* 2013; see 3-4-1 in Figure 8). Overall, the apparent maximum in the PL spectra (as labelled in Figure 8) was due to the relative intensity of the three bands

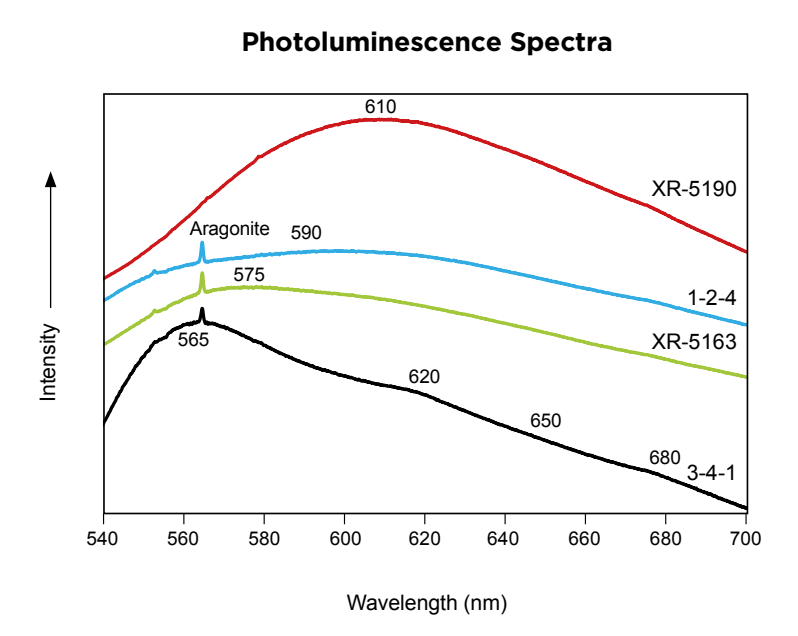

Figure 8: PL spectra are shown for the same *P. radiata* bead-cultured pearls (XR-5163 and XR-5190) and non-bead-cultured pearls (1-2-4 and 3-4-1) as in Figure 7. Three of the spectra (XR-5163, 1-2-4 and 3-4-1) have been normalised to the major Raman band of aragonite (appearing as a sharp band slightly above 560 nm, i.e. at 1085 cm^{-1}) and shifted vertically for clarity.

at 565, 590 and 620 nm. For the vast majority of the studied samples (110), the apparent PL maxima were in the orange to red region at 605–625 nm (e.g. XR-5190 in Figure 8); for 27 samples the maxima were positioned in the yellow to orange region at 580–600 nm (e.g. 1-2-4 in Figure 8); and nine cultured pearls showed maxima in the green to yellow region at 555–575 nm (e.g. XR-5163 in Figure 8).

UV-Vis-NIR Spectroscopy

The UV-Vis-NIR spectra of all the studied samples presented bands (appearing as minima in diffuse reflectance; Figure 9) in the visible range at around 410, 435 and 460 nm—possibly related to partially substituted (i.e. partially methylated) polyenic pigments—similar to those observed for freshwater cultured pearls (Karampelas *et al.* 2009). Some samples (of no particular colour)

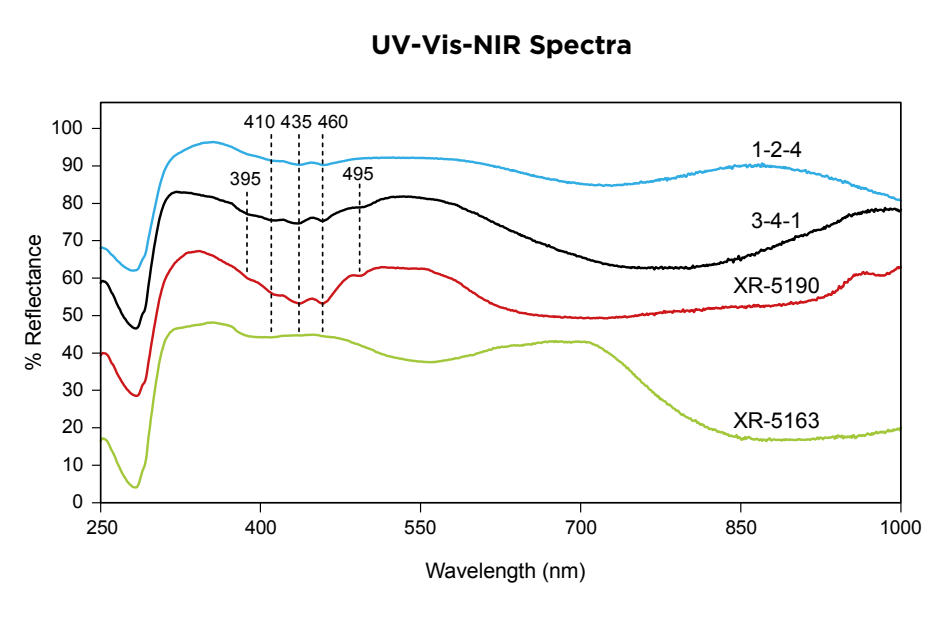

Figure 9: UV-Vis-NIR spectra for the same *P. radiata* bead-cultured pearls (XR-5163 and XR-5190) and non-bead-cultured pearls (1-2-4 and 3-4-1) as in Figures 7 and 8 are shown here for comparison. The spectra have been shifted vertically for clarity (–20% for XR-5163, +10% for 1-2-4 and +15% for 3-4-1).

displayed an additional band at 495 nm, possibly linked to a type of porphyrin (Nilpetploy *et al.* 2018; Karampelas *et al.* 2019a). Taken together, the series of bands recorded here differ from those of saltwater cultured pearls from other species (*P. maxima*, *P. margaritifera*, *P. maculata* and *Pteria* sp.; cf. Karampelas *et al.* 2011a, b; Karampelas 2012; Otter *et al.* 2017; Nilpetploy *et al.* 2018). Those at 435 and 460 nm have been observed in akoya cultured pearls (i.e. from *P. fucata*). However, those at 410 and 495 nm, along with another band at around 395 nm, have only been observed in *P. radiata* samples.

Chemical Analysis

The chemical composition of the cultured pearls from Abu Dhabi is presented in Table III and compared to previously published data on natural pearls from *P. radiata* fished off Bahrain, as well as bead-cultured pearls from *P. fucata* cultivated off Vietnam (Karampelas *et al.* 2019b) and Japan (from the DANAT reference collection).

All studied samples from Abu Dhabi presented low concentrations of Mn (always below the detection limit of EDXRF and sometimes below the quantification limit for LA-ICP-MS) and relatively high concentrations of Sr. The cultured pearls from *P. fucata* presented relatively higher amounts of Mn (>10 ppmw Mn) compared to the other samples. It was suggested by Gordon *et al.* (1970) that the water's Mn content is the most important factor affecting the Mn composition of molluscs, shells and possibly natural and cultured pearls. On the other hand, the Sr content of the inner part of saltwater aragonitic bivalves is influenced by the animal's growth rate (possibly linked to water temperature), as well as physiological processes (Stecher *et al.* 1996; Poulain *et al.* 2015; Wanamaker & Gillikin 2019). Some of the studied samples from Abu Dhabi had slightly lower Sr values than the other two types. Sodium was present in relatively high amounts in all samples, and in biogenic carbonate this element is related to water salinity and pH (Gordon *et al.* 1970). The Na concentrations were similar in the cultured pearls from Abu Dhabi and natural pearls from Bahrain; however, Na was slightly lower in the cultured pearls from Japan and Vietnam.

It has been suggested that Mg in aragonitic shells is related to physiological processes (Foster *et al.* 2008; Poulain *et al.* 2015). All samples in Table III presented somewhat similar Mg contents; only nine of the 146 cultured pearls from Abu Dhabi contained >500 ppmw Mg. Barium in biogenic aragonite shows a strong inverse correlation with water salinity and food supply; shell growth and an as-yet undetermined environmental factor are also thought to influence Ba content (Gillikin *et al.* 2008; Poulain *et al.* 2015). All the samples in Table III contained very low Ba (sometimes below the quantification limit). Natural pearls from *P. radiata* fished off Bahrain showed slightly higher Ba, with 23 of the 248 samples having >1.5 ppmw Ba. Figure 10 presents a plot of Sr vs. Ba, suggesting an overall positive correlation between these elements; this apparent trend needs further investigation.

Table III: Chemical analysis by LA-ICP-MS (in ppmw) of *P. radiata* bead-cultured and non-bead-cultured pearls from Abu Dhabi, *P. radiata* natural pearls from Bahrain, and *P. fucata* cultured pearls from Japan and Vietnam.[a]

Samples	Element	Range	Average (SD)	Median
P. radiata (Abu Dhabi, cultured), 146 samples, 438 analyses	Na	3440–7290	5200 (660)	4910
	Mg	55.2–1280	265 (166)	181
	Mn	BQL–5.96	1.03 (1.02)	0.48
	Sr[b]	448–1270	769 (186)	670
	Ba	BQL–0.85	0.22 (0.13)	0.15
P. radiata (Bahrain, natural), 248 samples, 248 analyses	Na	3340–7270	5250 (801)	5250
	Mg	29.5–477	147 (88.2)	131
	Mn	BQL–7.62	0.79 (1.38)	BQL
	Sr	518–1650	944 (219)	902
	Ba	BQL–4.32	0.78 (0.60)	0.58
P. fucata (Japan and Vietnam, cultured), 17 samples, 51 analyses	Na	2370–4950	4090 (502)	4150
	Mg	116–950	292 (165)	244
	Mn	0.48–18	6.35 (4.92)	4.70
	Sr	888–1860	995 (222)	933
	Ba	0.06–1.47	0.28 (0.34)	0.14

[a] The quantification limits of Mn were 0.26–1.28 and Ba were 0.02–0.17. Abbreviations: BQL = below quantification limit, SD = standard deviation.
[b] As measured by EDXRF spectroscopy, the contents of Sr in the same bead-cultured and non-bead-cultured pearls from Abu Dhabi were 734–1660 ppmw (average 1000 ppmw). Mn was below the EDXRF detection limit.

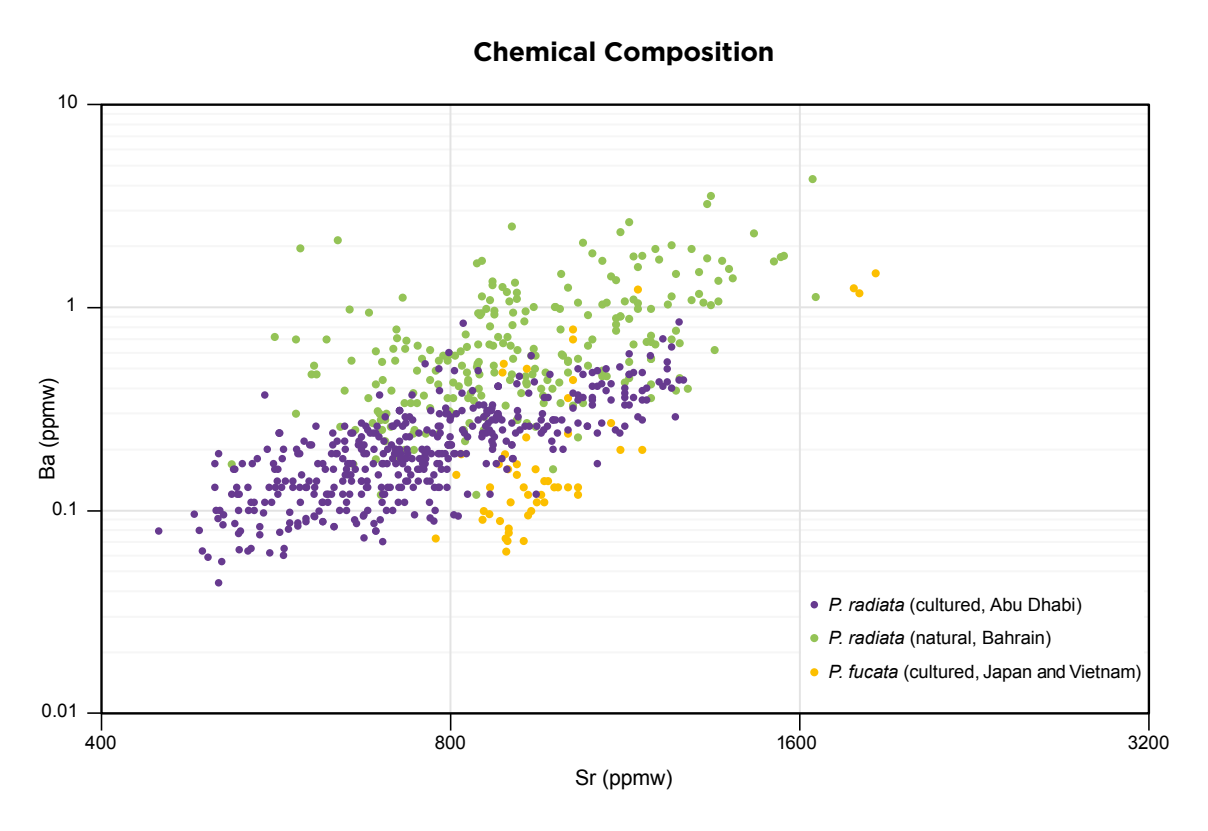

Figure 10: This binary plot compares the Sr and Ba contents of the *P. radiata* cultured pearl samples from Abu Dhabi with *P. radiata* natural pearls fished off Bahrain and *P. fucata* cultured pearls from Japan and Vietnam. Some of the studied samples from Abu Dhabi have lower Ba and Sr than the other two sample types.

CONCLUSION

This study of bead-cultured and non-bead-cultured products from the Abu Dhabi Pearls project in the UAE offers a complete gemmological analysis of cultured pearls from *P. radiata*. They showed a vast range of colours, from white to cream, light yellow to yellow, brown and various tones of grey with pink overtones, and some with iridescence. The vast majority of the cultured pearls luminesced green to greenish yellow under short-wave UV radiation and yellow to green under long-wave UV. With X-microradiography and micro-CT imaging, the bead-cultured pearls showed typical strong demarcation lines around the nuclei and sometimes large voids and calcium carbonate-rich areas with radial-like structures. Most of the non-bead-cultured pearls contained voids of variable dimension, similar to those observed in non-bead-cultured pearls from other molluscs, and different from those documented in natural pearls. Raman bands due to partially substituted (i.e. partially methylated) polyenes were recorded at around 1130 and 1520 cm^{-1} for most of the samples. Samples from *P. radiata* and *P. fucata* (i.e. akoya cultured pearls) are the only nacreous saltwater-cultured pearls found to date presenting such bands. UV-Vis spectroscopy revealed bands at 410, 435 and 460 nm in all samples, and these are also linked to the same partially substituted (i.e. partially methylated) polyenic pigments indicated by Raman spectroscopy. Some samples yielded an additional band at around 495 nm, possibly linked to a type of porphyrin. These bands differ from those recorded for cultured pearls from other species (*P. maxima*, *P. margaritifera*, *P. maculata* and *Pteria* sp.), and those at 410 and 495 nm are different from bands recorded for akoya samples (i.e. *P. fucata*). Chemical analyses of the most important trace elements in the studied cultured pearls from Abu Dhabi show results similar to those for *P. radiata* natural pearls fished off Bahrain.

Work is ongoing at the Abu Dhabi Pearls project to decrease the rate of bead rejection and improve the

percentage of gem-quality cultured pearls. A trademark for the term *Abu Dhabi Pearls* was recently registered, and these cultured pearls (Figure 11) will be commercially produced in the near future. In addition, further studies are needed of the non-bead-cultured pearl by-products to characterise their internal structures, as well as their chemical and spectroscopic features, in order to properly separate them from natural pearls from *P. radiata* fished off Bahrain and other regions in the Arabian Gulf.

Figure 11: These white-to-cream bead-cultured pearls were produced from the Abu Dhabi Pearls project. They range from 5.5 to 8.5 mm in diameter. Courtesy of the Abu Dhabi Pearls project.

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Diamonds from the Nassau Mountains, Suriname

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ABSTRACT: Alluvial diamonds have been found in Suriname since the late 19th century, but to date the details of their origin remain unclear. Here we describe diamonds from Paramaka Creek (Nassau Mountains area) in the Marowijne greenstone belt, Guiana Shield, north-eastern Suriname. Thirteen samples were studied, consisting mainly of euhedral crystals with dominant octahedral and dodecahedral habits. They had colourless to brown to slightly greenish body colours, and some showed green or (less commonly) brown irradiation spots. Surface features showed evidence of late-stage resorption that occurred during their transport to the earth's surface. The studied diamonds were predominantly type IaAB, with nitrogen as both A and B aggregates. In the DiamondView most samples displayed blue and/or green luminescence and concentric growth patterns. Their mineral inclusion assemblages (forsterite and enstatite) indicate a peridotitic (possibly harzburgitic) paragenesis.

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Since 1880, diamonds from Suriname (e.g. Figure 1) have been collected from alluvial deposits situated within the Marowijne greenstone belt. The initial finds took place in the Rosebel area, which later became part of the Rosebel Gold Mines concession (van Kooten 1954; Schönberger & de Roever 1974; Schönberger 1975; de Vletter 1998). A second occurrence was reported from the Paramaka Creek area of the Nassau Mountains (Headley 1913; see Figure 2), located about 85 km south-east of Rosebel. The creek has been worked extensively by artisanal gold miners, and in early 2018 diamonds were accidentally discovered in their tailings. There is currently no diamond mine in the area, but recently systematic diamond exploration was initiated there.

Although the geology of the Marowijne greenstone belt is fairly well known (see below), the original source of the alluvial diamonds remains unclear. Moreover, despite the rather long period that diamonds have been sourced from Suriname, they have not been previously studied in detail, and data on their mineral inclusions have also been lacking. This article characterises the external crystal morphology, mineral inclusions and other features of diamonds from Paramaka Creek in order to elucidate their source-rock environment and subsequent alluvial processes involved in their deposition.

GEOLOGY AND SOURCE OF THE DIAMONDS

The Marowijne greenstone belt of Suriname (Figure 3) forms part of a 1,500-km-long granite-greenstone terrane extending along the northern portion of the Guiana Shield from north-eastern Venezuela to Brazil's Amapá State. According to Kroonenberg *et al.* (2016), it formed during the Trans-Amazonian Orogeny (about 2,180–1,950 million years ago [Ma]) by the north-south convergence and eventual collision of the Amazonian and West African cratons. The dominant rock types are tholeiitic ocean-floor metabasalts, island arc meta-andesites and associated sediments of the Paramaka Formation, which are intruded by various types of igneous bodies (tonalite, trondhjemite and granodiorite). The area is overlain by metaturbidites of the Armina Formation and is intruded by two-mica granites. Unconformably overlying the earlier formations are epicontinental low-grade-metamorphosed fluvial sandstones and conglomerates of the Rosebel Formation. Small mafic to ultramafic plutons are scattered throughout the area, and the latter are typically metamorphosed into talc-chlorite-tremolite schists (Veenstra 1983; Naipal *et al.* 2019).

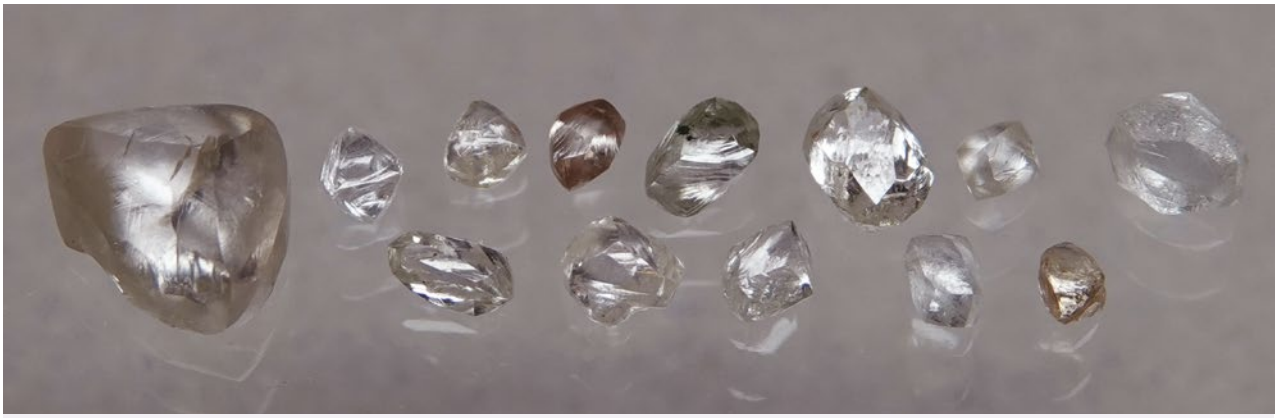

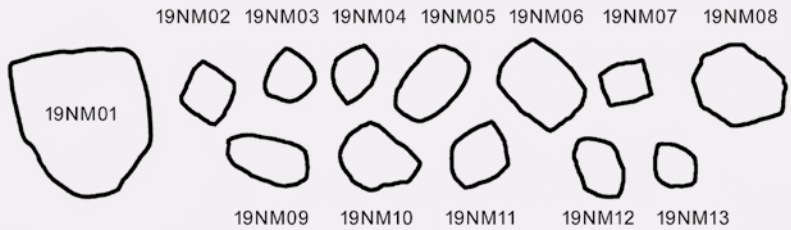

Figure 1: Thirteen diamonds (0.10–2.12 ct), typical of those recovered in Suriname since the late 19th century, were analysed for this study. The sample numbers are given in the key; see Table I for individual weights and sizes. Photo by J. C. Zwaan.

The Nassau Mountains form a horseshoe-shaped range that is mainly underlain by Paramaka Formation metabasalts (Figure 3) and associated rocks, and is covered by bauxite caps up to 500 m above sea level. Paramaka Creek (a tributary of the Marowijne [or Maroni] River) drains the mountains towards the east.

To date, gem-quality diamonds have been found in three known geological settings in the Guiana Shield: (1) in komatiitic volcaniclastic rocks (about 2,011 Ma) of the Inini greenstone belt in French Guiana (Capdevila *et al.* 1999); (2) in conglomerates of the Roraima Formation (about 1,843 Ma) in Venezuela (Santos *et al.* 2003) and Guyana (Tan *et al.* 2016), and (3) in kimberlite sills (about 730 Ma) in Guaniamo, Venezuela (Channer *et al.* 1998; Kaminsky *et al.* 2000). The source rocks of the alluvial diamond occurrences in Suriname (i.e. both the Rosebel and Paramaka Creek localities) are unknown.

MATERIALS AND METHODS

Thirteen diamonds from Paramaka Creek (Figure 1) were loaned to the authors from a collection of around 100 diamonds that were found by artisanal gold miners. They were studied at the Netherlands Gemmological Laboratory of the Naturalis Biodiversity Center, Leiden, the Netherlands. The diamonds were visually examined with a standard gemmological microscope and a Nikon Eclipse E600 POL polarising microscope to observe internal and external morphological and surface features.

The concentrations and aggregation states of nitrogen impurities in the diamonds were determined by Fourier-transform infrared (FTIR) spectroscopy, using a Thermo Nicolet iS50 FTIR spectrometer equipped with a 5× beam condenser. Measurements were obtained for the mid-infrared range in transmission mode with a resolution of 4 cm^{-1} and 200 scans per spectrum, using a KBr beam splitter and a DTGS KBr detector. The spectra were normalised to type IIa diamond (i.e. without any defect-induced absorption in the single-phonon region). Spectral deconvolution was performed using a spreadsheet provided by D. Fisher (De Beers Research Centre). Nitrogen abundances and type IaB aggregation states were estimated from the A- and B-defect components of the spectra using the IaA and IaB nitrogen absorption coefficients of Boyd *et al.* (1994, 1995).

Figure 2: The authors' team pans sediments from Paramaka Creek in search of diamonds. Photo by S. B. Kroonenberg.

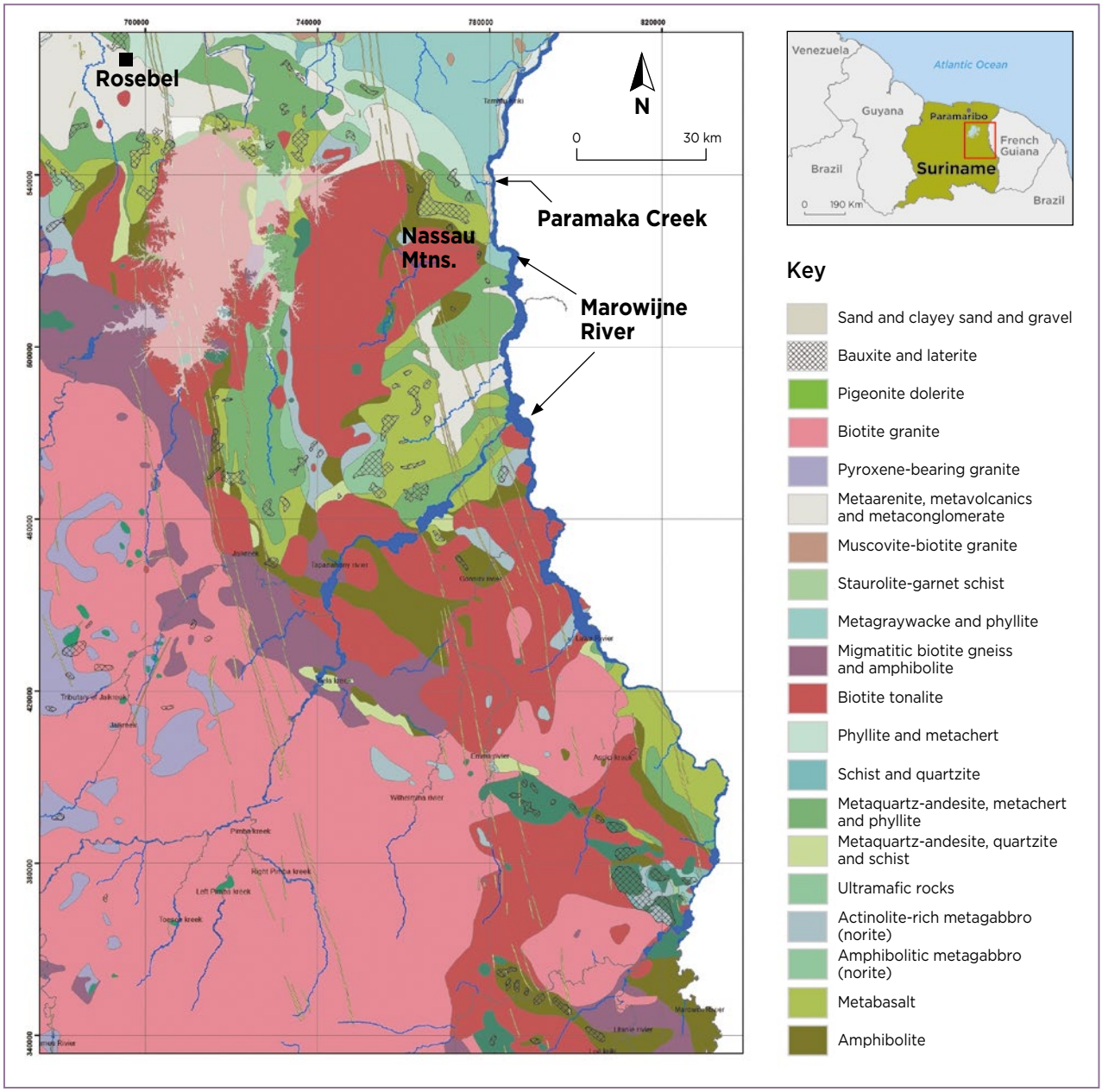

Figure 3: The geology of the Marowijne greenstone belt in north-eastern Suriname is shown on this map, together with known diamond locations in the Rosebel area and in Paramaka Creek (Nassau Mountains). Modified after Geological and Mining Service of Suriname (2018).

We observed luminescence using long-wave (365 nm) and short-wave (254 nm) UV radiation in a darkened room. Growth patterns and luminescence were further observed with a DiamondView instrument using high-intensity ultra-short-wave UV radiation (<230 nm).

Mineral inclusions were analysed using a Thermo Scientific DXR Raman microscope with 532 nm laser excitation. Raman spectra were collected in confocal mode in order to analyse individual inclusions on a micron scale (1–2 µm). Spectra were collected in the 1300–200 cm^{-1} range to avoid the strong Raman signal at 1332 cm^{-1} caused by the host diamond.

RESULTS

The characteristics of the diamonds are summarised in Table I and described below.

Weight, Size and Colour

The diamonds ranged from 0.10 to 0.36 ct, with the exception of one 2.12 ct crystal (Figure 1). The majority (seven) of the stones were colourless, one stone was colourless with a green 'skin', and two were colourless to slightly greenish. Three stones showed very pale to moderate brown colouration.

Table I: Characteristics of the studied diamonds from Paramaka Creek, Suriname.*

Sample number	Dimensions (mm)	Weight (ct)	Crystal morphology	Colour	Surface features/ radiation spots	Type	N content (ppma)	IaB (%)	UV fluorescence		DiamondView luminescence and growth patterns	Inclusions
									Long-wave	Short-wave		
19NM01	8.0 × 6.5 × 4.3	2.12	Triangular; rounded crystal with a prominent octahedral face	Colourless	Rounded/ none	IaA	250	8	Inert	Inert	Core: concentric growth zoning (alternating green and blue); rim: different domains of green angular growth zoning	None
19NM02	3.1 × 2.3 × 2.1	0.14	Octahedron	Colourless	Stepped growth/ brown and green	IaA	100	0	Inert	Inert	Green octahedral graining	None
19NM03	3.4 × 2.5 × 2.4	0.10	Flattened crystal with octahedral and dodecahedral faces; trigons present	Very pale brown	Stepped growth, negative trigons/ brown	IaAB	60	68	Inert	Inert	Concentric, irregular growth zoning (alternating blue and green layers)	None
19NM04	2.9 × 2.2 × 2.1	0.10	Distorted octahedron with residual dodecahedral faces	Moderate brown	Stepped growth/ none	IaAB	40	42	Inert	Inert	Alternating blue and green octahedral growth layers	None
19NM05	4.0 × 2.6 × 2.4	0.23	Distorted octahedral and dodecahedral faces	Colourless, green skin	Stepped growth/ green and brown	IaAB	140	80	Weak (blue)	Inert	Concentric growth zoning with a green core, a blue intermediate zone, and narrow alternating green and blue zones towards the rim	En, Fo
19NM06	4.7 × 3.2 × 2.9	0.36	Distorted octahedral and dodecahedral faces	Colourless	Stepped growth/ brown	IaAB	340	60	Inert	Inert	Blue concentric growth zoning with some narrow green zones	Fo
19NM07	3.5 × 2.8 × 2.1	0.10	Distorted crystal, mainly dodecahedral faces	Colourless	Dull lustre/ none	IaAB	100	77	Moderate (light blue)	Weak	Blue, with one narrow green concentric growth zone	En
19NM08	4.4 × 3.2 × 2.4	0.36	Crystal with smooth octahedral faces (including trigons) and etched dodecahedral faces	Colourless	Negative trigons/ none	IaA	310	13	Inert	Inert	Blue, with one narrow green concentric growth zone near the rim and complex green zoning in one corner	None
19NM09	4.2 × 2.2 × 1.6	0.12	Elongated crystal with dodecahedral faces	Colourless to slightly greenish	None/ green	IaAB	310	77	Moderate (light blue)	Weak	Blue concentric growth zoning	None
19NM10	3.4 × 3.1 × 2.1	0.19	Distorted crystal; octahedral faces dominant	Colourless to slightly greenish	None/ green	IaAB	250	54	Moderate (light blue)	Weak	Blue concentric growth zoning	None
19NM11	3.2 × 2.2 × 2.0	0.18	Distorted dodecahedron with residual octahedral faces	Colourless	Stepped growth/ green	IaAB	220	69	Moderate (light blue)	Weak	Octahedral zoning, showing green core, blue intermediate zone and narrow green zoning at the rim	None
19NM12	3.3 × 2.0 × 1.8	0.14	Flattened and elongated dodecahedron	Colourless	None/ none	IaAB	120	59	Weak (blue)	Inert	Blue concentric zoning, with a few green layers in between	None
19NM13	2.9 × 2.4 × 1.9	0.10	Slightly distorted (flattened) octahedron	Pale brown	Irregular/ green	IIa	nd	0	Inert	Inert	Orange-brown octahedral zoning, alternating with narrow inert layers; part of the crystal remained inert	None

*Abbreviations: En = Enstatite, Fo = Forsterite, nd = not detected.

Morphology and Surface Features

All the studied diamonds consisted of monocrystalline octahedra and dodecahedra (some with transitional forms between these two morphological types). Two octahedra showed typical stepped growth (Figure 4a). The largest crystal was triangular shaped and rounded, and had a prominent octahedral face. It resembled a macle but did not clearly show re-entrant angles. Other crystals were distorted, flattened or elongated.

Surface features consisted of triangular etch pits with negative trigons (Figure 4b), as well as a type of etching known as 'fine frosting' (Tappert & Tappert 2011) with numerous micro pits (Figure 4c), giving those diamonds a dull lustre. The crystal faces were almost free of abrasions, with edges that were mostly undamaged. Only a few small surface pits of unknown origin were observed on some of the crystals. The surfaces of two diamonds (samples 19NM04 and 19NM07) showed sets of straight lines parallel to octahedral planes that are indicative of plastic deformation (Tappert & Tappert 2011). Another important surface feature was the presence of green spots (isolated or clusters), and less commonly brown ones (Figure 4d), which indicate the diamonds were exposed to alpha radiation (Tappert & Tappert 2011).

Diamond Type and Nitrogen Content

The FTIR data showed that nine of the studied diamonds were type IaAB (e.g. Figure 5a), which have both A aggregates (nitrogen pairs; band at 1282 cm^{-1}) and B aggregates (four nitrogen atoms surrounding a vacancy; band at 1175 cm^{-1}). Three of the remainder were type IaA (Figure 5b), in which nitrogen as A centres dominates. One diamond had no detectable nitrogen impurities and is thus classified as type IIa (Figure 5c; cf. Breeding & Shigley 2009). The spectra of the IaAB diamonds also showed an absorption at 3107 cm^{-1} (Figure 5a), which in natural diamonds corresponds to an atomic configuration consisting of three nitrogen atoms, a vacancy and hydrogen (VN_3H; Goss *et al.* 2014).

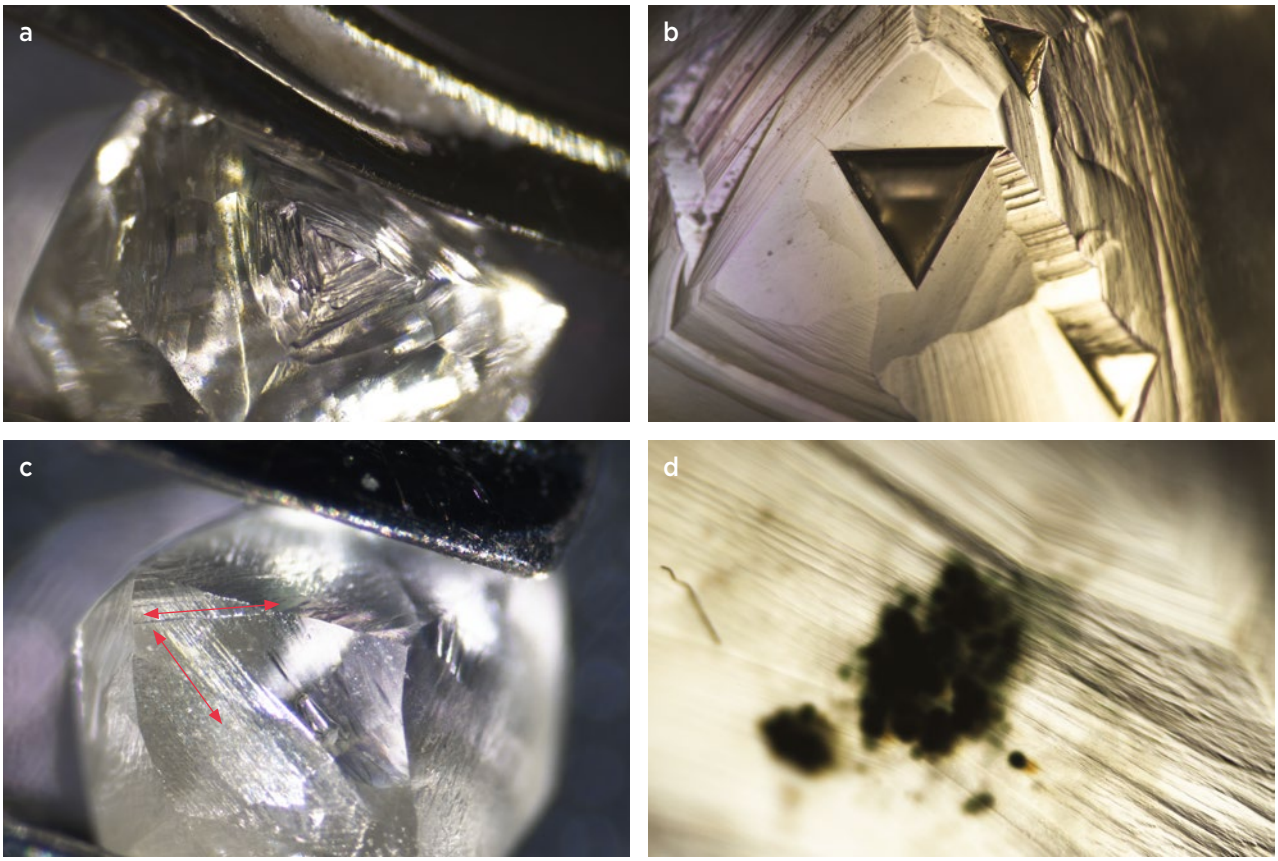

Figure 4: Various surface features are present on the investigated diamonds. (**a**) One octahedral face of sample 19NM11 shows partially resorbed stepped growth (image width 3.1 mm). (**b**) A large negative trigon occurs on a stepped octahedral face of sample 19NM03 (image width 1.4 mm). (**c**) Frosted dodecahedral crystal faces of sample 19NM07 show two faint sets of plastic deformation lines (see arrows; image width 3.7 mm). (**d**) A cluster of dark green radiation spots (including some brown areas, e.g. on the lower right) and a linear feature associated with radiation damage (left) occur on the surface of sample 19NM05 (image width 1.4 mm). Photomicrographs by R. Naipal.

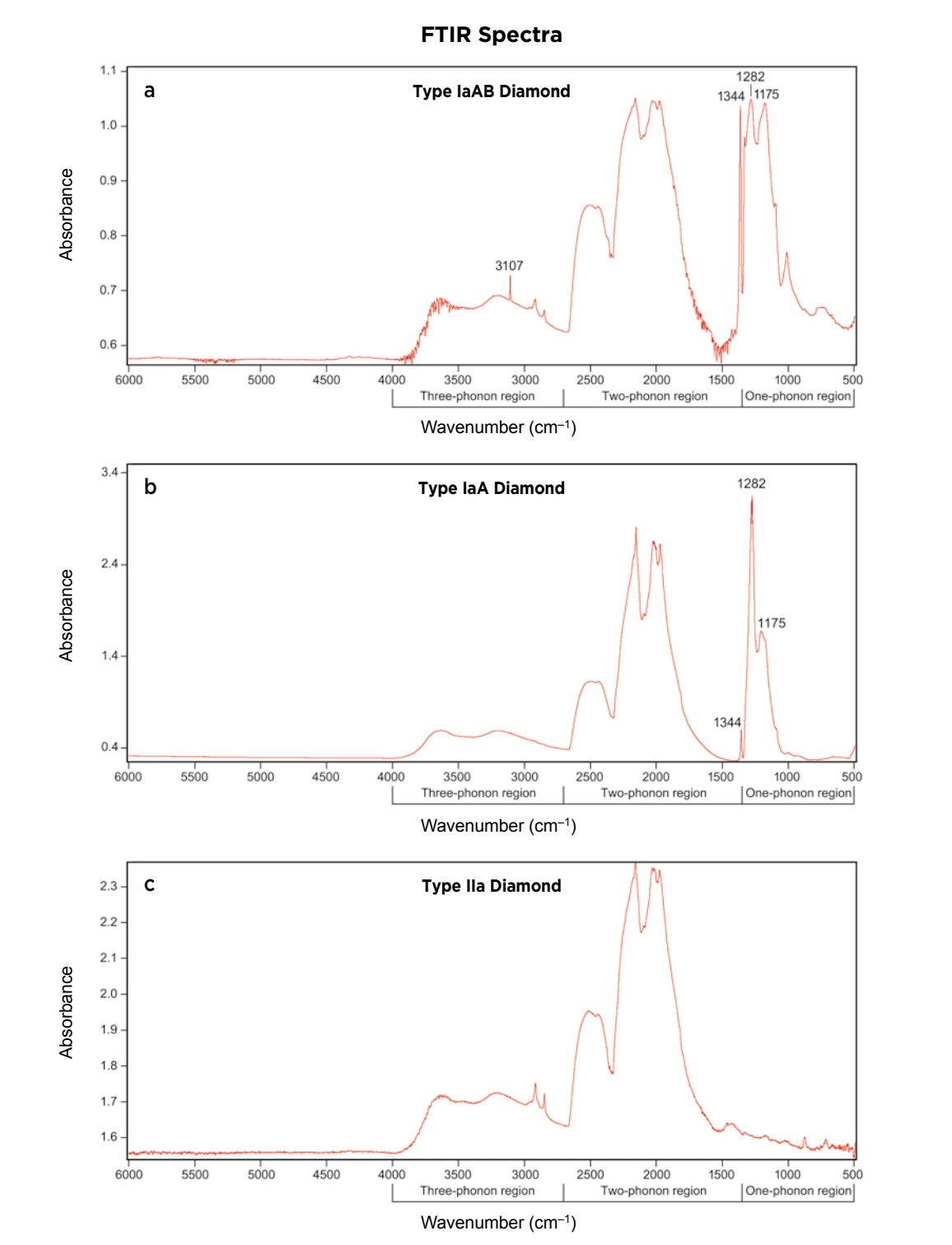

Figure 5: FTIR spectra are shown for the three different diamond types that were documented in this study. The one-phonon region (1332–400 cm^{-1}) is related to nitrogen defects, the two-phonon region (2665–1332 cm^{-1}) characterises carbon (diamond area) and the three-phonon region (4000–2665 cm^{-1}) is also intrinsic to diamond but in addition may show features of hydrogen impurities. (**a**) The spectrum of a type IaAB diamond (19NM05) displays the 1175 cm^{-1} band of B centres, 1282 cm^{-1} band of A centres, 1344 cm^{-1} band of single nitrogen and 3107 cm^{-1} band of hydrogen-related defects (VN_3H). (**b**) A type IaA diamond (19NM01) yields a spectrum in which A centres are dominant. (**c**) The type IIa diamond (19NM13) displays no detectable spectral features of nitrogen impurities. The features in the 3000–2800 cm^{-1} region are due to traces of oil left behind on the surfaces of the crystals after cleaning.

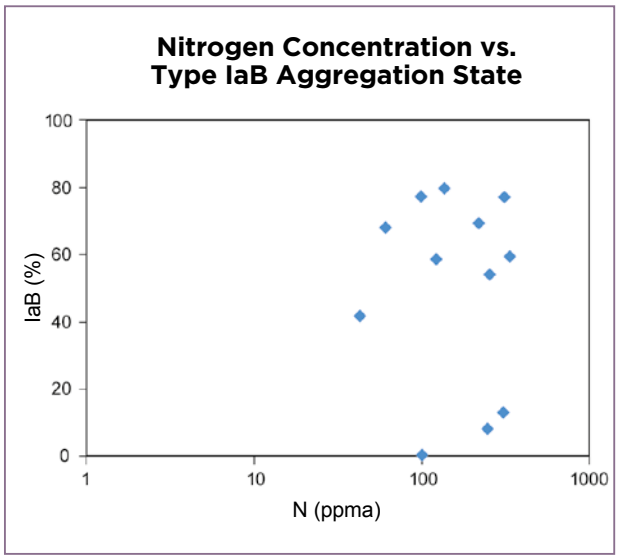

Figure 6: A plot of nitrogen concentration vs. IaB aggregation state shows that three diamonds predominantly contain A aggregates and nine diamonds contain B aggregates up to 80%.

For the single type IIa diamond (19NM13), the absence of detectable IR features in the one-phonon region indicates a nitrogen content of <5 ppm (Breeding & Shigley 2009). The spectra of most of the other diamonds had flat baselines, allowing robust fits during deconvolution, but samples 19NM03 and 19NM06, with variable baselines, gave slightly less reliable results. Overall, the nitrogen content of the 12 N-bearing diamonds ranged from 40 to 340 ppma and the nitrogen aggregation for the IaAB diamonds (expressed as the percentage of IaB content) was 42–80% (Table I; Figure 6).

Luminescence

Diamond can produce variable luminescence due to the interaction of UV radiation with impurities and imperfections in the crystal structure (e.g. Figure 7; Eaton-Magaña *et al.* 2007). Four of the diamonds showed moderate fluorescence to long-wave UV radiation (365 nm) and weak luminescence to short-wave UV (254 nm), and two diamonds showed weak fluorescence to long-wave UV and none to short-wave UV. The other seven crystals were inert (Table I).

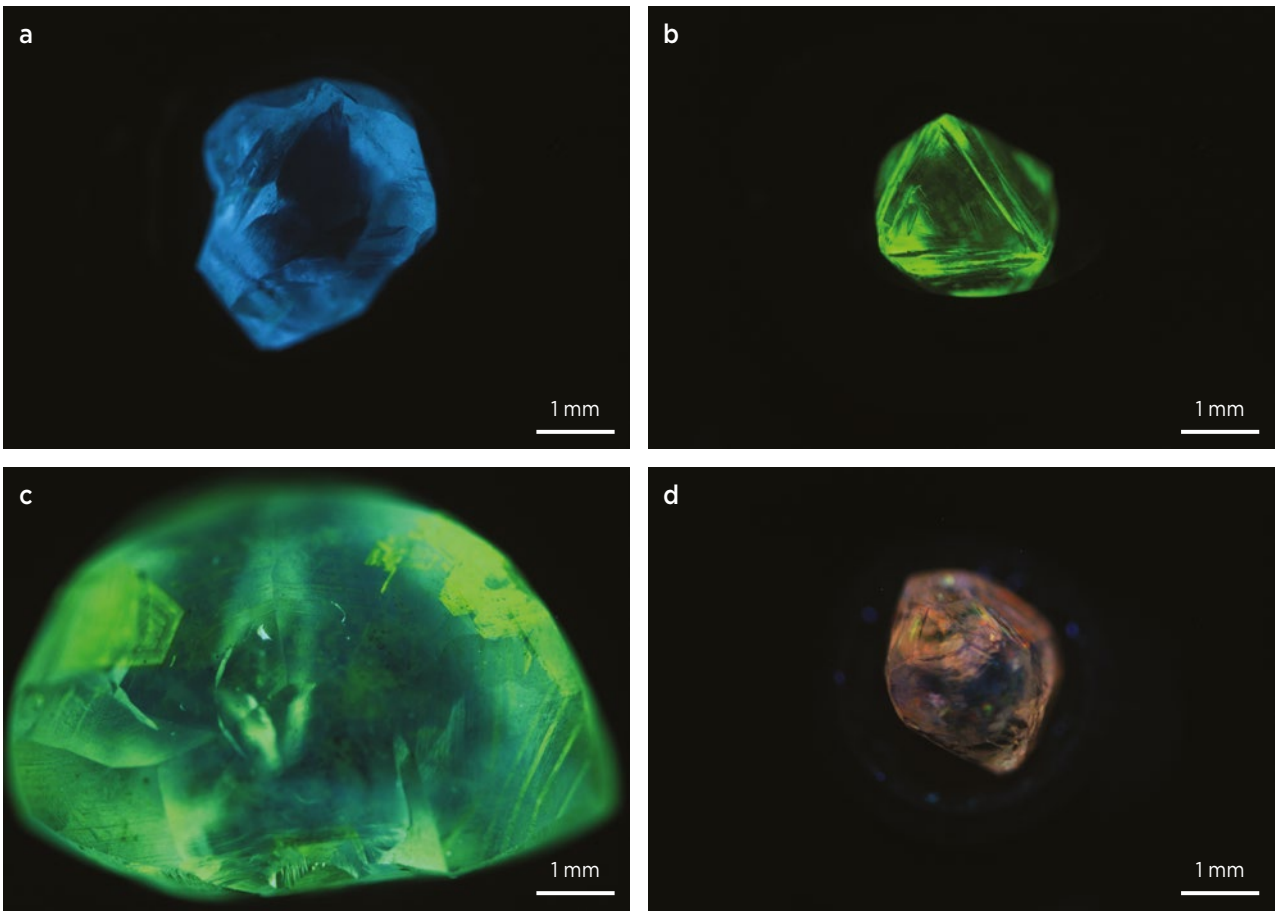

Figure 7: DiamondView images illustrate the range of reactions observed in the Suriname diamonds: (**a**) common blue fluorescence (19NM10); (**b**) green fluorescence (19NM02); (**c**) complex growth zoning (19NM01); and (**d**) orange-brown fluorescence in a type IIa diamond (19NM13). Photos by R. Naipal.

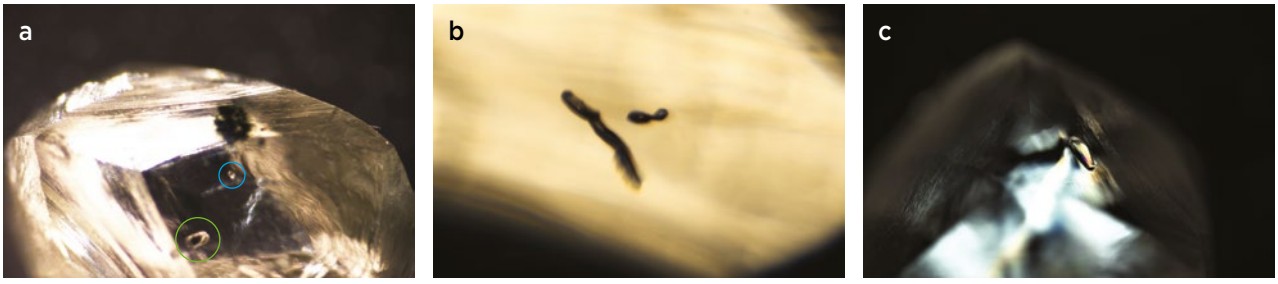

Figure 8: Mineral inclusions in the Suriname diamonds consist of enstatite and/or forsterite. (**a**) An elongated enstatite inclusion (green circle) coexists with a slightly rounded forsterite (blue circle) in sample 19NM05 (plane-polarised light, image width 3.7 mm). (**b**) Elongated forsterite inclusions are present in sample 19NM06 (plane-polarised light, image width 1.4 mm). (**c**) This euhedral, elongated, colourless enstatite occurs in sample 19NM07 (crossed polarisers, image width 2.8 mm). Photomicrographs by J. C. Zwaan.

Using the high-intensity short-wave UV radiation of the DiamondView, all samples fluoresced and revealed growth patterns (e.g. Figure 7). Most of the 12 type Ia diamonds showed blue fluorescence with growth patterns that commonly consisted of narrow green concentric bands. Blue luminescence (Figure 7a) in diamond is caused by nitrogen impurities in the form of N3 centres (three nitrogen atoms surrounding a vacancy). In addition, green fluorescence banding in the diamonds can be related to the H3 defect, which is caused by two nitrogen atoms separated by a vacancy (Breeding & Shigley 2009). One crystal showed overall green luminescence (Figure 7b), which could be due to dominating H3 defects or the presence of Ni-related defects (Wang *et al.* 2007). The patterns seen in the relatively large triangular rounded crystal (19NM01) indicate a complex growth history. Towards the centre, a simple concentric zonation was observed (blue-green), whereas the edges showed different domains of angular patterns (green; see Figure 7c). These structures might be related to different stages of growth.

The one type IIa diamond (19NM13; Figure 7d) fluoresced orange-brown in the DiamondView, although a part of the crystal remained inert. The orange-brown luminescence might be related to the presence of NV centres (cf. Soonthorntantikul & Wang 2016).

Mineral Inclusions

Only four of the 13 studied diamonds were found to contain inclusions, but not all of them could be identified with confidence based on Raman peak positions. Some other inclusions were positioned too deep in the crystals to obtain good Raman spectra.

Two different silicates were found in one diamond (19NM05; Table I): a colourless, elongated enstatite and a colourless, rounded forsterite (Figure 8a). Forsterite and enstatite inclusions were also identified in diamonds 19NM06 and 19NM07, respectively (Figures 8b and 8c).

Raman analyses of the forsterite inclusions showed two prominent features at 854 and 823 cm^{-1} (Figure 9a), which are due to $\nu_1+\nu_3$ frequencies caused by SiO_4 internal symmetric and asymmetric stretching, respectively. With the high spectral resolution of about 2 cm^{-1}, the positions of these analysed features closely corresponded to end-member forsterite (856 and 824 cm^{-1}), indicating olivine with very high forsterite composition (around Fo_{88}; cf. Chopelas 1991). Raman analyses of the enstatite inclusions (Figure 9b) showed prominent features at 1012 (Si-O stretching), 686, 664 (Si-O bending), 344 and 238 cm^{-1} (metal-oxygen bending and stretching), which is consistent with the spectrum of orthoenstatite (currently simply called enstatite; Chopelas 1999). Since most Raman frequencies in the enstatite-ferrosilite series decrease with increasing Fe content, the measured features are consistent with an almost pure enstatite composition. By comparison, a composition of $En_{0.975}Fs_{0.025}$ reported by Huang *et al.* (2000) gave very similar Raman frequencies at 1013, 686, 663, 343 and 239 cm^{-1}.

DISCUSSION

The stepped growth seen on the crystal faces of some of the Suriname diamonds indicates that they grew layer by layer in a relatively stable environment (Robinson 1979; Tappert & Tappert 2011). The trigons or etch pits on their surfaces mainly result from resorption processes that took place during their transport to the earth's surface (e.g. in a kimberlitic melt; Tappert & Tappert 2011). The absence of abrasion and percussion marks on the diamonds does not directly relate to the distance of transport from the diamond host rock; instead, it is likely to reflect the stream-bed gradient and the stream-bed lithology (Robinson 1979).

The observed radiation spots on the diamond surfaces might have been caused by the presence of radioactive

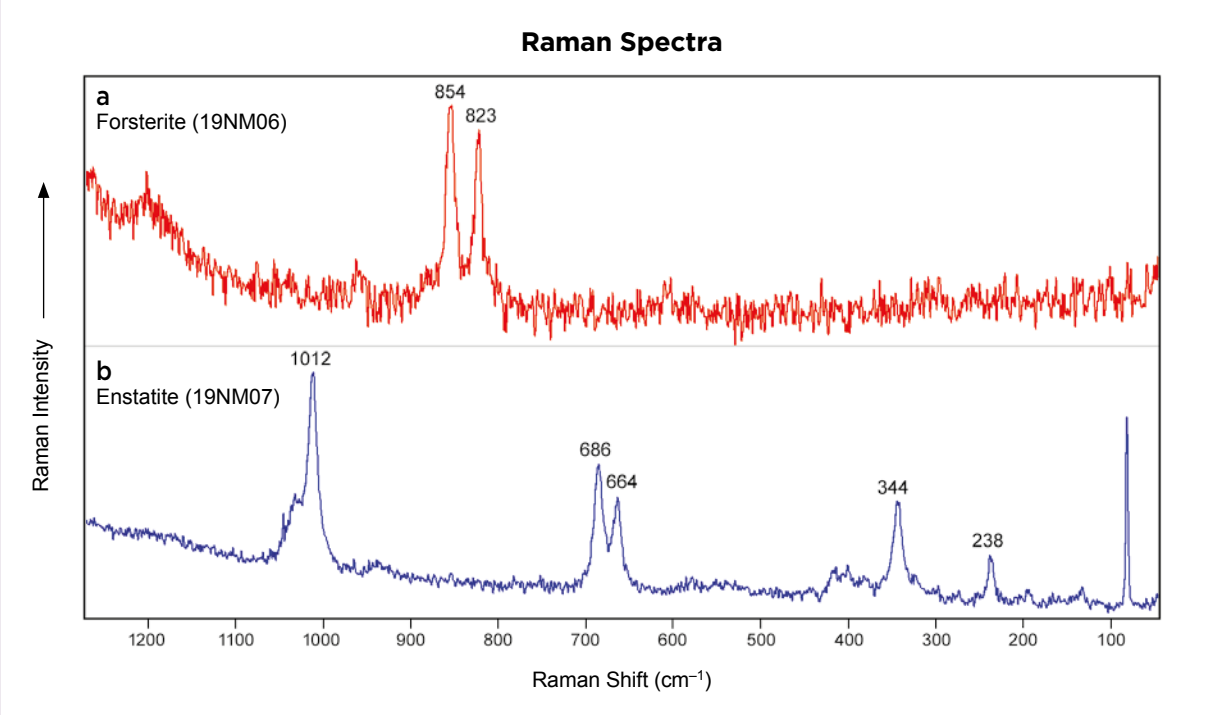

Figure 9: The Raman spectra of two different syngenetic silicate mineral inclusions found in the sample diamonds identify them as (**a**) forsterite and (**b**) enstatite.

elements, such as U and Th, in minerals adjacent to the diamonds in the alluvial environment (Tappert & Tappert 2011). Irradiation by radioactive decay causes carbon atoms to be expelled from the diamond crystal lattice within 20 µm of the surface, and the resulting vacancies form green colour centres that are present as localised spots or clusters of spots on a diamond's surface (Tappert *et al.* 2006). The green 'skin' present on three of the diamonds resulted from the same process but is probably the product of radioactive groundwater (Tappert & Tappert 2011).

The few brown spots noted on the study diamonds could have been derived from a kinetic reaction (one involving time and temperature) that affected the original green spots (Vance *et al.* 1973). Experiments have shown that green radiation spots turn brown in response to annealing at temperatures between 550 and 600°C (Vance *et al.* 1973; Eaton-Magaña & Moe 2016). As the reaction is time-related, much lower temperatures can produce the same effect over a longer period. Similar cases of green- and brown-spotted diamonds are mostly associated with long-term residence in meta-conglomerates, such as the diamonds in the U-bearing sediments of Witwatersrand, South Africa (Raal 1969); Guaniamo, Venezuela (Channer *et al.* 1998; Kaminsky *et al.* 2000); and Chapada Diamantina, Brazil (Vance *et al.* 1973; Vilela de Carvalho *et al.* 2018). The Paramaka Creek diamonds might have undergone a similar history of reworking and deposition in the Marowijne greenstone belt sediments. The presence of brown spots suggests that the diamondiferous rocks from the Marowijne greenstone belt must have reached temperatures higher than the greenschist facies or, possibly, were subjected to long periods under greenschist facies conditions.

Source of the Diamonds

Various theories have been proposed for the source of Suriname's diamonds. Van Kooten (1954) proposed that the diamonds from Rosebel were derived from the Rosebel Formation conglomerates in the area, but he did not find any diamonds in unweathered conglomerate outcrops. In addition, Schönberger (1975) washed many samples of weathered Rosebel Formation conglomerates without finding diamonds. Schönberger and de Roever (1974) and Schönberger (1975) suggested that the Rosebel diamonds were derived from an as-yet-undiscovered primary ultramafic source in the area. This conclusion was based on the distribution of the diamonds and the presence of accompanying minerals, such as chromian spinel and fuchsite (chromian muscovite) in the alluvial sediments containing the diamonds.

Recent exploration drilling by Iamgold Corporation

at the Rosebel gold mines showed that there are several conglomerate horizons in the Rosebel Formation, so it is feasible that a conglomerate other than the outcropping one washed by Schönberger (1975) is diamondiferous. Alternatively, it is possible that Schönberger did not wash enough material to find diamonds, as conglomerates and gravels may be very low grade (e.g. only 5 ct/100 t: Jacob *et al*. 2006), requiring the processing of very large samples to assess diamond potential.

Regarding the diamonds from Paramaka Creek (Figure 10), until now there have been no published investigations of their provenance.

Therefore the original primary source of the Suriname diamonds remains unknown, and further fieldwork is needed to look for possible indicator minerals that could lead to the original host rock. However, these minerals might be challenging to find due to the extensive tropical weathering and the possibility of extended fluvial transport during sediment reworking.

The randomly oriented and (partly) euhedral mineral inclusions in the diamonds are considered to be syngenetic. The assemblage of enstatite and forsterite indicates a peridotitic source, possibly harzburgitic (Stachel & Harris 2008). Similar diamond sources have been reported from reworked sedimentary environments (e.g. Chapada Diamantina, Brazil: Tappert *et al*. 2006; Vilela de Carvalho *et al*. 2018) and from alluvial deposits derived from weathered metakimberlites (e.g. Akwatia, Ghana: Stachel & Harris 1997; Melton *et al*. 2012). Our results for the Suriname diamonds contrast with those from Dachine in neighbouring French Guiana, which are genetically unrelated, of eclogitic origin and occur in volcaniclastic komatiite (Capdevila *et al*. 1999).

CONCLUSIONS

The majority of the diamonds analysed to date from the Marowijne greenstone belt in Suriname are colourless or light brown, sometimes with a green 'skin' or green (and less commonly brown) radiation spots on their surfaces. Few show evidence of damage due to alluvial transport. The coexistence of enstatite with forsterite as mineral inclusions indicates a peridotitic mantle origin. The aggregation state of nitrogen in most of the diamonds (type IaAB) implies that they experienced a higher temperature and/or longer residence time in the mantle than the less-common type IaA specimens. The high clarity of the diamonds and the absence of diamond indicator minerals suggest that they might have experienced extended sedimentary transport from a distal primary source. The Suriname diamonds have a different origin than those from French Guiana (i.e. eclogitic and hosted by volcaniclastic komatiite), but the primary source rock has not yet been found.

Figure 10: Paramaka Creek is an enigmatic source of diamonds, which have been recovered as a by-product of small-scale gold mining. Some of the tailings piles resulting from the gold mining are visible here in the middle and right centre. Photo by N. Sardjoe.

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Pink Axinite from Merelani, Tanzania: Origin of Colour and Luminescence

Maxence Vigier and Emmanuel Fritsch

ABSTRACT: Two pink axinites from Merelani, Tanzania, were characterised with standard gemmological techniques, energy-dispersive spectroscopy, and UV-Vis-NIR, Raman and luminescence spectroscopy. We compared them to three other samples from Merelani (pinkish orange, blue and near-colourless) and one brown axinite from Oisans, France. Chemical analysis revealed that the two pink axinites correspond to axinite-(Mg). UV-Vis-NIR spectroscopy revealed that the origin of the pink colouration is a large, asymmetric broad band centred at about 560 nm. Its position and shape are typical for Mn^{3+}. Manganese is also present in both samples as Mn^{2+}, and we surmise that natural radiation from nearby minerals converted some Mn^{2+} into Mn^{3+}. The orange luminescence of the axinites (weaker under short-wave UV radiation) is related to a broad emission band at 631 nm caused by Mn^{2+}, and a more unusual red luminescence is associated with features at 688 and 694 nm attributed to Cr^{3+}. Raman spectroscopy showed slight variations between the different axinite species, but further research is needed to associate each axinite end member with its characteristic Raman spectrum.

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Axinites are rarely encountered collector's stones that are most commonly brown, but may display attractive blue, yellow to orange, and (rarely) pink to purple colouration. Despite having sufficient hardness (Mohs 6–7), axinite is seldom found mounted in jewellery.

Axinite is the name of a borosilicate mineral group containing four different species (Burke 2008), and three of them have been found in gem quality:

- Axinite-(Fe): $Ca_4Fe_2^{2+}Al_4[B_2Si_8O_{30}](OH)_2$, formerly called ferro-axinite (the most common axinite species)
- Axinite-(Mg): $Ca_4Mg_2^{2+}Al_4[B_2Si_8O_{30}](OH)_2$, formerly called magnesio-axinite (e.g. Figure 1)
- Axinite-(Mn): $Ca_4Mn_2^{2+}Al_4[B_2Si_8O_{30}](OH)_2$, formerly called manganaxinite

A distinctive component of the axinite structure, which has triclinic symmetry, is the $B_2Si_8O_{30}$ group, in the centre of which two isolated BO_4 tetrahedra and two Si_2O_7 groups constitute a six-membered ring, while the other cations occupy sites in octahedral coordination with oxygen.

Axinite Colours

Both Fe^{2+} and Mn^{2+} are potentially colour-inducing ions. Nevertheless, axinite-(Mn) can be nearly colourless (Lauf 2007; see also www.mindat.org/min-1459.html) because Mn^{2+} is a poor absorber of visible light. However, when Mn^{2+} is present in a larger atomic proportion than in the axinite structure (e.g. in rhodochrosite, $MnCO_3$), then this ion can induce colour. All iron-containing axinites (whatever the species) are brown (Faye 1972; Pohl *et al.* 1982; Wilson *et al.* 2009; see also www.mindat.org/min-1459.html). Axinite-(Mg) does not contain any colour-causing cation in its nominal chemical composition, and is thus intrinsically colourless. However, it commonly shows various colours including yellowish orange, brown to pink and purple to blue (Quinn & Breeding 2005; Wilson *et al.* 2009; Pay 2017; see also Figure 1), which are probably due to different minor- and

Figure 1: Axinite from Merelani, Tanzania, can show various colours (top), and some of the samples depicted here exhibit strong reddish orange fluorescence to long-wave UV radiation (bottom). Based on their colouration and origin, all of these stones are most likely axinite-(Mg). The largest faceted gem weighs 4.22 ct. Courtesy of Bill and Elke Vance, Vance Gems; photos by Jeff Scovil.

trace-element impurities. The fourth member of the axinite group, tinzenite—ideally $Ca_2Mn_4^{2+}Al_4[B_2Si_8O_{30}](OH)_2$—contains less than 3 Ca per formula unit due to substitution of Ca^{2+} by Mn^{2+}. It appears to be intrinsically yellow to orange (depending on sample thickness), and this colour is presumably induced by Mn^{2+}, which in some cases may colour minerals orange (as in serandite or spessartine).

'Blue' axinite is known to contain vanadium (Jobbins *et al.* 1975), which Schmetzer (1982) related to the blue colouration for the first time, with an absorption band near 575 nm. More recent work clearly demonstrates that blue axinite is coloured by V^{3+} (Arlabosse *et al.* 2008), which induces a broad band at about 592 or 597 nm (Williams *et al.* 2014). This feature causes transmission in the blue region when viewed perpendicular to the flat Tanzanian crystals. A similar absorption feature has been documented in axinite-(Mg) from Merelani, Tanzania (http://minerals.gps.caltech.edu/FILES/Visible/Axinite/Index.html). The exact position of the absorption maximum depends on crystal orientation (axinite is biaxial), but overall the colour appears blue to blue-violet. Fritz *et al.* (2007) noted that blue zones in axinite-(Fe) from Pakistan showed an absorption maximum in the 580 nm range, but they did not analyse for vanadium.

A noticeable colour change is sometimes encountered in axinite (e.g. Lauf 2007; Williams *et al.* 2014), appearing blue-grey in fluorescent light or daylight, and purple in incandescent light. To date, this effect has been noticed only in some axinite-(Mg) and axinite-(Mn) specimens from Tanzania.

Axinite Pleochroism and Optic Character

Axinite is commonly described as being pleochroic (Gribble & Hall 1992; Association Française de Gemmologie 2013; see also http://webmineral.com/data/Axinite-(Mg).shtml). Pleochroism in Tanzanian axinite was mentioned for the first time by Jobbins *et al.* (1975). The pleochroism ranged from pale blue to violet to grey, and similar colouration was also noted decades later in various Tanzanian axinites (Jang-Green *et al.* 2007; Arlabosse *et al.* 2008; Williams *et al.* 2014), as well as pale yellow to green pleochroism (Milton *et al.* 1953).

Mineralogy textbooks mention axinite as being biaxial positive or negative. However, the optic character is rarely mentioned in gemmological journals. Jobbins *et al.* (1975) observed that Tanzanian axinite is biaxial positive in contrast to most axinites, which are biaxial negative. The book *Gemmes* (Association Française de Gemmologie 2013) indicates that axinite is biaxial negative, except for axinite-(Mg).

Axinite Luminescence

The fluorescence of axinite-(Mg) from Tanzania has been described as a distinct orange-red to long-wave UV radiation (365 nm) and a duller red under short-wave UV (254 nm; Jobbins *et al.* 1975). Similar descriptions of the luminescence for axinite-(Mg) or axinite-(Mn) are noted in the literature (Jang-Green *et al.* 2007; Lauf 2007; Arlabosse *et al.* 2008; Jaszczak & Trinchillo 2013; Pay 2017). By contrast, axinite-(Fe) is inert, which is not surprising since Fe often quenches luminescence (Fritsch & Waychunas 1994).

This Study

The present study investigates the origin of colour and luminescence in two dominantly pale pink axinites from Merelani, Tanzania, and compares their properties to those of axinite showing other colours. In addition to the two gems of interest, three of the other samples also came from Merelani, which has produced both axinite-(Mg) and axinite-(Mn) in gem quality.

Merelani is a famous mineral deposit located in northeast Tanzania, and is best known for its tanzanite and tsavorite (e.g. Wilson *et al.* 2009). The deposit occurs in the Neoproterozoic Mozambique Belt, an area with an extensive geologic history and hosting a variety of gem and mineral deposits (Malisa & Muhongo 1990; Malisa 2003, 2005; Olivier 2006; Feneyrol 2012; Harris *et al.* 2014). The Merelani area is underlain by metacarbonate and metasilicate rocks such as marble and graphite-bearing gneiss, which were affected by greenschist-facies retrograde metamorphism. The axinite there is commonly associated with an assemblage consisting of zoisite (tanzanite), grossular (tsavorite), tremolite, diopside, K-feldspar, muscovite, chlorite, prehnite and zircon.

MATERIALS AND METHODS

The six axinites studied for this report are listed in Table I. The two rare pink axinite cabochons (samples 2999 and 3000) were obtained through Dudley Blauwet. For comparison, two axinite crystals from Merelani (3356 and 3357) were acquired from Joyce van Dronkelaar-Kessy, and a faceted axinite (3355) from this locality was provided by Denis Gravier. In addition, we included a brown axinite (2290a) from Oisans, France, from the personal collection of author EF. All samples were studied in the form that they were originally received except for sample 2290a, which was polished to obtain two parallel windows.

Standard gemmological measurements were recorded for all six samples. RI and optic sign were obtained using an A. Krüss Optronic ER604 refractometer (resolution of 0.01).

Table I: Characteristics of the six axinite samples.

Sample no.	Locality	Dimensions (mm)	Weight (g)	Sample type	Colour	Photo*
2290a	Oisans, France	10.4 × 8.3 × 2.5	0.48	Parallel-polished rough	Brown	
2999	Merelani, Tanzania	19.8 × 6.0 × 4.8	1.11 (5.55 ct)	Cabochon	Bicoloured purplish pink and orangey pink; weak cat's eye	
3000	Merelani, Tanzania	19.2 × 10.6 × 3.4	1.18 (5.90 ct)	Cabochon	Pink	
3355	Merelani, Tanzania	4.5 × 3.7 × 2.5	0.06 (0.30 ct)	Rectangular cushion	Pinkish orange	
3356	Merelani, Tanzania	26.5 × 22.3 × 2.7	4.09	Flat crystal	Blue	
3357	Merelani, Tanzania	26.0 × 14.7 × 4.9	3.29	Flat crystal	Near-colourless	

* Photos by M. Vigier (2290a, 3000, 3356 and 3357) and Orasa Weldon (2999 and 3355).

Hydrostatic SG was measured with a Mettler-Toledo XS104 balance, using a semi-automated system. Reaction to UV radiation was observed with a Vilber-Lourmat VL-215.LC UV lamp, which includes two 15 W UV tubes (long- and short-wave) that are approximately 30 cm long. Observations were done at a fixed distance of 7 cm from the lamp, in a darkened room, against an inert black background. Internal features and pleochroism were observed with a Leica MZ6 binocular microscope with Nossigem gemmological observation attachments, including polarising filters.

Quantitative chemical analyses were obtained for all samples with a JEOL 5800 LV scanning electron microscope (SEM) equipped with a Princeton Gamma Tech (PGT) energy-dispersive spectrometer (EDS). The instrument featured an IMIX-PTS detector, which includes a 'high-resolution' (115 eV) Ge crystal and an ultra-thin polymer window that, under ideal conditions, can be used to detect elements as light as boron (if present as a major component of the material). The SEM was operated using a beam accelerating potential of 15 kV and a 0.5 nA current, with a 37° take-off angle to the detector. The working distance between the bottom of the column and the sample surface was 15 mm. Standards used were either pure elements or simple compounds. The data were processed using PGT software incorporating a Phi-Rho-Z correction. Oxygen was calculated from the EDS spectrum instead of from stoichiometry. Analytical

precision is estimated at 1–2% for samples that have a perfectly polished, flat surface perpendicular to the beam, which was not the case for most of the stones in this study.

Raman spectroscopy was performed on all samples with a Bruker MultiRAM Fourier-transform Raman spectrometer, equipped with an Nd:YAG laser at 1064 nm. The laser power was nominally 300 mW and the resolution was 4 cm^{-1}. Fifty spectra were accumulated per measurement. To obtain a better-quality Raman spectrum of sample 2290a, we used a Horiba Jobin Yvon T64000 dispersive Raman spectrometer equipped with a 514 nm Ar^+ laser (resolution of 4 cm^{-1}).

Ultraviolet-visible-near infrared (UV-Vis-NIR) absorption spectra were collected from all samples with a Magilabs GemmoSphere spectrometer, in the spectral range of 365–1000 nm with a sampling interval of 1.3 nm; only results for the approximately visible range are given in this article. The sample was placed at the bottom centre of an integrating sphere. This setup does not impose the rectilinear pathway of light from lamp to detector (as in standard spectrometers), and thus it analyses all light going through the sample. In addition, any potential luminescence that was excited by visible light in the gem was collected by the instrumentation.

Photoluminescence emission and excitation spectra were obtained for all samples using a Fluorolog-3 instrument from Horiba Jobin Yvon in conjunction with FluorEssence software. A Synapse CCD detector was coupled with an iHR320 spectrometer. Both excitation and emission measurements had a resolution down to 1 nm; enhanced resolution below 1 nm was obtained by juxtaposing several scans to cover a given spectral domain in several sections.

RESULTS

Standard Gemmological Data

The results of RI, optic character and SG measurements are presented in Table II. Because of the difficulties imposed by the shape or surface conditions of the samples, only average RI values (i.e. of the lowest and highest measurements) are reported. However, RI data are not reported for sample 2999 because it was not possible to obtain consistent measurements due to its shape and polish. The optic character of most of our samples was biaxial negative, except for two biaxial positive samples (both of which were axinite-(Mg), as specified below).

All of the axinites displayed pleochroism when observed with polarisers. For thin or pale samples, colour perception was enhanced by looking down the long direction of the crystals (i.e. longer optical path length). The pleochroic colours are shown in Figure 2 and summarised as follows:

- 2290a and 3356: blue, purple and brown (e.g. Figure 2a)
- 2999 and 3000: pale blue, pink and nearly colourless (e.g. Figure 2b)
- 3355 and 3357: pale blue, purple and yellow (e.g. Figure 2c)

In summary, the pleochroic colours are rather similar from one sample to another, varying mostly in intensity.

UV fluorescence reactions of our samples are described in Table II and illustrated in Figure 3. With the exception

Table II: Standard gemmological properties of the six axinites.

Sample no.	Average RI	Optic character*	SG	UV luminescence	
				Short-wave	Long-wave
2290a	1.68	B–	3.24	Inert	Inert
2999	—	—	3.19	Weak orange-red	Intense orange
3000	1.66	B+	3.15	Weak orange-red	Intense orange
3355	1.68	B+	3.10	Weak orange-red	Intense orange
3356	1.67	B–	3.20	Weak orange-red	Intense orange
3357	1.67	B–	3.21	Very weak purple	Moderate orange and purple

*Abbreviations: B– = biaxial negative, B+ = biaxial positive.

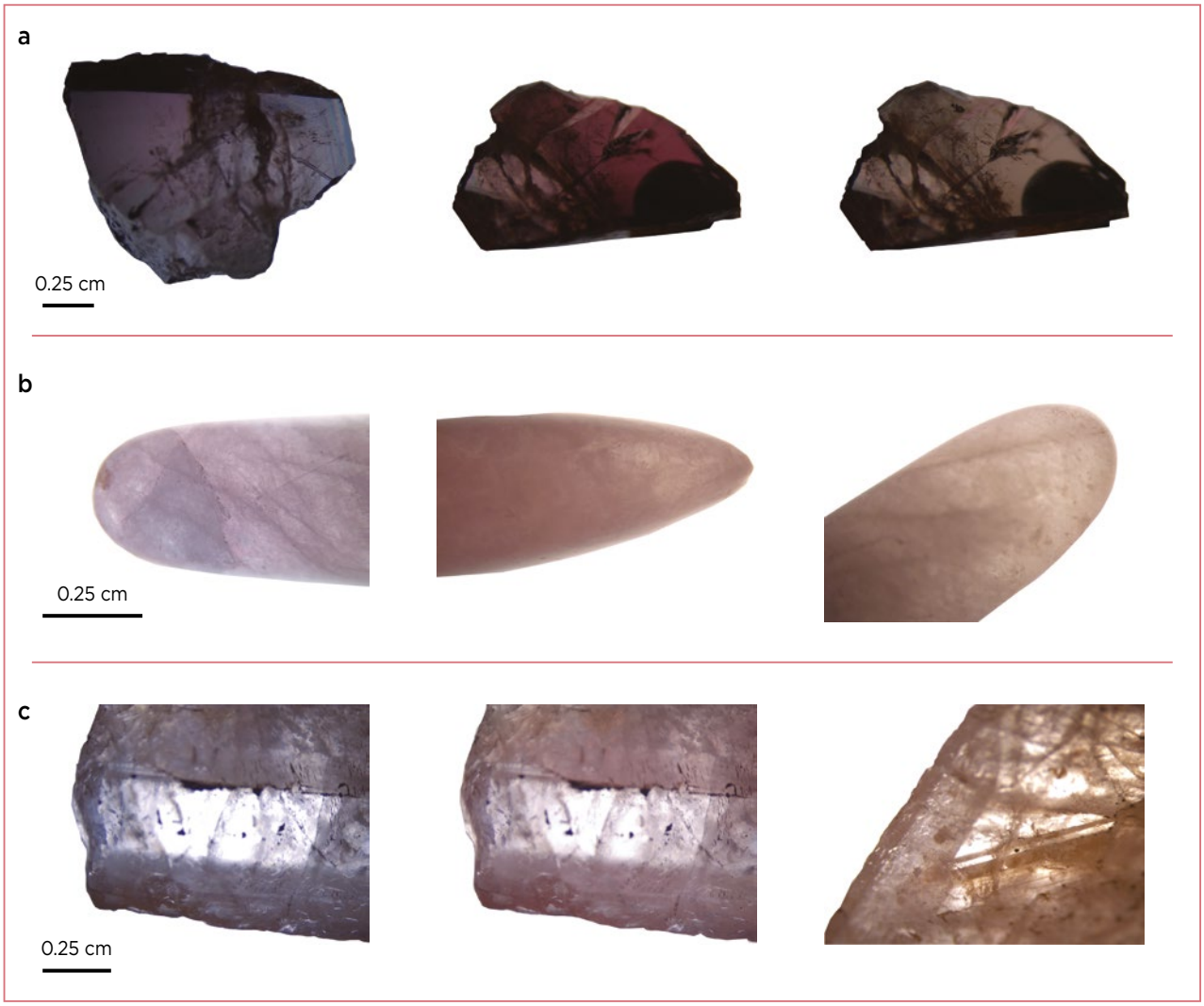

Figure 2: Pleochroism (here described in each photo from left to right) is shown for three representative samples from this study: (**a**) axinite-(Fe) sample 2290a, in blue, purple and brown; (**b**) axinite-(Mg) sample 2999, in pale blue, pink and nearly colourless; and (**c**) axinite-(Mn) sample 3357, in pale blue, purple and yellow. Photomicrographs by M. Vigier.

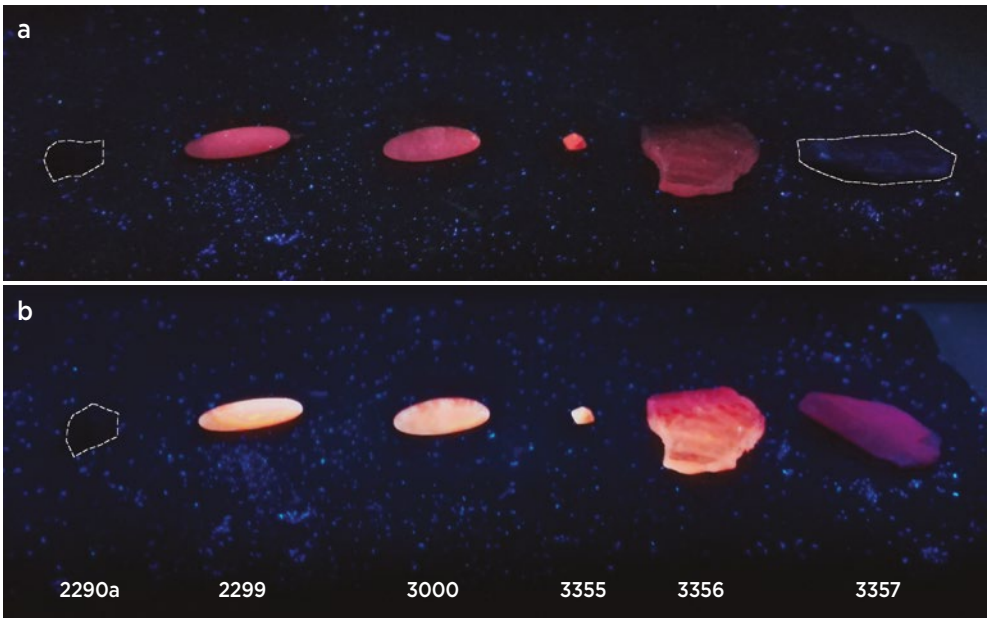

Figure 3: The six axinite samples are shown here in (**a**) short-wave and (**b**) long-wave UV radiation. Those showing very weak or no fluorescence are outlined. See Table I for sample weights. Photos by M. Vigier.

Figure 4: Axinite-(Mg) sample 2999 displays a weak cat's-eye effect, as well as colouration that ranges from orangey pink to purplish pink. The stone weighs 5.55 ct and is cut as a double cabochon. Photo by Orasa Weldon.

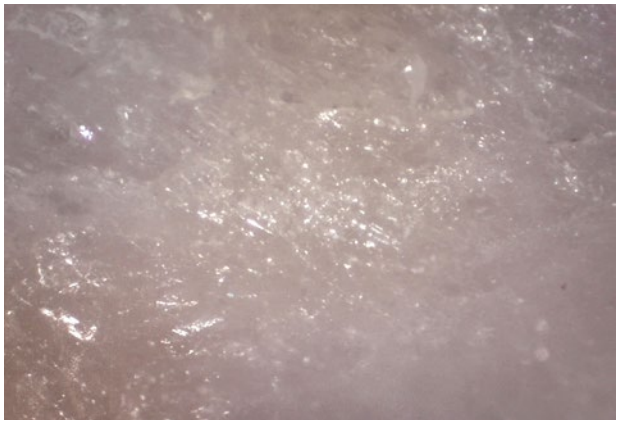

Figure 5: The cabochon in Figure 4 contains numerous tiny reflective fractures in a fairly consistent orientation that are responsible for its weak chatoyancy. Photomicrograph by Brendan M. Laurs; image width 1.0 mm.

of the brown sample (which was inert), the gems emitted mostly orange fluorescence, sometimes with a touch of red. The emission was weaker to short-wave UV, as is the case for the luminescence of many gems. For sample 3356, the crystal termination showed distinctly redder fluorescence than the rest of the stone. Sample 3357 displayed a weak purple luminescence.

Sample 2999 was bicoloured (purplish pink and orangey pink) and also showed weak chatoyancy, as illustrated in Figure 4. Magnification revealed that the cat's-eye effect was caused by reflections (sometimes iridescent) from many small, parallel fractures (possibly cleavages; Figure 5). The somewhat indistinct cat's-eye was directionally aligned along the length of the stone, indicating that the cabochon's elongate high-domed shape mainly controlled the distribution of the chatoyancy. The gem also contained a number of partially healed fissures consisting of fluid inclusions.

Chemical Composition

As axinite is a mineral group, it was desirable to determine which species of axinite our samples represented. For that purpose, SEM-EDS chemical analyses were compared to our Raman spectroscopy data (see below). Chemical analyses of the six samples are presented in Table III, and comparisons with chemical data taken from the literature for each of the three axinite species are available in the online data depository on *The Journal*'s website.

We looked for V and Cr with our instrumentation but did not detect either element (detection limits were high, at around 0.1% wt.%). Analysis of sample 3000 gave a total of only about 85%, and a carefully executed second round of analyses gave a similar low total, for which we have no explanation.

Two of the specimens approached end-member compositions—axinite-(Mg) sample 3000 and axinite-(Mn) sample 3356—whereas the other four were of intermediate composition (Figure 6). The bicoloured cabochon (2999) and the faceted stone (3355) were found to be axinite-(Mg) with significant Mn contents, whereas sample 3357 was axinite-(Mn). The brown sample 2290a was axinite-(Fe).

Raman Scattering

The Raman spectra of the six axinites were similar in general shape, as expected because of their common structure. Nevertheless, details of the band positions varied slightly according to the specific species (e.g. Figure 7). For example, the peak at 302 cm^{-1} in axinite-(Mg) was found at 308 cm^{-1} in axinite-(Fe), and the feature at 493 cm^{-1} in axinite-(Mg) moved to 486 cm^{-1} in axinite-(Fe). These were reproducible, measurable differences (which could therefore help with species identification). Although crystallographic orientation was not taken into account for these spectra, it would only affect the peak intensities and not peak positions, as is the case for vibrational spectroscopy.

Visible-range Absorption Spectroscopy

The main goal of this investigation was to determine the origin of the pink to purple colour in axinite. Figure 8 compares the absorption spectra obtained from the two pink axinites. The spectra were obtained perpendicular to the base of each cabochon, and not in a specific crystallographic orientation. However, both the peak positions and intensities may change with orientation, as is the case for electronic transitions. Nevertheless, based on the polarised spectra given for axinite-(Mg) from Merelani at http://minerals.caltech.edu/FILES/Visible/Axinite/Index.html, it appears that such changes are rather small.

The pink colouration is related to a broad, asymmetric band with an apparent maximum at about 560 nm

Table III: Chemical composition by SEM-EDS of the six axinite samples.*

Sample	Axinite-(Fe)	Axinite-(Mg)	Axinite-(Mg)	Axinite-(Mg)	Axinite-(Mn)	Axinite-(Mn)
Number	2290a	2999	3000	3355	3356	3357
Colour	Brown	Purplish pink and orangey pink	Pink	Pinkish orange	Blue	Near-colourless
Locality	France	Tanzania	Tanzania	Tanzania	Tanzania	Tanzania
Oxides (wt.%)						
SiO_2	42.34	43.13	39.60	45.47	42.66	41.82
Al_2O_3	17.01	18.01	16.19	18.37	17.33	16.76
FeO	6.94	0.10	0.11	nd	0.08	1.84
MgO	1.56	4.62	6.82	4.36	0.55	2.27
MnO	2.16	4.14	0.19	4.86	10.28	6.00
CaO	19.37	19.97	14.99	21.22	19.32	20.17
B_2O_3 calc	6.02	6.21	5.56	6.49	6.05	6.00
H_2O calc	1.56	1.61	1.44	1.68	1.57	1.55
Total	96.96	97.78	84.90	102.45	97.84	96.41
Cations per 32 (O, OH)						
Si	8.150	8.052	8.256	8.122	8.168	8.082
B	2.000	2.000	2.000	2.000	2.000	2.000
Al	3.858	3.962	3.978	3.866	3.910	3.818
Fe tot	1.118	0.016	0.020	nd	0.012	0.298
Mg	0.448	1.286	2.120	1.160	0.156	0.654
Mn	0.352	0.654	0.034	0.736	1.668	0.982
Ca	3.994	3.994	3.348	4.060	3.964	4.176
OH	2.000	2.000	2.000	2.000	2.000	2.000
Total cations (excluding OH)	19.920	19.966	19.754	19.946	19.878	20.010

*Abbreviation: nd = not detected.

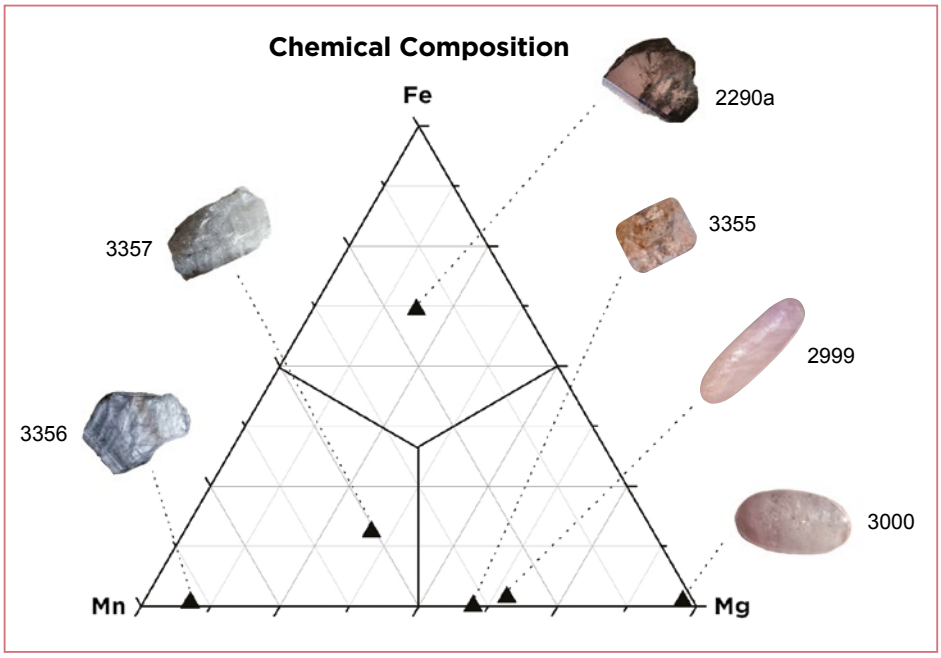

Figure 6: Chemical compositions (molecular proportions) of the six axinite samples are plotted in terms of the three end members axinite-(Fe), axinite-(Mn) and axinite-(Mg).

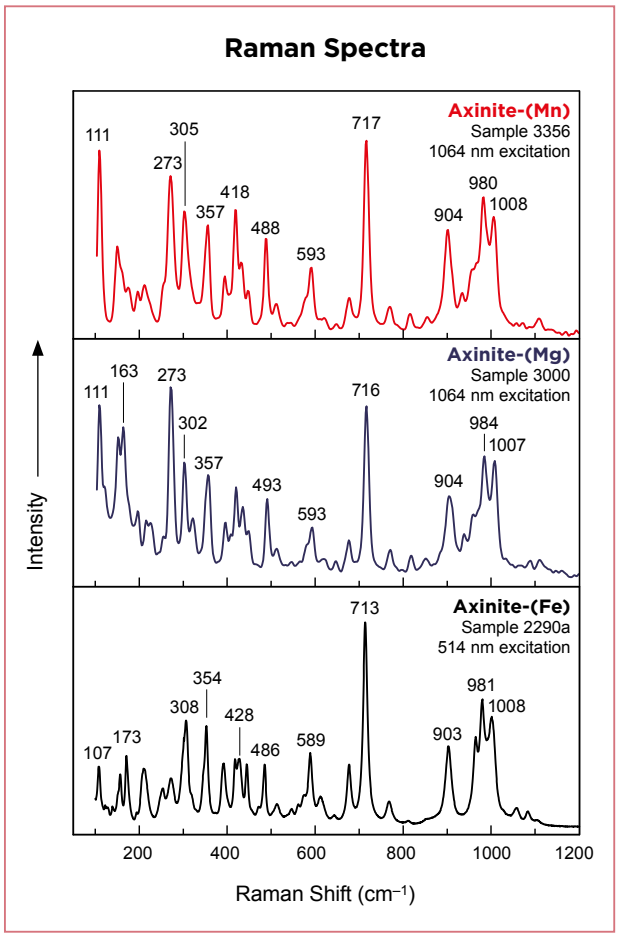

Figure 7: Raman spectra are shown for three samples that are most representative of axinite-(Mn), axinite-(Mg) and axinite-(Fe).

(again, see Figure 8). According to this band position, the 'pink' colour is actually a light purple. The band maximum being positioned higher than 550 nm favours a transmission window in the blue, thus inducing purple rather than pink. In sample 2999, a band at about 508 nm is present as well, absorbing green and blue, thus leading to a yellower hue that shifts the pink colour towards orangey pink. When the 508 nm peak is smaller than the one at 560 nm, purplish pink is seen.

Other features include a sharp peak at 412 nm with a shoulder at about 420 nm. These, and the broad band at 508 nm mentioned above, are well-known Mn^{2+} features, which should be accompanied by two weak, broad bands at higher wavelength, not clearly seen here (Burns 1993). Similar features would be expected to colour yellow to orange tinzenite, which is richer in Mn^{2+}. A small sharp feature recorded at 694 nm—appearing as a negative peak with the type of spectrometer used—is also encountered most notably in ruby. It is likely the result of Cr^{3+} emission (see below).

Figure 9 compares the absorption spectra of the pink axinites to those of the non-pink samples. The well-documented band at about 583 nm (depending on orientation) that is due to V^{3+} induced a pale blue-violet colour component, even though vanadium was below the detection limit of our SEM-EDS instrumentation (consistent with Arlabosse *et al.* 2008, although they detected approximately 0.1 wt.% V_2O_3 using long count times). According

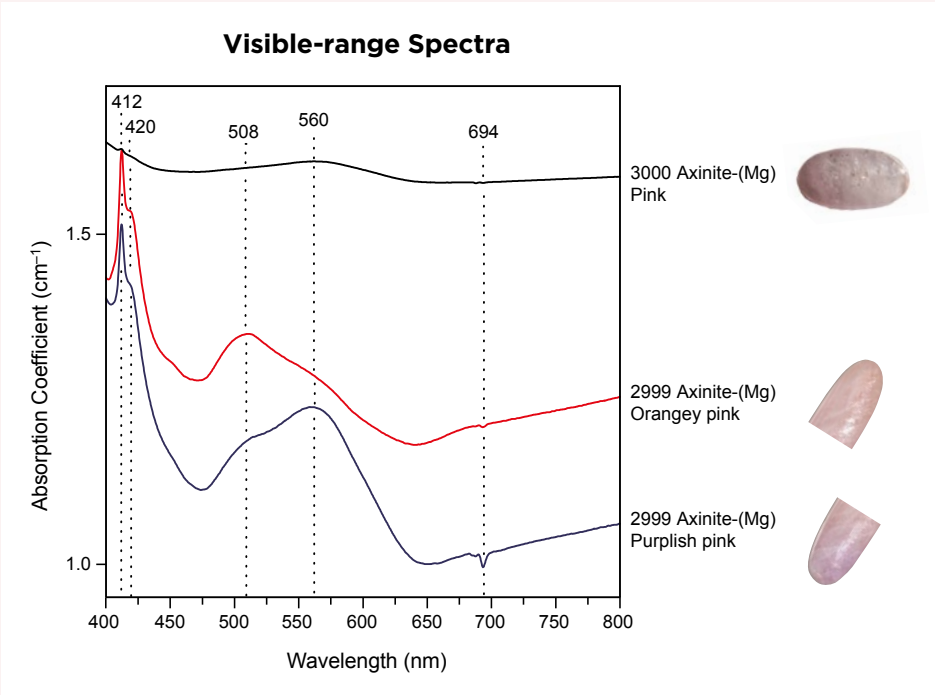

Figure 8: Visible-range absorption spectra are shown for pink axinite sample 3000 and for bicoloured sample 2999 (orangey pink and purplish pink portions). The pink colour is due to a broad, asymmetric band centred at about 560 nm. Other features include a sharp peak at 412 nm with a shoulder at about 420 nm, and a broad band at 508 nm. Spectra are offset vertically for clarity.

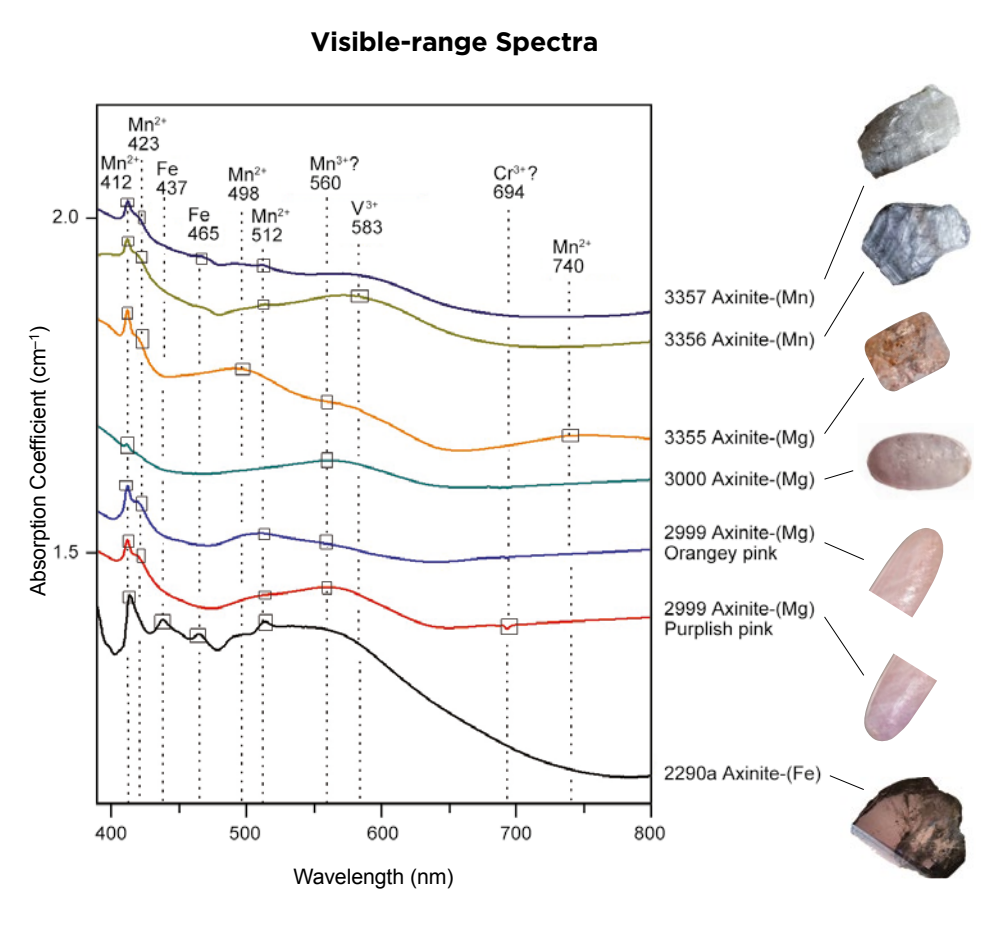

Figure 9: Visible-range absorption spectra are shown for all six axinites studied. The band at about 560 nm appears to cause colour only in the pink samples. Assignments to transition metal ions are also given for the other bands present. Spectra are offset vertically for clarity.

to previous studies, vanadium is not related to pink-to-purple colour in axinite, but rather to blue (Jobbins *et al.* 1975; Schmetzer 1982), as the absorption maximum is located further towards the red region.

Thus, the pink colouration of these axinites is associated with the asymmetric 560 nm band. Such an asymmetric band centred at about 550 nm is a classic feature of Mn^{3+} in many minerals and materials. For example, Mn^{3+} colours pink 'morganite' beryl, purple 'lepidolite' mica and pink-to-red 'rubellite' tourmaline (Reinitz & Rossman 1988; Platonov *et al.* 1989; http://minerals.caltech.edu/FILES/Visible/mica/index.html). In addition, we know there is at least 0.19 wt.% MnO in the two pink axinite gems. Therefore, there is enough manganese to have the small amount of Mn^{3+} necessary to cause the colour, as this ion is a strong light absorber. There are no other transition-element ions present that could cause this kind of absorption feature. As a consequence, the only interpretation consistent with all the data is that Mn^{3+} is responsible for the 560 nm feature, and therefore we propose that this ion is responsible for the pink colour in axinite. The pink to purplish pink is a mixture of red (transmission window above 640 nm) and some blue (transmission window between 450 and 500 nm), whereas in blue axinite the red is nearly fully absorbed.

Photoluminescence Emission and Excitation Spectroscopy

Figure 10 compares emission spectra obtained from two different-luminescing areas (showing typical orange and more reddish fluorescence) of sample 3000 under 365 nm (long-wave UV) excitation. A broad band (slightly less than 100 nm wide) with an apparent maximum at 631 nm is common to both spectra. This band is more intense for the orange-luminescing area. Although 631 nm is at the border between orange and red, the human eye is much more sensitive in the orange region (approximately 590–630 nm) so the perceived colour is a relatively pure orange. Two sharp peaks at 688 and 694 nm in the red region are also present, as expected, in the area of the sample showing more reddish luminescence.

Excitation spectra were then collected from sample 3000 to reveal which wavelengths excite the specific

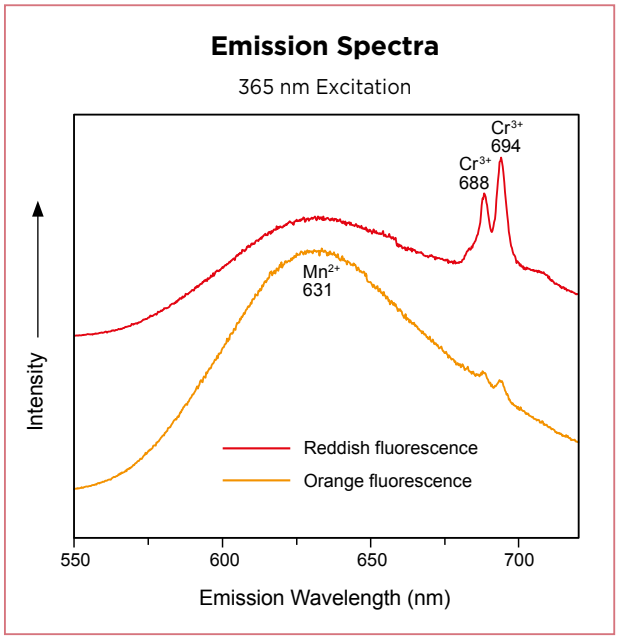

Figure 10: Emission spectra obtained using 365 nm (long-wave UV) excitation from two different areas of sample 3000 demonstrate that the orange luminescence of pink axinite is due to a large band centred at about 631 nm (related to Mn^{2+}) and the reddish fluorescence is caused by the addition of Cr^{3+} features at 688 and 694 nm (top spectrum).

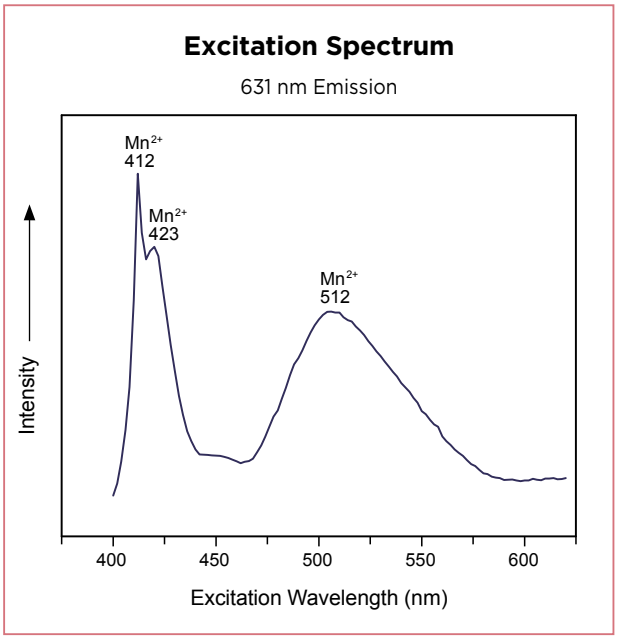

Figure 11: The excitation spectrum of axinite sample 3000 for 631 nm emission shows a close resemblance to the visible-range absorption spectrum of Mn^{2+} (i.e. the orangey pink portion of sample 2999 in Figure 8), which demonstrates that the orange luminescence is due to Mn^{2+}.

emissions at 631 nm (orange) and 694 nm (red). An excitation spectrum reveals which wavelengths excite a specific emission. These wavelengths thus represent the absorption(s) responsible for the emission, and comparing the excitation spectrum with the absorption spectrum in the visible range helps establish the origin of the luminescence. The excitation of the orange emission at 631 nm (Figure 11) is nearly identical in shape to the absorption of Mn^{2+} in the orangey pink portion of sample 2999 (Figure 8). As a consequence, the orange fluorescence of the axinite can be attributed to Mn^{2+}. This ion is well known to be responsible for this luminescence colour in a number of minerals (e.g. apatite, calcite and other carbonates, spodumene and many other silicates; El Ali *et al.* 1993; Robbins 1994). For the excitation of the red emission at 694 nm (Figure 12a), the features include absorption bands of Mn^{2+} as well as a sharp band about 648 nm, along with underlying, broad absorption in the 550–650 nm region. These last two features might be related to Cr^{3+} absorption, and they are indeed present at about the same positions in the excitation spectrum of ruby (Figure 12b), in which they are known to be due to emission from pairs of chromium ions, that is Cr^{3+}–Cr^{3+} (Robbins 1994; Gaft *et al.* 2005). In addition, the emission doublet (i.e. at 658 and 668 nm in the ruby spectrum) is quite characteristic of Cr^{3+} and has been documented in a number of minerals (Gaft *et al.* 2005). Thus, we surmise that the reddish component of axinite luminescence is due to Cr^{3+}, as also evidenced by the 694 nm feature in the visible absorption spectrum of the pink axinite. This result is not surprising, even though no Cr was detected in our chemical analysis: only trace amounts of chromium are needed to yield a distinct red luminescence. In fact, luminescence is one of the most sensitive techniques available to detect this element, even at very low concentrations (e.g. <1 ppm in solids; Gaft *et al.* 2005).

According to Jobbins *et al.* (1975), the presence of vanadium could reduce luminescence intensity in axinite, and this was verified in a blue colour-zoned crystal (Arlabosse *et al.* 2008). It is possible that V^{3+} could absorb some of the Mn^{2+} emission. However, our blue sample 3356 did not show less fluorescence than the axinites of other colours (i.e. without V).

DISCUSSION

The results obtained for the average RI measurements, optic character and SG values of our samples are consistent with data listed in the gemmological literature for axinite (Liddicoat 1987; O'Donoghue 2006; Association Française de Gemmologie 2013).

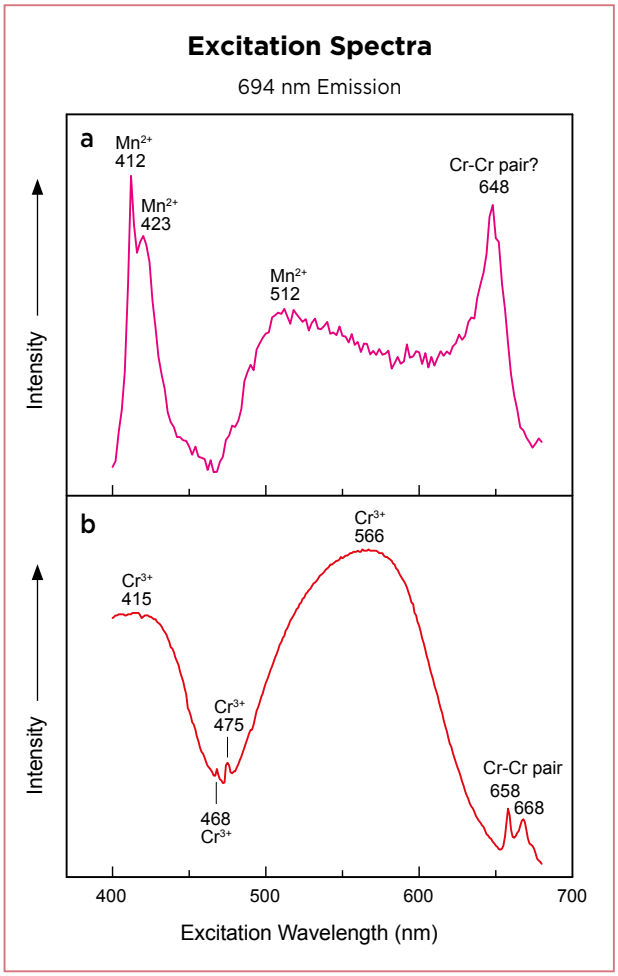

Figure 12: (**a**) The excitation spectrum of axinite sample 3000 for 694 nm emission is also related to Mn^{2+} absorption (cf. Figure 11), but shows an additional band at about 648 nm along with underlying, broad absorption in the 550–650 nm region. (**b**) Evidence of these features—ascribed to Cr-Cr ion pairs—is seen in the excitation spectrum of ruby for 694 nm emission.

Our Raman spectroscopy results for axinite-(Fe) were consistent with the detailed work of Frost *et al.* (2007). Although Raman spectroscopy cannot help assess origin of colour or luminescence, the spectra did reveal correlations with the three different axinite species represented by our specimens, providing support and confirmation of their identification based on chemical composition alone. A comparison of the reference spectra for the three axinite species in the RRUFF database also shows some consistent small differences in band positions, possibly due to variations in their chemical composition. Further work is needed to assess the exact Raman spectral band positions for the three axinite species in order for this technique to be helpful for gem identification. Relatively pure representatives of the different axinite end members, especially axinite-(Mn) and axinite-(Mg), should be carefully documented, in particular to establish the characteristic peak positions as they relate to composition. In addition, obtaining spectra from oriented samples would be helpful for evaluating the influence of crystal orientation on the relative intensity of the various bands.

We propose that Mn^{3+} is responsible for the pink colour of axinite. Ideally, it would have been preferable to obtain crystallographically oriented, polarised absorption spectra to further support our proposition. However, pink axinites are extremely rare and our samples were not transparent, so such spectra could not be obtained at this point. Another possible avenue of research would be to synthesise colourless Mn^{2+}-bearing axinite and then try irradiating it to obtain pink colouration due to Mn^{3+}.

At the Merelani deposit, the presence of some manganese as Mn^{3+} could be explained by prolonged exposure to nearby naturally occurring radioactive elements. One such source could be U impurities in zircon (Malisa 2005; Feneyrol 2012). In addition, Malisa (2003) detected higher-than-normal levels of U in igneous and sedimentary rocks in this area (although metamorphic units such as the graphite gneiss host rock were not mentioned). A third source of natural radioactivity could be K-bearing minerals present at Merelani, such as the fuchsite variety of muscovite and K-feldspar in the surrounding gneisses. Reinitz and Rossman (1988) showed that pink-to-red tourmaline from granitic pegmatites could be naturally irradiated by gamma rays from ^{40}K in the surrounding K-feldspar. At Merelani, the appearance of the pink colour would be expected to occur during retrograde metamorphism since the higher temperatures attained during peak prograde metamorphism (up to 691 °C; Feneyrol 2012) would destroy the pink colour.

CONCLUSION

We conclude that the colouration of the two pink Tanzanian axinites studied for this report results from Mn^{3+} absorption. This colouring agent is likely due to natural irradiation of a small portion of Mn^{2+} that is abundant in this deposit. The UV luminescence of axinite is due to two cations: Mn^{2+} and Cr^{3+}. The first induces the dominant orange colour and the second contributes red. The weak cat's-eye effect in one cabochon examined in this study is mostly due to a combination of parallel, reflective fractures (cleavages?) and the elongated high-domed cabochon cut. While characterising our samples with Raman spectroscopy, it became apparent that more work is needed to firmly establish the Raman spectral characteristics of axinite-(Mn), axinite-(Mg) and axinite-(Fe).

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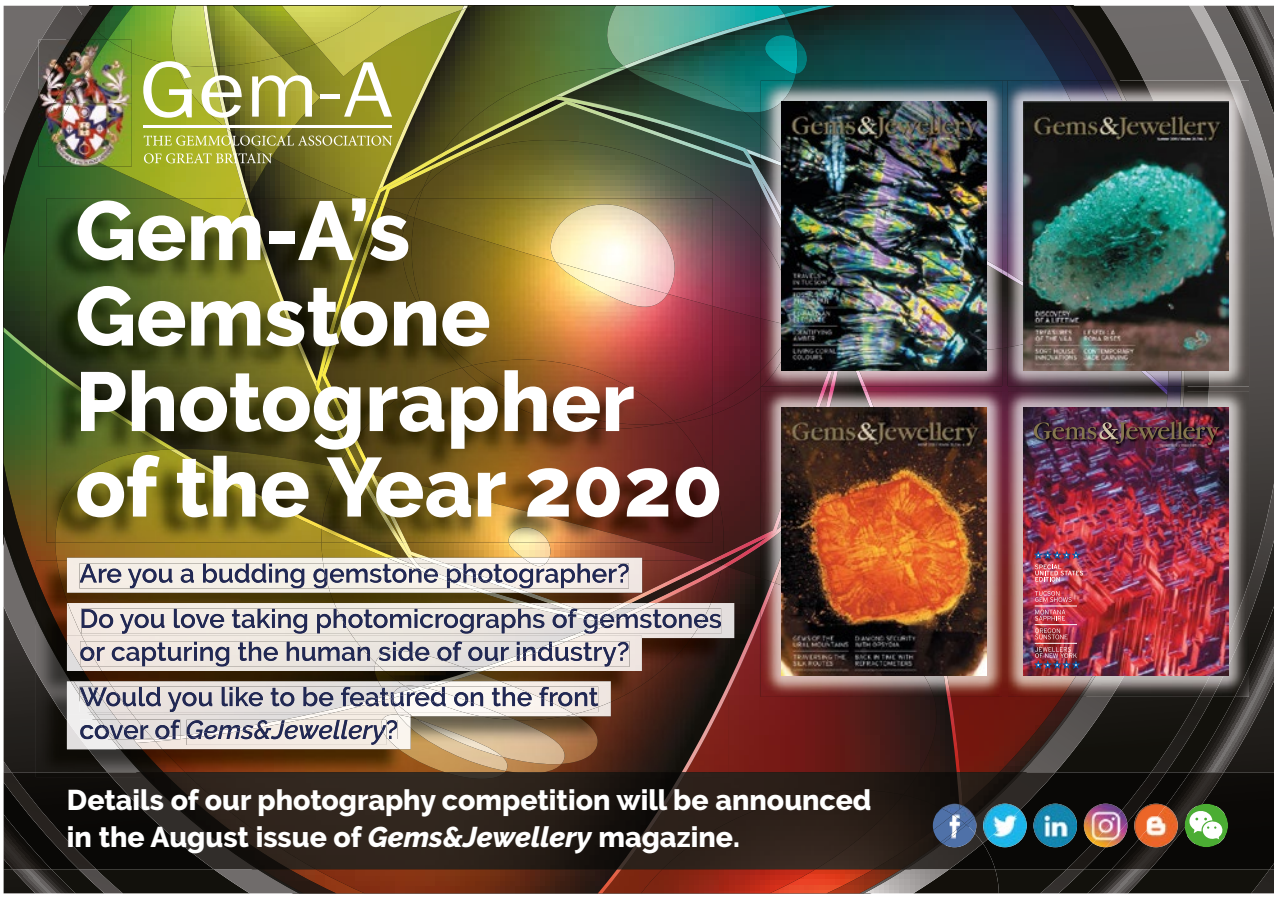

Figure 1: A panoramic view of the town of Yen The in Vietnam's Luc Yen District reveals karst landscapes that host agricultural land and gem mining areas. Photo by T. Sripoonjan.

A Journey to Luc Yen, Vietnam (February 2019)

Tasnara Sripoonjan, Waratchanok Suwanmanee, Doan Thi Anh Vu and Bhuwadol Wanthanachaisaeng

Vietnam is a long, mostly narrow country with an extensive coastline, measuring about 1,650 km from north to south but only 50 km wide at the narrowest point. The country is endowed with a wide range of mineral resources resulting from its diverse geological history. Since the 1980s, various gem materials including ruby, sapphire and spinel have been obtained from both primary and secondary deposits. Although mining activities decreased in recent years due to government regulations and dwindling reserves, some gems continue to emerge onto the global marketplace.

In January 2019, a research project was initiated by author BW titled 'Potential and Access Opportunity of Blue Sapphire Resources in Vietnam'. The goal was to investigate actively operating mines and potential gem deposits through two excursions. The first one took place in February 2019 to the Luc Yen District in the mountainous area of northern Vietnam (Figure 1), and the second trip was in June 2019 to Vietnam's southern provinces. Our team consisted of the authors, as well as Thai university professors in geology and earth sciences Drs Krit Won-in, Somruedee Sakkaravej, Natthapong Monarumit, Sarinya Paisarnsombat and Alongkot Fanka, and graduate student Teerarat Pluthametwisute (Figure 2). This report covers the trip to Luc Yen.

The group flew from Bangkok to Vietnam's capital city Hanoi, and then travelled north-west about 250 km by van to Luc Yen in Yen Bai Province. It took about 4½ hours, mostly on asphalt road, to reach the town of Yen The,

which is the capital of Luc Yen District (and there-fore this town is commonly known as 'Luc Yen'). Once in the Luc Yen area, we travelled on more winding, unpaved, secondary roads.

Geology of Luc Yen: The Luc Yen area has distinctive topo-graphy—commonly featuring karst landforms caused by the tropical weathering of marble bedrock—including steep hillslopes, sinkholes, caves and dramatic valleys. The geological setting of the gem deposits in Luc Yen can be divided into two north-west-trending domains separated by the Chay River Fault: Tan Huong-Truc Lau and Khoan Thong-An Phu (Figure 3). Tan Huong-Truc Lau pertains to metamorphic belts associated with a large-scale structure known as the Ailao Shan-Red River shear zone, which is located on the south-west side of the Chay River. This area is mainly composed of sillimanite-biotite-garnet gneiss and mica schist that are locally intercalated with marble and amphibolite. On the Chay River's north-eastern side,

Figure 2: The research team—shown here at Minh Tien near An Phu village—consists of (from left to right): Teerarat Pluthametwisute, Tasnara Sripoonjan, Alongkot Fanka, Sarinya Paisarnsombat, Waratchanok Suwanmanee, Somruedee Sakkaravej, Krit Won-in, Doan Thi Anh Vu, Bhuwadol Wanthanachaisaeng and Natthapong Monarumit. Photo courtesy of T. Sripoonjan.

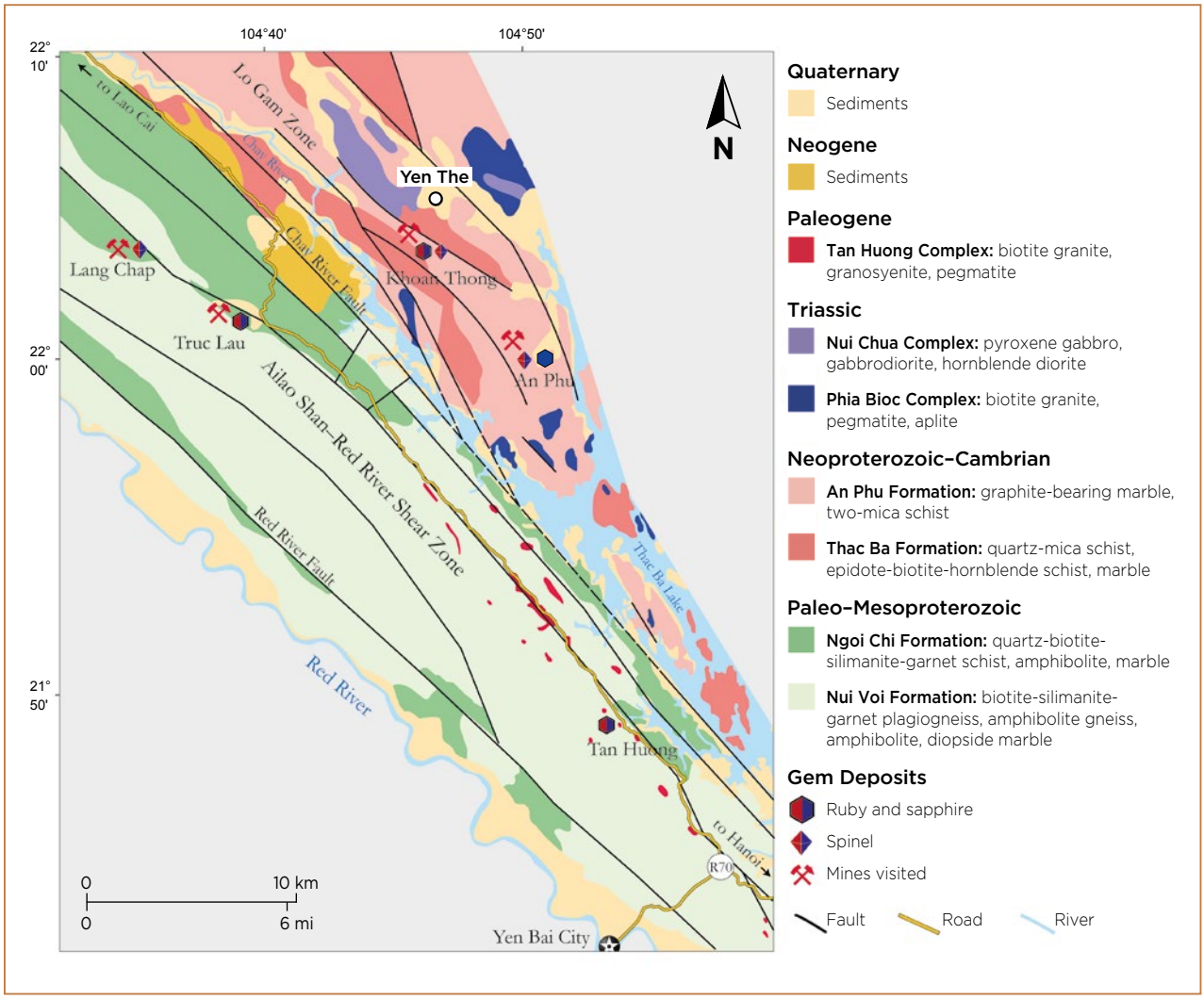

Figure 3: Gem deposits in the Luc Yen District include gneiss-hosted occurrences south-west of the Chay River Fault (e.g. Truc Lau and Lang Chap) and marble-hosted occurrences along the Lo Gam structural zone (e.g. Khoan Thong and An Phu). Adapted from Khoi *et al.* (2016).

the Khoan Thong-An Phu domain is mostly underlain by metasedimentary gneisses and mica schists together with marble. These rocks are locally intruded by granitic and pegmatitic dykes.

Truc Lau Deposit: The most recently discovered gem mining area in Yen Bai (opened in the 2000s) exploits eluvial and alluvial sediments. Rubies and sapphires are hosted by a gravel paleoplacer that underlies swamps and rice fields situated in a relatively large valley about 5 km long (Figure 4). High-quality star rubies have been found in this area. We visited one of the mining areas, but no work was being done on the weekend. Several small pits, approximately 2 m across and 2 m deep, were dug with hand tools by artisanal miners. The authors were told that a considerable quantity of corundum (usually very low or non-gem quality) was being found at that time.

Lang Chap Deposit: Located in remote jungle terrain near Khanh Hoa village, to the west-south-west of Yen The, Lang Chap (Figure 5) requires a four-wheel-drive vehicle to negotiate the muddy road, and is about a 1½-hour drive from the Truc Lau deposit. The area is underlain by weathered metamorphic rocks, including garnet schist. The miners excavate secondary deposits using primitive equipment. According to local gem traders, although recent production has been very limited, some high-quality spinel (including pinkish orange padparadscha-like material) is occasionally recovered.

Khoan Thong Deposit: Also called Tan Linh by locals, Khoan Thong (Figure 6) was formerly a flourishing gem mining area that was exploited by some Vietnamese-Thai joint ventures as well as independent miners. An abundance of gem-quality rubies and sapphires were

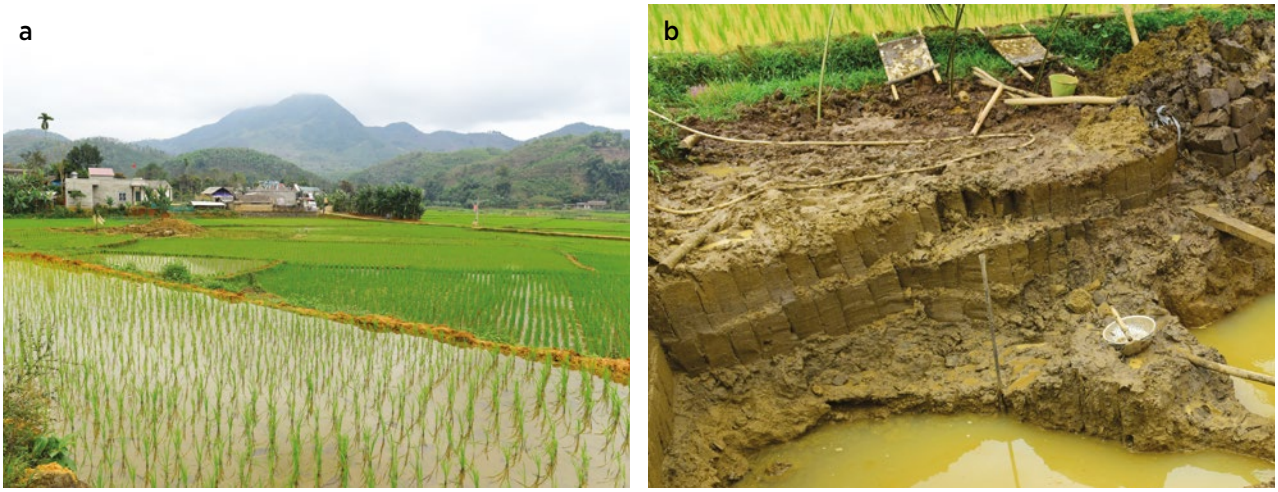

Figure 4: (**a**) Some gem mining in the Truc Lau area takes place within rice fields. (**b**) Small pits dug with hand tools explore secondary gem deposits at Truc Lau. Photos by T. Sripoonjan.

Figure 5: (**a**) The deposit at Lang Chap is being mined for spinel. (**b**) Spinel crystals are found embedded in pieces of white marble matrix. (**c**) Loose pieces of gem-quality spinel are also screened from the gravels. (**d**) These fine-quality spinels (up to about 1+ ct) reportedly came from the Lang Chap area (see tweezers for scale). Photos by T. Sripoonjan (a and c), T. Pluthametwisute (b) and B. Wanthanachaisaeng (d).

recovered there. An engraved stone sign at the entrance of the valley is inscribed with a message of thanks from Vietnam's prime minister to the group of geologists who discovered the gem deposit. Very little mining was underway during our visit. At one active operation near the foothills, we recovered some very small fine-quality rubies. We were told that other gems—such as sapphire, spinel and tourmaline—are also found there. Some of the gem-bearing soil was stockpiled near a small reservoir for washing in the future. We also saw mined-out primary deposits such as (1) a rock face consisting of marble and calc-silicate rocks, partly intruded by granitic and pegmatitic veins; and (2) a tunnel driven into one of the hillsides. The primary deposits were mined for ruby, sapphire and spinel (all typically cabochon quality), as well as tourmaline, pargasite and humite. At the home of a local miner we saw some rough and cut stones that were reportedly from this deposit.

Figure 6: (**a**) The Khoan Thong deposit is situated in a magnificent valley. (**b**) An inscription in stone is dedicated to the geologists who discovered the gem treasures there. (**c**) Small fine-quality rubies were found by the authors in secondary deposits. (**d**) Gems were also produced from primary deposits. (**e**) Black tourmaline is present in pegmatitic rocks. (**f**) Cabochon-quality rubies and sapphires (averaging about 2 ct) from Khoan Thong are offered for sale. All photos by T. Sripoonjan.

Figure 7: (**a**) Near An Phu village, agricultural land used for rice cultivation also hosts secondary gem deposits. (**b**) The trail to the An Phu spinel deposits is steep and slippery, and surrounded by dense jungle. (**c**) Wooden footbridges are used to cross grikes and sinkholes in the karst terrain. (**d**) Crystals of red-purple spinel and orange clinohumite are embedded in white marble host rock. (**e**) A cluster of 'cobalt'-blue spinels (up to about 3 mm each) shows attractive colouration. (**f**) At about 600 m elevation, miners have used a pneumatic jackhammer to extract spinel from the marble. (**g**) Blue spinel is associated with green pargasite in this sample from An Phu. Photos by T. Sripoonjan, except image e by B. Wanthanachaisaeng.

An Phu Deposits: Minh Tien, one of the most famous gem-mining areas in Vietnam, is located near An Phu village to the south-east of Yen The. We visited some mines that could only be reached by trekking for about 5 km (at least 3 hours) up a marble mountain that was about 750 m high (Figure 7). Along the way, we passed rice fields that were mined in places by the locals. As we ascended, the trail became flanked by dense vegetation and in places was shrouded by bamboo. It was wet and slippery, and our trek gradually became steeper among

sharp karst outcrops. Small wooden footbridges crossed solution fissures (grikes) and sinkholes. Eventually, we reached a marble cliff that had been mined for red, pink and purple spinel. Another nearby area was mined for 'cobalt'-blue spinel, which was most probably hosted by a forsterite-rich lens in the marble. These spinels were extracted using hand tools and a jackhammer. We obtained a number of attractively coloured spinel samples, some of which were associated with orange clinohumite or green pargasite. We also visited a mine near An Phu village where fine blue sapphire was found.

Luc Yen Gem Market: A local gem market was established in 1987 in Yen The (Figure 8), and continues to serve as the centre for trading in gemstones, rough material and crystal specimens from northern Vietnam. There were more than 50 vendors who opened daily at 6:30 am and closed before noon. Buyers were comprised of Vietnamese tradespeople from Hanoi and Ho Chi Minh City, as well as foreigners from various countries. The gems on display included spinel (most abundant), ruby, sapphire, aquamarine, fluorite, quartz, tourmaline, opal and jade, among others. Of particular interest to

Figure 8: (**a**) The sellers at the Yen The gem market are mostly women. (**b**) Spinel is the most popular gem material offered there. (**c**) A wide variety of faceted gemstones, reportedly from local mines, are offered for sale. (**d**) Nearby shops display carved stones and sculptures. (**e**) Blue sapphires from Luc Yen show light to dark blue colouration. (**f** and **g**) Gem 'paintings' are created using various crushed materials. Photos by T. Sripoonjan (a–e) and B. Wanthanachaisaeng (f and g).

the authors were high-quality blue sapphires that were reportedly from the An Phu area. Initial asking prices for gemstones were usually relatively high but prices were negotiable. Cabochon-quality material and some ornamental stones were typically offered at reasonable prices. The street near the gem market hosted more than 30 gem and jewellery shops, mostly displaying carved stones, sculptures and mineral specimens. Also offered were gem 'paintings' created using a variety of crushed gem materials (some of which were dyed) that were affixed with spray adhesive.

Reference

Khoi, N.N., Hauzenberger, C.A., Tuan, D.A., Häger, T., Nam, N.V. & Duong, N.T. 2016. Mineralogy and petrology of gneiss hosted corundum deposits from the Day Nui Con Voi metamorphic range, Ailao Shan–Red River shear zone (North Vietnam). *Neues Jahrbuch für Mineralogie, Abhandlungen*, **193**(2), 161–181, https://doi.org/10.1127/njma/2016/0300.

Acknowledgements

This project was supported by Thailand Science Research and Innovation TSRI/RDG62T0037. We are also grateful to Nguyen Van Tich and Nguyen Thi Huong Quynh for information and assistance in the field.

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Gem-A Notices

Gifts to the Association

Gem-A is most grateful to the following for their generous donations that will support continued research and teaching:

Barbara Kolator, United Kingdom, for a black coral branch from Hawaii, USA, collected in the 1940s–50s; rough blue opal from Durango, Mexico; and petrified wood from Holbrook, Arizona, USA.

Helen Serras-Herman, USA, for alabaster onyx (banded gypsum) and drusy quartz specimens from Arizona, along with a pamphlet on lapidary materials.

Webinars with Gem-A Live

At the end of March 2020, the UK began a period of national lockdown as a measure to combat the COVID-19 pandemic. Unfortunately, this meant that Gem-A had to cancel and postpone some in-house gemmology workshops and classes. This was a great disappointment for all the Gem-A team, but we didn't let it stop us from sharing our passion for gemstone education! On 1 April we launched a series of 'Gem-A Live' webinars, which have enabled hundreds of gemmology enthusiasts from around the world to get a free, weekly dose of fresh gem knowledge and ask our webinar hosts questions on the subjects presented.

The webinars, which cover topics such as titanium diffusion in sapphire, flux-healed ruby and composite gemstones, have been uploaded to Gem-A's new YouTube channel, **Gem-A Official Channel**, and are available to watch online now: www.youtube.com/c/GemAOfficialChannel.

One of our Gem-A Live hosts, Julia Griffith FGA DGA EG, sharing live gemmology with the global Gem-A community.

Upcoming Events: Watch this Space...

A celebration of entrants to Gem-A's Gem Empathy Award at the 2019 Hong Kong Jewellery & Gem Fair.

September 2020: Jewellery & Gem World Hong Kong

From 15 to 19 September 2020, Gem-A will return to Hong Kong to exhibit at Jewellery & Gem World 2020. Gem-A will exhibit at booth 3M204; if you're planning to attend, please come along to say hello to our team, find out about our courses and ask us any questions you like. We look forward to seeing you there.

Update: Gem-A Graduation and Presentation of Awards, London

Gem-A have made the very difficult decision to cancel the Gem-A Graduation and Presentation of Awards evening that was scheduled to take place in November 2020. We have held this prestigious event for as long as anyone at Gem-A HQ can remember, and we are deeply saddened we will not get to celebrate our Graduates' achievements in the traditional sense. We are looking at alternatives to ensure that we can still honour the accomplishments of our Graduates and will release details as soon as they are ready. This year's ceremony was due to take place at an exciting new venue, London's historic Church House, a Grade II listed building which neighbours London's iconic Westminster Abbey and Houses of Parliament. We look forward to holding a combined 2020/2021 Gem-A Graduation and Presentation of Awards in this great building next year.

London's Church House, situated in the heart of Westminster.

All events are subject to change due to the ongoing COVID-19 pandemic. Please check your Gem-A Membership emails and the Gem-A website for updates.

Learning Opportunities

Note: Event dates and formats are subject to change depending on the COVID-19 situation.

CONFERENCES AND SEMINARS

Goldschmidt Virtual 2020
21–26 June 2020
Online
https://goldschmidt.info/2020/index
Session of interest: Geochemistry of Gem Minerals – Indicators of Earth's History from Mantle Evolution to Crustal Provenance

Hong Kong International Jewellery Show
3–6 August 2020
Hong Kong
https://event.hktdc.com/fair/hkjewellery-en/s/291-General_Information/HKTDC-Hong-Kong-International-Jewellery-Show/Event-Schedule.html
Note: Includes a seminar programme

NAJA 54th Ace© It Mid-Year Conference
8–11 August 2020
Location to be determined
www.najaappraisers.com/html/conferences.html

Dallas Mineral Collecting Symposium
20–23 August 2020
Dallas, Texas, USA
www.dallassymposium.org

Amberif 2020: 27th International Fair of Amber & Jewellery
26–29 August 2020
Gdańsk, Poland
http://amberif.amberexpo.pl/title,Jezyk,lang,2.html
Note: Includes a seminar programme

19th Rendez-Vous Gemmologiques de Paris
7 September 2020
Paris, France
www.afgems-paris.com/rdv-gemmologique

Association for the Study of Jewelry and Related Arts (ASJRA) Annual Conference
12 September 2020
New York, New York, USA
www.jewelryconference.com

International Jewellery London (IJL)
13–15 September 2020
London
www.jewellerylondon.com
Note: Includes a seminar programme

Jewellery & Gem World Hong Kong
13–19 September 2020
Hong Kong
https://exhibitions.jewellerynet.com/9jg/
Note: Includes a seminar programme

Denver Gem & Mineral Show
18–20 September 2020
Denver, Colorado, USA
www.denvermineralshow.com
Note: Includes a seminar programme

inArt 2020: 4th International Conference on Innovation in Art Research and Technology
30 September–3 October 2020
Paris, France
https://inart2020.sciencesconf.org

CIBJO Congress
5–7 October 2020
Dubai, United Arab Emirates
www.cibjo.org/2020-cibjo-congress-to-take-place-in-dubai-october-5-7-hosted-by-dmcc

2020 American Society of Appraisers (ASA) International Conference
11–13 October 2020

Chicago, Illinois, USA
www.appraisers.org/Education/conferences/asa-international-conference

Japan Jewellery Fair 2020
14–16 October 2020
Tokyo, Japan
www.japanjewelleryfair.com/en
Note: Includes a seminar programme

Munich Show: Mineralientage München
30 October–1 November 2020
Munich, Germany
https://munichshow.de/?lang=en
Note: Includes a seminar programme

Chicago Responsible Jewelry Conference
5–7 November 2020
Chicago, Illinois, USA
https://responsiblejewelryconference.com

14th International Conference on New Diamond and Nano Carbons (NDNC)
10–14 January 2021
Kanazawa, Japan
www.ndnc2020.org

23rd FEEG Symposium—25th Anniversary
23–24 January 2021
Paris, France
www.feeg-education.com/symposium

NAJA 55th Ace© It Winter Conference
31 January–1 February 2021
Tucson, Arizona, USA
www.najaappraisers.com/html/conferences.html

AGTA Gemfair Tucson
2–7 February 2021
Tucson, Arizona, USA
https://agta.org/agta-gem-fair-tucson
Note: Includes a seminar programme

Tucson Gem and Mineral Show
11–14 February 2021
Tucson, Arizona, USA
www.tgms.org/show
Note: Includes a seminar programme

Inhorgenta Munich
19–22 February 2021
Munich, Germany
www.inhorgenta.com/index.html
Note: Includes a seminar programme

10th National Opal Symposium
31 March–1 April 2021
Coober Pedy, Australia
www.opalsymposium.org

American Gem Society Conclave
26–28 April 2021
Louisville, Kentucky, USA
www.conclave2021.americangemsociety.org

37th International Gemmological Conference (IGC 2021)
17–21 May 2021
Tokyo, Japan
www.igc-gemmology.org
Note: Includes field trips to jadeite deposits and a pearl farm

Swiss Gemmological Society Conference
30 May–1 June 2021
St Gallen, Switzerland
http://gemmologie.ch/en/current

Diamonds – Source to Use 2020
9–10 June 2021
Johannesburg, South Africa
www.saimm.co.za/saimm-events/upcoming-events/diamonds-source-to-use-2020

Jewellery in Texts: Texts in Jewellery
19 June 2021
London
www.societyofjewelleryhistorians.ac.uk/news

NAJ Summit
19–21 June 2021
Northamptonshire, East Midlands
www.naj.co.uk/summit
Note: Includes the IRV Valuers' Conference (19–21 June), NAJ's Better Business Seminar (20–21 June), the Retail Jewellers' Congress (21 June) and more

The Goldsmiths' Company Jewellery Materials Congress
18–20 July 2021
London
www.assayofficelondon.co.uk/events/event-programme-202021

Sainte-Marie-aux-Mines Mineral & Gem Show
24–27 June 2021
Sainte-Marie-aux-Mines, France
www.sainte-marie-mineral.com
Note: Includes a seminar programme

9th International Conference Mineralogy and Museums
24–26 August 2021
Sofia, Bulgaria
www.bgminsoc.bg
Note: Gem minerals and archaeogemmology are among the topics that will be covered.

3rd European Mineralogical Conference (emc2020)
29 August–2 September 2021
Krakow, Poland
https://emc2020.ptmin.eu
Sessions of interest: The Geology of Gem Deposits: A Session in Honour of Gaston Giuliani; Materials Sciences and Archaeometry for Cultural Heritage

NAJA 56th Ace© It Mid-Year Conference
30–31 August 2021
Chicago, Illinois, USA
www.najaappraisers.com/html/conferences.html

31st International Conference on Diamond and Carbon Materials
5–9 September 2021
Palma, Mallorca, Spain
www.elsevier.com/events/conferences/international-conference-on-diamond-and-carbon-materials

3rd International Conference on Tourmaline (TUR2021)
9–11 September 2021
Elba Island, Italy
www.tur2021.com

OTHER EDUCATIONAL OPPORTUNITIES

Gem-A Workshops and Courses
Gem-A, London
https://gem-a.com/education

Lectures with The Society of Jewellery Historians
Society of Antiquaries of London,
Burlington House, London
www.societyofjewelleryhistorians.ac.uk/current_lectures

- Gordon M. Walkden—The Rocks of Britain: Our Victorian Jewellery
  22 September 2020
- Kirstin Kennedy—TBA
  27 October 2020
- Charlotte Gere—Colour in Victorian Jewellery
  24 November 2020
- Jonathan Boyd—TBA, on his work as a jeweller
  26 January 2021
- Jack Ogden—Presidential Address (following AGM)
  23 February 2021
- Carol Michaelson—Chinese Jade Jewellery and Ornaments from the Neolithic to the Present
  27 April 2021
- Gonçalo de Vasconclo e Sousa—TBA, on Portuguese jewellery
  25 May 2021
- Karl Schmetzer—The late 14th-Century Royal Crown of Blanche of Lancaster
  22 June 2021
- TBA
  28 September 2021
- Three speakers TBA—New Research on Jewellery
  26 October 2021
- Ute Decker—Sculptural Minimalism & Fairtrade Gold: Philosophy, Provenance and Process
  23 November 2021

New Media

The Collection of EF Watermelon: Masterworks of the American Gem Art Movement

Ed. by Günther Neumeier, 2018 (printed 2019).
EF Watermelon, Old Lyme, Connecticut, USA, 104 pages, illus., ISBN 978-0692058442. USD52.00 hardcover.

This book documents the lifelong collecting passion of two gentlemen: Richard Freeman and James Elliot. This passion extended to three talented American gemstone artists: Susan Allen, Michael Christie and Turkmenistan-born Nicolai Medvedev. A statement by one of the artists (Susan Allen) on the book's title page sums up the pursuit of this gem art collection: 'A lifelong commitment to preserve the unique work of Susan Allen, Michael Christie and Nicolai Medvedev created an unexpected gift; a strong thread of purpose to our lives. The thread moved through time and tuned us to a resonance that was precious in its degree of presence.'

While the book contains little text, the writing is interesting and informative. An introduction by James Elliot details the start of the EF Watermelon partnership, which began in 1977 in Tucson (Arizona, USA) with a purchase of some tourmalines. This led to several buying trips to Brazil, and the establishment of Freeman and Elliot as world-class gem collectors. In the early 1980s they met Susan Allen, Michael Christie and Nicolai Medvedev. Thus began the journey that developed into a lifelong friendship and successful business. The introduction is followed by a foreword from C. R. 'Cap' Beesley titled 'The Renaissance of the American Gem Art Movement', in which he states 'This outstanding collection of objects of art celebrates an important phase in the realm of artistic achievement. It also celebrates and embodies the life's work of both the artists and the individuals that recognised the value and collectability of their creative endeavors'.

Next, renowned gem artist Lawrence Stoller provides a tribute to Susan Allen, noting that her technique of carving a transparent gemstone from the back requires her to think and carve in reverse. Then, world-famous gem photographer Robert Weldon describes photographing Allen's carvings. This brings us to page 10 and an introduction by Patrick Gaffey of Allen's carvings in the EF Watermelon collection, which are featured on the next 49 pages in full-page images. While it's impossible for me to select a favourite, the lion's head on page 13 is exceptional.

Page 60 brings us to Gaffey's introduction to Michael Christie. His elegant essence bottles are unique and exquisite, and are often enhanced by internal carvings by Susan Allen. I particularly liked Christie's quote, 'It's about loveliness', which describes the objects he creates from a wide variety of gem materials. The next 11 pages are filled with this loveliness, again documented perfectly by Weldon's photographs.

The final portion of the collection is again introduced by Gaffey, who gives a brief history of master artist Nicolai Medvedev. He is known for his complex boxes of gem intarsia, the most intricate form of stone inlay art. The following 27 pages show Medvedev's magnificent creations. The book concludes with an index of the works pictured, along with their dates of creation.

How fortunate we are that Jim Elliot and Richard Freeman were able to create the fabulous EF Watermelon art collection to showcase the magnificent creations of these three artists, which they share with us through this fine book. The works in this collection were also documented in a 76-page publication by EF Watermelon titled *The American Gem Art Collection of EF Watermelon Catalog* (2018, ISBN 978-0692058459), which provides information on each piece, including a brief description, dimensions and when it was created (and, for pieces by Michael Christie, the artist's original renderings). Both books can be ordered by emailing efwatermeloncoll@yahoo.com.

Bill Larson FGA
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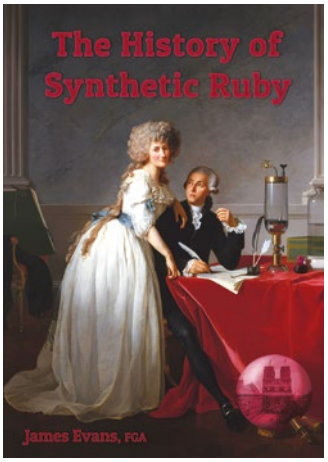

The History of Synthetic Ruby

By James Evans, 2020. Lustre Gemmology Ltd, Sheffield, South Yorkshire, https://lustregemmology.com/shop, 60 pages, illus., ISBN 978-1916165205. GBP18.00 softcover.

This pocket-sized book relates the historical background of synthetic ruby from 1782, when small rubies were first fused together, to the beginning of industrial production in 1902.

In Part I, 'The First Synthetic Ruby', the author traces the early developments, including the contributions of Antoine-Laurent Lavoisier, Robert Hare, Edward Daniel Clarke and Marc Antoine Augustin Gaudin. After Lavoisier invented the oxygen blowpipe in 1782, he was the first to fuse rubies together and the first to synthesise corundum from alumina. Thus, ruby fusion and synthesis first occurred 37 years earlier than previously thought. The next advances in blow-type technology were made by Hare. Clarke was the first to document corundum globules produced from the fusion of alumina in 1820, and Gaudin was pivotal as the first to produce synthetic ruby in 1834 by adding potassium chromate. The resulting material, unfortunately, was opaque.

The second part, 'The Gemmological Revolution', examines further developments which led to the production of large, transparent synthetic rubies on an industrial scale. Jacques-Joseph Ébelmen synthesised microscopic transparent rubies from a solution in 1847. Thirty years later Edmund Frémy and Charles Feil succeeded in synthesising transparent rubies of an appreciable size. Geneva flame-fusion synthetic rubies, from an unknown inventor, appeared in 1886. They were large and transparent, and were the first synthetic gemstones to trouble the jewellery industry. Auguste Verneuil developed a more efficient flame-fusion technique in 1892 and published the details of his method in 1902. The industrial production of synthetic ruby then began, which placed these vibrant red gems within reach of the general public.

This book grew out of the author's Gemmology Diploma project and is successful in presenting the most accurate, up-to-date information available on the subject. The work is well-researched and not overly technical, with easy-to-read text, and it is nicely illustrated with 40 images. It also includes an extensive bibliography. The author is passionate and knowledgeable about the subject, and the work is well-suited for enthusiasts of early gem history, gemmology students and gemmology tutors. *The History of Synthetic Ruby* is an enjoyable read and I highly recommend it.

Guy Lalous
FEEG
Brussels, Belgium

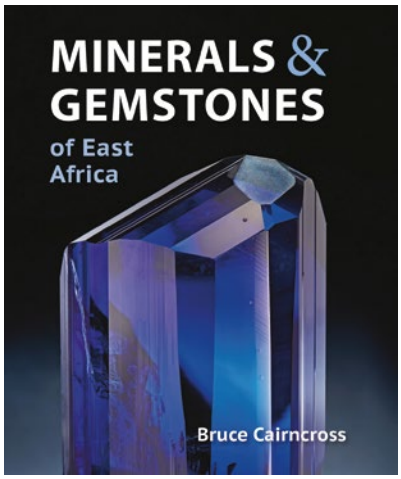

Minerals and Gemstones of East Africa

By Bruce Cairncross, 2019. Struik Nature/Penguin Random House South Africa, Cape Town, www.penguinrandomhouse.co.za/book/minerals-gemstones-east-africa/9781775845560, 160 pages, illus., ISBN 978-1775845560 or e-ISBN 978-1775846987. ZAR250.00 softcover or GBP6.99 Kindle edn.

This attractive book on both mineral specimens and cut gemstones of East Africa contains extensive information and features numerous fine, full-colour photographs of excellent specimens from talented mineral and gem photographers, including Jeff Scovil, Mark Mauthner, Malte Sickinger, the author himself and many others.

Gemstone expert Bruce Bridges sets the theme in the foreword on page 6 by noting the worldwide importance of the gem and mineral bounty of East Africa. A preface and introduction follow. The latter includes a brief review of the geology of East Africa, mentioning

Peter Keller's 1992 book titled *Gemstones of East Africa*, which covered Kenya, Tanzania and Uganda. This new book expands to showcase all five countries that make up East Africa: Burundi, Kenya, Rwanda, Tanzania and Uganda. Each country is discussed briefly in the introduction, noting the mineral resources found there, along with geographic maps.

The heart of the book (pages 22–132) consists of a thorough documentation in alphabetical order—from actinolite to zoisite—of each important mineral found in the region. This is an invaluable resource, easy to use and quite complete, and includes nomenclature, properties, illustrations and information on each species' occurrence in East Africa. For the majority of minerals the illustrations feature both a crystal and cut gemstone; the most important species have much more. For example, grossular has seven pages with more than 20 photographs. Zoisite has 11 pages filled with information and great photos of many world-class specimens, both crystals and cut gems.

The author has done an excellent job of documenting rare stones that only collectors are likely to know, such as wurtzite from Merelani and taaffeite from Tunduru in southern Tanzania. He mentions Ethiopian emeralds and opals as being outside the scope of this book but important enough to include; each is covered with photos and descriptive information.

Following the excellent 110-page alphabetical section, the author includes a page listing type-mineral species from East Africa, and an additional page of acknowledgements. These are followed by a valuable 'References and Further Reading' section (seven pages). The book concludes with an index that uses bold italic font to indicate pages containing illustrations.

Dr Bruce Cairncross is an accomplished author—and an excellent photographer—who has written many excellent books, mostly on minerals of southern Africa. This new volume on East Africa is of interest to mineral and gem collectors and gemmologists everywhere. I can highly recommend it as having real value for any library.

Bill Larson FGA
Pala International
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Other Book Titles

COLOURED STONES

Mineralogy and Geochemistry of Gems
Ed. by Panagiotis Voudouris, Stefanos Karampelas, Vasilios Melfos and Ian Graham, 2020. MDPI, Basel, Switzerland, 528 pages, ISBN 978-3039280766 or e-ISBN 978-3039280773, https://doi.org/10.3390/books978-3-03928-077-3. CHF115.50 softcover or free PDF. *Note*: This book is a printed edition of a special issue of the journal *Minerals*.

Moldavite: The Gemstone that Fell to the Earth
By Ladislav David Rejl, 2019. Self-published, 300 pages, ISBN 978-1792326516. USD75.00 hardcover.

CULTURAL HERITAGE

Along the Amber Route: St Petersburg to Venice
By C. J. Schüler, 2020. Sandstone Press, Inverness, Scotland, 320 pages, ISBN 978-1912240913 or e-ISBN 978-1912240920. GBP16.99 hardcover or eBook.

Byzantium and the West: Jewelry in the First Millennium
By Jeffrey Spier, 2020. Paul Holberton Publishing, London, 200 pages, ISBN 978-0983854647. GBP35.00 softcover.

Magical Gems in Their Contexts
Ed. by Kata Endreffy, Árpád M. Nagy and Jeffrey Spier, 2019. Proceedings of the International Workshop Held at the Museum of Fine Arts, Budapest, Hungary, 16–18 February 2012, Studia Archaeologica No. 229, L'Erma di Bretschneider, Rome, Italy, 382 pages, ISBN 978-8891312976 or e-ISBN 978-8891313003. EUR230.00 hardcover or EUR184.00 eBook.

A Taste for Green: A Global Perspective on Ancient Jade, Turquoise and Variscite Exchange
Ed. by Carlos Rodríguez-Rellán, Ben A. Nelson and Ramón Fábregas Valcarce, 2020. Oxbow Books, Barnsley, South Yorkshire, 192 pages, ISBN 978-1789252743 or ASIN B082KB4F33. GBP45.00 hardcover or GBP27.00 Kindle edn.

GEM LOCALITIES

Minerals of the Grenville Province: New York, Ontario, and Québec
By George W. Robinson, Jeffrey Chiarenzelli and Michael Bainbridge, 2019. Schiffer Publishing, Atglen, Pennsylvania, USA, 208 pages, ISBN 978-0764357657. USD34.99 softcover.

Minerals from Marbles of Carrara and the Apuan Alps [Italy]
By Cristian Biagioni, Paolo Orlandi, Stefano Camarda, Matteo Chinellato, Roberto Appiani, Lorenzo del Chiaro and Giovanni Sanguineti, 2019. LoGisma, Florence, Italy, 144 pages, ISBN 978-8894926156. EUR35.00 hardcover.

GENERAL REFERENCE

Gemmological Tables for the Identification of Gemstones, Synthetic Stones, Artificial Products and Imitations/Gemmologische Tabellen zur Bestimmung von Edelsteinen, Synthesen, künstlichen Produkten und Imitationen, 4th edn.
By Ulrich Henn, Tom Stephan and Claudio C. Milisenda, 2020. Deutsche Gemmologische Gesellschaft e.V. and German Gemmological Association, Idar-Oberstein, Germany, 42 pages, ISBN 978-3000648564 (English) or ISBN 978-3000648557 (German). EUR25.00 softcover.

Gems and Gemmology: An Introduction for Archaeologists, Art-Historians and Conservators
By Stefanos Karampelas, Lore Kiefert, Danilo Bersani and Peter Vandenabeele, 2020. Short Introductions to Cultural Heritage Science, Springer, Cham, Switzerland, 112 pages, ISBN 978-3030354480 or e-ISBN 978-3030354497, https://doi.org/10.1007/978-3-030-35449-7. EUR62.39 hardcover or EUR50.28 eBook.

Mineral Collections in Arizona [USA]
Ed. by Wendell E. Wilson, 2020. Mineralogical Record, Tucson, Arizona, USA, 200 pages. USD25.00 softcover.

Mineral Collections in the Pacific Northwest [USA]
Ed. by Wendell E. Wilson, 2019. Mineralogical Record, Tucson, Arizona, USA, 192 pages. USD25.00 softcover.

The Munich Show/Mineralientage München: Wer sammelt…
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**Article freely available for download, as of press time*

ERRATUM

In the Gem-A Notices section of *The Journal* Vol 36, No. 8 (pp. 776–785), Yi Shen (and not Li Shen, as mentioned in the errata included in Vol. 37 No. 1) should have been listed under 'Gemmology Diploma Passes with Distinction' rather than 'Gemmology Diploma Passes'. *The Journal* apologises for the error.

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The Journal of
Gemmology

Volume 37 / No. 3 / 2020

Characteristics of Chrysocolla Chalcedony

Ivory Species Identification

Stereoscopy in Asteriated Gemstones

Blue CVD Synthetic Diamonds

Amber from Khamti

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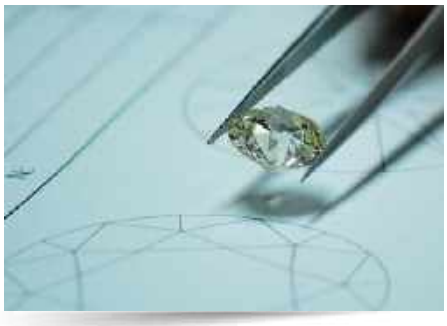

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The Journal of Gemmology

Volume 37 / No. 3 / 2020

Cover photo: *An article on pp. 262–280 of this issue describes the characteristics of chrysocolla chalcedony from Taiwan, Indonesia and USA. This pendant/brooch designed by Paula Crevoshay and Glenn Lehrer, called 'Georgia's Dream', features a 53.57 ct piece of chrysocolla chalcedony from Arizona, USA, that was carved by Lehrer, and is accompanied by another chrysocolla chalcedony (top, 3.59 ct pear shape) along with 52 blue zircons, 37 blue apatites, 43 tsavorites and 93 diamonds. Photo by Orasa Weldon.*

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The Editor-in-Chief is glad to consider original articles, news items, conference reports, announcements and calendar entries on subjects of gemmological interest for publication in *The Journal of Gemmology*. A guide to the various sections and the preparation of manuscripts is given at https://gem-a.com/membership/journal-of-gemmology/submissions, or contact the Editor-in-Chief.

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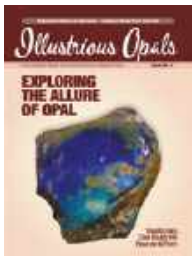

The first of four planned issues highlighting opal was released August 2020 from Beckett Media, the publisher of *Rock & Gem* magazine. It can be freely downloaded from www.rockngem.com/IllustriousOpals_series.pdf and includes articles on cutting, carving, terminology and colouration, as well as information on events and auctions and a showcase of opal specimens from the issue's sponsors.

Mintabie Opal Resource Evaluation Report

In January 2020, the Government of South Australia released the 2nd edition of its report *Mintabie Opal Resource Evaluation: Current Value of Opal Resources and Projected Value of Undiscovered Resources*, which reviews the potential of the area's remaining opal resources and includes a detailed geospatial analysis conducted in 2018. The report also discusses the current decline in production and proposes prospecting methods to help make new discoveries. Visit https://sarigbasis.pir.sa.gov.au/WebtopEw/ws/samref/sarig1/wci/Record?r=0&m=1&w=catno=2041901.

The Impact of COVID-19 on African Communities Affected by Diamond Mining

In June 2020, the Kimberley Process Civil Society Coalition released this report at www.kpcivilsociety.org/report/the-impact-of-covid-19-on-african-communities-affected-by-diamond-mining. It is accompanied by a 6 July webinar. The topics include the geography and nature of selected diamond mining areas in seven African countries, the health impact of COVID-19 and its effect on diamond mining, trading and socioeconomics, as well as support programs, regulations and human rights issues. The report ends with policy recommendations to support the affected communities.

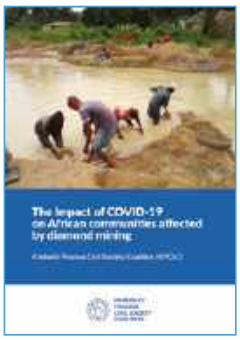

A Rough Cut Trade: Africa's Coloured-Gemstone Flows to Asia

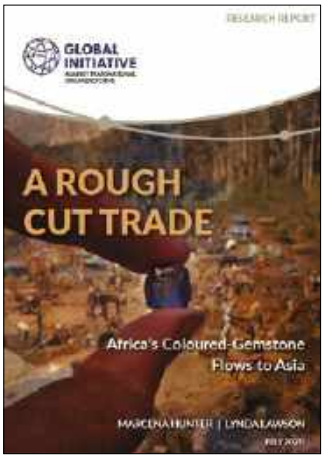

In July 2020, the Global Initiative Against Transnational Organized Crime released a report on the multi-billion-dollar international gem trade linking African suppliers with traders in Asia. The information is based on interviews with traders, gemmologists and government representatives, as well as other ongoing research. The 56-page report proposes that the informal nature of the trade in rough gem materials contributes to the potential for illicit activities and makes it difficult to improve conditions in mining communities. Recommendations are provided. Download the report at https://globalinitiative.net/africa-asia-gemstones-trade.

TRAFFIC Reports on Illicit Ivory Trade and Ivory Identification

TRAFFIC International is a UK-based charity organisation dedicated to global wildlife conservation and trade. In July 2020, it released a 76-page report titled *Trading Faces: A Snapshot of the Online Ivory Trade in Indonesia, Thailand and Viet Nam in 2016 with an Update in 2019*, which investigates the online trade in elephant ivory that continues to take place in these three countries. Download the report at www.traffic.org/site/assets/files/12981/three-country-ivory-report.pdf. This was followed in August 2020 by the fourth edition of *Identification Guide for Ivory and Ivory Substitutes*, which provides characteristic features of elephant, mammoth, walrus, whale, narwhal, hippopotamus and warthog ivories, along with natural and manufactured ivory substitutes, as well as modern methods of laboratory identification. This guide is available at www.traffic.org/site/assets/files/13065/identification-guide-for-ivory.pdf.

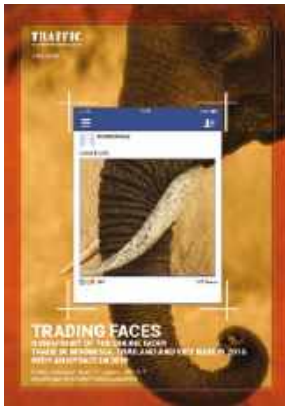

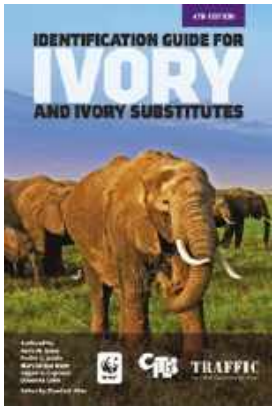

OTHER RESOURCES

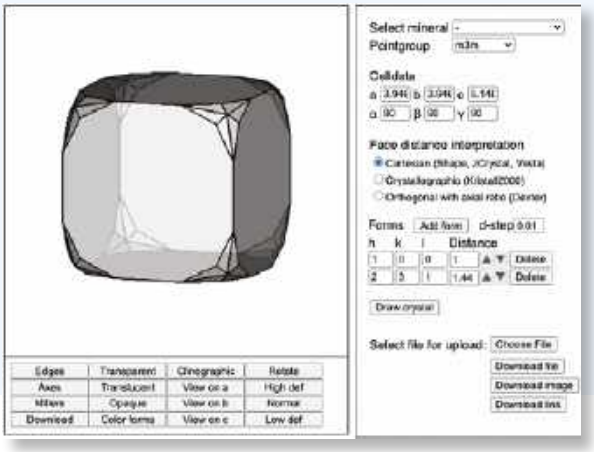

Crystal Models and Software

Holland-based Smorf Crystal Models, which offers crystallographically accurate plastic models of mineral crystals, is now providing free crystal-drawing software (Dexter, on the Windows platform) at www.smorf.nl/index.php#news. It enables the user to create a crystal drawing for essentially any mineral. The website also includes a link to purchase the company's pre-made plastic crystal models that are produced by 3D printing.

RJC Due Diligence Member Toolkit

The Responsible Jewellery Council (RJC) released this new contribution to its Code of Practices in August 2020. The toolkit includes a 46-page booklet, which describes the goals and methods for RJC members to 'exercise due diligence over their supply chains' according to the Organization for Economic Cooperation and Development or other RJC-recognised frameworks. Templates described in the booklet are provided in a separate download, with Word files the user can edit to include company-specific information before signing and endorsing each document. This is a requirement for RJC members, but others in the trade will likely find the information valuable. Download the booklet and tools at www.responsiblejewellery.com/support/cop-2019-walkthrough/provision-07.

Webinars and Other Online Resources for Gemmological Education

Various educational and gem industry organisations are providing webinars and archived video content of interest to gemmologists during the ongoing quarantines associated with the COVID-19 pandemic. The following add to the list of such resources provided in the previous issue of *The Journal*.

- The **Accredited Gemologists Association** offers webinars on pink diamonds from the Argyle mine in Australia, ruby treatments and current market conditions. Visit www.gotostage.com/channel/06607e7c75d5433eb5f81a1c669a85c3 to register and watch these webinars.

- **Christie's Collecting Guides** are an ongoing feature of this auction house's website. The online articles cover various subjects, often focusing on collecting items from specific jewellers and artists, as well as on more general topics such as ancient engraved gems, Art Deco jewellery and tips for collecting ancient jewellery. Visit www.christies.com/features?FeatureTypeID=10&CategoryID=8&T=F&LID=1.

- The **Far East Gem Institute** has a variety of fee-based 'On Demand Learning' webinars and other educational resources as videos and PDFs at https://fareastgem.institute/learn. Topics include heat treatment of corundum, amber from Myanmar, diamonds from Kalimantan (Indonesia) and more.

FAR EAST GEM INSTITUTE

- Podcasts from **Gemology Worldwide** cover topics such as 'Value with Richard Drucker', 'Emeralds with Jeffery Bergman', 'Trade Shows with Doug Hucker' and many more. Visit http://gemologyworldwide.com for a full listing.

GEMOLOGY WORLDWIDE

- **Home Gemmology**, from Rui Galopim de Carvalho, now has webinars archived at www.youtube.com/channel/UCfQJ4Jnf9LtZCTFB9RIaAuQ, which include topics such as Brazilian diamonds, Lalique jewellery, natural pearls, amethyst and coloured diamonds. The Home Gemmology Blog at www.ruigalopim.com/blog hosts a variety of online articles that have addressed topics such as historic Portuguese jewels, coral, pearls and more.

- **'The Divers of Sewa'**, a film by Dr Laurent Cartier, was released online in August 2020 at https://vimeo.com/444162165. The nine-minute video—which Dr Cartier premiered at the November 2019 Gem-A Conference—shows how artisanal divers search for diamonds in gravels beneath the Sewa River in Sierra Leone.

- **JewelleryAdvisor Pro**, from former Gem-A tutor Julia Griffith, hosts pre-recorded webinars on diamond formation, rare gems, the world's most expensive gems, and more at www.jewelleryadvisor.com/on-demand-webinars.

- **Jewelry Connoisseur**, a website from Rapaport USA, offers podcasts on period jewellery including 'The Enduring Appeal of Art Deco', 'Educating Estate Jewelry Collectors', 'Defining the Cartier Style' and 'Victorian Jewelry'. Visit http://jewelryconnoisseur.net/the-jewelry-connoisseur-podcast.

- **Jewellery Outlook**, an online trade magazine, offers webinars on a range of gem and jewellery marketing topics, such as the impact of COVID-19 on trade shows, digital advances in gem and jewellery trade practices, and more. Visit https://jewelleryoutlook.com/category/webinar-lists.

- **Les Enluminures**, a Paris-based art and antique gallery, offers videos and podcasts on various subjects of interest to gemmologists, such as historical jewellery pieces and interviews with experts such as Diana Scarisbrick, Beatriz Chadour-Sampson and Benjamin Zucker. Visit www.lesenluminures.com/video.

- **Martin Rapaport Webinars** has a YouTube channel with numerous webinars from diamond expert Martin Rapaport. They vary from brief 'editorials' to detailed 'State of the Diamond Industry' reports dealing with the effects of the virus pandemic. To view the full list, visit www.youtube.com/playlist?list=PLy2qi24iNJAT3MyYEp2bcPCDA09a7QhGF.

- **Mineral Talks Live** is a series of mineral-related webinars produced by the Mineralogical & Geological Museum at Harvard University, the Society of Mineral Museum Professionals and BlueCap Productions.

Episodes feature museum curators, mineral dealers and other prominent members of the mineralogical community. The webinars are archived on the BlueCap Productions YouTube channel at www.youtube.com/playlist?list=PLYUSEUgiTprl9Vh7ZLXu8x_hHp0dN_TDJ, which also hosts playlists containing video reports from past mineral shows and presentations given at Dallas Mineral Collecting Symposia at www.youtube.com/c/bluecapproductions/playlists.

- The **Museo del Gioiello Vicenza** website hosts webinars from their 'Tuesdays at the Jewellery Museum' series. Some of them are presented in English, such as 'Symbolism in High Jewellery' and 'The Future of Jewellery'. Visit www.museodelgioiello.it/en/webinar.

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- In addition to hosting webinars on their YouTube channel as mentioned in the previous issue, the **Responsible Jewellery Council** has made various webinars available on their website at www.responsiblejewellery.com/hub/news-and-events, including 'Responsible Sourcing of Gold and Diamonds in a Post-COVID-19 World', 'Gold Jewellery Industry in the Pandemic – Now and Future', business leadership discussions and other global jewellery topics.

- The annual **Rochester Mineralogical Symposium** was held online on 25 April 2020, and videos of the presentations are available at www.youtube.com/playlist?list=PL4AllrO7xkRd_rartqBETPUBxfAGwTx6f. The 13 talks cover apatite chemistry and inclusions, optically anomalous crystals, what's new in minerals and more. Abstracts from the e-symposium are also available at www.rasny.org/minsymp/47th RMS Program Notes.pdf.

- The **Symposium on the Effects of Covid-19 on ASMs [Artisanal and Small-Scale Miners] in the Gemstone Supply Chain** was held online 13–14 May 2020 and hosted by the Responsible Jewelry Transformative (producer of the Chicago Responsible Jewelry Conference). Day one covered grassroots initiatives to help small-scale gem miners, while day two moved to global projects. Videos highlighting these discussions from each day are available at https://the-symposium-on-artisanal-small-scale-gemstone-mi.heysummit.com.

What's New provides announcements of new instruments and technology, publications, online resources and more. Inclusion in What's New does not imply recommendation or endorsement by Gem-A. Entries were prepared by Carol M. Stockton unless otherwise noted.

Gem Notes

COLOURED STONES

Amazonite in Quartz from Bahia, Brazil

Gem-quality amazonite feldspar is well known from Brazil, particularly from pegmatites of the Early Proterozoic Itiúba alkaline massif in Bahia State (Couto 2000). During the February 2020 gem shows in Tucson, Arizona, USA, Leonardo Silva Souto (Gems in Gems, Teófilo Otoni, Minas Gerais, Brazil) had some new production of amazonite from Bahia that was notable for occurring together with transparent to translucent quartz (Figure 1). It was sold in Tucson as 'Paraíba amazonite' in reference to its bright blue to greenish blue colouration. It lacked the white, grid-like mottling that is usually associated with this feldspar variety.

The rough material first entered the market at the August 2019 Feira Internacional de Pedras Preciosas (FIPP) show in Teófilo Otoni, and the initial production consisted of about 400 kg of broken pieces. Since then, approximately 1,000 kg more amazonite has been mined, and approximately 20,000 carats of tablets and cabochons have been polished in sizes ranging up to about 32 × 26 mm. The material is reportedly not treated in any way, and displays various patterns and proportions of amazonite and quartz, as well as brown to black staining in some stones. A considerable portion of the material has been cut as bicoloured gems displaying a sharp demarcation between the amazonite and quartz (again, see Figure 1).

Figure 1: This polished tablet (8 × 6 mm) consists of amazonite and quartz from Bahia, Brazil. Photo by Vicky Rodríguez Garrido.

This material provides an alternative to the more expensive matrix specimens of Paraíba tourmaline with albite and/or quartz that have been polished for gem use.

Brendan M. Laurs FGA

Reference

Couto, P. 2000. *Gemologic Map of the State of Bahia—Explanatory Text*. CPRM – Serviço Geológico do Brasil, Salvador, Bahia, Brazil, 76 pp.

Blue Apatite in Jasper from Brazil

Gem-quality blue to greenish blue apatite from Bahia State in Brazil has been known since approximately 1990 and was mentioned by Koivula *et al.* (1993) as occurring in heavily etched crystals in association with jasper. During the February 2020 Tucson gem shows, Marco Campos Venuti (Gems in Gems, Seville, Spain) had some specimens of blue apatite in jasper that were produced fairly recently from an undisclosed locality, probably in Minas Gerais State. He first encountered the rough material in 2018, but it was of rather low quality, consisting of small (about 5 mm) opaque blue dots in jasper. Later, during the August 2019 FIPP show in Teófilo Otoni, Brazil, he obtained about 300 kg of much better-quality material containing larger-sized gem-quality apatite crystals that were up to 20–25 cm long and 10 cm wide. The apatite was often transparent and sometimes occurred in well-formed crystals within the jasper (e.g. Figure 2).

The jasper matrix is yellow-orange with dark spots, and appears similar to so-called Cheetah jasper from

Figure 2: Viewed in transmitted light, this slab shows well-formed crystals of apatite in a jasper matrix. Photo courtesy of Marco Campos Venuti.

Figure 3: The polished tablet of apatite in jasper weighs 2.13 ct and measures 11 × 8 mm. Photo by Vicky Rodríguez Garrido.

Brazil that has been cut into spheres, pyramids and other *objets d'art*. However, this is the first time that Campos Venuti is aware of apatite being associated with such material. So far he has cut about 300 cabochons and polished tablets/slabs ranging up to approximately 50 × 20 cm. Since the apatite is rather dark, the stones need to be cut thin enough for light to readily pass through them. The contrast between the blue apatite and orange jasper is rather striking (e.g. Figure 3), and it is unusual for this colour combination to occur in gem materials. The blue colour of the apatite is natural and the gems are reportedly not treated in any way. A few of the cabochons cut from this apatite show distinct chatoyancy.

Campos Venuti continues to experiment with the best way to process the rough material, which is challenging to work with since the apatite tends to detach from the jasper matrix. Smaller pieces of transparent apatite of 1–2 cm appear to be best faceted into gemstones, while specimens containing larger crystals of apatite will probably be cut and polished as slabs.

Brendan M. Laurs FGA

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Aquamarine Crystal with 'Enhydro' Inclusion from Brazil

The most common hosts for large fluid inclusions with movable gas bubbles—known as 'enhydros'—are quartz crystals and agate/chalcedony. Enhydros have also been documented in other materials such as emerald, tanzanite and gypsum (Johnson & Koivula 1999 and references therein). Perhaps the first mention of such inclusions in beryl was documented by Kesler *et al.* (2013, p. 398):

> In the 13th century…Albertus Magnus, a German medieval scholar and Archbishop of Cologne, wrote a book on lapidary ('de mineralibus') with a note on fluid inclusions in beryl, that states 'Beryl is a shining and transparent gemstone of pale color. The most precious kind is the one, in which you see water moving when you turn him' (translation from German provided by Albert Gilg).

During the February 2020 Tucson gem shows, Steve Ulatowski (New Era Gems, Grass Valley, California, USA) showed this author a remarkable aquamarine crystal from Brazil with an elongate enhydro inclusion (Figure 4). The specimen consisted of a transparent pale bluish green hexagonal prism that was terminated on one end and broken on the other end. It measured approximately 89 × 17 mm, and along its centre was a channel oriented parallel to the *c*-axis that was about 56 mm long and 3 mm wide that contained a movable gas bubble. As the crystal was rotated perpendicular to its length away from a horizontal orientation, the bubble slowly travelled the length of the channel, much like the behaviour of the bubble in a builder's level. The channel started at a growth disturbance located about 31 mm from the broken end of the crystal and extended to within nearly 2 mm

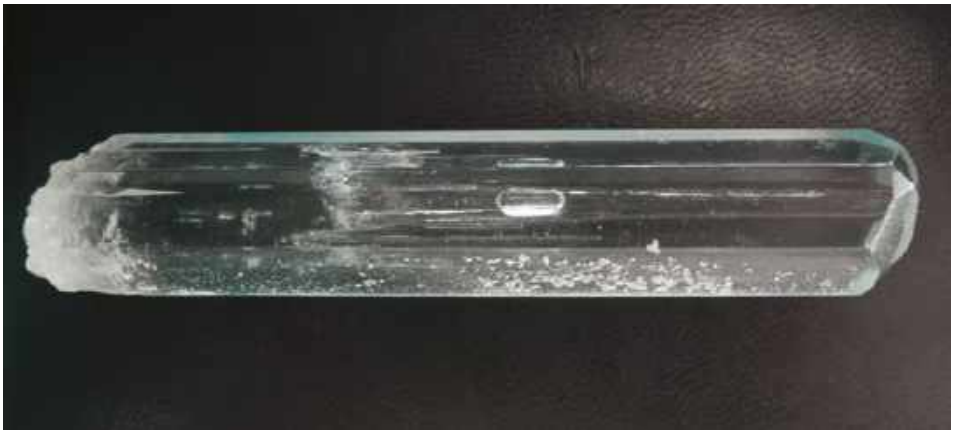

Figure 4: This aquamarine crystal contains an elongate growth channel oriented parallel to the *c*-axis that has a movable gas bubble (here, positioned about halfway along its length). The crystal measures approximately 89 × 17 mm, and the growth channel is about 56 mm long and 3 mm wide. Photo by B. M. Laurs.

of its termination; the channel narrowed slightly along its length. A tiny dimple on the flat termination of the crystal was present adjacent to where the growth channel ended, perhaps manifesting a dislocation associated with the formation of the channel (Figure 5).

Elongate two-phase (liquid and gas) fluid inclusions oriented parallel to the *c*-axis are quite common in beryl from granitic pegmatites (e.g. Cameron *et al.* 1951). The formation of these inclusions in such beryl crystals was described in detail by Sunagawa and Urano (2000) and Sunagawa (2005), who attributed them to a growth-dissolution-regrowth process that was due to local fluctuations in the supply and composition of the late-stage pegmatitic fluids. When foreign mineral grains are trapped on the growing crystal as inclusions, tube-like fluid inclusions are formed behind the particles, and dislocations in the crystal are generated from where the inclusion is enclosed. The resulting tube-like two-phase inclusions and associated dislocations are formed in the direction of the *c*-axis, 'and spiral growth proceeds from the outcrop of these dislocations on the {0001} face' (Sunagawa 2005, p. 242).

In the present crystal, it is interesting to note that the growth channel hosting the fluid inclusion nearly intersected the termination, and had it not been sealed by the final stages of the crystal's growth, then the fluid

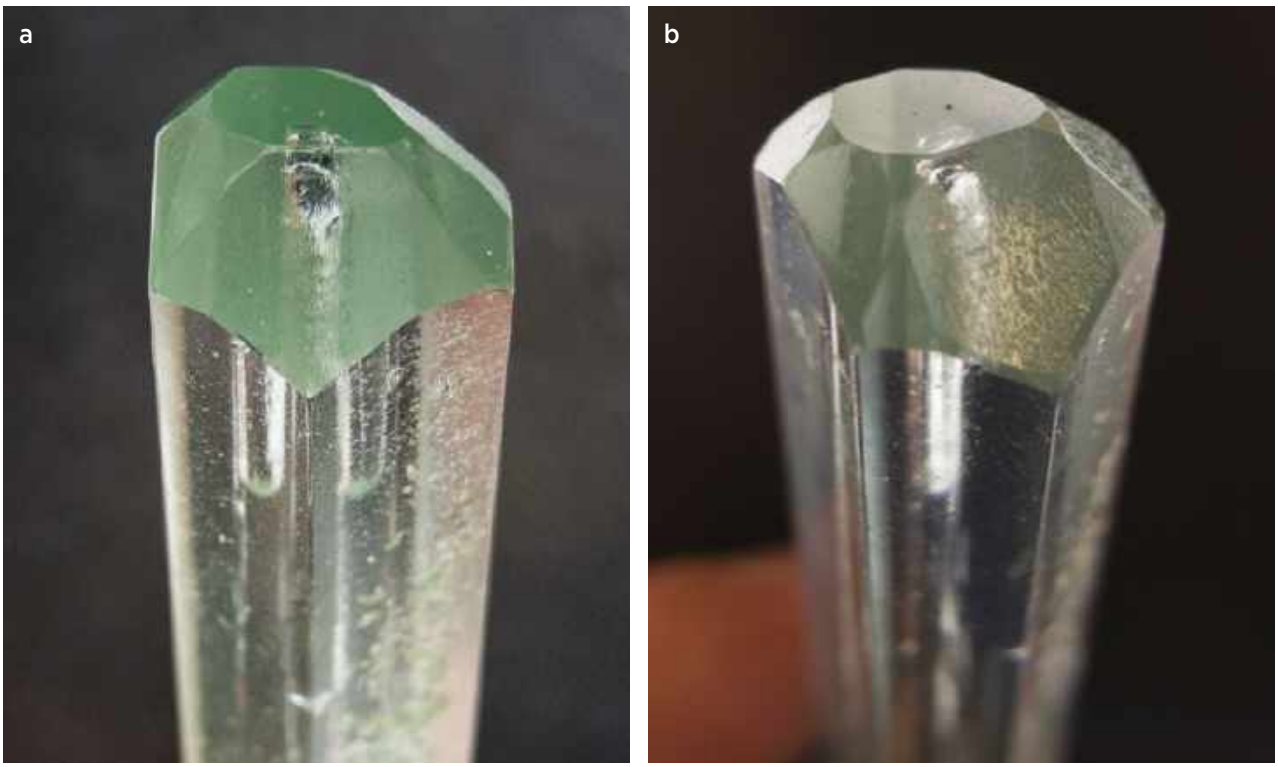

Figure 5: (**a**) The growth channel hosting the bubble ends within about 2 mm of the aquamarine crystal's termination. (**b**) In reflected light, a tiny dimple is visible as a dark spot on the flat termination of the crystal, and is located adjacent to where the growth channel ends. Photos by B. M. Laurs.

would have leaked out, leaving a hollow channel. It is rare for such large enhydros to be encountered in beryl, particularly with such a long distance along which the bubble can travel.

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Catapleiite from Mont Saint-Hilaire, Québec, Canada

Catapleiite is a hydrated zirconosilicate (ideally $Na_2Zr[Si_3O_9] \bullet 2H_2O$) that forms a solid-solution series with calciocatapleiite ($CaZr[Si_3O_9] \bullet 2H_2O$) and is a dimorph of gaidonnayite. It is monoclinic (while calciocatapleiite and gaidonnayite are orthorhombic), but the crystals typically show a tabular to platy pseudohexagonal morphology. Individual crystals range from millimetre size up to 5 cm, and they often form rosettes that can attain maximum dimensions of 15 cm (Wight 1992, 2011). Catapleiite occurs in a wide range of colours: colourless to beige, or tan to pale grey, and rarely light yellow, pale orange, pink and pale blue (Wight 1992), but in gem quality it seems only to be colourless. Although found worldwide, the scarcity of facetable material makes it a rare collector's stone. The best and largest specimens of catapleiite were mined from Mont Saint-Hilaire, La Vallée-du-Richelieu, Montérégie, Québec, Canada, which has been famous for producing a variety of rare minerals since the 1960s (Pendlebury 1964; Wight 1992, 1996). The largest known faceted catapleiite weighs 2.48 ct (Wight 2011).

The 0.43 ct catapleiite gemstone described here (Figure 6) was reportedly mined at Mont Saint-Hilaire in 2012 or earlier, and was recently characterised by the author in order to add more gemmological data to the literature. It showed the following properties: colour—colourless (appearing silvery white); lustre—dull but somewhat pearly; diaphaneity—transparent; RI—1.591–1.629; birefringence—0.038; optic character—biaxial positive; hydrostatic SG—2.77; magnetism—no reaction to an N52 (neodymium) magnet; Chelsea Colour Filter reaction—none; and fluorescence—inert to long- and short-wave UV radiation. These data are consistent with those reported previously for catapleiite (Wight 1992, 1996; O'Donoghue 2006), and are distinct from the properties of calciocatapleiite and gaidonnayite.

Microscopic examination revealed irregular veils, partially healed fissures and unevenly distributed highly reflective growth channels (Figure 7a, b). Also observed were negative crystals and a few bubble-like inclusions that could correspond to the 'bubbles' mentioned by Pendlebury (1964). Observations were obstructed somewhat by apparent growth features. Strain-like patterns of interference colours were visible throughout the stone when viewed between crossed polarisers (Figure 7c), and it remained uniformly bright when rotated in the polariscope. According to Chen and Chao (1973), catapleiite crystals from Mont Saint-Hilaire are invariably polysynthetically twinned, which may explain these optical features.

A visible-near infrared (Vis-NIR) spectrum was collected from the stone but, as expected for most colourless gem materials, it did not show any absorption features.

Figure 6: This 0.43 ct catapleiite (6.3 × 4.3 × 2.8 mm) is from a locality that is famous for producing rare minerals: Mont Saint-Hilaire, Québec, Canada. Photo by T. Cathelineau.

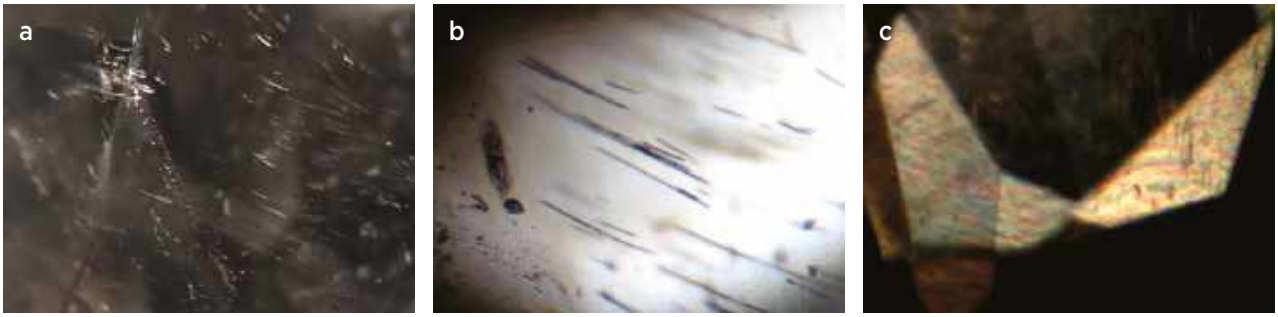

Figure 7: Microscopic examination of the catapleiite reveals (**a**) veils, partially healed fissures and unevenly distributed highly reflective growth channels; (**b**) growth channels; and (**c**) strain-like patterns of interference colours. Photomicrographs by T. Cathelineau, using (a) reflected light, (b) darkfield illumination and (c) crossed polarisers; image widths (a) 2 mm, (b) 0.6 mm and (c) 3 mm.

Infrared reflectance spectra were collected from several spots on the stone's table and pavilion facets, and all showed essentially the same pattern (Figure 8). The material's identification was confirmed by checking the pattern against the log(1/T) transformation of Russian and Norwegian catapleiite spectra (Chukanov 2014: samples TiSi69, TiSi149, TiSi208 and TiSi240). A spectrum for calciocatapleiite from Russia was slightly different (Chukanov 2014: sample TiSi76). The bands in the range of 1100–900 cm^{-1} are due to Si-O stretching vibrations and the band at 1650 cm^{-1} is attributed to non-degenerate H-O-H deformation vibrations (Aksenov *et al.* 2016).

The stone's photoluminescence (PL) spectra were collected using 254, 375 and 405 nm excitations to look for bluish white luminescence due to TiO_6 complexes (as mentioned by Gaft *et al.* 2015) and green luminescence due to UO_2^{2+} (http://fluomin.org/uk/fiche.php?id=278), but without success. For the 405 nm excitation, a very faint and broad asymmetric background from 400 to 700 nm (with a maximum at about 450 nm) was observed on which a narrow band, broadened at its base, was superimposed at 472 nm. This corresponded to the 3500 cm^{-1} Raman band (see RRUFF R060208 broad scan), which is associated with OH by analogy to IR bands (Aksenov *et al.* 2016).

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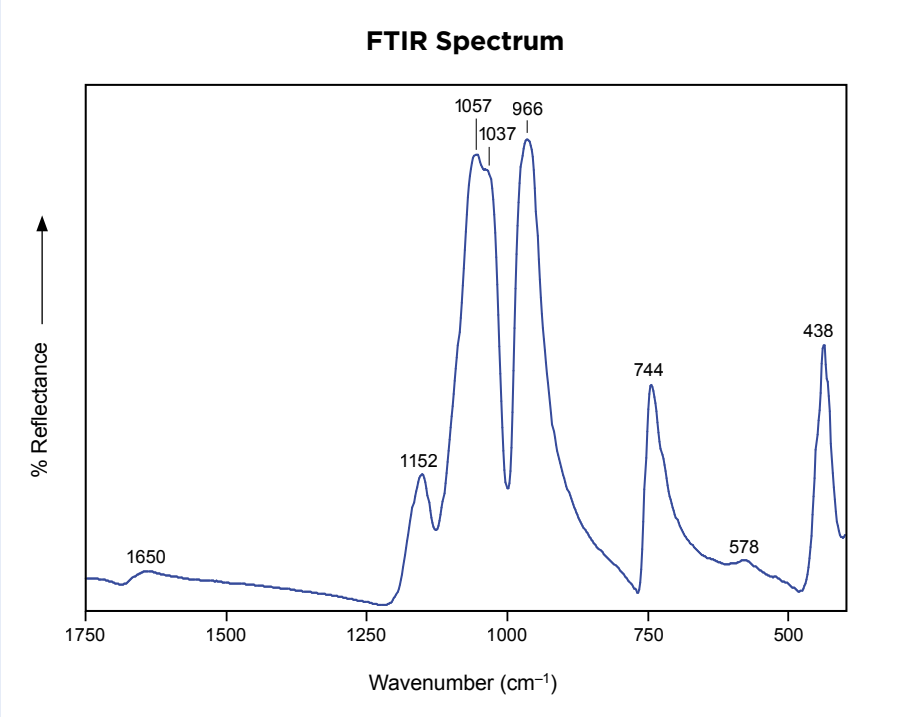

Figure 8: The IR reflectance spectrum of catapleiite is dominated by bands in the 1100–900 cm^{-1} range that are due to Si-O stretching vibrations.

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Chrysocolla Chalcedony from the Democratic Republic of Congo

The Democratic Republic of Congo (DRC) hosts some important copper deposits, which occasionally produce rough material that is polished into gemstones (e.g. Zwaan 2015).

During the February 2020 Tucson gem shows, this author was informed about a new find of attractive chrysocolla chalcedony from DRC by Boukoubongui Tchagole (Idar-Oberstein, Germany). The material was found in November 2019 and only a few pieces were available. It showed bright greenish blue colouration and good transparency (Figure 9).

Gem silica from DRC was briefly mentioned by Currier (2002), and the pieces seen recently in Tucson demonstrate the potential for high-quality chrysocolla chalcedony to be produced from DRC in the future.

Brendan M. Laurs FGA

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Figure 9: These samples of chrysocolla chalcedony are from a new find in DRC. The sawn piece of rough weighs 311 g and the cabochon is about 19 ct. Photo by B. M. Laurs.

Pink Diaspore from Afghanistan

Gem-quality diaspore is known mainly from Muğla Province in Turkey, and typically appears near-colourless to brownish green in daylight and lavender to pinkish yellow/brown in incandescent light (e.g. Duroc-Danner 1987; Hatipoglu & Chamberlain 2011). Since July 2018, some fine crystal specimens of Turkish diaspore have been produced that displayed attractive purple colouration (Southwood 2020; Wilson & Moore 2020). Pink to purple diaspore is also known from Myanmar (Shen & Lu 2018) and from the Ural Mountains in Russia (Spiridonov *et al*. 2006), but neither locality has produced material of facetable size/quality.

In mid-March 2020, one of the authors (MHS) learned about a new find of gem-quality pink diaspore from Afghanistan. According to his Afghan supplier, the mining area is located in 'Kama Goshta' near Jalalabad, which apparently corresponds to the Kama and/or Goshta Districts in Nangarhar Province of eastern Afghanistan. Author MHS initially obtained a single piece of rough weighing 2 g and a faceted stone that recut to 23.36 ct. He also saw a 146 g parcel of rough material containing pieces ranging from about 1 to 10 g (approximately 2.5 g on average) that was suitable for cutting stones of 1–10 ct (Figure 10). In May 2020 he obtained a 70 g parcel of rough (0.6–12 g pieces), which he had faceted into 35 stones ranging from 0.50 to 10.91 ct (e.g. Figure 11a). The cutting yield was very low due to the presence of cleavage fractures in the rough material. In addition, he acquired a faceted stone that recut to 46.97 ct (Figure 11b). This is the largest gemstone he is aware of from this deposit. Since that time, he has purchased several other gems weighing over 20 ct from the same supplier.

Figure 10: This parcel of rough pink diaspore is from a new find in Afghanistan. The stones range from about 1 to 10 g and the entire parcel weighs 146 g. Photo by M. H. Smith.

All the rough material seen by author MHS has been of similar colour, and the slight variations seen in the faceted stones were likely due to the various cutting orientations and the material's very strong pleochroism. The cut stones ranged from slightly brownish light pink to slightly brownish light purple. Viewed in different light sources there was no colour change, but a subtle colour shift was seen in which larger stones (>10 ct) appeared more pinkish in warm light and purplish pink in cool light. The following gemmological properties were collected by author MHS on two faceted stones weighing

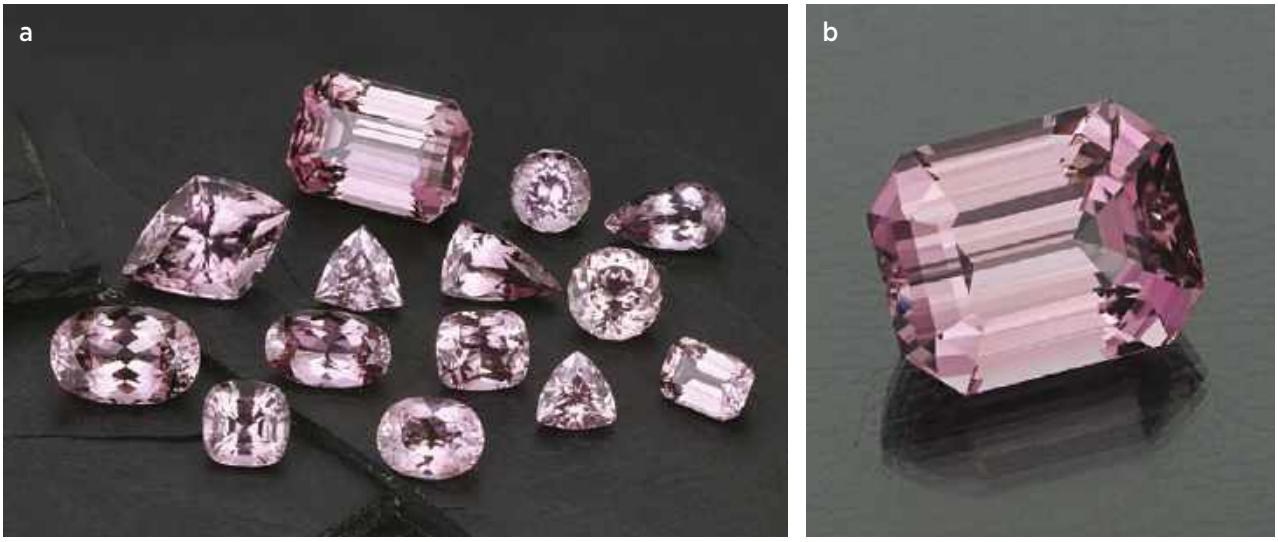

Figure 11: Pink Afghan diaspore has been faceted into attractive gemstones, and those shown here weigh (**a**) 2.05–23.36 ct and (**b**) 46.97 ct. The largest gem is now in the collection of Herb and Monika Obodda (Warwick, Rhode Island, USA). Photos by M. H. Smith.

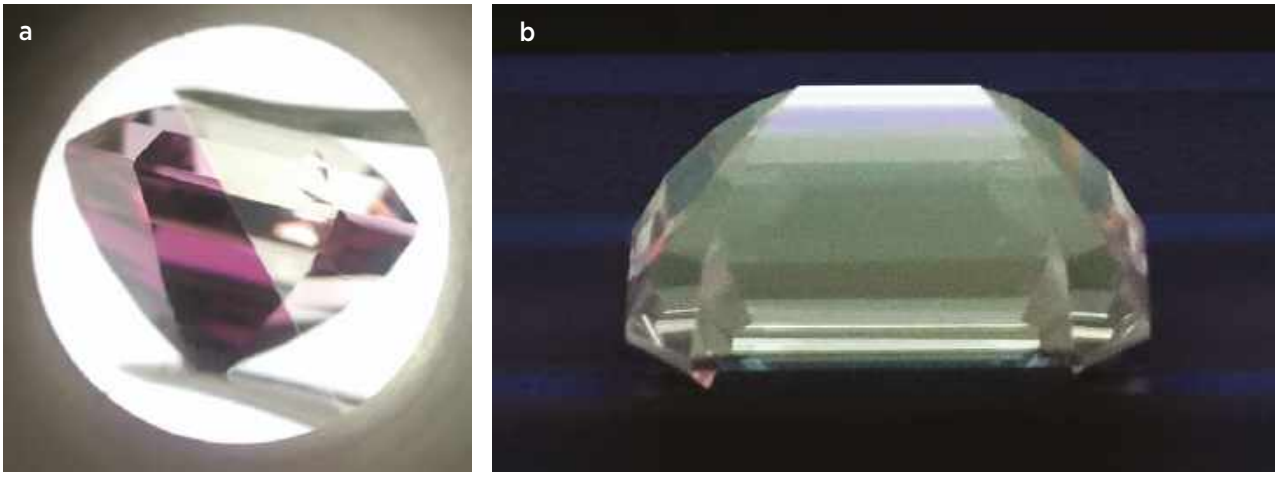

Figure 12: The Afghan diaspore shows (**a**) strong pleochroism and (**b**) weak chalky yellowish green fluorescence to short-wave UV radiation. Photos by M. H. Smith (a, 13.45 ct) and GIT (b, 23.36 ct).

13.45 and 23.36 ct: Pleochroism—very strong, in light yellow and dark purplish pink (Figure 12a); RI—n_α = 1.699–1.700, n_β = 1.720–1.721 and n_γ = 1.748–1.749; birefringence—0.049–0.050; optic character—generally B+; and hydrostatic SG—3.39–3.40.

The 23.36 ct stone was also examined at The Gem and Jewelry Institute of Thailand (GIT) in Bangkok, where the UV fluorescence was documented as inert to long-wave UV and weak chalky yellowish green under short-wave UV radiation (Figure 12b). In addition, the stone appeared reddish when viewed with the Chelsea Colour Filter. Chemical analysis by energy-dispersive X-ray fluorescence (EDXRF) spectroscopy using an EDAX Eagle III instrument showed traces of Ti, Fe, Ga, V and Cr. Polarised ultraviolet-visible (UV-Vis) absorption spectra were collected with a PerkinElmer Lambda 1050 spectrophotometer in two polarisation directions (purplish pink and near-colourless; Figure 13), and showed features at 398 nm (Fe^{3+}), 450 nm (Fe^{3+}) and 480 nm, as well as broad bands centred at about 400 and 550 nm (V^{3+} and Cr^{3+}; cf. Shen & Lu 2018). A transmission window above about 650 nm is responsible for the overall purplish pink colour of the stone. The

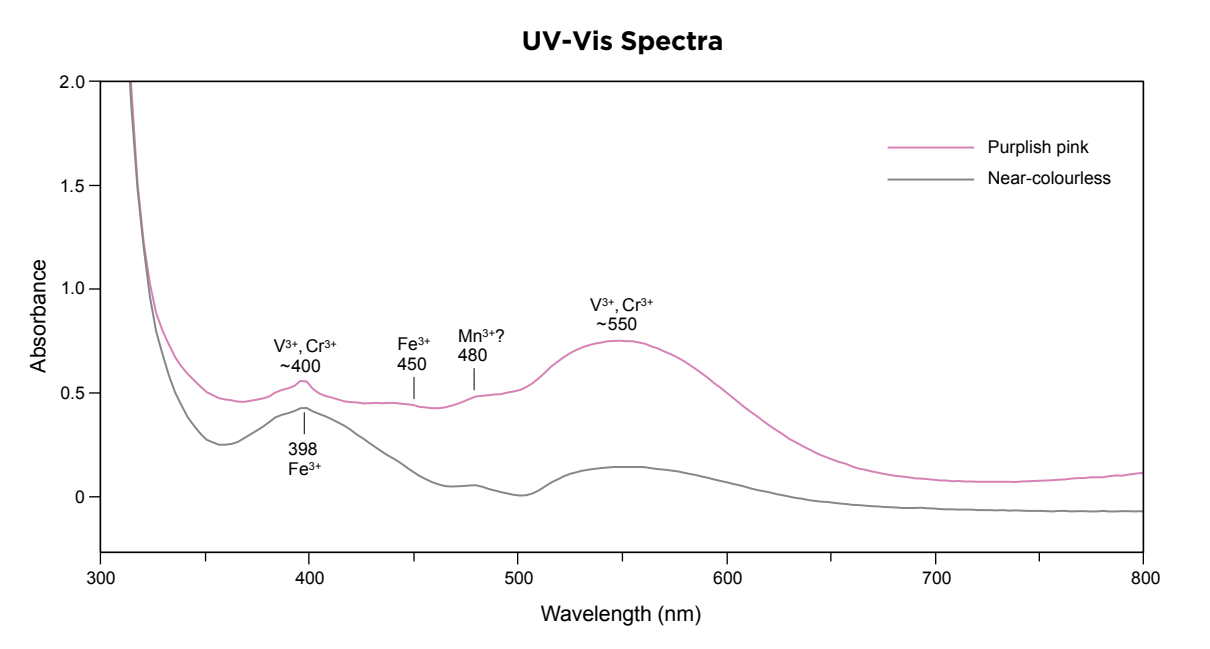

Figure 13: UV-Vis spectroscopy of the 23.36 ct diaspore reveals absorption features at about 398, 450 and 480 nm, as well as broad bands centred at about 400 and 550 nm. A transmission window above about 650 nm is responsible for the purplish pink colour of this diaspore. The path length of the beam was approximately 11 mm.

480 nm feature was not well defined in the spectra, but is probably related to Mn^{3+} (cf. GRR 73 at http://minerals.caltech.edu/FILES/Visible/diaspore/Index.html), which is a strong chromophore and could therefore influence the spectrum when present in very small amounts that are below the detection limit of EDXRF spectroscopy. The spectral features were more pronounced in the purplish pink direction, corresponding to the strong pleochroism, and indicate that the colouration of this pink diaspore is due to a combination of Fe^{3+}, V^{3+}, Cr^{3+} and probably Mn^{3+}.

The supplier of the Afghan diaspore indicated that there continues to be minor production of small- to medium-sized gems but that rough material suitable for cutting clean larger stones (20+ ct) is rare.

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Pink Fluorite from Inner Mongolia

The Huanggang mining complex is located approximately 30 km west of Linxi town, near the city of Chifeng in Inner Mongolia, China. This large Fe-Sn polymetallic ore deposit was discovered in 1959 and is exploited by several major mines (Lavinsky & Chen 2012; Mei *et al*. 2014).

During the February 2020 Tucson gem shows, Dr Robert Lavinsky (The Arkenstone, Richardson, Texas, USA) had pink fluorite from Huanggang mine no. 5 as mineral specimens and faceted stones (e.g. Figures 14 and 15). This is the first time that pink fluorite had been produced from this locality since an initial find in the latter part of 2010 that yielded translucent octahedral crystals up to 13 cm. At that time, many of the fluorites were broken off their matrix before the miners knew their value as mineral specimens. In addition, some of the fluorite was damaged by thermal shock due to temperature changes when they were taken out of the cold mines or even while being handled with bare hands (Lavinsky & Chen 2012).

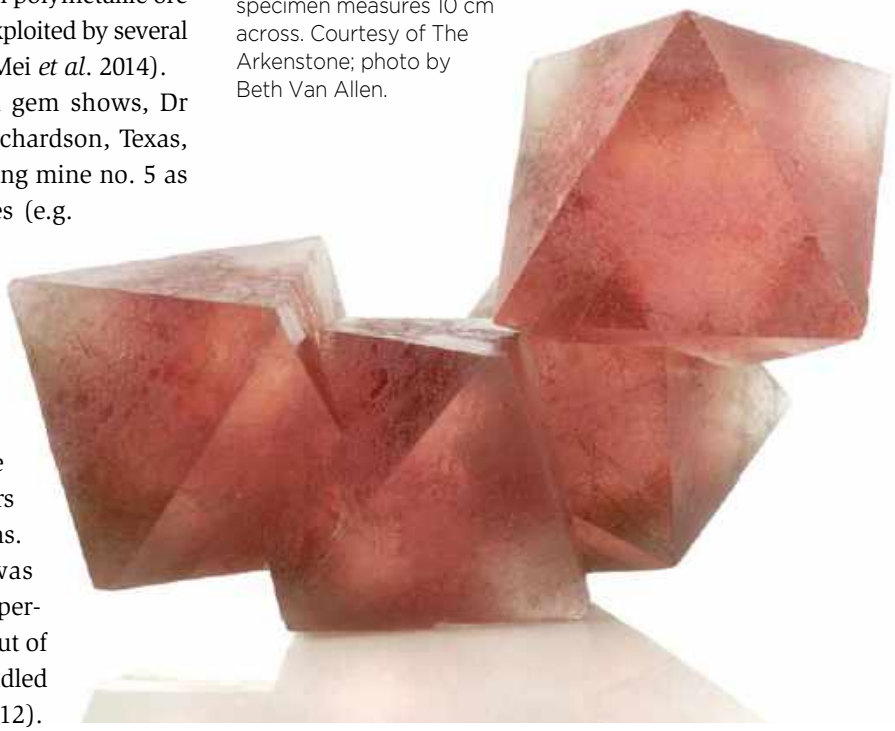

Figure 14: This fluorite crystal cluster was recently produced from Huanggang mine no. 5 in Inner Mongolia. The specimen measures 10 cm across. Courtesy of The Arkenstone; photo by Beth Van Allen.

Figure 15: (**a**) Weighing approximately 271 ct, this is probably the largest fine gemstone that was cut from the fluorite produced recently in Inner Mongolia (now in the Robert Lavinsky collection). (**b**) These fluorites are representative of more typical sizes cut from this find, and from left to right they weigh approximately 55, 24 and 46 ct; courtesy of The Arkenstone, and now in the collections of Gail and Jim Spann (Rockwall, Texas, USA) and The Smithsonian Institution (Washington DC, USA). Photos by Beth Van Allen.

The Huanggang fluorite that Lavinsky displayed in Tucson came from a large pocket that was mined—this time more carefully—from the edge of a skarn on 26–29 August 2019. Thousands of loose single octahedral crystals were associated with aggregates of pale grey-green byssolite and byssolite-included quartz. Also recovered were some crystal clusters (again, see Figure 14) and a few dozen large fluorite crystals (up to 16 cm). About 100 good-quality matrix specimens were produced, and approximately 5 kg of gem rough were obtained (mostly from broken crystals).

A total of about 100–150 gemstones have been faceted in China from this fluorite. Good-quality stones can range up to about 270 ct, but most are in the 25–50 ct range (e.g. Figure 15). The larger cut stones typically appear orangey pink while the smaller ones show less of an orangey tinge. Nearly all of them contain long straight or curved needles of byssolite. The fluorite is inert to long- and short-wave UV radiation.

In addition to the fluorite described here, gem-quality colourless scheelite (Williams *et al.* 2014) and quartz containing interesting patterns of dark inclusions (Laurs 2016) have also been produced from the Huanggang mines. As mining continues, it seems likely that additional interesting gem and mineral discoveries will take place there in the future.

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Natrolite from Java, Indonesia

Natrolite is a zeolite mineral that commonly forms radiating fibrous aggregates. It rarely occurs in facetable crystals, but creative gem cutters have polished the compact masses into cabochons to show their interesting radial textures (e.g. Laurs & Renfro 2017).

During the February 2020 Tucson gem shows, Joel Ivey (www.IndoAgate.com, Bangkok, Thailand) informed this author about natrolite cabochons from a new source in Indonesia—Nusa Kambangan Island, Cilacap Regency, Central Java. The natrolite-bearing area is located near

Figure 16: These cabochons of natrolite from Java, Indonesia, display radiating patterns. Photo by Yusef Sulaeman (Mineral and Art, Sukabumi, West Java, Indonesia).

a high-security prison, and Ivey's supplier indicated that the material is gathered by local villagers as well as prisoners. The mining is done with hand tools to a maximum depth of 3–5 m.

More than 2 tonnes of rough material have been sold to various cutting operations, and an additional 150 kg of rough has been stockpiled, in pieces up to approximately 80 mm. Several Indonesian workshops are cutting free-form cabochons (typically 15–40 mm) from this new material for sale through social media websites.

The identity of the Indonesian material as natrolite was confirmed by a report issued by a German gemmological laboratory. The cabochons are mottled white to pale pink or orangey pink, and take a good polish (Figure 16). Their colouration is different from the polished natrolite aggregates from Portugal that were documented by Laurs and Renfro (2017), which were mostly white with some yellow and black patterned staining.

Brendan M. Laurs FGA

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A Second Opal from Indonesia with an Insect Inclusion

In January 2019, media reports circulated about the discovery of a fossilised insect that was contained in opal rather than amber (e.g. Solly 2019). The specimen was subsequently described in the gemmological literature (Smith & Renfro 2019) and eventually studied in detail by Chauviré *et al.* (2020). The 5 mm insect was enclosed in mottled brown opal, showing local areas of play-of-colour, which came from the well-known opal deposits in West Java, Indonesia. Chauviré *et al.* (2020) identified the fossil as a probable exuvia (cast-off outer skin) of a cicada nymph, and indicated that it provides the first record of an animal fossil preserved in opal formed by weathering (although other instances have been documented in opal from hydrothermal settings).

During the February 2020 Tucson gem shows, Dr Robert Lavinsky showed this author another opal specimen that contained an entombed insect (Figure 17). The specimen was originally purchased on the resale jewellery market in Indonesia in December 2019 and reportedly came from the same mining area as the other insect-bearing opal specimen mentioned above. The piece measured 40.9 × 14.1 × 11.3 mm and weighed 23.05 ct, and consisted of white translucent to colourless transparent opal displaying small areas of play-of-colour. Dr Lavinsky was told by entomological experts that the insect was a bee. The lack of visible wings suggests to the present author that it could be the pupa of a solitary bee species (cf. www.livescience.com/44724-leafcutter-bee-fossils-la-brea.html).

A brief description of the specimen can be found on an auction website (https://fineart.ha.com/itm/nature-and-science/fossilized-bee-in-jelly-opal-pliocene-miocene-genteng-formation-java-indonesiaandlt-/p/5434-12001.s?ic4), which postulates that the bee could have been entrapped in amber that was then converted to opal over time. However, this scenario seems unlikely according to the very recent age of opal formation in the Javanese deposits (i.e. Late Pliocene through Holocene; Ansori 2010). Rather, the model proposed by Chauviré *et al.* (2020) appears equally applicable to the present specimen, in which the ground-dwelling insect was surrounded by silica-rich fluids, which subsequently turned into a gel and finally into opal.

Indonesia's play-of-colour opal deposits are situated in the Lebak Regency of Banten Province in West Java, where they are hosted by the Genteng Formation, which

Figure 17: This opal specimen (40.9 × 14.1 × 11.3 mm) contains what appears to be a fossilised bee. Courtesy of The Arkenstone; photo by Arjuna Irsutti.

consists of a layered volcanic series of pumice tuff, tuffaceous sandstone and claystone that has been weathered into a paleosol (Einfalt 2007; Tay *et al*. 2009; Ansori 2010). Opal formed from fluids circulating through porous volcanoclastic rocks (particularly pumiceous volcanic glass) during the weathering process. Opal mineralisation took place where the circulating silica-rich fluids were trapped by less permeable clay-rich layers, particularly in cavities that may have originated from the degradation of plant remains (Ansori 2010). According to geologist Joel Ivey (www.IndoAgate.com, Bangkok, Thailand), the opal mining area in Banten Province is also known to produce opalised snail shells, limb casts and logs. In some other West Java locations, the fossilised wood is associated with copper-bearing blue opal (Laurs 2018) and also pink opal.

Brendan M. Laurs FGA

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Bicoloured Phenakite from Russia

Phenakite is a beryllium silicate (Be_2SiO_4) with a Mohs hardness of 7½–8 that is not commonly encountered as a gemstone. An important source of gem-quality material is the well-known emerald mining area at Malyshevo in the central Ural Mountains of Russia, where phenakite crystals up to 13 cm in dimension occur in schist associated with beryl and chrysoberyl/alexandrite (Cook 2009).

Phenakite from Malyshevo is generally colourless or yellow-brown. In March 2020, gem dealer Dudley Blauwet (Dudley Blauwet Gems, Louisville, Colorado, USA) received a large parcel of mostly colourless Malyshevo phenakite that his supplier had cut from rough material which was recovered by local people searching the old mine tailings for alexandrite. Surprisingly, one of the stones (weighing 14.77 ct) was distinctly bicoloured in

Figure 18: This phenakite from Malyshevo, Russia, is distinctly bicoloured. The stone weighs 14.77 ct and measures 17.1 × 12.5 mm. Photo by Aria Agarwal/Dudley Blauwet Gems.

colourless and yellow-brown (Figure 18). In Blauwet's experience, only about 5% of the Russian phenakite shows the yellow-brown colouration, and this is the first time he had encountered a distinctly bicoloured stone after dealing in about 1,000 carats of faceted stones.

The bleaching of phenakite's colour upon exposure to UV radiation or high temperature indicates that it is associated with electron-hole centres, and Nikolaev *et al.* (2018) attributed the yellow-brown colouration to the paramagnetic complex $[PO_4]^{4-}$. This centre induces yellow-brown colouration in phenakite due to its strong absorption in the UV region of the spectrum, which gradually decreases through the visible range. In the phenakite described here, the $[PO_4]^{4-}$ radical was evidently present in sufficient amounts to cause yellow-brown colour in only half of the stone.

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Rhodonite from Southern Iran

Rhodonite is a calcium-manganese silicate ($CaMn_3Mn[Si_5O_{15}]$) that is found in metamorphosed manganese ore deposits and some hydrothermal ore veins (Bauer 1990). In most of Iran's Mn mines (e.g. south of Mashhad and in northern Kurdistan), rhodonite can be found in small quantities associated with other Mn-bearing minerals. However, until now there has been no report of gem-quality rhodonite occurring in significant quantities. In the summer of 2016, a vein of rhodonite was found associated with the Mn ore occurrence in the Fannuj (or Fanoj) ophiolite complex in southern Iran, and here we describe the occurrence and properties of this material.

An ophiolite is a remnant of oceanic lithosphere that has been tectonically emplaced onto continental margins during plate tectonic movements. The Fannuj ophiolite complex contains various ultramafic and mafic rocks, sometimes with thin radiolarite units (Sepidbar *et al.* 2020). The Mn ore typically occurs in the sedimentary sequence adjacent to the radiolarite units in the upper levels of the ophiolite, and is accompanied by rhodonite veins. These veins are often thin (less than 20 cm wide) and may attain lengths up to 10 m. Most of the rhodonite has been eroded and is collected from nearby secondary deposits. Pieces of rhodonite weighing up to 50 kg have been found.

The gem potential of most of the rhodonite appears rather low, and slicing it is helpful for evaluating its colour quality and ability to take a good polish (Figure 19). So far 200 kg of the rhodonite have been processed

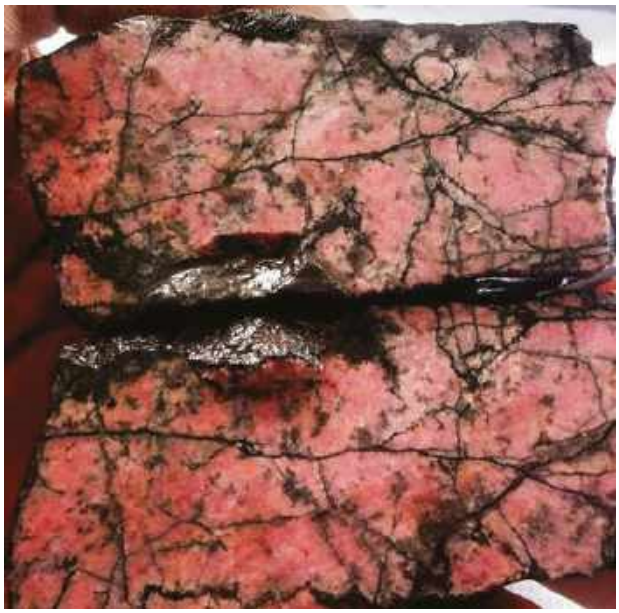

Figure 19: This rhodonite from southern Iran has been sliced into two pieces (5 × 12 cm each) to reveal the quality of the material. Photo by B. Rahinzadeh.

Figure 20: Iranian rhodonite has been fashioned into cabochons of various shapes (here, 1.2–3.0 cm wide). Photo by Behnam Zaheri.

Figure 21: This pendant features a 25 ct pear-shaped Iranian rhodonite cabochon that is surrounded by enamel designs. Photo by Farid Forqani.

into several hundred carvings and polished stones (e.g. Figure 20). Some of the rhodonite is being incorporated into various Iranian crafts, together with precious metals, tapestry or enamel (e.g. Figure 21).

The gemmological properties of six polished samples of the rhodonite were obtained at the Gemmological Centre of Shahid Beheshti University. The stones ranged from 1.2 × 1.5 cm to 2.5 × 3.2 cm, and were mostly pink with some yellow-pink and yellow areas, as well as conspicuous black veining. Their RI values ranged

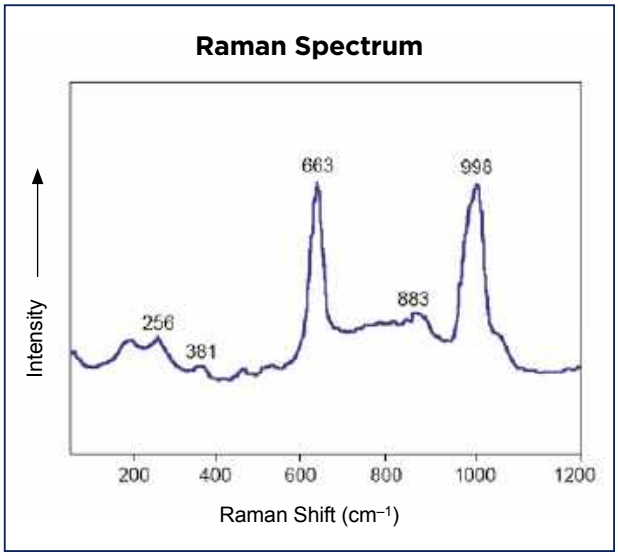

Figure 22: The Raman spectrum of a typical rhodonite sample from southern Iran reveals features that resemble those of rhodonite from other localities.

from 1.733 to 1.734, which are comparable to those of rhodonite from Val Malenco, Italy (RI = 1.73; Diella *et al.* 2014). The hydrostatic SG ranged from 3.4 to 3.7. Raman spectroscopy showed peaks at 256, 381, 663, 883 and 998 cm^{-1} (Figure 22), which resemble those seen in rhodonite reference spectra and in material from Val Malenco (Diella *et al.* 2014).

The carving and polishing done so far on the rhodonite from southern Iran shows that it has good potential for use as gemstones and *objets d'art*.

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Origin of Asterism in a Rare Four-Rayed Star Spessartine

Figure 23: This 37.78 ct spessartine cabochon displays a four-rayed star. Photo by M. P. Steinbach.

While attending the February 2008 Tucson gem shows, one of the authors (MPS) used a penlight to search through several thousand carats of spessartine cabochons from a new find at Loliondo, Tanzania, and was fortunate to discover one stone that showed a four-rayed star (Figure 23). The garnet was later documented in the author's book (Steinbach 2016, p. 537), and here we investigate the origin of its unusual asterism.

The oval cabochon weighed 37.78 ct and measured approximately 22 × 16 × 11 mm. Its body colour was orange, as is typical of spessartine. It displayed a weak four-rayed star showing acute and obtuse angles similar to those encountered in four-rayed star garnets of the pyrope-almandine series (e.g. Guinel & Norton 2006). The angles between the two branches of the star were approximately 70° and 110°, corresponding to two-fold axes. Walcott (1937, p. 41, figure 20) demonstrated that such a garnet should display multiple symmetrically equivalent four-rayed stars. Indeed, four additional very weak stars could barely be observed along the rim of the cabochon, and one of them was distinct enough to show, as expected, a four-rayed star with the same angular characteristics. The weakness of all these stars corresponded to the low density of linear features present in the stone.

The gem was translucent rather than transparent, due to the presence of intersecting partially healed fractures and 'fingerprints', as depicted in Figure 24a. The fingerprints consisted of two-phase (liquid-gas) inclusions that displayed various shapes (Figure 24b); such secondary fluid inclusions are commonly encountered in spessartine (cf. Knox & Laurs 2001, p. 288; Gübelin & Koivula 2005, pp. 448–451). In the present stone, some of these fluid inclusions were elongated and parallel to one another (Figure 24b, top centre)—apparently being oriented according to the host crystal—and they contributed somewhat to the asterism.

Photomicrography of other inclusions was challenging, but we observed lamellar features in parallelogram shapes. Numerous bundles of such cavities were present throughout the gem (Figure 25a). They were quite reminiscent of the hopper growth exhibited by spessartine crystals (e.g. Gübelin & Koivula 2005, p. 448). Those with a high length:width ratio (i.e. similar to acicular inclusions; Figure 25b) clearly contributed to the asterism. Raman spectroscopy and optical microscopy revealed that these lamellar-like inclusions

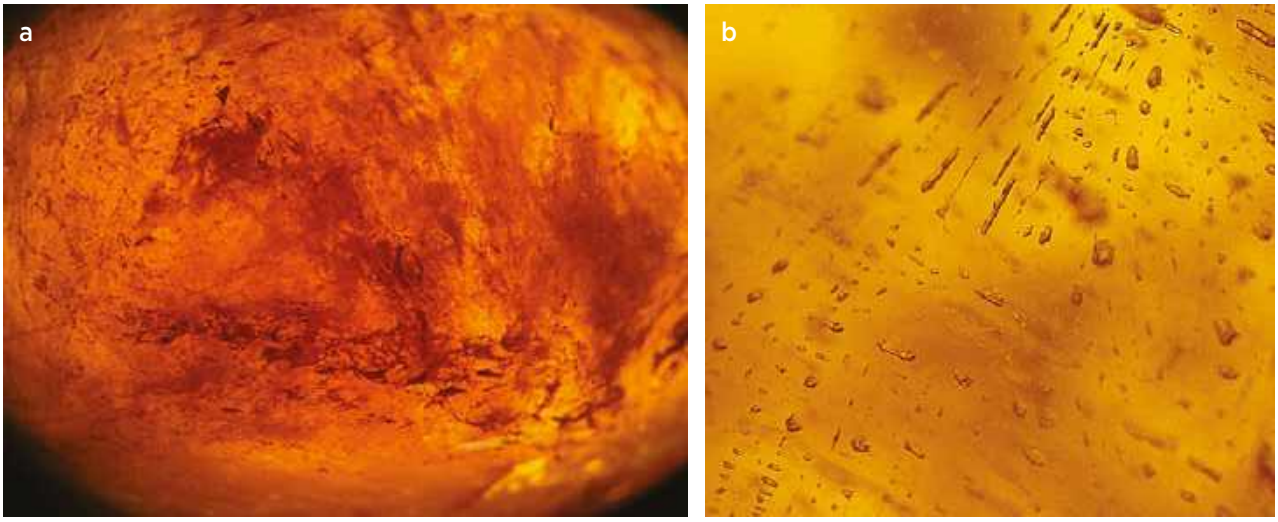

Figure 24: (**a**) Numerous partially healed fractures and 'fingerprints' cause the star spessartine to appear translucent. (**b**) The fingerprints consist of two-phase (liquid-gas) inclusions of various shapes. Photomicrographs by J.-P. Gauthier in transmitted light; field of view (a) 16 × 12 mm and (b) 0.9 × 1.0 mm.

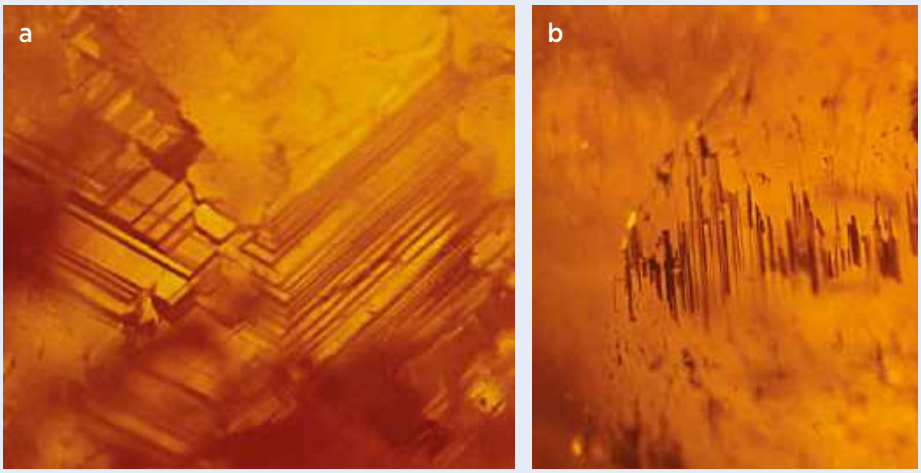

Figure 25: (**a**) Parallelogram-shaped structures and (**b**) oriented acicular features are present throughout the spessartine and are responsible for its asterism. Photomicrographs by J.-P. Gauthier in transmitted light; field of view (a) 1.0 × 1.2 mm and (b) 1.0 × 0.9 mm.

were thin fluid films. Similar flat fluid inclusions—less geometrical but characterised by 70° and 110° complementary angles—have been reported previously in spessartine from the USA (Knox & Laurs 2001, p. 288). Their submicron thickness is indicated by the presence of interference colours, as seen in the centre of Figure 26. It is likely that the asterism that was barely visible along other crystallographic directions at the rim of the cabochon was produced by light reflecting from different sides of the parallel arrays of these parallelograms. The transparency of these films is in agreement with the orangey appearance of the star, which owes its colour to the garnet matrix rather than to solid acicular inclusions. It also accounts for the weakness of the star, in contrast to the strong, sharp stars in garnets of the pyrope-almandine series that are caused by solid inclusions.

The present cabochon is possibly the only *four*-rayed star spessartine reported so far. Author MPS first encountered star spessartine shortly after the millennium, but that stone (which was from Sri Lanka) displayed a six-rayed star (Steinbach 2016, pp. 538–539).

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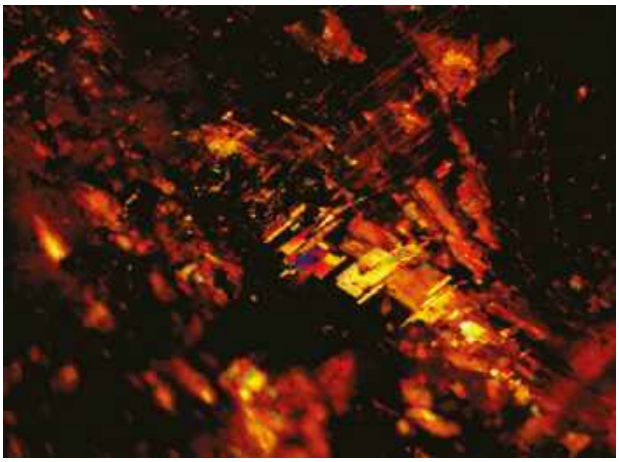

Figure 26: Parallelogram-shaped thin-film fluid inclusions in the spessartine show interference colours due to their submicron thickness. Photomicrograph by A. Delaunay in darkfield illumination; field of view 1.80 × 1.35 mm.

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A Rare Bicoloured Spinel

Recently, the GIT Gem Testing Laboratory (GIT-GTL) received for identification a bicoloured purple and greenish blue stone that weighed 0.57 ct and measured 7.02 × 3.32 × 2.27 mm (Figure 27). The stone was singly refractive with an RI of 1.718 and a hydrostatic SG value of 3.60. Observation with a gemmological microscope revealed oriented arrays of slender, short to elongate iridescent silk inclusions and minute particles in the purple colour zone (Figure 28), but no inclusions in the greenish blue portion. It was inert to both long- and short-wave UV radiation. The stone's RI and SG values, as well as its inclusion features, are typical for natural spinel.

UV-Vis-NIR spectroscopy, recorded with a Perkin-Elmer Lambda 950 spectrophotometer in the range of 300–1500 nm, showed absorption features at 371, 386, 458 and 555 nm for the purple zone, while the greenish blue portion displayed the same characteristics along with additional broad bands at 656 and 917 nm (Figure 29). These features were assigned by D'Ippolito *et al.* (2015) to Fe^{2+}, Fe^{3+} and Fe^{2+}-Fe^{3+} intervalence charge transfer (IVCT). In the spectrum of the purple zone, the absorptions at 371, 386 and 555 nm (all due to Fe^{2+}) create a transmission window in the blue-violet region which, combined with decreasing absorption in the red region, give rise to the purple colouration. The spectrum of the other colour zone, by contrast, shows stronger Fe^{2+} absorption at 371 and 386 nm, and the presence of a broad band at around 656 nm (due to Fe^{2+}-Fe^{3+} IVCT) combines to create a transmission window in the blue-green region, thus giving rise to the greenish blue colouration. We therefore infer that the greenish blue zone contains somewhat more Fe^{2+} and Fe^{3+} than the purple area, in agreement with a relatively higher total iron content in that portion of the sample (see below).

Figure 27: This 0.57 ct bicoloured purple and greenish blue stone was identified as spinel. Photo by A. Buathong.

PL spectroscopy of both the purple and greenish blue zones of the spinel, measured by a Renishaw inVia Raman microspectrometer using 532 nm laser excitation at room temperature, showed a series of emission centres at 671, 673, 675, 685, 686, 695, 697, 699, 704, 706, 708, 718 and 722 nm (Figure 30). This emission series perfectly matched the reference PL spectrum for spinel in the RRUFF database, and is known to be due to Cr^{3+} substituting for Al^{3+} in the octahedral site (e.g. Gaft *et al.* 2005; Skvortsova *et al.* 2011). Furthermore, the rather sharp peaks associated with the Cr-related emission centres in the PL spectra also indicate this stone has not been subjected to heat treatment (Saeseaw *et al.* 2009; Smith 2012).

Semi-quantitative chemical analysis of the stone's purple and greenish blue zones by EDXRF spectroscopy (using an Eagle III instrument) revealed the expected major amounts of Mg and Al, along with minor Fe, Si and Zn, and traces of V, Cr and Ga (Table I). Overall, the chemical data, when normalised to 100 wt.%, are

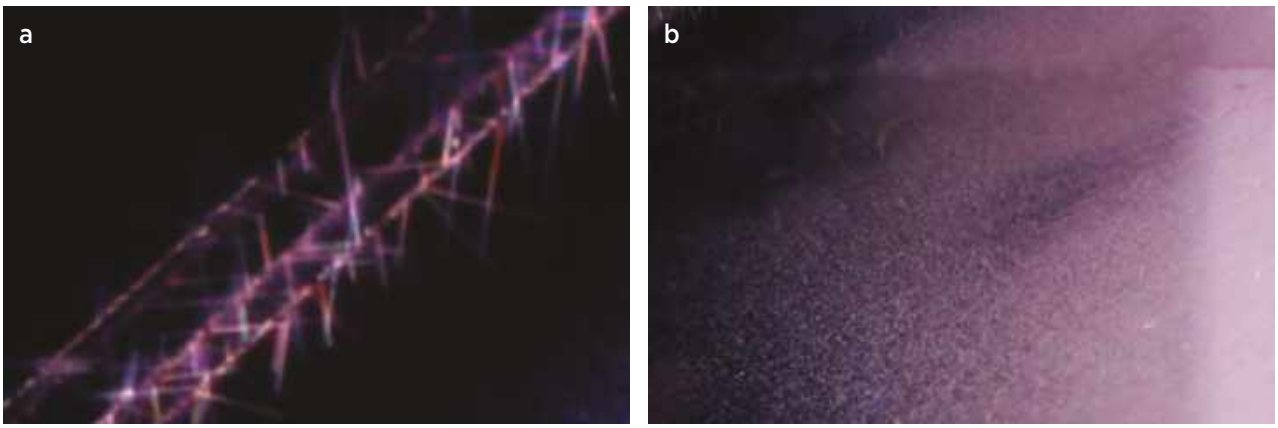

Figure 28: (**a**) Networks of iridescent silk and (**b**) minute particles were observed in the purple zone of the bicoloured spinel. Photomicrographs by A. Buathong; image widths 1.3 mm.

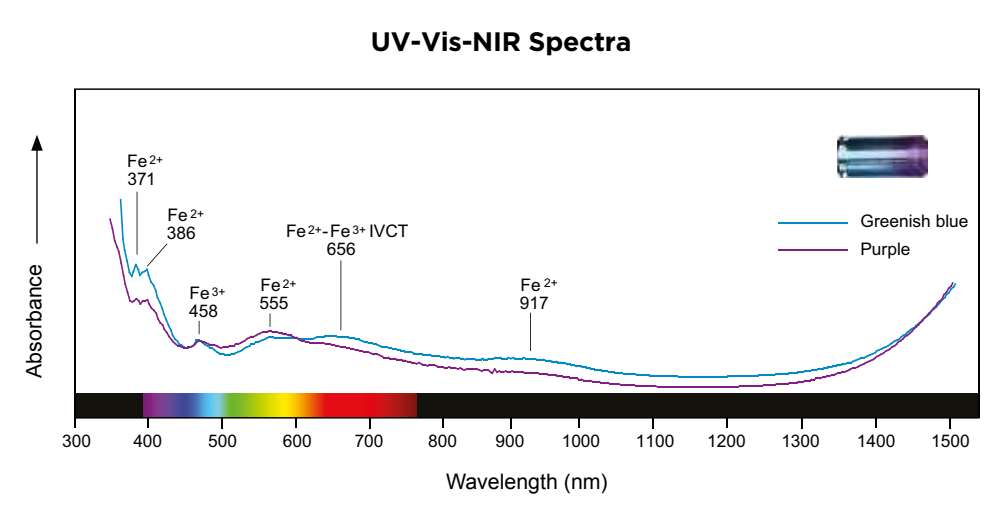

Figure 29: UV-Vis-NIR spectra of the purple and greenish blue zones of the spinel show absorption features related to Fe^{2+} and Fe^{3+}. The path length of the beam was about 2.3 mm.

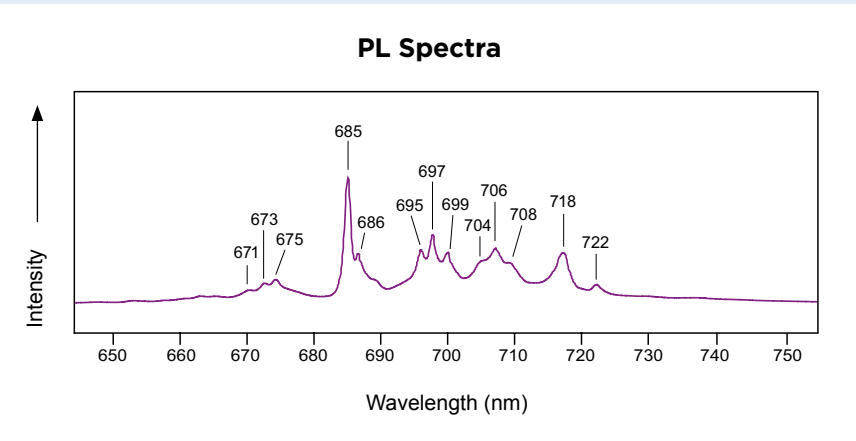

Figure 30: Time-resolved PL spectra of both colour zones of the spinel show a series of sharp Cr^{3+}-related emission centres, as illustrated by this spectrum of the purple zone.

Table I: Minor- and trace-element composition of the bicoloured spinel by EDXRF spectroscopy.

Oxides (wt.%)	Purple zone	Greenish blue zone
SiO_2	1.64	1.33
V_2O_5	0.05	0.06
Cr_2O_3	0.03	0.03
Fe_2O_3 (total)	2.56	2.77
ZnO	1.01	0.69
Ga_2O_3	0.04	0.06

consistent with the spinel composition ($MgAl_2O_4$)—wherein minor Zn^{2+} and, probably, Fe^{2+} substitute for Mg^{2+} in the tetrahedral sites and traces of Fe^{3+}, Si^{4+}, Cr^{3+}, V^{3+} and Ga^{3+} replace Al^{3+} in the octahedral sites.

The chemical composition of this stone, with significant Zn content (Muhlmeister *et al.* 1993) and the series of sharp Cr-related emission features in the PL spectra, indicates that it is a natural, unheated spinel. Even though spinel has commonly been found in a rather wide colour range—including colourless, red, blue, violet, green, brown, pink and black—bicoloured specimens such as this stone are very scarce (cf. DuToit 2012).

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Purple Tourmaline from Zambia

Tourmaline is not commonly encountered in the violet-to-purple colour range, so these authors were interested to see some new purple material that reportedly came from Zambia in 2019. A rough parcel of this tourmaline was obtained by Farooq Hashmi (Intimate Gems, Glen Cove, New York, USA) during the February 2020 Tucson gem shows. His supplier had about 100–150 g of rough material and Hashmi obtained several pieces that he kindly loaned for examination.

The crystals consisted of striated prisms with sharp edges and no evidence of alluvial transport (e.g. Figure 31). The ends of the prisms were formed by broken surfaces except for one that showed evidence of chemical resorption in the form of parallelogram-shaped etch pits. Most of the crystals had surface residues of rust-coloured material, as would be expected from lateritic soil. Their body colour was a fairly homogeneous medium-to-dark slightly greyish purple, and they showed strong dichroism in pale purple (lavender) and vivid purple. Internal features consisted of planar and irregular thin films, partially healed fractures marked by the presence of fluid inclusions ('trichites'), fissures, tubes and elongate colourless birefringent crystals; the last two features were oriented parallel to the *c*-axis.

Figure 31: This purple tourmaline (8.03 g) reportedly came from a new find in Zambia. Photo by B. M. Laurs.

Table II: SEM-EDS analyses of purple tourmaline from Zambia.*

Oxides (wt.%)	Average	Range
SiO_2	36.24	36.11–36.51
TiO_2	0.004	nd–0.02
B_2O_3 calc.	10.82	10.76–10.97
Al_2O_3	40.95	40.65–41.67
FeO	0.16	0.08–0.23
MnO	2.37	2.26–2.55
MgO	0.01	nd–0.02
CaO	0.46	0.39–0.56
ZnO	0.16	0.10–0.23
Li_2O calc.	1.67	1.64–1.70
Na_2O	1.80	1.64–1.89
K_2O	0.006	nd–0.01
H_2O calc.	3.47	3.35–3.69
F	0.65	0.50–0.81
Subtotal	98.68	97.97–99.90
–O=F	0.24	0.20–0.29
Total	98.44	97.94–99.67
Ions per 31 (O,OH,F)		
Si	5.813	5.764–5.828
Ti	0.001	nd–0.002
B	2.998	2.994–2.999
Al	7.743	7.714–7.78
Fe^{2+}	0.022	0.011–0.031
Mn	0.323	0.308–0.347
Mg	0.002	nd–0.005
Ca	0.079	0.067–0.095
Zn	0.019	0.013–0.028
Li	1.078	1.060–1.102
Na	0.559	0.531–0.590
K	0.001	nd–0.003
X-site vacancy	0.361	0.336–0.382
F	0.283	0.250–0.411
OH	3.713	3.642–3.964

* Five spots were analysed on the sample. All iron is reported as FeO, and Li_2O, B_2O_3 and H_2O were calculated by stoichiometry. Cr, Bi, V, Cu, Ba, Pb and Cl were analysed for but not detected (nd).

Figure 32: Faceting of a piece of the purple tourmaline yielded this 1.38 ct stone. Photo by Orasa Weldon.

Standard-based scanning electron microscopy-energy dispersive spectroscopy (SEM-EDS) chemical analysis of one of the crystals was performed by authors AUF and WBS using a JEOL JSM-6400 instrument with the Iridium Ultra software package by IXRF Systems Inc. The data showed the tourmaline was elbaite with a rather homogeneous composition (Table II). The main chromophoric element was Mn (average 2.37 wt.% MnO) and traces of Fe were also present (average 0.16 wt.% FeO). In addition, unusually high traces of Zn were measured (average 0.16 wt.% ZnO). This composition is similar to a violet elbaite from the DRC that was recently documented by Williams *et al.* (2018), except that the present tourmaline contained slightly less Mn, Ca and Mg.

Just before this issue was finalised, a piece of this tourmaline was faceted by Richard Vogl (Golden State Gem & Mineral, Huntington Beach, California, USA) into a 1.38 ct 'mini Portuguese' cut with 113 facets (Figure 32).

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Reference

Williams, C., Williams, B., Falster, A.U., Simmons, W.B. & Laurs, B.M. 2018. Gem Notes: Violet tourmaline from Democratic Republic of Congo. *Journal of Gemmology*, **36**(2), 106–107.

White to Beige Variscite from Kazakhstan

Variscite and metavariscite are hydrated aluminium phosphates ($AlPO_4 \bullet 2H_2O$) that form from the reaction of low-temperature phosphate-bearing surface waters with aluminium-rich rocks. The minerals typically occur as compact fine-grained aggregates; they appear white when pure, but usually show attractive yellowish to bluish green colouration (due to Cr^{3+}), and therefore may be confused with turquoise (Calas *et al.* 2005).

During the February 2020 Tucson gem shows, variscite showing unusual white to beige colouration was displayed by Rare Earth Mining Co. (Trumbull, Connecticut, USA). According to Rare Earth's Bill Heher, the material came from a new find in Kazakhstan and is being marketed as Ivory Creek variscite. He initially encountered it in August 2018, and first offered cabochons of this variscite at the September 2019 gem and mineral shows in Denver, Colorado, USA. From 180 kg of rough, Rare Earth has cut approximately 2,000 pieces (including 500 matched pairs) in various shapes that range from about 14 to 60 mm in maximum dimension. The material takes a good polish and displays black to yellowish brown veining in various patterns, similar to those seen in some 'spiderweb' turquoise. It reportedly has not been treated in any way.

Heher kindly loaned two samples for examination that showed the range of colouration available (Figure 33). Raman spectroscopy was performed by one of the authors (MR) using a Thermo Nicolet Almega micro-Raman system that employed a 532 nm solid-state laser and a thermoelectric-cooled CCD detector; the analyses confirmed that both samples were variscite.

Heher reported that the supply outlook for this material is good.

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Reference

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Figure 33: These cabochons show the range of colour of variscite from Kazakhstan. The pear shape measures 42.2 × 13.3 mm and the oval cut is 38.5 × 15.5 mm. Photo by B. M. Laurs.

SYNTHETICS AND SIMULANTS

Doublets Featuring Dioptase, Chrysocolla and Shattuckite from the Democratic Republic of Congo

Minerals from secondary copper ores commonly display bright colouration, sometimes in combination with interesting textures, and therefore may be polished into attractive cabochons. However, due to their softness and/or brittle nature, it may be necessary to stabilise such specimens with epoxy-type substances (e.g. Zwaan 2015) or attach them to a sturdy backing material as doublets.

During the February 2020 Tucson gem shows, Rare Earth Mining Co. displayed colourful doublets—showing blue, green, black and brown areas—that were prepared from a new find of secondary copper minerals in the DRC. Rare Earth's Bill Heher indicated that the material mainly consists of dioptase, chrysocolla and shattuckite, and that malachite and cuprite may be present in some pieces. A limited amount of rough material was recovered in 2018 and eventually found its way on to the market in 2019. Rare Earth cut a few dozen pieces ranging from about 20 to 70 mm in maximum dimension. The rock was first sliced into thin slabs, which were then affixed to a black resin backing material before being cut into various shapes.

Heher kindly loaned one sample for examination (Figure 34), and Raman spectroscopy was performed by one of the authors (MR) using a Thermo Nicolet Almega micro-Raman system that employed a 532 nm solid-state laser and a thermoelectric-cooled CCD detector. The analyses confirmed the presence of dioptase (green), chrysocolla (light to medium blue) and shattuckite (dark blue). Raman spectra could not be obtained from the brown and black areas, which apparently consisted of matrix material.

Figure 34: This colourful doublet (58.2 × 45.1 × 4.7 mm) consists of an assemblage of dioptase (green), chrysocolla (light to medium blue) and shattuckite (dark blue), which has been affixed to a durable backing material. Photo by Jeff Scovil.

The patterns and colours displayed by some of the doublets were reminiscent of landscapes. It is not clear how much of this material will be available in the future.

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and Melli Rose

Reference

Zwaan, J.C. 2015. Gem Notes: Stabilized shattuckite and bisbeeite from the Democratic Republic of Congo. *Journal of Gemmology*, **34**(8), 663–666.

Glass Imitation of a Garnet Pebble

Glass imitations of rough gem materials having the appearance of water-worn pebbles are well known in the trade (e.g. Laurs & Fritz 2015). Their abraded surface prevents close examination for diagnostic internal features such as gas bubbles and swirl marks that are indicative of glass. In addition, high-property manufactured glass can have RI and SG values that overlap those of the material being imitated (Hurwit 2003), making their detection even more difficult.

During the February 2020 Tucson gem shows, rough stone dealer Steve Ulatowski showed this author a 26.18 g purple 'pebble' that was offered as a garnet in Arusha, Tanzania, in December 2019 (Figure 35). Ulatowski knew it was an imitation because someone had polished a small window on its surface and examination with oblique illumination revealed a gas bubble in the otherwise clean interior, identifying it as manufactured glass. He took the gem to remove it from the market and once it was back in the USA he informed the dealer about its identity. Notably, Ulatowski obtained an RI of 1.76 and

Figure 35: Weighing 26.18 g, this gem 'pebble' was offered as a garnet in Arusha, Tanzania, and proved to consist of manufactured glass. Note the tiny gas bubble visible on the upper right side of the polished window. Photo by B. M. Laurs.

a hydrostatic SG value of 4.02, which are both consistent with a pyrope-almandine composition that would be expected for such a 'garnet' sample.

Ulatowski suspected that the piece may have been manufactured from a glass-ceramic material such as Nanosital, as described by Bergman (2017) for what appeared to be a water-worn pebble of colour-change garnet that was sold in Arusha in June 2017. That sample had an RI of 1.66, an SG of 3.48 and a Raman spectrum that was consistent with a glass-ceramic material. However, the present 'pebble' had higher properties than those typically encountered in glass-ceramics—which show an RI range of 1.61–1.72 and SG values of 2.91–3.98 (Vyshnevskyi *et al*. 2017)—and it therefore appears more likely that it was composed of a high-property manufactured glass.

This example serves as a reminder of the continued presence of convincing glass imitations of rough gem material on the international market.

Brendan M. Laurs FGA

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Vyshnevskyi, O., Khomenko, V., Kosorukov, O., Ripenko, V. & Kalinichenko, T. 2017. Glass-ceramics as imitation of gems. I. Gemological characteristic, composition, physical properties. *Mineralogical Journal*, **39**(3), 32–42, https://doi.org/10.15407/mineraljournal.39.03.032 (in Ukrainian with English abstract).

An Unusual Synthetic Fancy Sapphire Coloured by Co^{2+} and Co^{3+}

Recently, an intriguing synthetic sapphire was sent to the American Gemological Laboratories (AGL) in New York for testing. The 3.73 ct round mixed cut possessed an appealing greenish blue colour, which at first glance resembled copper-bearing tourmaline, apatite or zircon (Figure 36). Indeed, the client informed the author that it had been sold to him as a Paraíba-type tourmaline. However, the standard gemmological properties readily identified the sample as corundum, with RIs of 1.761–1.770, a birefringence of 0.009 and a hydrostatic SG of 3.99. In addition, the specimen had a pink/red reaction to the Chelsea Colour Filter.

When observed with magnification, the sample appeared clean, with a weak doubling of the back facets. However, fibre-optic lighting revealed wispy formations of faint particles that produced a reddish sheen (Figure 37). Inhomogeneous colour zoning was created by a repeating pattern of broad bands of alternating more- and less-saturated zones of the same hue when viewed in

Figure 36: This 3.73 ct melt-grown synthetic sapphire has an unusual colour, which more closely resembles that of Paraíba-type tourmaline, apatite or zircon than a variety of natural corundum. Photo by Alex Mercado and Bilal Mahmood, AGL.

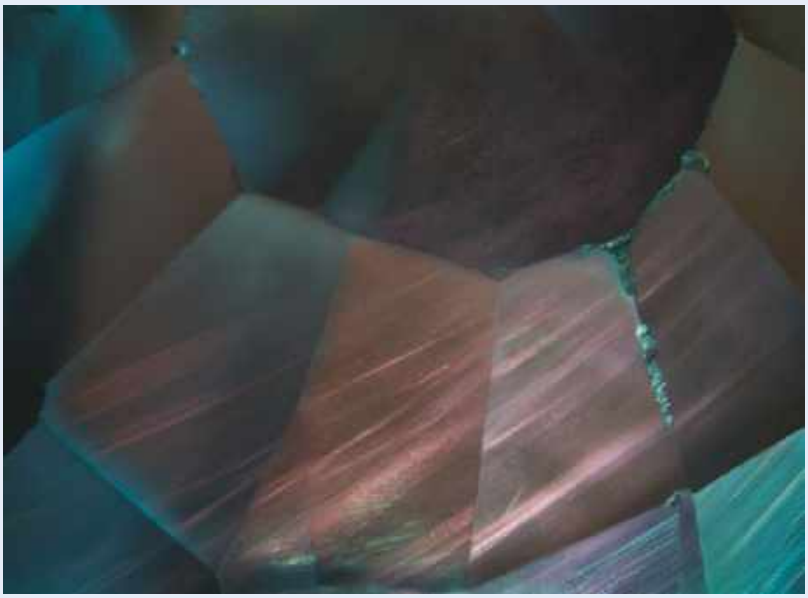

Figure 37: With fibre-optic lighting, faint wisp-like patterning of minute particles casts a reddish appearance in the synthetic sapphire. Photomicrograph by C. P. Smith; magnified 38×.

one direction; the more-saturated banding also followed a wispy distribution of faint particulates when viewed from another direction (cf. Zandi 2019).

Chemical analysis with EDXRF spectroscopy revealed traces of Fe (0.006 wt.%), Ti (0.002 wt.%) and Co (0.010 wt.%). Other trace elements commonly encountered in corundum—such as Cr, V and Ga—were not detected. Additionally, other elements that are sometimes encountered in blue-green synthetic corundum, such as Ni, were also not detected. Using PL spectroscopy, minute traces of Cr (i.e. below the detection limit of EDXRF spectroscopy) were revealed as an emission doublet at 693/694 nm.

All of these data readily confirmed the synthetic origin of this sapphire. However, its colour was unlike that of typical green Co-doped synthetic corundum that is occasionally encountered in the trade. As a result, a more in-depth spectral analysis was performed. UV-Vis spectroscopy recorded absorption bands at approximately 430/435, 470, 548, 590, 630 and 689 nm (see Table III and Figure 38a), as well as a broad band centred in the near-infrared at approximately 1380 nm (not shown). All of these features are related to divalent and trivalent cobalt (Co^{2+} and Co^{3+}; see, e.g., Schmetzer & Peretti 2000 and references therein). No absorptions were found that are related to other chromophores which may be present in synthetic corundum of various colours, such as Cr^{3+}, Fe^{3+}, V^{3+}, Ti^{4+}, Ni^{2+}/Ni^{3+} and Mn^{2+}. In the mid-infrared region of the spectrum, no structurally bonded OH groups were recorded.

As mentioned above, Co^{2+} and Co^{3+} are known contributors to colour in synthetic corundum (Table III).

Table III: UV-Vis-NIR absorption features (in nm) related to cobalt in synthetic corundum.

Vibronic progression	o-ray	e-ray
Co^{3+} absorptions		
Sharp band	689 (zero phonon)	—
Weak, broad band	~680 (2nd order)	—
Weak, broad band	~670 (3rd order)	—
Apex broad band	~655	~640
Apex broad band	~435	~430
Shoulder	—	~470 (unknown allocation)
Intensity comparison for the two dominant absorption bands	655 ≥ 435	640 << 430
Ill-defined bands (Co^{3+} or other potential contributors)		
Weak, broad band	530 (unknown allocation)	—
Faint, broad band	~500 (unknown allocation)	—
Shoulder on rising absorption	—	~345 (unknown allocation)
Co^{2+} absorptions (both o-ray and e-ray)		
Primary broad band	~630	
Secondary broad band	~590	
Tertiary broad band	~548	
Primary broad band	~1380	

Although not commonly seen as faceted samples, vibrant green colouration has been produced in synthetic corundum grown by the Verneuil method by doping with pure Co^{3+}, as well as with a combination of Co^{3+} and V^{3+} (see, e.g., Sandmeier 1930; Kammerling & Fritsch 1995; Kammerling 1996; Mayerson 2004). Figure 38b shows the spectral features of Co^{3+} in such a melt-grown green synthetic sapphire from the author's reference collection for which only cobalt (0.021 wt.%) was detected by EDXRF spectroscopy.

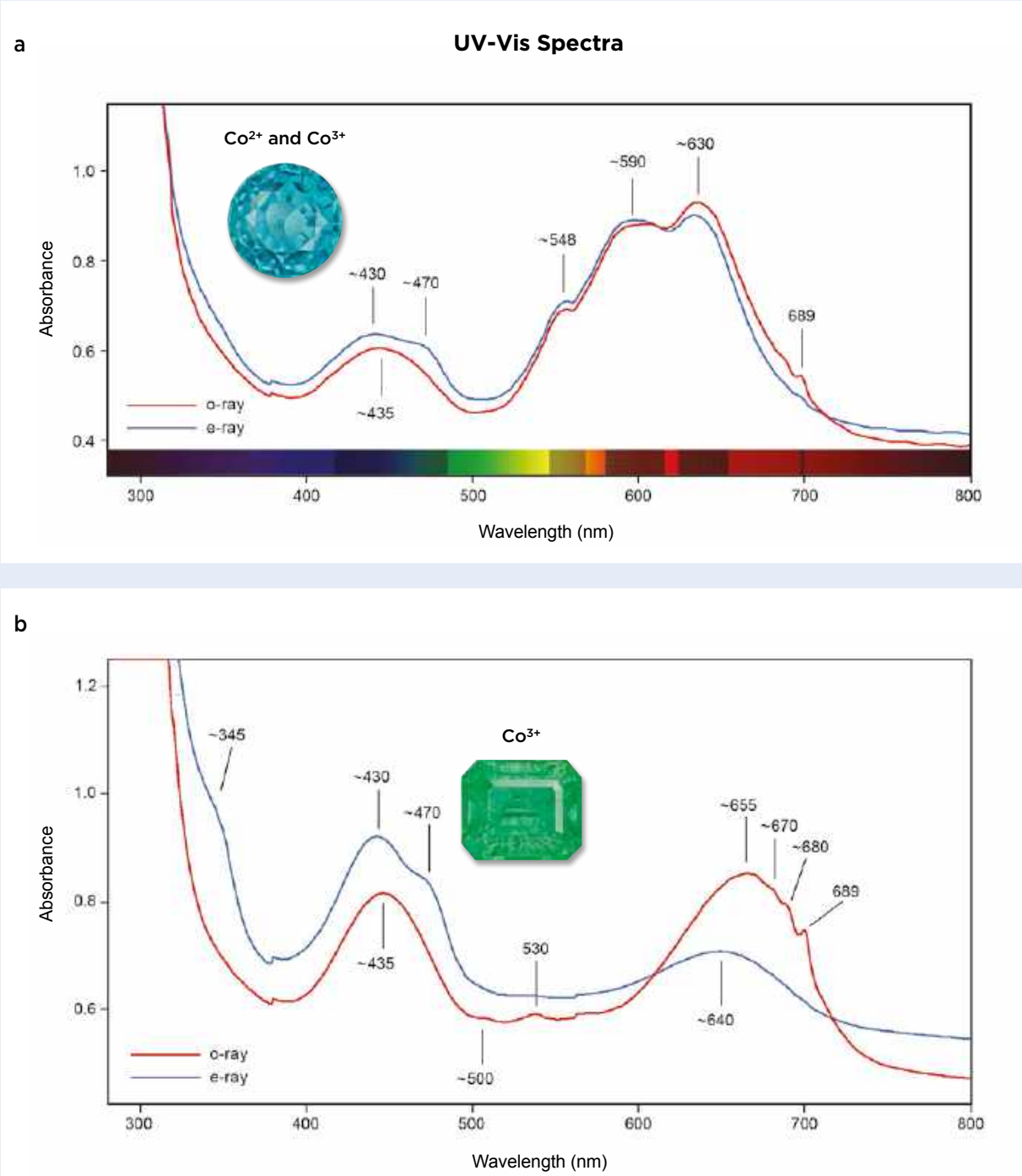

Figure 38: (**a**) Polarised UV-Vis spectroscopy of the 3.73 ct synthetic sapphire reveals a series of absorption bands associated with Co^{2+} and Co^{3+}. (**b**) Polarised spectra are shown for a vibrant green 8.38 ct synthetic sapphire predominantly coloured by Co^{3+} from the author's reference collection. The path length of the beam was approximately (a) 7.0 mm and (b) 7.7 mm. Inset photos by Alex Mercado and Bilal Mahmood, AGL.

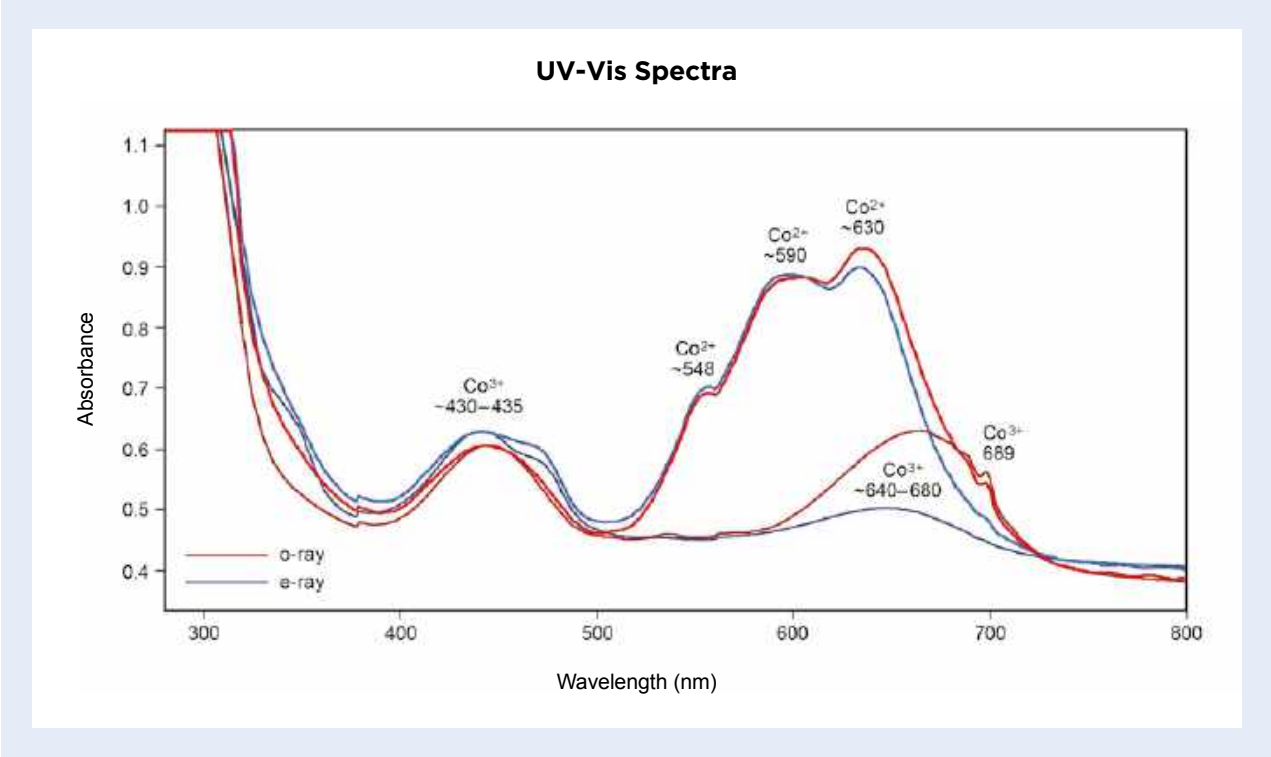

Figure 39: By overlaying the spectra in Figures 38a and 38b, the bands attributed to Co^{2+} and Co^{3+} can be more clearly distinguished. Additionally, the shoulder at approximately 470 nm is present in both samples and may or may not be due to Co^{3+}. Moreover, the position of this underlying band is not consistent with features associated with other well-known chromophores such as Cr^{3+}, V^{3+} or Fe^{3+}, or lesser-known chromophores such as Ti^{3+}, Ni^{3+} or Ni^{2+}.

By overlaying the spectra in Figures 38a and 38b, it is possible to differentiate between the bands that are related to Co^{2+} and Co^{3+} in the 3.73 ct synthetic sapphire (Figure 39). This also revealed some discrepancies with the band allocations for cobalt that have been reported in the literature (see, e.g., figure 6 in Schmetzer & Peretti 2000).

The intriguing and noteworthy aspect of this 3.73 ct synthetic sapphire is its unusual colour. This was the first time the author can recall seeing a synthetic sapphire of this particular colour—although it seems that a production has recently entered the marketplace (see also Zandi 2019)—and such examples demonstrate the addition of an intriguing new colour range to the existing synthetic corundum product line via a melt-growth process, such as flame-fusion (Verneuil) or pulling (Czochralski) techniques. Spectroscopy of this sample also clarified the allocation of spectral bands associated with Co^{2+} and Co^{3+}.

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MISCELLANEOUS

'Versatility of Genius' Cubic Zirconia

The author's 'World Heritage Collection of Gems' consists of a series of designs that honour different contributions by various countries to the world's cultural heritage. For instance, China is famous for its philosophy, Japan for its traditions, India for spiritual teachings and Spain for architecture. The pattern of facets conceived for each gem was inspired by renowned symbols or images from the respective countries. The collection currently consists of six designs—honouring China, Japan, Tibet, India, France and Italy—and the sixth one was displayed for the first time at the February 2020 Tucson gem shows. Called 'Versatility of Genius', it consists of a 387 ct cubic zirconia (CZ) that was completed at the end of January 2020. The conception and cutting of this gem—which honours Italy's contributions to cultural heritage—is described in this report.

Leonardo da Vinci (1452–1519) was an Italian artist and engineer who is best known for his paintings (e.g. the Mona Lisa and the Last Supper). Among Leonardo's architectural designs, the author was inspired by his sketches for a cathedral (Figure 40a). The mathematical harmony of his drawing, formed by the crossing of lines, continuing from one edge to another, served as the basis for the faceting design without needing significant changes (Figure 40b). It was clear, however, that faceting this pattern would be technically very difficult.

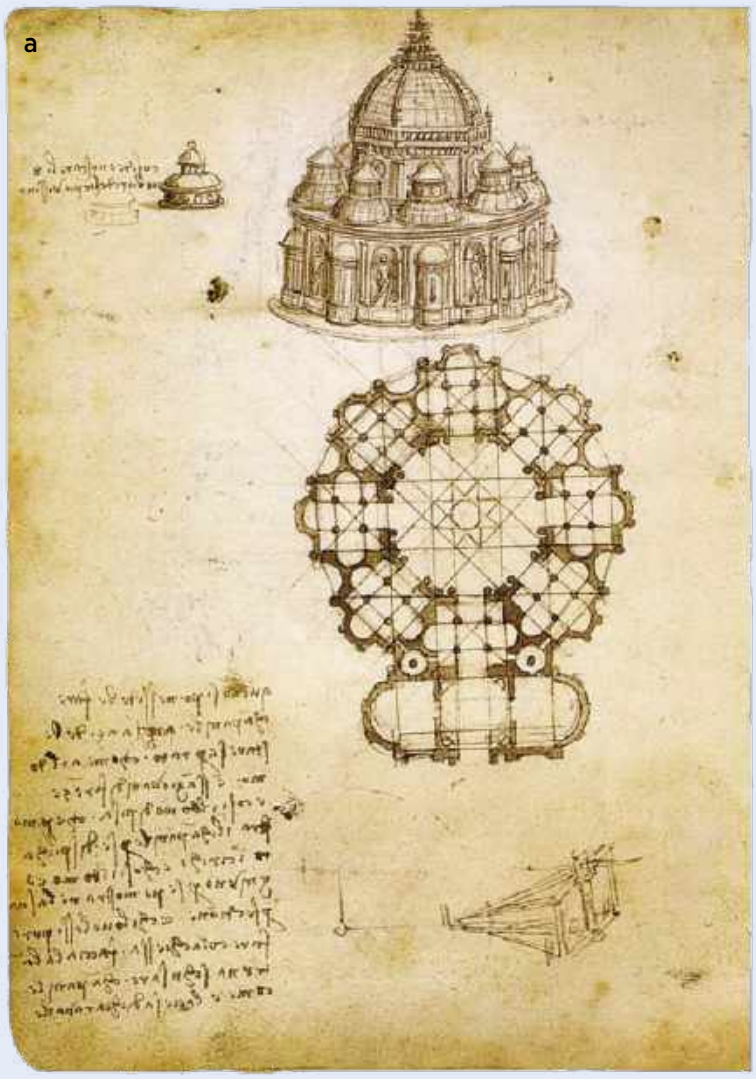

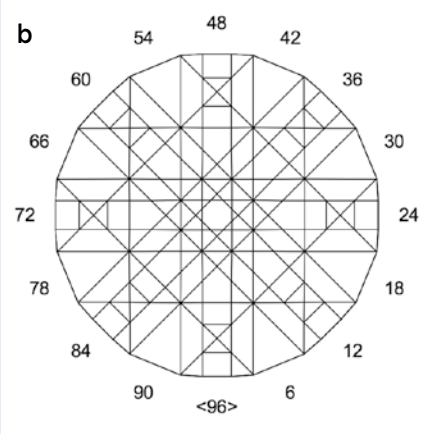

Figure 40: (**a**) This drawing by Leonardo da Vinci shows a bird's-eye view for a centrally arranged cathedral. Image courtesy of Wikimedia Commons; supplied by the Bibliothèque de l'Institut de France, Paris. (**b**) The faceting diagram for the crown of the Versatility of Genius CZ is based on Leonardo's sketch.

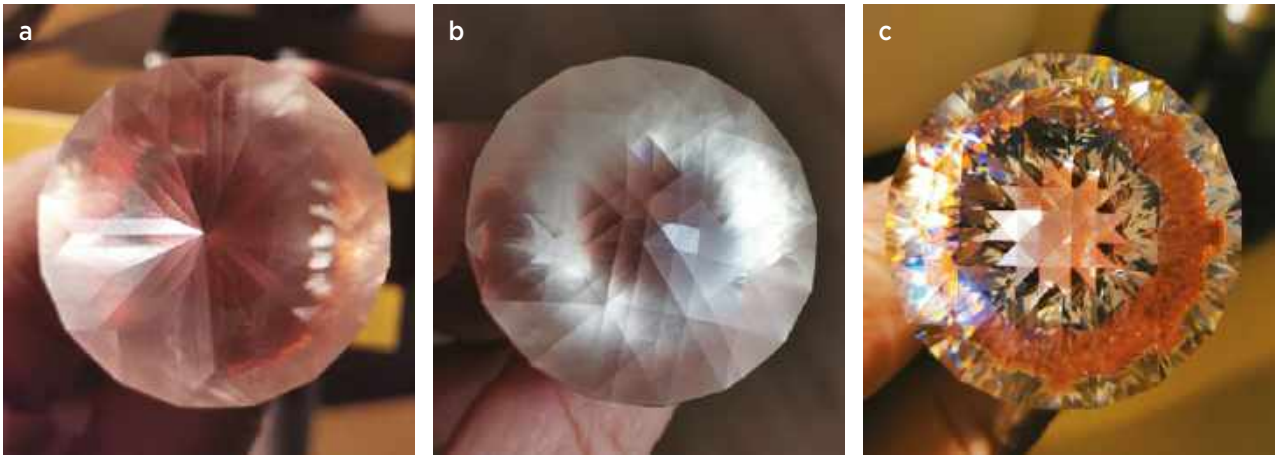

Figure 41: The steps in cutting the Versatility of Genius CZ include (**a**) forming the initial outline of the facets, as viewed here from the pavilion; (**b**) final cutting of the crown facets; and (**c**) pre-polishing. Photos by V. Tuzlukov.

After the design was drawn and the faceting diagram was constructed on a computer, the author studied the movement of a three-dimensional rendering and its incredible play of light. The synthetic material CZ was chosen for this work as being most suitable to fully express the beauty of this cut.

The primary condition for a successful outcome was precision. The faceting process consists of three stages: cutting the facets, pre-polishing and final polishing. Very often faceters approach the first stage casually, assuming they can correct things later, but this would not be possible in this case. Greater initial care is always needed on more complicated and very difficult designs such as this one.

It was first necessary to outline the pattern from which to create the facets so they would conjoin to form the desired optical effects. A preliminary outline of the main facet lines was done first, around which the next facets were grouped. The photos in Figure 41 reflect the steps in this process: initial outline (Figure 41a), final cutting (Figure 41b) and pre-polish (Figure 41c). A final polish then brought the facets to a mirror-like condition to facilitate the play of light, in which multi-coloured flashes were created by numerous inner reflections (Figure 42).

Figure 42: The Versatility of Genius CZ is the sixth contribution to the author's 'World Heritage Collection of Gems'. It weighs 387 ct and has 329 facets. Photo by Dmitry Stolyarevich.

After many long days of work, the finished gem was finally completed—with 329 facets and weighing 387 ct. Holding it in my hand I felt its pleasant heaviness, and my soul was filled with happiness that I had managed to embody in this work at least a shadow of the creation of the great master Leonardo da Vinci. I hope this 'Versatility of Genius' will serve as a source of inspiration to other masters, such as photographer Dmitry Stolyarevich, who captured the image in Figure 42, exactly portraying the meaning and character of this gem. Moreover, this exercise represents something new for gem faceting in my experience: using an ancient text to provide direction for one's imagination and then manifesting the gem that completes one's vision. I summarise the experience of its creation with the following: *When beauty of artistic images and precision of geometric drawings merge in the great Harmony, they reflect the multidimensional nature of Genius*.

Each design in the World Heritage Collection of Gems has been manifested in a natural stone and a synthetic one. After the CZ version of the Versatility of Genius was completed, the author also produced this cut in a 143.1 ct smoky quartz, which was completed in July 2020.

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Gemmological and Mineralogical Characteristics of Chrysocolla Chalcedony from Taiwan, Indonesia and the USA, and Their Separation

Min Ye and Andy H. Shen

ABSTRACT: Chrysocolla chalcedony is the most valuable form of chalcedony. To distinguish samples from three commercially important localities—Taiwan, Indonesia and the USA—we studied the gemmological, mineralogical and trace-element characteristics of this gem material. UV-Vis-NIR absorption spectra verified the colour-causing inclusions to be chrysocolla. Chemical analysis by EPMA showed that Si and Cu are the main components of chrysocolla chalcedony, and FTIR spectroscopy indicated that α-quartz was dominant in all samples. Examination of petrographic thin sections revealed that quartz was present as fine crystallites, relatively coarser crystals and radiating fibres (i.e. chalcedony), while backscattered-electron images showed that the chrysocolla usually formed irregular patches or fibrous rims and clusters. Raman spectral identification of associated minerals and LA-ICP-MS chemical analyses provided useful information for distinguishing chrysocolla chalcedony samples from the three origins, according to their: (1) diagnostic impurities, such as copper mineral mixtures, manganite and a vernadite-like mineral; and (2) trace elements, specifically U and Mo, together with Fisher-LDA data processing, for specimens without obvious impurity minerals. Both of these criteria should be considered for the most reliable separation of samples' geographic origin.

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Chrysocolla chalcedony[1], sometimes marketed as 'gem silica', is an attractive form of chalcedony that usually ranges from vivid blue to bluish green (e.g. Figure 1). The material is mainly coloured by the presence of chrysocolla inclusions (Shen *et al.* 2006). In recent years, the majority of fine-quality chrysocolla chalcedony on the Chinese market has come from Taiwan, Indonesia and the USA. Other sources include Peru, Mexico and Spain (Hyršl 2001; Emerson & Darley 2010; Koivula *et al.* 1992; Laurs 2015), from which material is gradually entering the Chinese market. Chrysocolla chalcedony from Taiwan usually has a more pleasing saturated blue colour, so its price is higher. Moreover, the authors are aware of material from other localities being represented as coming from Taiwan. As a result, there is a growing need to reliably identify the origin of chrysocolla chalcedony gems.

[1] The name *chrysocolla chalcedony* does not follow rigorous terminology according to the mineralogical nomenclature of silica minerals, in which granular fine-grained quartz is called *chert* and oriented fibrous quartz is termed *chalcedony* (Graetsch 1994). In this article we use *chrysocolla chalcedony* since this name is widely used and well known in the gemmological community.

Figure 1: A rough sample of chrysocolla chalcedony from Taiwan (8.47 g) is accompanied by four greenish blue cabochons that are (left to right) from the USA (1.82 ct), Taiwan (2.21 ct), Indonesia (1.07 ct) and the USA (3.16 ct). Samples courtesy of Songshan Lin; photo by Z. Zhang.

Until now, there have been few detailed studies of chrysocolla chalcedony. Earlier reports generally provided a brief description of the gemmological properties of material from specific origins (e.g. Koivula *et al.* 1992; Emerson & Darley 2010). Indonesian specimens were characterised in more detail by Einfalt and Sujatmiko (2006), who pointed out that varying proportions of chrysocolla and quartz may lead to a more uniform or mottled appearance. Detailed studies of Taiwan material were reported—in Chinese—by Lin (2008) and Chen *et al.* (2011).

This article describes the gemmological, mineralogical and trace-element characteristics of chrysocolla chalcedony from Taiwan, Indonesia and the USA. Specifically, we focus on the microstructure, chemical composition and impurity minerals. Finally, we compare relevant data and devise a set of criteria to help separate material from these three geographic origins.

LOCATION AND GEOLOGY

Chrysocolla forms as a secondary alteration product in the oxidation zone of copper sulphide mineralisation, with quartz as a common co-precipitate (Einfalt & Sujatmiko 2006). Therefore, chrysocolla chalcedony is mainly found co-existing with copper deposits.

Specimens from Taiwan mostly originate from the island's eastern coastal mountain range (Figure 2a), spanning from northern Hualien County to southern Taitung County. Currently, only the main Baofengxiang copper mine in Tungho township, located in Taitung County, is still active. Mineralisation took place during Miocene time, when late-stage hydrothermal fluids enriched in SiO_2 entered fractures associated with faults and penetrated gaps in andesitic breccia containing primary copper minerals, and then reacted to form chrysocolla chalcedony (Lin 2008). Due to lack of production, the availability of this gem material from Taiwan has rapidly diminished in recent years.

Indonesian chrysocolla chalcedony mostly comes from North Maluku Province. The deposits are located about 2,400 km east of Jakarta in the Bacan Archipelago, particularly on Kasiruta Island (Figure 2b). The mining sites are situated in pillow lavas of Oligocene age, occurring as chrysocolla-bearing quartz veins and small pods in the basaltic rock (Einfalt & Sujatmiko 2006).

Chrysocolla chalcedony from the USA is found in association with various copper deposits, including the Morenci, Inspiration and Ray mines in Arizona (Figure 2c; e.g. Laurs 2019). The Morenci mine is located in the Clifton-Morenci District, Greenlee County; the Inspiration

Figure 2: The locations of the chrysocolla chalcedony samples studied for this report are shown on these maps. (**a**) In Taiwan, the main deposit is located in the eastern coastal range. (**b**) In Indonesia, several localities are known in the Bacan Archipelago. (**c**) In the state of Arizona, USA, chrysocolla chalcedony is found at the Morenci, Inspiration and Ray mines.

mine is situated in the Globe-Miami District, Gila County; and the Ray mine is in the Ray District, Pinal County. At these localities, chrysocolla chalcedony is found in oxidised porphyry copper ore associated with intrusive igneous rocks ranging from granodiorite to quartz monzonite; the mineralisation took place about 75 to 50 million years ago during the Laramide orogeny (Creasey 1984; Enders 2000).

MATERIALS AND METHODS

For this study, we initially obtained 60 samples of chrysocolla chalcedony from Taiwan, Indonesia and the USA. The Taiwanese specimens were obtained from local private collectors. The Indonesian samples were donated by a major supplier of Indonesian gem material in Taiwan. The USA samples were purchased from a Taiwanese dealer who regularly visits the mining areas in the USA and South America, and we acquired samples immediately after he returned from trips to known USA localities.

After preliminary examination, we omitted approximately half of the samples because they were too pale (i.e. near-colourless) or too porous for gem use. We therefore focused on 29 samples (Figure 3), which included 10 from Taiwan (labelled TW), nine from Indonesia (labelled ID) and 10 from Arizona (labelled US-M for the Morenci mine and US-I/R for the Inspiration and Ray mines). All of them were doubly polished as 2–3 mm thick slabs for further testing.

The gemmological properties of all samples were documented using a refractometer, hydrostatic balance, standard gemmological long- and short-wave 4 W UV lamps, a Chelsea Colour Filter and a gemmological microscope at the Gemmological Institute, China University of Geosciences (Wuhan). Photomicrographs were taken with a Leica M205 A microscope. In addition, offcuts from all samples were prepared as petrographic thin sections and observed using an Olympus BX51 polarising microscope at the Resources Institute, China University of Geosciences (Wuhan).

Quantitative chemical analysis of all samples was conducted with a JEOL JXA-8100 electron probe micro-analyser (EPMA) at the State Key Laboratory of Geological Processes and Mineral Resources, China University of Geosciences (Wuhan). We used an accelerating voltage of 15 kV, beam current of 20 nA and beam diameter of 10 µm. One to three analyses were performed on each sample, consisting of more-transparent near-colourless areas, more-translucent blue portions and/or more-opaque whitish blue parts of the samples. We also obtained backscattered electron (BSE) images to help visualise the distribution of chrysocolla within the chalcedony.

Trace-element concentrations were determined for all samples by laser ablation inductively coupled plasma mass spectrometry (LA-ICP-MS) at the State Key Laboratory of Geological Processes and Mineral Resources, China University of Geosciences (Wuhan). The instrumentation consisted of an Agilent 7700 Series ICP-MS coupled with a GeoLasPro 193 nm excimer laser. The laser had a 3 Hz pulse rate and a 60 µm diameter spot size with a fluence of 6 J/cm^2. Reference materials included USGS glasses (BCR-2G, BHVO-2G and BIR-1G) and a NIST glass (SRM 610); ^{29}Si was used as the internal standard to calculate the concentrations of 55 trace elements with ICPMSDataCal software. One or two spots were analysed on each sample. Fisher linear discriminant analysis (Fisher-LDA) was performed using the SPSS (Statistical Product and Service Solutions) software package.

Ultraviolet-visible-near infrared (UV-Vis-NIR) absorption spectra in the range of 350–2500 nm were recorded for all samples with a JASCO MSV-5200 micro-spectrophotometer at the Gemmological Institute, China University of Geosciences (Wuhan). The sampling interval was 0.5 mm and the scan speed was 1,000 nm/min.

For infrared spectroscopy, a small area of each sample was ground into a fine powder and incorporated into KBr pellets (with a sample-to-KBr ratio of 1:200). For some samples showing variable diaphaneity, two areas were analysed: a more-translucent blue portion and a more-opaque whitish blue zone. The spectra were recorded in the 4000–400 cm^{-1} range with a Bruker Vertex 80 Fourier-transform infrared (FTIR) spectrometer at the Gemmological Institute, China University of Geosciences (Wuhan). The resolution was 8 cm^{-1} and 32 scans were collected for each sample. Spectra are presented in the range of 1600–400 cm^{-1}, where the most relevant features are seen.

Raman spectra of the chrysocolla chalcedony were obtained from smoothly polished blue areas of all samples using a Thermo Scientific DXR Raman microscope at the State Key Laboratory of Geological Processes and Mineral Resources, China University of Geosciences (Wuhan). The following parameters were used: 780 nm laser wavelength, 10 mW laser power, 25 µm aperture slit, 2.4–4.4 cm^{-1} resolution, 53–3300 cm^{-1} spectral range and 50 × objective lens. Spectra are presented in the 200–1200 cm^{-1} range, where the most diagnostic features occur. Selected impurity minerals in the chalcedony were identified using a Bruker Senterra R200-L Raman spectrometer at the Gemmological Institute, China

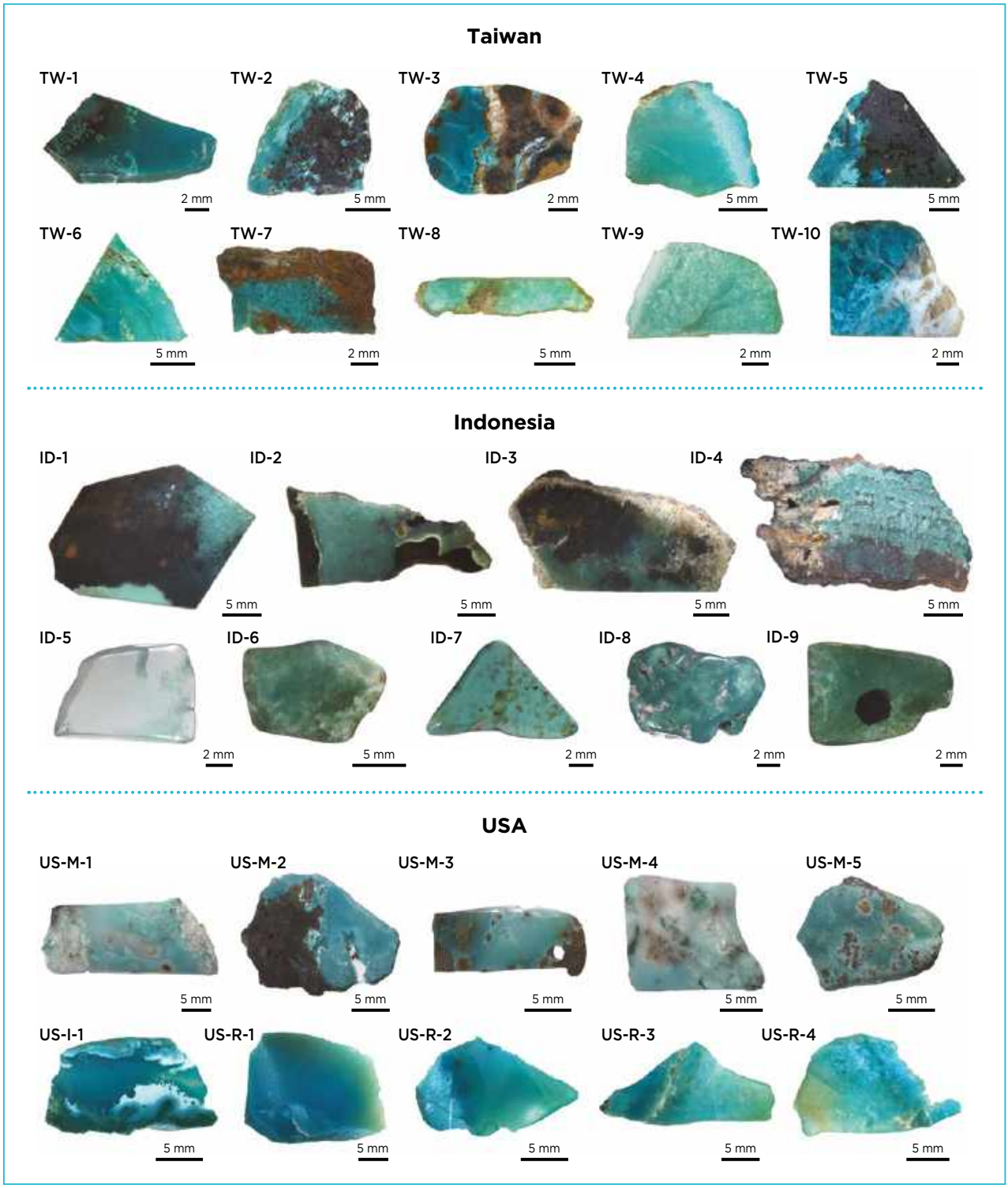

Figure 3: These 29 chrysocolla chalcedony specimens were characterised for this study. They are from Taiwan (TW), Indonesia (ID) and the USA (US-M = Morenci mine, US-I = Inspiration mine and US-R = Ray mine). Photos by M. Ye.

University of Geosciences (Wuhan), using the following parameters: 532 nm laser wavelength, 5 mW laser power, 50 × 1000 µm aperture slit, 3–5 cm^{-1} resolution, 45–3600 cm^{-1} spectral range and 50× objective lens.

Energy-dispersive X-ray fluorescence (EDXRF) chemical analysis of some dark impurity minerals was done using a Thermo Scientific ARL Quant'X spectrometer (equipped with an Rh tube and Peltier-cooled detector) at the Gemmological Institute, China University of Geosciences (Wuhan). We analysed for all elements that are available by this technique under various instrumental conditions.

RESULTS

Gemmological Characteristics

The gemmological properties of our samples are summarised in Table I. Material from the three localities had similar RIs, UV fluorescence and Chelsea filter reactions, but some differences were noted in their colour, diaphaneity, SG values and internal features.

Colour and Diaphaneity. The colour distribution in the chrysocolla chalcedony was generally not uniform. The Taiwanese samples ranged from intense blue to bluish green; the bright colouration of samples TW-5 and TW-10 was particularly attractive. The samples from Indonesia were pale blue to bluish green, and showed a limited range of brightness and saturation. Those from the USA were pale to highly saturated blue, with better colouration displayed by the US-I/R samples. The colouration was somewhat affected by the thickness of the slabs, with thin parts showing a less-saturated yellowish green.

Chrysocolla chalcedony is commonly not a very transparent gem material. The Taiwanese and USA samples ranged from translucent to semi-translucent. In general, the Indonesian samples showed greater transparency than those from the other two origins, ranging from semi-transparent to semi-translucent. Overall, an uneven diaphaneity was obvious in all samples.

In general, the colour and transparency depended on the proportions of chrysocolla and quartz. Too little chrysocolla resulted in pale colouration (although typically with good transparency), and too much chrysocolla also caused the material to appear pale coloured but with diminished transparency due to porosity and scattering of light from the chrysocolla inclusions. Samples containing a moderate amount of chrysocolla inclusions tended to show the most desirable combination of colour and transparency.

Specific Gravity. The SG range of samples from the different origins was quite broad and mostly overlapped. SG was mainly dependent on the different proportions of chrysocolla (SG about 2.00–2.40) and quartz (the major matrix material, SG = 2.65) in each sample. Those containing less chrysocolla commonly had higher SG values (e.g. ID-5: SG = 2.64). In some specimens, SG was affected by porosity (e.g. ID-8: SG = 2.39) or the presence of heavy impurity minerals (e.g. TW-1: SG = 2.70).

Internal Features. Observing the slabs with the gemmological microscope revealed their inhomogeneous nature. In the Taiwanese samples, chrysocolla was sometimes present as milky blue cloud-like inclusions (Figure 4a), or as globular or irregular cotton-like aggregates (Figure 4b). Green, yellowish brown and dark-coloured impurity minerals were also seen in some specimens, and fractures

Table I: Gemmological characteristics of the studied chrysocolla chalcedony samples from Taiwan, Indonesia and the USA.*

Property	Taiwan	Indonesia	USA
Colour	Intense blue to bluish green	Pale blue to bluish green	Pale to intense blue
Diaphaneity	Translucent to semi-translucent; usually low diaphaneity	Semi-transparent to semi-translucent; greater diaphaneity than those from Taiwan and the USA	Translucent to semi-translucent; generally low diaphaneity
RI	1.53–1.54	1.53–1.54	1.53–1.54
SG	2.26–2.70	2.30–2.64	2.38–2.63
Internal features	Chrysocolla formed cloud-like, globular or irregular aggregates. Green, yellowish brown and dark impurity minerals were present, and fractures were common. Malachite formed globular green aggregates.	Chrysocolla appeared mottled in the transparent matrix. Some dark or yellowish-to-orangey brown impurities were common. Pores and even small vugs were present. Malachite formed globular green aggregates.	US-M samples were quite mottled, with obvious unevenly distributed chrysocolla aggregates and dark impurity minerals; also malachite formed green needle-like radiating clusters. Some US-I/R samples contained irregular or rounded chrysocolla aggregates.

*Most samples were inert to long- and short-wave UV radiation except for TW-7 (moderate green to short-wave UV) and ID-4 (faint green to short-wave UV). None of the samples showed any reaction to the Chelsea Colour Filter. Internal features do not include minerals seen in areas of host rock adjacent to chrysocolla chalcedony. Abbreviations: US-M = Morenci mine and US-I/R = Inspiration and Ray mines, Arizona, USA.

were quite common. In the Indonesian samples, chrysocolla often created a mottled appearance within a rather transparent matrix (Figure 4c), usually with some dark or yellowish-to-orangey brown impurities (discussed in more detail below). Pores and even small vugs were present in some samples (Figure 4d). The US-M samples appeared quite mottled, with obvious uneven concentrations of chrysocolla aggregates and some dark impurities. In the US-I/R samples, the blue matrix was comparatively uniform and transparent; sometimes irregular or rounded pale blue chrysocolla aggregates were observed (Figure 4e, f).

Thin Section Observation

Examination of thin sections with cross-polarised light using a petrographic microscope revealed various microstructural features (Figure 5). In the Taiwanese specimens, quartz displayed three morphologies: fine crystallites (Figure 5a, mixed with inconspicuous chrysocolla); relatively coarser crystals, sometimes showing hexagonal growth striations (Figure 5a); and radiating fibres (i.e. chalcedony; Figure 5b, c). Chalcedony commonly surrounded the coarser-grained quartz and formed adjacent to chrysocolla aggregates (Figure 5b). Chrysocolla was sometimes not readily differentiable from quartz in cross-polarised light (i.e. where very fine grained; Figure 5a), but more commonly it showed anomalous interference colours (often yellowish green; Figure 5b). Occasionally, chrysocolla formed radiating spherical aggregates displaying various anomalous interference colours (Figure 5c).

In the thin sections from Indonesia, chrysocolla was seen dispersed in a fine-grained quartz matrix, and it commonly showed very pale green (Figure 5d, e) or brownish green (Figure 5f) anomalous interference colours. Similar to the Taiwanese samples, quartz was present as fine crystallites (Figure 5d, e; mixed with inconspicuous chrysocolla) or coarser crystals (Figure 5d–f), and sometimes as radiating fibres of chalcedony adjacent to chrysocolla aggregates (Figure 5e).

In the USA material, chrysocolla aggregates usually displayed brown anomalous interference colours in the US-M samples (Figure 5g), and yellowish green (Figure 5h) or dark green (Figure 5i) anomalous interference colours in the US-I/R specimens. The size of the quartz crystals varied considerably: the coarsest ones sometimes exceeded 1 mm (Figure 5g), while the smallest ones were usually less than 50 µm (Figure 5h). In addition, quartz sometimes formed radiating fibres of chalcedony in the USA samples (Figure 5i).

EPMA and LA-ICP-MS Analysis

BSE Imagery. Bright areas in BSE images correspond to higher overall atomic weight, and therefore BSE imagery

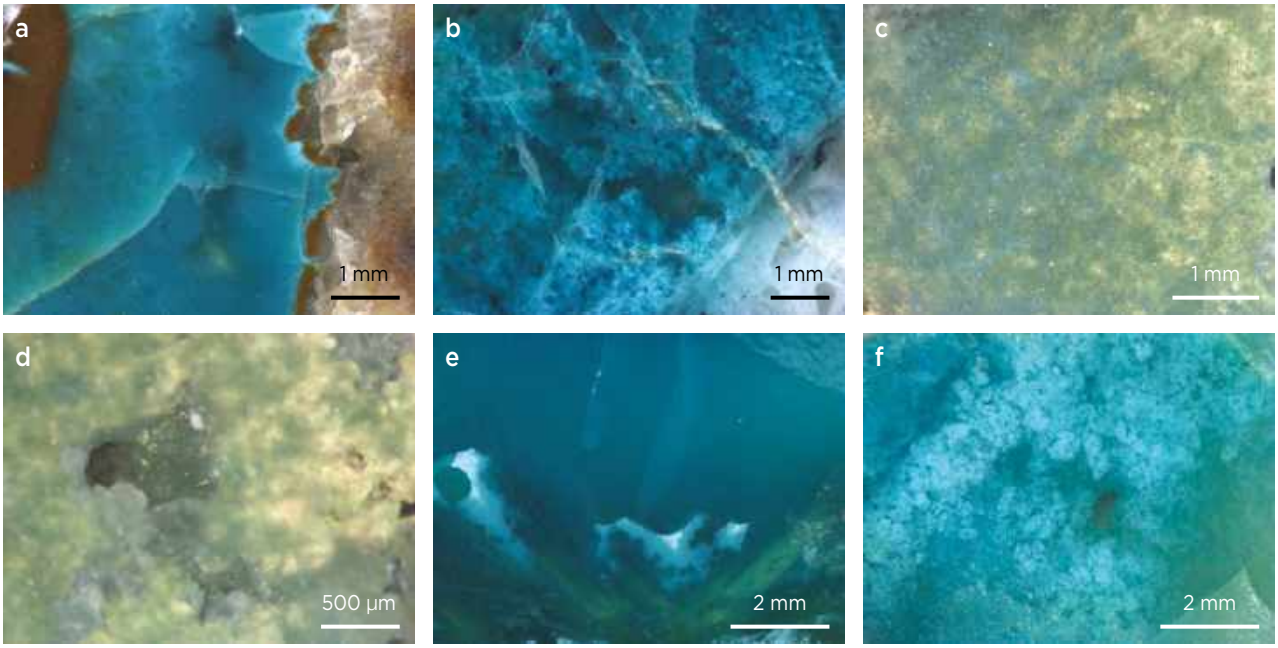

Figure 4: Viewed with the gemmological microscope, chrysocolla chalcedony commonly shows various inhomogeneities. (**a**) Cloud-like chrysocolla aggregates are present in sample TW-3. (**b**) Globular and irregular-shaped chrysocolla appears as cotton-like inclusions in specimen TW-10. (**c**) Chrysocolla in sample ID-3 occurs as mottled aggregates in a transparent matrix. (**d**) Small vugs also occur in specimen ID-3. (**e**) Irregular patches of whitish blue chrysocolla occur in a comparatively uniform blue matrix in sample US-I-1. (**f**) Rounded aggregates of whitish blue chrysocolla are present in specimen US-R-4. Photomicrographs by M. Ye in overhead lighting.

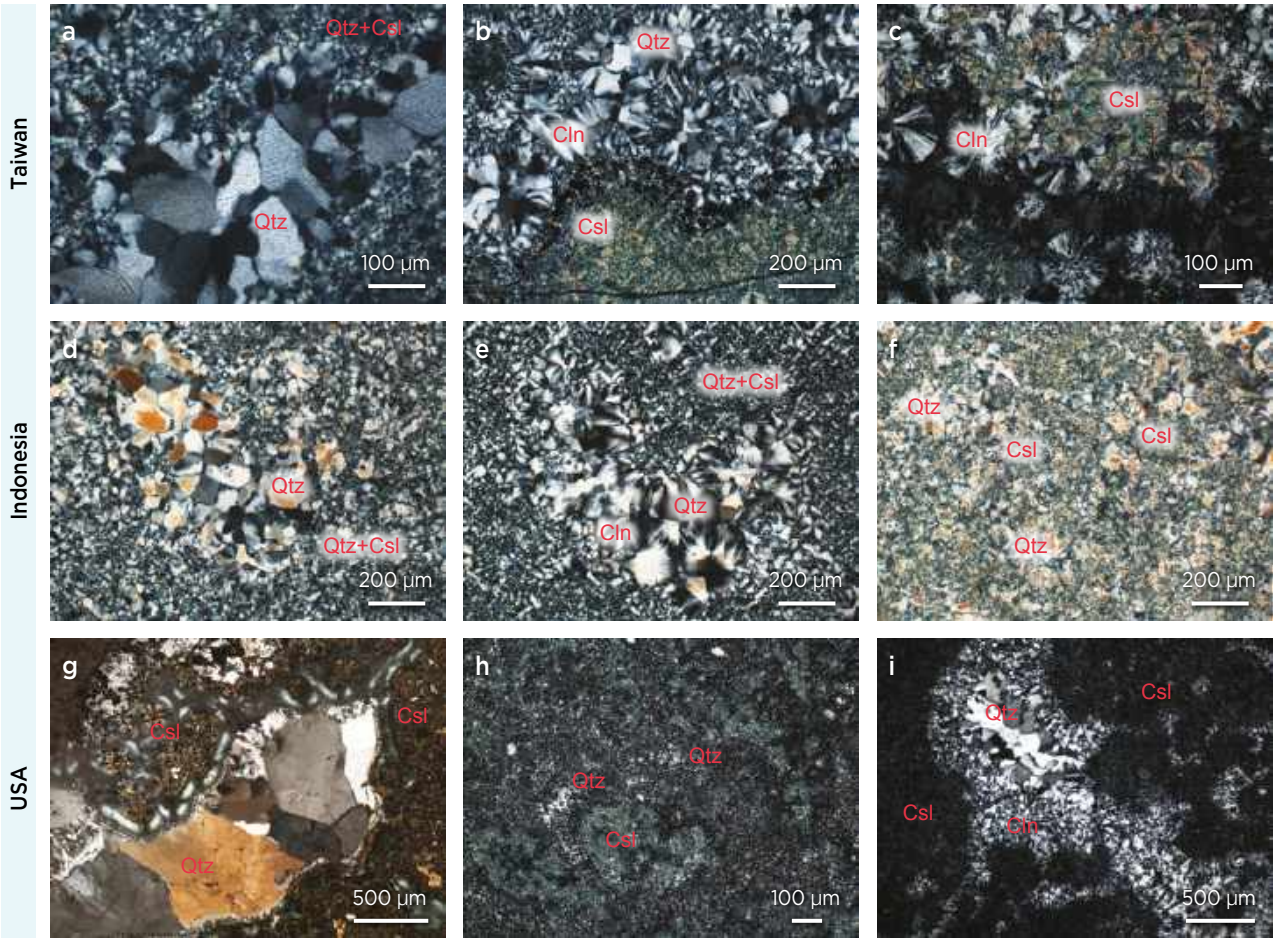

Figure 5: The typical appearance of chrysocolla chalcedony in petrographic thin sections is shown here in cross-polarised light for samples from Taiwan (a–c), Indonesia (d–f) and the USA (g–i). (**a**) The larger grains consist of crystalline quartz (Qtz) with hexagonal growth striations, which are surrounded by a mixture of fine-crystalline quartz and inconspicuous chrysocolla (Csl). (**b**) Chrysocolla aggregates show mostly yellowish green anomalous interference colours, while quartz occurs as fibrous chalcedony (Cln) and coarser crystals. (**c**) Chrysocolla forms distinct radiating spherical aggregates with bright anomalous interference colours, coexisting with spherical chalcedony. (**d**) An area of coarser-grained quartz is surrounded by a mixture of fine-grained quartz and chrysocolla. (**e**) Fine-grained chrysocolla aggregates surround chalcedony and locally coarser-crystalline quartz. (**f**) Fine-grained chrysocolla aggregates show brownish green anomalous interference colours. (**g**) An area of coarse-grained quartz (showing clear crystal boundaries and some growth striations) is surrounded by chrysocolla aggregates displaying anomalous interference colours that appear brown in finer-grained areas. (**h**) Chrysocolla aggregates displaying yellowish green interference colours are dispersed in micron-scale quartz. (**i**) Relatively coarse-grained quartz is surrounded by chalcedony and fine-grained chrysocolla aggregates showing dark green anomalous interference colours. (Note: In d–g, quartz shows some orange interference colours because those thin sections are a little thicker than the standard 30 µm.) Photomicrographs by M. Ye.

proved quite effective at revealing the distribution patterns of chrysocolla in chalcedony: the quartz-rich matrix appeared darker, while brighter areas had higher Cu, indicating greater chrysocolla content. Figure 6 shows representative BSE images of the blue areas of several samples.

In the Taiwanese specimens, chrysocolla usually formed irregular-shaped patches that were rimmed by a very thin layer of additional chrysocolla fibres (Figure 6a). Where the blue colour was relatively uniform, chrysocolla occurred as numerous small fibres forming various patterns (Figure 6b). Occasionally, chrysocolla was present as radiating spherical masses (Figure 6c).

In the Indonesian samples, fibrous chrysocolla commonly grew around irregular chrysocolla-quartz patches, or formed fibrous clusters (Figure 6d). Occasionally, the chrysocolla fibres formed radiating spherical (Figure 6e) or botryoidal aggregates displaying more than one chrysocolla-quartz growth layer (Figure 6f).

In the USA specimens, chrysocolla generally was present as radiating fibres around quartz domains (Figure 6g) or formed irregular-shaped accumulations (Figure 6h). Sometimes, these two distribution patterns coexisted (Figure 6i).

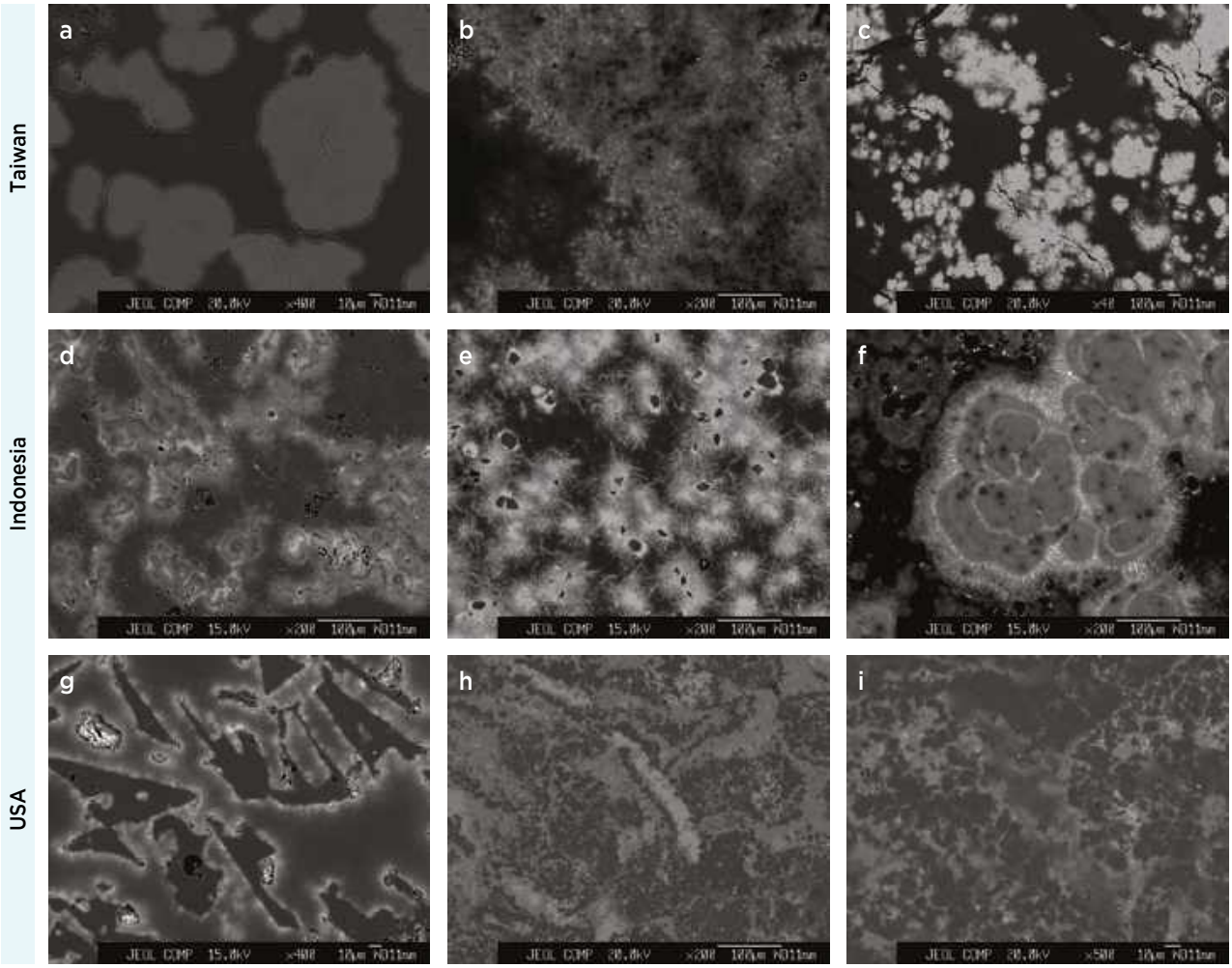

Figure 6: These representative BSE images are of samples from Taiwan (a–c), Indonesia (d–f) and the USA (g–i). (**a**) Irregular-shaped chrysocolla patches are surrounded by a very thin layer of chrysocolla fibres. (**b**) Aggregates of tiny chrysocolla fibres are present in some samples, as are (**c**) radiating spheres of chrysocolla. (**d**) Fibrous chrysocolla surrounds irregular chrysocolla-quartz patches. (**e**) Roughly spherical aggregates of fibrous chrysocolla are sometimes present. (**f**) Botryoidal aggregates sometimes have more than one chrysocolla-quartz layer, rimmed by radiating chrysocolla fibres. (**g**) Minute chrysocolla fibres radiate away from irregularly shaped quartz domains. (**h**) Irregular-shaped accumulations of chrysocolla also occur. (**i**) Fibrous chrysocolla is interspersed between irregular quartz-rich patches. Images by M. Ye.

Major Elements. The results of EPMA chemical analysis are listed in Table II. Si and Cu were the main components, and because of the presence of volatiles (such as water) the oxide sums were sometimes significantly less than 100 wt.%. The content of Si varied according to Indonesia > Taiwan > USA (averaging 87.42 > 80.77 > 76.89 wt.% SiO_2), while the amount of Cu showed the opposite trend of Indonesia < Taiwan < USA (averaging 11.27 < 16.38 < 19.02 wt.% CuO). Other elements such as Al, Mg and Ca were likely components of chrysocolla, as their values positively correlated with Cu in most samples; the concentrations of these elements were highest in the Taiwanese samples (averaging 0.42 wt.% Al_2O_3, 0.31 wt.% MgO and 0.38 wt.% CaO). The oxide concentrations of Na, K, Fe and Mn were all less than 0.1 wt.% (except for Fe in the USA samples, averaging 0.11 wt.% FeO).

Trace Elements. We analysed for 55 trace elements by LA-ICP-MS and then selected 14 of them that showed the best distinctions between the different origins; the results are summarised in Table III. The USA samples are separated into two groups (US-M and US-I/R) due to obvious compositional differences between them. One prominent feature of the Taiwanese samples was their abundant U content (averaging 5,040 ppmw), which was much higher than for our specimens from the other two origins (averaging less than about 50 ppmw). For the US-I/R samples, a high Mo content (averaging 7,720 ppmw) was diagnostic. Data for U and Mo are plotted in Figure 7, and show a distinct separation between the TW and US-I/R specimens. In addition, the Taiwanese samples contained more B (averaging 483 ppmw) and the US-I/R samples had greater Rb

Table II: Chemical composition by EPMA of chrysocolla chalcedony.*

Oxides (wt.%)	Taiwan	Indonesia	USA
SiO_2	38.55–99.54 (80.77)	49.51–99.21 (87.42)	39.09–98.40 (76.89)
CuO	0.09–48.18 (16.38)	0.22–46.71 (11.27)	0.36–48.74 (19.02)
Al_2O_3	<4.47 (0.42)	<0.16 (0.04)	<1.93 (0.27)
MgO	<2.36 (0.31)	<0.57 (0.08)	0.01–0.86 (0.24)
CaO	<2.14 (0.38)	<1.17 (0.20)	0.01–1.18 (0.29)
Na_2O	<0.30 (0.05)	0.01–0.47 (0.07)	<0.16 (0.03)
K_2O	<0.35 (0.06)	0.01–0.57 (0.07)	<0.10 (0.02)
FeO	<0.38 (0.04)	<0.04 (0.02)	<1.22 (0.11)
MnO	<0.27 (0.03)	<0.55 (0.09)	<0.10 (0.01)
Total	87.50–100.18 (98.46)	95.96–100.66 (99.18)	85.94–100.36 (96.89)

*Average concentrations are shown in parentheses.

(averaging 199 ppmw). Both the Taiwanese and US-I/R samples were rich in K (averaging 21,600 and 16,000 ppmw, respectively). Moreover, the Taiwanese samples were slightly higher in Na (averaging 1,160 ppmw), Sr (averaging 25.5 ppmw) and Ba (averaging 194 ppmw) than the specimens from the other two origins. Neither the Indonesian nor the US-M samples had much trace-element content (except Fe was greatest in the US-M samples, averaging 2,480 ppmw).

Spectroscopic Features

UV-Vis-NIR Absorption Spectra. All the samples showed very similar absorption spectra (e.g. Figure 8, red trace). A spectrum of a reference chrysocolla (blue trace, from author AHS's personal collection) showed the same absorption features: a broad band centred at 720 nm (due to Cu^{2+}; Shen *et al.* 2006), and three narrower bands at 1415, 1910 and 2257 nm. The narrower bands are attributed to various forms of hydroxyl bonds: the one at 2257 nm is from a combination of vibrations due to the bending and stretching of silanol groups (Si-OH); the

Table III: Selected trace-element concentrations by LA-ICP-MS in chrysocolla chalcedony.*

Elements (ppmw)	Taiwan	Indonesia	USA-M	USA-I/R
B	104–1170 (483)	<119 (68.4)	4.29–9.78 (7.34)	42.0–132 (83.8)
Na	142–3850 (1160)	71.1–742 (465)	59.0–208 (150)	142–445 (262)
K	585–48100 (21600)	105–518 (328)	19.2–291 (125)	8290–24500 (16000)
V	0.11–254 (75.9)	<65.0 (12.5)	16.9–74.2 (58.1)	4.83–66.3 (18.9)
Fe	<1610 (375)	<85.2 (20.9)	<12200 (2480)	<599 (232)
Ni	<37.4 (4.05)	<111 (30.4)	<4.81 (0.96)	<10.7 (7.39)
Ge	<3.02 (1.24)	<9.51 (2.56)	0.82–5.23 (3.55)	2.32–5.04 (3.72)
Rb	21.8–138 (70.9)	<1.17 (0.41)	0.06–3.70 (0.92)	110–347 (199)
Sr	2.23–96.3 (25.5)	<5.05 (2.64)	1.13–8.24 (4.44)	11.9–36.4 (22.9)
Mo	86.7–1010 (439)	<7.71 (2.14)	<30.3 (6.51)	**1030–20200 (7720)**
Ba	12.7–508 (194)	<4.22 (1.66)	<8.84 (2.52)	19.1–307 (142)
Ce	2.02–964 (157)	0.49–7.79 (2.41)	0.01–0.43 (0.14)	5.55–374 (101)
Sm	<3.99 (0.94)	<3.16 (0.68)	<0.36 (0.18)	0.07–23.7 (5.01)
U	**996–15300 (5040)**	9.98–147 (48.5)	2.28–58.2 (21.8)	11.2–90.0 (51.0)

*Average concentrations are shown in parentheses. Boldface numbers highlight high contents of U in Taiwanese samples and Mo in USA-I/R samples that are useful for distinguishing material from these localities.

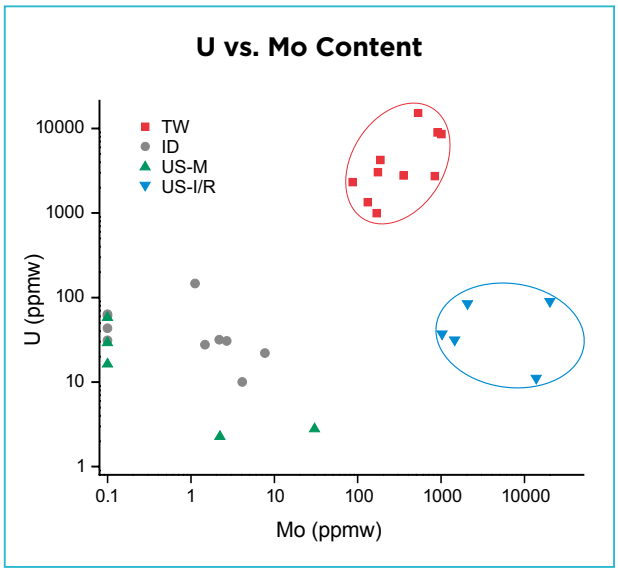

Figure 7: A logarithmic plot of U vs. Mo in chrysocolla chalcedony from the different localities shows high U with lower Mo in the Taiwanese samples, and low U with high Mo in the US-I/R specimens, making them easy to distinguish from the Indonesian and US-M samples (both of which contain much less U and Mo).

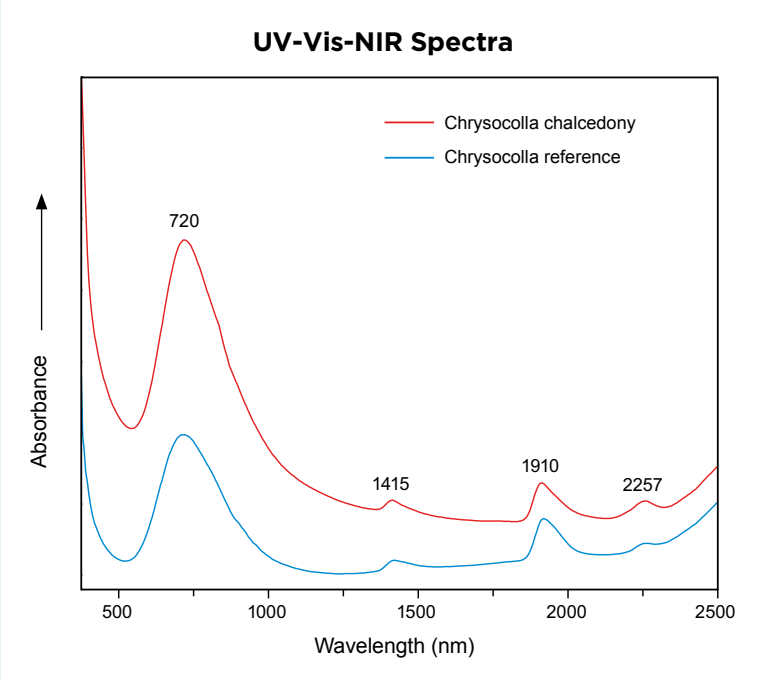

Figure 8: A typical UV-Vis-NIR absorption spectrum for chrysocolla chalcedony shows identical features to those of a reference sample of chrysocolla: a broad absorption band at around 720 nm and three narrow absorptions at 1415, 1910 and 2257 nm. The transmission window for chrysocolla chalcedony is centred at around 530–550 nm, which is shifted from about 520 nm in the reference chrysocolla, thus resulting in a slightly greener colouration in our samples as compared to nearly pure chrysocolla.

one at 1910 nm corresponds to a combination of vibrations from bending and stretching of molecular water (H_2O); and the one at 1415 nm is the first overtone of O-H stretching vibrations of both molecular and silanol-group water (total OH; Graetsch 1994; Shen & Keppler 1995).

For the reference chrysocolla, the transmission window in the visible region ranged from about 400 to 600 nm and was centred at around 520 nm (with a calculated dominant wavelength of 500 nm, consistent with its blue colour; unpublished data), while for the chrysocolla chalcedony samples in the present study the transmission window was generally centred at around 530–550 nm, thus giving rise to their greener hue.

FTIR Spectroscopy. Figure 9 shows representative FTIR spectra for chrysocolla chalcedony samples from each locality (see Table DD-1 in *The Journal*'s online data depository for a summary of the main absorption bands). Sample numbers are accompanied by B to indicate the more-translucent blue areas and WB to denote the more-opaque whitish blue areas of a specimen. Most samples showed the dominant IR absorption features of α-quartz (e.g. TW-8 B, ID-1 B and US-M-1 B): a strong band at 1090 cm^{-1} with a shoulder at 1167 cm^{-1}; a pair of bands at 798 and 780 cm^{-1}; and additional bands at 515 and 465 cm^{-1}. Those in the 1200–600 cm^{-1} region are assigned to Si-O stretching vibrational modes, and those from 600 to 400 cm^{-1} are associated with Si-O bending vibrational modes (Etchepare *et al.* 1974).

Chrysocolla is an amorphous or poorly crystallised mineral, so it can be difficult to detect by vibrational spectroscopy. Samples with detectable chrysocolla showed features of both quartz and chrysocolla (the latter displaying a main absorption band centred at 1030 cm^{-1}; e.g. TW-3 B, ID-4 B and US-M-3 WB in Figure 9). In those spectra, the 1090 cm^{-1} band of quartz shifted to a slightly lower wavenumber of 1085 cm^{-1}. In addition, the main IR band of chrysocolla (typically 1025 cm^{-1}; RRUFF sample R050053) shifted to a slightly higher wavenumber of 1030 cm^{-1}.

For areas of a sample showing different diaphaneity, the more translucent portion (B) showed stronger quartz bands, while the more opaque zone (WB) displayed mixed features of quartz and chrysocolla, or even just chrysocolla (e.g. TW-4, US-M-3 and US-I-1 in Figure 9).

Raman Spectroscopy. Figure 10 shows representative Raman spectra for comparatively uniform blue areas of our samples (see Table DD-2 in the data depository for a summary of the main peaks). Most of the samples had a strong Raman peak for α-quartz near 464 cm^{-1} (e.g. TW-1, ID-1 and US-M-4), which involves the bending vibrations of O-Si-O (Etchepare *et al.* 1974). In addition, some spectra contained an obvious peak near 501 cm^{-1} (e.g. TW-6, ID-9 and US-R-4), corresponding to the Si-O-Si symmetric stretching-bending modes of moganite (a monoclinic quartz polymorph that is often present in the microcrystalline fibrous structure of chalcedony and agate;

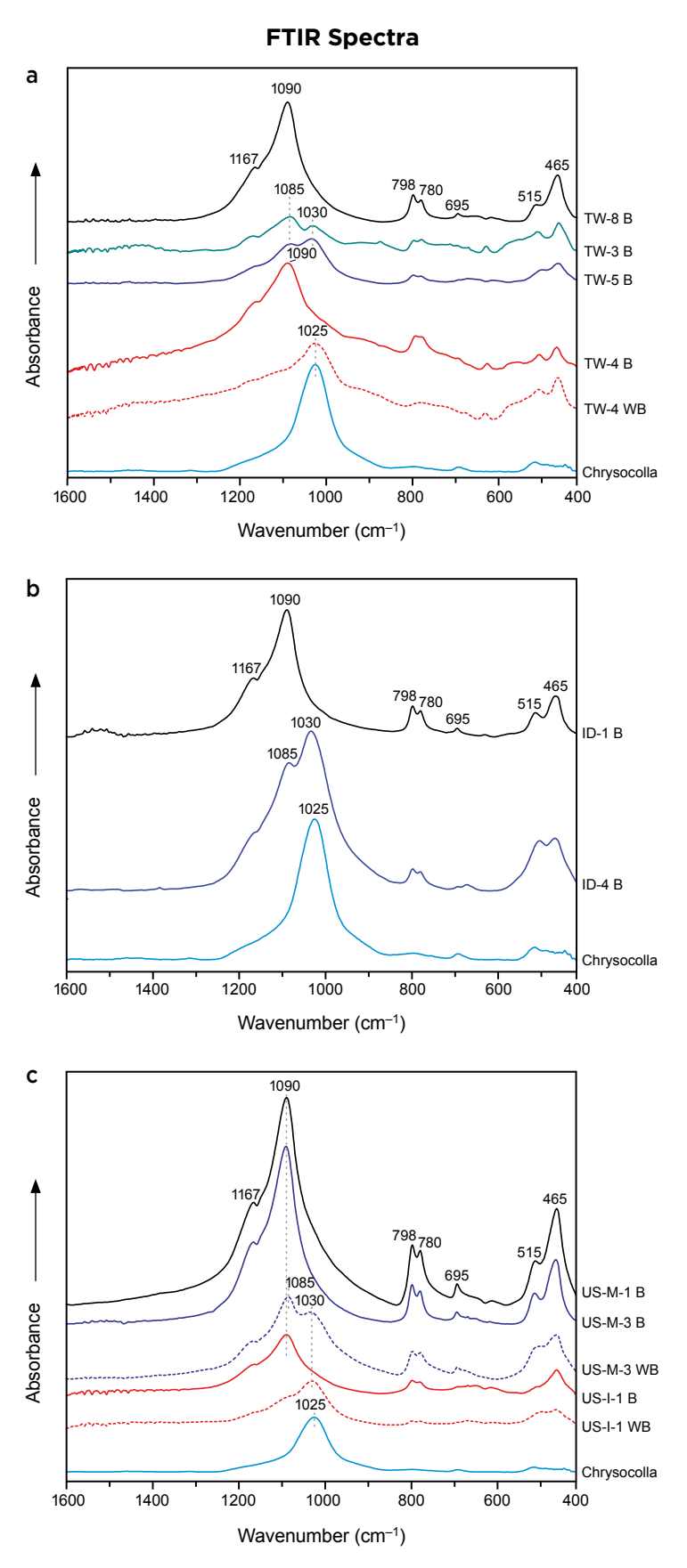

Figure 9: Typical FTIR spectra are shown for chrysocolla chalcedony samples from (**a**) Taiwan, (**b**) Indonesia and (**c**) the USA. A chrysocolla reference spectrum is included for comparison at the bottom of each group. Most spectra show typical IR absorption bands of α-quartz (e.g. TW-8 B, ID-1 B and US-M-1 B). When sufficient chrysocolla is present, the spectra include a mixture of bands attributed to quartz (main band at 1085 cm^{-1}) and chrysocolla (main band at 1030 cm^{-1}), such as for samples TW-3 B, TW-5 B, ID-4 B and US-M-3 WB. Sometimes just the spectral features of chrysocolla (main band at 1025 cm^{-1}) are present, as for specimen TW-4 WB.

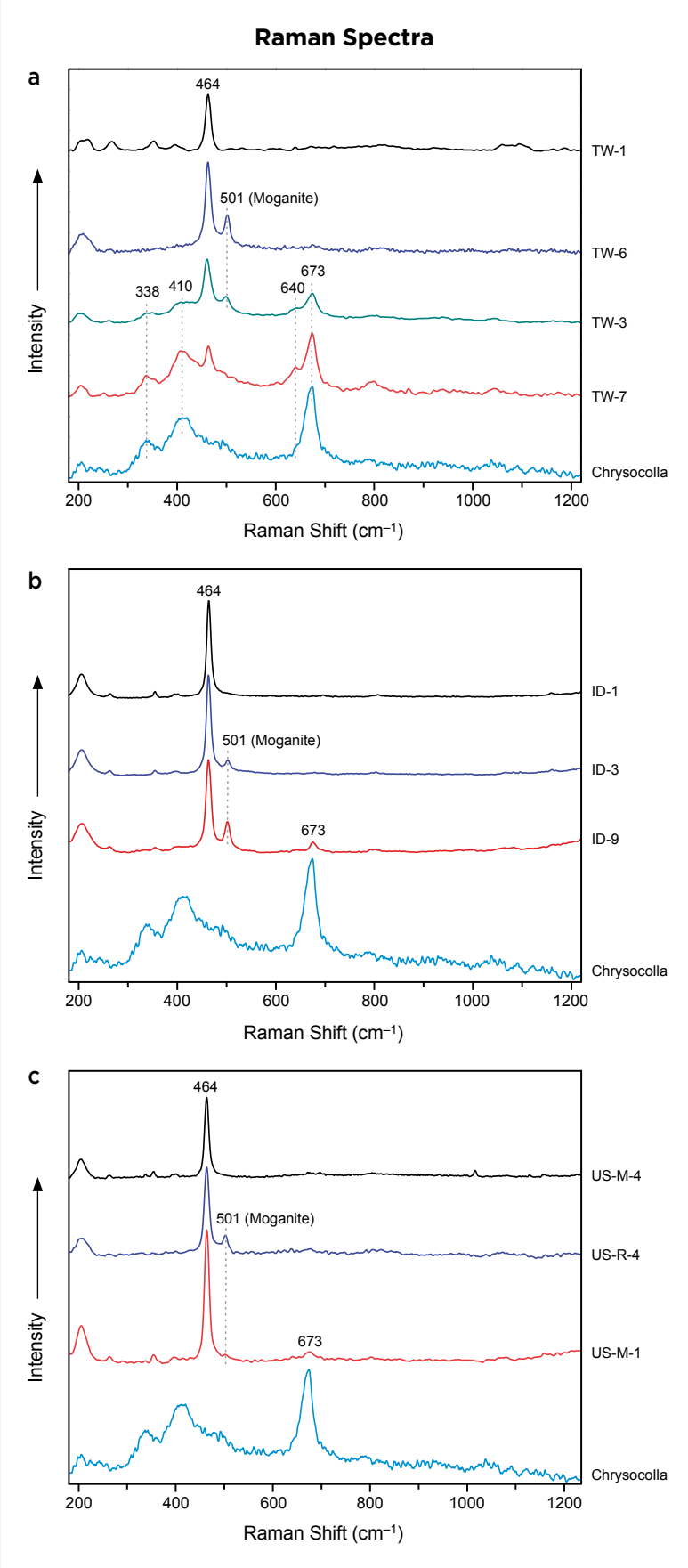

Figure 10: Representative Raman spectra are shown for chrysocolla chalcedony from (**a**) Taiwan, (**b**) Indonesia and (**c**) the USA. A chrysocolla reference spectrum is included for comparison at the bottom of each group. Most of the spectra show peaks typical of **α**-quartz (main peak at 464 cm^{-1}) and moganite (main peak at 501 cm^{-1}; e.g. TW-6, ID-3, US-R-4). When sufficient chrysocolla is present, the diagnostic Raman peak of chrysocolla at 673 cm^{-1} appears in the spectra (e.g. for samples TW-3, ID-9 and US-M-1). However, other Raman features of chrysocolla, including a shoulder at 640 cm^{-1} and peaks at 338 and 410 cm^{-1}, were only found in some Taiwanese samples (e.g. TW-3 and TW-7).

Kingma & Hemley 1994). The main chrysocolla peak at 673 cm^{-1} (RRUFF sample R050053) was present in some specimens (e.g. TW-3, ID-9 and US-M-1); again, chrysocolla is difficult to detect by vibrational spectroscopy. Other Raman peaks of chrysocolla at 338 and 410 cm^{-1} and the shoulder at 640 cm^{-1} were seen only in some Taiwanese specimens (e.g. TW-3 and TW-7), which might indicate better-crystallised chrysocolla in those samples.

Impurity Minerals

Most of the chrysocolla chalcedony specimens contained eye-visible inclusions, as well as some areas of host rock. Raman microspectroscopy was used to identify several of the corresponding impurity minerals.

Inclusions of malachite were present in the chrysocolla chalcedony of several specimens. In the Taiwanese and Indonesian samples, malachite formed globular green aggregates (Figure 11a, b), while in the US-M samples it occurred as needle-like radiating clusters (Figure 11c).

Other impurity minerals were identified in areas of host rock (Figure 12). In the Taiwanese samples, light yellowish brown calcite, yellowish brown goethite and brown hematite were common (Figure 12a, b), and sometimes chalcopyrite was observed (Figure 12a). In sample TW-7, we identified some tiny grains of native copper dispersed in the chalcedony matrix or forming aggregates (Figure 12b). In some specimens, black manganite surrounded chrysocolla aggregates and, occasionally, the rhombic section of these crystals was visible in petrographic thin sections (Figure 12c).

The impurity minerals in the Indonesian samples were different, with most consisting of various copper minerals. Tiny red cuprite crystals were visible using oblique illumination within yellow or orange aggregates (Figure 12d, e). These aggregates were probably composed of a mixture of nanometre-sized cuprite and quartz, and were usually surrounded by dark areas containing cuprite and tenorite (Figure 12d). We also found some native copper in sample ID-4 that was locally surrounded by cuprite (Figure 12f).

The US-M samples commonly contained brownish black or reddish brown hematite (Figure 12g, h), as well as numerous minerals typical of propylitic alteration, such as epidote, albite and chlorite (Figure 12h). Black impurities in the US-I/R samples consisted of a vernadite-like mineral (Figures 12i and 13).

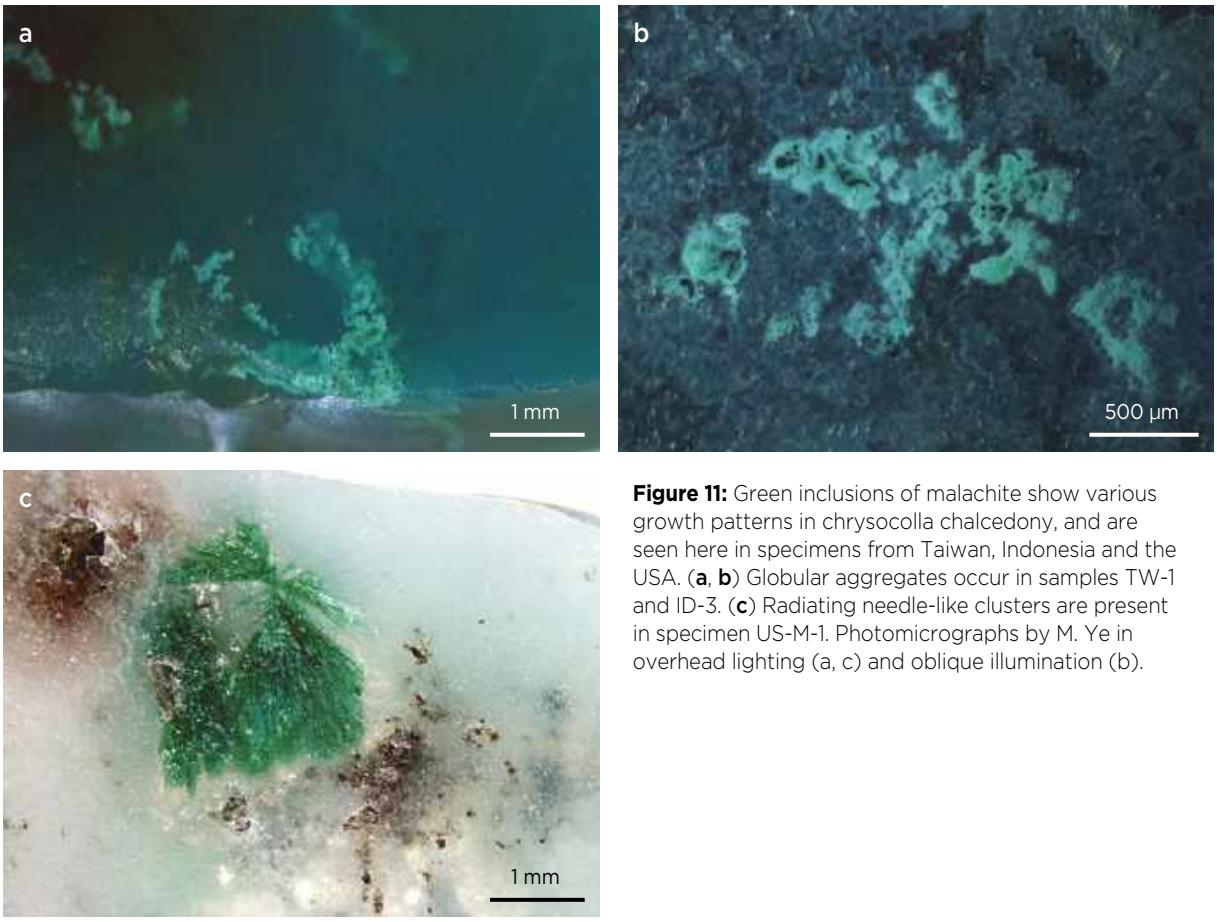

Figure 11: Green inclusions of malachite show various growth patterns in chrysocolla chalcedony, and are seen here in specimens from Taiwan, Indonesia and the USA. (**a**, **b**) Globular aggregates occur in samples TW-1 and ID-3. (**c**) Radiating needle-like clusters are present in specimen US-M-1. Photomicrographs by M. Ye in overhead lighting (a, c) and oblique illumination (b).

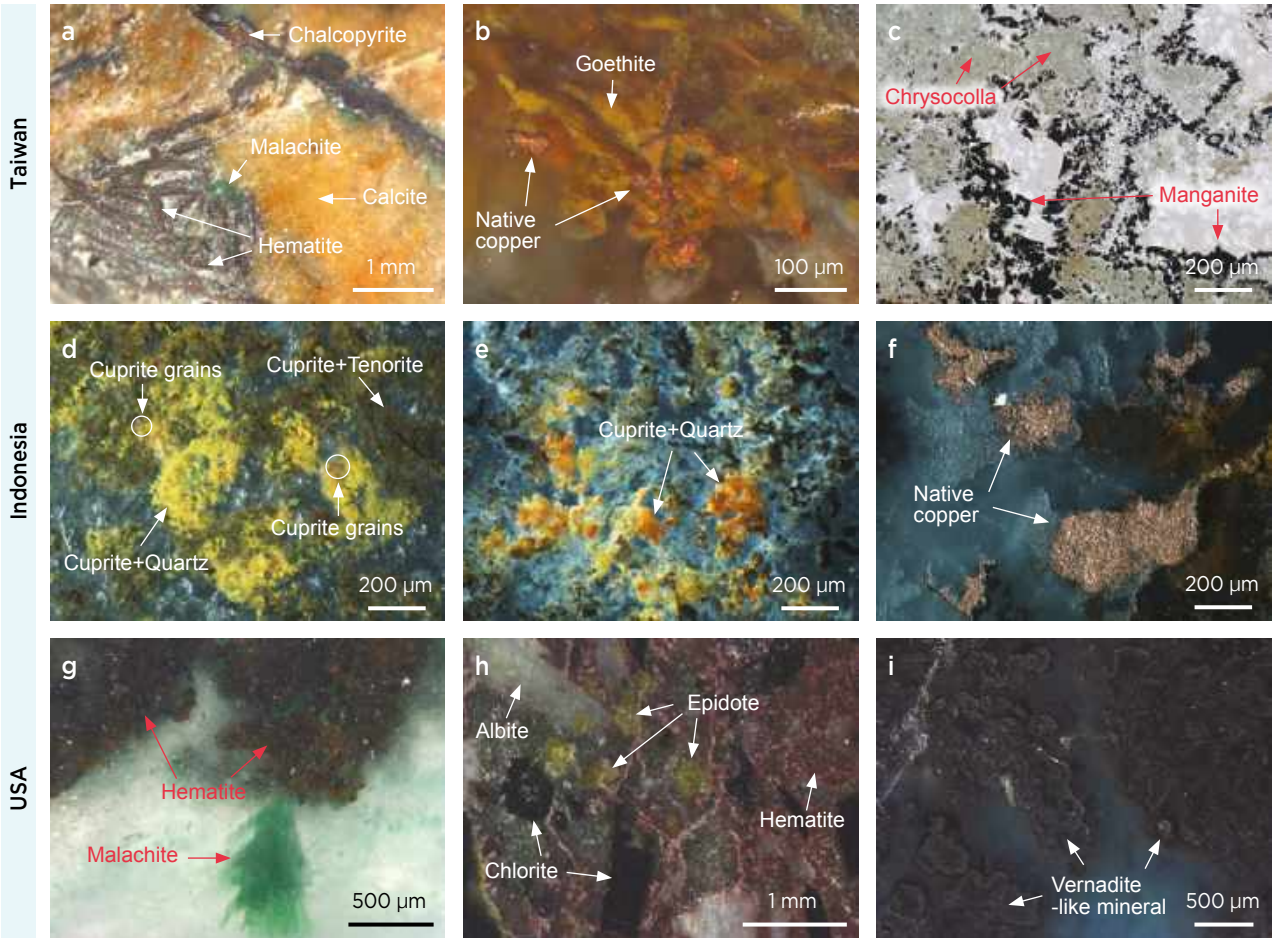

Figure 12: Various impurity minerals are observed in the host rock areas of the chrysocolla chalcedony. Images c–f were taken with a petrographic microscope from thin sections and the others were photographed with a gemmological microscope in polished slabs. (**a**–**c**) Samples from Taiwan contain calcite, goethite, hematite, malachite, chalcopyrite, native copper and manganite. (**d**–**f**) Specimens from Indonesia include various copper minerals, such as cuprite, tenorite and native copper. US-M samples show (**g**) areas of hematite (and adjacent malachite in the chrysocolla chalcedony), or (**h**) mineral assemblages that are typical of propylitic alteration. (**i**) A black vernadite-like mineral is present in some US-I/R samples. Photomicrographs by M. Ye with overhead lighting (a, b and g–i), plane-polarised light (c) and oblique illumination (d–f).

DISCUSSION

Major-Element Composition

The chemical constituents are consistent with a mixture of chrysocolla and quartz, with quartz being the main mineral. The Indonesian samples contained more quartz than those from the other two localities, which may be correlative with their better overall transparency. In the USA samples, chrysocolla was sometimes dispersed very unevenly (e.g. US-I-1 and US-R-2), thus leading to the high Cu averages.

We can estimate the proportion of chrysocolla and quartz in our samples using mineralogical methods (Zhao *et al.* 2004), considering that the chemical formula of chrysocolla is $(Cu,Al)_2H_2Si_2O_5(OH)_4 \bullet nH_2O$ (Anthony *et al.* 1990). EPMA results yielded the total Si contents of chrysocolla + quartz in more-translucent blue portions, more-opaque whitish blue zones and more-transparent near-colourless areas of our samples. Based on the Cu, Al, Mg and Ca concentrations, we calculated the Si content needed for chrysocolla. Then the Si content attributed to quartz was estimated by subtracting the Si in chrysocolla from the total Si content. This enabled us to calculate the following chrysocolla:quartz ratios:

Taiwan = from about $1{:}419_{(NC)}$ to $31{:}1_{(WB)}$
Indonesia = from about $1{:}504_{(NC)}$ to $3{:}1_{(WB)}$
USA = from about $1{:}176_{(NC)}$ to $40{:}1_{(WB)}$

Therefore, the more-transparent near-colourless portions (denoted above as NC) are dominated by quartz while the more-opaque whitish blue zones (WB) are enriched in chrysocolla. In the more-translucent blue areas, the chrysocolla:quartz ratios were intermediate between those of the other two types of areas.

Origin Determination Using Trace Elements

There are some obvious differences in trace-element composition between the samples from the different origins. Features that appear diagnostic for the Taiwanese samples are high U and lower Mo, and for the US-I/R samples, low U and high Mo (again, see Figure 7). To help further separate Indonesian and US-M samples, we performed statistical processing of our rather limited number of analyses using Fisher-LDA (see Li & Wang 2014; Zhang *et al.* 2019). Six trace elements were selected (B, V, Ni, Ge, Ce and Sm) by the software, and the following Fisher linear discriminant function equations were generated:

$$Y_{(ID)} = -6508.535 + (115.988 \times [B]) - (40.612 \times [V]) + (14.382 \times [Ni]) - (180.849 \times [Ge]) + (2179.482 \times [Ce]) + (3502.914 \times [Sm])$$

$$Y_{(US\text{-}M)} = -69.125 - (10.345 \times [B]) + (4.051 \times [V]) - (1.306 \times [Ni]) + (19.009 \times [Ge]) - (205.922 \times [Ce]) - (312.968 \times [Sm])$$

The cross-validation results were encouraging—nearly 100%—and three randomly selected 'unknown' samples fell into their correct origins. Nevertheless, the limited number of samples analysed means that this particular methodology is preliminary.

Identity of Impurity Minerals

Although cuprite crystals are intrinsically red, when the crystal size is very small (on the order of hundreds of nanometres), their apparent colour can range from yellow to orange to red (Markina *et al.* 2016). Both Raman spectra and chemical data showed that the yellow and orange aggregates in our Indonesian samples were composed of a mixture of cuprite and quartz, so they probably consist of nanometre-size cuprite dispersed in quartz.

Raman microspectroscopy of the dark areas of the US-I/R samples yielded a spectral pattern that was similar to vernadite (except for the 468 cm^{-1} quartz peak; Figure 13), but not identical. EDXRF analysis of those same areas showed the presence of Mn, Si, Cu and Co. The chemical formula of vernadite is $(Mn,Fe,Ca,Na)(O,OH)_2 \bullet nH_2O$ (Anthony *et al.* 1990), and trivalent Fe, Cu, Co and Ni can isomorphously substitute for quadrivalent Mn (Hu *et al.* 2009), which makes this mineral difficult to characterise chemically. Therefore, we make a general assumption that the dark areas of those samples are due to a vernadite-like mineral.

Genesis of Chrysocolla Chalcedony

Based on the identities and textures of the impurity minerals in chrysocolla chalcedony, we infer that the following genetic mechanisms took place (cf. Einfalt & Sujatmiko 2006): (1) the oxidation and dissolution of primary or

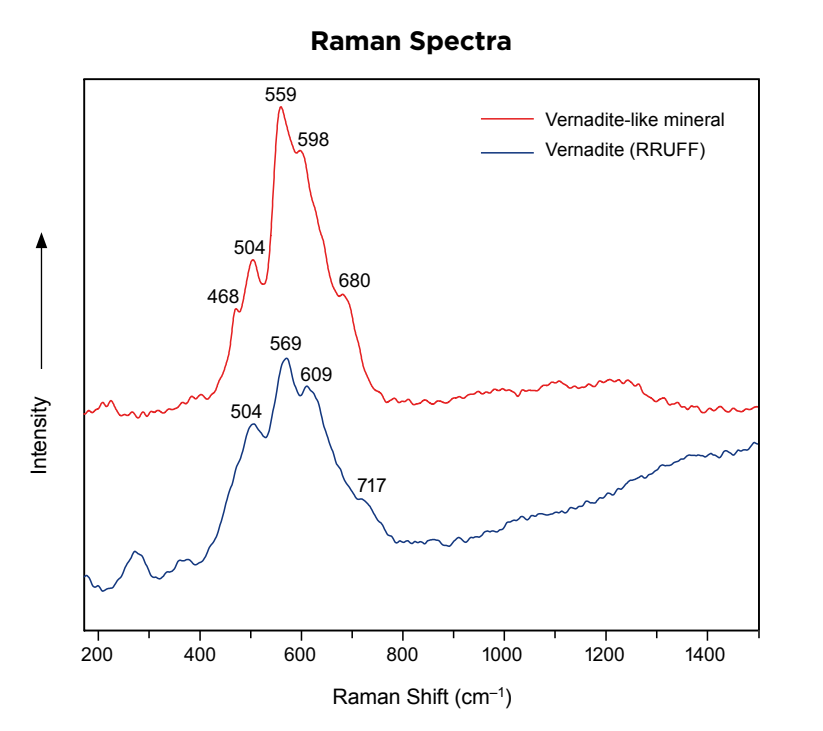

Figure 13: The Raman spectrum of the dark impurity mineral in the US-I/R samples is compared to a reference spectrum for vernadite (RRUFF sample R050053). Except for the weak peak at 468 cm^{-1} belonging to quartz, the spectral pattern of the dark mineral resembles that of vernadite. However, the peak positions are shifted somewhat.

secondary Cu-sulphides (e.g. chalcopyrite) resulted in an assemblage consisting of malachite, native copper, cuprite and tenorite; and (2) malachite and Cu-oxides reacted with silicic fluids to form Cu-silicates, and during this process chrysocolla co-precipitated with quartz.

From the observation of our thin sections, the following crystallisation sequence is inferred for chrysocolla chalcedony: (1) crystal growth initially proceeded rapidly in a Cu-bearing and strongly siliceous aqueous solution or gel, from which fine-crystalline quartz co-precipitated with chrysocolla; (2) the crystallisation rate slowed down as Si and Cu were depleted from the growth medium, yielding chrysocolla-quartz aggregates surrounded by fibrous quartz; and (3) coarser crystalline quartz (and even vugs) followed in a low-concentration siliceous solution or gel (cf. Wang & Merino 1990; Einfalt & Sujatmiko 2006).

The actual crystallisation and precipitation processes are likely to be more complex than described above.

CONCLUSIONS

Using various gemmological, mineralogical and geochemical techniques, we identified several differences in the impurity minerals and trace-element contents between chrysocolla chalcedony from Taiwan, Indonesia and the USA. Figure 14 provides a preliminary identification flow chart for differentiating samples from these localities:

(1) If impurity minerals are visible with an optical microscope, Raman analysis should be used to identify them. Material without observable impurity minerals should undergo trace-element analysis by LA-ICP-MS.

(2) For impurity minerals identified by Raman analysis:
- A copper mineral mixture (e.g. cuprite, tenorite and native copper) suggests Indonesian material.
- Black manganite occurs in Taiwanese material.
- An assemblage of iron (hydr)oxides, copper minerals (chalcopyrite and native copper) and calcite is also common in samples from Taiwan.
- A vernadite-like mineral occurs in material from the Inspiration and Ray mines in the USA.
- Minerals associated with propylitic alteration (epidote, albite and chlorite) may coexist with radiating malachite aggregates in samples from the Morenci mine in the USA.

(3) For trace-element concentrations determined by LA-ICP-MS:
- High U and lower Mo values typify samples from Taiwan.
- Low U and high Mo values are indicative of material from the Inspiration and Ray mines in the USA.
- Low U and low Mo values appear common in samples from Indonesia and the Morenci mine.
- Fisher-LDA analysis may be necessary to separate samples from Indonesia and the Morenci mine.

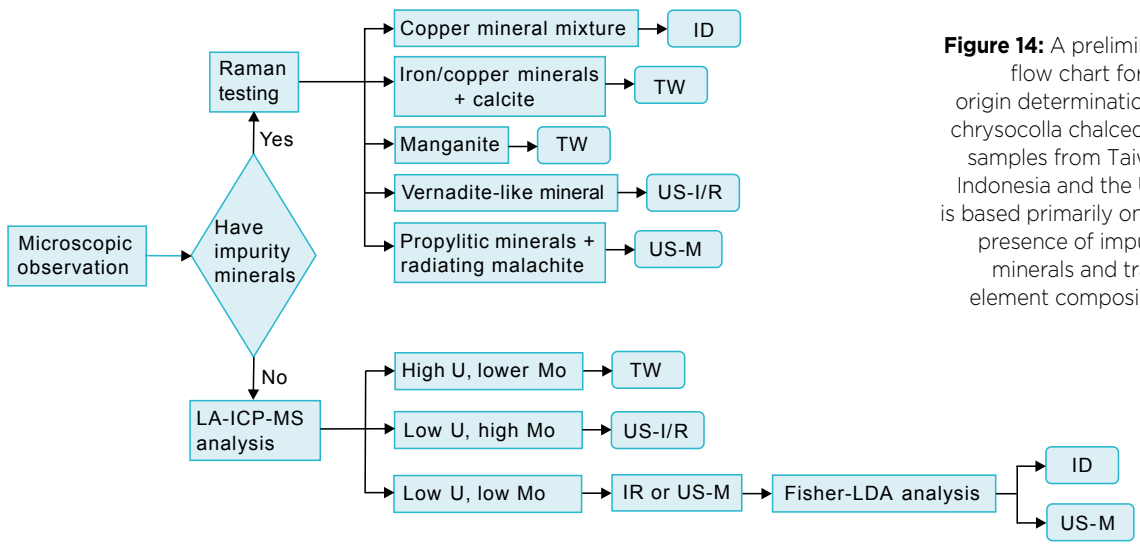

Figure 14: A preliminary flow chart for the origin determination of chrysocolla chalcedony samples from Taiwan, Indonesia and the USA is based primarily on the presence of impurity minerals and trace-element composition.

Figure 15: This necklace features chrysocolla chalcedony from Indonesia and Taiwan (approximately 8–15 ct) accompanied by diamonds and pink sapphires and set in 18 ct white gold. Photo courtesy of Taiwan She Say Jewellery Co.

Applying a combination of the approaches described above will help give a clearer determination of a sample's origin. The Fisher-LDA model established in this research is still at its early stage and further development is needed. In addition, more samples should be examined from the localities studied here and from other deposits (Peru and Mexico).

Chrysocolla chalcedony can be incorporated into beautiful jewellery pieces (see, e.g., Figure 15) that can be quite valuable, particularly when they contain well-matched stones. With decreasing production of high-quality material from some deposits, we expect that chrysocolla chalcedony from certain origins will become rarer (and also more valuable) in the future. Therefore, systematic research on the similarities and differences between chrysocolla chalcedony from various geographic locations is timely and necessary.

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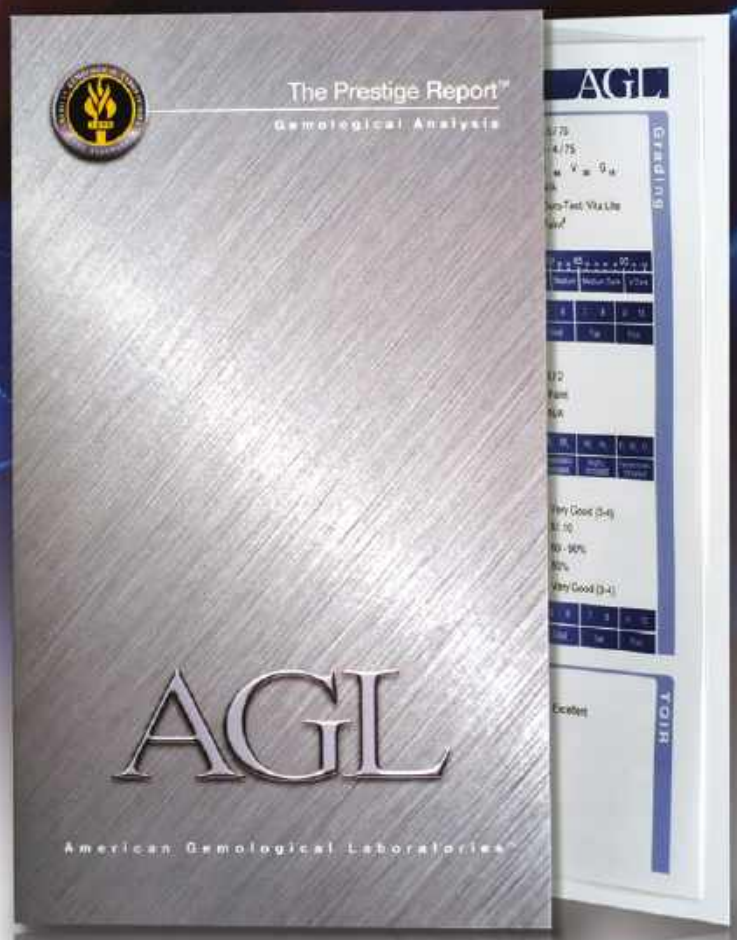

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A Case Study of Ivory Species Identification Using a Combination of Morphological, Gemmological and Genetic Methods

Laurent E. Cartier, Michael S. Krzemnicki, Mario Gysi, Bertalan Lendvay and Nadja V. Morf

ABSTRACT: Twenty-one items sold as mammoth ivory in China were submitted to the Zurich Institute of Forensic Medicine (University of Zurich, Switzerland) and SSEF for testing. The aim of this case study was to identify these samples using macroscopic morphological diagnostics, microscopic examination, FTIR spectroscopy, trace-element analysis and additional minimally destructive DNA analysis (of approximately 100 mg of powder) of a region of the cytochrome *b* gene to assign taxonomic identification. Morphological features (Schreger angles) shown by five of the samples were characteristic of extinct Proboscideans (mammoths), and one other specimen displayed unnatural layering that identified it as an ivory imitation. FTIR spectroscopy further showed the imitation was an artificial resin, while infrared spectra of the other samples displayed overlapping features characteristic of carbonated hydroxyapatite (i.e. ivory or bone). Like FTIR spectroscopy, trace-element chemistry cannot be used to separate species. DNA analysis could in some cases differentiate extinct (mammoth) from extant (African and Asian elephant) Proboscidean species, and also identified one specimen as cattle bone. Combining morphological, gemmological and genetic approaches can increase the amount of evidence available to identify the species origin of ivory.

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Ivory (e.g. Figure 1), a mammalian tooth or tusk of commercial interest, has been valued since ancient times (Espinoza & Mann 2000). Ivory is produced by a large number of animal taxa (e.g. walrus, warthog and whale), among which elephant ivory is the most studied due to its value, popularity and cultural importance (Campbell Pedersen 2015). African (*Loxodonta* spp.) and Asian (*Elephas maximus*) elephants, along with their extinct relatives (e.g. mammoths, *Mammuthus* spp.), belong to the mammalian taxonomic order Proboscidea. These taxa produce ivory that is made up of collagen and carbonated hydroxyapatite (Edwards *et al.* 2006), which can be finely carved and is therefore sought after.

Among the extinct Proboscidea species, only the ivory of the woolly mammoth (*Mammuthus primigenius*) is suitable for carvings and jewellery use, as this is the only species with tusks that have been well preserved since the end of the Pleistocene (10,000–11,000 years ago) in high-latitude permafrost areas (Nikolskiy *et al.* 2011). Ivory from *Mammuthus primigenius* is abundant in certain parts of Siberia and Alaska, and mammoth ivory has appeared more widely on the market in recent years (Vigne & Martin 2014), as restrictions on the international trade of elephant ivory have taken force (e.g. under the Convention on International Trade in Endangered Species of Wild Fauna and Flora, or CITES; www.cites.org/eng/niaps).

Figure 1: The 21 specimens submitted for testing (including a strand of 108 beads that are grouped together as sample no. 13) were purchased in China, where they were represented as 'mammoth ivory'. See Table I for sample weights. Photo by Vito Lanzafame, SSEF.

Given the regulations on elephant ivory, and the free trade in mammoth ivory, it is necessary to develop and apply scientific methods that can assign an ivory sample to its correct taxonomic species.

This article presents a case study exploring a range of methods used collectively to identify the species of 21 samples that were sold on the Chinese market as mammoth ivory. Our examination included morphological evaluation based on Schreger angles, Fourier-transform infrared (FTIR) spectroscopy and trace-element analysis of six selected specimens. When morphological assessment of the species was not possible, we performed DNA analysis.

BACKGROUND

Currently, the identification of elephant and mammoth ivories, and their distinction from other forms of ivory or imitations, rests largely on macroscopic morphological observation, although it can be supplemented by DNA analysis depending on the context. Morphological identification was outlined by Espinoza & Mann (2000) in a document that is widely used by customs agents and wildlife forensic scientists worldwide; this reference guide was updated in August 2020 (Baker *et al.* 2020). The main criterion to identify ivory is the presence of Schreger lines, which are present only in Proboscidean material. The angle formed by the Schreger lines can be used to differentiate between extant (recently living) African and Asian elephants, and extinct Proboscidea (mammoths), as explained below. However, Schreger lines are often not visible enough on processed (carved and polished) samples to make a conclusive identification.

Ivory has been studied using techniques such as Raman and Fourier-transform infrared spectroscopy (Edwards & Farwell 1995; Shimoyama *et al.* 2004; Edwards *et al.* 2006), along with detailed visual analysis and trace-element studies (Singh *et al.* 2006; Yin *et al.* 2013). However, as outlined by the United Nations in its *Guidelines on Methods and Procedures for Ivory Sampling and Laboratory Analysis* (UNODC 2014), FTIR and Raman spectroscopy can be employed to distinguish genuine carbonated hydroxyapatite-based ivory from ivory imitations such as resin, but FTIR spectroscopy should not be used to determine the animal species. Therefore, UNODC (2014) recommends that morphological and genetic methods be used for the forensic species identification of ivory.

Table I: Results of the morphological analysis of the 21 samples.

Sample no.	Item	Weight (ct)	Schreger lines visible?	CDJ[a] visible?	Schreger angle[b] (average and min.–max.)	Taxonomic identification[c]
1	Ring, carved	6.71	Yes	No	—	Proboscidea
2	Ring, carved	4.33	Yes	No	—	Proboscidea
3	Ring, carved	71.59	Yes	No	—	Proboscidea
4	Bangle	117.42	Yes	No	—	Proboscidea
5	Ring, carved	63.42	Yes	No	—	Proboscidea
6	Bead, carved	19.50	Yes	No	—	Proboscidea
7	Head and stand, carved	74.81	Yes	Yes (head)	83.2° (77°–87°)	Extinct Proboscidea
8	Plaque, carved	70.98	Yes	No	—	Proboscidea
9	Plaque, carved	211.13	Yes	Yes	94.2° (91°–99°)	Extinct Proboscidea
10	Plaque, carved	52.21	Yes	No	—	Proboscidea
11	Slab	10.36	No	No	—	Not possible
12	Plaque, carved	109.20	Yes	Yes	72.6° (53°–86°)	Extinct Proboscidea
13	Beads (108), drilled	~1.2 each	Yes	Yes (seven beads)	Two beads: 72.6° (70°–75°), 84.5° (82°–88°)	Extinct Proboscidea
14	Plaque, polished	17.91	Yes	No	—	Proboscidea
15	Snuff bottle	150.53	No	No	—	Not possible
16	Mammoth, carved	70.27	Yes	Yes (tusks)	Not possible (too small)	Proboscidea
17	Pipe mouthpiece, carved	47.62	No	No	—	Not possible
18	Bead, carved	59.46	Yes	No	—	Proboscidea
19	Stamp, carved	247.02	No	No	—	Ivory imitation
20	Stamp, carved	151.59	No	No	—	Not possible
21	Block, painted	82.78	Yes	Yes	82.2° (77°–86°)	Extinct Proboscidea

[a] CDJ = cementum-dentine junction.
[b] Schreger angles are provided only for samples on which the CDJ was visible.
[c] The standalone term 'Proboscidea' indicates that it was not possible to differentiate whether a specimen consisted of extant or extinct Proboscidean ivory.

Various genetic methods have been developed and used to identify species of Proboscidean ivory (Gupta *et al.* 2011; Wozney & Wilson 2012; Lee *et al.* 2013; Kitpipit *et al.* 2016, 2017; Conte *et al.* 2019; Ngatia *et al.* 2019). However, among these studies, only Lee *et al.* (2013) used the so-called *DNA barcoding* methodology—that is, using a specific and targeted genome region, which allows identification of both extinct and extant Proboscidean species, as well as the species of other types of ivory or ivory imitations (e.g. bone). All other previously applied techniques simply give a negative result (i.e. not Proboscidean ivory) if the ivory item originated from taxa other than those specifically targeted by the assay. Applying DNA barcoding methodology using universal primers[1] can be less sensitive than a species-specific assay, but it can provide additional information about a tested item, as it allows for the identification of a broad array of species. Such markers show variations between species, but are generally invariable within species; this makes them ideal for differentiating species

[1] For definitions of some terminology related to genetic testing, see the glossary on p. 157 of Cartier *et al.* (2018).

based on DNA (Tobe & Linacre 2010). Nevertheless, analysing these markers (based on Sanger sequencing) is not possible if a sample contains a mixture of DNA from different species. This is often the case when a specimen is very old and/or has little DNA (such as ivory from extinct Proboscideans), for which various contaminants (e.g. bacterial DNA, polishing residues or human DNA) can make up significant portions of the total DNA. To help deconvolute such species mixtures, a technique called *massive parallel sequencing* can be used (Budowle *et al.* 2016).

Although not employed in this study, isotopic analysis of ivory samples (van der Merwe *et al.* 1990; Ziegler *et al.* 2016) has been applied as an investigative technique to combat elephant poaching by further narrowing the geographic source region of an ivory sample. Another test—also beyond the scope of this article—to determine whether unknown specimens are from extinct or extant Proboscideans is age dating (e.g. carbon-14). This technique has been used to determine the age of seized elephant ivory (Schmied *et al.* 2012; Cerling *et al.* 2016), and has also been applied to mammoth samples (Basilyan *et al.* 2011), and could thus be useful to distinguish recent elephant ivory from extinct mammoth ivory. Furthermore, radiocarbon age dating can determine whether or not an elephant lived before or after the atomic 'bomb peak' (around 1950), and can thus be used to determine whether ivory should be classified as pre-CITES material (i.e. before 1 July 1975 for the Asian elephant and before 26 February 1976 for the African elephant; Brunnermeier *et al.* 2012; Schmied *et al.* 2012). Importantly, these dates and laws are not the same in every country; some are stricter or date further back than CITES regulations. For example, the UK has banned the sale of elephant ivory worked after 1947 (Harris *et al.* 2019).

MATERIALS AND METHODS

Twenty-one specimens (including multiple beads sold as a strand and classified as one sample; Figure 1 and Table I) were purchased as mammoth ivory from different dealers and shops in China and submitted to the Zurich Institute of Forensic Medicine and SSEF for testing.

Morphological Analysis Using Schreger Angles

The Schreger pattern was first described by Bernard Schreger (1800), and consists of sets of intersecting lines that radiate in a spiral fashion from the axis of a tusk (Trapani & Fisher 2003), as for example in Figure 2. According to Trapani and Fisher (2003, p. 429), 'light and dark regions forming these lines are thought to be macroscopic manifestations of systematic shifts in undulatory pathways of dentinal tubules, produced by odontoblasts as they move towards the tusk axis during dentin [*sic*] deposition'. The Schreger angle is the angle at which dextral and sinistral Schreger lines intersect. Outer Schreger angles (i.e. those closest to the outside of the tusk) are acute in extinct Proboscideans (i.e. mammoths) and obtuse in extant Proboscideans (i.e. elephants; Espinoza & Mann 1993, 2000). Mammoth ivory samples examined by Espinoza & Mann (2000) consistently showed outer Schreger angles that averaged below 100° (typically 73°), whereas the tested elephant specimens exhibited angles with averages above 100° (typically 124°). For samples with angles falling in the range of 90°–110°, it is important that multiple angle measurements be carried out and averaged (Espinoza & Mann 2000).

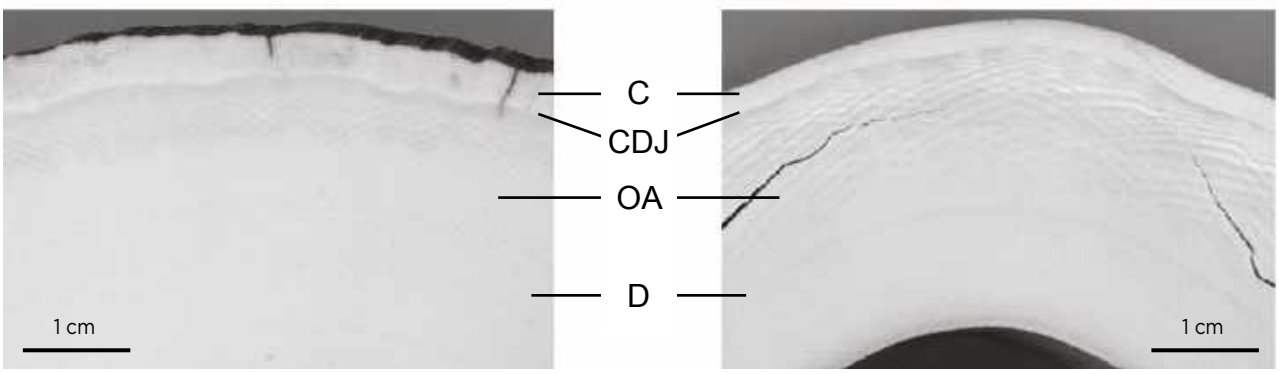

Figure 2: The angles formed by Schreger lines are shown here in extinct (left) and extant (right) Proboscidean ivory cross-sections. The outer Schreger angles (OA) in the dentine (D) closest to the cementum (C) show diagnostic differences. The cementum-dentine junction (CDJ) must be present in a sample for Schreger angles to be used reliably. Photos by Ed Espinoza.

The cementum (a layer of mineralised dental tissue which covers the outside of the tusk) must be visible for the correct reading of Schreger angles, in order to orient the sample within the tusk. Unfortunately, the cementum-dentine junction (CDJ) is not always present in worked specimens. Because only the outer Schreger lines can be used for diagnostic angle measurement, it is vital to orient a sample based on the presence of the CDJ. Research by Trapani and Fisher (2003) on specimens with and without cementum confirmed that if a sample cannot be oriented, and if the Schreger angles are measured from inner lines, then misidentifications can occur.

All 21 specimens in this study were subjected to meticulous microscopic and morphological characterisation, but only six of them were found to contain the CDJ and were therefore potentially useful for Schreger angle measurements.

Infrared and Chemical Analysis

All 21 samples were investigated by infrared spectroscopy at the Swiss Gemmological Institute SSEF using a Nicolet 550 FTIR spectrometer in transmission mode with the KBr pellet method (Khoshhesab 2012). An average of 0.5 mg of powdered material was taken from each ivory sample for each measurement. Spectra were collected in the range of 6000–400 cm^{-1} with a resolution of 0.5 cm^{-1} and 32 scans per spectrum at room temperature (25°C).

Trace-element chemistry cannot be used to clearly separate ivory species (more research and a larger data set are needed), and is thus provided here to contribute to the further chemical characterisation of ivory samples in general. Laser ablation inductively coupled plasma time-of-flight mass spectrometry (LA-ICP-TOF-MS) was used to determine the trace-element composition of six selected specimens (nos. 10, 11, 14, 16, 17 and 21). These were considered to be representative of the sample lot, and also nos. 11 and 17 could not be conclusively identified using other techniques and were thus selected for trace-element characterisation to obtain additional data. The analyses were performed at SSEF using a 193 nm ArF excimer laser (ESI/New Wave Research NWR193UC) coupled to a commercial ICP-TOF-MS unit (Tofwerk icpTOF) with helium as the carrier gas. A detailed description of this method and set-up can be found in Wang *et al.* (2016). TOF-MS allows simultaneous analysis of the full range of masses (from ^{7}Li to ^{238}U), so no pre-selection of elements (isotopes) of interest was necessary. To calculate element concentrations, we used NIST610 glass as an external standard and the stoichiometry of Ca in hydroxyapatite as an internal standard. Although not matrix-matched, this approach using NIST glass standards has been applied in numerous previous studies on biogenic calcium carbonates and phosphates (Lee *et al.* 1999; Cucina *et al.* 2007; Limbeck *et al.* 2015; and references therein). Each sample was measured at two different locations using an ablation spot size of 75 µm and 20 Hz ablation frequency.

Genetic Analysis

Genetic analysis was performed on 16 samples (i.e. those for which morphological analysis was not possible) at the Zurich Institute of Forensic Medicine, University of Zurich, Switzerland. The method for DNA extraction and the polymerase chain reaction (PCR) set-up selected to analyse the ivory specimens were standardised and validated in the ISO 17025 accredited laboratory facilities where this work was carried out. Although this methodology may not be typical for identifying Proboscidean ivory, it allows species identification also for non-Proboscidean samples.

Prior to DNA extraction, the samples were cleaned with Dr. Weigert 5% neodisher LM 3 detergent and rinsed with deionised water and 70% ethanol. About 100 mg of ivory powder were acquired from each specimen by drilling a small hole on the back or base of the sample. We used a Proxxon Micromot 50 (E) drill with a 4–6 mm diameter cone-shaped grinding bit, taking care to avoid heating up the specimen by not pressing hard and including regular pauses to let the drill head cool down. To avoid contamination, the powder produced from the initial external surface was discarded. The size and shape of some samples, and especially the desire to not alter the item's appearance, made the cleaning and drilling process very challenging.

DNA was isolated from the powdered ivory samples using a Thermo Fisher Scientific PrepFiler BTA Forensic DNA Extraction Kit, following the manufacturer's protocol for the extraction of DNA from calcified tissues (bone or tooth). For species identification, a region of the cytochrome *b* gene was amplified as described by Morf *et al.* (2013). A Beckman Coulter AMPure XP bead system was used to purify the PCR products, which were then quantified with a Thermo Fisher Scientific Qubit 4 fluorometer. To explore the utility of the massive parallel sequencing technique for performing species identification, sequencing libraries were constructed with the Thermo Fisher Scientific Ion Plus Fragment Library Kit and Ion Xpress barcode adapters, beginning with the end repair of the purified PCR products. End repair and all subsequent steps of the manufacturer's protocol were conducted by reducing all reaction volumes to one quarter and using 2.4 ng DNA input if possible.

The barcoded libraries were then quantified with a Thermo Fisher Scientific Ion Library TaqMan Quantitation Kit, and all samples were pooled with equimolar concentrations. The 26 micromolar pooled libraries were used for templating on a Thermo Fisher Scientific Ion OneTouch 2 System. Sequencing was carried out on a Thermo Fisher Scientific Ion PGM platform. Adapter-trimmed sequence data were exported to FASTQ files using the FileExporter Plugin within Torrent Suite 5.10 software. The sequences were quality filtered using USEARCH (Edgar & Flyvbjerg 2015) and clustered into operational taxonomic units (OTUs) with UPARSE (Edgar 2013) at 97% minimal identity threshold (default setting; other values were tested but did not make significant differences) and a minimal OTU size of 100 sequence reads (to analyse major components and exclude noise sequences).

The resulting sequences of the OTUs were then compared to DNA sequences stored in the online GenBank database of the National Center for Biotechnology Information (NCBI; Bethesda, Maryland, USA). We identified DNA sequence entries of the GenBank database that were most similar to the DNA sequences obtained from our samples by searching the database with the MegaBLAST function of NCBI. That way, each OTU was assigned to a taxonomic rank; ideally an OTU would correspond to a species. For each sample, read numbers pertaining to different taxonomic ranks were expressed as a percentage of the entire sequence read number. Sequences belonging to the domain of bacteria and OTUs that could not be identified via the MegaBLAST function were grouped together into one category. To exclude rare contaminants, taxonomic ranks below 10% of the total read number were not considered during evaluation of the sample. To see the relationship of the ivory DNA sequences of this study to those of extant Proboscideans and *Mammuthus primigenius*, a Bayesian phylogenetic tree was constructed using MrBayes version 3.2.7 software (Ronquist *et al.* 2012), as described by Lendvay *et al.* (2020). As reference data, we used five homologous DNA sequences of each extant Proboscidean species and *Mammuthus primigenius*, respectively. Furthermore, DNA sequences of the closely related rock hyrax (*Procavia capensis*) and dugong (*Dugong dugon*) were included as outgroup taxa. All reference data were downloaded from the GenBank database.

RESULTS AND DISCUSSION

Morphological Analysis

Schreger angles were successfully measured on five of the samples (with one sample [no. 5] consisting of two beads; see Table I). Figure 3 illustrates the location of the CDJ in one of these specimens, which is a prerequisite for morphological identification based on Schreger angles. The range of average measurements obtained from the five samples was 72.6°–94.2°. All of these measurement averages are below 100°, which according to Espinoza & Mann (2000) corresponds to the suggested limit to separate elephant ivory (above 100° average) from mammoth ivory (below 100° average). These five samples were thus conclusively identified as ivory originating from extinct Proboscideans. Therefore, further DNA analysis was not deemed necessary and was thus not carried out on those specimens.

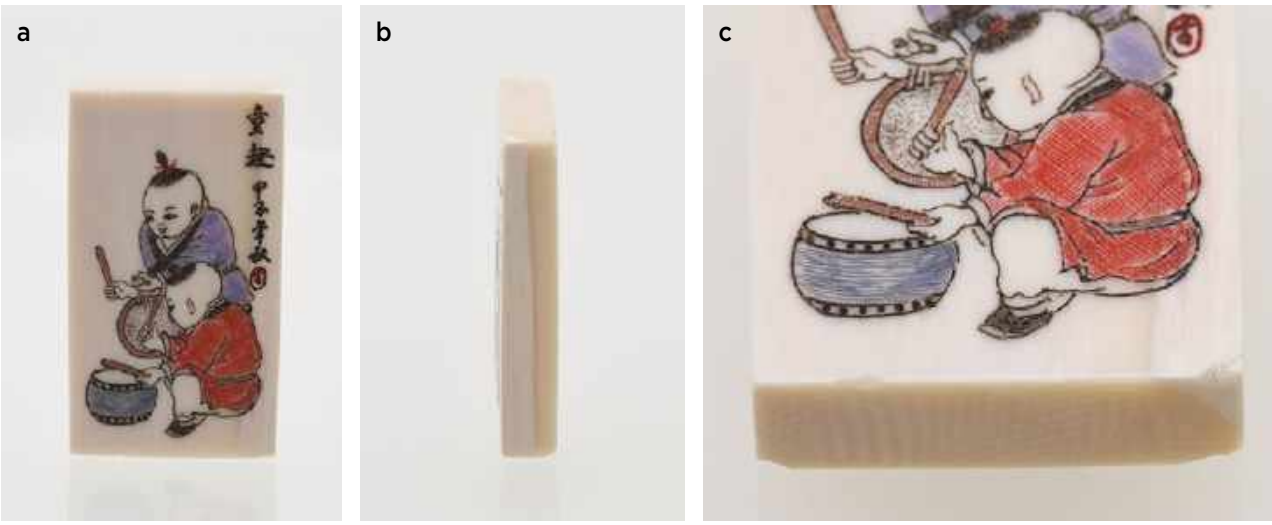

Figure 3: Sample 21 is a carved block of ivory (about 4 cm tall) that is decorated by a painting (**a**). Views of the side (**b**) and base (**c**) clearly show the cementum-dentine junction. The white part to the left in the side view is cementum, whereas the beige material on the right side is dentine. Image (c) shows cementum (white) at the upper right, next to the outer Schreger lines. The Schreger angle of these lines averaged 82.2°, which is characteristic of mammoth ivory. Photos by Vito Lanzafame, SSEF.

Although Schreger lines were observed in 11 other samples, their intersection angle could not be used due to orientation issues (absence of visible CDJ). Nevertheless, based only on the presence of the Schreger lines, these specimens could be identified as being Proboscidean.

The remaining five samples showed no Schreger lines, and no. 19 was visually identified as an ivory imitation based on the presence of a distinct layered structure intended to simulate the Schreger lines of ivory.

FTIR SPECTROSCOPY

All samples except for the ivory imitation showed FTIR spectral characteristics of carbonated hydroxyapatite (Figures 4 and 5; cf. Chang & Tanaka 2002; Grunenwald *et al.* 2014; Chappard *et al.* 2016). Figure 4 highlights a particular case (ivory bangle sample no. 4) where Schreger lines were visible but not conclusive for species identification (due to the absence of the CDJ). By contrast, specimen no. 19 yielded a very different FTIR spectrum dominated by sharp peaks (Figure 6) and was readily identified as an ivory imitation made of artificial resin (by comparison to the Thermo Scientific spectral library). The FTIR spectrum of sample no. 17 (see Figure 5) showed a characteristic carbonated hydroxyapatite spectrum, suggesting that it is of dentine or bone origin, but it could not be attributed to a specific species or species group with the methods used.

As (mammoth) ivory ages over time, carbonated hydroxyapatite can recrystallise. Furthermore, as weathering occurs, amide/phosphate ratios and carbonate/phosphate ratios can change (Jacob *et al.* 2008). Multiple factors can influence an FTIR spectrum (age, weathering state, crystallinity, collagen content and location of the sample in a tusk), so FTIR spectroscopy is not a reliable method to determine the species of ivory (see also UNODC 2014). This case study—and further unpublished research by the authors on elephant ivory from the SSEF reference collection—confirm this fact, as we could not identify clear distinguishing factors to separate elephant ivory from fossilised mammoth ivory based on FTIR spectral features.

This result is, however, different from that of Yin *et al.* (2013), who suggested a possible separation of modern elephant ivory from mammoth ivory based on FTIR spectroscopy, mainly by attributing observed differences in the spectra to the burial of mammoth ivory and related loss of water and degradation of collagen. Although such weathering-related processes are possible, their influence on FTIR spectra remains unclear (O'Connor *et al.* 2011). Our FTIR spectra of both modern elephant ivory and extinct (buried) mammoth ivory samples from the SSEF reference collection did not reveal any notable or conclusive difference in the hydroxyl range (3500–2900 cm^{-1}) or in the CH^- range (3000–2800 cm^{-1}). Based on our analyses, we thus presume that the spiky 'peaks' in the 3500–2900 cm^{-1} range of the FTIR spectra reported by Yin *et al.*

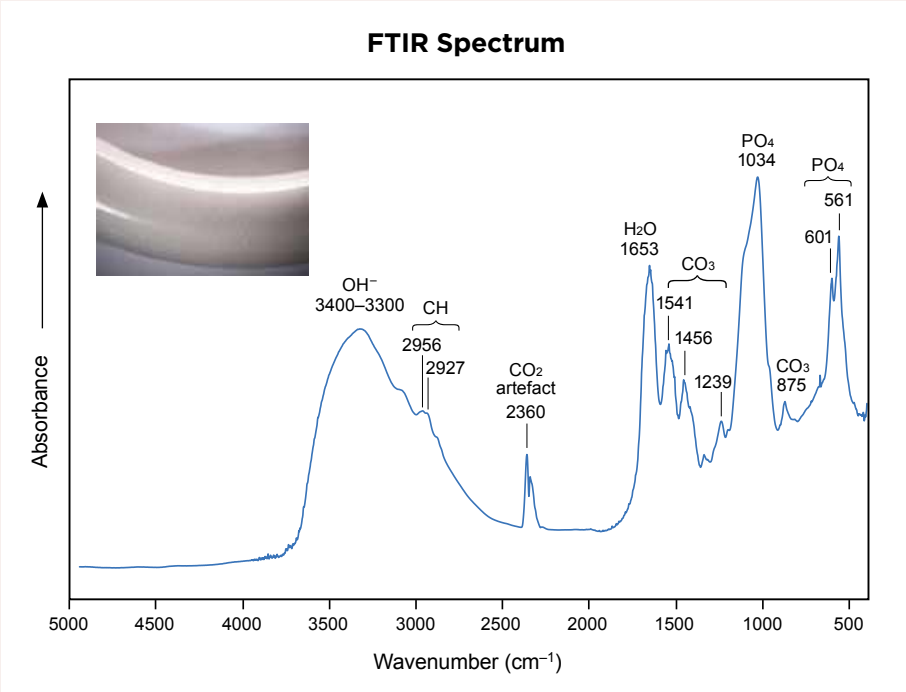

Figure 4: The FTIR spectrum of sample no. 4 (mammoth ivory bangle) shows absorption bands characteristic of carbonated hydroxyapatite (e.g. ivory and bone) and collagen. Peak attributions are after Hassan *et al.* (2016) and the artefact at 2360 cm^{-1} is from atmospheric CO_2. The inset shows Schreger lines in the bangle (which is approximately 1 cm thick; photo courtesy of SSEF), but the absence of the CDJ precludes identification based on Schreger angles.

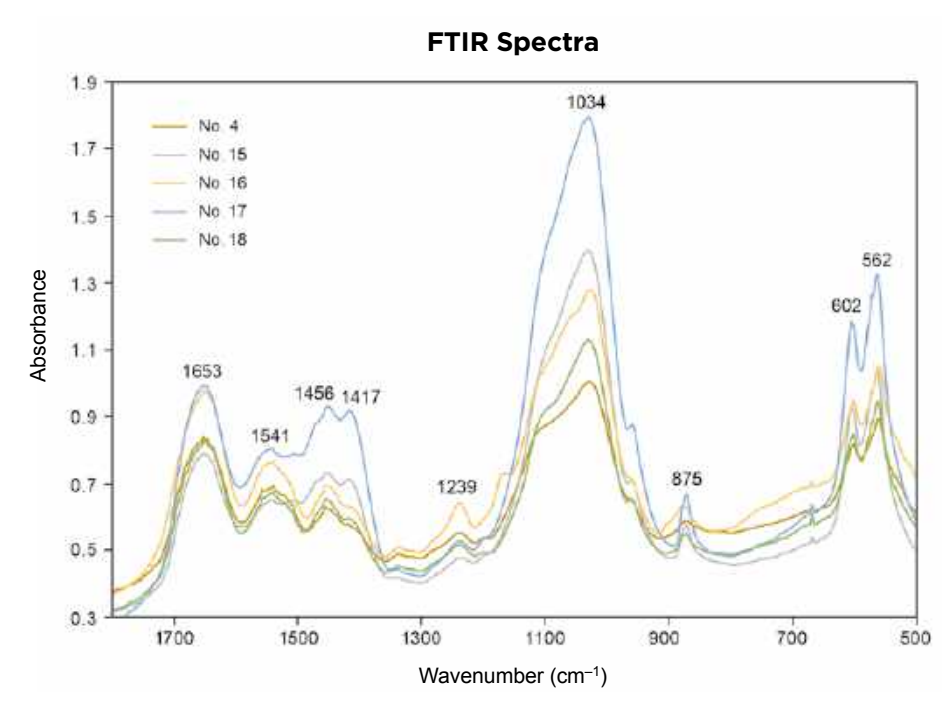

Figure 5: FTIR spectra (in the 1800–500 cm^{-1} range) of mammoth ivory (nos. 4 and 16) and undifferentiated Proboscidea (no. 18) are compared to cattle bone (no. 15, identified using DNA analysis) and one unidentified sample (no. 17). Regardless of their taxa, all these specimens show very similar spectral features characteristic of carbonated hydroxyapatite.

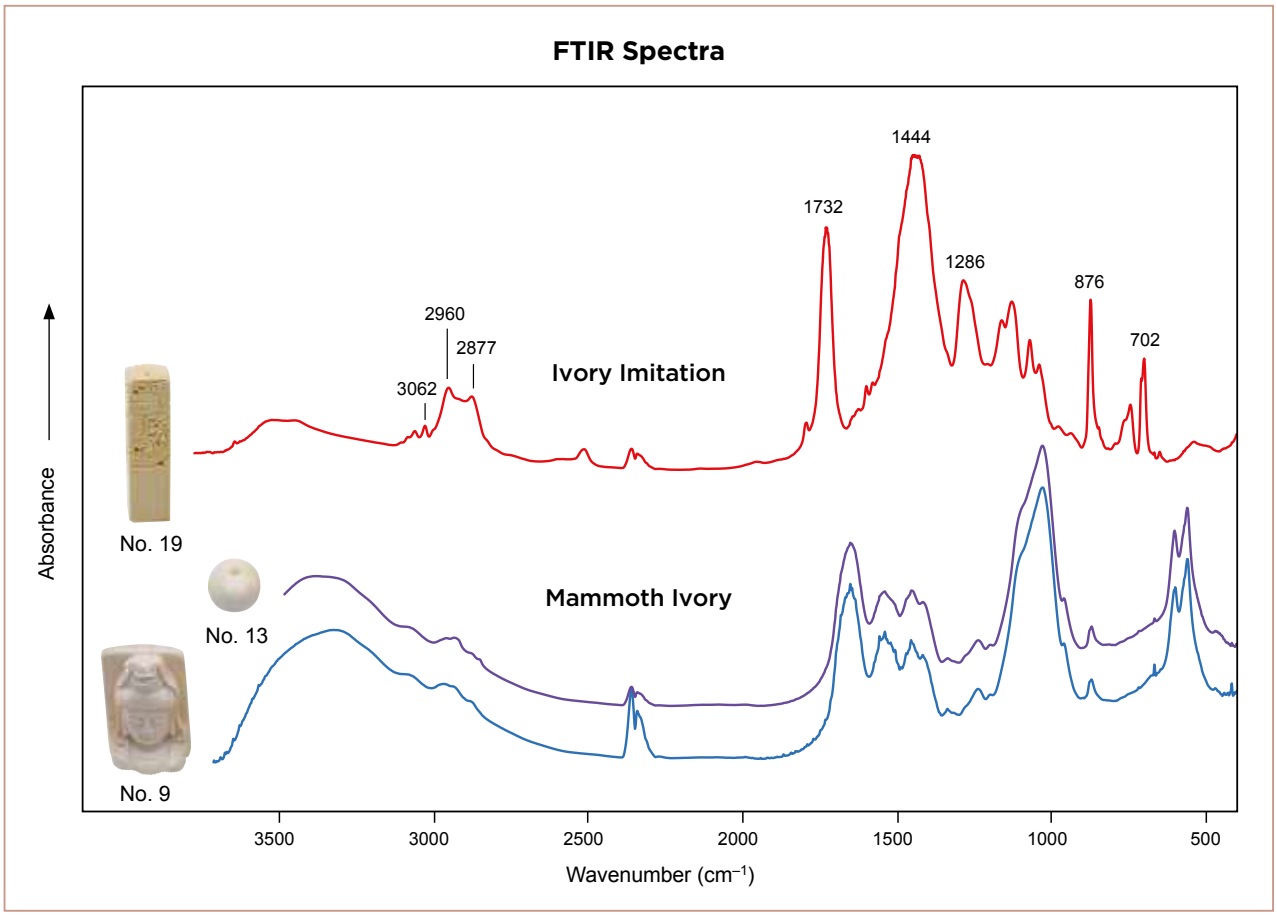

Figure 6: The FTIR spectrum of an ivory imitation (artificial resin, no. 19) is dominated by sharp polymer-related bands, and is compared to two samples of mammoth ivory (nos. 9 and 13) that display characteristic features of carbonated hydroxyapatite. Inset photos by Vito Lanzafame, SSEF; the specimens are 3.5 cm wide (no. 9), about 0.5 cm in diameter (no. 13) and 7 cm tall (no. 19).

(2013)—which were described by them as a result of water loss—are in fact artefacts due to total absorption in the hydroxyl range of their mammoth sample. In any case, the present study clearly reveals that species identification or age estimation (modern vs. fossil) of ivory based on FTIR spectroscopy is not reliable.

Trace-Element Analysis

Polycrystalline hydroxyapatite can accommodate a broad range of trace elements, primarily as substitutions for the large Ca^{2+} cation (Brown & Constantz 1994). A selection of relevant elements is listed in Table II for the six samples analysed by LA-ICP-TOF-MS. A comparison of our data to the literature (Kohn *et al.* 1999 and references therein) reveals high consistency with reported concentration ranges for fossil dentine. Each specimen was analysed on two randomly selected areas, and our data suggest that each one was very homogeneous in its trace-element concentrations. Interestingly, three of the samples (nos. 14, 16 and 21, all identified as extinct Proboscidea by their morphology or DNA testing, as covered below) showed distinctly higher Mg but lower concentrations of Fe, Sr and Ba compared to sample no. 10 (undifferentiated Proboscidea). Specimen no. 11 (which could not be identified) was characterised by relatively high Mn, Fe and, to some extent, Sr, Ba and rare-earth elements (REEs). This might be related to alteration during burial in soil (diagenesis), as this sample looked weathered and was reddish brown (Figure 7), as if stained by Fe-Mn (hydr)oxides. Specimen no. 17 (also not identifiable) differed in having higher Na, Zn, Ba and REEs compared to the other samples.

Genetic Analysis Based on a Region of the Cytochrome b *Gene*

DNA analysis was carried out on 16 of the 21 samples, and was successful for 15 of them. For one specimen (no. 11), no PCR product could be amplified, most likely

Table II: LA-ICP-TOF-MS trace-element data (in ppmw) for six selected samples.[a]

Sample no.	Spot	B	Na	Mg	Si	Cr	Mn	Fe	Zn	Sr	Ba	REE	Pb	U/Pb	Taxonomic identification (based on morphology or DNA)
10	1	7.85	4415	7653	266.3	1.186	153.9	639.2	34.17	994.3	95.28	0.208	0.153	0.10	Proboscidea
	2	7.45	4372	7381	265.7	1.054	147.6	614.4	36.62	971.9	92.89	0.193	0.166	0.12	
11	1	5.46	2700	1470	343.8	0.539	4808	26300	38.89	1315	768.8	1.236	0.061	0.30	Not possible
	2	5.90	2770	1468	321.6	1.132	4758	26260	40.24	1311	767.9	1.228	0.054	0.21	
14	1	8.28	3081	43370	339.3	1.124	0.899	31.69	25.81	318.3	48.16	0.125	0.108	0.12	Extinct Proboscidea
	2	7.61	3172	37830	281.7	0.902	0.850	24.41	27.36	316.9	46.74	0.083	0.180	0.10	
16	1	14.07	4172	42690	255.7	1.150	0.924	28.55	34.92	385.8	15.52	0.021	0.030	na	Extinct Proboscidea
	2	14.02	4297	41460	288.3	0.790	0.913	25.07	34.79	386.1	15.67	0.045	0.031	0.19	
17	1	5.95	8423	5554	218.4	0.653	0.931	26.94	121.9	609.4	719.7	1.112	0.633	0.01	Not possible
	2	6.05	8262	5467	199.4	0.451	1.164	25.47	136.8	599.7	752.9	1.221	0.755	na	
21	1	11.19	4905	39250	292.6	0.908	0.948	20.11	28.22	345.6	45.47	0.130	0.185	0.08	Extinct Proboscidea
	2	11.83	5205	36220	314.6	0.782	0.971	22.42	31.52	356.1	44.50	0.142	0.200	0.15	
Reference values (Kohn *et al.* 1999)		>10–10s	1000s	1000s	10–~100s	nr	nr	nr	100s–1000s	100s–~100	10s–~100	<1	nr	<1	Fossil dentine[b]

[a] Abbreviations: na = not applicable because U was below the detection limit; nr = not reported by Kohn *et al.* (1999).
[b] Range of values from Burchell's zebra (*Equus burchellii*), Guenther's dik-dik (*Rhynchotragus guentheri*) and Grant's gazelle (*Gazella granti*).

Figure 7: This weathered sample (no. 11; about 2 cm wide) was found to contain relatively high Fe and Mn concentrations. Its colour and chemistry might be related to alteration during burial in soil, resulting in impregnation with Fe-Mn (hydr)-oxides. Photo by V. Lanzafame, SSEF.

due to too little or too degraded DNA. By using massive parallel sequencing to analyse the genetic data, we were able to deconvolute mixtures and infer the different DNA contents of a specimen. Detected bacterial species were excluded as a possible origin. Any human DNA detected as a minor component in a mixture was considered a contaminant and was not included in the final taxonomic identification.

The taxonomic origin of nine samples was identified as extinct Proboscidea, one specimen originated from the genus *Bos* (wild and domestic cattle) and the DNA analysed for another sample was of human origin (Table III). The DNA extracts of the remaining four specimens were identified as DNA mixtures in which human DNA accounted for the largest part. The minor parts of these mixtures originated from the following taxonomic ranks: *Mammuthus* sp. (mammoths), *Loxodonta* sp. (African elephants), *Gallus gallus* (junglefowl, e.g. chickens) and bacteria.

Table III: Results for 16 samples based on DNA analysis, including total number of sequence reads per sample.*

Sample no.	Total no. of reads	*Mammuthus* sp.	*Homo sapiens*	*Loxodonta* sp.	*Bos* sp.	*Gallus gallus*	Bacterial or unidentifiable sequences	Sequences below threshold	Taxonomic identification
1	1012	70.7	14.7					14.7	Extinct Proboscidea
2	6850		73.1	13.2			13.3	0.3	Mixture
3	17855	98.8						1.2	Extinct Proboscidea
4	20580	98.5						1.5	Extinct Proboscidea
5	20285	98.5						1.5	Extinct Proboscidea
6	12070	95.3						4.7	Extinct Proboscidea
8	3251	30.2	66.7					3.1	Mixture
10	996		62.3			37.3		0.4	Mixture
11									Not possible
13	2939	99.5						0.5	Extinct Proboscidea
14	13931	73.9	21.3					4.8	Extinct Proboscidea
15	6317				62.9		33.2	3.9	*Bos* sp.
16	10958	56.7	41.8					1.6	Extinct Proboscidea
17	5974		81.5			12.0		6.6	Mixture
18	10833		93.1					6.9	*Homo sapiens*
20	14908	97.8						2.2	Extinct Proboscidea

* The read numbers pertaining to different taxonomic ranks are expressed as percentages of the entire sequence read number, and sequences of OTUs with less than 100 reads are grouped together with sequences of taxonomic ranks with less than 10% of the total read number in the category titled 'Sequences below threshold'.

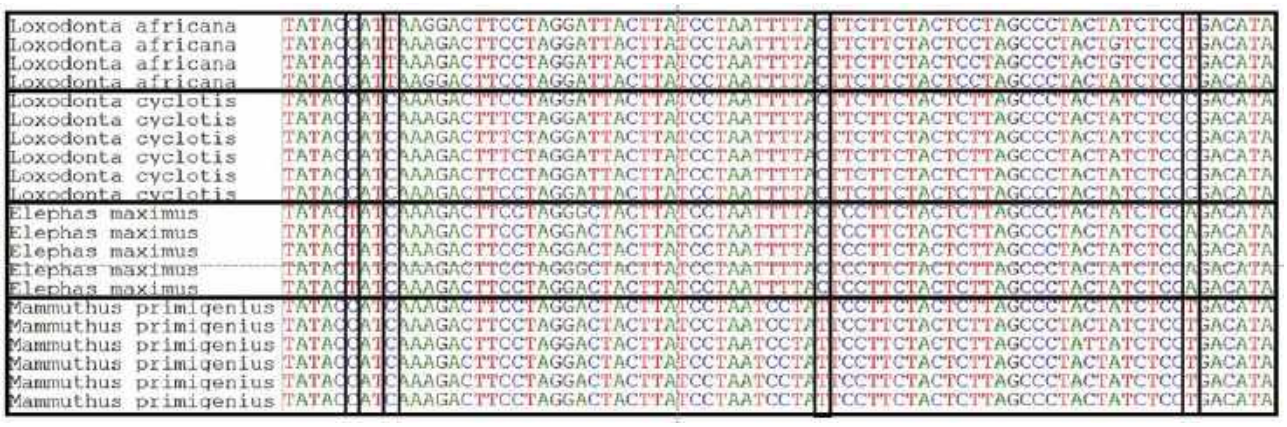

Figure 8: Nucleotide differences between extant Proboscidean species and the woolly mammoth (*Mammuthus primigenius*) are bracketed by vertical lines in this DNA sequence alignment of a short fragment of the mitochondrial cytochrome *b* gene.

Separating Mammoth and Elephant Ivory Using Genetic Analysis

To demonstrate how our genetic analysis is able to differentiate between elephant and mammoth ivory, we compared sequences from different Proboscideans in the online NCBI database. Figure 8 shows examples of nucleotide (A, C, G, T) differences between the extant Proboscidean species and the woolly mammoth (*Mammuthus primigenius*) in a short fragment (length: 78 base pairs) of the mitochondrial cytochrome *b* gene. The sequences of the extinct Proboscidea (length: 359 base pairs) obtained in this study showed 10 or more nucleotide differences from the sequences of African or Asian elephants found in the NCBI database.

These sequences from the extinct Proboscidean samples were included in a Bayesian phylogenetic tree containing sequences of extant Proboscideans and *Mammuthus primigenius* (Figure 9). A phylogenetic tree

Figure 9: This Bayesian phylogenetic tree displays the taxonomic position of our ivory samples identified as extinct Proboscidea. With high probability, these specimens group together with those of *Mammuthus primigenius*. Species names for the reference samples are followed by their NCBI GenBank accession numbers. Bayesian posterior probability values next to the branches indicate the levels of support that the specimens in that branch group together; a value greater than 0.95 is generally accepted as well-supported clustering.

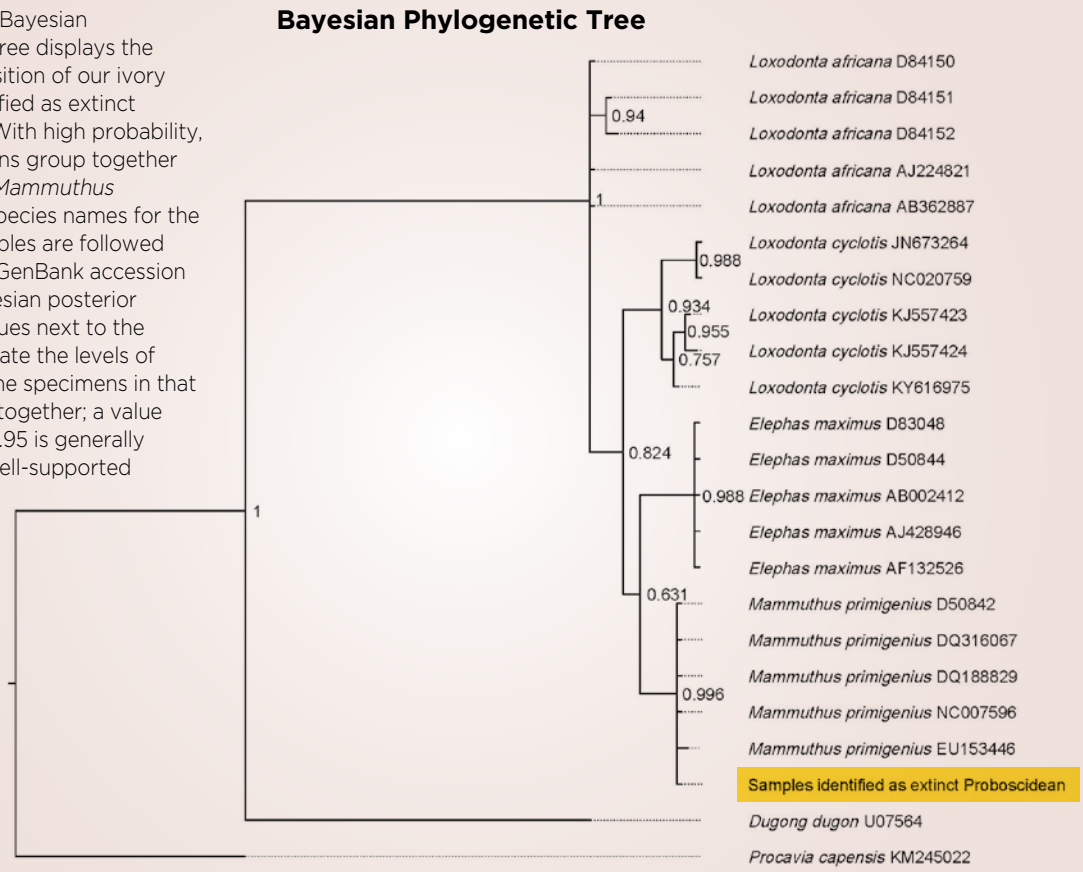

is a diagram representing evolutionary relationships among organisms. The included species are found at the tips of lines, referred to as tree branches. The pattern in which these branches connect represents how the species evolved from different common ancestors; a node represents a divergence event. In our phylogenetic tree, the identical DNA sequences obtained from nine of our tested samples grouped together, with high probability, with sequences of *Mammuthus primigenius*.

Combining the Results of the Morphological, Gemmological and Genetic Methods

By combining the results of all the analyses we conducted, we were able to determine the origin of all but two of the 21 samples (Table IV). Thirteen specimens were attributed to extinct Proboscideans (*Mammuthus* sp.). Five of these were identified by their morphological features (Schreger angles) and nine as a result of DNA analysis (different beads in sample no. 13 were identified by both techniques).

DNA analysis could not be used to specify the exact species of origin of four samples exhibiting inconclusive Schreger angles because their DNA extract consisted of a mixture of species. These samples were therefore identified as simply 'Proboscidean' since their extinct or extant origin could not be determined. Although the major component shown by genetic testing was ascribed to *Homo sapiens*, a human origin was ruled out due to the observed Schreger lines, so the presence of human DNA is considered contamination. Surprisingly, one of

Table IV: Taxonomic identification of the samples based on the methods used in this case study.

Sample no.	Taxonomic identification based on morphological analysis	Taxonomic identification based on DNA analysis	FTIR analysis	Taxonomic identification, considering results from all analyses
1	Proboscidea	Extinct Proboscidea	Carbonated hydroxyapatite	Extinct Proboscidea
2	Proboscidea	Mixture	Carbonated hydroxyapatite	Proboscidea
3	Proboscidea	Extinct Proboscidea	Carbonated hydroxyapatite	Extinct Proboscidea
4	Proboscidea	Extinct Proboscidea	Carbonated hydroxyapatite	Extinct Proboscidea
5	Proboscidea	Extinct Proboscidea	Carbonated hydroxyapatite	Extinct Proboscidea
6	Proboscidea	Extinct Proboscidea	Carbonated hydroxyapatite	Extinct Proboscidea
7	Extinct Proboscidea	Not performed	Carbonated hydroxyapatite	Extinct Proboscidea
8	Proboscidea	Mixture	Carbonated hydroxyapatite	Proboscidea
9	Extinct Proboscidea	Not performed	Carbonated hydroxyapatite	Extinct Proboscidea
10	Proboscidea	Mixture	Carbonated hydroxyapatite	Proboscidea
11	Not possible	Not conclusive	Carbonated hydroxyapatite	Not possible
12	Extinct Proboscidea	Not performed	Carbonated hydroxyapatite	Extinct Proboscidea
13	Extinct Proboscidea	Extinct Proboscidea	Carbonated hydroxyapatite	Extinct Proboscidea
14	Proboscidea	Extinct Proboscidea	Carbonated hydroxyapatite	Extinct Proboscidea
15	Not possible	*Bos* sp.	Carbonated hydroxyapatite	*Bos* sp.
16	Proboscidea	Extinct Proboscidea	Carbonated hydroxyapatite	Extinct Proboscidea
17	Not possible	Mixture	Carbonated hydroxyapatite	Not possible
18	Proboscidea	*Homo sapiens*	Carbonated hydroxyapatite	Proboscidea
19	Imitation	Not performed	Ivory imitation	Ivory imitation (artificial resin)
20	Not possible	Extinct Proboscidea	Carbonated hydroxyapatite	Extinct Proboscidea
21	Extinct Proboscidea	Not performed	Carbonated hydroxyapatite	Extinct Proboscidea

these specimens (no. 10) had a minor component attributed to the species *Gallus gallus*, but again because of the observed Schreger lines we know this sample did not originate from a chicken. A possible source of contamination could be residual chicken grease used to polish the specimen during manufacturing.

One sample originated from the genus *Bos* (no. 15; cattle bone) according to DNA analysis, and another (no. 19) was conclusively identified as an imitation of ivory made of artificial resin based on microscopic and FTIR analyses. Finally, two specimens (nos. 11 and 17) did not exhibit any Schreger angles, nor any other morphological characteristics indicative for ivory. DNA analysis of these items was also not successful—one sample exhibited too little or too degraded DNA, and the DNA extract of the other consisted of a mixture—so their taxonomic identification was not possible.

CONCLUSIONS

Various types of ivory may be encountered by gemmologists as *objets d'art*, jewellery and other items (e.g. Figures 1 and 10). This case study shows the challenges and limitations of distinguishing between these gem materials. To identify the nature (e.g. ivory or imitation) and species of 'ivory' samples, a combined approach using multiple techniques (in this study, morphological, gemmological and genetic) can be helpful in many instances. For this case study, determination began with morphological analysis (macroscopic and microscopic), which is the most readily available testing method. Samples not displaying orientable Schreger lines were tested further using DNA analysis. Techniques available in well-equipped gemmological laboratories (FTIR and LA-ICP-TOF-MS) were applied to further characterise

Figure 10: The carved mammoth-ivory leaves in these gold earrings are accented by diamonds and accompanied by ~2.4 ct of pink sapphires. Courtesy of Paul Farmer Goldsmith, Vail, Colorado, USA; photo by Jeff Scovil.

and document a selection of the samples, but they were not useful for identifying whether a specimen was from an extinct or extant Proboscidean species. Importantly for gemmologists, the presence of a cattle bone sample that had FTIR features similar to those of ivory shows the importance of integrating DNA analysis into origin determination when Schreger lines are not clearly visible or measurable.

Jacob *et al.* (2008) showed that the distribution of chemical elements in tusks is heterogeneous. They also proposed that isotopic rather than trace-element analysis might be more suitable for identifying the geographic source region of ivory species, but this method is outside the scope of this study. The portion of the tusk being analysed should be taken into account when carrying out trace-element and isotopic analysis of ivory specimens; if the CDJ is not present, then establishing a consistent sampling position is not possible. Furthermore, the degree of weathering (and presence of associated elements) in fossilised ivory samples, which can be 10,000 years or older, is a considerable factor to take into account. A larger reference database would be needed before attempting to use trace elements, and more specifically ultra-trace elements (e.g. REEs), to identify different ivory species.

Although the ivory trade has changed due to more stringent international regulations, material continues to be misrepresented on the market, and research such as outlined here is important to support elephant conservation work worldwide. Making techniques available to conclusively identify ivory species can help limit fraud, as in cases where poached elephant ivory is falsely declared as mammoth ivory. During an August 2019 CITES conference in Switzerland, a proposal was made (although ultimately retracted) to include mammoth ivory in CITES appendices. The ongoing interest in differentiating between extinct vs. extant ivory demonstrates the need for the reliable identification of ivory in the trade.

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Stereoscopy in Asteriated Gemstones Revisited

Thanh Nhan Bui, Pascal Entremont, Francesco Mazzero and Jean-Pierre Gauthier

ABSTRACT: This article documents an optical illusion displayed by the asterism of one of the largest-known star garnets. This dark brownish purple gem weighs 5,737 ct and exhibits a sharp, classical four-rayed star. The three-dimensional phenomenon—in which some or all branches of the asterism appear to float above the stone—is mainly visible due to the stone's large size. Such an illusion was partially documented for star and cat's-eye gemstones by Killingback (2005), who invoked the concept of stereoscopy to explain the effect. We report new observations of the phenomenon displayed by this garnet, as well as a star rose quartz, through stereoscopic images and anaglyphs. These show that the amplitude of the floating effect depends on the orientation of the star with respect to the observation plane.

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Asterism is an optical phenomenon that has been broadly reported in the gemmological literature, and comprehensively documented in a recent book on star gemstones (Steinbach 2016). Various authors have studied the optical effect that produces asterism and chatoyancy (e.g. Wüthrich & Weibel 1981; Killingback 2005). The effect is caused by the scattering of incident light from acicular inclusions near a stone's surface that are oriented in parallel directions depending primarily on the crystallographic symmetry of the host mineral.

The star or cat's-eye that is seen when such a sample is cut *en cabochon* may appear as if slightly above the stone, giving the impression that it floats over the cabochon (Moon & Phillips 1984). Using a large star rose quartz sphere as an example, Killingback (2005) demonstrated that the floating effect is present on all star and cat's-eye gemstones. When we observe a cabochon using both eyes together (whether unaided or through a binocular microscope), the visibility of the floating-effect optical illusion depends on the angle of the cat's-eye or the branches of the star relative to the observation plane (formed by both eyes), as well as the size of the stone.

Here, we describe this phenomenon in detail in a large four-rayed star garnet (Figure 1). Author PE noticed that

Figure 1: The 5,737 ct 'Two Pound Star' from the collection of author PE is a cabochon-cut garnet displaying a sharp four-rayed star. The size of this stone makes it easy to observe the stereoscopic effect of the star with unaided eyes, as documented in this article. Photo by T. N. Bui.

when observing the stone at certain angles, it sometimes gives the impression that it would be possible to insert an object between the two branches of the four-rayed star. This optical phenomenon can be explained by invoking the concept of stereoscopy. We also examine this effect using a six-rayed star rose quartz.

Stereoscopy dates back to the 19th century when Charles Wheatstone lectured to the Royal Society in London on this topic (Wheatstone 1838, 1852). Today, stereoscopy is widely exploited for three-dimensional (3D) imaging in numerous fields.

MATERIALS AND METHODS

The studied garnet was obtained in Jaipur, India, by author PE in around 1985. The stone is cabochon cut and weighs approximately 5,737 ct (about 95 × 82 × 68 mm), making it one of the largest-known star garnets; its weight gave author PE the idea to name it 'Two Pound Star'. The gem's existence was reported in the French press in the 1980s (e.g. de La Taille 1987, p. 83) and it was also published in the *Guinness Book of World Records* (McWhirter 1986). In addition, the stone has been illustrated in the gemmological literature (Schmetzer *et al*. 2002a, b), and it was recently displayed as part of the Entremont Collection at the first temporary exhibition of the new 'DIVA, Antwerp Home of Diamonds' museum in Belgium (Bui 2018). The garnet is accompanied by a 2015 report from GGTL Laboratories stating that it consists of pyrope-almandine with physical and chemical characteristics that are similar to those garnets from India.

For comparison, we also examined a six-rayed star rose quartz that was purchased by author FM in Madagascar in 2001. It consists of a semi-transparent pink sphere with a diameter of 45.20 mm and weight of 633.50 ct.

Both specimens were studied by means of visual observation, and the optical effects are explained using stereoscopy principles and techniques. A stereoscope is a device by which two photographs of the same object taken at slightly different angles are juxtaposed (a stereogram or stereograph) and viewed together. It mainly consists of a pair of lenses and a divider, which is placed between the images and the observer in order to force each eye to see the respective parts of the stereogram separately. Due to the similarity of the two images in the stereogram, the brain reconstructs them into a single image, creating a 3D effect.

Stereoscopic images are an effective way of illustrating the 'floating' asterism seen in star stones. A stereogram's pair of images—left and right—represents what is seen separately by the left eye and right eye, respectively. The difference in what the two eyes see is called *stereoscopic parallax*; it allows the brain to interpret what the eyes see as having depth (or depth perception). Usually, stereoscopic cameras have two objectives; a set-up using two cameras can also produce stereoscopic pictures. For this study, we used a single camera on a tripod affixed to a 7-cm-long slider to obtain pairs of pictures taken from different perspectives while keeping both the stone and the light source motionless. The gem in each pair of pictures was systematically positioned to simulate the convergence of two eyes. We used an average human interpupillary distance of about 65 mm and a distance of about 650 mm between the observer and the stone, yielding an angle of 2.87° for the eyes' convergence. The star rose quartz was photographed from the side, where a large partially healed fracture is located, to provide a frame of reference for the reader while observing the stereograms.

To see the 3D effect in stereograms with unaided eyes (i.e. without the use of a stereoscope): (1) place the image pair about 20 cm from your eyes (with the PDF sized at 75% if viewing them on a computer screen); (2) allow your eyes to relax, as if staring into the distance; (3) as your eyes defocus, the images of the stone will float sideways; (4) pay attention to the image that coalesces at the centre, where the 3D effect should be visible.

RESULTS

Four-Rayed Star Garnet

Figure 1 shows the overall appearance of the star garnet, illuminated at its centre with a torch, revealing the dark brownish purple body colour of the huge cabochon and highlighting its four-rayed star, which is caused by the presence of acicular inclusions oriented along crystallographic directions in the garnet. The piece is opaque, due partly to the abundance of needles that are responsible for the asterism, and also to other, opaque inclusions and the overall dark colour of the garnet. The two branches of the star intersect at approximately 70° and 110°, in agreement with the previous studies of star garnets (e.g. Guinel & Norton 2006 and references therein).

The branches of the four-rayed star garnet are shown as seen by each eye in the stereograms in Figure 2. In the particular orientation of the star relative to the observation plane in Figure 2a, the illusion is that the short horizontal branch is on the surface of the cabochon and the other one is floating above it. In other words, the horizontal branch and the surface of the cabochon appear as the

background, with the oblique branch floating above on a virtual surface. When the eye moves in a sideways direction relative to the fixed cabochon and light source, the oblique branch moves in the opposite direction. The illusion of depth between the two branches of the star is produced by the displacement of the oblique branch—in this case by a significant amount—due to binocular vision (the distance between the eyes) combined with certain observation conditions (the distance between the stone and the eyes), compared to the fixed horizontal branch, which lies along the observation plane. The phenomenon is strongly enhanced in this sample for this particular orientation of the branches because of the cabochon's large size.

The oval shape of the cabochon and, thus, the different curvature radii along its width and length do not contribute to the optical illusion. Instead, it is exclusively due to the stereoscopic effect. When one eye

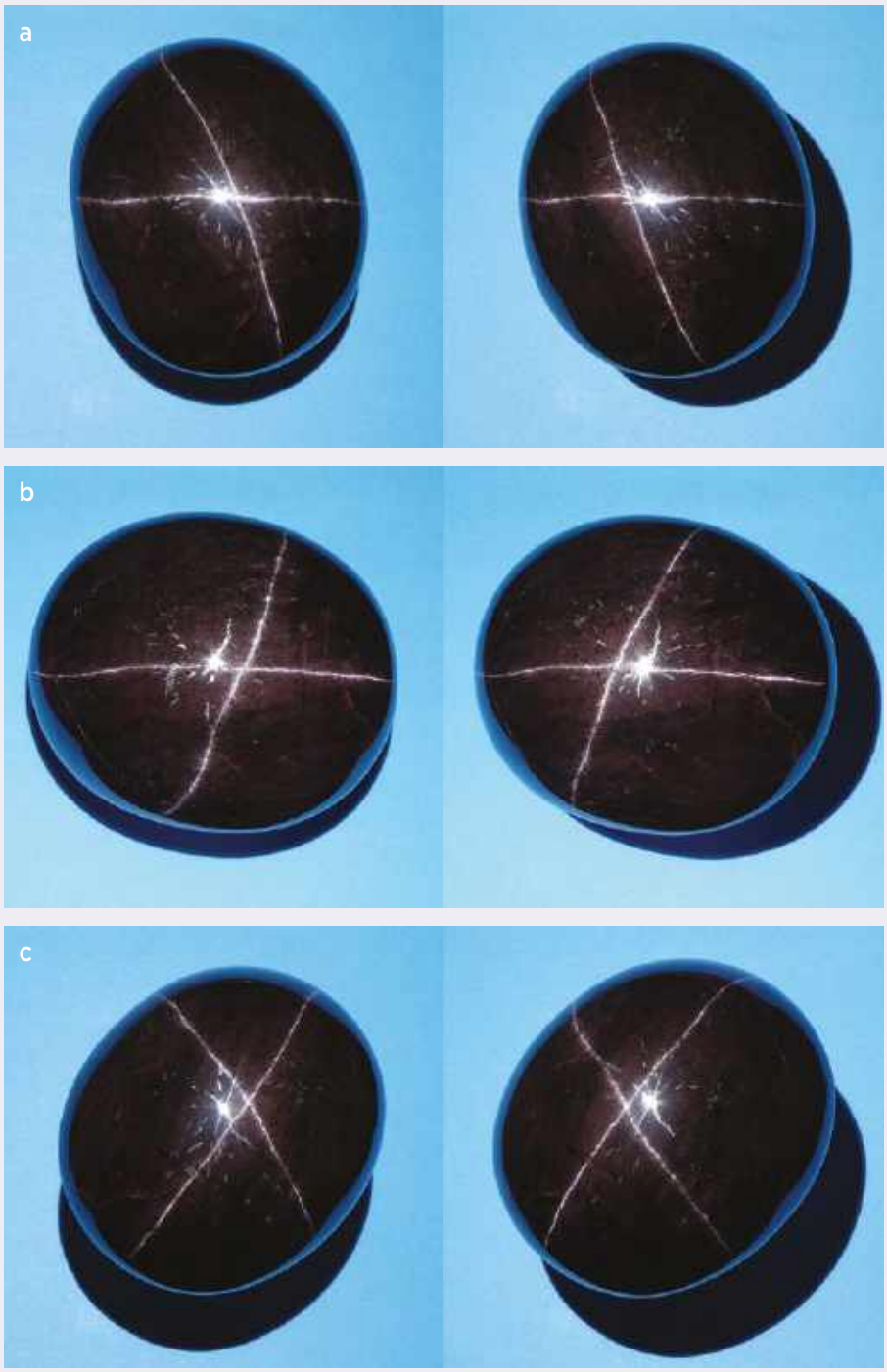

Figure 2: These stereograms consist of pairs of photos of the star garnet as seen (left) by the left eye and (right) by the right eye. In this sequence of images (a–c), the stone is rotated to show three different orientations of the star's branches. (**a**) This particular orientation of the branches of the star relative to the observation plane highlights the optical illusion caused by the stereoscopic effect, in which the long branch appears to float over the short one. (**b**) In this position, the stereoscopic effect causes the short branch to appear to float over the long one, similar to the condition in (a). (**c**) When the two branches are symmetrically oblique to the observation plane, they both appear to float above the surface of the cabochon at the same height. Photos by T. N. Bui.

is closed, the optical illusion disappears, and the eye remaining open observes a two-dimensional image.

The additional stereograms in Figure 2 show the star garnet in two other orientations: with the branch along the length of the cabochon horizontal (Figure 2b) and with both branches at symmetrically oblique angles (Figure 2c). When aligning the longer branch horizontally, it remains at a fixed position for both eyes (as previously illustrated in Figure 2a for the shorter branch), and the illusion is that the shorter branch floats above and in front of the longer horizontal one. When both branches are symmetrically oblique, the apparent gap between them disappears, but the impression is that both are floating above the cabochon. With further rotation of the stone, the relative position of these two branches above the cabochon appears to shift so that one branch is seen below the other one (and vice versa when turning it in the other direction).

So, by rotating the stone through 360°, beginning with the last-described orientation (Figure 2c), the branches are initially both seen floating above the cabochon, and then they appear to separate, such that the branch which appears to move in front of the other is the one rotating towards vertical. When one branch reaches the horizontal position, the two branches theoretically reach their maximum apparent separation distance (Figures 2a and 2b), where the horizontal branch seems stuck on the surface of the cabochon and the other one is floating above it. By continuing to rotate the stone in the same direction, the two branches get closer and once more are both seen floating above the cabochon when they again reach one of the four symmetrically oblique positions (e.g. Figure 2c).

Six-Rayed Star Rose Quartz

The floating effect reported by Killingback (2005) concerned the vertical branch of a six-rayed star in a rose quartz sphere. However, the observations we describe here consider the interactions among all the branches of the star. We photographed our rose quartz sphere by rotating it into three different orientations, in which one of the three branches is vertical (Figure 3a), one is at 45° to the vertical plane (Figure 3b) and one is horizontal (Figure 3c).

In the stereogram in Figure 3a, all three branches are seen as floating above the surface of the stone. (The vertical branch may appear slightly higher than the two others, but not by a significant amount.) In Figure 3c, the horizontal branch remains practically at the same position for both eyes and therefore seems stuck on the cabochon's surface, while the other two branches are symmetrically oblique and appear to float together at the same level above the horizontal branch. In Figure 3b, all three branches appear to float at different heights, but the illusion of depth between the branch closest to horizontal and the other two is more pronounced. These observations are similar to those described for the four-rayed star garnet, and correspond to a combination of the different viewing conditions.

Another representation of the stereoscopic effect can be seen by using '3D glasses' to view an anaglyph, in which both pictures comprising a stereogram are superimposed in the same frame. The 'left' picture is generally in red and the 'right' one in cyan. The interpretation of an anaglyph is accomplished with two colour filters—red for the left eye and cyan for the right eye, as used to create the traditional 3D glasses that at one time were widely used for watching 3D films (subsequently replaced by the current polarisation 3D systems). These complementary colours also allow 3D pictures to be reproduced in static images when viewed with these glasses.

This effect is illustrated in Figure 4a–c using the same conditions for the star rose quartz as in Figure 3a–c. The slightly different positions of the six-rayed star seen by each eye are responsible for the floating and stereoscopic effects, but they are more clearly illustrated in these anaglyphs. The illusion of depth between two branches is caused by the amount of their apparent displacement. Figure 4a shows a larger displacement for the vertical branch compared to the two oblique branches[1]. The floating effect reaches its maximum when a branch is vertical, weakens in the branch that gets closer to horizontal (Figure 4b) and is nil when a branch is horizontal (Figure 4c). The different amounts of displacement for each of the three oblique branches in Figure 4b express the different apparent heights of the floating effect observed in the corresponding stereogram (Figure 3b).

DISCUSSION

Star Garnets Showing Asterism

Star garnets of pyrope-almandine composition are known from various world localities such as Andhra Pradesh, India (Kumar *et al.* 1992), Ilakaka, Madagascar (Schmetzer & Bernhardt 2002), and Idaho, USA (Guinel & Norton 2006).

[1] The relative distance between the red and cyan representations of the same branch is consistent in one anaglyph but cannot be compared from one anaglyph to another because we used slightly different vertical axes for each orientation of the star to best highlight the stereoscopic effect.

The origin of asterism in almandine(-pyrope) has been described in detail (see, e.g., Walcott 1937; Schmetzer *et al*. 2002a; Guinel & Norton 2006). Walcott (1937) studied the crystallographic orientations of the needle-like inclusions in star garnets showing four rays, as well as displaying both four- and six-rayed asterism in the same sample. Schmetzer *et al*. (2002a) used Raman spectroscopy and Guinel and Norton (2006) employed electron diffraction to identify the needles in star garnets as rutile; the latter study also established the crystallographic orientation relationship between the inclusions and the host garnet.

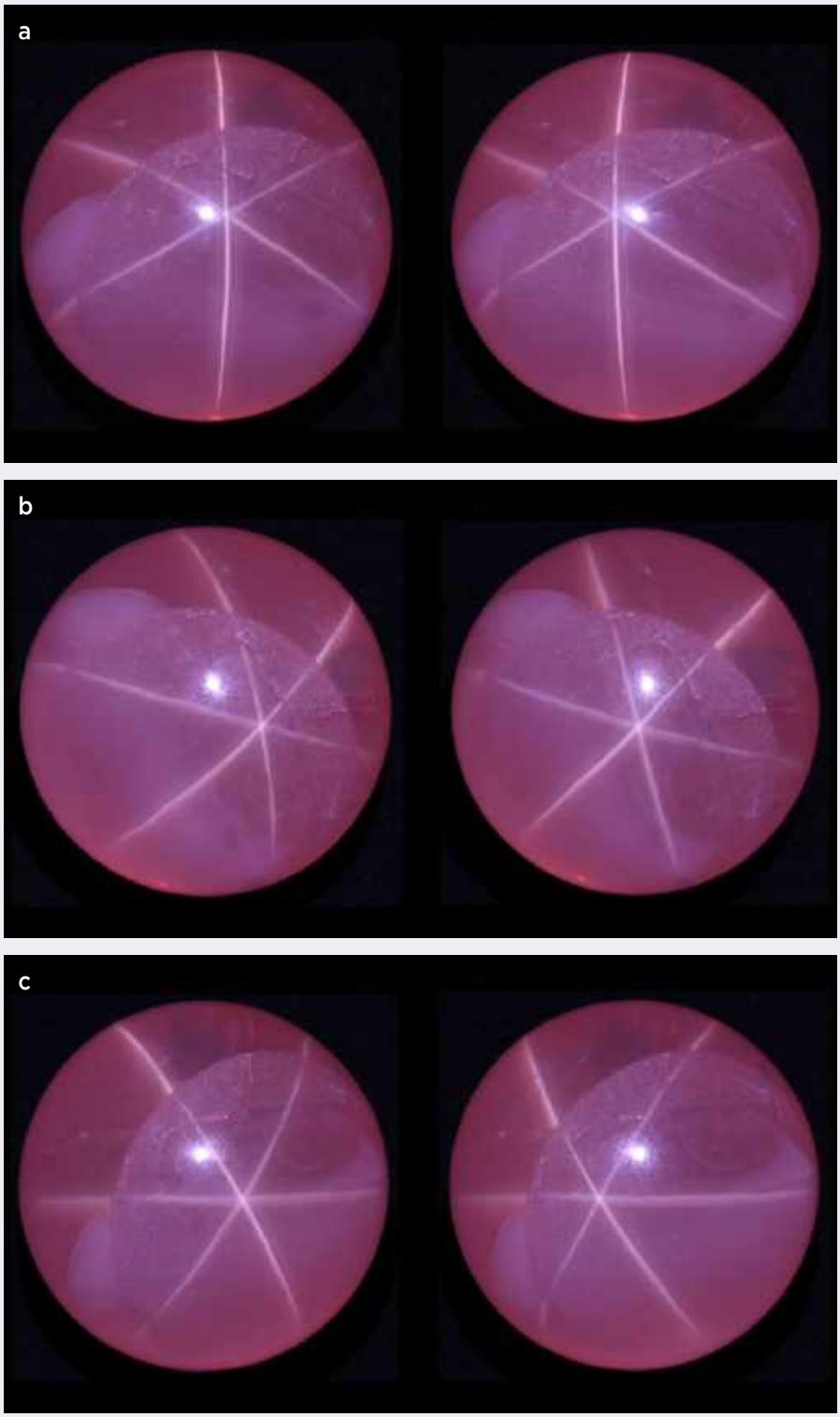

Figure 3: The stereograms of this rose quartz sphere (45.20 mm in diameter) illustrate the different stereoscopic effects that occur in six-rayed star stones. Three orientations of the branches are illustrated, in which (**a**) one branch is vertical, (**b**) one is at 45° to the vertical or horizontal plane and (**c**) one is horizontal. Differences in the perceived amounts that the branches appear to float above the stone are dependent on their orientations relative to the observation plane. Photos by F. Mazzero.

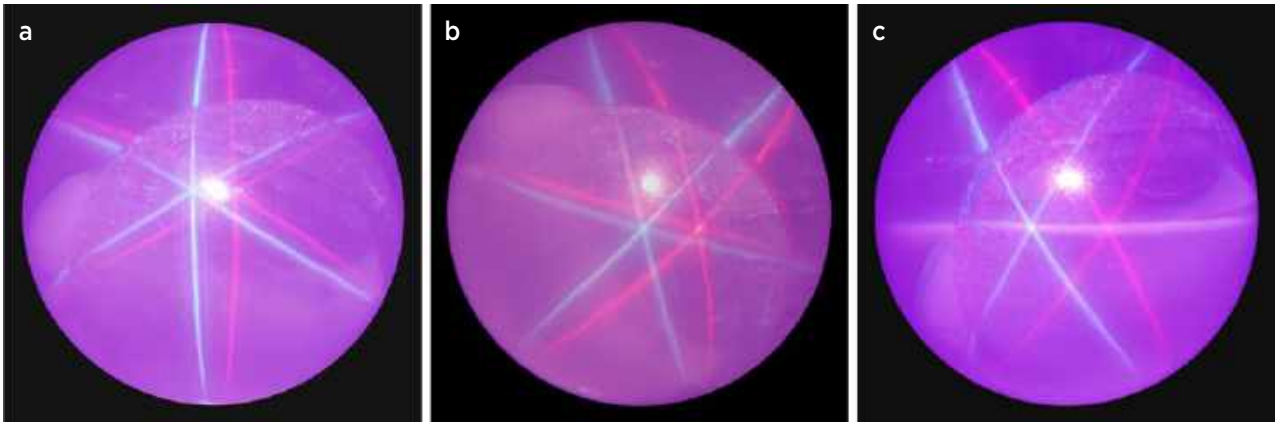

Figure 4: These three anaglyphs of the rose quartz sphere (a–c, corresponding to the stereograms in Figure 3a–c) show the separation of the rays that is responsible for the floating effect of a particular branch of the star and the illusion of variable depth between branches. Anaglyphs by F. Mazzero.

Origin of the Optical Phenomenon

To provide an explanation for the optical effects described in this article, it is convenient to trace the path of light using a ray diagram. Figure 5 provides a sketch of the entire light path, from the source to the eyes, which produces the cat's-eye phenomenon (or each branch of a star). The light is first refracted at the surface of the cabochon at B, then is reflected by an included needle at C and emerges at D towards the left eye L. Conversely, the light reaching the right eye R is first refracted at the surface of the cabochon at B', then is reflected by an included needle at C' and emerges at D'. Only the last parts of the light path (D–L and D'–R) need to be considered to explain the optical effects.

Figure 6 illustrates the anaglyph of one branch of the star in three different positions: (a) vertical, (b) oblique and (c) horizontal. Figure 6a corresponds to the condition illustrated in Figure 5, where the horizontal needles (C–C') are parallel to the observation plane and the resulting branch is thus vertical. D and D' belong to the two images of the vertical branch comprising the anaglyph (as seen in Figure 4a), which are clearly separated. The brain

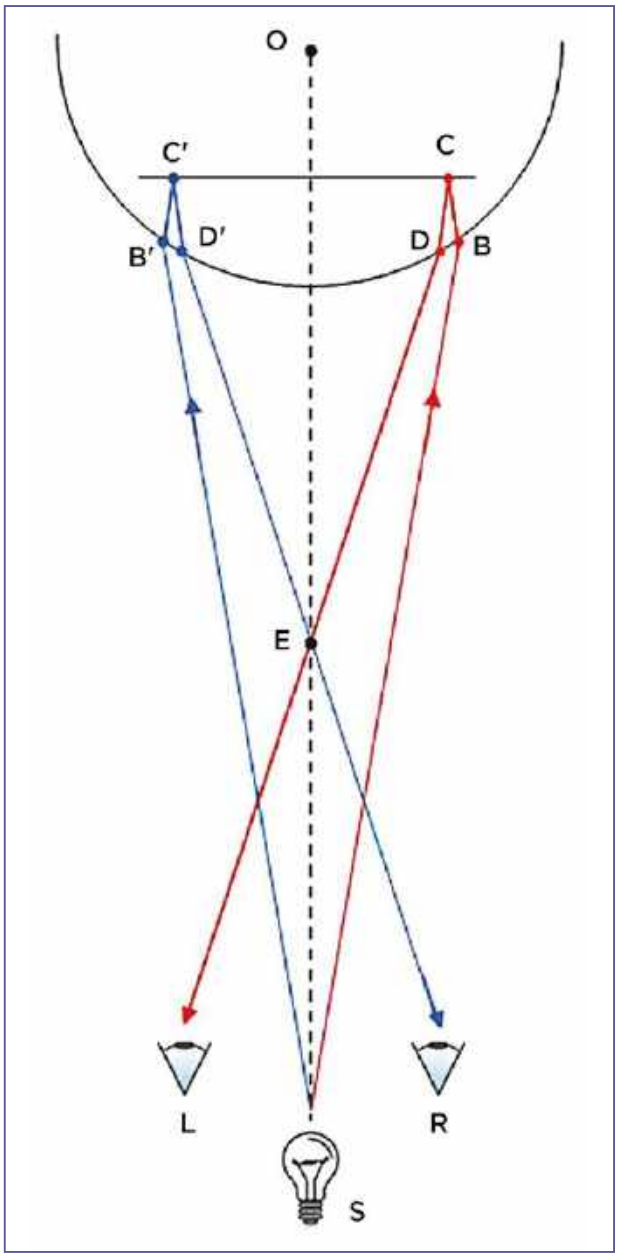

Figure 5: This diagram shows the entire light paths from the light source (S) to the eyes (L and R) for a set of horizontal needle inclusions parallel to the observation plane. The light reaches the sphere at B (red path) and is refracted on entering the stone and then is reflected from an included needle at C. It then returns to the surface of the sphere at D where it is refracted and travels to the left eye. In doing so, it crosses the axis OS at position E. Light reaching the other eye takes a mirror-image path (blue), entering the stone at B', reflecting at C', refracting at D' and crossing the axis at E to reach the right eye. The viewer's brain merges these two images into one so that the centre of the star appears to float above the sphere at E. This is the effect originally demonstrated by Killingback (2005).

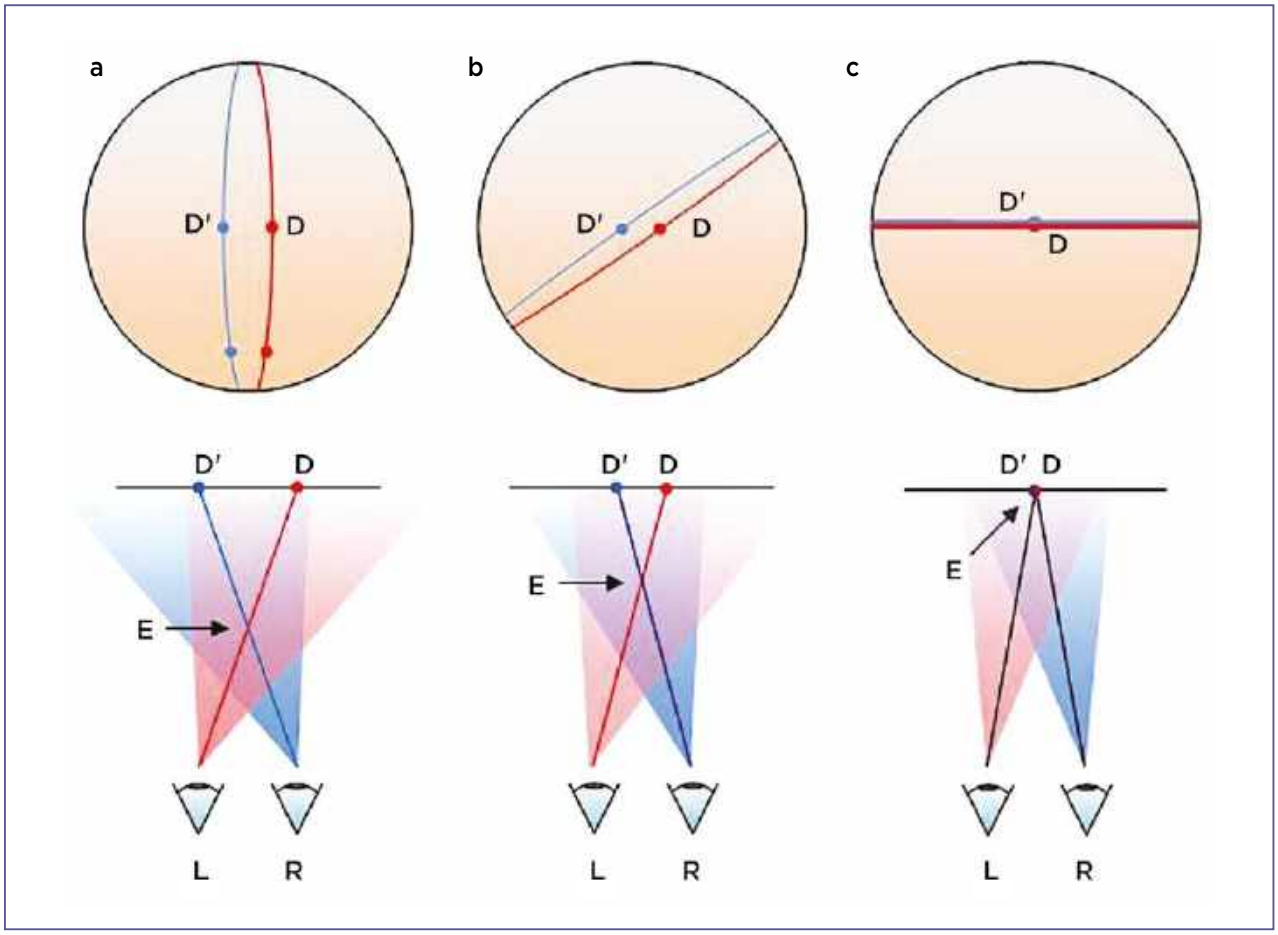

Figure 6: This sketch illustrates various positions for one branch of a star, corresponding to the orientations shown by the anaglyphs in Figure 4: (**a**) vertical, (**b**) oblique and (**c**) horizontal. The diagrams below show where the eyes focus at different levels E for each orientation of the stone. The colour convention is the same as that of classical anaglyphs (red for the left eye and cyan for the right eye). The vertical axis of the sphere is perpendicular to the drawing plane. These diagrams show only the last part of each light path, emerging from the stone at D and D' (see Figure 5) and then reaching each eye.

gathers them together above the stone's surface at the focal point of the light path reaching each eye (located at E). As the stone rotates around its vertical axis (O–S in Figure 5), the needles angularly shift away from the observation plane. The branch is then at an oblique angle, so the distance between the two equatorial dots is shorter and the focal point E thus moves closer to the stone (Figure 6b). Finally, when the stone is rotated so the needles are perpendicular to the observation plane, D and D' coincide (Figure 6c). The distance between the two equatorial dots is reduced to zero and the focal point is on the surface.

For the two pairs of dots in Figure 6a, the distance is greater between the two equatorial dots than between the subpolar ones. Consequently, the focus level should appear to get closer to the stone as the branch extends from the equator to the poles.

In a large cabochon or sphere such as those examined here, the stereoscopic phenomenon is visible to unaided eyes and is impressive to observe when slowly moving the stone. Thus, it is possible to observe a gradual transition between the different conditions described above.

CONCLUSION

This article expands on the stereoscopic phenomenon previously reported by Killingback (2005) for a cat's-eye or the branch of a star perpendicular to the observation plane. We observed additional features when considering all branches of a star, using both a four-rayed star garnet and a six-rayed star rose quartz as examples. Depending on the orientation of the branches relative to the observation plane, one branch appears to be in front of the other, and their separation distance and relative positions oscillate through a full 360° rotation of the sample.

Readily observable on cabochons of large size, the floating effect occurs in all chatoyant and asteriated

gemstones. However, it is less perceptible to unaided eyes on jewellery-size cabochons of a few tens of carats or less. Indeed, the distance from the observer and the small size of the stone are such that differences between the two images of the star, as perceived by each eye, are not sufficient for the brain to interpret them as having a stereoscopic effect. Nevertheless, on these smaller stones, stereoscopic pairs of photomicrographs could be taken to highlight the effect. In addition, this optical phenomenon is usually visible with a binocular microscope.

While the floating effect can be observed on all cat's-eye and star gemstones, the variable distance between branches, of course, is only seen in star stones. Along with the appeal of the asterism itself, the stereoscopic phenomenon constitutes an additional interesting feature displayed by large star stones.

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Identification of Type IIa Blue CVD Synthetic Diamonds from Huzhou SinoC Semiconductor Co. in China

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ABSTRACT: Gemmological and spectroscopic characteristics are reported for two type IIa blue CVD synthetic diamonds from Huzhou SinoC Semiconductor Science and Technology Co. Ltd, China. These are the first relatively large (1.76 and 2.63 ct) blue CVD synthetics examined in NGTC's laboratories, and their colour was slightly brighter than other blue synthetic diamonds that we have encountered. In the DiamondView, they fluoresced blue (with purple-red in one sample), which is unusual for CVD synthetics. The mid- and near-IR absorption spectra of one sample showed no hydrogen-related features, while the other synthetic diamond showed a weak absorption at 6853 cm^{-1} attributed to hydrogen. The spectra of both samples had a very weak line at 1332 cm^{-1} due to isolated nitrogen and a distinct band at 9282 cm^{-1} related to radiation. A very strong GR1 absorption feature was detected by UV-Vis-NIR spectroscopy. Photoluminescence spectra obtained at liquid-nitrogen temperature recorded emissions related to radiation (mainly in the 480–510 nm region), N-V and $[Si\text{-}V]^-$ centres, and several unassigned weak emissions. This combination of optical centres strongly suggests that these samples underwent post-growth treatment to improve their transparency before they were irradiated to produce blue colouration.

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China is the world's largest producer of industrial and gem-quality synthetic diamonds, particularly those grown under high-pressure, high-temperature (HPHT) conditions (Lu *et al.* 2019). Chemical vapour deposition (CVD) synthetic diamond growth technology in China is less well developed, and factory-scale production was lacking until 2012 (Song *et al.* 2012). However, in the past five years, many Chinese companies have begun producing CVD synthetic diamonds, and their products and growth technologies have rapidly developed. Some of these companies mainly produce relatively large, high-quality colourless or near-colourless material, such as Shanghai Zhengshi Technology, Hangzhou Chaoran and others (see, e.g., Lu *et al.* 2019). In addition to these products, other companies—such as Ningbo CrysDiam Industrial Technology and Huzhou SinoC Semiconductor Science and Technology Co. Ltd—can also produce relatively large fancy-colour CVD synthetic diamonds.

Blue CVD synthetic diamonds appeared on the market during the past several years, in sizes ranging from melee (0.007 ct) to 1.34 ct (Ardon & Want 2014; Åström & Scarani 2015; Moe *et al.* 2015; Eaton-Magaña 2018; Odake 2018). Their blue colour is due to irradiation. In March 2020, National Gemstone Testing Center's (NGTC) Beijing laboratory tested two relatively

Figure 1: The two type IIa blue CVD synthetic diamonds (1.76 ct loose and 2.63 ct mounted) examined for this study owe their colour to irradiation treatment. Photos by Z. Song.

large blue CVD synthetic diamonds from Huzhou SinoC Semiconductor Science and Technology Co. Ltd, and this article reports their gemmological and spectroscopic properties.

MATERIALS AND METHODS

The two CVD synthetic diamonds consisted of round brilliants weighing 1.76 ct (loose) and 2.63 ct (mounted in a ring; Figure 1). According to Huzhou SinoC Semiconductor Science and Technology Co. Ltd, which provided the samples, they are representative of commercial products being produced by the company. They were grown at a rate of about 21 µm per hour using the microwave plasma CVD growth technique with 6 kW power, 15–20 kPa pressure and 900–950°C temperature. The company also indicated that the samples had been HPHT treated to improve their transparency before being electron irradiated to produce their blue colour.

The following testing and analysis procedures were performed on both samples. A gemmological microscope was used to examine inclusions and anomalous birefringence. Fluorescence and phosphorescence were observed with the DiamondView instrument developed by De Beers Group. Fourier-transform infrared (FTIR) spectroscopy was performed using a Thermo Nicolet 6700 spectrometer in the range of 6000–400 cm^{-1} (128 scans at a resolution of 2 cm^{-1}). A QSpec Gem-3000 spectrophotometer was used to obtain ultraviolet-visible-near infrared (UV-Vis-NIR) absorption spectra at liquid-nitrogen temperature. A Renishaw inVia Raman microspectrometer was used to collect photoluminescence (PL) spectra with four laser excitations (325, 473, 532 and 830 nm) at liquid-nitrogen temperature.

RESULTS

The two synthetic diamonds had colour grades equivalent to Fancy blue (1.76 ct) and Fancy Intense blue (2.63 ct), and overall they showed brighter blue colouration than other synthetic diamonds we have encountered. The clarity grades of both samples were equivalent to VS_1. A few irregular dark inclusions were visible with magnification in both specimens (e.g. Figure 2) and appeared to consist of non-diamond carbon, as described for CVD synthetic diamond by Martineau *et al.* (2004).

With cross-polarised light, strong birefringence was another important feature of these CVD samples. The loose one showed low- to moderate-order interference colours, and the mounted specimen displayed moderate-

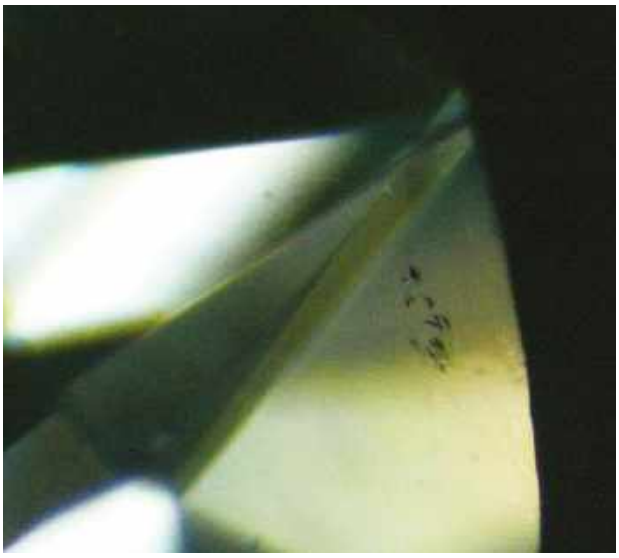

Figure 2: Dark inclusions (probably non-diamond carbon) are present in the blue CVD synthetic diamonds, as shown here in the 1.76 ct sample. Photomicrograph by Z. Song; magnified 50×.

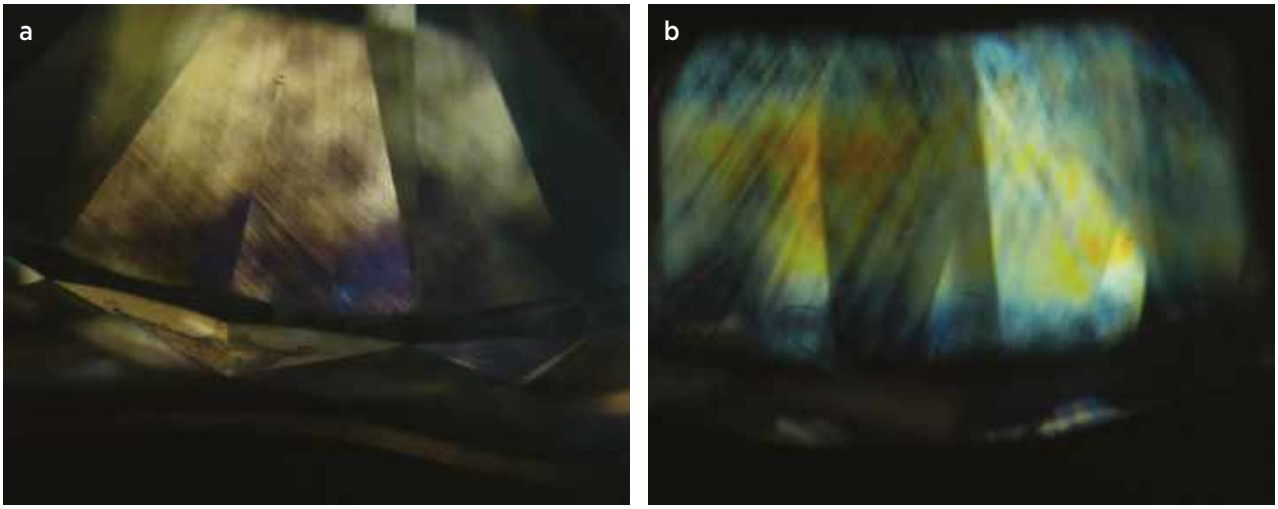

Figure 3: Strong birefringence is displayed by the (**a**) loose and (**b**) mounted CVD synthetic diamonds when observed with crossed polarisers. Photomicrographs by Z. Song; magnified 16×.

to high-order interference colours (Figure 3). The patterns were linear or grid-like, but not the Tatami structure typical of type IIa natural diamonds (Howell 2012).

Luminescence Features

As observed with a DiamondView, the loose sample fluoresced blue (with obscure growth structure), which is not typical for CVD synthetic diamonds. The mounted specimen fluoresced mottled blue and purple-red, and showed a distinct grid-like structure (Figure 4). The purple-red luminescence was different from the orange-red fluorescence commonly shown by as-grown CVD synthetic diamonds. In addition, the blue with added purple-red luminescence is seldom seen in natural diamonds (Eaton-Magaña & Shigley 2016). No phosphoresce was seen in either sample.

Spectroscopic Features

IR Spectra. In the mid-infrared region (Figure 5), neither sample showed significant absorption features related to nitrogen or boron impurities, except they both exhibited a very weak line at 1332 cm^{-1} attributed to isolated nitrogen (Zaitsev 2001); nevertheless, both samples were classified as type IIa. In the 3500–3000 cm^{-1} region there was no evidence of any H-related absorptions.

In the near-infrared range, we recorded a band at 9282 cm^{-1} in both samples and a very weak absorption at 6853 cm^{-1} in the 2.63 ct specimen (Figure 6).

UV-Vis-NIR Spectra. The UV-Vis-NIR spectra of both samples (Figure 7) displayed a distinct GR1 absorption at 741 nm, indicating exposure of these synthetics to radiation. Greater GR1 absorption was present in the

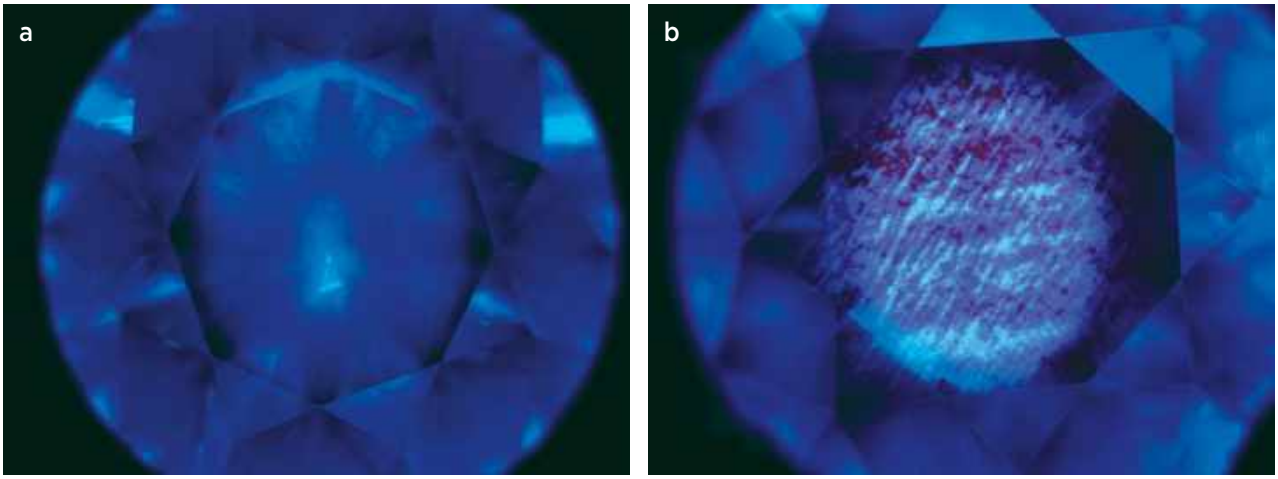

Figure 4: In the DiamondView, (**a**) the 1.76 ct synthetic diamond fluoresces blue and displays an indistinct structure, while (**b**) the 2.63 ct sample fluoresces mottled blue and purple-red and has a distinct grid-like structure. Photos by Z. Song.

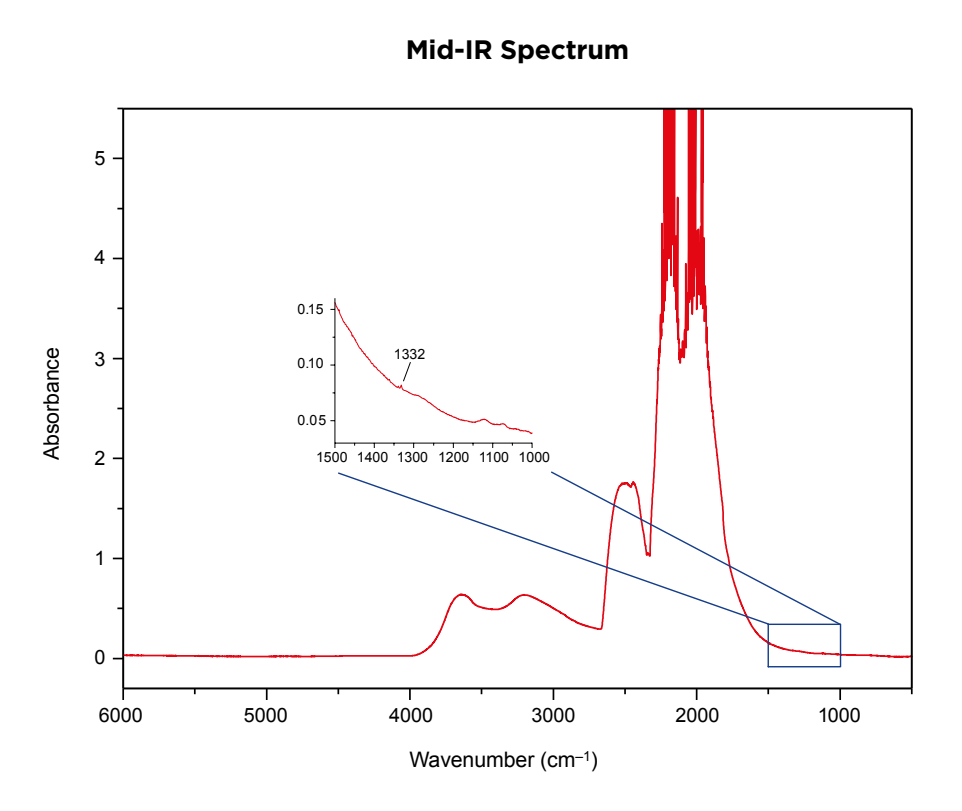

Figure 5: The mid-infrared spectrum of the synthetic diamonds reveals that they are type IIa, with a very weak 1332 cm^{-1} feature due to isolated nitrogen.

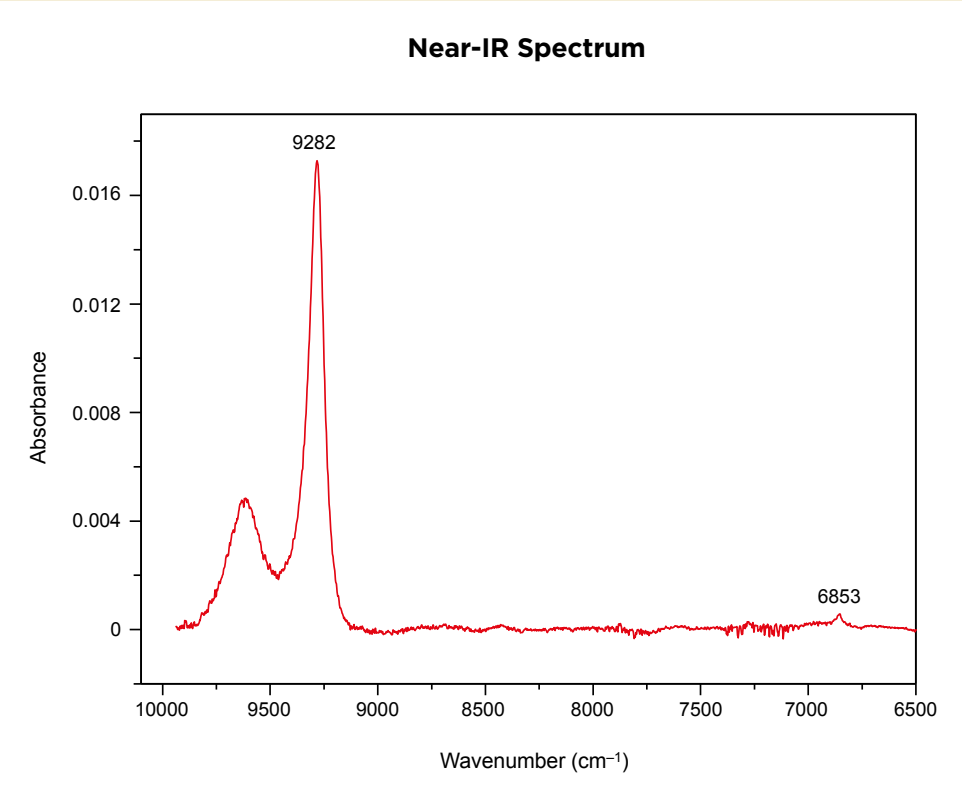

Figure 6: The near-IR spectrum of each synthetic diamond at room temperature shows the 9282 cm^{-1} (1077 nm) absorption band as an indicator of irradiation—as seen here for the 2.63 ct sample, which also has a very weak absorption at 6853 cm^{-1} attributed to hydrogen.

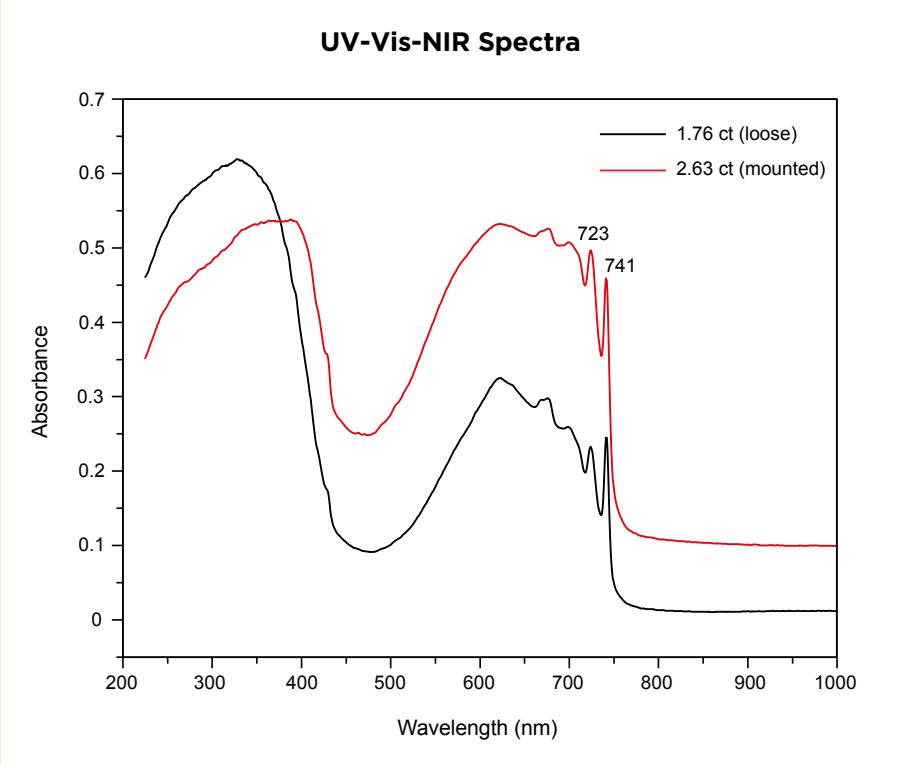

Figure 7: The UV-Vis-NIR spectra of both synthetic diamonds show strong absorption due to the GR1 centre. The slightly more intense blue colour of the 2.63 ct specimen correlates with its overall greater GR1 absorption.

more intensely blue sample. The blue colour of these synthetic diamonds is due to the transmission window at about 470 nm, which is related to strong absorptions due to irradiation (i.e. GR1 and others).

PL Spectra. Both samples showed similar PL spectra, and numerous emission lines were recorded with the different lasers (although no notable emissions were seen with 830 nm excitation).

With the 325 nm laser, both samples showed strong GR1 peaks related to irradiation and a distinct 777 nm luminescence line (Figure 8a).

With blue laser excitation (473 nm; Figure 8b), both samples displayed sharp peaks at 486.3, 488, 488.9, 490.7, 492 and 503.5 nm (3H); weak but sharp peaks at 489.9, 500.8, 503.2 (H3), 523.6, 530.7 and 531.6 nm; and (not labelled on Figure 8b) weak peaks at 494.1, 496.2, 498.5, 510.9, 515.9 nm and elsewhere. The main features excited by this laser are related to irradiation, including the ones at 488, 488.9, 492 and 503.5 nm (Breeding & Wang 2015).

Green laser excitation (532 nm) revealed moderate emission systems (compared to the intensity of the diamond Raman line) of N-V centres at 575 and 637 nm (Figure 8c). We did not observe the doublet emissions at 596.5 and 597.0 nm that usually occur in as-grown CVD samples (Martineau *et al.* 2004). An additional strong peak at 580 nm was also seen. The samples also showed strong silicon-related emissions at 736.6 and 736.9 nm (see inset in Figure 8c) due to the negative silicon-vacancy defect (Zaitsev 2001). Compared to the intensity of the diamond Raman line, both samples showed a very strong GR1 peak at 741 nm (i.e. much greater than the intensity of the Si-related emission at 737 nm: 741 nm/573 nm = 24 vs. 737 nm/573 nm = 1).

DISCUSSION

Most previously documented as-grown CVD synthetic diamonds have been colourless, near-colourless or brownish (Martineau *et al.* 2004; Wang *et al.* 2007). Specific absorptions in the mid-IR and near-IR regions, and doublet PL emissions at 596.5 and 597.0 nm, are important for separating as-grown from post-growth-treated CVD synthetics.

The specimens in this study had distinctly different characteristics from as-grown CVD synthetics. The 3123 cm^{-1} band is commonly observed in N-doped as-grown CVD synthetics, but was notably absent from the present samples. Very weak absorption at 1332 cm^{-1} due to isolated nitrogen was observed in the IR spectra of both samples (Figure 5). The 2.63 ct sample revealed a very

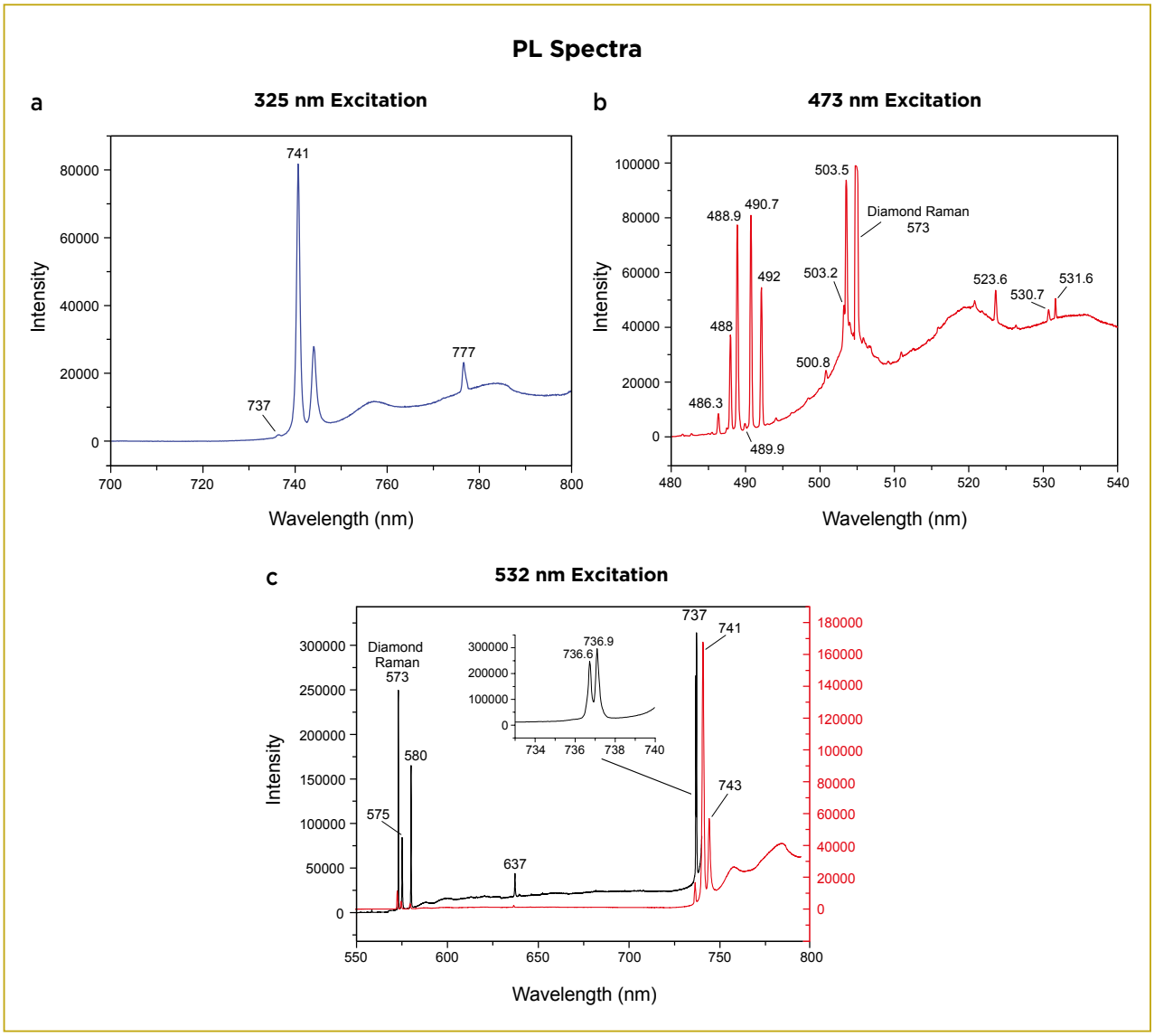

Figure 8: Numerous emission lines are present in the PL spectra of the synthetic diamonds obtained with (**a**) 325 nm, (**b**) 473 nm and (**c**) 532 nm excitations. The two traces shown for 532 nm excitation are from different test conditions, resulting in more distinct 575, 637 and 737 nm peaks exhibited by the black spectral line.

weak H-related line at 6853 cm^{-1}; the other one did not show any H-related features. All of these mid- and near-IR absorption features indicate that the two CVD samples had been HPHT treated before electron radiation, as indicated by the company that supplied them.

In the near-IR region, an absorption feature at 1077 nm (or 9282 cm^{-1} in Figure 6) was observed in both of the blue CVD synthetic diamonds. This feature is often observed in type Ia and IIa natural and synthetic diamonds after irradiation (Lyu *et al.* 2015). This centre is not associated with nitrogen, but possibly relates to a multi-vacancy complex (Zaitsev 2001). Vasilev *et al.* (2018) documented naturally irradiated diamonds showing absorption at 1077 nm. At room temperature this feature was weak compared to the absorption in the visible region, and it almost disappeared at 77 K. Although the spectrum in figure 2b of Vasilev *et al.* (2018) is not shown clearly, Prof. A. Collins (pers. comm. 2020) examined the original data files, which were kindly made available by Dr Vasilev, and the room-temperature spectrum was very similar to that shown in Figure 6 of the present article. We can therefore conclude that distinct 1077 nm absorption is a strong indicator of irradiation. However, the absence of absorption at 1077 nm does not mean that a synthetic or natural diamond has not been irradiated. There are examples of less heavily irradiated diamonds in which the 1077 nm centre was not detected when the absorption spectra were measured at 77 K (A. Collins, pers. comm. 2020).

PL spectroscopy of the two samples in the present

study showed that several centres were introduced during the electron-irradiation process, including those at 486.3, 488, 488.9, 492, 503.5, 515.9, 523.6, 580, 741 and 777 nm. In addition, a strong 490.7 nm peak was observed in the PL spectra of both samples (Figure 8b). Breeding and Wang (2015) found that this feature was not observed in diamonds with less than 25 ppm A aggregates. Because we did not examine the present specimens before they were irradiated, we cannot be sure whether this feature was introduced by irradiation. Therefore, more work is required to determine whether the irradiation process can introduce the 490.7 nm PL peak.

Both the 488.9 and 523.6 nm PL emissions can occur in irradiated type I and II diamonds (Collins & Rafique 1979; Breeding & Wang 2015; Hainschwang & Pamies 2019). The 488.9 nm line has been attributed to complexes involving carbon interstitials and isolated nitrogen (Collins & Rafique 1979) and will anneal out by 375°C. The authors have tested some irradiated natural rough diamonds with a weak 488.9 nm line, but after they were faceted it was no longer detected and a new line appeared at 488.4 nm. Although Hainschwang and Pamies (2019) reported that the 523.6 nm peak is related to nitrogen concentration and plastic deformation, but not to any specific form of nitrogen, the present study shows that a weak 523.6 nm line can be detected in CVD synthetic diamonds that contain a small amount of isolated nitrogen.

We detected a very strong 503.5 nm peak (3H centre) in the PL spectra of both samples. Along with the GR1, the 3H centre is a typical feature of irradiated diamond, often accompanied by a peak at 492 nm (Breeding & Wang 2015; Zaitsev *et al.* 2017). Although the 3H defect can be detected in some untreated natural type IIa and IIb diamonds (Eaton-Magaña & Lu 2011), a strong 3H is still a good indicator of irradiation. The other typical features of the 3H centre at 540.7 and 552.4 nm (Steeds *et al.* 1999; not shown in Figure 8) were also present in both samples.

We found that the intrinsic optical centre with its zero-phonon line at 580 nm can be very strong in irradiated CVD synthetic diamond. This 580 nm centre relates to a negatively charged interstitial vacancy pair ($I\text{-}V^-$; Zaitsev *et al.* 2017).

With 325 and 532 nm excitation, the PL spectra of both samples revealed the strong presence of the GR1 radiation centre, a defect correlated with an isolated vacancy. The intensity of the GR1 peak was about 24 times that of the diamond Raman line; this is much more intense than in untreated natural diamonds.

Breeding and Wang (2015) proposed that the 777 nm centre is introduced by radiation and should disappear when A-aggregate concentration increases up to 10%; this centre does not correlate to B or C centres. However, we have found the 777 nm centre in many untreated natural type IIa diamonds and occasionally in naturally irradiated type Ia diamonds. In addition, according to our unpublished research, the 777 nm peak can be introduced during irradiation of HPHT-treated type IIa diamonds. There is some relationship between the intensity of the GR1 centre and the presence of the 777 nm peak: the stronger the GR1 feature, the clearer the 777 nm peak. More work is needed to understand the exact structure of the 777 nm feature.

CONCLUSIONS

This is the first time NGTC has examined CVD synthetic diamonds that were irradiated to a blue colour. In the DiamondView, the loose sample described here showed blue florescence, as well as no observable layered growth structure typical of CVD products, which indicates how such material can be difficult to identify by this technique alone. The presence of a 9282 cm^{-1} band in the near-infrared spectral region, and the distinct GR1 and other lines displayed by these two CVD synthetic diamonds, proved that they were indeed irradiated. Moreover, there are no natural blue diamonds in which the colour is due to the presence of GR1 absorption, and so the blue colour, together with the UV-Vis-NIR spectral features, unambiguously show that these type IIa synthetic diamonds have been treated.

These two irradiated blue CVD synthetic diamonds provide a lot of information about defects produced during irradiation. The 3H system (503.5, 540.7 and 552.4 nm PL peaks), as well as the 488.9 and 523.6 nm PL features, exemplify that irradiated diamonds may display various combinations of defects, which reveal information about the production of such material. As CVD synthetic diamonds become more available and more complicated to identify, the most reliable option is to send samples to a gemmological laboratory.

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Amber from Khamti, Sagaing Region, Myanmar

Thet Tin Nyunt, Tay Thye Sun, Murali Krishnaswamy, Loke Hui Ying, Cho Cho, Naing Bo Bo Kyaw, Wai Yang Lai Aung and Chutimun Chanmuang N.

ABSTRACT: In the Pat-tar Bum area near Khamti in the Sagaing Region of northern Myanmar, amber is mined from Cretaceous limestone using underground and open-pit methods. Most of the amber ranges from yellow to dark brown, and it shows typical gemmological properties for amber. Inclusions in our samples consisted of flattened gas bubbles, fractures and brownish material (probably organic debris), and the authors have also seen pieces containing various types of animal remains such as an insect wing, spider and bird feather. FTIR and Raman spectra show features consistent with Burmese amber.

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Burmese amber, or Burmite, is sought after as a gem material and is also well known for hosting a wide variety of interesting invertebrate and plant inclusions. It is mainly recovered from deposits near Tanai (or Danai) in the Hukawng Valley of Kachin State, northern Myanmar, where several different amber varieties are found (e.g. Jiang *et al.* 2020). Other Burmese amber localities, which were discovered more recently, include Hti Lin (Tilin) in the Magway Region of western central Myanmar, and Pat-tar Bum (Pat-ta Bum) near Khamti (Hkamti) in the Sagaing Region of northern Myanmar.

The Pat-tar Bum deposits were initially mined during the British colonial period, but were abandoned in the 19th century and reopened in 2010. Due to an increase in amber demand from mainland China, mining activities increased at Pat-tar Bum in 2012–2013. This amber was briefly described by Liu (2018), and in January 2018 some of the present authors (TTN, CC and NBBK) visited several sites in the Pat-tar Bum area. Initial results of the authors' research were briefly presented by Thet Tin Nyunt *et al.* (2019), and this article provides more details on the geology, mining and gemmological properties of this amber (e.g. Figure 1).

Figure 1: This amber pendant (7.2 × 3.3 × 1.6 cm) from Khamti, Myanmar, displays attractive patterns formed by trapped organic debris. Photo by Thet Tin Nyunt.

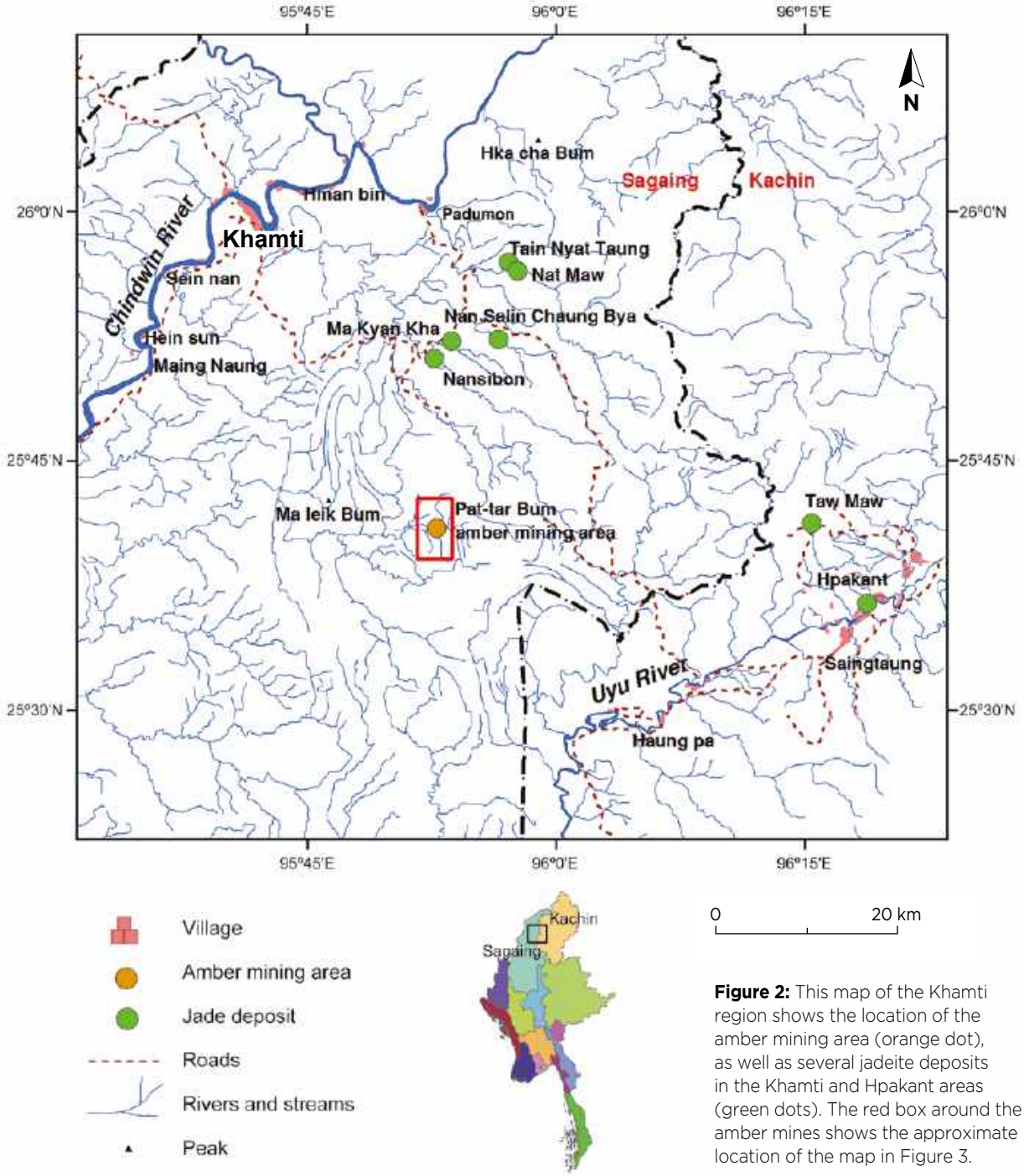

Figure 2: This map of the Khamti region shows the location of the amber mining area (orange dot), as well as several jadeite deposits in the Khamti and Hpakant areas (green dots). The red box around the amber mines shows the approximate location of the map in Figure 3.

LOCATION AND GEOLOGY

The Pat-tar Bum amber deposit is located near Nampilin stream about 40 km south-east of the town of Khamti (25°41′ N, 95°50′ E; Figure 2) and about 112 km south-west of Tanai. The specific sites visited by some of the authors include Lachun (also spelled Laychun and Lachon) Maw, which was the most productive mining area, as well as Kyat Maw, Shan Maw, Gyar (also spelled Kyar) Maw and Kyauk Tan Maw (Figure 3). ('Maw' means 'mine' in Burmese.)

The Khamti area is mostly underlain by Paleocene to Eocene molasse-type sedimentary units of the Paunggyi Formation. Cretaceous units are locally present, including

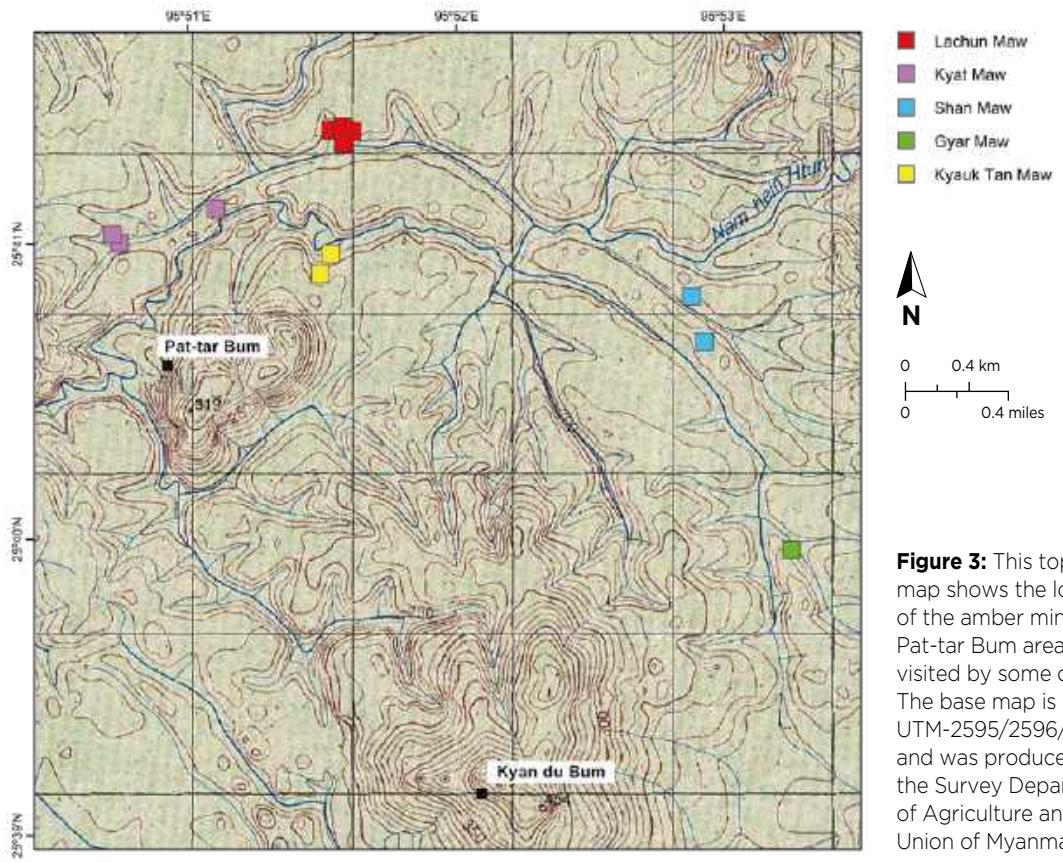

Figure 3: This topographical map shows the locations of the amber mines in the Pat-tar Bum area that were visited by some of the authors. The base map is part of UTM-2595/2596/2695/2696 and was produced in 2008 by the Survey Department, Ministry of Agriculture and Irrigation, Union of Myanmar.

the Kalaw Red Beds, the Kabaw Formation and other marine units including limestone; also occurring in the area are ultramafic and mafic intrusions of mostly Jurassic age (Soe Thura Tun *et al.* 2014). The intrusions are mainly represented by peridotite and serpentinite, and commercially important jadeite deposits are locally associated with the latter rock type (e.g. near Nansibon; Thin 2016).

The amber deposits are hosted by the Cretaceous limestone, which contains fossils that are of late Albian age (*Orbitolina* sp.; Mitchell 2018). The thickness of the amber-bearing limestone horizons ranges from several centimetres to nearly 1 m, and they are locally intercalated with sandstone and carbonaceous shaley limestone, sometimes together with carbonaceous materials (Figures 4 and 5).

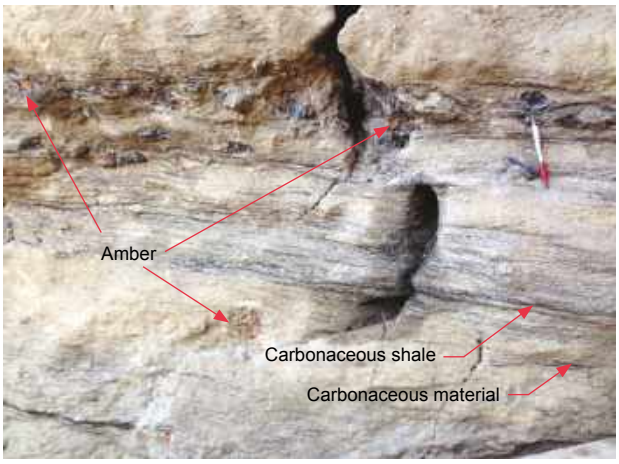

Figure 4: Khamti amber is hosted by limestone (shown here at Lachun Maw) that is sometimes intercalated with sandstone and locally contains carbonaceous material. See pen for scale; photo by Thet Tin Nyunt.

Figure 5: A miner exposes pieces of amber within limestone at Lachun Maw. The amber from this locality is typically yellow, yellowish brown, brown and dark brown. Photo by Thet Tin Nyunt.

Figure 6: This view of Lachun Maw shows the entrance of an adit that explores the amber-bearing limestone at a shallow angle along bedding planes. Photo by Thet Tin Nyunt.

Figure 7: A pulley system (see ropes and orange bucket) is being used to remove amber-bearing limestone from this adit at Lachun Maw. The mining crew then breaks open the pieces of limestone in search of amber. Photo by Thet Tin Nyunt.

MINING AND PRODUCTION

The Pat-tar Bum amber mining area covers 1,500 hectares and contains five major production sites (listed in the previous section), including 13 claim blocks where mining has been organised by Sea-Sun-Star Co. Ltd (Myitkyina, Myanmar) since 2010.

At Lachun Maw, amber mining is carried out by drilling and blasting a series of tunnels (adits or inclines) that follow the 20°–35° dip of the limestone (e.g. Figure 6). The blasted material is transported to the surface using a pulley system, and the limestone is then broken into smaller pieces to extract the amber (Figure 7). Vertical shafts called *lay-pin* are also used to reach the amber-bearing horizons (Figure 8). Each shaft measures 4 × 4 feet (1.2 × 1.2 m) and may attain depths greater than 5 m, such as at Kyat Maw. Upon reaching an amber-bearing layer, the miners then drive an adit along the bedding plane of the limestone. Open-pit mining is also carried out at Kyat Maw (Figure 9), Shan Maw and Gyar Maw, where 3–5 m of overburden must be removed to reach the amber-bearing limestone.

Although amber mining at Pat-tar Bum started in 2010, official production data began with fiscal year 2014–2015 (Table I). From 2014 to 2019, the total official production from Pat-tar Bum was about 6,655 kg with an appraised value of about MMK76,800,000 (Myanmar kyats; 1 kyat = 0.00055 British pound). According to a 1995 Myanma Gems Enterprise (MGE) law, the royalty for amber is 10% of the value established by MGE appraisers.

Figure 8: Vertical shafts are also used to reach the amber-bearing limestone, as shown here at Kyat Maw. This shaft is more than 5 m deep. Photo by Thet Tin Nyunt.

Figure 9: Open-pit mining for amber sometimes takes place, as shown here at Kyat Maw. The miners must use pumps to keep the pits from flooding with water. Amber from this mine tends to be dark brown, brown and yellow. Photos by Thet Tin Nyunt.

Table I: Approximate official production and appraised value of amber from Pat-tar Bum near Khamti, Myanmar.[a]

Fiscal year	Weight (kg)	Value (MMK)
2014–2015	555	6,400,000
2015–2016	2,400	6,900,000
2016–2017[b]	90	8,500,000
2017–2018	1,850	30,000,000
2018–2019	1,760	25,000,000

[a] Data obtained in 2019 from Myanma Gems Enterprise.
[b] Lower production was due to expiration of the mining licence in 2017 (nevertheless, a higher value than the previous year may have been due to greater demand). Operations were then carried out under a limited licence until a new mining licence was obtained during the 2017–2018 fiscal year.

MATERIALS AND METHODS

We characterised 21 amber samples (0.45–2.49 ct; Figure 10) that were obtained from the miners during the authors' visit to the Pat-tar Bum mining area. All of them were examined using basic gemmological tools such as a binocular microscope, refractometer, hydrostatic balance, and long- and short-wave UV lamps (Minerlight UVSL-25) at the Far East Gem Lab in Singapore.

Eleven of the samples (nos. KT01–KT10 and KT21) were prepared as doubly polished plates (about 0.80 mm thickness), and Fourier-transform infrared (FTIR) absorption spectra were obtained from those specimens in attenuated total reflectance (ATR) mode using a Bruker Tensor 27 spectrometer at the University of Vienna. Spectra were collected in the 370–4000 cm^{-1} range with an aperture of 1.5 mm and a resolution of 4 cm^{-1}.

Figure 10: The 21 samples of amber examined for this report range from 0.45 ct (small brownish piece at centre) to 2.49 ct (yellow sample on the far left). Photo by Tay Thye Sun.

Raman analysis of amber and other fossil resins is typically hampered by strong laser-induced luminescence, which virtually covers the entire visible range, so FT Raman is commonly preferred (Brody *et al.* 2001; Jehlička *et al.* 2004). For the present study, by contrast, we used a dispersive Raman system that consisted of a Horiba LabRAM HR Evolution spectrometer. Analyses were performed at the University of Vienna on the same 11 samples that were used for FTIR spectroscopy. In the spectral region of 100–2250 cm^{-1}, Raman shift was measured with a 785 nm diode laser (3 mW power at the sample surface), and in the region of 2250–4000 cm^{-1} Raman shift was analysed using a 633 nm He-Ne laser (8 mW power). In both cases the laser power was well below the threshold of any sample changes due to local absorption-induced heating. A grating with 1,800 grooves/mm (for 633 nm excitation) or 600 grooves/mm (for 785 nm excitation) was used to disperse the scattered light, resulting in a spectral resolution of about 0.7 cm^{-1} and 2 cm^{-1}, respectively. For further analytical details on the Raman spectroscopy system used, see Zeug *et al.* (2018).

RESULTS AND DISCUSSION

Standard Gemmological Properties

Our amber samples were mostly transparent and showed various colours including yellow, greenish yellow, 'golden' yellow, orange-yellow, brownish yellow and brown (Figure 10). The RI ranged from 1.53 to 1.54 (spot readings) and the SG commonly varied from 1.03 to 1.09. Both of these ranges are typical of amber (O'Donoghue 2006). Specimens yielding SG values greater than 1.09 consisted of amber associated with some matrix.

Microscopic examination revealed small areas of white matrix (probably carbonate material) attached to the amber (Figure 11a), flattened gas bubbles, step-like fractures (Figure 11b), irregular brownish inclusions (probably organic debris; Figure 11c) and surface patterns suggesting an imprint against another material (Figure 11d). No insect inclusions were found in the samples studied, although author NBBK previously acquired Khamti amber specimens from a local miner that contained biogenic materials, such as those having the appearance of a bird feather (Figure 12a), a spider (Figure

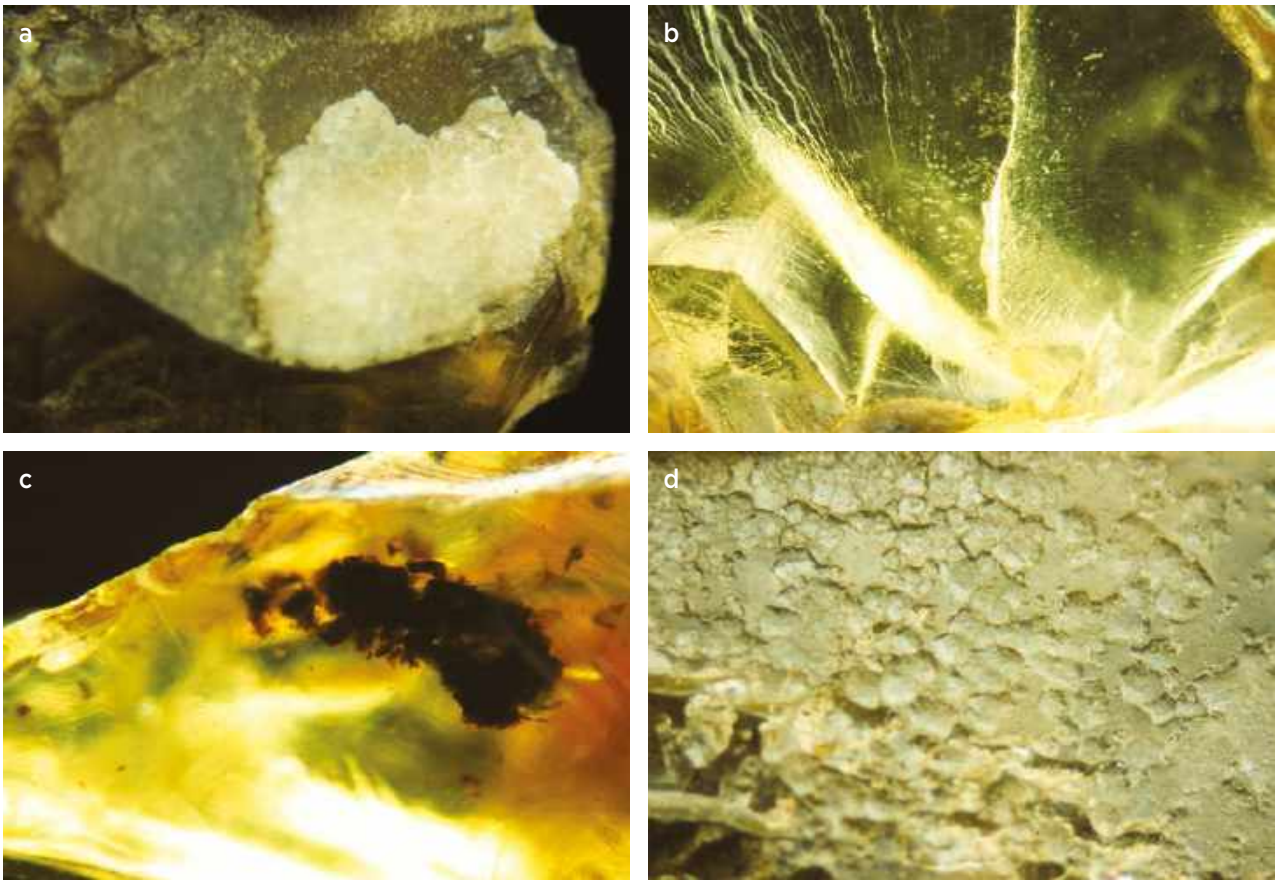

Figure 11: (**a**) White matrix material is sometimes attached to the amber. (**b**) This sample contains several flattened gas bubbles and its broken surface displays step-like fractures. (**c**) These irregular-shaped brownish inclusions probably consist of organic debris. (**d**) Surface patterns on some of the amber suggest contact with another material. Photomicrographs by Tay Thye Sun; magnified 10×.

Figure 12: Various biogenic inclusions can be found in Khamti amber, as shown by these polished examples that were obtained from a local miner by author NBBK, including those resembling (**a**) a bird feather, (**b**) a spider and (**c**) bits of insect wing with some organic debris. The samples measure (a) 3 × 2 cm, (b) 1.5 cm wide and (c) 4.5 × 2.5 cm. Photomicrographs by Tay Thye Sun.

12b) and bits of insect wing with some organic debris (Figure 12c). In addition, Liu (2018) reported various types of plant and animal remains in Khamti amber.

Most of our samples luminesced strong chalky blue under long-wave UV and weak chalky blue or greenish blue under short-wave UV radiation, which are typical of amber (see, e.g., Kocsis *et al*. 2020). Some of the darker brownish samples showed weak chalky blue or yellow emissions under long-wave UV radiation, whereas they appeared to be inert under short-wave UV. These observations differ appreciably from the pink UV-induced luminescence reported for some samples of Khamti amber by Liu (2018) and the unique violet fluorescence to long-wave UV that was recently documented in some Burmese amber (Zhang & Shen 2019; Jiang *et al.* 2020).

IR and Raman Spectroscopy

IR absorption and Raman spectra of the 11 analysed specimens of Khamti amber were quite similar to one another, and representative spectra are presented in Figure 13 for sample KT21. The IR features were dominated by a group of absorption bands at around 2800–3000 cm^{-1}, relatively narrow bands in the range of 950–1750 cm^{-1} overlaying a broad hump at 800–1400 cm^{-1}, and a weak broad band at around 3420 cm^{-1}. The positions and relative intensities of these features are similar to those seen in the IR spectra of Burmese amber reported by various authors (e.g. Tay *et al.* 2015; Liu 2018; Chen *et al.* 2019; Jiang *et al.* 2020). Likewise, the Raman spectral features shown by our samples resembled those of Burmese amber reported

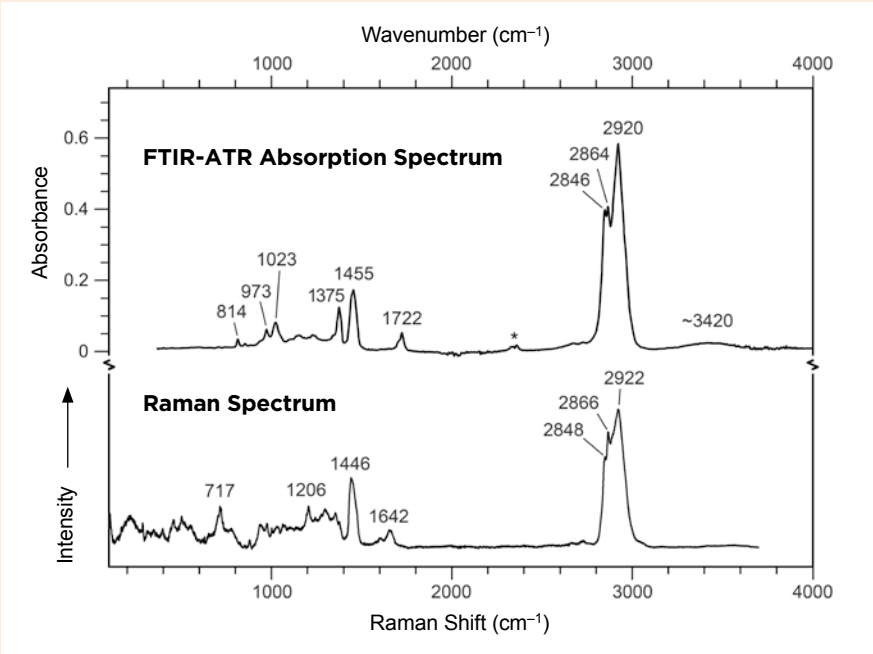

Figure 13: The FTIR-ATR spectrum of amber sample no. KT21 (top) shows features that are similar to those of Hti Lin and Tanai amber. The Raman spectrum of the same sample (bottom; with background corrected) shows no absorption bands at 3048, 1642 and 887 cm^{-1}, which confirms that it is amber and not copal. The asterisk in the IR spectrum marks an analytical artefact (absorption by CO_2 in the air).

by Brody *et al.* (2001). Compared to the FTIR spectrum obtained by Liu (2018), our samples did not show significant absorption in the 1050–1250 cm^{-1} region, and an additional band at 1764 cm^{-1} reported by Liu (2018) was not detected in our spectra.

The vibrational bands in the 2800–3000 cm^{-1} range can be attributed to symmetric and asymmetric stretching vibrations of saturated C–H bonds, such as in methylene (CH_2) and methyl (CH_3) groups. Also, the absence of any IR absorption band at around 3080 cm^{-1} caused by C=C bonds indicates a lack of unsaturated or aromatic organic compounds (see Brody *et al.* 2001; Abduriyim *et al.* 2009; Wagner-Wysiecka 2018; and references therein). The narrow, intense IR absorption band at 1722 cm^{-1} has been assigned to C=O stretching of carbonyl groups. Infrared absorption and Raman bands below 1500 cm^{-1} are due to diverse stretching and deformation vibrations; a detailed list of assignments was provided by Montoro *et al.* (2020). As expected, no features were observed at 3048, 1642 and 887 cm^{-1} in either the FTIR and Raman spectra, which would indicate (young) copal (Guiliano *et al.* 2007; Abduriyim *et al.* 2009; Wang *et al.* 2015); this is consistent with the mid-Cretaceous age of the amber, as indicated by the *Orbitolina* sp. fossils in the host limestone.

A broad absorption at around 3500 cm^{-1} (3420 cm^{-1} in our samples) can be attributed to O–H stretching (see Montoro *et al.* 2020 and reference therein). Considering the presence of carbonyl groups, this hydroxyl can be assigned to carboxylic acid, rather than molecular water, in Khamti amber. A similar O–H stretching band has been recorded in the FTIR spectra of Tanai amber (Jiang *et al.* 2020). Also, a broad band at 3400–3460 cm^{-1} has been observed in amber from the Dominican Republic, Colombia and Madagascar, and in some specimens from the Baltic (A. Abduriyim, pers. comm. 2019).

CONCLUSIONS

Khamti amber (e.g. Figure 14) resembles material from other Burmese deposits, and our samples also showed similar gemmological properties—such as RI, SG and UV fluorescence—to those of typical amber from the Hti Lin and Tanai regions. The occurrence of Khamti amber in *Orbitolina* sp. fossil-bearing limestone indicates that it must have formed prior to or during mid-Cretaceous times when it was incorporated into the marine sediments that formed the limestone. More samples should be studied to further investigate variations in UV fluorescence and IR spectra that have been documented in Khamti amber, and also for comparison with material from other localities in Myanmar and elsewhere.

Figure 14: This bracelet made of Khamti amber illustrates some of the colours and textures that can be found in material from this area of Myanmar. The largest pieces forming the bracelet are each about 1.5 × 3.0 cm. Photo by Thet Tin Nyunt.

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Gem-A Notices

Obituary

Spencer Currie FGA 1934–2020

It is with sadness that I report the passing of Spencer Currie.

A well-known and much-respected member of the gemmological community in New Zealand and Australia, Spencer first trained as a manufacturing jeweller. He then studied with Gem-A and passed his Diploma exam in 1978, travelling that year to London to receive his Diploma.

He was a founding member of the Gemmological Association of New Zealand in 1980, became President and an Honorary Member of this organisation, and sat on countless committees. He gave many lectures to students and fellow gemmologists, both in New Zealand and Australia. Highlights of Spencer's career include attending a Gem-A organised trip to Idar-Oberstein (Germany, 1998), giving presentations at the International Gemmological Conference in Goa (India, 1999) and Moscow (Russia, 2007), and being invited to speak at the Asian Gemmological Institute and Laboratory's 25th anniversary conference in Hong Kong (2008).

Spencer studied, documented and published on New Zealand copal (Kauri gum), determining that some ancient specimens found in coal deposits were in fact amber (see *The Journal*, Vol. 25, No. 6, 1997, pp. 408–416). He also wrote two other articles for *The Journal*, titled 'An unusual star diamond' (Vol. 20, No. 1, 1986, p. 52) and 'The brilliant cut – Analysis of weight by calculation' (Vol. 20, No. 3, 1986, pp. 171–176).

Spencer was also a keen lapidarist, was much involved with the South Auckland Rock and Mineral Club and won awards for some of his nephrite carvings. He was keen on photography (in general and pertaining to the photomicrography of gems) and was an avid collector of rocks and all things gemmological.

A truly gentle character, Spencer will be sadly missed by us in New Zealand. Spencer is survived by his wife Brenda, their three children and many grandchildren and great-grandchildren.

Donald Francey FGA
Auckland, New Zealand

A Webinar with the Editor

Go behind the scenes at *The Journal of Gemmology* by tuning in to our webinar session with Editor-in-Chief, Brendan Laurs FGA, on 24 September 2020 at 17:00 BST. Join us as we hear Brendan discuss the current issue of *The Journal*, explaining how the issue was assembled and focusing in greater detail on some of the fascinating feature articles and Gem Notes. To register your place, head to: https://linktr.ee/gemaofgb.

Did you miss our last session of Gem-A Live with Brendan? Head to the Gem-A You Tube Channel and watch it online now: https://youtu.be/-xTbMbZDtSo.

Learning Opportunities

Note: Event dates and formats are subject to change depending on the COVID-19 situation.

CONFERENCES AND SEMINARS

Association for the Study of Jewelry and Related Arts (ASJRA) Annual Conference
10–11 October 2020
Online
www.jewelryconference.com

2020 American Society of Appraisers (ASA) International Conference
12–13 October 2020
Online
www.appraisers.org/Education/events/asa-international-conference

Geological Society of America (GSA) Connects Online
26–30 October 2020
Online
https://community.geosociety.org/gsa2020/home
Session of interest: Gemological Research in the 21st Century: Gem Minerals and Localities

Munich Show: Mineralientage München
30 October–1 November 2020
Munich, Germany
https://munichshow.de/?lang=en
Note: Includes a seminar programme

Scottish Gemmological Association Conference
November 2020 (exact dates TBA)
Cumbernauld, Scotland
www.scottishgemmology.org

Chicago Responsible Jewelry Conference
6–7 November 2020
Chicago, Illinois, USA
https://responsiblejewelryconference.com

14th International Conference on New Diamond and Nano Carbons (NDNC)
10–14 January 2021
Kanazawa, Japan
www.ndnc2020.org

23rd FEEG Symposium—25th Anniversary
23–24 January 2021
Paris, France
www.feeg-education.com/symposium

NAJA 55th Ace© It Annual Winter Conference
31 January–1 February 2021
Tucson, Arizona, USA
www.najaappraisers.com/html/conferences.html

AGTA Gemfair Tucson
2–7 February 2021
Tucson, Arizona, USA
https://agta.org/agta-gem-fair-tucson
Note: Includes a seminar programme

Tucson Gem and Mineral Show
11–14 February 2021
Tucson, Arizona, USA
www.tgms.org/show
Note: Includes a seminar programme

Inhorgenta Munich
19–22 February 2021
Munich, Germany
www.inhorgenta.com/index.html
Note: Includes a seminar programme

International Colored Gemstone Association (ICA) Congress
March 2021 (exact dates TBA)
Shenzhen, China
www.icacongress2021.com

MJSA Expo
March 2021 (exact dates TBA)
New York, New York, USA
https://mjsa.org/eventsprograms/mjsa_expo
Note: Includes a seminar programme

10th National Opal Symposium
31 March–1 April 2021
Coober Pedy, Australia
www.opalsymposium.org

American Gem Society Conclave
26–28 April 2021
Louisville, Kentucky, USA
www.conclave2021.americangemsociety.org

37th International Gemmological Conference (IGC 2021)
17–21 May 2021
Tokyo, Japan
www.igc-gemmology.org
Note: Includes field trips to jadeite deposits and a pearl farm

Swiss Gemmological Society Conference
30 May–1 June 2021
St Gallen, Switzerland
http://gemmologie.ch/en/current

JCK Las Vegas
4–7 June 2021
Las Vegas, Nevada, USA
https://lasvegas.jckonline.com
Note: Includes a seminar programme

Diamonds – Source to Use 2021
9–10 June 2021
Johannesburg, South Africa
www.saimm.co.za/saimm-events/upcoming-events/diamonds-source-to-use-2020

Jewellery in Texts: Texts in Jewellery
19 June 2021
London
www.societyofjewelleryhistorians.ac.uk/news

NAJ Summit
19–21 June 2021
Northampton, East Midlands
www.naj.co.uk/summit
Note: Includes the IRV Valuers' Conference (19–21 June) and the JBN Retail Jewellers' Congress (21 June)

Sainte-Marie-aux-Mines Mineral & Gem Show
24–27 June 2021
Sainte-Marie-aux-Mines, France
www.sainte-marie-mineral.com
Note: Includes a seminar programme

The Goldsmiths' Company Jewellery Materials Congress
18–20 July 2021
London
www.assayofficelondon.co.uk/events/event-programme-202021

9th International Conference Mineralogy and Museums
24–26 August 2021
Sofia, Bulgaria
www.bgminsoc.bg
Note: Gem minerals and archaeogemmology are among the topics that will be covered.

3rd European Mineralogical Conference (emc2020)
29 August–2 September 2021
Krakow, Poland
https://emc2020.ptmin.eu
Sessions of interest: The Geology of Gem Deposits: A Session in Honour of Gaston Giuliani; Materials Sciences and Archaeometry for Cultural Heritage

31st International Conference on Diamond and Carbon Materials
5–9 September 2021
Palma, Mallorca, Spain
www.elsevier.com/events/conferences/international-conference-on-diamond-and-carbon-materials

3rd International Conference on Tourmaline (TUR2021)
9–11 September 2021
Elba Island, Italy
www.tur2021.com

Canadian Gemmological Association (CGA) Conference
22–24 October 2021
Vancouver, British Columbia, Canada
https://canadiangemmological.com

OTHER EDUCATIONAL OPPORTUNITIES

Gem-A Workshops and Courses
Gem-A, London
https://gem-a.com/education

Lectures with The Society of Jewellery Historians
Society of Antiquaries of London,
Burlington House, London
www.societyofjewelleryhistorians.ac.uk/current_lectures

- Niamh Whitfield—The 'Tara' Brooch: The Making of an Early Medieval Masterpiece from Ireland
  22 September 2020 (online)
- Lynne Bartlett—Titanium the Magical Metal
  27 October 2020
- Charlotte Gere—Colour in Victorian Jewellery
  24 November 2020
- Jonathan Boyd—His Work as a Jeweller
  26 January 2021
- Jack Ogden—Presidential Address (following AGM)
  23 February 2021
- Carol Michaelson—Chinese Jade Jewellery and Ornaments from the Neolithic to the Present
  27 April 2021
- Gonçalo de Vasconclo e Sousa—Portuguese Jewellery
  25 May 2021
- Karl Schmetzer—The Late 14th-Century Royal Crown of Blanche of Lancaster
  22 June 2021
- TBA
  28 September 2021
- Three Speakers TBA—New Research on Jewellery
  26 October 2021
- Ute Decker—Sculptural Minimalism & Fairtrade Gold: Philosophy, Provenance and Process
  23 November 2021

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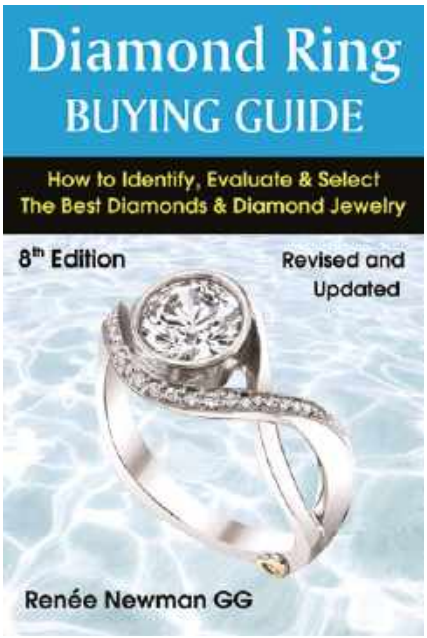

Diamond Ring Buying Guide, 8th edn.

By Renee Newman, 2020. International Jewelry Publications, Los Angeles, California, USA, www.reneenewman.com/diamond.htm, 149 pages, illus., ISBN 978-0929975542 or e-ISSN 978-0929975559. USD19.95 softcover or USD9.99 eBook.

The previous (7th) edition of the *Diamond Ring Buying Guide* was published 12 years ago, and it has been out of print for four years. This new edition retains a lot of the original information, but also includes many updates.

In the first chapter, the author proposes a set of price factors to judge diamond value by replacing the 'Four Cs' criteria of colour, clarity, cut and carat weight with a more complex value system consisting of six 'Cs' and two 'Ts': cut quality, colour, carat weight, cutting style, clarity and creator (natural vs. laboratory grown), plus transparency (cloudiness) and treatment status. The 'creator' factor is new in this edition, reflecting the upsurge of synthetic diamonds being used in jewellery.

Chapter 2 has been shortened and focuses on why diamonds are so valued. Distinctive and prized properties include diamond's exceptional hardness; its resistance to high temperatures, radiation and chemicals; its electrical and heat conduction properties, as well as insulation from heat; and the aesthetic allure of its brightness and fire.

The next several chapters deal with each of the six 'Cs' and two 'Ts'. Chapter 3 covers carat weight and includes a useful table compiled by the Gemological Institute of America displaying corresponding weights and diameters of well-cut round-brilliant diamonds. A chapter on shape and cutting style describes these aspects and explains branded and non-traditional diamond cuts, accompanied by photos of examples. Excellent images also help illustrate an extended discussion on how shape affects price.

Chapter 5 deals with colour, with revised text and new photos. It includes the effect of fluorescence on colour and price, the subjectivity of diamond colour grades, fancy-colour diamonds and treatments that affect colour. An updated table provides recently realised auction prices. The following chapter, on cut quality, explains how to judge the quality of cut for fancy-shape diamonds as well as round-brilliant cuts. It includes what to look for in face-up and profile views, with new photos that demonstrate specific examples. Next comes a chapter on how to evaluate clarity and transparency, with photos illustrating how to search for inclusions, graining, surface features and more. Lighting, magnification, positioning and focus can all affect success in locating inclusions and other features. Photos also illustrate differences in transparency.

Chapter 8 focuses on synthetic diamonds, reviews various growth methods, and discusses the benefits of both laboratory-grown and natural diamonds. A section on how to detect synthetic diamonds lists the basic gemmological tests that are currently available. All-new photographs help make this chapter current.

The following chapter on diamond imitations is very helpful, with tips on how to spot simulants using a little observation, without expensive tools or equipment. A separate section deals with synthetic moissanite, warning that it can show up as 'diamond' on a thermal tester. Some of the newer synthetic moissanites even fool moissanite detectors.

A chapter on diamond treatment covers all the important types: laser drilling, fracture filling, coatings and irradiation with heat, along with descriptions of low-pressure, high-temperature (LPHT) treatment and high-pressure, high-temperature (HPHT) treatment. It also includes a new section on the factors involved in pricing colour-enhanced diamonds, accompanied by new colour photos.

A new chapter on diamond-grading reports helps the reader know what to look for on a report, but with a warning that not all grading labs are equal.

A chapter on gold, platinum and palladium helps the consumer decide on the characteristics they prefer in their setting, accompanied by terminology pertaining to precious metals. A well-organised chart contrasts white gold with platinum. The benefits and cautions of 14-ct vs. 18-ct gold are compared, as are the pros and cons of the different metals. The metalworking procedure of Japanese origin known as *mokume gane* is also profiled.

A new chapter on silver has been added, explaining its history and standards. It includes a review of various brand names of silver that have been treated with anti-tarnish alloys such as those containing copper or germanium. Another new chapter covers alternative metals, which are quickly finding acceptance on the marketplace. Short descriptions of each metal are accompanied by a discussion of their advantages and disadvantages, including stainless steel, tungsten, tungsten carbide, titanium, cobalt-chrome and tantalum.

A chapter on setting styles describes popular mounting techniques, including prong, channel, bezel, bead, pavé, flush and bar settings, along with invisible setting, a method of displaying stones without visible metal support. Situations reveal which mountings might be best for people with different wearing needs. New to this edition is a section with tips on what to look for in a well-made, secure setting. Selecting a ring style is also a personal choice, but the author poses practical questions to consider when choosing such a significant piece of jewellery. Many new photos are featured in this chapter.

The next chapter covers how to clean and store a diamond, along with how to prevent it from being 'switched'. The latter entails knowing your diamond's unique characteristics and establishing a long-term relationship with your jeweller. The book concludes with a chapter that gives shopping pointers, followed by a new section on the chemical, physical and optical properties of diamond and a thorough bibliography.

This book can be used by consumers who are not necessarily interested in becoming diamond experts, but who want to feel more informed about the material and the industry in general when considering a purchase. The book is also a helpful sales tool for those in the retail jewellery industry. It outlines what a consumer should know and what information a salesperson should be responsible for. An amazing amount of excellent information has been packed into this portable paperback that can accompany the prospective buyer to the jewellery store or sales office. The numerous updated photographs help illustrate current styles, and the streamlined text addresses commonly asked questions and concerns.

Jo Ellen Cole
Cole Appraisal Services
Los Angeles, California, USA

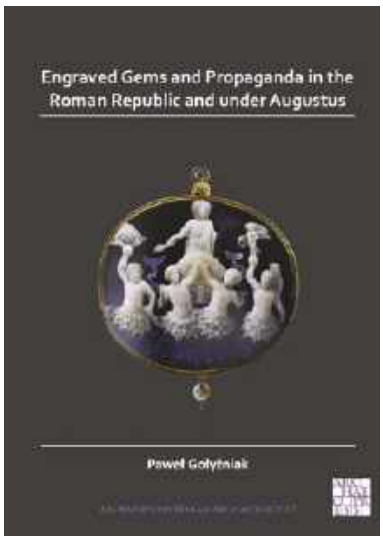

Engraved Gems and Propaganda in the Roman Republic and Under Augustus

By Paweł Gołyźniak, 2020. Archaeopress Roman Archaeology 65, Archaeopress Publishing Ltd, Oxford, https://tinyurl.com/yb9j6lr3, 606 pages., illus., ISBN 978-1789695397 or e-ISBN 978-1789695403. GBP90.00 hardcover or free PDF.

This lengthy volume is a revised version of a PhD thesis presented to Jagiellonian University, Krakow, Poland. The author charts the development and use of engraved gems from the earliest Roman Republic, when they signified self-advertisement of the owner and wearer. From the time of Sulla onwards they conveyed a political message that could be distributed to or worn by followers and allies. Pompey, Caesar and Octavian (who became Augustus) were especially adept at this. With Octavian we are in very familiar territory, made well known by Paul Zanker in his classic work *The Power of Images in the Age of Augustus* (1988).

Gołyźniak's achievement has been to place Imperial propaganda on gems into the context of a long history. To my knowledge only one previous author has attempted

anything like this—Marie-Louise Vollenweider in her *Die Porträtgemmen der römischen Republik* (1974), which only deals with portraits—while Gołyźniak covers a whole range of pictorial and symbolic subject matter. And with more than a thousand figures (mainly colour photographs) spread over 130 pages, he has provided a veritable *musée imaginaire* for the gem enthusiast.

Following an introductory section dealing with the research aims and methodology is a short theoretical discussion on the nature of propaganda. Next is a general section on how gems were used by the Romans of the Republic: in triumphs, collected for their own sake and presented to temples, for personal branding and self-promotion, and to promote family and political faction, often emphasising abstract ideas by the use of symbols. In later periods the gems acquired by close supporters of those with supreme power, especially Octavian (63 BC–14 AD), were extremely precious items—often cameos carved in the round or cameo vessels.

The bulk of the book collects, illustrates and evaluates the evidence for the use of engraved gems as propaganda. The beginnings in the 3rd and 2nd centuries BC were concerned with Italic gems, following the Etruscan tradition. Then we are on more familiar ground, as Roman glyptic takes on a more Hellenised appearance, as with the well-known portrait in a gold setting (probably of Scipio Africanus) cut by Herakleides, and a garnet signed by Daidalos perhaps depicting Titus Quinctius Flamininus, both of the 2nd century BC. However, in that time of increasing conflict and Roman expansion, the many gems depicting warriors and battle scenes took on a particular resonance, and sometimes they related to particular events.

It is with Sulla (138–78 BC), who sealed documents with an image of himself receiving Jugurtha bound from Bocchus, as reproduced on coins struck for him, that we can begin to see a wider use of gems as propaganda. Here, as elsewhere, Gołyźniak sees how coins—which are, when all is said and done, pieces of bullion sealed by an authority as a guarantee of fineness—contribute to the theme and often depict subjects also seen on intaglios. Marius, Sulla's great rival, does not seem to have used glyptic to the same degree. However, during the period of the civil wars, both Pompey and Caesar became increasingly involved in this sort of propaganda, with gem engravers working for them, and disseminating images to ordinary soldiers and others by means of glass copies. Apart from portraiture, gems depicting Romans being victorious over Celts allude to Caesar's Gallic Wars, while symbols of victory and prosperity might bear charged political overtones. Cameos then began to come in, including a strongly Hellenising one evidently from Spain in the Content Family Collection that depicts jugate busts of Caesar and his divine ancestor, Venus. A cameo formerly in the Ionides Collection shows an elephant trampling a fish, which recalls Caesar's famous coins of an elephant trampling a serpent.

However, only after Caesar's assassination in 44 BC does the book reach its climax. Brutus and the Republicans employed gems to a limited degree, as did Mark Antony, after their defeat, but it is clear that Octavian was the supreme master of using gems of all sorts as a medium to secure and maintain power. His engraved gems employed portraiture, myth and symbolism to ally himself with the divine, as had Julius Caesar to a lesser extent.

Useful distribution maps of the Roman Empire show where provenanced gems associated with particular personalities have been found. Not surprisingly, in many cases they cluster around Rome and central Italy, the centre of power where reputations were won and lost.

I have only two criticisms. First, as with other books on gems, users will often find themselves browsing the plates. The list of associated figure credits is daunting, and it is very hard to relate those plates to the extensive catalogue, let alone to the text, because the figures are in a separate section at the end of the book rather than being dispersed throughout, near their relevant text. Second, and this is especially pertinent to readers of this journal, it would be good to know how the gems used in propaganda at the higher end of the market related to the gem trade at the time. My own favourite gem is a sapphire cameo with which Vollenweider began her great study of gem engraving in the Late Republic and early Empire, in *Die Steinschneidekunst und ihre künstler in Spätrepublikanischer und Augusteischer zeit* (1966). This gem is illustrated in colour in my catalogue of the Fitzwilliam Museum in Cambridge (*Classical Gems in the Fitzwilliam Museum*, 1994), but here (in figure 972) it is only in black and white. As other exotic and beautiful gems show, it was only under Augustus that the use of gems in propaganda achieved its full potential.

With these small caveats, this volume—splendidly produced at an extraordinarily low price for what it contains (and actually free to download in PDF format)—is a book of enduring worth. Gołyźniak deserves our gratitude for writing one of the best books on Roman gems to have been published for a very long time.

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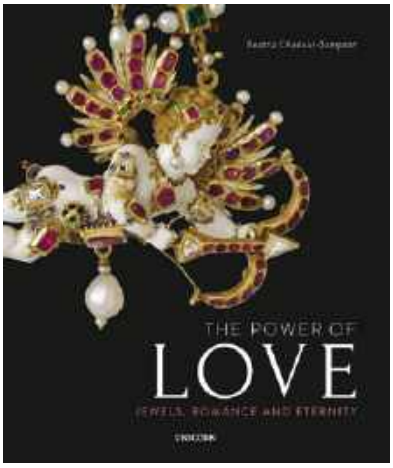

The Power of Love: Jewels, Romance and Eternity

By Beatriz Chadour-Sampson, 2019. Unicorn Publishing Group, London, www.unicornpublishing.org/page/detail/The-Power-of-Love/?k=9781911604464, 144 pages, illus., ISBN 978-191164464. GBP25.00 hardcover.

Jewellery and the themes of love and marriage have inspired goldsmiths and artists for millennia. In this well-written and beautifully illustrated book, renowned jewellery historian Beatriz Chadour-Sampson explores romance, love and courtship translated into jewellery. To explore the intimate relation we have with jewellery and how it is worn and created, the reader is taken on a journey from antiquity to the Middle Ages and from the early modern period to the modern era in six chapters. The focus of the book is on jewellery from western Europe and several famous examples are reviewed. The crown of Princess Blanche from the late 14th century (extensively discussed in a feature article of *The Journal*, Vol. 37, No. 1, 2020, pp. 26–64) is but one of the stunning pieces that can be admired for their symbolism, craftsmanship and use of materials.

Rings take centre stage in this publication, which is not surprising, considering the author's role as curator and researcher for the Alice and Louis Koch Collection of rings in Switzerland. As symbols of enduring love and worn directly on the body, rings are considered intimate pieces of jewellery and are therefore particularly suitable to tell the story of love and marriage. And perhaps there is a more pragmatic reason for the number of rings depicted in this publication. Rings are easy to keep, cherished by multiple generations and small enough that they tend to survive better under archaeological circumstances.

In discussing the development of marriage and betrothal, the use and meaning of diamonds is very important. The author shares an interesting reference from the 1st century AD that differs from the common idea that diamonds were used for wedding and betrothal rings only from the Late Middle Ages onwards. Physical examples and references from the 8th to 11th centuries could shed more light on this fascinating topic, but the scarcity of material from this period is a well-known gap in European jewellery history.

This book is full of wonderful pieces of sumptuous jewellery, but one of my favourites is actually very humble: a ring given by Napoleon Bonaparte to his first consort, Joséphine de Beauharnais (1763–1814). A simple golden band with the initials 'NB', some light blue enamel and the inscription *amour sincère* (sincere love) tells us that deep and profound love does not always have to be translated into big jewels covered in gemstones. Whether this was Joséphine's actual engagement ring is unclear, because a sapphire- and diamond-set *toi e moi* ring auctioned in 2013 was claimed as the official one given to her by Napoleon in 1796. This was one of the times when, in reading this book, I missed the use of notes. Luckily, the select bibliography offers enough sources to continue the quest.

Because love is such a universal theme, it would have been nice to include examples other than just western European ones, but perhaps this is an idea for a follow-up publication. This book is not written as a reference catalogue, nor is discussing the pieces in detail the aim of this publication. That being said, this book is a must-read for anyone interested in the jewellery of love. And because so many pieces of jewellery have survived since they are love-related, this book could serve well as a general introduction to students of jewellery history.

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Rubellite—Tourmaline Rouge

Ed. by William B. Simmons, Gloria A. Staebler, David W. Bunk, Alexander U. Falster, Sarah L. Hanson and Karen W. Webber, 2019. Mineral Monograph No. 20, Lithographie, Arvada, Colorado, USA, https://tinyurl.com/yxvmf6hl, 148 pages, illus., ISBN 978-0983632399. USD40.00 softcover.

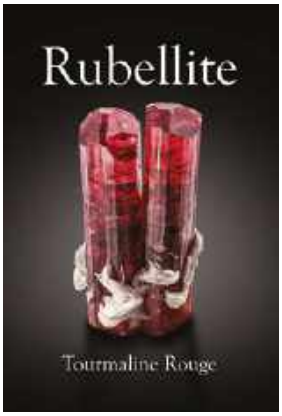

Rubellite—Tourmaline Rouge is a 138-page extravaganza of superb images, illustrations, information and anecdotes about the aesthetically outstanding red tourmaline, as well as the tourmaline mineral group in general. The monograph is structured in a logical and easy-to-read fashion, beginning with a history of rubellite and followed by in-depth sections on tourmaline—its chemistry, colour and sources—with examples of rubellite found across the globe. The various sections are written by 13 expert authors, with illustrations contributed by more than 40 other individuals. The ensemble is harmoniously orchestrated by chief editors Gloria Staebler and Dr William (Skip) Simmons into an informative and illustrative text that could equally complement a tourmaline scholar's bookshelf or adorn someone's living-room table. Although titled 'Rubellite'—the pink-to-red variety of tourmaline that is known to occur in various species (i.e. elbaite, liddicoatite, rossmanite, darrellhenryite and uvite)—this work is, in reality, an overview of tourmaline, with a special emphasis on this colour range.

Who cannot appreciate the outstanding beauty of tourmaline? The sharp, intricate terminations, the perfectly aligned striations and, above all, the intense and varied colours make it special. I'm personally fascinated by this mineral, and I'm extremely lucky to have access to an outstanding suite of specimens in the Mineralogical and Geological Collections at Harvard University. Despite feeling quite well versed in the tourmaline mineral group, I nonetheless found myself immersed in *Rubellite*. I have personally seen some of the most spectacular specimens of rubellite pictured in the monograph, yet I learned a great deal about some of the most important localities and their discoveries, geology, and history of mining and production.

The monograph starts with an historical overview of rubellite, including its misidentification as 'ruby' in jewellery pieces and a fascinating discussion about what may be the oldest worked rubellite as an intaglio of Alexander the Great. The following sections explain tourmaline's structure and crystallography, its varied colouration and its formation in granitic pegmatites. These are accompanied by photos of beautiful gem-quality rubellite crystals. Next, the reader is treated to a nearly chronological 'tour' of some of the most important rubellite-bearing pegmatite localities, beginning with the 1668 discovery of tourmaline in the Ural Mountains of Russia. There are three main areas for rubellite and multi-colour tourmaline in Russia: the central Ural Mountains, the Malkhan range and the Borschovochny Ridge. Red tourmalines from Russia, similar to those from the Jonas mine in Brazil, are of a unique deep colour intensity. The next section covers rubellite from the Czech Republic, especially a pegmatite at Rožná, which is the type locality for lepidolite mica and rossmanite tourmaline. This section includes a wonderful short biography of Prof. George Rossman, after whom this tourmaline species was named. A shorter article on rubellite from Italy's Elba Island depicts some excellent examples of multicoloured specimens in matrix.

In the USA, there are two main localities for tourmaline, and both compete in terms of colour and quality of material produced. These are California (Pala and Mesa Grande Districts), where some of the largest and most abundant elbaites have been found, and the Dunton Quarry in Maine. The history of these localities is described, including the connection between California tourmaline and the Chinese Qing dynasty. The descriptions outline the various ownership of the mines throughout the years, important discoveries and decisions that factored into their successes.

Four sections are dedicated to 'Pan-African' pegmatites. One of them, on tourmaline from Madagascar, provides a detailed account of the different districts and characteristics of each deposit, including Anjanabonoina, the well-known producer of colourful liddicoatite that is typically sliced perpendicular to the *c*-axis. Two sections on Minas Gerais, Brazil, cover the Serra do Cruzeiro (Cruzeiro and Chiá mines, sources of outstanding rubellite specimens and bicoloured elbaite) and the Jonas mine (which produced some of the largest and most aesthetically pleasing rubellite crystals ranging up to 1 m long, including the 'Rocket' and other famous pieces such as the 'Joninha'). The last section, on Pan-African pegmatites, covers Nigeria's Abuja mine, which has produced intense red as well as bicoloured tourmalines.

The final sections of the monograph consider examples from Vietnam and a summary of other worldwide localities such as Malaga in Spain. Located only 150 km from where I grew up, I am ashamed to say I never knew about this Spanish locality for tourmaline, but I am now keen to return and visit! The book ends with an informative reference list that mostly pertains to tourmaline localities.

Until now I did not realise that some of the most important pegmatitic rubellite discoveries of the last 50 years were clustered in the 1970s: the 'Blue Cap' pocket from California in 1972, the 'Jolly Green Giant' tourmaline from the 'Big Pocket' in Maine during the same year and the famous Jonas pocket in Brazil in 1978. When, I wonder, will the next big rubellite discovery be made?

What makes this monograph exceptional is the excellent use of maps, illustrations of gem-bearing pockets, pictures of miners and amazing specimens, together with all of the fascinating histories, which leads to an immersive experience. The colour illustrations range from single crystals with perfect terminations, to crystal clusters and aesthetically pleasing matrix specimens, to ancient carvings and modern artistic gem cutting. This is an essential book for any aficionado, collector or scientist interested in tourmaline.

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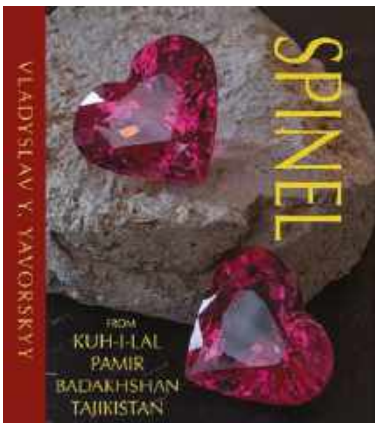

Spinel from Pamir

By Vladyslav Y. Yavorskyy, 2019. Yavorskyy Co. Ltd., Hong Kong, www.gemstonesbook.com, 236 pages, illus., ISBN 978-1733486002. USD180.00 hardcover.

Vladyslav Yavorskyy's sixth volume on gemstones covers the remarkable spinels from Kuh-i-Lal in the Pamir Mountains of Tajikistan. Those who are familiar with Yavorskyy's other books know that text is minimal and great photos abound—perhaps more so in this volume than in previous ones. The text of the five chapters was written by Anne Carroll Marshall, with photo captions by Vladyslav and Samantha Yavorskyy. The photos were captured by the author in colour and black-and-white using a Leica M6 film camera, and the spinels are indicated as all being natural and untreated.

Chapter 1 covers history, with an excellent summation of Pamir spinel from times before Marco Polo. This is followed by the great spinels set in crown jewels, including those of Iran, Russia and England, especially the famous Timur 'Ruby', a 352.5 ct spinel set for Queen Victoria in 1853. Also pictured are wonderful spinel necklaces sold at auction.

Chapter 2, on mining, offers a fascinating excerpt from the 2015 dissertation *Mineralogical Features and Genesis of the Kuh-i-Lal Spinel Deposit* (translated from Russian). This chapter is filled with photos of miners and beautiful, faceted red and pink spinel gems on facing pages.

Chapter 3 covers legends of the Pamirs. One of these legends includes Alexander the Great, who crossed the Panj River in 329 BC and met his third wife, Roxanne, in Tajikistan. This chapter contains spectacular photos of the Pamir Mountains and colourful faceted spinels, some mounted in fine jewellery.

Chapter 4, on Kuh-i-Lal village, contains mostly black-and-white candid photographs of the local people taken by the author, with each facing page showing colourful faceted spinels. The text on page 108 covers some historic spinels, including the famous 170 ct Black Prince's 'Ruby'—mounted as the central decoration in the Imperial State Crown of England—which is thought to be of Kuh-i-Lal origin. Page 144 mentions the biggest discovery at Kuh-i-Lal when, in 1985, the largest known red spinel—26,000 ct—was found. A photo shows the piece being held by export company officials.

Chapter 5 is about the people of the Pamir Mountains. It features images of the local inhabitants (mostly in colour), accompanied by photos of fashioned spinels, often in pairs or even preformed rough sets. I particularly enjoyed a close-up photo of the boots of a local shepherd 'made from car tyres'. Then on pages 177 and 178 are two half-page pictures: on the left 'from rough crystal 380 ct' and on the right a '180 ct world's largest faceted red spinel'. Okay, that's just showing off!

The final pages include endnotes, further reading and some additional text from the Russian study mentioned in chapter 2, followed by photos of several more faceted spinels and the author's afterword.

This book is a labour of love by an artist. Everyone who enjoys gemstones should have this and Yavorskyy's other volumes in their library. My only small critique is that the quantity of spinels shown here makes them look almost too common!

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Ed. by Mechthild Schulze-Dörrlamm, 2020. Kataloge: Vor- und Frühgeschichtlicher Altertümer **42**, Verlag des Römisch-Germanisches Zentralmuseums, Mainz, Germany, 336 pages, ISBN 978-3795423513 (in German). EUR90.00 hardcover.

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Ed. by Antje Bosselmann-Ruickbie, 2019. Byzanz zwischen Orient und Okzident **13**, Verlag des Römisch-Germanisches Zentralmuseums, Mainz, Germany, 188 pages, ISBN 978-3884673157. EUR43.00 hardcover.

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Ancient Egyptian Jewelry: 50 Masterpieces of Art and Design
By Nigel Fletcher-Jones, 2020. The American University in Cairo Press, Cairo, Egypt, and New York, New York, USA, 116 pages, ISBN 978-9774169656. USD19.95 hardcover.

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By Oytun Camcigil, 2020. Gilgamesh Art Publishing, London, 312 pages, ISBN 978-1908531575. GBP49.96 hardcover.

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Shaun Leane
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COMPILATIONS

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Lab Notes. Diamond with cavities showing radiation evidence • 'Matryoshka' diamond from Siberia, Russia • Graphitic cavities on diamond • Corundum inclusions in diamond • Solid carved dark gray diamond ring • Clarity-enhanced glass imitating emerald • Large grandidierite • Electronic device in a bead-cultured pearl • Fluorescence spectroscopy to detect pearl color treatments • Fossilized shell blister and blister pearl • Saltwater bead-cultured pearl with laminated nucleus • Bismuth glass-filled Burmese star ruby. *Gems & Gemology*, **56**(1), 2020, 126–139, www.gia.edu/gg-issue-search?ggissueid=1495312555038&articlesubtype=labnotes.*

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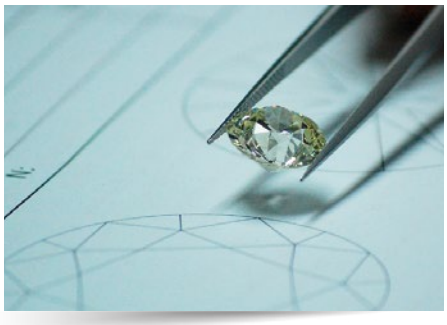

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Cover photo: *Burmese rubies are prized for their bright red colouration, and these 1.39 and 2.19 ct stones also contain interesting inclusions, which are described in a Gem Note on pp. 346–348 of this issue. Photo by Bilal Mahmood, American Gemological Laboratories.*

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What's New

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Presidium ARI

In September 2020, Presidium released its ARI diamond verification instrument. It uses UV radiation absorption to help identify natural versus CVD- and HPHT-grown synthetic diamonds, as well as synthetic moissanite. The handheld unit measures only 190 × 46 × 25 mm and tests colourless (D–J) samples, loose and mounted, as small as 0.02 ct. For additional information, including a video demonstration and downloadable user handbook, visit https://presidium.com.sg/psdproduct/ari-by-presidium.

NEWS AND PUBLICATIONS

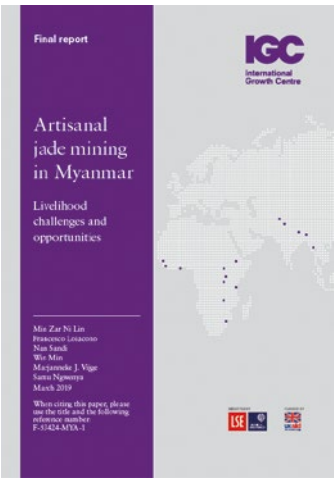

Artisanal Jade Mining in Myanmar

This 51-page report from the International Growth Centre in London was originally issued in March 2019 and made available online in April 2020. It provides an overview of Myanmar's jade sector, its political economy, characteristics of the artisanal 'hand-pickers', labour and social conditions at the mines, and conflicts between the artisanal miners and larger companies. It concludes with suggestions to improve the working conditions for the artisanal jade mining sector in Myanmar. Download the report at www.theigc.org/wp-content/uploads/2020/04/Lin-et-al-2019-Final-Report.pdf.

Consumer and Trade Report on Synthetic Diamonds

In October 2020, USA-based MVI Marketing LLC released *Gaining Critical Mass: 2020 Lab Grown Diamond Consumer & Trade Research Report*, which was prepared in association with the International Grown Diamond Association and *Instore* magazine. Some key findings include: (1) in 2020, 80% of jewellery consumers have heard about lab-grown diamonds, up from only 58% in 2018; (2) many diamond retailers report that up to 50% of customers ask about lab-grown diamonds; and (3) 8% of the 1,027 jewellery consumers surveyed had purchased synthetic diamonds. The report can be purchased for USD125.00 at www.themveye.com/premium-reports.php.

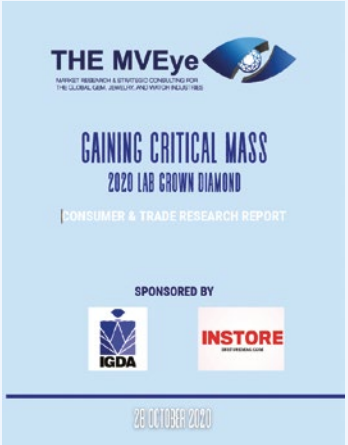

Gem Testing Laboratory (Jaipur, India) Newsletter

GJEPC INDIA
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LAB INFORMATION CIRCULAR
RED-BROWN 'HPHT' SYNTHETIC DIAMOND STRING

The September 2020 (Vol. 77) issue of GTL Jaipur's *Lab Information Circular* is available to download at https://gtljaipur.info/lab-information-circular1.aspx. It reports on strands of red-brown type Ib HPHT-grown synthetic diamond beads, a 43 ct yellow-brown phenakite, azurite in K-feldspar, a 149 ct violet Maxixe-type beryl, 'caramel spice' variegated opal, yellow-green magnesite sold as 'lemon chrysoprase' and amethyst with inclusions of goethite (not 'cacoxenite').

ISO Report on Grading Polished Diamonds

In September 2020, the International Organization for Standardization (ISO, Geneva, Switzerland) released ISO standard 24016:2020, titled *Jewellery and Precious Metals — Grading Polished Diamonds — Terminology, Classification and Test Methods*. The 55-page document 'specifies the terminology, classification and the methods that are used for the grading and description of single unmounted polished diamonds over 0,25 carat (ct)'. It applies only to natural, unmounted, polished diamonds and not to fancy-coloured, synthetic or treated diamonds (except as specified in the document) or assembled stones. The report is available for CHF178.00 in electronic or hardcopy format. Visit www.iso.org/standard/79795.html.

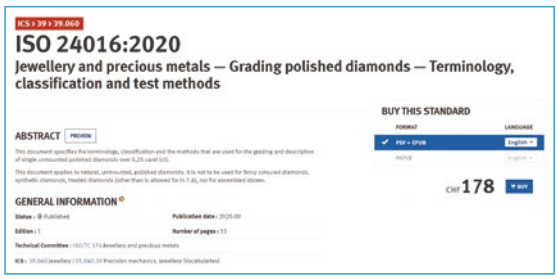
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"BLUE JADE": A Rare Jadeite-Jade
LAB UPDATE
A RARE COLORLESS GARNET

GIT Lab Reports on Blue Jadeite and Colourless Garnet

In August–September 2020, The Gem and Jewelry Institute of Thailand (GIT, Bangkok) posted reports at www.git.or.th/articles_technic_en.html about two unusual gem materials. In the first report, two samples of greenish blue to blue-green jadeite were found to be coloured by a combination of Ti and Fe, while Cr—the primary chromophore in green jadeite—was essentially absent. The second report describes a 0.38 ct grossular that lacked any chromophores (as shown by EDXRF and UV-Vis spectroscopy) and was therefore colourless, which is rare for garnet.

The National Association of Jewellers
Whitepaper
The role of Jewellery in the lives of UK consumers
Supported by
The Goldsmiths' Company
CMJ

NAJ White Paper on Jewellery and UK Consumers

In July 2020, the National Association of Jewellers (NAJ) in London released a report supported by the Company of Master Jewellers and the Goldsmiths' Company titled *The Role of Jewellery in the Lives of UK Consumers*, which profiles opinions gathered in autumn 2019 from more than 2,500 UK consumers. The findings indicate that 70% of consumers had purchased jewellery in the previous five years, and only 7% would consider purchasing online. Many, however, spend less than GBP100.00, well below the mean price for a 'significant jewellery purchase'. Download the report at www.thegoldsmiths.co.uk/company/today/news/2020/07/29/naj-research.

OTHER RESOURCES

Webinars and Other Online Resources for Gemmological Education

Since the arrival of the COVID-19 pandemic, various educational and gem industry organisations have provided webinars and other archived video content of interest to gemmologists. Additionally, recordings of some conferences that have streamed online during the pandemic have been made available for public viewing. The following items add to the list of such resources that have been featured in previous issues of *The Journal*.

- The **39th World Diamond Congress**, co-hosted by the World Federation of Diamond Bourses and the International Diamond Manufacturers Association, was held online 14–15 September 2020. Recordings of the opening session, closing session, a guest lecture on 'Marketing Diamonds to Future Generations' and the 2020 Young Diamantaires Meeting that took place during the conference are available at www.youtube.com/channel/UChzc3v8PFSZVpZYYc2Qqu7w.

- The **African Diamond Conference** webinar series was held online in October 2020 in lieu of its postponed second conference. Three webinars cover: (1) the state of the diamond market, (2) creating shared value in the future and (3) 'Telling the Real Diamond Story'. A closing statement is provided by Namibia's Minister of Mines, who is also chair of the African Diamond Producers Association. The videos can be viewed on the Antwerp World Diamond Centre's website at www.awdc.be/adc20.

- The **American Opal Society**, in conjunction with the Muzeo Museum and Cultural Center (Anaheim, California, USA), organised three webinars in September–October 2020 under the theme 'Opals Unveiled'. The first one, called 'Intro to Opal: Featuring Opals of Australia', is now available online. The others, titled 'Opals in the Americas' and 'How to Purchase Opal and Opal Jewelry', will be uploaded in the future. Visit https://muzeo.org/event/opalsunveiled.

- **Branko Gems** (Vancouver, British Columbia, Canada) and **Analytical Gemology & Jewelry** (New York, New York, USA) teamed up to present a webinar series on synthetic diamonds in October–December 2020. The videos feature experts who contributed to the recently released 3rd edition of the book *Laboratory-Grown Diamonds*. View the webinars at www.youtube.com/channel/UCtL81xZ4k7vDZtiF79UYZPg and www.brankogems.com/shop/product-category/webinars.

- **The Gem and Jewelry Institute of Thailand** has a webinar series called 'GIT Talk', which is available at www.youtube.com/playlist?list=PL2WH62cAeZKjGWF6T2MKSu9MyUbFB4qky. Most of the recordings are in Thai, but some are in English. They cover topics such as coloured stone marketing and colour terminology.

- **Initiatives in Art and Culture** (IAC, New York), in collaboration with De Beers, organised a virtual event in October 2020 titled 'All That Glitters'. A panel discussion covered responsible mining in the jewellery supply chain and leadership in responsible practice, and was followed by an awards presentation. Register and watch the 2.5-hour video at www.wirestream.tv/customer/iac/2020/10-28.

- **JewelleryNet.com** (Hong Kong) hosts numerous webinars on its 'Jewellery & Gem Knowledge Community' web page at https://jewellerynet.com/en/webinar. Most of the webinars were posted in September–October 2020, in conjunction with the Jewellery & Gem Digital World online event that took place 27–29 October. Others form a series titled 'Return & Recovery' about business strategies for dealing with challenges posed by the COVID-19 pandemic. The webinars feature various industry experts and are mostly in English.

- ***National Jeweler***'s 'My Next Question' webinar series started in September 2020 and is available at www.nationaljeweler.com/webinars/recorded-webinars. The recordings feature insights on topics such as marketing, photomicrography, gem legends and royal jewels.

- The **South Orange County Gem and Mineral Society** (San Clemente, California, USA) offers videos of several online presentations from a variety of speakers at www.youtube.com/channel/UCp1119BoRsRpsAqx6o0dwmg/videos. Topics include opal, rare and unusual gems of California, Native American jewellery, coloured diamonds, Montana sapphires and the Cheapside Hoard.

- **Vicenzaoro** (Vicenza, Italy), in collaboration with the Italian Gemmological Institute, offers a series of 'Gem Talks' webinars at www.youtube.com/playlist?list=PLrsoaKqEfAlVzHw4ayR9V_82ueY9fWdCO. Many were recorded at the January 2020 Vicenzaoro gem fair, where presentations (in English or Italian) covered topics pertaining to quartz, ruby and tanzanite.

MISCELLANEOUS

Peretti Museum Foundation

The Peretti family founded this Swiss-based non-profit foundation in 2020 to showcase the scientific contributions of Dr Adolf Peretti, including his collection of more than 2,000 gems, minerals and fossils. The Foundation plans to build a public museum devoted to paleontology, mineralogy and earth sciences, and supports research and collaboration with other scientists. The foundation's website (www.pmf.org) has videos on ruby, amber and perettiite-(Y) from Myanmar, as well as charity work done by Dr Peretti. It also contains extensive information about perettiite-(Y), and hosts a new publication titled *Journal of Applied Ethical Mining of Natural Resources and Paleontology (PMF Journal)*, with the first issue covering 'Ethics, Science and Conflict in the [Burmese] Amber Mines'.

Peretti Museum Foundation

What's New provides announcements of new instruments/technology, publications, online resources and more. Inclusion in What's New does not imply recommendation or endorsement by Gem-A. Entries were prepared by Carol M. Stockton, unless otherwise noted.

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COLOURED STONES

Celestine from Madagascar

Celestine (or celestite, coelestite) is named after the Latin *caelestis*, alluding to the colour of the sky. It is a strontium sulphate ($SrSO_4$) of the baryte group, where the other isostructural members are baryte ($BaSO_4$), anglesite ($PbSO_4$) and anhydrite ($CaSO_4$). A solid-solution series exists between celestine and baryte, and the name *baritocelestine* is sometimes used for barium-rich celestine. Celestine is colourless to pale blue, although rare orange material has been found in Ontario, Canada (Bernstein 1979).

Although celestine occurs worldwide, Madagascar is the main source and has produced many hundreds of tons of geodes showing pale blue colour, including the world's finest specimens. The mining area is located north and west of Sakoany village in the Mahajanga (Majunga) region on the north-western coast of Madagascar, near the mouth of Betsiboka River (Pezzotta 1999; Wilson 2010; Pezzotta & Pezzotta 2020). Celestine is most commonly seen on the market as tumbled stones and mineral specimens, and is sometimes fashioned into cabochons. It is rarely encountered as faceted stones; its low hardness (Mohs 3–3½), perfect cleavage and brittleness make it difficult to facet.

The 4.22 ct faceted celestine in Figure 1 is reportedly from Madagascar and was characterised by the author to add more gemmological data to the literature on this collector's stone. It showed the following properties: colour—almost colourless with a very faint greyish blue tint; pleochroism—light green-blue, light bluish violet and colourless; lustre—vitreous; diaphaneity—transparent; RI—1.620–1.631; birefringence—0.011; optic character—biaxial positive; hydrostatic SG—3.98; magnetism—diamagnetic (repelled by an N52 neodymium magnet); Chelsea Colour Filter reaction—none; and fluorescence—inert to long- and short-wave UV radiation. These characteristics are consistent with those previously reported for celestine (O'Donoghue 2006). Microscopic observation (up to 40×) showed no visible inclusions.

Infrared (IR) reflectance spectra were collected from several spots on the stone's table and pavilion facets, and a representative spectrum is provided in Figure 2. Although the anisotropy of the material significantly modified the pattern in the 1300–1000 cm^{-1} range, overall the data matched the reference spectrum published by Hainschwang and Notari (2008). It is possible to distinguish celestine from baryte using IR spectroscopy because the ν_1 band (stretching mode) is at 991 cm^{-1}, versus 981 cm^{-1} for baryte. Three bands (ν_4) at 614–618, 643 and 654 cm^{-1} for celestine (compared to 610–614, 635 and 648 cm^{-1} for baryte) can also be used, but the patterns of these bands are sensitive to anisotropy. The bands' assignments were reported by Lane (2007).

Visible-range spectra (Figure 3) were collected for each polarisation direction corresponding to the three pleochroic colours, and the path lengths were used to calculate absorption coefficients. The E||b spectrum (green-blue) consisted of two broad bands at 425 and 618 nm that created a transmission window at about 510 nm. The E||c spectrum (bluish violet) was similar to E||b, but one of the broad bands (605 nm) was somewhat shifted towards the blue region and it lacked

Figure 1: This 4.22 ct celestine (9.4 × 7.6 × 6.4 mm) is reportedly from Madagascar. It was fashioned by Ottorino Invernizzi from a crystal taken from a mineral specimen. Photo by T. Cathelineau.

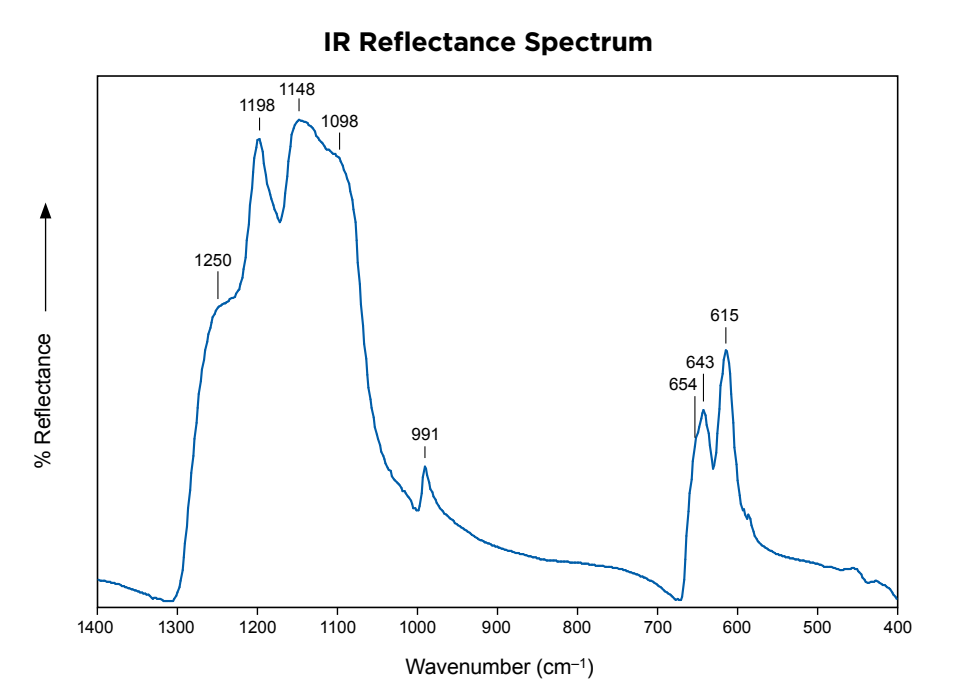

Figure 2: The IR reflectance spectrum of celestine is characterised by bands in the ranges 1200–1080 and 680–580 cm^{-1}, as well as a ν_1 band at 991 cm^{-1}.

the 425 nm band. An asymmetric band (shoulder) on the low-wavelength side of the 605–618 nm absorption is due to an underlying band at around 575–585 nm. The E||a spectrum (colourless) was rather flat.

The causes of colour in celestine were studied with EPR spectroscopy by Bernstein (1979), who reported the presence of colour centres due to radiation damage; no more recent work appears to have been published. Bernstein (1979) indicated that the 425 nm band is related to SO_2^-, the 575–585 nm band might be due to SO_3^- and the 605–618 nm feature is associated with O^-. These centres are stabilised by the presence of trace components, primarily K^+ substituting for Sr^{2+}. Bernstein (1979) also performed heat-treatment experiments and found that thermal bleaching occurred at just 200°C for heating durations of a minute to several days; the colour could be restored by irradiation.

Celestine has been reported in the literature to be sometimes 'fluorescent', with a white, blue or even red reaction to UV radiation. A broad photoluminescence (PL) emission band usually peaking between 430 and 500 nm has been possibly connected to Pb^{2+} centres, but this has not been confirmed (Gaft *et al.* 2015). Other studies have proposed several other possible luminescence causes, such as organic impurities and Eu^{2+} (Tarashchan 1978), and at low temperature (77 K), O_2^-, VO_4, TiO_4 and MoO_4 (Gaft *et al.* 1985). The stone described here was analysed by PL spectroscopy using 254, 375 and 405 nm excitations at room temperature, but no photoluminescence was detected.

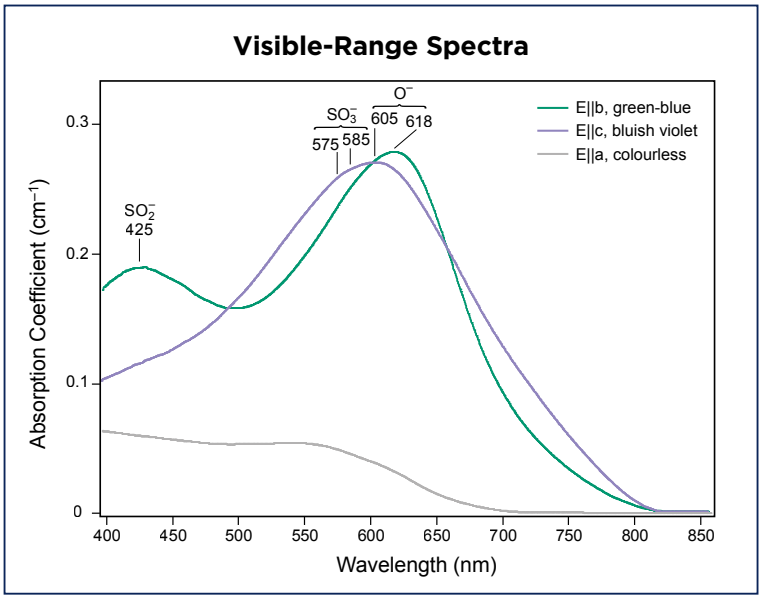

Figure 3: Polarised visible-range spectra are shown for the green-blue (E||b), bluish violet (E||c) and colourless (E||a) pleochroic directions of the 4.22 ct celestine. The major absorption bands are due to O^-, SO_3^- and SO_2^-.

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Vesuvianite (Idocrase) and Apatite Inclusions in Ruby Identifiable by Infrared Spectroscopy

Recently, two rubies weighing 1.39 and 2.19 ct (see the cover of this issue) were submitted to the American Gemological Laboratories (AGL) separately for testing, and they provided an opportunity to expand the range of inclusions identifiable in corundum using infrared spectroscopy. Routine origin testing indicated that both samples originated from Myanmar (Burma).

The 2.19 ct ruby contained a variety of internal features, including groups of near-colourless to slightly greenish crystals (Figure 4). Raman micro-spectroscopy identified several of the surface-reaching inclusions as vesuvianite (also known as idocrase). While all of the ruby's standard gemmological properties were consistent with those of natural corundum, the mid-infrared (IR) spectra showed several anomalous features, which we suspected were due to the vesuvianite inclusions: a dominant compound structure between approximately 3700 and 2700 cm^{-1} with bands at approximately 3580, 3475, 3260, 3180 and 3086 cm^{-1}, as well as a series of weaker bands positioned at approximately 5018, 4515, 4235, 4200 and 4105 cm^{-1} (Figure 5). Analysis of

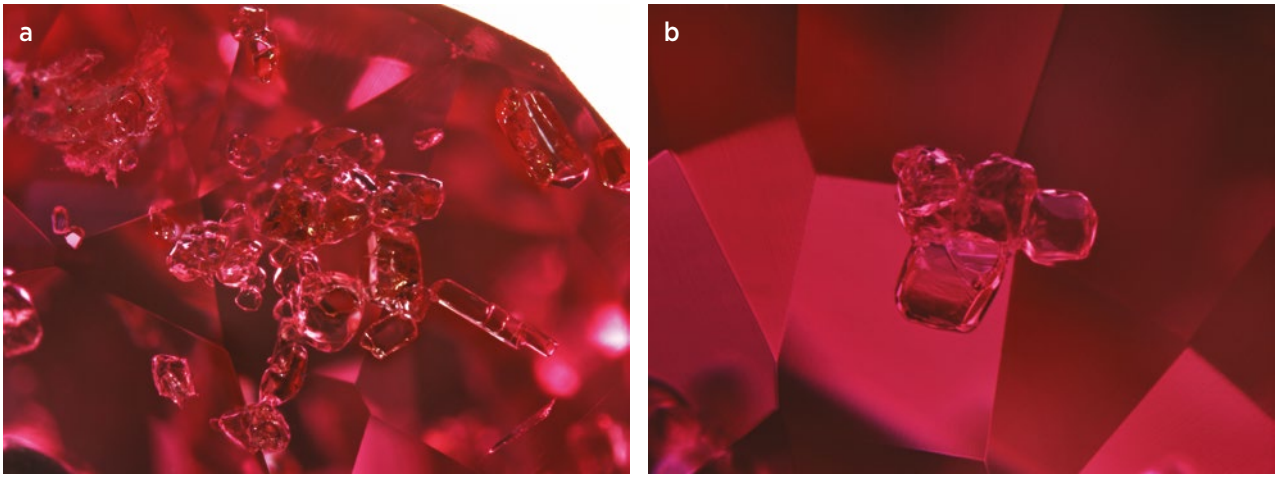

Figure 4: These groups of near-colourless to slightly greenish crystals in the 2.19 ct Burmese ruby were initially identified by Raman micro-spectroscopy as vesuvianite. Photomicrographs by C. P. Smith; magnified (a) 38× and (b) 78×.

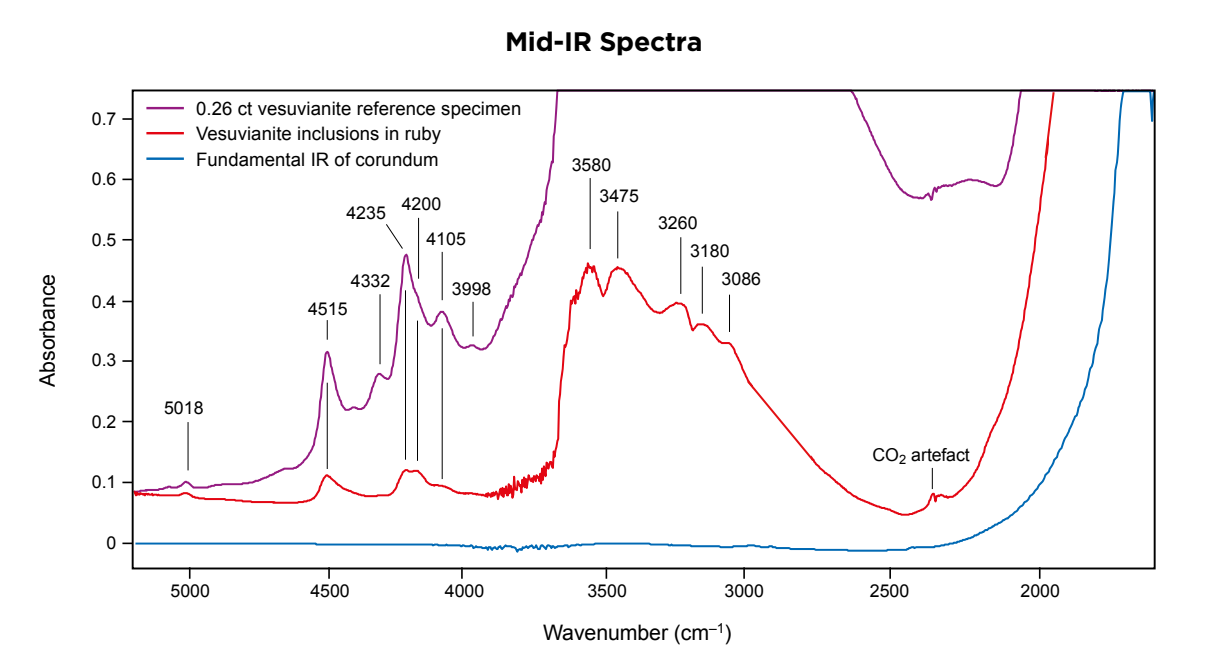

Figure 5: The mid-IR spectrum of the 2.19 ct ruby reveals a series of absorption bands that identified the presence of vesuvianite inclusions. Shown for comparison is the reference spectrum for a 0.26 ct vesuvianite (path length 2.5 mm). The vesuvianite spectrum shows total absorption between approximately 3700 and 2700 cm^{-1}, whereas the small size of the vesuvianite inclusions in the ruby permitted the features in this region to be fully resolved. Corundum is anhydrous and is therefore typically free of such bands.

a vesuvianite from the AGL reference collection (again, see Figure 5) proved that the anomalous features in the ruby spectrum were indeed due to these inclusions.

Because vesuvianite absorbs strongly in the mid-IR region of the spectrum, even minute inclusions can give a distinct IR signal. In fact, when collecting our reference spectra for vesuvianite it was necessary to analyse a small sample (0.26 ct) because larger ones yielded spectra that saturated significant regions of the spectrum, making the comparison with our ruby spectrum difficult. The area of the spectrum in which the 0.26 ct reference vesuvianite showed total absorption corresponded to the region of the compound band structure in the 2.19 ct ruby, and a comparison with published literature (e.g. Groat *et al.* 1995; Bellatreccia *et al.* 2005) also showed that the anomalous peaks resolved in this ruby were consistent with IR features reported for vesuvianite.

Vesuvianite is a hydrous sorosilicate that commonly forms in skarns as a result of the regional metamorphism of limestone (Groat *et al.* 1992). Marble units resulting from metamorphosed limestone are well known to host ruby mineralisation in the Mogok Valley region of Myanmar. Vesuvianite was first identified in ruby (from Myanmar) by Renfro and Koivula (2017). One of the present authors (CPS) has previously observed the IR features described above in a few other rubies, but until now their relation to the presence of vesuvianite inclusions was not recognised.

The 1.39 ct ruby contained several colourless euhedral mineral inclusions, including one particularly large crystal directly under the table (Figure 6). The crystals

Figure 6: Shown here is a particularly large near-colourless apatite crystal located just under the table facet of the 1.39 ct Burmese ruby. Photomicrograph by C. P. Smith; magnified 28×.

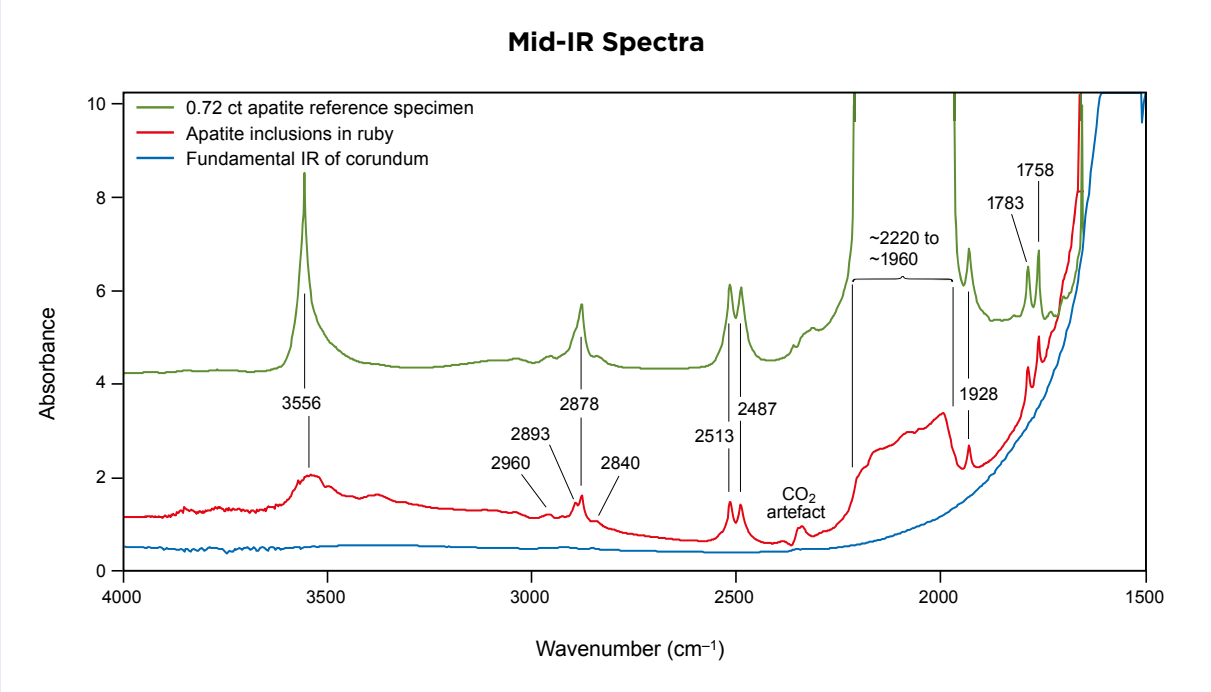

Figure 7: The mid-IR spectrum of the 1.39 ct Burmese ruby reveals a series of absorption bands related to the presence of a large apatite inclusion. Shown for comparison is the reference spectrum for a 0.72 ct apatite (path length 4.5 mm). While the apatite spectrum shows total absorption between approximately 2220 and 1960 cm^{-1}, the structure of this band can be seen for the apatite inclusion in the ruby. Corundum is anhydrous and is therefore typically free of such bands.

exhibited a morphology common for apatite inclusions in ruby. Infrared spectroscopy of this sample displayed a series of bands not typically associated with corundum, at approximately 3556, 2960, 2893, 2878, 2840, 2513, 2487, 1928, 1783 and 1758 cm^{-1}, as well as a compound structure between about 2220 and 1960 cm^{-1}. Comparison with the mid-IR spectrum of a faceted apatite from the AGL reference collection proved that these features were related to apatite (Figure 7). Apatite occurs as a protogenetic inclusion in rubies and sapphires from a number of sources around the world (see, e.g., Gübelin & Koivula 2008; Hughes 2017).

With this research, the catalogue of minerals identifiable by FTIR spectroscopy as inclusions in corundum continues to expand (see, e.g., Smith *et al.* 2020). This emphasises the usefulness of applying a range of analytical techniques to help identify and recognise inclusions occurring within a host gemstone.

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Tourmaline with Cassiterite Inclusions

Tourmaline is well known for its range of colours, but not so much for its variety of inclusions. Most of the time it simply contains elongated filamentary two-phase fluid inclusions referred to as 'trichites'. While cataloguing some older samples in the collection of the French Gemmological Laboratory, we came across a tourmaline of unknown geographical origin that contained some unusual octahedral inclusions (Figure 8).

The 0.90 ct tourmaline was a medium dark, slightly greenish blue, and was fashioned as a buff top. The gem's RI was about 1.62–1.64 and its hydrostatic SG was 3.08, confirming it was a tourmaline. It contained a number of small, almost perfectly octahedral-appearing crystals with slightly rounded shiny faces (Figure 9). In some observation directions they appeared dark brownish green, but when reflected light was added they looked more brownish. The brownish green appearance probably resulted from the surrounding tourmaline colour combined with the colour of the inclusions.

A Raman spectrum of a surface-reaching inclusion was obtained with a Renishaw InVia Raman spectrometer using 514 nm excitation and a standard resolution of 4 cm^{-1}. The spectrum showed major peaks at about 1061, 718, 635, 375 and 224 cm^{-1}, and the CrystalSleuth software associated with the RRUFF database revealed a match for cassiterite (SnO_2). One common shape of cassiterite crystals—the tetragonal bipyramid—looks very much like a regular octahedron, and the typical brown colour of cassiterite is also consistent with this identification.

To obtain confirmation, we performed chemical analysis of the surface-reaching inclusion (which measured up to 50 µm in dimension) using a JEOL JSM-5800LV scanning electron microscope equipped with a SANx EDS SDD detector. The analysis revealed Sn and O, the components of cassiterite, and a small Si signal, likely from the matrix. Qualitative analysis of the tourmaline host indicated the presence of Si, Al and Na, with traces of Fe and Mn. This is consistent with an elbaite composition, although B and Li are too light to be detected with this instrument. In addition, Fe is known to contribute to the dark blue colour of tourmaline (i.e. indicolite). Backscattered-electron (BSE) mode showed high contrast between the inclusions and the matrix, confirming the presence of heavy elements such as Sn (Figure 10).

The association of gem-quality tourmaline with cassiterite is uncommon. Gübelin and Koivula (1986, p. 241) mentioned acicular inclusions of tourmaline in gem cassiterite, but not the reverse. They described inclusions

Figure 8: This 0.90 ct tourmaline (approximately 7.6 × 5.9 × 3.3 mm) contains unusual crystal inclusions, which are visible here in brightfield illumination in the left part of the stone. Photo by E. Fritsch.

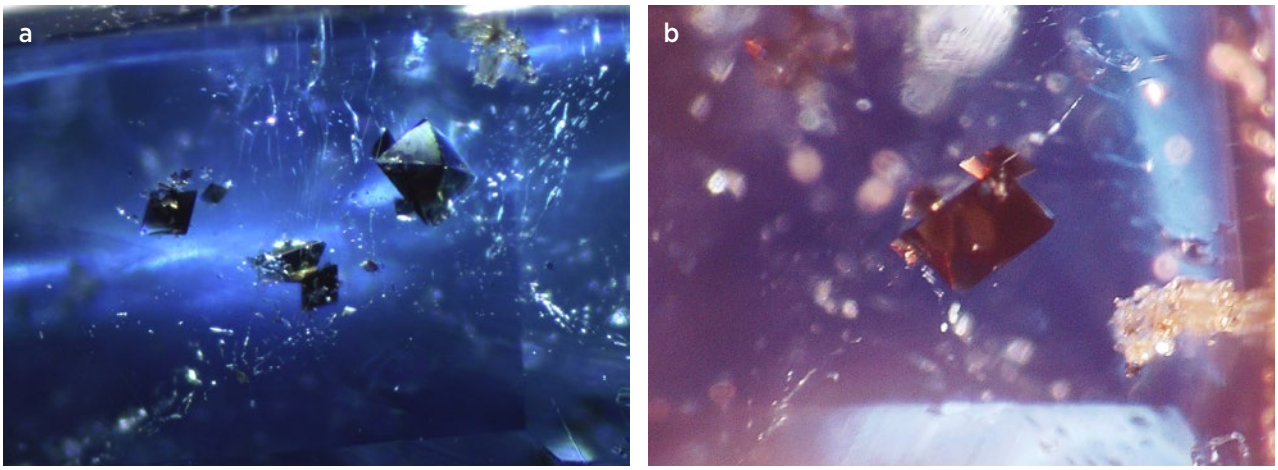

Figure 9: (**a**) In some observation geometries, the octahedral-appearing crystals look brownish green. (**b**) With the addition of reflected light, the inclusions look dark brown. Photomicrographs by A. Delaunay; image widths (a) 1.8 mm and (b) 1.5 mm.

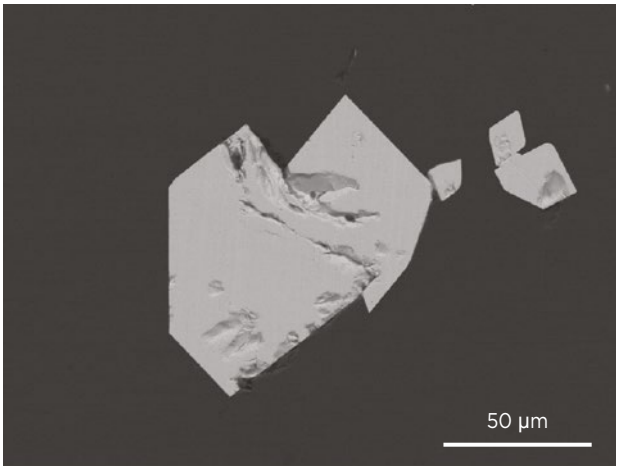

Figure 10: In this BSE image, the surface-reaching cassiterite inclusions appear much lighter grey than the surrounding tourmaline host, confirming the presence of heavy elements—in this case Sn. Image by N. Stephant.

of cassiterite mostly in quartz but also, in one case, in beryl. Subsequently, Gübelin and Koivula (2005, p. 585) showed cassiterite inclusions in quartz that displayed a well-formed octahedral shape.

The association of cassiterite with tourmaline (typically schorl) is known in granitic pegmatites, and Sn is one of the high field-strength elements (i.e. high valence: Sn^{4+}) to be incorporated latest in pegmatite minerals, occurring further from the granitic source than most others. It forms in moderately to highly evolved complex pegmatites with spodumene or petalite, and is typically associated with Sn, Ta and Cs mineralisation (Simmons *et al.* 2003). Grassi (2014) described cassiterite crystals from the Usakos tourmaline mine in Namibia that are very close in size and shape to the ones described here. In addition, Usakos is well known for producing gem-quality blue elbaite, so it is a possible locality of origin for this unusual gem.

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DIAMONDS

Pale Yellow Type IIa Diamond Coloured by H4 Centres

Type IIa diamonds are generally colourless, brown or pink, and some can turn yellow after HPHT annealing by the formation of substantial nitrogen-related defects (Wang *et al.* 2003). In addition, Lu and Wang (2010) described an untreated greenish yellow type IIa diamond coloured by the H3 centre.

Recently, the National Gemstone Testing Center's (NGTC) Shenzhen laboratory examined a 1.29 ct cushion modified brilliant-cut diamond with a pale yellow (M) colour (Figure 11). It had no detectable nitrogen-related absorptions in the mid-infrared region, but the near-

Figure 11: This 1.29 ct pale yellow type IIa diamond owes its colour to H4 centres. Photo by W. Zhu.

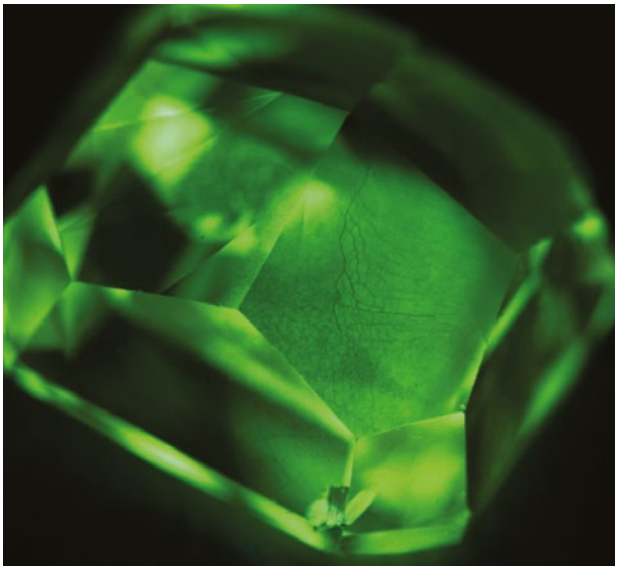

Figure 12: This DiamondView image of the 1.29 ct diamond in Figure 11 shows strong green fluorescence and a well-developed polygonal pattern associated with natural type II diamonds. Photo by Z. Song.

infrared spectrum revealed an obvious radiation-related absorption at 9280 cm^{-1}. This line is equivalent to the 1.149 eV centre and anneals out at temperatures above 1000°C (Zaitsev 2001). Such intense absorption often appears in irradiated blue and green diamonds.

The UV-Vis-NIR absorption spectrum, collected at liquid-nitrogen temperature, revealed a relatively high concentration of the H4 defect, with its zero-phonon line at 495.8 nm. The H4 centre consists of four nitrogen atoms separated by two vacancies, and can produce a yellow body colour and green fluorescence (Shigley & Breeding 2013).

DiamondView imaging (Figure 12) showed strong green fluorescence and a well-developed polygonal pattern associated with lattice dislocations characteristic of natural type II diamonds. We therefore concluded that the present diamond was natural and not synthetic. A similar fluorescence structure was observed in a type II diamond containing the H3 centre (Johnson 2010).

Microscopic observation revealed a fracture near the girdle (Figure 13) that displayed etch patterns. There were also brown radiation stains along its edge, presumably caused by radioactive fluids penetrating into the fracture (again, see Figure 13; cf. Breeding *et al.* 2018). Photoluminescence (PL) spectroscopy with 473 and 532 nm excitation showed radiation-related defects such as the GR1, 3H and other vacancy-related centres, including H4, H3 and NV. Multiple PL analyses of various spots on the stone showed a greater intensity of the 3H centre in the areas with radiation stains than in the rest of the diamond, while the H3 centre showed the reverse trend (Figure 14). The H3 centre is composed of two nitrogen atoms separated by a single vacancy. Photoluminescence related to the 3H centre is associated with isolated self-interstitials and disappears after heating to about 420°C (Steeds *et al.* 1999).

The strong PL intensity of the H4 centre provided good evidence for the origin of the diamond's yellow body colour. This is the first pale yellow type IIa diamond coloured by H4 centres caused by natural irradiation that has been seen in NGTC's laboratories.

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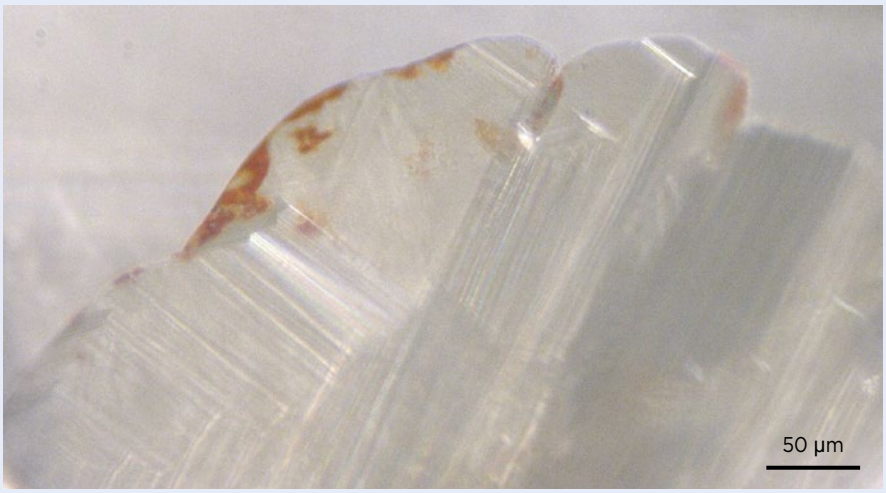

Figure 13: Radioactive fluids penetrated into this fracture in the diamond and caused brown radiation stains. Photomicrograph by W. Zhu.

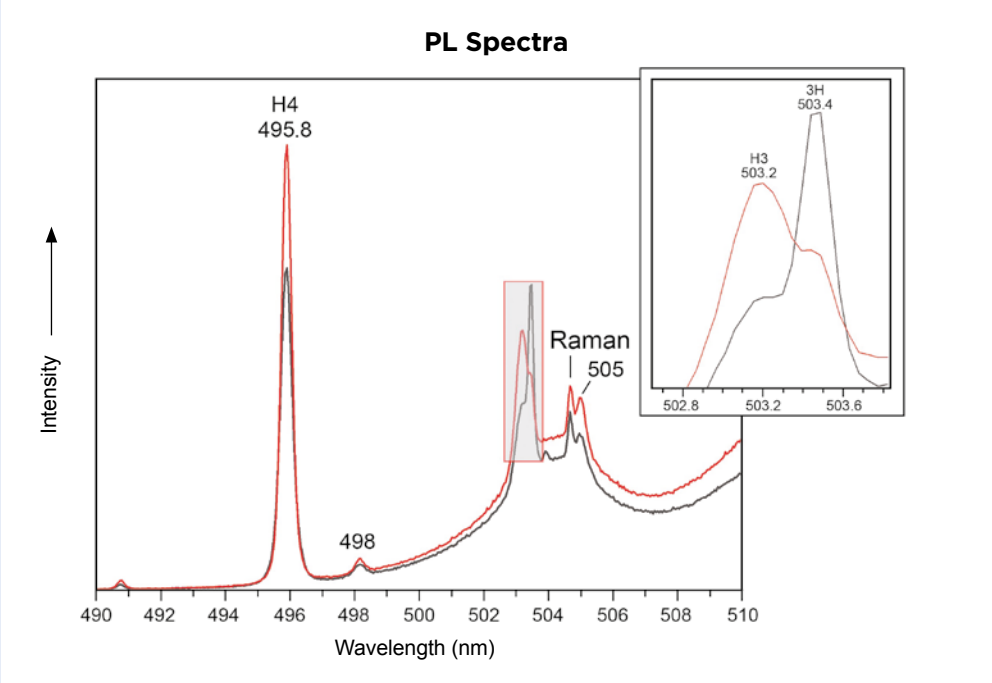

Figure 14: PL spectroscopy with 473 nm excitation shows a reverse in the relative intensity of the H3 and 3H defects between areas containing radiation stains (black trace) and other parts of the diamond (red trace).

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SYNTHETICS AND SIMULANTS

History Revisited—A Quartz 'Soudé Emerald'

Synthetic emeralds have become more affordable and prevalent, so one might expect to see fewer emerald imitations. However, in recent years, various types of assembled or composite imitations (triplets known as 'soudé emeralds' in the past) have continued to appear. These have traditionally been composed of crown and pavilion layers of colourless synthetic spinel or quartz that are bonded together with a thin green-coloured layer (Anonymous 1940; Webster 1952). Other materials that have been reported for triplets imitating emeralds include natural or synthetic beryl, glass or petalite, but almost any light-coloured or colourless material could be used.

Recently submitted to the Stone Group Laboratories was an emerald-cut green specimen set in a ring with two round brilliant diamonds (Figure 15). The colour was what might be expected for emerald. The specimen was inert

Figure 15: The emerald-cut green specimen (approximately 9.0 × 13.2 mm) set with diamonds in this ring turned out to be a classic type of quartz triplet known as 'soudé emerald'. Photo by B. Williams.

to long-wave UV radiation and no reaction was observed with a Chelsea Colour Filter. Observation with 10× magnification revealed surface scratches and abrasions, as well as partially healed, fluid-filled fissures, as are commonly seen in emeralds, but these were noticeably less complex in structure (Figure 16). Further observation revealed that the inclusions did not continue across the girdle plane. A side view with immersion readily revealed the composite structure of the sample (Figure 17). Abrasions at the exposed girdle edges drew attention to apparent separations along the bonding plane between the crown and pavilion due to wear and, perhaps, cleaning.

We were curious as to the exact components of the triplet, and a GemmoRaman-532SG spectrometer confirmed both the crown and pavilion to be quartz. The natural (i.e. not synthetic) origin of the quartz was indicated by the presence of natural inclusions and confirmed by FTIR spectroscopy. UV-Vis spectroscopy performed with a GemmoSphere instrument showed a broad band centred at about 730 nm and a strong absorption in the violet to UV region of the spectrum, which together produced a transmission window in the green region at about 520 nm (Figure 18). A spectrum of a Brazilian emerald shown for comparison displays a transmission window at a similar wavelength formed by distinct absorptions due mainly to Cr^{3+} with contributions from V^{3+}, Fe^{2+} and Fe^{3+}.

It seems possible that this triplet could have been a 'soudé emerald' that was inherited or otherwise recycled from old jewellery, presumed to be natural and then re-set into the present ring. In any case, this quartz triplet serves as a reminder that old-fashioned emerald imitations may still be encountered in today's market.

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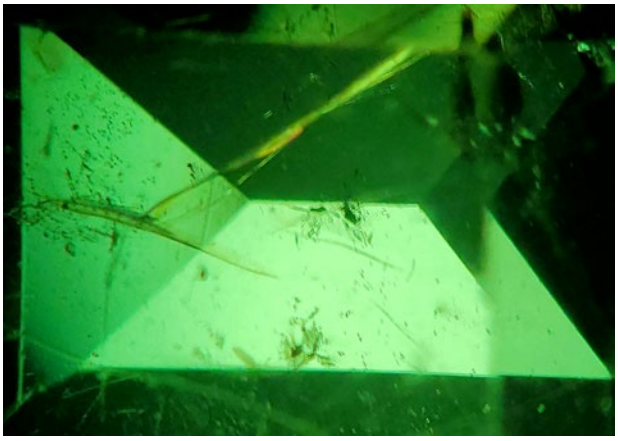

Figure 16: Fluid inclusions in the triplet resemble those seen in emeralds but are less complex. Photomicrograph by B. Williams; image width 7 mm.

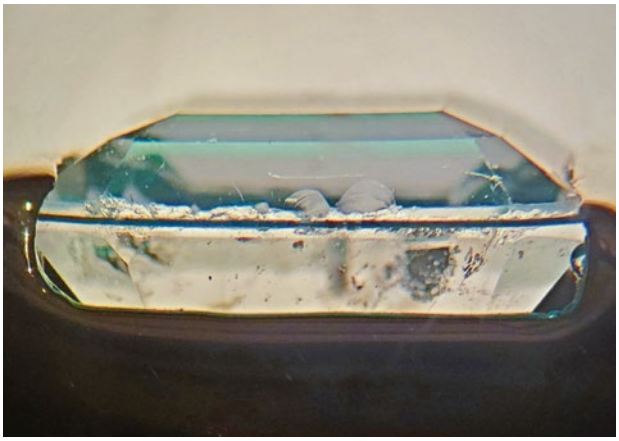

Figure 17: A side view of the girdle of the triplet clearly reveals a coloured intermediate layer. Photo by B. Williams, using darkfield illumination and immersed in water.

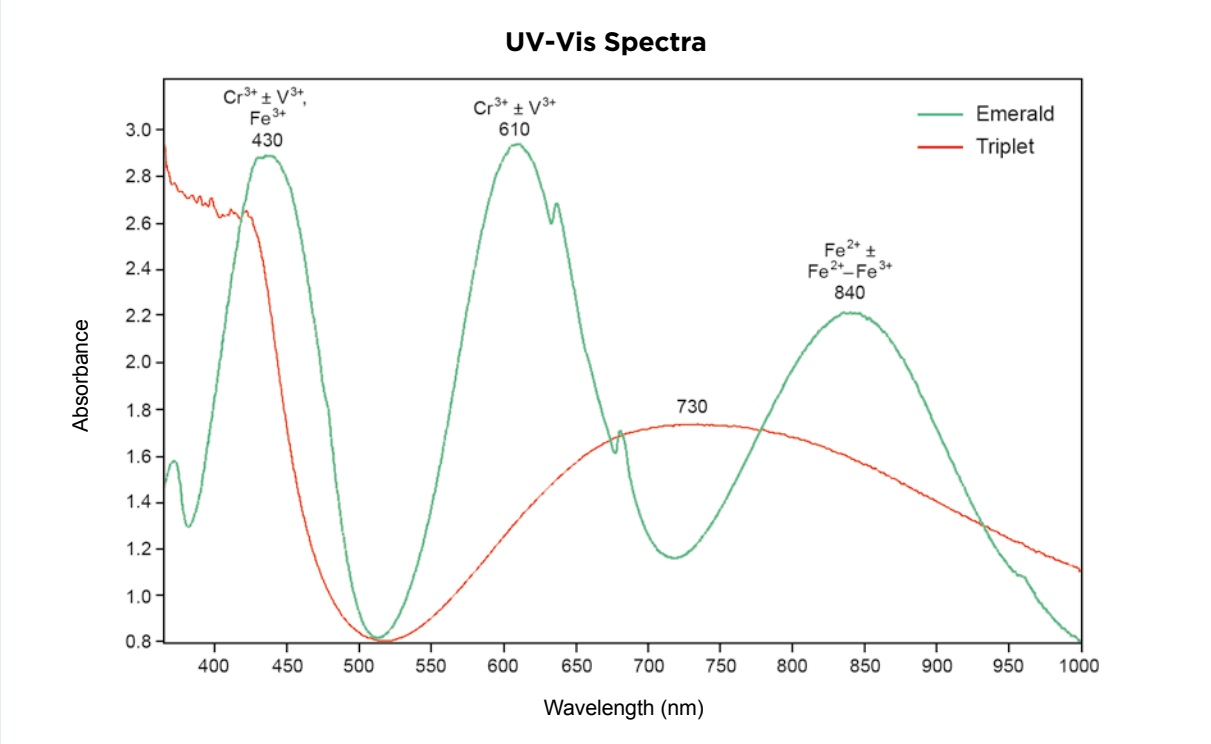

Figure 18: UV-Vis spectroscopy of the triplet shows a transmission window in the green region at about 520 nm, similar to that seen in the spectrum of a Brazilian emerald. While the absorption features recorded for the emerald are mainly due to Cr^{3+}, those of the triplet are attributed to a dye in the coloured layer.

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Synthetic Rock Crystal Clusters on the Chinese Market

In recent years there have been various reports of synthetic quartz containing inclusions that would be expected in natural quartz (e.g. Ng-Pooresatien 2015; Skalwold 2016), which show ongoing developments in such laboratory-grown material. However, little has been published on the presence of synthetic quartz crystal clusters (see, e.g., Clifford & Klipov 2015; JGGL 2019).

In June 2020, a team from NGTC visited China's largest crystal market, located in Jiangsu Province. The group obtained a 1.24 kg crystal specimen—sold as natural quartz—that consisted of numerous transparent colourless crystals pointing in different directions that contained local areas of green colouration (Figure 19). The crystals were composed of a hexagonal prism and a rhombohedron, with horizontal parallel striations and polygonal etchings on the surfaces of the hexagonal prism, which are similar to those typically seen on natural quartz crystals. The green-coloured areas were produced by abundant particles of different sizes, with a clear boundary between green and colourless zones, as might be expected for chlorite-included quartz. However, on one side of the cluster, a group of crystals displayed unusual colour banding that was perpendicular to the direction of crystal growth (Figure 20). This aroused suspicion that the sample was not composed of natural rock crystal quartz.

Several colourless crystals were removed from the cluster for further examination. Their RIs were 1.544–1.550 (birefringence 0.006) and their hydrostatic SG values were in the range of 2.56–2.58. The upper RI value and birefringence were slightly lower than those expected for quartz, and the SG range was also low. With magnification, we observed a large number of 'fingerprint'-like

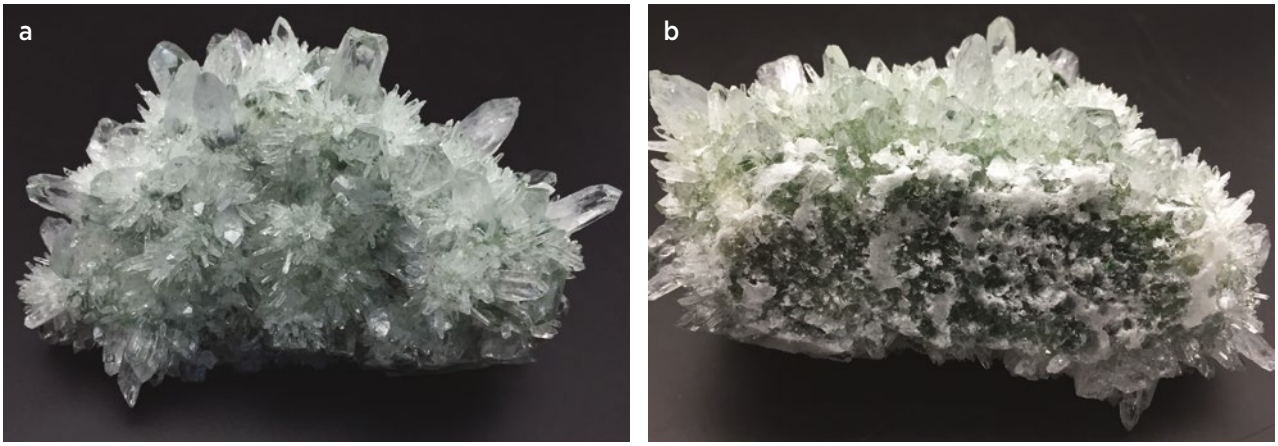

Figure 19: (**a**) This 1.24 kg specimen, which proved to consist of synthetic quartz, displays many colourless crystals oriented in different directions that locally contain green areas. (**b**) Viewed from the reverse side, the cluster exhibits additional areas of green colouration. Photos by H. Dai.

Figure 20: This group of crystals (160 mm long) on one side of the synthetic quartz cluster displays conspicuous colour banding perpendicular to the direction of crystal growth. Photo by H. Dai.

gas-liquid inclusions, arranged in indistinct, irregular curved planes that extended in various directions (Figure 21), as typically seen in natural quartz. No 'breadcrumb' inclusions typical of synthetic quartz were seen. The green areas of the crystals remained green when viewed with a Chelsea Colour Filter, while natural green quartz appears light red (Ma *et al.* 2011).

IR absorption spectra were recorded for the colourless and green areas of the crystals in transmission mode using a Thermo Nicolet 6700 infrared spectrometer (Figure 22). The colourless crystals lacked the bands at 3379, 3483 and 3595 cm^{-1} that are characteristic of natural quartz, and displayed bands at 3585, 3432, 3294 and 3194 cm^{-1} that are typical of synthetic quartz (Zecchini & Smaali 1999; Ng-Pooresatien 2015). The green areas of the crystals showed an additional absorption band at 5520 cm^{-1}, but lacked the band at 4455 cm^{-1} that has been reported in natural green quartz (Ma *et al.* 2011).

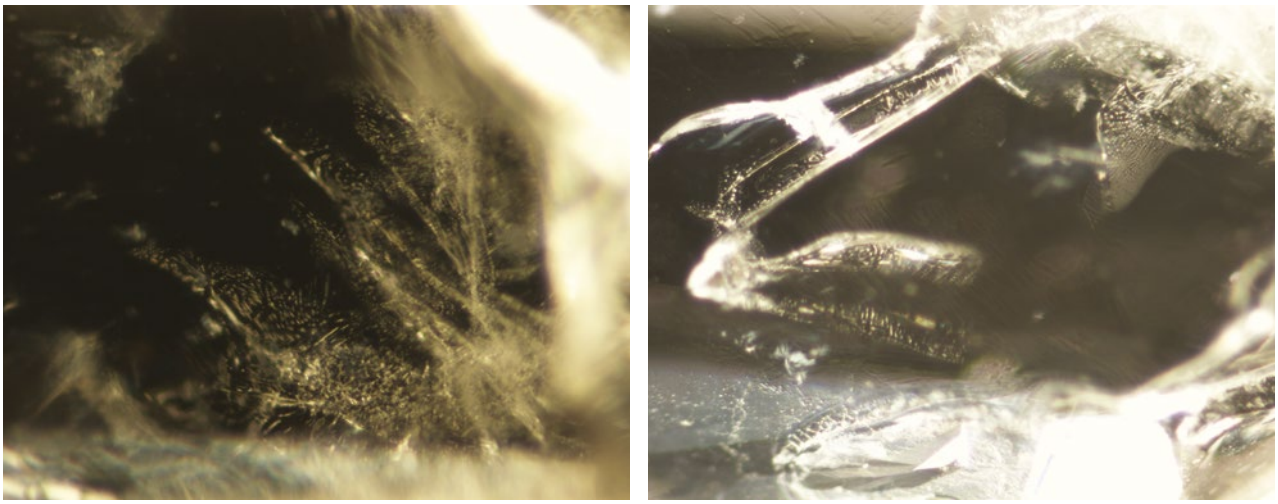

Figure 21: The synthetic quartz contains numerous gas-liquid inclusions, which appear similar to those seen in natural quartz. Photomicrographs by H. Dai; magnified 30×.

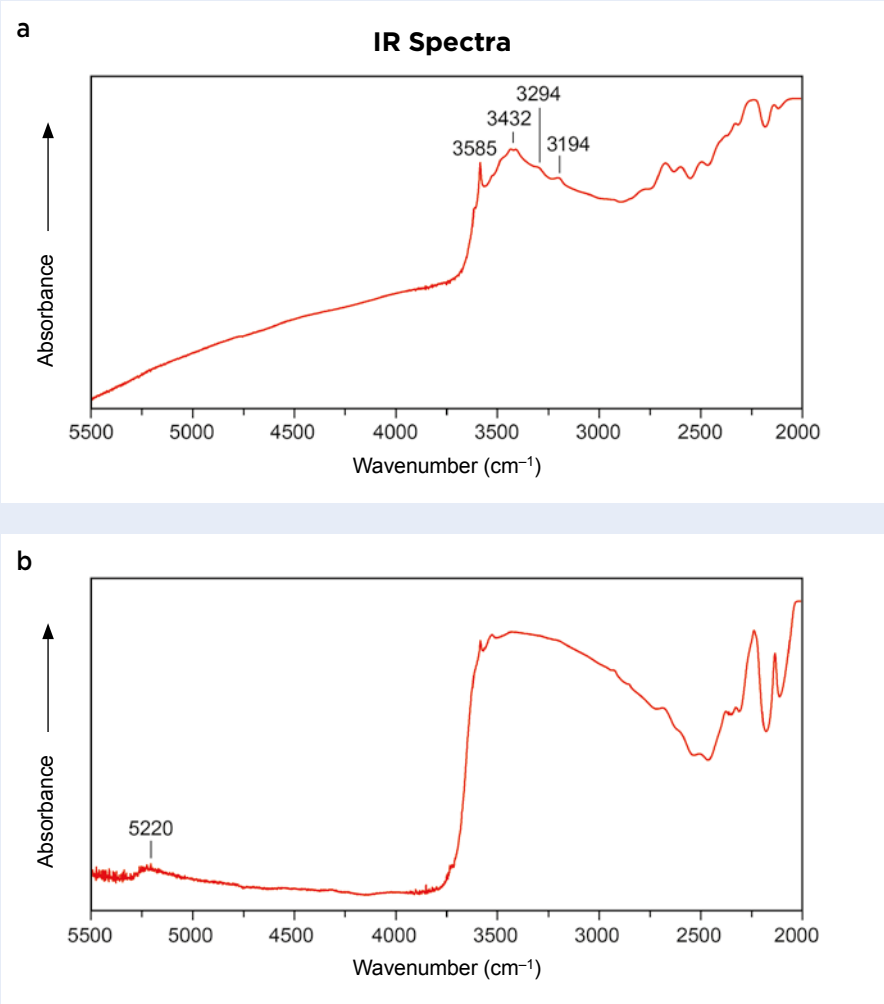

Figure 22: (**a**) The IR absorption spectrum of a colourless crystal from the specimen shows bands at 3585, 3432, 3294 and 3194 cm^{-1} that are typical of synthetic quartz. (**b**) The spectrum of a green portion of a crystal from the specimen shows an additional band at 5220 cm^{-1} and lacks the feature at 4455 cm^{-1} previously reported in natural green quartz.

Therefore, we concluded that the sample was composed of synthetic rock crystal quartz.

This specimen is similar to some of those pictured in the brief report by JGGL (2019), and it also resembles certain crystal clusters being offered (as natural) by various sellers on the internet. The appearance on the market of such material is an important reminder that not all synthetic quartz crystals consist of single columnar plates, but they also can be grown as clusters. Furthermore, such natural and synthetic quartz crystals can have a very similar visual appearance, with identical inclusion features. Therefore, IR absorption spectroscopy may be necessary to separate them.

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TREATMENTS

Cobalt Glass-Filled Sapphires and the Chelsea Colour Filter: A New Technique

The Chelsea Colour Filter (CCF) was developed in 1934—initially as a means to separate natural and synthetic emerald (Popley 1934)—by Basil Anderson and James Payne at the gem testing laboratory of the London Chamber of Commerce. It works by transmitting certain wavelengths of light in the green-yellow and the extreme red end of the visible spectrum. Although it is less effective today for separating emeralds than when it was first introduced, the CCF remains an essential part of a gemmologist's basic kit for quickly distinguishing between similarly coloured gem materials. The CCF can be used to rapidly separate simulants in stone parcels, particularly blue ones. For example, blue sapphires show no reaction to the CCF (and therefore appear green), while blue glass coloured by cobalt will appear red.

At the February 2020 Accredited Gemologists Association (AGA) Tucson Conference in Arizona, USA, Gem-A Instruments Manager Sam Lloyd presented a workshop called 'Gem-Fun with Filters!', and the new CCF technique described here was discovered when setting up for the workshop, as a curiosity, following the demonstration of other filters used to detect the presence of foreign substances in gemstones. For example, a colour filter can help identify dye in jadeite because it creates greater contrast between the dye and the jadeite. In the case of cobalt glass-filled sapphires, the Co-bearing glass and the sapphire have different responses under the CCF, so the contrast between them becomes obvious.

The CCF is typically held up to the eye to view samples laid on a white background that are illuminated with oblique incandescent light. With the new technique described here, the incandescent light is transmitted through the sample, and the stone is viewed from above with the aid of a loupe or microscope (Figure 23).

Two of the sample sets used at the AGA conference workshop were blue parcels: one consisted mostly of synthetic sapphires mixed with samples of Co-bearing glass, and the other contained mostly synthetic sapphires with some Co glass-filled sapphires. The results observed when using the CCF in the traditional way were very similar for each set: the synthetic sapphires appeared green, while the Co-bearing glass imitations and the Co glass-filled sapphires appeared red (e.g. Figure 24). The results for the glass-filled sapphires varied slightly depending on how much filling they contained. The stones with a light to moderate amount of glass filling showed a less distinct brownish red colour, while those with a higher percentage of glass filling showed a red response similar to that of Co glass.

As seen in Figure 25, the amount of Co-bearing glass filler in a sapphire can be observed because the filled fractures appear distinctly red against the green colour of the host sapphire. This works regardless of the amount of filling within a sapphire, although if a stone is heavily filled then sometimes the contrast is not as clear and a brighter light source is required. It is also important

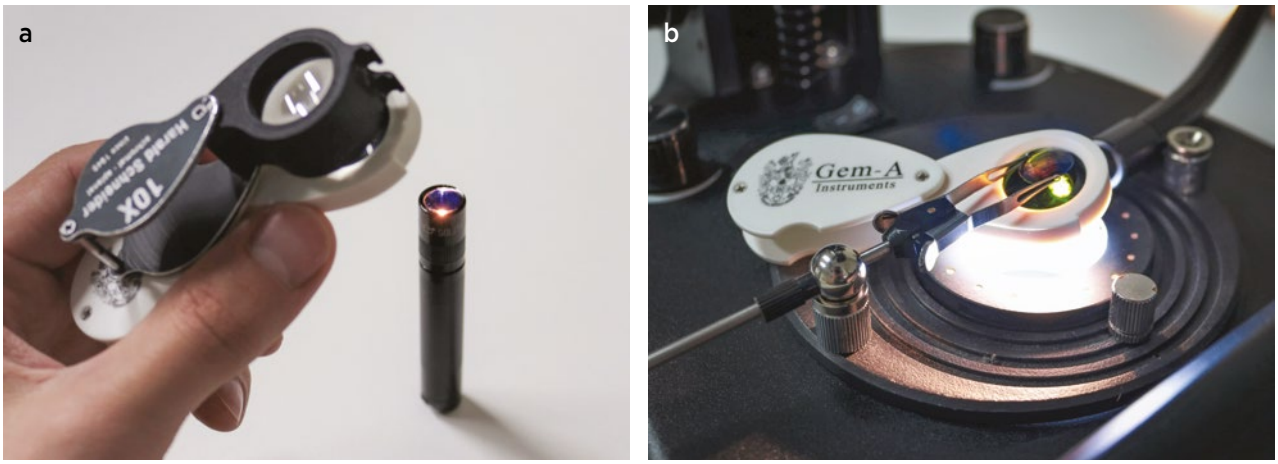

Figure 23: The new CCF technique described here for Co glass-filled sapphires involves the use of transmitted incandescent light. (**a**) A pen torch can be employed to transmit light through the sample, with the CCF positioned between the sample and a loupe. (**b**) The same method can be used with a gemmological microscope, with the CCF between the stone and the light source. Stronger illumination (such as fibre-optic lighting) works better for more heavily filled stones. Photos © C. D. Bexfield.

Figure 24: A Co glass-filled sapphire in this parcel of synthetic sapphires (1.05–2.23 ct) stands out due to its red appearance when viewed through the CCF in the traditional way with oblique incandescent light. Photo © C. D. Bexfield.

to rotate the stone and view it from all angles. In our samples we noticed the presence of gas bubbles in some areas of the glass filling that did not show a red response, suggesting that portions of the sapphires may have been filled with Pb-bearing glass before or after filling with Co-bearing glass.

The use of a microscope (with higher magnification than a loupe) can make it easier to see the colour differences, and therefore can help with estimating the percentage of Co-bearing glass filling within a sapphire, which is otherwise challenging due to the similarity in RI between the sapphire and the glass filling.

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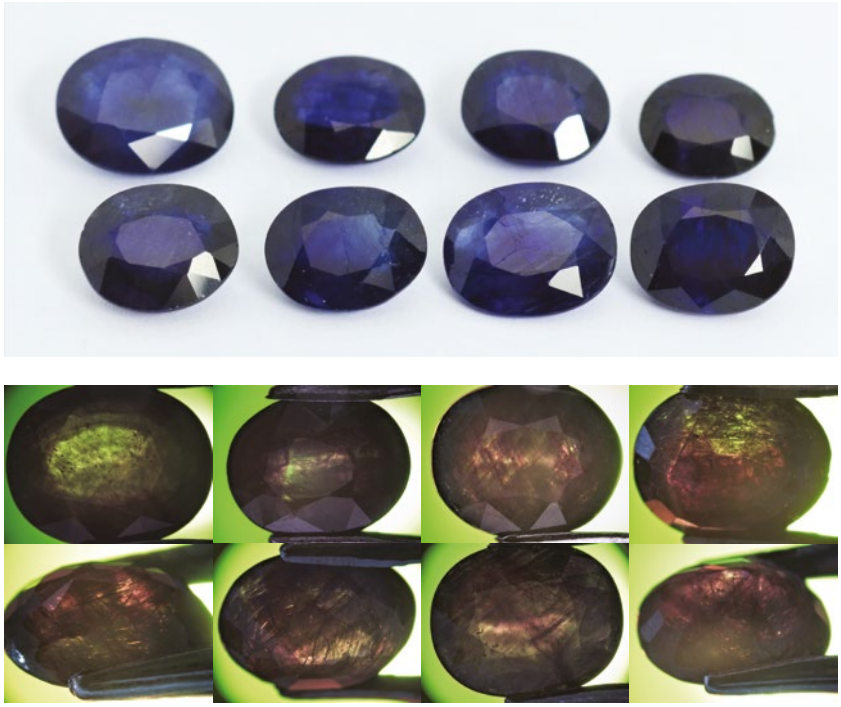

Figure 25: (Top image) These sapphires (3.27–6.73 ct) contain varying amounts of Co-bearing glass filler. (Bottom images) The same stones are shown with the new transmitted-lighting CCF technique, using a microscope with 15× magnification and brightfield illumination with fibre-optic incandescent lighting. The distribution of red colouration corresponds to the presence of Co glass-filled fractures, and more heavily filled stones show an overall darker red appearance. Photos © C. D. Bexfield.

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ERRATA

1. In the Gem Note titled 'Chrysocolla from the Ray Mine, Arizona, USA' (see *The Journal*, Vol. 36, No. 6, 2019, p. 499), *chrysocolla* should have been referred to as *chrysocolla chalcedony*.
2. In the Literature of Interest section of *The Journal*, Vol. 37, No. 2, 2020, the articles from *Rivista Italiana di Gemmologia/Italian Gemological Review* should have been indicated as being published in issue No. 9.
3. In the Gem Note titled 'Rhodonite from Southern Iran' (see *The Journal*, Vol. 37, No. 3, 2020, pp. 246–247), the correct spelling of the first author's surname is Rahimzadeh.

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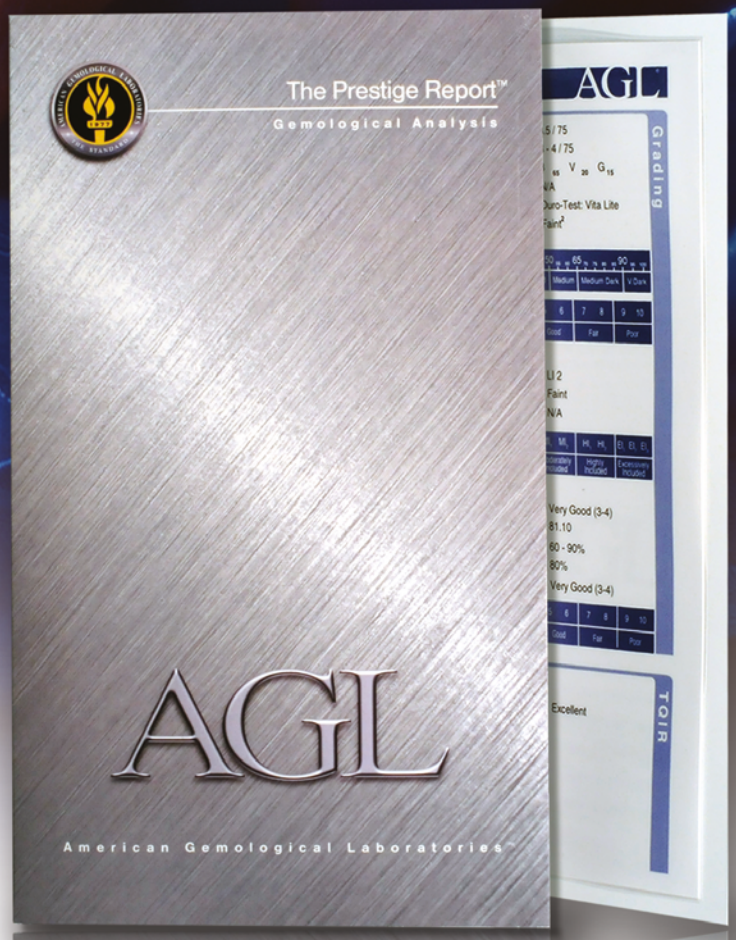

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Figure 1: This image of the Imperial State Crown in the British Crown Jewels shows the 'Black Prince's Ruby' (a 170 ct red spinel) and, below it, the Cullinan II diamond weighing 317.40 ct. Royal Collection Trust/© Her Majesty Queen Elizabeth II, 2016 (RCIN 3170).

The Black Prince's Ruby: Investigating the Legend

Jack M. Ogden

ABSTRACT: A 170 ct red spinel set in the Imperial State Crown in the crown jewels of the United Kingdom has long been called the 'Black Prince's Ruby' and is one of Britain's best-known gems. It has been popularly associated with Edward the Prince of Wales—the 'Black Prince'—who lived in the 1300s. This article reconsiders available evidence to substantiate the elements of its supposed early history. While the Black Prince almost certainly obtained one or more large spinels in Spain, other large spinels (generally known in the past as *balas*) reached English royal treasuries at around this same time, and no specific surviving gem can be conclusively associated with the prince. The spinel now in the crown has certainly been a part of royal regalia since the later 1600s, and probably for a century before that, but its earlier history cannot be traced. Its link with the Black Prince was suggested only in the 1760s, based on an unsubstantiated, and later disputed, identification of the gem in a portrait.

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The 'Black Prince's Ruby', a 170 ct red spinel set in the Imperial State Crown (Blair 1998; see Figures 1 and 2), is associated with one of the best-known tales about a gemstone. It links history with a beautiful gem, and gives gemmologists the opportunity to expound on how it is actually not a ruby, but rather a red spinel. The recent history and a gemmological study of the gem published in 1998 treated its connection with Edward the Prince of Wales (also known as the Black Prince) as no more than legendary (Blair 1998, Vol. 2, p. 57). However, myriad repetitions of the story still appear in print and online, with little consideration of its veracity or source.

The story is that in 1367 Peter I—the king of Castile and León on the Iberian Peninsula (1350–1369)[1], who was sometimes known as Don Pedro, Pedro the Cruel or Pedro the Just—gave the gem to the Black Prince in return for English military support. From the Black Prince the gem supposedly passed down to King Henry V of England (1413–1422), who wore it in a crown over his helmet at the famous Battle of Agincourt in 1415. According to the legend, it eventually ended up in its present prominent place in the British Imperial State Crown.

Even some influential writers recount the story as fact. One such was George John Younghusband, Keeper of the Jewel House at the Tower of London from 1917 to 1944, who told the story in his books on the crown jewels with no caveats as to its veracity (Younghusband & Davenport 1919, pp. 55–56; Younghusband 1921, pp. 144–151). To help separate fact from fiction, this article looks at original information sources where possible. These documents generally use the term *balas* (with myriad spellings) for what we know as red spinel.

RED KING TO CRUEL KING

The first 'episode' in the usually recounted legend of the Black Prince's Ruby is its supposed transfer from Don Pedro to the Black Prince in 1367. Fourteenth-century Spain was divided between rival Christian and Nasrid Muslim kingdoms. Muhammad VI, the Muslim king of the emirate of Granada, known in Spanish as *El Rey Bermejo* ('The Red King') due to his red hair, was fighting both his second cousin Muhammad V and Don Pedro, and then he decided to side with the latter. In 1362, Muhammad VI went to meet with Don Pedro and took with him—to smooth the way—what historian José Antonio Conde described as 'the richest and most precious jewels he had, as well as emerald and balas stones' (Conde 1874, p. 298).[2] Lisan Al-Din Ibn Al-Khatib, in his *The Complete Source on the History of Granada* written in 1369, commented 'He might just as well have thrown himself into the mouth of a hungry tiger thirsting for blood; for no sooner had the infidel dog [Don Pedro] cast his eye over the countless treasures which Mohammed and the chiefs…brought with them, than he conceived the wicked design of murdering them and appropriating their riches' (Gayangos 1843, p. 361).

More details were provided by Pedro López de Ayala, a contemporary of Don Pedro, whose chronicles on the kings of Castile included a comprehensive account of Don Pedro's life.[3] López de Ayala reported that upon his arrival, Muhammad VI was seized and then 'searched separately to see if he had some jewels with him and

Figure 2: This computer rendering of the Black Prince's Ruby (which measures approximately 4.3 cm long) is based on the photographs and drawings in Blair (1998). Image © J. Ogden.

[1] The years given in parentheses after the names of monarchs are the dates of their reigns.

[2] *…las mas ricas joyas y preciosas alhajas que tenia, así en pedrería de esmeraldas y baláges…*

[3] Pedro López de Ayala lived from 1332 to 1407 and this copy of his text (MSS/10219, Biblioteca Nacional de España, Madrid, Spain) dates to within a century after his death.

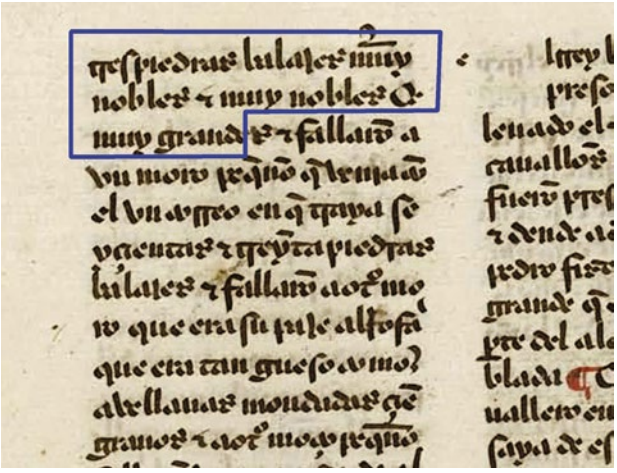

Figure 3: The top three lines on this page from *Crónica del Rey Don Pedro* by Pedro López de Ayala, held in the Biblioteca Nacional de España (MSS/10219, f. 166v), says *tres piedras balaxes muy nobles – muy nobles e muy grandes* ('three balas stones very noble – very noble and very large'). © Biblioteca Nacional de España.

they found on him three balas, very noble and very large…each as big as a pigeon's egg…' (Llaguno Amirola 1779, p. 346, 346 n.).[4] The vast number of other gems with his companions included a collection of 730 balas in the baggage of one pageboy (Llaguno Amirola 1779, pp. 346–347, 346 n.). A portion of the relevant passage in a manuscript of López de Ayala's chronicle is shown in Figure 3. Muhammad VI was soon killed and the treasures appropriated. Barely had the blood dried than Pedro wrote a will which listed numerous jewels set with balas, including two collars (neck ornaments), each with a 'very large balas' (*un balax muy grande*), specifically noted as coming from Muhammad VI. These two collars were bequeathed to Don Pedro's eldest daughters Beatrice and Constanza, who also were each to receive a second collar with 'a large balas stone' (*una piedra balax grande*), and thus presumably smaller than those from Muhammad VI (Llaguno Amirola 1779, pp. 562, 563–564).

THE BLACK PRINCE

King Edward III of England (1327–1377) supported Don Pedro by sending an army to Spain in 1366 with his eldest son, Edward Prince of Wales, popularly known as the 'Black Prince', reputedly because of his black armour.[5] In 1845, Richard Ford published his monumental *A Hand-Book for Travellers in Spain*, in which he briefly mentioned the Black Prince. He also described the assassination of Muhammad VI and the seizure of his treasures including 'a huge ruby' which 'Don Pedro gave to the Black Prince after the Victory at Navarete' (Ford 1845, p. 258). The Battle of Navarrete (more correctly the Battle of Nájera) took place on 3 April 1367 near Nájera in La Rioja, northern Spain (Figure 4). In his second edition, Ford gave more detail: among the gems was specified '"three huge rubies," big as a pigeon's egg — *huevo de Paloma*' (Ford 1855, p. 186). The specific words used and the quote in Spanish show that Ford had based this information from López de Ayala's chronicle. It is unclear, however, where the story in both these additions came from, that one particularly large ruby had been given to the Black Prince after the Battle of Navarrete and that this was the gem now in the Imperial State Crown (Ford 1845, p. 258). Ford also mentioned another contemporary account of Muhammad VI's assassination and seizure of his riches that 'Gayangos found, in an Arabic MS. [manuscript] in the British Museum' (Ford 1845, p. 258). This was Pascual Gayangos's translation of Algerian historian al-Maqqari's history of Muslim Spain, written in around 1600, based on a text in the British Museum (Gayangos 1840 & 1843). This text mentioned the bare facts of the assassination and seizure, but it said nothing about any ruby/balas or the Black Prince.

Prosper Mérimée, a French historian and author, wrote a description of Don Pedro's life, largely based on López de Ayala's account but also drawing on a wider range of other chronicles, including many unpublished ones (Mérimée 1848). In 1849 James Pearse translated Mérimée's work into English and added a footnote in which he mistakenly assumed that Ford had said that the Arab manuscript translated by Gayangos specifically mentioned Don Pedro giving the large 'ruby' to the Black Prince (Mérimée 1849, p. 76 n.). Pearse also mentioned the pigeon's-egg size of the gems, but derived this from Sir John Talbot Dillon's history of Don Pedro where 'balas' was mistranslated as 'pearls' (Dillon 1788, p. 190).

The present author has found no certain indication that one of the Red King's balas was given to the Black Prince by Don Pedro, but we do hear of another that, supposedly, was. Bertrand du Guesclin (also known as 'The Black Dog of Brocéliande') was a French military commander who fought against Don Pedro and the Black

[4] *E luego que el Rey Bermejo fué preso , fué catado á parte si tenia algunas joyas consigo , é falláronle tres piedras balaxes muy nobles é muy grandes…tan grande cada una como un huevo de paloma…*

[5] Other explanations have been given. John Hughes (1706, p. 215 n.) says 'he was call'd the *Black Prince*, not from his Colour, but Fierceness in Battel'.

Figure 4: In this painting of the Battle of Nájera (or Battle of Navarrete) on 3 April 1367, the Black Prince is heading the troops on the left, in a brightly coloured tunic, clasping the hand of Don Pedro to show their allegiance. Image courtesy of Wikimedia Commons, from a 15th century manuscript of Jean Froissart's *Chronicles*, Bibliothèque nationale de France, FR 2643, f. 312v.

Prince, and was captured at the Battle of Navarrete. He indicated that Don Pedro's most valuable treasure had been a large, gem-encrusted gold-and-silver table of amazing beauty and inestimable value that took four men to carry (Le Febvre 1692, pp. 153–154, 163). Don Pedro's great-grandfather (presumably Alfonso X) had received it in payment of ransom for a king of Granada. In its centre was *une grosse escarboucle* (a big carbuncle, i.e. red stone) that was described as having two remarkable properties: it shone at night with as much brightness as the sun in broad daylight and it turned black when near poison (Le Febvre 1692, p. 154). According to du Guesclin, Don Pedro presented this extraordinary table to the Black Prince to help enlist his support (Le Febvre 1692, pp. 165, 180).

Du Guesclin's description of the table, while perhaps not entirely reliable, at least supports the existence of a particularly noteworthy red gem, and that it may have ended up in the Black Prince's hands. The Black Prince's will included '…our large table of gold and silver full of precious relics, and in the middle a cross of the wood of the Holy Cross, and the said table garnished with gems and pearls, that is, twenty-five balas, thirty-four sapphires, fifty large pearls and many other sapphires, emeralds and small pearls…' (Nichols 1780, p. 71).[6] This table was bequeathed to a college at Ashridge in Buckinghamshire, England. There is nothing in the will to say that it came from Don Pedro, but Francis Godwin mentioned that 'a wonderful sumptuous and costly table decked with gold and precious stones' had been given by Don Pedro to the Black Prince (Godwin 1601, p. 218). This one, however, was sold by him to Thomas Arundel, Bishop of Ely and later Archbishop of Canterbury (1353–1414) for 300 marks (Godwin 1601, p. 275). The table was to stay in Ely in perpetuity, but it disappeared, 'devoured', in Joshua Barnes' words, by 'time, or avarice, or sacrilege' (Barnes 1688, p. 683). If there had been a central huge spinel in the table, perhaps the Black Prince had extracted it.

[6] *…notre grand table d'or & d'argent tout pleyn dez precieuses reliques, et en mylieu un croiz de ligno sancte crucis, et la dite table est garniz de pierres et de perles cest assavoir vingt cynk balois, trentquartre safirs, cinquant perles grosses et pluso's outres safirs, emeraudes, et perles petitz…*

BACK IN ENGLAND

The Black Prince returned to England in 1371. Then, in 1377, what were called the 'Jewels of Spain' were pledged by his father Edward III to raise money (Stratford 2012, p. 13). The Jewels of Spain were gold and gem-encrusted royal military accoutrements consisting of a crown, a helmet (*palet*), a sword with belt and a saddle with stirrups. They were perhaps brought to England by the Black Prince, but there is no confirmation of this, and they may also have reached England through the marriage of Constanza, daughter of Don Pedro, to John of Gaunt, the Black Prince's brother, in 1371. The first object listed in a valuation of this treasure, in handwriting of the period, was a 'Spanish Crown' set with numerous gems including a large balas weighing 181 ct (Palgrave 1836, Vol. 3, pp. 309–312).

It should be noted that several large balas were already in royal hands in England by this time, including at least one coming from Spain. A manuscript in the possession of the Society of Antiquaries, London, includes a list drawn up in the period 1299–1300 of the jewellery and other treasures owned by Edward I (1272–1307). This list includes a large gold crown with balas once owned by 'Blanche of Spain' (Topham 1787, p. 353); it is one of the earliest uses of the term *balas* (here spelled *baleis*) in an English document. It refers to Blanche of Castile (1188–1252), wife of Louis VIII of France and niece to King John of England. In addition, an inventory from 1303 listed what might be a different gold crown with several large balas, which Edward I had used at his coronation, and another royal inventory from 1324 included *Un baleise bele et grosse* (a balas beautiful and large) among the unset gems (Palgrave 1836, Vol. 3, p. 137; Cole 1844, p. 277). A treasury inventory from the time of Edward II (1307–1327) mentioned several balas, two of which sound important—one forming the pommel of a gold cup and another described as 'beautiful' (Palgrave 1836, Vol. 3, pp. 124, 137). There is another very large balas which might have reached England at around this time: via Don Pedro's daughter Constanza, wife of John of Gaunt, to whom he had bequeathed a collar set with a very large balas.[7] One might doubt whether Don Pedro had managed to keep much of his treasure intact to pass on to his daughters, but when he was assassinated by his brother in 1369, his chambers were found to contain a huge quantity of gems, jewellery and other treasures (Llaguno Amirola 1779, p. 557). Whether any of this actually reached his intended beneficiaries is unknown.

The 181 ct balas in the crown from the Jewels of Spain was valued at 5 marks per carat. (This is seemingly the earliest recorded use of 'carat' for a gem weight in England.) The *mark* (the gold Noble coin) was two-thirds of an English pound in value, making the gem worth £603.33, the value of about 7 kg of gold.[8] This indeed might have been the Black Prince's Ruby, as several have suggested over the years (see Stratford 2012, p. 3). The weight of the medieval carat in modern terms is not known exactly, but 181 ct for the balas in the Spanish Crown would be in the same order of magnitude as 170 ct reported for the Black Prince's Ruby when it was examined out of its setting in the 1980s (Blair 1998, Vol. 2, p. 55).[9]

The Spanish Crown pledged by Edward III in 1377 was redeemed in 1378 (Stratford 2012, p. 12), by which time both Edward III and the Black Prince were dead and the latter's son, Richard II, was on the English throne. In 1399 Richard II was deposed, and around this time a detailed list of his treasures was written on a parchment roll that is 28 m long. This extraordinary record was only rediscovered in the National Archives in Kew in the 1990s (Stratford 2012). The 1,206 entries in this list include all the Jewels of Spain, named as such, apart from the crown. The *ca.* 1377 valuation of the Jewels of Spain had noted that six large balas and 40 small pearls from the Spanish Crown had been (or were intended to be) redeployed in a 'Grand Crown', so perhaps it was broken up (Palgrave 1836, Vol. 3, pp. 309–310). This would not be surprising, as English royalty would hardly wish to wear a Spanish crown. There were 11 crowns listed in Richard II's extensive inventory containing some three hundred balas in total (Stratford 2012, pp. 145–147). The seventh on the list is the crown of Blanche of Lancaster recently discussed in this journal (Schmetzer & Gilg 2020). Many of the balas in these crowns are described as large (*grosses balays*), but none is noted as being particularly huge and the sheer number of them suggests that they were

[7] One of the gems specified in John of Gaunt's own will was 'the good ruby' (*le bonne rubie*; Nichols 1780, p. 155).

[8] This can be calculated because the gold Noble coin of Richard II weighed about 7.6 g.

[9] The medieval carat has been equated to 1/150 of a troy ounce, or 0.207 g in modern terms, but exact comparisons are impossible. Collins (1955, pp. 12–13 n.) rightly observed that this recording of the weight of a gem is unique for its period and must show that the stone was considered truly exceptional.

of relatively modest size. The Grand Crown (*une grand coronne*), number nine in the inventory, was valued at £33,584, an extraordinarily high price for the time (Stratford 2012, p. 263). The gems made up all but £250 of this value and must have been something special, but they are described in far briefer terms than those in the other crown. The only gems in it described as large are two rubies (*ii grosses rubies*), while the other gems are listed in the most cursory of terms—balas, sapphires, emeralds and Scottish pearls (*balays, saphirz, emeraudes et perles d'Escoce*; Stratford 2012, p. 147). It would seem that even if some of the gems in the Spanish Crown had been used to spruce up the Grand Crown, these did not include the 181 ct balas.

HENRY V AND THE BATTLE OF AGINCOURT

The next episode in the usually recounted story of the Black Prince's Ruby its association with King Henry V (1413–1422). Henry V was a skilful military leader and at the Battle of Agincourt in 1415 he defeated the French. The king fought in the thick of it and, so the legend goes, the Black Prince's Ruby was set in a gold crown over the king's helmet and it survived when the crown was hacked from his helmet. As George John Younghusband said, with patriotic zeal but no reservations, 'Thus went forth Henry V on the morn of Agincourt, and glittering on the front of his coroneted helmet was the great ruby' (Younghusband 1921, pp. 146–147).

An early account of the Battle of Agincourt from Thomas Elmham, in his *Life of Henry V*, was written about three years after the battle. He said, 'The crown of the king was broken off his helmet by an axe' (Curry 2000, p. 47).[10] Two teenage heralds present at the battle—Jean Le Fèvre on the English side and Jehan de Waurin on the French side—later wrote almost identical accounts of the battle. The relationship between their accounts, and to an earlier one, is unclear. Although each of their versions differs slightly, both say that a group of 18 French knights had sworn to knock the crown off the King's head or die in the attempt. And, in Le Fèvre's words, 'one of them with an axe in his hand struck on the king's basinet [a helmet with visor] such a heavy blow that it knocked off one of the fleurons of his crown' (Morand 1876, p. 250; Curry 2000, p. 157).[11] All these knights were killed. A slightly later chronicle from around 1340 adds that at the battle '1 pece [piece] of his croune was broken, which afterward was founden and broughte to hym' (British Library Harley MS 53; Brie 1908, p. 555). Some accounts of the battle refer to the crown on Henry V's helmet as having gems, and from the reign of his son, Henry VI (1422–1461), there is a 1423 valuation that includes 'the golden crown for the basinet' (*la Corone d'or pur les Basinet*; Strachey & Blyke 1767–1777, p. 215). This is described as set with numerous gems and pearls with four of the balas valued at £133 6s 8d (£133.33). This may have been the one Henry V wore at Agincourt. Martin Holmes has suggested that the relatively high price listed for the four balas on this crown was 'evidence that one at least of them must have been of particular size and value' (Holmes 1937, p. 80). (Nevertheless, the single large balas in the Spanish Crown had been valued much higher, at just over £600.) Of course, kings had more than one crown; as we have seen, the long inventory of Richard II's treasure mentioned above listed 11 of them. An anonymous *ca*. 1417 account of the Battle of Agincourt—the *Gesta Henrici Quinti*, the earliest we have—notes that when it started, 'the negligence of the royal servants' allowed the French to plunder 'the kings' valuable treasure, his sword and crown…' (Curry 2000, p. 35).[12] The author here, a chaplain, who should know, said 'I, who am now writing this and was then sitting on a horse among the baggage at the rear of the battle' (Curry 2000, p. 35). Other sources say much the same thing. For example, a chronicle from Ruisseauville Abbey, near the site of the battle, probably dating to within 15 years of the battle, said that Henry V wore a gold crown on his helmet in the battle and that 'two crowns of gold and of precious stones' (*deux courons d'or et de pierres pretieuses*; Anonymous 1834, p. 141) were stolen from his baggage.

There might be no specific mention of a particularly large balas in connection with Henry V and the Battle of Agincourt, but there is a record of 'a large fleur-de-lys, garnished with one great balays, and one other balays, one ruby, three great sapphires, and ten great pearls';

[10] For the original Latin text of Elmham's account, see Cole (1858). All the sources quoted in this paragraph, and more, are discussed in detail in Curry (2000).

[11] *…l'un d'eux, d'une hache qu'il tenoit, le féry sur son bachinet ung si grant cop qu'il luy abaty l'un des flourones de sa couronne…*

[12] For the original Latin text of the *Gesta Henrici Quinti*, see Taylor and Roskell (1975). The stolen sword supposedly belonged to King Arthur.

this was one of the crown segments pledged to provide the money to pay Henry V's brother (the Duke of Clarence) and his retinue during the French campaign (Nicolas 1832, appendices on p. 15; Stratford 2013). This pledge was made on 12 July 1415, which was three months before Agincourt, so it cannot have been the one chopped off the crown during the battle (British Library MS Add. 4600). It was redeemed in 1429–1430 during the reign of Henry VI (Nicolas 1832, appendices on p. 15; Palgrave 1836, Vol. 2, p. 131). It was also listed with another smaller segment from the same crown in an undated inventory of the time of Henry VI (Palgrave 1836, Vol. 2, p. 245). Pledging the crown in several segments does not imply that it had been broken; it was more likely disassembled. Crowns of the period were often composed of several sections hinged together, such as the famous crown of Blanche of Lancaster (Schmetzer & Gilg 2020).

A MULTIPLICITY OF LARGE SPINELS

The great balas in Henry V's pawned crown segment might have been brought back from Spain by the Black Prince, and it may even be the one that is now in the Imperial State Crown, but as we have seen already there were several large balas present in late medieval England. Two are particularly relevant here. Biagio Dolfin was a Venetian merchant in the early 1400s trading gems between Venice, Alexandria and London. Two letters relating to his trade, discovered by Maria Pia Pedani in the State Archives in Venice, concern two large spinels offered for sale via his brother-in-law and another Venetian merchant in London (Pedani 2002). The first letter from Venice, dated 2 April 1413, revealed that a large balas was being offered to a London customer of whom Dolfin notes, 'I think he is a person who has the mint there [in London]' (Pedani 2002, p. 6). Presumably this was someone close to royalty, if not buying on behalf of them. The weight was not recorded, but based on its selling price of 1,200 ducats, Pedani suggested that it likely weighed between about 150 and 225 ct.

Even more pertinent is the letter from Dolfin at the beginning of the following year, 1414, concerning another large balas, this time offered directly to Henry V. The letter stresses that the king was particularly keen to buy this gem because he wanted two large balas for a new crown to wear for his upcoming marriage to Catherine, the French king's daughter. There was haggling—opening at £240 asked, with £120 offered—but sadly we have no record of whether a deal was eventually made. Here Pedani calculated the likely weight to be between about 138 and 207 ct (Pedani 2002, p. 6). Henry V's wedding was postponed because the war with France—and thus with his betrothed's father—intervened. The second Dolfin letter indicates that Henry V already had one large balas, but was this the one that had been in English royal hands for some time, perhaps from the Spanish Crown, or the one Dolfin had sold the year before? In either case, both Dolfin letters predate the pawning of the crown segment with its 'great balays'.

The quantity of spinels in Europe around that period should not be underestimated. The 1423 inventory mentioned above also included a collar, the parts set with numerous gems, the clasp set with 'the largest cut balas' (*la pluis 'gros Baleis d'entaille*; Strachey & Blyke 1767–1777, p. 214). The combined value of the large balas and four large pearls in the clasp was £800, thus comparable to the balas in the Spanish Crown, but the balas was described as cut, which would seemingly rule out the gem we know as the Black Prince's Ruby. An inventory of Edward VI dated 1446 lists 'the Rich Crown of King Edward' that was garnished with four large balas, four balas 'of a lesse sorte' and 38 balas 'of dyvers sorte' (Palgrave 1836, Vol. 3, pp. 2–3). In 1503, when Henry VII's daughter Margaret married James IV of Scotland (1488–1513), the Scottish Herald John Young accompanied her from London to Edinburgh.[13] In his account of the wedding, he described the king as wearing a 'Bonnet Blak, with a ryche Balay', but no further details are given for this gem (Leland 1774, p. 293).

Meanwhile in France, in 1417 Bartholomew Sac loaned the French Crown 23,000 *livre tournois*, taking as security several balas. These included a pear-shaped gem weighing 175 ct, a pierced one of 142 ct, another of 102 ct and a further one called *tête de coq* ('the rooster head') which weighed 174 ct and was also described as being pierced (Mirot 1940, p. 139). Also in 1408 the Duc de Berry purchased the *balai d'Orange*, and the duchess of Orléans the *balay de Venise* (Coville 1888, p. 47; Guiffrey 1894, p. XCIII; Mirot 1940, p. 147). In other medieval inventories we hear of more, such as the *balai de la châtaigne*, the *balai du pape* and the *balai de David* (Guiffrey 1894, p. XCIII). This naming of large spinels continued. Jean Baptiste Tavernier later illustrated three large balas owned by King Louis XIV in

[13] England and Scotland had different monarchs then. The union came with James VI of Scotland, who became James I of Britain in 1603.

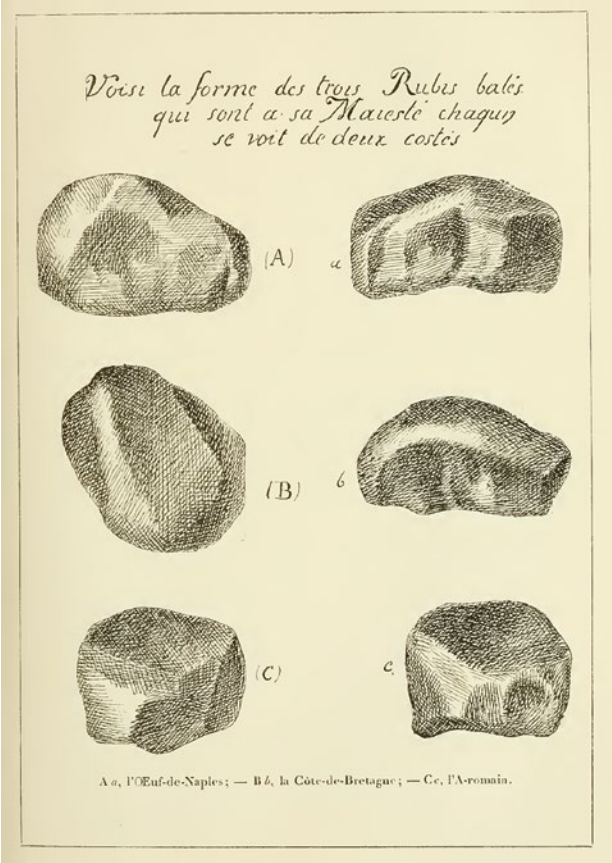

Figure 5: This drawing by Jean Baptiste Tavernier shows three large balas of King Louis XIV, annotated by Germain Bapst to give their names: *l'OEuf-de-Naples, la Côte-de-Bretagne* and *l'A-romain*. From Bapst (1889, p. 249).

the 17th century: *l'OEuf-de-Naples, la Côte-de-Bretagne* and *l'A-romain* (Figure 5; Tavernier 1677, pl. 2 facing p. 338; Bapst 1889, pp. 247–272). If the English had named their royal spinels, unravelling the story of the Black Prince's Ruby might have been a far easier task.

FIRMER GROUND IN THE 1500S

There are two surviving manuscripts of the so-called Jewel Book of Henry VIII (1509–1547), one written in 1521 and the other undated but perhaps a few years later (Palgrave 1836, Vol. 2, pp. 259–298; Trollope 1884).[14] These list the royal jewels and silver in the Tower of London at that time. They are largely identical, although there are spelling differences. Both start with 'the kingis crowne of golde' and among the large number of gems on this was 'a greate balance broken' or 'a greate balace brooken' (Palgrave 1836, Vol. 2, p. 259; Trollope 1884, p. 158). The description of the balas in Henry VIII's crown as 'broken/brooken' is a possible hint that we might now be looking at the Black Prince's Ruby. This gem has been fixed in a backed setting for much of its recent history, but it was removed for study in 1965 and 1986 (Blair 1998, Vol. 2, p. 61). The report of the 1986 examination said: 'The back is crudely cut away, as if a section of the stone had been sheered [*sic*] off by accident' (Blair 1998, Vol. 2, p. 55).

Possibly this balas in Henry VIII's crown had passed down from earlier kings, perhaps even from the Black Prince, but this is by no means certain. At least one other important balas had arrived in England early in Henry's reign, and from Spain. In 1515, an ambassador from King Ferdinand of Aragon had presented Henry VIII's wife Catherine of Aragon with a balas 'large and very precious' (*un balax grande muy rico*; Zurita y Castro 1610, f. 397 v). Catherine's mother, Queen Isabella I of Castile, had owned a considerable amount of impressive jewellery including 'two balas, the size of a pigeon's egg' (*deus ballais dela granfeur de ung heuf de colon*) and 'a large balas the size of a tennis ball' (*ung grant ballais del grandeur d'ung esteus [esteuf]*).[15] Perhaps the gem brought to England was one of these. It might also be relevant that Isabella was the great-granddaughter of Constance, the daughter of Don Pedro to whom he had bequeathed one of the large balas he had taken from Muhammad VI.

Descriptions of the Great Crown during the reign of Queen Elizabeth I (1588–1603) describe it in almost identical terms to those in Henry VIII's inventory, but whereas the latter says the great balas was broken, three inventories of Elizabeth's say, with typical variations in spelling, that it was 'whole', 'hole' or 'hoole' (Figure 6; British Library Harley NS 1650; British Library Stowe MS

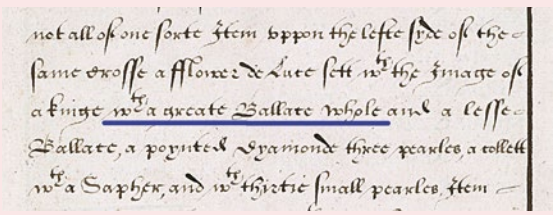

Figure 6: The description of the 'Greate Crown' in the 1596 inventory of jewels and other goods of Queen Elizabeth I says 'with a greate Ballace whole'. © British Library Board, Stowe MS 556.

[14] In the 1521 inventory, the few gems missing from the crown are named and described as 'with the king'; the other inventory just mentions the empty settings. This may suggest that this latter inventory was compiled later when the then-current whereabouts of the gems was unknown.

[15] The details of Queen Isabella's spinels can be found in Roger Machado's 1488–1489 report of the embassy to Spain and Portugal (Gairdner 1858, pp. 171, 178).

555; British Library Stowe MS 556; Collins 1955).[16] This may suggest that the damaged balas had been replaced with a whole one that was not broken.

It is just as possible, however, that 'broken/brooken' in the Henry VIII inventories really meant 'broached', that is pierced, as suggested by Shakespeare's use of *broken* for 'broached' in, aptly, his *Henry VIII* (Act 5, Scene 1). The Black Prince's Ruby is pierced, with several drill holes probably dating back to its far earlier history. It is unlikely that 'whole', 'hole' and 'hoole' in the Elizabethan inventories meant the great balas then in the crown had a hole through it.

Almost a year to the day after Elizabeth I died, an inventory was drawn up of the 'Jewelles remayninge in an yron cheste in the secrete jewelhouse wth in the Tower of London', and first on the list was 'a Crowne Imperyall' with 'uppon the top a verye greate ballace perced' (Palgrave 1836, Vol. 2, pp. 299–300). In the so-called Ditchley portrait of Elizabeth painted by Marcus Gheeraerts the Younger *ca.* 1592 (Figure 7), she wore a large red gem surmounting her elaborate headdress that appears to have a pin passing through it. Scottish diplomat Sir James Melville mentioned the 'fair ruby, gret lyk a racket [tennis] ball' (presumably a balas) that Elizabeth showed him in 1564 (Melville 1827, p. 122). Although Melville makes no mention of either a break or a piercing, it is noteworthy that he uses the same size comparison as had been applied to one of Queen Isabella I of Castile's gems, not impossibly the one that had been sent to Catherine, wife of Henry VIII. The Black Prince's Ruby in the Imperial State Crown today is 4.3 cm high, its largest dimension (Blair 1998, Vol. 2, p. 55).

Figure 7: A detail of a portrait of Queen Elizabeth I shows a large red gem, probably a spinel, surmounting her head. Portrait by Marcus Gheeraerts the Younger, *ca.* 1592. National Portrait Gallery, London, inv. no. NPG 2561.

[16] Two of the British Library manuscripts can be viewed online: www.bl.uk/manuscripts/FullDisplay.aspx?ref=Stowe_MS_555 and www.bl.uk/manuscripts/FullDisplay.aspx?ref=Stowe_MS_556.

By comparison, a tennis ball discovered in the rafters of Westminster Hall in the 1920s, dated to the late 15th to very early 16th century and now in the Museum of London (A23402), is 4 cm in diameter (see https://collections.museumoflondon.org.uk/online/object/119138.html).

POSSIBLE LOSS AND RETRIEVAL

Even if the balas in Henry VIII's crown and that in Elizabeth I's was one and the same, it cannot be traced down to today's Imperial State Crown with complete certainty. In 1649, Oliver Cromwell interrupted the monarchy. Charles I was executed that same year, and much of the royal regalia were broken up and sold. The often-repeated story is that the Black Prince's Ruby was sold under Cromwell for just £4, but this is almost certainly incorrect (Brand 1806, p. 286; Holmes 1937, p. 84; Collins 1955, p. 12 n.; Blair 1998, Vol. 2, pp. 58–59). No clear record exists of the large balas being sold in Cromwell's time, and it might have been fortuitously 'saved' by being among the crown jewels pawned by Henrietta Maria (Charles I's wife) in the early 1640s to help fund the fight against the Parliamentarians, although it proved difficult to sell some of the more valuable pieces (White 2017, pp. 62–63).

With the restoration of the monarchy and the arrival of Charles II (1660–1685) on the throne in 1661, two new crowns were made for his coronation. Of these, the Crown of State was 'most remarkable for a Wonderful large Ruby, set in the midle of one of the four Crosses, esteemed worth Ten Thousand Pounds' (Sandford 1687, p. 41). Although he was writing about the coronation of James II, who was Charles II's brother and successor, Sandford makes it clear that the Crown of State illustrated in his book (Figure 8) was made for 'the Coronation of His late Majesty King Charles the Second'. The large red gem might have been among the crown jewels earlier pawned and later redeemed, or it could have been the 'large Orientall ruby' sold to Charles II for his coronation (Blair 1998, Vol. 2, p. 58). In either case, its identification with the Black Prince's Ruby in today's Imperial State Crown is clear, as proven by a painting of the Crown of State as remade for George I (1714–1727), the first certain colour illustration of the gem (Figure 9). The only question comes from the text below the painting, which says that 'the Balass in the cross in front was ~~put~~ given to the Crown by King James II'. James was Charles II's successor. This might have come from a misunderstanding of Sandford's 1687 account, or it may reflect some now-forgotten part of the gem's history.

It seems reasonable, if not certain, to equate the large gem in Charles II's crown with Queen Elizabeth I's 'racket ball' and perhaps Henry VIII's 'broken balas', but what prompted the story that it could be traced back a further 200 years to the Black Prince's campaign in Spain?

Figure 8: A drawing of the Crown of State used at the coronation of Charles II in 1661 shows 'a Wonderful large Ruby, set in the midle of one of the four Crosses' (Sandford 1687, p. 41). Used with permission of the New York Public Library, Digital Collections.

THE BIRTH OF THE LEGEND

It was only during Elizabeth I's reign, in 1569, that Richard Grafton provided us with the first recorded use of the name 'Black Prince', whom he described as 'a noble and famous man' and says was reckoned 'the Flower of all Chyualrye [chivalry] throughout all the worlde' (Grafton 1809, p. 332). In the succeeding century, the Black Prince obtained almost mythical status. A play titled *The Black Prince*, by Irish statesman and dramatist Roger Boyle the Earl of Orrery, premiered in 1667 and extolled this hero's virtues: 'An English prince, whose fame appear'd so bright, as never any since his time was known' (Boyle 1669, p. 62). If there was any written or oral tradition then that a spectacular gem in the royal crown had belonged to the Black Prince, surely it would have been mentioned somewhere in the many books of the period that praised him.

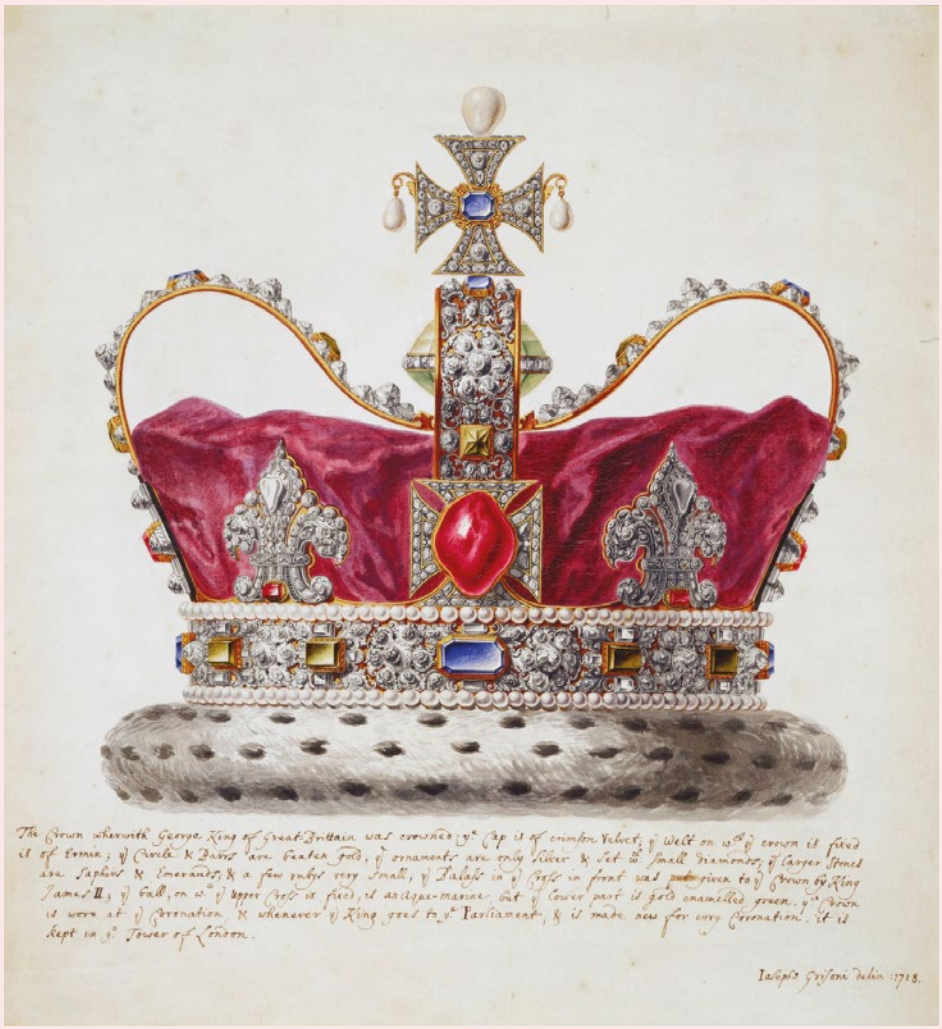

Figure 9: A watercolour of King George I's Crown of State, with a description by John Talman written below, is signed and dated on the lower right with 'Iosephs Grisoni delin: 1718.' The red gem is the same size and shape as the Black Prince's Ruby (spinel) now in the Imperial State Crown. Royal Collection Trust/© Her Majesty Queen Elizabeth II, 2016 (RCIN 913015).

The first suggestion of a link between the large spinel in the Imperial State Crown and the Black Prince only came a century after Charles II's coronation. British politician Horace Walpole was an eminent art historian with a keen interest in engraved gems and jewels. In 1765 he described a painted portrait with a hand-written note on the back saying that it depicted the Black Prince (Walpole 1765, p. 26). This note was written by the English politician Arthur Onslow (1691–1768), who had obtained the painting from Betchworth Castle in Surrey (Grose & Astle 1775, p. 169).[17] In 1775, *The Antiquarian Repertory* printed an engraving of this portrait (Figure 10), but the present author has been unable to trace the original painting. No further documentation was cited to substantiate the identification of the man as the Black Prince, but Walpole considered 'there is great reason to believe [it] was painted at the time' seemingly because 'It represents him in black armour…with a golden lion on his breast', and 'He has a hat with a white feather, and a large ruby, exactly in the shape of the rough ruby still in the crown' (Walpole 1765, p. 26 n.).

But this identification as the Black Prince was soon doubted. In 1786 Richard Gough pointed out that 'the lion rampant, as here [on his tunic], is neither the Black Prince's coat [of arms] nor crest', and also that he was not actually shown wearing armour (Gough 1786, p. cxliii). A generation later, the antiquary James Dallaway said 'The claim of this, as a genuine portrait of the Black Prince, is at least apocryphal. I cannot but consider it as of a much later age…' (Dallaway 1826, p. 45 n.).

Unfortunately, there is no way to uncover the basis for Onslow's identification. Later authorities have been equally sceptical of the portrait's dating on various

[17] Betchworth Castle was destroyed in the 1830s by none other than Henry Thomas Hope, who inherited the Hope diamond from his uncle Henry Phillip Hope.

stylistic grounds. In addition, identification of the man depicted is hindered by the lack of any surviving certain portraits of the Black Prince to use for comparison (see, e.g., Blair 1998, Vol. 2, p. 57). Also note that the gem shown in the portrait is hardly what Walpole described as 'exactly in the shape' of the Black Prince's Ruby, since it lacks its characteristic pear-shaped form. However, its generic oval shape does look very much like the stone in Sandford's drawing of the Crown of State (Figure 8), which was probably the only representation Walpole had seen. Nevertheless, Walpole seems to be the first to have suggested a possible link between the gem in the Imperial State Crown and the Black Prince. Not surprisingly, this appealing possibility was soon quoted widely. In the 18th and 19th centuries, the increasing nationalism in Britain coupled with idealised views about medieval chivalry had again made the Black Prince a hugely appealing hero (Gribling 2017).

We can note that the rampant lion on the tunic in the portrait might be more expected for a Scottish prince. So, ironically, the gem shown could still be that now in the Imperial State Crown if it was the one that James IV of Scotland had worn in his bonnet at his wedding (see above) and which, perhaps, had passed down to his great-grandson James I of Britain.

Figure 10: This etching shows a painting once in Betchworth Castle, which Horace Walpole suggested represented the Black Prince wearing the gem. From *The Antiquarian Repertory* (Grose & Astle 1775, p. 169).

CONCLUSIONS

It is possible that the Black Prince obtained a large spinel while he was in Spain and then brought it to England in the 14th century, which long after was set in the Imperial State Crown in the crown jewels of the United Kingdom. However, there was more than one large spinel in royal circles in England in the late medieval period which might have passed down to the present crown jewels. There is no evidence that the English King Henry V wore a large spinel in the crown above his helmet at the Battle of Agincourt in 1415, as often stated. So, although we can trace the Black Prince's Ruby back to the 1600s with some certainty and agree that it likely was set in royal crowns in the 1500s, its association with the Black Prince is far more speculative. Historically, there is the likelihood that the Black Prince returned from his Spanish campaign with at least one large red spinel, and whether or not the painting described by Horace Walpole in 1765 actually shows the prince or if he is wearing such a gem is irrelevant. To suggest, however, that one of his gems is the one now in the Imperial State Crown, as Walpole did, is still no more than appealing speculation.

A surprisingly high number of large red spinels circulated in late medieval European royal circles. Most of these would have had a polished form similar to that of the Black Prince's Ruby, with their origin in the medieval Islamic world. Nevertheless, the weight of the large balas in the Spanish Crown (181 ct) described in an English inventory in 1371 is close enough to make it a particularly strong contender, and perhaps further research and discoveries will allow us to link this gem more certainly with the Black Prince. This is not an impossibility; the 28-m-long treasure inventory of Richard II was only rediscovered in the 1990s. It would be exciting to be able to establish a firm historical link back from the Imperial State Crown to the Black Prince, perhaps even to the *grosse escarboucle* (big carbuncle) that supposedly shone as bright as the sun and was literally once worth a Spanish king's ransom.

An unresolved issue is what happened to the numerous spinels of significant size that once circulated in medieval Europe. A possible answer is that some of them went back to the East. By the 17th century they were in high demand among the Mughal Indian rulers, and there is plenty of documentary evidence that this demand was profitably catered to by the East India Company and other European trading companies, which brought them from Europe (Ogden 2019, p. 542). Some of the magnificent Mughal spinels now in Western collections therefore could have made the East-to-West journey not once, but twice.

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A Study of Emeralds from Davdar, North-Western China

Di Cui, Zongting Liao, Lijian Qi, Qian Zhong and Zhengyu Zhou

ABSTRACT: At the Davdar mine in Xinjiang, north-western China, emeralds are hosted mainly by carbonate, quartz-carbonate and quartz veins cutting metasedimentary rocks, and are associated with minerals such as hematite, dolomite, quartz, orthoclase and albite. Sixteen rough emeralds obtained during the authors' visit to the mining area in 2019 were studied by standard gemmological techniques and various spectroscopic methods (FTIR, Raman, UV-Vis-NIR and EPR), as well as LA-ICP-MS chemical analysis. The analysed samples were mostly coloured by Cr, and showed a wide range of Fe, V, Mg and alkali contents, along with relatively low Cs, Rb and Sc. UV-Vis-NIR spectra showed features at 370 nm (Fe^{3+}), 430 nm (Cr^{3+} with contributions from V^{3+} and possibly Fe^{3+}), 580–630 nm (Cr^{3+} and V^{3+}), 638 and 683 nm (Cr^{3+}), and 850 nm (Fe^{2+} and possibly Fe^{2+}–Fe^{3+} interactions). In addition, the more V-rich emeralds displayed a distinct V^{3+} absorption band at about 385–395 nm. Notably, the chemical composition of Davdar emeralds shows significant overlap with those from Panjshir, Afghanistan.

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Davdar emeralds are sometimes described as 'emeralds of the Silk Road'. The deposit was discovered in around 2000 and the stones have appeared on the gem market since late 2003, but particularly since 2008 when the mines became more productive (Blauwet *et al.* 2005; Michelou & Pardieu 2009; Schwarz & Pardieu 2009; Marshall *et al.* 2012). The emeralds are notable for their attractive green colour, and in some cases they are quite transparent (e.g. Figure 1). The mine is located near Davdar (also spelled Dafdar or Dabdar) village in Taxkorgan Tajik Autonomous County, which is in the south-western part of Xinjiang near China's borders with Pakistan, Afghanistan and Tajikistan (Figure 2). The workings are located just east of Davdar village, at coordinates 37°20′52.48″ N, 75°25′42.56″ E and an elevation of about 3,600 m. Davdar is the second reported emerald occurrence in China, with the first being the Malipo (or Dyakou) deposit in Yunnan Province, where emeralds were discovered in the late 1980s during mining for tungsten (Xue *et al.* 2010; Hu & Lu 2019).

Previous studies have documented Davdar emeralds' chemical composition, fluid inclusions, stable isotope geochemistry and geographic origin characteristics (Schwarz & Pardieu 2009; Marshall *et al.* 2012; Saeseaw *et al.* 2014, 2019). However, the mining areas comprising the Davdar deposit (called Mine 1, Mine 2 and Mine 3 by the local workers) have not been fully described and studied in the field, although one of the occurrences was surveyed by Michelou & Pardieu (2009). During a field investigation of Davdar Mine 1 and Mine 2 by some of the authors (DC, LQ and QZ) in the summer of 2019, emeralds were obtained directly from the miners and collected *in situ*, and this article characterises them in detail.

HISTORY AND PRODUCTION

Mining activities initially developed during 2003–2005 in an area of a few square kilometres using bulldozers, hand tools and other equipment (Blauwet *et al.* 2005; Marshall *et al.* 2012). For several years the deposit was operated by Guimin Wong (Uyghur name = Ayineur Manglick), who obtained a legal mining permit in 2003 and set up the Kashi Junlin Mining Co. Ltd in 2004. The deposit is now owned by the local government, and there has been no mining since 2012, when activities

Figure 1: The fine-quality Davdar emeralds shown here were collected by local miners between 2009 and 2012. Most of the crystals weigh 0.4–0.6 g. Photo © Jia Maliding.

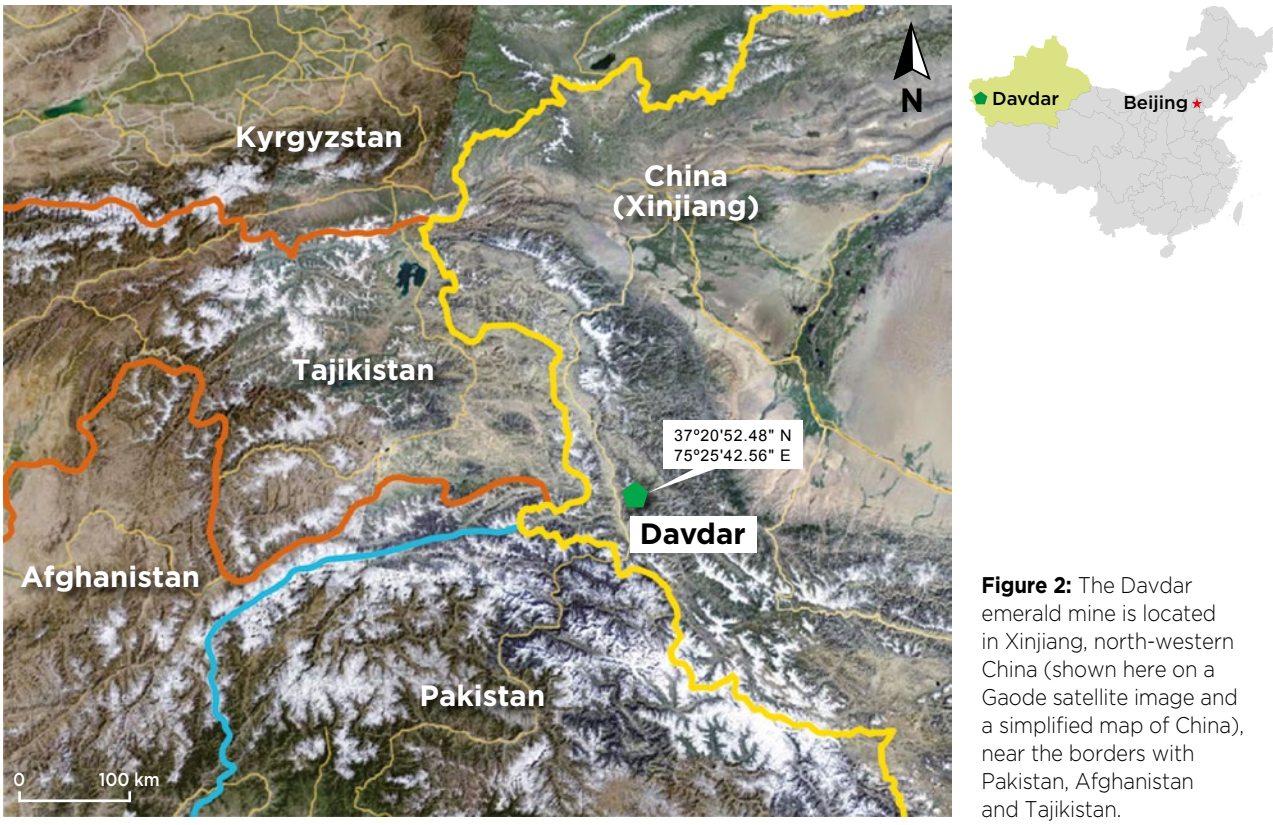

Figure 2: The Davdar emerald mine is located in Xinjiang, north-western China (shown here on a Gaode satellite image and a simplified map of China), near the borders with Pakistan, Afghanistan and Tajikistan.

were suspended due to regulations associated with a wildlife reserve in the area. In order for emerald mining and exploration to resume, new documents would need to be authorised by the local government.

The total output of rough emerald from Davdar is estimated at up to 25,000 carats (with gem-quality material constituting more than 10,000 carats), and the typical size range of fine-quality rough stones is 1–2 ct, although they may reach up to dozens of carats (Guimin and Alex Wong, pers. comm. 2020). The local miners and marketers have traditionally been from the Tajik ethnic group from the Xinjiang Uyghur Autonomous Region. Most Davdar emeralds have been traded into the local gem market near the town of Hongqilapu in the vicinity of China's borders with Pakistan, Afghanistan and Tajikistan. Guimin Wong currently sells Davdar emeralds from her stockpile in the gem markets of Ürümqi (the capital city of Xinjiang) and Shenzhen, China.

GEOLOGY

A geological survey of the Davdar emerald occurrence was performed in 2003–2004 by the Xinjiang Provincial Bureau of Geology and Mineral Resources (Brigade No. 2 2004). The deposit is located at the junction of the Karakorum-Kunlun-Pamir mountains and is underlain by the Early Silurian Wenquangou Group, which is bounded on the north-east by secondary structures related to the Taaxi Fault (Figure 3; Zhou *et al.* 2018). The Wenquangou Group is composed of siliciclastic rocks and sedimentary carbonates (e.g. pelitic siltstone, mudstone, quartz sandstone and minor conglomerate) with carbonate rock intercalations (Marshall *et al.* 2012). The emerald-bearing veins are hosted by metasedimentary units in which sandstone, dolomitic limestone and black carbonaceous slate are the main host rocks for the mineralisation (An 2006). Field observations by the present authors show

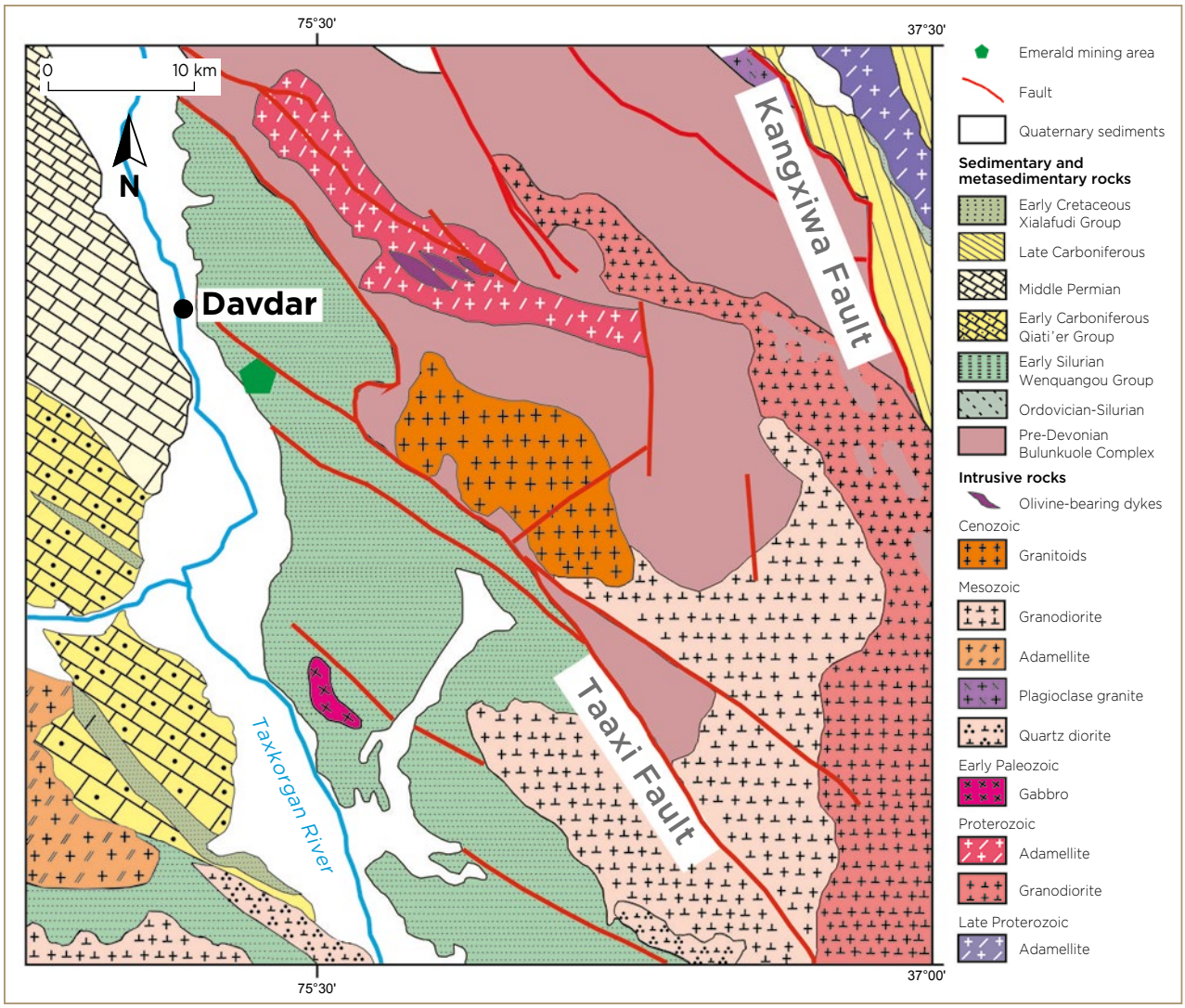

Figure 3: The Davdar emerald deposit is hosted by the Early Silurian Wenquangou Group, as shown in this simplified geologic map (modified from Zhou *et al.* 2018).

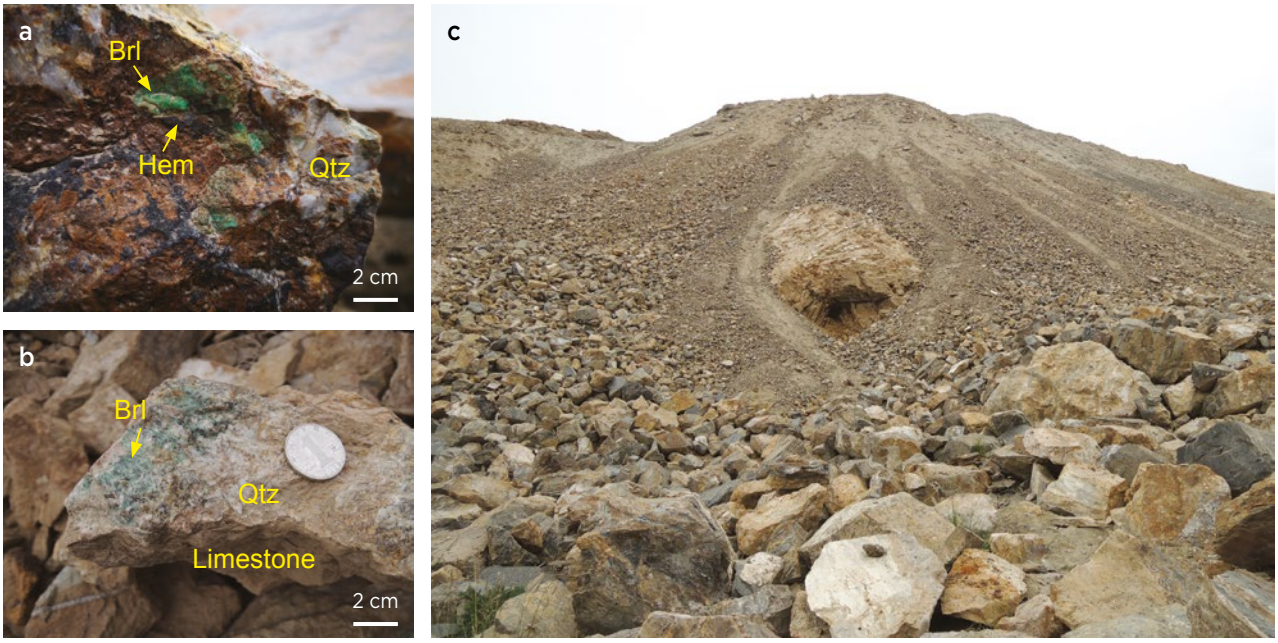

Figure 4: Characteristics of emerald mineralisation at the Davdar deposit are evident from (**a**) a quartz vein with minor accessory minerals such as hematite cross-cutting the host rock; (**b**) limestone with a vein surface containing non-gem-quality emerald and quartz; and (**c**) an outcrop with a small tunnel (approximately 1.5 × 1.0 m) at its base that has been mined for emeralds. Abbreviations: Brl = beryl (emerald), Hem = hematite and Qtz = quartz. Photos © L. Qi.

that the emerald-bearing veins are generally composed of quartz and carbonate minerals such as calcite associated with minor albite and hematite. The carbonate, quartz-carbonate and quartz veins are prospecting indicators for emerald mineralisation (Figure 4). Hematite, which is widely distributed in the veins, is regarded as another prospecting indicator by local miners.

Giuliani *et al.* (2019) noted similarities in the geographic and geologic environments between the emerald deposits in Davdar and in Panjshir, Afghanistan (located about 500 km to the west-south-west). Both are hosted by layered metasedimentary rocks (up to lower amphibolite facies) in veins that are predominantly composed of quartz and carbonate, and therefore they may share a similar genetic model. Giuliani *et al.* (2019) provisionally assigned both deposits to a type IIB (tectonic metamorphic-related) formation classification.

MATERIALS AND METHODS

Sixteen rough Davdar emerald samples (DC-1–DC-16) were chosen for testing. DC-1 through DC-13 were broken crystals obtained from local miners, and DC-14–DC-16 consisted of non-gem-quality emerald-bearing vein material obtained by the authors during their visit to the mining areas. Samples DC-1–DC-13 weighed 0.09–0.38 g, and they were cut and polished on two surfaces (parallel and perpendicular to the *c*-axis). Samples DC-14–DC-16 were cut and polished into slabs weighing 12.74, 20.37 and 18.17 g, respectively; they consisted of non-gem-quality emerald with hematite, carbonate, quartz and surrounding rock. The samples are pictured in Table I.

Microscopic features were observed and photographed using a GI-M6S91 gemmological microscope base manufactured by Nanjing Baoguang Technology Co. Ltd that was fitted with a Leica S9i digital stereo microscope equipped with a camera. RI measurements were acquired with a desktop refractometer for samples DC-1–DC-13, and SG values were obtained hydrostatically on these same emeralds. All samples were examined with standard 2–4 W long- and short-wave UV lamps and a Chelsea Colour Filter.

Spectroscopy was performed at the Laboratory of Gem and Technological Materials, Tongji University, Shanghai, China. Raman spectra were collected from all 16 samples with a Horiba Jobin Yvon LabRAM HR Evolution confocal micro-Raman spectrometer equipped with 325 and 532 nm lasers. The laser power was around 50 mW. Raman spectra of the emeralds were obtained in the 3800–3500 cm^{-1} range with the 325 nm laser using a grating of 1,800 grooves/mm. Raman spectra of accessory minerals were acquired in the 2000–100 cm^{-1} range with the 532 nm laser using a grating 600 grooves/mm, a scan time of 10 s, and two scans with the 50× objective of the microscope. Fourier-transform infrared (FTIR) transmission spectra were obtained for a representative sample (DC-1) with a Bruker Tensor 27 FTIR spectrometer. The nominal

Table I: Physical properties of Davdar emerald samples (photos © D. Cui).

Photo	Sample no.	Size (mm)	Weight (g)	Colour	Transparency	RI	Birefrin-gence	SG
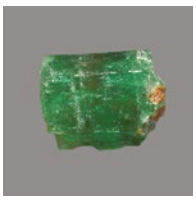	DC-1	4 × 4 × 6	0.15	Green	Translucent	1.578–1.586	0.008	2.56
	DC-2	7 × 6 × 7	0.40	Yellow-green	Translucent	1.580–1.587	0.007	2.57
	DC-3	5 × 4 × 2	0.11	Yellow-green	Translucent	1.581–1.588	0.007	2.61
	DC-4	4 × 5 × 2	0.09	Yellow-green	Translucent	1.577–1.584	0.007	2.62
	DC-5	3 × 4 × 4	0.11	Blue-green	Translucent	1.578–1.585	0.007	2.71
	DC-6	5 × 4 × 3	0.10	Blue-green	Transparent	1.575–1.582	0.007	2.70
	DC-7	3 × 4 × 4	0.25	Blue-green	Translucent	1.574–1.581	0.007	2.68
	DC-8	3 × 4 × 3	0.09	Yellow-green	Translucent	1.578–1.585	0.007	2.76

Photo	Sample no.	Size (mm)	Weight (g)	Colour	Transparency	RI	Birefrin-gence	SG
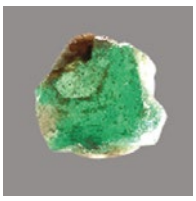	DC-9	4 × 3 × 2	0.09	Blue-green	Transparent	1.578–1.586	0.008	2.71
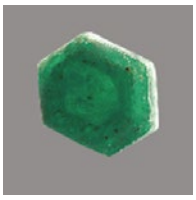	DC-10	4 × 3 × 4	0.10	Green	Translucent	1.578–1.585	0.007	2.65
	DC-11	6 × 4 × 3	0.14	Green	Translucent	1.580–1.588	0.008	2.70
	DC-12	3 × 3 × 4	0.10	Green	Translucent	1.579–1.586	0.007	2.62
	DC-13	7 × 7 × 3	0.38	Green	Translucent	1.576–1.583	0.007	2.57
	DC-14	23 × 20 × 7	12.74	Light green	Semi-translucent	–	–	–
	DC-15	27 × 22 × 10	20.37	Light green	Semi-translucent	–	–	–
	DC-16	36 × 24 × 8	18.17	Light green	Semi-translucent	–	–	–

resolution was 4 cm^{-1} and 32 scans were recorded. The scan speed was 10 kHz with a raster of 5 mm in the range of 8000–2000 cm^{-1}. Ultraviolet-visible-near infrared (UV-Vis-NIR) absorption spectra were obtained from all 16 samples with a GEM-3000 UV-Vis spectrometer manufactured by Guangzhou Flag Electronic Technology Co. The spectra were acquired at room temperature with a resolution of 1 nm, integration time of 110 milliseconds, average number of 20 times, smoothness of 1 and scan range of around 210–1000 nm.

Backscattered electron (BSE) imagery and chemical analysis of the accessory minerals in sample DC-13 were undertaken at the State Key Laboratory of Marine Geology of Tongji University using a JEOL JXA-8230 electron probe micro-analyser (EPMA) equipped with an energy-dispersive spectrometer. We used an accelerating voltage of 15 kV, a beam current of 10 nA and a beam diameter of 3 µm. Oxide compositions of the analysed minerals were calibrated against natural and synthetic mineral standards, and the ZAF procedure was used for data reduction.

Trace-element analysis of the 16 emeralds was conducted by laser ablation inductively coupled plasma mass spectrometry (LA-ICP-MS) using an Agilent 7900 ICP-MS combined with a Teledyne Cetac Analyte HE LA system at the Laboratory of Mineral Microanalysis in the Ore Deposit and Exploration Centre, Hefei University of Technology, Hefei, China. Detailed operating conditions for the instrumentation and data reduction were described by Zong *et al.* (2017). For this study, the spot size and frequency of the laser were set at 40 µm and 8 Hz, respectively. Data were calibrated against various reference glasses (NIST610, NIST612, NIST614, GSC-1G, GSD-1G and BCR-2G) without using an internal standard (Liu *et al.* 2008). Each analysis incorporated a background acquisition of approximately 40 s followed by 40 s of data acquisition from the sample. Six to nine spots were measured across colour-zoned samples (two to five spots for others). The samples were analysed on the same polished surfaces that were used for Raman spectroscopy.

Electron paramagnetic resonance (EPR) spectroscopy of sample DC-7 was performed with a Bruker EMX-8/2.7 electron-spin resonance spectrometer at the Test Centre of East China University of Science and Technology, Shanghai, China. The EPR measurements were made at room temperature using about 200 mg of powdered sample contained in a pure silica tube. Experimental conditions included a microwave frequency of 9.88 GHz, modulation frequency of 100 kHz, modulation amplitude of 4 G, microwave power of 2 mW, scan time of 42 s and spectral resolution of 1,024 points.

RESULTS

Standard Gemmological Properties

The standard gemmological properties of the 16 Davdar emeralds are listed in Table I. The samples ranged from semi-translucent to transparent and were light to dark blue-green to yellow-green. RI values were n_o = 1.584 ± 0.004 and n_e = 1.578 ± 0.004 with a birefringence of 0.007 ± 0.001, and SG ranged from 2.56 to 2.76. All of the samples were inert to both long- and short-wave UV radiation, and appeared green (i.e. showed no reaction) under the Chelsea filter while being illuminated with fibre-optic illumination.

Most of the emerald samples displayed colour zoning. Some were strongly colour zoned parallel to the hexagonal prism $\{10\bar{1}0\}$, and exhibited bands of near-colourless to green or yellowish green that showed variable thickness when viewed parallel to the *c*-axis (e.g. Figure 5).

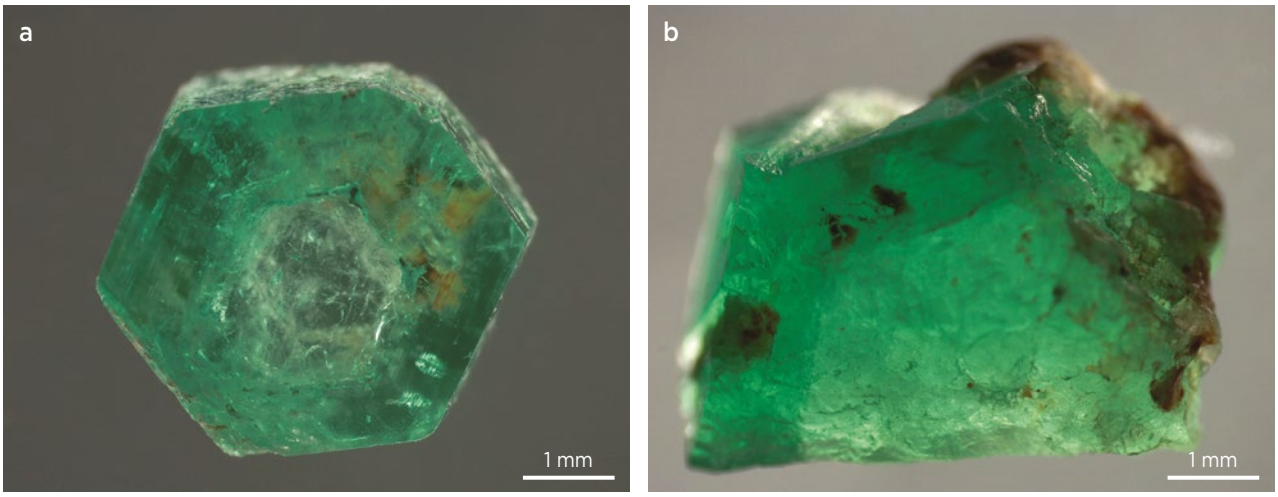

Figure 5: Colour zoning is evident when looking down the *c*-axis of Davdar emerald samples DC-4 (**a**) and DC-11 (**b**). Photos © D. Cui.

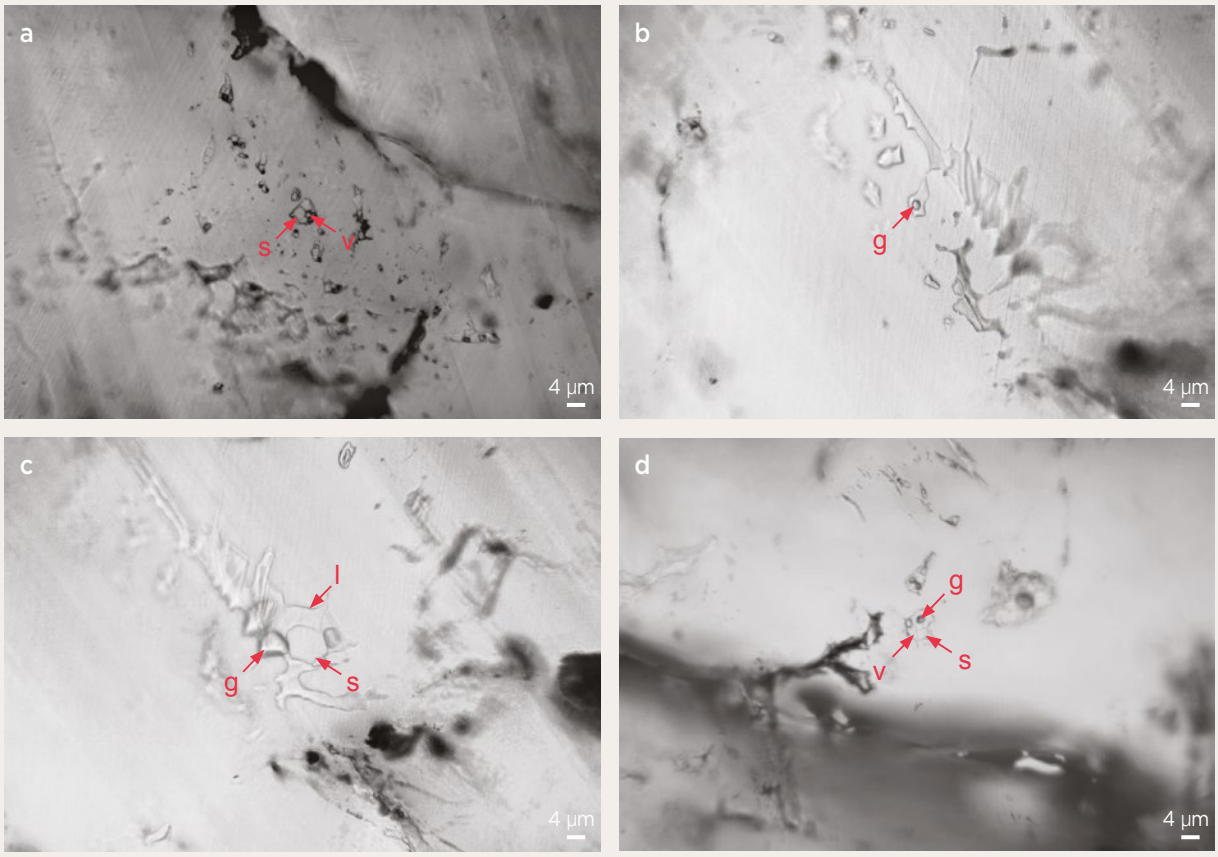

Figure 6: Two-phase (liquid + gas/vapour) and three-phase (liquid + solid + gas/vapour) inclusions are common in Davdar emeralds, as seen here in samples DC-9 (**a**–**c**) and DC-11 (**d**). Abbreviations: l = liquid, g = gas, s = solid and v = vapour. Photomicrographs © D. Cui in brightfield illumination.

Microscopy revealed abundant two-phase (liquid + vapour) and three-phase (liquid + vapour + solid) inclusions (Figure 6). They ranged from sub-microscopic to 10 µm, and most occurred in trails along partially healed fractures or formed isolated inclusions. The solid mineral within the three-phase inclusions might be halite (Marshall *et al.* 2012), but could not be discerned by Raman spectroscopy.

Minerals associated with the emeralds were observed microscopically and identified by Raman spectroscopy and BSE imaging as dolomite, quartz, orthoclase, albite and minor apatite (Figures 7 and 8a). In addition,

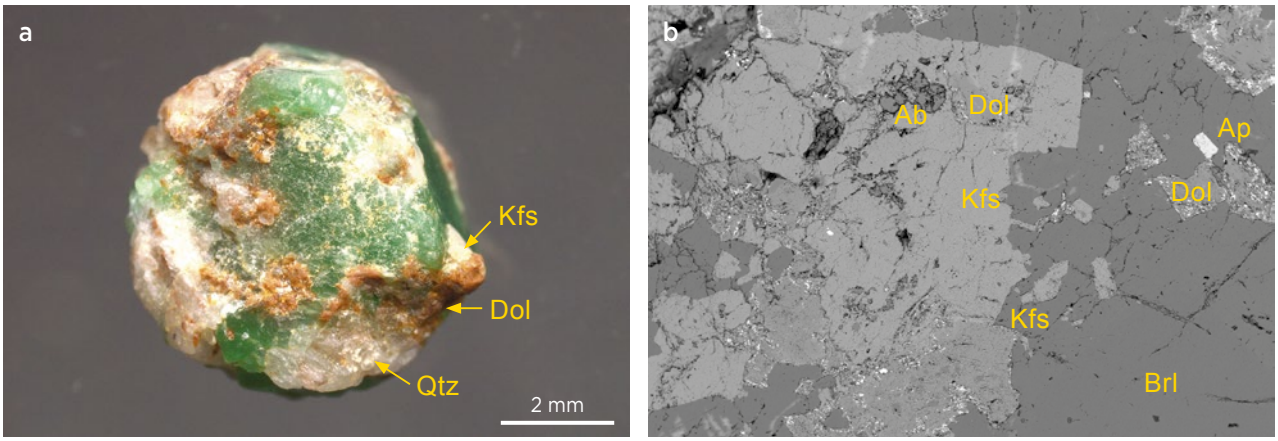

Figure 7: Associated minerals identified in Davdar emeralds include albite (Ab), apatite (Ap), dolomite (Dol), orthoclase (K-feldspar or Kfs) and quartz (Qtz). Sample DC-13 is seen here (**a**) before being partially polished (photo © D. Cui) and (**b**) on a polished surface using BSE imagery (image © Linmin Zhang).

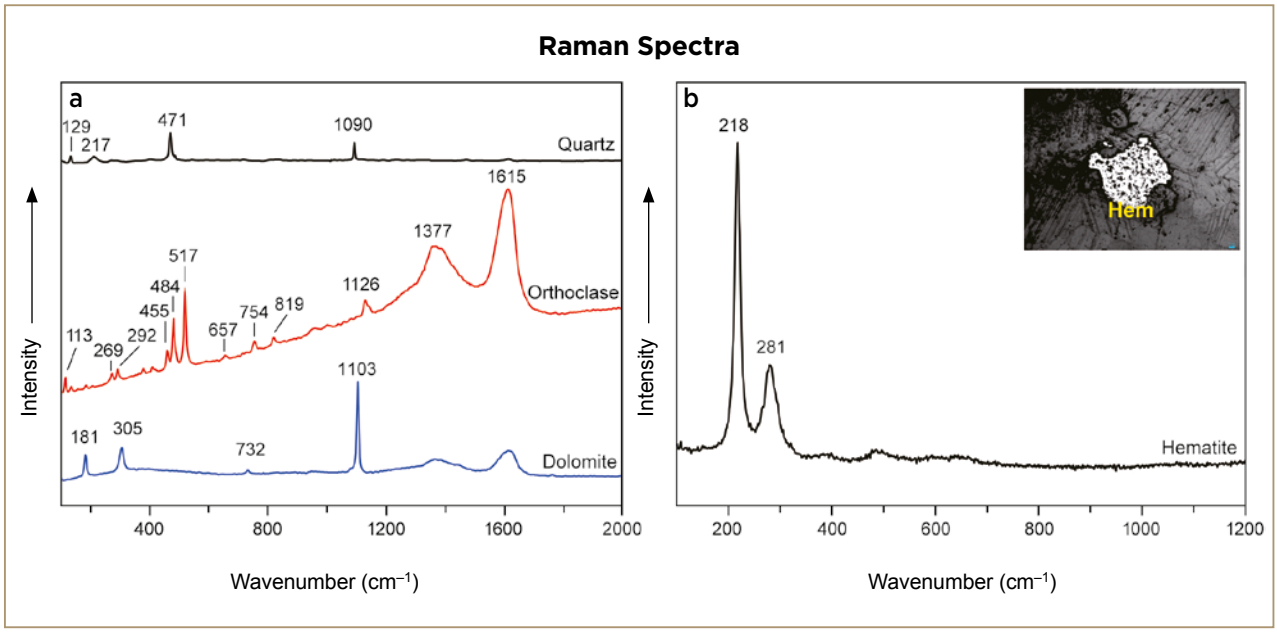

Figure 8: (**a**) Raman spectroscopy of some minerals associated with Davdar emerald sample DC-1 confirm their identity as quartz, orthoclase and dolomite. (**b**) In addition, hematite (Hem) was identified in sample DC-15 (photomicrograph © D. Cui).

hematite was identified by Raman spectroscopy (Figure 8b). EPMA analyses of these minerals in one sample are reported in Table II. Some emeralds with poor transparency contained what appeared to be a yellowish brown weathering product consisting of carbonates with hematite.

FTIR Spectroscopy

Representative FTIR spectra for E⊥c and E||c (Figure 9) showed weak bands in the ranges 4600–4000 cm^{-1} and 2900–2800 cm^{-1} associated with M-OH stretching vibrations and Cl^-, respectively (Shi 1999; Qi *et al.* 2002). A band at 2348 cm^{-1} is related to anti-symmetric

Table II: Electron microprobe analyses of accessory minerals at specific spots in sample DC-13.[a]

Oxides (wt.%)	Albite	Apatite	Dolomite	Dolomite	Orthoclase	Orthoclase
	DC-13-04	DC-13-02	DC-13-03	DC-13-06	DC-13-01	DC-13-05
SiO_2	69.26	nd	nd	nd	63.59	65.15
Al_2O_3	19.27	nd	nd	0.02	18.25	18.34
FeO[b]	nd	0.18	5.12	6.83	0.02	0.01
MnO	nd	0.01	0.46	0.26	nd	0.01
CuO	0.01	nd	0.01	0.01	0.04	nd
MgO	nd	0.02	13.73	16.64	nd	nd
CaO	0.05	55.21	34.46	29.19	0.05	0.04
Na_2O	11.55	0.06	0.01	0.02	0.72	0.67
K_2O	0.22	nd	0.02	0.01	16.93	16.93
P_2O_5	nd	41.26	0.07	0.15	0.04	nd
Total	100.36	96.75	53.87	53.11	99.63	101.14

[a] The accuracy of major elements is about 1%. Abbreviation: nd = not detected (<0.01 wt.%).
[b] All Fe is reported as FeO.

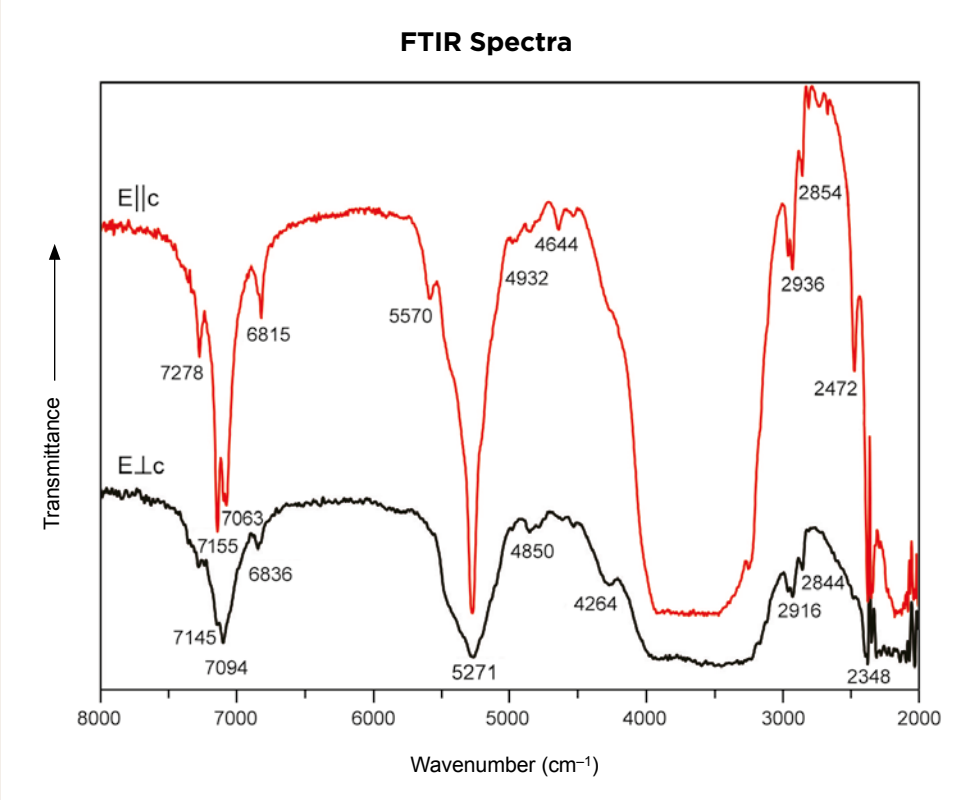

Figure 9: FTIR transmission spectra of representative Davdar emerald sample DC-1 in the range 8000–2000 cm^{-1} show features associated with type I and type II H_2O molecules, as well as other constituents. See Table III for band assignments.

stretching vibrations of CO_2 molecules (Yu *et al.* 2017). Strong bands near 7100 and 5200 cm^{-1} are attributed to double-frequency and frequency vibrations caused by type I and type II H_2O molecules in structural channels, as specified in Table III.

Raman Spectroscopy

Figure 10 illustrates representative Raman spectra of the core and rim of colour-zoned samples DC-4 and DC-12, measured in the range of OH^- and H_2O-molecule vibrations at 3500–3800 cm^{-1}. According to Huong *et al.* (2010), bands centred at approximately 3608 and 3598 cm^{-1} belong to type I H_2O (i.e. without an alkali ion nearby) and type II H_2O (i.e. with an alkali ion nearby), respectively. The positions of these bands can vary by a few wavenumbers. In this study, the features at 3613–3614 cm^{-1} (type I H_2O) and at 3601–3604 cm^{-1} (type II H_2O) showed significant intensity differences in the zoned samples, indicating relatively greater type II H_2O in the lighter-coloured core and more type I H_2O in the greener rim. However, the spectra of most of our samples showed that type II H_2O was dominant overall.

Table III: Principal FTIR vibrational bands in the 8000–2000 cm^{-1} range in Davdar emeralds.

Constituent	E||c	E⊥c	Mode of vibration (Qi *et al.* 2002; Yu *et al.* 2017)
Type I H_2O	7063	7145	Double-frequency vibration
Type II H_2O	7155	7094	Double-frequency vibration
Type I H_2O	5570	—	Frequency vibration
Type II H_2O	5271		Frequency vibration
CO_2	2348		Stretching vibration

Trace-Element Analysis

LA-ICP-MS data for the 16 emerald samples are summarised in Table IV. All of them contained abundant chromophore elements that varied over a relatively wide range: Cr = 1591–5919 ppmw, V = 454.5–12040 ppmw and Fe = 701.7–14700 ppmw. Some samples contained relatively high Cr and Fe, while others showed high V and low Fe. The Cr/V ratio ranged from 0.2 to 6.8. The emeralds contained comparatively low Rb and Cs, as well as traces of Ni and Ga. Mg ranged up to 12000 ppmw, averaging 7040 ppmw. Total alkali concentrations (Li + Na + K + Rb + Cs) averaged 8994 ppmw (2543–16070 ppmw); Na, K, Rb and Cs contents averaged 8478, 312, 20 and 26, respectively.

Table IV: Chemical composition of 16 Davdar emeralds obtained by LA-ICP-MS.*

Sample no.	DC-1	DC-2	DC-3	DC-4 rim	DC-4 core	DC-5	DC-6	DC-7	DC-8
Colour	Green	Yellow-green	Yellow-green	Yellow-green	Lt. ylo.-green	Blue-green	Blue-green	Blue-green	Yellow-green
No. analyses	2	2	6	7	2	2	3	2	3
Element (ppmw)									
Li	239.2–248.2	113.7–157.6	102.8–318.3	94.18–419.2	114.5–443.9	149.7–160.2	129.3–139.1	117.4–274.1	118.8–264.3
Na	8399–8811	8154–11440	7695–11300	8993–11690	9238–11000	7537–8189	6522–7399	8559–9869	6190–10150
Mg	9797–9953	6463–7128	6208–8061	6360–9398	7115–7940	4793–8673	5400–5541	10380–10600	4714–11180
K	279.1–285.9	163.2–220.7	212.6–318.3	235.5–395.1	221.0–295.8	304.6–1610	184.1–243.5	376.0–403.0	137.5–452.5
Sc	34.18–38.59	103.8–232.9	32.76–220.1	35.80–248.7	36.87–299.1	39.20–95.05	103.7–134.0	40.13–243.5	63.29–194.8
Cr	2347–2463	3335–3746	1674–4487	1790–5424	1781–4027	3902–4909	4143–4429	2746–3144	2152–4112
V	467.9–501.8	956.4–1169	707.7–1514	689.7–1443	682.1–1248	927.0–1067	883.6–928.6	567.4–1356	725.8–1528
Fe	5139–5323	8445–10700	4620–11650	5642–14700	5491–12760	7079–10350	6480–7171	6572–13980	6568–13440
Ga	17.49–19.38	25.27–28.96	19.32–37.39	19.39–33.83	19.54–33.79	40.35–76.45	25.10–29.54	19.30–39.95	22.88–37.81
Rb	17.29–19.86	16.53–20.75	20.65–32.31	22.04–39.69	20.09–30.56	23.40–42.12	10.41–14.02	21.75–32.47	11.48–29.19
Cs	26.00–26.59	22.13–30.65	24.70–40.60	23.46–43.93	21.33–37.24	27.68–33.69	15.18–17.79	27.08–39.89	23.60–38.06
Ni	19.82–20.75	14.91–15.64	18.38–22.03	16.53–20.20	17.14–20.68	20.65–76.02	18.60–22.00	19.44–24.44	13.42–24.76
Cr/V	4.7–5.3	3.2–3.5	2.2–3.4	1.9–3.9	2.6–4.3	4.2–4.6	4.7–4.8	2.3–4.8	2.1–3.2
Sample no.	**DC-9**	**DC-10**	**DC-11**	**DC-12 rim**	**DC-12 core**	**DC-13**	**DC-14**	**DC-15**	**DC-16**
Colour	Blue-green	Green	Green	Green	Lt. green	Green	Lt. green	Lt. green	Lt. green
No. analyses	2	2	3	4	5	5	5	5	5
Element (ppmw)									
Li	129.7–138.2	246.5–249.3	191.4–206.7	116.4–213.6	200.3–217.4	112.0–163.1	123.0–127.1	22.48–142.6	136.5–143.8
Na	5171–8217	8914–9099	4339–11960	7119–9670	8531–10110	9350–10710	7172–7836	2431–15360	5820–8518
Mg	6295–9490	9285–9354	3076–9017	4976–9800	5659–7846	8094–10550	5146–5478	2207–12000	4684–5182
K	432.8–850.2	262.9–432.8	109.6–311.0	162.8–282.2	222.7–477.2	329.4–527.1	169.9–189.0	67.6–506.8	176.0–729.1
Sc	71.88–186.9	33.45–35.52	37.14–88.66	30.55–202.8	27.25–33.55	18.39–260.0	227.9–268.1	131.1–279.8	221.9–298.8
Cr	3294–3313	2670–2739	3632–3818	3338–3598	2799–3148	1917–5193	2868–2894	1591–2738	2440–2759
V	770.8–1232	454.5–474.6	565.2–1020	523.2–1451	512.5–622.4	566.1–1233	11000–12040	4062–4918	8852–9802
Fe	7054–11270	5103–5652	7338–7408	5278–9399	4685–5383	4580–13360	1840–1982	701.7–3300	2205–3589
Ga	25.20–35.19	17.00–17.86	16.92–28.37	16.52–35.03	17.83–28.21	19.71–33.02	28.59–30.31	10.93–23.76	32.31–36.12
Rb	10.41–25.13	16.40–18.21	8.79–25.67	14.10–27.87	19.39–21.15	16.76–30.56	12.52–14.66	4.51–30.64	9.77–15.88
Cs	16.10–29.23	24.38–25.67	18.72–30.21	27.25–34.63	27.87–29.96	21.31–37.98	21.76–24.14	5.47–31.42	19.48–21.47
Ni	14.20–16.80	21.36–22.54	6.29–24.50	14.10–28.03	10.40–24.75	17.20–22.43	nd	nd	nd
Cr/V	2.7–4.3	5.8–5.9	3.7–6.4	2.5–6.8	5.1–5.5	2.7–5.5	0.2–0.3	0.3–0.6	0.2–0.3

* Except for zoned samples DC-4 and DC-12, spots were analysed in random locations. The accuracy is about 10%.
Abbreviations: nd = not detected, Lt. = light, ylo. = yellow.

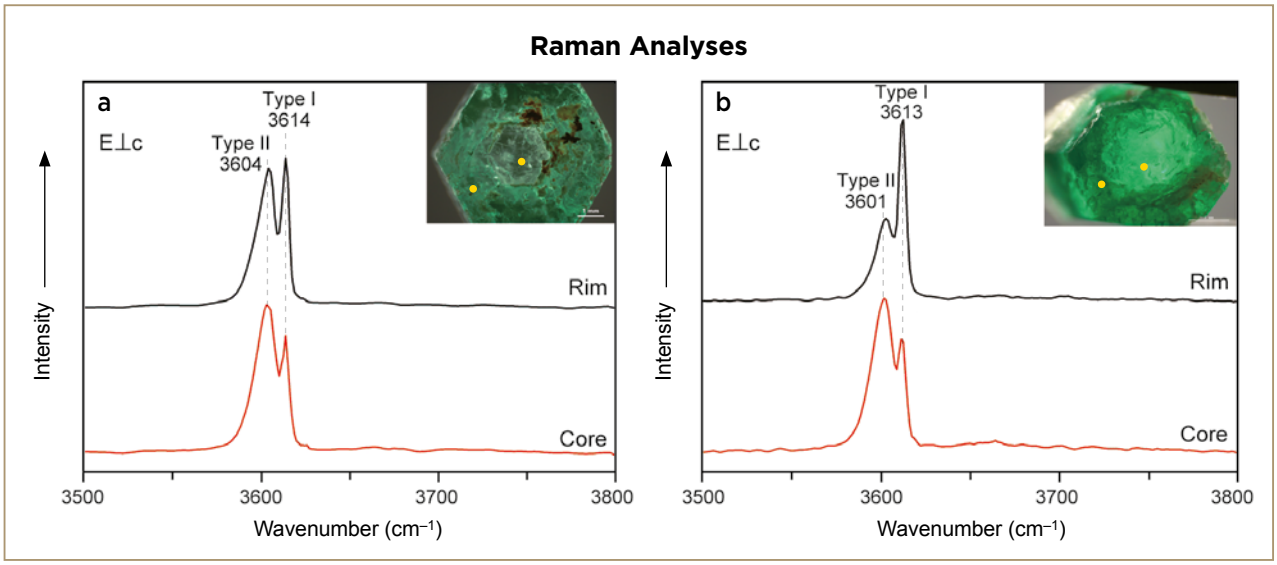

Figure 10: Raman spectra of colour-zoned Davdar emerald samples DC-4 (**a**) and DC-12 (**b**) display features characteristic of different proportions of type I and type II H_2O in the core and rim of each crystal. Inset photomicrographs © D. Cui; the yellow dots indicate the locations analysed.

Figure 11 shows the chemical zonation in colour-zoned samples DC-4 and DC-12. Their colour variations from core to rim were consistent with the contents of Cr and V. Overall, these were measured as 0.26–0.87 wt.% Cr_2O_3 and 0.10–0.20 wt.% V_2O_3 in DC-4, and 0.41–0.53 wt.% Cr_2O_3 and 0.08–0.21 wt.% V_2O_3 in DC-12. Higher concentrations of Cr and V together contributed to the greener colouration of the rims. It is also worth noting that the rims were low in alkalis, while the cores had higher alkali and Mg + Fe contents. The total content of Na_2O + K_2O in the rims of both samples ranged from 1.21 to 1.62 wt.% (again, see Table IV). Figure 10 demonstrates that the Raman intensity ratio I_{3604}/I_{3614} of sample DC-4 was higher in the core than the rim; the same trend was noted for sample DC-12. Therefore, as expected the type II H_2O Raman band increased in intensity together with the alkali content of the emerald cores.

UV-Vis-NIR Spectroscopy

UV-Vis-NIR spectra of relatively high-Fe Davdar samples (e.g. DC-1; Figure 12) displayed dominant Fe and Cr features. The broad absorption bands at 430 and 580–630 nm are due to Cr^{3+} with contributions from V^{3+} (Li & Zhu 2002; Saeseaw *et al.* 2014, 2019; Bai *et al.* 2019; Hu & Lu 2019). The peaks at 638 and 683 nm are also associated with Cr^{3+} (Saeseaw *et al.* 2014, 2019). Distinct Fe^{3+}

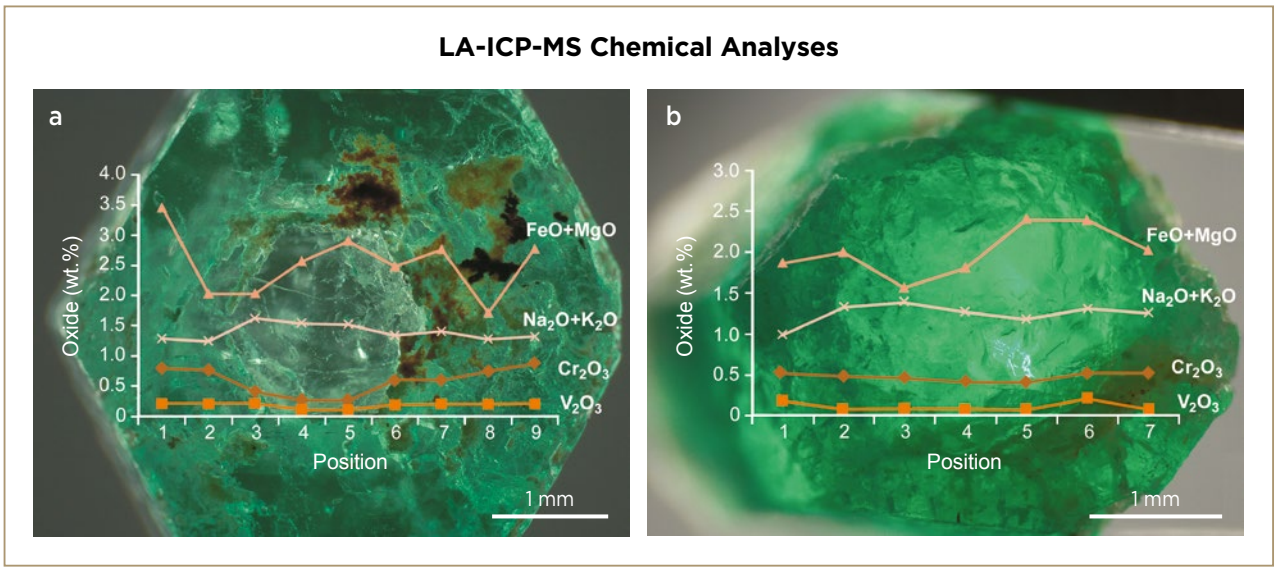

Figure 11: LA-ICP-MS data for selected oxides superimposed on photos of samples DC-4 (**a**) and DC-12 (**b**) illustrate how chemical composition varies with colour zoning across the emerald crystals. Photomicrographs © D. Cui.

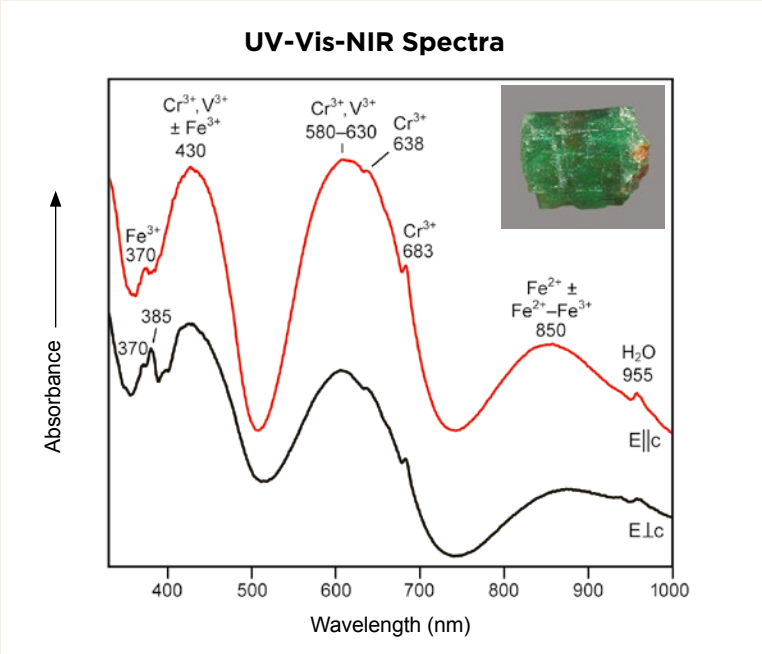

Figure 12: Polarised UV-Vis-NIR absorption spectra of high-Fe emerald sample DC-1 (containing an average of 2405 ppmw Cr, 485 ppmw V and 5231 ppmw Fe) show Fe^{2+}- and Fe^{3+}-related peaks, as well as Cr^{3+} and V^{3+} features, in both spectral orientations.

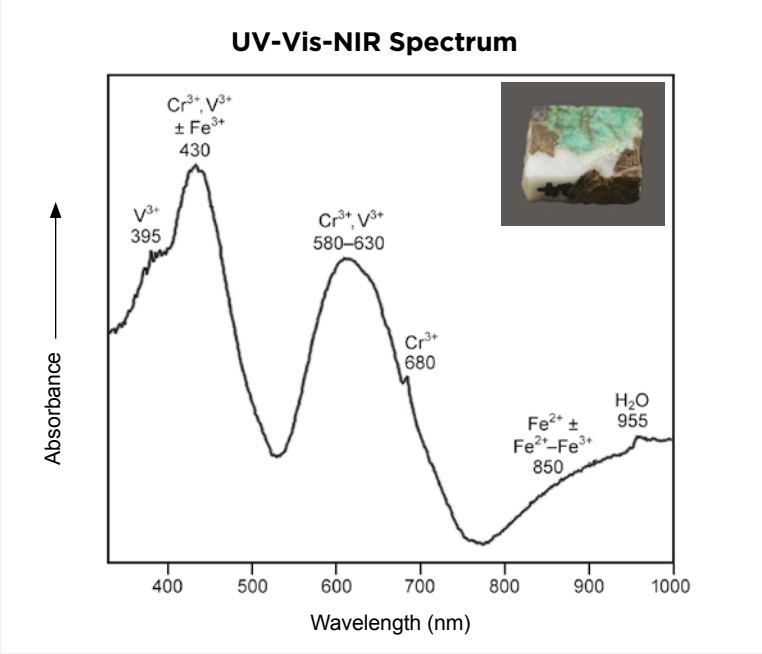

Figure 13: The UV-Vis-NIR absorption spectrum of high-V emerald sample DC-15, measured in a random direction, displays Cr- and V-dominant bands (with a shoulder at 395 nm due to V^{3+}), and Fe^{2+}- and Fe^{3+}-related features of variable intensity.

absorption occurred at around 370 nm and may also have contributed to the 430 nm band (Marfunin 1984; Zhang *et al.* 2012; Andersson 2019). Moreover, a weak, narrow Fe^{3+} band at about 385 nm was visible only for E⊥c polarisation, while the 370 nm Fe^{3+} feature could be observed in both the E⊥ c and E||c orientations. A band in the near-infrared region at around 850 nm is attributed to Fe^{2+} in octahedral (Khaibullin *et al.* 2003) or tetrahedral (Taran & Rossman 2001) structural sites. This Fe^{2+}-related feature is typically in the range of 810–830 nm (Taran & Vyshnevskyi 2019 and references therein), and the reason for the shift to 850 nm in our Davdar emeralds is unknown. Shao *et al.* (2014) proposed that this band (specifically at 842 nm) in Fe-rich Russian hydrothermal synthetic emerald may be caused by the combined effect of Fe^{2+} and Fe^{2+}–Fe^{3+} intervalence charge transfer. A peak at about 955 nm is related to the presence of H_2O (Wood & Nassau 1968).

Non-gem-quality Davdar emeralds containing relatively high amounts of V (samples DC-14–DC-16) showed UV-Vis-NIR absorption features comparable with previous studies (Figure 13; cf. Schwarz & Pardieu 2009; Saeseaw *et al.* 2014). The spectra displayed Cr^{3+}- and V^{3+}-dominant

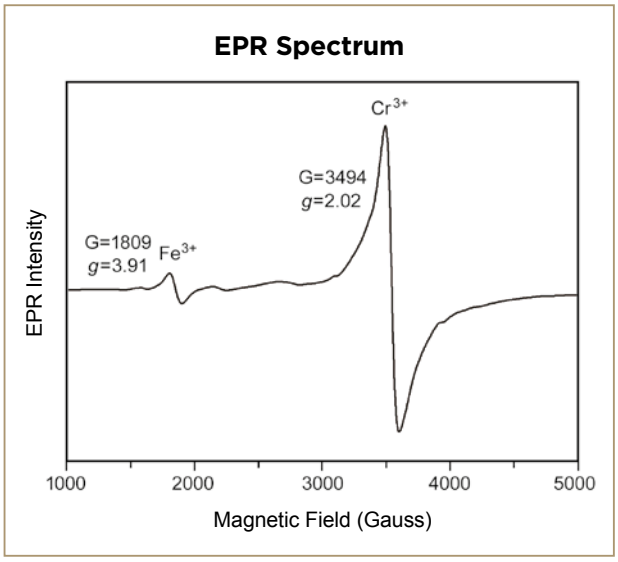

Figure 14: A representative powder EPR spectrum of emerald sample DC-7 shows signals for Cr^{3+} and Fe^{3+} centres.

features, along with bands of variable intensity related to Fe^{2+} and possibly Fe^{2+}–Fe^{3+} interactions. Schwarz and Pardieu (2009) noted that Davdar emeralds show intense Cr^{3+} and V^{3+} features, with a distinct V shoulder at about 380 nm. This shoulder was present in the absorption spectra of our high-V samples at around 385–395 nm (see, e.g., Figure 13). However, our spectra differed from data presented by Saeseaw *et al.* (2014), which showed the broad Fe^{2+}-related band but no Fe^{3+} in Davdar emeralds.

EPR Spectroscopy

EPR spectroscopy uses magnetic fields to measure the transitions between magnetic energy levels of transition metals with unpaired electrons (for more details, see Zhao 1991 and Pan & Nilges 2014). The interaction between the unpaired electrons and the applied magnetic field is described by its *g* value.

The representative EPR spectrum in Figure 14 displays the typical electronic paramagnetic signal of transition-metal ion substitutions in the X-band EPR. It presents two strong lines at about 3500 and 1800 G that are likely associated with the colouration mechanisms of Cr^{3+} and Fe^{3+}, respectively. The peak at about 3500 G ($g \approx 2$) can be assigned with some confidence to Cr^{3+} ions associated with the large zero-field splitting of Cr^{3+} ions (Ohkura *et al.* 1987). The peak at about 1800 G ($g \approx 4$) is probably related to paramagnetic behaviour corresponding to Fe^{3+} (Lin *et al.* 2013; Hu & Lu 2019). However, the Cr^{3+} centre might also be overlapped by Fe^{3+} ion-related centres for similar *g* factors (Hu & Lu 2019). Peaks centred at $g \approx 2$ were assigned to Fe^{3+} because of a classical spin Hamiltonian of a $3d^5$ ion in octahedral symmetry (Gaite *et al.* 2001). EPR spectra of Fe^{3+} have been reported previously by others who also proposed that these ions occupy $A1^{3+}$ sites (Dvir & Low 1960; Blak *et al.* 1983; Ollier *et al.* 2015). Given the presence of vanadium in Davdar emeralds revealed by chemical analysis, V^{3+} might require low-temperature analytical conditions in order to be seen in the X-band EPR due to outer paired electrons (Hu & Lu 2019).

DISCUSSION

Chromophores in Davdar Emeralds

The concentrations of chromophores reported for Davdar emeralds show large ranges (see Table V). In this study, most of our samples contained more Cr than V, with Cr/V ratios of 1.9–6.8 (see Table IV). However, three non-gem-quality high-V samples had Cr/V ratios of 0.2–0.6. The UV-Vis-NIR spectra of these high-V emeralds displayed an absorption shoulder at about 385–395 nm (see, e.g., Figure 13), which has previously been assigned to V^{3+} in vanadium-doped synthetic emerald (Schmetzer *et al.* 2006). This absorption was also described as typical of high-quality Davdar emeralds with enriched V contents (Schwarz & Pardieu 2009; Saeseaw *et al.* 2014).

The AlO_6 octahedron is the structural unit that is key for the colouring of emerald because the ionic radii of Cr^{3+} (0.615 Å), V^{3+} (0.640 Å) and Fe^{3+} (~0.740 Å) are similar enough to that of Al^{3+} (0.535 Å) in the octahedral site to allow substitution (Shannon 1976). The substitution of Cr^{3+}, V^{3+}, Fe^{2+} and Fe^{3+} in the AlO_6 octahedra appears to follow the typical crystal-field behaviour that directly leads to colouration (Hu & Lu 2019). As suggested by Schwarz and Schmetzer (2002) and Schmetzer *et al.* (2006), yellowish green, green and bluish green emeralds reveal distinct absorption bands of

Table V: Summary of chemical composition data reported for Davdar emeralds.

Element (ppmw)	This study	Marshall *et al.* (2012)*	Saeseaw *et al.* (2014, 2019)	Schwarz & Pardieu (2009)
Cr	1591–5919	1231–4652	146–5630	1000–3000 (some 8000–9000)
V	455–12040	1428–2176	657–6960	1000–8000
Fe	701.7–14700	1166–2488	1170–6430	4000–11000
Cs	5.47–40.60	Not analysed	5.96–41.20	30–50 (some up to about 3000)

* Data of Marshall *et al.* (2012) have been recalculated as ppmw.

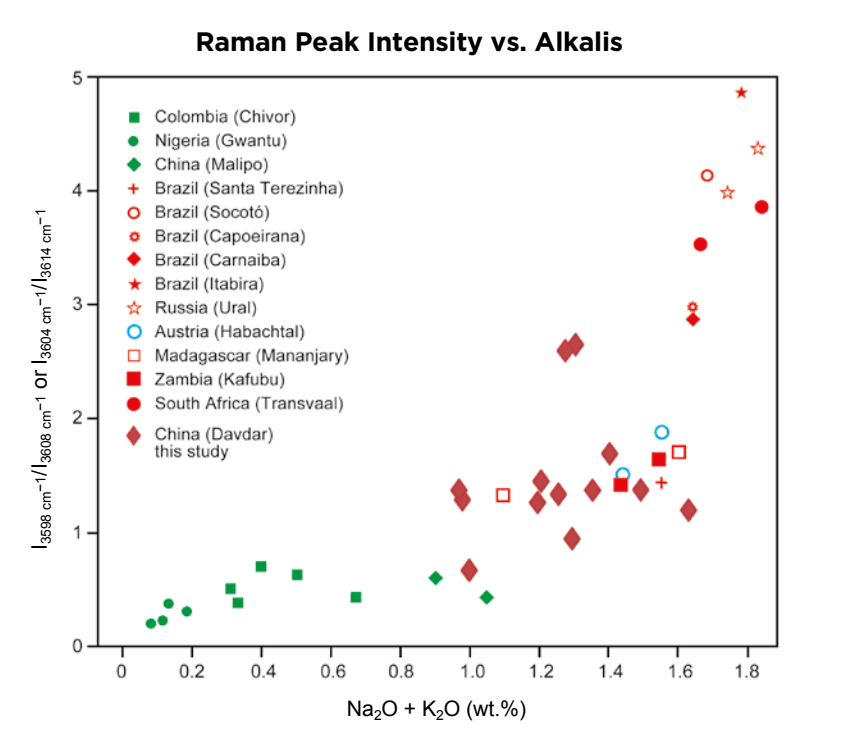

Figure 15: This plot shows the ratio of the Raman peak intensity (I) of the two water bands vs. the amount of alkalis (wt.% $Na_2O + K_2O$) for emeralds from various localities. The intensity ratios of the 3608 cm^{-1} (or 3614 cm^{-1}) and 3598 cm^{-1} (or 3604 cm^{-1}) bands are related to type I and type II water, respectively. The values for Davdar emeralds are from this study, and the other data are from Huong *et al.* (2010).

Cr, V or both in the red and blue-to-violet range. Considering the great variability of Cr, V and Fe concentrations in Davdar emeralds, Cr and V may sometimes occur in amounts necessary to yield the relatively saturated green colour of fine-quality emerald. While our high-Fe samples were mostly dominated by Cr, their bluish tinge could be associated with the presence of Fe.

Type I vs. Type II H_2O and Associated Alkali Content

Characteristics of channel water types can help provide useful information about the geographic origin of emerald. The FTIR spectra of our Davdar emeralds revealed that the bands for type II H_2O at 7155, 7094 and 5271 cm^{-1} were greater in intensity than those for type I H_2O at 7063, 7145 and 5570 cm^{-1}, in both the E||c and E⊥c directions (Figure 9; see also Table III for specific band assignments). Thus, the Davdar emeralds in this study were generally richer in type II H_2O. This is in contrast to the results obtained by Saeseaw *et al.* (2014), who recorded FTIR spectra for Davdar emeralds showing dominant type I H_2O with associated relatively low alkali contents (8840 ppmw total, on average, for the alkalis Li, Na, K, Rb and Cs).

Our samples contained total alkalis of around 9050 ppmw on average, with a range of 2540–16070 ppmw. Figure 15 illustrates that the total alkali concentration of Davdar emerald samples could be classified as 'medium' (1–2 wt.%) according to Karampelas *et al.* (2019), with a Raman peak intensity ratio I_{3604}/I_{3614} that was mostly >1 (i.e. 0.65–2.73), compared to low-alkali emeralds such as those from Colombia's Chivor mine, with an I_{3598}/I_{3608} ratio of <1 (Huong *et al.* 2010). The I_{3604}/I_{3614} ratio was >1 for all of our high-alkali Davdar samples, for which $Na_2O + K_2O$ = 1.18–1.62 wt.%. Only one Davdar spot analysis yielded a ratio of <1 (for $Na_2O + K_2O$ = 0.98 wt.%). We also found that as Mg + Fe concentrations and alkali cations increased, the type II H_2O band became more intense than the type I H_2O band.

A previous study (Qiao *et al.* 2019) showed a tentative correlation between water type and the contents of ($Na_2O + K_2O + Cs_2O$) and (MgO + FeO). In the emerald structure, the substitution of Al^{3+} by bivalent ions such as Mg^{2+}, Fe^{2+} or both requires a coupled substitution. The channels must then be occupied by alkali ions such as Na^+, Rb^+ and Cs^+ (usually Na^+), to balance the reduction in positive charge (Giuliani *et al.* 2019), as follows:

$$Al^{3+} = Mg^{2+} + Na^+_{(channel)}$$
$$Al^{3+} = Fe^{2+} + Na^+_{(channel)}$$

To summarise, the alkali content in emerald is controlled by the presence of $(Mg + Fe)^{2+}$ in the host rock or in the mineralising fluid (Qiao *et al.* 2019). Based on previous literature (Saeseaw *et al.* 2014), Davdar emeralds

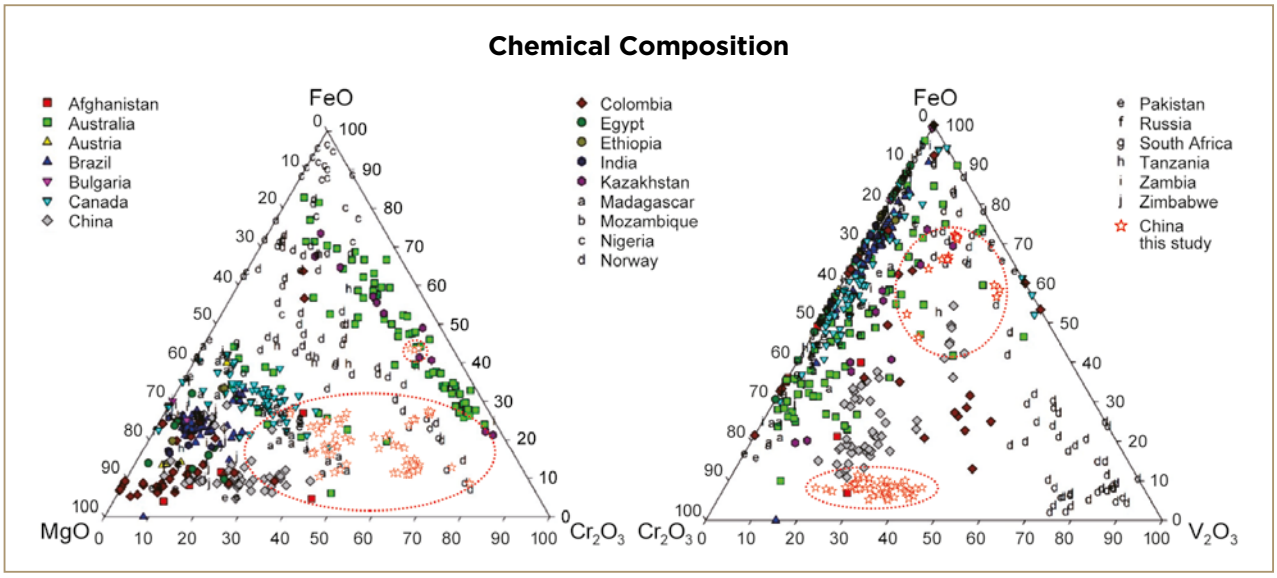

Figure 16: These ternary plots adapted from Giuliani *et al.* (2019) show emerald compositional data from worldwide localities with superimposed analyses of Davdar samples from this study.

are dominant in type I H_2O, suggesting they mineralised in an alkali-poor environment. However, our research shows that Davdar emeralds cannot be absolutely divided into being dominant in type I or type II H_2O, considering the variations in alkali-metal concentrations in their colour zones, which characterise multiple growth zones and the evolution of the mineralising environment (from alkali-rich to alkali-poor and from type II to type I H_2O). Overall, the alkali variations could be affected by the evolution of the mineralisation and the presence of local alkali-poor vs. alkali-rich environments.

Chemical Fingerprints of Davdar Origin

Our Davdar emerald samples showed relatively large ranges of Cr, V and Fe compared to those reported in previous studies (see Table V; Schwarz & Pardieu 2009; Marshall *et al.* 2012; Saeseaw *et al.* 2014, 2019), while the amount of Cs was similar to the results given by Saeseaw *et al.* (2014, 2019). The contents of Mg ranged from 2207 to 12000 ppmw, and Fe attained values up to 14700 ppm. Ternary diagrams of FeO–MgO–Cr_2O_3 and FeO–Cr_2O_3–V_2O_3 (Figure 16) show considerable overlap with data for emeralds from other localities, so these elements cannot be used to differentiate Davdar emeralds.

Emeralds appear to be sensitive to slight changes in their geological formation environments, which can impart unique trace-element signatures in material from different geographic localities (Saeseaw *et al.* 2019). Thus, variations in certain trace elements may be helpful for fingerprinting emeralds (Schwarz & Pardieu 2009; Saeseaw *et al.* 2014, 2019; Hu & Lu 2019). Figure 17 shows a plot of Fe vs. Ga data together with published data for emeralds from other deposits in Asia (Schwarz & Pardieu 2009; Zhang *et al.* 2012). This approach proved useful for separating Davdar emeralds from those of Pakistan, Russia and Malipo in China. However, it also confirmed the similarity of Davdar emeralds to those from Panjshir, Afghanistan, with a nearly complete overlap in their compositional fields. Plotting our Davdar emerald data on the Li vs. Cs diagram of Saeseaw *et al.* (2014) gave similar results (Figure 18). Davdar samples analysed in this study contained values for Li (22–444 ppmw) and Cs (5–41 ppmw) that commonly overlapped emeralds from Panjshir (78–268 ppmw Li and 11–97 ppmw Cs; Saeseaw *et al.* 2014, 2019).

Saeseaw *et al.* (2019) showed plots of Fe vs. Rb and Fe vs. Cs that appeared to be helpful for separating Davdar from Afghanistan emeralds, but the range of Fe contents obtained in this study varied too widely for such plots to be effective. Therefore, more research is needed for the reliable geochemical separation of emeralds from these two localities.

CONCLUSION

Davdar emeralds (e.g. Figure 19) formed in quartz-carbonate, carbonate and quartz veins with associated minerals such as hematite, dolomite, quartz, orthoclase and albite. Their chemical composition showed wide ranges of Fe, Cr and V (with mostly Cr>V), and relatively low Sc, Rb and Cs. Some non-gem-quality samples with V>Cr presented a distinct V absorption shoulder in their UV-Vis-NIR spectra. The chemical evolution of zoned Davdar emeralds indicates that they precipitated from

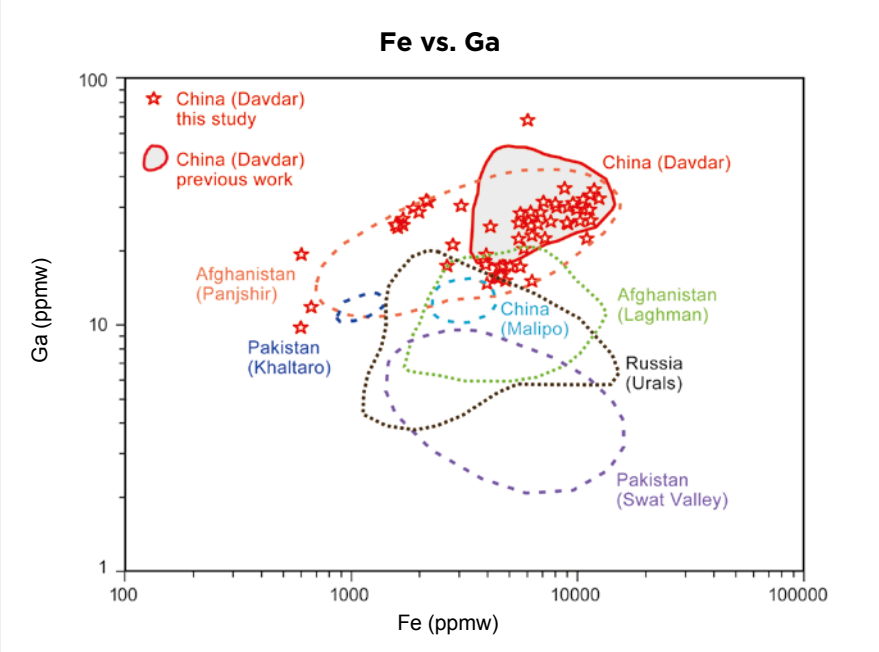

Figure 17: A logarithmic plot of Fe vs. Ga in emeralds from Davdar with compositional fields from some emerald deposits in Asia (from Schwarz & Pardieu 2009 and Zhang *et al.* 2012) shows the similarity of Davdar emeralds to those from Panjshir, Afghanistan.

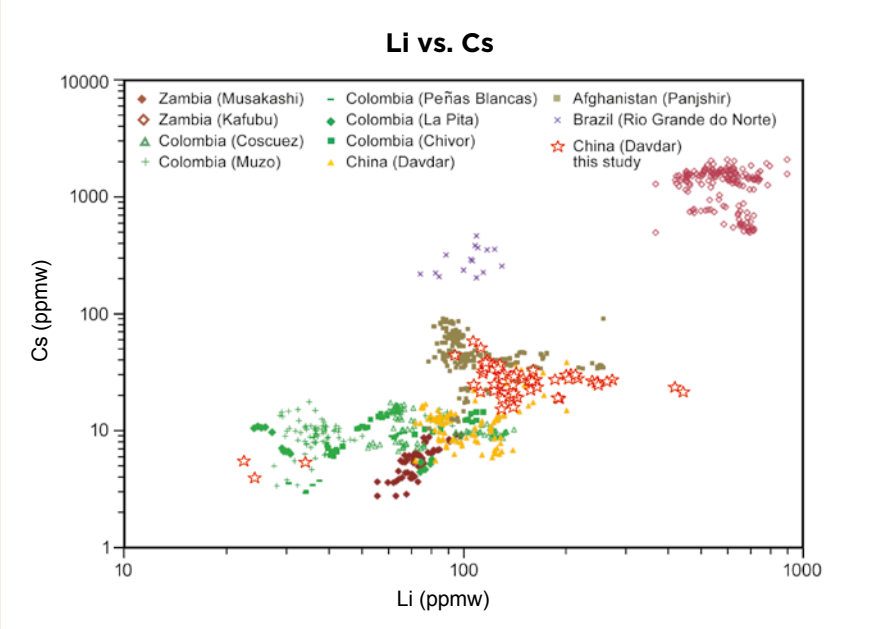

Figure 18: A logarithmic plot of Li vs. Cs in emeralds from various localities from Saeseaw *et al.* (2014)—with data from this study added for Davdar emeralds—also shows the similarity in chemical composition between stones from Davdar and Panjshir.

alkali-rich to alkali-poor conditions. Most samples were dominated by type II H_2O in their structural channels, although type I H_2O was more abundant in the rims of zoned samples. LA-ICP-MS data for Fe, Ga, Cs, Li and Sc offer useful information for differentiating Davdar emeralds from those of other localities except, in some cases, material from Panjshir, Afghanistan.

Figure 19: These diamond-set earrings feature Davdar emeralds (1.80 and 1.60 ct) and show the potential of this deposit to produce attractive gem-quality material. Courtesy of Fan Yaozeng; photo © Z. Zhou.

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Characterisation of Pink-to-Red Spinel from Four Important Localities

Chawalit Chankhantha, Ratthaphon Amphon, Habib Ur Rehman and Andy H. Shen

ABSTRACT: Most pink-to-red spinel that is currently available on the global gem market originates from moderate- to high-grade metamorphic rocks. For this study, we characterised 60 such spinels from Myanmar, Tajikistan, Tanzania and Vietnam. They ranged from pink to red with orange or blue modifiers due to combinations of the chromophores Cr^{3+}, V^{3+} and Fe^{2+}. The most common mineral inclusions in the samples from Myanmar, Vietnam and Tanzania were apatite crystals and graphite platelets, and we also observed zircon in the spinels from Tanzania. Octahedral negative crystals and partially healed fractures were present in samples from all four origins, while dislocations/needles were found only in those from Tanzania and Vietnam. Linear discriminant analysis of chemical data obtained by LA-ICP-MS was performed using seven elements (Ti, V, Cr, Fe, Zn, Ga and Sn) and provided potential criteria for separating spinels from these four important localities.

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Most gem-quality spinel is $MgAl_2O_4$ with the substitution of various minor-to-trace elements in the structural sites (Bowles *et al.* 2011). So-called *normal spinel* has the composition AB_2O_4, where A (Mg^{2+}) refers to the tetrahedral site and B (Al^{3+}) is the octahedral site. Another structural form of spinel is *inverse spinel*, for which the formula is written as $B(AB)O_4$, as seen in the structure of magnetite (Deer *et al.* 1992).

Gem-quality spinel (e.g. Figure 1) occurs mainly in East Africa, Central Asia and South East Asia. Most of the deposits are hosted in marble that has undergone metamorphism to amphibolite–granulite facies. In East Africa, gem spinel occurs in marbles and calc-silicate rocks that belong to the Neoproterozoic Mozambique Belt formed during the Pan-African orogeny (750–450 million years ago; Keller 1992; Balmer *et al.* 2017). Central Asia's spinel deposits are hosted by the Himalayan mountain belt, which formed during the Tertiary collision (since 45 million years ago) of the Indian Plate northward into the Eurasian Plate. This geologic activity resulted in massive

Figure 1: This 1.23 ct spinel is from Mogok, Myanmar. Photo courtesy of Poetry Gems & Jewelry, Chiang Mai, Thailand.

marble units that contain ruby, spinel and other gems (Garnier *et al.* 2008). Spinel deposits in South East Asia are found in various types of marble units that resulted from the metamorphism of an ancient carbonaceous platform. Regional metamorphism of these marbles (i.e. in Vietnam and Myanmar) took place during the Indosinian (250–240 million years ago) and Himalayan orogenies (Lepvrier *et al.* 2008; Huong *et al.* 2012).

Although small quantities of gem spinel have been mined in Sri Lanka, Madagascar, Pakistan, Nepal and Kenya (Okrusch *et al.* 1976; Shigley *et al.* 1990), most of the production in the pink-to-red colour range that is available today comes from four major localities: Myanmar, Tajikistan, Tanzania and Vietnam. In Myanmar, spinel has been mined from both primary and secondary deposits in the Mogok area, situated in the north-eastern part of the Mogok metamorphic belt, adjacent to the north-south trending Shan Scarp and Sagaing Fault (Chhibber 1934; Thein 2008; Themelis 2008). In addition, spinel is occasionally found in skarns (contact zones between carbonate rocks and magmatic intrusions) and in placer deposits of the Namya (or Nanyaseik) area in northern Myanmar (Aung & Zin 2018). In Tajikistan, spinel was first discovered at the historical Kuh-i-Lal mine, hosted by the Goran metamorphic series in the south-western Pamir Mountains (Hubbard *et al.* 1999). The spinel deposits mostly consist of enstatite-forsterite rocks associated with magnesian skarns (Kievlenko 2003). In Tanzania, spinel mining takes place in the Mahenge area, mainly at Ipanko (Pardieu & Hughes 2008; Kukharuk & Manna 2019). Vietnamese red-to-pink spinel occurs as crystals disseminated in marble units in the Luc Yen area, Yen Bai Province. The deposits are located in the Lo Gam tectonic zone and are hosted by the Thac Ba and An Phu metasedimentary sequences (Garnier *et al.* 2005; Pham Van *et al.* 2013).

In the current gem market, the price of pink-to-red spinels from Myanmar (e.g. Figure 1) is higher than those from other sources. It is therefore important to be able to identify the geographical origin of spinel in this colour range. Although a few reports on the geographical origin of gem spinel have been published (Malsy & Klemm 2010; Giuliani *et al.* 2017), multivariate statistical methods such as linear discriminant analysis have not been applied previously. In this study, we investigate the separation of pink-to-red spinel from Myanmar, Tajikistan, Tanzania and Vietnam using gemmological characteristics, internal features, spectroscopic data and multivariate statistical analysis of chemical data.

MATERIALS AND METHODS

We examined a total of 60 samples consisting of 15 spinels from each of four localities: Myanmar, Tajikistan, Tanzania and Vietnam (Figure 2 and Table I). The

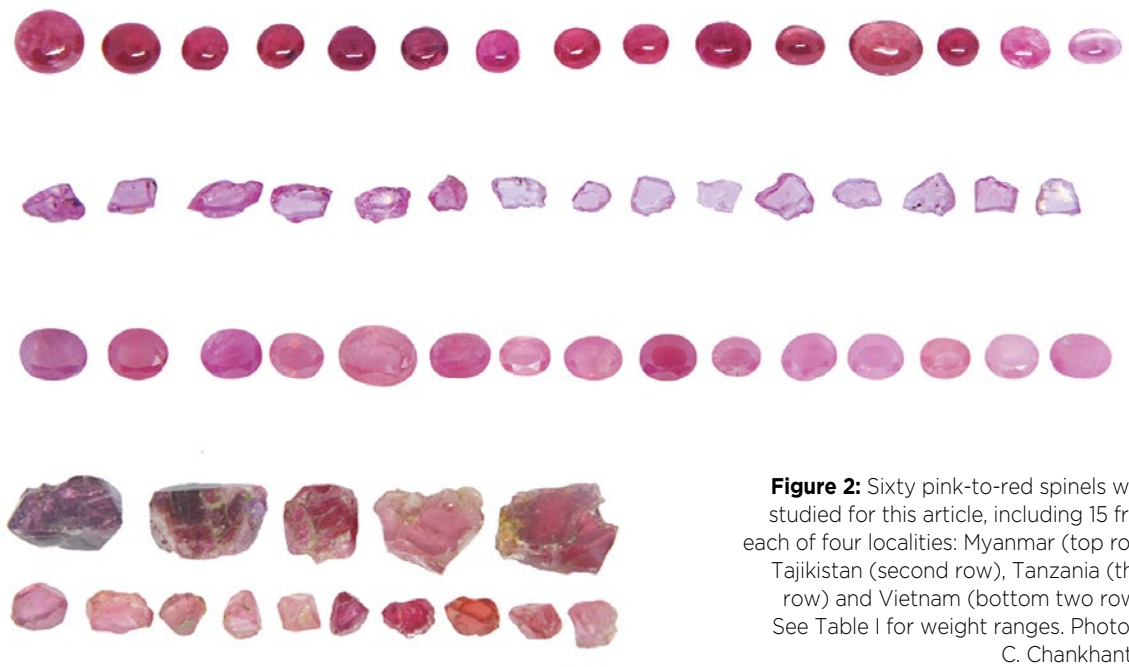

Figure 2: Sixty pink-to-red spinels were studied for this article, including 15 from each of four localities: Myanmar (top row), Tajikistan (second row), Tanzania (third row) and Vietnam (bottom two rows). See Table I for weight ranges. Photo by C. Chankhantha.

Table I: Gemmological properties of the studied spinels.*

Property	Myanmar (Mogok)	Tajikistan (Kuh-i-Lal)	Tanzania (Mahenge)	Vietnam (Luc Yen)
Weight (ct)	0.54–3.01	0.19–0.84	0.77–2.95	0.92–6.95
Colour	Red to pink	Pink to purplish pink	Pink to red, some slightly orangey	Orangey pink to purplish pink and pink-red
Diaphaneity	Transparent	Transparent	Transparent to semi-transparent	Transparent
RI	1.716–1.720	1.712–1.714	1.715–1.720	1.714–1.720
SG	3.59–3.61	3.58–3.60	3.60–3.62	3.59–3.61

* All samples fluoresced moderate to strong red to long-wave UV radiation and were inert or fluoresced weak red to short-wave UV.

samples from Myanmar were cabochons and those from Tanzania were faceted, while the others mostly consisted of broken pieces with polished windows.

The samples were examined using standard gemmological instruments for their RI and hydrostatic SG values. Fluorescence was viewed under long-wave (366 nm) and short-wave (254 nm) UV radiation. Microscopic observations and photomicrography of internal features were recorded using a Leica M205 A microscope equipped with transmitted lighting and fibre-optic illumination. Mineral inclusions were identified using a Bruker Senterra R200-L Raman micro-spectrometer equipped with a 532 nm laser (20 mW laser output power and spot size of 50 µm). The Raman spectra were interpreted using OriginPro 2018 software and compared to spectra in the RRUFF database.

Ultraviolet-visible (UV-Vis) absorption spectra were collected from two samples from each locality using a Jasco MSV-5200 spectrometer, in the range 250–800 nm, with a slit width of 2.0 mm, a data interval of 1.0 nm and scan speed of 266.75 nm/min.

Chemical analyses of five samples from each locality were performed using laser ablation inductively coupled plasma mass spectrometry (LA-ICP-MS) at Wuhan Sample Solution Analytical Technology Co. Ltd with an Agilent 7700 Series ICP-MS coupled with a GeoLas Pro 193 nm excimer laser. The laser employed a 5 Hz pulse rate and a 44 µm diameter spot size. Reference materials included USGS glasses (BCR-2G, BHVO-2G and BIR-1G) and NIST glass (SRM 610), and ^{29}Si was used as the normalised element to calculate the concentrations of 55 elements with ICPMSDataCal software (Liu *et al.* 2008).

Multivariate statistical analysis of the LA-ICP-MS chemical data was performed by linear discriminant analysis (LDA) using the IBM SPSS Statistics software package (version 26). LDA is a statistical tool that aims to maximise between-class variance while minimising within-class variance in order to group information and provide reliable, accurate classification criteria (Fisher 1936; McLachlan 2004; Guo *et al.* 2007).

RESULTS AND DISCUSSION

The gemmological properties of the spinels are summarised in Table I. The Myanmar samples were predominantly red, while those from Tajikistan were pink to purplish pink. The spinels from Tanzania were pink to red (some with a slightly orangey cast), and those from Vietnam were orangey pink to purplish pink and pink-red. The tone of the stones ranged from light to medium and the saturation was pale to moderate. No colour zoning was observed. The samples were mostly transparent, although some from Tanzania appeared cloudy due to numerous tiny inclusions.

Gemmological Properties

The RI of the samples varied from 1.712 to 1.720 and the SG range was 3.58–3.62 (Table I). The lowest RI and SG values were measured for the spinels from Tajikistan. All samples were isotropic without anomalous birefringence, and all displayed moderate to strong red fluorescence to long-wave UV radiation and were weak red or inert under short-wave UV radiation. These properties are consistent with those of gem-quality spinels reported in the literature (Malsy & Klemm 2010; Bowles *et al.* 2011).

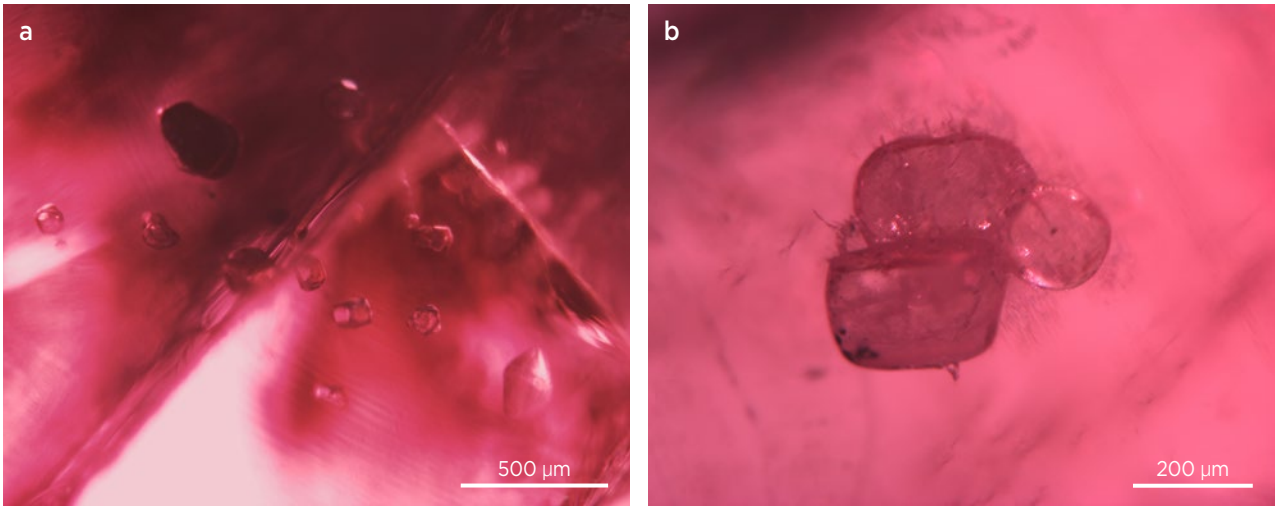

Figure 3: Apatite inclusions are seen here in spinels from (**a**) Myanmar and (**b**) Vietnam, and were also noted in the Tanzanian samples. Photomicrographs by C. Chankhantha.

Microscopic Features

The internal characteristics of spinel from various localities have been reported previously by different researchers (e.g. Gübelin & Koivula 1986; Malsy & Klemm 2010; Phyo *et al.* 2019). In our samples, colourless apatite (Figure 3) occurred as single crystals and clusters in the spinels from Myanmar, Tanzania and Vietnam. Black graphite platelets (Figure 4) were also found in the samples from these localities. The graphite was derived from the metamorphism of organic substances (Giuliani *et al.* 2008). The spinels from Tajikistan contained only some negative crystals and 'fingerprints' (Figure 5), and these features were also seen in samples from the three other localities. In our samples we did not observe any apatite crystals with graphite attached to their surface, sometimes known as 'belly button' inclusions (Gübelin & Koivula 2005).

The spinels from Tanzania commonly contained numerous short needles or particles oriented parallel to octahedral {111} directions (Figure 6), giving them a somewhat cloudy appearance. These needles or particles were possibly caused by the exsolution of högbomite, as previously mentioned by Schmetzer and Berger (1992). Some of the Tanzanian samples also contained zircon inclusions that were usually surrounded by a tension crack (Figure 7).

The most common inclusions in our samples from Vietnam were dislocation needles, usually oriented along crystallographic directions (Figure 8a), which appear to be diagnostic for spinel from this locality (Malsy & Klemm 2010; Hughes *et al.* 2019). Some of the Vietnamese samples also contained planar arrays of octahedral negative crystals (Figure 8b).

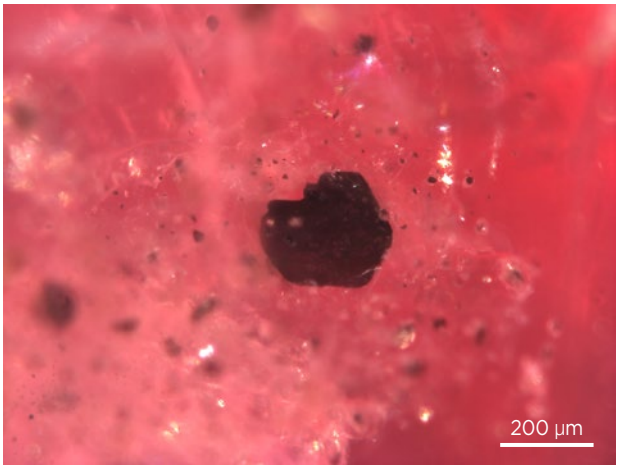

Figure 4: Graphite platelets, shown here in a spinel from Tanzania, were observed in samples from Myanmar and Vietnam. Photomicrograph by C. Chankhantha.

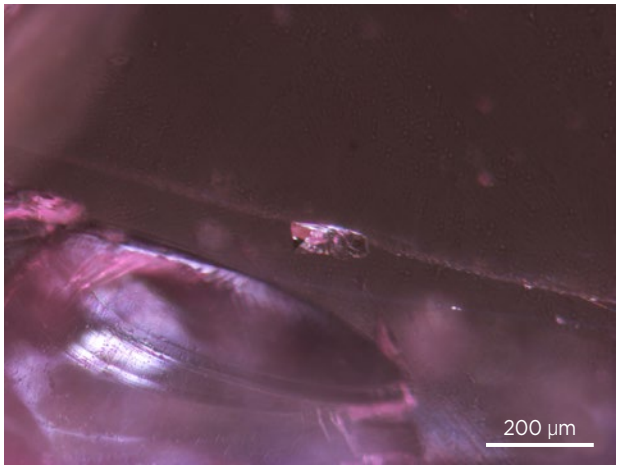

Figure 5: This negative crystal with a 'fingerprint' is typical of the relatively few inclusions seen in our spinel samples from Tajikistan. Photomicrograph by C. Chankhantha.

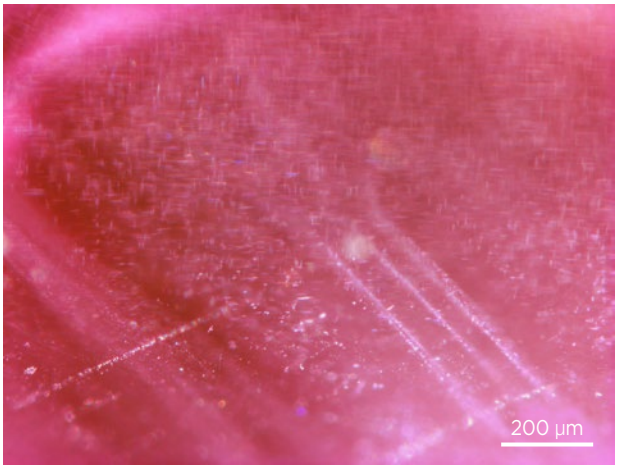

Figure 6: Numerous short needles oriented parallel to octahedral {111} directions contribute to a cloudy appearance exhibited by some of our Tanzanian spinels. Photomicrograph by C. Chankhantha.

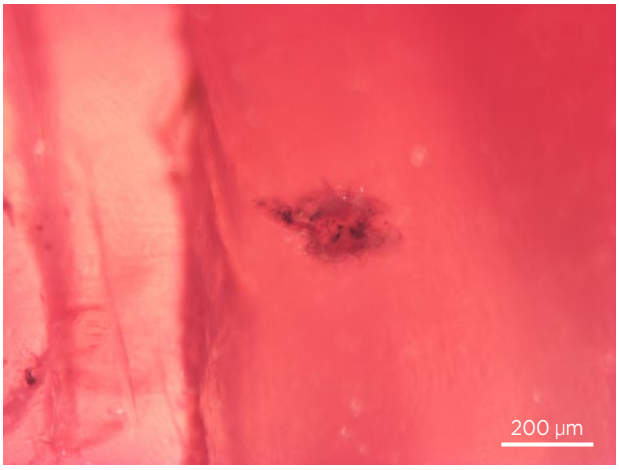

Figure 7: Zircon crystals occurred in some of the spinels from Tanzania. This one is surrounded by a tension crack. Photomicrograph by C. Chankhantha.

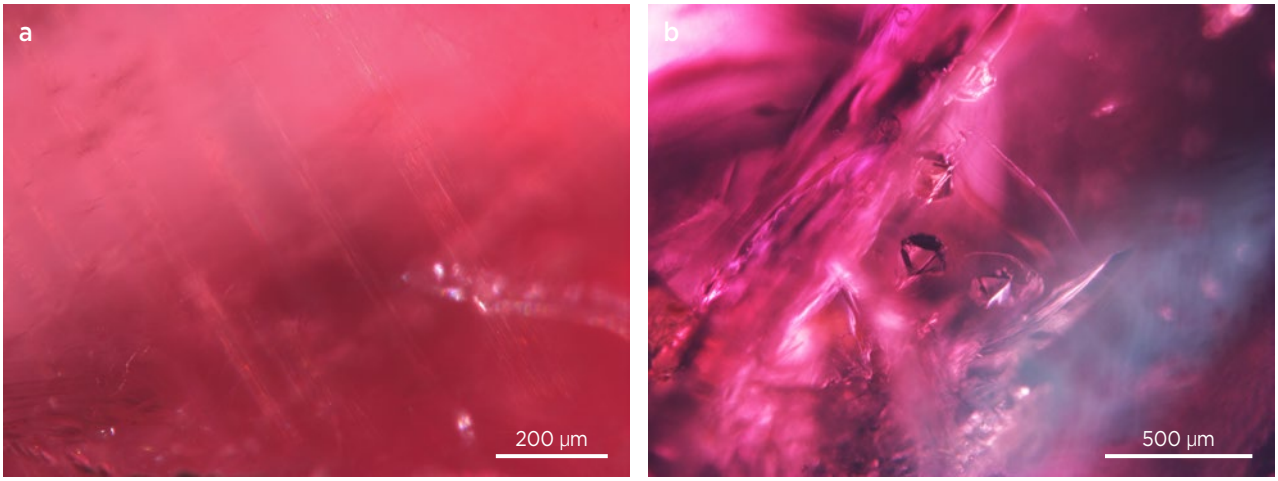

Figure 8: (**a**) Parallel dislocation needles aligned in crystallographic directions appear to be a diagnostic feature of Vietnamese spinel. (**b**) Octahedral negative crystals are present in this Vietnamese spinel. Photomicrographs by C. Chankhantha.

UV-Vis Absorption Spectra

All of the spinel samples revealed well-known Cr^{3+} absorption bands at 392, 415 and 538 nm (Figure 9). Some had an orangey hue, probably due to V^{3+} (Kleišmantas & Daukšytė 2016), although the absorption bands of Cr^{3+} and V^{3+} are generally superimposed (Schmetzer *et al.* 1989; Malsy & Klemm 2010; Andreozzi *et al.* 2019). Also present in the spectra was a peak at 372 nm due to Fe^{2+}.

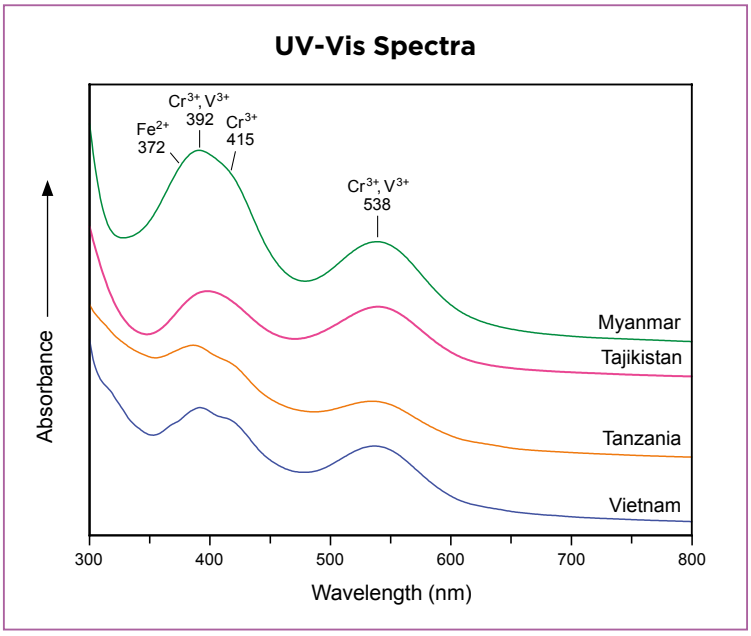

Figure 9: Representative UV-Vis absorption spectra of spinel from all four localities reveal absorption bands related to Cr^{3+}, V^{3+} and Fe^{2+}.

Table II: Chemical composition of the studied spinels, as determined by LA-ICP-MS.*

Element (ppmw)	Myanmar (Mogok)	Tajikistan (Kuh-i-Lal)	Tanzania (Mahenge)	Vietnam (Luc Yen)
Ti	441–1270 (923)	107–197 (156)	70.7–97.5 (83.2)	24.8–157 (106)
V	560–1050 (870)	261–432 (336)	513–1520 (1040)	525–1600 (969)
Cr	9130–15600 (12900)	280–475 (409)	871–2640 (1840)	772–3460 (1940)
Fe	657–2010 (1140)	2160–4250 (3190)	2470–4300 (3330)	4630–11600 (7920)
Ni	6.22–40.6 (18.3)	nd–3.65 (0.87)	3.01–16.0 (12.5)	nd–42.1 (20.6)
Zn	482–4320 (2210)	589–755 (676)	3450–5520 (4640)	200–1460 (674)
Ga	61.0–226 (165)	159–316 (231)	153–214 (181)	81.4–238 (152)
Sn	24.9–38.9 (30.3)	42.1–53.6 (49.0)	29.0–43.5 (35.4)	46.6–58.5 (52.4)

* Average amounts are shown in parentheses; nd = not detected.

Chemical Composition

LA-ICP-MS data for the studied spinels are summarised in Table II. The chromophores Cr, V and Fe were present in various concentrations, whereas Ti, Ni, Ga and Sn were generally low. In addition, Zn was present in significant amounts.

The red Burmese spinels contained the highest contents of Cr, and Ti was also somewhat elevated, as compared to data for the other three localities. The Tanzanian spinels showed the highest Zn contents (3450–5520 ppm), which could be considered characteristic of material from this deposit. Next highest in Zn were the Burmese spinels, ranging from 482 to 4320 ppm. This is consistent with some studies that have shown Zn to be higher in Mogok spinels compared to those from Tajikistan and Vietnam (Malsy & Klemm 2010). The concentrations of Ga and Sn in our spinels did not vary in any significant way. The pink spinels from Tajikistan showed low to moderate values for Ti, Fe and Zn along with the lowest average concentrations of Cr and Ni among the four deposits. The Luc Yen spinels had the highest average Fe content (7920 ppm).

Discrimination of the pink-to-red spinels from the four localities was initially attempted by plotting V+Cr, Fe and Zn in a ternary diagram (Figure 10). While our samples from Myanmar and Tanzania could be distinguished from the other localities, the spinels from Vietnam and Tajikistan showed some overlap and thus require another method of separation.

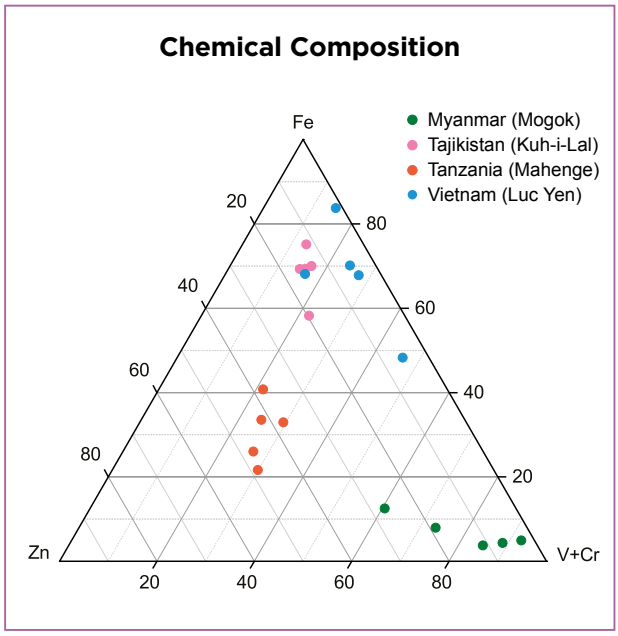

Figure 10: This ternary plot of V+Cr, Fe and Zn shows separate groupings for spinels from Myanmar and Tanzania, but considerable overlap for samples from Vietnam and Tajikistan.

Linear Discriminant Analysis

LDA has been applied to country-of-origin determination for various gem materials, such as corundum (Pornwilard *et al.* 2011; Giuliani *et al.* 2020; Krebs *et al.* 2020), Cu-bearing tourmaline (Blodgett & Shen 2011), nephrite jade (Luo *et al.* 2015, 2018; Yu *et al.* 2018) and peridot (Zhang *et al.* 2019). We applied LDA to our spinel data using the elements Ti, V, Cr, Fe, Zn, Ga and Sn as possible independent variables. (Nickel was not included in the final data processing since we found that it did not provide any significant effect on the LDA results). Calculations based on these seven variables yielded three linear discriminant functions (DFs):

$$DF1 = (Cr \times 0.001) + (Zn \times 0.001) - (Ga \times 0.003) - (Sn \times 0.121) + 0.056$$

$$DF2 = (Ti \times 0.002) + (V \times 0.004) - (Cr \times 0.001) + (Zn \times 0.001) - (Ga \times 0.015) - (Sn \times 0.049) - 0.923$$

$$DF3 = (Ti \times 0.001) + (V \times 0.003) + (Fe \times 0.001) + (Ga \times 0.008) + (Sn \times 0.139) - 13.757$$

When evaluating LDA results, the so-called eigenvalue provides an indication of the effectiveness of the discriminant functions for differentiating groups (Norušis 1990). In this work, the eigenvalue was highest for DF1 (37.053), followed by DF2 and DF3 (13.761 and 5.091, respectively). All three DFs were selected to build the classification model, in order to provide better separation between groups.

Two- and three-dimensional scatter diagrams produced from these DFs successfully separated our spinel samples into four discriminant areas according to the different localities (Figures 11 and 12). Cross-validation indicated that these results were nearly 100% accurate. Nevertheless, the present analyses of our samples provide only a preliminary data set, and further chemical data should be evaluated with this technique. LDA could provide a complementary tool to determine the geographic origin of spinel samples, but such distinctions should also include other factors to increase precision, such as gemmological and internal characteristics.

Comparison of Spinel Geological Environments and Compositions

Gem-quality spinel typically forms during moderate- to high-grade metamorphism in various lithologies, including calc-silicate rocks and marbles (e.g. Balmer *et al.* 2017) or skarns (e.g. Gorghinian *et al.* 2013). Spinel is also found in placers derived from these rocks (e.g. Thein 2008). The concentrations of elements such as Fe, Zn, Cr and V in spinel are controlled by the local geological environment (e.g. based on their abundance in either the initial protolith or in the host marble; Giuliani *et al.* 2017; Pham Van *et al.* 2018).

In Myanmar, spinel is typically found in granulite-facies marbles in the Mogok Metamorphic Belt formed during the Himalayan orogeny (Iyer 1953; Giuliani *et al.* 2017). These marbles are comprised of calcite, dolomite,

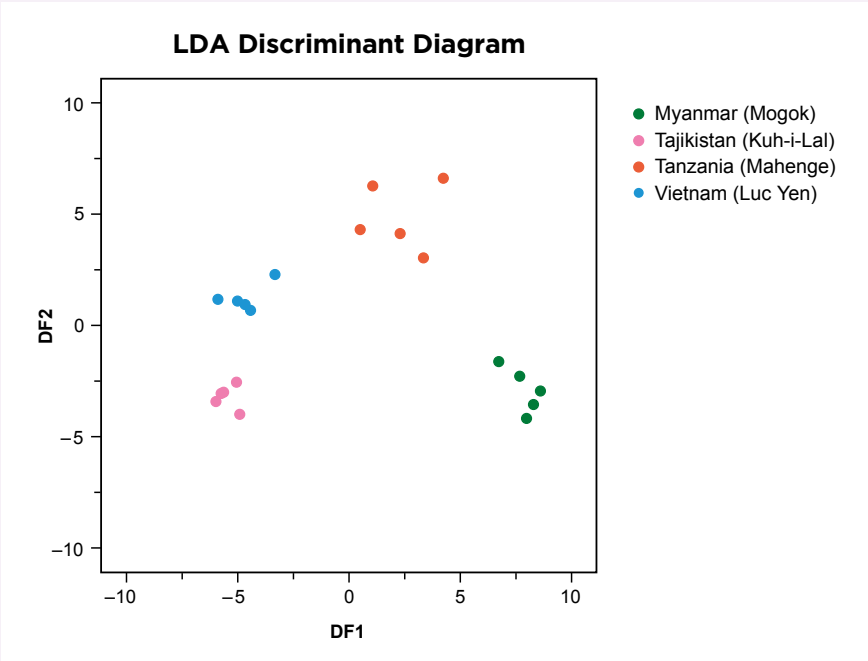

Figure 11: A two-dimensional plot of two of the linear discriminant functions obtained by LDA displays four groupings that distinguish pink-to-red spinels from the different localities.

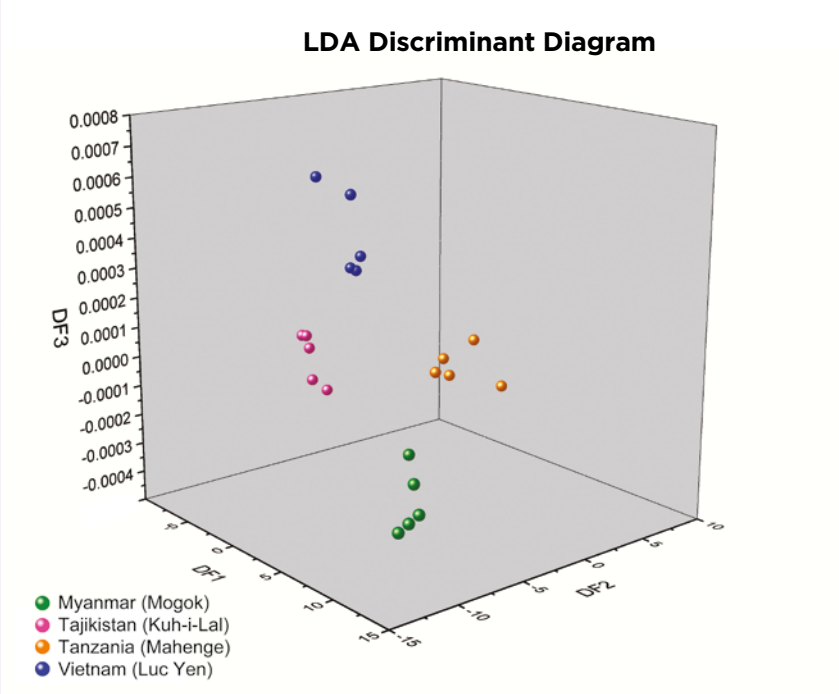

Figure 12: A three-dimensional plot of all three linear discriminant functions obtained by LDA also shows a clear separation for the pink-to-red spinels from the four localities.

diopside, chondrodite, pargasite, clinohumite, forsterite, phlogopite, apatite, dravite, pyrite and graphite (Zaw *et al.* 2015). The Burmese spinels in this study typically contained relatively low Fe (657–2010 ppm), consistent with the nature of the marble host rock. It has been proposed that such Fe-poor spinels originated from pure marbles (Themelis 2008), while the Cr chromophore came from relicts of nearby initial magmatic rocks (Schwarz *et al.* 2008) or entered the sedimentary basin as impurities in clays (Garnier *et al.* 2008) prior to metamorphism. The red colouration of spinel is intensified by Cr content, and our Mogok spinels contained elevated Cr (up to 15600 ppm) compared to our samples from the other localities (again, see Table II). In addition, the Ti content of our Mogok spinels (441–1270 ppm) was higher than our samples from elsewhere.

In Tajikistan, spinel mineralisation at Kul-i-Lal is hosted by enstatite-forsterite rocks associated with magnesian skarns (Hubbard *et al.* 1999; Kievlenko 2003), and either formed during upper amphibolite- to granulite-facies metamorphism or derived from a metasomatic by-product of fluid infiltration during contact metamorphism (Giuliani *et al.* 2017). The relatively low Cr and V concentrations in our spinels from this source—which probably are related to the composition of the host rocks—are consistent with their lighter colour compared to the other samples.

In the Mahenge area of Tanzania, spinel crystallised in dolomitic marbles that underwent granulite-facies metamorphism (approximately 750–850°C at 9.5–12 kbar) within the Neoproterozoic Mozambique Belt (Möller *et al.* 2000; Hauzenberger *et al.* 2007; Giuliani *et al.* 2015). The mineral assemblage is characterised by corundum-calcite-plagioclase-phlogopite ± dolomite, pargasite, sapphirine, titanite and tourmaline (Balmer *et al.* 2017). The Mahenge spinels in this study are characterised by significantly greater Zn (3450–5520 ppm) than in those from the other three localities. The Zn could have been derived from the decomposition of biotite (Tajčmanová *et al.* 2009) or the breakdown of staurolite (Stoddard 1979; Spry 1982).

In Luc Yen, Vietnam, spinel formed in calcitic to dolomitic marbles within the Lo Gam tectonic zone, which forms the eastern part of the Red River shear zone (Pham Van 1996; Garnier *et al.* 2005). The marbles contain calcite, dolomite, forsterite, clinohumite, pargasite, phlogopite and chlorite (Hofmeister 2001). Although the mineralisation at Luc Yen is similar to that of Mogok, and likewise took place during the Himalayan orogeny, the chemical composition of Luc Yen spinel differs significantly by its higher Fe contents (4630–11600 ppm), which exceeded the values obtained for our samples from the other three localities.

Despite the limited amount of data obtained in this study for each specific locality, the chemical results appear to be typical for these geological settings when compared to some previous studies (Malsy & Klemm 2010; Giuliani *et al.* 2017).

CONCLUSIONS

Pink-to-red spinels (e.g. Figure 13) make up a significant part of the coloured stone market, and most of the production comes from marble-hosted deposits. The pink-to-red spinels examined for this study from Myanmar (Mogok), Tajikistan (Kuh-i-Lal), Tanzania (Mahenge) and Vietnam (Luc Yen) showed overlapping gemmological characteristics except that the RI range of samples from Tajikistan was lower than the values obtained for the other localities. Many of the internal features in our spinels from the four localities were similar, but some could be indicative of specific origins, such as the short needles in the Mahenge material and the dislocation needles in the Luc Yen spinels.

Elements such as Ti, V, Cr, Fe and Zn can be factors in spinel origin determination. Among the samples from the four localities examined in this study, those from Mahenge were highest in Zn, whereas the Mogok spinels were relatively Ti rich and Fe poor, and the Luc Yen spinels were generally Fe rich. Nevertheless, compositional overlap can be a problem for spinel origin determination. Statistical analysis by LDA of seven elements (Ti, V, Cr, Fe, Zn, Ga and Sn) was successful at separating our spinel samples according to their four localities. Although only a limited dataset was obtained in this study, our results suggest that LDA could be a useful diagnostic tool for origin determination of pink-to-red spinels when combined with gemmological properties and internal features.

Figure 13: These spinels are from Myanmar (left, 2.39 ct and centre, 1.83 ct) and Tanzania (right, 3.34 ct). Courtesy of RareSource, Chattanooga, Tennessee, USA; photo by Orasa Weldon.

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Flower-Shaped Trapiche Ruby from Mong Hsu, Myanmar: A Revised Growth Mechanism

Isabella Pignatelli, Gaston Giuliani, Christophe Morlot, Michel Cathelineau and Shang I (Edward) Liu

ABSTRACT: Two polished slices of flower-shaped trapiche ruby from Mong Hsu were analysed by X-ray computed tomography and X-ray micro-fluorescence. They are characterised by the presence of a core overgrown by two layers of ruby (with the outer one forming the 'petal' shape), and these three domains were previously attributed by Liu (2015) to a multi-stage growth mechanism. The present research indicates that these specimens show textural sector zoning associated with chemical sector zoning. In agreement with literature data, three different growth sectors are identified: a pinacoidal growth sector (corresponding to the core) and two sets of dipyramidal growth sectors with different inclinations with respect to the *c*-axis. The core, middle and outer layers are thus growth sectors of the same crystal, and no successive stages are needed to explain their formation. Therefore, the growth model proposed for other trapiche rubies from Myanmar also applies to the formation of these flower-shaped specimens. The distinctive shape of these rubies is due to weathering of the growth sectors and the sector boundaries.

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The Mong Hsu marble-hosted ruby deposits in Myanmar are famous for producing non-trapiche (Smith & Surdez 1994; Peretti *et al.* 1995, 1996) and trapiche rubies (Schmetzer *et al.* 1996; Sunagawa *et al.* 1999). Mong Hsu rubies have a number of prominent features that differ from those of the Mogok deposits, including their crystal habits, the presence of a dark violet to blue core surrounded by a red rim, colour banding, small twin lamellae and the presence of OH groups revealed by infrared spectroscopy (Smith & Surdez 1994; Smith 1995). In the present article, we examine two unusual flower-shaped trapiche rubies from Mong Hsu (Figure 1)—previously described by Liu (2015)—in order to re-evaluate the mechanism of their formation.

Non-trapiche rubies from Mong Hsu show various habits (Smith & Surdez 1994; Peretti *et al.* 1995), and are bounded by pinacoidal *c* {0001} faces and hexagonal dipyramidal faces $\{hh\overline{2h}l\}$, sometimes associated with small rhombohedral *r* $\{10\bar{1}1\}$ faces. Second-order *a* $\{11\bar{2}0\}$ prism faces have also been observed in some samples. The smaller dipyramidal faces are *n* $\{22\bar{4}3\}$, whereas the larger dipyramidal ones have often been reported as *v* $\{44\bar{8}1\}$ or *ω* $\{14\ 14\ \overline{28}\ 3\}$, and less commonly as *z* $\{22\bar{4}1\}$ or *w* $\{11\bar{2}1\}$. The $\{14\ 14\ \overline{28}\ 3\}$ indices are too high for smooth faces, and it is possible that they consist of alternating microsteps between $\{11\bar{2}0\}$ and {0001} faces (Sunagawa 1995; Sunagawa *et al.* 1999). The most common habits are characterised by the presence of *c*, *n*, *r* and *ω* or *v*, as shown in Figure 2; other habits are rarely encountered (Smith & Surdez 1994). A growth sector corresponds to each face and is indicated by the same Miller indices.

Trapiche rubies from Mong Hsu were described in detail by Schmetzer *et al.* (1996, 1999). The trapiche

Figure 1: Two flower-shaped trapiche rubies (each slice is about 5–7 mm diameter and 1.0–1.5 mm thick) from Mong Hsu were analysed for this study: samples FS02 (left) and FS03 (right). Photos reproduced from Liu (2015).

pattern is easily recognisable in sections cut perpendicular to the crystallographic *c*-axis (Figure 3). It consists of gemmy portions generally corresponding to the hexagonal dipyramidal growth sectors, which are separated by yellowish to white sector boundaries of fluid and solid inclusions such as fine-grained calcite, dolomite and K-Al-Fe-Ti silicates mixed with corundum and secondary Fe-bearing minerals formed during the weathering process (Schmetzer *et al.* 1999; Sunagawa *et al.* 1999; Garnier *et al.* 2002a, b). In some sections, these boundaries extend from the corners of a hexagonal core (i.e. pinacoidal growth sector). The presence and size of the core depend on the position of the slice along the crystal (Pignatelli *et al.* 2019). In sections cut near the ends of a crystal, the core is larger, while slices cut between an end and the centre have a smaller core. If the section passes through the centre of the crystal, then there is no core and the sector boundaries intersect in a central point. The colour of both the core and surrounding growth sectors is due to the presence of chromophores in the corundum structure (i.e. Cr, V and Ti; Peretti *et al.* 1996; Schmetzer *et al.* 1999; Garnier *et al.* 2002a, b).

Trapiche rubies are also characterised by the presence of tube-like voids filled by solids, liquid and gas. These voids originate from the core or sector boundaries and develop into the growth sectors (Schmetzer *et al.* 1996; Sunagawa *et al.* 1999). Primary and secondary fluid inclusions are similar in both trapiche and non-trapiche rubies, and the fluids belong to the CO_2-H_2S-COS-S_8-AlO(OH) system (Giuliani *et al.* 2018). Variations in density of the carbonic phase reflect differences in fluid pressure in the metamorphic marble system. These variations lead to changes in the driving-force conditions during the growth of the rubies and allow for the formation of the trapiche texture (Giuliani *et al.* 2018; Pignatelli *et al.* 2019).

Liu (2015) described flower-shaped trapiche rubies from Mong Hsu that do not show the classical trapiche pattern because their core is surrounded by two layers of ruby sectors. Weathering of the outer sectors gave them

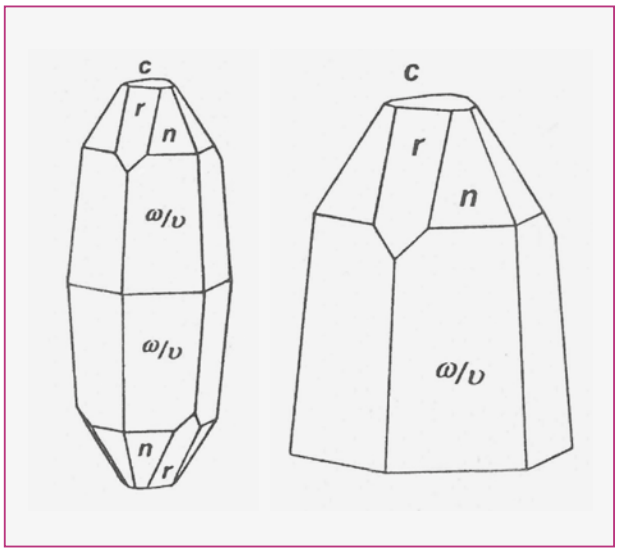

Figure 2: The most common habits of rubies from Mong Hsu are characterised by the presence of *c*, *n*, *r* and *ω* or *υ* faces (modified from Smith & Surdez 1994); other habits are rarely encountered.

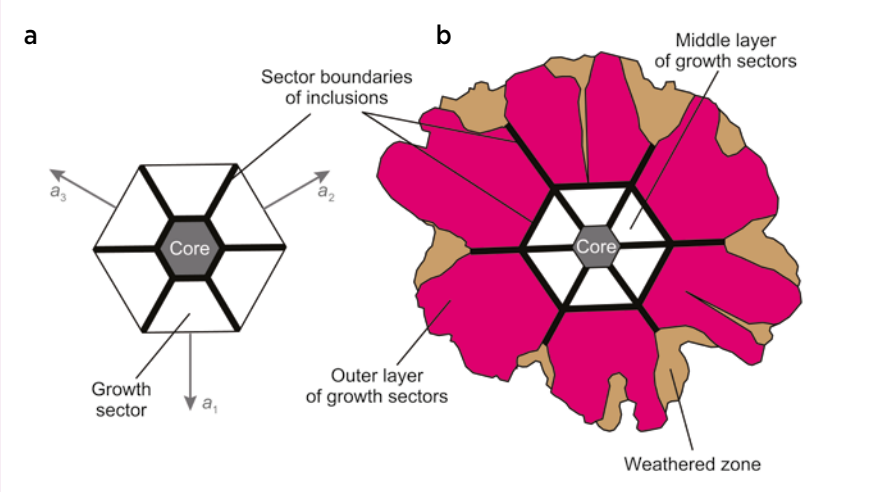

Figure 3: This schematic representation of the trapiche texture seen in a section perpendicular to the *c*-axis illustrates the difference between a classical trapiche ruby (**a**) and a flower-shaped trapiche ruby (**b**).

their characteristic 'petal' shape. In the present study, slices of two of these flower-shaped trapiche rubies (again, see Figure 1) were examined by optical microscopy, X-ray computed tomography (CT) and X-ray micro-fluorescence (XRF). The insights provided allow us to infer the growth mechanism of these peculiar ruby specimens.

MATERIALS AND METHODS

A total of five flower-shaped trapiche rubies were obtained in the cities of Yangon (in 2011) and Mogok (in 2013) by one of the authors (Liu 2015). These samples were 5–7 mm in diameter and 1.0–1.5 mm thick, and were cut and polished as slices perpendicular to the *c*-axis. Two of these samples (FS02 and FS03) were examined for this study.

CT scanning is a non-destructive technique that has been used to reveal unseen rubies within their host rock (Bouts 2014), as well as three-dimensional (3D) interior details of trapiche rubies (Morlot *et al.* 2016; Richard *et al.* 2019). For the present study, CT data were collected with a Phoenix Nanotom S scanner, using resolutions of 3.75 and 3.23 µm/voxel, and an X-ray tube tension of 75 kV. The Nanotom tomography produced files with voxel (3D pixel) resolutions between 30 and 0.6 µm/voxel as a function of the sample size.

Virtual cross-sections were extracted from these to yield textural details (e.g. porosity) and to detect the presence of phases with different densities in the samples. VGStudio and Avizo 9.5 software were used to calculate the volume occupied by the porosity, cavities and solid inclusions, which were identified using a segmentation process based on their contrast in the tomographic images. This contrast is due to differences in their attenuation coefficient, which depends on the kinds of atoms, radiation and the cross sections of X-ray interactions with matter.

XRF mapping was performed using a Bruker M4 Tornado spectrometer. The system has an Rh X-ray tube with polycapillary optics, providing an X-ray beam with a diameter of 25–30 µm on the sample. The X-ray tube was operated at 50 kV and 200 µA, and X-rays were detected by a 30 mm^2 XFlash silicon drift detector with an energy resolution up to 135 eV. All analyses were done under a vacuum of 20 mbar. Semi-quantitative element maps were generated for Cr, Fe, V and Ti for ruby, and K, Si and Ca for other minerals within areas of the samples measuring 4 × 4 mm over a period of 60 s. Data acquisition and processing were carried out using Bruker software supplied with the instrument (Flude *et al.* 2017).

Scanning electron microscopy (SEM) and electron probe micro-analysis (EPMA) were not employed in this study because the carbon coating necessary for these analyses would be difficult to remove due to the porosity of the samples.

RESULTS

Textural Description

Optical Observation. Both of the flower-shaped ruby samples FS02 and FS03 were characterised by a central hexagonal area (corresponding to the 'disc' of aster-type flowers) surrounded by radiating 'petals'. The specimens consisted of the following textural zones (Figures 1 and 3b):

- A small hexagonal core, 0.38–0.43 mm across, free of solid inclusions and deep red in colour. The core appeared darker than the surrounding ruby sectors

and was delimited by sector boundaries with a high concentration of inclusions.

- A hexagonal zone around the core, referred to by Liu (2015) as the 'middle layer'. It was 1.53–2.38 mm across and formed by six trapezoidal sectors separated by yellowish to white sector boundaries. The latter extended from the corners of the core towards the outer zone of the crystal, along ‹10$\bar{1}$0› directions. The outer extent of the middle layer was delimited by a thin corona of inclusions of similar aspect and colour to those of the six sector boundaries cross-cutting the whole ruby.
- An 'outer layer' surrounding the middle layer. It consisted of six wider sectors, irregular in size and shape, separated by the sector boundaries. These six sectors showed various degrees of weathering, giving them the appearance of heart-shaped or clothes peg-shaped petals (Liu 2015).

Visual observations also revealed that the sector boundaries of inclusions had a herringbone pattern similar to that observed in trapiche emeralds (Pignatelli *et al*. 2015). The boundaries contained a complex mineralogical assemblage that was difficult to identify due to the small sizes of the individual minerals.

Eye-visible elongated tube-like voids were almost perpendicular to the hexagonal dipyramidal faces of the crystals. They followed the sector boundaries and extended from them into the layers without any directional disturbances.

CT Scans. The tomographic investigations showed in detail the sector boundaries of inclusions and their distribution in both samples. The CT images confirmed that the inclusions surrounded the core and developed from its corners outward towards the growth sectors (Figure 4). The CT images through FS03 also showed a gradually tapered shape of the core (Figure 4b). The

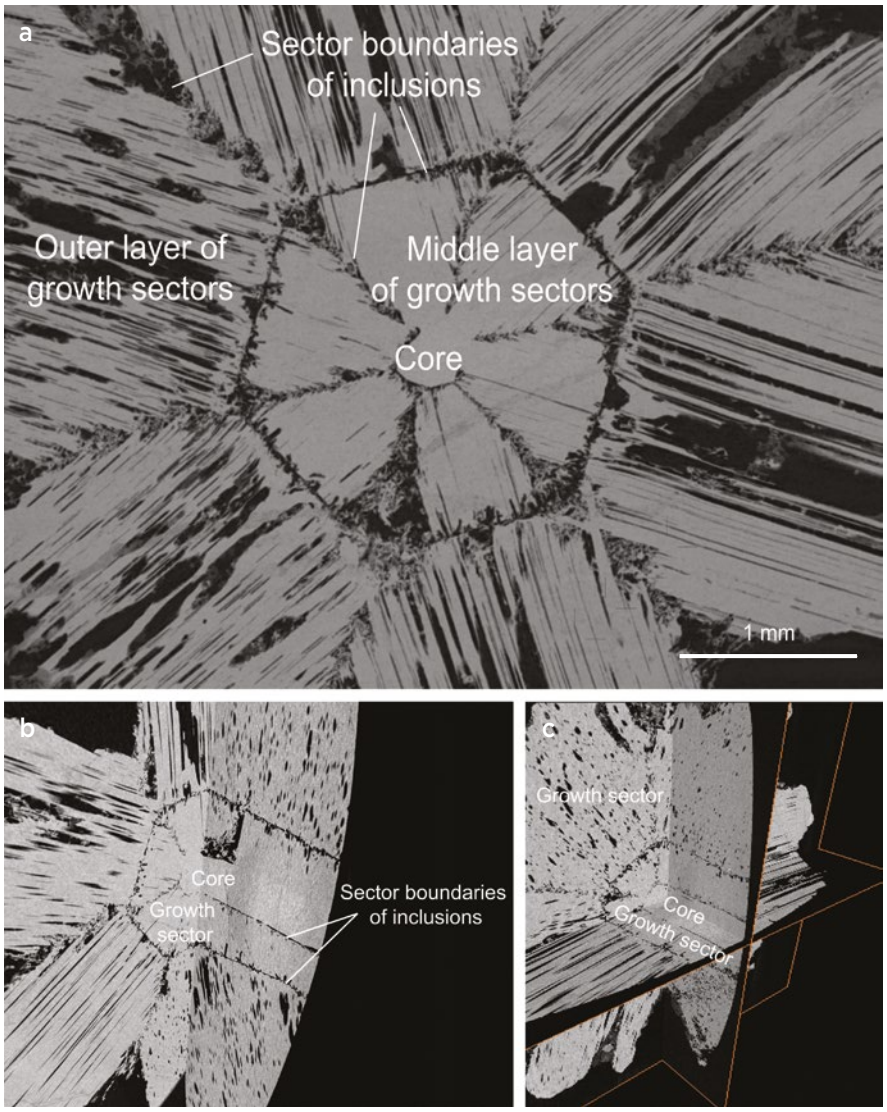

Figure 4: CT images of sample FS03 show the spatial distribution of the core, middle and outer layers. (**a**) The image of a section perpendicular to the *c*-axis shows the spatial relationship between the core, growth sectors and sector boundaries. (**b**) A combination of two cross-section images, oriented perpendicular and parallel to the *c*-axis, shows that the size of the core slightly decreases from the lower right to the upper left in the image parallel to the *c*-axis. (**c**) A combination of three images—the section perpendicular to the *c*-axis with two sections parallel to the *c*-axis—shows the tube-like voids are oriented approximately perpendicular to the face of each growth sector.

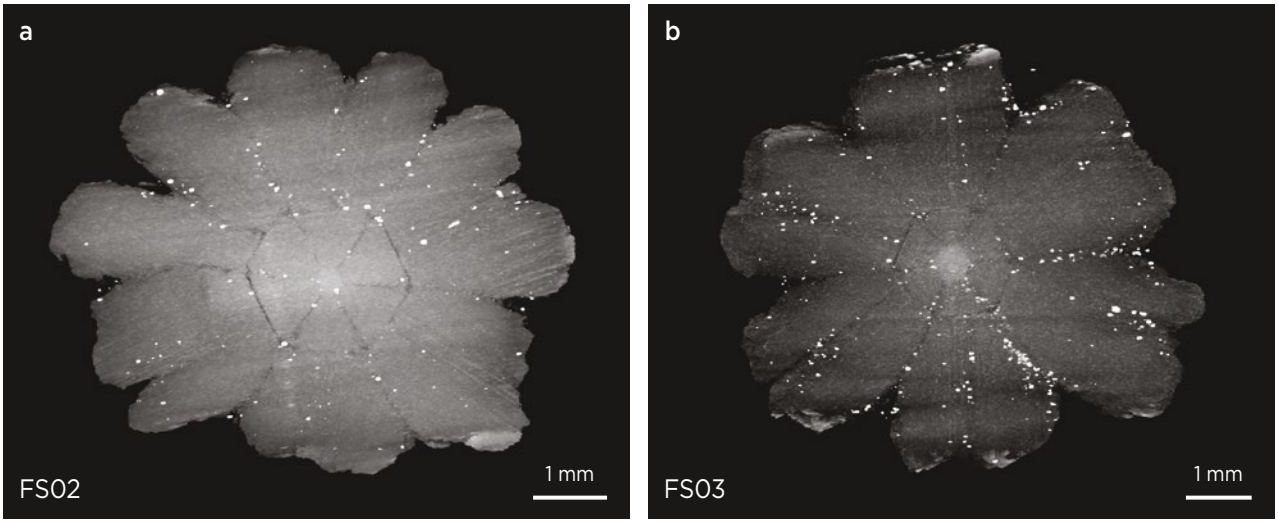

Figure 5: These CT images show the distribution of solid inclusions (white) in samples FS02 (**a**) and FS03 (**b**). The volume occupied by these inclusions is less than 0.01% of the total volume of each sample. These inclusions are scarce within the growth sectors and are mostly concentrated along the sector boundaries. Most of the solid inclusions in the growth sectors are in the areas where weathering occurred.

cores of both samples could be seen by slight contrast differences in the CT images (Figure 5). Higher contrast was evident in the core of FS03 (Figure 5b), probably due to its greater concentration of transition metals.

The distribution of solid inclusions in the two samples was also shown by the CT scans (again, see Figure 5). These inclusions were more numerous in sample FS03, and their diameter varied between 16 and 188 µm. The volume occupied by solid inclusions in samples FS02 and FS03 was calculated as 29.73 and 37.35 mm^3, respectively —less than 0.01% of the total volume of each specimen.

Solid inclusions were scarce within the growth sectors of both samples; they were concentrated mostly along the sector boundaries. Those within growth sectors seemed to be more abundant in areas where weathering occurred. There was no correlation between the positions and the sizes of solid inclusions in the different growth sectors (Figure 5).

The CT images confirmed the presence of tube-like voids in the growth sectors (Figure 6), which crossed both the middle and outer layers without any deviations or perturbations. Some were straight, while others became curved near the edges of the crystal and resembled a feathered headdress (Figure 6a, b). In sections parallel to the *c*-axis, straight tube-like voids seemed to be perpendicular to the outer face of each growth sector (Figures 4c and 6c).

The porosity of each sample, as shown for example by the slices in Figure 7, represented 4.3% and 14% of the total volume of samples FS02 and FS03, respectively. The zones of higher porosity were the main locus for weathering.

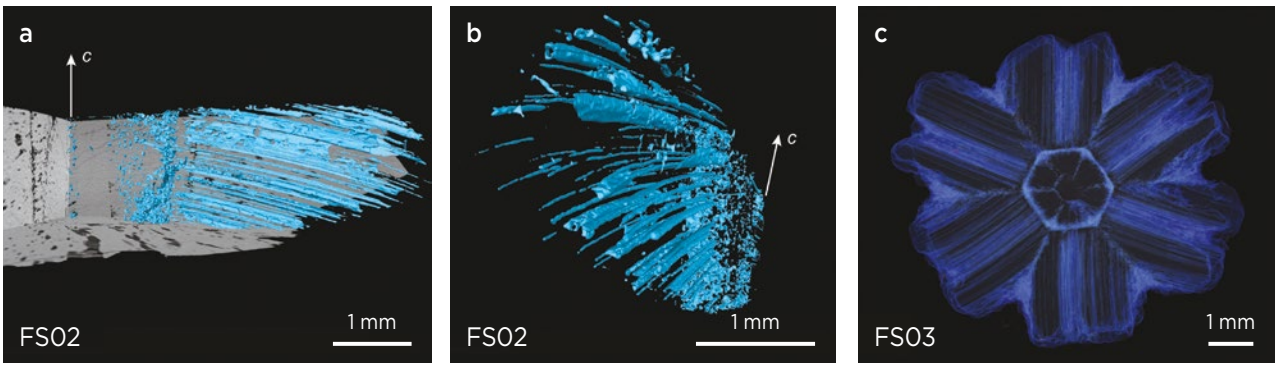

Figure 6: CT images of tube-like voids in the growth sectors show that some of them become curved near the edges of sample FS02 (**a** and **b**). The tube-like inclusions are generally straight and almost perpendicular to the growth sectors, as seen in FS03 (**c**).

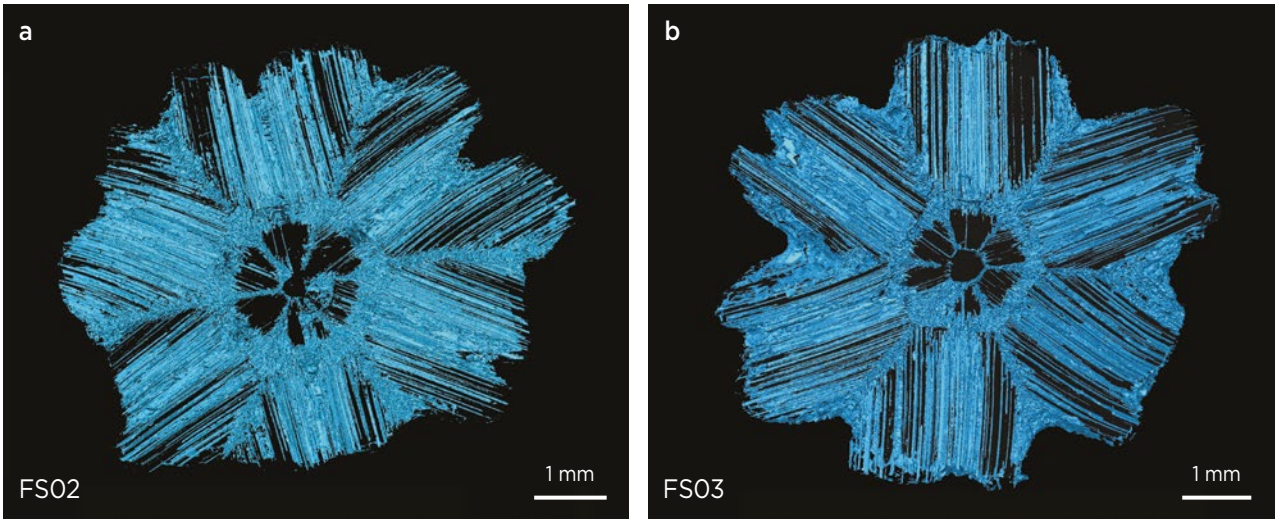

Figure 7: CT images show areas of high porosity and voids in samples FS02 (**a**) and FS03 (**b**). The porosity corresponds to 4.3% and 14% of the entire sample volume of FS02 and FS03, respectively. Note that while Figure 6c shows only the tube-like inclusions, here Figure 7b shows the porosity plus other kind of voids, including the tube-like ones.

XRF Mapping

XRF mapping of the two samples characterised the chemical zoning and colour variations in the core, sector boundaries and two growth layers. The compositional maps in Figure 8 (FS02) and Figure 9 (FS03) show the distribution of the main chromophores detected in the two rubies (i.e. Cr, V, Fe and Ti). The slightly curved surface of each sample prevented complete and regular chemical compositional mapping because it caused distortion in imaging the distribution of the elements, as shown by Figure 8b. Useful elemental mapping was therefore only possible for the central portion of each sample, but the analysed area still encompassed both of the layers adjacent to the core (although only the inner part of the outer layer).

Sample FS02. This specimen revealed a clear pattern of Cr among the different textural zones (Figure 8b, c). The distribution of Cr, V and Ti underscored the growth history of the ruby from the centre to the periphery, indicating that no twin lamellae were present, and thus it is a single, untwinned crystal.

High Cr concentrations were found in the core and in the outermost part of the middle layer (Figure 8b), whereas lower Cr concentrations were found in growth sectors of the outer layer. The Cr concentrations at the outermost borders of the crystal (visible in Figure 8b) are not discussed here because they could be artefacts due to the slightly curved surface. For this reason, we focus on compositional maps from the inset area indicated on Figure 8b. These maps (Figure 8c–f) reveal the following features:

- The core was rich in V and Cr, without any Fe or Ti.
- The middle layer was divided into two distinct areas: one closer to the core that was poor in Cr and an outer area rich in Cr. The Cr-poor area also showed greater V, as well as Ti, that gradually increased inward toward the core. The outer Cr-rich zone contained low V and no Ti.
- The outer layer was characterised by low Cr and moderate V, while Ti was low to absent.
- The entire area was very poor in Fe; this element was mainly concentrated along the sector boundaries and in fractures.

Sample FS03. This specimen yielded very different compositional maps (Figures 9c–f) from those observed for sample FS02:

- Cr was concentrated in the middle layer, nearly absent from the core and absent from the outer layer.
- V was present in very low concentrations throughout the sample, more or less equivalent to the background noise of the analysis.
- The core and both layers were Fe-free. Higher Fe concentrations were located in the sector boundaries surrounding the middle layer.
- Ti was somewhat elevated in the core and decreased in the middle layer.

Solid Inclusions. These were present along the sector boundaries in both the middle and outer layers (see Figure 5). In the absence of SEM and EPMA investigations, the nature of these inclusions was determined from the XRF data (e.g. for sample FS02, as shown in Figure 10c–f).

The Si and Ca maps show the presence of silicates and carbonates along the sector boundaries. The K and Si maps show concentrations of these elements in a fracture cross-cutting the sample (Figure 10b); they probably correspond to the presence of phyllosilicates or K-feldspar. The Ti and V maps in Figure 8 clearly show rounded Ti- and V-rich solid inclusions (possibly V-bearing rutile). The sector boundaries of inclusions were underscored by higher concentrations of Fe and Ca in the absence of Cr and Ti. The main component of these areas was Fe, which was also regularly distributed in the tube-like voids, suggesting the presence of iron oxides or hydroxides formed during the weathering process.

DISCUSSION

The flower-shaped trapiche rubies from Mong Hsu show a textural sector zoning as already described in the literature for other trapiche minerals, such as emerald, tourmaline, andalusite, staurolite and garnet (Rice & Mitchell 1991; Rice *et al.* 2006; Wilbur & Ague 2006; Schmetzer *et al.* 2011; Pignatelli *et al.* 2015). The textural sector zoning is characterised by the presence of inclusions along the boundaries between neighbouring growth sectors (Andersen 1984). The textural zoning can be associated with chemical sector zoning, when growth

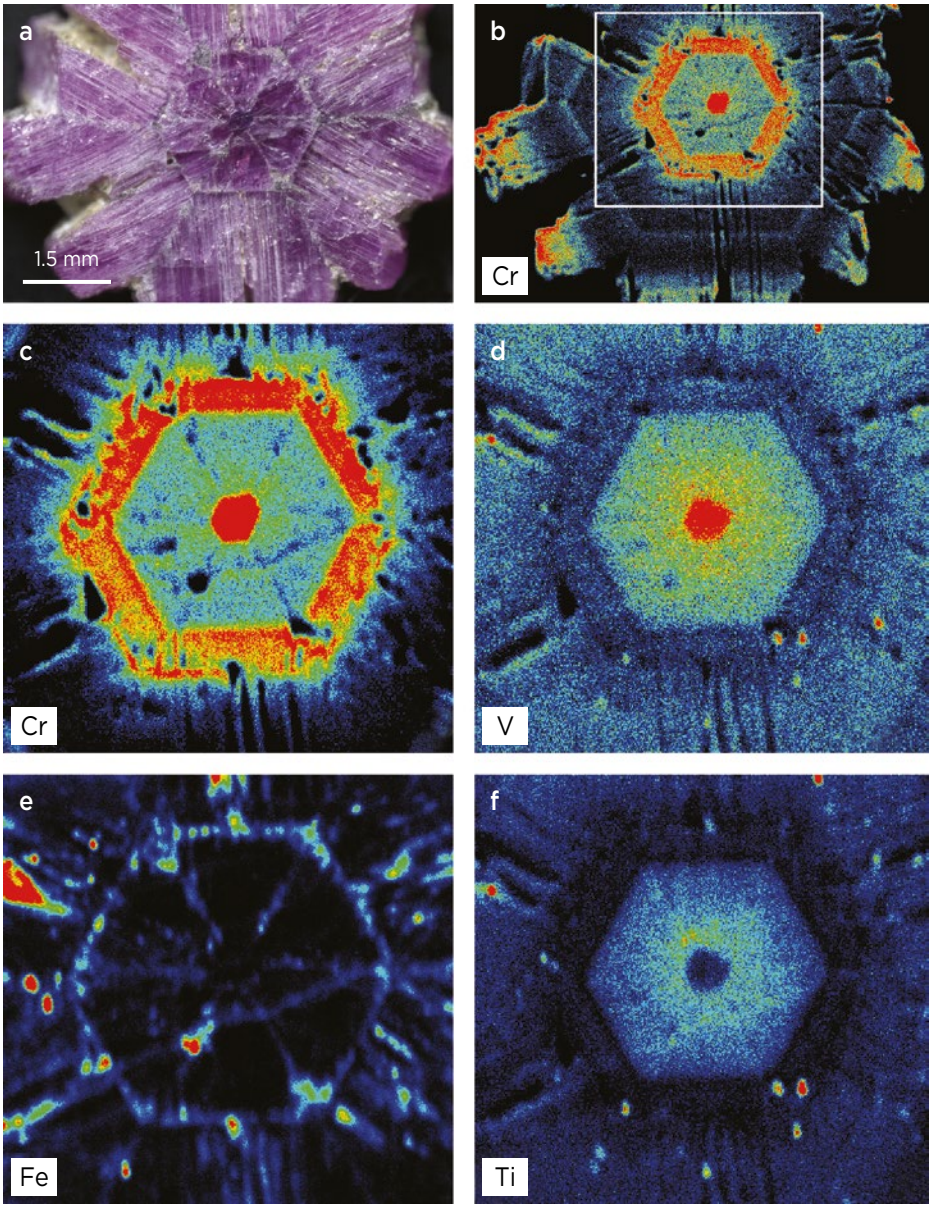

Figure 8: (**a**) The slightly curved surface of the flower-shaped trapiche rubies, here shown on sample FS02, caused artefacts when mapping the trace-element distribution of the sample. For this reason, we considered only the data within the white inset in (**b**). The XRF maps show the distribution of Cr (**c**), V (**d**), Fe (**e**) and Ti (**f**). The colours in the maps indicate the concentration of an element along a spectral scale from most (red) to least (blue). The red areas seen in the outer layer for Cr in (b) are likely artefacts resulting from the curved surface of the sample. Photo (a) by M. Cathelineau.

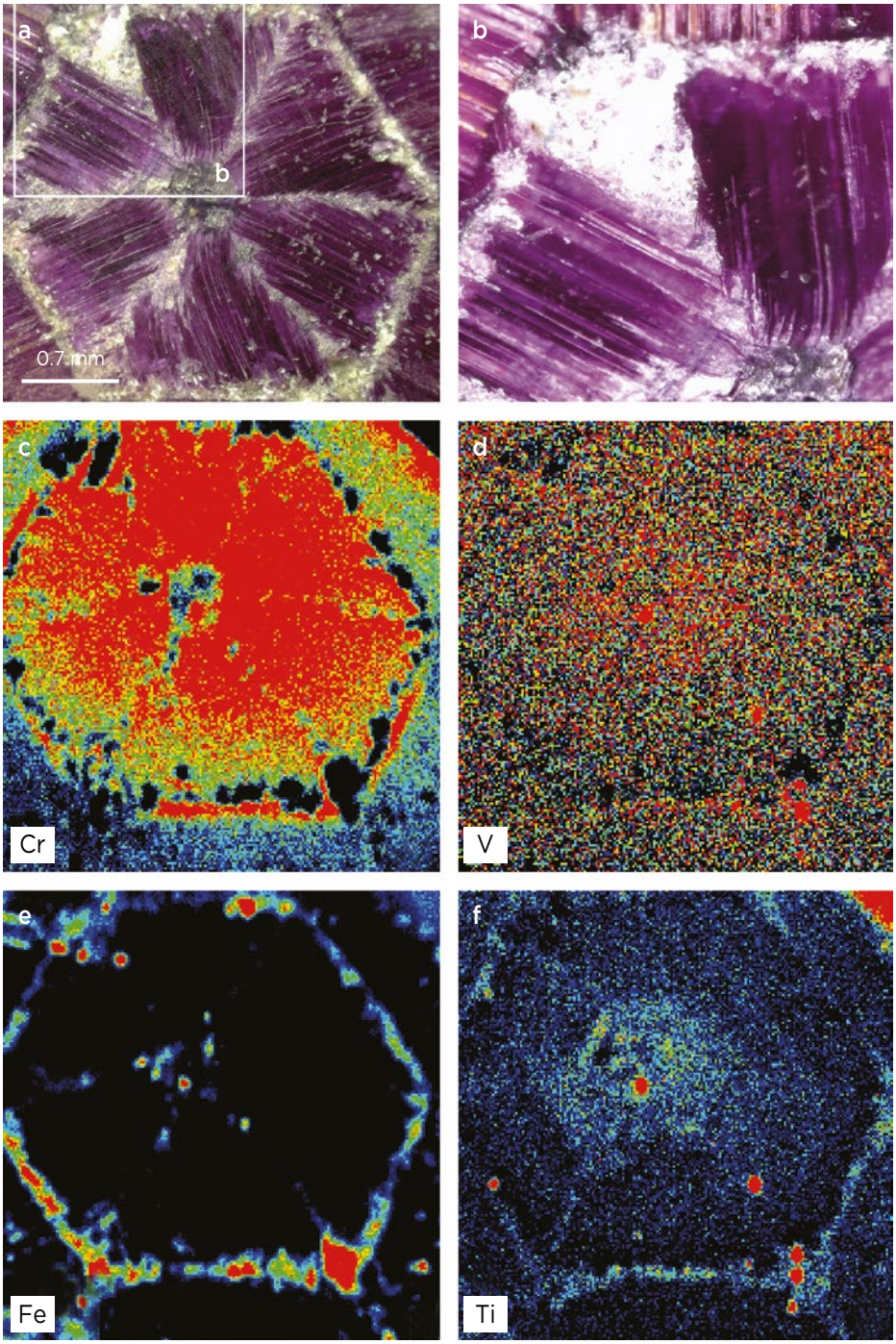

Figure 9: (**a**) The central region of sample FS03 was also investigated by XRF mapping. (**b**) This enlarged portion of the core and middle layer shows in more detail the tube-like voids in the growth sectors, as well as the herringbone pattern of the sector boundaries of inclusions. The XRF maps show the distribution of Cr (**c**), V (**d**), Fe (**e**) and Ti (**f**). The colours in the maps indicate the concentration of an element along a spectral scale from most (red) to least (blue). Photos (a, b) by M. Cathelineau.

sectors that are not crystallographically equivalent have different compositions. For the two flower-shaped rubies examined here, our CT and XRF results indicate the presence of both types of zoning. In sample FS03, the chemical zoning allows for the distinction of at least three types of growth sectors: first, the Ti-bearing and Cr-poor core, which corresponds to a pinacoidal {0001} sector. The growth sectors in the middle layer are richer in Cr than those in the outer layer (Figure 9c). According to the most common habits observed in rubies from Mong Hsu, there should be two groups of dipyramidal growth sectors having different inclinations with respect to the *c*-axis (Smith & Surdez 1994; Peretti *et al.* 1995). Their exact indexation is hampered by the fact that these flower-shaped trapiche ruby specimens are polished slices, so their crystal habit is no longer recognisable. As the presence of rhombohedral $\{10\bar{1}1\}$ sectors could not be confirmed, we omitted them from our 3D model of the crystal habit (Figure 11a). Even if the $\{10\bar{1}1\}$ sectors were present, their size would be small and their projection would fall along the directions of sector boundaries, which would make them difficult to see considering the

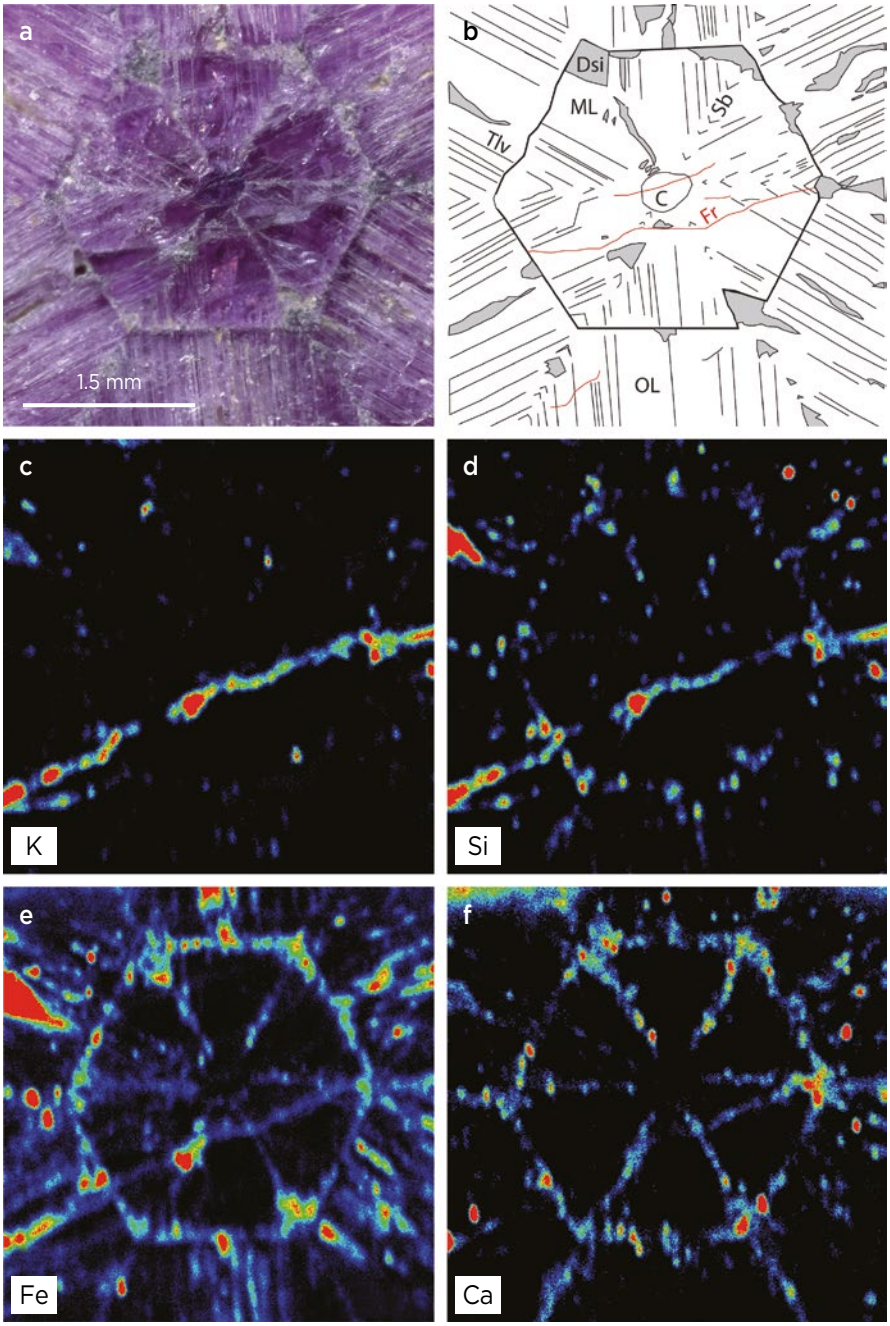

Figure 10: XRF maps of sample FS02 show the chemical composition of its solid inclusions along sector boundaries and in a fracture. (**a**) This photo of the sample shows the area mapped. (**b**) A corresponding drawing shows the inclusions associated with the trapiche texture (in grey) and the weathering of the crystal. Late meteoric fluids were concentrated in fractures (shown in red) and infiltrated at the corners of the growth sectors and along tube-like voids. Most of the solid inclusions (e.g. Fe-oxides/hydroxides) are concentrated in these weathered zones. The abbreviations in the drawing are C = core, ML = middle layer, OL = outer layer, Sb = sector boundaries, Tlv = tube-like voids and Dsi = dissolution and infilling by late solids of the tube-like voids and parts of the sector boundaries. XRF maps show the distribution of K (**c**), Si (**d**), Fe (**e**) and Ca (**f**). The colours in the maps indicate the concentration of an element along a spectral scale from most (red) to least (blue). Photo (a) by M. Cathelineau.

concentrations of inclusions and porosity in those areas.

Sample FS03 was not cut through the centre of the crystal; if it were, no core would be visible (Figure 11b). Instead, it corresponds to a cross-section shifted along the *c*-axis, which is confirmed by the CT images showing that the size of the core slightly decreases along a cross-section of the slice. Both the dipyramidal and pinacoidal growth sectors are recognisable in this cross-section (Figure 11c), which closely reproduces the chemical sector zoning observed in the XRF maps.

The same conclusion can be reached for sample FS02 which, like FS03, has three types of growth sectors: a pinacoidal one corresponding to the core and two groups of dipyramidal growth sectors—one for the middle layer and the other for the outer layer. However, the Cr zoning on the XRF map could be misleading and could lead us to suppose the presence of additional growth sectors in the middle layer. This is excluded by CT data, which underscore the absence of sector boundaries of inclusions and porosity between the Cr-poor and Cr-rich zones within the middle layer. Thus, the variation in Cr within this layer is due to growth banding resulting from fluctuations in growth rates, which can favour the incorporation of impurities.

A considerable concentration of tube-like voids is present within the growth sectors of these trapiche rubies.

Two possible mechanisms have been reported in the literature to explain the presence of these voids in trapiche minerals. Both mechanisms involve the formation of dislocations:

(1) Tube-like voids can form by dissolution along dislocation bundles if the supersaturation of the growth medium decreased after crystal growth (Scandale & Zarka 1982; Authier & Zarka 1994). These dislocations are perpendicular to the front of each growth sector and proceed with it during growth.

(2) Tube-like voids could also form from dislocations due to the trapping of syngenetic solid inclusions. In this case, the dislocations start from the inclusions and can propagate straight, oriented close to the growth direction of the sector in which they lie, but they usually have a non-crystallographic direction (Klapper 2000, 2010).

The first mechanism seems to agree with the observations of this study and those reported for other trapiche rubies from Myanmar (Schmetzer *et al.* 1999; Sunagawa *et al.* 1999).

Some tube-like voids appeared curved in proximity to the edges of the crystal, as shown in Figures 6a and 6b. This could be due to the fact that ruby FS02 was likely deformed under pressure during the final phase of its growth. Thus, the curvature of the tube-like voids results from the fact that the dislocations modified their directions during the formation of the crystal, adopting new directions for which their energy was minimal within the growth layer. The deformation could be related to local tectonic constraints happening during regional metamorphism and, thus, during trapiche growth in rock lithology of different competence such as marble, calc-silicate and schist.

The flower shape of the analysed trapiche rubies is due to weathering, which affected both the growth sectors and the sector boundaries. In the growth sectors, the weathered zones created V- or U-shaped inlets, as previously observed in Colombian trapiche emeralds (Bernauer 1933). The yellowish colour of the sector

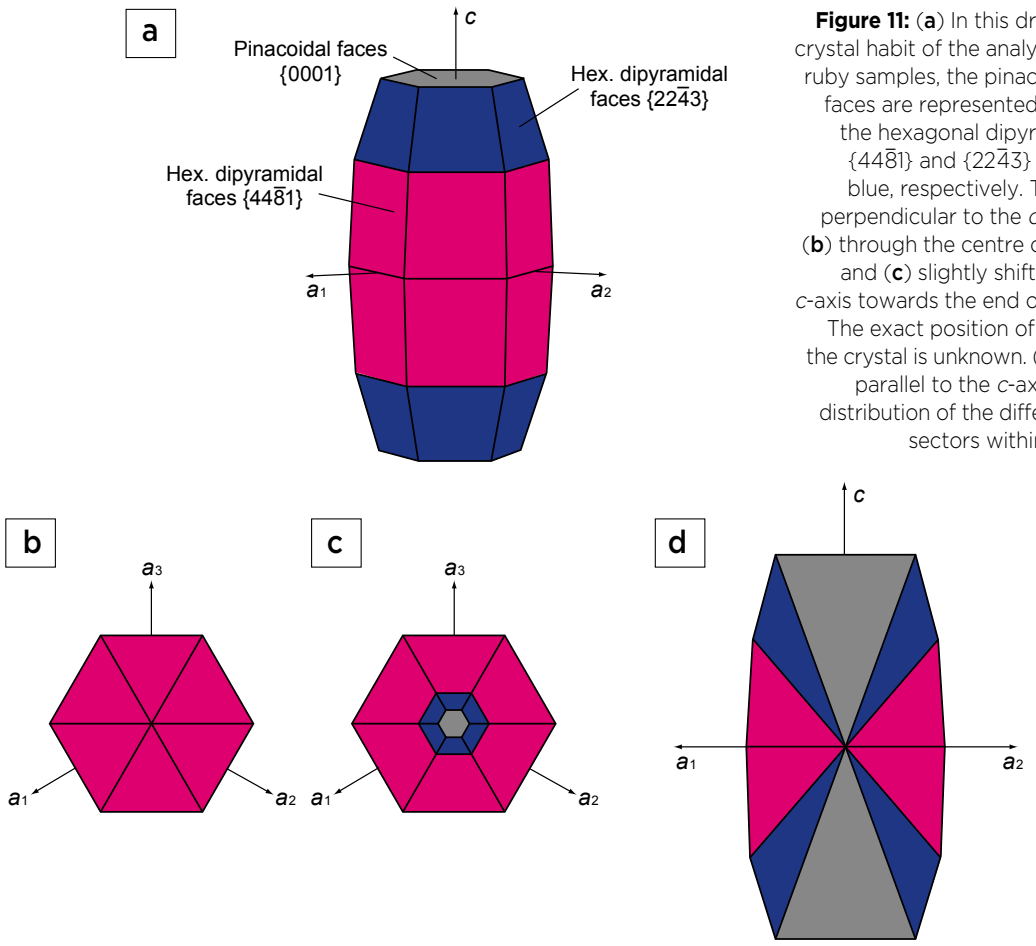

Figure 11: (**a**) In this drawing of the crystal habit of the analysed trapiche ruby samples, the pinacoidal {0001} faces are represented in grey, and the hexagonal dipyramidal faces {44$\bar{8}$1} and {22$\bar{4}$3} are pink and blue, respectively. Two sections perpendicular to the *c*-axis are cut (**b**) through the centre of the crystal and (**c**) slightly shifted along the *c*-axis towards the end of the crystal. The exact position of each slice in the crystal is unknown. (**d**) A section parallel to the *c*-axis shows the distribution of the different growth sectors within the crystal.

boundaries is also due to weathering, which is associated with the deposition of iron oxides/hydroxides, as shown by the Fe distribution in the XRF maps (Figures 8e and 10e) and also described by Sunagawa *et al.* (1999). Weathering was favoured by the porosity of the boundaries, as underlined by the CT data, and as reported previously for trapiche ruby and emerald (Schmetzer *et al.* 1999; Garnier *et al.* 2002a, b; Pignatelli *et al.* 2015).

The complex mineralogical assemblage within the sector boundaries consists of carbonates, K-Si minerals, Fe-oxides/hydroxides and a Ti-bearing mineral (probably V-rutile) according to previous data on trapiche rubies from the same locality (Garnier *et al.* 2002a, b and reference therein). The K-Si minerals are present in a fracture and could be related to micas or K-feldspar as described by Garnier *et al.* (2002a, b).

The difference between the texture shown by these flower-shaped trapiche specimens and classical trapiche rubies has been attributed to multi-stage formation (Liu 2015). This formation hypothesis consists of five stages. During the first three stages, a flower-shaped ruby formed as a classical trapiche (according to the growth model proposed by Sunagawa *et al.* 1999), during which the core, middle layer and sector boundaries developed. Then two additional stages resulted in the formation of the sector boundaries and growth sectors of the outer layer. Based on the XRF and CT data collected in the current study, the middle and outer layers are different growth sectors of the same crystal, and all sectors formed together. Thus, no additional stages are needed for their formation, and the genetic model proposed by Sunagawa *et al.* (1999) for classical trapiche rubies from Myanmar is also applicable to flower-shaped trapiche rubies.

CONCLUSION

The two samples of flower-shaped trapiche rubies from Mong Hsu described in this study show both textural and chemical sector zoning. CT scanning and XRF mapping revealed the presence of three types of growth sectors: a pinacoidal one, which corresponds to the core of each sample, and two sets of dipyramidal growth sectors forming the middle and outer layers. The growth sectors are characterised by variations in trace-element composition, as shown by XRF maps.

The formation mechanism of these flower-shaped trapiche rubies is the same as proposed for other trapiche crystals from Mong Hsu, according to the model developed by Sunagawa *et al.* (1999), without adding further growth stages. However, such flower-shaped specimens are rare because the ruby must be sliced at a location perpendicular to the *c*-axis where both sets of dipyramidal growth sectors are present, whereas most sections contain only one of them (cf. Peretti *et al.* 1995). In comparison with other trapiche ruby samples, the appearance of the flower-shaped rubies is due to the combination of: (1) the crystal habit (i.e. the number of faces and growth sectors) and the position of the slice within the host crystal; and (2) the weathering of the growth sectors and sector boundaries, giving the aspect of clothes-peg-shaped petals.

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Update on Emeralds from the Mananjary-Irondro Area, Madagascar

Vincent Pardieu, Supharart Sangsawong, Léonard Cornuz, Victoria Raynaud and Sarocha Luetrakulprawat

ABSTRACT: Emerald deposits in eastern Madagascar near Mananjary were discovered in the 1970s by Jeannot Andrianjafy and have yielded some high-quality emeralds. There are currently a few mining sites being worked by Andrianjafy's children. This article characterises emerald samples that were collected in 2019 at two of the deposits—Ambodivandrika and Ambatomaneno, in the northern and southern parts of the area, respectively—where the mineralisation occurs in schist associated with pegmatites. The samples from each deposit showed some significant differences in their internal features and trace-element composition (i.e. alkalis and others such as Mn, Zn and Ga). Emeralds from both mines share many characteristics with those from other schist-type deposits, such as in Zambia, Brazil and elsewhere.

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For the past three decades, Madagascar has supplied some attractive emeralds to the gem trade. Most of the deposits are situated on the eastern side of the island in the Mananjary-Ifanadiana area near Irondro, about 50 km south-west of the coastal city of Mananjary.

Levat (1912) first mentioned the occurrence of emerald in Madagascar, and Sinkankas (1981) described small grains found in secondary deposits along with kyanite in the Mananjary-Ifanadiana area. Hänni and Klein (1982) characterised emeralds from the Ankadilalana mine (known today as Ambodibakoly) near the town of Kianjavato, and Chikayama (1989), Campbell (1991) and Kleyenstüber (1991) also documented emeralds from the Mananjary area. Schwarz and Henn (1992) described the Morafeno mining area, and Thomas (1993) also visited several emerald prospects in the Mananjary region. Ranorosoa (1993) studied the Mananjary area for her thesis work, and Schwarz (1994) described the internal features of emeralds from various deposits there. Pezzotta (1999) mentioned Mananjary emeralds and nearby gem-bearing pegmatites, and Cheilletz *et al.* (2001) showed the relation between emerald mineralisation at Mananjary and at another genetically different deposit in southern Madagascar. Chan Peng (2003) built models for the formation of the Mananjary emerald deposits, Moine *et al.* (2004) investigated the composition of the mineralising fluids, and Vapnik *et al.* (2006) examined the formation of the deposits based on fluid inclusions. Clanin (2012) described emerald mining activities near Mananjary in 1991 and reported that the mineralisation was hosted by biotite-amphibolite schist intruded by pegmatites.

In March 2018 and December 2019, author VP visited the Mananjary area in order to collect emerald reference samples, first for the Bahrain Institute for Pearls and Gemstones (DANAT) in 2018 (Karampelas *et al.* 2019), and then in 2019 for his private reference collection. The samples described in this article were collected during that second visit (e.g. Figure 1).

The Mananjary deposits have been controlled by Le Quartz Cie since the first emerald fragments were discovered near the village of Morafeno in the 1970s by Jeannot Andrianjafy, a Malagasy gem merchant and

prospector. After securing mining licences and making some alliances with the local 'kings' (Pardieu 2018a), Andrianjafy explored the region further. Within 10 years he discovered more than 15 deposits on both the north and south sides of the road linking Fianarantsoa to Mananjary (Pardieu 2020a). He has worked these deposits with his family under Le Quartz Cie for the past 50 years (Pardieu 2018b). Some additional mining activities in the area have also been undertaken by a few other Malagasy mining ventures, more or less in partnership with foreign financers (e.g. Clanin 2012).

GEOLOGY

The emeralds of the Mananjary area occur as euhedral crystals in phlogopite ± hornblende schists within altered amphibolite bodies. The deposits are situated in rocks of the Manampotsy Group, suggesting a uniform genetic context for the whole area (Chan Peng 2003; Tucker *et al.* 2012). Emerald and fluorine-rich phlogopite formed between hornblende grains or replaced Cr-bearing amphibolite due to alteration by K-F-Be-rich hydrothermal fluids. The mineralisation occurred spatially 'at the contact between pegmatite and lenticular bodies of hornblendites' (Vapnik *et al.* 2006, p. 143), and the associated alteration created a sharp reaction front composed of a distinctive mineralogical assemblage: hornblende, phlogopite, plagioclase, calcite, quartz, chlorite and emerald. The inclusions found in the emeralds reflect their growth environment, which suggests pegmatitic interaction (fluorite, tourmaline) with the amphibolite (magnesite; Gübelin & Koivula 2008).

The emerald-bearing rocks were metamorphosed and folded twice; the first deformation produced flat recumbent eastward-verging folds, and then east-west shortening created vertical folds along a north-south trend (Moine *et al.* 2004). Deformed orthogneiss in the area is related to magmatism that occurred 800 million years ago (Ma; Handke *et al.* 1999), while the pegmatites and veins associated with emerald mineralisation were emplaced during the Pan-African tectono-metamorphic event at around 530–500 Ma (Markl *et al.* 2000), or 490 ± 8 Ma based on the age dating of the associated phlogopite ($^{40}Ar/^{39}Ar$ method; Cheilletz *et al.* 2001). The pressure-temperature conditions were estimated at 8 ± 1 kbar and 700 ± 30°C for rocks of the Mananjary area (Chan Peng 2003), and 1.5 kbar and 250–450°C for emerald genesis (Vapnik *et al.* 2006).

Figure 1: Two rough emeralds from Ambodivandrika, Madagascar (left 0.2 g and right 3.45 g) that were studied for this article are shown with a faceted pear-shape emerald (0.86 ct), also reportedly from Madagascar. The faceted stone is courtesy of Asia Lounges, Bangkok, Thailand; photo by Arjuna Irsutti.

The key process for the formation of the emerald deposits was the introduction of mantle-derived CO_2-rich fluids along the Ifanadiana-Angavo mega-shear zone (15 km west of the emerald-bearing area) and the presence of crustal H_2O-rich fluids related to the pegmatites and veins (Vapnik *et al.* 2006). Therefore, Madagascar's emerald deposits may be classified as being associated with pegmatites in mafic-ultramafic rock, in a tectonic-magmatic context (i.e. type IA, as described by Giuliani *et al.* 2018, 2019). Other worldwide emerald deposits categorised similarly include Itabira-Nova Era in Brazil, the Kafubu area of Zambia and the Kenticha pegmatite field in Ethiopia.

MINING AND PRODUCTION

The Mananjary-Irondro emerald-producing area is mainly active during the dry season from May to December. Then with heavy rains the mining usually ceases. In 2018 mining stopped earlier, in September, because of a presidential election that took place in November.

In the southern part of the deposit area, near Morafeno village, the main active operation is at Ambatomaneno, on the top of a hill (see Figures 2 and 3). It is an open-pit operation, and during author VP's 2019 visit there were 18 miners, led by Patricia Andrianjafy (daughter of Jeannot Andrianjafy). They were working with a bulldozer and

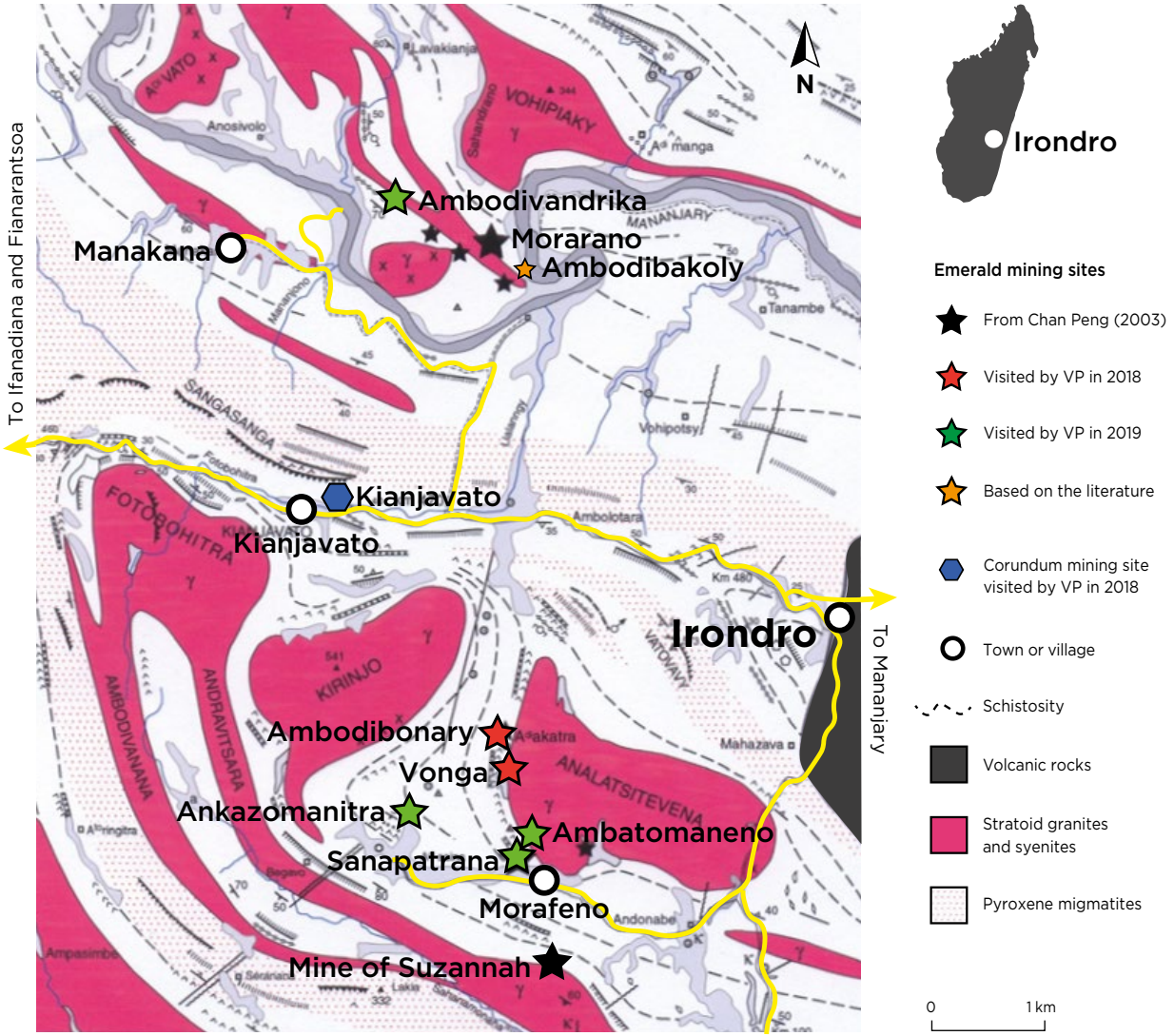

Figure 2: This geological map of the Mananjary region (modified after Chan Peng 2003) shows the locations of the deposits visited by author VP in 2018 and 2019, as well as other emerald mines and a corundum deposit that lies in between the two emerald areas.

Figure 3: This aerial drone view (looking south-east) of the southern part of the emerald-producing area shows the Le Quartz Cie mining camp in the foreground. In the background, on top of the hill on the left, is the Ambatomaneno emerald mine. On the right are the tailings of the dormant Sanapatrana mine. Photo by V. Pardieu.

some hand tools, but no explosives, as a deliberate choice not to damage the emeralds. They extracted emeralds from weathered rocks composed of mica-rich layers associated with pegmatites. The production was mainly composed of light bluish green emeralds (e.g. Figure 4) up to about 20 g.

The Sanapatrana open-pit mine near Ambatomaneno (again, see Figures 2 and 3) has been inactive for several years. Sanapatrana reportedly produced more than 7 tonnes of emeralds since its discovery in 1984. Just west of these pits is the Ankazomanitra mine, where Patricia Andrianjafy is prospecting. No mining activity was seen at Ambodibonary or Vonga (Figure 2), where Jean Luc Andrianjafy (father of Jeannot) has been working in recent years.

North of the Kianjavato-Irondro road, Patricia Andrianjafy was also working at Ambodibakoly (Figure 2) with, reportedly, the support of an investor from Dubai, but

Figure 4: Samples from the recent production at Ambatomaneno display the light bluish green colour typical of emeralds from this mine. The stones shown here range up to approximately 1 g. Photo by V. Pardieu.

Figure 5: This aerial drone view (looking south-east) shows Christian Andrianjafy's camp (centre foreground) and the Ambodivandrika emerald mine (white cliff over a burned area). Other emerald mines are also visible (as areas lacking vegetation) in the same alignment as on the geological map in Figure 2. Photo by V. Pardieu.

author VP was not able to visit that mine. However, mining was witnessed at Ambodivandrika (Figure 5), where Christian Andrianjafy (another son) was working with 19 people, also using only hand tools to avoid damaging the emeralds. As at Ambatomaneno, mining was taking place in weathered mica-rich rocks intruded by pegmatites; the emeralds were associated with phenakite and, reportedly, alexandrite. More than 1 kg of emeralds were seen by author VP, including some highly transparent material showing good colour and clarity, and some fine emerald crystal specimens over 20 g (e.g. Figure 6).

Figure 6: These rough emeralds and crystal specimen (about 8 cm long) are from recent production at Ambodivandrika. The rough material (0.2 to 0.4 g) has been clipped to remove included portions. The area of the crystal near the termination is well formed and very clean, while the rest of the stone is much more included. Photo by V. Pardieu.

MATERIALS AND METHODS

Eight emeralds obtained from Ambodivandrika in the northern part of the mining area and seven emeralds from Ambatomaneno in the southern part were studied for this article (Figure 7). These samples were classified as 'D-type' (obtained from a miner but not at the mine) and 'C-type' (obtained at the mine but without witnessing the mining of the specific stones), respectively, according to the cataloguing system of Pardieu (2009, 2020b). They consisted of broken pieces and partial crystals that weighed 0.08–3.45 g and ranged from pale to intense bluish green. Two samples (i.e. one from each mining area) were prepared with windows polished perpendicular to the *c*-axis for spectroscopy.

The emeralds were characterised at ICA | GemLab in Bangkok, Thailand. Photomicrographs of internal features were captured with a Canon EOS 750D camera using darkfield, brightfield, diffused and oblique illumination, together with a fibre-optic light source when necessary. Standard gemmological data were collected from seven samples. Refractive indices were obtained with a refractometer produced by World Jewelry Tools Co. Ltd (Bangkok, Thailand), SG was measured hydrostatically with a calibrated Mettler Toledo JP1203C electronic balance, fluorescence was checked with long-wave (365 nm) and short-wave (254 nm) UV radiation, and a GIA polariscope was used to observe optic character.

Ultraviolet-visible-near infrared (UV-Vis-NIR) spectra were collected on the two windowed samples using a Jasco V-770 spectrophotometer with a resolution of

Figure 7: The 15 emeralds shown here were characterised for this study. The samples on the left are from Ambodivandrika (0.13–3.45 g) and those on the right are from Ambatomaneno (0.08–1.54 g). Some of the latter samples appear pale-coloured due to their shallow thickness. Photo by Nutnicha Sripadungcharoen.

2.0 nm. Fourier-transform infrared (FTIR) spectroscopy was performed on all samples using a Thermo Nicolet iS50 FTIR spectrometer equipped with an XT-KBr beam splitter and DTGS-KBr detector operating with a 4× beam condenser. The resolution was 4 cm^{-1}.

Chemical analyses of all samples were obtained using laser ablation inductively coupled plasma mass spectrometry (LA-ICP-MS) with a Thermo Fisher Scientific iCAP Q ICP-MS coupled with a Q-switched Nd:YAG laser operating at a wavelength of 213 nm. The analytical parameters included a laser spot size of 40 µm in diameter, a fluence of around 10 J/cm^2 and a 10 Hz repetition rate. NIST 610 and NIST 612 glasses were used for calibration standards. The time-resolved signal was processed with Qtegra ISDS software using silicon (^{29}Si) as the internal standard, applying a theoretical value of 31.35 wt.% for beryl.

RESULTS AND DISCUSSION

The emeralds from Ambodivandrika were relatively intense bluish green, while those from Ambatomaneno were generally paler bluish green. Standard gemmological testing yielded RIs of n_o = 1.591 ± 0.001 and n_e = 1.583 ± 0.001, with a birefringence of 0.009 ± 0.001. The SG values were 2.75 ± 0.02. No systematic differences were noted in the RI and SG values between emeralds from the two different mining areas. A doubly refractive reaction was observed with the polariscope. The samples were inert to both long- and short-wave UV radiation.

Samples from both areas had black to brown micaceous material on their outer surfaces. Examination with a gemmological microscope revealed that the emeralds from Ambodivandrika were relatively clean, while those from Ambatomaneno appeared somewhat cloudy. Internal features in the Ambodivandrika samples included reddish brown and black dendritic inclusions (Figure 8a), as also seen in emeralds from the Kafubu area in Zambia (Zwaan *et al.* 2005; Saeseaw *et al.* 2014) and in other schist-hosted emeralds (Hänni *et al.* 1987). They also contained elongate colourless inclusions with concentric equatorial fractures (Figure 8b), similar to those seen in Brazilian emeralds from Nova Era (Hänni *et al.* 1987).

The samples from Ambatomaneno contained irregular two-phase (fluid-gas) inclusions with relatively large bubbles (Figure 8c), similar to those documented in emeralds from Shakiso in Ethiopia (Renfro *et al.* 2017) and the Belmont mine in Brazil (Hänni *et al.* 1987). Iridescent platelets were seen in one Ambatomaneno sample (Figure 8d), similar to those commonly encountered in Russian emeralds (Palke *et al.* 2019). Overall, there was some overlap in the internal features seen in the samples from Ambodivandrika and Ambatomaneno. Although fluorite, tourmaline and magnesite have been reported previously in Madagascar emeralds (Gübelin & Koivula 2008), these were not seen in our samples.

The UV-Vis-NIR spectra (Figure 9) revealed electronic transitions of Cr and Fe. The most prominent features were Cr^{3+} absorption bands at about 430, 600, 639 and 683 nm, Fe^{3+} absorption at 372 nm, and the broad feature at 810 nm that is due to Fe^{2+} and possibly Fe^{2+}–Fe^{3+} interactions, typical of schist-hosted emeralds (Saeseaw *et al.* 2014, 2019). The Cr^{3+} absorptions were more pronounced in the Ambodivandrika sample. Both spectra are similar to those of schist-type emeralds from other localities such as Brazil, Ethiopia, Russia and Zambia (Karampelas *et al.* 2019).

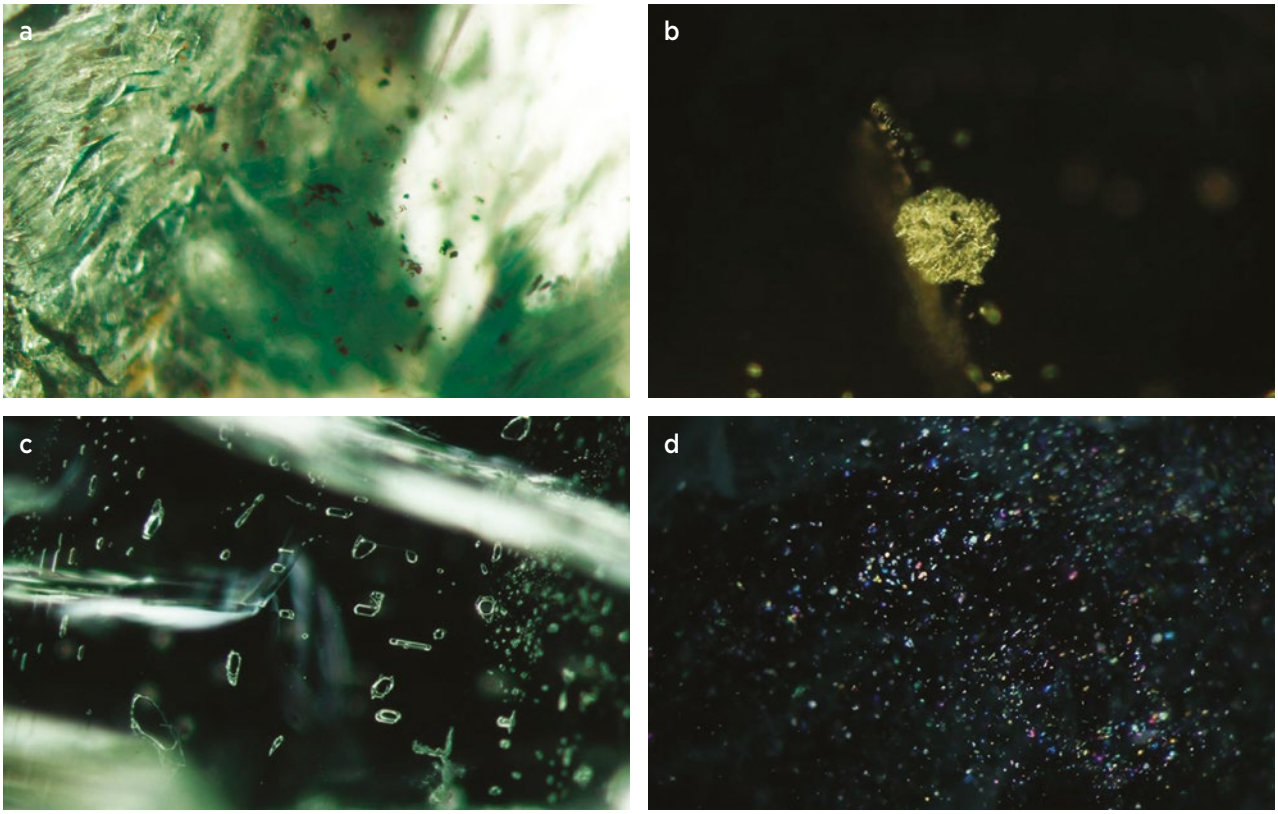

Figure 8: Microscopic examination of the Madagascar emerald samples reveals various internal features. Emeralds from Ambodivandrika contain reddish brown and black dendritic inclusions (**a**, image width 1.4 mm), and may also display elongate colourless inclusions with concentric equatorial fractures (**b**, image width 1.5 mm). Emeralds from Ambatomaneno show irregular-shaped two-phase inclusions with large bubbles (**c**, image width 14.8 mm), and may also contain iridescent reflective platelets (**d**, image width 2.2 mm). Photomicrographs by S. Luetrakulprawat.

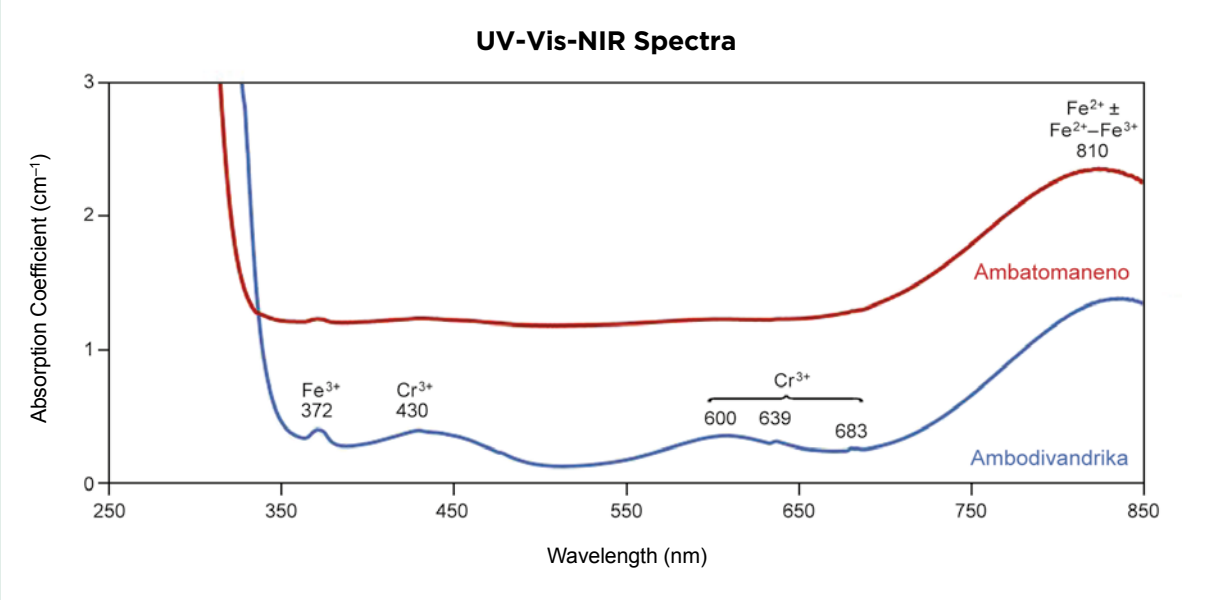

Figure 9: UV-Vis-NIR spectra (for the o-ray) of the Madagascar emeralds reveal typical features for Cr^{3+}, Fe^{2+} and Fe^{3+}, with weaker Cr^{3+} features in the Ambatomaneno samples. The top spectrum is offset vertically for clarity.

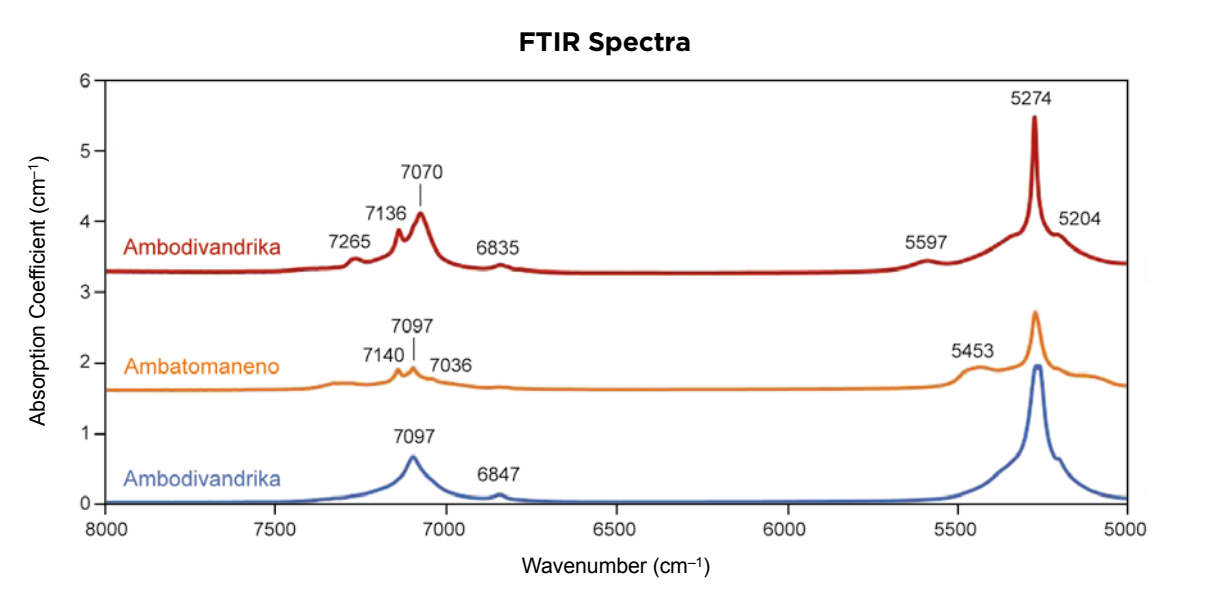

Figure 10: FTIR spectra of the Madagascar emeralds show three basic patterns, but they all reveal a series of water-related bands at 7500–6500 cm^{-1} and at around 5270 cm^{-1}. The spectra are offset vertically for clarity.

The FTIR spectra (Figure 10) showed three different patterns of water-related bands from 7500 to 6500 cm^{-1} and at around 5270 cm^{-1} (Saeseaw *et al.* 2014).

LA-ICP-MS analysis (Table I) revealed minor amounts of Mg, Na, Fe, K and Cr, as well as traces of Li, Sc, V, Mn, Co, Ni, Zn, Ga, Rb and Cs. The chromophores Cr, V and Fe were present in significant amounts, particularly Fe. The Cr/V ratio was relatively high compared to

Table I: LA-ICP-MS analyses of the studied emeralds from Madagascar.[a]

Element (ppm)	Ambodivandrika (8 samples)			Ambatomaneno (7 samples)		
	Min.–Max.	Average	Median	Min.–Max.	Average	Median
Li	56–129	108	112	35–65	55	57
Na_2O (wt.%)	1.67–2.05	1.84	1.80	0.54–1.48	1.25	1.34
MgO (wt.%)	2.69–3.15	2.95	2.97	0.93–2.49	2.09	2.26
K	592–2510	1758	1950	935–3020	2046	1960
Sc	24–48	35	33	19–66	42	38
V	96–118	107	108	52–99	79	86
Cr	1120–1590	1341	1325	232–983	559	545
Mn	4–14	10	11	9–19	15	16
Fe	9790–11100	10500	10500	3320–10400	8498	9370
Co	2–4	3	3	2–3	3	3
Ni	23–33	27	26	9–33	20	20
Zn	9–15	11	11	29–47	36	35
Ga	5–8	7	6	10–17	13	13
Rb	139–210	171	168	44–79	60	63
Cs	508–853	654	660	97–202	129	108
Cr/V	11–15	12	13	5–11	7	6
Na_2O/MgO	0.57–0.73	0.62	0.60	0.56–0.67	0.60	0.59
Total alkalis (wt.%)[b]	1.54–1.73	1.63	1.63	0.51–1.38	1.16	1.21

[a] Three spots were measured on each sample.
[b] Total alkalis = Sum of the concentrations of Li + Na + K + Rb + Cs.

that for emeralds from other localities (cf. Karampelas *et al*. 2019). In addition, the alkali contents (Na, K, Rb and Cs) of these samples were rather high, whereas Li was relatively low compared to other type IA emerald occurrences (e.g. Ethiopia, Russia, Zimbabwe and Zambia; Giuliani *et al*. 2019). Comparing samples from the two mining areas, the emeralds from Ambodivandrika showed significantly higher contents of most trace elements than those from Ambatomaneno, particularly for alkalis such as Na, Rb and Cs. However, the contents of K, Mn, Zn and Ga were slightly higher in emeralds from Ambatomaneno. These trends probably reflect differences in the chemical signature of the local geology between the two mining areas.

CONCLUSIONS

The recent visits by author VP to the emerald deposits near Mananjary enabled the study of reference samples obtained on site at two different mines in the southern and northern parts of the emerald-mining region. The samples from Ambodivandrika were relatively cleaner and more intense bluish green than those from Ambatomaneno. Internal features in the Ambodivandrika emeralds generally consisted of reddish brown and black dendritic inclusions as well as elongate colourless inclusions with concentric equatorial fractures, while the Ambatomaneno samples mainly contained two-phase (fluid-gas) inclusions and iridescent thin films, with some overlap between the samples from the two mining areas. The emeralds from Ambodivandrika generally contained more trace-element impurities than those from Ambatomaneno.

This study shows that emeralds from different deposits in eastern Madagascar may show some significant differences in their inclusions and chemical composition, and therefore Malagasy emeralds deserve more detailed study. The deposits appear to have good potential for the additional production of fine, light to deep green emeralds with good transparency.

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Gem-A Notices

COVID-19 NOTICE

In this unprecedented year, we continue to see the effects of the COVID-19 pandemic impacting global economies, businesses and individual livelihoods, which have challenged our very way of life. Our great Association has also seen the impact of the pandemic on our finances and business activities. Despite these uncertainties, Gem-A's management team and staff have continued to work tirelessly to support the Association's core functions of education and membership. While this has meant some internal changes to our business operations, as announced in Membership communications from Gem-A's CEO Alan Hart FGA DGA, we would like to reassure our Members that the Association remains strong and resilient. Through the various operational measures undertaken over the past six months, we will see the uncertain times through and be in a position to improve, grow and flourish in the future.

GEM-A GRADUATION AND PRESENTATION OF AWARDS

Due to the global pandemic, Gem-A made a very difficult decision to cancel the Gem-A Graduation and Presentation of Awards that was scheduled to take place in November 2020. For the January 2020 examinations, 233 students passed our Gemmology and Diamond Diploma examinations, and 16 of them passed with Distinction. Every year over our long history we have celebrated our graduates, some of whom come from across the globe to attend the awards ceremony in London and become part of our prestigious gemmology community. Last year we celebrated our 2019 graduates with a ceremony at the Royal Institution of Great Britain (e.g. see photo).

Although times have changed and social distancing rules mean that we cannot meet in person for now, we would like to give our heartiest congratulations to our January 2020 graduates. Due to the postponement of the Gem-A June examinations until September 2020, this graduate list and the 2020 Prize and Medal winners will be announced in the following issue of *The Journal* (Vol. 37, No. 5, 2021). Next year, we look forward to holding a combined 2020/2021 Gem-A Graduation and Presentation of Awards at London's historic Church House.

GEMMOLOGY DIPLOMA PASSES

Azra Aadil, Sri Lanka
Nicole J. Ahline, United States of America
Jean-Marie Albanese, France
Musharraf Ali Anver, Sri Lanka
Nalin Prasantha Ariyadasa, Sri Lanka
Tianxing Bai, P.R. China
Yuan Bai, P.R. China
Anouska Banks, United Kingdom
Yang Bao, P.R. China
José Silva Baptista, Portugal
Manon Bigot, France
Min Cao, P.R. China
Qiaoqiao Cao, P.R. China
Wing Sum Nicole Chan, Hong Kong (S.A.R.)
Chi-Lan Chang, Taiwan (R.O.C.)
Chin-Cheng Chang, Taiwan (R.O.C.)
Yu-Hsien Vivian Chang, Taiwan (R.O.C.)
Mutong Che, P.R. China
Anqi Chen, P.R. China
Gang Chen, P.R. China
Jun Chen, P.R. China
Kanglin Chen, P.R. China
Shuming Chen, P.R. China
Xin Chen, P.R. China
Xu Chen, P.R. China
Xingyu Chi, P.R. China
Kris Chien, P.R. China
Cheung Choi, Hong Kong (S.A.R.)
Shiyuan Cui, P.R. China
Tong Cui, P.R. China
Xinyi Deng, P.R. China
Ruoke Ding, P.R. China
Naimeng Dong, P.R. China
Hana Downing, United Kingdom
Joëlle Dufour, Canada
Qianyu Fan, P.R. China
Yue Fan, P.R. China
Jia Feng, P.R. China
Jiaqi Feng, P.R. China
Quan Shun Feng, P.R. China
Fazzari Nathalie Marie France, Madagascar
Cordelia Jane Fraser, United Kingdom
Fangfang Fu, P.R. China
Lanying Fu, P.R. China
Fang Gao, P.R. China
Jingya Gao, P.R. China
Tianyuan Gao, P.R. China
Xiang Gao, P.R. China
Yujia Gao, P.R. China
Yuxuan Gao, P.R. China
Julie Gau, France
Xiuhua Gong, P.R. China
Gandi He, P.R. China
Jing He, P.R. China
Rundi He, P.R. China
Zhaoran He, P.R. China
Wei Ting Hsu, Taiwan (R.O.C.)
Danyan Hu, P.R. China
Xing Ji, P.R. China
Ying Jia, P.R. China
Yusi Jia, P.R. China
Bohan Jiang, P.R. China
Mingming Jiao, P.R. China
Lucy Jupp, United Kingdom
Barbara Kentish Barnes, United Kingdom
Kitty Annelike India Kimber, United Kingdom
Ying-Hui Kuo, Taiwan (R.O.C.)
Yu-Po Lee, Taiwan (R.O.C.)
Jinlian Lei, P.R. China
Kam Fai Leung, Hong Kong (S.A.R.)
Jing Li, P.R. China
Lanbing Li, P.R. China
Ling Li, P.R. China
Qianmin Li, P.R. China
Wei Hao Li, Taiwan (R.O.C.)
Xiangyi Li, P.R. China

Xuyang Li, P.R. China
Yan Li, P.R. China
Dandan Liang, P.R. China
Haoran Lin, P.R. China
Jiaying Lin, P.R. China
Zhaoying Lin, P.R. China
Jie Liu, P.R. China
Lina Liu, P.R. China
Niya Liu, P.R. China
Qiuhua Liu, P.R. China
Tianlin Liu, P.R. China
Zhengyu Long, P.R. China
Yifan Lu, P.R. China
Yingrong Lu, P.R. China
Junyue Luo, P.R. China
Tianyu Luo, P.R. China
Aung Ko Lwin, Myanmar
Ke Ning Ma, P.R. China
Shijing Ma, P.R. China
Xingyi Mao, P.R. China
Myrna-Ivy Martinet, France
Ian Bruce McLeod, United Kingdom
Ran Meng, P.R. China
Lydia Micallef, United Kingdom
Fabienne Michaud, France
Fei Mo, P.R. China
Yunfei Mo, P.R. China
Fathima Tasneema Mohamed, Sri Lanka
Chao Peng, P.R. China
Hui Peng, P.R. China
Yizhou Qian, P.R. China
Ying Ren, P.R. China
Yuenan Ren, P.R. China
Anna Robertson, United Kingdom
Afat Rustamova-Ferris, United Kingdom
Valentina Scuderini, United Kingdom
Sarah Marie Suzanne Senzer, Canada
Yanran Shang, P.R. China
Min Hua Shi, Hong Kong (S.A.R.)
Than Than Soe, Myanmar
Michaela Stephan, United States of America
Laura Suades Vall, United Kingdom
Ling Sun, P.R. China
Ning Sun, P.R. China
Sufang Sun, P.R. China
Susi Taylor, United Kingdom
De Jack Teh, Malaysia
Po Chun The, P.R. China
Ying-Shuo Tseng, Taiwan (R.O.C.)
Lung Shing William Wai, P.R. China
Bo-Syong Wang, Taiwan (R.O.C.)
Chuchu Wang, P.R. China
Dan Wang, P.R. China
Han Wang, P.R. China
Jing-Yi Wang, Taiwan (R.O.C.)
Lijuan Wang, P.R. China
Lin Wang, P.R. China
Luwei Wang, P.R. China
Siyu Wang, P.R. China
Xiaohui Wang, P.R. China
Yanzhou Wang, P.R. China
Yimeng Wang, P.R. China
Yu Wang, P.R. China
Helena Waudby, United Kingdom
Zhen Wei, P.R. China
He Weng, P.R. China
Madison Rose Whitman, United States of America
Dongyuan Wu, P.R. China
Lanxi Wu, P.R. China
Yueqin Wu, P.R. China
Zhenhuan Wu, P.R. China
Jingwen Xiao, P.R. China
Guangbing Xing, P.R. China
Ning Xu, P.R. China
Sihan Xu, P.R. China
Kang Yang, P.R. China
Puyue Yang, P.R. China
Tian Zhen Yang, P.R. China
Xia Yang, P.R. China
Jingya Ye, P.R. China

Xinyi Ye, P.R. China
Ting-Hsuan Yen, Taiwan (R.O.C.)
Mingshu Yin, P.R. China
Mengying Yu, P.R. China
Yue Yu, P.R. China
Lei Zhang, P.R. China
Li Zhang, P.R. China
Yamin Zhang, P.R. China
Yang Zhang, P.R. China
Yang Yang Zhang, P.R. China
Yiwu Zhang, P.R. China
Yongli Zhang, P.R. China
Yu Qi Zhang, P.R. China
Yue Zhang, P.R. China
Yuhui Zhang, P.R. China
Kehan Zhao, P.R. China
Meiqiao Zhao, P.R. China
XiaoChuan Zhao, P.R. China
Xuenan Zhao, P.R. China
Ziqi Zhao, P.R. China
Ziyan Zhao, P.R. China
Zhou Zhou, P.R. China
Hong Zhu, P.R. China
Xiaoxin Zhu, P.R. China
Ruiyan Zuo, P.R. China

GEMMOLOGY DIPLOMA PASSES WITH MERIT

Zi Wen Bao, P.R. China
Dongxu Chen, P.R. China
Juglair Léa, France
Yihan Li, P.R. China
Xin Liu, P.R. China
Yuning Liu, P.R. China
Hongyu Lyu, P.R. China
Yuanmeng Song, P.R. China
Chen Wang, P.R. China
Xinxin Xiao, P.R. China
Xinyue Xu, P.R. China
Nan Zhang, P.R. China

GEMMOLOGY DIPLOMA PASSES WITH DISTINCTION

Renping Cheng, P.R. China
Xinying Shi, P.R. China
Ziyi Wang, P.R. China
Siyi Zhu, P.R. China

DIAMOND DIPLOMA PASSES

Sorrel Auger-Cerrone, United Kingdom
Damon Andrew Neish Barker, United Kingdom
Ting Yan Chiu, Hong Kong (S.A.R.)
Etienne Du Toit, United Kingdom
Edward John Evans, United Kingdom
Ka Yee Keung, Hong Kong (S.A.R.)
Kin Man Kong, P.R. China
Bo-Xuan Lin, Taiwan (R.O.C.)
Yu-Hung Lin, Taiwan (R.O.C.)
Yuen Hoi Ling Helen, Hong Kong (S.A.R.)
Mei Sze Olive Lo, P.R. China
Chiemi Sasajima, Italy
Po-Jui Ting, Taiwan (R.O.C.)
Jen-Hao Tung, Taiwan (R.O.C.)
Chi Him Jerome Wai, P.R. China
Helena Waudby, United Kingdom
Ching Yip Wong, Hong Kong (S.A.R.)
Wenxian Xu, P.R. China

DIAMOND DIPLOMA PASSES WITH MERIT

John Nils Axelson, United Kingdom
Astrid Bosshard Schreckenberg, Switzerland
Fung Yee Chan, Hong Kong (S.A.R.)
Robert Patrick Hart, United Kingdom
Ka Yee Leung, Hong Kong (S.A.R.)
Laura Suades Vall, United Kingdom

DIAMOND DIPLOMA PASSES WITH DISTINCTION

Rebecca Sophie Block, United Kingdom
Patricia Campion, United Kingdom
Valeria Di Cola, United Kingdom
Carolyn Harrington, United Kingdom
Su Myat Htet, Myanmar
Katrina Hughes, United Kingdom
Ceylan Ismail, United Kingdom
Leyla Ismail, United Kingdom
Amanda Pollarolo, United Kingdom
Masumi Sakai, Japan
Stacie Anne Tayler, United Kingdom
Joanna Wyganowska, United Kingdom

MEMBERSHIP RENEWAL NOTICE

Gem-A Members are at the heart of everything we do. In this unprecedented year, the support and well wishes conveyed by our Members have reinforced our efforts to do everything possible to maintain our great Association and its core functions of education and membership. At the end of October we started our annual Membership renewal run, and your support has never been more important than now. Head over to the Gem-A website to securely pay for your annual Membership. Renew before 31 December 2020 to benefit from the early-bird fee of £110. We have streamlined our payment options by introducing GoCardless and PayPal subscription services. We also still accept bank transfers, but due to the current pandemic we kindly discourage you from sending cheques, and we are unable to take payments over the phone. If you need assistance with your renewal, Gem-A's Membership Secretary is available via email at membership@gem-a.com. Through your Membership renewal, you will be able to continue enjoying Gem-A's quarterly publications and other benefits, including being part of a highly regarded and well-respected global network of gemmology professionals.

GIFTS TO THE ASSOCIATION

Gem-A is most grateful to our generous donors, who support continued research and teaching:

Christopher P. Smith, USA, for developing and donating a customised database for recording information on all of Gem-A's stone samples and literature, and making it accessible to Gem-A USA.

GEM-A ANNUAL GENERAL MEETING 2020

Due to the current pandemic and social distancing rules, the Gem-A Council made the decision to hold the Gem-A Annual General Meeting (AGM) online for the very first time. The 2020 AGM will be held on 16 December 2020 at 17:00 GMT. Members have received notification by email to register for the AGM and receive secure online access to submit their votes on the AGM resolutions. The results from the online voting will be announced at the AGM. The online AGM will provide a safe and effective opportunity for Members globally to participate and vote on the resolutions of the Association. For those who cannot attend, the AGM will be recorded and uploaded to the Members area of the Gem-A website.

A WEBINAR WITH THE EDITOR

Go behind the scenes at *The Journal of Gemmology* by tuning in to our ongoing webinar series with Editor-in-Chief Brendan Laurs FGA, on 27 January 2021 at 17:00 GMT.

Join us as we hear Brendan discuss the current issue of *The Journal* with Gem-A's CEO Alan Hart FGA DGA. To register your place, head to https://linktr.ee/gemaofgb. Did you miss our previous sessions of Gem-A Live with Brendan? Head to Gem-A's YouTube Channel and watch them now: www.youtube.com/c/GemAOfficialChannel.

Learning Opportunities

Note: Event dates and formats are subject to change depending on the COVID-19 situation.

CONFERENCES AND SEMINARS

23rd FEEG Symposium—25th Anniversary
~~23–24 January 2021~~ Postponed to January 2022
Paris, France
www.feeg-education.com/symposium

NAJA 55th Ace© It Virtual Conference
30–31 January 2021
Online
www.najaappraisers.com/html/conferences.html

AGTA Gemfair Tucson
2–7 February 2021
Tucson, Arizona, USA
https://agta.org/agta-gem-fair-tucson
Note: Includes a seminar programme

Hong Kong International Jewellery Show
3–7 March 2021
Hong Kong
https://event.hktdc.com/fair/hkjewellery-en/HKTDC-Hong-Kong-International-Jewellery-Show

10th National Opal Symposium
31 March–1 April 2021
Coober Pedy, Australia
www.opalsymposium.org

17th Annual Sinkankas Symposium – Agate & Chalcedony
April or May 2021 (exact date TBA)
Carlsbad, California, USA
https://sinkankassymposium.net

American Gem Society Conclave
26–28 April 2021
Louisville, Kentucky, USA
www.conclave2021.americangemsociety.org

Swiss Gemmological Society Conference
30 May–1 June 2021
St Gallen, Switzerland
http://gemmologie.ch/en/current

JCK Las Vegas
4–7 June 2021
Las Vegas, Nevada, USA
https://lasvegas.jckonline.com
Note: Includes a seminar programme

14th International Conference on New Diamond and Nano Carbons (NDNC)
6–10 June 2021
Kanazawa, Japan
www.ndnc2020.org

Diamonds – Source to Use 2021
9–11 June 2021
Johannesburg, South Africa
www.saimm.co.za/saimm-events/upcoming-events/diamonds-source-to-use-2020

Jewellery in Texts: Texts in Jewellery
19 June 2021
London
www.societyofjewelleryhistorians.ac.uk/news

NAJ Summit
19–21 June 2021
Northampton, East Midlands
www.naj.co.uk/summit
Note: Includes the IRV Valuers' Conference (19–21 June) and the JBN Retail Jewellers' Congress (21 June)

Jewellery & Gem ASIA Hong Kong
24–27 June 2021
Hong Kong
https://exhibitions.jewellerynet.com/6jg

Sainte-Marie-aux-Mines Mineral & Gem Show
24–27 June 2021
Sainte-Marie-aux-Mines, France
www.sainte-marie-mineral.com
Note: Includes a seminar programme

MJSA Expo
August 2021 (exact dates TBA)
New York, New York, USA
https://mjsa.org/eventsprograms/mjsa_expo
Note: Includes a seminar programme

NAJA 55th Ace© It Mid-Year Conference
14–17 August 2021
Location TBA
www.najaappraisers.com/html/conferences.html

9th International Conference Mineralogy and Museums
24–26 August 2021
Sofia, Bulgaria
www.bgminsoc.bg
Note: Gem minerals and archaeogemmology are among the topics that will be covered.

3rd European Mineralogical Conference (emc2020)
29 August–2 September 2021
Krakow, Poland
https://emc2020.ptmin.eu
Sessions of interest: The Geology of Gem Deposits: A Session in Honour of Gaston Giuliani; Materials Sciences and Archaeometry for Cultural Heritage

13th Annual Portland Jewelry Symposium
September 2021 (exact dates TBA)
Portland, Oregon, USA
https://portlandjewelrysymposium.com

31st International Conference on Diamond and Carbon Materials
5–9 September 2021
Palma, Mallorca, Spain
www.elsevier.com/events/conferences/international-conference-on-diamond-and-carbon-materials

3rd International Conference on Tourmaline (TUR2021)
9–11 September 2021
Elba Island, Italy
www.tur2021.com

OTHER EDUCATIONAL OPPORTUNITIES

Gem-A Workshops and Courses
Gem-A, London
https://gem-a.com/education

Lectures with The Society of Jewellery Historians
Society of Antiquaries of London, Burlington House
www.societyofjewelleryhistorians.ac.uk/current_lectures

- Jonathan Boyd—I Can't String a Sentence Together: Jewellery and Words/Words and Jewellery
  26 January 2021
- Jack Ogden—The Black Prince's Ruby: Investigating the Legend
  23 February 2021
- Carol Michaelson—Chinese Jade Jewellery and Ornaments from the Neolithic to the Present
  27 April 2021
- Gonçalo de Vasconclo e Sousa—Portuguese Jewellery
  25 May 2021
- Karl Schmetzer—The Late 14th-Century Royal Crown of Blanche of Lancaster
  22 June 2021
- Charlotte Gere—Colour in Victorian Jewellery
  28 September 2021
- Three Speakers TBA—New Research on Jewellery
  26 October 2021
- Ute Decker—Sculptural Minimalism & Fairtrade Gold – Philosophy, Provenance and Process
  23 November 2021

New Media

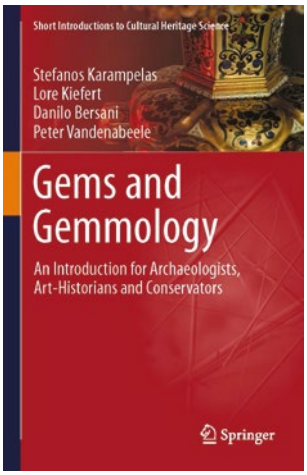

Gems and Gemmology: An Introduction for Archaeologists, Art-Historians and Conservators

By Stefanos Karampelas, Lore Kiefert, Danilo Bersani and Peter Vandenabeele, 2020. Short Introductions to Cultural Heritage Science series, Springer, Cham, Switzerland, 112 pages, illus., ISBN 978-3030354480 or e-ISBN 978-3030354497, https://doi.org/10.1007/978-3-030-35449-7. EUR62.39 hardcover or EUR50.28 eBook.

It is common in archaeological circles that an excavator or curator might lovingly describe a piece of jewellery, a Greek gold necklace perhaps, and then simply say something such as 'set with red stones'. The general lack of familiarity with gems and gemmology among archaeologists and art historians is self-evident, and a simple introductory text aimed at this target audience has been long-awaited. This book, sadly, is not it.

The first impression of the book is that it is quite brief, at only 112 pages and with just four chapters covering 'Gems Through the Ages', 'Gem Analysis', 'Gem Treatments, Synthetics and Imitations' and 'Archaeometrical Questions (Case Studies)'. Further perusal of the book shows that it has minimal visual appeal. Surely a book introducing art historians and archaeologists to gems and their study should be visually attractive and inspiring, especially when there are so many remarkable historic pieces and a wealth of interesting gems to draw from. Examples might include 4,000-year-old lapis lazuli beads from Mesopotamia; Roman jewellery containing diamonds, sapphires, amethysts, etc.; and early faceted gems in Medieval treasuries. However, the authors provide just three illustrations of gems that date to before around 1200 AD. By comparison, numerous illustrations show gemmological equipment, FTIR spectra, trace-element plots, etc. I am not convinced that a 112-page introductory text needs, for example, to describe the parts per million of boron in blue diamonds. The archaeologist, curator or conservator only needs to know what is possible with modern laboratory equipment, with clear examples.

The detailed coverage of 'classical' gemmological tools—such as the loupe, refractometer, polariscope, and so on—should have placed more emphasis on the use of the loupe. It is the most essential and portable of equipment, and seems more relevant in a brief introduction than, say, talking about the K and L levels of electrons. It is useful to know that advanced laboratory equipment can distinguish between ancient emeralds from Egypt and Pakistan, but for the archaeologist it would also be useful to know more simply that a non-Egyptian source might be suggested by the brighter-green, better-clarity and typically differently polished emeralds that began to be seen in some later Roman jewellery.

The four authors are all top experts in their fields, but none is a specialist in jewellery or gem history, and this is where gaps become particularly noticeable. The historical bits often seem to rely on older secondary sources and typically gemmological rather than archaeological or historical ones. This gives a somewhat outdated view of the subject. As an example, the book states that the Egyptian emerald mines were worked from 'at least 2000 BCE'. This is an old misunderstanding that was laid to rest in Egyptological circles at least as far back as the 1960s (in fact, there is no evidence for emerald use in Egypt before about 300 BCE). The book has a brief discussion of nomenclature issues with the quartz varieties, but no mention of a seminal work that specifically addresses these in an archaeological/historical context: Margaret Sax's 'The recognition and nomenclature of quartz materials with specific reference to engraved gemstones' (*Jewellery Studies*, **7**, 1996, 63–72). The chapter on treatments, synthetics and imitations is very much oriented to recent work, with no mention of the heat treatment of carnelian, for example, that dates back more than 4,000 years, or the heat crackling and dyeing of rock crystal in surviving Roman and Renaissance examples.

The book largely ignores the considerable recent research on early lapidary techniques, from how diamond chips were used in drilling and engraving other gem materials (by at least 500 BCE) to the introduction

of emery as an abrasive (probably by about 2000 BCE), before which sand was the primary option. Lapidary techniques might seem peripheral to gemmology, but you cannot study early gems without at least a framework for how they were worked. To give a simple example, a faceted sapphire bead cannot be Bronze Age. It is odd to say, as this book does, that gem cutting 'radically improved after the industrial revolution' (i.e. 1700s) but totally ignore the huge leap in lapidary work that came with the introduction of continuous rotary motion powered by the crank and flywheel in the 15th century.

The chapter on 'Archaeometrical Questions (Case Studies)' devotes almost 10% of the book's length to a fairly in-depth look at the gems set in Medieval and Renaissance treasures in Einsiedeln Abbey and the Basel Cathedral Treasury, both in Switzerland. Very interesting, but the book is aimed at 'students who need an introduction…and professionals who want to refresh their knowledge'. Where are the case studies of gemmological examinations of such things as humbler beads and little engraved gems, which can be no less illustrative of 'gemmology' but represent the types of gems most likely to be encountered by students and professionals?

Conservators are also included in the target audience given in the book's subtitle, but there is no chapter that covers the challenges of the degradation of some gem materials, a subject equally important to the excavating archaeologist. Durability is a defining feature of a gem, alongside beauty and rarity, but the durability of older gems, particularly long-buried ones, cannot always be taken for granted and thus beauty is threatened. Even garnets in archaeological objects can show surface etching caused by weathering, and there can be considerable selective etching of the different colour bands in agates that have spent millennia underground. Pearls and amber are particularly affected by long burial. At one extreme, pearls can disappear completely; at the other is the precipitation of calcite onto their surfaces. It is surprising for a book on gems partly aimed at conservators to lack a chapter tackling important issues that can impact such objects' conservation.

At the start of this review, I mentioned an archetypical archaeologist or art historian labelling a gem as a 'red stone'. That is better than making an uneducated guess at its identity. What they need is a guide that allows them to make a more educated and provisional suggestion of identity, helps them to understand why correct identification is important, and tells them in an inspirational way of the potentials for gemmology and gemmological science in their fields. They are still waiting.

Dr Jack M. Ogden FGA
London
United Kingdom

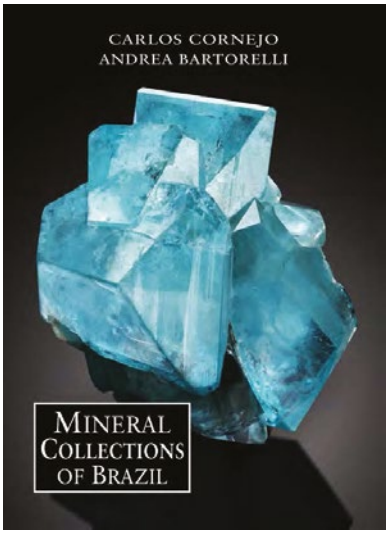

Mineral Collections of Brazil/ Coleçóes Minerais do Brasil

By Carlos Cornejo and Andrea Bartorelli, 2020. Solaris Edições Culturais, São Paulo, Brazil, solarised@terra.com.br, 792 pages, illus., ISBN 978-8589820134 (English) or ISBN 978-8589820127 (Portuguese). USD120.00 hardcover.

This comprehensive and monumental 792-page book follows a previous work by the same authors titled *Minerals & Precious Stones of Brazil* that was published in 2010. In the words of co-author Carlos Cornejo, 'With this book, we seek to highlight…Brazilian mineralogy, gemmology and palaeontology, leaving a historical record not only of the specimens, but also of the people who extract, collect, study, and preserve them.… In essence, this book is about presenting the most beautiful, interesting or rare pieces of collectors, institutions and mineralogical museums in Brazil' (p. 6). Co-author Andrea Bartorelli added that, where possible, sponsorship from the book's participants helped cover the cost of the respective chapters. The authors were surprised by 'the eager turnout of over 70 private collectors, museums and public institutions' (p. 7), which allowed this greatly expanded edition to include collections consisting of fossils, meteorites, lithic artefacts, faceted gemstones and jewellery.

The table of contents lists 75 sections comprising six main chapters. The book starts with an introduction consisting of a preface by each author and a review of

important mineralogical discoveries reported in various European publications, beginning with the early 16th century. Included as the book's first illustration is an image from Conrad Gesner's 1565 *De Omni Rerum Fossilium* that concerns Brazilian green tourmaline. The historical review also covers subjects such as 'The gold fever that conquered Brazil', the diamond cycle, José Bonifácio de Andrada e Silva (Brazil's first and foremost mineralogist), mineralogical collections and many other interesting topics. The introduction is wonderfully illustrated with images of people, important finds, mines, crystals and gemstones (including many historic photographs), providing a good background before moving on to the various important collectors and collections.

The first chapter, titled 'Mineralogical Collections', is organised alphabetically by name of the collector, beginning with Álvaro Lúcio, who is well known in the USA as a participant at the Tucson gem shows for decades. For each person whose collection is documented in this section, we get a glimpse into why and what they collect, along with a history of their acquisitions. Each person provides interesting stories about their collections, alongside photos of their favourite or important pieces. The chapter finishes with a one-page table on page 329 that provides a chronological listing of 72 Brazilian type-minerals (i.e. those first discovered in Brazil) that was compiled by Daniel Atencio. It starts with chrysoberyl (documented in 1789) and ends with breyite (described in 2018).

The following chapter covers 'Public Museums and Private Collections', starting with the geoscience museum at the University of San Paulo (USP). This well-documented section covers the history, collections and some of the finer specimens at 12 different Brazilian museums. My personal favourite is the 'Owl's Eye' agate at the USP museum that is shown on page 337.

The next chapter, titled 'Mineralogists and Geologists', includes Daniel Atencio (who created the list of Brazilian type-minerals mentioned above), Paulo and Marizilda Sinátora das Neves, Antonio Luciano Gandini, Gilson Essenfelder, Wendell E. Wilson, Thomas Campbell and Odúlio José Marensi de Moura.

This is followed by the chapter 'Mines, Miners and Mineral Traders'. This section includes Brazilian traders as well as foreign dealers, such as Americans Daniel Trinchillo and Robert Lavinsky, Italian Marco Tironi, and others. Localities described in this chapter are the Pederneira and Cruzeiro tourmaline mines and the Laranjeiras emerald mine. Many photos of famous specimens illustrate this chapter.

The next chapter, 'Meteorites and Tektites', includes Wilton Pinto de Carvalho's 'PhD in meteorites', followed by sections on André Moutinho and Carlo Bottelli. Again, this section is well illustrated with fine photographs, including some of the people discussed.

The final chapter is titled 'Gems, Stone-Cutting and Jewelry'. It features a large variety of colour photographs of objects that have made Brazil famous worldwide in the gem and jewellery trade. Diamond, emerald, tourmaline, topaz and beryl appear on page after page, with some stones mounted in beautiful jewellery by Brazilian designers.

This book is an amazing attempt to cover nearly all aspects of Brazil's gems, minerals, fossils, meteorites, collectors, mines and museums. I believe it mostly succeeds, and I give it high praise. I do think the very heavy (1.2 kg) book might have been more effective as two volumes, although that might have made it too expensive.

For anyone who loves gems, minerals or jewellery—or Brazil—this book is exciting and full of excellent information not usually found in a single reference.

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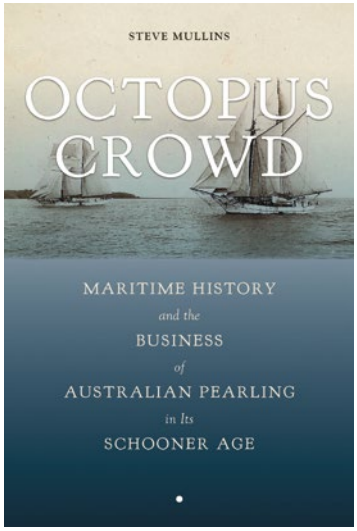

Octopus Crowd: Maritime History and the Business of Australian Pearling in Its Schooner Age

By Stephen Mullins, 2019. University of Alabama Press, Tuscaloosa, Alabama, USA, www.uapress.ua.edu/product/Octopus-Crowd,7074.aspx, 336 pages, illus., ISBN 978-0817320249 (print) or 978-0817392383 (eBook). USD54.95 hardcover or eBook.

This book describes pearling in the area encompassed by the Coral, Arafura and Timor Seas (north of Australia) from the mid-19th century to the first quarter of the 20th century (around the end of World War I), and the commercial appearance of saltwater cultured pearls. During this period, the area was an important source of natural nacreous saltwater pearls, in addition to the waters of the Arabian Gulf and off Central America. In the Australian waters, *Pinctada maxima* bivalves were fished (in which larger natural pearls could be found compared to those obtained elsewhere). Natural pearls averaged 12% of the value of Australian pearling production, and the other 88% came from the inner nacreous part of the shell ('mother-of-pearl'), which was of great interest for the button industry during this period.

The book is well written and includes an important list of notes and a bibliography, but with few, mostly archival, figures. It focuses on the evolution from skin divers to full-dress helmet divers, and on the development from non-specific vessels to pearling luggers about 9–12 m long and the schooners that carried them. The parallel changes from shore-based pearling to floating stations (sometimes called 'floating sweatshops' because of the working conditions)—where 100-tonne schooners remained at sea for months and ferried about a dozen pearling luggers together with full-dress helmet divers—increased the pearling companies' profits.

Changes in the pearling workforce according to the region and time period are also described. In Western Australia, local aborigines were employed initially, with Indonesians (usually referred to as 'Malays') increasing over time. In the Torres Strait, the workforce initially was composed of South Sea Islanders, indigenous Torres Strait Islanders and Melanesians, which were gradually replaced by Malays, Filipinos (or 'Manilamen'), Japanese and Sri Lankans. The book offers several insights into workforce changes, worker rights, mistreatment of workers, conflicts with the indigenous peoples and related legislation. Information is also provided about resource depletion, cyclones that devastated pearling operations, politics and jurisdictions shaped by the pearling industry.

Details about 'pearl king' James Clark, Australia's most influencial pearler and head of the powerful Clark Combination syndicate, enliven the book. The syndicate was also named the 'Octopus Crowd', after cartoonists of the day used the octopus to caricature the money grubbers, and from this comes the title of the book.

Following the book's introduction are 10 chapters. Chapters 1, 2 and 3 describe the early development of pearling on Australia's north-east coast, which extended to the Torres Strait (between Australia and New Guinea) during the 1860s and 1870s. They also cover how pearling became an important industry for Queensland at the start of the 1880s, as well as development of the passage to Western Australia and the floating pearling stations during the mid-1880s.

Chapter 4 considers the legislation challenges created by these floating stations, as they were beyond the three-mile limit of shore-based operations. It goes on to describe how, towards the end of the 1880s, some pearlers returned to the Torres Strait, while others went to the Netherlands East Indies (a Dutch colony in Southeast Asia), triggering discussions between the British and the Dutch. Chapters 5, 6 and 7 revisit the Torres Strait during the 1890s, where opposition ongoing between shore-based pearlers and floating-station owners also involved legislation that outlawed foreigners from owning or leasing pearling luggers.

Chapters 8, 9 and 10 describe the introduction of the 'White Australia' policy in 1901, the challenges to large operations of securing a workforce, the move of the Clark Combination syndicate to the Netherlands East Indies, the transformation of this region due to the pearling operations, the consequences to the market linked with World War I and the return of the Clark Combination to Western Australia. Then, the book's conclusion describes the end of the 'schooner age' and beginning of the syndicate that formed around the end of World War I, mainly due to changes in Australia's socio-political landscape that no longer supported small pearling operations.

Although the book does not focus on natural pearl fishing, it will be interesting for gemmologists who want to know more about the sociological issues of the industry. It well represents the evolving situations of the region during this period of time, with notes and references to help the reader dig further if desired.

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COMPILATIONS

***G&G* Micro-World.** Böhmite in corundum • Chabazite in Ethiopian opal • Fluorophlogopite in Burmese spinel • Unusual-shaped rutile in Russian emerald • Sapphire with negative crystal containing mobile graphite daughter crystal • 'Windmills' in sphalerite • Trapiche-like pattern in Pakistani emerald • Pyrite in quartz. *Gems & Gemology*, **56**(2), 2020, 292–297, www.gia.edu/gg-issue-search?ggissueid=1495318944465&articlesubtype=microworld.*

Gem News International. Purplish pink diaspore from Afghanistan • Fossil ivory carved by Lee Downey • 'Fragility of the Eternal' kunzite • Petrified wood from the Russian Far East • 85 g rough Cu-bearing tourmaline from Mozambique • Natrolite from Indonesia • Field trip to Crater of Diamonds, USA • Greenish blue glass imitating gem silica • Marble imitation of rough jadeite. *Gems & Gemology*, **56**(2), 2020, 298–316, www.gia.edu/gg-issue-search?ggissueid=1495318944465&articlesubtype=gni.*

Lab Notes. Cat's-eye andradite • Quench-crackled dyed blue chalcedony resembling Larimar • Irradiated blue diamond with interesting DiamondView image • Diamond with multiple radiation stains • Hemimorphite resembling Paraíba tourmaline • Purple Montana sapphire • Sapphire with negative crystal containing a mobile CO_2 bubble • Mozambique pink sapphire • HPHT-processed CVD synthetic diamonds with low color grades • HPHT synthetic pink diamond with unstable color. *Gems & Gemology*, **56**(2), 2020, 281–291, www.gia.edu/gg-issue-search?ggissueid=1495318944465&articlesubtype=labnotes.*

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